Astro 210
Lecture 26
March 28, 2011

Announcements

- Good news: no homework due this week
- Bad news: Hour Exam 2 this Friday

  `www: info online`

Last time: tests of solar nebula theory

- young and forming stars and disks

  Q: what's predicted by solar nebula theory? what's observed?
- exoplanets around mature stars: detection methods
- reflex motion *Q: what's that? what does it tell you?*

  `www: simulations, data`

  what doesn't it tell you?
- transits *Q: what are they? what do they tell you?*

  `www: data`

Extra-Solar Planets: Results to Date

as of today:

- 538 exoplanets, 449 planetary systems
  $\gg$ planet count in solar system!
- 493 planets found via reflex motion
- of these, 177 found via transits
  ...but *Kepler* is monitoring > 1200 transit candidates!
- 21 planets found by direct imaging

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?

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!`

plenet mass $M > 4M_{\rm Jupiter}$,
moves between ~ 0.9 AU to 0.04 AU!

observed exoplanets eccentricities span range
from $e = 0$ to $e = 0.935$!

iClicker Poll: Exoplanet Non-Surprises

Of the following properties of exoplanets
discovered by techniques available to date...
which should **not** come as a surprise?
that is, couldn't have been any other way

A most exoplanet masses are large: $M \approx M_{\text{Jupiter}}$

B many exoplanets observed with large eccentricities $e > 0.2$

C exoplanet semimajor axes not too large: $a \leq 6$ AU

Exoplanets: Trends and Mysteries

No Surprise: new planets are massive
$\Rightarrow$ needed to get big, observable velocity wobble
if not massive, could not have found!
selection effect=bias: doesn't prove all planets massive
since couldn't find low mass with this technique
$\rightarrow$ largeness of detected mass is statement about detection method,
not about planet properties

Big Surprise: very short periods found
$\rightarrow$ planets are **very** near stars!
ex: τ Boo is 3.6 $\times$ Jupiter mass,
but closer than Mercury's orbit!
nothing like our Jovian planets! "hot Jupiters"

`www: exoplanet fraction vs heavy element content of host star`
Q: what does this mean?

Exoplanet Trends Continued

Role of heavy elements

- planets more common around stars with high levels of heavy elements (“metals”)

$\rightarrow$ clues to formation...

Multiple-Planet Systems

- dozens multiple-planet systems seen thus far

Planet Sizes

- in transiting systems can find planet size around that of Jovian planets $\rightarrow$ density $<$ rocky, iron
  $\rightarrow$ these are gas giants, not terrestrial!
- since 2009: about 20 “super-earths” found mass $\leq 10 M_{\oplus}$

Exoplanet Trends Continued

Masses

more massive planets easier to find

larger star reflex motions, larger transit eclipses

$\Rightarrow$ first discoveries all Jupiter mass or more

but as techniques have improved,detect smaller masses

now:

Atmospheres

atmospheres detected for a few transiting planets

$\rightarrow$ only possible for close-in giants in transiting systems

Q: how would this work?

results:

- "hot Jupiters" have gaseous atmospheres
- hydrogen, water vapor, sodium detected
- evidence for clouds, atmospheric circulation!

Spins

for some transiting planets, can measure spin vs orbit angle
i.e., equivalent of Earth's 23.5° tilt

results:

still very new, but trends seem to be

- spins found at wide range of obliquity angles
  $\rightarrow$ no clear preference for spin alignment with orbit axis!
  appears to sharply contradict solar nebula theory

The Habitable Zone

habitable zone defined as:
region around a star
  where planets can contain liquid water
Q: is this a reasonable definition? alternatives?

last semester–candidate habitable zone planet: Gleise 581g
host star is not solar like, but low-mass "M dwarf"
5th planet found around star, via reflex motion
  have to subtract wobble effects of other planets
but even more recently: competing group redid subtraction
  not assuming circular orbits, no evidence for GL 581g!

Q: lessons?

Exoplanet Statistics: As of Jan 2011

after searching nearby stars, can compare:
stars with planets found via reflex motion
vs total stars searched
ratio gives fraction/percentage of planet-bearing systems

Results

⋆ about $\approx 10\%$ of solar-type stars
have planets of masses (0.3 to 10)$M_{\rm Jupiter}$
and orbital period $P = 2 - 2000$ days

⋆ extrapolation of observed trends suggests
about $\approx 20\%$ of stars have gas giants at $a \leq 30$ AU

Q: what does this tell us? not tell us? possible biases?

Q: what does all of this mean for solar nebula theory?

Extra-Solar Planets: Implications

Solar Nebula theory: giant planets born far from star
Data: Giant exoplanets found very close
$\Rightarrow$ Theory is incomplete/wrong!

New Planets, New Questions:

1. Who is normal: them or us?
e.g., maybe SS is common, but
others more likely to be found by this technique
Note: current techniques can only now see Jupiter around
nearby star using this method

2. What's up with the very close orbits?

Maybe some giant planets born close in?

Q: why would this be surprising?

Maybe some giant planets be born far, move in?

if so: what stops them from falling into star?

`www: planet eating sketch`

recent **`www: Hubble`** evidence this happens!

3. How to get large eccentricity?

exoplanets show no preference for circular orbits

average exoplanet eccentricity $>$ *all* solar system planets!

Why no large e in SS?

Breaking News: The Kepler Revolution

`www: NASA Kepler` space mission recently launched
precision monitoring of thousands of stars for transits

Feb. 2, 2011: *Kepler* announces discover of

- **1235** planet candidates
- correcting for bias due to edge-on geometry:
  $> 33\%$ of stars have one or more planets!
- planet radii: span earth sized to Jupiter-sized
  `www: size distribution`

Q: why are these numbers important?

- **54** candidates are in the habitable zones
  of their host stars
- the first 6-planet system found

Exoplanets: The Future

Kepler will take time to check for "false positives"
which will be about $\sim 20\%$ of the candidates
so ~ 1000 confirmed planets will be found!
$\rightarrow$ more major announcements expected soon

much excitement,
will play major role in Astrophysics in upcoming decade

Anyway: planets common.
$\Rightarrow$ good news in search for life elsewhere...

Stay tuned!