Physics 235

Extragalactic Astrophysics
Prof. Crystal Martin
Initial Stellar Mass Function

Is it universal?

A successful theory would predict where the IMF differs from that measured in the Milky Way.
EVIDENCE FOR A NONUNIFORM INITIAL MASS FUNCTION IN THE LOCAL UNIVERSE


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ABSTRACT

Many of the results in modern astrophysics rest on the notion that the initial mass function (IMF) is universal. Our observations of a sample of HI selected galaxies in the light of Hα and the far-ultraviolet (FUV) challenge this result. The extinction-corrected flux ratio F_{Hα}/F_{FUV} from these two tracers of star formation shows strong correlations with the surface brightness in Hα and the R band: low surface brightness (LSB) galaxies have lower F_{Hα}/F_{FUV} ratios compared to high surface brightness galaxies as well as compared to expectations from equilibrium models of constant star formation rate (SFR) using commonly favored IMF parameters. Weaker but significant correlations of F_{Hα}/F_{FUV} with luminosity, rotational velocity, and dynamical mass as well as a systematic trend with morphology, are found. The correlated variations of F_{Hα}/F_{FUV} with other global parameters are thus part of the larger family of galaxy scaling relations. The F_{Hα}/F_{FUV} correlations cannot be due to residual extinction correction errors, while systematic variations in the star formation history (SFH) cannot explain the trends with both Hα and R surface brightness nor with other global properties. The possibility that LSB galaxies have a higher escape fraction of ionizing photons seems inconsistent with their high gas fraction, and observations of color–magnitude diagrams (CMDs) of a few systems which indicate a real deficit of O stars. The most plausible explanation for the correlations is the systematic variations of the upper mass limit M_u and/or the slope γ which define the upper end of the IMF. We outline a scenario of pressure driving the correlations by setting the efficiency of the formation of the dense star clusters where the highest mass stars preferentially form. Our results imply that the SFR measured in a galaxy is highly sensitive to the tracer used in the measurement. A nonuniversal IMF would also call into question the interpretation of metal abundance patterns in dwarf galaxies as well as SFHs derived from CMDs. 

Keywords: galaxies: ISM – galaxies: stellar content – stars: formation – stars: luminosity function, mass function

Online-only material: color figures
Stochasticity, a variable stellar upper mass limit, binaries and star formation rate indicators

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ABSTRACT

Using our Binary Population And Spectral Synthesis (BPASS) code we explore the effects on star formation rate indicators of stochastically sampling the stellar initial mass function (IMF), adding a cluster-mass-dependent stellar upper mass limit and including binary stars. We create synthetic spectra of young clusters and star-forming galaxies and compare these to observations of Hα emission from isolated clusters and the relation between Hα and far-ultraviolet (FUV) emission from nearby galaxies. We find that observations of clusters tend to favour a purely stochastic sampling of the IMF for clusters less than 100 $M_\odot$, rather than the maximum stellar mass being dependent on the total cluster mass. It is more difficult to determine whether the same is true for more massive clusters. We also find that binary stars blur some of the observational differences that occur when a cluster-mass-dependent stellar upper mass limit is imposed when filling the IMF. The effect is greatest when modelling the observed Hα-to-FUV star formation rate ratios in galaxies. This is because mass transfer and merging of stars owing to binary evolution create more massive stars and stars that have greater mass than the initial maximum imposed on the stellar population.

Key words: binaries: general – H II regions – galaxies: star clusters: general – galaxies: stellar content.
Dwarf-sensitive absorption features increase systematically with velocity dispersion, consistent with a varying IMF, such that galaxies with deeper potential wells have more dwarf-enriched mass functions.
The Formation of Population III Binaries from Cosmological Initial Conditions

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Previous high-resolution cosmological simulations predicted that the first stars to appear in the early universe were very massive and formed in isolation. Here, we discuss a cosmological simulation in which the central 50 $M_\odot$ (where $M_\odot$ is the mass of the Sun) clump breaks up into two cores having a mass ratio of two to one, with one fragment collapsing to densities of $10^{-8}$ grams per cubic centimeter. The second fragment, at a distance of $\sim$800 astronomical units, is also optically thick to its own cooling radiation from molecular hydrogen lines but is still able to cool via collision-induced emission. The two dense peaks will continue to accrete from the surrounding cold gas reservoir over a period of $\sim$10^5 years and will likely form a binary star system.
Fig. 1. Mass-weighted average density (left column), \( \text{H}_2 \) fraction (middle column), and temperature (right column) projected through a cube centered on the center of mass of the two-core system with a side length of 3500 AU. The bottom row is the final output of the simulation, the middle row is 555 years previous, and the top row is an additional 591 years before the middle row (1146 years before the end of the simulation). Gravitationally bound cores with a minimum density of \( 3.0 \times 10^{-12} \) g cm\(^{-3} \) have been outlined with thick lines in the bottom row; core A is on the left, and core B is on the right. Field of view is 3500 AU.
First Stars
“Population III”

The minimum mass that a virialized gas cloud must have in order to be able to cool in a Hubble time is computed, using a detailed treatment of the chemistry of molecular hydrogen.
Molecular Fraction Needed for Collapse vs. Molecular Fraction Produced

The molecular fraction produced in a Hubble time

Minimum halo temperature needed for baryonic collapse.
Minimum Virial Temperature Needed to Collapse

Virialization requires $\rho/\langle\rho\rangle=18\pi^2$. At constant entropy that's $T/T_{\text{igm}} = (18\pi^2)^{2/3}$.

No radiative cooling mechanism can help here.

$T_{\text{cool}} < t_{\text{hubble}}$

$T_{\text{vir}} < T_{\text{CMB}}$

$T_{\text{igm}}$
Minimum baryonic mass is redshift dependent

In CDM, low mass halos collapse first. But does the primordial gas cool?

\[ t_{\text{cool}}(H_2) = t_H \]

\[ \delta_{\text{crit}} = 3 \sigma (M,z) \]

For halos that formed early \((z_{\text{vir}} > 100)\), the gas can’t cool if \(M_h < 10^4 M_0\).

For halos that formed late \((z_{\text{vir}} < 10)\), the gas can’t cool if \(M_h < 10^8 M_0\).

\[ T_{\text{vir}} \approx 442 K \Omega_{m,0}^{1/3} (M/10^4 M_0)^{2/3} [(1+z_{\text{vir}})/100] \]

Expected in halos with \(T_{\text{vir}} = 10^3 - 10^4 K\). These halos form in abundance at \(z < 30\). 
Molecular Fraction Depends on P

Fig. 16.—(a) Ratio of H\textsubscript{i} to H\textsubscript{2} surface density plotted against the hydrostatic disk pressure at the midplane, as given by Elmegreen (1989). The straight dashed line represents the mean slope of −0.8. (b) Molecular fraction plotted against midplane pressure. The straight dashed line represents the slope of 1.7 predicted by Elmegreen (1993). Data for the Milky Way is based on Dame et al. (1993), adopted a stellar scale length of 3 kpc (Sackett 1997) and \( \Sigma_+ = 35 M_\odot \) \( \text{pc}^{-2} \) at the solar circle (Gilmore et al. 1989). [See the electronic edition of the Journal for a color version of this figure.]