

Index

Page numbers in *italic* refer to figures

Abbreviations: SETI = search for extraterrestrial intelligence

- 51 Pegasi b exoplanet 92
- Adams, Douglas 142
- adaptive scenarios, evolution of intelligence 134–5, 137
- aestivation 12
- ALH 84001 meteorite 83–4
- Alpha Centauri triple-star system 141
- Anaxagoras 3–4
- Anaximander 3–4
- Anchordoqui, Luis 27
- ancient Greece, SETI 3–4
- Andromeda galaxy 34
- antibiotic resistance, bacteria 122
- apes *see* primates
- appendages, evolution 58–9, 126–7, 131
- archaea 46, 47
- Arcturus star 27
- Arecibo message 10, 37, 142
- Arecibo telescope, Puerto Rico 10, 91–2
- Aristarchus 3–4
- arms *see* appendages
- Arrhenius, Svante 112
- arthropods, evolution 50
- asexual reproduction, RIM definition of life 14
- ASKAP (Australian Square Kilometre Array Pathfinder) 10
- astronomical units (AU) 79, 79
- astrophotography 7
- atmospheres of exoplanets *see* biosignatures (atmospheric)
- autospermia 114
- bacteria, antibiotic resistance 122
- Berkeley SETI Research Center, California 141
- Betelgeuse 27
- Big Bang 34–7
- bilateral symmetry 40, 58, 126, 131
- binary star systems 95
- Biological Universe, The* (Arthur) 110
- biology of alien life 18, 39–40, 108–11, 138–40; *see also* evolution of organisms; nature of extraterrestrial life; parallel life school
- biosignatures, atmospheric 6, 9, 54
- definitions 99–100
- exoplanets 99–101

- habitability 64
- Mars 83
- spectroscopy 100–3, 102
- time until discovery of life 106–7
- Venus 80–2
 - see also oxygen biosignatures;
 - photosynthesis
- birds
 - intelligence 16
 - natural selection 116
- BLC-1 (Breakthrough Listen
 - candidate 1) 141
- brain size, evolution 131–4, 133
 - and human technology 136–7
 - see also intelligent life
- Breakthrough Initiatives, SETI 87, 98, 140–2
- Bruno, Giordano 4
- Capella star 27
- carbon-based life
 - biology of alien life 110, 111
 - common misunderstandings 154–5
 - information-storage capacity 41, 110
 - origins of life on Earth 41–2
- carbon dioxide, planetary
 - atmospheres 100–1
- Carrington event 66
- Cassini* missions, to moons of
 - Saturn 85–7
- cell-based life
 - common misunderstandings 154–5
 - origins of life on Earth 43, 44
 - see also eukaryotic cells; prokaryotic cells
- cephalization, evolution 58, 126, 131; see also brain size; intelligent life
- cetaceans (dolphins and whales), intelligence 16
- CFCs (chlorofluorocarbons), technosignatures 143
- chemistry of life 41–2; see also carbon-based life; water
- chemosynthesis 29, 33, 124–5, 129
- Chile, VLT (Very Large Telescope) 5
- chimpanzees 131, 132; see also primates
- choanoflagellates, evolution 117
- Chudnovsky, Eugene 27
- circumstellar habitable zone 71, 72, 155
- cladistics 50; see also classification of organisms
- classification of galaxies 24
- classification of organisms 49–52; see also cladistics; tree of life
- classification of stars 30
- CMEs (coronal mass ejections) 66
- Cocconi, Giuseppe 141
- Cockell, Charles 110
- CoLD (Confidence of Life Detection)
 - scale 81
- comets 87
- common misunderstandings 154–6
- complexity, evolution of 52, 53; see also intelligent life; multicellular organisms; plants
- contrasting life school, biology of alien life 108–11
- convergent evolution 109, 116; see also parallel life school
- Convergent Evolution on Earth: Lessons for the Search for Extraterrestrial Life* (McGhee) 109
- Conway Morris, Simon 109, 111
- Copernicus 4, 21–2, 31
- coronagraphs 107
- coronal mass ejections (CMEs) 66
- cosmic dark age 35–6
- cosmic structures
 - galaxies 23–7, 24

172 INDEX

- cosmic structures (cont.)
 planetary systems 31–3
 stars 27–31
 where to look for life see distribution of life
- Cosmic Zoo, The* (Schultze-Makuch and Bains) 110
- Cottrell, Geoff 5
- cryptobiosis 12, 13
- Cuvier, Georges 50
- cyanobacteria 47–8, 123
- dark energy 140
- Darling, David 109
- Darwin, Charles 115
- day length, and habitability 64
- definition of life 10–15, 13, 115
 common misunderstandings 154
 RIM definition 11–15
- definitions, other
 biosignatures 99–100
 intelligence 15–17, 57
 microbes 46–7
 multicellularity 52
 observable universe 20–3
- Deneb star 27
- Destiny or Chance Revisited* (Stuart Ross Taylor) 32
- dinosaurs 66, 72, 116
- direct-imaging space telescopes 94
- distance from Earth, criteria for SETI 96
- distance from Sun, planets of solar system 78–80, 79
- distribution of life through universe xvi, 18, 19
 importance of stars 28–31, 30
 observable universe 20–3
 planetary system 31–3
 possibility of life within stars 27–8
 references/further reading 158–60
 size of search field 25
- temporal dimension 36–7
- divergent radiation, evolution 117–19
- DNA 41–2
- dolphins, intelligence 16
- Dyson spheres, technosignatures 143
- Earth
 formation 32
 human evolution 131–5, 133
 origin of life 40–3, 44, 69–70
 oxygen 103–4
 elements of life
 arriving from space 112, 113
 Big Bang 34–7
 primordial nucleosynthesis 34–5
 recombination 35
 stars 28, 30–1
- ELT (Extremely Large Telescope), planned for Chile 107
- Enceladus, moon of Saturn 18, 85–6, 87
 energy creation, importance of
 stars 28–9
- Epsilon Eridani, searching for
 technosignatures 140–1
- Equations of Life, The* (Cockell) 110
- eukaryotic cells 45
 evolution 48
 unicellular 46–7
- Europa, moon of Jupiter 18, 86
- Europa Clipper* probe 87
- Europa Report* film 78
- evolution of organisms 3, 19
 bilateral symmetry 58
 broad features, alien life 39–40
 carbon-based life 41–2
 cells 43, 44
 cephalization 58
 extraterrestrial life 108–11
 intelligence 56–60, 126–8, 131–5, 133
 language 59
 manipulative appendages 58–9

- microbes 44–9
- movement/muscles/nerves 57
- multicellular 45, 46, 49–54, 53
- origins of life on Earth 40–3, 44
- plants 55–6
- references/further reading 160–1
- sociality 59
- speed of 29–30, 36
- time needed for evolution 28, 29, 30, 65–8
- universal constraints on 124
- water 42
- see also eukaryotic cells; prokaryotic cells; tree of life
- Exoplanet Atmospheres* (Seager) 105–6
- exoplanets 31–3
 - atmospheric
 - spectroscopy 100–3, 102
 - biosignatures 6, 99–101
 - evolution of organisms 119–21, 120
 - ideal criteria 95–6
 - lifespan of planets 34
 - likelihood of life 68–71, 72–6, 74, 94–5, 104–5
 - naming conventions 92, 93, 96
 - natural selection 115–16
 - oxygen as biosignature 101–6, 104
 - potentially habitable 96–9, 97
 - references/further reading 164–5
 - stages in the life of a planet 129–31
 - time until discovery of life 106–7
 - timeline of discovery of planets 91–4
- expanding universe 22–3
- extinction of life 129–30; see also mass extinction events
- Extraterrestrial: The First Sign of Intelligent Life Beyond Earth* (Loeb) 88
- extraterrestrial life, impacts of
 - finding 151–3; see also nature of extraterrestrial life; search for extraterrestrial intelligence
 - false-positive technosignatures 142
 - Fermi paradox/Enrico Fermi 144–50, 148, 156
 - 51 Pegasi b exoplanet 92
 - finches, Galapagos 122
 - flares, stars 66, 95
 - fossils 99–100
 - evolution of intelligence 131
 - Martian 83–5
 - fourth dimension see time
 - Frail, Dail 91–2
 - fungi, evolution 50
 - galactic habitable zone 71–2, 155
 - Galapagos archipelago 122
 - galaxies 23–7
 - classification 24
 - galactic habitable zone 71–2, 155
 - Galileo 4–5, 20
 - Galileo* spacecraft 85–7
 - geography of alien life see distribution of life
 - Goldilocks zone 63–5
 - Gould, Stephen Jay 121, 124
 - gravitational waves 140
 - Great Oxygenation Event 48, 144
 - Greaves, Jane 80–2
 - Greece, ancient, SETI 3–4
 - Green, James 1–2, 3, 81, 106, 142
 - greenhouse effect
 - Mars 83
 - Venus 64
 - habitability xv–xvi, 39, 61–2
 - exoplanets 96–9, 97
 - likelihood of inhabited planets 68–71, 72–6, 74
 - Mars 61, 63–4, 83
 - references/further reading 161–2
 - time needed for evolution to occur 65–8

174 INDEX

- habitable zones 63–5, 73
 circumstellar 71, 72, 155
 galactic 71–2, 155
 ideal criteria for habitable
 exoplanets 95
 haematite, Mars 83
 Hennig, Willi 50
Hen's Teeth and Horse's Toes
 (Gould) 124
 heterokonts, evolution 50, 124
 hibernation of organisms 12
 historical perspectives
 human technology 135–7
 observable universe 20
 SETI 3–5
 telescopes 4–6
Homo genus 131–5, 133
 hot Jupiters 32, 93
 Hoyle, Fred 112
 Huang, Su-Shu 63
 human/s
 evolution 131–5, 133
 intelligence 16–17
 technology 135–7
 humanoid form, intelligent life 139
Huygens probe, Titan 78, 85
 hydrothermal vents 41, 59, 70

Imagined Life (Trefil and
 Summers) 27, 110
Inevitable Humans in a Lonely Universe
 (Conway Morris) 109
 information storage, carbon-based
 life 41, 110
 inheritance
 and natural selection 115
 RIM definition of life 13–14
 intelligent life
 biology of alien life 121–3, 138–40
 definitions 15–17, 57
 evolution 56–60, 126–8
 human evolution 131–5, 133
 human technology 135–7
 impacts of finding extraterrestrial
 life 151–3
 references/further reading 167–8
 stages in the life of a planet 129–31
 see also brain size; search for
 extraterrestrial intelligence;
 technosignatures

 James Webb Space Telescope (JWST) 2,
 7, 106, 107
 Jodrell Bank, England 10
JUICE (Jupiter Icy Moons Explorer) 87
 Jupiter
 habitability 61–2
 moons of 85–7

 Kepler, Johannes 31
 Kepler-186 f exoplanet 93
 Kepler-452 b exoplanet 96, 97, 97–8
 Kepler Space Telescope 7
 Kepler-90 planetary system 32
 Kershenbaum, Arik 110
 Kraken Mare, Titan 87

 La Silla observatory, Chile 93
 land plants, evolution 55–6, 123–4
 language, evolution 59, 134
 laser signals 141
 legs see appendages
Life Everywhere (Darling) 109
Life's Solution (Conway Morris) 109
 lifespan of planets 34, 37, 64
 lifespan of stars 28, 29, 30, 64, 95–6
 light harvesting see photosynthesis
 light years 21
 likelihood of alien life
 common misunderstandings 154–5
 exoplanets 68–71, 72–6, 74, 94–5,
 104–5

- panpermia 113, 114
 - philosophical impacts of finding 152
 - solar system 89–90
- Linnaeus, Carl 50
- liquid water belt (habitable zone) 63–5;
 - see also water
- Loeb, Avi 88
- Lowell, Percival 5
- Luna 2* spacecraft 78
- Luyten b exoplanet 142
- LUVOR (Large Ultra-Violet, Optical, and Infra-Red) proposed space telescope 7–8, 94, 106, 107
- mammals, intelligence 16
- manufacture of elements see elements of life
- Marconi, Guglielmo 17
- Mars 22
 - habitability 61, 63–4, 83
 - SETI 5, 78, 82–5
- Mars and Its Canals* (Lowell) 5
- Mars as the Abode of Life* (Lowell) 5
- marsupial mammals, evolution 116, 118, 118
- mass extinction events 65–6
- Maxwell, James Clerk 17
- Mayor, Michel 92
- McGhee, George 109
- media reporting, SETI 3, 81, 84, 142
- Mercury
 - habitability 63–4
 - spin–orbit resonance 67
- metabolism
 - habitability 62
 - RIM definition of life 11–12, 13
- meteorite, Martian 83–4
- methane, planetary atmospheres 105
- METI (messaging extraterrestrial intelligence) 24, 37
- microbes
 - biology of alien life 110
 - definition 46–7
 - evolution 44–9
 - fossils 83–5
 - searching the solar system 78, 81–2
- Milky Way 23–7, 24
 - Fermi paradox 147, 148
 - galactic habitable zone 71, 72
 - likelihood of inhabited planets 73–5, 74
 - Orion spur 25, 26, 37–8, 72
 - SETI 37–8
- Milner, Yuri 87
- misunderstandings, common 154–6
- Monod, Jacques 121
- moons
 - Earth's 66–8, 78
 - Enceladus 18, 85–6, 87
 - Europa 18, 86
 - habitability 72–3
 - SETI 85–7
 - Titan 78, 85, 86–7
- Morrison, Philip 141
- Morse message (1963) 142
- movement, evolution 57, 126, 127, 131
- multicellular organisms
 - biology of alien life 110
 - common misunderstandings 154–5
 - evolution 45, 49–54, 53, 117
 - number of times they evolved 49, 50–2, 69
 - prokaryote multicellularity 46
- multiple-star systems 95
- muscles, evolution 57, 126, 127, 131
- naming conventions, exoplanets 92, 93, 96
- natural selection
 - evolution of intelligence 137
 - parallel life school 114–16

176 INDEX

- natural selection (cont.)
 terminological simplifications 121–3
 see also evolution
- Natural Selection* (Williams) 114–15
- nature of extraterrestrial life xvi, 39–40
 autopermia 114
 conflicting hypotheses 108–11
 intelligence 126–8
 panspermia 111–14
 photosynthesis 123–5
 references/further reading 166–7
 see also biology of alien life; parallel life school
- nerves, evolution 57, 126, 127, 131
- New Horizons* spacecraft, flyby of Pluto 78
- nuclear fusion, extraterrestrial technology 151
- observable universe 20–3
 common misunderstandings 154
 radius 22–3
 see also distribution of life
- observed universe 20, 154
- octopuses 16, 139
- On the Origin of Species* (Darwin) 115
- On the Revolutions of the Celestial Spheres* (Copernicus) 31
- open-mindedness 137, 139
- orbital eccentricity, and habitability 63–4
- organic chemistry see carbon-based life
- origins of life on Earth 40–3, 44, 69–70
- origins of possible life, Mars 82
- Orion spur, Milky Way 25, 26, 37–8, 72
- Other Minds* (Godfrey-Smith) 16
- 'Oumuamua interstellar object 87–8, 89, 143
- oxygen biosignatures 6, 54, 56, 101–6, 104
 common misunderstandings 155
- SETI 24, 25
- spectroscopy 101–3, 102
 see also photosynthesis
- Ozma, Project 5, 140–2
- panspermia 81–2, 111–14, 113
- parallel life school 108–11
 common misunderstandings 155–6
 intelligence 126–8, 138
 natural selection 114–16
 panspermia 111–14
 photosynthesis 123–5
 terminological simplifications 121–3
 tree of life 116–21, 118, 120
- parochial biology (contrasting life school) 108–11
- pattern and process distinction, evolution 116
- Perseus arm, Milky Way 25
- Perseverance* rover, Mars 83
- philosophical impacts, finding extraterrestrial life 152–3
- phloem vessels, plants 55
- phosphine, putative discovery on Venus 80–2
- photosynthesis 48, 54, 121–5
 impacts of finding extraterrestrial life 151
 where to look 144
 see also oxygen biosignatures
- photography (astrophotography) 7
- placental mammals, evolution 116, 118, 118
- planet 9 90
- planets
 lifespan 34, 37, 64
 stages in the life of 129–31
 see also exoplanets; solar system
- plants, complex/higher 55–6, 123–4;
 see also photosynthesis

- plate tectonics 70
- plumes of water, moons of Jupiter and Saturn 85–6
- Pluto
 - habitability 63–4
 - New Horizons* craft flyby 78
- potato blight 50
- primates 131
 - brain size 132
 - evolution 127
 - intelligence 16
- primordial nucleosynthesis 34–5
- process and pattern distinction, evolution 116
- Project Ozma 5, 140–2
- prokaryotic cells 45, 46
- Proxima b exoplanet 96, 97, 97, 98
- Proxima Centauri star 96, 97
- pulsars, planets orbiting 91–2

- Queloz, Didier 92
- Quintana, Elisa 93

- radial symmetry, evolution 40, 50
- radio signals 17, 57, 139–42
- radio telescopes 8–10
- Rare Earth* (Ward and Brownlee) 18–19, 110
- red algae 49
- red dwarf stars, tidal locking 68
- religious impacts of finding extraterrestrial life 152
- reproduction, and natural selection 115; *see also below*
- RIM (reproduction, inheritance, metabolism) definition of life 11–15, 13, 62
- RNA world hypothesis 42
- rocky exoplanets 95
- rogue planets 27, 33, 72–3

- Sagittarius arm, Milky Way 25
- Saturn, moons of 85–7
- Schiaparelli, Giovanni 5
- scientific impacts of finding extraterrestrial life 151
- search for extraterrestrial intelligence (SETI) xvi, 37–8
 - biology of alien life 18
 - definition of intelligence 15–17
 - definition of life 10–15, 13
 - geography of alien life 18
 - history of search 3–5
 - imminence/timescales 1–3
 - passive/active searching 24
 - questions we need to ask ourselves 17–19
 - references/further reading 157–8
 - solar system 77–8
 - telescopes 4–10, 9
 - time until discovery of life 106–7
 - where to look *see* distribution of life through universe
- segmented worms, evolution 50
- sensationalization, media reports 3, 81, 84, 142
- SETI *see* search for extraterrestrial intelligence
- SETI Institute, California 141
- sexual reproduction, RIM definition of life 14
- sexual selection 137
- shadow life 41
- silicon-based organisms 3, 41–2
- Sirius star 27
- slime moulds 44
- social impacts, finding extraterrestrial life 151–2
- sociality, evolution 59
- solar system 3, 18, 31–2, 33
 - bodies/constituent parts of 90
 - common misunderstandings 155

178 INDEX

- solar system (cont.)
 distances of planets from the sun 78–80, 79
 habitability 63–4, 72
 interstellar objects 87–8
 likelihood/number of inhabited planets 89–90
 Mars 82–5
 moons of Jupiter and Saturn 85–7
 ‘Oumuamua interstellar object 89
 oxygen biosignatures 103–4
 references/further reading 162–4
 spacecraft/missions 77–8
 stages in the life of a planet 129–31
 Venus 80–2
- Sonar Calling radio message sent by humans 142
- space telescopes 7, 94, 106–7
- spatial distribution of life *see* distribution of life
- spectroscopy 8, 9, 100–3, 102
- spin–orbit resonance, Mercury 67
- Spitzer Space Telescope 106
- sponges 117
- Sputnik 1* spacecraft 77
- stars 27–31
 classification 30
 energy creation 28–9
 flares and coronal mass ejections 66
 ideal size for planets with life 95
 importance to life on orbiting planets 28–31
 lifespan 28, 29, 30, 36, 64, 95–6
 manufacture of elements needed for life 28, 30–1
 possibility of life within stars 27–8
 visible with naked eye 27
- stromatolites 84, 99
- subsurface water, moons of Jupiter and Saturn 86
- Sun 28–9, 66
- symmetry of organisms *see* bilateral symmetry; radial symmetry
- synchronous rotation, tidal locking 66–8
- tardigrades 12, 13, 42, 112
- Tau Ceti star 96, 97, 140–1
- technology, human 135–7
- technosignatures of intelligence 54, 56, 99, 130, 139–40
 Fermi paradox 144–50, 148
 other than radio waves 143–4
 specific projects searching for 140–2
 sent by humans 141–2
- telescopes 5–10, 9
 historical perspectives 4–6
 radio telescopes 8–10
 size factors 6–7
 space 7
 spectroscopy 8, 9
 wavelengths of light 7–8
- Telescopes: A Very Short Introduction* (Cottrell) 5
- temperate zone (habitable zone) 63–5
- temporal dimensions *see* time
- terminological simplifications, parallel life school 121–3
- terraspermia 114
- terrestrial plants 55–6, 123–4
- TESS (Transiting Exoplanets Survey Satellite) space telescope 7
- Theia 32
- tidal heating 86–7
- tidal locking 66–8
 time factors
 pace of discovery 106–7
 SETI 34–7
- time-independent features, life on Earth 40
- time needed for evolution to occur

- habitability 65–8; *see also* lifespan of stars
- intelligence 128, 149
- Titan 78, 85, 86–7
- TOI 700 (700th TESS Object of Interest) 96, 97
- transit method of exoplanet detection 93–4
- TRAPPIST (Transiting Planets and Planetesimals Small Telescope), Chile 93
- TRAPPIST-1 planetary system 93–4
- tree of life 49–52, 116–21, 118, 120
- trees, evolution of 55–6

- universal biology *see* parallel life school

- variation, and natural selection 115
- vascularity, plants 55
- Vega star 27
- Venera spacecraft 78
- Venus
 - atmosphere 80–2, 103–4
 - habitability 63–4
 - Venera spacecraft 78
- Very Short Introduction to Astrobiology* (Catling) 11
- Viking 1 and 2 landers, Mars 82

- Villanueva, Geronimo 82
- VLT (Very Large Telescope), Chile 5
- Voyager spacecraft 78, 143

- Wallace, Alfred Russel 137
- water, liquid 33, 42
 - habitable zones 63–5
 - Mars 82–5
 - moons of Jupiter and Saturn 85–7
- wavelengths of light, telescopes 7–8, 9
- Webb Space Telescope 2, 7, 106, 107
- Weryk, Robert 87
- whales, intelligence 16
- wheels, universal constraints on evolution 124
- where to look *see* distribution of life through universe
- Whittaker, Robert 50
- Wickramasinghe, Chandra 112
- Williams, George C. 114–15
- Wolszczan, Aleksander 91–2
- Wyndham, John 138

- xylem, vascularity in plants 55

- Zoologist's Guide to the Galaxy, The* (Kershnerbaum) 110