

AST-06

OSP SCIENCE
INTERNSHIP PROGRAM



Dynamics of M32: Target Stars, Serendipitous Stars, and the Effects of Blending

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Why do we study the M32 Galaxy?

**Andromeda
(M31)**

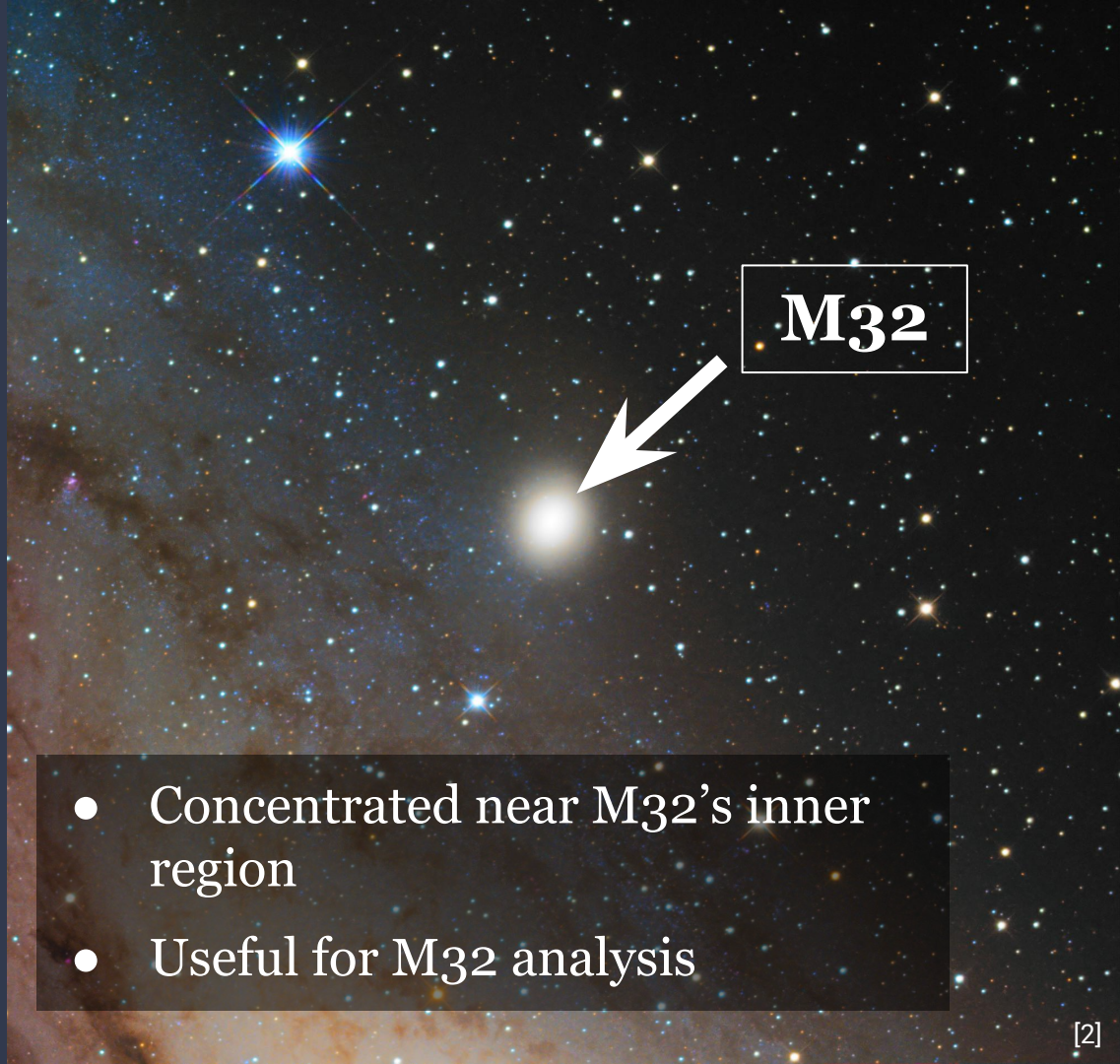
Compact ellipticals (cE) - small
elliptical galaxies that are unusually
dense and bright for their size.

M32



What are Serendipitous Stars?

- Unintentionally discovered
- Not target stars
- Spectra needs to be connected with photometry



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

Central Idea

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

Datasets: Keck DEIMOS and HST PHAST

DEIMOS: Deep Extragalactic Multi-Object Spectrograph

Keck II 10-m optical telescope, Hawaii



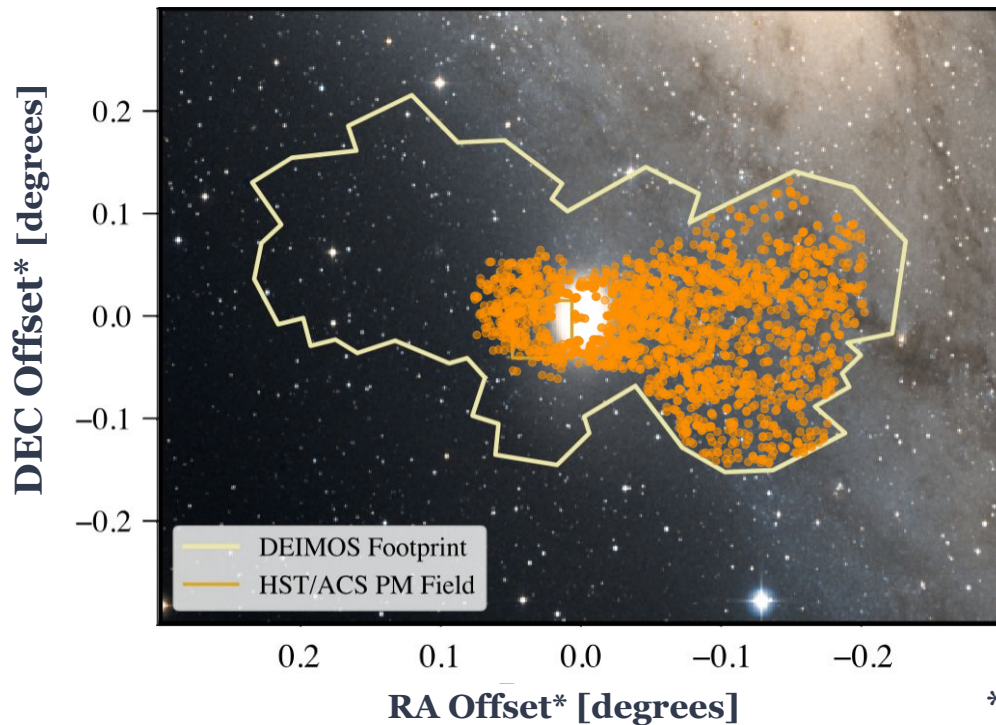
PHAST: Panchromatic Hubble Andromeda Southern Treasury

Hubble Space Telescope/ACS (WFC)



Dataset: Footprint on the Sky

Keck DEIMOS Dataset Overlaid on M32 Image



*from M32's center

Goals

1. Analyze what additional dynamical information can be extracted from serendipitous sources
2. Examine the effects of blending

(Data mapped by AST-o8)

1. Data Preprocessing

- Analyze velocity measurement quality
- Applying velocity corrections

3. Modeling Velocities

- Fit multiple kinematical components: M32, M31 disk, M31 spheroid, Giant Stellar Stream, and Milky Way
- DYNESTY fitting scheme

2. Color-Magnitude Diagram

- Classification of stars
- Target vs. serendip

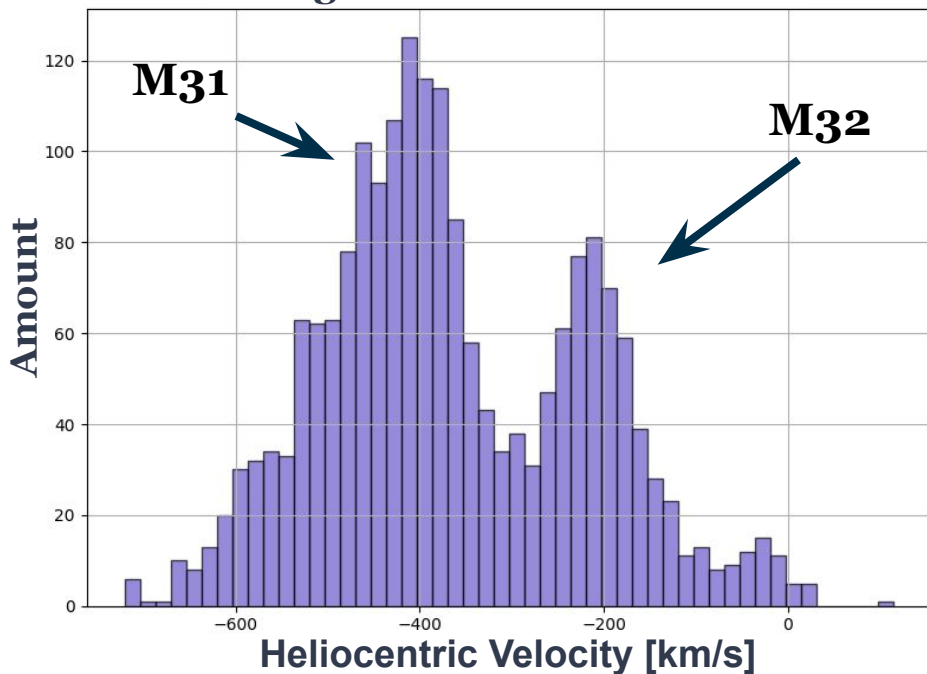
4. Analysis of Diagram and Model

- Sub-dataset model comparisons

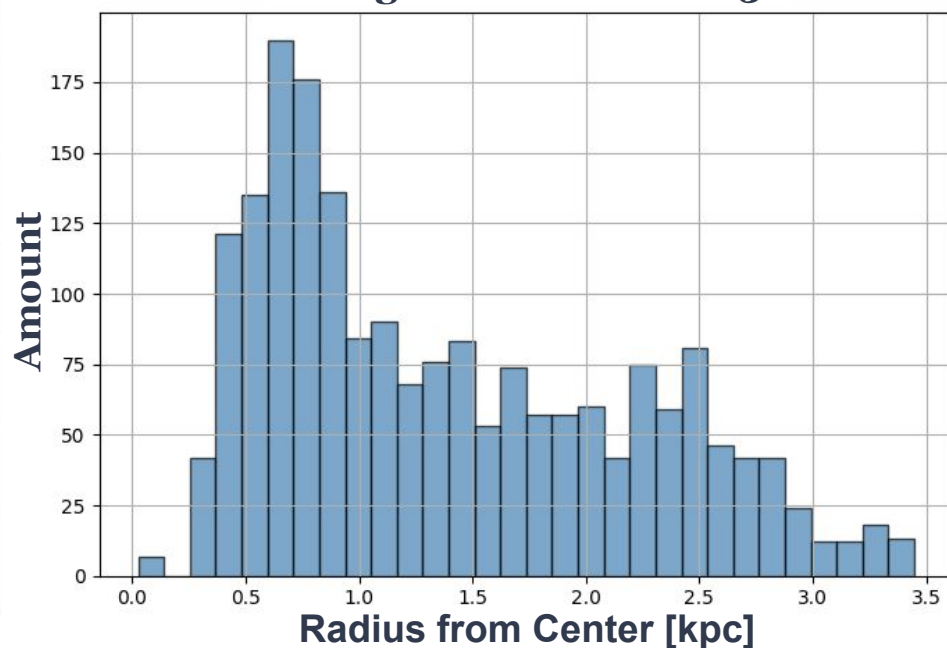
Data Processing: Velocity Distribution

Two main peaks → source of dataset

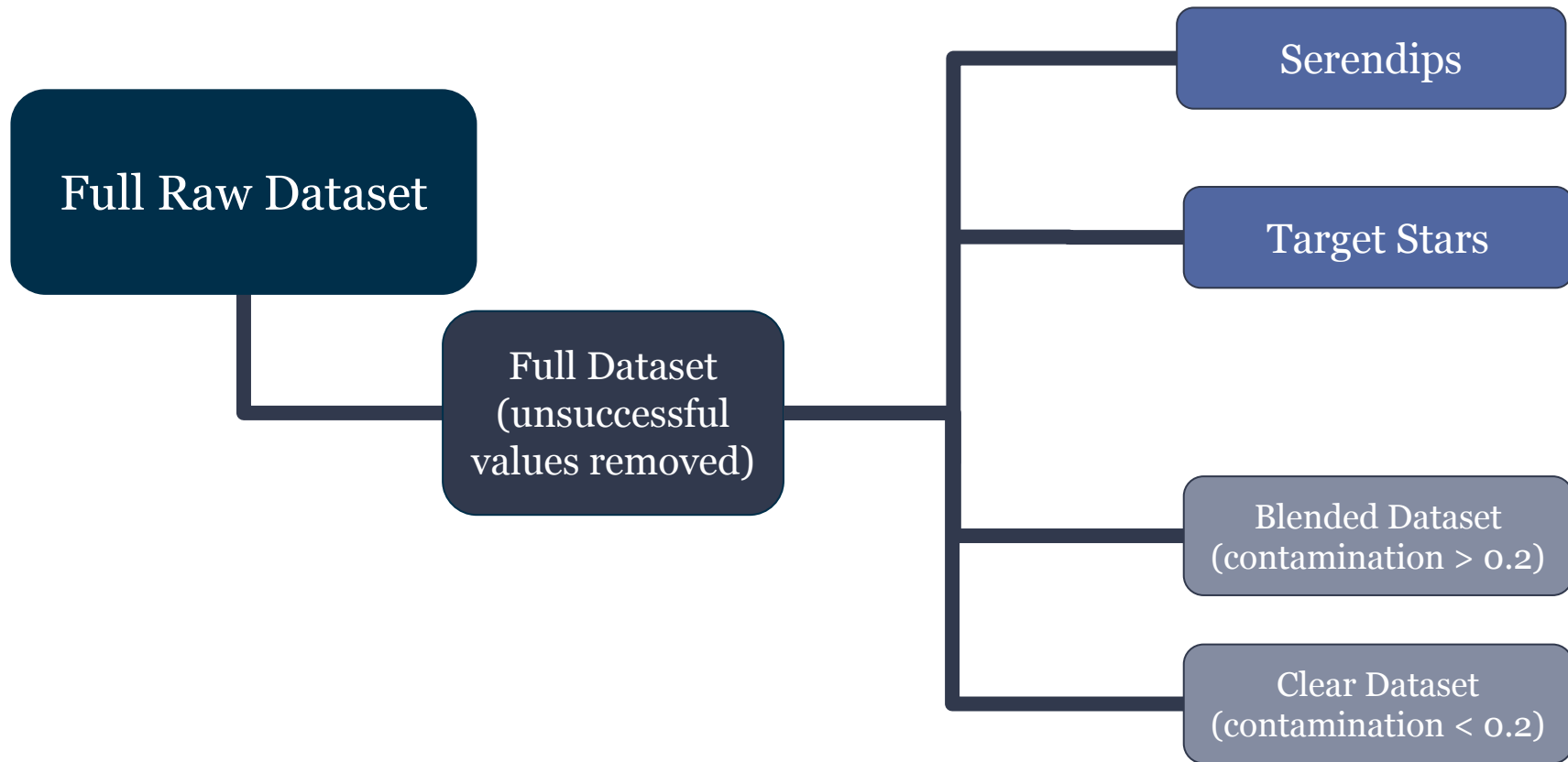
Histogram of Stellar Velocities



Histogram of Stars in M32



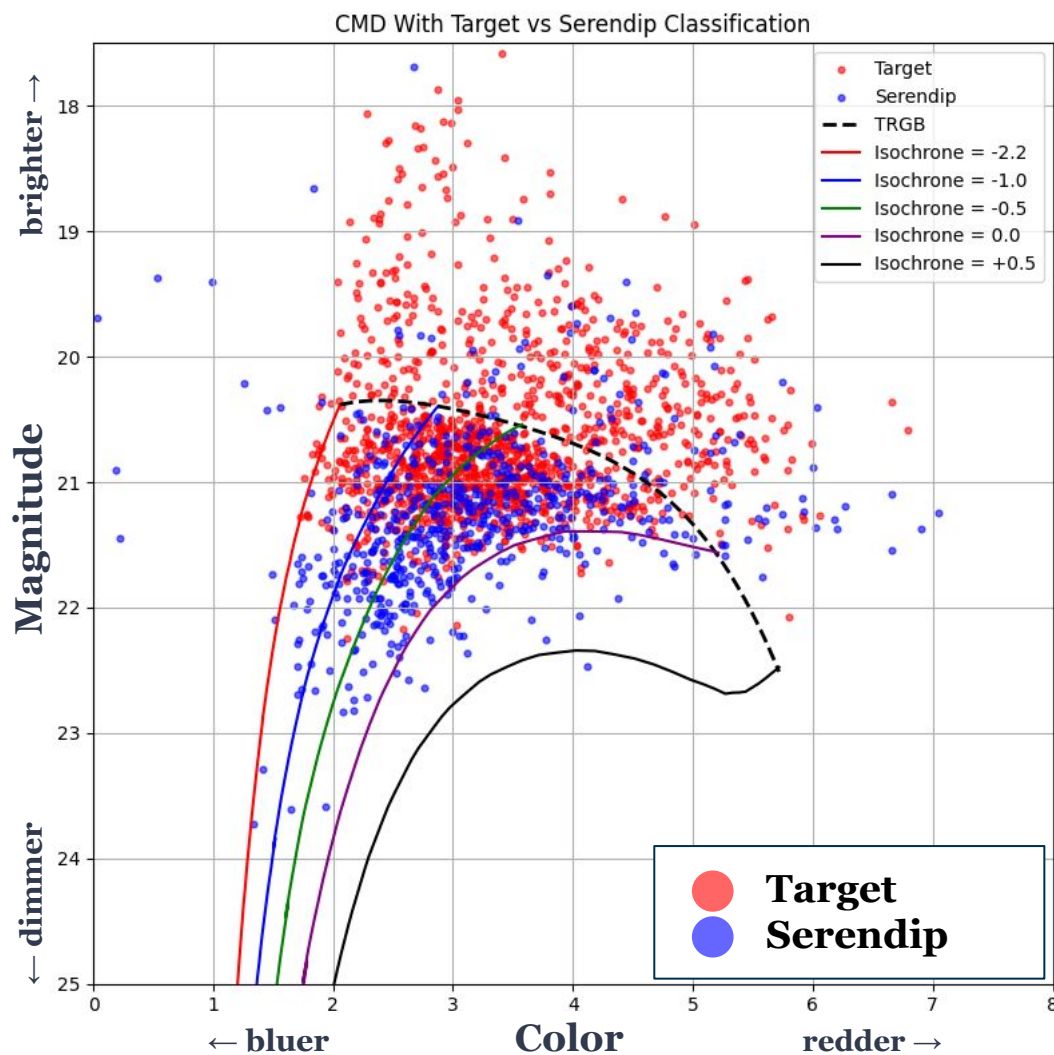
Sorting data



Color-Magnitude Diagram

Data Processing: Photometry from PHAST Catalog

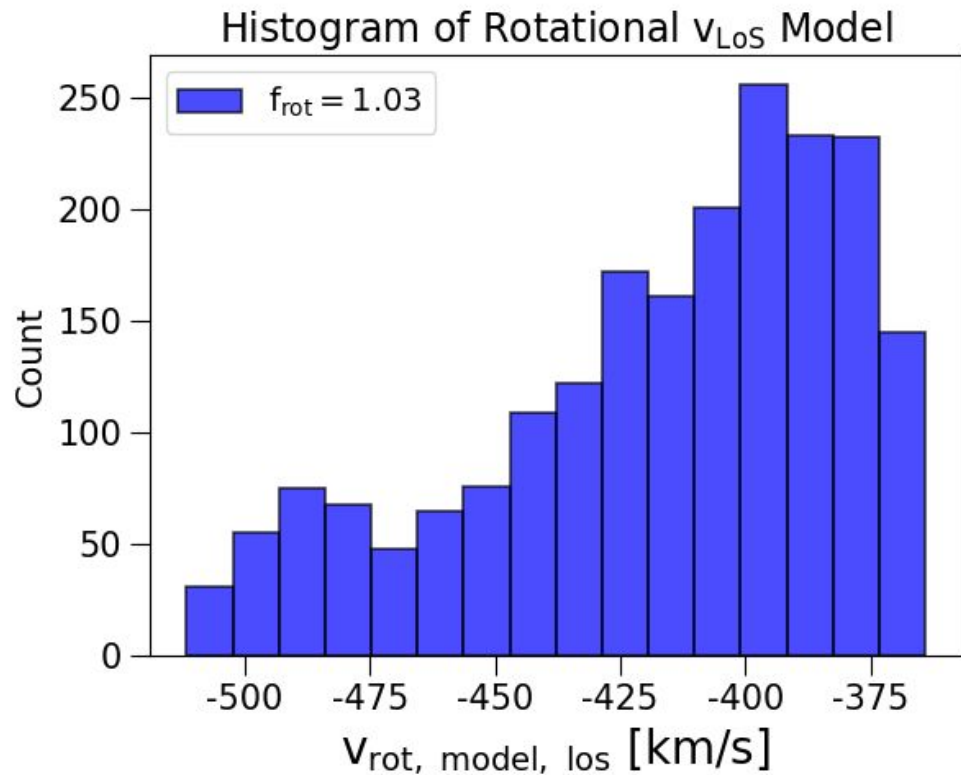
(data from AST-o8)



Kinematical Modeling

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

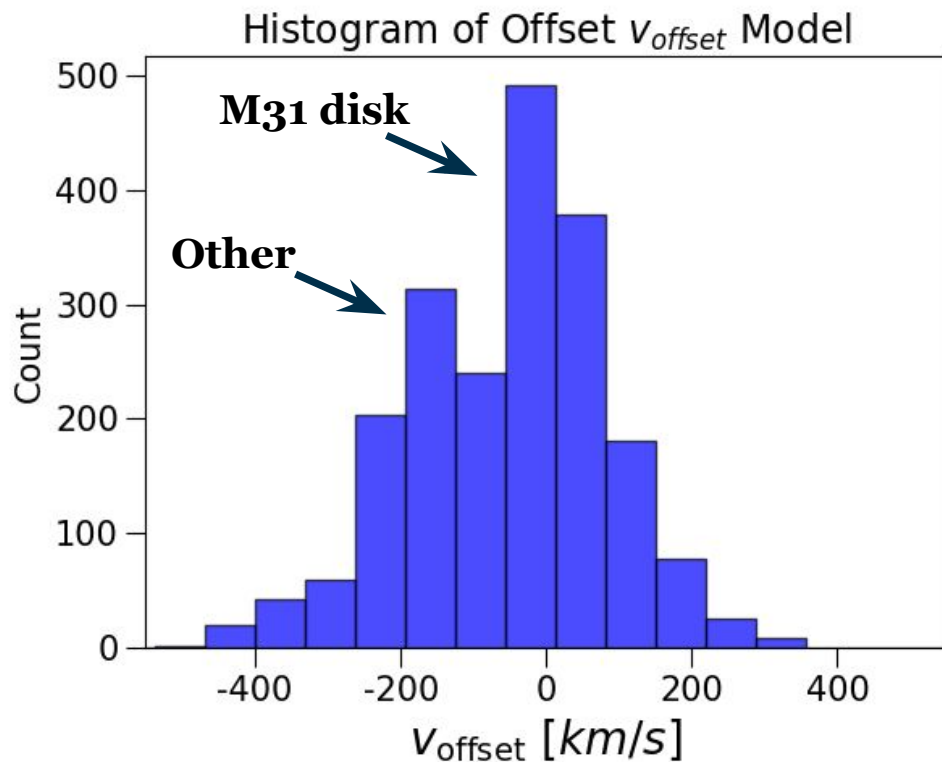
Modeled LoS velocity
of dataset sample
according to M31's HI
disk velocity



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

V_{offset} calculation with tilted HI disk model

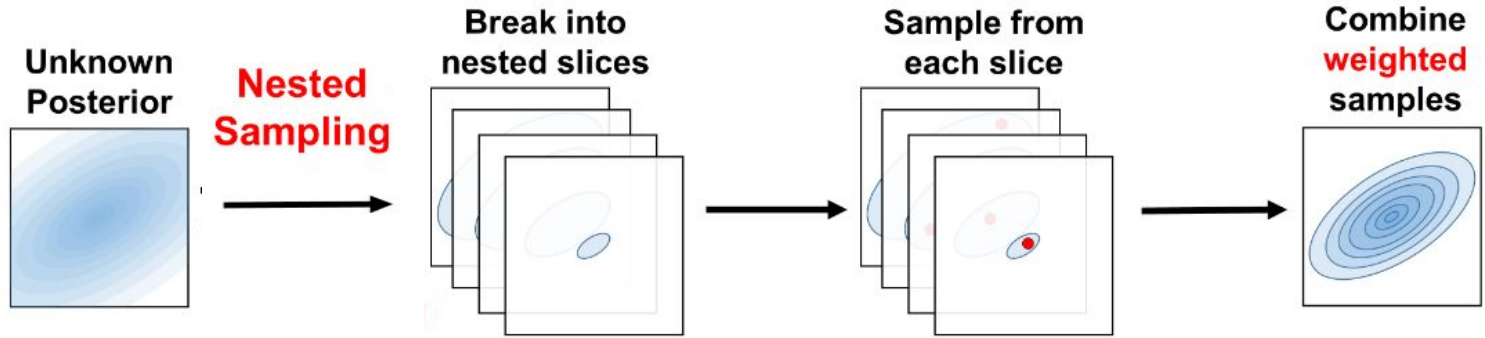
$$v_{\text{offset},j} = v_{\text{mod,los},j} - v_{\text{los},j}$$



Kinematical Modeling

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

DYNesty



- Tool used to estimate (fit) mathematical distributions of the dataset.
- Constructs **probability distributions** of each model parameter, 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

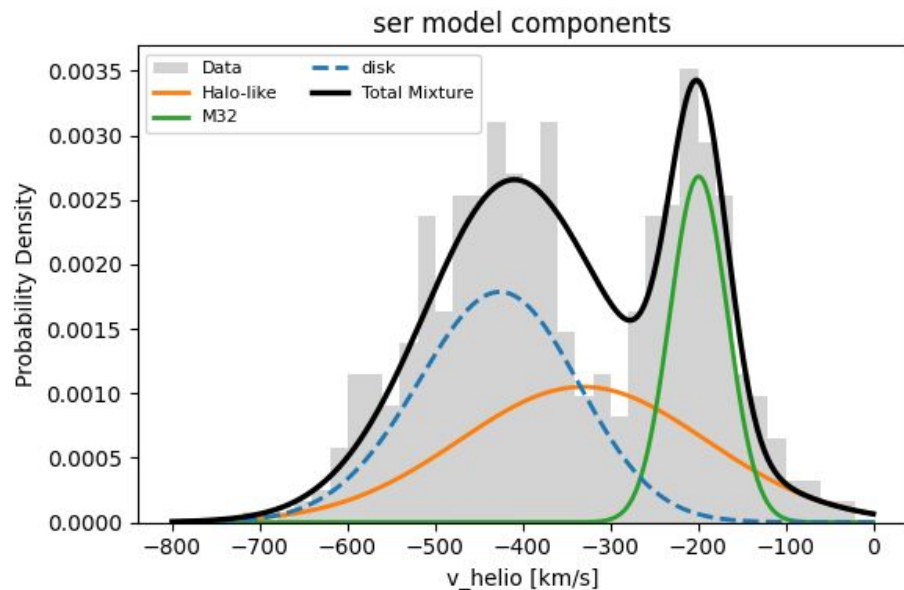
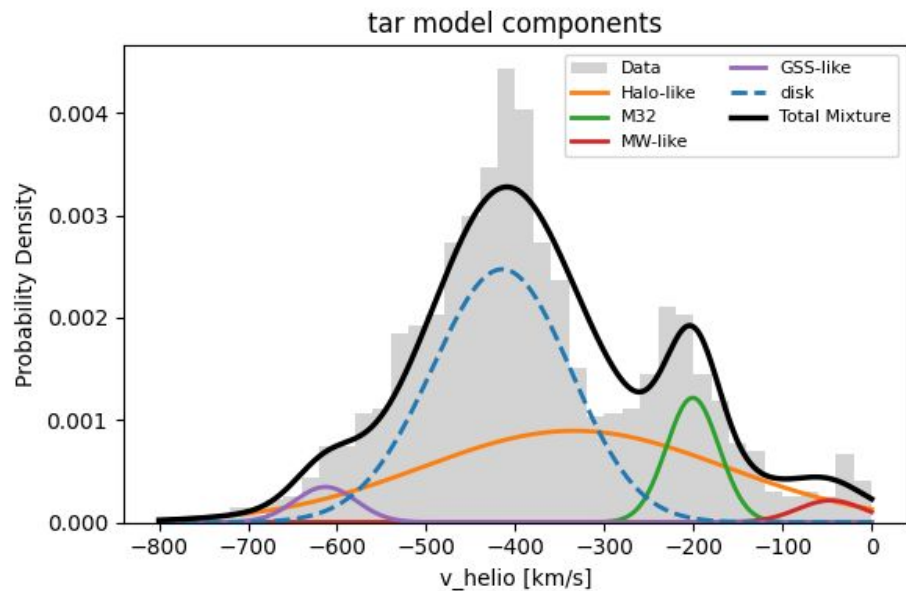
Sample	3-Component	4-Component (GSS)	4-Component (MW)	5-Component
All stars	-13071.187 +/- 0.164	-13070.868 +/- 0.198	-13068.743 +/- 0.205	-13068.633 +/- 0.262
Target	-9101.957 +/- 0.145	-9098.587 +/- 0.182	-9100.026 +/- 0.182	-8567.896 +/- 0.167
Serendips	-3955.529 +/- 0.105	-3959.815 +/- 0.123	-3956.990 +/- 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

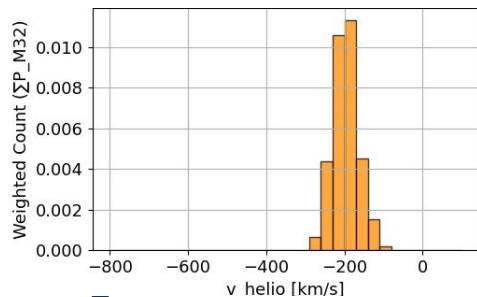
Model Comparison with the Optimized Parameters



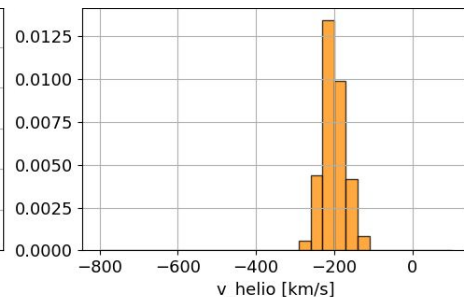
Notice how the serendip dataset seem to contain **more** M32 stars than the target sample group? (fraction almost **doubling**: 9% -> 22%)

P_{M32} -Weighted Histogram of Heliocentric Velocity

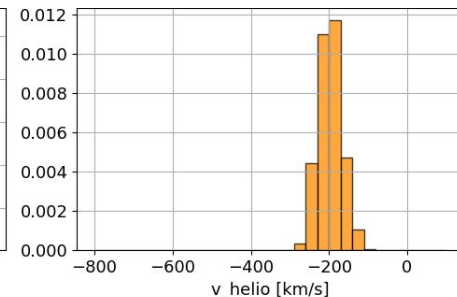
Background (N = 616)



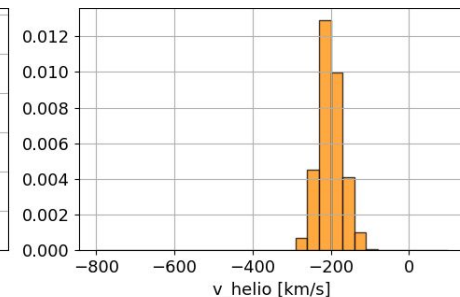
Target (N=1359)



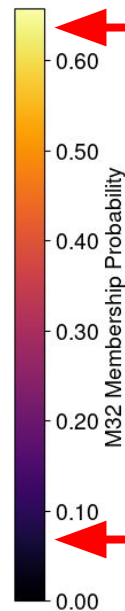
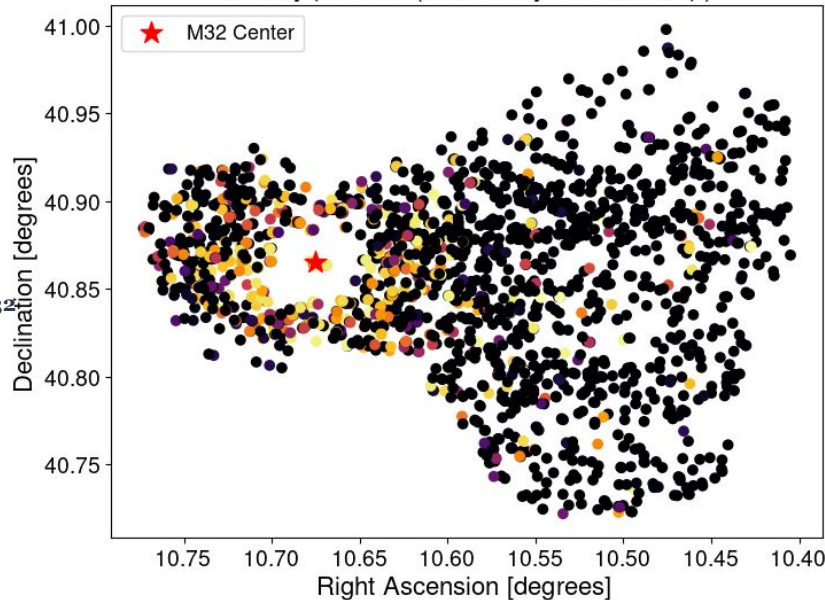
Clean (N=1553)



Blended (N=412)



On-sky position (colored by membership)



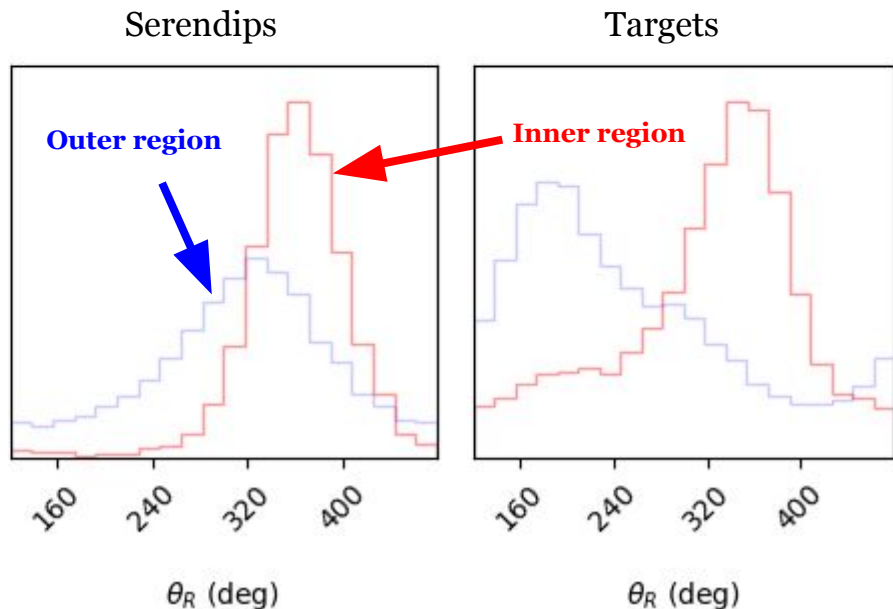
More likely to belong to M32

More likely to be from other sources

Visualization with P_{M32}

Future Work

Rotational Axis Estimation



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

Acknowledgements

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University of California, Santa Cruz

Max Kogan and his interns, AST-o8

References and Citations

[1]: [Westend61](#)

[2]: [LBL Cosmology \(Smoot\)](#)

[3]: [USRA/EPOD](#)

[4]: [DEIMOS/UCOLick](#)

[5]: [W. M. Keck Observatory](#)

[6]: [ESA/Hubble](#)

[Escala et al. \(2025\)](#), [Chemin et al. \(2009\)](#), [Speagle \(2020\)](#) and all citations that lie therein

Appendix

CMD plotting, isochrones

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

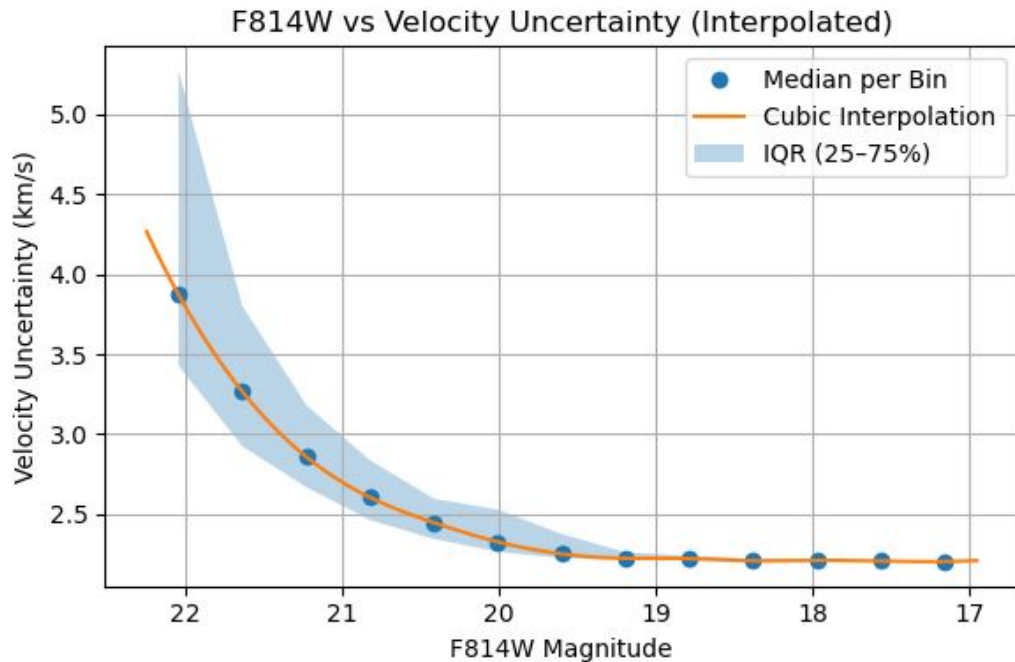
Add cmd 28 isochrones

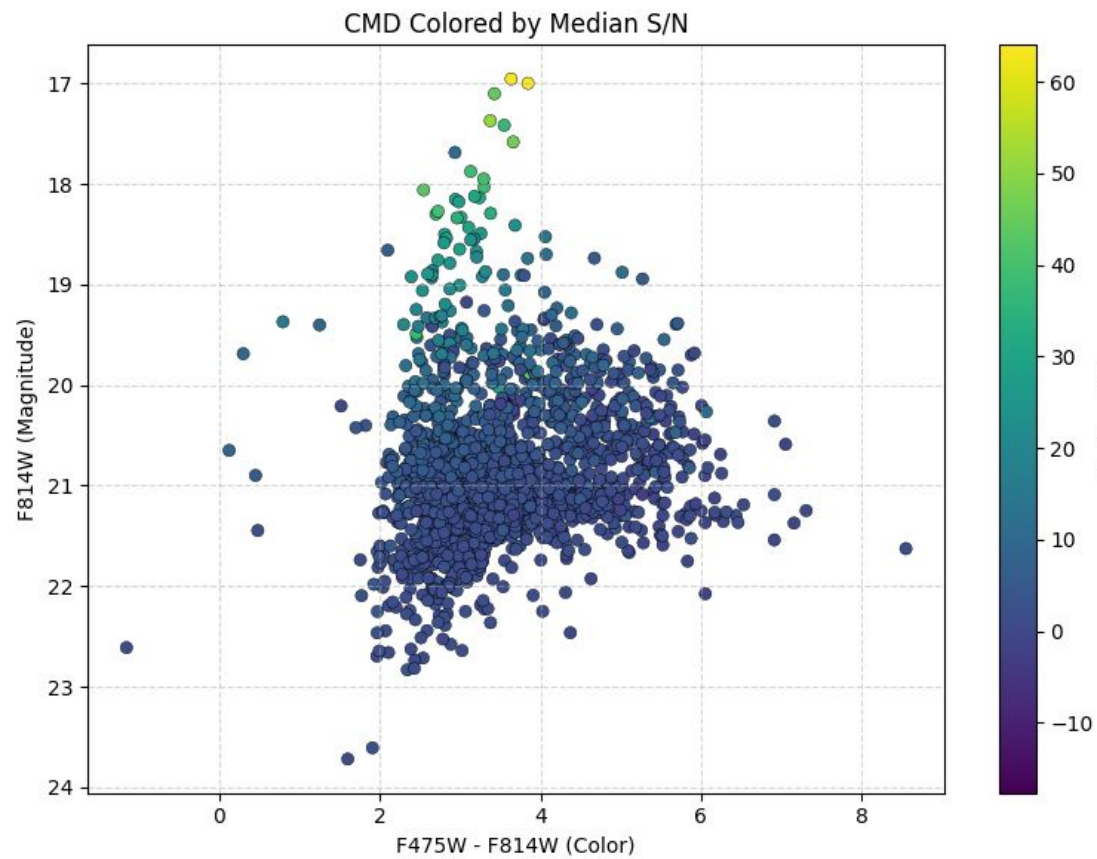
Isochrone generator link: <https://stev.oapd.inaf.it/cgi-bin/cmd>

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

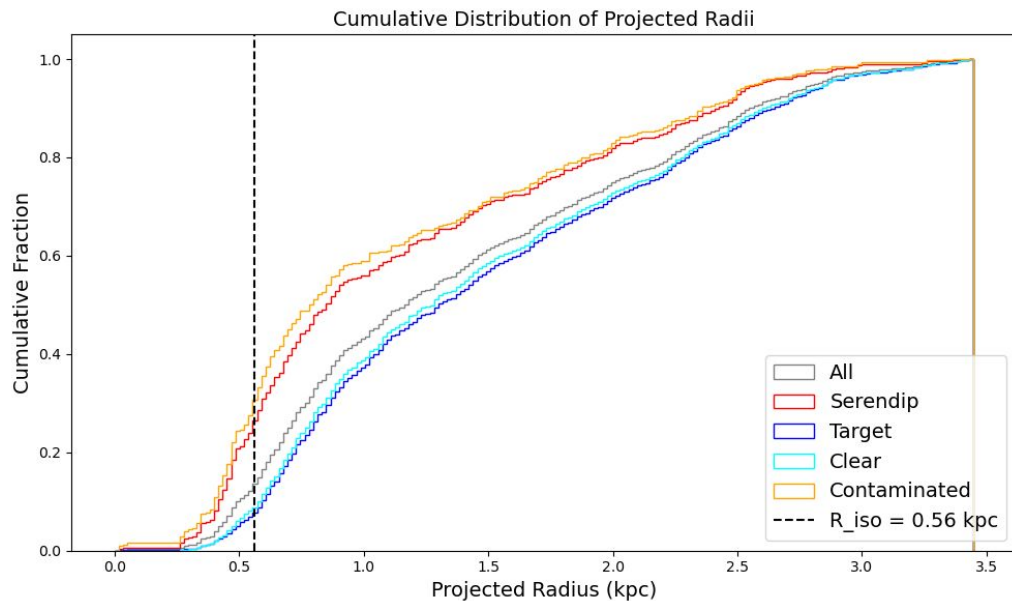
$$\begin{array}{c} \text{Posterior} \\ | \\ P(\Theta | \mathbf{D}, M) \end{array} = \frac{\begin{array}{c} \text{Likelihood} \\ | \\ P(\mathbf{D} | \Theta, M) \end{array} \begin{array}{c} \text{Prior} \\ | \\ P(\Theta | M) \end{array}}{\begin{array}{c} P(\mathbf{D} | M) \\ | \\ \text{Evidence} \end{array}} \equiv \frac{\mathcal{L}(\Theta) \pi(\Theta)}{Z}$$

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 $-\log(Z)$.

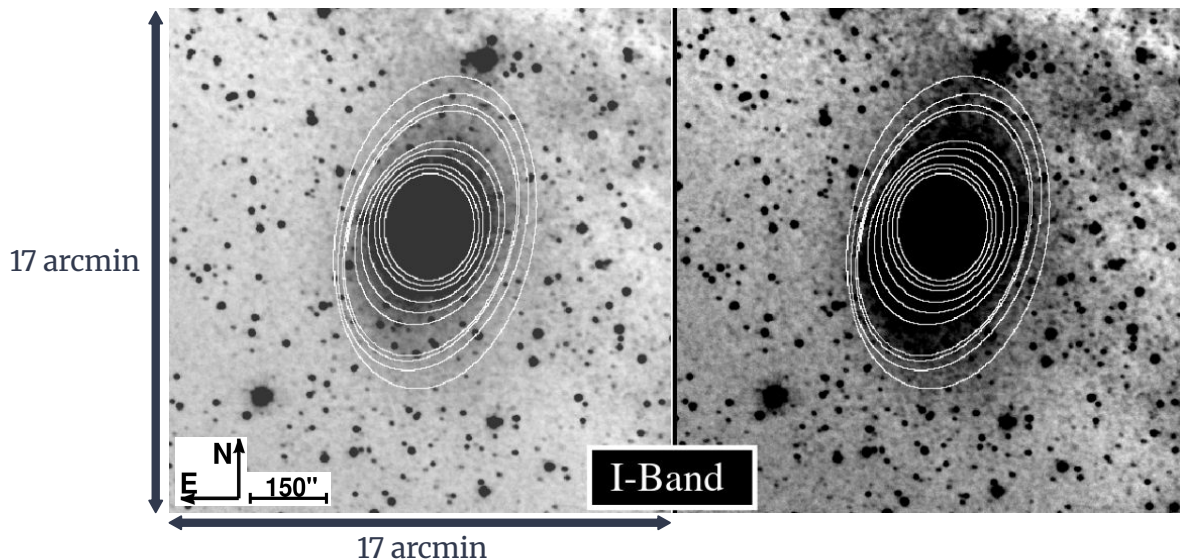
The DYNesty sampler was introduced by Joshua S. Speagle (CfA), in Speagle (2020)

Distribution of Stars



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

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} .