The Cosmos

Planets & Life

PHYS 214

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Please start all class related emails with “214:”

Pop Quiz 3

- Covering material since the last pop quiz (weeks 4,5,6)

Today’s Lecture

- Brief comments on the midterm
- Detecting Extrasolar planets

Midterm comments

- Short answers marked – multiple choice hopefully finished by the end of this week
- From my perspective, I thought the exam was comparatively straightfoward with no hidden surprises
  - 1/3 of the MC were taken from in class quizzes
  - With the exception of the radiation balance question, all the calculations had been set before as homeworks
- Some students did not finish in the allotted time
- One student got 29.5/30 and quite a few others got over 28/30 in the short answer
- Revised marking scheme:
  - I originally said 75% of marks come from midterm (25%) and final (50%)
  - I will now take 75% of your final mark as the best of midterm(25%)+final(50%) or final alone
  - If you got a low score in the midterm you can effectively forget about it and put your effort into the final

Midterm review & final structure

- Once I have all the marks collated I will go through the short answer questions
- In response to the issue of time, the structure of the final will be
  - 2 hours
  - 50 MC (equivalent to 25 in one hour)
  - 3 of 5 short answer (equivalent to 1.5 in one hour)

Outline for our two lectures on Extrasolar planet detection

- What is our **definition** of a planet?
- How have we found Extra-Solar Planets (ESPs?)
- How many ESPs have we found?
- What are the properties of these ESPs and their host stars?
- How might we detect **life** on ESPs?

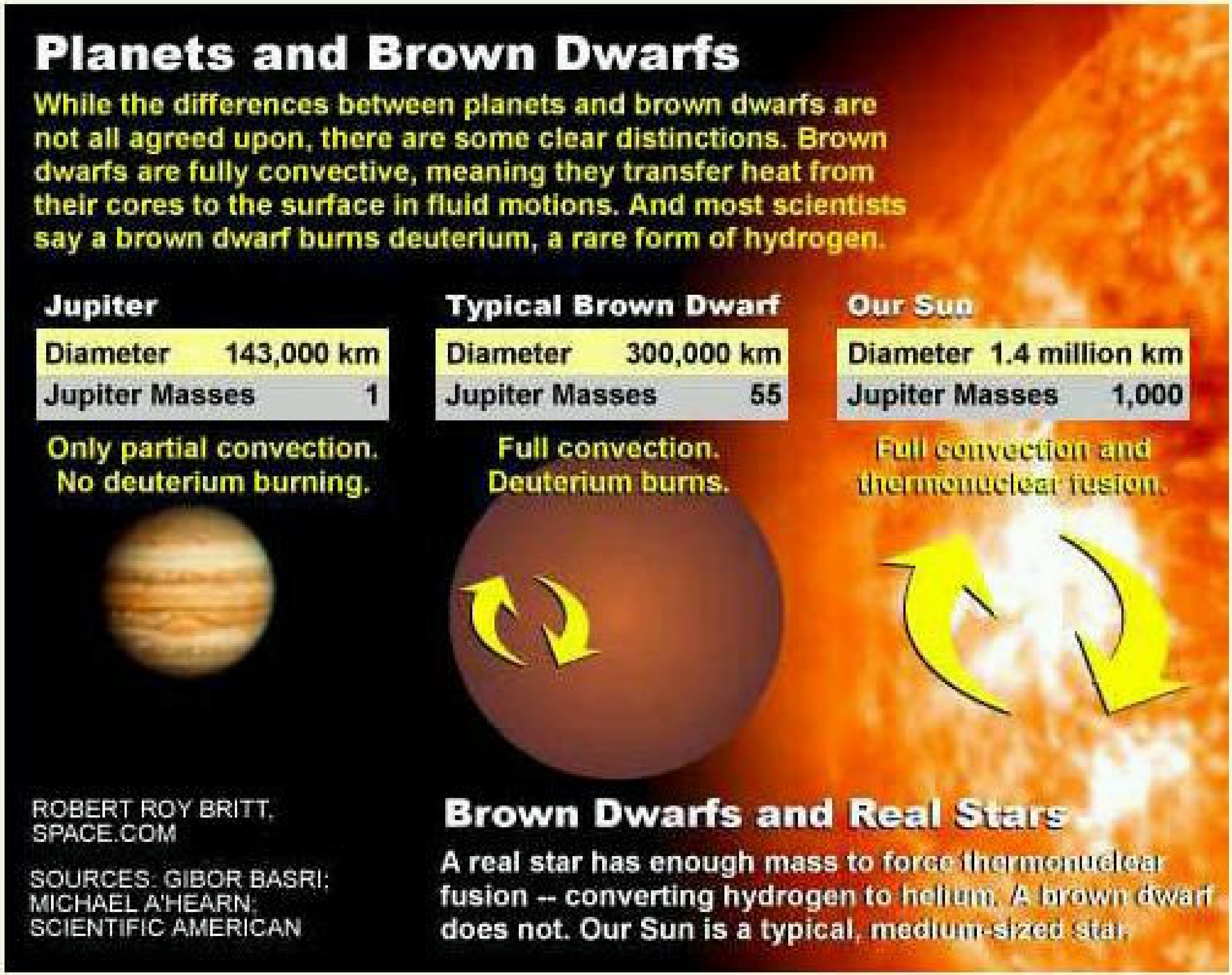
Planets and Brown Dwarfs

- We need to have a **clear definition** of what a planet is. We need to consider **low-mass** stars and **brown dwarfs** (failed stars)

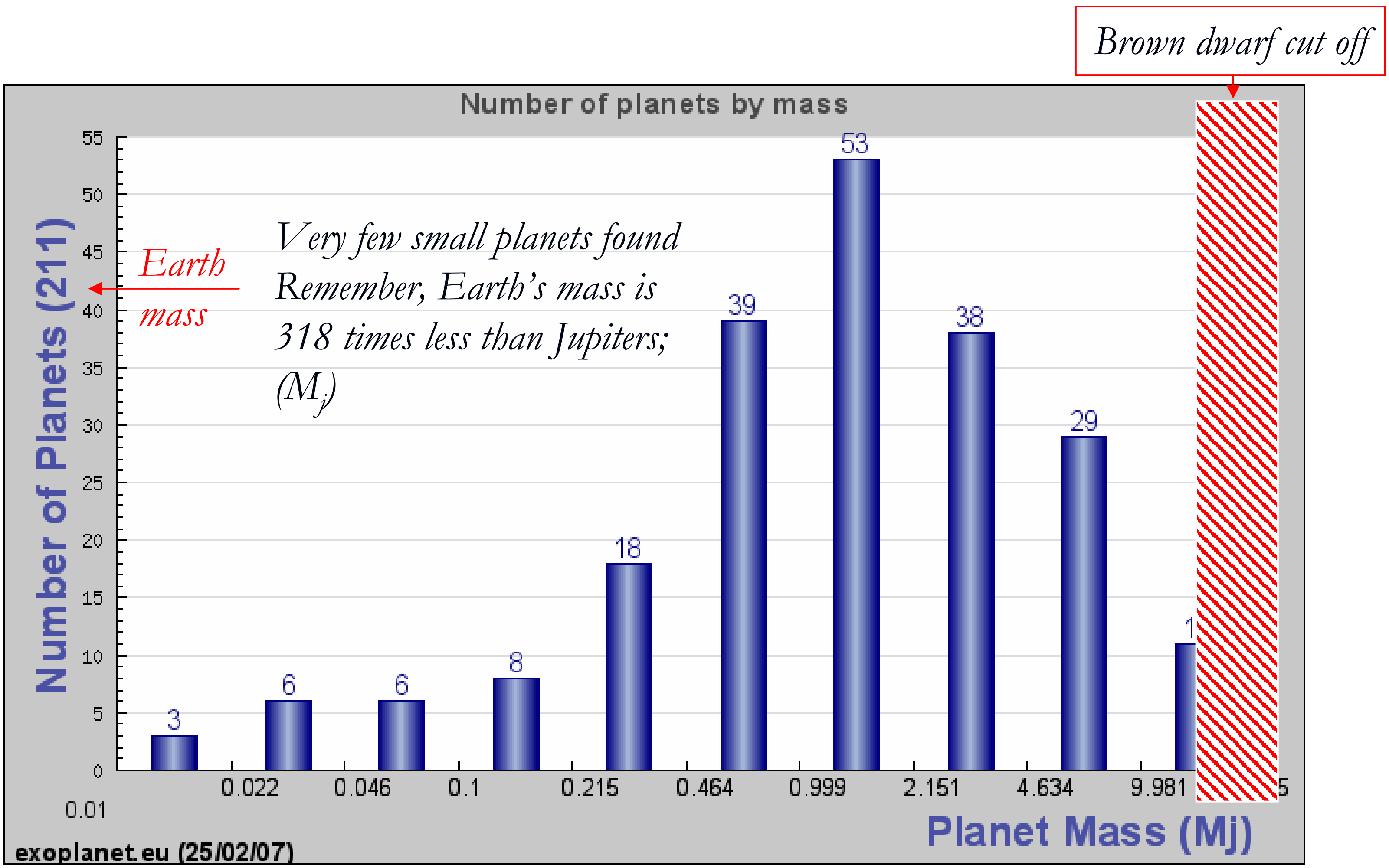
  (1) Stars: we define a star as an object massive enough to burn H in its core. This requires a mass > 0.08 solar masses

  (2) Brown Dwarfs: These are objects which formed similar to stars, but not big enough to fuse H. They can burn deuterium (D).

- Not clear how small brown dwarfs could be; could they be as small as "planets"? How do we distinguish planets and BDs?


Planets and Brown Dwarfs
While the differences between planets and brown dwarfs are not all agreed upon, there are some clear distinctions. Brown dwarfs are fully convective, meaning they transfer heat from their cores to the surface in fluid motions. And most scientists say a brown dwarf burns deuterium, a rare form of hydrogen.
Jupiter
Diameter 143,000 km
Jupiter Masses 1
Only partial convection. No deuterium burning.
Typical Brown Dwarf
Diameter 300,000 km
Jupiter Masses 55
Full convection. Deuterium burns.
Our Sun
Diameter 1.4 million km
Jupiter Masses 1,000
Full convection and thermonuclear fusion.
ROBERT ROY BRITT, SPACE.COM
SOURCES: GIBOR BASRI; MICHAEL A'HEARN; SCIENTIFIC AMERICAN
Brown Dwarfs and Real Stars
A real star has enough mass to force thermonuclear fusion -- converting hydrogen to helium. A brown dwarf does not. Our Sun is a typical, medium-sized star.

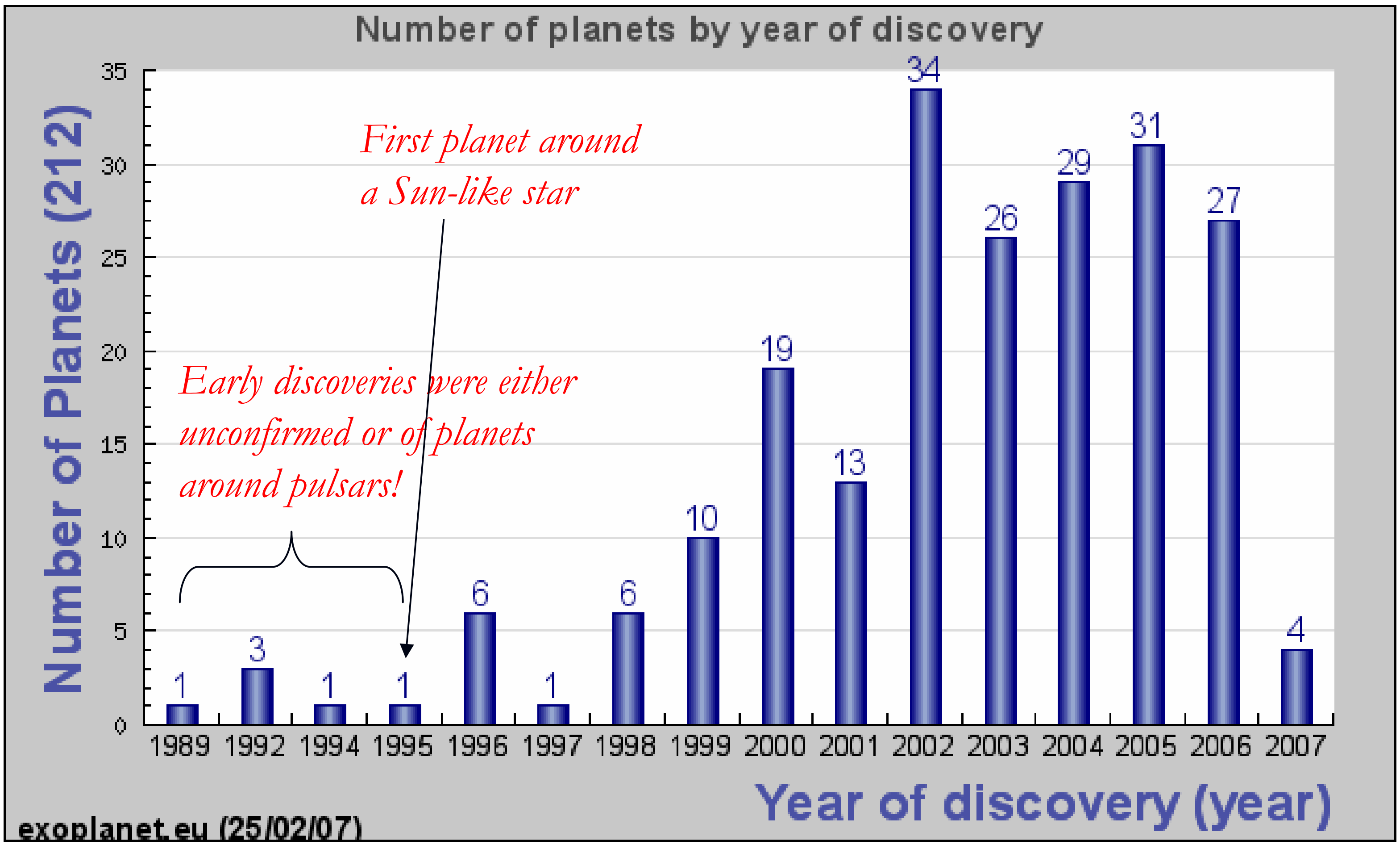
Number of planets detected as a function of mass



Most planets 0.5 M_j and up

History of Planet Finding

- A mere 12 years ago we had almost no knowledge of extrasolar planets



How to detect extrasolar planets

- There are several possible ways to find ESPs:
- Detection of **radio messages** from intelligent civilizations: we will discuss this later (nothing so far!)
  - Of course, technically, this doesn't mean we have detected a planet
- **Wobbles** in star's position or velocity caused by planets orbit around star
- Observe star's motion directly (astrometry) – long history but unsuccessful
- **Planetary transits**: planet blocks off some of star's light
- **Gravitational microlensing**
- Observe the planets **directly** (i.e. take a picture)

Stellar "wobbles" – the Doppler technique

- All most all planetary stars have been found using this technique
- Before discussing it in detail, it is useful for us to review Kepler's Laws of Planetary Motion
  - These laws were formulated before Newton explained gravity
- This will set the basis for understanding many of the issues that will come up

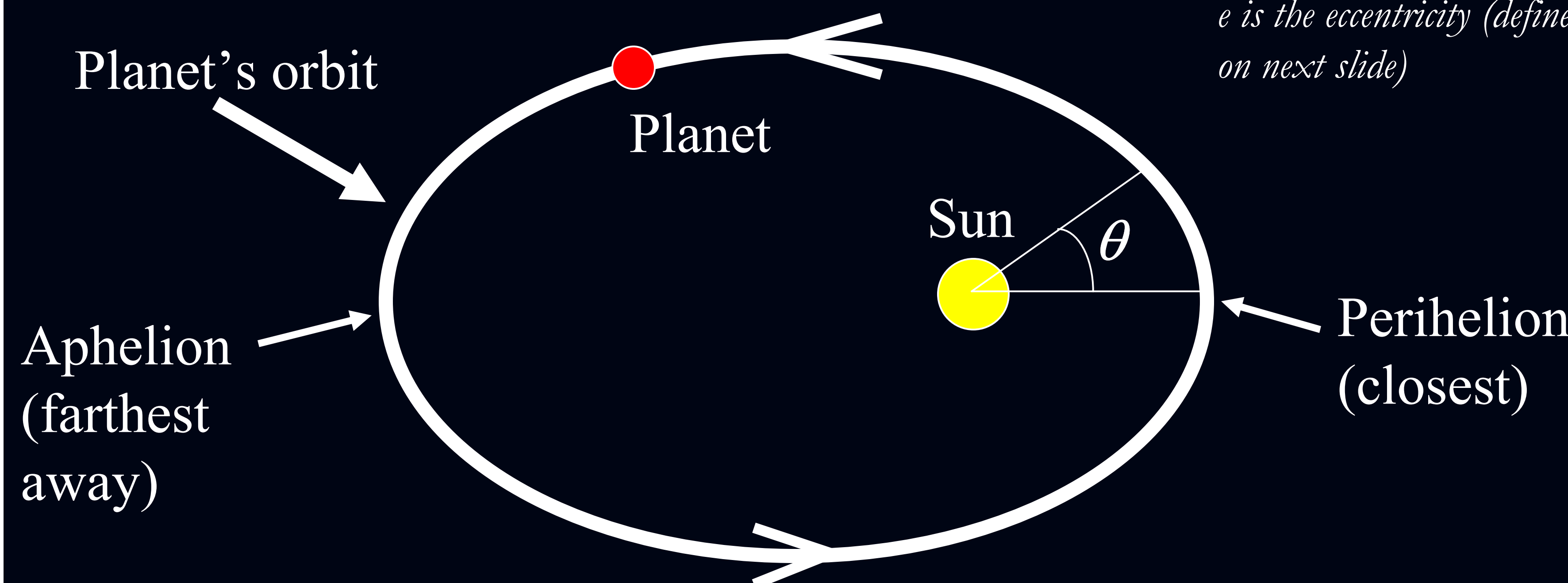
(1571-1630)

Kepler's First Law

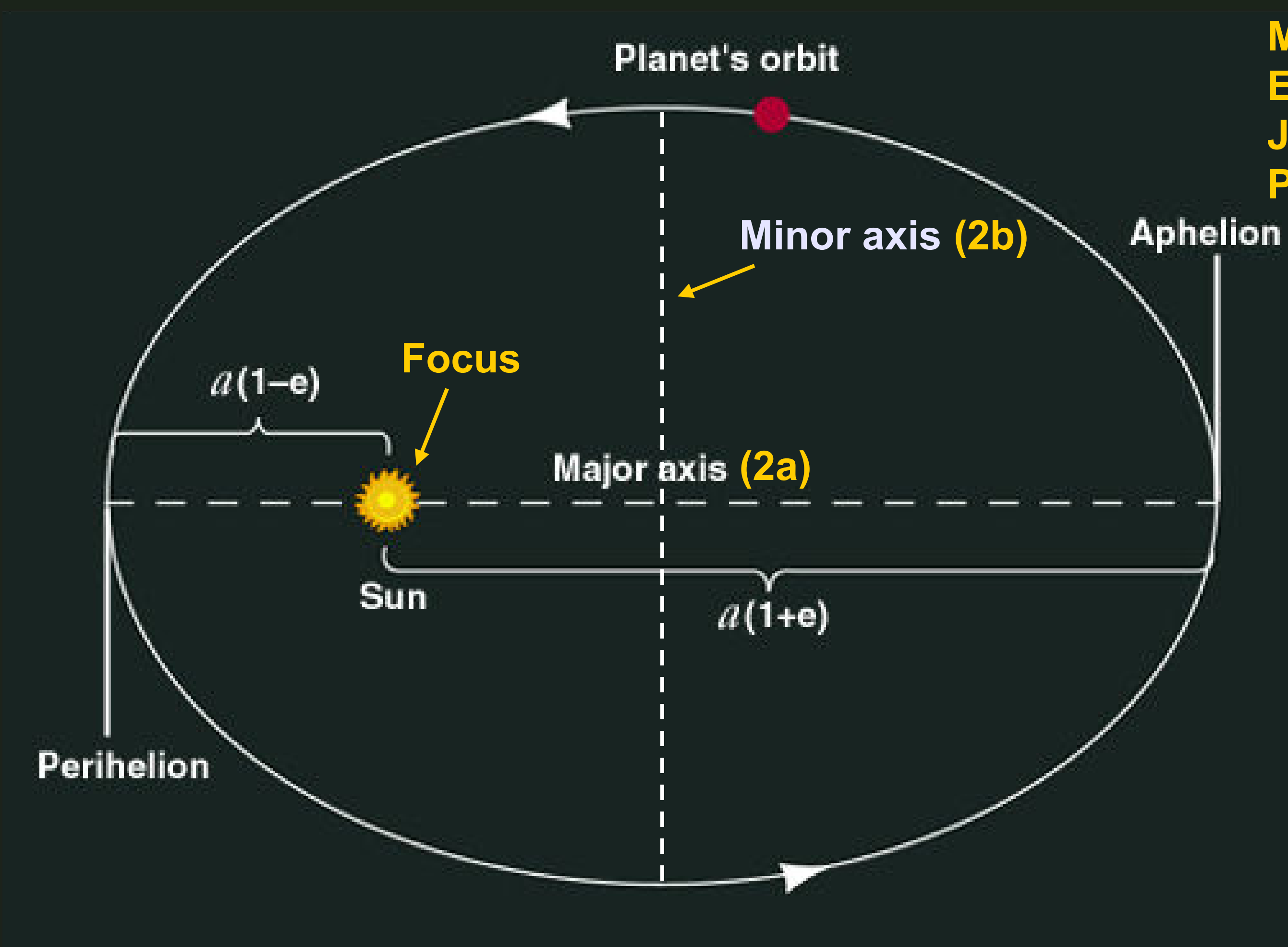
- The orbital paths of the planets are ellipses with the Sun at one focus

$$r = \frac{p}{1+e\cos\theta}, \quad p = a(1-e^2)$$

a is the semi-major axis, e is the eccentricity (defined on next slide)



Geometry of ellipses



Eccentricity values:

Mercury	e=0.21
Earth	e=0.02
Jupiter	e=0.04
Pluto	e=0.25

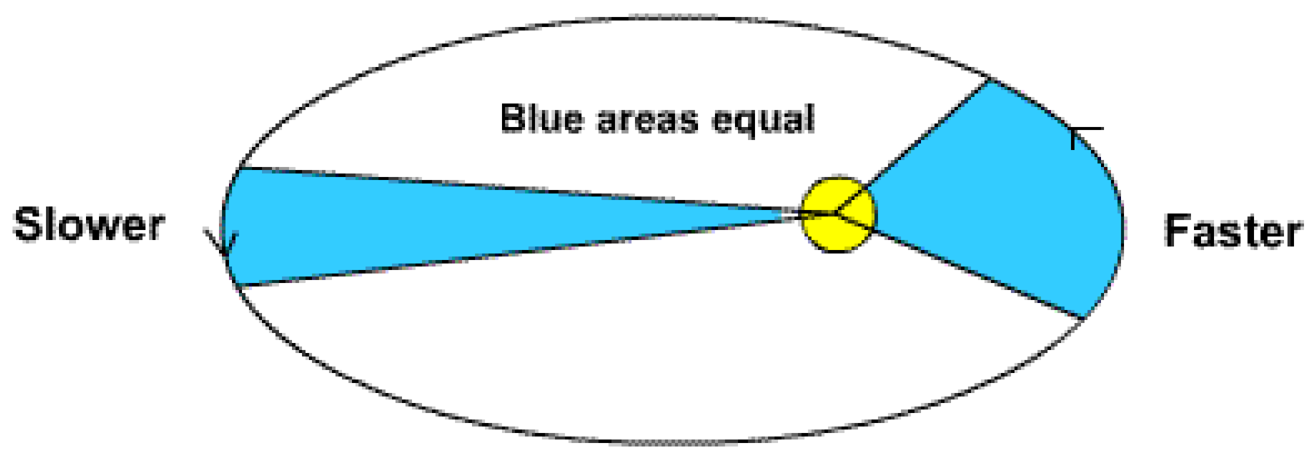
Semi-major axis (a) is half major axis

Semi-minor axis (b) is half minor axis

Eccentricity, $e=(a-b)/a$ measures flattening of the ellipse
$e=0$: circle
$e \rightarrow 1$: straight line

Kepler's Second Law (conservation of angular momentum)

- An imaginary line from the Sun to any planet sweeps out an equal area of the ellipse in equal periods of time



- *Very roughly: speed is proportional to 1/distance*

Kepler's Third Law

- The square of the planet's orbital period, P, is proportional to the cube of its semi-major axis, a
  - P^2 is proportional to a^3
- We now know this relationship is defined exactly by

$$\left(\frac{P}{2\pi}\right)^2 = \frac{a^3}{G(M+m)}$$

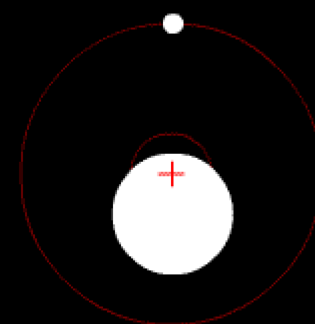
- M = mass of Sun, m=mass of planet
- P is measured in seconds, $P/2\pi$ is time per radian, use SI units to calculate a in metres

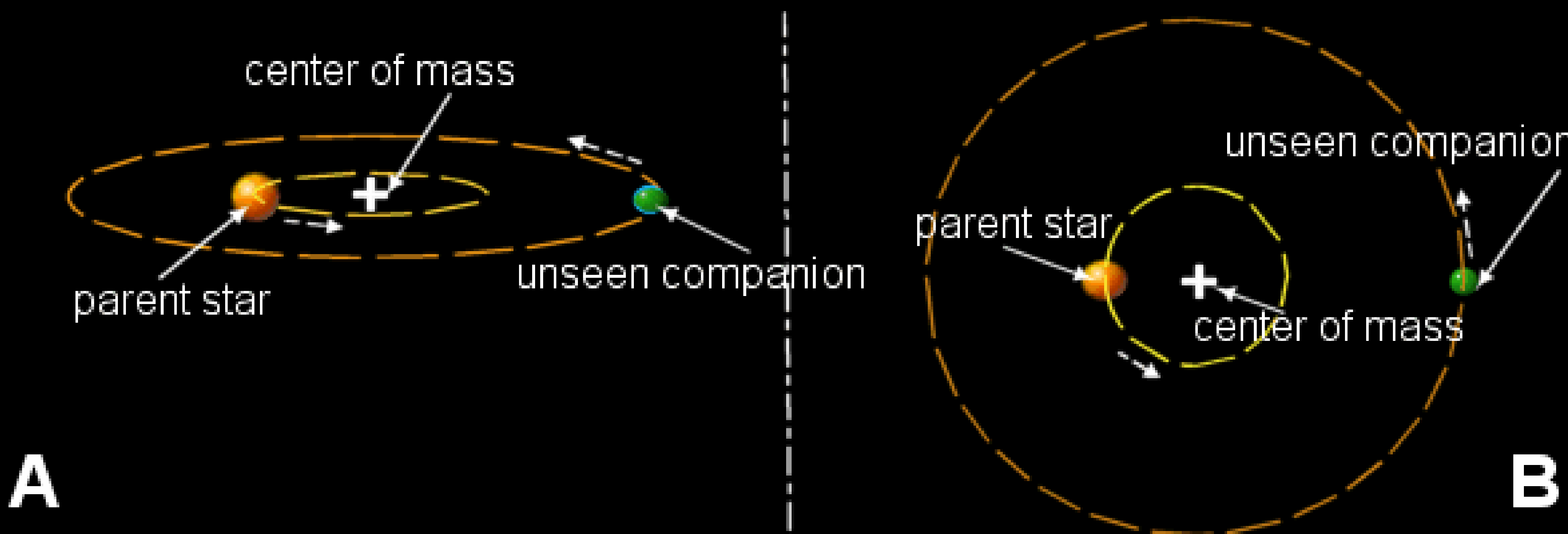
Key issues/problems with Kepler's Laws

- *Planetary orbits are ellipses*
- If we look at planetary motion from outside the system, the second law tells us we may see periods when the planet is moving slower & faster
  - Doesn't have to look like the motion of a harmonic oscillator, which would be true for circular orbit
- One key aspect of the Laws is wrong – namely the First Law
  - The Sun orbits around the *centre of mass* of the combined planet-star system
  - Planets therefore make stars "wobble"
  - Given sufficiently accurate measurements we can detect this motion

Doppler Technique

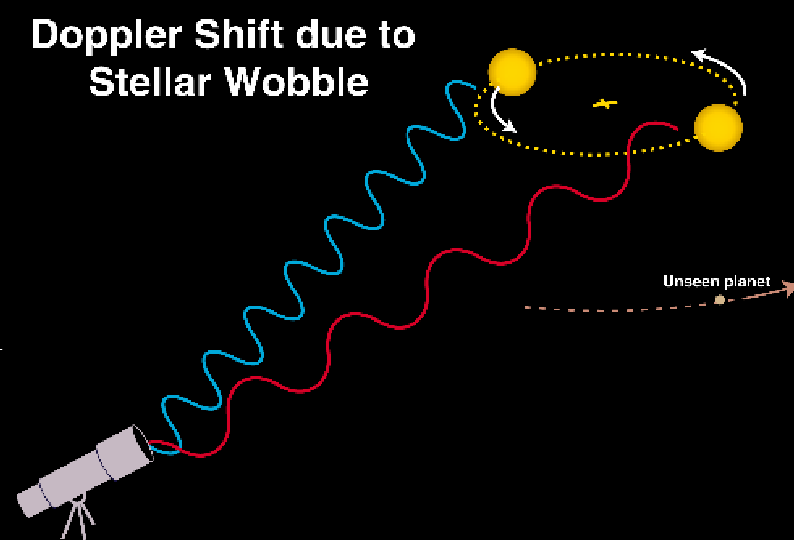
- 200 of the 212 extrasolar planets have been detected using this technique





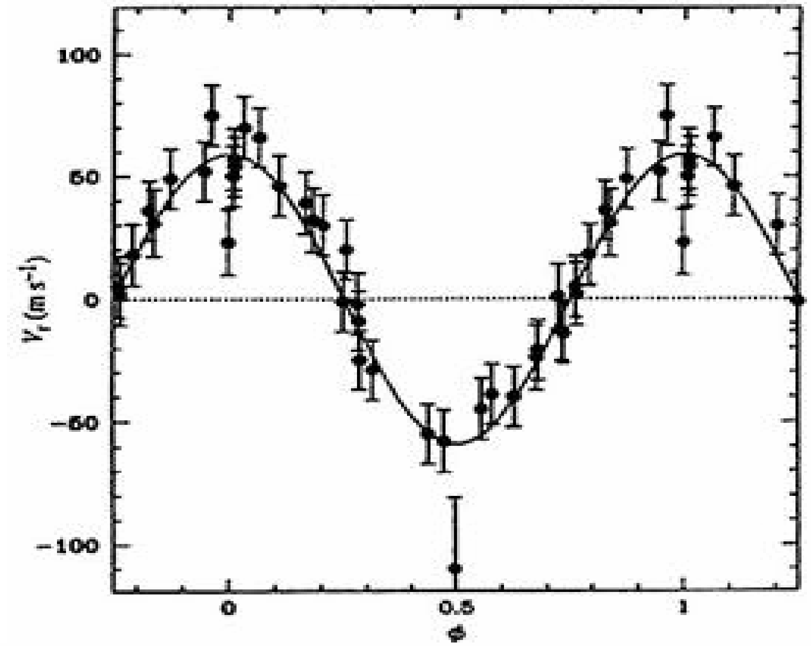
Measurement of velocity change

- Doppler technique only measures that part of star's velocity **along the line of sight**
- The changes in velocity are **small** and **hard to measure**, between few m/sec to ~100 m/sec
- Requires special spectroscopic setup: **high spectroscopic resolution** to measure such small velocities
- **1995:** Swiss team (Michel Mayor & Didier Queloz) announced the first extra-solar planet (*51 Pegasus*). An American team (Marcy, Butler & co) have found most extrasolar planets so far

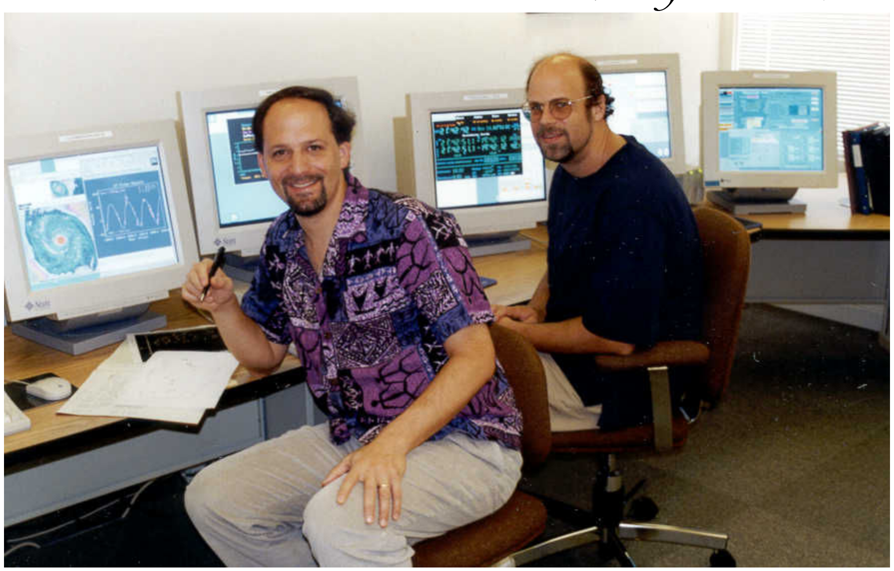


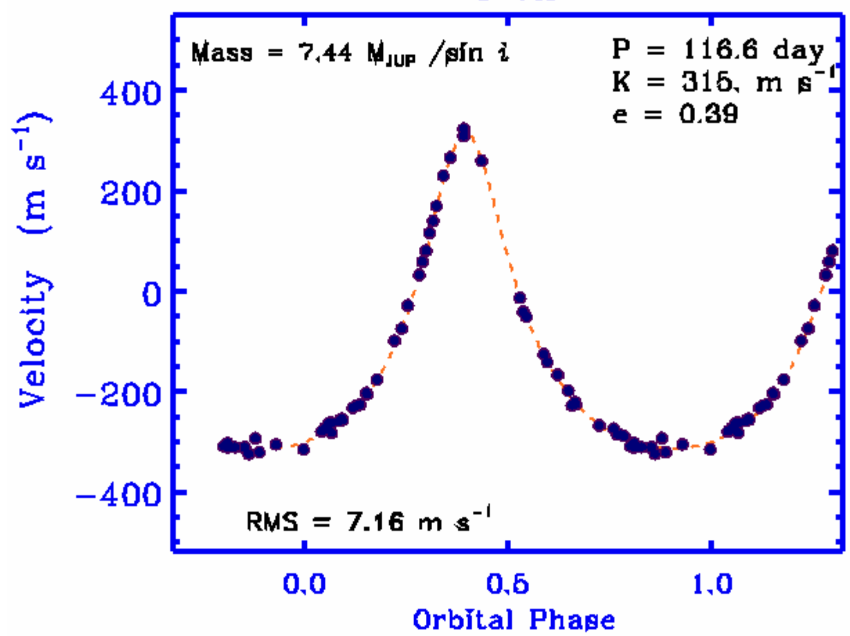
Mayor & Queloz

Measured Doppler shifts



Marcy & Butler





Extracting information from the Doppler shifts

(1) The period of the signal tells us the orbital period

(2) The shape of the signal tells us about the orbital eccentricity

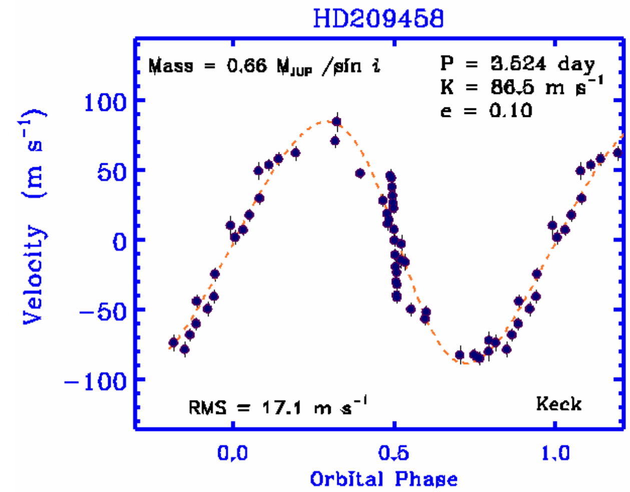
(3) Period+star's speed+star type:

    Planet's orbital radius & velocity

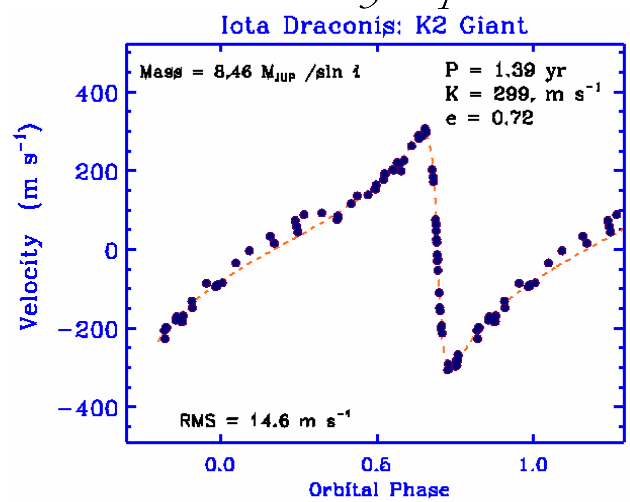
    Approximate estimate of planet's mass

(4) Combine with other data (e.g. transit information) to calculate planets mass exactly & density

Almost circular orbit

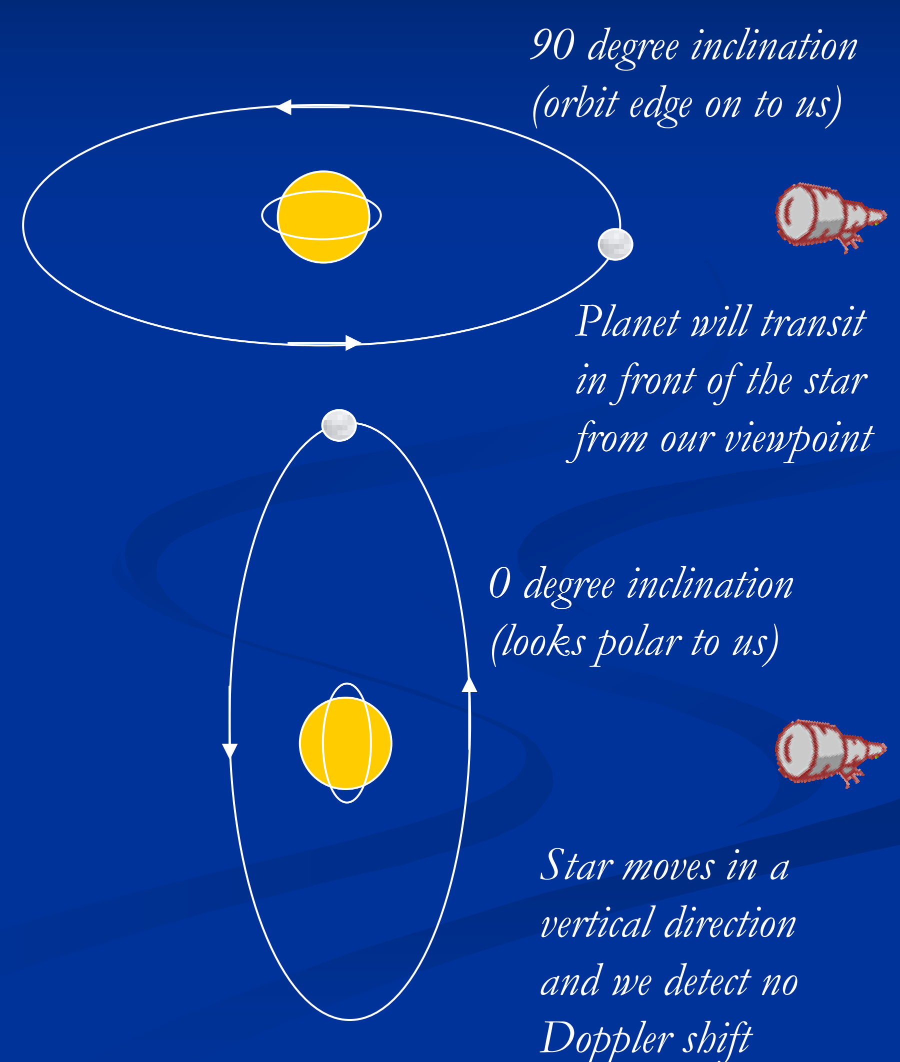


Very elliptical orbit



Why an approximate estimate of mass?

- Depends upon the inclination of the planetary orbit relative to the line of sight
- The inclination angle, i, *is defined* as being 90 degrees when edge on to us
- We do not know this angle without transit information
- Thus we measure the component of motion towards us, which is proportional to sin(i)
- The estimated planet mass, M_{est}, is thus $M_{est}=M_{pl}\sin(i)$
  - Where M_{pl} is true planet mass



Probing planetary atmospheres with Spitzer

Spitzer movie

Summary of lecture 15

- Detecting extrasolar planets is difficult due to the large ratio in mass and luminosity between stars and planets
  - Even 12 years ago we had almost no information about the number of extrasolar planets
  - Now we have over 200 catalogued
- The most effective method of detecting planets at the moment is via Doppler shift of stars around the common centre of mass
  - Still limited to detecting Jupiter sized planets
  - Doppler shift measurements can provide information about period, planetary velocity and mass

Next lecture

- More on detecting extrasolar planets
  - Alternative methods such as lensing and transits
- Properties of the planets we have detected
- Constraining the probability of stars having planets (p_p) in the Drake Equation