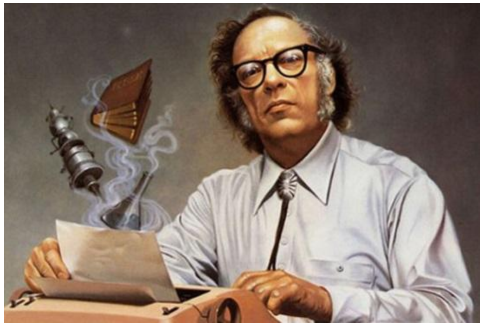
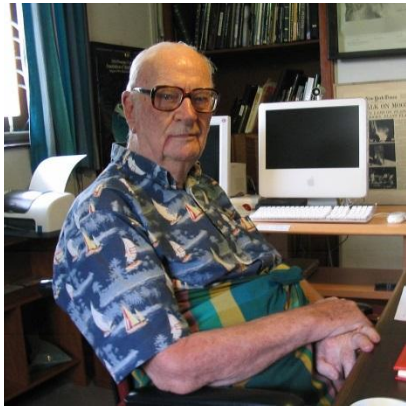
# ExtraSolar Planets

**When I was growing up, we watched Star Trek and Star Wars:**


**And we read the great science fiction writers, like Isaac Asimov and Arthur C. Clarke**





**In all of these works of fiction, the galaxy and the Universe is full of planets orbiting other stars.**

**But until just before you were born . . actually, now, 30 years ago; <u>no one had ever detected a planet orbiting another star</u>.**

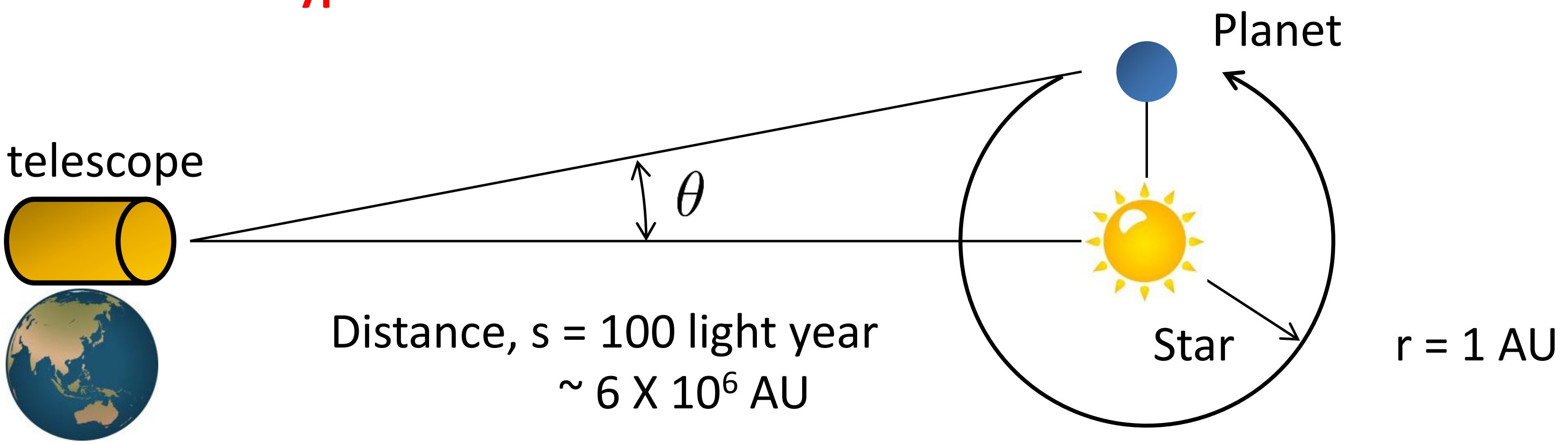
**Today, we know of about 5000 exoplanets in about 3600 systems!**

**Asimov and Clarke were right, <u>the galaxy is full of planets</u>.**

# How do you Detect an Extrasolar Planet?

You might think that to find a planet orbiting another star, all you need to do is to look through a really big telescope, but it's not so simple,

**consider some typical numbers:**




As seen from the Earth, the maximum angular separation between the planet and the star is

$$\theta \approx \frac{r}{s} \text{ (in radians)}$$

$$\theta \approx 2 \times 10^{-7}\ rad \approx 10^{-5\circ} \approx 0.03''$$

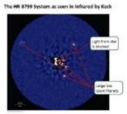
**So, you would need a telescope with really good resolving power.**

# How do you Detect an Extrasolar Planet?

**But there's an even bigger problem:**

- Planets shine in the visible part of the spectrum by reflected light.
- **Therefore, the planet would be about ten billion times fainter than the star that it's right beside in our telescope view!**

So, detecting planets around other stars directly is very very difficult.
But it has been done (Keck, 2012) in the infrared (where planets are brighter and stars are fainter). **That's one reason the JWST is an infrared telescope.**



So, how have we detected the presence of all of those planets during the last 30 years? **There are two indirect methods:**

- Observe the motion of the star which can be perturbed by the gravity of the planet – **Astrometric and Doppler Method**

- Observe the brightness of the star to change periodically as as a planet passes in front of it and behind it – **Transit Method**
  *(Ask me what I said when I first heard about this technique.)*

# Astrometric and Doppler Detection

When we talked about planetary orbits, we didn't tell the whole story!

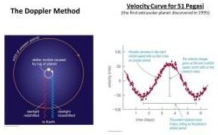
When a planet orbits a star, both the planet and the star actually orbit their common center of mass, and

- The higher the planet mass, the more the star moves
- The closer the planet is to the star, the faster the star moves

**So, if we can track the motion of the star, we can infer the presence of a planet even if the planet can't be detected directly.**

**Astrometric Method**: attempts to detect any wobble in a star's position on the sky due to the orbiting planet. This would work best for nearby stars, and to date, only one planet has been discovered by this method (although this may change with ESA's GAIA mission)

**Doppler Method**: detects the periodic Doppler Shift in the Star's Spectrum which gives the star's radial velocity

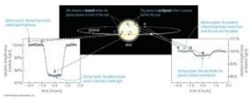



**Why were planets like 51 Peg b the first planets discovered? (LC)**

The method works best for high mass planets (high star velocity) and short period orbits (need at least one orbit to establish period).

# <u>Transit Method</u>

If the geometry of the extrasolar system is favorable, a planet may pass in front of its star (transit) and then behind it (eclipse). The transit is best observed in the visible spectrum and the eclipse in infrared.



**What can we learn from the Doppler and the Transit Detections?**

- The **Doppler Method** gives:
  - the planet's mass
  - orbital period, and hence the orbital semimajor axis **How? (LC)**
  - orbital eccentricity

- The **Transit Method** gives:
  - orbital period, and hence the orbital semimajor axis
  - **(LC)** Radius of the planet
  - the planet's atmospheric composition and temperature (in principle, not yet done, JWST is trying to do this)

**So to get the very important quantity, <u>the density</u>, we need information from both the Doppler and Transit methods.**

# History of ExtraSolar Planet Discoveries

**Astronomers had been trying to detect planets around other stars for more than 100 years with no success at all until the 1990's:**

1990: **Alex Wolszczan** discovered pulsar planets, the first planets outside our solar system. Pulsars are the dense remnants of high mass stars that emit regular radio pulses, i.e. neutron stars.

1995: **Michel Mayor and Didier Queloz** discover the first planet orbiting a Sun-like star 51 Pegasi using the Doppler Method. It is a massive Jupiter-sized planet with a 4 day orbital period, a ***"Hot Jupiter".***

**LC, have you heard of Mayor and Queloz recently? Why?**

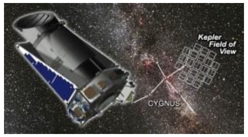
*In 2019, they were awarded the Nobel Prize in Physics.*

The next few years, **Geoff Marcy and Paul Butler** using the Doppler Method find dozens of extrasolar planets *in data that they already had!* All are ***"Hot Jupiters",*** i.e. massive planets in short period orbits – **Why was this found? Are they gas giants?**

1999: **David Charbonneau** discovers HD 209458b, the first planet using the Transit Method. This permitted determination of planetary density – the **"Hot Jupiters"** are gas giants. But . . . ?

# The Kepler Mission (2009 to 2013)

The **Kepler Satellite** monitored the brightness of ~150,000 stars in a large field of view. **A periodic change in brightness indicates a possible planetary transit of the star.**

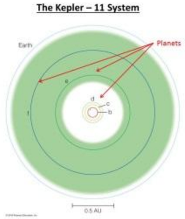



The goal of the Kepler Mission was to determine if Earth-Size planets exist in Earth-Like orbits – i.e. in the habitable zone of the star (the region around the star where liquid water could be present.) They have found several and many more will likely be confirmed.

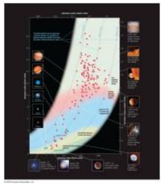
Update: As of today, Kepler has discovered about 4500 planets with about 2400 of those confirmed by ground-based observations. Of the confirmed planets, about 30 are less than twice an Earth mass in their star's habitable zone.

**The Kepler – 11 System:**

Your author gives as an example, the Kepler – 11 system of six known planets.



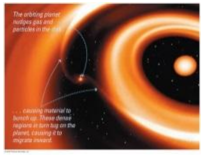
# The Diversity of ExtraSolar Planets



Perhaps the biggest surprise of the last 30 years is not so much that planets that orbit other stars do exist in large numbers, **but that they come with such a diverse range of characteristics.**

But, there's one question we haven't addressed:

- **How did the "Hot Jupiters" get to where we observe them, i.e. so close to their stars; did they form there?**
- Although not completely settled, it is believed that these giant planets formed where they should, i.e. far from their stars, but then migrated inward due to gravitational interactions with the gas disk in the nebula.
- This is a difficult thing to analyze, but it does lead to a question: *"why didn't our gas giants migrate?"*



**Just recently:** in September 2016, it was announced that an Earth-sized planet orbits the nearby star Proxima Centauri. Wouldn't Asimov and Clarke be thrilled!

**What's the error in the video at ~54 sec (LC)?**

*(the star and the planet must have velocities in the opposite directions)*

**To keep track of all of these planets, NASA maintains an ExoPlanet Site.**