VERA C. RUBIN OBSERVATORY

U.S. National Science Foundation

U.S. DEPARTMENT of ENERGY | Office of Science

Behind the Scenes: *Stellar Safari*

Clare Higgs (EPO Astronomer, Vera C. Rubin Observatory)
Ardis Herrold (Senior Education Specialist, Vera C. Rubin Observatory)
Justine Schaen (Senior Education and Engagement Specialist, NSF NOIRLab)

Welcome to Behind the Scenes: *Stellar Safari*

Please tell us about yourself in Chat.

- Where are you located?
- What is your current role?
- What grade levels do you work with?

Trifid and Lagoon Nebulea from Rubin's First Look images
Credit: NSF–DOE Vera C. Rubin Observatory

Workshop Code of Conduct

Always be respectful and kind. A variety of viewpoints and approaches are opportunities for discussion and learning. Do not assume that you understand more or better than others.

Be present. This experience will be what you make of it. Please leave non-urgent tasks, email, and texts for later.

Goals of the Workshop

- Gain a better understanding of the science
- Give insight into the details of the authentic data analysis process
- Highlight student misconceptions or learning confusions
- Demonstrate tips for how to use the widgets
- Provide an opportunity for you to ask questions

Meet Rubin Observatory

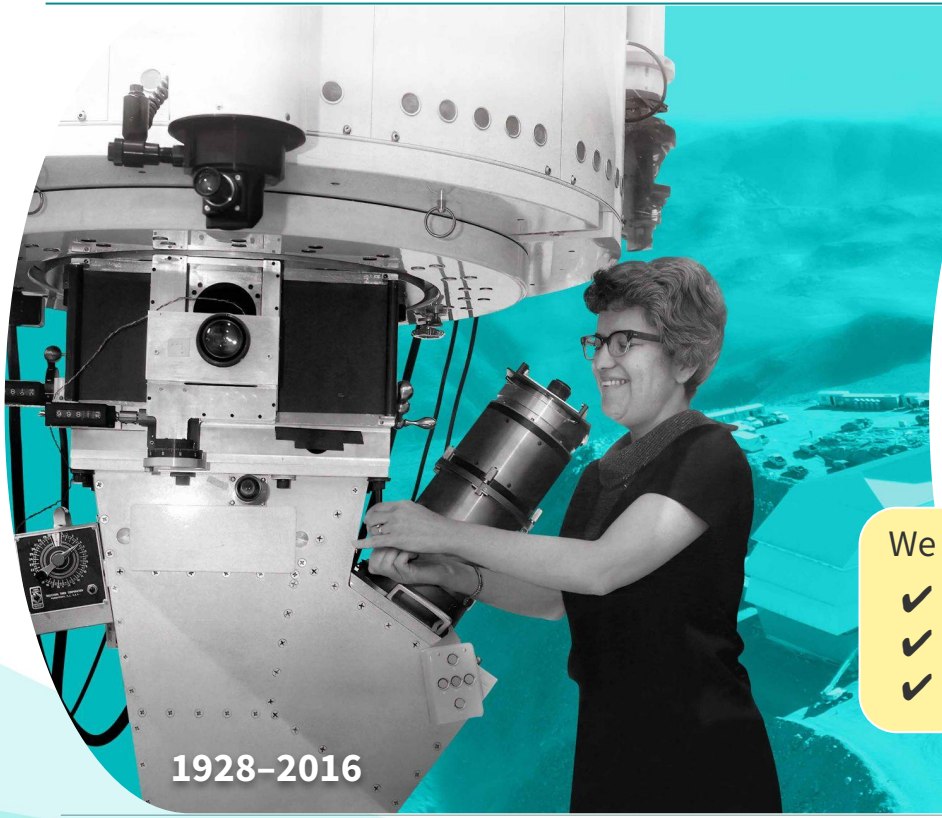
Located on **Cerro Pachón**, in the Coquimbo region of Chile

Jointly funded by the **U.S. National Science Foundation** and the **U.S. Department of Energy, Office of Science**

VERA C. RUBIN OBSERVATORY | U.S. National Science Foundation | U.S. DEPARTMENT of ENERGY | Office of Science

NOIRLab | AURA | SLAC NATIONAL ACCELERATOR LABORATORY

Honoring Vera C. Rubin — A Cosmic Trailblazer



Who was she?

- Provided the first convincing evidence for dark matter
- Advocated for women in astronomy

Rubin Observatory is the **first major US Observatory named for a woman**

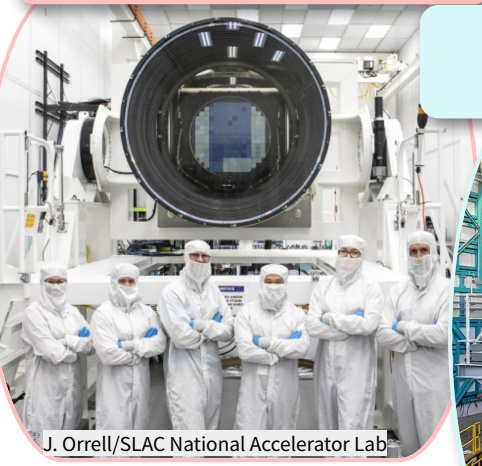
We are proud of our namesake:

✔ NSF–DOE Vera C. Rubin Observatory
✔ Vera C. Rubin Observatory
✔ Rubin Observatory

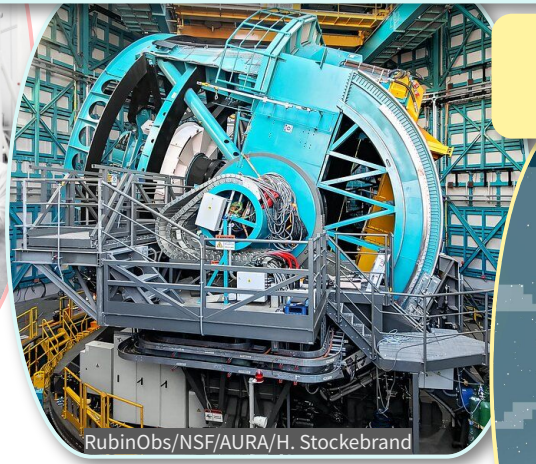
Mission: Capture the Cosmos

The greatest astronomical movie of all time

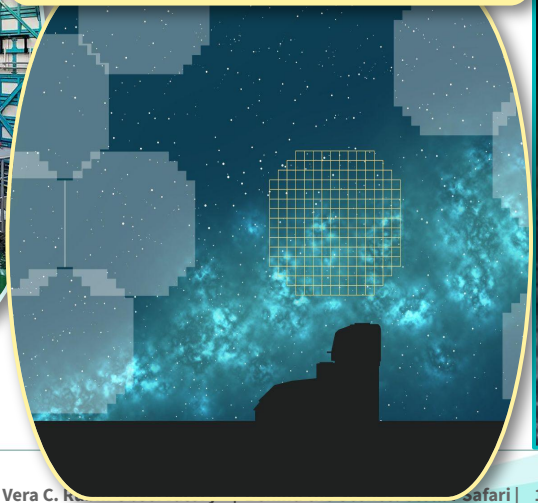
Wide Field of View
Largest digital camera ever built


J. Orrell/SLAC National Accelerator Lab

Speed
Novel three-mirror design


RubinObs/NSF/AURA/H. Stockebrand

Ability to see faint objects
Across the entire Southern sky



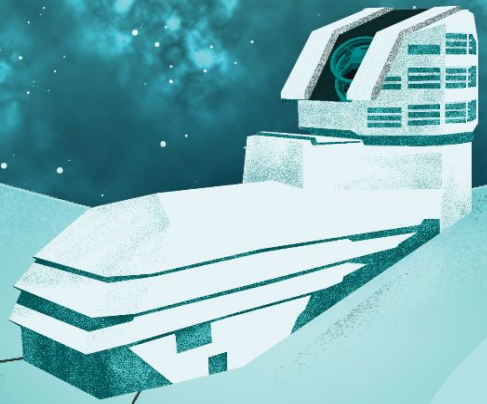
KEY SCIENCE AREAS

Milky Way Structure & Formation

How did the Milky Way form and evolve? Rubin will help us make the best map of our home galaxy yet.

Solar System Census

What will a detailed inventory of our Solar System reveal that we couldn't see before? Rubin will show us millions of new asteroids and comets, and so much more.



Dark Matter & Dark Energy

They make up 95% of our Universe, but what are they… and what are they doing? Rubin is a brand new tool to help us learn more about their nature & behavior.

The Changing Sky

What can we learn from dynamic events like pulsating stars and supernova explosions? Rubin will bring the night sky to life, yielding a treasure trove of discoveries.

Rubin Education Investigations

Coloring the Universe

Stellar Safari

Surveying the Solar System

Observable Universe

Hazardous Asteroids

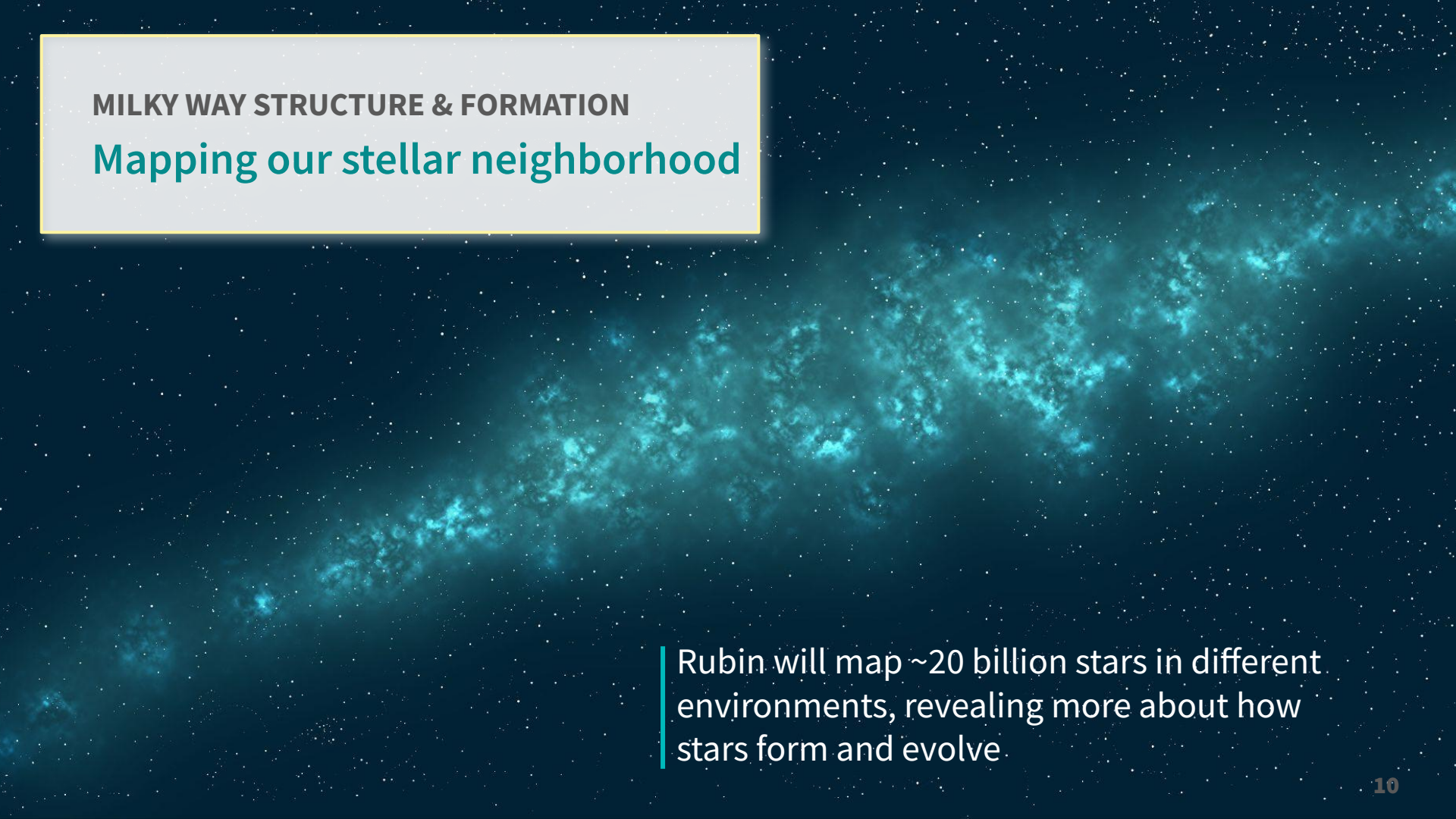
Exploding Stars

Expanding Universe

Credit: Rubin Obs/NSF/AURA

MILKY WAY STRUCTURE & FORMATION

Mapping our stellar neighborhood

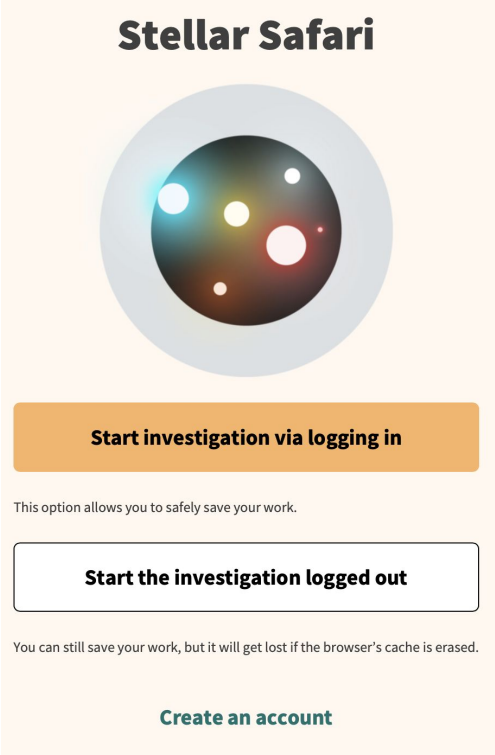


Rubin will map ~20 billion stars in different environments, revealing more about how stars form and evolve

Optional: Log in to reference the investigation

Go to:
https://rubinobservatory.org/education/investigations

- Click on Stellar Safari
- Choose how you will start the investigation (logged in or out)
- To use the “log in” option, you must first create an account.
- Logging in allows you to go through the investigation without having to answer the questions.



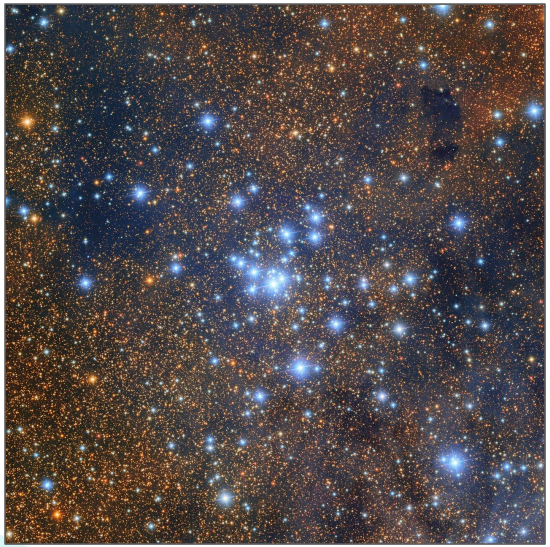
Investigating Stars in the Wild with Rubin

- Will be able to image distant & faint stars (*~20 billion*)
- Will lead to a better understanding of stellar evolution
- Will lead to better insights into the formation of galaxies

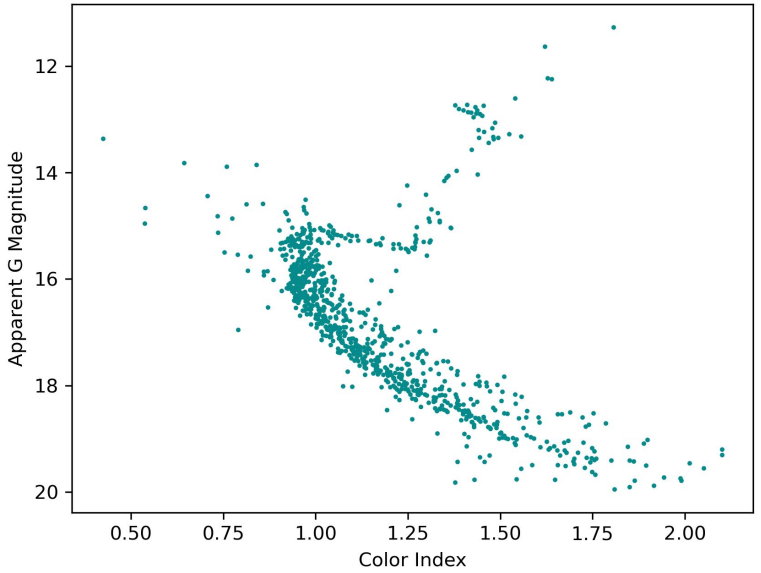
Messier 21 from Rubin's First Look images
Credit: NSF–DOE Vera C. Rubin Observatory

Stellar Safari in a nutshell - Part 1

Students use Color-Magnitude Diagrams (CMDs) to compare properties of main sequence stars in a cluster.



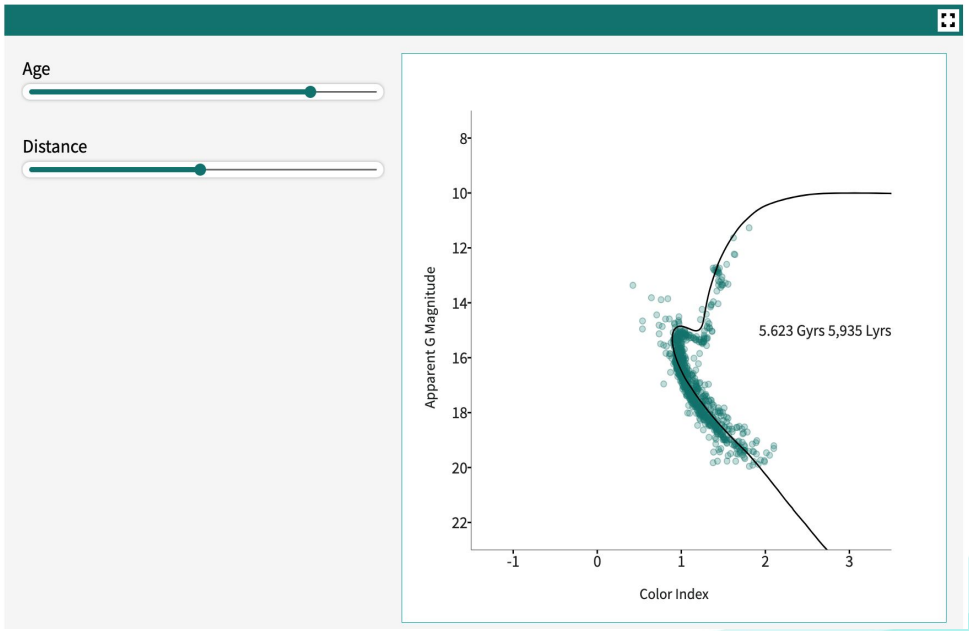
Messier 21 from Rubin's First Look images
Credit: NSF–DOE Vera C. Rubin Observatory



Stellar Safari in a nutshell - Part 2

Students use Color-Magnitude Diagrams (CMDs) to determine the distances to and ages of stars in clusters.

Messier 21 from Rubin's First Look images
Credit: NSF–DOE Vera C. Rubin Observatory



Data in Stellar Safari

The Stellar Safari investigation currently uses:

- stellar data provided by the European Space Agency Gaia mission
- catalogued by Hunt & Reffert 2023
- isochrones from Mesa Isochrones and Stellar Tracks (MIST).

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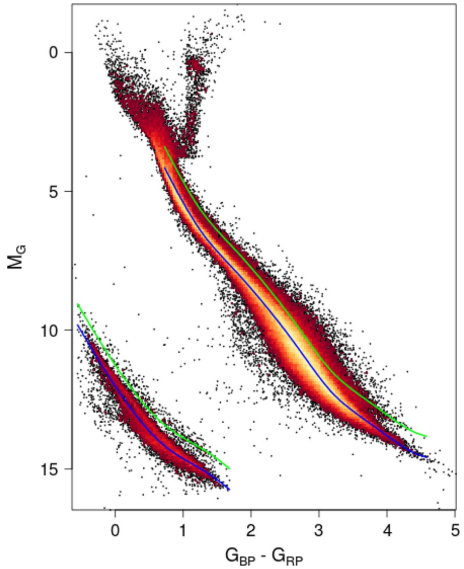
Gaia Catalog

- Gaia was a ESA, space based telescope, launched in 2013 and concluded in 2025
- Made an exquisite map of the Milky Way, including many parallax measurements
  - A 3D map of the Milky Way ← note that this is different than Rubin!
- Measured ~1.7 billion stars



Credit: ESA/Gaia/DPAC; Map: CC BY-SA 3.0 IGO

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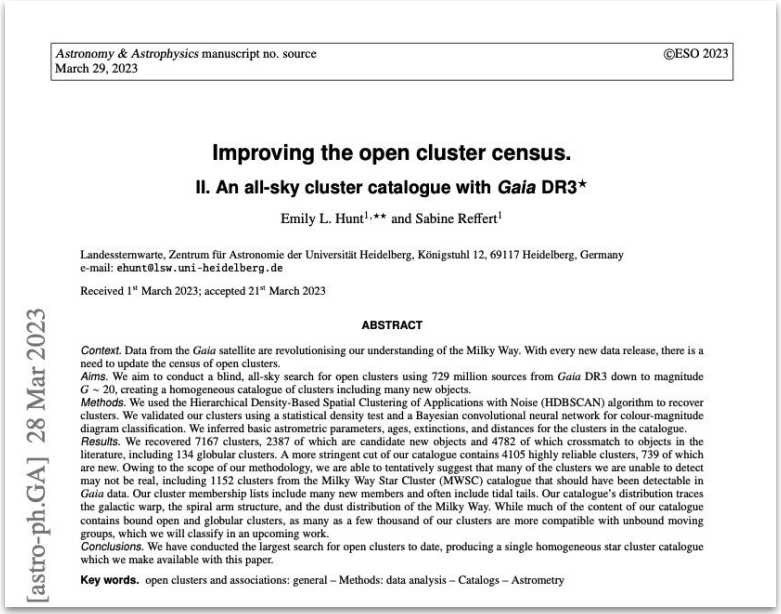

Astronomy & Astrophysics manuscript no. source
March 29, 2023

Improving the open cluster census.

II. An all-sky cluster catalogue with *Gaia* DR3⋆

Emily L. Hunt[1,⋆⋆] and Sabine Reffert[1]

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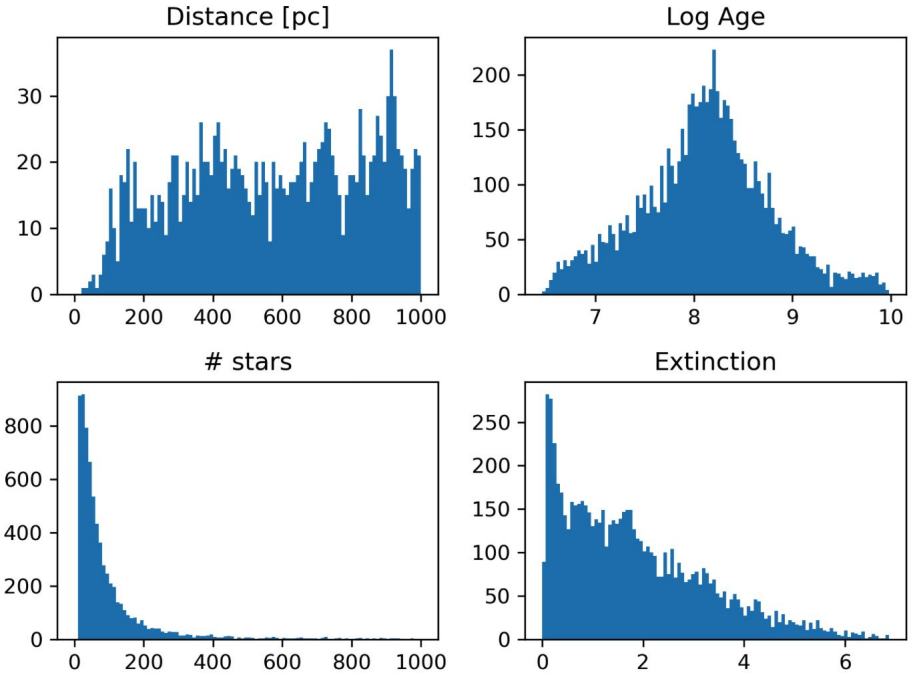
ABSTRACT

Context. Data from the *Gaia* satellite are revolutionising our understanding of the Milky Way. With every new data release, there is a need to update the census of open clusters.
Aims. We aim to conduct a blind, all-sky search for open clusters using 729 million sources from *Gaia* DR3 down to magnitude $G \sim 20$, creating a homogeneous catalogue of clusters including many new objects.
Methods. We used the Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN) algorithm to recover clusters. We validated our clusters using a statistical density test and a Bayesian convolutional neural network for colour-magnitude diagram classification. We inferred basic astrometric parameters, ages, extinctions, and distances for the clusters in the catalogue.
Results. We recovered 7167 clusters, 2387 of which are candidate new objects and 4782 of which crossmatch to objects in the literature, including 134 globular clusters. A more stringent cut of our catalogue contains 4105 highly reliable clusters, 739 of which are new. Owing to the scope of our methodology, we are able to tentatively suggest that many of the clusters we are unable to detect may not be real, including 1152 clusters from the Milky Way Star Cluster (MWSC) catalogue that should have been detectable in *Gaia* data. Our cluster membership lists include many new members and often include tidal tails. Our catalogue's distribution traces the galactic warp, the spiral arm structure, and the dust distribution of the Milky Way. While much of the content of our catalogue contains bound open and globular clusters, as many as a few thousand of our clusters are more compatible with unbound moving groups, which we will classify in an upcoming work.
Conclusions. We have conducted the largest search for open clusters to date, producing a single homogeneous star cluster catalogue which we make available with this paper.

Key words. open clusters and associations: general – Methods: data analysis – Catalogs – Astrometry

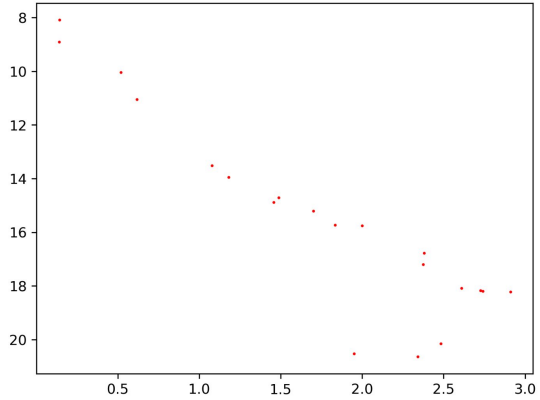
Cluster Catalog

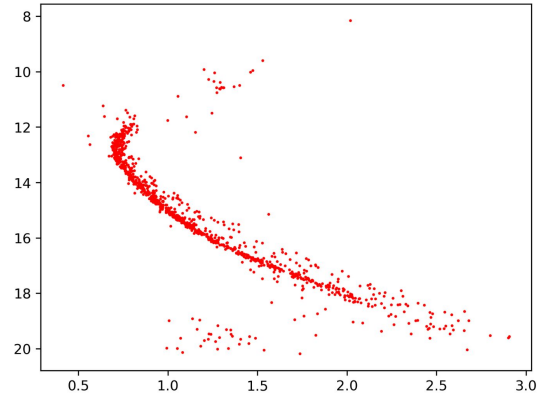
- Taking the stellar catalog from Gaia and assigning cluster membership
- 729 million sources → over 7000 clusters, including 134 globular clusters
- Include parameters about the cluster like ages, metallicity, extinction and distance
- Sorted to find clusters with a large number of stars, different distances and ages

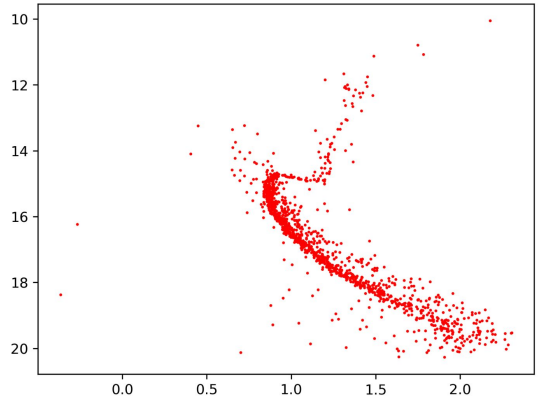


“Good” clusters

Well populated clusters are easier to interpret!







Data in Stellar Safari

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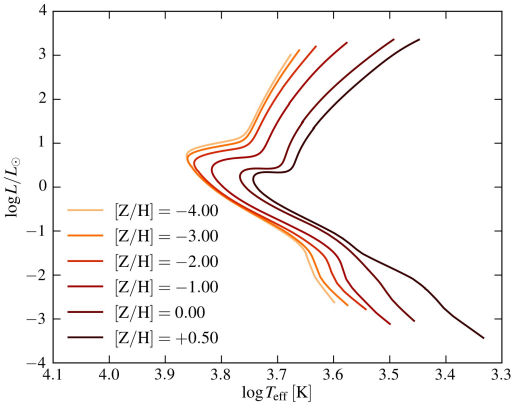
- isochrones from Mesa Isochrones and Stellar Tracks (MIST).

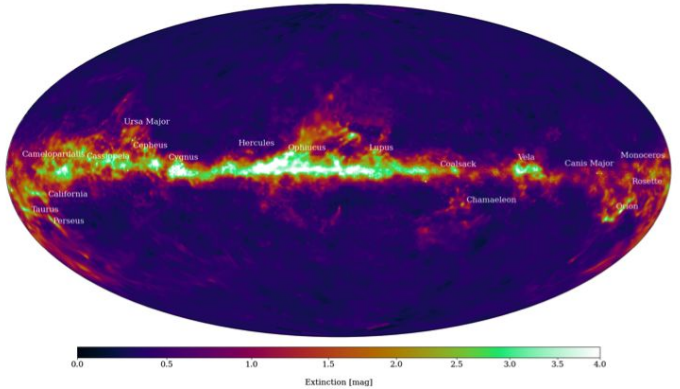
Isochrone Libraries for each cluster

- Isochrones are models of a single stellar population and change sha based on different parameters like
  - Age
  - Distance
  - Metallicity
  - Extinction
- Each cluster has an isochrone library from MIST, a model, that has the appropriate metallicity and extinction
- The library has a range of models for each age



Credit: MIST

Credit: Dharmawardena et al. 2024



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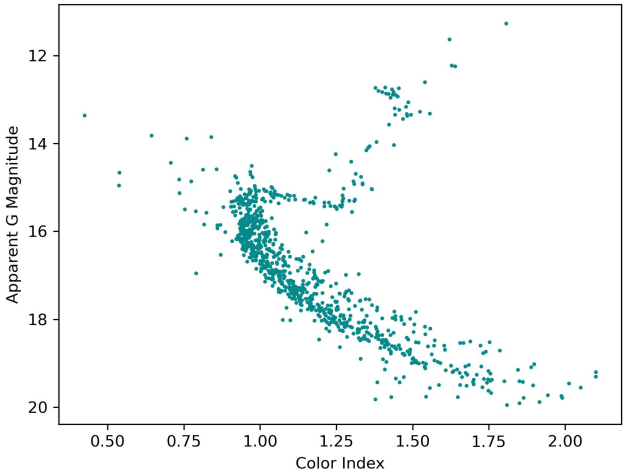
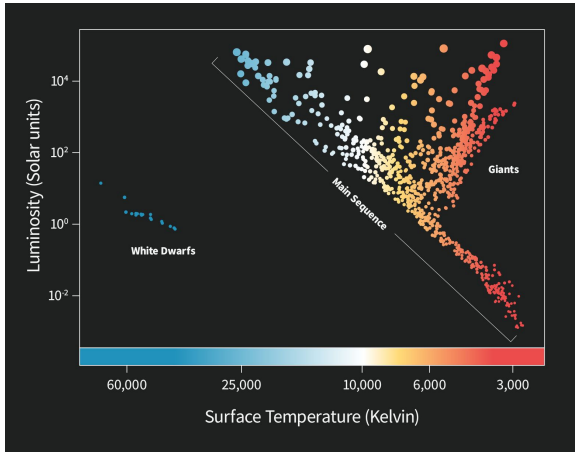
And Rubin? What will change?

Color-Magnitude vs. H-R diagrams

Similar but different!

Look at the axes, be aware that the names are often used interchangeably





Color Magnitude Diagrams
Observed parameters (from photometry)

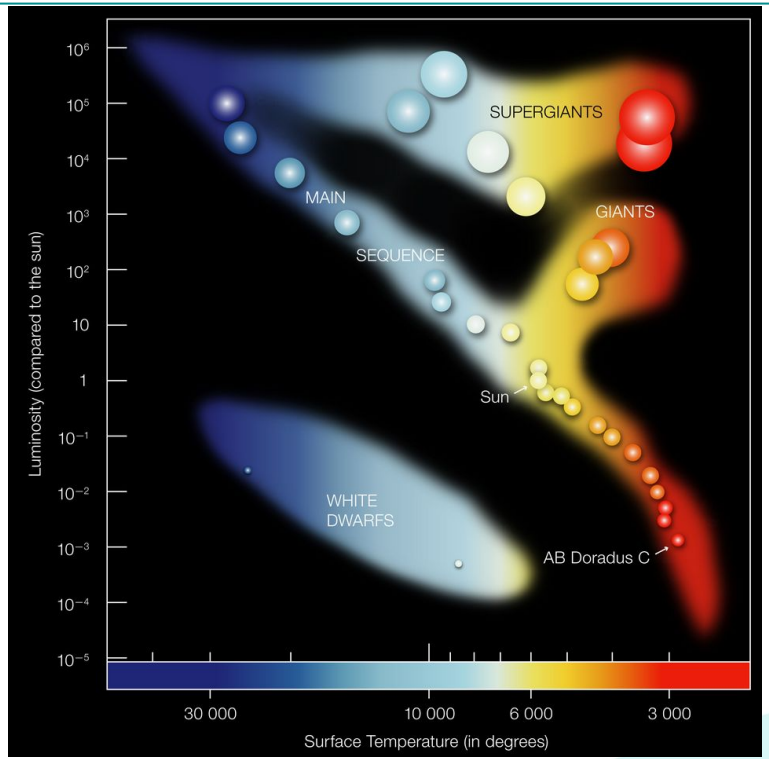
Hertzsprung- Russell Diagrams
Physical (derived) parameters

H-R Diagram Misconceptions

H-R Diagram axes are not linear, and the x-axis increases in value to the left.

Typical H-R diagrams often misrepresent the relative sizes of stars and their relative distributions.

The Sun's position near the center of the diagram can lead to the idea that it is mid-range in both temperature and brightness… an "average" star.

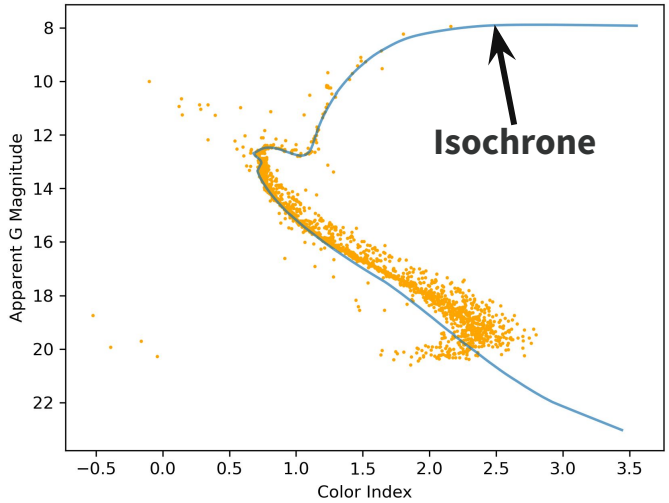


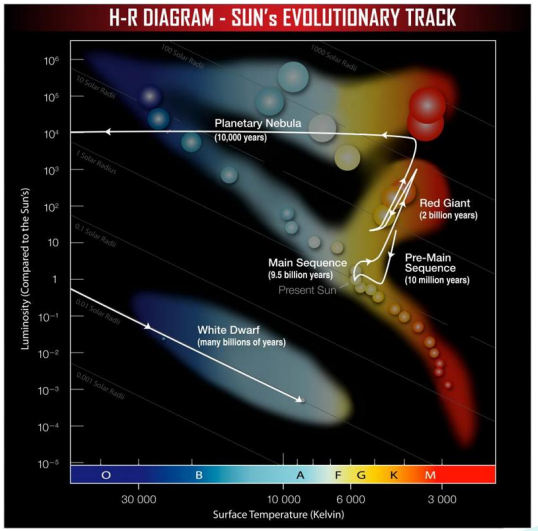
Credit: European Southern Observatory

What is an isochrone?

It describes a group of stars of a certain age, not an evolutionary path of a star!

A stars does not “evolve” along an isochrone.





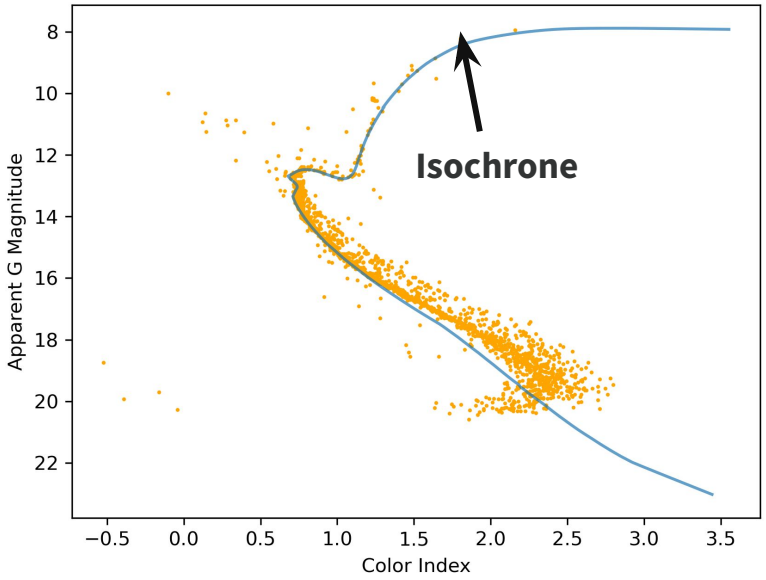
Credit: Chandra X-ray Observatory

Isochrone Confusions

All stars along an isochrone are the same age, but not the same stage of evolution.

When talking about isochrones the terms “older” and “younger“ may be used to describe the age of stars in *years.*

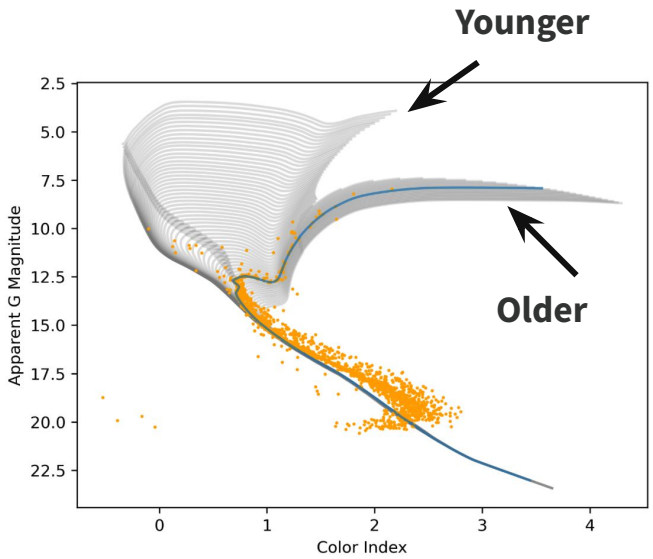
Where as when talking about evolutionary tracks in H-R, “older” and “younger“ may be used to describe their *evolutionary stage*- which are not the same!

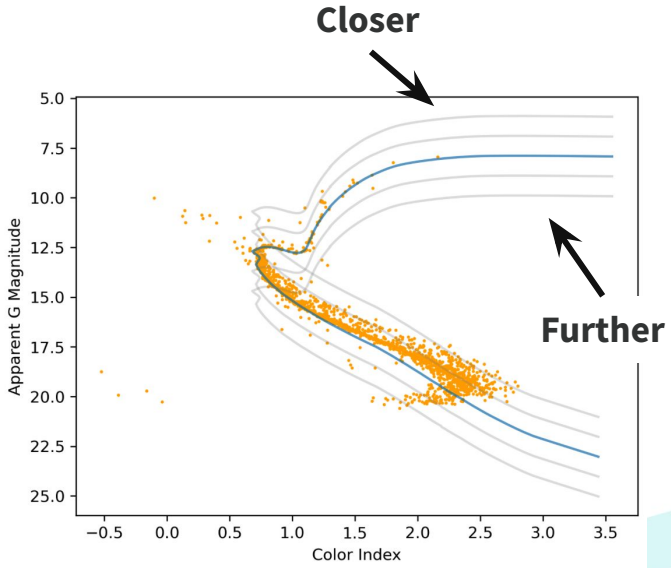


What is an isochrone?

It describes a group of stars, not an evolutionary path of a star!

- Includes various parameters like age, distance, metallicity, extinction

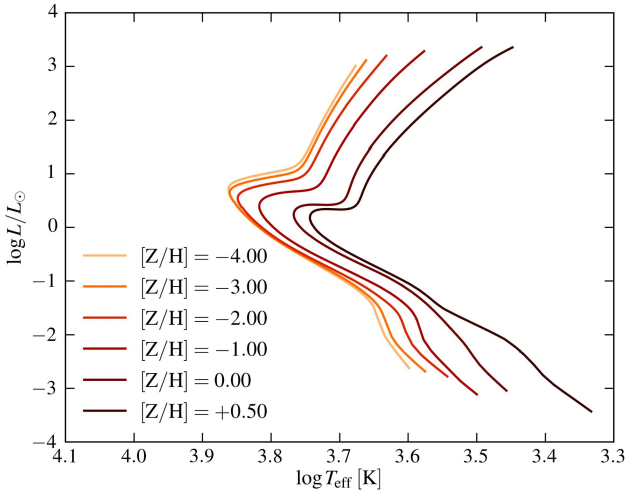




Why do we look at clusters only?

Isochrones represent a single population:

- One age
- One metallicity
- One distance
- One extinction



Credit: MIST

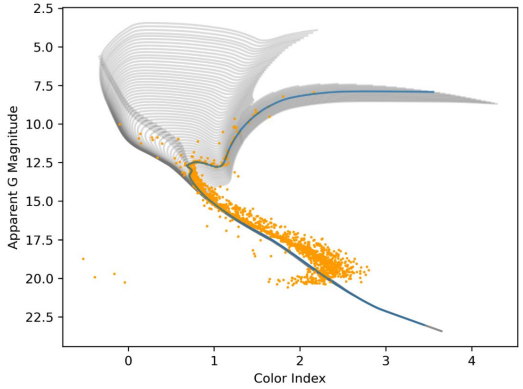
Clusters are reasonably representative of a single age at a single distance with a common metallicity and extinction

- Students fit the age and distance
- Metallicity and extinction are already taken care of by selection of the isochrone library

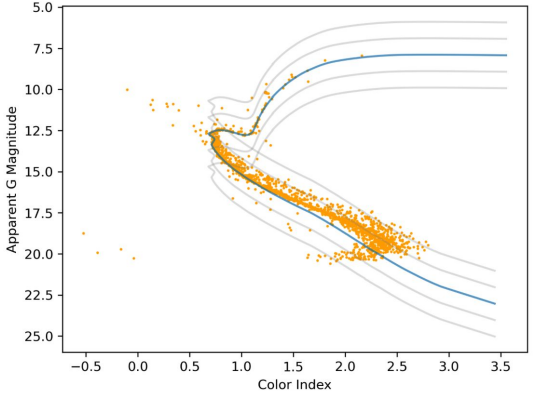
Isochrone Library

The isochrone changes shape with age, but just changes position with distance.

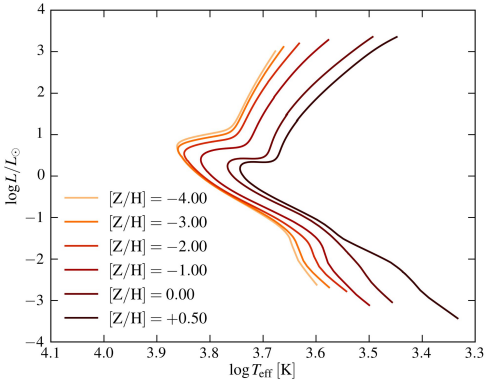
Age



Distance



Metallicity

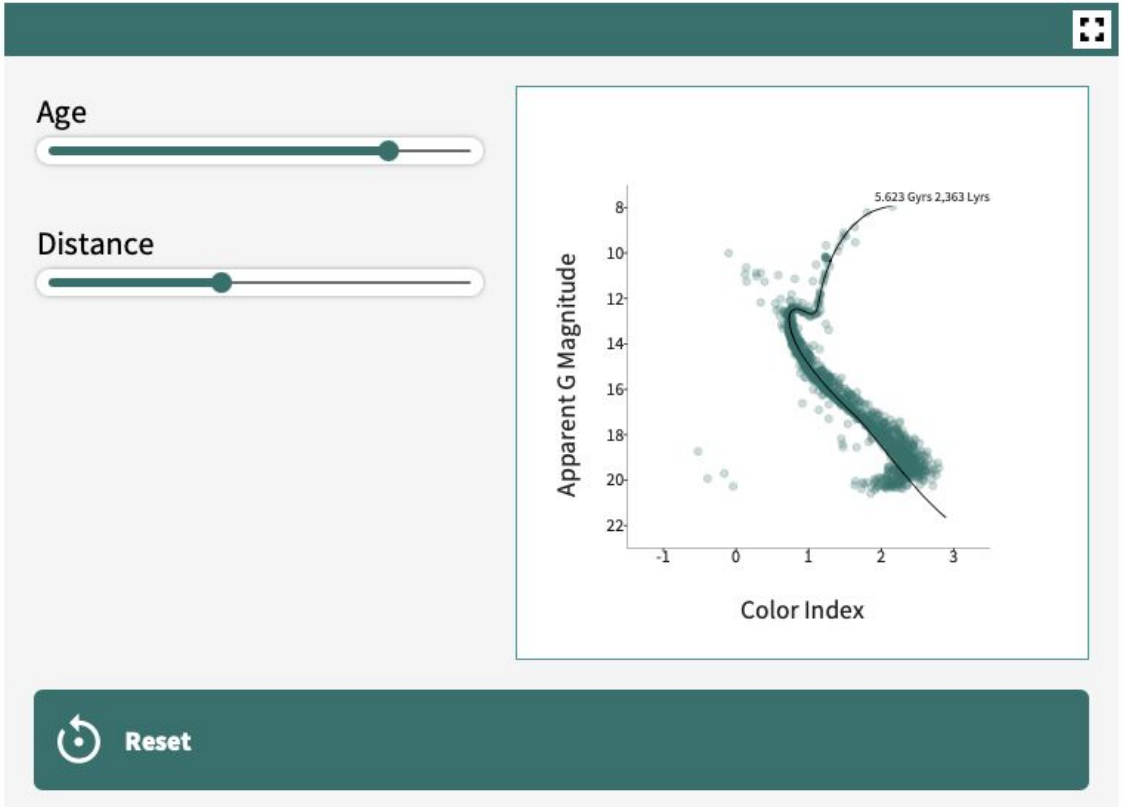


Credit: MIST

Demo of the Isochrone Fitting Tool in the Investigation

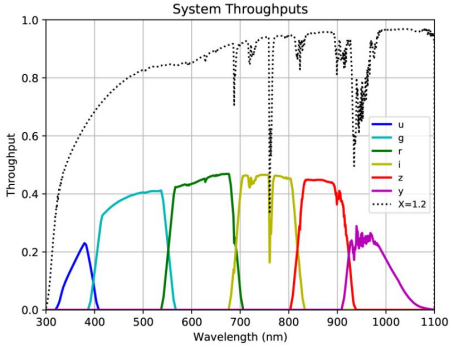
(Investigation page 9)

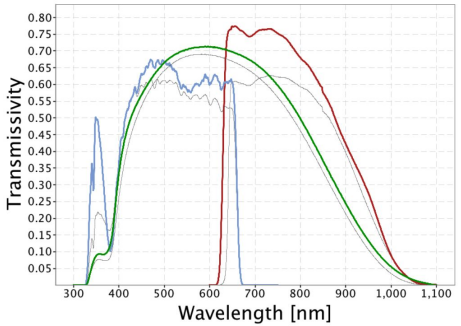
BLV students can fit the data using voiceover options



What will look different when Rubin data is included?

- Different filters
- Rubin is deeper, fainter and lots more stars!
- More scatter
  - Gaia created a 3D map





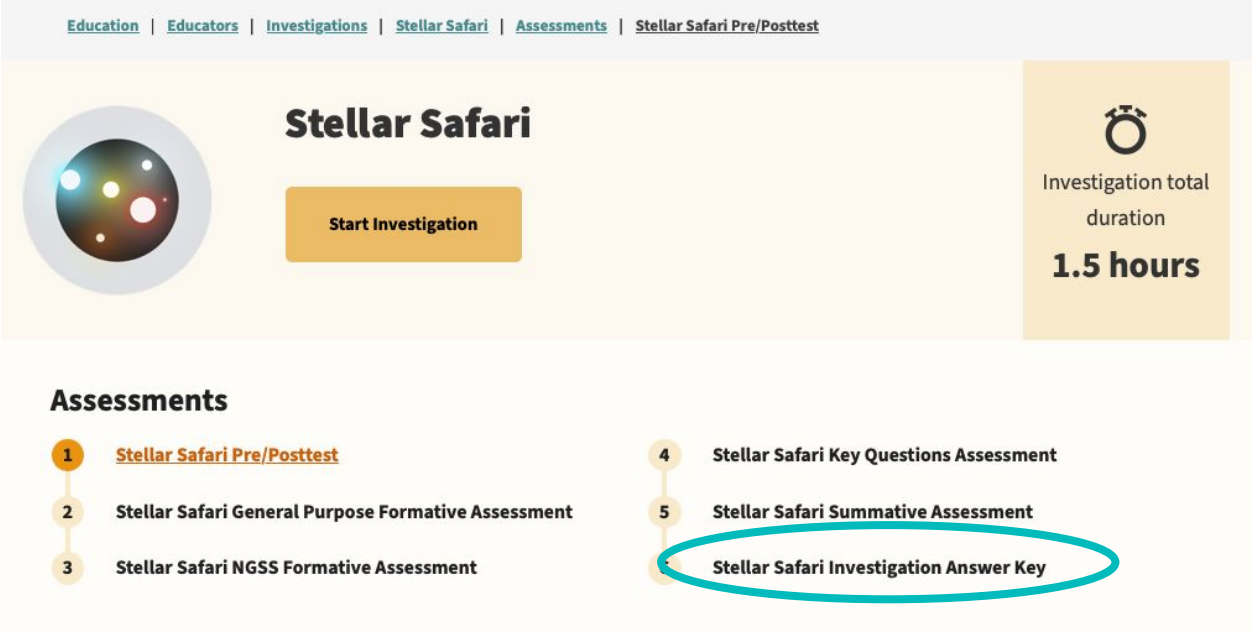
Credit: ESA/Gaia/DPAC, P. Montegriffo, F. De Angeli, C. Cacciari

Rubin

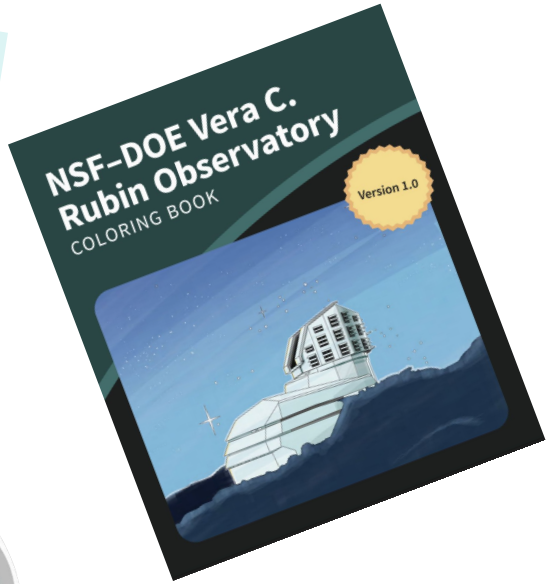
Gaia

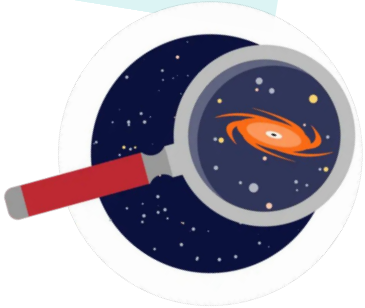
New! Investigation Answer Key

Option 6 (once you are logged in to view assessments)



Rubin Education First Look Resources





For more information, visit
rubinobservatory.org/education

Citizen Science - It’s happening!

Rubin will have an exciting number of citizen science projects, we have our first project live, with more to come

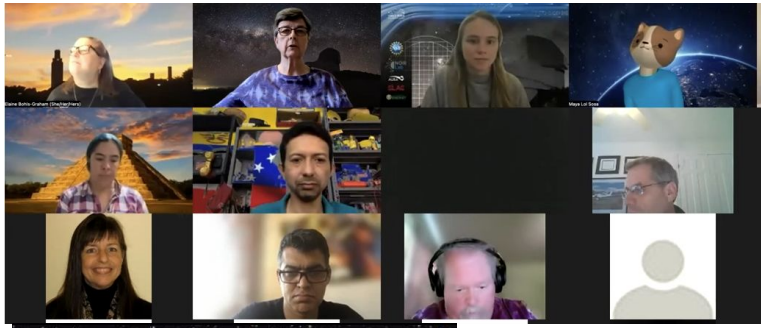
For projects, visit: *zooniverse.org/rubin*

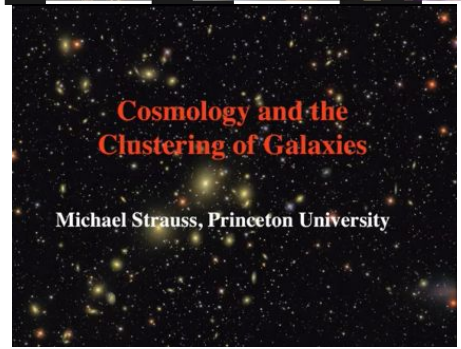
By scanning images from the Rubin Observatory’s LSST, participants will look for telltale signs of activity, like faint tails or surrounding comae, that reveal the presence of volatile ices.

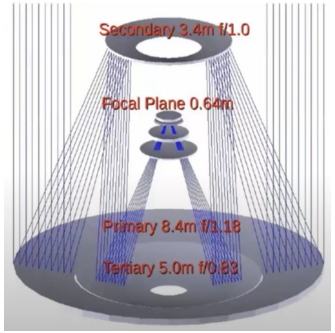
Professional Development Resources

The professional development web page contains recorded webinars, implementation tools and more!

Contact us to arrange a free teacher training session for your group.







Coming Soon!

Beginning of Operations - October 24
Start of the Legacy Survey of Space and Time

AMTA Expanding Universe Webinar, Nov 18
More “Behind the Scenes” webinars, dates TBD

H. Stockebrand

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