How many explosions does one need? Quantifying supernovae in globular clusters from iron abundance spreads

Henriette Wirth, Tereza Jerabkova, Zhiqiang Yan, Pavel Kroupa, Jaroslav Haas and Ladislav Šubr

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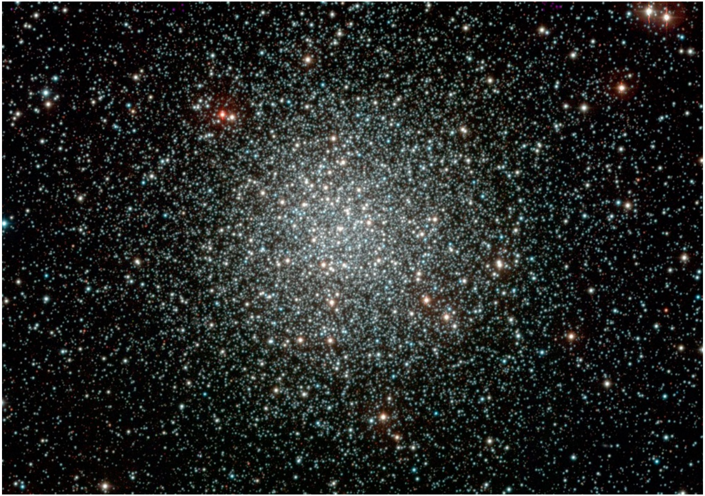

Figure: NGC 3201, obtained with the WFI instrument on the ESO/MPG 2.2-m telescope at La Silla, Credit:ESO

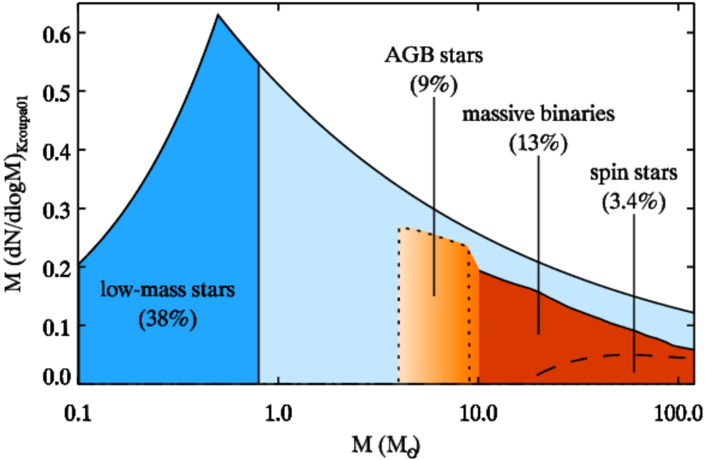

Figure: The IMF with different polluters and their mass fractions (Cottrell & Da Costa, 1981; Decressin et al., 2007; D'Ercole et al., 2008; de Mink et al., 2009; Wang et al., 2020).

Iron in globular clusters

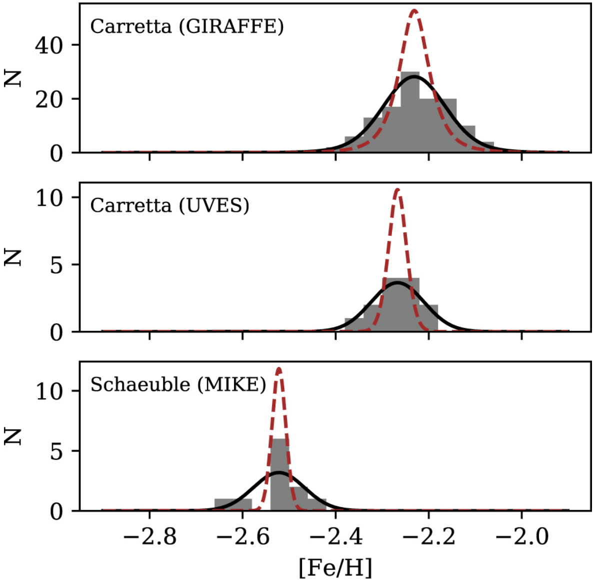

Figure: The iron abundances of stars in NGC 4590 from three different surveys (Bailin, 2019).

Iron in globular clusters

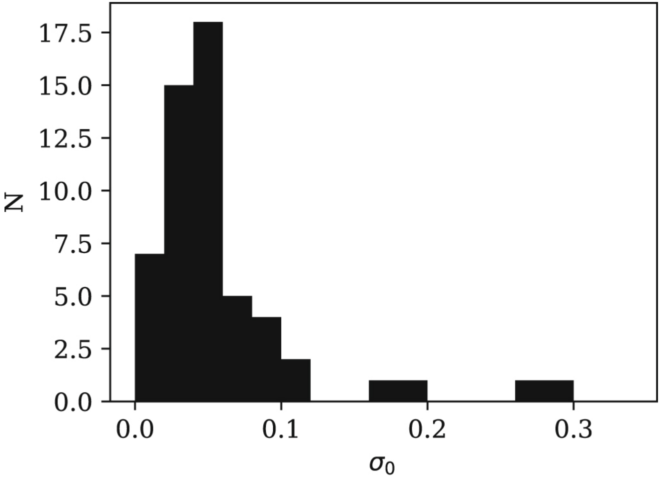

Figure: The iron abundance spread for 55 Milky Way GCs (Bailin, 2019).

The number of SNe

Wirth et al. (2021):

$$M_{\mathrm{iron}} = p_{\mathrm{iron},\odot}\left(10^{[Fe/H]+\sigma_{[Fe/H]}} - 10^{[Fe/H]-\sigma_{[Fe/H]}}\right) \times M_{\mathrm{ini}}\left(\frac{1}{\epsilon} - 1\right)$$

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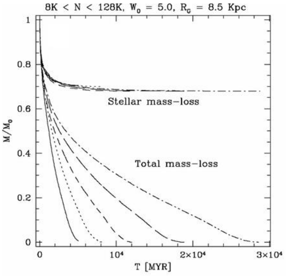

Figure: Mass loss of GCs based on N-Body simulations (Baumgardt & Makino, 2003).

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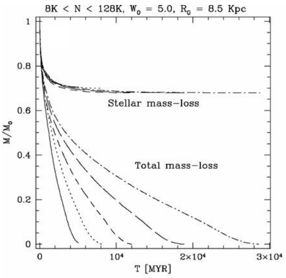

$$\rightarrow \; 0=\beta \left[\frac{\frac{M_{\mathrm{ini}}}{\langle m\rangle}}{\ln(\gamma \frac{M_{\mathrm{ini}}}{\langle m\rangle})}\right]^{x} \frac{R_{\mathrm{ap}}}{\mathrm{kpc}} (1-e) \frac{1-\frac{M(t)}{p_{SE} M_{\mathrm{ini}}}}{\frac{t}{\mathrm{Myr}}} - 1$$

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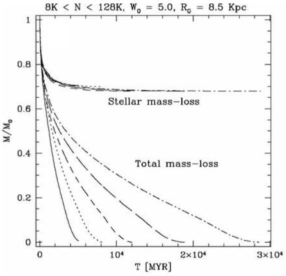

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Maoz & Graur (2017):

$$m_{\mathrm{SN}} = 0.074 M_{\odot}$$

The number of SNe

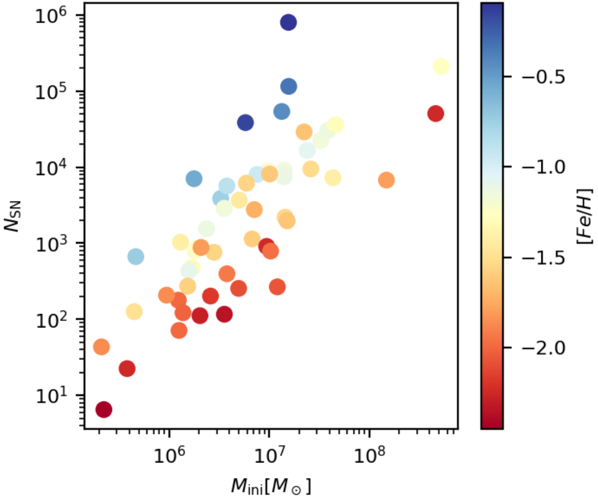

Figure: The number of SNe needed over the initial, coulorcoded for the mean iron abundance (Wirth 2022 in submission).

The time SF ends

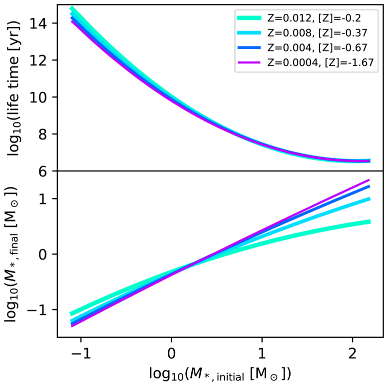

Figure: The life time and remnant mass of stars based on their initial mass(Yan et al., 2019).

The time SF ends

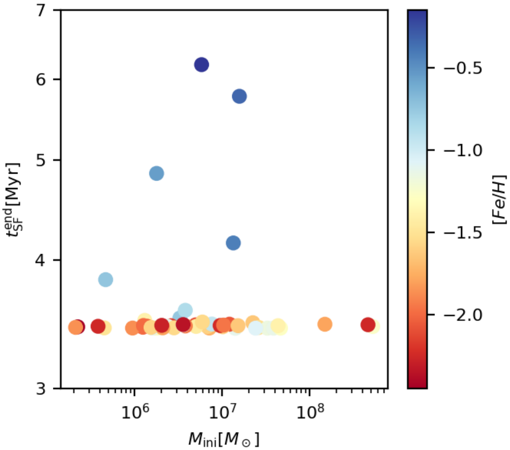

Figure: The time after which SF ends (Wirth et al. 2022 in submission). The empty dots are the solution using the canonical IMF the filled ones assume a top-heavy one.

Summary

- multiple populations of stars with different metallicities exist in GCs
- iron abundance spreads exist in some of them
- up to 10^5 SNe per GC (excluding Terzan 5)
- SF ends after $\sim 3.5 - 4\ \mathrm{Myr}$

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Backup

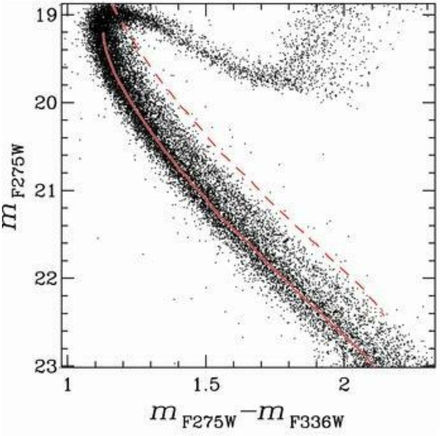

Figure: HR-diagram of the main sequence of 47 Tuc(Milone et al., 2012).

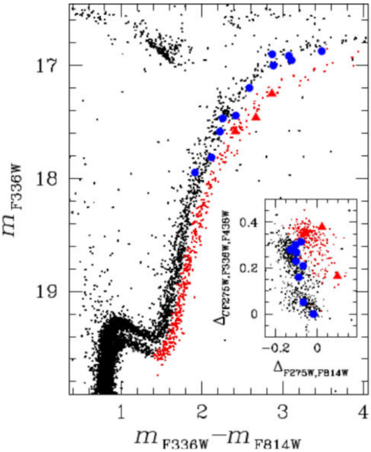

Figure: HR-diagram and Chromosome map of the red giant branch NGC 1851(Marino et al., 2019).

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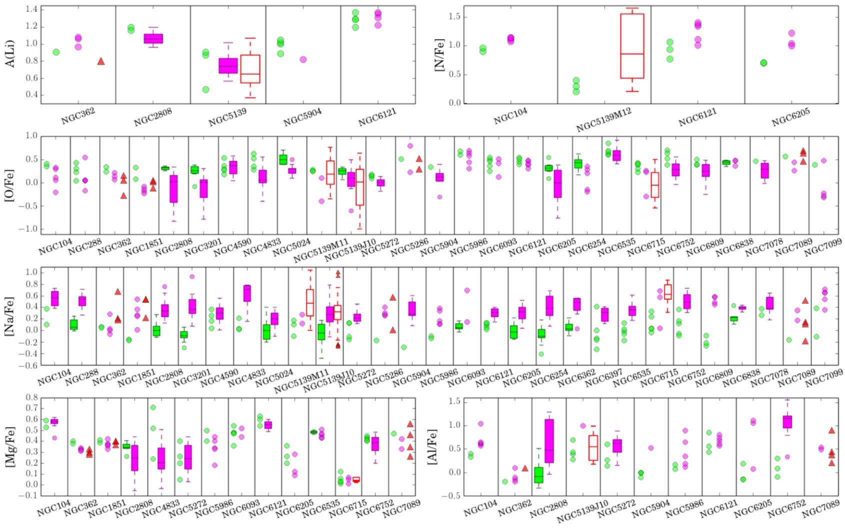

Figure: Different light element abundances for different GCs(Marino et al., 2019).

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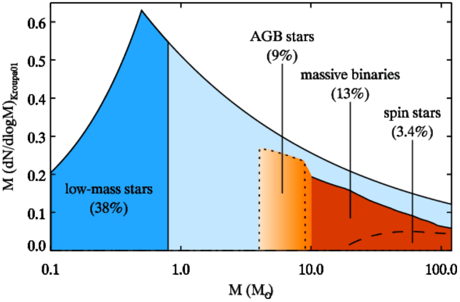

Figure: Different polluters and their mass fractions(Cottrell & Da Costa, 1981; Decressin et al., 2007; D'Ercole et al., 2008; de Mink et al., 2009; Wang et al., 2020).

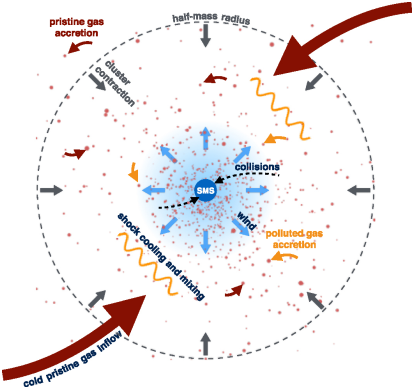

Figure: A supermassive star polluting the surrounding stars(Gieles et al., 2018).

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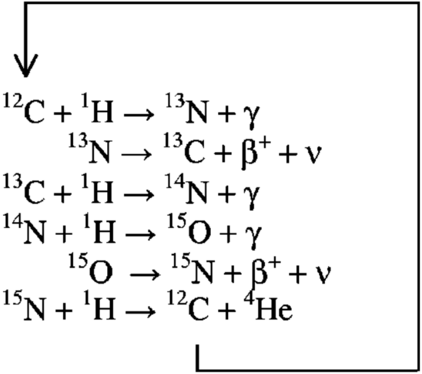

Figure: The CNO cycle (Nesaraja et al., 2001).

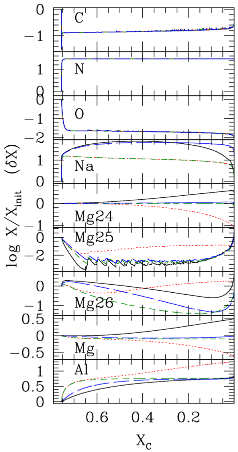

Figure: The evolution of central abundances in a 60 $M_{\odot}$ rotating star (Decressin et al., 2007).

Backup

Baumgardt & Makino (2003); Wirth et al. (2021):

$$0 = \beta \left[\frac{\frac{M_{\rm ini}}{\langle m \rangle}}{\ln(\gamma \frac{M_{\rm ini}}{\langle m \rangle})} \right]^{x} \frac{R_{\rm ap}}{\rm kpc} (1 - e) \frac{1 - \frac{M(t)}{p_{SE} M_{\rm ini}}}{\frac{t}{\rm Myr}} - 1$$

$$p_{\rm SE} = -0.61 + 0.52\alpha_3$$

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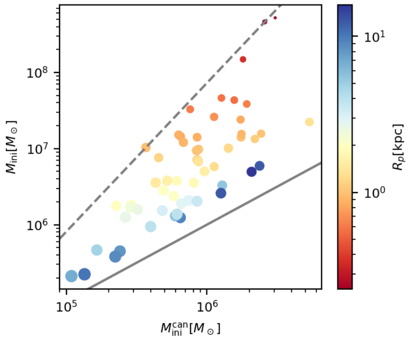
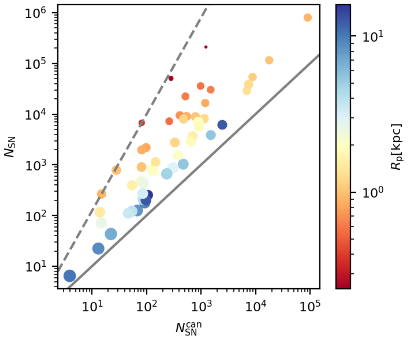


Figure: The initial masses computed using the canonical IMF compared to the ones assuming a top-heavy IMF (Wirth et al. 2022 in submission). The dashed grey line is

$$\frac{\rm M_{ini}}{\rm M_\odot} = 1.4 \times 10^{-4} \left(\frac{\rm M_{ini}^{can}}{\rm M_\odot}\right)^{2.0}.$$



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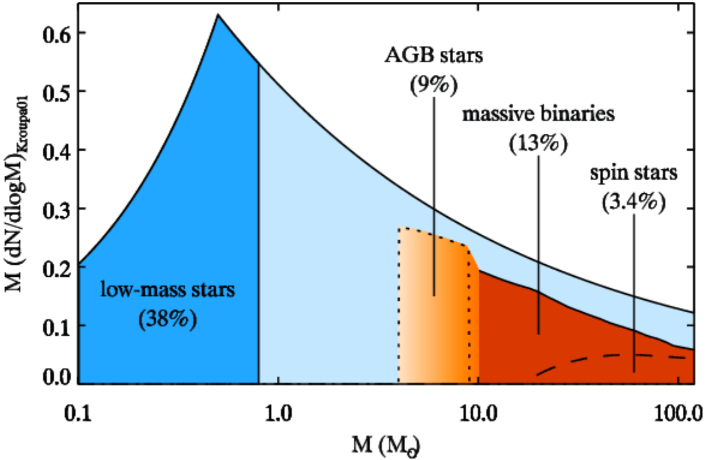

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Kroupa (2001)

$$dN = \xi(m)dm \qquad \xi(m) = k_i m^{-\alpha_i}$$

$$\alpha_1 = 1.3, \qquad 0.08 \le \frac{m}{M_\odot} \le 0.5,$$

$$\alpha_2 = 2.3, \qquad 0.5 < \frac{m}{M_\odot}.$$

Backup

Yan et al. (2021)

$$dN = \xi(m)dm \qquad\qquad \xi(m) = k_i m^{-\alpha_i}$$

$$\alpha_1 = 1.3 + Z_\odot \Delta\alpha(10^{[Z/H]_{\rm ini}} - 1), \qquad 0.08 \leq \frac{m}{M_\odot} \leq 0.5,$$

$$\alpha_2 = 2.3 + Z_\odot \Delta\alpha(10^{[Z/H]_{\rm ini}} - 1), \qquad 0.5 \leq \frac{m}{M_\odot} \leq 1,$$

$$\alpha_3 = \begin{cases} 2.3, & y < -0.87, \\ -0.41y + 1.94, & y \geq -0.87, \end{cases} \qquad 1 < \frac{m}{M_\odot},$$

$$y = -0.14[Z/H]_{\rm ini} + 0.99 \log_{10}\left(\rho_{\rm gas}/(10^6 M_\odot {\rm pc}^{-3})\right).$$

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