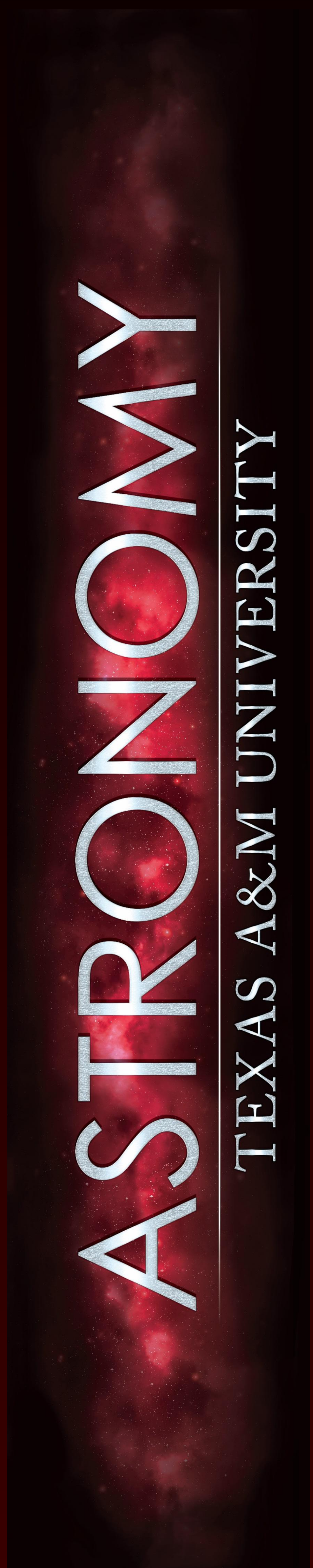
Exploring the Proper Motion of the Andromeda Galaxy with Gaia



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ABSTRACT

In this project, I explore the three-dimensional motion of the Andromeda Galaxy (M31). Using publicly available data from the Gaia space telescope, I focus on measuring M31's proper motion. My goal is to understand the methods and reasoning presented in the recent lecture and related research. I am working to replicate the source selection process to match previous research samples and gain a better understanding of M31's motion through the cosmos.

INTRODUCTION

The Andromeda Galaxy is the closest major galaxy to the Milky Way and is believed to be on a collision course with our galaxy. This is based on measurements from the Hubble Space Telescope (HST) back in 2012. Measuring M31's proper motion will help predict the future evolution of the Milky Way and the Local Group.

At M31's distance (~780 kpc), galaxies are expected to show tiny proper motions (~tens of μas/yr). Using Gaia EDR3, I study M31's motion relative to the celestial reference frame. By selecting red and blue stars in M31 and comparing them to background quasars and AGNs, I assess how systematics impact these measurements.

FINDING M31

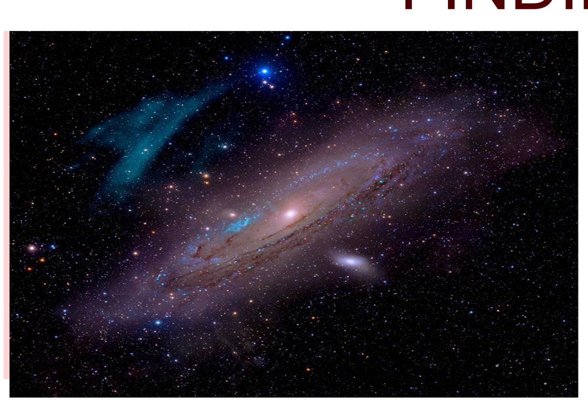

Figure 1. Optical image of the Andromeda Galaxy (M31). Image credit: Marcel Drechsler, Xavier Strottner, Yann Sainty, J. Sahner, and T. Kottary.

To identify stars belonging to M31, I began by selecting all Gaia sources within a 2° radius of M31's center (RA = 10.68°, Dec = 41.27°). A parallax distance cut corresponding to 10 kpc was applied to remove foreground stars located between the Milky Way and M31.

Next, I applied a CMD cut: $G > 16$ and $-1 < BP{-}RP < 4$, followed by color-excess cut to remove sources with poor BP/RP photometry. Then applied RUWE > 0.3, ipd_gof_harmonic_amplitude < 0.1, and ipd_frac_multi_peak < 2 to filter unreliable or binary sources. To isolate young blue stars: $BP{-}RP < 0.5$, $G < 20$. For red stars: $BP{-}RP > 1.6$, $G > -1.4(BP{-}RP) + 20.65$, $G < 20$.

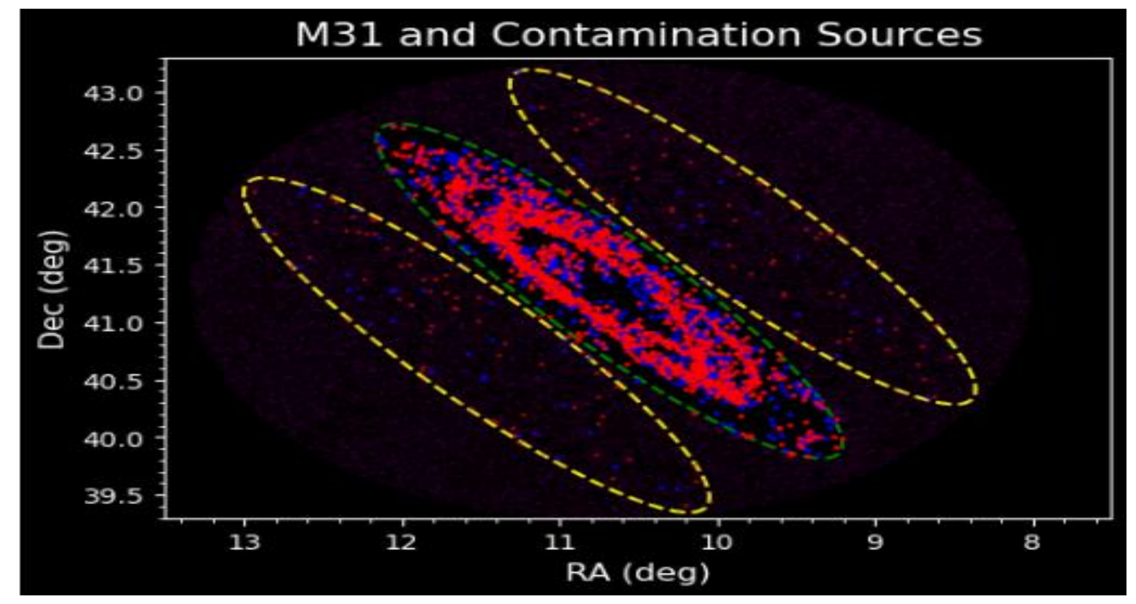

Figure 2. Sky view of three sections. The main green dashed ellipse is centered on M31, and the yellow dashed ellipses are used to estimate contamination from foreground stars. The red and blue dots represent sources that remain after all quality and selection cuts were applied.

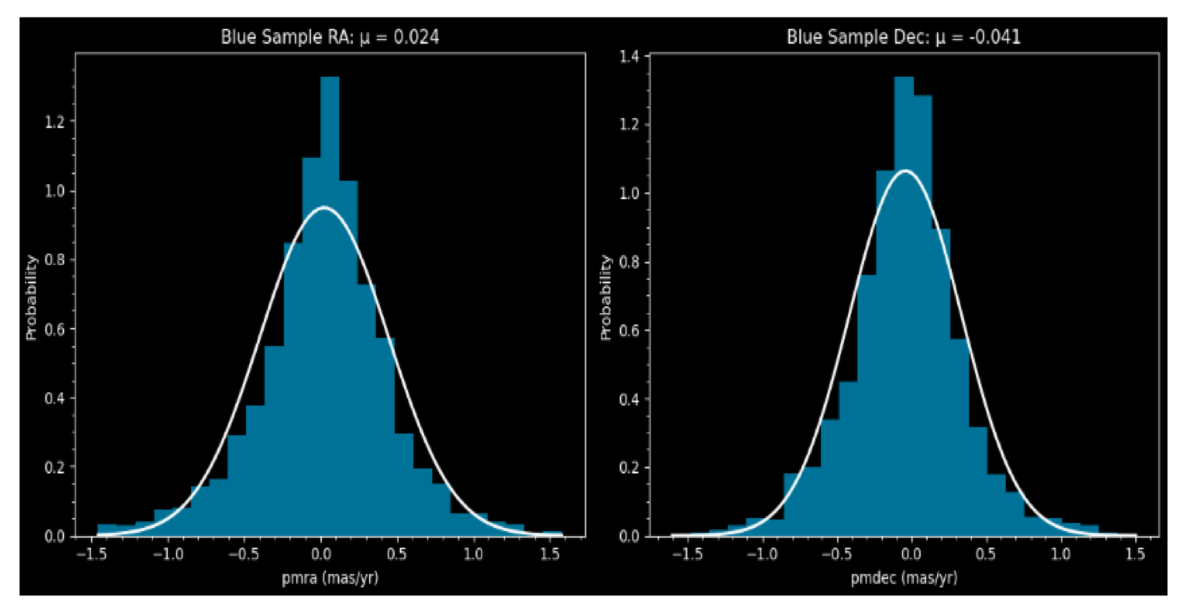

Figure 3. Gaussian fit to the proper motion in RA and Dec for the blue sources. The blue sample from within the main disk shows a roughly smooth distribution centered near zero. The final blue sample contains 1,905 sources.

A proper motion cut was applied to both the red and blue samples using the blue sample as the reference. The mean and standard deviation of the blue sample's proper motions were used to define the cut applied to both groups. $|\mu_\alpha - \mu_{blue,\alpha}| < 0.19 + 3\sigma_{\mu\_blue,\alpha}$ and $|\mu_\delta - \mu_{blue,\delta}| < 0.19 + 3\sigma_{\mu\_blue,\delta}$.

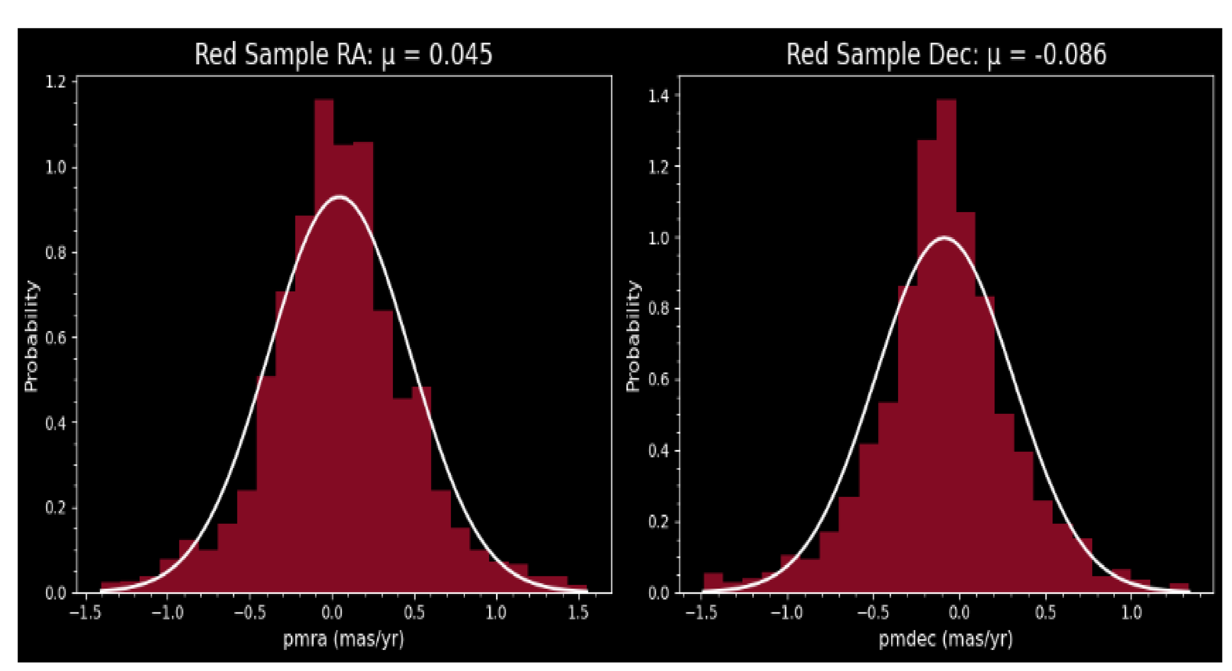

Figure 4. Gaussian fit to the proper motion in RA and Dec for the red sources. The red sample from within the main disk shows a roughly smooth distribution centered near zero. The final red sample contains 1,524 sources.

Celestial Reference Frame

Gaia's celestial reference frame is calibrated using quasars because they are bright, far away, and appear as point sources. Quasars are a type of AGN (active galactic nucleus), meaning they are powered by matter falling into a supermassive black hole at the center of a galaxy. This makes them extremely luminous and stable on the sky. This is perfect for defining a fixed background. Ideally, the mean proper motion of a quasar (μ_α, μ_δ) is 0 μam/yr.

Figure 5: Artist rendering of an active galactic nucleus (AGN) or quasar. *Image credit: NASA/ESA/CSA/Joseph Olmsted, STScI.*

From Gaia DR3, I selected sources flagged as quasars candidates and AGN's, then matched their source IDs to the EDR3 sample. This resulted in 13,100 AGN sources and 15,423 QSO candidates. The mean proper motion of the AGN sample was 0 μas/yr in RA and 0.001 μas/yr in Dec, while the QSO candidates had a mean of 0.001 μas/yr in RA and –0.003 μas/yr in Dec. These small but non-zero values suggest possible systematic error in the measurements.

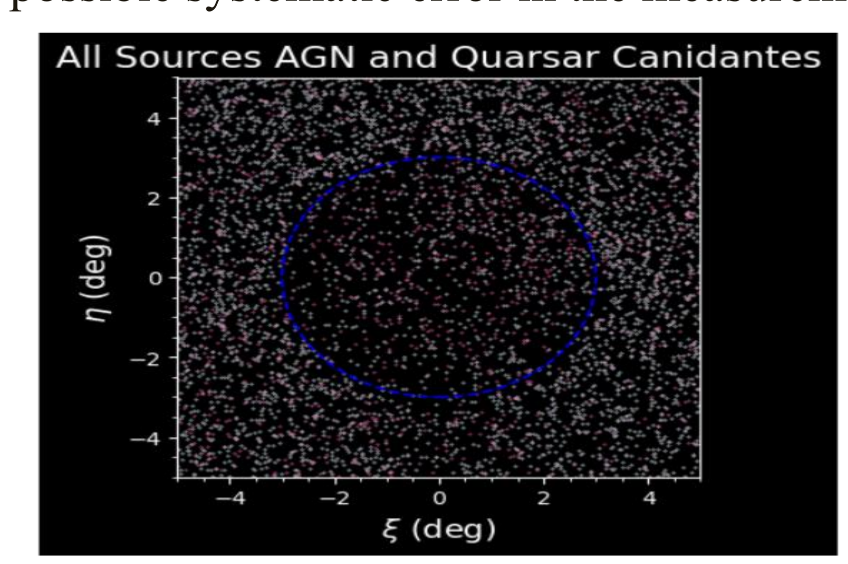

Figure 6. Positions of all AGN (green) and quasar (pink) candidates plotted on the sky around M31. These background sources help check for systematic uncertainties in the celestial reference frame CRF.

CONCLUSION

Using Gaia EDR3, I selected red and blue sources in M31 and compared their proper motions to background quasars and AGNs. Small but non-zero motions in the reference quasars suggest the presence of systematic uncertainties. My results are consistent with the low proper motion expected at M31's distance. I plan to continue working on this project by measuring the standard deviation to see how consistent my results are with those from other studies.

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