hamburger sternwarte

Massive Star Formation with RT-MHD Simulations

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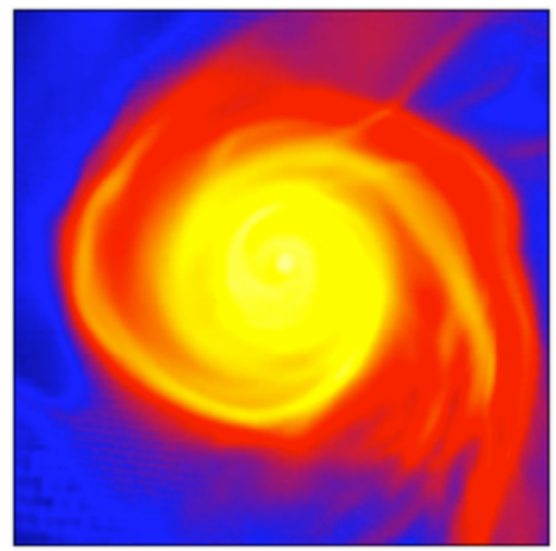
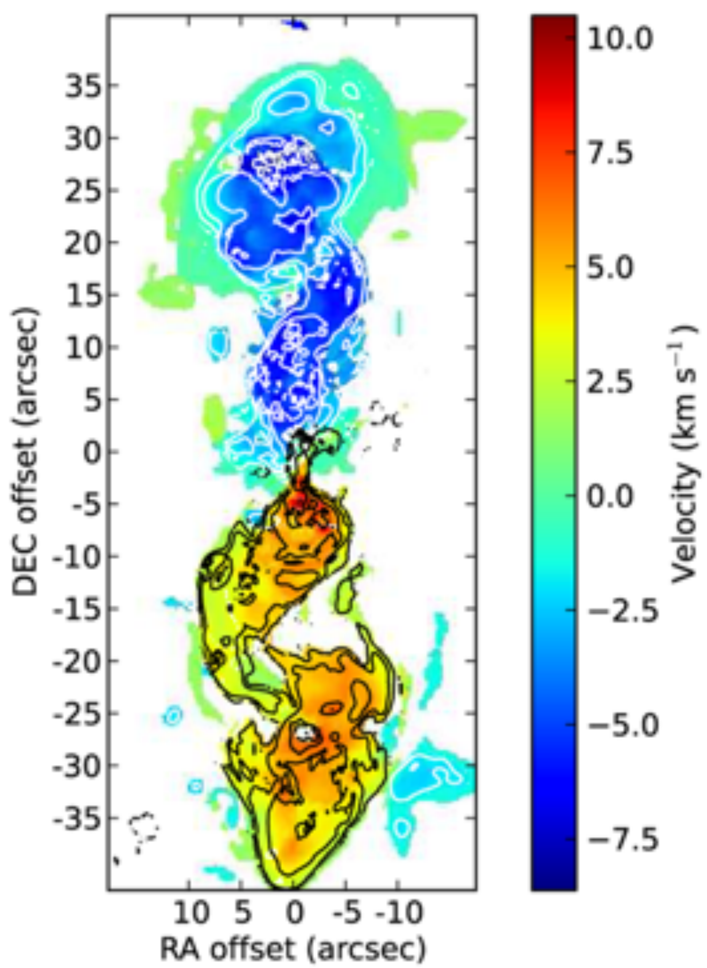
Formation of Massive Stars

- Radiation Feedback

- Disc Formation around Massive Protostars



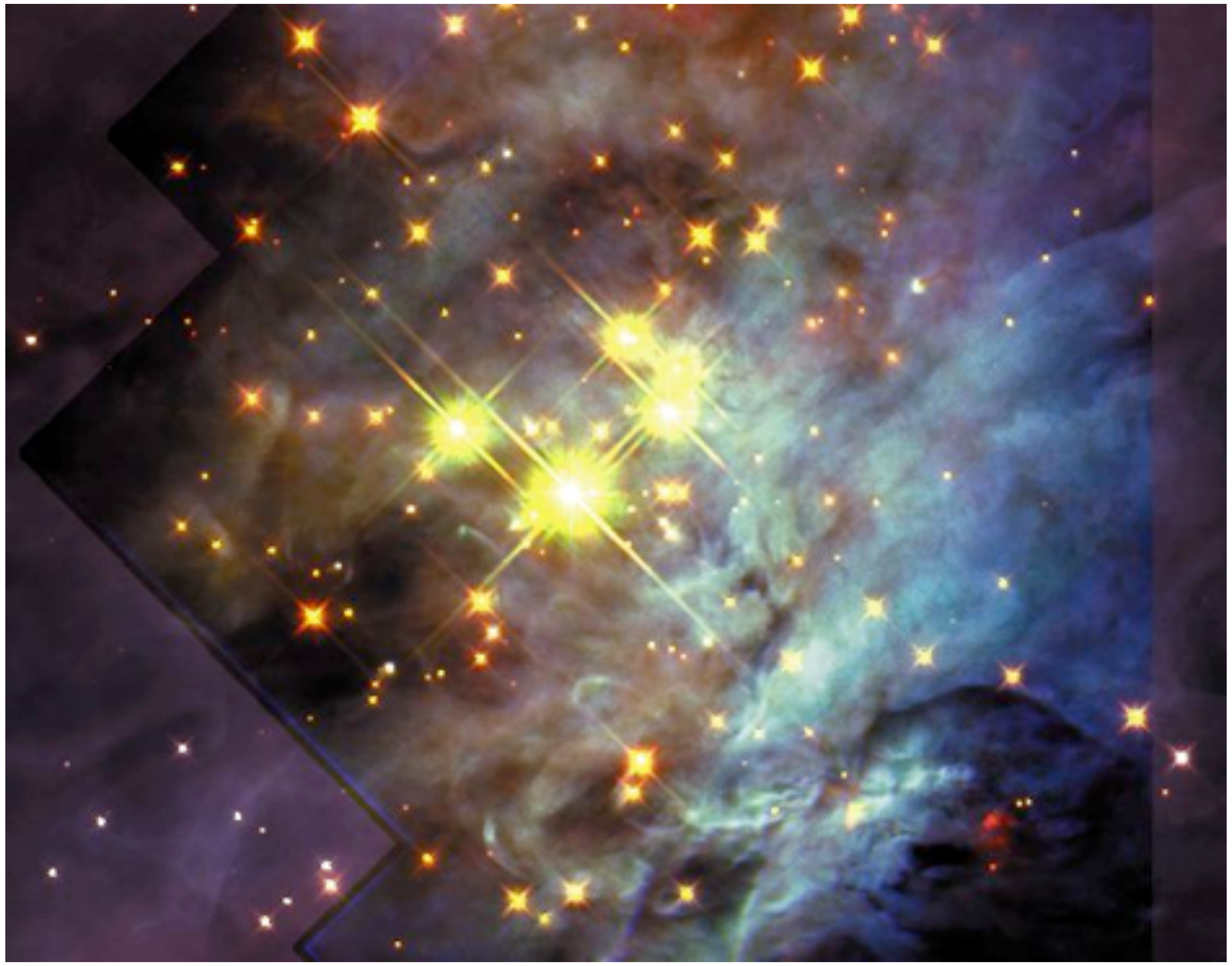
- 

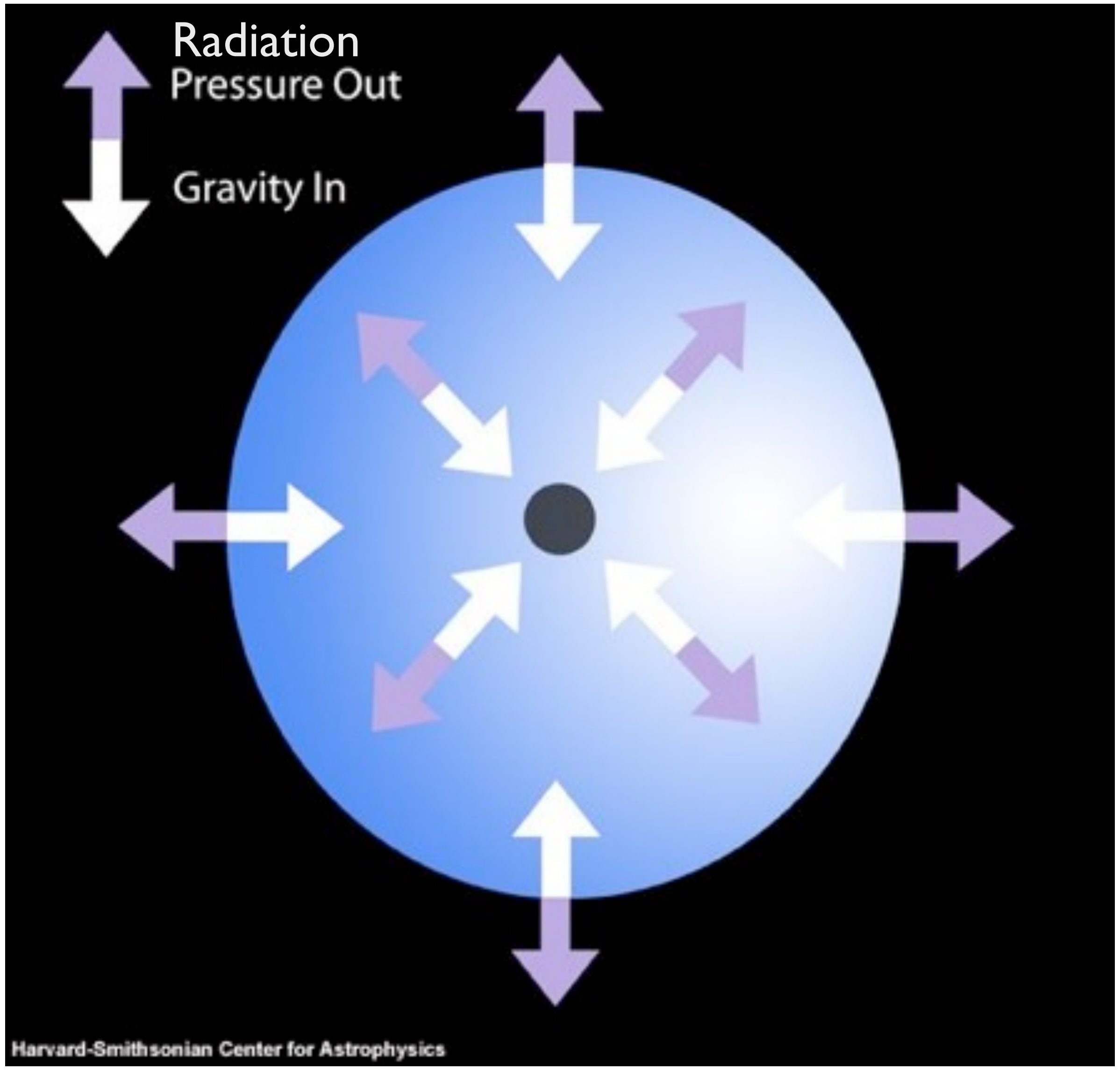
Magnetically driven Outflows

Formation of massive stars

Problem:

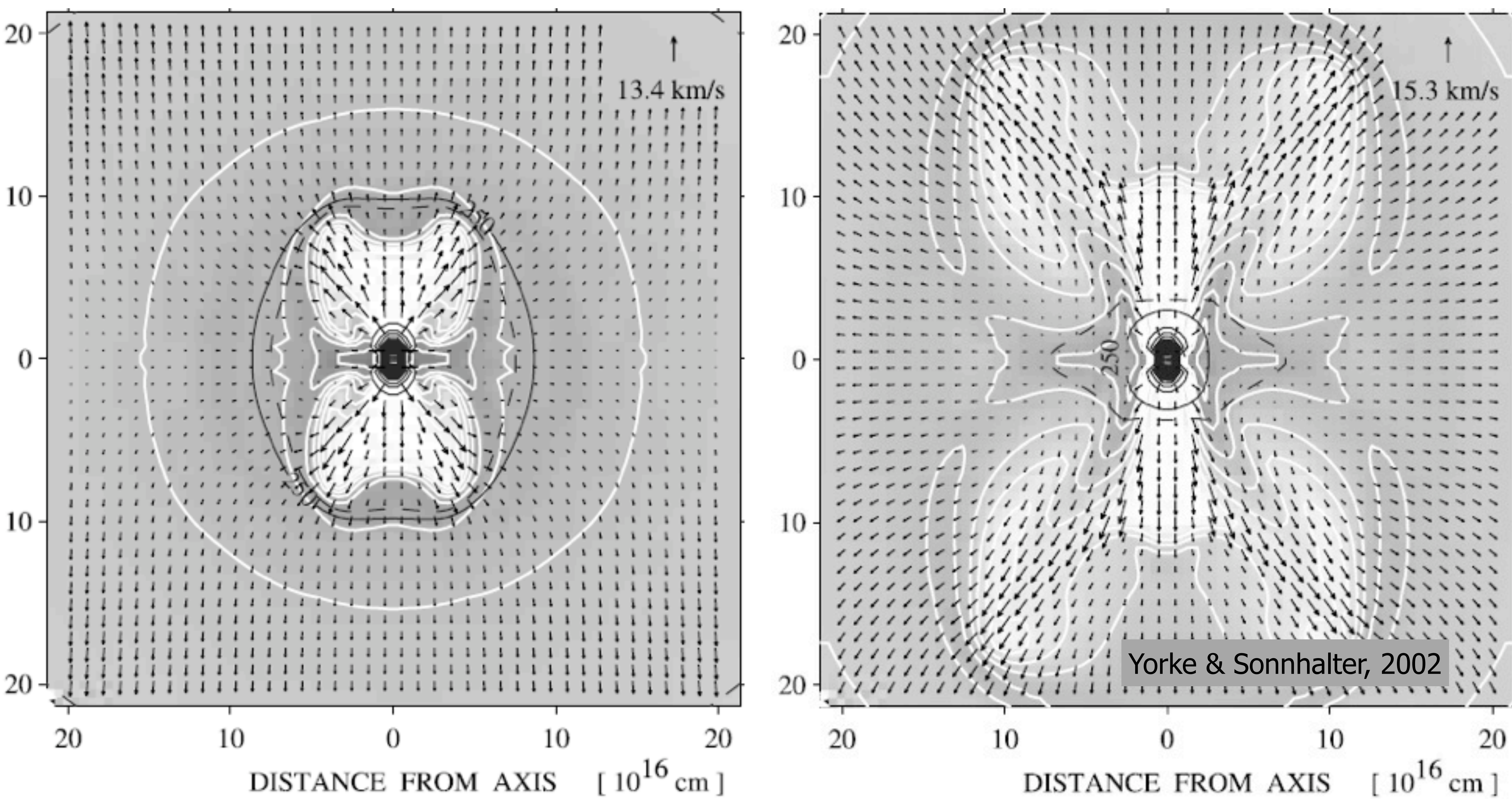
- massive stars gain most of their mass on the main sequence (e.g. *Appenzeller & Tscharnuter 1974*)
  → strong radiation pressure (e.g. *Larson & Starrfield 1971; Kahn 1974*)
  → how to overcome the Eddington limit ($M \gtrsim 30\ \mathrm{M}_\odot$)?





Formation of massive stars

2D calculations by Yorke & Sonnhalter 2002

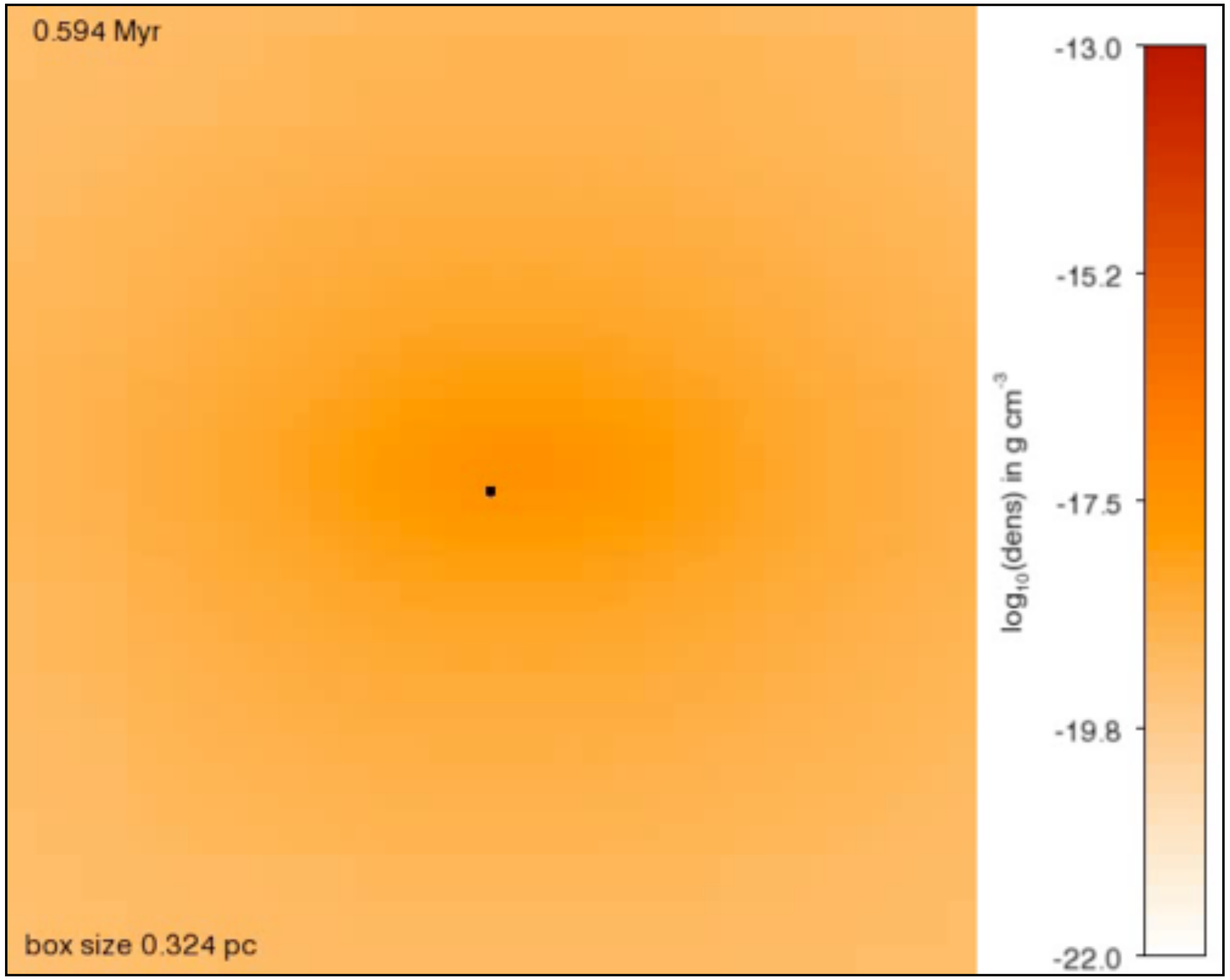


→ mass accretion through disc structure

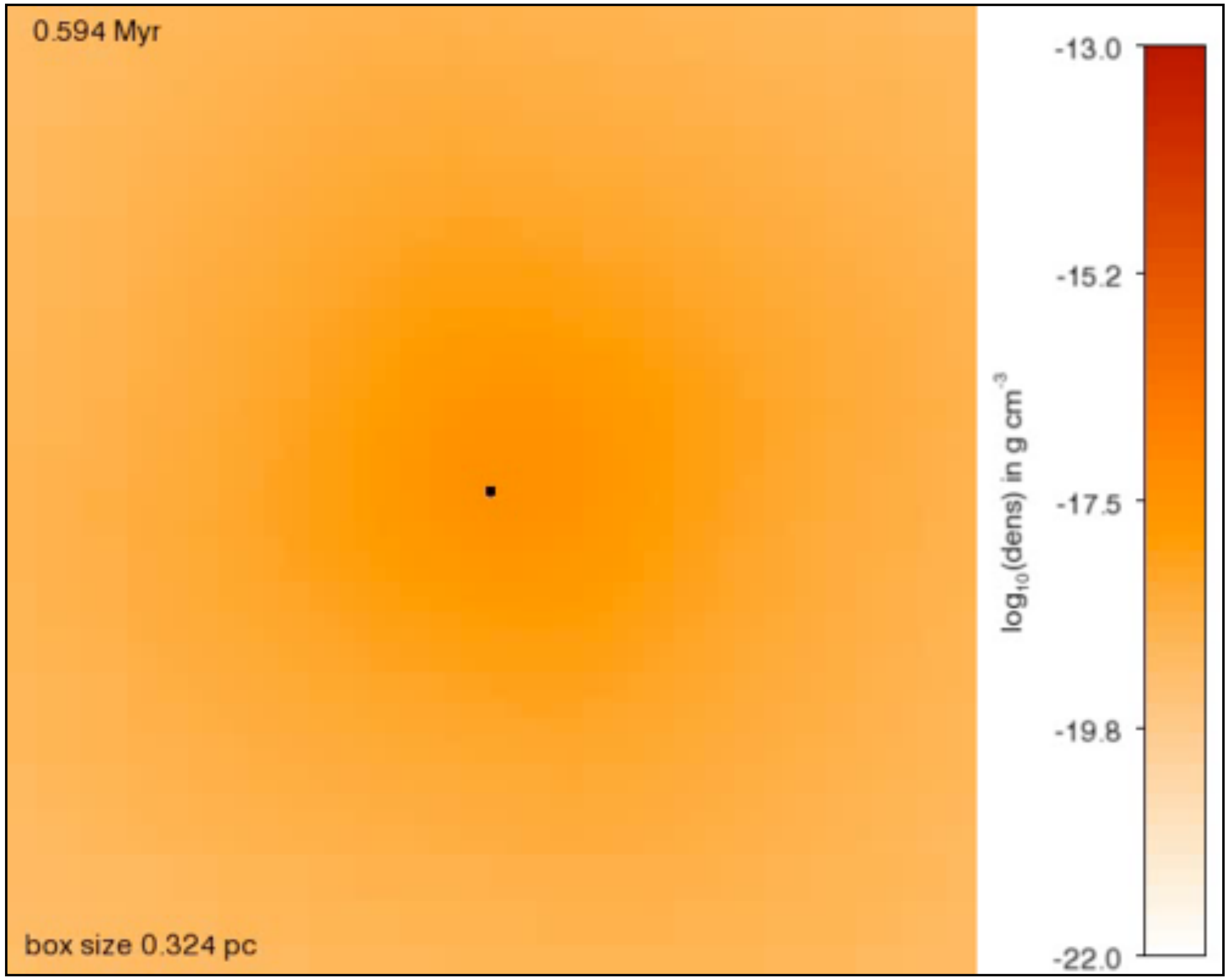
→ relaxed limits ($\gtrsim 40\ M_\odot$)

Massive Star Formation: Dynamics of HII Regions

Simulations of massive (1000 M_{sol}) collapsing cloud cores with radiation feedback (ionising radiation)



Disk edge on



Disk plane

Peters et al. 2010, 2011

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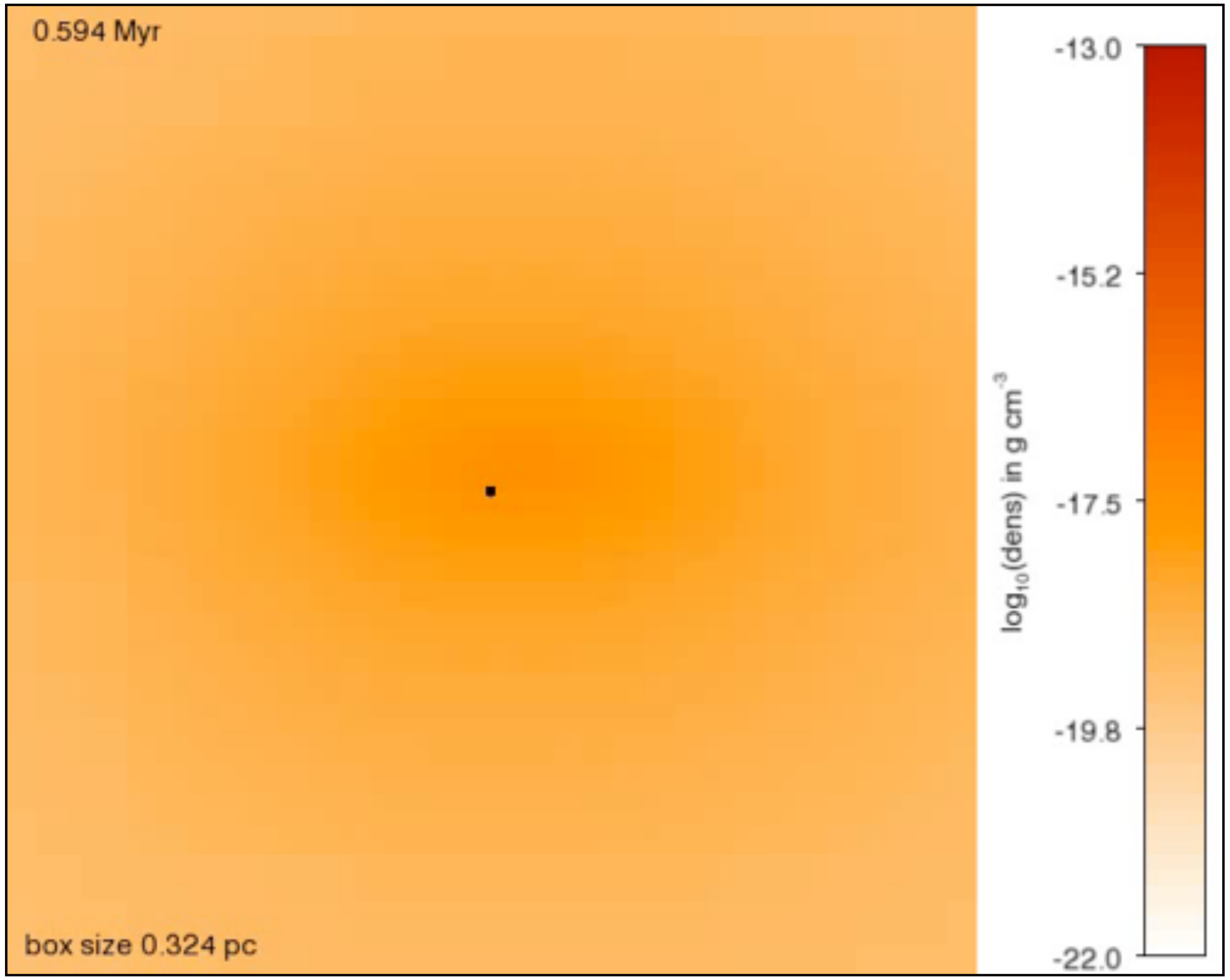

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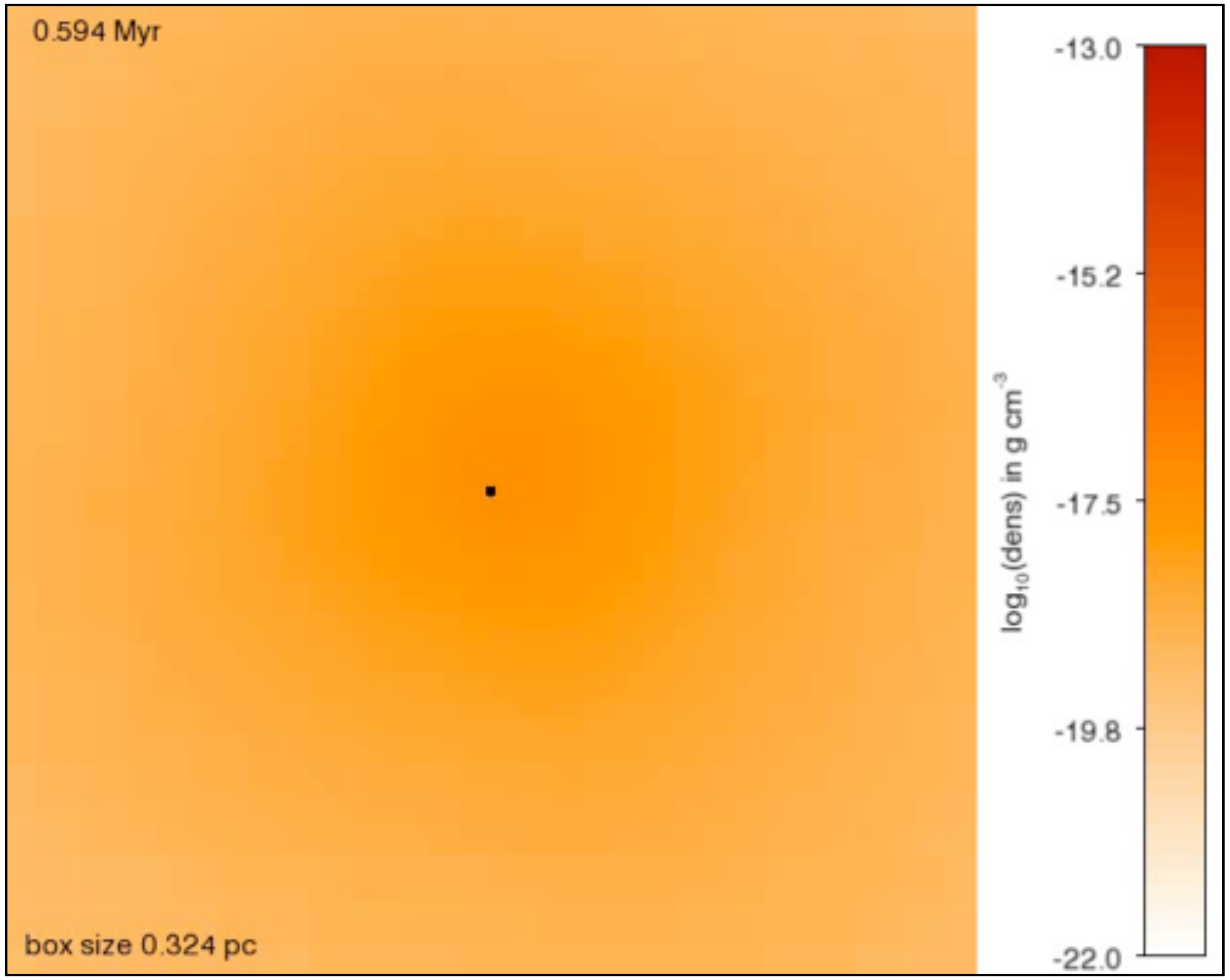
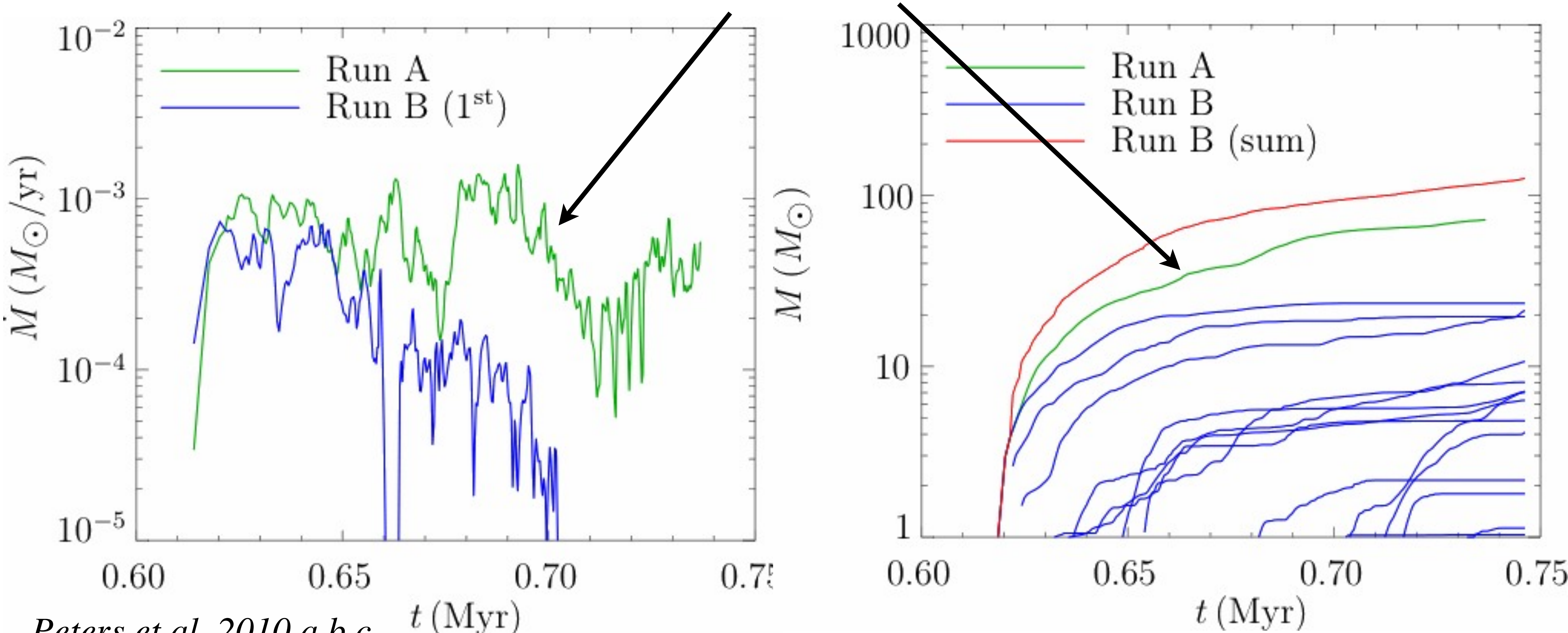


Disk plane

Peters et al. 2010, 2011

Multiple protostars: Dynamics of the H II Region

Run A: *artificial* suppression of fragmentation

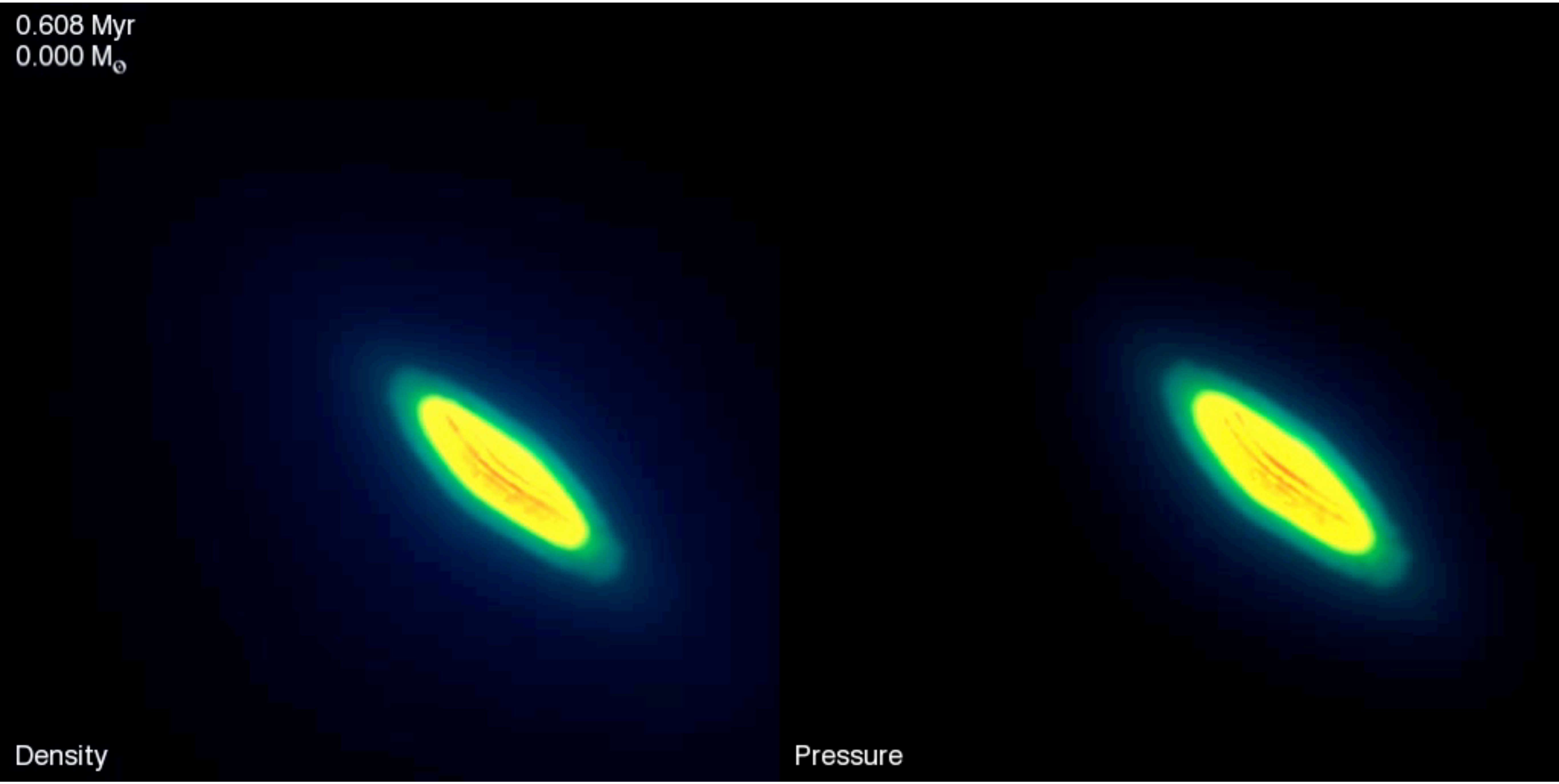


Peters et al. 2010 a,b,c

- ionization feedback does **not** shut off accretion
- but fragmentation-induced starvation (**FIS**)
  → cuts off accretion from the most massive star
- massive stars form in cluster

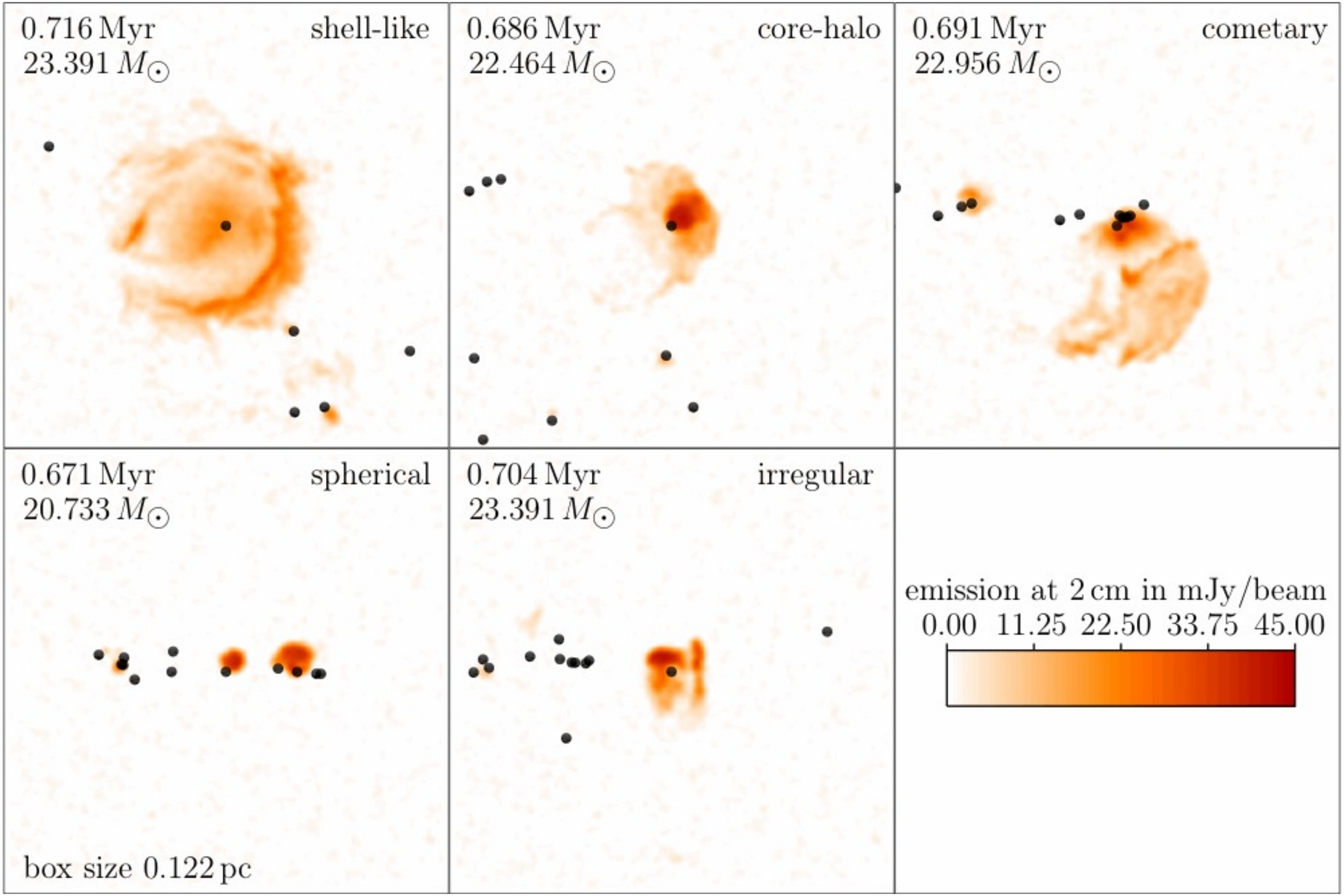
Massive Star Formation: Dynamics of HII Regions

Run B: formation of multiple stars

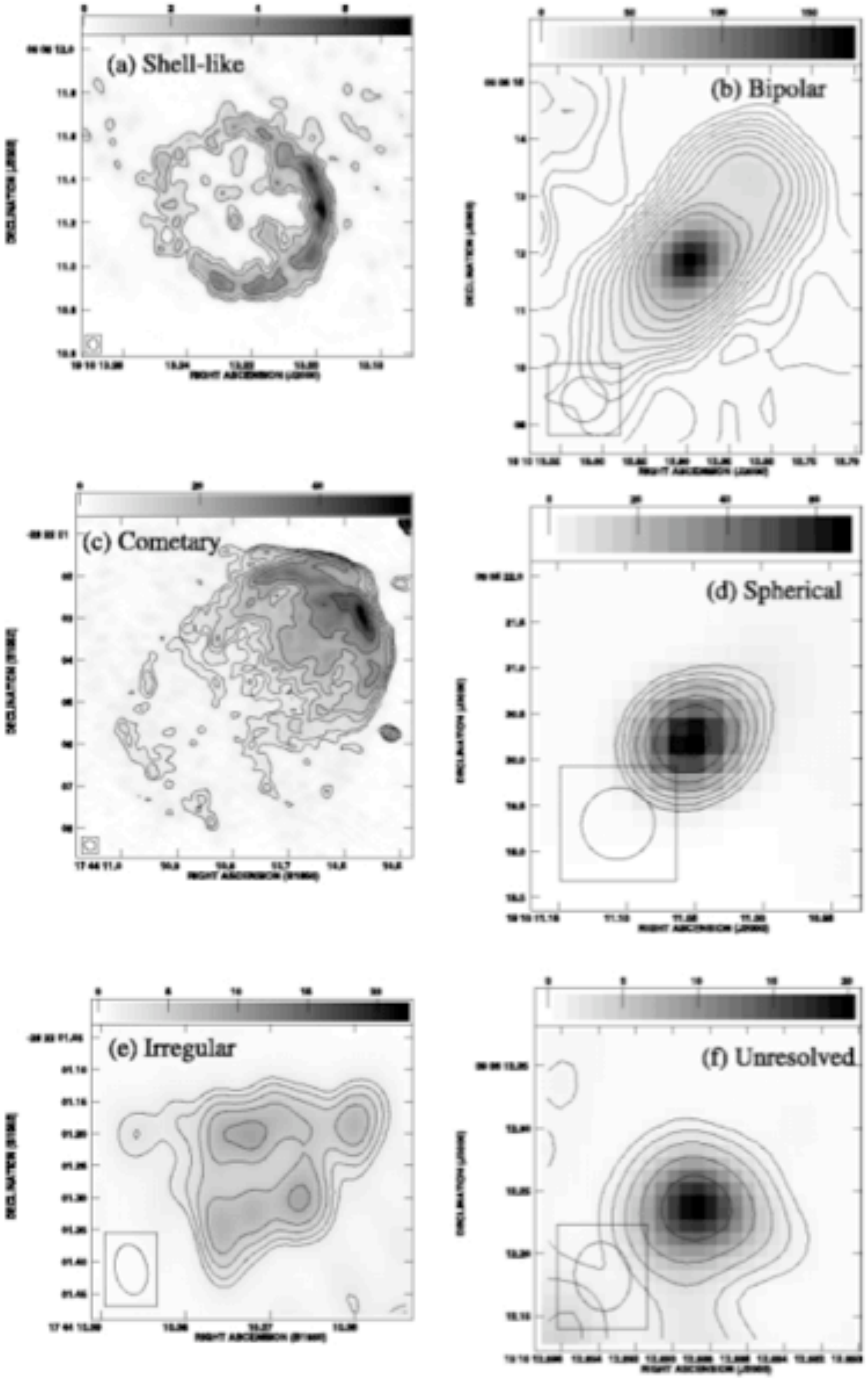


courtesy: Zilken, NIC, Jülich

H II Region Morphologies



H II Region Morphologies



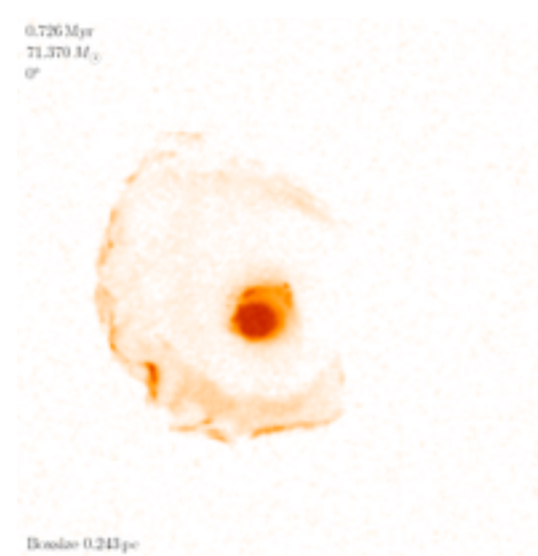
morphologies from *De Pree et al. 2005*

Table 3
Percentage Frequency Distribution of Morphologies

Type	WC89	K94	Run A	Run B
Spherical/Unresolved	43	55	19	60 ± 5
Cometary	20	16	7	10 ± 5
core–halo	16	9	15	4 ± 2
Shell-like	4	1	3	5 ± 1
Irregular	17	19	57	21 ± 5

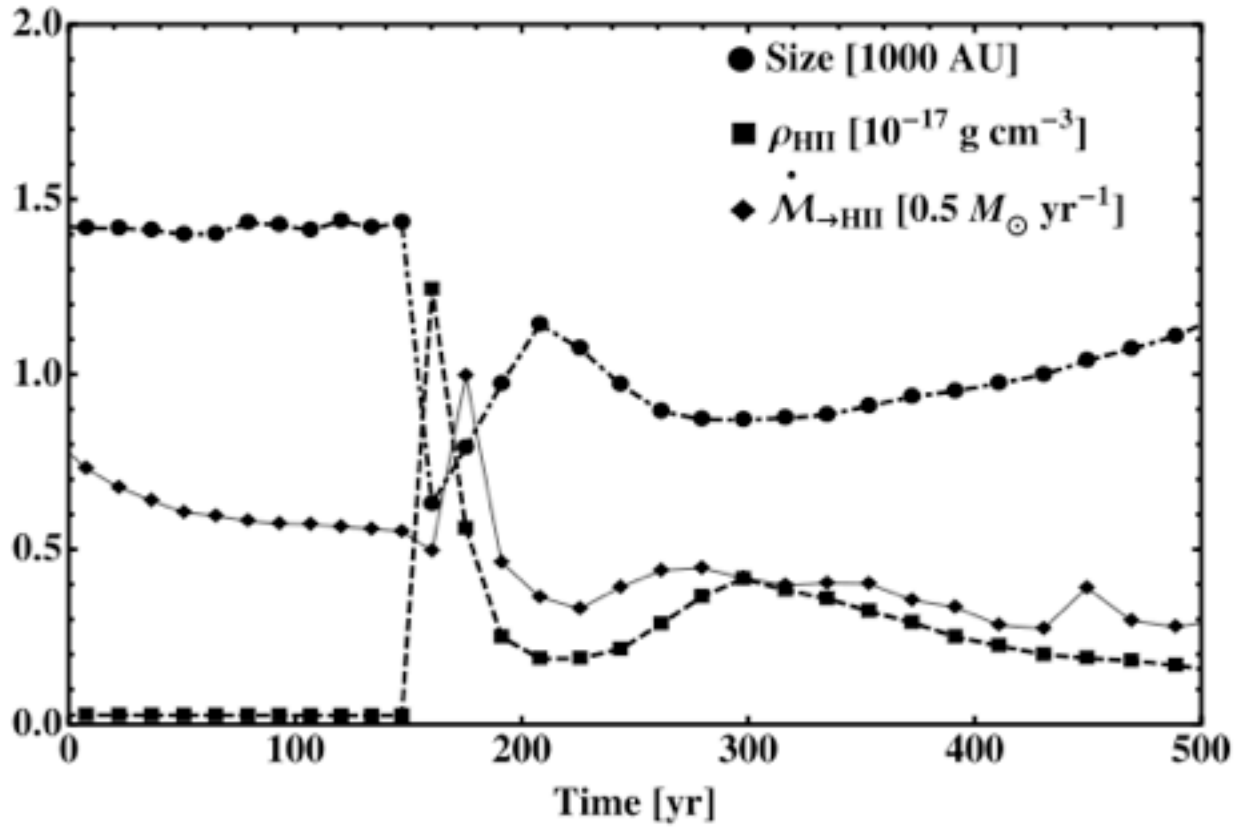
Peters et al. 2010b

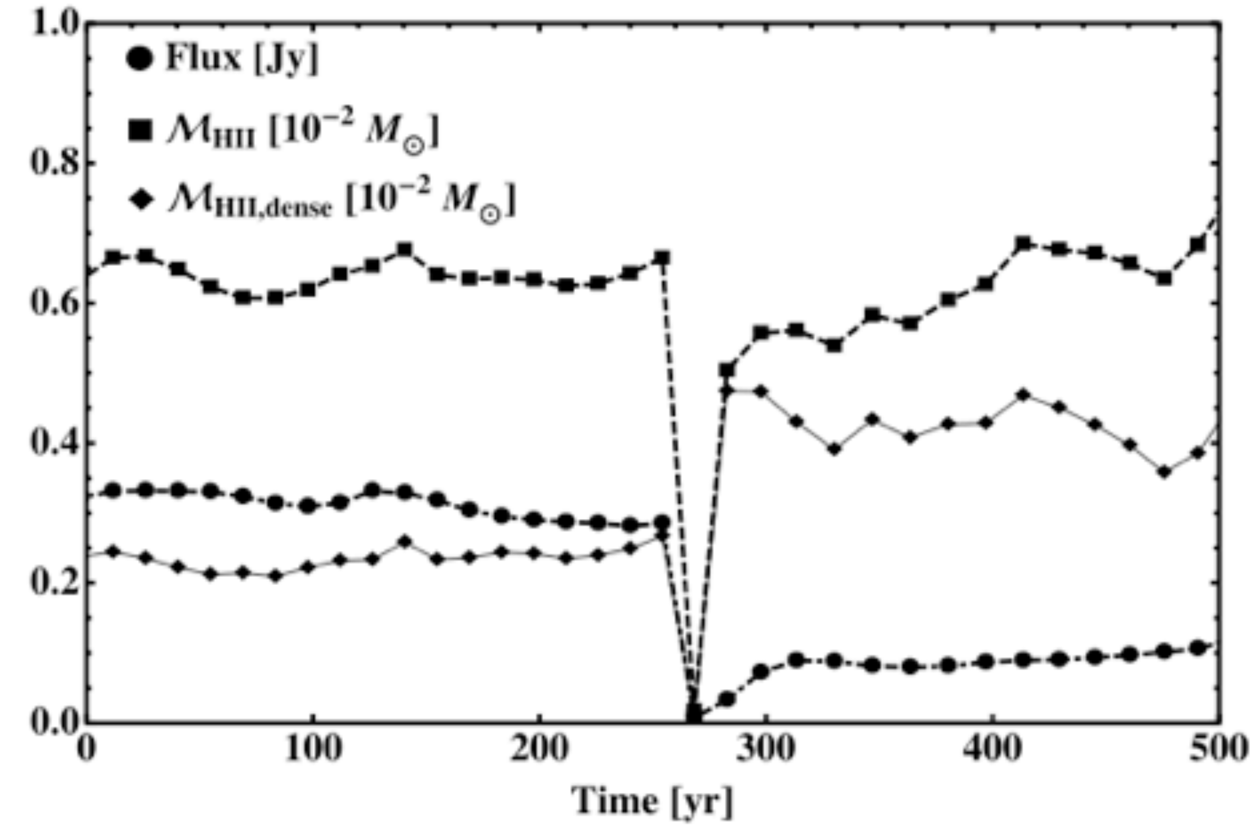
- only clustered SF match observed statistics



morphology at different viewing angles

Observational Tests: Time Variability



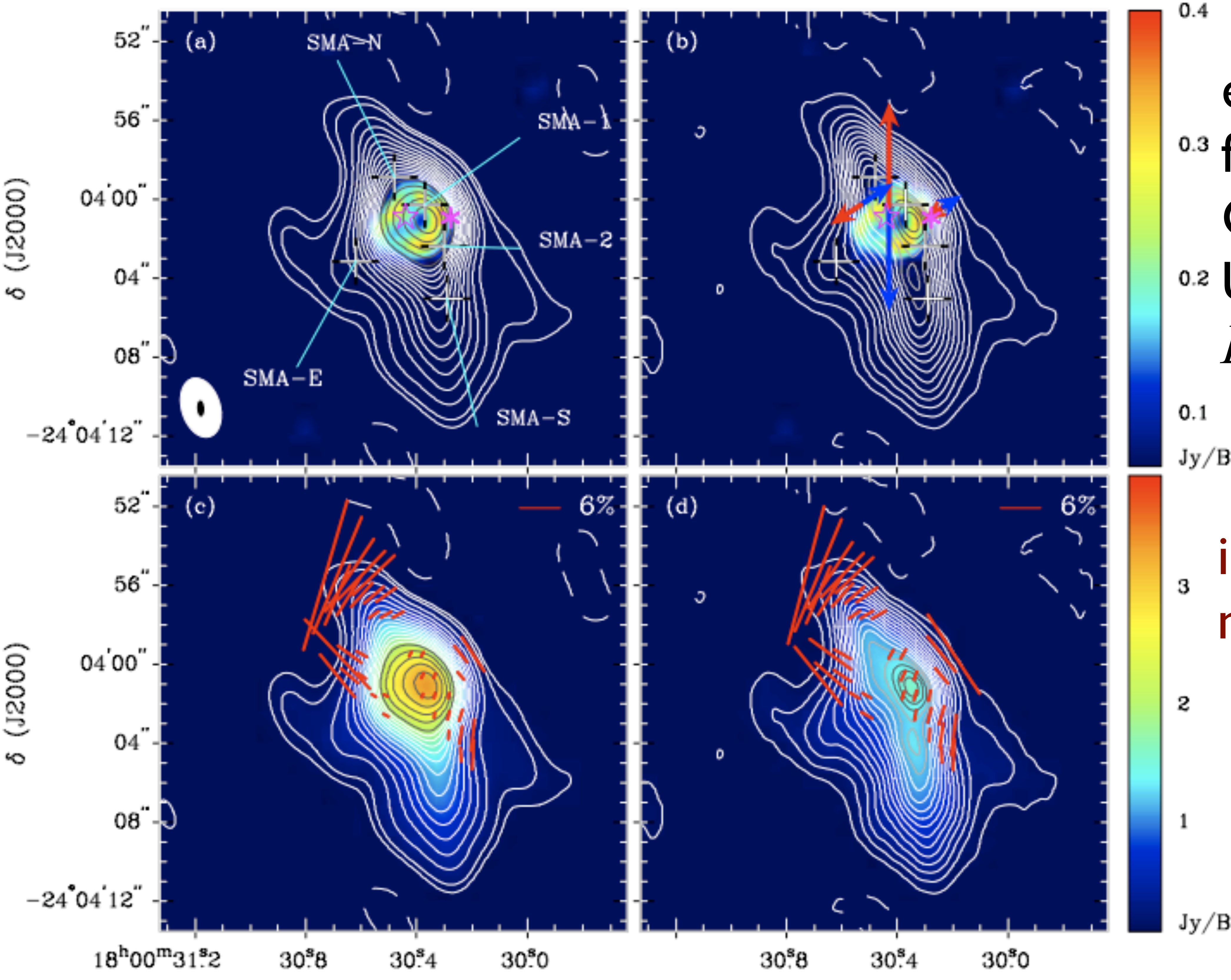


Galvan-Madrid et al. 2011

- UC and HC HII regions are highly time variable
  → unsteady accretion onto the massive star
  → quenching and re-expansion of HII regions

- in agreement with observation (e.g. *Galvan-Madrid* 2008; *Franco-Hernandez & Rodriguez* 2004)

Magnetic fields during Massive Star Formation



Tang et al. 2004

e.g. Massive star forming region G5.89-0.39 UHII

$B \sim 2\text{-}3$ mG

influence of magnetic fields?

Collapse of Massive Cloud Cores

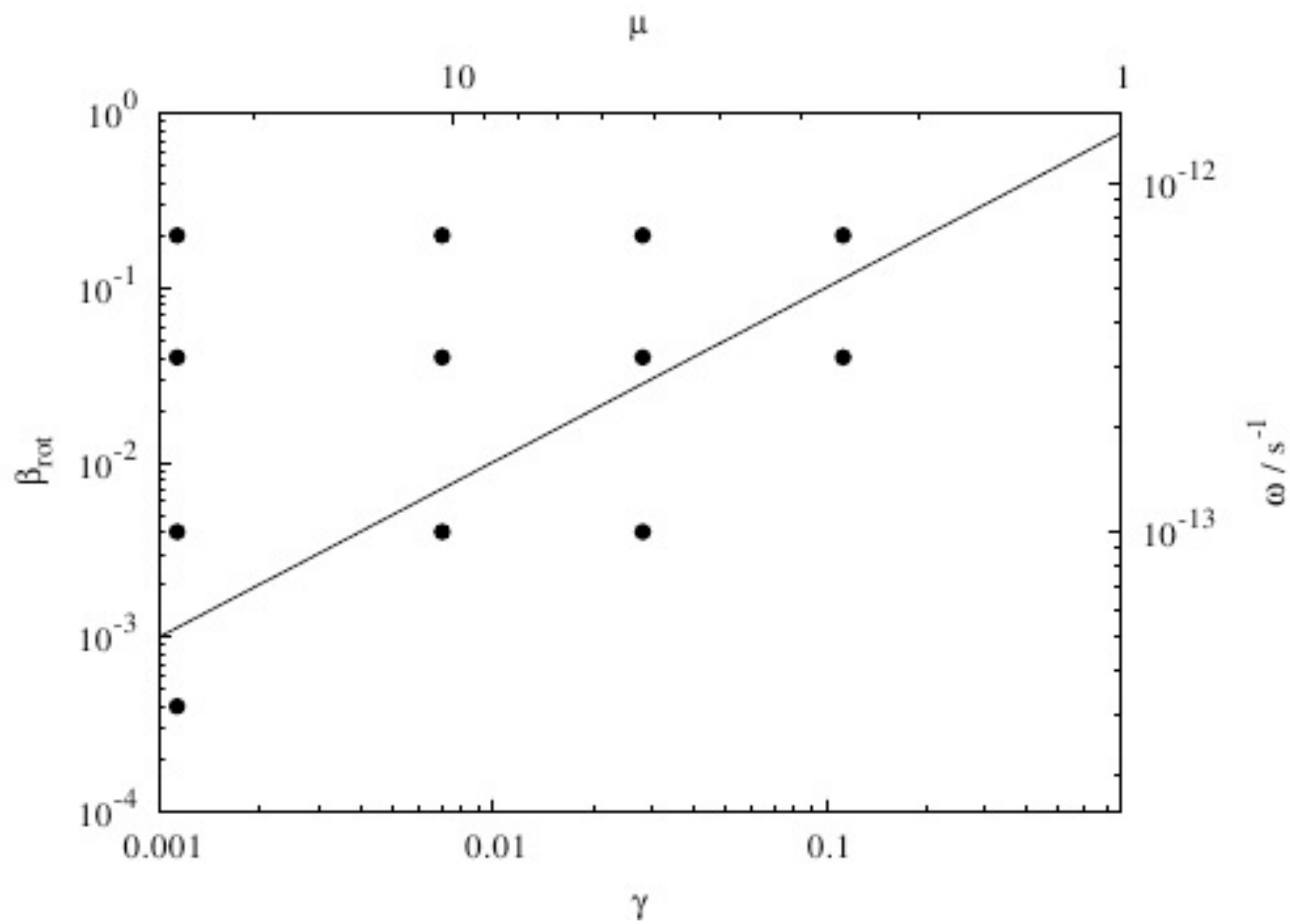
Parameter study with 3D Simulations of rotating massive collapsing cloud cores

- $M_{core} = 100\ M_{sol}$
- $R_{core} = 0.125$ pc
- density profile: $\rho \sim r^{-1.5}$
- $\rho_{core} = 2.3 \times 10^{-17}$ g cm^{-3}

- rotation with $\beta = 4 \times 10^{-4} - 0.2$

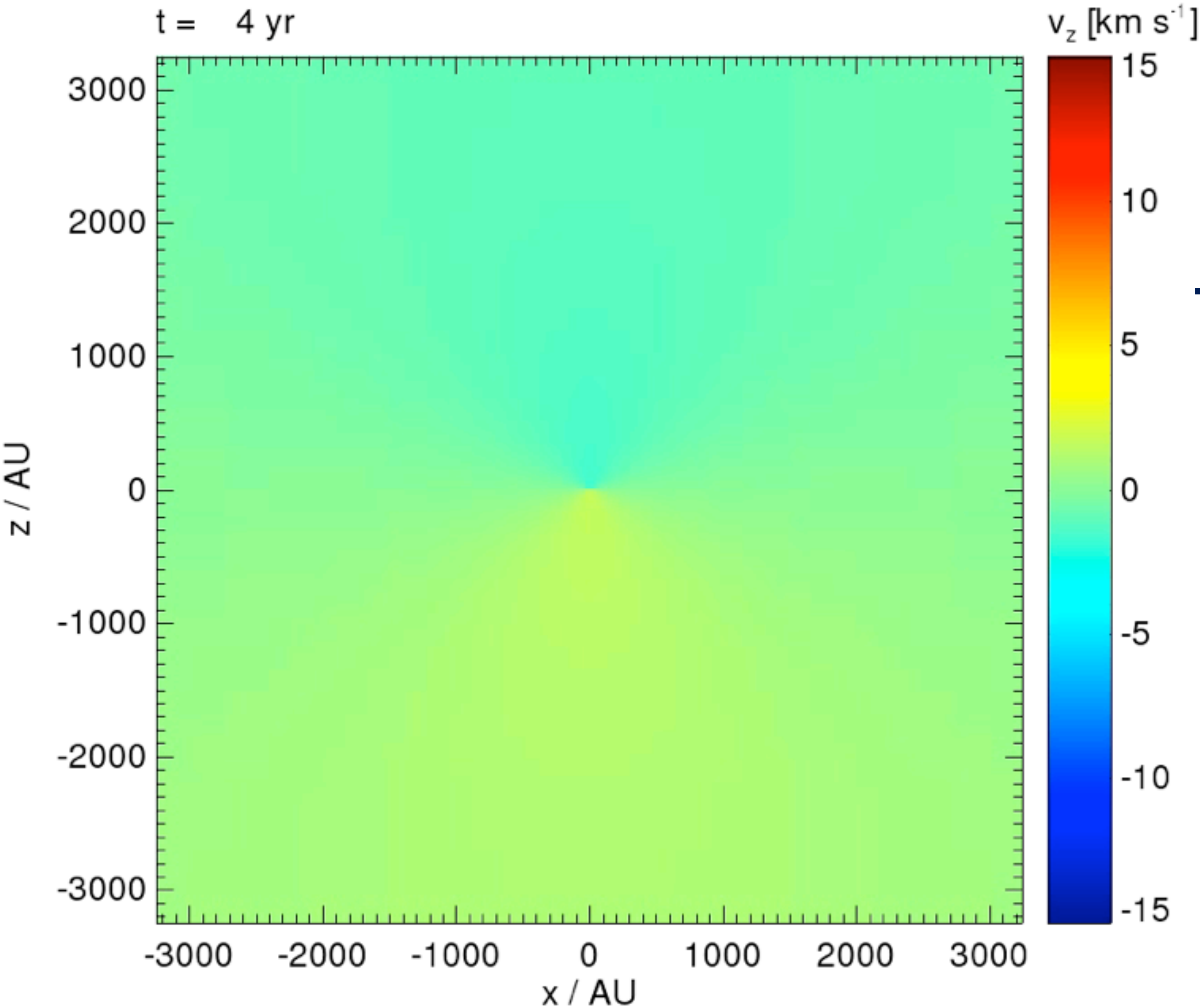
- mass-to-flux: $\mu = 2.6 - 26\ \mu_{crit}$
- $B_z = 1.3 - 0.13$ mG
  aligned with rotation axis

- resolution: 4.7 AU



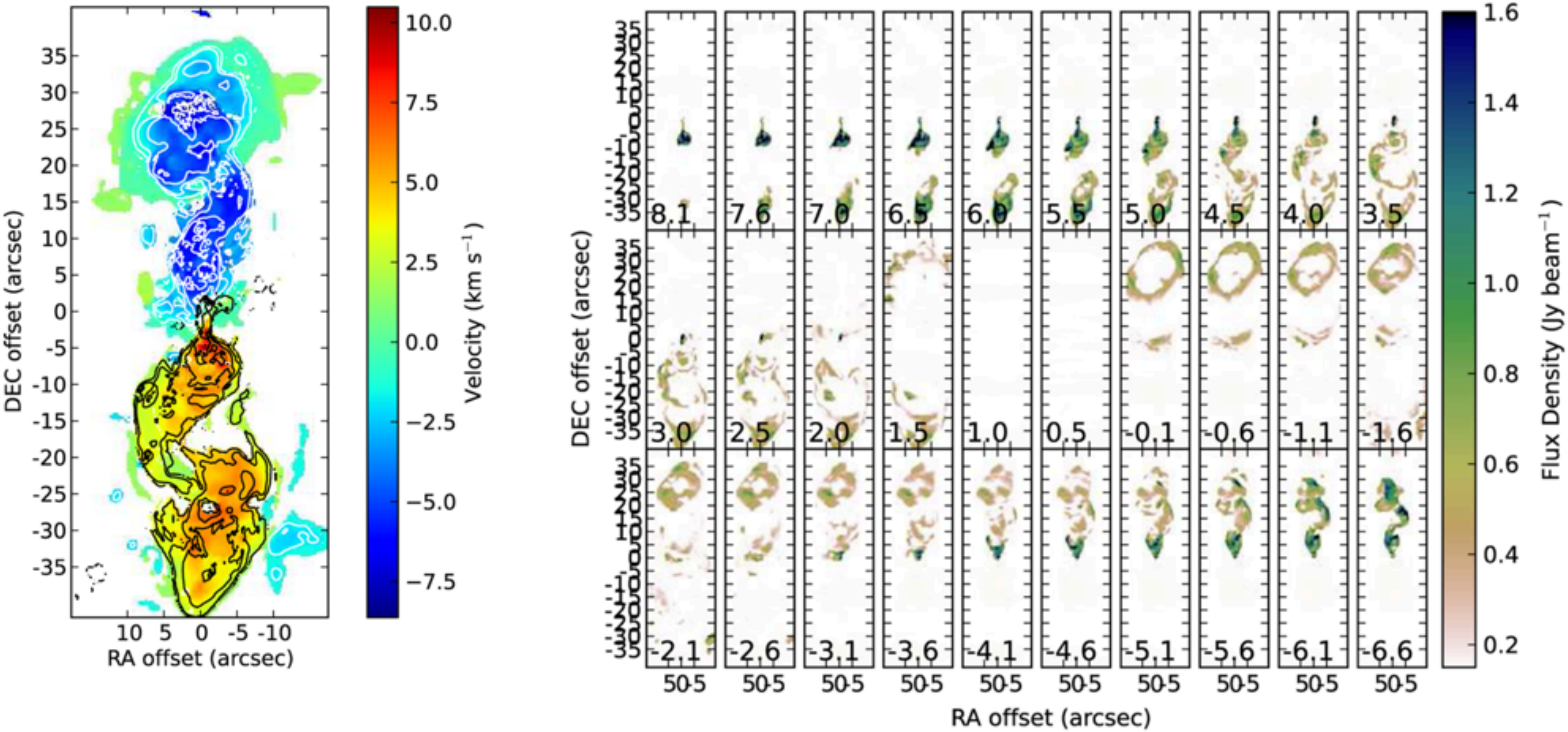
Seifried, RB, Klessen, Duffin, Pudritz 2011

Magnetically driven outflows



→ disc winds expected also around massive protostars before ionization sets in

Magnetically driven outflows



Peters, Klaassen, Seifried, RB, Klessen 2014

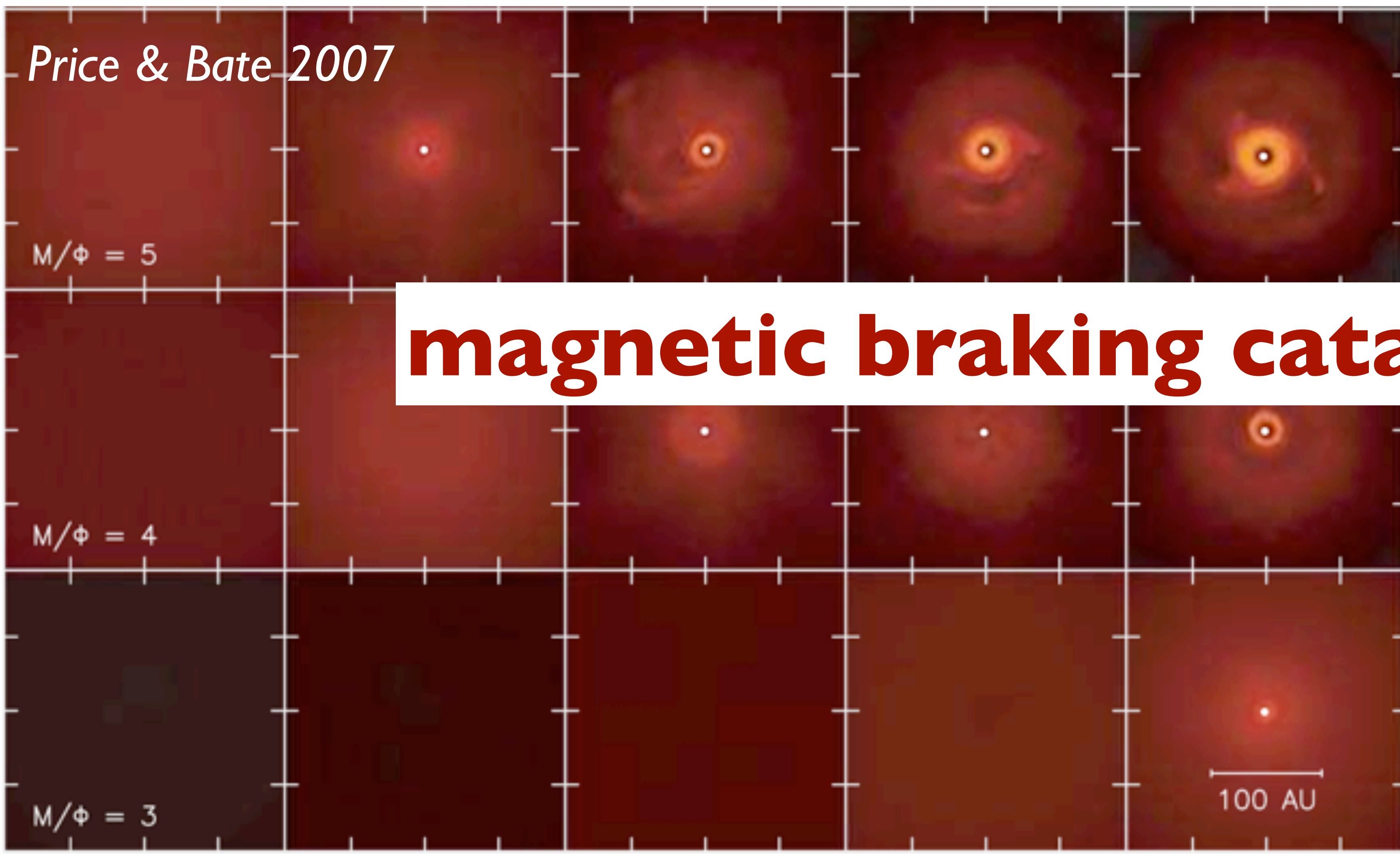
$\Longrightarrow$ Helical structure similar to outflow around the A-type star HD 163296 (D = 122 pc)

$\Longrightarrow$ see Pam Klaassen's talk

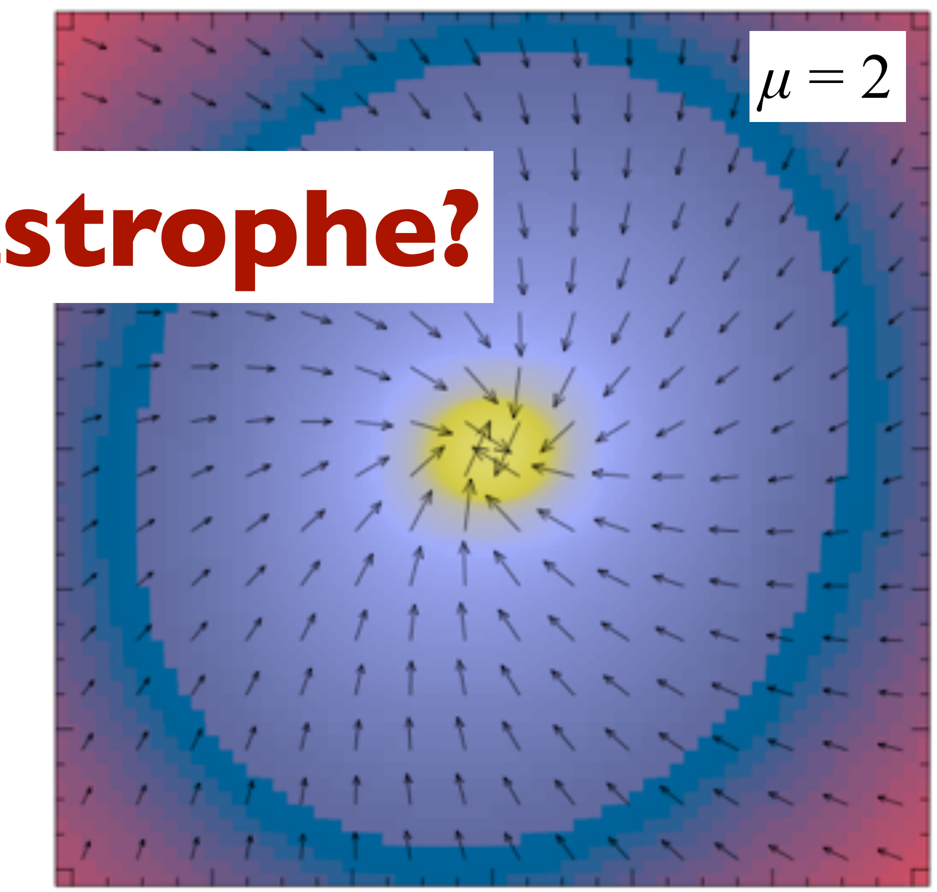
Star Formation: Early-type discs

$\Longrightarrow$ discs necessary for disc winds / outflows

- observed magnetic fields indicate $\mu < 5$ (e.g. *Crutcher et al.* 2010)



magnetic braking catastrophe?

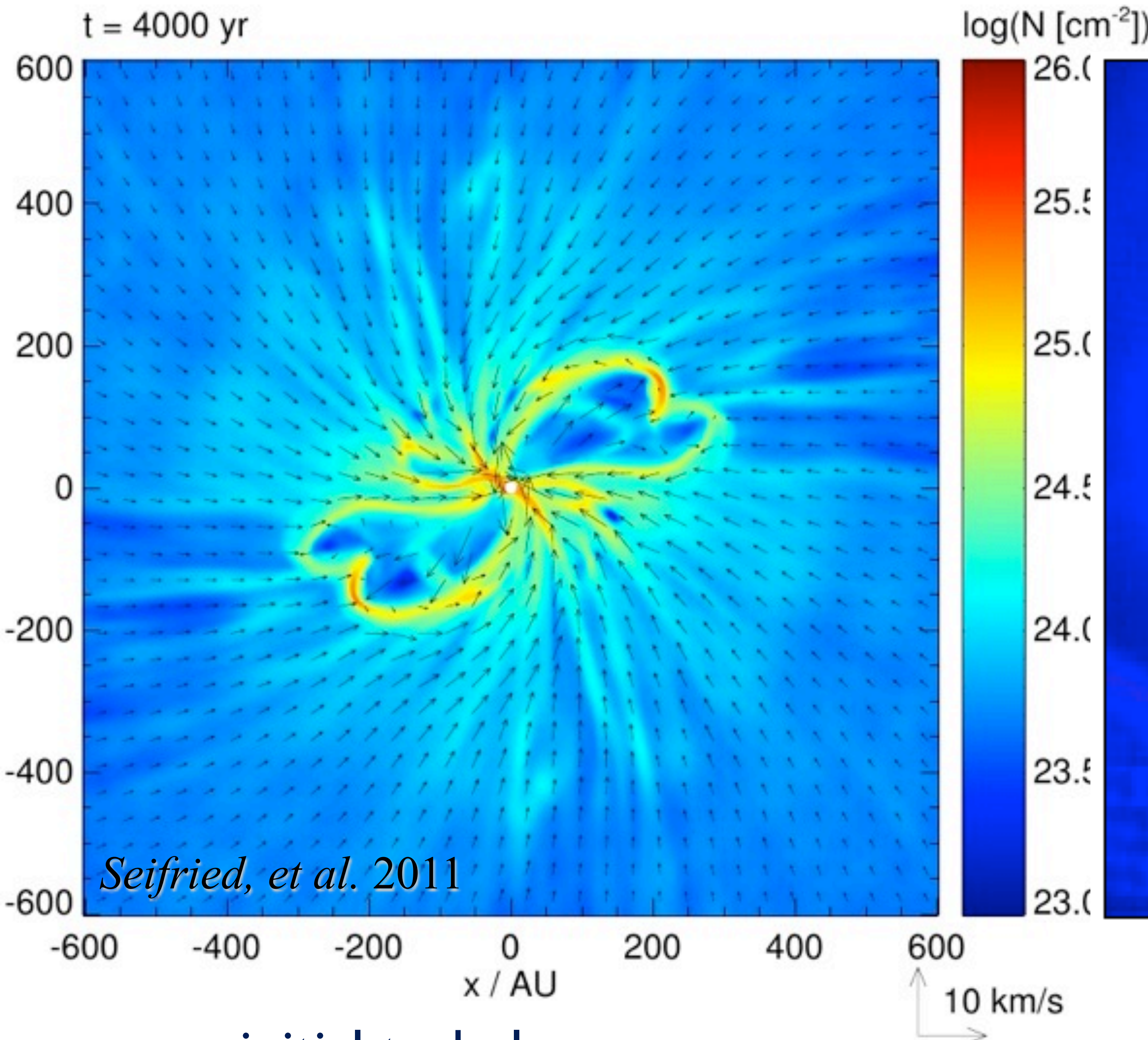


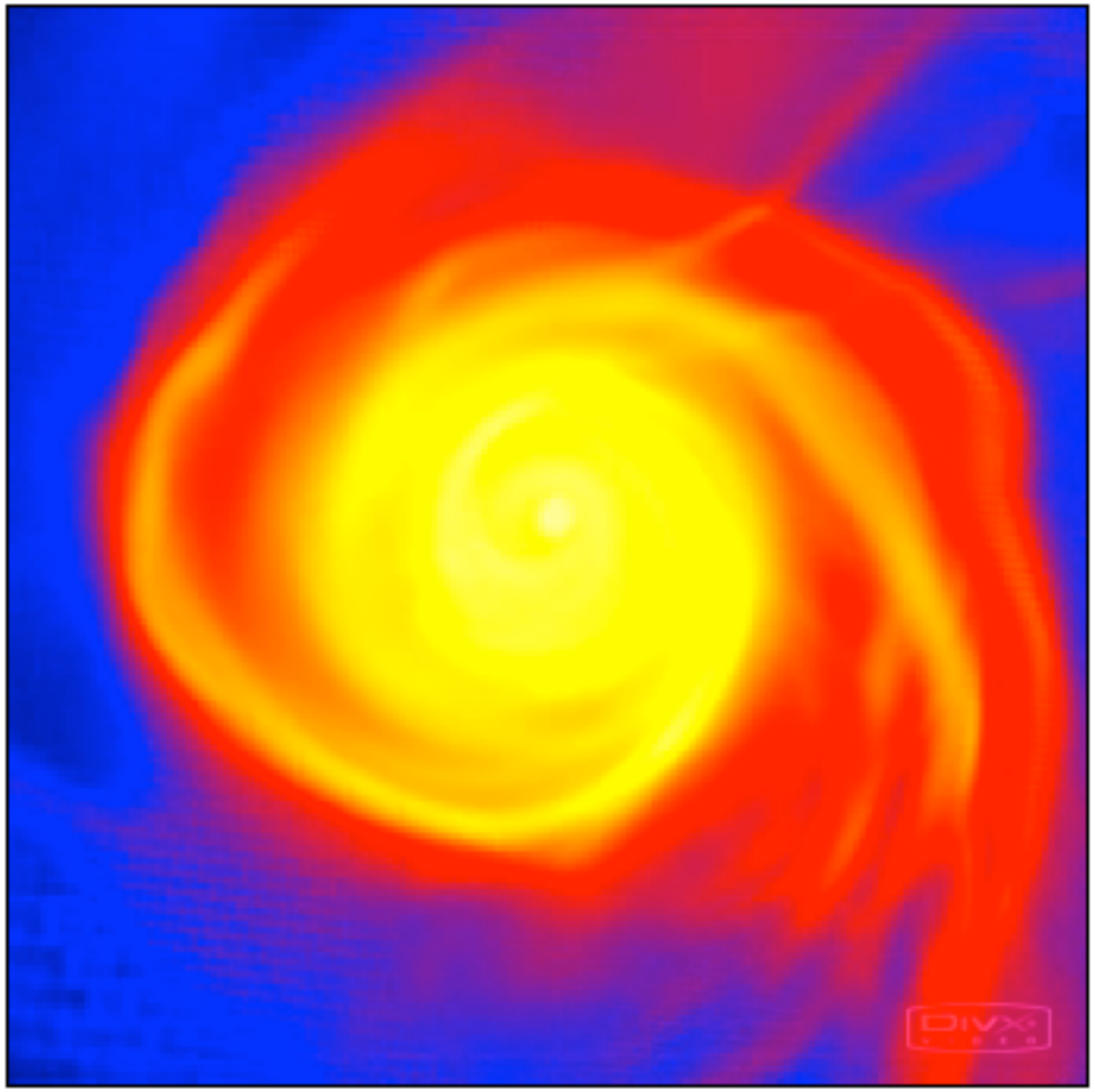
Hennebelle & Teyssier 2008, ...

$\Longrightarrow$ ***too*** efficient magnetic braking

$\Longrightarrow$ ***no*** disc formation with smooth initial conditions

Turbulence vs. no turbulence

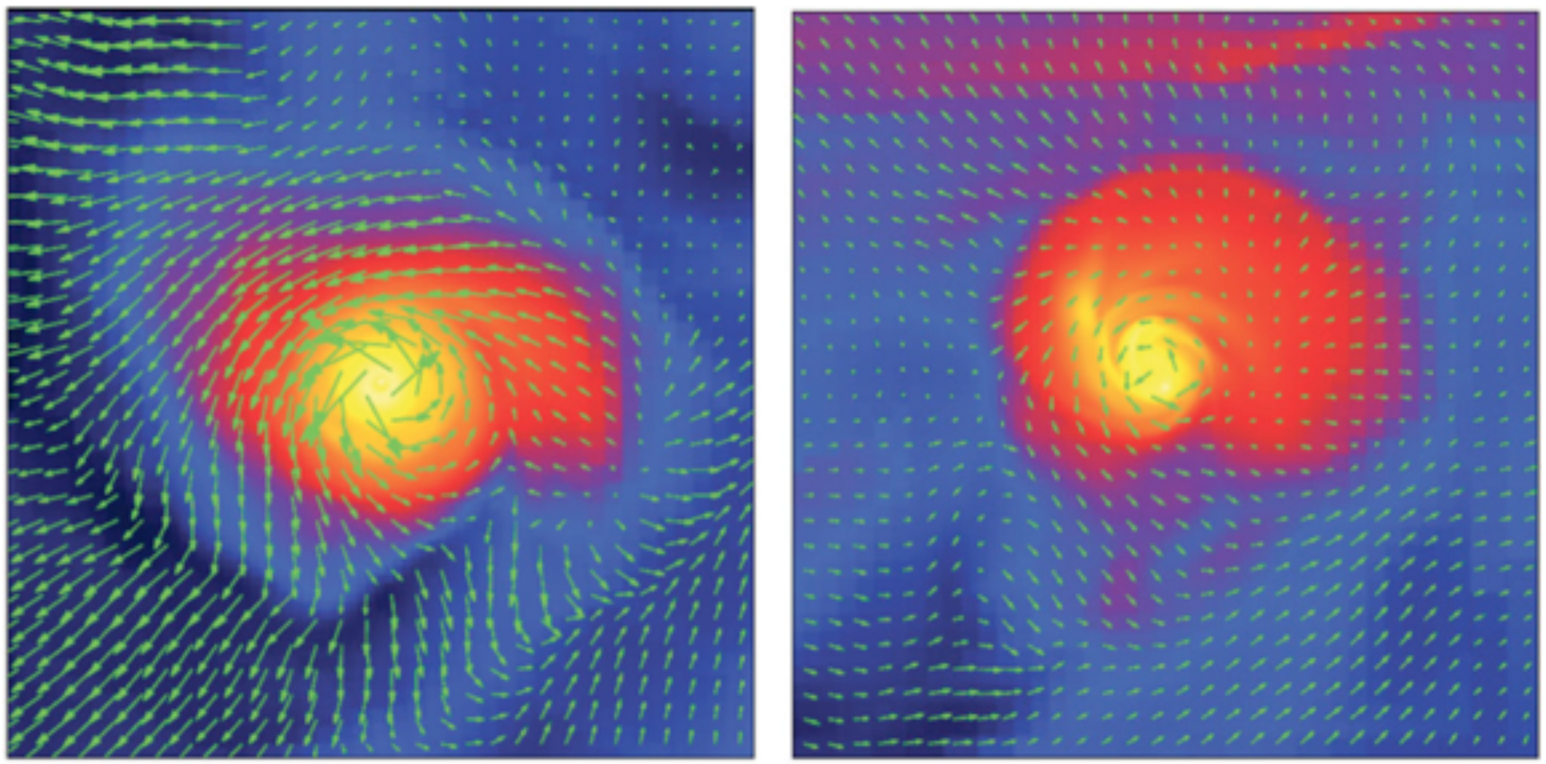




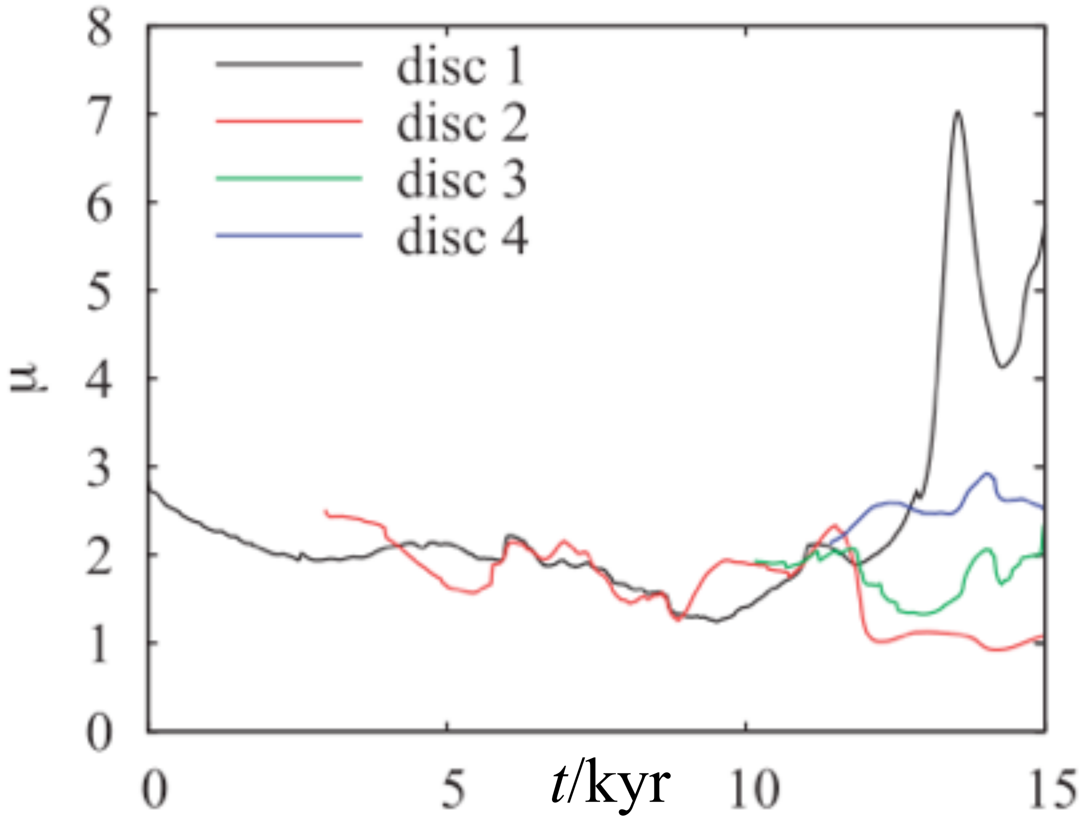
- **no** initial turbulence
  → efficient *magnetic braking*
  → no proto-stellar discs

- **with** initial **turbulence**
  → formation of Keplerian discs
  (*Seifried et al.* 2012)

Disc formation with Turbulence



Seifried, et al. 2012



- large, replenished local angular momentum by shear flows & filaments
- initial large-scale coherent field becomes distorted
- no magnetic flux loss necessary

Summary

- Ionization feedback does **not stop** accretion
  → radiation escapes through funnels & holes

- Secondary star formation slows down/prohibit accretion onto the massive proto-star
  → fragmentation-induced starvation (**FIS**)

- UC/HC HII highly time **variable**
  → morphology of HII regions changes / depending on viewing angle

- Magnetic fields + discs
  → launch of disc winds / **outflows** around massive proto-stars

- **Turbulence** solves *magnetic braking catastrophe*