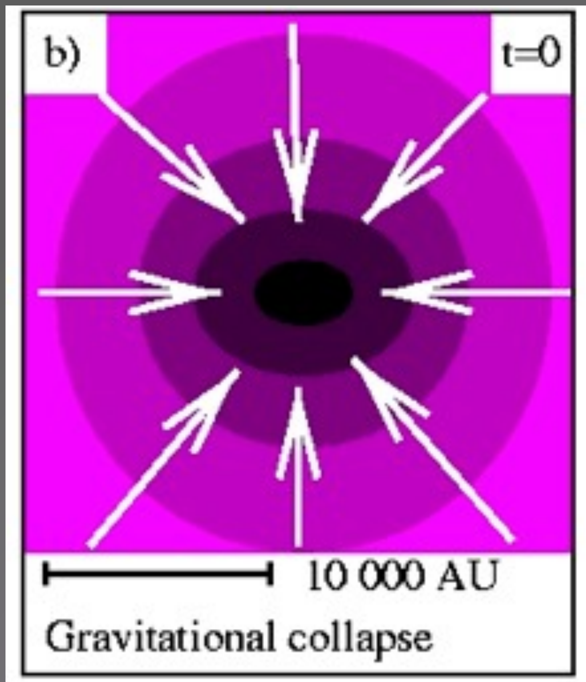
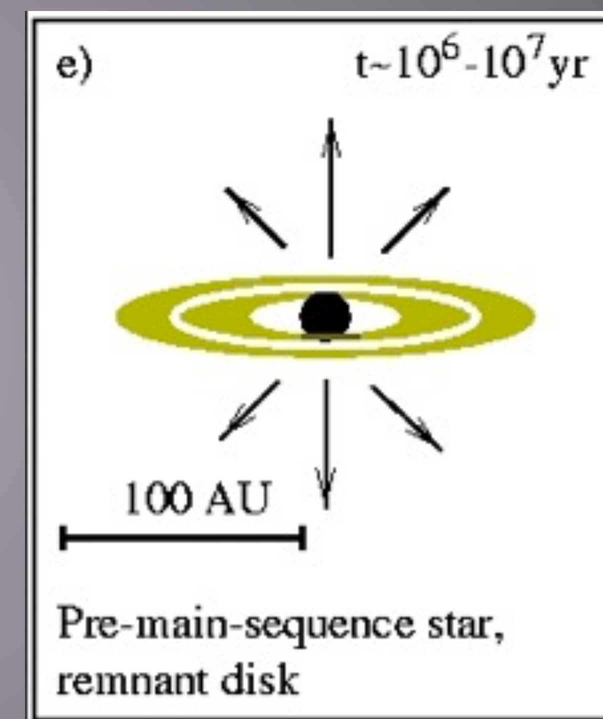
Tracing Protostellar Evolution using Gas Kinematics

Christian Brinch
University of Copenhagen



From infall...

...to rotation

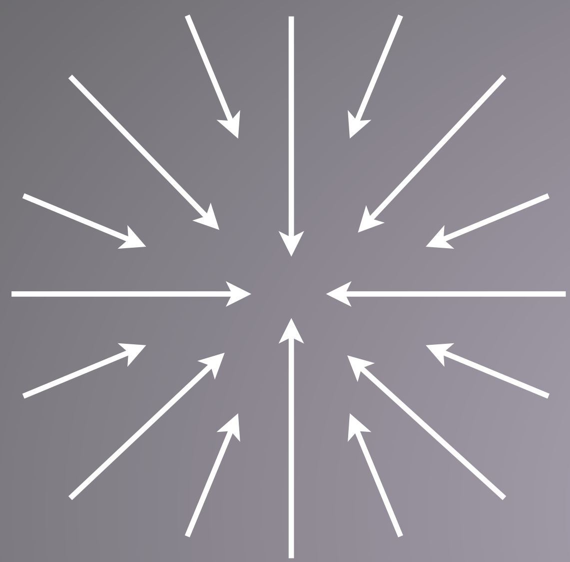
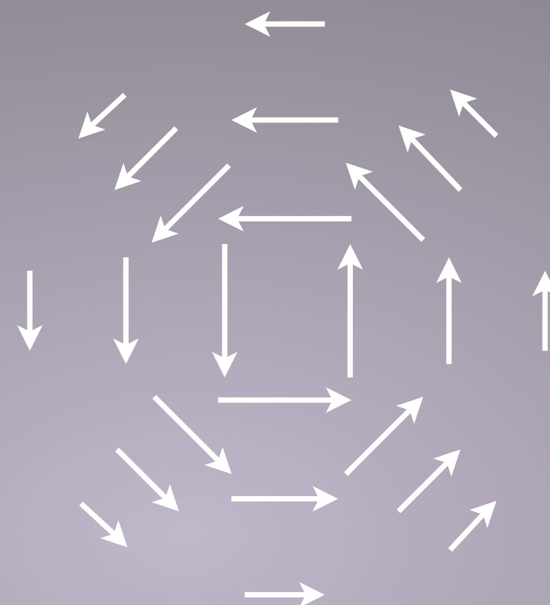


Questions:

- How do protostars accrete over time?
- What is the chemical history of the material in PP-disks?
- What role does the environment play?

(Figure by M. Hogerheijde)

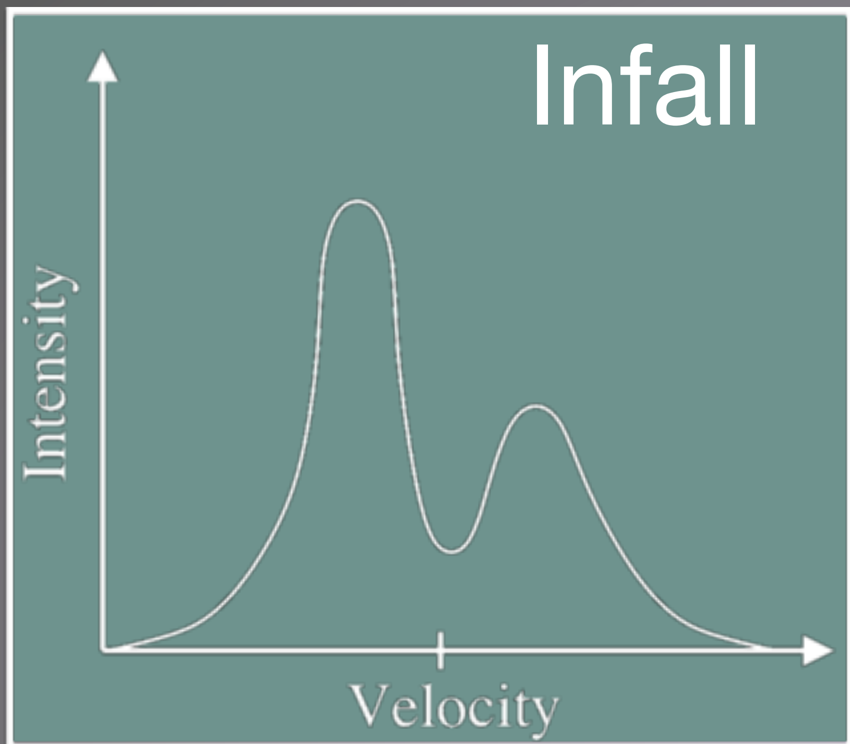
Parameterizing the gas flow

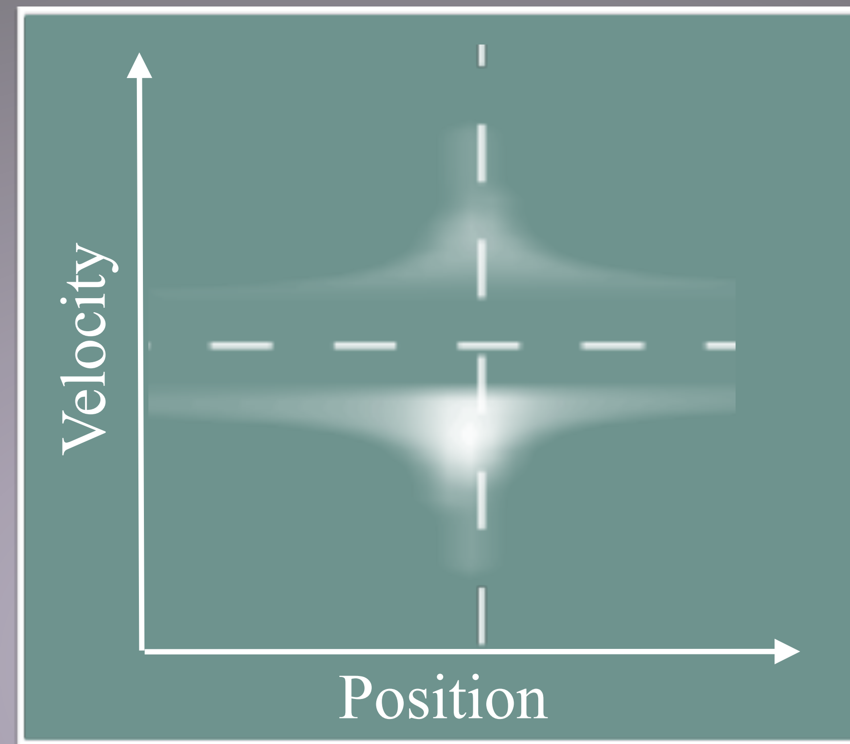
p  +(1-p)  $= \vec{v}$; p=[0,1]

$$\vec{\mathbf{v}} = \begin{pmatrix} v_r \\ v_\phi \end{pmatrix} = \sqrt{\frac{GM_*}{r}} \begin{pmatrix} -\sqrt{2}\sin\alpha \\ \cos\alpha \end{pmatrix}$$

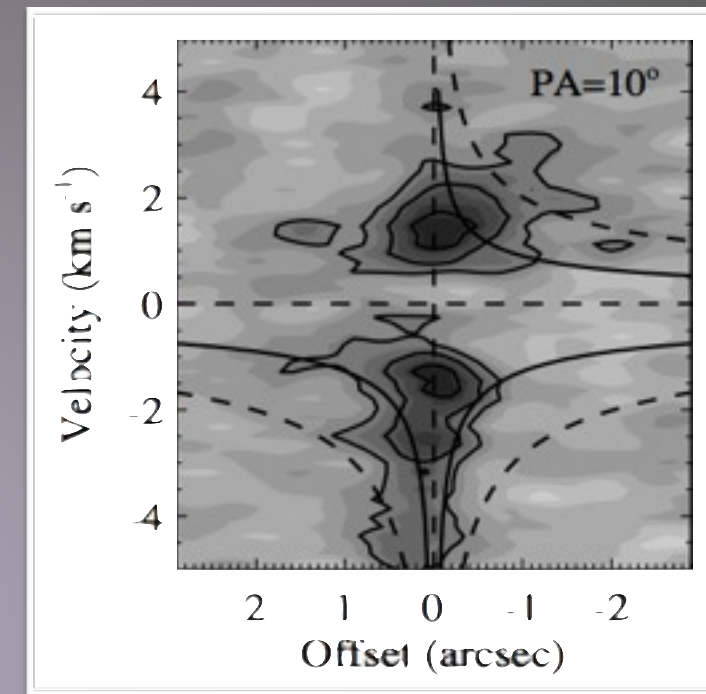
(Brinch et al., 2008)

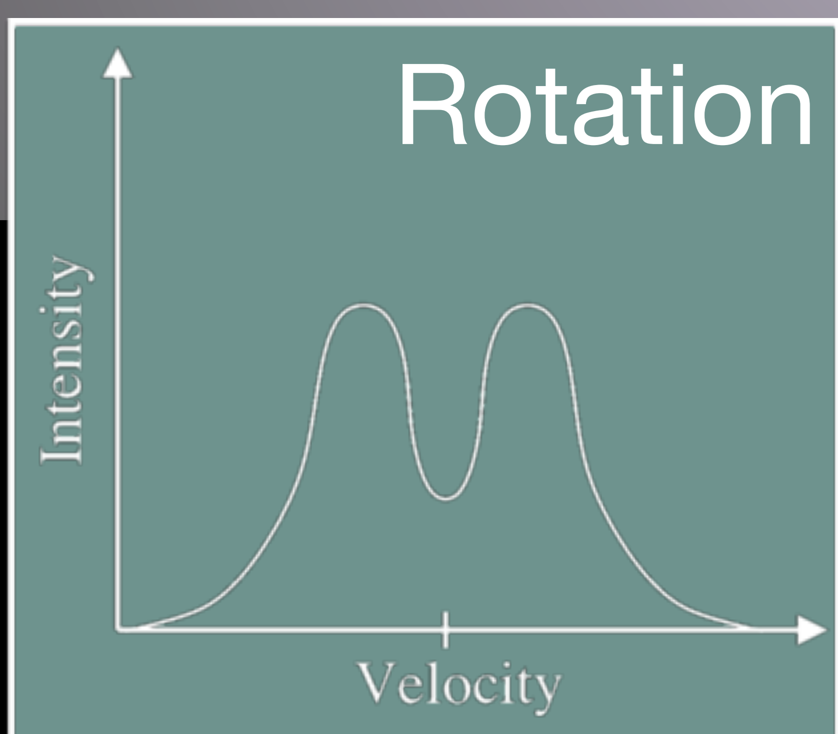
Spectra & P-V diagrams

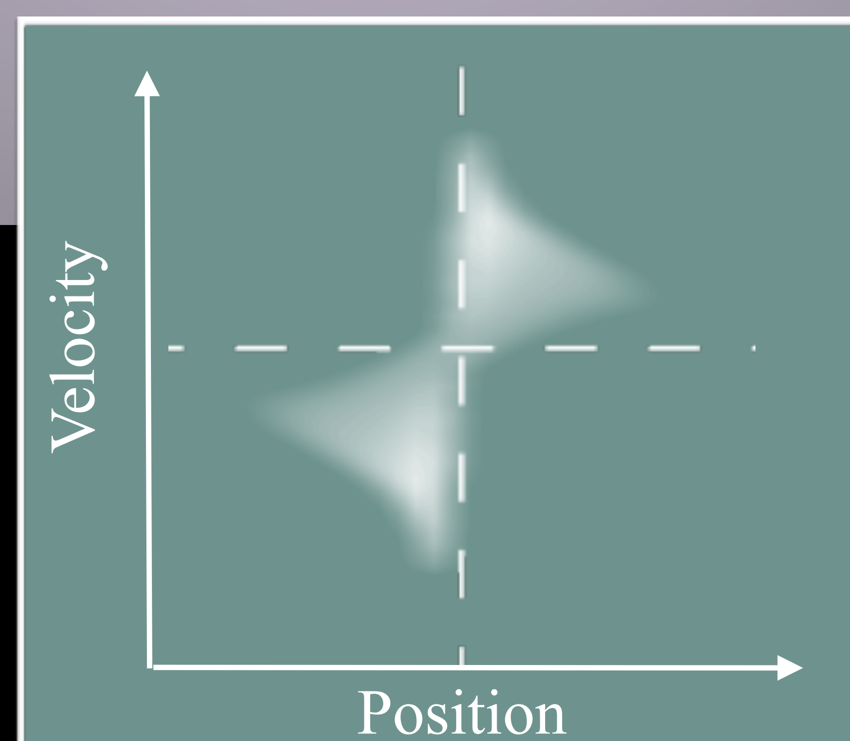




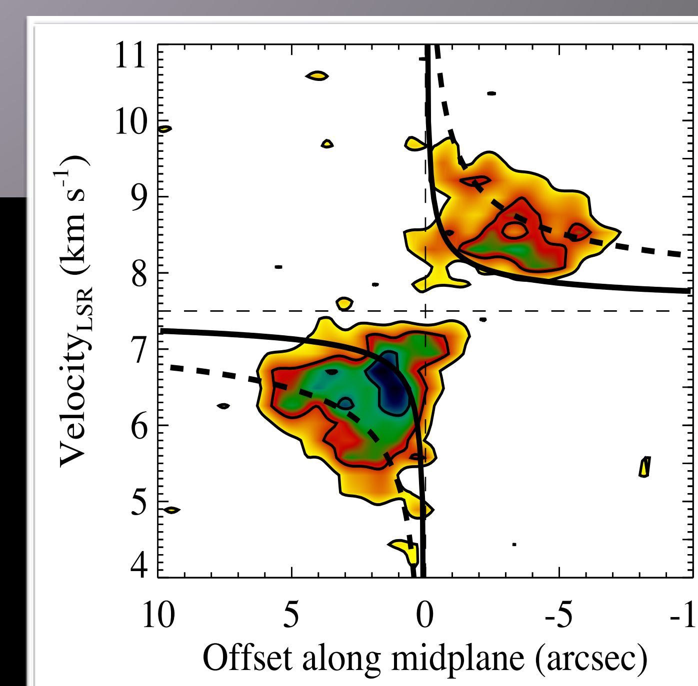
IRAS 2A

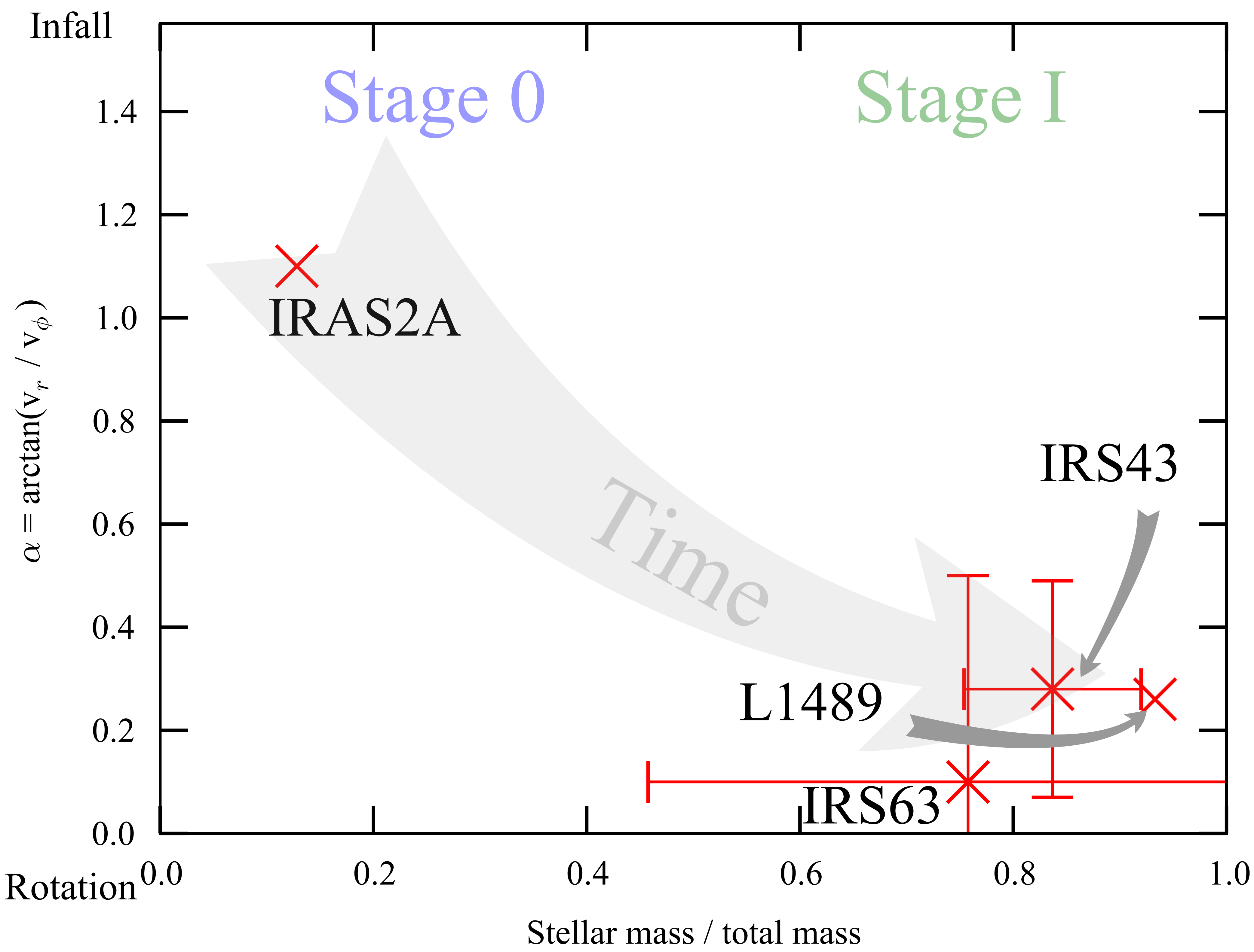






L1489 IRS

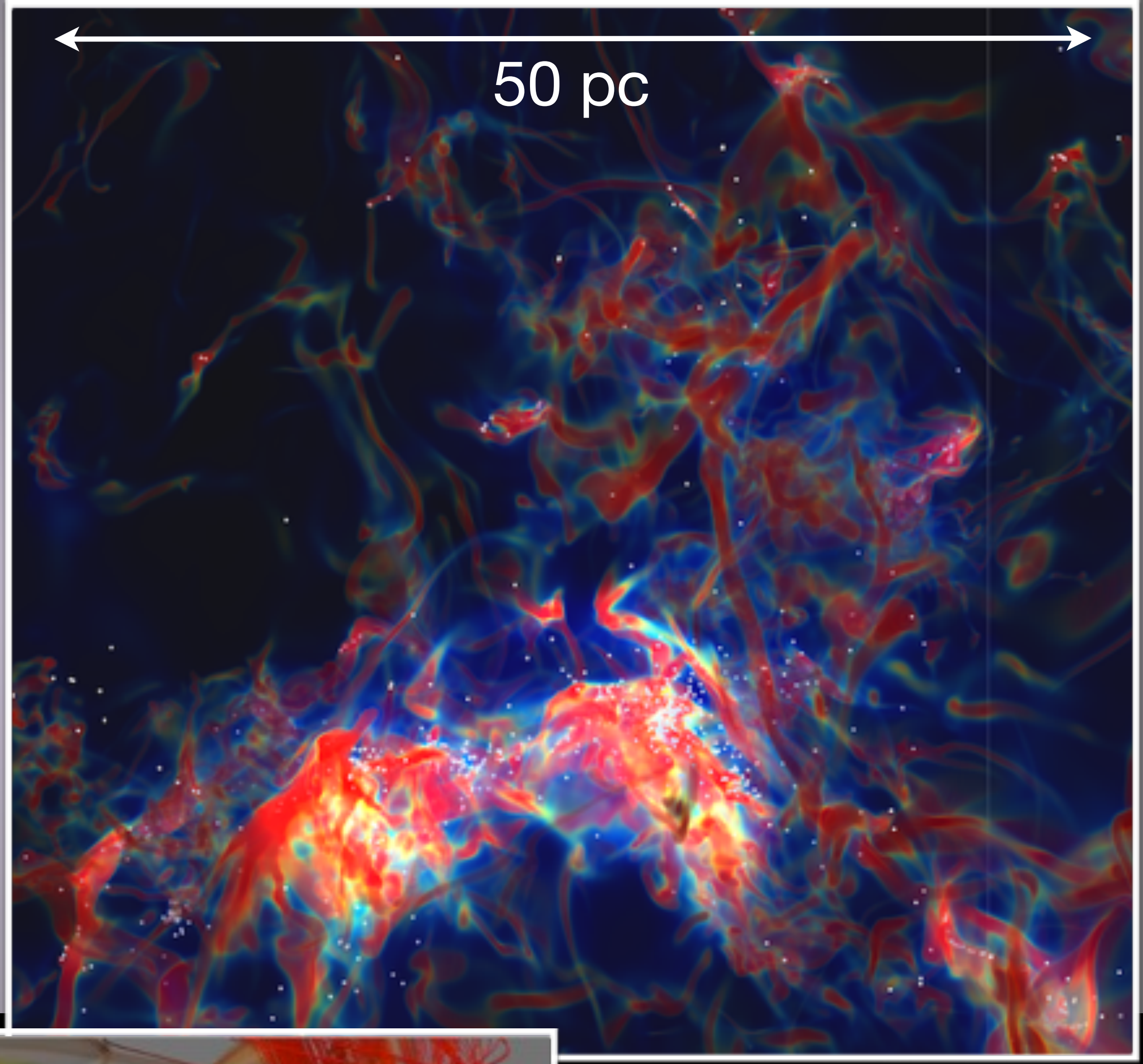


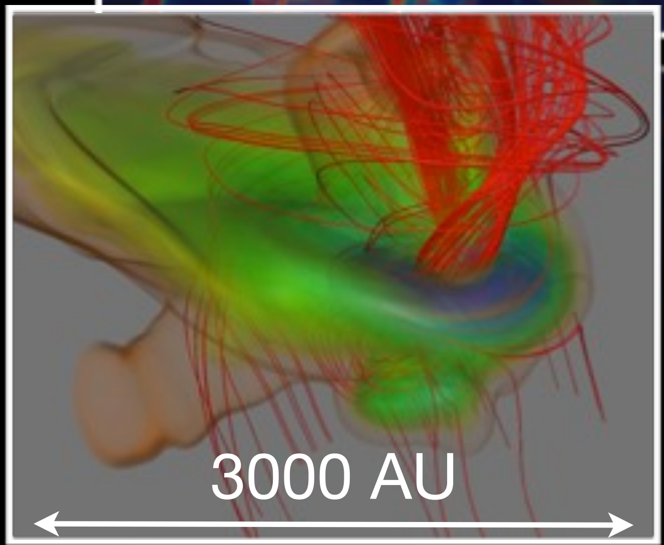


Infall
Rotation
Stage 0
Stage I
Time
IRAS2A
IRS43
L1489
IRS63
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
$\alpha = \arctan(v_r / v_\phi)$
Stellar mass / total mass

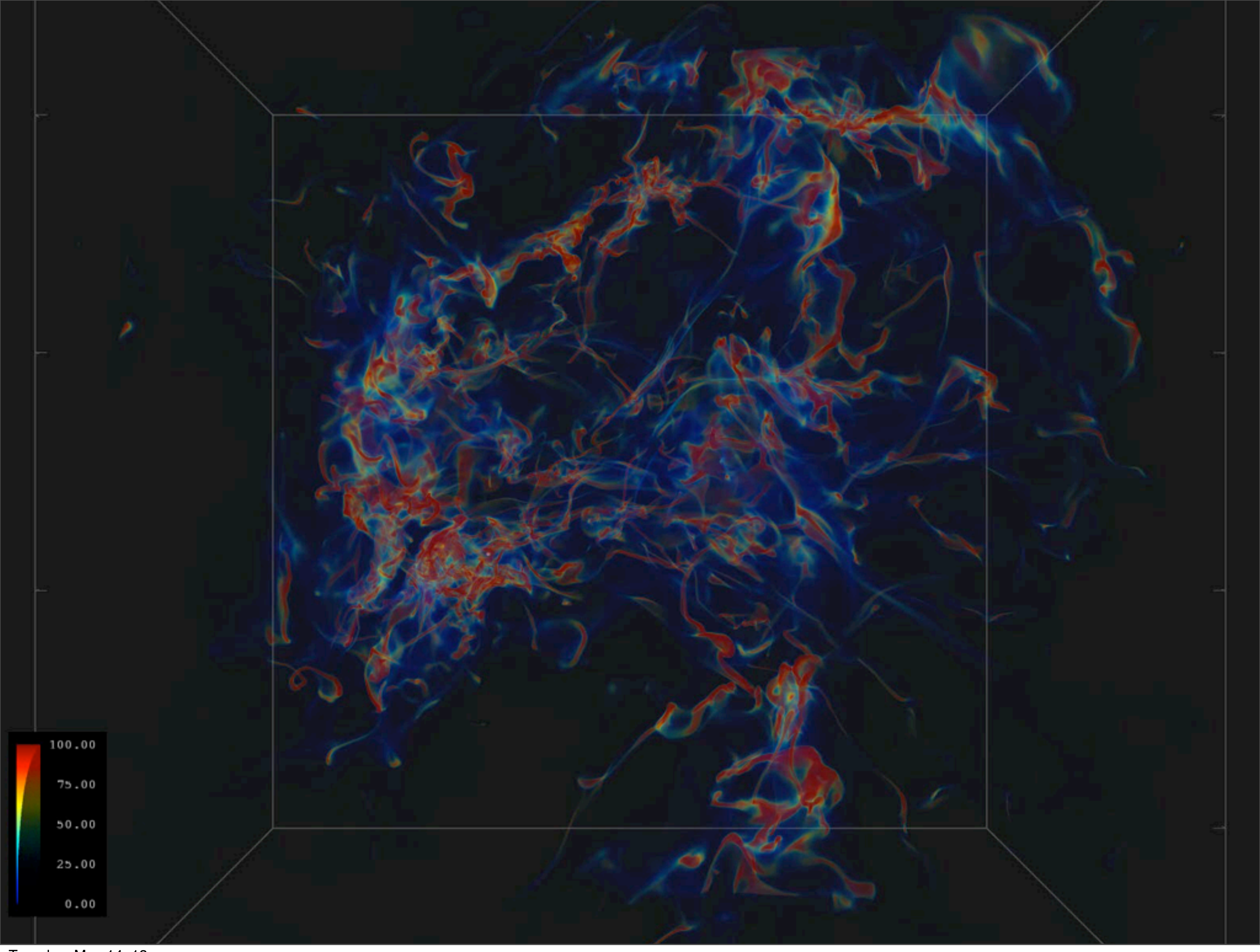
Numerical star formation

- Copenhagen simulation
  (Haugbølle, Padoan, and Nordlund, in prep.)
- Ramses MHD with 256^3 base grid + 9 AMR levels ~ 10^9 grid cells (512^3 is currently running)
- 2000 cores for a month ~1.5 million cpu hours
- Tens of thousands stars



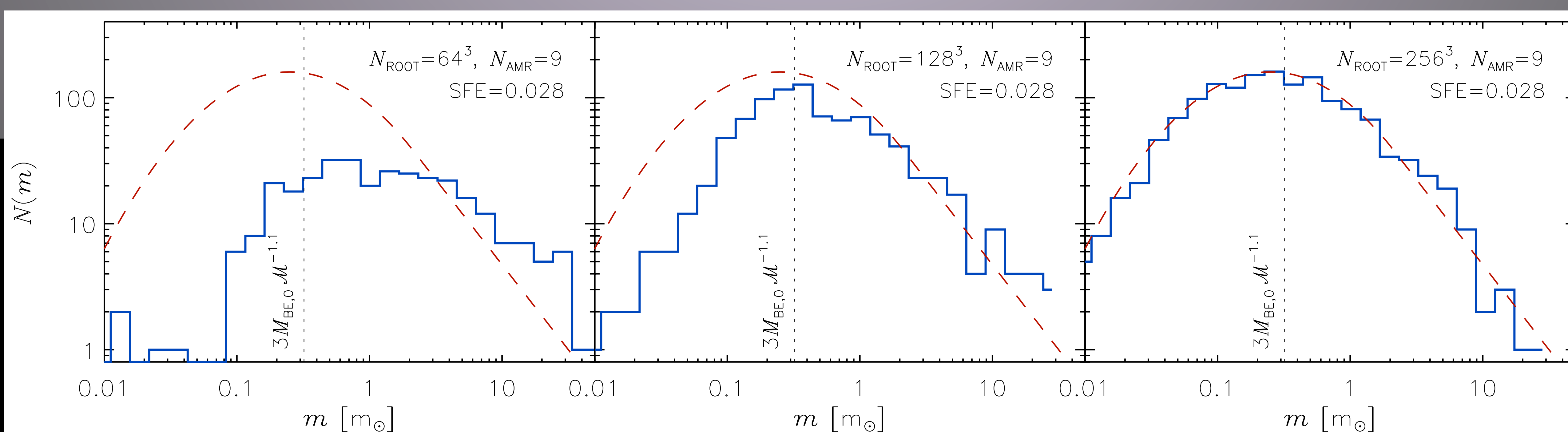


30 AU resolution


100.00
75.00
50.00
25.00
0.00

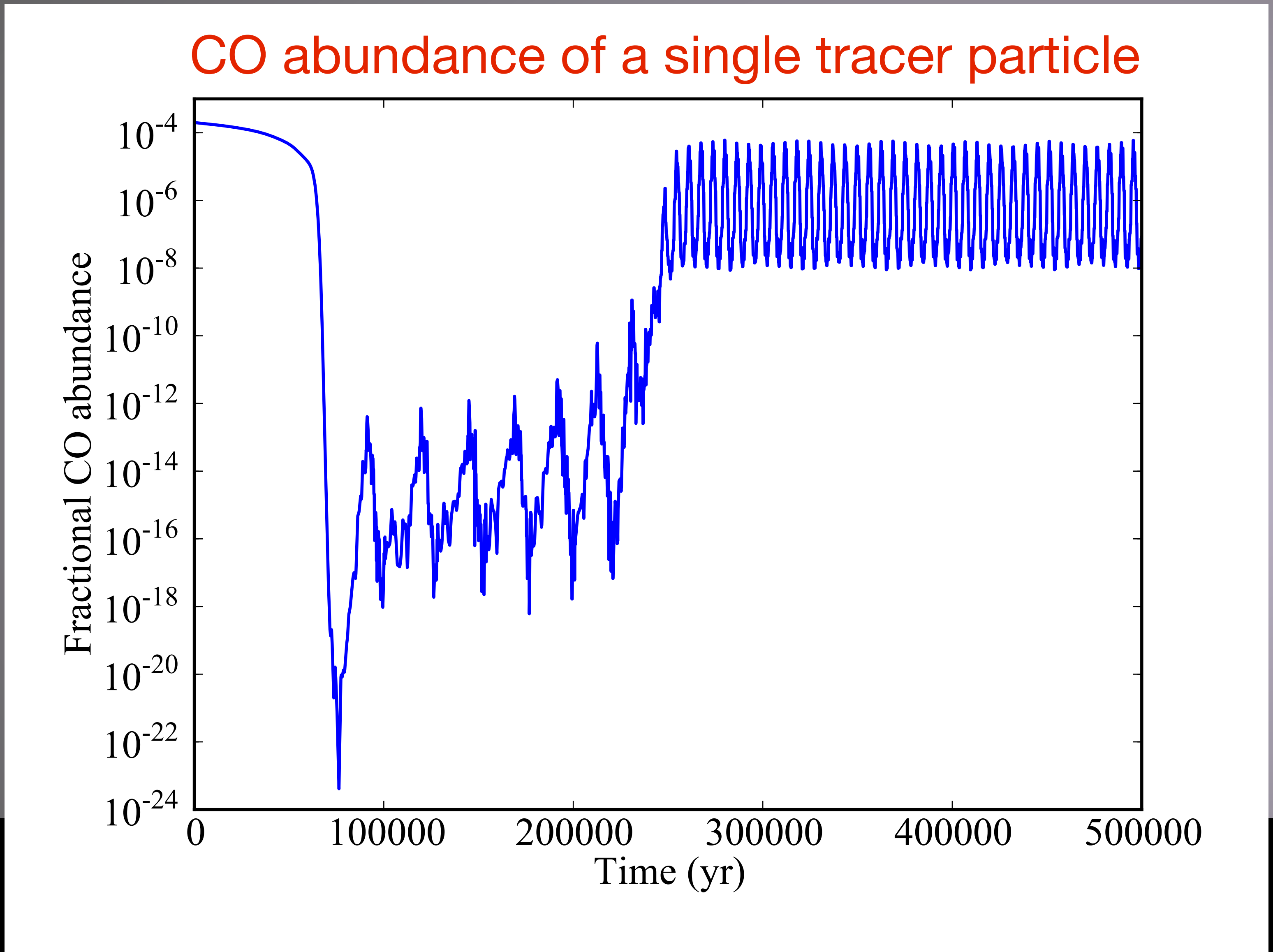
Getting ISM qualities right

- The simulation reproduces...:
  - the star formation rate
  - the initial mass function
  - the stellar mass accretion rate

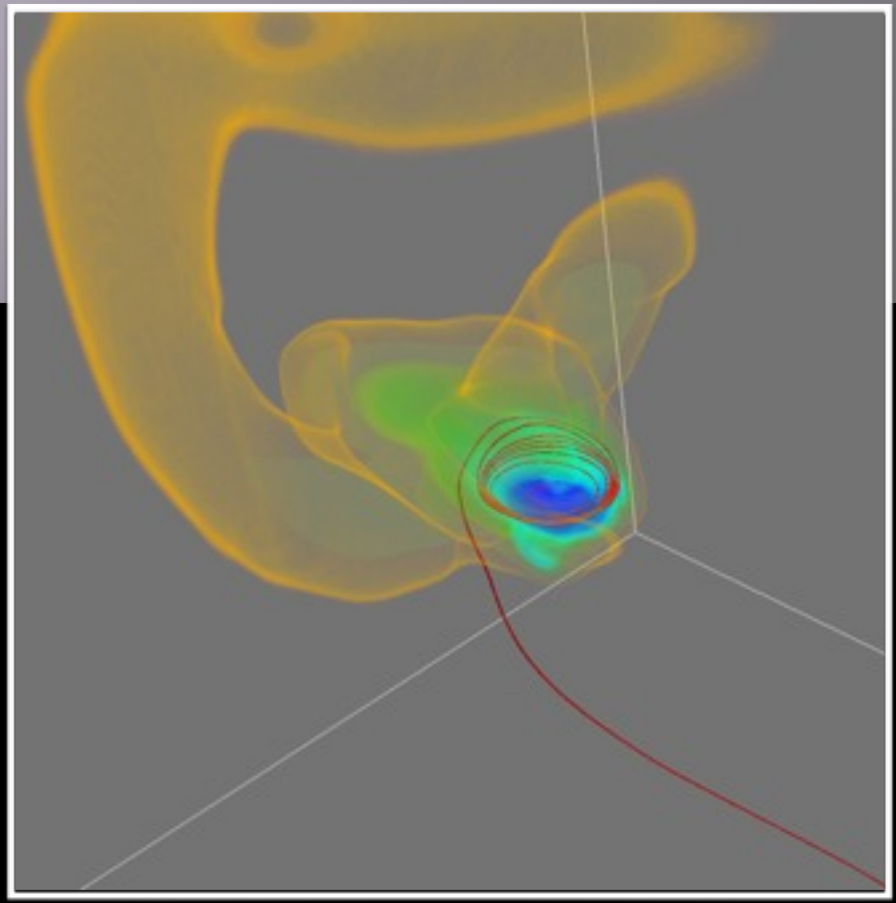


(Haugbølle et al., in prep.)

Tracing chemistry in Ramses

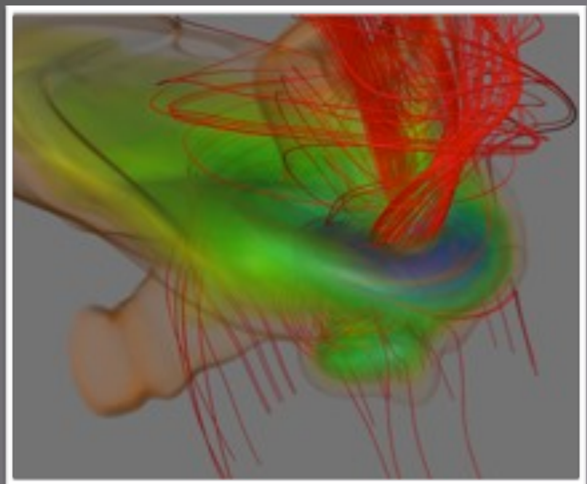


- Tracer particles follow desorption and freeze-out
- Chemical reactions can be included as well



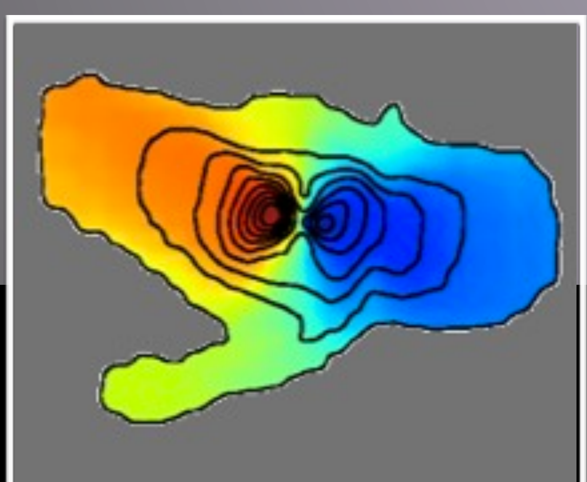
Method based on (van Weeren 2009)

Ramses cut-out



Radmc3D
(Thermal structure)

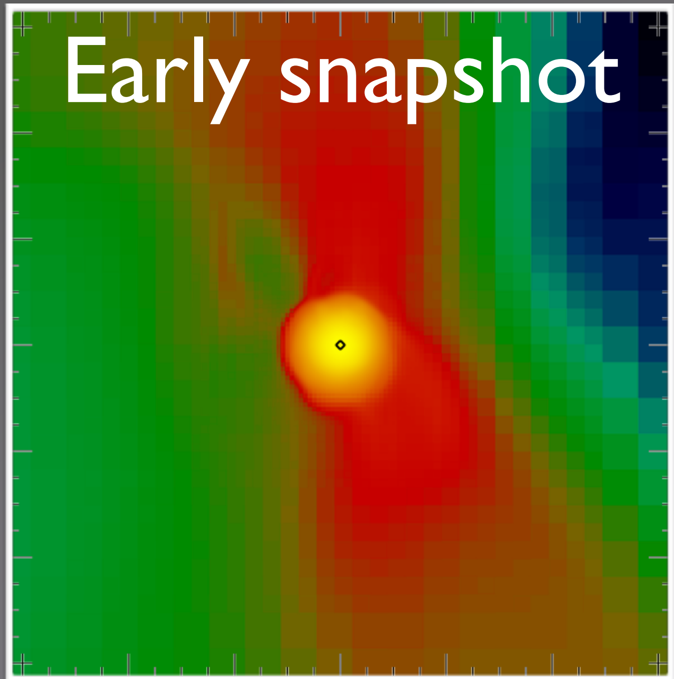
“the Pipeline”



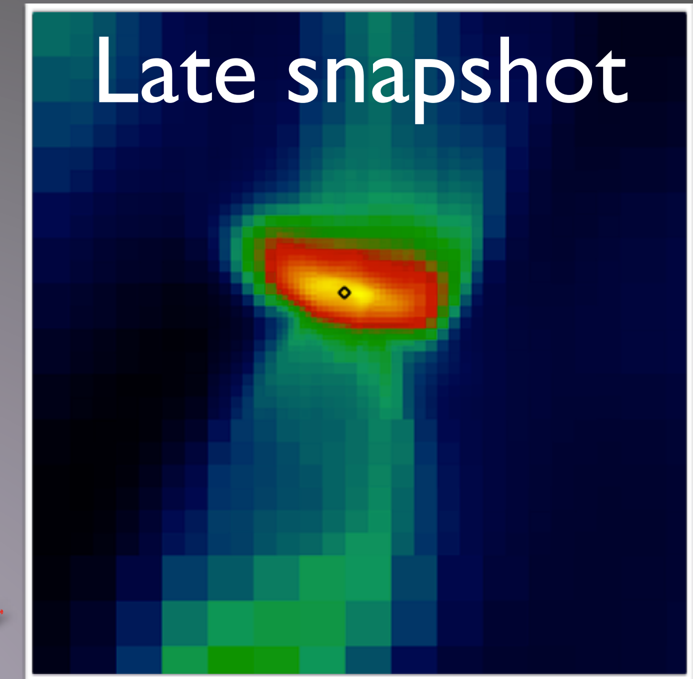
Randomize AMR grid
and add abundances

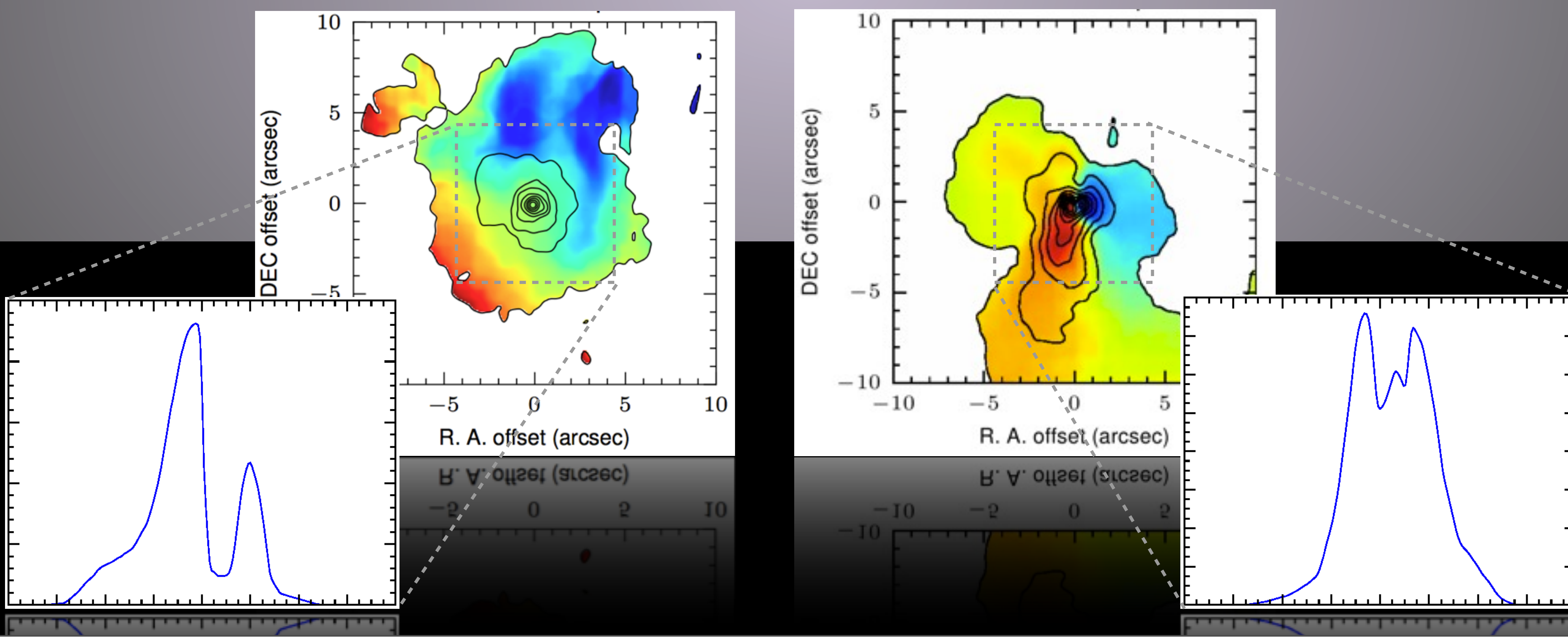
LIME
(Molecular excitation & RT)

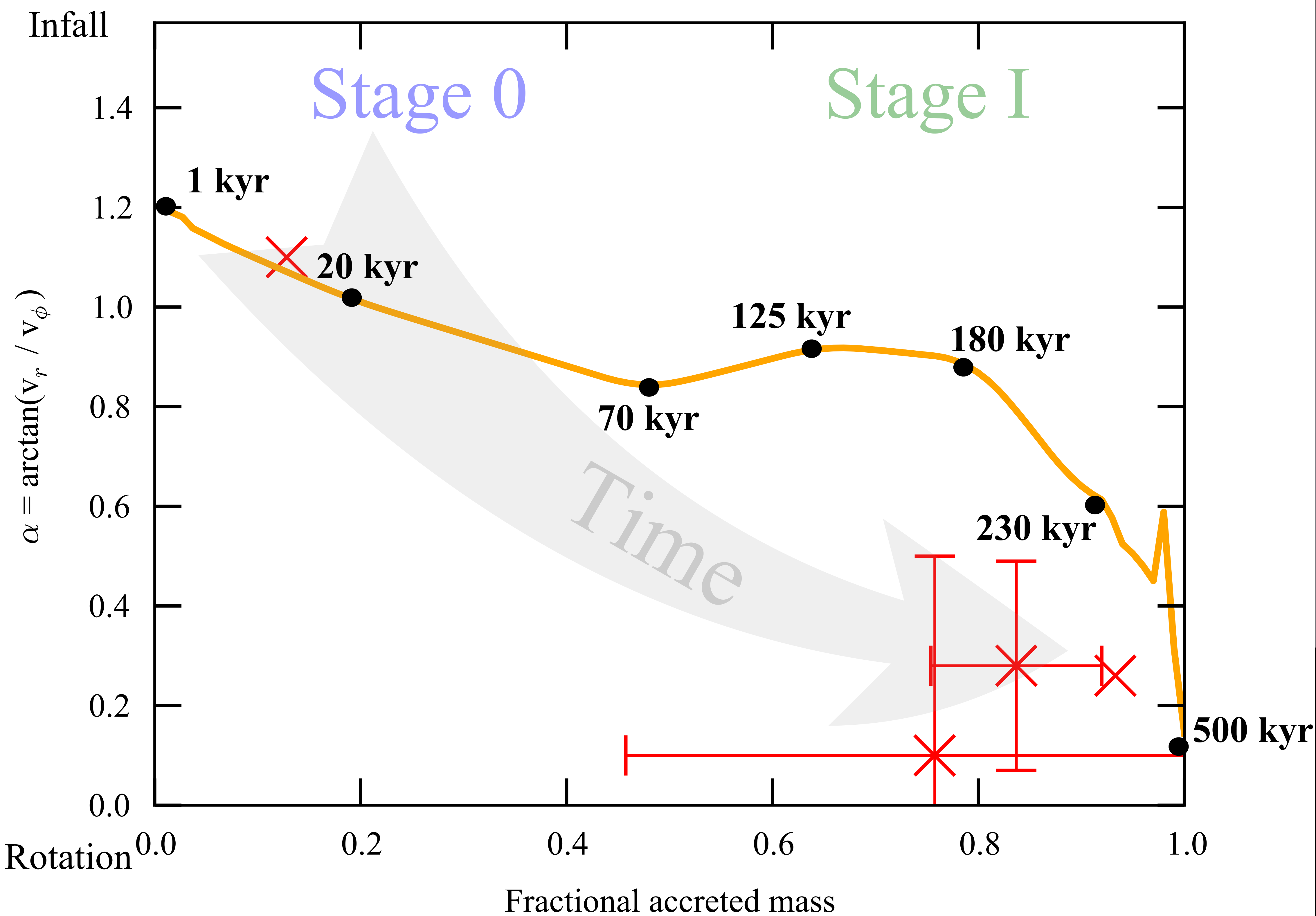
Pipeline

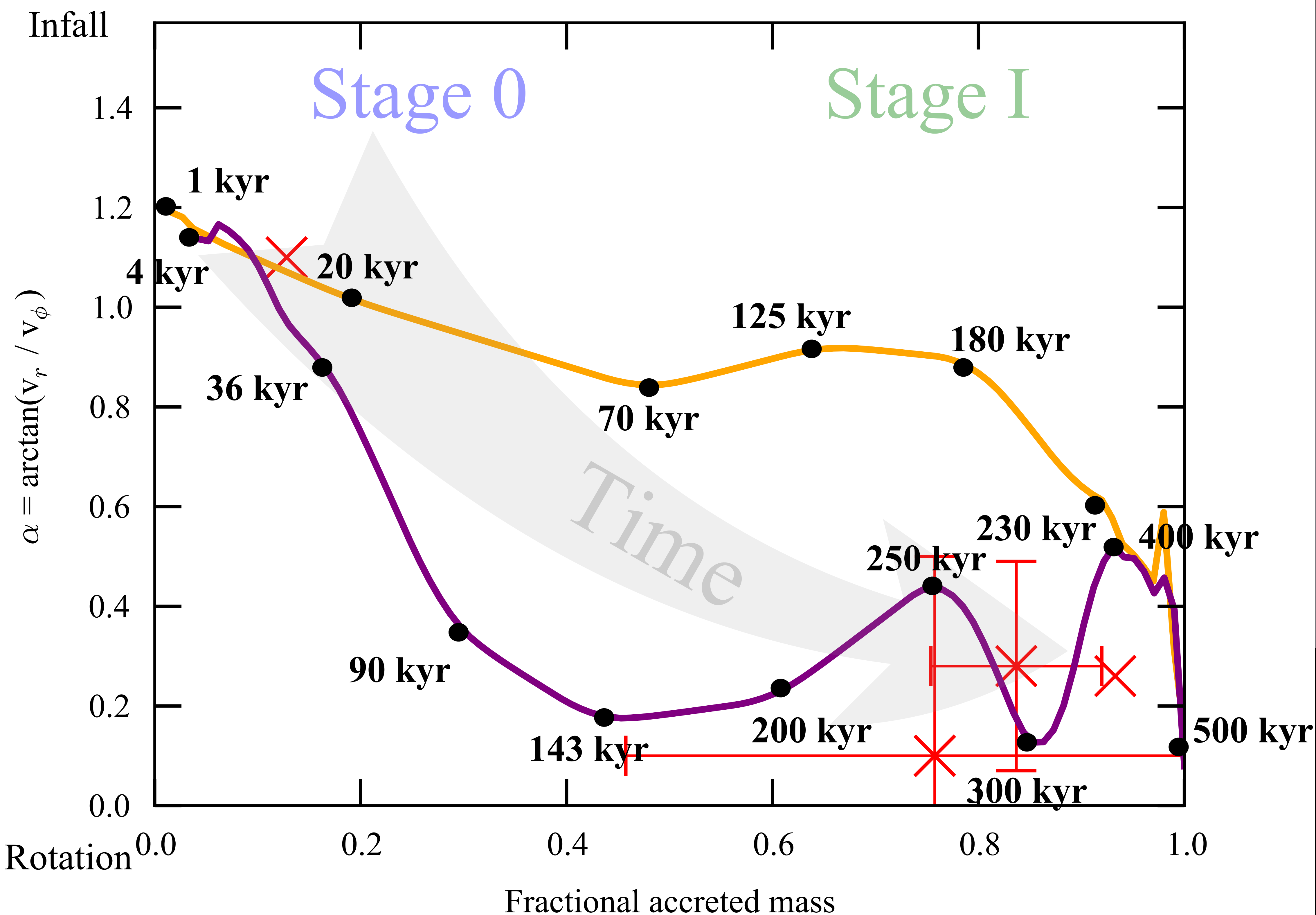


A simulated low-mass protostar seen in HCO^+ J=3-2

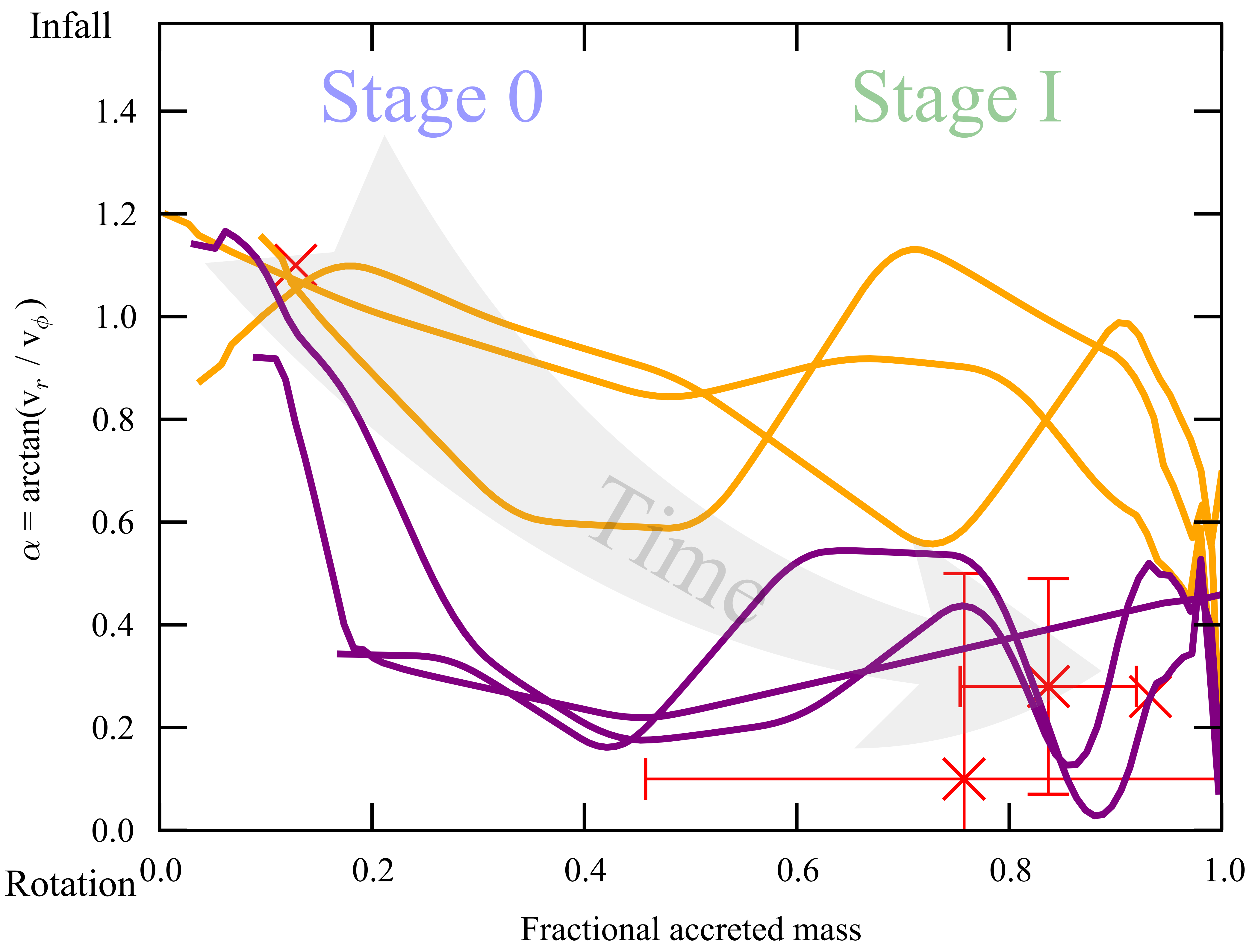





Infall
Rotation
Stage 0
Stage I
Time
1 kyr
20 kyr
70 kyr
125 kyr
180 kyr
230 kyr
500 kyr
α = arctan(v_r / v_φ)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Fractional accreted mass

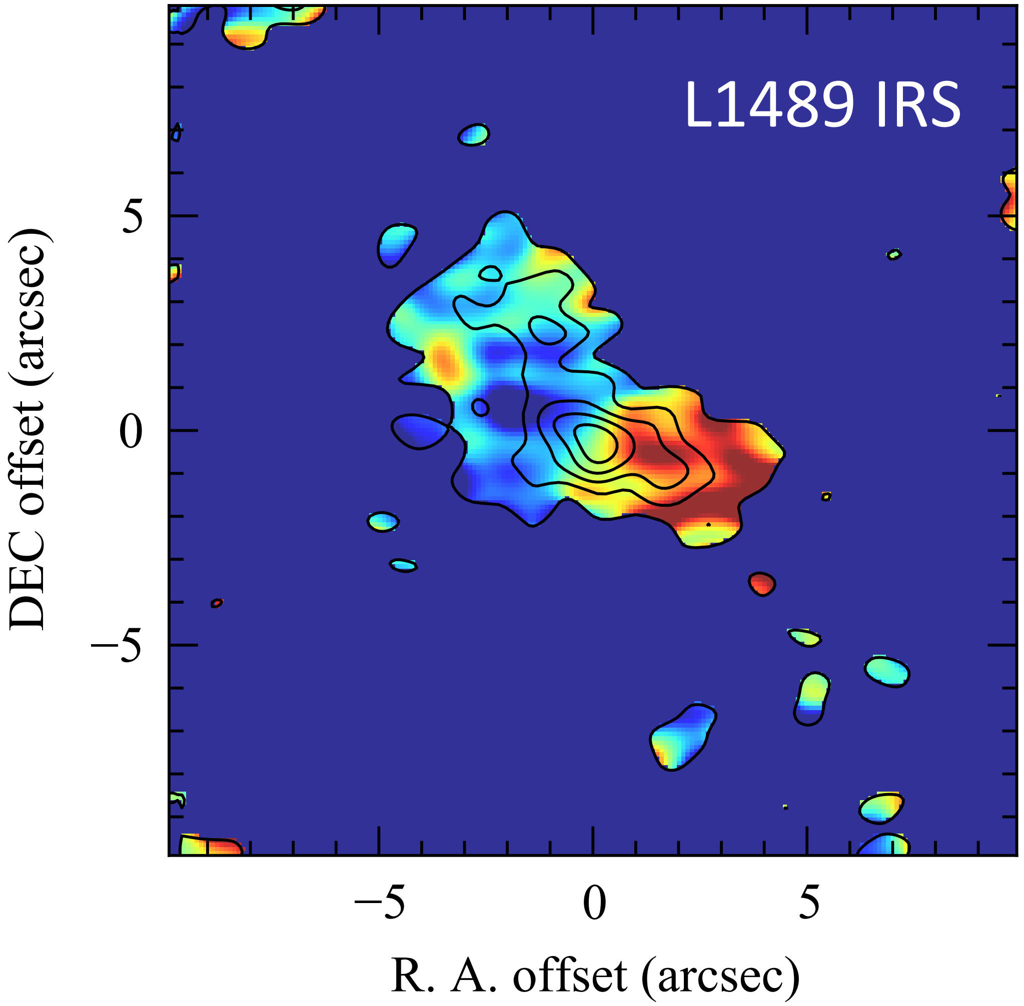


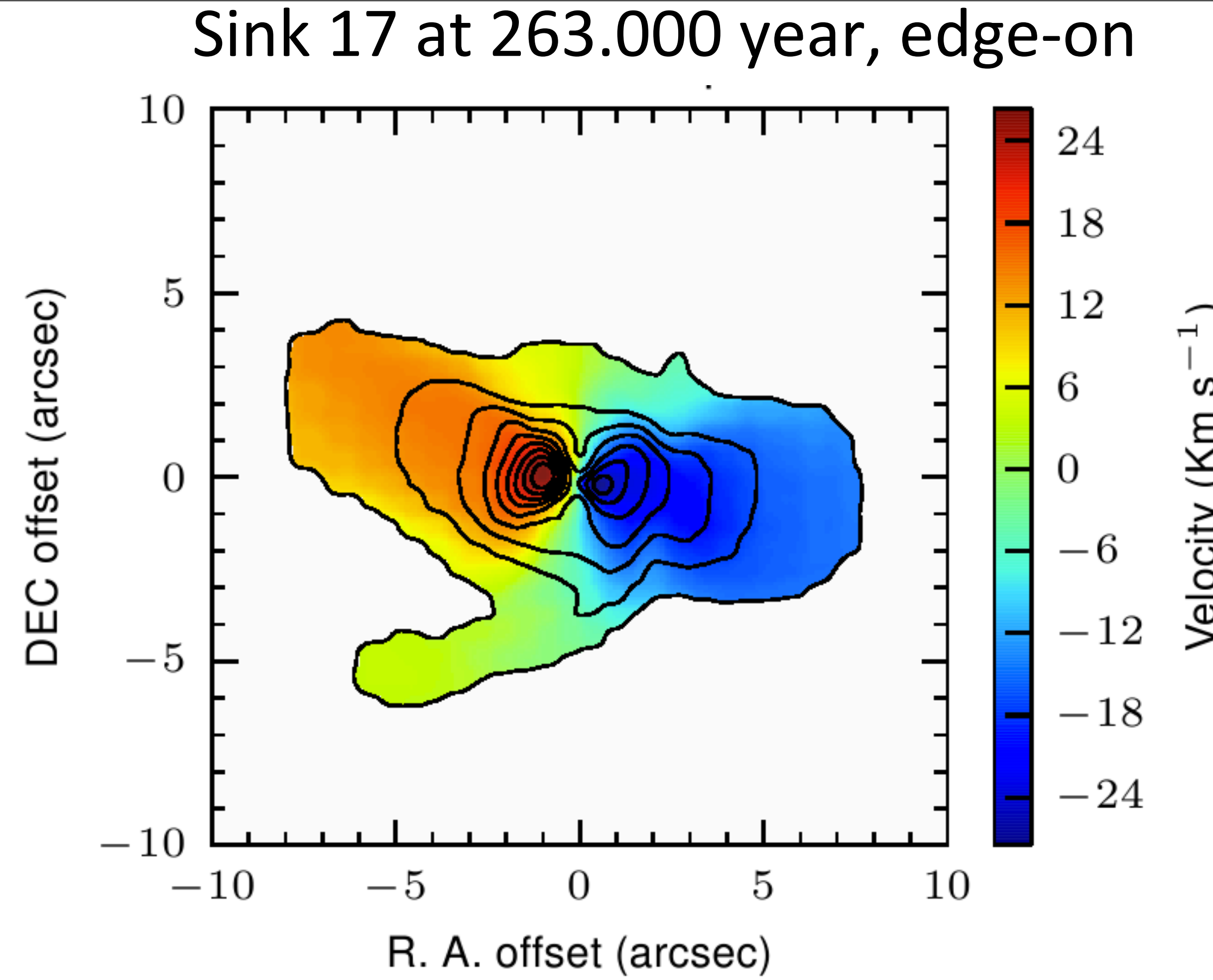
Tuesday, May 14, 13

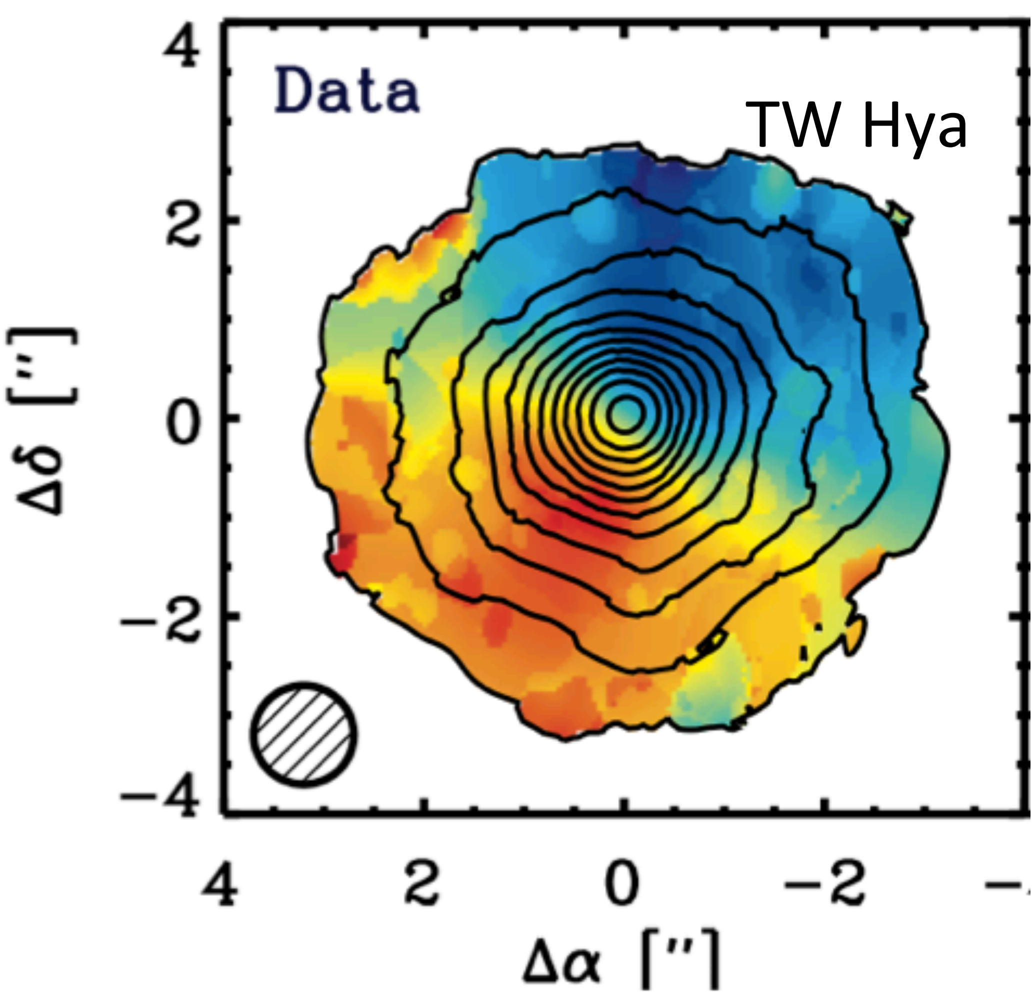

Infall
Stage 0
Stage I
Time
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
$\alpha = \arctan(v_r / v_\phi)$
Rotation
0.0
0.2
0.4
0.6
0.8
1.0
Fractional accreted mass

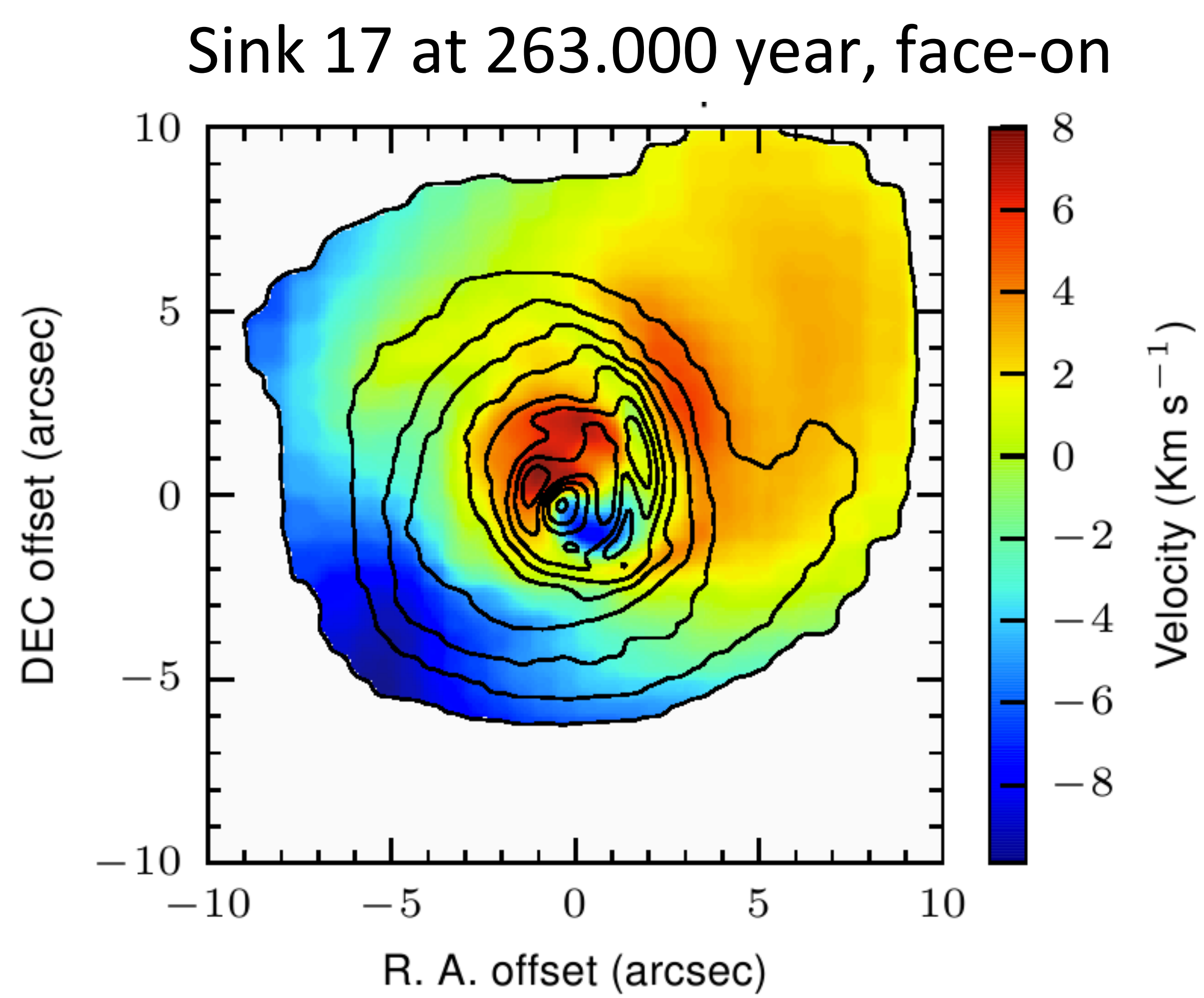
Conclusions...

- The gas velocity field can be used to determine the evolutionary stage of YSOs when calibrated with simulated sources
- With a set most likely matches to data of sources from the hydro-simulation, it is possible to predict the physical and chemical future of an observed YSO
- Environment seems to play an important role for the accretion history of YSOs


L1489 IRS
DEC offset (arcsec)
R. A. offset (arcsec)
5
0
−5
−5
0
5

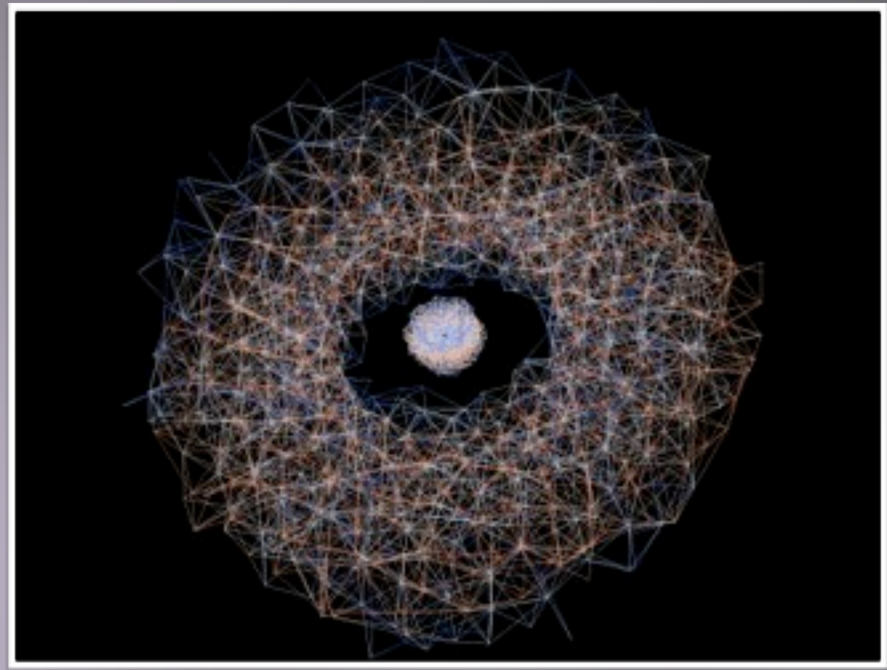

Sink 17 at 263.000 year, edge-on
DEC offset (arcsec)
R. A. offset (arcsec)
Velocity (Km s^{-1})
10
5
0
−5
−10
−10
−5
0
5
10
24
18
12
6
0
−6
−12
−18
−24

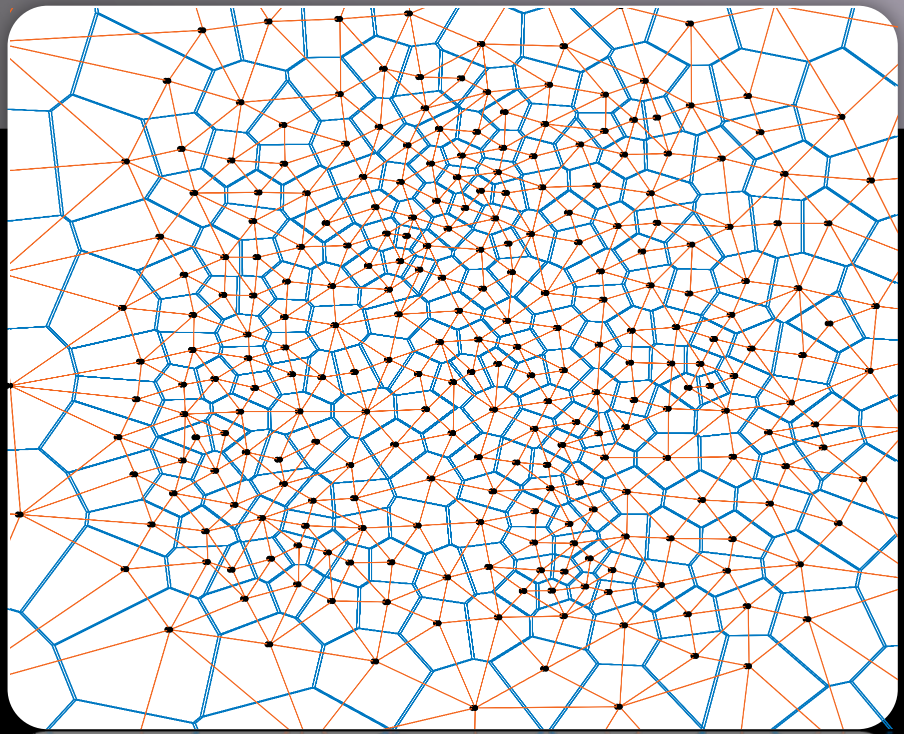

Data
TW Hya
Δδ ["]
Δα ["]
4
2
0
−2
−4
4
2
0
−2

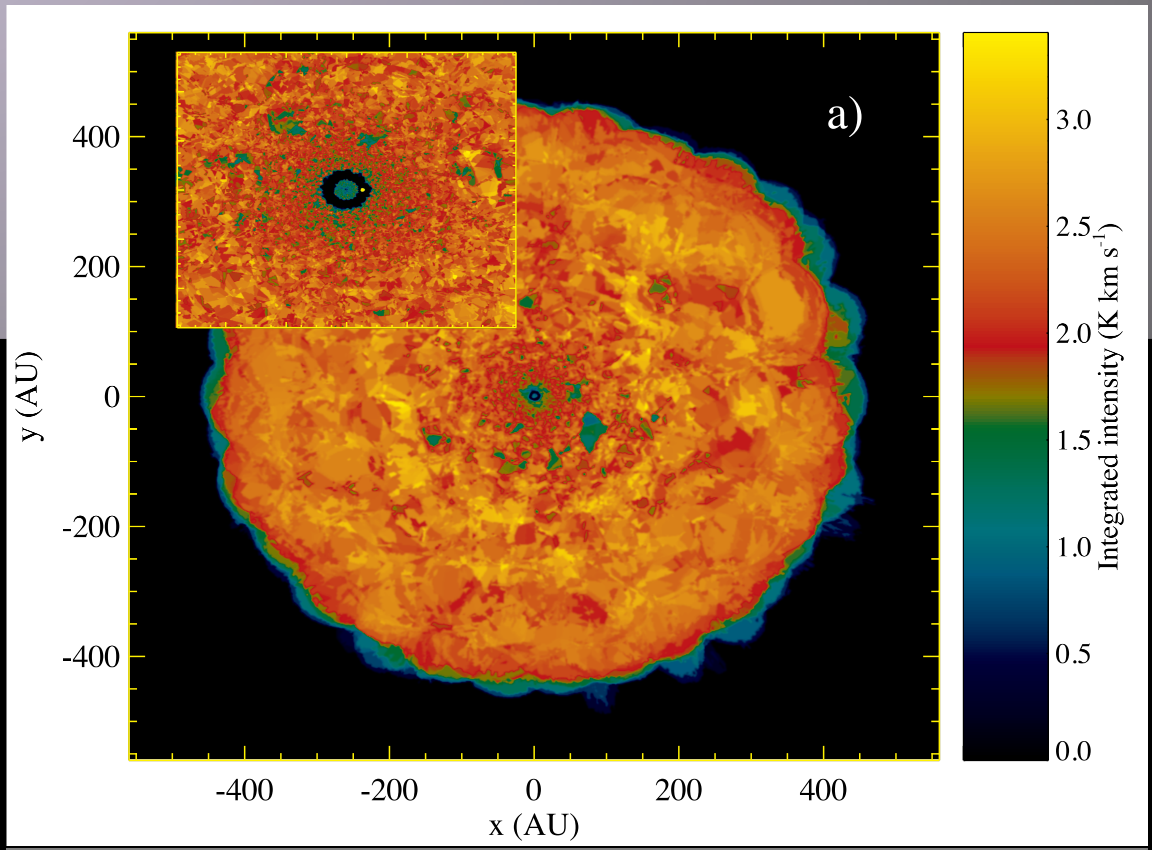

Sink 17 at 263.000 year, face-on
DEC offset (arcsec)
R. A. offset (arcsec)
Velocity (Km s^{-1})
10
5
0
−5
−10
−10
−5
0
5
10
8
6
4
2
0
−2
−4
−6
−8

LIME Line modeling engine

- Using a Voronoi grid to speed up transport => 3D
- Large dynamic range in scales
- Similar resolution as AMR
- Available for download!







(Brinch & Hogerheijde 2010)