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ASTRONOMY METHODS

Astronomy Methods is an introduction to the basic practical tools, methods and phenomena that underlie quantitative astronomy. Taking a technical approach, the author covers a rich diversity of topics across all branches of astronomy, from radio to gamma-ray wavelengths. Topics include the quantitative aspects of the electromagnetic spectrum, atmospheric and interstellar absorption, telescopes in all wavebands, interferometry, adaptive optics, the transport of radiation through matter to form spectral lines, and neutrino and gravitational-wave astronomy. Clear, systematic presentations of the topics are accompanied by diagrams and problem sets. Written for undergraduates and graduate students, this book contains a wealth of information that is required for the practice and study of quantitative and analytical astronomy and astrophysics.

Hale Bradt is Professor Emeritus of Physics at the Massachusetts Institute of Technology. Over his forty years on the faculty, he carried out research in cosmic ray physics and x-ray astronomy, and taught courses in Physics and Astrophysics. Bradt founded the MIT sounding rocket program in x-ray astronomy, and was a senior or principal investigator on three NASA missions for x-ray astronomy. He was awarded the NASA Exceptional Science Medal for his contributions to HEAO-1 (High Energy Astronomical Observatory 1), the 1990 Buechner Teaching Prize of the MIT Physics Department, and shared the 1999 Bruno Rossi prize of the American Astronomical Society for his contributions to the RXTE (Rossi X-ray Timing Explorer) program.

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Cover illustrations

Views of the entire sky at six wavelengths in galactic coordinates. The equator of the Milky Way system is the central horizontal axis and the galactic center direction is at the center. Except for the x-ray sky, the colors represent intensity with the greatest intensities lying along the equator. In all cases, the radiation shows an association with the galactic equator and/or the general direction of the galactic center. In some, extragalactic sources distributed more uniformly are evident. The captions below are listed in frequency order (low to high). The maps are also in frequency order as follows: top to bottom on the back cover followed on the front cover by top inset, background map, lower inset.

Radio sky at 408 Hz exhibiting a diffuse glow of synchrotron radiation from the entire sky. High energy electrons spiraling in the magnetic fields of the Galaxy emit this radiation. Note the *North Polar Spur* projecting above the equator to left of center. [From three observatories: Jodrell Bank, MPIfR, and Parkes. Glyn Haslam *et al*., MPIfR, SkyView]

Radio emission at 1420 MHz, the spin-flip (hyperfine) transition in the ground state of hydrogen, which shows the locations of clouds of neutral hydrogen gas. The gas is heavily concentrated in the galactic plane and shows pronounced filamentary structure off the plane. [J. Dickey (UMn), F. Lockman (NRAO), SkyView; *ARAA* **28**, 235 (1990)]

Far-infrared (60–240 μm) sky from the COBE satellite showing primarily emission from small grains of graphite and silicates ("dust") in the interstellar medium of the Galaxy. The faint large S-shaped curve (on its side) is emission from dust and rocks in the solar system. Reflection of solar light from this material gives rise to the zodiacal light at optical wavelengths. [E. L. Wright (UCLA), COBE, DIRBE, NASA]

Optical sky from a mosaic of 51 wide angle photographs showing mostly stars in the (Milky Way) Galaxy with significant extinction by dust along the galactic plane. Galaxies are visible at higher galactic latitudes, the most prominent being the two nearby Magellanic Clouds (lower right). [©Axel Mellinger]

X-ray sky at 1–20 keV from the A1 experiment on the HEAO-1 satellite showing 842 discrete sources. The circle size represents intensity of the source and the color represents the type of object. The most intense sources shown (green, larger, circles) represent accreting binary systems containing a compact star, either a white dwarf, neutron star, or a black hole. Other objects are supernova remnants (blue), clusters of galaxies (pink), active galactic nuclei (orange), and stellar coronae (white) [Kent Wood, NRL; see *ApJ Suppl*. **56**, 507 (1984)]

Gamma-ray sky above 100 MeV from the EGRET experiment on the Compton Gamma Ray Observatory. The diffuse glow from the galactic equator is due to the collisions of cosmic ray protons with the atoms of gas clouds; the nuclear reactions produce the detected gamma rays. Discrete sources include pulsars and jets from distant active galaxies ("blazars"). [The EGRET team, NASA, CGRO]

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HALE BRADT

Massachusetts Institute of Technology

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To Dottie, Elizabeth, Dorothy,
$(\text{Bart})^2$, Ben, and Rebecca

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Hale Bradt
Frontmatter
More information

Contents

List of figures — *page* xiv
List of tables — xviii
Preface — xix
Acknowledgments — xxii

1 Astronomy through the centuries — **1**
1.1 Introduction — 1
1.2 Early development of astronomy — 1
First astronomers • Renaissance
1.3 Technology revolution — 7
Telescopes, photography, electronics, and computers • Non-optical astronomy
1.4 Interplay of observation and theory — 10
Stars and nebulae • Galaxies and the universe • New horizons

2 Electromagnetic radiation — **22**
2.1 Introduction — 22
2.2 Photon and non-photon astronomy — 23
Photons (electromagnetic waves) • Cosmic rays and meteorites • Neutrino and gravitational-wave astronomy
2.3 Electromagnetic frequency bands — 25
Wavelength and frequency • Photon energy • Temperature
2.4 Photons and the atmosphere — 29
Atmospheric absorption • Interstellar absorption

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CAMBRIDGE

Cambridge University Press
978-0-521-53551-9 - Astronomy Methods: A Physical Approach to Astronomical Observations
Hale Bradt
Frontmatter
More information

3 Coordinate systems and charts **34**

3.1 Introduction 34

3.2 Coordinates on a celestial sphere 35
Mathematical sphere at "infinity" • Celestial coordinate systems – Horizon coordinates – Equatorial coordinates – Why equatorial coordinates? – Galactic coordinates – Ecliptic coordinate system – Reference frames • **Transformations**

3.3 Solid angle on the celestial sphere 45

3.4 Surveys, charts, and catalogs 48
Photographs and charts – Palomar, SRC, and ESO sky surveys – Finding charts – Printed charts • **Catalogs of celestial objects** • **Names of astronomical objects** – Constellations – Stars – Modern names ("telephone numbers")

4 Gravity, celestial motions, and time **57**

4.1 Introduction 58

4.2 Gravity – Newton to Einstein 58

4.3 Apparent motions of stars 60
Horizon coordinate system • **Annual motion** – Sun and the ecliptic – Sun and dark-sky observations – Parallax of star positions – Stellar aberration • **Precession of the earth** – Torque due to a ring of mass – Rate of precession – Nutation – Calendar – Zodiac • **Proper motion** – Motion on celestial sphere – Peculiar motion and local standard of rest – Solar motion

4.4 Lunar and planet motions – eclipses 72
Eclipses of the sun and moon – "Orbits" of the moon and sun – Total and partial solar eclipses – The 18-year saros cycle – Wonder and science – Corona in x rays and visible light – Lunar eclipses • **Planets**

4.5 Measures of time 80
Time according to the stars and sun – Sidereal time – Mean solar time • **Universal and atomic times** – Universal time (UT) and earth spin – Greenwich mean sidereal time (GMST) at 0 h UT – Ephemeris second – Atomic time (TAI) – Universal coordinated time (UTC) and leap seconds – Terrestrial time (TT) – Barycentric times • **Julian date (JD)** • **Epochs for coordinate systems** • **Signals from pulsars**

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CAMBRIDGE

Cambridge University Press
978-0-521-53551-9 - Astronomy Methods: A Physical Approach to Astronomical Observations
Hale Bradt
Frontmatter
More information

5 Telescopes **98**

5.1 Introduction 98

5.2 Information content of radiation 99

5.3 Image formation 100
Focusing systems – Focal length and plate scale – Aperture and deposited energy – Telescope configurations • **Non-focusing systems** – Tubular and modulation collimators – Multiple pinhole collimator • **Some real telescopes**

5.4 Antenna beams 112
Meaning of a "beam" • **Point spread function** • **Diffraction** – Fraunhofer diffraction – Radio resolution – Optical resolution – X-ray resolution

5.5 Resolution enhancement 119
Isophase patches and speckles • **Speckle interferometry** • **Adaptive optics** – Deformable mirrors – Sensing the wavefront shape – Complete system

6 Detectors and statistics **130**

6.1 Introduction 130

6.2 Position-insensitive detectors 131
Photomultiplier and photometry • **Proportional counter**

6.3 Position-sensitive detectors 137
Position-sensitive proportional counters • **Charge-coupled device** – Structure of a CCD – Exposure to light – Readout of the image – Utility in optical astronomy – Adaptive imaging – Utility in x-ray astronomy

6.4 Gamma-ray instruments 145
EGRET experiment • **Detector subsystems –** Plastic scintillator anticoincidence – Spark chamber detection of electron–positron pair – Timing scintillation detectors (up–down discrimination) – Energies and arrival directions • **BATSE experiment**

6.5 Statistics of measurements 151
Instrumental noise • **Statistical fluctuations – "noise"** – Poisson distribution – Normal distribution – Variance and standard deviation – Measurement significance –Statistical traps • **Background** – Propagation of errors – Background subtraction – Low and high background limits – Bright and faint source observations • **Comparison to theory** – Finding parameters and checking hypotheses – Least squares fit – Chi square test

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CAMBRIDGE

Cambridge University Press
978-0-521-53551-9 - Astronomy Methods: A Physical Approach to Astronomical Observations
Hale Bradt
Frontmatter
More information

7 Multiple telescope interferometry **175**

7.1 Introduction 176

7.2 Two-telescope interference 177
Principle of interferometry • Equatorial observation – Transmission of radiation – Reception – Earth rotation – Position of source • **North-Pole observation • All-sky fringe patterns • Point-source response** – Wavefront samples – Summed waves – Multiplied waves – Signal processing • **Fourier plane** – Spatial frequencies – Projected baseline

7.3 Mapping the sky 197
Cross-correlation or "shading" method – Bins on the sky – Cross-correlation – Equal weighting of time intervals • **Fourier analysis of sky brightness** – Principle of aperture synthesis – Arbitrary sky brightness distribution – Visibility – Phase of visibility function – Sky brightness • **Cleaning algorithms**

7.4 Arrays of telescopes 208
Multiple baselines • Radio arrays • Very long baseline interferometry (VLBI) • Optical and x-ray interferometry

8 Point-like and extended sources **218**

8.1 Introduction 219

8.2 Unresolved point-like sources 220
Spectral flux density • Flux density • Luminosity • Fluence

8.3 Astronomical magnitudes 224
Apparent magnitude – Magnitudes and fluxes – Spectral color bands – Conversion from magnitudes to SI units – Color indices • **Absolute magnitudes – luminosity • Bolometric magnitude** – Bolometric Correction – Absolute bolometric magnitude and luminosity

8.4 Resolved "diffuse" sources 234
Specific intensity – Concept of specific intensity – Power received by antenna – Average specific intensity • **Spectral flux density revisited** – Relation to specific intensity – Specific intensity of pulsars • **Surface brightness** – Power emitted from a surface – Equality of emitted and received intensity ($B = I$) – Liouville's theorem • **Energy flow – names, symbols, and units • Volume emissivity** – Relation to specific intensity – Line-of-sight emissivity (power column density)

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CAMBRIDGE

Cambridge University Press
978-0-521-53551-9 - Astronomy Methods: A Physical Approach to Astronomical Observations
Hale Bradt
Frontmatter
More information

9 Properties and distances of celestial objects 253

9.1 Introduction 254

9.2 Luminosities 254

9.3 Masses 256
Earth and sun • Moon • Spiral galaxies and the Galaxy • Clusters of galaxies and the virial theorem

9.4 Temperatures 260
Thermal and non-thermal radiation • Temperature measurements – Kinetic temperature – Color temperature – Effective temperature – Excitation temperature – Ionization temperature – Saha equation

9.5 Distances and sizes 265
Distance ladder • Moon, earth, and sun • Trigonometric parallax • Distances to open clusters – Convergence – Distance to a cluster star – Distance to the cluster • **Secular and statistical parallaxes** – Secular parallax – Statistical parallax • **Standard candles • Spectroscopic classification • Galactic center and Crab nebula distances • Cepheid and RR Lyrae variables • Hubble law** – Receding galaxies – Expanding universe – Value of Hubble constant – Redshift – Size and age of the universe • **Extragalactic "standard candles"** – Luminosity functions – Supernovae – Line-broadening in galaxies – Surface brightness fluctuations • **Ultimate goals**

10 Absorption and scattering of photons 298

10.1 Introduction 298

10.2 Photon interactions 300
Photon–electron interactions – Rayleigh scattering – Thomson scattering – Compton scattering • **Photon absorption in the CMB • Photon–atom interactions** – Photoelectric absorption and absorption lines – Emission nebulae – Pair production near a nucleus

10.3 Extinction of starlight 306
Grains in the interstellar medium • Extinction parameters – Extinction coefficient – Extragalactic sources – Color excess (reddening) – Frequency dependence • **Dust–hydrogen association**

10.4 Cross sections 314
Cross section as target • Mean propagation distance – Exponential absorption – Mean free path – Mass units and opacity – Optical depth • **Cross section and extinction coefficient**

10.5 Photoelectric absorption in the interstellar medium 321
Photoelectric effect • Cosmic abundances – Abundances by number – Mass fractions • **Propagation distances in the interstellar medium** – Effective cross section – Survival distances – Astronomy through gases

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CAMBRIDGE

Cambridge University Press
978-0-521-53551-9 - Astronomy Methods: A Physical Approach to Astronomical Observations
Hale Bradt
Frontmatter
More information

11 Spectra of electromagnetic radiation 333

11.1 Introduction 333

11.2 Plots of spectra 334
Energy and number spectra • Spectral reference band – Frequency and wavelength – Frequency and energy • **Spectral bin widths**

11.3 Continuum spectra 339
Free–bound, bound–free and free–free transitions • Optically thin thermal bremsstrahlung – Radiation from a hot plasma – Plasma parameters determined – Shocks in supernova remnants, stellar coronae, H II regions • **Synchrotron radiation • Blackbody radiation** – Spectrum – Radio spectra and antenna temperature – Cosmic microwave background – Stars

11.4 Spectral lines 354
Absorption and emission lines – Origin of spectral lines – Stars and nebulae – Permitted and forbidden lines – Spectral lines at non-optical frequencies • **Line strengths and shapes** – Equivalent width – Damping and thermal profiles – Turbulent motions and collisional broadening – Saturation and the curve of growth

11.5 Formation of spectral lines (radiative transfer) 365
Radiative transfer equation (RTE) – Intensity differentials – Intensity variation with optical depth • **Local thermodynamic equilibrium • Solution of the RTE • Limiting cases** – Summary

12 Astronomy beyond photons 378

12.1 Introduction 379

12.2 Neutrino observatories 379
Neutrinos from the sun • Homestake mine experiment – Neutrino–chlorine conversions – Argon decay – Sweeping for argon atoms – Solar neutrino problem • **Second generation experiments** – Gallium detectors – Super-Kamiokande – Cerenkov radiation • **Neutrino oscillations and more**

12.3 Cosmic ray observatories 388
Primary and secondary fluxes – Storage in the Galaxy – Nuclear component – Electromagnetic component – Muon component – Cosmic ray astronomy • **Extensive air showers** – Growth and decay – Cerenkov radiation and fluorescence – Detection of EAS – Fly's Eye – Auger project • **Gamma-ray primaries – TeV and EeV astronomy**

12.4 Gravitational-wave observatories 399
Orbiting neutron stars – Hulse–Taylor pulsar – Energy loss rate • Gravitational waves – Distortion of space – Quadrupole radiation • **Merger of neutron-star binary** – Variable quadrupole moment – Strain – Detection in Virgo cluster – Final chirp • **Detectors** – Resonant bars – Laser interferometers – Multiple antennas – Low frequency antenna in space

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978-0-521-53551-9 - Astronomy Methods: A Physical Approach to Astronomical Observations
Hale Bradt
Frontmatter
More information

Credits, further reading, and references 415
Appendix – Units, symbols, and values 418
Index 422

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978-0-521-53551-9 - Astronomy Methods: A Physical Approach to Astronomical Observations
Hale Bradt
Frontmatter
More information

Figures

1.1	Stonehenge	*page* 2
1.2	Ptolemaic system	3
1.3	Crab nebula	4
1.4	Brahe, Galileo, Kepler	6
1.5	Trifid nebula	12
1.6	Orion nebula	13
1.7	Pleiades	14
1.8	Ring nebula	15
1.9	Globular cluster M10	16
1.10	Andromeda nebula M31	17
1.11	Hubble redshift	18
2.1	Bands of the electromagnetic spectrum	26
2.2	Atmospheric absorption	30
3.1	Celestial sphere and the earth	36
3.2	Horizon coordinate system	38
3.3	Galaxy: bulge, corona, globular clusters, spiral arms	41
3.4	Galactic coordinates	41
3.5	Celestial sphere, equatorial and galactic coordinates	42
3.6	Discrete radio sources, 1420 MHz	43
3.7	Solid angle element	46
4.1	Star motions in horizon coordinate system	61
4.2	Trigonometric parallax	64
4.3	Stellar aberration	65
4.4	Earth precession	67
4.5	Solar eclipse, tracks of sun and moon	74
4.6	Sun in x rays and visible light during eclipse	78

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CAMBRIDGE

Cambridge University Press
978-0-521-53551-9 - Astronomy Methods: A Physical Approach to Astronomical Observations
Hale Bradt
Frontmatter
More information

5.1 Thin lens focusing 101
5.2 Telescope focusing systems 105
5.3 Tubular collimator and multiple pinhole mask 107
5.4 Galactic center in x rays, BeppoSAX WFC image 109
5.5 Telescope beam, resolution and FWHM 113
5.6 Fraunhofer diffraction 116
5.7 Diffraction by circular aperture, Airy disk 118
5.8 Adaptive optics, interference of wavefronts 120
5.9 Speckle interferometry imaging 123
5.10 Hartmann wavefront sensor 126
5.11 Adaptive optics system 127
5.12 Galactic center image using adaptive optics 128

6.1 Photometry and the photomultiplier tube 132
6.2 Proportional counter 134
6.3 Charge-coupled device (CCD) 139
6.4 CCD readout 141
6.5 EGRET gamma-ray experiment 146
6.6 BATSE gamma-ray burst experiment 150
6.7 Poisson distribution, three mean values 154
6.8 Poisson and normal distributions, $m = 100$ 156
6.9 Least squares fits 167
6.10 Chi square tests 170
6.11 Chi square probabilities 171

7.1 Principle of interferometry 178
7.2 Two equatorial telescopes on spinning earth 180
7.3 Two telescopes at North Pole on spinning earth 184
7.4 Lines of position and source location 185
7.5 Electronic processing and all-sky lines of visibilty 186
7.6 Interference wave forms 190
7.7 Projected baseline $\boldsymbol{b}$ and tangent plane 193
7.8 "Shading" method for creating map 198
7.9 Very Large Array (VLA) and VLBA 210
7.10 Twin quasar 0957+561 210
7.11 Cygnus A with lobes, VLA image 211
7.12 Capella image with optical interferometry 213

8.1 Flux and luminosity from a point source 223
8.2 *UBV* transmission curves 227
8.3 Antenna beam, source element, spherical coordinates 236
8.4 Specific intensity, surface receiving flux 240

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CAMBRIDGE

Cambridge University Press
978-0-521-53551-9 - Astronomy Methods: A Physical Approach to Astronomical Observations
Hale Bradt
Frontmatter
More information

8.5	Surface brightness, radiation leaving a surface	242
8.6	Geometry, surface brightness = specific intensity	243
8.7	Specific intensity from shells at r and $2r$	244
8.8	Specific intensity from element of transparent cloud	248
8.9	Emission from a column	249
9.1	Energy levels of two ionization states	264
9.2	Sizes and distances of astronomical objects	267
9.3	Moving cluster method	271
9.4	Upsilon, tau and radial velocity components of a star	275
9.5	Distance to H_2O masers in Sgr B-2	278
9.6	Cepheid intensity variations	280
9.7	Luminosity function of globular clusters	287
9.8	Surface brightness fluctuations on a CCD chip	290
9.9	Distance ladder	293
10.1	Hydrogen atom, energy levels	305
10.2	Interstellar reddening by cloud and in galactic disk	307
10.3	Extinction vs. frequency plot	312
10.4	Dust–hydrogen correlation in Galaxy	313
10.5	Cross section for atom, attenuation in volume element	315
10.6	Cross section vs. frequency in matter, sketches	322
10.7	Effective photoelectric cross sections in ISM	325
10.8	Ultraviolet and x-ray survival distances in Galaxy	328
11.1	Sketches, emission lines, absorption line, continuum	334
11.2	Spectra of Crab nebula and pulsar	336
11.3	Exponential spectra, three plots	342
11.4	Theoretical spectrum, optically thin thermal plasma	344
11.5	X-ray spectra of Puppis A and Capella	345
11.6	Ideal and real radio spectra	346
11.7	Power-law spectrum, sketch	347
11.8	Blackbody spectra, linear and log-log plots	349
11.9	Cosmic microwave background (CMB) spectrum	352
11.10	Optical stellar spectra, Canopus and η Carinae	353
11.11	Origins of spectral lines, light bulb and 3 observers	356
11.12	Spinning star, origin of emission and absorption lines	357
11.13	Radio molecular spectra	360
11.14	Equivalent width and saturation, sketches	361
11.15	Line profiles, thermal and damping	363
11.16	Curve of growth	365
11.17	Radiative transfer, source, cloud and observer	366

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CAMBRIDGE

Cambridge University Press
978-0-521-53551-9 - Astronomy Methods: A Physical Approach to Astronomical Observations
Hale Bradt
Frontmatter
More information

11.18	Radiative transfer, intensity vs. optical depth	370
11.19	Line formation, optical depth and intensity vs. frequency	372
12.1	Solar neutrino spectrum	381
12.2	Cerenkov light directionality and "smoke ring" in water	386
12.3	Primary and secondary cosmic rays in atmosphere	391
12.4	Extensive air shower and detector array	393
12.5	Auger observatory for ultra high energy primaries	397
12.6	Hulse–Taylor binary pulsar orbital decay	401
12.7	Ring of test masses in gravitational waves, two polarizations	403
12.8	Close binary of two neutron stars, final chirp	405
12.9	Gravitational wave detectors, bar and interferometer	409

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Cambridge University Press
978-0-521-53551-9 - Astronomy Methods: A Physical Approach to Astronomical Observations
Hale Bradt
Frontmatter
More information

Tables

2.1	Frequency–wavelength correspondence	*page* 27
3.1	Examples of equatorial celestial coordinates	39
4.1	TT and TAI offsets relative to UTC	87
6.1	Sample values of Poisson function P_x	155
6.2	Normal distribution probabilities	157
8.1	Solar apparent magnitudes	228
8.2	Photometry bands: Johnson–Cousins–Glass system	228
8.3	Star types: absolute magnitudes and bolometric corrections	234
9.1	Mass, luminosity, and energy examples	255
9.2	Size (radius) and distance examples	266
9.3	Surface brightness fluctuations, example	292
10.1	Absorption parameters	319
10.2	Solar-system abundances	323
11.1	Prominent emission lines in Orion nebula	359
A1	Base units: Système Internationale (SI)	418
A2	Some SI derived units	418
A3	SI prefixes	419
A4	Energy-related quantities	419
A5	Physical constants	420
A6	General astronomical constants	421
A7	Constants involving time	421

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Cambridge University Press
978-0-521-53551-9 - Astronomy Methods: A Physical Approach to Astronomical Observations
Hale Bradt
Frontmatter
More information

Preface

This volume is the first part of notes that evolved during my teaching of a small class for junior and senior physics students at MIT. The course focused on a physical, analytical approach to astronomy and astrophysics. The material in this volume presents methods, tools and phenomena of astronomy that the science undergraduate should incorporate into his or her knowledge prior to or during the practice and study of quantitative and analytical astronomy and astrophysics.

The content is a diverse set of topics ranging across all branches of astronomy, with an approach that is introductory and based upon physical considerations. It is addressed primarily to advanced undergraduate science students, especially those who are new to astronomy. It should also be a useful introduction for graduate students or postdoctoral researchers who are encountering the practice of astronomy for the first time. Algebra and trigonometry are freely used, and calculus appears frequently. Substantial portions should be accessible to those who remember well their advanced high school mathematics.

Here one learns quantitative aspects of the electromagnetic spectrum, atmospheric absorption, celestial coordinate systems, the motions of celestial objects, eclipses, calendar and time systems, telescopes in all wavebands, speckle interferometry and adaptive optics to overcome atmospheric jitter, astronomical detectors including CCDs, two space gamma-ray experiments, basic statistics, interferometry to improve angular resolution, radiation from point and extended sources, the determination of masses, temperatures, and distances of celestial objects, the processes that absorb and scatter photons in the interstellar medium together with the concept of cross section, broadband and line spectra, the transport of radiation through matter to form spectral lines, and finally the techniques used in neutrino. cosmic-ray and gravitational-wave astronomy.

I choose to use SI units throughout to be consistent with most standard undergraduate science texts. Professional astronomers use cgs units, probably because everyone else in the field does. Unfortunately, this precludes progress in bringing

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Hale Bradt
Frontmatter
More information

the various science communities together to one system of units. It is also a significant hindrance to the student exploring astronomy or astrophysics. In this work I vote for ease of student access and encourage my colleagues to do likewise in their publications. I do violate this in at least one respect. In avoiding the historical and highly specialized astronomical unit of distance, the "parsec", I use instead the better understood, but non-SI, unit, the "light year" (LY), the distance light travels in one year. This is a well defined quantity if one specifies the Julian year of exactly 365.25 days, each of exactly 86 400 SI seconds, or a total of 31 557 600 s per year.

Other features to note are. (*i*) problems are provided for each chapter; and approximate answers are given where appropriate; (*ii*) units are often given gratuitously (in parentheses) for algebraic variables to remind the reader of the meaning of the symbol; (*iii*) equation, table, figure, and section numbers in the text do not carry the chapter prefix if they refer to the current chapter, to improve readability; (*iv*) tables of useful units, symbols and constants are given in the Appendix, and (*v*) quantitative information is meant to be up to date and correct, but should not be relied upon for professional research. The goal here is to teach underlying principles.

In teaching this course from my notes, I adopted a seminar, or Socratic, style of teaching that turned out to be extremely successful and personally rewarding. I recommend it to teachers using this text. I sat with the students (up to about 20) around a table, or we would arrange classroom desks and chairs in a circular/rectangular pattern so we were all facing each other, more or less. I would then have the students explain the material to their fellow students ("Don't look at me," I often said). One student would do a bit, and I would move on to another. I tried very hard to make my prompts easy and straightforward, to not disparage incorrect or confusing answers, and to encourage discussion among students. I would synthesize arguments and describe the broader implications of the material interspersed with stories of real-life astronomy, personalities, discoveries, etc.

These sessions would often become quite active. During this discussion, the text is available to all and is freely referenced. To ease such referencing, all equations are numbered, labels are provided for many of them, and important equations are marked with a boldface arrow in the left margin. The students had to work hard to prepare for class, and thus got much out of the class discussion. And it was great fun for the teacher. In good weather, we would move outdoors and have our discussion on the lawn of MIT's Killian Court.

I hope to publish other portions of these notes in future volumes. The second should follow shortly; its working title and current chapter titles are:

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Hale Bradt
Frontmatter
More information

Astrophysics Processes – Physical Processes that Underlie Astronomical Phenomena

Kepler's laws and the mass function
Special theory of relativity in astronomy
Kinetic theory and thermodynamics
Radiation from accelerating charges
Thermal bremsstrahlung radiation
Synchrotron radiation
Blackbody radiation
Compton scattering
Hydrogen spin-flip radiation
Propagation in phase space
Dispersion and Faraday rotation
Gravitational lensing

The author asks his readers forbearance with the inevitable errors in the current text and asks to be notified of them. Comments and suggestions are welcome.

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