The collisional formation of massive stars

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Model of Bonnell, Bate & Zinnecker 1998 (BBZ) proposed because:

- A) theoretical difficulties with accretion due to p _rad (Wolfire & Casinelli 1989; but see Edgar & Clarke 2003, Sonnhalter & Yorke 2002)
- B) lack of observed discs in massive protostellar cores but see Cesaroni et al 2006 (PPV) et seq.

BUT: ARE THERE (EXOTIC?) ENVIRONMENTS WHERE COLLISIONS ARE EVER IMPORTANT?

Required densities for stellar collisions on Myr timescale is high (~ 10^8 /pc^3)

Stolte et al 2006

Cluster	M_{total} ($M_\odot$)	Extent (pc)	r_{core} (pc)	ρ_{core} ($M_\odot$ pc^{-3})	Age (Myr)
Arches	10^4	1 (?)	0.2	3×10^5	2–3
NGC 3603 YC	$>7 \times 10^3$	4.4	0.2	10^5	1–3
R136	2×10^4	4.7	0.02	5×10^4	1–5
Orion	10^3	3	0.2	4×10^4	0.3–1
Antennae starbursts	10^4–10^6	1–10	?	10^3	1–20
Milky Way GCs	10^4–few 10^5	Few pc	≈1	10^2–10^6	10 Gyr

...collisions unimportant for observed clusters in their current states....

Elements of (BBZ) model:

(spherical, non-rotating gas, all gas onto stars)

i.e. t_M >> t_dyn

Adiabatic accretion onto star cluster results in shrinkage:

$$r \propto M^{-3}$$

Can understand in terms of preservation of adiabatic invariant (e.g. angular momentum)

Or revirialisation after accretion of gas with

Model scalings

- $R \sim M^{-3}$

Don't need to accrete much mass to ensure density rises DRAMATICALLY

- $N \sim M^{9}$
- $\rho \sim M^{10}$
- $V \sim M^{2}$

Velocity dispersion increases more mildly (=> encounters remain in grav focused regime)

Model limitations

- Adiabatic regime requires Mdot < v^3/G (for v = initial velocity cluster vel. dispersion)

- More amply satisfied during collapse (once adiabatic => always adiabatic)

- If cluster fed by gas free-falling from outer cluster/reservoir, adiabatic condition implies v for cluster > v for reservoir

End state

- If adiabatic regime persists`forever’ are collisions inevitable if keep on accreting?
- Bonnell & Bate 2002 found “no” - needed to boost collision cross-section to get collisions before clusters puff up due to few body effects
- => Clarke & Bonnell (2008) argued that collisions require large N, massive clusters (not ONC!)

Follow up with Monte Carlo code (Freitag & Benz 2001,2002)

- Models of spherical clusters in dynamical equilibrium
- Include secular effects:

  a) accretion

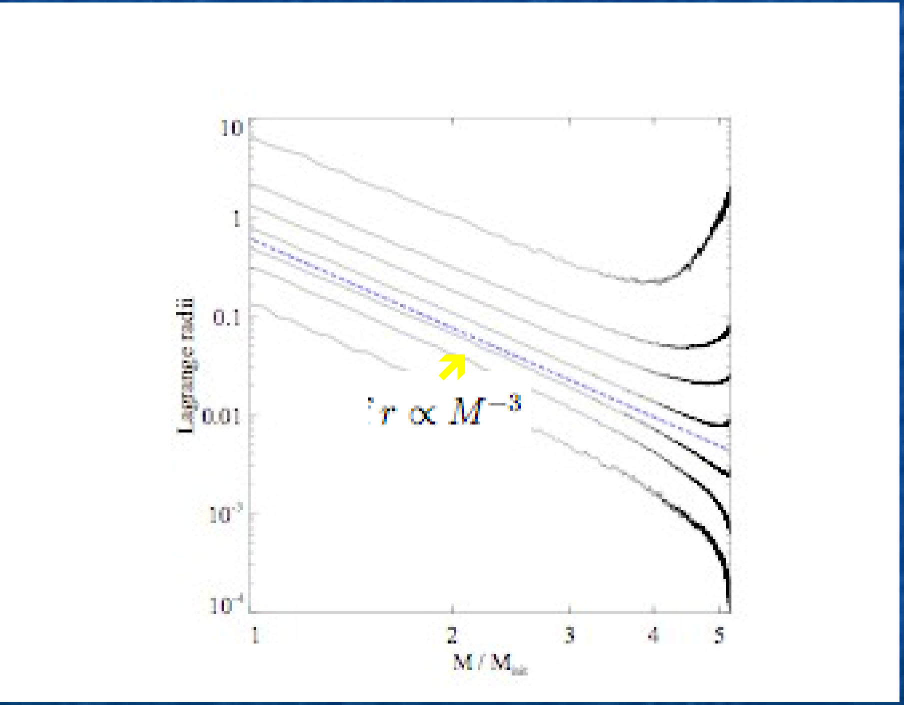
  b) two-body relaxation

Equal mass stars !

- Estimate collision rate through post-processing

Results

End of adiabatic regime



← Puffing up

← Core collapse!

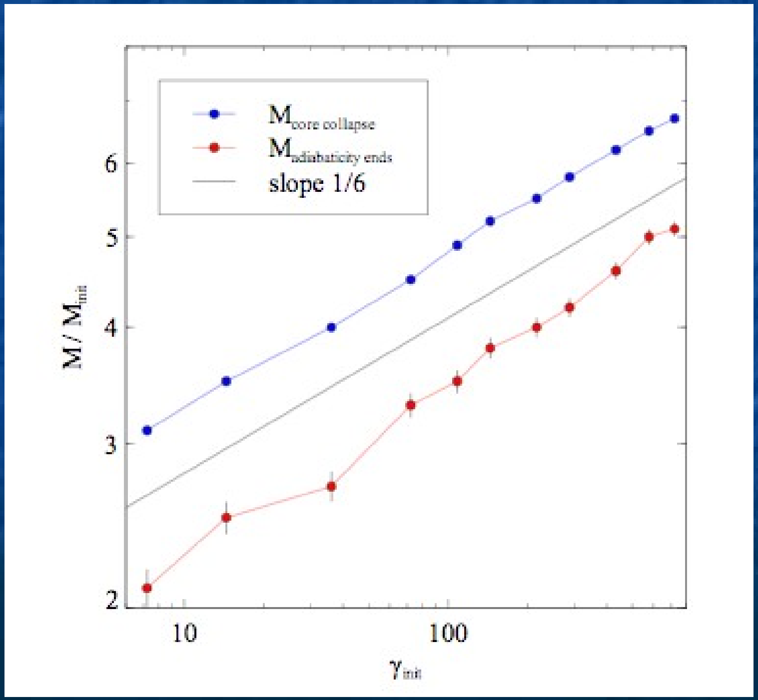
End of adiabatic regime when t_2r ~ t_Mdot (= M/Mdot)

- Ratio of t_2r/t_Mdot (initially large) scales as M^-6

$$M_f \propto \gamma_{init}^{\frac{1}{6}}$$

Where

$$\gamma \equiv \frac{t_{2r}}{t_{\dot{M}}}$$



✔

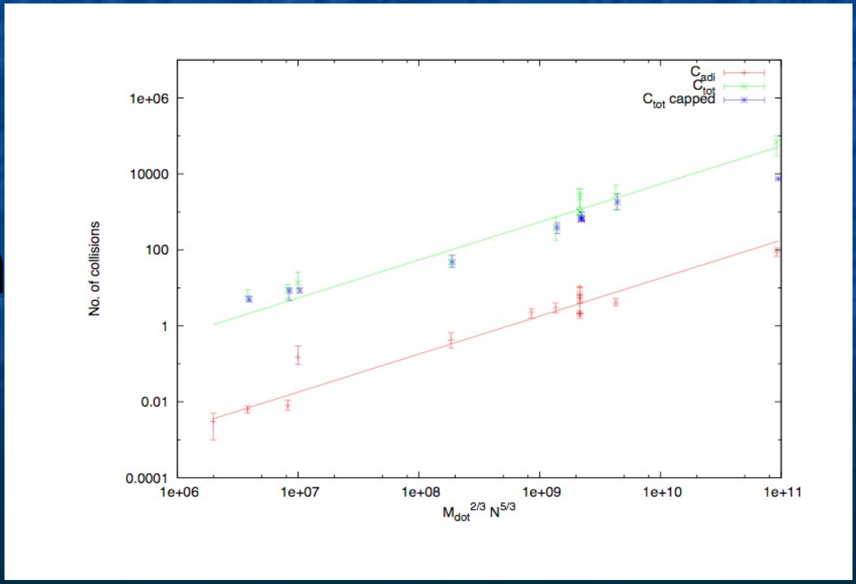
Estimate number of collisions in adiabatic phase (collapse homologous)

- Number of collisions per mass doubling time scales as M^10 during collapse so can relate total collisions to number collisions in first mass doubling time and

$\gamma \equiv \frac{t_{2r}}{t_{\dot{M}}}$ (since $M_f \propto \gamma_{init}^{\frac{1}{6}}$)

find C_adi proportiona

to N^5/3 Mdot^2/3

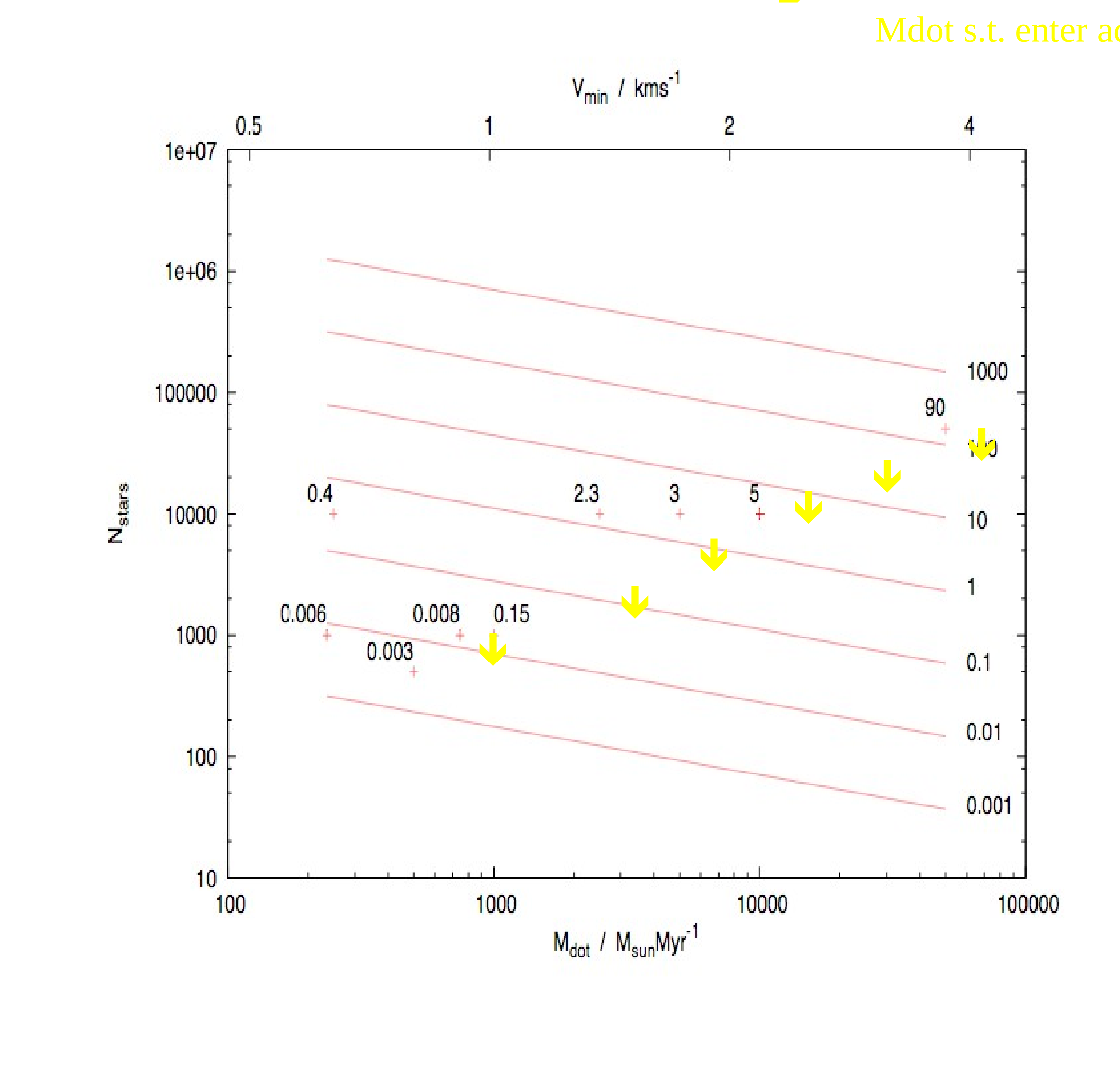


(Clarke & Bonnell 2008)

Numerical values (red contours = number of collisions in adiabatic regime)

Minimum initial velocity as function of

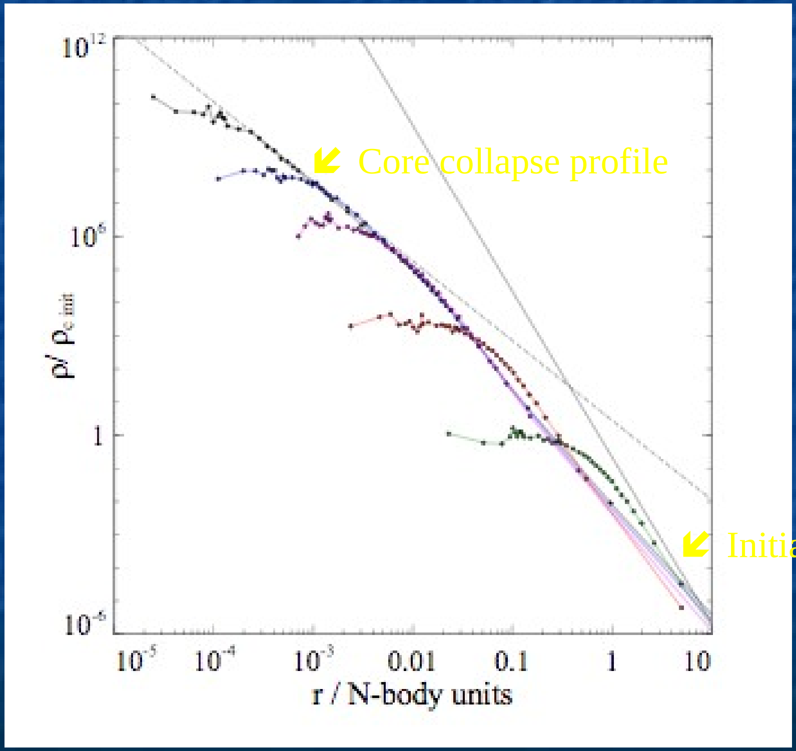
Mdot s.t. enter adiabatic collapse



Have to be below arrows to drive collapse in a Myr

$\Rightarrow$ NEED VERY HIGH N (~ 10^4 -10^5) TO GET EVEN A FEW COLLISIONS

But adiabatic regime is not the end of the story - also examine collisions during core collapse

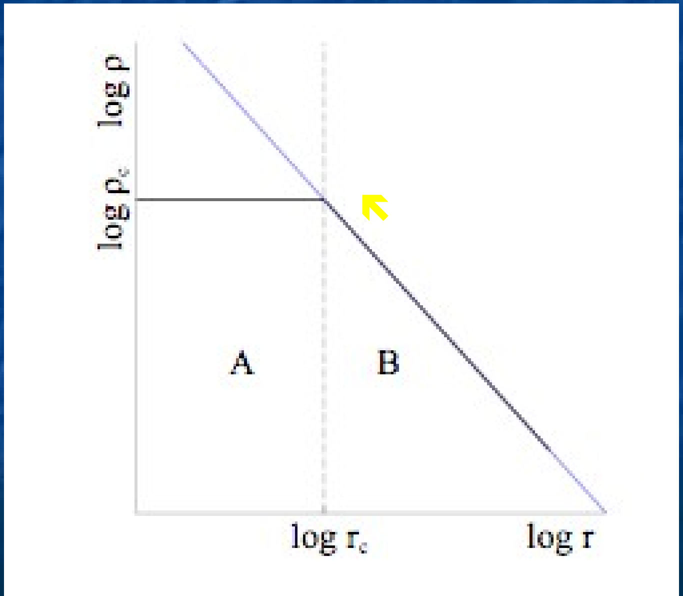


Core collapse profile

Initial Plummer profile

Schematic of density evolution

during core collapse



Collisions predominantly from ~ r_c

As approach core collapse, system evolves on ~ core relaxation time

Time to core collapse $\tau = t_{2r}/\eta,$

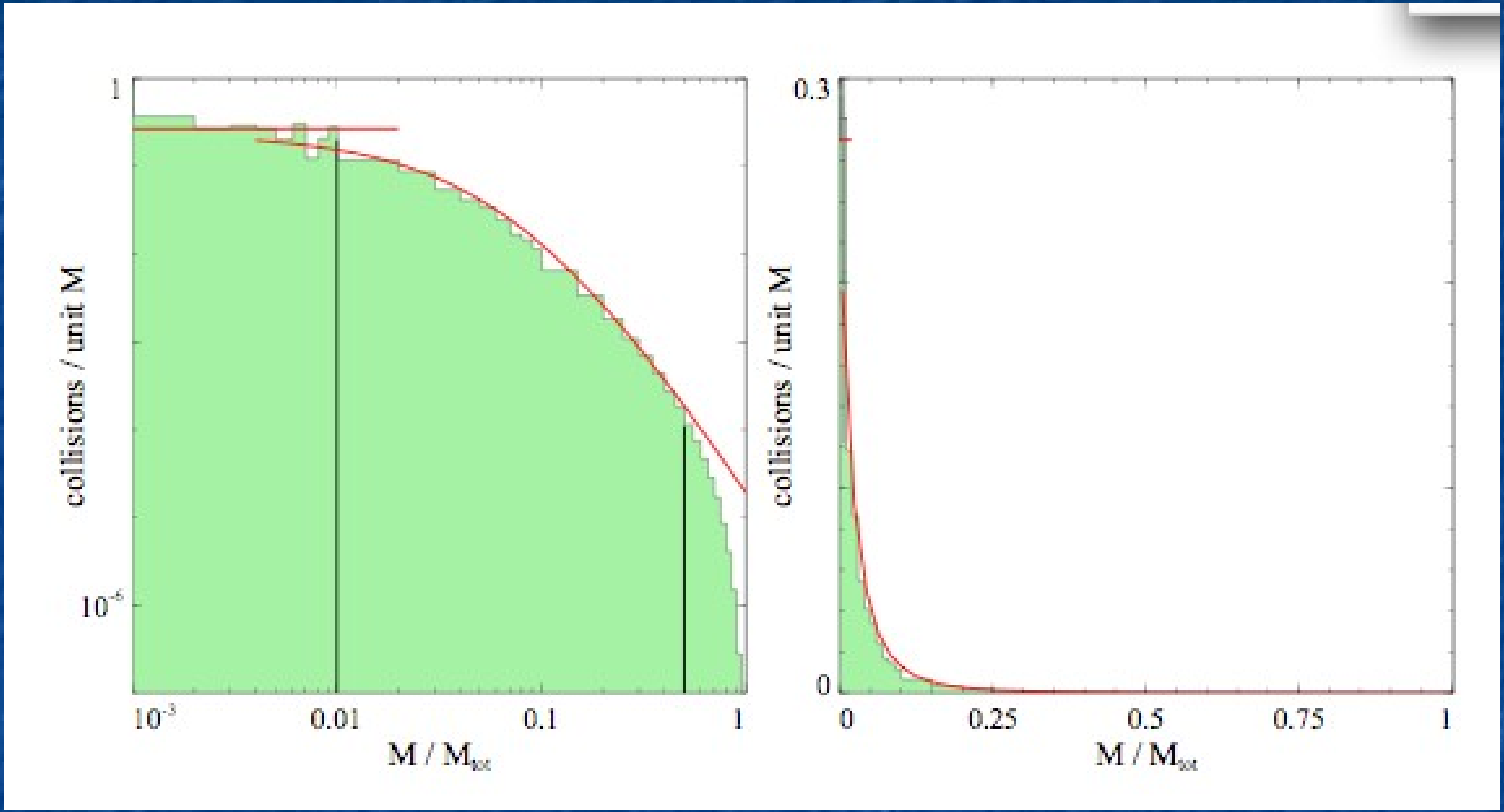
Evolution of core radius $r_c \propto (\tau\eta)^{5/9}$

Evolution of collision rate $\dot{C}_{tot} \propto r_c^{-1.6}$

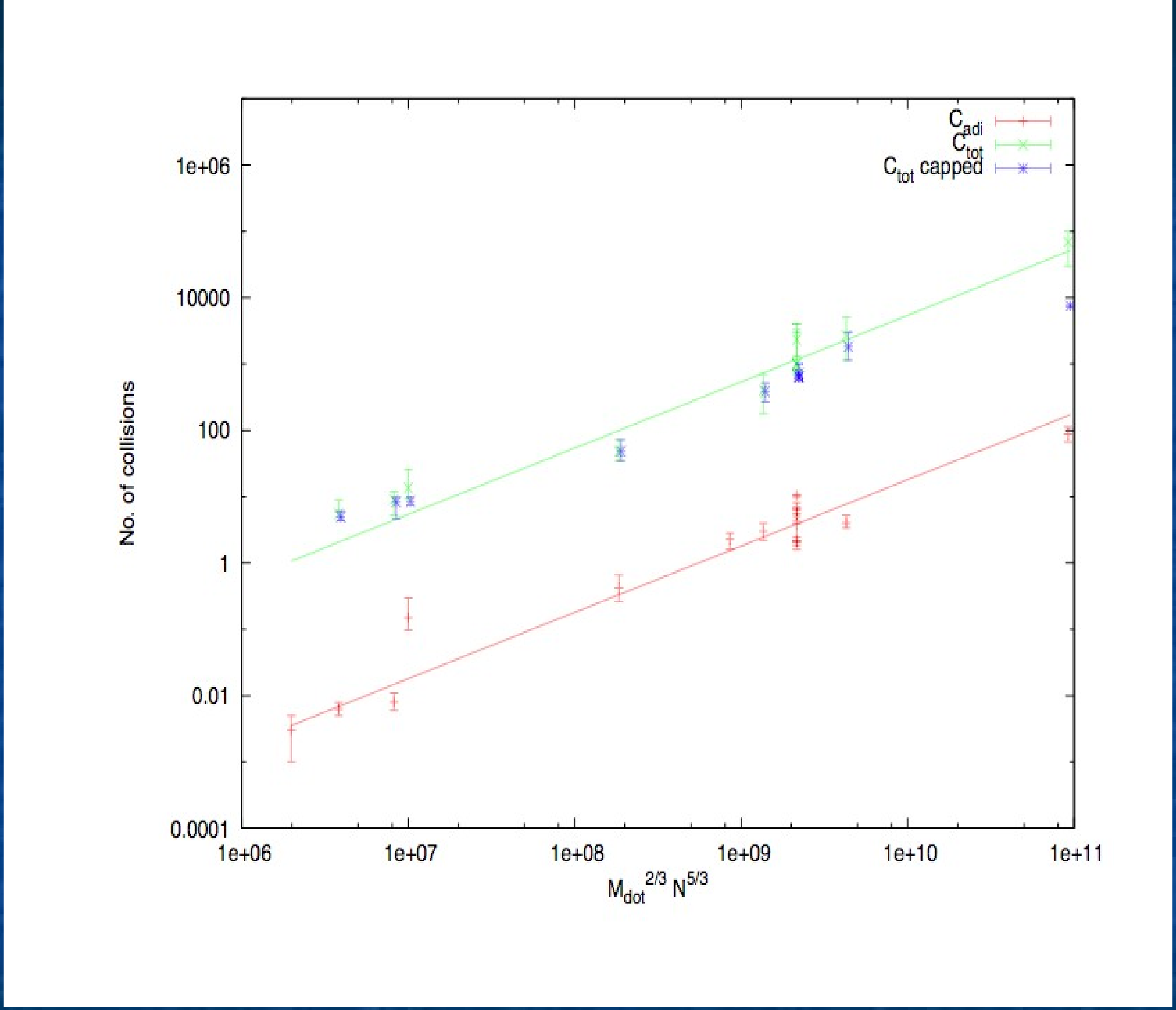
=> $\dot{C} \propto (\tau\eta)^{8/9}$

total number of collisions converges

Where the collisions occur



Mostly within innermost 10% of mass

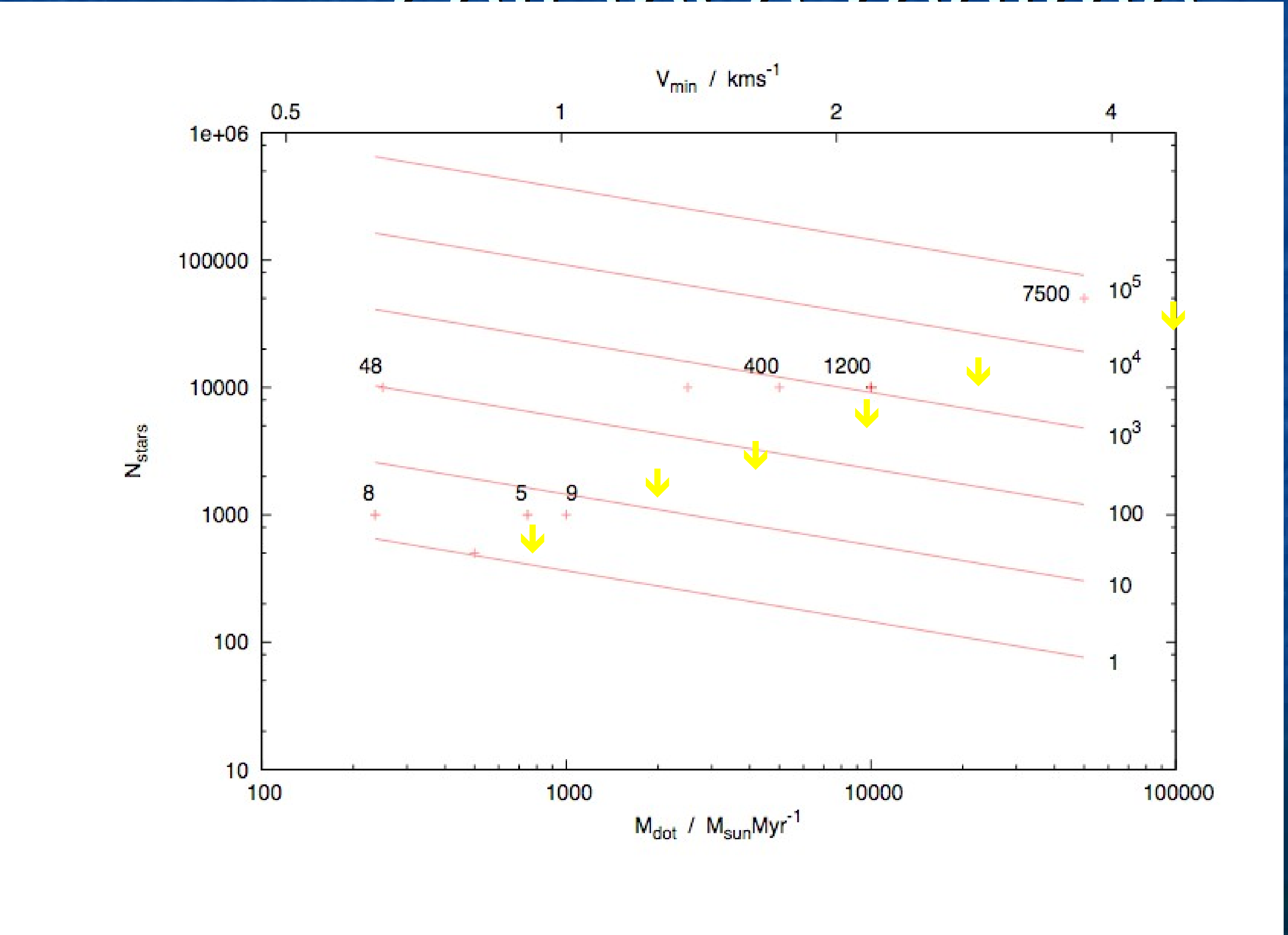


Collisions during core collapse

Collisions in adiabatic regime

Factor 30!

Red contours denote number of collisions in core collapse regime



Interesting number of collisions in core collapse regime in populous clusters

But would binaries prevent core collapse?

- Three-body binaries only effective in small N clusters

- Primordial binaries? Maybe, but need substantial population of sub-AU binaries

Conclusion

- Don't expect many collisions in adiabatic regime even in large N, massive clusters

- But collision yield rises by ~ 30 if core collapse goes to completion- now astronomically interesting in large N, massive systems

Do you get latter phase in realistic case (primordial binaries + mass spectrum)?

Adding the realism:

. Include mass spectrum in Monte Carlo (large N) simulations

. Nbody + accretion calculations to include binaries (Nbody6 + “negative stellar winds”)