

· James Kasting ·

*How to Find a
Habitable Planet*

◦ ◦ ◦ ◦ ◦

PRINCETON UNIVERSITY PRESS
PRINCETON AND OXFORD

Contents

o o o

Preface xi

Part I: Introduction • 1

<i>Chapter 1</i>	Past Thinking about Earth-Like Planets and Life	3
•	The Habitable Zone and the Importance of Liquid Water	5
•	Carl Sagan and the Drake Equation	9
•	Other Perspectives on Planetary Habitability: Rare Earth and Gaia	11

Part II: Our Habitable Planet Earth • 15

<i>Chapter 2</i>	Critical Updates on How Planets Are Built	17
•	The Conventional Wisdom regarding Planet Formation	18
•	Where Did Earth's Water Come From?	21
•	New Models for Planetary Accretion and Delivery of Water	23
•	Could Earth's Water Have Come from Comets?	25
•	An Up-to-Date Simulation of Planetary Accretion	28
<i>Chapter 3</i>	Long-Term Climate Stability	32
•	Solar Evolution Theory	32
•	Solar Mass Loss?	36
•	Electromagnetic Radiation and the Greenhouse Effect	37

Contents

• Planetary Energy Balance	41
• The Faint Young Sun Problem	42
• Possible Solutions to the Problem	45
• The Carbonate-Silicate Cycle and Controls on Atmospheric CO ₂	49
• The CO ₂ -Climate Feedback Loop	53

Chapter 4 More Wrinkles in Earth's Climate History 57

• The Phanerozoic Climate Record	58
• Precambrian Climate	63
• Geologic Evidence for the Rise of Atmospheric O ₂	65
• Cause of the O ₂ Rise: Cyanobacteria	68
• Methane, Methanogens, and the Universal Tree of Life	71
• The Archean Methane Greenhouse	75
• The Paleoproterozoic Glaciation	77

Chapter 5 Runaway Glaciation and "Snowball Earth" 80

• Milankovitch Cycles and the Recent Ice Ages	81
• Ice Albedo Feedback and Climatic Instability	86
• Evidence for Low-Latitude Glaciation	88
• Mechanisms for Explaining Low-Latitude Glaciation	90
• Snowball Earth	92

Part III: Limits to Planetary Habitability • 97

Chapter 6 Runaway Greenhouses and the Evolution of Venus' Atmosphere 99

• The History of Water on Venus	100
• The Classical Runaway Greenhouse Effect	103
• An Alternative Runaway Greenhouse Model	106
• Evolution of Venus' Atmosphere	111

Chapter 7 The Future Evolution of Earth 116

• High-CO ₂ Atmospheres and Temperature Limits for Life	116
• Future Solar Evolution and Lifetime of the Biosphere	118
• A Geoengineering Solution to Solar Luminosity Increases	121

<i>Chapter 8</i>	The Martian Climate Puzzle	125
•	Evidence for Liquid Water near Mars' Surface	126
•	CH ₄ in Mars' Atmosphere?	130
•	Evidence That Water Flowed in Mars' Distant Past	131
•	When Did the Martian Valleys Form?	135
•	How Warm Was Early Mars?	136
•	Mechanisms for Warming Early Mars	138
•	Where Are the Carbonates?	144
<i>Chapter 9</i>	Is the Earth Rare?	147
•	Planetary Size / Magnetic Fields	147
•	Ozone and Ultraviolet Radiation	152
•	Availability of Nitrogen and the Importance of N ₂	155
•	Is Plate Tectonics Common?	157
•	A Planet's Impact Environment	161
•	Stabilization of Earth's Obliquity by the Moon	164
<i>Chapter 10</i>	Habitable Zones around Stars	171
•	Historical Attempts to Define the Habitable Zone	171
•	A More Modern Model for the Habitable Zone around the Sun	176
•	Hertzsprung-Russell Diagrams and Main Sequence Stars	179
•	Habitable Zones around Other Stars	181
•	Problems for Planets Orbiting Early-Type Stars	185
•	Problems for Planets Orbiting Late-Type Stars	188
•	Further Extensions of the Habitable Zone Concept	191
•	The Galactic Habitable Zone	192

Part IV: How to Find Another Earth • 195

<i>Chapter 11</i>	Indirect Detection of Planets around Other Stars	197
•	Barnard's Star	198
•	The Astrometric Method	199
•	Pulsar Planets	205
•	The Doppler Effect	207

Contents

• The Radial Velocity Method	210
• Gravitational Microlensing	216
Chapter 12 Finding and Characterizing Planets by Using Transits	221
• Transits of Mercury and Venus	221
• Transits of Extrasolar “Hot Jupiters”	222
• Space-Based Transit Searches: <i>CoRoT</i> and <i>Kepler</i>	227
• Observing Exoplanet Atmospheres during Transits	229
• Secondary Transit Spectroscopy	233
• Characterizing Earth-Like Planets around M Stars	235
Chapter 13 Direct Detection of Extrasolar Planets	239
• What Wavelength Region Should We Choose?	240
• Infrared Interferometers: <i>TPF-I</i> and <i>Darwin</i>	245
• Searching for Planets at Visible Wavelengths: <i>TPF-C</i>	248
• The Visible Occulter: <i>TPF-O</i>	253
• Nearby Target Stars	254
Chapter 14 The Spectroscopic Search for Life	258
• Spectral Resolution	259
• The Visible/Near-IR Region: <i>TPF-C</i> or <i>-O</i>	260
• The Thermal-IR Region: <i>TPF-I</i> or <i>Darwin</i>	266
• Looking for Life on Early Earth-Type Planets	269
• Possible False Positives for Life	271
• Polarization Measurements: Looking for the Glint of Surface Water	274
• The Holy Grail: Simultaneous Detection of O ₂ and Reduced Gases	276
Chapter 15 Prospects for the More Distant Future	284
• NASA’s <i>Life Finder</i> Mission	284
• Using the Sun as a Gravitational Lens	287
• The Drake Equation Revisited: The Search for Extraterrestrial Intelligence	290
Notes	299
Index	317