San Diego State University

LEGUS Star Cluster Age Distribution Analysis of NGC 1566

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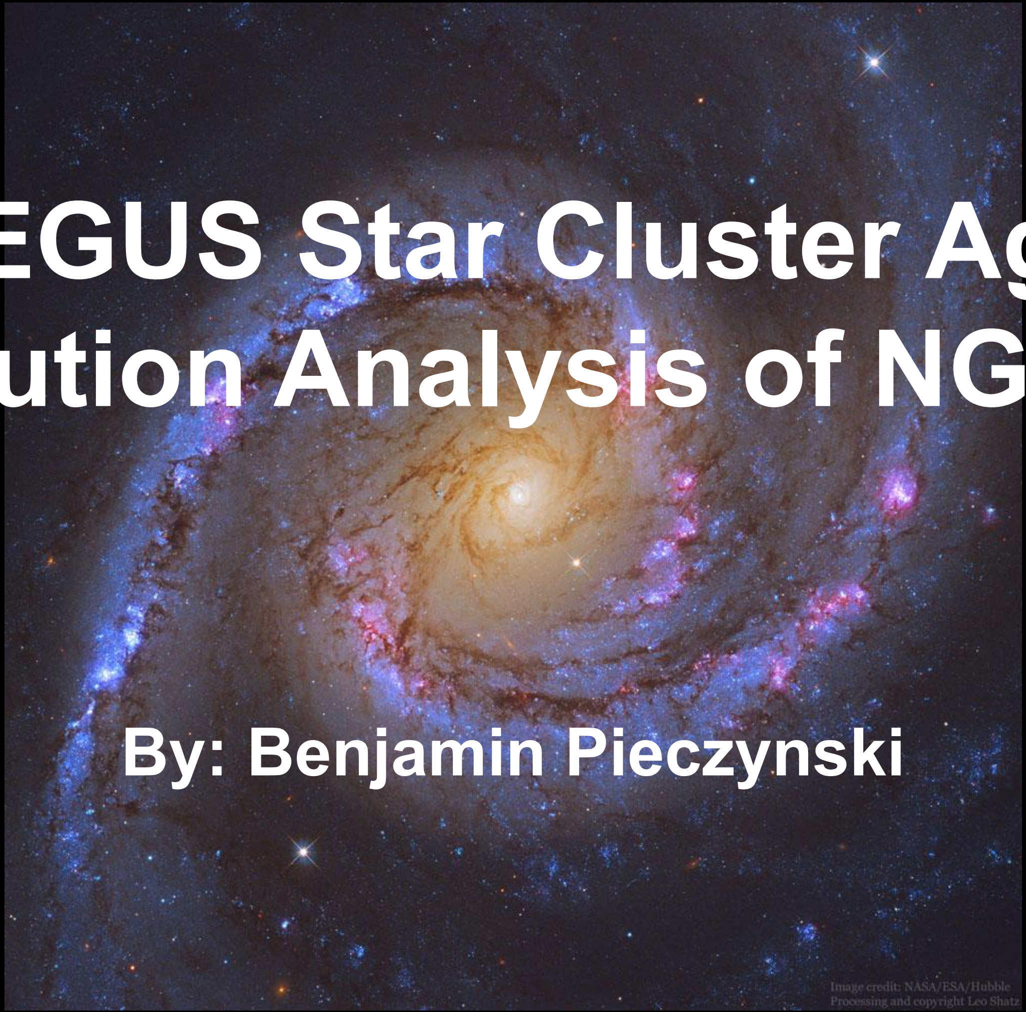
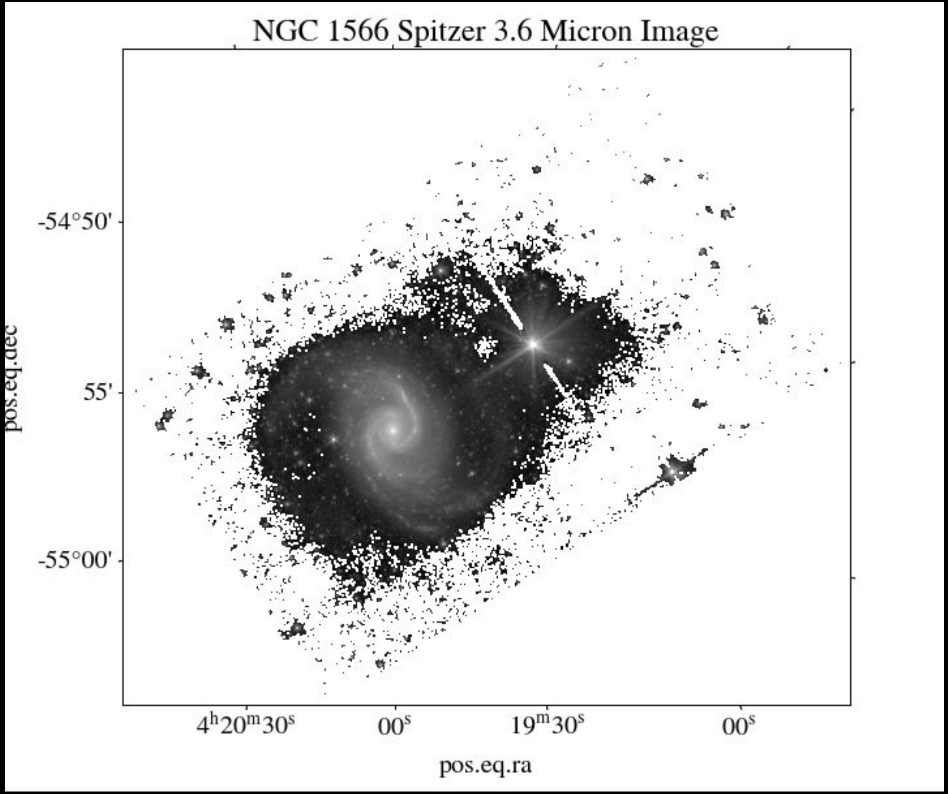


NGC 1566

- Type: SAB(rs)bc and is a Seyfert galaxy
- Distance 21.3 Mpc
- $M_* = 6.5 \times 10^{10} M_\odot$
- $L = 1.2 \times 10^{11} L_\odot$
- Dark Matter Fractions 0.58 - 0.66

Sources:
Elagali et al. 2019, Meurer et al. 2006



Spiral Structure from Star Cluster Distributions

Simulations

- Dobbs & Pringle (2010) modeled gas flow in spiral galaxies for different excitation mechanisms
  - Self-Excitation: through local instabilities or density wave theory (Lin & Shu 1964; Bertin et al. 1989)
  - External tidal effects (companion galaxies / collisions)
  - Internal tidal Effects (central rotating bar)

Star Cluster Distribution Analysis

- UBVI Hα measurements to age date clusters
  - HST WFC3 or WFPC2
- Chandar et al. 2017 studied M51 to use star cluster age distributions to study possible spiral structure excitation mechanisms.

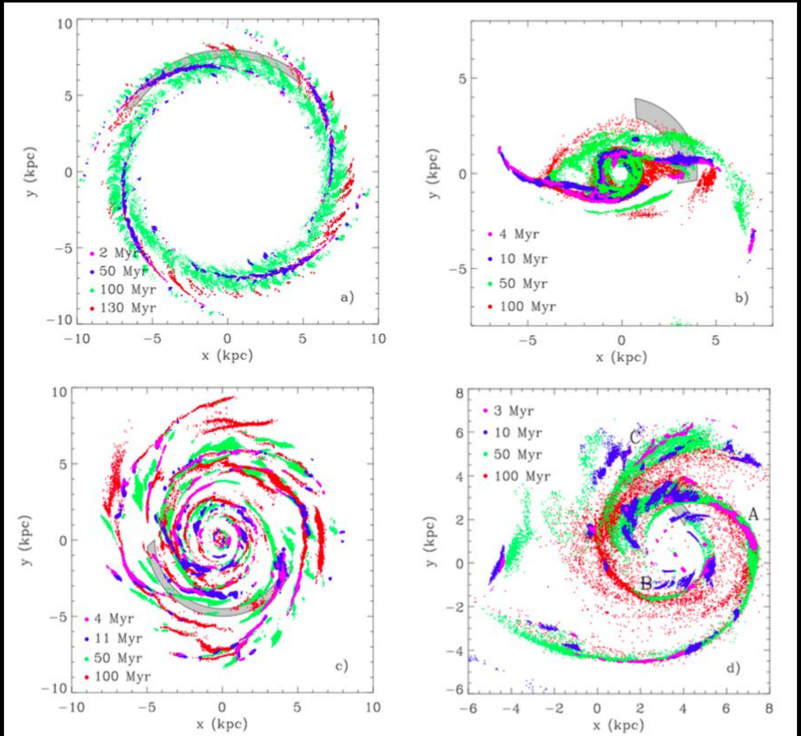


Figure from Dobbs & Pringle (2010) showing star cluster distributions for different excitation mechanisms.

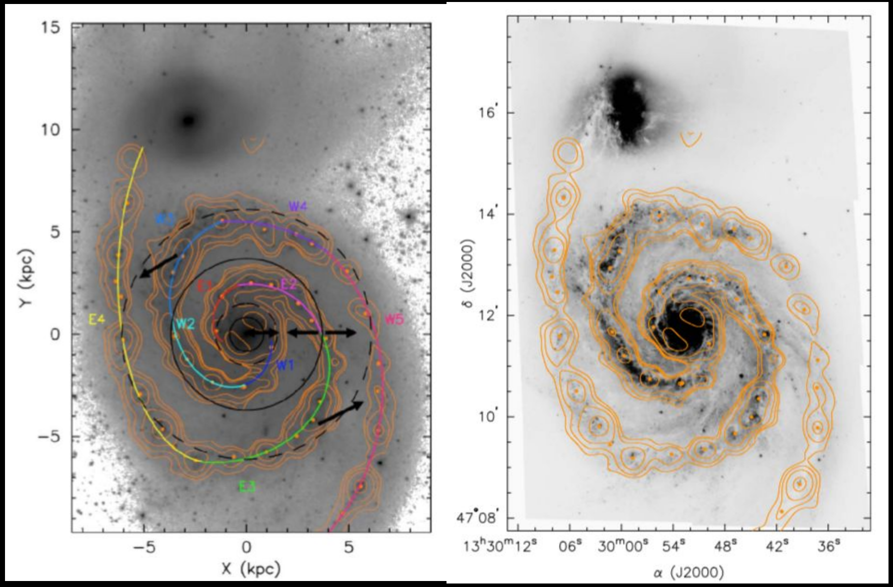
Methods: Studying Star Cluster Distributions

Methods by Chandar et al. 2017

- Derived cluster ages from UBVI Hα measurements (Chandar et al. 2011)
- Use 3.6μ Spitzer images to define spiral arms
  - Logarithmic spiral arms
- Assign clusters located within 2 kpc to each arm
- Separate clusters by age (< 6 Myr, 6-30 Myr, 30-100 Myr, 100-400 Myr)

Findings

- Star cluster distribution peaks in the center of the arms, increase width at older ages.
- Inner spiral arms consistent with a density wave
- Outer spiral arms consistent with an interacting galaxy



Figures from Chandar et al. 2017 showing how spiral arms are defined from 3.6μ peaks in M51.

Why Study NGC 1566 ?

Observational Justification

- HST WFC3 frame captures significant portions of spiral arms
- Available 3.6μ Spitzer images
- LEGUS catalog contains age dated clusters in a large sample size - 2448 clusters (Calzetti et al. 2015)

Scientific Justification

- Can compare with Dobbs & Pringle (2010) to determine excitation mechanisms.
- Study consistency with a Density Wave Theory
- Study the spatial distribution of clusters in the arms

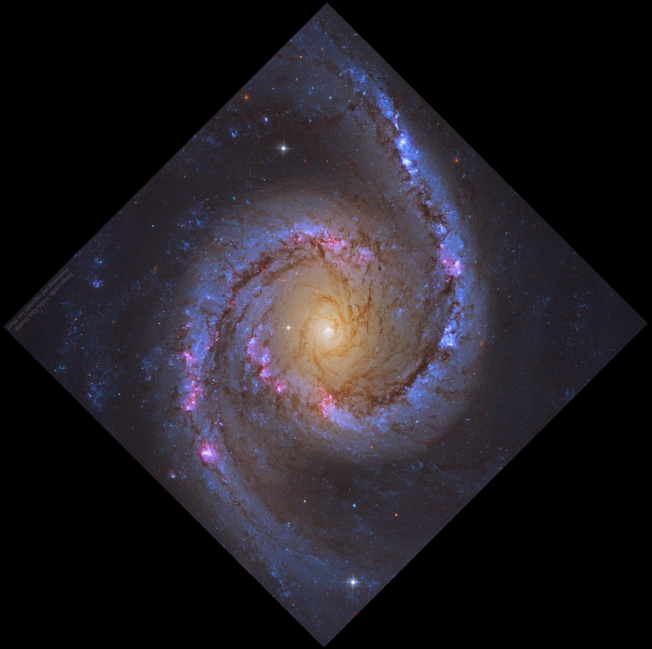
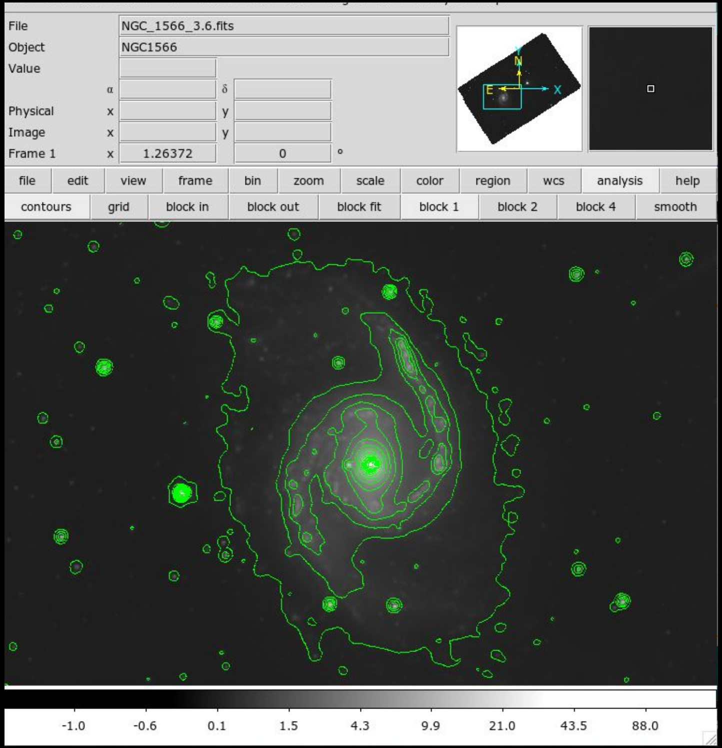


Image Credit: NASA/ESA/HUBBLE
Processing and copyright: Leo Shatz

LEGUS Star Cluster Data

- LEGUS - Legacy ExtraGalactic UV Survey (Calzetti et al. 2015)
- Uses five-band imaging with HST WFC3 and parallel optical imaging with the Advanced Camera for Surveys
- Goal: provide complete inventories of young stellar cluster populations
    - 50 nearby galaxies
    - Ages, masses, extinctions, and spatial distributions
- Cluster Photometry
    - Uses SExtractor (Bertin & Arnouts 1996) to extract sources
    - Filter through candidate clusters using DOLPHOT
- Age dating clusters
    - Automatically and manually filter through the candidates
    - Use χ^2 minimization based SED fitting

Defining Spiral Arms



- Make a contour plot of a 3.6μ Spitzer image
  - Locate peak emission
- Manually fit a logarithmic spiral arm equation to the emission peaks

$$R = A exp[(2\pi / m - \varphi) - tan(i)]$$

R = *radius*

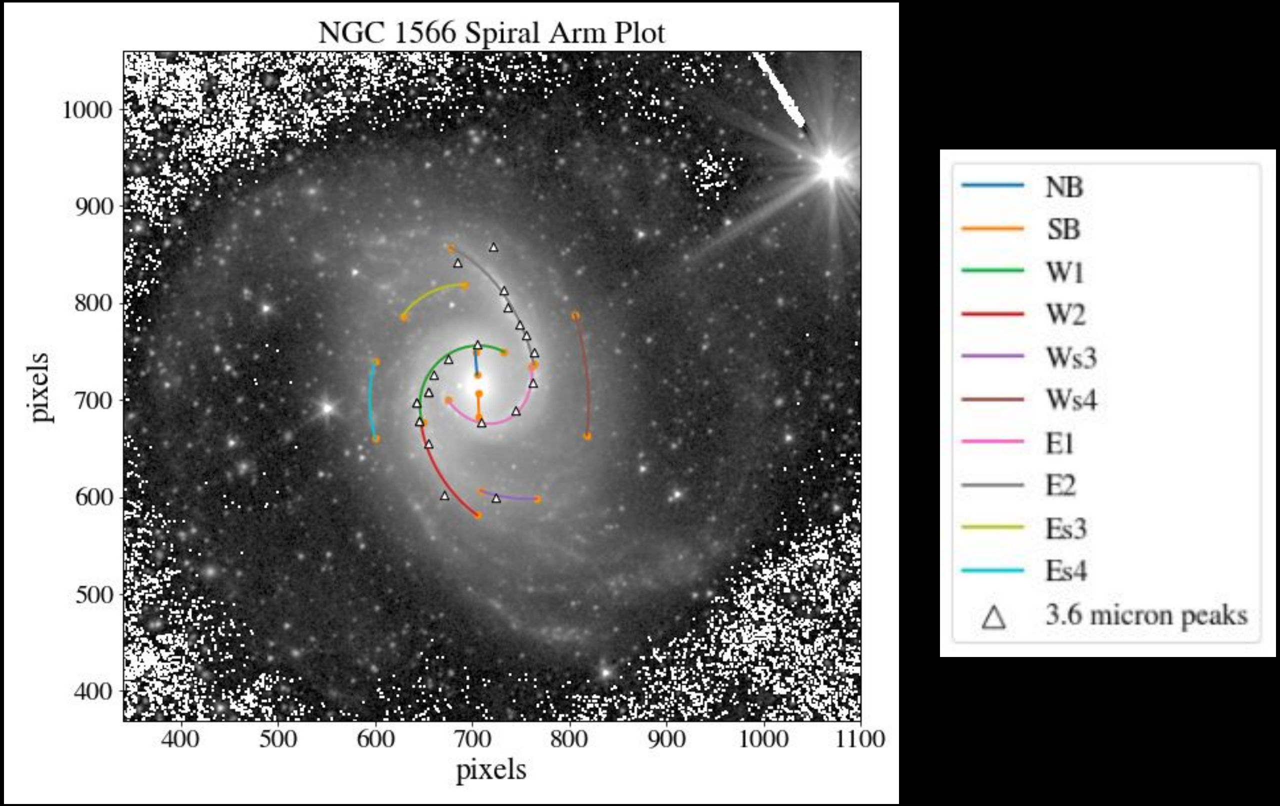
A = amplitude

m = number of spiral arms

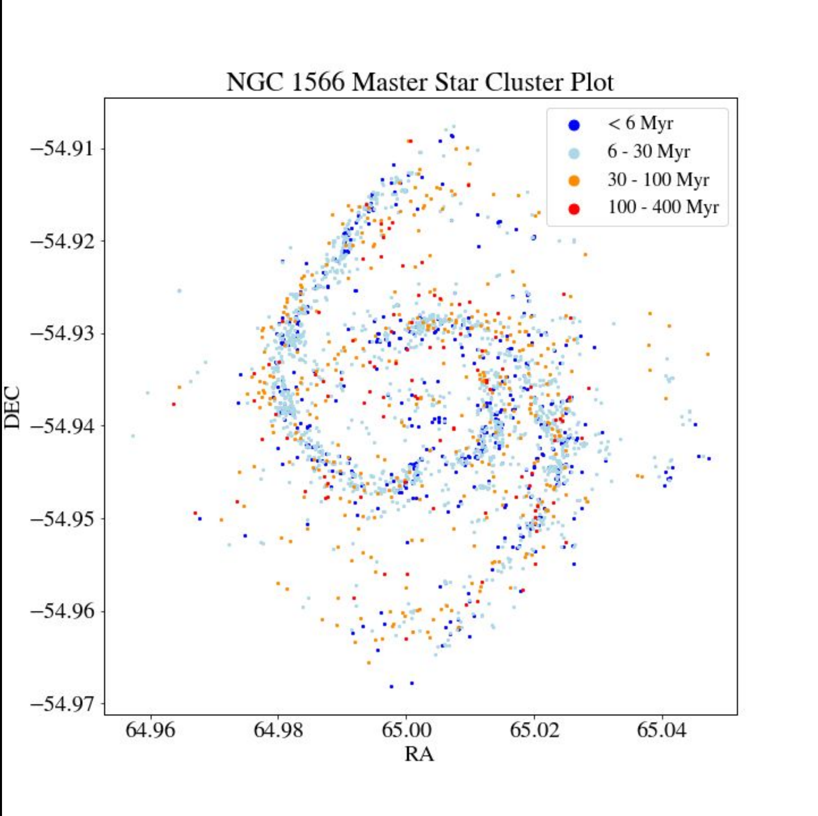
φ = polar angle

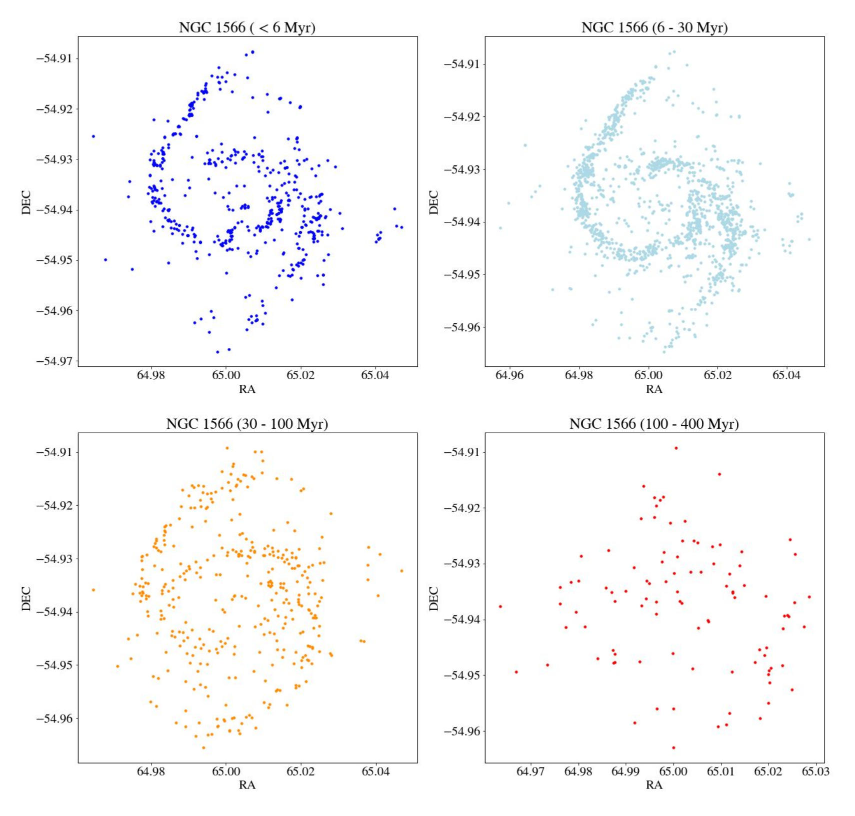
i = pitch angle

Defining Spiral Arms



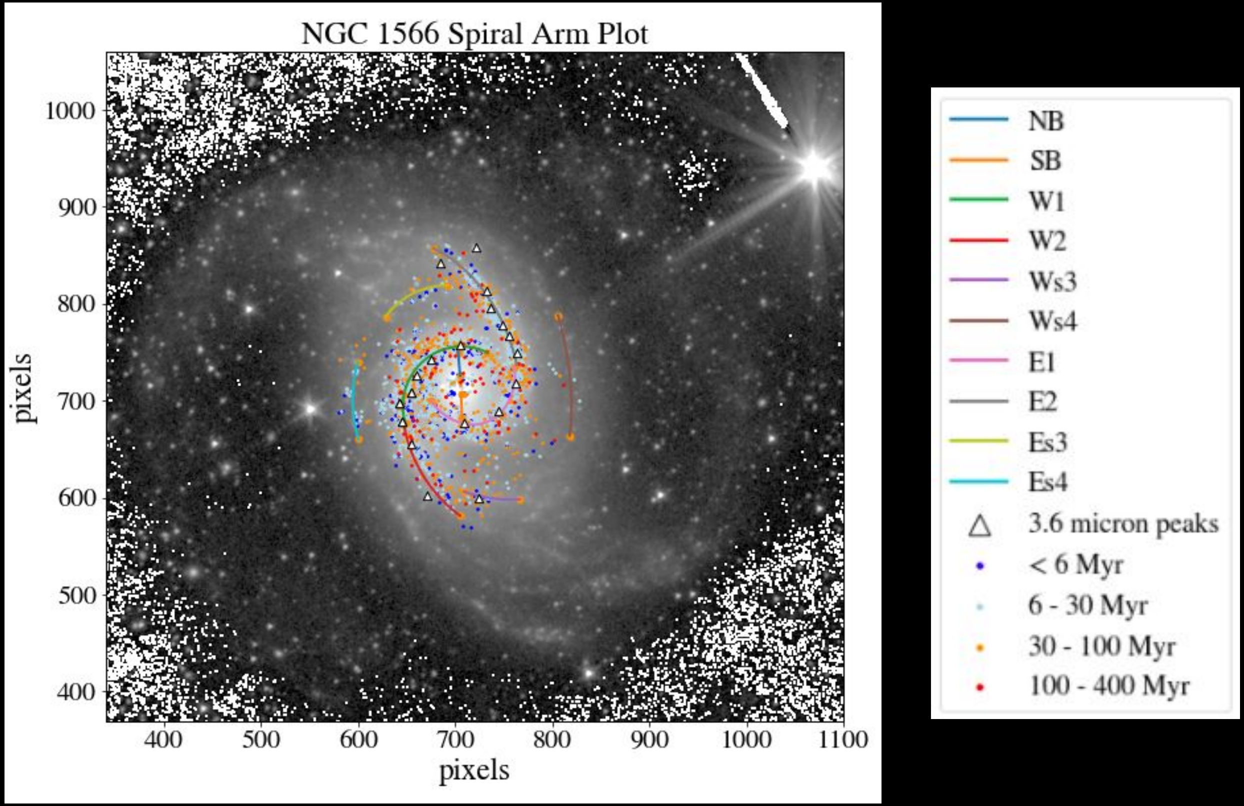
Assigning Clusters to Arms



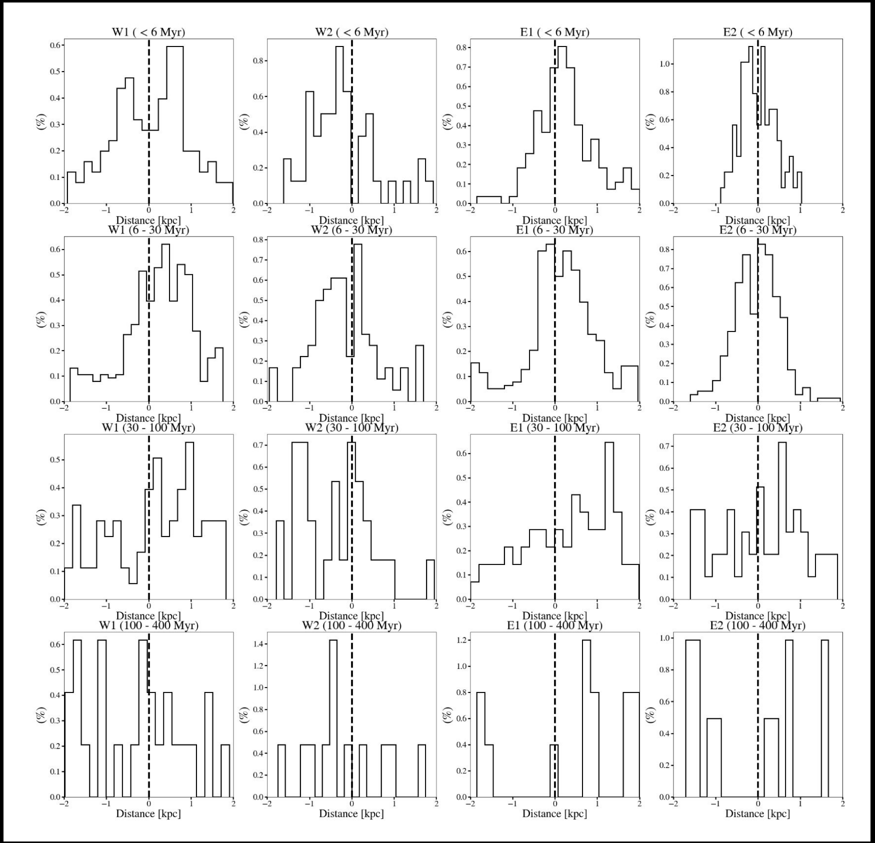


Assigning Clusters to Arms

- If clusters are within 2 kpc they are assigned to the nearest arm segment point.
- This results in an arm assignment
- Examine the distribution of clusters from the center of the arm structure
    - Negative - inner arm
    - Positive - outer arm

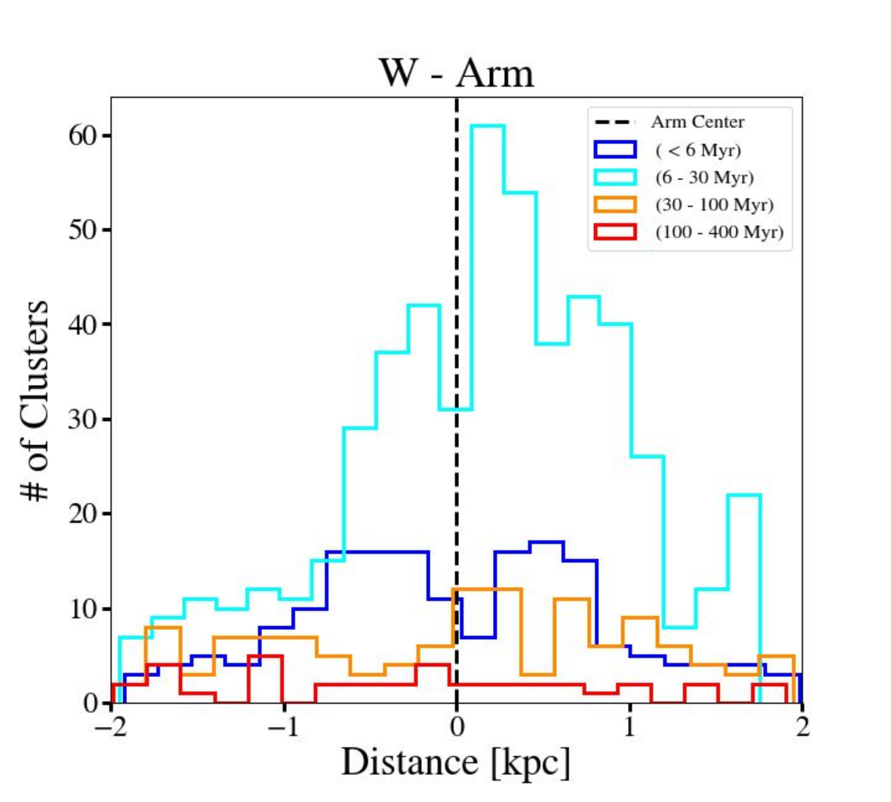


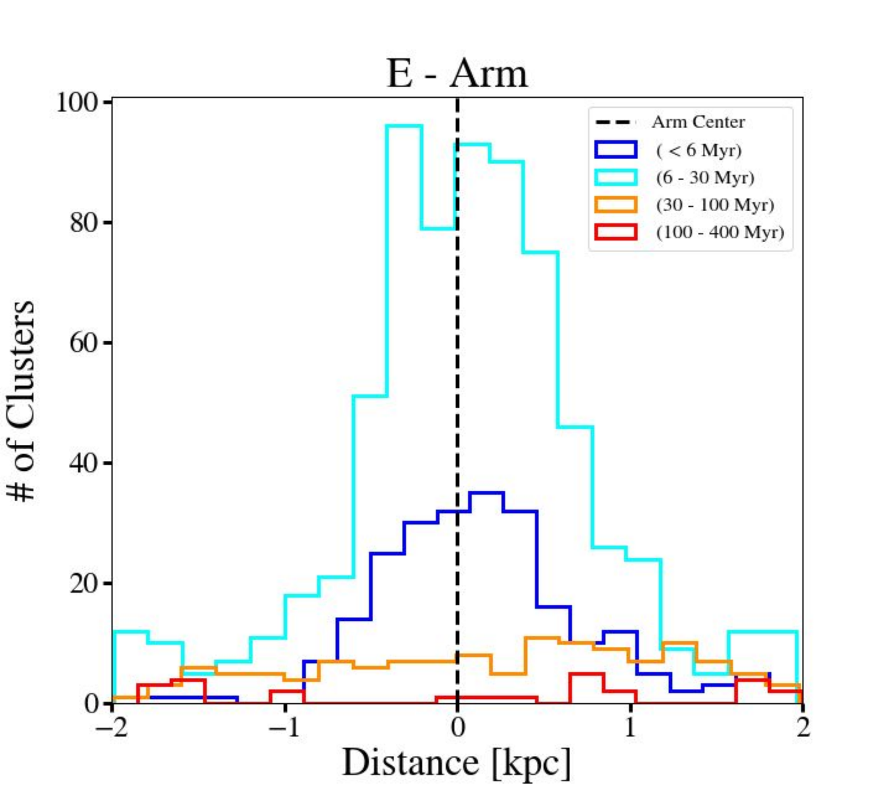
Star Cluster Age Distribution



- Area of each bar normalized to 1
  - For each set of cluster ages
  - 20 bins
- Dashed line is the center of the arm
  - Negative distance - inner arm
  - Positive distance - outer arm
- There was only sufficient data for the primary arms
  - Substructure typically had fewer than 10 clusters
- Each arm segment demonstrates and increase in distribution width as cluster age increases

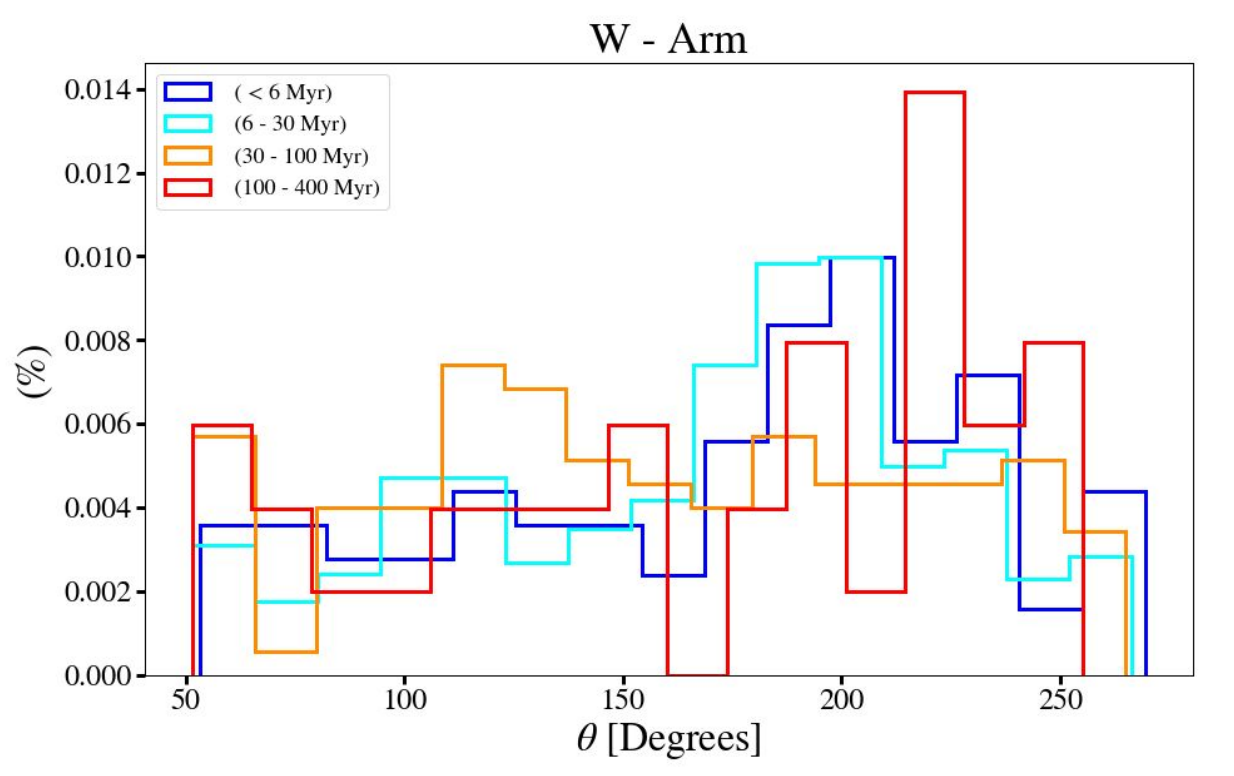
Star Cluster Age Distribution





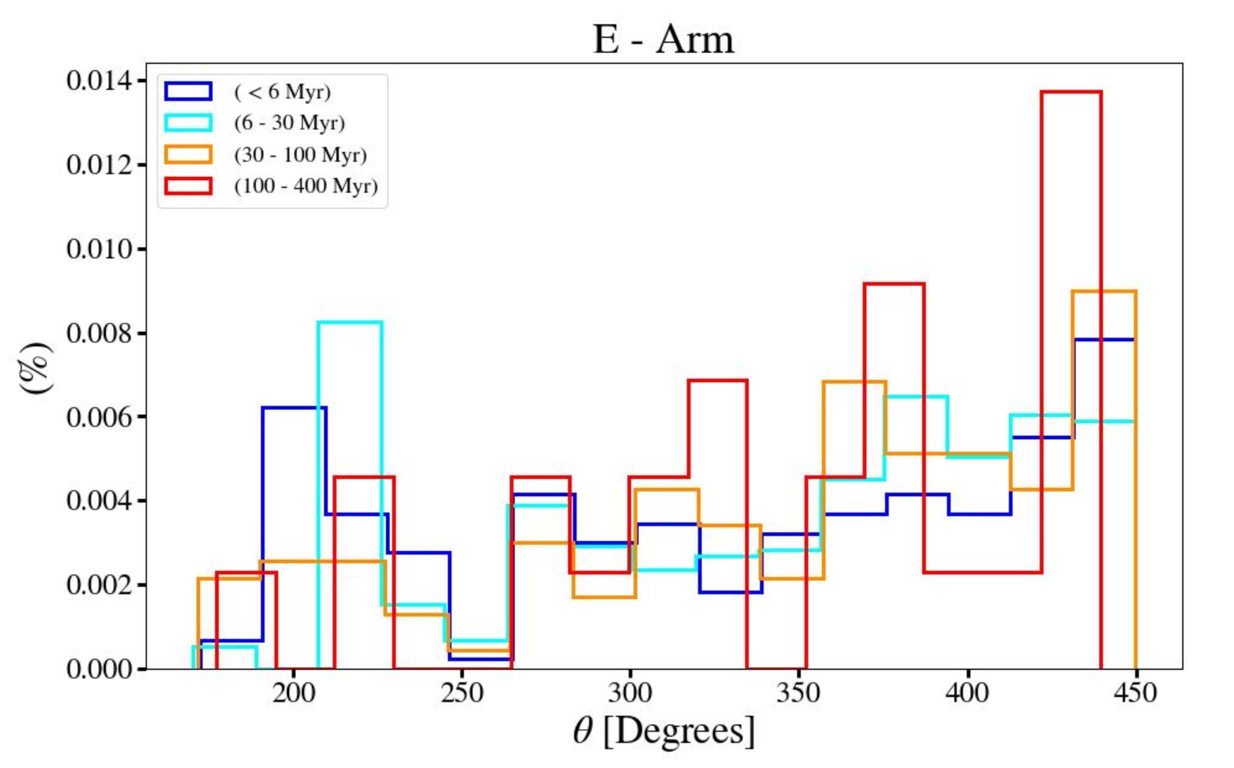
Star Cluster Age Distribution

- Represents cluster position in the West arm
  - $\boldsymbol{\theta}$ - N of E
- Normalized to 1 for each age group
- Comparing to Dobbs & Pringle (2010) to determine excitation mechanism
- Displays monotonic sequence - consistency with a density wave and bar models.



Star Cluster Age Distribution

- Represents cluster position in the East arm
  - $\boldsymbol{\theta}$ - N of E
- Normalized to 1 for each age group
- Comparing to Dobbs & Pringle (2010) to determine excitation mechanism
- Displays monotonic sequence - consistency with a density wave and bar models.



Star Cluster Age Distribution - Findings

- **NGC 1566 shows star clusters peak in the center at younger ages and disburse over time**
  - Older clusters have wider distance distributions
  - Consistent with Dobbs & Pringle (2010) and similar result to Chandar et al. 2017
- **Both the West and East Arms display monotonic sequences of star cluster age distribution**
  - Consistent for the fixed pattern speed model (density wave theory)
  - Consistent for the bar unstable model
  - Agrees with Dobbs & Pringle (2010) and Shabani et al. (2018)

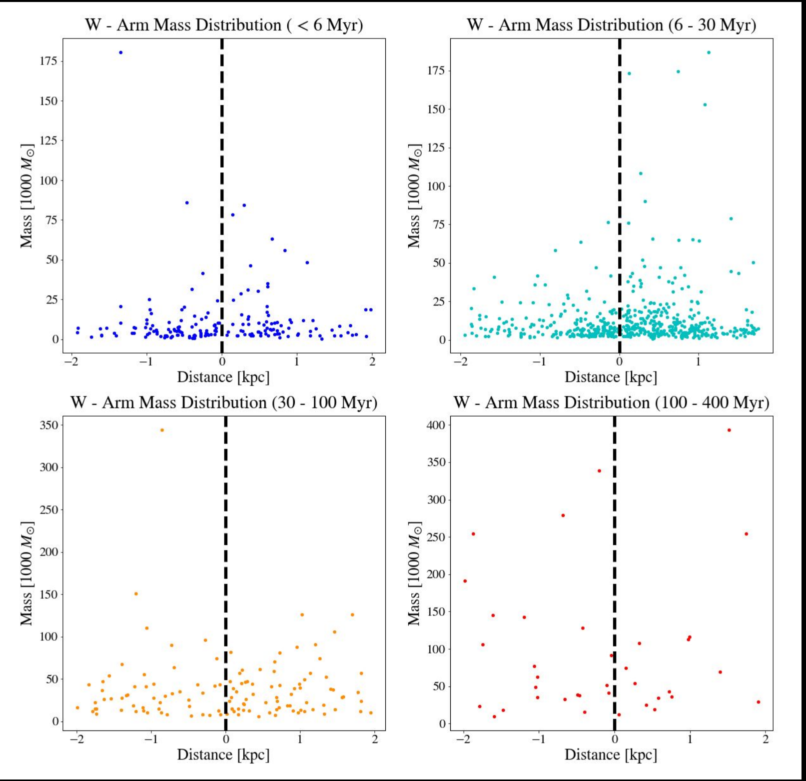
West Arm

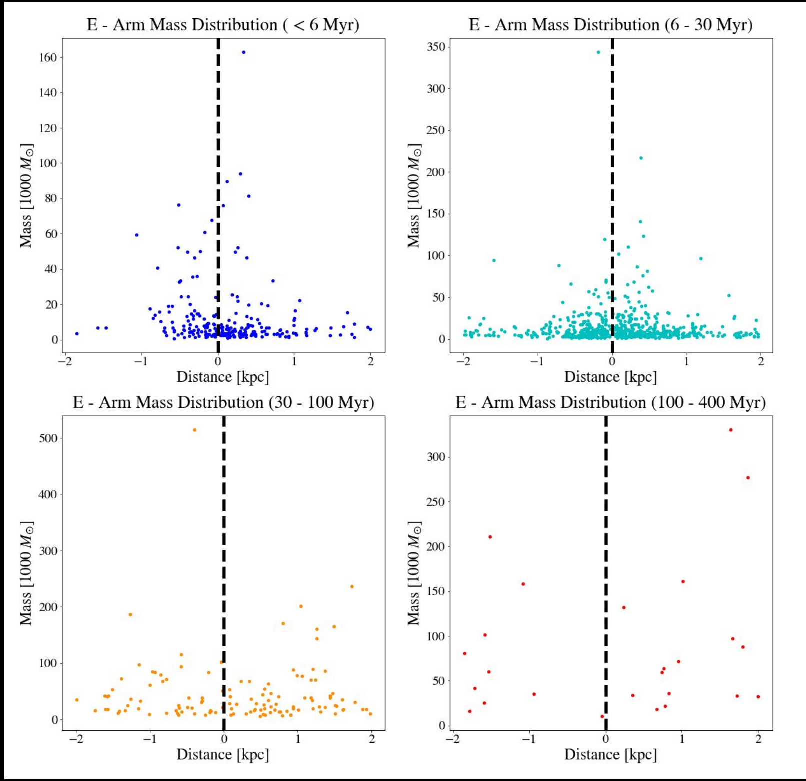
ages	mean Dist [kpc]	median Dist [kpc]	σ Dist [kpc]
str13	float64	float64	float64
< 6 Myr	-0.006384	-0.093584	0.854428
6 - 30 Myr	0.158724	0.197902	0.805578
30 - 100 Myr	0.025075	0.146356	1.033819
100 - 400 Myr	-0.232757	-0.200775	1.058411

East Arm

ages	mean Dist [kpc]	median Dist [kpc]	σ Dist [kpc]
str13	float64	float64	float64
< 6 Myr	0.145586	0.10292	0.604285
6 - 30 Myr	0.070157	0.090407	0.705812
30 - 100 Myr	0.200962	0.363238	0.994919
100 - 400 Myr	0.137123	0.673023	1.339077

Star Cluster Mass Distribution





Star Cluster Mass Distribution - Findings

- **The median NGC 1566 star cluster mass increases with the cluster ages**
  - Massive clusters having more gravity and can avoid mass loss
  - Would indicate the larger the cluster the longer it could survives
  - Consistent with Kroupa (2001)
- **Plausible that larger clusters form in the center of the arms**
  - Could be due to higher gas density
  - Needs more analysis

West Arm

ages	mean mass	median mass	σ mass
str13	float64	float64	float64
< 6 Myr	11274.914368	5677.5	18923.955323
6 - 30 Myr	12981.342857	7195.0	19373.966066
30 - 100 Myr	38287.430894	28600.0	39284.213336
100 - 400 Myr	95949.621622	53960.0	94604.077278

East Arm

ages	mean mass	median mass	σ mass
str13	float64	float64	float64
< 6 Myr	11782.500426	5458.0	18610.710575
6 - 30 Myr	12875.116382	6838.0	21737.031394
30 - 100 Myr	46570.603175	27160.0	59442.035047
100 - 400 Myr	87936.8	60240.0	81387.116608

NGC 1566 - Key Findings

- **The star cluster distribution peaks in the center of the arms, and the distribution width increases with age.**
  - Consistent with Dobbs & Pringle (2010)

- **Both the West and East Arms displays monotonic sequences of star cluster age distribution**
  - This agrees with ‘Density Wave theory’ and models for a barred spiral galaxy (Dobbs & Pringle 2010)

- **Findings in agreement with Shabani et al. (2018)**

- **The median NGC 1566 star cluster mass increases with cluster age**

- **Evidence that larger clusters could form in the center of NGC 1566 arms**
  - Needs more analysis

Future Work

- Apply this method to different galaxy types
- Observe NGC 1566 sub structures that have insufficient cluster data
- Investigate the formation of larger clusters in the center of spiral arms

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References

Elagali, A., Staveley-Smith, L., Rhee, J., et al. 2019, MNRAS, 487, 2797. doi:10.1093/mnras/stz1448

Meurer, G. R., Hanish, D. J., Ferguson, H. C., et al. 2006, ApJS, 165, 307. doi:10.1086/504685

Dobbs, C. L. & Pringle, J. E. 2010, MNRAS, 409, 396. doi:10.1111/j.1365-2966.2010.17323.x

Lin, C. C. & Shu, F. H. 1964, ApJ, 140, 646. doi:10.1086/147955

Bertin, G., Lin, C. C., Lowe, S. A., et al. 1989, ApJ, 338, 78. doi:10.1086/167182

Chandar, R., Chien, L.-H., Meidt, S., et al. 2017, ApJ, 845, 78. doi:10.3847/1538-4357/aa7b38

Chandar, R., Whitmore, B. C., Calzetti, D., et al. 2011, ApJ, 727, 88. doi:10.1088/0004-637X/727/2/88

Fazio, G. G., Hora, J. L., Allen, L. E., et al. 2004, ApJS, 154, 10. doi:10.1086/422843

Calzetti, D., Lee, J. C., Sabbi, E., et al. 2015, AJ, 149, 51. doi:10.1088/0004-6256/149/2/51

Bertin, E. & Arnouts, S. 1996, A&AS, 117, 393. doi:10.1051/aas:1996164

Shabani, F., Grebel, E. K., Pasquali, A., et al. 2018, MNRAS, 478, 3590. doi:10.1093/mnras/sty1277

Kroupa, P. 2001, From Darkness to Light: Origin and Evolution of Young Stellar Clusters, 243, 387

Thank you!
Any Questions?