A non-universal IMF in Galactic stellar clusters

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NBIA & STARPLAN
The Galactic field IMF

Stellar Initial Mass Functions

- Salpeter55
- MS79
- Kennicutt83
- Scalo86
- KTG93
- Kroupa01
- BG03
- Chabrier03

mass fraction per dex

mass (m / M_{solar})
The Most “popular” IMF functional forms

The multi-exponent power law (Kroupa 2002, Kroupa 2013):

\[ \xi(m) = k \begin{cases} 
\left( \frac{m}{m_{H}} \right)^{-\alpha_0}, & m_{\text{low}} \leq m \leq m_{H}, \\
\left( \frac{m}{m_{H}} \right)^{-\alpha_1} \left( \frac{m_{H}}{m_{0}} \right)^{\gamma_1}, & m_{H} \leq m \leq m_{0}, \\
\left( \frac{m}{m_{H}} \right)^{-\alpha_2} \left( \frac{m_{H}}{m_{0}} \right)^{\gamma_2}, & m_{0} \leq m \leq m_{1}, \\
\left( \frac{m}{m_{H}} \right)^{-\alpha_3} \left( \frac{m_{H}}{m_{0}} \right)^{\gamma_3}, & m_{1} \leq m \leq m_{\text{max}},
\end{cases} \]

with exponents
\[ \begin{align*}
\alpha_0 &= +0.30, & 0.01 \leq m / M_{\odot} &\leq 0.08, \\
\alpha_1 &= +1.30, & 0.08 \leq m / M_{\odot} &\leq 0.50, \\
\alpha_2 &= +2.30, & 0.50 \leq m / M_{\odot} &\leq 1.00, \\
\alpha_3 &= +2.35, & 1.00 \leq m / M_{\odot} &.
\end{align*} \]

The lognormal distribution (Chabrier 2003, 2005):

\[ \xi(\log m) = 0.076 \times \exp \left\{ -\frac{(\log m - \log 0.25)^2}{2 \times 0.55^2} \right\}, \quad m \leq 1 M_{\odot} \]

\[ = 0.041 m^{-1.35 \pm 0.3}, \quad m \geq 1 M_{\odot} \]

The STPL (single power law tapered) IMF (de Marchi & Parecse 2002; Parravano et al. 2010):

\[ \xi(\log M) = k M^{-\Gamma} \left\{ 1 - \exp \left[ -\left( \frac{M}{M_{\text{ch}}} \right)^{\gamma+\Gamma} \right] \right\} = k M^{-1.35} \left\{ 1 - \exp \left[ -\left( \frac{M}{0.42} \right)^{0.57+1.35} \right] \right\} \]

\[ 0.1 \leq M / M_{\odot} \leq 120 \]
The IMF of young (< 2 Myrs) embedded/semi embedded Stellar Clusters

rho-Ophiucus

Luhman & Rieke 1999; Luhman 2000, ++
The IMF of Open Stellar Clusters

comparing the slope at the intermediate-to-high mass end

Massey et al. 1995a,b
Massey 2003
The IMF of Open Stellar Clusters

comparison of the slope at the intermediate-to-high mass end

Sharma et al. 2008
The IMF of Starburst Clusters: Arches, NGC 3603, ...

Figer 1999; Stolte et al. 2005, Kim et al. 2006
Espinoza et al. 2010, Habibi et al. 2014

Stolte et al. 2006
Characterizing The IMF of stellar clusters

I-overplotting the binned MF with the field IMF

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Characterizing The IMF of stellar clusters

II-Fitting the binned MF using a $\chi^2$ minimization

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See also Maiz Appelaniz & Ubeda 2005
Characterizing The IMF of stellar clusters

III- Bayesian statistics: Bayes Theorem

\[ P(M_i|D) = \frac{P(M_i)P(D|M_i)}{P(D)} \]

Avoids:
- The effects of the bin size
- Making subjective choices about break points

Allows for:
- Including the effects of individual uncertainties on masses
- Effects of completeness
- Use of prior information
Application to young Galactic Stellar Clusters

Case of tapered power-low likelihood function

\[ \xi(\log M) = kM^{-\Gamma} \left( 1 - \exp \left( -\frac{M}{M_{\text{ch}}} \right)^{-\Gamma} \right) \]

No overlap in the parameters at the 1\(\sigma\) confidence limit

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Application to young Galactic Stellar Clusters

Case of “Chabrier”-like likelihood function

No overlap in the parameters at the 1σ confidence limit

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Effect of completeness & mass uncertainties

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Compare the different likelihood functions

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IMF of Galactic clusters not universal!

- Dynamical effects
- Binarity corrections needed
- Larger samples, uncertainty measurements on individual masses
- Derive masses using several stellar evolutionary models

what is the parent distribution of the IMF parameters?
In the presence of accretion on cores
Variations of the SFE and IMF

\[
\frac{dN(r,M,t)}{dt}_{\text{acc}} = \left(-\frac{\partial N}{\partial M} \frac{\dot{M}}{M} - \frac{\partial \dot{M}}{\partial M} N\right)(r,M,t)
\]
\[ \frac{dN(r,M,t)}{dt}_{acc} = \left( -\frac{\partial N}{\partial M} \dot{M} - \frac{\partial \dot{M}}{\partial M} N \right) (r,M,t) \]

Data points: Orion A+B cloud
Johnstone & Bally 2006?

Dib et al. 2010
\[
\frac{dN(r,M,t)}{dt}_{acc} = \left( -\frac{\partial N}{\partial M} \frac{\dot{M}}{\partial M} - \frac{\partial \dot{M}}{\partial M} N \right)(r,M,t)
\]

In low-mass clusters: no tail at high stellar masses

Dib et al. 2010
Application to the Orion Cloud and the ONC

Dib et al. (2010)
Variations with the cores properties

Effect of varying the lifetimes of the cores + stopping effect of feedback

Dib et al. 2010
calculate instantaneous cross section of collision between contracting objects of Masses $M_i$ and $M_j$ and integrate over the mass spectrum.

$$\sigma(M_i, M_j, r, t) = \pi \left( R_i(t) + R_j(t) \right) \left[ 1 + \frac{2G(M_i + M_j)}{2v^2(R_i(t) + R_j(t))} \right]$$

$$\frac{dN(r, M, t)}{dt}_{\text{coal}} = \frac{1}{2} \eta(r) \int_{M_{\text{min}}}^{M} N(r, m, t) N(r, M - m, t) \sigma(m, M - m, r, t) v(r) \, dm$$

$$- \eta(r) N(r, M, t) \int_{M_{\text{min}}}^{M_{\text{max}}} \int_{M_{\text{min}}}^{M_{\text{max}}} N(r, m, t) \sigma(m, M - m, r, t) v(r) \, dm \, dr$$

$\alpha = 0.4$

$\beta = 1.8$

Slope = $-3/(4-\beta)-1 = -2.33$

Dib et al. 2007
Core coalescence: application to Starburst Clusters

Dib et al. 2007
Take-home point 2

Star formation processes that can generate “non-standard” primordial IMFs in clusters exist.

What is their frequency?

What is the parent distribution of the IMF parameters?