

STAR CLUSTERS

Lecture 1 Introduction



Nora Lützgendorf (ESA)



Its a school, so...



➔ ASK QUESTIONS!!!

- ➔ If you don't understand the content...
- ➔ If you don't understand the language...

➔ TAKE NOTES

- ➔ This is the most text on a slide you will see ;)



Outline

1. Career

2. Introduction

a. What is a star cluster?

b. What kind of clusters do we know?

c. Where do we find them?

d. Characteristics



Outline

1. Career

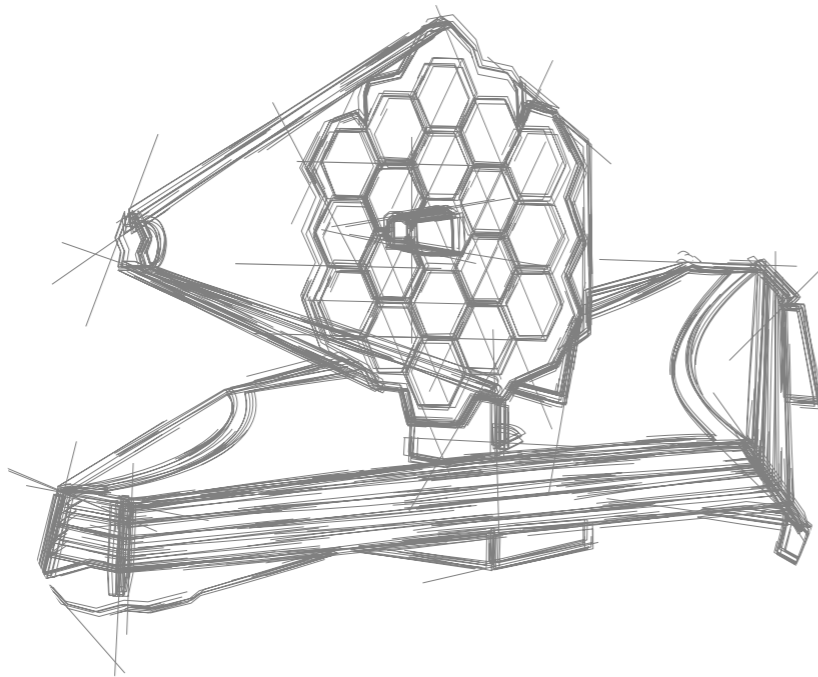
2. Introduction

- a. What is a star cluster?
- b. What kind of clusters do we know?
- c. Where do we find them?
- d. Characteristics

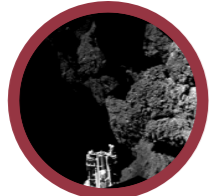


Current Position

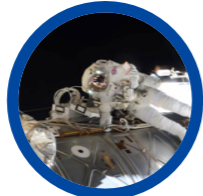
JWST/NIRSpec Instrument and Calibration Scientist



European Space Agency



space science



human spaceflight



exploration



launchers



operations



navigation



earth observation



telecommunications



technology



James Webb Space Telescope

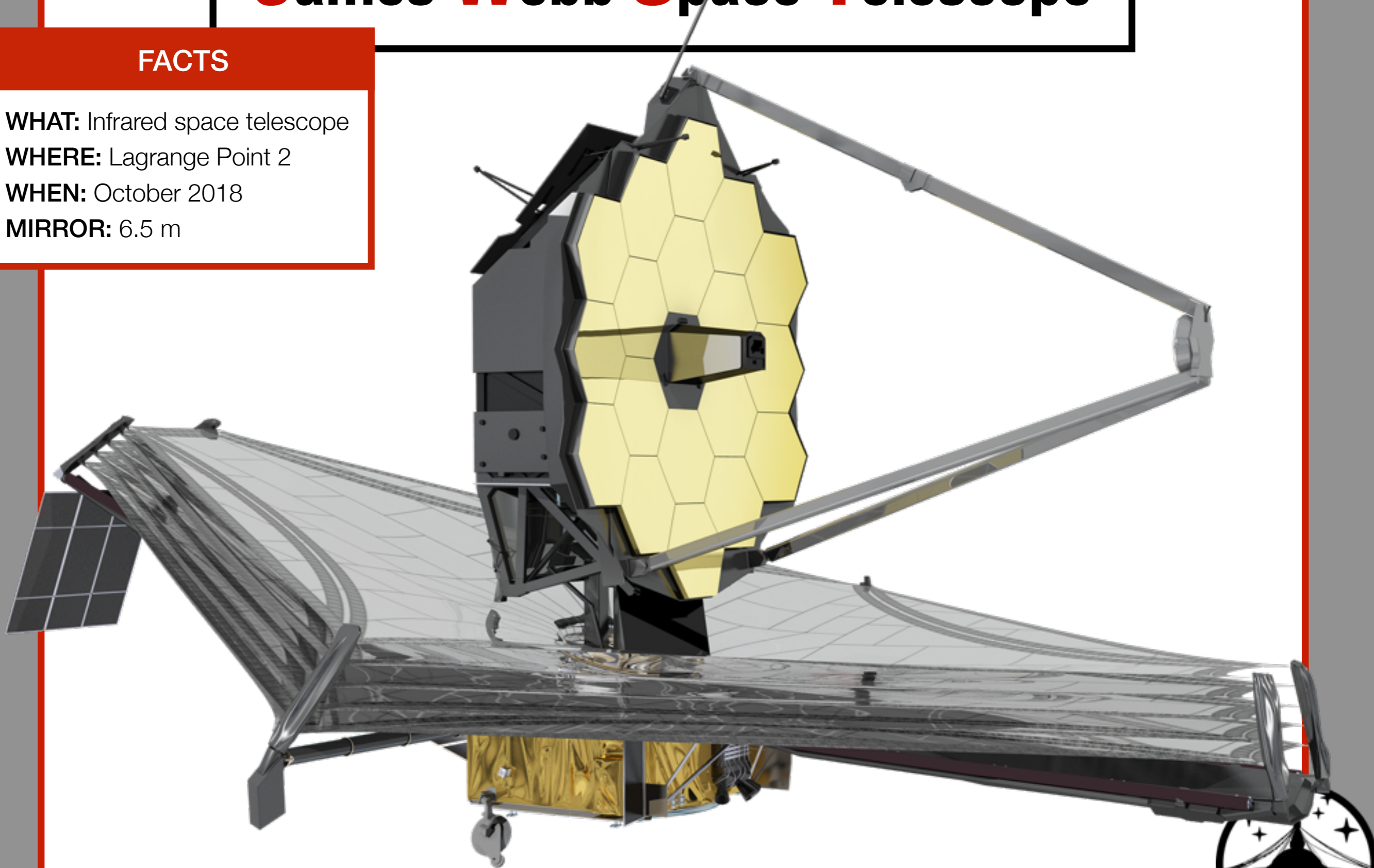
FACTS

WHAT: Infrared space telescope

WHERE: Lagrange Point 2

WHEN: October 2018

MIRROR: 6.5 m



James Webb Space Telescope



James Webb Space Telescope



Current Position

LAUNCH SEGMENT



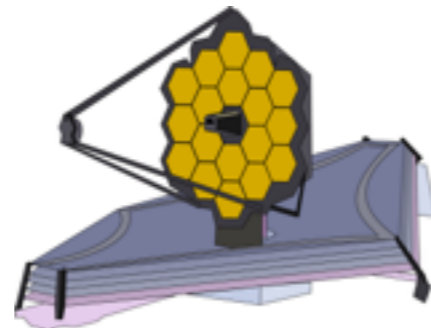
Payload adapter

Launcher (Ariane 5)

Launch site services



OBSERVATORY SEGMENT



Spacecraft (bus, sunshield...)

Telescope

Payload module (ISIM) and instruments

NIRCam

NIRSpec

FGS/NIRISS

MIRI

GROUND SEGMENT



Science and operation center (STScI)

15 ESA staff members

Common systems (deep space network)



Provided by NASA



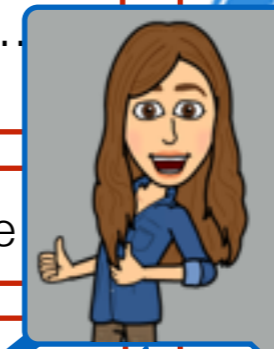
Provided by ESA



European Space Agency



Provided by CSA

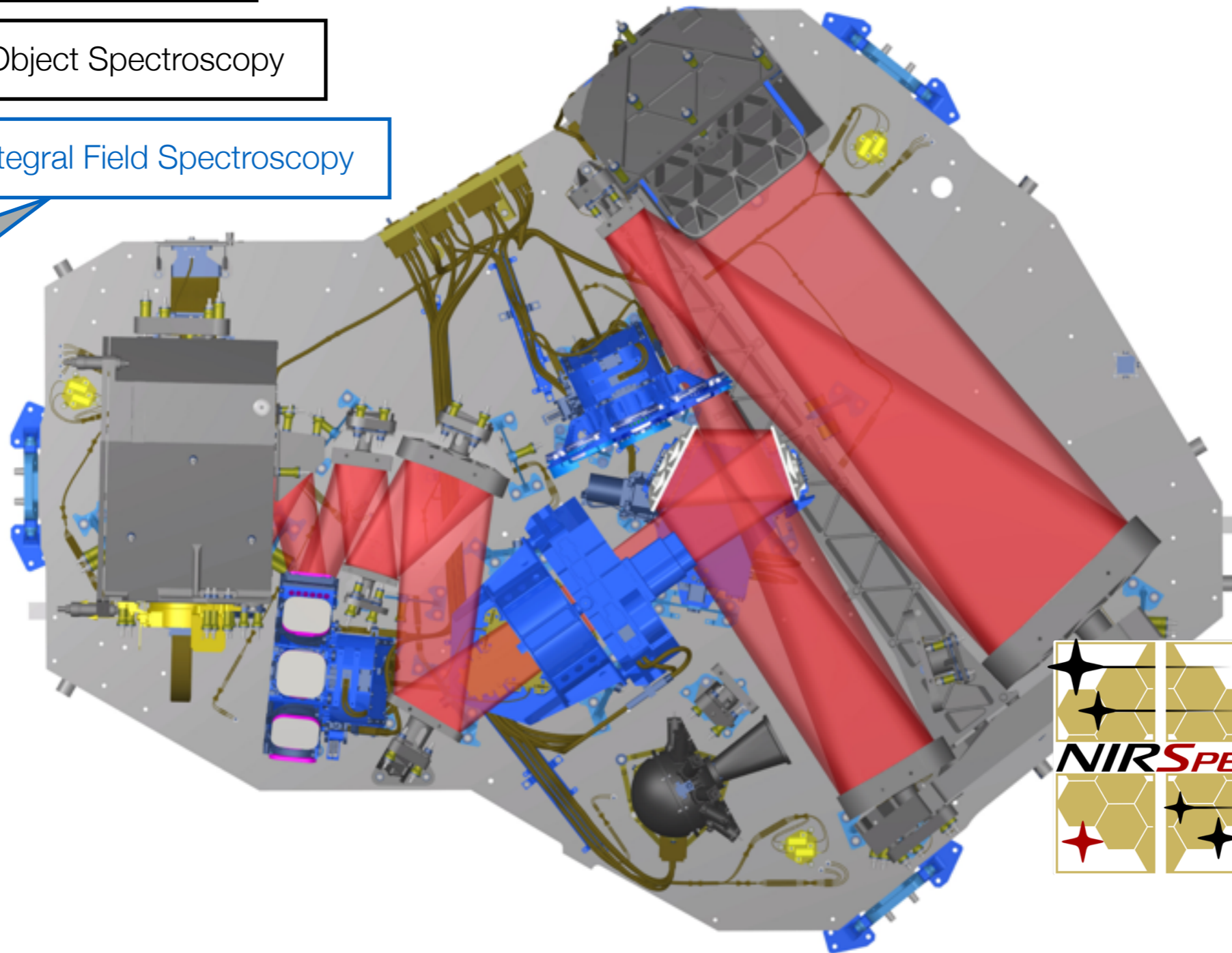


NIRSpec

Fixed Slit Spectroscopy

Multi Object Spectroscopy

Integral Field Spectroscopy



Tasks

BEFORE LAUNCH (2018)

- 80% duties, 20% science
- assist in calibration campaigns (like Cryo Vacuum Tests at NASA)
- reduce and analyze data from these campaigns
- create calibration files for the instruments (flat-fields, darks, ...)
- assist in GTO observation preparations



Making sure the instrument is usable for doing Astronomy

AFTER LAUNCH

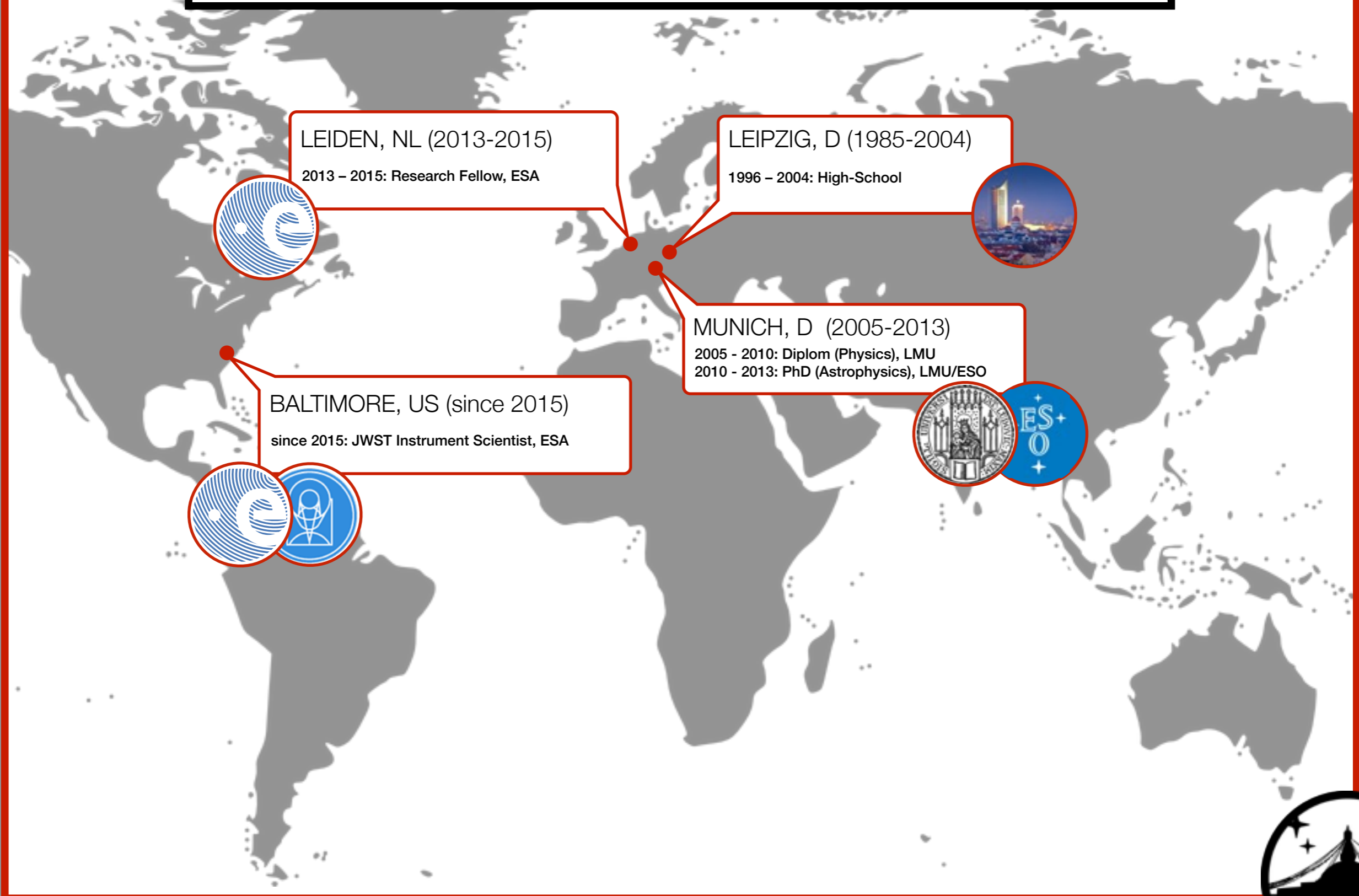
- 50% duties, 50% science
- commissioning (final calibration and science verification of the instrument)
- user support (help astronomers to observe with the instrument)
- calibration monitoring (degrading of hardware, change in instrument...)
- ...



Making sure astronomers use the instrument most efficiently



How did I get here?



LEIDEN, NL (2013-2015)
2013 – 2015: Research Fellow, ESA

LEIPZIG, D (1985-2004)
1996 – 2004: High-School

MUNICH, D (2005-2013)
2005 - 2010: Diplom (Physics), LMU
2010 - 2013: PhD (Astrophysics), LMU/ESO

BALTIMORE, US (since 2015)
since 2015: JWST Instrument Scientist, ESA



Outline

1. Career

2. Introduction

- a. What is a star cluster?
- b. What kind of clusters do we know?
- c. Where do we find them?
- d. Characteristics



Introduction

“The Milky Way is nothing else but a mass of innumerable stars planted together in clusters”

- Galileo Galilei (1610)



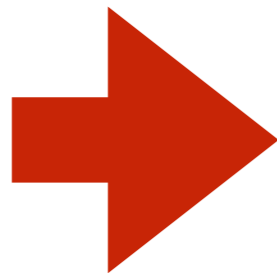
Introduction

“Most stars form in clusters”

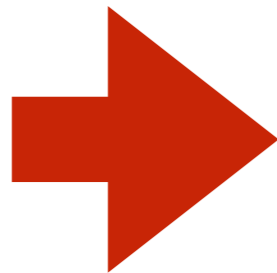
- Lada & Lada (2003)



Star Cluster



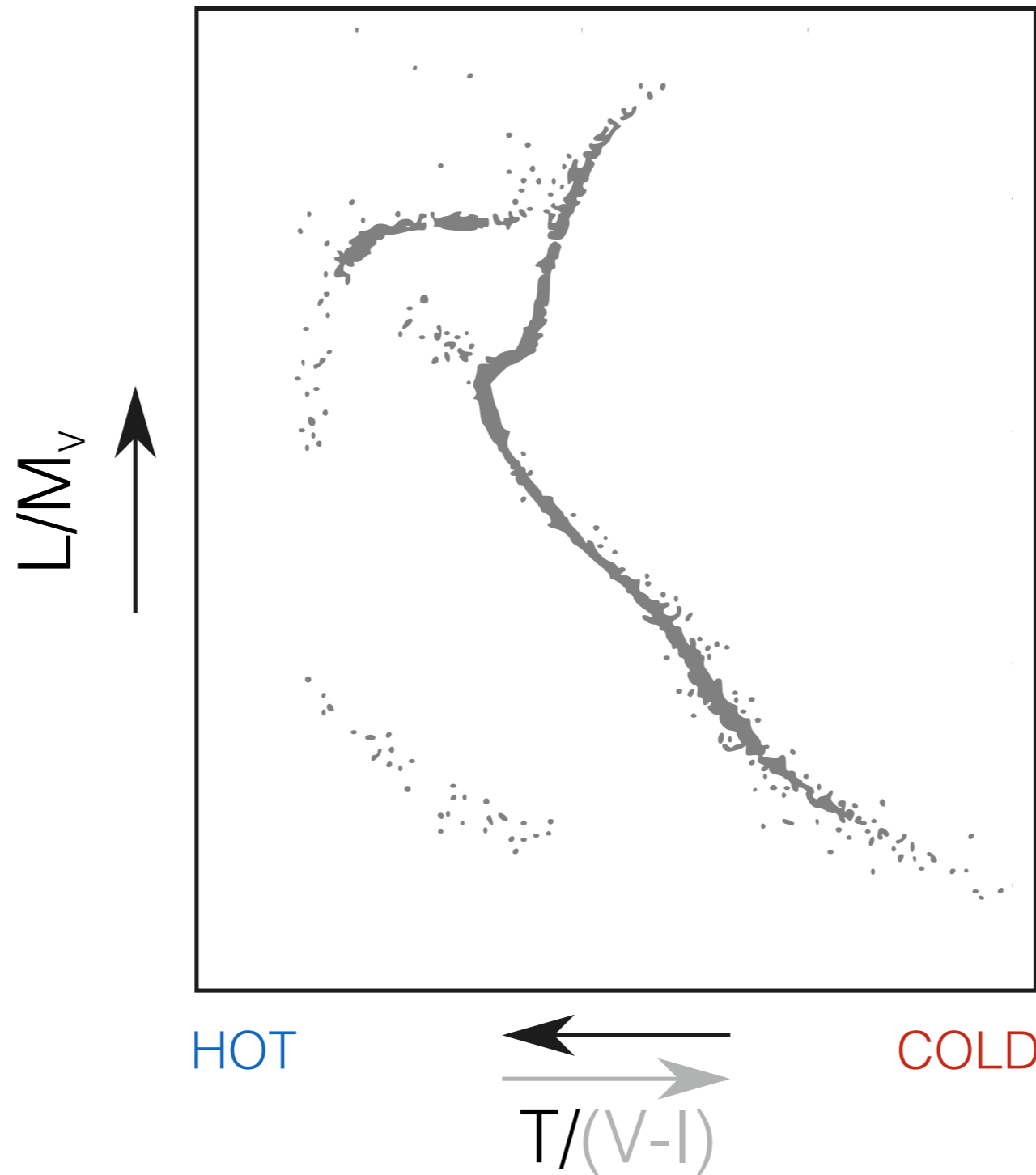
Collection of stars roughly **born at the same time**



Collection of stars that are **gravitationally bound**



Excursion: Color-magnitude diagram

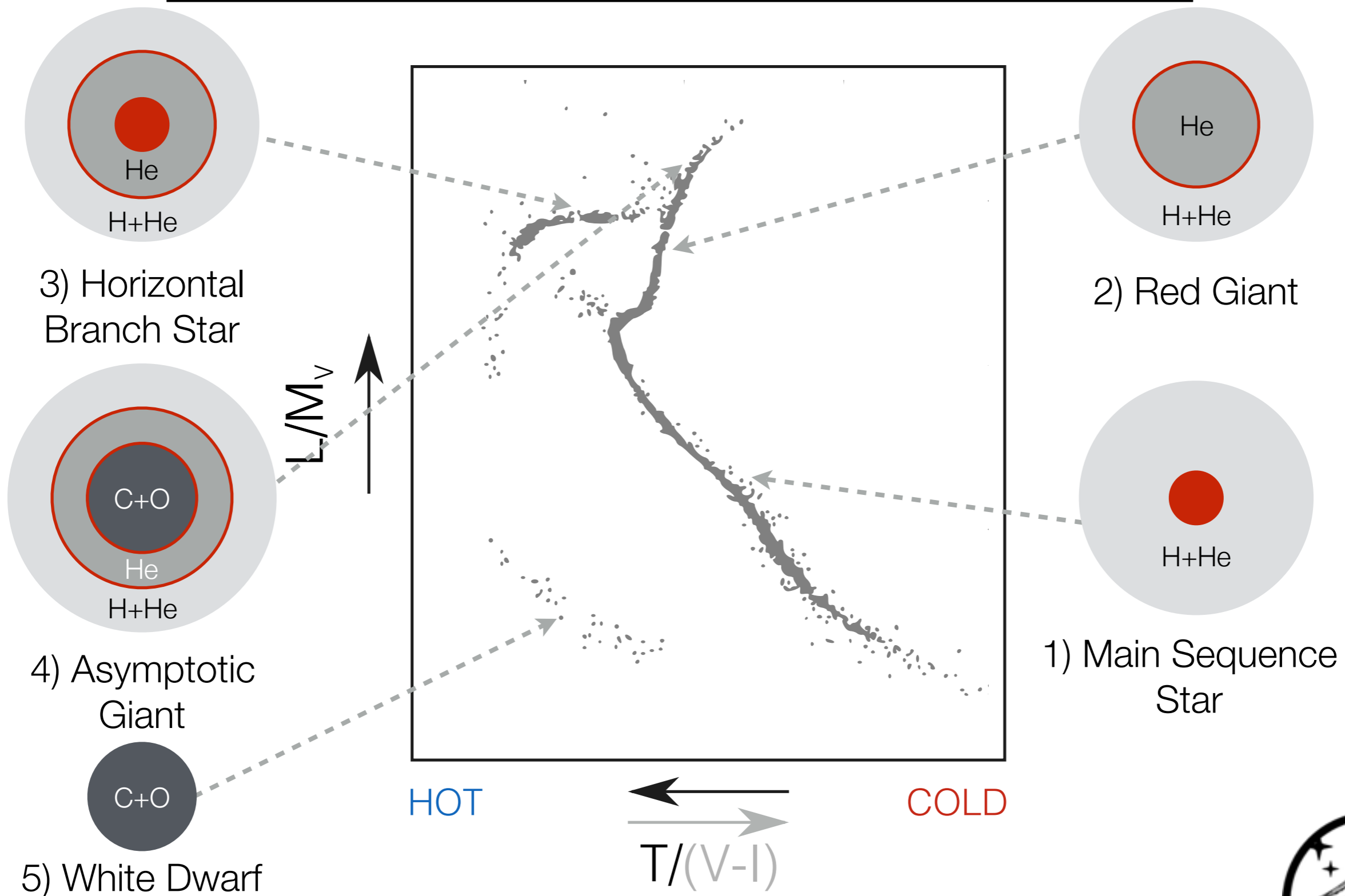


Constructing The Hertzsprung–Russell Diagram for Globular Star Cluster Omega Centauri

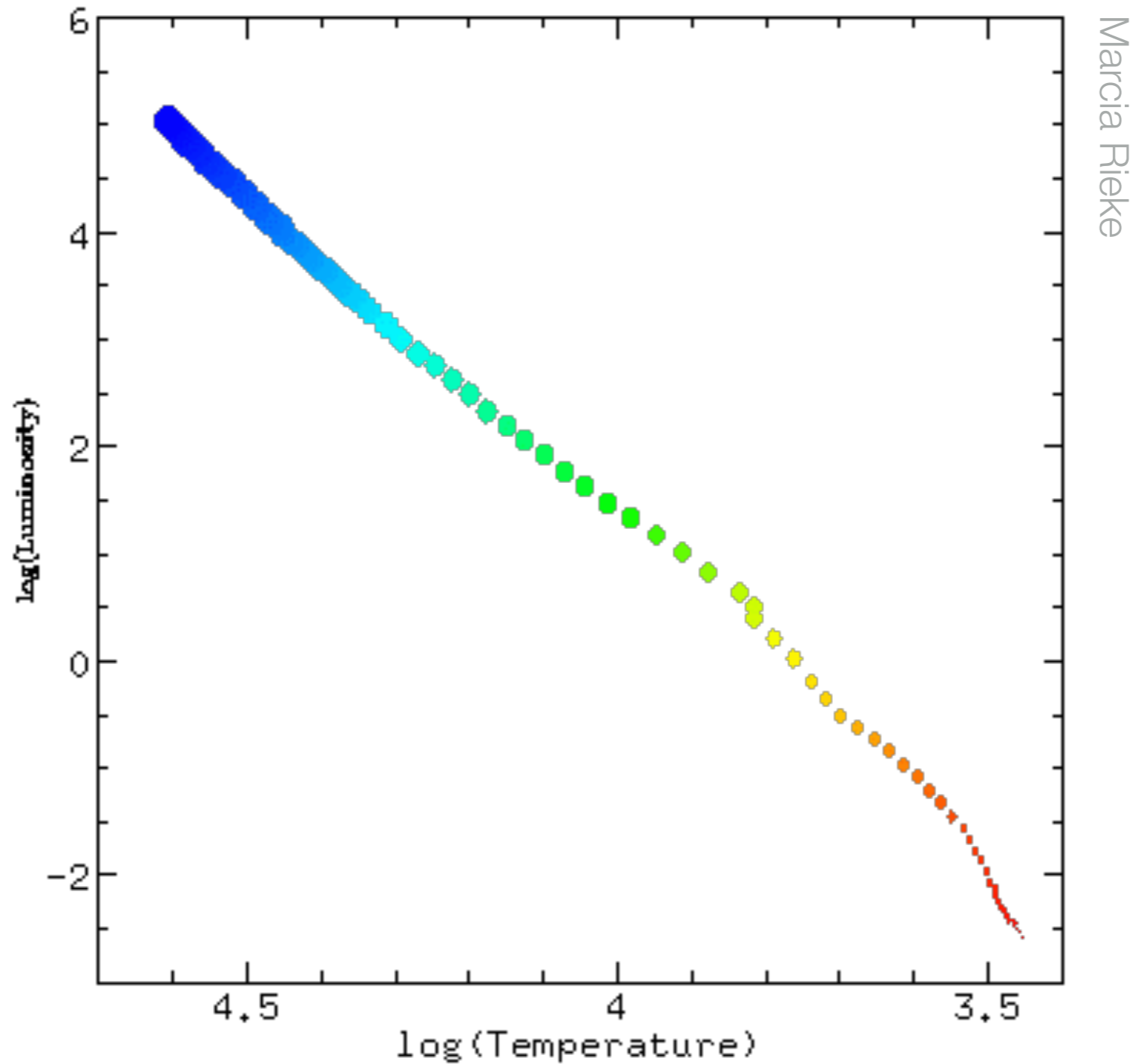
Video can be found here:

<http://hubblesite.org/newscenter/archive/releases/2010/28>

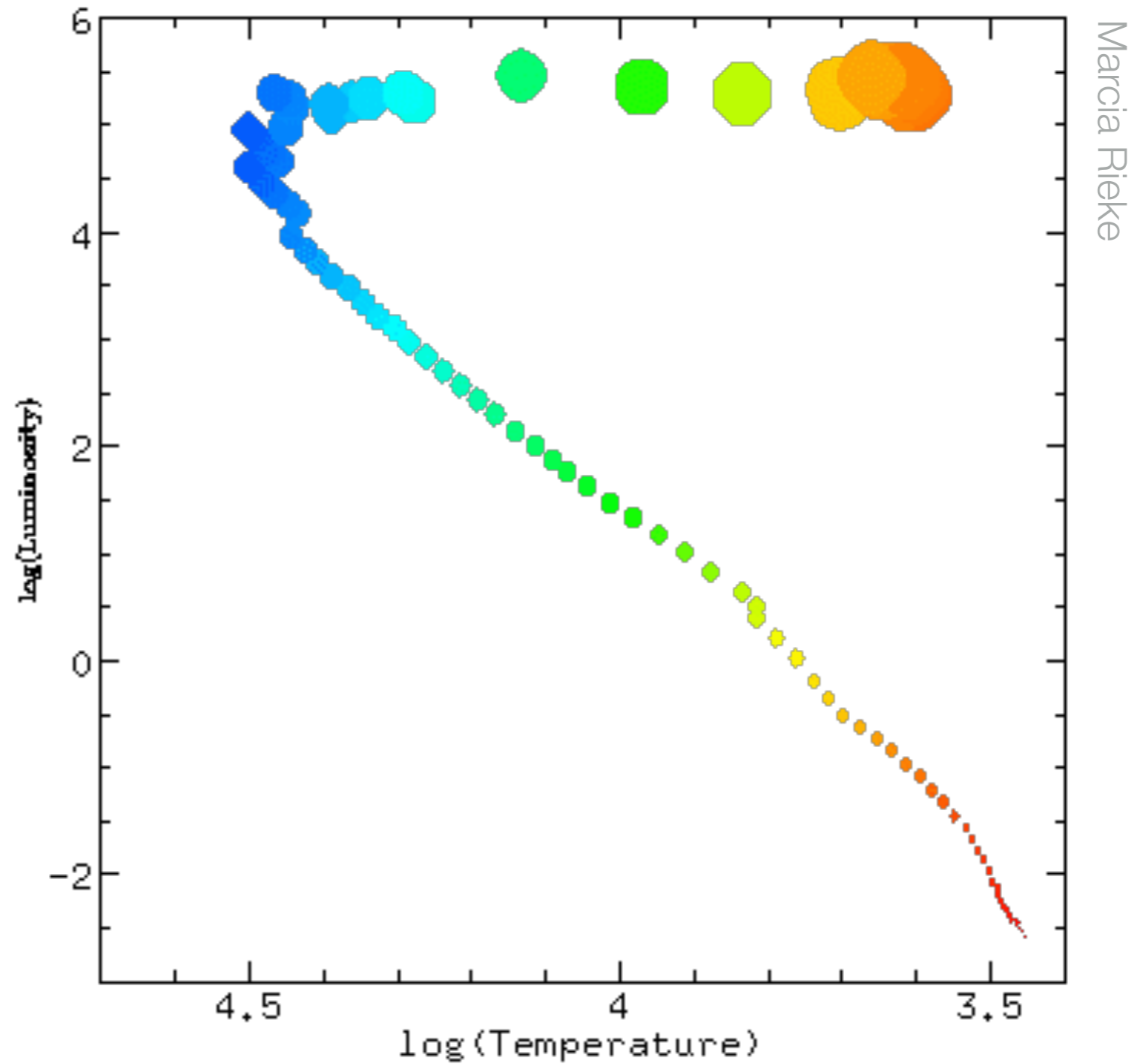
Excursion: Color-magnitude diagram



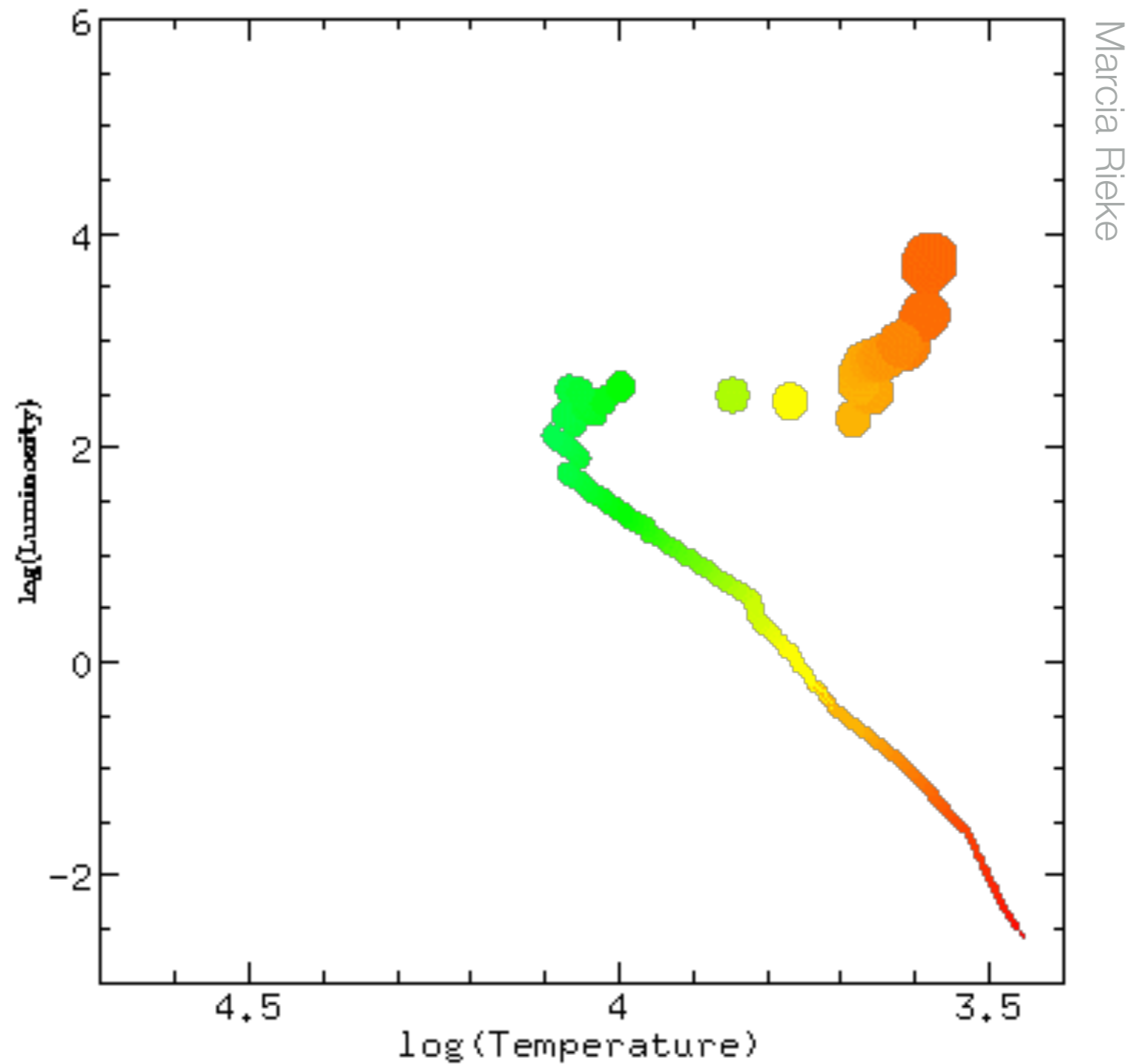
Excursion: Color-magnitude diagram



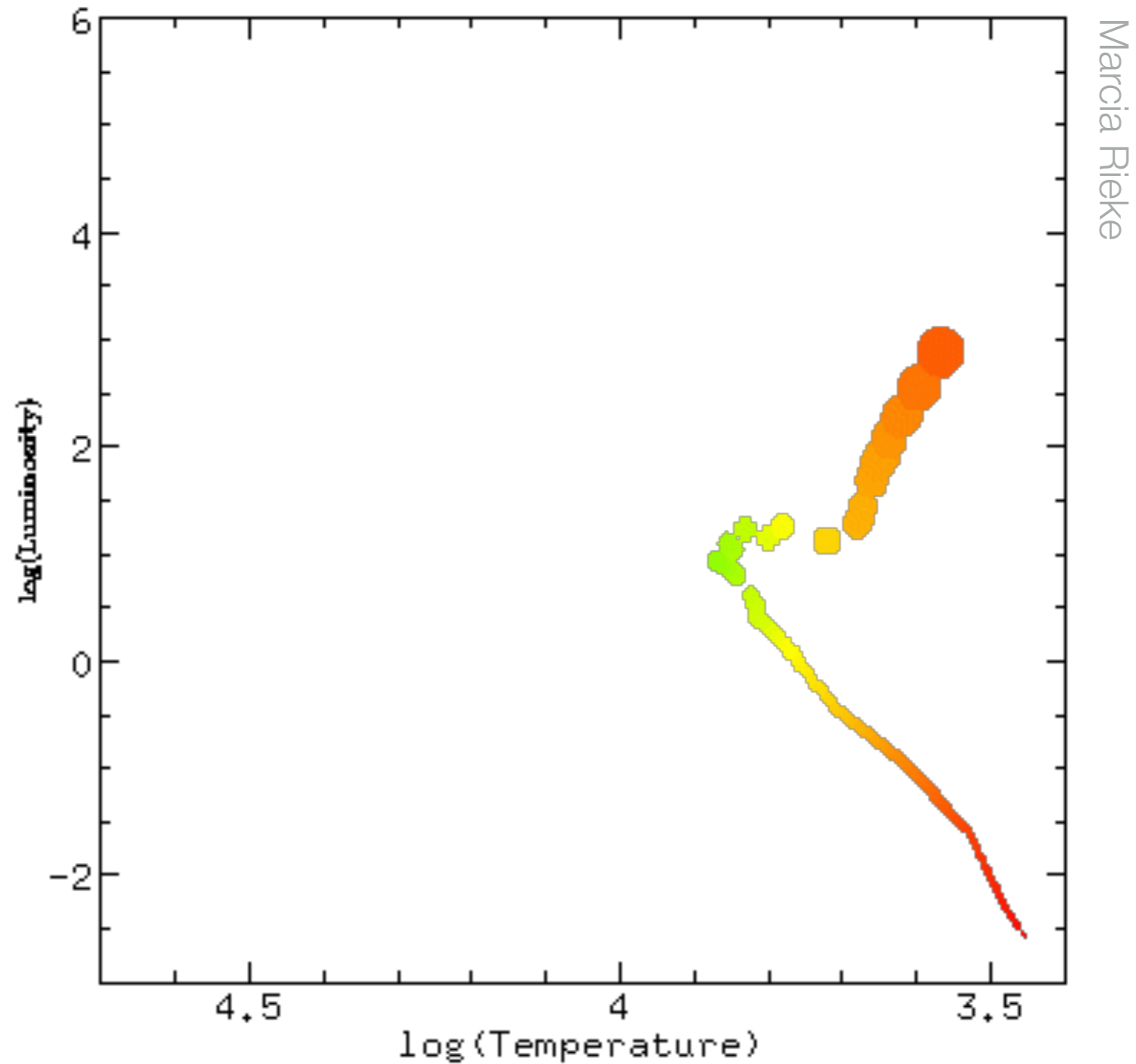
Excursion: Color-magnitude diagram



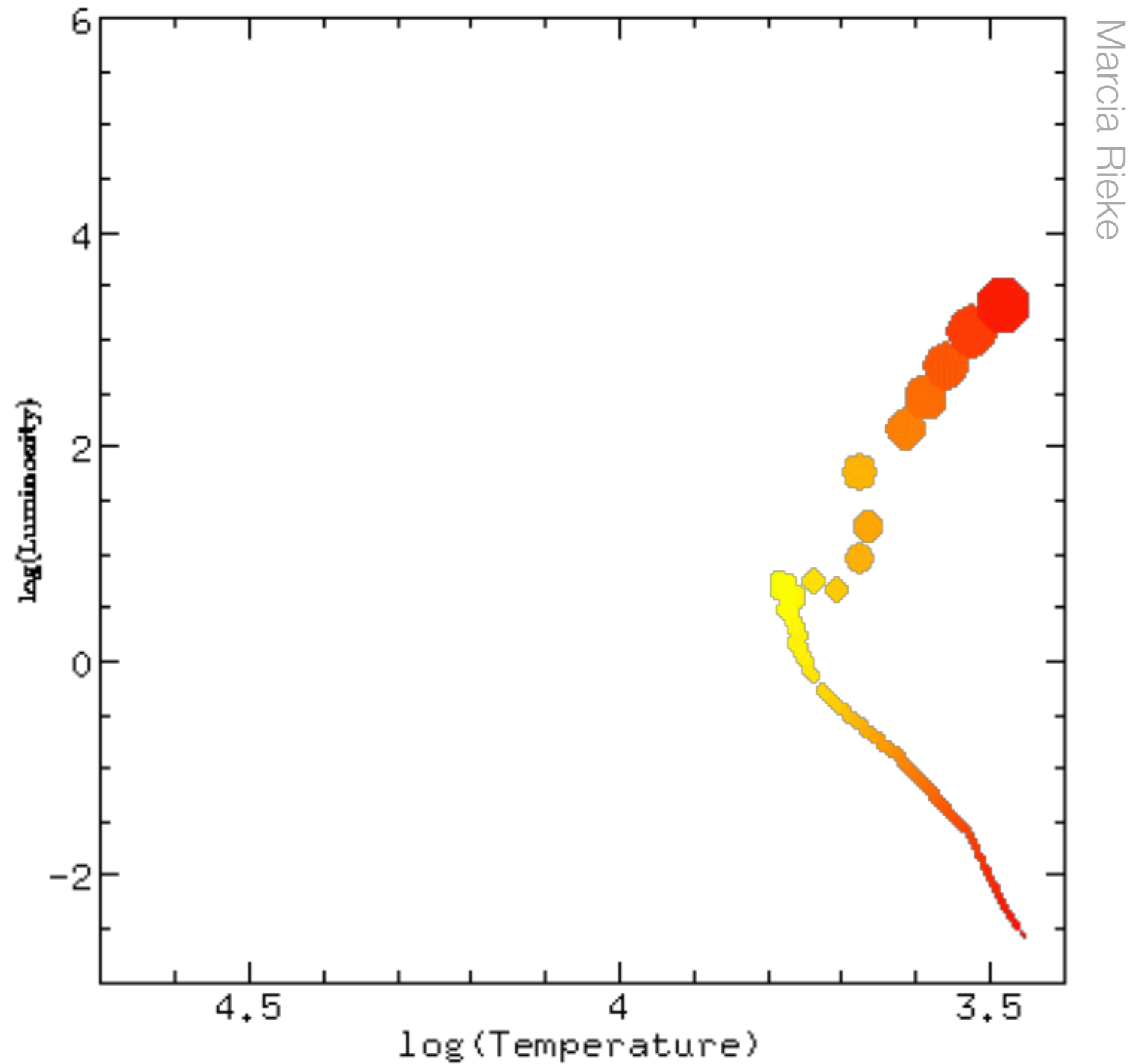
Excursion: Color-magnitude diagram



Excursion: Color-magnitude diagram



Excursion: Color-magnitude diagram



Types of clusters

N stars

100 -1000

$1e4-1e6$

$1e4-1e5$

$1e5-1e7$

$1e6-1e8$



OB
Associations

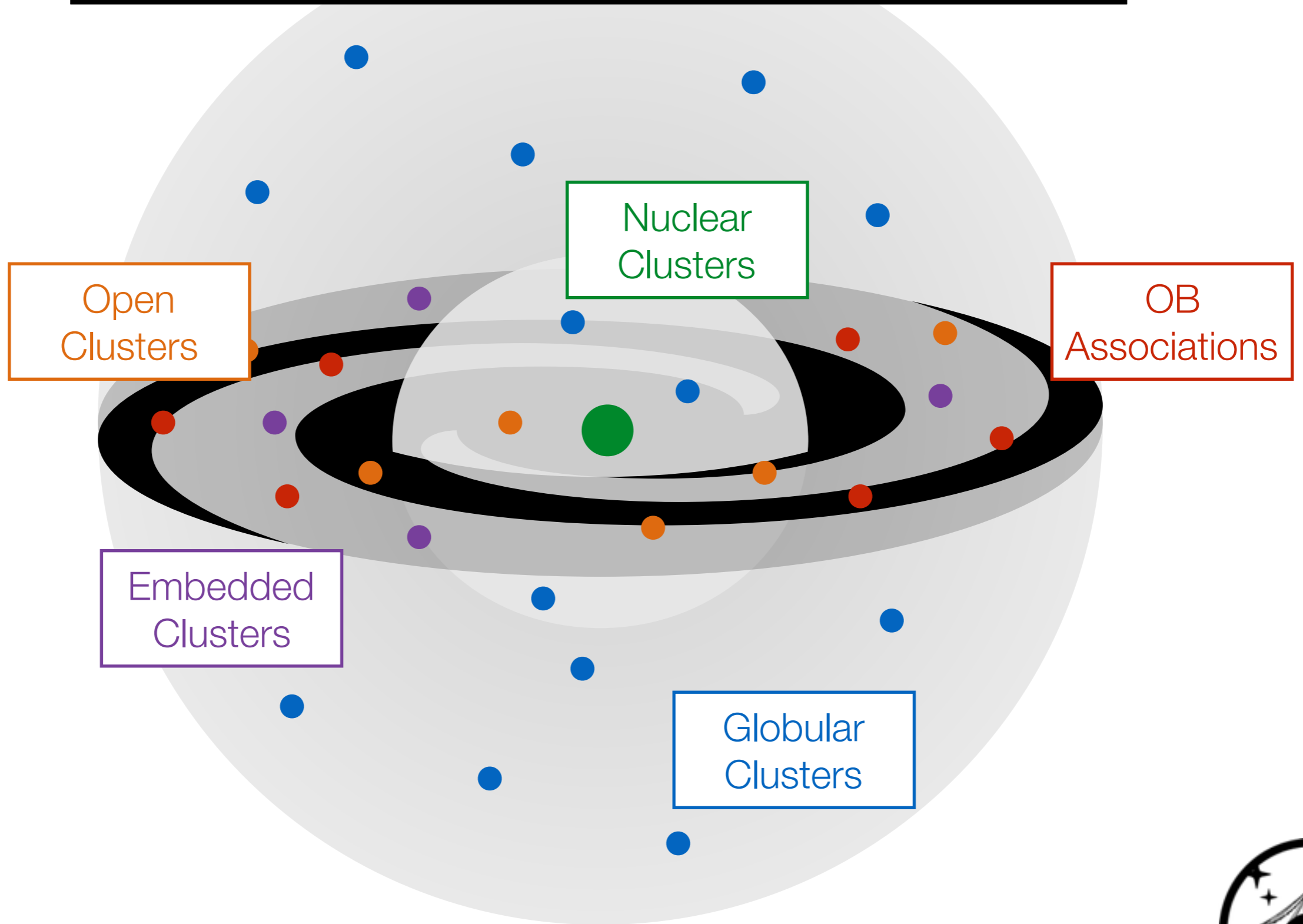
Embedded
Clusters

Open
Clusters

Globular
Clusters

Nuclear
Clusters

Environment



Types of clusters

N stars

100 -1000

$1e4-1e6$

$1e4-1e5$

$1e5-1e7$

$1e6-1e8$



**OB
Association**

Embedded
Clusters

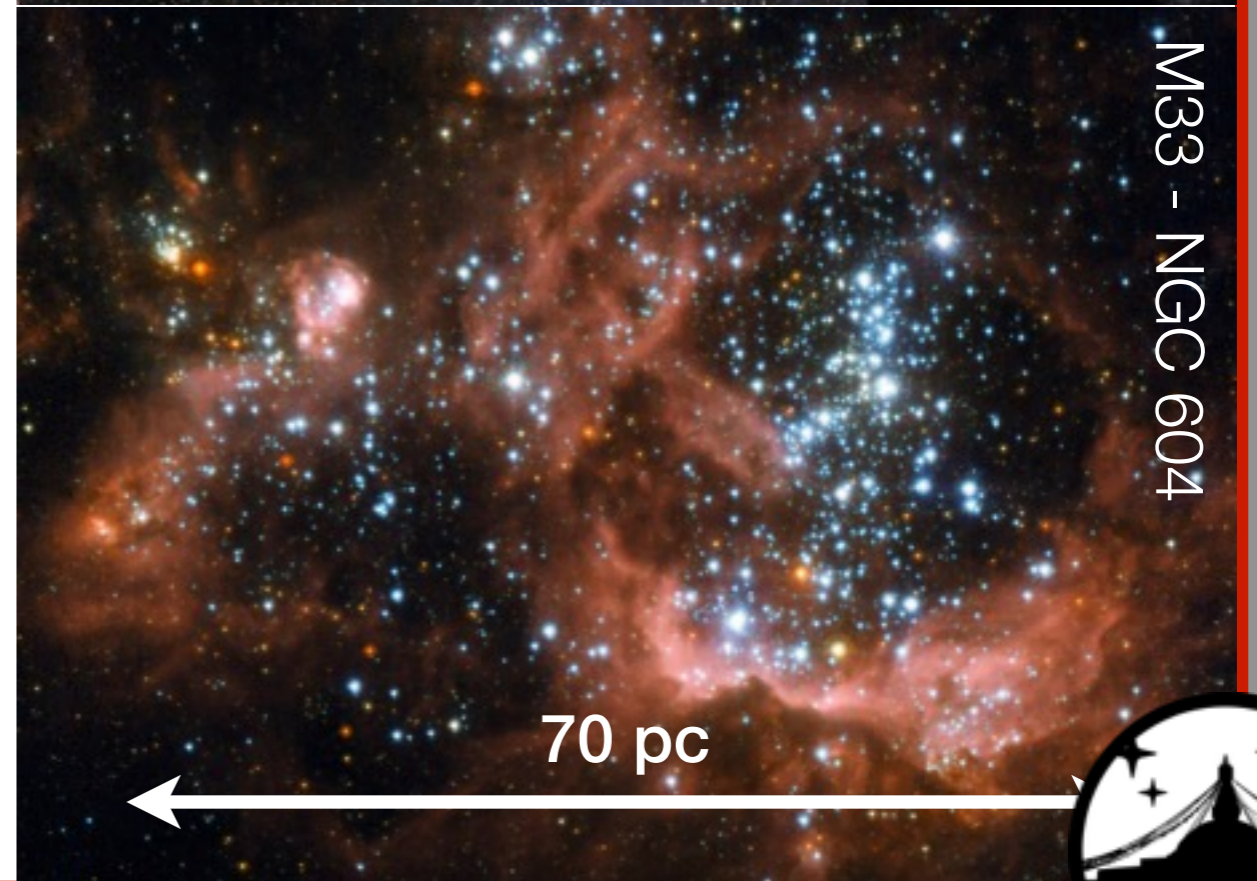
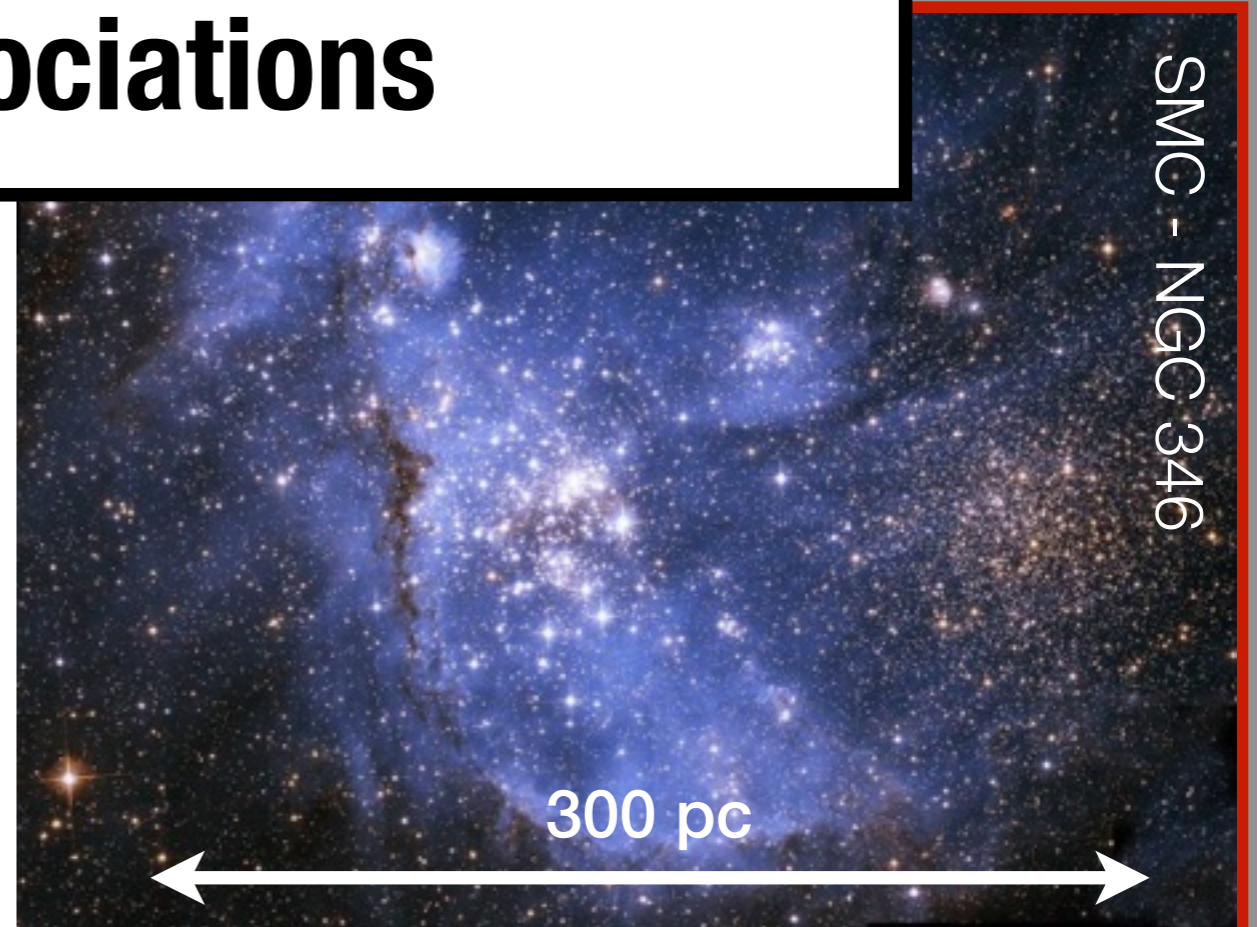
Open
Clusters

Globular
Clusters

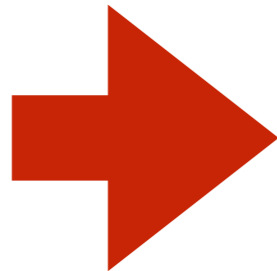
Nuclear
Clusters

OB Associations

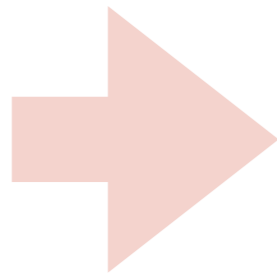
- 20 - 500 pc
- 0.1 stars/pc
- gravitationally unbound
- 12 within 650 pc



Star Cluster



Collection of stars roughly **born at the same time**



Collection of stars that are **gravitationally bound**



Types of clusters

N stars

100 -1000

1e4-1e6

1e4-1e5

1e5-1e7

1e6-1e8



OB
Associations

**Embedded
Clusters**

Open
Clusters

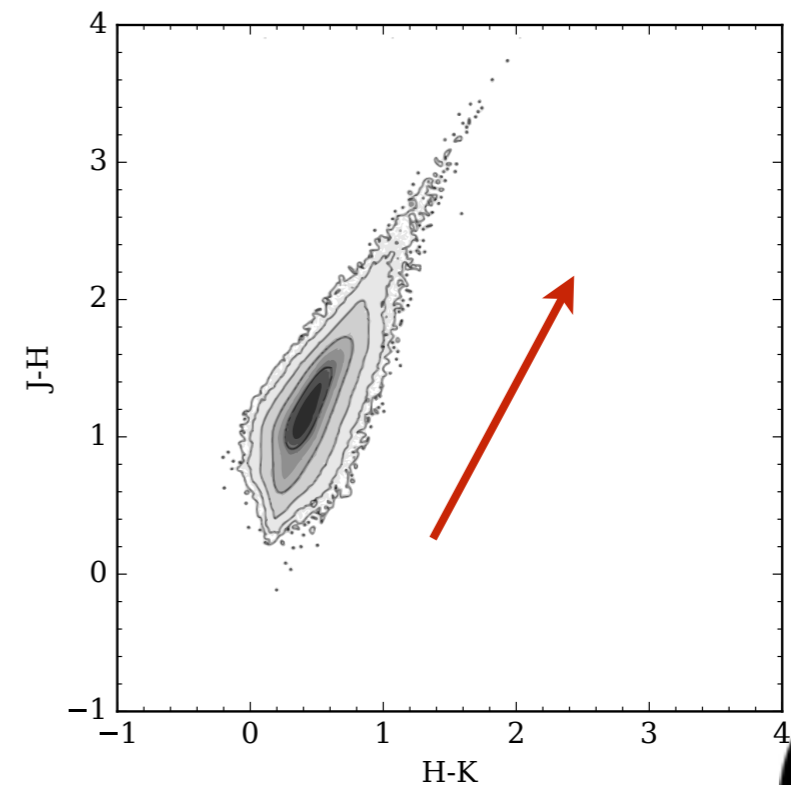
Globular
Clusters

Nuclear
Clusters

Embedded clusters



- 1 - 10 pc
 - 100 - 1000 stars/pc³
 - age < 5 Myr
 - may or may not be bound
 - still gas in / around the cluster
- ➔ High extinction



Embedded clusters

Video can be found here:
<https://www.youtube.com/watch?v=JcqlTOrijtk>

1 pc



Types of clusters

N stars

100 -1000

1e4-1e6

1e4-1e5

1e5-1e7

1e6-1e8



OB
Associations

Embedded
Clusters

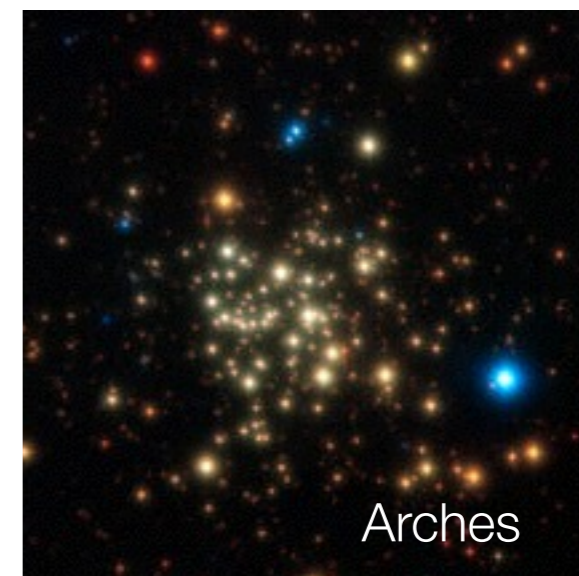
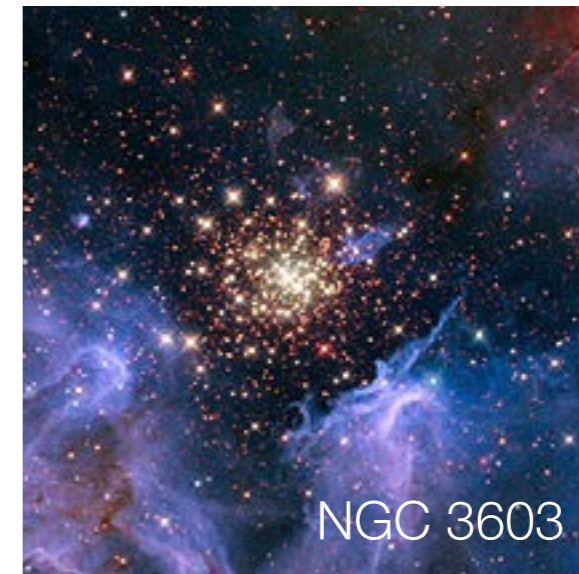
**Open
Clusters**

Globular
Clusters

Nuclear
Clusters

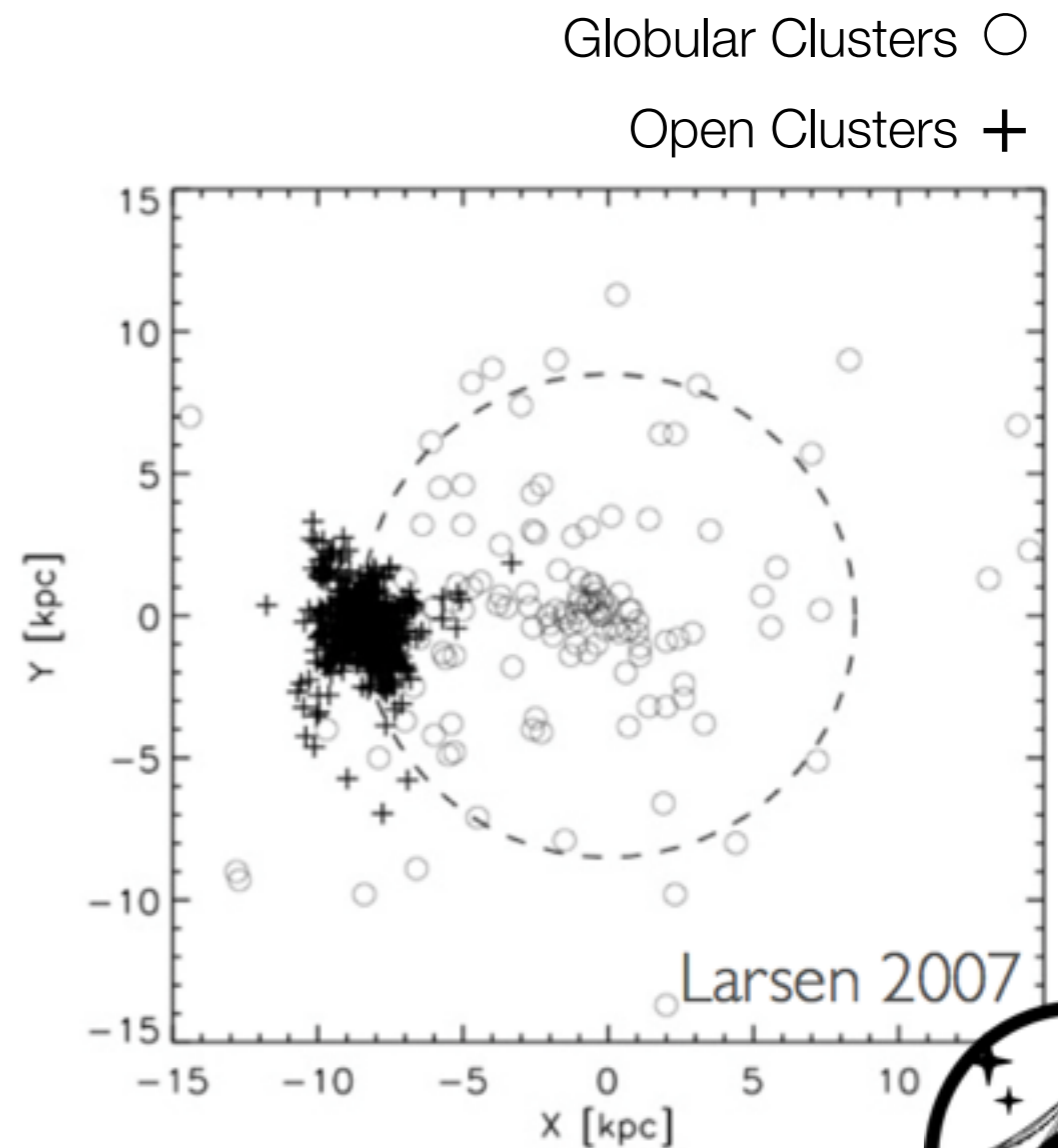
Open clusters

- core radii $\sim 2\text{pc}$
- mass $\sim 100 - 1000 M_{\text{SUN}}$
- age: between 3 Myr and a few Gyr
- no gas left
- gravitationally bound



Open clusters - Observations

- ~ 2000 identified
 - ➔ 1e5 within the Galaxy! (*extinction*)



Types of clusters

N stars

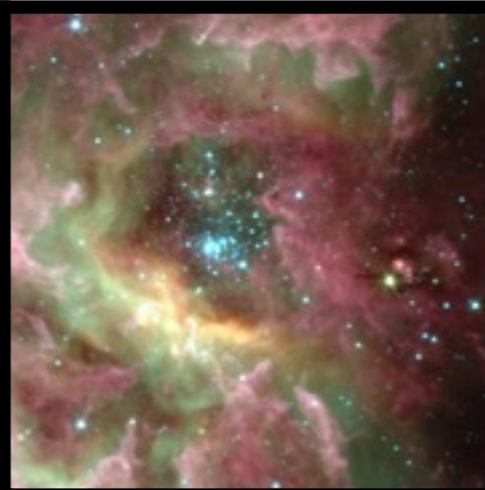
100 -1000

$1e4-1e6$

$1e4-1e5$

$1e5-1e7$

$1e6-1e8$



OB
Associations

Embedded
Clusters

Open
Clusters

**Globular
Clusters**

Nuclear
Clusters

Globular Clusters

- 1-30 pc
- mass $\sim 10^4 - 10^6 M_{\text{SUN}}$
- gravitationally bound
- age: 10 - 12 Gyr

➔ **oldest objects in the universe!**



Globular Clusters

- 1-30 pc
- mass $\sim 10^4 - 10^6 M_{\text{SUN}}$
- gravitationally bound
- age: 10 - 12 Gyr

➔ **oldest objects in the universe!**



Globular Clusters - Are dense

DENSITY $\sim 10^3$ 1/pc³

SUN

ALPHA CENTAURI

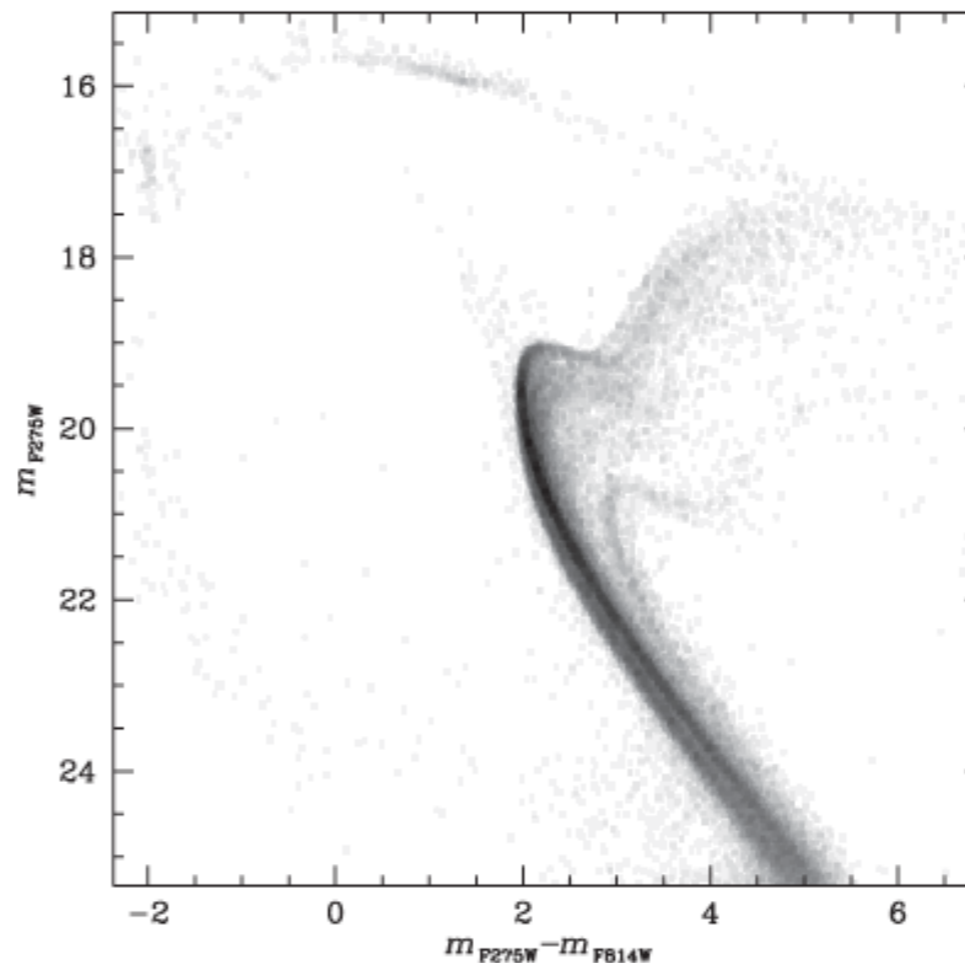


Globular Clusters - Not what expected

PAST:

- All stars formed at the same time
- All stars have the same chemical composition

TODAY: (see Lecture 2)

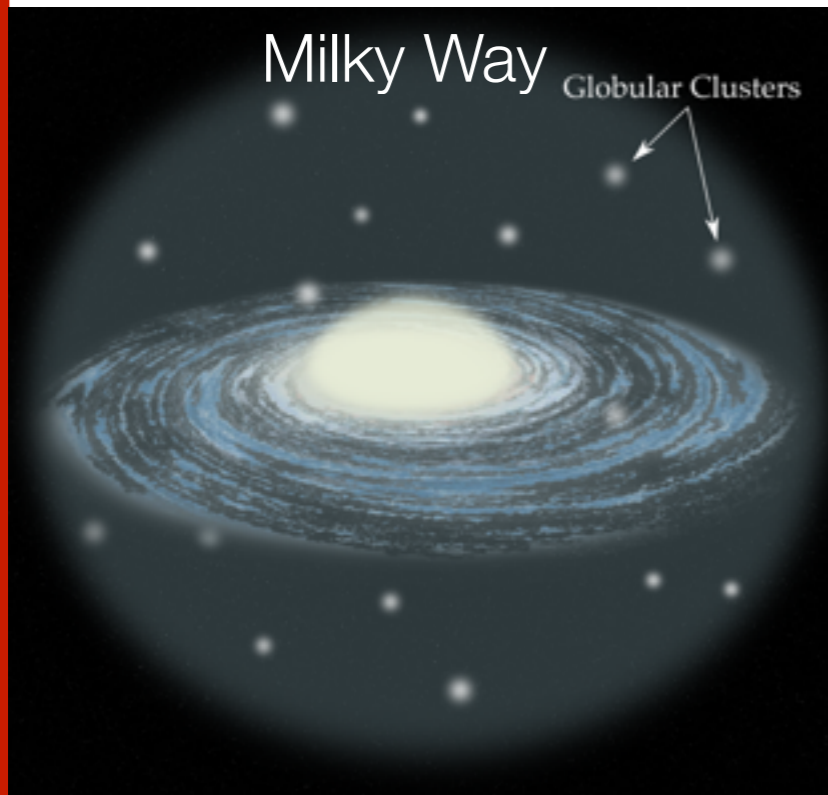


Omega Centauri, Bellini et al., 2011

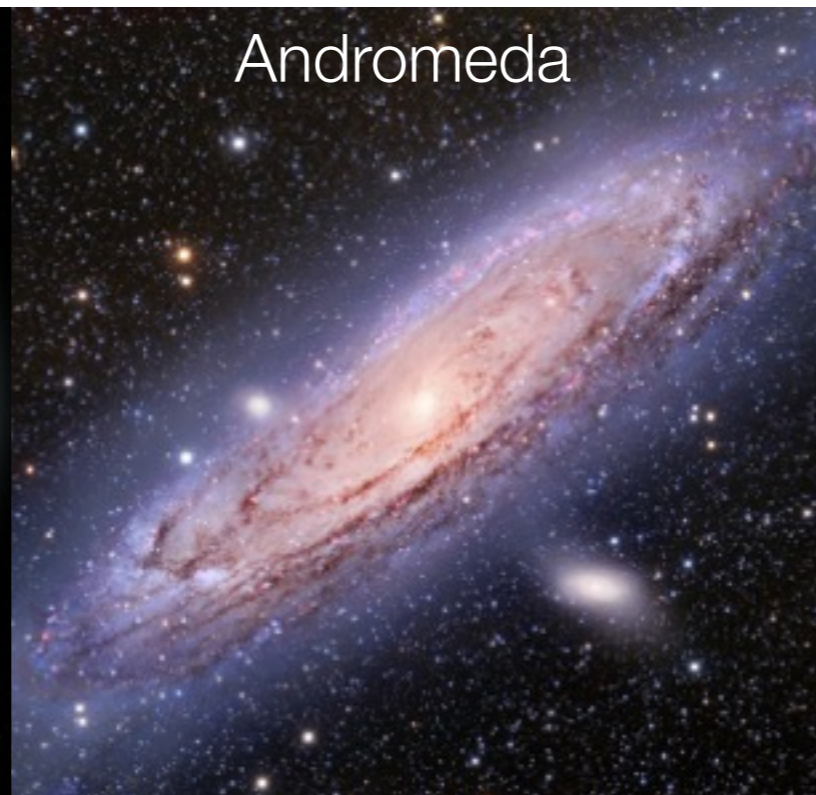


Globular Clusters - Live in Galaxies

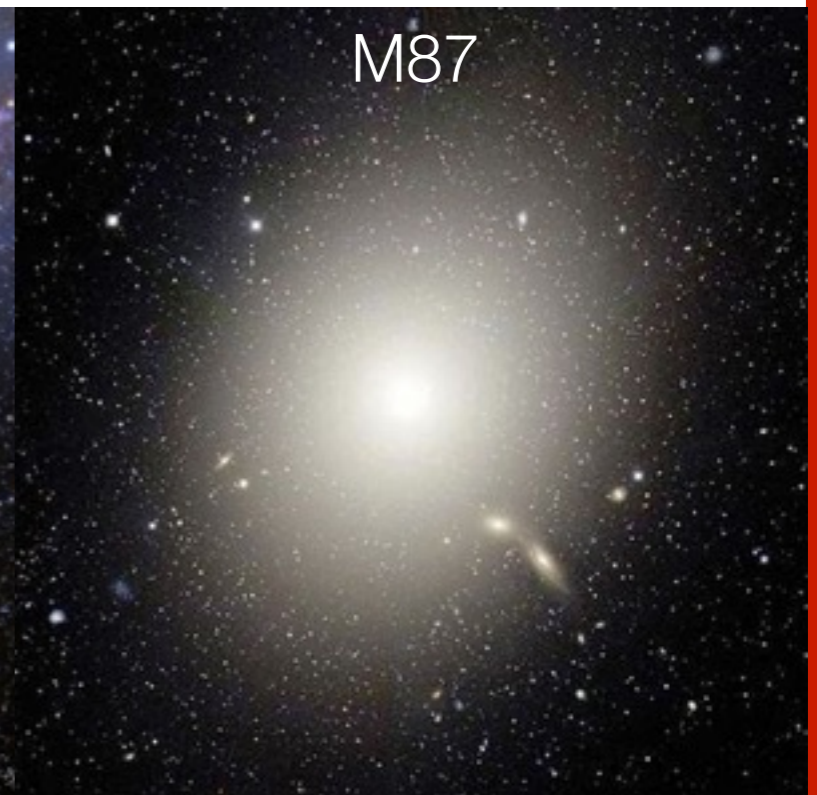
Always around galaxies



~200 GCs



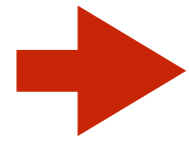
~500 GCs



~15 000 GCs

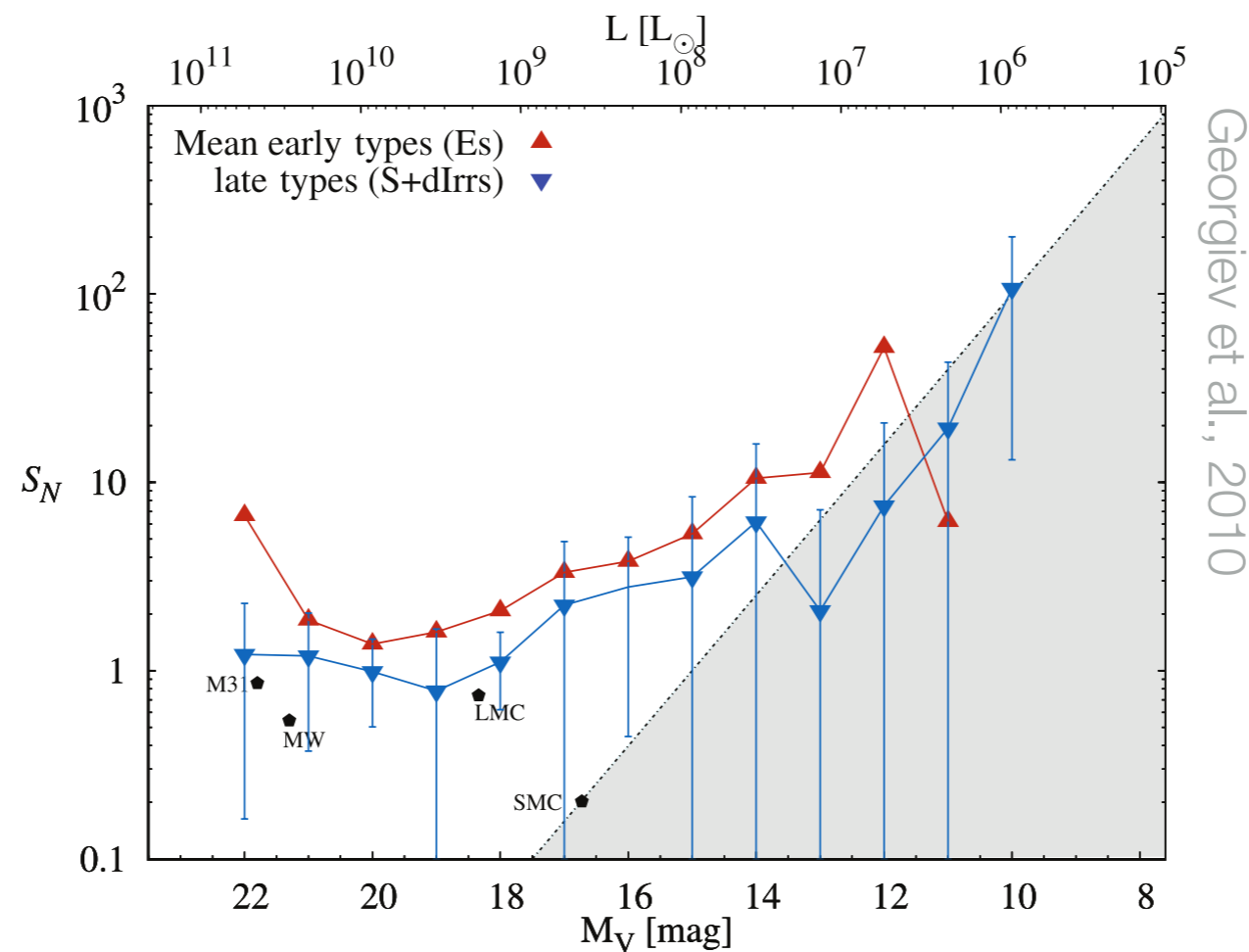


Globular Clusters - Specific Frequency

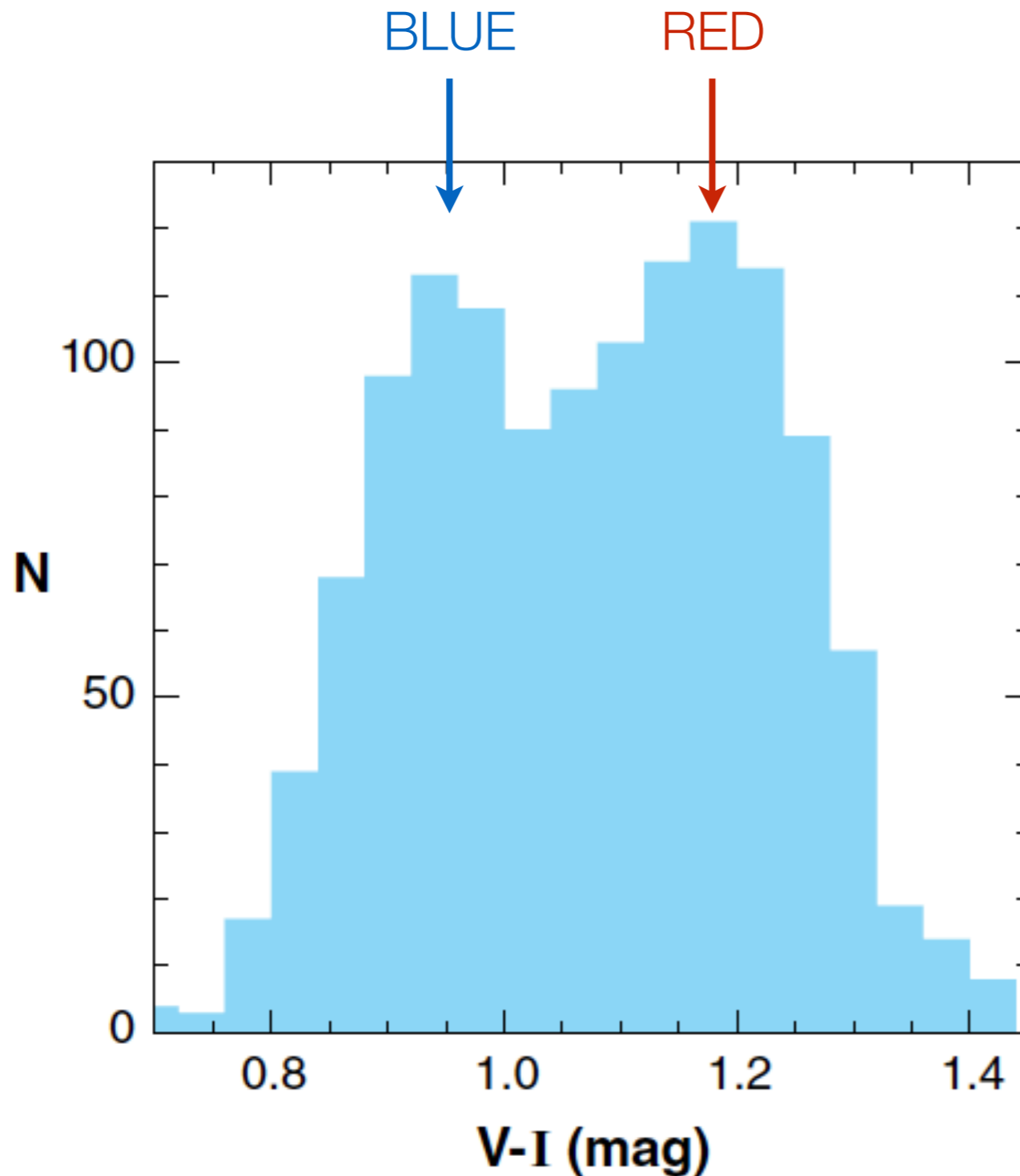


Number of Globular Clusters in a galaxy divided by the galaxy's luminosity: $S_N = N_{GC}/L_G$

- Formation efficiency of Globular Clusters relative to field stars
- Depends on galaxy type (higher in ellipticals)



Globular Clusters - Bimodality



Blue Globular Clusters

- metal-poor
- galaxy halo
- larger

Red Globular Clusters

- metal-rich
- bulge/disk
- smaller

Young Massive Clusters

- Young cluster populations forming today
- Maybe forming Globular Clusters???
- Formation Environments:



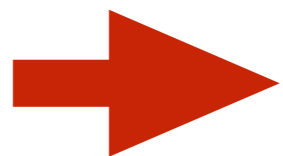
Galaxy Mergers



Spiral Galaxies



Starbursting Dwarfs



High Star Formation

Types of clusters

N stars

100 -1000

1e4-1e6

1e4-1e5

1e5-1e7

1e6-1e8



OB
Associations

Embedded
Clusters

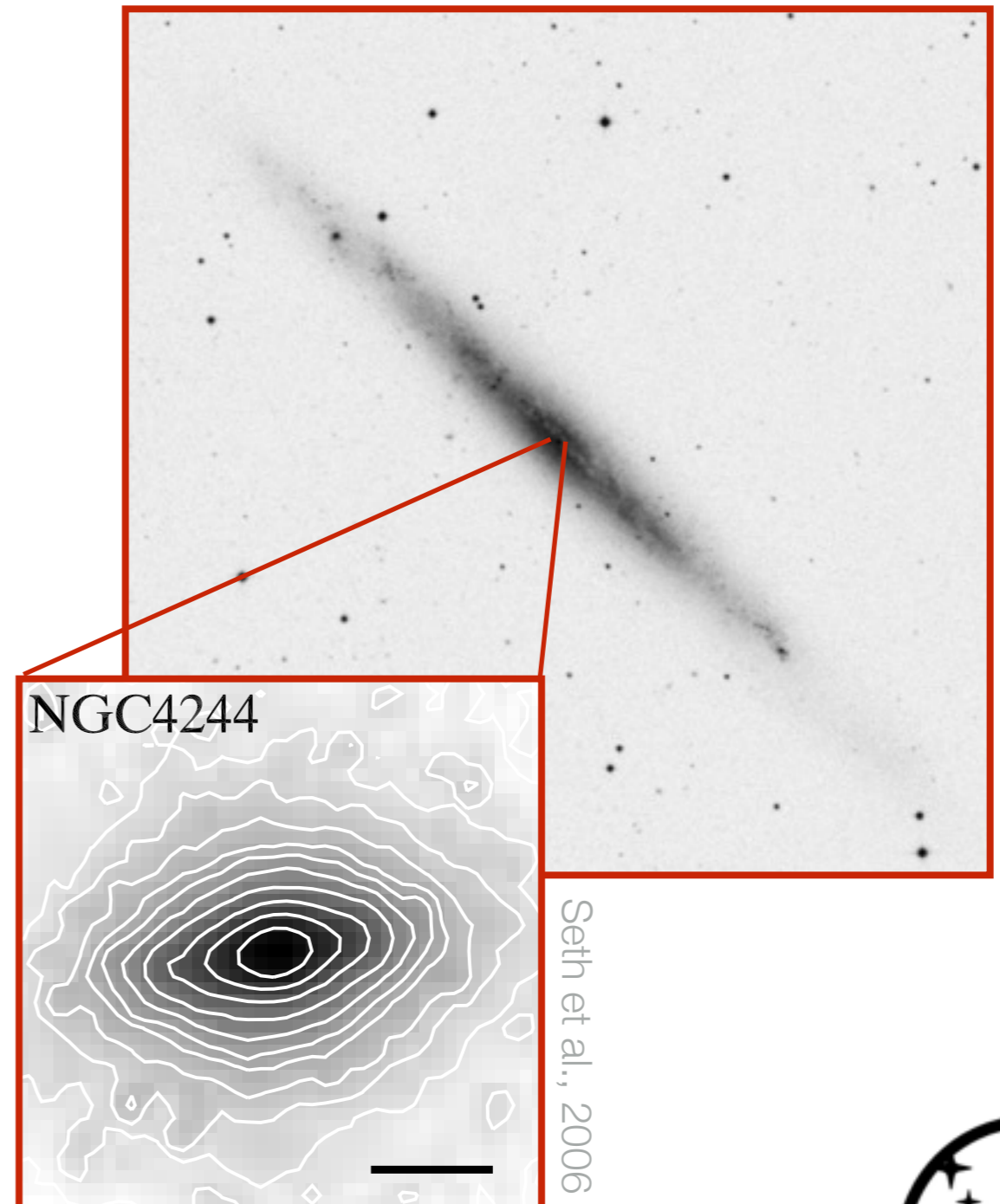
Open
Clusters

Globular
Clusters

**Nuclear
Clusters**

Nuclear Clusters

- 1-30 pc
- mass $\sim 10^5 - 10^8 M_{\text{SUN}}$
- age: multiple epochs of star formation
- centers of galaxies
- gravitational bound
- co-existing with black hole
- **densest objects in the universe**



Nuclear Clusters - Are super dense

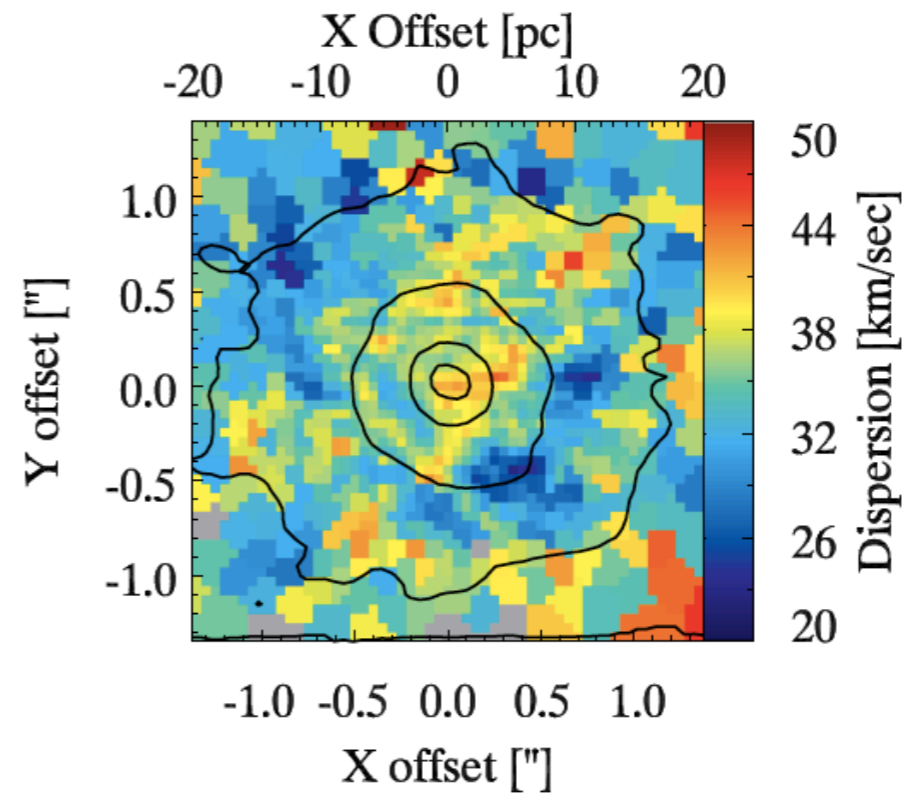
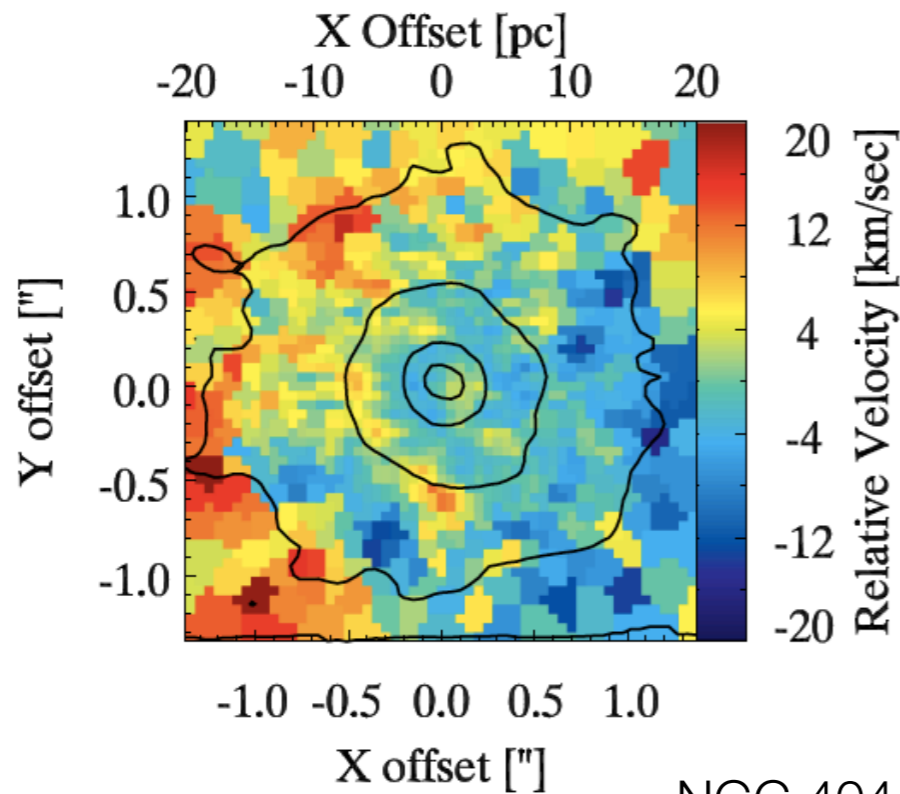
DENSITY $\sim 10^6$ 1/pc³

SUN

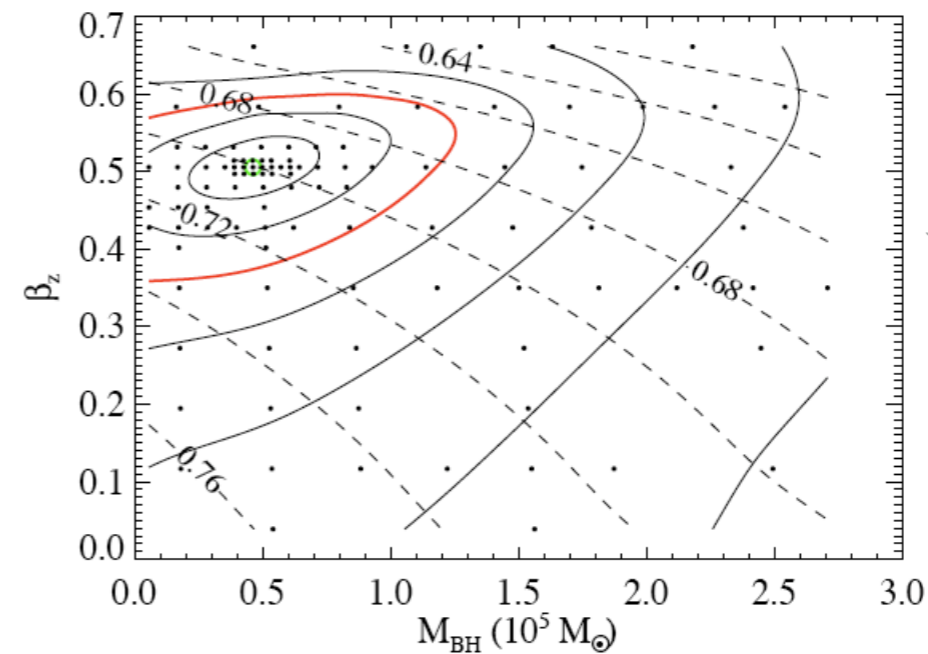
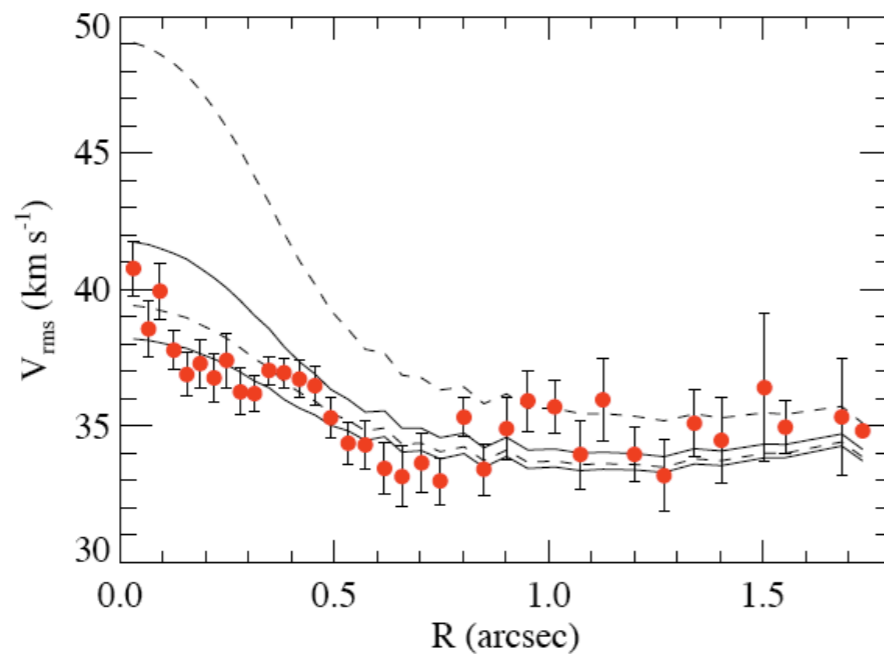
ALPHA CENTAURI



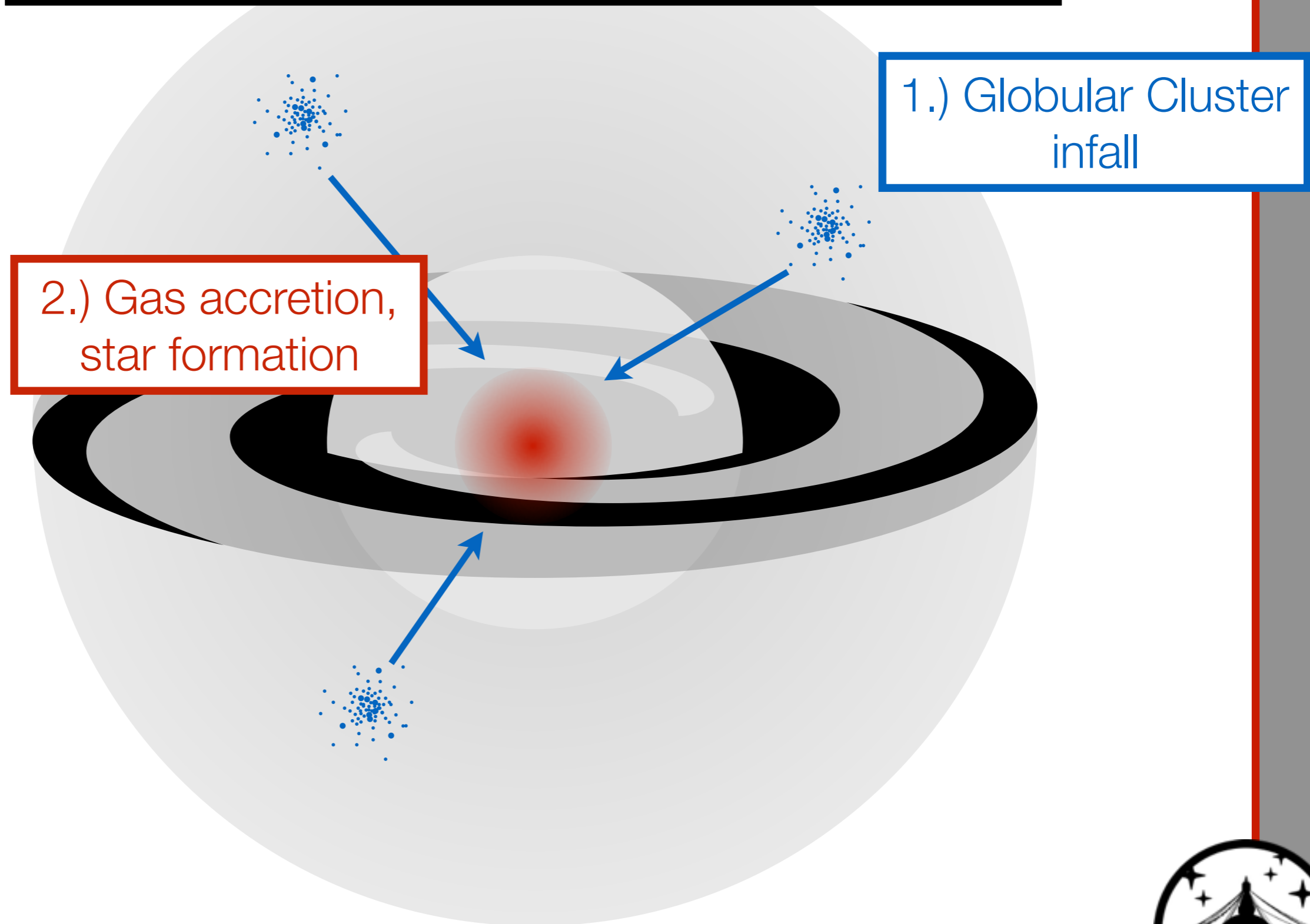
Nuclear Clusters - Host black holes



NGC 404



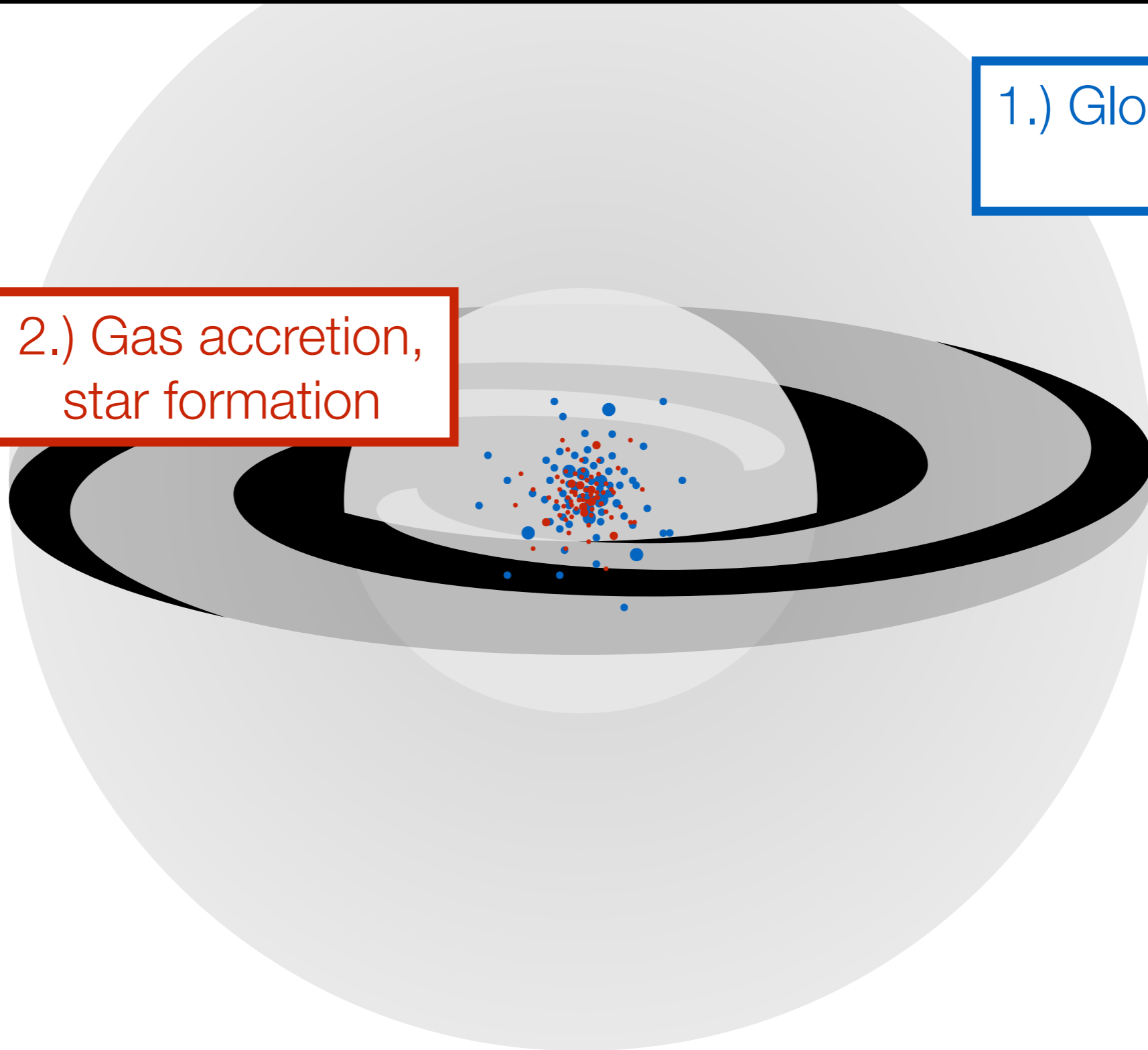
Nuclear Clusters - Formation



Nuclear Clusters - Formation

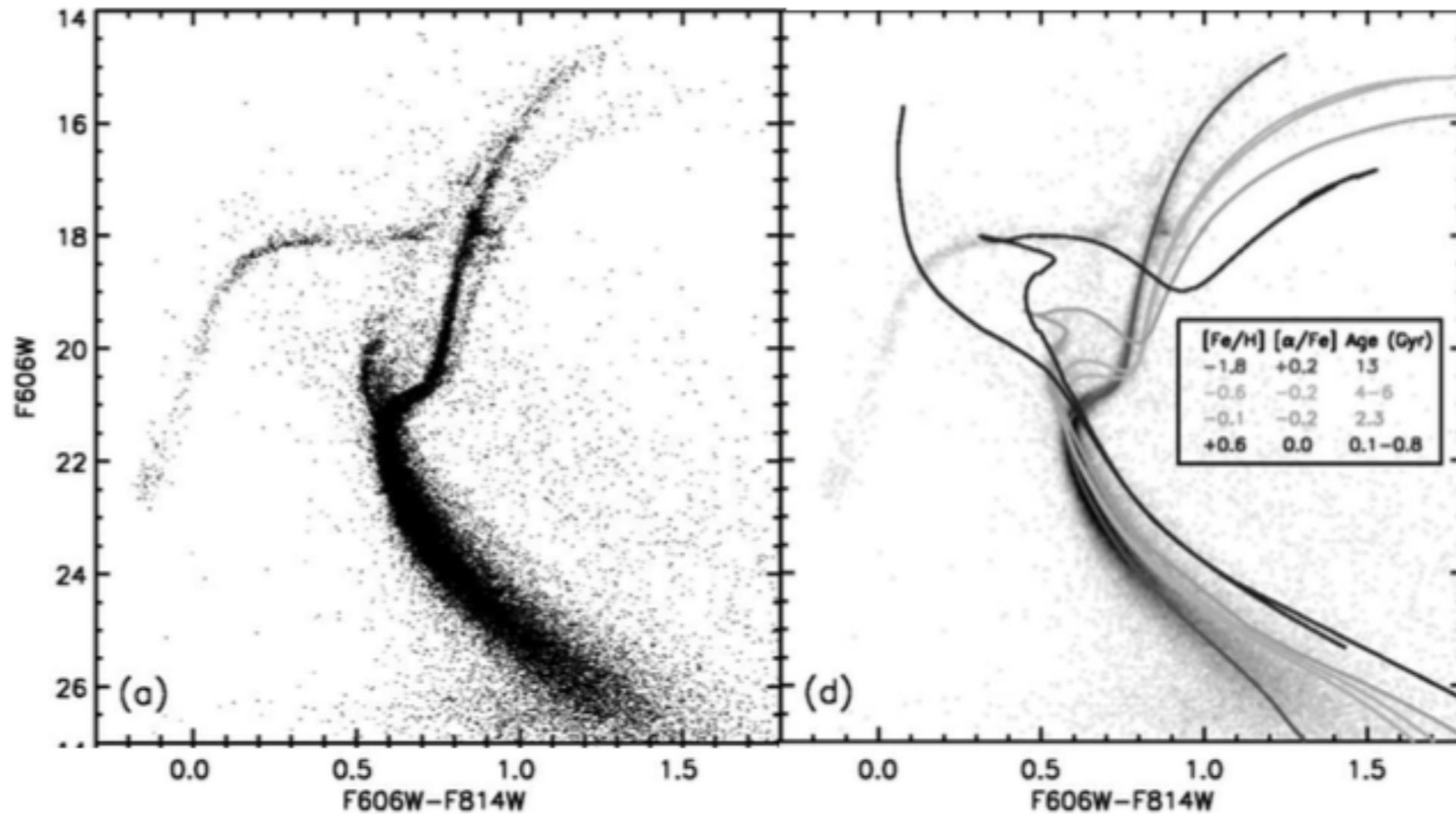
1.) Globular Cluster
infall

2.) Gas accretion,
star formation



Nuclear Clusters - Multiple populations

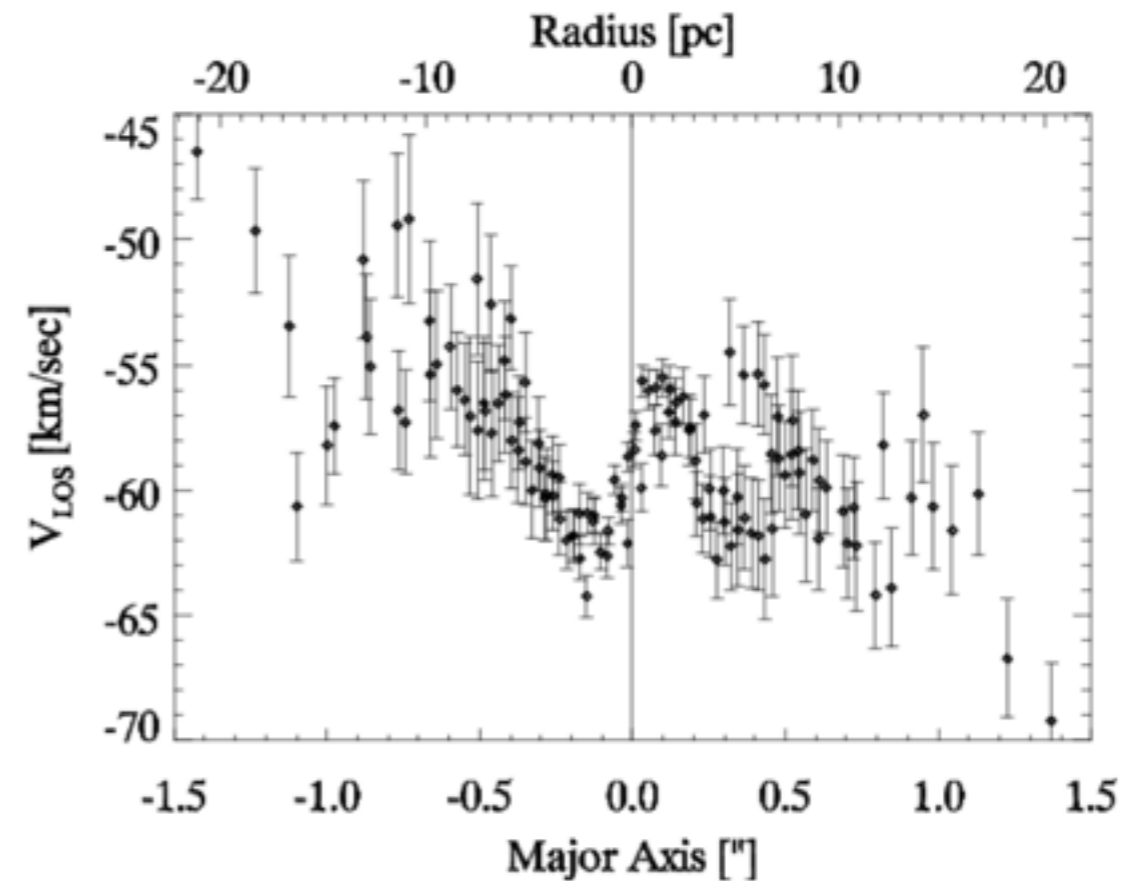
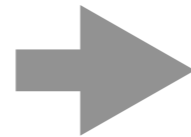
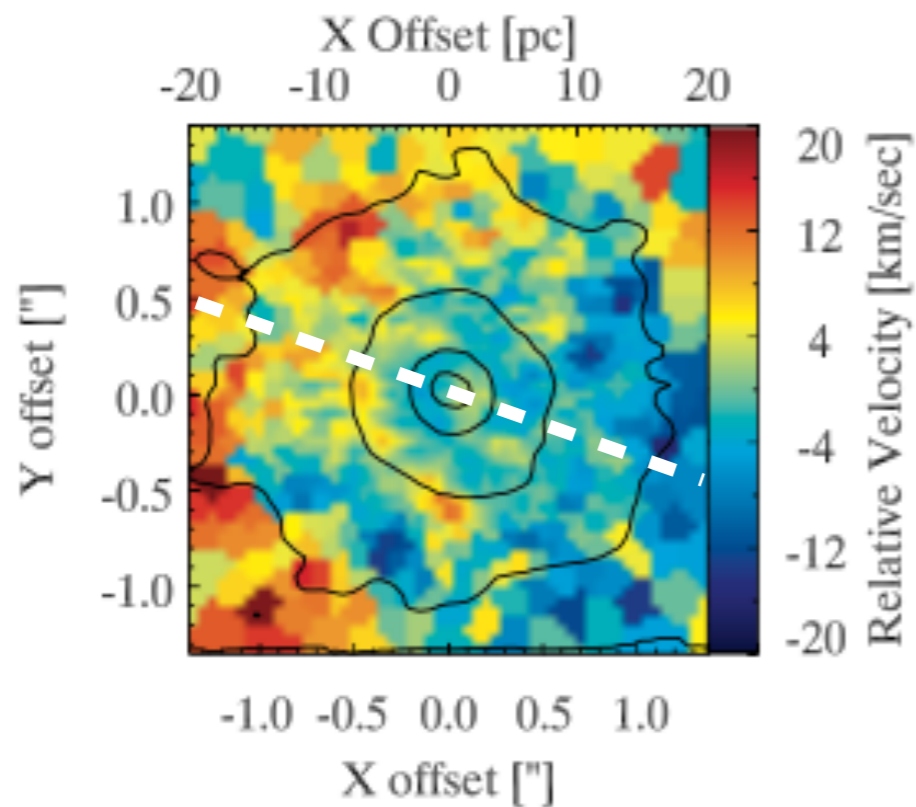
Sgr/M54



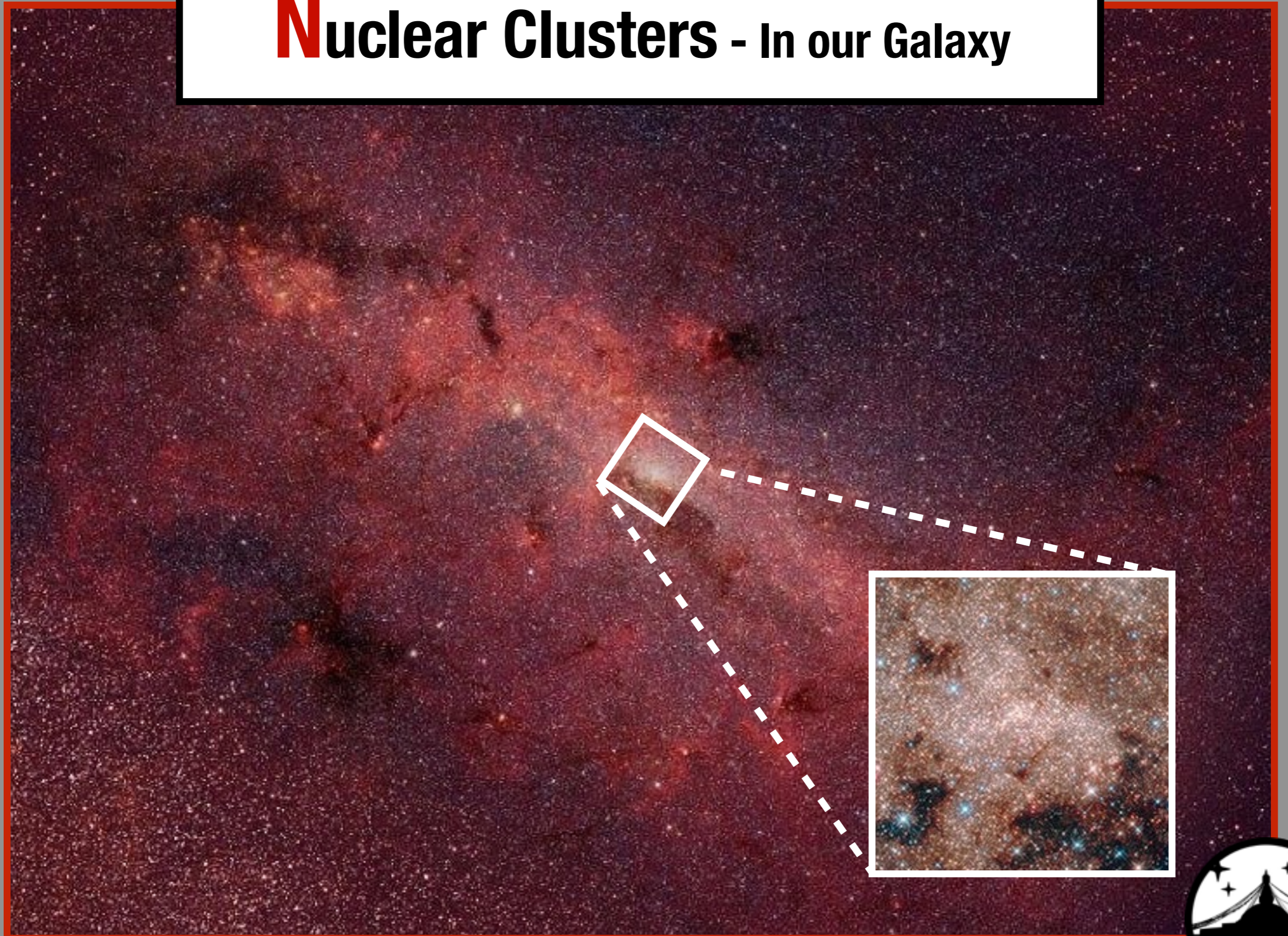
Siegel et al., 2007



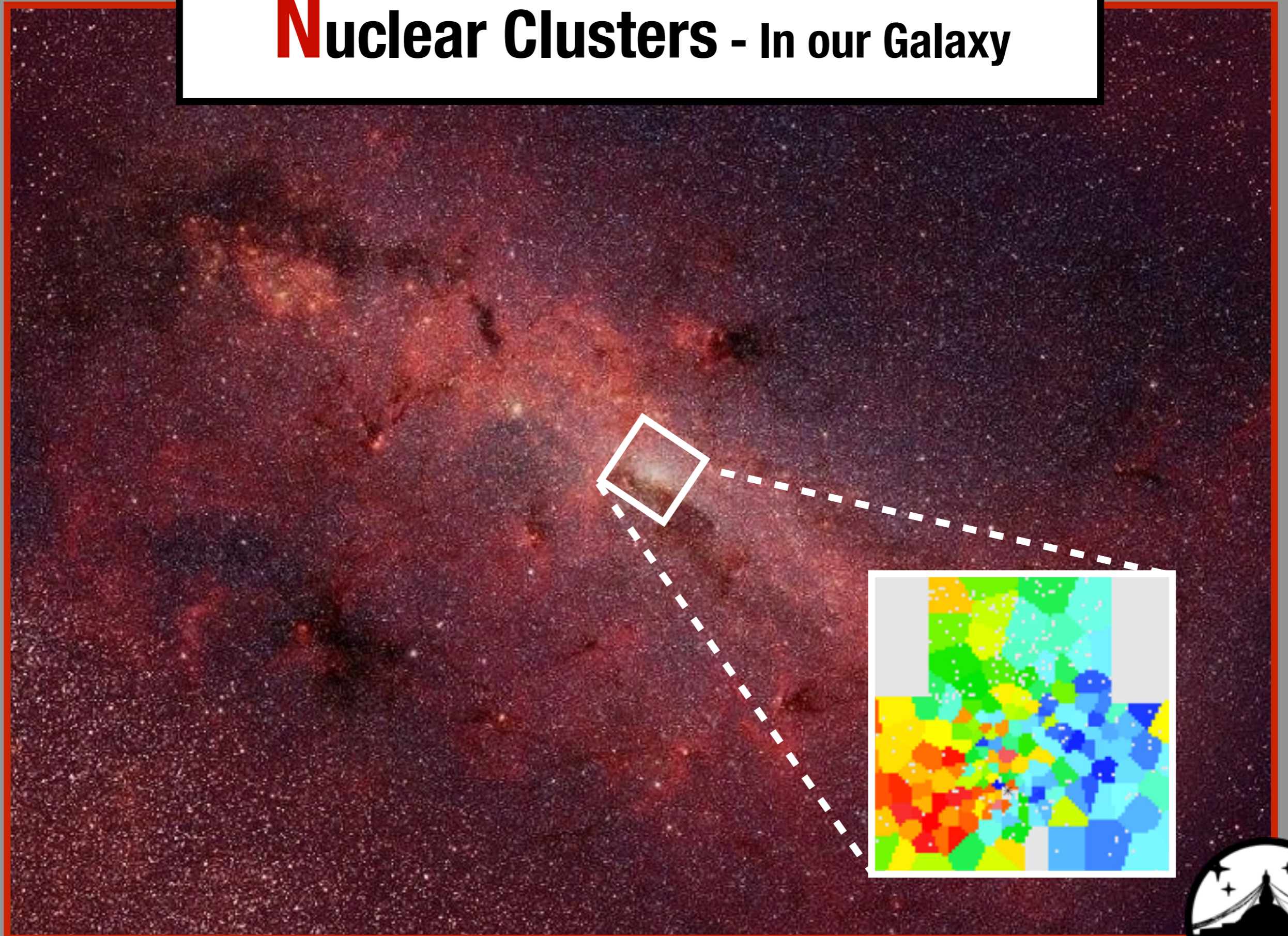
Nuclear Clusters - Peculiar kinematics



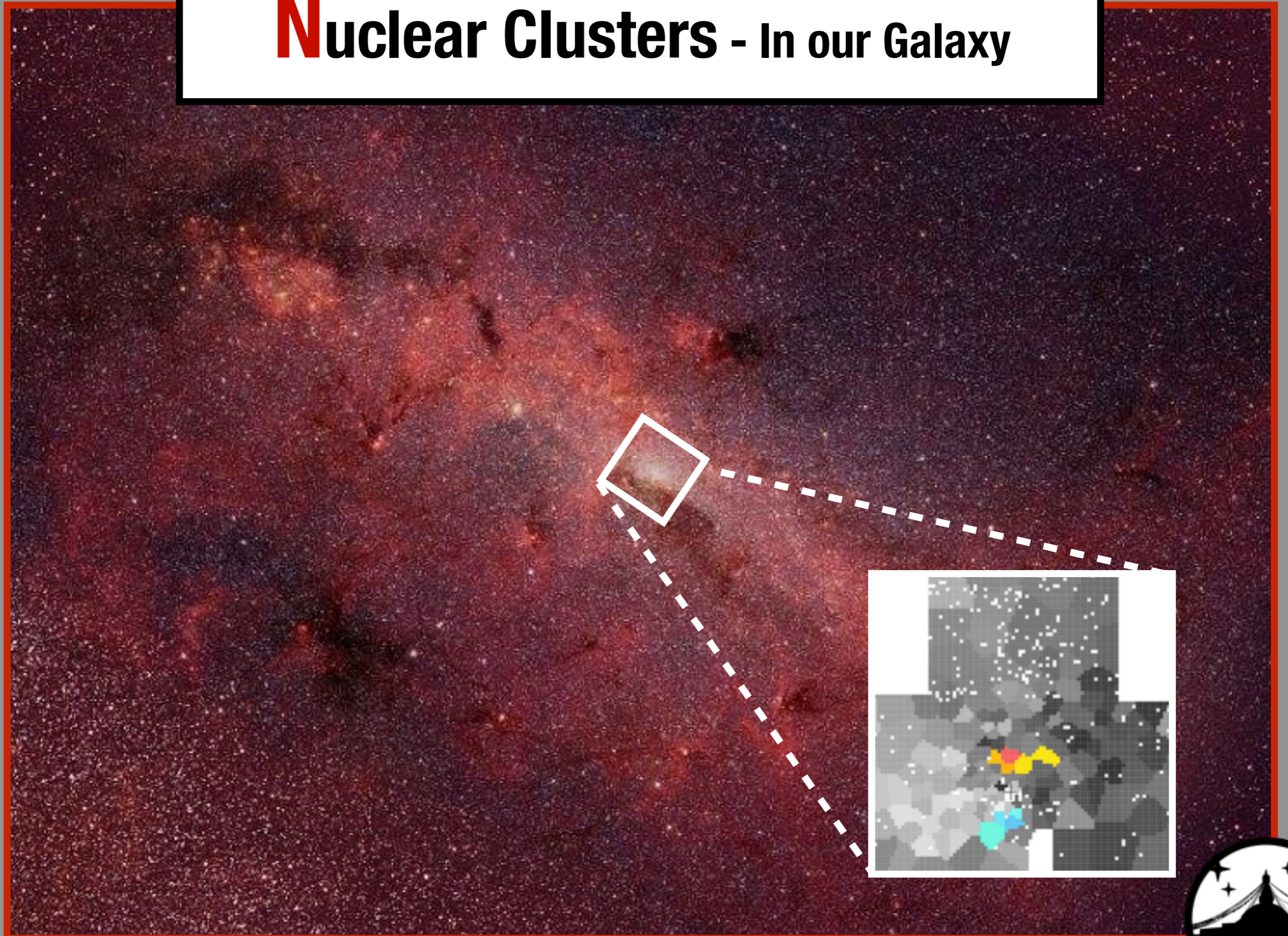
Nuclear Clusters - In our Galaxy



Nuclear Clusters - In our Galaxy



Nuclear Clusters - In our Galaxy



Summary

1. Star Clusters:

→ Collection of stars roughly born at the same time (sometimes gravitationally bound)

100 -1000

$1e4-1e6$

$1e4-1e5$

$1e5-1e7$

$1e6-1e8$



OB
Associations

- in the disk
- gravitationally unbound

Embedded
Clusters

- in the disk
- still gas left

Open
Clusters

- in the disk
- gravitationally bound

Globular
Clusters

- in the halo/
bulge
- oldest objects
in the universe

Nuclear
Clusters

- at the center
of the galaxy
- densest
objects in the
universe