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THE DEBATE CONCERNING 'RED' SIRIUS

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A long-standing question in the history of astronomy concerns whether Sirius, the Dog Star (α CMa), could have changed its intrinsic colour since Antiquity. Half a dozen Greek, Roman and Near Eastern sources refer to Sirius as "reddish", whereas since at least the Renaissance it has always shone a brilliant bluish white. So the question has been posed: could Sirius have changed from reddish to white since Antiquity?

At first sight, this might seem a reasonable possibility: stars do evolve and suffer various kinds of changes during their lifetimes. Could these ancient references to Sirius's redness be evidence for an evolutionary change during the historical period? Most astronomers consider this unlikely, because stellar evolution generally takes eons, not a mere 2,000 years, to produce significant results. Accordingly, they usually reject the ancient evidence for 'red' Sirius out of hand. Yet that evidence is strong: the chief piece comes from Ptolemy himself in the star catalogue contained in Books 7 and 8 of his *Almagest*. There Ptolemy lists over a thousand stars, describing their positions on the ancient constellation figures, giving their measured coordinates, and estimating their visual magnitudes. In delineating Canis Major, Ptolemy describes Sirius as "The [star] on the mouth, brightest, called 'the Dog', and reddish".[1]

There is no doubt about what Ptolemy means. He bluntly says "reddish" and other ancient sources corroborate him, and so the 'red' Sirius question cannot be swept under the rug. But since it was first posed in 1760, it has never found an adequate solution, despite the major attention it has received from astronomers.[2] Instead, it has become a kind of astronomical albatross perpetually circling at a distance from mainstream theory, refusing to go away. Most astronomers feel certain that Sirius cannot have changed colour since Antiquity, so why do these unaccountable references to its redness exist? What do they mean? Why has astronomy been unable to rid itself of them?

The present paper will begin to answer these questions. I say "begin" because a full answer lies outside the scope of a single paper. Rather, the present paper will begin by reviewing in detail the past 230 years of work on 'red' Sirius, showing what it achieved and the direction to which it points for a solution. In a subsequent paper in this journal I hope to pursue that direction and present the rest of my proposed solution.[3] But first it seems best to take stock of where the debate currently stands.

Up to the present, a good deal of evidence has been collected, but it is of a contradictory nature: almost as many ancient texts call Sirius white, as call it

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reddish. And although a good deal has been said about all these texts in print, the general quality of this discussion has been low. Misconceptions and misinformation are the rule rather than the exception in the 'red' Sirius debate, whose most recent phase (1960–93) has been little more than a careless popularization.[4] There are legitimate questions to be asked about Sirius's redness, but they must be approached more carefully and thoroughly than has so far been the rule.

Three approaches have been used to provide an answer. The first two have in common that they take the ancient evidence at face-value as a description of Sirius's intrinsic colour. On the one hand, those investigators who could not bring themselves to believe in a real colour change (the majority at all times), have usually rejected the evidence as an error either made by the ancients themselves or generated through miscopying manuscripts of their works. Those investigators, on the other hand, who could stomach a real colour change, set about trying to explain it astrophysically, but never with success despite strenuous efforts.[5]

A third approach was indicated by German investigators between about 1900 and 1927, but until recently no one has pursued it very far. This takes the ancient references to Sirius's redness not as assessments of its intrinsic colour, but as a product of terrestrial atmospheric effects, combined with ancient cultural concerns about the ambivalent nature of "the Dog" (as the Greeks and Romans called Sirius). This approach, which I hope to present in a future paper in this journal, can account for the existence of *both* reddish and white colour assessments, and does not conflict with Sirius's current evolutionary status. But for the present, I want to begin by reviewing the genesis of the 'red' Sirius debate, by assessing the principal contributions so far made to it, by clarifying the ancient evidence, and by showing why the first two approaches are inadequate. Once that is done, the path will be clear finally to resolve the matter.

Prehistory of the Debate

The problem of 'red' Sirius seems to have begun with the Islamic astronomers in the Middle Ages. Already in the ninth century, al-Farghānī in his treatise discussing Ptolemaic astronomy, the *Elements*, silently dropped the description, although he continued to call Arcturus, Aldebaran, and Betelgeuse reddish just as Ptolemy had done and just as they still are today.[6] Then a century later, the great Persian astronomer al-Sūfī did the same thing: his *Description of the fixed stars*, partially meant as a revision of Ptolemy's star catalogue, described Arcturus, Aldebaran, Betelgeuse, Antares, Algol, and Alphard as reddish, but not Sirius.[7] Since al-Sūfī's action agrees with al-Farghānī's, it seems clear that they rejected Ptolemy's description, although neither of them explicitly noted that.

There are, however, two problems with al-Sūfī's revision. First, he has excluded Pollux from the list of reddish stars, although Ptolemy had included it. This is not too bothersome, because Pollux is the least coloured of Ptolemy's

	Canis conſtellatio.38.							
1	Quæ in ore fulgentiſſima eſt & uocatur canis & eſt ſubruffa.	♓	17	40	Au.	39	10	1
2	Quæ in dorſo	♓	19	40	Au.	35	0	4
3	Quæ in capite	♓	21	20	Au.	36	30	5
4	Borealis duarum quæ ſunt in collo	♓	23	20	Au.	37	45	4
5	Auſtralis ipſarum	♓	25	20	Au.	40	0	4
6	Quæ in pectore	♓	20	30	Au.	42	40	5
7	Borealis duarum quæ ſunt in genu dextro	♓	16	10	Au.	41	15	6
8	Auſtralis ipſarum	♓	16	0	Au.	42	30	5
9	Quæ in extremitate anterioris pedis	♓	11	0	Au.	41	20	3
10	Antecedens quæ ſunt in genu ſiniſtro	♓	14	20	Au.	46	30	5
11	Sequens ipſarum	♓	16	10	Au.	45	50	5
12	Sequens duarum quæ ſunt in humero ſiniſtro	♓	24	40	Au.	46	10	4
13	Præcedens ipſarum	♓	21	40	Au.	47	0	5
14	Quæ eſt in cruris ſiniſtri radice	♓	26	40	Au.	48	45	3
15	Quæ ſub uentre inter crura	♓	23	40	Au.	51	30	3
16	Quæ ſub poplite pedis dextri	♓	23	0	Au.	55	10	4
17	Quæ in extremitate pedis dextri	♓	9	40	Au.	53	45	3

FIG. 1. Stars of the constellation of Canis Major, from a Latin translation of the *Almagest* printed in Venice in 1528. The first star is "on the mouth, brightest, called 'the Dog' and reddish ('subrussa')". Courtesy of Owen Gingerich.

reddish stars (B–V = 1.0). More disturbing is that while al-Sūfī's list of reddish stars is otherwise correct and while he correctly adds Alphard (α Hya, B–V = 1.4) to the list, his addition of Algol (β Per, B–V = –0.1) is badly mistaken. Algol is bluish white and should never appear reddish. On the other hand, Algol is so faint (mag. 2.1) that it stands near the limit of the naked-eye's ability to detect colour. And so much difficulty and uncertainty attends the estimation of colours by the eye in any but the brightest stars (such as Sirius) that even well-trained modern observers sometimes get them wrong. A famous case involves Julius Schmidt, an acute observer and director of the Athens Observatory in the nineteenth century. Schmidt also observed Algol as reddish yellow in 1841 and saw even Arcturus as white for several years beginning in 1852.[8] On the other hand, Sirius is so much brighter than any other star that it is inconceivable for a serious observer to get its colour wrong.

After the Middle Ages and into the early modern period, despite the fact that Ptolemy became much better known to European astronomers through the publication of the *Almagest* in Latin translation (Figure 1) and in the Greek original early in the sixteenth century, still no one seems to have remarked in print on the strangeness of Ptolemy's colour for Sirius. Even Tycho Brahe in his star catalogue, where he discusses Ptolemy's errors, says nothing about this most curious error. Neither, it seems, does Johannes Kepler despite his lengthy discussion of Sirius in Antiquity as well as a separate discussion of star colours, where he reveals that Sirius is colourless (that is, white) and scintillates with all the colours of the rainbow.[9] In fact, no printed source seems to mention the curiosity of 'red' Sirius until 1632, when Libert Froidmont, a professor of theology at

Louvain, noted with amazement in his commentary to Seneca's *Naturales quaestiones* (1.1.7), where Seneca speaks of 'red' Sirius: "Have you ever *really* seen Sirius, Seneca? I have often, and its flame is closer to the flash of silver or steel than to bronze."[10]

This dearth of comment seems to call for some explanation, but it is hard to be sure of one. It may simply be that Tycho, Kepler and others had the same reaction that many modern astronomers have had, namely that Ptolemy and others made an error in calling Sirius reddish, or at least that there was some kind of scribal error in their manuscripts.[11] Such reactions are understandable: Ptolemy's star catalogue, for example, is indeed full of errors, both his own and those of his copyists. Already Islamic astronomers knew that Ptolemy's value for the constant of precession was too small, and that contrary to appearances he had not measured afresh all the positions of the stars in his catalogue. Al-Sūfī complained that Ptolemy, like others after him, had copied his positions from the works of his predecessors, modifying the longitudes with a calculated value of precession. Tycho noted the same thing, and that even worse, through centuries of hand copying and then printing, Ptolemy's erroneous positions had been corrupted.[12] The result was a set of random deviations from an erroneous starting point. It may be that because of these well-known problems, and also because Ptolemy does not repeat the description of Sirius as "reddish" in his astrological treatise, the *Tetrabiblos*, Islamic and Renaissance Christian astronomers silently dismissed the *Almagest*'s description as yet another error.[13]

I wish to emphasize, however, before proceeding further, that despite these doubters we can today feel certain that Ptolemy knew what he was doing when he called Sirius reddish. The problem of 'red' Sirius is different from the star positions, because with those we have a variety of senseless deviations from what Ptolemy must actually have written. No other information from Antiquity corroborates the positional errors. With Sirius's redness, however, there are half a dozen other ancient sources independent of Ptolemy that corroborate him.[14] Thus we have a *tradition* in Antiquity of calling Sirius reddish. The fact of a tradition precludes the possibility that Ptolemy or his manuscripts are presenting merely a random error.

The Debate Begins (1760–1839)

Another consideration should perhaps be taken into account. The dominant paradigm of physics in Islam and Christendom until the seventeenth century was Aristotle. The heavens were a 'cosmos', an eternal order of unchanging, uniform being and motion. Until this physical account was rejected, no one could really expect Sirius to have changed. Tycho and Kepler helped initiate the process of rejection, but it took time for the idea of cosmic mutability to establish itself.

One area in which that began to happen from the mid-seventeenth century

onwards involved variable stars. More generally, in the eighteenth century there were speculations that the cosmos itself might be subject to change. In this context there was a renewed readiness to take seriously the possibility that Sirius might once have been red. And so in 1760 Thomas Barker, a little-known English scientist, initiated the debate by publishing an article in the *Philosophical transactions of the Royal Society*, entitled "Remarks on the mutations of the stars".[15]

Barker's article was relatively short (7 pages), but within its compass he presented many of the arguments and much of the evidence that have been endlessly recycled up to the present day in favour of 'red' Sirius. A detailed consideration of Barker's article can thus clarify many aspects of the debate.

Barker begins (p. 498) by stating that changes in stellar magnitudes are well-known. The star at the end of Eridanus, which Ptolemy noted as of the first magnitude, is now of the third, δ UMa has faded, and a number of stars have disappeared completely since Antiquity.[16] He then notes in particular that the nova of 1604 actually *changed colour* as it faded. Thus he prepares his audience for the possibility of a new kind of stellar change: a star that while not having faded, has yet changed colour markedly since Antiquity. He is aware of the novelty of his suggestion and wants to place it respectably into the context of contemporary astronomy.

With this as an introduction, Barker rapidly moves (p. 499) to the core of his contention: in general the colours of the stars and planets are the same as in Antiquity; the stars that Ptolemy called "reddish" all still are — with one exception. Sirius is now quite white, he continues, but ancient authors call it red. He then lays out his evidence in increasing order of importance, starting from Aratus's Greek astronomical poem, the *Phaenomena*, moving on to Cicero's Latin 'translation' of that, then proceeding to the poetry of Horace, next to Seneca, and finally the crowning trophy, Ptolemy's description in the *Almagest*. I will follow his arguments in order.

Aratus's *Phaenomena*, a poem composed in the mid-third century B.C., describes the appearance and movements of the constellations. When Aratus reaches Canis Major he says the following:

> Just such is the guardian that under his [*i.e.* Orion's] rising back
> appears, the Dog, who stands below [him] on both feet,
> variegated....
>
> Aratus, *Phaenomena* 326–8

This is as much as Barker quotes (pp. 499–500 of his article) in Greek.[17] Like many after him, apparently he did not realize that this passage does *not* refer to Sirius. A glance at the rest of the passage demonstrates this conclusively:

> variegated, not conspicuous in all his parts. Instead along his
> belly he rises dark, while the tip
> of his chin is marked by a terrible star which most

piercingly scorches. Humans call this
Sirius....

Aratus, *Phaenomena* 328–32[18]

Barker seizes on the word 'variegated' (ποικίλος in Greek), which he notes does not expressly mean red, but suggests that at least the word shows that Sirius was not the same colour as other stars. This is false, as the rest of the quotation shows. Aratus clearly means to say only that Canis Major is marked by a great difference in the *brightness* of the stars that compose it: the stars on his belly are faint, but the one on his chin (Sirius) is brilliant. But having hastily erred in these matters, Barker errs again when he turns to Cicero (p. 500).

Cicero, the great Roman orator and statesman, in his youth (early first century B.C.) 'translated' Aratus into Latin. It was not what we understand by 'translation', for the Romans translated almost nothing from Greek into Latin in our sense of the word: they did not need to because all educated Romans spoke and read Greek. What Cicero and others after him did with Aratus was to draw inspiration from him for poetic creations of their own. Cicero's production is in fact rather close to Aratus's original, but is still by no means an attempt to represent in Latin precisely what Aratus said in Greek. The project of using Cicero to explicate Aratus's meaning is therefore a delicate task. Yet this is what Barker attempts. He cites the lines from Cicero's poem which correspond to Aratus's description:

For under his feet there shines with a ruddy light
that famous blazing Dog, refulgent with the light of stars.

Cicero, *Aratea* 33.107–8[19]

Barker seizes on the phrase "with a ruddy light" to explain Aratus's word 'variegated', saying "it appears [that Cicero] either understood [variegated] to mean red, or knowing by his own view it was so, thought it the proper interpretation" (p. 500). Yet once again an examination of Cicero's text reveals that he was not talking about Sirius, but about Canis Major. It is surprising that the phrase "refulgent with the light of *stars*" did not reveal this immediately to Barker. How can one star gleam with the light of more than one star? Already the reader can get a taste for the general quality of the 'red' Sirius debate. It is a sad truth that Barker has been the father not only of one of its principal contributions, but also its generally low quality.

Cicero's usage of the term "ruddy" calls for some comment. Latin astronomical poetry frequently uses terms implying redness simply as an elegant equivalent for "bright". This is emphatically *not* the norm for prose or even for other genres of Latin poetry and has no bearing on Greek usage at all. Cicero himself employs this usage twice more in his 'translation': once to describe the constellation Virgo (*Aratea* 33.322); and again (*Aratea* 33.412) to describe the constellation Cygnus. Neither of these constellations contains bright reddish stars, but both do contain bright *white* stars (Spica and Deneb). Four centuries later, the

Roman poet Avienus did the same thing, but far more profusely: he used words indicating redness eighty times in the 1878 lines of his *Phaenomena*, or about once every 23 lines.

Barker next (p. 500) turns to Horace (late first century B.C.). He quotes (in Latin) part of two verses from the *Satires*. An accurate translation reads:

> whether the ruddy Dog Star splits
> mute statues—
>
> Horace, *Satires* 2.5.39–40[20]

It is hard to know what to make of these lines, when they are quoted out of context in this way. How can a star split statues open? The lines seem bizarre. And recent commentators on 'red' Sirius have not even understood as much as Barker printed. One book, for example, provides the mistaken translation: "the red Dog Star divides its children."[21] If modern astronomers have had difficulty accepting Ptolemy as evidence for 'red' Sirius, Horace seems beyond the pale of consideration. Accordingly, he has been curtly dismissed as a "mere poet", and "copier of Cicero".

But before we send Horace packing, we ought to be certain of what he means. These lines are part of a satire on legacy hunters at Rome. Horace sets the scene for the satire in the Underworld at the end of the famous interview between Odysseus and the dead seer Tiresias, which Homer had depicted in Book 11 of his Greek epic poem, the *Odyssey*. Horace evokes this scene of the *Odyssey* for his Roman audience, but gives it a new, *Roman* ending. Having just received important information about his homecoming from Tiresias, Horace's Odysseus then goes on to ask him how he will recover the fortune that his wife's suitors have squandered. Tiresias absurdly advises him to become a legacy hunter. Let him attach himself to some rich old man without children and attend to his every wish. Let him pursue his patron's legal business out-of-doors in the Roman forum no matter how brutal the weather:

> persist and be hard, whether the ruddy Dog Star splits
> mute statues or Furius, stuffed with fatty tripe,
> spits up white snow on the wintry Alps.
>
> Horace, *Satires* 2.5.39–41[22]

The mixing of Greek and Roman elements in a mock-heroic setting for ignominious behaviour are part of the humour. Another part is Horace's attack on a rival poet called Furius (i.e. "madman"), who stuffs himself with cheap food and spews out bloated verses about snow on the Alps. Clearly this is imaginative and not a scientific disquisition. For us, however, only one point need be noted: the contrast between the ruddy Dog Star that symbolizes the heat of summer (capable of splitting statues open) and the white snows of the frigid Alpine winter. Commentators on the 'red' Sirius debate have frequently suggested, of course, that the red/white contrast is merely symbolic and has nothing to do with

real evidence for an anciently reddish Sirius. That may be so, but because of Ptolemy and the other sources we cannot be sure. Horace does not provide ideal evidence, but we cannot just dismiss him either.

Much more straightforward is the Roman philosopher Seneca (early to mid-first century A.D.), to whom Barker next turns (pp. 500–1). In his prose treatise on nature, the *Naturales quaestiones*, Seneca discusses the causes of fiery phenomena in the sky such as lightning and meteors; he mentions Aristotle's opinion (*Meteorologica* 1.4.341b) that the Earth exhales different varieties of particles into the air, some of which catch fire. Seneca then remarks:

> Nor is it strange if the Earth's exhalation is of every sort and diverse, when in the sky too the colour of objects is not uniform, but rather the red of the Dog Star is piercing, while that of Mars is mild, and Jupiter has none, its glow being translated into clear light.
>
> Seneca, *Naturales quaestiones* 1.1.7[23]

This passage has always been recognized as the most compelling evidence beyond Ptolemy's. It is straightforward and unambiguous. Yet even so it has often been misunderstood. Usually the key words are summarized as saying that "Sirius is redder than Mars". But that is not what Seneca means. He says that "the red of the Dog Star is *piercing* (*acrior*), while that of Mars is *mild* (*remissior*)", meaning that Sirius's redness is somehow vivid and striking, while Mars's is flat and nondescript. It is a question of greater vividness, not a deeper shade of red. After Seneca, Barker adduces (p. 501) his "most undeniable evidence", namely Ptolemy's description of Sirius in the *Almagest*.

Barker is also aware (pp. 501–4) that there is potentially some counter evidence, which he wishes to forestall. He does this because for him Sirius is *either* red *or* white; the possibility that it could be both colours at once does not occur to him. So he must discredit the evidence for a white Sirius. He does so by attacking the Roman prose writer Hyginus whose text could be construed as describing Sirius as white. In this case, however, Barker is on good ground, because although at first sight Hyginus's text might appear to support an anciently white Sirius, a closer reading shows that it does not.

Hyginus (probably late first century B.C.) in a Latin prose treatise on astronomy and constellation mythology, which reproduces earlier Greek information now mostly lost, describes Canis Major as follows:

> But the Dog [*i.e.* Canis Major] has ... on its head ... another [star], which Isis is thought to have established in her own name, and to have called Sirius on account of the *candor* of its fire, because it is of such a sort that it is seen to shine beyond the rest [of the stars]; and so, in order that [humans] might recognize it better, [she is thought] to have called it Sirius.
>
> Hyginus, *De astronomia* 2.35[24]

The difficulty for Barker is that Hyginus speaks here of the "*candor*" of Sirius's

flame. This could either mean "whiteness" of flame or "brightness" of flame depending on the context. Barker argues rightly that here *candor* must be taken as "brightness". This is chiefly because taking *candor* as whiteness does not produce good sense: "... and to have called Sirius on account of the *whiteness* of its flame, because it is of such a sort that it is seen to shine beyond other stars." Whatever else the ancients might have said about it, Sirius was universally known for its *brightness*.

Barker then draws his article to a close, having assembled all the ancient texts that unequivocally attest to redness, namely those from Ptolemy, Seneca, and (probably) Horace. He spuriously appended Aratus and Cicero as additional evidence, and he correctly rejected Hyginus's putative evidence for whiteness. After Barker, all six of these texts appeared again and again in the 'red' Sirius debate with little addition, for over a hundred years.

Astronomy was slow to accept Sirius's ancient redness, although acceptance grew in the nineteenth century. J.-J. Lalande, in the first edition of his influential textbook *Astronomie* published in 1764, just four years after Barker's article, expressed grave doubt about the matter, considering the evidence insufficient for so extraordinary a change. But by the time his book appeared in its third edition in 1792, he spoke more cautiously, indicating that J.-S. Bailly explained such colour changes as due to different degrees and properties of incandescence.[25] Because physics seemed to offer explanation, Lalande was willing at least to consider Barker's arguments.

After Lalande, F. T. Schubert took up the matter enthusiastically in his textbook *Populäre Astronomie*, published between 1804 and 1810 in St Petersburg. Like Lalande, he classified 'red' Sirius as some kind of variable star, a category that at the time included novae, which were known to change colour. But whereas Lalande had given three explanations of variables that did not involve violent changes, Schubert imagined cosmic catastrophes.[26] Concerning Sirius he said: "What a complete revolution must have occurred on this sun, or at least in its atmosphere! and what far greater catastrophe must those stars have suffered, whose place in the heavens is no longer found, whose fire has therefore been quenched, if we will not accept the destruction of complete stellar systems."[27] Perhaps Schubert's context amid the Napoleonic wars after the French Revolution has something to do with this dire vision, but though exaggerated it shows how completely a notion of dynamism had taken hold in astronomy.

During the early decades of the ninetenth century there seems to have been nothing more to say about 'red' Sirius, and so there is an hiatus in publication until 1839. It was then, in more settled times, that Sir John Herschel brought up the matter again in print. In a letter to H. C. Schumacher, the editor of *Astronomische Nachrichten*, Herschel responded to Schumacher's enquiry regarding recent developments in η Carinae, a irregular variable star involved in a vast emission nebula in which Herschel took great interest during his years in South Africa. Herschel responded that he had last seen η Carinae the preceding

April and it had faded considerably.

He then called on astronomers to give more attention to detecting non-periodic changes in the apparent brightnesses of stars, because, as he said,

> I am convinced ... that changes not periodical will be found to prevail to a very much greater extent than is now supposed, and which I would suggest may be accounted for by ... inequality in the degree of opacity of different regions [of space], and of movements going on in the opake matter whatever it be. In short by supposing the existence of some sort of cosmical *cloudiness* subject to internal movements depending on causes of which we are ignorant. Of the nature of these super-atmospheric clouds of course no conjecture can yet be formed, but some argument for their being of a material nature *may* be drawn from the strange observation of Ptolemy that Sirius was in his time one of the 6 red stars.... It seems much more likely that a red colour should be the effect of a medium interfered [*sic*] than that in the short space of 2000 years so vast a body should have actually undergone such a material change in its physical constitution [Herschel's emphasis]".[28]

Thus, Herschel proposed the first concrete physical mechanism to explain 'red' Sirius. He seems to have thought that his "cosmical cloudiness" could act merely to colour Sirius's light without dimming it. In this way, he could avoid the disturbing notion that so large a body as Sirius might have intrinsically changed in a cosmically brief period. However, as we now know, in order for interstellar (or circumstellar) matter to change Sirius's colour significantly, it would inevitably have to dim Sirius markedly. Recent work suggests that a dimming of 3 visual magnitudes would be necessary to alter Sirius's B–V colour index from its present value of 0.0 to 1.0, giving it the same colour as Pollux, the least reddish of Ptolemy's red stars.[29] Of course, such a difference is out of the question because Sirius would then have a visual magnitude of about 1.5, making it the equal of ε CMa. Gone would be the brilliant Dog Star of the ancients, which Ptolemy *explicitly* called the brightest star in the sky.[30] Herschel does not seem to have understood the inevitability of this dimming, but strangely, astronomers as recently as 1992 have pursued absorption as a viable physical explanation, adding the modern refinement of a Bok globule as the absorbing agency. Several have even spent time with large modern telescopes looking for evidence of absorption.[31]

Tentative Acceptance (1839–74)

After Herschel's letter, 'red' Sirius came into the mainstream in the middle years of the nineteenth century. Although no widely accepted explanation for the change existed, gradually with some scepticism more authors began to speak of the matter and to accept Barker's arguments. No one had a strong reason to doubt 'red' Sirius, and perhaps it seemed that in time physics would explain the matter. The

eminent French astronomer, François Arago, director of the Paris observatory, in 1842 stated: "with everything well considered and weighed, it seems then that Sirius was formerly reddish, and that in less than 2000 years it has changed from that colour to a most unequivocal white."[32] In 1843, Francis Baily in his revision of Ptolemy's star catalogue treated the change as definite, stating that this was a point on which Ptolemy could not well be mistaken.[33] Yet others still regarded the matter with scepticism. W. H. Smyth, for example, in the 1844 first edition of his famous *Cycle of celestial objects*, while taking pains to describe Barker's arguments, called the change extraordinary.[34] But 'red' Sirius's moment of glory was just around the corner. It came in 1850 with the publication of vol. iii of the massive natural history by one of the most famous scientists of the day. Alexander von Humboldt's German masterpiece, *Kosmos*, was soon translated into English and French, and was reprinted many times over the next two decades.[35]

Humboldt's account of 'red' Sirius is brief, but important in two respects. First, Humboldt bluntly states that "Sirius ... affords the only example of a historically proved change of colour ... whether [this colouring process has occurred] in the star's photosphere itself, or in wandering cosmic clouds".[36] And second, Humboldt gives a philological account of Ptolemy's term for 'reddish', lest anyone doubt that Ptolemy really did mean 'reddish'. Since this matter has continued to interest commentators on 'red' Sirius until today, it will be useful to consider the question for a moment.[37]

Ptolemy's word for reddish, ὑπόκιρρος, as Greek literature demonstrates, is a scientific term indicating a pale shade between red and yellow. It is a compound adjective, whose simplex form is κιρρός. This latter term the Greek physician Galen sets into a series with λευκός (white), μέλας (dark/black), ξανθός (blonde/flaxen), and ἐρυθρός (red) as colour descriptions for different types of wine.[38] We can set these terms into a spectrum from the lightest white wine (λευκός), to a yellowish white wine (ξανθός), to a κιρρός wine, to a red wine (ἐρυθρός), and finally to a dark red or purplish wine (μέλας). This spectrum shows that κιρρός is a rather vague term, describing some shade between yellowish and reddish. The prefix ὑπο- indicates 'somewhat' or 'faintly'. A reasonable approximation is therefore pale yellowish orange or 'flame-coloured', but the shade is not precise. This vagueness corresponds to the vague English term 'reddish' when applied to stars. In common parlance "reddish stars" include anything from Capella (B–V = 0.8, yellow) to Antares (B–V = 1.8, deep orange). Ptolemy in fact classifies Antares, Betelgeuse, Arcturus, Aldebaran and Pollux as ὑπόκιρρος. And it seems to be the only word for 'reddish' that he uses in the *Almagest* and the *Tetrabiblos*. Humboldt, however, in his discussion introduced terms such as "fire-yellow" (*feuergelb*) and "fire-red" (*feuerroth*), which suggested a far more vivid colour than ὑπόκιρρος signifies. After Humboldt it was common to say that Ptolemy called Sirius "fiery red", a vast exaggeration. Ptolemy called Sirius "reddish" in the vague sense defined above.[39]

Those who chose to mention 'red' Sirius between 1850 and 1874 were inclined to accept that it really had changed colour. In 1854, for example, Hervé Faye in his *Leçons de cosmographie* said so flatly. Others were more cautious, but no one seems to have denied it. Arago in his *Astronomie populaire* (1854), the redoubtable T. W. Webb in his *Celestial objects for common telescopes* (1859), which went through five editions in the nineteenth century and is still in print today, as well as A. Guillemin in his *The heavens* (1872), a book edited by the likes of Sir Norman Lockyer and Richard Proctor, all admitted that Sirius seemed to have changed colour. It was as close as 'red' Sirius ever came to widespread acceptance.

Further Debate and Rejection (1874–1927)

But gradually voices of determined opposition arose. During the final decades of the nineteenth century, the first theories of stellar evolution based on spectral classification and thermodynamics were developed.[40] One unresolved question centred on the status of the red stars: were they only the ancient, dying embers of formerly brilliant white stars, or could some of them also be quite young and in the process of heating up? There was much disagreement. Norman Lockyer (almost alone) championed the latter idea and attempted to identify red stars actually in the process of heating. But the mainstream of astronomy inclined against the notion of young red stars.[41]

This was the background for the next phase of debate. If red stars are old, then Sirius could not have been red in Antiquity. Realizing this, prominent astronomers began to take a strong interest in the ancient evidence for Sirius's redness, subjecting it to stiff scrutiny and rejecting it. They were preceded by some years by the Danish astronomer H. C. F. C. Schjellerup, who in 1874 published an edition of the Arabic text of al-Sūfī's book, *Description of the fixed stars*, along with a French translation. In his preface to the translation, Schjellerup attempted to discredit the evidence for 'red' Sirius. He proceeded by a two-pronged attack. First, he rejected the evidence of Cicero by stating that Cicero had "rather freely" translated Aratus, not yet realizing the bogus nature of both Cicero's and Aratus's 'evidence' in any case. Then he suggested that Horace had merely followed Cicero's lead, and that Seneca had done the same to Horace. This attack obviously founders. Horace could not have followed Cicero, when Cicero never called Sirius red.

The second prong involved Schjellerup's suggestion that Ptolemy himself had never actually called Sirius red, but that instead what we have is an error in our Greek manuscripts of the *Almagest*. The Greek text as we presently find it identifies Sirius as "the [star] on the mouth, brightest, called 'the Dog', and reddish". Schjellerup proposed that Ptolemy had actually written "the [star] on the mouth, brightest, called 'the Dog' and 'Sirius'".[42] Schjellerup found it strange that Ptolemy would call Sirius "the Dog" without also using its "proper" name.

After all he had called Arcturus, Regulus, and Antares by their proper names, so why would he not do the same for Sirius? A corruption must have crept into our Greek text during the centuries of hand copying. As corroboration for this notion, Schjellerup cited what he took to be evidence among the Islamic astronomers that their Greek manuscripts of the *Almagest* did not contain the description of Sirius as reddish either.

Let us begin from Ptolemy's Greek text. In Schjellerup's day there was as yet no critical edition of Ptolemy. The printed texts of the *Almagest*, such as the 1538 first edition by Grynaeus and Francis Baily's 1843 version of the star catalogue, were based on only a few manuscripts and these not the best. Other Greek manuscripts existed from the Middle Ages, but they had as yet not been systematically surveyed. Since the star catalogue in particular was known to contain so many variant readings in the different manuscripts, it was legitimate to wonder whether when one had surveyed the majority of manuscripts, one would find that the description of Sirius as "reddish" was an error found in only a few of them. After 1903, when J. L. Heiberg finished his beautiful critical edition of the *Almagest*, it was clear that the surviving Greek manuscript tradition was unanimously in favour of 'red' Sirius.

From another point of view, however, this was to be expected all along. Schjellerup's notion that Ptolemy must have used the name "Sirius" because that is the stars's proper name is mistaken. In fact, in all the extant writings of Ptolemy, Hipparchus, and Geminus (the three most important ancient Greek astronomical writers preserved) the word 'Sirius' never seems to occur *at all*. All three astronomers call Sirius only "the Dog", precisely the name that we do find in our manuscripts of the *Almagest*. Indeed, Geminus explicitly says that the star was called by the same name as the constellation, "the Dog".[43] So Ptolemy does call Sirius by its proper name.

As for the Arabic tradition, again Schjellerup was mistaken. Schjellerup claimed in effect that while the current Greek text of the *Almagest* speaks of there being six reddish stars, al-Battānī mentions only five; and since al-Sūfī does not regard Sirius as a reddish star, all this shows that the Islamic astronomers received a list of only five reddish stars from Ptolemy, and that the current Greek text of the *Almagest* must have fallen into error *after* the time of al-Battānī and al-Sūfī. In fact, we know now through the painstaking work of Paul Kunitzsch that the medieval Arabic translations of the *Almagest* (to which Schjellerup did not have access) show that the Greek originals from which they were translated did indeed call Sirius reddish.[44] And one of the few correct and useful points that the astronomer T. J. J. See later introduced into the debate through his extensive work on 'red' Sirius was to show that Schjellerup relied on a very poor Latin translation of al-Farghānī, which he mistook for al-Battānī and which contained what is either a manuscript error or a printer's error. A better Latin translation showed that al-Farghānī did not say that there were five "reddish (*rubeae*) stars", but that there were five "nebulous (*nubeae*) stars", precisely the number

given in the *Almagest*.[45] Schjellerup certainly took some false steps in his arguments, but I do not wish to denigrate his work. His translation of al-Sūfī's book is a boon to all who cannot read Arabic and so have no direct access to this important monument in the history of visual astronomy.

Schjellerup's contemporaries did not realize his mistakes, and since his was the best-articulated attack on Barker's arguments so far, his effect on the debate was profound. When Camille Flammarion published his elegant *Les étoiles et les curiosités du ciel* in 1882, he accepted every one of Schjellerup's assertions, as did W. T. Lynn, a frequent commentator on 'red' Sirius during the period, who wrote a letter to *The observatory* magazine in 1887 to remind everyone of Schjellerup's conclusions, which he carefully repeated. Lynn made a further point of great value when he noted that Seneca's description could in fact refer to "certain occasions when atmospheric conditions would certainly give Sirius a reddish appearance". These conditions are an essential element in resolving the debate, as German investigators later divined. Sirius is the only star bright enough to be seen actually rising or setting in the Mediterranean sky. At the crucial phases of heliacal rising and setting, when the Greeks and Romans most characteristically observed Sirius, it was apt to shine reddish in the same way that the rising or setting sun can shine reddish on the horizon due to atmospheric absorption of the bluer rays in the Sun's light. Sirius is also apt to scintillate near the horizon, and when it does so it visibly flashes in different colours, among which reddish and orange hues are easily observable.[46] The hypothesis that Sirius's redness is in some way a product of scintillation and absorption has repeatedly surfaced in the debate without ever being fully exploited.

Lynn himself did not do so in his letter to *The observatory*, because immediately after mentioning it he asserted that there was another way out of the problem of Seneca's evidence: the text of the *Naturales quaestiones* might be corrupt. According to this notion, what Seneca had actually written was not "the red of the Dog Star", but "the gleam of the Dog Star". This would read much more naturally, he assures us. So once again the debaters tried to sweep the evidence away, because it made no sense to them. The problem for Lynn, however (as he later admitted), was that his suggestion for "emending" the text made it absurd: "the *gleam* of the Dog Star is piercing, while that of Mars is mild, and Jupiter has none, its glow being translated into clear light." Jupiter has no gleam?

Agnes Clerke also agreed with Schjellerup in the first edition of her book, *The system of the stars*, adding that Cicero "was much more of a rhetorician than a natural philosopher". On the other hand, G. F. Chambers, in the fourth edition of his *A handbook of descriptive and practical astronomy*, still faintly assented to the change in Sirius's colour as real, but after detailing several other more recently alleged cases of colour changes, he concluded: "I am much inclined to view all such statements as these with distrust." This is the attitude astronomers increasingly took after the end of the century.[47]

The rapid reversal from tentative acceptance to rejection that appears in the

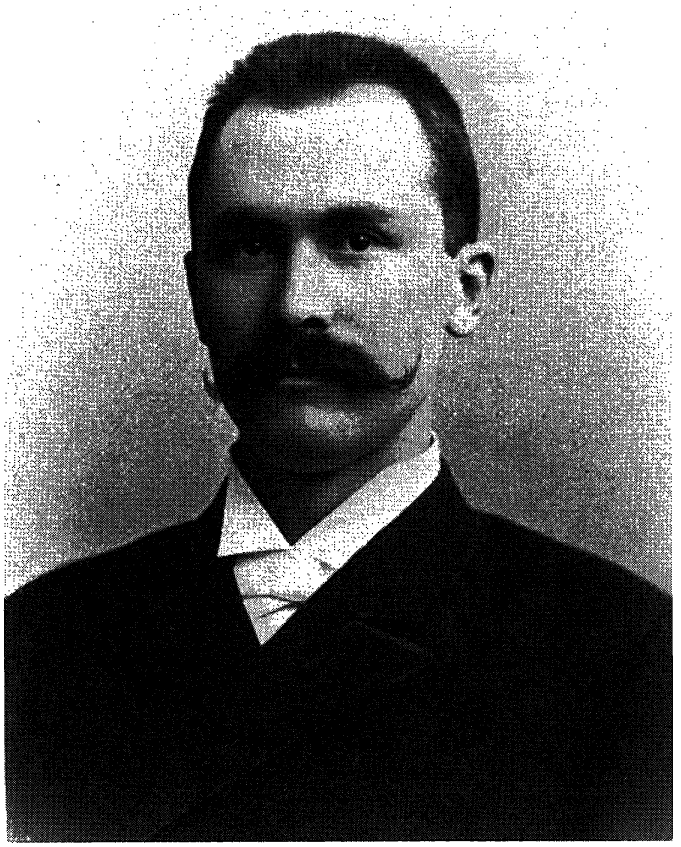

Fig. 2. T. J. J. See in his twenties, while a doctoral student in Berlin.

debate as a result of the publication by Schjellerup is interesting, because it shows how quickly astronomers were willing to get rid of 'red' Sirius, if someone gave them an opportunity. They could even help by supplying rationalizations (like Clerke's attack on Cicero) and ill-considered textual emendations (like Lynn's). It was not that anyone understood the evidence properly or had given a reliable account of it. Rather, 'red' Sirius now conflicted with astronomical theory, and astronomers wanted to be rid of it.

But it would not go away so fast. A 'red' Sirius counterattack commenced in 1892 under the direction of T. J. J. See (Figure 2), who published a series of substantial and apparently exhaustive articles in *Astronomy and astrophysics*, the forerunner of the *Astrophysical journal*.[48] See was determined to make the most convincing case for 'red' Sirius, and he succeeded. The paper he published, although partially discredited in 1897, in the long run proved to be the most influential of all the works ever published on the question. However, before turning to this paper, it will be useful to say a few words about the man himself.

No one in the history of astronomy has stirred up so much general animosity as See.[49] In the course of a decade starting in 1892 he went from being a newly appointed instructor at the University of Chicago — where he was fired in 1896 — to being an assistant at the Lowell Observatory — where he was fired in 1898 — to being a professor at the US Naval Observatory, from which he was sent off in 1902 to the naval time-keeping station at Mare Island, California, far from universities and telescopes. Some of the work he did was good, but much of it was unsound and negligent. He craved recognition for his "outstanding" merit, which led him to publish fallacious papers, announce bogus results, and become involved in acrimonious personal disputes with other astronomers. In his lifetime he was ostracized from professional astronomy and he is today remembered as a crackpot. His biography has the ominous title, *Brief biography and popular account of the unparalleled discoveries of T. J. J. See*.[50] In view of his character, his writings on 'red' Sirius must necessarily be approached with caution. But approached they have been, by many twentieth-century investigators. Indeed, aside from Barker, no other extended discussion of the ancient sources has been available in English until recently.

See published two versions of his paper, the first written when he was a graduate student with high hopes for the future, and the second thirty years later amid the ruins of his career, when he had few opportunities left to attract attention. The tone of his first paper is still reasonable and its argument is fairly plausible for an audience that has little opportunity to analyse the ancient texts independently. It is this version that I will take up first.

The relevance of 'red' Sirius to contemporary astrophysics first comes into the open in See's paper. See directly links the two by saying: "The results of [my] research seem to establish beyond doubt the ancient redness of [Sirius], and therefore ... the investigation will be interesting to astronomers who are studying problems of Cosmical Physics...."[51] Later he states: "Since therefore Sirius was formerly red, and is now white, it follows that some of the red stars become white in the course of ages, and this we may perhaps infer to be the general law of colour in celestial evolution."[52] He has reached these important conclusions, he implies, from "legitimate principles of historical research", and so will anyone else who follows the same principles.[53] Thus, in effect, he claims to have learned astrophysics from history. Unfortunately, however, the quality of See's "historical research" turns out to be too low to justify the hope of learning anything real. His investigative strategy primarily aims at heaping up passages from ancient authors with insufficient regard for their content or context. Most of them merely refer to Sirius as "fiery", "burning", or "parching" and say nothing directly of its colour. Apparently See hoped that by piling up as many passages as possible, he would overwhelm his audience into belief. In the short run this did not work well; in the long run it has been more effective. At the same time, though, See appears to have done what others did not do: manipulate his evidence and perhaps deceive in order to persuade. I will take up some typical

examples to illustrate his procedures.

See begins his article by asserting that Barker's original 1760 paper "seemed so conclusive that for a long time the change of color [in Sirius] appears to have been accepted as an item of scientific belief". But recently, he continues, doubt has been thrown on some of the evidence; therefore, he has decided to examine critically all the ancient testimony he can find. "I shall now proceed", he asserts, "to give briefly the evidence ... and to review in the proper place the criticisms hitherto advanced, nearly all of which happen to be erroneous. We shall usually proceed in chronological order."[54] Thus, in a reasonable tone and with a business-like beginning, he turns to Homer.

Homer, See says, does not distinctly indicate Sirius's colour, but he does associate Sirius with fevers and fires — just as did the other Greeks — and there must have been a reason for this, because other stars were not likewise associated. "The evil omens", he continues, "attributed to Sirius were perhaps the natural outcome of astrological superstitions widely spread in Antiquity respecting the 'influences' of bodies of a ruddy color, which were looked upon as 'angry' deities". See then rightly adduces the example of the planet Mars, to which malign and fiery influences were attributed in Antiquity, whereas Jupiter shone with a clear and "salutary" light. Thus, he concludes, it seems we can explain the association of Sirius and fire, only if Sirius were reddish in Antiquity. There is no obvious reason why the ancients should associate a white Sirius with malign influences.[55]

See's argument is nearing the truth, but then it veers abruptly away. See categorically denies at several points that Sirius's redness can have anything to do with atmospheric effects caused by the Earth.[56] He thereby loses his best chance to explain 'red' Sirius in a way supported by the ancient evidence viewed as a whole and not piecemeal.

On the other hand, the apparent sophistication of See's argument in comparison with what came before is notable. And he gives every *appearance* of learning. He quotes Greek and Latin authors extensively in the original languages and has clearly done a great deal of homework. Yet the appearances are deceptive. His failure to offer his astronomical audience any translations of the ancient texts may conform to what was expected at the turn of the century, but it also conceals his ignorance. A case in point is See's treatment of Aratus on pp. 272–3 of his paper. See quotes Aratus in Greek, but still does not expose the error that Barker and others had made in interpreting him. Indeed, See compounds it by maintaining that "the only meaning that can with any probability be assigned to [ποικίλος = variegated] is 'ruddy'". This is false, but only a reader knowledgeable in Greek will realize this. See goes on to say that Hipparchus in his extant commentary on Aratus did not dispute the application of ποικίλος, and that considering "the scrupulous care which characterized all of Hipparchus's work, it would seem that he must have considered [ποικίλος] a correct description of Sirius". Actually, Hipparchus would have known that

ποικίλος was being applied to Canis Major, *not* to Sirius.

See next proceeds to Cicero. Again he preserves the reigning misinterpretation, but adds to it another error, by stating categorically that in "the whole of [Cicero's] writings, as I have found by careful investigation, Cicero does not use the word 'rutilus' (or any other word meaning red) in speaking of any other heavenly body except the planet Mars...". 'Rutilus' (ruddy) was the word that Cicero had used to characterize the light of Canis Major in his 'translation' of Aratus. See's statement is quite false and to assert it so categorically shows that he was at least hasty. I have already noted that in the 'translation' of Aratus alone, Cicero twice more calls celestial bodies (Virgo and Cygnus) "ruddy".[57] Since See was well able to find evidence useful for his purposes, it seems unlikely that if he really investigated carefully, he did not find other places where Cicero used words for redness.

Three other cases of error involve See's treatment of Germanicus's and Avienus's 'translations' of Aratus, and the astrological poem of Manilius (whose name See persistently misspelled as "Manillius" even 30 years later in his revised article). Germanicus Caesar was a great Roman general and adopted son of the Emperor Tiberius. He lived in the first century A.D. and to him is credited another Latin 'translation' of Aratus, although his authorship of the poem is today widely doubted. Avienus seems to have lived in the fourth century A.D., and he produced the last ancient Latin 'translation' of Aratus. Manilius, on the other hand, seems to have been roughly contemporary with Germanicus, and he composed an astrological poem that drew on Aratus, but was not another 'translation'. In Germanicus's case, See again (pp. 273–4) categorically states that he called only one celestial body reddish, namely Sirius. This is false, because in the first place it is Canis Major that Germanicus calls reddish, not Sirius; and second, because Germanicus also calls the constellation Aries reddish.[58] In the case of Avienus (p. 274), See scornfully dismisses him, failing in the process to note that Avienus directly calls Sirius bluish white.[59] The same applies to Manilius (p. 377). See selects three quotations that he finds useful from Manilius, but unaccountably fails to notice the prime quotation that speaks of Sirius as bluish white.[60] His failure to notice this quotation remained even thirty years later in his republished article, despite the fact that G. V. Schiaparelli (Figure 3) in an essay well-known to him had pointed it out.[61] Thus, when See then categorically states on p. 383 of his 1892 article that "there is no [ancient] authority who affirms that the star was white", we must wonder whether this error was innocent. Even a glance at his 1892 article shows that he invested a huge amount of research into it. Despite the mistakes he made, could he really have been totally ignorant of Manilius and Avienus?

One other error is worth noting. On p. 372, See quotes and discusses a text from the astronomical writer Geminus, which concerns the possibility that Sirius might affect terrestrial weather through "exhalations" which stars were thought to emit. Geminus opposed the idea. Contrary to his usual procedure of avoiding

Fig. 3. G. V. Schiaparelli (from Amand Freiherr von Schweiger-Lerchenfeld, *Atlas der Himmelskunde* (Vienna, 1898), 185).

translations, this time See translates:

> For this star (Sirius) is of the same nature as all the rest of the stars. And whether the stars are fiery [πύρινος] or clear [αἰθέριος], all have the same power, and exhalations ought to proceed from the multitude of the stars rather than from Sirius.

One's suspicions should immediately be aroused because the second sentence makes no sense. If the stars all have the same nature, why should exhalations proceed from the multitude of stars *rather* than Sirius? The explanation is that See has mistranslated, possibly because his version suits his argument better than a correct translation would. What the text actually says is:

> For this star shares in the same material [i.e. is composed of the same matter] as all the rest of the stars. Now, whether the stars are composed of fire [lit. "are fiery"] or composed of aether [lit. "are aethereal"], they all possess the same force, and the exhalation from the Dog ought to be overpowered by [that of] the majority of the stars.
>
> Geminus, *Elementa astronomiae* 17.32–33[62]

As Schiaparelli noted in 1897 in his tactful but firm refutation of See's argument,

Geminus says nothing about the colour of star-light here; rather, he is speaking about the material of which stars may be composed, either fire or 'aether' (the Aristotelian fifth element). But See has misinterpreted Geminus's text into a distinction between Sirius's having a "fiery" colour (i.e. red) and the majority of stars' having a "clear" colour, which better suits his argument.

The list of See's errors could be extended: he provides an erroneous analysis of Columella on p. 378 and of a triad of Roman festivals on pp. 379–80. And while his discussion of Hyginus on pp. 373–6 is usable, and he correctly notes on pp. 381–2 that Schjellerup erred in regard to al-Battānī, he has made a mess in analysing Schjellerup's errors. So we are left with a paper that is quite unreliable, especially for those ignorant of Greek and Latin. A specious and often plausible argument beguiles one into believing that See has done his homework well.

See's paper received a cool and mixed reaction. Lynn, for example, publicly offered corrections to his own earlier statements, but did not endorse the colour change. Agnes Clerke, on the other hand, now did support the change on the strength of See's argument, but only unobtrusively, in footnote to the revised third edition of her *A popular history of astronomy during the nineteenth century*.[63] The major powers of astronomy, though, were hostile. In 1896–97, Schiaparelli published another lengthy examination of the evidence in two essays.[64] In the first, he was not yet aware of See's work, so he presents conclusions uninfluenced by that. By the time of the second, however, Schiaparelli had read and digested See's arguments and made several important criticisms. Schiaparelli was always firmly set against a colour change.

Moving from See to Schiaparelli is astonishing. Schiaparelli presents an orderly analysis of real learning. We may profoundly disagree with his conclusions, but we must respect the knowledge of Antiquity, of classical languages, and of ancient texts that he possessed when by profession he was an astronomer. He presents important new evidence, correctly points out long entrenched errors, and openly displays a diffidence about his results which deserves our sympathy.

His strategy in the first paper is to attack the credibility of Ptolemy's text as strongly as possible, then to discredit the 'evidence' erroneously drawn from Aratus's 'translators', next to show the unreliability of Horace and Seneca, and finally to focus on the counter evidence for Sirius's ancient whiteness, most of which he presented for the first time in print. His concern is explicitly with the contradiction that exists between an anciently 'red' Sirius and the reigning model of stellar evolution.[65]

He begins his offensive with Ptolemy. Schjellerup is his guide in attacking the *Almagest*'s text as erroneous, so that this part of Schiaparelli's argument we can neglect as mistaken. Schiaparelli does, however, add two new points of interest. First, he notes that in the *Tetrabiblos*, Ptolemy describes Aldebaran, Antares, and Arcturus as reddish (ὑπόκιρρος) but not Sirius, which would be

strange if it really had been reddish in Antiquity. Then Schiaparelli produces a novel argument: Ptolemy had constructed an astrological star list, he notes, in which individual stars and groups of stars were assimilated in astrological power to the powers of the planets. The basis for the assimilation is often clearly the similarity of colour between star and planet.[66] Schiaparelli exhibits a synopsis of Ptolemy's list for fourteen first-magnitude stars, giving their modern colours and ancient astrological assimilations. He notes that whereas Betelgeuse, Aldebaran and Antares are primarily assimilated with Mars, Sirius is primarily assimilated to Jupiter (plus a little bit of Mars), which makes sense only if Sirius was white in Antiquity.[67]

In fact, the evidence is not so clear-cut. Betelgeuse is not named by itself, but only in conjunction with Bellatrix (γ Ori, B–V = –0.2). Arcturus and Regulus are both assimilated to Mars *and Jupiter* — in that order — despite having visibly different colours (deep yellow and white). If we view the evidence critically, there does seem to be a pattern of colour assimilations, although other factors clearly intervene as well. And it does seem strange that Sirius was not strongly assimilated to Mars if it was really reddish in Antiquity. So on the whole, the *Tetrabiblos* does offer evidence worth considering, but that evidence is not decisive.

Schiaparelli next turns to Aratus and his 'translators'. He correctly points out for the first time that neither Aratus, nor Cicero, nor Germanicus was referring to Sirius in their respective descriptions, but instead to Canis Major, while Avienus calls all and sundry "reddish".[68] He tries to develop a more complicated case with Horace. This is the least adequate part of his paper, and his frustration seems detectable in his tone. He argues at length that Horace was not referring to Sirius at all, but instead to Procyon. Not that Procyon was reddish in Antiquity, Schiaparelli admits, but Horace took over the word from religious ritual and applied it with great liberty to Procyon.[69]

Turning to Seneca, Schiaparelli fastens on quirks. He feels he must admit that Seneca really did mean Sirius, but still he says, the explanation for Seneca's assessment of Sirius as red probably lies in an error: some astronomer friend of Seneca's may have shown him Sirius when it was rising and when Jupiter and Mars were well up in the sky. The redness that Seneca attributes to Sirius, Schiaparelli implies, was merely the effect of atmospheric absorption, which Seneca did not understand, being a novice at observing. The idea that Seneca's description must result from the caprice of a novice's first observing session is too insubstantial to need a response.[70]

Schiaparelli's attacks fail. The *Almagest*'s text is secure and no one has been able to explain away Seneca. Given this, it is pointless to maintain that Horace was not really referring to Sirius's redness. The three essential 'red' Sirius texts remain.

After dealing with the evidence for Sirius's redness, Schiaparelli turns to evidence for its whiteness. He first adduces the passage I have already discussed

from Hyginus, which appears in fact not to refer to Sirius's whiteness. But then Schiaparelli makes a positive contribution of the greatest significance to the debate: he introduces two new passages. The first of these comes from the astrological poem of Manilius, where he describes the constellations and their astrological effects. When he reaches Sirius, Manilius notes its enormous powers to influence the world in diverse ways:

> Sure proof that the star has this power are its colour and quivering of the fire that sparkles in its face. Hardly is it inferior to the Sun, save that its abode is far away
> and the beams it launches from its sea-blue face are cold.
> In splendour it surpasses all other constellations, and no brighter star
> is bathed in Ocean or returns to heaven from the waves.
>
> Manilius, *Astronomica* 1.407–11 (transl. by G. P. Goold)[71]

Manilius expressly calls Sirius "sea-blue" (*caeruleus*), a poetic term that includes very light, bluish white shades of colour. So for Manilius, Sirius could not have been reddish in Antiquity, but must have been its present bluish white.

Schiaparelli then cites the Greco-Egyptian astrologer Hephaestion of Thebes (fourth/fifth centuries A.D.), who reports that the Egyptians used to observe Sirius at its heliacal rising. Based on its appearance, they would draw an omen for the quality of the upcoming year:

> ...if the star [i.e. Sirius] rose great and white and if it came through with its colour, then the Nile's current would rise high and there would be abundance; but if it was flame-coloured [πυρρός] and the colour of red ochre [μιλτώδης] there would be war.
>
> Hephaestion of Thebes, *Apotelesmatica* 1.23.30[72]

Hephaestion goes on to indicate other colours that Sirius could show, but the two noted above (white and reddish) are enough to illustrate the essential point, which Schiaparelli drives home forcefully: these differences in appearance are the product of atmospheric absorption caused by the Earth. Such absorption routinely causes white Sirius to vary in apparent colour (from white to reddish) even today, depending on the state of the atmosphere when it rises. On the other hand, an intrinsically reddish star cannot show such a colour variation: a white star can sometimes appear reddish in our atmosphere, but a reddish star cannot appear white. So Hephaestion's description makes sense *only* if Sirius was intrinsically white in Antiquity.[73]

Schiaparelli's second paper, published a year later, deals with matters raised by See. We will concentrate on its most important points. First, Schiaparelli notes that See's method of piling up references to Sirius as "burning", "drying", etc., proves nothing about its colour. He himself is capable of more than doubling the pile. But he notes that it is still not complete, and then asks what is the use of enlarging it: a similar list can be piled up for the Sun, but that does not

prove the Sun to have been "fiery red" in Antiquity.[74] And second, Schiaparelli firmly exposes See's misunderstanding of Geminus, noting that "I do not believe that many will subscribe to [See's] manner of interpretation".[75]

With this ends everything of importance in Schiaparelli's papers. Despite my criticisms, I want to reiterate that his work is of high quality considering that he was an astronomer working on ancient texts, and it is unfortunate that his papers have been much less read than See's. But Schiaparelli chose to publish in Italian and in the acts of an obscure, scholarly journal, whereas See published in English in a leading periodical devoted solely to astronomy. The result has been that in the most recent phase of the debate (1960–93), almost no one has shown a knowledge of Schiaparelli, whereas See's name figures prominently.

Astronomers at the turn of the century, however, did pay attention to Schiaparelli. Simon Newcomb, in 1901 in his first published comments on the debate, declared in favour of Schiaparelli and for the notion that scintillation played a large role in ancient estimates of Sirius as reddish. Lynn, on the other hand, could not make up his mind. In January 1902 he declared for See; but by March, after reading Schiaparelli, he had had second thoughts, yet was concerned that now Procyon might have changed colour (an idea that Schiaparelli had explicitly excluded), and so reverted to his 1887 suggestion that Seneca's text might be corrupt. Agnes Clerke was not interested in vacillations. In three major books that appeared between 1902 and 1905 she openly supported the change, going so far as to say: "[A] learned discussion by Dr. T. J. J. See, moreover, enforces the belief that Sirius was absolutely *red* eighteen hundred years ago" (Clerke's emphasis).[76]

Gradually, and especially among German researchers, the idea that Sirius's impressive scintillation might explain the ancient references to its redness began to gain wider currency. In 1906, J. Plassmann noted: "In the case of this bright star ... its red flashes are so clearly seen that possibly the statement from Antiquity that it is a red star can be explained in this way."[77] The classical scholar F. Boll, whose major production centred on ancient astronomy and astrology, agreed with him, noting that it also made sense of Ptolemy's assimilation in the *Tetrabiblos* of Sirius to Jupiter primarily *plus a little bit* of Mars. It made sense of the literary passages that called Sirius "sea-blue", the second of which Boll mentioned in print for the first time in 1909.[78] This comes from the poet Avienus, one of the 'translators' of Aratus. Avienus, despite characterizing many different stars as "reddish", explicitly calls Sirius "sea-blue":

> But Meton took the first beginnings of the year
> [to be] when Phoebus [*i.e.* the Sun] burnt Cancer with ruddy star,
> and when the ocean far away held aloft the belt of Orion,
> and when Sirius blazed with sea-blue star.
>
> Avienus, *Phaenomena* 1373–6[79]

Another classicist, W. Gundel, in 1907 referred to a different passage of Cicero,

where the author discusses the local practices of the Greeks on the Aegean island of Ceos.[80] The Ceans made it a practice yearly to observe Sirius's heliacal rising in late July and from its varying appearances to derive an omen for the following year:

> Indeed, we have heard that the Ceans are accustomed to observe carefully every year the rising of the Dog Star, and — as Heraclides of Pontus writes — to derive a prediction as to whether the year is going to be healthful or pestilential. If the star rises rather faint and misty so to speak, then the sky is thick and dense so that its exhalations are going to be oppressive and pestilential. But if the star appears brilliant and very clear, then that signifies that the sky is thin and pure, and therefore healthful.
>
> Cicero, *De divinatione* 1.57.130[81]

The significance of this passage is that in conjunction with Hephaestion it shows how common it was in the Mediterranean to observe Sirius at its rising and to attribute great importance to its atmospherically induced appearances. The absorption and scintillation hypothesis to explain Sirius's ancient redness thereby gains even greater plausibility.

From a different direction, F. X. Kugler, one of the founders of the modern study of Mesopotamian astronomy, noted in 1907 the existence of a cuneiform text which speaks of Sirius "glowing like copper". Subsequent study has revealed that this text also relates to Sirius's colour *at its rising*. By 1910, all the most important texts relating to Sirius's colours in Antiquity had been mentioned in print and the direction of the ultimate solution had been indicated, but no one was able to put everything together in a detailed and convincing way, with the result that A. S. Eddington in 1911 could still say that from Ptolemy's evidence it "seems almost conclusive that Sirius was a redstar [*sic*]".[82]

On the other hand, by now Schiaparelli's work seems to have become known in some form to most astronomers, many of whom appear to have rejected 'red' Sirius on the strength of it. In an essay in 1917 on ancient astronomical observations, Boll tells us that the astronomer H. Osthoff, an expert in stellar colours, had informed him that astronomers considered the 'red' Sirius debate concluded by Schiaparelli's papers. Nevertheless, Boll attempted to clarify the ancient evidence and reiterated the idea of atmospheric scintillation and absorption as the probable source of 'red' Sirius.[83]

Little more was heard of the debate until 1920, when Osthoff himself published an article. Then in 1924 P. Sarasin discussed possible evidence for Sirius's ancient whiteness derived from the Avestan hymns of ancient Persia, the first time that this had been done. In 1926, Schiaparelli's student L. Gabba edited his essays on ancient astronomy (including the 'red' Sirius essays) and published them in a three-volume set. Most important, however, was See's reissue in somewhat revised form of his earlier work. This occurred in 1927. Why he chose to do so just then is unclear, but perhaps he was prompted by the appearance of

Schiaparelli's essays. However that may be, See's own revised essay, printed in the *Astronomische Nachrichten*, provoked a outburst of articles and notes on the question in the same year.[84] Then 'red' Sirius essentially vanished for the next thirty years before resurfacing in the 1960s, supported by developments in astrophysical theory that had taken place in the interim, and by a renewed interest in See's 1927 article. To understand the later debate it will be helpful to consider briefly See's revised article.

Despite See's claim at the beginning of the article, "Up to the present time the details of my extensive researches on this problem have never been printed...", and that "... an *abstract*, indeed, was printed in Astronomy and Astrophysics, April and May, 1892" (See's emphasis), the 1927 essay is almost identical in content to the 1892 paper. The chief difference between the two lay in the fervour and prolixity of See's rhetoric: by 1927 professional exile and the imbalance of See's psyche seem to have taken their toll. His temper may quickly be plumbed at two points in the essay: in column 247, after a torrent of repetitious eloquence calling for objectivity and modesty before the mystery of 'red' Sirius, See gravely informs us that the laws of probability render a change in Sirius's colour since Antiquity overwhelming; a footnote specifies the odds as 16×10^{24} to 1 in favour. Another footnote at the bottom of columns 251–2 details See's nostalgic story of his visit in the 1890s to Alexandria, where he searched for the site of Ptolemy's and Hipparchus's observatory, and reflected on the sad decline of the city. He quotes in German some romantic sentiments that could be reflections on his own career:

> There she lay before us, the city of the millennia, and looked like a widow in her grief. The centuries that lie upon her, the olive trees weighed down with age, the sepulchres with their white stone, the rocks pierced through by time, the walls in ruins, everything reminds one of the harsh occurrences that this city has suffered.[85]

Perhaps See looked back at his 'red' Sirius work with nostalgia too; it was one of the few products of his scholarship that had not brought a torrent of protest upon him. Sadly, however, even in its revised 1927 form, his article is full of misinformation.

See begins his article by claiming that it is a full presentation of the data, in which the ancient authors have been examined with "the most scrupulous care, and we believe therefore that nothing of importance has been overlooked".[86] But while he shows clear signs of knowing what others had written on 'red' Sirius since 1897 — he mentions Schiaparelli's work explicitly, and strongly protests against the wide-spread view that 'red' Sirius was to be explained through scintillation and absorption — he still maintains that "there is no [ancient] authority who says that [Sirius] was white".[87] It is hard to believe See's good faith here, but easy to understand that he could not admit any counter evidence to 'red' Sirius, if he was to maintain the façade of his work's decisive achievement.

Thus in spite of his own undoubted scouring of the ancient sources as well as the work of Schiaparelli and others, See still says nothing about the evidence of Manilius and Avienus. He continues to misinterpret Geminus (though Schiaparelli had printed a correct translation and Manitius's German version had been available since 1898), as well as Columella and the Roman festival of the Robigalia, and he adds some new errors. In column 260, he mistranslates Seneca, although a correct translation would have helped his case. See translates the first sentence of the passage in which Seneca calls Sirius reddish as "It is not wonderful if Earth of every kind and varied evaporation takes place...". But the Latin actually says: "Nor is it strange if the Earth's exhalation is of every sort and diverse...."[88]

In the end, See conceives of his task as defending the underdog, Ptolemy, whose "divine" achievement in the *Almagest* has been challenged by unfair detractors:

> I have always felt confident that his own record of the color of Sirius and other stars was founded upon the same regard for the truth of the ages. And thus if I have restored the authority of the greatest of the Greek astronomers, as to the aspect of the brightest of the fixed stars, at the most flourishing period of the School of Alexandria, and thus rescued a priceless and everlasting record from threatened oblivion, the object of the historical researches entered upon at Berlin 35 years ago will have been attained.[89]

See's projection of confidence in his argument, his appearance of learning, his maintenance of a solid wall against the evidence for Sirius's ancient whiteness, and lengthy pleas for objectivity probably all had an effect in persuading some (especially future) investigators.

In the 1920s, however, no one in the English-speaking world seems to have bothered with See. But he did provoke the Germans. J. Plassmann, the editor of *Die Himmelswelt*, composed two notes which were portentous for the future of the debate. He noted that while for decades he had sided with the scintillation hypothesis to explain 'red' Sirius, the gravity of See's philological proofs made him waver. If a change from red to white seemed implausible for Sirius itself in what was cosmically so short a period of time, perhaps one should look to Sirius B, the white dwarf companion of the main-sequence primary (Sirius A), which had been discovered in 1862. A nova-like flare-up might somehow be implicated, Plassmann suggested.[90] Both these ideas, that See had sound philological proofs and that one should look to Sirius B for an explanation of the redness, had futures ahead of them half-a-century later, as we shall see.

On the other hand, H. Osthoff was negative. In two polite but firm critiques he examined See's claims. The second and more detailed critique appeared in *Die Himmelswelt*.[91] Osthoff was the first researcher to suggest the need to examine the large body of folklore surrounding Sirius in Antiquity in order to explain the ancient reddish references, but of this he gave only a sketch. Instead, he

reminded his audience of Boll's evaluation of the relevant evidence, and renewed Schiaparelli's criticisms of See's historical method, specifically that See mostly piled up passages calling Sirius "fiery" or "flaming" or "parching".[92] Osthoff then praised See's industry and care in collecting and researching, but pointed out that the passages from Manilius and Avienus calling Sirius "sea-blue" were missing. "From all his sources", Osthoff noted, politely alluding to See's bias, "he draws the conclusion that Sirius was formerly red".[93]

But if Osthoff was critical of See, he was also unsure where the answer was to be found. He criticized the hypothesis of scintillation and absorption — no doubt thinking about Ptolemy — by saying: "But does an experienced observer let himself be deceived by this? At higher altitudes coloured scintillations diminish and the true colour of the star can be easily recognized. Likewise it is questionable whether one may adduce as an explanation the redness of the star at rising and setting which results from the unfavourable air of the lowest strata. Why is this false colour not also cited in the case of all other white stars?"[94] These are important questions which are still in need of an answer today.

E. Dittrich also had something to say in the *Astronomische Nachrichten* about See's work.[95] He praised "meritorious and toilsome collections" like See's, but pointed out that Roman texts also called Sirius "sea-blue". He raised the hypothesis of scintillation and absorption, discussing in that context Mesopotamian traditions preserved in cuneiform texts. These strongly support the hypothesis, although they leave unanswered Osthoff's questions as to why Ptolemy or any experienced observer would characterize Sirius by its atmospherically induced colours. Dittrich quoted parts of Mesopotamian texts, which say such things as: "if Sukudu [=Sirius] is red...", and "in the days of cold, hail, and rain showers, in the days when KAK.SI.DI [=Sirius] shines which is as red as copper...".[96] The latter text (whose final words had been quoted by Kugler in 1907) refers to the acronychal risings of Sirius in December, according to Dittrich. It is from texts such as these, he suggests, that 'red' Sirius originally arose.

On the other hand, A. Stenzel supported 'red' Sirius on the basis of his studies of Egyptian traditions.[97] In Egypt, Sirius represented Soped (or Sothis in Greek) who was holy to Isis, the great goddess of Dendera where she was known as Hathor, the daughter of Nut, the Egyptian sky goddess, and the daughter or wife of Ra, the sun god. Texts from Dendera and elsewhere frequently speak of Isis-Hathor as "golden". She is spoken of as having been born from Nut as a black-red female child.[98] From these traditions Stenzel argued that the Egyptians saw Sirius as a reddish or golden star.

Finally, the evidence so far adduced in the debate was summarized by W. Gundel in a note published in 1927. This has exercised almost no influence over the subsequent debate, despite its enormous utility, because it was printed where astronomers would never find it, in the great encyclopaedia of classical civilization, *Paulys real-Encyclopädie der classischen Altertumswissenschaft*. Gundel also adduced further evidence in support of the scintillation and

absorption hypothesis, but nothing has come of this until recently.[99]

After Gundel, the debate over 'red' Sirius finally died down, after a century of controversy.[100] It was not that the fundamental questions were actually solved; rather, astronomers seem to have lost interest, once they were convinced that Sirius could not really have been reddish 2,000 years ago. Thus the problem of why any ancient texts ever called Sirius reddish still remained. It was widely felt that the answer somehow lay in atmospheric effects, rather than in an intrinsic colour change. But not everyone agreed.

Death and Resurrection (1959–93)

For the thirty-two years following 1927, 'red' Sirius largely vanished from the scene. Its astrophysical utility had been outlived. Indeed, it was now a liability, as the modern theory of stellar evolution took shape.

But gradually a niche opened up around 1960, by which time a new generation of astronomers was active who were unfamiliar with the details of the earlier debate. It was then that a revival of the discussion was initiated by Zdeněk Kopal, the expert on binary stars. The argument has continued until today. Those who have contributed to the recent debate fall into two camps: the main group are ordinary, practising astronomers who have been intrigued by the possibility that astrophysics might be able to explain an historically observed change in the Sirius system. They have almost all been unaware of the conflicts in the ancient evidence and of the arguments evolved by their predecessors over the previous two centuries, and have been content with vague information that "Ptolemy and the Babylonians called Sirius red". They have conceived of their job as not to analyse the validity of the historical information first, but to evolve a physics for it. Researchers of the second (much smaller) group have argued over the historical information, reviving the results of the earlier study and attempting to extend them in a limited way.[101]

Kopal revived the debate in 1959 in his book *Close binary systems*, because he was interested in the problem posed by the evolution of the Sirius binary. The brilliant primary, Sirius A, is a 2.25 solar-mass main-sequence star, while the secondary, Sirius B, is a 1.05 solar-mass white dwarf. The evolutionary problem is to explain how the more massive star can still be on the main-sequence, when the less massive star has already reached white dwarf status. Kopal explained that Sirius B must once have been much more massive than Sirius A, leading to more rapid evolution, and that B must have lost considerable mass at a late stage in its life. In that case, however, B must have been a red giant in the past, its light and colour overpowering those of A, making the system look like a reddish star to the naked-eye on Earth. Kopal then with evident satisfaction resuscitated 'red' Sirius:

> ... in the old days when scholars knew their Latin and Greek better than astronomy, considerable attention was attracted by the fact that the majority

> — if not all — astronomical authorities of the ancient world described Sirius as a 'red' star — a fact quite at variance with its blue-white colour as we know it today. This apparent discrepancy gave rise to a lively discussion reflected in an extensive literature on the subject, in which our intrepid astronomical ancestors eventually routed the philologists by the weight of the argument that so profound a change in the colour of a star in a time-span of some 2000–3000 years was a sheer physical impossibility. In the time which elapsed since this discussion died down, our knowledge of the probable trends of stellar evolution progressed considerably — and, behold, arguments can now be advanced (unknown to our predecessors) which make it at least plausible that, some time in the past, Sirius may indeed have appeared as a red star and very much brighter than now.[102]

The erroneousness of this account is remarkable, but not rare in the 'red' Sirius debate. Ancestral classicist-astronomers are evoked, who turn out to be T. J. J. See, as we gather from a footnote; the "majority — if not all — [ancient] astronomical authorities" called Sirius reddish, as though there was anyone besides Ptolemy who fitted that bill; and the astronomers "routed the philologists" — of course, because only Boll and Gundel had ever been involved in the debate, and their participation was marginal. Kopal does confirm that the debate had indeed died down from 1927 to 1959. But along with that dying down, any real knowledge of the debate's history also expired: past astronomers just did not understand astronomy, Kopal mistakenly supposed, whereas today we are much more expert and we can probably explain 'red' Sirius astrophysically. This was the clarion call for the most recent and ill-conceived phase of the debate.

In 1961, H. M. Johnson took up the call. He was more aware of the debate's history than later researchers, but still analysed the problem astrophysically.[103] He too, like almost all later researchers, concentrated on the evolution of Sirius B. Nothing could be done for Sirius A's colour, so that colour — the original focus of the debate — was now permanently dropped. Johnson confirms Kopal's point that Sirius B must have been a red giant at some time in the past (a point on which all modern astronomers would agree). But, Johnson asked, can Sirius B have evolved from a red giant to a white dwarf on the time-scale demanded by the evidence of Ptolemy and the Islamic astronomers, roughly a thousand years? This was the question he attempted to answer. He considered several possibilities: mass loss through solar wind, nova ejection, or supernova explosion. None of these seemed physically appropriate, either because of time-scales or because there was no evidence of a circumstellar shell of lost mass detectable around Sirius. Nevertheless, he called for further study, to detect nebulosity photographically or to look for its tell-tale absorption lines in Sirius's spectrum. Still, in the absence of evidence for circumstellar gas he concluded that probably "no major loss of mass from Sirius B has occurred since the time when the ancients called Sirius reddish".[104]

Johnson did make one valuable contribution, though. He consulted with several Chinese scholars who found curious astrological omens, such as one from Sima Qian (first century B.C.) in the *Tianguanshu* (*Book of asterisms*) which forms Chapter 27 of *Shiji* (*Historical records*). This states: "When the points ... of Lang [=Sirius] change colour, there will be more robberies and thieves...." Another states: "When the colour is yellow or white and bright, it signifies good fortune; if the points turn red, military disturbances will arise."[105] These sound similar to the omens that Hephaestion of Thebes reported from the Egyptians. Johnson did not know what to make of them, but we can see now that they might be omens derived from the scintillation and absorption of Sirius's light and perhaps should be classed with the evidence for Sirius's ancient whiteness.

After Johnson, D. Lauterborn took up the cause of 'red' Sirius in 1968–69, at two conferences concerned with the study of mass loss in single and binary stars. Lauterborn himself was concerned with the production of white dwarfs containing a large mass in rather widely separated binary systems. Work had been done on binaries whose stars were less massive and either in contact or nearly so, but he was interested in modelling the possible evolution of the Sirius binary. In the course of his work he showed that, given a primary star of 5 solar-masses and a secondary of 2 in a circular orbit of 300 solar radii, mass transfer through the Roche-lobe from the primary to the secondary would occur, once the primary had expanded en route to becoming a giant. By the end of the mass transfer, the primary would be stripped down to a 1 solar-mass white dwarf and the circular orbit would expand to 815 solar-radii. This begins to approach the actual Sirius system, but large and important differences remain.[106]

At the first conference, held in Trieste in September 1968, Lauterborn expressed three important ideas regarding his findings: first, for him See's work had definitely settled the question of Sirius's ancient colour in favour of reddish; second, theoretical arguments made it probable that the contraction phase from a red giant to white dwarf, once it set in, would only require somewhat more than a thousand years to complete (although, he hastened to add, that did not mean that Sirius's ancient redness could definitely be explained in this way); and third, a more probable explanation of 'red' Sirius was that Sirius B experienced a thermal runaway. In this process, after losing almost all of its hydrogen and helium envelope and thereby becoming a white dwarf, Sirius B's residual envelope surrounding its carbon-oxygen core would suddenly ignite and expand enormously for something like a thousand years, thereby mimicking a red giant. At the end of this phase, Sirius B would rapidly return to its normal white dwarf appearance.[107]

At the second conference, held in Elsinore, Denmark, in September 1969, Lauterborn, after noting several difficulties with his work, repeated the idea that rapid evolution from red giant to white dwarf might explain 'red' Sirius. But B. Paczynski, whose interests lay in the evolution of white dwarfs, soon pointed out a fatal flaw in Lauterborn's scenario: even granted that stars quickly cross

the Hertzsprung gap from red giants to white dwarfs, they are extremely hot when they arrive and it would require a million years for a star like Sirius B to cool sufficiently to match its present temperature. "So I cannot think about any possible fit with Ptolemy's observations", Paczynski concluded.[108] His remarks seem to have discouraged Lauterborn decisively, because when the latter published a paper on mass exchange the following spring, he dropped all reference to 'red' Sirius.[109]

If Lauterborn was discouraged, new parties dabbled in the question, made uncertain contributions, and then departed. But a change in the tone of the debate was becoming noticeable. By the mid- to late 1970s, archaeoastronomy was slowly being born and with it a new interest in the cultural phenomena that condition how people approach nature. The positive side of this development has been that Western astronomy has gradually become more open to exploring the mythology and folklore of traditional cultures in their approach to the sky. 'Red' Sirius no longer had to be either a question of historical evidence ("either Sirius was reddish or it was white in Antiquity"), or a number-crunching conundrum for astrophysicists ("we will be able to explain the physics eventually"). It could be a challenge, inviting analysis of a complex non-scientific astronomical tradition. This is what my own previously published work on 'red' Sirius attempts to do.

After Lauterborn, K. D. Rakos caused a stir in 1974 by claiming that, based on his measurements of Sirius B's light curve with a photoelectric photometer, he obtained an absolute visual magnitude and U–V colour index that indicated that Sirius B was the brightest and hottest white dwarf known. He connected this to 'red' Sirius by suggesting that Ptolemy's description and his own measurements suggested Sirius B might be less than 2,000 years old.[110] I. W. Lindenblad, however, an expert on the Sirius system, immediately protested and pointed to inconsistencies in Rakos's data, an error in his computations, and probable instrumental defects, as the causes of Rakos's results. Lindenblad asserted: "The evidence, then, for a possible explanation of ... remarks by Ptolemy and Seneca on the ancient redness of Sirius is weak."[111]

The remainder of the debate up to 1993 may be dealt with rather briefly. On the one hand, a number of popular articles have sought to present the debate to general readers. Since none of these articles breaks new ground and most of them are indebted (often openly) to See for their information, they need not detain us.[112] Another group of articles belongs to debates carried out in the late 1970s and 1980s in the pages of *The observatory*, *Nature*, and elsewhere. These too present nothing of sufficient interest as to need comment.[113]

From a different quarter, in 1981 Fang Li-Zhi presented further evidence from Sima Qian's *Shiji* (*Historical records*).[114] This indicates that white is the colour associated with Sirius, red with Antares, yellow with Betelgeuse, blue with Bellatrix (γ Ori), and black or "dim" with Mirach (β And). These colours are the five canonical colours of Chinese astrology and the five selected stars were made

to conform with the five colours. Nevertheless, the general pattern makes sense with reference to the actual colours of these stars, since at present Sirius and Bellatrix are bluish white in colour, Antares and Betelgeuse are deep orange, and Mirach is the faintest of the five stars. So long as we do not demand scientific precision in colour evaluation from this text, it may be relevant to the 'red' Sirius debate. For surely, if Sirius really had been a reddish star in Antiquity, the Chinese would never have fitted it into this astrological grouping in such a way that it corresponded to the colour "white".

But the best analysis of the Chinese texts that has so far appeared in print was published in English in 1993 by Jiang Xiao-yuan.[115] After extensive study of all relevant sources, Jiang concludes that there are only four useful references to Sirius's colour from ancient China. They all connect Sirius's nature astrologically to the element whose corresponding colour was *white*. Indeed, in the *Jinzhou Zhan* ("Jinzhou book of prognostication") which comes down under the name of Liu Biao, Liu connects Sirius as well as *Vega* to white, thus perhaps suggesting that both stars were alike in colour.[116] Nowadays both stars do indeed share the same colour index (B–V = 0.0).

On the astrophysical front we may note a few final developments. In 1986, F. C. Bruhweiler, Y. Kondo, and E. M. Sion published the most useful note on the astrophysics of 'red' Sirius yet seen.[117] This appeared in *Nature* and it examined the most widespread hypotheses for an intrinsic change: a rapid transition from red giant to white dwarf in the historical period, interstellar dust absorption (the descendent of John Herschel's "cosmical cloudiness"), and a thermonuclear runaway. Their results are largely negative. They point out that a recent transition from red giant status cannot be reconciled with Sirius B's present effective temperature of approximately 27,000°K, which fits an age of about 10,000,000 years. Also, when Sirius B made its transition, it would probably have formed a planetary nebula. But their extensive search for stellar ejecta based on data from the IUE and Copernicus satellites reveals nothing. They conclude: "Based on these results, we find it hard to support the supposition that the Sirius stellar system has recently ejected any type of detectable nebulosity or gaseous shell."[118] Subsequently, in 1987, P. C. Joss, S. Rappaport and W. Lewis published an article in the *Astrophysical journal* in which they discussed observational tests for the proposed relationship between the mass of a giant star's core and its radius.[119] In the course of their article they talk about the Sirius system and argue strongly that Sirius B developed in its final giant phases by means of mass loss through its Roche-lobe. They then reflect on whether this mass transfer could help to explain 'red' Sirius. They suggest that mass loss would have speeded up Sirius B's white dwarf transition at the very end of its red giant years, and it could help partially to explain the lack of a gaseous shell or nebulosity around the system, because Sirius A could have accreted some of the outflow. But the problem of Sirius B's present temperature remains. They conclude that lobe overflow, while it is strongly indicated for some distant era

in the Sirius system, is "probably [an] unsatisfactory explanation for the reported transition [in the colour] of Sirius [during the historical period]".[120]

In their 1986 letter to *Nature*, Bruhweiler, Kondo and Sion next take up interstellar absorption. Concerning the properties of interstellar (or circumstellar) dust, they note "... there cannot be reddening without [absorption]". To redden Sirius by means of such dust even as much as Pollux, the least reddish of Ptolemy's six reddish stars, would require a dimming of 3 magnitudes, making Sirius fainter than at least 20 other stars. But this *directly* contradicts Ptolemy's and other ancient authors's explicit statements that Sirius was the brightest of the stars.[121] All theories of interstellar absorption are fundamentally erroneous for this reason, no matter how well-intentioned. Nevertheless, several parties have continued to look for evidence of interstellar absorption or even a previously unobserved third member of the Sirius system which might have passed close to A and B in Antiquity and thereby drawn off matter from the pair to cause a temporary circumstellar shell of reddening gas.[122]

This leaves the only known astrophysical theory that *might* work: a thermonuclear runaway. Bruhweiler, Kondo, and Sion discuss the theory in large qualitative terms for Sirius B, but to date no one appears to have investigated the details, either of theory or of observation, to determine whether a runaway really could work. So we must conclude that at present there is no known astrophysical theory that demonstrably can explain an anciently reddish Sirius. Of course, by now it should be obvious that we do not want one, because then what would we do with Manilius, Avienus and Hephaestion, not to mention the Chinese sources? It is easy to sympathize with the impatience expressed by P. C. Steffey, when he terms the recent phase of the debate "a *hoax* — as bad as Erich von Däniken's 'ancient astronauts'" (Steffey's emphasis), perpetrated by "careless ... popularizers".[123]

Conclusion

The inadequacy of the debate over 'red' Sirius up to the present is manifest. Much of what has been contributed to it is fundamentally unreliable and so much ill-considered speculation has been put forth that the debate itself has fallen into disrepute. There are legitimate questions to be asked about 'red' Sirius: why, for example, do these ancient references exist when the Sirius binary could not have appeared different in the age of Ptolemy from how it appears today? Is the explanation to be found in the hypothesis of scintillation and absorption? And if so, why did the ancients characteristically observe Sirius on the horizon? Why did they attribute such importance to the redness Sirius shows at rising? And above all, why did Ptolemy — a practised astronomer — choose to characterize Sirius with a spurious colour visible only at rising? The discussion that I have provided will suggest answers to most of these questions. The rest I hope to answer for this journal's audience in a future paper.

REFERENCES

1. The translations of all texts in this paper are my own unless otherwise noted. By "brightest" Ptolemy means "the brightest star in the sky". See G. J. Toomer, *Ptolemy's Almagest* (New York, 1984; hereafter cited as Toomer), 387, 405 and note 88. The Greek text ("ὁ ἐν τῷ στόματι λαμπρότατος καλούμενος Κύων καὶ ὑπόκιρρος") can be found in J. L. Heiberg (ed.), *Claudii Ptolemaei opera quae exstant omnia*, i: *Syntaxis mathematica*, ii (Leipzig, 1903; hereafter cited as Heiberg), 142. For a discussion of Ptolemy's term 'reddish', see below in the text at ref. 39.
2. A full bibliography of red Sirius would contain about one hundred items. Since 1970 alone there have been nearly forty discussions. See refs 112, 113, and 115 for recent bibliographic samples.
3. I have already published work on this solution elsewhere. See Roger Ceragioli, "The riddle of red Sirius", in C. L. N. Ruggles and N. J. Saunders (eds), *Astronomies and cultures* (Niwot, Col., 1993), 67–99.
4. See the remarks of P. Steffey, "Red Sirius silliness", *Sky and telescope*, lxxxiv (1992), 246, quoted below at ref. 123.
5. J. D. Fernie, "Bloody Sirius", *American scientist*, lxxvii (1989), 429–31, p. 430, remarks that astrophysics has "bent over backward to accommodate a historically red Sirius".
6. For al-Farghānī's text and a Latin translation see J. Golius (ed.), *Muhammedis fil. Ketiri Ferganensis, qui vulgo Alfraganus dicitur, elementa astronomica, Arabicè et Latinè* (Amsterdam, 1669), 74.
7. For al-Sūfī's text and a French translation see H. C. F. C. Schjellerup (ed.), *Description des étoiles fixes* (St Petersburg, 1874; reprinted Frankfurt am Main, 1986), 217–22.
8. For Schmidt's career see J. Ashbrook, *The astronomical scrapbook* (Cambridge, Mass., 1984), 251–8. For his colour observations see A. M. Clerke, *The system of the stars* (London and New York, 1890), 147. On the subject of star colours and visually observing them, see P. C. Steffey, "The truth about star colors", *Sky and telescope*, lxxxxiv (1992), 266–73, p. 268; and K. Lundmark, "Luminosities, colours, diameters, densities, masses of the stars", in *Handbuch der Astrophysik*, v/1: *Das Sternsystem* (Berlin, 1932), 363–88, pp. 371–5 and 383–6 for the difficulties involved.
9. For the discussion of Sirius in Antiquity see W. von Dyck and M. Caspar (eds), *Johannes Kepler: Gesammelte Werke*, vii: *Epitome astronomiae Copernicanae* (Munich, 1953), 3.5, pp. 235–41; for the colours see *ibid.*, ii: *Astronomiae pars optica* (Munich, 1939), 6.12, p. 229: "Canis, omnes successive colores iridis [induit].... Canis, cujus est crystallinus color...."
10. "Bonā fide, vidisti umquam Caniculam, Seneca? Ego saepè: et flammam ejus argenteo fulgori, aut adamanti propiorem, quàm pyropo", in J. Lipsius (ed.), *L. Annaei Senecae philosophi operaquae extant omnia*, 3rd edn (Antwerp, 1632), 683–4, note 48.
11. For some recent writers proposing these explanations, see: Patrick Moore, *The new guide to the stars* (New York, 1974), 118; *idem*, *Astronomers' stars* (New York and London, 1989), 57; and Steffey, *op. cit.* (ref. 4).
12. For al-Sūfī's complaint about the deceptiveness of his predecessors, see Schjellerup (ed.), *Description* (ref. 7), 29ff. For his statement of Ptolemy's procedure, see *ibid.*, 42. For Tycho's discussions see J. L. E. Dreyer (ed.), *Tychonis Brahe Dani opera omnia*, ii: *Astronomiae instauratae progymnasmata* (Copenhagen, 1915), 150–1; and iii: *Stellarum octavi orbis inerrantium accurata restitutio* (Copenhagen, 1916), 335–7. Modern discussions of the star catalogue's errors can be found in Toomer, 14–16; and C. H. F. Peters and E. B. Knobel, *Ptolemy's catalogue of stars* (Washington, D.C., 1915), 7–15.
13. For the *Tetrabiblos*'s description of Sirius, see *Tetrabiblos* 1.9.21, in F. Boll and A. Boer (eds), *Claudii Ptolemaei opera quae exstant omnia*, iii/1: *ΑΠΟΤΕΛΕΣΜΑΤΙΚΑ* (Leipzig, 1957), 29, lines12–13.
14. I quote only three sources for Sirius's redness in this paper. Others can be found in Ceragioli, *op. cit.* (ref. 3), 88–94 and footnote 39.

15. T. Barker, "Remarks on the mutations of the stars", *Philosophical transactions of the Royal Society*, li (1760), 498–504.
16. The last two claims are mistaken. On the first claim, see Toomer, 386, note 85.
17. "Τοῖός οἱ καὶ φρουρὸς ἀειρομένωι ὑπὸ νώτωι / φαίνεται ἀμφορτέροισι Κύων ὕπο ποσσὶ βεβηκώς, / ποικίλος", in E. Maas (ed.), *Arati Phaenomena*, 2nd edn (Berlin, 1955), 20. Barker's text errs in leaving out the word "his (οἱ)". All of his quotations are in the original languages without accompanying English translation.
18. "ποικίλος, ἀλλ' οὐ πάντα πεφασμένος· ἀλλὰ κατ' αὐτὴν / γαστέρα κνάυεος περιτέλλεται, ἡ δέ οἱ ἄκρη / ἀστέρι βέβληται δεινῶι γένυς, ὅς ῥα μάλιστα / ὀξέα σειριάει· καί μιν καλέουσ' ἄνθρωποι / Σείριον...", in Maas (ed.), *op. cit.* (ref. 17), 20–21.
19. "Namque pedes subter rutilo cum lumine claret / feruidus ille Canis stellarum luce refulgens", in J. Soubiran (ed.), *Cicéron: Aratea, fragments poétiques* (Paris, 1972), 172.
20. "seu rubra Canicula findit / infantis statuas", in E. C. Wickham and H. W. Garrod (eds), *Q. Horati Flacci opera*, 2nd edn (Oxford, 1901).
21. D. Malin and P. Murdin, *Colours of the stars* (Cambridge, 1984), 88–91, p. 88.
22. "persta et obdura, seu rubra Canicula findet / infantis statuas, seu pingui tentus omaso / Furius hibernas cana nive conspuet Alpis", in Wickham and Garrod (eds), *op. cit.* (ref. 20).
23. "Nec mirum est, si terrae omnis generis et varia evaporatio est, dum in caelo quoque non unus appareat color rerum, sed acrior sit Caniculae rubor, Martis remissior, Iovis nullus in lucem puram nitore perducto", in T. H. Corcoran (ed.), *Seneca: Naturales quaestiones*, i (Cambridge, Mass. and London, 1971), 18–19.
24. "Sed Canis habet ... in capite ... alteram, quam Isis suo nomine statuisse existimatur et Sirion appellasse propter flammae candorem, quod eius modi sit ut praeter ceteras lucere videatur; itaque, quo magis eam cognoscerent, Sirion appellasse", in Gh. Viré (ed.), *Hygini de astronomia* (Stuttgart and Leipsig, 1992), 83–84.
25. J.-J. Lalande, *Astronomie*, 1st edn, i (Paris, 1764), 212, and 3rd edn, i (Paris, 1792), 267; and J.-S. Bailly, *Histoire de l'astronomie moderne*, nouvelle édn, ii (Paris, 1785), 704–11, especially p. 707.
26. For Lalande's explanations see *op. cit.* (ref. 25), 3rd edn, i, 267–8. Bailly had already critiqued these ideas in *op. cit.* (ref. 25), 698–704. For Schubert's remarks see F. T. Schubert, *Populäre Astronomie*, i (St Petersburg, 1804), 273; and iii (St Petersburg, 1810), 132–3.
27. "Welche totale Revolution muß auf dieser Sonne, oder wenigstens in ihrer Atmosphäre vorgegangen seyn! und welche nochweit größre Katastrophe müssen diejenigen Sterne erlitten haben, deren Stelle am Himmel nicht mehr gefunden wird, deren Feuer also erloschen ist, wenn man nicht den Untergang ganzer Sonnensysteme annehmen will", Schubert, *op. cit.* (ref. 26), iii, 132–3.
28. J. F. W. Herschel, "Brief des Baronets", *Astronomische Nachrichten*, xvi (1839), no. 372, cols 187–90, cols 187–8.
29. See F. C. Bruhweiler, Y. Kondo and E. M. Sion, "The historical record for Sirius: Evidence for a white-dwarf thermonuclear runaway?", *Nature*, cccxxiv (1986), 235–7, p. 236; and J. M. Bonnet-Bidaud and C. Gry, "The stellar field in the vicinity of Sirius and the color enigma", *Astronomy and astrophysics*, cclii (1991), 193–7, p. 194.
30. See ref. 1. Others also called it brightest: Hyginus, *De astronomia* 2.35 (see ref. 24); Manilius, *Astronomica* 1.410–11 (see ref. 71).
31. See Bonnet-Bidaud and Gry, *op. cit.* (ref. 29); *idem*, "L'énigme de la couleur de Sirius", *Recherche*, xxiii (1992), no. 239, 105–7, p. 107; and S. B. Mutz and S. Wyckoff, "Preliminary results from a search for a nebula in the vicinity of Sirius" (abstract), *Bulletin of the American Astronomical Society*, xxiv (1992), 1301. In the same articles, Bonnet-Bidaud and Gry also suggest that a putative third member of the Sirius system in a high-eccentricity orbit could occasionally pass close enough to the main pair to draw off an envelope of matter that could act as the absorbing agency.
32. "Tout bien examiné, tout bien pésé, il semble donc que Sirius était jadis rougeâtre, et qu'en moins de 2000 ans il est passé de cette teinte au blanc le moins équivoque", from *Annuaire du Bureau*

des Longitudes, 1842, 353. This was unavailable to me, but G. V. Schiaparelli quotes these words in his article, "Rubra Canicula", *Atti dell'i. R. Accademia di Scienze Lettere ed Arti degli Agiati di Rovereto*, iii/2/2 (1896), 1–37, p. 4; reprinted in his *Scritti sulla storia della astronomia antica*, i/2 (Bologna, 1926), 181–211, p. 183.

33. F. Baily, "The catalogues of Ptolemy, Ulugh Beigh, Tycho Brahé, Halley, Hevelius, deduced from the best authorities", *Memoirs of the Royal Astronomical Society*, xiii (1843), 8.
34. W. H. Smyth, *A cycle of celestial objects*, ii: *The Bedford catalogue* (London, 1844), 160.
35. A. von Humboldt, *Kosmos* (Stuttgart, 1850), iii; English translation, *Cosmos* by E. C. Otté (London, 1851); and French translation, *Cosmos* by H. Faye (Paris, 1851).
36. "Sirius gewährt ... das einzige Beispiel einer historisch erwiesenen Veränderung der Farbe ... sei es in der Photosphäre des Sternes selbst, sei es in wanderden kosmischen Gewölken", von Humboldt, *op. cit.* (ref. 35, 1850), 169–70.
37. See for example Steffey, *op. cit.* (ref. 4).
38. G. Helmreich (ed.), *Galeni in Hippocratis de victu acutorum commentaria quattuor*, in *Corpus medicorum graecorum* (Leipzig and Berlin, 1914), V, ix/1, 218, lines 9–10. See also Galen, *De methodo medendi*, 12.4, in C. G. Kühn (ed.), *Medicorum graecorum opera quae extant* (Leipzig, 1825), x, 834, lines 4–6, where Galen gives "flame-coloured" (πυρρός) or "pale" (ὠχρός) as synonyms for κιρρός.
39. Another misleading suggestion of Humboldt's was that Ptolemy called the majority of stars "yellow". This is based on *Almagest* 8.3 [= Heiberg, 182 and Toomer, 406], where Ptolemy speaks of constructing a celestial globe on which he will mark most of the stars with a ξανθός (blonde/flaxen) colour. This is hardly an appraisal of the actual colours that most stars show. Nevertheless, it was soon taken up into the debate and so represented.
40. For a detailed account see David DeVorkin, "Stellar evolution and the origin of the Hertzsprung-Russell diagram", in O. Gingerich (ed.), *The general history of astronomy*, iv: *Astrophysics and twentieth-century astronomy to 1950*, Part A (Cambridge, 1984), 90–108.
41. DeVorkin, *op. cit.* (ref. 40), 93–94, and Fig. 6.1.
42. For Schjellerup's attacks see his *Description* (ref. 7), 25.
43. Geminus, 3.14, in C. Manitius (ed.), *Geminus: Elementa astronomiae* (Leipzig, 1898), 40.22–42.3. Geminus (probably 1st century B.C.) was a textbook writer on mathematical subjects.
44. For a brief discussion of the Arabic translations and manuscripts see Toomer, 2–4. Kunitzsch speculates that because red Sirius made no sense to the Arabs, they gradually dropped the description from their translations of the *Almagest*. At present the description is found only in a part of the surviving Arabic manuscripts. See P. Kunitzsch, *Der Almagest, die Syntaxis Mathematica des Claudius Ptolemäus in arabisch-lateinischer Überlieferung* (Wiesbaden, 1974; hereafter cited as *Der Almagest*), 230–2 and 320–2.
45. See Ptolemy, *Almagest* 8.1 [= Heiberg, 168–9 and Toomer, 399]. 'Nebulous stars' are close groupings of small stars, some of which may not be resolvable with the naked-eye. The small stars around λ Orionis and Praesepe in Cancer count as "nebulous stars" in the *Almagest*.
46. For descriptions see S. Newcomb, *The stars* (New York and London, 1901), 122; M. E. Martin, *The friendly stars* (New York and London, 1907), 110; and G. P. Serviss, *Astronomy with the naked eye* (New York and London, 1908), 43. For a photograph of the effect see *Sky and telescope*, lxxviii (1989), 154.
47. G. F. Chambers, *A handbook of descriptive and practical astronomy*, 4th edn, iii: *The starry heavens* (Oxford, 1890), 39; and Clerke, *op. cit.* (ref. 8), 146–7.
48. T. J. J. See, "History of the color of Sirius", *Astronomy and astrophysics*, xi (1892), 269–74, 372–86; "Explanation of the mystery of the Egyptian phoenix", *ibid.*, 457–61; "Note on the history of the color of Sirius", *ibid.*, 550–2. This set of articles is hereafter cited as See, "History".
49. On his life and character consult C. J. Peterson, "A very brief biography and popular account of the unparalleled T. J. J. See", *Griffith observer*, liv (1990), no. 7, 2–16.
50. W. L. Webb, *Brief biography and popular account of the unparalleled discoveries of T. J. J. See* (Lynn, Mass. and London, 1913).

51. See, "History", 269.
52. *Ibid.*, 386.
53. *Ibid.*, 552.
54. *Ibid.*, 269.
55. *Ibid.*, 270 in reference to Homer, *Iliad*, Book 22, lines 29–32.
56. For example, See, "History", 271 and 383.
57. Cicero, *Aratea*, Fragment 33, lines 322 and 412.
58. For Aries see Germanicus, 4.78, in D. B. Gain (ed.), *The Aratus ascribed to Germanicus Caesar* (London, 1976), 48. See did not know it, because he used an old edition of Germanicus, but the line referring to Canis Major that he found in his text (line 341 of Buhle's Leipzig, 1801 edition) was not by Germanicus but an interpolation from Avienus (*Phaenomena* 749). In fact, therefore, Germanicus does not refer even to Canis Major as "ruddy". See's "evidence" from Germanicus thus totally evaporates.
59. Avienus, *Phaenomena* 1376 (see ref. 79).
60. Manilius, *Astronomica* 1.409 (see ref. 71).
61. G. V. Schiaparelli, "Rubra Canicula ii", *Atti dell'i. R. Accademia di Scienze Lettere ed Arti degli Agiati di Rovereto*, 3rd ser., iii/1 and 2 (1897), 1–24, pp. 9–11; reprinted in his *Scritti sulla storia della astronomia antica*, i/2 (Bologna, 1926), 212–34, pp. 221–3. This reprint and the reprint of "Rubra Canicula" (ref. 32) will together be referred to as *Scritti*.
62. "ὁ γὰρ ἀστὴρ οὗτος τῆς αὐτῆς οὐσίας κεκοινώνηκε πᾶσι τοῖς ἄστροις· εἴτε γὰρ πύρινά ἐστιν, εἴτε αἰθέρια τὰ ἄστρα, τὴν αὐτὴν δύναμιν ἔχει πάντα· καὶ ὀφείλει κατακρατεῖσθαι ὑπὸ τοῦ πλήθους τῶν ἄστρων ἡ ἀπὸ τοῦ Κυνὸς ἀποφορά." Compare my translation with that of C. Manitius, an expert on ancient Greek astronomy: "Denn dieser Stern ist von demselben Stoff wie alle Sterne. Mögen nämlich die Sterne aus Feuer oder aus Äther bestehen, alle besitzen die nämliche Kraft. Auch müßte von der großen Zahl der Sterne die vom Hundsstern ausgehenden Kraftäußerung aufgehoben werden". Greek text and German translation in Manitius (ed.), *op. cit.* (ref. 43), 192–3, end of each page.
63. W. T. Lynn, "Color of Sirius in ancient times", *Astronomy and astrophysics*, xi (1892), 634–5; "The alleged red colour of Sirius in ancient times", *The observatory*, xv (1892), 264–5; A. M. Clerke, *A popular history of astronomy during the 19th century*, 3rd edn (London, 1893), 453, note 6.
64. Schiaparelli, *opera cit.* (refs 32 and 61).
65. Schiaparelli, "Rubra Canicula", 2–3 [= *Scritti*, 182–3]. H. Samter, who wrote a review article presenting Schiaparelli's results to the German public, focused on contradiction even more sharply. See H. Samter, "War Sirius jemals rot?", *Himmel und Erde*, ix (1897), 543–52, especially p. 544.
66. Ptolemy does not explicitly say this, but at least one other ancient astrologer took it for granted and attributed the doctrine to Ptolemy. See Hephaestion of Thebes, *Apotelesmatica* 1.3.1 in D. Pingree (ed.), *Hephaestio Thebanus: Apotelesmatica*, i (Leipzig, 1973), 32.8–11.
67. Schiaparelli, "Rubra Canicula", 11–2 [= *Scritti*, 190–1] in reference to Ptolemy, *Tetrabiblos* 1.9.21 in Boll and Boer (eds), *op. cit.* (ref. 13), 29.12–13.
68. Schiaparelli, "Rubra Canicula", 13–16 [= *Scritti*, 191–4].
69. *Ibid.*, 17–28 [= *Scritti*, 194–204].
70. *Ibid.*, 28–29 [= *Scritti*, 204–5].
71. "magna fides hoc posse color cursusque micantis / ignis ad os. vix sole minor, nisi quod procul haerens / frigida caeruleo contorquet lumina vultu / cetera vincuntur specie, nec clarius astrum / tingitur oceano caelumque revisit ab undis", in G. P. Goold (ed.), *Manilius: Astronomica* (Cambridge, Mass. and London, 1977), 36–37.
72 "μεγάλου δὲ καὶ λευκοῦ ἀνατείλαντος τοῦ ἄστρου καὶ διαπορευομένου τῷ χρώματι ὡς τὰ κύματα μέγαν τὸν Νεῖλον ἔσεσθαι καὶ εὐφορίαν, πυρροῦ δὲ ὄντος καὶ μιλτώδους πόλεμος ἔσται", in Pingree (ed.), *op. cit.* (ref. 66), 73.4–7.

73. For Schiaparelli on Hyginus see "Rubra Canicula", 29–30 [= *Scritti*, 205–6]; on Manilius see *ibid.*, 31 [= *Scritti*, 206–7]; on Hephaestion see *ibid.*, 32–4 [= *Scritti*, 207–9].
74. Schiaparelli, "Rubra Canicula ii", 6–9 [= *Scritti*, 219–21].
75. See *ibid.*, 9–11 [= *Scritti*, 221–3]. For the quote see p. 10 [= *Scritti*, 222].
76. Simon Newcomb, *The stars* (New York and London, 1901), 121–2; W. T. Lynn, "The colour of Sirius in ancient times", *The observatory*, xxv (1902), 63; *idem*, "The alleged change of colour in Sirius", *The observatory*, xxv (1902), 130–2; A. M. Clerke, *A popular history of astronomy during the 19th century*, 4th edn (London, 1902), 375, note 3; *idem*, *Problems in astrophysics* (London, 1903), 255–6; and *idem*, *The system of the stars*, 2nd edn (London, 1905), 135–6.
77. "Bei diesem hellen Stern sind ... die roten Blitze so deutlich zu sehen, daß möglicherweise die Angabe aus dem Altertum, er sei ein roter Stern, hierdurch erklärt werden kann", in J. Plassmann, *Die Fixsterne* (Kempten and Munich, 1906), 115, note *.
78. F. Boll, "Fixsterne", *Paulys real-Encyclopädie der classischen Altertumswissenschaft* (Stuttgart, 1909), xii, 2416.
79. "Sed primaeva Meton exordia sumpsit ab anno / torreret ruti locum Phoebus sidere Cancrum, / cingula cum veheret pelagus procul Orionis / et cum caeruleo flagraret Sirius astro", in J. Soubiran (ed.), *Aviénus: Les Phénomènes d'Aratos* (Paris, 1981), 151.
80. W. Gundel, *De stellarum appellatione et religione Romana* [= Religionsgeschichtliche Versuche und Vorarbeiten, iii/2; Giessen, 1907), 34.
81. "Etenim Ceos accepimus ortum Caniculae diligenter quotannis solere servare coniecturamque capere, ut scribit Ponticus Heraclides, salubrisne an pestilens annus futurus sit. Nam si obscurior et quasi caliginosa stella extiterit pingue et concretum esse caelum ut eius adspiratio gravis et pestilens futura sit; sin inlustris et perlucida stella apparuerit significari caelum esse tenue purumque et propterea salubre", in A. S. Pease (ed.), *M. Tulli Ciceronis de divinatione* (Urbana, Ill., 1921; repr. New York, 1979), 327–8.
82. F. X. Kugler, *Sternkunde und Sterndienst in Babel*, i: *Babylonische Planetenkunde* (Münster, 1907), 242 (the star mentioned as "glowing like copper", KAK.SI.DI, is now understood to be Sirius); A. S. Eddington, "Star", *Encyclopaedia Britannica*, 11th edn (1911), xxv, 784–93, p. 788, middle of left col.
83. F. Boll, "Astronomische Beobachtungen im Altertum", *Neue Jahrbücher für das klassische Altertum*, xxxix (1917), i, 25–27.
84. H. Osthoff, "Die Farbenangaben in den altbabylonischen Sternverzeichnissen und die Farbe des Sirius", *Die Himmelswelt*, xxx (1920) (this was unavailable to me); P. Sarasin, "Ueber die Farbenveränderung des Sirius in historischer Zeit", *Verhandlungen der naturforschenden Gesellschaft in Basel*, xxxv (1923–24), ii, 58–59; Schiaparelli, *Scritti*; and T. J. J. See, "Historical researches indicating achange in the color of Sirius, between the epochs of Ptolemy, 138, and of Al Sūfi, 980, A.D." (hereafter cited as See, "Historical researches"), *Astronomische Nachrichten*, ccxxix (1926–27), Sondernummer, cols 245–72.
85. "Da liegt sie vor uns, die Stadt der Jahrtausende, und erschien wie eine Witwe in ihrer Trauer. Die Jahrhunderte, welche auf ihr liegen, die vor Alter sinkenden Ölbäume, die Grabmäler mit den weißen Steinen, die von der Zeit durchlöcherten Felsen, das zerstreute Gemäuer, alles erinnert an die schweren Begegnisse, die diese Stadt erlitten hat", in See, "Historical researches", 251–2.
86. See, "Historical researches", 245 and 272.
87. *Ibid.*, 245, 272 and 268.
88. For full text see ref. 23.
89. See, "Historical researches", 272.
90. J. Plassmann, "Die Farbe des Sirius", *Die Himmelswelt*, xxxvii (1927), 137, and "Die Farbe des Hundssternsim Altertum, Nachschrift des Herausgebers", *ibid.*, 163–5.
91. H. Osthoff, "Zur Farbe des Sirius im Altertum", *Astronomische Nachrichten*, ccxxix (1926–27), cols 443–4, and "Die Farbe des Hundssterns im Altertum", *Die Himmelswelt*, xxxvii (1927), 158–63.

92. Concerning Boll, see Osthoff, "Die Farbe", 161–3; concerning the piling up of passages, see *ibid.*, 160–1.
93. *Ibid.*, 162.
94. "Ob sich dadurch aber ein erfahrener Beobachter täuschen läßt? In größeren Höhen nehmen die farbigen Strahlenblitze ab und lassen die wahre Farbe des Sternes leicht erkennen. Ebenso fraglich ist es, ob man die Röte des Sternes beim Auf- und Untergange in folge der ungünstigen Luft der untersten Schichten zur Erklärung heranziehen darf. Warum ist diese falsche Farbe nicht auch bei allen andern weißen Sternen angeführt?", *ibid.*, 163.
95. A. Dittrich, "Woher das Epitheton 'rot' für Sirius stammt", *Astronomische Nachrichten*, ccxxxi (1927–28), cols 385–6.
96. *Ibid.*, cols 385–6: "wenn der Sukudu rot ist"; "in den Tagen der Kälte, des Hagels und der Regenschauer, in den Tagen, wo KAK.SI.DI aufleuchtet, welcher rot wie Kupfer ist...." A. K. Grayson, *Assyrian royal inscriptions*, ii (Wiesbaden, 1976), 55 includes a full translation of this text. It forms part of an annalistic account apparently of the reign of the Assyrian King Ashur-bel-kala, who ruled from 1073 to 1056 B.C. The quoted lines come for a description of the king's hunting exploits. Grayson translates as follow: "At the time of cold, frost, (and) ice, at the time of the ascension of Sirius when it is red like molten copper, he [arranged] (and) formed herds of ... gazelles, etc."
97. A. Stentzel, "Ägyptische Zeugnisse für die Farbe des Sirius im Altertum", *Astronomische Nachrichten*, ccxxxi (1927–8), cols 387–92.
98. *Ibid.*, col. 390.
99. W. Gundel, "Sirius", in *Paulys real-Encyclopädie der classischen Altertumswissenschaft*, ii/5 (Stuttgart, 1927), 314–51, pp. 325–7. For the new evidence see *ibid.*, 326.45–58 and Ceragioli, *op. cit.* (ref. 3), 88–94 and footnote 39.
100. Three late comers to the debate add nothing of importance: J. Bosler, *Cours d'astronomie*, iii (Paris, 1928), 13, note 3; Lundmark, *op. cit.* (ref. 8), 386–8; and A. Pannekoek, *A history of astronomy* (London, 1961), 157, translated from the Dutch original: *De Groei van ons Wereldbeeld* (Amsterdam, 1951), 127. Pannekoek, although having published at the dawn of the recent phase of the debate, belongs in spirit to the older phase.
101. The principal and almost sole investigator to revive and extend has been R. H. van Gent. For his bibliography see ref. 113.
102. Z. Kopal, *Close binary systems* (London, 1959), 542–3.
103. H. M. Johnson, "Stellar evolution and the color of Sirius", *Astronomical Society of the Pacific leaflets*, viii (1962), no. 383.
104. *Ibid.*, 8.
105. *Ibid.*, 6–7.
106. D. Lauterborn, "White-dwarf production in binary systems of large separation", in M. Hack (ed.), *Mass loss from stars* (New York, 1969), 262–6; and the discussion of D. Lauterborn and B. Paczynski, reported in K. Gyldenkerne and R. M. West (eds), *Mass loss and evolution in close binaries* (Copenhagen, 1970), 191–3.
107. Lauterborn, *op. cit.* (ref. 106), 266.
108. Lauterborn and Paczynski, *op. cit.* (ref. 106), 192–3.
109. D. Lauterborn, "Evolution with mass exchange of case C for a binary system of total mass 7M$\odot$", *Astronomy and astrophysics*, vii (1970), 150–9.
110. K. D. Rakos, "Photoelectric measurements of Sirius B in UBV and Strömgren system", *Astronomy and astrophysics*, xxxiv (1974), 157–8.
111. I. W. Lindenblad, "On K. D. Rakos' photoelectric measurements of Sirius B", *Astronomy and astrophysics*, xli (1975), 111–12.
112. The most important of this bibliography is as follows: S. P. Maran, "Red, white, and mysterious", *Natural history*, lxxxiv (1975), no. 7, 82–87; R. Burnham, *Burnham's celestial handbook*, i (New York, 1978): Andromeda-Cetus, 392–4; K. Brecher, "Sirius enigmas", *Technology review*, lxxx (1977), no. 2, 52–63, pp. 54–57, reprinted in K. Brecher and M. Feirtag (eds), *Astronomy*

of the ancients (Cambridge, Mass. and London, 1979), 91–115, pp. 95–102; D. Malin and P. Murdin, *Colours of the stars* (Cambridge, 1984), 88–91; Fernie, "Bloody Sirius", *op. cit.* (ref. 5); and Moore, *op. cit.* (ref. 11, 1989), 53–57.

113. Here the most important bibliography is: F. D'Antona and I. Mazzitelli, "Constraints on the corona model for Sirius B", *Nature*, cclxxv (1978), 726–7; R. H. van Gent, "Red Sirius", *Nature*, cccxii (1984), 302; W. Schlosser and W. Bergmann, "An early-medieval account on the red colour of Sirius and its astrophysical implications", *Nature*, cccxviii (1985), 45–46; T. B. Tang, "Star colours", *Nature*, cccxix (1986), 532; J. Manfroid and A. Heck, "A propos de la couleur de Sirius", *Ciel et Terre*, cii (1986), no. 6, 151–2; S. C. McCluskey, "The colour of Sirius in the sixth century", *Nature*, cccxxv (1987), 87; R. H. van Gent, "The colour of Sirius in the sixth century", *ibid.*, 87–88; W. Schlosser and W. Bergmann, "The colour of Sirius in the sixth century", *ibid.*, 89; B. Warner and C. Sneden, "HD 38451: J. R. Hind's star that changed colour", *Monthly notices of the Royal Astronomical Society*, ccxxxiv (1988), 269–79; R. H. van Gent,"The colour of Sirius", *The observatory*, cix (1989), 23–24; P. Bicknell, "Sirius and Manilius", *ibid.*, 58–59.
114. Fang Li-Zhi, "A brief on astrophysics in China today", *Chinese astronomy and astrophysics*, v (1981), 1–10, p. 4.
115. Jiang Xiao-yuan, "The colour of Sirius as recorded in ancient Chinese texts", *ibid.*, xvii (1993), 223–8. J.-M. Bonnet-Bidaud and C. Gry in three articles, "Sirius and the colour enigma", *Nature*, cccxlvii (1990), 625; "The stellar field in the vicinity of Sirius and the color enigma", *Astronomy and astrophysics*, cclii (1991), 193–7; and "L'énigme de la couleur de Sirius", *Recherche*, xxiii (1992), no. 239, 105–7, have also attempted to analyse Sima Qian, but not convincingly. Jiang says of their work: "This is a complete misunderstanding of the real meaning of the text", Jiang Xiao-yuan, *op. cit.* (ref. 115), 228, note 6. T. B. Tang, "Did Sirius change colour?", *Nature*, ccclii (1991), 25 also takes strong exception to their analysis.
116. Jiang Xiao-yuan, *op. cit.* (ref. 115), 226–7.
117. Bruhweiler *et al.*, *op. cit.* (ref. 29).
118. *Ibid.*, 235.
119. P. C. Joss, S. Rappaport and W. Lewis, "The core mass-radius relation for giants: A new test of stellar evolution theory", *Astrophysical journal*, cccxix (1987), 180–7.
120. *Ibid.*, 185–6.
121. See refs 1, 24 and 71 above.
122. Bonnet-Bidaud and Gry, *op. cit.* (ref. 115, 1991), 194–6, and *op. cit.* (ref. 115, 1992), 107; and Mutz and Wyckoff, *op. cit.* (ref. 31).
123. Steffey, *op. cit.* (ref. 4).