#### **SUBJECT**

```
Α
AAVSO (American Association of Variable Star Observers), Spectroscopic Database (AVSpec), 2:15
Abell 21 (Medusa Nebula), 2:56, 59
Abell 85 (galaxy), 4:11
Abell 2384 (galaxy cluster), 9:12
Abell 3574 (galaxy cluster), 6:73
active galactic nuclei (AGNs). See black holes
Aerojet Rocketdyne, 9:7
airglow, 6:73
al-Amal spaceprobe, 11:9
Aldebaran (Alpha Tauri) (star), binocular observation of, 1:62
Alnasl (Gamma Sagittarii) (optical double star), 8:68
Alpha Canum Venaticorum (Cor Caroli) (star), 4:66
Alpha Centauri A (star), 7:34–35
Alpha Centauri B (star), 7:34-35
Alpha Centauri (star system), 7:34
Alpha Orionis. See Betelgeuse (Alpha Orionis)
Alpha Scorpii (Antares) (star), 7:68, 10:11
Alpha Tauri (Aldebaran) (star), binocular observation of, 1:62
amateur astronomy
  AAVSO Spectroscopic Database (AVSpec), 2:15
  beginner's guides, 3:66, 12:58
  brown dwarfs discovered by citizen scientists, 12:13
  discovery and observation of exoplanets, 6:54-57
  mindful observation, 11:14
  Planetary Society awards, 5:13
  satellite tracking, 2:62
  women in astronomy clubs, 8:66, 9:64
Amateur Telescope Makers of Boston (ATMoB), 8:66
American Association of Variable Star Observers (AAVSO), Spectroscopic Database (AVSpec), 2:15
Andromeda Galaxy (M31)
  binocular observations of, 12:60
  consumption of dwarf galaxies, 2:11
  images of, 3:72, 6:31
  satellite galaxies, 11:62
Antares (Alpha Scorpii) (star), 7:68, 10:11
Antennae galaxies (NGC 4038 and NGC 4039), 3:28
Apollo missions
  commemorative postage stamps, 11:54–55
  extravehicular activity distance and time, 4:13
  total lunar samples, 4:13
Apollo 13 mission
  interview with Jim Lovell, 4:18-27
  overview of, 4:18-27
  planned extravehicular activity, 4:13
  3D images of, 4:28-35
Apollo 17 mission, 3:11
A-PUFFERs (Autonomous Pop-Up Flat Folding Explorer Robots), 7:13
Aguila (constellation), observations within, 8:50–51
Arecibo Observatory, cable failure, 12:12
ARIEL (Atmospheric Remote-sensing Infrared Exoplanet Large-survey) mission, CASE instrument, 3:9
Arp 84 (Heron Galaxy; NGC 5394 and 5395), 4:9
Arp-Madore 2026-424 (galaxy collision), 3:7
```

```
Arrokoth (Ultima Thule; 2014 MU<sub>69</sub>)
   officially named, 2:9
   overview of New Horizons flyby, 1:28
  planet formation and, 6:11
Artemis program
   contract for engines, 9:7
   graduation of first class of astronauts eligible for, 5:15
   proposed first mission, 1:25
ASASSN (Comet C/2018 N2), 3:70
asterisms. See also names of specific asterisms
   defined, 9:44
   observing, 9:44-49
asteroids
   See also names of specific asteroids
  Centaurs, 9:9
   closest flyby to Earth, 12:9
   crater from ancient impact on Earth, 5:10
   Earth ice age possibly caused by dust from collision of, 1:11
   effect of radiation from giant dying stars on, 6:9
   originating in other star systems, 8:70, 11:12
   search for dangerous near-Earth objects, 8:11
   zodiacal positions in early 2020, 5:15
astroimaging
   Canon EOS Ra camera, 5:62-63
   Chroma Technology filters, 9:60-61
   suggestions to mitigate impact of Starlink satellites on, 12:11
   wide-field imaging, 8:52-55
astronauts
   Al Worden, 7:9
   brain and pituitary gland changes in microgravity, 8:13
   Christina Koch, 6:11
   coating to prevent lunar dust from clinging, 4:9
   graduation of first class eligible for Artemis program, 5:15
   heart muscle tissue study, 7:9
   high number of applicants, 8:9
   Jim Lovell, 4:18-27
   longest time in space for a woman, 6:11
   melatonin for prevention of bone loss, 1:11
   microgravity and intestinal cells, 4:11
   oral contraceptives and clotting, 9:9
   past and future of manned space exploration, 5:18
   smart glove for, 3:7
   treatment of blood clot, 5:11
   Twins Study (Scott and Mark Kelly), 1:24
   vegetables grown in space, 7:8-9
astronomers
   Elijah Hinsdale Burritt, 5:52-55
   John Russell Hind, 1:60
   V.M. Slipher, 5:31–35
astronomy
   astronomy guides, 4:64, 12:58
   beginner's guides, 3:66
   challenges during the summer, 7:66
   commemorative postage stamps, 11:50-55
   comparing Earth's geologic timescale to distant celestial objects, 10:30-35
   creating calendar of upcoming observational opportunities, 1:64
```

```
Ghost Hunt, 9:62
  mindful observation, 11:14
  observations during February, 2:64
  observations from Costa Rica, 9:54-59
  observing nothing, 4:16
  observing pairs of objects, 2:56-59
  subitization, 3:14
  top ten stories of 2019, 1:20-31
  visceral thrill of viewing astronomical objects, 8:16
  women in astronomy clubs, 8:66, 9:64
astronomy guides, 3:66, 4:64, 12:58
Astronomy magazine
  Star Products, 10:54-61
  top 10 stories of 2019, 1:20-31
Atik (Burnham 535) (double star), 1:58
ATLAS. See Comet C/2019 Y4 (ATLAS)
ATMoB (Amateur Telescope Makers of Boston), 8:66
atmospheres
  composition of atmosphere of Earth, 8:12
  composition of atmosphere of Neptune, 9:12, 12:43-44
  composition of atmosphere of Titan, 9:31
  composition of atmosphere of Uranus, 9:12, 12:43-44
  composition of atmospheres of giant planets, 9:12
  composition of atmospheres of terrestrial planets, 8:12
  developing planetary atmospheres, 2:11, 9:68-69
  effect of magnetic fields on exoplanet atmospheres, 3:9
  effects of dusty, 10:9
  effects of life on composition of, 9:27
  imaging Antares' atmosphere, 10:11
  meteors in atmosphere of Mars, 4:71
  pressure changes on Pluto, 9:9
  searching for life by probing exoplanet atmospheres, 9:24-26
  temperature of upper atmosphere of Neptune, 9:12
  water in atmosphere of Jupiter, 6:12
  water vapor in atmosphere of Europa, 3:12
  water vapor in atmosphere of exoplanets, 1:16
  weight of column of air on Earth, 8:12
Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL) mission, CASE instrument, 3:9
atomic clocks, 1:14
atoms, why not expanding at same rate as space, 4:70
aurorae
  "dunes," 6:7
  on exoplanets, 7:9
  images of, 6:72
Australia Telescope Compact Array, 1:50, 52
Autonomous Pop-Up Flat Folding Explorer Robots (A-PUFFERs), 7:13
B
Baby Nebula (Soul Nebula; IC 1848), 6:71, 8:73
Barnard 4 (dark nebula), 1:59
Barnard 22 (dark nebula), 2:70-71
Barnard 92 (dark nebula), 8:68
Barnard 93 (dark nebula), 8:68
Barnard 150 (Seahorse Nebula), 5:71
Barnard's E (dark nebulae), 8:51
```

```
Barnard's Star, 7:30, 32
Barnard's Star b (exoplanet), 4:50
barred spiral galaxies. See names of specific barred spiral galaxies
Bear Claw Nebula (Hartl-Dengl-Weinberger 2; Sharpless 2-200), 4:73
Beehive Cluster (M44), 2:72
Belt of Orion (Rake; Three Kings) (asterism), 9:47
Bennu (asteroid)
  landing rehearsals, 12:11
  physical sample of surface, 1:31, 9:7
BepiColombo mission, flyby of Earth, 8:13
Beta Canum Venaticorum (Chara) (star), 4:66
Beta Ceti (star), 11:60
Beta Orionis. See Rigel (Beta Orionis)
Betelgeuse (Alpha Orionis) (star)
  binocular observation of, 1:62
  brightness and shape changes, 6:7, 10:7, 12:12
  brightness during future supernova, 7:71
  outburst of hot gas as possible cause of dimming, 12:12
  star spots as possible cause of dimming, 10:7
"Biden" (2012 VP113) (dwarf planet), 1:45-48
Big Bang
  origin of concept, 6:32-33
  puzzling problems affecting concept of, 5:20-29
binary star systems (double stars)
  See also names of specific binary star systems
  exoplanets orbiting, 1:64, 5:9
  formation of, image of intertwined protoplanetary disks, 2:9
binocular astronomy
  astronomy guides, 4:64
  Celestron Nature DX ED 10x50 Binoculars, 2:60-61
  observations within Canes Venatici, 4:66
  observations within Canis Minor, 3:64
  observations within Cetus, 11:60
  observations within Corvus, 5:66
  observations within Delphinus, 9:66
  observations within Orion, 1:62
  observations within Sagittarius, 8:68
  observations within Scorpius, 7:68
  observing Andromeda Galaxy and companions, 12:60
  observing Mira, 10:62-63
black dwarfs, when Sun will become a black dwarf, 4:70-71
black holes
  See also Sagittarius A* (Sgr A*)
  calculating mass of, 3:68
  closest to Earth, 9:12
  coronas, 11:12
  in dwarf galaxies, 5:11
  first image of, 1:20–21, 30–31, 10:16–17
  gravitational waves ringing after merger of, 1:11
  intermediate-mass, 8:13, 12:10
  largest detected explosion from, 6:9
  lighter than expected, at center of galaxy, 11:7
  most massive discovered, 4:11
  nested, 3:9
  possibility that "Planet Nine" is a black hole, 3:8-9
  possible, within Fireworks Galaxy, 1:14
```

```
primordial, 3:8-9
  ruling out as origin of some FRBs, 10:7
  supermassive, collisions between, 12:62
  supermassive, stunting star formation in dwarf galaxies, 2:12
  supermassive, tearing apart massive star, 2:11
  three at center of merging galaxies, 4:12
  Tidal Disruption Events, 5:11
  X-shaped twin jets erupting from, 9:11
Blaze Star (T Coronae Borealis; T CrB) (binary star system), 7:62
Blue Origin, Blue Moon lander, 1:25
Boeing CST-100 Starliner, 1:25
Bolshoi Azimuthal Telescope, comparison of mirror sizes, 5:11
Broken Engagement Ring (asterism), 9:48
brown dwarfs
  discovered by citizen scientists, 12:13
  discovered by Spitzer Space Telescope, 6:21
  wind speed on, 8:14
Bubble Nebula (NGC 7635), 3:18–19
Burnham 535 (Atik) (double star), 1:58
Burritt, Elijah Hinsdale, 5:52-55
Butterfly Nebula (Bug Nebula; NGC 6302), 3:22, 10:72
\mathbf{C}
California Nebula (NGC 1499), 1:56-57, 8:13
Callisto (moon of Jupiter), historical observations of, 11:46-49
Canberra Deep Space Communication Complex (CDSCC), 1:54
Canes Venatici (constellation), binocular observations within, 4:66
Canis Minor (constellation), binocular observations within, 3:64
Canon EOS Ra camera, 5:62-63
carbon
  exchanged in breathing, 7:14
  origin of in stars, 7:14
Carina Nebula (NGC 3372), 2:73, 3:22-23, 6:23
Cartwheel Galaxy, 1:12
Cassiopeia A (supernova remnant), 6:25
Castor (double star), 2:58-59
Cat's Paw Nebula (NGC 6334), 6:22-23
CDSCC (Canberra Deep Space Communication Complex), 1:54
Cederblad 110 (reflection nebula), 9:70
Cederblad 111 (reflection nebula), 9:70
Cederblad 112 (reflection nebula), 9:70
Celestron
  Nature DX ED 10x50 Binoculars, 2:60-61
  60th anniversary of, 10:48-53
cement, solidifying in microgravity environment, 1:11
Centaurs, origin of, 9:9
Centaurus A (NGC 5128), 2:70-71
Cerberus Fossae (feature on Mars), 6:8
Ceres (dwarf planet), briny sea beneath surface of, 12:11
Cetus (constellation), binocular observations within, 11:60
Chamaeleon Infrared Nebula, 9:70
Chang'e-3 mission, survival time, 3:11
Chang'e-4 mission
  ground-penetrating radar, 6:10
  maintaining communication with, 9:68
```

```
overview of mission, 1:22-23
Chang'e-5 mission, 1:23
Chara (Beta Canum Venaticorum) (star), 4:66
chemistry
  formation of elements, 5:45–47
  formation of elements heavier than iron, 12:62–63
Chroma Technology filters, 9:60-61
Circlet of Pisces (asterism), 9:45-46
Coalsack Nebula, 12:31
Coathanger (asterism), 9:45–46
Comet 1P/Halley, commemorative postage stamps, 11:52-54
Comet 2I/Borisov, 1:10-11, 2:26-27, 8:13
Comet 109P/Swift-Tuttle, as most dangerous object, 10:12
Comet 260P McNaught, 3:69
Comet C/1995 O1 (Hale-Bopp), commemorative postage stamps, 11:52
Comet C/2017 T2 (PanSTARRS), 7:73
Comet C/2018 N2 (ASASSN), 3:70
Comet C/2019 Y4 (ATLAS)
  breakup of, 8:9
  images of, 8:72, 9:72
Comet C/2020 F3 (NEOWISE)
  images of, 12:64-65
  overview of, 10:8-9
Comet C/2020 F8 (SWAN), 10:72
  See also names of specific comets
  determining origin from other stars, 8:70
  discovered by SOHO, 10:11
  formation of, 1:9
conjunctions, of Jupiter and Saturn, 12:14
constellations
  See also names of specific constellations
  movement of Sun in the elliptic, 2:13
  percentage of time Saturn spends in each, 3:8-9
  position of asteroids in early 2020, 5:15
contact binaries. See names of specific contact binaries
Cor Caroli (Alpha Canum Venaticorum) (star), 4:66
Corvus (constellation), binocular observations within, 5:66
cosmic expansion
  effects on concept of Big Bang, 5:26-28
  origin of concept, 6:32-33
cosmic rays, radiation shielding for proposed quantum computers, 12:11
Cosmic Reef (NGC 2014 and 2020), 7:7
cosmic web, studying via algorithm inspired by slime mold, 7:12
cosmology, puzzling problems affecting concept of Big Bang, 5:20–29
Cosmos (television series), 4:44–49
COVID-19 pandemic
  attack on science and, 9:12
  Curiosity rover mission team working from home during, 8:13
  scientists' view of interesting times, 10:64
  telescopes and observatories closed due to, 8:10-11
Crab Nebula (M1), 3:26
Crab pulsar, 10:12
craters
  See also names of specific craters
  on Earth, ancient asteroid impact, 5:10
```

```
on Moon, history of, 2:28-35
Crew Dragon capsule
   first spaceflight, 1:25
   splashdown, 11:7
   transporting astronauts to ISS, 9:8–9
CubeSats, to test orbit of proposed lunar space station, 1:11
Curiosity rover
   mission team working from home during COVID-19 pandemic, 8:13
   panoramic surface image, 7:9
   selfie image of, 2:14
CVMP 1 (planetary nebula), 6:9
Cygnus Loop (Veil Nebula), 6:69
Daniel K. Inouve Solar Telescope, first solar image from, 6:7
Dark Doodad (Sandqvist 149) (dark nebula), 4:72, 12:31
dark energy
   composition of universe, 5:28
   effects on concept of Big Bang, 5:28
dark matter
   composition of universe, 5:28
   effects on concept of Big Bang, 5:23-26
   galaxies lacking, 3:44-51, 4:10-11
   gravitational lensing and, 1:69
   identifying and colorizing in imagery, 11:62
   lack of visible interaction with light, 1:69
   simulation of galaxy formation without, 6:9
   X-rays from, 7:9
dark nebulae, observed by Gaia mission, 12:28-31. See also names of specific dark nebulae
Dark Shark Nebula (LDN 1235), 1:70
DART (Double Asteroid Redirection Test) mission, purpose of, 10:9
DAVINCI+ (Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging Plus) mission, 6:9
Dawn spacecraft, briny sea beneath surface of Ceres, 12:11
Deep Space Atomic Clock, 1:14
Deep Space Network (DSN), ground breaking for Californian radio antenna, 6:9
Delphinus (constellation), binocular observations within, 9:66
Delta Geminorum (Wasat) (double star), 2:58–59
Delta Scuti stars, 9:10
Didymos (binary asteroid system), 10:9
Dimorphos (asteroid moonlet), 10:9
Double Asteroid Redirection Test (DART) mission, purpose of, 10:9
Double Bubble Nebula (NGC 2371–2), 2:58–59
double stars. See binary star systems (double stars); names of specific binary star systems
Draco Trio (galaxy group), 4:58, 61
Drake equation, 9:26
Druyan, Ann, interview with, 4:44-49
DSN (Deep Space Network), ground breaking for Californian radio antenna, 6:9
dust clouds, mapping in 3D, 10:21
dwarf galaxies
   See also names of specific dwarf galaxies
   lacking dark matter, 4:10-11
   supermassive black holes in, 5:11
   supermassive black holes possibly stunting star formation in, 2:12
dwarf planets. See names of specific dwarf planets
Dyson, Freeman, death of, 6:9
```

```
Ε
Eagle Nebula (M16), 3:21, 6:23
Earth
  as ancient water world, 7:9
  comparing geologic timescale to distant celestial objects, 10:30-35
  comparison of orbital planes, 5:13
  composition of atmosphere, 8:12
  crater from ancient asteroid impact discovered, 5:10
  effects of life on composition of atmosphere, 9:27
  ice age possibly caused by dust from asteroid collision, 1:11
  length of ancient day on, 7:13
  Operation IceBridge, 4:14
  slowing rotation of, 10:12
  weight of column of air, 8:12
EBLM J0555-57Ab (star), physical properties of, 7:27
  lunar, 9:73, 12:16
  solar, 1:32-35, 7:72, 9:50-53
E-ELT (European Extremely Large Telescope), comparison of mirror sizes, 5:11
EHT (Event Horizon Telescope), 10:16-19
elliptic, 2:13
elliptical galaxies
  See also names of specific elliptical galaxies
  best for spring and fall observation, 4:58-61
  formed from colliding spirals, 8:71
emission nebulae. See names of specific emission nebulae
Enceladus (moon of Saturn)
  origin of "tiger stripes," 4:11
  subsurface oceans, 9:22-23
Endeavor spacecraft, 11:7
Engagement Ring (asterism), 2:57
ESA (European Space Agency). See names of specific spacecraft and missions
ESO (European Southern Observatory), Visible and Infrared Survey Telescope for Astronomy (VISTA), 1:9
Eta Corvi (star), dust and debris belts surrounding, 7:50-55
Europa (moon of Jupiter)
  historical observations of, 11:46-49
  subsurface oceans, 9:22-23
  water vapor in atmosphere of, 3:12
Europa Clipper spacecraft, 3:12
European Extremely Large Telescope (E-ELT), comparison of mirror sizes, 5:11
European Southern Observatory (ESO), Visible and Infrared Survey Telescope for Astronomy (VISTA), 1:9
European Space Agency (ESA). See names of specific spacecraft and missions
Event Horizon Telescope (EHT), 10:16-19
ExoMars mission
  ExoMars Trace Gas Orbiter, 1:31
  launch postponement, 7:9
  study of ancient life on Earth in preparation for mission, 3:11
extrasolar planets (exoplanets)
  See also names of specific exoplanets
  amateur discovery and observation of, 6:54–57
  completion of TESS's primary mission, 12:11
  defining super-Earths, 6:68-69
  discovered via aurora-like radio signals, 7:9
  effects of crowded star cluster on planet formation, 9:7
```

```
estimate of number of Earth-like, 10:9
  first image of multiple exoplanets orbiting star, 11:12
  gas giant orbiting red dwarf, 2:14
  gravitationally interactive orbits, 11:9
  habitable zones, 9:25
  hottest known, 5:15
  impact of magnetic fields on "Goldilocks" exoplanets, 3:9
  machine-learning algorithms to recognize signals of, 12:11
  nearest possibly habitable, 4:50-51
  only 100 light-years from Earth, 5:11
  orbiting double star systems, 1:68, 5:9
  orbiting red dwarf, 8:13
  orbiting white dwarf, 4:12
  possible image of formation of, 9:10
   "super-puffs," 4:11
  suspected exoplanet turns out to be minor body collision, 8:14
  variation in shape of, 10:70–71
  water vapor in atmosphere of, 1:16
extraterrestrial life
  Drake equation, 9:26
  estimate of number of intelligent communicating civilizations in Milky Way, 10:7
  searching for by probing exoplanet atmospheres, 9:24-26
  searching for by seeking out alien signals, 9:26-27
  searching for through robotic and sample-return missions, 9:20–24
Eyes (NGC 4435 and NGC 4438) (galaxy pair), 4:54-55
F
False Comet (asterism), 9:48–49
"Farout" (2018 VG18) (dwarf planet), 1:44-46
fast radio bursts (FRBs)
  See also names of specific fast radio bursts
  overview of discoveries regarding, 1:29
  pinpointing of second repeating FRB, 5:14
  ruling out central black holes as origin of some, 10:7
Ferrero 6 (planetary nebula), 5:71
15 and 17 Canum Venaticorum (double star), 4:66
Fireworks Galaxy (NGC 6946), 1:14, 6:34
594 Mireille (asteroid), 5:15
Fomalhaut b (minor body collision), 8:14
Fornax Dwarf (elliptical dwarf galaxy), 4:60
40 Persei (Struve 431) (double star), 1:57-58
471 Papagena (asteroid), 11:58
frame-dragging, 6:12
FRB 180916.J0158+65 (fast radio burst), 5:14
FRBs, See fast radio bursts (FRBs); names of specific fast radio bursts.
G
G255.8+10.9 (planetary nebula), 9:70-71
Gaganyaan mission, 7:7
Gaia mission
  comparison of mirror sizes, 5:11
  dark nebulae observed by, 12:28-31
  finding Sun's siblings, 7:48-49
  mapping dust clouds in 3D, 10:21
  measuring parallax, 10:20
```

```
Radcliffe Wave star-forming region, 10:20–21, 23
  repeated collisions between Milky Way and Sagittarius, 9:9
  third data release, 1:31
  warped shape of Milky Way, 7:7
Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE), 6:20–21
galaxies
  See also names of specific galaxies; names of specific types of galaxies
  classification of, 6:33-34
  discovery of, 6:28-32
  dust shrouding massive early galaxy, 2:9
  early completion of star formation, 5:11
  image of colliding, 4:9
  lacking dark matter, 3:44-51, 4:10-11
  number of, 6:34–35
  redshift, 6:32
  shocked gas generated by merger of, 5:12
  simulation of formation without dark matter, 6:9
  "super spiral," 2:11
  variety of, 6:35
  X-galaxies, 9:11
galaxy clusters, collisions between, 9:12. See also names of specific galaxy clusters
Galileo Galilei, artwork of, 11:24-31
Gamma Equulei (double star system), 9:66
Gamma Sagittarii (Alnasl) (optical double star), 8:68
Gamma Virginis (Porrima) (double star), 4:56
Ganymede (moon of Jupiter)
  historical observations of, 11:46-49
  infrared map of north pole, 11:7
Gateway lunar outpost
  CubeSats to test orbit of, 1:11
  HALO module, 10:9
gegenschein, 5:70
Gemini North and South Telescopes, comparison of mirror sizes, 5:11
Geminid meteors
  image of, 9:71
  source of, 4:11
  in 2020, 12:50-51
Geography of the Heavens, The (Burritt), 5:52–55
Ghost Hunt, 9:62
Ghost of Cassiopeia (IC 63) (reflection nebula), 4:73
Giant Magellan Telescope (GMT), comparison of mirror sizes, 5:11
GJ 667 c (exoplanet), 4:51
GJ 3323 b (exoplanet), 4:50-51
GJ 3512 b (exoplanet), 2:14
Glenn, Annie, 9:7
Gliese 625 b (exoplanet), 4:51
Gliese 832 c (exoplanet), 4:50–51
GLIMPSE (Galactic Legacy Infrared Mid-Plane Survey Extraordinaire), 6:20–21
globular clusters
  See also names of specific globular clusters
  observing through the seasons, 6:58-63
  wrenched apart by gravitational forces, 11:10
GMT (Giant Magellan Telescope), comparison of mirror sizes, 5:11
"Goblin" (2015 VG387) (dwarf planet), 1:45-46
gold
  formation of, 12:62-63
```

```
stellar origin of, 11:40-45
Gran Telescopio Canarias, comparison of mirror sizes, 5:11
gravitational lensing, dark matter and, 1:69
gravitational waves
   first signal seen with one detector, 5:9
   ringing after black hole merger, 1:11
   spectrum, 10:11
   suggesting birth of intermediate-mass black hole, 12:10
  brain and pituitary gland changes in microgravity, 8:13
   cement solidifying in microgravity environment, 1:11
   globular clusters wrenched apart by gravitational forces, 11:10
   microgravity and intestinal cells, 4:11
Great Square of Pegasus (asterism), 9:44-45
Grus Triplet (galaxy group), 1:72
GW190521 (gravitational wave), 12:10
Η
h3945 (double star), 1:62
Habitation and Logistics Outpost (HALO) module, 10:9
Haidinger's Brush, 10:66
Hale Telescope, comparison of mirror sizes, 5:11
Hale-Bopp (Comet C/1995 O1), commemorative postage stamps, 11:52
HALO (Habitation and Logistics Outpost) module, 10:9
Hartl-Dengl-Weinberger 2 (Bear Claw Nebula; Sharpless 2-200), 4:73
Hayabusa2 spacecraft
   departure from Ryugu, 3:7
   Mobile Asteroid Surface Scout (MASCOT) rover, 3:11
   overview of mission, 1:26–27
HBC 672 (star), 11:66
HD 162826 (star), 7:48
HD 186302 (star), 7:49
Head of Hydra (asterism), 9:47-48
Headphone Nebula (JE 1; PK 164+31.1), 11:65
Heart Nebula (IC 1805), 6:71
helicopters
  Ingenuity drone, 11:9
   possibility of using on Mars, 5:68-69
Helix Nebula (NGC 7293), 1:12, 6:25
Herbig-Haro 46/47 (protostar), 6:21
Hercules Cluster (M13), 6:62
Heron Galaxy (Arp 84; NGC 5394 and 5395), 4:9
Hertzsprung-Russell (HR) diagram, 7:11, 59
Hind, John Russell, 1:60
Hind's Crimson Star. See R Leporis (Hind's Crimson Star)
Hind's Variable Nebula (NGC 1555), 1:60
Hippocamp (moon of Neptune), discovery of, 1:22
Hockey Stick (NGC 4656/7), 5:61
HR (Hertzsprung-Russell) diagram, 7:11, 59
HR 6819 (double star system), 9:12
Hubble Deep Field image, 3:29
Hubble Space Telescope
   annual image of Saturn, 1:11
   comparison of mirror sizes, 5:11
   memories of first-light image and reaction, 6:16
```

```
overview of, 3:18-29
  30th anniversary of, 1:31, 3:18–29, 7:7
Hubble Ultra Deep Field image, 3:29
Huygens spaceprobe, survival time, 3:11
Hygiea (asteroid), considered dwarf planet, 3:9
hypervelocity stars, 7:29
IC 10 (starburst galaxy), 8:73
IC 63 (Ghost of Cassiopeia) (reflection nebula), 4:73
IC 348 (star cluster), 1:58, 5:11
IC 750 (galaxy), 11:7
IC 972 (planetary nebula), 4:57
IC 1805 (Heart Nebula), 6:71
IC 1848 (Baby Nebula; Soul Nebula), 6:71, 8:73
IC 2087 (reflection nebula), 2:70-71
IC 2118 (Witch Head Nebula), 9:72
IC 2163 (spiral galaxy), 2:59
IC 2944 (Running Chicken Nebula), 10:72
InSight lander
  marsquakes, 6:8-9
  overview of mission, 1:26-27
Intergalactic Wanderer (NGC 2419) (globular cluster), 6:59-60
International Space Station (ISS)
  AI robot, 4:11
  heart muscle tissue study, 7:9
  longest time in space for a woman, 6:11
  SpaceX delivers astronauts to, 9:8–9
  vegetables grown on, 7:8-9
Io (moon of Jupiter), historical observations of, 11:46-49
iron, raining on exoplanet, 7:13
irregular galaxies. See names of specific irregular galaxies
ISS. See International Space Station (ISS)
J
James Webb Space Telescope (JWST)
  adjusted launch date, 11:9
  comparison of mirror sizes, 5:11
  connection of two halves of, 1:11
JE 1 (Headphone Nebula; PK 164+31.1), 11:65
Jewel Bug Nebula (NGC 7027), 10:9
Jezero Crater (feature on Mars), 6:47
Job's Coffin (asterism), 9:66
Johnson, Katherine, death of, 6:7
JUICE (JUpiter ICy moons Explorer) mission, 3:12
Juno spacecraft
  See also Jupiter
  array of cyclones, 4:11
  infrared map of Ganymede's north pole, 11:7
  See also names of moons orbiting; names of specific missions to
  ammonia "mushballs," 12:9
  cloud features of, 8:57
  comparison of orbital planes, 5:13
  composition of atmosphere, 9:12
```

```
conjunction with Saturn, 12:14
  formation of comets, 1:9
  hexagonal array of cyclones, 4:11
  historical observations of Galilean moons, 11:46-49
  image of, 3:20
  image of with Saturn and Mars, 11:65
  increase in size needed to become a star, 10:70
  number of moons, 6:11
  observing at opposition, 8:56-59
  radiation belt, 2:68-69
  thunderstorms on, 12:9
  water in atmosphere of, 6:12
JUpiter ICy moons Explorer (JUICE) mission, 3:12
JWST. See James Webb Space Telescope (JWST)
K
K2-18 b (exoplanet), 1:16
Kapteyn's Star, 7:34
Kazachok science platform, 1:31
KBOs (Kuiper Belt objects). See names of specific Kuiper Belt objects
KELT-9 b (exoplanet), 5:15
Kemble's Cascade (asterism), 9:46-47
Kepler space telescope, comparison of mirror sizes, 5:11
Kepler-1649 c (exoplanet), 8:13
Keystone (asterism), 9:48-49
Kids (asterism), 9:46
Kitt Peak National Observatory, Dark Energy Spectroscopic Instrument, 3:11
Koch, Christina, 6:11
Kuiper Belt objects (KBOs). See names of specific Kuiper Belt objects
L
Lagoon Nebula (M8), 5:72, 6:23
Large Binocular Telescope, comparison of mirror sizes, 5:11
Large Magellanic Cloud (LMC)
  collision between SMC and, 11:21, 23
  dark matter and, 11:20
  imaged by Spitzer Space Telescope, 6:27
  Magellanic Stream, 11:21
  mapping star formation in, 1:9
  oddly orbiting stars within, 11:19-21
  overview of, 11:16-23
Laser Interferometer Gravitational-Wave Observatory. See LIGO (Laser Interferometer Gravitational-Wave Observatory)
Late Heavy Bombardment (LHB), 2:28-35
LBN 468 (interstellar dust cloud), 11:64
LDN 673 (dark nebula), 3:72
LDN 1235 (Dark Shark Nebula), 1:70
Le Gentil 3, 12:30
lenticular galaxies. See names of specific lenticular galaxies
Leonid meteors, 12:49-50
LHA 120-N150 (star forming region), 8:74
LHB (Late Heavy Bombardment), 2:28-35
life, origin of. See extraterrestrial life
light
  airglow, 6:73
  dark matter and, 1:69
```

```
Earthshine, 7:73
   gegenschein, 5:70
   red rainbows, 6:64
   reflections of sunset producing double-sun effect, 4:62
   volcanic and mock-volcanic twilights, 11:56
  zodiacal light, 6:73
LIGO (Laser Interferometer Gravitational-Wave Observatory)
   gravitational waves suggesting birth of intermediate-mass black hole, 12:10
   sensitivity of, 10:11
Little Pinwheel Galaxy (NGC 3184), 5:58, 9:73
LMC. See Large Magellanic Cloud (LMC)
LMC N63A (supernova remnant), 3:74
Lobster Claw Nebula (Sharpless 2-157), 5:72–73
Local Group of galaxies, studying analogues of, 4:73
Lost Galaxy (NGC 4535), 4:54, 5:61
Lovell, Jim, 4:18–27
Lowell Observatory
  biography of V.M. Slipher, 5:31–35
   125th anniversary overview, 2:44–49
Lozenge (asterism), 9:49
Luna 3 mission, 10:25-29
lunar eclipses
   January 2020, 9:73
   June 2020 (penumbral), 12:16
Lynds #78 (dark nebulae group), 12:31
Lynds #79 (dark nebulae group), 12:31
Lynds #86 (dark nebulae group), 12:31
Lynds #141 (dark nebulae group), 12:30
Lynds #283 (dark nebulae group), 12:29-30
Lynds #300 (dark nebulae group), 12:30
Lynds #339 (dark nebulae group), 12:30
Lynds #346 (dark nebulae group), 12:30
Lynds #352 (dark nebulae group), 12:29-30
Lynds #393 (dark nebulae group), 12:29-30
Lynds #399 (dark nebulae group), 12:29-30
M
M1 (Crab Nebula), 3:26
M2 (globular cluster), 6:63
M3 (globular cluster), 6:60-61
M4 (globular cluster), 6:61-62, 7:68
M5 (globular cluster), 6:60–61
M8 (Lagoon Nebula), 5:72, 6:23
M10 (globular cluster), 6:63
M12 (globular cluster), 1:72, 6:61, 62-63
M13 (Hercules Cluster), 6:62
M15 (globular cluster), 6:62, 63, 7:72
M16 (Eagle Nebula), 3:21, 6:23
M20 (Trifid Nebula), 5:72
M22 (globular cluster), 6:62
M24 (nebulosity), 8:68
M30 (globular cluster), 6:63
M31. See Andromeda Galaxy (M31)
M32 (elliptical galaxy), 4:59, 12:60
M35 (star cluster), 2:58
```

```
M38 (star cluster), 2:58
M42. See Orion Nebula (M42)
M44 (Beehive Cluster), 2:72
M45. See Pleiades star cluster (M45)
M46 (open cluster), 5:70
M47 (open cluster), 5:70
M49 (elliptical galaxy), 4:61
M51 (Whirlpool Galaxy), 3:26-27
M53 (globular cluster), 6:60
M55 (globular cluster), 6:63
M57 (Ring Nebula), observing star at center of, 8:64
M58 (barred spiral galaxy), 4:56–57
M59 (elliptical galaxy), 4:61
M60 (elliptical galaxy), 4:61
M61 (spiral galaxy), 4:53-54
M63 (Sunflower Galaxy), 4:66, 6:34
M68 (globular cluster), 6:60
M79 (globular cluster), 6:63
M80 (globular cluster), 6:61, 7:68
M81 (galaxy), 6:26-27
M83 (Southern Whirlpool Galaxy), 4:72
M84 (elliptical galaxy), 4:60
M86 (lenticular galaxy), 4:60-61
M87 (elliptical galaxy)
  first image of black hole at center of, 1:20-21, 30-31, 10:16-17
  observing, 4:61
M89 (elliptical galaxy), 4:61
M90 (spiral galaxy), 4:56-57
M92 (globular cluster), 6:63
M94 (spiral galaxy), 4:66
M97 (Owl Nebula), 8:72
M101 (Northern Pinwheel Galaxy; NGC 5457), 3:52-55, 6:26-27
M104 (Sombrero Galaxy), 4:52–53, 56, 6:32
M105 (elliptical galaxy), 4:60
M106 (spiral galaxy), 3:23
M108 (spiral galaxy), 8:72
MACHOs (massive compact halo objects), 11:20
Magellan Telescopes, comparison of mirror sizes, 5:11
magnetars, possible formation of from star collisions, 2:10–11
magnetic fields
  effect on exoplanet atmospheres, 3:9
  imaging Sun's magnetic field lines, 8:15
  of Neptune, 12:42-43
  of Uranus, 12:42-43
Many Worlds Interpretation, 7:64
Markarian's Chain (galaxy group), 5:64
  See also names of moons orbiting; names of specific missions to
  angular size and magnitude during 2020, 2:15
  "canals," 4:16
  Cerberus Fossae, 6:8
  closest approach to Earth, 11:9
  comparison of orbital planes, 5:13
  composition of atmosphere, 8:12
  contract for rocket fuel production from deposits on, 2:11
  historical imaginings of, 10:68
```

```
history of rovers sent to, 6:51
  image of with Jupiter and Saturn, 11:65
  image of with nebulae, 5:72
  image of with Pleiades star cluster, 1:70
  Jezero Crater, 6:47
  lack of ancient global magma ocean, 7:7
  marsquakes, 6:8–9
  meteors in atmosphere of, 4:71
  methane cycle, 9:21
  observing at opposition, 10:44-47
  observing through filters, 10:47
  panoramic surface image, 7:9
  possibility of using helicopters on, 5:68-69
  searching for life through robotic and sample-return missions, 9:20-22
  terminology, 10:45
  timing missions to, 11:9
Mars 2020 mission. See Perseverance rover (Mars 2020)
Mars Odyssey spacecraft
  future of, 12:25–26
  instrumentation of, 12:22
  orbit of, 12:23
  overview of, 12:20-27
MASCOT (Mobile Asteroid Surface Scout) rover, 3:11
massive compact halo objects (MACHOs), 11:20
Medusa Nebula (Abell 21), 2:56, 59
MeerKAT radio telescope, X-galaxies, 9:11
Menkib (star), 1:57
Mercury
  comparison of orbital planes, 5:13
  composition of atmosphere, 8:12
  tilt to the elliptic, 2:13
  transit of, 2:73, 3:13
Messier catalog, observational marathon, 3:60–63
meteor showers
  classes of, 12:51
  Geminids, 4:11, 9:71, 12:50-51
  Leonids, 12:49-50
  naming of, 8:46-47
  origin of, 8:46
  Perseids, 3:72, 8:44-49
  Quadrantids, 12:51
  in 2020, 1:64, 12:48-51
  Ursids, 12:51
meteorites
  crater from ancient impact on Earth, 5:10
  defined, 8:45-46
  formation of, 6:68
  micrometeorites, 8:28–35
meteoroids, defined, 8:45
meteors
  in atmosphere of Mars, 4:71
  defined, 8:45
  facts about, 8:46, 12:51
methane, Mars' methane cycle, 9:21
Methuselah Nebula (MWP 1), 6:72
Mice (interacting spiral galaxies), 3:28
```

```
micrometeorites, 8:28-35
Milky Way Galaxy
  See also Sagittarius A* (Sgr A*)
  ancient burst of supernovae and star formation, 4:13
  estimate of number of intelligent communicating civilizations in, 10:7
  globular cluster wrenched apart by gravitational forces, 11:10
  images of, 2:72, 3:70–71, 6:73
  near infrared image of center, 5:74
  newer techniques for seeing within, 10:14-23
  path of Sun's movement through, 6:69
  Radcliffe Wave star-forming region, 5:12
  repeated collisions with Sagittarius, 9:9
  satellite galaxies, 11:61–62
  speed of star fleeing, 3:9
  vacillating speed of central bar, 12:9
  warped shape of, 7:7
Mini Coathanger (asterism), 9:48–49
Mira (star), 10:62–63
Mirach's Ghost (NGC 404), 4:59-60
Mobile Asteroid Surface Scout (MASCOT) rover, 3:11
Moon (Earth's)
  See also names of specific missions to
  apparent size of, 10:12
  blackdrop effect, 3:16–17
  coating to prevent lunar dust from clinging, 4:9
  contract for rocket fuel production from deposits on, 2:11
  cratering history, 2:28–35
  definitive map of, 8:14
  eclipses of, 9:73, 12:16
  far side of, 10:24-29
  five geological periods, 9:12
  formation of, 2:28–35
  geological model for finding ice on, 10:9
  image of halo, 8:73
  image of passing through Earth's penumbra, 6:72, 9:73
  image of with Beehive Cluster, 2:72
  image of with Venus and Earthshine, 7:73
  images of, 1:72, 4:73, 5:72, 11:65
  Last or Third Quarter Moon, 6:14
  multiple sources of ice on, 2:11
  New Moon, 11:62
  observing at First Quarter, 3:56-59
  Saber's beads, 3:16-17
  Strawberry Moon, 1:72
  subsurface investigation of farside, 6:10
  Ultimately Large Telescope concept, 11:9
moons, possible destroyed exomoon causing ring around Tabby's Star, 1:9. See also names of specific moons
Mount Stromlo Observatory, 1:51, 54–55
multiple-star systems. See binary star systems (double stars)
MWP 1 (Methuselah Nebula), 6:72
N
N185 (superbubble object), 8:73
Naiad (moon of Neptune), orbital resonance with Thalassa, 3:10
Nancy Grace Roman Space Telescope, renaming of, 9:9
```

```
NASA (National Aeronautics and Space Administration)
  See also names of specific spacecraft and missions
  death of Katherine Johnson, 6:7
  ground breaking for Californian radio antenna, 6:9
  Operation IceBridge, 4:14
  private contract for rocket fuel production from deposits on Moon and Mars, 2:11
  proposals for future missions, 6:9
  SpaceX delivers astronauts to ISS, 9:8-9
  Webby Awards, 9:12
National Science Foundation Vera C. Rubin Observatory, 5:9
nebulae
  See also names of specific nebulae
  exploring, 5:44-47
  3D images of, 5:44-47
NEOWISE. See Comet C/2020 F3 (NEOWISE)
  See also names of moons orbiting
  comparison of orbital planes, 5:13
  composition of, 12:43
  composition of atmosphere, 9:12, 12:43-44
  magnetic field of, 12:42-43
  moons of, 12:44-46
  number of moons, 6:11
  overview of, 12:40-47
  ring system, 12:44-45
  temperature of upper atmosphere, 9:12
  unrealized missions to, 12:46
neutrinos, 12:9
Neutron star Interior Composition Explorer. See NICER (Neutron star Interior Composition Explorer) mission
neutron stars
  brightest X-ray burst from, 3:10
  calculating mass of, 3:68
  first map of, 4:14
  mass of heaviest known, 1:12
  in SN 1987A, 11:10
New Horizons spacecraft
  See also Pluto
  overview of Ultima Thule flyby, 1:28
  trajectory of, 9:11
NGC 147 (elliptical galaxy), 4:59
NGC 185 (dwarf spheroidal galaxy), 4:59
NGC 205 (elliptical galaxy), 4:59, 12:60
NGC 225 (Sailboat Cluster), 9:73
NGC 246 (planetary nebula), 11:60
NGC 253 (spiral galaxy), 11:60
NGC 404 (Mirach's Ghost), 4:59-60
NGC 584 (lenticular galaxy), 4:60
NGC 1052-DF2 (ultra-diffuse galaxy), 3:44–51
NGC 1052-DF4 (ultra-diffuse galaxy), 3:44-51
NGC 1097 (spiral galaxy), 6:26-27
NGC 1300 (barred spiral galaxy), 3:24–25
NGC 1333 (reflection nebula and star cluster), 1:58–59, 5:11
NGC 1342 (open cluster), 1:58-59
NGC 1398 (barred spiral galaxy), 6:33
NGC 1400 (elliptical galaxy), 4:60
NGC 1407 (elliptical galaxy), 4:60
```

NGC 1499 (California Nebula), 1:56-57, 8:13 NGC 1530 (barred spiral galaxy), 6:31 NGC 1555 (Hind's Variable Nebula), 1:60 NGC 1579 (Northern Trifid Nebula), 1:58–59 NGC 1807 (star cluster), 2:58–59 NGC 1817 (star cluster), 2:58-59 NGC 1907 (star cluster), 2:58 NGC 2014 (nebula), 7:7 NGC 2020 (nebula), 7:7 NGC 2070 (Tarantula Nebula), 3:27, 6:74 NGC 2158 (star cluster), 2:58 NGC 2183 (nebula), 2:59 NGC 2185 (nebula), 2:59 NGC 2207 (spiral galaxy), 2:59 NGC 2276 (spiral galaxy), 2:57 NGC 2300 (lenticular galaxy), 2:57 NGC 2371–2 (Double Bubble Nebula), 2:58–59 NGC 2392 (nebula), 12:11 NGC 2395 (open cluster), 2:56, 59 NGC 2419 (Intergalactic Wanderer) (globular cluster), 6:59-60 NGC 2438 (planetary nebula), 5:70 NGC 2633 (elliptical galaxy), 2:57 NGC 2634 (elliptical galaxy), 2:57 NGC 2634A (galaxy), 2:57 NGC 2683 (UFO Galaxy), 5:56-58 NGC 2775 (spiral galaxy), 12:66 NGC 2835 (spiral galaxy), 11:65 NGC 3079 (spiral galaxy), 5:58 NGC 3175 (spiral galaxy), 4:73 NGC 3184 (Little Pinwheel Galaxy), 5:58, 9:73 NGC 3201 (globular cluster), 6:60 NGC 3310 (spiral galaxy), 5:58 NGC 3372 (Carina Nebula), 2:73, 3:22–23, 6:23 NGC 3384 (elliptical galaxy), 4:60 NGC 3448 (spiral galaxy), 5:59 NGC 3572 (emission nebula and star cluster), 11:64 NGC 3576 (Statue of Liberty Nebula), 9:71 NGC 3620 (spiral galaxy), 9:70 NGC 3631 (spiral galaxy), 5:59 NGC 3749 (spiral galaxy), 9:74 NGC 3893 (spiral galaxy), 5:59 NGC 4026 (spiral galaxy), 5:59 NGC 4038 and NGC 4039 (Antennae galaxies), 3:28 NGC 4111 (spiral galaxy), 5:60 NGC 4125 (elliptical galaxy), 1:60, 4:60 NGC 4216 (Silver Streak Galaxy), 4:53-54 NGC 4244 (Silver Needle Galaxy), 5:60 NGC 4390 (spiral galaxy), 3:72 NGC 4414 (spiral galaxy), 5:60 NGC 4429 (spiral galaxy), 4:54 NGC 4435 and NGC 4438 (Eyes) (galaxy pair), 4:54-55 NGC 4535 (Lost Galaxy), 4:54, 5:61 NGC 4536 (spiral galaxy), 4:54-55 NGC 4567 and NGC 4568 (galaxy pair), 4:56, 12:11 NGC 4627 (spiral galaxy), 5:61

NGC 4631 (spiral galaxy), 5:61

NGC 4656/7 (Hockey Stick), 5:61 NGC 4697 (elliptical galaxy), 4:61 NGC 4725 (spiral galaxy), 5:61 NGC 4731 (galaxy), 4:56-57 NGC 4762 (barred spiral galaxy), 4:57, 5:61 NGC 4856 (spiral galaxy), 4:57 NGC 4921 (barred spiral galaxy), 6:28-29 NGC 5018 (elliptical galaxy), 2:74 NGC 5022 (spiral galaxy), 2:74 NGC 5033 (spiral galaxy), 5:60 NGC 5128 (Centaurus A), 2:70-71 NGC 5350 (spiral galaxy), 7:73 NGC 5353 (lenticular galaxy), 7:73 NGC 5354 (lenticular galaxy), 7:73 NGC 5371 (spiral galaxy), 7:73 NGC 5394 and 5395 (Heron Galaxy; Arp 84), 4:9 NGC 5457 (Northern Pinwheel Galaxy; M101), 3:52–55, 6:26–27 NGC 5468 (spiral galaxy), 7:74 NGC 5634 (globular cluster), 4:56–57 NGC 5982 (elliptical galaxy), 4:61 NGC 6144 (globular cluster), 6:62, 7:68 NGC 6240 (merging galaxies), 4:12, 12:62 NGC 6302 (Butterfly Nebula; Bug Nebula), 3:22, 10:72 NGC 6334 (Cat's Paw Nebula), 6:22-23 NGC 6338 (galaxy group merger), 5:12 NGC 6652 (globular cluster), 9:11 NGC 6709 (open cluster), 8:50 NGC 6741 (planetary nebula), 8:51 NGC 6744 (barred spiral galaxy), 6:33 NGC 6749 (globular cluster), 8:51 NGC 6751 (planetary nebula), 8:51 NGC 6755 (open cluster), 8:51 NGC 6756 (open cluster), 8:51 NGC 6772 (planetary nebula), 8:51 NGC 6781 (planetary nebula), 8:51 NGC 6804 (planetary nebula), 8:51 NGC 6883 (open cluster), 8:72 NGC 6946 (Fireworks Galaxy), 1:14, 6:34 NGC 7000 (North America Nebula), 1:74, 6:23 NGC 7027 (Jewel Bug Nebula), 10:9 NGC 7293 (Helix Nebula), 1:12, 6:25 NGC 7582 (galaxy), 1:72 NGC 7590 (galaxy), 1:72 NGC 7599 (galaxy), 1:72 NGC 7635 (Bubble Nebula), 3:18-19 NICER (Neutron star Interior Composition Explorer) brightest X-ray burst detected by, 3:10 first map of neutron star, 4:14 Nobel Prize in physics, winners in 2019, 2:9 North America Nebula (NGC 7000), 1:74, 6:23 Northern Fly (asterism), 9:46 Northern Pinwheel Galaxy (M101; NGC 5457), 3:52-55, 6:26-27 Northern Trifid Nebula (NGC 1579), 1:58-59

novae. See names of specific novae; supernovae

#### 0 observatories See also names of specific observatories closed due to COVID-19 pandemic, 8:10-11 comparison of mirror sizes, 5:11 domes versus roll-off roofs, 1:18 tips for owning, 5:16 top 5 in Australia, 1:50-55 occultations, of planets as viewed from Earth, 1:68-69 Omega Nebula (Swan Nebula), 5:9 1ES 1927+654 (black hole), 11:12 1I/2017 U1. See 'Oumuamua (1I/2017 U1) open clusters. See names of specific open clusters Operation IceBridge, 4:14 Opportunity rover, survival time, 3:11 Orion (constellation), binocular observations within, 1:62 Orion Nebula (M42) image of, 1:12 imaged by Spitzer Space Telescope, 6:22 Orion spacecraft, 1:25 OSIRIS-REx mission landing rehearsals, 12:11 physical sample of asteroid surface, 1:31, 9:7 'Oumuamua (1I/2017 U1) (interstellar object) overview of, 2:18-27 shape of, 8:9 Owl Nebula (M97), 8:72 P Pakan's 3 (asterism), 9:47 PanSTARRS (Comet C/2017 T2), 7:73 Parker Solar Probe findings of, 4:9 source of Geminids, 4:11 Parkes Observatory, 1:52-54 parsecs, definition of, 2:69 Perseids August 2019, 3:72 August 2020, 8:44-49 Perseus Molecular Cloud image of, 5:11 observations within, 1:56–59 Perseus OB2 Association (star grouping), 1:56 Perseverance rover (Mars 2020 mission) Ingenuity drone, 11:9 instrumentation of, 6:46–53 landing of, 6:46 landing site, 6:47 launch of, 11:8 Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE), 11:9 overview of, 6:44–53, 11:8–9 returning samples, 6:51-52 scheduled launch date, 1:31, 6:45 Philae lander, survival time, 3:11 philately (stamp collecting), 11:50-55

```
Phoenix Stream (former globular cluster), 11:10
photons, propelling solar sails, 3:69
physicists, Freeman Dyson, 6:9
Pickering's Triangle (portion of Veil Nebula), 6:70
Pioneer 10 spaceprobe, trajectory of, 9:11
Pioneer 11 spaceprobe, trajectory of, 9:11
PK 164+31.1 (Headphone Nebula; JE 1), 11:65
PKS 2014-55 (X-galaxy), 9:11
"Planet Nine" (Planet X)
  overview of search for, 1:44-49
  possibly a black hole, 3:8
   trans-Neptunian objects and, 7:10
planetary nebulae, bipolar, 7:12. See also names of specific planetary nebulae
Planetary Society, 5:13
planet-forming disks, image of, 11:66
planets
   See also extrasolar planets (exoplanets); names of specific planets
   collecting atmospheric gas during formation, 2:11
   developing atmospheres, 9:68-69
   effects of dusty atmosphere, 10:9
   occultations of, as viewed from Earth, 1:68-69
Pleiades star cluster (M45)
   image of with Mars, 1:70
   image of with Venus, 9:70
   See also New Horizons spacecraft
   atmospheric pressure changes, 9:9
   comparison of orbital planes, 5:13
   hot formation of, 10:9
   subsurface oceans, 10:9
   tilt to the elliptic, 2:13
Polaris (double star), 2:57
Porrima (Gamma Virginis) (double star), 4:56
protoplanetary disks
   effects of crowding in star cluster, 9:7
   gas "waterfalls," 2:11
   intertwined around binary star system, 2:9
Proxima Centauri b (exoplanet), 4:50
Proxima Centauri (star), 7:34–35
pulsars, first map of, 4:14. See also names of specific pulsars
Q
Quadrantid meteors, 12:51
quantum computers, 12:11
quantum mechanics
   Many Worlds Interpretation, 7:64
   Schrödinger's cat, 7:64
quasars. See also names of specific quasars
Queqiao satellite, 9:68
R
R Coronae Borealis (variable star), 6:66
R Leporis (Hind's Crimson Star)
  binocular observation of, 1:62
   discovery of, 1:60
```

```
Radcliffe Wave star-forming region, 5:12, 10:20–21, 23
radiation belts, 2:68-69
radio astronomy
  See also fast radio bursts (FRBs)
  ground breaking for Californian radio antenna, 6:9
  imaging Antares' atmosphere, 10:11
  X-galaxies, 9:11
rainbows, red, 6:64
Rake (Belt of Orion; Three Kings) (asterism), 9:47
RAS (Royal Astronomical Society), bicentennial of, 11:51-52
red dwarfs, gas giant orbiting, 2:14. See also names of specific red dwarfs
reflection nebulae. See names of specific reflection nebulae
Rho Ophiuchi cloud complex, 12:31
Rigel (Beta Orionis) (star)
  binocular observation of, 1:62
  image of, 9:72
Ring Nebula (M57), observing star at center of, 8:64
ring systems
  around Neptune, 12:44-45
  around Saturn, 6:20, 8:58
  around Uranus, 12:44-45
  possible ring around Tabby's Star from destroyed exomoon, 1:9
Ritchey-Chrétien telescopes, 3:30–35
RMC 136a1 (Wolf-Rayet star), physical properties of, 7:26
robots
  A-PUFFERs, 7:13
  connectable robots for exploration of Saturn's moons, 2:11
  searching for life through robotic missions, 9:20-24
  sent to ISS, 4:11
Rosalind Franklin rover, 1:31
Ross 128 (red dwarf), 7:34
rovers
  See also names of specific rovers
  A-PUFFERs, 7:13
  history of rovers sent to Mars, 6:51
Royal Astronomical Society (RAS), bicentennial of, 11:51–52
RR Lyrae variable stars, 7:56-61
RS Puppis (variable star), 2:15
Rubin's Galaxy (UGC 2885), 5:13
Running Chicken Nebula (IC 2944), 10:72
Ryugu (asteroid)
  departure of Hayabusa2, 3:7
  overview of Hayabusa2 mission, 1:26-27
S5-HVS1 (star), 7:29
Sagan, Carl, 4:44-49
Sagittarius (constellation), binocular observations within, 8:68
Sagittarius (satellite galaxy), repeated collisions with Milky Way, 9:9
Sagittarius A* (Sgr A*) (black hole)
  bubbles associated with, 1:9
  confirming nature of, 10:16-18
  imaging, 10:18-19
  possible companion black hole, 4:9
  star in precessing, rosettelike orbit around, 8:9
```

```
timing of flare up, 2:12
Sailboat Cluster (NGC 225), 9:73
Sandqvist 149 (Dark Doodad) (dark nebula), 4:72, 12:31
satellite galaxies
  detecting around Andromeda, 11:62
  number of around Milky Way, 11:61-62
satellites
  See also names of specific satellites
  amateur tracking of, 2:62
  proposed "orbital-use fee," 9:9
  spy satellite capabilities, 2:62
Saturn
  See also Cassini spacecraft; names of moons orbiting
  cloud features of, 8:58
  comparison of orbital planes, 5:13
  composition of atmosphere, 9:12
  conjunction with Jupiter, 12:14
  connectable robots for exploration of moons, 2:11
  image of, 1:11
  image of with Jupiter and Mars, 11:65
  number of moons, 6:11
  observing at opposition, 8:56-59
  outermost ring, 6:20
  percentage of time spent in each constellation, 3:9
  ring features of, 8:58
  rising number of moons discovered orbiting, 2:15
  tilt to the elliptic, 3:9
SAX J1808.4–3658 (neutron star/brown dwarf pair), 3:10
Schrödinger's cat, 7:64
science
  COVID-19 and attack on science, 9:12
  perception and user interfaces, 8:62
  scientists' view of interesting times, 10:64
Scorpius (constellation), binocular observations within, 7:68
Seahorse Nebula (Barnard 150), 5:71
Search for ExtraTerrestrial Intelligence (SETI), 9:26
Segment of Perseus (asterism), 9:47
Serpens reflection nebula, 11:66
Serpens South star cluster, 6:25
SETI (Search for ExtraTerrestrial Intelligence), 9:26
Sgr A*. See Sagittarius A* (Sgr A*) (black hole)
Sharpless 2-115 (emission nebula), 5:71
Sharpless 2-124 (emission nebula), 2:71
Sharpless 2-157 (Lobster Claw Nebula), 5:72-73
Sharpless 2-200 (Bear Claw Nebula; Hartl-Dengl-Weinberger 2), 4:73
Sharpless 2-201 (emission nebula), 8:73
Sharpless 2-207 (emission nebula), 7:73
Sharpless 2-208 (emission nebula), 7:73
Sharpless 2-231 (emission nebula), 10:72
Sharpless 2-232 (emission nebula), 10:72
Sharpless 2-235 (emission nebula), 10:72
Sharpless 2-312 (emission nebula), 9:70–71
Siding Spring Observatory, 1:52–53
Silver Needle Galaxy (NGC 4244), 5:60
Silver Streak Galaxy (NGC 4216), 4:53-54
Simonyi Survey Telescope, comparison of mirror sizes, 5:11
```

```
Sirius A (star)
  expanding to red giant, 5:69
  overview of, 7:32-33
Sirius B (star), possibility of going supernova, 5:69
61 Cygni (star), 7:33
Slipher, V.M., 5:31-35
Sloan Digital Sky Survey, largest 3D map of the universe, 11:9
Small Magellanic Cloud (SMC)
  collision between LMC and, 11:21, 23
  Magellanic Stream, 11:21
  mapping star formation in, 1:9
  overview of, 11:16-23
Small Sagittarius Star Cloud (asterism), 9:49
smell, sense of, 9:34
SN 1987A (supernova)
  appearance of, 8:70–71
  image of, 3:25
  neutron star in, 11:10
  reflected light rippling outward from, 11:20
SN 2002dd (supernova), 3:29
SOHO (Solar and Heliospheric Observatory), comets discovered by, 10:11
solar eclipses
  December 2019, 7:72
  June 2020, 1:32–35
  December 2020, 9:50-53
Solar Orbiter mission
  instrumentation of, 8:25
  launch of, 1:31, 6:10
  orbit of, 8:22
  overview of, 8:18-27
  test images, closest ever taken, 11:7
solar sails, 3:69
solar system
  comparison of orbital planes, 5:13
  counterclockwise orbits, 10:71
  Eta Corvi as analogue for formation of, 7:50–55
  rate of impacts in, 2:28-35
  tilt of planets to the elliptic, 2:13
Sombrero Galaxy (M104), 4:52–53, 56, 6:32
Soul Nebula (Baby Nebula; IC 1848), 6:71, 8:73
Southern Whirlpool Galaxy (M83), 4:72
space debris (space junk), proposed "orbital-use fee," 9:9
Space Launch System
  contract for engines, 9:7
  testing, 1:25
spacecraft
  See also names of specific spacecraft
  atomic clocks and navigation, 1:14
  connectable robots for exploration of Saturn's moons, 2:11
  leaving solar system, 9:11
  longest crewed landing, 3:11
  survival rates of unmanned landers, 3:11
SpaceShipTwo (VSS Unity), 1:25
SpaceX
  See also names of specific spacecraft and missions
  first Crew Dragon capsule spaceflight, 1:25
```

```
returning astronauts from ISS, 11:7
   Starlink satellites, 3:9, 12:11
   transporting astronauts to ISS, 9:8–9
spiral galaxies
   See also names of specific spiral galaxies
   forming elliptical after collision, 8:71
   observing edge-on and face-on, 5:56-61
   "super spiral" galaxies, 2:11
Spitzer Space Telescope
   best images of past 16 years, 1:12
   decommissioning of, 6:13
   final target, 8:13
   overview of mission, 6:18-27
  plans to shut down, 1:74
Spring Triangle (asterism), 9:46–47
SS1 (star), 7:49
stamp collecting (philately), 11:50–55
star clusters, effects of crowding on planet formation, 9:7. See also names of specific star clusters
Stargate (asterism), 9:48
Starlink satellites
  launch of second sixty, 3:9
   report with suggestions to mitigate impact of on observation, 12:11
Starmus Festival, preview of sixth, 12:52-66
stars
   See also names of specific stars; names of specific types of stars
  bubbles associated with, 2:13
   carbon originating in, 7:14
   categorization of, 7:11
   collisions between, 5:68
   cyclic evolution of, 7:16-23
   death of, 7:16-23
   Delta Scuti stars, 9:10
   diagram of Sun's neighbors, 7:30-31
   effect of radiation from giant dying stars on asteroids, 6:9
   fastest, 7:29
   formation of, 5:47-48, 7:16-23
   formation of in Large and Small Magellanic Clouds, 1:9
   giant magnetic spots on, 10:9
   "green," 4:16
   habitable zones, 9:25
   Hertzsprung-Russell (HR) diagram, 7:11
   hottest, 7:27
  hypervelocity, 7:29
   images of star trails, 1:70-71, 2:71, 3:71, 5:71, 6:70
   increase in size needed for Jupiter to become a star, 10:70
   largest, 7:25
   most massive, 7:26
   origin of gold, 11:40-45
   in precessing, rosettelike orbit around black hole, 8:9
   RR Lyrae variable stars, 7:56–61
   smallest, 7:27
   speed of star fleeing Milky Way, 3:9
   starspots, 3:69
   supermassive black holes possibly stunting formation of in dwarf galaxies, 2:12
   that formed from same nebula as Sun, 7:44-49
   thrown to galactic fringes by supernovae, 8:13
```

```
torn apart by supermassive black hole, 2:11
Statue of Liberty Nebula (NGC 3576), 9:71
STELLINA observation station, 8:60-61
Struve 431 (40 Persei) (double star), 1:57-58
Subaru Telescope, comparison of mirror sizes, 5:11
subitization, 3:14
Sun
  black dwarf-stage, 4:70-71
  campfires, 11:7
  classification of, 7:24
  clockwise orbit of galactic center, 10:71
  closest images of, 11:7
  diagram of features of, 8:23
  diagram of neighboring stars, 7:30-31
  distance from Earth, 7:24
  eclipses of, 1:32–35, 7:72, 9:50–53
  effects of expansion of, 9:69
  electromagnetic spectrum, 7:70
  elements within, 2:68
  findings of Parker Solar Probe, 4:9
  first image from Daniel K. Inouye Solar Telescope, 6:7
  imaging of magnetic field lines, 8:15
  lack of sunspots, 4:16
  luminosity of, 7:24
  mass of, 7:24
  missions to, 8:24
  overview of Solar Orbiter mission, 8:18-27
  path of movement through Milky Way, 6:69
  position in the elliptic, 2:13
  radius of, 7:24
  reflections of sunset producing double-sun effect, 4:62
  stability and docility of, 8:12
  stars that formed from same nebula as, 7:44-49
  temperature of, 7:24
  transit of Mercury, 2:73, 3:13
Sunburst Arc Galaxy, 3:28
Sunflower Galaxy (M63), 4:66, 6:34
sunspots
  lack of, 4:16
  on other stars, 3:69
superclusters. See names of specific superclusters
Super-Kamiokande neutrino observatory, 12:9
supernovae
  See also names of specific supernovae
  ancient burst of in Milky Way, 4:13
  throwing stars to galactic fringes, 8:13
SWAN (Comet C/2020 F8), 10:72
Swan Nebula (Omega Nebula), 5:9
T
T Coronae Borealis (T CrB; Blaze Star) (binary star system), 7:62
Tabby's Star, possible ring from destroyed exomoon, 1:9
Tarantula Nebula (NGC 2070), 3:27, 6:74
Tau Ceti e (exoplanet), 4:50
Tau Ceti (star), 7:33
```

```
TDEs (Tidal Disruption Events), types of, 5:11
Teegarden's Star, 7:34-35
telescopes
   See also names of specific telescopes
   adaptive optics, 12:13
   advent of electronic imaging, 2:52-55
   Cassegrain, 3:33
   Celestron's 60th anniversary, 10:48-53
   closed due to COVID-19 pandemic, 8:10-11
   comparison of mirror sizes, 5:11
   debate over best type of, 1:18
   lunar Ultimately Large Telescope concept, 11:9
   map of world's largest, 8:11
   Newtonian, 3:33
   prime focus, 3:33
   Ritchey-Chrétien, 3:30–35
   steadiest terrestrial spot for, 11:9
   Vaonis STELLINA observation station, 8:60-61
   visceral thrill of viewing astronomical objects, 8:16
TESS (Transiting Exoplanet Survey Satellite)
   completion of primary mission, 12:11
   Delta Scuti stars, 9:10
Thalassa (moon of Neptune), orbital resonance with Naiad, 3:10
Theta Aurigae (double star), 2:58
Theta Delphini (star), 9:66
Thirty Meter Telescope, comparison of mirror sizes, 5:11
37 (asterism), 9:46–47
Three Kings (Belt of Orion: Rake) (asterism), 9:47
3200 Phaethon (asteroid), 4:11
Tidal Disruption Events (TDEs), types of, 5:11
Titan (moon of Saturn)
   climate change and formation of lakes on, 1:11
   composition of atmosphere, 9:31
   searching for life, 9:23-25
   smell of, 9:28-35
TOI 1338 b (exoplanet), 5:9
Transiting Exoplanet Survey Satellite. See TESS (Transiting Exoplanet Survey Satellite)
trans-Neptunian objects (TNOs)
   discovery of 139 with movement-spotting algorithm, 7:10
   search for Planet Nine, 1:44-49
TRAPPIST-1 (red dwarf)
   physical properties of, 7:27
   possibly habitable exoplanets orbiting, 4:51, 6:20-21
Trident mission, proposal for, 6:9, 12:47
Trifid Nebula (M20), 5:72
Triton (moon of Neptune)
   composition of, 12:46
   overview of, 12:46-47
   possible subsurface ocean on, 12:46-47
  proposed mission to, 6:9, 12:47
2012 VP<sub>113</sub> ("Biden") (dwarf planet), 1:45–48
2014 MU<sub>69</sub>. See Arrokoth (Ultima Thule; 2014 MU<sub>69</sub>)
2015 VG<sub>387</sub> ("The Goblin") (dwarf planet), 1:45-46
2018 VG<sub>18</sub> ("Farout") (dwarf planet), 1:44-46
2020 QG (near-Earth asteroid), 12:9
TXS 0128+554 (galaxy), 12:13
```

```
TYC 8998-760-1 (star system), 11:12
U Geminorum (dwarf nova), 1:60
UFO Galaxy (NGC 2683), 5:56-58
UGC 695 (low-surface-brightness galaxy), 1:12
UGC 2885 (Rubin's Galaxy), 5:13
UGC 9749 (Ursa Minor Dwarf) (elliptical galaxy), 4:61
Ultima Thule. See Arrokoth (Ultima Thule; 2014 MU<sub>69</sub>)
Ultimately Large Telescope concept, 11:9
universe
  expansion of, 4:70
  formation of elements, 5:45-47
  largest 3D map of, 11:9
  puzzling problems affecting concept of Big Bang, 5:20-29
  theories of size of, 2:16
Universe Splitter app, 7:64
uranium, formation of, 12:62-63
Uranus
  See also names of moons orbiting
  comparison of orbital planes, 5:13
  composition of, 12:43
  composition of atmosphere, 9:12, 12:43-44
  magnetic field of, 12:42-43
  moons of, 6:11, 12:44-46
  overview of, 12:40-47
  ring system, 12:44-45
  unrealized missions to, 12:46
Ursa Minor Dwarf (UGC 9749) (elliptical galaxy), 4:61
Ursid meteors, 12:51
UY Scuti (red supergiant star), physical properties of, 7:25
V
V of Taurus (asterism), 9:47
V Sagittae (binary star system), 5:11
Van den Bergh 149 (reflection nebula), 1:70
Van den Bergh 150 (reflection nebula), 1:70
Vaonis STELLINA observation station, 8:60-61
variable stars
  See also names of specific variable stars
  AAVSO Spectroscopic Database (AVSpec), 2:15
  binocular observations of Mira, 10:62-63
  RR Lyrae stars, 7:56-61
Veil Nebula (Cygnus Loop), 6:69
Venera 13 spaceprobe, survival time, 3:11
  apparent retrograde motion of, 7:70-71
  comparison of orbital planes, 5:13
  composition of atmosphere, 8:12
  image of with Moon, 7:73
  image of with Pleiades star cluster, 9:70
  images of, 11:65
  naked-eye observations of crescent, 2:66
  observing in spring, 2:50–51
  temperature of if placed at orbital distance of other planets, 12:63
```

```
volcanoes on, 11:9
Venus' Mirror (asterism), 9:47
VERITAS (Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy) mission, 6:9
Very Large Telescope (VLT), comparison of mirror sizes, 5:11
Victoria (asteroid), 1:60
Viking lander, 4:16
Virgin Galactic, VSS Unity (SpaceShipTwo), 1:25
Virgo (constellation), observations within, 4:52–57
Virgo interferometer, gravitational waves suggesting birth of intermediate-mass black hole, 12:10
VISTA (Visible and Infrared Survey Telescope for Astronomy), 1:9
VLT (Very Large Telescope), comparison of mirror sizes, 5:11
Voyager 1 spaceprobe, trajectory of, 9:11
Voyager 2 spaceprobe
  enters interstellar space, 3:9
   trajectory of, 9:11
VSS Unity (SpaceShipTwo), 1:25
vulcanism
   on Mars, 7:7
   on Venus, 11:9
   volcanic and mock-volcanic twilights, 11:56
W
W. M. Keck Observatory, comparison of mirror sizes, 5:11
W43A (planetary nebula), 7:12
Wasat (Delta Geminorum) (double star), 2:58-59
WASP-39b (exoplanet), 3:26
WASP-76 b (exoplanet), iron rain on, 7:13
   in atmosphere of Europa, 3:12
   in atmosphere of exoplanet, 1:16
   in atmosphere of Jupiter, 6:12
   on Ceres, 12:11
   covering ancient Earth, 7:9
   ice on Ganymede, 11:7
   ice on Moon, 2:11, 10:9
   on Pluto, 10:9
   possible subsurface ocean on Triton, 12:46–47
   reflections of sunset producing double-sun effect, 4:62
Water Jar (asterism), 9:44, 46
Webby Awards, 9:12
Westerlund 2 (star cluster), 9:7
Whirlpool Galaxy (M51), 3:26–27
white dwarfs
   See also names of specific white dwarfs
   giant planet orbiting, 4:12
  measuring rotation speed via frame-dragging, 6:12
Wide Field Infrared Survey Telescope, renaming of, 9:9
WISE 0855-0714 (star), 7:34
WISE 1049-5319 (star), 7:34
Witch Head Nebula (IC 2118), 9:72
Wolf 359 (red dwarf), 7:33
Wolf 1061 c (exoplanet), 4:50-51
Wolf-Rayet stars, 7:26, 28
Worden, Al, 7:9
WR 102 (Wolf-Rayet star), physical properties of, 7:28
```

WR 134 (Wolf-Rayet star), 8:72

#### X

X-galaxies, 9:11 X-ray astronomy all-sky view, 10:7 brightest X-ray burst from neutron star, 3:10

#### Y

Y of Virgo (asterism), 9:48 Yerkes Observatory change of ownership, 3:7 comparison of mirror sizes, 5:11 Yutu-2 rover ground-penetrating radar, 6:10 overview of mission, 1:22–23

### Z

Zeta Ophiuchi (star), 1:12, 6:24–25 Zeta Persei (star), 1:56–57 zodiacal light, 4:73, 6:73

#### TITLE

#### Α

Adaptive optics, 12:13 Anatomy of a cosmic swan, 5:9 Anatomy of the observer, 11:14 Ann Druyan on Cosmos and Carl Sagan's legacy, 4:44-49 Apollo 13 in 3D, 4:28-35 Arecibo dish damaged after cable snaps, 12:12 Arrokoth flyby hints at how planets formed, 6:11 Asteroids on the prowl, 5:15 Astronomers find 139 new minor planets, 7:10 Astronomers see our Sun spin threads of plasma, 8:15 Astronomers spot a bowed bridge, 9:12 Astronomers weigh satellites' impact on night sky, 12:11 Astronomy guides: Readers' picks, 12:58

#### В

Behold the X-ray sky, 10:7 The best conjunction ever, 12:14 Betelgeuse's stellar sneeze, 12:12 Black hole loses its crown—then gets it back, 11:12 Bye-bye, solar system!, 9:11

Astronomy's electronic revolution, 2:52-55

#### $\mathbf{C}$

California stars in Spitzer's final mosaic, 8:13 Campfires on the Sun, 11:7 Canon's new astro camera, 5:62-63 Cataclysm in the early solar system, 2:28-35 A celestial hourglass, 6:9 Celestial scraps, 10:12 Celestron celebrates 60 years, 10:48-53 Charting the 19th-century heavens, 5:52–55 Chill with year-end meteors, 12:48-51 Chinese rover peers beneath the lunar farside, 6:10 Chroma filters, 9:60-61 The closest known black hole to Earth, 9:13 Cogito, ergo sum?, 8:62 Collect the cosmos in stamps, 11:50–55 Colorful winter stars, 1:62 Comet C/2020 F3 (NEOWISE) lights up July skies, 10:8-9 Comparing the Apollo missions, 4:13 The coolest cat on the web, 7:64 Cosmic clouds 3D, 5:44-51 A cosmic pretzel, 2:9 Creating the universe's most powerful magnets, 2:10–11 Curiosity snaps a celebratory selfie, 2:14 Curiosity views the martian horizon, 7:9 Curve to Corvus and beyond, 5:66

#### D

The dance of Neptune's moons, 3:10

### Astronomy Magazine Article Title Index

Decoding the Hertzsprung-Russell diagram, 7:11 Deep-sky observing from Costa Rica, 9:54–59 A dim galaxy rich in dark matter, 1:12 Discover exoplanets from your backyard, 6:54–57 Dissecting Andromeda, 12:60 Do all galaxies have dark matter?, 3:44–51 A dolphin's tale, 9:66 Don't miss the Perseids, 8:44–49

#### E

Earth's largest telescopes close amid COVID-19 outbreak, 8:10–11 Enjoy the sky's great globulars, 6:58–63
Excavating cosmic fossils, 8:28–35
Explore Markarian's Chain, 5:64
Explore Sagittarius, 8:68
Explore the heart of Virgo, 4:52–57
Explore the Moon at First Quarter, 3:56–59
Explore the world of galaxies, 6:28–35
Exploring ancient life in Australia, 3:11

#### F

Farewell to a small universe, 2:16 February's finest sights, 2:64 "Fire" in the sky, 11:56 The first map of a neutron star, 4:14 Found: Crater from 790,000-year-old asteroid strike, 5:10 A fresh look at our home star, 8:18–27

#### G

A galactic collision, 4:9
Get ready for Starmus VI, 12:52–56
A ghostly space face, 3:7
Giant planet atmospheres, 9:12
Giant planet found around white dwarf, 4:12
Giant wave of star-forming clouds lies near the Sun, 5:12
Going to the dogs, 4:66
Gold from the stars, 11:40–45
Gravitational wave spectrum, 10:11
The great asterism hunt, 9:44–49
Growing space salad, 7:8–9

#### Η

Hindsight, 1:60
How does smell work?, 9:34
How Enceladus earned its stripes, 4:11
How Galileo blended science and art, 11:24–31
How pulsating stars unlock our universe, 7:56–61
How stars are born and die, 7:16–23
How the planets line up, 5:13
How the Ritchey-Chrétien telescope was born, 3:30–35
How we'll find life in the universe, 9:18–27
Hubble captures cometary breakup, 8:9
Hubble's cosmic reef, 7:7
Hubble's greatest hits, 3:18–29

#### Hubble's latest snap of Saturn, 1:11

#### I

The illusion of disciplines, 10:64
In praise of nothing, 4:14
In pursuit of Planet Nine, 1:44–49
Inside the Perseus Molecular Cloud, 1:56–59
InSight detects marsquakes, proving seismic activity, 6:8–9
Intermediate and advanced guides, 4:64
Invitation to the Dark Side, 1:18
Iron rains from the sky on this world, 7:13
Is Eta Corvi a window to our past?, 7:50–55
Is Planet Nine a tiny black hole?, 3:8
Is T CrB rising?, 7:62
Is the Big Bang in crisis?, 5:20–29

#### J

A jewel of a nebula, 10:10 Jim Lovell remembers: Triumph over tragedy, 4:18–27

#### L

Launching a mission to Mars, 11:9 Learning the hard way, 9:16 Life on the wide side, 8:52–55 Lightning and 'mushballs' on Jupiter, 12:9 Location matters, 9:7 Lowell Observatory turns 125, 2:44–49 The lunar blackdrop effect, 3:16–17 Lunar storyline, 9:14

#### M

Mars' splendid show, 2:15
MeerKAT solves a boomerang-shaped mystery, 9:11
Meet an easy-to-use imaging scope, 8:60–61
Meet our second-ever interstellar visitor, 1:10–11
Meet the Deep Space Atomic Clock, 1:14
Meet the most extreme stars, 7:24–29
Mercury transits the Sun, 3:13
Mine Aquila's deep-sky gems, 8:50–51
A month of change, 3:64
The Moon's farside unveiled, 10:24–29
More galaxies found to be missing dark matter, 4:10–11
The most moons, 6:11
The mystery and majesty of the ice giants, 12:40–47

#### N

NASA astronauts graduate with eye toward Artemis, 5:15 NASA drives a Mars rover from home, 8:13 NASA retires the Spitzer Space Telescope, 6:13 A neutron star lurking in Supernova 1987A, 11:10 A new look at a close neighbor, 1:9 New solar scope sees first light, 6:7 New year, new sky, 1:64 The next generation of telescopes, 5:11

### Astronomy Magazine Article Title Index

NICER sees brightest X-ray burst yet, 3:10 No crystal balls, 6:16

#### O

Observations of Jupiter's moons, 11:46–49
Observatory odds and ends, 5:16
Observe Jupiter and Saturn at their best, 8:56–59
Observe winter's twin treats, 2:56–59
Old star reveals young jets, 7:12
One galaxy, three supermassive black holes, 4:12
Our 10th annual Star Products, 10:54–61
Our first interstellar visitor, 2:18–27
Our nearby gentle giant, 5:13
Our new view of the Milky Way, 10:14–23
Our Sun is strangely docile, 8:12

#### P

Pearl in the mist, 8:64
A penumbral challenge, 12:16
Perseverance begins journey to the Red Planet, 11:8–9
Picking a beginner's guide, 3:66
A planet is born, 9:10
Pluto may have formed hot and fast, 10:10
Pop-up robot scouts practice their skills, 7:13
Prepare for launch: Perseverance, 6:44–53

#### R

Radio telescopes image Antares' atmosphere, 10:11 Red rainbows, 6:64
Reflections on a sunset, 4:62
Rekindling dreams, 5:18
Researchers map dark matter via slime mold, 7:12
Riches of the Scorpion, 7:68
The ringed world wanders, 3:9
Rising from the ashes, 11:10
Run a Messier marathon, 3:60–63

#### S

Satellite tracking for amateurs, 2:62 Scientists find black hole missing link, 12:10 The search for dangerous asteroids continues, 8:11 Second repeating fast radio burst tracked, deepening mystery, 5:14 Secrets of the Northern Pinwheel Galaxy, 3:52-55 See Mars at its best, 10:44-47 See Venus at its best, 2:50-51 Set your sights on the Red Planet, 10:68 A shadow crosses South America, 9:50-53 Shining light on dark nebulae, 12:28-31 Shocking scene, 5:12 The sky's best elliptical galaxies, 4:58-61 Solar Orbiter heads for the sun, 6:10 Spacecraft survival rates, 3:11 SpaceX's Crew Dragon delivers NASA astronauts to ISS, 9:8-9 Spitzer captures a stellar playground, 5:11

Spitzer's scrapbook, 1:12
Stand under the ring of fire, 1:32–35
Stellar database encourages amateur submissions, 2:15
Stellar neighbors close-up, 7:30–35
Strange Moon rising, 6:14
Subitize the sky, 3:14
Summertime observing, 7:66
The Sun and the stars, 2:13
The Sun's lost siblings, 7:44–49
Supermassive black holes stunt dwarf galaxies, 2:12
A suspected exoplanet disappears before Hubble's eyes, 8:14
Swirling space-time reveals white dwarf's past, 6:12

#### Т

A tale of two galaxies, 11:16–23
Target a changing crown jewel, 6:66
Target asteroid Papagena, 11:58
Target edge-on and face-on galaxies, 5:56–61
Telescopes and mirrors, 3:33
Terrestrial atmospheres, 8:12
TESS unlocks the secret of Delta Scuti stars, 9:10
This is the definitive Moon map, 8:14
Tiny star, giant planet, 2:14
Top 10 space stories of 2019, 1:20–31
Tour five great Australian observatories, 1:50–55
A tribute to carbon, 7:14
20 years around the Red Planet, 12:20–27
The 2020 Ghost Hunt, 9:62
Two exoplanets seen circling a Sun-like star, 11:12

#### V

Vader's TIE fighter?, 12:13 Venus' crescent, 2:66 View Earth through a cosmic lens, 10:30–35 Visit the nearest 14 habitable exoplanets, 4:50–51 V.M. Slipher's expanding universe, 5:31–35

#### W

Warm and not so fuzzy, 6:18–27
Water vapor detected in Europa's atmosphere, 3:12
Water vapor found on a potentially habitable exoplanet, 1:16
We test: Celestron's Nature Binoculars, 2:60–61
A whale's tale, 11:60
What does Titan smell like?, 9:28–35
What else besides photons?, 8:16
What is the horizontal branch?, 7:59
When the Milky Way erupted in 100,000 supernovae, 4:13
Women in astronomy clubs, 8:66, 9:64
The wonder of Haidinger's Brush, 10:66
The wonderful variable star, 10:62–63

#### X

X-ray flashes reveal a possible black hole, 1:14

# Astronomy Magazine Article Title Index



Y Young stars blow bubbles, 2:13

## **AUTHOR**

A				
Aerts, Leo				
Observations of Jupiter's moons, 11:46–49				
1				
В				
Bakich, Michael E.				
Celestron celebrates 60 years, 10:48–53				
Charting the 19th-century heavens, 5:52–55				
Chill with year-end meteors, 12:48–51				
Don't miss the Perseids, 8:44–49				
Enjoy the sky's great globulars, 6:58–63				
Explore the heart of Virgo, 4:52–57				
Explore the Moon at First Quarter, 3:56–59				
Get ready for Starmus VI, 12:52–56				
The great asterism hunt, 9:44–49				
Mine Aquila's deep-sky gems, 8:50–51				
Run a Messier marathon, 3:60–63				
See Mars at its best, 10:44–47				
See Venus at its best, 2:50–51				
A shadow crosses South America, 9:50–53				
The sky's best elliptical galaxies, 4:58–61				
Stand under the ring of fire, 1:32–35				
Berman, Bob				
Anatomy of the observer, 11:14				
The best conjunction ever, 12:14				
Celestial scraps, 10:12 Farewell to a small universe, 2:16				
Invitation to the Dark Side, 1:18				
Lunar storyline, 9:14				
Observatory odds and ends, 5:16				
In praise of nothing, 4:14				
Strange Moon rising, 6:14				
Subitize the sky, 3:14				
A tribute to carbon, 7:14				
What else besides photons?, 8:16				
Betz, Eric				
Chinese rover peers beneath the lunar farside, 6:10				
The closest known black hole to Earth, 9:13				
A dim galaxy rich in dark matter, 1:12				
Earth's largest telescopes close amid COVID-19 outbreak, 8:10-11				
Growing space salad, 7:8–9				
InSight detects marsquakes, proving seismic activity, 6:8–9				
Iron rains from the sky on this world, 7:13				
The next generation of telescopes, 5:11				
Pluto may have formed hot and fast, 10:10				
The search for dangerous asteroids continues, 8:11				
SpaceX's Crew Dragon delivers NASA astronauts to ISS, 9:8–9				
Brasch, Klaus Observations of Lucitor's magnet 11,46,40				
Observations of Jupiter's moons, 11:46–49				
Buongiorno, Caitlyn Betelgeuse's stellar sneeze, 12:12				
A jewel of a nebula, 10:10				
11,0				

### Astronomy Magazine Article Author Index

Launching a mission to Mars, 11:9 Lightning and 'mushballs' on Jupiter, 12:9 Radio telescopes image Antares' atmosphere, 10:11 Rising from the ashes, 11:10 Scientists find black hole missing link, 12:10  $\mathbf{C}$ Cable, Morgan L. What does Titan smell like?, 9:28–35 Cannistra, Steve Life on the wide side, 8:52-55 Carlson, Erika K. The dance of Neptune's moons, 3:10 A galactic collision, 4:9 How Enceladus earned its stripes, 4:11 NASA retires the Spitzer Space Telescope, 6:13 New solar scope sees first light, 6:7 NICER sees brightest X-ray burst yet, 3:10 Water vapor detected in Europa's atmosphere, 3:12 Cendes, Yvette A neutron star lurking in Supernova 1987A, 11:10 The Sun's lost siblings, 7:44–49 Chaple, Glenn Astronomy guides: Readers' picks, 12:58 Explore Markarian's Chain, 5:64 February's finest sights, 2:64 Intermediate and advanced guides, 4:64 New year, new sky, 1:64 Picking a beginner's guide, 3:66 Set your sights on the Red Planet, 10:68 Summertime observing, 7:66 Target a changing crown jewel, 6:66 Target asteroid Papagena, 11:58 Women in astronomy clubs, 8:66, 9:64 D Davis, Joel The mystery and majesty of the ice giants, 12:40–47 Dorminey, Bruce Stellar neighbors close-up, 7:30–35 E Eicher, David J. Ann Druyan on Cosmos and Carl Sagan's legacy, 4:44–49 Apollo 13 in 3D, 4:28–35 Cosmic clouds 3D, 5:44-51 Deep-sky observing from Costa Rica, 9:54–59 Explore the world of galaxies, 6:28–35 V.M. Slipher's expanding universe, 5:31–35 Evans, Ben A fresh look at our home star, 8:18–27 The Moon's farside unveiled, 10:24–29

F

```
Falk, Dan
  How Galileo blended science and art, 11:24-31
  Tour five great Australian observatories, 1:50-55
G
Goldstein, Alan
  View Earth through a cosmic lens, 10:30–35
Η
Hall, Jeffrey
  Lowell Observatory turns 125, 2:44-49
Hallas, Tony
  Canon's new astro camera, 5:62-63
  Chroma filters, 9:60-61
Harrington, Phil
  Colorful winter stars, 1:62
  Curve to Corvus and beyond, 5:66
  Dissecting Andromeda, 12:60
  A dolphin's tale, 9:66
  Explore Sagittarius, 8:68
  Going to the dogs, 4:66
  A month of change, 3:64
  Our 10th annual Star Products, 10:54-61
  Riches of the Scorpion, 7:68
  We test: Celestron's Nature Binoculars, 2:60-61
  A whale's tale, 11:60
  The wonderful variable star, 10:62-63
Haynes, Korey
  Arrokoth flyby hints at how planets formed, 6:11
Hester, Jeff
  Cogito, ergo sum?, 8:62
  The coolest cat on the web, 7:64
  The illusion of disciplines, 10:64
  Learning the hard way, 9:16
  No crystal balls, 6:16
  Rekindling dreams, 5:18
  Satellite tracking for amateurs, 2:62
Hooper, Dan
  Is the Big Bang in crisis?, 5:20–29
Hubbell, Jerry
  Discover exoplanets from your backyard, 6:54–57
Hyman, Randall
  Our new view of the Milky Way, 10:14-23
J
Johnson-Groh, Mara
  Meet our second-ever interstellar visitor, 1:10-11
K
Kaler, Jim
  How stars are born and die, 7:16-23
Klesman, Alison
  Anatomy of a cosmic swan, 5:9
  Astronomers see our Sun spin threads of plasma, 8:15
```

### Astronomy Magazine Article Author Index

California stars in Spitzer's final mosaic, 8:13 Campfires on the Sun, 11:7 Comet C/2020 F3 (NEOWISE) lights up July skies, 10:8-9 Curiosity snaps a celebratory selfie, 2:14 The dance of Neptune's moons, 3:10 Decoding the Hertzsprung-Russell diagram, 7:11 The first map of a neutron star, 4:14 A galactic collision, 4:9 A ghostly space face, 3:7 Giant planet atmospheres, 9:12 Giant wave of star-forming clouds lies near the Sun, 5:12 Gravitational wave spectrum, 10:11 How the planets line up, 5:13 Hubble's cosmic reef, 7:7 Iron rains from the sky on this world, 7:13 Location matters, 9:7 Meet our second-ever interstellar visitor, 1:10–11 Meet the Deep Space Atomic Clock, 1:14 The most moons, 6:11 NASA drives a Mars rover from home, 8:13 NASA retires the Spitzer Space Telescope, 6:13 A new look at a close neighbor, 1:9 NICER sees brightest X-ray burst yet, 3:10 Old star reveals young jets, 7:12 One galaxy, three supermassive black holes, 4:12 Our first interstellar visitor, 2:18–27 Our nearby gentle giant, 5:13 Pop-up robot scouts practice their skills, 7:13 Second repeating fast radio burst tracked, deepening mystery, 5:14 Shocking scene, 5:12 Solar Orbiter heads for the sun, 6:10 Spacecraft survival rates, 3:11 Stellar database encourages amateur submissions, 2:15 The Sun and the stars, 2:13 Supermassive black holes stunt dwarf galaxies, 2:12 Swirling space-time reveals white dwarf's past, 6:12 Telescopes and mirrors, 3:33 Terrestrial atmospheres, 8:12 TESS unlocks the secret of Delta Scuti stars, 9:10 Top 10 space stories of 2019, 1:20-31 What is the horizontal branch?, 7:59 X-ray flashes reveal a possible black hole, 1:14 Young stars blow bubbles, 2:13 L Loomis, Ilima Excavating cosmic fossils, 8:28-35 M May, Brian Apollo 13 in 3D, 4:28–35 Cosmic clouds 3D, 5:44-51 McLaughlin, Hailey Rose A celestial hourglass, 6:9

Astronomers spot a bowed bridge, 9:12

Hubble captures cometary breakup, 8:9 MeerKAT solves a boomerang-shaped mystery, 9:11 NASA retires the Spitzer Space Telescope, 6:13 Solar Orbiter heads for the sun, 6:10 A suspected exoplanet disappears before Hubble's eyes, 8:14 Vader's TIE fighter?, 12:13 When the Milky Way erupted in 100,000 supernovae, 4:13 N Naeye, Robert How we'll find life in the universe, 9:18–27 Naone, Erica Astronomers find 139 new minor planets, 7:10 Nemo, Leslie Found: Crater from 790,000-year-old asteroid strike, 5:10  $\mathbf{O}$ Olsen, Knut A tale of two galaxies, 11:16-23 O'Meara, Stephen James "Fire" in the sky, 11:56 Hindsight, 1:60 Inside the Perseus Molecular Cloud, 1:56-59 Is T CrB rising?, 7:62 The lunar blackdrop effect, 3:16–17 Observe Jupiter and Saturn at their best, 8:56-59 Observe winter's twin treats, 2:56–59 Pearl in the mist, 8:64 A penumbral challenge, 12:16 Red rainbows, 6:64 Reflections on a sunset, 4:62 Target edge-on and face-on galaxies, 5:56-61 The 2020 Ghost Hunt, 9:62 Venus' crescent, 2:66 The wonder of Haidinger's Brush, 10:66 P Parks, Jake Astronomers find 139 new minor planets, 7:10 Bye-bye, solar system!, 9:11 Comparing the Apollo missions, 4:13 A cosmic pretzel, 2:9 Creating the universe's most powerful magnets, 2:10–11 Curiosity views the martian horizon, 7:9 Do all galaxies have dark matter?, 3:44-51 Exploring ancient life in Australia, 3:11 Found: Crater from 790,000-year-old asteroid strike, 5:10 Giant planet found around white dwarf, 4:12 Growing space salad, 7:8–9 How does smell work?, 9:34 Hubble's latest snap of Saturn, 1:11 Is Planet Nine a tiny black hole?, 3:8 Meet the most extreme stars, 7:24-29 Mercury transits the Sun, 3:13 More galaxies found to be missing dark matter, 4:10–11

### Astronomy Magazine Article Author Index

NASA astronauts graduate with eye toward Artemis, 5:15 The next generation of telescopes, 5:11 Our Sun is strangely docile, 8:12 Perseverance begins journey to the Red Planet, 11:8-9 A planet is born, 9:10 Prepare for launch: Perseverance, 6:44-53 In pursuit of Planet Nine, 1:44–49 Researchers map dark matter via slime mold, 7:12 Spitzer captures a stellar playground, 5:11 Spitzer's scrapbook, 1:12 This is the definitive Moon map, 8:14 Tiny star, giant planet, 2:14 Water vapor detected in Europa's atmosphere, 3:12 Water vapor found on a potentially habitable exoplanet, 1:16 When the Milky Way erupted in 100,000 supernovae, 4:13 Secrets of the Northern Pinwheel Galaxy, 3:52-55 R Raynor-Evans, Katrin Collect the cosmos in stamps, 11:50-55 Redd, Nola Taylor Cataclysm in the early solar system, 2:28-35 Is Eta Corvi a window to our past?, 7:50-55 20 years around the Red Planet, 12:20-27 S Sarajedini, Ata How pulsating stars unlock our universe, 7:56-61 Schindler, Kevin Lowell Observatory turns 125, 2:44-49 Shubinski, Raymond Gold from the stars, 11:40–45 Meet an easy-to-use imaging scope, 8:60-61 T Talcott, Richard Asteroids on the prowl, 5:15 Hubble's greatest hits, 3:18-29 Jim Lovell remembers: Triumph over tragedy, 4:18–27 Mars' splendid show, 2:15 The ringed world wanders, 3:9 Warm and not so fuzzy, 6:18-27 Thompson, Samantha Astronomy's electronic revolution, 2:52–55 V Voller, Ron How the Ritchey-Chrétien telescope was born, 3:30-35 Telescopes and mirrors, 3:33 W Wenz, John Researchers map dark matter via slime mold, 7:12

Visit the nearest 14 habitable exoplanets, 4:50–51 Wilds, Richard P.
Shining light on dark nebulae, 12:28–31

#### Z

Zastrow, Mark
Arecibo dish damaged after cable snaps, 12:12
Astronomers weigh satellites' impact on night sky, 12:11
Behold the X-ray sky, 10:7
Black hole loses its crown—then gets it back, 11:12
Comet C/2020 F3 (NEOWISE) lights up July skies, 10:8–9
Two exoplanets seen circling a Sun-like star, 11:12