The impact of metallicity on the dynamics of young star clusters

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AIM:
We investigate the impact of stellar evolution and dynamics onto core collapse and post-core collapse phase in young massive ($M \sim 3 \times 10^4 M_\odot$) star clusters (SCs) with different metallicities.

CODE:
STARLAB software environment (Portegies Zwart et al. 2001), with upgraded stellar evolution recipes, including metallicity dependence of black hole mass (Mapelli & Bressan 2013)

SIMULATIONS:
100 direct N-body simulations ($N=50000$) of SCs with metallicity $Z = 1, 0.1, 0.01 Z_\odot$
King model with $W_0=5$
SET A: dense SCs ($r_{\text{vir}} = 1$ pc), SET B: loose SCs ($r_{\text{vir}} = 5$ pc)

RESULTS: The evolution of the half-mass radius depends on how the core collapse timescale ($t_{\text{cc}}$) and the stellar evolution timescale ($t_{\text{se}}$) compare

SET A: $t_{\text{cc}} \sim t_{\text{se}}$
Fig. 1: Total binary binding energy $E_b$ (top panel), core radius $r_c$ (middle panel) and half-mass radius $r_{\text{hm}}$ (bottom panel) as a function of time for SCs of different metallicities. Solid red line: $Z=0.01 Z_\odot$, dashed black line: $Z=0.1 Z_\odot$, dotted blue line $Z=1 Z_\odot$. $E_b$ is normalised to the initial average kinetic energy of a star in the SC ($k_b T_0$). Each line is the median value of 10 runs. Dense SCs with initial $r_{\text{vir}} = 1$ pc, $N=5 \times 10^4$, $W_0 = 5$. With these initial conditions, $t_{\text{cc}} \sim 3$ Myr is comparable to $t_{\text{se}} \sim 6$ Myr.

– Binary hardening is delayed in metal-rich SCs, because of stronger stellar winds,
– core collapse occurs at the same time, independently of metallicity,
– core radius expansion occurs earlier in metal-rich SCs, because of stellar winds,
– half-mass radius expands more in metal-poor SCs, because of heating by binary hardening (~15% larger $r_{\text{hm}}$ than that of metal-poor SCs)

SET B: $t_{\text{cc}} \gg t_{\text{se}}$
Fig. 2: Same as Fig. 1, but for looser SCs ($r_{\text{vir}} = 5$ pc, $N=5 \times 10^4$, $W_0 = 5$). Because of the longer two-body relaxation timescale, these SCs have a core collapse timescale much longer than the timescale of mass loss by stellar evolution ($t_{\text{cc}} \gg 6$ Myr – $t_{\text{se}}$).

– Evolution dominated by the stellar mass loss, which is a source of heating and causes the SCs to expand,
– core collapse delayed in metal-rich SCs (only $Z=0.01 Z_\odot$ SCs undergo core collapse before 100 Myr),
– binary hardening starts in post-collapse phase, ONLY in metal-poor SCs
– half-mass radius begins to expand more than that of metal-rich SCs (differences in half-mass radius <10% throughout the simulations)


Two heating processes:
Stellar mass loss
• makes potential well shallower
• stronger in metal-rich SCs
• relevant in the early life of the SC
Binary hardening
• increases the kinetic energy
• enhanced in metal-poor SCs
• relevant only after core collapse

Core radius oscillations in dense SCs are driven by strong three-body encounters,
– the oscillation strength increases for the decreasing metallicity of the SC,
– the higher maximum remnant mass in low-metallicity SCs explains the stronger and more frequent three-body encounters