TESTING THE ROLE OF EXTERNAL UV RADIATION ON THE FORM OF IMF AT THE LOW-MASS END IN YOUNG CLUSTERS

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ABSTRACT

In the star formation process, the mass of a star at birth is an important physical quantity as it determines the subsequent evolutionary path of the star. In this process, the vital role of external UV radiation from nearby massive stars in the form of the Initial Mass Function (IMF), at the very low mass end is yet to be understood. Hence a systematic, high sensitive observational analysis of a sample of regions under diverse UV environments is imperative. We obtain the IMF down to the brown dwarf regime for 8 young clusters (<5 Myr) located at the Galactocentric distance (Rg) of range ~6-12 kpc along with the nearby cluster IC348 using deep near-IR photometry and data from GAIA-DR2. These clusters are embedded in diverse massive stellar environments of radiation strength $\log(L_{FUV}/L_{sun})$ ~2.6 to 6.8 ergs/s and $\log(L_{EUV})$ ~42.2 to 50.85 photons/s. We test for any systematic variation of the form of IMF and its characteristic mass with respect to the radiation field strength in these clusters. This work is the first of its kind to obtain the very low mass end of the IMF of these distant clusters and to verify the role of external UV radiation on its universality.

DATA USED

- Deep near Infra red data in J (1.2μm), H (1.6μm) and K (2.2μm) bands.
- ***Observations***: 4m Mayall Telescope, Kitt Peak National Observatory, Arizona, Extremely Wide Infrared Imager (NEWFIRM)
- ***Surveys***: UKIRT Infrared Deep Sky Survey (UKIDSS), Massive Young Star forming complex study in IR & X-ray (MYStIX) Survey
- Our NIR photometry is complete down to 0.08$M_\odot$

CLUSTERS UNDER STUDY

IC1848 - West	IC1848 - East
Cygnus OB2	Stock 8
NGC 1893	NGC 2244
NGC 2362	NGC 6611

SAMPLE SELECTION

- The clusters have well-defined pre-main sequence population in the J vs J-H color-magnitude diagram.
- The clusters have uniform reddening.
- Young clusters of age < 10 Myr with galactocentric distance ~ 6-12 kpc.

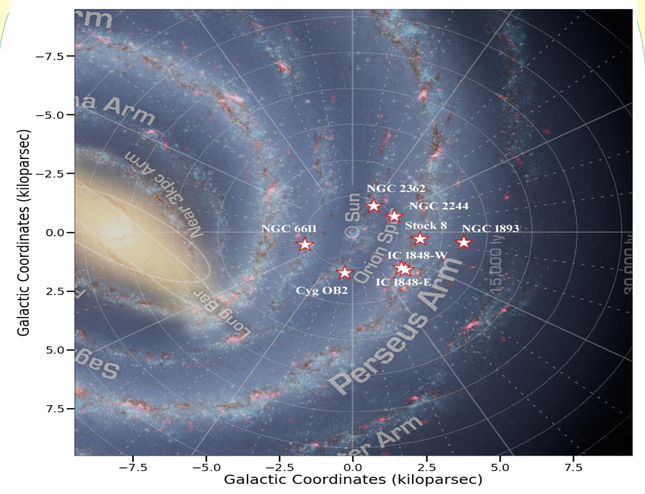

Fig 1: Spatial distribution of the 8 clusters with respect to the Sun and the Galactic centre.

ANALYSIS

1 Distance Estimation:

- Clusters for which distance calculated using GAIA DR2 was unvailable we used the GAIA DR2 parallax from Bailer-Jones et al. (2018) to estimate the distances.
- Sources within cluster radius with parallax uncertainty <0.2 mas were considered.
- (In Fig2.) Distance to IC1848-W was found to be 2.2 ± 0.4 kpc.

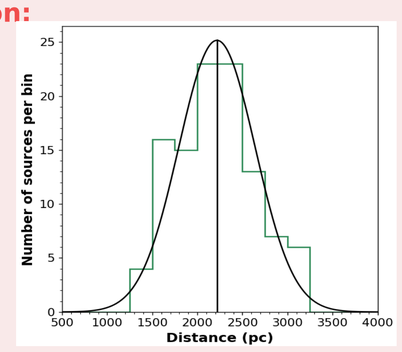

Fig 2: Histogram of Distance for the sample cluster IC1848-W

2 Extinction Estimation:

- We use the empirical relation between extinction and colour-excess due to reddening with the known intrinsic colour value to estimate the extinction (Ak) for all the clusters.
- (In Fig3.) Extinction (Ak) for IC1848-W was found to be 0.14 ± 0.05 mag.

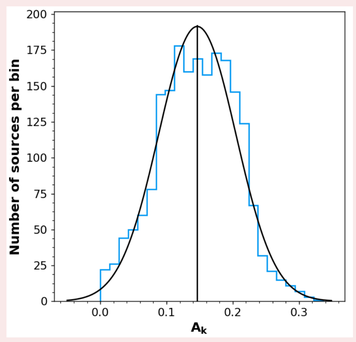

Fig 3: Histogram of Extinction towards sample cluster IC1848-W

3 Age Estimation:

- The VOSA SED analyser[2] was used to obtain the age of the clusters.
- (In Fig4.) HRD of sources in IC1848-W with age < 10Myr. The luminosity and T_{eff} were obtained from the VOSA SED analysis. Baraffe et al.(2015) evolutionary tracks and isochrones are shown as white dotted and continuous lines respectively.

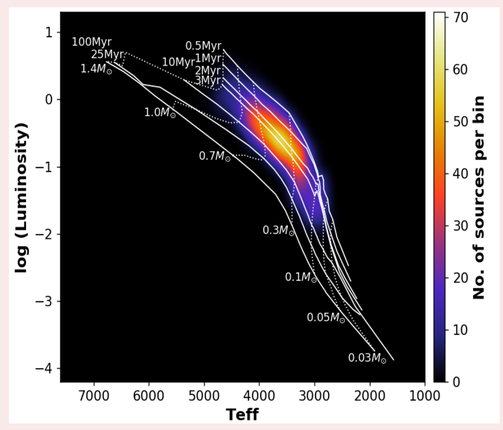

Fig 4: HR diagram of sources in IC1848-W.

4 Field Star Decontamination:

- To remove field stars from cluster sample a nearby control field was used.
- (In Fig5.) The sequence on the left in (a) & (b) is the field star population, the extra sequence to the right in (a) is the candidate PMS cluster members.
- Statistical subtraction was performed.
- The dotted line in (c) is the mean of the gaussian curve fitted for the colour axis. The continuous line marks the mean±3σ. The sources between the continuous lines are taken as possible cluster members.

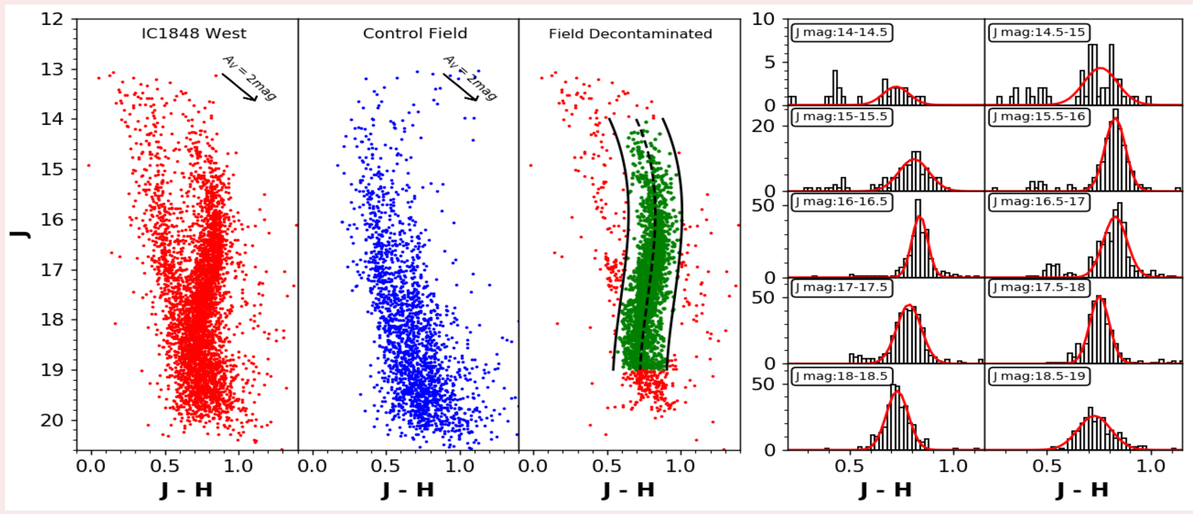

Fig 5: (a) Sample cluster IC1848-W (b) Reference field (c) Probable cluster members after statistical decontamination (d) Sample histogram to estimate the locus of the PMS population

5 Mass Estimation:

- Mass of the individual cluster members were obtained from mass-magnitude relation using PMS stellar evolutionary models (Baraffe et al.(2015) for sources <1.4$M_\odot$; Siess et al.(2000) for sources > 1.4$M_\odot$)
- System IMF for the field decontaminated PMS sources within 90% photometric completeness(~13-18mag i.e. ~3-0.08$M_\odot$) was obtained by counting the number of stars in a logarithmic mass interval of bin size, log(m) = 0.2.

Cluster Parameters

Cluster	Distance (kpc)	Age (Myr)	Extinction (Ak)
IC1848 West	2.2 ± 0.4	2 ± 1	0.14 ± 0.05
IC1848 East	2.3 ± 0.5	2 ± 1	0.21 ± 0.07
Cygnus OB2	1.7 ± 0.3	2± 2	0.54 ± 0.08
Stock 8	2.2 ± 0.4	3 ± 2	0.15 ± 0.07
NGC 1893	3.7 ± 0.6	2 ± 3	0.15 ± 0.07
NGC 2244	1.5 ± 0.1	2 ± 3	0.10 ± 0.06
NGC 2362	1.3 ± 0.1	3 ± 2	0.04 ± 0.03
NGC 6611	1.7 ± 0.1	2 ± 1	0.29 ± 0.11

RESULTS

Initial Mass Function:

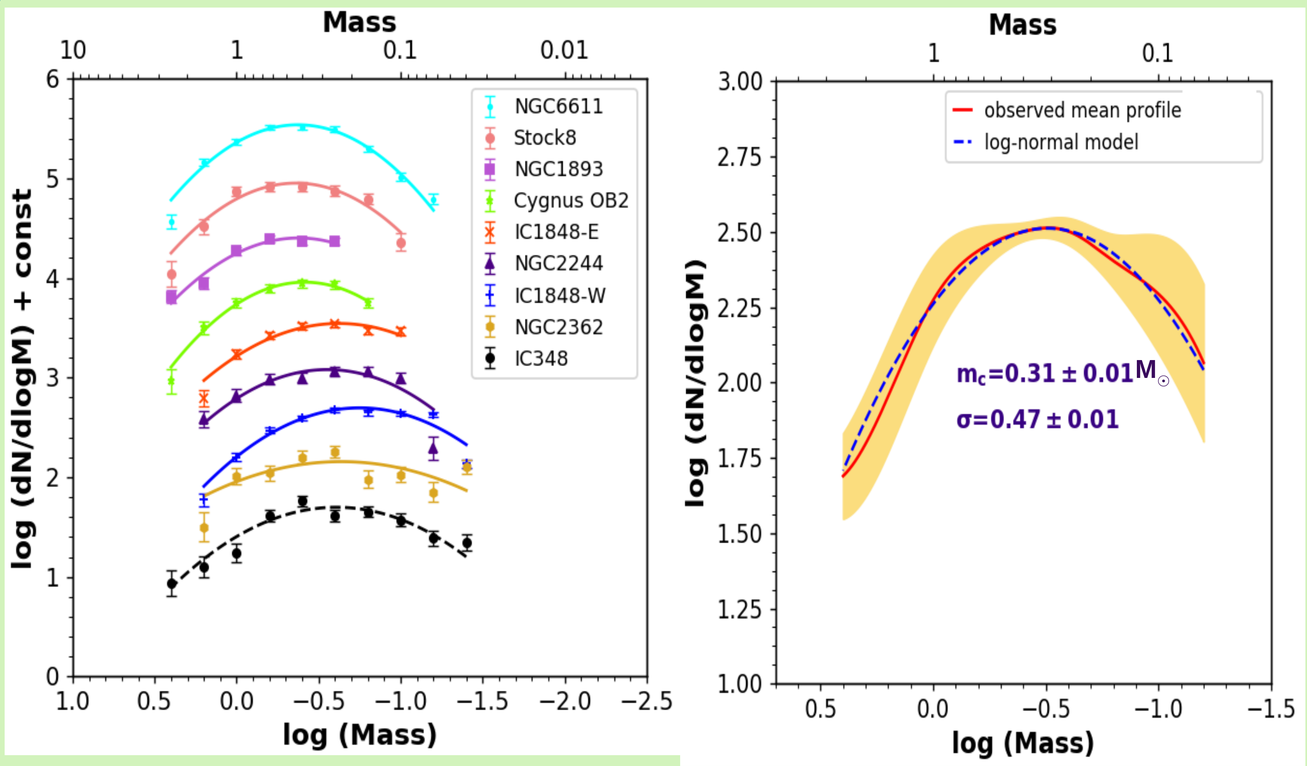

Fig 6: (Left) IMF for all the clusters. Error bars denote the Poisson error on each data point. The curves are the log-normal fits to the individual cluster IMF. The mean of the characteristic mass and σ of all the 9 clusters is m_c=0.32±0.05 and 0.49±0.07. (Right) Red curve is the mean of all the clusters in each mass bin of the left figure and the blue dotted curve is the Chabrier (2003) log-normal distribution. The shaded region marks the 1σ deviation from the mean.

Effect of external factors on the form IMF and on the characteristic mass:

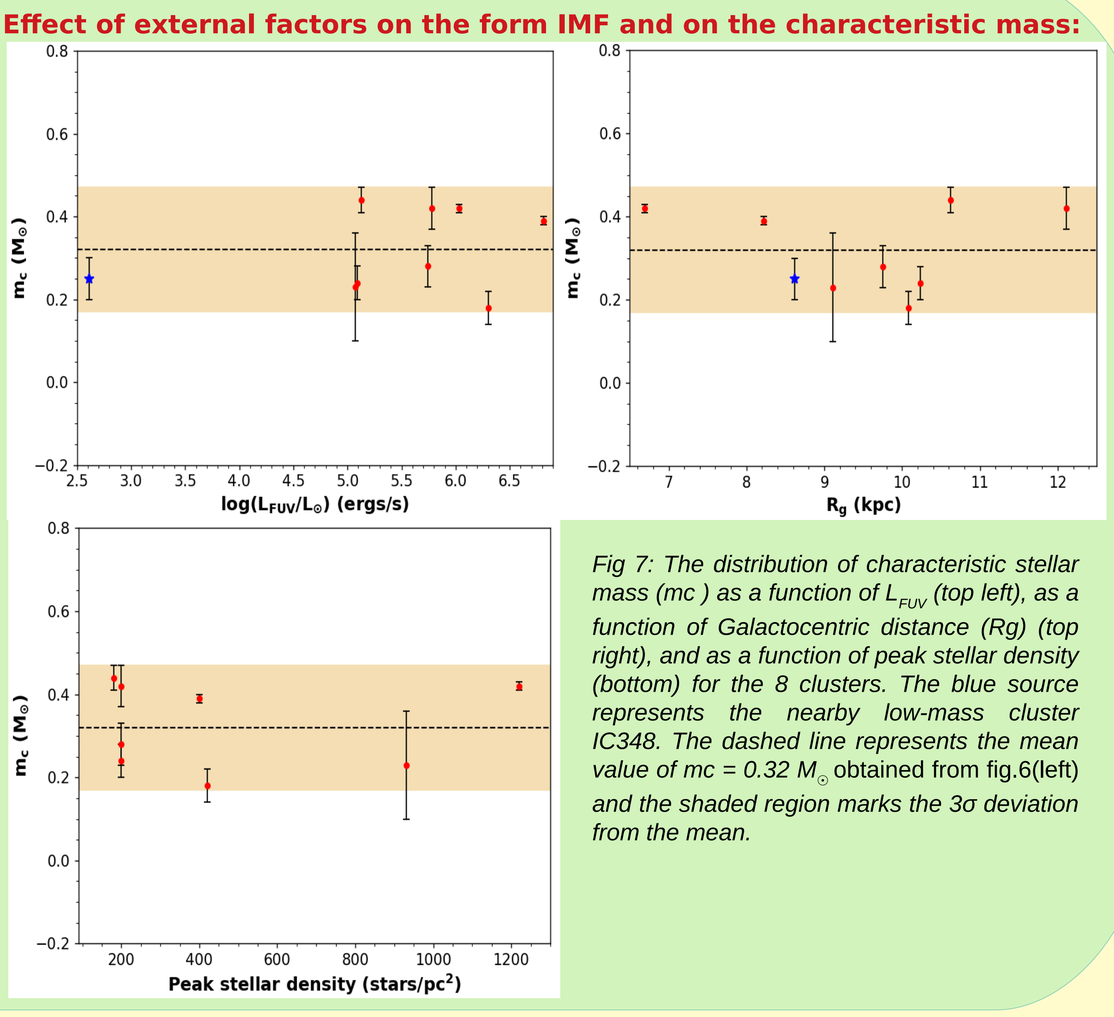

Fig 7: The distribution of characteristic stellar mass (mc) as a function of L_{FUV} (top left), as a function of Galactocentric distance (Rg) (top right), and as a function of peak stellar density (bottom) for the 8 clusters. The blue source represents the nearby low-mass cluster IC348. The dashed line represents the mean value of mc = 0.32 $M_\odot$ obtained from fig.6(left) and the shaded region marks the 3σ deviation from the mean.

CONCLUSION

- We have studied the IMF of 8 young clusters with a distinct, well-defined Pre-Main Sequence population in J-H vs J colour-magnitude diagram. Our deep **NIR photometry is complete down to the brown dwarf limit** (0.08$M_\odot$).
- The clusters are embedded in radiation environments of field strength, **$\log(L_{FUV}/L_{sun})$ ~2.6 to 6.8 ergs/s** and molecular cloud mass of 10^4 to 10^5 $M_\odot$ with peak stellar density at the cluster centers **~170 - 1220 stars/pc².**
- Using surface density analysis we have obtained the radius and center of the clusters. We have obtained probable PMS membership by meticulous statistical subtraction of the control field population.
- Using GAIA DR2 parallax data, we have estimated the distance to the clusters and the clusters are located at **R_G ~ 6-12 kpc.** Except Cygnus OB2, all the clusters have **A_K ~ 0.05 - 0.3mag** (i.e., A_V < 2.5 mag) with a narrow spread of ~ 0.07 mag, showing that the reddening variation within the adopted radius is relatively low in the clusters. The mean age of our regions lie in the range **~ 1-3 Myr**, implying that the clusters are indeed young and thus the effect of dynamical evolution is expected to be minimal.
- The Initial Mass function is obtained using the mass-luminosity relation and was found to have a uniform trend for all the 8 clusters. A mean fit of the curves, gives **m_c= 0.31 ± 0.01 $M_\odot$ and σ = 0.47 ± 0.01.**
- **We do not find any strong dependence of radiation field strength, galactocentric distance and stellar density on the shape of IMF as well as on characteristic stellar mass.**
- **We do not find any significant deviation in the form of IMF** at the very low mass end, implying that the role of external factors due to massive stars has only a weak role in shaping the IMF.
- **This study is the first of its kind, to obtain the low-mass end of the Initial Mass Function of distant rich young clusters**.

REFERENCES

Bailer-Jones C. A. L., et al. 2018, AJ, 156, 58; Baraffe, I., 2015, A&A, 577, A42; Chabrier G., 2003, PASP, 115, 763; Siess L., Dufour E., Forestini M., 2000, A&A, 358, 593;
[2]http://svo2.cab.inta-csic.es/theory/vosa/