A Question and Answer Guide to Astronomy

Second Edition

Are we alone in the Universe?
Was there anything before the Big Bang?
Are there other universes?
What makes stars shine?
Where does Earth's water come from?
Why is the night sky dark?
Was there ever life on Mars?
How do telescopes work?

This engaging guide book answers all these questions and hundreds more, making it a practical reference for anyone who has ever wondered what is out in the cosmos, where does it all come from, and how does it all work? Richly illustrated in color throughout, it gives simple yet rigorous explanations in non-technical language, summarizing current astronomical knowledge, without overlooking the important underlying scientific principles. This second edition includes substantial new material throughout, including the latest findings from the New Horizons, Rosetta, and Dawn space missions, and images from professional telescopes such as the Hubble Space Telescope and the Atacama Large Millimeter Array.

Carol Christian is a scientist at the Space Telescope Science Institute in Baltimore, MD. She is the Hubble Space Telescope Outreach Project Scientist, supporting the HST mission in all things regarding information for the media, educators, and the general public. She also participates in a number of podcasts on iTunes. In previous years she was the Head of the Office of Public Outreach at STScI and established a number of Internet educational and outreach initiatives.

Jean-René Roy is a retired astronomer who was a professor at Laval University, Québec, Canada from 1977 to 2000. Since then he has served as Deputy Director and Head of Science at the Gemini Observatory in Hawai'i and Chile and worked at the Large Facilities Office of the National Science Foundation and finally at the Space Telescope Science Institute. He has done research on the Sun, the interstellar medium, and the evolution of gas-rich galaxies.

A Question and Answer Guide to Astronomy

Second Edition

Carol Christian
Space Telescope Science Institute, Baltimore, USA

Jean-René Roy
Laval University, Quebec, Canada

CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

4843/24, 2nd Floor, Ansari Road, Daryaganj, Delhi – 110002, India

79 Anson Road, #06-04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781316615263

First published 2008 as *250 réponses à vos questions sur L'astronomie*
by Editions du Gerfault/La Compagnie Des Editions de la Lesse (Paris)
English translation published 2010
Second edition 2017

Printed in Singapore by Markono Print Media Pte Ltd

A catalogue record for this publication is available from the British Library

Library of Congress Cataloging-in-Publication Data
Names: Christian, Carol, 1950– | Roy, Jean-René, 1943–.
Title: A question and answer guide to astronomy / Carol Christian, Jean-René Roy.
Other titles: 250 réponses à vos questions sur l'astronomie. French
Description: [Revised 2017]. | Cambridge : Cambridge University Press, 2017.
| "First published 2008 as 250 réponses à vos questions sur l'astronomie"–T.p. verso.
| "English translation published 2010, revised 2017"–T.p. verso. | Includes bibliographical references and index.
Identifiers: LCCN 2016040127 | ISBN 9781316615263 (pbk. : alk. paper)
Subjects: LCSH: Astronomy–Miscellanea. | Astronomy–Popular works.
| Astronomy–Amateurs' manuals.
Classification: LCC QB52 .B45 2016 | DDC 520–dc23
LC record available at https://lccn.loc.gov/2016040127

ISBN 978-1-316-61526-3 Paperback

Contents

Preface xiii

The Sky Viewed from Earth 1

1 How many stars are visible to the naked eye? 1
2 How many constellations are there? 1
3 Do all civilizations recognize the same constellations? 3
4 How are stars named? 4
5 How can planets be spotted in the night sky? 5
6 Why did ancient astronomers study the sky so intently? 6
7 Why were the Greek and Roman gods associated with the different planets? 7
8 Can we learn anything from the astronomical phenomena reported in the Bible? 7
9 Who were the most important astronomers of antiquity? 8
10 What were the early contributions of the Chinese, Indian, and Islamic civilizations to astronomy? 9
11 Is there a southern polar star? 12
12 Are the stars fixed or do they move? 12
13 What causes the seasons? 13
14 What is the precession of equinoxes? 15
15 Why is the day divided into 24 hours? 16
16 Have days on Earth always been the same length? 17
17 How do sundials work? 17
18 How could the ancient astronomers predict eclipses? 18
19 How can the Sun be used to find directions? 19
20 What is sidereal time? 19
21 How was the time zone system established? 20
22 What is a shooting star? 21
23 What causes meteor showers? 22
24 What causes the bright beams of light that stream out from the setting Sun? And what causes sundogs? 23
25 Why is the setting Sun red? 25
26 Why are sunsets usually more colorful than sunrises? 26
27 What is the green flash? 26
28 Why do we never tan in the late afternoon, even though the Sun's rays still feel hot? 27
29 Why do stars twinkle? 28
30 Why does the Moon look so large at the horizon? 29
31 Astrology, astronomy, astrophysics . . . what are the differences? 30

The Earth and Moon System 33

32 How has the size of the Earth been measured? 33
33 How has the mass of the Earth been measured? 34
34 How old is the Earth? 36
35 What is inside the Earth? 39
36 Where did the water on Earth come from? 41
37 Do any of the other planets have oceans? 43
38 Where does the oxygen of our atmosphere come from? 45
39 What caused the "ice ages" on Earth? 46
40 What causes the Earth's magnetic field? 48
41 Does the Earth's magnetism affect people? 49
42 Why is the magnetic north different from the geographic north? 50
43 What causes the "northern lights"? 52
44 What is the greenhouse effect? 54
45 How did the Moon form? 56
46 Why is the Moon covered with craters? 58
47 What are the large dark areas on the Moon? 59
48 What does the far side of the Moon look like? 60
49 Does the Moon have the same composition as the Earth? 61
50 Why does the Moon lack an atmosphere? 63
51 Why does the Moon always present the same face to Earth? 63
52 Why does the Moon, rather than the Sun, cause most of our tides? 64
53 If the tide is mainly caused by the attraction of the Moon, why is there a simultaneous high tide on the Earth's opposite side, facing away from the Moon? 65
54 Is it just coincidence that the apparent diameters of the Moon and the Sun are the same? 67
55 How often do solar eclipses occur? 67
56 How can one tell if the Moon is waning or waxing? 69
57 What has been learned from our exploration of the Moon? 70
58 How useful would it be to return to the Moon? 72
59 What explains the dim light suffusing the dark portion of a crescent Moon? 73
60 "Moonstruck!" Is human behavior influenced by the Moon? 74

The Sun and the Solar System 75

61 How did the solar system form? 75
62 Is any trace of our "ancestral" supernova still in existence? 77
63 How far out does our solar system extend? 78
64 How old is the Sun? 80
65 Has the Sun always been as bright as it is now? 80
66 What is the Sun's future? 81
67 What will happen to the Earth when the Sun dies? 81
68 How hot is the Sun? 82
69 What causes sunspots? 84

70 Do sunspots influence the weather on Earth? 86
71 Who was responsible for overturning the geocentric system? 87
72 How was the distance to the Sun measured? 89
73 Is the distance between Earth and the Sun changing? 91
74 How can we know the mass of the Sun? 91
75 What is solar radiation pressure? 91
76 What is the solar wind? 92
77 What is the difference between a star and a planet? 93
78 What is a brown dwarf? 94
79 Why are some planets rocky and others gaseous? 95
80 What are the interiors of planets and satellites like? 96
81 Where do the names of the planets come from? 97
82 What is Bode's law? 98
83 What is Planet X? 99
84 Why is Pluto no longer called a planet? 100
85 Why do some planets have many satellites and others, none? 102
86 How can Mercury survive so close to the Sun? 104
87 Why does Venus have phases like the Moon? 105
88 What are asteroids? 106
89 What is zodiacal light? 107
90 What is the Great Red Spot on Jupiter? 108
91 What are Saturn's rings made of? 109
92 Do all the planets orbit in the same direction? 110
93 What are the Lagrange points? 111
94 Why did the comet Shoemaker–Levy 9 break up as it approached Jupiter? 112
95 Can planetary alignments cause catastrophic events on Earth? 113
96 Did asteroids cause the mass extinctions on Earth? 114
97 Where did the asteroid implicated in the extinction of the dinosaurs fall? 115
98 What could be done if an asteroid threatened to collide with Earth? 116
99 What is the Kuiper belt? 118
100 Where do comets come from? 118
101 What are comets made of? 119
102 In the age of space probes, is it still useful to observe the planets with telescopes? 121
103 What do the Mars rovers do? 121
104 Why colonize Mars? 123
105 Which way to Mars? 124
106 What is solar sailing? 124
107 How could the Voyagers explore so many planets and satellites in one trip? 126

Stars and Stellar Systems 129

108 Why do stars shine? 129
109 What are stars made of? 130

110 Why are stars round? 132
111 How many stars are there in our galaxy? 132
112 How are the brightnesses of stars measured? 134
113 How are the distances to stars measured? 135
114 Parsecs? Light-years? Why not miles or kilometers? 137
115 How are the masses of stars determined? 138
116 How big are stars? 139
117 What are the biggest stars known? 140
118 How old are the stars? 142
119 How old is the oldest star? 142
120 Do stars really come in different colors? 143
121 How many different kinds of star are there? 144
122 How do stars die? 146
123 What is a nova? A supernova? 149
124 What is a double star? 153
125 What are Cepheid variables? 153
126 What is a pulsar? 154
127 Do stars ever collide? 155
128 Are we really made of stardust? 156
129 Which star is closest to us? 157
130 Between stars that die and stars that are born, is the population of our galaxy growing or shrinking? 158
131 Are there any isolated stars, outside of the galaxies? 158
132 What is a runaway star? 159
133 What are star clusters? 160
134 Could nuclear fusion, the process that fuels the stars, be tamed to solve our energy problems? 162

Galaxies and the Universe 165

135 What is the Milky Way? 165
136 What are the Magellanic Clouds? 166
137 How does the sky appear in different wavelengths? 168
138 What is a nebula? 169
139 How empty is space? 171
140 How many different types of galaxy are there? 173
141 What type of galaxy is the Milky Way? 175
142 How many galaxies are there in the universe? 177
143 How old is the universe? 177
144 How did the universe begin? 179
145 How do we know that the universe is expanding? 182
146 How fast is the universe expanding? 184
147 Who invented the term “Big Bang?” 184
148 Does the universe have a center? 185
149 What is the cosmic background radiation? 187
150 What is cosmic inflation? 189

151 When did the first stars form? 191
152 How did the first galaxies form? 192
153 What was there before the Big Bang? 193
154 What is string theory? 194
155 If the universe is expanding, are we also expanding? 195
156 What explains the redshift of light? 195
157 How big is the universe? 197
158 Is there an edge to the universe? 198
159 What is the nature of gravity? 199
160 What is a black hole? 202
161 Can anything escape from a black hole? 204
162 What is dark energy? 204
163 If we cannot see dark matter, how do we know that it exists? 206
164 Were the laws of physics the same in the early universe as they are now? 208
165 How much antimatter is there in the universe? 209
166 How did the theory of relativity affect astronomy? 211
167 What is meant by "four-dimensional space?" 213
168 Can anything go faster than the speed of light? 214
169 Why does everything in the universe rotate? 216
170 Why is the night sky dark? 217
171 What is the anthropic principle? 218
172 What is the fate of the universe? 220
173 What major questions remain to be answered in astronomy? 221
174 How can we hope to comprehend the *astronomical* numbers which astronomy confronts us with? 222
175 Is there a difference between the cosmos and the universe? 223
176 Have any astronomers won the Nobel Prize? 224

Life in the Universe 227

177 What is life? 227
178 How did life begin on Earth? 228
179 Could life on Earth have originated in outer space? 231
180 Why is water so important for life? 231
181 Could life evolve from a chemical element other than carbon? 233
182 How do molecules form in the interstellar medium? 233
183 What are extremophiles? 234
184 Given favorable conditions, will life inevitably appear? 235
185 Where in the universe would life have the best chance of appearing? 236
186 What kind of planetary conditions may determine the emergence and development of life? 237
187 What are the odds that other intelligent life exists in our galaxy? 238
188 Where else in the solar system could life exist? 240
189 How are exoplanets detected? 242
190 How could we detect the presence of life outside the solar system? 245

191 Could the human race ever colonize exoplanets? 246
192 Could aliens have visited the Earth? 246
193 How could we communicate with other civilizations in the Galaxy? 247
194 Does life violate the second law of thermodynamics? 249

Amateur Astronomy and Citizen Science 253

195 Interested in amateur astronomy? What are the first steps? 253
196 Which telescope should you choose? 254
197 What can be seen with an amateur telescope? 257
198 What is a Dobsonian telescope? 258
199 What is a Schmidt–Cassegrain? 259
200 What are the Messier objects? 260
201 Where are skies the darkest? 261
202 What important discoveries have amateurs made? 262
203 Can amateur astronomers participate in research programs? 263
204 What is citizen science? 265
205 You think you have made a discovery: what should you do? 267
206 Where and how can meteorites be found? 267
207 How does one become a professional astronomer? 267
208 How can you find an amateur astronomy club? 269

Telescopes 273

209 How do refracting and reflecting telescopes differ? 273
210 What does a large modern telescope look like? 274
211 What are the most common optical configurations? 276
212 How is the performance of a telescope measured? 277
213 What is the shape of a telescope mirror? 278
214 How are telescope mirrors made? 280
215 What is a Schmidt telescope? 281
216 Why are telescopes housed in domes? 282
217 Reflection, refraction, diffusion, dispersion . . . want a short refresher? 284
218 . . . and diffraction? 284
219 How does astronomical spectroscopy work? 286
220 How is the resolving power of a telescope defined? 288
221 Do celestial objects look bigger through a large telescope? 289
222 Who invented the telescope? 290
223 What major improvements have been made in telescopes since Galileo's time? 291
224 Why do astronomers want ever-larger telescopes? 294
225 What are the largest optical telescopes today? 295
226 Where were the earliest observatories? 298
227 How did the modern observatory evolve? 299
228 How does the atmosphere degrade telescope images? 300
229 What is adaptive optics? 301
230 Where are the best astronomical sites? 303

231 What are the advantages of observing from space? 305
232 What are the main space observatories? 305
233 Which orbits are used for space telescopes? 309
234 Would the Moon be a good site for an observatory? 310
235 How is a space telescope pointed? 311
236 What is an astronomical interferometer? 312
237 How did radio astronomy come about? 313
238 How does a radio telescope work? 314
239 What can we learn from observations at radio wavelengths? 317
240 What is a submillimeter telescope? 318
241 What does an X-ray telescope look like? 318
242 How does a gamma-ray telescope work? 320
243 How are gravitational waves detected? 321
244 How are neutrinos detected? 323

Unit Conversion and Basic Physical and Astronomical Measurements 324
References 325
Bibliography 328
Index 333

Preface

Human beings are curious by nature and have marveled at the night sky ever since our *Homo sapiens* ancestors first gazed up into the heavens. What is "up there"? Why do stars shine? How did the universe begin? Does life exist elsewhere? What is on the other side of the Moon?

Astronomy is one of the oldest sciences, but modern physics and technology, coupled with observations from space, have recently generated a stupendous wave of new knowledge. Most of our earliest questions about the nature of the universe have now been answered, and many unexpected, intriguing new findings have been made, findings that invite us to be both humble and bold. And one need not be a professional astronomer or physicist to understand them.

Our intention in writing this book has been to offer to the general reader a summary of current astronomical knowledge, generously illustrated and provided with rigorous but simple explanations while avoiding mystifying professional jargon.

This book is a revised edition of the one first published in English in 2010. We have updated the material following recent findings and discoveries. Some questions and answers are additions and a few old ones have been dropped. We have restructured and reorganized chapters to follow a more logical sequence of topics, and the content and approach remain the same of those of the first edition.

The many "windows" on astronomy in this book do not exhaust the topic, but we hope that they will pique the curiosity of our readers and stimulate them to explore further, by navigating the Internet or by consulting some of the many fine publications on astronomy such as those suggested at the end of this book. Most important of all, we hope that they will find renewed wonder in the night sky!

April 2009, June 2016

Acknowledgments

We would like to thank Yves Bely for leading the first edition of the book, Sally Bely for help in the editing, and Hélène Allard for sharpening key concepts for the general reader. We are also grateful to Nathalie Bely and Robert Macpherson for several illustrations and their many useful comments.

We are most grateful to Vince Higgs, Charlotte Thomas, Jonathan Ratcliffe, and Zoë Lewin at Cambridge University Press for their support and editorial assistance.

Units and Numbers

We have used the metric system almost exclusively. Conversion factors for English equivalents can be found in the appendix.

In astronomy, distances, times, and temperatures are truly "astronomical numbers," in which the long strings of zeros are awkward and cumbersome. We have therefore often used scientific notation, in which numbers are expressed in powers of 10. The exponent of 10 is the number of places by which the decimal point must be shifted to express the number (left for negative exponents, right for positive exponents). For example, $2.5 \cdot 10^3$ is 2500, 10^6 is 1 followed by 6 zeros, or 1 million, and 10^{-6} is 0.000 001.

Notation

References are given through the text by the names of the authors, e.g. Espenak and Meeus 2006 or Abbott *et al.* 2016 for multiple authors, with details in the list of references at the end of the book.

References to related questions are noted by the letter Q followed by the number of the question. For example, (Q. 30) refers to question 30.

The night sky viewed from northern Chile with the central part of the Milky Way in full view. Credit: ESO/S. Guisard.