Notes - LEGUS Star Cluster Age Distribution Analysis of NGC 1566

Benjamin Pieczynski

1. NGC 1566 Background

NGC 1566 is a type SAB(rs)bc galaxy located at a distance of 21.3 Mpc (Elagali et al. 2019). The galaxy is one of the brightest known a Seyfert galaxies. The galaxy also has a stellar mass $M_{*} = 6.5 \times 10^{10} M_{\odot}$ and Luminosity $L = 1.2 \times 10^{11} L_{\odot}$ (Meurer et al. 2006). Dark Matter fractions of 0.62, 0.58 and 0.66 (Elagali et al. 2019). The galaxy has well two well defined arms with some asymmetry in HI. It is thought that ram pressure interactions with the IGM can affect the HI disc of NGC 1566 and is possibly the reason for the asymmetries seen in the HI morphology of NGC 1566 (Elagali et al. 2019).

The Image taken by the HST Wide Field Camera 3 (WFC3) was on the first slide, so this is the field of view and instrument used by LEGUS to determine the star clusters.

2. Spiral Structure from Star Cluster Distributions

Understanding the nature and origin of spiral structure in galaxies remains a fundamental problem in astrophysics. Previous observational methods using the transition of stellar ages across the arms have been unreliable and have, with the exception of a few cases, lead to results inconsistent with 'Density Wave Theory'. 'Density Wave Theory' (Lin & Shu 1964; Bertin et al. 1989) is the idea that Quasi-steady stable modes in the stellar disk result in long-lived quasistatic spiral structure. Essentially there is a fixed pattern speed of increased density while the stars orbit at different speeds outside of the co-rotation radius.

To better understand excitation mechanisms, Dobbs & Pringle (2010) modeled gas flow in spiral galaxies for the case of self-excitation through local instabilities and density waves, and excitation through external(companion galaxies or interactions) and internal(central rotating bar) tidal effects. To model the formation of stellar clusters they determined that a cluster would form in positions where gas densities were significantly higher than the background density at different time frames relative to the current frame. They then tracked the gas as it moved to its position at the current frame. The "current frame" is represented in the figure on this slide. This shows star cluster age distribution for different excitation mechanisms (fixed-pattern speed, bar-unstable, flocculent, and interacting).

Dobbs & Pringle suggested that UBVI Hα observations could be used to age date clusters. This can be done by using the HST WFC3 images of galaxies. Chandar et al. (2017) decided to study the interacting galaxy M51 to determine spiral structure excitation mechanisms and compared with the results of the simulations.

3. Methods: Studying Star Cluster Distribution

This project followed methods outlined by Chandar et al. (2017). Cluster ages were derived from UBVI Hα measurements by the HST's WFPC2 using χ^2 fitting with stellar population models (Chandar et al. 2011). Next they defined spiral arms by locating peaks in 3.6μ emissions from Spitzer Space Telescope data. This traces the light from old stars, which is the dominant stellar mass component. The arms are defined by a logarithmic spiral arm equation(more on that later). A cluster is assigned to an arm segment when it is within 2 kpc of that segment, where distance is calculated from the cluster position to the closest point in the arm segment. Clusters are then separated by age ($<$ 6 Myr, 6-30 Myr, 30-100 Myr, 100-400 Myr). Then we can analyze the spatial distribution of these clusters through different plots and compare with Dobbs & Pringle (2010).

Quick summary of some of Chandar et al. (2017) findings:

- Star cluster distributions peak in the arms and the widths of the distributions increase somewhat at older ages, similar to predictions from Dobbs & Pringle (2010).
- Inner spiral arms were consistent with 'density wave theory'.
- Outer spiral arms consistent with the model for external tidal interactions (interacting galaxy).

Image shows how 3.6μm peaks were used to map the spiral arms.

4. Why Study NGC 1566?

Observational justification: The HST WFC3 frame captures nearly the entirety of the galaxy's well defined spiral arms. There are available 3.6μ images available via the Spitzer IRAC camera (Fazio et al. 2004). LEGUS catalog contains age dated clusters in a large sample size (2448) (Calzetti et al. 2015).

Scientific justification: It will be plausible to determine an excitation mechanism from NGC 1566 by comparing with the results from Dobbs & Pringle (2010) and using the methods of Chandar et al. (2017). These methods also allow us to study if there is consistency with density wave theory. The study will produce an in dept analysis of the star cluster distribution in NGC 1566. The potential to search for a trend between cluster location, age, and mass.

5. LEGUS Star Cluster Data

The Legacy ExtraGalactic UV Survey (LEGUS) is a star cluster catalog for 50 nearby galaxies (Calzetti et al. 2015). LEGUS uses data from Five band imaging with the HST WFC3 along with Advanced Camera for surveys. The projects goal was to provide complete inventories of young stellar cluster populations, which includes ages, masses, extinction, and spatial distributions. LEGUS conducts cluster photometry using SExtractor (Bertin & Arnouts 1996) to extract potential cluster sources. Using DOLPHOT they will filter through cluster candidates in order to throw out erroneous data. More data filtering is conducted when they automatically and manually filter through the remaining candidates. To derive the age, mass, extinction, and uncertainties of the candidate clusters, LEGUS uses χ^2-minimization-based-SED fitting.

We obtained star cluster data for NGC 1566 through the LEGUS catalog.

6. Defining Spiral Arms

Used DS9 to make a contour plot of 3.6μ emission for a Spitzer image of NGC 1566. After locating the peaks we use a logarithmic spiral arm equation to manually fit the arms to the emission peaks.

$R = Aexp[(2\pi/m - \phi) - tan(i)]$

R = radius, A = amplitude, m = number of spiral arms, ϕ = polar angle, i = pitch angle

Image on the next slide shows our results for defining NGC 1566 spiral arms. The Spiral arms were well defined by the emission peaks, but corresponding substructure was difficult to measure (sample size was not sufficient for these regions as well). These compare well to NGC 1566 spiral arms mapped by Shabani et al. (2018).

7. Assigning Clusters to Arms

1st slide: Like Chandar et al. (2017), star clusters were separated by ages into 4 age groups; $<$ 6 Myr, 6-30 Myr, 30-100 Myr, and 100-400 Myr. Noticeably more clusters at 6-30 Myr and noticeably fewer clusters at ages 100-400 Myr. (Note: Python flipped RA)

2nd slide: Master star cluster plot superimposed onto the spiral arm plot. Cluster is assigned to an arm segment when it is within 2 kpc of that segment, where distance is calculated from the cluster position to the closest point in the arm segment, just like Chandar et al. (2017).

8. Star Cluster Age Distributions

1st slide Examining at how star clusters are distributed by age away from our definition of the center of the arm. Attempted to make histograms for substructures that were defined, but there were often fewer than 10 clusters in the entire data-set, so it wasn't sufficient for the study. This does improve the results for the West and East arms as it prevents clusters from being incorrectly assigned. The histograms produced were normalized to 1 for each segment and each cluster age group. These plots indicate that the clusters peak towards the center of the arms at younger ages and disperse over time, which is consistent with Dobbs & Pringle (2010).

2nd slide Combined each segment into the overall arm for both the West and East arms. This displays the increase in distribution width in different ages for both arms. This also displays a representation for the sample size for each cluster age. After 30 Myr the number of clusters decreases, likely due to open clusters dispersing (Shabani et al. 2018).

3rd and 4th slide Cluster position projected onto the nearest point of the assigned arm. θ measured North from East. Values of θ = 360 would be equivalent to 0° North above East. Normalized to one for each cluster age group. Displays a monotonic sequence of cluster ages for both the West and East arms, which is consistent with Dobbs & Pringle (2010) models for density wave theory and barred spiral models.

9. Star Cluster Age Distribution - Findings

NGC 1566 shows star clusters peak in the center at younger ages and disburse over time. This is consistent with Dobbs & Pringle (2010) and similar result to M51 distributions (Chandar et al. 2017). Both the West and East Arms display monotonic sequences of star cluster age distribution which is consistent for the fixed pattern speed model (density wave theory) and the bar unstable model. This is in agreement with Dobbs & Pringle (2010) and Shabani et al. (2018)

10. Star Cluster Mass Distribution

The first slide shows the plots of stellar mass ($1000 \times M_{\odot}$) with distance to the center of the arm in kpc. The plots indicate that there might be a connection between higher mass clusters forming towards the center of the arms, where gas likely would be the most dense. This is not clear and would likely need further analysis.

Findings

The median NGC 1566 star cluster mass increases with the cluster ages. Would indicate the more massive the cluster cluster the longer the cluster could last, consistent with Kroupa (2001). Plausible that larger clusters form in the center of the arms, could be due to higher gas density. This claim needs more analysis.

11. Key Findings and Future Work

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

(2) 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). Hence I find that both play a role as the excitation mechanisms of the spiral structure in NGC 1566.

(3) Findings in agreement with Shabani et al. (2018). They studied star cluster gradients in the arms and found that it was consistent with density wave theory and the models of Dobbs & Pringle (2010).

(4) The median NGC 1566 star cluster mass increases with cluster age.

(5) Evidence that larger clusters could form in the center of NGC 1566 arms, however this needs more analysis.

Future work: This method can be applied to different spiral galaxies to further explore excitation mechanisms. Many of the galaxies in the LEGUS cluster don't have complete coverage for all the arms of each spiral galaxy. This could serve as an example on why we need to have observational coverage of entire galaxies via mosaics. The mass distribution of NGC 1566 could be explored in greater detail, especially where more massive clusters are forming.

12. Acknowledgements

Thank you to Dr. Li-Hsin Chien for being an amazing mentor. I owe so much of where I am today to your guidance and support during my time at Northern Arizona University.

Thank you Dr. Rubin for a great semester and for the suggestion to use the LEGUS star cluster catalog. Deriving the star cluster ages would have been a paper in itself.

Thank you Giaky, Sam, and Spencer for practicing the night before the presentation.

This work is based [in part] on observations made with the Spitzer Space Telescope, which was operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA.

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