AST SPECIAL TOPICS: EXOPLANETS
MISC. LECTURE NOTES: SPRING 2015

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Week 3: Star formation and protoplanetary disks

Star formation: the briefest overview ever.

- CO and dust: the observational view of star formation sites in the Galaxy
  - In terms of composition and mass, star-forming clouds are mostly cold ($T \sim 10 - 100$ K) H_2 — but you can't detect it! (*Why?*) So emission from CO, the next most abundance molecule (N(CO):$N(H_2) \sim 10^{-4}$), is used as a proxy for (tracer of) H_2[1].
  - First all-sky survey of CO in the Galaxy (and more recent update) were by Dame et al. (1987. 2001):
    `http://www.cfa.harvard.edu/mmw/MilkyWayinMolClouds.html`
    Planck Mission's updated CO map:
    `http://planck.ipac.caltech.edu/image/planck15-002c`
  - Because the typical gas/dust ratio in molecular clouds is ∼100, cold dust is another proxy for the distribution of Milky Way molecular (cloud) mass[2]:
    `http://planck.ipac.caltech.edu/image/planck15-002b`
- Relevant size & mass scales for star formation: conceptually, the Jeans radius & mass help here. For a self-gravitating cloud, one can balance kinetic & potential energy , since the former should just "outweigh" the latter for collapse to commence. The Jeans radius then falls right out as

  $$R_J \sim (\frac{\pi k T}{\mu m_H^2 G n})^{1/2}$$

  where T and n are the typical temperature and density of a molecular cloud. Try plugging in numbers like $T = 30$ K, $n = 10^4$ g cm^{-3} and $\mu = 2$ (why?) and see what you get for R_J. ($R_J \sim 1$ pc?)

[1] This will be very important soon, when we discuss protoplanetary disks.
[2] This will be very important soon, when we discuss protoplanetary disks.

The Jeans mass is then just

$$M_J \sim \frac{4\pi}{3} R_J^3 m_H n$$

So, typical Jeans masses for the conditions above ($T = 30$ K, $n = 10^4$ g cm^{-3} and $\mu = 2$) are a few $\times 10^4$ $M_\odot$. Again, don't believe me on this...plug in numbers and check.

- Some relevant timescales to ponder

Free-fall timescale: start from gravitational force exerted on a particle of mass m at radius r within a cloud of total mass M spread over a radius R:

$$ma(r) = -\frac{GmM(r)}{r^2}$$

hence

$$\frac{d^2r}{dt^2} = -\frac{GM(r)}{r^2}$$

hence (dimensionally)

$$-\frac{R}{t^2} \approx -\frac{GM(r)}{r^2}$$

hence

$$t_{ff} \approx (\frac{R^3}{GM})^{1/2}$$

Plug in numbers for R, M: t_{ff} ~1600 s for present-day Sun; $t_{ff} \sim$ a few $\times 10^2$ for solar-mass cloud w/ $R \sim 1$ AU; $t_{ff} \sim 10^5$ yr for a solar-mass cloud the size of the Oort cloud (check me, on the last estimate!)

Kelvin-Helmholtz timescale: During pre-main sequence evolution, stars are producing all of their luminosity via (a) release of gravitational potential energy and (b) accretion of fresh material from their disks. Mechanism (a) is governed by the K-H timescale. Start from available gravitational potential energy for a star of mass M and radius R:

$$\Omega \approx -\frac{GM^2}{R}$$

and then (from simple dimensional analysis) the Kelvin-Helmholtz timescale is given by

$$t_{KH} \approx \frac{\Omega}{L_\star}$$

For a ~1 $M_\odot$ star of a few $R_\odot$ shining at a few $L_\odot$ — see typical pre-MS evolutionary tracks (discussed later!) — the K-H timescale is a few million to tens of millions of years (again, check me!).

- The Shu et al (1987, ARAA, 25, 23) cartoon summary of the four main stages of star (and planet) formation — Fig. 7 — was long the "industry standard": `http://www.annualreviews.org/doi/pdf/10.1146/annurev.aa.25.090187.000323` It's worth thinking about this cartoon in the context of the size, mass, and time scales just discussed.
- The observational analog to the Shu cartoon is the Class 0/I/II/III protostar/pre-MS star classification system, which is based solely on the slopes of infrared spectral energy distributions (plus the ratio of submm/far-IR flux to bolometric flux, in the case of Class 0). A recent (observational) review/analysis of this system in the context of Spitzer and Herschel imagery & photometry is included in Dunham et al.'s (2014) review in Protostars & Planets VI: `http://arxiv.org/pdf/1401.1809v2.pdf`
- Pre-MS evolutionary tracks — i.e., paths of pre-MS stars of a given mass in the H-R diagram, prior to H detonation — provide the means to translate the age since "formation" of a (proto)star of given mass to its observable properties, i.e., protospheric temperature and luminosity. Examples abound in the literature; Fig. 4 in Shu et al. (1987; see above), though very old and out of date, is good for purposes of illustration.

No wait: this overview of protoplanetary disks will be the briefest overview ever.

- Will probably present highlights (i.e. equations) from Calvet & d'Alessio chapter in book "Phys Proc in CS Disks around Young Stars" plus...
- summarize disk structure paper(s) such as Gorti et al. (2011)
- describe observed properties of a well-studied disk(s) (e.g., TW Hya) in some detail

Week 4: Evolution of protoplanetary disks

- DIGRESSION: how do we determine stellar ages (not to mention masses & temperatures)? Will probably briefly walk through Soderblom's (2010, ARAA) review
- Will probably present closely follow Williams & Cieza's (2011) ARAA review, "Protoplanetary Disks and Their Evolution"

Week 5: Giant planet formation

Week 6: Terrestrial planet formation