Looking for Exoplanets

VI

Instruments

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Looking for Exoplanets - Status

NASA data (10-26-21)

• 4,538 confirmed exoplanets
• 7,854 candidate exoplanets
• 3,369 planetary systems

Discovery Methods

• Astrometry 1
• Radial Velocity 880
• Transit 3,428
• Microlensing 118
• Imaging 54

Planet Types

• Gas Giant (1,443)
• Neptune-like (1,535)
• Super Earth (1,389)
• Terrestrial (166)
• Unknown (5)
Looking for Exoplanets – Instruments - Telescopes

Refractors

Reflectors
Looking for Exoplanets – Instruments - Telescopes

• **Yerkes Observatory** of the University of Chicago, is located at Williams Bay on Lake Geneva in southeastern Wisconsin

• It contains the largest **refracting telescope** (40 inches [1 meter]) in the world

• It has been used for solar and stellar spectroscopy, photographic parallaxes, and double-star observation

• Cincinnati Observatory has a 16 inch refractor
## Looking for Exoplanets – Instruments – Telescopes in U.S.

<table>
<thead>
<tr>
<th>Telescope</th>
<th>Size</th>
<th>Type</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMT (2027)</td>
<td>30m</td>
<td>optical</td>
<td>Mauna Kea, HI</td>
</tr>
<tr>
<td>Keck I &amp; II Telescopes</td>
<td>2x10m</td>
<td>optical</td>
<td>Mauna Kea, HI</td>
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<tr>
<td>Large Binocular Telescope</td>
<td>2x8.4m</td>
<td>optical</td>
<td>Mt. Graham, AZ</td>
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<td>Hobby-Eberly Telescope</td>
<td>10m</td>
<td>optical</td>
<td>Fort Davis, TX</td>
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<tr>
<td>Subaru Telescope</td>
<td>8.2m</td>
<td>optical</td>
<td>Mauna Kea, HI</td>
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<td>Gemini N. Telescope</td>
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<td>Mauna Kea, HI</td>
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<td>MMT Observatory</td>
<td>6.5m</td>
<td>optical</td>
<td>Mt. Hopkins, AZ</td>
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<td>Hale Telescope</td>
<td>5.1m</td>
<td>optical</td>
<td>Palomar Mtn, CA</td>
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<td>Discovery Telescope</td>
<td>4.3m</td>
<td>optical</td>
<td>Mormon Lake, AZ</td>
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<td>Mayall Telescope</td>
<td>4m</td>
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<td>Kitt Peak, AZ</td>
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<td>Very Large Array</td>
<td>28x25m</td>
<td>radio</td>
<td>Socorro, NM</td>
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<td>Green Bank Telescope</td>
<td>100m</td>
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<td>Goldstone Observatory</td>
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<td>radio</td>
<td>Barstow, CA</td>
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<td>LIGO Hanford</td>
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<td>gravitational</td>
<td>Richland, WA</td>
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<td>LIGO Livingston</td>
<td>2x4km</td>
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Mount Wilson Observatory (MWO) is an astronomical observatory in Los Angeles County, California. The MWO is located on Mount Wilson, a 1,740-meter (5,710-foot) peak in the San Gabriel Mountains near Pasadena. The 100-inch (2.5 m) Hooker telescope was the largest aperture telescope in the world from its completion in 1917 to 1949. It was used by Edwin Hubble to determine that some nebulae were actually galaxies outside our own Milky Way. Hubble, assisted by Milton L. Humason, discovered the presence of the redshift that indicated the universe is expanding.
Looking for Exoplanets – Instruments - Spectrograph

• A spectrograph splits light into its component wavelengths

• First, light travels from a telescope through a small opening in the spectrograph to a collimating mirror that lines up all entering rays of light parallel to one another before they reach a finely scored plate of glass known as a **diffraction grating**

• The grating bends red light in a different way from orange light, which bends a little differently from yellow light and so on, spreading the many wavelengths into a **spectrum**

• Rotating the diffraction grating controls which wavelengths of light reach another mirror, which in turn focuses these wavelengths onto a photodetector

• The detector converts photons into electrical signals that a computer interprets to measure the strength of different wavelengths
Looking for Exoplanets – Instruments – Telescopes Ground Based - Gran Telescopio Canarias

• The Gran Telescopio Canarias (GTC) is a 10.4 m (410 in) reflecting telescope located at the Roque de los Muchachos Observatory on the island of La Palma, in the Canaries, Spain.

• The Project is a partnership formed by several institutions from Spain and Mexico, the University of Florida, the National Autonomous University of Mexico and the Instituto de Astrofísica de Canarias (IAC).

• It is the world's largest single-aperture optical telescope.
Looking for Exoplanets – Instruments - Telescopes - Keck

• The W. M. Keck Observatory is a two-telescope astronomical observatory at an elevation of 4,145 meters (13,600 ft) near the summit of Mauna Kea in Hawaii

• Both telescopes have 10 m (33 ft) aperture primary mirrors

• They use of active optics to operate smaller mirror segments as a single, contiguous mirror

• Each primary mirror is made of 36 hexagonal segments that work together as a unit

• Each segment is 1.8 meters wide, 7.5 centimeters thick, and weighs half a ton

• On the telescope, each segment is kept stable by a system of active optics, which uses extremely rigid support structures in combination with three actuators under each segment

• During observation, the computer-controlled system of sensors and actuators dynamically adjusts each segment's position relative to its neighbors, keeping a surface shape accuracy of four nanometers

• As the telescope moves, this twice-per-second adjustment counters the effects of gravity and other environmental and structural effects that can affect mirror shape
• As light from distant celestial objects enters our atmosphere it gets disturbed by our ever-moving atmosphere.
• Light is distorted due to the temperature variations in atmospheric cells.
• As light travels slightly faster in less dense warm air, the resultant refraction is non-uniform.
• Adaptive optics compensates for this, resulting in a much sharper images.

• Each mirror segment is kept stable by a system of active optics, which uses extremely rigid support structures in combination with three actuators under each segment.
• The computer-controlled system of sensors and actuators dynamically adjusts each segment's position relative to its neighbors, keeping a surface shape accuracy of four nanometers.
• As the telescope moves, this twice-per-second adjustment counters the effects of gravity and other environmental and structural effects that can affect mirror shape.
Looking for Exoplanets – Instruments – Telescopes - Extremely Large Telescope

• The Extremely Large Telescope (ELT) is an astronomical observatory currently under construction

• When completed, it is planned to be the world's largest optical/near-infrared extremely large telescope

• Part of the European Southern Observatory (ESO) agency, it is located on top of Cerro Armazones in the Atacama Desert of northern Chile.

• The design consists of a reflecting telescope with a 39.3-metre-diameter (130-foot) segmented primary mirror and a 4.2 m (14 ft) diameter secondary mirror, and will be supported by adaptive optics

• The observatory will gather 100 million times more light than the human eye, and be able to correct for atmospheric distortion

• It has around 256 times the light gathering area of the Hubble Space Telescope and would provide images 16 times sharper than those from Hubble
Looking for Exoplanets – Instruments – Telescopes - Ground Based-Magellan II

• The **Magellan Telescopes** are a pair of 6.5-meter-diameter (21 ft) **optical telescopes** located at Las Campanas Observatory in Chile

• First light for the telescopes was on September 15, 2000 for the Baade, and September 7, 2002 for the Clay

• A consortium consisting of the **Carnegie Institution for Science, University of Arizona, Harvard University**, the **University of Michigan** and the **Massachusetts Institute of Technology** built and operate the twin telescopes

• They are generally acknowledged to provide the best **natural seeing** of any ground-based optical/IR telescopes

• Elevation 8,255 ft
The Lick Observatory near San Jose, CA has been looking into the heavens since the Victorian Era, but its newest survey platform is straight out of the 21st century.

The Automated Planet Finder Telescope (APF) is a fully robotic 2.4-meter optical telescope will scan the entirety of the sky above Mount Hamilton over the next decade.

Paying special attention to 1,000 nearby (within 100 light years) stars and cataloging about 10 each night.

The project is looking for rocky planets with a mass 1 – 20 times that of Earth.

APF uses a high resolution spectrograph to obtain radial velocity measurements (Doppler effect data) from its observation of the preprogrammed star sets gathered over the course of months.

If low-mass planets are orbiting these stars the data will reveal their presence.
Optical Telescopes - Comparison
Looking for Exoplanets – Instruments - Space Telescopes
Looking for Exoplanets – Instruments - Space Telescopes - Hubble

• **Hubble Space Telescope (HST)** was launched on the Space Shuttle on April 24, 1990

• Deployed on April 25, 1990

• It has a 2.4 meter reflecting telescope that operates in low Earth orbit

• Several significant problems were discovered soon after orbital operations started

• Perhaps the most significant problem was an *improperly ground primary mirror*, resulting in blurry images

• Flexing of the original solar panels, as the spacecraft passed in and out of sunlight during its orbit, created stability problems

• Both of these problems were corrected during subsequent servicing missions
The Spitzer Space Telescope, formerly the Space Infrared Telescope Facility (SIRTF), is a retired infrared space telescope launched in 2003 and retired on January 30, 2020.

Spitzer used the transit photometry and gravitational microlensing techniques to search for exoplanets.

Spitzer discovered HD 219134 b in 2015, a rocky planet about 1.5 times as large as Earth in a three-day orbit around its star and an unnamed planet found using microlensing located about 13,000 light-years (4,000 pc) from Earth.

In 2016, Spitzer was used to discover five of a total of seven known planets around the star TRAPPIST-1.

All are approximately Earth-sized and likely rocky.
The discovery of exoplanets grew exponentially in the years following with the launch of the Kepler Space Telescope.

The Delta II rocket carrying NASA's Kepler spacecraft lifted off March 6, 2009 from Cape Canaveral, Florida.

The Kepler mission was designed to survey our region of the Milky Way galaxy to discover Earth-size and smaller planets in or near the habitable zones around stars.

- Were rocky planets could have liquid water on the surface
- And determine the fraction of stars that might have such planets around them

After the second of Kepler’s four gyroscope-like wheels failed in 2013, Kepler completed its prime mission that November and began its extended mission, K2.

The spacecraft was retired in 2018, but Kepler data are still being used to find exoplanets.
Looking for Exoplanets – Instruments - Space Telescopes - Kepler

- The **Kepler** space telescope was launched March 7, 2009 by NASA to discover Earth-size planets
- It was placed in an Earth-trailing heliocentric orbit
- After nine and a half years of operation, the its reaction control system fuel was depleted
- **NASA** announced its retirement on October 30, 2018
- It was designed to survey a portion of Earth's region of the Milky Way to discover Earth-size exoplanets in or near habitable zones
- And estimate how many stars in the Milky Way have such planets
- Its sole scientific instrument was a photometer that continually monitored the brightness of approximately 150,000 main sequence stars in a fixed field of view
- **Transit method** data were transmitted to Earth, then analyzed to detect periodic dimming caused by exoplanets that cross in front of their host star
- **Kepler** observed 530,506 stars and detected 2,662 exoplanets (~0.5%)
Looking for Exoplanets – Instruments - Space Telescopes - TESS

• The Transiting Exoplanet Survey Satellite (TESS) is designed to discover thousands of exoplanets in orbit around the brightest dwarf stars in the sky.

• Its mission (launch in 2018), a two-year survey of the solar neighborhood, TESS monitored the brightness of stars for periodic drops caused by planet transits.

• TESS is finding planets ranging from small, rocky worlds to giant planets, showcasing the diversity of planets in the galaxy.

• TESS finished its primary mission, July 4, 2020, by imaging about 75% of the starry sky as part of a two-year-long survey.

• TESS is now in an extended mission.
• TESS confirmed exoplanets 166
• TESS candidate exoplanets 4,604
Looking for Exoplanets – Instruments - Space Telescopes - Webb

- **Webb** is NASA’s largest and most powerful space science telescope ever constructed

- **Webb’s** enormous size and frigid operating temperature present extraordinary engineering challenges

- After launching from French Guiana, the observatory will travel to an orbit about one million miles away from Earth and undergo six months of commissioning in space—unfolding its mirrors, sunshield, and other smaller systems; cooling down; aligning; and calibrating

- Webb is an international collaboration between NASA, the ESA (European Space Agency) and the Canadian Space Agency
Looking for Exoplanets – Instruments - Space Telescopes - Webb

- Webb’s primary mirror is 21.3 feet (6.5 meters) across
- The mirror is comprised of 18 gold-plated hexagonal deployable segments
- Webb’s five-layer deployable sunshield is the size of a tennis court
- Webb has several science instruments:
  - Near-Infrared Camera (NIRCam)
  - Near-Infrared Spectrograph (NIRSpec)
  - Mid-Infrared Instrument (MIRI),
  - Near-Infrared Imager
  - Slitless Spectrograph (NIRISS) with the Fine Guidance Sensor (FGS)

- It will orbit the Sun around the second Lagrange point (L2) about 1 million miles from earth
Looking for Exoplanets – Instruments - Space Telescopes - Webb

The Hubble Space Telescope orbits around the Earth at an altitude of ~353 miles above it.

Webb will not actually orbit the Earth - instead it will sit at the Earth-Sun L2 Lagrange point, 930,000 miles away. At the L2 point Webb’s solar shield will block the light from the Sun, Earth, and Moon. This will help Webb stay cool, which is very important for an infrared telescope. As the Earth orbits the Sun, Webb will orbit with it - but stay fixed in the same spot with relation to the Earth and the Sun. Webb will orbit around the L2 point. It won’t stay completely motionless at a fixed spot.
Looking for Exoplanets – Instruments - Space Telescopes - Webb

- **Seeking Light from the First Galaxies in the Universe**
  - Webb will directly observe a part of space and time never seen before.
  - Webb will gaze into the epoch when the very first stars and galaxies formed, over 13.5 billion years ago.
  - Ultraviolet and visible light emitted by the very first luminous objects has been stretched or “redshifted” by the universe’s continual expansion and arrives today as infrared light.
  - Webb is designed to “see” this infrared light with unprecedented resolution and sensitivity.

- **Exploring Distant Worlds and the Solar System**
  - Webb will also be a powerful tool for studying the nearby universe.
  - Scientists will use Webb to study planets and other bodies in our solar system to determine their origin and evolution and compare them with exoplanets.
  - Webb will also observe exoplanets located in their stars’ habitable zones and can determine if and where signatures of habitability may be present.
  - Using a technique called transmission spectroscopy, the observatory will examine starlight filtered through planetary atmospheres to learn about their chemical compositions.
Next Session

Some Exoplanets