Looking for Exoplanets

Astrometry
Direct Imaging

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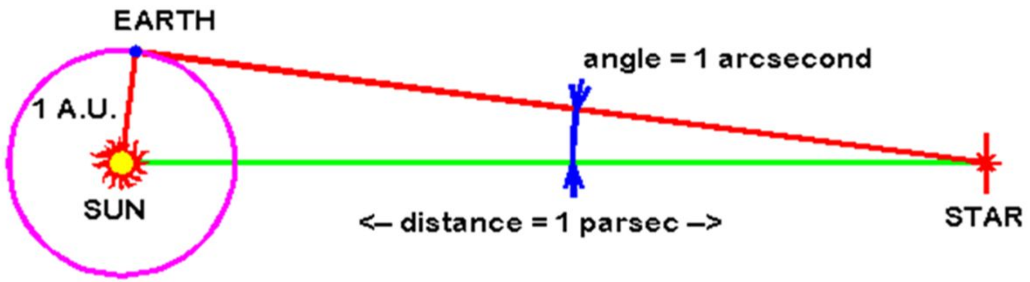
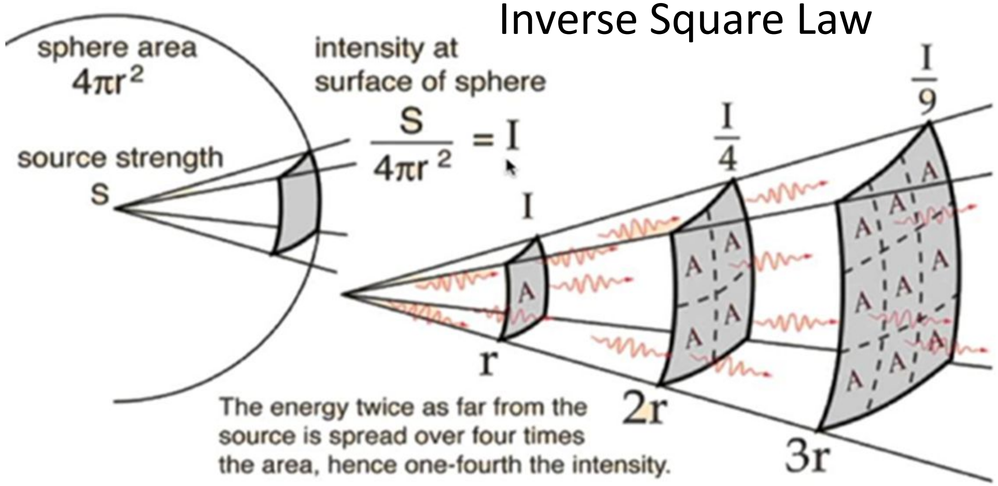
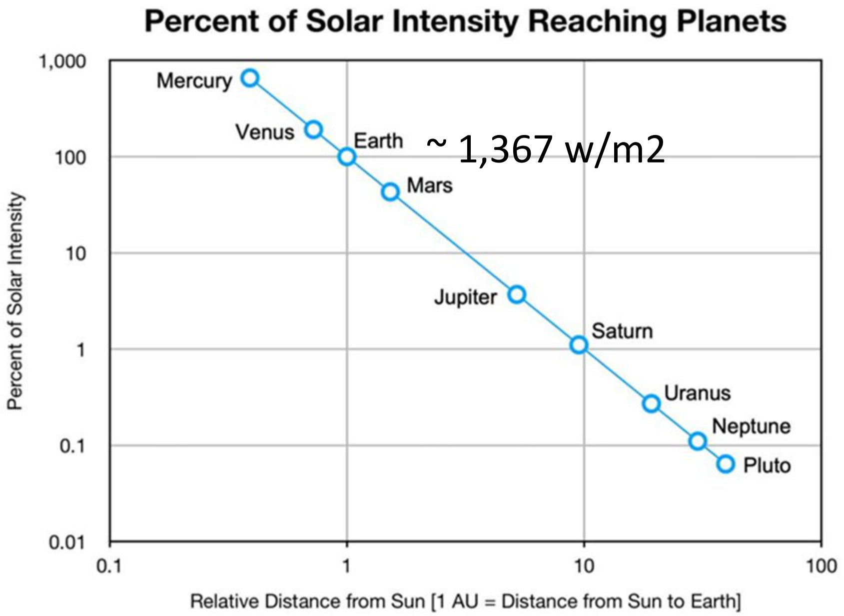
Looking for Exoplanets-Distances

- There are 3,600 arcseconds in one degree
- One parsec is 206,265 AU (or 3.26 light-years)
- One **parsec** is the distance to an object whose parallax angle is one **arcsecond**
- One **parsec** is 3.26156378 **light years**



Inverse Square Law

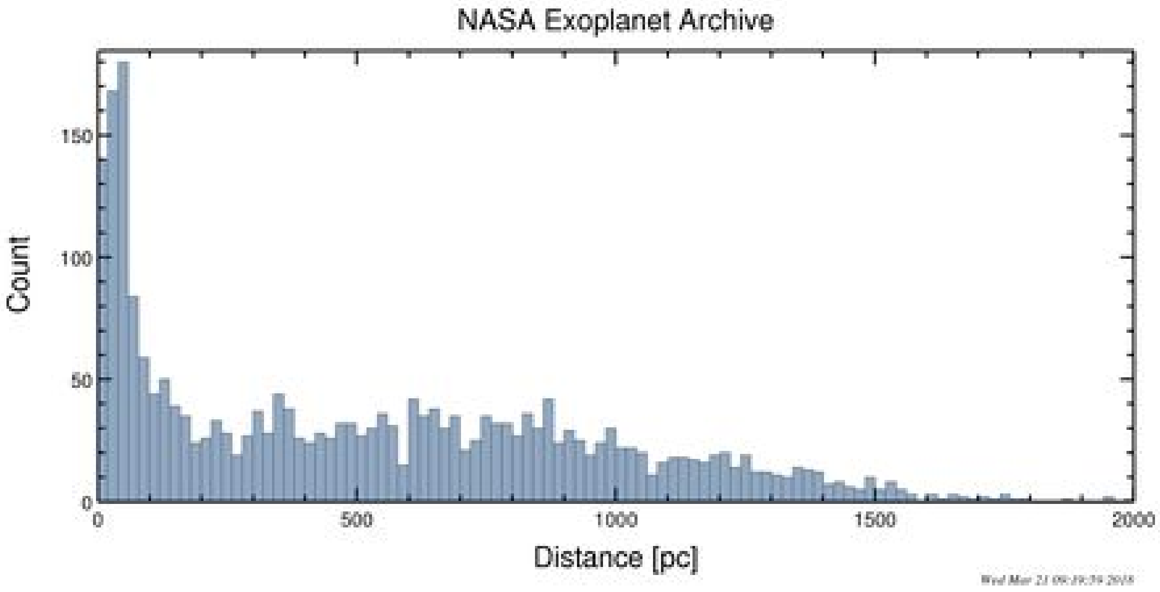




~ 1,367 w/m2

Looking for Exoplanets-Distances

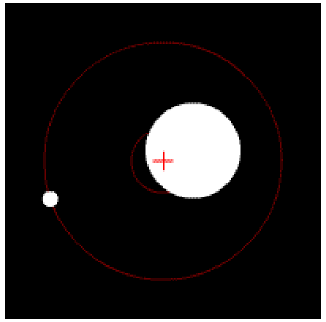
- **Astrometry** and **Direct Imaging** rely on capturing light from distant stars
- Great distances to stars and the **Inverse Square Law** result in extremely low levels of light intensity at Earth
- At the surface of the **Sun** the intensity of the solar radiation is
- ~ 6.33×10 7 W/m 2 (watts, per square meter)
- At Earth (1AU) the Sun's intensity is ~1,367 W/m 2
- Light year-The distance that light travels in a vacuum in one year, approximately 9.46 trillion kilometers (5.88 trillion miles)
- 1 LY =63,066 AU
- 100 LY=6,306,600 AU
- Sun's intensity at 100 LY =0.000001592 that at **Earth (**1.592E-6)



100 LY = 30.65 parsecs

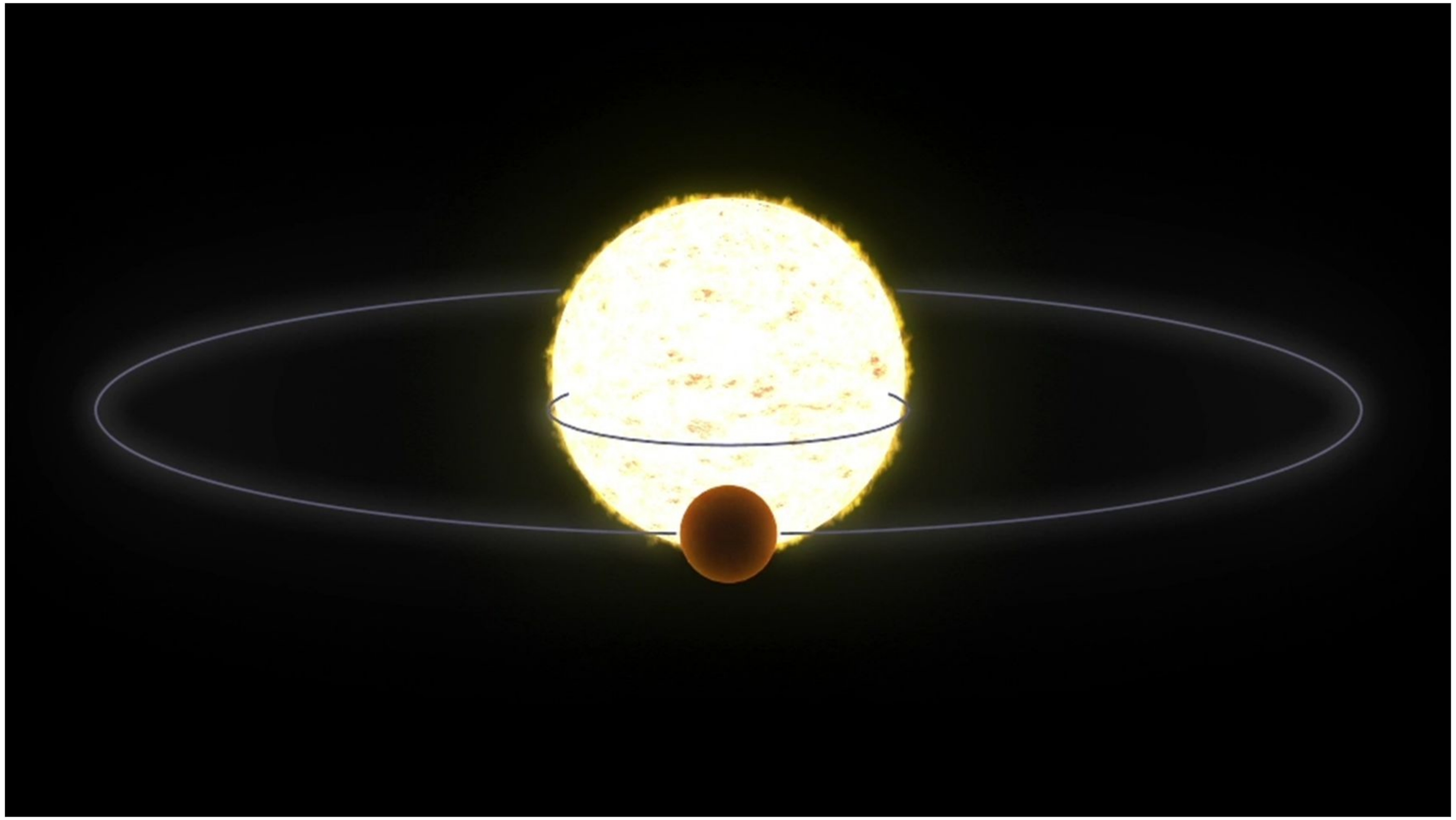
Looking for Exoplanets - Astrometry

- **Astrometry** consists of precisely measuring a star's position in the sky, and observing how that position changes over time
  - Originally, this was done visually, with hand-written records
- Late in the 19th century, the use of photographic plates greatly improving the accuracy of the measurements
  - It also created a data archive
- If a star has a planet, then the gravitational influence of the planet will cause the star itself to move in a tiny circular or elliptical orbit
- Effectively, star and planet each orbit around their mutual center of mass (barycenter)
- Since the star is more massive, its orbit will be much smaller
- The mutual center of mass (barycenter) may lie within the radius of the star
- It is easier to find high mass planets around low-mass stars, especially brown dwarfs

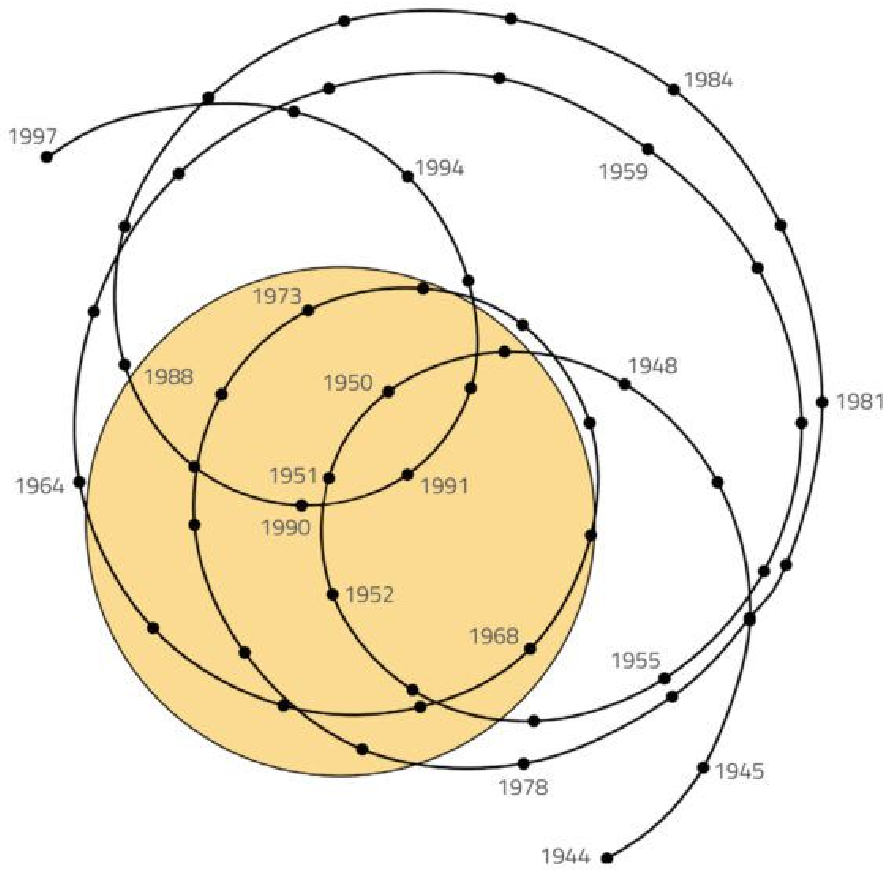


https://en.wikipedia.org/wiki/Barycenter#/media/File:Orbit4.gif

Looking for Exoplanets - Astrometry



Looking for Exoplanets - Astrometry



- Motion of the **Sun** over time
- The black line shows the wobbling path of the **Sun** from 1944 to 1997 as the planets of the Solar System pull on it
- The yellow circle indicates the **Sun'**s size

Looking for Exoplanets - Astrometry

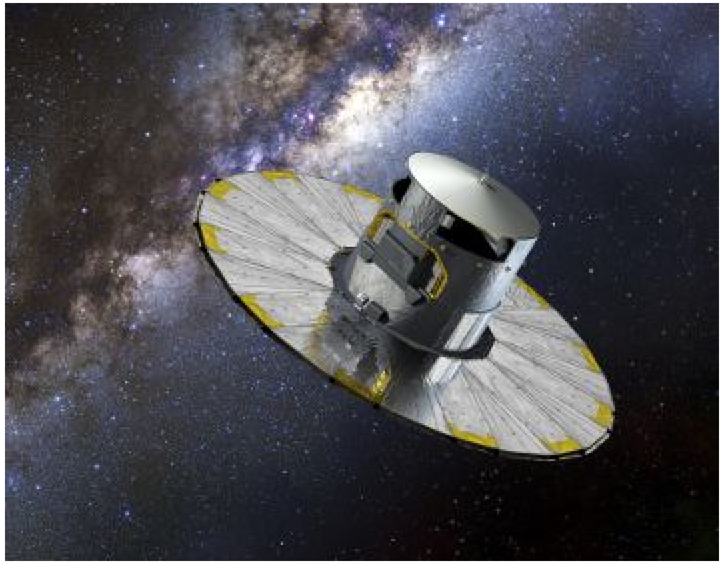
- **Astrometry** is the oldest search method for exoplanets
- It was originally popular because of its success in characterizing astrometric binary star systems
- It dates back at least to the late 18th century
- Unfortunately, changes in stellar position are so small—and atmospheric and systematic distortions so large—that even the best ground-based telescopes cannot produce precise enough measurements
- All claims of a planetary companion of less than 0.1 solar mass, as the mass of the planet, made before 1996 using this method are likely spurious

- In 2002, the **Hubble Space Telescope** did succeed in using **astrometry** to characterize a previously discovered planet around the star **Gliese 876**

    - Atmosphere bends light chaotically, causing telescopic images to waver and smear
    - Atmosphere is responsible for poor transparency when it absorbs and scatters light, causing faint objects to appear even fainter than they really are

Looking for Exoplanets - Astrometry

- **GAIA** is a **European Space Agency (ESA**), space observatory launched in 2013
  - It is expected to operate until c. 2022
- It uses **astrometry -** measuring the positions, distances and motions of stars with great precision
- Its mission is to construct the largest and most precise 3D space catalog ever made
- Including approximately 1 **billion** astronomical objects
  - Stars, planets, comets, asteroids and quasars, etc
- The spacecraft monitors each of its target objects about 70 times over the first five years of the mission to study the precise position and motion of each target
- **GAIA** is expected to detect thousands to tens of thousands of **Jupiter-sized** exoplanets beyond the Solar System!



- **GAIA** data is released in stages
- The first data release, **GAIA DR1** was in 2016
- It was based on 14 months of observations made through September 2015

Looking for Exoplanets - Astrometry

- Planets are far less massive than stars, but they still exert a gravitational pull on them
- The gravitational forces between a planet and its star causes the pair to orbit a shared center of mass that is often within the star itself, although not right in the middle
- The result is that the star appears to wobble as it moves in a tiny orbit around the shared center of mass
- The pull of **Jupiter** on the **Sun**, for example, causes the **Sun** to wobble with an average velocity of 12 m/s as it orbits a center of mass close to its surface
- The **astrometric** method relies on detecting this almost imperceptibly small wobble in stars situated many light years away- high demands on the sensitivity of instruments
- A **Sun**-sized star 42 light years away (ten times further than our closest neighboring star, Proxima Centauri) would wobble by only a fifth of a millionth of a degree under the influence of a planet like **Jupiter**
- This is equivalent to seeing the **International Space Station** from the Earth moving **1.5 mm** in its orbit
- The effect of an **Earth-sized planet** would be some 1600 times smaller
- Very few of known exoplanets have been found using the **astrometric** method

Looking for Exoplanets – Direct Imaging

- **Direct Imaging** consists of capturing images of exoplanets directly by searching for the light *reflected* from a planet's atmosphere at **infrared** wavelengths
- At infrared wavelengths, a star is only likely to be about **1 million times brighter** than a planet reflecting light
- At visible light wavelengths, a star is typically a **billion times brighter** than a planet's reflected light
- So far, only a handful of planets have been discovered by **Direct Imaging**
- While challenging compared to indirect methods, this method is the most promising when it comes to characterizing the atmospheres of exoplanets
- Chemical composition via spectroscopy
- So far, 100 planets have been confirmed in 82 planetary systems using this method
- Many more are expected to be found in the near future

Looking for Exoplanets – Direct Imaging

- **Direct Imaging** is is less prone to false positives
- The **Transit Method** is prone to false positives in up to 40% of cases involving a single planet system (necessitating follow-up observations)
- Planets detected using the **Radial Velocity Method** require confirmation
  - Why it is usually paired with the **Transit Method**
- **Direct Imaging** allows astronomers to actually see the planets they are searching for
- By examining the spectra reflected from a planet's atmosphere, astronomers are able to obtain vital information about its composition
- This information is intrinsic to exoplanet characterization and determining if it is potentially habitable

Looking for Exoplanets – Direct Imaging

- **Direct Imaging** works best for planets that have wide orbits and are particularly massive (such as gas giants)
- It is also very useful for detecting planets that are positioned “**face-on**”, meaning that they do not transit in front of the star relative to the observer
- This makes it complimentary to radial velocity, which is most effective for detecting planets that are “edge-on”,

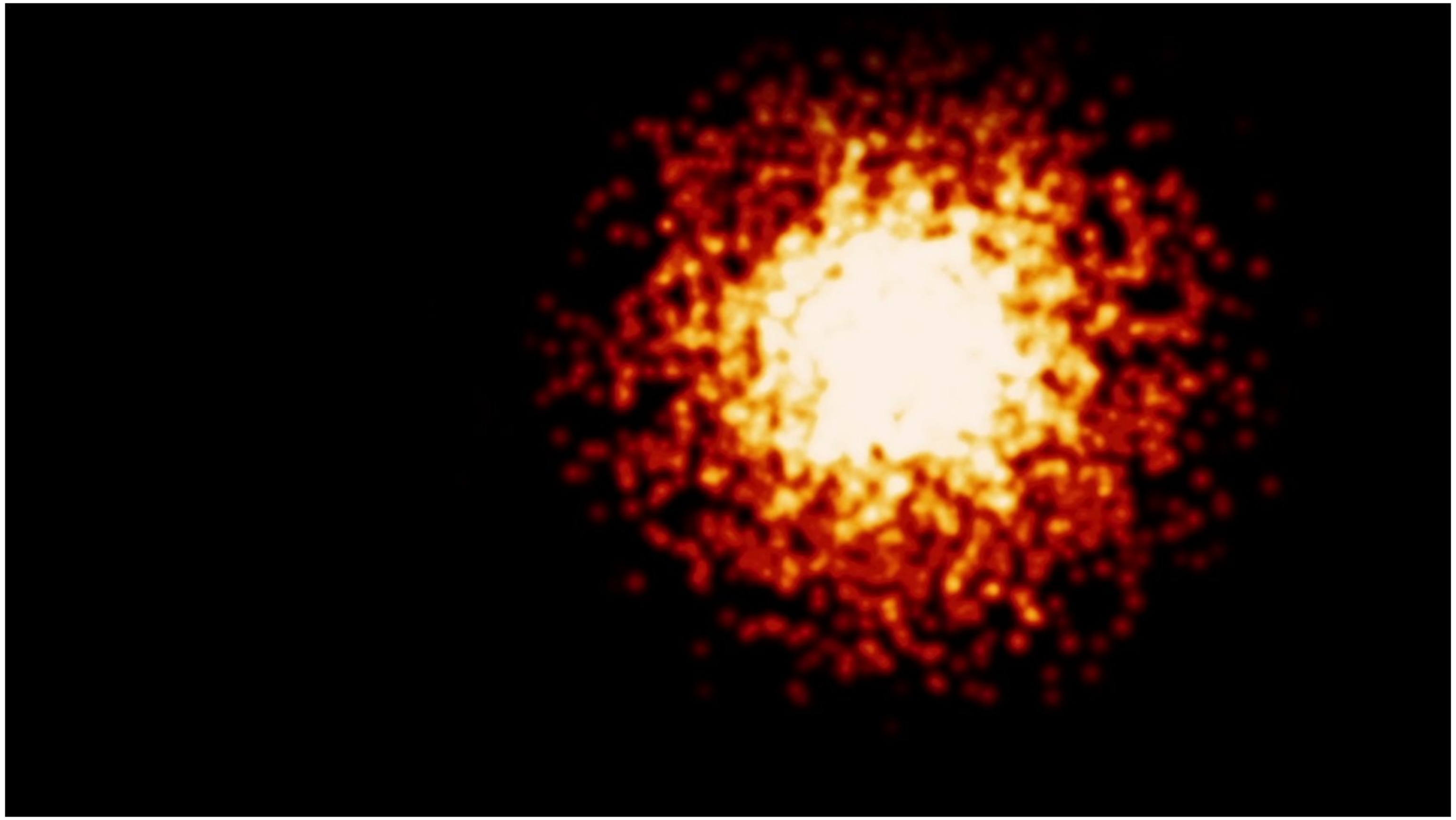
Orbital motion of the HR8799 system

- https://www.youtube.com/watch?v=gcHXGZaS_6Mre planets make transits of their star

Looking for Exoplanets – Direct Imaging

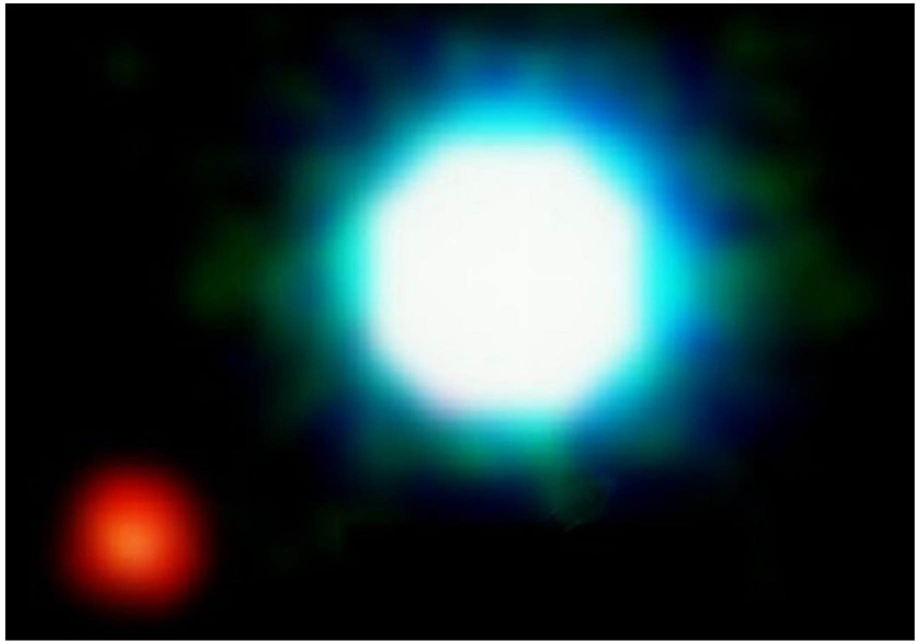
- **Direct Imaging** is **rather** difficult because of the obscuring effect light from a star has
- It is very difficult to detect the light being reflected from a planet's atmosphere when its parent star is so much brighter
- Opportunities for **Direct Imaging** are very rare using current technology
- For the most part, planets can only be detected using this method when they orbit at great distances from their stars or are particularly massive
- This makes it very limited when it comes to searching for **terrestrial** (aka. "Earth-like") planets that orbit closer to their stars
- **Direct Imaging** method is not particularly useful for searching for potentially-habitable exoplanets

Looking for Exoplanets – Direct Imaging



Looking for Exoplanets – Direct Imaging

- The first **exoplanet** detection made using this technique occurred in ***July of 2004***, when a group of astronomers used the **European Southern Observatory's (ESO) Very Large Telescope Array (VLTA)**
- They imaged a planet several times the mass of **Jupiter** in close proximity to **2M1207** – a **brown dwarf** located about 200 light years from **Earth**
- A **brown dwarf** is a star like object that is not massive enough to sustain nuclear fusion in its hydrogen core
- It does not have high surface temperature or luminosity like a "real" star

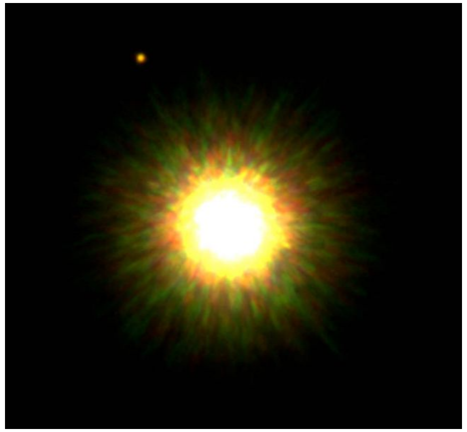


- Image of a planetary-mass object in orbit around brown dwarf **2M1207**, taken by a group of astronomers led by **Gael Chauvin** in July of 2004

Looking for Exoplanets – Direct Imaging

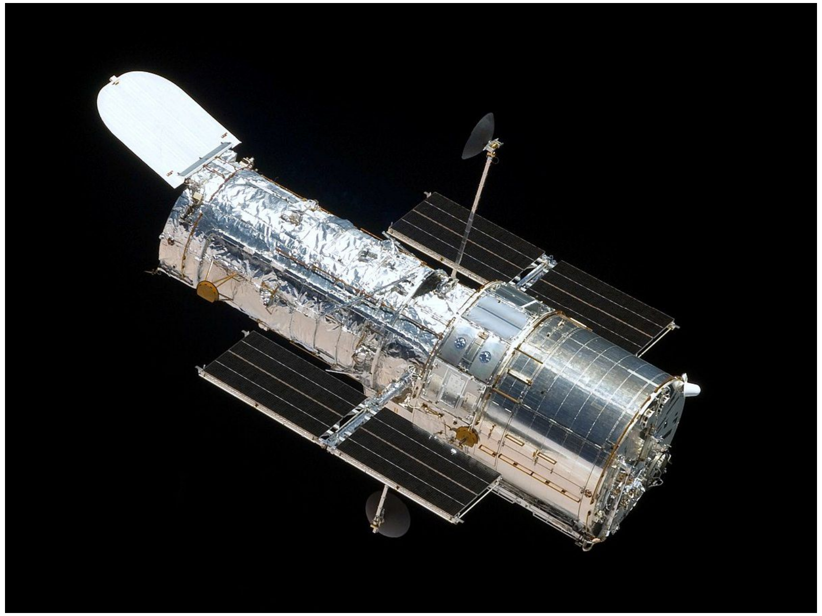
- In 2005, further observations confirmed this exoplanet's orbit around **2M1207**
- However, some have remained skeptical that this was the first case of "**Direct Imaging**", since the low luminosity of the brown dwarf was what made the detection of the planet possible
- In addition, because it orbits a brown dwarf has led some to argue that the gas giant is not a proper planet

- In September of 2008, an object was imaged with a separation of 330 AU around its host star, **1RXS J160929.1-210524** – which is located 470 light-years away in the Scorpius constellation
- However, it was not until 2010 that it was confirmed to be a planet and a companion to the star
- The planet , **1RXS J160929.1-210524 b** , is about 8 times mass of **Jupiter**
- Orbital radius is **330 AU**
- It take **6505.9 years** to complete one orbit of the star



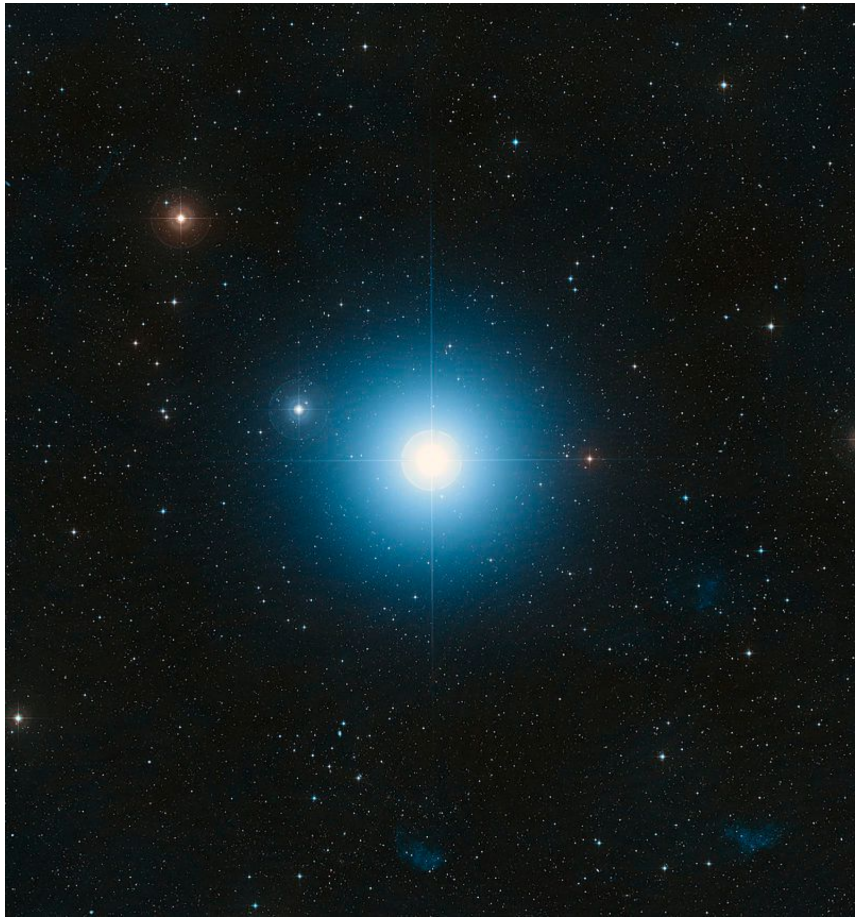
Looking for Exoplanets – Direct Imaging

- On November 13th, 2008, a team of astronomers announced that they captured images of an exoplanet orbiting the star **Fomalhaut** using the **Hubble Space Telescope**
- The discovery was made possible thanks to the thick disk of gas and dust surrounding **Fomalhaut**, and the sharp inner edge which suggests that a planet had cleared debris out of its path
- Follow-up observations with **Hubble** produced images of the disk, which allowed astronomers to locate the planet
- Another contributing factor is the fact that this planet, which is twice the mass of Jupiter, is surrounded by a ring system that is several times thicker than Saturn’s rings, which caused the planet to glow quite brightly in visual light



- **HST** was launched into low Earth orbit in 1990
- It features a 7 ft 10 in mirror
- Its five main instruments observe in the **ultraviolet**, **visible**, and **near-infrared**
- HST's orbit outside the distortion of atmosphere allows it to capture extremely high-resolution images with substantially lower background light than ground-based telescopes

Looking for Exoplanets – Direct Imaging



DSS image of **Fomalhaut**

- **Fomalhaut** was the first stellar system with an extrasolar planet candidate (designated **Fomalhaut b**, later named **Dagon**) imaged at *visible wavelengths*
- Analysis of existing and new data suggests **Fomalhaut b** is **not** a planet, rather an expanding dust disk resulting from a former collision
- The image was published in Science in November 2008

Looking for Exoplanets – Direct Imaging

- Advantages
- For humans "Seeing is believing"
- Direct imaging can provide scientists with valuable information about the planet
- Direct imaging works best for planets that orbit at a great distance from their stars so that they are not lost in the star's glare
- It also works best for planetary systems that are positioned face-on when observed from Earth
- This makes it complementary to the radial velocity method, which is most effective for planetary systems positioned edge-on to Earth and planets orbiting close to their parent star

- Disadvantages
- With current observation technology, direct imaging is possible on very rare occasions
- It is most likely to succeed when conditions are just right, namely when **a bright planet orbits at a great distance from a nearby star**
- Because of these strict limitations, direct imaging is not a good candidate for large-scale surveys searching for new exoplanets

Looking for Exoplanets - Status

NASA data (10-6-21)

- 4525 confirmed exoplanets
- 7761 candidate exoplanets
- 3357 planetary systems

Discovery Methods

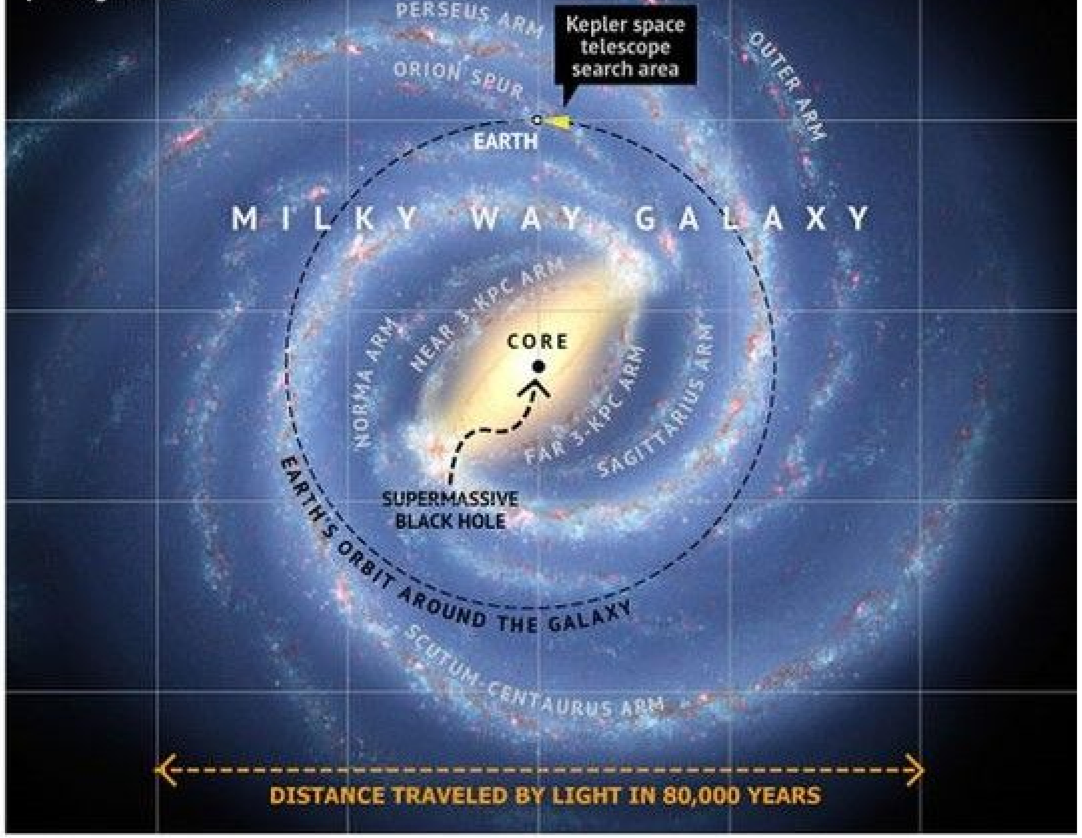
• Astrometry	1
• Direct Imaging	54

Planet Types

• Gas Giant	(1433)
• Neptune-like	(1532)
• Super Earth	(1389)
• Terrestrial	(166)
• Unknown	(5)

160 billion planets and counting

Astronomers have confirmed about 700 planets beyond our solar system as of early 2012, but the latest statistical analysis suggests that our galaxy likely harbors more than 100 billion alien worlds. One in six of the Milky Way's 100 billion stars may have a Jupiter-size planet, while nearly two-thirds may host a world slightly larger than Earth. But the search continues for a true "Earth twin" — a rocky planet the size of ours that is capable of supporting life as we know it.



SOURCES: THE JOURNAL NATURE, LYNETTE COOK, MARK A. GARLICK, MILKY WAY GALAXY MAP BY ROBERT HURT

Looking for Exoplanets

Next session

- Search Methods
  - Radial Velocity method
  - Transit method