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Lecture #36: Planets Around Other Stars

- Extrasolar Planets!
  - Theory
  - Observations
    - Detection methods
    - Results to date...
  - Implications for "Habitable Zones"
- Reading: Chapter 13

"There are countless suns and countless earths all rotating around their suns in exactly the same way as the seven planets of our system. We see only the suns because they are the largest bodies and are luminous, but their planets remain invisible to us because they are smaller and non-luminous. The countless worlds in the universe are no worse and no less inhabited than our Earth."

Giordano Bruno (1584) in De l'infinito universo e mondi

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The Main Point(s)

There are other solar systems besides our own! Recent evidence has been found for mostly Jovian-class planets orbiting other Sun-like stars in our galaxy. Most of the planets found so far seem to be very unlike those in our own solar system, though.

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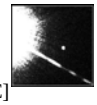
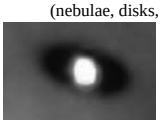
Should planetary systems exist around other stars?



- Philosophically, why not? [*e.g.*, Epicurus, 350 BC]
  - Planets exist around 1 star, there are billions of stars, therefore...
- Theoretically, why not?
  - The conditions that we believe led to the formation of the planets in our solar system involve "universal" laws of physics and chemistry. Planets could form anywhere that the "experiment" is repeated.
- Observationally, why not?
  - We see evidence for the early stages of this process all around us (nebulae, disks, brown dwarfs...)



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Fine... So how could we find these "extrasolar" planets?

- Direct methods (most satisfying)
  - Take pictures of them!
  - But requires resolution that is *impossible* with current technology, even from space telescopes
- Indirect methods (require more support)
  - Measure star's brightness change from eclipses
  - Measure "wobble" of star/planet system
  - Measure Doppler shift of star/planet system
  - Measure changes in timing of pulsars

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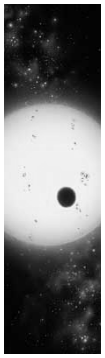
Planetary Eclipse Method



- By chance, some planetary orbits may be aligned edge-on to our line of sight
- Rare, but there are LOTS of stars...
- Periodically (and predictably), a planet could *transit* across the disk of the star, dimming its light by a tiny amount
- Amount of dimming gives planet size
- BUT: Can this tiny change be separated from "natural" stellar variations?

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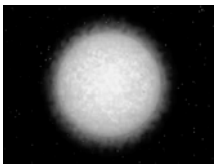
Planetary Transit?

Example: transit of a putative planet of the star HD209458.



- Tiny change in signal: Must have ultra-sensitive instruments
- Signal must repeat periodically: Gives period of planet
- Star must be monitored for a long time to be certain that sunspots or other variable features are not being mistaken for a planet

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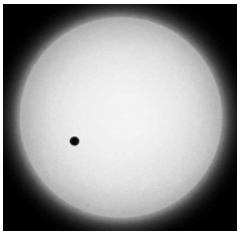
HD 149026b: New Transiting Planet

- Announced June, 2005.
- Orbits the sun-like star HD 149026
- Roughly equal in mass to Saturn, but significantly smaller in diameter.
- Takes just 2.87 days to circle around its star.
- Upper atmosphere temperature is around 2,000 degree Fahrenheit.



Artist's concept of HD149026 and planet

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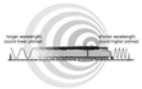
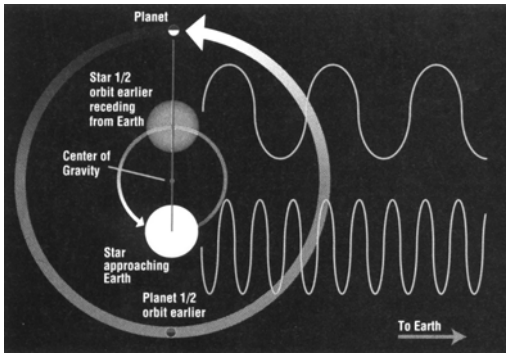
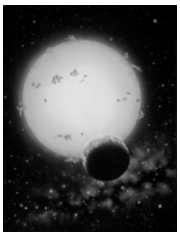
Doppler Shift Method



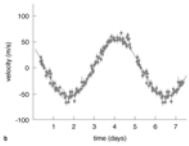
- Recall that planets don't actually orbit stars; both planets & stars orbit their common *center of mass*
- So a star with a massive enough planet could appear to move alternately towards and away from the observer, Doppler shifting its spectral lines
- Very sensitive method, but also requires *time*
  - Since the technique is only a few years old, the results obtained to date must be *biased* towards massive planets in short-period orbits (largest Doppler shifts)



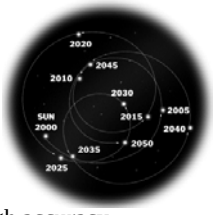
Example: 51 Pegasus



- One of the first extrasolar planets "discovered" by astronomers
- 51 Peg is a solar-type star
- Exhibits periodic Doppler signal
- Consistent with a planet about 45% the mass of Jupiter orbiting only 0.05 AU from the star (4.2 day period)
- VERY strange! Typical or not?



Stellar "Wobble" Method

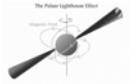


- A star with massive enough planets will appear to "wobble" across the sky
- Detectable by *astrometry*, the science of measuring star positions to extremely high accuracy
- Example: The Sun would appear to wobble with a period of about 12 years (Jupiter's orbital period) to an extraterrestrial observer
- BUT: Requires lots of *time* and high quality data

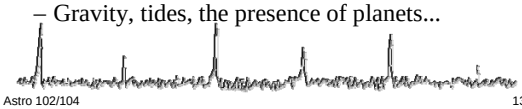
Example: Lalande 21185

- Red dwarf star only 8.3 light years from the Sun
- Close to us: implies large parallax motion
- Analysis of 50 years of astronomical observations of the star's position indicates a slight wobble as the star has moved relative to the background stars
  - Consistent with effect of 1 to 3 Jupiter-sized planets
  - But evidence still sketchy... needs more time...

Pulsar Timing

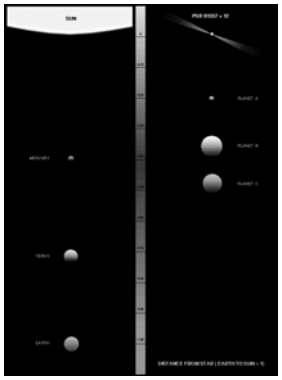


- Pulsars are rapidly-spinning neutron stars
  - Spin period is typically a few *milliseconds*
- They are *extremely* accurate natural clocks
- Changes in the spin period can be caused by external forces
  - Gravity, tides, the presence of planets...

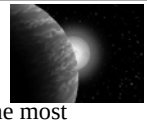


PSR 1257+12

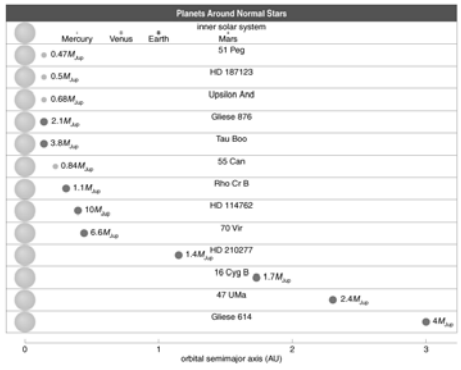
- The first extrasolar planets were indirectly "discovered" around this pulsar in 1992
- Extremely accurate modeling of subtle periodic changes in the pulsar's spin
- Strange place for planets!
  - A pulsar is the "dead" core of an exploded star
  - How did planets survive?
- Is the interpretation correct? If so, is this a typical system?



Planets Planets Planets!



- The Doppler shift method has been the most successful detection technique to date
- Planets have now been inferred around 250+ stars
- Most are in the 1 to 10 Jupiter mass range
- Most are *extremely* close to their star
- Many are in highly eccentric orbits
- An important question arises:
  - Is our solar system atypical???
  - Is this method overly biased towards "hot Jupiters"?



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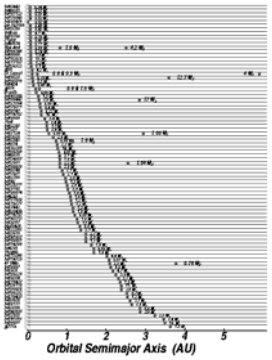
A recent "census" of extrasolar planets

- These are the planets inferred to be causing the observed Doppler shifts in the spectra of solar-type stars in the Sun's neighborhood
- These are also the *easiest* planets to find using the Doppler method...
- About 1000 stars surveyed so far within ~100 light years of the Sun



http://exoplanets.org/massradiiframe.html

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Implications for Life Out There...

- If there are many "Hot Jupiters" out there, are any likely to be hospitable to life?
  - Very high surface temperatures
  - Enormous gravity
  - Tidally synchronized orbit very close to star
- But maybe they have satellites?
- And a precious few have recently been found at more "reasonable" heliocentric distances...
- And over time, more smaller planets may be found
- What defines a star's "habitable zone"?

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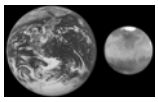
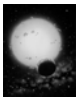
Habitable Zones



- Concept: Habitable Zone



- A *Habitable Zone* is defined as the distance from a star within which liquid water could exist stably
- Obviously depends on the size & temperature of the star and the atmospheric pressure of the planet

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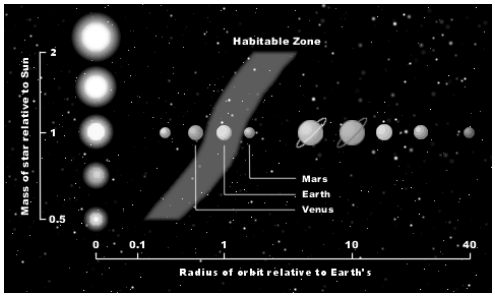

Example: Our solar system's habitable zone (the "Goldilocks" scenario...)

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Habitable Zones

- A *Habitable Zone* is defined as the distance from a star within which liquid water could exist stably
- Other factors also influence "habitability":
  - Gravity (hold an atmosphere but don't crush life...)
  - Rotation Rate (want stable day/night temperatures)
  - Tilt (don't want seasons too severe)
  - Eccentricity (don't want changes in sunlight too severe)
  - Heliocentric distance (don't want excessive tidal forces)
  - Age (want stability over *time* if life to flourish...)

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Planet detection uncertainties...

- The Doppler shift and astrometry methods do not actually measure the mass of an orbiting planet: they actually measure mass times the inclination of the orbit ($M \cdot \sin i$)
  - If the planet's orbit is edge on to us, ($M \cdot \sin i$) = M (good!)
  - If the orbit is highly inclined, ($\sin i$) < 1 and M could in fact be *much* larger than if ($\sin i$) = 1 (bad!)
- Implication: Some of the large Jovian planets may really be small binary star companions, rather than planets...
- Need other ways to determine/constrain inclination
  - Eclipses: must be 0° inclination
  - Observations of stellar surface features (just now becoming possible...)
  - Can see the star-like blackbody radiation from a stellar companion?

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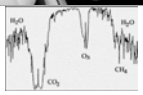
The future...



- Methods of *Direct* detection being explored
  - Problem is that the star is 10^6 to 10^9 brighter than any planetary companions!

- Best prospect is *interferometry*
  - Image stars at very high resolution using small telescopes to simulate one very large telescope (recall: resolution is proportional to diameter)
- Groundbased interferometry beginning now
- Space-based interferometry within 10 years?

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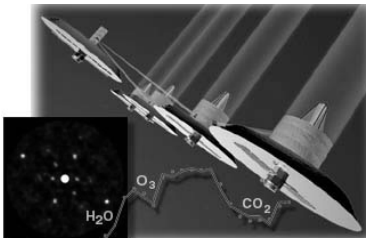
NASA's "Terrestrial Planet Finder"

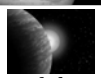
- Four 3.5 m space telescopes flying in formation in near-Earth space
- Provides resolution equivalent to a 75 m to 1000 m telescope!
- Launch: ???
- 5 year mission

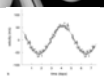


Theoretically, TPF *could* resolve Earth-sized planets around nearby solar-type stars and obtain spectra of the atmospheres of these planets...

But: many cost, technologic hurdles remain…

Summary





- Current observations and theoretical considerations suggest that extrasolar planets should exist
- Several methods for *indirect* detection of extrasolar planets have yielded compelling evidence for their existence... And more are announced every month
  - Stellar Doppler shifts provide most of the evidence
  - Eclipsing planets, pulsar planets, planets from astrometry
  - Results are surprising and unlike our solar system!
  - Are our theories wrong or are the methods biased?
- Prospects good for *direct* imaging of Earth-sized extrasolar planets within 10-15 years...

Next Lecture...

- Exobiology I
  - What is Life?
  - Case Study: Origin of Life on Earth
    - Data
    - Models
    - Experiments
- Reading: Chapter 24.1-24.3