Investigating Anomalies in Astrometry of AGNs in *Gaia* Data

David Forester[1], Varoujan Gorjian[2], Lenee Mason[3], Michelle Riordan[4], Ben Senson[5], Dominic DeMatte[1], Rachel Susan[1], Scott Pickslay[1], Daniel Cazacu[1], Julia DeGuzman[1]

[1]Mission Vista High School, Oceanside, California
[2]Jet Propulsion Laboratory/Caltech, Pasadena, California
[3]Copiague Middle School, Copiague, New York
[4]Police Activities League of Egg Harbor Township & Atlantic County, Egg Harbor Township, New Jersey
[5]Madison Metropolitan School District Planetarium and Madison College, Madison, Wisconsin

Abstract

Gaia is an astrometric mission measuring the position of millions of objects in the sky. An active galactic nucleus (AGN) is one example of such objects, and some AGNs register as having parallax or proper motion. AGNs should not register parallax or proper motion as they are in other galaxies, and are therefore far too distant for us to detect their parallax or proper motion. The Wide-field Infrared Survey Explorer (WISE) is a mission that has repeatedly mapped the sky in infrared wavelengths, and cataloged three quarters of a billion objects, of which there are over 4 million AGNs, which allows us a much larger sample size than what *Gaia* has identified on its own.

Our team has cross-matched AGNs from WISE with sources in *Gaia* Data Release 3 (DR3) that have proper motion. With this larger catalog of anomalous targets, we have performed analysis to see if there are other unique characteristics or environmental factors that they tend to share in an effort to gain insight as to why these anomalous readings are happening. This includes cross-referencing them with optical sky surveys and other data sets.

Methods

Souchay et al. (2022) matched 592,809 sources from the LQAC-5 AGN catalog with *Gaia* Early Data Release 3 (EDR3) which led to 416,113 crossmatched celestial objects. Of these candidates, 41 AGNs with large proper motion (h >10 mas·yr-1) were identified.

Our team crossmatched identified AGNs from the WISE R90 catalog (Assef et al. 2018) with sources in *Gaia* DR3. This provided us with over a million objects. Of those we selected those with a proper motion in the DR3 data, and had a signal to noise ratio (SNR) of at least 3, we excluded those with SNR>5 due to a high proportion of stellar objects. We also excluded other objects based on other known anomalies such as the combined Moon-South Atlantic Anomaly, or excessive pixel density, often from diffraction spikes. This left us with 2,077 objects. We visually inspected over a thousand of them starting with the lowest SNR values and rejected 228 due to ambiguities.

Next, we analyzed the on-sky distribution of the various subsets of objects as well as color-color plots. We then cross-referenced our 773 accepted objects with SIMBAD and found that most with a match were identified as AGNs or quasars. Finally, we compared all subsets to a list of multiple and lensed quasars from Makarov and Secrest (2023).

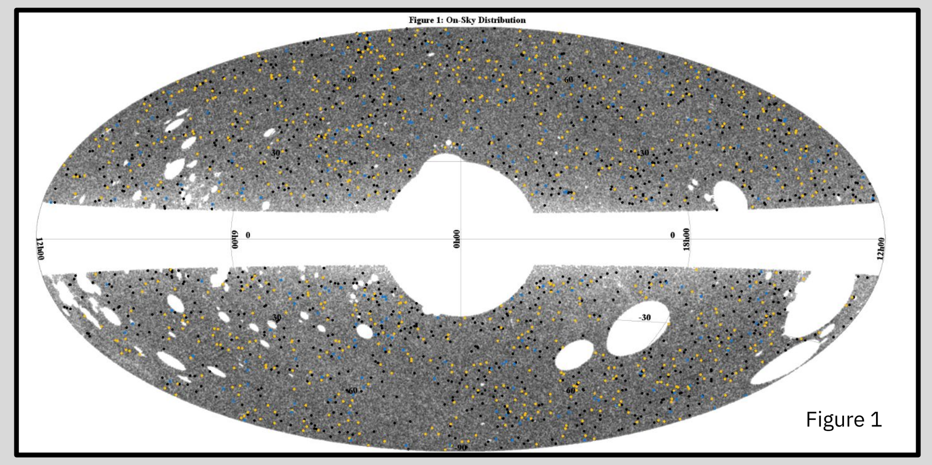

Figure 1

Legend

- WISE-*Gaia* AGN (1,058,417)
- AGN with proper motion (2,077)
- Accepted (773)
- Rejected (228)

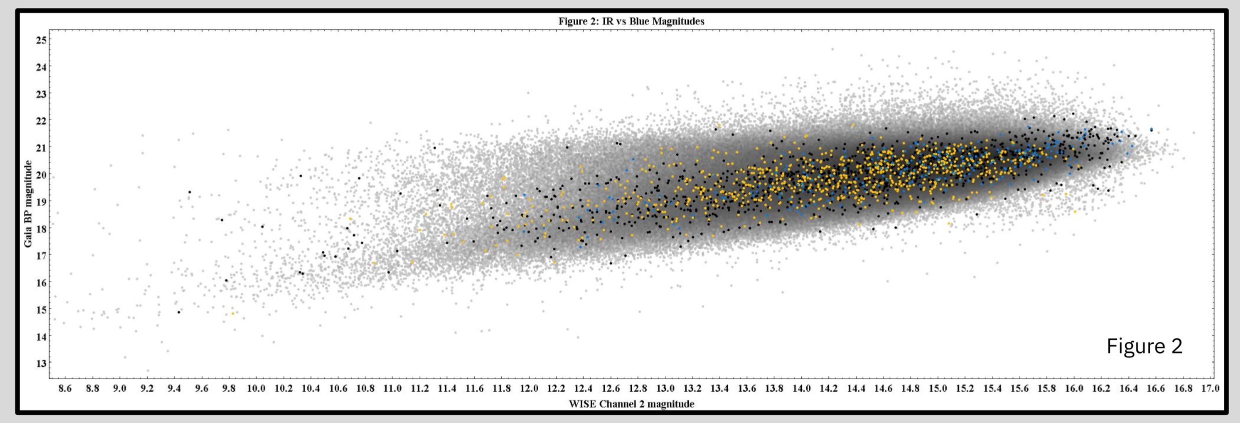

Figure 2

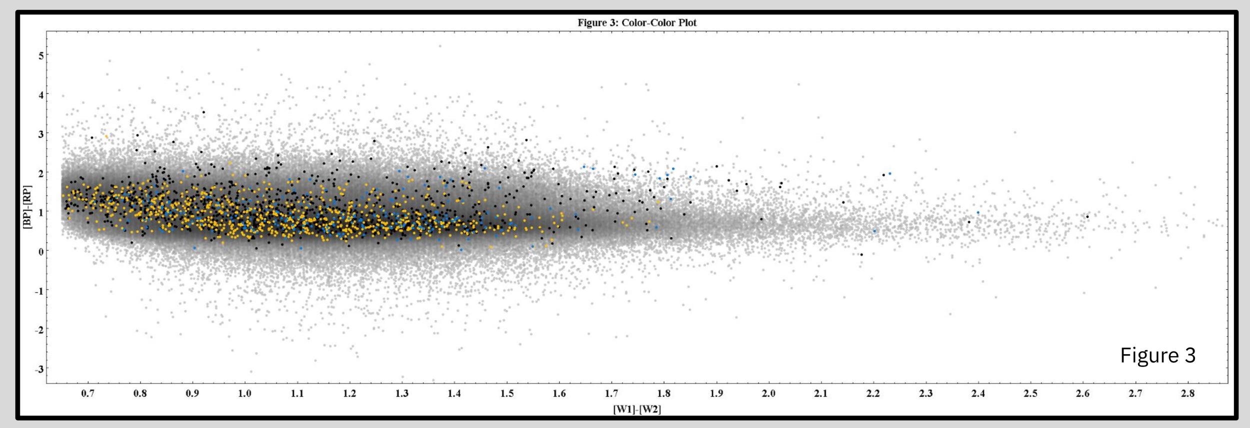

Figure 3

References

Assef, R. J., et al. "The WISE AGN Catalog." 2018 ApJS 234 2

Gaia Collaboration et al. 2016, The Gaia mission, A&A, 595, A1

Gaia Collaboration et al. 2023, Gaia DR3: Summary of the contents and survey properties, A&A, 674, A1

Makarov, V. V., & Secrest, N. J. 2022 ApJS 933 28

Makarov, V. V., & Secrest, N. J. 2023 ApJS 264 4

Souchay, J., et al. 2022, A&A, 660, A16

Wright, E., et al. 2010, "The Wide-field Infrared Survey Explorer (WISE): Mission Description and Initial On-orbit Performance" AJ, 140, 6

Acknowledgements

We gratefully acknowledge funding via NASA Astrophysics Data Analysis Program.

This research has made use of the NASA/IPAC Infrared Science Archive, which is funded by the National Aeronautics and Space Administration and operated by the California Institute of Technology.

This work has made use of data from the European Space Agency (ESA) mission *Gaia* (https://www.cosmos.esa.int/gaia), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement.

Introduction

Proper motion is an apparent change in position of an astronomical object due to that object actually moving through space laterally or vertically relative to our position (transverse motion) which is measured by its angular shift, in seconds of arc per year The further away an object is, the faster its transverse motion must be in order to have its proper motion detected by us over years or decades. Other limitations arise due to resolving power, or how well we can accurately distinguish between two very close points in the sky.

Our goal is to compile a catalog of as many AGN candidates as possible that have proper motion in *Gaia* Data Release 3 (DR3), so that we can do statistical analysis in order to draw meaningful conclusions about why there are so many AGN candidates that are registering proper motion.

Summary & Conclusions

We found the on-sky distribution of vetted AGN candidates with proper motion was consistent with the parent AGN data set (Fig. 1), as was a comparison of magnitudes in the WISE W2 and *Gaia* BP filters (Fig. 2), which ruled out dust extinction, and finally all color-color plots (Fig. 3) showed that our objects were well within the main distribution of the parent set.

When we looked up our accepted objects in SIMBAD, almost all of them that we found a match for were quasi-stellar objects, Seyferts, or other AGN related classifications. Only a small minority were stellar, even among those with the highest proper motions, suggesting that, in our selected sample, misidentification is not the primary cause of the abundance of AGN candidates with a proper motion measurement by *Gaia*.

Finally, when we crossmatched with a list of double AGN candidates, we found 2,242 matched with our 1 million objects which represents just over 0.212%. Out of our 2,077 selected objects, 101 matched (4.86%), 34 of those were in our accepted 773 objects (4.40%), while only 3 were found in rejected targets (1.32%). This included many with enough separation to be resolved. All of this suggests that multiple quasars may have some confounding effect on *Gaia's* ability to accurately measure proper motion similar to the finding of Makarov and Secrest (2022), and that our overall sample may include other as of yet unknown multiple or lensed quasars, though it remains to be seen at what proportion, and whether there are additional contributing factors to the misassignment of proper motion values.