STARS – S10

Wladimir (Wlad) Lyra
Brian Levine

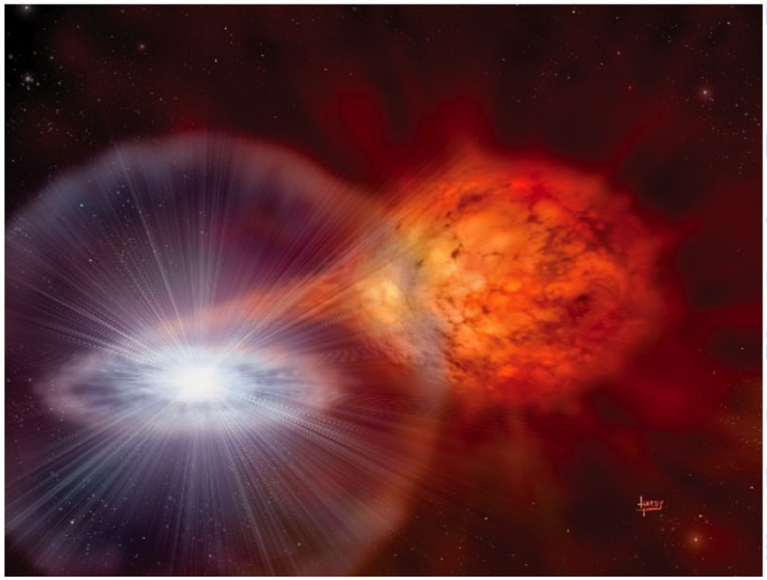
AMNH After-School Program

American Museum of Natural History

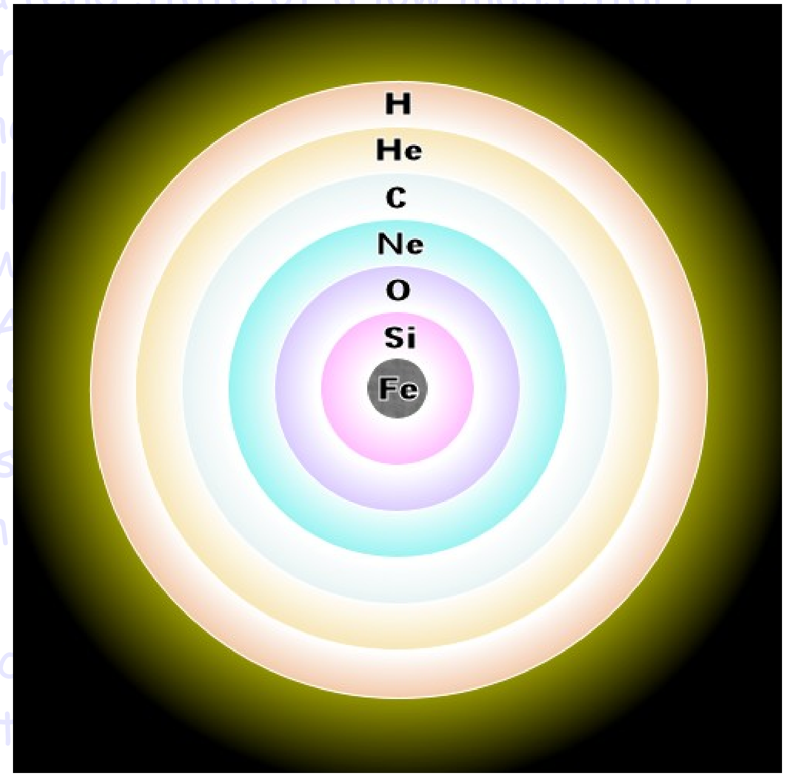
From last class

Type II Supernovae: Core collapse, Lots of Oxygen and Carbon, little Iron

Type Ia Supernovae: C-O white dwarf binary, lots of iron



Carbon Detonation: No remnant left



Neutronization: Iron is lost

Hydrogen 21 cm line is due to a variation in spin.

Interstellar nebulae. Absorption, Reflection, Emission.

Absorption. Lots of gas and dust blocking light.

Reflection. Same object, but illuminated by nearby stars.

Emission. Ionized by nearby OB stars. Emits in Ha upon recombination..

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Galaxy is enriched in alpha elements first, then Iron

Standard Candle: well defined luminosity

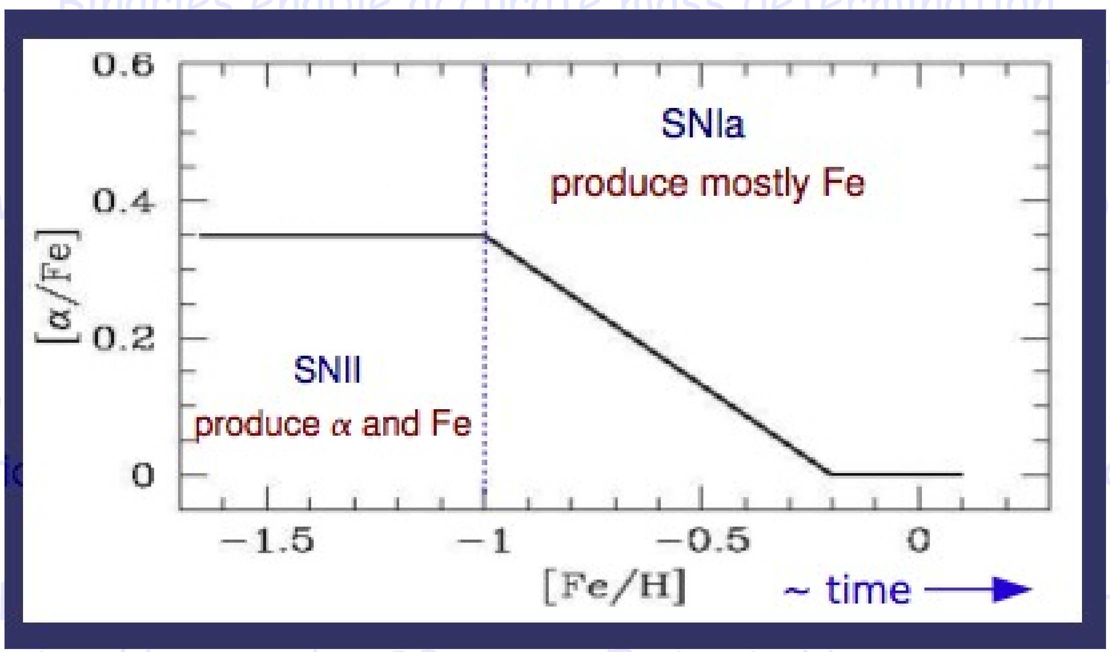
SN Ia is a naked core – good standard candle. SN II has a huge envelope.

Binaries. Wide or close. Wide means wide. Close means close.

Wide binaries: Visual and Astrometric.

Close binaries: Eclipsing and Spectroscopic.

Binaries enable accurate mass determination.



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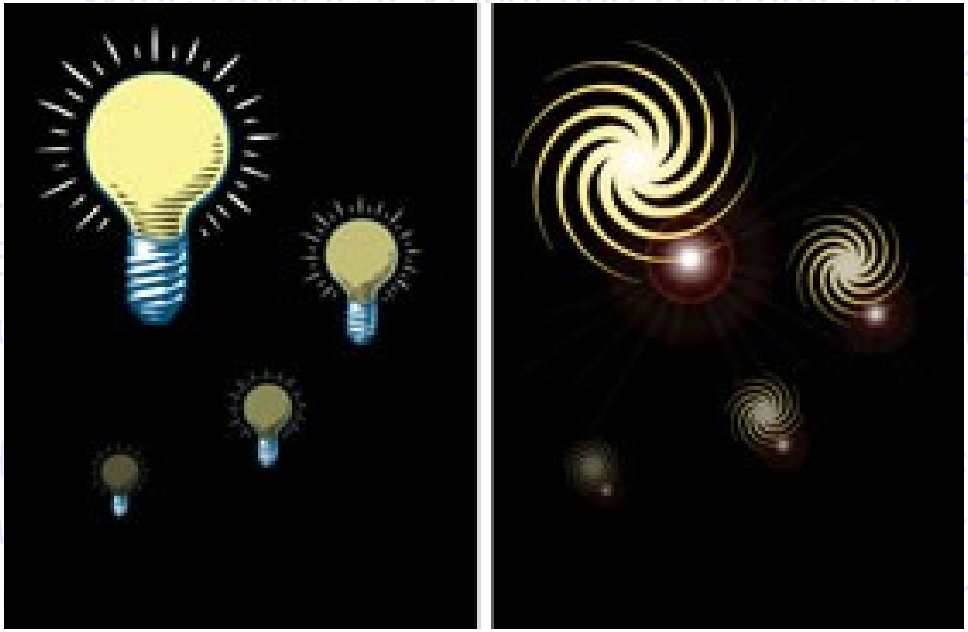

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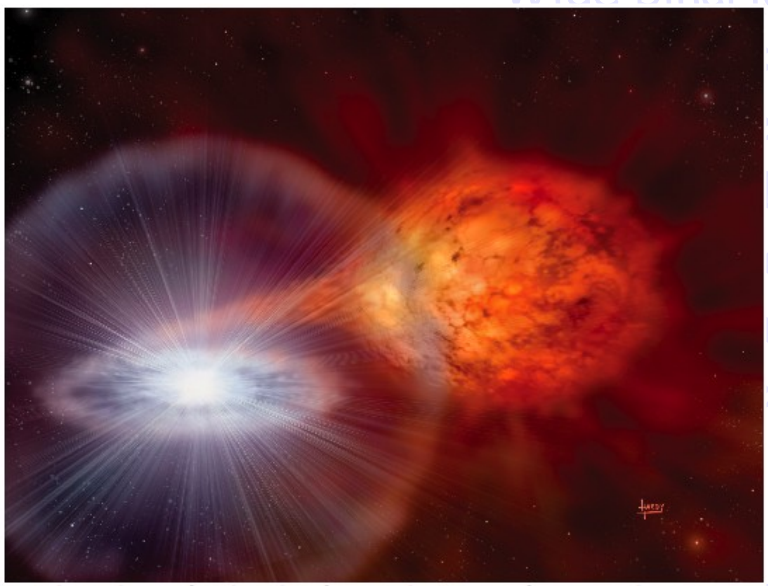
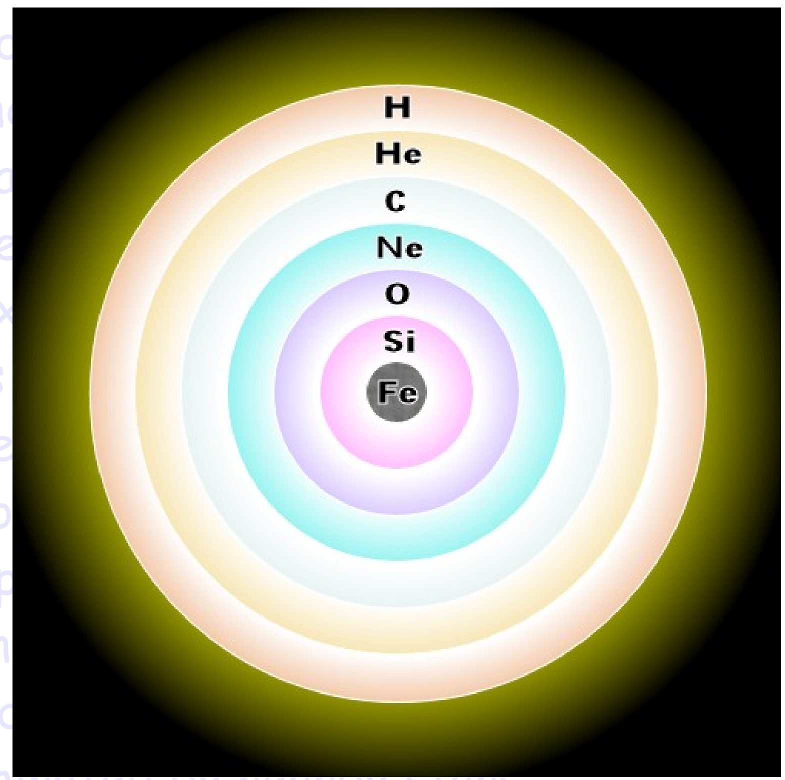


Artist's rendition of a white dwarf accumulating mass from a nearby companion star. This type of progenitor system would be considered singly-degenerate.

Image courtesy of David A. Hardy, © David A. Hardy/www.astroart.org.



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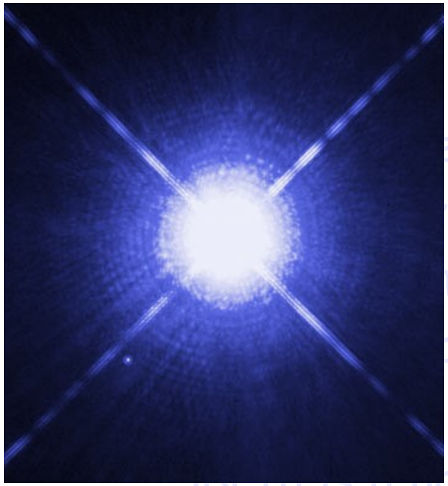

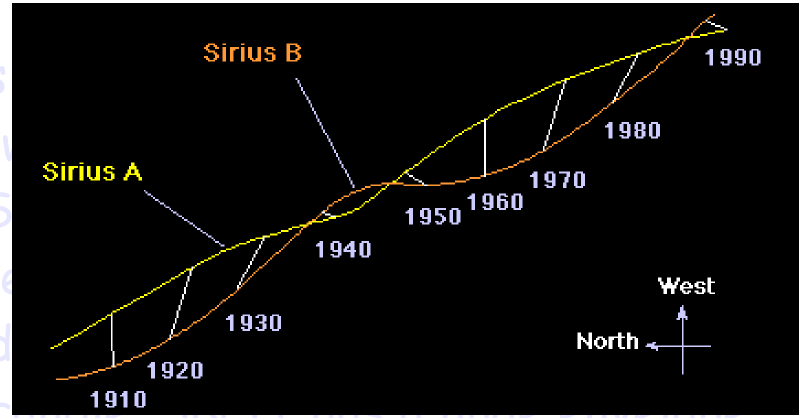

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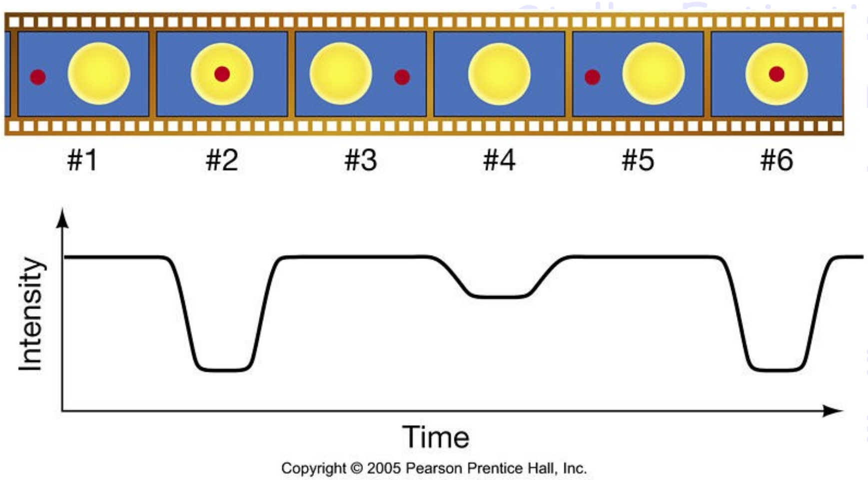

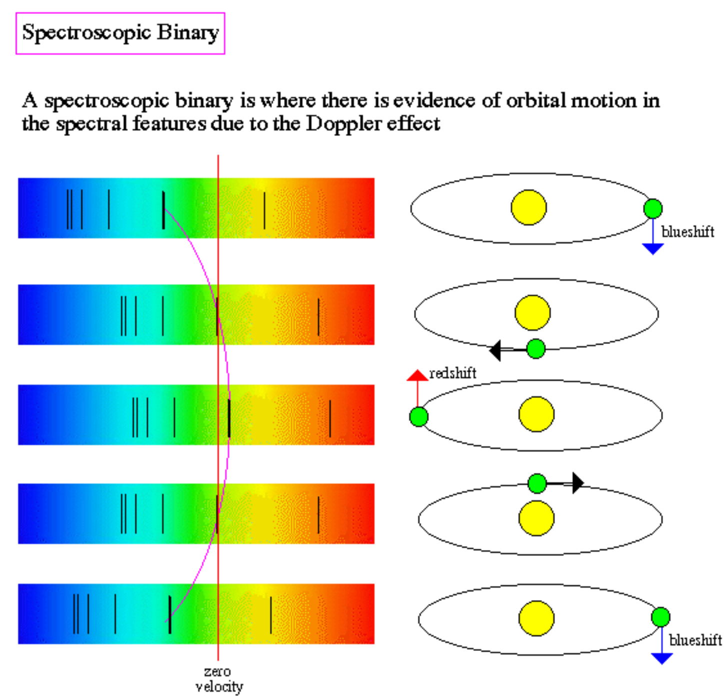

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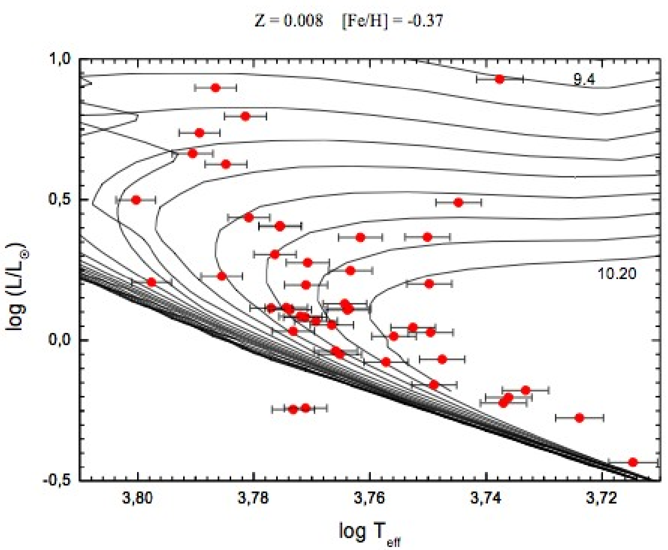

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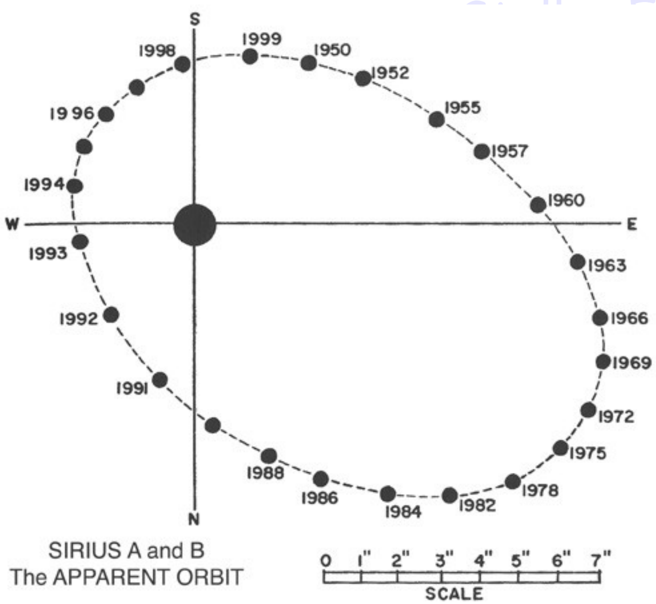
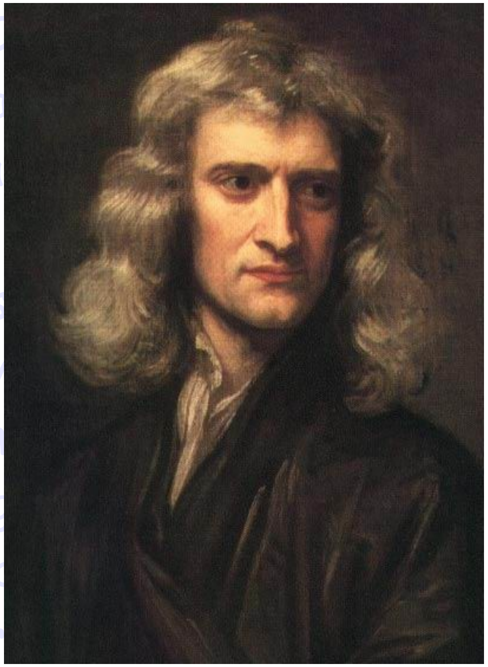


$$F = -\frac{G\,M\,m}{r^2}$$



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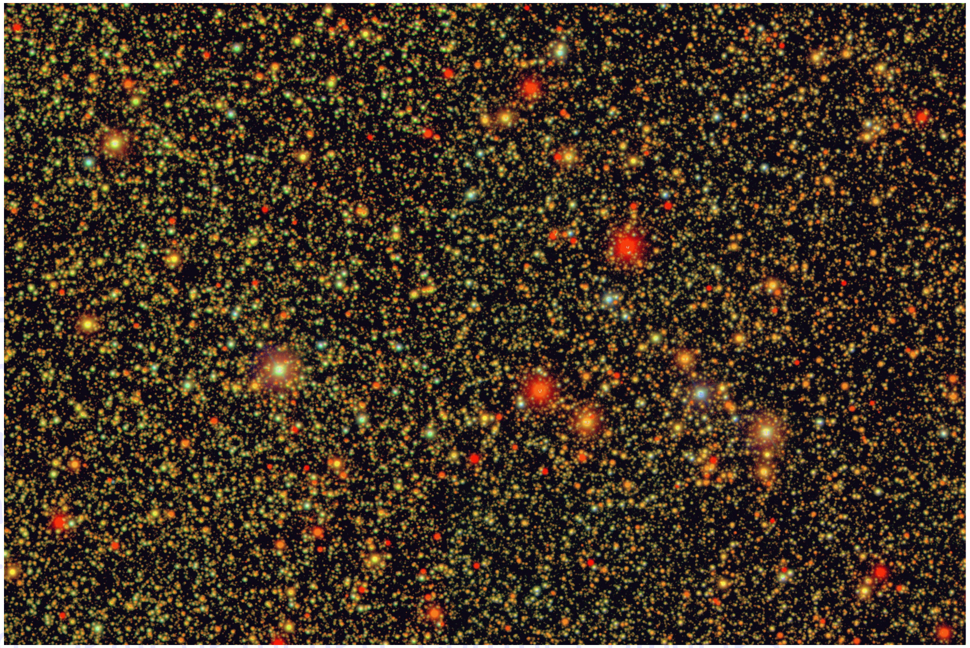

Roche Lobe, Lagrange Point. Detached, Semi-detached, Contact Binaries.

Stellar Extinction. The Galaxy is a foggy place.

Extinction is wavelength-dependent. Blue is scattered. Stars look reddened.

Infrared has little extinction.

Hydrogen 21 cm line is due to a variation in spin.

The Galaxy glows in the 21 cm line. We mapped the Galaxy in this radiation.

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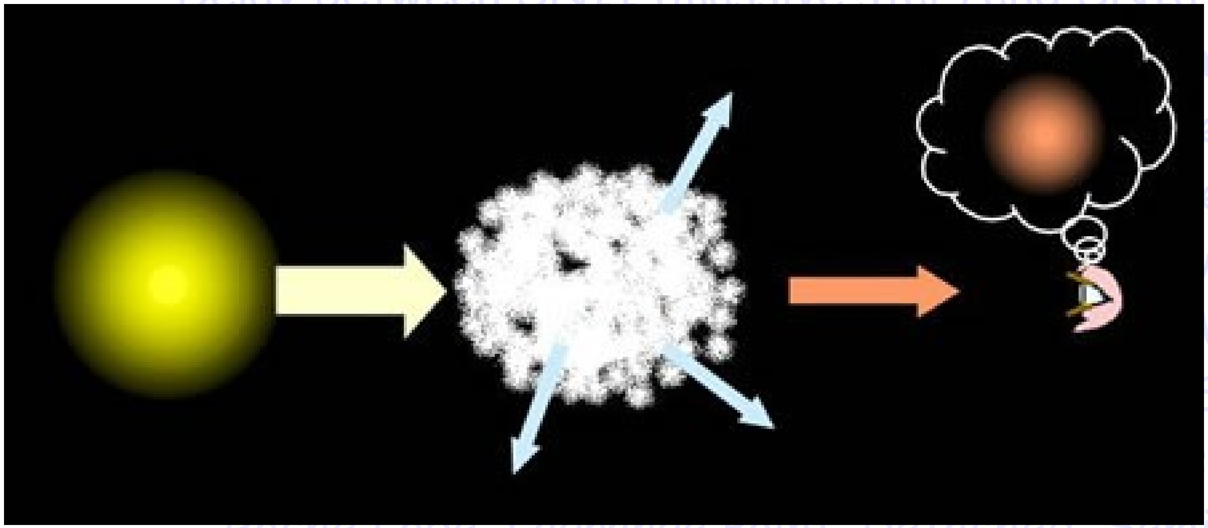

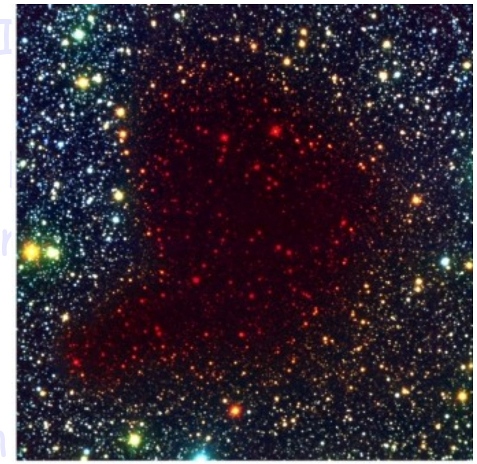

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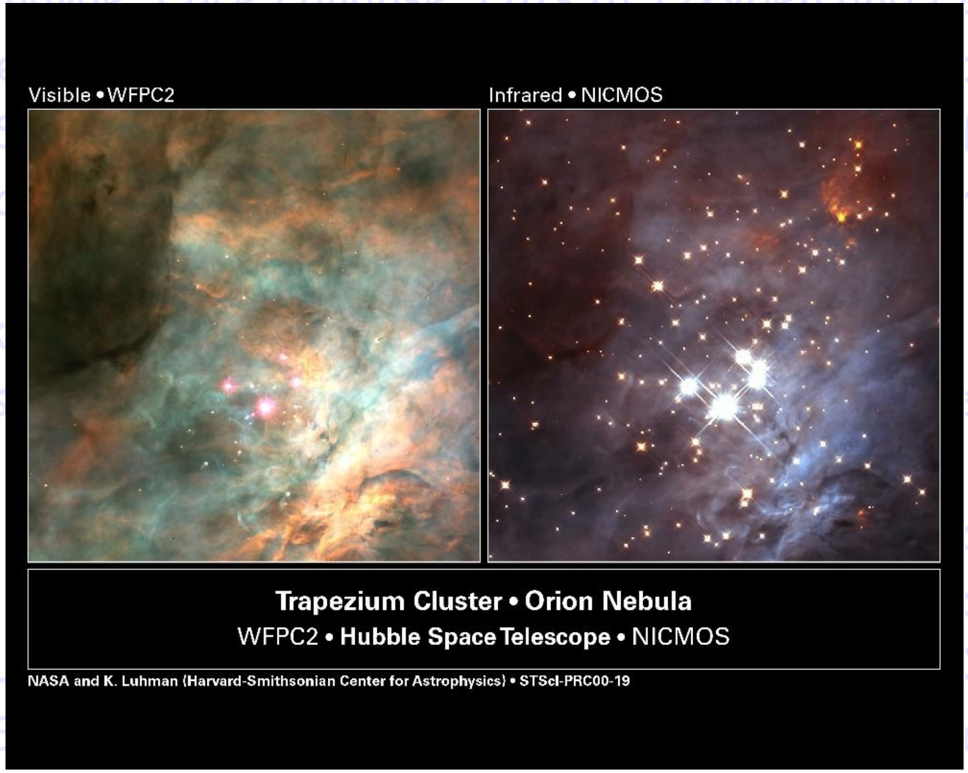

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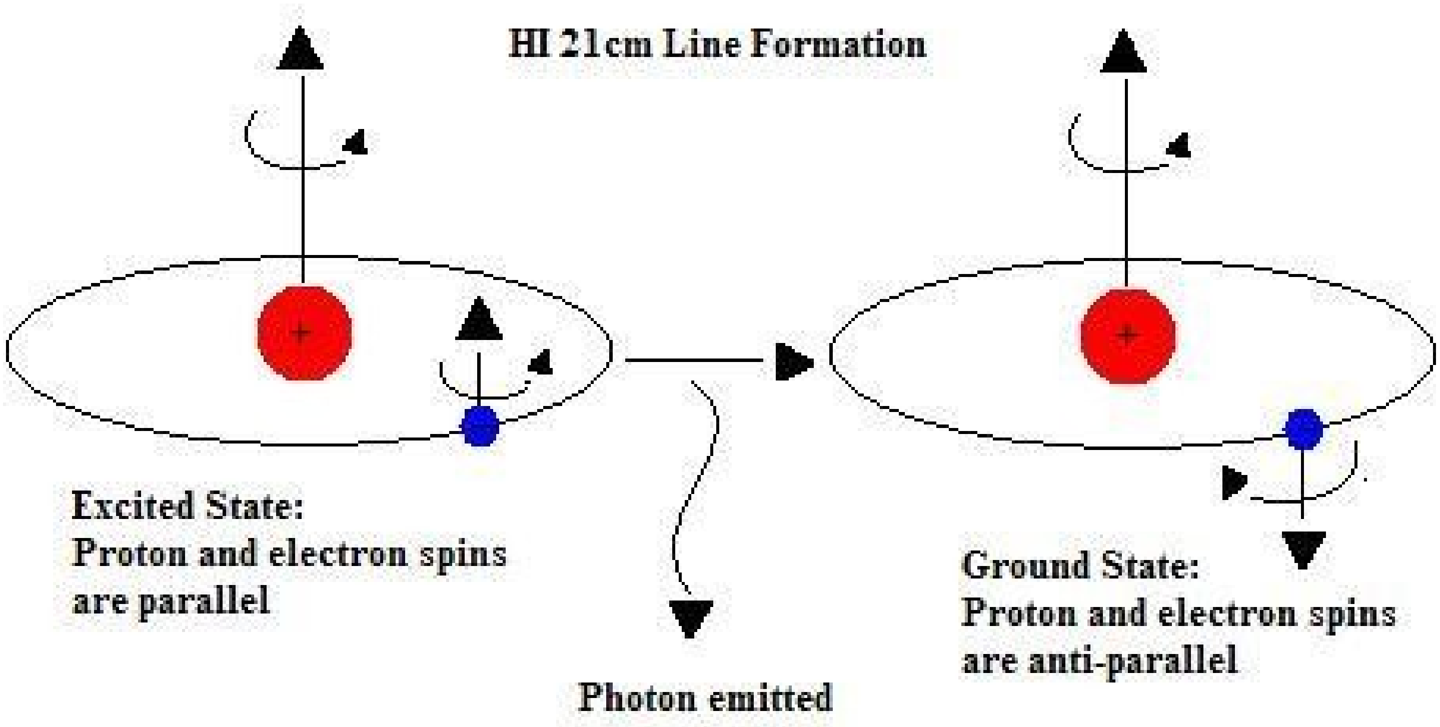

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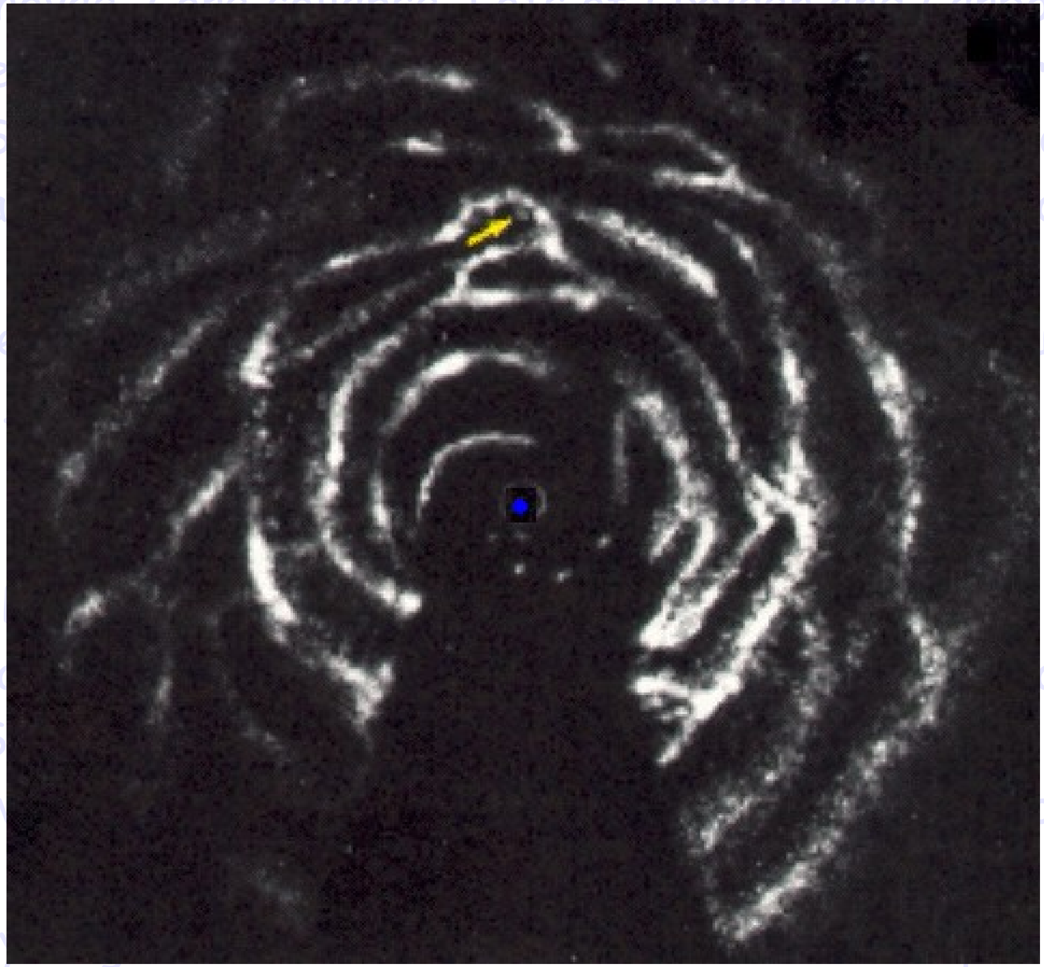

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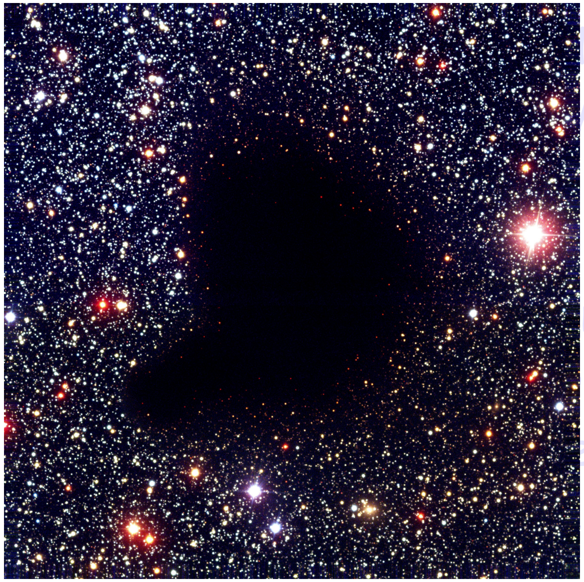

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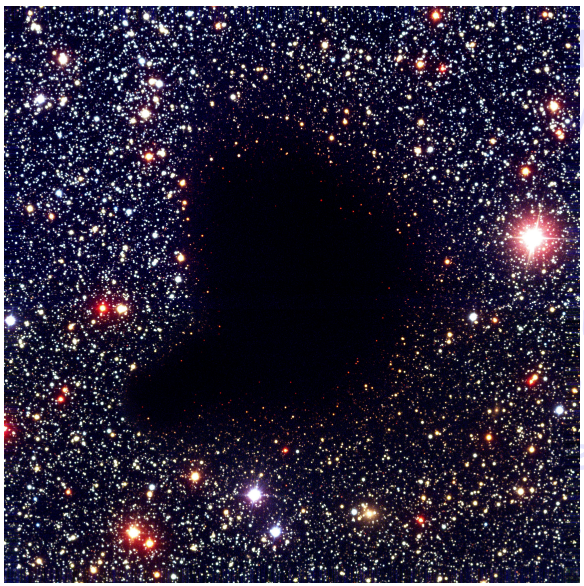

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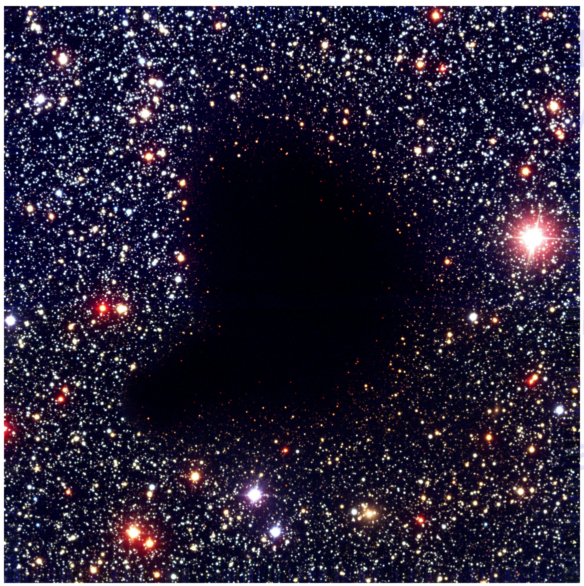

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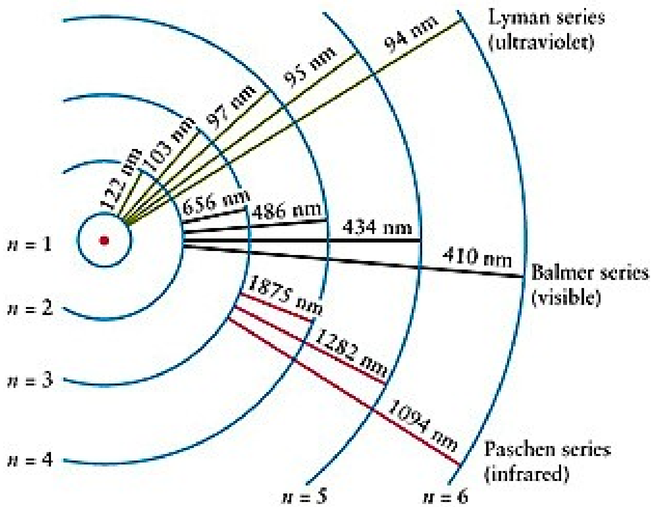

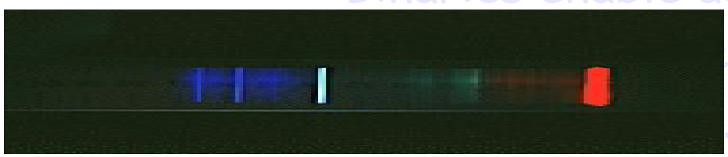

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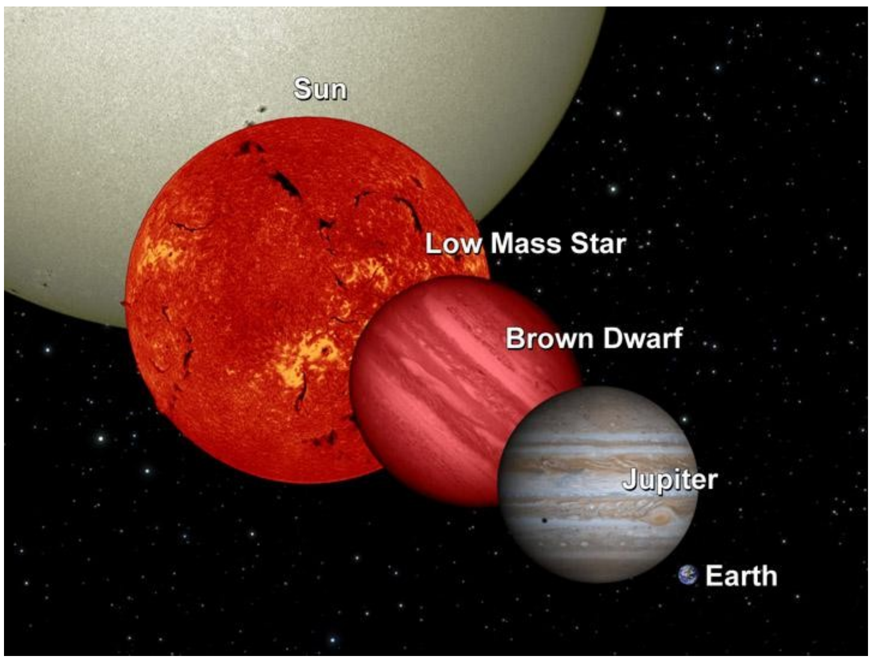
Outline

- Substellar Objects
  - Hydrogen Burning Limit
  - Brown dwarfs
  - Deuterium Burning Limit
  - Free floating planets
- Planet detections
  - Methods
    - Radial Velocity
    - Transit
    - Microlensing
    - Direct imaging
- Exoplanet statistics
- Circumstellar disks
- The Kepler mission

Brown Dwarfs - Runt Stars

Brown dwarfs are objects with mass
below the **Hydrogen Burning Limit** of **0.08 $M_\odot$**



Star formation does not "know" about a hydrogen burning limit. Objects above and below it are formed.

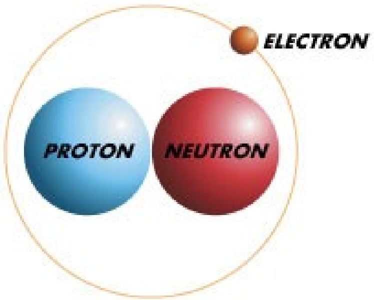
Brown dwarfs are the runts of the litter.

Also called **Substellar Objects**

They do ***not*** burn Hydrogen,
but they burn **Deuterium**

Deuterium Burning

Deuterium (^{2}H): an isotope of Hydrogen.



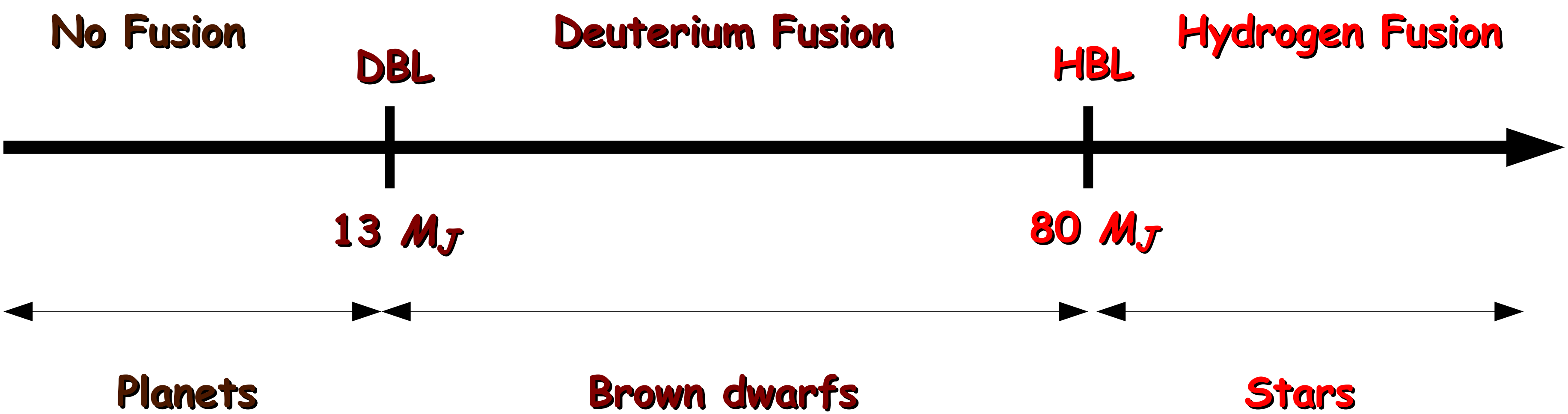
Deuterium has the **same charge** as hydrogen,
but is **heavier** – thus **easier to fuse**.

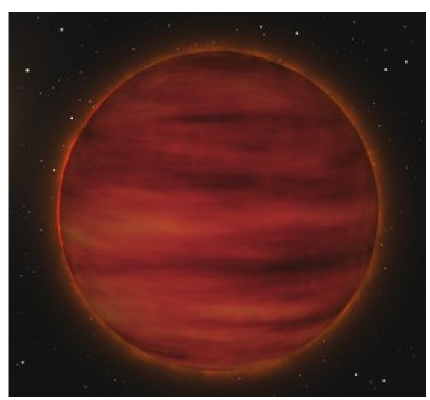
Hydrogen fusion requires temperatures of 10 million K,
but deuterium fuses at much lower temperatures.

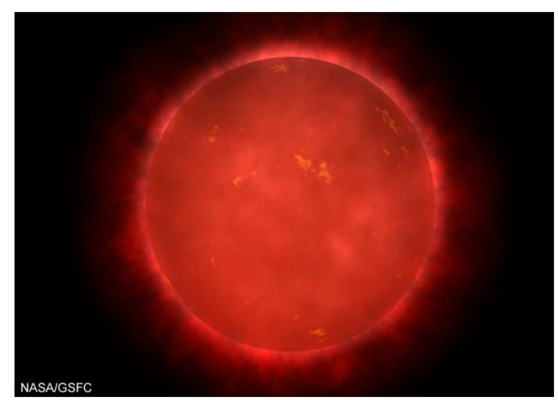
Mass Range

Hydrogen Burning Limit (0.08 $M_\odot$ – 80 M_J)

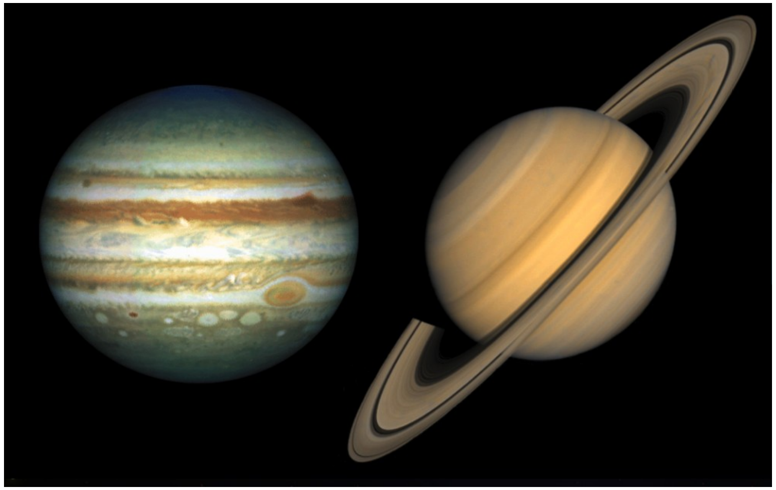
Deuterium Burning Limit (0.013 $M_\odot$ – 13 M_J)







Radii of Brown Dwarfs



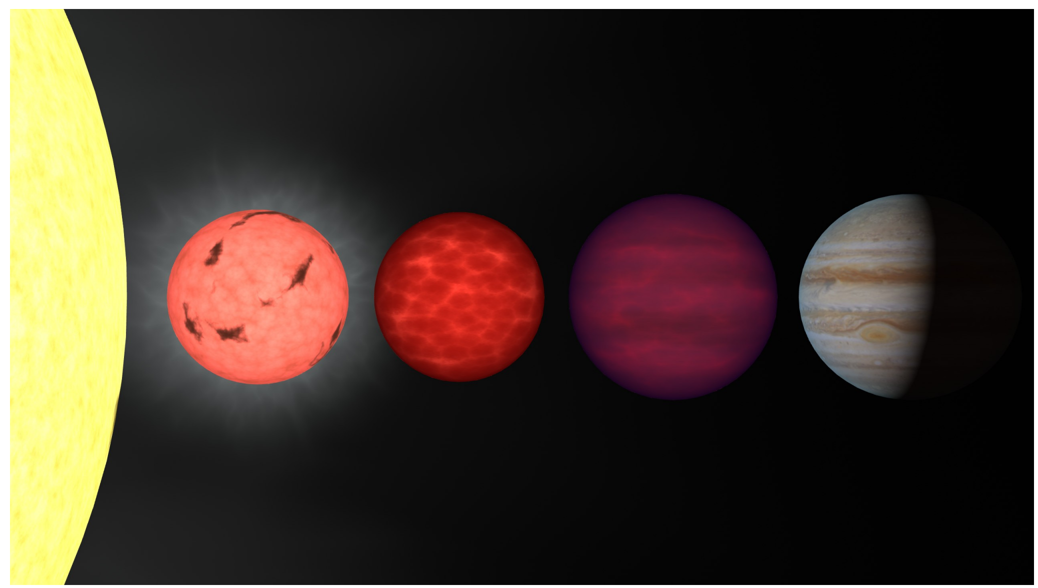
Jupiter is 3x more massive than Saturn

Yet their radii are similar.

Why?

They are partially degenerate!
In this regime, adding mass
just makes stuff denser.

The same applies to brown dwarfs



Brown dwarfs of all masses
(13 – 80 M_J)
are Jupiter-sized

Brown dwarf evolution

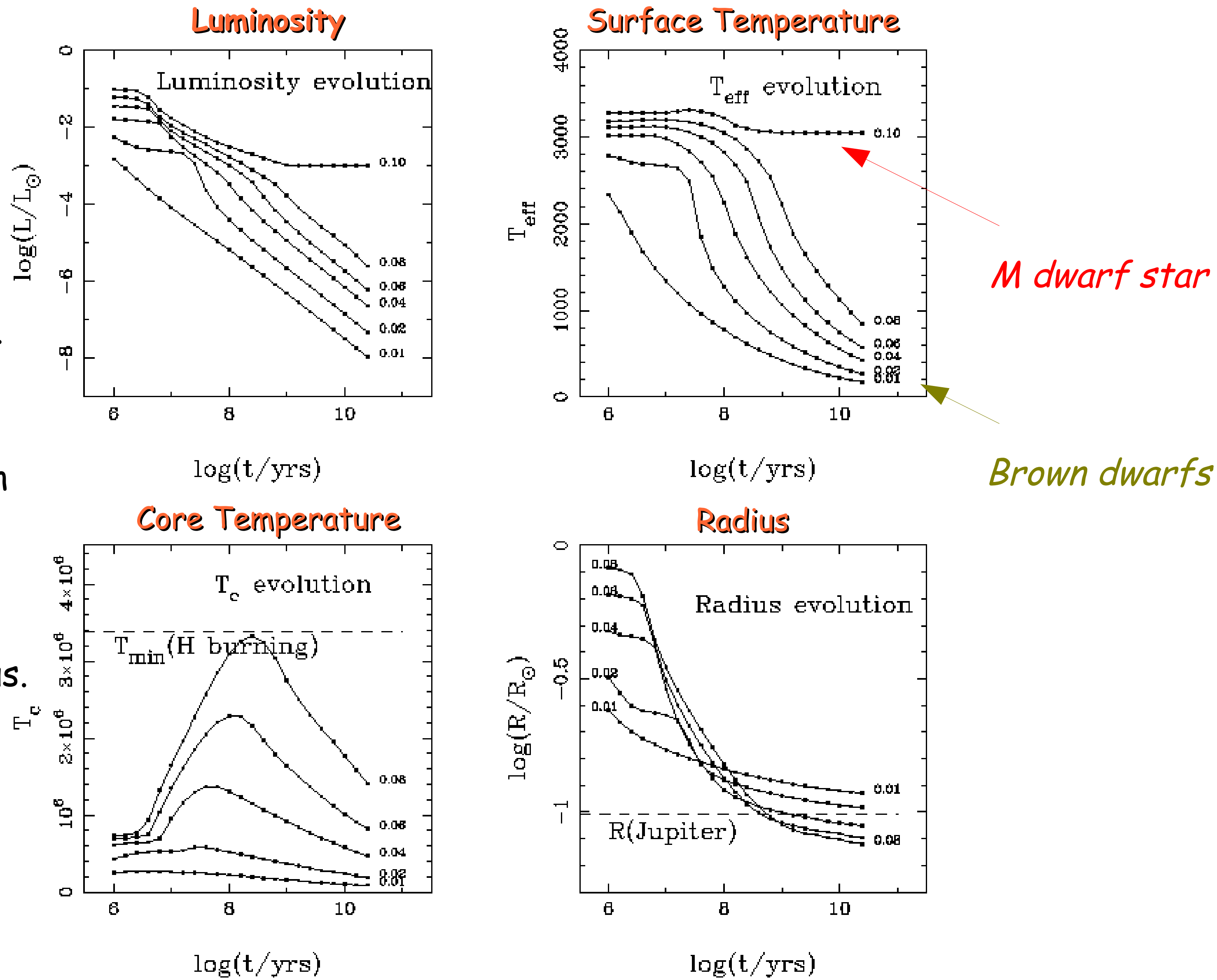
Deuterium fusion only lasts for 10^7 years !!
Brown dwarfs evolution after that is basically cooling

1) Deuterium burning
(constant temperature,
luminosity and radius)

2) Contraction. Radius falls.
Core temperature rises.

3) Never achieves hydrogen
burning temperatures.
Core goes degenerate.

4) Cooling at constant radius.

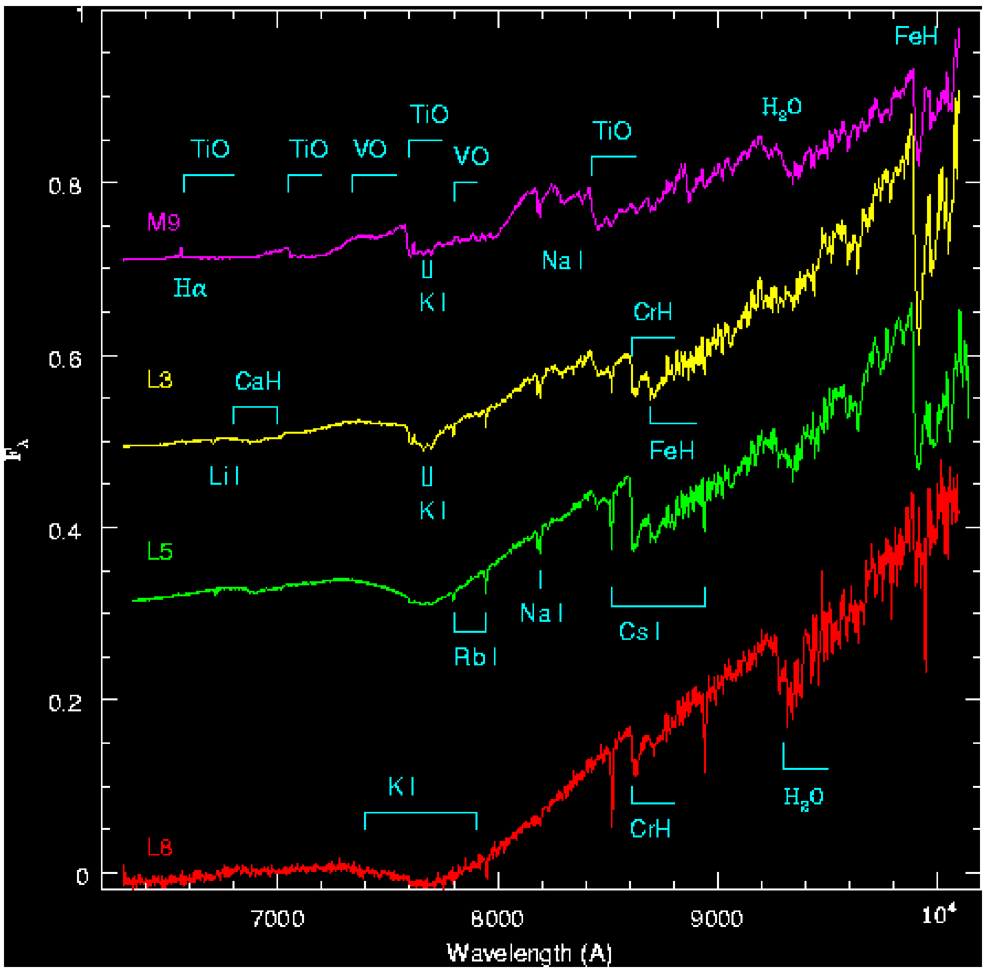


Brown dwarf atmospheres

Three new spectral types

OBAFGKM LTY

L dwarfs



Temperature range – 1300 – 2000 K

Spectral features – H_2O, hydrites, no TiO

T dwarfs

Temperature range – 700 – 1300 K

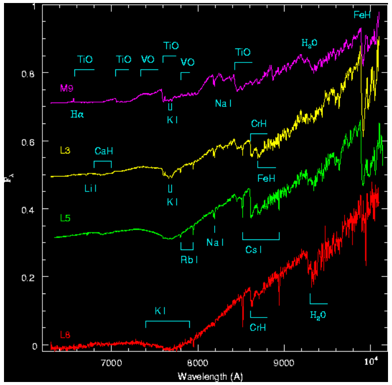
Spectral features – CH_4, no visible radiation

Y dwarfs

(not yet observed)

Temperature range - >700 K

(Predicted) Spectral features - NH_3



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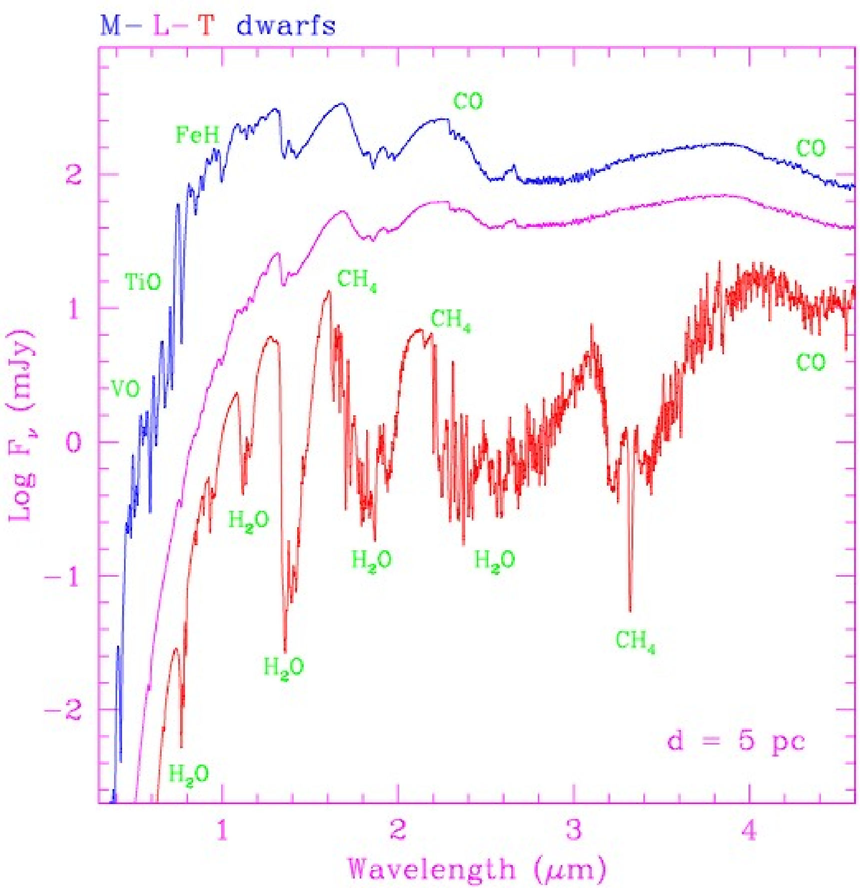

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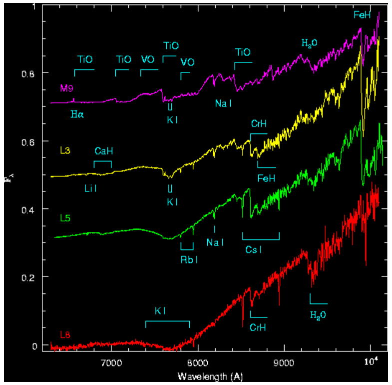

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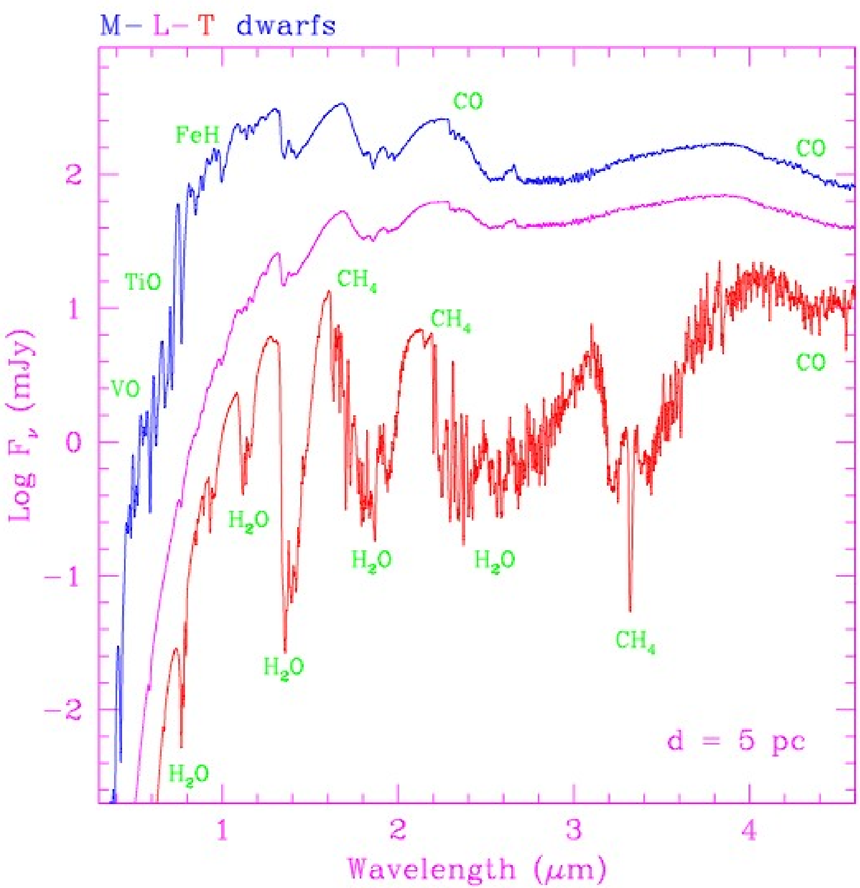


Y dwarfs

(not yet observed)

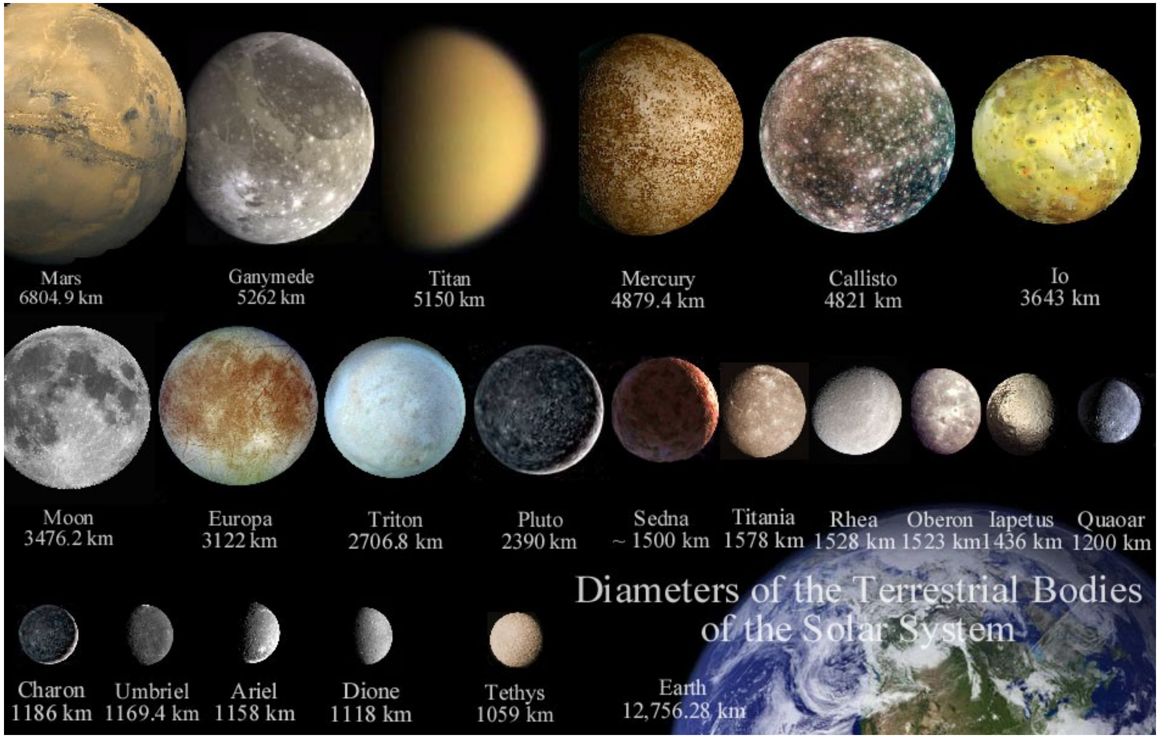
Temperature range - $T < 700$ K
(Predicted) Spectral features - NH_3

Free floating planets

As deuterium fusion is fast,
the transition between brown dwarfs and planets is blurred

Plus, the IMF does not stop at the Deuterium Burning Limit

There should be **planetary mass objects** orbiting in the Galaxy, **unbound to stars**,
in much the same way that moon-sized stuff – Pluto for instance – freely orbit the Sun



Free floating planets

As deuterium fusion is fast,
the transition between brown dwarfs and planets is blurred

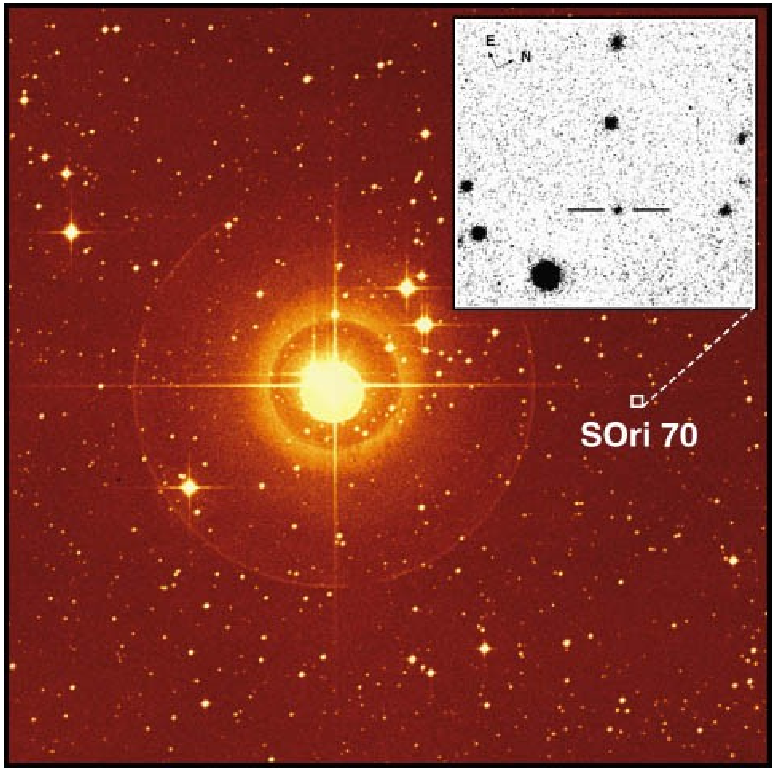
Plus, the IMF does not stop at the Deuterium Burning Limit

There should be **planetary mass objects** orbiting in the galaxy, **unbound to stars**,
in much the same way as moon-sized stuff – Pluto for instance – freely orbit the Sun

S Ori 70: best candidate.
Mass estimated in 3 M_J

<u>**Suggested names**</u>

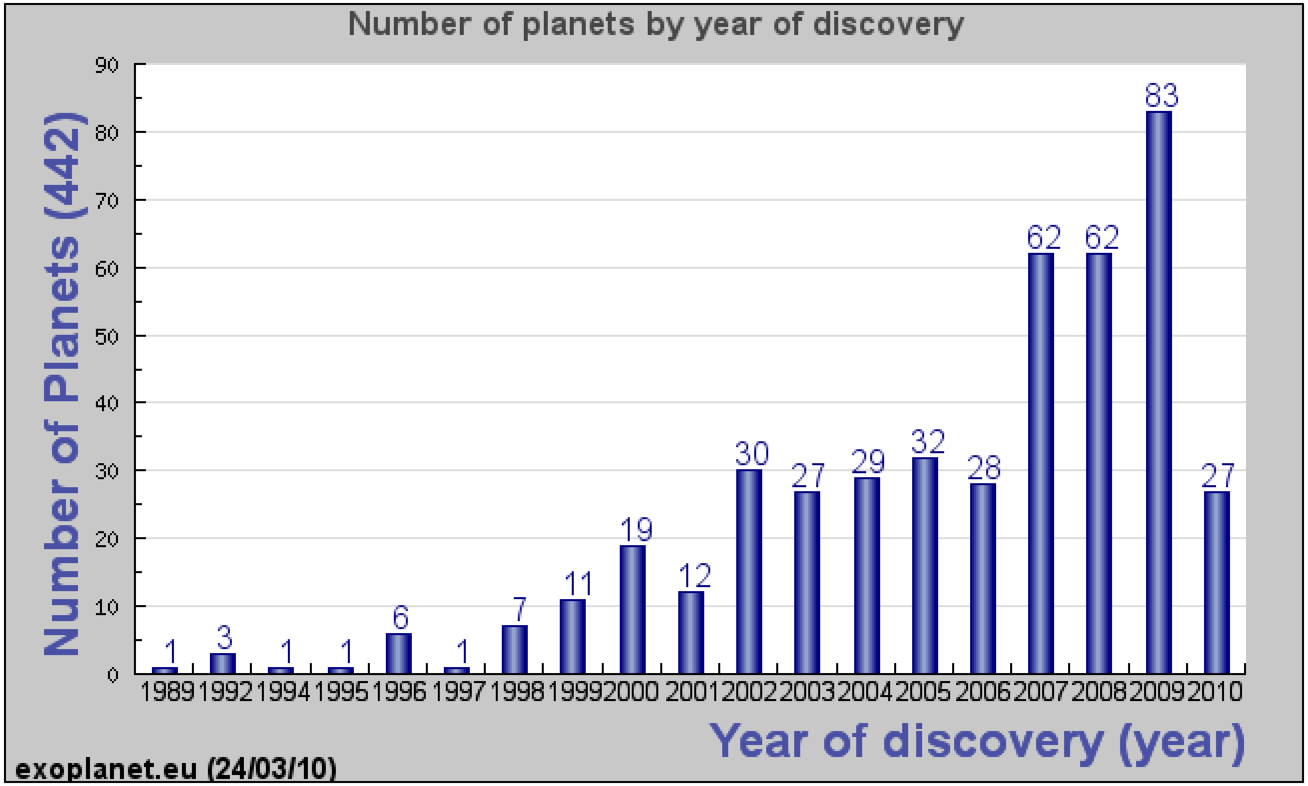
Free floating planet
Rogue planet
Interstellar planet
Sub-brown dwarf
Planetar



Extrasolar planets

Extrasolar planets

Rate of discoveries

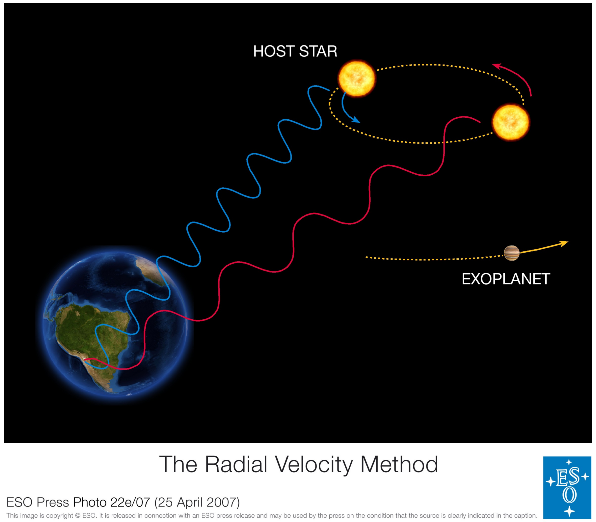


442, and counting!

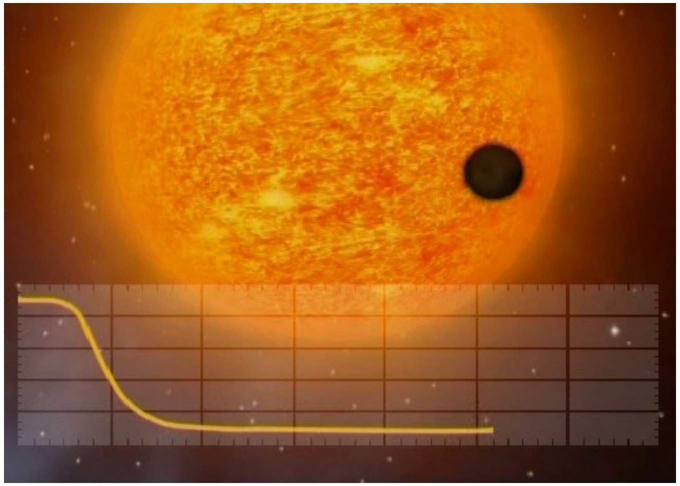
(Maybe already 443 since we started this class)

Extrasolar planets

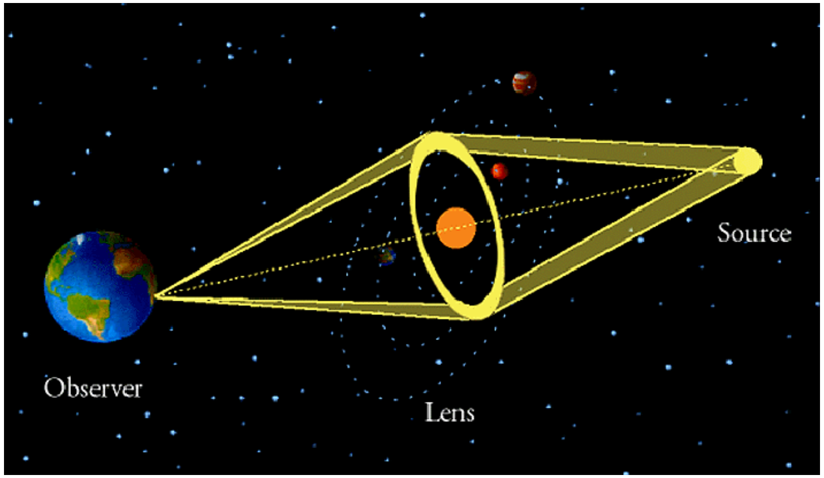
Detection methods



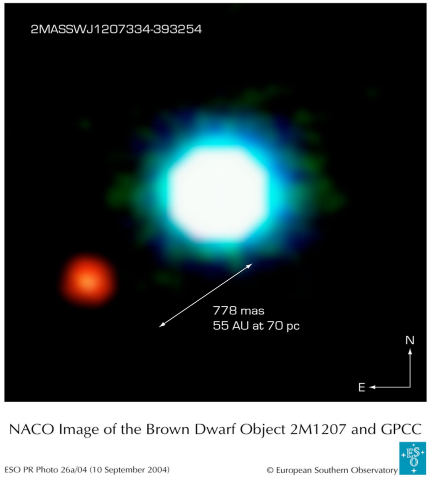
Radial Velocity



Transit

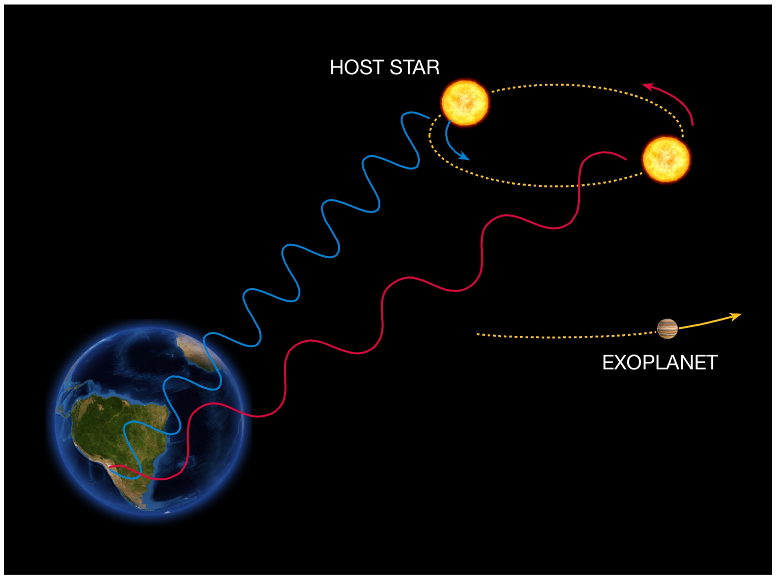


Microlensing



Direct Imaging

Extrasolar planets – Radial Velocity



The Radial Velocity Method

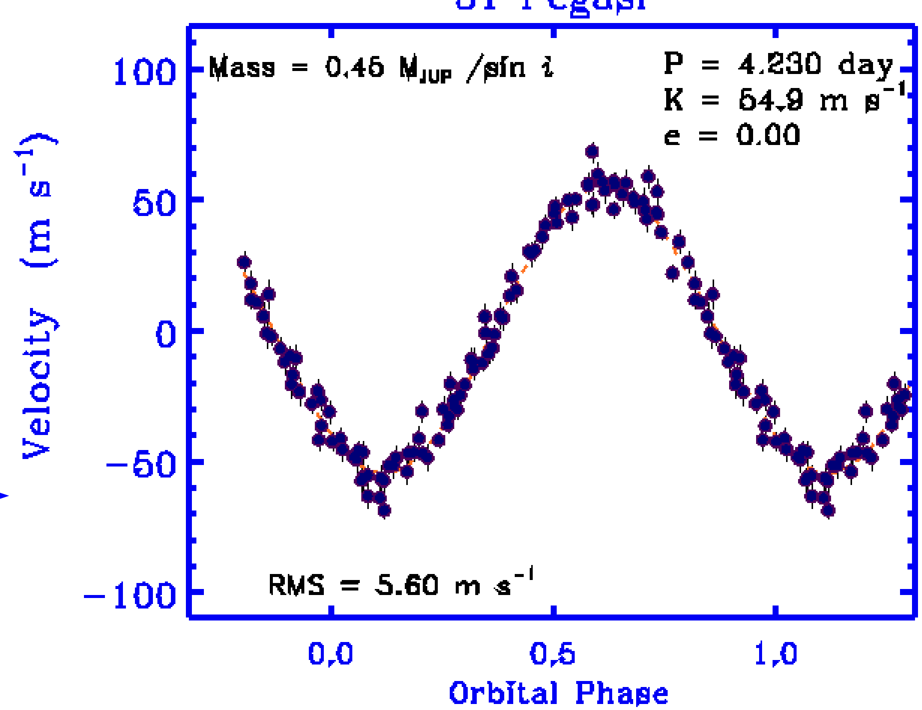
ESO Press Photo 22e/07 (25 April 2007)

The most successful method

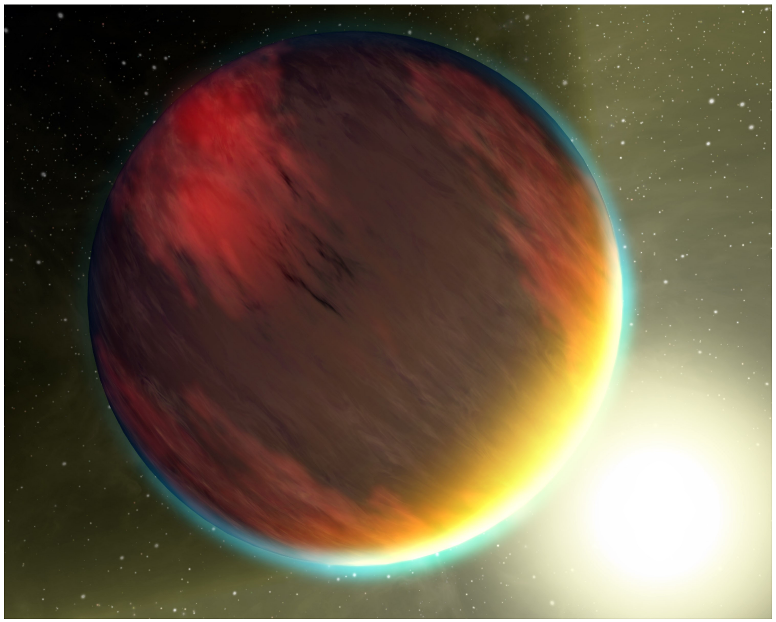
Star and planet orbit a common center of mass

Measure radial velocity curves for thousands of stars and hope for the best

The first planet discovered around a main sequence star 51 Peg b

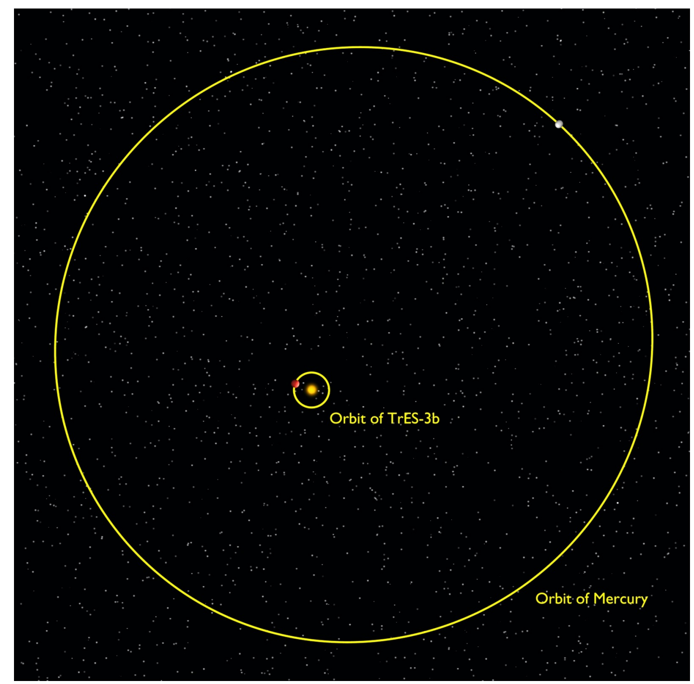


Extrasolar planets – Radial Velocity



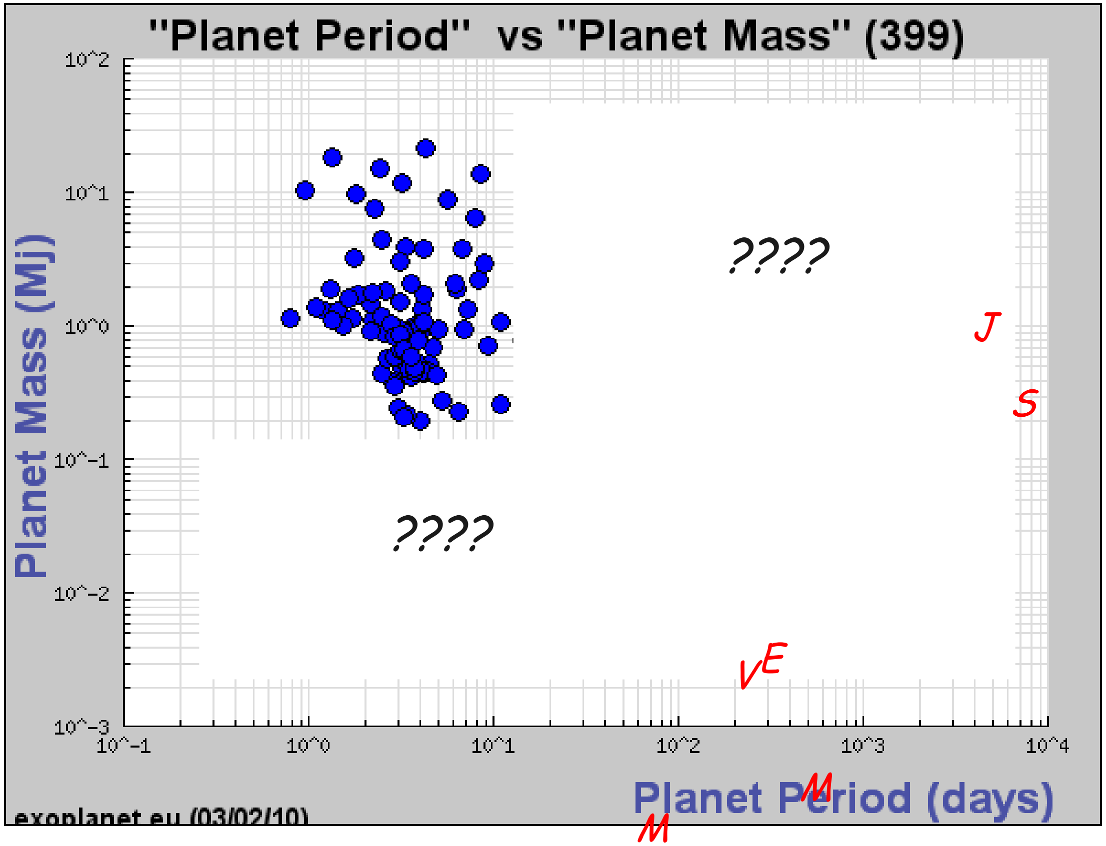
Biased towards large wobbles

High velocities (big sinal)
Short periods (No need for long monitoring)

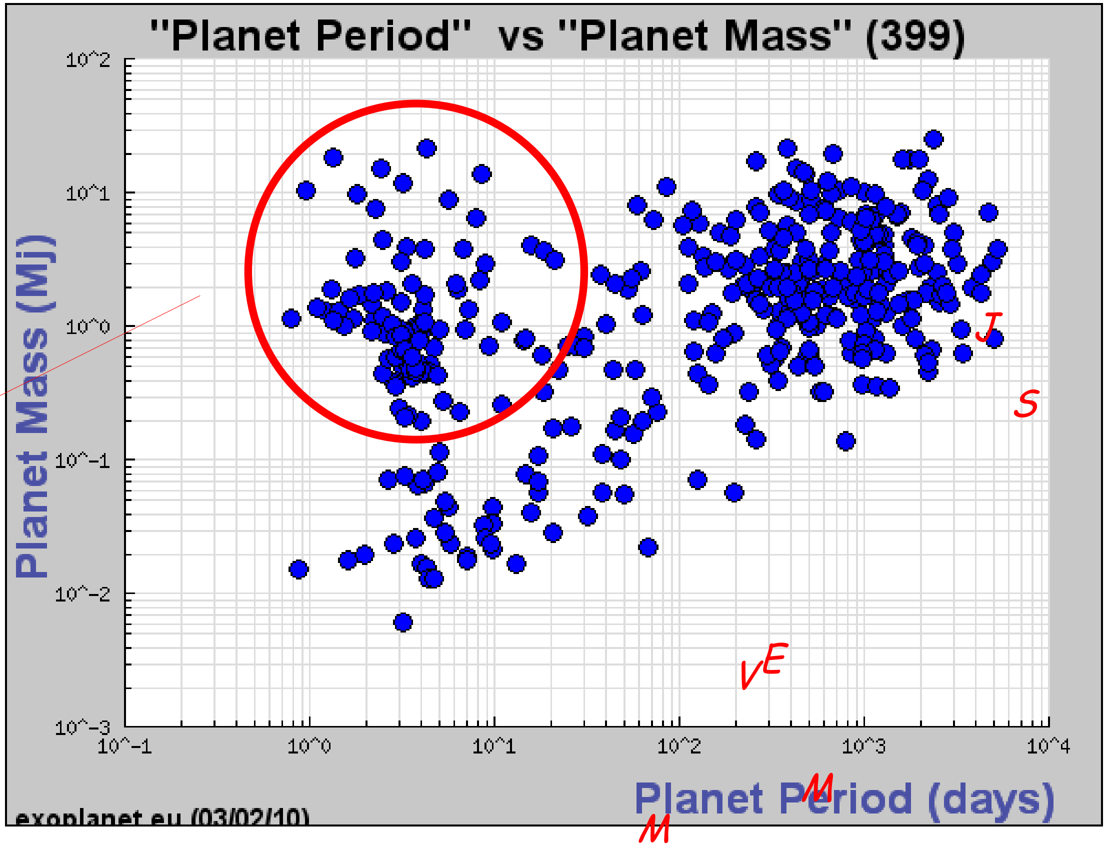


The technique preferentially finds
big planets close to their stars
(aka ***Hot Jupiters***)

Extrasolar planets – Radial Velocity



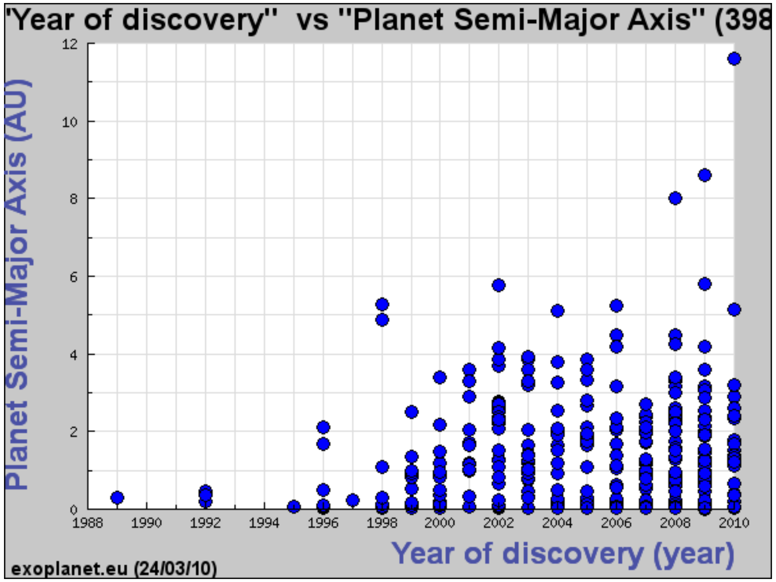
Extrasolar planets – Radial Velocity



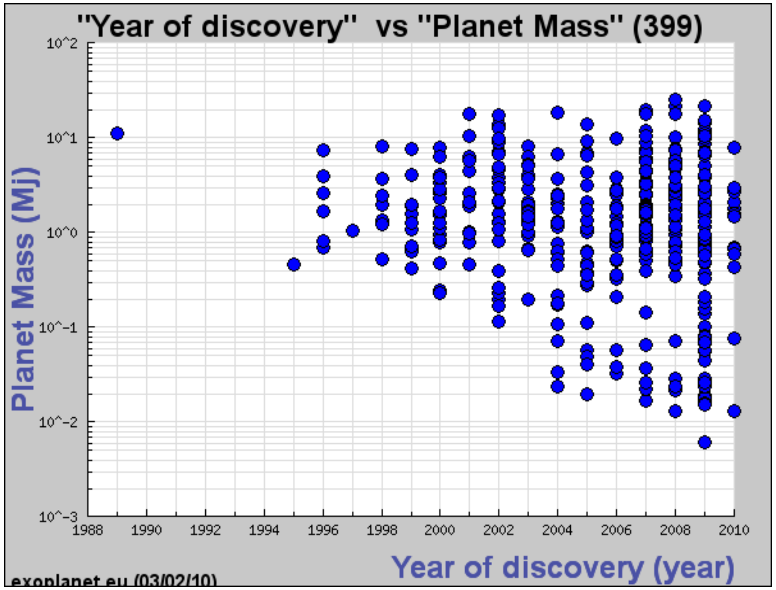
The tip of the iceberg

Extrasolar planets – Radial Velocity

In time...

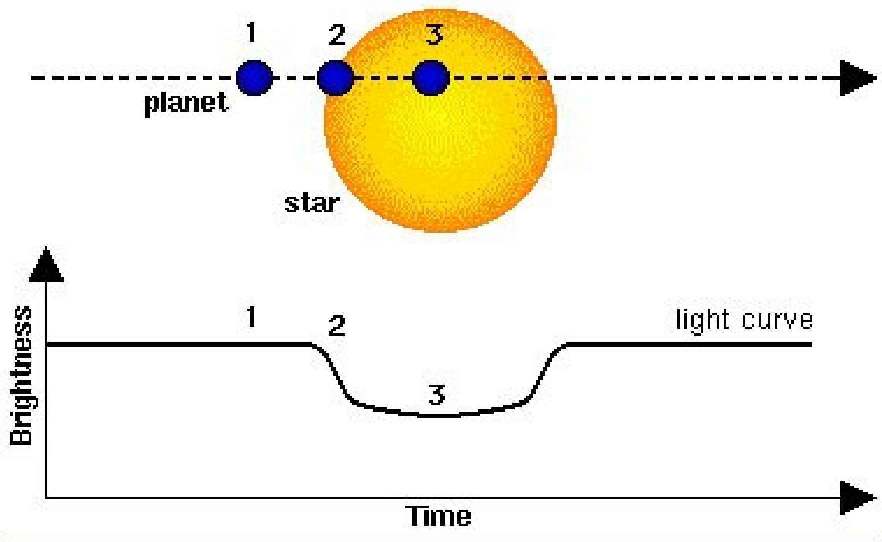


.... we have access to wider orbits...



.... and the sensitivity of the technique increased, allowing for the detection of lower mass planets.

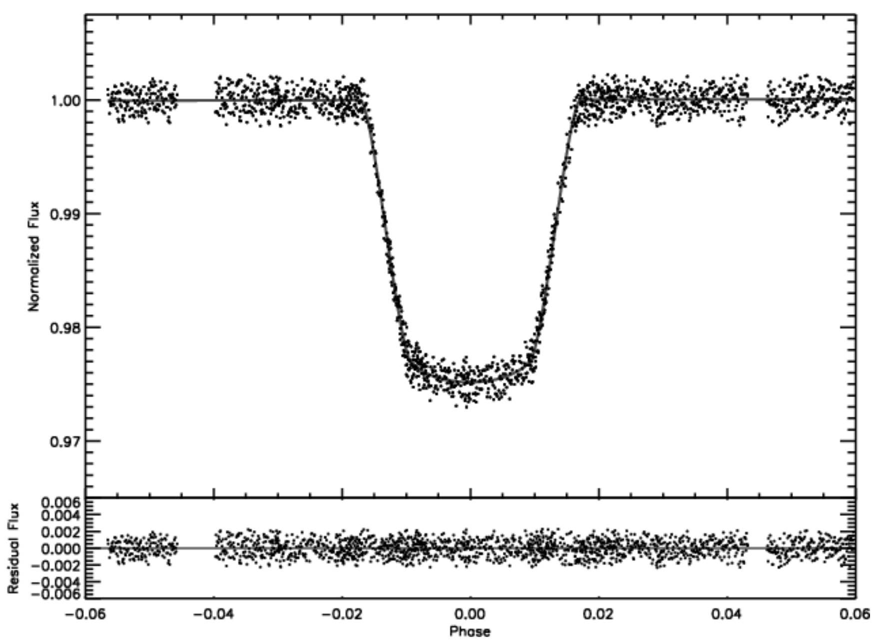
Extrasolar planets - Transit



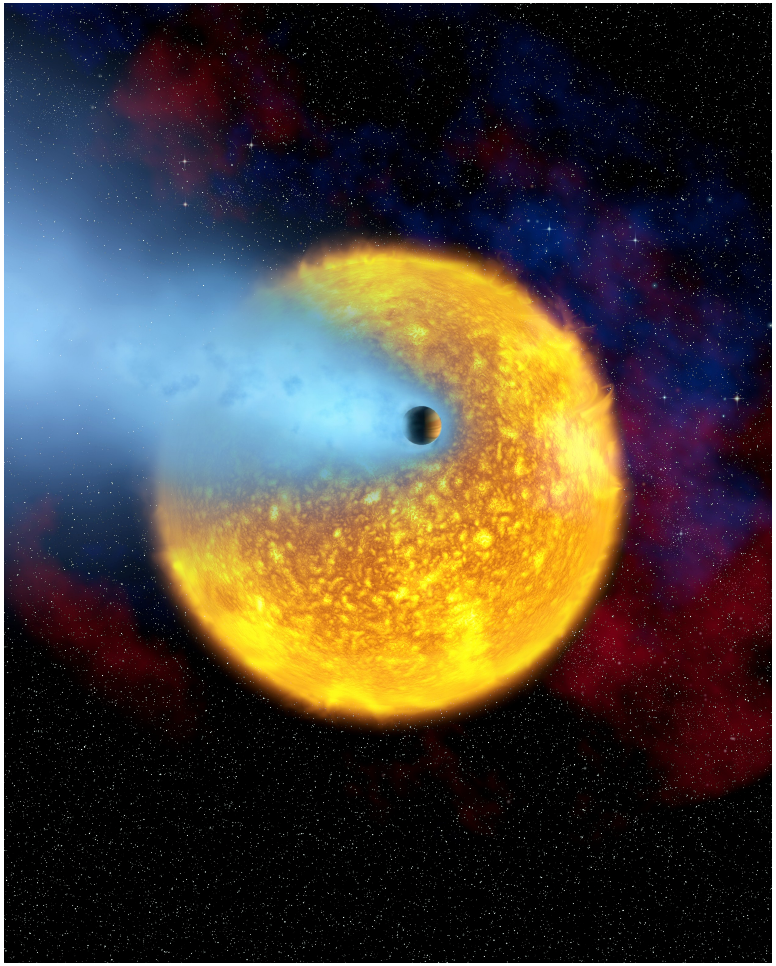
The planet transits the star if the orientation of the orbit is favorable

A Jupiter-size planet produces a 0.02 magnitude dip. Detectable!!

Measure light curves for thousands of stars and hope for the best

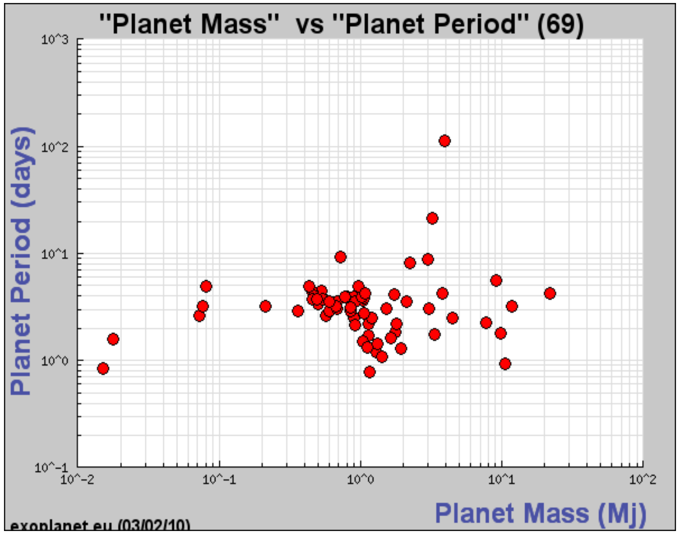


Extrasolar planets - Transit



Probability of favorable orientation depends on the

$$\frac{\textbf{Size of the star}}{\textbf{Size of the orbit}}$$

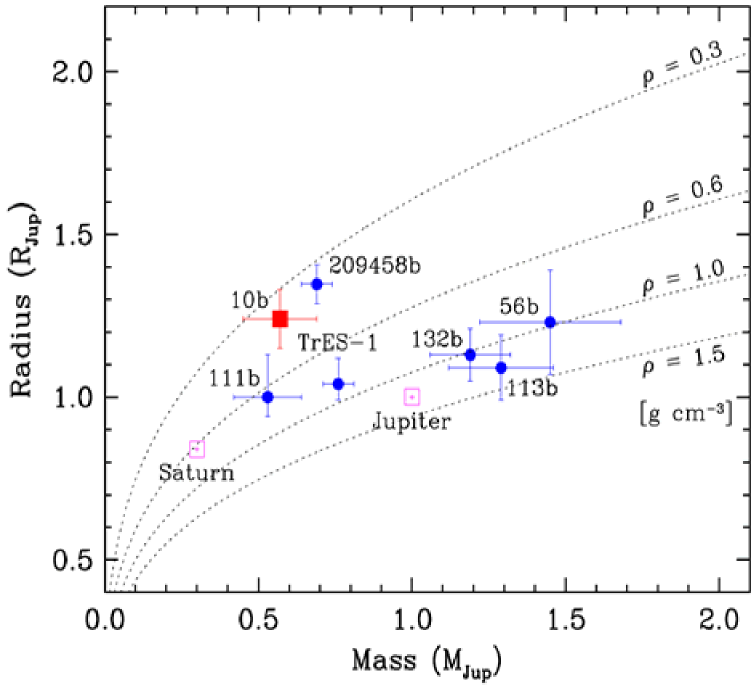


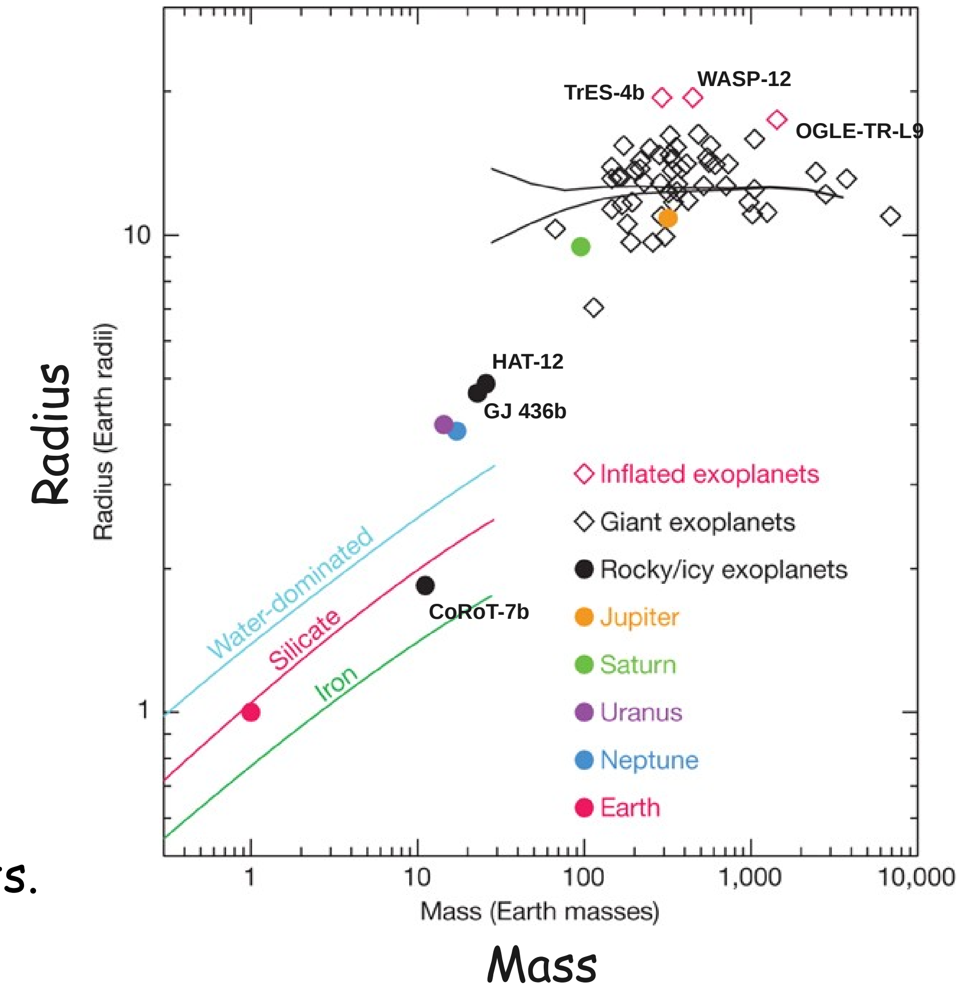
Also biased towards short period planets (small orbits)

Extrasolar planets - Transit

Transits allow for determination of both mass and radius!

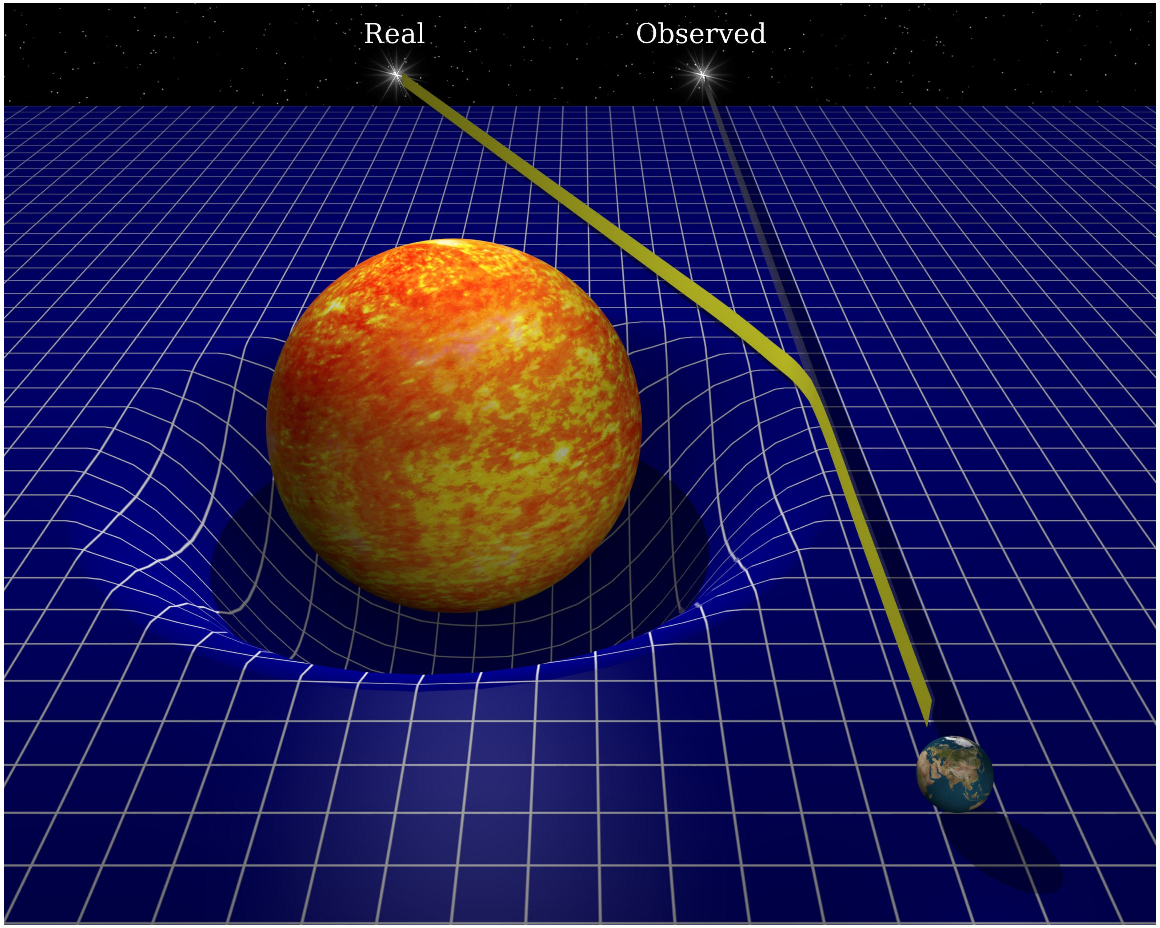
We can measure **densities**...





... and make educated guesses about **composition and structure** of the planets.

A little General Relativity



Einstein Equation

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

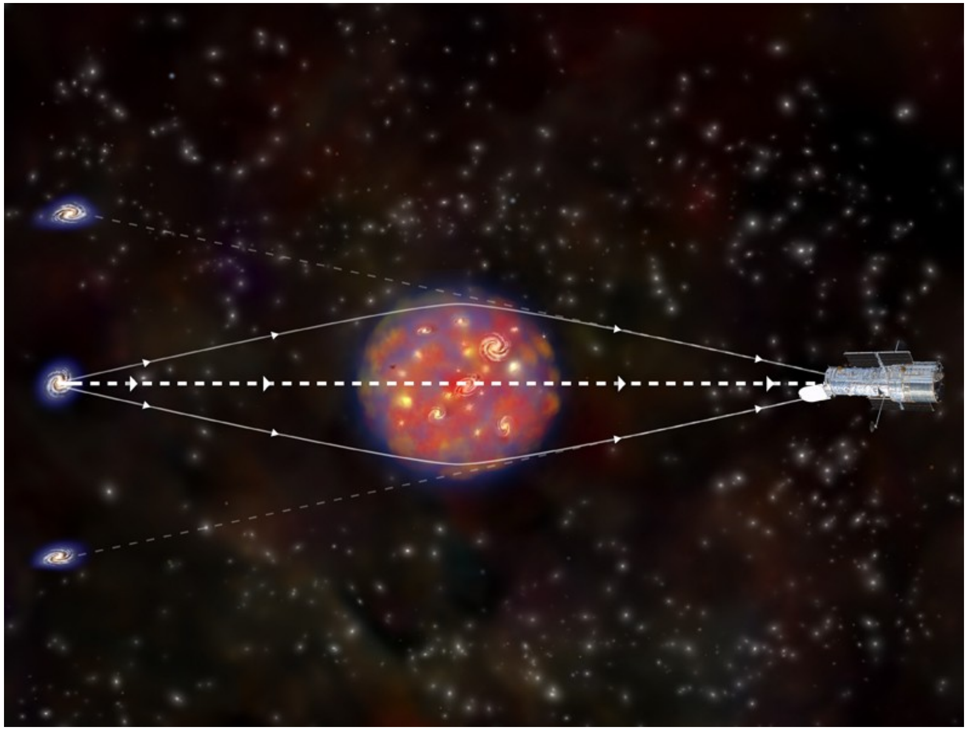
Curvature of Spacetime

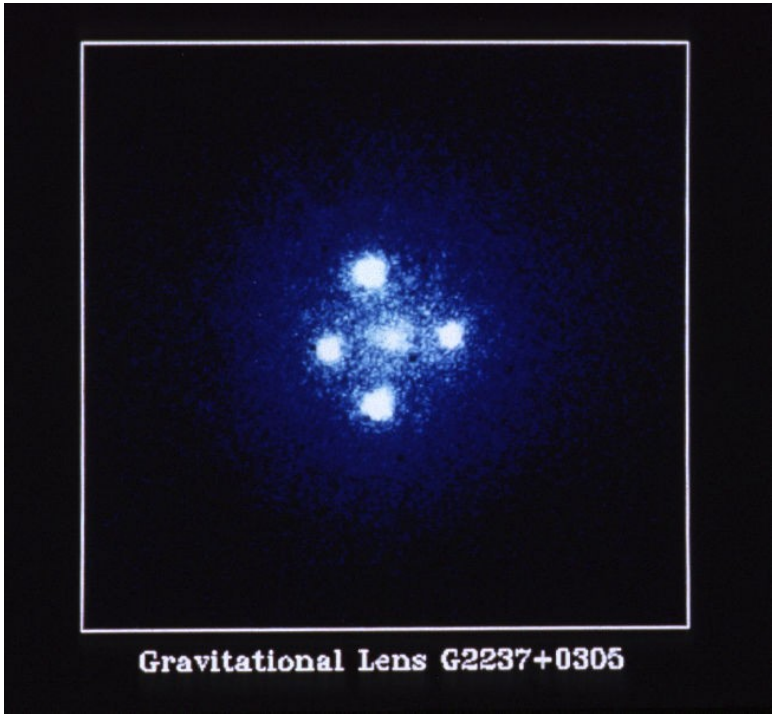
Mass and Energy

Gravity curves space, bending lightrays

"***Mass tells Space how to bend, Space tells Mass how to move***"

Gravitational Lensing

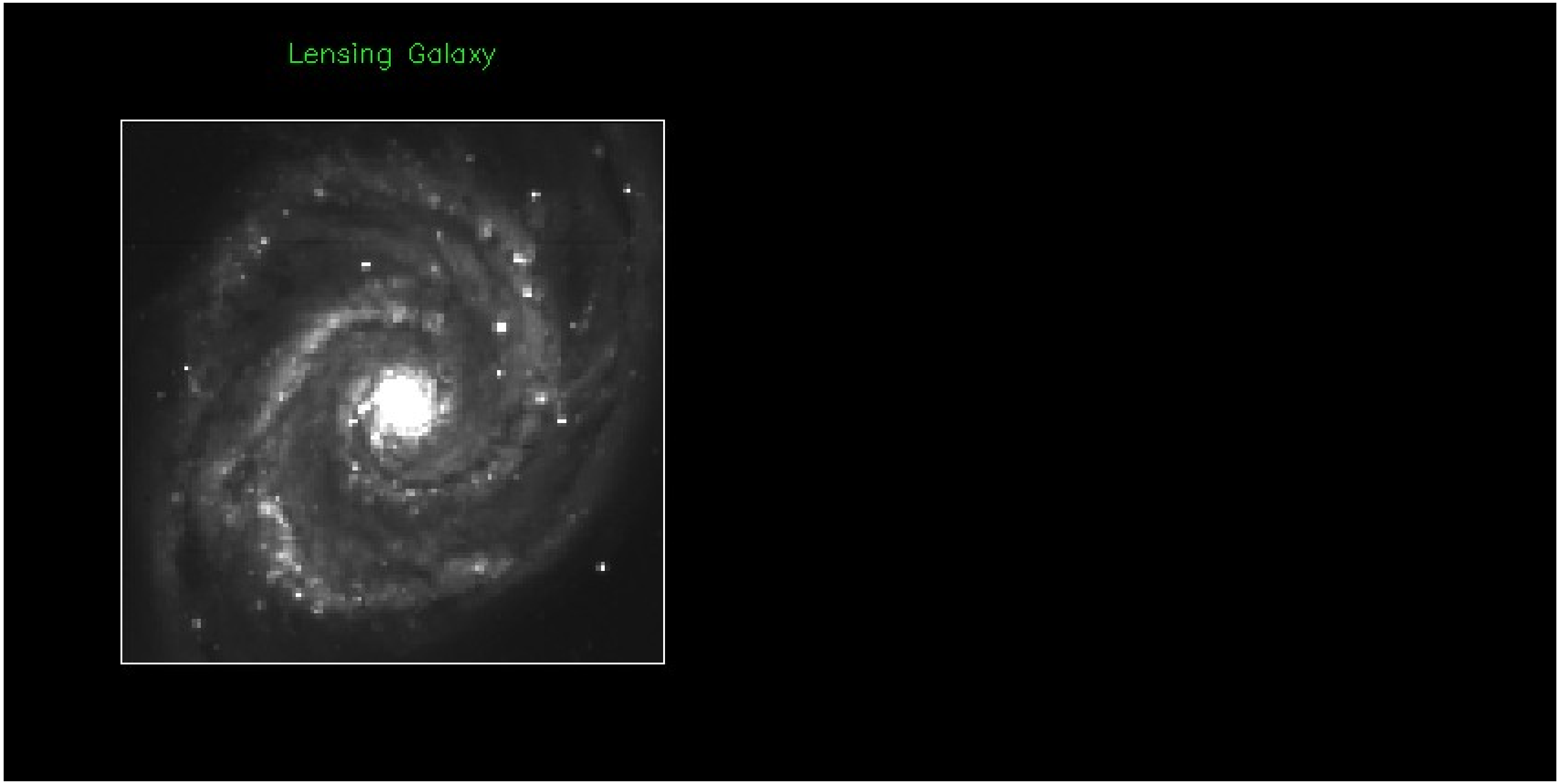




Gravity curves space, bending lightrays

We see multiple images of a lensed object.

Gravitational Lensing



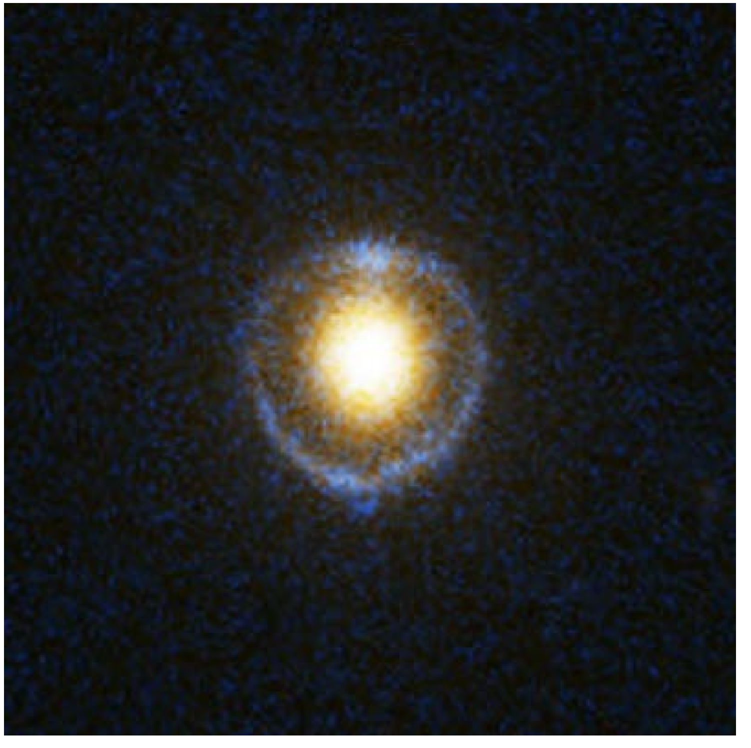
Gravitational Lensing

Lensing by a galaxy cluster

Multiple Arcs

Gravitational Lensing

Under perfect alignment, we see an
Einstein Ring



Gravitational Lensing

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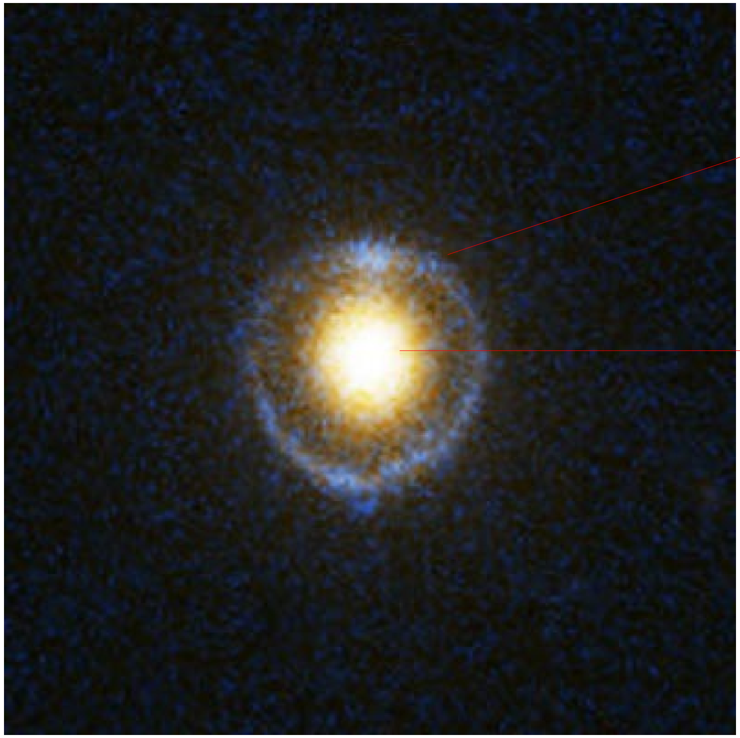
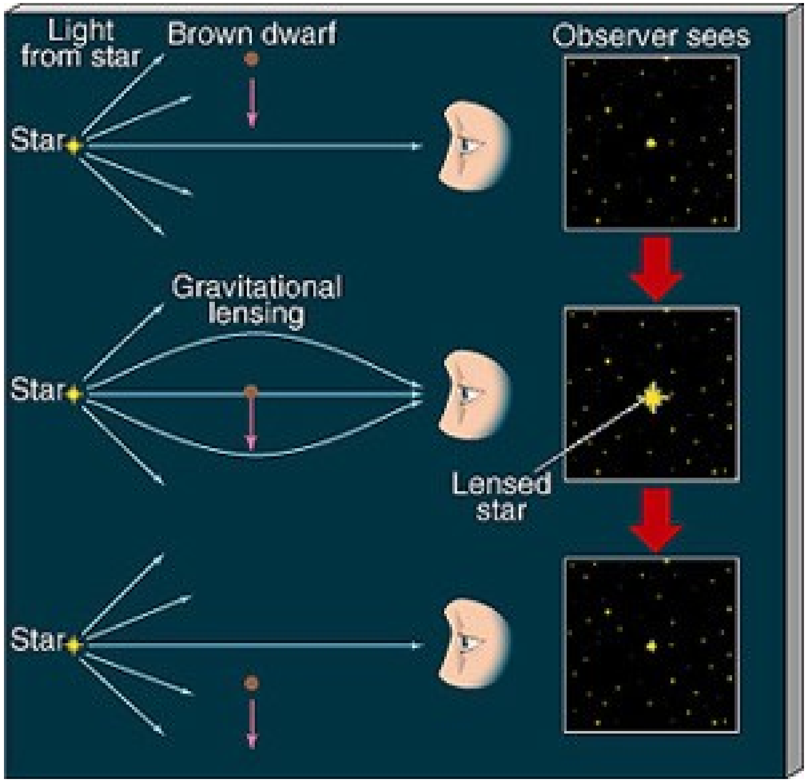


Background lensed object

Foreground object (the lens)

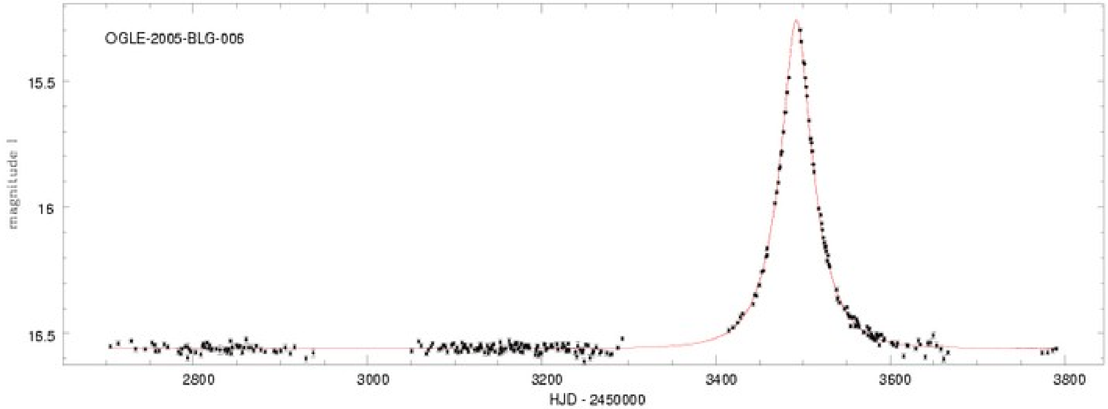
Microlensing



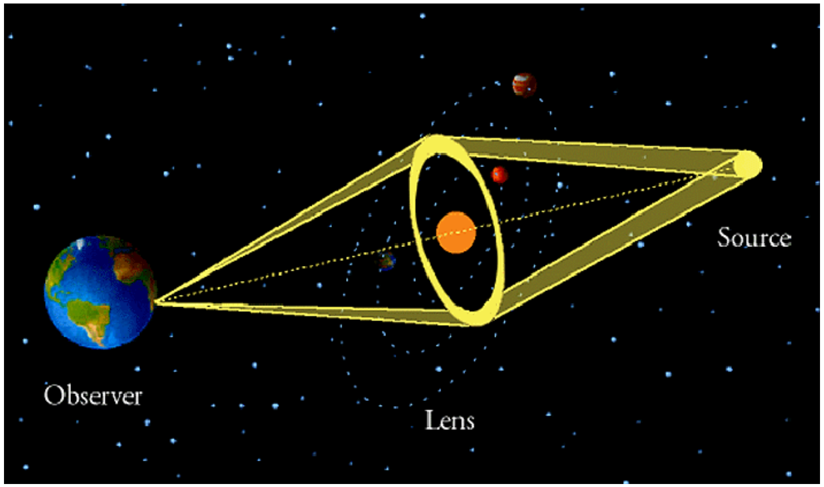
Microlensing
is a gravitational lensing event produced not by a galaxy but by a **star or substellar object**

We do not resolve the multiple images: They all appear blurred

The lensing event is seen as a magnification of the lensed star.

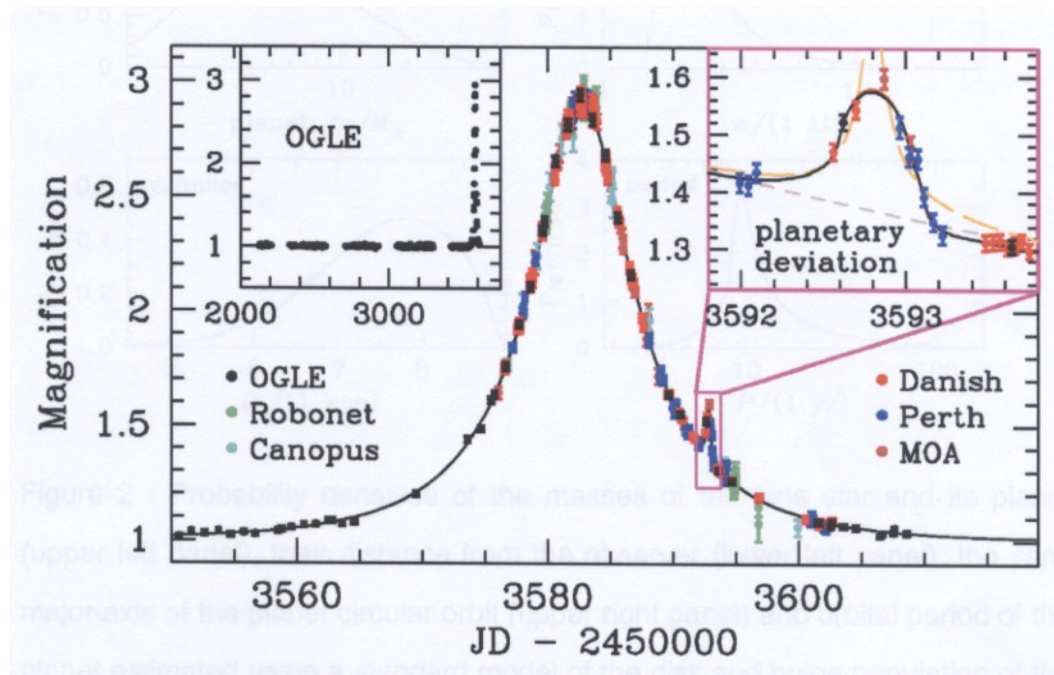


Extrasolar planets - Microlensing

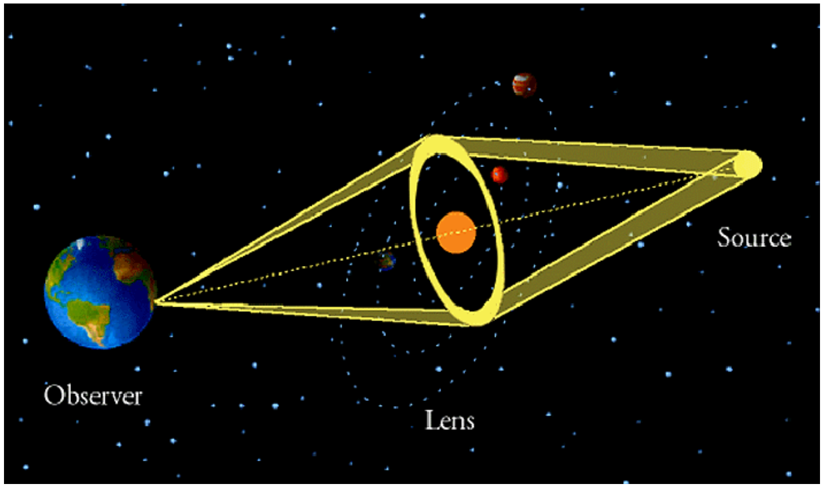


A planet around a lens star will produce a secondary lensing event

Monitor thousands of stars and hope for the best



Extrasolar planets - Microlensing



A planet around a lens star will produce a secondary lensing event

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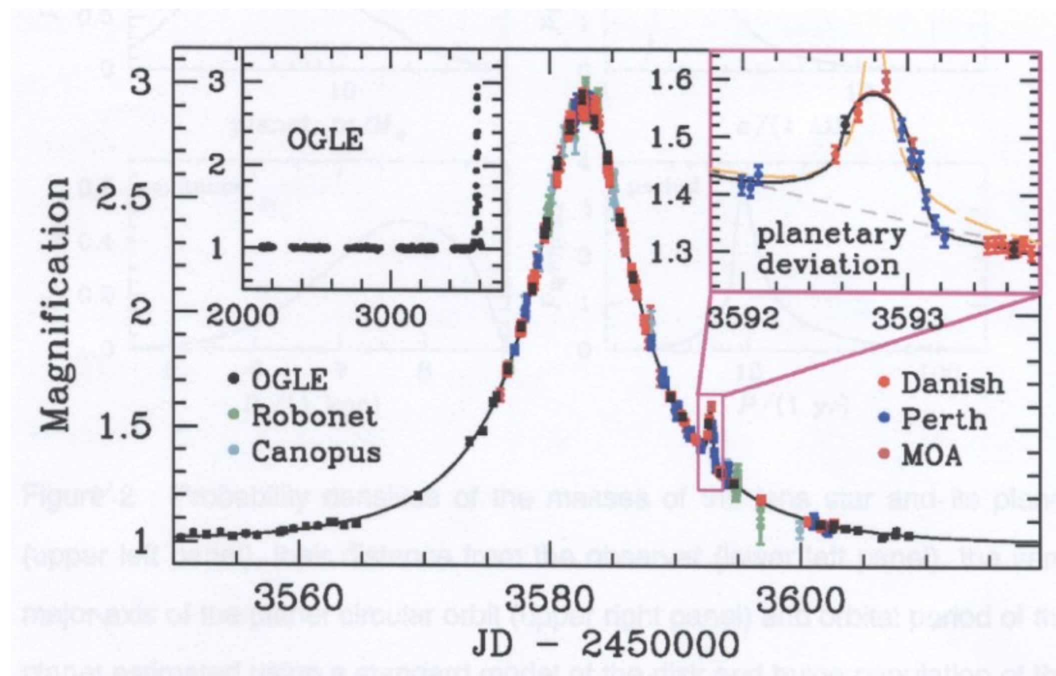
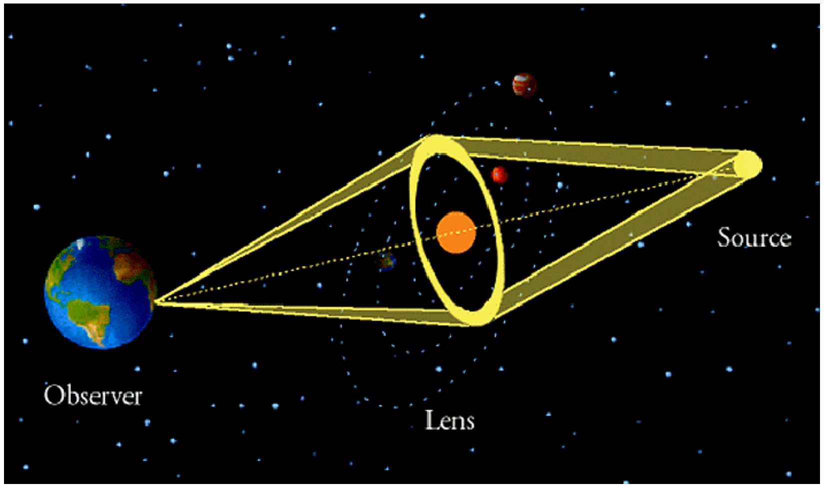
Biased towards low mass stars (why?)



Extrasolar planets - Microlensing

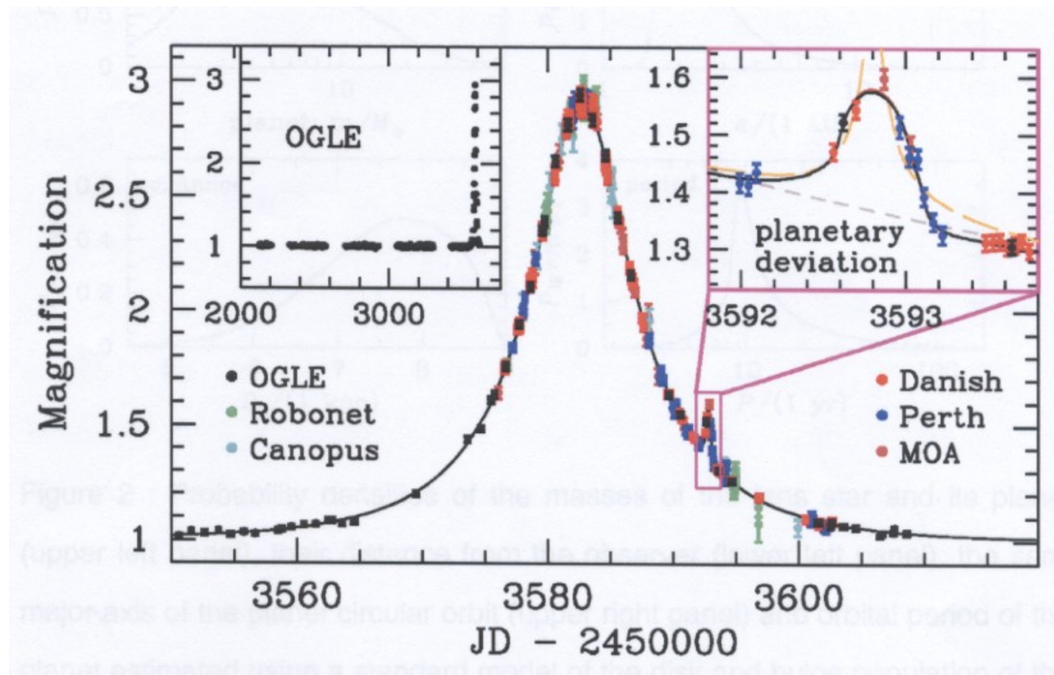


A planet around a lens star will produce a secondary lensing event

Monitor thousands of stars and hope for the best

Biased towards low mass stars (why?)

Because they are more numerous!
The lens star will more likely be a M star than a G star or whatever



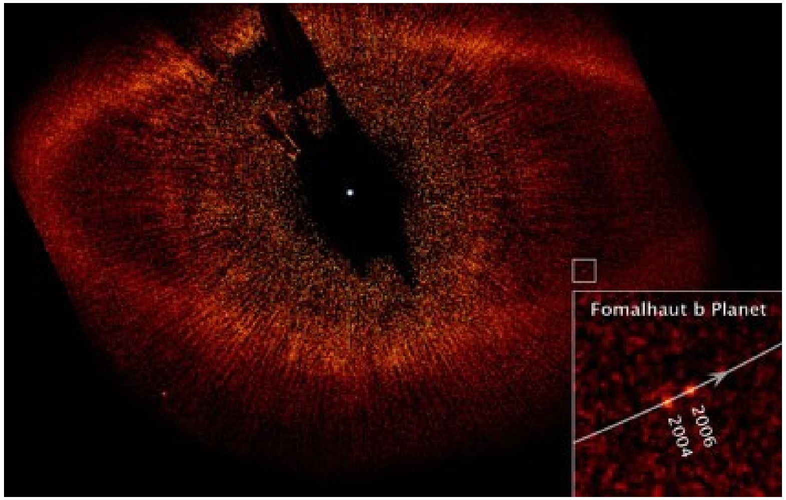
Extrasolar planets – Direct Imaging

A firefly next to a lighthouse

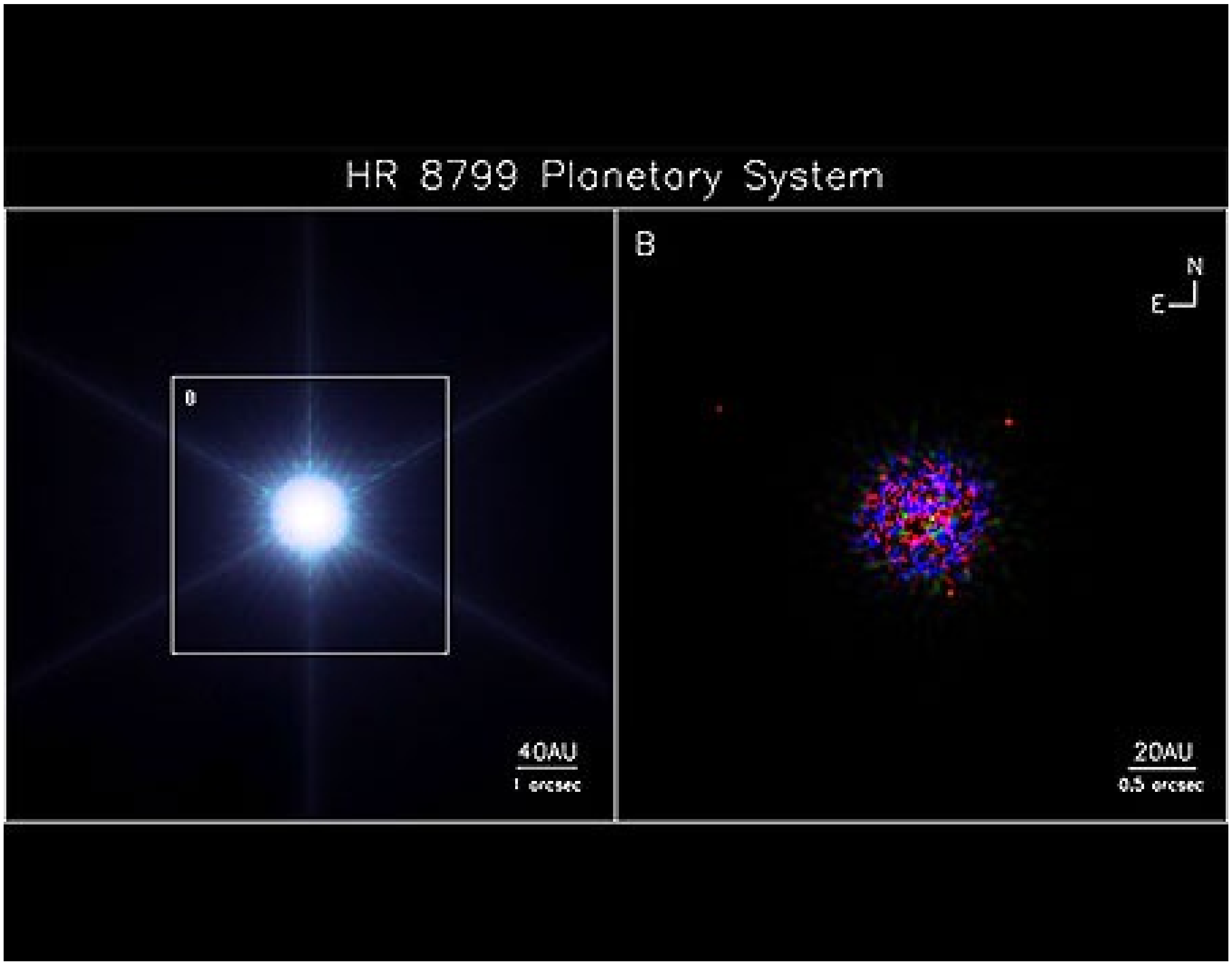
Block the starlight
and check the surroundings

**"Block-image" thousands of stars
and hope for the best**

Fomalhaut
A3V star, V=1.2
8 parsecs away



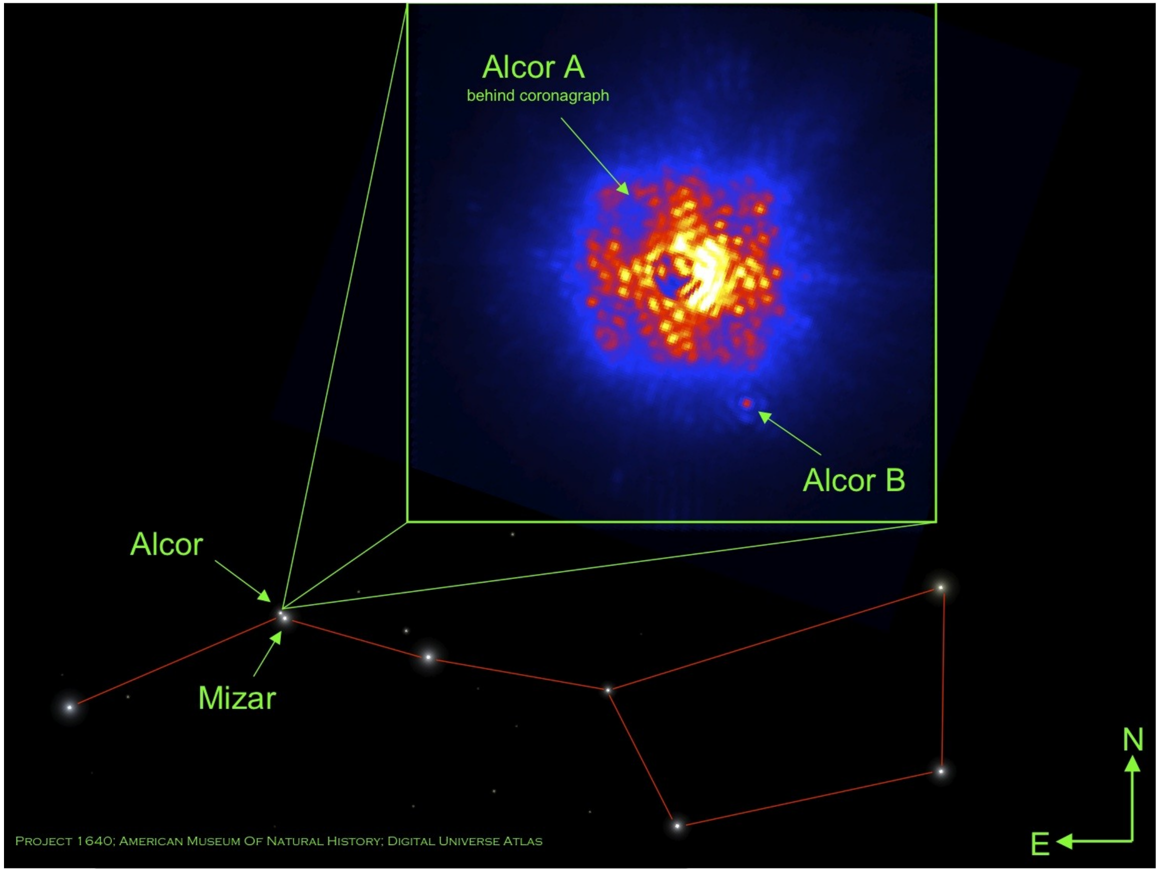
Extrasolar planets – Direct Imaging



3 planets around HR 8799

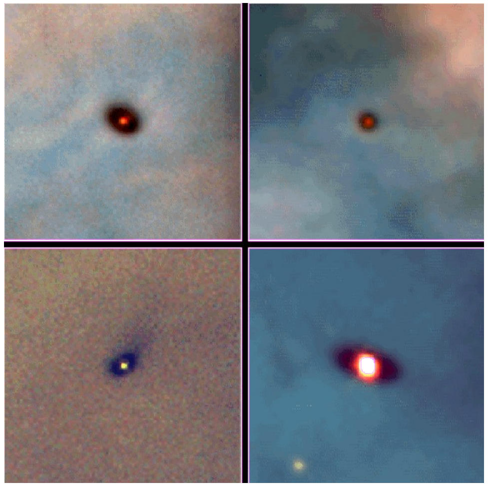
Extrasolar planets – Direct Imaging

Sometimes you find things you were not looking for...

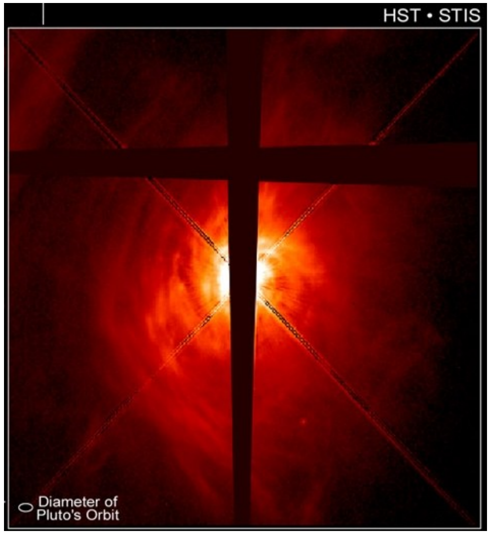


A previously unknown **red dwarf** around Alcor

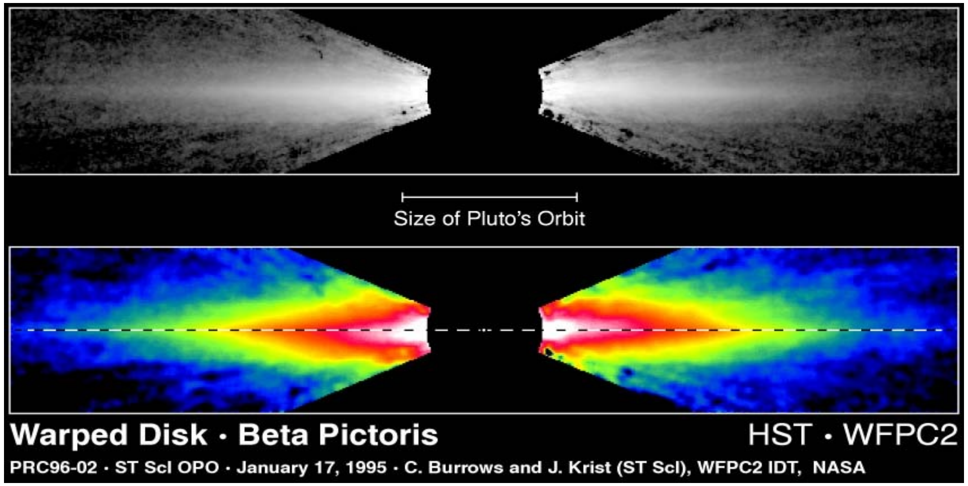
Planetary Cradles – Circumstellar Disks



Disks in the Orion Nebula
Dark against a bright background



Disk around AB Aurigae
Warm dust shines in Infrared

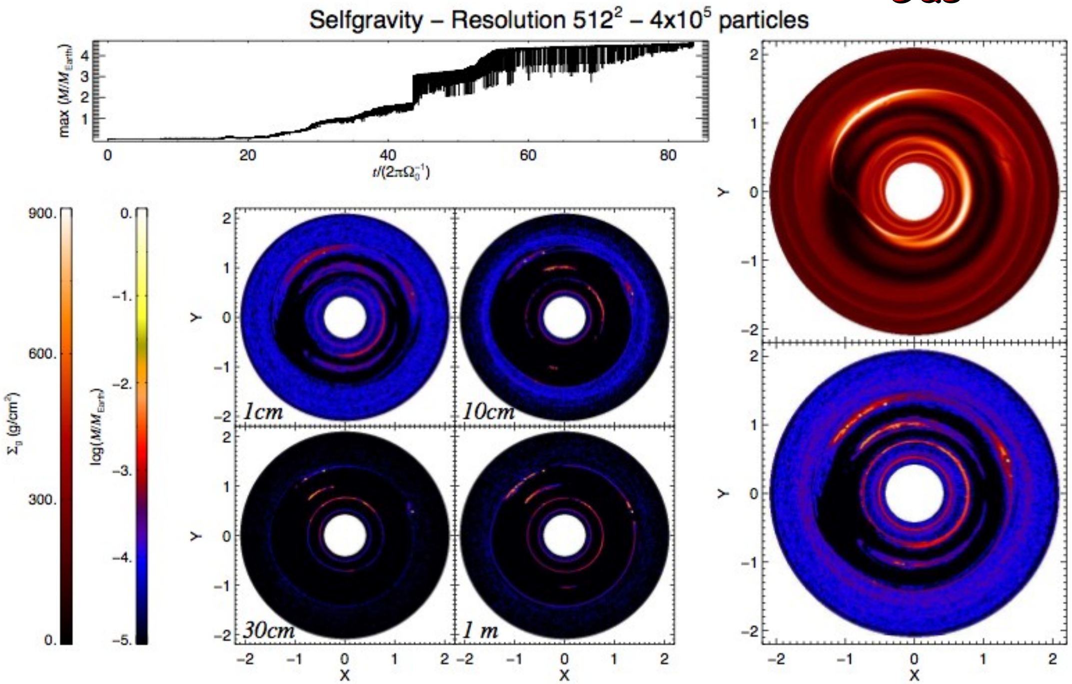


Massive disk around Beta Pictoris

The wake of a planet in the AB Aurigae disk

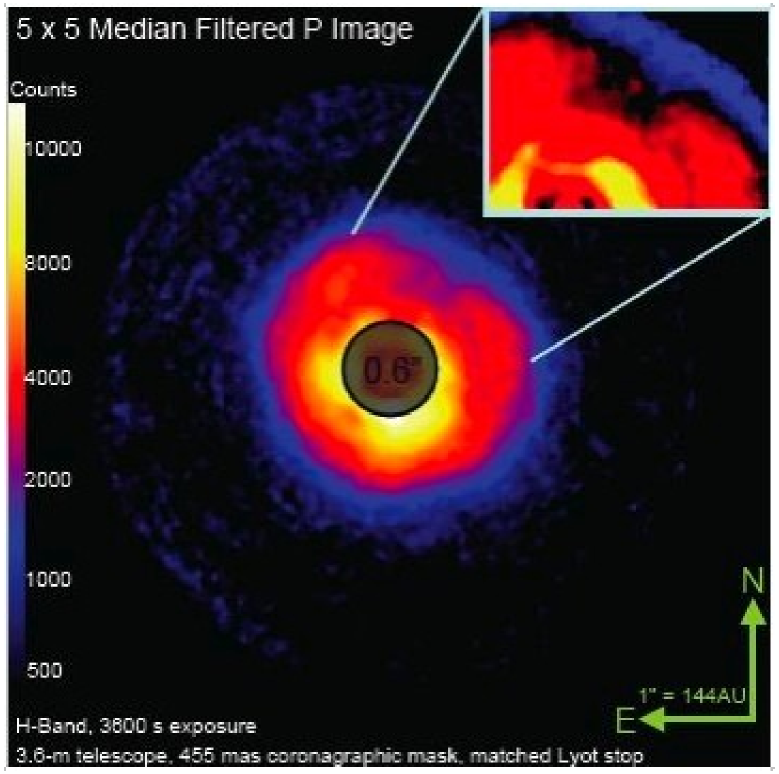
Theoretical prediction

Gas



Dust

Observation



The wake of a planet in the AB Aurigae disk

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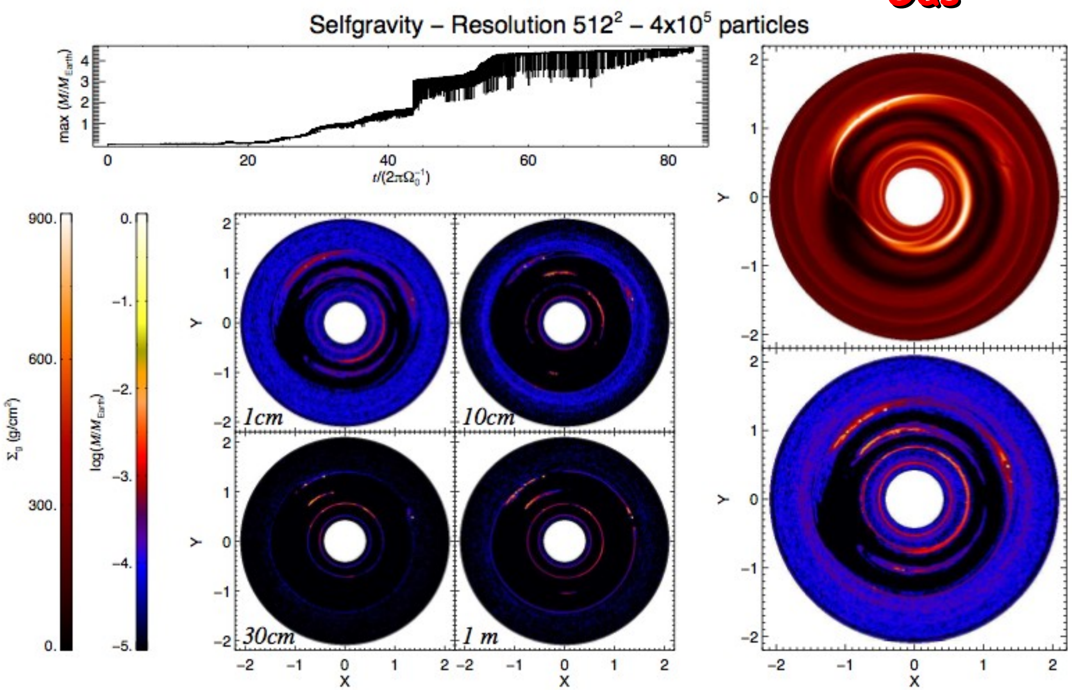
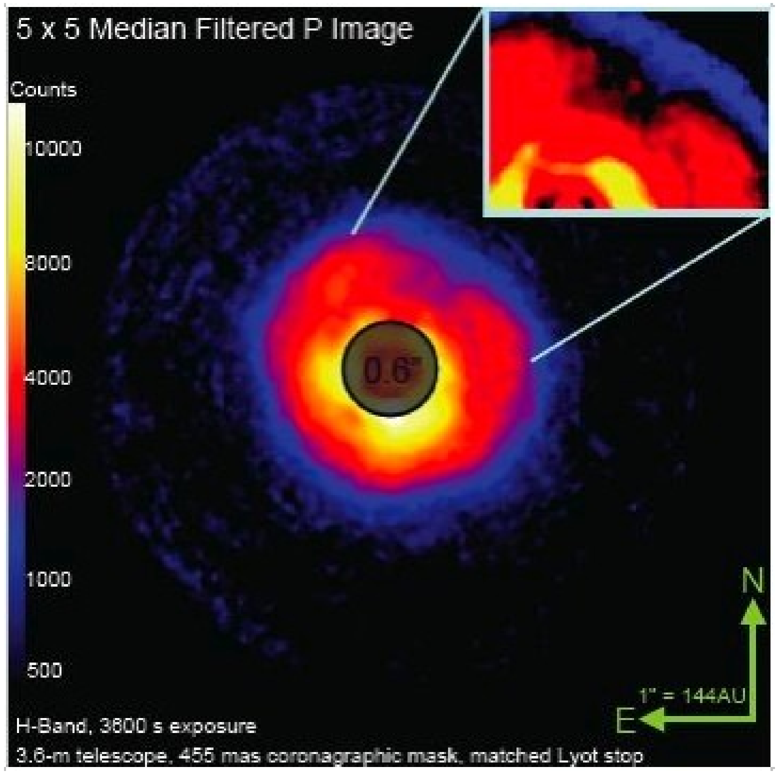


Dust

Lyra et al. (2009)

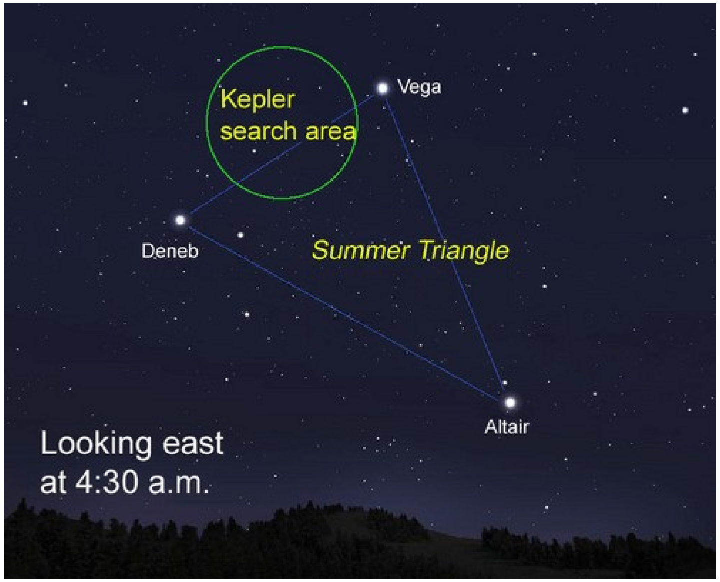
Observation



Oppenheimer et al. (2009)

Go AMNH !!

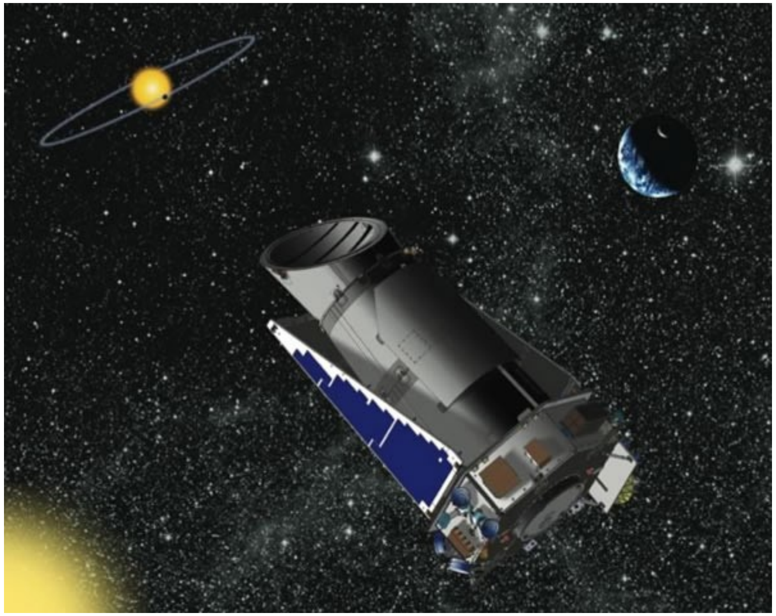
Kepler mission



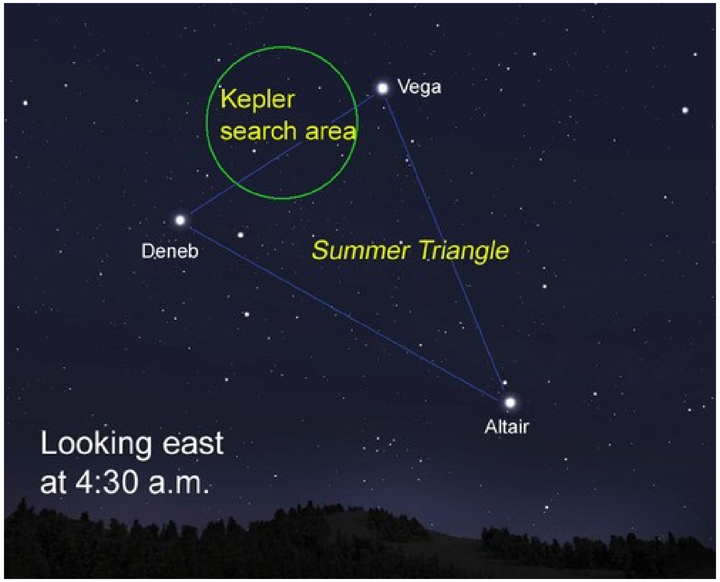
Goal: Detect transits of Earth-sized exoplanets

Measure light curves
for thousands of stars
and hope for the best

Continuously observe a single area of the sky,
monitoring 150,000 stars



Kepler mission



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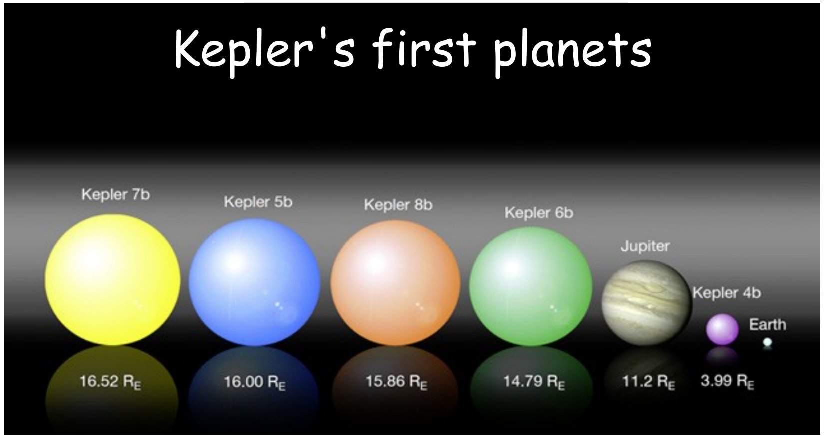

Hot Jupiters. More of the same.
But stay tuned!!