The formation and fragmentation of Pop III(.1) protostellar discs

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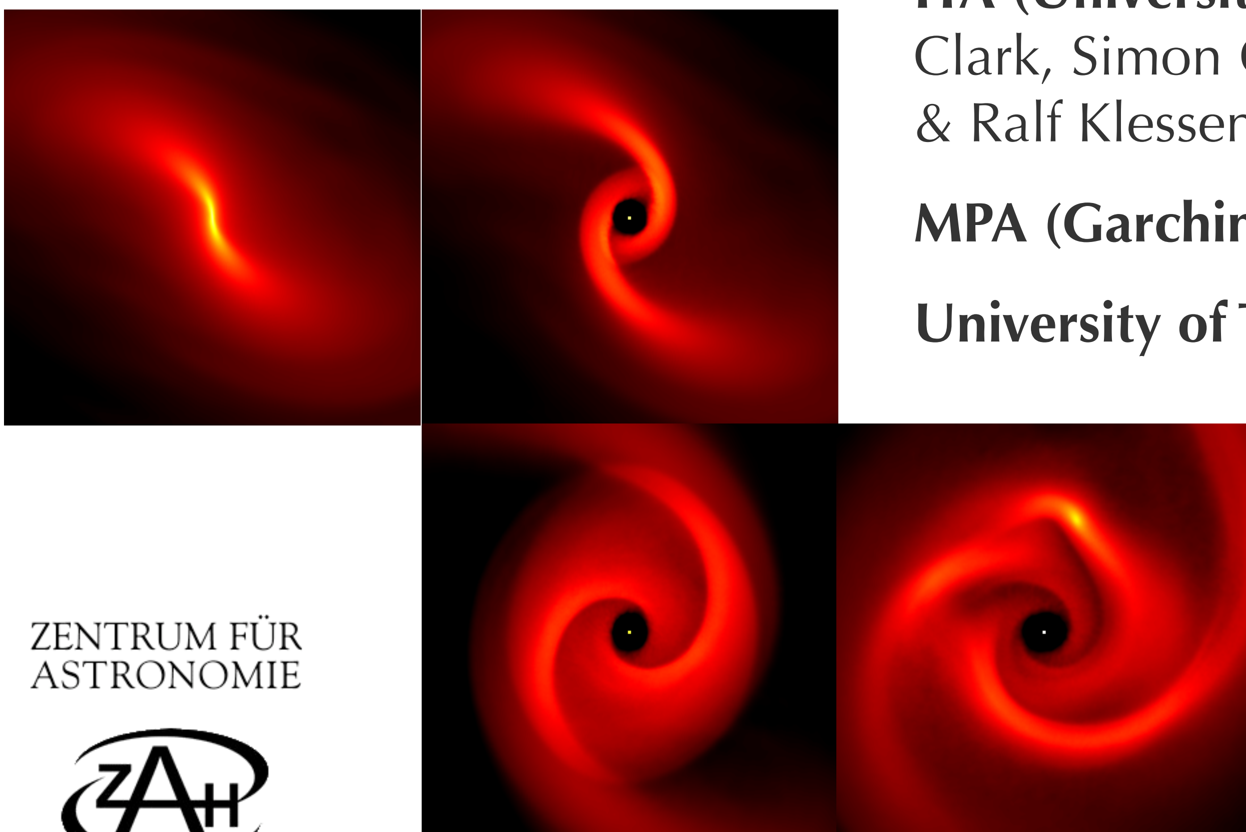

ZENTRUM FÜR ASTRONOMIE

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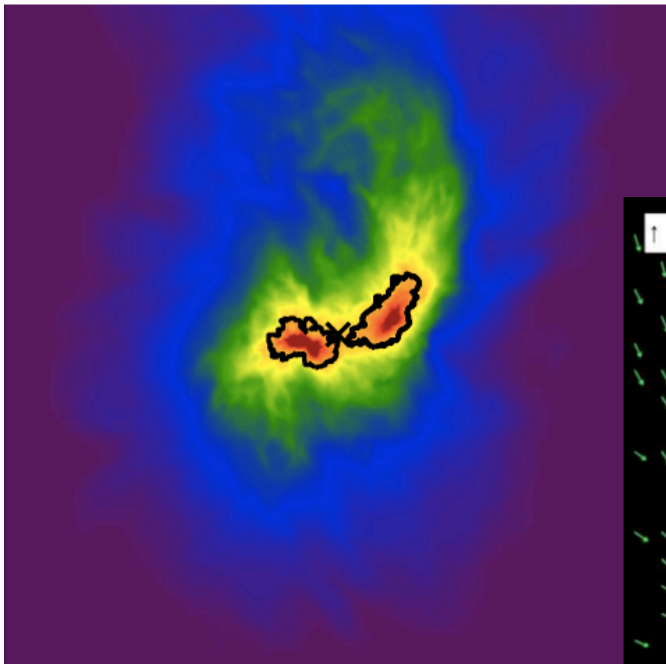
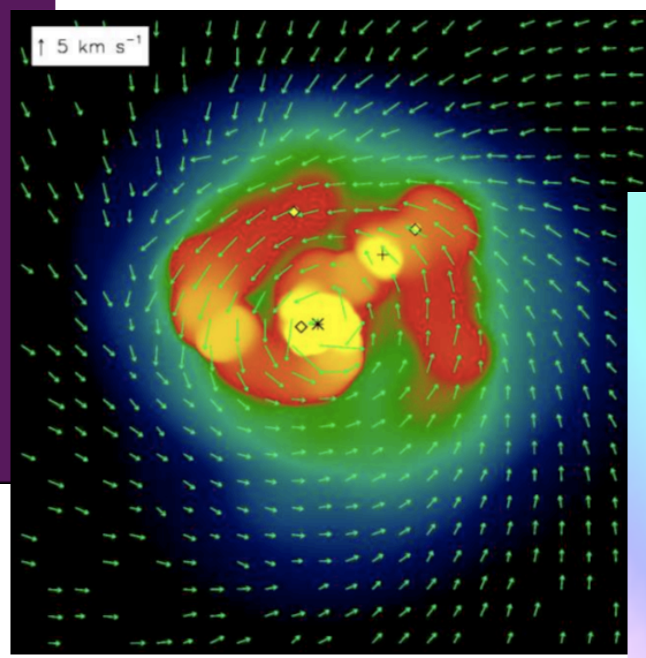
Are we seeing a paradigm shift?

Turk, Abel & O'Shea (2009)



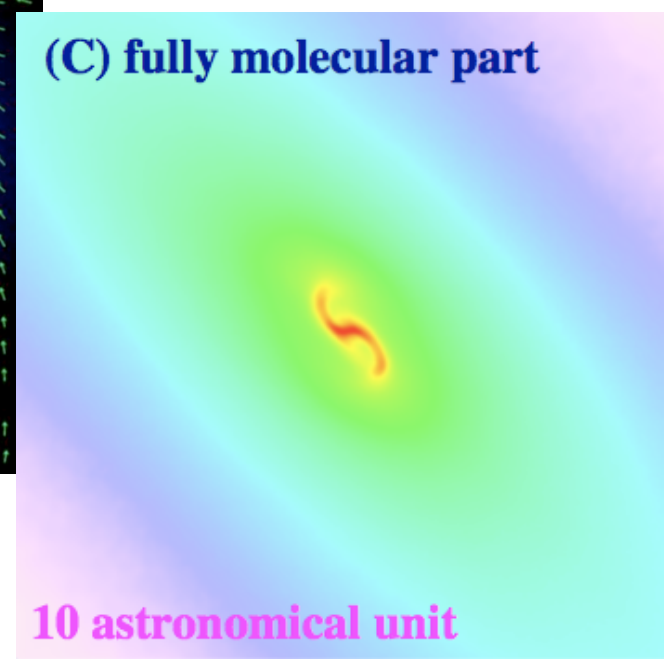
1800 au

Stacy, Greif & Bromm (2010)



2500 au

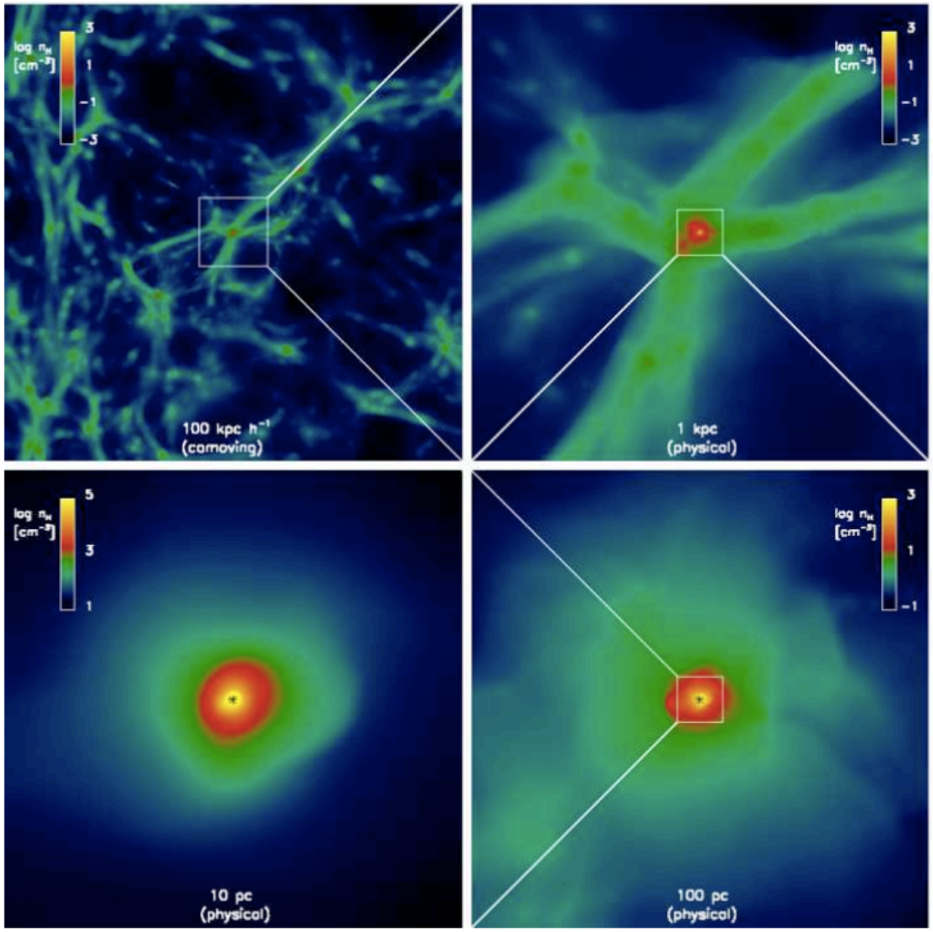
Yoshida, Omukai & Hernquist (2008)



Cosmological initial conditions

Initial conditions from a cosmological GADGET2 simulation (performed by T. H. Greif, similar to that in Stacy et al 2010):

- 200 kpc (co-moving) cosmological box
- Λ-CDM: $\Omega_m = 1 - \Omega_\Lambda = 0.3$; $\Omega_b = 0.04$; $h = H_0/100$ km $s^{-1}Mpc^{-1} = 0.7$; $\sigma_8 = 0.9$
- Evolved from $z = 99$ to 22, when baryons first become self-gravitating



Stacy, Greif & Bromm (2010)

Then re-zoom the simulation:

- Go from Thomas' 5 M_{sun} SPH resolution to 0.05 M_{sun}, and run collapse to $n = 10^{13}$ cm^{-3}.
- Refine final stages of collapse to 0.001 M_{sun} resolution --> 200,000 SPH particles in disc

Additional components

Chemical processes:

- 3-body H_2 formation heating.
- Rotational + vibrational line-emission from H_2 (Glover & Abel 2008).
- At high densities, H_2 energy levels are computed accounting for the escape-probability for the photons (Yoshida et al 2006).
- Collision induced emission (CIE; Ripamonti & Abel 2004) + reduction by continuum absorption (see Matt Turk).

Luminosity feedback (See Rowan Smith's poster for more details):

$$R_* = 26 M_*^{0.27} (\dot{M}/10^{-3})^{0.41}$$

$$L_{acc} = G M_* \dot{M} / R_*$$

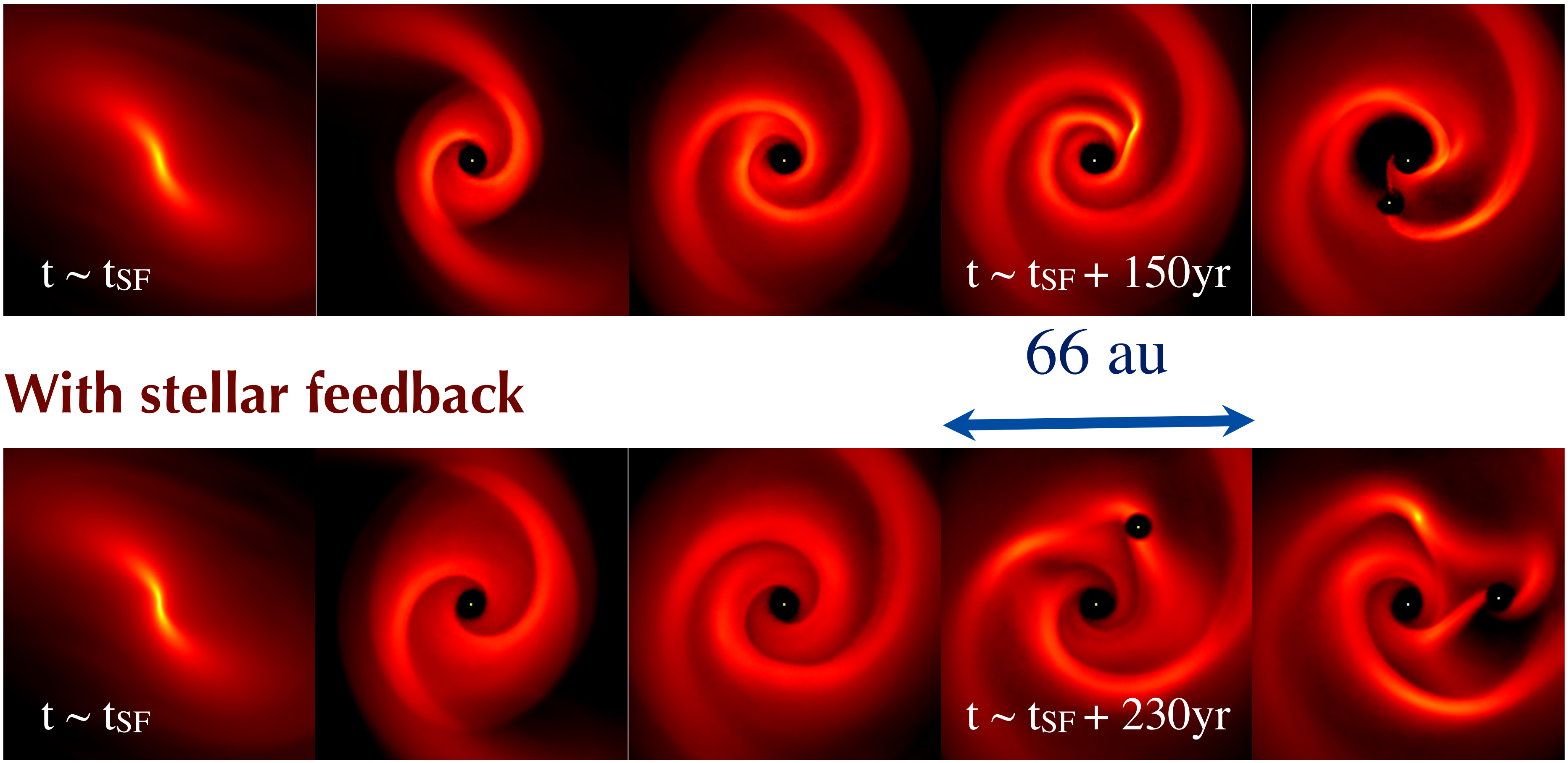
$$\Gamma_{acc} = \rho_g \kappa_P \left(\frac{L_{acc}}{4 \pi r^2} \right)$$

- Mass-radius relationship from Stahler, Palla & Salpeter (1986).
- Plank mean opacities from Mayer & Duschl (2005).
- We fix L_{acc} at 10^{-3} M_{sun} yr^{-1} in our current simulations.

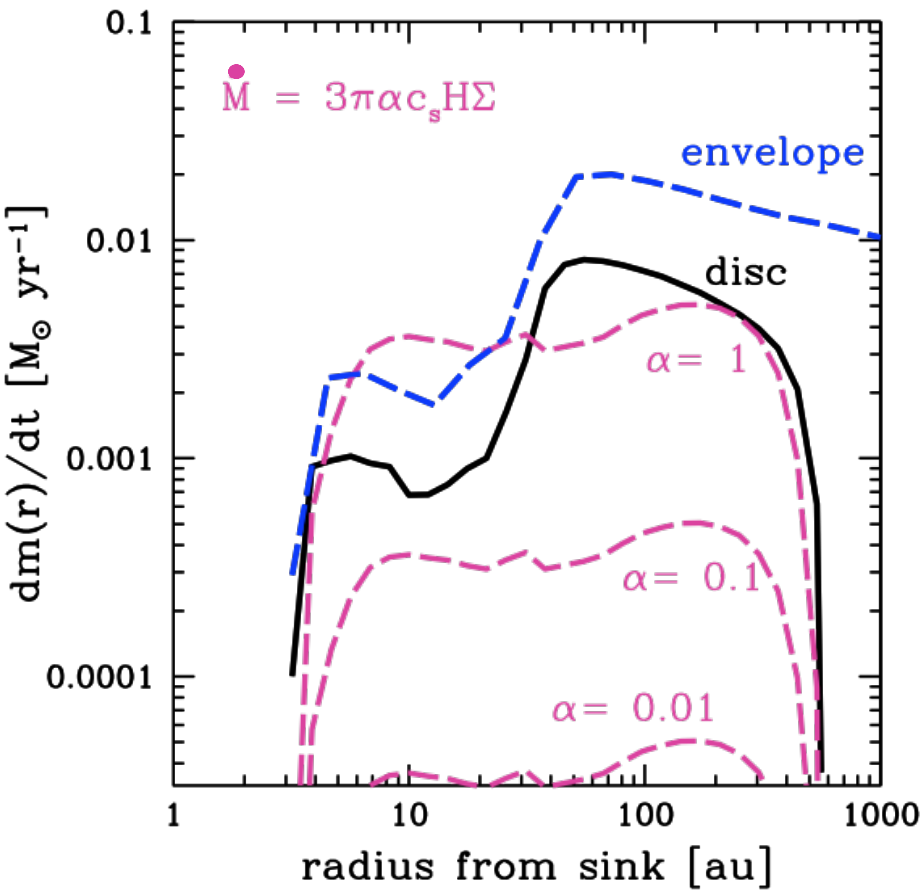
Evolution of the protostellar disc

No stellar feedback

With stellar feedback



Accretion through the disc

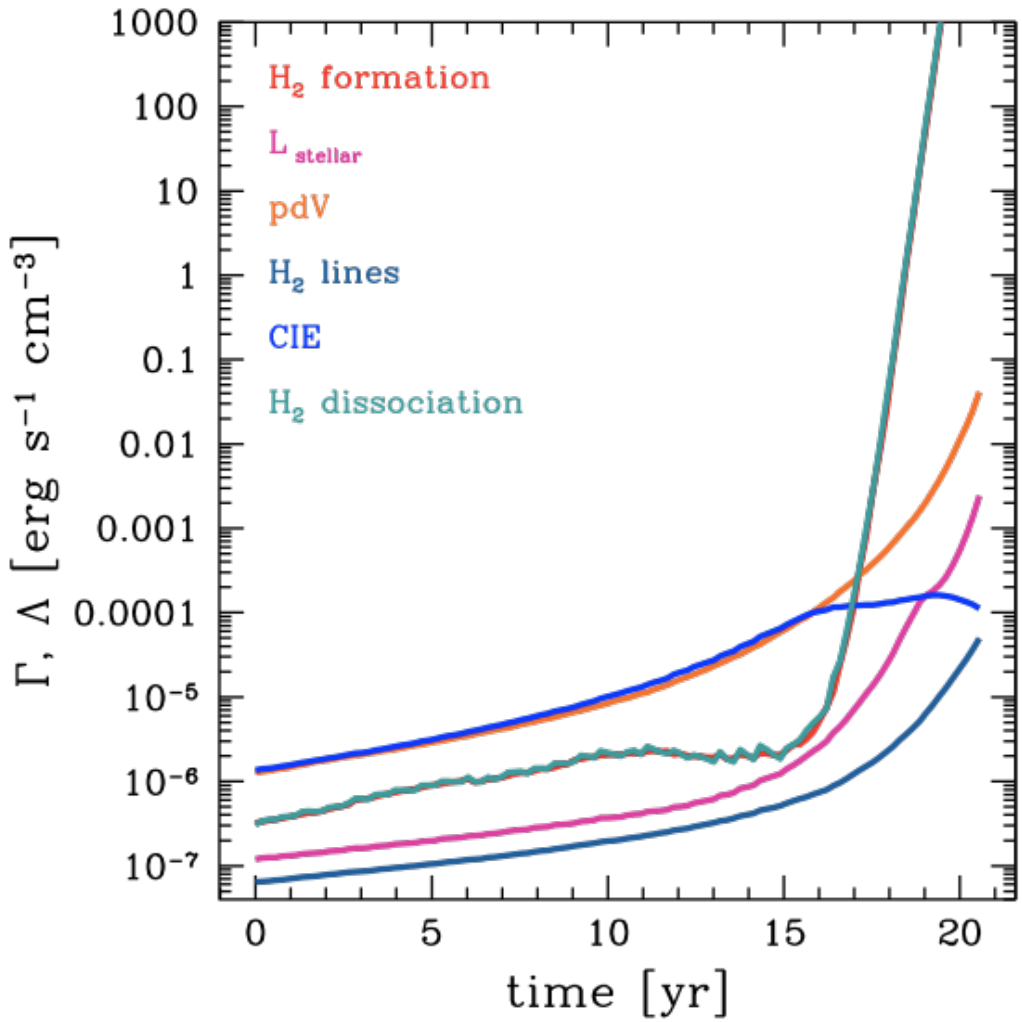


- At these early times, the accretion rate rate through the disc is significantly smaller than the material coming through the envelope.
- Disc is unable to process the in-falling gas -> Disc has to grow.
- Assuming 'thin α- disc' model requires very large values of α (>1), to rid disc of in-falling material.
- Gravitational torques saturate at around α ≈ 1.

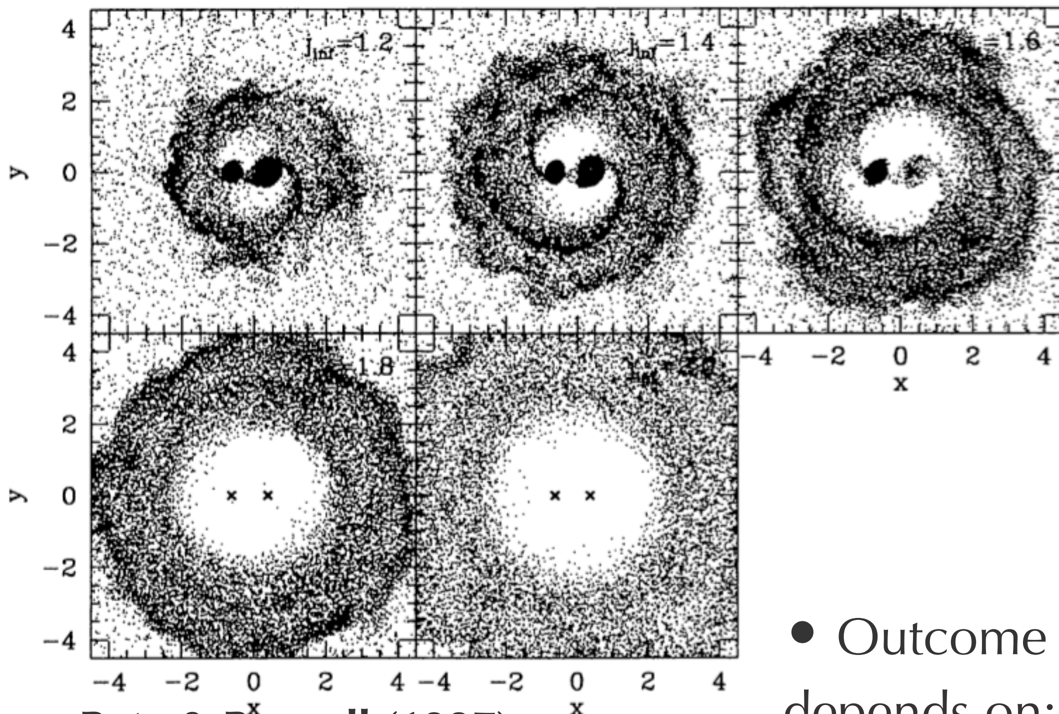
Heating/cooling balance

With stellar feedback

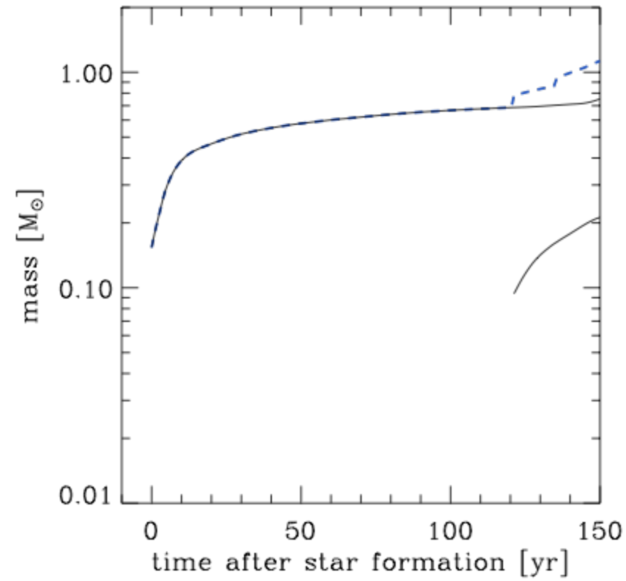
- Accretion luminosity from star at these radii is significantly less than compressional heating.
- Main coolant in disc comes from collision-induced emission (CIE)
- As temperature rises and region goes into collapse, H_2 dissociation takes over.
- Given that the disc is fully molecular, this provides a huge thermal sink for the pdV heating.

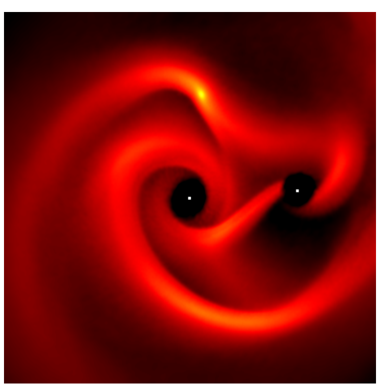


Fate of the young stellar system



Bate & Bonnell (1997)





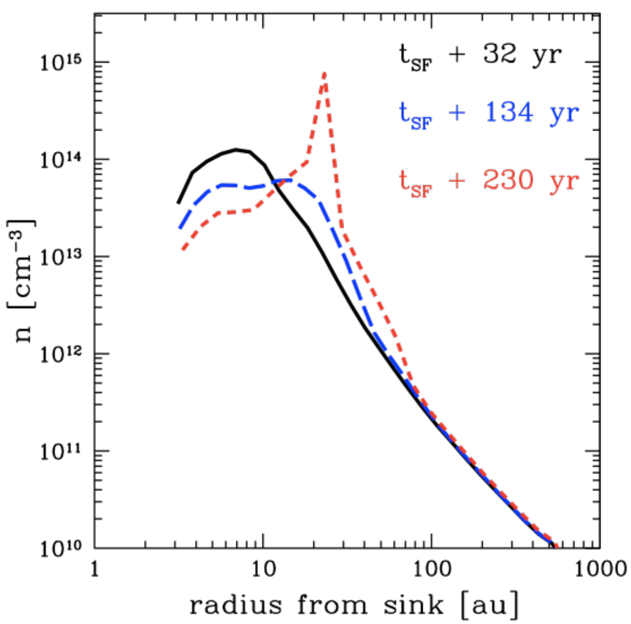
- Outcome of accretion onto binary system depends on:
- mass ratio of the binary $q = m_2/m_1$
- specific angular momentum of orbit, j_{orbit}
- and in-falling gas, j_{infall}
- For $j_{infall} \sim j_{orbit}$ of secondary, accretion drives q --> 1: massive stellar twins?

Summary

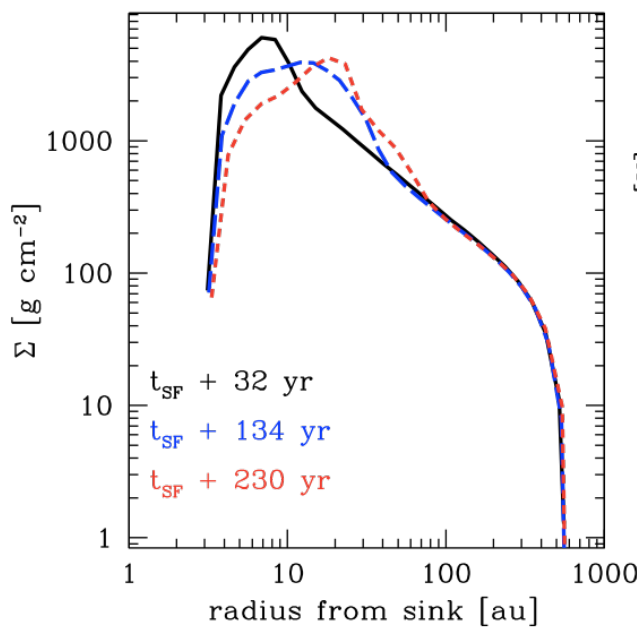
- The accreting accretion discs around POPIII protostars are gravitationally unstable and the angular momentum transport is dominated by gravitational torques.
- Despite the high accretion rate through the disc, the system is unable to process in the incoming gas -- > disc becomes Toomre unstable.
- The densities and temperatures in the disc allow them to tap into 2 extremely efficient cooling sources: collision-induced emission and H_2 dissociation.
- The discs are hence extremely unstable to fragmentation, even when the effects of accretion luminosity heating are included.
- One possible fate of these young systems is the formation of massive twins.
- Possibly accompanied by the ejection of further low-mass members.

Disc properties

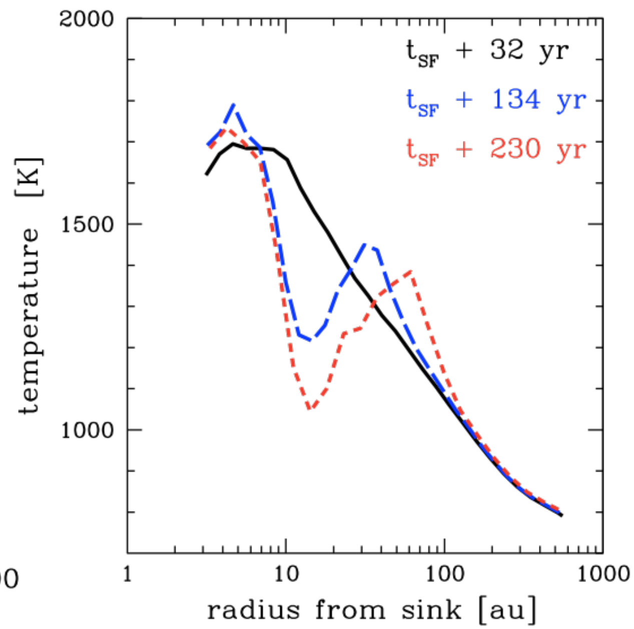
Number density



Surface density



Temperature



Toomre parameter