The Cosmos

Planets & Life
PHYS 214

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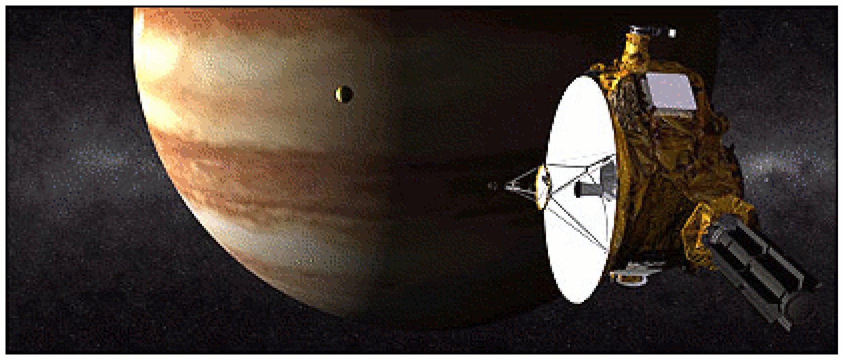
Nasa probe set for Jupiter flyby

By Paul Rincon
Science reporter, BBC News



Nasa's New Horizons spacecraft, launched from Earth just over a year ago, is heading for a close encounter with the giant planet Jupiter.

The flyby should let the probe test its instruments before being hurled away by Jupiter's gravity towards the distant target of Pluto and its moons.

The plutonium-powered spacecraft will make its closest approach to Jupiter at 0543 GMT (0043 EST) on Wednesday.

This gravity "kick" will accelerate the probe by 14,000km/h (9,000mph).

This should send it hurtling towards Pluto at 84,000km/h (52,000mph).

> **We have a very narrow window in space that we have to hit**
>
> Dr Alan Stern, Southwest Research

With closest approach coming 13

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Today's lecture

- Assignment 1 marked – will hand them back on Friday
- Assignment 2 due today, hand it in at the end of the lecture if you haven't already
- Assignment 3 will be posted tonight (tomorrow at latest)
- More on extrasolar planets
  - More detections techniques
  - Characteristics of the planets we have found
  - Constraining the probability of planets around stars p_p in the Drake equation, and the number of planets in the HZ n_E

Astrometric measurements of stellar wobbles

- A star's movement within the Milky Way galaxy is called its proper motion
- Because the motion is so slow*, we can only observe it for stars that are sufficiently close to the Sun
  - Approximately a straight line on the sky
- The presence of planets, and the associated "wobble" of the star will lead to a curving trajectory on the sky

The Sun is actually moving at ~200 km s^{-1} around the galaxy, but the distances to cover are large and we are actually looking at differences in local motions between stars

Astrometric measurements

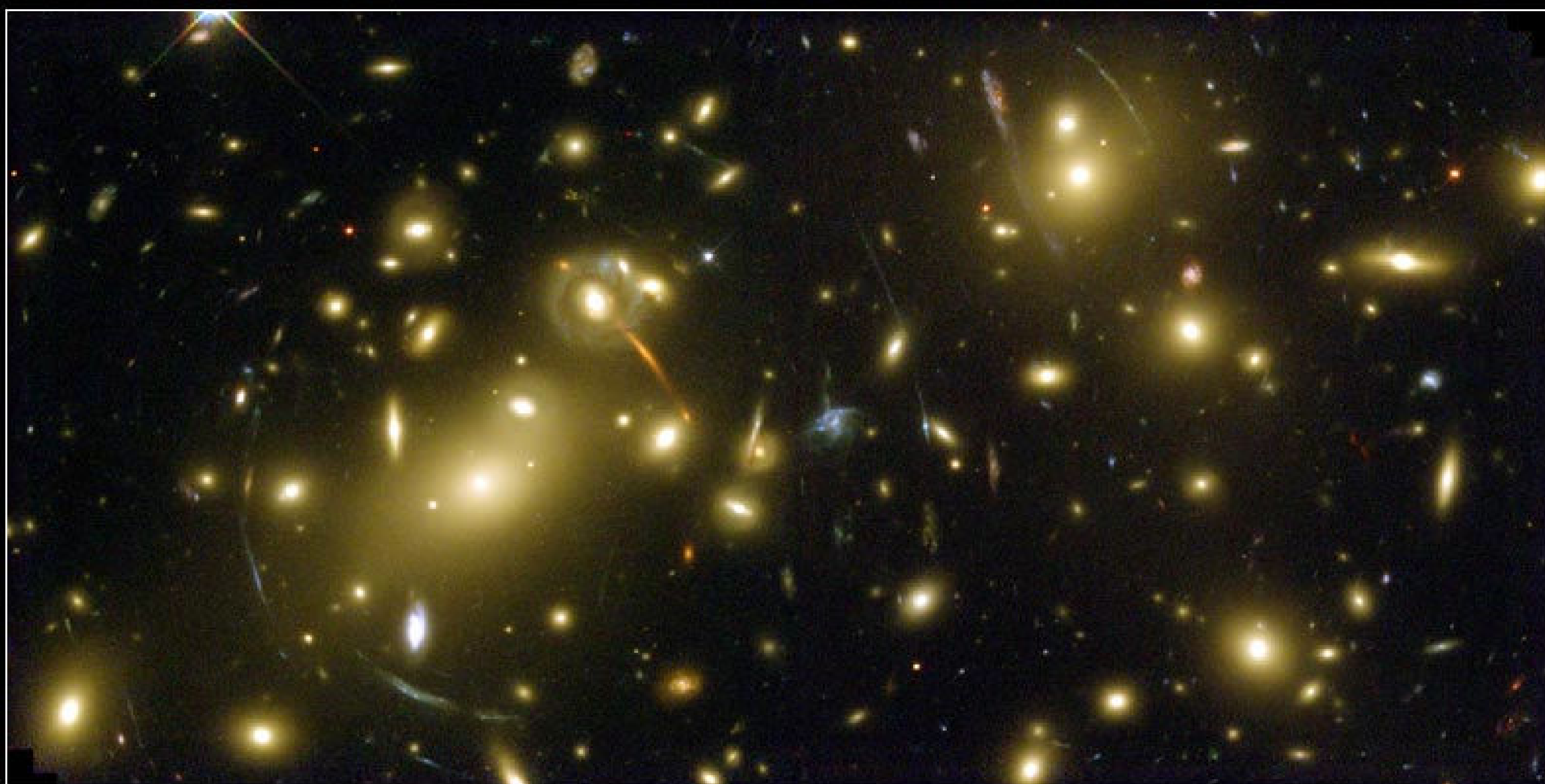
- As with Doppler measurements, method is most sensitive to large planets
- Great hope for this area comes from two sources
  - Ground-based *interferometers* on the Keck and VLT telescopes*
  - Space-based missions such as the Space Interferometry Mission (SIM)

**estimated we can measure a movement of 3000 km for the nearest stars, can detect Uranus size planets up to 60 ly away*

(2014-15)

Gravitational Microlensing

- This is one of the spectacular predictions of the Theory of General Relativity
- Given sufficient amounts of mass, light paths can be bent just as in a lens

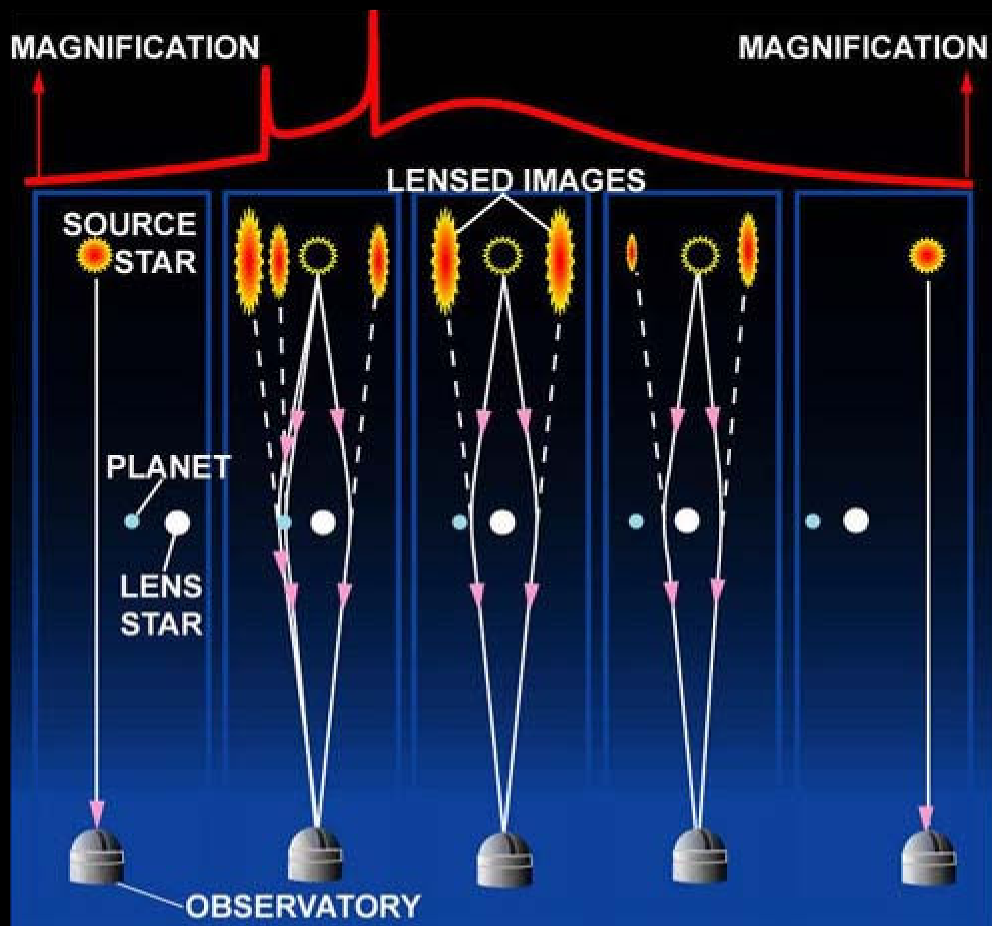


Galaxy Cluster Abell 2218 **HST • WFPC2**

NASA, A. Fruchter and the ERO Team (STScI) • STScI-PRC00-08

Microlensing

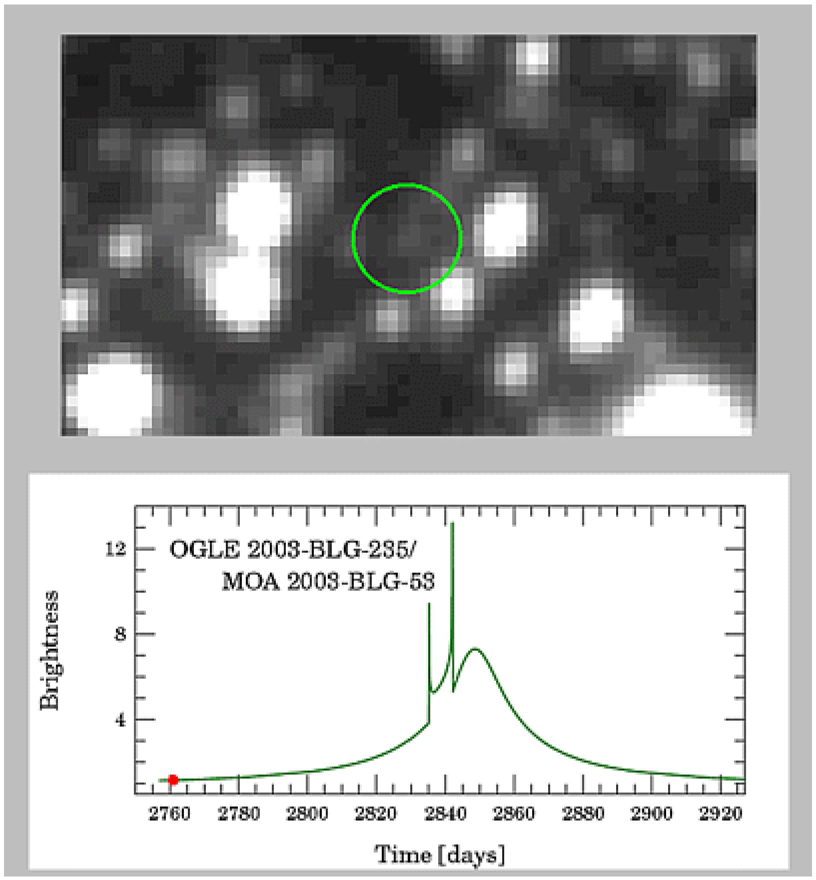
- This happens when a planet or star moves in front of a more distant star and very briefly magnifies it – ***microlensing can even detect Earth sized planets at 1-5 AU distances!***

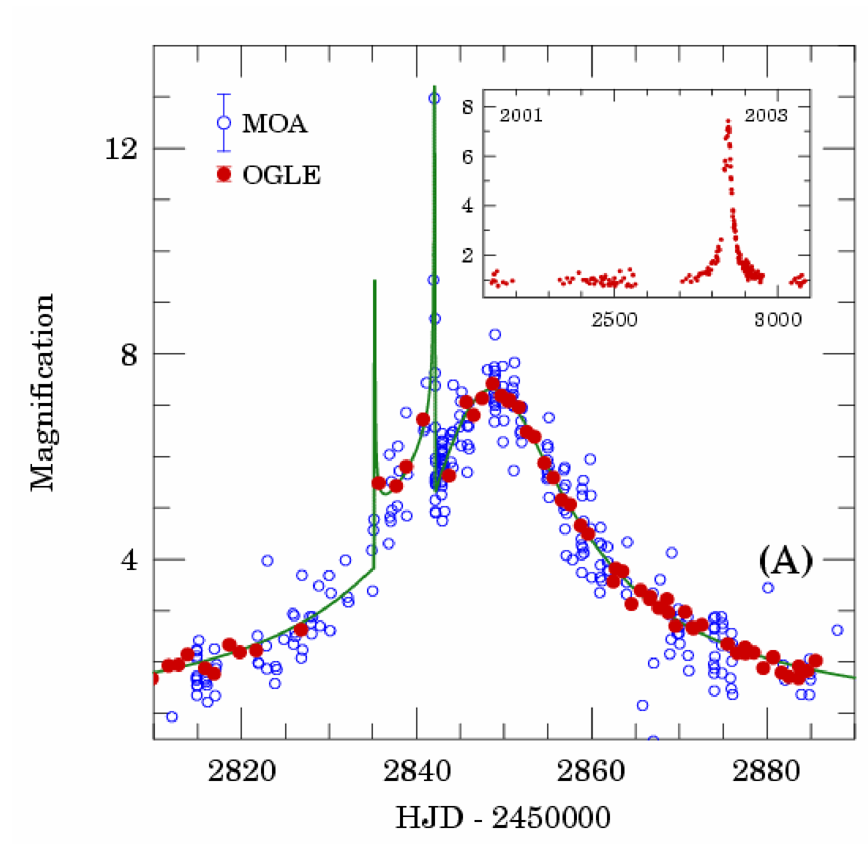


Planetary signal appears on top of the magnification from the star in this case.

Size and shape of the peak is sensitive to the mass and position of the planet

Successful detection from the OGLE survey





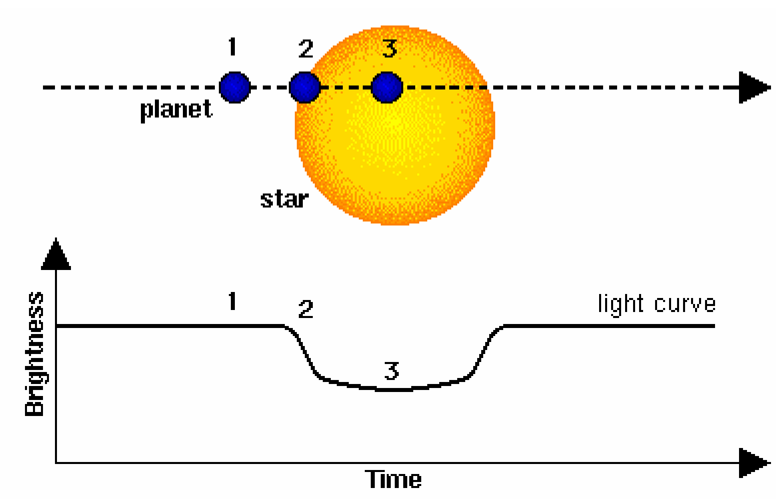
Probably a planet ~2 M_J a distance of ~3 AU from its star
A total of 4 planets have been found by this method.

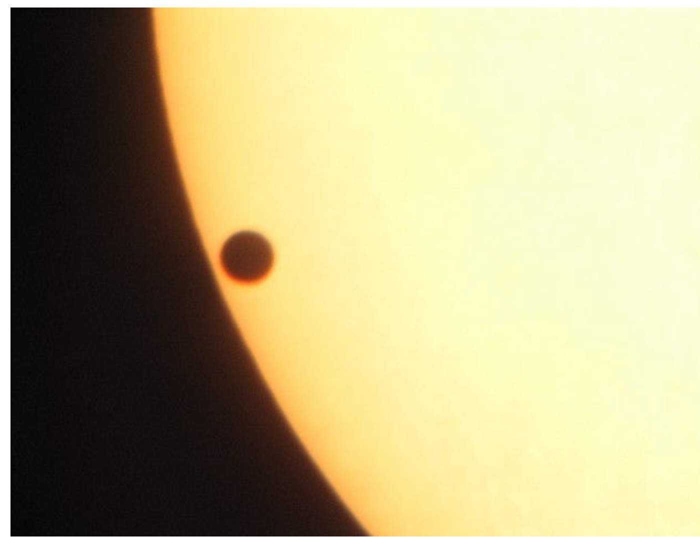
The main problem with microlensing…

- Discovery of a microlensing object happens by chance
  - The lensing object has to pass in front of the region you are looking at just the right time
  - Once it happens, that is it – no second chances
- Consequently have to monitor lots of stars, very carefully
  - Events happen in a matter of hours to days at most

Planetary transits

- A planet passing in front of a star can **block** and **dim** some of the star's light, something like 1-2% for a "hot Jupiter*", with durations of typically hours





- This is similar to studies of **eclipsing binary stars:** can get planet's **size**, **distance from star**, and **orbital period**. With **velocity measurements**, could then get planet's **mass** and hence **density** (rocky, gas giant?)

**Massive planet like Jupiter that is very close to the star*

Issues with transits

Advantages

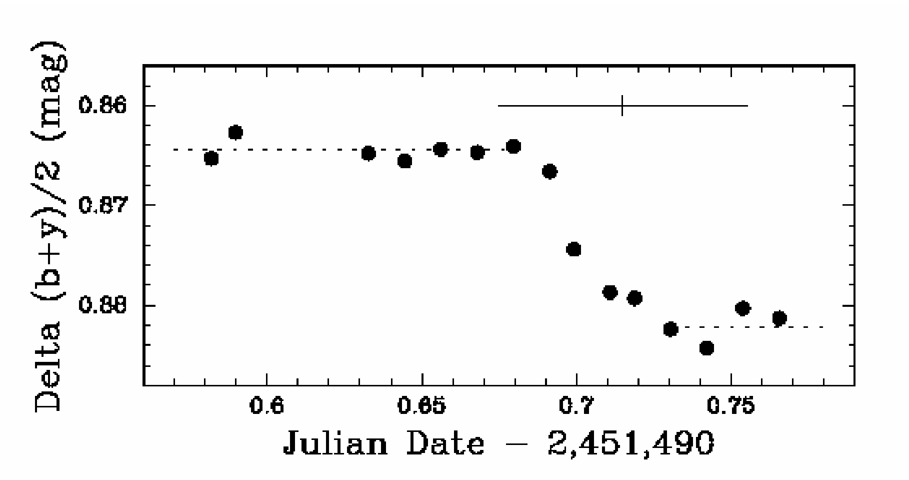
- Sensitive to **Earth-sized** planets, unlike most other methods. Better than microlensing, because you can **followup**
- The geometry is known (edge-on), simplifying things

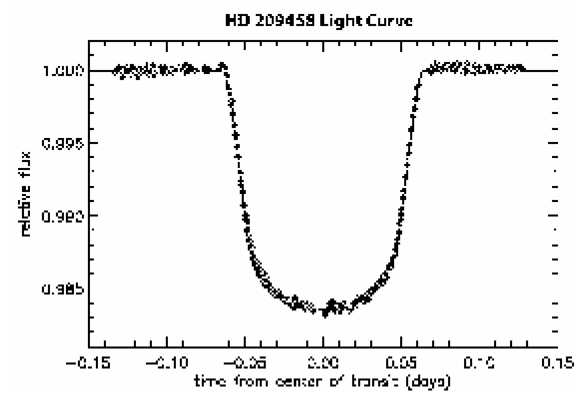
Disadvantages

- Planet orbit has to be edge-on to us to see transit. This will be **rare**, so **lots** of stars have to be monitored
- The brightness dip is small, so difficult to measure

Results

- HD209458 was first established as having a planet by Doppler techniques (2000), however the transit was actually found in the data from the Hipparcos satellite taken in 1991!

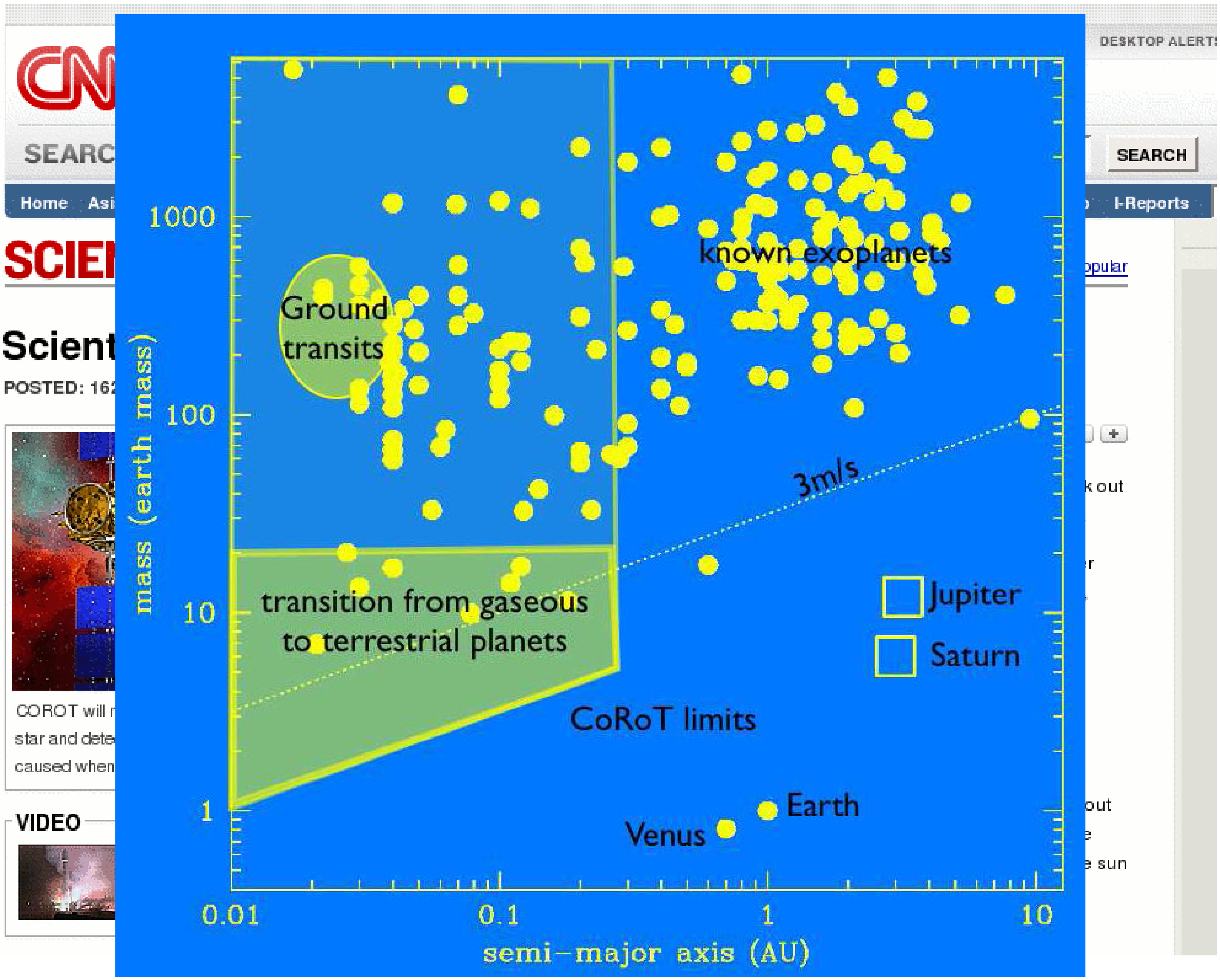




- With the velocity data, the planet's **radius, mass**, and **density** could be determined: it is definitely a **gas giant**

- HST spectra found Na, H, O, and C in the planet's upper atmosphere, which is escaping from the star (because the planet is so near its star, and thus so hot)

Surveys monitoring 100,000s stars are currently running (such as OGLE, STARE)



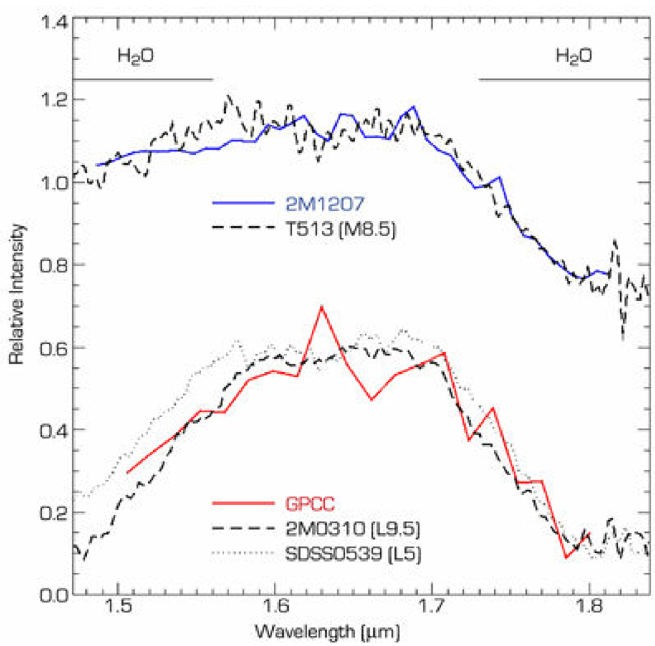
mass (earth mass)
1000
100
10
1
0.01
0.1
1
10
semi−major axis (AU)
Ground transits
known exoplanets
3m/s
transition from gaseous to terrestrial planets
CoRoT limits
Jupiter
Saturn
Earth
Venus

Direct imaging

- Observing planets **directly is hard!**
  - -- Planets shine mostly by **reflected light**
  - -- Planets are ~1 billion times **fainter** than star
  - -- Planets are **very close** to their stars (1 AU at 1 pc is 1” in angular size (atmospheric resolution limit).
- Need very high **angular resolution** and **blocking** of light from star. Possible from the ground with **extreme adaptive optics** and a **coronagraph** (e.g. Gemini), or **interferometery. Even better in space** (e.g. JWST, Terrestrial Planet Finder, SIM)
- Works best in IR, where the contrast between star and planet is lowest, and with smaller, fainter stars

1st direct detection

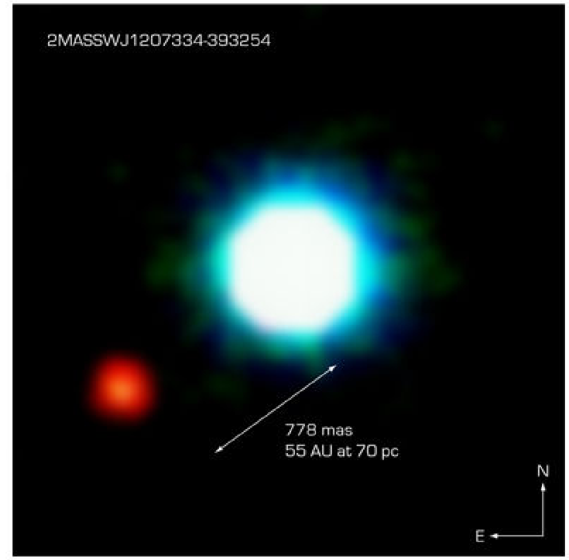
Imaged with the VLT in 2004 and confirmed in 2005.
Star is (faint) Brown Dwarf (appearing white in this infrared image), distance 53 pc
Orbiting planet, 3.5± 1 M_J ,1.5 R_J , 41 AU
Spectrum shows evidence for water absorption



Near-infrared Spectrum of the Brown Dwarf Object 2M1207 and GPCC

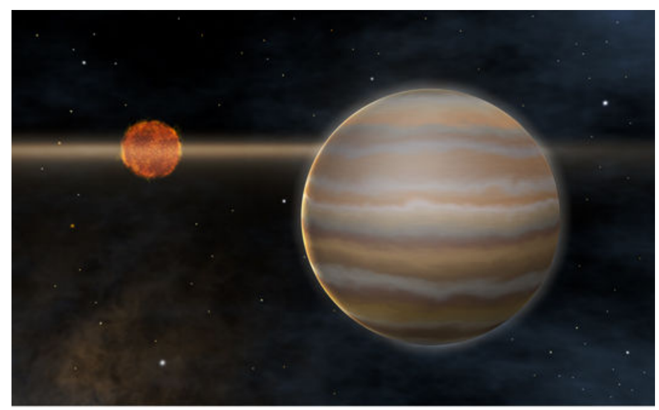
ESO PR Photo 26b/04 (10 September 2004) © European Southern Observatory

GPCC=giant planet candidate companion



NACO Image of the Brown Dwarf Object 2M1207 and GPCC

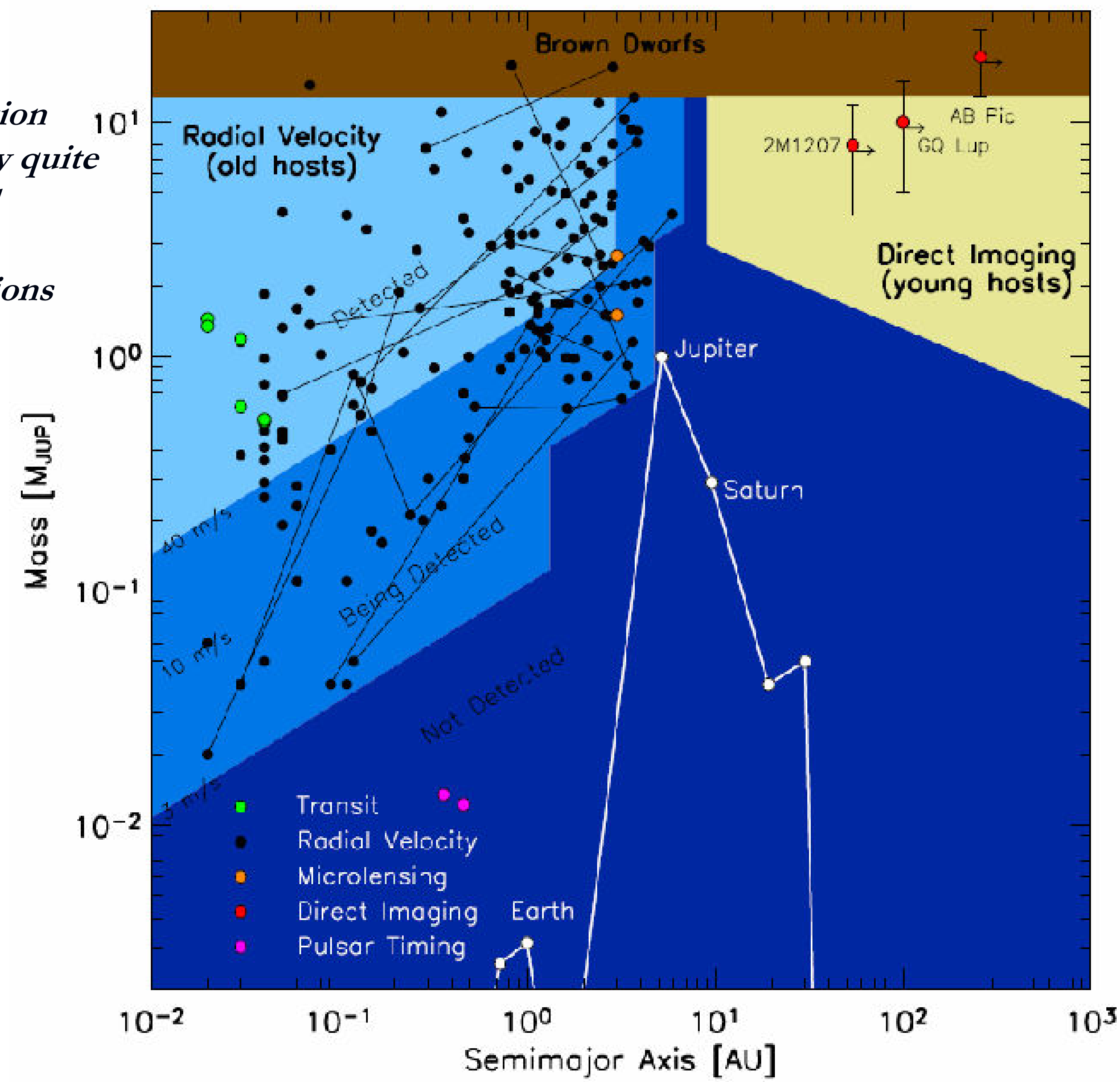
ESO PR Photo 26a/04 (10 September 2004) © European Southern Observatory



Artist's rendering of the 2M1207 System

ESO PR Photo 14c/05 (30 April 2005) © ESO

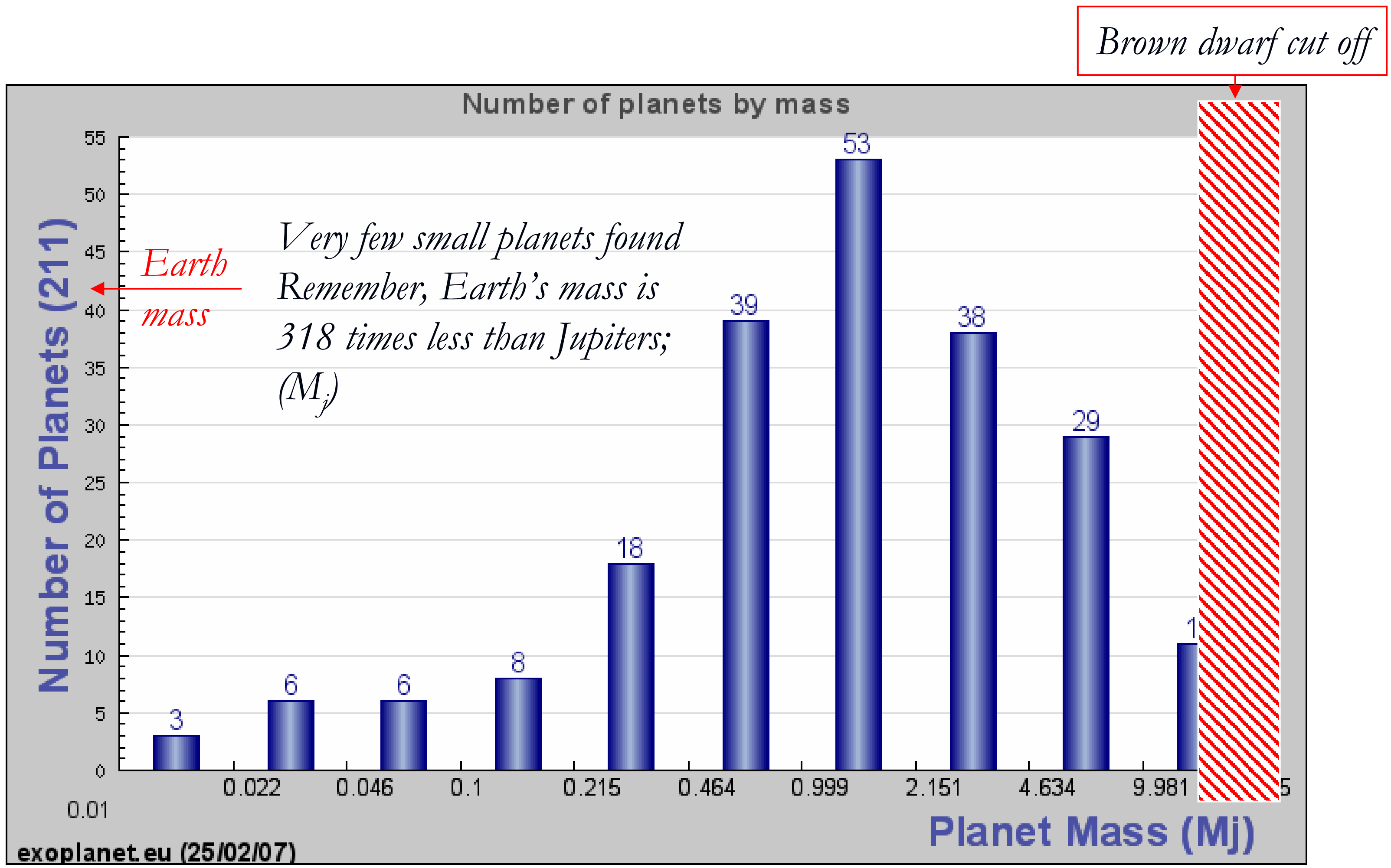
The different detection methods are actually quite complementary and explore different masses and separations



Properties of Extrasolar Planets

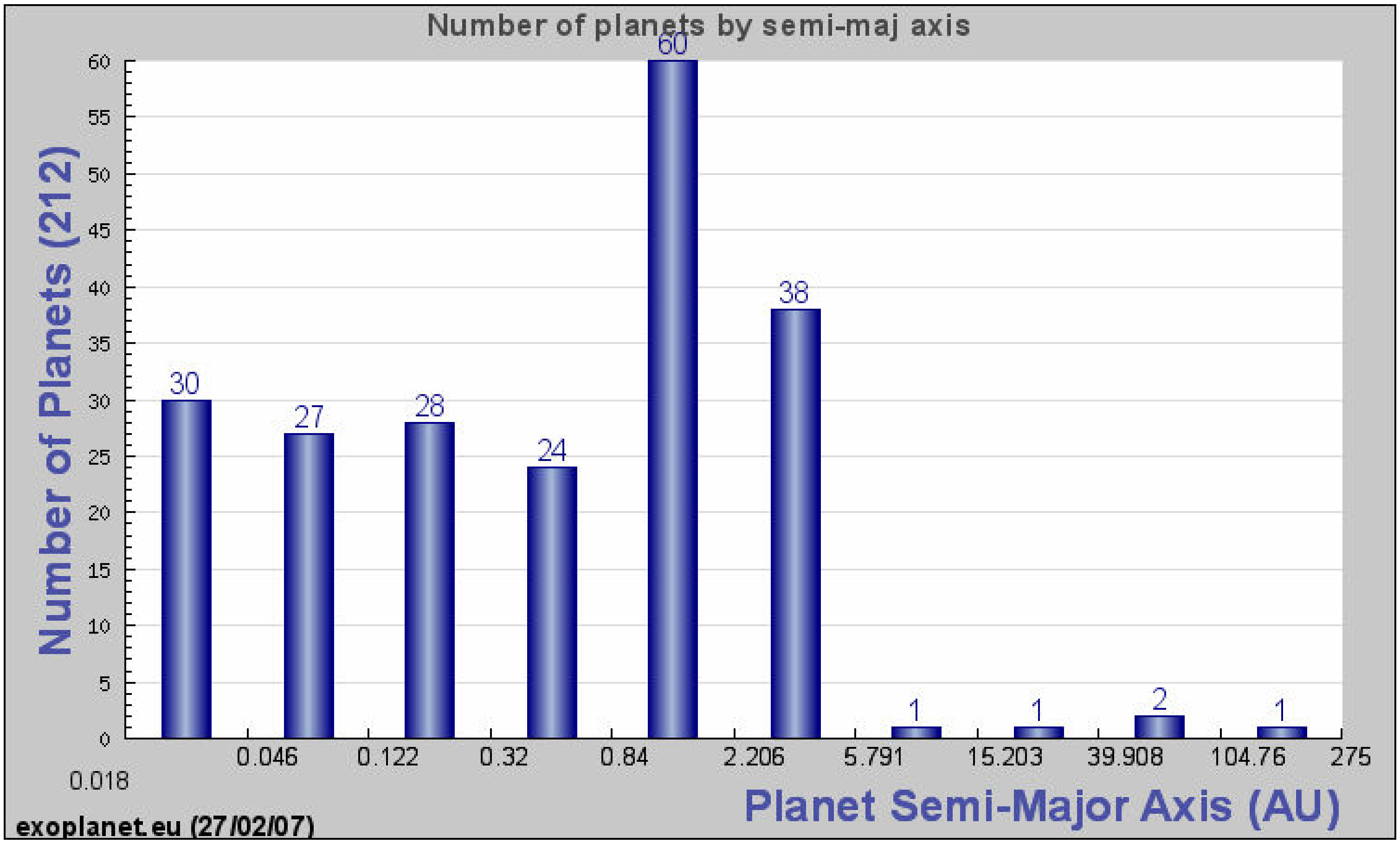
- As of Feb 2007, 212 planets have been found around ~180 stars, 200 of these planets using the **Doppler technique**
  - -- At least 10% of stars surveyed have detected planets (fraction depends on stellar **metallicity**-- see below)
  - -- Orbital periods from few to thousands of days!
- 21 stars have **multiple planets** (2 or more planets)
- **Almost all giant planets:** most techniques are **sensitive** to massive planets close to their stars (Earth-mass planets difficult at present time). This is an important **selection effect** we have to bear in mind.

How massive are the planets?



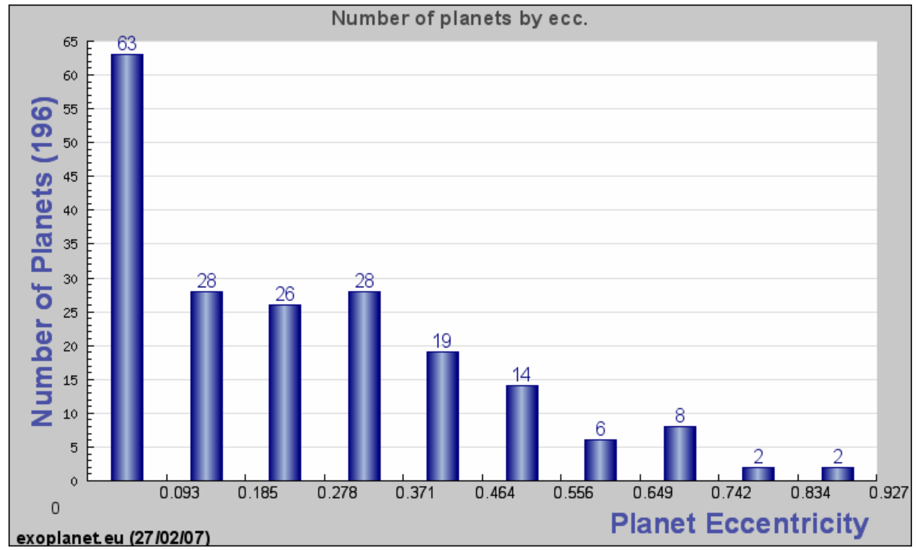
Most planets 0.5 M_j and up

How far from their respective stars are they?

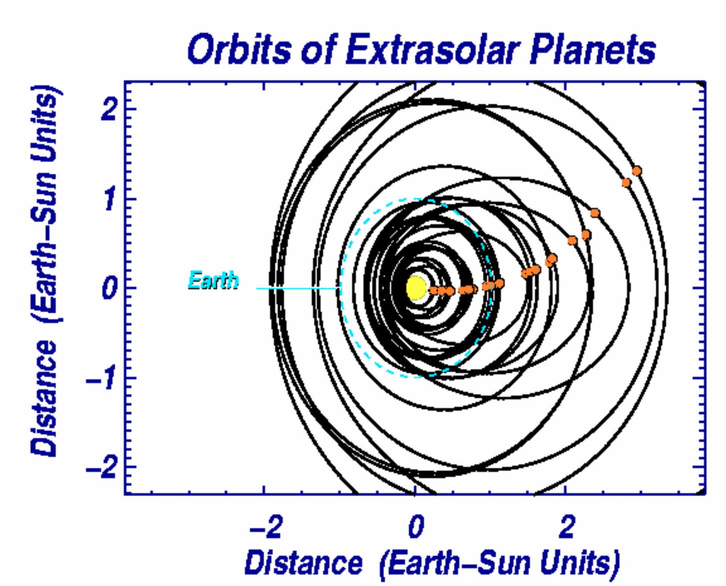


Strong bias towards close in gas giants due to detection method

What kind of orbital eccentricities have we found?



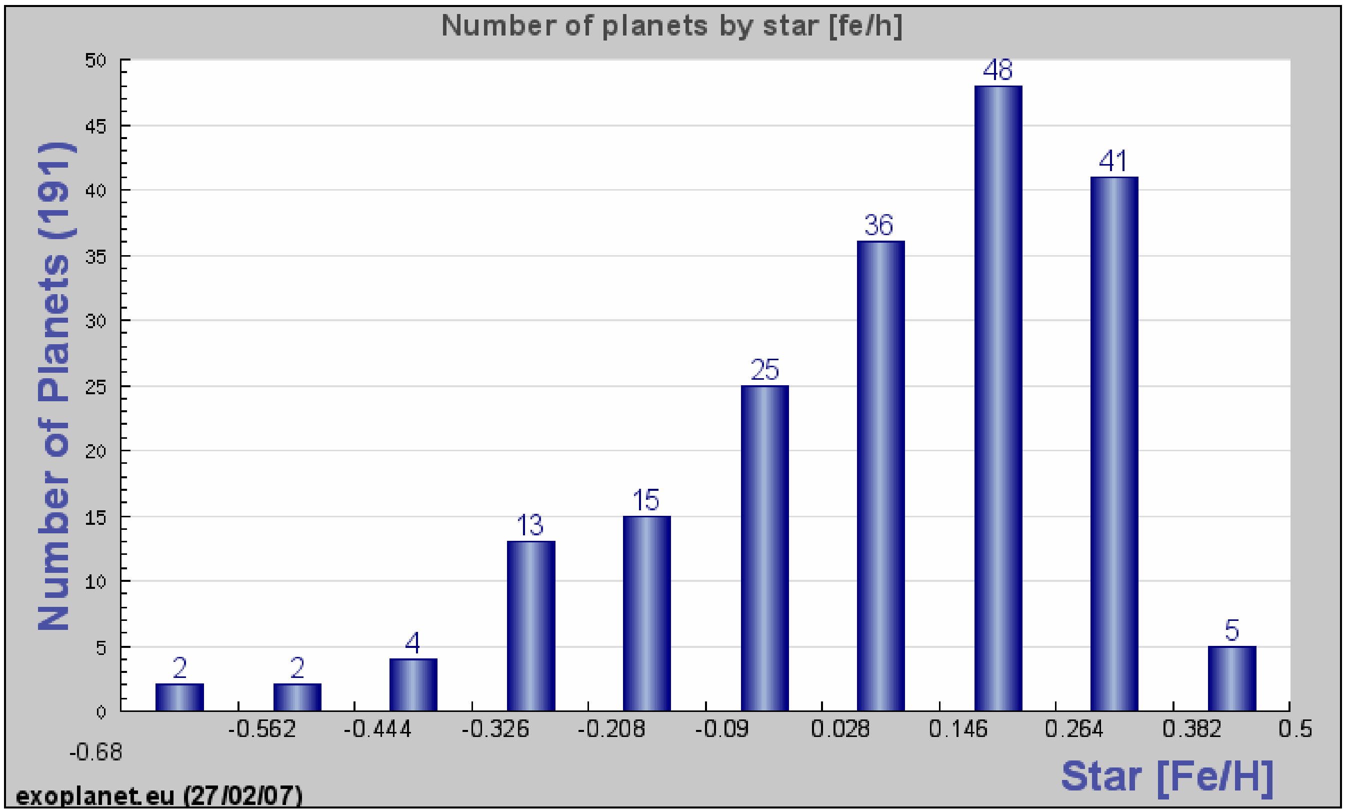
Most of the orbits are quite elliptical – some very strongly!



Many ESPs are on **very eccentric** orbits!
Unlike our solar system
Not good for life: extreme hot/cold cycles, additional season-type behaviour on top of any axial tilt issues

What kind of star do they orbit around?

Most stars with planets have greater than solar [Fe/H] values



**We measure the amount of heavy elements in a star by looking at the log of the ratio of the Fe to H in stars, relative to that value for the Sun, so that zero corresponds to solar abundance.*

Puzzles in the data

- Our **planet formation model** predicts **near-circular orbits**: planets form from condensations in rotating disk of gas and dust

- Compare our solar system: **gas giants much further out**

  -- the results we are seeing in the data is partly a **selection effect**: most sensitive to **massive, inner** planets; but will improve with time

- Still, this doesn't explain everything: how did these planets get **so close**? Unlikely they could have **formed** so close.

  -- just too hot for material to condense to form gas giants

Migration of Gas Giants

- **Current thinking:** They formed out at several AU, then **migrated inward** due to tidal/friction effects in solar nebula
- **Type I migration**: interaction between giant planet and circumstellar gas/dust disk pushes planet **inwards**
- **Type II migration:** Gap in disk opens and migration slows, takes approximately 100 times longer to move a given distance
- Have to halt the process: removal of disk; tidal/magnetic interactions between planet/star/disk
- Multiple-giant cases can explain high-eccentricity orbits by resonances or close encounters between giants
- Not clear how difficult it is for Earth-mass planets to form and survive under giant planet migration
- Quite likely every planetary system has lost planets ...

Type II Migration

Movie by Dr Pawel Artymowicz (U. of Toronto)

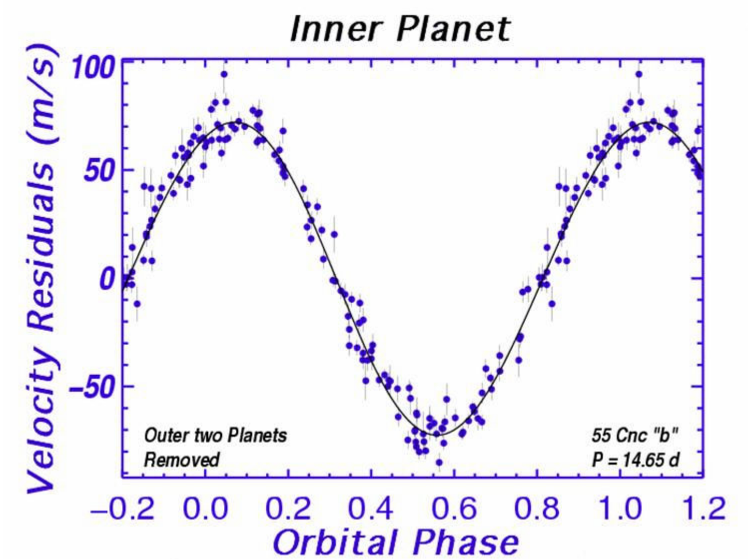
Implications for finding Earth-like Planets

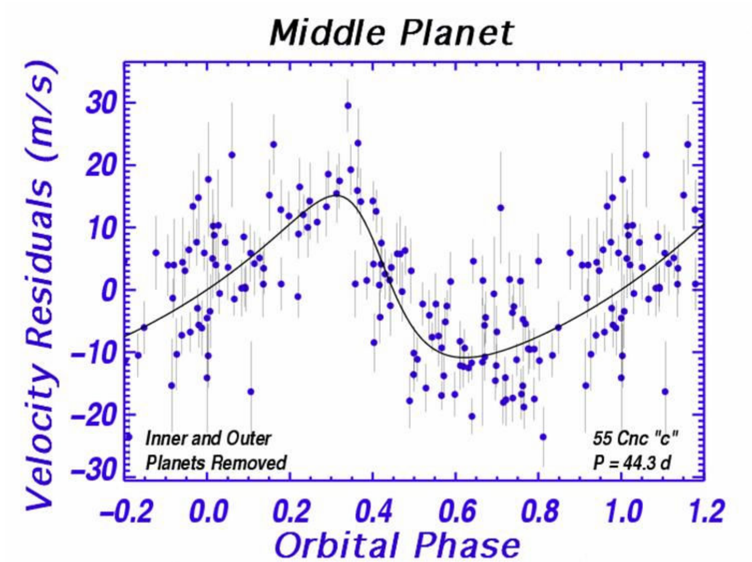
- **Having Jupiter-sized planets** in **elliptical orbits, near their host stars, really decreases chances of forming Earth-sized planets**
- We need: Jupiter-sized planets in Jupiter orbits (circular and >5 AU from their stars)! Only then can we be (more) secure that Earth-sized planets can form within the **habitable zone**
- Doppler technique **biased against** finding such planets: ones closer to their stars have **shorter periods** and easier to detect
- However, ~12+ years on, we are now starting to find such **Jupiter analogues!**

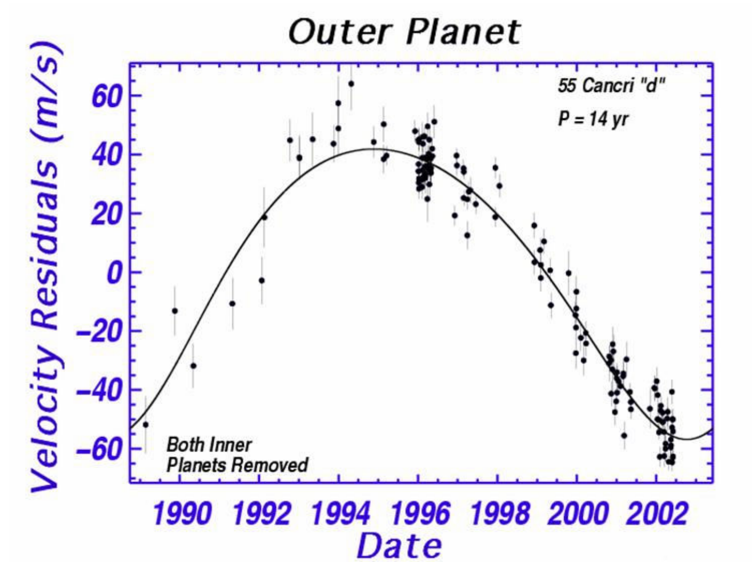
55 Cancri: a 3-planet system!

(1) 15 days, 0.84 M_J, 0.115 AU
(2) 44 days, 0.21 M_J, 0.24 AU
(3) 14 **yrs**!, 4 M_J, 5.9 AU

Compare Jupiter at 5.2 AU, e = 0.04, P = 11.9 years

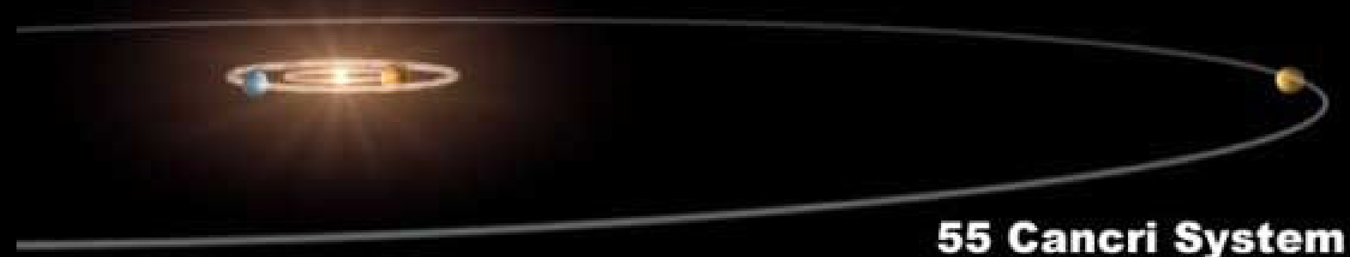






Comparison to our Solar System

Recent observations suggest there is a 4th planet in the interior!



55 Cancri is a G8 dwarf – surface temperature 5250 K

Detecting evidence of life on extrasolar planets

- **Direct sampling**: send a probe! Pretty damn hard ...
- **IR spectrum** of exoplanet gives temperature of surface and/or atmosphere, and atmospheric composition

  -- If H_2O vapour and CO_2 found, and if temp right for liquid water and carbon compounds -- conditions good for life
- Strong O_3 (ozone) would indicate O_2 and a **biosphere** (e.g. oxygenic photosynthesis).
- Spectra might also detect atmospheric gases or effects of chlorophyll, or by changes in the light-curve with time

Constraining p_p the probability of a suitable star having planets

- 10% of all the stars surveyed so far have planets
- We've found over 200 planets
  - Implies that we are starting to getting pretty good statistical errors ($\sigma \propto \sqrt{(1/n)}$)
- We can say with a fairly high amount of confidence that p_p=0.1 (at least to within a factor of 3 say)

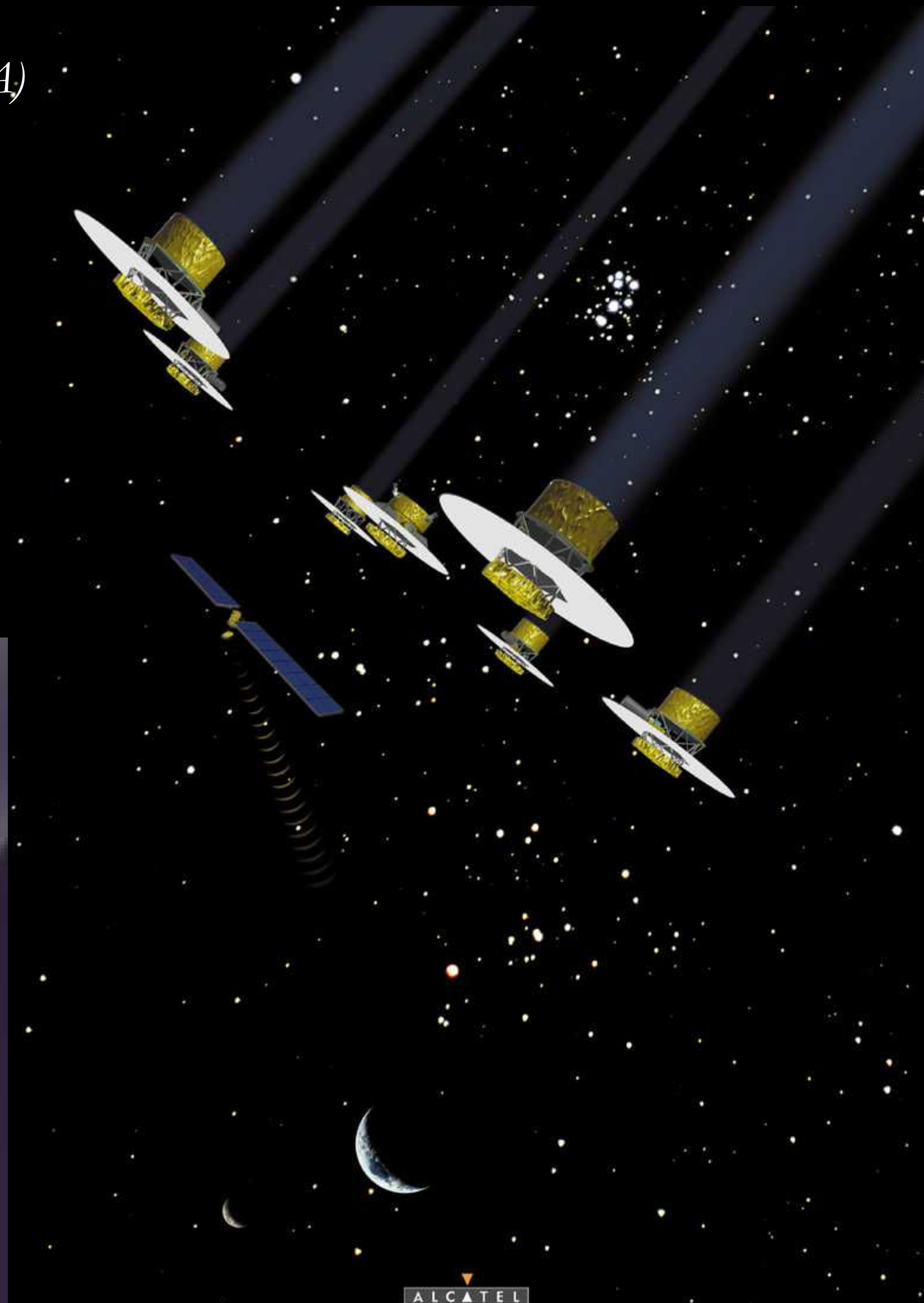
What about n_E – number of planets in the habitable zone?

- It is much harder to place constraints on this parameter
  - Current detection techniques are too dependent upon massive planets being close in to stars
  - A good answer to this question awaits the first generation of Earth-like planet finding missions
- This is the first of the variables in the Drake Equation that we really don't have a good answer for
- For our solar system it is between 1 & 3, (Venus & Mars are borderline) however if one of the gas giants was 1 AU distant perhaps the number could be bigger because of the large number of satellites associated with gas giants
- Hence we speculate…
- n_E~1 or lower? Especially if there are special circumstances on Earth (see upcoming lecture on "Rare Earth" hypothesis)

Finding Earth-like planets

- Doppler technique (on current telescopes) will **never find Earth-like planets:** their velocity wobbles are simply **too low**
- We need **different techniques:** we have discussed two already that should yield Earth-size planets: **transits** and **microlensing**
  -- lots of ground-based programs at the moment
- Space-based missions hold **much promise:**
  - **<u>Transit</u>**: COROT, Eddington, Kepler (within next few years)
  - **<u>Interferometry</u>**: SIM, **TPF**, Darwin (within next 15-20 years)
- The interferometry instruments **and/or** large ground-based telescopes should be able to **directly detect** extra-solar planets and **life gases** in their atmospheres!

Darwin (ESA)



Next decade instruments – very ambitious, huge potential payoffs

TPF (NASA)

Summary of lecture 16

- Astrometric, transit, microlensing and direct imaging all provide alternative methods for finding extrasolar planets
  - Of these methods only microlensing & transits are sensitive to Earth sized objects (*at present*)
- Because of the inherent bias towards finding large planets "close in" in Doppler surveys, most of the planets discovered thus far are gas giants
  - Most of the discovered planets are also on quite eccentric orbits
- By using the results from extrasolar planetary surveys we have been able to pin down p_p with reasonable accuracy
- n_E remains a challenge though…

Next lecture

- Classifying Life
- Guest lecture next Friday (8^{th} March) by Dr Virginia Walker (Biology) on extremeophiles