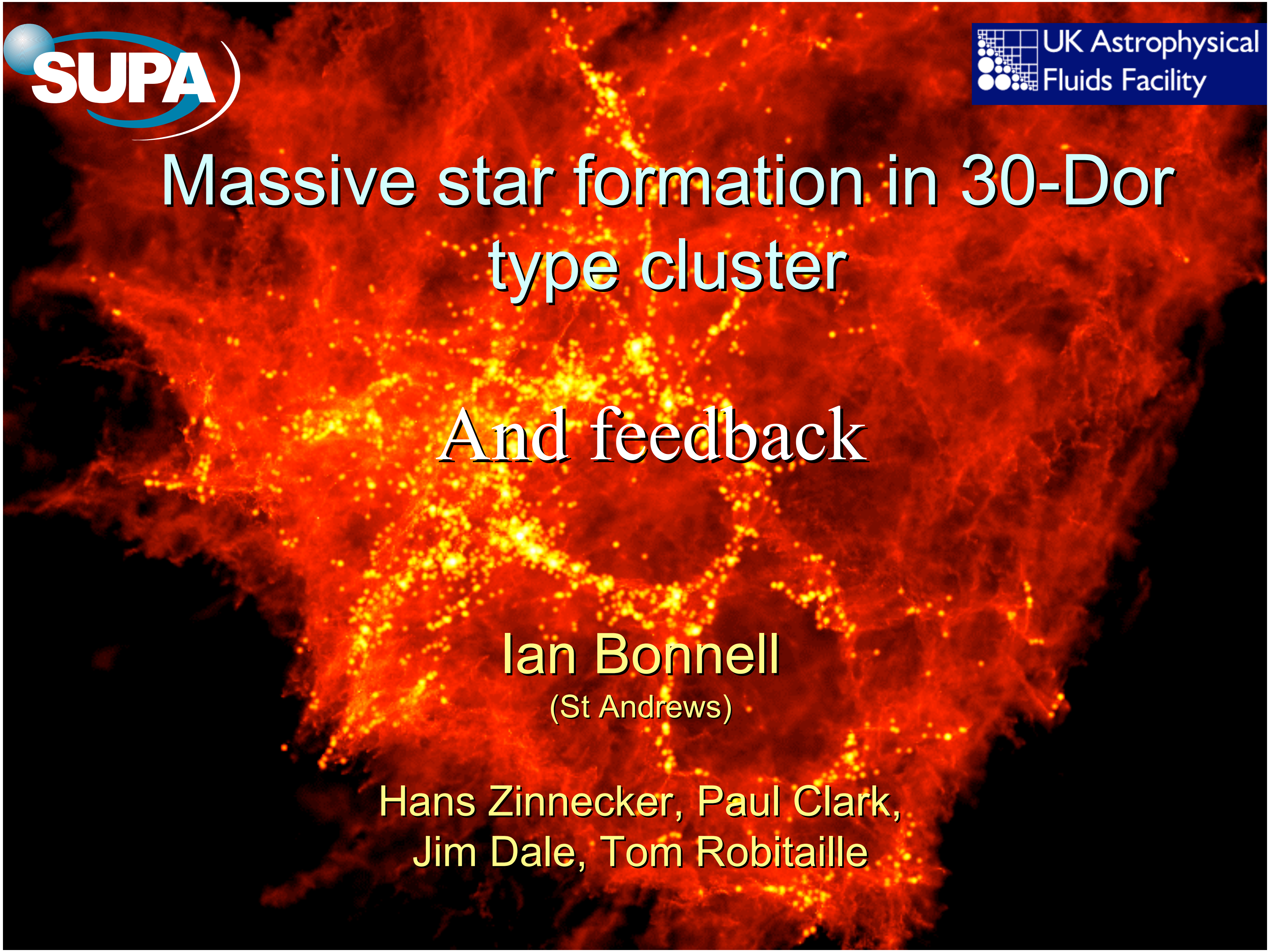


Massive star formation in 30-Dor type cluster

And feedback

Ian Bonnell
(St Andrews)

Hans Zinnecker, Paul Clark,
Jim Dale, Tom Robitaille

30 Doradus

Total mass

10^6 M_{sun}

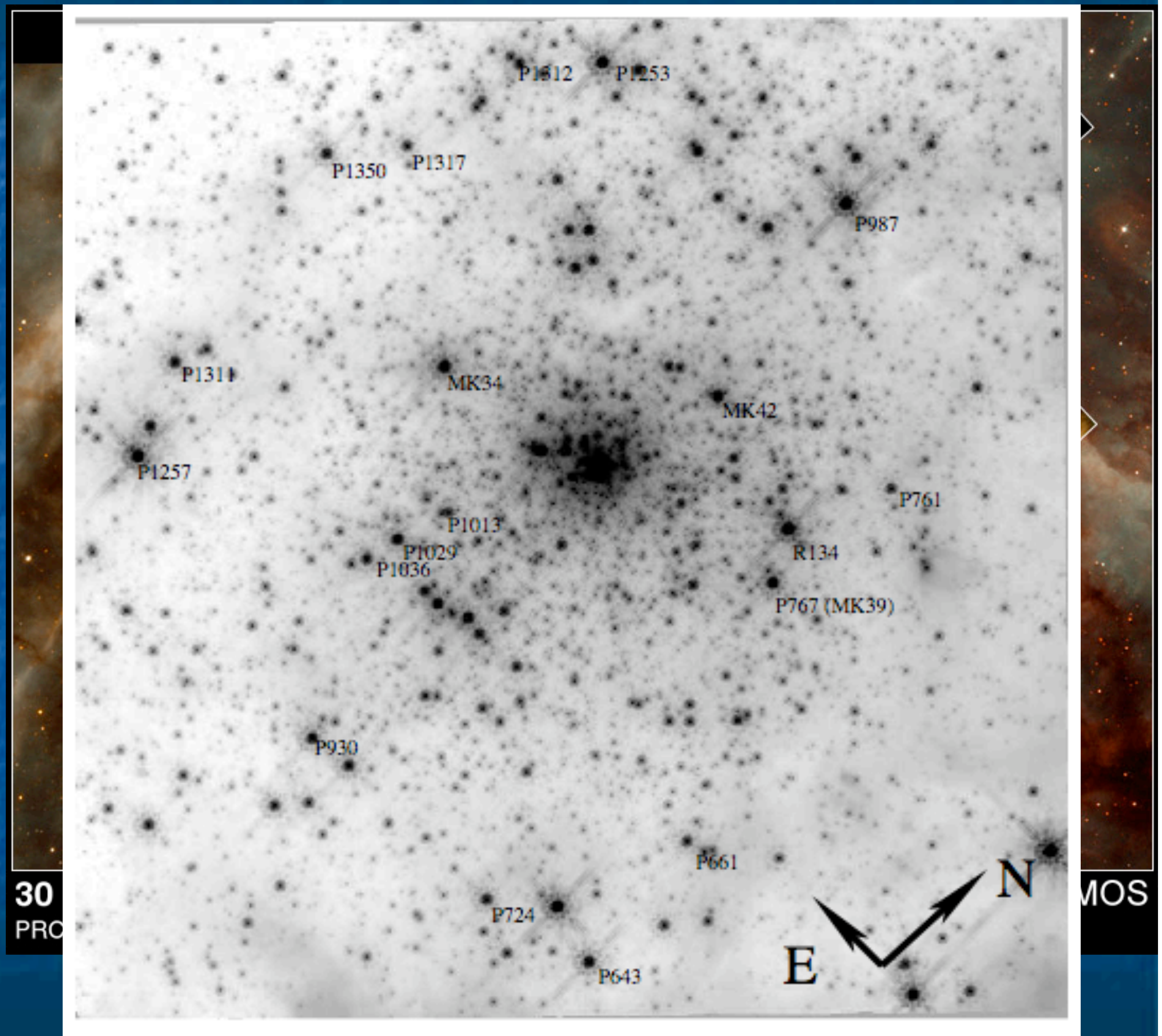
R136: rich central cluster

~10^4 M_{sun}

in 0.25 pc

'Distributed' O-stars

Consistent with hierarchical cluster formation?



Andersen et al 2007

Initial conditions

- 10^6 M_{sun} in 50 pc radius
- Gaussian density distribution
  - Mean density: 2 M_{sun} pc^{-3} ; n ~ 10^2 cm-3

NO FEEDBACK

  - T_{init} ~ 50 K

  - M_{Jeans} ~ 250 M_{sun}

- Turbulent support : E_{kin}~|E_{grav}| ; Mach 12.5
- 2.5 10^7 SPH particles; M_{min}~ 4 M_{sun}
- Sink radii: 0.05 pc

Formation of very massive stellar cluster

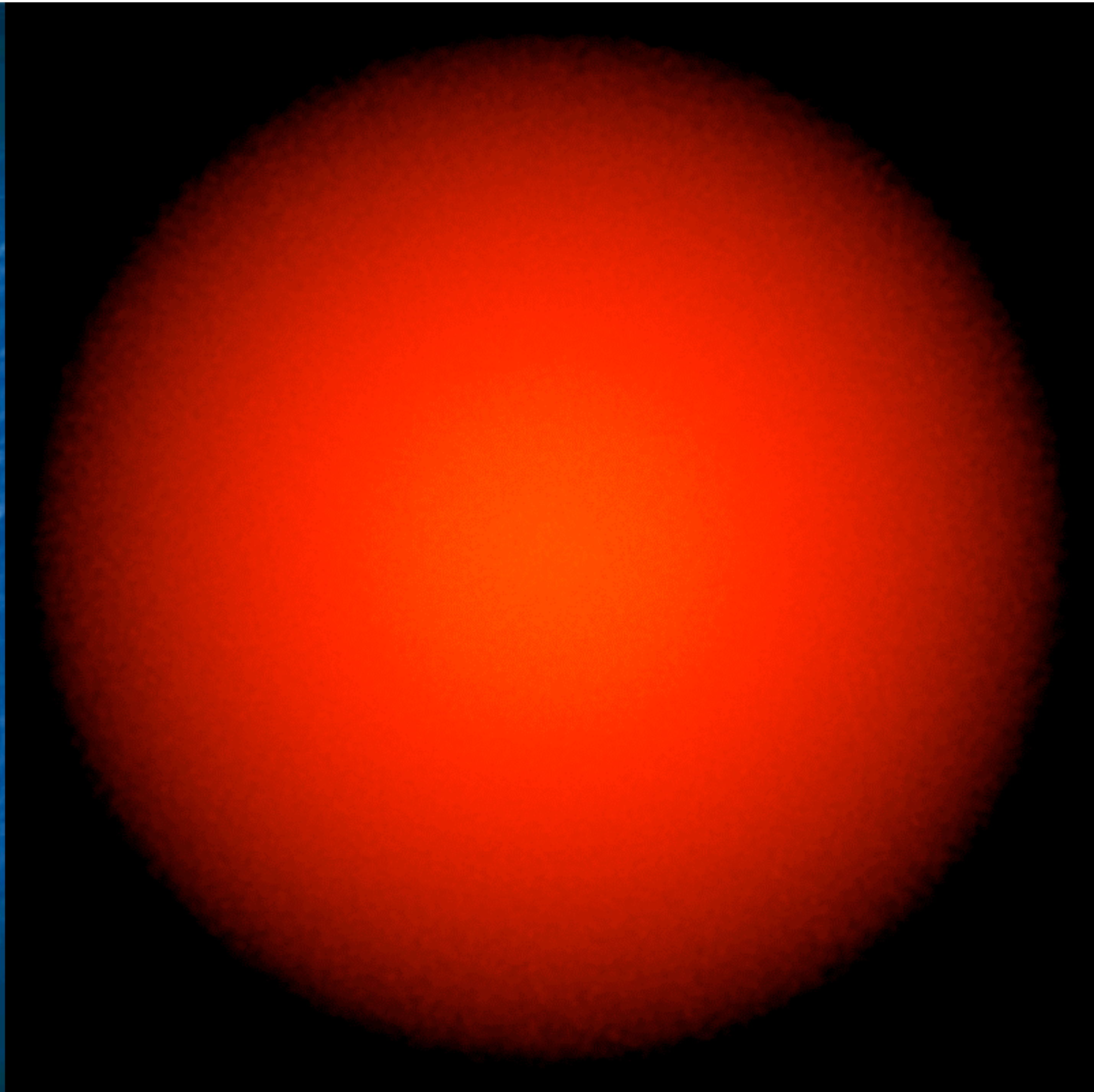
10^6 M_{sun} in 100 pc

Forms ~ 6000 sinks

with 10^5 M_{sun}

Resolves to 4 M_{sun}

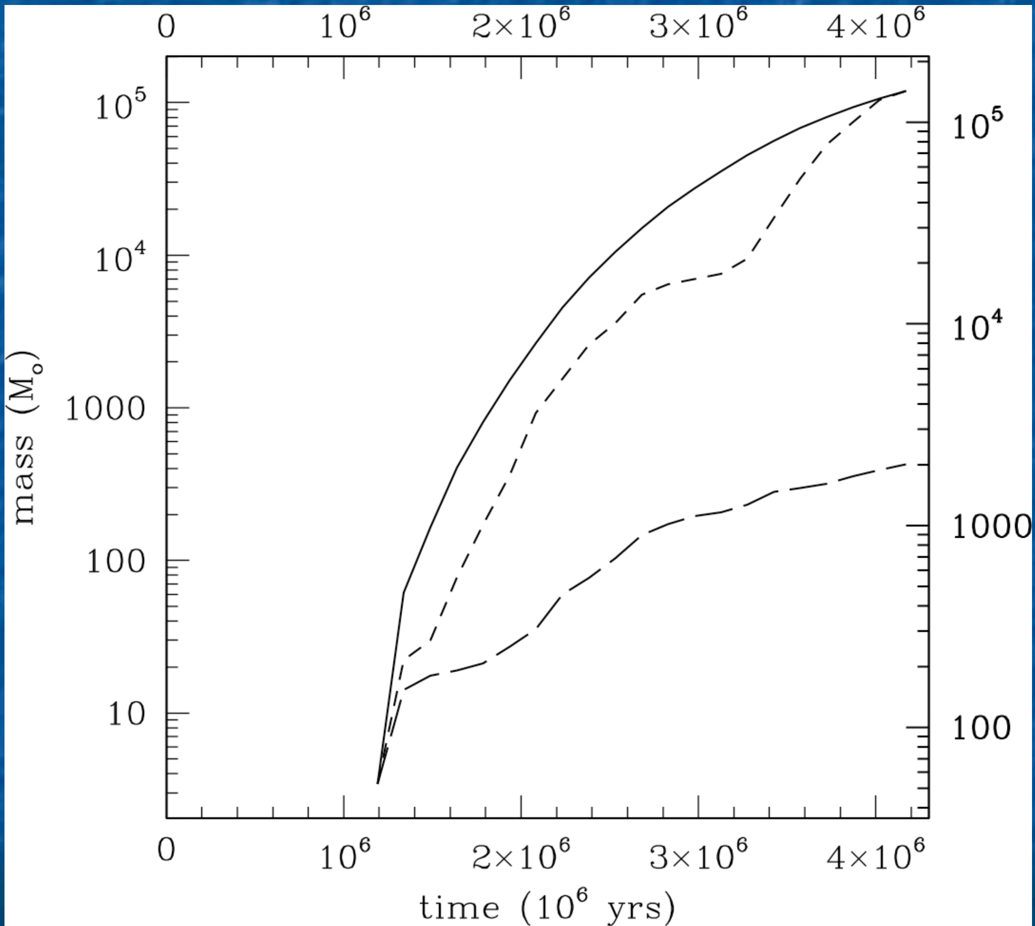
Bonnell, Clark & Zinnecker in prep



Evolution of massive cluster

Total mass in sinks $\sim 10^5\ M_{sun}$

~ 6000 sinks



Max. cluster mass density

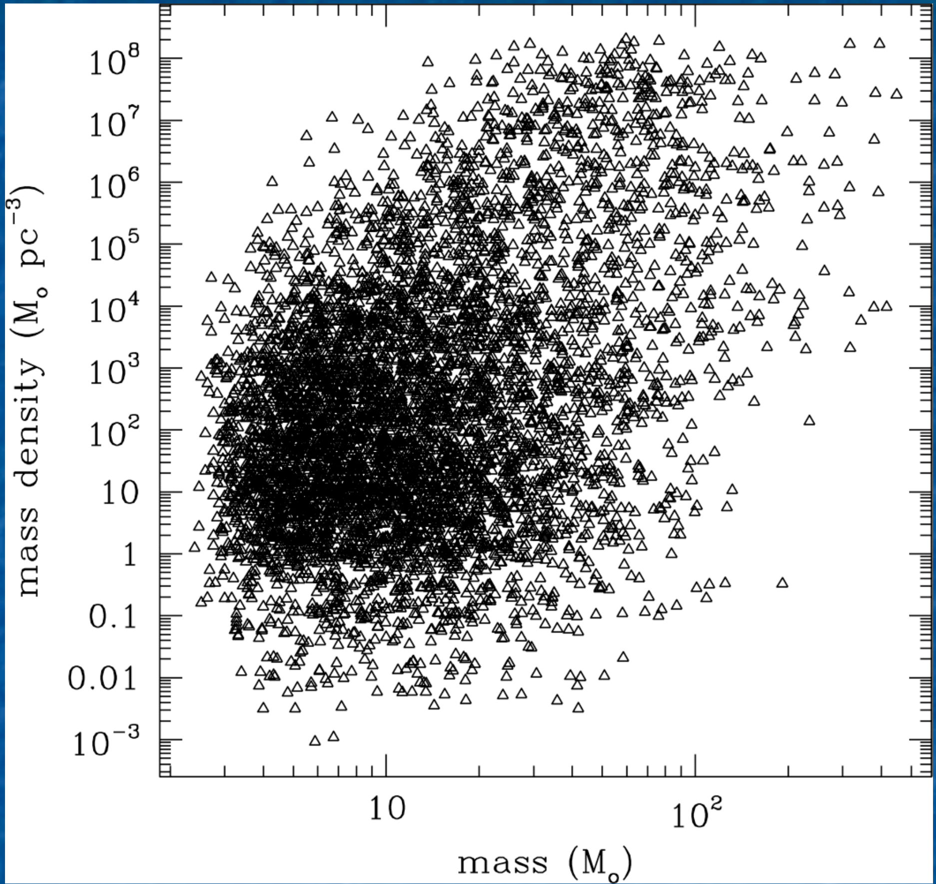
(0.25 pc rad)

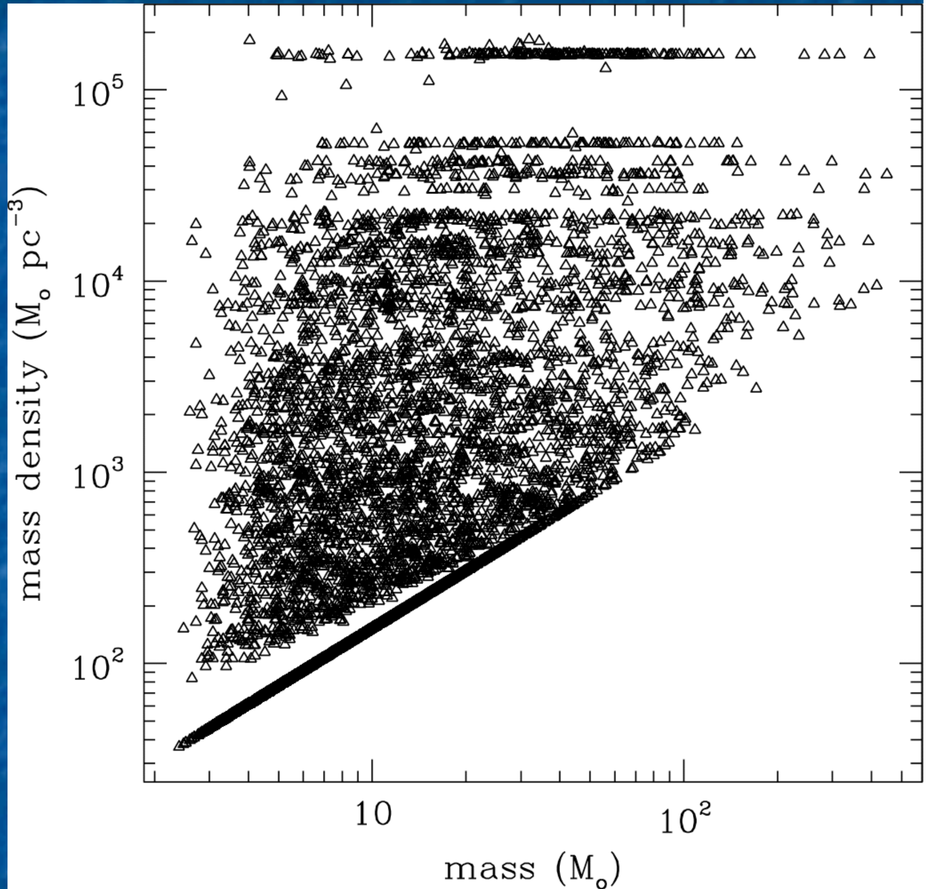
$\sim\ 10^5\ M_{sun}\ pc^{-3}$

Most massive sink ~ 400 M_{sun}

Star formation over several Myr : Age spreads

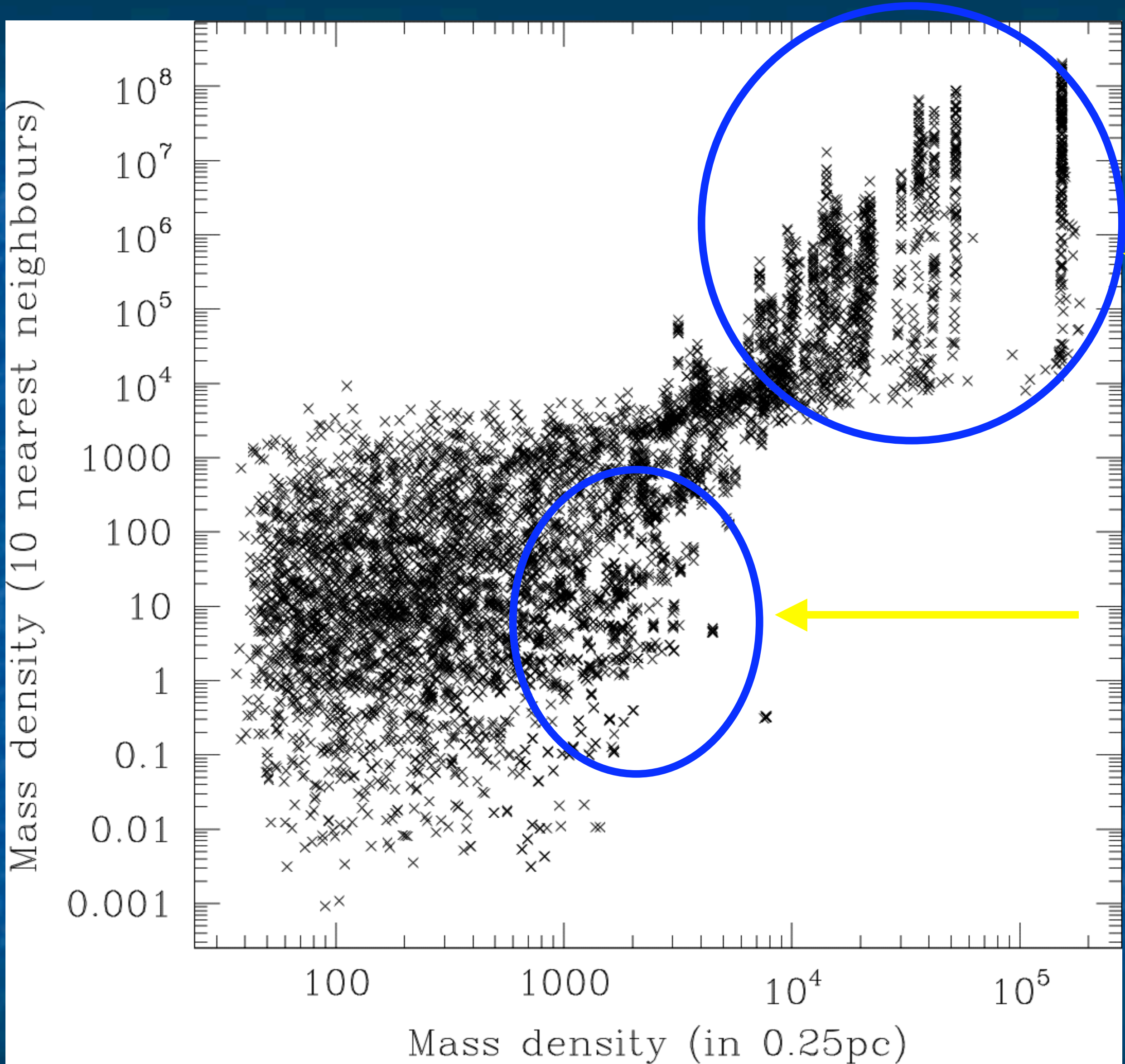
Mass density in sinks





Mass density using 10 nearest neighbours

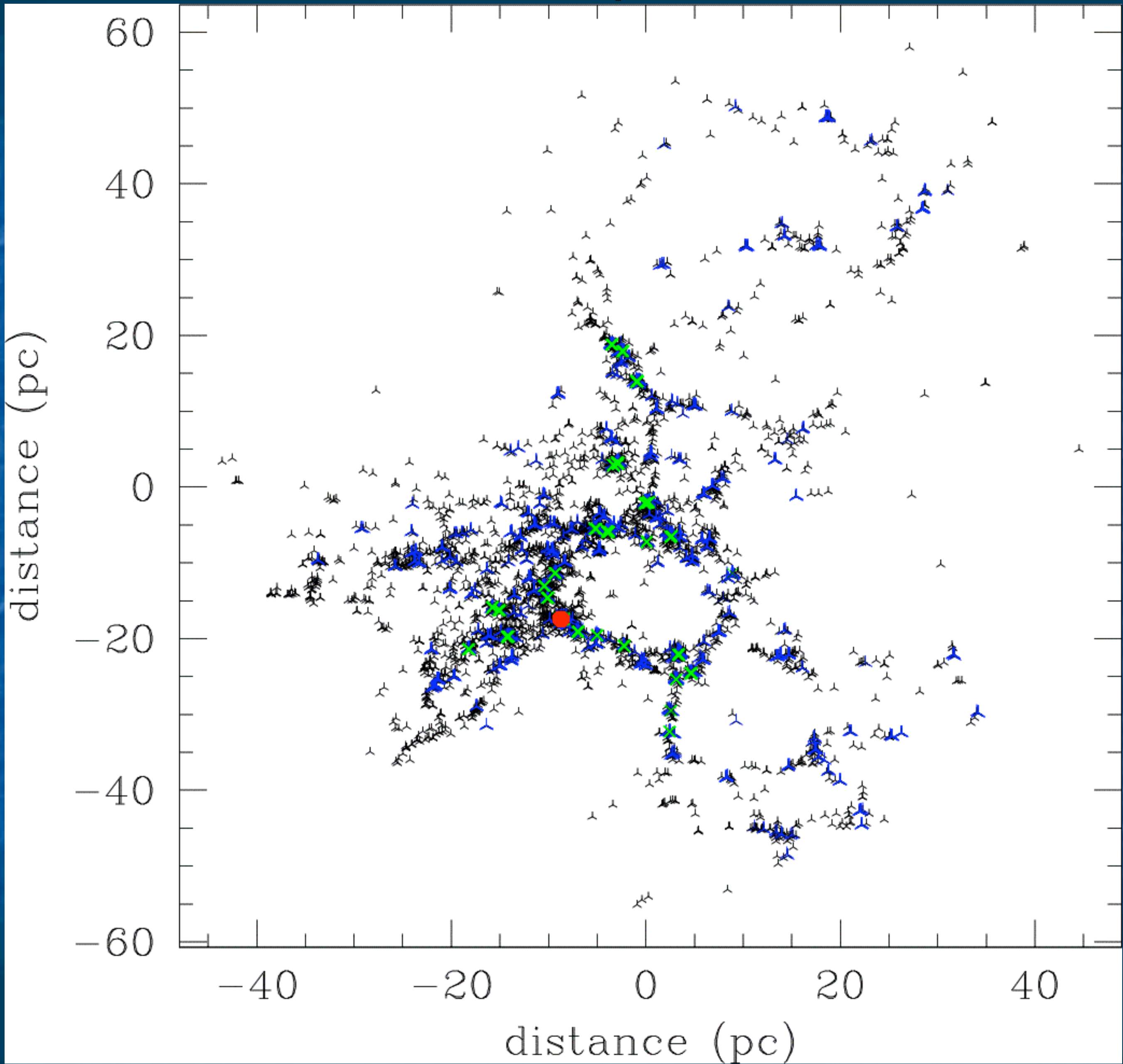
Mass density in 0.25 pc



Both in M_{sun} pc^{-3}

- Rich O-star clusters
- ~ isolated O stars
  - ONC-like

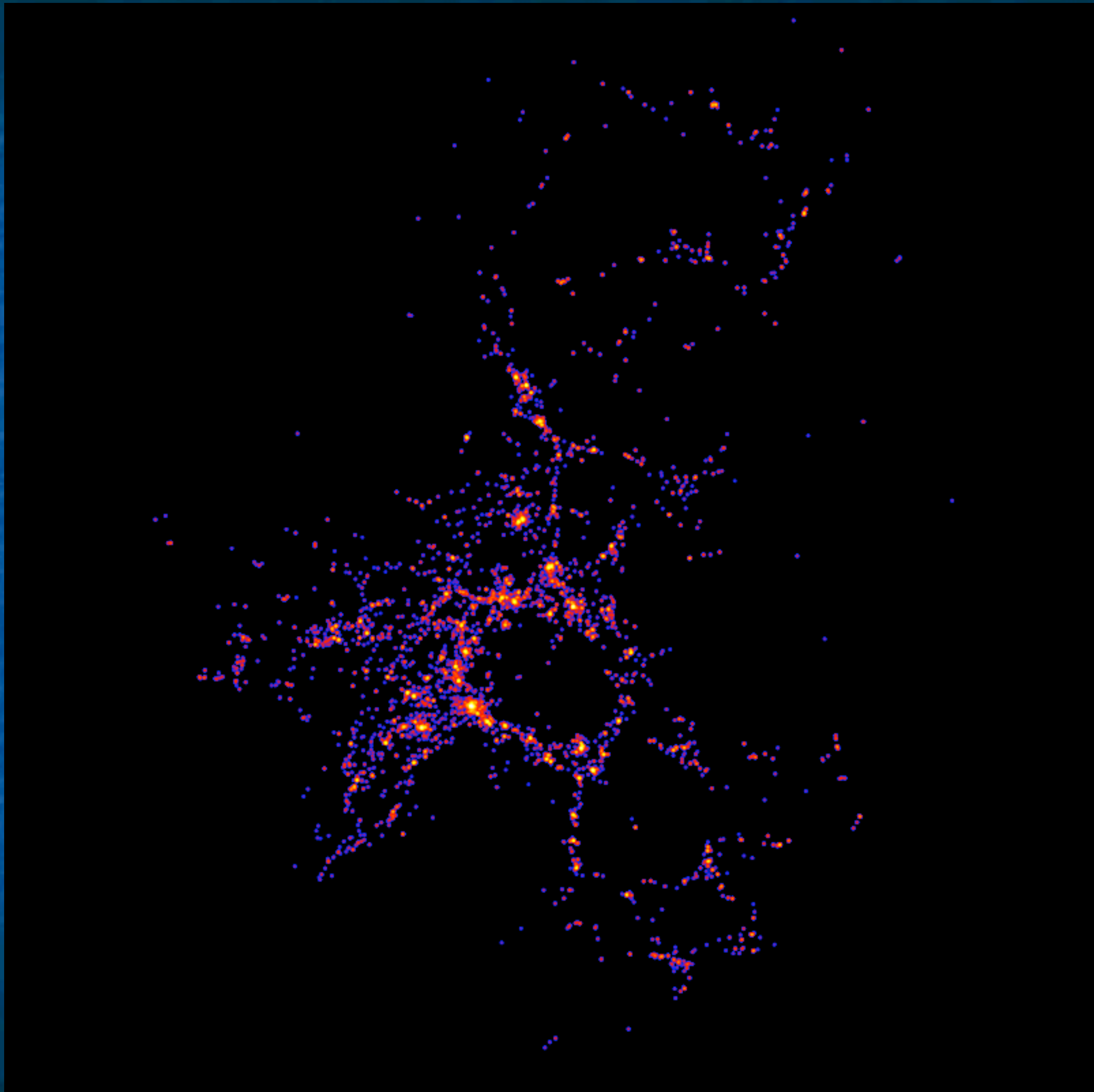
Sink positions



> 10^5 M_{sun} pc^{-3}

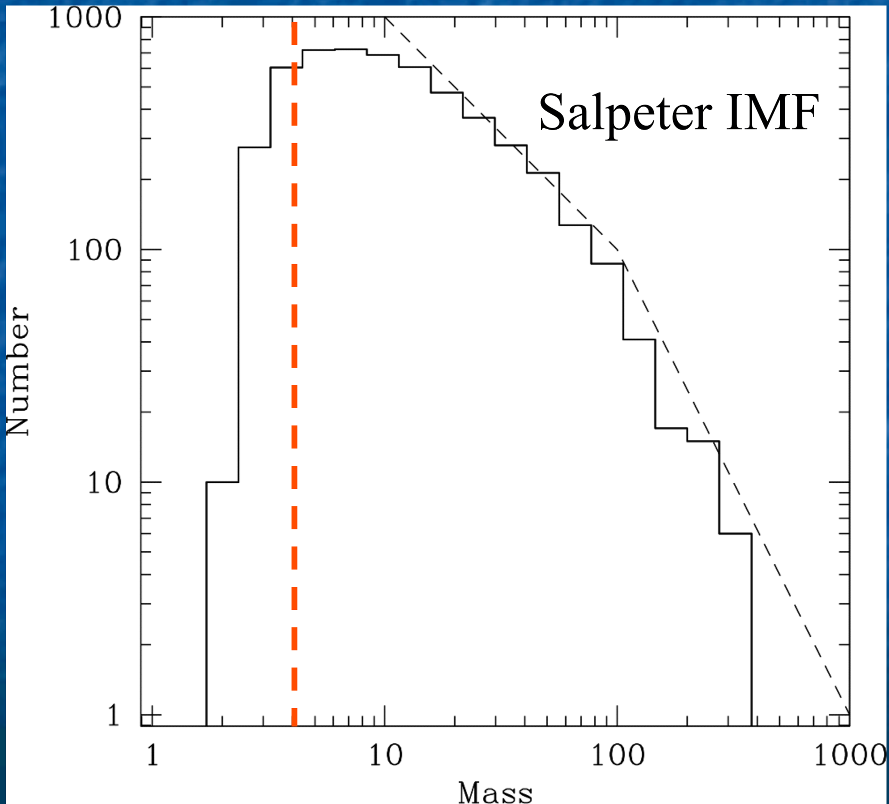
> 10^4 M_{sun} pc^{-3}

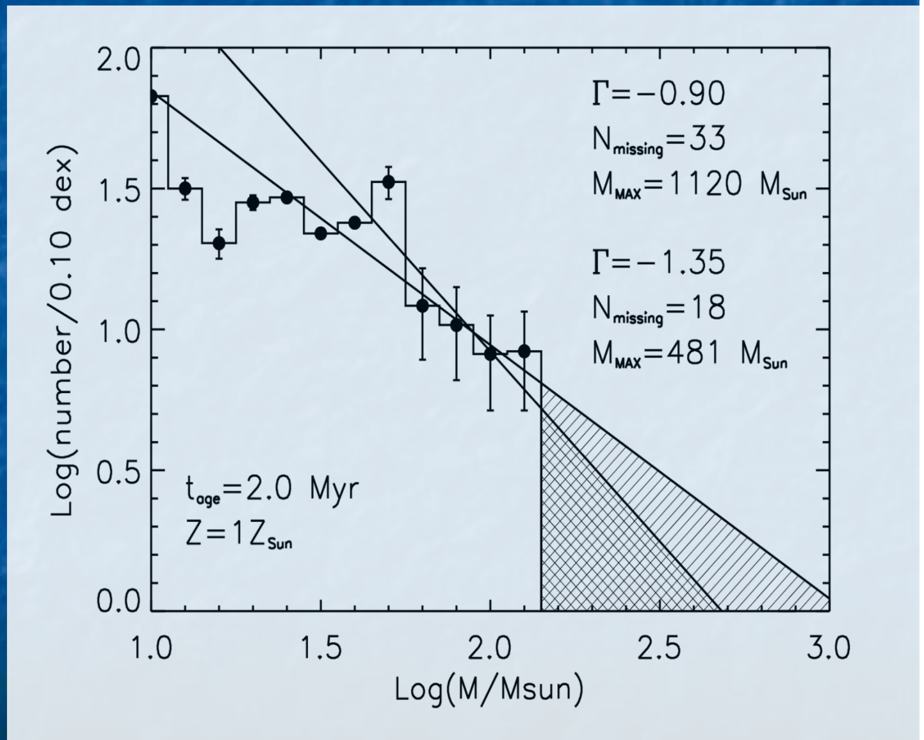
> 10^3 M_{sun} pc^{-3}



Upper-mass limit?

- Massive stars formed by accreting from large reservoir
- Does a time limit imply mass limit?





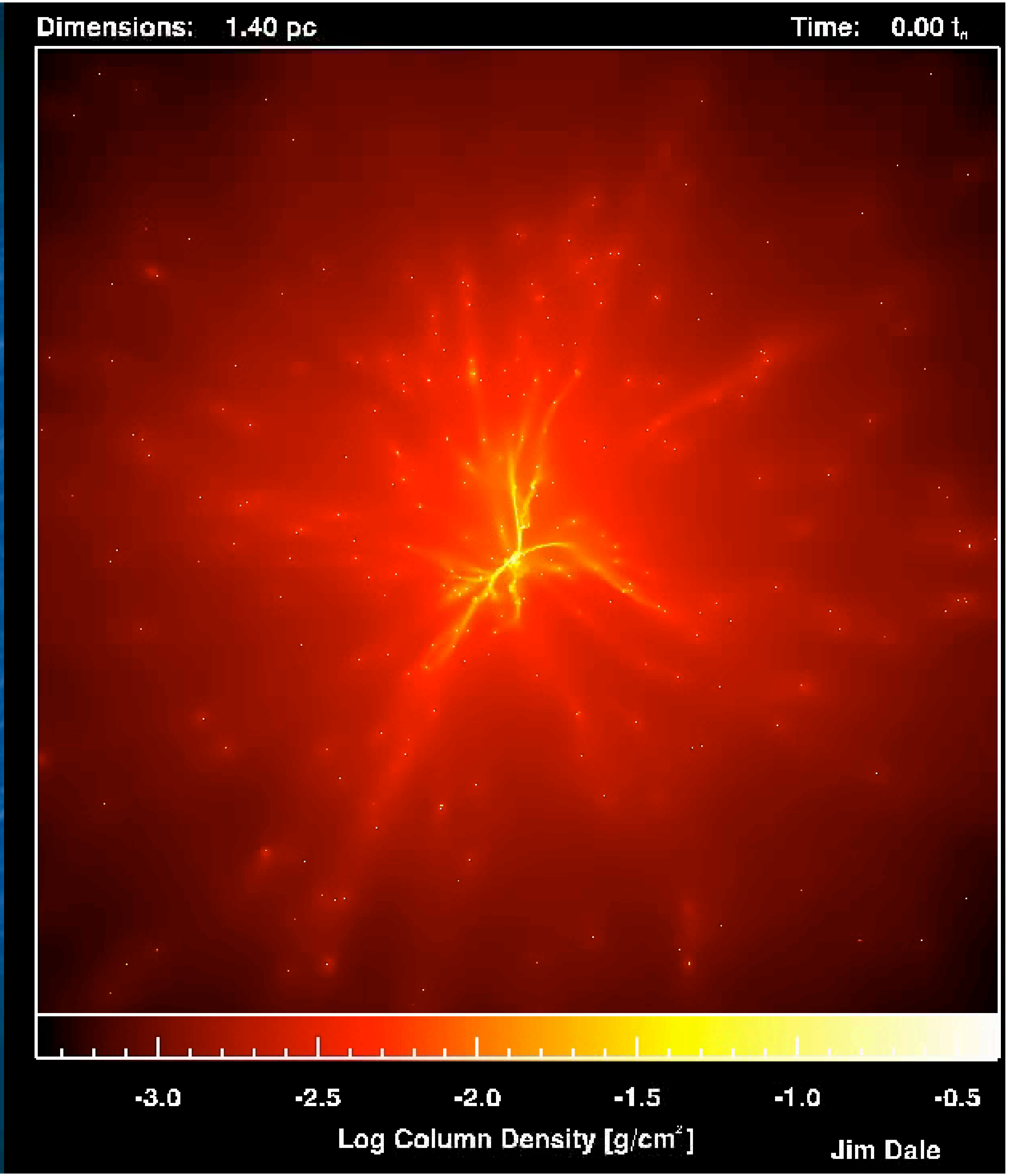
D. Figer

Feedback from OB stars

- 10^3 M_{sun} cluster
- **Ionisation from massive stars**
- **HII region one-sided**
- **Accretion continues relatively unimpeded**

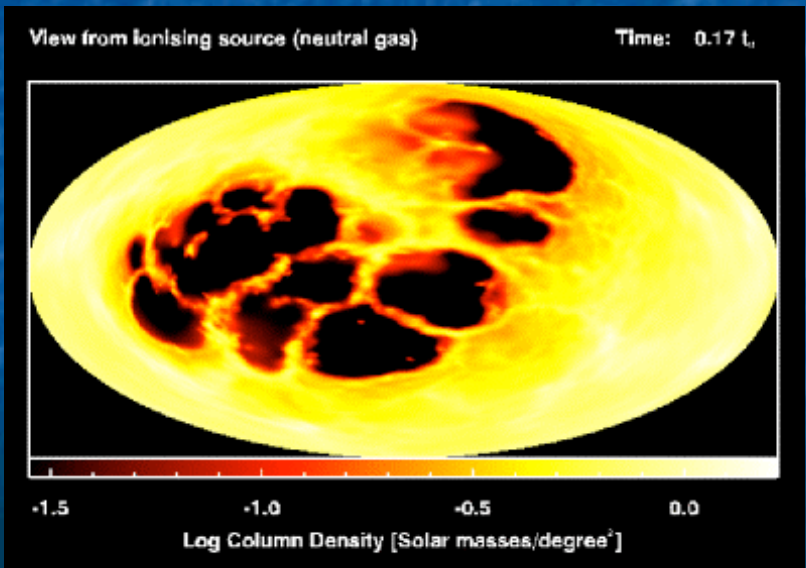
Dale et al. 2005

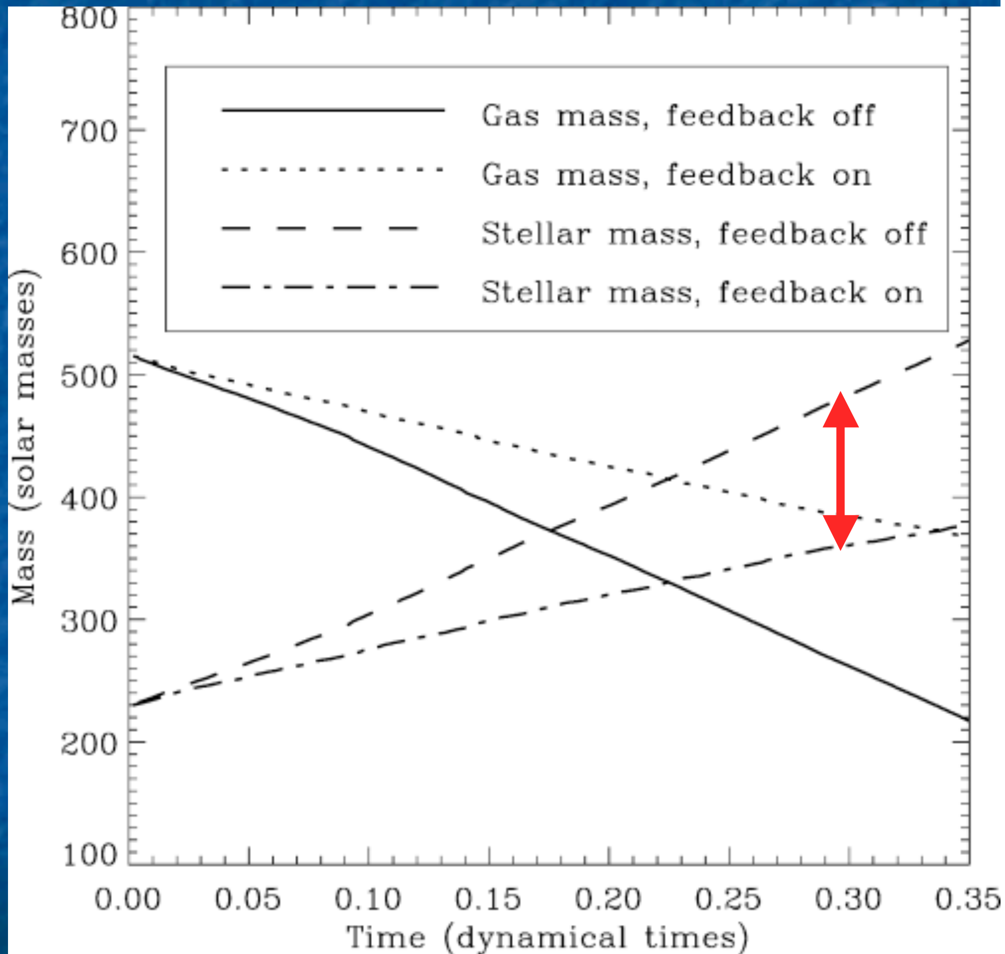
UK Astrophysical Fluids Facility



Feedback and Accretion

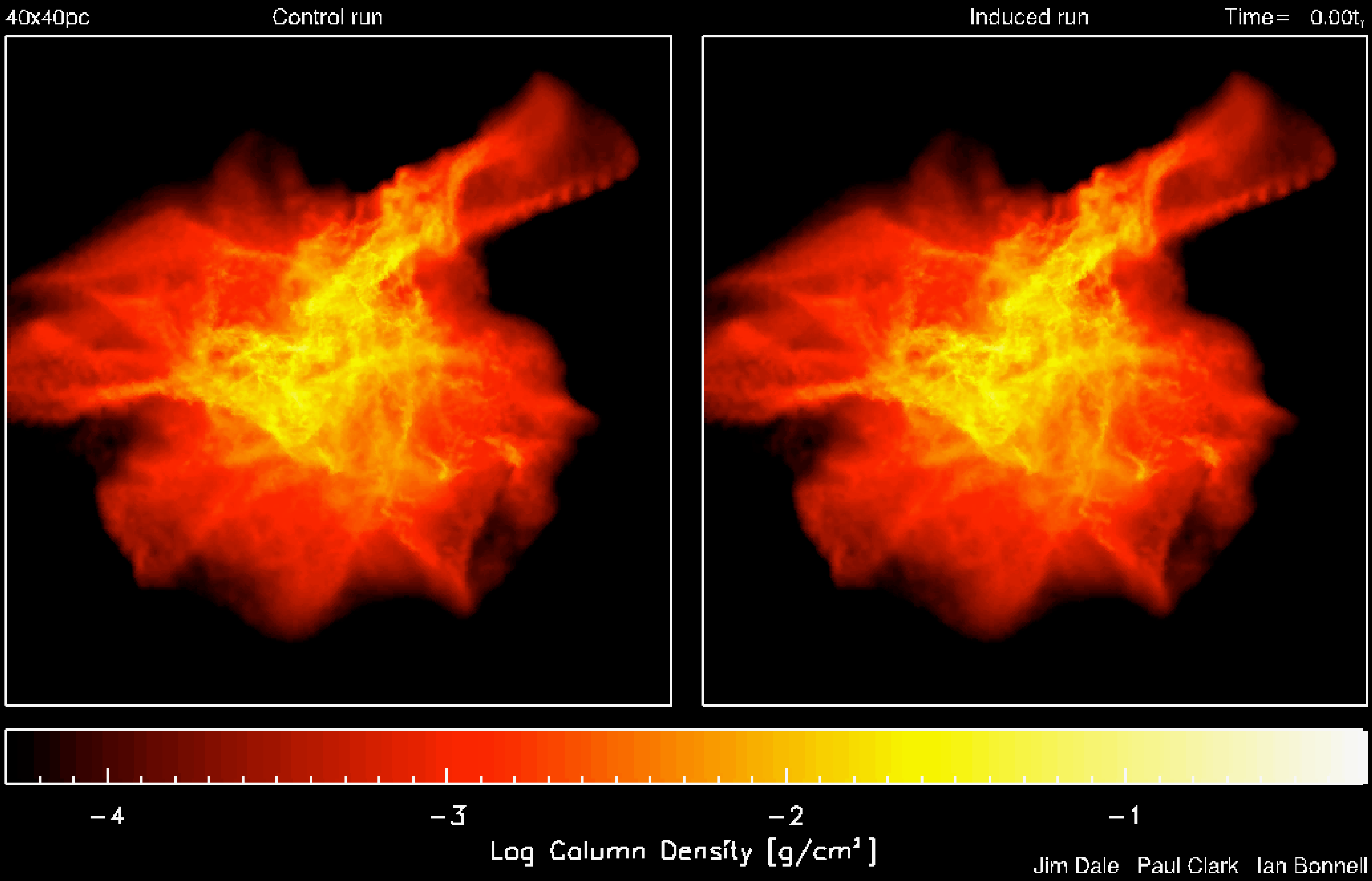
- Accretion largely unimpeded by feedback
  - Dale et al 2005; Krumholz etal 2005
- Escapes along preferential directions





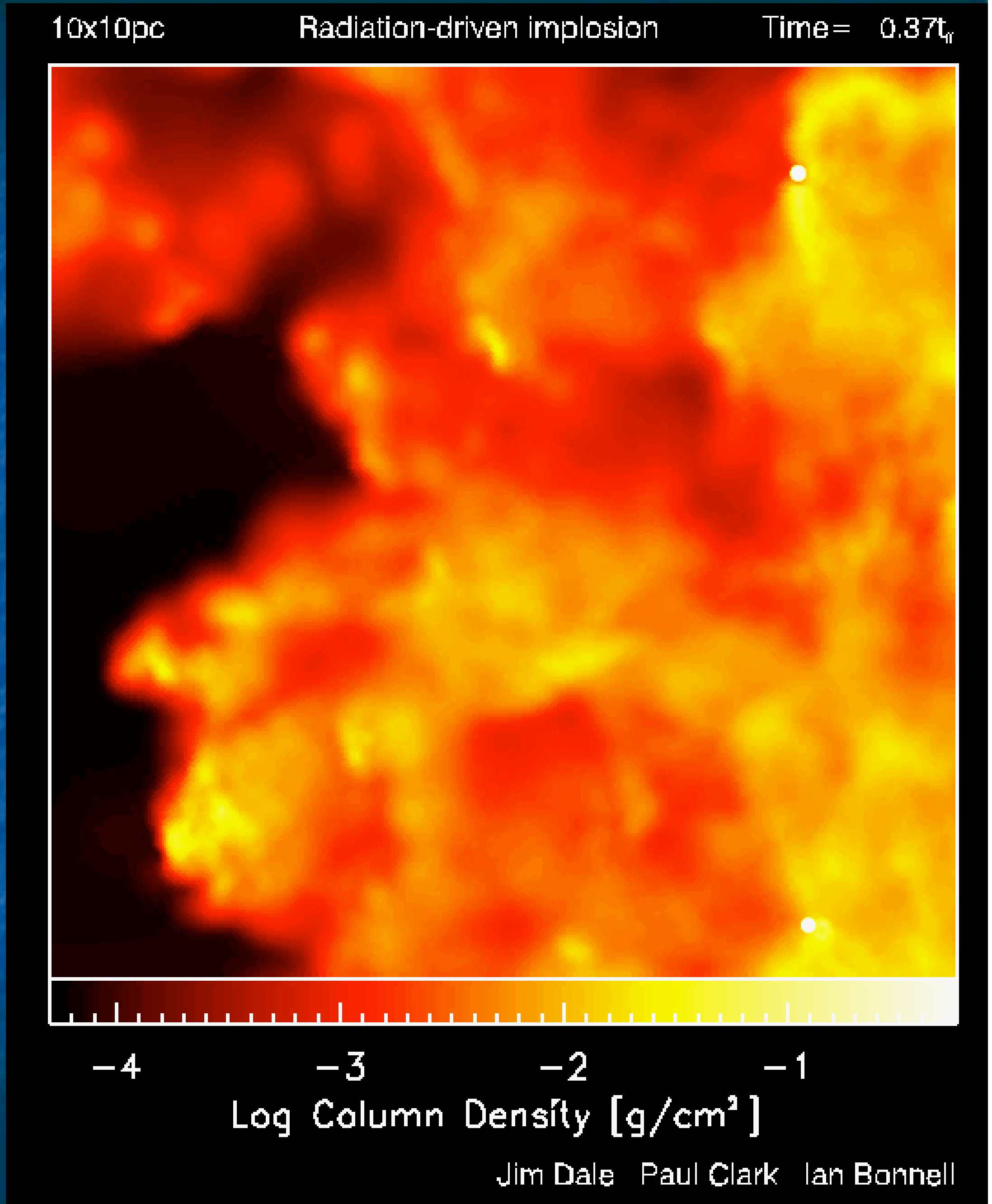
Dale et al 2005

Triggering of star formation



Radiative driven implosion

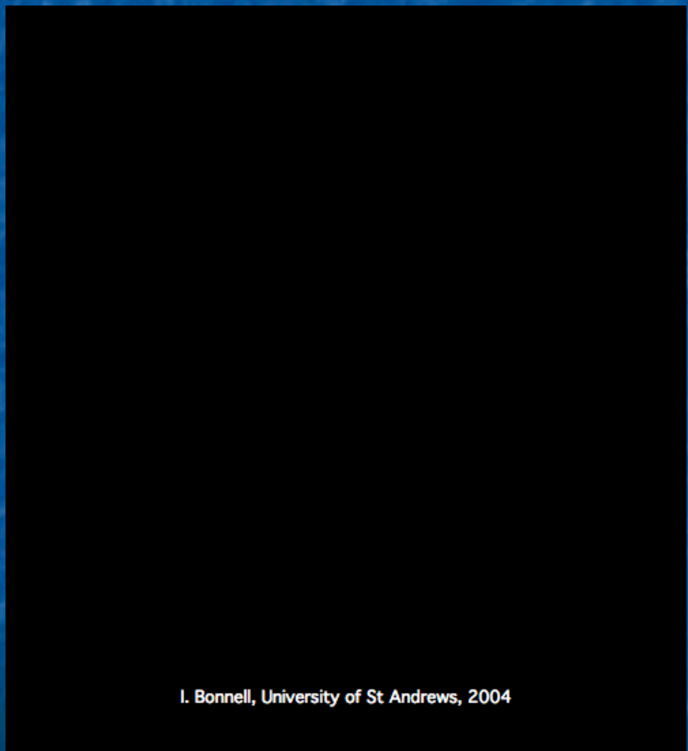
- Some SF triggered
  - 1/3 more stars
- Some just revealed
- Can we tell which?
  - Not from end-result
- Need observable tests, predictions



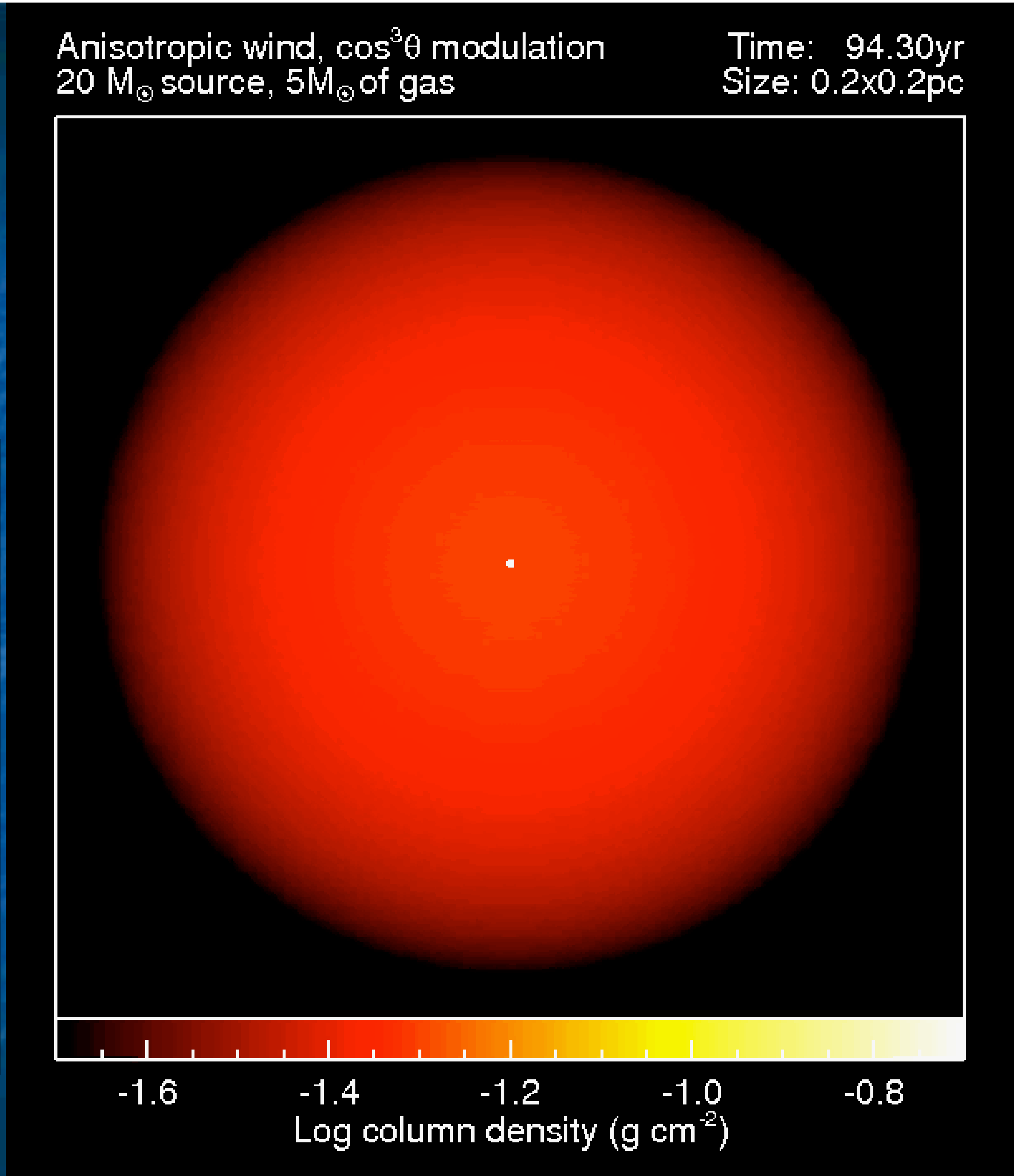
UK Astrophysical Fluids Facility

Winds/outflows from young stars

Weakly collimated flow

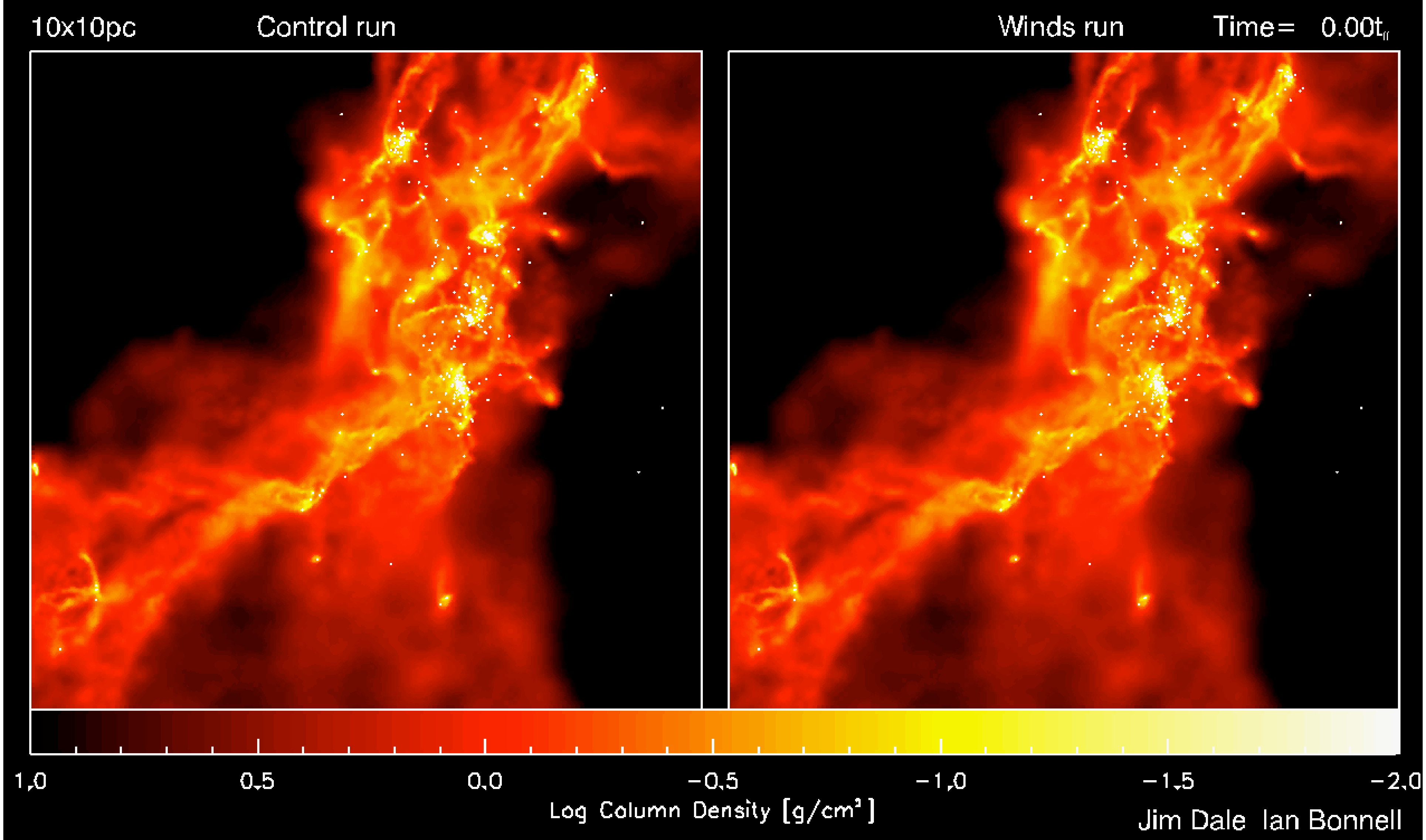


Externally collimated flow

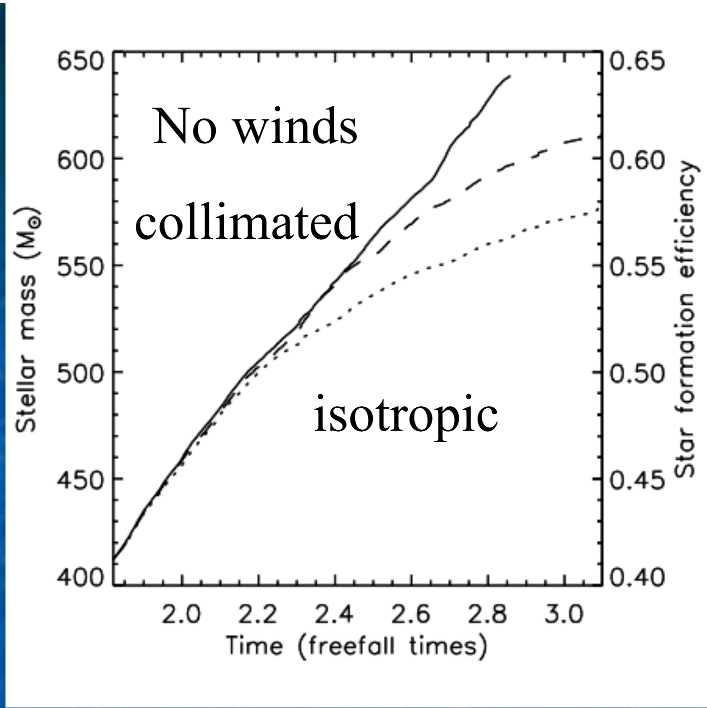


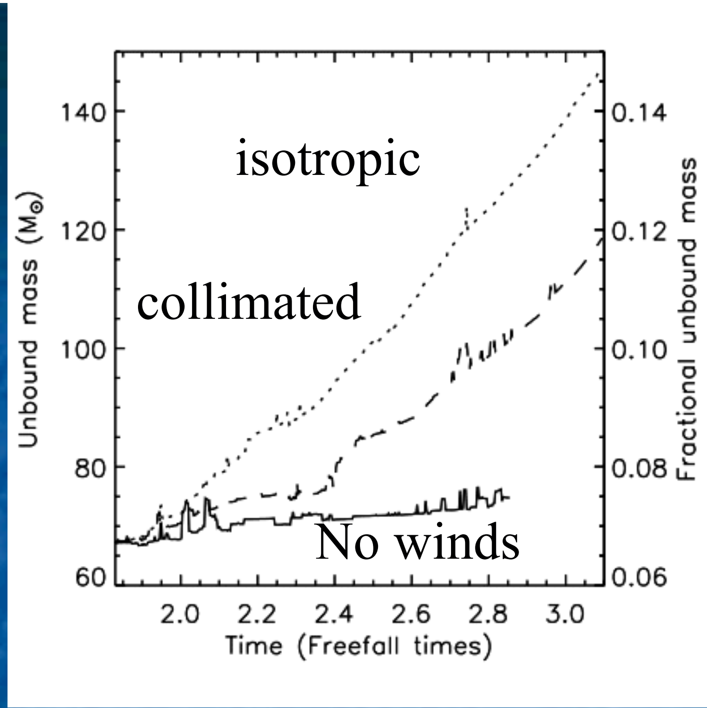
J. Dale

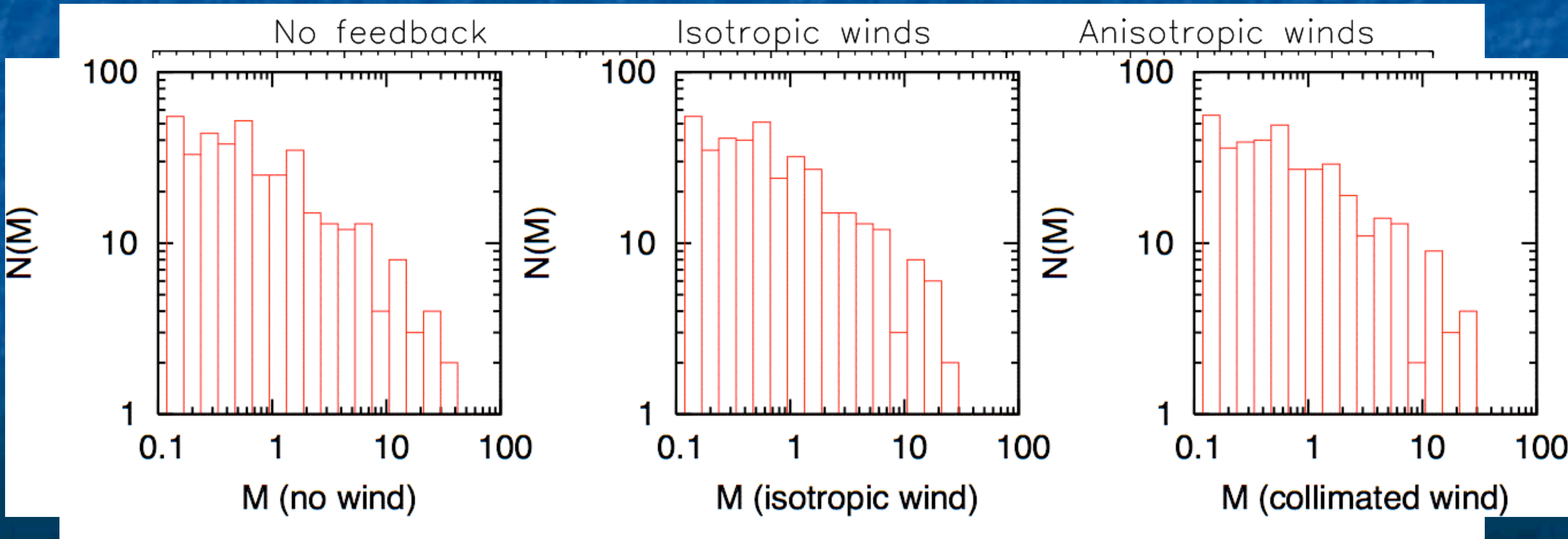
Feedback from stellar winds



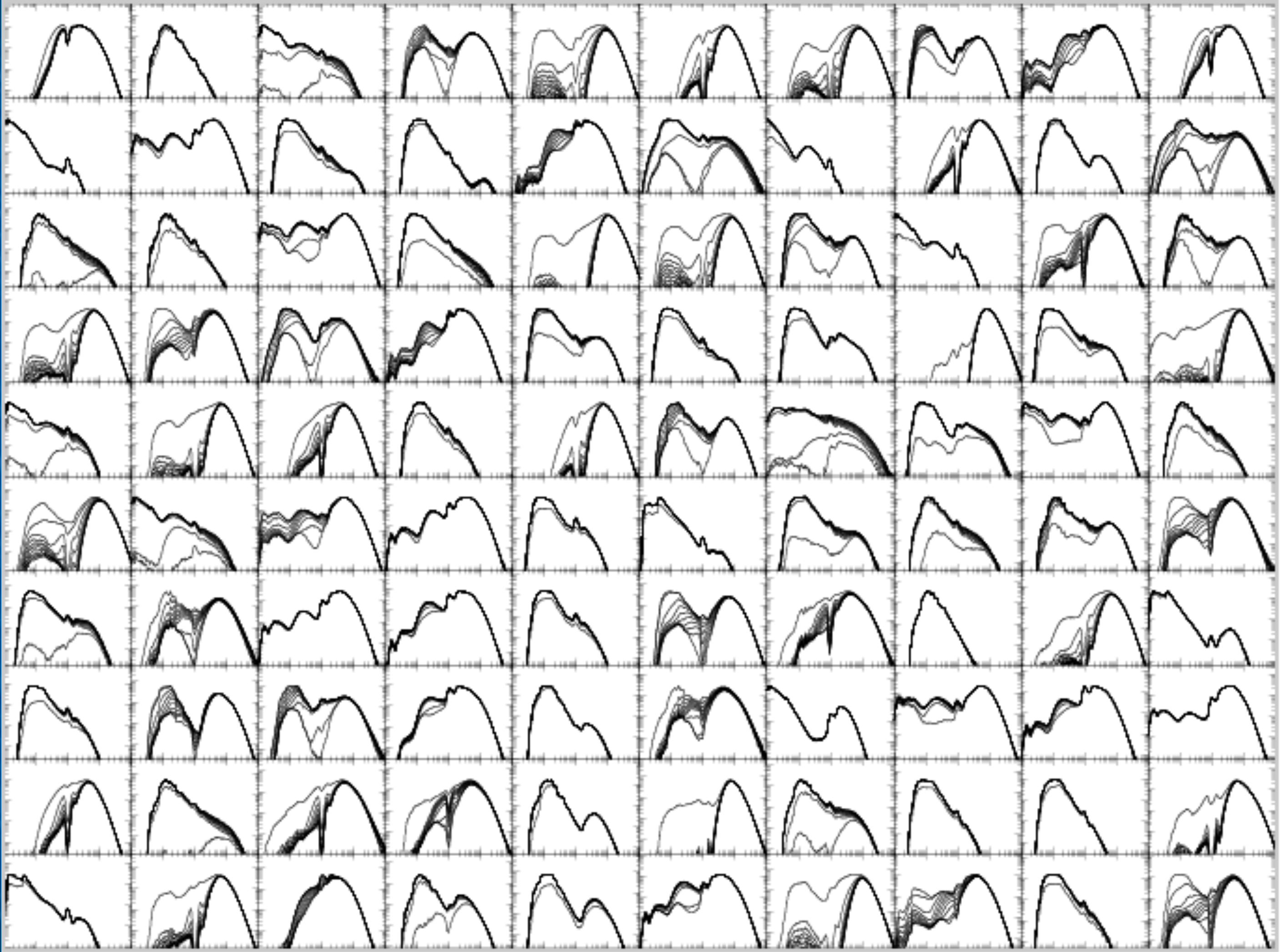
Winds have moderate effect on accretion rates


No winds
collimated
isotropic
Stellar mass (M⊙)
Star formation efficiency
Time (freefall times)
650
600
550
500
450
400
0.65
0.60
0.55
0.50
0.45
0.40
2.0
2.2
2.4
2.6
2.8
3.0


isotropic
collimated
No winds
Unbound mass (M⊙)
Fractional unbound mass
Time (Freefall times)
140
120
100
80
60
0.14
0.12
0.10
0.08
0.06
2.0
2.2
2.4
2.6
2.8
3.0


No feedback
Isotropic winds
Anisotropic winds
N(M)
100
10
1
0.1
1
10
100
M (no wind)
M (isotropic wind)
M (collimated wind)

Monte Carlo: Radiative transfer



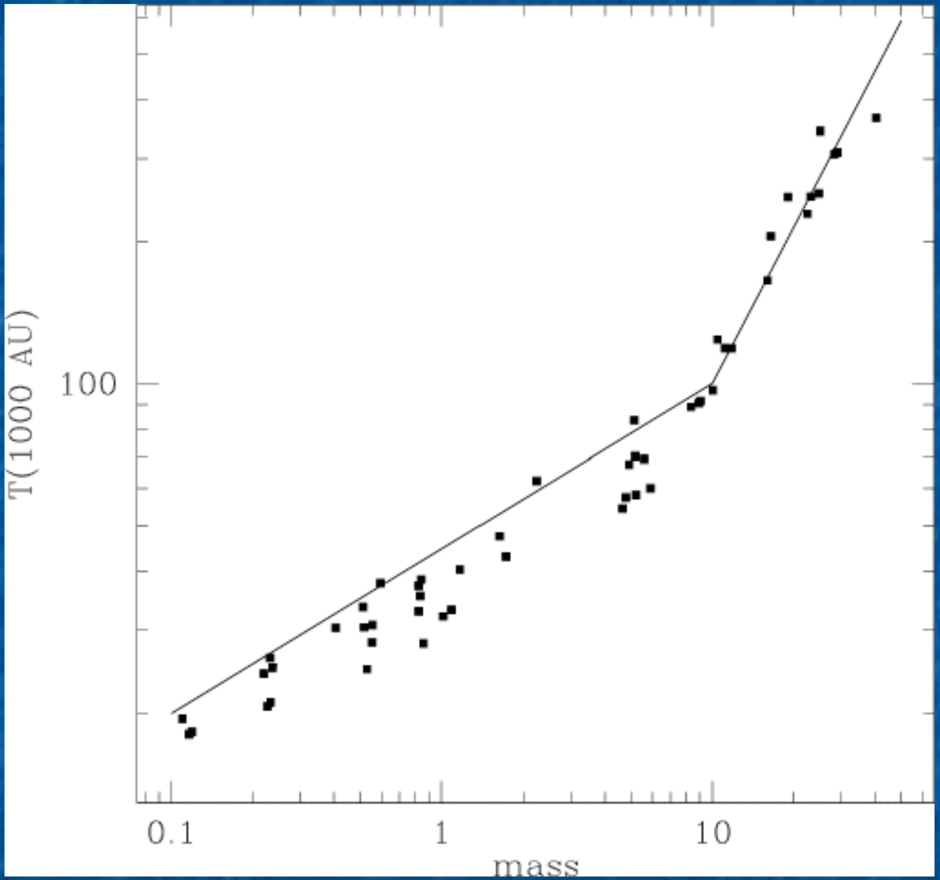
Robitaille et al 2006

RT: a simplified approach

- fudge to MC models

$$T = 100K\left(\frac{M}{10M_o}\right)^a\left(\frac{R}{1000AU}\right)^q$$

  - a: 0.33 M < 10
  - a: 1.1 M > 10
  - q: -0.4 to -0.5



Overestimates feedback

- Spherical symmetric
- Isolated
  - Underestimates column densities
  - Ignores cluster structure, discs etc

1000 M_{sun} cluster

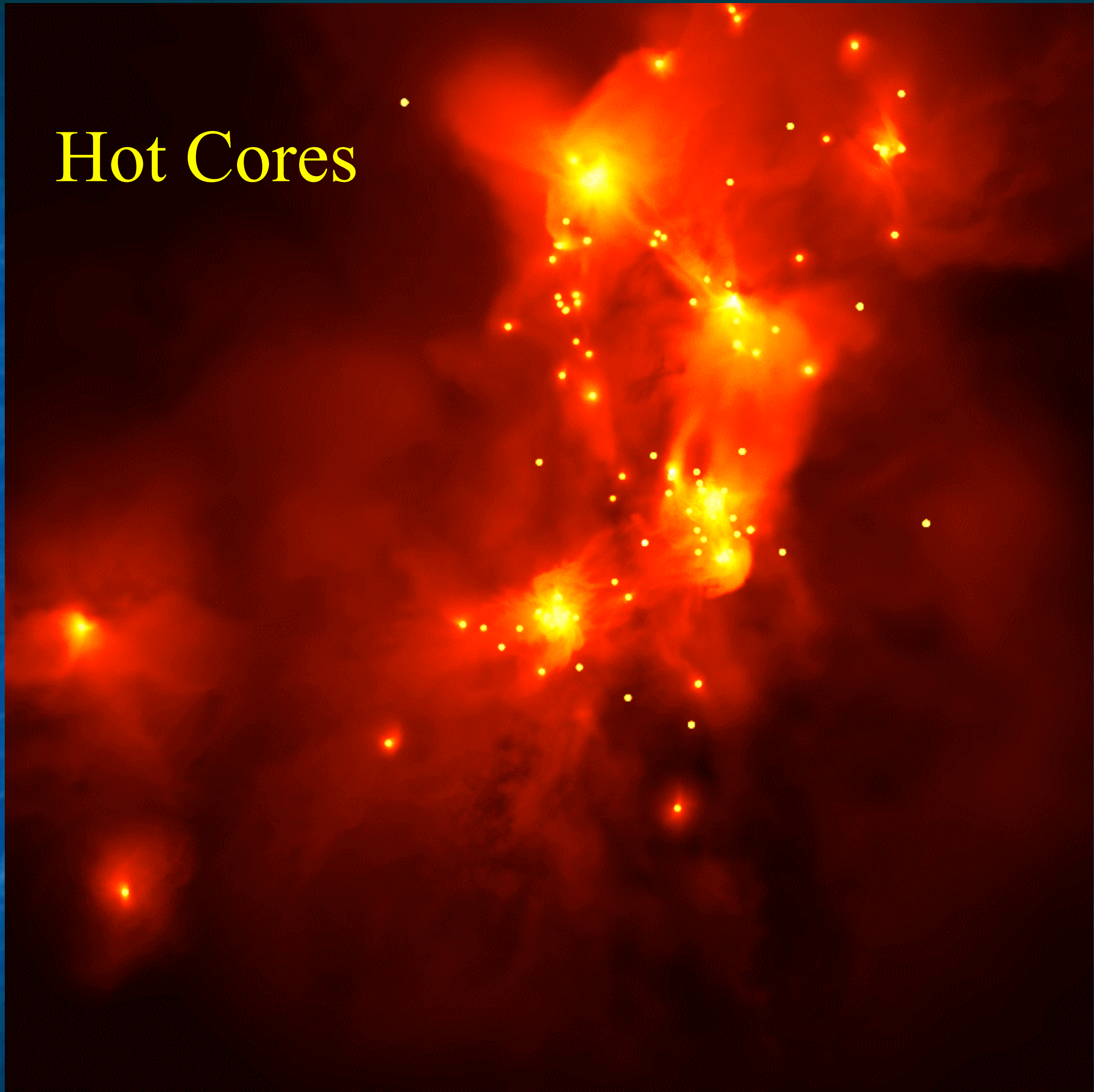
T 10-100K

Fragments

- Early
- Large separations

Later fragmentation suppressed

- Heating from massive stars



- Cluster formation with MC-RT fudge
- Upper limit on radiative heating

Early fragmentation unaffected

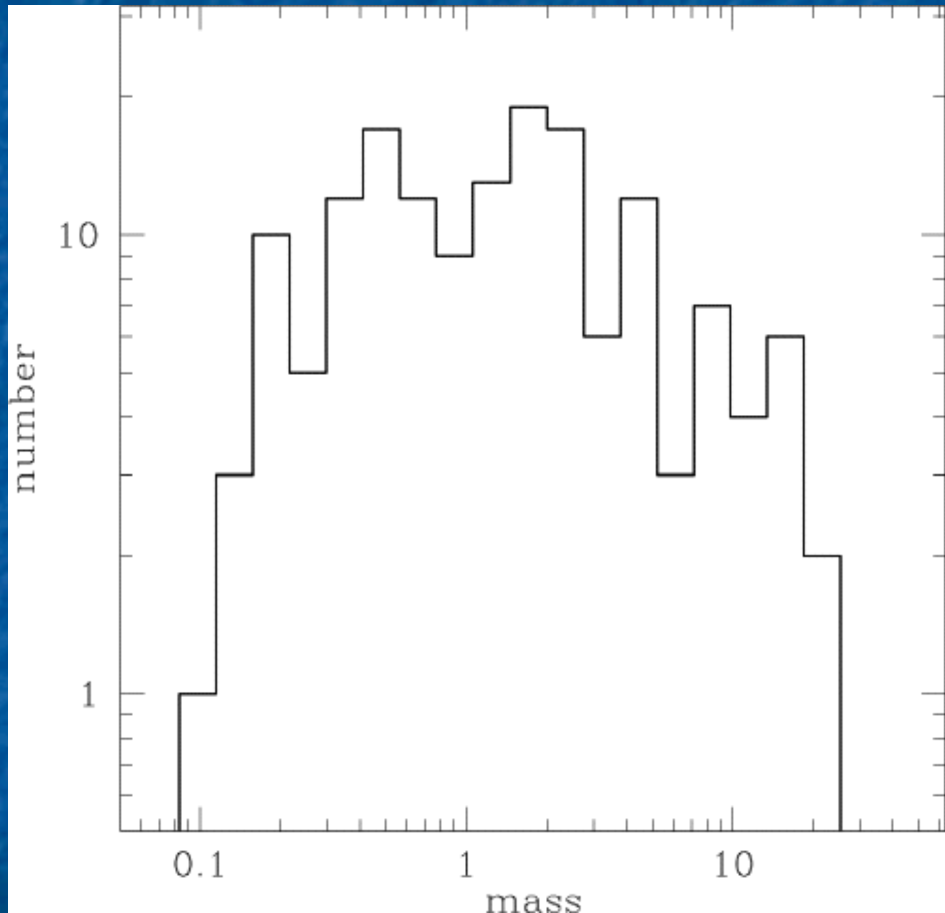
- 1/4 of stars

Accretion in hot cores

Forms massive stars

- But fewer stars
- higher mean mass
  - Shallow IMF

No late formation of massive cores in cluster



- Infalling gas accreted

Conclusions

- Massive SF in 30 Doradus consistent with hierarchical cluster formation
  - age spread ~ several Myr
- 'Distributed' O-stars should have small clusters
- Feedback
  - Doesn't stop competitive accretion
  - Maximal radiative feedback will change IMFs
  - No massive cores form in clusters