AST-06

Analyzing the Dynamical Signatures of M32 by Using the Resolved Stellar Population

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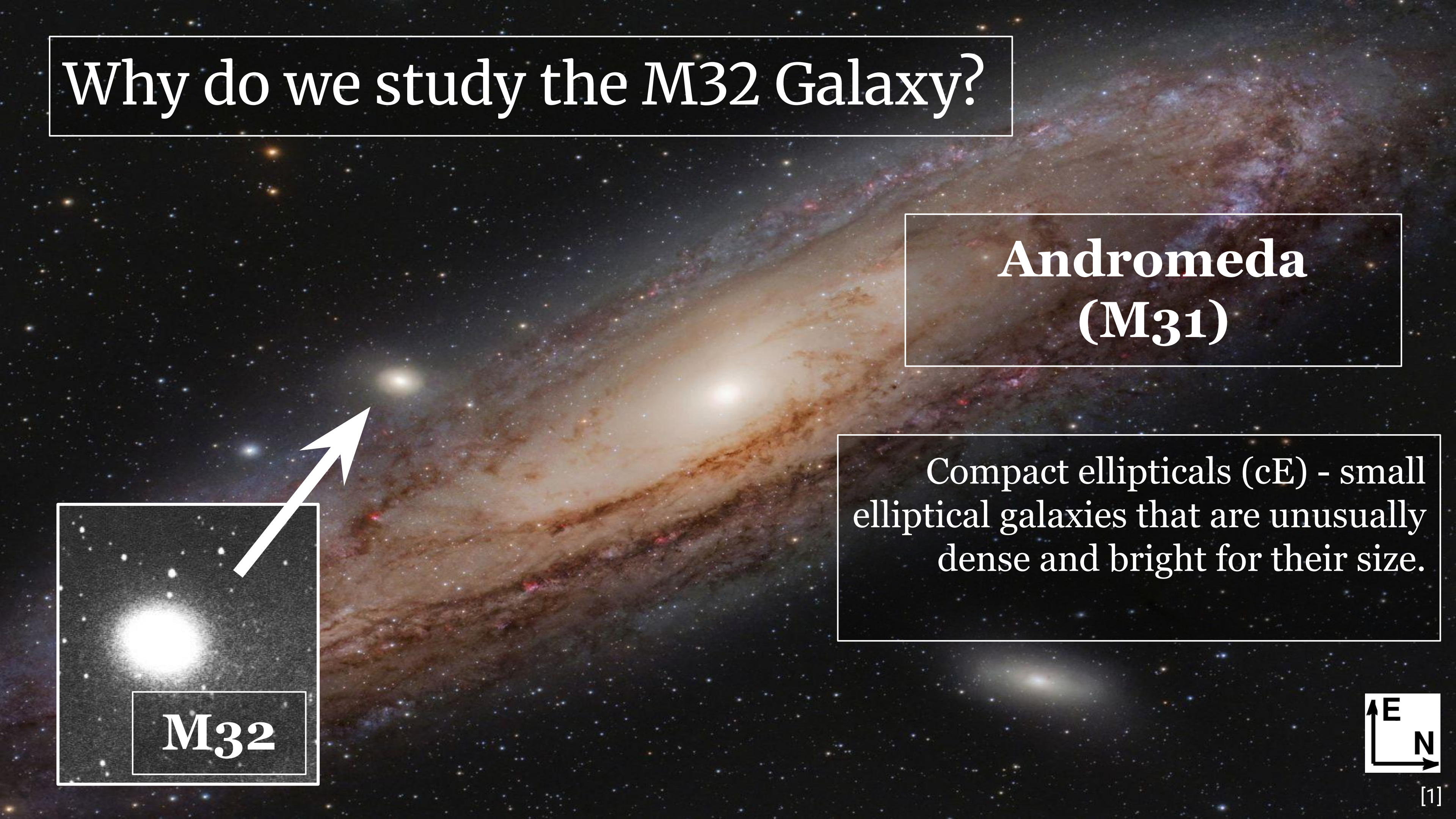
SCIENCE INTERNSHIP PROGRAM

Why do we study the M32 Galaxy?

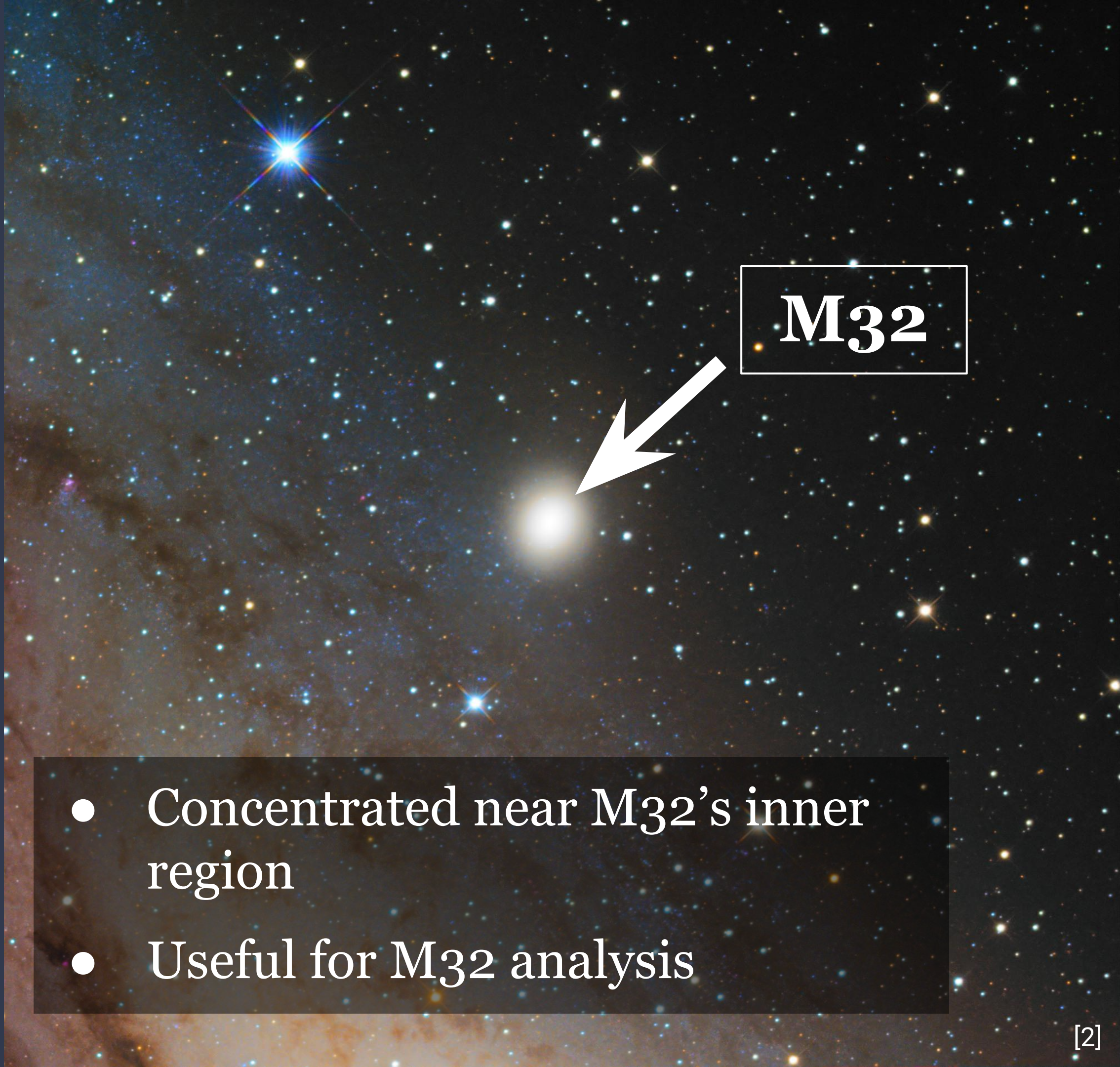


Compact ellipticals (cE) - small elliptical galaxies that are unusually dense and bright for their size.

[1]

What are Serendipitous Stars?

- “Unintentionally” discovered
- Not target stars
- Require careful spectroscopic analysis



- Concentrated near M32’s inner region
- Useful for M32 analysis

Central Question

Dissecting the stellar population of the M32 **compact elliptical** galaxy

Dataset Source: DEIMOS and PHAST

DEIMOS: Deep Extragalactic Multi-Object Spectrograph

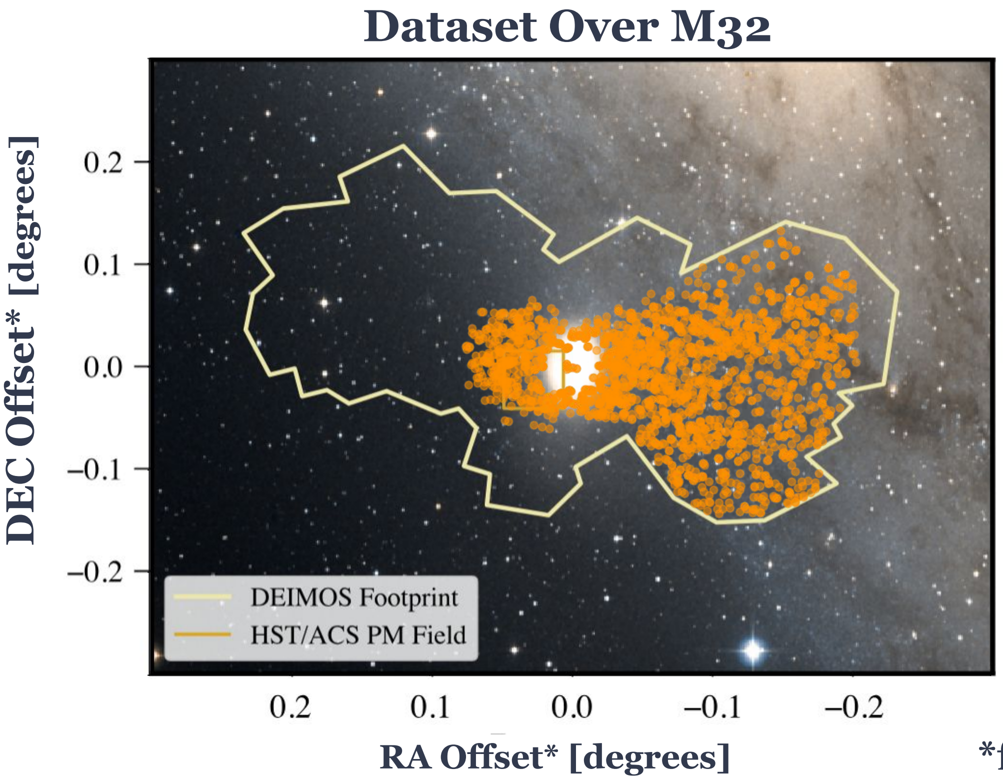
Keck II 10m Optical Telescope, Hawaii

PHAST: Panchromatic Hubble Andromeda Southern Treasury

Hubble Space Telescope/ACS (WFC)

[3], [4], [5]

Dataset: Celestial Sphere Footprint



*from M32's center

Goals

1. Sort stars by photometric properties

2. Analyze the distributions of stars

3. Determine unusual trends and confirm known ones

(Data mapped by AST-08)

Data Preprocessing

- Analyze velocity measurement quality
- Applying velocity corrections

Modeling Velocities

- DYNESTY - velocity distributions (Attempt to sort data into respective sources)
- Andromeda disk-like and M32-like components

Color-Magnitude Diagram

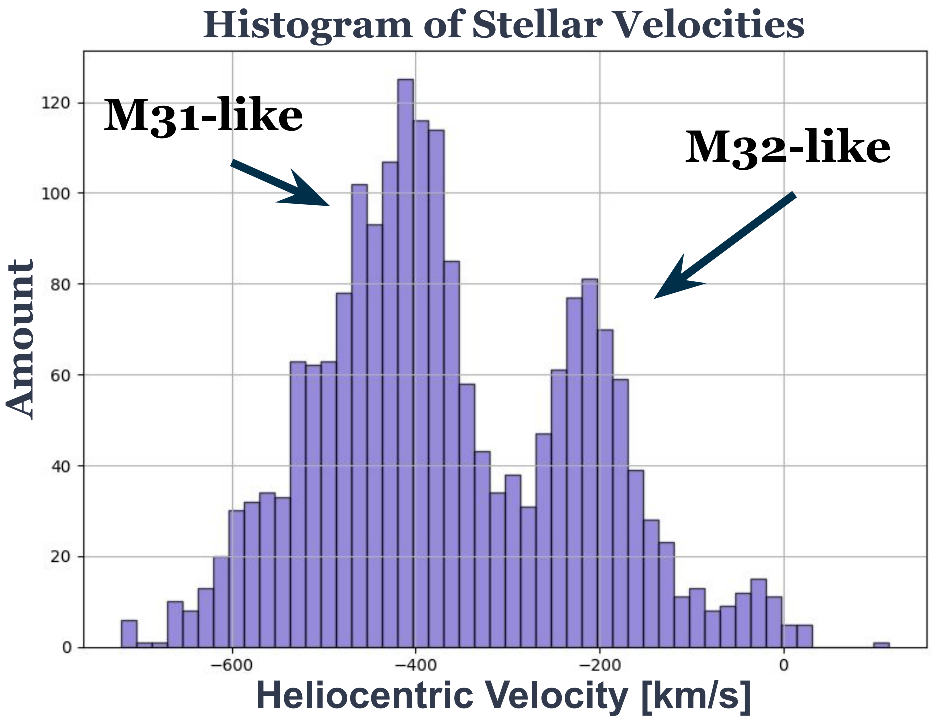
- Classification of stars
- RGB vs AGB
- Target vs Serendip

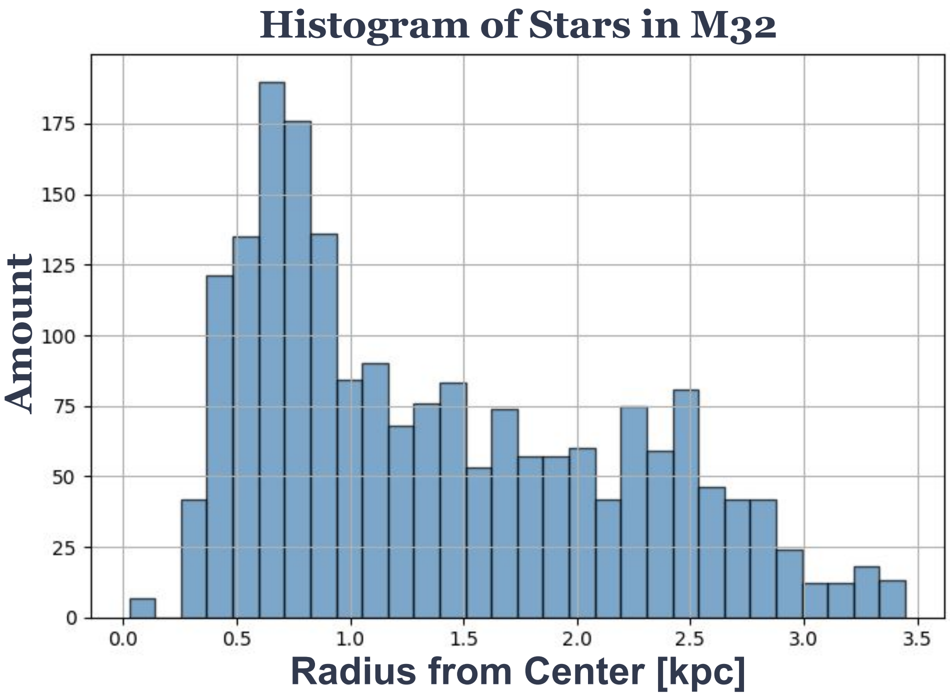
Analysis of Diagram and Model

- Sub-dataset model comparisons

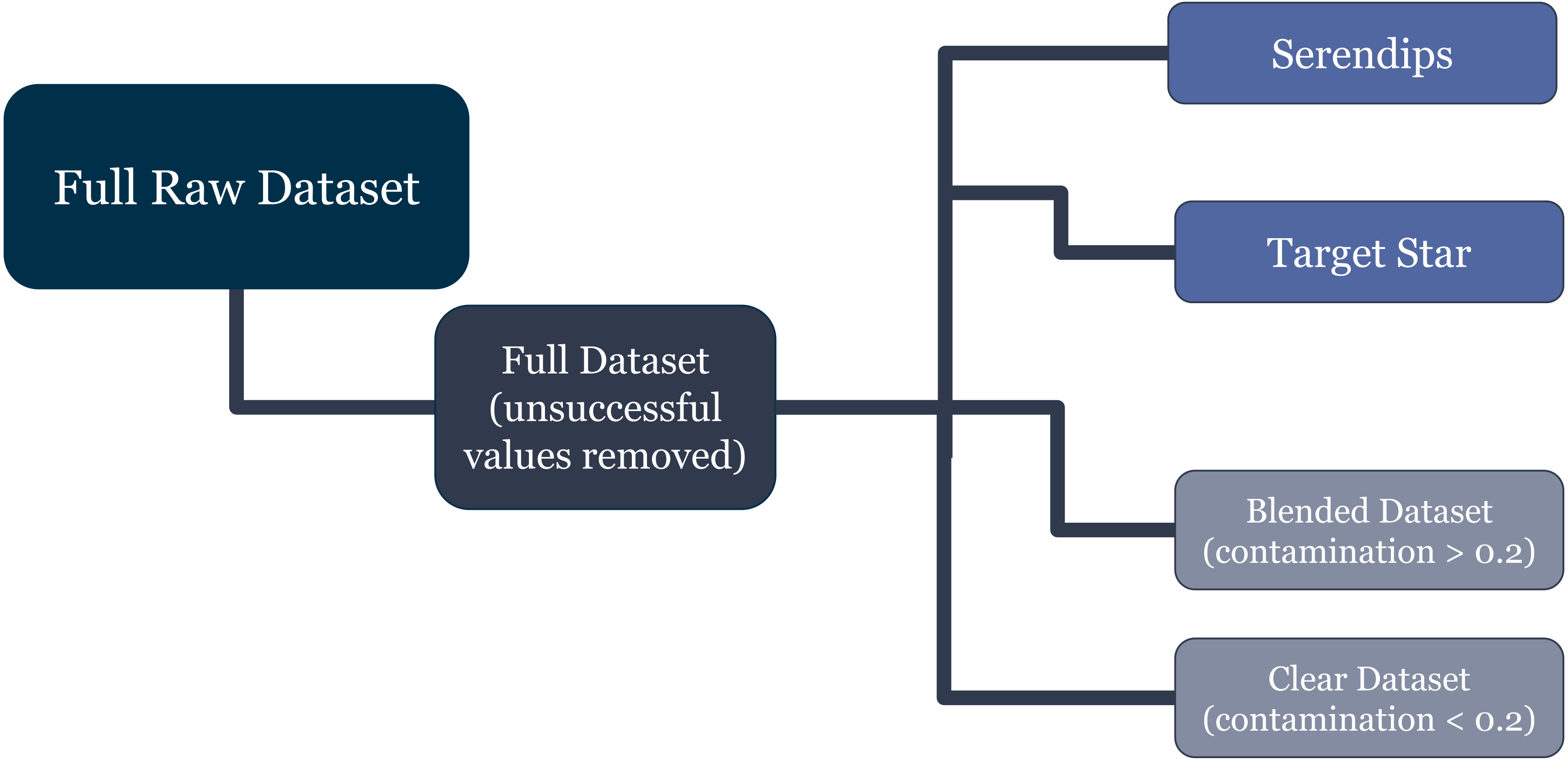
Data Processing: Velocity Distribution

Two main peaks → source of dataset





Sorting data

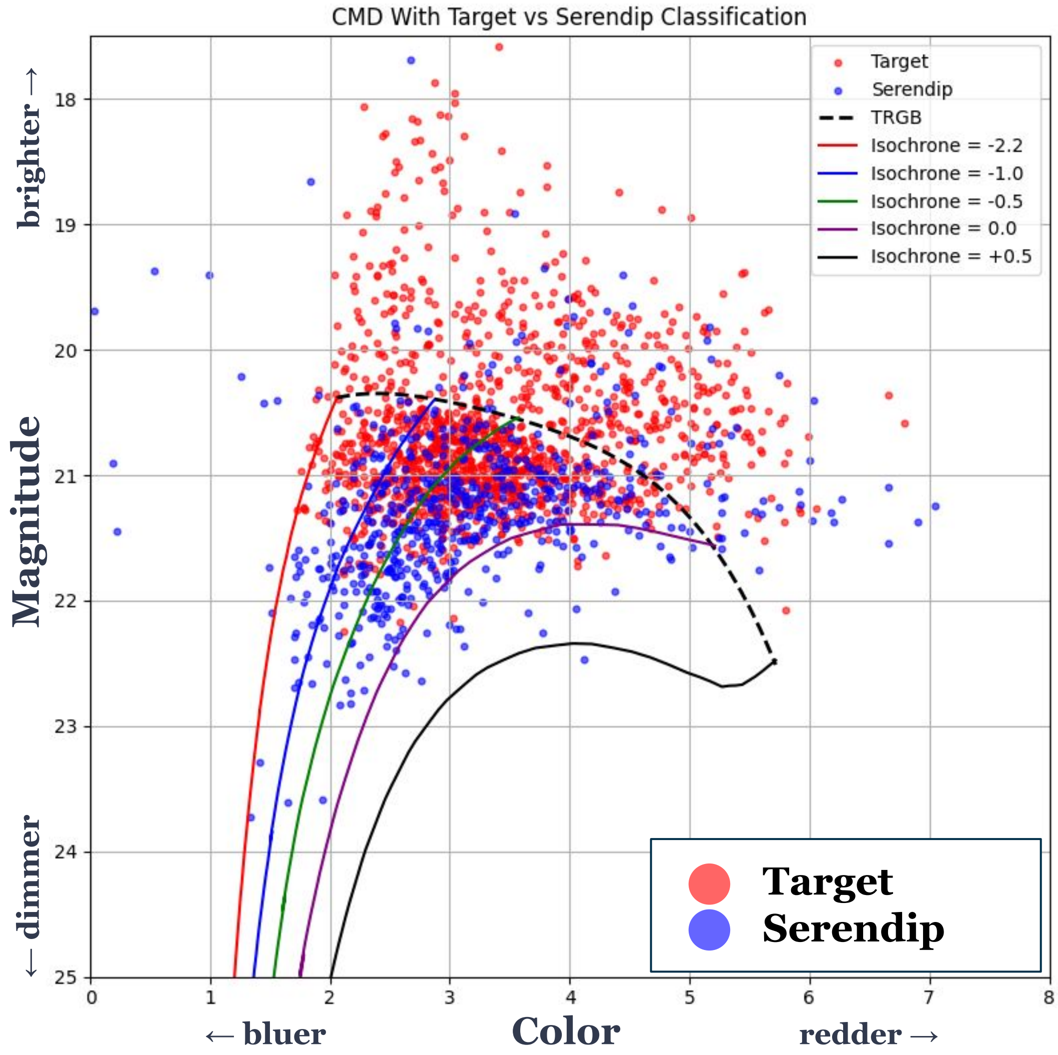


Color-Magnitude Diagram

Data Processing:

Photometry from PHAST Catalog

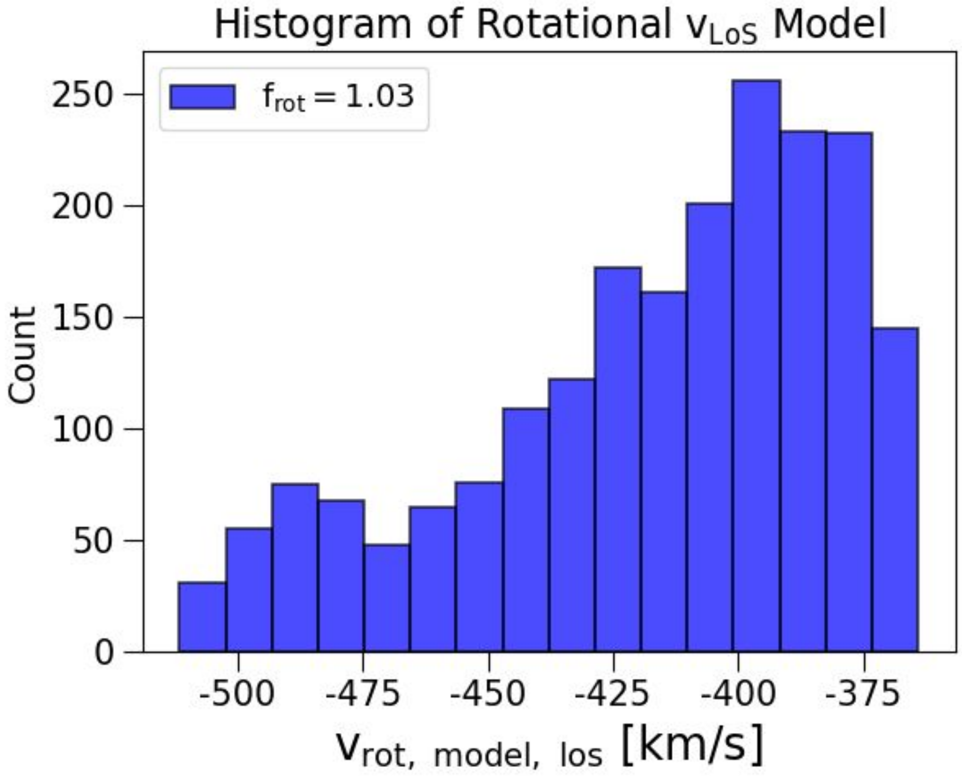
(data from AST-08)



Kinematical Modeling

Phase 1: Tilted ring model (Chemin et al. 2007)

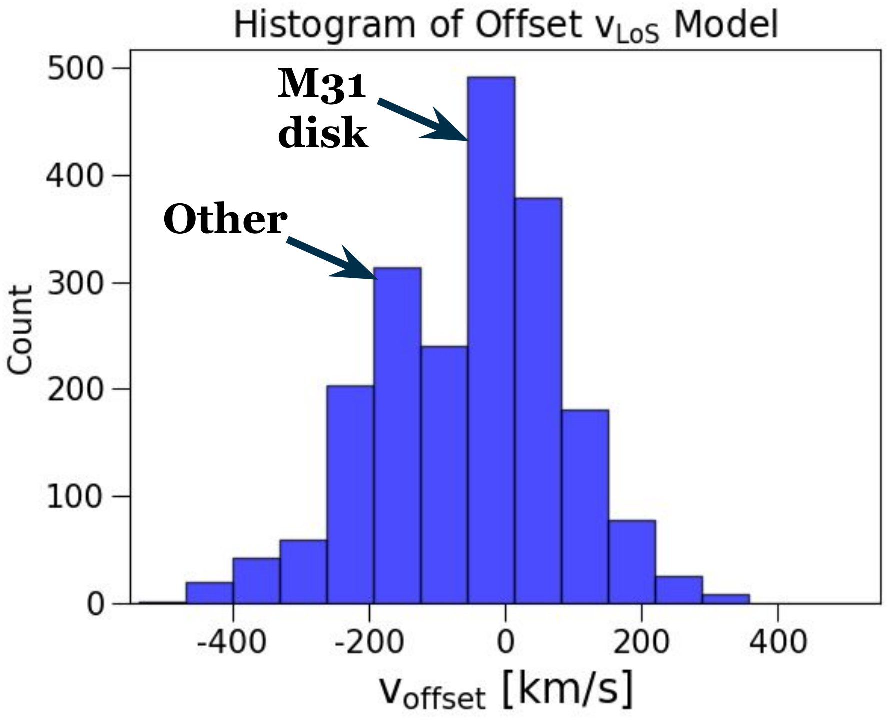
Modeled LoS velocity of dataset sample according to M31's HI disk velocity



$$v_{\mathrm{mod,los},j} = v_{\mathrm{sys,M31}} + f_{\mathrm{rot}} \times v_{\mathrm{HI,rot,d}}$$

V_offset calculation with tilted HI disk model

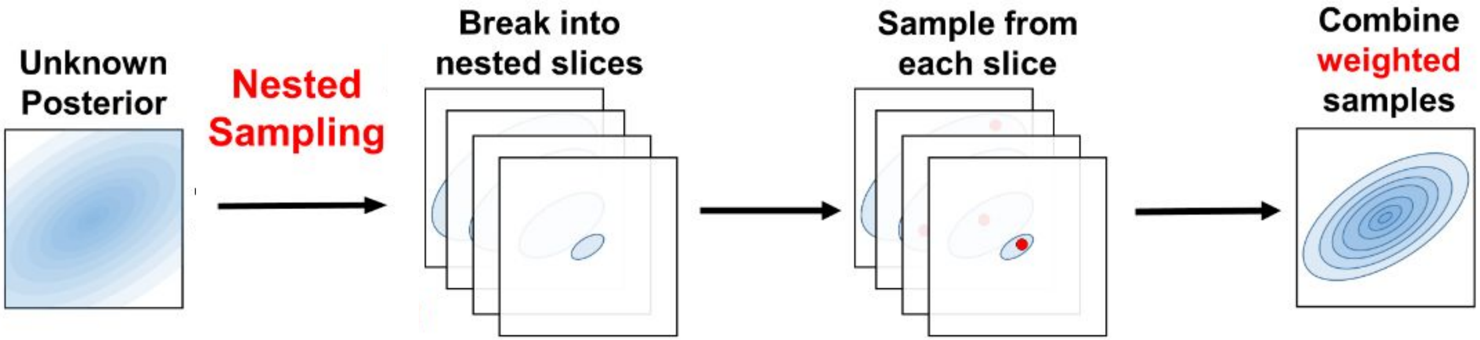
$$v_{\mathrm{offset},j} = v_{\mathrm{mod,los},j} - v_{\mathrm{los},j}$$



Kinematical Modeling

Phase 2: Rotating+Offset model (Escala et al. 2025)

DYNESTY



- Tool used to estimate mathematical distributions of the dataset.
- Constructs a **probability distribution** of model parameters based on how well they explain the observed data.

Why DYNESTY

- DYNESTY uses "dynamic nested sampling"
- Extremely efficient for up to 30 parameters
- Less fine-tuning required
- Higher sampling compared to other models

Results: Dynamic Nested Sampling

Comparison of log(Z) values across models using the same prior volume

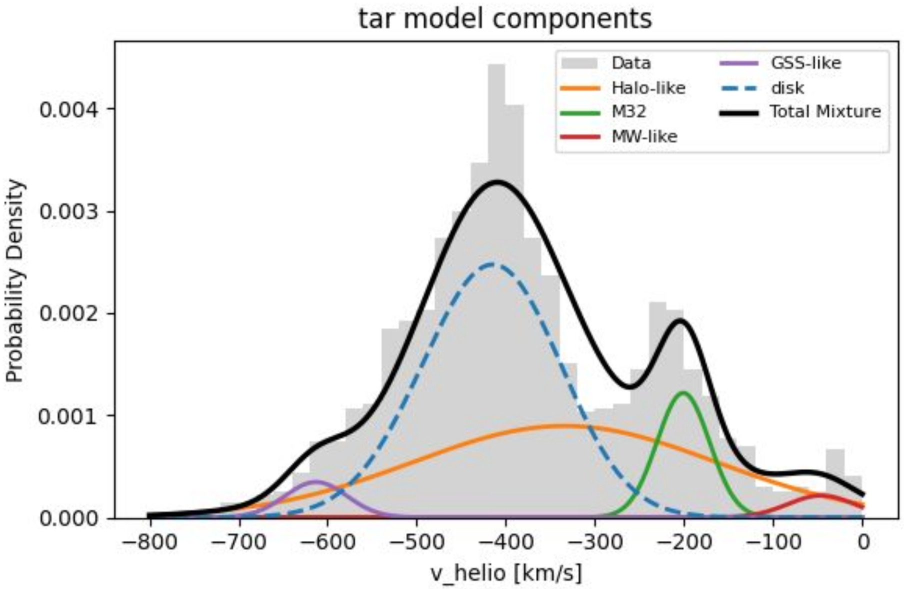
Sample	3-Component	4-Component (GSS)	4-Component (MW)	5-Component
All stars	-13071.187 +/- 0.164	-13070.868 +/- 0.198	-13068.743 +/- 0.205	**-13068.633 +/- 0.262**
Target	-9101.957 +/- 0.145	-9098.587 +/- 0.182	-9100.026 +/- 0.182	**-8567.896 +/- 0.167**
Serendips	**-3955.529 +/- 0.105**	-3959.815 +/- 0.123	-3956.990 +/- 0.120	-3961.922 +/- 0.141
Clear	-10153.156 +/- 0.151	-10151.004 +/- 0.187	-10151.607 +/- 0.179	**-10149.412 +/- 0.210**
Blended	**-2904.980 +/- 0.096**	-2909.064 +/- 0.117	-2908.085 +/- 0.118	-2912.178 +/- 0.137

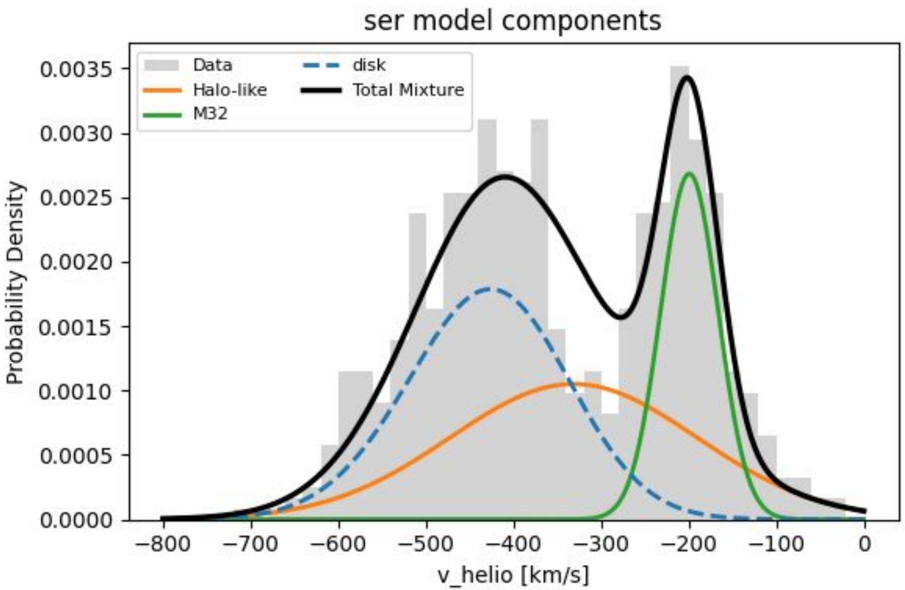
Optimized Parameters

Serendips, Blended

All stars, Target, Clear

Model Comparison with the Optimized Parameters

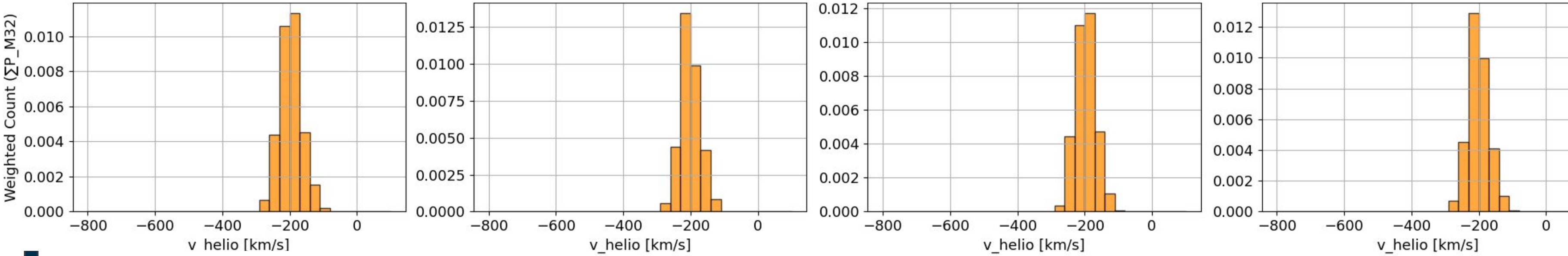




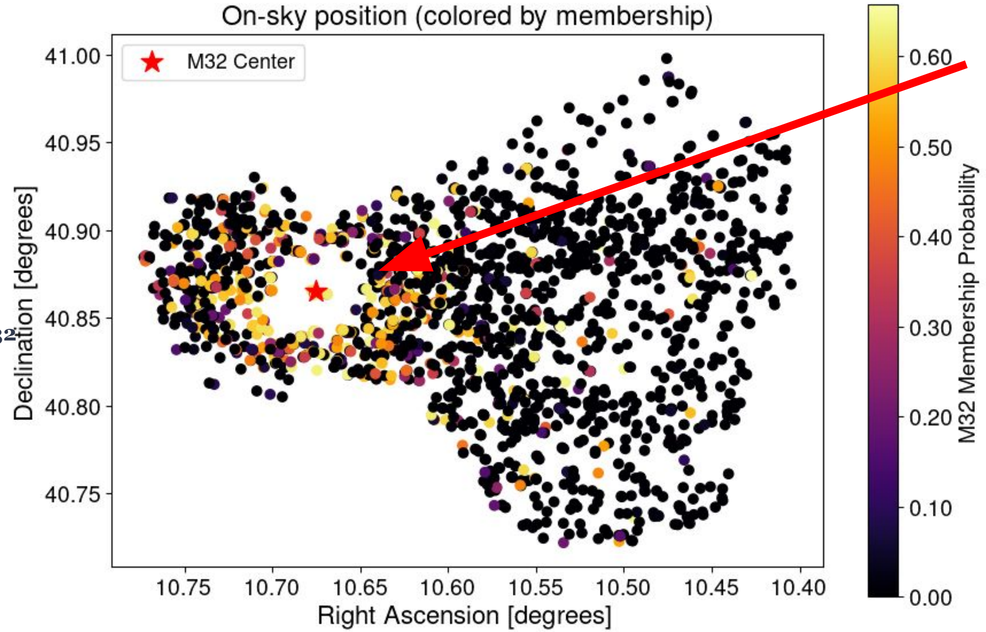
Notice how the serendip dataset seem to contain **more** M32 stars than the target sample group? (fraction almost **doubling**: 9% ->22%)

P_{M32}-Weighted Histogram of Helio Velocity

Serendips (N = 616) **Target (N=1359)** **Clean (N=1553)** **Blended (N=412)**



Visualization with P_{M32}

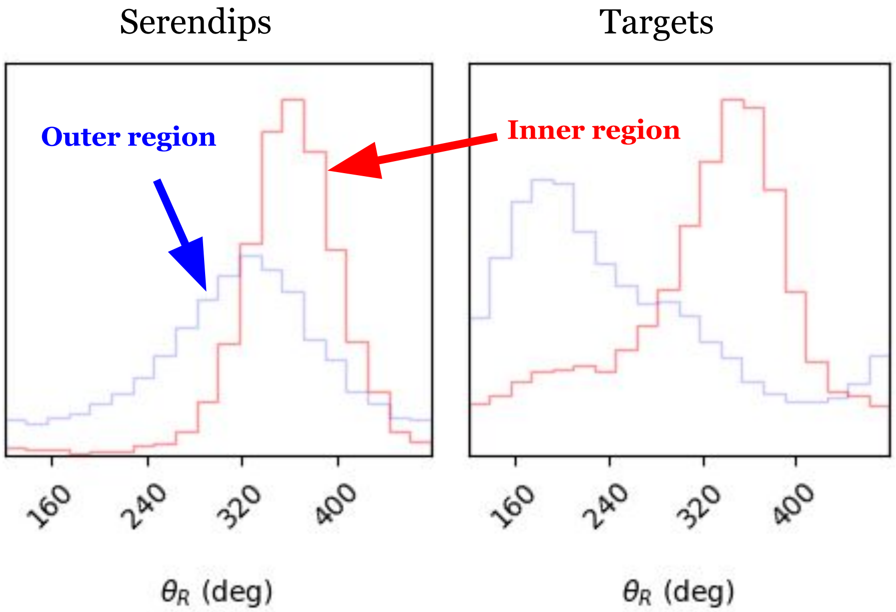


More likely to be M32 sourced

More possibility of being from other sources

Future Work

Rotational Axis Estimation



- M32 Membership Probabilities
- Kinematical differences between inner and outer regions:
  1. Tidal interactions
  2. Dark matter halo → no way to measure
- 2 models:
  1. Rotational model
  2. Linear velocity gradient model

Acknowledgements

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Max Kogan and his interns, AST-08

References and Citations

[1]: https://cdn.mos.cms.futurecdn.net/hCXYB5YKXzdq2WEHYEe36d-1200-80.jpg.webp

[2]: https://epod.usra.edu/.a/6a0105371bb32c970b017d3ee575b4970c-pi

[3]: https://www.ucolick.org/~phillips/deimos_ref/DEIMOSlogo.jpg

[4]: https://www2.keck.hawaii.edu/inst/common/Keck_Logo_Tag_Transparent.png

[5]: ps:

https://www.messier-objects.com/messier-32-le-gentil/

https://esahubble.org/images/potw1011a/

https://www.universetoday.com/articles/messier-32

http://www.messier.seds.org/m/m032.html

https://astropixels.com/stars/Polaris-01.html

Appendix

CMD plotting, isochrones

RGB and AGB stars split by tip of RGB line: best 4th degree fit for 28 PARSEC isochrones defined over -2.2 ≤ [M/H] ≤ 0.5, 12Gyr (1.2*10^10 year) stars.

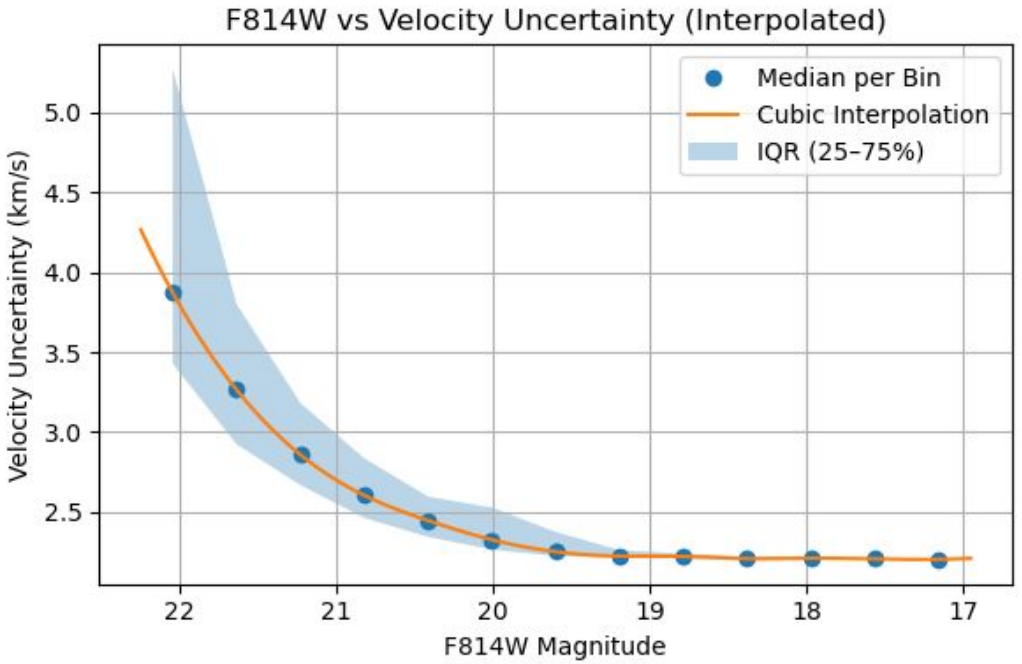
Add cmd 28 isochrones

Isochrone generator link: https://stev.oapd.inaf.it/cgi-bin/cmd

Data quality

Quality of data increases as stars become brighter. This manifests in the velocity uncertainty quantity. The term comes from the cross-correlation of spectrum and velocity during velocity measurement.

Quality of light from stars can be characterized by signal-to-noise ratio (Shot/Poisson noise: arises during measurement through CCDs). Brighter stars (lower magnitudes) have higher signal-to-noise ratio (better quality).



DYNESTY: Bayesian Statistical Approach

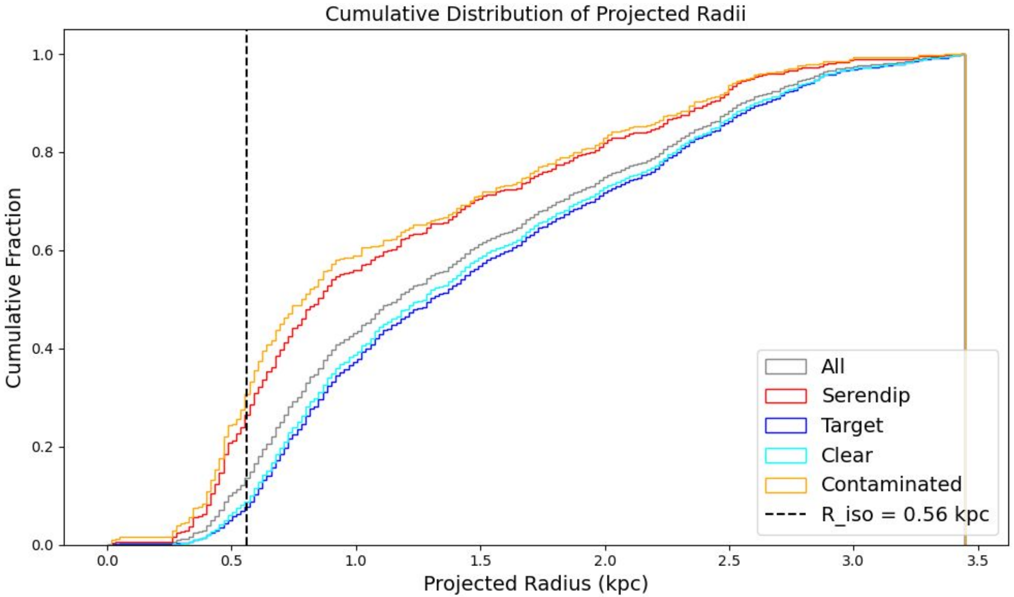
$$\underbrace{P(\Theta|\mathbf{D}, M)}_{\text{Posterior}} = \frac{\overbrace{P(\mathbf{D}|\Theta, M)}^{\text{Likelihood}}\,\overbrace{P(\Theta|M)}^{\text{Prior}}}{\underbrace{P(\mathbf{D}|M)}_{\text{Evidence}}} \equiv \frac{\mathcal{L}(\Theta)\pi(\Theta)}{\mathcal{Z}}$$

Given likelihoods and assumed priors, DYNESTY calculates evidence. We use this evidence term to calculate our posterior distribution.

Our algorithm's result is to minimize $-\log(\mathcal{Z})$.

The DYNESTY sampler was introduced by Joshua S. Speagle (CfA), in Speagle (2020)

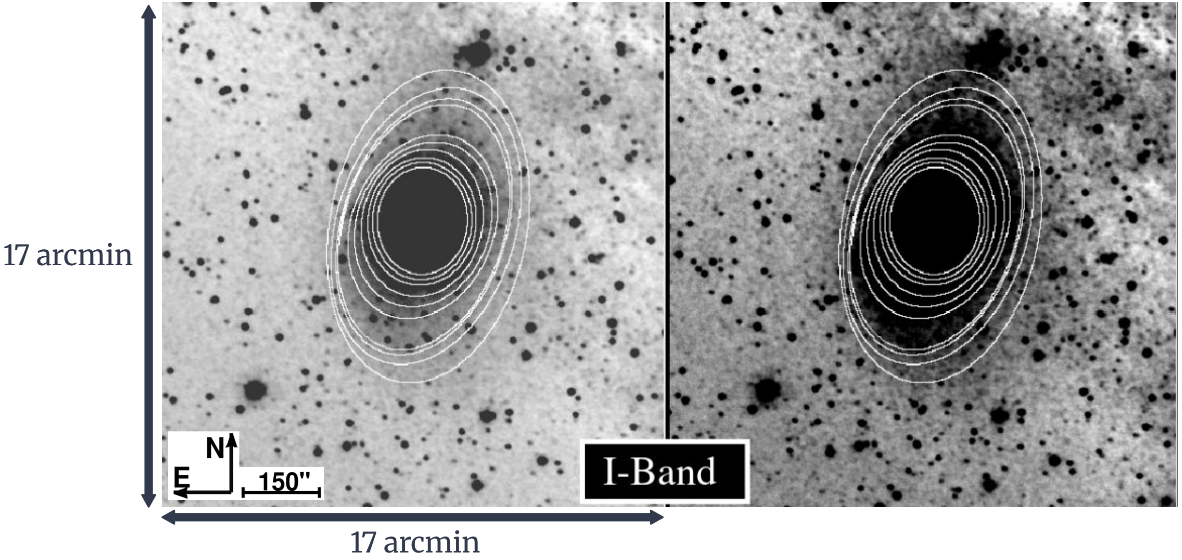
Distribution of Stars



R_{iso}: Radius at which a slight deviation exists in surface brightness

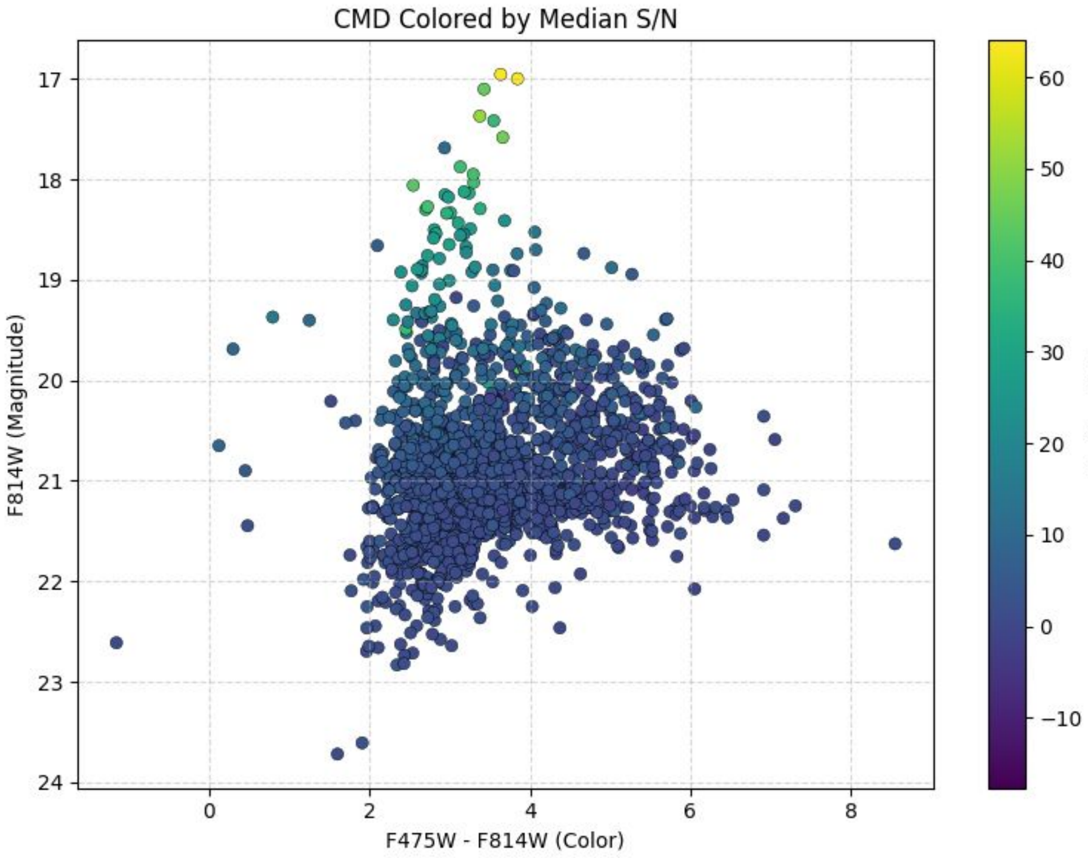
Comparison of log Z values across models using the same prior volume

M32 Morphology



Isophotes (contour lines of same brightness) in the I-band. Diagram from Choi et al. (2002). Note the twist.

M32 is a cE (compact elliptical) galaxy. Though some papers state that M32 is axisymmetric, others claim it to be a triaxial galaxy.
The latter is reinforced by the existence of the isophote twist at R_{iso}.


CMD Colored by Median S/N
F814W (Magnitude)
F475W - F814W (Color)
17
18
19
20
21
22
23
24
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2
4
6
8
60
50
40
30
20
10
0
−10