Stochastic star formation under scrutiny in M33 and the LMC

R. A. González-L.[1,2,3], P. Kroupa[2,3], J. Pflamm-Altenburg[2,3], G. Bruzual[1]

[1] INSTITUTO DE RADIOASTRONOMIA Y ASTROFISICA, UNAM, MEXICO

[2] ARGELANDER INSTITUT FÜR ASTRONOMIE, UNI-BONN, GERMANY

[3] HELMHOLTZ-INSTITUT FÜR STRAHLEN- UND KERNPHYSIK, UNI-BONN, GERMANY

r.gonzalez@crya.unam.mx

Abstract

► We show, with very high confidence, that the masses of the most massive young (< 10 Myr) star clusters in the flocculent galaxy M 33 decrease with increasing galactocentric radius, in contradiction with a constant shape and upper mass limit of the cluster mass function. Moreover, by comparing the radial distributions of gas surface densities and most massive cluster masses, we find that $M_{max} \propto \Sigma_{gas,total}^{3.8\pm0.3}$, $M_{max} \propto \Sigma_{H2}^{1.2\pm0.1}$, and $M_{max} \propto \Sigma_{SFR}^{0.9\pm0.1}$. Hence, given the systematic radial trend of maximum cluster mass and the correlation with Σ, we can rule out stochastic star formation in M33. The change of the maximum cluster mass there must be due to physical causes.

Introduction

► The stellar initial mass function (IMF) and the initial mass function of star clusters (ICMF) are two of the most fundamental distribution functions in astronomy. While their form seems to be universal, there is less agreement about how the high-mass regime of both functions is populated. The upper mass limits are treated to be independent of the environment, and therefore the typical mass of the most massive object that occurs in a sample should increase with the size of the sample. However, in the case of the IMF, there is a growing amount of evidence that massive stars are not forming in low-mass star clusters (Weidner & Kroupa 2006; Weidner et al. 2010; Hsu et al. 2012), and that the most massive galaxies have a bottom-heavy IMF (Ferreras et al. 2013). While things are less clear for the ICMF, Larsen (2009) has found that if the mass distribution of young clusters is fitted by a Schechter type function, its knee is located at larger masses for starburst than for normal galaxies.

► In parallel with this, significant efforts have been undertaken to try to understand the relation between gas surface density (Σ_{gas}) and star formation rate (SFR; i.e., the star formation law). Empirical correlations have been found between the disk star formation rate surface density, Σ_{SFR}, and Σ_{gas} –either total, neutral or molecular (usually based on CO). And here, too, the SFRs inferred, respectively, from the Hα line and the FUV flux are not consistent with a universal IMF.

This project

► We look into these issues from two angles, using a sample of < 10 Myr star clusters in M33 compiled by Sharma et al. (2011). Firstly, we demonstrate by using bins with equal number of star clusters that the masses of the most massive ones decrease with increasing galactocentric radius, therewith ruling out a purely randomly sampled constant ICMF. Next, we find correlations between the third most massive cluster mass, M_{3rd}, and Σ_{gas}, Σ_{H2} and Σ_{SFR}, using published gas data and the same cluster sample.

Future work: the Magellanic Clouds

Available data

UV: Swift (2120, 2310, 2910 Å) and GALEX (1550, 2300 Å).

Optical continuum: u, v, b, i. Project MCPS (Las Campanas).

Hα: projects MCELS and SHASSA (CTIO).

IR: 3.6, 4.5, 5.8, 8.0, 24, 70, 160 μm. Project SAGE (Spitzer).

Radio: 21 cm line and 20 cm continuum (ATCA & Parkes), and ^{12}CO(J=1→0) (Mopra) to estimate Σ_{HI}, Σ_{H2} and Σ_{SFR}.

Determine young (< 20 Myr) and very young (<3 Myr) samples

Galaxy kinematics changes the medium surrounding clusters.
Massive stars disappear soon.

Obtain cluster age, *Z*, *E(B-V)*, hence mass

Method 1: stellar main sequence turn-off point in CMD.
Method 2: if method 1 is unavailable, fit stellar and/or cluster SEDs with current evolutionary models.

Search for correlations between

Masses of clusters and environment conditions as traced by Σ_{HI}, Σ_{H2} and Σ_{SFR}.
Masses of clusters and mass of their most massive star.

Methodology: bins with equal number of clusters in M33

► In order to exclude possible size of sample effects, we divide the sample of 356 star clusters with M> 600 $M_\odot$ in equal bins with 17 clusters. If star formation is stochastic, there should be no radial dependence of the *i*-th most massive star cluster. In each bin we determine the 1st to 5th most massive star clusters. These are shown in Fig. 1, *left*, connected by solid lines. There is a trend for the mass to decrease with radius. The radial distance dependence of the *i*-th most massive star cluster can be described by a linear fit: $\log_{10}(M_{cl}/M_\odot) = a\,(r/\text{kpc}) + b$ (eq. 1), where M_{cl} is the cluster mass and *r* is the galactocentric radius.

► We also perform a Monte Carlo experiment. For each bin, we draw N=17 star clusters from an ICMF $\xi_{cl}(M_{cl}) = dN/dM_{cl} \propto M^{-\beta}$, with β = 2, lower mass limit $M_l = 600 M_\odot$, and upper mass limit $M_{up} = 10^7 M_\odot$. The 1st to 5th most massive star clusters are identified and fitted like the observational data. Fig. 1, *right*, shows the distribution of the slope *a* after 10^6 repetitions. The observed slope of the 3rd most massive star cluster if all star clusters are considered is a = 0.146. The probability that a slope of *a* = 0.146 or steeper is the result of a randomly sampled ICMF with a radius-independent upper mass limit of $10^7 M_\odot$ is 1.3×10^{-9}.

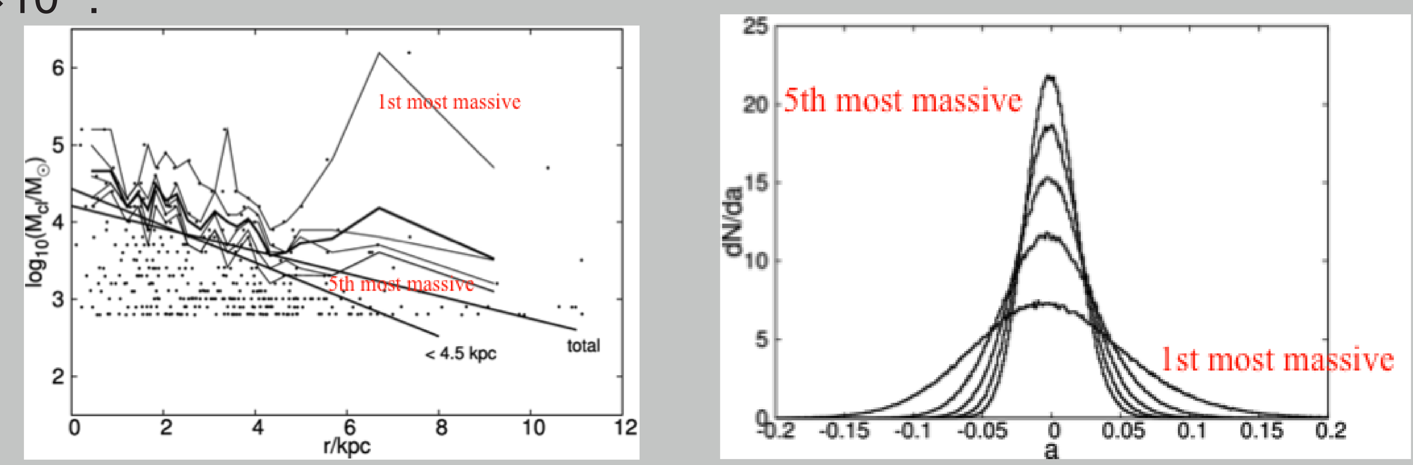

Figure 1: *Left:* radial position and mass of young star clusters (points) in M33, from Sharma et al.(2011), above the completness limit of 600$M_\odot$. The thick straight lines show the linear fit by eq. 1 to the 5th most massive star cluster for two cases: (i) only star clusters with a galactocentric radius smaller than 4.5 kpc, (ii) all star clusters (Pflamm-Altenburg et al. 2013). *Right:* The distribution functions of the slope *a* in eq. 1 for the 1st (widest Gaussian), 2nd, 3rd, 4th, and 5th (narrowest Gaussian) most massive clusters as a result of Monte Carlo simulations for case (i) (Pflamm-Altenburg et al. 2013).

Gas and star formation rate densities

► We find correlations between cluster mass, and gas and SFR surface densities of the form: $\log_{10} M_i = \beta_x' \log_{10} \Sigma_x + \alpha_x'$, where M_i is the mass of the *i*-th most massive star cluster, and *x* stands for HI, H_2, total gas or SFR. Fig. 2, *left,* shows $\log_{10}$ of star cluster mass versus $\log_{10}\Sigma$, in bins with equal N, for a sample of clusters with a completeness limit of 1000 $M_\odot$. We get, for the 3rd most massive cluster, $M_{3rd} \propto \Sigma_{gas}^{3.8\pm0.3}$; $M_{3rd} \propto \Sigma_{H2}^{1.2\pm0.1}$; $M_{3rd} \propto \Sigma_{SFR}^{0.9\pm0.1}$. No correlation is found between M_{3rd} and HI. The Kolmogorov-Smirnoff test shows that, indeed, the mass cumulative probability distributions for clusters with $M_{clust} > 10^3 M_\odot$ change smoothly with radius.

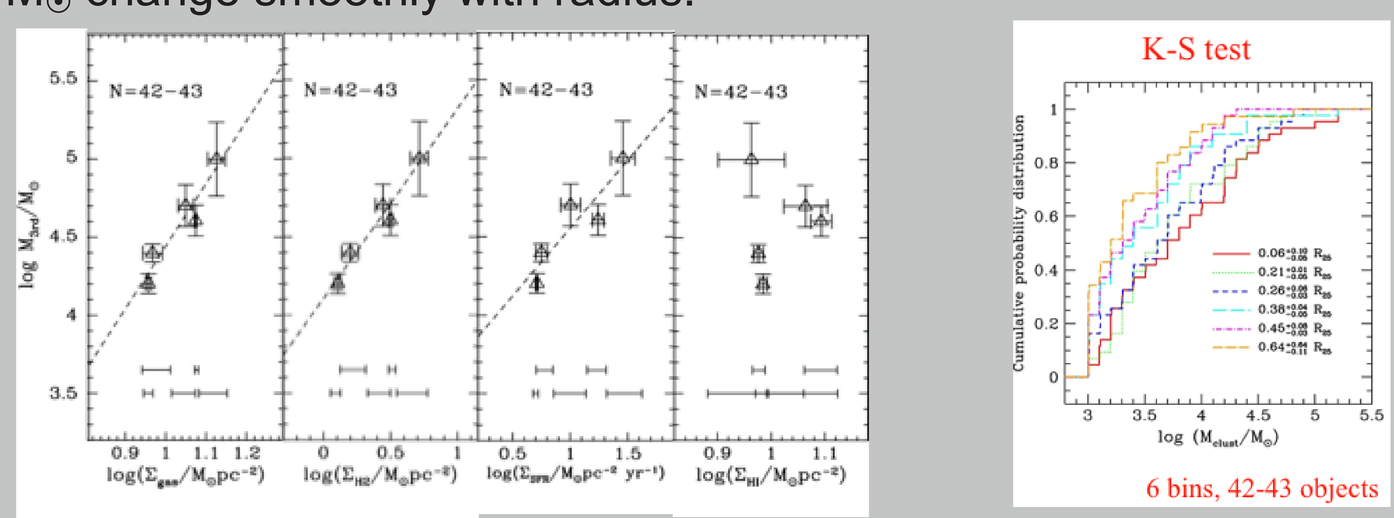

Figure 2: *Left:* M33, $\log_{10} M_{3rd}$ vs. $\log_{10} \Sigma_{gas}$, Σ_{H2}, Σ_{SFR}, and Σ_{HI}; *dashed line:* linear fit. Number of clusters in each bin N=42-43. The bar at the bottom of each panels shows surface density ranges of the bins (González-Lópezlira et al. 2013). *Right:* K-S test; cumulative distributions of mass for clusters with $M_{clust} \geq 10^3 M_\odot$, in the six annuli whose median radii are indicated.

Conclusions

► The formation of very massive clusters seems to be increasingly suppressed with larger galactocentric radius in M33. This is not a size of sample effect.

► A significant correlation exists between massive cluster mass, and gas and SFR surface densities. This correlation is not a size-of-sample effect, either.

► Very massive star clusters seem to require special physical conditions to form.

► A possible alternative is that the ICMF is not universal but, rather, has a slope that changes from β ′ ≈ 1.2 in the inner kpc of the galaxy to ≈ 2 at 4 kpc and beyond.

► **If the ICMF and IMF depend on the SFR, recalibration of SF tracers and of mass- to-light ratios may be required.**

References

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