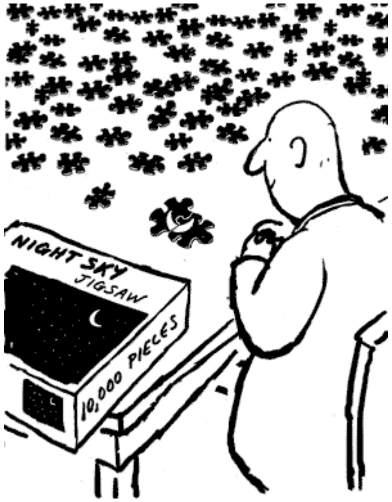
Observational ISM and Star Formation



This Class (Lecture 14):
Kristen Samuels/Britt Lundgren

Next Class:

Nick Indriolo/Alfredo Zenteno

Music: *Rocket Man* – Elton John

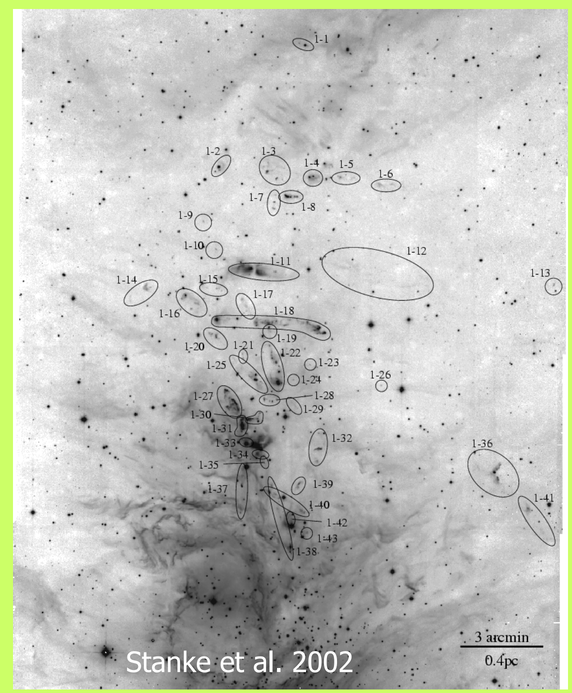
Outline

- Outflows, outflows, outflows
- Disks (SEDs)

Remember Outflows?

- Outflows and jets are ubiquitous and necessary in star formation.
- They transport angular momentum away from protostar.
- The are likely formed by magneto-centrifugal disk-winds.
- Collimation is caused by Lorentz forces.
- Gas entrainment can be due to various processes: turbulent entrainment, bow-shocks, wide-angle winds, etc…
- They inject significant amounts of energy in the ISM, may be important to maintain turbulence.
- They disrupt their maternal clouds, eventually.

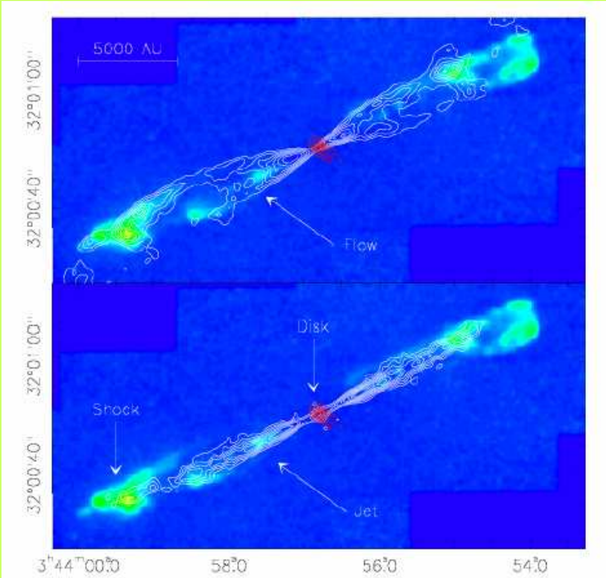
Outflows in Orion: Impacts?



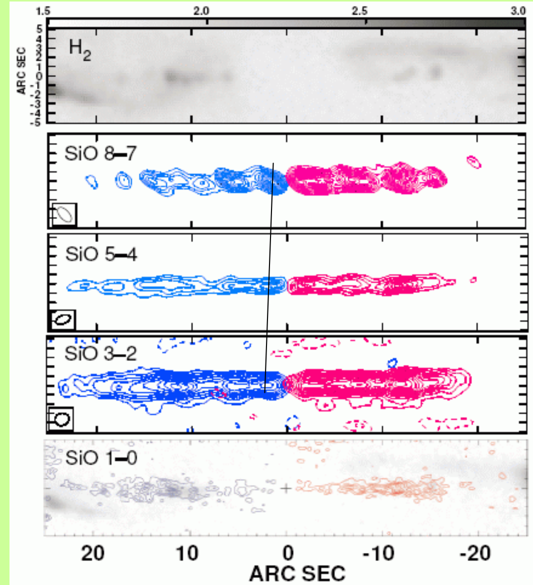
Stanke et al. 2002

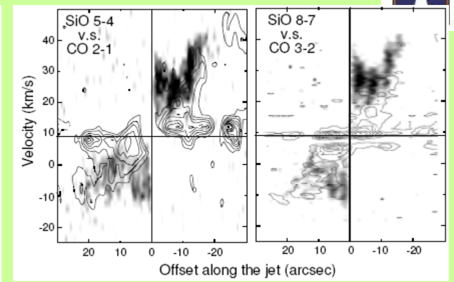
HH211

- Nicely seen in both H_2 and molecules.
- Panels show gas at 2 different velocity ranges: low (top) and high (bottom)
- Gueth et al. 1999



Jet Entrainment in HH211





- Warmer gas closer to source
- Jet-like SiO emission always at larger velocities than CO at the same projected distance

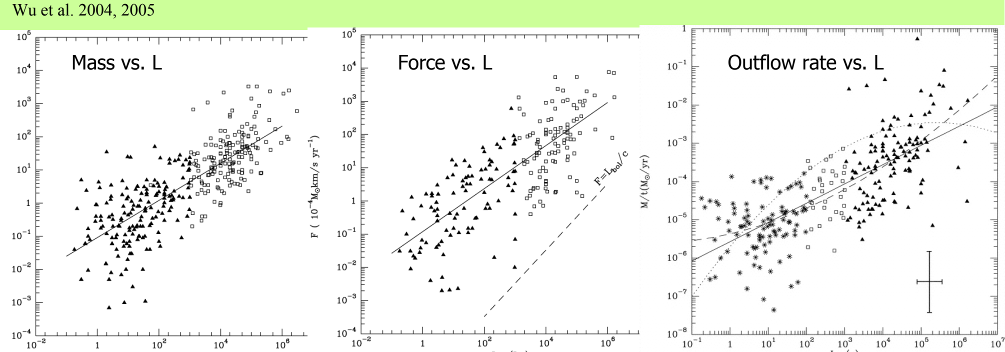
From Hirano et al. 2006, Palau et al. 2006, Chandler & Richer 2001, Gueth et al. 1999, Shang et al. 2006

http://www.mpia.de/homes/beuther/lecture_ss05.html

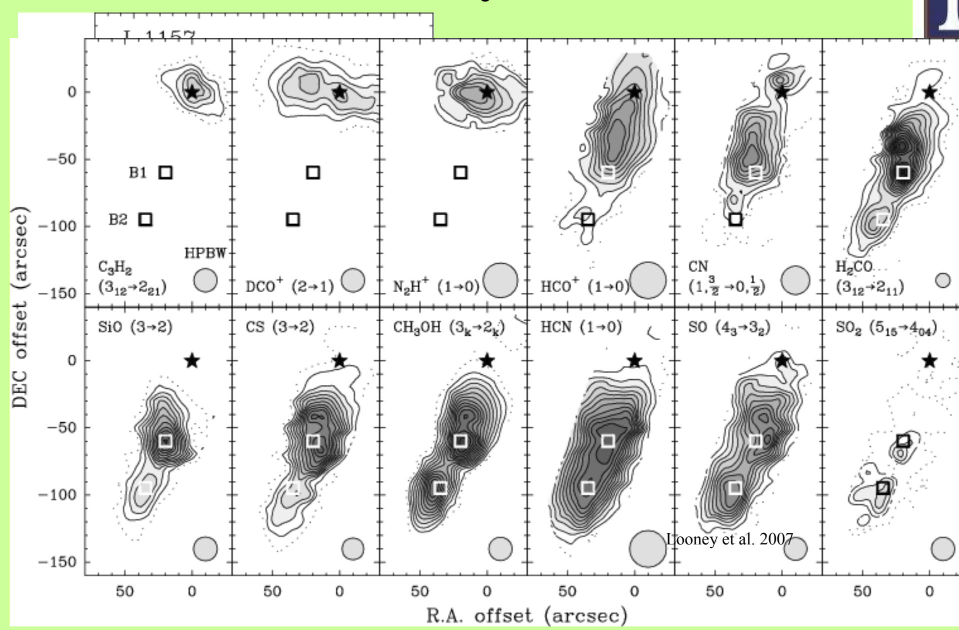
General Outflow Properties

- Jet velocities 100-500 km/s ⇔ Outflow velocities 10-50 km/s
- Estimated dynamical ages between 10^3 and 10^5 years
- Sizes between 0.1 and 1 pc
- Force provided by stellar radiation too low (middle panel)
  → non-radiative processes necessary!

Wu et al. 2004, 2005

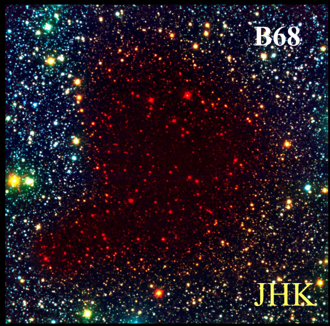


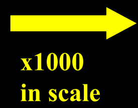
Chemistry: L1157

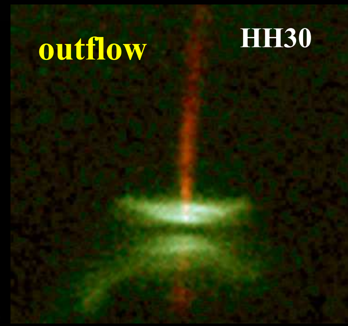


Bachiller et al. 2001

How are stars and planets made?

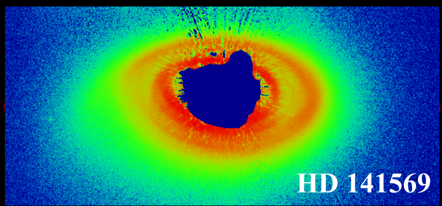






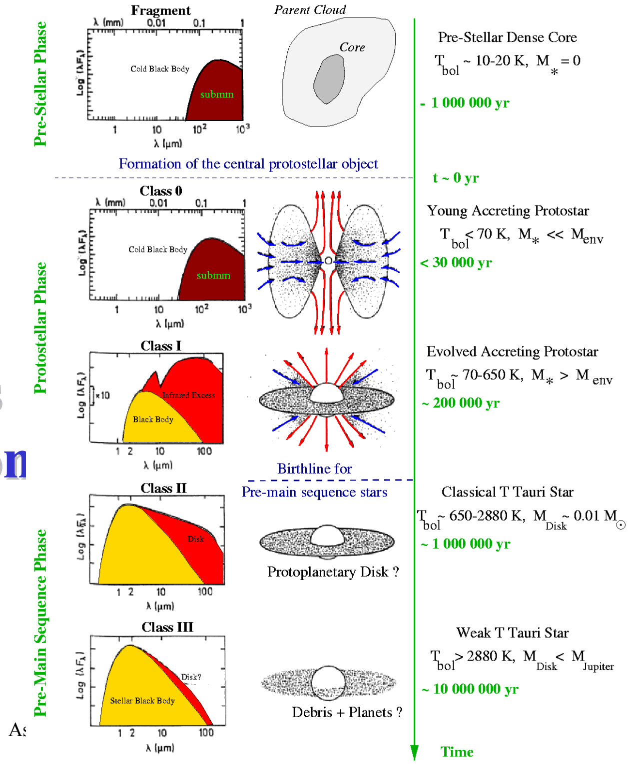
Cloud collapse

Rotating disk



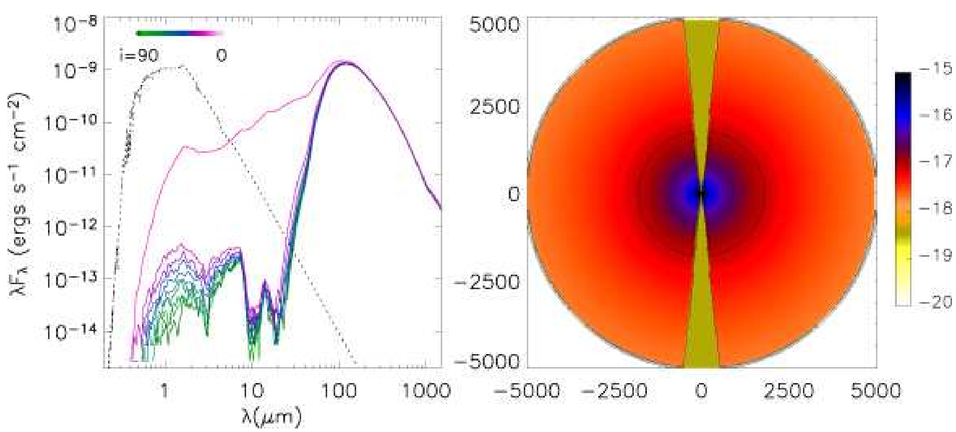
Planet formation

Cartoon of Low-Mass Star Formation



http://www.mpia.de/homes/beuther/lecture_ss05.html

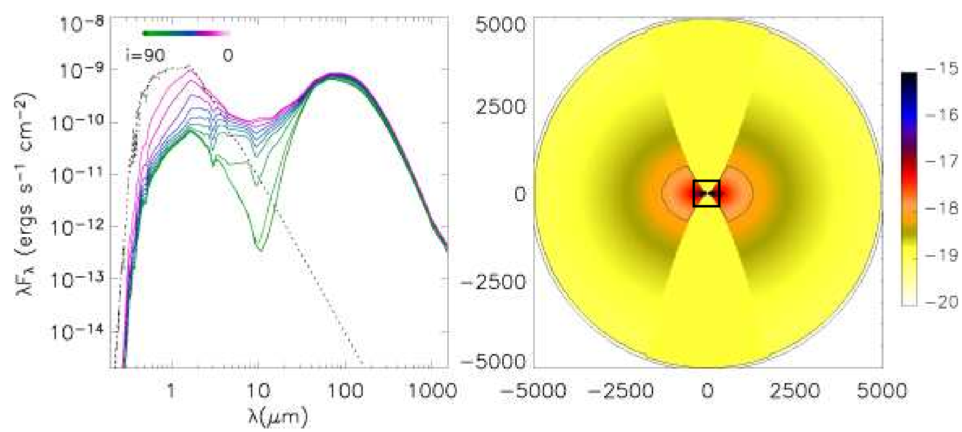
Collapsing Cloud + Star + Disk



Class 0

Whitney et al. 2003

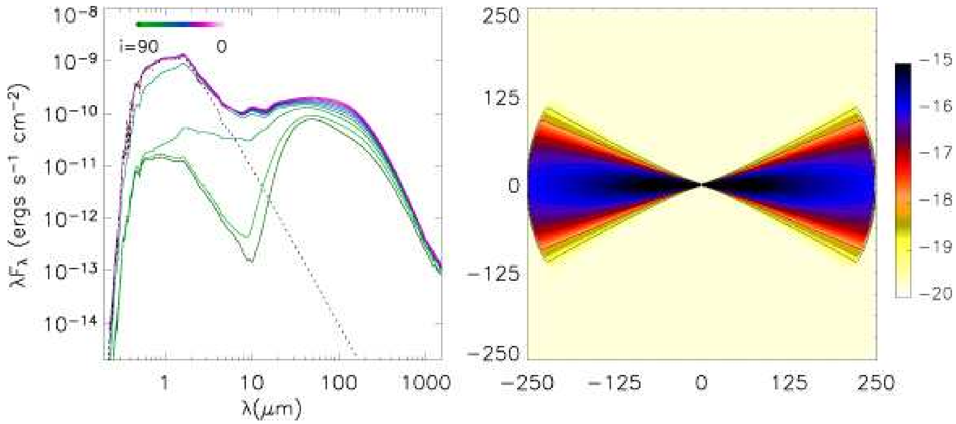
Collapsing Cloud + Star + Disk



Class I

Whitney et al. 2003

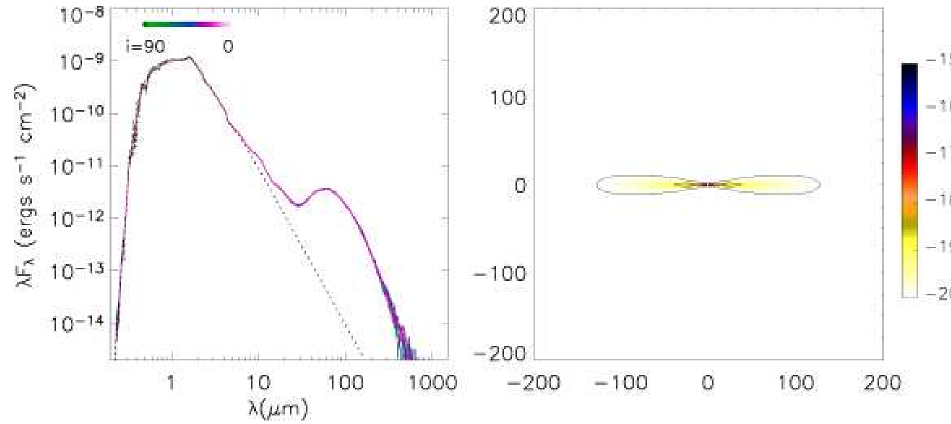
Collapsing Cloud + Star + Disk



Class II

Whitney et al. 2003

Star + Disk

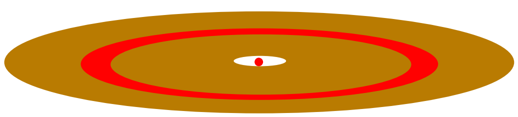


Class III

Whitney et al. 2003

Multi-Color Blackbody Disk SED

Let's play with a simple perfect blackbody disk (no dust properties)



$$I_\nu(r) = B_\nu(T(r))$$

Take an annulus of radius *r* and width *dr* covers a solid angle:

$$d\Omega = \frac{2\pi r dr}{d^2}\cos i$$

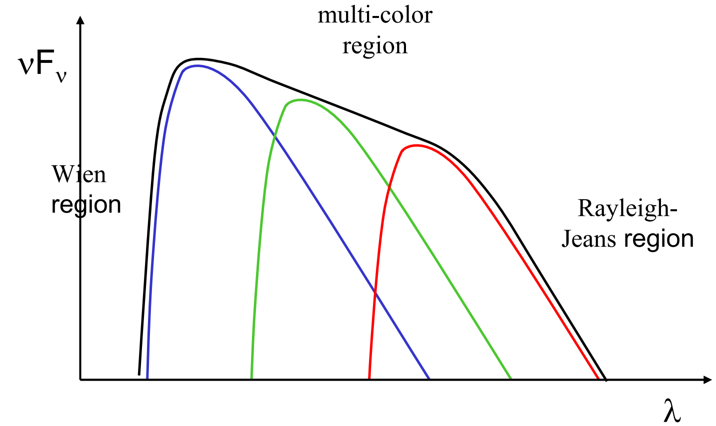
and flux is:

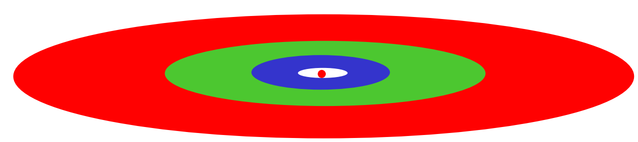
$$F_\nu = I_\nu d\Omega$$

Total flux observed is then:

$$F_\nu = \frac{2\pi \cos i}{d^2}\int_{r_{in}}^{r_{out}} B_\nu(T(r))\, r dr$$

Multi-Color Blackbody Disk SED



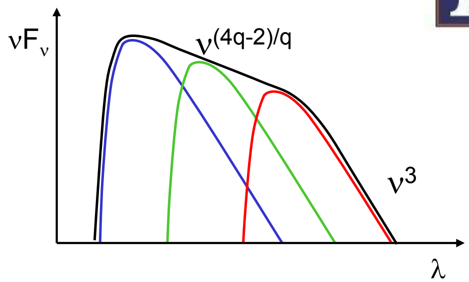


Multi-Color Blackbody Disk SED

Rayleigh-Jeans region:

Slope is the Planck function:

$$\nu F_\nu \propto \nu^3$$



Multi-color region:

Assume a temperature profile of disk:

$$T(r) \propto r^{-q} \longrightarrow r \propto T^{-1/q}$$

Emitting surface: $S \propto r dr \propto r^2 \propto T^{-2/q} \propto \nu^{-2/q}$

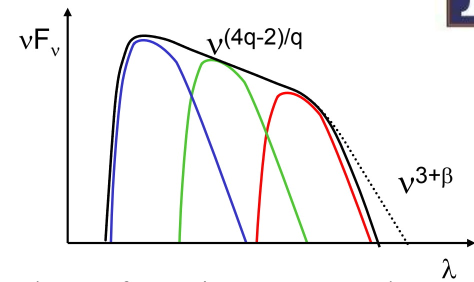
Peak energy Planck: $\max(\nu B_\nu) \propto T^4 \propto \nu^4$

Location of peak Planck: $\nu \propto T$

$$\rightarrow \nu F_\nu \propto S \max(\nu B_\nu) \propto \nu^{-2/q}\nu^4 = \nu^{(4q-2)/q} \longrightarrow \boxed{\nu F_\nu \propto \nu^{(4q-2)/q}}$$

Disk with finite optical depth

Multi-color part stays roughly the same, because of energy conservation



Rayleigh-Jeans part modified by slope of opacity. Suppose that this slope is:

$$\kappa_\nu \propto \nu^\beta$$

Then the observed intensity and flux become:

$$I_\nu(r) = (1 - e^{\tau_\nu}) B_\nu \approx \tau_\nu B_\nu \propto \kappa_\nu B_\nu$$

$$\boxed{\nu F_\nu \propto \kappa_\nu \nu B_\nu \propto \nu^{3+\beta}}$$