Not-So Runaway Growth of Massive Black Holes

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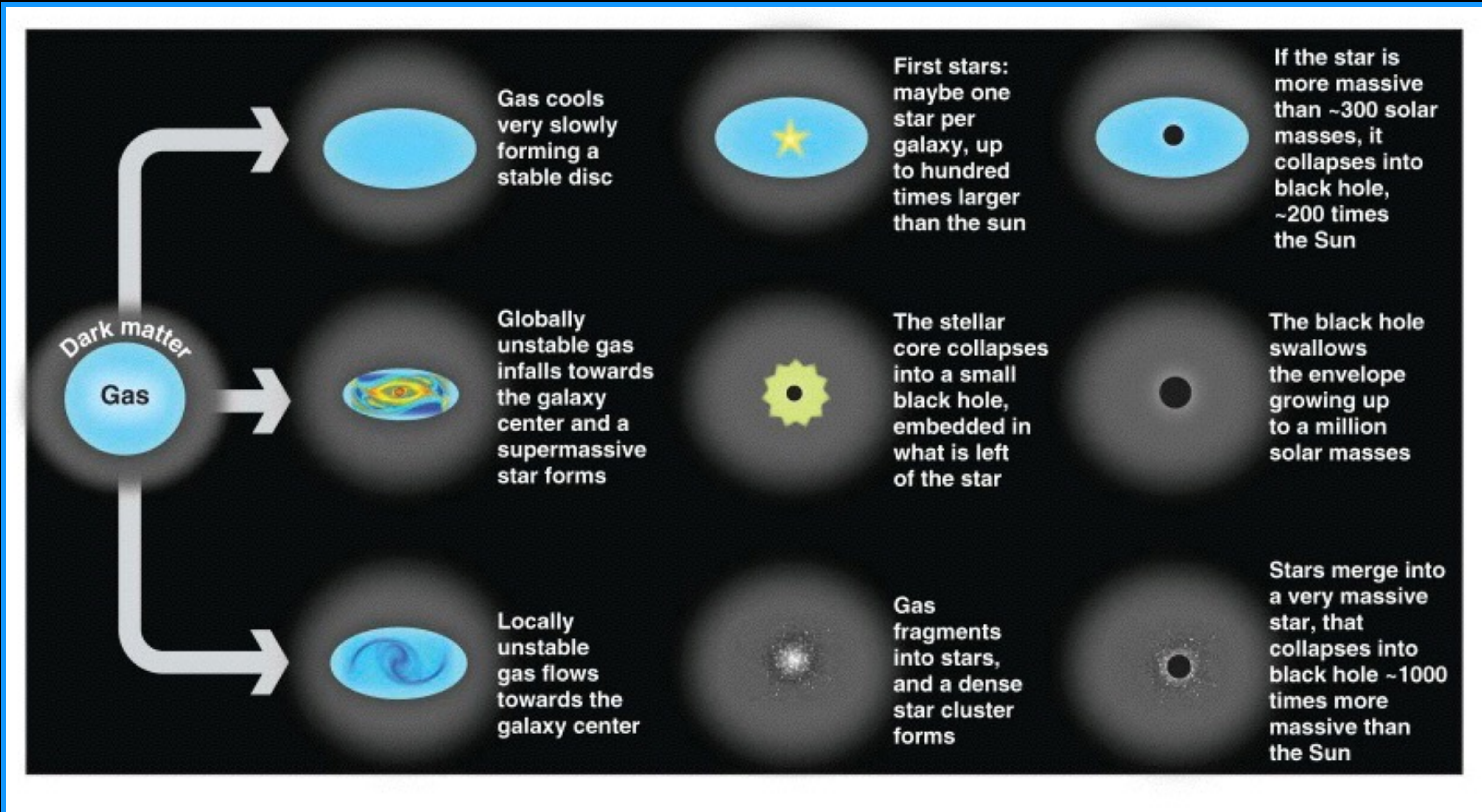
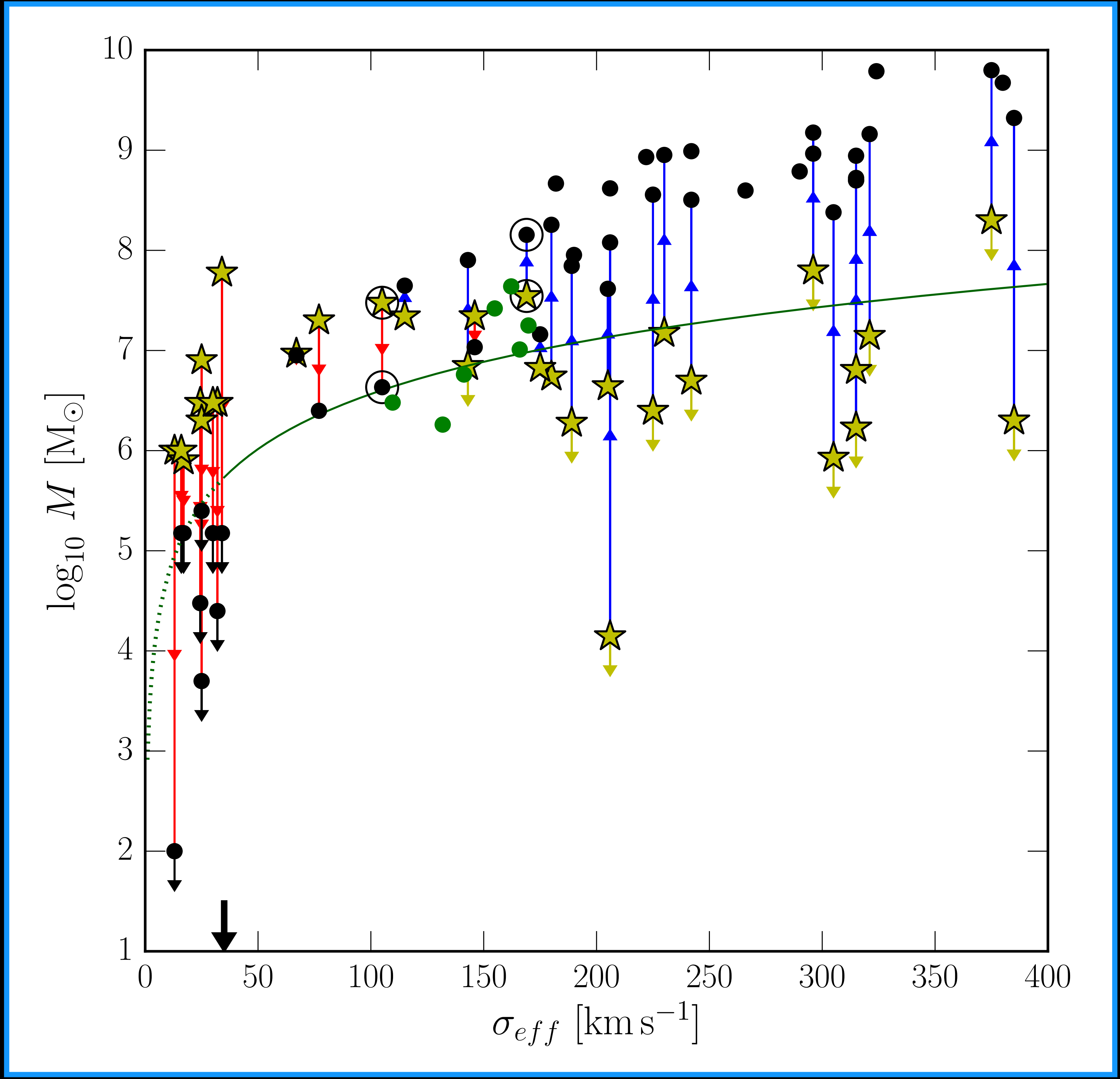
MBH Seeds



(Marta Volonteri)

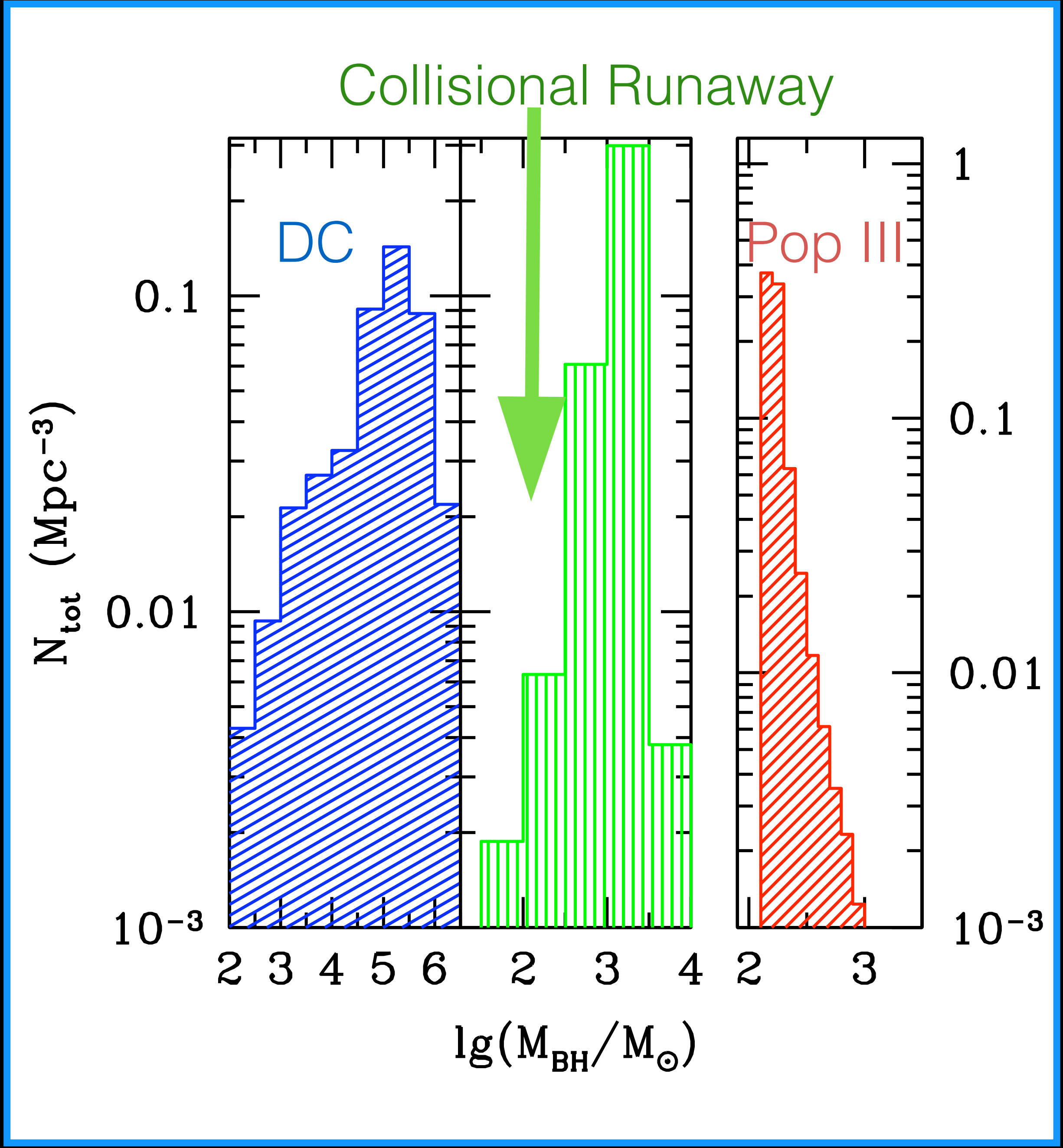
Nuclear Star Clusters and MBHs



(Stone, Küpper, & Ostriker 16)

Runaway Collisional Growth

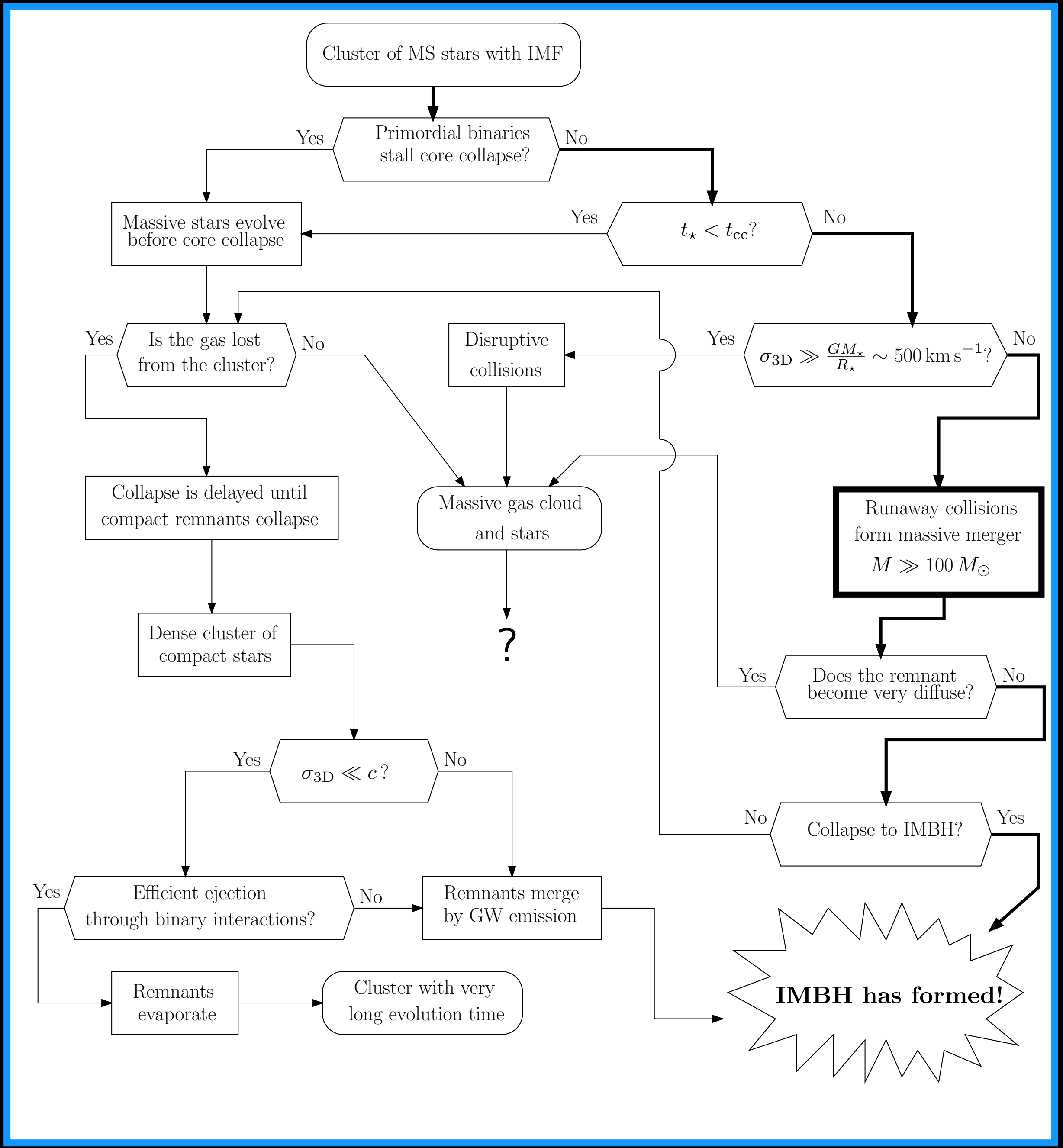
- Third channel for SMBH seed formation at high z
  - ✦ Intermediate in mass between pop III and direct collapse



(Sesana 11)

Runaway Collisional Growth

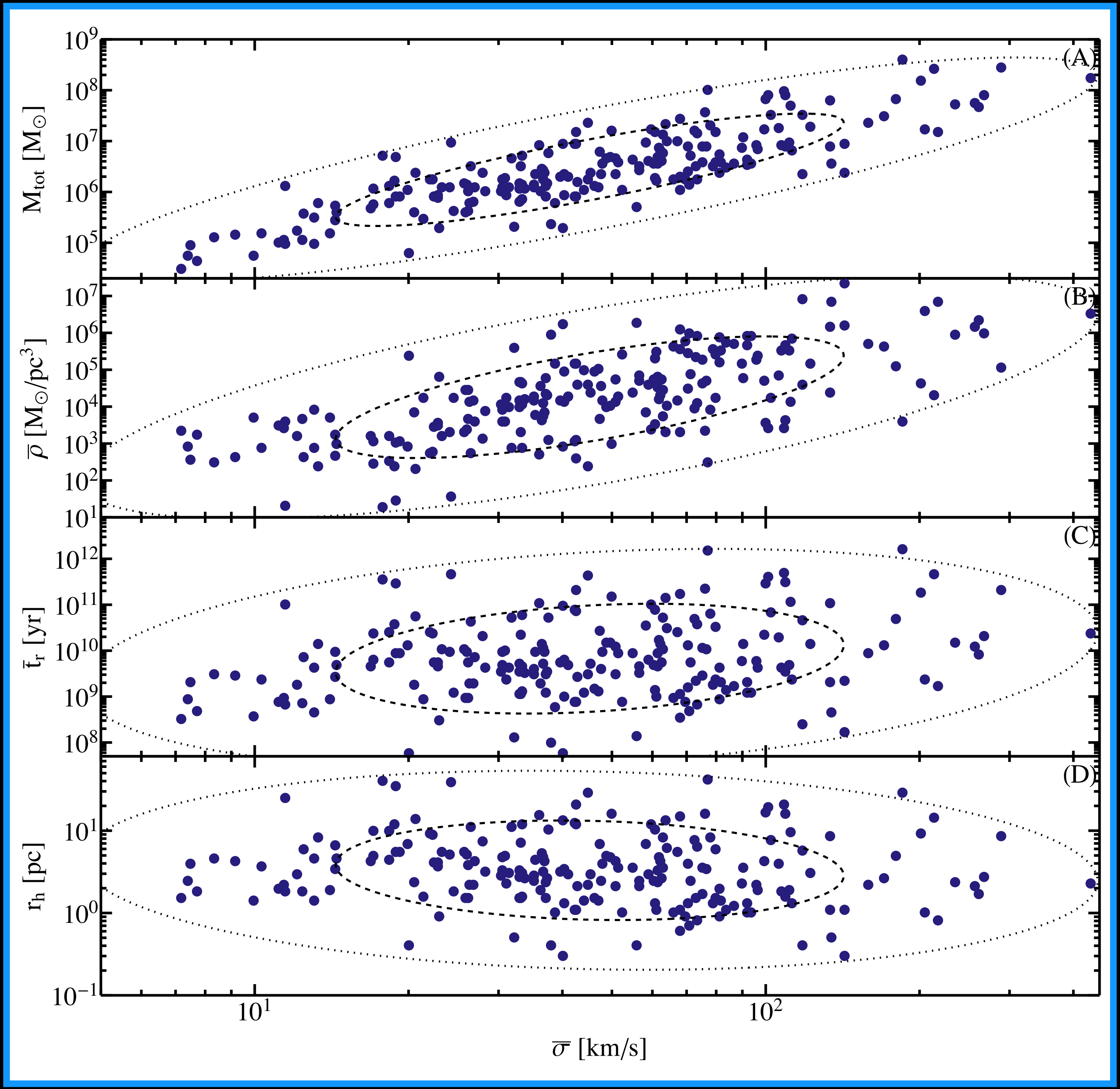
- Third channel for SMBH seed formation at high z
  - ✦ Intermediate in mass between pop III and direct collapse
- Several variants
  - ✦ Supermassive star
  - ✦ Compact remnant subcluster
  - ✦ **We propose slow low-z runaway through tidal encounters in NSCs**



(Gurkan+04)

Observed NSCs

- Densest stellar systems in the universe
  - ✦ Generally higher M_*, σ than globular clusters
- BH content depends on origin, but nonzero
- We use sample of Georgiev & Böker: ~200 NSCs fit to King models
  - ✦ Central densities high but uncertain

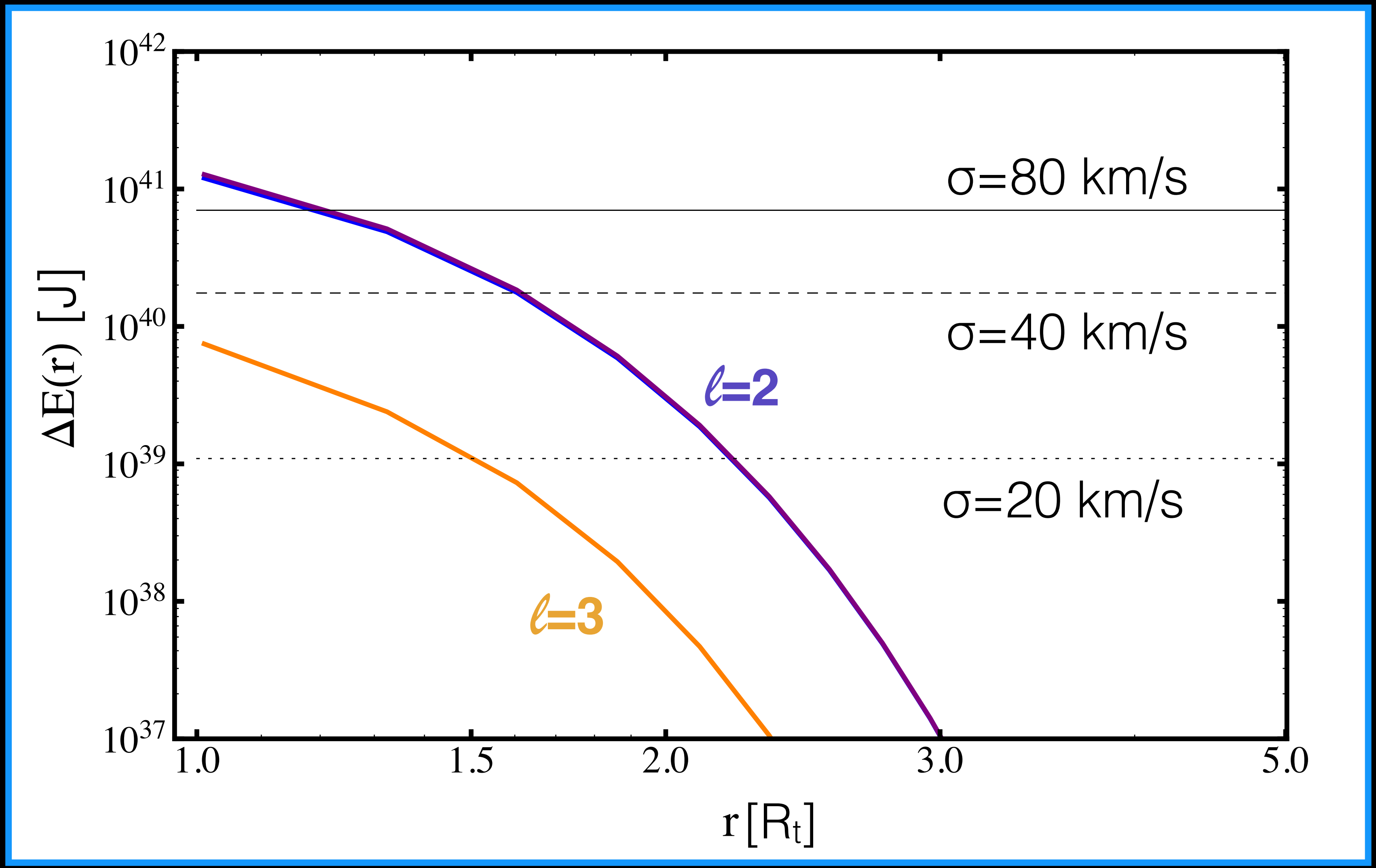


(Stone, Küpper, & Ostriker 16)
(Mostly from Georgiev & Böker 14)

NSC Evolution

- Relaxation time $t_r << t_H$
    - ✦ Roughly isothermal if isolated (and lacking MBH)
- Qualitative difference from open/globular clusters: often σ>40 km/s (Miller & Davies 12)
    - ✦ Energetically possible to burn *all* primordial binaries (need average $\rho>10^5 M_\odot/pc^3$ to do this in a Hubble time)
    - ✦ 2+1 scatterings (BH + 2 stars) inefficient at ejecting BHs for σ~10s km/s
- Expectation: core collapse deeper and achieved sooner/more frequently; survivable for BHs

Tidal Capture



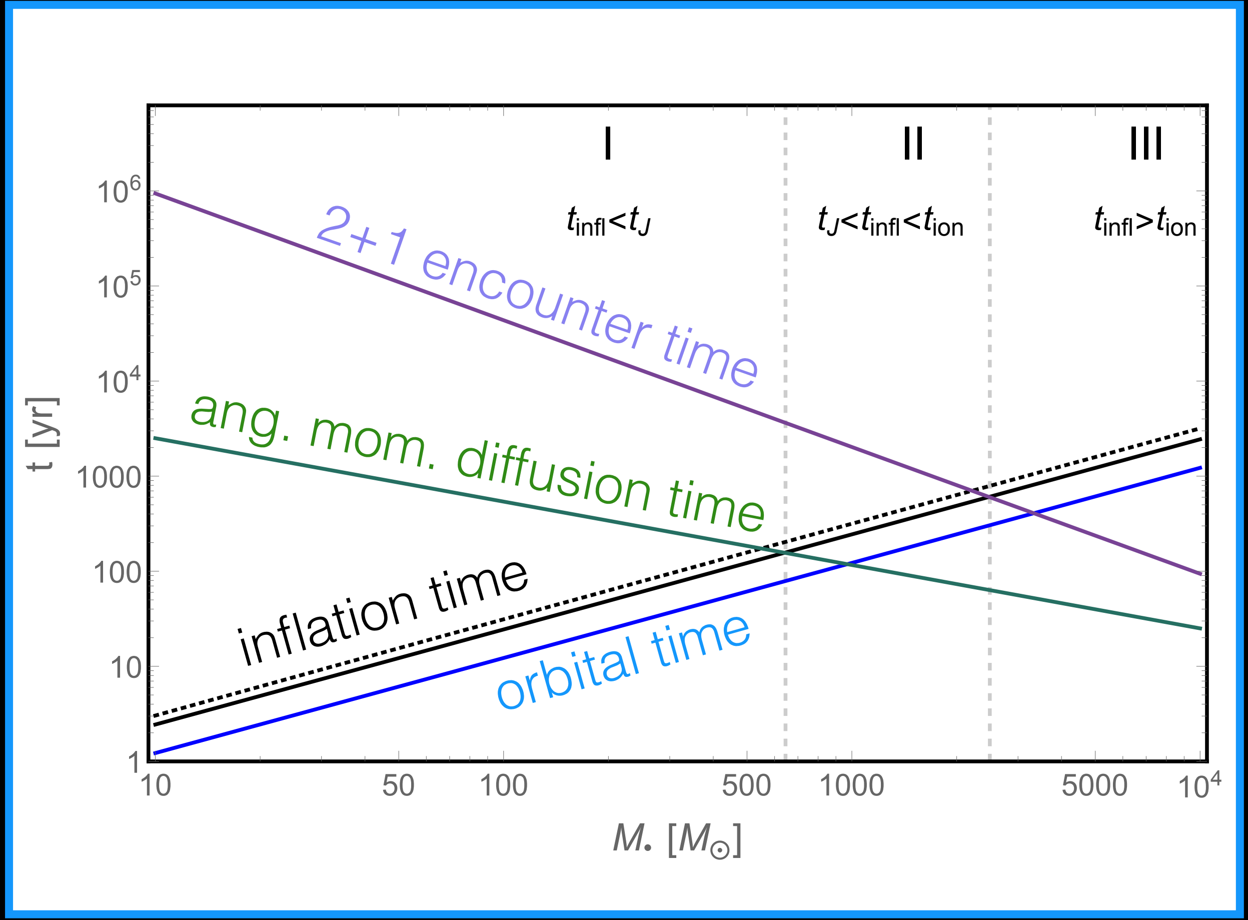
(Stone, Küpper, & Ostriker 16)

- Close passage of hyperbolic orbit binds two stars together
- Excess orbital energy ΔE deposited into mode spectrum Y_{lm}

$$\Delta E = \frac{GM_\star^2}{R_\star}\left(\frac{M_\bullet}{M_\star}\right)^2 \sum_{\ell=2,3\ldots}^{\infty}\left(\frac{R_\star}{R_{\rm p}}\right)^{2\ell+2} T_\ell(R_{\rm p})$$

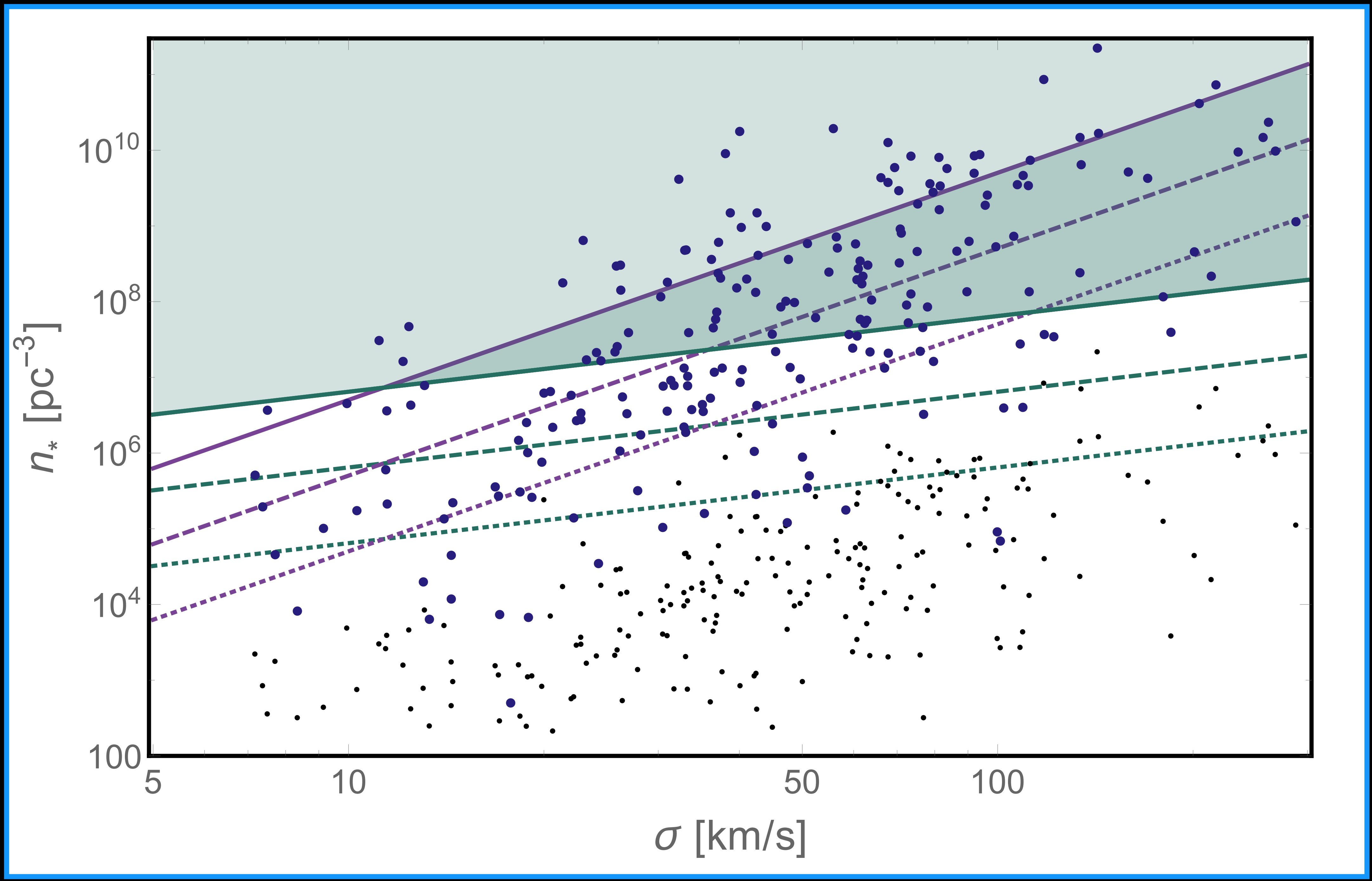
Evolution of Tidal Captures

- Isolated tidal capture binary random walks in energy
- Interacting tidal capture binary random walks in angular momentum too
- Outcome depends on $M_\bullet$
    - ✦ $M_\bullet$ small: star inflates and is consumed in runaway partial disruptions (Ivanov+07)
    - ✦ $M_\bullet$ large: complex dynamical outcome from cluster interactions
- **Runaway growth: $dM_\bullet/dt \propto M_\bullet^{4/3}$**
    - ✦ Reach first e-fold in a Hubble time if central $\rho > 10^7 M_\odot/pc^3$



(Stone, Küpper, & Ostriker 16)

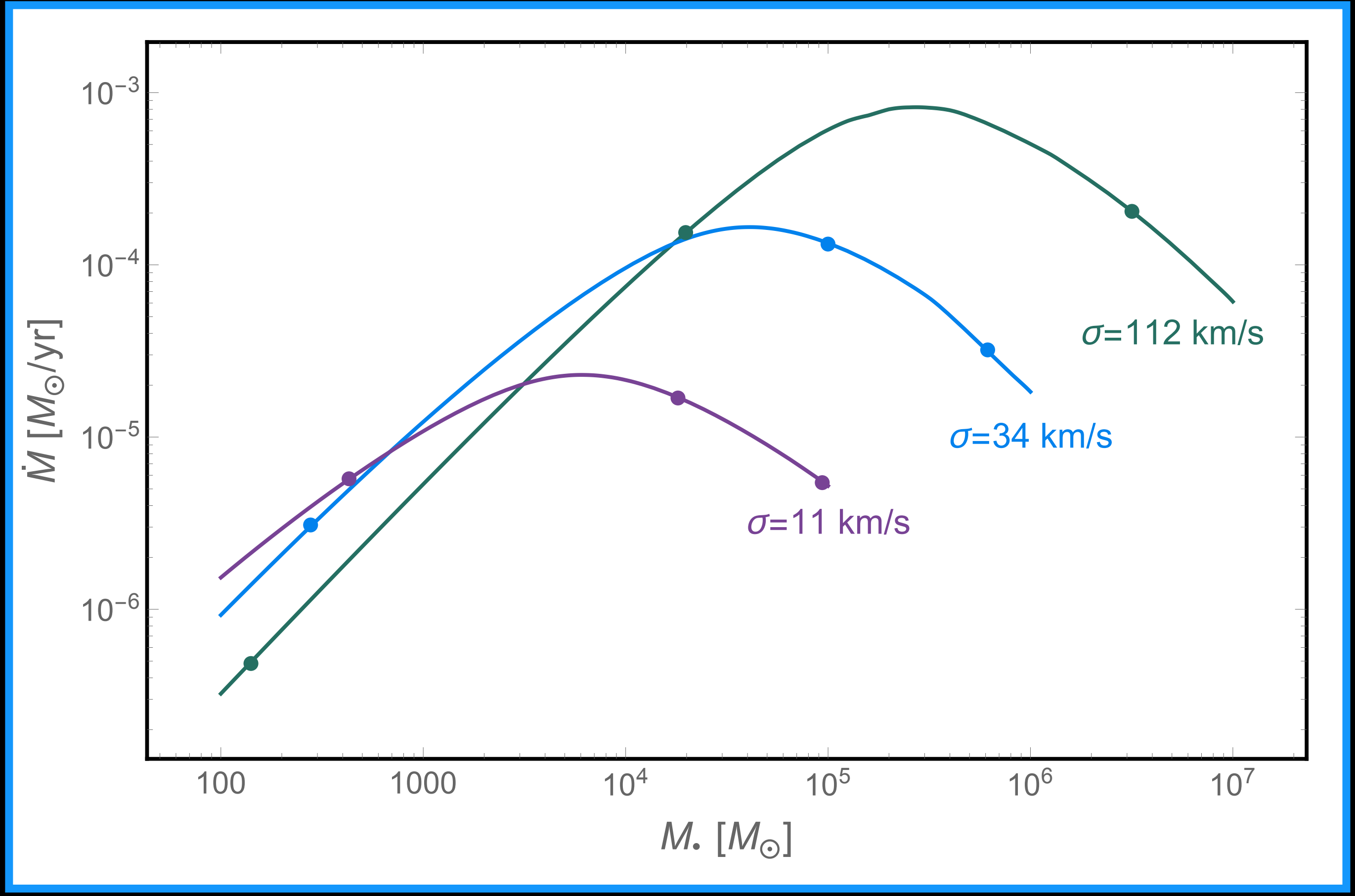
Tidal Capture Runaways



(Stone, Küpper, & Ostriker 16)

Saturation of the Runaway

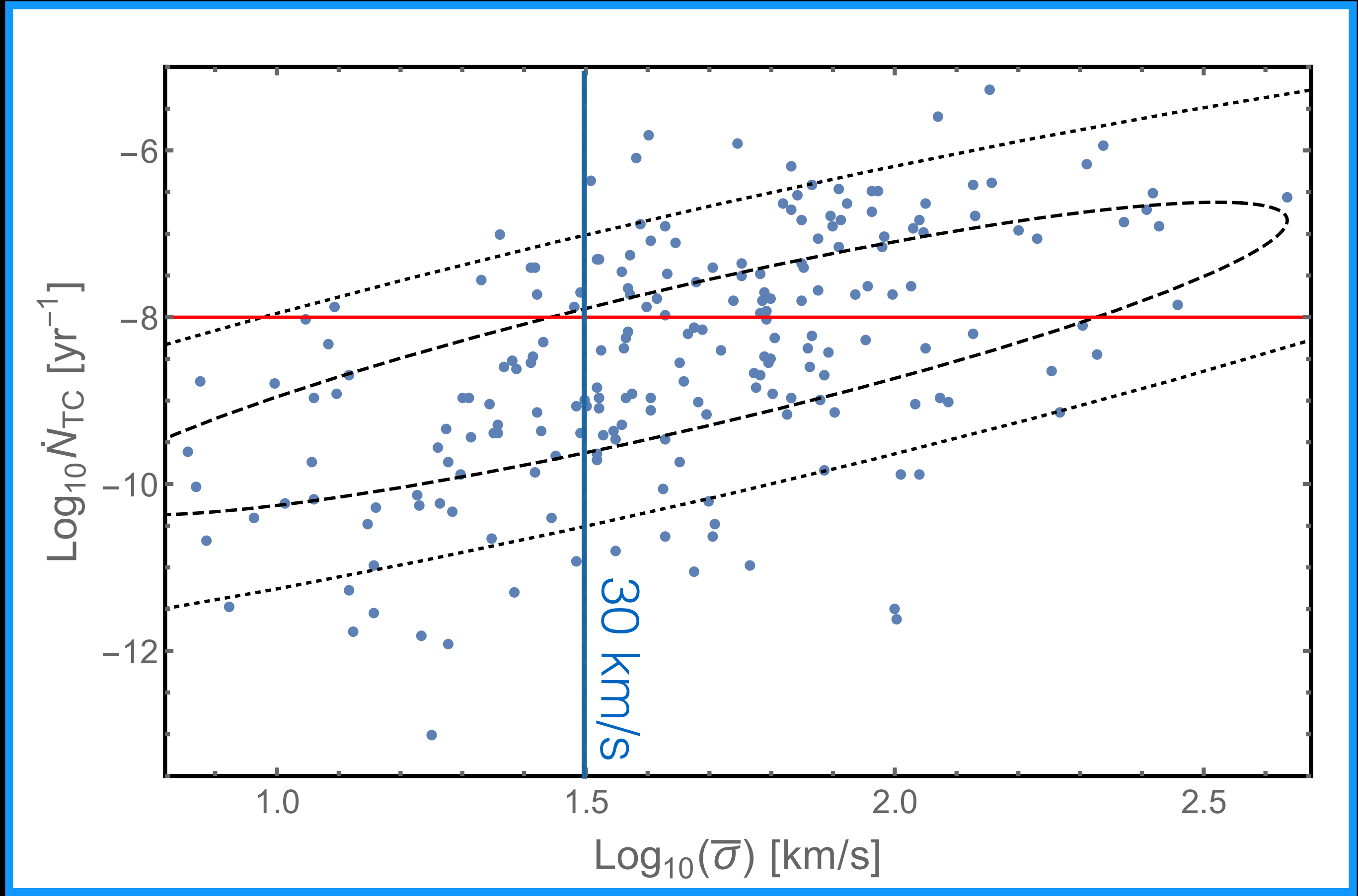
- Core eaten at super-exponential rate, $dM_\bullet/dt \propto M_\bullet^{4/3}$
  - ✦ Tidal disruptions continue if tidal captures deactivate
- After NSC core consumed, $dM_\bullet/dt \propto M_\bullet^{-1}$
  - ✦ Growth enters diffusion-limited loss cone regime
  - ✦ Growth saturates at $M_\bullet \sim (M_* t \sigma^3/G)^{1/2} \sim 10^6 M_\odot (\sigma/50\mathrm{km/s})^{3/2}$



(Stone, Küpper, & Ostriker 16)

Observational Implications

- Many undetected MBHs in NSCs with σ>40 km/s ?
    - ✦ Observational coincidence [?]: most NSCs with σ<30-40 km/s below runaway tidal capture rate threshold!
- Tidal disruption rates from "saturated" BHs grown in this way consistent with semi-empirical estimates (Stone & Metzger 16)



(Stone, Küpper, & Ostriker 16)

Conclusions

- **Runaway tidal captures possible in clusters above critical σ (~40 km/s), ρ (~$10^7 M_\odot/pc^3$)**
  - ✦ Often slower runaway than other varieties
  - ✦ These criteria reflect bottom end of NSCs hosting observed SMBH population
- Uncertainties:
  - ✦ Evolution of tidal capture binaries for large $M_\bullet$
  - ✦ Periods of super-Eddington accretion at peak of runaway
  - ✦ Exogenous effects on NSC evolution
  - ✦ And, of course: approximate analytic estimates!
- Super-exponential growth slows after cluster core consumed
- **Runaway MBH growth saturates at $M_\bullet \sim (M_* t \sigma^3/G)^{1/2} \sim 10^6 M_\odot (\sigma/50\text{km/s})^{3/2}$**