Star formation in the spiral galaxy NGC 4736★

Farhanul Hasan[1], Alison Crocker[1]

1. Department of Physics, Reed College, Portland, OR, 97202

Introduction: Low star formation in galactic centers

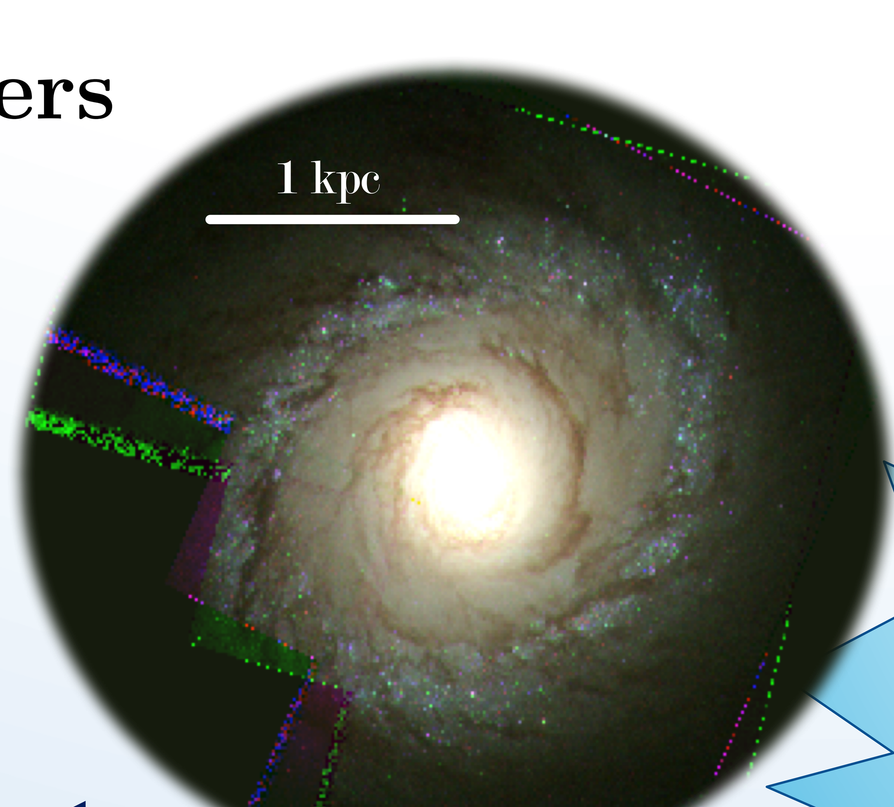
Galactic centers are known to host intense gas densities, pressures, temperatures and other extreme conditions similar to star-bursting galaxies.

Kennicutt (1998) showed that star formation increases with the availability of cold gas:

$$\Sigma_{SFR} \propto \Sigma_{gas}^{1.4}$$

Despite favorable conditions, star formation at the center of the Milky Way and many spiral galaxies has been observed to be inefficient.

NGC 4736, a spiral galaxy 4.66 Mpc away and ~13 Gyr old, that lacks a strong nuclear bar



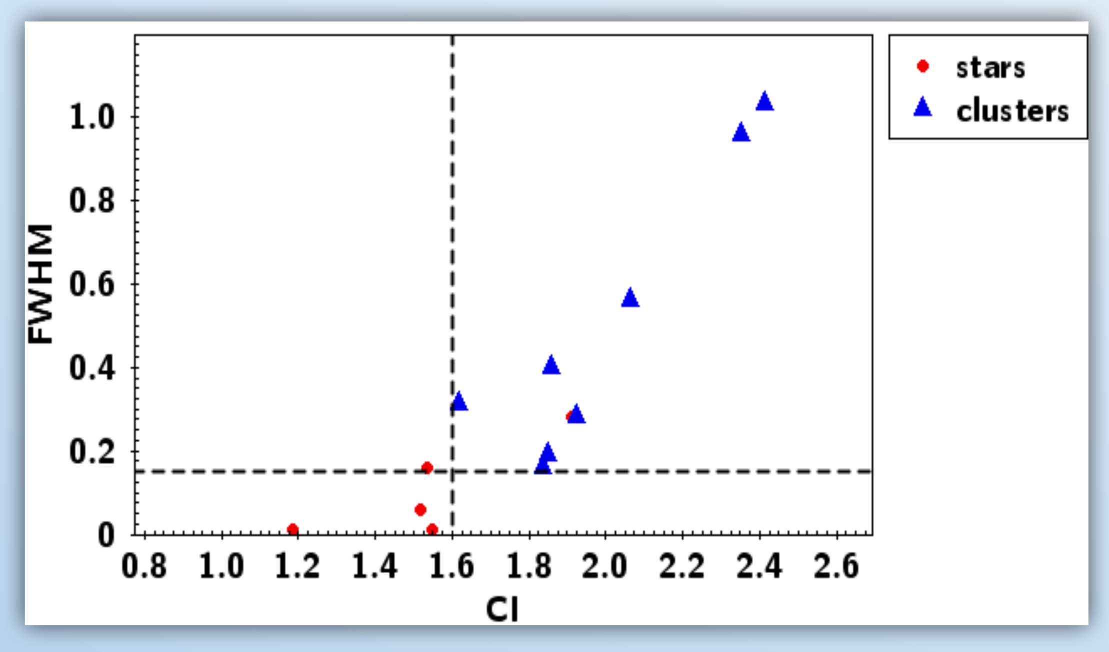
Young, massive star clusters are excellent tracers of star formation.

Most, if not all, stars form in clusters, making star clusters the fundamental units of star formation.
Typical indicators like UV and IR are dominated by old stars and AGN in the inner regions.

Our Aim: Identify and age-date young star clusters in NGC 4736 to estimate the Star Formation Efficiency (SFE) in its center and spiral arms.

Data and sources

- We used *Hubble Space Telescope's (HST)* images of NGC 4736 in F336W (**"U"**), F450W (**"B"**), F555W (**"V"**), F656N (**"Hα"**) and F814W (**"I"**) bands, taken by the Wide Field Planetary Camera 2 (WFPC2).
- We used the DAOFIND algorithm (Stetson 1987) to detect stellar sources from background -subtracted images.
- Sources were selected if they were detected in U,B,V and at least one of Hα and I bands.
- Circular aperture photometry was performed in a 2.5 px (~5.5 pc) radius.
- Sizes were measured: Concentration Index (CI) and Full Width at Half Maximum (FWHM).



Training set showing separation of stars from clusters.

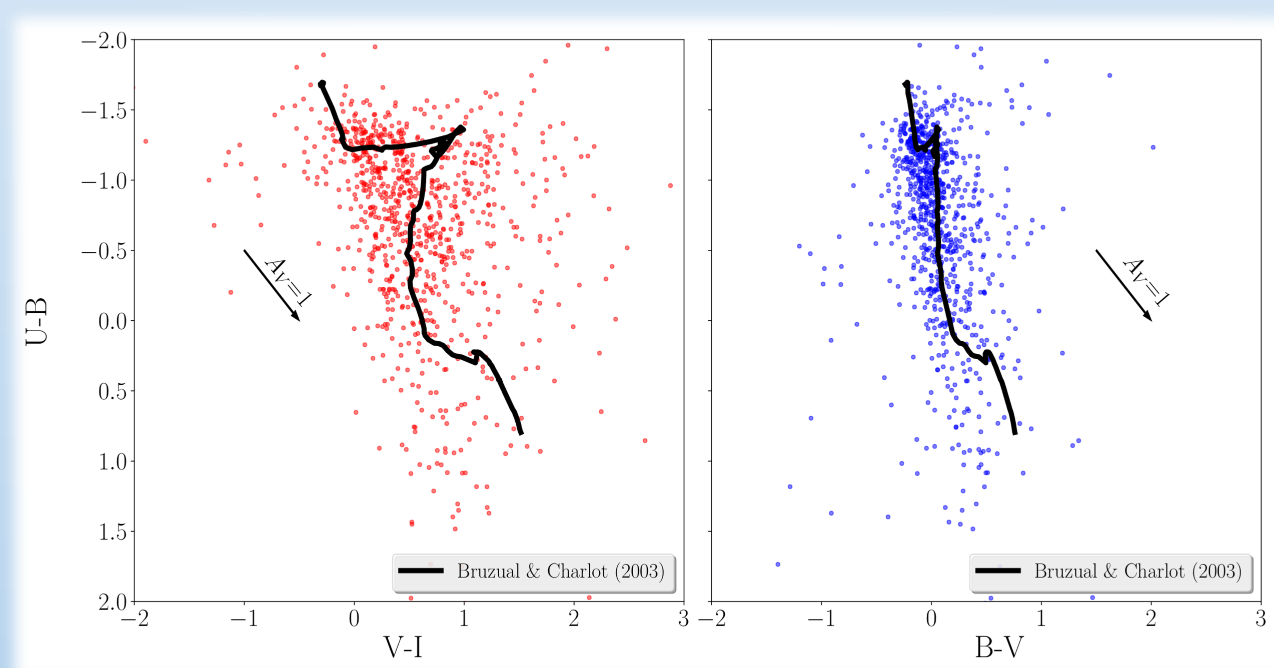
1. Creating a catalog of star clusters

Following the approach of Chandar et al. 2016, we handpicked a training set to guide our process of **separating stars from clusters**, A star cluster satisfies the following criteria:

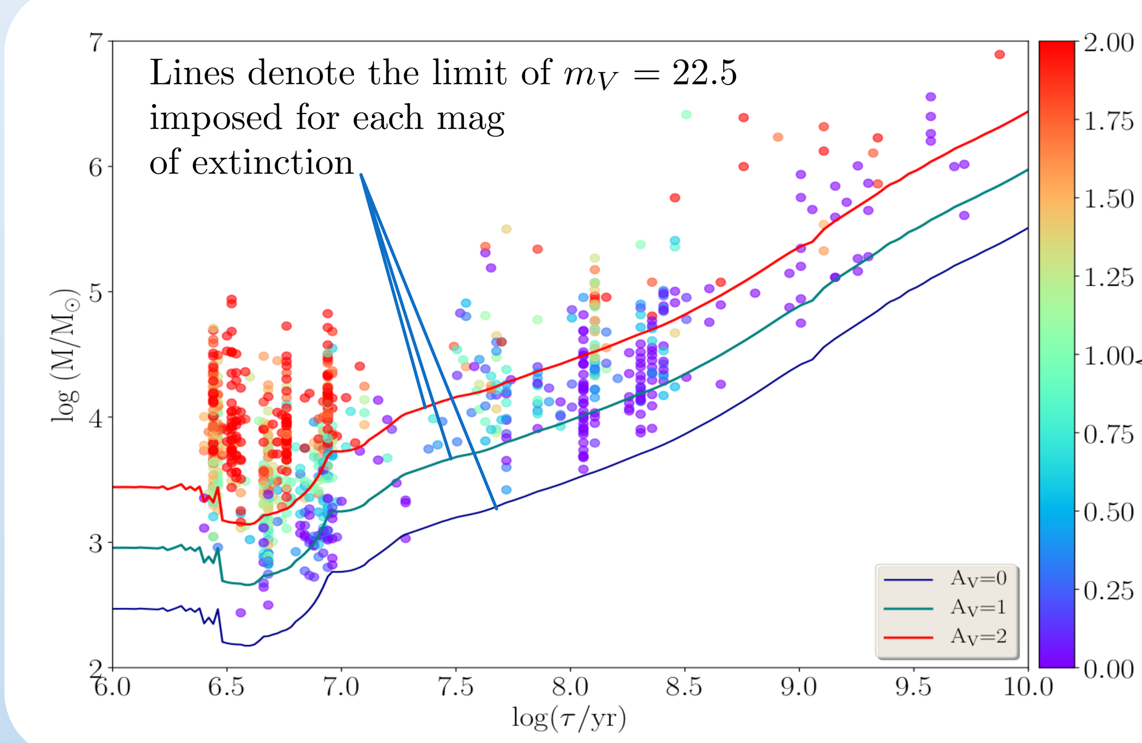
- Brighter in V-band: $m_V \lesssim 22.5$ or $M_V \lesssim -5.8$
- Bigger in size: $1.6 \leqslant$ CI $\leqslant 2.8$ and 0.2 px $\leqslant$ FWHM $\leqslant 5$ px
- Sources that are not close pairs (within 2 pc of each other)

2. Ages and masses from stellar evolutionary models

- We compared our observed magnitudes to those predicted by stellar population synthesis models (2003).
- The age, τ, extinction, A_V, and mass, M, of each cluster are obtained from the best fits to the models.



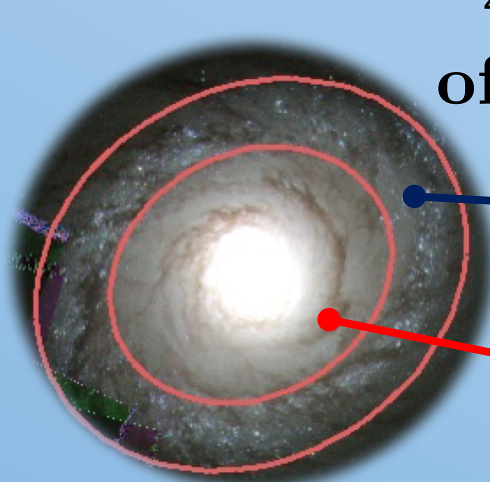
Colors of our sources, with the scatter showing the actual data and black tracks showing the expected evolutionary sequence from models.

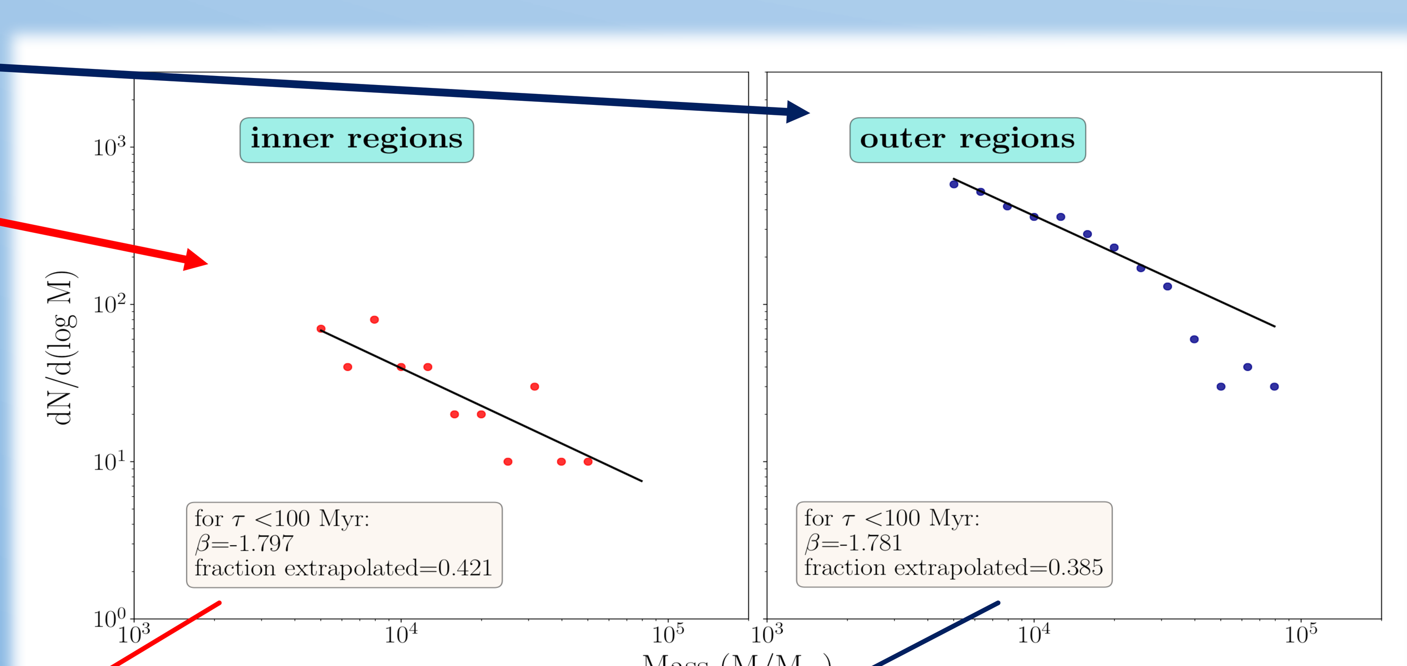


3. Mass-age distribution shows large number of young clusters

- Clusters span the age of the galaxy, but very young ones (< 3 Myr) are embedded in birth clouds.
- Total mass of clusters formed over a certain timescale helps us infer the cluster formation rate (CFR).

4. Mass functions help us extrapolate mass of low-mass clusters below our detection limit

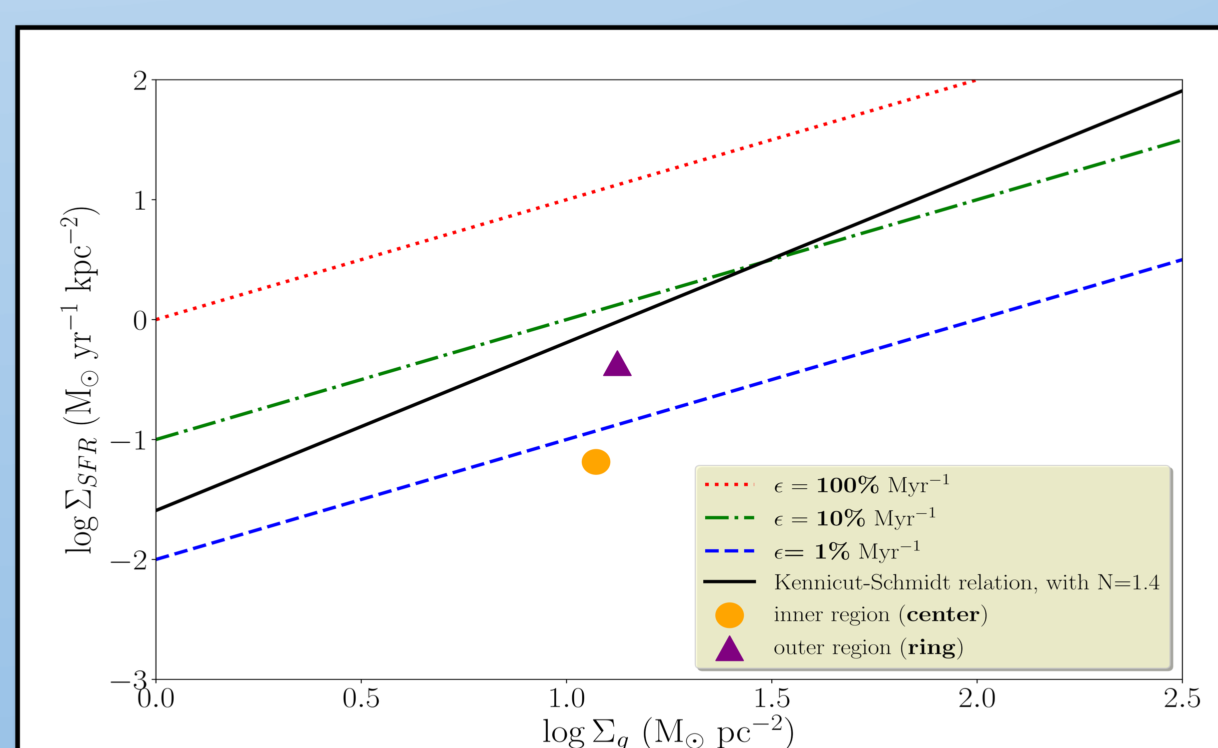




- Much fewer clusters found in the center
- MF approximated well by single power law:

$$dN/d\log M \propto M^{\beta}$$

- More clusters found in the outer regions
- MF approximated by power law up to $\sim 3\times10^4 M_\odot$
- Truncation at high-mass end



For gas densities, we used:

- HI map from the THINGS survey (Walter et al. 2008)
- CO map from the HERACLES survey (Leroy et al. 2009)
- α_{CO} factors from Sandstrom et al. 2013.

5. SFE is lower than predicted; lower in the center

- We quantified Cluster Formation Efficiency (CFE) – fraction of all SF occurring in bound clusters – by using Kruijssen's (2012) function* of galaxy-scale observables, like the rotation curve and Σ_g.
- Σ_{SFR} is calculated from the ratio $\frac{\text{CFR}}{\text{CFE}}$, SFE is the fraction of cold gas used up in Star formation per Myr.

*CFE IDL routine is available at: *www. mpa-garching.mpg.de/cfe*

Quantity	inner region (center)	outer region (ring)
$\log \Sigma_g$ (M$_\odot$/pc^{-2})	1.07	1.12
Cluster formation rate (M$_\odot$/yr)	0.012	0.068
Cluster formation efficiency (%)	8.99	9.91
Star formation rate (M$_\odot$/yr)	0.107	0.951
$\log \Sigma_{SFR}$ (M$_\odot$ yr^{-1} kpc^{-2})	-1.19	-0.36
Star formation efficiency (%)	0.55	3.26

Table: Despite similar gas densities, the center of NGC 4736 is forming stars less efficiently than the ring.

Epilogue: Star formation may be episodic

Our results support the idea that star formation may be a cyclic process; NGC 4736 is undergoing a quiescent period following one of rapid starburst. Turbulent gas motions and the effect of the supermassive black hole might also be important considerations in explaining the surprisingly inefficient star formation at the center. Next, we'll test the predictions of Krumholz et al's (2017) dynamical model to the evidence for ongoing and/or past bursts of star formation.

References

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