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The stellar field in the vicinity of Sirius and the color enigma *

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Abstract. Several ancient texts have suggested that the bright star Sirius may have been red in the recent past. We present here new evidence from an observation record found in Chinese sources (~100 BC) in which mention is made of a colour change of Sirius. In this paper, we also report on photometric observations of the stellar field around Sirius with the aim to find the possible causes of the colour change(s) of the stellar system within historical times. We proposed as possible causes, objects external to Sirius A–B, namely a small interstellar cloud or a third body interacting with the system. We show that both could have caused an observed reddening effect consistent with the historical record, and we find that two stars in the field may have the right characteristics and orbits to interact with Sirius.

Key words: Sirius – interstellar medium – stars: colours of – triple stars

For more than hundred years and again in the recent years a dispute has been going on, as to whether or not Sirius, now recognized to be a binary system containing a white dwarf, has been red sometime in the relatively recent past. Several authors (see Brecher 1979; Schlosser & Bergmann 1985) maintain that a good number of ancient texts of Babylonian, Graeco-Roman, or medieval authors contain the evidence that Sirius was a red star; while others (Tang 1986; van Gent 1984; McCluskey 1987) argue that in most sources, the "evidence" originates from mistranslations or misidentification of the star. Probably one of the most reliable references is that of Ptolemy (150 AD), who classified Sirius as "hipokkiros" (reddish) among stars like Arcturus, Aldebaran, Pollux, Antares and Betelgeuse which all have $(B-V)$s higher than 1 (for the discussion of the Greek and Latin texts, see T. See 1926).

Among the different hypotheses put forward lately to explain a red Sirius some 2000 yr ago, most rely on recent evolution of the white dwarf itself (Schlosser & Bergmann 1985; Bruhweiler et al. 1986) or of the binary system (Joss et al. 1987). They face the problem of an unrealistic short timescale for stellar evolution. Joss et al. (1987) showed that Sirius was probably an interactive system at some time in the past and suggested that the giant-white dwarf transition might have been significantly shortened if triggered by Roche-lobe overflow.

Others authors (d'Antona & Mazzitelli 1978; and later Bruhweiler Kondo & Sion 1986) suggested that Sirius B, a white dwarf for already several millions of years, went through a short pseudo-red-giant phase due to instabilities connected with H-burning in thin shells still occurring in hot atmospheres of hydrogen white dwarfs. There is no evidence nowadays of an ejected envelope. We performed very sensitive observations of interstellar Na I from the ESO CAT at La Silla, showing no detectable absorption by matter in front of Sirius. Our result is consistent with the limit for interstellar absorption derived by Bruhweiler et al. (1986) from IUE observations of ultraviolet absorption lines.

To explain the colour change, we decided to explore completely different possibilities which involve the action of a distinct object, external to the binary system Sirius A–B. For this purpose, we have undertaken the photometric study of the stellar field around Sirius, a stellar field which is generally inaccessible by standard techniques because of the brightness of the primary component and which has been overlooked up to now. We show that either the occurrence of a small interstellar cloud crossing our line of sight to Sirius (see also Gry & Bonnet-Bidaud 1990), or of a third component in the system, interacting for a short time with Sirius A, is compatible with observations and could produce the hypothetically observed colour change(s) of Sirius.

2. The Chinese evidence

It is not our purpose here to discuss the interpretation of ancient texts. However the case is intriguing, and we think it is important not to loose the opportunity of learning something from the historical observations, which might shed light not only on the nature of Sirius, but also possibly on the evolution of stars, or on our close neighbourhood.

First we note that several chinese records, such as those from Sima Qian's "Historical records" (Shiji) (van Gent 1984; Tang 1986) or from Ma Xu & Lisheng (van Gent 1984), all referring to Sirius as a white star, have been quoted recently in the literature to challenge the reality of the colour change. Surprisingly, one very important piece of information has been ignored so far in the same Han dynasty history book (Shiji) of the historian and astronomer Sima Qian (145 B.C.–87 B.C.). We recall that Sima Qian is famous for having collected all historical and scientific materials available at his time after the burning of the books ordered by the emperor

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* Based on observations collected at the ESO La Silla Observatory.

Qin Shihuangdi in 213 B.C.; therefore making it possible to trace chinese history and science back to a much earlier date.

The information is contained in the "Book of Heavenly Bodies" (Tian guan shu, Chap. 27 of Shiji) and was discovered during the stay of one of us in China. The record is shown and translated in Fig. 1. According to the use at that time, the astronomical observation is followed by astrological predictions. The astronomical content of Shiji is generally not questionned and has proved to be highly reliable in the cases (comets or planets motions) when direct confirmation can be performed. Since the work of Sima Qian is a compilation of ancient sources, no definitive date can be ascertained to the record, but it shows that (a) colour change(s) of Sirius may have been noticed by the chinese astronomers earlier than 2000 yr ago. The term "horn" (jiao) also suggests some asymetry in the aspect of Sirius at that time.

3. Hypothesis of a small interstellar globule

We suggest that the transient red colour of Sirius could have an interstellar origin. The hypothesis of interstellar extinction has been addressed before (see Bruhweiler et al. 1986).

We discuss here the so-called small globules, discovered by Bok in the 1940's, that are the smallest units of dark nebulae that have been observed. Their sizes lie between 0.01 and 0.1 pc and their masses between 0.1 and 1.0 $M_\odot$ (Bok et al. 1971). For obvious observational reasons, they are usually seen as dark regions in front of bright emission nebulae, but their physical association with the nebulae is still open to question. About 200 globules are known within 150 pc from the Sun (Bok & Cordwell 1973), therefore the presence of a small globule in front of Sirius should have a non-negligible probability. In a previous paper (Gry & Bonnet-Bidaud 1990), we calculate that an interstellar globule of 0.01 $M_\odot$ in mass and 0.02 pc in diameter, would induce the required reddening of $E(B-V)=1$ during the period of time when Sirius transits behind the cloud. The column density of such a cloud would be $N(\mathrm{H}) \sim 5.4\ 10^{21}$ at cm^{-2}. With its actual proper motion (1.3 arcsec yr^{-1}), it would take Sirius about 1000 yr to cover the extent of such a motionless globule. The extinction produced together with the reddening would have given Sirius a magnitude of 1.5, and would not have removed it from the first magnitude family of stars.

This hypothesis is thus compatible with observational reports. We also point out that in this case, the colour changes to red and back to white would have occurred progressively and this could explain why they were never reported as special events in the antiquity.

4. An interacting third companion?

Alternatively, we consider also the possibility that the colour change of Sirius might result from the interaction of a third companion within the Sirius A–B binary. The occurrence of multiple systems in the solar neighbourhood is very high (Allen 1973), the closest triple star α-Centauri being one of the best examples, and hierarchical triples have also been considered recently in the Galaxy, to explain for instance the long periodicities of several X-ray binaries such as GX 17+2 (Bailyn & Grindlay 1987) or Cyg X-3 (Molnar 1986; see also Bonnet-Bidaud & Chardin 1989).

A triple Sirius has been sometimes invoked in the past by making reference to a suspected very close-by companion on which all observations, based on pure visual inspections, are either discordant or dubious (see e.g. Gatewood & Gatewood 1978) and are therefore irrelevant here.

If Sirius is a typical hierachical system in which a low-mass star is in a wide eccentric orbit around the inner A–B binary, the periodical irruption of this low mass (and therefore yet undetected) companion inside the inner binary could cause enough matter to be expelled to produce the observed reddening. To test this hypothesis, we undertook optical observations to search for this companion.

4.1. The observations

We performed optical photometric observations with the 1.5 m Danish telescope at the European Southern Observatory (ESO La Silla, Chile). A series of (2'.5 × 4') images centered on Sirius were obtained with a CCD camera attached to the Cassegrain focus of the telescope through *UBVI* Johnson and Gz Gunn filters. To reduce the contribution of direct and diffuse light from Sirius itself ($m_v = -1.5$), a small plastic cone was stuck onto the entrance window of the CCD camera. Its circular projected size was recomputed from the image to be ≈25″.

A plywood mask with eight circular apertures was set-up at the entrance of the telescope to suppress the strong spikes pattern resulting from the light diffusion onto the secondary mirror supports. The diffuse light aureole from Sirius was later removed from the images by a two-dimensional median filter.

Figure 2 shows the resulting image for the Gunn Gz filter. It reveals a number of stars usually lost in the bright glare of Sirius using standard photographic techniques and which were not previously measured. The central mask dimension (≈25″) prevents measuring the white dwarf companion, Sirius B. The remaining spikes could not be removed as they have the same spatial frequencies as the stellar objects.

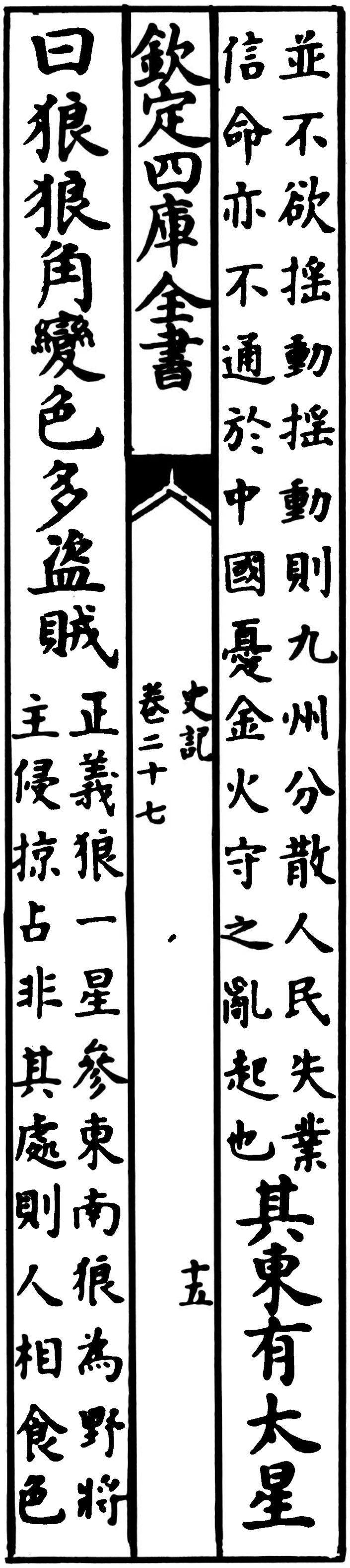
The coordinates of each bright star inside the frame were determined by Gaussian-fits to a precision better than 0″.7, and their positions relative to Sirius were computed. The photometric calibration makes use of 4 standard stars. Because of the process of removing the Sirius diffuse light, the precision obtained on the derived magnitudes and colours are not better than about ±0.3 mag. The final results for the 9 brightest stars in the CCD field are summarized in Table 1. The last column gives the absolute magnitude of the star derived on the assumption that the star lies at the distance of Sirius (2.7 pc).

4.2. Possible third body and its orbit

We note that no star brighter than an apparent magnitude of $m_v > 14$ (absolute magnitude $M_v > 17$ if at Sirius distance) is seen.

This excludes the possibility of a companion more massive than 0.1 $M_\odot$ and indicates that a Sirius companion, if any, would have to be close to the lower mass limit (≈0.08 $M_\odot$) at which stellar configurations are able to sustain thermonuclear reactions.

Unfortunately, these objects on either sides of the mass limit are not well known and their identification is therefore uncertain (see Kafatos et al. 1986). They are however very red, thus among the nine brightest objects in our sample the best candidates to belong to the Sirius system are the 2 stars which appear to be redder than M8 type stars, namely star 4, with M_v around 20, $B-V=3.0$ and $V-I=2.8$, and marginally star 3, with $M_v=19.2$, $B-V=2.0$ and $V-I=2.5$. Their distances from Sirius are 76″ for star 4 and 60″ for star 3, which implies, since the system is 2.7 pc away, projected distances of respectively 205 and 165 AU.


並不欲搖動搖動則九州分散人民失業
信命亦不通於中國憂金火守之亂起也其東有太星
欽定四庫全書 史記 卷二十七 五
曰狼狼角變色多盜賊正義狼一星參東南狼為野將
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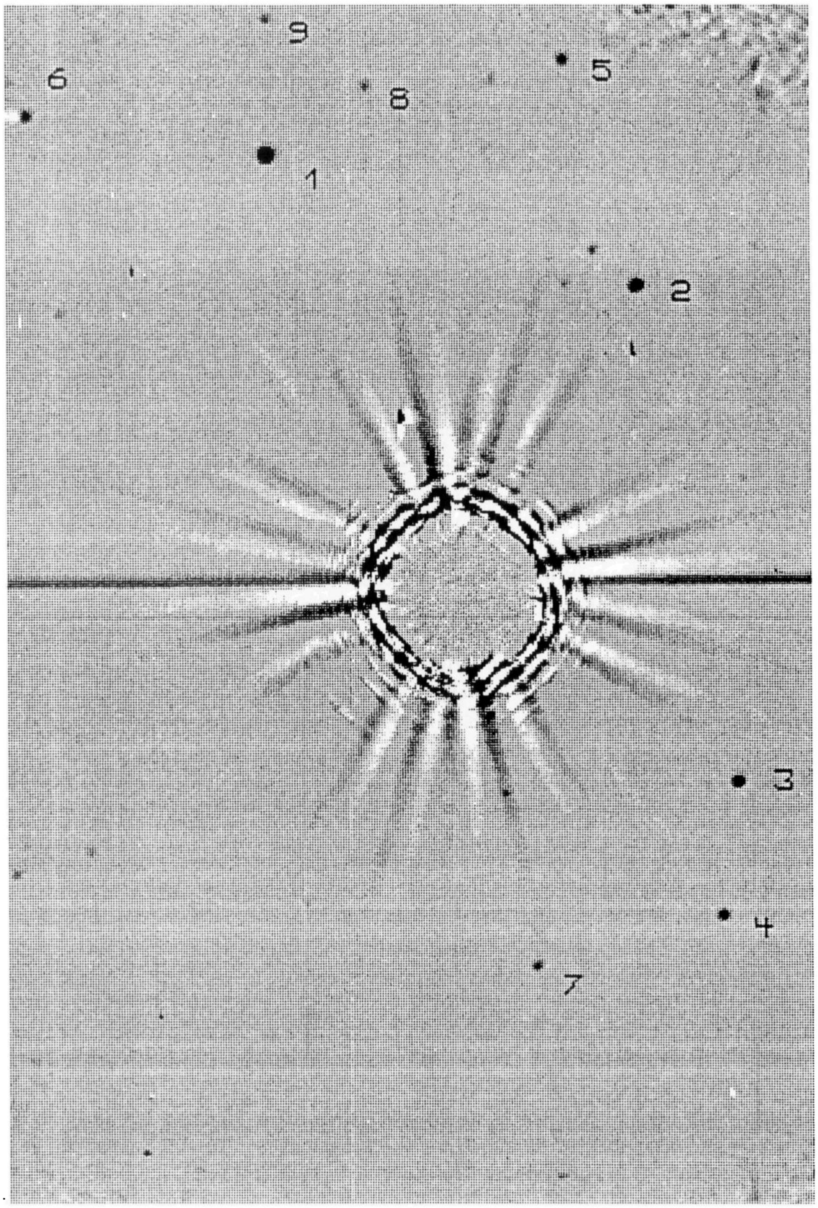

Fig. 2. (*above*) The (2.′5 × 4′) star field around Sirius (north is to the top, east is to the right). Contamination light from Sirius has been removed. Regular radial patterns are residual diffusion spikes. Sirius is at center of the central circular mask. The 9 brightest stars in the field are numbered. Their positions relative to Sirius A and characteristics are given in Table 1

Fig. 1. (*left*) The chinese record taken from the Han dynasty (∼100 BC) history book called "Shiji" (Historical Records) compiled by Sima Qian. The text is from the Chap. 27, "Tian guan shu" (Book of Heavenly Bodies). The paragraph concerning Sirius is in large heavy characters in the right and left columns and should be read from top to bottom and right to left. It translates literally as:
"*At East/ there is/ bis/ star/ called/ Wolf/*
/ Wolf/ horn/ changes/ colour/ , /many/ thieves/ robbers/"
Wolf is the chinese name for Sirius. The term "horn" (jiao) suggests some asymmetry in the aspect of Sirius at that time. This document is extracted from the Qing-ding-si-ku-quan-shu (ed. Zhong Hua Shu Ju 1959/9)

Table 1. Relative positions and magnitudes of the brightest stars in a small field around Sirius. Positions are given in arcsec relative to Sirius A. Uncertainities are ±0″.7 on positions and ±0.3 mag on magnitudes (see text)

Star	RA (″)	Dec (″)	$V(B-V)$	$B-V$	$V-I$	$V(V-I)$	M_v (at 2.7 pc)
1	−35.41	79.82	14.2	1.3	2.0	14.2	17.1
2	32.33	55.65	14.5	0.9	1.5	14.6	17.4
3	50.45	−35.71	16.4	2.0	2.5	16.4	19.2
4	47.67	−60.33	17.2	3.0	2.8	17.2	20.1
5	18.91	97.10	16.6	0.3	2.1	16.6	19.4
6	−78.93	86.78	16.8	1.1	2.3	16.9	19.7
7	13.64	−69.91	–	–	2.3	17.6	20.4
8	−17.23	92.02	–	–	2.2	17.9	20.7
9	−35.47	104.55	–	–	2.0	17.8	20.6

For interaction to occur, two conditions are required on the orbital elements of the third companion: a period P_3 longer than ≈ 2000 yr (the last interaction) and an approach distance (d) to the inner A–B binary of the same order than the average Sirius A–B separation i.e. 20 AU. The first condition yields a semi-major axis $(a_3/\mathrm{AU}) \geqq [(M_t+m)/M_\odot]^{1/3}\,[P_3/\mathrm{yr}]^{2/3} \geqq 230$ AU, where M_t and m are respectively the mass of the inner binary and of the companion; while the second imposes an eccentricity ($e_3 \geqq 0.9$) such that $d \approx a_3(1-e) \leqq 20$.

These orbital elements are consistent with the position of either of the two above very red objects at proximity of Sirius. With a period ratio $(P_3/P_2) \geqq 40$ (P_2 being the inner binary period), such hierachical triple will be stable in most cases (Soderhjelm 1982; Bailyn & Eggleton 1983).

The typical interaction time will be $\tau \approx (1-e_3^2)^{1/2} \cdot (1-e_3) P_3 \geqq 90$ yr, but the reddening effect may in fact be much longer than this interaction time.

The effect of the third companion passage inside the inner binary will likely be the stripping of matter from the larger cross-section star, Sirius A.

The total ejection needed to explain the historical records is $M = f\,N_h\,L^2$ where L is the characteristic length of the ejected cloud, N_h the required column density ($5.4\;10^{21}$ at cm^{-2}) deduced from the observed reddening (see Sect. 3) and f a factor depending on the geometry of the cloud ($f = 4\pi/3$ for a spherical cloud but as low as $f \leqq 0.4$ if highly asymmetric).

For a cloud size of the order of the inner binary orbit (≈ 20 AU), the amount of ejected matter will be $\leqq (1.4–15)\;10^{-7}\,M_\odot$, small compared to the mass of Sirius. We saw that the Chinese record could be interpreted as suggesting an asymmetric ejection. In this case, a $0.08\,M_\odot$ companion will have to dissipate less than 0.2% of its kinetic energy at periastron to strip off the required matter from Sirius A. The third object will only introduce small effects on the inner binary orbital parameters which are still poorly known after only two orbits since the discovery. For instance it will introduce an apsidal motion (see Guinan & Maloney 1985) $\dot{w} = 1.4\;10^{-3}$ deg yr^{-1} small compared to the present accuracy on $w = 147.27 \pm 0.54$ deg (Gatewood & Gatewood 1978).

A hierachical triple Sirius may therefore reproduce the temporary reddening reported by some historical sources. It is worth investigating in greater detail the nature of the two very red faint stars seen in the proximity of the Sirius A–B binary. Determination of their radial velocity may help to determine if they are physically associated with the central pair ($V_r = -7$ km s^{-1}) but composition of their own orbital velocity in an orbit of unknown inclination may prevent from doing so. Apart from obtaining their detailed spectra to derive their spectral class and distance, the best chance is of course to measure in the future either a parallax and/or a large proper motion.

5. Conclusion

Although we do not claim to have found the right explanation, we have shown that it is possible to find external causes to the transient red colour of the system Sirius A–B. These causes invoke either the presence of a small isolated Bok globule crossing in front of the system, or the existence of a third body in the system, which in the circumstances would be at least close to the stellar mass limit, corresponding to the brown dwarfs.

Both objects being invoked here are supposed to exist in the neighbourhood of the Sun, although they have not yet been observed.

Hence, the search for them as a possible explanation for the red colour of Sirius, would also be a good opportunity to try to observe these objects in the solar neighbourhood.

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