Astro 210

Lecture 24

March 14, 2018

Announcements

- **HW7 due online in PDF, Friday 5:00 pm**
- Office hours: instructor 2:00-3:00 pm today
  TA: 3:30-4:30 pm tomorrow (yay!)
- **Night Observing this week**
  Campus Observatory. Tonight, tomorrow **8–10 pm**
  note later times–solstice approaches!
  bring **report form** available on Moodle
  take and submit **selfie** while there

Theory of Solar System Origin: Executive Summary

stars born in cold gas & dust clumps: molecular clouds
"gravitational collapse": runaway contraction

angular momentum: centrifugal barrier to collapse
most matter $\rightarrow$ proto-Sun
high-angular momentum matter: protoplanetary disk around sun

gas ρ, matter state (presence of ices) change with R
water/ice "snow" line at $R_{\mathrm{snow}} \sim 3$ AU:
Inner/Outer planet boundary!

Disk Gaps and Planets

As proptoplanets/planets arise in a disk
their gravitation influence can clear out disk material
in the disk annulus around the planet's orbit radius

so the protosolar nebular theory predict: a protoplanet/planet
can create a *gap* in the disk

Note: small "shepherd" moons maintain gaps in Saturn's rings!

Q: what observable predictions does Solar Nebula theory make for young stars, mature planet-bearing stars?

Testing Solar Nebula Theory

This is a special time!

Now seeing planets, planet formation around other stars

Solar Nebula theory should work generally
$\longrightarrow$ should apply to these systems too
...though some details might vary *Q: why?*

General Predictions of Solar Nebula Theory

In forming stars (protostars):

1. young protostars have gas disk
2. older protostars have planetesimal disk
3. protoplanets can open gaps in disks

In fully-formed star and planet systems:

1. small planets near star
2. massive planets farther away
3. orbits nearly circular
4. orbit planes near stellar equator

Problem: solar nebula theory built to explain one data point (SS)! $\rightarrow$ is the model "fine–tuned"?

iClicker Twofer: Bets on Planet Formation

Vote your conscience!

Which prediction seem most solid to you?

- A young protostars have gas disk
- B older protostars have planetesimal disk
- C small planets near star
- D massive planets farther away
- E planet orbits nearly circular

In same list: which prediction seems least solid?

Test I: Young Stars

evidence from direct imaging:
50% – 100% of youngest stars surrounded by gas disk
disks are common and perhaps unavoidable!

`www:  Orion HST montage`
`www:  protoplanetary disks in Orion`
`www:  Orion disks set of 4`
`www:  Orion disks side view (really disks)`

disks thick, blocks light
$\rightarrow$ enough material to make planets
$\rightarrow$ agrees with Solar Nebula theory!

evidence for disk formation!
Orion objects: “proplyds” = protoplanetary disks

Dusty Disks

Some older protostars and fully-formed have spectrum that has two peaks → two temperatures
- optical emission from the hot surface of star, and
- infrared emission from dust in disk!

Recently: can *image* the disks in the infrared
warm dust: small (mm-sized) particles heated by star → thermal IR

`www:` β `Pic disk w/star`

`www: ALMA: HL Tau, TW Hyd`

ALMA in Chile is most powerful mm-wave telescope
has revolutionized study of planet formation
- disks seen with multiple gaps!
- disks seen in binary proptostars (each star has disk)

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!**
3. gaps found in some disks? **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
- orbit planes near stellar equator

Test II: Exoplanets

Exoplanets = extra-solar planets = planets around other stars
⋆ have been sought for centuries!
⋆ first positive, definitive detection: 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
$\longrightarrow$ 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 $a = F/m \rightarrow a_\star \ll a_{\mathrm{planet}}$
- 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?

Center of Mass Reminder

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: Transits

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?