

FROM THE DEATH OF THE SOLARIANS TO THE BIRTH OF ASTROPHYSICS

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Abstract: William Herschel's solar model in which the Sun was believed to be a dark solid body surrounded by two atmospheres, of which the outer was luminous, continued to be accepted by astronomers well into the nineteenth century. Developments in spectroscopy and in our understanding of thermodynamics eventually led to the abandonment of this model in favour of one in which the Sun was considered to be gaseous throughout, but traces of the older theories can be found even in the early twentieth century.

Keywords: solar models, gaseous stars, Arago, Eddington, Emden, Faye, Herschel, Janssen, Kirchhoff, Lane, Lockyer.

1 INTRODUCTION

In a recent contribution to this *Journal*, Michael Crowe (2011) has shown that the belief that the Sun might possibly be inhabited survived for a surprisingly long time into the nineteenth century. As Crowe points out, such a belief is quite incompatible with our modern knowledge of the structure and evolution of the Sun and other stars. There is, therefore, a related question to ask: when did it come to be generally believed that the Sun is gaseous throughout? The answer to this question is again that the belief was not generally accepted until surprisingly late—early in the twentieth century. We who were active in research in the twentieth century tend to think of it as a period of unequalled growth not only in astronomy but also in the other sciences. The nineteenth century, however, was also a period of rapid growth, if one measures that growth by comparing what was known at the beginning of the century with what was known by its end, even if that progress sometimes seemed slow to those working during that time. Our understanding of solar structure, in particular, seemed to change slowly and some were reluctant to adopt new ideas, and this is but one example of changes in all the sciences during the nineteenth century. At the beginning of that period, scientists still called themselves 'philosophers'; by the end, they were referring to themselves as 'men of science'. (Most of them were men then, and many disliked the neologism 'scientist' coined by William Whewell in response to the poet Samuel Taylor Coleridge criticizing the use of the word 'philosopher'.)

2 HERSCHEL'S SOLAR MODEL

As Crowe made clear, the generally accepted solar model at the beginning of the nineteenth century was basically the one described by William Herschel (Figure 1; 1795; 1801). The French astronomer François Arago (Figure 2; 1786–1853) described it well both in his *Astronomie Populaire*, published posthumously, and in an

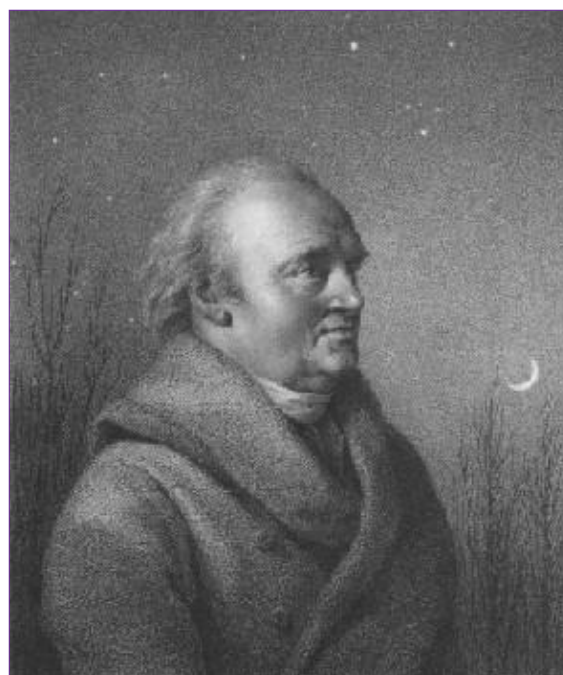


Figure 1: Sir William Herschel, 1738–1822 (courtesy: <http://www.sterrenkunde.nl/deepsky/hulp/middelen-ol.htm>)

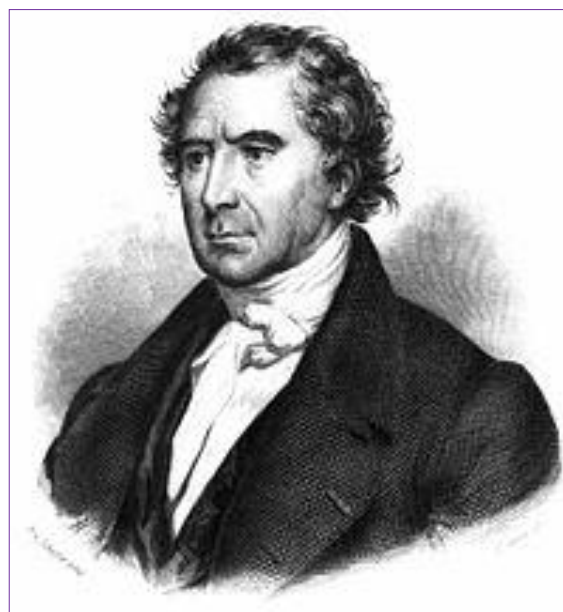


Figure 2: François Arago (courtesy: en.wikipedia.org).



Figure 3: A photograph of Sir John Herschel, taken by Julia Margaret Cameron in 1867 (courtesy: en.wikipedia.org).

account of his lectures published anonymously by “... *un de ses élèves* ...”, which went through several editions during Arago’s lifetime (Anonymous, 1849; Arago, 1855: 131-132). In these works Arago set out a tripartite model of the Sun: (i) a nucleus or core, which was a “... dark body ...” (French *corps noir*); (ii) a very dense cloudy atmosphere; (iii) a luminous atmosphere which, he adds, German astronomers have called the *photosphere*. This he describes as the generally accepted model of the Sun. As Crowe has also pointed out, he thought it quite possible that intelligent beings could exist on the central dark body, but explicitly refrained from saying that he believed that they actually did so. He also pointed out in the anonymous version of his lectures that human beings could not exist



Figure 4: Hermann von Helmholtz (courtesy: en.wikipedia.org).

there, since they would have 28 times the weight they experienced here on Earth. He further stated that if the Sun were incandescent throughout, then life could not possibly exist there. Arago was convinced that he had found proof that the visible surface of the Sun was gaseous and neither solid nor liquid. He had observed the Sun with the polariscope (his own invention) and found that sunlight was not polarized, either from the centre of the solar disc or from the limb, whereas light that he observed from the limb of an incandescent solid body was polarized.

This latter conclusion was to be criticized by Arago’s contemporary, J.F.W. Herschel (Figure 3; 1792–1871). A large part of the younger Herschel’s library is now in the possession of the University of Toronto (Broughton, 2013, and private communication) and includes an Italian translation of *Leçons d’Astronomie*, the anonymous account of Arago’s public lectures. John Herschel wrote in the margin of his copy: “???This is simply absurd”. The ‘absurdity’ could not have been Arago’s notion that the visible surface of the Sun was a luminous atmosphere, since Herschel shared that belief. Rather, it was Arago’s claim that his polarization observations had *proved* the surface to be gaseous that Herschel criticized, as he later made clear in the fifth edition of his *Outlines of Astronomy* (Herschel 1858: 245-246). If the surface of the Sun were a *rough* incandescent solid, Herschel argued, Arago would have obtained the same result.

3 THE TURNING POINT

In a later paper, John Herschel (1864: 219) opened his discussion with the following remark:

The physical constitution of the sun and the nature of the source from which its expenditure of light and heat is supplied, must be regarded as by far the most important astronomical problem which remains unsolved ...

Indeed, it remained unsolved into my own lifetime and, as we know, astronomy had to draw on the related science of physics to find the solution. In 1854, Hermann von Helmholtz (Figure 4; 1821–1894) first speculated in a lecture that the source of the Sun’s light and heat was gravitational contraction—a notion that surely implied a gaseous model for the Sun. The lecture was not published for many years: eventually A.J. Meadows (1970) reprinted an English version of it that was published in 1907. Meadows’ book, incidentally, is an excellent source for this period, not only because of his own historical introduction, but because he also reprints (in translation if necessary) several of the seminal papers. It is perhaps because of this long delay in Helmholtz’ publication that we now speak of Kelvin-Helmholtz contraction, but that is a little unfair since Kelvin first tried to

explain the Sun's source of heat by the influx of meteoric material, and turned his attention to the contraction hypothesis only when he realized that the other was totally inadequate.

The real turning point, however, came from another branch of physics, namely, spectroscopy. In 1861, Gustav Kirchhoff (Figure 5; 1824–1887) published two important papers (both reprinted by Meadows). The first (Kirchhoff, 1861a) was an account of the experiments he and Bunsen had performed on the line spectra of elements which showed that the spectrum of the Sun and stars could be explained by assuming that the photosphere was surrounded by a cooler atmosphere that selectively absorbed the continuous photospheric radiation. The second paper (Kirchhoff, 1861b) contained Kirchhoff's Law, that the emitting and absorbing powers of material bodies are proportional, and it also introduced the modern concept of a *black body*. Clearly, the addition of a cooler atmosphere *above* the photosphere made the assumption of a similarly cooler atmosphere *below* it look like an unlikely complication, especially because Kirchhoff believed the photosphere to be an incandescent solid. Nevertheless, many found it difficult to abandon the elder Herschel's solar model.

4 NEW BEGINNINGS

We have already referred to John Herschel's 1864 paper, which was titled "On the solar spots". Many of the papers in this period that were concerned with the nature of the Sun in fact dealt at some length with sunspots. This was because, on the tripartite model, the spots were thought of as windows through which we were able to see the surface of the putative dark body of the Sun. Although this 1864 paper is often cited as presenting a gaseous model for the Sun, I do not read it as a clear endorsement of the idea. There are two significant comments in the paper. On page 222 Herschel wrote: "... the enormous pressure at the surface of its solid globe (if it have any such) ..." and, on the following page,

It is inconceivable, indeed, that the actual surface of the solid globe (*if there be any such definite surface*) surrounded as it is by an *enceinte* of such a temperature as that of the photosphere, should be otherwise than in a state of the most vivid incandescence. (Herschel, 1864: 223, his italics).

Clearly, John Herschel was beginning to have doubts about his father's model but he did not seem ready to abandon it completely. Indeed, Meadows points out that even in the 1869 edition of his *Outlines of Astronomy* the younger Herschel still put forward the elder's model of the Sun.



Figure 5: Gustav Kirchhoff (courtesy: en.wikipedia.org).

In the same year Angelo Secchi (Figure 6; 1818–1878,) also discussed the possibility of a gaseous Sun in one of two papers which have recently been translated and published on line (Secchi, 1864). Again, however, there is no more than a suggestion that the Sun might be completely gaseous, although Secchi does explicitly say that he does not believe in Herschel's model.

Early in the following year, the French astronomer Hervé Faye (Figure 7) presented two papers to the Academy of Sciences in Paris titled: "Sur la constitution physique du soleil." (Faye, 1865a; 1865b). They are often referred to as two of the first papers to propose a gaseous model of the Sun but, despite their title, like the earlier papers of Herschel and Secchi, they are largely concerned with sunspots. Only towards the end of the second paper does Faye (who



Figure 6: Angelo Secchi (courtesy: en.wikipedia.org).



Figure 7: Hervé Faye, 1814–1902 (courtesy: en.wikipedia.org).

worked under Arago at the Paris Observatory and clearly thought of himself as Arago's successor) venture to speculate a little on the nature of the Sun and stars. He proposed three stages in a star's life. The first, which he tentatively identified with planetary nebulae, was a diffuse object that would show an emission-line spectrum. The *fluid* (i.e. not explicitly gaseous) mass then contracts, the outer layers cool, a photosphere is formed, some molecules even form, a typical stellar spectrum is seen, and the light emitted from any part of the solar (or stellar) disc is not polarized, as Arago had found. In this stage contraction could supply heat and light, as Helmholtz had suggested. Finally, the star would cool further, the photosphere would become very thick and assume the consistency of a liquid, paste, or even a solid.



Figure 8: The image of Sir Norman Lockyer that appeared in 1909 in the *Proceedings of the Royal Society* (courtesy: en.wikipedia.org).

Light from the limb of the object would then be seen to be polarized. This discussion is entirely qualitative and Faye did not put forward a mathematically- or physically-coherent model of a gaseous star.

The honour for making that important advance undoubtedly goes to J. Homer Lane (1819–1880) in a paper published in 1870. Lane's work and its significance have been thoroughly discussed by Powell (1988). Lane appears to have entertained his ideas for some time before publishing but held back because he himself did not think them fully plausible. Perhaps he was encouraged by the papers by Faye and Herschel as well as one by William Thomson, Lord Kelvin (1862) which introduced the concept (and term) of *convective equilibrium*—which was the basis of his own model. (The concept of *radiative equilibrium* was introduced by Karl Schwarzschild (1906) much later.) Because Lane was a physicist rather than an astronomer, he was not as enamoured as his predecessors had been with Herschel's tripartite model. He was also more familiar with the advances that were being made in thermodynamics and the kinetic theory of heat and this, no doubt, helped him to devise a physically-coherent model.

However, there were still problems. What we would now call the effective temperature of the Sun was poorly known, with estimates ranging very widely. More importantly, Lane and his contemporaries were well aware that the pressures at the centre of a wholly gaseous Sun would be enormous and that the laws for ideal gases could not be expected to apply there, yet the solar model assumed the ideal-gas laws. Van der Waals' corrections to those laws were not published until 1881 and, even after Lane, investigators such as Georg August Dietrich Ritter (1826–1908) and Jacob Robert Emden (1862–1940) continued to assume that the ideal-gas laws applied. This was a real barrier to the acceptance of wholly gaseous stars right up to the time of Eddington. Another was the belief that if the photosphere was gaseous the limb of the Sun should not appear sharp—hence Kirchhoff's solid photosphere. Ritter soon followed Lane with a series of eighteen papers published in *Wiedemann's Annalen*, the sixteenth of which was translated and reprinted in the *Astrophysical Journal* (Ritter, 1898) and is also available on line. The classic text, of course, is Emden's famous book, *Gaskugeln*, which appeared early in the twentieth century (Emden, 1907).

5 OBSERVATIONAL ADVANCES

Nineteenth-century advances in methods of observing the Sun played an important role in advancing the understanding of the nature of that star. At the beginning of the century, prominences and the corona could be observed

only during a total solar eclipse and astronomers were uncertain whether these phenomena were appendages of the Sun or of the Moon. Secchi is credited with having shown at the eclipse of 1860 that they must be appendages of the Sun and the invention of the spectro-helioscope independently by J. Norman Lockyer (Figure 8; 1836–1920;) and Jules Janssen (Figure 9; 1824–1907;) settled the matter and enabled prominences to be studied in much more detail. A photosphere that was only a relatively thin ‘luminous atmosphere’, underneath which was a cooler cloudy atmosphere would seem less likely when it was understood that massive jets of gas could be thrown up above that photosphere. Janssen (1879) appears to have accepted the new ideas; he quotes Arago’s opinion:

... if anyone asked me if the Sun could be inhabited by a civilization like ours, I would not hesitate to say ‘yes’ ... [and adds] Such a reply would be almost ridiculous today.

It is of interest that Crowe (2011) points out that Lockyer still believed in the possibility of solar life in 1870—he appears not to have been so easily convinced of the new ideas as his rival Janssen had been, although in 1869, together with the chemist E. Frankland, Lockyer wrote a paper in which they rejected Kirchhoff’s solid or liquid photosphere, saying that the latter must be “... cloudy or gaseous or both.”

In another respect, however, Lockyer was ahead of his time, although for a wrong reason. Because he worked at low spectroscopic dispersions, he could not always distinguish between closely neighbouring Fraunhofer lines in the solar spectrum. He came to believe that the spectra of iron and calcium had some lines in common and he regarded this as evidence that atoms could be broken down into something simpler and these simpler bodies produced what he called the ‘basic lines’. Later, he came close to the modern concept of ionization (Meadows, 1970: 73-81) and all this before the discovery of the electron, let alone Ernest Rutherford’s work on atomic structure.

6 DENOUEMENT

As we all know, it was the early work of Arthur Stanley Eddington (Figure 10; 1882–1944) that finally brought us to our modern concepts of stellar structure, but even he was imbued with nineteenth-century ideas from which he had to break loose. In a recent paper, Matthew Stanley (2007) has pointed out that Eddington wrote an article on “Stars” for the famous eleventh edition of the *Encyclopædia Britannica* in which the following statement is found:

The spectrum consists of a continuous band of light crossed by a greater or less number of dark absorption lines or bands. As in the case



Figure 9: A painting of Jules Janssen by Jean-Jacques Henner (courtesy: en.wikipedia.org).

of the Sun, this indicates an incandescent body that might be solid, liquid, or a not too rare gas, surrounded by and seen through an atmosphere of somewhat cooler gases and vapours ... (Eddington, 1911).

It is almost incredible that this should have been written by the man who, within the next two decades, was to lay the foundations of all our modern ideas of stellar structure and evolution. We might recall, however, that James Hopwood Jeans’ (1919) famous work on the stability of rotating fluid masses, published even later, treated both compressible and incompressible (liquid) fluids.

Emden’s *Gaskugeln* had been published some three years before Eddington wrote his encyclo-



Figure 10: Sir Arthur Eddington (courtesy: en.wikipedia.org).

pædia article and we know that he read the book at some time, because he often cited it in later work. In fact, we know that Eddington owned a copy because D.S. Evans (1998: 102, 108) records that he purchased it after that man's death. We don't know whether Eddington had read Emden before he wrote the article for the *Britannica*. The key to understanding Eddington's hesitancy in accepting a gaseous model for the Sun rests, of course, in the phrase "... a not too rare gas". That models based on the laws for ideal gases should be able accurately to represent real stars was still rather hard to believe. We can see this even more clearly in Eddington's (1927) great work, *The Internal Constitution of the Stars*, in which he presents the mass-luminosity relation. At the time, it was believed that giant stars could perhaps be described by theories based on the laws for ideal gases, but that dwarf stars, including the Sun, could not. Eddington's comment on his discovery that the one relation satisfied both kinds of star is worth quoting:

The agreement with observations was a complete surprise for it was not at all the result that was being looked for. Nearly all the accurate data relate to dwarf stars; Capella had been used to fix one of the constants of the curve; and it was reluctantly decided that no other truly gaseous stars were available to test the curve. (Eddington, 1927: 164).

He soon, of course, saw the solution: atoms in the deep interiors of stars were stripped of all their electrons and the nuclei, being much smaller than the neutral atoms, could behave *en masse* like an ideal gas. Lockyer was vindicated in a surprising way: the last obstacle to accepting completely gaseous stars had been removed, and modern astrophysics was born. Even then, however, Eddington was reluctant to accept the conclusion adumbrated in Cecilia Payne's (1925) thesis *Stellar Atmospheres*, that the stars, including the Sun, were predominantly composed of hydrogen. It took several more years for that to be accepted. The full story is well described by David DeVorkin (2000: 199-220) and I cannot improve on that treatment here.

After I had completed a draft of this paper, my attention was drawn to a paper by Robitaille (2011) which covers much the same ground as I have attempted to do in this paper. Robitaille presents the history in support of his argument, not generally accepted, that the Sun is composed of hydrogen in the liquid metallic phase.

7 CONCLUDING DISCUSSION

At the beginning of this paper I suggested that the expansion of astronomical knowledge, and indeed all scientific knowledge, was as rapid in

the nineteenth century, in comparative terms, as it was in the twentieth. This may seem counter-intuitive; after all, the second half of the twentieth century was one of explosive growth in astronomy. We became able to observe from above the Earth's atmosphere and in many wavelength regions other than the optical one. The diameters of the largest optical telescopes available doubled in the same period and plans are well advanced for further increases. New types of objects that we never even suspected (e.g. pulsars and quasars) have been found. Cosmology has developed from being largely speculation to becoming a rigorous science. In the particular matter of the nature of the Sun and stars, we have built well on Eddington's foundations. If we look outside astronomy, we recall that physics underwent two major revolutions in the early twentieth century, and in biology the famous discovery of the structure of DNA completely revolutionized the whole science with effects that are impacting each one of us directly. How could the nineteenth century equal this tremendous progress?

To answer that last question, we must recall how little was actually known at the beginning of the nineteenth century. No distance to any star other than the Sun was known. More importantly, the necessary physics for understanding stellar structure still had to be developed. We have seen how astronomers had to adopt the techniques of spectroscopy and photography and to digest the developments of thermodynamics and the kinetic theory of heat. We might also recall that the nineteenth century saw the growth of studies in electricity. Faraday's experiments, although not directly impacting astronomy, led to Clerk-Maxwell's derivation of the equations of electro-magnetism which, in turn, were to impact on Einstein's relativity theory. If, again, we look outside astronomy and physics to biology, we see Darwin's theory of evolution, which was more fundamental and probably about as revolutionary as the discovery of the structure of DNA. Coincidentally, each of those discoveries came about halfway through their respective centuries.

What lessons can we learn from this story? First, the story illustrates a dictum often ascribed to Max Planck to the effect that new ideas do not win acceptance, their opponents die out. If one looks at the birth dates of the people discussed in this paper, one is struck by the fact that nearly all those born in the eighteenth century either stuck with the tripartite solar model or abandoned it only very reluctantly. On the other hand, nearly all those born in the nineteenth century were open to the new ideas which, in fact, they helped to develop. More important, perhaps, is the lesson that can be summed up in another famous quotation: "Those who cannot remember the past are condemned to repeat it

...” (Santayana, 1905: 284).

Contemplation of this history should instill a proper humility about some of our own ideas. It is easy to laugh at the notion of a dark core at the centre of the Sun, let alone the idea of solar-ians, but the astronomers who entertained such ideas were arguing reasonably by analogy from the only astronomical body of which they had direct experience, namely, the Earth. They could do no better until other branches of science were sufficiently developed. Our ideas of stellar structure, at least for the main-sequence stars, are now probably surely founded. We are most unlikely to see a revolution in them as far-reaching as the one described here. There are other areas of our science, however, where we are still on uncertain ground. Will astronomers one or two hundred years hence marvel at the confidence with which we talk of ‘dark energy’ and ‘dark matter’—or perhaps even of the ‘Big Bang’—every bit as much as we marvel that a scientist of the stature of Arago could confidently state that the Sun was a dark body surrounded by a dense cloudy atmosphere and an outer luminous one?

Crowe (2011) mentions Arago’s story of a Dr Elliot, tried at the Old Bailey for murder, whose friends mounted a defence of insanity on the grounds that Elliot believed in the possibility of an inhabited Sun. Crowe also records Arago’s dry comment that the opinions of a madman have now become generally accepted. Unfortunately, he leaves off the final (to us) ironic twist: “The anecdote appears to me to be worthy of figuring in the history of the sciences.” (Arago, 1855)!

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