Announcements



- WebWorK due on Wednesday
- Lab Group A tonight on Exoplanets
- Test 2 one week from Friday (Oct 26)!
 - I'll post study materials later this week
- No class Friday for Mid-Semester Day!
- Poll: rembold-class.ddns.net

In the News





In the News





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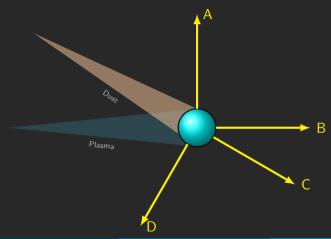




Review Question!



The comet below has grown tails as it nears the Sun. Based on the position of the tails, which arrow indicated the direction towards the Sun?

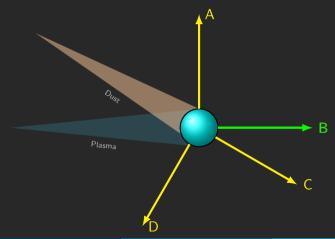


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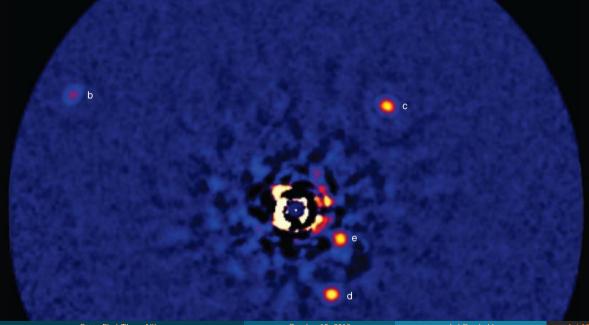
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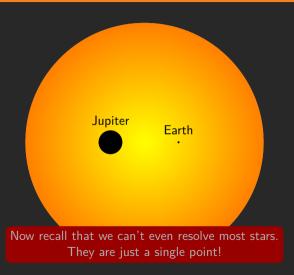


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Why are planets so hard to see?





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Tricky Measurements

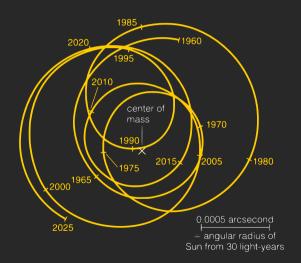


So how do we manage to look for planets outside the solar system?

Gravity Tugs!



- Recall that planets actually orbit the center of mass between the planet and Sun
- For most planets, this point is still inside the Sun, but it's not at the center of the Sun
- Hence you can get a bit of "wobble"
- Most effective for huge, quickly rotating planets
- How do we make sure precise measurements though?



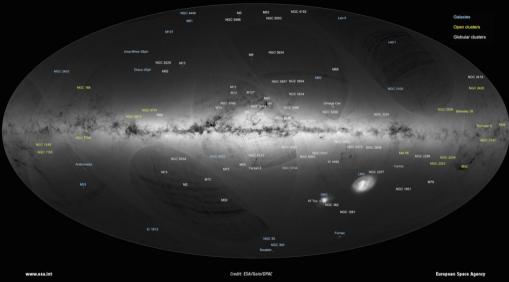
Astrometric Method



- Utilizes extremely careful measurements of a stars location against it's background stars
- We need a ridiculous level of precision
- More "obvious" planets would have longer orbits, meaning we'd need to observe them longer to see their effects
- Pretty limited so far, but ESA GAIA spacecraft in action!
 - Satellite hanging out at L_2
 - Need to know it's position to within 150 m every day!
 - Downloads more data than all three data centers can handle at peak times

→ GAIA'S FIRST SKY MAP





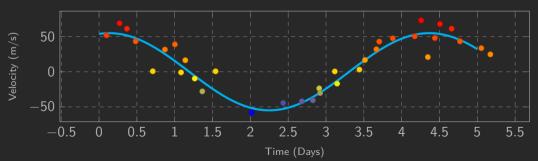
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Doppler Method



- Time to put our spectra to use!
- Blueshift means it's coming toward us, redshift away from us
- Works so long as we aren't looking at the system perfectly from above
- Orbital motion will give a sinesoidal pattern in velocity



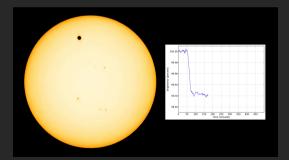


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Mass Transit



- Detecting the *tiny* change in brightness when a planet moves in front of a star
- Only works if we are seeing the system mostly "edge-on"
- Can sometimes also detect an eclipse (usually in infrared) when planet goes behind star
- Need to find regular dips in brightness with a regular period to be sure of a planet

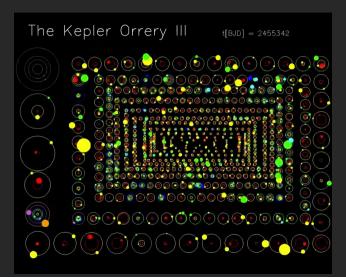


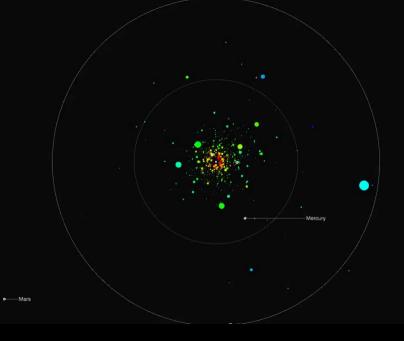
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Kepler! (More Machine than Man)



- The Kepler satellite's sole mission is detecting transits of exoplanets
- Findings thus far:
 - Candidates found: 4706
 - Confirmed Planets: 2330







What can we tell from discovered exoplanets?

Period of orbit: from any method



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- Distance from Star: from the period and Kepler's 3rd Law



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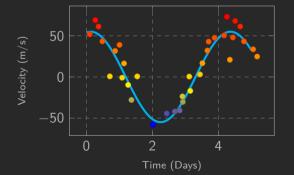


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- Composition/Temperature: from transits

The Mass



- Momentum is conserved for the star-planet system
- Can get the distance of the planet via Kepler's 3rd Law
- If we know the mass of the star, this means we can estimate the mass of the planet!

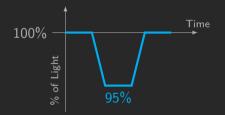


$$egin{aligned} M_{ extit{planet}} &= rac{M_{ extit{star}} extit{V}_{ extit{planet}}}{ extit{V}_{ extit{planet}}} \ &= rac{M_{ extit{star}} extit{V}_{ extit{star}} extit{P}_{ extit{planet}}}{2\pi \, a_{ extit{planet}}} \end{aligned}$$

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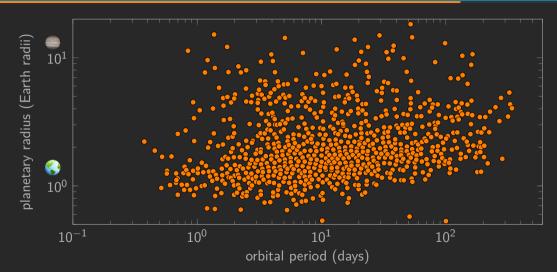
• The fraction of the light drop tells us the size of the planet as compared to the size of the star



% of Light
$$=$$
 $\frac{\text{Area of Planet}}{\text{Area of Star}}$ $=$ $\frac{\pi r_p^2}{\pi r_s^2}$ $=$ $\frac{r_p^2}{r_s^2}$

Characteristics of Exoplanets

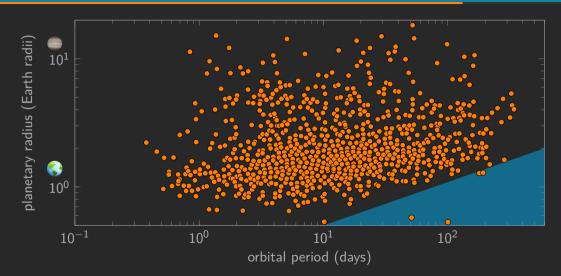




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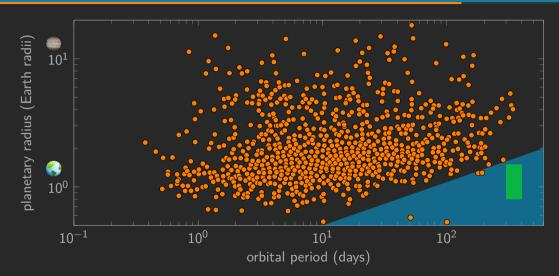
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Characteristics of Exoplanets





What We See



- Planets have a wide variety of densities:
 - Lightest the density of styrofoam
 - Heaviest the density of iron
- Planets have a wide variety of compositions:
 - Metal rich terrestrial worlds
 - H/He rich "Hot Jupiters"
- "Super Earths"
- "Water Worlds"
- Planets with multiple suns (Tatooine)
- Data suggests about a quarter of stars have exoplanet systems
 - Implies at least 50 billion planets in our galaxy alone!

Wrinkles in our Theories



- How do we explain "Hot Jupiters"?
 - Would seem contrary to our nebula formation/accretion methods
 - Nothing so far works better as a theory though
 - Planetary Migration?
 - Planet slowly loses energy through gravity waves in the early dust
 - Loss of energy would means its orbit shrinks
 - Some recent evidence to suggest this may indeed be happening