# Other Planetary Systems (Chapter 13)

## Extrasolar Planets

Is our solar system the only collection of planets in the universe?

# Based on Chapter 13

- No subsequent chapters depend on the material in this lecture
- Chapters 5, 8, 10, and 11 on “Light”, “Formation of the solar system”, “Planetary atmospheres”, and “Jovian planet systems” will be useful for understanding this chapter.

# Goals for Learning

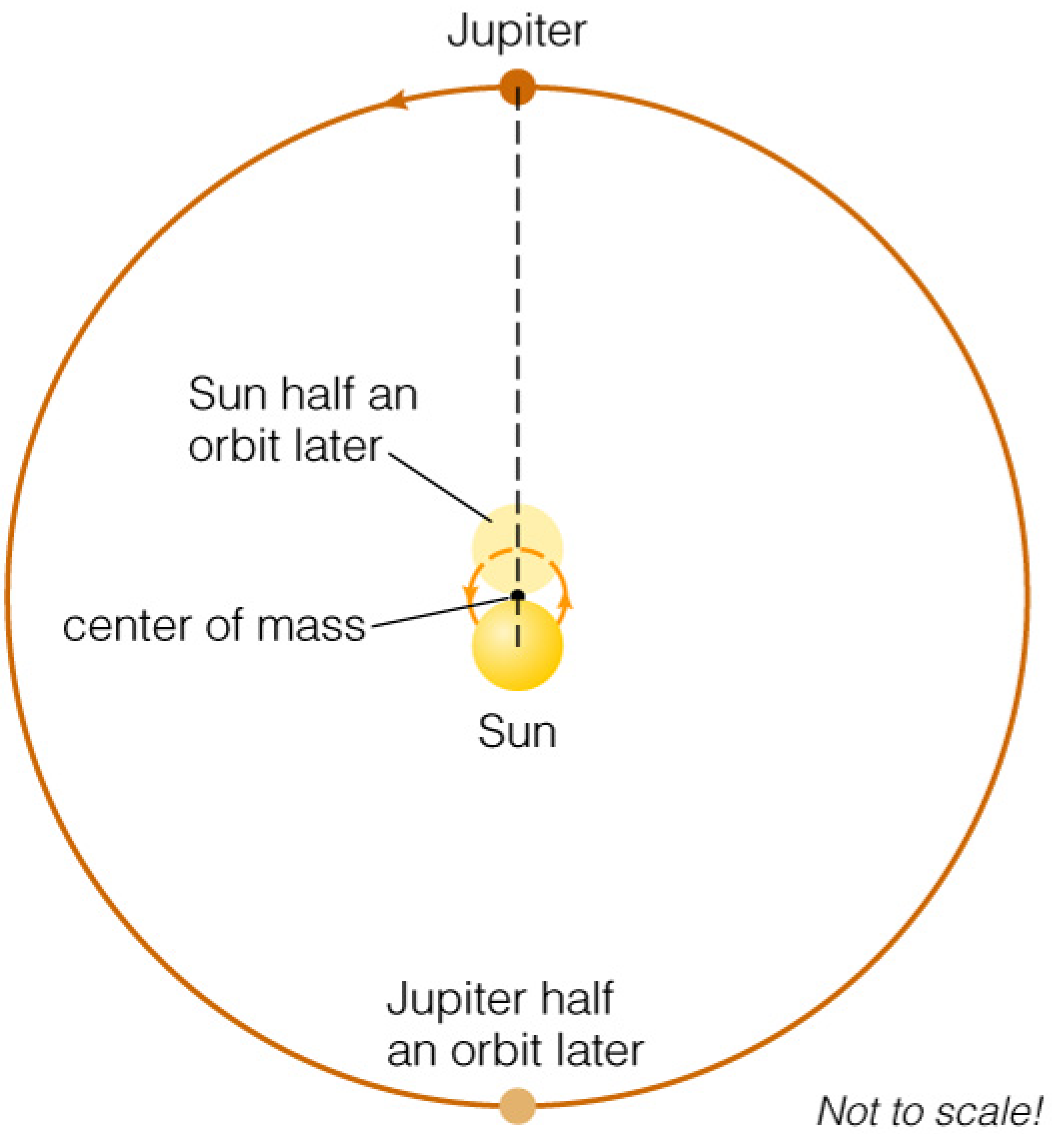
- How can extrasolar planets be detected?
- What can we learn about extrasolar planets?
- What are extrasolar planets like?
- How do planets form?

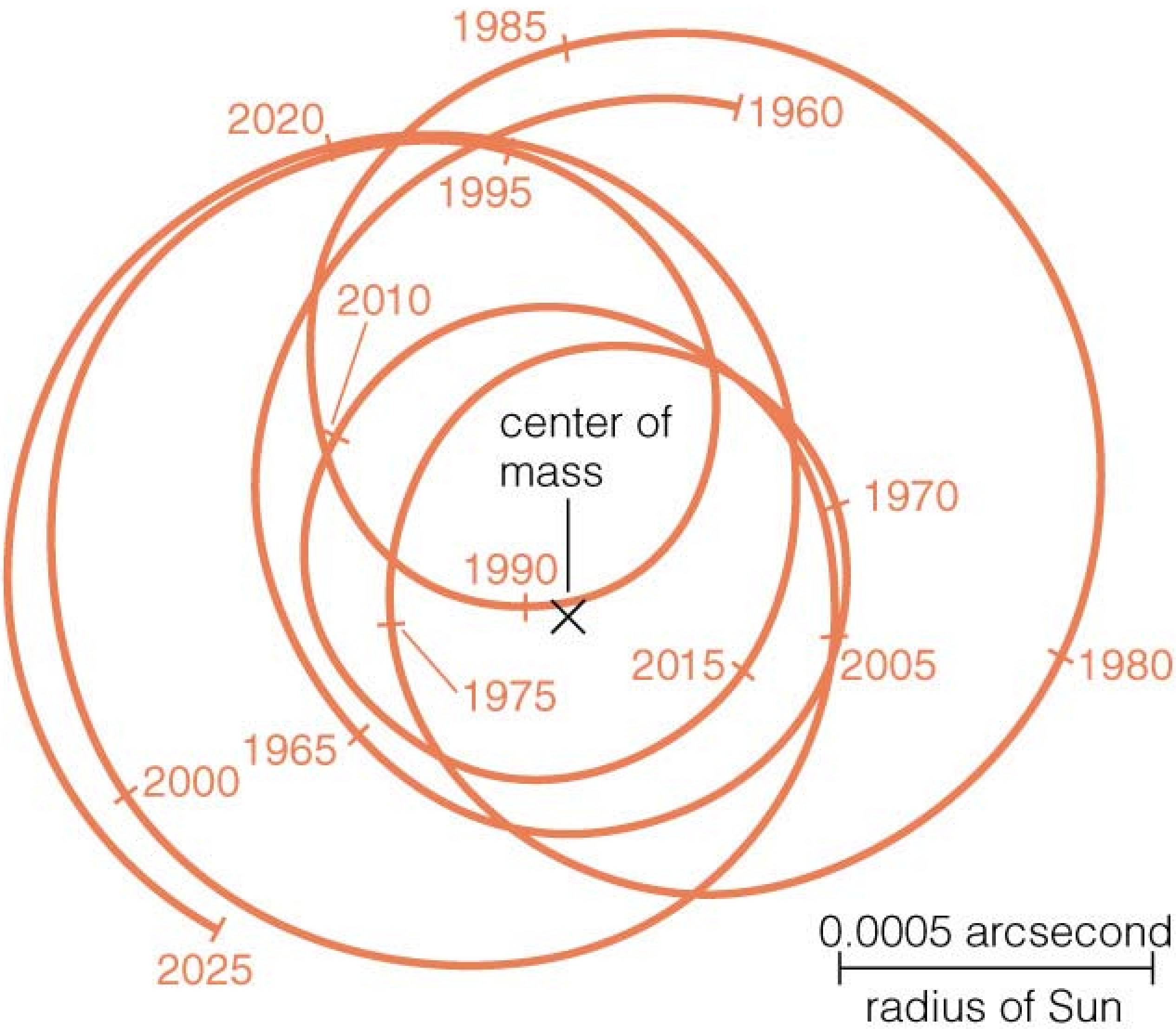
# Extrasolar planets are likely

- Other stars are distant suns
- Successful nebular theory for formation of our solar system suggests that planetary systems are a natural consequence of star formation
- Why didn't you learn about extrasolar planets in elementary school?

# Detection Difficulties

- Sun-like star is a billion times brighter than reflected light from a Jupiter-like planet
  - Ratio is more favourable at infra-red than visible wavelengths
- Angular separation of star and planet is very small
  - 0.003 arc-seconds for Jupiter-Sun from 10 light-years away
- But over 100 extrasolar planets have been found in the last ten years


Jupiter
Sun half an
orbit later
center of mass
Sun
Jupiter half
an orbit later
Not to scale!




Position of the Sun from 30 light-years away, width of figure is 100x less than HST resolution



If ET observed the Sun moving like this, he could determine the masses, orbital distances and eccentricities for Jupiter, Saturn, and so on using Newton's Law of Gravity

Massive planets far from Sun cause Sun to move the most distance

Massive planets close to Sun cause Sun to move the fastest

# Astrometric Detection Technique

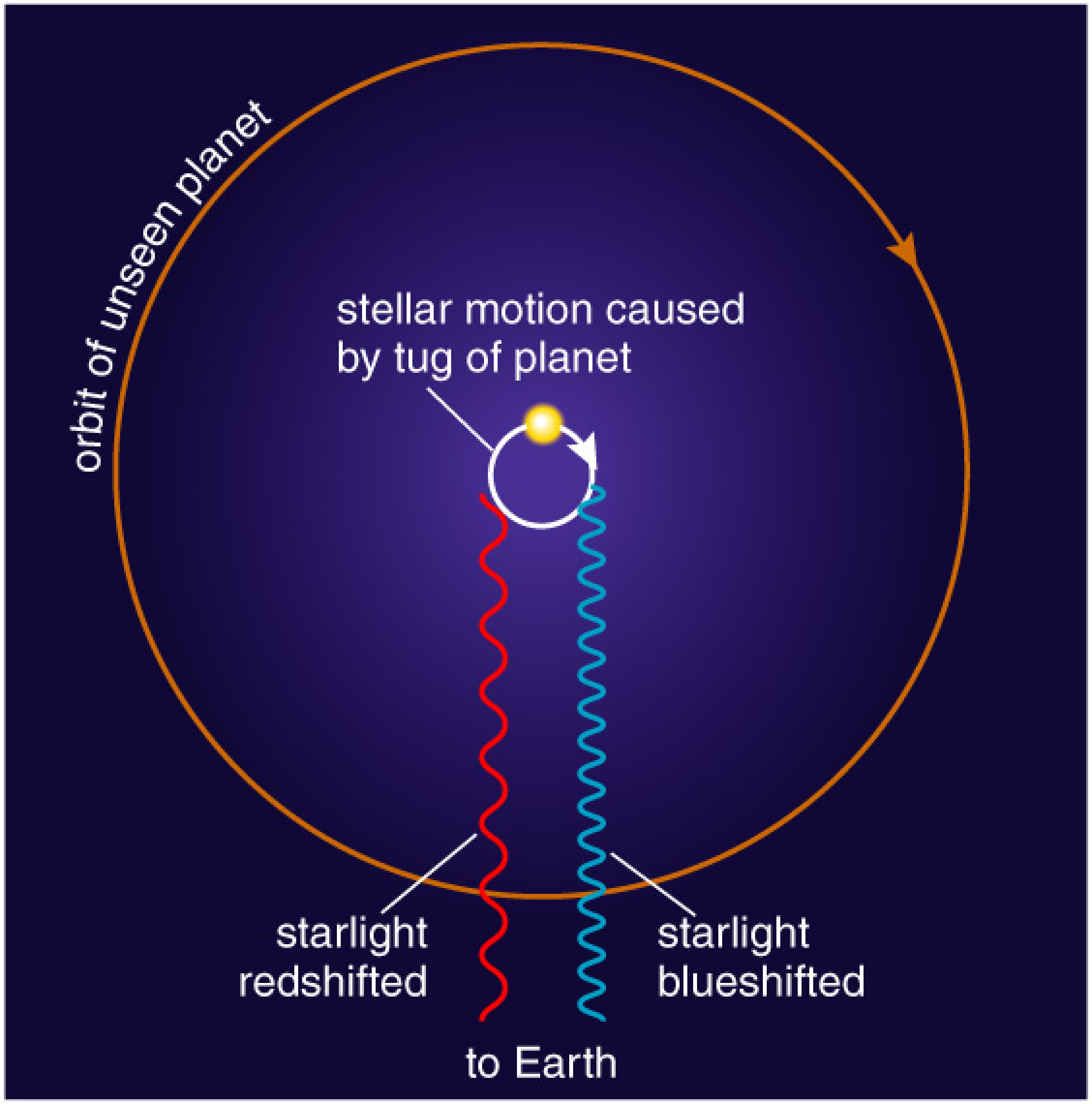
- Measure position of a star relative to very distant background stars
- What kinds of planets will this technique detect most easily?
  - Distance between planet and star
  - Mass of planet

- This technique has not detected many planets yet

# Doppler Shift

- $v / c = (\lambda_{shifted} - \lambda_{rest}) / \lambda_{rest}$
- v = speed of emitting object
- c = speed of light
- $\lambda_{rest}$ = usual wavelength of this spectral line
- $\lambda_{shifted}$ = shifted wavelength of this spectral line

# Doppler Technique



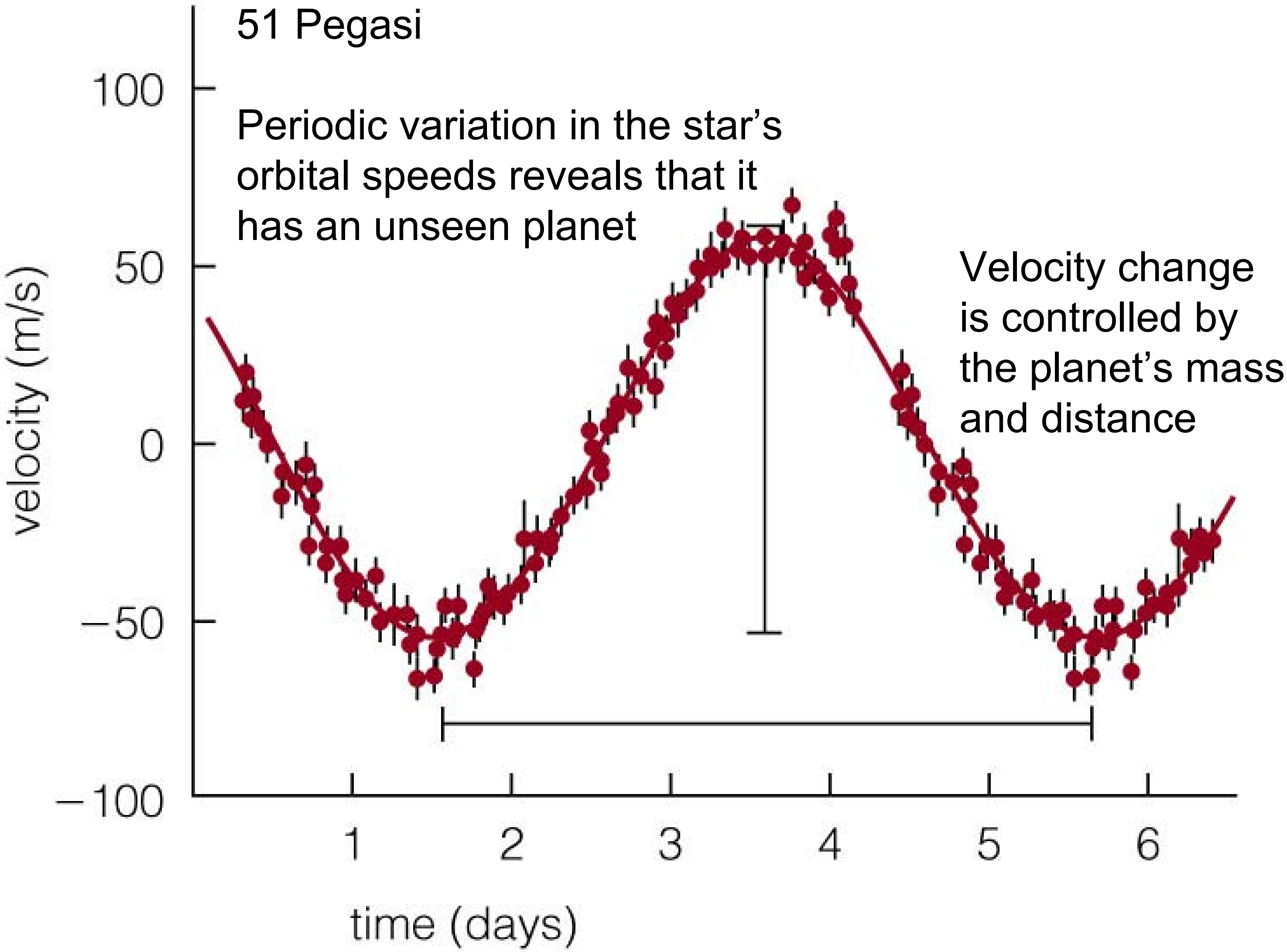

Planet's tug on star causes starlight to be Doppler shifted



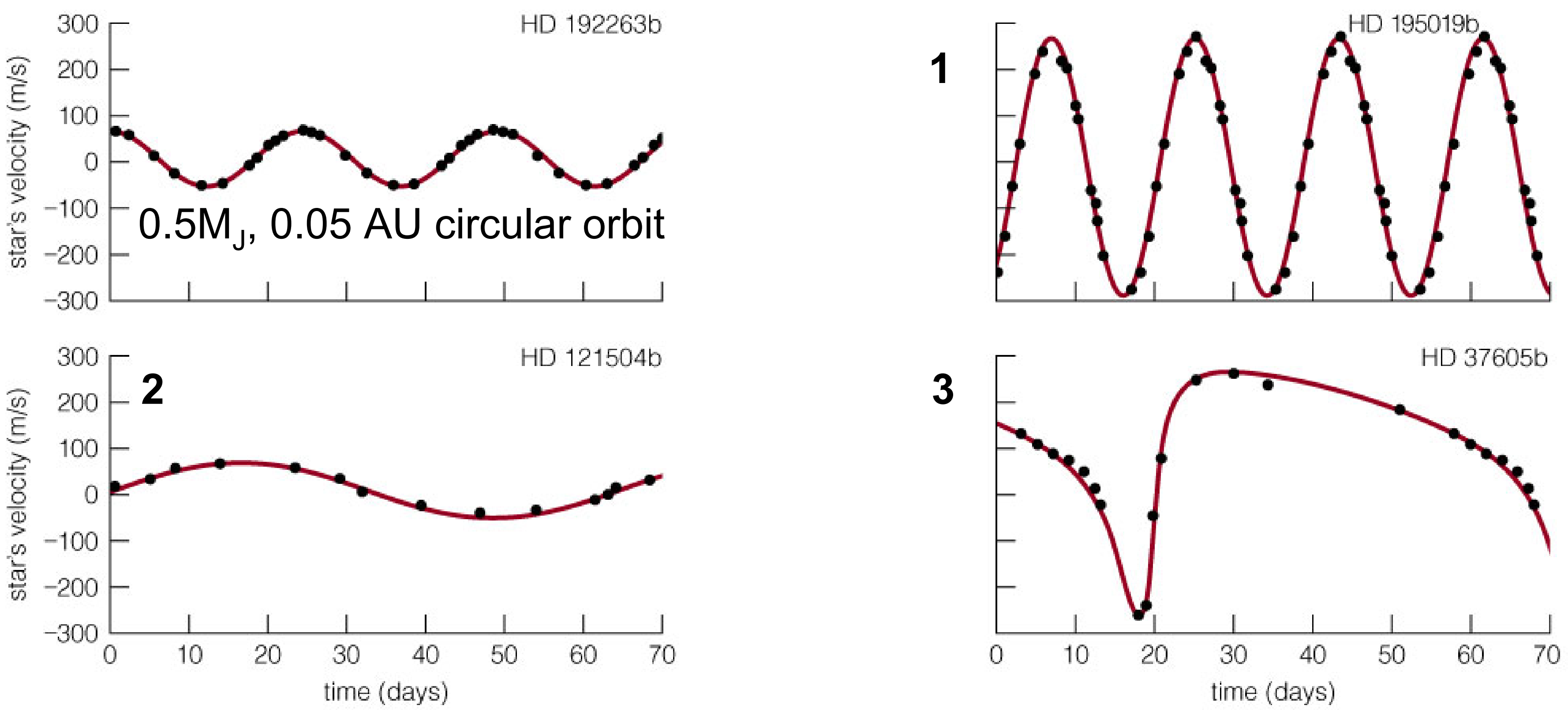
<u>What kinds of planets will this technique detect most easily?</u>

Distance between star and planet
Mass of planet

This technique has discovered most of the known extrasolar planets




Period is controlled by planet's orbital period, which is fixed by the mass of the star and the star-planet distance

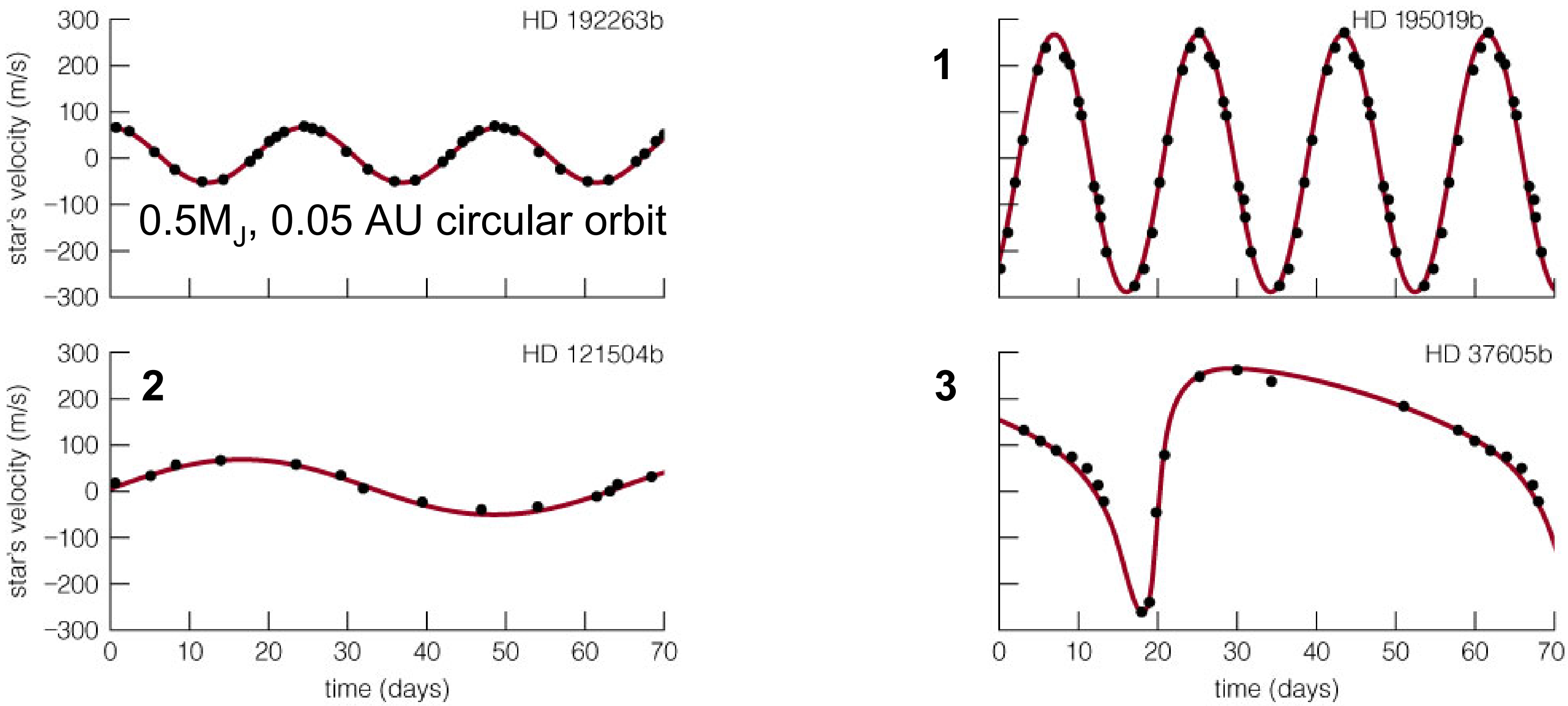





1: Periods are the same. Orbital distances? Doppler shift of (1) is greater. Which planet is heavier?

2: Longer period for (2). Orbital distances?

3: Longer period for (3). Orbital distances? Weird asymmetric lightcurve. Is orbit circular?

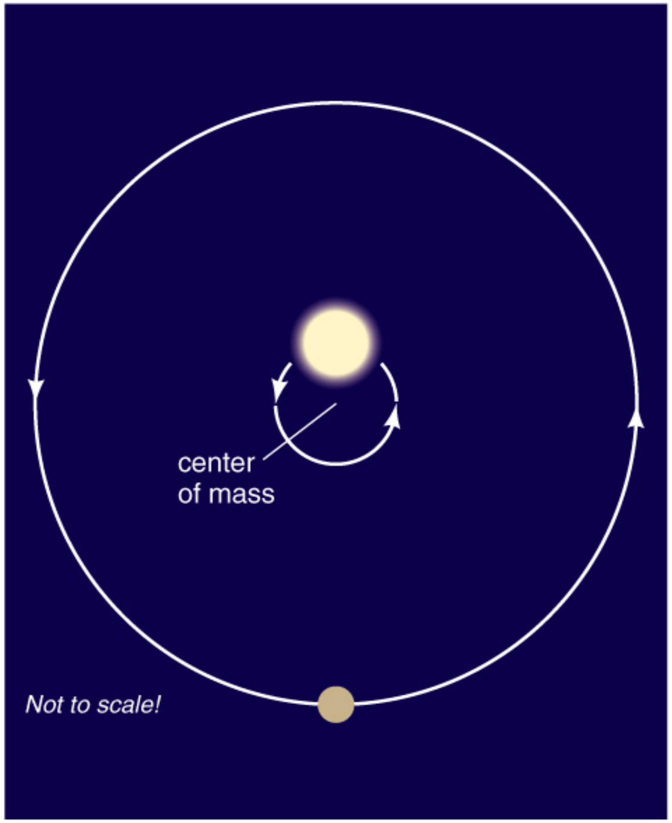





1: Same period, larger Doppler shift. Same orbit, more massive planet

2: Longer period, smaller Doppler shift. More distant orbit, SAME mass

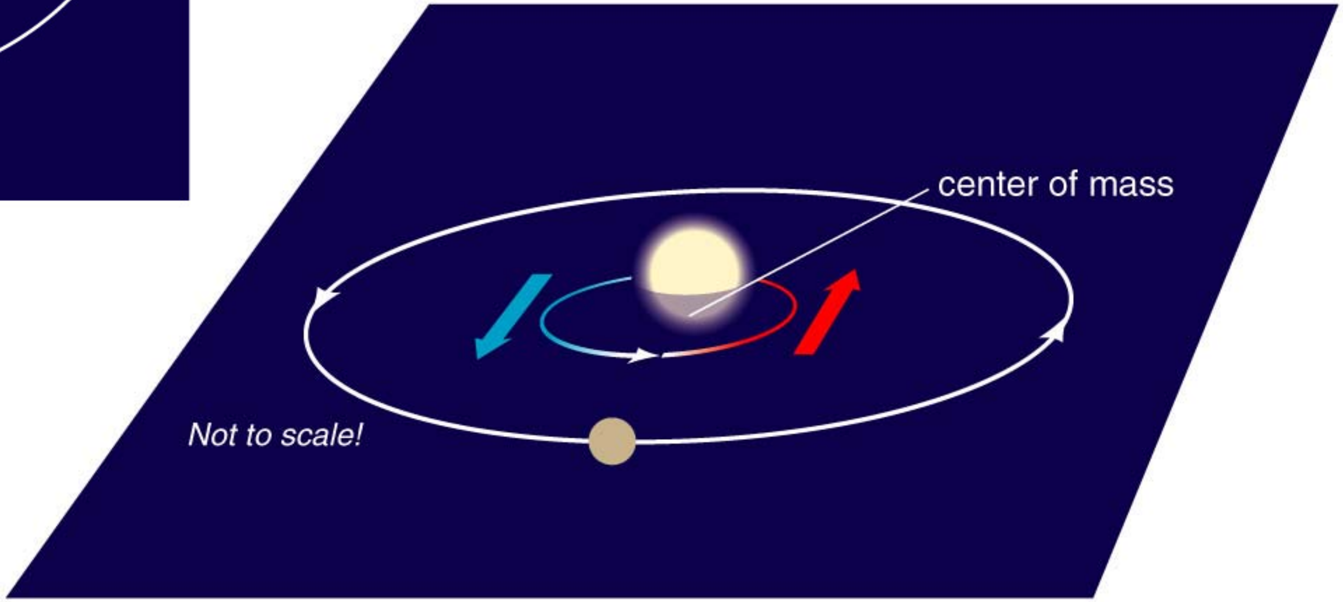
3: Longer period, larger Doppler shift, asymmetric curve. More distant orbit, more massive planet, eccentric orbit




Orbit plane appears face-on to us
Like looking down from above star's north pole
No observed Doppler shift

Orbit plane appears edge-on to us
Some observed Doppler shift

Is this a problem?



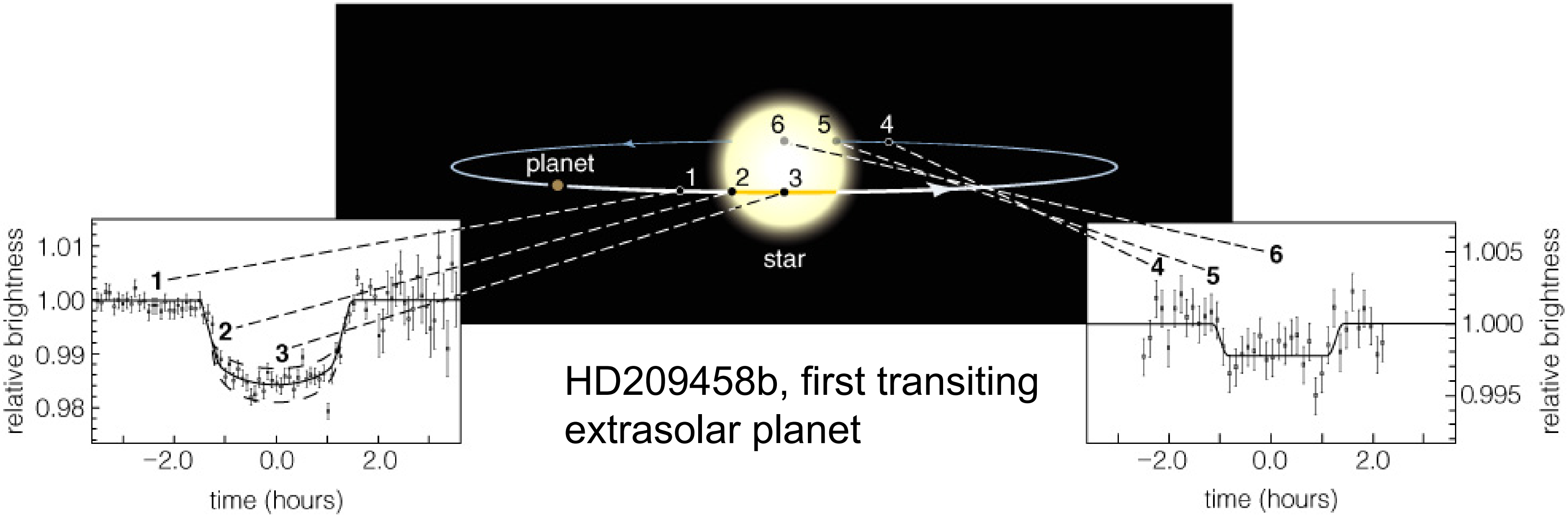
# Doppler Limitations

- Biased towards massive planets close to their star
  - Most known extrasolar planets are heavier than Jupiter, but closer to their Sun than Earth
  - Massive -> Larger Doppler shift
  - Close -> Short orbital periods
- <u>Does this mean that there are no small extrasolar planets orbiting far from their stars?</u>

# Transit Technique

- Dark planet passes in front of bright star, star’s brightness decreases slightly
- Only visible from Earth if we’re looking at the orbital plane edge-on

Transit of Venus
2004




HD209458b, first transiting extrasolar planet

Planet transits in front of star
Visible observations



Planet is eclipsed by star
Infra-red observations

Most of the time, visible light seen on Earth is the total of the star's light and the planet's light. Same for infra-red

What happens when planet transits in front of star?

What happens when planet is eclipsed by star? (planet is behind star)

What do we learn from the size of the dip in the lightcurve?

# What do we Learn?

- Orbital plane is edge-on, minimum mass of planet is actual mass
- Size of dip gives planetary radius, hence density of planet – composition

- Shape of dip gives some information about planet's atmosphere
- Dip at different wavelengths also gives information about planet's atmosphere

# Direct Detection

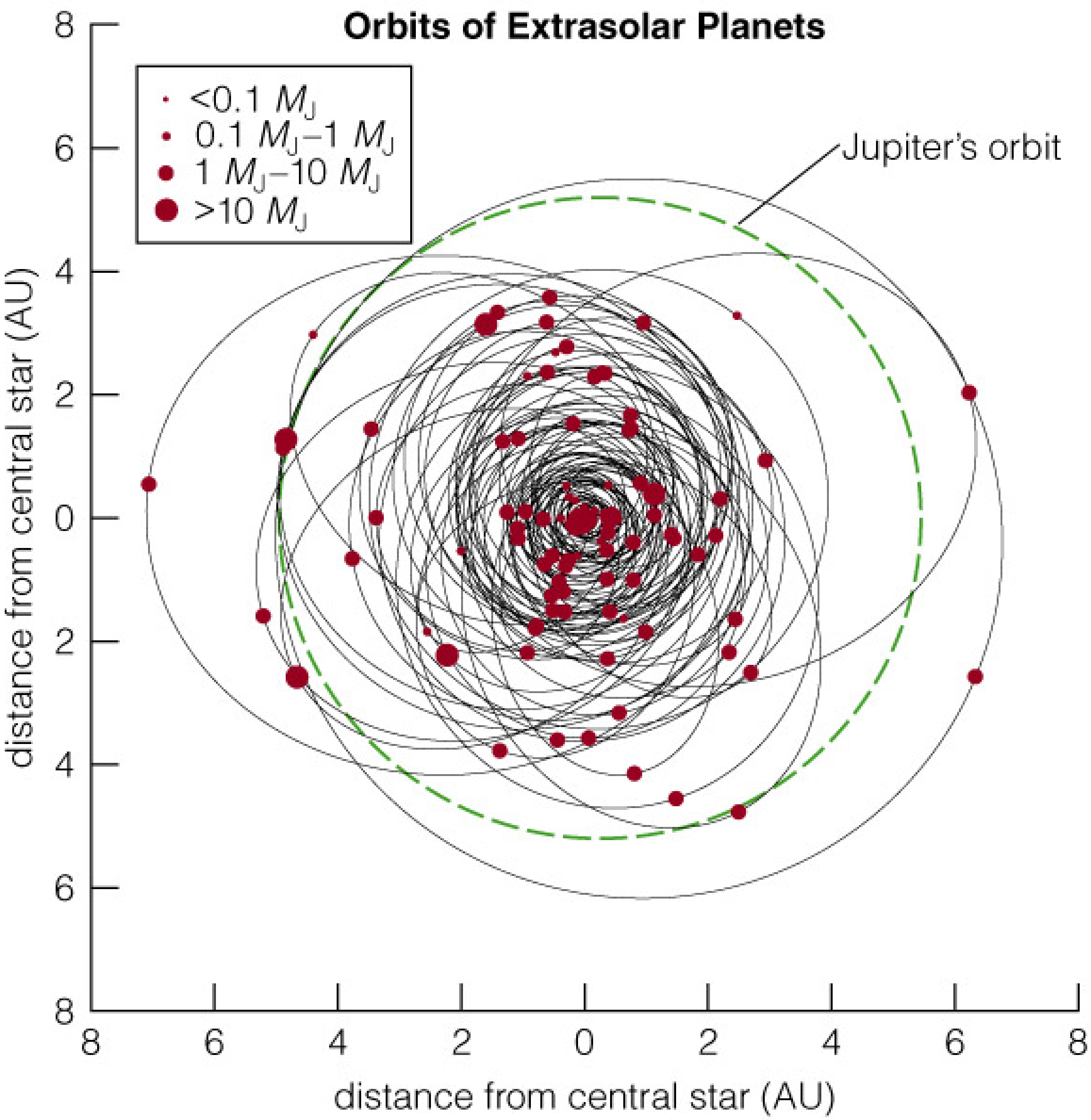
- Image or spectrum of a planet
- Image
  - Need incredible angular resolution AND
  - Either put a shade in front of the star, but not the planet, to block out the starlight
  - Or have very sensitive instrument that can observe changes in starlight of 1 part per billion
- Spectrum
  - Need very sensitive instrument that can observe changes in starlight of 1 part per billion
- Easier in infra-red than visible
- First successful image likely soon

# Questions

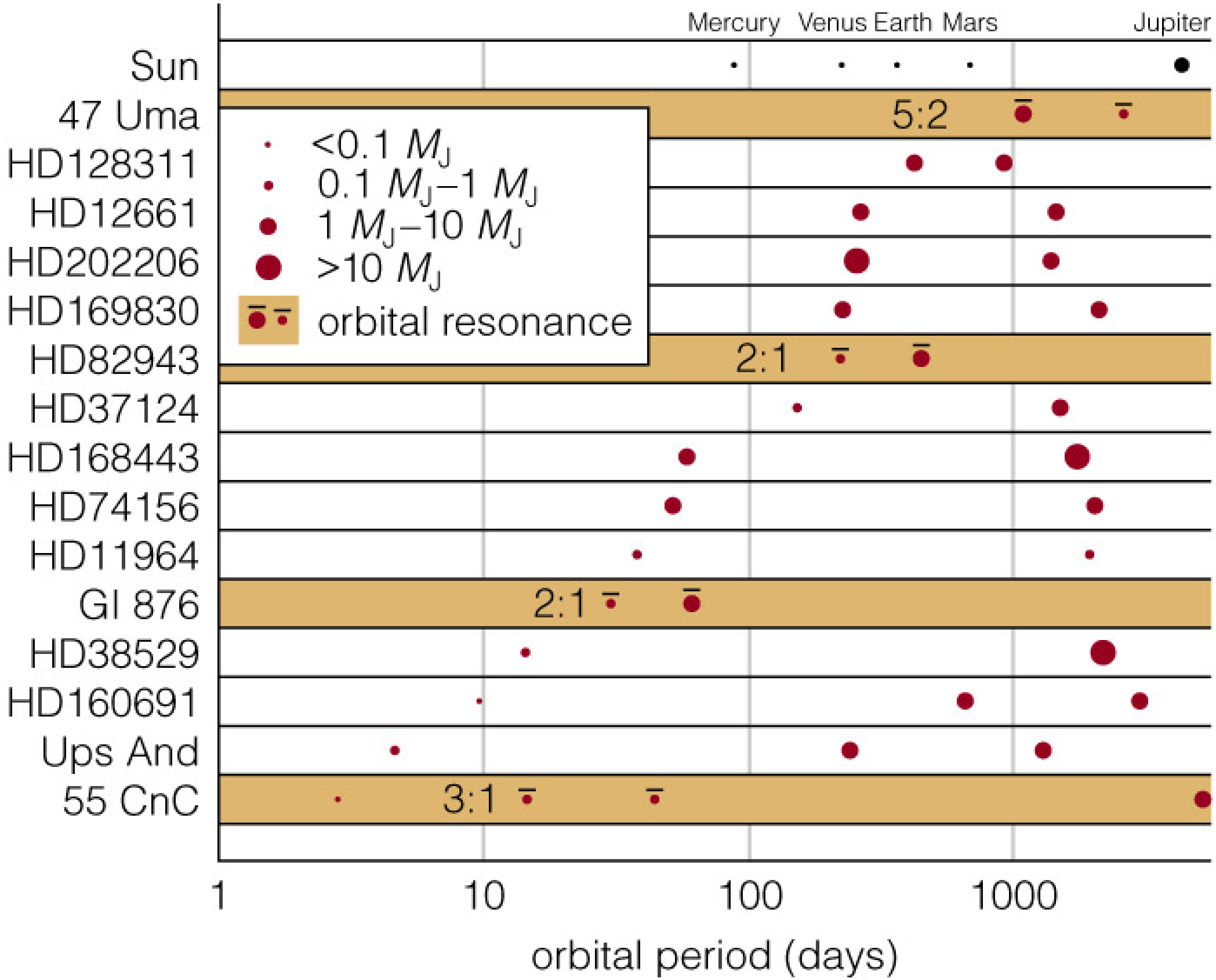
- Do most solar systems contain small, inner terrestrial planets and large, outer jovian planets?
- Are there other types of planets?
- Can the nebular theory explain structure of extrasolar planetary systems?
- Is the structure of our solar system common or rare?

Census of extrasolar planets

How does this compare to our solar system?




Orbits of 146 extrasolar planets




15 multi-planet systems



Lots of examples of orbital resonances

Likely to become more common as additional, smaller planets are found around these stars

Where do we see orbital resonances in our solar system?

# Sizes and Densities

- Are massive extrasolar planets made of hydrogen/helium, ices, or rock?
- Few sizes known yet from transits
  - Sizes greater than than Jupiter are common
  - Densities less than Jupiter’s are common
- Are they made of something less dense than hydrogen or helium?
- Transiting planets are close to their stars, so they are very hot. They are “puffed up.”

# Hot Jupiters

- Many extrasolar planets orbit close to their star than Mercury does with eccentric orbits
  - Why unlike our solar system?
- Likely to have hot clouds of “rock dust”
- Likely to have a banded, stripy appearance
- Likely to have strong winds diverging from hot side of planet

# Formation of Other Solar Systems

- Nebular theory predicts that jovian planets can only form far from parent star
  - Need lots of ices to capture gas, ice can't condense close to star
- Form with circular orbits
  - Collisions, which occur frequently if orbit is not circular, make orbit circular
- Seems like that jovian planets DO form far from star in circular orbit
  - What happens after that?

# Migration

- The nebula can alter the orbit of a new planet (what force?)
- Theory says:
  - planets migrate inwards
  - eccentricities increase
- Why didn't this happen here?

# Nebular Theory was Incomplete

- Discovery of extrasolar planets has shown that planetary migration and orbital resonances are more important in solar system formation than we thought
- Doppler technique (bias towards massive, close-in planets) only shows planets around 1 in 10 nearby stars
- Will other 9 be like our solar system (nebular theory is good) or not (nebular theory is not good)?

# Goals for Learning

- How can extrasolar planets be detected?
- What can we learn about extrasolar planets?
- What are extrasolar planets like?
- How do planets form?

# Goals for Learning

- How can extrasolar planets be detected?
  - Astrometry. Watch position of star in sky
  - Doppler shift. Detect motion of star as both star and planet orbit their centre of mass
  - Transit. Star's brightness drops when it is obscured by planet

# Goals for Learning

- What can we learn about extrasolar planets?
  - Orbital period, distance, and eccentricity
  - Mass
  - Radius
  - Density
  - Composition (limited information)

# Goals for Learning

- What are extrasolar planets like?
  - Most have masses between 0.1 and 10 $M_J$ and are probably hydrogen
  - Many orbit very close to their star, which makes them very hot
  - No Earth-mass planets have been detected yet
  - No rocky terrestrial planets have been detected yet

# Goals for Learning

- How do planets form?
  - Other planetary systems generally support the formation ideas of the nebular hypothesis
  - But inward migration of planets and orbital resonances seem very important in many planetary systems
  - We are still learning how planets form

- http://www.dustbinman.com/images/photos04/transit.jpg
- http://antwrp.gsfc.nasa.gov/apod/image/9801/betapic_stis_big.jpg