# Introducing:

## the Age Ladder Science Analysis Group (SAG)

Rachael L. Beaton

Associate Astronomer, Space Telescope Science Institute

Art by Rami Farouk

# Origin of the Age Ladder SAG

Two years ago at AAS243 in New Orleans, the COPAG hosted a Workshop on UV Science.

## Cosmic Origins at AAS 243

The 243rd American Astronomical Society (AAS) Meeting (aka the "AAS Winter Meeting") took place in New Orleans, LA, from 7 – 11 January 2024.

**AAS 243 website**

LOCATION
**New Orleans, LA**

DATE
**7 – 11 January 2024**

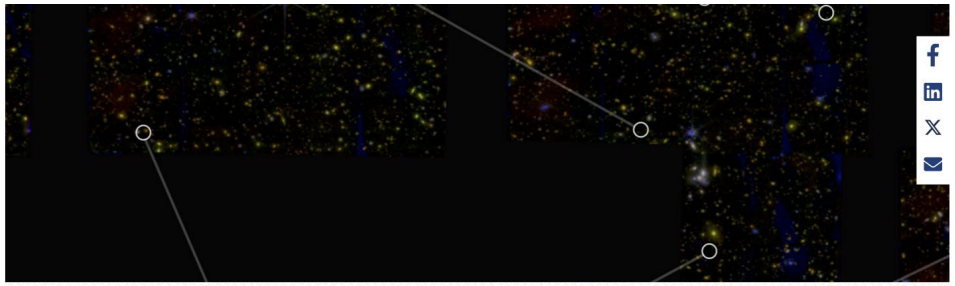
COMMUNITY
**COPAG**

TYPE
**Meeting**

### Saturday January 6, 2024

**Physics of the Cosmos & Cosmic Origins + Astronomy on Tap event**

| Time | Topic | Speakers |
|---|---|---|
| 7:00pm – 9:00pm | Supermassive Black Holes: Monsters of the Universe. | Ryan Hickox (Dartmouth College) |
| 7:00pm – 9:00pm | Trivia Game | |
| 7:00pm – 9:00pm | From the Big Bang to Biosignatures: Revealing the ~14 Billion Year Story of How the Cosmos Became Habitable with NASA | Rachael Beaton (STScI) |

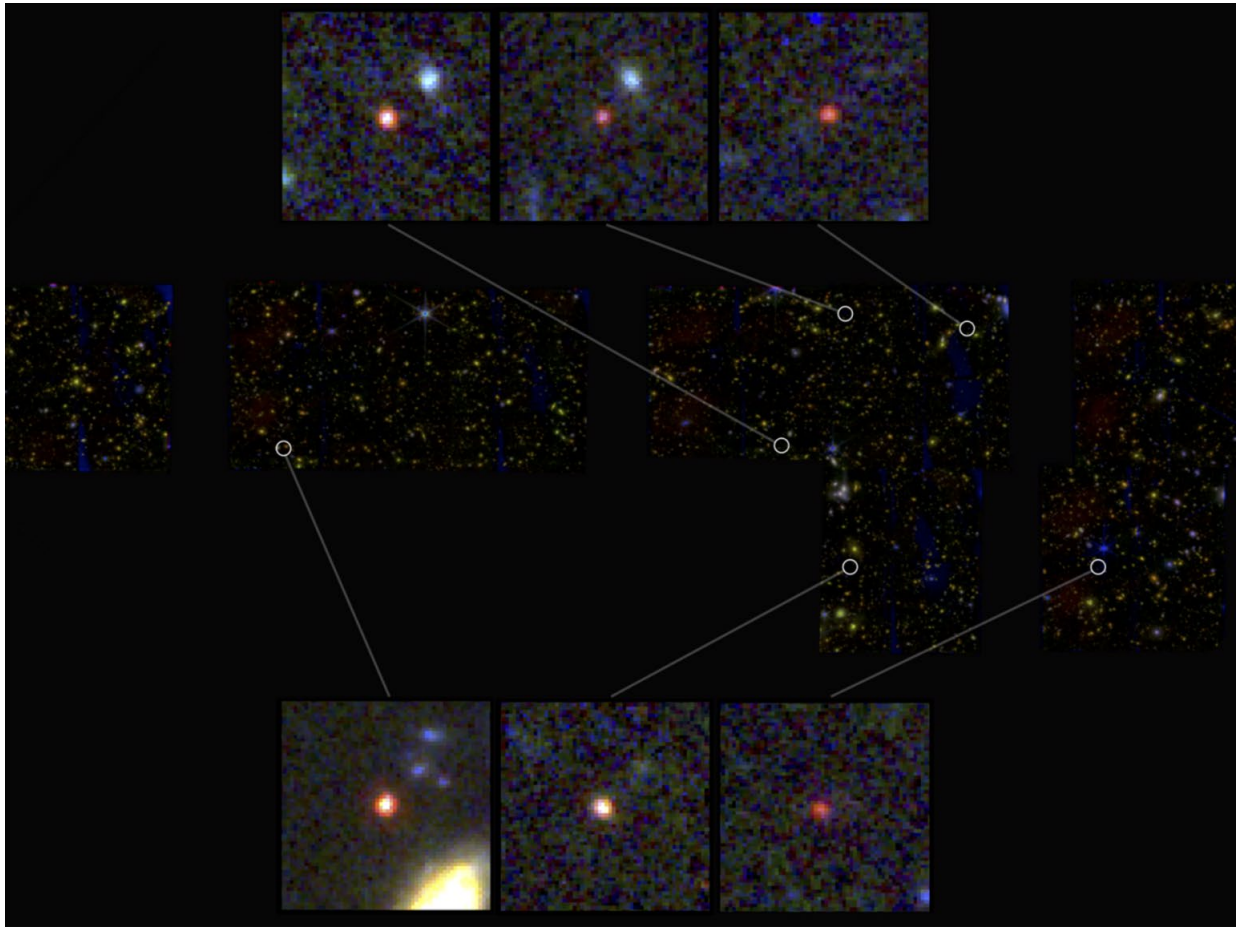


News

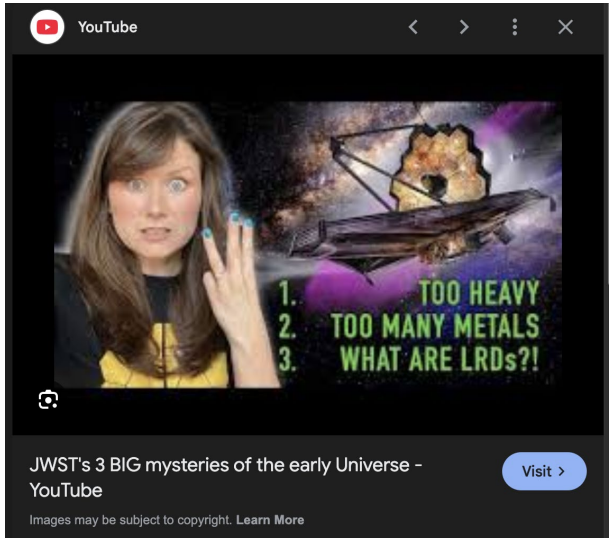
Discovery of massive early galaxies defies prior understanding of the universe

At the time one of the hottest topics in astronomy were the massive galaxies found in the early Universe.

# Origin of the Age Ladder SAG



Labbé et al. 2023 demonstrated a population of galaxies 600 Myr into the age of the Universe that were too massive to have formed in 600 Myr. Calling into question the Standard Model of the Universe.




This got a lot of press!

# Origin of the Age Ladder SAG

One of our panelist posed the question:

Do we need a framework that maps age techniques across space and time like the distance ladder?

**Credit:** NOIRLab/NSF/AURA/P. Horálek

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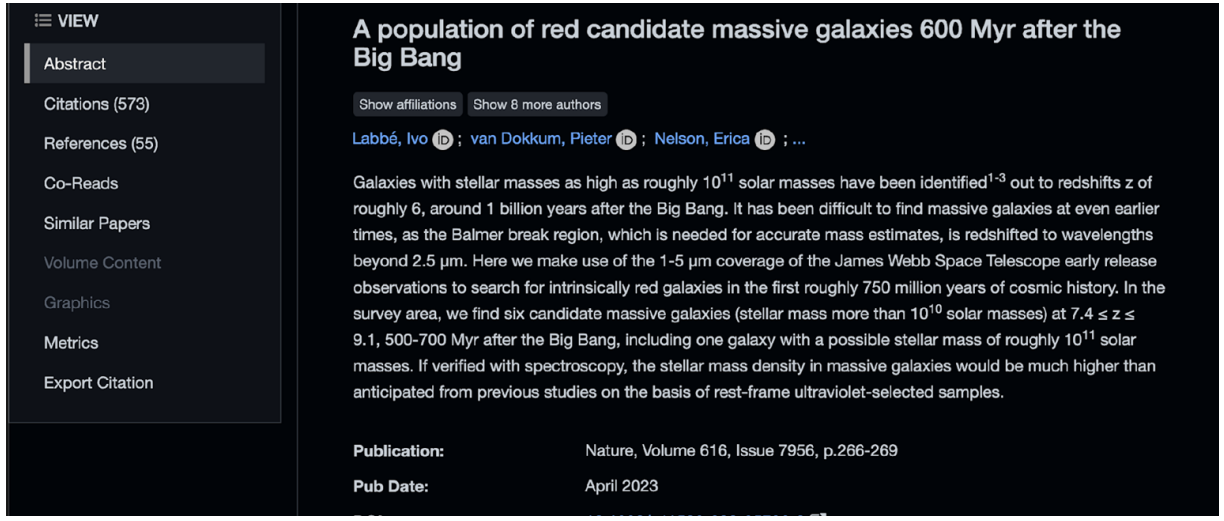
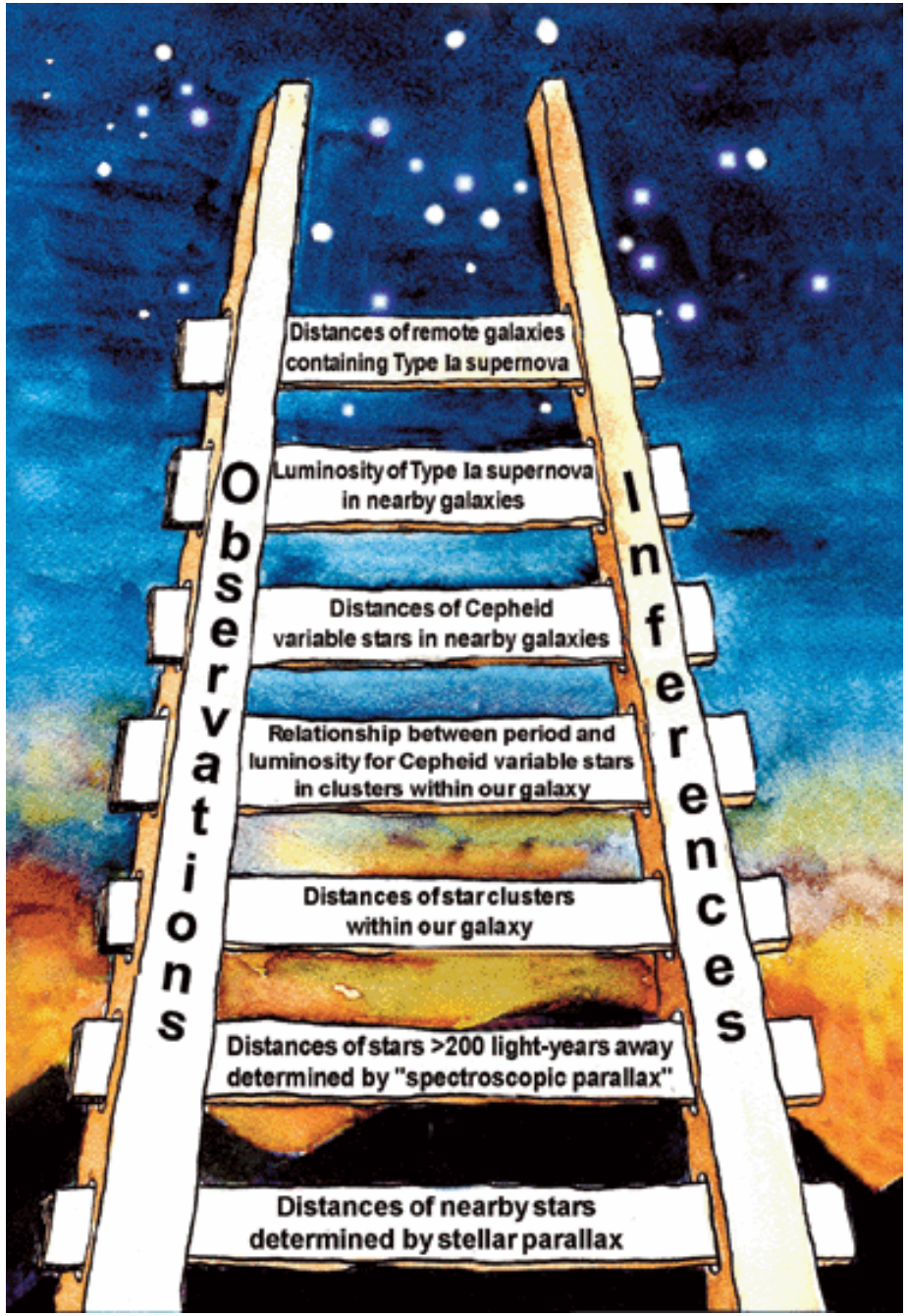



543 Papers later, there is some evidence that the original finding could be explained through other means (see eg.,

BUT the COPAG EC still thinks the concept is really good! And we are kick-starting a Science Analysis Group (SAG) to investigate the concept.




# What is a Ladder?

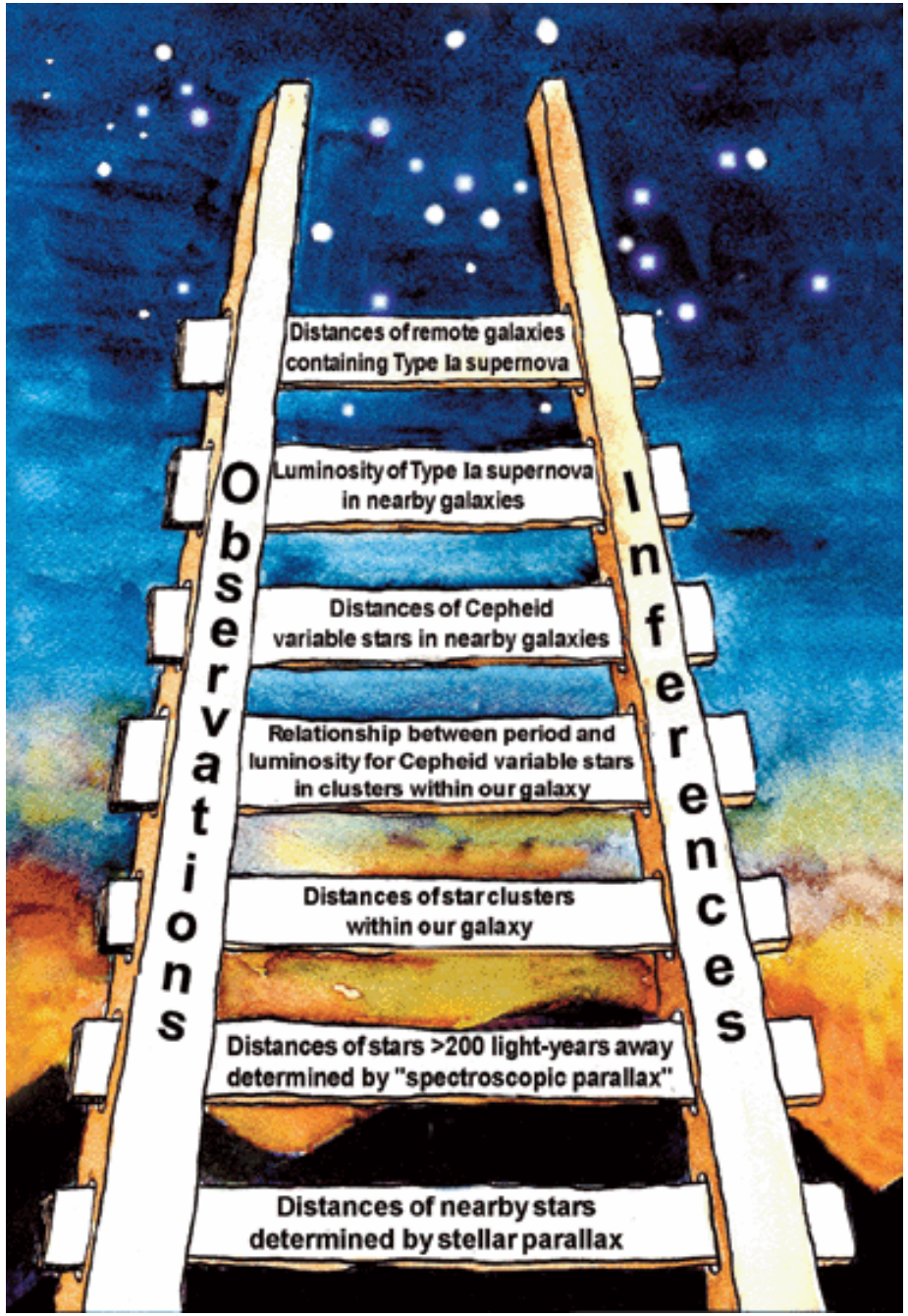
In astronomy, we have many methods of measuring the same fundamental quantity that vary based on the observational scenario:

- Individual stars
- Resolved stellar populations in clusters or galaxies
- Unresolved stellar populations in clusters
- Unresolved stellar populations in galaxies

with techniques selected based on the observational data:

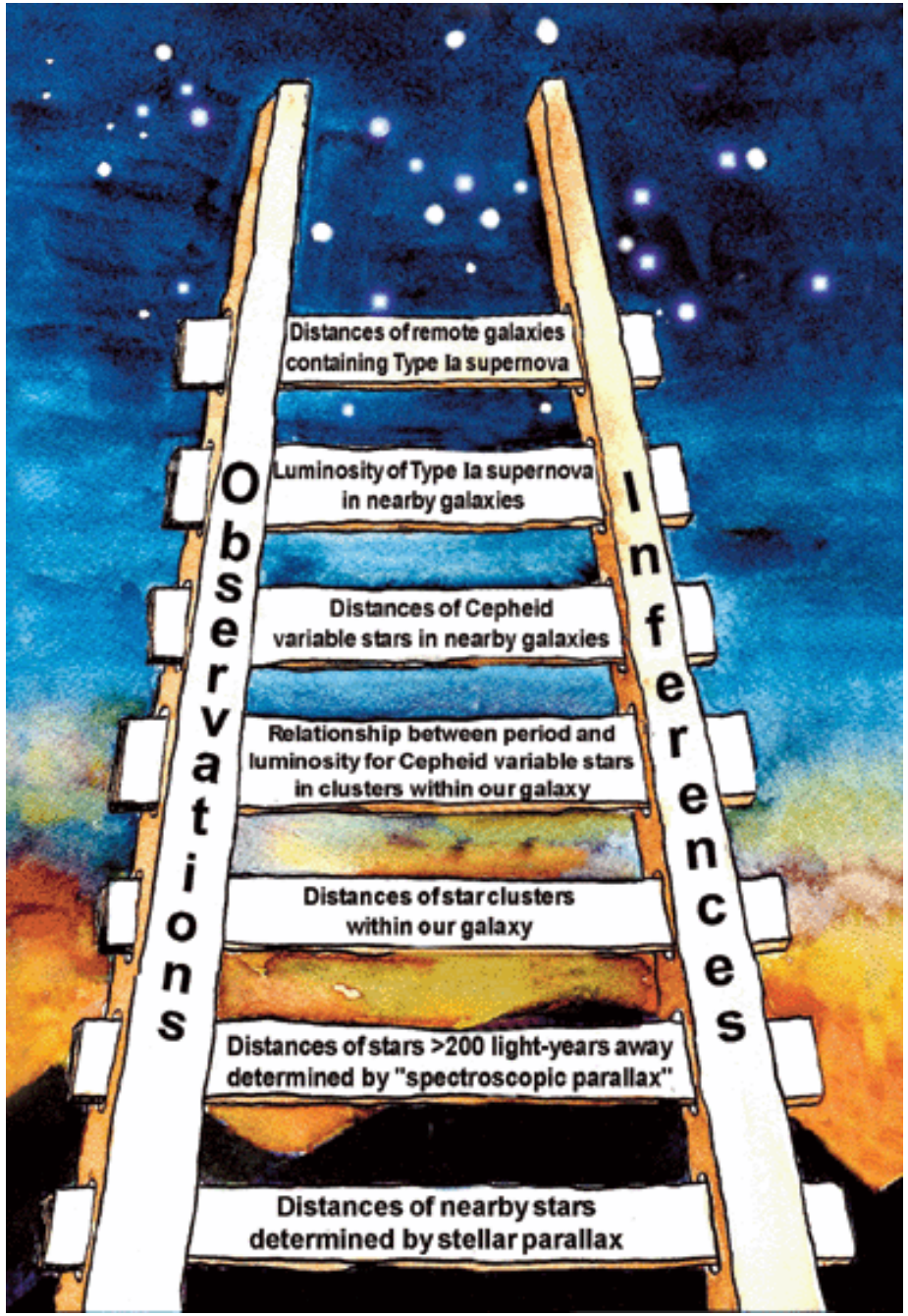
- Photometry
- Light Curves
- Spectroscopy
- Interferometry

and typically, also requiring theoretical models.




# What is a Ladder?

The ladder is a framework that ties together different methods that can be applied in different astrophysical contexts that are tied together at rungs where multiple methods can be used simultaneously.

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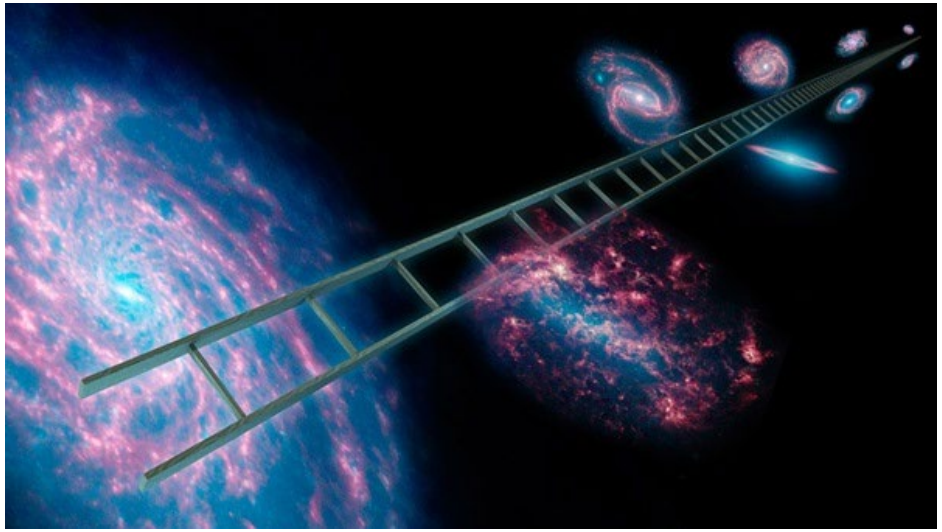


The distance ladder works to tie together distance measurement techniques spanning from nearby stars to redshift ~2 (and beyond) for cosmology.

# Goals of the Age Ladder SAG

- Gather different uses of the term “age” in different Cosmic Origins scientific contexts (Stars, Galaxies, Diffuse Gas/Cosmic Ecosystems) and technology contexts (IR, UV).

- Survey modern age measurement techniques and precisely quantify the workflow from observations to age determination.

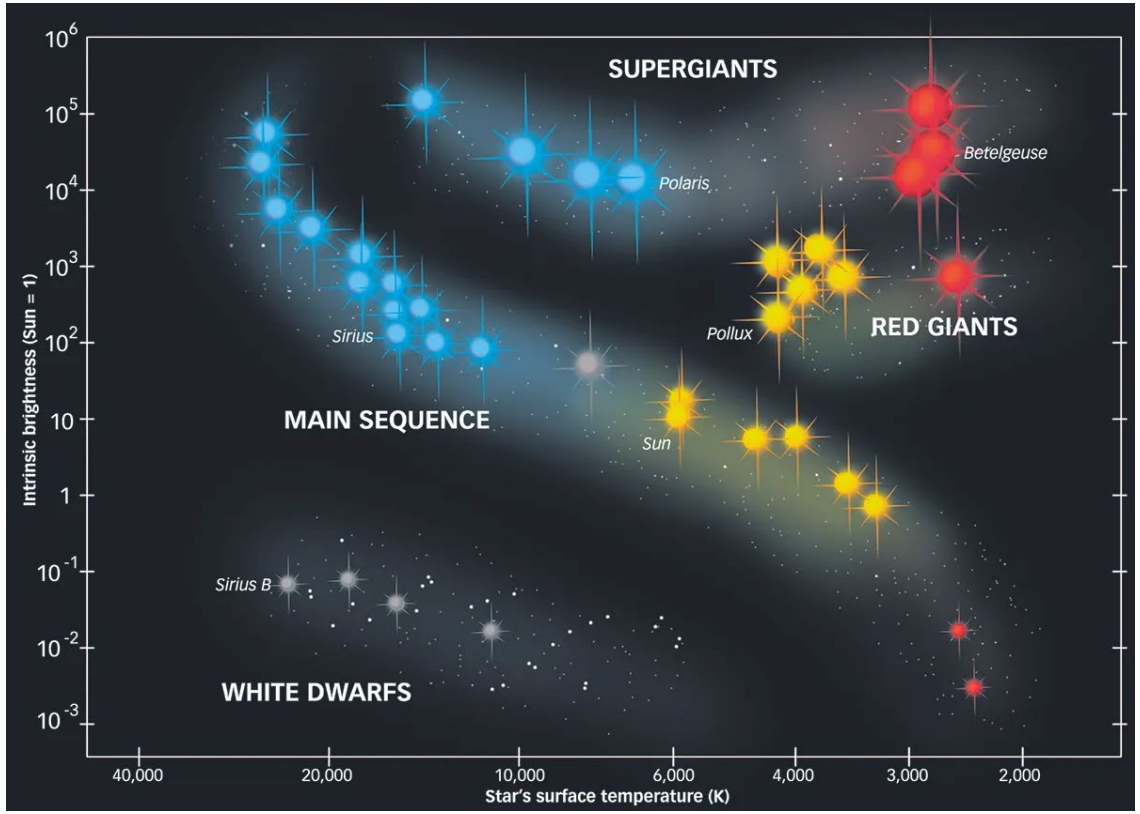
- Identify astronomical objects where distinct techniques are/could be applied to cross calibrate age measurements.
  - This is a proposed age ladder.

- Articulate “science gaps” in our understanding of age measurements that are observational or theoretical.
  - This sets the stage for how to implement the age ladder.

Art by Rami Farouk

# A sampling of the nuances for Resolved Stars:

9 Orders of Magnitude

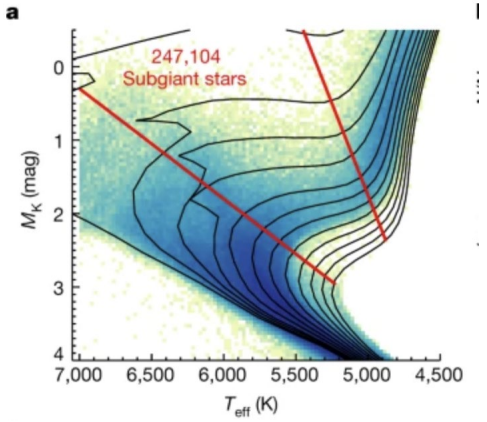



And about ~14 Billion Years in Age

A range of 40,000 degrees in temperature.

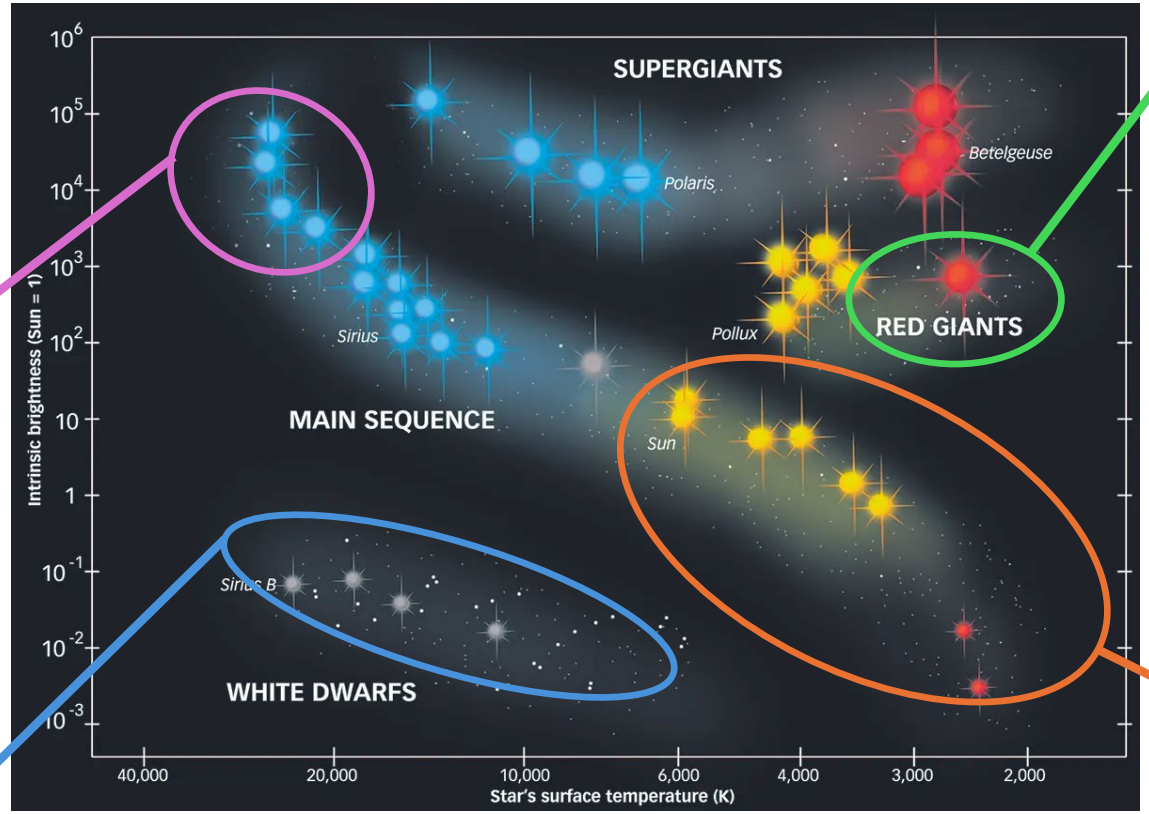
# A sampling of the nuances for Resolved Stars:

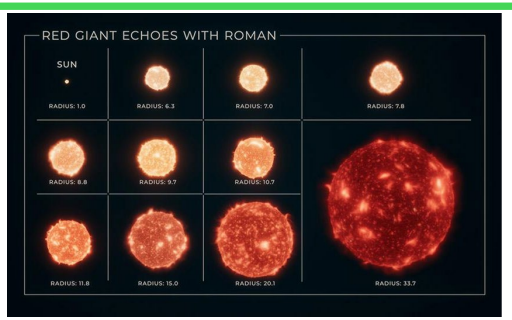
The main sequence turn off (MSTO) is exceptionally sensitive to mass (age).




Xiang & Rix 2022

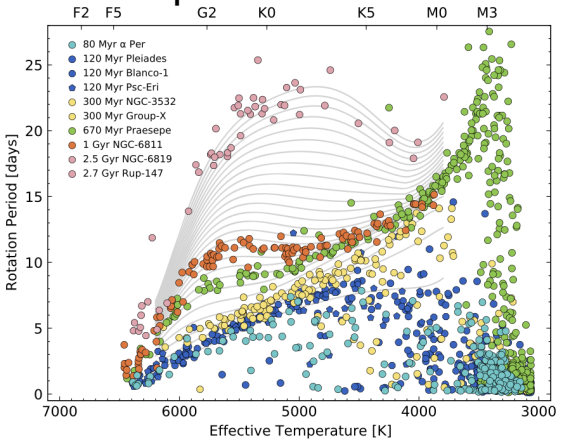
The white dwarf cooling sequence is one of the best clocks in the universe!




Red giants can have individual masses estimated!

In young star clusters, we measure spin-down rates in main sequence stars.




Bouma et al. 2023

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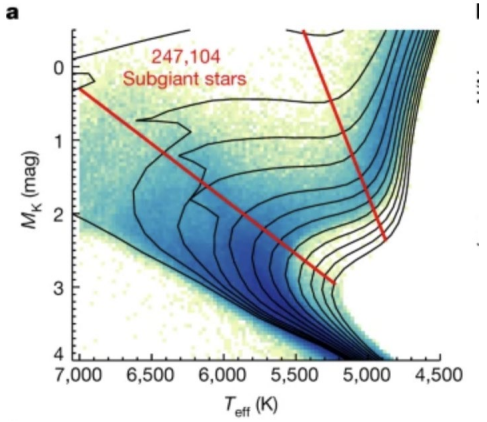


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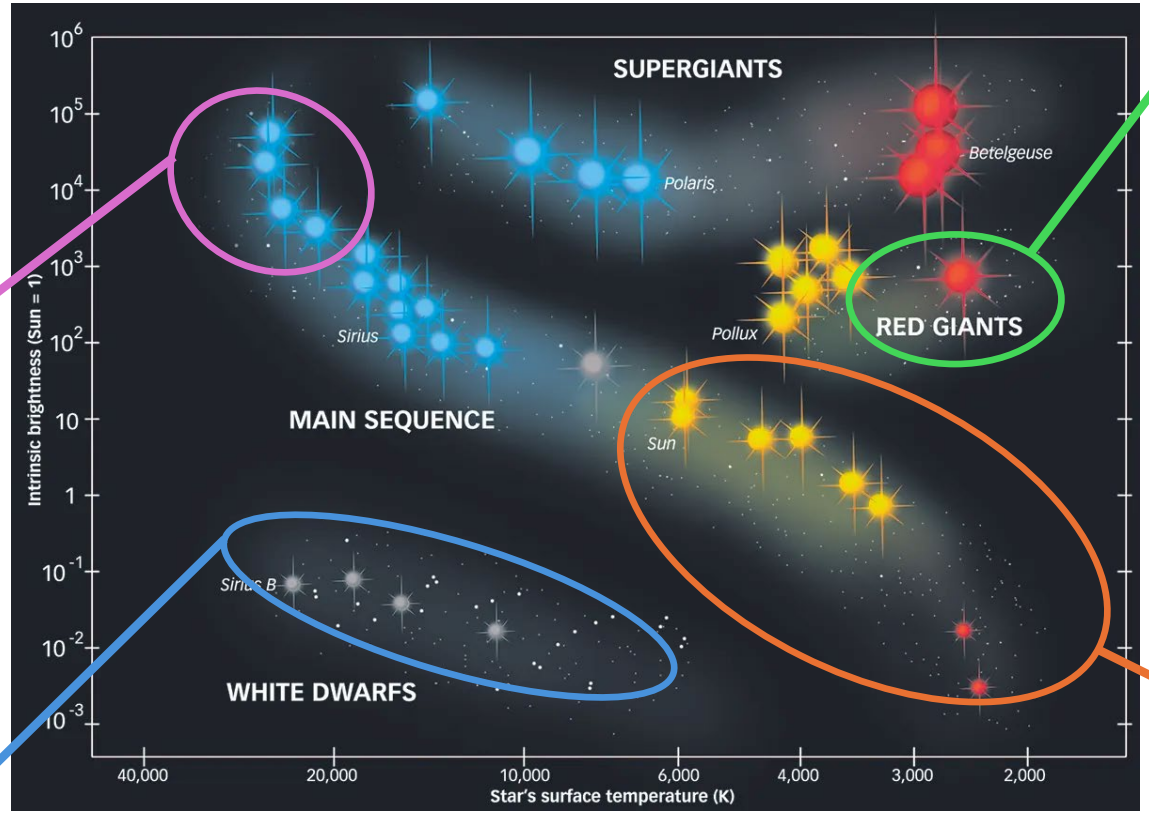


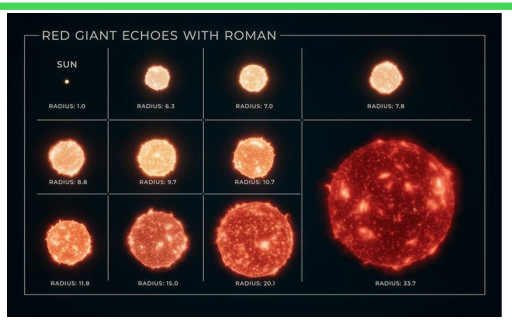


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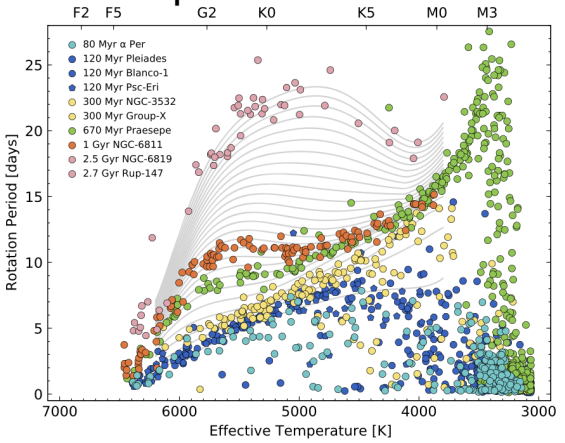


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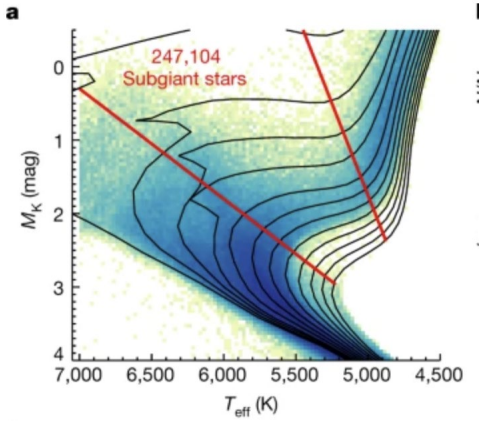


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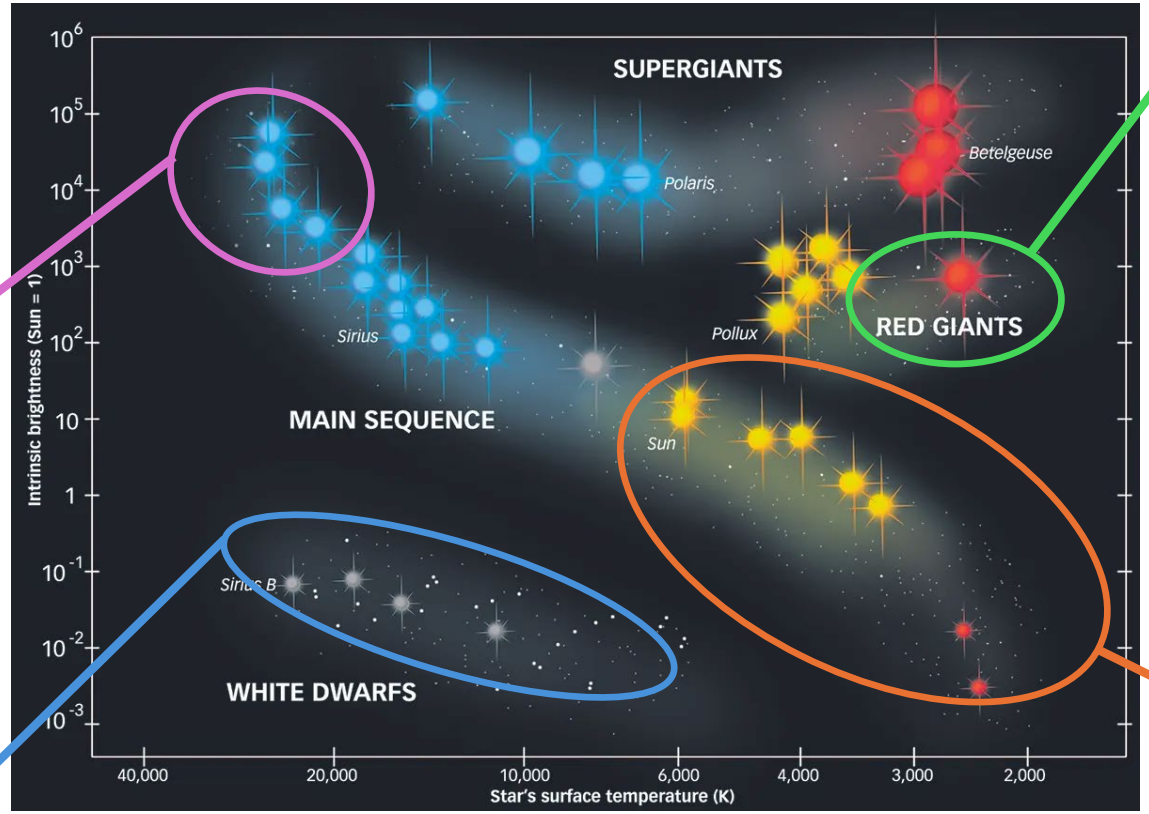


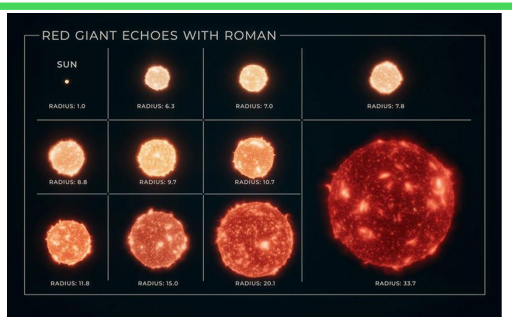


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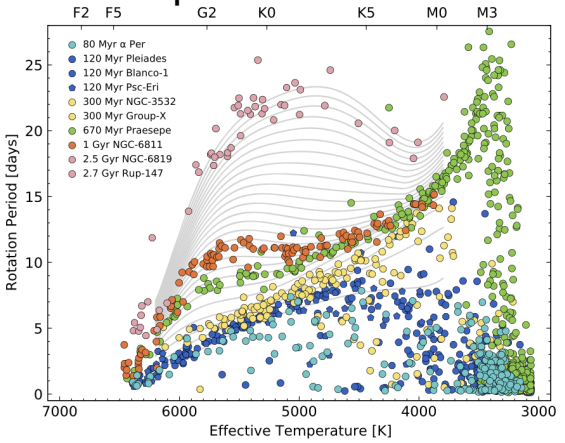


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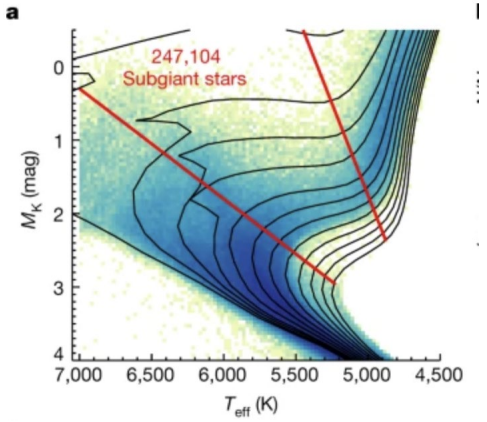


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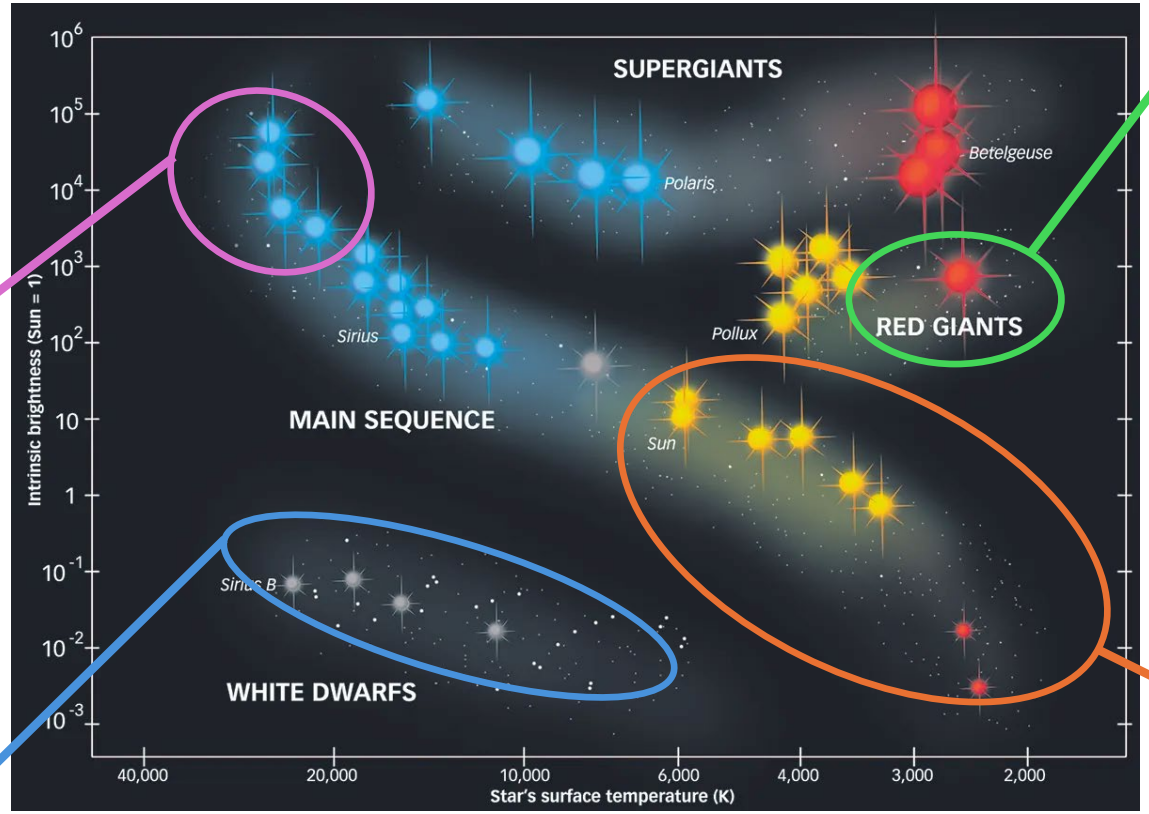


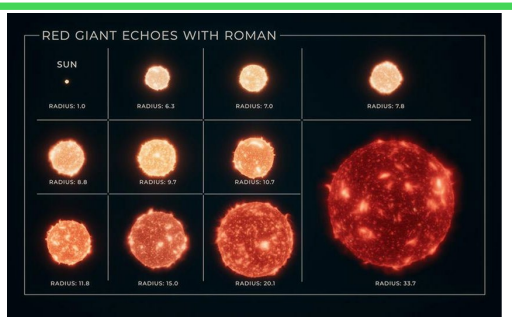


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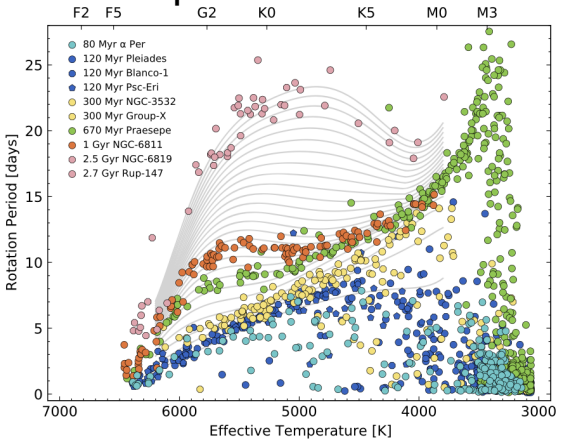


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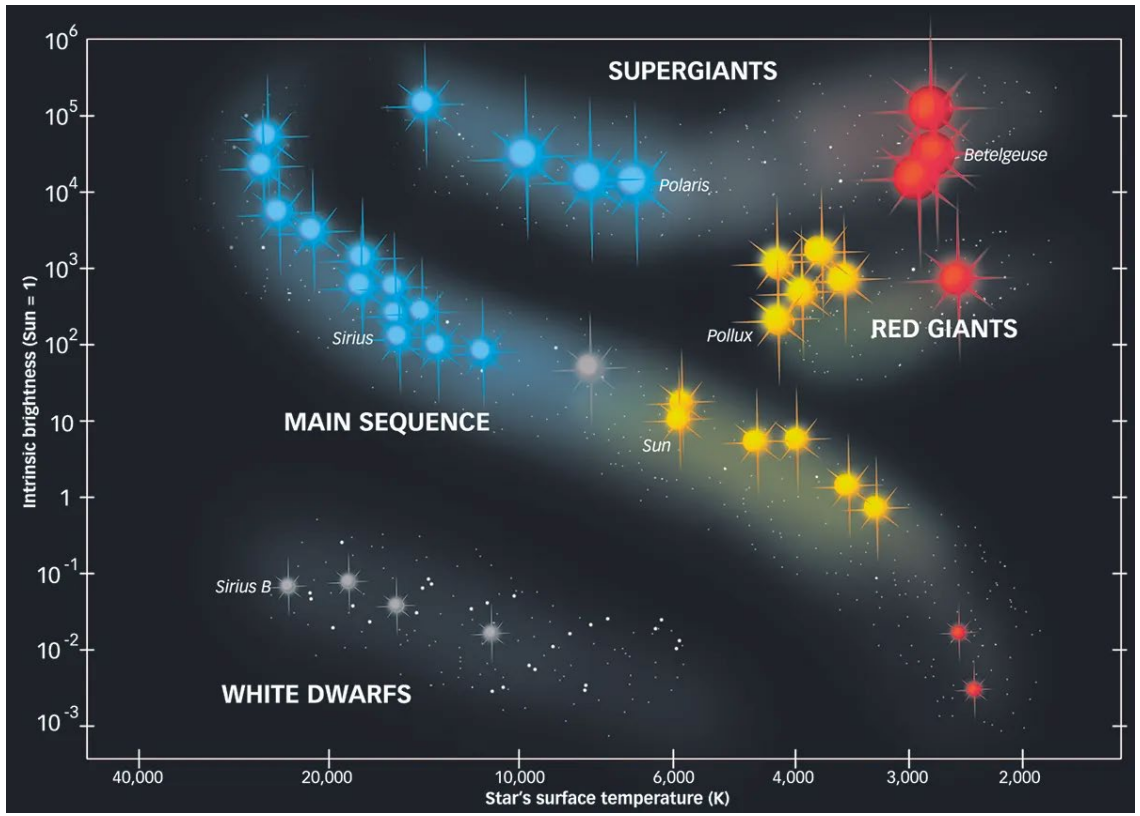


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White Dwarf Cooling Sequence

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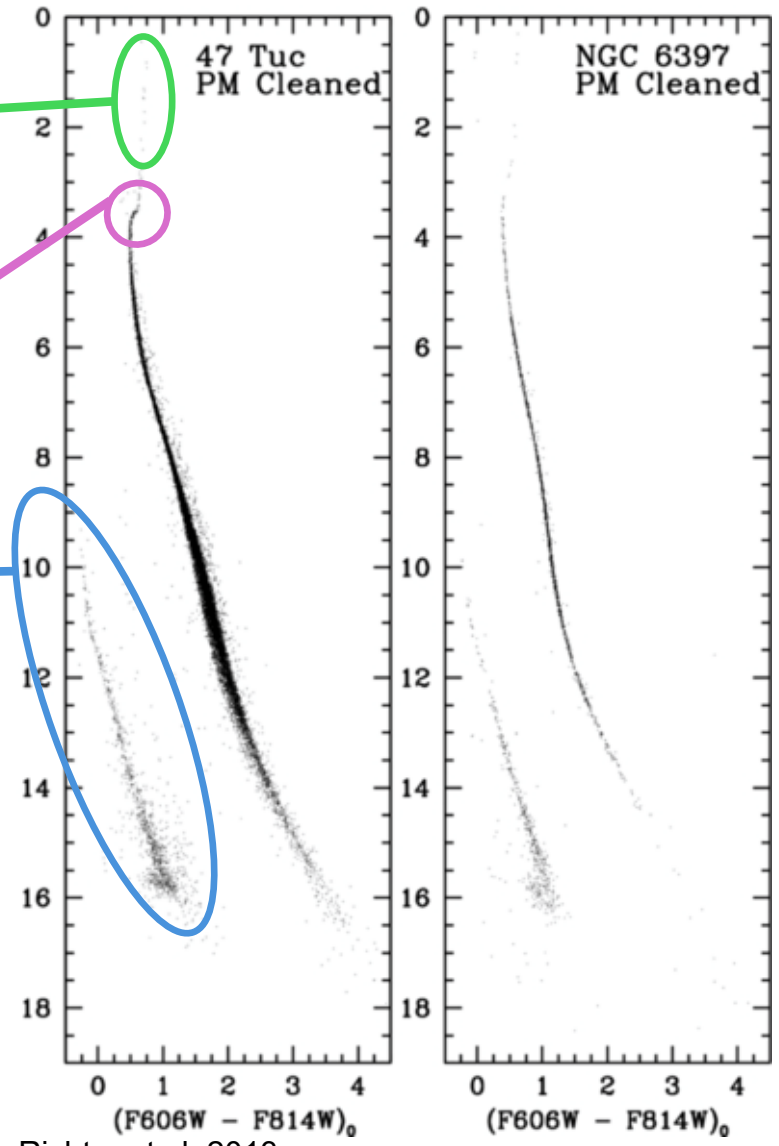
125 HST Orbits




Richter et al. 2013

Both 47 Tuc and NGC6397 are “old” and techniques for intermediate or young populations cannot be tested.

Open Clusters have the widest age span, but live in the disk of the Milky Way and require proper motions and deep photometry to build diagrams like these.

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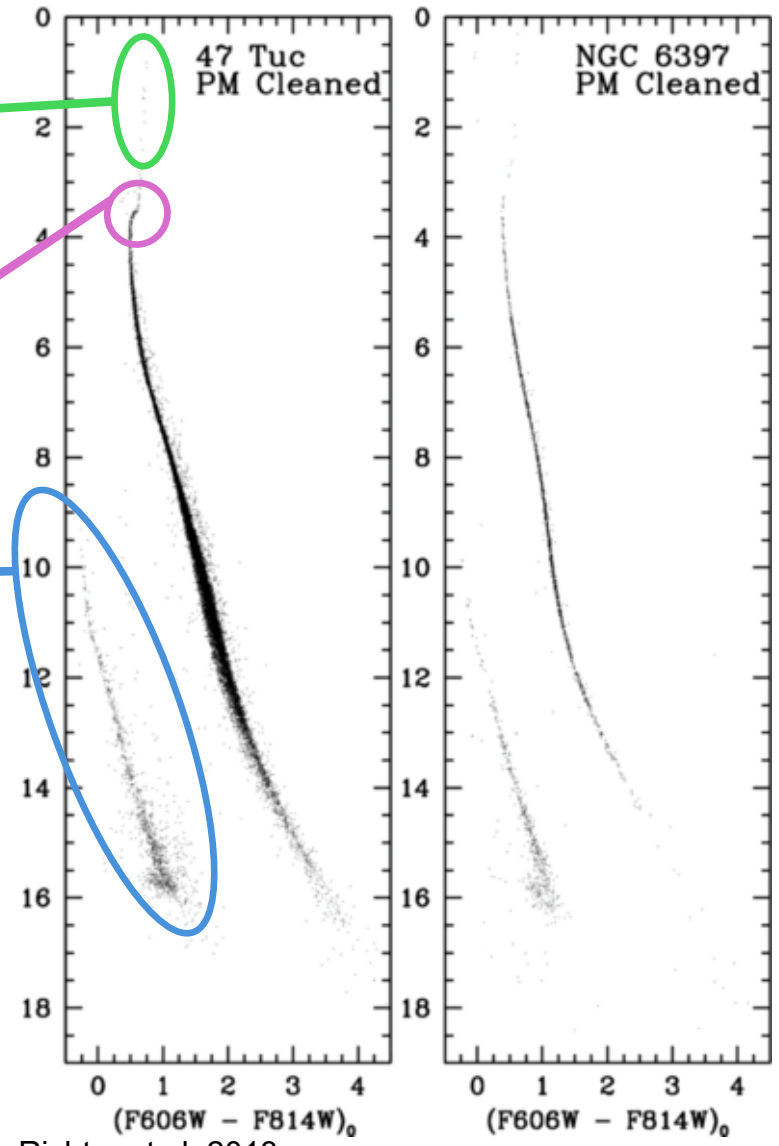


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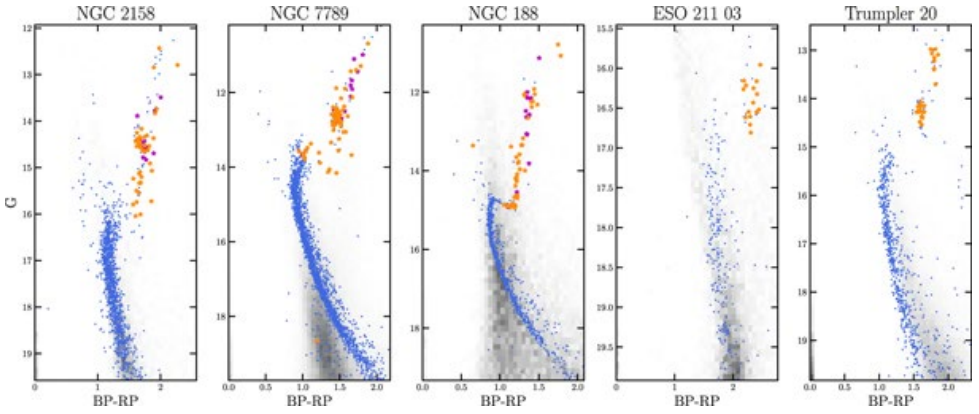
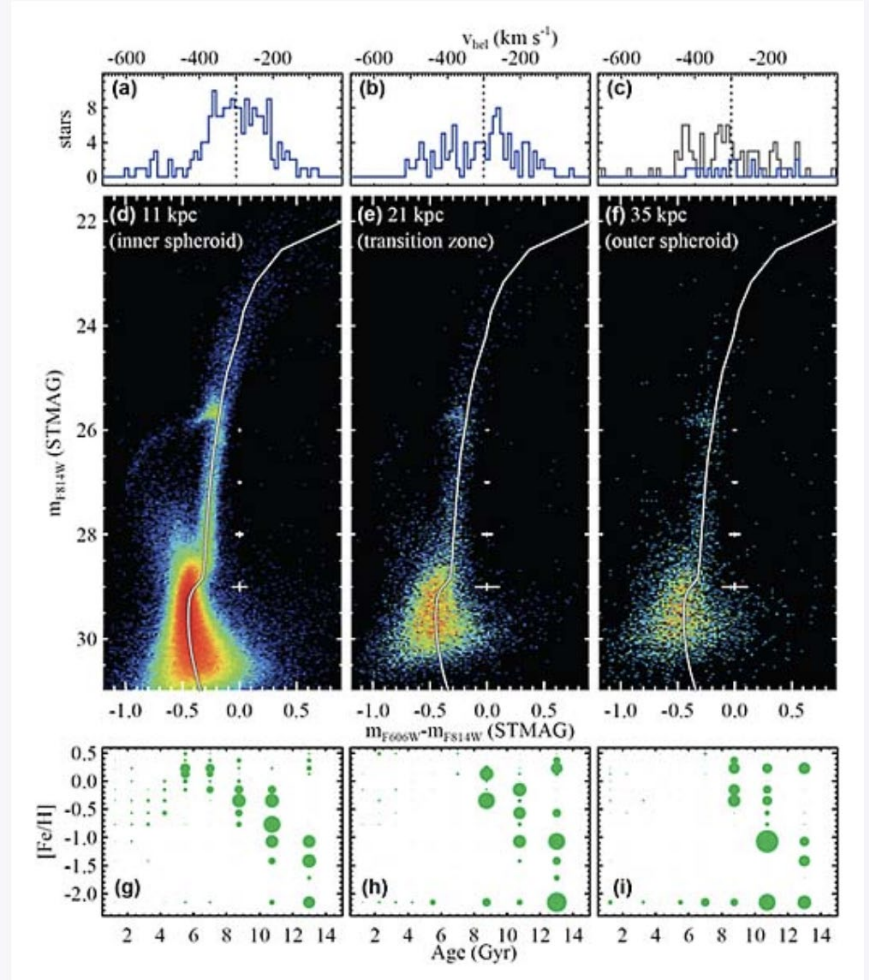



Myers et al. 2022

# Star Formation Histories in Galaxies

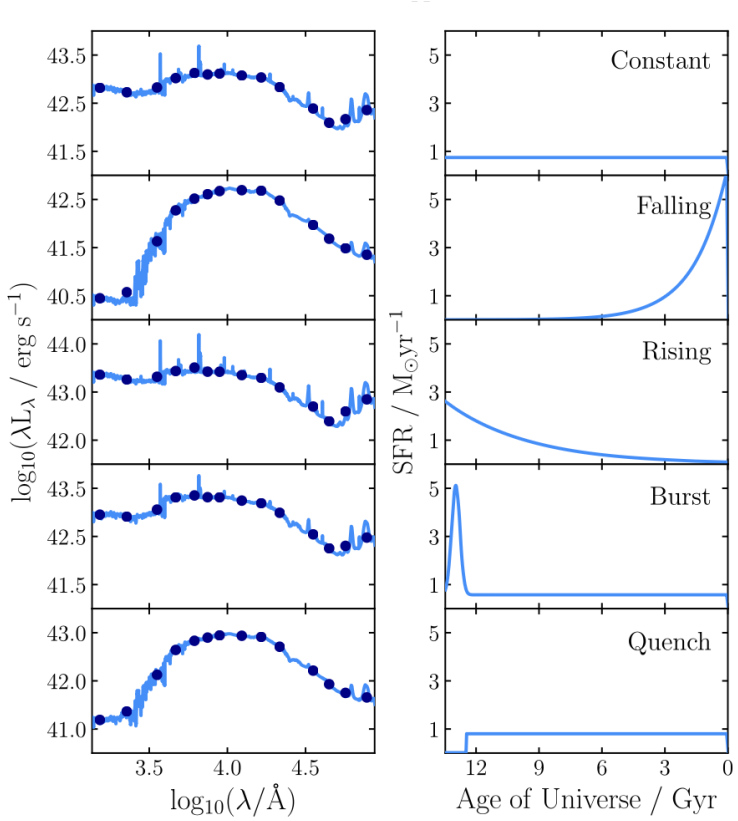
## When you can resolve into stars…




Brown et al. 2008

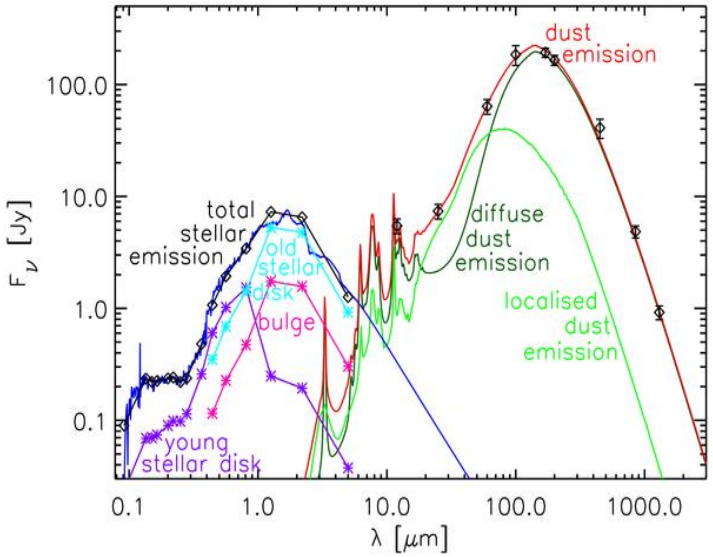
## When you cannot resolve into stars …

### Rest Frame UV to Optical




Carnhall et al. 2024

### Broad Wavelength SEDs




Popescu et al. 2011

# the Age Ladder SAG:

- Need broad range of expertise spanning multiple:
  - Rest & observed wavelengths
  - Resolved and Unresolved
  - Types of observations (e.g., spectra and photometry)

- Want broad community input to identify the “rungs” of the ladder:
  - where can we can do individual star and stellar sequence techniques?
  - where can we do resolved star and unresolved star work?
  - where can we do clusters and regular galaxy measurements?
  - where can models in different regimes be self consistent?

Art by Rami Farouk

# Why now?

- **JWST** continues to probe the distant universe
- **HST-HWO** Preparatory Projects may provide more insight into UV in nearby universe for application in distant systems
- **Roman** with 200x FOV of HST and 100x FOV of JWST:
  - Galactic Bulge Time Domain Survey (GBTDS) will provide Kepler-like baselines for rotation, seismology
  - High Latitude Wide Area Survey (HLWAS) will provide slitless spectroscopy across large areas of the sky
  - High Latitude Time Domain Survey will go very deep in a relatively large region of the sky.
  - General Astrophysics Programs combine ground-based FOV with HST PSF stability for star clusters
- **SphereX & Euclid** Spectrophotometry
- **ESA Missions**:
  - **Gaia** Data Release 4
  - **Euclid** Photometry
  - **Plato** Light Curves

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