

Sirius Matters

Astrophysics and Space Science Library

EDITORIAL BOARD

Chairman

W. B. BURTON, *National Radio Astronomy Observatory, Charlottesville, Virginia, U.S.A.* (bburton@nrao.edu); *University of Leiden, The Netherlands* (burton@strw.leidenuniv.nl)

F. BERTOLA, *University of Padua, Italy*

J. P. CASSINELLI, *University of Wisconsin, Madison, U.S.A.*

C. J. CESARSKY, *European Southern Observatory, Garching bei München, Germany*

P. EHRENFREUND, *Leiden University, The Netherlands*

O. ENGVOLD, *University of Oslo, Norway*

A. HECK, *Strasbourg Astronomical Observatory, France*

E. P. J. VAN DEN HEUVEL, *University of Amsterdam, The Netherlands*

V. M. KASPI, *McGill University, Montreal, Canada*

J. M. E. KUIJPERS, *University of Nijmegen, The Netherlands*

H. VAN DER LAAN, *University of Utrecht, The Netherlands*

P. G. MURDIN, *Institute of Astronomy, Cambridge, UK*

F. PACINI, *Istituto Astronomia Arcetri, Firenze, Italy*

V. RADHAKRISHNAN, *Raman Research Institute, Bangalore, India*

B. V. SOMOV, *Astronomical Institute, Moscow State University, Russia*

R. A. SUNYAEV, *Space Research Institute, Moscow, Russia*

Recently Published in the ASSL series

- Volume 354: *Sirius Matters*, by Noah Brosch. 978-1-4020-8318-1, March 2008
- Volume 353: *Hydromagnetic Waves in the Magnetosphere and the Ionosphere*, by Leonid S. Alperovich, Evgeny N. Fedorov. Hardbound 978-1-4020-6636-8
- Volume 352: *Short-Period Binary Stars: Observations, Analyses, and Results*, edited by Eugene F. Milone, Denis A. Leahy, David W. Hobill. Hardbound ISBN: 978-1-4020-6543-9, September 2007
- Volume 351: *High Time Resolution Astrophysics*, edited by Don Phelan, Oliver Ryan, Andrew Shearer. Hardbound ISBN: 978-1-4020-6517-0, September 2007
- Volume 350: *Hipparcos, the New Reduction of the Raw Data*, by Floor van Leeuwen. Hardbound ISBN: 978-1-4020-6341-1, August 2007
- Volume 349: *Lasers, Clocks and Drag-Free Control: Exploration of Relativistic Gravity in Space*, edited by Hansjörg Dittus, Claus Lämmerzahl, Salva Turyshev. Hardbound ISBN: 978-3-540-34376-9, September 2007
- Volume 348: *The Paraboloidal Reflector Antenna in Radio Astronomy and Communication – Theory and Practice*, by Jacob W.M. Baars. Hardbound 978-0-387-69733-8, July 2007
- Volume 347: *The Sun and Space Weather*, by Arnold Hanslmeier. Hardbound 978-1-4020-5603-1, June 2007
- Volume 346: *Exploring the Secrets of the Aurora*, by Syun-Ichi Akasofu. Hardbound 978-0-387-45094-0, July 2007
- Volume 345: *Canonical Perturbation Theories – Degenerate Systems and Resonance*, by Sylvio Ferraz-Mello. Hardbound 978-0-387-38900-4, January 2007
- Volume 344: *Space Weather: Research Toward Applications in Europe*, edited by Jean Liliensten. Hardbound 1-4020-5445-9, January 2007
- Volume 343: *Organizations and Strategies in Astronomy: Volume 7*, edited by A. Heck. Hardbound 1-4020-5300-2, December 2006
- Volume 342: *The Astrophysics of Emission Line Stars*, by Tomokazu Kogure, Kam-Ching Leung. Hardbound ISBN: 0-387-34500-0, June 2007
- Volume 341: *Plasma Astrophysics, Part II: Reconnection and Flares*, by Boris V. Somov. Hardbound ISBN: 0-387-34948-0, November 2006
- Volume 340: *Plasma Astrophysics, Part I: Fundamentals and Practice*, by Boris V. Somov. Hardbound ISBN 0-387-34916-9, September 2006
- Volume 339: *Cosmic Ray Interactions, Propagation, and Acceleration in Space Plasmas*, by Lev Dorman. Hardbound ISBN 1-4020-5100-X, August 2006
- Volume 338: *Solar Journey: The Significance of Our Galactic Environment for the Heliosphere and the Earth*, edited by Priscilla C. Frisch. Hardbound ISBN 1-4020-4397-0, September 2006
- Volume 337: *Astrophysical Disks*, edited by A. M. Fridman, M. Y. Marov, I. G. Kovalenko. Hardbound ISBN 1-4020-4347-3, June 2006
- Volume 336: *Scientific Detectors for Astronomy 2005*, edited by J. E. Beletic, J. W. Beletic, P. Amico. Hardbound ISBN 1-4020-4329-5, December 2005

For other titles see www.springer.com/astronomy

Sirius Matters

Noah Brosch

Tel Aviv University
Tel Aviv, Israel

Dr. Noah Brosch
The Tel Aviv University
Wise Observatory and Dept.
of Astronomy & Astrophysics
School of Physics and Astronomy
69978 Tel Aviv
Israel
noah@wise.tau.ac.il

ISBN: 978-1-4020-8318-1

e-ISBN: 978-1-4020-8319-8

Library of Congress Control Number: 2008926593

© 2008 Springer Science+Business Media B.V.

No part of this work may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, microfilming, recording or otherwise, without written permission from the Publisher, with the exception of any material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work.

Cover illustration: A combination of nine frames from the STScI on-line digitized POSS2/UKSTU IR & POSS2/UKSTU blue images, illustrating the brightness of Sirius. The center of mosaic is at RA = 6:45:08.9, Dec = -16:42:58. The sky area coverage is $2^{\circ}.75 \times 2^{\circ}.73$. Image processing: Anurag Shevade. Used with permission.

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

Contents

List of figures	ix
List of tables	xvii
1 Introduction	1
2 Historical perspective	5
2.1 Introduction	5
2.2 Egypt and the ancient Middle East	9
2.3 Ancient Greece and Rome	20
2.4 Africa and Arabia	27
2.5 India, China, and the Far East	29
2.6 North and South America	29
2.7 Polynesia and Australia	31
2.8 Jewish connections	31
2.9 Conclusions	32
3 Mysteries of the Sirius system	35
3.1 The issue of historical redness	35
3.2 Explanations for redness	48
3.3 The binary nature of Sirius	52
3.4 The Dogon tribe and a modern Sirius mystery	60
3.5 Conclusions	68
4 Approaching modern times	71
4.1 The discovery of Sirius B: a tale of gravity	71
4.2 A third body in the Sirius system?	79
4.3 Modern searches for a third companion	83
4.4 Conclusions	88
5 Modern optical measurements	89
5.1 Astrometry	91
5.1.1 The <i>Hipparcos</i> Satellite	93
5.2 Photometry	96

5.3	Spectroscopy	99
5.3.1	Rotation	107
5.3.2	Magnetic field	110
5.3.3	Gravitational Redshift and Spectra of Sirius B . . .	112
5.4	Conclusions	117
6	Modern non-optical observations	119
6.1	Infrared	119
6.2	UV and EUV measurements	121
6.3	High energy observations	125
6.4	Basic stellar parameters	127
6.5	Conclusions	129
7	The neighborhood of Sirius	131
7.1	Interstellar matter	132
7.2	Very small LISM structures in the Milky Way	141
7.3	Stars in the neighborhood of Sirius	145
7.4	Conclusions	147
8	The perspective of stellar structure	149
8.1	Upper main-sequence stars and Sirius A	149
8.2	White dwarfs and Sirius B	152
8.3	Conclusions	163
9	The perspective of stellar evolution	165
9.1	Evolution of a main-sequence A star: Sirius A	167
9.2	Evolution of a white dwarf: Sirius B	169
9.3	Binary star evolution: Sirius as population representative .	179
9.4	Conclusions	183
10	Sirius revealed – a synthesis of the information	185
10.1	Sirius analogs	185
10.2	Sirius-basic data	188
10.3	Synthesis of information	190
10.3.1	Specific models for Sirius	190
10.3.2	Red color in antiquity	196
10.4	Conclusions	199
	References	203
	Index	215

List of figures

1.1	Facade of the Walker Art Center in Minneapolis (Photograph by the author).	2
2.1	Pointing to Sirius, using Orion's belt. Sky chart produced with the <i>Cartes du Ciel</i> freeware.	6
2.2	Sky photograph of the Canis Majoris constellation. The vertical extent ($\Delta\delta$) of the image is approximately 27° and the horizontal is about 2^h25^m ($\sim 34^\circ$). Sirius is the brightest star that stands out considerably above all the other stars in this image. Courtesy Akira Fujii/David Malin images. The image was obtained by Akira Fujii on large format color-reversal (<i>transparency</i>) film using a high-quality standard camera lens.	7
2.3	Section of a map showing stars seen in the northern hemisphere drawn in 1469 by Giovanni Cinico. The Big Dog constellation is shown with a halo around the head to emphasize the brilliance of Sirius, and the dog runs after the darker lesser dog Procyon.	8
2.4	Section of a map from 1590 showing the Canis Major constellation with the special mention of <i>Canicula</i> , i.e., Sirius.	8
2.5	Section of a map from 1709 that shows the Big Dog constellation with <i>Syrius</i> the bright star.	9
2.6	The Palette of Narmer, dated at about 2925 BCE.	11
2.7	Detail on the top part of the Palette of Narmer. The person following king Narmer is his sandal bearer, depicted with a star above his head; this star is sometimes interpreted as Sirius.	12
2.8	The square zodiac from the Hathor temple at Denderah, now exhibited in the Louvre in Paris.	13

2.9 Drawing of the square zodiac from the Hathor temple, from J. Bentley’s *A Historical View of Hindu Astronomy* (1823) Plate VIII, to help identify the figures in the actual picture shown in Figure 2.8. Hathor is the reclining cow above the center and to the right (*number 43*) with the star between its horns. 14

2.10 Detail from the square zodiac from the Hathor temple at Denderah, showing Sirius as a star between the horns of the cow Hathor. 15

2.11 Sirtush, the “dragon of Babylon”, as depicted on the reconstructed Ishtar gate of Babylon exhibited at the Pergamon Museum in Berlin (Image downloaded from the Wikipedia, free for use under the Creative Commons Attribution Share-Alike 2.5). 18

2.12 Sirtush of the Ishtar gate from the Pergamon Museum in Berlin shown on an East German stamp. 18

2.13 Ancient Nineveh star map shows Sirius as the sharply pointed arrow. 19

2.14 Enlargement of the celestial globe on the shoulder of the Atlas Farnese sculpture shows Sirius as the bright star at the head of the Big Dog, with rays of light emanating from it (just off the palm of Atlas, by the prow of the ship). (Photographed in 1998 by Dr. Gerald Picus and used with his permission). 22

2.15 The planisphere of Geruvius, from ~2nd century CE, shows two dogs near the bottom end and above the writing. The leftmost larger dog is labelled *Syrius*. It chases a smaller dog called *Anncanis*. 23

2.16 Reproduction of the circle of stones with sight-lines, with the original medicine wheel at Bighorn in Wyoming, erected at the Valley City State University in North Dakota. One sight-line of this ancient observatory, probably used by Native Americans to predict the seasons, was claimed to be pointing to the rising location of Sirius. 30

3.1 Segment of the slab of Hatra. According to Tuman (1983), the giant figure represents Orion the hunter, and the middle dog of the three, colored reddish on the slab, symbolizes Sirius. 42

3.2 Chinese ideograms of the poem describing the colors of Sirius. 45

3.3	The relatively bright stars in the Canis Majoris region of the sky are all rather blue, more than the usual percentage in a randomly selected sky area. Data from the 4th edition of the Bright Stars Catalog (Hoffleit & Jaschek 1982).	53
3.4	Color-magnitude diagram [M_V vs. (B-V)] for stars listed in Gliese's Catalog of nearby stars (third edition) that have their B-V color listed. Sirius is located near the upper-left corner of the plot, but it is not the extreme point.	54
3.5	The apparent motion of Sirius for about one century, as plotted in 1884 by Flammarion.	55
3.6	The apparent motion of Sirius among the stars since 5,000,000 years ago (courtesy Dr. R. Van Gent). The tick marks are plotted every 10^5 yrs for $\pm 10^6$ yrs, but for times $\pm 10^5$ years near the present they are plotted every 10,000 years. The IAU borders of the constellations are plotted together with stars brighter than 5th mag.	58
3.7	Dogon ritual mask dance (Photograph by Dr. Galen R. Frysinger, used with his permission).	60
3.8	Another Dogon ritual mask dance (Photograph by Dr. Galen R. Frysinger, used with his permission).	61
3.9	The trajectory of the star Digitaria around Sirius (after Figure <i>iii</i> in GD). Two positions of Digitaria are marked, one near Sirius (DP) and another far from it (DL).	63
4.1	The orbit of Sirius B around Sirius A, with the location of the faint star plotted for a number of years in the first half of the twenty-first century. The angular size of the semi-major axis of the orbit is $7''.5$. North is down and East is to the right.	74
4.2	Relevant parameters that define the orbit of a binary star, after Minnaert 1969. The vertical arrow points to the observer (Earth).	75
4.3	Sirius A and B can be seen in this image obtained with a digital camera on the Mt. Wilson 60-inch telescope. Note the cross pattern of the diffraction caused by the supports of the focal assembly at the prime focus, as well as smaller spikes from other obstructions in the light path. The distance between the two components of the binary at the time this image was obtained was about 5 arcsec and Sirius B is the tiny image to the left of the bright star (Credit: Jimmy Westlake, Colorado Mountain College, reproduced with permission).	78

4.4	Track of Sirius on the background of neighboring stars, from Bonnet-Bidaud et al. (2000), showing stars that could have been mistaken as physical companions in the Sirius system if seen at the proper time. Sirius is blocked off in the image for the epoch of observation, 2000, and its track as well as that for Sirius B are plotted.	86
4.5	Stellar identifications on the image of the Sirius neighborhood from Bonnet-Bidaud et al. (2000). The axes' units are arcsec.	87
5.1	Section of a star map showing CMa, from the Star Atlas drawn by Johannes Hevelius in the sixteenth century. . . .	90
5.2	The fluid borders of constellations (here of Canis Majoris) were plotted so as late as 1923 (from Becker 1923).	91
5.3	The changing distance to Sirius ± 5 Myrs around the present time modifies its apparent magnitude. This plot shows the apparent magnitude of Sirius in absence of interstellar extinction (<i>solid line</i>) and assuming a uniformly-distributed extinction of 3.5 mag kpc^{-1} (<i>dashed line</i>). I am indebted to Dr. R. Van Gent for producing this figure.	94
5.4	The changing distance to Sirius ± 0.5 Myrs around the present time also modifies its apparent magnitude in comparison with other bright stars. This plot is following Tomkin (1998). Sirius is represented here by filled circles, α Cen by filled squares, Canopus by open diamonds linked with a dot-dashed line, and Vega by open triangles linked with a dashed line. Sirius is our brightest star only for a limited period.	95
5.5	The optical spectrum of Sirius A shown here extends from $4,000 \text{ \AA}$ to $4,900 \text{ \AA}$. Its dominant features are the deep and broad Balmer (Hydrogen) lines, characteristic of a main-sequence A-type star.	99
5.6	The optical spectrum of Sirius A (image shown with two different display scales at the top and spectrum tracing shown at the bottom) shows the deep and broad Balmer (Hydrogen) lines, characteristic of a main-sequence A-type star. The spectrum was obtained with a small telescope and a transmission grating, and is included here courtesy of John A. Blackwell, Northwood Ridge Observatory.	100

5.7	This <i>HST</i> image of the Sirius system, with exquisite angular resolution, was obtained by rolling the spacecraft to distance the Sirius A spikes from the white dwarf. Sirius A is the bright stellar image at the center, shown here as negative, and Sirius B is the faint star near the bottom left spike (NASA image).	115
5.8	The full HST spectrum of Sirius B from Barstow et al. (2005) shows an exquisite display of the wide Balmer lines.	116
5.9	The blue part of the HST spectrum of Sirius B from Barstow et al. (2005) shows the excellent fit of the observations (points) to the theoretical spectrum (continuous line).	116
6.1	The first UV spectrum of Sirius obtained by the astronauts Lovell and Aldrin from the <i>Gemini 12</i> spacecraft (from Spear et al. 1974).	122
6.2	The extreme ultraviolet spectrum of Sirius shows clearly the contribution of the white dwarf. This is a combination of the short-wave and long-wave spectra obtained by the <i>EUVE</i> satellite during a 92,430 s observation performed at the end of November 1996 (from Holberg et al. 1998).	125
6.3	This <i>Chandra</i> X-ray image of the Sirius system, with exquisite angular resolution, shows two X-rays sources; the brighter one is Sirius B, the white dwarf, and the fainter image is Sirius A (NASA image).	126
6.4	The spectral energy distribution of the Sirius system, from 1,100 to 8,080 Å (Code et al. 1976), shows clearly the contribution of Sirius B at wavelengths below $\sim 2,200$ Å. The spectrum of the A-type primary is characterized by strong and deep Balmer absorption lines. Using more modern observations it may be possible to produce a better-quality SED.	128
6.5	The derived mass and radius of Sirius B from Barstow et al. (2005) matches quite well the theoretical relation for carbon-core WDs. The ellipses are 1σ and 2σ confidence contours from Holberg et al. (1998). The error bars represent fits to observations obtained with different gratings.	129
7.1	Artist impression of the distribution of very local ISM (Source: Priscilla Frisch and American Scientist).	131
7.2	The distribution of the local interstellar material up to a distance of 500 pc from the Sun. This is Figure 4 from Lucke (1978) and is based on the E(B-V) color excess of $\sim 4,000$ O and B stars plotted here as dots. The lowest contour in this plot corresponds to $N(\text{HI})=5\times 10^{20}$ cm ⁻²	133

- 7.3 The distribution of the local interstellar material in the immediate neighborhood of the Sun. This is Figure 2 from Ferlet (1999) and shows the presence of different environments for the Sun and for Sirius. The vectors point to more distant stars. 139
- 7.4 The color-absolute magnitude diagram for stars in the Sirius supercluster, after Eggen (1998). All stars but Sirius line-up properly with the “classical” isochrone for an age of 4×10^8 yr. Sirius itself is the uppermost point in the left side of the diagram and is off the general relation. 146
- 8.1 HR diagram based on stars with spectral classification by Houk (from Sowell et al. 2007). The spectral types are marked on the horizontal axis and the luminosity classes are indicated to the right of the plot. The areas of the circles scale to the number of stars per spectral type and luminosity class. There are 113,286 stars plotted. 154
- 8.2 The mass-radius relation derived by Chandrasekhar and Kohari, as shown by Gamow (1940). The axes’ labels in the diagram are in Tamil, Chandrasekhar’s language. The left part of the curve plots Solar System bodies: the Moon, the Earth, Saturn, and Jupiter (from left to right up to the peak). 157
- 8.3 The original Hamada & Salpeter (1961) relation between the mass (*horizontal axis*) and the radius (*vertical axis*) of white dwarfs of different compositions. The almost-vertical arrows indicate the location of WDs with Hydrogen envelopes. The dashed curves represent neutron star models; the dotted ones are models by Chandrasekhar. 159
- 8.4 Testing the mass-radius relationship of Hamada & Salpeter (1961) with accurate measurements of white dwarfs (from Provencal et al. 1998). Sirius B is the rightmost point in this diagram, with the highest mass among the plotted WDs. . . 163
- 9.1 Theoretical HR diagram showing the evolutionary paths off the main- sequence for metal-rich stars of different initial masses, after Iben (1967). Various development stages are numbered. 166
- 9.2 Initial (*horizontal axis*) vs. final (*vertical axis*) mass for single white dwarfs (from Weidemann 1977). Mass estimates for a few objects are compared with different theoretical predictions. The best-fitting relation seems to be that of Hills & Dale (1973). 171

- 9.3 Atmospheres of two WDs (Figure 1 from D’Antona & Mazzitelli 1990). The top panel shows the stratification of a remnant from a $1.0 M_{\odot}$ star now an $0.6 M_{\odot}$ WD; the bottom represents the stratification in an $0.84 M_{\odot}$ remnant from a $3.0 M_{\odot}$ star. The dotted curves show the distribution of ^4He , the short-dashed ones represent ^{12}C , and the long-dashed ones the distribution of ^{16}O 174
- 9.4 Initial vs. final mass for single white dwarfs (from Umeda et al. 1999). The different curves represent different metallicities of the progenitor star. The uppermost points of each track indicate that off-center Carbon ignition occurs in these models, thus they would be the highest masses for Carbon–Oxygen cores. 177
- 9.5 Initial vs. final mass for single white dwarfs (from Kwok 2000). 178
- 9.6 Equi-potential surfaces and Lagrangian points in a binary star system. The heavy contour joining the envelopes of the two stars is the cross-section of the Roche lobe along the orbital plane. 180
- 9.7 Masses and compositions of white dwarfs as function of the mass of the progenitor star, in a Case B Roche lobe overflow (from Iben 1991). Sirius B should lie, according to its mass, near the top end of the Carbon–Oxygen WDs. 182
- 9.8 Magnetic fields in binary stars. This is Figure 3 of Li & Wickramasinghe (1998) and illustrates the configuration of the magnetic field in a binary system. Region W represents the wind zone and region D is the “dead” zone, where the magnetic field lines of the two stars join up. 183
- 10.1 Cooling behavior of three WDs following Wood (1995). The figure shows the effective temperature as a function of time in years for a $1.0 M_{\odot}$ WD model (*solid line*), a $0.9 M_{\odot}$ WD (*dashed line*), and $0.8 M_{\odot}$ WD (*dot-dashed line*). The horizontal line corresponds to the present effective temperature of Sirius B. The $1 M_{\odot}$ model reaches the present-day effective temperature of Sirius B after 122 Myrs. 196

List of tables

3.1	Historical references supporting a red color for Sirius (in Mediterranean civilizations, after See 1927)	40
3.2	Chinese historical reference for star properties, from the first century BCE	46
3.3	Zenith distance and airmass evaluations	49
4.1	Photometry of stars in the immediate neighborhood of Sirius (from Bonnet-Bidaud & Gry 1991)	84
5.1	Rotation of Sirius A (Dravins et al. 1990)	109
7.1	ISM clouds in the line of sight to Sirius	140
8.1	Recognized types of white dwarfs and their characteristics .	155
9.1	Lifetimes of stars with different masses (years) for different stages of evolution	166
10.1	Summary information for the Sirius stars	189