Astro 210
Lecture 26
October 25, 2010

Announcements
  Hour Exam 2 Friday
  similar setup, format, as last exam
  `www: exam info page`

Last time:
testing the solar nebula theory
Q: why do we look elsewhere to test theory for here?
Q: what does solar nebular theory predict for young stars? for mature planetary systems?

Young stars:
Q: what do we see?
Q: how does it square with the solar nebula predictions?

Solar Nebula Scorecard: Midterm Grades

General Predictions of Solar Nebula Theory

In forming stars (protostars):

1. young protostars have gas disk? **check!**
2. older protostars and fully formed stars have particle-bearing disk? **check!**

Solar Nebula Theory status:
Woo hoo! so far so good!
theory works up through disk formation
how about planets themselves?

recall Solar Nebula predictions:

- giant planets far from stars
- rocky planets close in
- orbits nearly circular

Test II: Exoplanets

Exoplanets = extra-solar planets = planets around outher stars
⋆ have been sought for centuries!
⋆ first positive, definitive dectection: 1994 (around dead star)
⋆ first detection around normal star: 1995

What took so long?
Exoplanet detection is a huge technical challenge
Q: Why?

Q: possible workarounds?

Challenges for Planet Hunters

Can't "just look" – glare!
feeble light from planet drowned out by star flux
$\rightarrow$ need a more clever workaround

Several detection techniques have been proposed
three of these have already borne planetary fruit!

Successful strategies thus far involve:

- look for planet(s) effect on host star
- get lucky
- both of the above

Planet Effects on Host Stars: Reflex Motion

recall Newton III: since star exerts gravity force on planet
planet *must* exert *same* force on star!

- *both* must accelerate! the star moves ("reflex motion")
  ...but $a = F/m \rightarrow a_\star \ll a_{\text{planet}}$
- both stars and planet orbit fixed "center of mass"

thus:

- the star moves too!
- what remains fixed is the center of mass
  a point on the line connecting the star and planet

consider two objects of equal masses $m_1 = m_2$

Q: where is center of mass?

Q: how do distances r_1, r_2 to COM compare?

iClicker Poll: Center of Mass

consider two objects of **unequal** mass $m_1 > m_2$
in orbit around their common, fixed center of mass

Where is the center of mass located?

A closer to the larger mass m_1

B closer to the smaller mass m_2

C exactly halfway beween the two masses

Center of Mass

Newton II: $a \propto F/m$
+ Newton III: $F_{p\,on\,\star} = -F_{\star\,\mathrm{on\,p}}$
$\Rightarrow$ F magnitude same, heavier object accelerated less
$\Rightarrow$ star moves slower, nearer to COM

• distances to center of mass:
total star-planet distance: $r_\star + r_\mathrm{p} = a$
and $m_\star r_\star = m_\mathrm{p} r_\mathrm{p}$
so: $r_\star / r_\mathrm{p} = m_\mathrm{p} / m_\star \ll 1$
$\Rightarrow$ and so $v_\star \ll v_p$ but $\neq 0$!

How to use this?
• in practice, can't track star orbit path – too small on sky
• but can look for "wobble" in star speed
1995: detection!

Planet Detection by Good Luck

if very lucky, planet orbit plane seen edge-on
so planet sometimes passes in front of star
⋆ causes partial eclipse of host star!
⋆ star dimming small but observable

Strategy: monitor light from candidate stars
look for brightness changes
as planet crosses ("transits") star's disk

Q: What is expected "light curve" of flux $F(t)$ vs time t?
Q: How to verify signal was due to a planet?
Q: How to use signal to learn about planet?

Extra-Solar Planets: Results to Date

to date: >350 exoplanets found around live stars!
$\gg$ # in solar system!

- most found via reflex motion
- a few now found via transits
  extra info available in these cases (HW 8)

What have we learned?
Getting the most from observable reflex motion

1. measure star P = planet P

Q: if I know the period, can I get more?

Exoplanet Properties: Decoding the Wobble

Exoplanet Observable: 1. Wobble Period P

Kepler, Newton: $a^3 = k(m_\star + m_p)P^2$ (HW: put in k and solve)

$\Rightarrow$ planet semi-major axis a!

`www: exoplanet census plot`

note power of Kepler's laws: get distance
without measuring directly, but just by studying wobble cycle

2. measure max wobble speed $v_\star$

Q: what does this tell us?

Exoplanet Observable: 2. Wobble Amplitude $v_\star$

wobble speed $v_\star \to$ planet mass

how? $v_\star =$ speed of star w.r.t. COM

diagram: star, planet speeds

$\vec{R}_{\text{CM}} = m_p/(m_p + m_\star)\vec{r}_p + m_\star/(m_p + m_\star)\vec{r}_\star = 0$, $r = r_p + r_\star$

$m_\star v_\star = m_p v_p$ mom. cons.

COM formulae $\to m_p$

Note: planet orbit plane can be tilted w.r.t. sky

Q: if so, how is observed $v_\star$ affected?

Q: if so, is planet mass overestimated or underestimated?

`www: exoplanet mass data`

Q: what is typical mass found so far? is this a surprise?

3. measure wobble speed pattern versus time

Q: what does this tell us?

Exoplanet Observable: 3. Wobble Change vs Time $v_\star(t)$

orbit eccentricity from shape of $v_\star$ vs t

if circular $\rightarrow$ perfect sinusoid

if eccentric: not sinusoidal

Q: recall Keplerian speed behavior–what's $v(t)$ for high e?

`www: 51 Peg Doppler curve, e=0.014`

`www: 16 Cyg Doppler curve, e=0.67`

`www: HD 860606, e=0.92! Found in 2001!`

at least $4M_J$, goes from $\sim$ 0.9 AU to 0.04 AU!

$\rightarrow$ range from 0 to 0.935!

not clear how to manage this!