EVOLUTION OF THE FOUCAULT-SECRETAN REFLECTING TELESCOPE

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Abstract: Léon Foucault developed the silvered-glass reflecting telescope in collaboration with the instrument maker Marc Secretan. Almost immediately, they began selling 4- and 8-(French)-inch Newtonian telescopes in wooden tubes to amateurs. Several 4-inch examples have survived. As Foucault attempted to make larger diameters he moved from spherical to paraboloidal mirrors and developed tests to determine the errors of the surfaces he was polishing, of which the knife-edge test is the most informative and sensitive. The errors were then corrected with *retouches locales*, i.e. local repolishing. He also introduced the concept of *pouvoir optique*, or optical power, to characterize the performance of his mirrors. He made several professional reflecting telescopes, culminating in the 80-cm instrument now at the Marseilles Observatory. A number of his instruments are illustrated in physics textbooks of the time. Foucault predominantly adopted an *f*/6 focal ratio with a prism secondary close to the prime focus and a microscope-like eyepiece assembly to bring the image to the observer. In 1865, with Marc's son Auguste, Foucault announced a metal-mounted 10-cm alt-az amateur instrument, which soon became available in larger sizes and with equatorial mounts. Several examples survive. In 1866 the head of the Secretan workshop, Wilhelm Eichens, split from the firm. Marc died in 1867, followed by Foucault in 1868. Foucault's pupil Adolphe Martin published some of Foucault's mirror- and lens-making secrets. Martin worked with both Eichens and, episodically, the Secretan firm; but though able to figure small mirrors he proved incapable of finishing 80- and 120-cm ones begun under Foucault destined for the Toulouse and Paris Observatories. Auguste Secretan associated with Paul and Prosper Henry for mirror figuring. The Secretan offering of silvered-glass telescopes reached its apogee in 1874 with advertised diameters from 10 to 80 cm. Auguste died that year and the firm was taken over by his cousin Georges Secretan. Production of silvered-glass reflectors and other scientific instruments languished, and focal ratios slowed. Production appears to have revived after R. Mailhat became Director of the company's workshops and then founded his own firm. In 1903 the Secretan Company offered a simplified 125-mm reflector designed specially for members of the Société Astronomique de France, perhaps promoted by Georges' son Paul. Foucault-style reflecting telescopes were offered by other makers too, including Jules Duboscq, Édouard Lutz and Albert Bardou. Following Georges' death in 1906 the Company was operated by Paul before being sold to Charles Épry in 1906 who associated with Gustave Jacquelin in 1913. Only 125- to 200-mm amateur reflectors were offered in their 1924 and 1942 catalogues. Non-specific advertisements for reflectors continued beyond amalgamation with the Morin Company in 1963, but disappeared after a subsequent merger with the Société de Recherches et de Perfectionnements Industriels c.1967.

Keywords: Reflecting telescope, silvered glass, Léon Foucault, Secretan firm, Wilhelm Eichens, Adolph Martin, Henry brothers.

1 INTRODUCTION

A key step in the development of the modern telescope was the invention in 1856–1859 of the silvered-glass reflector by Léon Foucault (1819–1868; Figure 1). Reflective elements are of course exempt from chromatic aberration, and compared to speculum metal, glass permitted cheaper, lighter, stiffer and less-brittle mirrors with a smaller coefficient of thermal expansion. When darkened by sulphide, the silver surface could be renewed without the refiguring required by tarnished metal mirrors. Crucially, Foucault's method of *retouches locales,* or *local corrections* (whereby errors of form were discerned by optical testing and then corrected with local repolishing) opened the way to large apertures with fast focal ratios. (Here, and throughout this paper, all translations from the French are mine unless stated otherwise.) The superior reflectivity of silvered glass promoted the subsequent development of Cassegrain and other systems with two reflections. It is no wonder that Foucault's invention has been described by Ray Wilson, the renowned optical designer, as "... *one of the most important advances in the history of the reflecting telescope.*" (Wilson, 1996: 414; his italics).

I have outlined Foucault's development of the silvered-glass reflector elsewhere (Tobin, 1987 and especially 2003). Here I establish the advances and their chronology in greater detail, taking account of newly-discovered manuscript and printed material (e.g. Foucault, 1852–1865; 1857a; 1863; Sebert, 1867–1868).

Foucault's telescope experiments were conducted in association with the Swiss-born mathematician Marc Secretan (1804–1867; Figure 1), who was the owner of a large firm making precision instruments as well as being the Paris Observatory's official optician. Secretan was from Lausanne. He had trained as an advocate, but had taught mathematics at the Collège (now Université) de Lausanne before moving to Paris where he had partnered with the optician N.M.P. Lerebours (1807–1873). When the partnership

Figure 1: (left) Léon Foucault (1819–1868), photographed by the Paris-based Robert J. Bingham, no doubt in the 1860s (courtesy: www.thenewstribe.com); (right) Marc Secretan (1804–1867) (after: de Gramont and Peigné, 1902; courtesy: Bibliothèque Nationale de France).

expired in December 1854 he had become sole owner of the firm (Thiac, 1858), which for many years continued to invoke the name of Lerebours & Secretan in its advertising (e.g. Table 1; Brenni, 1994). At some point, Foucault entered into an exclusive contract with Secretan for the commercialization of his reflecting telescope (Rayet, 1868: 232). In this paper, I attempt to outline how the design of Foucault-Secretan reflecting telescopes evolved over time. This is interesting for at least three reasons:

(1) We can see how the design and underlying science developed.
(2) We can track how scientific and commercial constraints affected these changes and gain insights into the scientific instrument-making trade.
(3) The chronology will be useful to curators and others attempting to date and understand specific Foucault-Secretan reflectors.

We can divide such heritage instruments into three classes:

(i) There are the unique instruments that were produced by Foucault as he developed his telescope-making ideas.
(ii) There are the generally-larger telescopes produced for professional astronomers. These two categories sometimes overlap, as with Foucault's biggest and best-known telescope, the 80-cm reflector now at the Marseilles Observatory.
(iii) There are the mostly-smaller instruments sold to amateur astronomers or educational institutions.

Secretan died in June 1867, though as we shall see, he had already relinquished command of the firm to his son Auguste François (1833–1874). Foucault died the following February. This paper primarily concerns instruments developed by Foucault with Marc and Auguste Secretan. However the Secretan firm continued to trade in one form or another, advertising reflecting telescopes until the 1960s. I outline what little I have been able to discover concerning these subsequent developments, providing, I hope, a skeleton which others may be able to flesh out.

There were six principal sources of information available for putting together this narrative:

(1) Foucault's own publications and the very few of his private papers that have survived. In this context, the scientific papers inventoried after his death (Tobin, 2003: xii) include a tantalizing "List of mirrors made by Foucault" which unfortunately has not survived (Inventaire des Divers Cotes, n.d.: Cote 11ème, pièces 25 à 26).

Table 1: Catalogues by the Secretan firm and direct successors (Épry, Jacquelin) that mention silvered-glass reflecting telescopes. Several are absent from the *Handlist of Scientific Instrument-Makers' Trade Catalogues* (Anderson et al., 1990). See Notes 1–3 for how I dated undated ones. Since the 1924 and 1942 catalogues occasionally appear on sales sites such as eBay, often with wildly inaccurate date attributions, Figure 2 reproduces their covers and title pages. Trading and workshop addresses are cited because these may help in dating individual instruments accompanied by trade cards or similar documentation. The catalogue previous to the 1858 'Addition' was Lerebours and Secretan (1853), then trading from 13 Place du Pont-Neuf with workshops at 23 Rue de l'Est.

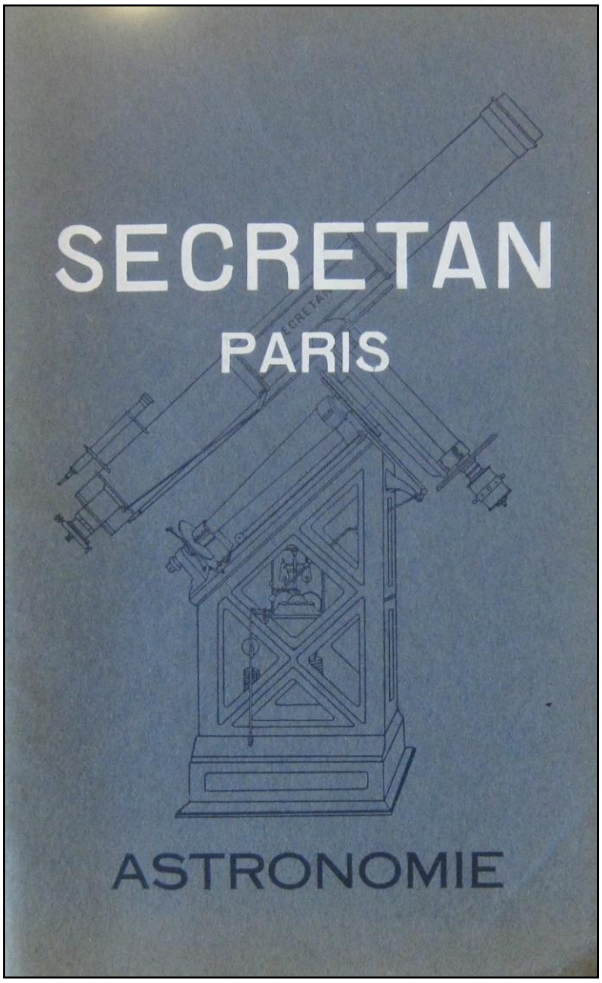
Date	Full title *Sales address* Workshop address (if given) *Location of copies*
1858	Maison Lerebours & Secretan. Secretan, Successeur. Addition relative aux nouveaux instruments d'acoustique. Janvier 1858. Addition relative aux nouveaux instruments d'optique. Errata au Catalogue de 1853. *13, place du Pont-Neuf, à Paris.* *Princeton University Library, bound with Kœnig (1873) and other ephemera (call no. ReCAP 8209.532). Available via books.google.com or www.hathitrust.org (incomplete scans).*
1868	Extrait du Catalogue de SECRETAN successeur de Lerebours & Secretan. Opticien de Sa Majesté l'Empereur, de l'Observatoire et de la Marine. Optique. – Électricité. – Calorique. – Pneumatique. – Météorologie. – Balances. – Mathématiques. – Nivellement. – Arpentage & Géodésie. – Astronomie. *Place du Pont Neuf, 13.* Rue Méchain, 9. *Bibliothèque National de France (call no. 8° WZ 3942).*
1874	Catalogue et Prix des Instruments d'optique, de physique, de chimie, de mathématiques, d'astronomie, et de marine Qui s'éxécute ou se trouvent dans les Magasins et Ateliers de SECRETAN, Successeur de Lerebours et Secretan, Constructeur d'instruments de précision à l'usage des sciences. Deuxième partie. Géodésie, Astronomie, Météorologie, Marine (appareils divers). *13, Place du Pont-Neuf.* 9, rue Méchain *Bibliothèque Nationale de France (call nos. V-52642, M-8901).*
1878a	Catalogue SECRETAN. Instruments usuels par G. Secretan, Membre de la Société de Géographie. Première partie. Optique. *13, Place du Pont-Neuf.* 28, Place Dauphine et 24, Boulevard d'Enfer. *Bibliothèque Nationale de France (call nos. 4° V 626, M-8889).*
1878b	Exposition universelle de 1878. Exposition SECRETAN. Classe 15. Par G. Secretan, Membre de la Société de Géographie. *13, Place du Pont-Neuf.* 28, Place Dauphine et 24, Boulevard d'Enfer. *Cornell University (call no QC373.06 S44). Available via www.hathitrust.org for US users only.*
1885	Maison LEREBOURS et SECRETAN. Secretan, Successeur. Catalogue illustré, orné de 569 figures. Troisième partie. Instruments de précision, comprenant: Physique générale, Chaleur, Lumière, Acoustique, Magnétisme, Électricité statique, Électricité dynamique, Mécanique, Marine, Météorologie et Instruments divers. *13, Place du Pont-Neuf.* *NOAA Central Library, Silver Spring (item No. 12307 m/0215 L 615)*.
c.1898	Maison Lerebours & Secretan. G. SECRETAN S^{seur}, Opticien-Constructeur. (No further title. Cover shows a woodcut of a meridian circle and the contents relate to terrestrial and astronomical refracting telescopes, reflecting telescopes, meridian circles, accessories and sextants.) *13, place du Pont-Neuf* *Smithsonian Institution, on-line at www.sil.si.edu/DigitalCollections/Trade-Literature/Scientific-instruments . Extracts given when a copy was sold on eBay in 2008 indicate the Smithsonian copy lacks a final dozen or so pages of illustrations.*
c.1898	Maison Lerebours & Secretan. G. SECRETAN S^{seur}, Opticien-Constructeur. (No further title. Cover shows a woodcut of a meridian circle and the contents relate to terrestrial and astronomical refracting telescopes, reflecting telescopes, meridian circles, accessories and sextants.) *13, place du Pont-Neuf* *Smithsonian Institution, on-line at www.sil.si.edu/DigitalCollections/Trade-Literature/Scientific-instruments . Extracts given when a copy was sold on eBay in 2008 indicate the Smithsonian copy lacks a final dozen or so pages of illustrations.*
1901–1902	G. SECRETAN, Successeur de Lerebours & Secretan. Extraits du Catalogue de la Maison Secretan. *13, Place du Pont-Neuf* *In L'Industrie Française des Instruments de Précision (1901–1902), pp. 247–252. On-line at Digital Mechanism and Gear Library, www.dmg-lib.org and Smithsonian Institution www.sil.si.edu/DigitalCollections/Trade-Literature/Scientific-instruments .*
1906a	M^{son} Lerebours & Secretan. G. SECRETAN, Ingénieur-Opticien, S^{uccr}. Catalogue d'Astronomie & d'Optique faisant suite à celui de Géodésie. Ch. V, Astronomie; Ch. VI, Météorologie; Ch. VII, Baromètres; Ch. VIII, Jumelles & longues-vues; Ch. IX, Microscopes; Ch. X, Instruments pour explorateurs. *13, Place du Pont-Neuf.* 28, Place Dauphine et Quai de l'Horloge, 41. *Musée des Arts et Métiers, on-line at cnum.cnam.fr .*
1911a[1]	Ancienne Maison LEREBOURS et SECRETAN. G. SECRETAN. Catalogue et Prix. Ch. EPRY, Constructeur, Successeur. Geodésie, Topographie, Nivellement, Astronomie, Sciences. *Anciennement Place du Pont-Neuf 13, et Chaussée d'Antin, 11* *Actuellement Tous nos services 40, rue Hallé (XIV^{e})*

	Musée des Arts et Métiers, on-line at cnum.cnam.fr .
1915	Lerebours et Secretan. Maison fondée en 1789. SECRÉTAN. Ch. Épry & Jacquelin, Succ^{rs}. Instruments d'Astronomie. Optique Scientifique. *20, Boulevard Saint-Jacques.* *Musée des Arts et Métiers, on-line at cnum.cnam.fr .*
1924[2]	Lunettes Astronomiques. Ancienne Maison Lerebours & Secretan, Fondée en 1789. SECRETAN. Ch. Épry & Jacquelin, Succ^{rs}. *151, Boulevard Auguste-Blanqui, Paris (XIII^{E}).* 12–20, Boulevard St-Jacques. *Trilingual catalogue (French, English, Spanish), private collection of Guy Barbel.*
1942[3]	Instruments Astronomiques. Anciennes Maisons: Lerebours & Secretan fondée en 1789; Georges Prin, Successeur de W. Eichens & P. Gautier. SECRETAN, Ch. Épry & Jacquelin, Successeurs. Société à Responsabilité limitée. Capital 650 000 francs. *151, Boulevard Auguste Blanqui, Paris (XIII^{E}).* Ateliers à Cachan (Seine), 55, Rue Etienne-Dolet. *Bibliothèque Nationale de France (call no. 8° WZ 3942) and author's collection, on-line at archive.org .*

2) Advertisements and catalogues produced by the Secretan firm and others (Tables 1–4). Some of the latter have become available on-line in recent years, but the resource is limited because few relevant catalogues were produced during the years when Foucault was developing the silvered-glass telescope. And unfortunately advertisements printed on the covers of magazines have often been discarded when libraries bound individual issues into volumes, or have been bound out of order, though usefully a number of examples have been reprinted by Andrews (1994; 1996) and Thiot (1995), and some survive in the digitizations of Google Books and NASA's Astrophysics Data System.

(3) Evidence from surviving telescopes, of which I have been keeping a tally for more than two decades.

(4) Comments in the popular and specialised press, particularly by the Abbé François Moigno (1804–1884) in the weekly science reviews *Cosmos* and *Les Mondes,* which he edited and largely wrote, and by the physicist and astronomer Jacques Babinet (1794–1872) in the *Jour-*



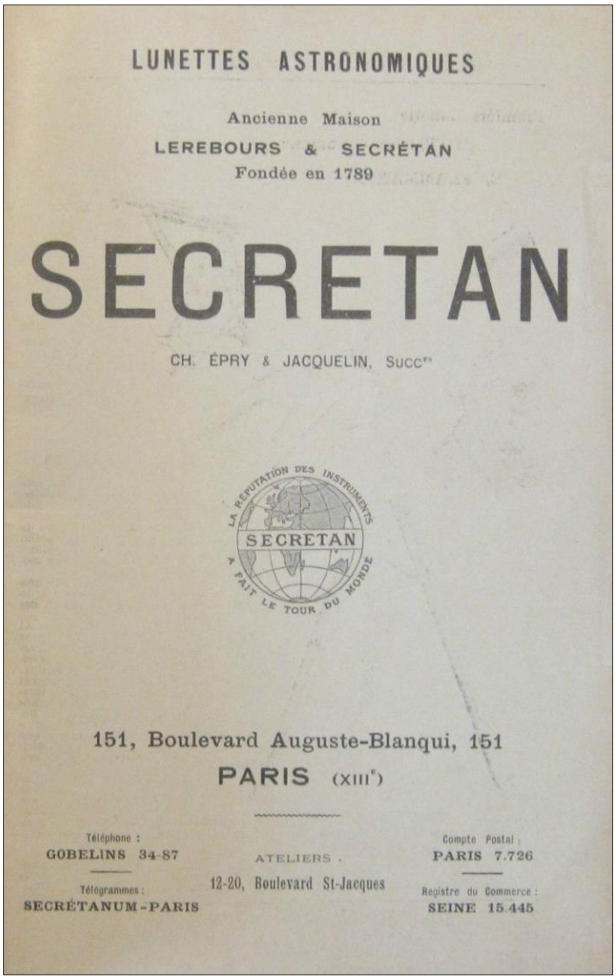
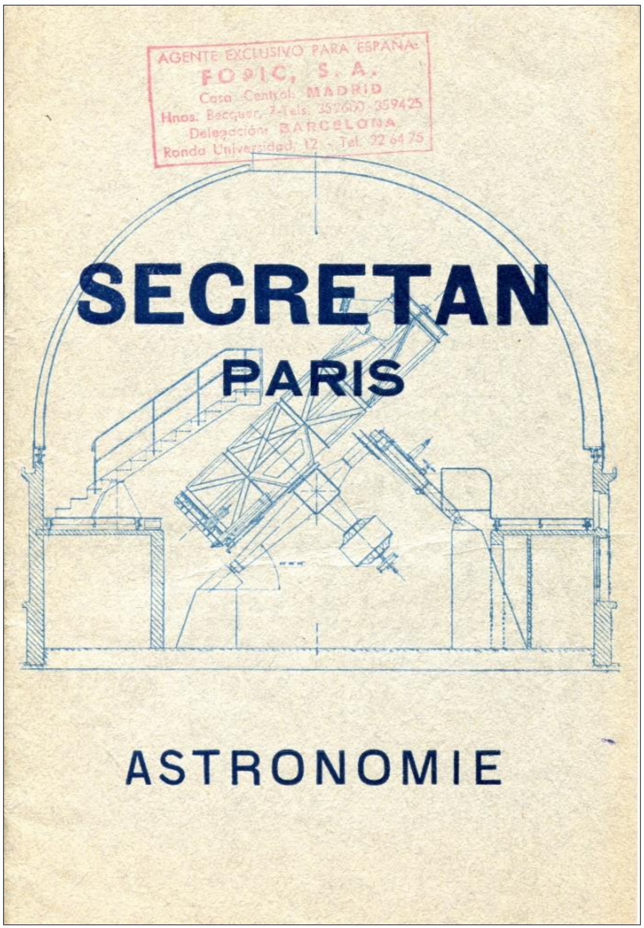
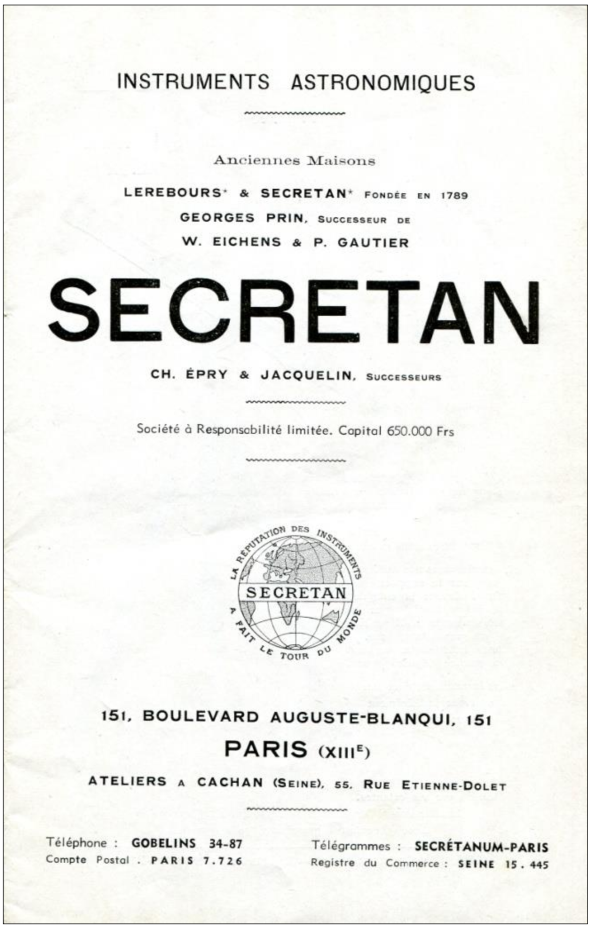


Figure 2: Covers and title pages for the Secretan catalogues first published in 1924 (this page) and 1942 (on page 110). The former were later distributed with overstamped dates of 1926 (buff wrappers) and 1929 (blue wrappers); a similar fate probably befell the latter catalogue too (after: eBay advertisements and author's collection).




INSTRUMENTS ASTRONOMIQUES

Anciennes Maisons

LEREBOURS* & SECRETAN* FONDÉE EN 1789
GEORGES PRIN, SUCCESSEUR DE
W. EICHENS & P. GAUTIER

SECRETAN

CH. ÉPRY & JACQUELIN, SUCCESSEURS

Société à Responsabilité limitée. Capital 650.000 Frs

LA RÉPUTATION DES INSTRUMENTS SECRETAN A FAIT LE TOUR DU MONDE

151, BOULEVARD AUGUSTE-BLANQUI, 151
PARIS (XIII^E)
ATELIERS A CACHAN (SEINE), 55, RUE ETIENNE-DOLET

Téléphone : GOBELINS 34-87 Télégrammes : SECRÉTANUM-PARIS
Compte Postal . PARIS 7.726 Registre du Commerce : SEINE 15.445

nal des Débats, a daily Parisian newspaper for which Foucault also wrote until 1862.

(5) The accounts and administrative correspondence of the Paris Observatory, which have recently become available to researchers.

(6) Perhaps unexpectedly, there are illustrations and descriptions in contemporary physics textbooks. Indeed, it was once I had understood that some of these descriptions related to unique instruments, rather than to commercial models (cf. Section 6 below), that the available information fell into a reasonably coherent pattern and I was prompted to write this paper.

Nevertheless, the evidence is often fragmentary, so the reader must keep in mind that as additional details become available, some of what follows may need revision.

To keep the main text short and readable, I relegate many of the details to Notes. Numerous illustrations are provided to help curators and others evaluate any newly-discovered Foucault-Secretan telescope. It should be noted that in French the word ‘télescope’ has become specific to a reflecting telescope and will be used in this sense here. A refractor is a ‘lunette’.

Table 2: Dimensions (as given), prices and other details for silvered-glass telescopes and unmounted mirrors advertised in Secretan and successors’ catalogues, as cited in Table 1. All are mounted in metal unless preceded by ‘W’ indicating a wooden mount. Figure numbers refer to this paper and indicate woodcuts that illustrated the catalogues.

Catalogue	Alt-azimuth mounting	Equatorial mounting
1858 *See also Figure 5*	W, 108 mm, 250 fr, Figure 5 W, 216 mm, 1,600 fr	
1868	10 cm, 550 fr, Figure 51	16 cm, 1,800 fr W, 16–80 cm, 1,600–25,000 fr, Figures 50 and 34
	Silvered, parabolized mirrors: “...200 fr per square of 10 centimetres...”	
1874 *See also Appendix 2*	10 cm, 500 fr, Figure 51 160 mm, 1,200 fr 200 mm, 2,000 fr	6 cm, 1,800 fr 16 cm, motorized, 2,500 fr 20 cm, motorized, 4,500 fr 30 cm, motorized, 9,000 fr 40 cm, motorized, 18,000 fr

		50 cm, motorized, 35,000 fr W, 16 cm, 1,650 fr, Figure 50 W, 16 cm, motorized, 2,350 fr W, 20 cm, motorized, 4,000 fr W, 30 cm, motorized, 6,000 fr W, 40 cm, motorized, 9,000 fr W, 50 cm, motorized, 13,000 fr W, 80 cm, motorized, 29,000 fr, Figure 34
	Silvered, parabolized mirrors: 150 fr per 10-cm x10-cm square circumscribing the mirror	
1878a *Instruments usuels*	10 cm, 500 fr, Figure 51 160 mm, 1,200 fr 200 mm, 2,000 fr	"See our astronomy catalogue (1874) for all instruments of position"
	Silvered, parabolized mirrors: diameter 10 cm, 150 fr; 16 cm, 385 fr; 20 cm, 600 fr; 30 cm, 935 fr; 40 cm 2,400 fr; 50 cm, 3,750 fr; 60 cm, 5,400 fr; 80 cm, 12,000 fr	
1878b *Exposition universelle*	Figure 51 "In my 1878 catalogue will be found all the instruments for elementary astronomy, and in my 1874 catalogue all those, so-called 'of position,' for the use of observatories ..."	
1885	10 cm, 500 fr 160 mm, 1,200 fr 200 mm, 2,000 fr "For more details, see our 1878 catalogue..."	
c.1898	100 mm, 450 fr, Figure 51 135 mm, 750 fr 160 mm, 1,000 fr 200 mm, 1,750 fr "The focal lengths initially adopted have been increased to improve the image and permit celestial photography."	
	Telescope mirrors: diameter 100 mm, 80 fr; 135 mm, 150 fr; 160 mm, 200 fr; 180 mm, 260 fr; 200 mm, 320 fr; 225 mm, 500 fr; 250 mm, 675 fr; 300 mm, 800 fr; 400 mm, 1,300 fr.	
1901–1902	"Foucault telescopes with silvered-glass mirrors"	
1906a	100 mm, 450 fr, Figure 51, plus two others with full tripod and table mount 125 mm, 750 fr 160 mm, 1,000 fr 200 mm, 1,750 fr 125 mm "specially destined for members of the Société Astronomique de France", 300 fr, Figure 84.	100 mm, 1,000 fr 125 mm, 1,300 fr 160 mm, 1,800 fr 200 mm, 3,800 fr
	Telescope mirrors: diameter 100 mm, 80 fr; 125 mm, 150 fr; 150 mm, 200 fr; 200 mm, 320 fr; 225 mm, 550 fr; 250 mm, 550 fr; 300 mm, 750 fr; 400 mm, 1,300 fr	
1911a	160 mm, f/6, 1,000 fr 200 mm, f/6, 1,750 fr 250 mm, f/6, 2,600 fr 125 mm, f/8, Société Astronomique de France, 450 fr	
1915	Figure 86 (left, centre) 100 mm, 425 fr; fine adjustments, 605 fr 125 mm, 520 fr; fine adjustments, 700 fr 140 mm, 690 fr; fine adjustments, 870 fr 160 mm, 1,000 fr; fine adjustments, 1,200 fr 180 mm, 1,360 fr; fine adjustments, 1,560 fr 200 mm, 1,830 fr; fine adjustments, 2,500 ft Eyepieces sold separately, 15 fr each.	Figure 86 (right)
	Parabolic mirrors: diameter 70 mm, 75 fr; 80 mm, 100 fr; 110 mm, 150 fr; 125 mm, 200 fr; 130 mm, 225 fr; 140 mm, 275 fr; 160 mm, 375 fr; 200 mm, 600 fr; 250 mm, 900 fr; 300 mm, 1,400 fr; 350 mm, 2,000 fr; 400 mm, 2,600 fr	
1924	Figure 86 (left, centre) 125 mm, 2,000 fr; fine adjustments, 2,500 fr 140 mm, 2,750 fr; fine adjustments, 3,250 fr 160 mm, 4,000 fr; fine adjustments, 4,750 fr 200 mm, 7,000 fr; fine adjustments, 8,000 fr	Figure 86 (right)
1942	Figure 86 (centre) 125 mm, fine adjustments 160 mm, fine adjustments 200 mm, fine adjustments The 160-and200-mm instruments have plane-mirror secondaries rather than a prism.	

Table 3: Catalogues by other Parisian instrument makers that include silvered-glass telescopes, up until the early 20th century.

Date	Full title *Sales address* Workshop address (if given) *Location of copies*
1860 Chevalier	Catalogue explicatif et illustré des instruments d'optique et de météorologie usuelles de la Maison Charles-Chevalier, ingénieur. *158, Palais Royal* 1bis, Cour des Fontaines, près le Palais-Royal (Ci-devant quai de l'Horloge) *Bibliothèque Nationale de France (call no. 8° W 6070) and on-line at Smithsonian Institution, www.sil.si.edu/DigitalCollections/Trade-Literature/Scientific-instruments .*
1864 Duboscq	Catalogue systématique des Appareils d'Optique construits dans les ateliers de J. Duboscq, élève et successeur de M. Soleil. *21, Rue de l'Odéon* *Bibliothèque Nationale de France (call no. 8° V 4382) and on-line at Musée des Arts et Métiers, cnum.cnam.fr .*
1867 Duboscq	Catalogue systématique des Appareils d'Optique construits dans les ateliers de J. Duboscq, élève et successeur de M. Soleil. *21, Rue de l'Odéon* *Bibliothèque Nationale de France (call no. 8° V 4382) and on-line at Musée des Arts et Métiers, cnum.cnam.fr .*
1870 Duboscq	Catalogue systématique des Appareils d'Optique construits dans les ateliers de J. Duboscq, élève et successeur de M. Soleil. *21, rue de l'Odéon* *Bibliothèque Nationale de France (call no. 8° V 4382) and on-line at Smithsonian Institution, www.sil.si.edu/DigitalCollections/Trade-Literature/Scientific-instruments .*
1872 Lutz	Catalogue des instruments d'optique construits par Édouard Lutz, opticien fabricant. *49, Boulevard Saint-Germain (49, Rue des Noyers)* *Bibliothèque Nationale de France (call no. 8° V 4382) and on-line at Smithsonian Institution, www.sil.si.edu/DigitalCollections/Trade-Literature/Scientific-instruments .*
1874 Picart	Catalogue alphabétique des appareils d'optique, polarisation, projections, lumière, microscopes construits par A. Picart *20, Rue Mayet, Faubourg Saint-Germain, ci-devant, Boulevard de Montparnasse, 38* *Bibliothèque Nationale de France (call no. 8° V 4382).*
1876 Duboscq	Catalogue systématique des Appareils d'Optique construits dans les ateliers de J. Duboscq, élève et successeur de M. Soleil, père. *21, Rue de l'Odéon* 30, Rue Monsieur-le-Prince *Bibliothèque Nationale de France (call no. 8° V 4382) and on-line at Musée des Arts et Métiers, cnum.cnam.fr .*
1882 Lutz	Catalogue des instruments d'optique construits par Édouard Lutz, opticien fabricant. *82, Boulevard Saint-Germain* *Bibliothèque Nationale de France (call no. 8° V 4382) and Musée National de l'Éducation, Rouen (call no. 2006.06403).*
1885 Duboscq	Maison Jules DUBOSCQ fondée, en 1819, par SOLEIL père. Historique & Catalogue de tous les instruments d'optique supérieure appliqués aux science et à l'industrie. *21, Rue de l'Odéon* *Bibliothèque Nationale de France (call no. 8° V 4382) and on-line at Smithsonian Institution, www.sil.si.edu/DigitalCollections/Trade-Literature/Scientific-instruments .*
1889 Pellin	Maison Jules DUBOSCQ Fondée, en 1819, par SOLEIL Père. Ph. PELLIN, Ingénieure civil, Successeur. Historique & Catalogue de tous les Instruments d'Optique supérieure appliqués aux science & à l'industrie. *21, Rue de l'Odéon* *Musée des Arts et Métiers, on-line at cnum.cnam.fr .*
c.1890 Lutz	Extrait du Catalogue générale des instruments d'optique construits par Édouard Lutz, Opticien, Officier de l'instruction publique. *65, Boulevard Saint-Germain* 65, Boulevard Saint-Germain *Author's collection, on-line at archive.org .*
1892 Bardou	Instruments d'Optique. A. Bardou. Prix Courant. *55, Rue de Chabrol* *Collection of P. Brenni.*
1893 Ducretet & Lejeune	Catalogue des Instruments de Précision de E. Ducretet & L. Lejeune. Première et deuxième partie. Physique Générale. *75, Rue Claude Bernard, Paris* *University of Michigan, on-line at archive.org .*
1899 Bardou	Instruments d'optique. Maison Bardou Fondée en 1819. J. Vial, Ing^{r} E.C.P. Successeur. Fourunisseur du Ministère de la Guerre, du Ministère de la Marine et des Gouvernements étrangers. *59, rue Caulaincourt (Ci-devant 55, rue de Chabrel), Paris.* *Sold on eBay in 2016. Seller's extracts on-line at archive.org .*

1900 Pellin	Instruments d'Optique Et de Précison. Ph. Pellin, Ingénieur des Arts et Manufactures. Successeur de Jules Duboscq. V^{e} Fascicule. Réflexion – Réfraction – Vision. *21, rue de l'Odéon* 30, rue Monsieur-le-Prince *Smithsonian Institution, on-line at www.sil.si.edu/DigitalCollections/Trade-Literature/Scientific-instruments . Lacks covers.*
1905 Ducretet	Catalogue raisonné des Instruments de Précision de E. Ducretet. Première et Deuxième parties. Physique Générale. 5ème édition. *75, Rue Claude Bernard, Paris* *Musée des Arts et Métiers, on-line at cnum.cnam.fr .*
c.1908 Mailhat	Ateliers de Mécanique et Optique pour les Sciences et l'Industrie. R. Mailhat, Constructeur. *41, Boulevard Saint-Jacques, Paris (14^{e})* *Erfgoedbibliotheek Hendrik Conscience, Anvers (Antwerp). This copy is overstamped "ACTUELLEMENT 10, Rue Emile-Dubois & 25, Rue de la-Tombe-Issoire PARIS (14^{e})", the addresses given by Mailhat (1909).*
c.1913 Mouronval	Mécanique & Optique pour les Sciences et l'Industrie. Ateliers R. MAILHAT, Ex-Directeur et aquéreur des Anciens Ateliers Secrétan. MOURONVAL Successeur, Ancien élève de l'École polytechnique. Catalogue d'Astronomie A2. *Formerly: 30, Rue du Faub^{g} St-Jacques & 41, Boul^{d} St-Jacques.* *Currently: 10, Rue Émile-Dubois, Paris (XIV^{e}).* *Musée des Arts et Métiers, on-line at cnum.cnam.fr .*

Table 4: Dimensions (as given), prices and selected other details for silvered-glass telescopes advertised in the catalogues listed above in Table 3. Figure numbers refer to this paper and indicate woodcuts or photographs that illustrate the catalogues.

Catalogue	
1860 Chevalier	"NEW TELESCOPE WITH MIRRORS, In silvered glass, M. Léon Foucault's system. This system promises great services in astronomy, because one can now make big telescopes much more easily than with completely dioptric designs. 200. M. Léon Foucault's Télescope, of 108 mm aperture, 52 cm focal length, with stand. 250 fr"
1864 Duboscq	"282. Silvered-glass mirrors with correctly spherical, elliptical or parabolic surfaces. (M.L. Foucault's local-correction method.) 81 mm diameter 625 [mm] focal length 200 fr 108 mm " " " 250 " 135 mm " 810 " 350 " 160 mm " 920 " 500 " 283. Telescopes of L. Foucault's system having the diameters and focal lengths indicated above."
1867 Duboscq	"283. Telescopes of L. Foucault's system having various diameters and focal lengths."
1870 Duboscq	"266. Telescopes of L. Foucault's system, having various diameters and focal lengths." (A handwritten annotation indicates prices from 500 to 3,000 fr.)
1872 Lutz	166. Foucault system telescopes with the same diameters, focal lengths and prices as given for mirrors alone in Duboscq's 1864 catalogue. "167. Foucault telescope. – M. Bourbouze's arrangement. The mirror can be replaced by an achromatic objective. – One can screw on a straight-through eyepiece so as to transform the *télescope* into a field or astronomical *lunette*. The same eyepiece can serve as a microscope. The objective can be mounted on a separate stand for projection experiments. It can also be used for photography 600 fr."
1874 Picart	"Telescope, M. Foucault's, 0^{m} 10 diameter 550 fr idem idem 0^{m} 16 diameter 1,200 fr idem idem 0^{m} 20 diameter 2,000 fr"
1876 Duboscq	"231*bis.* Foucault system telescopes, according to diameter and focal length of the mirrors. From 500 to 4,000 fr."
1882 Lutz	"240. Foucault telescope – Figure 90 (top) – The instrument's body is in brass, polished and varnished, or varnished matt black. It is suspended by two steel trunnions which engage in two pierced cast-iron risers, between which the body of the instrument passes freely. These two risers are attached to a moving circular base set on a cast-iron triangular foot, with three levelling screws, which can be placed on a table such that the horizon or the zenith can be scrutinized in every direction by seated or standing observer. The finder placed looks as good in a drawing room as in a physics laboratory, can replace a telescope that is seven near the mirror is easy to use for astronomical pointing. This instrument, easily portable, which or eight times more voluminous, costing three times as much. 241. Foucault telescope. – New very portable model, with finder, 80-mm diameter mirror, 1 terrestrial and 2 astronomical eyepieces magnifying from 80 to 200 times, mounted on a pillar and cabriole legs in brass, carrying box. 350 fr. 242. Foucault telescope, with finder, 105-mm (4-*pouce*) mirror, 1 terrestrial and 3 astronomical eyepieces magnifying from 80 to 300 times, divided altitude circle, mobile base on triangular cast-iron foot with 3 levelling screws. Figure 90 (top). 700 fr."

<table>
<tr><td></td><td colspan="2">243. As 242, except 135-mm (5-pouce) mirror, 4 astronomical eyepieces, magnifications 100–450. Divided azimuth scale and stop button. Figure 90 (top). 900 fr.
244. As 243, except 140-mm (5½-pouce) mirror, magnifications 150–550. 1,000 to 1,500 fr.
245. As 167 in 1872 catalogue, but without mention of Bourbouze. 700 to 800 fr.</td></tr>
<tr><td>1885 Duboscq</td><td colspan="2">“368. Telescopes of L. Foucault’s system, according to diameter and focal length of the mirrors, from 500 to 4,000 fr.”</td></tr>
<tr><td>1889 Pellin</td><td colspan="2">“574. Telescope with Foucault mirror of $0^{m}.10$ opening, two eyepieces (model in wood 300 fr
575. Telescope with Foucault mirror of $0^{m}.10$, model in brass, with finder, Figure 51 500 fr
576. Telescope with $0^{m}.16$ mirror 1,100 fr
577. Telescope with $0^{m}.20$ mirror 2,000 fr
All the instruments in the present Catalogue are made in our Workshops.
The instruments are marked M^{on} Jules Duboscq Ph. Pellin”</td></tr>
<tr><td>c.1890 Lutz</td><td colspan="2">149. As No. 241 in 1882 catalogue. 350 fr.
150. As No. 242 in 1882 catalogue. Figure 90 (top). 700 fr.
“151. Bigger telescopes, according to the diameter 900 to 1,500 fr.”</td></tr>
<tr><td>1892 Bardou</td><td colspan="2">“AZIMUTHAL TELESCOPES with silvered glass mirror
45. Telescope with finder; glass mirror of 10-cm diameter, parabolized and silvered; mounted in cast iron, six-branched stand for observing standing up; three eyepieces magnifying from 50 to 200 times. Figure 51. 450 fr.”
46. As No. 45, except 16-cm mirror, 60–300 magnifications 1,050 fr.
47. As No. 45, except 20-cm mirror, 65–400 magnifications 1,800 fr.
“EQUATORIAL TELESCOPES Mounting in metal
48. Telescope with finder with prism; glass mirror of 16-cm diameter, parabolized and silvered; equatorial mounting; 20-cm declination circle; hour-angle circle 37-cm in diameter; 4 eyepieces magniflying from 60 to 300 times; Figure 92”</td></tr>
<tr><td>1893 Ducretet & Lejeune
(Froment successor)</td><td colspan="2">“Foucault telescope with 10-cm diameter mirror, silvered by Foucault’s process. Mounted in cast iron. Supplementary foot. Four eyepieces. Finder. Dark glass for the Sun. 600 fr.”
Motorized equatorial mount and direct vision spectroscope available separately.</td></tr>
<tr><td>1900 Pellin
(Duboscq successor)</td><td colspan="2">“206. Telescope with Foucault mirror, mounted azimuthally, with finder, 100-mm diameter mirror, 3 eyepieces magnifying from 50 to 200 times. 490 fr. Figure 51.
207. Telescope ditto, 160-mm diameter mirror, 3 eyepieces magnifying from 60 to 300 times. 1,200 fr.
208. Telescope ditto, 200-mm mirror, 3 eyepieces magnifying from 65 to 400 times. 2,000 fr.”</td></tr>
<tr><td>1905 Ducretet</td><td colspan="2">As in 1893 catalogue</td></tr>
<tr><td></td><td>Alt-azimuth mounting</td><td>Equatorial mounting</td></tr>
<tr><td rowspan="2">c.1908 Mailhat</td><td>Figure 51
100 mm, 475 fr
135 mm, 825 fr
160 mm, 1,100 fr
180 mm, 1,450 fr
200 mm, 1,850 fr
225 mm, 2,350 fr
250 mm, 2,850 fr
All come with a squat, 3-legged foot; the two smallest sizes have an interchangeable tripod</td><td>Figure 83
100 mm, 1,700 fr
135 mm, 2,000 fr
160 mm, 2,500 fr
180 mm, 3,500 fr
200 mm, 4,440 fr
225 mm, 5,500 fr
250 mm, 7,000 fr</td></tr>
<tr><td colspan="2">“The focal length is about 7 times the diameter of the mirror”</td></tr>
<tr><td>c.1913 Mouronval</td><td>Figure 51
100 mm, 375 fr without foot, 475 fr with
135 mm, 680 fr without foot, 825 fr with
160 mm, 940 fr without foot, 1,100 fr with
180 mm, 1,260 fr without foot, 1,460 fr with
200 mm, 1,630 fr without foot, 1,850 fr with
225 mm, 2,090 fr without foot, 2,350 fr with
250 mm, 2,530 fr without foot, 2,850 fr with
275 mm, 3,110 fr without foot, 3,500 fr with
300 mm, 3,900 fr without foot, 4,350 fr with
“We also make Cassegrain types... We also make these telescopes with a simplified mount, a wooden mount, etc.”</td><td>Engraving of Figure 83
Available for fixed or variable latitude, and optionally with slow motions in hour angle only, with slow motions and divided circles on both axes, and with a clockwork motor. Sample prices: 100-mm mirror, fixed latitude, no options 800 fr, full options 1,650 fr; corresponding variable-latitude prices 900 and 1,780 fr. For a 200-mm mirror respective prices are 2,500, 3,950, 2,775 and 4,285 fr. For a 300-mm mirror, 5,700, 8,200, 6,200 and 8,840 fr.</td></tr>
</table>

2. SPHERICAL MIRRORS

2.1 The First Reflector

Foucault was appointed as Paris Observatory’s physicist in 1855 as part of the reorganisation concomitant with the appointment of a new Director, Urbain Le Verrier (1811–1877), of Neptune-discovery fame (e.g. Lequeux, 2009a; Tobin, 2003). An immediate task, which Foucault never completed, was to figure a pair of 29-inch (74- or 75-cm) diameter crown and flint glass discs into a telescope objective. For lens testing Foucault knew he would need a collimator, but this led to a vicious circle, since a collimator lens could not be tested without another collimator. However a mirror can be self-tested by placing a pinprick light source close to its centre of curvature and using a microscope to examine the tightness and symmetry of the resulting neighbouring image. Foucault tried to make a metal collimator mirror, but quickly switched to glass as a substrate, which he knew could be made reflective via the chemical deposition of silver from unheated silver nitrate solution using a process discovered in the 1830s by the German chemist Justus von Liebig (1803–1873). Foucault had written about the procedure in 1845 (Foucault, 1845) and five years later had employed silvered glass for his fingernail-sized spinning mirror used to compare the speeds of light in air and water (Tobin, 1993). Getting a good silver layer on a bigger surface was more difficult, however, and it took six months to master the process (Foucault, 1857a), which he improved in co-ordination with a Mr Robert and a Mr James Power, the licensees in Paris of patented improvements to a procedure devised by a certain Thomas Drayton of Brighton in England.[4] When the Scottish physicist Sir David Brewster (1781–1868) visited Foucault in June 1857, he was shown the entire process. "After deposition the silver surface is slightly rough," he noted, "or rather not well polished, but it is polished to perfection by a little cotton and a small quantity of rouge." (Gordon, 1869: 282). A few months later Foucault visited Sir John Herschel (1792–1871) in England and gave him a small mirror (Figure 3) and a piece of platinized glass which appear to reflect his investigations into ways to make glass reflective (Thoday, n.d.).

Of course a collimator mirror can equally act as a telescope mirror. As Foucault wrote (1857b: 339) "... the collimator in turn became a new telescope."

Foucault presented his first, small telescope at the end of January 1857 to a Saturday-night meeting of the Société Philomathique (Foucault, 1857c; 1857d) and a fortnight later in a written note sent to the more-austere Académie des sciences (Foucault, 1857b; 1857e). Reporting on the meeting, Babinet wrote "Amongst astronomical news, I see nothing more important than the new type of reflecting telescope devised by M. [Monsieur] Foucault ..." (Babinet, 1857a). Foucault told the Academy that his telescope had a "... 10-cm diameter ..." and a 50-cm focal length (Foucault, 1857b: 340), values repeated later (Foucault, 1859a). But elsewhere (correcting an obvious misprint) he wrote that the instrument had a "... useful ..." (Foucault, 1857a) or "... real ..." (Foucault, 1858a: 47; or 1858b) diameter of 9 cm, and when what was presumably the same instrument was taken to observe the total solar eclipse in Spain in 1860, it was inventoried as of 11-cm size (Enumération des objets, 1860). In his *Mémoire* on telescope making published in early 1860, Foucault added that mounted as a Newtonian, the mirror he had shown at the Académie "... gave good images and permitted magnifications of 150–200 times … It has been preserved as the first example that was presented to a learned society."[5] (Foucault, 1859a: 198).

Figure 3: Tarnished silvered mirror roughly 100 mm in diameter given to Sir John Herschel when Foucault visited him at Collingwood on 11 September 1857. The mirror is much faster than those made by Foucault for astronomical use, who also gave Herschel a sector of platinized glass. The interest appears to have been methods for making glass reflective. The two items are now in the Science Museum, London, inventory 1943-55 (author's photograph).

Figure 4 shows a small Newtonian telescope conserved at the Paris Observatory. The associated transport box has "L. Foucault" written on it in his handwriting. Besides being fitted-out to accept the telescope, the box has space for three

Figure 4: Probably Foucault's first telescope from January 1857 (Paris Observatory inv. 251). The aperture stop that slots at the front of the mirror cell has been raised to be more evident. Its diameter is 3¼ French inches (*pouces)* or 88 mm. The focal length of the mirror is 530 mm, corresponding to an *f*/6.0 focal ratio (courtesy: Observatoire de Paris/F. Auffret).

Table 5: Sizes of astronomical objective lenses offered by Secretan in 1868.

Diameter specified In catalogue	0m11	0m135	0m16	0m19	0m217	0m244	0m27	0m30	0m325	0m35	0m38
Supposed (pouces)	4	5	6	7	8	9	10	11	12	13	14
actual diameter (mm)	108.3	136.3	162.4	189.5	216.6	243.6	270.7	297.8	324.8	351.9	379.0

eyepieces. The woodwork of the telescope tube is simple, and there is no stand, indicative of a prototype. I think it probable that this is Foucault's first telescope, at least as far as the mounting is concerned, but that the mirror could be one of at least two produced at about the same time, as I explain in a footnote.[6] Inside the tube, a metal arm survives which once held a reflective prism to turn the light through 90° towards the eyepiece assembly, which, like the prism, has been lost. The idea of using a prism dates back to Newton in 1672 (e.g. Cohen, 1993) and optical layouts using prisms were published in his *Opticks* in 1704 and later in Diderot and D'Alembert's *Encyclopédie* (1767). I will discuss Foucault's prism and eyepiece choices further in Sections 2.3.1 and 2.3.2.

Why is there a multiplicity of quoted sizes—9, 10 and 11 cm—and how might they square with the internal diameter of the mirror cell and full diameter of the mirror shown in Figure 4, which are 121.5 mm?

A first point to consider is that Foucault would almost certainly have used a glass blank from Secretan's optical shop. Table 5 lists Secretan's lens sizes from the very-detailed catalogue "Extract ..." published in 1868 (see Table 1). The stated metric dimensions seem strange until it is realized that they actually correspond to integral numbers of French inches (≡ 27.069 mm), which to avoid confusion with Imperial units, I will henceforth refer to as *pouces.* (The glassmaker Georges Bontemps (1799–1883) confirms that "... opticians have generally kept the use of *pouces* for objective diameters." (Bontemps, 1868: 690).) The *pouce* was divided into 12 *lignes,* so we can expect to find halves, thirds, quarters and sixths as common divisions. Foucault's 121.5-mm glass blank is not a dimension appearing in Table 5, but does correspond closely to 4 *pouces* 6 *lignes*, or 4½ *pouces*.

For any reflecting telescope, there is an inevitable ambiguity concerning the term 'diameter'. Does a numerical value refer to the full dimension of the mirror, to the diameter to which it is stopped down in its mount, to the entrance aperture if not defined by the mirror stop, or even to the inner or outer diameters of the tube, which are easy to measure and may plausibly be given in descriptions published in auction-house or similar catalogues? For Foucault's 11 and 9 cm, the answer would seem to be that the lip against which the mirror would have rested has an inner diameter of 112 mm, while the inner diameter of the sliding stop is 88 mm (my measurements), the aperture at which Foucault ultimately used his telescope. Further, 112 and 88 mm correspond closely to 4¹/₆ and 3¼ *pouces.* This use of pre-revolutionary units was not limited to optics. Tobin et al. (2007) have shown that this was also the case for the pendulum bobs engineered by Gustave Froment (1815–1865) with which Foucault made his famous public demonstrations of the Earth's rotation in 1851 and 1855. It is also apparent that Foucault liked round, even numbers, preferring to state the 6⅓ *pouces* (172 mm) of his Panthéon bob as 18 rather than 17 cm. Characterising his first telescope as '10-cm' falls into this tradition, and we shall see or suspect similar fuzziness in the characterisation of other telescopes. Already the stated 50-cm focal length gives a second example. Barrose (pers. comm., 2002) has tested the mirror shown in Figure 4. Its focal length is actually 530 ± 0.5 mm. The edges are turned down over at least 1 cm, consistent with ultimately stopping it down to less than 10 cm for good performance. With an 88-mm stop, the mirror was used at *f*/6.0.

2.2 Larger Apertures

Foucault had shaped his 10-cm mirror using the standard optical-fabrication procedure of the time. A copper 'ball' and 'basin' were turned to approximately the desired mirror curvature on a lathe. They were then worked against each other using progressively finer emery until they slid over each other with equal ease in all directions, indicating matched spherical surfaces. Next the mirror blank was ground against the ball until it too matched. The ball was then covered with paper which acted as a matrix to hold the finer, softer rouge used to polish the mirror surface (Foucault, 1859a). Three months after presenting his first telescope, Foucault (1857a) reported using the same procedures to complete a 16-cm mirror with a 1.50-metre focal length (~f/9). (Later he claimed "... a real aperture of $0^{m}.18$ ..." (Foucault 1858a: 47; or 1858b), and even later stated that he had made a 22-cm mirror with 1.5-m focal length (Foucault, 1859a: 198). Was he misquoting from memory, or were there several mirrors?) At the same time, he was busy working on a mercury switch for spark coils and an improved Nicol-type polarizing prism, followed by an overseas trip to show off his telescope and prism at the Dublin meeting of the British Association for the Advancement of Science.[7] Perhaps this was why the first test on the sky of what populariser Moigno described as a mirror of "… seven *pouces*, approximately eighteen centimetres ..." was not until 24 September 1857, ten days after Foucault's return to Paris (Moigno, 1857a):

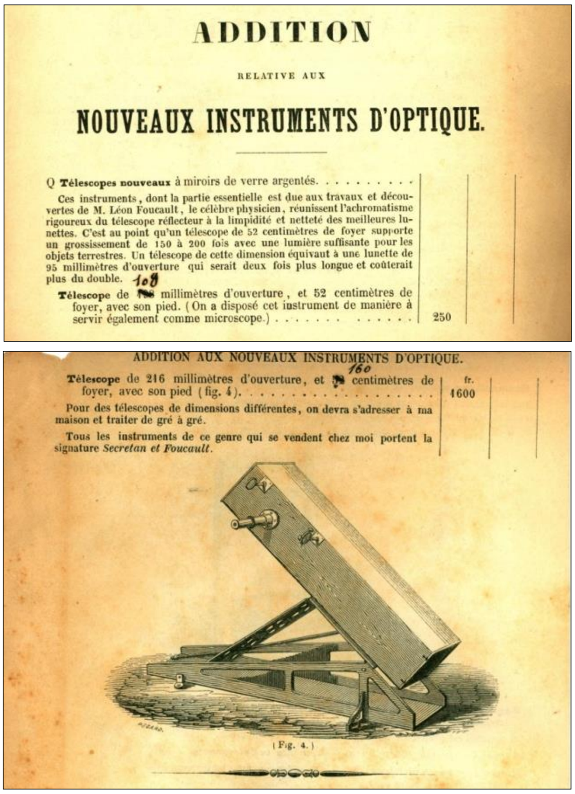
> … Seen in this second mirror, Jupiter was a magnificent sight; we saw distinctly five distinct equatorial belts with different widths and perfectly outlined … the instrument easily provided real magnifications of 2 to 300 times; stars appeared very round and perfectly defined in the eyepiece; the amount of light was considerably more than with the previous mirror type [metal].

Seven *pouces* is actually 189.5 mm. Perhaps initially only the interior 6 *pouces* (16 cm) were well formed.

2.3 Small Telescopes for Sale

Foucault and Secretan now had a product to sell. Babinet continued to mention Foucault's telescope in his newspaper column: in November 1857 he praised its performance on land and sky, for perceiving ships at night, and even for scrutinizing insects "... at a small distance ..." (Babinet, 1857b). Two months later Secretan published a 4-page addition to his catalogue in which Foucault telescopes were advertised, including a woodcut (Table 1; Figure 5).

Produced perhaps in haste, the 'Addition' contains a number of errors. The advertisement, minus the engraving, was repeated on a flyleaf of a brochure published in August 1858, which confirms the penned-in corrections seen in Figure 5 (Lissajous, 1858: 13).[8] The advertised *ouvertures* (apertures) of 108 and 216 mm are indubitably 4 and 8 *pouces,* with focal lengths corresponding to 19 (or perhaps 19½) and 60 *pouces*, respectively. Foucault himself was more circumspect concerning the apertures: in May (1858a: 47; or 1858b) he announced "... real apertures ..." of 9 and 18 cm, and (no doubt rounded) focal lengths of 0.50 and 1.50 m, respectively.


ADDITION

RELATIVE AUX

NOUVEAUX INSTRUMENTS D'OPTIQUE.

Q **Télescopes nouveaux** à miroirs de verre argentés. . . . .

Ces instruments, dont la partie essentielle est due aux travaux et découvertes de M. Léon Foucault, le célèbre physicien, réunissent l'achromatisme rigoureux du télescope réflecteur à la limpidité et netteté des meilleures lunettes. C'est au point qu'un télescope de 52 centimètres de foyer supporte un grossissement de 150 à 200 fois avec une lumière suffisante pour les objets terrestres. Un télescope de cette dimension équivaut à une lunette de 95 millimètres d'ouverture qui serait deux fois plus longue et coûterait plus du double.

Télescope de 108 millimètres d'ouverture, et 52 centimètres de foyer, avec son pied. (On a disposé cet instrument de manière à servir également comme microscope.) 250

ADDITION AUX NOUVEAUX INSTRUMENTS D'OPTIQUE.

	fr.
Télescope de 216 millimètres d'ouverture, et 160 centimètres de foyer, avec son pied (fig. 4).	1600

Pour des télescopes de dimensions différentes, on devra s'adresser à ma maison et traiter de gré à gré.

Tous les instruments de ce genre qui se vendent chez moi portent la signature *Secretan et Foucault*.

(Fig. 4.)

Figure 5. Four- and 8-*pouce* Foucault telescopes advertised in January 1858 in a 4-page "addition" to Secretan's catalogue (Table 1). Two typographical errors have been corrected in ink. It is announced that the instruments are signed, and that larger sizes are available by negotiation (courtesy: R. Smeltzer).

The advertised prices are 250 fr (francs) for the smaller telescope and 1,600 fr for the larger one.[9] To put these sums in context, Foucault's annual salary as Observatory Physicist was 5,000 fr. The 250-fr price for the 4-*pouce* is to be compared with the 600 fr charged for an astronomical-quality 95-mm refractor with finder and pillar-and-claw table stand, but no slow motions (Lerebours and Secretan, 1853: 19). As Babinet (1857a) had noted earlier, "The price is … much less than everything that has gone before." By early 1859 Secretan's billhead was heralding Foucault-system *télescopes* (Figure 6).[10]

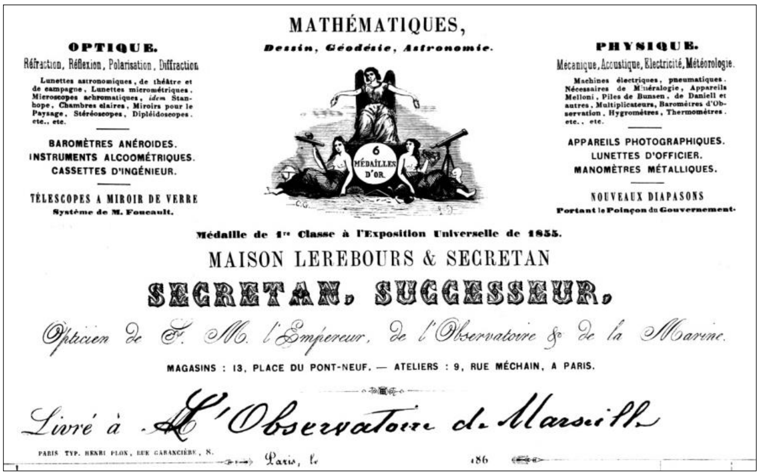


Figure 6: Billhead from the early 1860s trumpeting the wide variety of Secretan products, including Foucault-system telescopes (after: Secretan, 1864; courtesy: www.e-corpus.org).

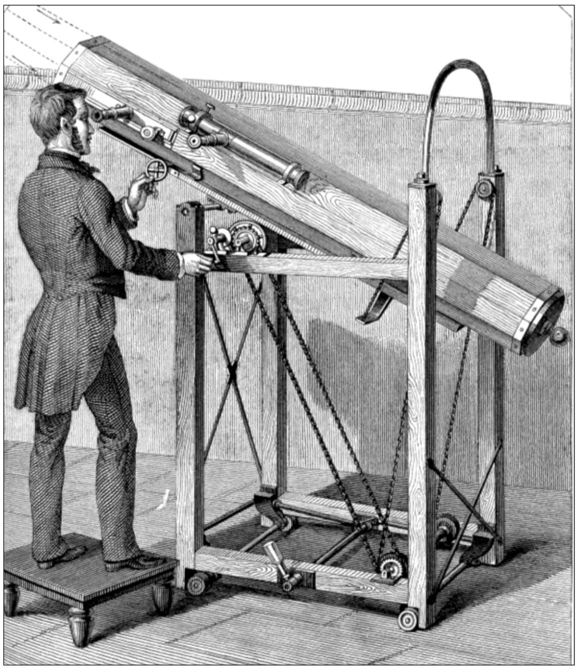


Figure 7: Foucault telescope built c.1858 by Froment for the École Polytechnique, taken from Ganot's *Cours de Physique* (1859a) (courtesy: F. Gires/ASEISTE).

2.3.1 8-*pouce* Telescopes and a Telescope for the École Polytechnique

I am unaware of any extant 216-mm Foucault-Secretan telescope. The "Fig. 4" woodcut of the catalogue 'Addition' claims to represent one (Figure 5), but given its conformity with the 4-*pouce* instruments discussed in the next section, this must be another error. However, an illustration of a Foucault reflector published in a physics text in 1858 may indicate what the 8-*pouce* telescopes were like.

Adolphe Ganot (1804–1887) was a private physics tutor to science and medical students. He was also the prolific author of two physics textbooks (Khantine-Langlois, 2006; Simon, 2009; 2011). Taking advantage of advances in the printing industry, both were highly illustrated with woodcuts ('xylographs'), and both were frequently revised to take account of new developments. Ganot's *Traité Élémentaire de Physique*, first published in 1851, was the more technical, and was praised by Foucault (1853) as a "... charming work, simply written ..." The *Cours de Physique* was simpler, aimed at "... society people ... and persons foreign to the notions of mathematics ..." (Ganot, 1859a: title page). Its illustrations of apparatus often included human users rather than the disembodied hands or eyes characteristic of the more-formal *Traité*. By the time Ganot relinquished authorship in 1880 or 1881, the *Traité* and *Cours* print runs had totalled 204,000 and 51,500 copies respectively (Ganot, 1880).

The first edition of the *Cours* and the eighth edition of the *Traité* are nominally dated 1859, but in fact were published in September and October 1858 (Journal Général de l'Imprimerie, 1858b; 1858c; 1858d; 1858e). Figure 7, from the *Cours*, shows a Newtonian telescope "... brought back into fashion by the recent improvements which M. Foucault has just brought to the construction of the concave mirror ..." (Ganot, 1859a: 372).[11] The octagonal wooden tube is mounted on an alt-azimuth stand reminiscent (i) of William Herschel's 10-foot telescopes because of its rectangular wooden cage structure, and (ii) of Cauchoix's mount because of its adjustment chains. In Figure 7 the observer's right hand adjusts these chains to alter the telescope's altitude, while his left hand turns a worm gear to track the target in azimuth.

Adopting the man's height to be that of Foucault to set the scale (1.65m, Tobin, 2003: 18—people were smaller in the nineteenth century), we can gauge from Figure 7 that the mirror had a 20–25 cm diameter and a focal length of about 160 cm, concordant with Secretan's advertisement and a mirror that is spherical if the effective focal ratio is 162 cm/18 cm ≈ *f*/9. However, Ganot clearly states that this telescope was made by Froment, not Secretan (Ganot, 1859a: 372). In any case, the octagonal wooden tube and a substantial stand seem inevitable features for a reflector of this size, consistent with a much higher price compared to the more-simply mounted 4-*pouce* instruments discussed in the next section.

Figure 8 shows the optical layout, which unlike Figure 7 was printed in both the *Cours* and

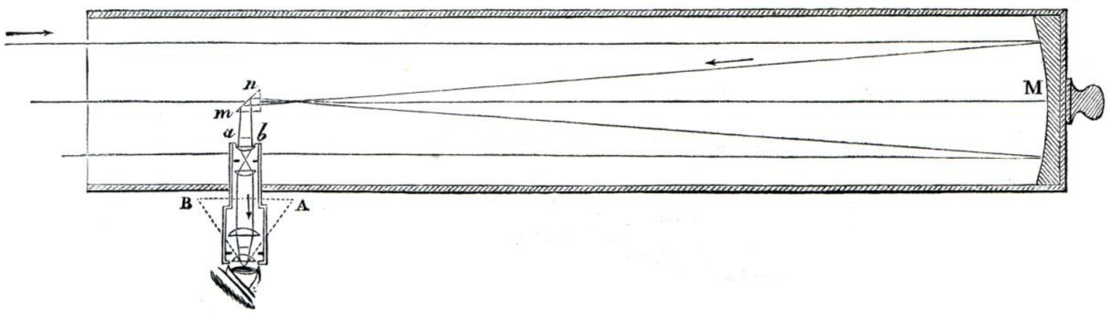


Figure 8: The optical layout of Froment's Foucault reflector. This diagram was published in both Ganot's *Cours* and *Traité* (1859a; 1859b) (courtesy: F. Gires/ASEISTE).

the *Traité.* The proportions in Figure 8 have obviously been distorted for clarity, but the knob behind the mirror in both Figures 7 and 8 makes it clear that both relate to the same instrument, which the *Cours* states was made for France's prestigious École Polytechnique. The ray diagram in Figure 8 does not conform with the accompanying descriptions since if paraxial rays cross before the prism they cannot also form an extended image at *ab*. (This error was corrected in the 10th edition of the *Traité* (Ganot, 1862), where to simplify the pedagogy the four-part eyepiece assembly was reduced to only a single lens which is shown convex, though this is a simplification because the complex eyepiece and relay lenses adopted by Foucault give upright images.) As with the instrument shown in Figure 4, Figure 8 indicates that a small prism bends the optical path through 90º. A pair of relay lenses re-images the prime focus to outside the tube where different eyepieces can be interchanged to obtain different magnifications. The relay lenses permit the use of a small prism and have the added advantage of furnishing an upright image, which is desirable commercially for terrestrial use. Echoing Foucault (1858d: 165), Ganot (1859b: 442) characterised this lens arrangement as "... a veritable microscope ...", and indeed the resolvable detail in the intermediate image would have been at the micrometre scale. Available magnifications of 50× to 800× were stated, with 10× for the magnification of the finder. For focusing, the eyepiece assembly and prism were mounted on a slider which could be moved *parallel* to the length of the tube via a rack and pinion. In Figure 7 the focus knob attached to this pinion is visible directly above the azimuth wheel.

This telescope has not survived in the collections of the École Polytechnique (Thooris, pers. comm., 2014).

2.3.2 4-*pouce* Telescopes

The woodcut in the Secretan catalogue 'Addition' of January 1858 (Figure 5) undoubtedly represents a 4-*pouce télescope*. The following September, a weekly illustrated paper, the *Magasin Pittoresque,* published its own engravings complete with observer (Figure 9). Four months later, another weekly, the *Musée des Sciences,* reprinted the 'Addition' woodcut (Lecouturier, 1859).

At least seven of these small Foucault-Secretan telescopes have survived, listed in Table 6. Figure 10 shows general views of one telescope. The optics are laid out as for the École Polytechnique device (Figure 8), except that the prism is fixed and focussing involves moving the eyepiece and relay lenses with a rack-and-pinion in a direction *perpendicular* to the tube. The instrument is mounted as an alt-azimuth in a square, wooden tube catalogued as walnut (S. Turner, pers. comm., 1998; Wolf, 2014). The altitude is set by a pair of hinged boards, one of which engages with notched racks, akin to a reading stand. Each notch changes the elevation by 2 degrees (Wolf, 2014). In the other board, a knurled knob and screw (missing in Figure 10) presses against a brass cup and provides fine altitude adjustment. For alignment in azimuth the whole telescope must be moved.

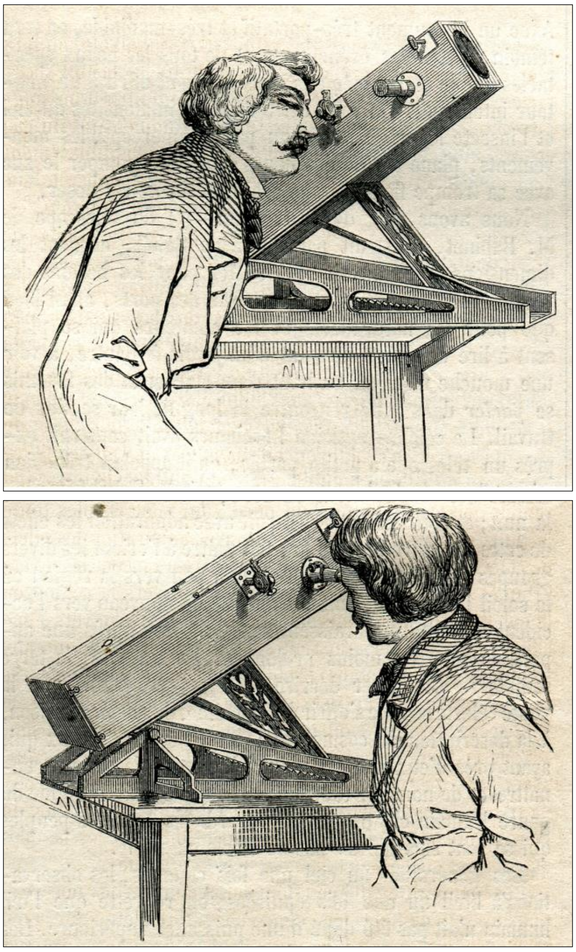


Figure 9: Foucault-Secretan 9-cm wooden-tubed reflector. (Upper) Using the finder sights. (Lower) Using the telescope. The engravings were printed again in another science weekly in mid-1862 (Zurcher, 1862) (after: De l'astronomie observatrice, 1858: 312; author's collection).

Duplicate pairs of hinge knuckles and a removable keeper rod permit the tube to be attached with the eyepiece on either right or left.

Lithographed operating instructions have survived with the Smithsonian Institution instrument (Figure 11). I have endeavoured to render their extraordinary mixture of officialese and colloquialisms in the translation given in Appendix 1.

On one side of the tube is a circular label signed by Foucault to guarantee authenticity (Figure 12). For most, the woodwork is stamped

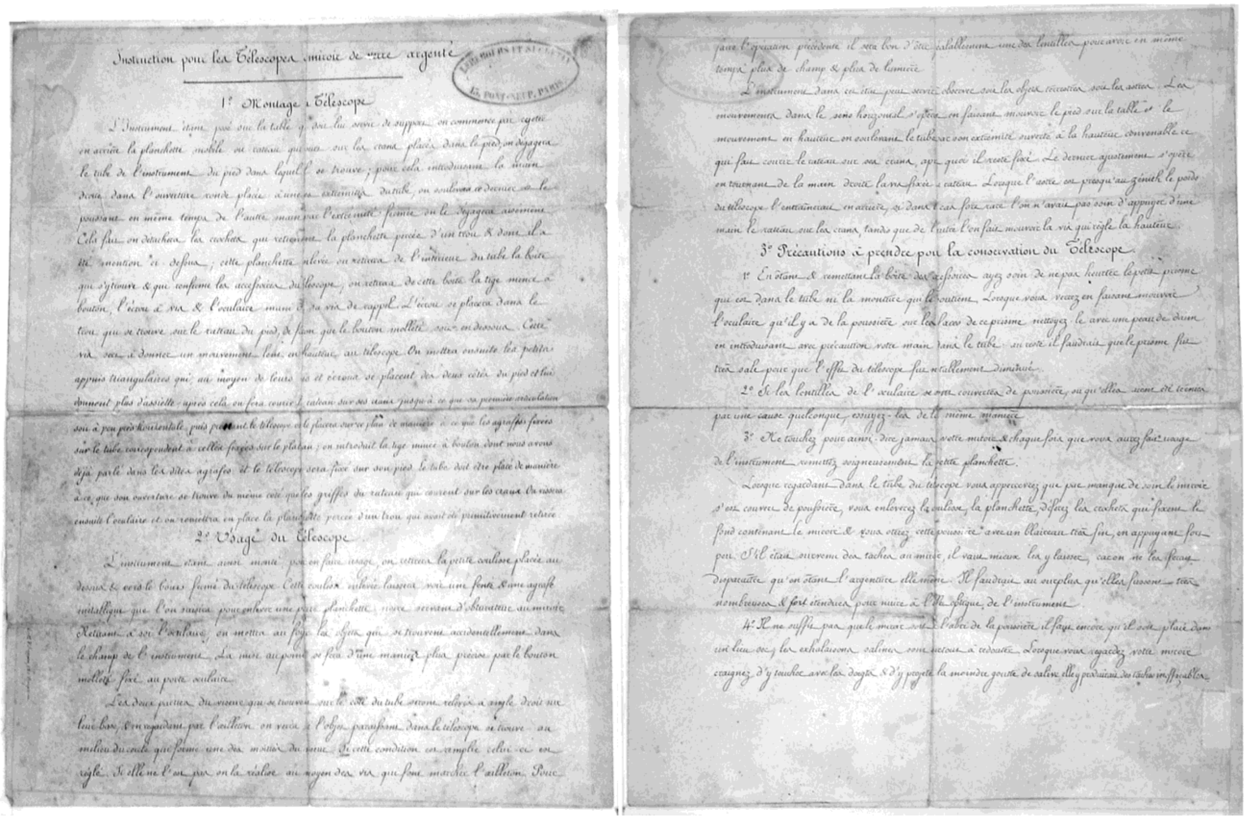
Table 6: Known surviving 4-*pouce* Foucault-Secretan telescopes mounted in square wooden tubes. I have only personally examined the Science Museum one. Information about the rest has been provided by others or garnered from photographs.

Collection/inventory number	Secretan serial number	Comments	Additional description and/or images
Prytanée National Militaire, La Flèche	2	Finder with objective lens and eyepiece.	
	3	Geometric finder.	Chanteloup (2004: 194) www.aseiste.org
Private collection of Prof. Edward D. Wolf, Trumansburg, NY / TRE16	4	Has been renovated by Wolf. Geometric finder.	Wolf (2014)
Deutsches Museum, Munich / 9051	?	An altitude meter has been added.	Auflage (1983: 90)[12]
Smithsonian Institution, Washington / 1979.0889 and NMHT 330623	none surviving	Finder sights have been displaced. Has been remounted equatorially.	Tobin (2003: 290, 291)
Science Museum, London / 1971-479	26	Mirror-cell wooden body and retaining brass sleeve have been reversed; mirror is held by four wooden fingers. Woodwork has been strengthened with brass straps. Finder with objective lens and eyepiece.	collectionsonline.nmsi.ac.uk
Private collection of Patrick Fuentes, France	42	Serial number on body and mirror, which has a 90-mm diameter. Geometric finder. Probably original dust cover.	www.astrosurf.com/rtaa/ rtaa2011_expo.html

Figure 10: The Wolf wooden-tubed No. 4 reflector before restoration (courtesy: Auction Team Breker).

with a serial number (Figure 13).

Figure 14 shows a mirror cell. The mirror is mounted against a brass sleeve. A folded copper sheet acts to cover the mirror when not in use. A small sliding hatch (Figure 15, also visible closed in Figure 10) gives access to this cover. I have measured the overall diameter of the Science Museum mirror as well as the effective aperture defined by the retaining sleeve. These and other measures are reported in Table 7. The concordance of the optical properties (effective diameter, focal length) strengthens the case that the Paris Observatory instrument is a prototype for the commercialized versions. We can further conclude (i) that a smaller, 4-*pouce* mirror blank was adopted for initial production, later reduced and metricated to 90 mm, (ii) that the 4-*pouce* dimension probably referred to the *outer* diameter of the tool used to cut the blank which in consequence is slightly smaller, (iii) that the Secretan advertisements (Figure 5; Lissajous, 1858) were puff concerning the *ouverture* of the telescope, whereas (iv) Foucault was accurate in stating a 9-cm real aperture, but rounded when quoting a ‘0^{m}.50’ focal length. This leads to tentative predictions concerning the 8-*pouce* size of telescope, should an example emerge. The mirror blank will be a millimetre or two less than 8 *pouces* in diameter with effective aperture of 6½ *pouces*, and the focal length will be closer to 60 *pouces* than the 1.50 m quoted by Foucault. In all cases where I have information, the mirror glass has no colour cast or tint, suggesting that optical glass was used, though not necessarily of the best quality, since internal bubbles and striations are of no importance for a mirror.


Instruction pour les Télescopes à miroir de verre argenté

1° Montage du Télescope

2° Usage du Télescope

3° Précautions à prendre pour la conservation du Télescope

Figure 11: Lithographed instructions accompanying the Smithsonian Institution telescope (courtesy: Steven Turner).

Figure 12: Foucault's signature guaranteeing authenticity of the Science Museum telescope (author's photograph).

Figure 13: Serial numbers stamped into the wood of the Wolf 9-cm telescope No. 4. (From left) (a) Under the tri-angular stabilising feet. (b) At the mirror-cell end of the square tube. (c) In a flange of the mirror cell. (d) Under the altitude adjustment hinge (courtesy: Ed Wolf).

Figure 14: Mirror cell of the Wolf telescope No.4 before renovation. The copper dust slide is disengaged. The silvering is absent in places and heavily tarnished elsewhere (courtesy: Ed Wolf).

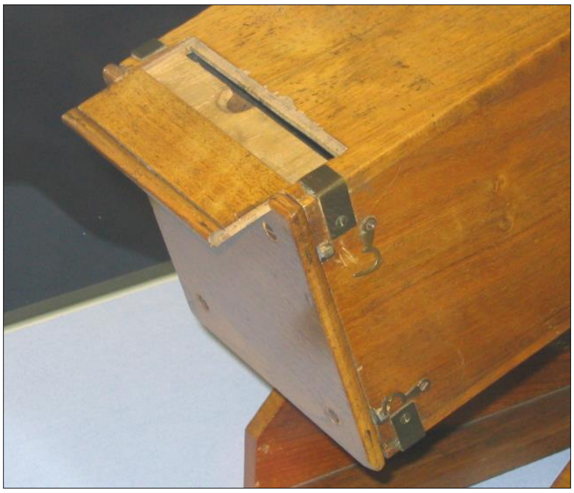


Figure 15: Access hatch to the mirror dust slide of the Science Museum telescope No. 26 (author's photograph).

Table 7: Properties of some early Foucault-Secretan telescopes in square wooden tubes.

Telescope	Full mirror diameter	Effective aperture	Focal length
Obs. Paris, Inv. 251	121.5 mm	88 mm	530±0.5 mm
Secretan 'Addition' 1858 and Lissajous, 1858: 13	*"108 millimètres d'ouverture"*		*"52 centimètres de foyer"*
Wolf, No. 4, TRE16	106.36 mm	87.25 mm	533 mm
Science Museum, No. 26, 1971-479	106.6±0.5 mm	87.5±0.5 mm	
Fuentes, No. 42	90 mm		540 mm
Conversions	*4" ≡ 108.28 mm* *4½" ≡ 121.81 mm*	*3¼" ≡ 87.97 mm*	*19" ≡ 514.31 mm* *19½" ≡ 527.85 mm*

Figure 16: No. 42 9-cm telescope, with eyepiece assembly held by friction, geometric finder and what appears, from the match of the wood, to be an original square dust shutter. The serial number is marked on the body of the instrument and is also engraved on the glass in writing that resembles Foucault's writing (Fuentes, pers. comm., 2015) (after: www.astrosurf.com/rtaa/rtaa2011_expo.html).

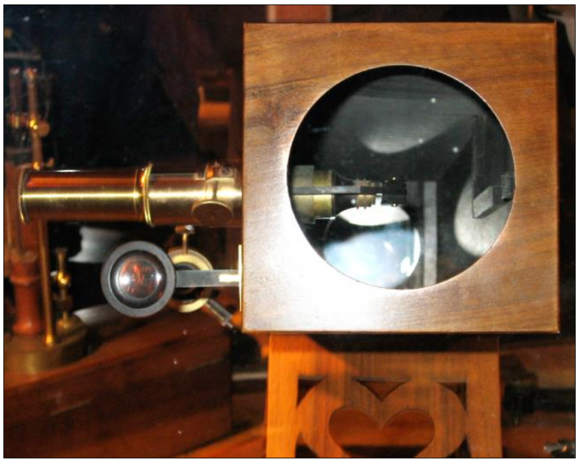


Figure 17: Prism and eyepiece assembly of the Prytanée No. 2 telescope (courtesy: D. Bernard).

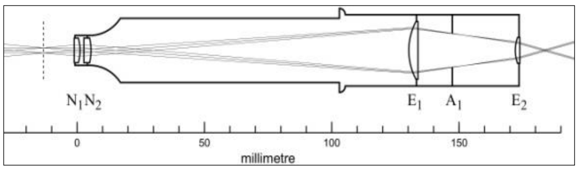


Figure 18. Optical layout and ray trace for the eyepiece assembly of the Wolf 4-pouce telescope No. 4. The ray trace corresponds to the maximum field of view and a relaxed eye (see text); the dashed line indicates the corresponding entrance focal plane For component parameters, consult Table 8. Friction alone retains this assembly within a close-fitting, movable outer sleeve displaced by a rack and pinion.

Some of the telescopes have clearly been modified. The Science Museum mirror cell has been reversed and its woodwork has been strengthened with brass brackets. The Smithsonian tube has been remounted as an equatorial and the finder rings displaced (Tobin, 2003: 290). Shims have been added behind the Wolf telescope mirror.[13] The instructions of Appendix 1 reveal telescopes delivered without any cover to block the entrance aperture, so a cork and wood bung at the Science Museum and a metal stopper at the Deutsches Museum must be later additions. However, the design seems to have evolved to include a cover, because the Fuentes *télescope* No. 42 (Figure 16) has a covering plate which looks original because of the closely matching timber (and hooks, cf. Figure 21).

Other differences also seem original. The eyepiece assemblies of the Deutsches Museum and Fuentes telescopes appear to be held and focused by friction alone (e.g. Figure 16), and this is concordant with the woodcuts of Figures 5 and 9. Yet the lithographed instructions refer to an "... eyepiece furnished with its adjusting screw …", and indeed the other five telescopes have a rack-and-pinion focusing device and their eyepiece assemblies have a different appearance.

Figure 17 shows how the first optical surface of the relay lenses can lie close to the reflecting prism. Figure 18 sketches the eyepiece assembly for the Wolf telescope. There are obvious similarities with the simplified achromatic microscopes sold by Secretan, from which the design was evidently derived (Figure 19; see also Table 11). The nose-piece is composed of two, presumably achromatic elements, N_1, N_2, and there is a Huygens-like eyepiece, E_1, E_2. The ray bundles shown correspond to the fully-illuminated mirror and an eye focussed on infinity. Dotted lines indicate the corresponding focal plane of the assembly, which when the telescope is adjusted of course coincides with the prime focus of the mirror. The field-of-view is limited by the stop A_1 and corresponds to 1.9 mm diameter at this prime focus or 0.2° on the sky. Although A_1 is slightly mis-sized and misplaced, this is not a significant issue because of the narrowness of the ray bundles. There is good eye relief, but the exit pupil is only a millimetre or so in diameter, with the result that floaters in the eye will have been very evident (confirmed by Wolf, pers. comm., 2014). The magnification is 145×. The diameter of the circular aperture at the front of the Science Museum telescope tube is 95.0mm (3½ *pouces*) sufficient for a 0.8° unvignetted field-of-view, confirming that the field is limited by the stop A_1.

From the eyepiece boxes and contents shown in Figure 20 it can be seen that at least sometimes the eyepiece assembly was delivered with a third nose-piece lens to provide additional magnification options, as for the simplified achromatic microscope. A second 'veritable microscope' could also be supplied, with a blunter nosepiece, perhaps indicative of a larger field of view (cf. Section 8.1 below). For storage and transport the eyepiece box could be slipped into the telescope tube: retaining rails are visible to the right in Figure 17.

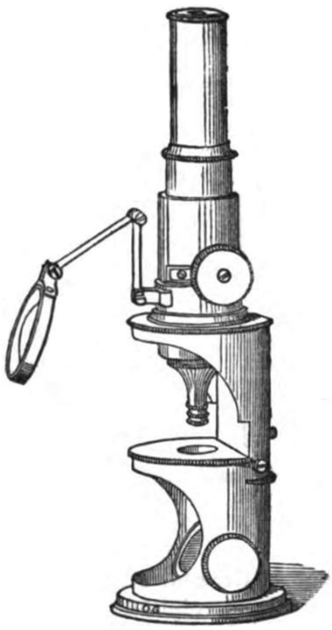


Figure 19: Lerebours' simplified achromatic microscope sold with three stackable nosepiece lenses, rack-and-pinion focusing and even a right-angle prism option (not illustrated) for horizontal use. The similarity with certain of the Foucault-Secretan telescopes is evident (after: Lerebours and Secretan, 1853: 7; courtesy: Universiteitsbibliotheek Gent via Google Books).

Table 8: Lens and aperture specifications for the Wolf TRE16 eyepiece assembly (Wolf, pers. comm. 2014). Measurement uncertainties ~0.5 mm for diameters and ~1 mm for positions and focal lengths. The equivalent focal length is –7.2 mm. For an eye focused at infinity, the entrance focal plane position is –13.2 mm. See also Figure 18.

Component	Position (mm)	Clear diameter (mm)	Focal length (mm)
N_1	0.0	9.0	21
N_2	4.1	9.0	32
E_1	132.1	21.0	41
A_1	147.4	12.5	
E_2	173.0	9.4	21

The finder too appears to have been available in two forms. Figure 21 compares the finders of the Prytanée instruments Nos. 2 and 3. The former has a tubeless telescope as finder whereas the latter only has sight holes. Optical finders are also found on the Science Museum and Smithsonian Institution instruments, but all others have geometrical ones. Nevertheless, it is finder lenses that are mentioned in the lithographed instructions (Appendix 1). The eye-end alignment screws are also mentioned in the instructions and are apparent on the engravings and on all of the seven surviving telescopes (e.g. Figures 10, 16, 17 and 21). The whole instrument could be packed away in a transport box (illustrated in Wolf, 2014). For this, the finder rings fold flat.

For the smaller telescope Secretan's cata-

Figure 20: (Upper) Eyepiece box of the Prytanée No. 2 telescope, with the 'blunt' style of eyepiece assembly (courtesy: L. Chanteloup/PNM). (Lower) Eyepiece box of the Science Museum No. 26 telescope with an eyepiece assembly like the 'simplified achromatic microscope' seen in Figure 19. *Three* nosepiece lenses have been unscrewed from the associated tube. An indentation for the blunt assembly is seen; the blunt assembly itself is pictured at collectionsonline.nmsi.ac.uk (author's photograph). A note attached to the No. 2 box indicates that the cone-like indentation was provided for a dust brush. Another indentation present in both boxes must be for the eyepiece of the finder that equips each instrument (see text).

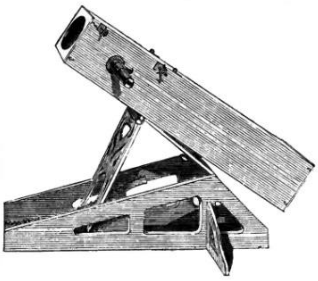
Figure 21: Comparison of the finder provisions on the two Prytanée *télescopes*. No. 2 (upper) is provided with an eyepiece and objective lens (see also Figure 17). Thumb-screws and a sprung-loaded pin permit optical alignment with the main telescope. For No. 3 (lower) the arrangement is purely geometric. A peep-hole defines a viewpoint for a sighting ring. Cross hairs have subsequently been soldered across this ring, but are unlikely to have been effective owing to the eye's inability to focus simultaneously on a nearby object and the sky (courtesy: L. Chanteloup/PNM).

logue 'Addition' adds the intriguing claim "(This instrument has been arranged so that it can also serve as a microscope.)" (Figure 5). It is unclear what is meant, and this possibility is not addressed in the lithographed instructions. The 1853 Lerebours & Secretan Catalogue offered a "Microtélescope ..." (1853: 40), a metal-mirrored reflecting telescope invented by Noël Lerebours

Figure 22: The Wolf 4-*pouce* telescope used to image a wasp's wing. A ~2-cm aperture was used to select the best part of the surviving mirror silvering. It was possible to focus on the specimen placed about 4 m in front of the mirror with the eyepiece assembly still just held by the rack-and-pinion mounting sleeve. Field diameter ~8.4 mm (courtesy: Ed Wolf).

(Lerebours père) in 1818 (Le Rebours, 1915). This microtélescope could serve both as a telescope and as a "... microscope enabling the examination of an insect placed at distance ..." (Lerebours and Secretan, 1853: 40). Of course if the telescope can be focused on sufficiently nearby objects, the magnification will act like a microscope, and we have seen that Babinet reported examining insects this way. This seems the likely interpretation of the advertisement, and Figure 22 shows a wasp's wing imaged thus by the Wolf telescope despite the tarnished and fragmentary state of its mirror silvering (cf. Figure 14). But as an alternative, the 'veritable microscope' of the eyepiece assembly can be unscrewed and in the absence of any stand used as a hand-held microscope, as I have veri-

FIG. 1351.



FOUCAULT'S REFLECTING TELESCOPE.

118 SCIENTIFIC INSTRUMENTS MANUFACTURED BY NEGRETTI & ZAMBRA,

	Each. £ s. d.	Each. £ s. d.
1351 **Foucault's Reflecting Telescope,** for terrestrial and astronomical observations. The novelty and improvements of this telescope, are principally in the use of a new reflecting surface for the large speculum, glass worked of a suitable curve, and coated upon the surface with perfectly pure silver. The eye piece or power is an achromatic microscopic arrangement of lenses mounted on the side of the body of the telescope, the image being received from the large speculum by a prism, and the reflected image examined by the microscopic eye piece, which is fitted with a fine rack work adjustment. With these arrangements, high magnifying powers can be used, and large field of view, combined with full body of light, is obtained at a considerably lower price than the old expensive form of reflecting telescopes with metal speculum. The telescope is mounted on a light but firm table stand of polished walnut wood, having simple and convenient adjustments (fig. 1351) . . . . . . With simple instructions for re-silvering the speculum.		15 0 0

Figure 23: Foucault's telescope advertised in Negretti & Zambra's catalogue for 1859 (courtesy: Google Books and Internet Archive).

fied with the No. 13 and 20-cm telescopes discussed below in Sections 6.2 and 8.1. Whatever was meant, this cannot have proved to be an important sales feature, and the claim was not repeated in later catalogues and advertisements.

Foucault's 4-*pouce* telescope was imported into England by Negretti & Zambra in London. Figure 23 shows the corresponding entry from their 1859 catalogue. The price, £15, was a 50% mark-up on the £10-equivalent of the French price. This does not seem unreasonable, but some years later an anonymous critic complained that for such a telescope, this was "... a price considerably beyond its merits ..." (Silvered mirror telescopes, 1867: 176). The telescope was still in Negretti & Zambra's catalogue as late as 1887, "Supplied to order ...", now for £20 (Negretti & Zambra, 1887: 255). This is enigmatic, because this form of telescope was rapidly superseded in Paris (see Section 8.1).[14]

The serial numbers (Table 6) suggest that forty or more of these 4-*pouce* telescopes were made (see also Section 11).

3 EVALUATING PERFORMANCE

Returning to mid-1857, Foucault then suffered a setback. A "... 40-cm ..."[15] glass disc had been poured, but two months' work showed it would not keep its form (Foucault, 1857a). Foucault attributed this to over-rapid cooling. Presumably grinding and polishing released stresses, changing the shape. He vowed to pay attention to this factor in the future. Foucault did not specify the source of his glass, but the following year he was working with Saint Gobain glass.

Foucault experienced another difficulty at this time: Le Verrier tried to sack him. Details are outlined elsewhere (Tobin, 2003), but he resisted.

Progress was rapid in 1858 and is fairly fully documented. In early March Foucault reported a 32-cm diameter mirror to the Société Philomathique, which he reckoned could separate ⅔ of an arc second, revised a week later to half an arc second, though he did not specify how he determined these values (Foucault, 1858e; 1858f). In May he reported that he had also completed a 36-cm mirror.[16] Both, he said, "... give very good images at the prime focus of $3^{m}.50$." (Foucault, 1858a: 47; or 1858b). This corresponds to *f*/11 and *f*/10 respectively. "But to escape from vague estimates which might give rise to delusions," he added, "I wanted to express numerically the optical quality of these two mirrors considered as telescope objectives." To do this he used a target ruled with equal black and white lines which he removed to the point at which he could no longer resolve the lines with the mirror. With this new procedure he found that his 32-cm mirror

> ... shows distinctly the two-thirds of an [arc] second, or in other terms that it renders separately visible two points separated by the three-hundred thousandth part of their distance from the mirror. (Foucault, 1858a: 48; or 1858b).

He continued:

> The sharpness so defined makes it possible to compare instruments without having to try them side by side; thus it will be possible to eliminate the equivocal, and evaluate meaningfully the progress possible with this new design of telescope.

4 PARABOLIZATION AND POUVOIR OPTIQUE

Thus far Foucault's telescopes were sufficiently slow or small that spherical aberration was minor and good images could be achieved with spherical mirrors, though by modern criteria they were slightly outside what would be acceptable for visual use. (Scaling computations presented in Figure 5.4 of Rutten and van Venrooij (2002), a 9-cm mirror needs parabolizing if faster than ~*f*/8, an 18-cm if faster than ~*f*/11, and a 36-cm if faster than ~*f*/14.) Foucault's next advance was to produce an ellipsoidal mirror, presented at the Société Philomathique on 15 May 1858. This mirror had an announced 24-cm diameter with foci at 1.10 and 9 m. "Without wanting to go into practical details ...", Foucault (1858g: 49; or 1858h) stated that this had been done "... by hand repolishing of the surface and attentively following the successive changes in the optical effects." In other words, he had begun to use at least some of the three optical tests which he would ultimately use to guide the final corrective repolishing of his mirrors—tests which, as Sir John Herschel put it, made the errors of form "... glaringly conspicuous" (Herschel, 1860: 142). On 3 July Foucault reported having parabolized a second mirror of the same size,[17] with a focal length of 1 m (i.e. ~*f*/4.2) capable of resolving two points separated by 1/250,000th of their distance from the mirror (Foucault, 1858i; 1858j). This was only eight years after his spinning mirror experiment had shown that light travels slower in water than in air, so driving the final nail into the coffin of the particle theory of light, which predicted the opposite. For images that are affected by aberrations, stopping down the objective usually *improves* image quality. Foucault was palpably pleased to find that his image quality was *poorer* if he reduced the illuminated area of the mirror with a movable diaphragm, a result which:

> … agrees fully with theoretical predictions, because in the wave theory the convergence of a conical beam is all the more exact if the extreme rays cross over at a wider angle (Foucault, 1858i: 52; or 1858j).

I note that this first parabolic mirror cannot be the one used in the École Polytechnique telescope on account of the significantly different focal ratio (see also Section 6.2 below).

At the beginning of August Foucault outlined his progress in a *Mémoire* sent to the Académie des Sciences, where it was presented by the physicist J.-B. Biot (1774–1863) (Foucault, 1858k). "... a deep silence reigned in the chamber ..." reported Moigno (1858b), indicative of the academicians' interest in this work. Foucault had parabolized a 33-cm mirror (focal length

Figure 24: Wooden models used by Foucault when explaining his knife-edge test (Paris Observatory, inv. 244). The test reveals errors of form in exaggerated relief. At left, there has been too much polishing in a ring midway between centre and edge. At right, the center is overpolished and the edge is turned down (courtesy: Observatoire de Paris/F. Auffret).

2.25m, *f*/7) which in calm air on the morning of 22 July 1858 had split the close double star γ^2 Andromedae, which at the time had a separation of about 0.5″ (Woolley and Symms, 1937). In a fuller text in *Cosmos*, Foucault (1858d) noted that it took less than 6 hours to turn the initial mirror surface into a paraboloid. He also introduced the *pouvoir optique*, or optical power, defining it as the cotangent of the angular spacing of his test grid when just resolved. The test grid was now ruled on a plate of silvered glass by Froment. Froment probably also built the telescope tube and mount.[18] Foucault measured 400,000 for the optical power of his 33-cm mirror.[19]

Almost immediately the 33-cm reflector was used from Foucault's house on the rue d'Assas by his friends and neighbours to observe Donati's Comet (C/1858 L1; e.g. see Faye, 1858a; Moigno, 1858c; 1858d; 1858e). Hervé Faye (1814–1902), one of Foucault's colleagues at the Observatory, opined that "... for optical power, for perfection of the images, M. Foucault's telescope left me wanting for nothing more." (Faye, 1858b: 775). Drawings were made by a certain Charles Bulard (1825–1905), one of the numerous individuals whom Le Verrier had fired from the Observatory. A further invention was also announced (Moigno, 1858f). Foucault mounted the mirror on an inflatable rubber cushion, and via a nozzle at the eyepiece adjusted the pressure in order to counteract gravitational flexure of the glass and so obtain optimum image quality. In the opinion of England's Astronomer Royal, Sir George Airy (1801–1892) "The success of this contrivance is complete." (Report of the Council, 1860: 147). It should be noted that Foucault will almost certainly already have used rubber bladders, which were commonly used for storing gases, when employing limelight earlier in his career (e.g. Fizeau and Foucault, 1844).

Figure 25: The only remaining vestige of Foucault's first 33-cm telescope may be this chipped 33-cm mirror preserved in Algiers at the Centre de Recherche en Astronomie, Astrophysique et Géophysique (formerly the Observatoire d'Alger) (courtesy: Françoise Le Guet Tully and Marc Heller).

At the end of 1858 Foucault sent details of his optical tests to the Académie, where they were presented by the crystallographer Henri de Senarmont (1808–1862) (Foucault, 1858l; Moigno, 1858g). To outline them briefly: the first involved examining the tightness of the image of a point source with an eyepiece. The second involved examining the image of a rectangular grid of wires. The third, the knife-edge test, involved looking at the mirror from downstream of the image of a point source. How the light dimmed when the image was cut through by a sharp edge revealed shape errors in exaggerated relief, indicating where *retouches locales* were needed (Figure 24). Foucault also published his tests in greater detail in Moigno's *Cosmos* (Foucault, 1858m). They soon became availabe in English (Foucault, 1859c; Herschel, 1860). For a modern overview of the three tests, see e.g. Tobin (2003).

5 LARGE APERTURES FOR PROFESSIONAL ASTRONOMY

While all this was happening, Le Verrier had returned to the fray against Foucault. In mid-1858 he cut off Foucault's salary and forbade him entry to the Observatory (Favé, 1858). This is no doubt why, in his paper published in August's *Cosmos*, Foucault had concluded (1858d, 168):

> These results … are also of some interest because of the modest expenditure that has sufficed to obtain them. Thanks to the selflessness of the honourable and learned maker M. Secretan, who for two years has not ceased to put the resources of [his] great enterprise at my disposal, these costs have remained within such bounds that a single individual has been able to bear them.

The final comment is slightly disingenuous, as I will discuss in Section 7. Nevertheless, although the resources within his control would have permitted Foucault to acquire and polish larger mirrors at Secretan's works, to mount them as telescopes he needed institutional support.

Exactly what happened next is not completely clear. In December 1858, Moigno (1858h) reported that Bulard would become observer at a refounded Algiers Observatory, taking with him a 50-cm Foucault telescope. Two weeks later Moigno added that Foucault was "... at this moment putting the final touches to a 50-cm telescope." (1859a: 33). This is partially confirmed a fortnight later by Le Verrier, who was doubly indignant because the reorganisation of the Algiers Observatory wrenched control from the Ministry of Education and the Paris Observatory, *and* because Foucault was supporting this new enterprise with a telescope. He complained that "... a big mirror … is finished, that it is very good … but that it is destined for the Algiers Observatory!" (Le Verrier, 1859; his underlining). Yet when Bulard went off to Algeria in September 1859, it was not a 50-cm instrument but Foucault's 33-cm telescope, the one used to observe Donati's Comet, that he took with him, probably with two mirrors,[20] at least one of which appears to have survived (Figure 25). Algiers Observatory inventories show that the telescope was not equatorially mounted (e.g. Trépied, 1884).

Foucault filled some time by incorporating an aberration-correcting silvered-glass mirror within a catadioptric microscope, which Bulard used to make some hasty sketches of human blood corpuscles (Foucault, 1878). Happily, a truce with Le Verrier was called early in 1859 thanks to the intervention of the Emperor's aide-de-camp (Tobin, 2003).

Reading between the lines is now necessary. Foucault returned to the production of a ~40-cm mirror. In his telescope-making *Mémoire* written a little later, he stated that "... attacking a diameter of 42 cm, the workman assigned to shape the mirror failed on five separate attempts." (Foucault 1859a: 198). This is more-or-less confirmed by a bill issued by Secretan on 22 June 1859 for the supply of a "... 0^{m}41 ..." disc and corresponding telescope tube, eyepieces and accessories. Included in the invoice was redoing the surface four times, and a fifth change involving a change of curvature (Secretan, 1859b). It was at this point, Foucault continued, that he felt "... the imperious necessity of studying the form of the surfaces ..." and developed his three test procedures. But they had been devised many months earlier with smaller mirrors! Foucault appears to have been simplifying, and also in his claim that it was only then that he had the idea of applying a local correction. His next comment is bitter but illuminating. "This idea, decried by the artisans, nevertheless succeeded perfectly ..." (Foucault 1859a: 199). The *retouches locales* on smaller surfaces had been done at Foucault's home on the rue d'Assas, and my reading is that he encountered opposition introducing them in Secretan's workshop. Be that as it may, in July Le Verrier was telling the Académie that Foucault had completed a 2.50-m focal-length *télescope* for the Observatory, whose mirror diameter is variously described as 40 cm, 15 *pouces*, or 42 cm (Foucault, 1859a; 1859d; Moigno, 1859b). It would seem at this point that the mirror was mounted in a temporary tube placed on an old "... chain mount ..." (Secretan, 1859b). Early in the new year, Secretan (1860a) billed for a full equatorial mount and 42-cm mirror cell, which would seem to be the full mirror diameter.[21] Figures 26–29 show the telescope.

Figure 26: The 40-cm telescope made by Foucault and Secretan for the Paris Observatory in 1859 (inv. 212). The original eyepiece assembly has been replaced. Coarse adjustment in declination in achieved via the support rod. Fine adjustment is provided by a screw engaging the underneath of the tube (cf. Figure 31) (courtesy: astro2009.futura-sciences.com and X. Plouchart).

The equatorial mount was the work of Wilhelm Eichens (1818–1884), the head of Secretan's workshop (Figure 30). For the mirror, ordinary commercial crown glass from the Saint Gobain glassworks was used, which has a green tint. The disc was ground to shape in the Paris factory

Figure 27: The 40-cm telescope is signed "Secretan à Paris" near the declination circle. The cursive font is also found in the firm's signature on photographic lenses. There is no lock or fine adjustment (cf. Figure 41), these functions being provided by the rod and hinged plank seen in Figure 26 (author's photograph).

Figure 28: To improve strength while minimizing weight, the mirror of the Paris Observatory 40-cm reflector has a curved back, which was polished for monitoring progress during silvering. The mirror is no longer held on an air bag. The green tint is characteristic of St Gobain crown glass (author's photograph).

of Louis Sautter (1825–1912) who, like Secretan, was Swiss-born. Sautter's trade included the manufacture of Fresnel lenses for light-houses, so he had the equipment to work large pieces of glass. In order to increase stiffness but reduce weight the mirror was given a convex rear, doubling in thickness from edge to centre. As to

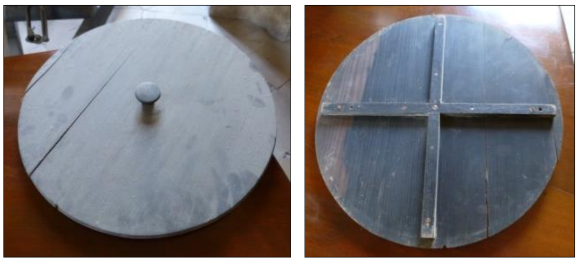


Figure 29: The dusty tube cap for the 40-cm reflector is made of thin wood strengthened with a wooden cross which also acts to hold the cap in position in the tube (author's photographs).

actual thicknesses, and without referring specifically to the 40-cm telescope, Foucault (1859a: 234) wrote of central thicknesses of "... at least a tenth of the diameter." The mirror front was then worked spherical against a metal ball. The final polishing and *retouches locales* to paraboloidal shape were done at the Observatory. Despite the internal stresses of ordinary glass, the mirror held its optical form, although it was necessary to counteract gravitational sagging with an inflatable cushion. Ultimately, this contrivance cannot have been considered satisfactory, and was replaced in 1867 or 1868 by an adjustable metal spring (Figure 28).[22] The optical layout followed that adopted previously (Figure 8) except for an important innovation. The prism and relay-lens pair of the microscope introduced spherical aberration. These Foucault corrected with *retouches locales* to the primary mirror. "... contrary to normal usage," he wrote (Foucault, 1859d: 86), this arrangement "… con-

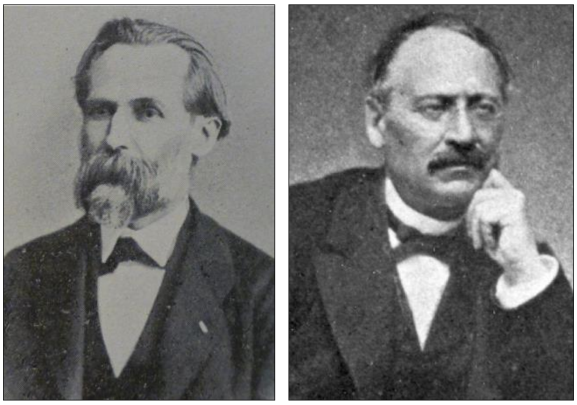


Figure 30: (Left) F. Wilhelm Eichens (1818–1884). (Right) Adolphe A. Martin (1824–1896). Details about both are scanty. Eichens was born in Berlin (Légion d'Honneur, 1862) and according to Caplan (2012) was declared legally insane towards the end of his life. Sebert (1896) gives a brief account of Martin, who died in Caen (Registre d'État Civil, 1896) (both after: de Gramont and Peigné, 1902; courtesy: Bibliothèque Nationale de France).

sists of correcting the eyepiece by the objective …" and many decades later was to lead to problems with at least two of his large professional telescopes when it had been forgotten that the mirror was not corrected on its own, but in combination with the prism and relay lenses.[23] Figure 29 shows the tube cap. Probably it is a replacement installed in 1867 (Eichens, 1867a), but its design is no doubt original because it is similar to that of the Paris Observatory 20-cm reflector discussed below (Section 6.2) and the telescope presented in Figure 100. "... chimney currents ..." were later noted as the "... plague of all reflectors ..." (Silvered mirror telescopes, 1867: 178). Aeration vents near the mirror were duly pierced.[24] The instrument could separate γ^2 Andromedae and had an optical power of 480,000, determined from a new design of resolution target composed of a leaf of ivory inscribed with groups of black lines spaced by 1, ½, ⅓, ¼, … 1/10 mm and placed at 80 m.[25] Charles Wolf (1827–1918) and Georges Rayet (1839–1906) later used this telescope equipped with a dispersive, multiple prism to discover the hot, emission line stars which now bear their name (Wolf and Rayet, 1867).

The 40-cm telescope was considered portable. It was taken to observe the solar eclipse in Spain in 1860 (Chacornac, 1860a; 1860b). Le Verrier showed it off in Metz in April 1866 at a regional meeting of the Association Scientifique de France, of which he was the founder (Terquem, 1866: 227). It was also taken to observe solar eclipses in 1868 from the Malay peninsula in what is now Thailand (Orchiston and Soonthornthum 2017; Stephan, 1868) and in 1905 from Guelma in Algeria (Stephan, 1911). For this latter eclipse, the prism was replaced by a plane mirror to give a larger field and to bring the focus to the tube wall. Presumably this is the plane mirror now present in the telescope. Plate L2 of Stephan (1911) shows the telescope on an inclined ramp in order to adapt the polar axis to the North African latitude. The air vents are evident.

While he was completing the 40-cm telescope, Foucault wrote a comprehensive forty-page memoir detailing his procedures, which appeared in the 1859 volume of the Paris Observatory *Annales*, actually published in March 1860 (Foucault, 1859a; Journal Général de l'Imprimerie, 1860a). The dean of Britain's amateur astronomers commented on the "... praiseworthy liberality ..." of this (Webb, 1863: 130). Figure 31 from Foucault's memoir shows his adopted wooden mount with a rod to stabilise the tube in declination (cf. Figure 26). A handy knurled knob not far from the eyepiece allowed the observer to make fine adjustments in declination.

With his procedures published, printed evidence of Foucault's telescope-making now becomes sparser.

In early January 1860 Le Verrier petitioned the Education Minister for 45,000 fr to build and house what was to be Foucault's largest telescope (Le Verrier, 1860b).[26] But before this, Foucault had already ordered two large discs of glass, of 80- and 85-cm diameter.[27] One might expect that the 85-cm disc was conceived as a ball for working the smaller disc, but its specifications contradict this idea (Sautter, 1861).[28] In any event, it was the 80-cm disc that Foucault chose to shape, and he judged the size too great to work in the usual way against a similarly-sized ball. The initial spherical surface was engendered with a 50-cm glass tool and frequent checks with a spherometer. Polishing was performed by hand (Figure 32). The mirror was finished in early 1862 with a useful aperture of 78

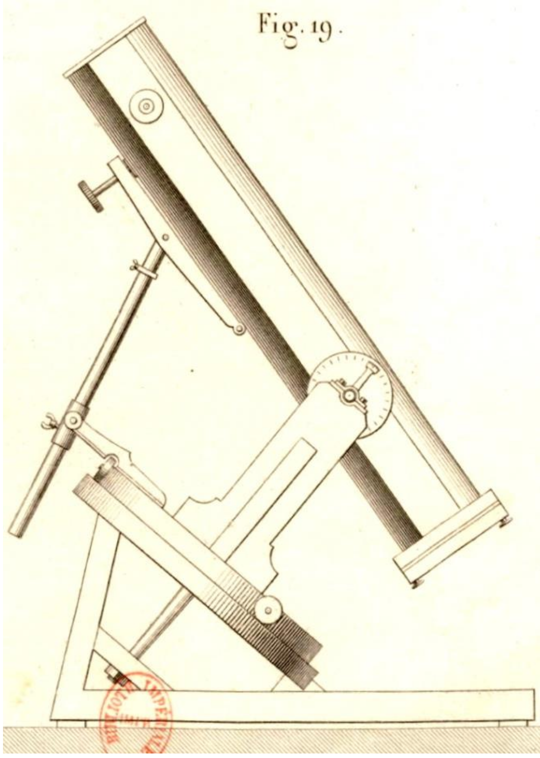


Figure 31: Eichens' mount, as illustrated in Foucault's memoir on telescope-making (after: Foucault, 1859a: Plate I; courtesy: gallica.bnf.fr).

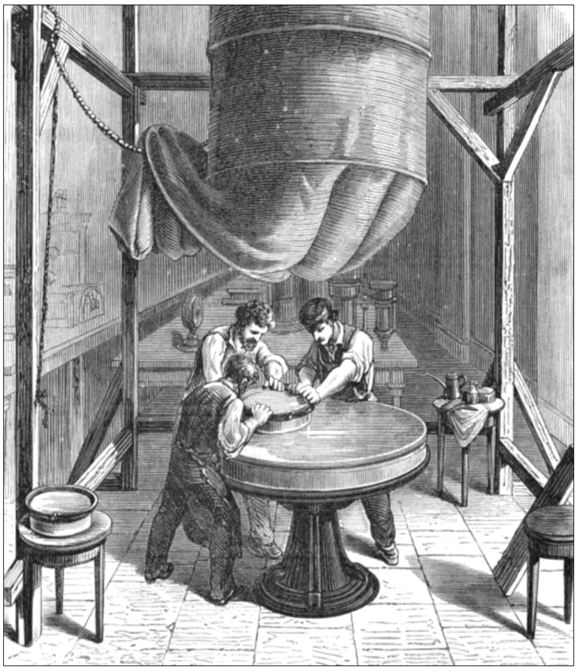


Figure 32: For diameters up to about 40 cm Foucault worked the mirror against a glass 'ball'. The increased forces needed to figure larger sizes were counteracted by employing several workmen or by suspending the upper piece from springs. Final polishing was accomplished with smaller tools, as illustrated here for the 120-cm mirror worked by Foucault's pupil Adolphe Martin in the 1870s. A decade earlier Foucault (1864a) had thought it "... extremely likely ..." that machine polishing would be needed for a mirror this big, and indeed the 120-cm mirror was not a success. The mirror is shown being worked in the Meridian Room of the Paris Observatory. The vertical cloth tube indicates that it was tested making use of the zenithal well that pierces the height of the Observatory (after: *L'Illustration*, No 1668, 117 (1875); author's collection).

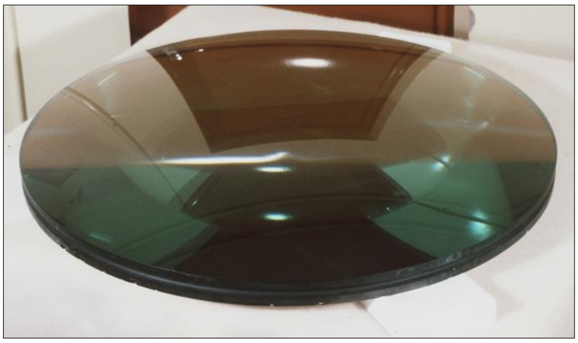


Figure 33: Foucault's largest telescope mirror, nominally of 80-cm diameter, completed in 1862. The groove in the edge is for attaching manipulating cords during polishing (author's photograph).

cm and a 4.5-m focal length (Foucault, 1862a; Figure 33).[29] It was temporarily mounted as an alt-azimuth instrument and used in Paris. It seems the mirror was mounted on an air bag, since a Secretan bill (1861b) includes 54 fr for a "Cushion in rubber", but the contrivance had disappeared by 1876 when the Scottish astronomer Charles Piazzi Smyth (1819–1900) visited Marseilles and noted "Mirror back all naked and exposed, very green glass and supported merely by a bar of wood across a central pad." (Brück, 2003: 44). In 1864 the telescope was remounted equatorially and installed under the clearer

Figure 34: Flyer from the Secretan firm c.1864 advertising the Marseille 80-cm reflector, now converted to an equatorial mount with a regulated clockwork drive. For photographs of the instrument, see Tobin (1987; 1998) and Tobin and Holberg (2008) (courtesy: Ville de Toulouse, Archives municipales, 5M40/1).

skies of Marseilles (Tobin, 1987). Figure 34 shows a flyer distributed by the Secretan firm illustrating the new mount. In his telescope-making memoir Foucault (1859a: 235) had written of Eichens' equatorial stand that "... nothing will prevent the addition of a clockwork motor as needed." Beginning in 1862 Foucault began to work on speed regulators, and the flyer shows and its text trumpets a regulated clockwork drive, which was powered by a 60-kg weight (Secretan, 1863). The complex history of such drives has already been broached by Caplan (2012), Darius and Thomas (1989), and myself (Tobin, 2003), and merits further study. The fixed eyepiece seen in Figure 34 proved impractical for a telescope of this size. In 1865–1866 the tube was cut down and the eye piece, prism

Figure 35: Toulouse Observatory's 33-cm Foucault telescope, much modified. Initially mounted as an alt-azimuth, an equatorial mount was under construction in 1863 (Petit, 1863). The base was strengthened in 1874 by Brunner. This photograph dates from after 1891, the year when a cast-iron mount by Eichens was installed, salvaged from another telescope (Lœwy, 1891), but before the tube was replaced with a metal one (Baillaud, 1899) (author's photograph from an original at the Paris Observatory).

and relay lenses set on a carriage that could revolve around the axis of the telescope tube to a more convenient angle (Foucault, 1865; Tobin, 1987: Figure 7).

Other professional telescopes were also made about this time. A 33-cm telescope was made for the Toulouse Observatory in about 1860 (Petit, 1863; Figure 35). The Musée des Arts et Métiers in Paris conserves a 33-cm Foucault mirror with almost the same declared focal length as Foucault's first 33-cm mirror (Figure 36).[30] Is this the Toulousian or even the original 33-cm one returned to Paris, or a remnant of yet another instrument? In September 1861 Bulard, now Director of the Algiers Observatory, returned to Paris to take delivery of a 50-cm telescope (Le Guet Tully et al., 2003). Was its mirror the one Moigno referred to in early 1859, or another one? The Algiers instrument was later remounted, but its mirror is now lost. As in Marseilles, a hump-backed observing 'bridge' was installed for eyepiece access (Le Guet Tully et al., 2003: 31, cf. Tobin, 1987: Figure 7). In 1863 Secretan quoted for an 80-cm telescope for Toulouse. Foucault began work on its mirror before his death, but the instrument was not delivered until 1875 (with a new mirror), and first put to use on 1 February 1876 (Bach et al., 2002; Lamy, 2008; Tisserand, 1876; Figure 37).[31] Also in 1863, Saint Gobain cast glass blanks for a 120-cm reflector for the Paris Observatory. Prompted no doubt by the success of the 80-cm telescope, this larger instrument had been suggested to the Education Minister as early as April 1862 (Le Verrier,

Figure 36: Front (left) and rear views of a 330-mm mirror attributed to Foucault conserved by the Musée des Arts et Métiers in Paris. The focal length claimed on a paper label is 2.29 m, close to the 2.25 m announced by Foucault. One might think that the octagonal wooden cell once formed part of a telescope. In this case, the black marks visible in the rear view would be paint to reduce reflections and the mirror would now be reversed for display purposes. But if this were the case, one would also expect the exposed circular cut of the wood around the mirror to be blackened too. The mirror is made of clear glass. The tarnished concave surface is protected behind an octagonal sheet of thin glass (author's photographs).

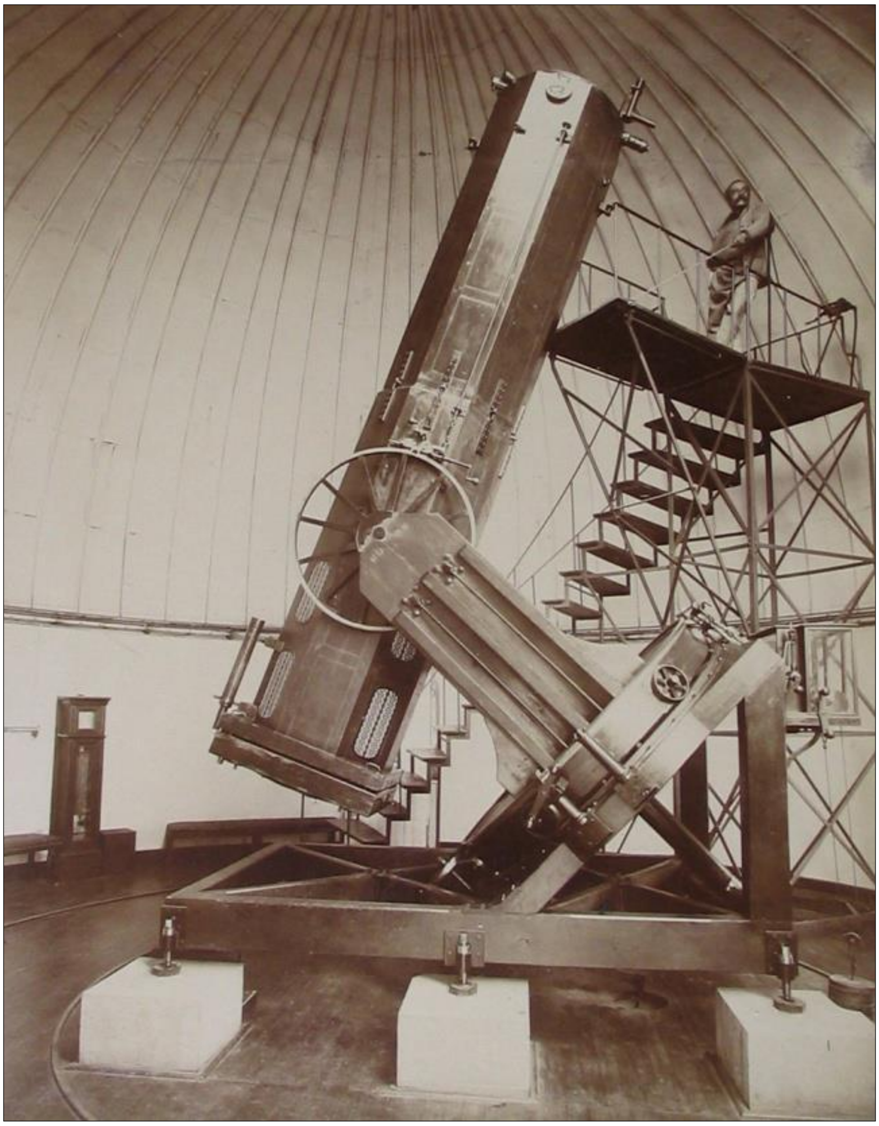


Figure 37: The Toulouse 80-cm telescope begun by Foucault. Following Foucault's death the mirror was worked unsatisfactorily by Adolphe Martin (see Section 7). The telescope was finally delivered with a new 84-cm mirror figured by the Henry brothers. Similarities with the Marseilles telescope are evident. The eyepiece appears to be moveable around the tube, as for the Marseilles 80-cm telescope after modification in 1865. In 1889 the wooden mount was replaced by a metal one built by Paul Gautier (e.g. Baillaud, 1899) (author's photograph from an original at the Paris Observatory).

Figure 38: Palais de la Découverte telescope, formerly the property of Félix Worms de Romilly. The sliding focusing plate and control knob are visible at the front of the tube (cf. Figures 7 and 40) but the eyepiece has been removed and its mounting hole covered with a circular brass plate (see text). The highly-polished octagonal tube is decorated with a slight step close to the position of the declination axis. The handle of one of two hand cranks for tracking in hour angle can be seen (author's photograph).

1862). A note from Foucault (1862b) estimated 30,000 fr for the cost of the optics. Again, there was a long delay before the telescope was finally delivered in 1876, but it proved unsatisfactory, as will be discussed further in Section 9.1.

In the 1860s the Bal Bullier, a dancing hall close to the Observatory, was decorated with some 240 'curiosities' for the amusement of clients, including a scale model of a Foucault silvered-glass telescope (Rouget, 1869). Did the model represent the Marseilles telescope, or perhaps the planned 120-cm one for Paris?

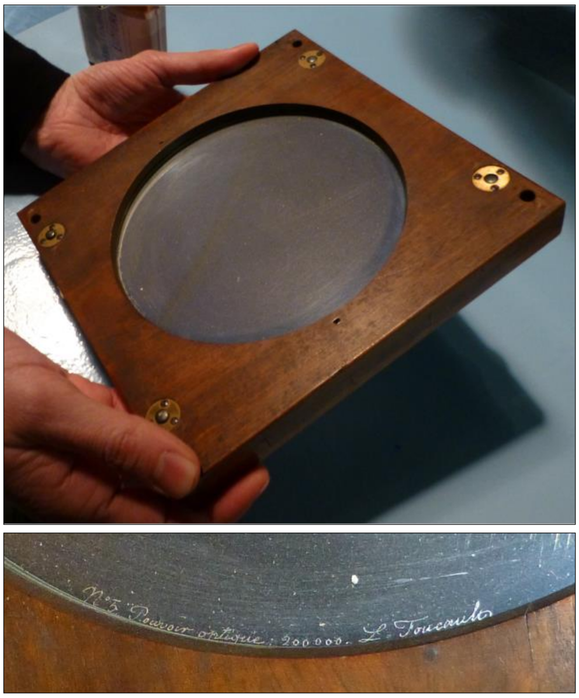


Figure 39: (Upper) Palais de la Découverte telescope mirror cell. (Lower) Foucault's inscription and signature at the edge of the mirror, which perhaps were made using a diamond because an inventory of Secretan's shop (Sebert, 1867–1868) mentions "3241° A [diamond] for writing" (author's photographs).

6 FOUR MORE TEXTBOOK ILLUSTRATIONS

Four textbook illustrations from the early 1860s reveal further details concerning the development of Foucault-Secretan telescopes at this time.

6.1 A Telescope Illustrated by Ganot (1860)

Figure 38 shows a telescope currently on display in the geometrical optics room of the Palais de la Découverte science centre in Paris. Some of the history of this device has recently been outlined by Trap and Tobin (2014). At the beginning of the twentieth century, the telescope was examined by the physicist Aimé Cotton (1869–1951; Cotton, 1905), who in 1937 removed the prism and eyepiece to convert it into a collimator for use in a speed-of-light demonstration in the newly-opened Palais de la Découverte (Kwal and Lesage, 1937: 232–234). We measured the mirror (Figure 39). Its full diameter is 153 ± 1 mm, close to 5⅔ *pouces* (Cotton (1905: 44*) quotes a "... useful diameter ..." of 15.2 cm), but the retaining brass collar reduces the effective aperture to 143 ± 1 mm, close to 5¼ *pouces*. The focal length is 680 ± 1 mm, corresponding to *f*-ratios of 4.4 and 4.8 depending on whether the full or effective mirror diameter is considered. Foucault engraved his signature into the metal plates of some of the daguerreotypes he snapped as a Sunday pass-time when a medical student in the early 1840s (Tobin, 2003: 36). Thus it is unsurprising that he inscribed this mirror with "N° 5 Pouvoir optique: 200 000. L. Foucault." (Figure 39). This is the only one of his known mirrors that is signed, perhaps because it was made for a friend.

This telescope belonged to Félix Worms de Romilly (1824–1903), who if not an intimate, was certainly a very close acquaintance.[32] Worms de Romilly, or de Romilly as he later styled himself, was from a rich banking family and had studied law, but his passion was for physics. In 1888 he was President of the Société Française de Physique (French Physics Society) to which he bequeathed the telescope. In his will the telescope's fast focal ratio was explicitly stated to be unique (e.g. Société Française de Physique, 1903):

> The focus lies at a distance five times the diameter of the mirror: this is a difficulty which he [Foucault] only faced up to this one time.

This of course is not true. Foucault's first parabolic mirror was faster. But there can be no doubt that when Ganot (1860: 451) illustrated the 9th edition of his *Traité* with a Foucault reflector described as having "... a mirror of only 0^{m}.16 diameter ..." and a horizontal extent "(*l* = 0^{m}.70)" that the model for the accompanying woodcut (Figure 40) was de Romilly's telescope. The 9th edition was published on 18 June 1860 (Journal Général de l'Imprimerie, 1860b; 1860c), which provides an upper limit to the date of manufacture. The focus mechanism sliding *along* the length of the tube is clearly visible in the woodcut and Figure 38, and parallels the arrangement adopted for the École Polytechnique telescope (Figure 7). This arrangement must have proved unsatisfactory—probably the prism vibrated and perhaps there was a lateral image shift during focusing. In all other Foucault-Secretan instruments the prism is fixed and focus is achieved by moving only the eyepiece and relay lenses, and in a direction *perpendicular* to the length of the tube. Combined with the low serial number on the mirror (Nº 5), this suggests a date of early summer 1858 for this instrument, after Foucault's invention of the *pouvoir optique* and way to parabolize mirrors, which is nevertheless after the adoption of a fixed prism for the commercialized 4-*pouce* telescopes discussed in Section 2.3.2. We can imagine that Foucault gave this unique mirror to his friend Worms de Romilly who had Secretan install it in a luxurious polished-wood equatorial mounting with fine brass fittings. An Irish artisan visitor to an Exposition Universelle in Paris in a later decade commented on these two aspects of French work—sanding prior to varnishing using emery paper attached to a wooden pattern, which "... gives to the work a very square and uniform appearance ...", and "... the very fine quality of the brass used in their instruments, in regard to the closeness of the grain, and the absence of air bubbles ..." (Lambert, 1879: 476).[33] "... beautifully fitted up …" was the simpler comment provided by a former assistant at the Cambridge Observatory who had inspected several Foucault reflectors in Secretan's shop (Breen, 1863: 472).

The setting circles are divided to 1 minute in hour angle and 20 arcmin in what turns out to be north polar distance, further divided to 1 arcmin by a vernier (Figure 41). Use of the polar distance is not surprising, since it was still commonly used at the time, for example in the Paris Observatory *Annales* (e.g. Le Verrier, 1860c), the Cape Catalogue (e.g. Stone, 1873), or in the reports of new nebulae discovered with the Marseilles 80-cm *télescope* (e.g. Stephan, 1884). Figure 42 shows that the mirror does not appear to be made of tinted glass, though this is not definitive. Tints in photographs are not always reliable, and the illumination in the Palais de la Découverte geometrical optics room is low such that my eye might not have discerned a faint col-

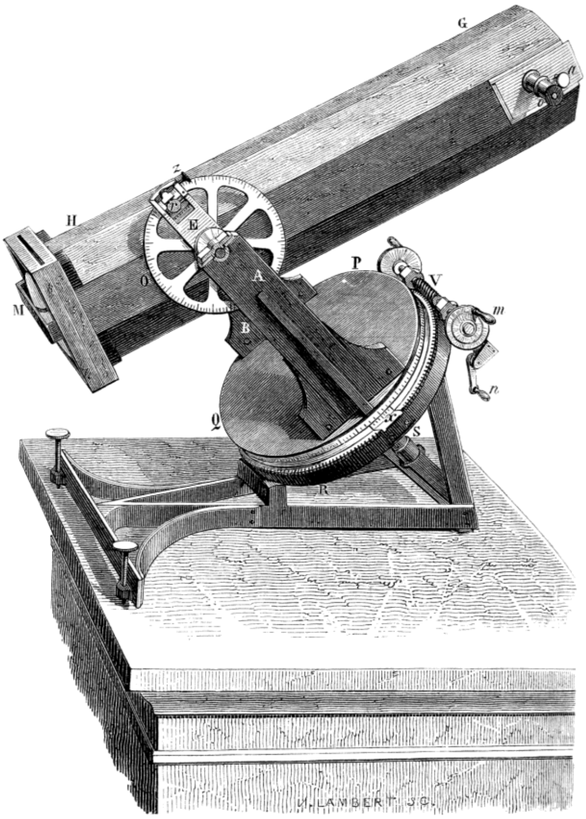


Figure 40: The Palais de la Découverte telescope represented in Ganot's *Traité Élémentaire de Physique* (1860) (courtesy: F. Gires/ASEISTE).

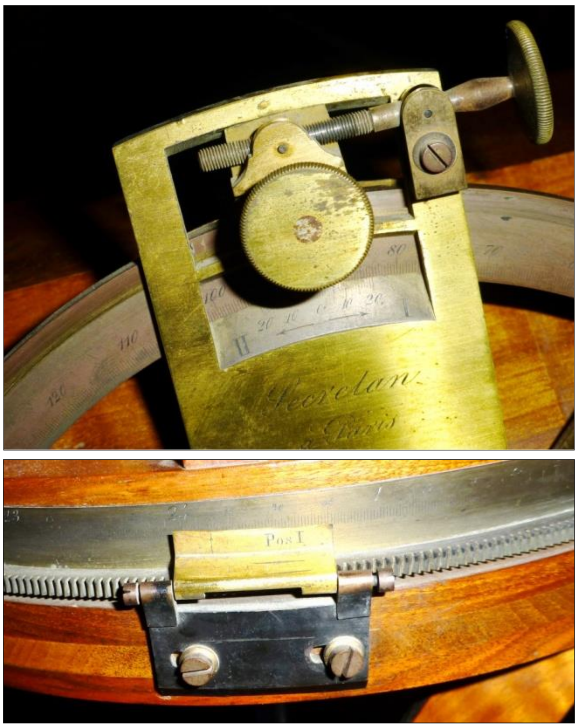


Figure 41: (Upper) Details of the declination setting circle, vernier and Secretan's name for the Palais de la Découverte telescope. The circle is calibrated in terms of north polar distance, 180°–0°–180°. The face-on knurled knob is the declination lock; the side-on screw is a fine adjustment. (Lower) Hour-angle circle, numbered 1–24 in hours increasing westwards, in accordance with the normal convention of a target's hour angle increasing with time (author's photographs).

Figure 42: The rear of the Palais de la Découverte mirror and mirror cell. The mirror rear was polished to permit monitoring of the silver deposition on the front (Foucault, 1859a). Heads are visible for four pairs of counteracting screws that provide for alignment of the optical axis of the mirror (author's photograph).

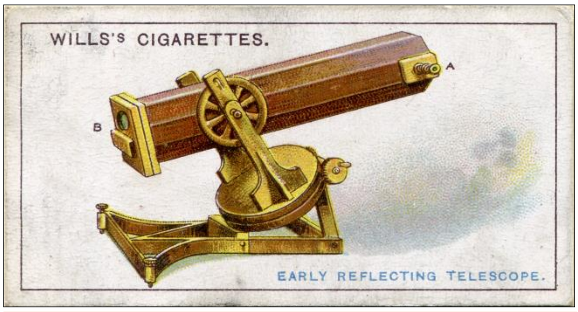


Figure 43: A Wills cigarette card inspired by the Worms de Romilly telescope. Dating from 1915, this was the 29th in a series of 50 on 'Famous Inventions'. The text on the reverse asserts that this is Newton's telescope! (Author's collection).

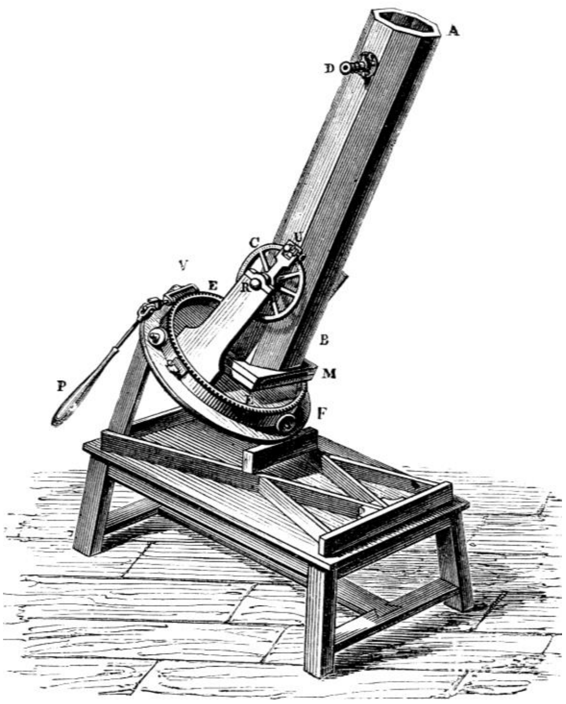


Figure 44: Foucault telescope illustrated in Drion and Fernet's *Traité de Physique Élémentaire* (1861). By means of the jointed rod thickening into a hand-hold the observer could track an object in hour angle while observing at the eyepiece (author's collection).

ouration. The mirror is held in place by a three-fingered spring and stout metal bar. The use of clear glass supports a date prior to early 1859, when Foucault states that he began using green-tinted St Gobain glass.

The woodcut shown in Figure 40 continued to appear in Ganot's *Traité* for over three decades, last appearing in the 21st edition in 1894 (Maneuvrier, 1894: 504). Ganot explicitly reserved the rights to his illustrations, but the engraving was reproduced by de Parville in his obituary of Foucault (1869: 168), and clearly inspired a modified version with background cityscape used by Clerc (c.1882: 478), and even a cigarette card (Figure 43)!

6.2 A Telescope Illustrated by Drion and Fernet (1861)

In the first edition of their *Traité de Physique Élémentaire,* published in 1861, Charles Drion (1827–1862) and Émile Fernet (1829–1905) published a woodcut of a Foucault *télescope* (Figure 44). It was stated that:

> This figure was made from a telescope of small dimensions which M. Foucault has had made, and which he has kindly made available to us: the construction details are the same as for those made, in bigger sizes, for the Paris Observatory. (Drion and Fernet, 1861: 814).

This strongly implies that the instrument was *not* made for the Paris Observatory. Using the engraving over a decade later in a new book, the *Cours de Physique*, Fernet (1875: 440) was even more explicit: "... a telescope that Foucault had had made for himself ..." And indeed, we have seen that Foucault explicitly stated that it was only when he wanted to attack larger apertures that he needed the Observatory's support.

It might therefore seem unlikely that the instrument illustrated by Drion and Fernet is the 20-cm reflector preserved at the Paris Observatory (Figure 45), but the resemblance is striking.[34] (An invoice shows that the major differences—the declination support rod, hinged plank and fine adjustment screw—were later additions: Eichens, 1868.) That it is the same telescope was made clear in 1876 when Albert Lévy (1844–1907), formerly of the Observatory, reused the woodcut in a textbook he was revising (Delaunay, 1876).

The 20-cm reflector was taken to observe the aforementioned solar eclipse in Spain in 1860 (Enumération des objects, 1860), but in a planning document Le Verrier (1860a) noted that "It will be necessary to acquire this $0^{m}.20$ telescope ..." for the sum of 1,200 fr. Evidently Foucault *did* build this instrument for himself, but sold it on to the Observatory![35] Like the 40-cm telescope, the woodwork is rough, but the more-important metalwork is as carefully made as for the Worms de Romilly telescope. This is an instrument built for cost-conscious researchers, not for rich amateurs. The declination lock and fine control carry the signature and date “Secretan / Paris. / (1860)”.

The mirror and its cell have been lost, but measurements I have made of the tube and eyepiece assembly show that its focal length must have been within a centimetre or so of 1.00 metre, a value confirmed by e.g. Wolf and

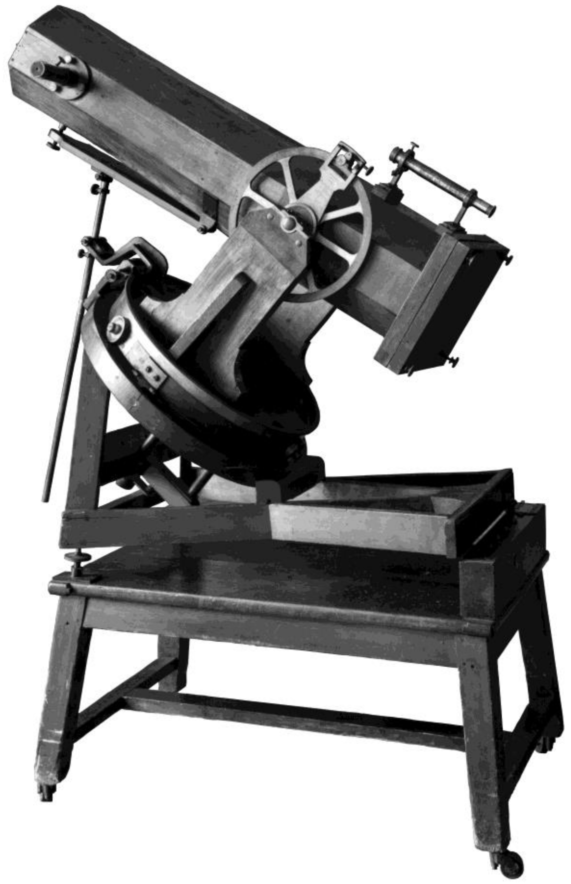


Figure 45: 20-cm reflector conserved at the Paris Observatory (inv. 174) photographed some years ago. The stabilising rod, hinged plank and adjustment screw for setting the declination are apparent. The mirror and its cell have been lost: the wooden plate closing the tube is a modern addition (cf. Figure 31). For a colour photograph, see Tobin (1998) (courtesy: Bibliothèque de l’Observatoire de Paris).

Rayet (1865), and Danjon and Couder (1935: 690). The identity of focal lengths makes it seem very probable that the mirror was Foucault’s first parabolic one, completed in July 1858 (see Section 4).[36] Perhaps this is why Le Verrier later described the telescope as “... (a masterwork from his hands!) ...” (Le Verrier, 1868a: 394), a sentiment echoed by Adolph Martin (see Section 7), who described the mirror as “... the most perfect ...” produced by Foucault (Wolf and Martin, 1874: 277). Even if its ‘24-cm’ diameter was in reality 9 *pouces*, the cell could have been big enough. The ‘20-cm’ characterisation of the telescope in fact corresponds to the

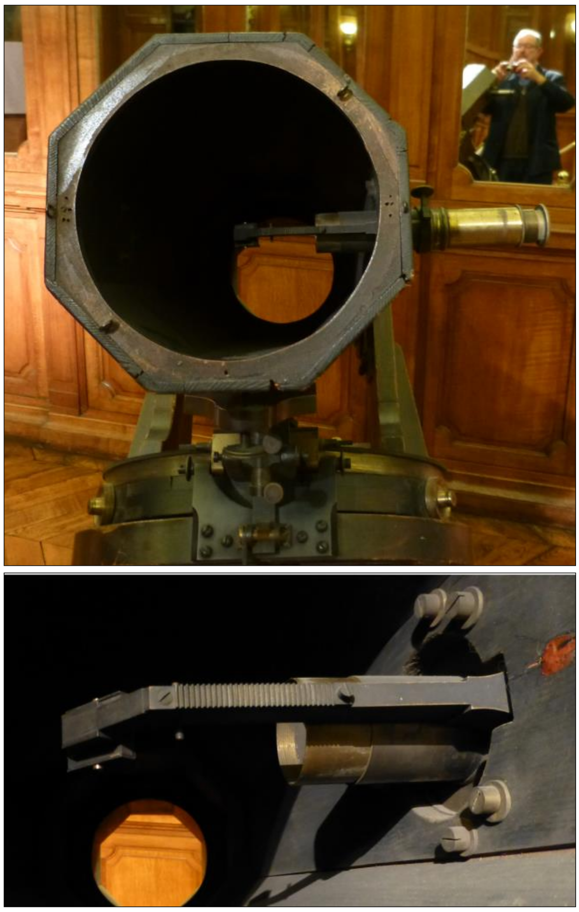


Figure 46: (Upper) The Paris Observatory 20-cm telescope is characterized by the 200-mm diameter aperture at the front of the tube. (Lower) A rack gear attached to the arm supporting the prism is no doubt part of the device used to support and adjust the photographic plate in Wolf and Rayet’s lunar-eclipse photography in 1865. The opposite edge of the arm shows wear marks, as from a moveable carriage (author’s photographs).

inner diameter of the aperture at the front of the tube (Figure 46). With a larger mirror, this is the entrance aperture in an optical sense, and physically the most meaningful designation. The 20-cm telescope was taken to observe the 1860 solar eclipse (Enumeration des objets, 1860), but the claim that it was taken to observe the 1868 eclipse (Lequeux, 2009a: 159) is mistaken.[37]

The design of the eyepiece differs from the 4-*pouce* instruments. I was unequipped to measure individual lenses, but Figure 47 sketches the

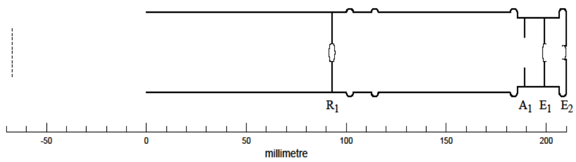


Figure 47: Layout of the eyepiece assembly of the Paris Observatory 20-cm telescope. The form of the inner surfaces of the eyepiece lenses could not be determined. The dashed line indicates the entrance focal plane. The eyepiece is not matched to the focal ratio of the primary mirror so must be a special one built for the Wolf-Rayet photography trials.

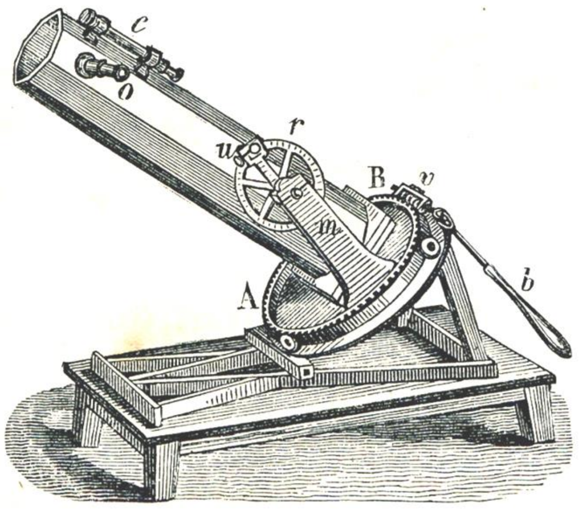


Figure 48: Woodcut presumably inspired by Figure 44 (after: Daguin, 1862; or 1863; courtesy: F. Gires/ASEISTE).

layout. The field of view is about 13 mm, or 0.75° on the sky, but the eyepiece is certainly not original because with the relay lens, R_1 some 150 mm distant from the focal plane, the eyepiece captures very little of the light of the telescope's ~f/5 beam. The large separation allows for the insertion of additional elements into the optical path, as indicated by a rack gear on the arm supporting the prism (Figure 46, lower). Presumably the eyepiece dates from the early lunar-eclipse photography by Wolf and Rayet (1865), where there will have been plenty of light.[38] They explain:

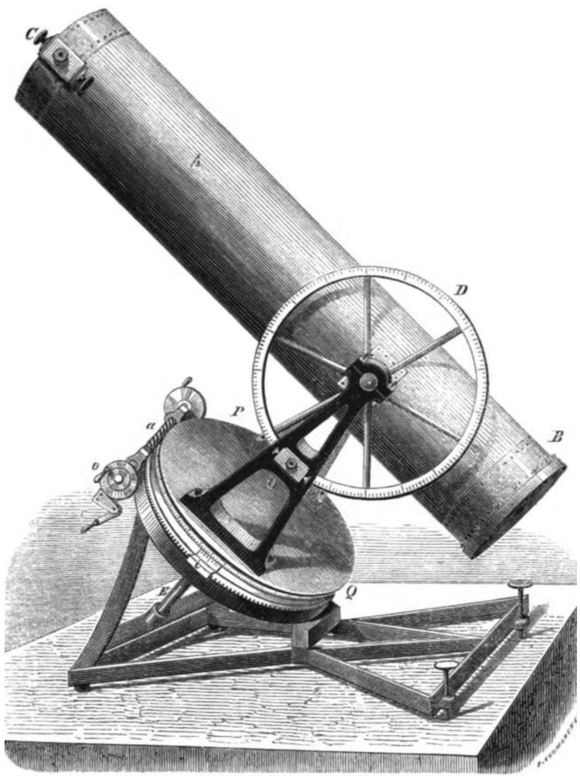


Figure 49: A Foucault telescope adapted for celestial photography in the early 1860s by Désiré van Monckhoven (see text). It is equipped with a filar micrometer at *C* (after: Monckhoven, 1863; courtesy: Google Books).

> The sensitized collodion surface is placed beyond the prism, in the focal plane of the mirror. Focusing is effected by moving the plate holder to the point where, through the eyepiece, one sees a net image of both the celestial object and the surface of the glass plate that is to be sensitized.

Since the specialized eyepiece is still in place, it would appear the telescope was not subsequently used for any major scientific purpose; and I have found no record of any later use. However a "... prismatic glass ..." was added to an eyepiece in 1867, suggestive of specroscopy trials (Eichens, 1867b). The "... Body ..." was repaired and the declination strut etc. were added in 1868 (Eichens, 1868). A Paris Observatory photograph shows the 20-cm among several Observatory telescopes ready to observe the 1907 transit of Mercury, but the sky was cloudy (Observation du passage de Mercure, 1907).

The Drion and Fernet woodcut would appear to be the inspiration behind an illustration later published by Pierre Adolphe Daguin (1814–1884), a Physics Professor at the University of Toulouse, who in 1866 became Director of the Toulouse Observatory. Figure 48 shows this woodcut, which first appeared in the second edition of his *Traité Élémentaire de Physique Théorique et Expérimentale* (1862) and later his *Cours de Physique Élémentaire* (1863).

6.3 A Telescope Illustrated by Monckhoven (1863)

Figure 49 is an illustration of a modified Foucault-Secretan telescope first published in 1863 in the 4th edition of the *Traité Général de Photographie* by the Belgian photographer Désiré van Monckhoven (1834–1882). He noted that Foucault's telescopes were "... the most apt for the reproduction of the heavens by photography ..." on account of their fast focal ratio (Monckhoven, 1863: 371). The foot was stated to be cast iron, but it would seem the rest of the telescope was originally in wood. Monckhoven implied he replaced the declination pillars by iron ones, and stated that he changed the octagonal wooden tube for a circular one in pine with metal reinforcements. The mirror was supported on a ring of straw! He acknowledged that the mount was stable, but added "It has a serious disadvantage, which is the difficulty of attaching a clockwork drive, because the friction in the system is large and irregular." (Monckhoven, 1863: 373). For photography the prism and eyepiece assembly were removed and a plate carrier with a thread for focusing was inserted at prime focus.

The interest of Figure 49 is the indication that by 1863 Secretan was providing base structures in cast iron for at least some of his small equatorial reflectors. Monckhoven's engraving was reused by Figuier (1869).

6.4 A Telescope Illustrated by Jamin (1866)

Figure 50 shows a wood-mounted telescope. The earliest appearance of this engraving that I have found is in the first edition of the *Cours de Physique de l'École Polytechnique* (1866), by Jules Jamin (1818–1886), Professor of Physics in that institution. Despite a certain resemblance to Ganot's xylograph (Figure 40), the focal ratio is clearly slower, and the eyepiece focus motion is perpendicular to the tube. The engraving is not due to Jamin, however, because it appears again in the catalogue "Extract ..." published by the Secretan firm two years later (Table 1; Section 9.1). Its appearance in 1866 shows that such telescopes were commercially available by this date, and we can suspect several years earlier. However the sole surviving telescope akin to that shown in Figure 50 that I am aware of is the 40-cm instrument made for the Reverend J.B.Z. Bolduc (1818–1889) in Quebec, and now in that city's Musée de la Civilisation. It was ordered in 1866 and completed in 1867 (Nadeau, 1943; 1944; also Lemay, 1979 for a more recent illustration).[39]

7 ARRANGEMENTS WITH SECRETAN—AND ADOLPH MARTIN

Marc Secretan's trade was diverse. Besides making and selling the wide variety of items that appeared in his catalogues, his enterprise built novel equipment to order, and was paid for this service. Foucault was punctilious about this distinction, as illustrated by an event in 1862 involving another instrument maker with whom he worked, Jules Duboscq (1817–1886): Foucault was annoyed that there had been a confusion between "... the achievements of the savant and those of the artisan …" (Moigno: 1862a: 447).[40] But when Foucault wrote about the costs that an individual client could bear (Section 5), he was being disingenuous. In February 1852, Louis-Napoléon Bonaparte, then still the Prince-President, had given him 10,000 fr to pay for the previous year's pendulum experiment in the Panthéon and to finance his future research. An additional 8,500 fr had followed by 1860 (Foucault, 1852–1865).[41] Between February 1858 and May 1859 Foucault paid Secretan *télescope* bills of almost 1,875 fr from these funds. Thereafter manufacture of professional telescopes and sales of amateur instruments must have begun to bring in money, because in January 1863 Foucault received an equalisation payment from Secretan of 114.30 fr, and when Secretan died four years later, Foucault was owed a further 6,264.60 fr, though over what period this had accumulated is unstated (Sebert, 1867–1968).

Also in 1863, the commercial arrangement between Foucault and Secretan plausibly evolved. Foucault was not one for "... patient and insipid drudgery …" (an expression he used in a newspaper article (Foucault, 1852)), and no doubt he found tedious the finishing of 40 or more 4-*pouce* mirrors, guaranteed by his signature. Indeed, as we will see in the next paragraph, in order to restrict demand Foucault kept his prices high. He decided to recruit an assistant. It is not known why he decided upon Adolphe Martin (1824–1896; Figure 30), a physics teacher at the Collège Sainte Barbe, Paris' oldest school, founded in the fifteenth century. Martin had devised what was subsequently called the tintype and other new positive photographic processes (Martin, 1852; 1853). Perhaps they met through the Société Française de Photographie, of which Foucault was a founding member and regular contributor, and where from 1861 Martin began presenting talks on photographic procedures (e.g. Foucault, 1861; Martin, 1861). It was later noted that Martin

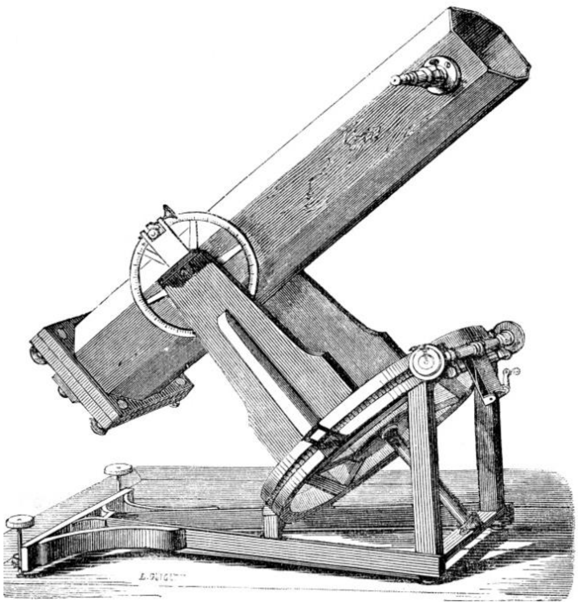


Figure 50: Engraving of a smaller, wood-mounted Foucault-Secretan telescope published in 1866 in a textbook, and probably previously in Secretan advertising matter (after: Jamin, 1866; courtesy: F. Gires/ASEISTE).

> ... had generously put useful inventions into the public domain, which were profitably exploited [by others] … without trying to preserve the fruits of his efforts for himself and his family. (Sebert, 1896: 941).

Although Foucault had published details of his procedures, it was another thing to put them into practice. A letter reveals that by the spring of 1863 Foucault had initiated Martin into the details of mirror testing and *retouches locales*. Reading between the letter's lines, it would seem that Martin was prepared to be as free with his new-gained optical knowledge as with his photographic inventions. This was not what Foucault wanted! He put his collaborator firmly in place:

> Having you yourself succeeded in applying the methods to two telescope mirrors, you ask me what I think would be the best course of action in the interest of science and art ...
>
> I think that after having received private instruction which led directly to rapid success, it would be correct and fair to keep the advanage you have acquired to yourself …

Recalling perhaps the artisans' scepticism concerning *retouches locales*, he continued:

> … the time has not yet come to spread these procedures to workshops where they cannot be properly applied … keep the knowledge ... to yourself until we agree by common accord that the time has come to make the methods known.
>
> In this way we shall be two, and only two. But if we want to remain masters of the situation, we have to agree how to satisfy the needs of clients without delay. So far, I have not shied away from asking a certain price which restricts demand and also maintains the dignity of the savant … You will soon realise that it is more advantageous and just as dignified to bring a surface to perfection as to give a lecture, or draft a questionable text.
>
> In summary, dear Sir, I find nothing better to say to you about this matter than to advise you to do just as I have done so far (Foucault, 1863).[42]

Martin acquiesced, but after Foucault's death in 1868 revealed some of the trade secrets: how Foucault had standardized on an *f*/6 focal ratio and adapted his parabolization procedure to fit within a shorter optical shop "... of which I was the sole other person who knew ..." (Martin, 1868a: 1058; also 1870a); how he made a 35-cm diameter optical flat so that lenses could be tested in autocollimation (Foucault, 1869; Martin, 1869; 1870b); and how he adapted his procedures to making lenses (Acloque, 1987; Saint-Claire Deville, 1868). A receipt dated just after Marc Secretan's death indicates the amounts that Martin, and presumably Foucault, charged for shaping mirrors: 120 fr for 10-cm, 384 fr for 16-cm, and 2,400 fr for 50-cm diameters (Martin, 1867).[43] Martin evidently subcontracted from Foucault, not Secretan, because at his death Foucault was owed 2,736.65 fr by the Secretan firm, of which 1,320 fr were paid on as owing to Martin (Crosse, 1868).

Still in 1863, in its spring, Martin devised a simpler and more-certain mirror-silvering procedure in which invert sugar replaced oil of cloves as the reducing agent. True to form, he announced his improved process, and subsequent refinements, widely and freely (Martin, 1863a; 1863b; 1863c; 1868b; 1868c; 1875). According to Foucault's friend Henri Saint-Claire Deville (1818–1881), this was the process thereafter used by Foucault (Saint-Claire Deville, 1868), although Foucault himself (1864b) wrote that Martin's solutions "... according to me, have the fault of working too fast." The procedure was later explicitly offered by at least one independent instrument maker (Laurent, 1878).

Arrangements were also changing on the Secretan side. Marc Secretan's first wife had died, and in 1859 he had remarried (Sebert, 1858). His new wife was French, but it seems that in due course the couple set up household in Lausanne, where his four daughters and mentally-handicapped son lived. This is because he signed powers of attorney in 1861 and 1864 allowing his other son, Auguste, who lived in Paris, to run the company for two and then six months during absences in Switzerland (Tandeau de Marsac, 1861; 1864). Auguste's role in running the company was clearly growing. In 1864, for example, Moigno (1864: 487) referred to "... the Misters Secretan, father and son." when writing about the company. A final power of attorney, signed in March 1865 in an increasingly spidery hand, gave Auguste control of the firm without time limit (Sebert, 1865). After Marc's death two years later it was stated that he had been "... back in Lausanne for more than a year ..." (Sebert, 1867–1868) and Gaudin (1867) confirmed that Auguste had been in charge of the firm for several years.

Foucault's 35-cm flat, probably completed in 1864, opened the way to testing by autocollimation and to optically-perfect lenses. Elsewhere I have outlined the subsequent story of Foucault's lens-making, his belief developed in 1860 that refractors were actually to be preferred to reflectors for low-contrast objects, and his conviction that the premier astronomical instrument would be a siderostat (Tobin, 2003). According to Le Verrier (1868b: 22), it was he who pushed Foucault and Secretan to create "... a beautiful optics institute ..." and enter into a more formal contract for the construction of professional objective lenses, signed on 22 March 1865.[44] Perhaps Auguste was also involved. Be that as it may, it would seem that Auguste was an impetus behind the next development in the commercialisation of Foucault's small telescopes: metal mountings.

8 METAL-TUBED TELESCOPES

8.1 A 10-cm Instrument

With their wooden stand lacking fine adjustment in azimuth, the 4-*pouce* telescopes can hardly have been very practical for tracking celestial objects. An improved product was clearly needed. Perhaps there was commercial pressure too. The catalogue produced in 1864 by Jules Duboscq advertised small silvered-glass mirrors and telescopes (Tables 3 and 4; see also Section 10). In any case, a letter from Auguste announced the Secretan company's new product in Moigno's *Les Mondes* in October 1865:

> I have just finished a new model of M. Léon Foucault's telescope with a parabolic, silvered-glass mirror, which has been built at the request of one of our physics teachers and for one of the great colleges of our city (Secretan, 1865b: 272).

Secretan went on to state a 10-cm mirror diameter with the expected *f*/6, 60-cm focal length, and a tube in "... bronzed copper ..." with fork in cast iron. A cast-iron foot was available for observing sitting down and a wooden tripod for observing standing up. The price was 550 fr, more than double the earlier wood-mounted instruments of the same size. Was this to 'restrict demand', at least in part? Magnifications from 60× to 220× were possible, a performance equalling that of a refractor costing 1,200 fr. The telescope gave an upright image and inverted sugar was used in the silvering. Secretan's letter was accompanied by an engraving (Figure 51). At the time, Moigno was delivering monthly public science lectures, and showed off the telescope at the next one (Moigno, 1865). The Paris Observatory immediately ordered two (Secretan, 1865c).

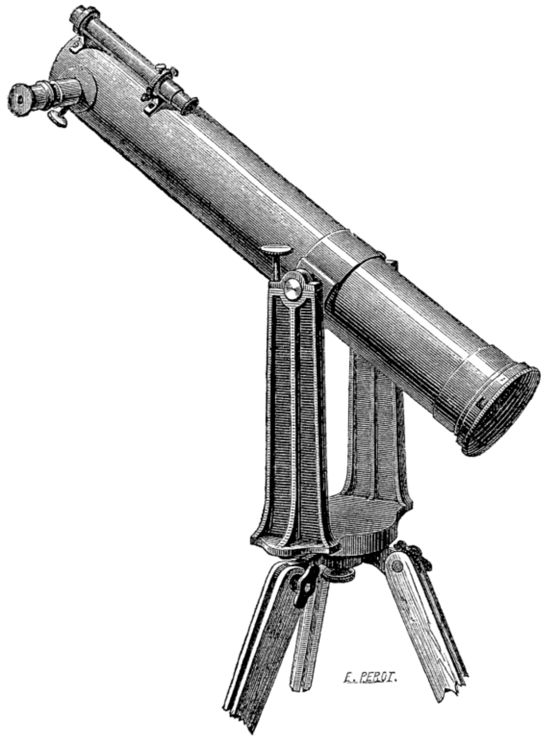


Figure 51: Woodcut of the 10-cm alt-azimuth telescope announced by Auguste Secretan in the autumn of 1865 (after: Secretan, 1865b).

The Lycée Louis le Grand in Paris has a telescope of this general form in its museum (Figure 52). The tripod is different, but similar in its altitude joint to ones sold by Secretan (e.g. Lerebours and Secretan, 1853: Figure 59). It would appear to be original rather than a subsequent replacement because there are no trunnions or support band around the tube (cf. Figure 51). The rear of the mirror cell has slotted fixtures for retaining screws, whereas the—presumably later—telescopes shown in Figures 55

Figure 52: 10-cm telescope at the Lycée Louis le Grand in Paris. There is no signature or serial number. Clockwise from left: (a) Overall view. Is the tripod original or a substitution? It is more stable than the one equipping Nos 13 or 236 (Figures 53 and 62), the legs of which easily splay open. (b) View of the front of telescope and dust cap, which screws on. (c) Mirror cell and spring. The mirror has been lost. (d) Bayonet attachment of the mirror cell to the telescope tube (author's photographs).

Figure 53: Secretan No. 13 metal-tubed 10-cm reflecting telescope, overall view (author's photograph).

Figure 54: Secretan No. 13 10-cm reflector, view of eyepiece, brass dust cap, finder and finder-alignment mechanism. The weighty dust cap with bayonet pins and crudely-cut slots to retain it (not visible) looks to be a replacement. Any lost cap must have been held on by friction, because there is no screw thread on the tube, unlike other 10-cm instruments (author's photograph).

and 61 simply have countersunk holes. The instrument looks very much like a prototype. Is the Lycée Impérial Louis le Grand (as it was then called) the 'great college' in question? Or could it have been the Lycée Saint Louis? Foucault's friend Jules Lissajous (1822–1880) was a physics teacher there, although not a very conscientious one (Brasseur, 2010). Another Saint-Louis suspect must be Émile Fernet, who had earlier published the engraving of Foucault's 20-cm telescope shown in Figure 44.

Figure 55: Secretan No. 13 reflector, mirror cell, maker's mark and serial number (author's photograph).

Figure 56: Secretan No. 13 reflector, mirror-cell back removed showing the clear glass and flat rear of the 100-mm mirror and the leaf spring that keeps it in position (author's photograph).

I know of very few examples of these 10-cm telescopes, listed in Table 9, though they were offered by Secretan and other makers until at least 1900 (see Sections 9 and 10).

Figures 53–57 show an instrument that I chanced across on the sidewalk outside an antiques dealer in Saint Ouen near Paris, with serial number 13. The mirror has a flat back and a metric diameter, 100.3 ± 0.2 mm, which the cell reduces to an optical diameter of 92.2 ± 0.2 mm. I obtained contradictory measurements concerning its focal length, which nevertheless must be no more than ~5mm different from the expected 600 mm.[46] The reflecting prism has approximately-square entrance and exit faces of 11–12 mm sides.

Figure 58 and Table 10 report the layout of its eyepiece assembly, which has been redesigned compared to the wooden-mounted 4-*pouce* instrument shown in Figure 18. It no longer looks to be a quick adaptation from a microscope design, and has more baffling, but if dated 1865, the design is prior to the rigorous sine condition soon to be introduced by Ernst

Figure 57: Secretan No. 13 10-cm reflector, prism assembly (upper) in position, and (lower) removed (author's photographs).

Abbé. As with the Figure 18 instrument, only one eyepiece has survived. The equivalent focal length of the eyepiece proper is much the same as that of the 4-*pouce* instrument (30 vs. 41 mm) but the overall magnification is much less (65× vs. 165×). This is because the increased diameter and spacing of the relay lenses R_1, R_2 has increased the field of view to 0.62 ± 0.05°, as measured from the Moon and confirmed, near enough, from the ray trace (Figure 58). The ray trace shows that the field is defined by stop S_3 and vignetted by S_2. Since the eyepiece assembly performs acceptably as a microscope, the poor performance of No. 13

Table 9: Known surviving 10-, 16- and 20-cm Foucault-Secretan telescopes mounted in metal tubes.

Collection/inventory number	Marked serial no. and [date]	Supposed mirror diameter (cm)	Mount	Comments	Additional description and/or images
Lycée Louis le Grand, Paris	none	10	alt-az, fixed-leg tripod	Prototype?	www.aseiste.org
Tobin, Vannes	13	10	alt-az, tripod		tobin.fr
Offered on eBay.it June 2016	53	10	alt-az, tripod bracket, legs missing	Optics lost. Signed as for No. 13, brass parts as for No. 61, cap for eyepiece port as for No. 236	
Prytanée Nationale Militaire, La Flèche	61	10	alt-az, scroll legs		Chanteloup (2004: 193) www.aseiste.org
Van Spengen auction, Hilversum	?	10	alt-az, scroll legs		
Wolf, FRE1	236	10	alt-az, tripod		Wolf (2014)
Wolf, TRE17	18 [1866]	16	equatorial, table		Wolf (2014)
Musée Gassendi, Digne-les-Bains, 1967.2.61	59	16	equatorial		Turner (2006: 201–202) www.aseiste.org
Harvard University, Cambridge, 1997-1-0303	?	16	alt-az, scroll legs	*f*/7?	dssmhi1.fas.harvard.edu/emuseumdev
Observatoire Camille Flammarion, Juvisy	?	16	dual alt-az and equatorial mount[45]	*f*/6?	www.culture.gouv.fr/documentation/merimee/PDF/sri11/IM91001426.pdf (misidentified)
Observatoire de Rouen	?	16	alt-az	*f*/10? purchased 1884	
Observatoire de Dax	lost	16	equatorial	Mirror and cell lost	Flammarion (1890: 860)
Christie's auction South Kensington	lost	16	equatorial	motorized HA drive	Christie's (2008). Sale BKS-5429, lot 23
Museu da ciência, Coimbra. AST.I.098	67	20	equatorial	purchased 1874	www.astro.mat.uc.pt
Groupe d'Astronomie du Dauphiné	[1877]	20	equatorial		

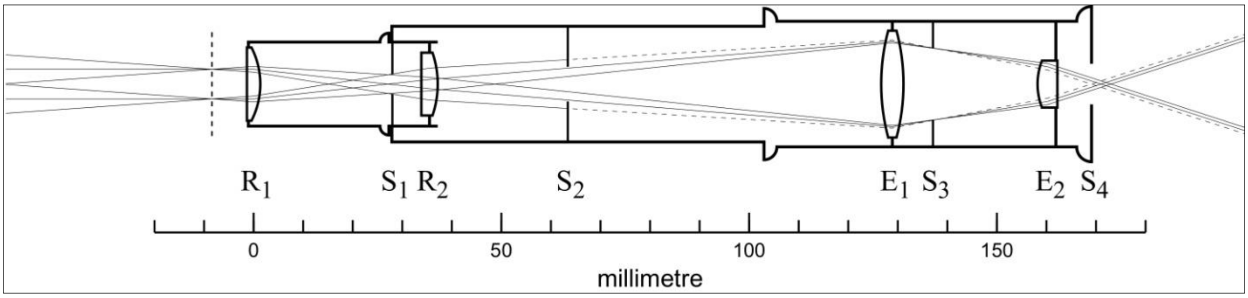


Figure 58: Optical layout and ray trace for the eyepiece assembly of the No. 13 telescope. The ray trace corresponds to a field of view of 0.57° and a relaxed eye. The dashed line indicates the corresponding entrance focal plane. For component parameters, consult Table 10.

as a telescope must be ascribed to problems with the mirror (see Note 45).

The externally-similar telescope in the collection of the Prytanée National Militaire in La Flèche carries serial number 61 (Figure 59). Photographs given by Chanteloup (2004: 193) show that it has survived with scroll legs and, like the Louis-le-Grand instrument, the dust cap is attached by a more-satisfactory screw thread. In addition, the optical arrangement is different. The mirror is considerably thinner than the 18.35-mm thickness of the No. 13 mirror, and is mounted in a threaded sub-cell. A cover is provided for the sub-cell, seen in Figure 60, which shows the contents of the accessories box. An associated handwritten label indicates that the

Table 10: Lens and aperture specifications for the Secretan Number 13 eyepiece assembly (my measurements). Measurement uncertainties are ~0.5 mm for positions and diameters and ~1.0 mm for focal lengths. The equivalent focal length is –9.3 mm. For an eye focused at infinity, the entrance focal plane position is –8.4 mm. See also Figure 58.

	Position (mm)	Clear diameter (mm)	Focal length (mm)
R_1	0.0	14.8	27.1
S_1	28.0	4.0	
R_2	35.5	12.7	32.9
S_2	63.4	7.0	
E_1	128.9	21.6	35.1
S_3	137.1	14.5	
E_2	160.2	9.5	21.8
S_4	169.1	8.2	

long tubes are terrestrial eyepieces, which must thus contain inverting lenses, while five small eyepieces are for celestial use.[47] The relay lenses have thus been eliminated, and it is true that increasing the focal length of the mirror by ~5 cm results in the standard Newtonian arrangement with only some off-axis vignetting by the prism, which is of similar size to the one in No. 13. The terrestrial and celestial eyepieces are presumably the same as those offered as standard with 108- to 190-mm *lunettes* (Secretan, 1874: 74).

Figure 59: Signature and serial number of the No. 61 10-cm telescope preserved at the Prytanée National Militaire (courtesy: L. Chanteloup/PNM).


Figure 60: Accessories box for the No. 61 telescope. At upper left is the covered mirror sub-cell. The long tubes are terrestrial eyepieces while the small eyepieces are for celestial use (courtesy: L. Chanteloup/MNP).

Figure 61 shows a 10-cm telescope sold in the Netherlands in 2010. Figure 62 shows an instrument in the aforementioned Wolf collection. The signature specifies serial number 236 and R. Mailhat as director of Secretan's workshops (Figure 63). The instrument can thus be dated to rather later, 1888–1894, the period when Mailhat (d. 1923) occupied this role (see Section 9.2). Figure 64 shows the eyepiece box (see also Figure 69). The optical arrangement has returned to the Foucault-Secretan standard, suggesting that the Prytanée National Militaire telescope may be a special case. The dust cap screws on, like No. 61. Troubetzkoy (1916) gives a photograph of another 10-cm instrument, which appears to have been modified by the addition of a counterweight.


Figure 61: Upside-down photograph of a metal-mounted 10-cm telescope sold on 22 October 2010 by the Van Spengen auction house in Hilversum. The scroll legs are apparent (courtesy: www.vanspengen.nl).

It is plausibly this form and 10-cm size of Foucault-Secretan alt-azimuth telescope that was described appreciatively as "... the good fortune of astronomy dabblers." (Cristal, 1875: 67). At about the same time, this telescope was immortalized in stone for a statue which graces the entrance gate to the Nice Observatory (Figure 65). The telescope was still advertised in the 1906 Secretan catalogue (Figure 66).

8.2 16-cm Apertures

The Secretan firm moved on to provide a larger aperture and an equatorial mounting. Figure 67 shows another telescope from the Wolf collection, which has the serial number 18 and date 1866 on the mirror cell (Figure 68). Its mirror diameter is 160 mm for a usable diameter in its cell of 149.5 mm. The mirror has a convex back and the glass has little or no green tint. The telescope is equatorially mounted. The eyepiece assembly has not been examined in detail but appears broadly similar to that of the metal-tubed 10-cm instruments, with the exception that the relay lenses are more separated, presumably to adapt to the greater focal length of the mirror (Figure 69). Figure 70 shows a similar instrument acquired by the Bishop of Digne, Julien Meirieu (1800–1884), which from its serial number must date between 1866 and 1874 (see Table 9). The bases of these two telescopes are made of cast iron, as with Monckhoven's telescope shown in Figure 49. Figure

Figure 62: General view of 10-cm telescope from the Wolf collection, Secretan serial No. 236, dated to 1888–1894. The tripod is similar to that equipping telescope No. 13, but the eyepiece barrel diameter is less (see Table 11) (courtesy: E. Wolf).

Figure 63: Signature of the No. 236 telescope (courtesy: E. Wolf).

Figure 64: The eyepiece box for telescope No. 236. When the eyepiece assembly is removed from the telescope tube, dust can be prevented from entering with the cap seen at upper left. The misprint "Maison Lerebourg & Secretan" on the business card surprises, but less-so when it is understood that in French "Lerebourg" and "Lerebours" are homophonous. The card gives 30, rue du Faubourg Saint-Jacques as the workshop address (cf. Table 1 and Section 9.2) (courtesy: E. Wolf).

Figure 65: Statue personifying astronomy holding a Secretan10-cm telescope at the gates of the Observatoire de Nice. Signed "G.J. THOMAS PARIS 1881", the sculptor is Gabriel-Jules Thomas (1824–1905). A first version in plaster dated 1877 is preserved at the Musée Camille Claudel in Nogent-sur-Seine (see www.culture.gouv.fr/documentation/joconde/fr/pres.htm)(courtesy:cadsol.ovh.org /Alpes-Maritimes and D. Collin).

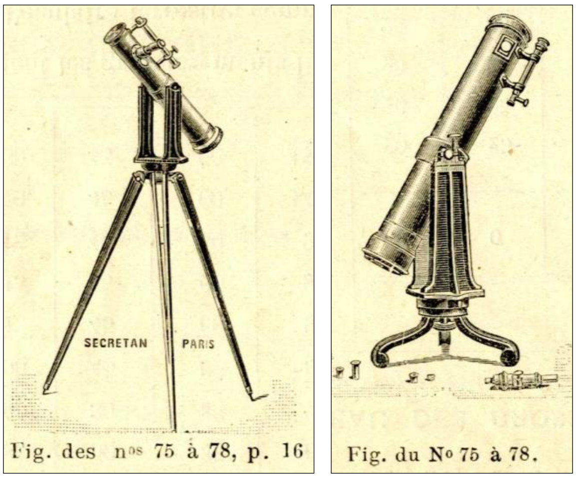


Figure 66: The 10-cm telescope still on sale in 1906, illustrated with tripod and scroll legs. The catalogue also printed the Figure 51 xylograph (after: Secretan, 1906a: 17; courtesy: I. Taillebourg, CNAM).

Figure 67: Metal-mounted 16-cm Foucault-Secretan telescope No. 18, dated 1866. In 1880 it was purchased by José Batlle y Ordonez (1856–1929), who was later President of Uruguay. The polar axis is set for a latitude of 35°, which is correct for Montevideo, but the hour-angle circle is labelled for the northern hemisphere (courtesy: E. Wolf).

Figure 68: Serial number and signature on telescope No. 18 (courtesy: E. Wolf).

71 shows a 16-cm instrument which belonged to the astronomy popularizer Camille Flammarion (1842–1925); it is explicitly stated that it was made by Foucault (L'Observatoire de Juvisy, 1887: 326–327).

9 SUBSEQUENT DEVELOPMENTS

9.1 1866 to 1874

We have already encountered Wilhem Eichens, who mounted Foucault's larger telescopes. When the case was being made for him to receive the Légion d'honneur in 1862, Foucault (1862e) noted his capacity to "... imagine the mechanical details needed to transform a theoretical idea into reality …" and summed up his crucial rôle in the company:

> Although the instruments in question have been made in the firm known by the Secretan name, in reality all these works of precision mechanics are the creations of M. Eichens, who for many years has been head of the workshops, and, one can say, of the company.

Figure 69: Eyepiece assembly comparison for the three Wolf collection telescopes with eyepiece and relays lenses detached. (Upper) 16-cm telescope, No. 18. (Middle) 10-cm telescope, No. 236. (Bottom) 4-*pouce* telescope, No. 4. In all cases, friction holds the 'microscope' barrel in the rack-and-pinion focus slider, which has a throw of about 2½ cm (courtesy: E. Wolf).

However, some discord arose.[48] A break-up threatened. In a letter which shows more understanding of human nature than usually attributed to him, Le Verrier wrote (1867) that he "... did everything to avoid this split ...", but as Eichens (1866) explained to him in August 1866:

> Yesterday I received a letter from M. Secretan son in which in elliptical but clear terms he told me that there could be no sort of arrangement with Monsieur his father and that in consequence our separation on October 1 was maintained.

Eichens went on to say that he was therefore setting up his own business, "... trusting to the protection of God and those people who have given me proof of their support ..."; and indeed, the Observatory subsequently contracted with him directly.

With its mechanical capacities amputated, the Secretan company's exhibit at the Paris Exposition Universelle of 1867 concentrated on optical productions, though a model was exhibited of the Paris Observatory equatorial refractor delivered in 1860. Sources differ as to exact items displayed: evidently they changed over time (e.g. Exposition Secretan, 1867; Lissajous, 1868; Moigno, 1867; Rayet, 1868). Lenses figured by Foucault's methods were shown, and at some point the new 10-cm alt-azimuth reflector may have been exhibited (Mesnard, 1868); but all agree on the presence of a 16-cm, *f*/6, silvered-glass telescope, equatorially-mounted in metal (except for Weld (1868a) who—presumably mistakenly—claimed a 9.4-inch (239-mm) mirror). "... this instrument," one commentator said, "was certainly the most interesting one exposed by M. Secretan." (Mesnard, 1868: 84). "... a most excellent instrument ..." said another, for whom "The chief interest consisted in the speculum, which was one of Foucault's." (Weld, 1868b: 427).[49] Camille Flammarion opined that Secretan's instruments, telescopes included, were "... built with a distinctive coquettishness and elegance." (Flammarion, 1867). The St Gobain company exhibited "... very fine discs designed for the mirrors of reflecting telescopes" (Barnard, 1869: 521).

At the end of June, half-way through the exhibition, Marc Secretan died while in Lausanne. Auguste took sole charge of the business. In the next year a catalogue "Extract ..." was published (Table 1), perhaps to capitalize on interest generated by the exhibition. It is a curious work in that its foreword, signed simply "SECRETAN", speaks of "The frequent contact that I had the good fortune to have with M.L. Foucault ..." Is this the father or the son writing?[50]

The 10-cm alt-azimuth and 16-cm equatorial instruments were the only metal-mounted telescopes offered; the latter cost 1,800 fr (Table 2). Both were advertised with a set of four eyepieces. All mirrors were stated to be *f*/6. Wood-mounted equatorials were also offered with apertures from 16 to 80 cm. The price for a mirror alone was "... 200 francs per square of 10 centimetres ...", for which the "... amplifying power is obtained by doubling its diameter in millimetres …" such that a 20-cm mirror, for example, cost 800 fr and permitted a maximum useful magnification of 400×. On a 10-cm mirror the mark-up would thus appear to be 80 fr over the 120 fr charged by Martin and Foucault for its polishing. The catalogue printed all three of the Secretan woodcuts already encountered (Figures 34, 50 and 51).

Figure 70: A similar 16-cm telescope to that shown in Figure 67, described by Bennett (2009: 566) as one of the "... highlights ..." of the Musée Gassendi in Digne. The eyepiece assembly is missing. The curved mirror rear rests against a matching curved metal cross, which arrangement probably facilitates collimation. The instrument was restored in 1991 (Turner, 2006). The arms of the original owner are engraved on the tube (courtesy: Collection Musée Gassendi, Digne-les-Bains).

To promote its business, no doubt, the Secretan firm made these three engravings available to others. They were reproduced by many authors, such as, for the 10-cm telescope: Exposition Secretan (1867), Guillemin (1874; 1882), Jamin (1866; 1870), and Marion (1867); for the smaller wooden telescope: Jamin (1866,

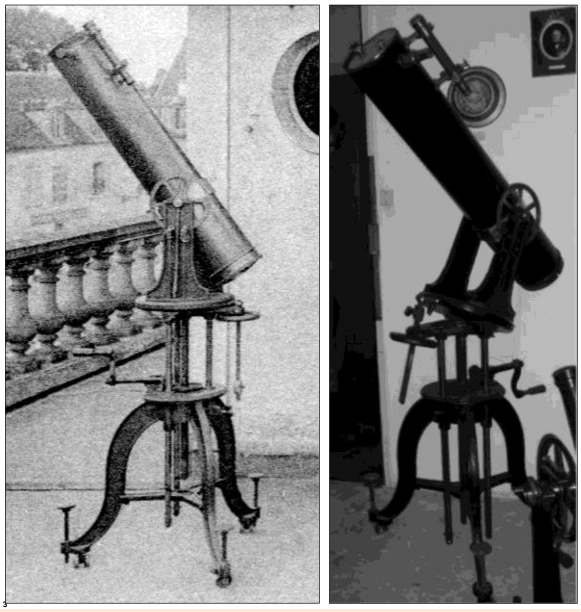


Figure 71: A 16-cm reflector from Flammarion's observatory at Juvisy, seen (left) on a postcard, and (right) in a modern photograph. The metal cambriole-leg stand can be adjusted to provide either an alt-azimuth or equatorial mount and is a modification (author's collection; and courtesy: G. Artzner).

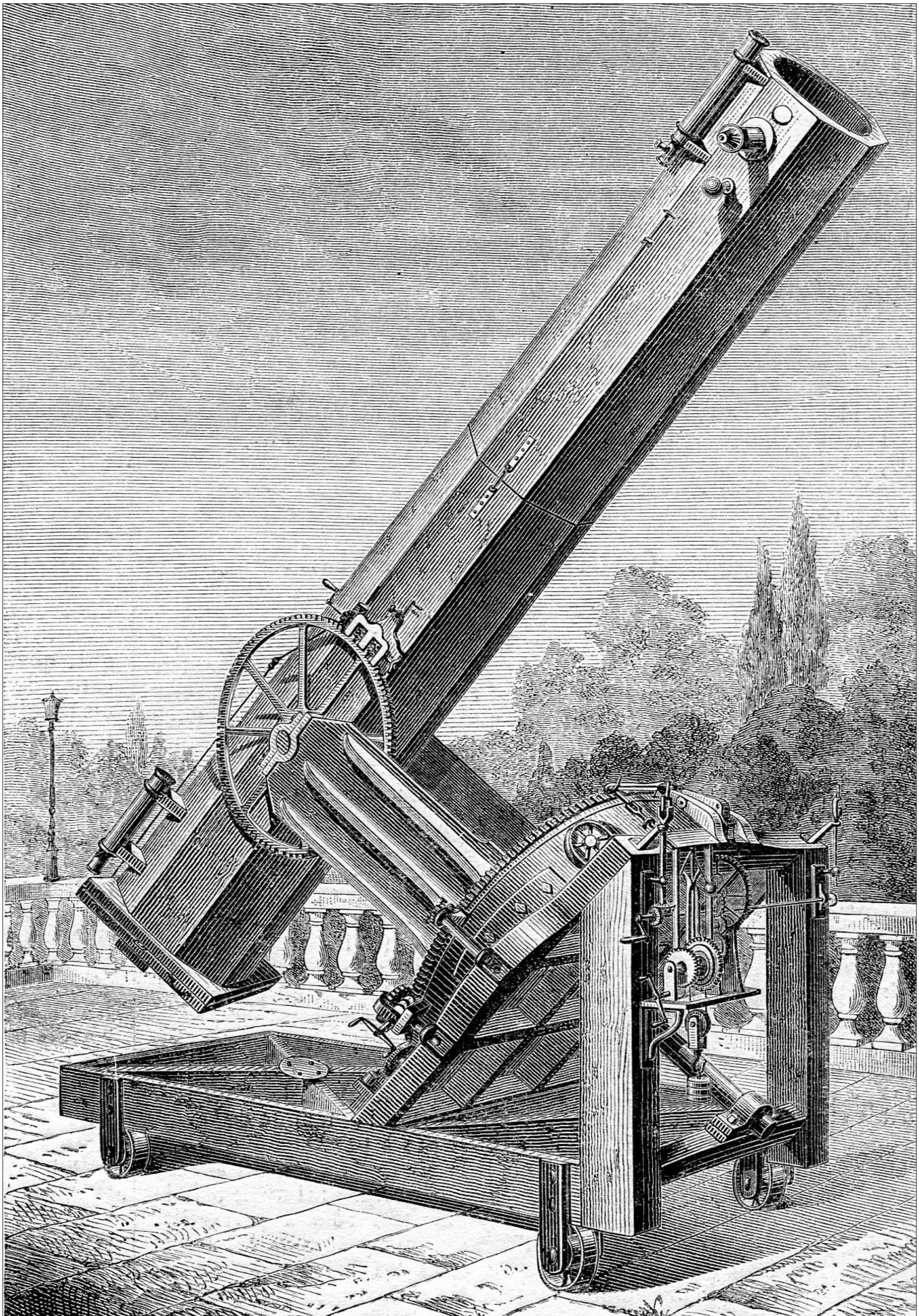


Figure 72: The 80-cm telescope on the Paris Observatory terrace, prior to its removal to Marseilles. Woodcut commissioned for Guillemin's *Le Ciel* (1864: 603) and reused in other Hachette publications (author's collection).

as already noted) and Rayet (1868); and for the Marseilles 80-cm telescope: André and Rayet (1874), Angot (1881), de Parville (1865, amputated of the two onlookers on the right), Figuier (1869), Jeunesse (1865, also amputated), Marion (1867), and Moigno (1864), who claims his to be the first publication of the xylograph. Publishing earlier, Boutan and d'Almeida (1861) had used the illustration from the Observatory's *Annales* (Figure 31), while the science writer Amédée Guillemin (1826–1893) went so far as to commission a private picture of the 80-cm telescope for his luxuriously-produced *Le Ciel* (Figure 72).

I am unaware of any other contemporary illustrations of Foucault-Secretan telescopes. As will be discussed in Section 10, the xylograph of the 10-cm metal telescope was later printed in several other instrument-makers' catalogues.

As a result of Marc's death, an inventory was made of the business (Sebert, 1867–1868). It comprises some 3,700 entries, most of which concern other subjects, but nevertheless it offers glimpses of how the firm built reflecting telescopes. It includes a series of glass discs for working mirrors, three devices for examining their surfaces, two associated stands, and two copper basins for silvering (entries 3361, 3492, 3494 and 3334), but otherwise there are no special tools.

There are raw materials such as slabs of Saint Gobain glass, "Metal for telescopes ...", and polishing necessities like paper and rouge (entries 3389, 3325, 3380 and 3370). There are some copper fittings and several eyepieces (entries 3067, and 2973, 2975 and 3061). There are also six copper boxes for puzzling 10-mm diameter telescope mirrors (entry 3335). Presumably 10-cm is meant. (Is the mirror-sub cell of the Prytanée National Militaire telescope (Figure 60) part of such a box?) Besides the 16-cm telescope on show at the Exposition Universelle, valued at 1,000 fr, there was a 40-cm instrument in the shop on the Place du Pont-Neuf, valued at 4,057 fr (entries 3550 and 3546). Presumably this is Bolduc's telescope awaiting despatch to Canada (Section 6.4). The quoted prices for such silvered-glass telescopes in 1874 were 1,800 and 9,000 fr, respectively (see Appendix 2): the differences suggest the commercial markup. In the workshops on the Rue Méchain there was a 16-cm mirror "… with striations …" which given its 5-fr value must have been unsatisfactory; two 10-cm *télescopes* "... in the hands of the workmen …", and also an uncompleted 80-cm one, which must be the instrument intended for Toulouse (entries 3428, 3009 and 3008). But there were no reflecting telescopes in stock, which contrasts with the many microscopes, spyglasses and other refracting telescopes available off the shelf. This suggests that silvered-glass telescopes were made to order, even for small sizes. This would seem to be true for many of the specialised instruments in the firm's catalogues, which were not in stock either.

The next misfortune to befall the firm was Foucault's death in February 1868, although he had fallen ill the previous summer. The firm was now deprived of both mechanical and optical expertise. Indicative of the company's difficulties is the fact that when Paris Observatory decided it needed a second 40-cm reflector, it did not order it from the Secretan company. The mirror was ordered from Martin, and the rest of the optics and the mounting from Eichens, whose mount (Figure 73) considerably resembles earlier instruments. About this time Eichens produced another design, seen in a 20-cm reflector built before 1874 for a certain Monsieur Séguin (Figure 74).

Figure 73: Not a Foucault-Secretan telescope! This 40-cm reflector for the Paris Observatory was completed in 1871. The mirror was figured by Martin for a cost of 2,400 fr (Martin, 1870c). The mechanical work, the 25-mm crown-glass prism and achromatic eyepiece were supplied by Eichens (6,500 fr: Eichens, 1871b). The tube is metallic. Although metal tubes reduce chimney currents, it was found necessary to insert four aeration vents near the mirror some months later (Eichens, 1872). The lower control rod locks the triangular structure in declination. The upper rod serves to move the tube against the structure, so providing fine control. The declination circle on the other side of the tube is very similar to the one on the Foucault-Secretan 40-cm telescope (Figure 27) (courtesy: astro2009.futura-sciences.com and X. Plouchart).

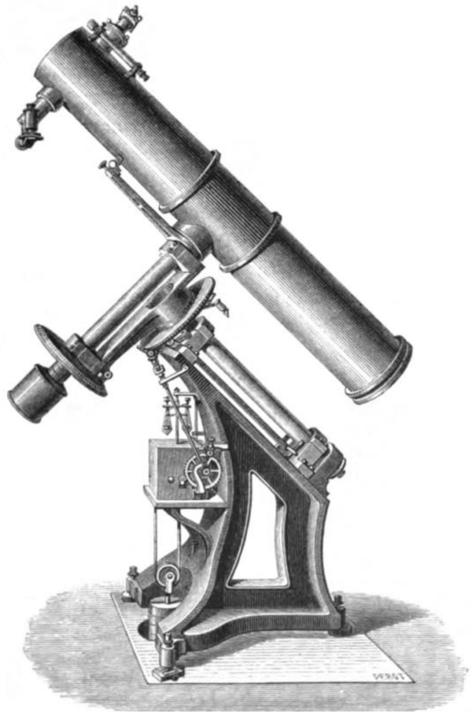


Figure 74: A 20-cm, f/7 silvered-glass reflector mounted by Eichens before 1874. A similar instrument dated to 1877 is conserved at the Université de Montpellier-2 (e.g. www.collections.univ-montp2.fr). I suspect the mirrors were made by Martin (after: André and Rayet, 1874: 121; courtesy: Google Books).

It would seem that Martin also continued to work for Secretan directly; but with little enthusiasm, perhaps because he was busy building mirrors for 1868 solar-eclipse and 1874 Transit-of-Venus expeditions.[51] In any case, Secretan reported in late 1873 that "M. Martin, either incapacitated, or through ill will ..." had not worked on the Toulouse 80-cm mirror (Lamy, 2008: 5, his translation). Paris Observatory also contracted with Eichens and Martin to finish building the 120-cm reflector which finally entered service in 1876 (Figure 75). Eichens' work was exemplary, but it is notorious that Martin dishonestly hid his inability to produce a satisfactory mirror (e.g. Tobin, 1987).

The Second Empire fell at Sedan in September 1870. Paris was soon besieged for four months, followed by the bloody suppression of the Paris Commune in May 1871. During the siege a large Prussian shell fell on the Secretan workshop on the Rue Méchain. Auguste reported it destroying a "... fairly considerable ..." number of astronomical objectives and caused "... 18 to 20,000 francs …" of damage (Secretan, 1871). But neither an essential machine for dividing circles nor Foucault's optical flat for testing objectives was damaged. "... relative to the risks run," Auguste concluded, "I have again been very lucky." His luck continued three years later when a fire broke out in the shop on the Place du Pont-Neuf and was mastered reasonably quickly (Faits divers, 1874; L'incendie de la nuit dernière, 1874).

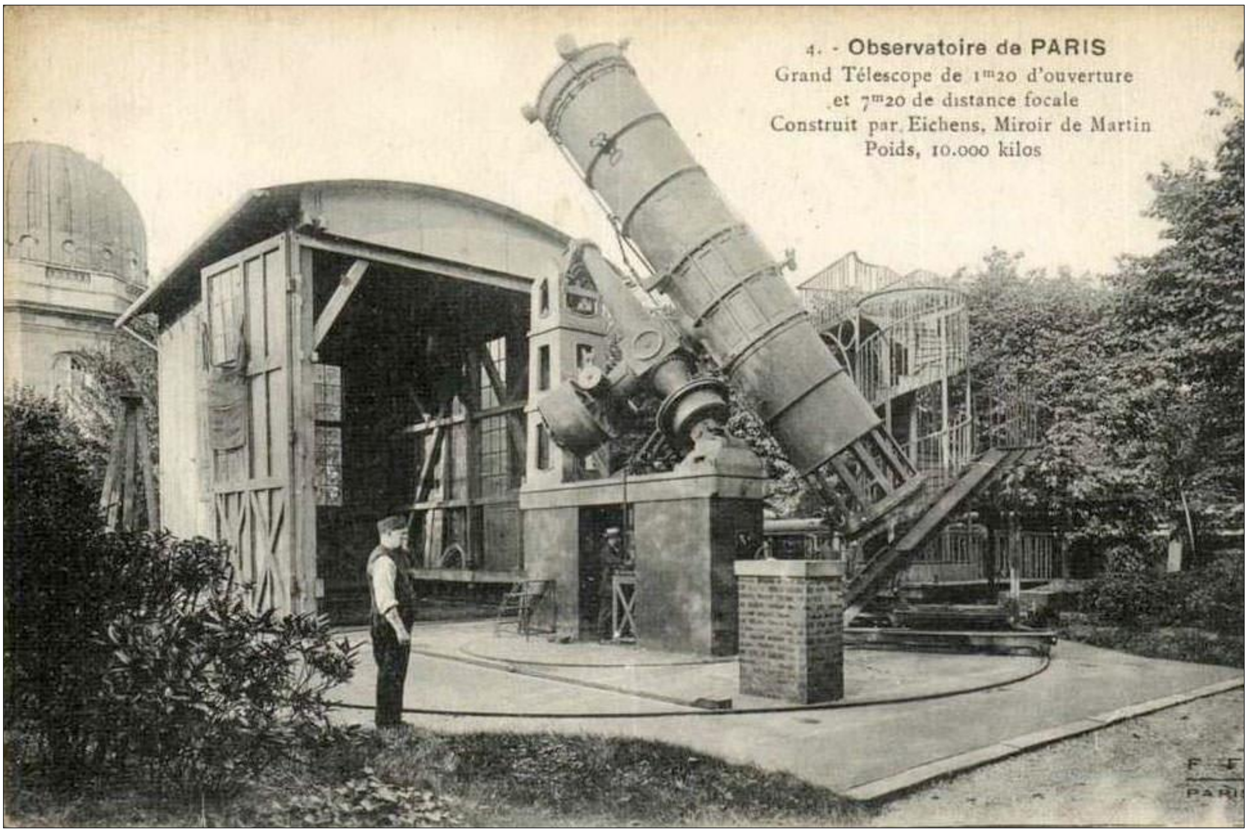


Figure 75: The 120-cm reflecting telescope, enclosure and helical observing platform. Proposed in 1862, the mirror blank was cast the following year, but the telescope was not completed until 1876. The optics never performed satisfactorily. Paris Observatory's east wing and dome are visible in the background (courtesy: www.cparama.com).

According to Flammarion, salvation for Auguste's optical fabrication problems came in about 1873 when Flammarion (1874a) introduced him to the brothers Paul (1848–1905) and Prosper (1849–1903) Henry. The Henrys had been working at Paris Observatory since the mid-1860s, in the Meteorological Department. In about 1871 they had built a 30-cm silvered-glass reflector in their spare time, in consequence of which they were transferred to astronomical work and began to make mirrors and lenses, it would appear both for the Observatory and privately. In November 1873 Auguste was able to report that he had "... become independent for small-sized mirrors ..." as well as "... for those of large sizes." (Lamy, 2008: 5, his translations). During 1874 the Henrys shaped a new, 84-cm mirror for the Toulouse telescope (Figure 37). The mirror is signed "Secrétan Opt[icien]. Parabolisé par M.M. Henry fr[èr]es. Paris 1874" (Pérolle, n.d.). Another signed Henry mirror of slightly later date is the ~f/6 301.0 ± 0.5-mm diameter mirror from the "... $0^{m}.30$ ..." telescope owned by M. Jules Thore of Dax (Flammarion, 1890: 860), and now at the Observatoire de Dax. Inscriptions read "Parabolisé par M.M. Henry frères Paris 1879 Nº 30" and "Pouvoir optique – 450 000" (Soulu and Dupouy, pers. comm., 2016). The octagonal tube of this instrument in unpolished wood has survived and is of characteristic Secretan conception.

In early 1874 Auguste Secretan finally produced the long-promised catalogue of astronomical and other instruments (Table 1).[52] It was the complement to a catalogue of chemical and other equipment published 12 years earlier (Secretan, 1862b). The 1874 catalogue represents the apogee of Auguste's work, and the silvered-glass telescope in particular, with the greatest offering and the most detail. "We congratulate him for his efforts and we applaud his successes." wrote a reviewer (Dufour, 1874). I have translated relevant parts of this key document in Appendix 2. The catalogue reprinted, slightly-edited, the descriptions of optical testing and optical power published by Foucault in the Observatory's *Annales*, vaunted in a company advertisement as "... all the more valuable because one looks for them in vain in most of the usual treatises." (Maison Secretan, 1876). Introducing this section, Auguste alluded to difficulties with optical fabrication, saying "We had the good fortune to meet Messieurs the Henry brothers, who were very willing to try to fill the gap left by Foucault." (Secretan, 1874: 110). The range of metal-mounted, alt-azimuth telescopes was extended to include 160- and 200-mm apertures. Figure 76 shows a 160-mm example. With equatorial mountings, available apertures were 16, 20, 30, 40 and 50 cm. Figure 77 presents a surviving 20-cm instrument.

Figure 76: Alt-azimuth 16-cm reflecting telescope conserved at Harvard University (see Table 9). Two locking screws are provided for the altitude axis (cf. Figure 53). The eyepiece assembly is not attached, but is similar to those of other metal-mounted instruments (courtesy: Collection of Historical Scientific Instruments, Harvard University).

Figure 77: Equatorially-mounted 20-cm reflector, serial number 67, acquired in 1874 by the University of Coimbra (see Table 9) (courtesy: Observatório Astronómico da Universidade de Coimbra).

Figure 78: 16-cm telescope with motor drive offered for sale by Christie's South Kensington in 2008 (see Table 9). The original mirror and cell are missing and have been replaced, so there is no signature or serial number. The eyepiece lenses are also lost. Like the Milan telescope (Figure 93), the tube has an additional external ring (courtesy: J. Duncan).

Wood-mounted telescopes were still available for "... institutions whose budgets are too limited ..." (Secretan, 1874: 96), with apertures of 16, 20, 30, 40, 50, 60 and 80 cm. The 16-cm instruments, both wood- and metal-mounted, were also advertised with a motor drive. Figure 78 shows such a telescope. The additional ring around the tube of the latter suggests that its tube can be split into two, perhaps to facilitate transport, unless it is just strengthening or permitted rotation of the prism and eyepiece to a convenient viewing position. Figures 77 and 78 reveal setting circles arranged essentially as for the Worms de Romilly *télescope* (Section 6.1).[53] For those who wanted to make their own tube and mount, the price of parabolized mirrors had fallen to 150 fr per 10-cm square.

Auguste had not long to live. Heart disease had become manifest during his service with the ambulances during the siege of Paris and had worsened in the spring of 1874. He was at work on 9 October when an aneurysm burst externally, killing him in a pool of blood. Summing Auguste up, Flammarion (1874a, his italics) wrote of a man "... so hard-working and so good. Secretan was not a *commercial trader*, but a true *artist*, at every instant sacrificing his own interests for the love of science."

Figure 79: (Left) Georges Secretan (or Secrétan) (1837–1906) (after: Obituary, 1906; courtesy: Bibliothèque Nationale de France). (Right) Gustave Jacquelin (1879–1939) (after: Flammarion, 1939; author's collection).

9.2 1874–1906

Auguste was unmarried. His cousin Georges Emmanuel Secretan (1837–1906), who had been a language teacher at the Collège de Lausanne, took over the business (Figure 79). It was under Georges that the firm sometimes began to use an 'é' in its publications – Secrétan.

For the first decade or so, Georges appears to have let innovation wither. According to a French commentator writing in 1889, "... from having been a very important manufacturing house thirty years ago ..." the firm had "... concentrated on supplying routine instruments since the death of M. Secrétan." (Teisserenc de Bort, 1891: 630). The catalogue published in 1878 (Tables 1 and 2) offers only 10- 16- and 20-cm silvered-glass telescopes (i.e. items 379–381 of the 1874 catalogue), though unmounted mirrors up to 80-cm are advertised. The only telescope illustrated is the 10-cm alt-azimuth one (Figure 51), and this is also the case in the brochure published for that year's Exposition Universelle in Paris (Tables 1 and 2). The 1885 catalogue offered only 10- 16- and 20-cm silvered-glass telescopes, with no illustrations. Telescope prices remained unchanged since 1874 (Appendix 2 and Table 2).

The reduced place allocated to silvered-glass telescopes in the Secretan catalogues no doubt mirrors the fact that the last quarter of the nineteenth century was a time when reflectors found little favour with astronomers, whether amateur or professional.

The slow uptake by professionals has been discussed by Lequeux (2009b). Part of the reason may have been the failure of the Edinburgh 24-inch and Paris 120-cm silvered-glass reflectors in the 1870s (Brück and Brück, 1988; Tobin, 1987) and the supposed failure of the (metal-mirrored) Great Melbourne Telescope. Gascoigne (1996) has claimed that the real problem with this telescope was that it was primarily conceived for making pencil-and-eye sketches of nebulae, which were no longer of any scientific interest. Despite this, Orchiston et al. (2017) have recently shown that the Melbourne telescope was nevertheless used very effectively for pioneering spectroscopic observations. In addition, silvered-glass reflectors were considered temperamental and difficult-to-use. Cornu (1876) admired the stability of focus of a photographic refractor compared to the "... constantly varying ..." focal position of a reflector when the ambient temperature changed. Even such advocates as the 'silvered-glass' astrophotographers Isaac Roberts (1829–1904) and A.A. Commons (1841–1903) came out in favour of refractors for the *Carte du Ciel* project in 1887. Roberts considered reflectors unsuitable for use by "... an ordinary assistant ..." (Congrès Astrophotographique International, 1887: 37), while Common reportedly compared them "... somewhat ungallantly, to the female sex" (Turner, 1912: 25).

The production of silvered-glass reflectors for amateurs also seems to have stalled in the last decades of the century. In an American report on the 1889 Exposition Universelle in Paris we read (Hastings, 1891: 226):

> It was somewhat surprising not to find reflecting telescopes, that is, the modern silver-on-glass type, better represented in the Exhibition, in view of the fact that it was invented in Paris, and that it is supposed to be peculiarly the amateur's construction … The suggestion that this type of telescope has become nearly as unattractive to the amateur as it has to the professional astronomer is obvious.

The report includes the interesting detail that the "... 9.9 inch ..." (250 mm) mirror exhibited by Secretan was figured by the Henry brothers, with the slow focal-ratio *f*/10. Figure 80 shows a 16-cm Secretan reflector acquired five years earlier, in 1884, by the Observatoire Populaire de Rouen (Libert, 1902). It, too, has a slow focal ratio, ~*f*/10. In 1885 a local Rouen observer, Ludovic Gully (b. 1841), reported that his 20-cm Secretan reflector was "... not very nett (it needs to be replaced by M. Secretan) ..." (Gully, 1885).[54] The implication might be that speed and economy of fabrication were forcing the Secretan firm to supply slower mirrors, because we have seen from the Dax instrument (Section 9.1) that the Henrys were quite capable of figuring *f*/6 ones. The company's c.1898 catalogue claims the change was "... to improve the image and permit celestial photography." (Table 2).

Camille Flammarion may partly have been responsible for amateur disenchantment with reflectors. As early as 1867 in a newspaper article he had written:

> … for amateur astronomers, we admit that, in our opinion, at equal power, a refractor is always preferable to a reflector. It is much easier to set a refractor on a star than to search for its reflection in a *télescope*, and much easier to apply it to various studies (Flammarion, 1867).

This text was reprinted as part of a compilation (Flammarion, 1870: 177), but his opinion probably had most effect on telescope buyers when propounded in a supplementary volume to his influential *Astronomie Populaire.* He had got used to pointing reflecting telescopes, admitting (Flammarion, 1882: 685) that the Foucault-Secretan 10-cm reflectors were "... simple and elegant, and very nice to use … [but] advises for preference refractors ..." because their objectives do not deteriorate, unlike reflectors whose

> … mirrors get spotted with the smallest drop of rain, and, especially in the air of big cities, tarnish, and require resilvering from time to time. This is a drawback and a source of worries and trouble.

Nevertheless, the 1870s did give rise to a new design of mount. Figure 81 shows a 200-mm example on which Secretan's name and the date 1877 are engraved. I have not found this form of equatorial mount in any Secretan catalogue, but Flammarion did include a woodcut of such a telescope in his *Les Étoiles* published in 1882 (Figure 82). The design appeared with an hour-angle drive in a photograph (Figure 83) in the c.1908 catalogue (Table 3) of R. Mailhat who bought part of the Secretan workshops in 1894 (see next paragraph). As with the 40-cm Eichens-Martin telescope (Figure 73), a triangular structure on the declination axis forms part of the coarse and fine controls in declination. The change of mount was perhaps definitive, because telescopes with the previous form of metal mount for which there is an established date all date from prior to 1877 (Figure 67 – 1866; Figure 77 – 1874 or before).

Figure 80: Secretan 16-cm alt-azimuth reflector at the Observatoire de Rouen dating from 1884 (see Table 9). The focal ratio is ~*f*/10 (courtesy: www.astrosurf.com/obsrouen).

Figure 81: An equatorial 200-mm Foucault-Secretan telescope dated 1877 belonging to the Groupe d'Astronomie du Dauphiné (GAD) (see Table 9). The GAD received it as a gift from the University of Grenoble and electrified the drive (Pouget, pers. comm., 2015). The finder telescope differs from those shown in Figures 82 and 83, suggesting it is a replacement (courtesy: G. Auzet).

Our French commentator from 1889 continued: "But recently Monsieur G. Secrétan has built up his workshops again ..." (Teisserenc de Bort, 1891: 630). This appears to have involved moving them to a new location, 30 rue du Faubourg Saint-Jacques, near the Observatory, and appointing Mailhat as their head from 1 January 1889 (Mailhat, 1909).[55] There was a link to Eichens and Secretan, because Mailhat had been trained by Paul Gautier (1842–1909), who in turn had worked for Secretan and later Eichens, taking over Eichens' business in 1880 (Brenni, 1996a). However the workshop build-up may have been modest. In 1894 it appears the premises were expropriated; and deciding to set up on his own, Mailhat bought their contents, which he says he "... immediately reorganised to return to the building of major astronomical instruments as well as the fashioning of objectives and mirrors, which had been abandoned." (Mailhat, c.1908: 3). From the Secretan viewpoint, old equipment was updated, and model optical and mechanical workshops were installed in new, larger premises, which judging from a letterhead were located at 41, quai de l'Horloge, not far from the retail shop on the Place du Pont-Neuf (Secretan, 1895; 1915).[56] It seems the company archives, which would be so informative had they survived, were split between the two firms. The Secretan direct successors claimed to be "... heirs to the [Lerebours & Secretan] archives ..." (Secretan, 1915:5), while Mailhat's successor stated that his company

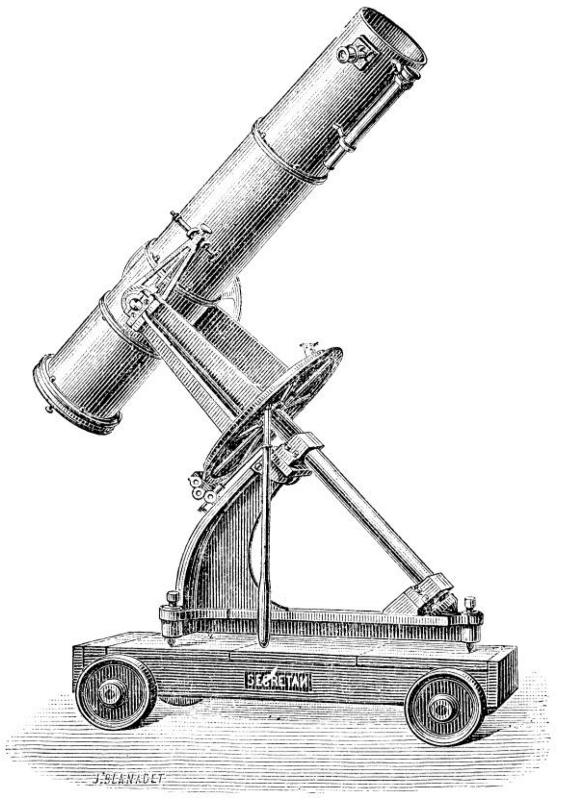


Figure 82: An engraving of a telescope similar to the one shown in Figure 81 was published by Flammarion (1882) and elsewhere. The reversed 'N' in Secretan is a common engraver's error (after: Desbeaux, 1891: 182; courtesy: F. Gires).

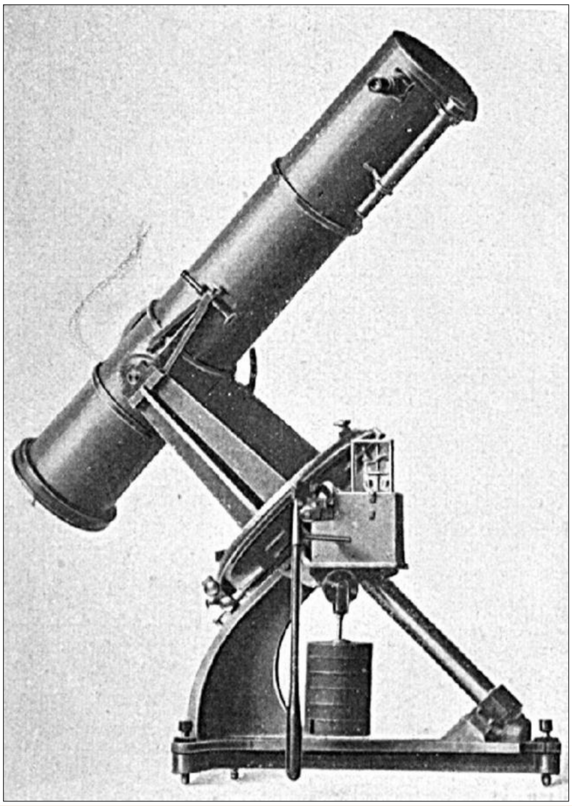


Figure 83: A telescope similar to the one in Figure 81, but incorporating an hour-angle drive. This photograph from Mailhat's catalogue c.1908 was the model for an engraving in the c.1913 catalogue of his successor Mouronval (Table 3). Another form of the photograph was printed by Troubetzkoy (1916) (courtesy: Erfgoedbibliotheek Hendrik Conscience, Antwerp).

> ... possesses, in its archives, documentary reminders of the great accomplishments in precision construction: The elaboration of Foucault's work on silvered-glass mirrors; Auguste Secrétan's optical work; The original Eichens-Secrétan drawings of the first large astronomical instruments, etc. (Mouronval, c.1913: 1).

As the century drew to a close, Georges' surviving son Paul Victor (b. 1879) became involved in the running of the business, as indicated by business letters signed by him (Secretan, 1895; 1896). His father had been a founding member of the Société Astronomique de France in 1887. In November 1902 Paul joined the Society (Présentation de nouveaux sociétaires, 1902), signifying an increasing interest in astronomy. Six months later a letter from "... M[onsieur] SECRETAN ..." (without specifying which one) announced that a 125-mm reflecting telescope had been developed "... for the use of amateurs …" and an example given to the Société Astronomique de France (Touchet, 1903: 312). Was Paul repeating Auguste's feat of developing a new model as his father aged? The focal ratio was *f*/8. Figure 84 shows an engraving of this instrument taken from the 1906 Secretan catalogue, attributed to Georges, where it was stated that the model was "... specially destined for members of the Société Astronomique de France ..." (Secretan, 1906a: 16; for a photograph, see Secretan, 1906b: 415). With three eyepieces giving magnifications of 80, 150 and 200 times, the price was 350 fr. Figure 85 shows an example.

9.3 After 1906

Georges Secrétan died in October 1906 (Obituary, 1906). Paul and his sister Alice (b. 1878) inherited the business. Paul ran the firm for 5 years. He and Alice then sold it to Charles Épry (Ventes de fonds de commerce, 1911: 72). Épry produced a first catalogue in the autumn of 1911 which listed the new 125-mm reflector (with two eyepieces changed and an increased price) and old-style Foucault reflectors of 160- to 250-mm diameter (Table 1). In 1913 Épry associated with Gustave Jacquelin (1879–1939; Figure 79) (Flammarion, 1939). Despite being occupied with war supply, they published an extensive astronomy, science and optics catalogue in 1915 (Table 1). Amateurs were evidently an important market because the catalogue was illustrated with vignettes and biographies of scientists such as Tycho Brahé, Newton, Arago and Foucault, and provided a reading list of popular works by Flammarion, the Abbé Théophile Moreux (1867–1954), and others. Épry and Jacquelin clearly felt that Mailhat (and perhaps others) were abusing the Secretan name because they stated that they were the "Sole successors ..." of Lerebours &

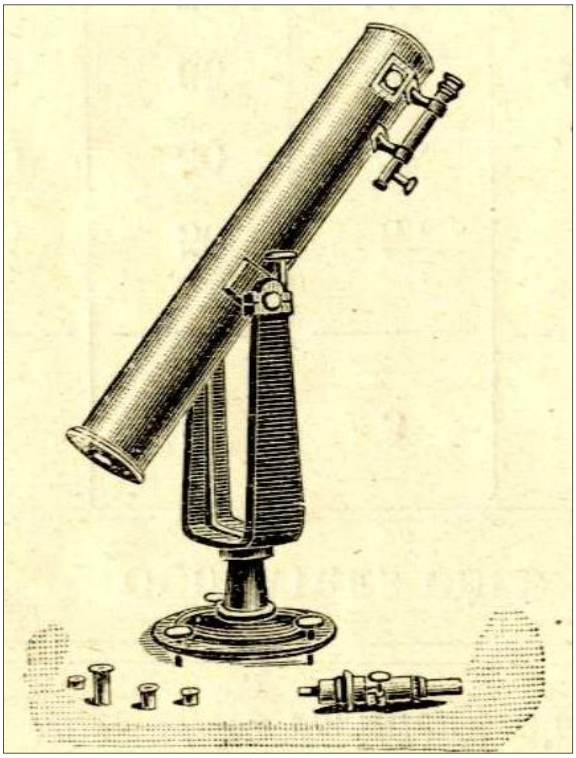


Figure 84: The new reflecting telescope "... of simple construction ..." devised by Secretan for amateurs in 1903 (after: Secretan, 1906a: 17; courtesy: I.Taillebourg, CNAM).

Secretan. "To shield our clients ... all our instruments carry our mark 'SECRETAN PARIS'..." (Secrétan, 1915: 5). They continued:

> ... and to strengthen the guarantee we have adopted new dimensions for the diameters of our optical elements, such that the small difference with the dimensions usually adopted suffices at a glance to distinguish our objectives amongst many others.

Figure 85: A surviving example of the simplified telescope. The cap is leather (courtesy: www.astrobin.com).

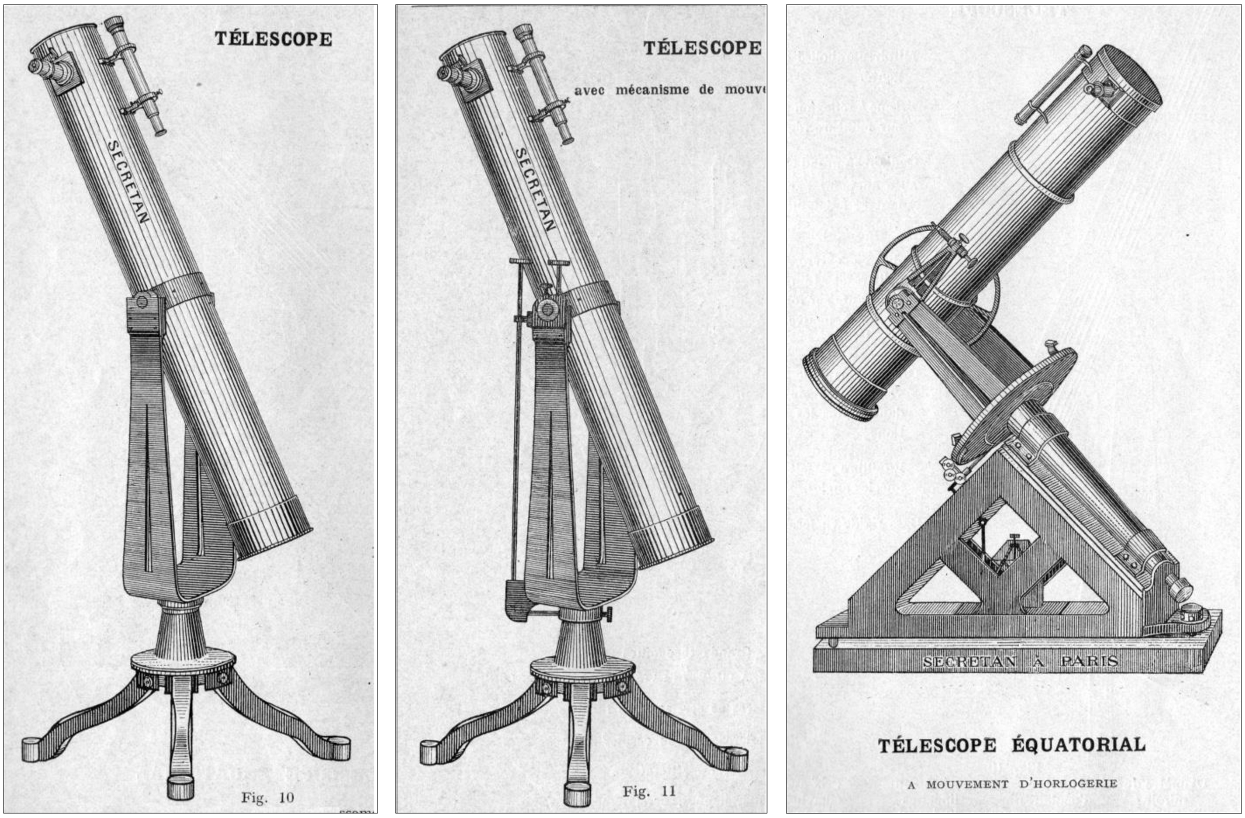


Figure 86: New forms of Foucault-Secretan telescope presented in Secretan's 1915 and 1924 catalogues. (Left) The 'amateur' form of Figure 84 modified by a cast-iron triple foot. (Centre) The same with fine adjustments in altitude and azimuth. (Right) An equatorial mount (after: the 1924 catalogue; courtesy: G. Barbel).

Although some new mirror diameters were offered in 1915 (140 and 180 mm, Table 2), this change applied primarily to refracting telescopes (cf. the 1911 catalogue, page 75).

The 1915 catalogue incorporated three new engravings of reflectors, shown in Figure 86. Small alt-azimuth instruments were offered with a surprisingly finely-divided range of sizes (Table 2). Focal ratios were not stated, but appear to be about *f*/8. The accompanying tables of magnification, if not misprinted, appear to take account of eyepiece aberrations and perhaps seeing. Optical test certificates and guarantees were supplied. The silvering was treated with a "... protective coating ..."[57] so "... maintaining its shine for many years." (Secrétan, 1915: 31, 29). I am unaware of any surviving telescope like those shown in Figure 86, which are probably too modern and considered of too little interest to have entered public collections.

The next Secretan catalogue was produced in 1924. The offering of small reflectors was reduced from six to a more-reasonable four sizes. Prices had more than tripled, reflecting the high inflation that had begun during the 1914–1918 war and was to continue until the depression of the early 1930s (Tableau de l'Inflation, 2015; see also Note 2 concerning overstamping of the 1924 catalogue).

The final Secretan catalogue that I have found is a slim one (28 pages) published in 1942. Georges Prin (1885–1959) was the successor to Paul Gautier (King, 1955). The Prin firm was incorporated into the Secretan company in 1934—a sort of homecoming! —and this was advertised on the catalogue's title page (Figure 2; Table 1) and, from the late 1940s, in advertisements in *L'Astronomie* and no doubt elsewhere.[58] Pride of place in the catalogue was given to the recently-completed 120-cm Newtonian reflector at the new French national observatory at Saint-Michel de Provence, which figured on the cover as an engineering drawing and inside as a photograph. This telescope reused the mirror from the ill-fated Martin-Eichens 120-cm Paris reflector (Section 9.1), reworked by the optician André Couder (1897–1979), and certain parts of Eichen's mounting (Prin, 1942). Soon afterwards a 4-cm chip flaked off the mirror edge during re-silvering, releasing stresses and destroying the image quality (Variétés, 1944; Figure 87).

The range of small reflectors was reduced yet further in the 1942 catalogue—only 125-, 160- and 200-mm diameters, with fine coordinate adjustments only; and for the larger sizes the reflecting prism was replaced by a plane mirror. The forks were stated to be in aluminium. The occupation years were again a time of double-digit inflation, which is no doubt why no prices were quoted.

In March 1963 the Secretan company amalgamated with the Henri Morin company, founded in the 1880s, and known particularly for surveying and drawing equipment (Legros and Boyelle-Morin, 1963). The new entity traded as Etablissements H. Morin-Secretan. The last advertisements that I have found for Morin-Secretan appear in *L'Astronomie* in the 1960s and include "Télescopes" (Figure 88). Around 1967 the firm merged with the Société de Recherches et de Perfectionnements Industriels (SRPI), a company that had been formed in 1918. This probably heralded the end of almost two centuries of telescope making by the firm, whether of reflectors or refractors, because I have found no Morin-Secretan-SRPI advertisements.[59] The joint company took out patents until at least 1981, and subsequently disappeared.

10 FOUCAULT-STYLE TELESCOPES BY OTHER MAKERS

The superiority of Foucault's reflectors was quickly apparent. In his 1860–1861 catalogue of available instruments, the optician Arthur Chevalier (1830–1872) noted that metal-mirrored reflectors were "... completely abandoned ..." and that with silvered glass, Foucault had "... recently developed practical means for producing reflecting telescopes ..." (Chevalier, 1860–1861: 67)

As we have seen, commercial restructuring meant that other companies also offered Foucault reflectors. Eichens left the Secretan firm in 1866 and produced the mechanical parts for many telescopes. Eichens' successor, Gautier, remounted the Toulouse 80-cm reflector in metal beginning in 1886 (for an engineering drawing and photograph, see Bach et al., 2002: 191–193). In the same year Gautier contracted to build a similar equatorial telescope for the newly-founded La Plata Observatory, with a mirror figured by the Henry brothers (Hussey, 1914). Gautier and the Henrys also built the 1-metre *grand télescope* for the Observatoire de Meudon, installed in 1891. Its revolutionary *f*/3 mirror was designed for photography and diffuse-object spectroscopy (Janssen, 1896). We have seen that Martin provided silvered-glass mirrors for eclipse and Transit of Venus expeditions. A 38-cm diameter mirror (focal length = 1.42 m, ~*f*/4) was polished by a Monsieur Cache, a worker in the Bardou company of optical fabricants, for observations of the 1871 solar eclipse (Flammarion, 1874b: 248; Janssen, 1873: 107).

The above were all professional instruments. But the Secretans rapidly lost the monopoly for the supply of amateur silvered-glass telescopes as well. I have found 'Télescopes de Foucault'

Figure 87: Martin's mirror from the Paris 120-cm telescope was refigured in the 1930s by the optician André Couder and installed in 1942 at the Observatoire de Haute-Provence. The mirror was chipped soon afterwards and is now on display at the Observatory. The damage has been hidden by the large bevel (courtesy: www.obs-hp.fr).

offered in the catalogues of several other Parisian instrument makers (Tables 3 and 4). It must be noted that re-badging and on-selling was common in the Parisian scientific-instrument trade (Brenni, 1989; 2002), so it is very possible that some of the equipment sold by others may have still been made by Secretan or successors. Further, some components, such as iron castings, may well have been outsourced, and thus were perhaps available to several instrument makers. (There are no items obviously intended for casting in the 1867 inventory of Secretan's business (Sebert, 1867–1868).) The aforementioned Arthur Chevalier offered what is clearly the Foucault-Secretan 4-*pouce* télescope for on-sale in an 1860 catalogue (Tables 3 and 4), and we have seen that Duboscq offered small reflectors as early as 1864.

In his later catalogues Duboscq continued to offer "*Télescopes*, L. Foucault system", but with less details specified (Table 4). Foucault and Martin apparatus for the "... inspection and veri-

Figure 88: One of the last Morin-Secretan advertisements briefly mentioning reflecting telescopes ("Télescopes") (after: Etablissements H. Morin-Secretan, 1964; courtesy: Google Books

INSTRUMENTS D'OPTIQUE A L'USAGE DES SCIENCES

CINQ MÉDAILLES DE 1re CLASSE

GRANDE MÉDAILLE D'OR A L'EXPOSITION DE MOSCOU 1872

Ed LUTZ

FOURNISSEUR DES ÉCOLES FRANÇAISES ET ÉTRANGÈRES

Rue des Noyers, 49 (boulevard Saint-Germain).

SPECTROMÈTRES
DE
MM. BUNSEN et KIRCHHOFF

Spectroscopes de poche. 25 fr.

LUNETTES DE ROCHON
POUR MESURER LES DISTANCES

NOUVEAU MODÈLE DE
DIABÉTOMÈTRE DE ROBIQUET
ET DE
SACCHARIMÈTRE

PRISMES DE NICOL
DEPUIS 3 FRANCS LA PIÈCE

TÉLESCOPES DE FOUCAULT
Nouveau modèle.

MIROIR : DIAMÈTRE, 10 CENTIMÈTRES 1/2
CORPS : 85 CENTIMÈTRES
AVEC CHERCHEUR
1 OCULAIRE TERRESTRE
2 OCULAIRES ASTRONOMIQUES
ACCOMPAGNÉS D'UNE
BONNETTE EN VERRE NOIR.

LES OCULAIRES
PEUVENT SERVIR POUR MICROSCOPES

MONSIEUR,

J'ai l'honneur de vous présenter la photographie d'un nouveau modèle de télescope, à miroir parabolique, en verre argenté, de M. FOUCAULT, et de vous donner la description de cet appareil en quelques mots qui suffiront pour vous faire apprécier les avantages de cette nouvelle construction.

Le corps de l'instrument est en cuivre poli et verni ; il est supporté par deux tourillons en acier, montés sur deux montants en fonte de fer, entre lesquels le corps de l'instrument passe librement ; ces deux montants reposent sur un pied-de-biche en fonte de fer, qui peut se placer sur une table, en sorte que l'horizon et le zénith peuvent être interrogés dans tous les sens par l'observateur assis ou debout.

Le chercheur, placé près du miroir, est d'une manœuvre facile pour le pointage astronomique.

Le grossissement varie, suivant trois jeux d'oculaires, de 80 à 300 fois, ce qui permet d'observer Mercure, Vénus, Saturne, les étoiles doubles, les montagnes de la Lune, les taches du Soleil, les nébuleuses, etc.

Cet instrument, très-portatif, qui fait aussi bonne figure dans un salon que dans un cabinet de physique, peut remplacer un télescope sept à huit fois plus volumineux et coûtant trois fois plus.

Le prix de ce Télescope complet est de . . . . 500 francs.
Renfermé dans une boite en noyer. . . . . 25 fr. en plus.

En espérant, que vous voudrez bien m'accorder votre confiance, que je m'efforcerai de justifier,
J'ai l'honneur de vous prier d'agréer, Monsieur,
l'assurance de ma parfaite considération.

ED. LUTZ.

PARIS. — IMPRIMERIE DE E. MARTINET, RUE MIGNON, 2

Figure 89: Printed letter sent to potential customers in the 1870s advertising Édouard Lutz's "New model" 10½-cm Foucault telescope (courtesy: R. Smeltzer).

fication ..." of plane and curved surfaces was offered in 1885 (Duboscq, 1885: 112). The following year the Duboscq firm was taken over by Philibert Pellin (1847–1923; Brenni, 1996b). The Pellin catalogue for 1900 reprinted the engraving shown in Figure 51 and offered 100-, 160- and 200-mm "Foucault mirror" telescopes for 490, 1,200 and 2,000 fr respectively (Tables 3 and 4).

The case of the manufacturing optician Édouard Lutz, born in Riga in 1832, is intriguing. On 8 November 1883 he wrote to Flammarion, reminiscing:

> … the first Foucault *télescopes* were built in my firm, in the time of my predecessor, Mon-

> sieur Berthaux, and under the orders of Monsieur Foucault himself, as well as with Monsieur Fizeau's help, and that since this time (1852–53) I have worked to improve and simplify the design … and facilitate portability … (Fuentes, pers. comm., 2015).

The dates 1852–1853 are clearly wrong, and Lutz's claim that the first Foucault telescopes were made by his predecessor is not substantiated by Foucault's writings. Nor is Lutz's spelling certain: at death, his predecessor was recorded as Antoine Sedelly Bertaud (1802–1862) (Registre d'État Civil, 1862). One of Bertaud's specialities was cutting crystals. He certainly cut glass and crystals for Fizeau (e.g. Fizeau, 1862: 440). Perhaps he also cut the Iceland spar for Foucault's polarising prism in 1857, i.e. the time when Foucault was beginning his telescope work, and this is the origin of Lutz's confusion. Other —much later—authors claim rather that Bertaud was already using a system of local corrections in his work, and this was the inspiration for Foucault's *retouches locales* (d'Ocagne, 1904: 398; Laussedat, 1875: 1287; 1901: 125). Whatever the truth, the company was well-prepared to take up Foucault's ideas.

It is unclear when Lutz took over the Bertaud firm,[60] but he did produce a catalogue in his own name in 1872, in which he offered Foucault photometers and polarising prisms as well as "Foucault system" reflectors with exactly the same diameters, focal lengths and prices as offered by Duboscq in 1864 (Table 4). Was Lutz on-selling Duboscq wares? Several facts suggest it may have been the inverse. Lutz's catalogue included a novelty not listed by Duboscq—a "Foucault telescope – M. Bourbouze's arrangement" with an accessory achromatic lens (Table 4).[61] In various ways this 'Swiss-army-knife' instrument could serve as projector, refractor, microscope (using the eyepiece assembly) or photographic camera! At about the same time Lutz sent potential customers a printed letter advertising a "New model" 10½-cm Foucault *télescope* with a pasted-on photograph (Figure 89).[62] In modified forms, this telescope appeared in later catalogues produced in 1882 and c.1890 (Tables 3 and 4). Figure 90 shows the associated engraving. At the Paris Exposition Universelle in 1878 Lutz showed a Foucault-type mirror. (At the same exhibition the Radiguet company exhibited an equatorial *télescope* with a mirror finished by one of the Henrys (Garnault, 1878: 475).) In 1890 Lutz gave one of his 16-cm reflecting telescopes to the Société astronomique de France (Armelin, 1890). Lutz died in 1895 (Registre d'État Civil, 1895), and subsequently similar 15-, 13- and then 10-cm instruments were offered in catalogues dated from 1907 to 1928 by Les Fils d'Émile Deyrolle, a firm better-known for biological supplies (Figure 90; 1907: 72; 1910: 110; 1928: 105).[63] Figure 91 shows what appears, on account of the longer collar fixing the altitude trunnions to the tube, to be a surviving Lutz instrument in Athens.

The previously-mentioned Bardou firm was founded in 1819 (see Table 3, 1899 catalogue)

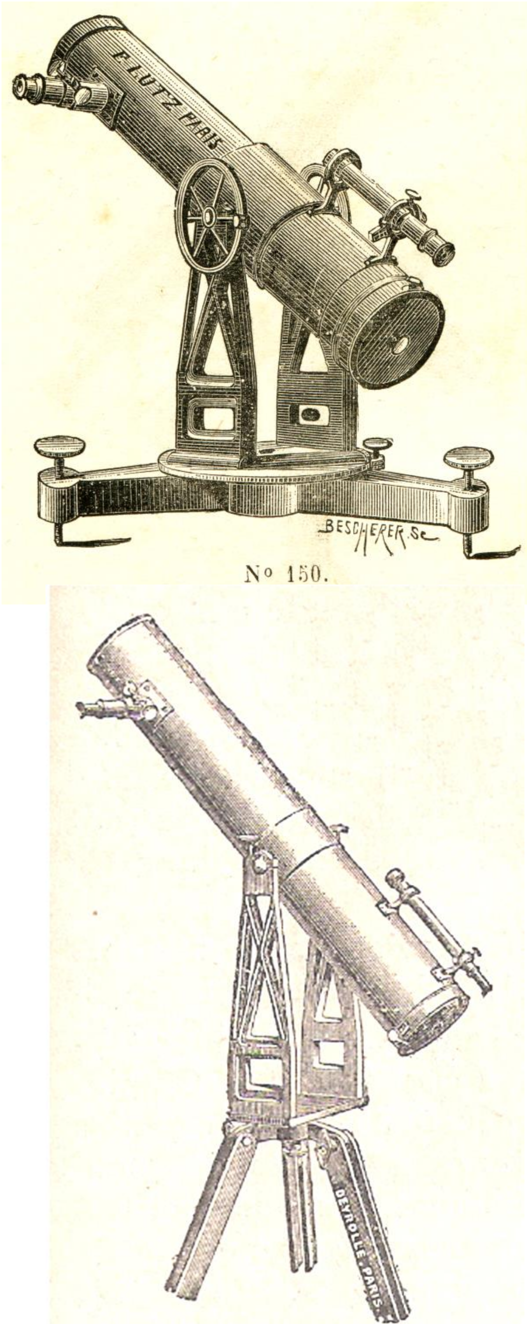


Figure 90: (Top) Engraving of Lutz Foucault-system telescopes from the firm's 1882 and c.1890 catalogues (Table 3). (Bottom) A similar style of telescope offered by the Deyrolle firm in the early twentieth century (after: Les Fils d'Émile Deyrolle, 1928: 105; courtesy: P. Brenni).

and towards the end of the century became an important supplier of small refractors, advertising frequently in Flammarion's monthly *Astronomie* magazine in the years around 1890.[64] Advertisements in 1888 and 1890[65] announced the availability of a catalogue, which I have not been

Figure 91: Remnants of what is probably a Lutz 4-*pouce* reflector (courtesy: Museum of Science and Technology, University of Athens).

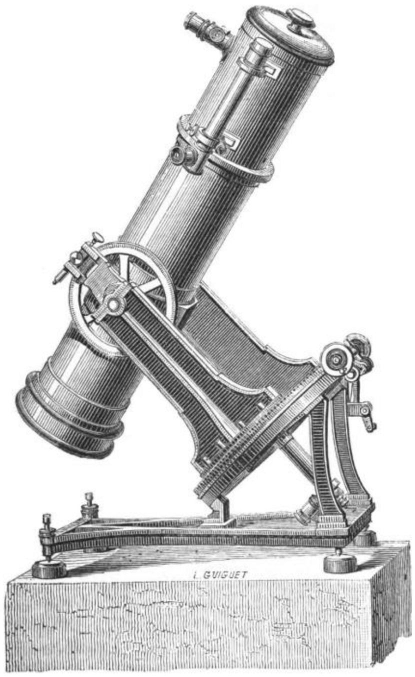


Figure 92: Woodcut of equatorially-mounted 10- to 20-cm reflecting telescopes printed in the 1892 Bardou catalogue (Tables 3 and 4) (after: Towne, 1896: 287; courtesy: Google Books).

Figure 93: A 20-cm reflector, conserved by the Istituto Leone XIII in Milan which from comparison with Figure 92 appears to have been supplied by the Bardou company. The Istituto was founded in 1893, so the telescope perhaps dates from after then (courtesy: P. Brenni).

able to find, with "Télescopes à miroir Foucault" as a category. A Bardou catalogue dated 1892 offered 10-, 16- and 20-cm alt-azimuth and equatorial *télescopes* (Tables 3 and 4), illustrated with woodcuts. For the alt-azimuth instruments, Secretan's original xylograph from 1865 was reproduced (i.e. Figure 51), though recut by another engraver, Louis Guiguet, who also provided the equatorial illustration shown in Figure 92. (These two woodcuts were also printed in practical astronomy books written by Gélion Towne (1890; 1896).) Figure 93 shows what is no doubt a 20-cm example of such a Bardou equatorial in Milan, though the instrument is unsigned. Figure 94 shows an ~f/7 alt-azimuth with an 108.7 ± 0.2 mm full-diameter mirror (i.e. essentially 4 *pouces*) stamped "A. BARDOU, PARIS". Denis Albert Bardou (b. 1841) says he took over from his father in 1865 (Légion d'honneur, 1892) and the instrument presumably dates

Figure 94: 4-*pouce* telescope belonging to the Lycée Janson de Sailly in Paris. The inset shows A. Bardou's name stamped at centre rear of the mirror cell (author's photographs).

from between then and his death in 1893 (Registre d'État Civil, 1893). Although the optical layout is basically the same as for a Foucault-Secretan telescope, the mounting does not conform to that illustrated in Figure 51 and the Bardou catalogues. The tube has a prominent brass ring at its mouth and is attached to the elevation axis by two plates rather than an encircling band. The Bardou stamp is surprisingly discreet compared to the exuberant signatures found on many A. Bardou refractors, raising the question of whether the Figure 94 telescope really was made by Bardou or on-sold from another manufacturer. However the form of its prism mount (Figure 95) is the same as for the Milan instrument, supporting the Bardou firm as the manufacturer of both telescopes. Nevertheless, why do the 1892 and 1899 catalogues illustrate the Secretan mount from 1865? Was this to save engraving fees, or did the firm just on-sell Secretan telescopes in the 1890s? After Albert Bardou's death the firm was taken over by J. Vial, and by 1899 (Tables 3 and 4) had ceased offering equatorial *télescopes*.

Ducretet & Lejeune (1893) and Ducretet (1905) offered a 10-cm instrument with cast iron mounting, tripod, four eyepieces, finder and solar filter for 600 fr. A direct-vision spectroscope and equatorial mount were available as extras.

We have seen that R. Mailhat left the Secretan business to set up independently in 1894. His c.1908 catalogue and the c.1913 catalogue of his successor Francis Mouronval[66] (1881–1954) both reprint Figure 51 and offer a range of alt-az and equatorial silvered-glass reflectors with surprisingly-small size increments (Table 4). An advertisement from c.1913 offers a telescope which looks in many ways similar to Figure 51, except that it has an equatorial mount which is adjustable in latitude (Figure 96; Mouronval, 1911). A wood-mounted telescope at the Musée

Figure 95: Prism arm of the Janson de Sailly 4-*pouce* telescope. The arm in the Milan telescope (Figure 93) is similar, and provides a distinguishing feature from Secretan instruments (e.g. Figures 17, 46 and 57) (author's photograph).

des Confluences in Lyon is attributed to Mailhat, with the date range 1857–1868 (Figure 97; Musée des Confluences, 2009: 50). The date range is improbable, but not the attribution since the c.1913 catalogue adds "We also make … telescopes with a simplified mount, with a wooden mount, etc." (Mouronval, c.1913: 17).

Individual amateur astronomers also made silvered-glass telescopes, which in general are easy to identify because they do not match authenticated Foucault-Secretan designs. However, opticians sold mirrors on their own, which could then be mounted by amateurs. Secretan furnishes examples in 1874 (Appendix 2) as well as 1878a, c.1898, 1906a and 1915 (Table 1). A certain L. Cotessat ran an advertisement in 1890 offering 29-cm parabolized silvered-glass mirrors for 125 fr (Cotessat, 1890). Silvered-glass mirrors were also offered by Apoil (1904),[67] Mailhat (c.1908), and Mouronval (c.1913). An example of a self-mounted mirror is provided by the lunar

Figure 96: Mailhat-Mouronval advertisement showing a Newtonian reflector on a variable-latitude mount (cf. Table 4). The tube and fork resemble the Foucault-Secretan design from 1865 (Figure 51) (after: Mailhat and Mouronval, c.1913; courtesy: Google Books).

Figure 97: Wooden-tubed telescope attributed to "Ateliers R. Mailhat 1857–1868". The dates are improbable, because though similar to Foucault-Secretan wooden tubes, there are differences of detail (such as the round wooden mirror cell and the form of the fork) and the Mailhat firm dates from 1894 (after: Musée des Confluences, 2009: 50).

observer Casimir Marie Gaudibert (1823–1901; Obituary, 1901) who in about 1871 bought a 216-mm (8-*pouce*) primary mirror and an elliptical secondary mirror from an "... optician of the first rank ..." (who might or might not have been Secretan, given the focal ratio of *f*/7.6) and mounted it himself (Gaudibert, 1886: 375). Another example is furnished by Troubetzkoy (1917) who mounted or remounted a 10-*pouce* Secretan-Henry mirror (Figure 98). The possibility thus exists that a non-Secretan mount might contain a Secretan or even a Foucault mirror.

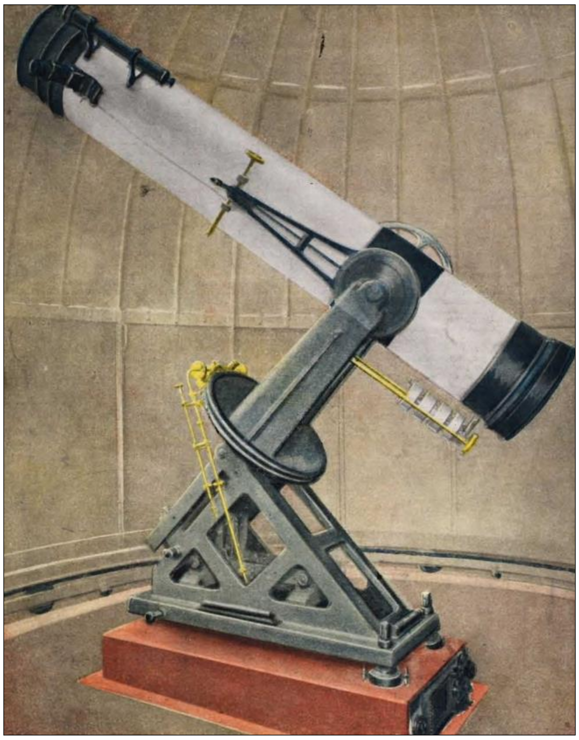


Figure 98: Equatorial Newtonian telescope incorporating a 10-*pouce* Henry-Secretan mirror. Troubetzkoy (1917) says he mounted the mirror himself, and the base is similar to a variable-latitude one invented by him (Troubetzkoy, 1919). However the tube and declination controls show many similarities with Foucault-Secretan instruments (cf. Figures 51 and 82) (after: Troubetzkoy, 1917; courtesy: introni.it).

11 HOW MANY TELESCOPES?

According to Babinet (1858), *Le Magasin Pittoresque*, the magazine that published the engraving of Foucault's first commercial telescope (Figure 9) had a circulation of 90,000. How many sales of non-professional telescopes may have resulted?

The disappointing answer is, not many. Taking the first design of 4-*pouce* mirrors mounted in a square wooden tube, the known serial numbers range from 2 to 42 (Table 6). For 10-cm mirrors in metal mountings the range is 13–236, and since the values for larger diameters fall within this range too, it seems that there may be only one sequence of numbers for metal mounts (Table 9). These serial numbers are to be compared with those on Secretan refractors, which towards the year 1900 could reach 2,306 (Wolf, 2014: FRA4), and even as high as 3,700 (Marine et Instruments Scientifiques, 2012). We can therefore expect sales of some tens for the first design and the low hundreds for metal-mounted silvered-glass *télescopes* compared to the several thousand refractors sold by the Secretan company.

Corroboration for these low numbers of reflectors comes from enumerations of public and private observatories published by Flammarion. In 1877, only the Marseilles 80-cm is listed explicitly as "... built by Foucault ..." (Flammarion, 1877a). The characterization "... Foucault *télescope* ..." applies to instruments in private hands: two 16-cm telescopes, one owned by Hippolyte Barnou, the architect of Flammarion's future observatory at Juvisy-sur-Orge, who used it to help Flammarion produce a corrected edition of Dien's *Atlas Céleste* (Flammarion, 1877b), and the other, equatorially-mounted, by a former naval officer, a Monsieur Le Roux de Villars; Flammarion's own telescope at his then-home on the Avenue de l'Observatoire, described as a 20-cm instrument (i.e. not the 16-cm seen in Figure 71), and another of the same size belonging to Dr E.M. Lescarbault (1814–1894) of Vulcan notoriety;[68] and a 40-cm instrument belonging to the wealthy Ghent sugar-refiner Adolphe Neyt (1830–1892).[69] Soon afterwards, Flammarion noted that "... several ..." 10-cm telescopes had been mounted as "... highly precise ..." equatorials (Flammarion, 1882: 685) and signalled a 10-cm Foucault reflector at the newly-founded Zacatecas Observatory (Flammarion, 1884). By 1890, Lescarbault was listed as also having a 30-cm Foucault *télescope,* Flammarion said he owned both 16- and 20-cm ones, and a Monsieur D. Raffard in Gien possessed a 10-cm one (Flammarion, 1890: 858–861). A 135-mm Lutz reflector was owned in Bayonne by Émile Daguin (1844–1930), son of the aforementioned P. A. Daguin (Section 6.2; Flammarion, 1930). A handful of other *télescopes* is listed without mention of origin, although at least the two belonging to Jules Thore of Dax were of Secretan manufacture: the 30-cm Henry reflector mentioned in Section 9.1, and a claimed "... $0^m.15$ ... " instrument (no doubt 16 cm, Table 9), both now at the Observatoire de Dax (Soulu, pers. comm., 2016). The original dust cap has survived for the latter, and attaches via a pair of rotating fingers, as seen also for Flammarion's 16-cm telescope (Figure 71, right).

I have no information as to whether instruments produced in the twentieth century were numbered. The 1942 Secretan catalogue uses an engraving to illustrate the available reflectors (the same one as Figure 86, centre). Refractors are illustrated with photographs, so the lack of a photograph of a *télescope* suggests it was some time since one had been made.

12 TWO CASE STUDIES

I now apply the findings of this paper to evaluate two *télescopes* recently advertised by dealers.

12.1 Cambi Casa d'Aste, Genoa

Figure 99 shows a reflecting telescope put up for sale in 2006 by an Italian auction house (Asta di Strumenti Scientifici, 2006). The instrument was described as a Herschel-type Newtonian telescope scope with a glass mirror and original multi-coloured cardboard dust cap, and a circular plane mirror to direct light to the eyepiece. The tube outer diameter and length were given as 18 and 98 cm, respectively; and the telescope was ascribed an English or French origin in the late eighteenth or early nineteenth century.

The optical arrangement is clearly Newtonian and not Herschelian. The presence of a glass mirror shows it must postdate 1857. The equatorial mount shows similarities with those shown in Figures 31 and 44, so I feel its author must have read Foucault's description of his procedures in the Paris Observatory *Annales* as well as Drion and Fernet's *Traité.* This makes the early 1860s the earliest possible date for its construction, and perhaps favours a French origin. However the difference in detail of the fork, mirror cell, brasswork etc., and the use of a secondary mirror show that it was not made by the Secretan company. Corroborating this conclusion is the ~*f*/8 focal ratio suggested by the ~12-cm size of the aperture, which is too slow for a Foucault mirror. The dust cap may be old, but given such items' propensity to damage and replacement, I am agnostic about its originality.

Figure 99: Telescope offered for sale by the Cambi Casa d'Aste auction house in 2006. For an assessment, see Section 12.1. Now in the collection of Fausto Casi, Arezzo (courtesy: Cambi Casa d'Aste, Genoa).

12.2 Galérie Liova, Paris

Figure 100 shows a *télescope* offered by a Parisian gallery in 2012–2013, and more recently auctioned at the Hôtel Drouot, where I was able to inspect it. It was described as built on Dobsonian principles, attributed to Marc Secretan, and dated to around 1840 (Joron-Derem, 2015: 55).

The telescope has an alt-azimuth mount and Newtonian optics, which are features of the ideas of John Dobson (1915–2014) for large, inexpensive, transportable amateur reflectors, but the association is anachronistic because Dobson's ideas date from the second half of the twentieth century and the instrument does not incorporate pyrex, teflon and other modern materials (e.g. Dobson, 1991; Sinnott and Dobson, 1980).

The telescope is unsigned, and I am unaware of any Secretan advertisement for alt-azimuth telescopes in octagonal wooden tubes, but there can be no doubt it originated in the Secretan work-

Figure 100: The telescope auctioned at the Hôtel Drouot in November 2015. For an assessment, see Section 12.2. (Top) Overall view. The base measures 360 × 362 mm. Unlike the de Romilly telescope (Figure 38), the slats composing the octagonal tube have no decorative step. Their exposed length is 930 mm. Now in the collection of Vivek Hira, New York (courtesy: galerie-liova.com). (Bottom left) Mirror cell and (bottom right) mirror dust slide (author's photographs).

shop, because of numerous similarities with signed instruments. Perhaps the lack of a name indicates the instrument was first purchased through the intermediary of another Parisian instrument maker.

The optical arrangement is standard, with a prism and eyepiece assembly incorporating relay lenses. The mirror has a convex rear. Its full diameter is 160 ± 1 mm, but the effective aperture is probably 154 ± 1 mm, defined by the wooden circle at the front of the octagonal tube. A few small bubbles are visible within the glass, which has a slight green tint that is particularly evident because of a large chip in the mirror back. The centre of the prism is located approximately 89 cm from the pole of the mirror. Plausibly the focal length is a centimetre or two more, suggesting a focal ratio of ~*f*/5.7 for the full mirror and ~*f*/5.9 in practice. The eyepiece and prism assembly are held in place in the same way as for the Paris Observatory 20-cm telescope with a substantial circular brass plate and three knurled knobs (cf. Figure 45).

The polished brass and wood is reminiscent of the Worms de Romilly telescope (Figure 38) and of the equatorial mounts—Figure 50—still advertised in 1874. Unlike the de Romilly instrument, however, the brass mirror cell extends to the back of the square wooden plate in which it is inserted (Figure 100, bottom left, cf. Figure 42). In this it resembles the Paris Observatory 40 cm (Figure 28). A pair of threaded holes and marks on the brass show that a bar, now lost, once supported the mirror, as for the de Romilly and 40-cm telescopes. The dust cap is similar in conception to the Paris Observatory 20- and 40-cm telescopes (e.g. Figure 29) except that the round wooden disc, which is fragile in these instruments, has been strengthened between the struts with additional quarter-circles of wood. Also following the 40-cm conception is a mirror dust-slide held in position against the front of the mirror cell by lateral springs (Figure 100, bottom right). The finder is similar if not identical to the one on the No. 13 10-cm telescope (Figure 54).

All these features suggest an earliest possible date of about 1860, inferred from the 20- and 40-cm telescopes. However, the metric mirror diameter shows the telescope dates from after the introduction of metric sizes. When was this? Certainly by 1865 (Section 8), but perhaps earlier since the No. 42 4-*pouce télescope* has a metric diameter. In addition, the focal ratio suggests a date before standardization on *f*/6. But if a date within a few years of, say, 1863, seems plausible, it must be remembered that Secretan built instruments to order, and the absence of such a *télescope* from the 1874 catalogue does not necessarily exclude construction considerably later under the stewardship of Auguste or even Georges Secretan.

13 CONCLUDING REMARKS

We see some general and unsurprising influences in the story of the Foucault-Secretan telescope. Turner (1993: 26) has identified delight, luxury, ostentation, and scientific need as some of the "... essential aspects ..." involved in the development of a scientific instrument. Scientific need and, no doubt, delight drove Foucault to develop the silvered-glass reflector. We can compare the simple woodwork of prototypes and professional telescopes (e.g. Figures 4, 26 and 45) with the luxury of models made for amateurs (e.g. Figures 38 and 100) and the ostentation of an owner's arms engraved thereon (Figure 70). We can also see how the design for amateurs moved from the original, wooden, table-top model of 1857 (Figure 9) to a wide range of more practical—but more expensive—metal-tubed ones with alt-azimuth and equatorial mounts in the 1860s and 1870s (Figures 51 and 78), followed by a retrenchment of the range, possible difficulties in maintaining an *f*/6 focal ratio, and the introduction of a cheaper, simplified model in 1903 (Figures 84 and 85), which nevertheless was later improved with fine adjustments (Figure 86, centre). An expansion of the range of available apertures in 1915 unsurprisingly did not persist.

The microscope-style eyepiece assembly also evolved (Figures 18 and 58), and finally was (presumably) abandoned when a secondary mirror substituted for the prism for larger apertures in the 1940s (Table 2). Table 11 reports the barrel diameters for certain instruments. For the smaller apertures the value was standardised at about 23.9 mm until at least the 1860s, but later lost half a millimetre. There is no optical reason for the bigger diameter found in the Paris Observatory 20-cm telescope. Perhaps the reason was mechanical, to provide firm support for the micrometer used during the 1860 eclipse expedition, Wolf and Rayet's photographic plates in 1865, etc.

The Secretan company signed its wares in a variety of ways (Figures 12, 27, 41, 55, 59, 63 and 68).[70] This surprises in the modern epoch of registered trade marks. Also variable was the presence of a date. Serial numbers were only applied to non-professional production models, for which there is no unequivocal example of an un-numbered instrument (Tables 6 and 9). An un-numbered instrument might indicate one on-sold by another supplier, such as Chevalier or Negretti & Zambra.

The end of Newtonian-reflector production by Morin-Secretan was no doubt related to the amalgamation with SRPI in about 1967, and not because of competition from the Schmidt-Cassegrain design, which although it had appeared commercially, only really bloomed from the

Table 11: For five Foucault-Secretan telescopes, outside diameters of the part of the eyepiece assembly that slips into the focusing mechanism (or retaining ring for the 20-cm instrument), and outside diameters of the eyepieces alone. Barrels are not completely round, so the measured range is reported. The measurements show that variations of ~0.1 mm produce close fits, which provides a criterion for judging whether differences between instruments are significant, which they are not for Nos 4, 13 and 18. Measurements of a simplified achromatic microscope are given for comparison, which confirm that the eyepiece assembly of the 4-*pouce* wood-mounted telescopes was an adaptation and not a direct copy of the microscope design.

Telescope	Figures (this paper)	Assembly diameter (mm)	Eyepiece diameter (mm)
4-*pouce* wood-mounted (Secretan No. 4, Wolf TRE16)	10, 69	23.78–23.87	24.76–24.77
20-cm wood-mounted (Paris Observatory)	45, 46	35.8	
10-cm metal-mounted (Secretan No. 13)	53, 54	23.75–23.80	24.70–24.75
16-cm metal-mounted (Secretan No. 18, Wolf TRE17)	67, 69	23.87–23.92	1: 24.70–24.72 2: 24.62–24.64 3: 24.68–24.70 4: 24.70–24.71
10-cm metal-mounted (Secretan No. 236, Wolf FRE1)	62, 64, 69	23.40–23.45	50x: 23.58–23.62 80x: 23.60–23.62 150x: 23.72–23.74 200x: 23.70–23.72
Simplified achromatic microscope	19		24.85–24.90

1970s onwards (Manly, 1994).

This paper contains many uncertainties. It is only a start to research on Foucault-Secretan telescopes and their heritage, but one which I hope provides a structure for further work. The history of individual professional instruments could be extended. For instruments outside Paris, the use of both local and Parisian archives is essential. As an example, the accounting and other material in the Paris Observatory archives has revealed additional details concerning the Marseilles 80-cm reflector beyond what I presented in Tobin (1987). Extensive material is available for an instructive history of the ill-fated Eichens-Martin 120-cm telescope from its origins under Foucault and Le Verrier to its rebirth at Saint Michel.

The evolution of the mechanical design could be studied. Did declination supersede north polar distance on setting circles, and if so, when? (At the end of the nineteenth century Baillaud (1896: 5) was still writing that declination is "... often replaced by the *north polar distance*, its complement.") Questions remain concerning amateur instruments. For example, Schechner and Launie (2014) have made a detailed study of three 4-inch refractors made by the Alvan Clark firm all dating from 1871, and found surprising differences in every measurable dimension, revealing a production that was more workshop-based than industrial. How standardized were Foucault-Secretan products? The 4-*pouce* instruments show variations in their eyepieces and finders which appear to be original but unadvertised purchase options. The 10-cm telescopes show differences in dust-cap design and eyepiece offerings. Is the millimetre difference in eyepiece diameters and half-millimeter difference in overall assembly diameters between telescopes Nos 13 and 236 (Table 11) indicative of a wider revision of dimensions? Telescopes' optical performance would also merit investigation, as has been done, for example, for telescopes made by William Herschel (e.g. Mills and Hall, 1983, and references therein). When exactly did optical dimensions become metricated and the focal ratio standardize to *f*/6, and how rigid was this standardization? The design of the Foucault-Secretan 1865 10-cm telescope (Figure 51) influenced many other makers (e.g. Table 4, Figures 89 and 98) and it would be interesting to understand if this was simple emulation or whether subcontracting was involved —or even intervention by Foucault, as claimed by Lutz, whose products and relationship with Duboscq merit deeper investigation.

To answer these questions it would be desirable to find more telescopes, both by Secretan and other makers. Since a number of the known instruments derive from religious and/or teaching institutions (La Flèche, Quebec, Digne, Milan...), the storerooms of such establishments may be fertile territory for discoveries,[71] but many others may languish in private attics or cellars. Most of the known Foucault-Secretan *télescopes* date from the 1870s or before. It is obviously desirable that more recent instruments be discovered, especially from the twentieth century, and that examples should enter public collections. A fuller study of trade literature and advertising would be instructive,[72] as would a comparison with the production of reflecting telescopes and their uptake by British makers such as Henry Cooper Key (1819–1879), George With (1827–1904), George Calver (1834–1927) and John Browning (c.1831–1925)—whose *Plea for Reflectors,* first published in 1867, makes no mention of Foucault!

This paper was possible, in part, because Léon Foucault's invention of the silvered-glass telescope coincided with the mass introduction of woodcut illustrations in magazines and books in the nineenth century; and because of the easy inclusion of numerous images in a purely-electronic journal in the twenty-first. We can only agree with Foucault when he wrote (1853) "... let us loudly proclaim the importance of the service rendered to science by the publication of illustrated works ..."

14 NOTES

1. The date comes from an advertisement dated October 1911, nine months after Épry's acquisition of the firm, mentioning "... the new illustrated catalogue ..." (Épry, 1911b; a similar advertisement and another from earlier in the year are reproduced by Andrews, 1996: 92). The catalogue's "Avant-propos" notes "The present catalogue does not mention all the instruments that we can supply to the public. The Astronomy catalogue should be consulted." Presumably the 1906 catalogue is meant (Table 1, 1906a).
2. The catalogue is undated but an accompanying letter from the Secretan firm indicates it was published in 1924. It is rubber-stamped with the date "MAR 1929" and 30% price increases. On commercial web-sites such as fleaglass.com, ars-longa.fr and eBay.com I have seen copies with claimed dates of 1924, 1926 and 1929.
3. Date determined from the legal deposit stamp on the Bibliothèque Nationale copy, 10 July 1942.
4. Within a month of the grant of Drayton's first patent in England (1843) a French patent application was deposited in the name of Joseph Brown (1844). The processes were identical, so Brown was presumably an agent. According to Kopp (1859), the essential oils used in the solutions caused reddish-brown spots to appear on the silver surface after a while, which led to revisions in the process (Drayton, 1848a; 1848b). Additions to the Brown patent show that by 1851 Power was acting as representative for the holder of the 1844 patent. Note also the bibliography by Kanthack (1920).
5. With this last sentence and an accompanying footnote Foucault acknowledges that in the previous spring the Munich optician Carl Steinheil (1801–1870) had announced in a newspaper that he had produced a similarly-sized (4-inch) reflector using Liebig's silvering process, though the instrument only supported a magnification of 100× (Steinheil, 1856; see also Steinheil, 1858). According to Kopp (1859) Steinheil compensated the spherical aberration of his mirrors with a negative lens incorporated in the eyepiece. However, in his 1860 price list Steinheil advertised 4-, 6-, 9- and 12-inch parabolic mirrors with focal ratios *f*/6, *f*/6, *f*/10 and *f*/9 respectively. The three largest sizes were available made up as telescopes in the 1860s (Steinheil, 1860; 1867). Brachner (1987: 4) writes "As far as I know not one of these interesting Steinheil-Liebig mirror telescopes has survived." Unmounted parabolic mirrors with the offer to mount them according to the purchaser's wish appeared in the Steinheil firm's catalogue as late as 1907 (Steinheil Söhne, 1907).
6. Foucault's note to the Académie (1857b) referred to his mirror and telescope in the singular, but a fortnight later Babinet referred to mirrors and telescopes in the plural (Babinet, 1857a). In planning the Paris Observatory expedition to Spain to observe the 1860 total solar eclipse, Le Verrier (1860a) proposed taking, inter alia, "Two little reflectors of $0^{m}.10$" which "... [already] exist, at least for one of them ..." In the event, it was just "A $0^{m}.11$ reflector in its box ..." that was taken (Énumeration des objets, 1860). This suggests that in early 1857 Foucault had figured two 10-cm mirrors of acceptable quality, but only had a single tube in which to test them as a Newtonian telescope.

   The telescope mirror is now inventoried by the Paris Observatory as No. 250, and the tube and rectangular transport box as No. 251. Previously the identification was IA-19-63b for the tube and box, which were catalogued as having been donated by a "prof. Nughes" of the École Centrale des Arts et Manufactures. Foucault considered that he had privately financed the development of his small telescopes, and perhaps his first instrument was amongst the residue of scientific apparatus bequeathed to his friend Jules Regnauld (1820–1895). 'Prof. Nughes' is no doubt Émile Nugues (1870–1963), who graduated from the École Centrale in 1894 and taught there until 1941 (Obituary, 1964). He would be a later owner. Perhaps the items were gifted to the Observatory around 1950 when Nugues gave translations made by him of optical works by Karl Schwarzschild and Sigfried Czapski to the Observatory Library (Ms 1039 and Ms 1040). No provenance is given for the mirror, IA-19-63a, which was catalogued as having a diameter of 112.5 mm (i.e. 4 *pouces* 2 *lignes*), which actually corresponds to the inner diameter of the lip against which it abutted. In fact, the full diameter of the mirror is 4 *pouces* 6 *lignes*, and it is just too tight a fit to slip into the wooden mirror cell. Perhaps this is due to shrinkage of the wood over 150 years, but one must consider that it might be one of several of this size polished by Foucault. Nughes was an amateur telescope maker, but the non-metric diameter makes it seem unlikely that it could be one of his mirrors.

On the outside of the lid of the transport box there are the illegible remains of a label which according to catalogue details is a shipping label to the Royal Astronomical Society (RAS) in London. Foucault took his telescope with him when he talked about his telescope at the meeting of the British Association for the Advancement of Science in Dublin during the summer of 1857 (Foucault, 1858c) and visited Sir John Herschel in Kent on his way home. Perhaps the telescope went to the RAS then, but more plausibly it was sent without its creator when Warren De la Rue (1815–1889) presented Foucault's work to the Society in March 1859 (Foucault, 1859b). The presence of a transport box is not in conflict with this being the instrument taken to Spain in 1860.

7. That Foucault took a telescope with him is confirmed by Babinet (1857b) and British Association (1857: 168), where it is reported that Foucault's presentation of his telescope in Dublin was "... warmly applauded … [and provoked] an animated discussion ..." Some of these comments (from G.J. Stoney, T. Grubb and Rev. T.R. Robinson) are reported by Wells (1858: 224). Foucault, however, felt crowded out by Lord Rosse's Leviathan. See Tobin (2003: 204).

8. The Lissajous pamphlet carries no date, but the *Journal Générale de l'Imprimerie* (1858a) indicates that it was published on 14 August 1858. The focal length given for the 216-mm aperture is 162 cm, which is presumably more accurate than the 160 cm correction seen in Figure 5.

9. The 250 fr price is confirmed implicitly by a British source which 4 years later quoted £10 (The Great Foucault Telescope, 1862). (The conversion rate was 25 francs/pound—see Note 14.) In the scientific papers that were inventoried after Foucault's death (see Tobin, 2003: xii), cote 4ème pièce 429 records that the Emperor Napoléon III paid 300 fr for a small telescope: "Lettre de Mr Thélin envoyant 300 f pour prix d'un petit télescope construit pour l'Empereur." Charles Thélin (1801–1880) helped Louis-Napoléon escape from imprisonment in Ham in 1846 and was later his private treasurer.

10. The earliest invoice that I have found written on a billhead vaunting Foucault's telescopes is dated 1 February 1859 (Secretan, 1859a). The workshops were at 73, Rue du Faubourg Saint Jacques. In the first half of 1860 they moved to 13 Rue Méchain; in 1862 their address was 9 Rue Méchain (cf. Figure 6). A billhead from 1887 still mentions Foucault telescopes (seen on todocoleccion.net). The workshops were then at 54 Rue Daguerre.

11. This illustration disappeared from the 8th edition of Ganot's *Cours* (1881). In the 9th edition, reworked by Maneuvrier (1887), the Worms de Romilly telescope (Figure 40) was inserted, to be replaced in the following edition (Ganot-Maneuvrier, 1904) by a woodcut of the Paris 120-cm reflector. The 120-cm reflector first appeared in the *Traité* in 1894 (Maneuvrier, 1894).

12. Note that on page 91 of this publication a photograph of Hippolyte Fizeau is misidentified as representing Léon Foucault.

13. Seven round shims cut from newspaper have been inserted between the mirror of Wolf No. 4 and the wooden back of the mirror cell. I have been unable to identify the newspaper, but the shims carry advertisements for books published in 1858 as well as legal notices concerning Largentière in the Ardèche. Use of a newspaper from the south of France, far from Paris, suggests the shims are an addition after purchase.

14. That the 4-*pouce* telescopes were imported at the beginning is explicitly stated by Webb (1863). One might wonder if Negretti & Zambra later made replicas themselves, but the next line in their 1887 catalogue refers to other reflecting telescopes "... constructed to order", so "Supplied to order ..." strongly implies brought-in goods. In 1879 the price was 18 guineas (Negretti and Zambra, 1879). The Negretti & Zambra catalogues carry no dates. I adopted those from Anderson et al. (1990) for 1859, from the British Library catalogue for 1879, and the evidence of a review (Recent Publications, 1887: 181) for 1887. I used an exchange rate of 25 fr/£ (Bureau des Longitudes, 1858), a value which had not changed significantly three decades later, being based on gold (Bureau des Longitudes, 1887).

15. One might think this was a 15-*pouce* disc (≡ 406 mm), were it not that at about this time Moigno (1857b: 653) wrote of Foucault having crossed "... the distance which separates a 4-*pouce* from a 7-*pouce*, a 7-*pouce* from a 17-*pouce*, etc.", in which case '40-cm' was considerably rounded (17 *pouce* ≡ 460 mm). To add to the confusion,

Foucault himself later referred to the repeated failure of a 42-cm mirror (Foucault, 1859a: 198), but I think this is another disc (see Section 5).

16. Moigno (1858a) describes this mirror as a 35-cm one. Probably it was actually of 13 *pouce*s diameter (≡ 352 mm), which Foucault, with his penchant for even numbers, might have described as 36 cm. The 32-cm mirror was perhaps actually 12 *pouces* (≡ 324.8 mm) in diameter.

17. Elsewhere, Foucault reported that the two mirrors had a 25-cm diameter, showing that he did not always favour even numbers (Foucault, 1858d). Presumably their size was actually 9 *pouces* (≡ 243.6 mm).

18. Ganot (1859b: 442) reports that the 33-cm telescope was built by "... Froment and Secretan …". Perhaps Froment's contribution was limited to the test grid; but it seems more plausible that he was also involved in the mounting, as for the École Poytechnique instrument (Section 2.3.1). Foucault's Louis-Napléon account book shows that from January 1857 he made frequent payments to Froment, usually of 100 fr, totalling 1,400 fr by August 1858, after which they became sporadic, adding only 344.50 fr more by the end of 1859. The first payment was explicitly ascribed "... for supplies" (Foucault, 1852–1865). As an inventive physicist Foucault may well have been using Froment's constructional skills for a variety of other projects at this time which have not come down to us, but presumably any telescope work was included in these amounts.

19. Towards the end of the century, Baillaud (1893: 127) inversed Foucault's definition of the optical power and claimed that "... Foucault showed that it is about 1″ for a 13-cm objective." Foucault's optical power is of course different from the Rayleigh-criterion 'power', $D/1.22\lambda$, because of the striped nature of the target and the eye's spectral sensitivity. Scrutiny of Baillaud's text shows that actually he is referring to the Rayleigh-criterion resolution, $1.22\lambda/D$, for which the quoted value corresponds to a wavelength λ = 520 nm and a Foucault-style power of 16,000 per centimetre. In fact, Foucault claimed a *pouvoir optique* of "... 150,000 units per $0^{m}.10$ of diameter." (1859a: 220). Based on his announced values for the 24/25-cm, 33-cm, 40-cm and Worms de Romilly mirrors, I obtain 12,000 per centimetre.

20. In November 1859 it was reported that Bulard was "... provided with ... two silvered speculum reflecting telescopes" (Miscellaneous Intelligence, 1859). In describing observations of the 1860 total solar eclipse with this instrument, Bulard wrote

> Except for the mirror, it is the same instrument that I used to observe Donati's comet in 1858. For the eclipse, I had to use a non-silvered mirror, of M. Foucault's system. (Moigno, 1861: 328).

If Bulard was meaning that the telescope was not 'the same' because of the removal of the silver from its mirror, it seems odd to specify that the unsilvered mirror was 'of M. Foucault's system.' Further support for there having been two mirrors comes from the fact that it is not until after 1874 that Bulard had the capacity to resilver a desilvered mirror (Soulu, pers. comm., 2014). A second 33-cm mirror is preserved in Algiers in addition to the one shown in Figure 25, but from its metal mounting with a surviving trunnion, it would appear to be the flat heliostat mirror installed in 1883 for solar photography (Trépied, 1884).

21. I measured 410 mm for the inner diameter of the mirror retaining ring seen in Figure 28, so the mirror diameter must be near 42 cm. The circular aperture at the sky end of the tube is warped. When in the meridian, its vertical and horizontal diameters are 404 and 408.5 mm respectively. The horizontal diameter of the mirror-cell aperture is 395 mm. (All dimensions ±1 mm.) With a ~2.5 m tube, these figures indicate an unvignetted field-of-view of about 15 arcmin. The 1859 and 1860 Secretan bills were for 1798.50 and 2730 fr respectively. There is no charge for *retouches locales*, which Foucault no doubt did as part of his Observatory duties.

22. When the 40-cm (and 20-cm) telescopes were shipped to Spain in 1860, the packing list detailed "... two rubber cushions" (Enumération des objets, 1860). In early 1868 Eichens invoiced for modifications to the 40-cm mirror cell to provide three support points and a three-pronged spring with adjustment screw (Eichens, 1868).

23. The telescopes were the Algiers 50-cm (Lagrula, 1932) and the Marseilles 80-cm (Tobin, 1987). One must wonder if similar problems did not occur when Stephan replaced the 40-cm's prism by a flat mirror for the 1905 eclipse, since he does not address the issue in his report (Stephan, 1911).

24. Exactly when is not clear. Secretan billed for having made openings in the "... bois blanc ..." tube in 1861, and again in 1865 for having "... remis en place l'ancien corps ..." into which six holes had been cut "... garnis de toile métallique ..." with an "... encadrement en cuivre", which sounds very like the surviving arrangement (Secretan,

1861a; 1865a; one of six vents is visible in Figure 26). Were initial vents enlarged, or was the chain-mount tube also used on the equatorial mount?

25. It is sometimes unclear for his test targets whether Foucault was referring to individual line widths or their double, the pattern repeat distance. By stating that 1/6-mm spacing at 80 m corresponds to an optical power of 480,000 and a splitting of 0.4″ it is clear that he is referring to the pattern repeat distance.

26. The draft incorporates a note by Foucault who estimated 21,200 fr for the cost of the telescope proper, of which 2,000 fr were for the mirror blank and glass ball for working the initial spherical surface, 1,000 fr for working the surface, 500 fr for the prism-eyepiece assembly, 600 fr for silvering expenses, and 5,000 fr for the motor drive. The contract with Secretan was signed on 15 September (Le Verrier and Secretan, 1860). Major invoices followed on 1 November (Sautter, 1861: 1,977 fr, but see Note 27), 31 December (Secretan, 1860b), 30 July 1861 (Secretan, 1861b) and 14 July 1862 (Secretan, 1862a) totalling 12,831.45 fr.

27. On 22 October 1859 Foucault paid Sautter an advance of 1,000 fr for the provision of two "... big 80^c discs." (Foucault, 1852–1865). On 10 February 1860 he paid a Sautter bill of 1,927 fr for two discs "... of 0.80^c and of 0.85^c", which sum was reimbursed by the Education Ministry in March 1861 (Foucault, 1852–1865). This must be reconciled with an invoice issued by Sautter (1861) on 19 January 1861. It is a duplicate of an original dated 1 November 1860, for the casting and lathing of 80- and 85-cm discs, in execution of an order passed on 12 October 1860. The invoiced amount is 1,977 fr, almost the same as Foucault's payment in February 1860. Although the invoice was approved by Le Verrier, and is annotated with inventory numbers, Sautter has not countersigned indicating receipt of payment. Paperwork can often postdate action, so perhaps this invoice just reflects Paris Observatory officialising Foucault's original order and justifying reimbursement. In any case, Foucault's initial payment of 1,000 fr was presumably ultimately actually used for other purposes.

28. Sautter's bill (1861) indicates that both discs had a concave face "... doucie ..." i.e. fine ground, ready for optical polishing. The reverse faces were convex, left rough for the 85-cm disc but polished for the smaller disc, which also had a furrow cut in its edge for attaching ropes to facilitate manipulation (see Figure 33 and Tobin, 2003: Plate XIX).

29. In Tobin (1987) I quote 788 mm for the mirror diameter and 4.54 m for its focal length. The 788-mm diameter has recently been confirmed by Caplan and Ruiz (pers. comm., 2015). The radius of curvature of the convex surface is approximately 1.2 m.

30. The mirror Inv. 14050 was given to the Musée des Arts et Métiers in 1907 by the microscope-manufacturer Alfred Nachet (1831–1908). This tends to support an attribution to Foucault, because Nachet had collected other items indubitably associated with Foucault—daguerreotypes now in the Museum of the History of Science in Oxford and in the Optisches Museum in Jena, and microscopes made or owned by Foucault (Nachet, 1929). As displayed, the mirror is protected by an octagonal pane of glass. This made measuring the mirror difficult, but its diameter and thickness do not differ by more than a millimetre or so from 330 mm and 28 mm respectively. The poor optical quality of the protective pane made it difficult to check whether the 229 cm focal length claimed on a paper label visible in Figure 36 is accurate, but the points at which (i) my own image inverted and (ii) one of my fingers showed little parallax with its image in the mirror suggest that the focal length might be half a metre greater. The Musée des Arts et Métiers holds another mirror, acquired in 1975 from a deceased anonymous donor who attributed it to Foucault (Inv. 22507, dossier d'oeuvre). The attribution to Foucault is highly improbable since the mirror is made of metal. I measured its diameter as 252 ± 1 mm and thickness as 30 ± 1 mm. I could not determine the focal length, but it is greater than 5½ m, which suggests the object may not even be a telescope mirror.

31. At the end of 1862 Sautter billed for cutting to size a 801-mm glass disc with a 9.60-m radius concave surface and a 1.80-m radius convex surface (Sautter, 1862). Buoyed by the success of the 80-cm mirror completed at the beginning of the year, did Foucault and Le Verrier have the unused 85-cm disc cut to shape for another mirror of similar size? From the masses quoted in an earlier bill (Sautter, 1861) it would seem the disc would have been quite thick enough.

32. Shreds of evidence indicate the relationship. On 2 December 1852 (the day of Louis-Napoléon Bonaparte's coup d'état), Worms de Romilly took his friend (and later French Prime Minister) Émile Ollivier (1825–1913) to vist Foucault, where discussion centered on Foucault's "... beautiful experiments on

the motion of the Earth" (Ollivier, 1961: 136). Three years later Worms de Romilly wrote to Ollivier about lunching with "... le Foukmann ...", adding "So there's my man who's putting down more and more roots at the Observatory through his own forcefulness despite the lofty Blond [i.e. Le Verrier]" (de Romilly, 1855). About the same time, Worms de Romilly corresponded with Foucault concerning his (Foucault's) induction machine (Inventaire Des Diverses Cotes, n.d.: Cote 11ème, pièce 11 "Letter on an induction experiment (draft)", pièce 12 "ditto", pièce 13 "Monsieur de Romilly's reply (same subject)"). On "Saturday 20 August …" in a later year, which is probably 1859 but might be 1864, Worms de Romilly's wife, Elisa (1834–1880) wrote to Foucault thanking him for his intervention in some affair, inviting him for the afternoon, and noting that "Félix was enchanted with the letter you wrote him, because it shows him that you liked his parrot." (de Romilly, n.d.). Finally, a funeral oration for de Romilly mentions "... his friend Léon Foucault ..." (Mascart, 1903).

33. Lambert also commented on the informality, longer hours and Sunday working in French workshops compared to Irish ones, as well as greater opportunities for self-improvement in Paris than Dublin. "With such opportunities … can we wonder that the French workmen have acquired for themselves so high a reputation for intelligence and skill?" (Lambert, 1879: 478).

34. The stabilising rod was subsequently broken but has recently been repaired. The finder telescope has also disappeared. It had a 27-mm diameter and was a later addition, being installed by Eichens after the Siege of Paris (Eichens, 1871a).

35. A summary of the 20,000-fr expedition expenditure is provided by Le Verrier (1861). Purchase of the 20-cm telescope is not mentioned, but presumably was included in the sum of 4295.50 fr paid to Secretan "... for the construction of instruments."

36. The Paris Observatory conserves a 212 ± 1 mm diameter mirror (inv. 259) which the inventory speculates might be from the 20-cm telescope. It has many of the characteristics of a Foucault mirror—a polished, curved back, green-tinted glass, and a furrow around the edge. However, the furrow is deep, the edges are bevelled and the mirror is accompanied by a note "Mirror belonging to me, C. Wolf." I do not think this is the original Foucault mirror, but perhaps it is a substitute used by Wolf. It would be enlightening to measure its focal length. Could it be the 21-cm mirror made by Martin for the 1868 solar eclipse (Note 37 and Janssen, 1868)?

37. Two French expeditions observed the 1868 eclipse. The mission to the Malay peninsula took a 20-cm reflector while the one to India took a 21-cm instrument (Janssen, 1868; Stephan, 1868). Both mirrors were parabolized by Martin (see Section 7). Doubtless it was this 20-cm telescope that was used on the return journey to observe a transit of Mercury from Marseilles (Figuier, 1869).

38. The text was reprinted in at least three other publications with 'Rayet' corrupted to 'Reiset' (Astronomie photographique, 1866; Lacroix, 1865; Schnaiter, 1865). Modestly, Rayet does not mention this work in his history of astronomical photography (Rayet, 1887). The brass plateholder, rack and 24 glass plates for photography cost 55 fr and a new prism 12 fr (Secretan, 1866a; 1866b). Another special eyepiece had been procured when the telescope was taken to Spain.

39. Musée de la Civilisation accession No. 1993.3. Nadeau (1943: 237) notes that the telescope is signed "Secrétan à Paris, 1867". I am surprised by the 'é'. The mirror has a pale green tint. Not appreciating the reason, Nadeau finds it "... fairly bizzare ..." that the back of the mirror is curved. The eyepiece assembly is a "... veritable compound microscope ..." The base of the foot is like that of the 20-cm (Figure 45).

40. The incident involved a note presented to the Académie by Duboscq (1862) concerning Foucault's heliostat for photographic enlargements. In fact the note had been written by Foucault, as indicated by a draft in his handwriting (Foucault, 1862c). In reporting the presentation for *Cosmos*, Moigno innocently referred to "... their heliostat ..." (1862b: 470). Annoyed, Foucault prepared a letter (1862d) that Duboscq sent to *Cosmos* protesting the amalgam between scientist and constructor (Moigno, 1862a).

41. The 10,000 fr were given on 17 February 1852. On 29 September 1855 the Emperor's aide-de-camp wrote that having heard of Foucault's electrical experiments, Louis-Napoléon had decided to fund his future work (Favé, 1855). However, it was not until 4 November 1856 that Foucault took up this offer, receiving 2,000 fr. Subsequent payments were 1,500 fr and 2,000 fr on 18 February and 1 September 1858, and 3,000 fr on 1 February 1860. A week after the 1852 payment Foucault paid Froment's outstanding bill for the Panthéon demonstration (which was only 887 fr). A

week after the September 1858 payment he paid a Secretan bill for 890.40 fr. Nine days after the 1860 payment he paid a Sautter bill for 1,927 fr (see Note 27). It would seem Foucault sought out Louis-Napoléon whenever short of cash! After 1860 the telescopes were bringing in money, as perhaps were his electric arc and heliostats developed with Duboscq, and the Emperor's subventions ended.

42. This letter is a copy, in someone else's hand, in a subfolder entitled "1. Lettre rélative à des recherches d'optique. Recettes et dépenses." In order, the letter is followed by the account book (Foucault, 1852–1865) and a bill (Martin, 1867). The date of the letter invalidates my suggestion (Tobin, 2003: 265) that Foucault's relation with Martin may have begun in 1865.

43. These sums are roughly proportional to the surface areas of the mirrors. The receipt details work on two 10-cm, two 16-cm and one 50-cm mirror. Only half the price of the 50-cm was owing to Martin, presumably because Foucault contributed to its polishing. The inventory after Secretan's death mentions two 10-cm telescopes "... in the hands of the workmen …" and one 16-cm instrument on display at the Exposition Universelle, but there is no mention of a second 16-cm or 50-cm mirror (Sebert, 1867–1868). Perhaps they had already been sold, or had not yet been delivered.

44. In the hope that the agreement might have been registered, I searched the records of the following Paris notaries without success: Études XXIX and XLIX (Foucault notaries), and Études XLIV and XCVII (Secretan notaries). In the scientific papers that were inventoried after Foucault's death (see Tobin, 2003: xii) cote 11ème pièces 121 à 124 record "Projet de Traité avec Secretan." Is this the contract referred to by Rayet in 1868 (see Section 1)?

45. The stand carries a plate indicating "LANGLOIS SGDG rue de Bondy, 70". Alexandre-Eugène Langlois patented his camera foot in 1856 (Catalogue des Brevets, 1857). He was still in business in May 1868 (Langlois, 1868). The mirror and its cell are missing in Figure 71 (right) because they were being renovated (Fuentes, pers. comm., 2015). The mirror is the one announced as "Property of Camille Flammarion" exhibited at the 2011 Rencontre Transfrontalière d'Astronomie in Hendaye (www.astrosurf.com/rtaa/rtaa_images/expo/mirfouc160_1880053.jpg). It is dated to 1866 with focal length 960 mm (i.e. *f*/6) and has a convex rear. The slow-motion mechanisms are undersized and fragile (Fuentes, pers. comm., 2015). An engraving showing the telescope appears in Flammarion (1868: 301).

46. Measured by placing a pin adjacent to its image at the centre of curvature, the mirror's focal length was found to be 595.3 ± 1.0 mm, in which case the prime focus would lie within the reflecting prism, which is not impossible. The focal length was also obtained from mechanical dimensions and by relaxed-eye focusing of the telescope on a cross 1.02 km away and measurement of the position of R_1 (Figure 58) with respect to the exit plane of the prism. I assumed a crown glass prism of refractive index 1.5 and the position of the entrance plane of the eyepiece shown in Figure 58, which agrees to 0.25 mm with a value measured directly. A focal length of 605.7 ± 1.5 mm was found with the whole mirror illuminated, and 601.7 ± 1.5 mm with the mirror masked down to a 20-cm circle which gave a markedly better image. Has the glass slumped? Has the mirror been reworked, inexpertly? Or perhaps the modern aluminium coating is irregular because though the Sun can be seen through a small, sausage-shaped region towards the centre, elsewhere the coating is too thick to transmit any light.

47. Magnifications of 59× and 110× are given for the long and short terrestrial eyepieces, respectively. The lower row of celestial eyepieces are numbered, from left, 6, 8 and 5, with magnifications 300×, 350× and 150×. Missing are eyepieces numbered 2 and 4 with magnifications 70× and 112×.

48. It is strange that when the 80-cm mirror was silvered in 1862 it was Eichens personally who billed for the service, rather than the Secretan firm (Eichens, 1862). Was private work the point of discord? Eichen's address was 7 Rue Méchain, next-door to the Secretan workshops.

49. The notaries making the inventory after Marc Secretan's death turned to the Exposition Universelle on 20 September 1867. Only four astronomical items were on display: a 16-cm reflecting telescope with metal equatorial mount, and 95-, 135- and 160-mm astronomical objectives (Sebert, 1867–1868).

50. As well as on the title page, the year 1868 appears on the legal deposit stamp on the copy in the Bibliothèque Nationale. However, the publication does not appear in either the 1867 or 1868 *Bibliographie de la France*.

51. Martin's work on telescopes, daguerreotype photography on silvered glass, and sidero-

stat mirrors during 1872–1873 for the Transit of Venus expeditions is described in Commission du Passage de Vénus (1877). With Eichens he also built a 40-cm Foucault-style siderostat for Lord Lindsay's Transit of Venus expedition (André and Rayet, 1874; Brück, 2004). See also Note 37.

52. The 1874 catalogue does not appear in the *Bibliographie de la France*. The publication date derives from a review published in March (Dufour, 1874).

53. For the Digne and Coimbra telescopes the location of the declination clamp differs from other comparable instruments (Figures 70 and 77 vs. Figures 45, 50 and 67). For the Digne instrument, at least, I suspect this is the result of inexpert reassembly at some juncture. The 180°–0°–180° scale on its declination axis is inappropriate for declination and the clamp index mark is misplaced by a few degrees from the equator. If the clamp were in the usual location the scale would read polar distance.

54. Because of the poor image quality, Gully did not realise that he had seen the (super) nova S Andromedæ. Libert (1902) (and the Rouen Observatory web-page www.astro surf.com/obsrouen) claim that Gully used the 16-cm reflector for this missed discovery, but that Gully's instrument was a different one seems confirmed by several different references to its 20-cm size (Gully, 1885; 1893; Venus le jour de sa conjunction, 1887).

55. Mailhat (c.1908: 3) says he was "... called ..." to head Secretan's workshops in 1888, which is not incompatible with his actually taking charge on 1 January of the following year. Afterwards Secretan advertisements mentioned his name as workshop director (e.g. Secrétan, 1890; 1893). Albert Rellstab was a later workshop head (e.g. Présentations et admissions, 1897).

56. Mailhat (1909) gives 30, Faubourg Saint-Jacques as the Secretan workshop address in 1889. An advertisement from the previous year has it at 54, Rue Daguerre, hardly much further from the Observatory (Secrétan, 1888). The evidence for expropriation comes from Épry (1911a: inside cover) and the date from Secretan (1915: 5). Mailhat's new premises were plausibly opposite the expropriated ones, because an advertisement from the early 1900s gives as address "41–42, Boulevard Saint-Jacques ... (opposite: 30, Faubourg Saint-Jacques)" (Andrews, 1994: 196).

57. Presumably the ~0.5-μm layer of celluloid varnish tried at Meudon Observatory by Perot (1909), the efficaciousness of which is perhaps attested by the reprinting of the method in *L'Astronomie* (Pérot, 1911 'Gelatine bichromate' had earlier been used on the 33-cm and perhaps 80-cm Foucault telescopes in Toulouse (Izarn, 1894).

58. Google Books snippet views reveal such advertisements from 1949 to 1963. Advertisements through 1948 make no mention of Prin, nor do ones following the takeover by Morin in 1964.

59. Morin-Secretan continued to appear in *L'Astronomie* cover-page listings of "Informations, adresses utiles" until early 1968, i.e. a little after the merger with SRPI, but perhaps these insertions were arranged prior to the fusion with SRPI.

60. In a form filled in for the 1878 Exposition Universelle, Lutz states the firm was founded in 1828 and that he "Took possession ..." of it in 1862 (Lutz, 1878), which is the year of A.S. Bertaud's death. However, the firm traded under Bertaud's widow's name as late as 1870 (e.g. Dupin, 1870: 123). To add to the confusion, H. Duplouich (in L'Industrie Française des Instruments de Précision, 1901–1902: 154) claims that the firm was founded by Berthaud (with an 'h') in 1848, and that he, Duplouich, took over in 1896. This latter claim seems likely since Lutz died on 1 October 1895 (Registre d'État Civil, 1895). In 1847 an almanach refers to "Bertaud ...", which by 1855 had become "Bertaud j[eun]e ..." (Almanach-Bottin, 1855: 965; Annuaire générale, 1847: 539). Perhaps between 1847 and 1855 A. S. Bertaud took over from a father or brother.

61. P. Fuentes (pers. comm., 2015) owns an *f*/6 Lutz reflector with a useful diameter of 125 mm but a 135-mm mirror with a convex rear. Is this a 125-mm instrument as advertised in Lutz's catalogue? Jean-Gustave Bourbouze (1825–1889) was a talented physics technician at the Sorbonne. He devised and manufactured a host of demonstration apparatus. I have no evidence that would corroborate the claim by the notoriously unreliable Louis Figuier (1890) that Barbouze collaborated with Foucault.

62. The letter is bound in the same volume as the 1858 Secretan catalogue 'Addition' (Table 1), but is not digitized at hathitrust.org. Lutz's 1882 and c.1890 catalogues equate 105 mm with 4 *pouces*, so the 10½-cm designation may or may not have indicated a change from the 108 mm advertised in the 1872 catalogue (Table 4).

63. The 1928 catalogue describes the instrument as having a 10-cm mirror and 80-cm

length, which is plausible when compared to the 85-cm length stated for the Lutz 10½-cm instrument (Figure 89). Apart from the diameters, the entries in the 1907, 1910 and 1928 catalogues are identically-worded, but 80-cm lengths would imply very fast focal rations for 13- and 15-cm mirrors. Misprints in diameters and/or lengths seem probable.

64. Harvard University Library holds volumes 1–9 (1882–1890) and 11–13 (1892–1894) of *L'Astronomie: Revue Mensuelle d'Astronomie Populaire, de Météorologie et de Physique du Globe.* The covers of the individual monthly issues have been retained in the bound volumes which are available (with difficulty) via Google.

65. Every issue in 1888 except December, for which the cover is missing, and July 1890. I have been unable to examine covers for 1891 (see Note 64).

66. "Mouronval" bought the firm in 1909 (Ventes de fonds de commerce, 1909: 1117). I have found references in 1911 and 1913 to the firm as "Mailhat & Mouronval Frères" so it appears that Francis Edmond's twin brother Pierre Paul (1881–1956) was associated with the firm, at least briefly (Adresses relatives aux appareils décrits, 1911; Mailhat and Mouronval Frères, 1913). The Mouronvals advertise their training at the École Polytechnique; the matriculation registers available at bibli-aleph.polytechnique.fr confirm that no other Mouronvals attended the school.

67. A copy of this rare pamphlet is preserved in the Paris Observatory Archives (Ms 1133-2 Frères Henry. Échanges avec des fabricants d'optique).

68. Lescarbault and Foucault may plausibly have been acquainted with each other, since in their medical studies both passed *externe* in the same year, 1843. Of the 124 candidates passed, Foucault was ranked 18th, Lescarbault 124th (Conseil Général des Hospices Civils de Paris, 1842).

69. If Flammarion intended to signpost Foucault-Secretan telescopes, I suspect he is mistaken concerning Neyt, whose famous lunar photographs—which admittedly date from a decade earlier—were taken with Browning-With silvered-glass reflectors of 9¼ and 10¼ English-inch clear aperture (e.g. De Vylder, 1877; Neyt, 1869).

70. From photographs it appears that a "SECRETAN A PARIS" signature was even applied *along* the length of the tube of a 16-cm metal-mounted alt-azimuth instrument offered recently by a fraudulent Uruguayan seller (Petrunin, pers. comm., 2015). This telescope is not included in Table 9.

71. For example, Moigno (1859c) states that he facilitated the acquisition of a Foucault telescope by the fabulous Bancker collection in Philadelphia (e.g. Simpson, 1995). What became of this instrument? It is presumably not the Smithsonian Institution telescope (Table 6), which was purchased in October 1979 from a dealer in Paris (Roux-Devillas, 12 Rue Bonaparte – S. Turner, pers. comm., 2015).

72. For an example of what might be done, see Hill (2005). The scientific papers inventoried after Foucault's death (see Tobin, 2003: xii) cote 11ème pièce 118 record "Secretan circular concerning his new model of reflecting telescope." Possibly this document advertised the 10-cm metal-tubed telescope.

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17 APPENDICES

17.1 Appendix 1 – English Translation of Instructions Accompanying the Smithsonian Institution 4-*Pouce* Telescope

The instructions are lithographed from handwriting and occupy the front and back of a single sheet (Figure 11). Recto, they are marked with an oval stamp "LEREBOURS ET SECRETAN – 13, PONT-NEUF, PARIS" and at lower left the lithographer's name ("Lith. V. Janson 18r Dauphine").

[recto]

Instructions for Telescopes with silvered-glass mirrors

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1. Setting up the Telescope

The instrument having been placed on the table which will act as its support, one begins by pushing to the back the small movable board or rake which runs in the notches placed in the foot; one will remove the tube of the instrument from the foot in which it is stored; for that insert the right hand in the round opening placed at one end of the tube, one will lift this latter by pushing it at the same time on the closed end with the other hand, one will free it easily. That done one will undo the hooks which retain the board pierced with a hole & that was referred to above; this board removed, one will slide out from the inside of the tube the box which is there & which contains the telescope accessories; one will take from this box the thin rod with a knob, the nut and thread, and the eyepiece furnished with its adjustment screw. The nut will be placed in the hole that is located in the rake of the foot such that the knurled knob is underneath. This screw acts to give the slow movement in height to the telescope. Next one will install the small triangular feet which by means of bolts and nuts attach at either side of the base and give it greater stability; after that, one will run the rake along the notches to the point at which the first folding board is approximately horizontal, then taking the telescope, one will place it on this plane in such a way that the fasteners fixed to the tube align with those fixed on the board; one inserts the thin rod with a knob that we have already spoken of in the said fasteners and the telescope will be attached to its base. The tube must be placed in such a way that its opening is on the same side as the claws of the rake which runs on the notches. One will then screw in the eyepiece and one will put back the board pierced with a circular hole that was removed at the beginning.

2. Use of the Telescope

The instrument being thus set up, to make use of it, one will withdraw the little hatch located above and towards the closed end of the telescope. This hatch removed exposes a slit and a metal hook which one will seize in order to remove a little black slide that acts as a shutter for the mirror. Bring the eyepiece towards oneself, one will focus on the objects that by chance are in the field of view. The focus will be made more accurately with the knurled knob attached to the eyepiece support.

The two parts of the finder located on the side of the tube will be unfolded from their bases & by looking through the spyhole one will see if the object that appears in the telescope is centred in the circle which forms the other half of the finder. If it is not, one centres it with the screws which adjust the spyhole. For

[verso]
the preceding operation, it will be wise first to remove one of the lenses to have at the same time both more field & more light.

In this state the instrument can serve to observe either terrestrial objects or celestial bodies. Movements in the horizontal direction are effected by moving the base on the table and movements in height by raising the tube by its open end to the appropriate height, which makes the rake run along the notches after which it stays fixed. The final adjustment is made by turning the screw fixed to the rake with the right hand. When a celestial body is nearly at the zenith the weight of the telescope can tip it over backwards if, in this very rare circumstance, one has not been careful to use a hand to keep the rake engaged in the notches, while with the other one turns the screw which adjusts the height.

3. Precautions to take to preserve the Telescope

1. When removing and replacing the accessory box be careful not to knock the small prism which is in the tube nor the strut which holds it. When you see by moving the eyepiece that there is dust on the surfaces of this prism clean it with a piece of suede inserting your hand carefully into the tube; besides, the prism needs to be very dirty before the effect of the telescope is noticeably diminished.

2. If the lenses of the eyepiece are covered with dust, or they have been dulled by whatever cause, wipe them in the same way.

3. So to speak never touch your mirror & each time you have made use of the instrument be careful to replace the little shutter.

When looking down the telescope tube you perceive that through lack of care the mirror is covered with dust, you will remove the hatch, the shutter, undo the hooks which attach the base containing the mirror & you will remove this dust using a very fine shaving brush with very little pressure. If there are marks on the mirror, it is best to leave them because one can only make them disappear by removing the silvering itself. In addition, they need to be very numerous and very extensive to harm the optics of the instrument.

4. It is not enough that the mirror be sheltered from dust, it must also be kept in a dry place, above all salty vapours are to be feared. When you look at your mirror, fear touching it with your fingers & spluttering the least drop of saliva, it will produce indelible stains.

17.2 Appendix 2 – English Translation of Extracts from Secretan’s 1874 Catalogue

[Page 76]

Reflecting Telescopes with Silvered-Glass Mirrors

379 Newtonian telescope, with 10-cm diameter glass mirror, parabolized and silvered by the methods of Léon Foucault, mounting in cast iron, additional 6-lath stand for observing stand-

ing up; four eyepieces magnifying from 60 to 200 times, dark glass for the Sun; a finder (Fig. 73 [*this paper's Figure 51*])

500 francs

380 The same, with a mirror of 160-mm aperture; five eyepieces, maximum magnification 350 times; same accessories as previously.

1200 francs

[Page 77]
381 The same, with a mirror of 200-mm aperture; six eyepieces; maximum magnification 400 times; same accessories as previously.

2000 francs

[Page 94]

Equatorial Reflecting Telescopes

METAL MOUNTINGS

427 Telescope with silvered-glass mirror of 16-cm aperture, 1-metre focal length, equatorial mounting entirely in metal, hour-angle circle of 37-cm diameter, declination circle of 20-cm diameter, divided on brass; lighting apparatus; maximum useful magnification 320 times; a finder.

1800 francs

428 The same, with clockwork drive and isochronous governor.

2500 francs

[Page 95]
429 The same with mirror of 20-cm aperture, 1m20 focal length, 47-cm hour-angle circle, 33-cm declination circle; maximum useful magnification 400 times.

4500 francs

430 The same with mirror of 30-cm aperture, 1m80 focal length, 75-cm hour-angle circle, 45-cm declination circle; maximum useful magnification 600 times.

9000 francs

431 The same with mirror of 40-cm aperture, 2m40 focal length, 1-m hour-angle circle, 60-cm declination circle; maximum useful magnification 800 times; two finders.

18000 francs

432 The same with mirror of 50-cm aperture, 3-m focal length, 1m50 hour-angle circle, 80-cm declination circle; maximum useful magnification 1000 times.

35000 francs

WOODEN MOUNTINGS
(FIG. 86 [*this paper's Figure 50*])

We still give prices in our catalogue for telescopes with equatorial mountings in wood, although this option is far inferior to that of numbers 427 to 432.

[Page 96]
Their lower price means they may still be chosen by institutions whose budgets are too limited to envisage metal mountings. The dimensions of the circles, the magnifications, the focal lengths and all accessories are the same as in the previous numbers.

433 Telescope with silvered-glass mirror, 16-cm aperture, wooden equatorial mounting, brass hour-angle and declination circles.

1650 francs

434 The same with clockwork drive and isochronous governor.

2350 francs

434bis The same, mirror of 20-cm aperture.

4000 francs

435 The same, mirror of 30-cm aperture.

6000 francs

[Page 97]
436 The same, mirror of 40-cm aperture.

9000 francs

437 The same, mirror of 50-cm aperture.

13000 francs

438 The same, mirror of 80cm aperture, 5-m focal length, 2-m diameter hour-angle circle, reading directly to 20s in time, 1m12 declination circle reading to 15" via verniers; 8 astronomical eyepieces; maximum useful magnification 1600 times (Fig. 87 [*this paper's Figure 34*]).

29000 francs

In 1864 we built a similar instrument for the Marseilles Observatory; in 1874 we supplied one to the Toulouse Observatory.

[Page 109]

Silvered Mirrors

481 Concave glass mirrors, silvered and parabolized by Foucault's procedures. The price for every ten centimetre square contained within the square circumscribing the circumference of the mirror is

150 francs

482 Glass mirrors that are rigorously flat, silvered by the same procedures, able to serve as an artificial sky for collimation. Same price as concave mirrors number 481.

We re-silver telescope mirrors at the following prices.

Mirror of	$0^{m}.10$	4 francs 50 centimes
	$0^{m}.16$	7 francs 50 centimes
	$0^{m}.20$	20 francs
	$0^{m}.30$	40 francs
	$0^{m}.40$	50 francs
	$0^{m}.50$	70 francs

For mirrors of greater diameter, prices will be set by mutual agreement.

Dr William Tobin was for many years on the academic staff of the Department of Physics & Astronomy at the University of Canterbury, Christchurch, New Zealand, where he introduced CCD detectors at Mount John University Observatory, which he used (*inter alia*) to make observations of eclipsing binary stars in the Magellanic Clouds. He has now retired to Brittany. His work on Foucault has won several prizes: the Arthur Beer Memorial Prize 1991–1993, the *Prix spécial du jury* of the *Prix du livre de l'astronomie–Haute Maurienne-Vanoise 2003*, and the Informa Healthcare Award 2006. In 2012 William was the opening lecturer in the Transit of Venus Lecture Series at the National Museum of New Zealand-Te Papa Tongarewa in Wellington. Following this, he prepared a profusely-illustrated paper on "Transits of Venus and Mercury as Muses" about ways in which these transits have inspired artistic creation of all kinds, and subsequently this paper was *published in this journal (Volume 16, Number 3, pages 224–249, 2013).*