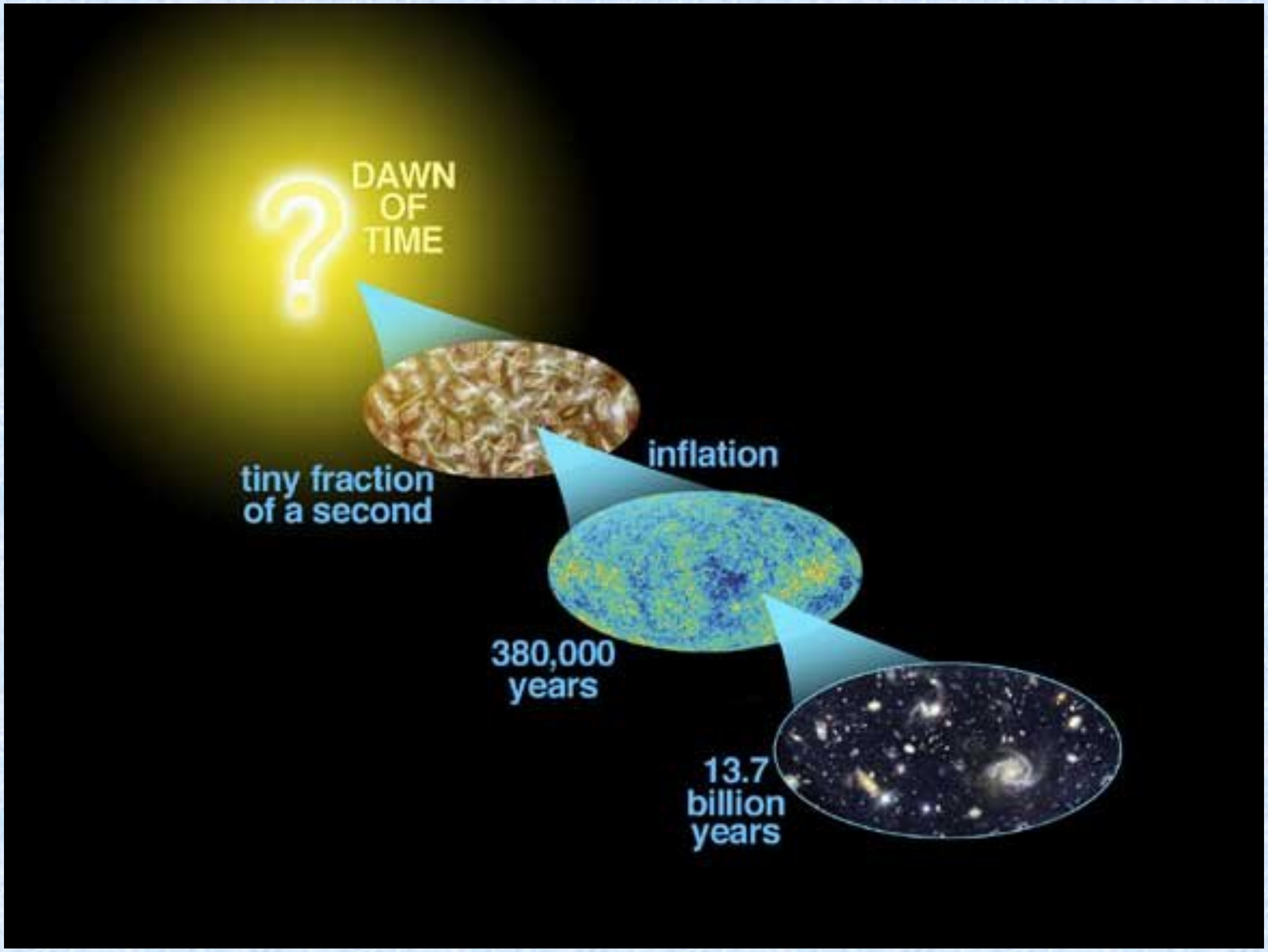
Origins



Lecture 9; April 29 2014

Previously on Origins

- Demarcation: what is science?
- Falsification: how do you test scientific theories?

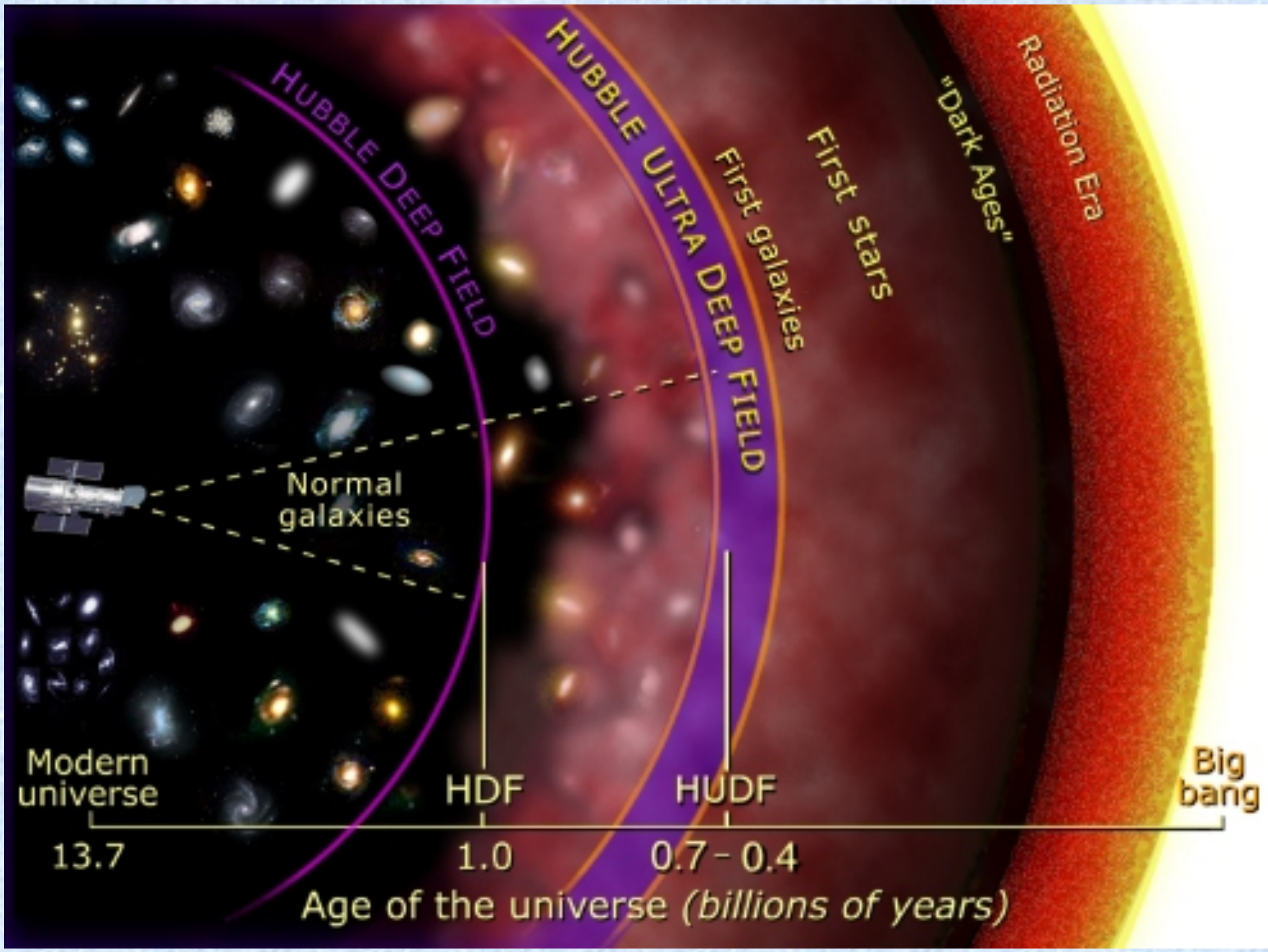
Today on Origins

- Repeatibility: science and the supernatural
- Corroboration: what is a “good” scientific theory
- Is Earth a special/unique place?

Physical cosmology

- **Experiments and Observations force us to modify/change our view of the Universe. Examples:**
  - Galileo's observations of Sun spots proved that the heavens are not time-invariant
  - Hubble's measurement of galaxy redshifts showed that the Universe is not static
  - High speed motions of stars in galaxies show that either we do not understand gravity or there is a large amount of "dark matter", i.e. different stuff that the ones that makes you and me (and Earth)

Tools of the trade: Telescopes as time machines



Physical cosmology: a fundamental dilemma

- Experiments and observations can only be from one point in space and time: Earth now.
- Yet we would like to construct a scientific theory that describes the universe everywhere and at all times.

…and its solution

- Hypothesis: our local sample of the universe is no different from more remote and inaccessible places
- This assumption is deeply rooted in two fundamental principles of physics:
  - The laws of physics (whatever they are!) do not depend on space and time. Popper calls it "*the principle of the uniformity of nature*"
  - Physical explanations of natural phenomena should be as simple as possible (Ockham's razor)

A testable working solution

- We can measure whether we are in anyway in a special place in the Universe.
  - We will discuss this at length in this class
- We can test the laws of physics through observations. Examples:
  - Spectroscopy of distant stars and galaxies to probe atomic physics. Do we see the same transitions?
  - Constants of nature (such as the electron charge). Where they different a few billion years ago?

Unexplained…

- There are plenty of phenomena we do not "understand". Example:
  - How does your cell-phone work?
- However, they are **measurable phenomena with repeatable experiments**
- Technology may appear "magic" or "myth" but it IS FUNDAMENTALLY NOT

…vs magic/miracles

- Magic and miracles imply a behavior that differs than expected - i.e. NON REPEATABLE
- If miracles were proven to exist, this would falsify one of the fundamental hypothesis of science, that is that the laws of nature do not “bend” to people’s or (deity’s) will.
- SCIENTIFIC EVIDENCE OF MAGIC/MIRACLE WOULD BE MOST REVOLUTIONARY AND TRANSFORMATIVE

A “good” scientific theory

- What constitutes a “good” scientific theory?
- If a theory can never be proven right, how is one theory better than another?
  - Note the use of the derogatory expression “just a theory” by creationists
- According to Popper:
  - The better theory is the one that passes more stringent tests, both in number and in quality
  - The better theory is the more falsifiable one, if it doesn’t fail
- Old theories often become limiting cases of new theories
  - (e.g. Newton vs Einstein)

How about validating the method?

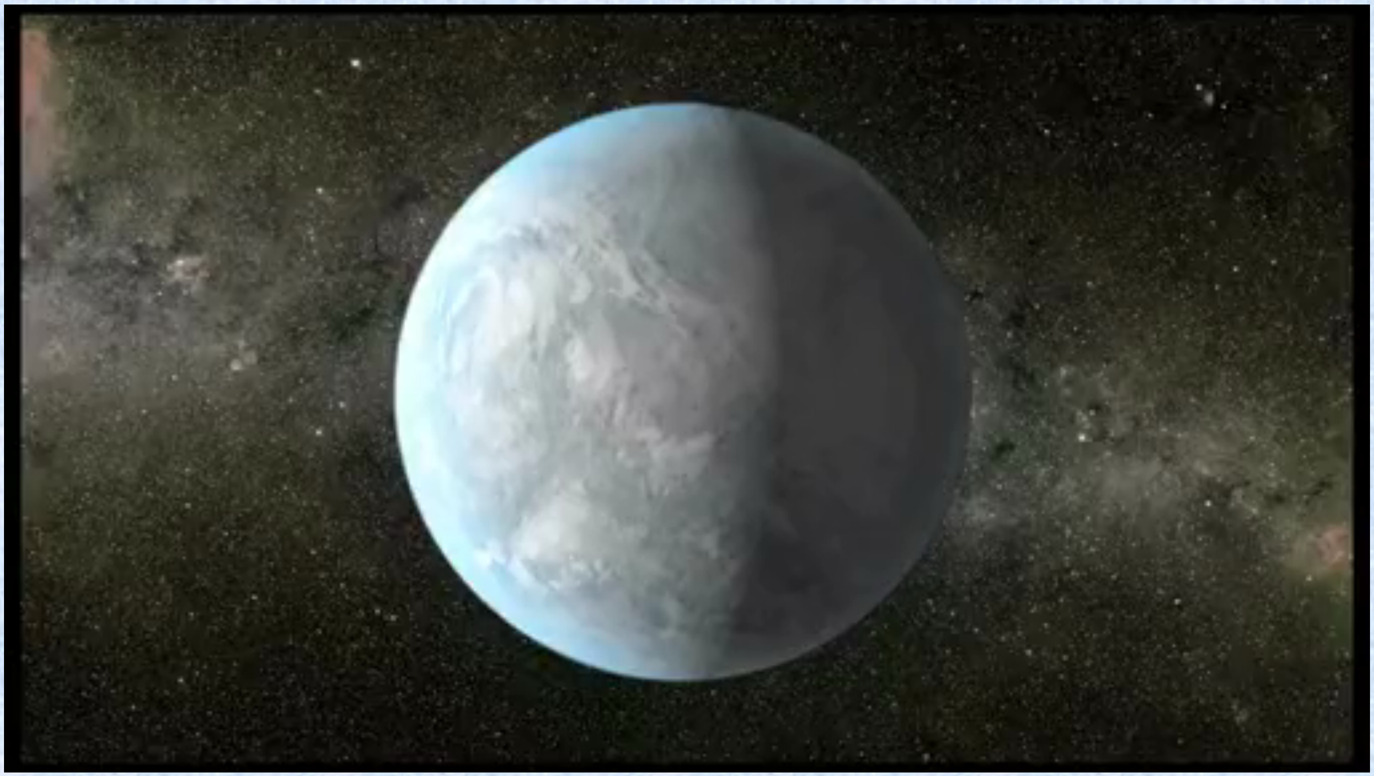
- What constitutes a “good” method?
- Is the scientific method good?
- Does the question even make sense?
- My view is that a method is good as long as it allows you to achieve what you want. What do you want?
- The scientific method answers some questions/obtain some results. What are they?
- If we need to answer other questions we need different tools.

Outline:
Is Earth a special/unique place?

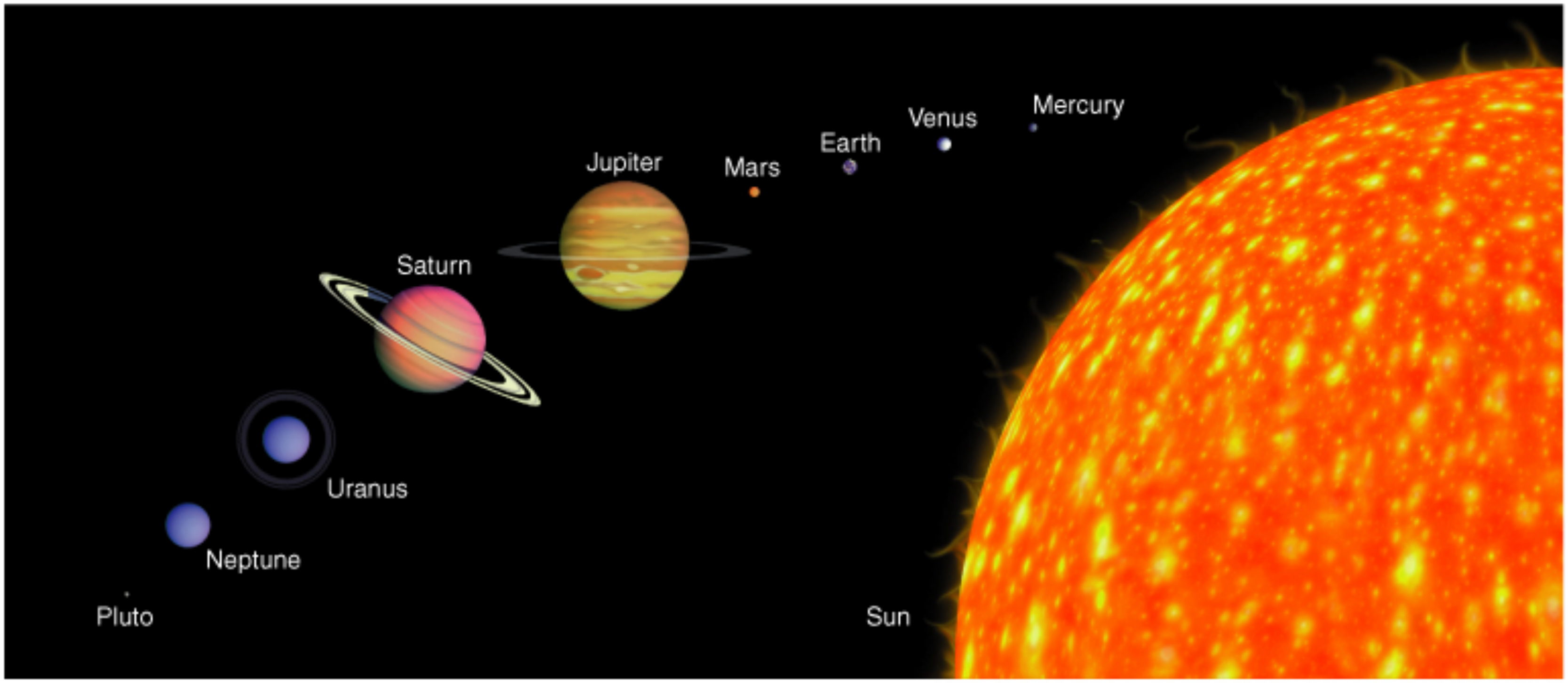
- Extrasolar planets
  - Techniques
  - State of the art
  - Limitations
- Habitable Planets
  - Selection effects
- Extraterrestrial life
  - Drake's Equation

A physicist's answer

- We phrase the question in statistical terms:
  - How frequent are planets like the Earth?
  - In other words, is Earth "unique"?
- Let's take a look! Let's measure!



But before looking at exoplanets…



How many planets does our solar system have?

What is a planet?

2006 IAU RESOLUTION B5: Definition of a Planet in the Solar System

- Contemporary observations are changing our understanding of planetary systems, and it is important that our nomenclature for objects reflect our current understanding. This applies, in particular, to the designation "planets". The word "planet" originally described "wanderers" that were known only as moving lights in the sky. Recent discoveries lead us to create a new definition, which we can make using currently available scientific information.

2006 IAU RESOLUTION B5: Definition of a Planet in the Solar System

- The IAU therefore resolves that planets and other bodies, except satellites, in our Solar System be defined into three distinct categories in the following way:
  - (1) A planet is a celestial body that
    - (a) is in orbit around the Sun,
    - (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and
    - (c) has cleared the neighborhood around its orbit.
  - (2) A "dwarf planet" is a celestial body that
    - (a) is in orbit around the Sun,
    - (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape2,
    - (c) has not cleared the neighborhood around its orbit, and
    - (d) is not a satellite.

2006 IAU RESOLUTION B5: Definition of a Planet in the Solar System

- The IAU therefore resolves that planets and other bodies, except satellites, in our Solar System be defined into three distinct categories in the following way:
  - (3) All other objects,except satellites, orbiting the Sun shall be referred to collectively as "Small Solar System Bodies".
- Notes:
  - The eight planets are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.
  - An IAU process will be established to assign borderline objects to the dwarf planet or to another category.
  - Class 3 currently includes most of the Solar System asteroids, most Trans-Neptunian Objects (TNOs),comets, and other small bodies.

2006 IAU RESOLUTION B6: Pluto

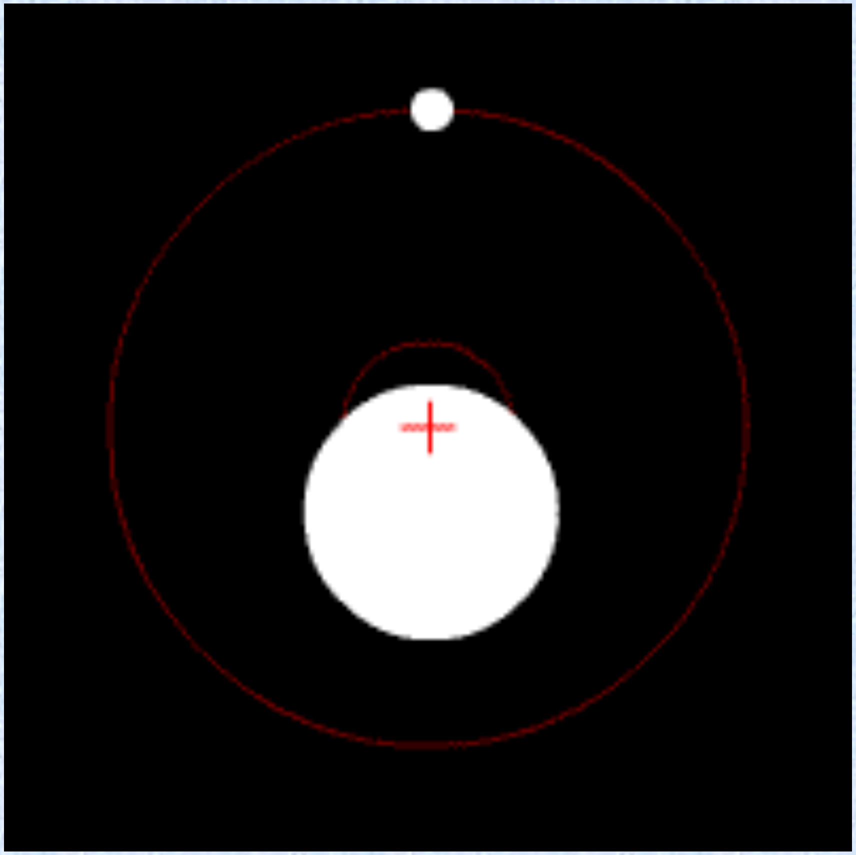
- The IAU further resolves:
  - Pluto is a "dwarf planet" by the above definition and is recognized as the prototype of a new category of Trans-Neptunian Objects.
  - An IAU process will be established to select a name for this category.

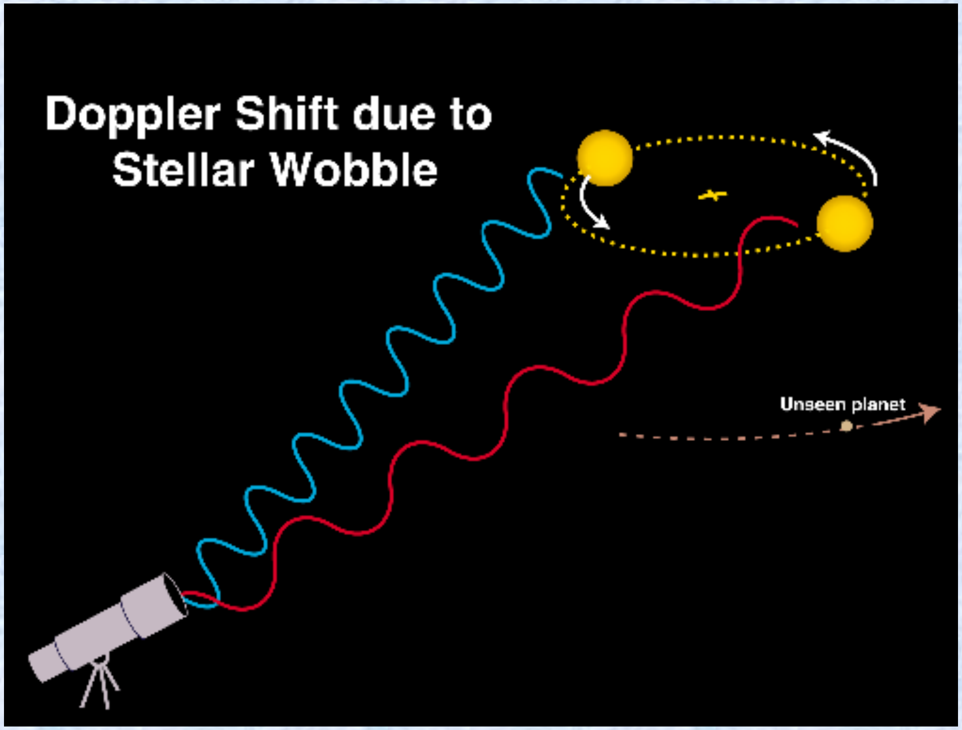
Extrasolar planets

- A minimalist definition. Celestial body that is:
  - Gravitationally bound to a star
  - No nuclear fusion
- How do we find them? As of today
  - Radial velocities: 507
  - Transit: 302
  - Microlensing: 18
  - Direct Imaging: 30
  - Timing: 16 (not discussed here)

http://exoplanet.eu/

Radial Velocities

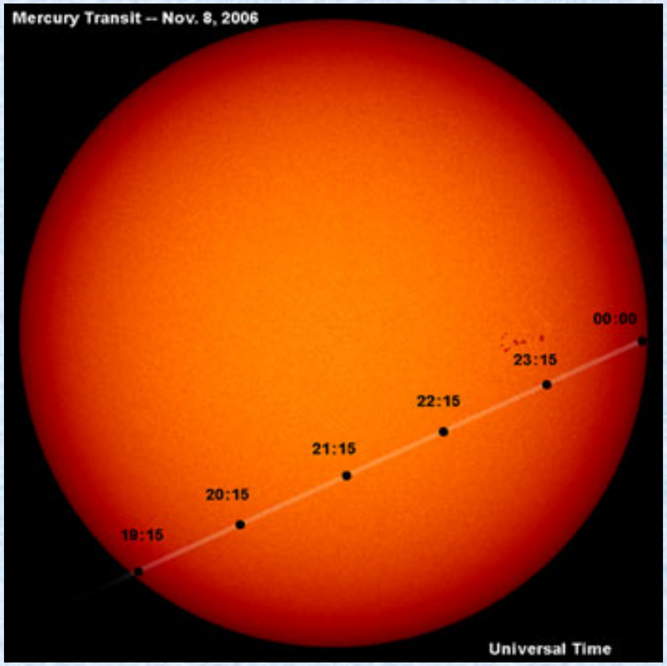




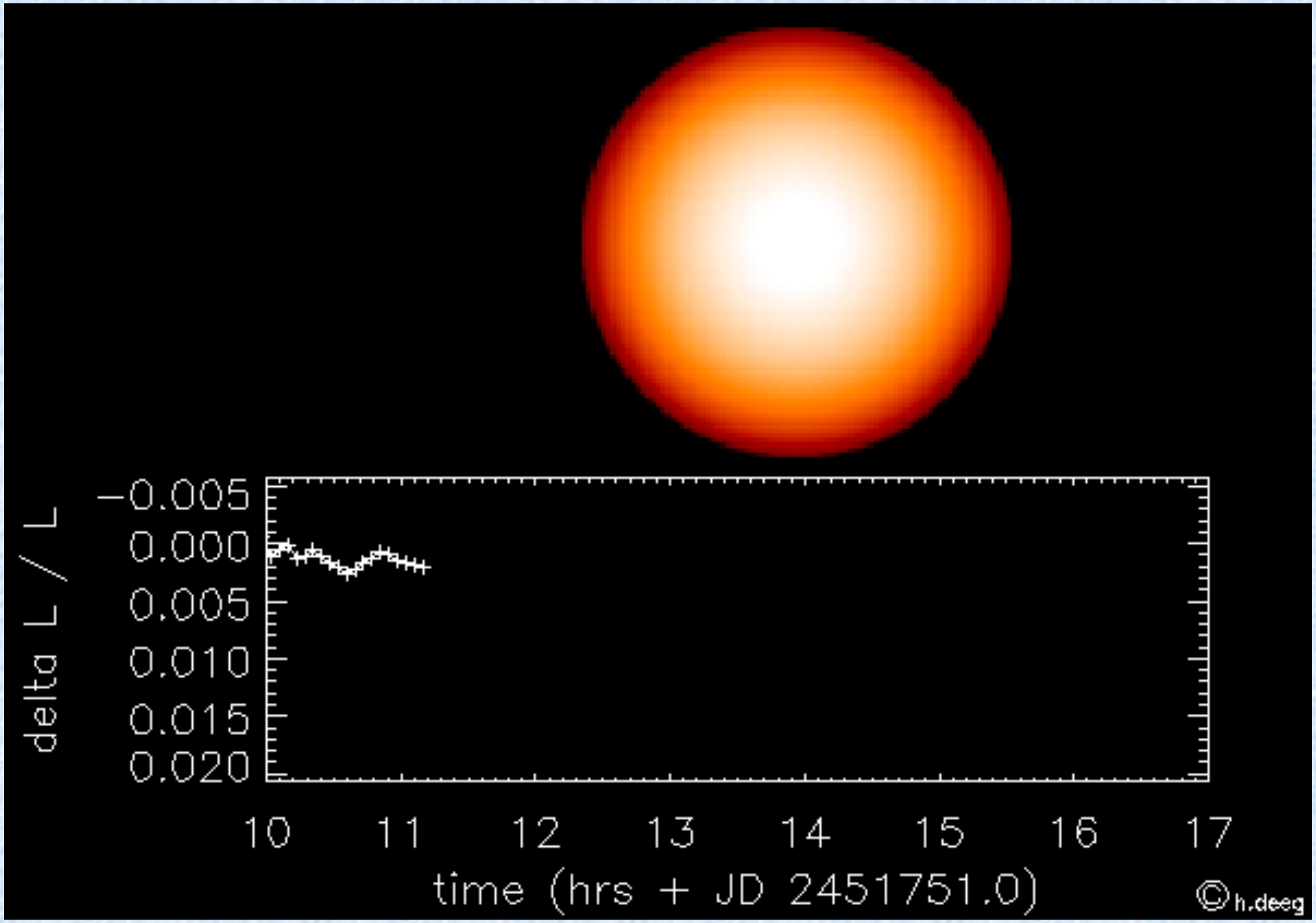
Very difficult measurement! Speed <m/s. Orbital inclination

Planet Transit

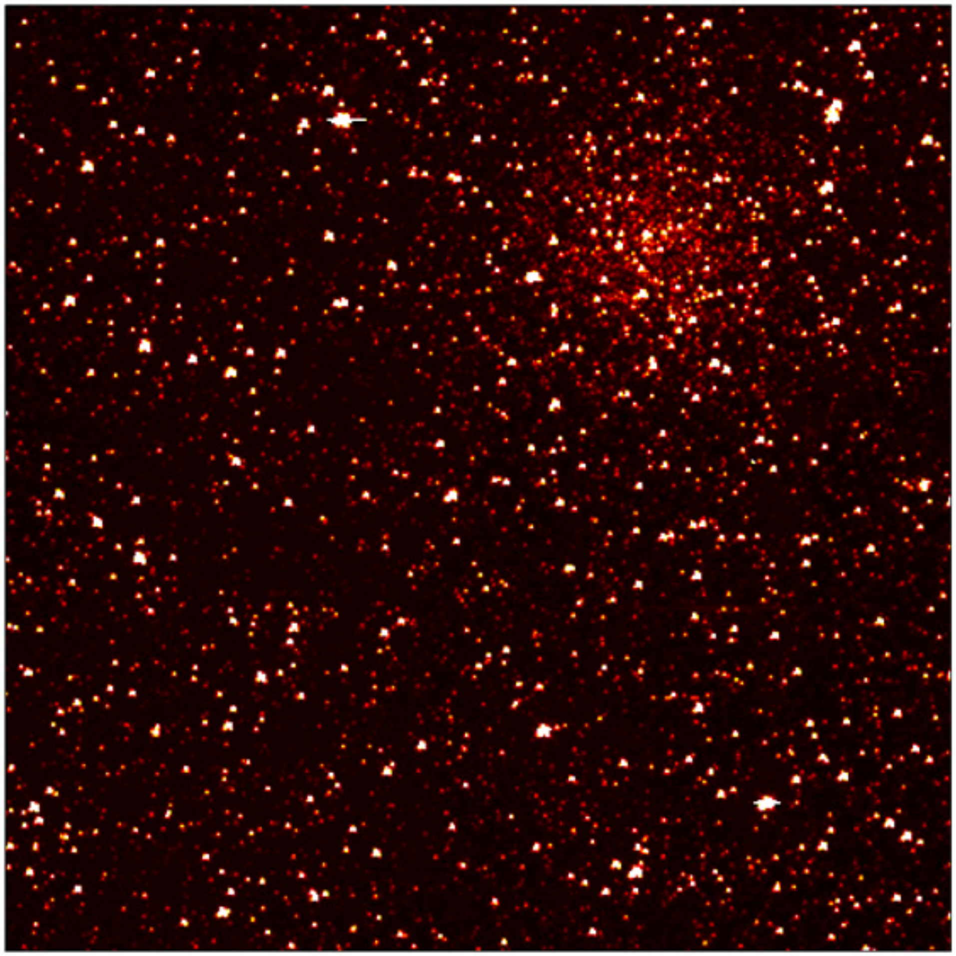
Mercury's 2006 transit
as imaged by
NASA satellite Soho

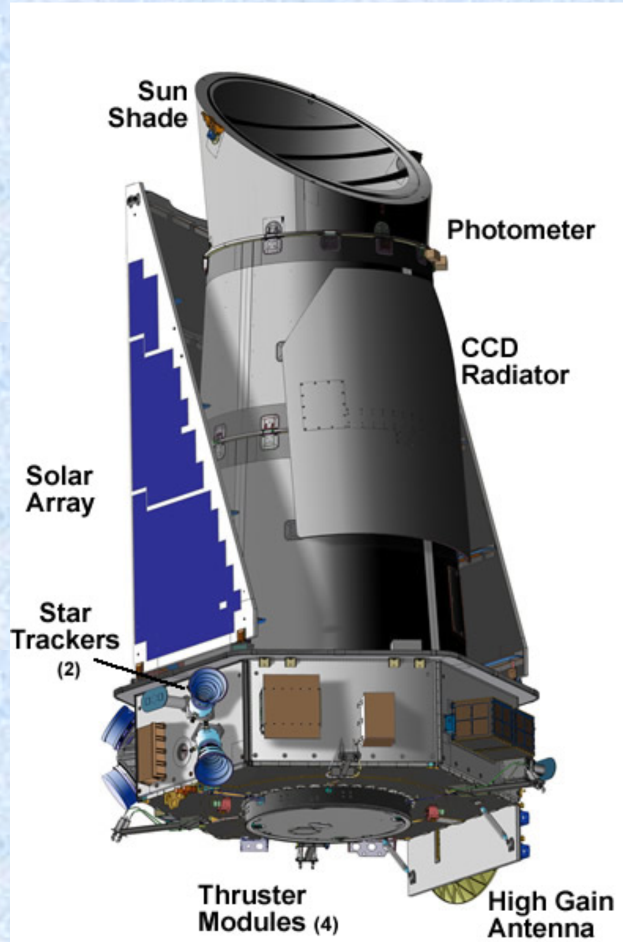


Extrasolar Planets Transit



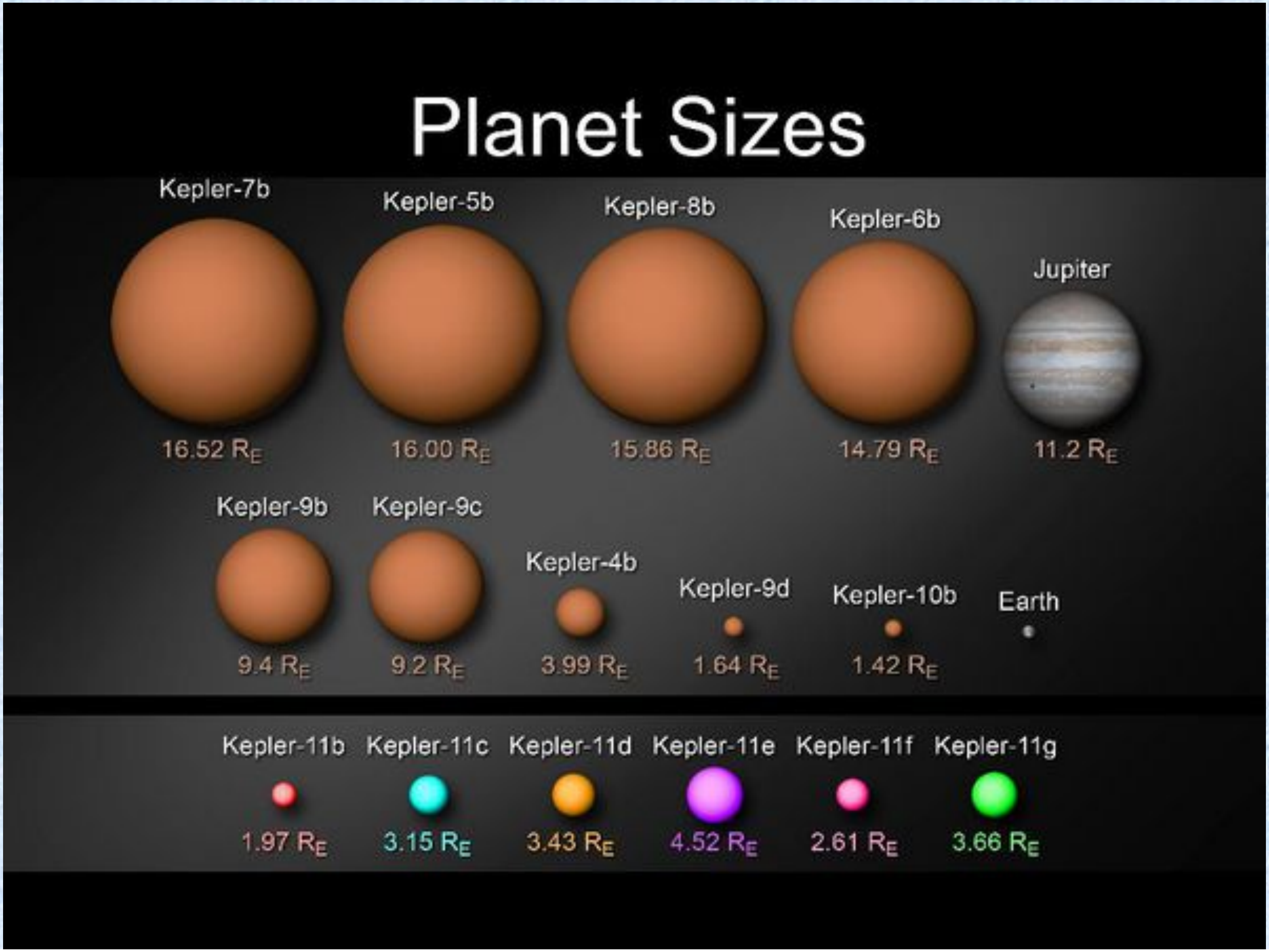
Planet Transit: Kepler



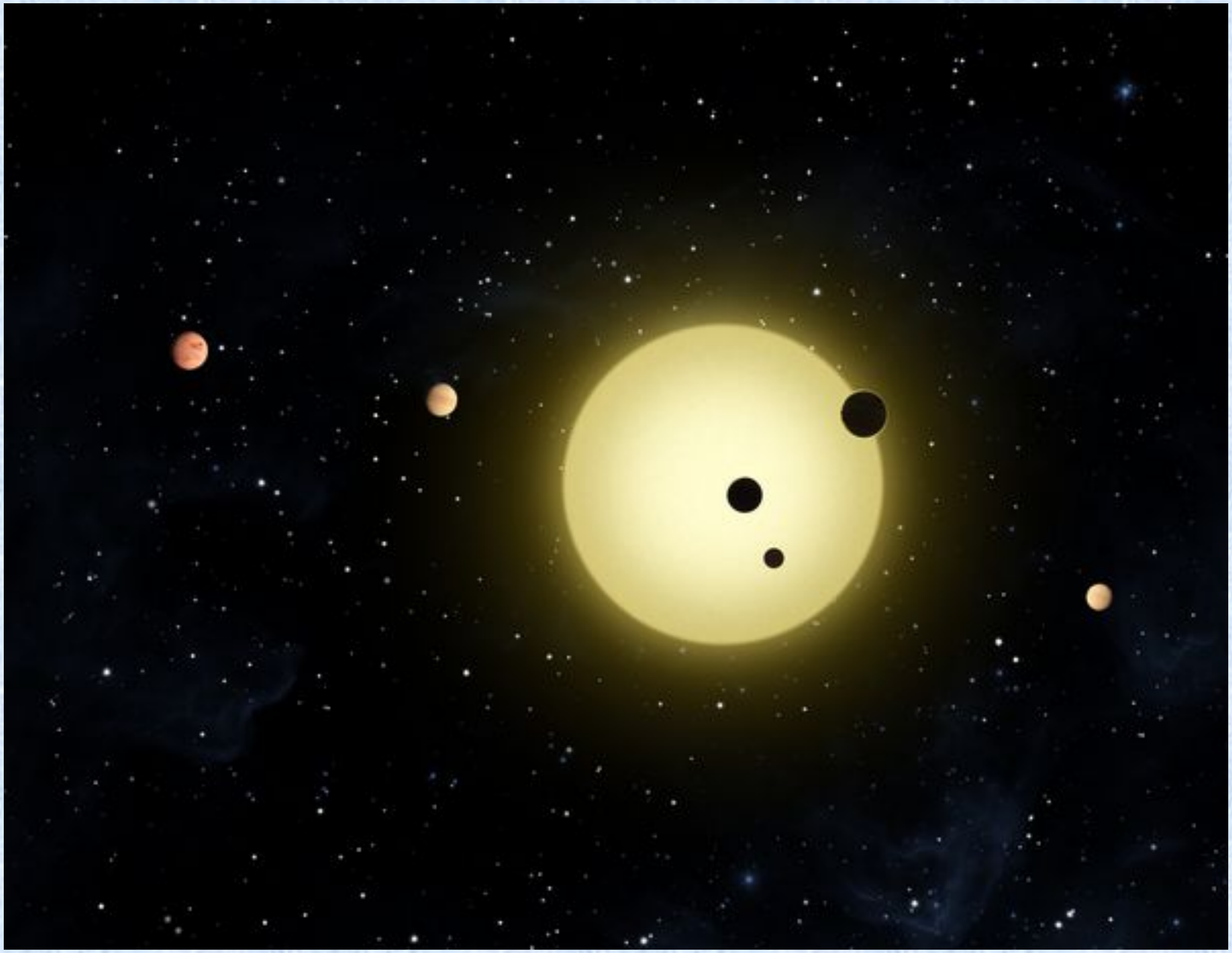


Launched 3/6/9; first light 4/8/9; expect ~50 “Earths”

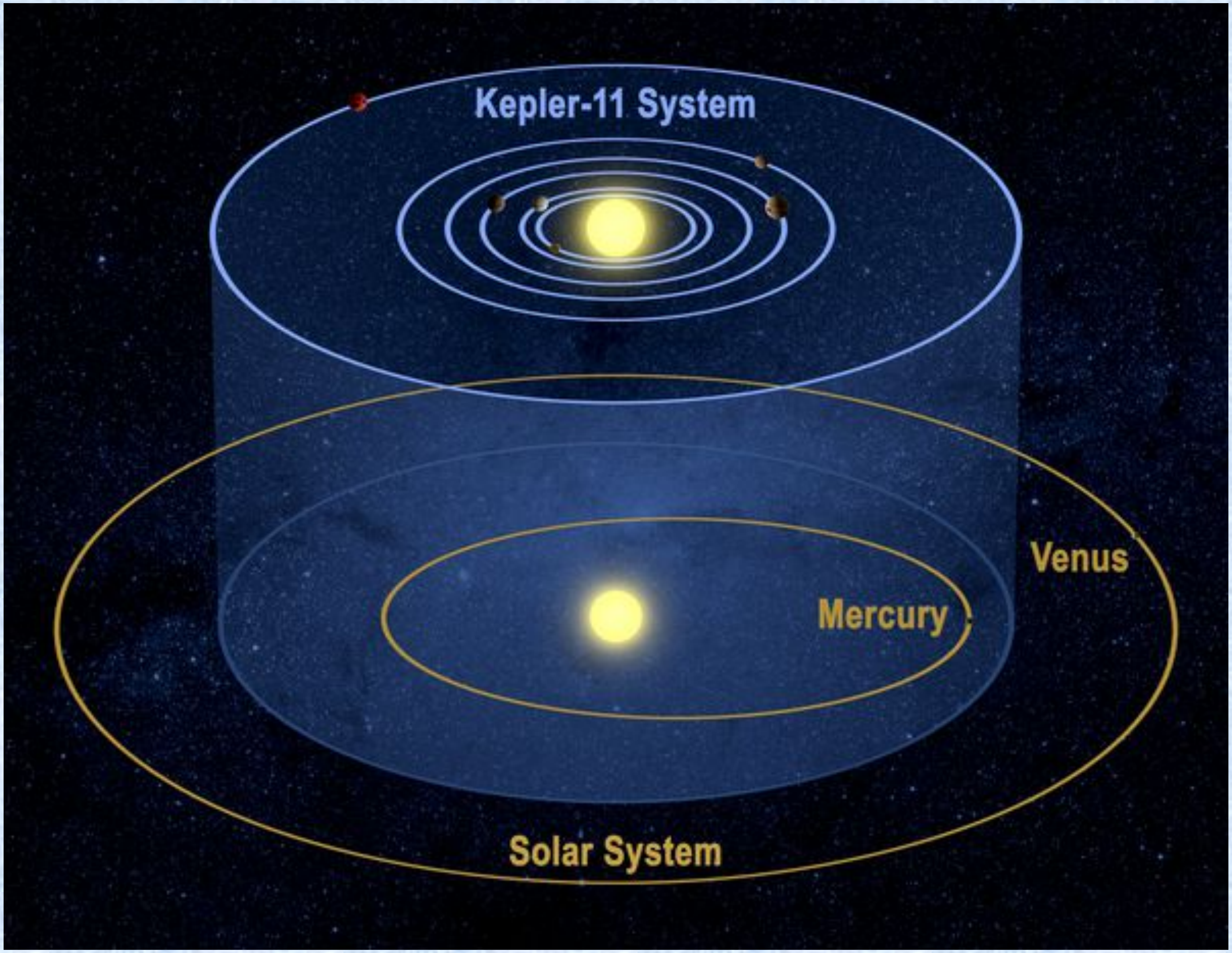
Kepler's new planets



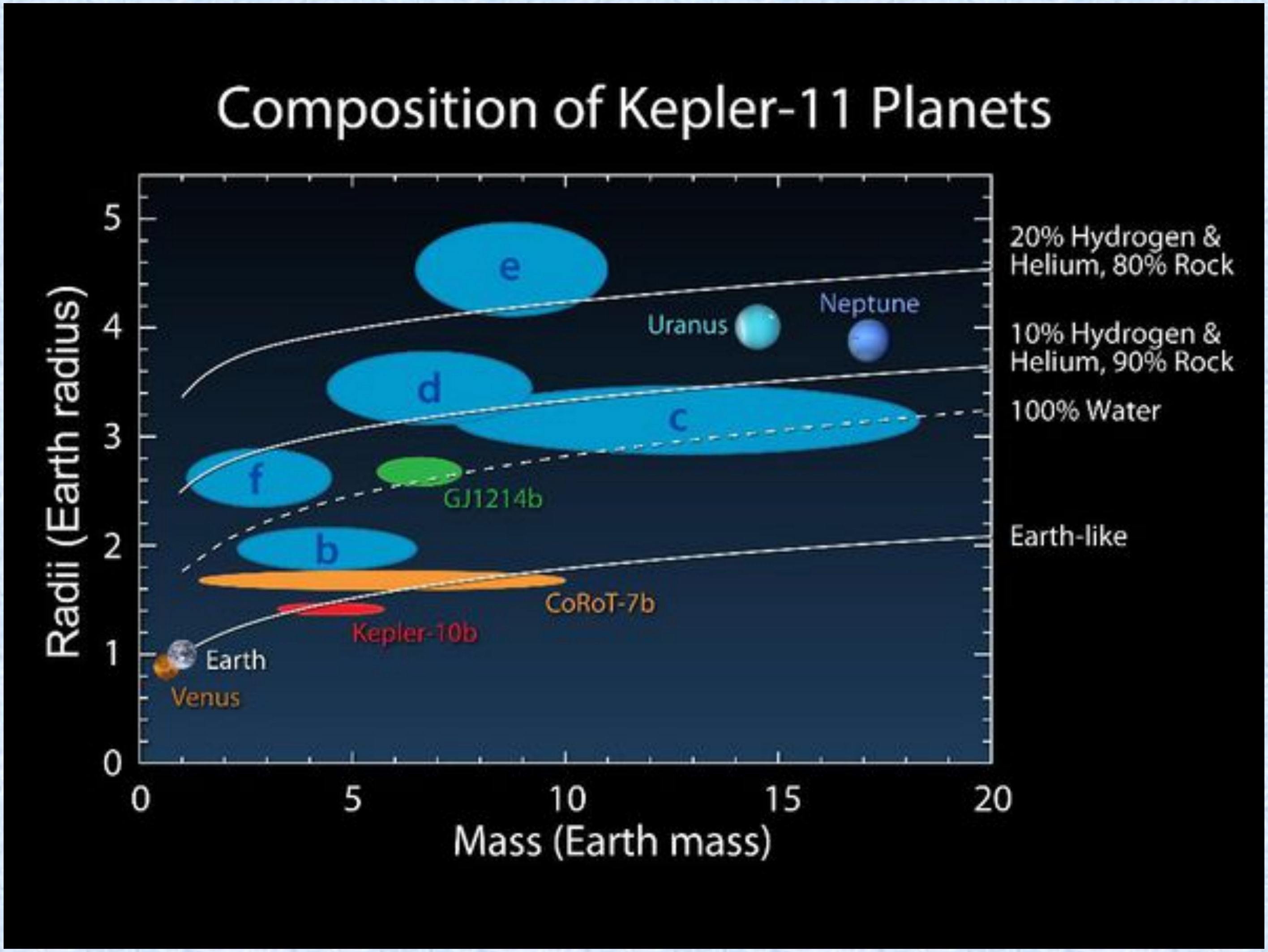
The amazing system Kepler 11



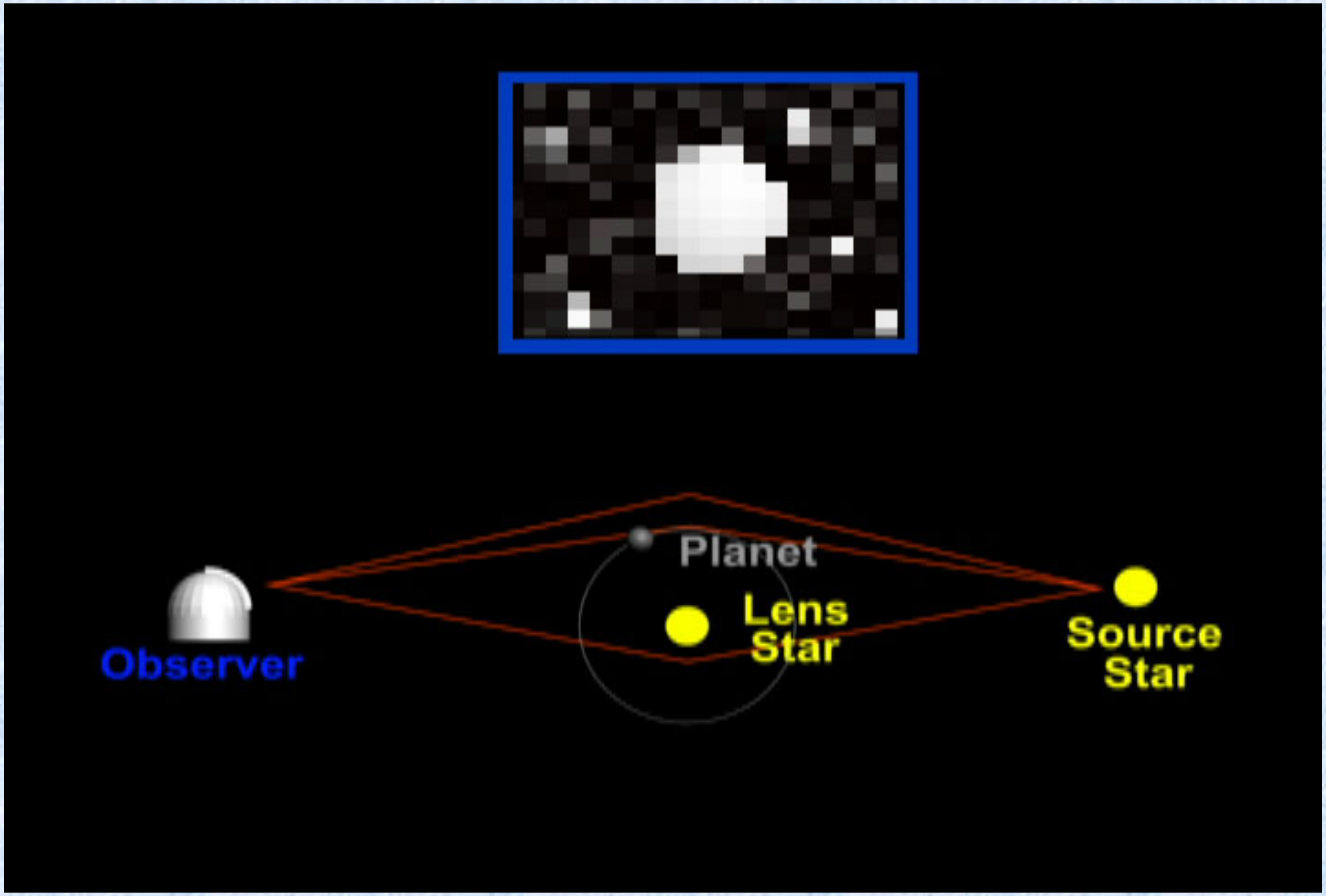
The amazing system Kepler 11



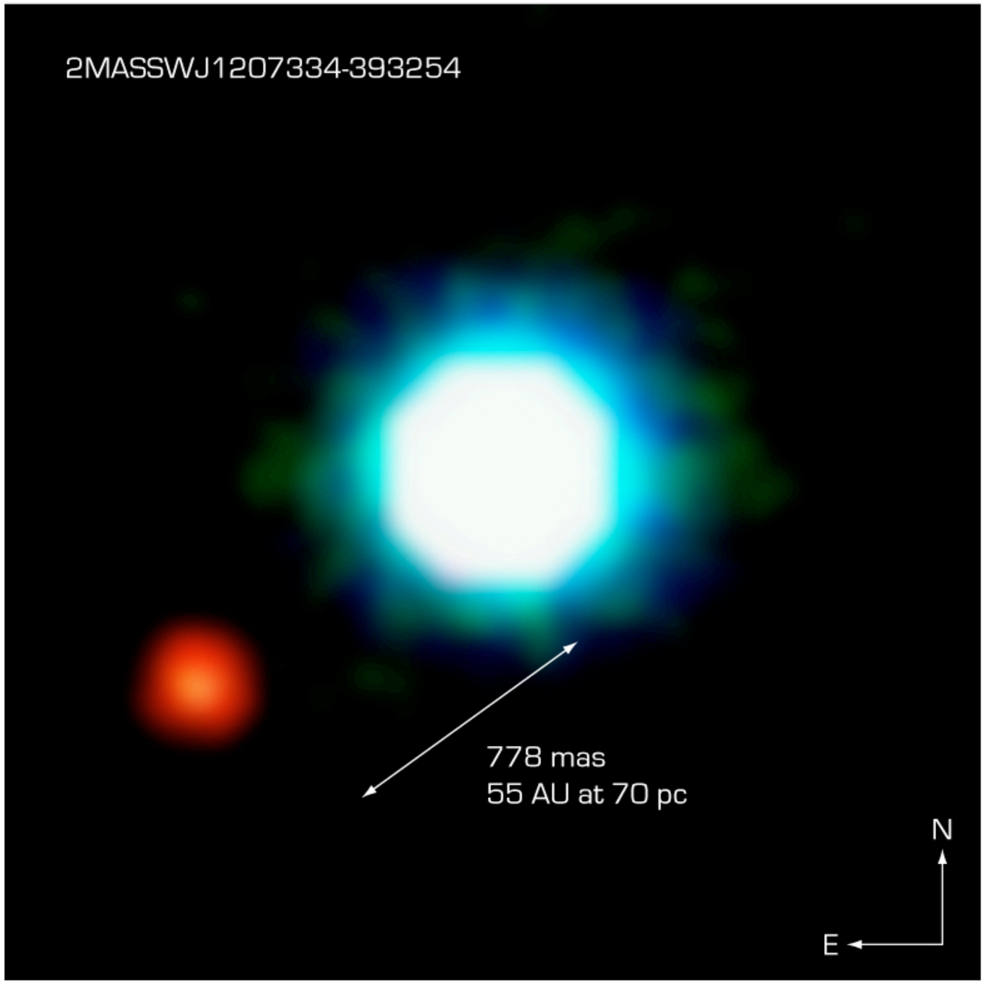
The amazing system Kepler 11



Microlensing



Direct Imaging

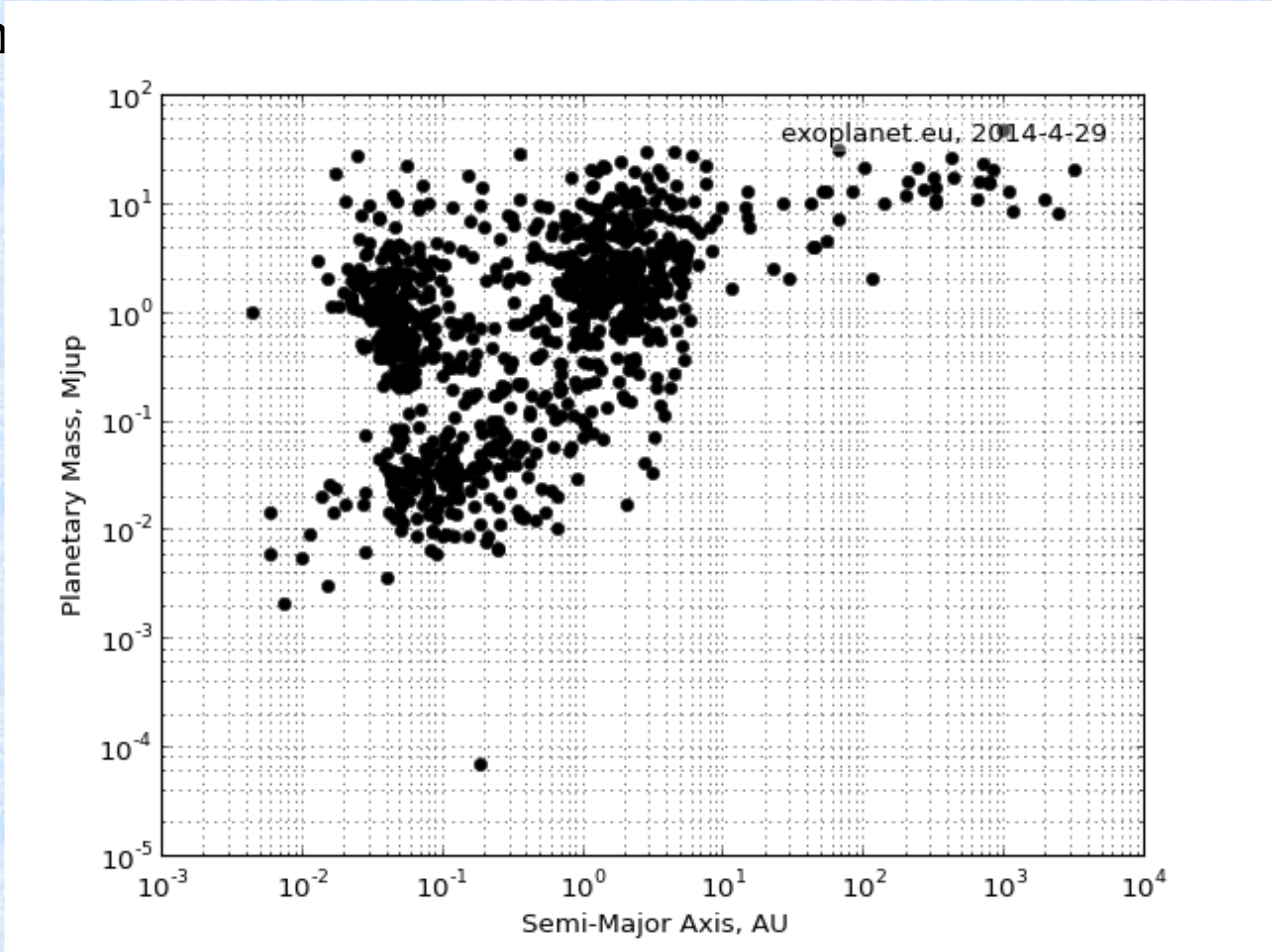


NACO Image of the Brown Dwarf Object 2M1207 and GPCC

ESO PR Photo 26a/04 (10 September 2004)

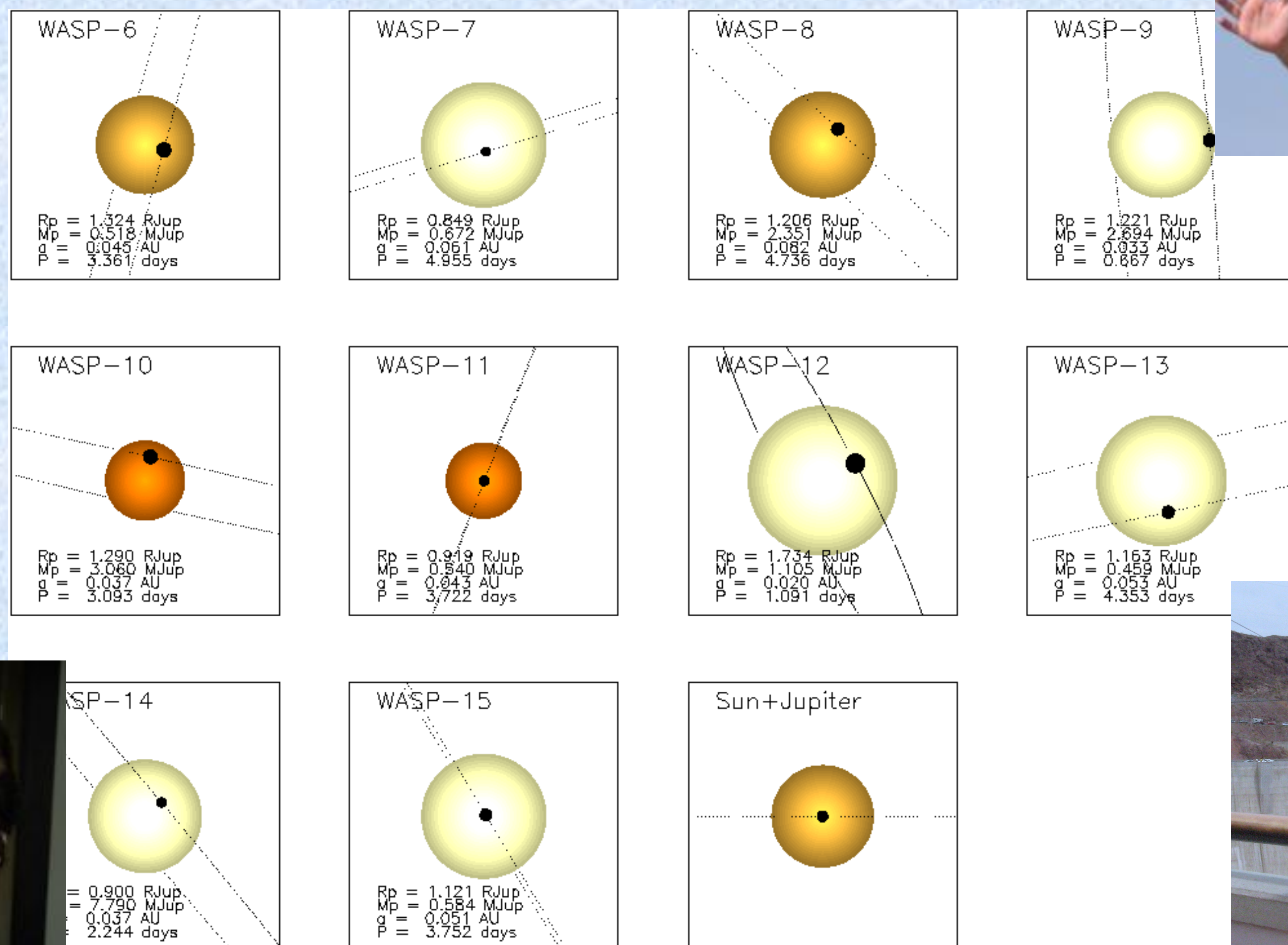
Summary of findings

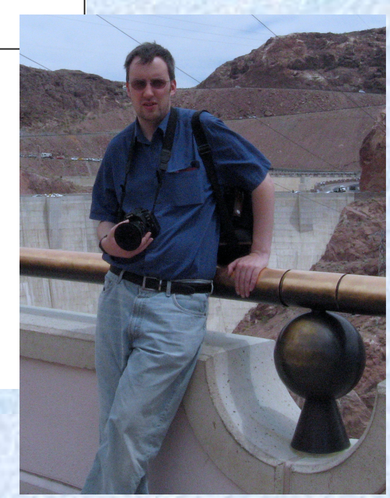
5-10% of stars surveyed show planets. Fraction increases with abundan



Check out http://exoplanet.eu

Planet Hunting in Santa Barbara





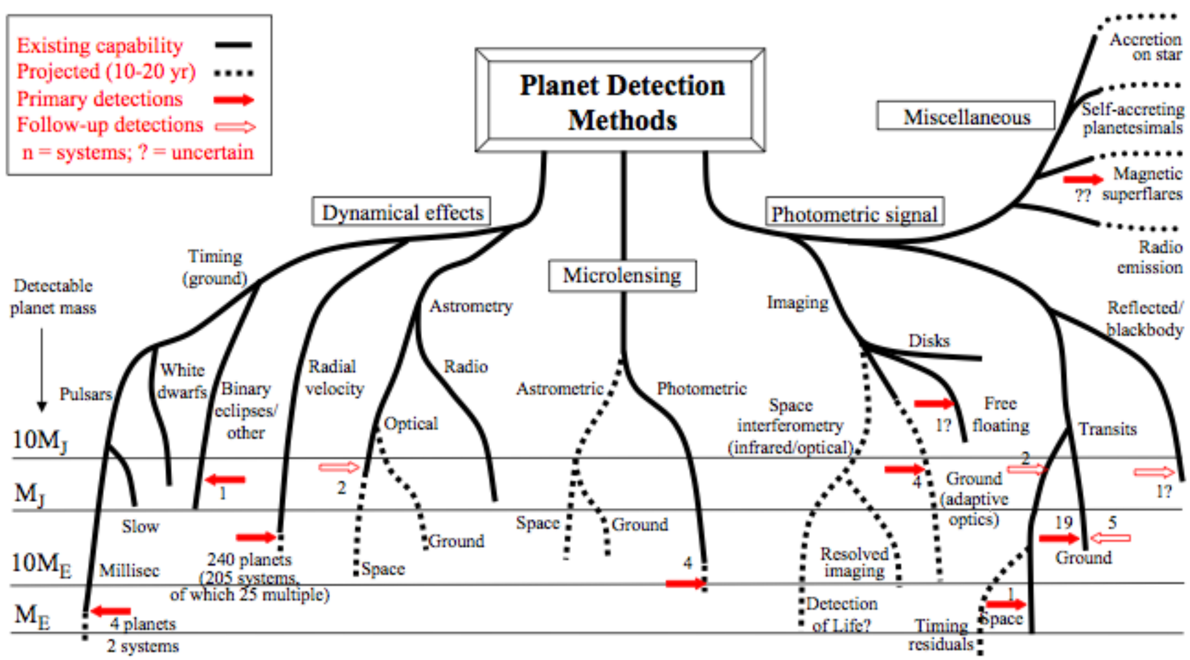
Limitations. Selection effects

- Most methods depend on ratio of properties of star and planet. Small planets are hard to find!
  - Mass ratio (wobble)
  - Luminosity ratio (direct detection)
  - Radius ratio (transit)
- And on orbital properties. Small orbits are easier to find.
  - We have only surveyed for 10 years, it's hard to find long periods

Future prospects

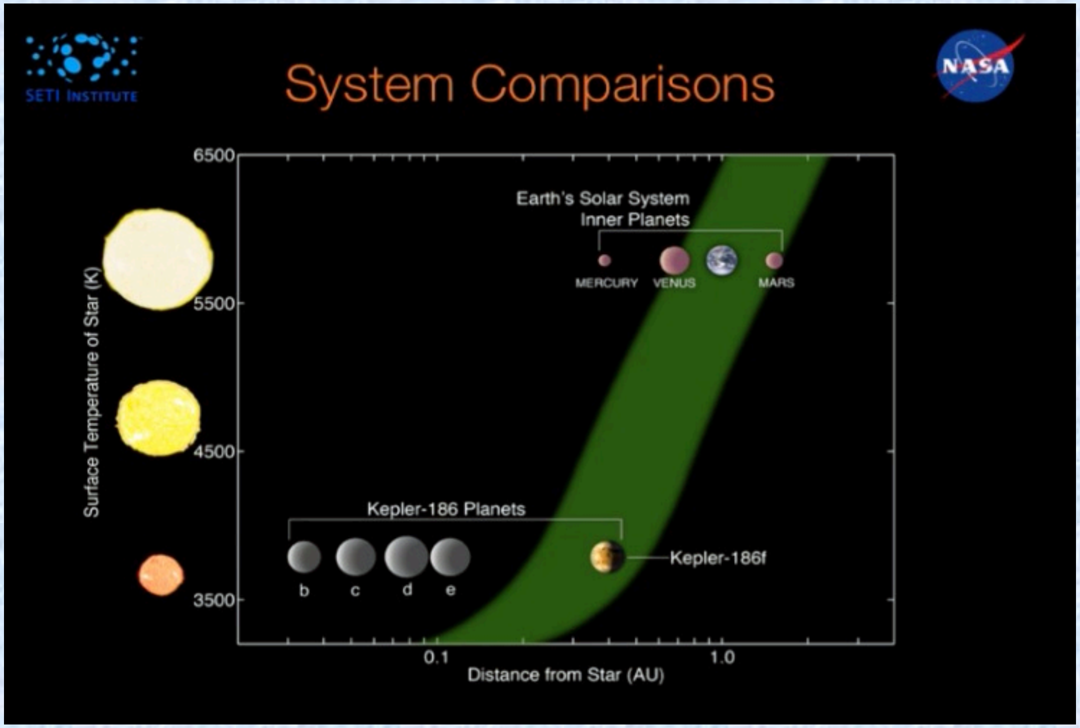
Planet Detection Methods

Michael Perryman, Rep. Prog. Phys., 2000, 63, 1209 (updated 3 October 2007)



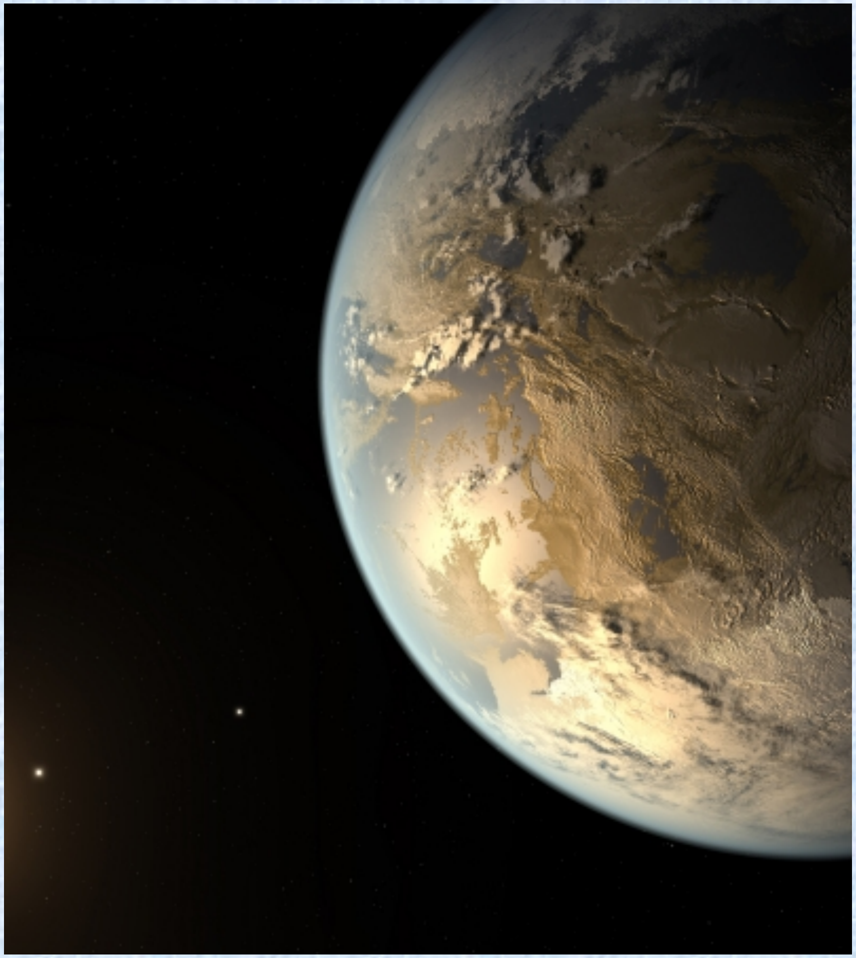
Habitable planets

- When is a planet habitable?
- For humans:
  - Liquid Water? (distance from star)
  - Gravity? (mass range)
  - Atmosphere?
  - Rocky? (mass range)
  - Shielded by meteors?
  - Stable orbit?
- For other forms of life?
  - Very difficult to say



A habitable planet?

- Mass similar to Earth
- Liquid water on the surface



movie

Extraterrestrial life: how many?

Drake Equation

$$N = R \times f_s \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- R average rate of star formation
- f_s fraction of good stars that have planetary systems
- n_e number of planets aound these stars within an "ecoshell"
- f_l fraction of those planets where life develops
- f_i fraction of living species that develop intelligence
- f_c fraction of intelligent species with communications technology
- L lifetime of the "communicative phase"

Check out: http://www.pbs.org/lifebeyondearth/listening/drake.html

Crude estimates

- R*~1/yr (large stars are too "fast"; small stars are too "cold")
- fp~1 (most sun-like stars probably have planets)
- Ne? 1 like our own?
- fl~1? Life arose very fast on Earth
- fi? 1
- fc? 1
- L? >100yr
- =>N=10? More in section
- If you are interested, read article by Bounama et al. posted on the web site describing more sophisticated models.
- *According to their model*, complex life is common enough that there is a chance to detect life in the atmosphere of a planet within the next decades!

Summary:
Is Earth a special/unique place?

- What does the question mean?
- How do we find planets?
- What are habitable planets?
  - Selection effects
- Is there extraterrestrial life?
  - Drake's Equation

The End

See you on Thursday!