PHILIP'S

ASTRONOMY ENCYCLOPEDIA

A comprehensive and authoritative A–Z guide to the Universe

FOREWORD BY LEIF J. ROBINSON
Editor Emeritus, *Sky & Telescope* Magazine

GENERAL EDITOR SIR PATRICK MOORE

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STAR MAPS CREATED BY WIL TIRION

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Managing Editor *Caroline Rayner*
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HOW TO USE THE ENCYCLOPEDIA

Alphabetical order

'Mc' is treated as if it were spelled 'Mac', and certain shortened forms as if spelled out in full (e.g. 'St' is treated as 'Saint'). Entries that have more than one word in the heading are alphabetized as if there were no space between the words. Entries that share the same main heading are in the order of people, places and things. Entries beginning with numerals are treated as if the numerals were spelled out (e.g. **3C** follows **three-body problem** and precedes **3C 273**). An exception is made for **HI region** and **HII region**, which appear together immediately after **Hirayama family**. Biographies are alphabetized by surname, with first names following the comma. (Forenames are placed in parentheses if the one by which a person is commonly known is not the first.) Certain lunar and planetary features appear under the main element of names (e.g. **Imbrium, Mare** rather than Mare Imbrium).

Cross-references

SMALL CAPITALS in an article indicate a separate entry that defines and explains the word or subject capitalized. '*See also*' at the end of an article directs the reader to entries that contain additional relevant information.

Measurements

Measurements are given in metric (usually SI) units, with an imperial conversion (to an appropriate accuracy) following in parentheses where appropriate. In historical contexts this convention is reversed so that, for example, the diameter of an early telescope is given first in inches. Densities, given in grams per cubic centimetre, are not converted, and neither are kilograms or tonnes. Large astronomical distances are usually given in light-years, but parsecs are sometimes used in a cosmological context. Particularly in tables, large numbers may be given in exponential form. Thus 10^3 is a thousand, 2×10^6 is two million, and so on. 'Billion' always means a thousand million, or 10^9. As is customary in astronomy, dates are expressed in the order year, month, day. Details of units of measurement, conversion factors and the principal abbreviations used in the book will be found in the tables on this page.

Stellar data

In almost all cases, data for stars are taken from the HIPPARCOS CATALOGUE. The very few exceptions are for instances where the catalogue contains an error of which the editors have been aware. In tables of constellations and elsewhere, the combined magnitude is given for double stars, and the average magnitude for variable stars.

Star Maps pages 447–55

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FRONTMATTER IMAGES
Endpapers: **Andromeda Galaxy** The largest member of the Local Group, this galaxy is the farthest object that can be seen with the naked eye.
Half-title: **Crab Nebula** This nebula is a remnant of a supernova that exploded in the constellation of Taurus in 1054.
Opposite title: **M83** Blue young stars and red HII emission nebulae clearly mark out regions of star formation in this face-on spiral galaxy in Hydra.
Opposite Foreword: **NGC 4945** This classic disk galaxy is at a distance of 13 million l.y. Its stars are mainly confined to a flat, thin, circular region surrounding the nucleus.
Opposite page 1: **Earth** This photograph was obtained by the Apollo 17 crew en route to the Moon in 1972 December.

THE GREEK ALPHABET

α Α alpha	η Η eta	ν Ν nu	τ Τ tau
β Β beta	θ Θ theta	ξ Ξ xi	υ Υ upsilon
γ Γ gamma	ι Ι iota	ο Ο omicron	φ Φ phi
δ Δ delta	κ Κ kappa	π Π pi	χ Χ chi
ε Ε epsilon	λ Λ lambda	ρ Ρ rho	ψ Ψ psi
ζ Ζ zeta	μ Μ mu	σ Σ sigma	ω Ω omega

MULTIPLES AND SUBMULTIPLES USED WITH SI UNITS

Multiple	Prefix	Symbol	Submultiple	Prefix	Symbol
10^3	kilo-	k	10^3	milli-	m
10^6	mega-	M	10^6	micro-	m
10^9	giga-	G	10^9	nano-	n
10^{12}	tera-	T	10^{12}	pico-	p
10^{15}	peta-	P	10^{15}	femto-	f
10^{18}	exa-	E	10^{18}	atto-	a

SYMBOLS FOR UNITS, CONSTANTS AND QUANTITIES

a	semimajor axis	*L*	luminosity	*t*	time
Å	angstrom unit	L_n	Lagrangian points	*T*	temperature (absolute), epoch
AU	astronomical unit		(*n* = 1 to 5)		(time of perihelion passage)
c	speed of light	l.y.	light-year	T_{eff}	effective temperature
d	distance	m	metre, minute	*v*	velocity
e	eccentricity	*m*	apparent magnitude, mass	W	watt
E	energy	m_{bol}	bolometric magnitude	y	year
eV	electron-volt	m_{pg}	photographic magnitude	*z*	redshift
f	following	m_{pv}	photovisual magnitude	α	constant of aberration,
F	focal length, force	m_v	visual magnitude		right ascension
g	acceleration due to gravity	*M*	absolute magnitude,	δ	declination
G	gauss		mass (stellar)	λ	wavelength
G	gravitational constant	N	newton	μ	proper motion
h	hour	*p*	preceding	ν	frequency
h	Planck constant	*P*	orbital period	π	parallax
H_0	Hubble constant	pc	parsec	ω	longitude of perihelion
Hz	hertz	*q*	perihelion distance	Ω	observed/critical density
i	inclination	q_0	deceleration parameter		ratio, longitude of ascending
IC	*Index Catalogue*	*Q*	aphelion distance		node
Jy	jansky	*r*	radius, distance	°	degree
k	Boltzmann constant	*R*	Roche limit	′	arcminute
K	degrees kelvin	s	second	″	arcsecond

CONVERSION FACTORS

Distances
1 nm = 10 Å
1 inch = 25.4 mm
1 mm = 0.03937 inch
1ft = 0.3048 m
1 m = 39.37 inches = 3.2808 ft
1 mile = 1.6093 km
1 km = 0.6214 mile
1 km/s = 2237 mile/h
1 pc = 3.0857×10^{13} km = 3.2616 l.y. = 206,265 AU
1 l.y. = 9.4607×10^{12} km = 0.3066 pc = 63,240 AU
Temperatures (to the nearest degree)
°C to °F : ×1.8, +32
°C to K : +273
°F to °C : −32, ÷1.8
°F to K : ÷1.8, +255
K to °C : −273
K to °F : ×1.8, −460

Note: To convert temperature *differences*, rather than points on the temperature scale, ignore the additive or subtractive figure and just multiply or divide.

CONTRIBUTORS

Philip's would like to thank the following contributors for their valuable assistance in updating and supplying new material for this edition:

Alexander T. Basilevsky, Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow, Russia
Richard Baum, UK
Peter R. Bond, FRAS, FBIS, Space Science Advisor for the Royal Astronomical Society, UK
Neil Bone, Director of the BAA Meteor Section and University of Sussex, UK
Dr Allan Chapman, Wadham College, University of Oxford, UK
Storm Dunlop, FRAS, FRMetS, UK
Tim Furniss, UK
Peter B. J. Gill, FRAS, UK
Dr Ian S. Glass, South African Astronomical Observatory, South Africa
Dr Monica M. Grady, The Natural History Museum, London, UK
Dr Andrew J. Hollis, BAA, UK
James B. Kaler, Department of Astronomy, University of Illinois, USA
William C. Keel, Department of Physics and Astronomy, University of Alabama, USA
Professor Chris Kitchin, FRAS, University of Hertfordshire, UK
Professor Kenneth R. Lang, Tufts University, USA
Dr Richard McKim, Director of the BAA Mars Section, UK
Mathew A. Marulla, USA
Steve Massey, ASA, Australia
Sir Patrick Moore, CBE, FRAS, UK
Dr François Ochsenbein, Astronomer at Observatoire Astronomique de Strasbourg, France
Dr Christopher J. Owen, PPARC Advanced Fellow, Mullard Space Science Laboratory, University College London, UK
Chas Parker, BA, UK
Neil M. Parker, FRAS, Managing Director, Greenwich Observatory Ltd, UK
Martin Ratcliffe, FRAS, President of the International Planetarium Society (2001–2002), USA
Ian Ridpath, FRAS, Editor *Norton's Star Atlas*, UK
Leif J. Robinson, Editor Emeritus *Sky & Telescope* magazine, USA
Dr David A. Rothery, Department of Earth Sciences, The Open University, UK
Robin Scagell, FRAS, Vice President of the Society for Popular Astronomy, UK
Jean Schneider, Observatoire de Paris, France
Dr Keith Shortridge, Anglo-Australian Observatory, Australia
Dr Andrew T. Sinclair, former Royal Greenwich Observatory, UK
Pam Spence, MSc, FRAS, UK
Dr Duncan Steel, Joule Physics Laboratory, University of Salford, UK
Nik Szymanek, University of Hertfordshire, UK
Richard L. S. Taylor, British Interplanetary Society, UK
Wil Tirion, The Netherlands
Dr Helen J. Walker, CCLRC Rutherford Appleton Laboratory, UK
Professor Fred Watson, Astronomer-in-Charge, Anglo-Australian Observatory, Australia
Dr James R. Webb, Florida International University and the SARA Observatory, USA
Dr Stuart Weidenschilling, Senior Scientist, Planetary Science Institute, USA
Professor Peter Wlasuk, Florida International University, USA
John Woodruff, FRAS, UK

Contributors to the 1987 edition also include:
Dr D. J. Adams, University of Leicester, UK
Dr David A. Allen, Anglo-Australian Observatory, Australia
Dr A. D. Andrews, Armagh Observatory, N. Ireland
R. W. Arbour, Pennell Observatory, UK
R. W. Argyle, Royal Greenwich Observatory (Canary Islands)
H. J. P. Arnold, Space Frontiers Ltd, UK
Professor W. I. Axford, Max-Planck-Institut für Aeronomie, Germany
Professor V. Barocas, Past President of the BAA, UK
Dr F. M. Bateson, Astronomical Research Ltd, New Zealand
Dr Reta Beebe, New Mexico State University, USA
Dr S. J. Bell Burnell, Royal Observatory, Edinburgh, UK
D. P. Bian, Beijing Planetarium, China
Dr D. L. Block, University of Witwatersrand, South Africa
G. L. Blow, Carter Observatory, New Zealand
Professor A. Boksenberg, Royal Greenwich Observatory (Sussex, UK)
Dr E. Bowell, Lowell Observatory, USA
Dr E. Budding, Carter Observatory, New Zealand
Dr P. J. Cattermole, Sheffield University, UK
Von Del Chamberlain, Past President of the International Planetarium Society
Dr David H. Clark, Science & Engineering Research Council, UK
Dr M. Cohen, University of California, USA
P. G. E. Corvan, Armagh Observatory, N. Ireland
Dr Dale P. Cruikshank, University of Hawaii, USA
Professor J. L. Culhane, Mullard Space Science Laboratory, UK
Dr J. K. Davies, University of Birmingham, UK
M. E. Davies, The Rand Corporation, California, USA
Professor R. Davis, Jr, University of Pennsylvania, USA
D. W. Dewhirst, Institute of Astronomy, Cambridge, UK
Professor Audouin Dollfus, Observatoire de Paris, France
Commander L. M. Dougherty, UK
Dr J. P. Emerson, Queen Mary College, London, UK
Professor M. W. Feast, South African Astronomical Observatory, South Africa
Dr G. Fielder, University of Lancaster, USA
Norman Fisher, UK
K. W. Gatland, UK
A. C. Gilmore, Mt John Observatory, University of Canterbury, New Zealand
Professor Owen Gingerich, Harvard-Smithsonian Center for Astrophysics, USA
Dr Mart de Groot, Armagh Observatory, N. Ireland
Professor R. H. Garstang, University of Colorado, USA
L. Helander, Sweden
Michael J. Hendrie, Director of the Comet Section of the BAA, UK
Dr A. A. Hoag, Lowell Observatory, USA
Dr M. A. Hoskin, Churchill College, Cambridge, UK
Commander H. D. Howse, UK
Professor Sir F. Hoyle, UK
Dr D. W. Hughes, University of Sheffield, UK
Dr G. E. Hunt, UK
Dr R. Hutchison, British Museum (Natural History), London, UK
Dr R. J. Jameson, University of Leicester, UK
R. M. Jenkins, Space Communications Division, Bristol, UK
Dr P. van de Kamp, Universiteit van Amsterdam, The Netherlands
Professor W. J. Kaufmann, III, San Diego State University, USA
Dr M. R. Kidger, Universidad de La Laguna, Tenerife, Canary Islands
Dr A. R. King, University of Leicester, UK
Dr Y. Kozai, Tokyo Astronomical Observatory, University of Tokyo, Japan
R. J. Livesey, Director of the Aurora Section of the BAA, UK
Sir Bernard Lovell, Nuffield Radio Astronomy Laboratories, Jodrell Bank, UK
Professor Dr S. McKenna-Lawlor, St Patrick's College, Co. Kildare, Ireland
Dr Ron Maddison, University of Keele, UK
David Malin, Anglo-Australian Observatory, Australia
J. C. D. Marsh, Hatfield Polytechnic Observatory, UK
Dr J. Mason, UK
Professor A. J. Meadows, University of Leicester, UK
Howard Miles, Director of the Artificial Satellite Section of the BAA, UK
L. V. Morrison, Royal Greenwich Observatory (Sussex, UK)
T. J. C. A. Moseley, N. Ireland
Dr P. G. Murdin, Royal Greenwich Observatory (Sussex, UK)
C. A. Murray, Royal Greenwich Observatory (Sussex, UK)
I. K. Nicolson, MSc, Hatfield Polytechnic, UK
J. E. Oberg, USA
Dr Wayne Orchiston, Victoria College, Australia
Dr M. V. Penston, Royal Greenwich Observatory (Sussex, UK)
J. L. Perdrix, Australia
Dr J. D. H. Pilkington, Royal Greenwich Observatory (Sussex, UK)
Dr D. J. Raine, University of Leicester, UK
Dr R. Reinhard, European Space Agency, The Netherlands
H. B. Ridley, UK
C. A. Ronan, East Asian History of Science Trust, Cambridge, UK
Professor S. K. Runcorn, University of Newcastle upon Tyne, UK
Dr S. Saito, Kwasan & Hida Observatories, University of Kyoto, Japan
Dr R. W. Smith, The Johns Hopkins University, USA
Dr F. R. Stephenson, University of Durham, UK
E. H. Strach, UK
Professor Clyde W. Tombaugh, New Mexico State University, USA
R. F. Turner, UK
Dr J. V. Wall, Royal Greenwich Observatory (Sussex, UK)
E. N. Walker, Royal Greenwich Observatory (Sussex, UK)
Professor B. Warner, University of Cape Town, South Africa
Professor P. A. Wayman, Dunsink Observatory, Dublin, Ireland
Dr G. Welin, Uppsala University, Sweden
A. E. Wells, UK
E. A. Whitaker, University of Arizona, USA
Dr A. P. Willmore, University of Birmingham, UK
Dr Lionel Wilson, University of Lancaster, UK
Professor A. W. Wolfendale, University of Durham, UK
Dr Sidney C. Wolff, Kitt Peak National Observatory, USA
K. Wood, Queen Mary College, London, UK
Les Woolliscroft, University of Sheffield, UK
Dr A. E. Wright, Australian National Radio Astronomy Observatory, Australia

The progress of astronomy – or, more precisely, astrophysics – over the past century, and particularly the past generation, is not easily pigeon-holed.

On the one hand, profound truths have tumbled abundantly from the sky. Here are four diverse examples:

1. Our universe began some 14 billion years ago in a single cataclysmic event called the Big Bang.
2. Galaxies reside mainly in huge weblike ensembles.
3. Our neighbouring planets and their satellites come in a bewildering variety.
4. Earth itself is threatened (at least within politicians' horizons) by impacts from mean-spirited asteroids or comets.

On the other hand, ordinary citizens may well feel that astronomers are a confused lot and that they are farther away than ever from understanding how the universe is put together and how it works. For example, 'yesterday' we were told the universe is expanding as a consequence of the Big Bang; 'today' we are told it is accelerating due to some mysterious and possibly unrelated force. It doesn't help that the media dine exclusively on 'gee-whiz' results, many of them contradictory and too often reported without historical context. I can't help but savour the pre-1960s era, before quasars and pulsars were discovered, when we naïvely envisioned a simple, orderly universe understandable in everyday terms.

Of course, all the new revelations cry out for insightful interpretation. And that's why I'm delighted to introduce this brand-new edition. So much has been discovered since it first appeared in 1987 . . . so much more needs to be explained!

It's sobering to catalogue some of the objects and phenomena that were unknown, or at least weren't much on astronomers' minds, only a generation or two ago.

The one that strikes me most is that 90% (maybe 99%!) of all the matter in the universe is invisible and therefore unknown. We're sure it exists and is pervasive throughout intergalactic space (which was once thought to be a vacuum) because we can detect its gravitational influence on the stuff we can see, such as galaxies. But no one has a cogent clue as to what this so-called dark matter might be.

Masers, first created in laboratories in 1953, were found in space only 12 years later. These intense emitters of coherent microwave radiation have enabled astronomers to vastly improve distance determinations to giant molecular clouds and, especially, to the centre of our Galaxy.

A scientific 'war' was fought in the 1960s as to whether clusters of galaxies themselves clustered. Now even the biggest of these so-called superclusters are known to be but bricks in gigantic walls stretching across hundreds of millions of light-years. These walls contain most of the universe's visible matter and are separated from each other by empty regions called voids.

The discovery of quasars in 1963 moved highly condensed matter on to astronomy's centre stage. To explain their enormous and rapidly varying energy output, a tiny source was needed, and only a black hole having a feeding frenzy could fill the bill. Thus too was born the whole subdiscipline of relativistic astrophysics, which continues to thrive. Quasars are now regarded as having the highest energies in a diverse class called active galaxies.

Gamma-ray bursts, the most powerful outpourings of energy known in the universe, only came under intense scrutiny by astronomers in the 1990s (they had been detected by secret military satellites since the 1960s). The mechanism that leads to this prodigious output is still speculative, though a young, very massive star collapsing to form a black hole seems favoured.

A decades-long quest for extrasolar planets and closely related brown-dwarf (failed) stars came to an abrupt end in 1995 when the first secure examples of both entities were found. (By a somewhat arbitrary convention, planets are regarded as having masses up to several times that of Jupiter; brown dwarfs range from about 10 to 80 Jupiters.) Improved search strategies and techniques are now discovering so many of both objects that ordinary new ones hardly make news.

One of the greatest successes of astrophysics in the last century was the identification of how chemical elements are born. Hydrogen, helium, and traces of others originated in the Big Bang; heavier elements through iron derive from the cores of stars; and still heavier elements are blasted into space by the explosions of very massive stars.

The discovery of pulsars in 1967 confirmed that neutron stars exist. Born in supernova explosions, these bodies are only about 10 kilometres across and spin around as rapidly as 100 times a second. Whenever a pulsar's radiation beam, 'focused' by some of the strongest magnetic fields known, sweeps over the Earth, we see the pulse. In addition to being almost perfect clocks, pulsars have allowed studies as diverse as the interstellar medium and relativistic effects. Finally, unlike any other astronomical object, pulsars have yielded three Nobel Prizes!

Tantalizing though inconclusive evidence for extraterrestrial life accumulates impressively: possible fossil evidence in the famous Martian meteorite ALH 84001, the prospect of clement oceans under the icy crust of Jupiter's satellite Europa, and the organic-compound rich atmosphere of Saturn's moon Titan. And then there is the burgeoning catalogue of planets around other stars and the detection of terrestrial life forms in ever more hostile environments. All this suggests that we may not be alone. On a higher plane, despite many efforts to find extraterrestrial intelligence since Frank Drake's famous Ozma experiment in 1960, we haven't picked up E.T.'s phone call yet. But the search has barely begun.

The flowering of astrophysics stems from the development of ever larger, ever more capable telescopes on the ground and in space. All the electromagnetic spectrum – from the highest-energy gamma rays to the lowest-energy radio waves – is now available for robust scrutiny, not just visible light and long-wavelength radio emission as was the case in as recently as the 1950s.

Equally impressive has been the development of detectors to capture celestial radiation more efficiently. In the case of the CCD (charge-coupled device), trickle-down technology has allowed small amateur telescopes to act as though they were four or five times larger. Augmented by effective software, CCDs have caused a revolution among hobbyists, who, after nearly a century-long hiatus, can once again contribute to mainstream astrophysical research.

Increasingly, astronomers are no longer limited to gathering electromagnetic radiation. Beginning late in the last century, they started to routinely sample neutrinos, elementary particles that allow us to peek at such inaccessible things as the earliest times in the life of the universe and the innards of exploding stars. And the gravitational-wave detectors being commissioned at the time of this writing should allow glimpses of the fabric of spacetime itself.

Astronomy has involved extensive international collaborations for well over a century. The cross-disciplinary nature of contemporary research makes such collaborations even more compelling in the future. Furthermore, efforts to build the next generation of instruments on the ground and especially in space are so expensive that their funding will demand international participation.

Where do astronomers go from here? 'Towards the unknown' may seem like a cliché, but it isn't. With so much of the universe invisible or unsampled, there simply have to be many enormous surprises awaiting!

When it comes to the Big Questions, I don't know whether we are children unable to frame our thoughts, or teenagers at sea, or adults awash in obfuscating information. Researchers find the plethora of new discoveries – despite myriad loose ends and conundrums – to be very exciting, for it attests to the vibrancy and maturation of the science. Yet, as we enter the 21st century, astronomers are still a very long way from answering the two most common and profound questions people ask: what kind of universe do we live in, and is life pervasive?

Leif J. Robinson
Editor Emeritus, *Sky & Telescope* magazine