Astro 210

Lecture 23

October 18, 2010

Announcements

- HW 7 due Friday
- Night Observing due Friday
- Night Observing raindates: tonight & tomorrow
  info and schedule online
- no class meeting Wednesday!

Last time: finished Solar System tour

Pluto & Kuiper belt *Q: what's the connection?*

Origin of the Solar System

theory building!
recall: geocentric/heliocentric theories...

Input solar system data, laws of physics

Output: Model
sequence of events, predictions for evolution up to present

3-Minute Essay #2

List patterns in the solar system to be explained by a theory of solar system origin.

Include at least:

- one property common to all planets, and
- one property in which classes of planets differ.

Solar System Data to be Explained

orbits, spins

- planet orbits in ecliptic plane
- rough spin/orbit alignments
- but some spins misaligned

Terrestrial/Jovian differences:

composition

location

size

spacing

debris: comets, asteroids

Theory of Solar System Origin: Protosolar Nebula

stars born in cold gas & dust clumps: molecular clouds
Q: what's dust, in astro context?
`www: HST Eagle Nebula`

Initial protosolar material a small parcel of larger cloud
- cold gas & dust
- spinning: net angular momentum $\neq 0$
  Q: why is $\vec{L} \neq 0$ a reasonable assumption?

For simplicity: imagine first a cold cloud
with *zero* spin
i.e., *zero* angular momentum

Q: forces on particles in cloud?
Q: response of particles to these forces?

Q: why is coldness important for this to work?

Gravitational Collapse

ignoring spin:
particles in cold cloud feel forces of

- gravity
- thermal pressure

but if cloud is cold: T low, prssure $P = \rho kT/m_{\text{particle}}$ small
$\rightarrow$ only important force is gravity

diagram: cloud $\rightarrow$ collapse
gravity $\rightarrow$ inward motion $\rightarrow$ denser $\rightarrow$ stronger gravity
$\rightarrow$ runaway!
"gravitational collapse"

Q: why doesn't collapse continue until all matter $\rightarrow$ point?

iClicker Poll: Contraction of a Spinning Swarm

Consider a swarm of particles, spinning around an axis

Which is easier?

A moving a particle *parallel* to spin

$\downarrow$ toward midplane

B moving a particle *perpendicular* to spin

$\leftarrow$ toward spin axis

C both motions equally easy

Nebular Collapse: Birth of Sun and Disk

indeed, most matter compressed $\to$ central "proto-Sun"

but real pre-stellar clouds are clumpy parts of larger nebulae
$\to$ turbulent motions
$\to$ clumps have random but nonzeror spins: $\vec{L}_{\text{init}} \neq 0$

spin $\to$ axial but not spherical symmetry
describe with cylindrical coordinates (r, θ, z)

$\to$ collapse not spherical
angular momentum "centrifugal barrier" along R, but not z
$\Rightarrow$ collapse easier along z
$\Rightarrow$ protoplanetary disk
diagram: disk

∞

disk $\to$ planet & debris orbit planes, spin axes

Protoplanetary Disk

protosolar material with highest angular momentum
"spared" from going into Sun $\rightarrow$ remains as orbiting disk
disk ingredients: mostly H and He gas
with "sprinkle" ($\sim$ 2% by mass) of microscopic dust
disk motion: feels gravity of proto-Sun
$\rightarrow$ moves in Keplerian orbits
non-circular velocity components $\rightarrow$ 0 *Q: why?*

due to T drop with distance R from Sun:
gas ρ, matter state (presence of ices) change with R *Q: how?*
what physical effects important for ice formation?

disk velocities: matter interactions occur
with non-circular (i.e., radial) velocity components
i.e., elliptical radial motions lead to collisions/heating: friction

- frictional drag forces drive radial motions to zero
- protosolar disk circularized $\rightarrow$ low-eccentricity planet orbits

temperature gradients and disk structure
hotter near (proto)Sun, cooler farther away

- higher gas presser closer: gas disk "puffier" nearby

what about solids? dust, ice?
key: condensation gas $\rightarrow$ solid

- rocks, metals $T_{\rm cond} \sim 1000 - 2000$ K high!
- ice: $T_{\rm cond} \sim 100 - 200$ K low!

Q: so what does this mean for what kinds of solids form where?

water/ice "snow" line at $R_{\text{snow}} \sim 3$ AU:
Inner/Outer boundary!

- $< R_{\text{snow}}$: only dust (rocky material) can exist as a solid (no ice): limited raw material
  $\rightarrow$ small, rocky planets formed there
- $> R_{\text{snow}}$: lighter elements (water, CO_2) can also exist as a solid (along with dust)
  $\rightarrow$ more raw material available $\rightarrow$ larger protoplanets

$\Rightarrow$ origin of Jovian/terrestrial composition differences!