

# COSMIC HISTORY OF THE INTEGRATED GALACTIC STELLAR INITIAL MASS FUNCTION: A SIMULATION STUDY

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## ABSTRACT

Theoretical and indirect observational evidence suggests that the stellar initial mass function (IMF) increases with redshift. On the other hand, star formation rates (SFRs) may be as high as  $100 M_{\odot} \text{ yr}^{-1}$  in starburst galaxies. These may lead to the formation of massive clusters, hence massive stars, making the integrated galactic stellar initial mass function (IGIMF) top-heavy (i.e., the proportion of massive stars is higher than that of less massive stars). We investigate the joint effect of evolving the IMF and several measures of SFRs in dependence on the galaxy-wide IMF. The resulting IGIMFs have slopes  $\alpha_{\text{IGIMF}}$  in the high-mass regime, which is highly dependent on the minimum mass of the embedded cluster ( $M_{\text{min}}$ ), SFR, and mass-spectrum indices of embedded clusters ( $\beta$ ). It is found that for  $z \sim 0-2$ ,  $\alpha_{\text{IGIMF}}$  becomes steeper (i.e., bottom-heavy), for  $z \sim 2-4$ ,  $\alpha_{\text{IGIMF}}$  becomes flatter (i.e., top-heavy), and from  $z \sim 4$  onward,  $\alpha_{\text{IGIMF}}$  again becomes steeper. The effects are faster for higher values of  $\beta$ .  $\alpha_{\text{IGIMF}}$  is also for higher values of  $M_{\text{min}}$ . All of these effects may be attributable to the joint effect of increasing the temperature of the ambient medium as well as varying the SFR with increasing redshift.

**Key words:** galaxies: evolution – stars: evolution – stars: formation

## 1. INTRODUCTION

The form of the stellar initial mass function (IMF) is considerably debated in the present era, as it describes the nature of stellar populations, the ratio of high-mass to low-mass stars, and influences the dynamical evolution of star clusters, as well as the star formation history of the whole galaxy. It is usually derived using an observed luminosity function together with an assumed mass-to-light ratio for the stars under consideration. IMFs, as suggested by various authors, are generally either of Salpeter type (Salpeter 1955) or consist of either segmented power laws (Salo 1986) or lognormal type (Chabrier 2003), with a turnover at some characteristic mass  $m_c$ . The power-law slope at high masses is probably close to the Salpeter value (Salpeter 1955) with  $\frac{dN}{dm} \propto m^{-\alpha}$ , and  $\alpha = 2.35$  with an uncertainty  $\sim 0.3$  (Chabrier 2003). There are conflicting views and evidence of the universality of the IMF at the present time, e.g., to some extent there is evidence of mass segregation in young massive clusters (Zwart et al. 2010 and references therein) and some variations in starburst galaxies (Gunawardhana et al. 2011). In contrast, there are bottom-heavy IMFs in massive ellipticals (Ferreira et al. 2013) and no direct evidence for rapid variation of the IMF within the Milky Way disk (Kroupa 2001; Chabrier 2003). Again, there is the possibility of variation of the IMF with time (hence redshift), metallicity, and environment. Larson (2003, 2005) has argued that the characteristic mass is primarily determined by the Jeans mass, which depends on the temperature. Hence, with an increase in temperature (the cosmic microwave background temperature was higher at higher redshift), one might expect that low-mass star formation would be disfavored, resulting in a top-heavy IMF with a temperature scaling with redshift as  $(1+z)$ . Therefore, at sufficiently high redshift, mass scales as  $(1+z)^2$ , increasing the fraction of

high-mass stars. Larson (2005) has suggested that at  $z = 5$  the characteristic mass may be higher than the present day's value by an order of magnitude.

It is clear from various recent observations that stars form in embedded clusters (Lada & Lada 2003; Kroupa 2005). These clusters also follow a mass function, which is again a power law,  $\xi_{\text{cl}}(M) \propto M_{\text{cl}}^{-\beta}$ . This is known as the embedded cluster mass function (ECMF). The maximum mass of the ECMF,  $M_{\text{cl,max}}$ , has been found to depend on the star formation rate of the galaxy (Weidner & Kroupa 2004; Bastian 2008) and is given as

$$M_{\text{cl,max}} = 8.5 \times 10^4 \times \text{SFR}^{0.75}, \quad (1)$$

where the SFR is in  $M_{\odot} \text{ yr}^{-1}$ . Weidner et al. (2013) have suggested a time-dependent IMF for elliptical galaxies to account for an excess of low-mass stars in these galaxies. They modeled the SFR as a function of time. The SFR reaches a maximum initially and then asymptotically reduces to zero with time. They have discussed a two stage star formation scenario in giant elliptical galaxies and have given an alternative hypothesis over time-independent bottom-heavy IMFs in these galaxies. They have proposed that initially there is a strong starburst stage with a top-heavy IMF, which is followed by a prolonged stage with a bottom-heavy IMF. The latter results from many low-mass clouds (i.e., a high value of beta) being formed as a result of the fragmentation of the gaseous component. A similar trend for SFRs has also been found for various elliptical galaxies as a function of redshift (Spaan & Carollo 1997). Various theoretical models for star formation are difficult to test, as current observational results from cosmological studies do not measure IMF slopes and SFRs for individual galaxies, but instead study indirect evidence for

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