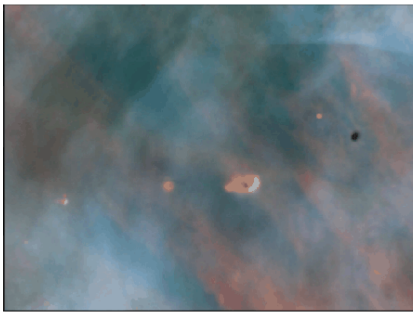
The 'proplyds' of Orion

- Many protostars are surrounded by opaque, dusty discs at ages of a few Myr.
- Our solar system appears to be the fossil of a similar disc:
  - Flattened
  - Circular orbits
  - 99% of angular momentum stored in outer planets' orbits.

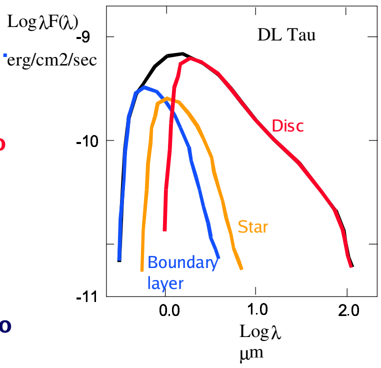


T Tauri stars

- Ages typically 1 to 10 Myr
- Still fully-convective, contracting towards zero-age main sequence
- Masses in range 0.5 to 2.0 Msun
- "Classical" TTS: strong, low-excitation optical and UV emission lines and continuum
- Complex velocity fields in emission lines: winds, downflows
- "Weak-line" TTS: little or no optical emission-line activity, but starspot and coronal X-ray activity

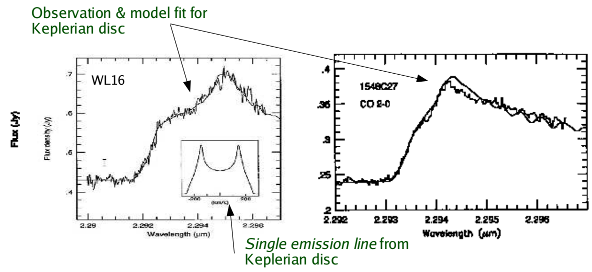
UV/optical/IR energy distributions:

- UV/optical continuum "veiling".
- Strong optical/UV line emission.
- IR excess from 10 to 1000K dusty disc.
- Disc masses up to ~0.1 M_{sun}.
- Radii of order 10 to 100 AU.
- Accretion rates up to 10^{-7} M_{sun} y^{-1}.



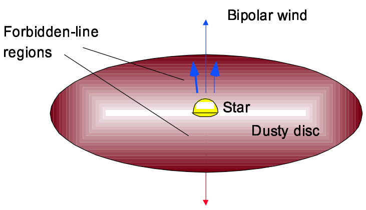
Evidence for Keplerian discs

- Solar System: Circular, coplanar orbits.
- Remnant discs: Vega, β Pic.
- Double-peaked rotation profiles of infrared CO bandheads (Carr et al 1993, ApJ 411, L37).



Obscuration of forbidden-line emission

- Forbidden-line emission from the bipolar wind of a T Tauri star is only seen blue-shifted.
- Receding side of flow is obscured -- by an opaque disc?

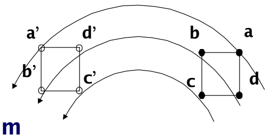


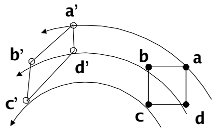
Evidence for active accretion

- Non-accreting discs can reprocess starlight.
- T(R) relation has same power-law index ($T \propto R^{-3/4}$) for accreting and non-acreeting disc
- Can give $L_{disc} \leq L_{star}/4$ (see Shu et al. 1987, Ann. Rev. Ast. 1987: 25-81: Section 6)
- Reprocessing can't explain:
  - extreme emission-line activity in CTTS
  - 'blue veiling' continuum emission
  - discs with $L_{disc} > L_{star}/4$

What is shear viscosity?

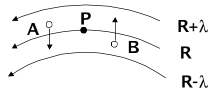
- **Shearing is absent in 2 simple cases:**
  - uniform translational motion, v=const.
  - uniform (solid-body) rotation.
- **Transport of (angular) momentum orthogonal to gas motion, by**
  - chaotic motion of gas molecules, or
  - turbulent motions of fluid elements.
- **Arises when fluid elements on neighbouring streamlines slide past each other (shearing).**
- **Chaotic motion characterised by**
  - length scale λ (~ mean free path or size of largest eddies)
  - mean speed $\tilde{u}$ (~ sound speed or turnover speed of largest eddies)



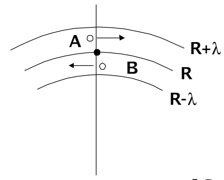


Shear velocity in rotating fluid

- **Chaotic motions carry particles into adjacent annuli:**
  - Length scale λ
  - Mean chaotic speed $\tilde{u}$



- **Consider frame corotating with P:**
  - P rotates at $\Omega(R)$
  - shear velocities u relative to radial "spoke" through P, also rotating at $\Omega(R)$:



$$u(r) = r(\Omega(r) - \Omega(R))$$

$$\Omega(R+\delta r) \cong \Omega(R) + \delta r \Omega' \text{ , where } \Omega' \equiv \frac{d\Omega}{dr}$$

NB: Rigid rotation => no shear.

Shear and chaotic particle drift

- **Shear velocities of particles A (+) and B (-) relative to P:**

$$u(R \pm \frac{\lambda}{2}) = (R \pm \frac{\lambda}{2})[\Omega(R \pm \frac{\lambda}{2}) - \Omega(R)]$$

$$= \pm \frac{\lambda}{2}(R \pm \frac{\lambda}{2})\Omega'$$

- **Mass crosses surface r=R at equal inward and outward rates per unit arc length:** $H\rho\tilde{u}$ [kg m^{-1}s^{-1}]

Disc height

Mass density

Mean chaotic particle speed

- **Surface density:** $\Sigma \equiv H\rho$ [kg m^{-2}]

Torque=net angular momentum flux

- **Torque G(R) per unit arc length *l* exerted on outer ring by inner ring=net (outward-inward) angular momentum flux.**

$$\delta G(R)/\delta l = \Sigma\tilde{u}[r_B.u(r_B) - r_A u(r_A)]$$

$$= \Sigma\tilde{u}[(R-\frac{\lambda}{2}).(-\frac{\lambda}{2})(R-\frac{\lambda}{2})\Omega'$$

$$-(R+\frac{\lambda}{2}).(\frac{\lambda}{2})(R+\frac{\lambda}{2})\Omega']$$

$$= -\Sigma\tilde{u}\lambda R^2\Omega' \text{ to first order in } \lambda.$$

- **Total torque on inner ring by outer:**

$$G(R) = 2\pi R \nu \Sigma R^2 \Omega'$$

-ve for Keplerian disc

Boundary length

kinematic viscosity $\nu=\lambda\tilde{u}$