Extreme stellar dynamics: Runaway collisions in dense stellar clusters

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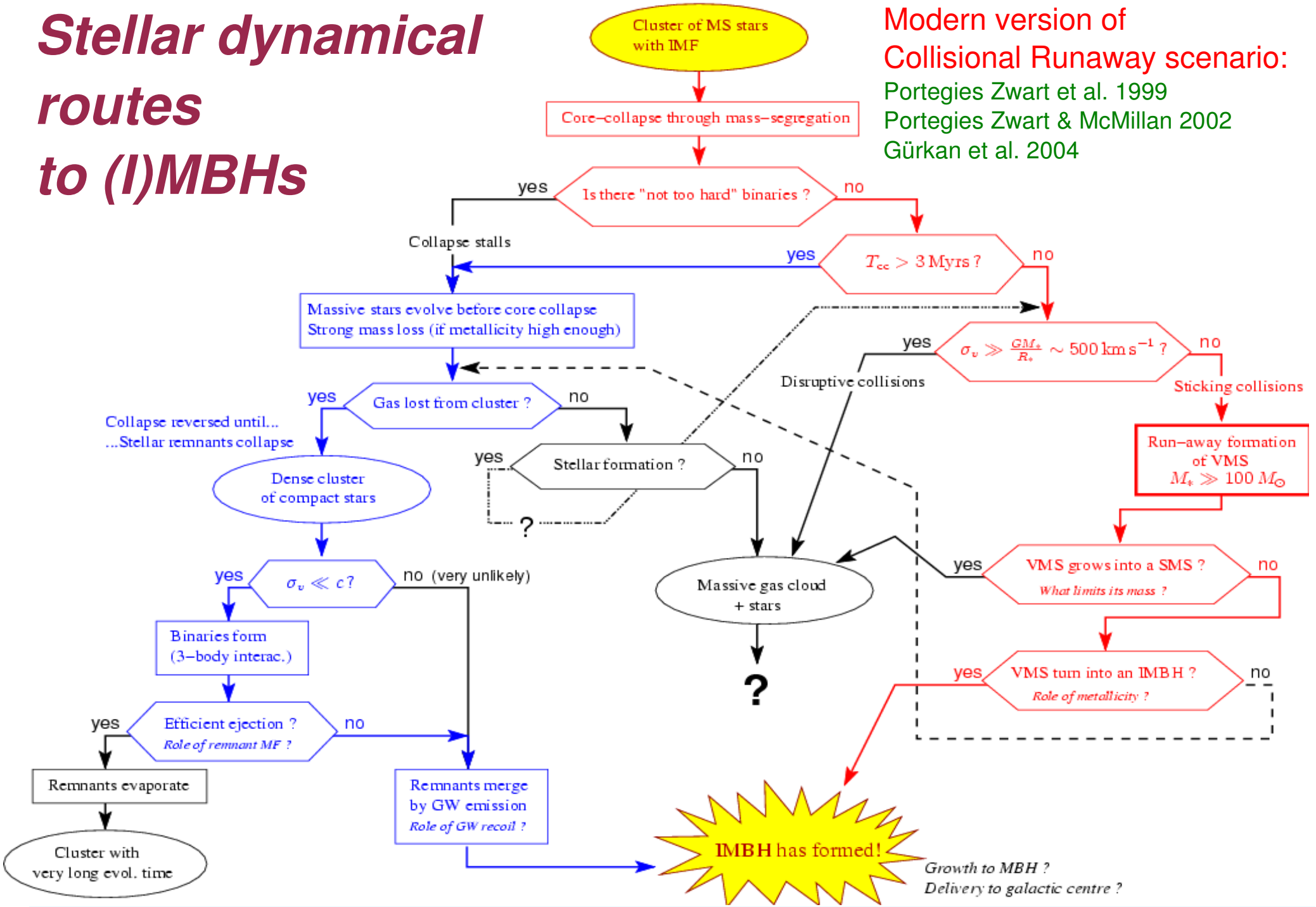
Stellar dynamical routes to (I)MBHs



Modern version of Collisional Runaway scenario:

Portegies Zwart et al. 1999

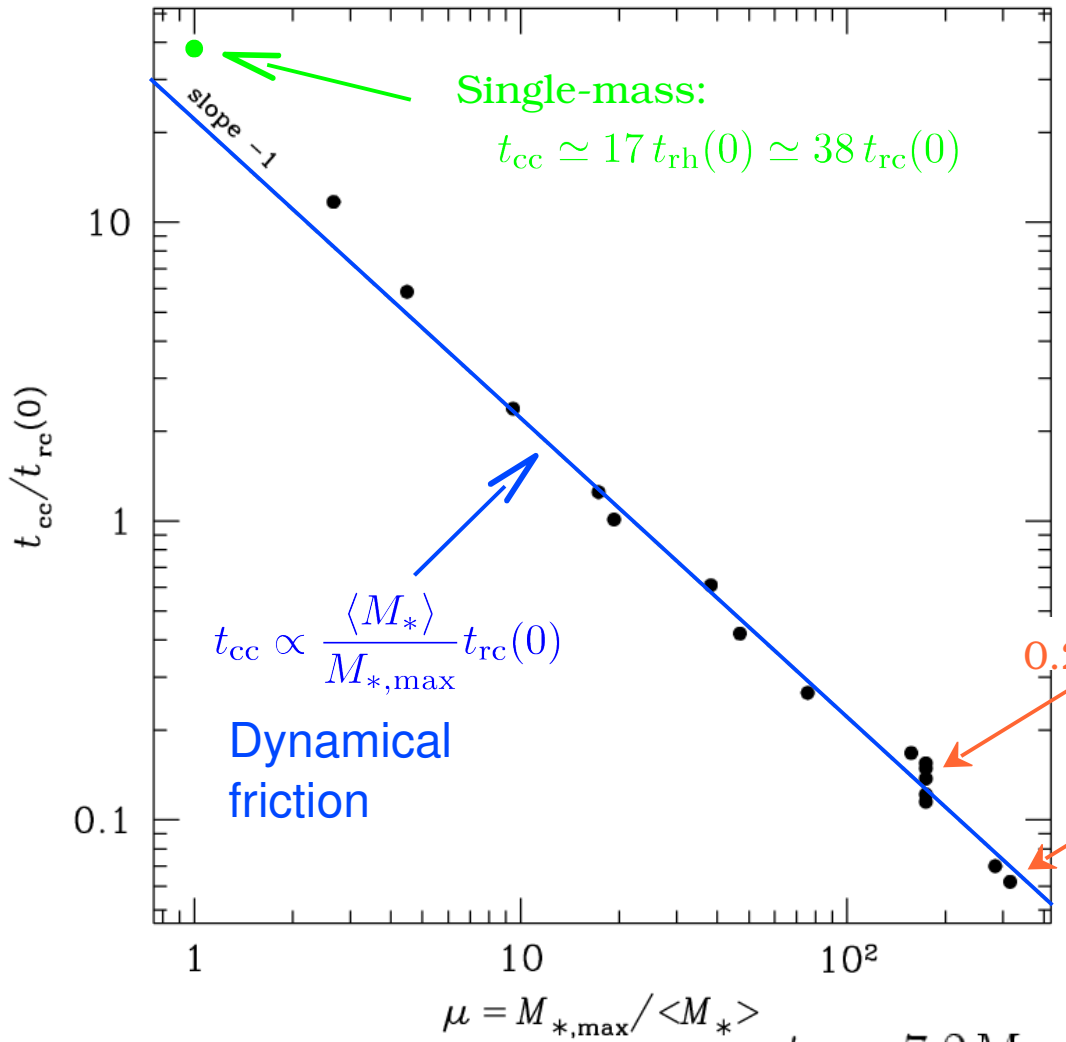
Portegies Zwart & McMillan 2002

Gürkan et al. 2004

How fast is core collapse?

Gürkan et al. 2004
Freitag unpublished

MC runs with various mass functions, $N \geq 300{,}000$



$$t_{cc} \lesssim 0.15 t_{rc}(0)$$

$$t_{rc} = 7.2\,\mathrm{Myr} \left(\frac{\sigma_{1D}}{10\,\mathrm{km\,s^{-1}}}\right)^3 \left(\frac{n}{10^6\,\mathrm{pc^{-3}}}\right)^{-1} \left(\frac{\langle m_* \rangle}{0.5\,\mathrm{M_\odot}}\right)^{-2}$$

Runaway growth in short t_{cc} clusters

MC simulations with N =3x10^5-9x10^6

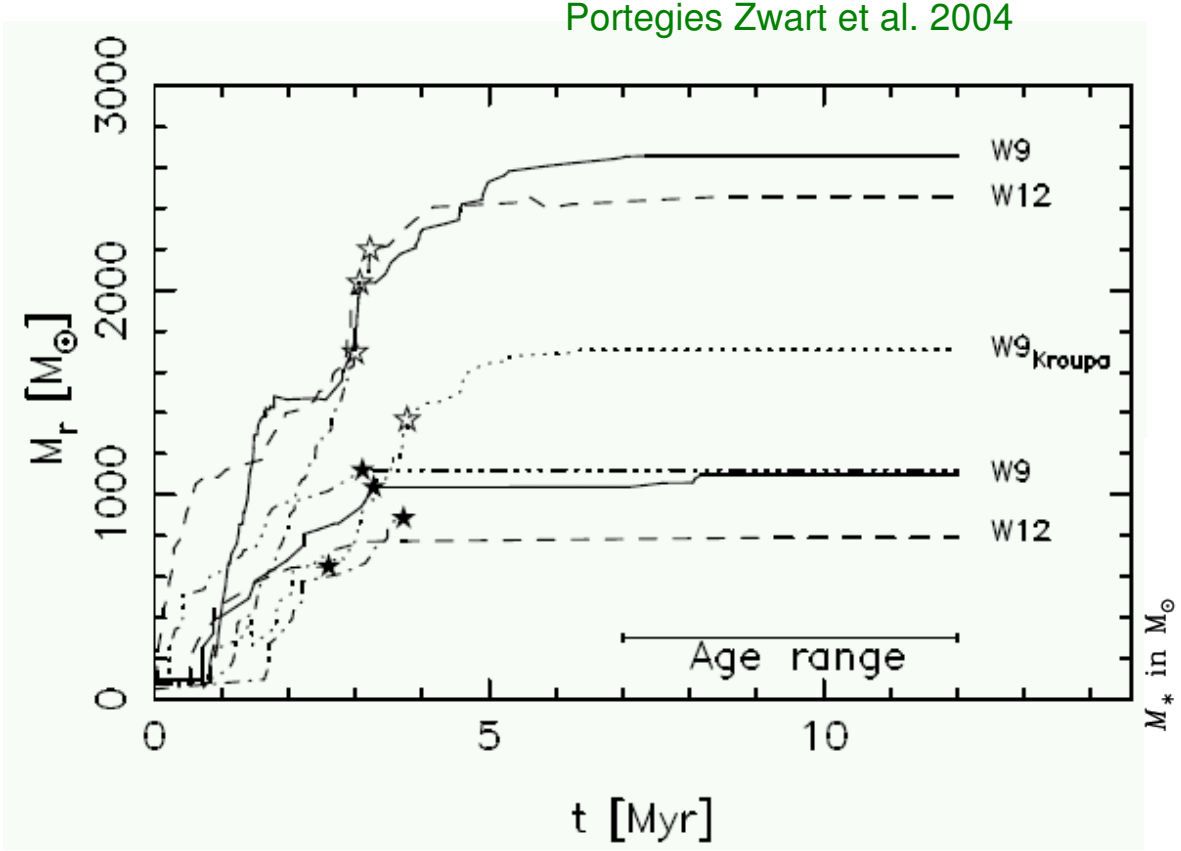
Freitag et al. 2005b

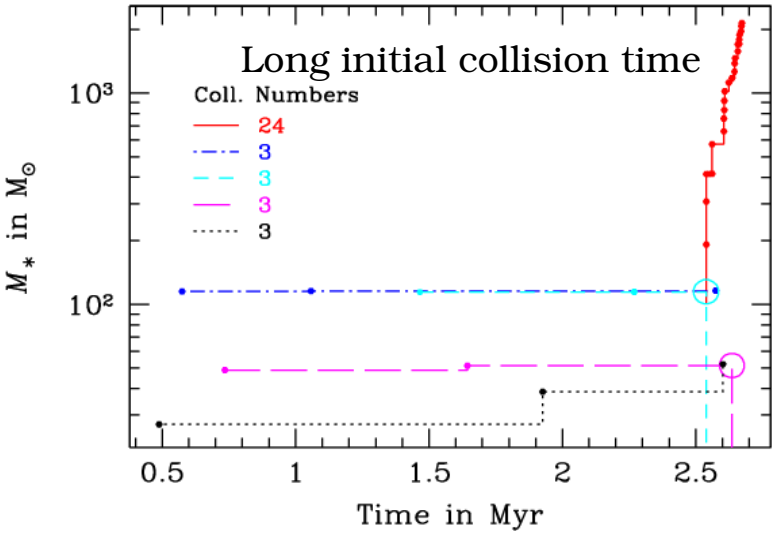
❢ no binaries

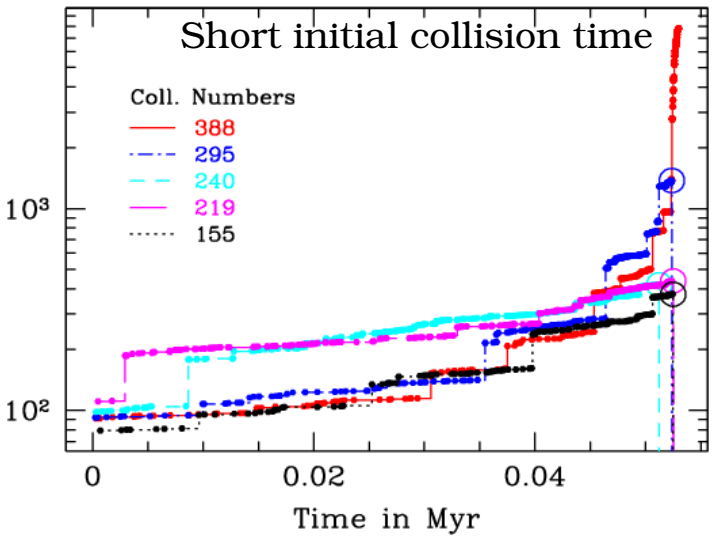
☺ "realistic" coll.

N-body simulations with N =1.3-5.9x10^5

Portegies Zwart et al. 2004







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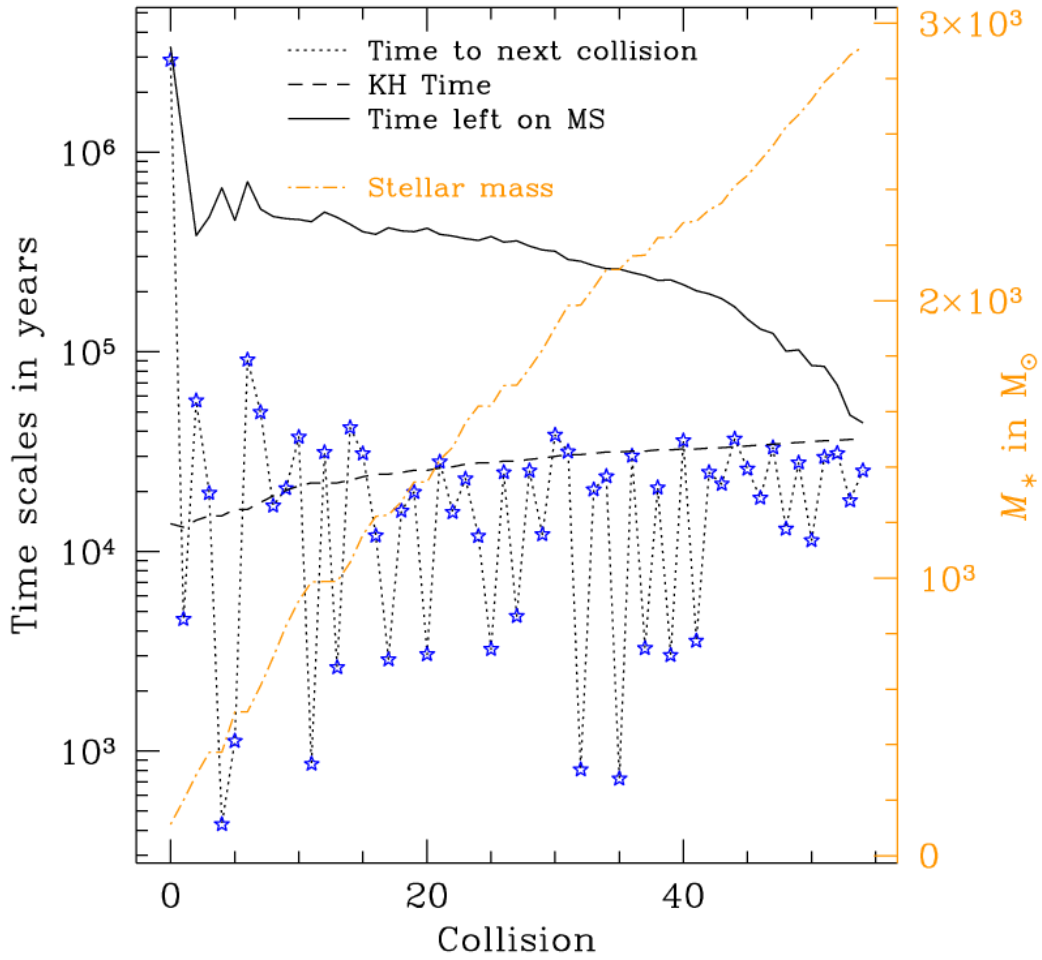
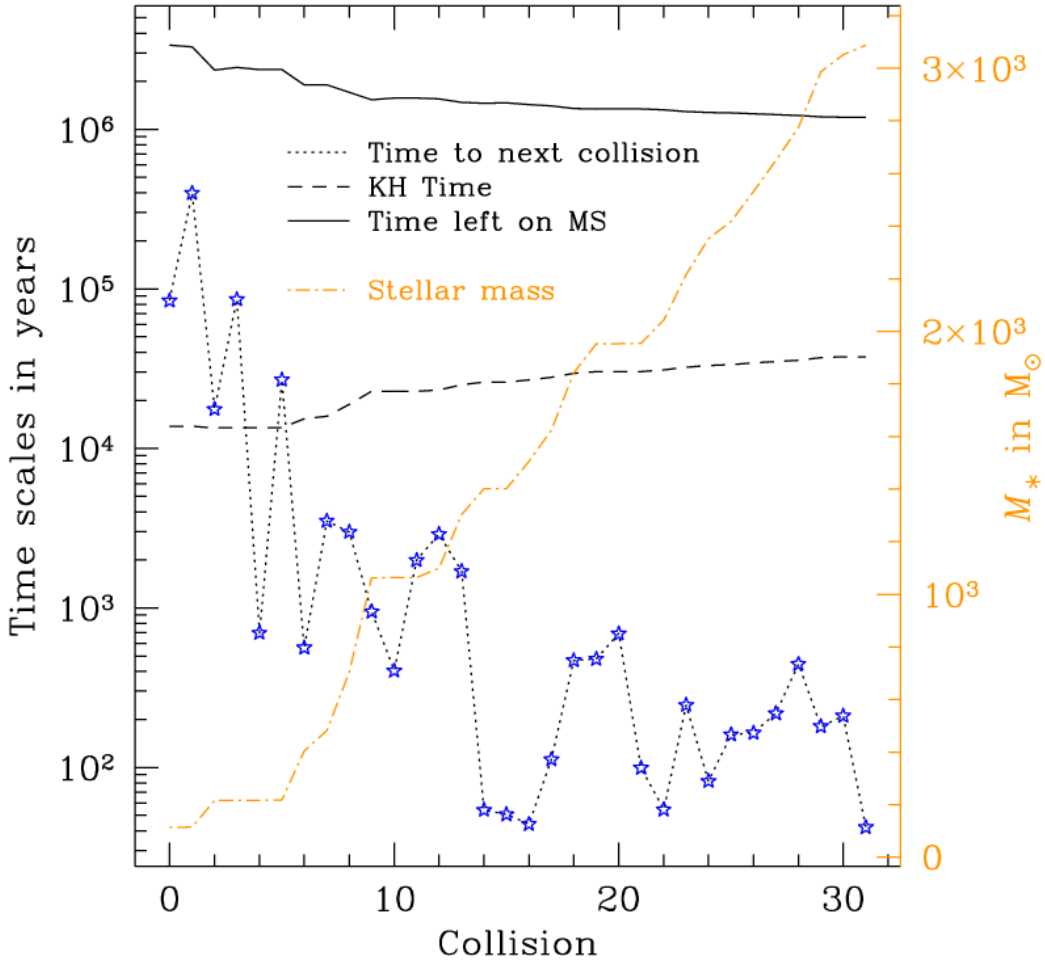
Runaway time scales

Freitag et al. 2005b

Long initial collision time



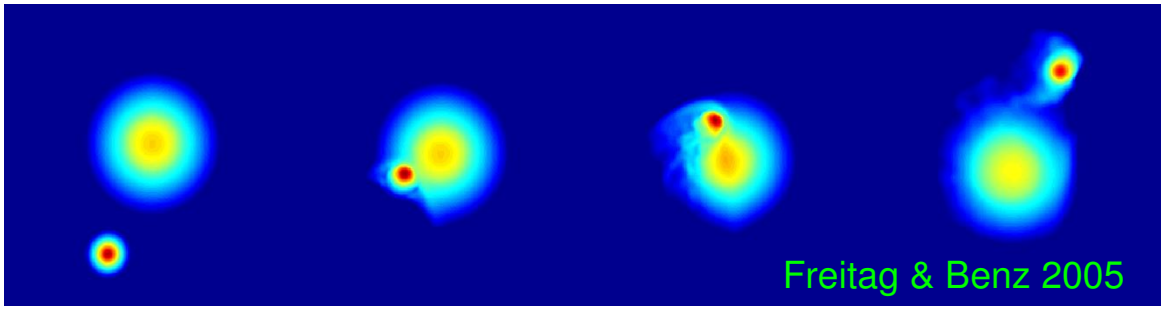
Short initial collision time



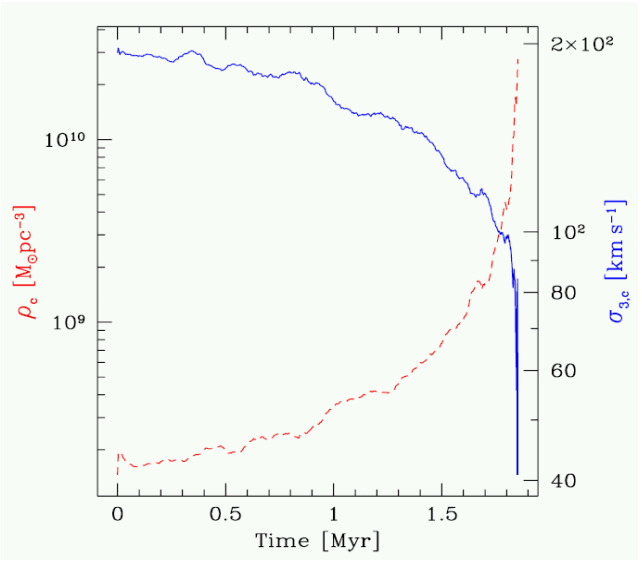
Most mass from impactors with $M_* > 70\ M_\odot$

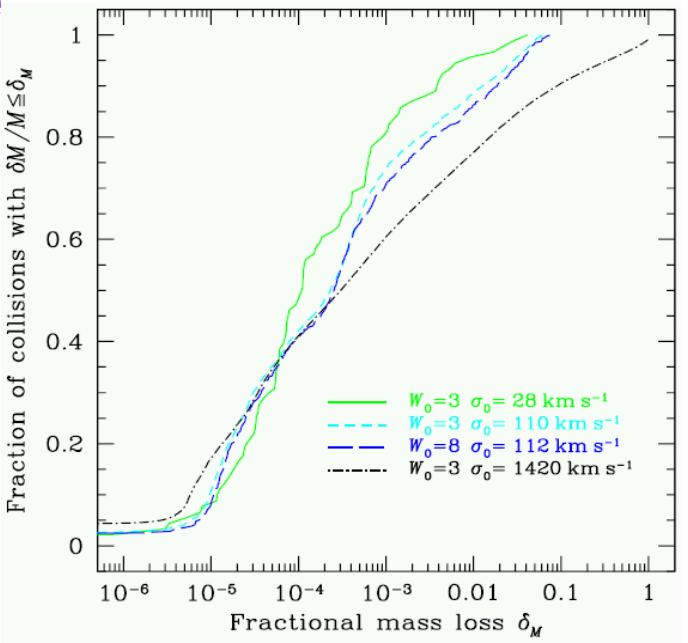
Runaway star probably out of thermal equilibrium

Role of collision physics



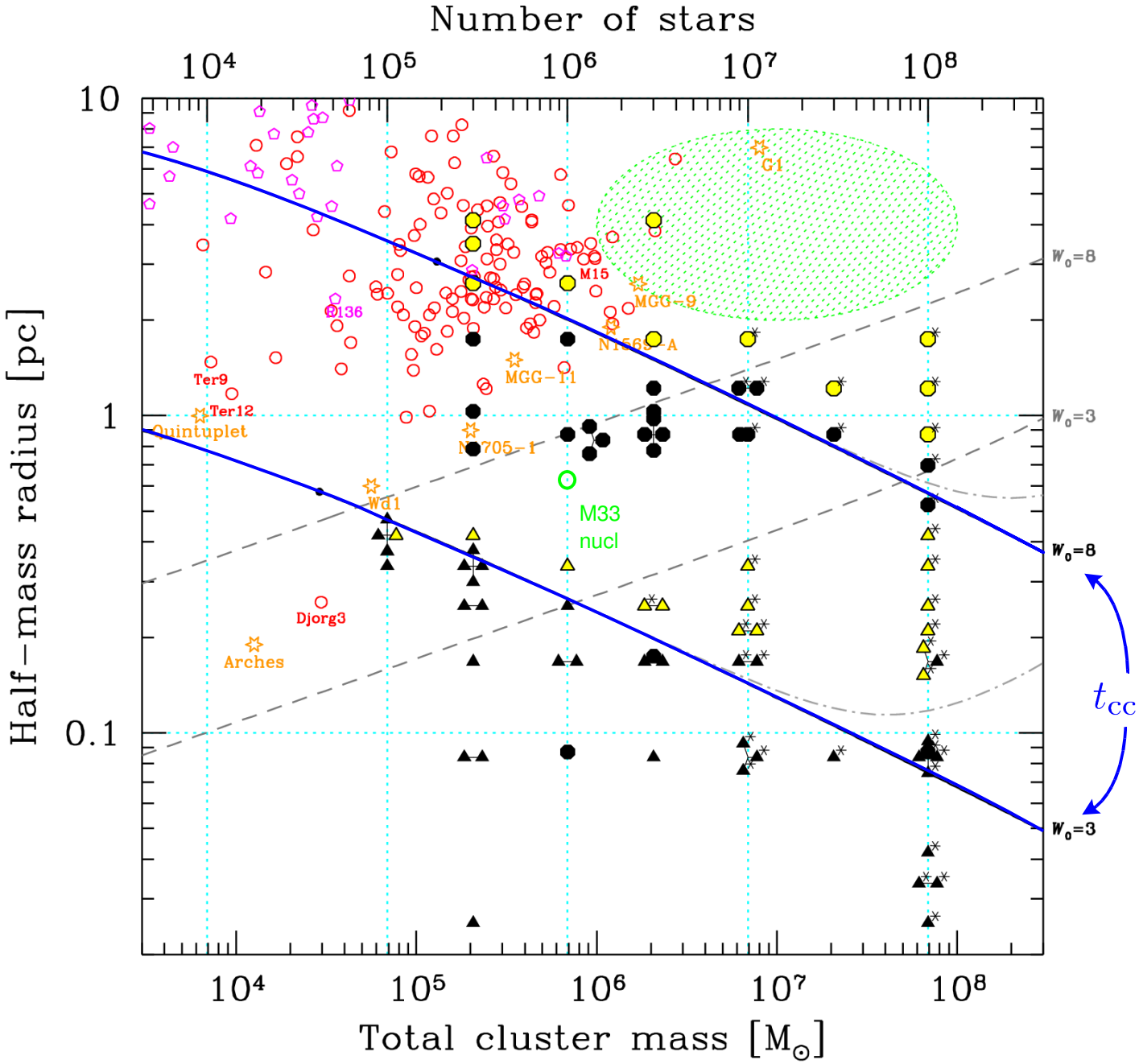
- Mass loss in normal MS-MS collisions well known
  - Little mass lost in mergers or fly-bys unless very high V_{rel}
  - 10% mass loss required to prevent runaway (Freitag et al. 2005b)
  - Segregation causes V_{rel} to decrease





- Collision product is not normal!
  - "Transparent" to impactors? (Colgate 67)
  - Common envelope phase? (with ≥2 cores)

Cluster runaway conditions



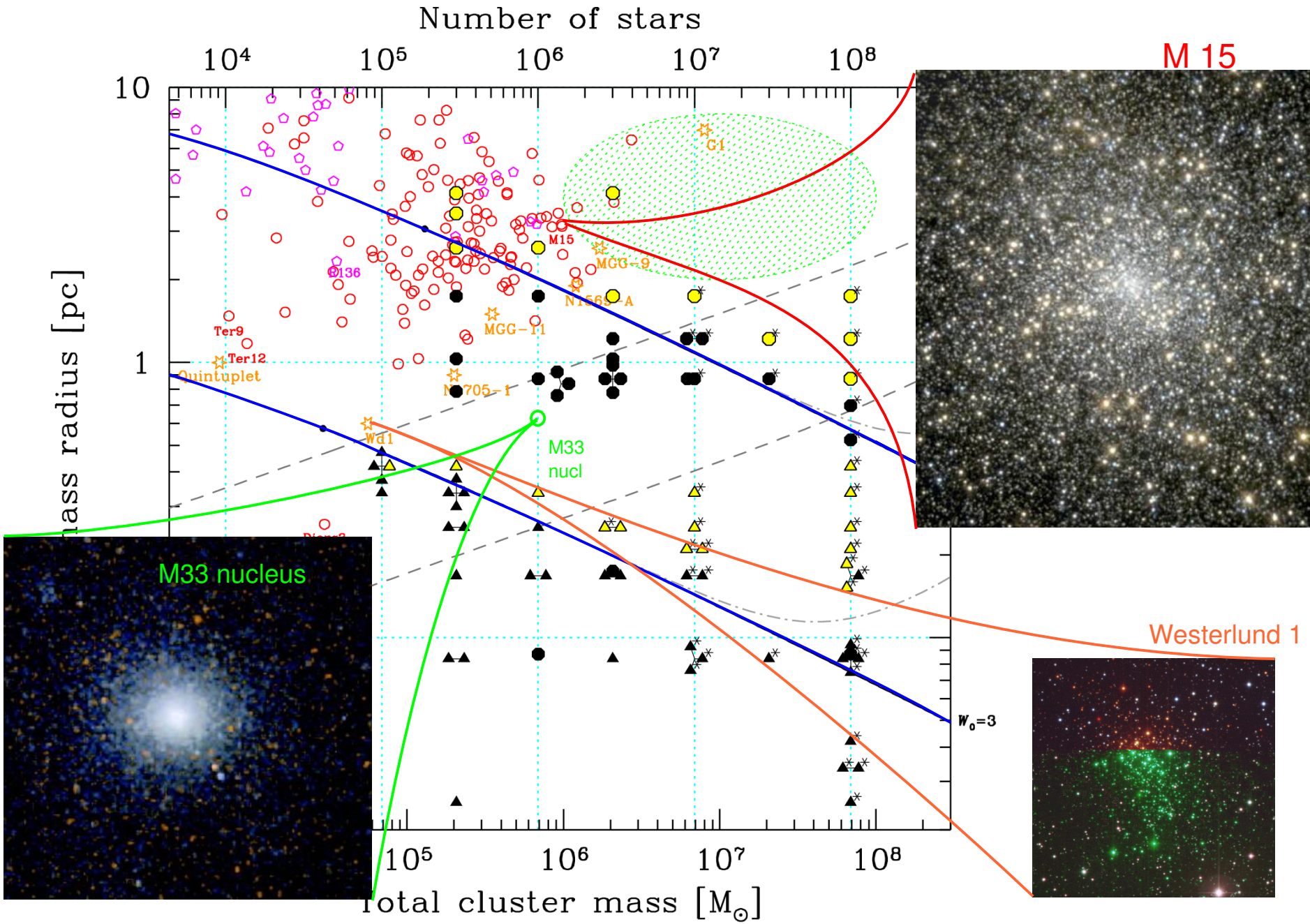
Freitag et al. 2005b

MC simulation results

- W_0=8 no runaway
- W_0=8 runaway
- W_0=3 no runaway
- W_0=3 runaway

$$t_{\rm cc,rlx} = 0.12\, t_{\rm rc}(0) = 3\,{\rm Myr}$$

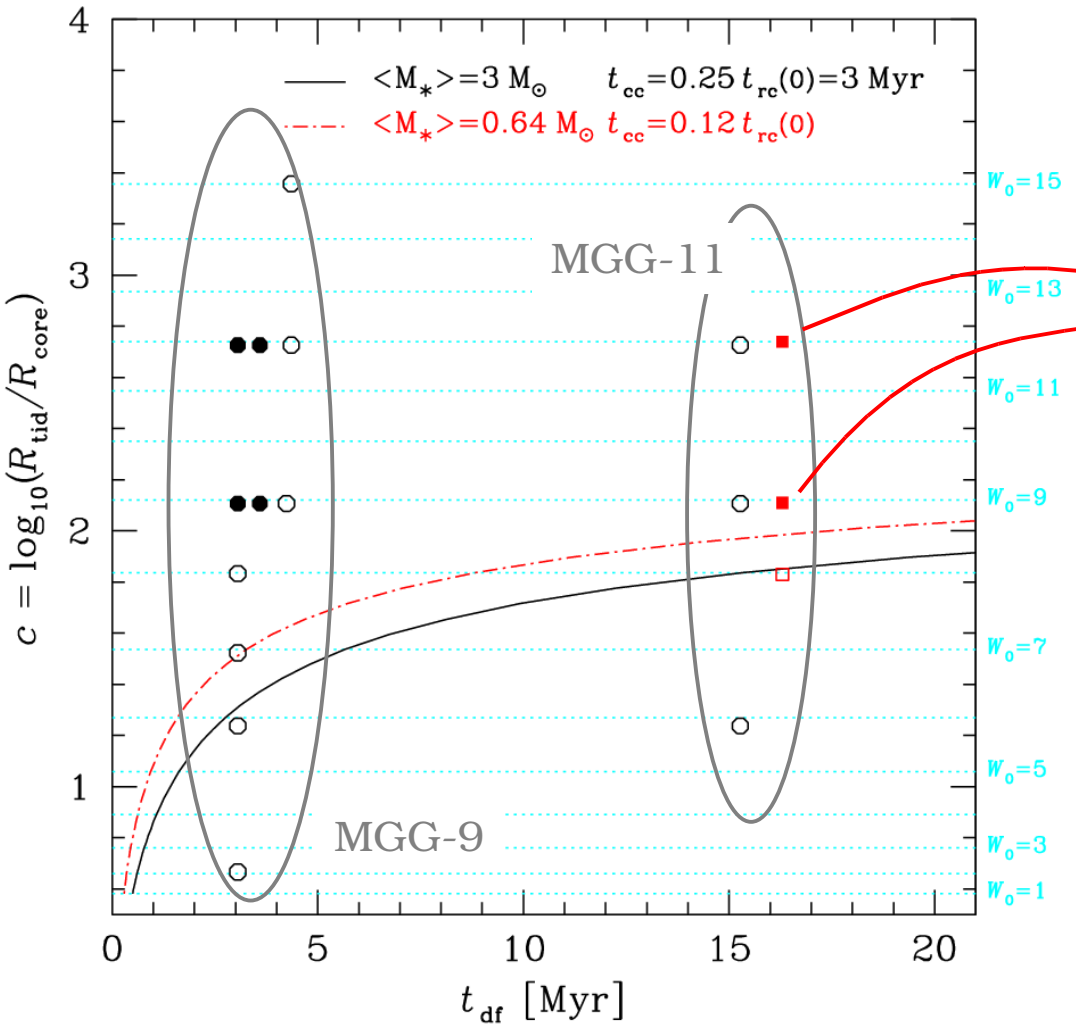
Cluster runaway conditions



Conditions for runaway: N-body vs MC

Portegies Zwart et al. 2004: Models for M82 clusters

Nature 428, 724

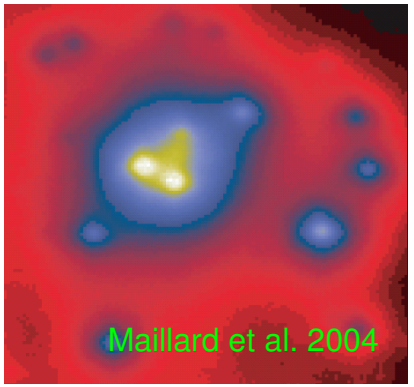


- MGG-9 too small for MC simulations!
- MGG-11 MC models with large star number show runaway for $W_0 > 8$
- Role of binaries?

Inspiral of clusters with IMBH in galactic centers

- "Missing link" between IMBH and SMBH? Ebisuzaki et al. 2001
  - Suggested by $M_{runaway}/M_{clust} \approx 0.1\text{-}0.2\%$ Portegies Zwart & McMillan 2002, Gürkan et al. 2004, 2005 (in prep.), but see Portegies Zwart et al. 2004, Freitag et al. 2005
- Explain the young stars at MW center?
  - IMBH to avoid early disruption of cluster
  - Core collapse concentrates massive stars
  - Other IMBH-hosting clusters on the way? (IRS13, IRS16)

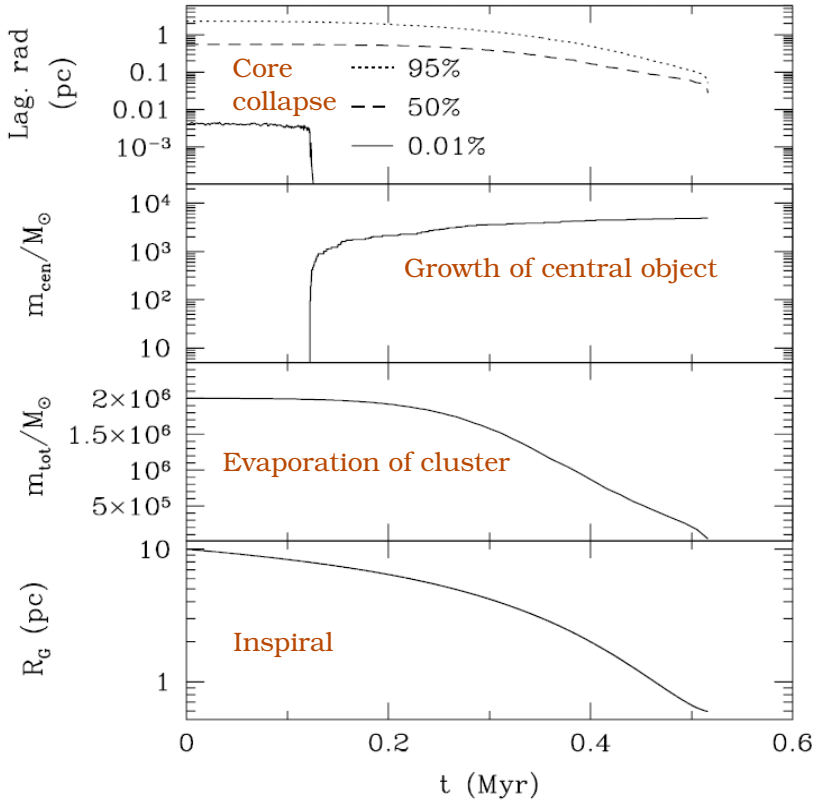
Hansen & Milosavljevic 2003, Kim et al. 2004, McMillan & Portegies Z. 2004, Gürkan & Rasio 2005



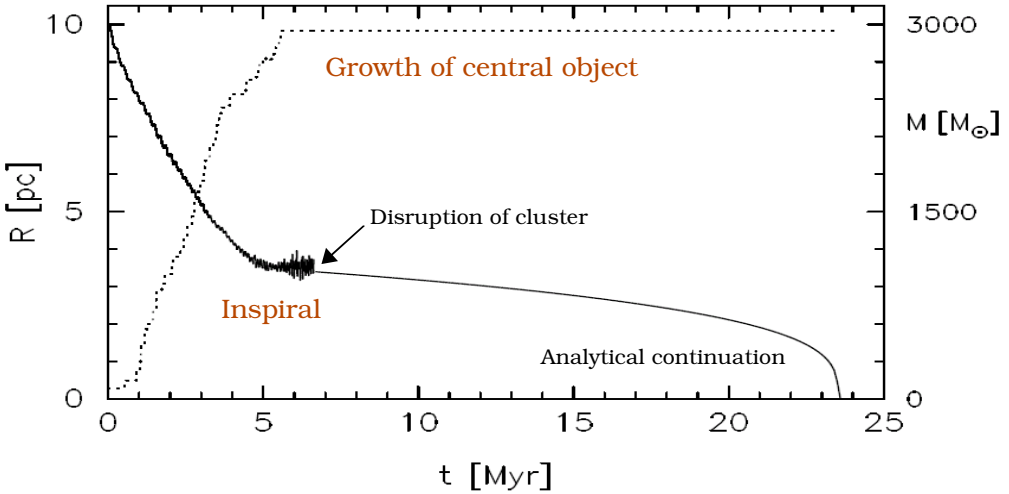
  - But how to avoid leaving too many massive stars on the way?
- Excellent GW sources for LISA! Miller 2005

IMBH growth and cluster inspiral

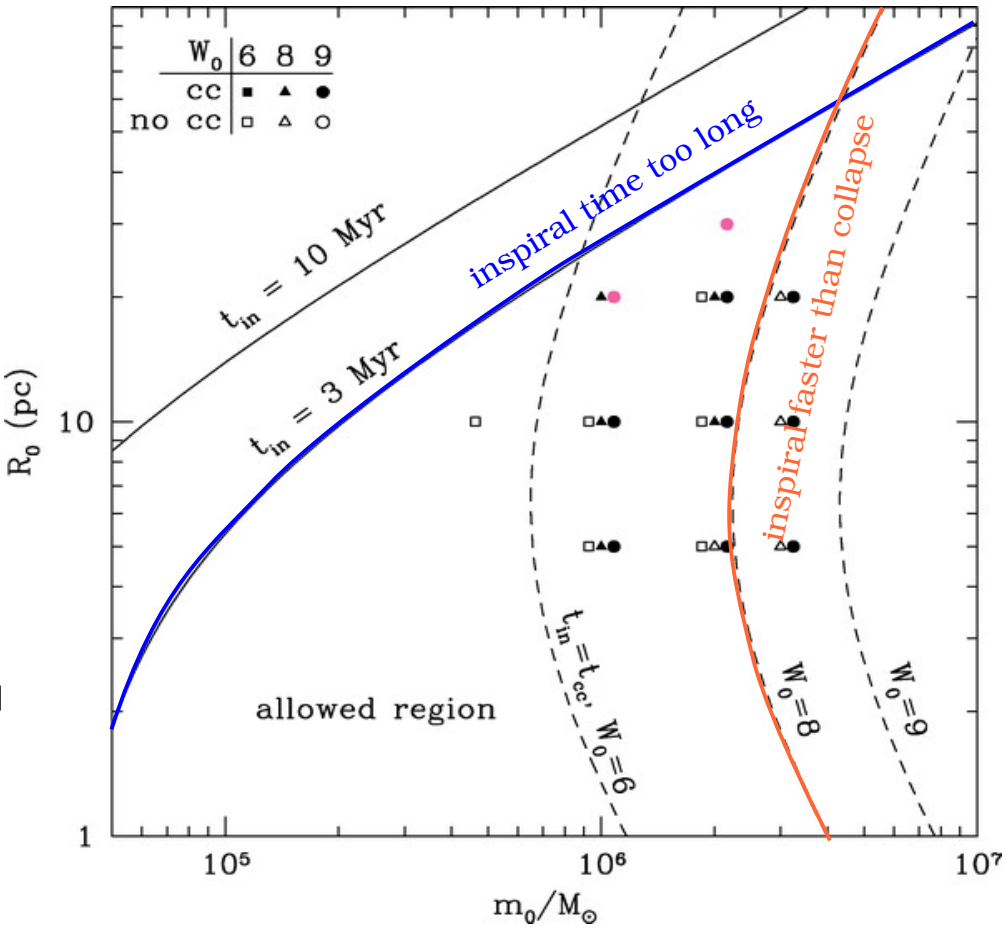
MC simulations by Gürkan and Rasio (2005)



N-body simulations by McMillan & Portegies Zwart (2004+)



Parameter space for successful deposition of young stars
Gürkan and Rasio (2005)



More on this in Steve McMillan's talk!

Role of binaries

- Dynamically formed binaries
  - Foster collisions in small-N systems
  - Probably won't form before collisions start in large-N systems

Portegies Zwart et al. 1999
Portegies Zwart & McMillan 2002

- Primordial binaries
  - N-body simulation (N=1.3x10^4 f_b=0.1)
    - Little role (slight *increase* in runaway mass)
  - MC simulations (N=0.5-1x10^6 f_b=0.02-0.1)
    - Do not prevent runaway
    - Allow concurrent runaways!

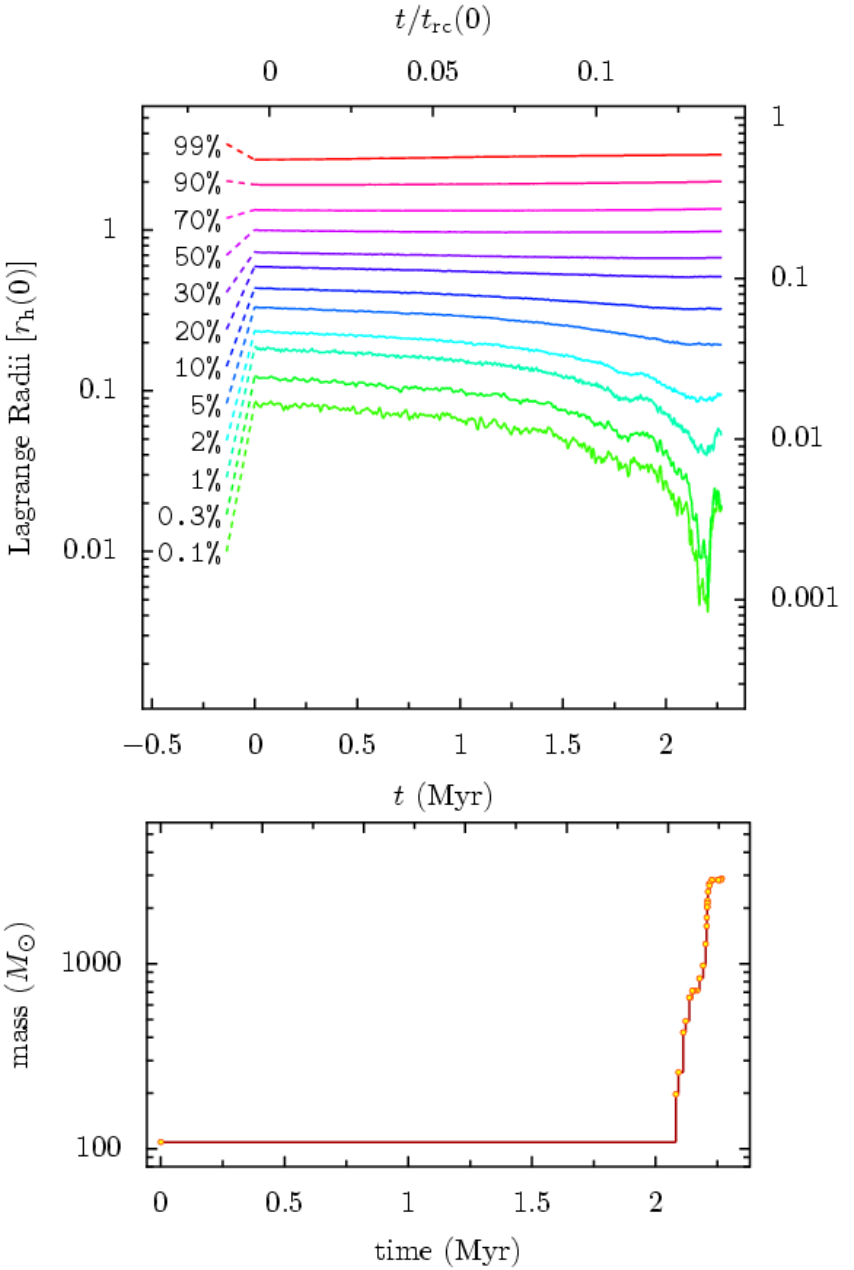
Portegies Zwart et al. 2004

❢ very concentrated model (W_0=12)

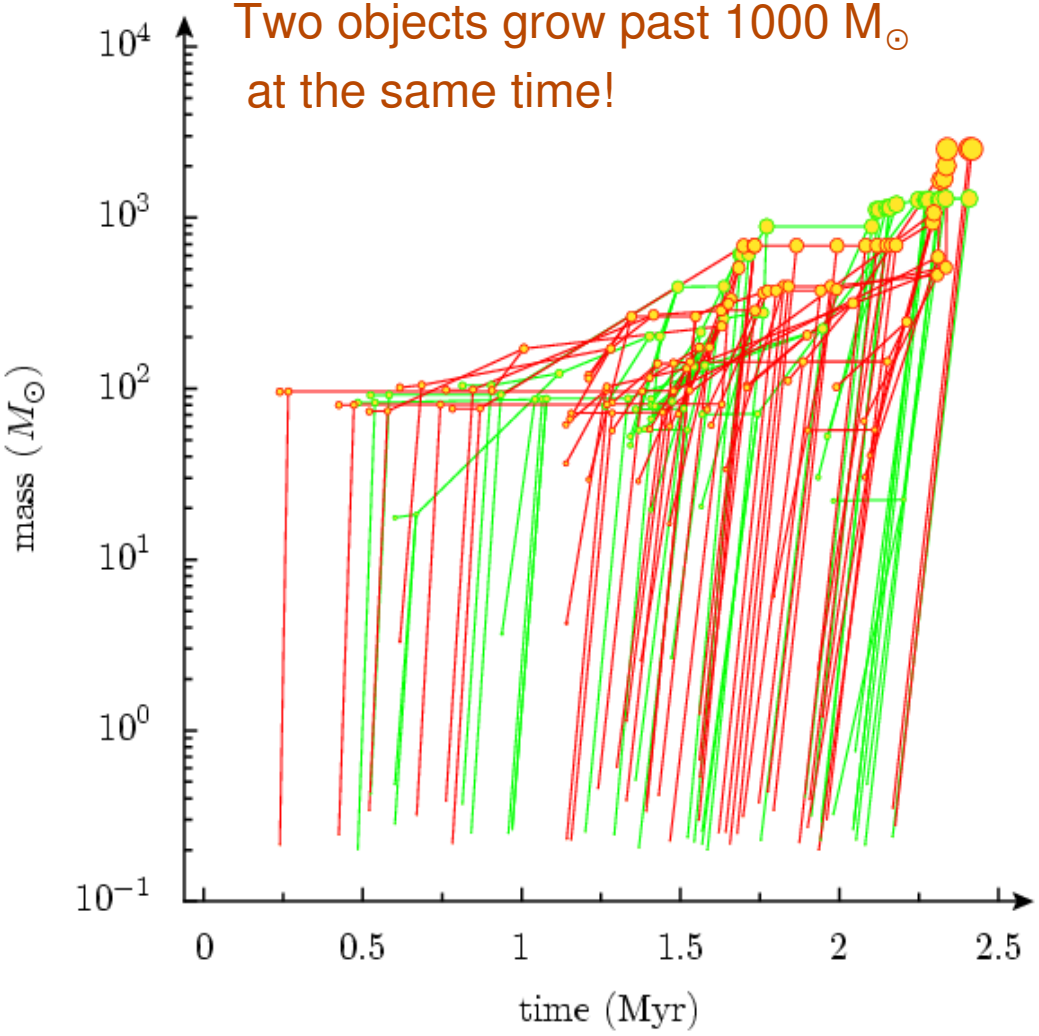
Gürkan et al., in preparation

Large-N simulations with primordial binaries

Gürkan et al., in preparation

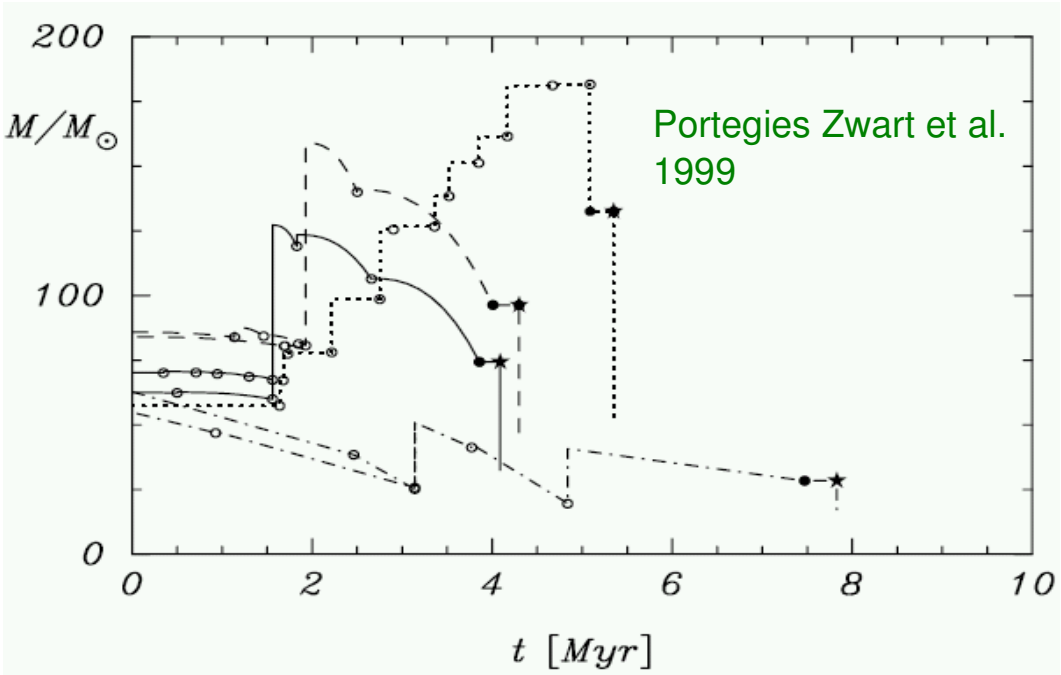


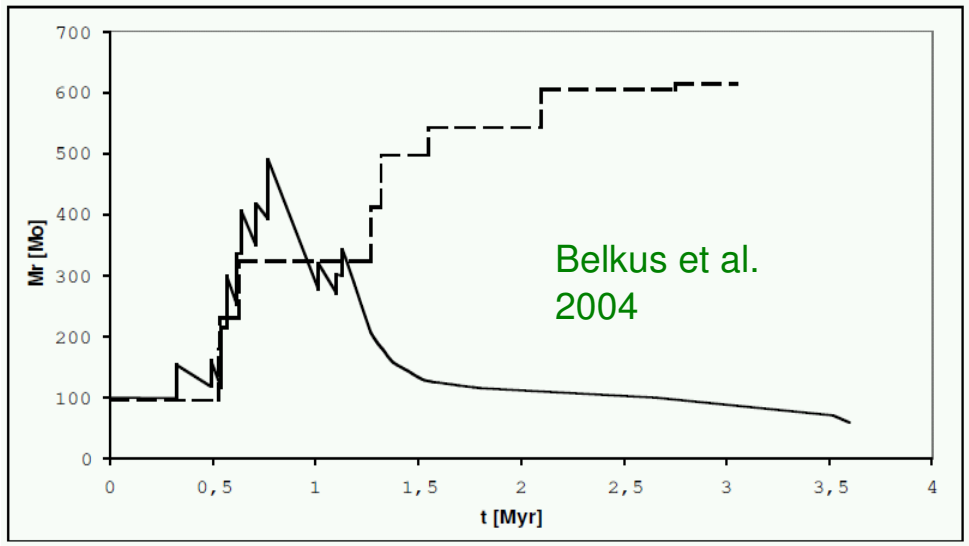
Two objects grow past 1000 $M_\odot$ at the same time!



Role of stellar mass loss

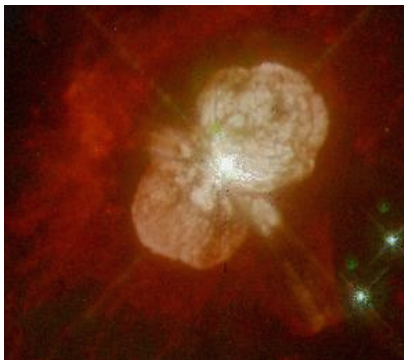
- Growth of VMS: race between collisional gain and mass loss
  - Average growth rate during runaway 10^{-3}-0.1 $M_\odot$/yr
  - Loss rate unknown but may be large as star is big and luminous
  - Losses may win when collision frequency decreases
  - Can collisions suspend stellar evolution?





Collisional runaways: Open questions

- What determines the final mass of the VMS?
  - The stellar dynamics? Loss-cone effects...
  - The hydrodynamics? VMS becomes “transparent”...
  - The VMS evolution? Violent mass-loss... (cf Pistol star, η Carinae)

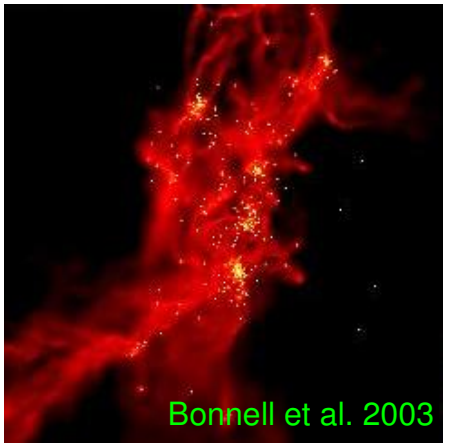


- Will the VMS turn into an IMBH?
  - Strong post-MS mass loss and pulsational instability unless very low metallicity
- Runaway collisions in “small” clusters $N_* \lesssim 10^6$
  - Role of binaries?
    - May stop central density increase
    - May foster collisions
  - Minimum number of massive stars to drive collapse?

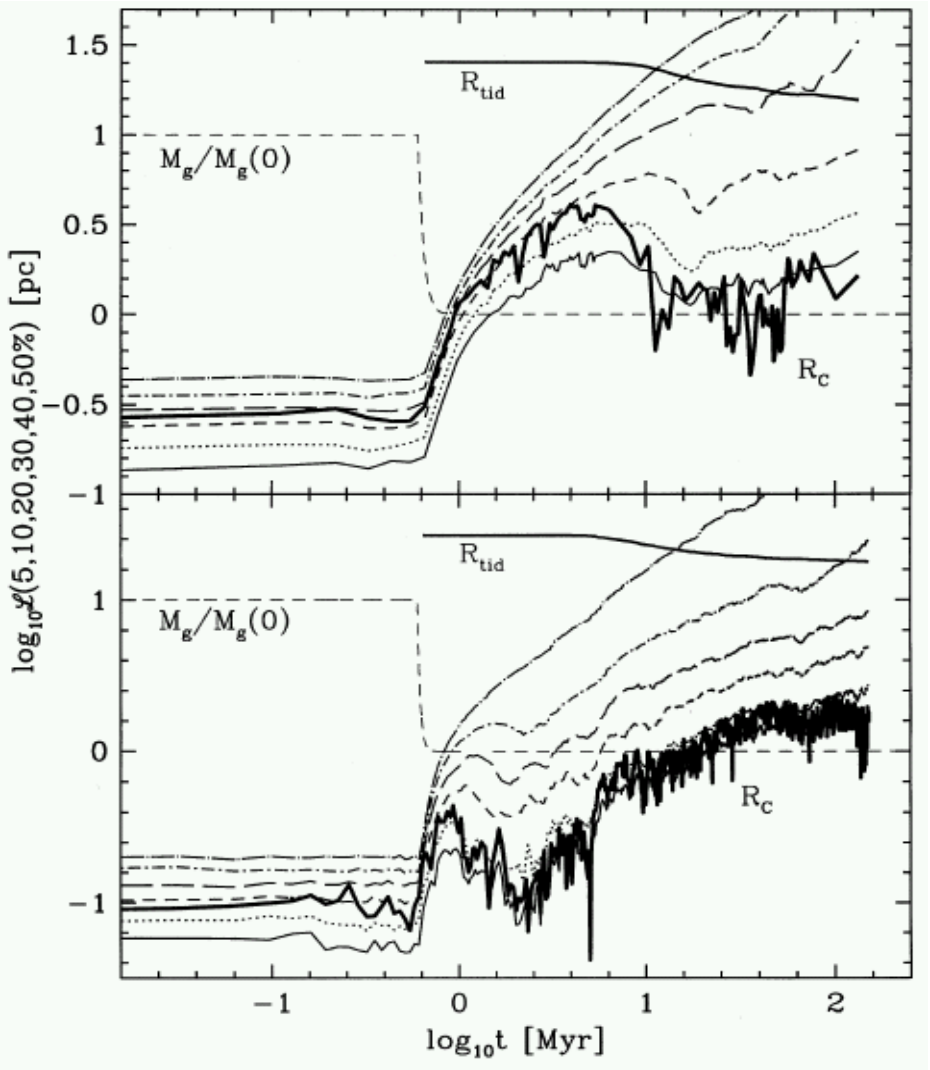
How to reconcile large-*N* MC results with smaller-*N* *N*-body results?

- Runaway in cluster formation context
  - Pre-MS phase (low-*M* stars larger)
  - Residual gas (2-3× mass in stars)
    - Cluster initially much more compact ⇒ collisional?
    - Differential accretion ⇒ more segregation
    - Cluster expands at gas expulsion ⇒ stops collisions

Soria 2005



Runaway stopped by gas expulsion?



N-body simulation by Kroupa et al. 91

- Young clusters already devoid of gas at ~1-2 Myr
- Most clusters disrupted by mass loss
  - Explains cluster-less ULXs?