PROCEEDINGS OF SCIENCE

IMF variations and their implications for Supernovae numbers

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The stellar initial mass function (IMF) integrated over an entire galaxy is an integral over all separate star-formation events. Since most stars form in star clusters with different masses the integrated IMF becomes an integral of the (universal or invariant) canonical stellar IMF over the star-cluster mass function. This integrated IMF is steeper (contains fewer massive stars per G-type star) than the canonical stellar IMF. Furthermore, observations indicate a relation between the star-formation rate of a galaxy and the most luminous stellar cluster in it. This empirical relation can be transformed into one between the star-formation rate of a galaxy and a maximum cluster mass. The assumption that this cluster mass marks the upper end of a young-cluster mass function leads to a connection of the star-formation rate and the slope of integrated IMF for massive stars. This integrated IMF varies with the star-formation history of a galaxy. Notably, large variations of the integrated IMF are evident for dwarf galaxies. One important result is that the number of type II supernovae per star is supressed relative to that expected for a canonical IMF, and that dwarf galaxies have a supressed number of supernovae per star relative to massive galaxies. For dwarf galaxies the number of supernovae per star also varies substantially depending on the galaxy assembly history.

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1. The stellar IMF

Star formation takes place mostly in embedded clusters, each cluster containing a dozen to many million stars. Within these clusters stars appear to form following a universal initial mass function (IMF) with a Salpeter power-law slope or index ($\alpha = 2.35$, [5, 2]) for stars more massive than $1\,M_\odot$, $\xi(m) \propto m^{-\alpha}$, where ξdm is the number of stars in the mass interval $m, m+dm$. This has been found to be the case for a wide range of different conditions in the Milky Way (MW), the Large and Small Magellanic clouds (respectively LMC, SMC) and other galaxies.

2. The (embedded) cluster IMF

Several studies show that star clusters also seem to be distributed according to a power-law embedded cluster mass function (ECMF), $\xi_{\rm ecl} = k_{\rm ecl} M_{\rm ecl}^{-\beta}$, where $dN_{\rm ecl} = \xi_{\rm ecl}(M_{\rm ecl})\; dM_{\rm ecl}$ is the number of embedded clusters in the mass interval $M_{\rm ecl}$, $M_{\rm ecl} + dM_{\rm ecl}$ and $M_{\rm ecl}$ is the mass in stars. In the solar neighbourhood [4] find a slope $\beta = 2$ between 50 and 1000 $M_\odot$, while in the SMC and LMC [1] find $\beta \sim 2 - 2.4$ and [10] find $\beta \sim 2 - 2.4$ for $10^4 \leq M_{\rm ecl}/M_\odot \leq 10^6$ in the Antennae galaxies. We therefore assume a single-slope power-law ECMF with $\beta = 2.35$ between 5 $M\odot$ and $10^6\,M_\odot$.

3. The star-formation-rate–maximal-cluster-mass relation

In [9] we derived a relation (shown in Fig. 1) between the maximal cluster mass in a galaxy and the current star formation rate (SFR) of the galaxy,

$$\log_{10}(M_{\rm ecl,max}) = \log_{10}(k_{\rm ML}) + (0.75 \cdot \log_{10} {\rm SFR}) + 6.77,$$

where $k_{\rm ML}$ is the mass-to-light ratio, typically 0.0144 for young (< 6 Myr) clusters. This eq. connects the IMF via the ECMF with the properties of a galaxy.

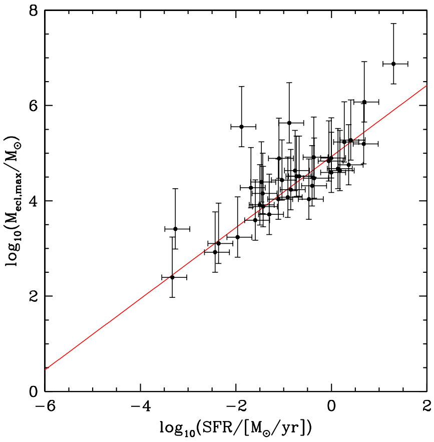

Figure 1: The solid line shows the star-formation-rate–maximal-cluster-mass relation from [9] while the dots with the error bars are the observations.

4. The integrated galaxial initial mass function (IGIMF)

As in our model all stars are born in clusters following a universal IMF but also clusters are formed from a universal ECMF, the mass function for all stars born in all clusters, which we call the integrated galaxial initial mass function (IGIMF), becomes the following integral ([6]),

$$\xi_{\rm IGIMF}(m) = \int_{M_{\rm ecl,min}}^{M_{\rm ecl,max}(SFR)} \xi(m \le m_{\rm max})\, \xi_{\rm ecl}(M_{\rm ecl})\, dM_{\rm ecl}.$$

As seen in Fig. 2 the resulting IGIMFs are always steeper than the input canonical stellar IMF.

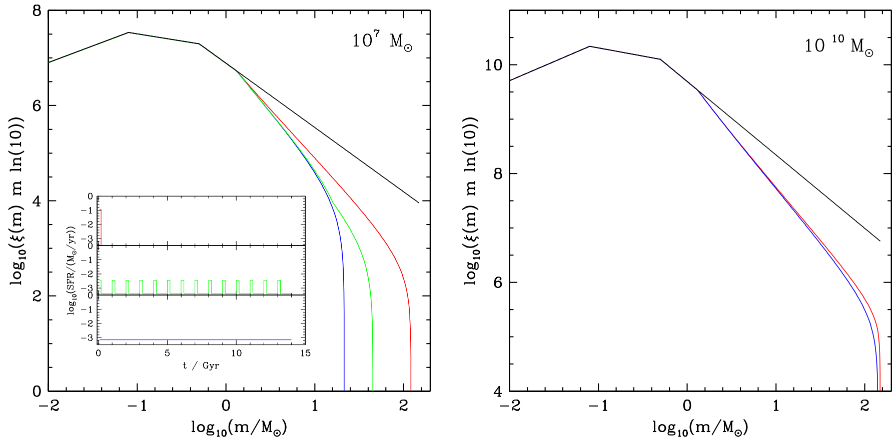

Figure 2: Left panel: Integrated field mass functions for a galaxy with a stellar mass of $10^7 M_\odot$ with different star-formation histories (single initial-burst of 100 Myr, periodic SF of 100 My every 900 Myr and constant SFR over 14 Gyr, respectively, from top to bottom) shown in the small box. The IMF slope above 1 $M_\odot$ is $\alpha_3 = 2.35$, while the ECMF slope β is 2.35. Right panel: The same for a galaxy with $10^{10} M_\odot$ stellar mass. Both taken from [8].

5. Results & Conclusions

- The IGIMFs must be steeper (see left panel of Fig. 3) than the stellar IMF and vary with galaxy type (see Fig. 2).
- Chemical enrichment histories, the number of SNII per star and mass-to-light ratios calculated with an invariant Salpeter IMF cannot be correct for any galaxy.
- The number of supernovae per star (see right panel of Fig. 3) is possibly significantly lower over cosmological times than for an invariant canonical IMF.
- Irrespective of how old a galaxy is it will always appear less chemically evolved than a more massive equally-old galaxy as a result of the steeper IGIMF.
- The scatter in chemical properties must increase with decreasing galaxy mass.

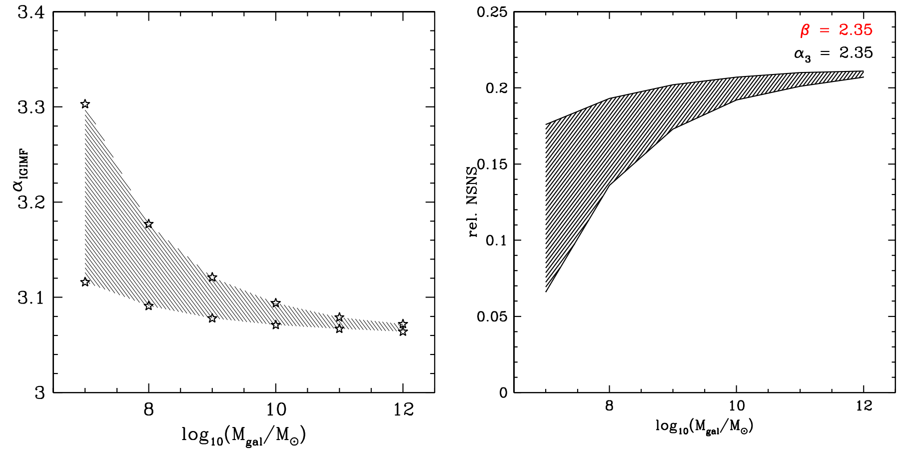

Figure 3: Left panel: IGIMF slopes above $\sim 1.3\,M_\odot$ in dependence of the stellar galaxy mass for $\alpha_3 = 2.35$ and $\beta = 2.35$. The lower limit of the shaded region results from single initial-burst models while the upper limit is from continuous models. The IGIMF thus becomes steeper with reducing stellar mass, thus resulting in systematic differences in the chemical evolution of different galaxy types. Also in the low-mass regime a larger scatter in chemical properties is to be expected. Right panel: The number of SNII per star relative to the same number for a constant canonical IMF as a function of galaxy mass for $\alpha_3 = 2.35$ and $\beta = 2.35$. The upper limit of the shaded region results from single burst models while the lower limit is deduced from continuous star-formation models. While for galaxies with large stellar masses the value is about 20% of the corresponding canonical IMF value it drops significantilly for galaxies with lower stellar mass. Both panels are from [8].

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