Protostars and pre-main-sequence stars

Jeans' mass - minimum mass of a gas cloud of temperature T and density ρ that will collapse under gravity:

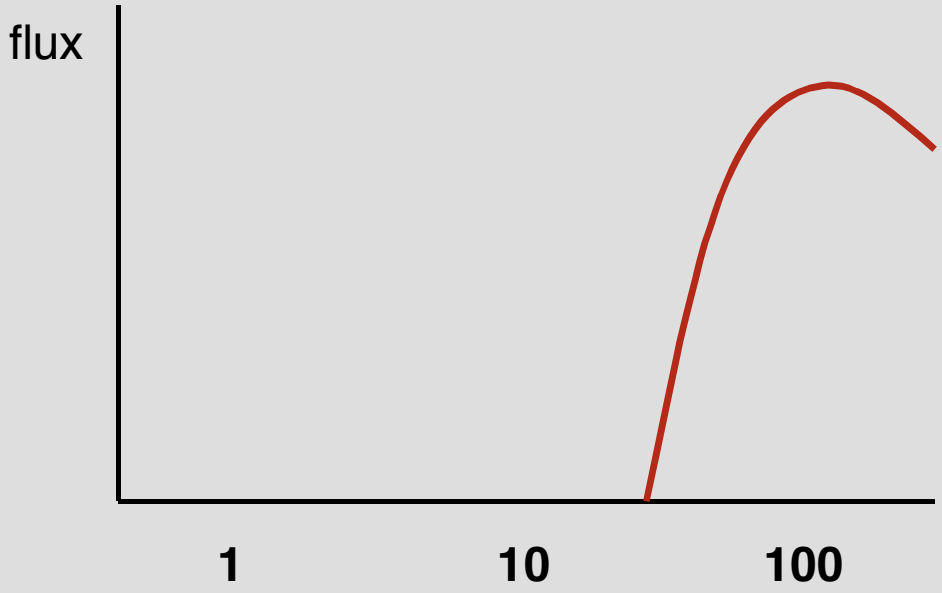
$$M_J = \left(\frac{R_g}{G}\right)^{3/2} \left(\frac{3}{4\pi}\right)^{1/2} T^{3/2} \rho^{-1/2}$$

Several stages of collapse:

- Initial isothermal collapse - still optically thin
- Collapse slows or halts once gas becomes optically thick - heats up so pressure becomes important again
- Second phase of free-fall collapse as hydrogen molecules are broken up - absorbs energy and robs cloud of pressure support
- Finally forms protostar with radius of 5 - 10 R_{sun}

All this happens very rapidly - not easy to observe

Observationally, classify young stellar objects (YSOs) by looking at their **spectral energy distributions** (SEDs). Four main classes of object have been identified:

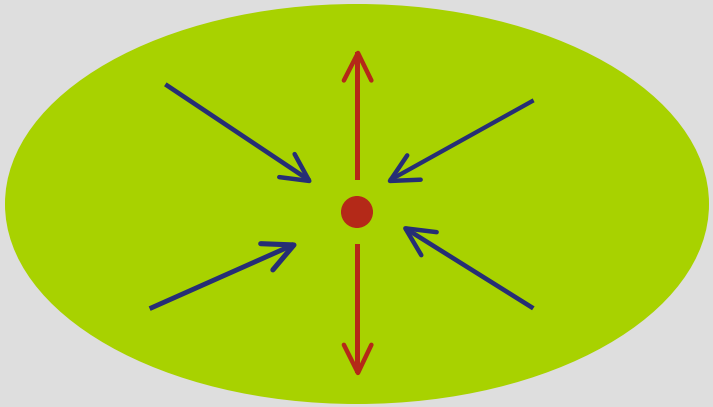


Class 0 source

Observationally, this is a source whose SED peaks in the far-infrared or mm part of the spectrum. No flux in the near-infrared (at a few microns). Effective temperature is several 10s of degrees Kelvin.

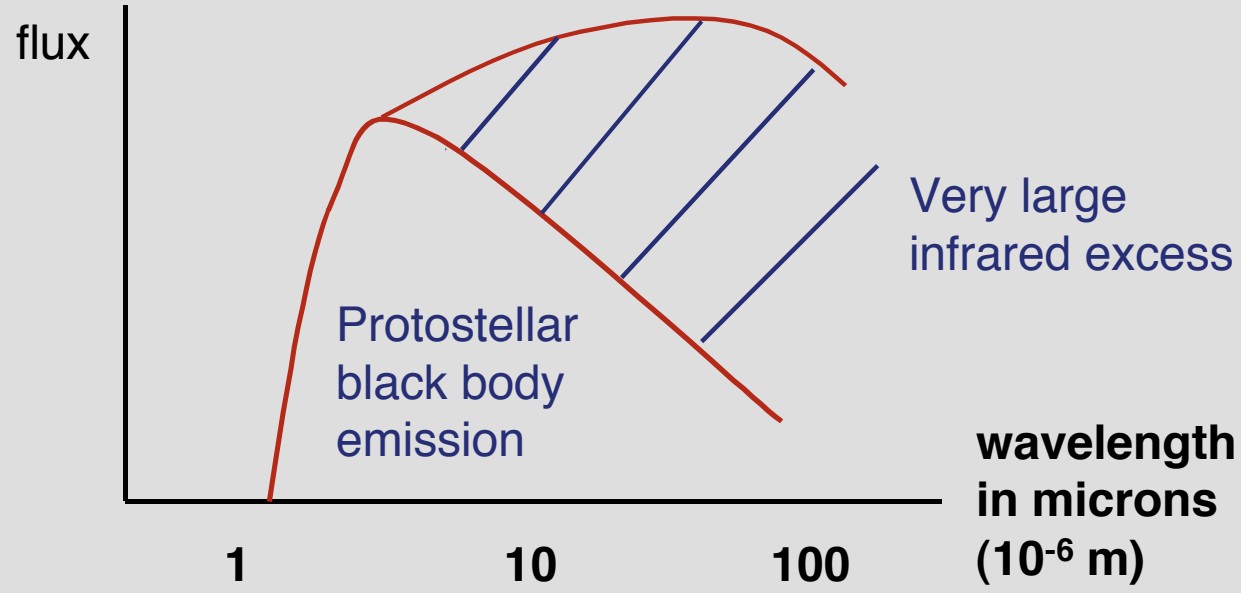
What are Class 0 sources?

- Still very cool - not much hotter than molecular cloud cores. Implies extreme youth.
- Deeply embedded in gas and dust, any shorter wavelength radiation is absorbed and reradiated at longer wavelengths before escaping.
- Fairly small numbers - consistent with short duration of the initial collapse.
- Outflows are seen - suggests a protostar is forming.



Earliest observed stage of star formation…

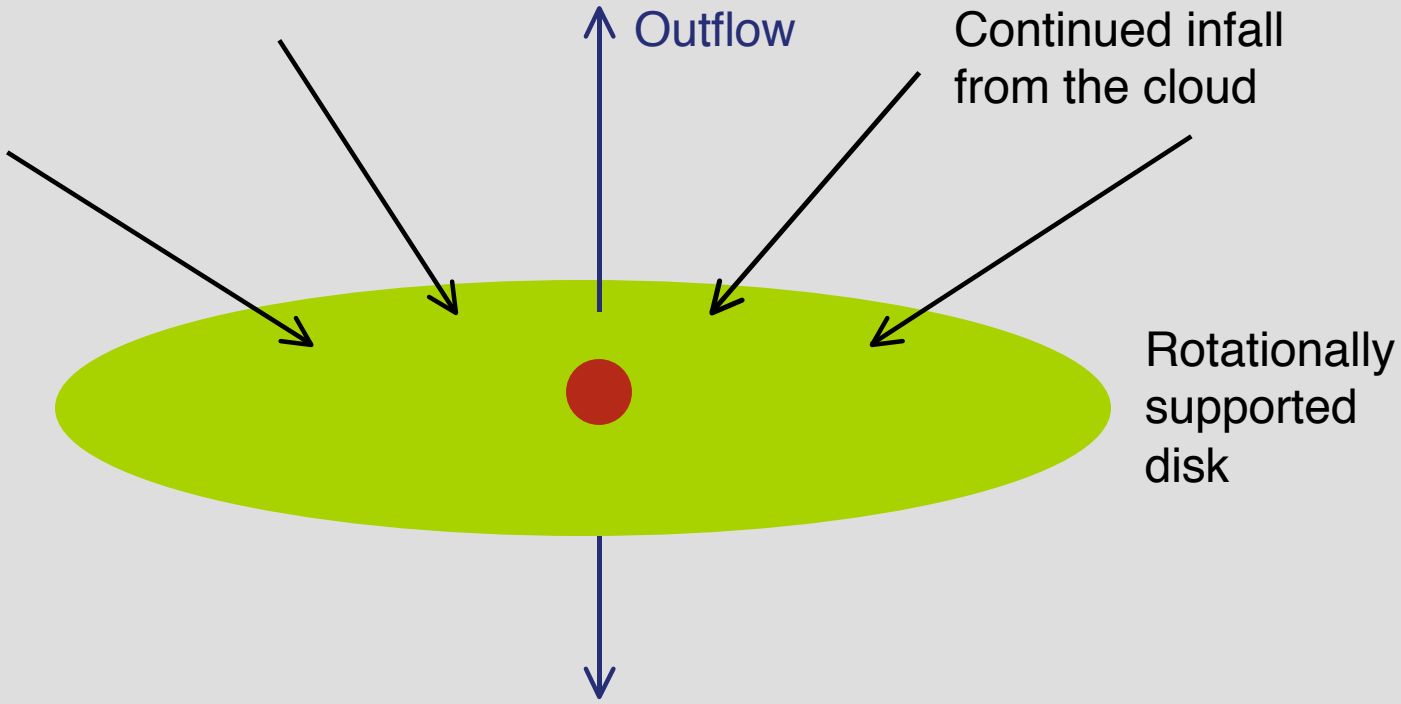
Class 1



Class 1 sources also have SEDs that rise into the mid and far infrared. But they differ from Class 0 in having detectable near infrared flux.

Still not seen at visible wavelengths.

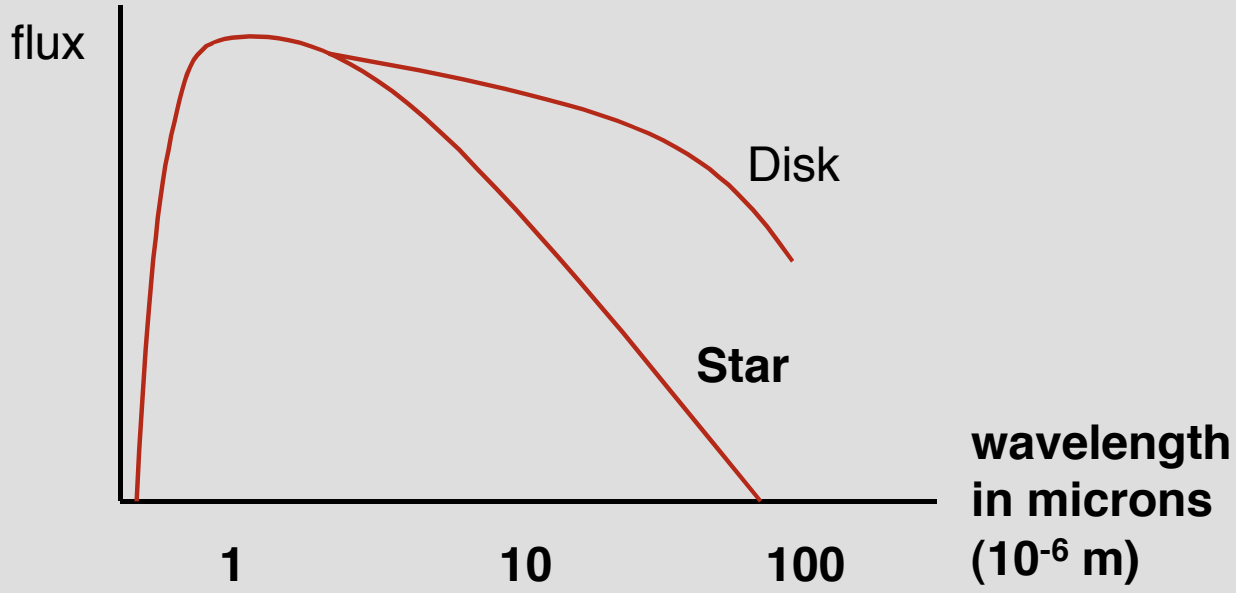
Structure of Class 1 sources:



Still can't see the star itself, but dust has cleared enough to see the hot gas and dust close to the star.

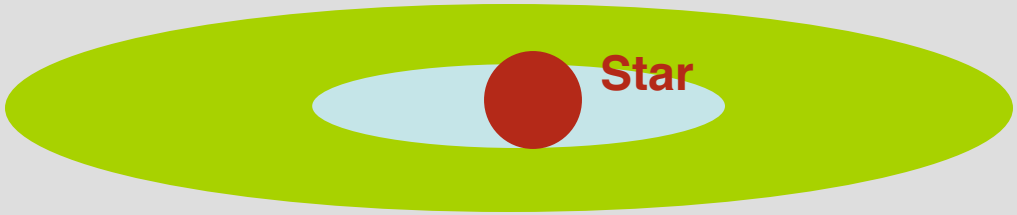
Absorption and reradiation of this near-infrared flux by the dust in the envelope produces the far-infrared peak.

Class 2 sources: Classical T Tauri stars

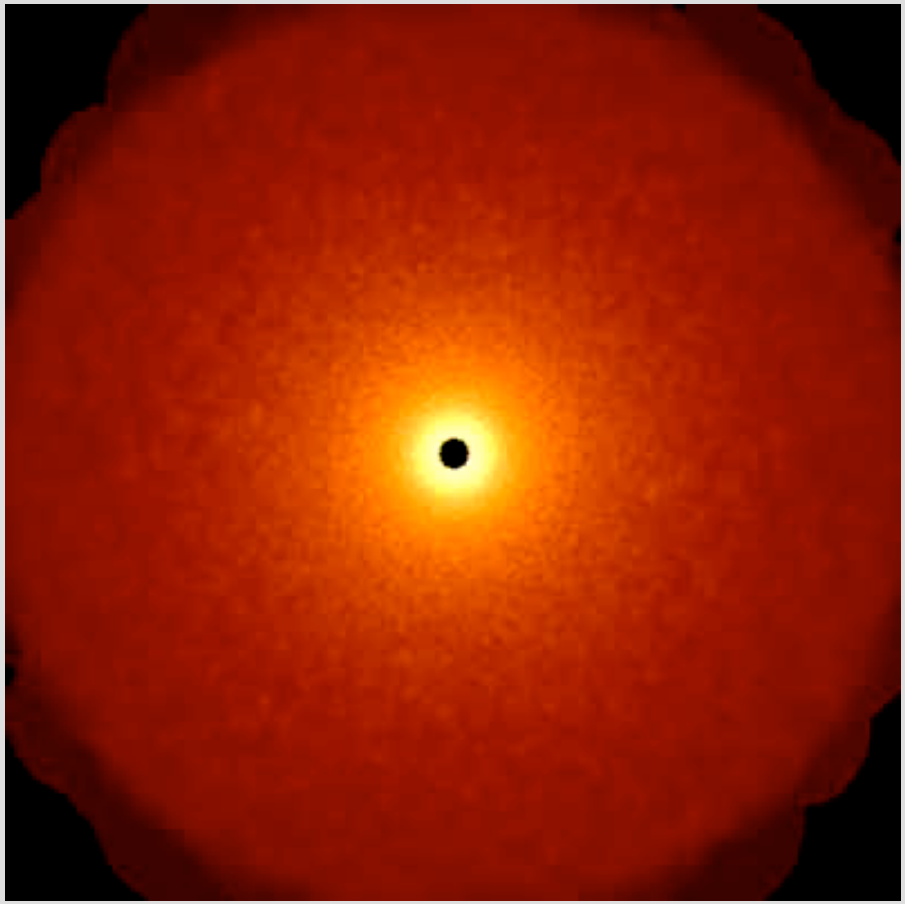


Flat or falling SEDs in the mid-infrared
Optically visible pre-main-sequence stars

Also called **classical T Tauri stars**, after the prototype star T Tauri in the Taurus star forming region.



Protostellar or protoplanetary disk of gas and dust

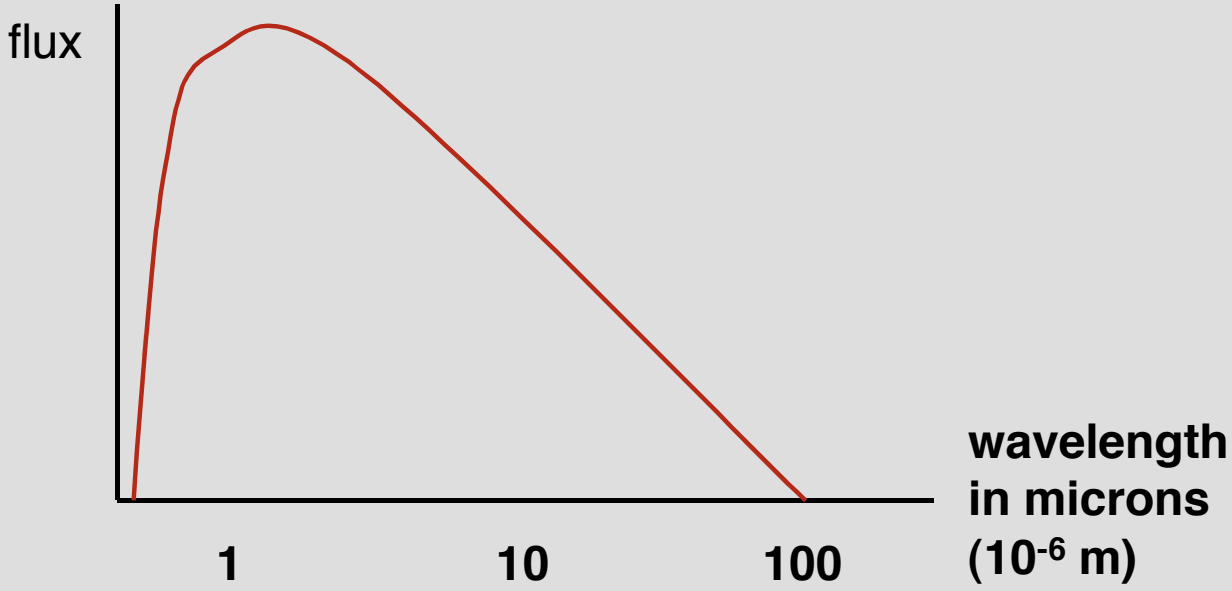


By this stage almost all of the collapsing cloud has settled onto the star or onto a disk surrounding the star.

From most angles we can see the young star directly.

Disk slowly drains onto the star over several million years.

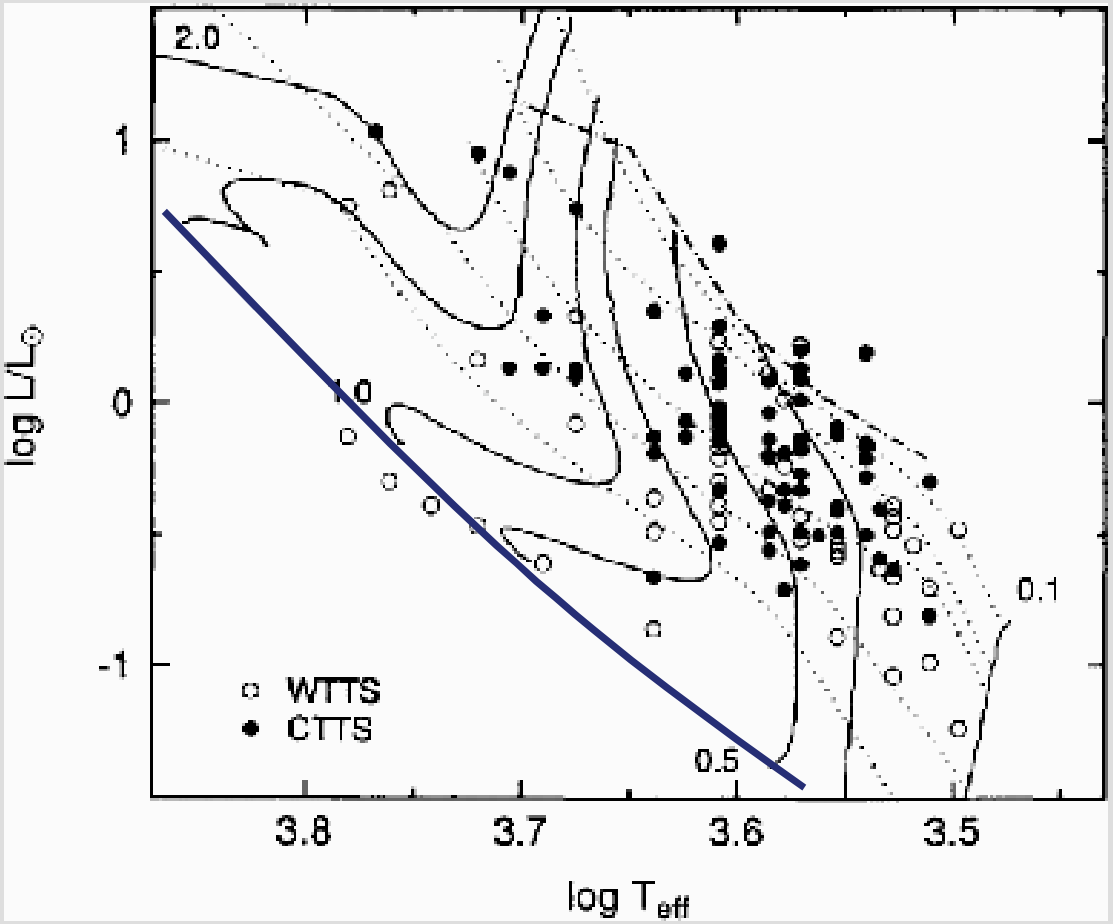
Class 3 sources: Weak-lined T Tauri stars



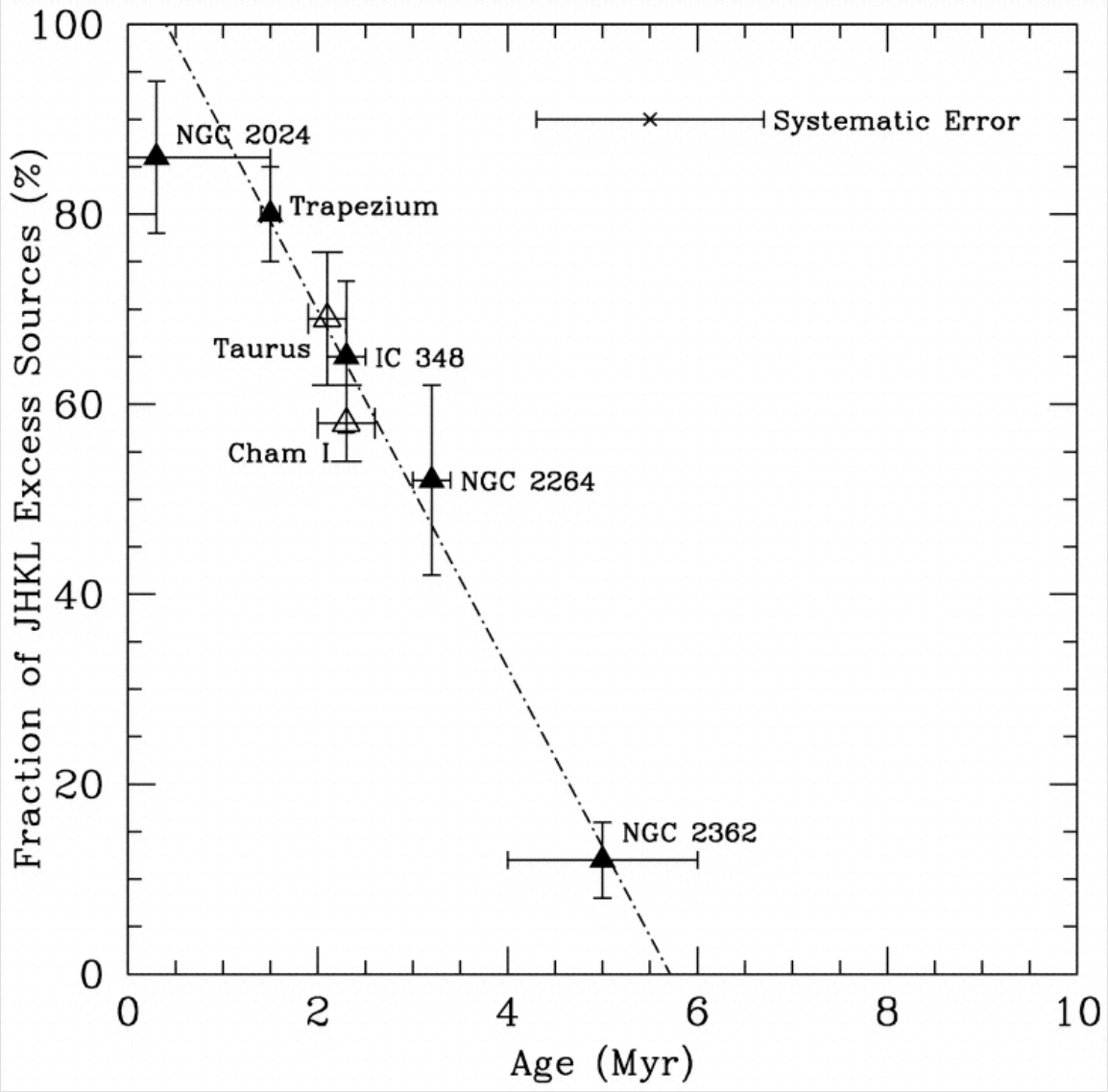
Fairly normal stellar SEDs, but more luminous than main sequence stars of the same effective temperature (ie they lie above the main sequence).

Also more active (eg in X-ray emission) than ordinary main sequence stars.

HR diagram for young stars



Filled circles: class 2 sources (classical T Tauri stars)
Open circles: class 3 sources (weak-lined T Tauri stars)



Fraction of stars with near-infrared excess emission (disks) as a function of the age of the cluster they are in.