Multiple stellar populations in star clusters

Or:

Gluttonous Star Clusters: when they can not get enough

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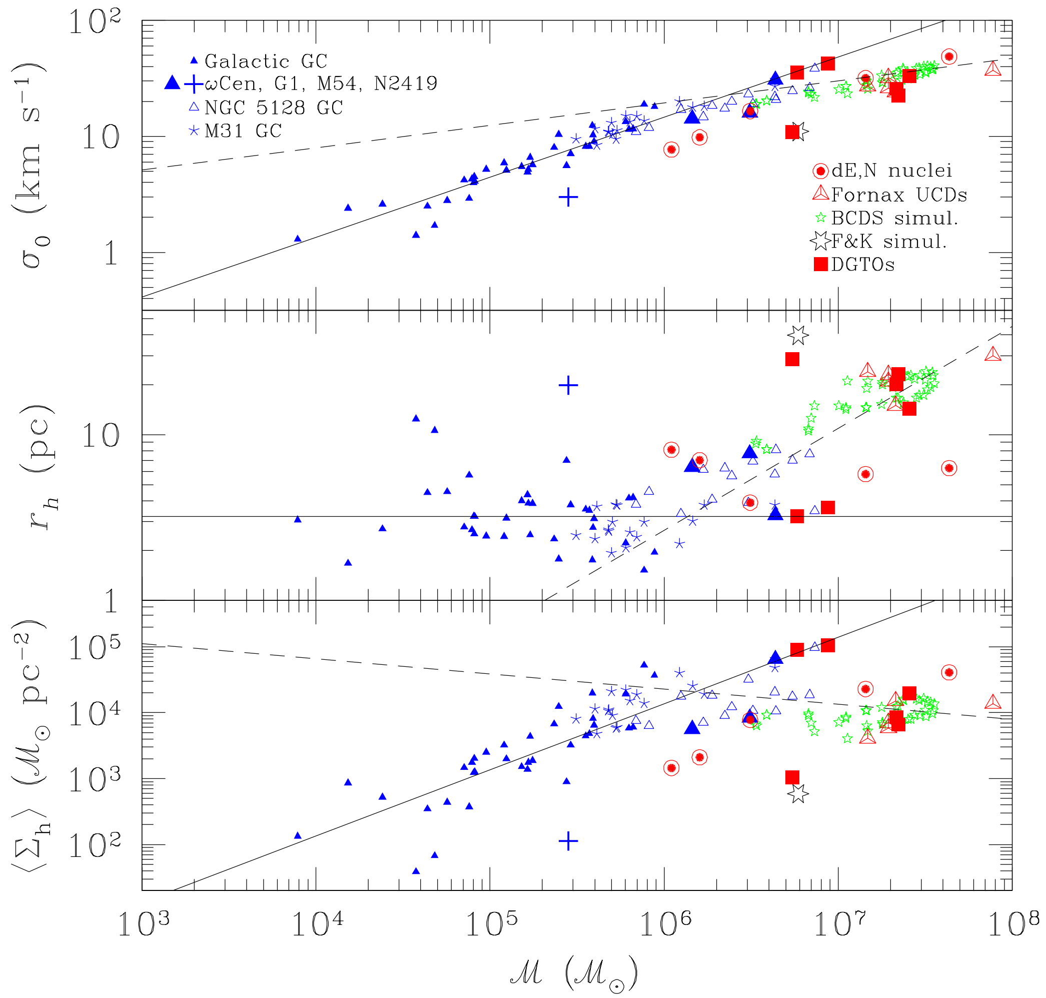
Peculiar clusters

cluster	M_{cl}	peculiarity	reference
Ω Cen	$2.5 \cdot 10^6\ \mathrm{M}_\odot$	metallicity spread	Freeman & Rodgers (1975)
		three stellar populations	Hilker & Richtler (2000)
G1	$8 \cdot 10^6\ \mathrm{M}_\odot$	metallicity spread	Meylan et al. (2001)
M54	$2 \cdot 10^6\ \mathrm{M}_\odot$	metallicity spread	Sarajedini & Layden (1995)
NGC 6388	$1.1 \cdot 10^6\ \mathrm{M}_\odot$	two distinct populations?	Ree et al. (2002)
NGC 6441	$1.6 \cdot 10^6\ \mathrm{M}_\odot$	two distinct populations?	Ree et al. (2002)

masses are from McLaughlin & van der Marel (2005), G1 from Baumgardt et al. (2003)

Mass-Radius-Relation



Haşegan et al. (2005)

Nuclear clusters

Walcher et al. (2005):

- 9 cluster in late-type bulgeless spiral galaxies
- M_{cl} = $8 \cdot 10^5$–$6 \cdot 10^7$ M$_\odot$
- M/L_I^{dyn} = 0.17–1.46

Suggestion: ”*...NCs are protobulges that grow by repeated accretion of gas and subsequent star formation.*”

What happens at

$10^6\ M_\odot$?

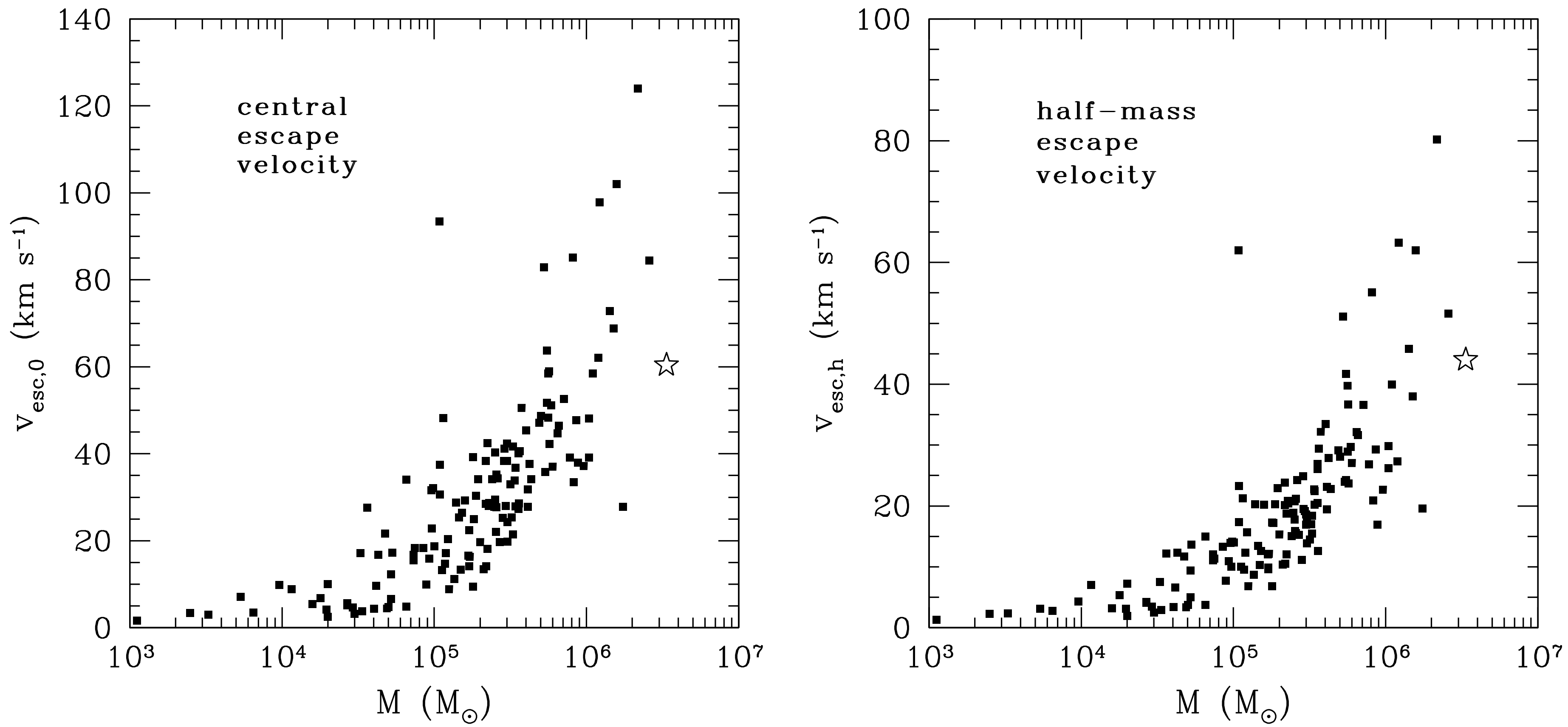
All peculiarities
are associated with
the observed or assumed
existence of
multiple stellar populations.

Material from inside?

- Very massive star clusters can retain AGB-wind material (Smith et al., 2000; D'Antona & Caloi, 2004).
- terminal velocity of AGB winds $\sim$15 km s^{-1} (Loup et al., 1993)

Material from inside?

Escape velocity of 141 MW-GC



Gnedin et al. (2002)

Material from outside?

ISM components

phase	T/K	n/cm^{-3}	filling factor
molecular	10–20	10^2–10^6	1–2
cold atomic	50–100	20–50	
warm atomic	6000–10 000	0.2–0.5	$\sim$50
warm ionised	$\sim$8000	0.2–0.5	
hot ionised	$\sim10^6$	$\sim$0.0065	$\sim$50

Ferrière (2001)

Model: basic equations

(1) $$\frac{\partial \rho}{\partial t} + \nabla \bullet (\rho \mathbf{v}) = 0$$

(2) $$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \bullet \nabla)\, \mathbf{v} = -\frac{\nabla P}{\rho} - \nabla \Phi$$

(3) $$\frac{\partial \epsilon}{\partial t} + \mathbf{v} \bullet \nabla \epsilon = -P \nabla \bullet \mathbf{v} + \frac{\Gamma}{\rho} - \frac{\Lambda}{\rho}$$

(4) $$\Delta \Phi = 4 \pi G \rho$$

(5) $$P = f(\rho, \epsilon)$$

Model: simplified

static & stationary case:

(6) $$\frac{1}{\rho}\nabla P = -\nabla\Phi$$

only external potential:

(7) $$\Phi(r) = -GM_{\mathrm{cl}}\left(r^2 + b_{\mathrm{pl}}^2\right)^{-1/2}$$

isothermal ideal gas

(8) $$P = \rho\frac{k_{\mathrm{B}}}{\mu m_{\mathrm{u}}}T$$

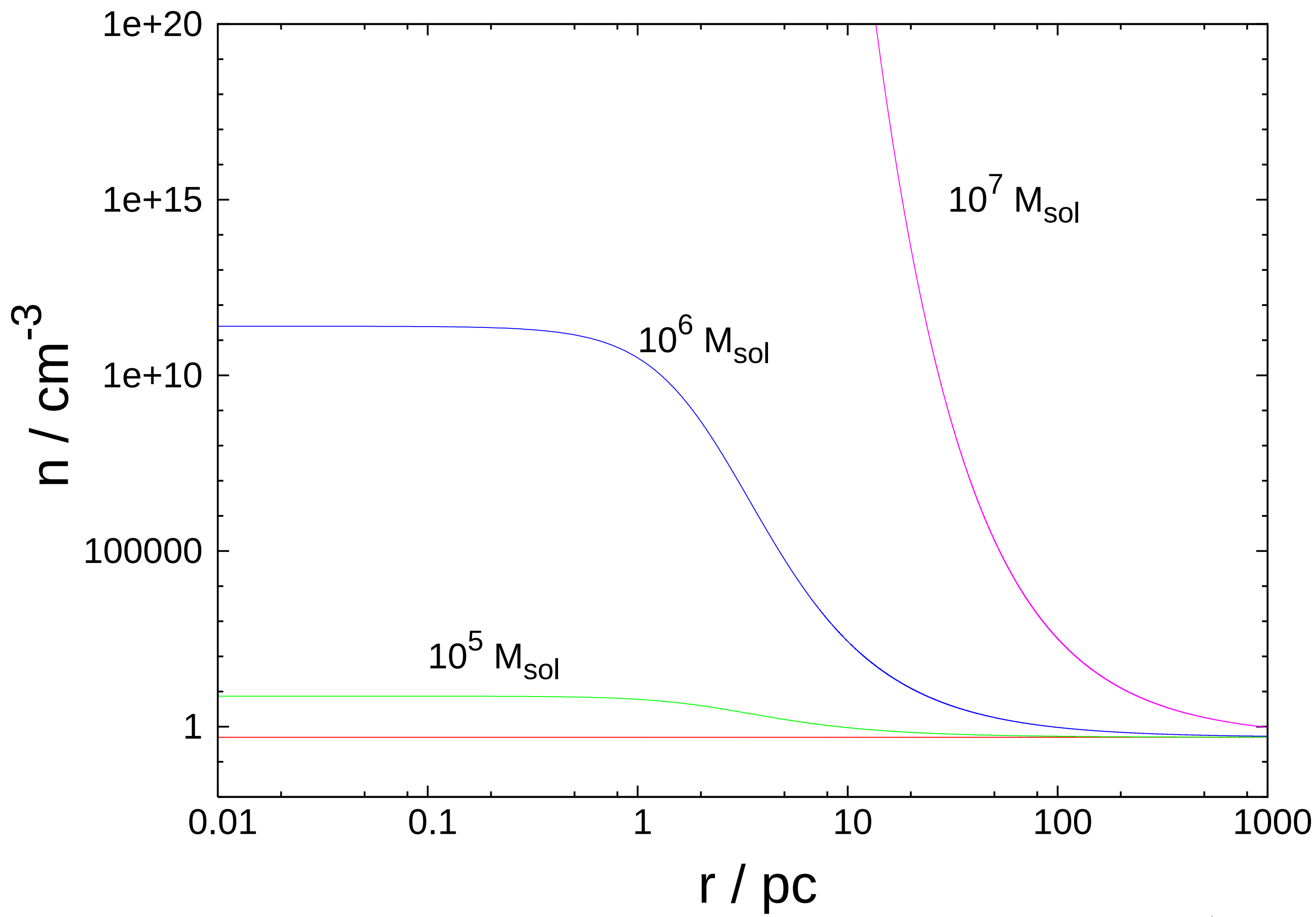
Model: solution

isothermal gas in equilibrium:

(9) $$\rho = \rho_0 \, e^{- \frac{\mu m_{\mathrm{u}}}{k_{\mathrm{B}} T} \, (\Phi(r) - \Phi_0)}$$

at $+\infty : \Phi_0 = 0$, $\rho_0 = \rho_{\mathrm{ISM}}$

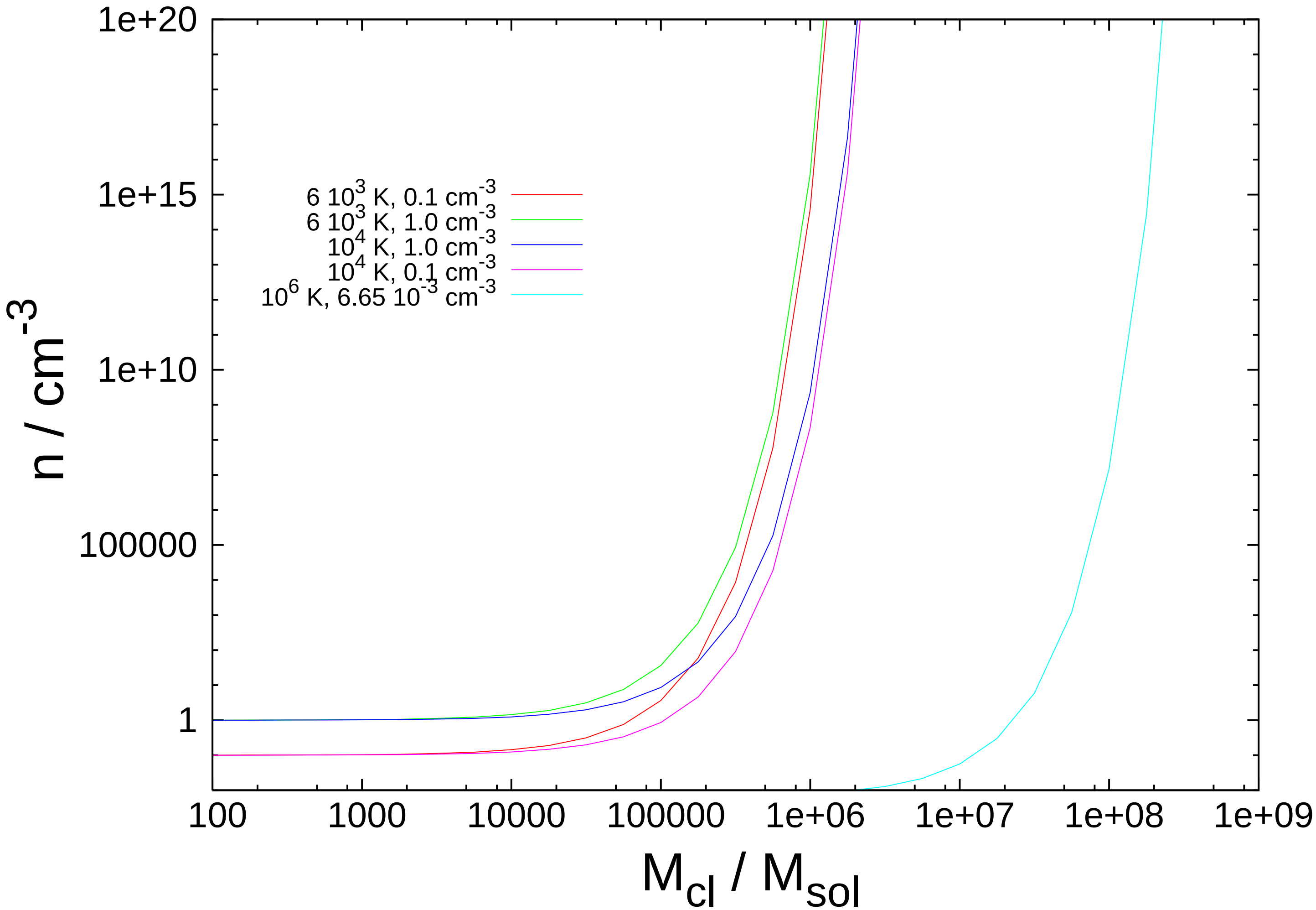
Density profile



warm ISM: T=8000 K, n_0=0.5 cm^{-1}

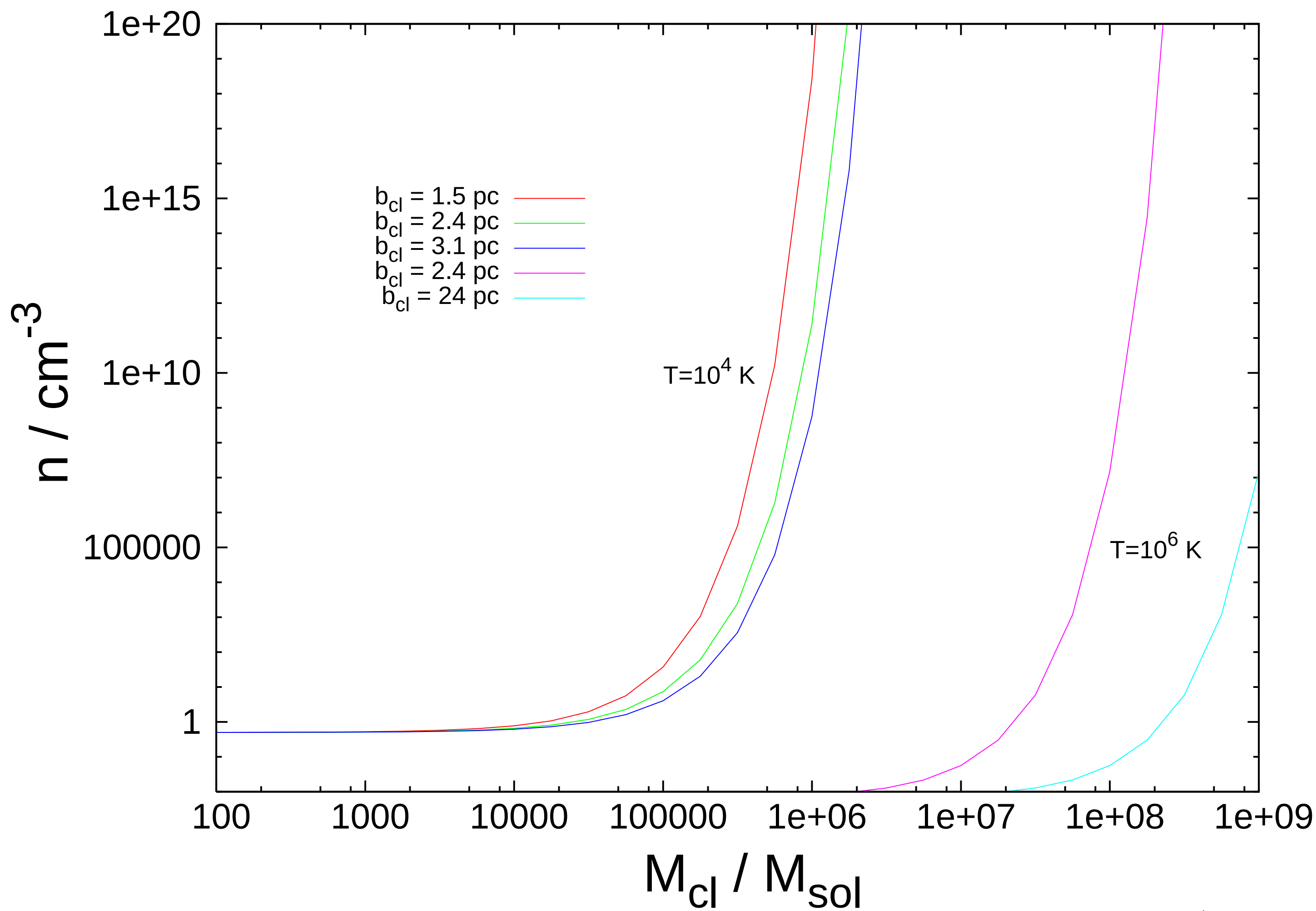
cluster: $\bar{r}_{\rm h}$=3.2 pc $\leftrightarrow$ $\bar{b}_{\rm pl}$=2.4 pc

Central particle density – cluster mass (1)



warm ISM: T=6000–10 000 K, n_0=0.1–1.0 cm^{-1}
cluster: $\bar{r}_{\rm h} = 3.2$ pc $\leftrightarrow$ $\bar{b}_{\rm pl}$=2.4 pc

Central particle density – cluster mass (2)



warm ISM: T=8000 K, n_0=0.5 cm^{-1}

cluster: $\bar{r}_{\rm h}$=2.0–4.2 pc $\leftrightarrow$ $\bar{b}_{\rm pl}$=1.5–3.1 pc

Conclusions

- In the static isothermal model the density of the warm component of the ISM becomes singular at the cluster centre above a cluster mass of 10^6 $M_\odot$ and for observed cluster half-light radii.
- Runaway cooling leads to further accretion of gas until stopped by star formation.
- Massive stars cluster are condensation germs for (giant) HI/molecular clouds: both within them or behind them.
- Increasing mass of a cluster leads to a faster orbit decay through dynamical friction.

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