



# Contents

<b>1. Astrophysical Information .....</b>	<b>1</b>
1.1 Carriers of Information .....	1
1.2 Collecting and Analysing Information .....	7
1.2.1 Photons .....	7
1.2.2 Spectral Coverage .....	9
1.2.3 Measurement of Intensity .....	10
1.2.4 Spectral Analysis .....	12
1.2.5 Rapid Photometry .....	13
1.2.6 Imaging, Spatial Resolution .....	14
1.2.7 Spin, Polarization .....	16
1.2.8 Space-Time Reference Frames .....	17
1.2.9 Treatment and Storage of Information .....	17
1.3 Strategies and Costs .....	21
<b>2. The Earth's Atmosphere .....</b>	<b>23</b>
2.1 Physical and Chemical Structure of the Atmosphere .....	23
2.1.1 Vertical Structure .....	23
2.1.2 Constituents .....	25
2.2 Absorption of Radiation .....	28
2.3 Atmospheric Emission .....	34
2.3.1 The Emission of the Night Sky .....	34
2.3.2 Thermal Emission .....	36
2.4 Scattering of Radiation .....	39
2.5 Turbulent Structure of the Earth's Atmosphere .....	41
2.5.1 Turbulence in the Lower and Middle Atmosphere .....	41
2.5.2 Ionospheric Turbulence .....	47
2.6 Ground Observing Sites .....	48
2.6.1 Visible, Infrared ( $\lambda < 30 \mu\text{m}$ ) and Millimetre ( $\lambda > 0.5 \text{ mm}$ ) Observations .....	48
2.6.2 Radioastronomical Observations .....	50
2.7 Observations from Space .....	51
2.8 Exercises .....	56
<b>3. Photometry .....</b>	<b>58</b>
3.1 Radiometry .....	58
3.2 Blackbody Radiation .....	62
3.3 The Magnitude System .....	63

3.4 Atmospheric Transmission .....	66
3.5 Calibration and Intensity Standards .....	66
3.5.1 Radiofrequencies ( $\lambda \gtrsim 1 \text{ mm}$ ) .....	67
3.5.2 Infrared and Visible .....	69
3.5.3 Ultraviolet and X-Rays ( $0.1 \lesssim \lambda \lesssim 300 \text{ nm}$ ) .....	75
3.5.4 Gamma Rays .....	77
3.5.5 Global Spectra .....	77
3.6 Exercises .....	79
<b>4. Measurement and Processing of Signals .....</b>	<b>81</b>
4.1 Fourier Transforms .....	82
4.1.1 Definitions and Properties .....	82
4.1.2 Physical Quantities and Fourier Transforms .....	93
4.2 Random Processes and Variables .....	96
4.2.1 Random Variables .....	96
4.2.2 Random or Stochastic Processes .....	103
4.2.3 Physical Measurements and Estimates .....	111
4.3 Astronomical Signals .....	116
4.3.1 Signal Reception .....	116
4.3.2 Signal and Fluctuations. Noise .....	121
4.3.3 Signal Processing .....	125
4.4 Fundamental Fluctuations .....	131
4.4.1 Quantum Noise .....	134
4.4.2 Thermal Noise .....	137
4.5 Exercises .....	140
<b>5. Detectors .....</b>	<b>146</b>
5.1 Physical Principles of the Detection of Electromagnetic Radiation .....	147
5.1.1 Photon Detection .....	147
5.1.2 Detection of the Electromagnetic Field .....	153
5.2 Astronomical Detectors .....	157
5.2.1 Photocathode Detectors .....	161
5.2.2 Television Scanning Detectors .....	165
5.2.3 Solid State Imagers .....	169
5.2.4 Photographic Plates .....	175
5.2.5 Detectors for the Visible and Ultraviolet: The Choice ..	177
5.2.6 Other Infrared Detectors ( $1\text{--}100 \mu\text{m}$ ) .....	178
5.2.7 Radiofrequency Detection: Generalities .....	182
5.2.8 Radiofrequency Detection: Receivers .....	187
5.2.9 X-ray ( $0.1\text{--}10 \text{ keV}$ ) and Gamma-ray ( $> 10 \text{ keV}$ ) Detection .....	193
5.3 Neutrino Detection .....	200
5.3.1 Inelastic Reaction Detectors .....	200
5.3.2 Momentum Transfer Detectors .....	202

5.4 Gravitational Wave Detection .....	204
5.5 Exercises .....	206
<b>6. Images .....</b>	<b>209</b>
6.1 Space-time Properties of Radiation .....	210
6.1.1 Degree of Coherence of the Electromagnetic Field .....	210
6.1.2 The Zernike-van Cittert Theorem: Etendue of Coherence .....	213
6.1.3 Coherence and Photon Statistics .....	217
6.2 Image Formation .....	218
6.2.1 Diffraction at Infinity. Pupils .....	218
6.2.2 Pupils and Spatial Filtering .....	222
6.2.3 Aberrations .....	227
6.3 Telescopes .....	230
6.3.1 Radiotelescopes, Radioastronomical Images ( $\lambda \gtrsim 1$ mm) .....	230
6.3.2 Telescopes for the Visible, Infrared and Ultraviolet .....	237
6.3.3 X-ray Telescopes (0.1–10 keV) .....	248
6.3.4 Gamma-ray Telescopes (> 10 keV) .....	250
6.4 Image Degradation by the Atmosphere .....	251
6.4.1 Modification of a Wavefront by an Inhomogeneous Medium .....	252
6.4.2 Image Formation .....	255
6.5 Image Processing .....	263
6.5.1 The Principal Solution .....	263
6.5.2 Methods of Information Restitution .....	264
6.5.3 Image Coding .....	267
6.6 Exercises .....	269
<b>7. Spectral Analysis .....</b>	<b>274</b>
7.1 Astrophysical Spectra .....	274
7.2 Spectrometers: General Concepts .....	277
7.3 Interferometric Spectrometers .....	280
7.3.1 General Criteria .....	280
7.3.2 Interference Filters .....	281
7.3.3 Grating Spectrometers .....	281
7.3.4 Fourier Transform Spectrometer .....	291
7.3.5 Fabry-Pérot Interferometer .....	297
7.3.6 Bragg Crystal Spectrometer (X-Rays) .....	299
7.3.7 X-ray Spectroscopy: Bolometers .....	301
7.4 Heterodyne Spectroscopy .....	302
7.4.1 Multichannel Spectrometers .....	304
7.4.2 Acoustic Spectrometer .....	304
7.4.3 Autocorrelation Spectrometer .....	305
7.4.4 Submillimetric Developments .....	306
7.5 Resonance Spectrometers .....	308
7.6 Exercises .....	309

<b>Appendix: Physical and Astronomical Constants .....</b>	<b>311</b>
<b>General Bibliography .....</b>	<b>313</b>
<b>Bibliography to Chaps. 2–7 .....</b>	<b>315</b>
<b>Subject Index .....</b>	<b>323</b>

