Krittika Summer Projects 2024

Pinpricks on the Vortex - Unveiling Nearby Galaxy Evolution with Star Clusters

Endterm Report

Surya Vinod Nambiar

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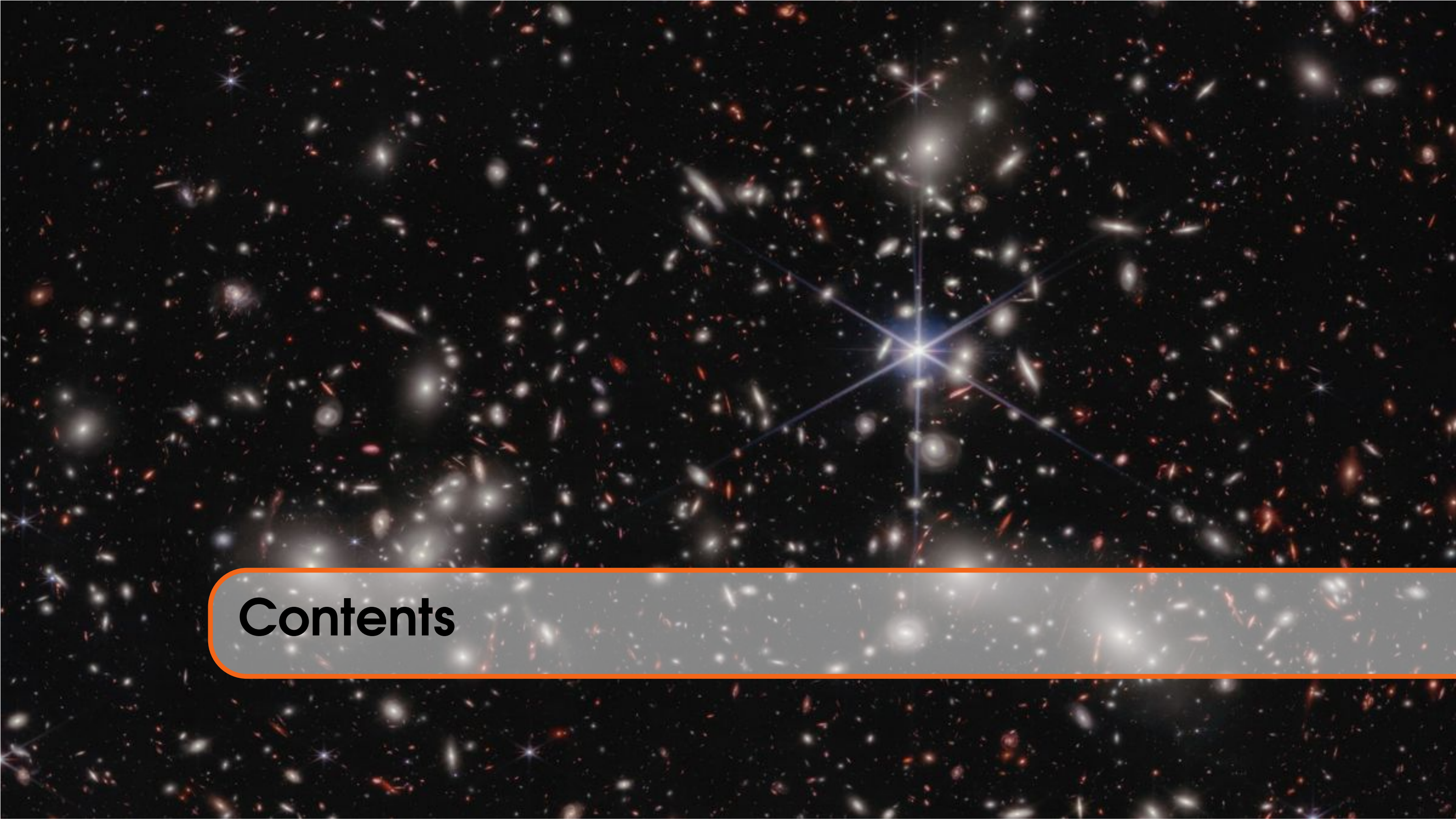
Abstract

The Milky Way may be closest to our hearts, but to truly understand how stars and clusters evolve over time, we need to examine a much larger population across different galaxies. Thanks to the collaborative efforts of the PHANGS project, several nearby spiral galaxies have been imaged across a wide wavelength range—from UV with Hubble, infrared with JWST, to radio with ALMA. These comprehensive observations offer tremendous insights into the properties of these galaxies.

In this project, we will focus on one aspect of these galaxies: their star cluster systems. First, we will use Hubble images to perform aperture photometry on the cluster locations to measure their brightness in different wavelength bands. This data will help us determine the ages of the star clusters. We will then correlate their spatial locations within the galaxies with their ages to identify any interesting trends.

PHANGS Hubble images have been used to perform arpeture photometry on the galaxy NGC4303, and the output has been verified with the PHANGS catalog. The values thus obtained were used to plot color-color diagrams of the different clusters. We then plot c1 clusters and c2 clusters and check for trends in age.

We divide the clusters into young, middle-aged, and old clusters. Finally, we check the correlation with the ALMA gas distribution density and the clusters of different ages (young, middle, and old).



Contents

1 Star Clusters 5

1.1 Introduction 5

1.2 Open clusters 5

1.3 Globular cluster 6

2 PHANGS 7

2.1 Physics at High Angular resolution in Nearby GalaxieS (PHANGS) Project 7

3 Aperture Photometry 9

3.1 Approach Method 9

3.1.1 Displaying the galaxy image FITS files from Hubble 9

3.1.2 Getting cluster positions and plotting them 9

3.1.3 Using aperture photometry to extract cluster fluxes 10

3.1.4 Checking correlation with PHANGS values 10

3.1.5 Calibration using absolute magnitude formula and applying corrections 12

4 Age determination 13

4.1 Color-color diagrams 13

4.2 Cluster morphological classes 14

4.2.1 C1 clusters 14

4.2.2 C2 clusters 14

4.2.3 C3 clusters 14

4.3 Making a color-color diagram 14

4.4 Finding ages of C1 and C2 clusters 16

4.5 Making a composite RGB image 18

4.6 Dividing the clusters into young, middle and old 19
4.7 Checking correlation with ALMA gas density distribution 21

Bibliography 23

Index 25

1. Star Clusters

1.1 Introduction

Star clusters are large groups of stars which are bound together by gravitation. There are two main types of star clusters namely Open and Globular cluster. Globular clusters are dense groups of ten thousand to millions of old stars that are gravitationally bound together. Open clusters, on the other hand, are looser groups of stars, usually with fewer than a few hundred members, and are often very young.

1.2 Open clusters

Open clusters typically contain a few hundred stars and span up to 30 light-years across. They are much less densely populated than globular clusters, leading to weaker gravitational binding.

Open clusters differ significantly from globular clusters. While globular clusters are spherically distributed, open clusters are confined to the galactic plane and typically found within spiral arms. They are generally young, with ages up to a few tens of millions of years, though there are rare exceptions that are a few billion years old.

Notable open clusters include the Pleiades and Hyades in Taurus, as well as the Double Cluster of h and Chi Persei. Open clusters often feature hot, young blue stars. Although these stars have relatively short lifespans of a few tens of millions of years, open clusters usually disperse before these stars die.

Open clusters that are still covered by their progenitor molecular cloud are called embedded clusters.

1.3 Globular cluster

Globular clusters are roughly spherical groupings of 10,000 to several million stars, packed into regions spanning 10 to 30 light-years across. They typically consist of very old Population II stars, just a few hundred million years younger than the universe itself. These stars are mostly yellow and red, with masses less than two solar masses. Such stars dominate because hotter and more massive stars have already exploded as supernovae or evolved into white dwarfs through planetary nebula phases. However, a few rare blue stars, known as blue stragglers, exist in globular clusters. These are thought to form from stellar mergers in the clusters' dense inner regions.

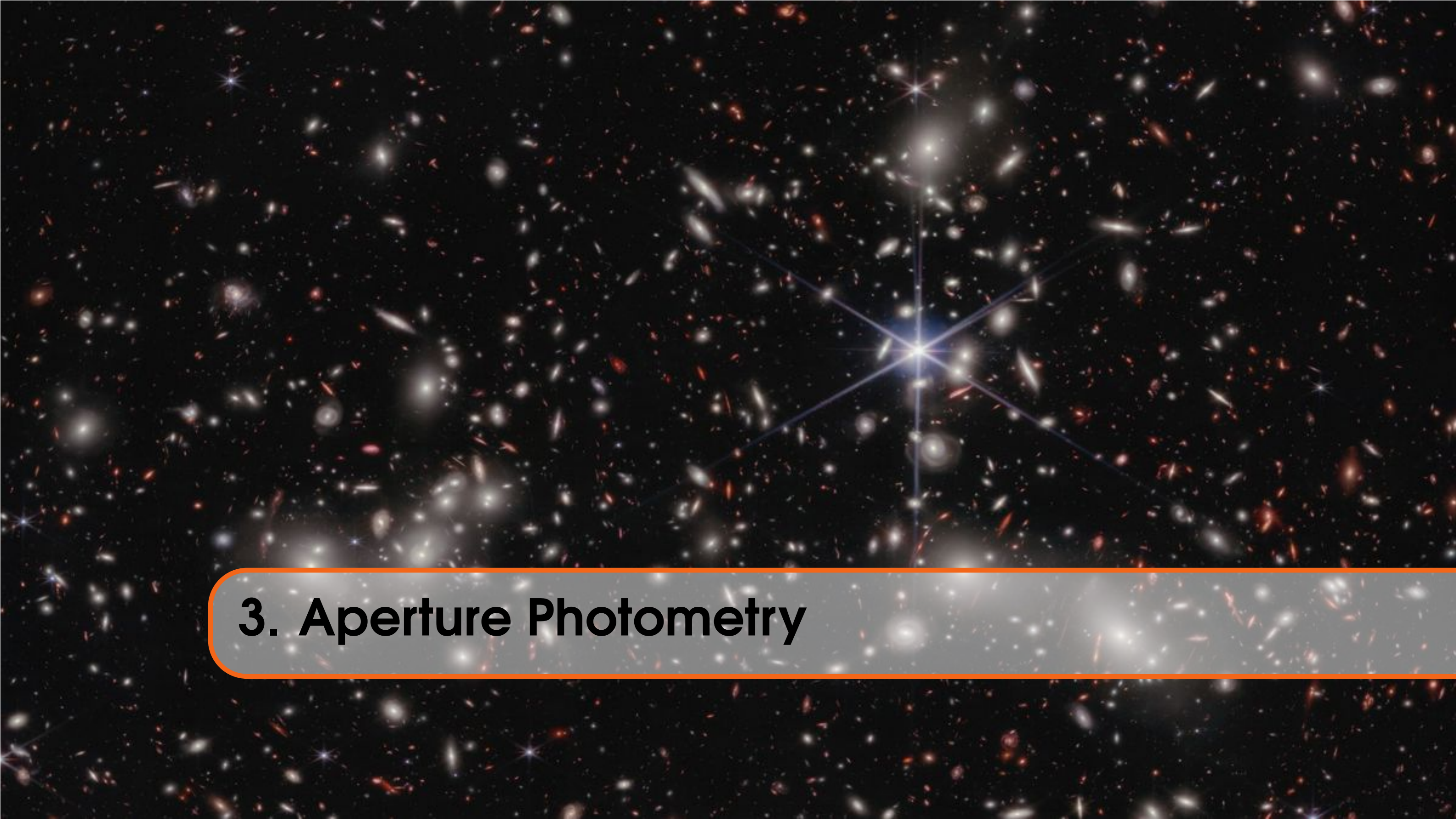
In the Milky Way galaxy, globular clusters are distributed roughly spherically within the galactic halo. They orbit the Galactic Center in highly elliptical orbits, surrounding the center in a nearly spherical distribution.

In this project we will mostly be studying globular clusters.

2. PHANGS

2.1 Physics at High Angular resolution in Nearby GalaxieS (PHANGS) Project

Physics at High Angular Resolution in Nearby GalaxieS (PHANGS) is a significant and long-standing initiative supported by over 150 astronomers worldwide. PHANGS aims to make high-resolution observations of nearby galaxies using several telescopes, including ALMA, Hubble, JWST, and the VLT. The project's goal is to understand the interplay between the small-scale physics of gas and star formation.
By observing nearby galaxies, PHANGS seeks to understand how physics at or near the "cloud" scale is affected by galaxy-scale conditions, how these conditions influence smaller scale processes, and how they impact the evolution of entire galaxies. The observations are conducted in ultraviolet, visible, radio, and near- and mid-infrared light. The telescopes used include NASA's James Webb Space Telescope(JWST), Hubble Space Telescope(HST) , Very Large Telescope's Multi-Unit Spectroscopic Explorer(VLT), and Atacama Large Millimeter/submillimeter Array(ALMA).
We are using the PHANGS-HST images and catalog of the galaxy NGC4303 to do this project.



3. Aperture Photometry

3.1 Approach Method

3.1.1 Displaying the galaxy image FITS files from Hubble

The astropy library was used for analysing the FITS image file from PHANGS-HST and coding was done in python. First, the data file was extracted and read and the galaxy image was generated (Refer Figure 3.1).

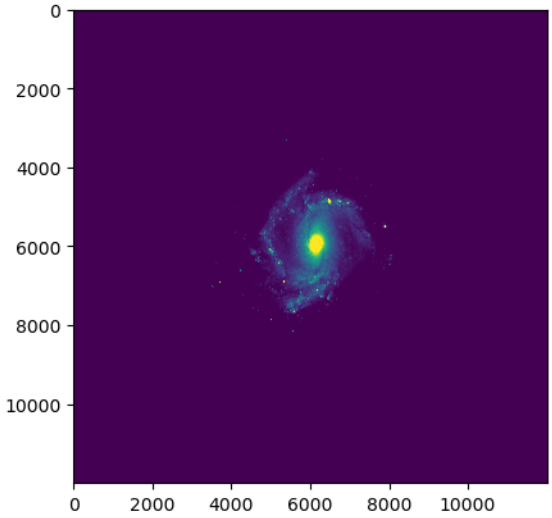


Figure 3.1: Image of the Galaxy (f814w)

3.1.2 Getting cluster positions and plotting them

The PHANGS-HST catalog of the galaxy was used to find the positions of the clusters which were then plotted on the image (Refer Figure 3.2) by mapping the sky coordinates to pixel coordinates.

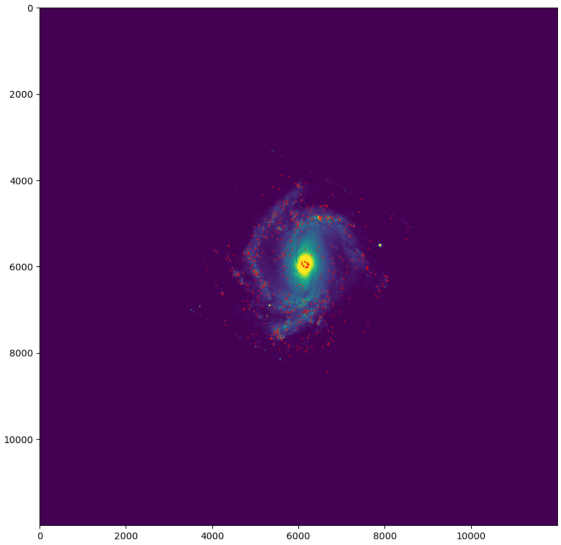


Figure 3.2: Image of the Galaxy with cluster positions marked (f814w)

3.1.3 Using aperture photometry to extract cluster fluxes

Aperture photometry was carried out at the obtained cluster positions by using the photutils library. A circle of 4 pixels radius was used to compute the flux of the cluster and a circlular annulus of inner radius 7 and outer radius 8 units was used to compute the background flux.

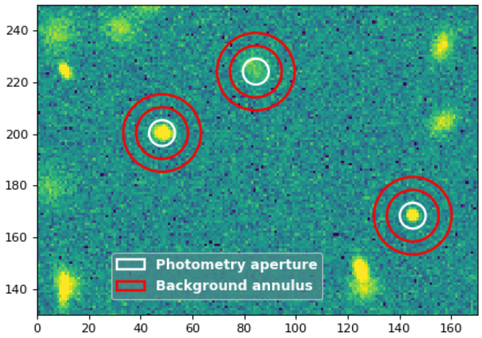


Figure 3.3: Reference figure of Aperture and Annulus for photometry

The background flux was subtracted from the cluster flux to obtain the actual flux of the cluster.

3.1.4 Checking correlation with PHANGS values

The astroquery library was used to find a zero point source which was non-variable and was away from the centre of NGC4303. The point used was 185.475332, 4.461374 and the band used was f814w (Refer Figure 3.4). Apparent magnitude(m)

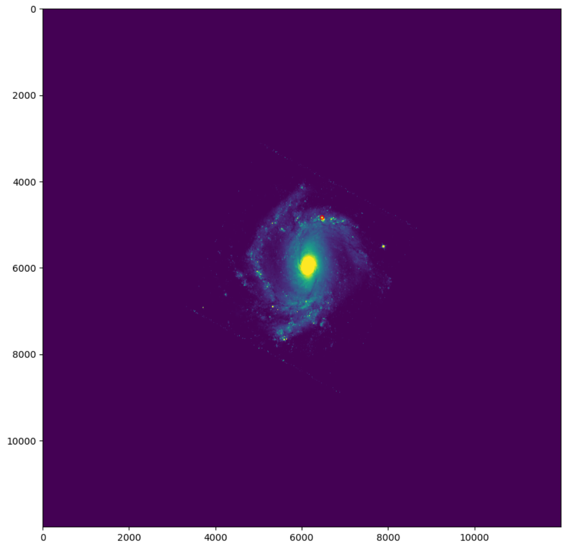


Figure 3.4: Zero point plotted on the image (f814w)

was computed using the formula

$$m = r + 2.5log10(flux)$$

where the reference magnitude (r) was obtained using reference point by astroquery. The value obtained was verified with the value from the catalog.

The obtained zero point apparent magnitude value was used to find the apparent magnitude of all the clusters. The computed magnitudes were plotted against the magnitudes from the PHANGS catalogue and a offset line with 1:1 slope was obtained (Refer Figure 3.5).

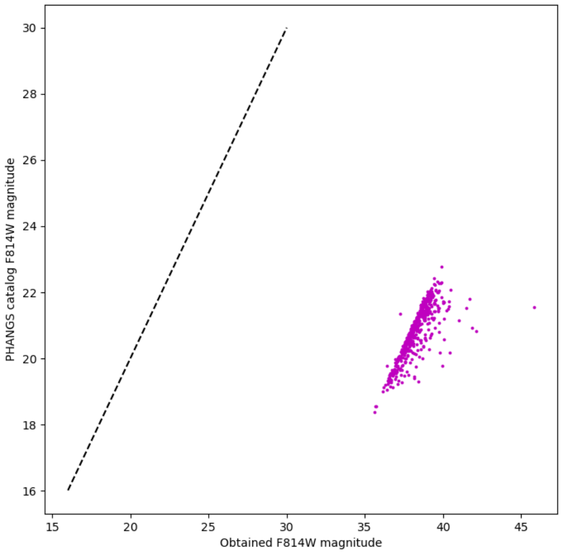


Figure 3.5: PHANGS magnitude for f814w vs Obtained magnitude using zero point for f814w

3.1.5 Calibration using absolute magnitude formula and applying corrections

The absolute magnitude(M) was calculated using the formula:

$$M = -2.5log10(flux(inpixelunits) * conversionfactor) + 8.9$$

The correction factors applied for different wavelengths are given below:

Band	VEGA correction	Extinction correction	Aperture correction
f275w	1.4	0.121	-0.93
f336w	1.158	0.0979	-0.86
f438w	-0.178	0.0.798	-0.77
f555w	-0.048	0.0618	-0.74
f814w	0.395	0.0329	-0.86

Table 3.1: Correction factors

The graph obtained is a 1:1 line with negligible offset which indicates that the photometry done was correct (Refer Figure 3.6).

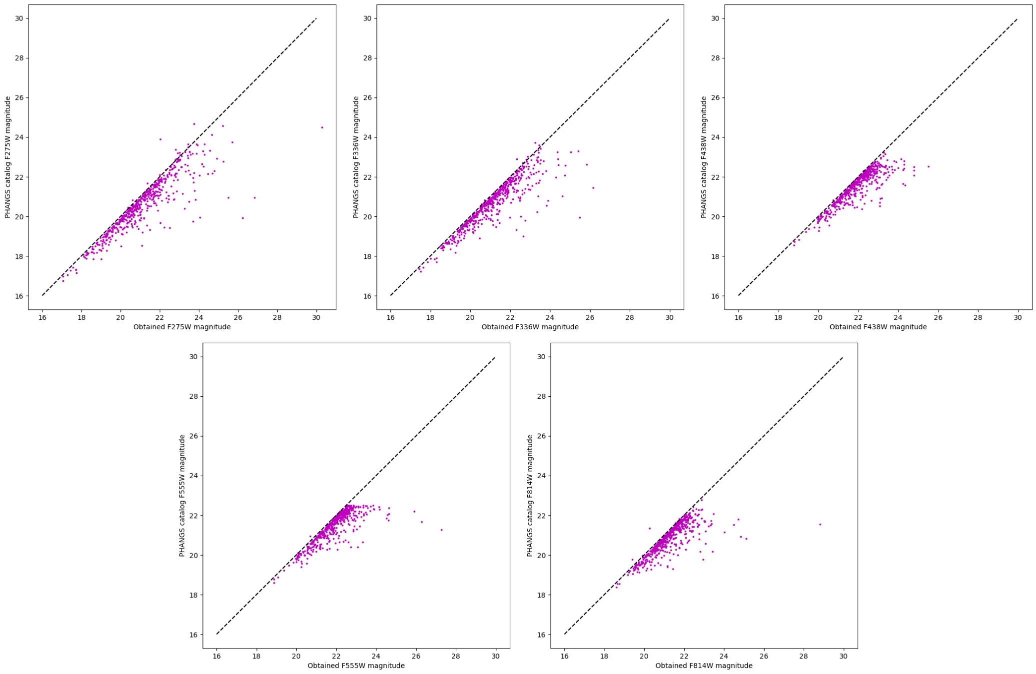
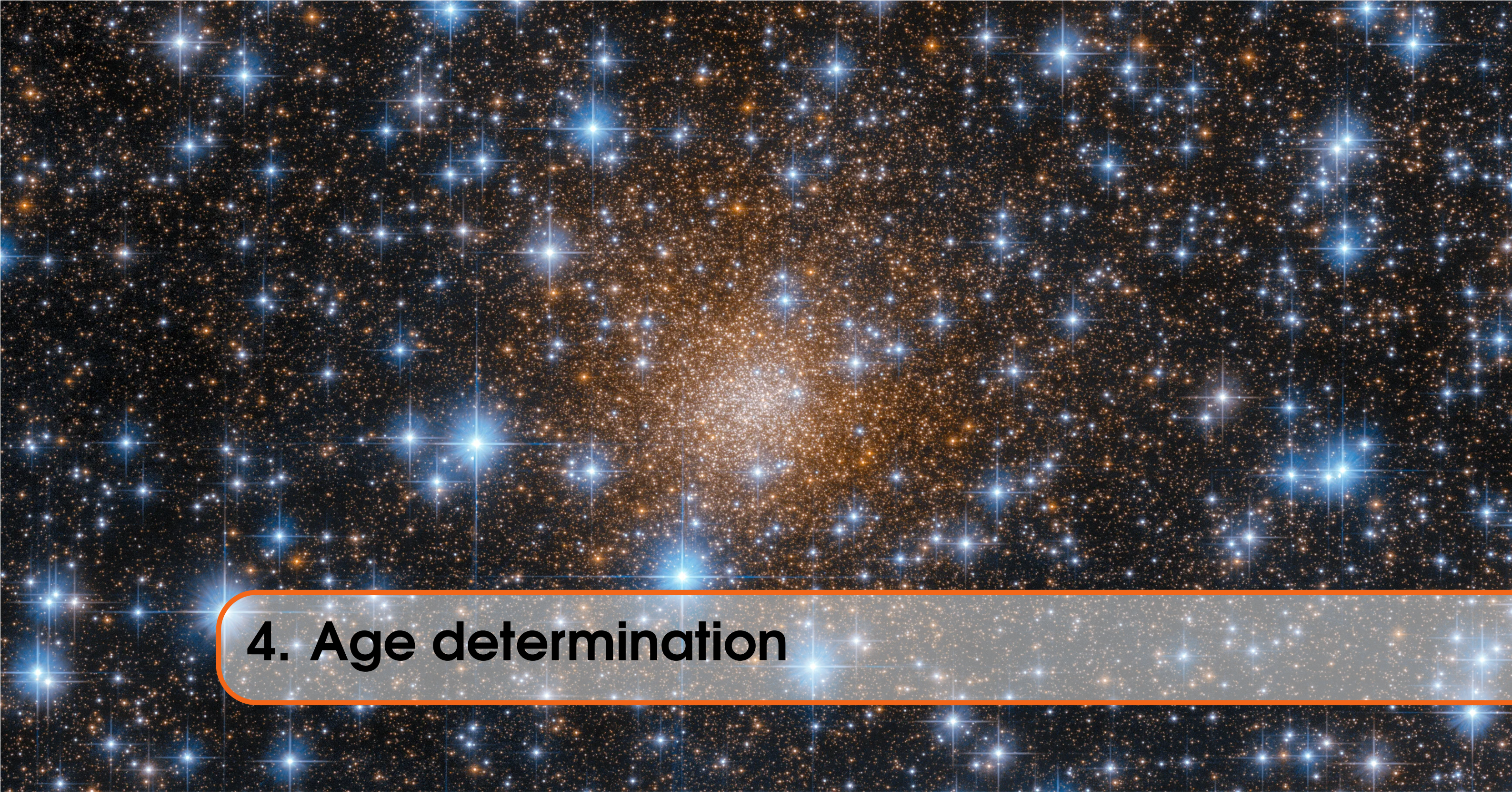


Figure 3.6: PHANGS magnitude for various wavelengths vs Absolute magnitude with corrections



4. Age determination

4.1 Color-color diagrams

Color-color diagrams are diagrams with the differences in magnitudes of two bands in the axes.Here we are plotting the color-color diagrams with the BC03-model track to determine their age (Refer Figure 4.1).

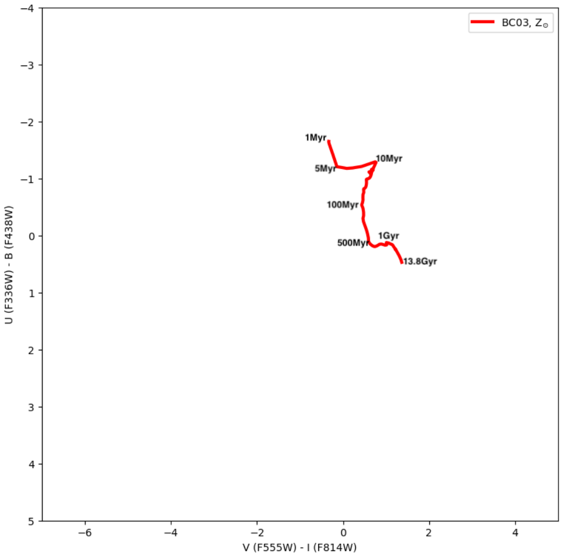


Figure 4.1: BC03-model track

4.2 Cluster morphological classes

4.2.1 C1 clusters

They are single-peaked, symmetric and are predominantly older than 10 Myr.

4.2.2 C2 clusters

They are single-peaked, asymmetric and younger.

4.2.3 C3 clusters

They are multi-peaked, asymmetric with compact associations, and younger. We are predominantly focusing on C1 and C2 clusters.

4.3 Making a color-color diagram

Using the arperture photometry data, the color-color diagram is made. On seeing the diagram, most of the clusters are middle-aged (10–500Myr old). Gaussian-weighted 2D histograms were implemented to make the contour plots (Refer Figure 4.2).

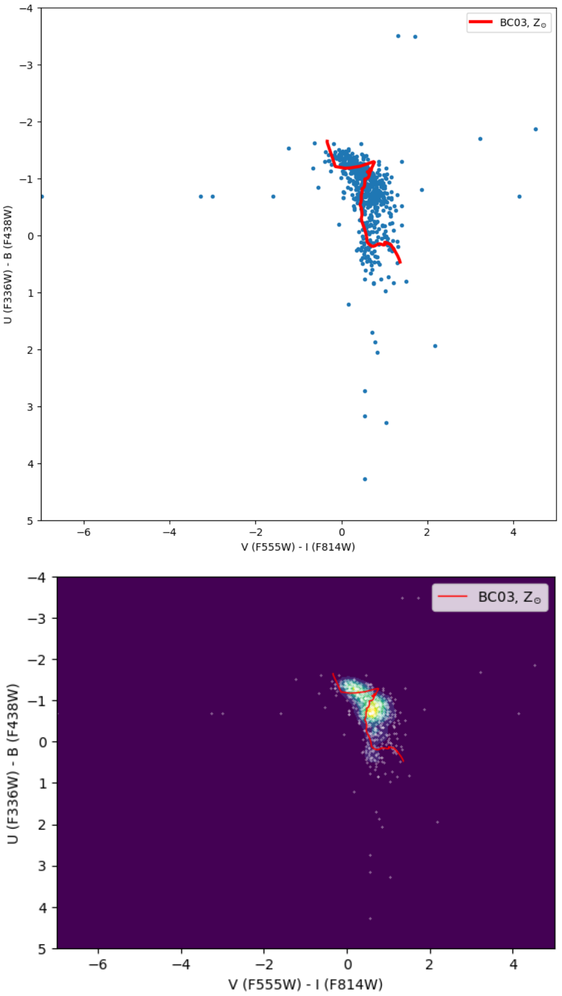


Figure 4.2: Scatter and contour color-color diagrams of the clusters

4.4 Finding ages of C1 and C2 clusters

The color-color diagrams of C1 and C2 clusters are made separately by using the data from the HST catalog to segregate the clusters. By observing the diagrams, it is seen that C2 clusters are predominantly younger in age (<10Myr) while C1 clusters are predominantly middle-aged (10-500Myr), as expected (Refer Figures 4.3 and 4.4).

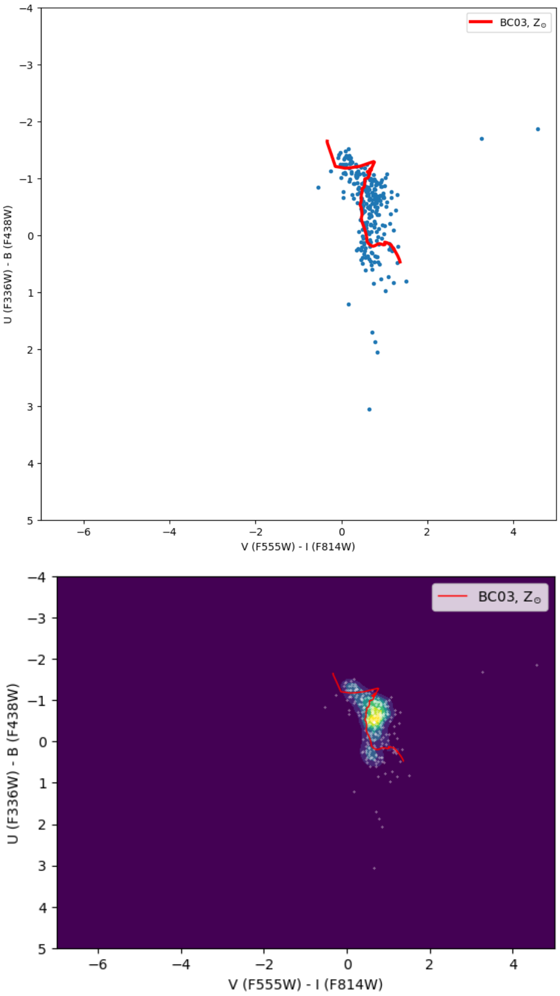


Figure 4.3: Scatter and contour color-color diagrams of C1 clusters

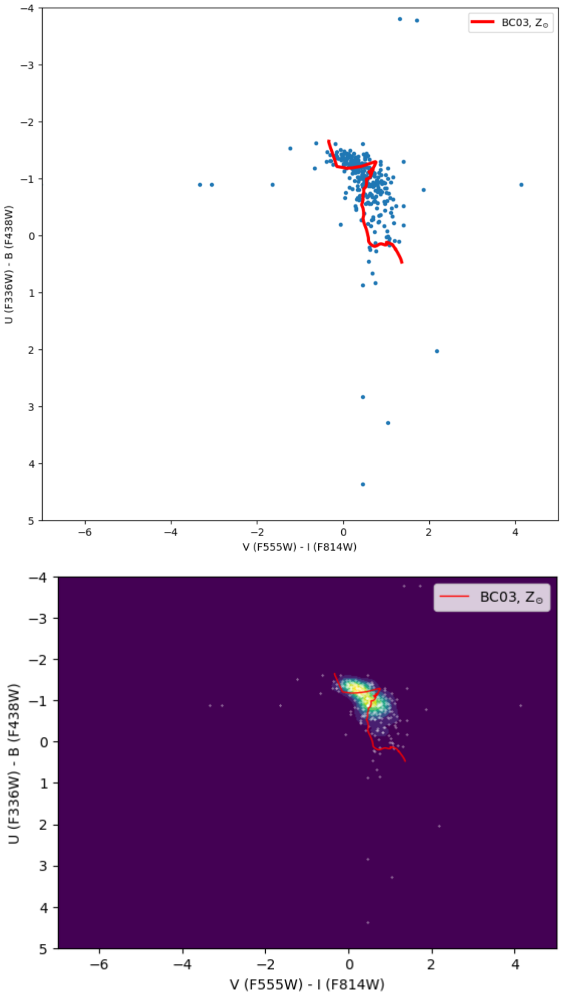


Figure 4.4: Scatter and contour color-color diagrams of C2 clusters

4.5 Making a composite RGB image

The astropy library was used to stack individual band images to make a composite image. The bands used were f814w, f555w, and f438w for red, green, and blue respectively (Refer Figure 4.5).

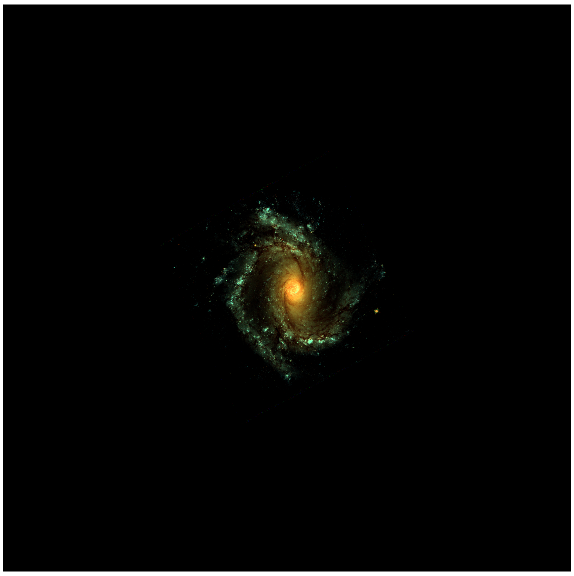


Figure 4.5: The composite RGB image of the galaxy NGC4303

4.6 Dividing the clusters into young, middle and old

We use matplotlib to plot lines passing through the points of age 10Myr, 100Myr on the BC03-model track and use this to classify galaxies into young (<10Myr), middle (10-500Myr) and old (>500Myr) (Refer Figure 4.6). The clusters of various ages are overplotted separately on the composite RGB image (Refer Figure 4.7).

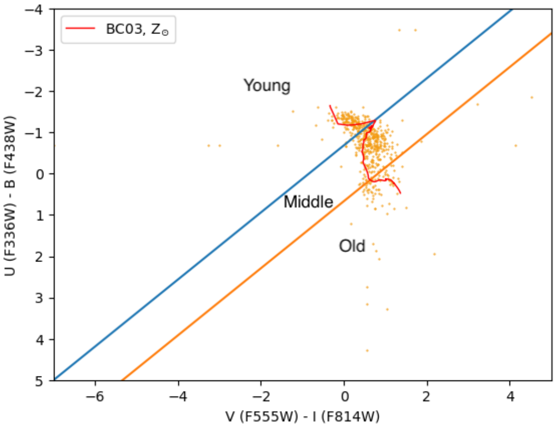


Figure 4.6: Lines plotted demarcating the age groups

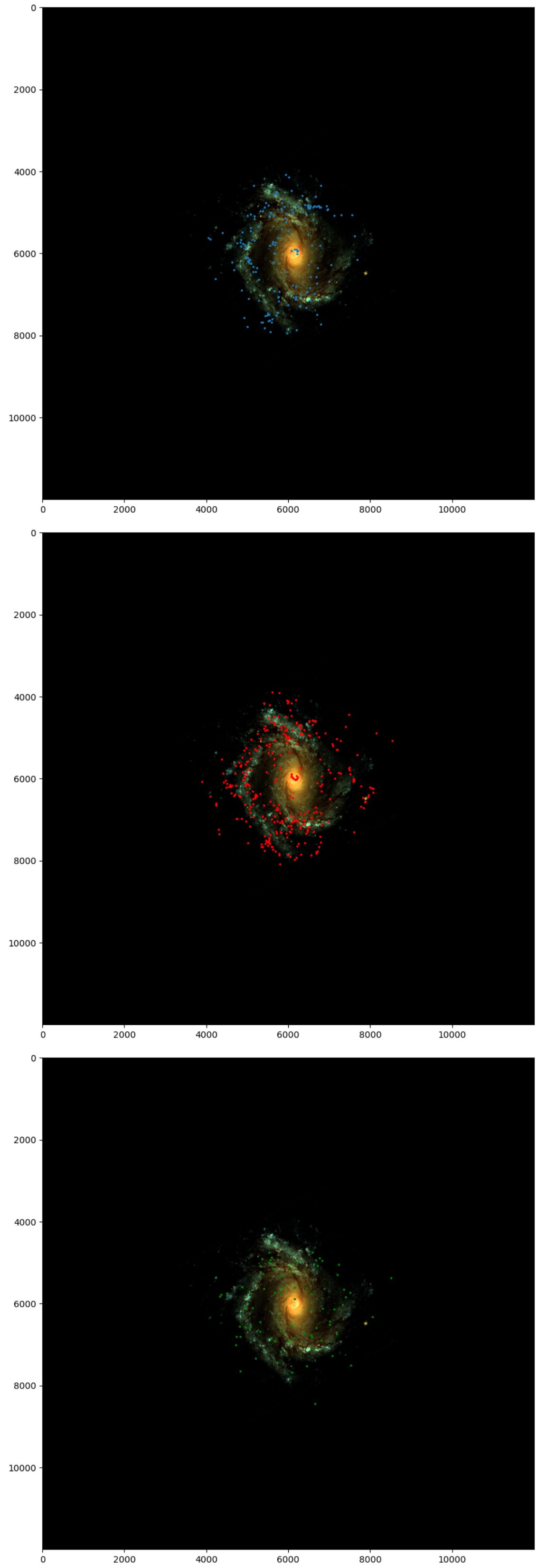


Figure 4.7: Clusters of various age groups plotted on the RGB image (From left to right : young, middle- aged and old

4.7 Checking correlation with ALMA gas density distribution

The clusters of various ages are overplotted separately on PHANGS-ALMA gas distribution density data. On observing the diagrams, the young clusters have a higher correlation with the data, followed by middle-aged clusters, and the old clusters have the least correlation (Refer Figure 4.8).

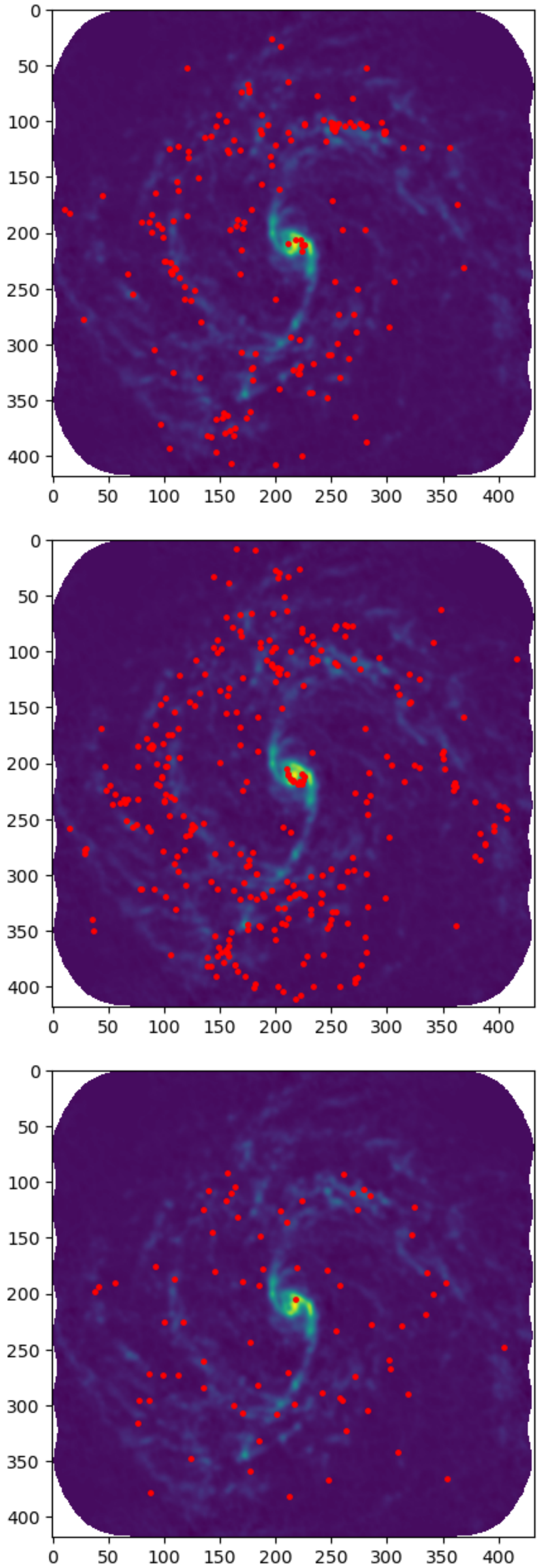
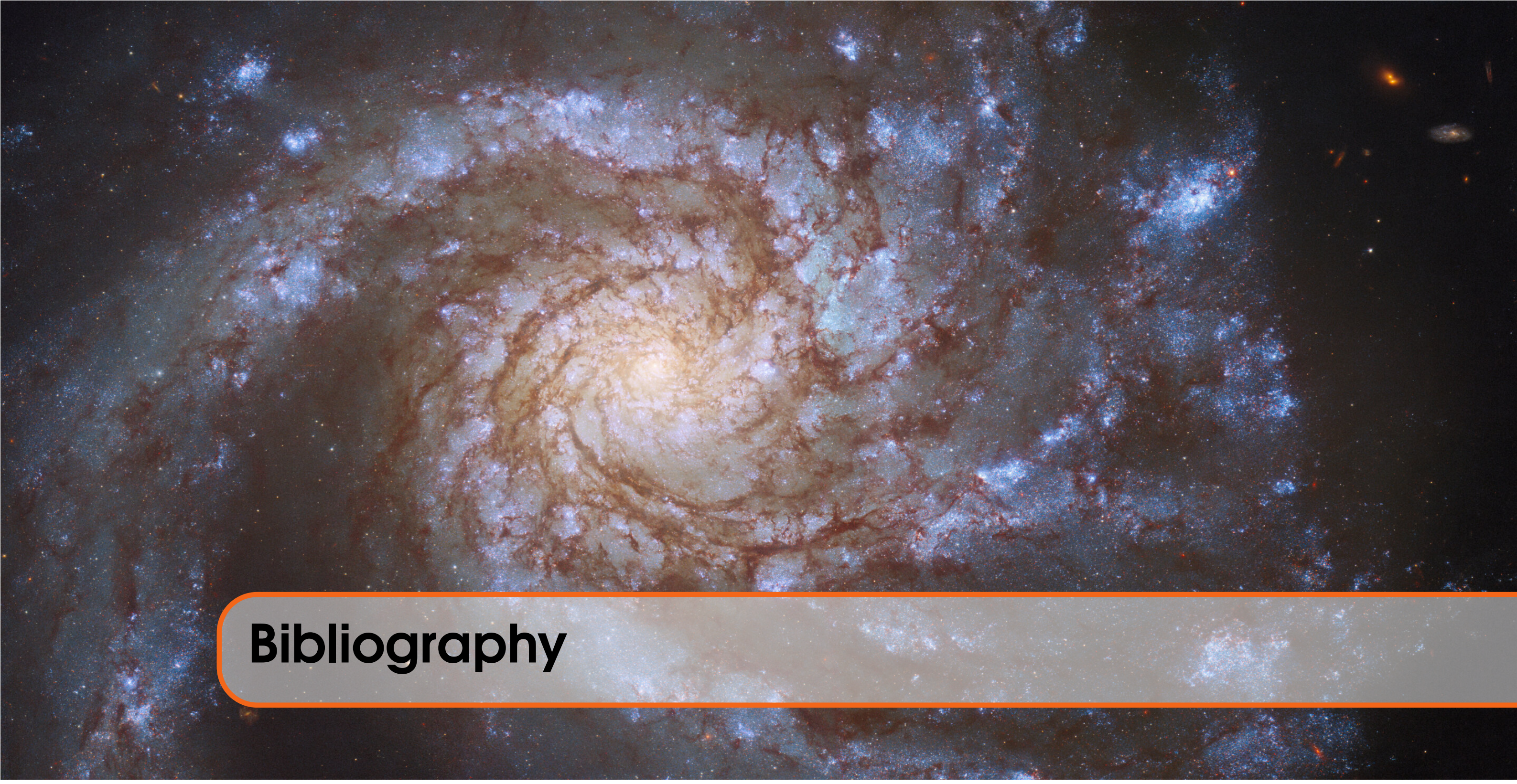


Figure 4.8: Clusters of various age groups plotted on the ALMA gas density distribution (From left to right : young, middle- aged and old



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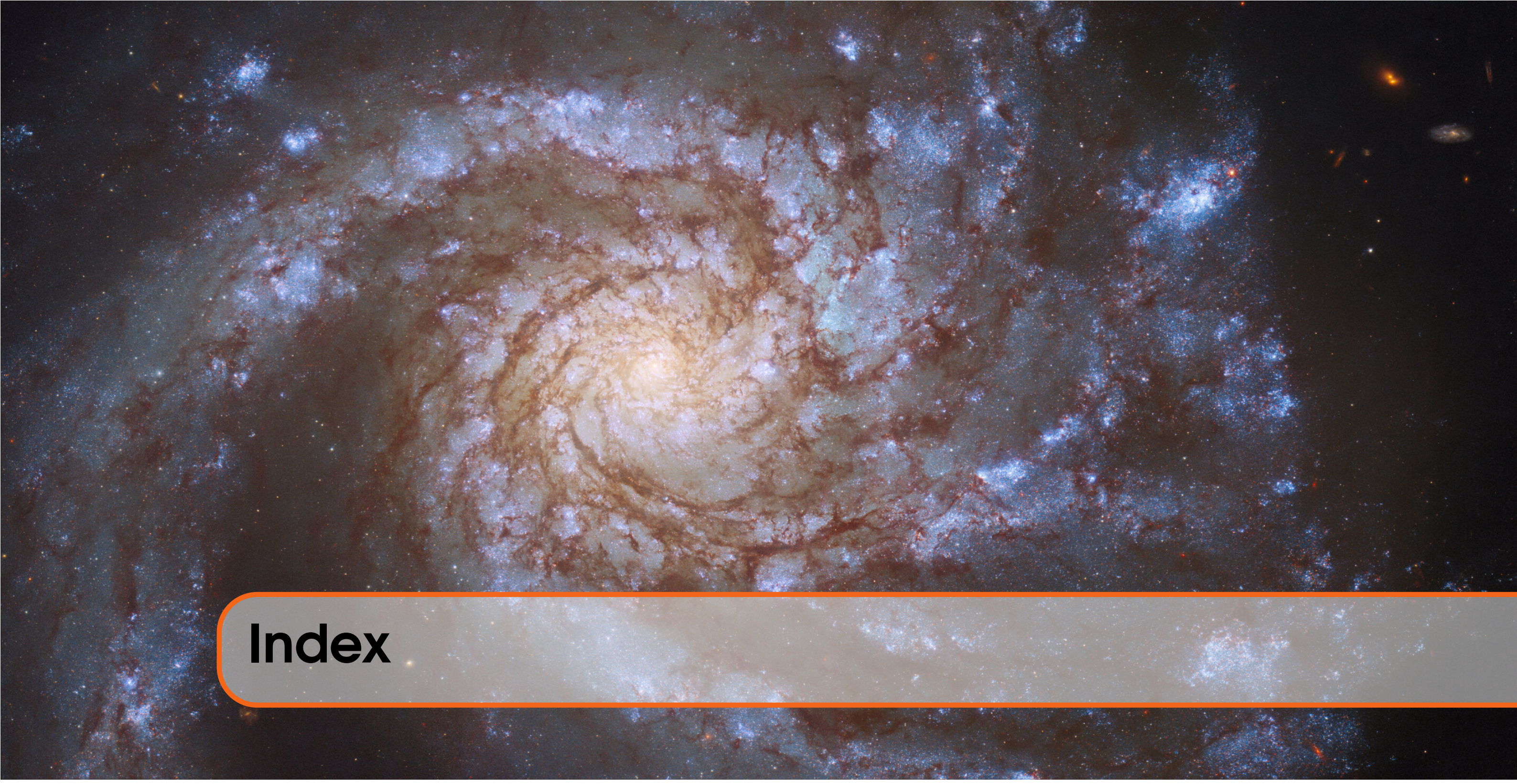

Index

A

Age determination 13
Aperture Photometry 9
Approach Method 9

C

C1 clusters 14
Calibration using absolute magnitude formula and applying corrections 12
Checking correlation with ALMA gas density distribution 21
Checking correlation with PHANGS values 10
Cluster morphological classes 14
Color-color diagrams 13

D

Displaying the galaxy image FITS files from Hubble 9
Dividing the clusters into young, middle and old 19

F

Finding ages of C1 and C2 clusters . 16

G

Getting cluster positions and plotting them 9
Globular cluster 6

I

Introduction 5

M

Making a color-color diagram 14
Making a composite RGB image . . . 18

O

Open clusters 5

P

PHANGS 7
Physics at High Angular resolution in Nearby GalaxieS (PHANGS) Project . . 7

S

Star Clusters 5

U

Using aperture photometry to extract cluster fluxes 10