Building a Catalog of AGN with Erroneous Parallaxes Using WISE and *Gaia*

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Abstract

Gaia is an impressively precise astrometric and photometric survey mission which has amassed data on millions of objects across the sky. Some of the objects are Active Galactic Nuclei, AGN, the luminous cores of galaxies where supermassive black holes are found. Gaia has determined a nonzero parallax for many AGN; these determinations are known to be incorrect due to the vast distances at which AGN are found. We used ~4.5M AGN identified (90% reliability) in the Wide-field Infrared Survey Explorer (WISE) catalog (Assef et al, 2018) and cross-referenced them with *Gaia* DR3, resulting in 2,581 AGN with nonzero parallaxes (S/N≥3). We then visually inspected 728 of them using the Digitized Sky Survey (DSS), Sloan Digital Sky Survey (SDSS), Two Micron All Sky Survey (2MASS), Spitzer Enhanced Imaging Products (SEIP), and WISE catalogs to determine environmental or other factors which could lead to nonzero measurements of parallax. We have constructed a catalog of these AGN with incorrectly measured parallaxes which our analyses showed did not have potentially confounding sources nearby. This catalog should provide a new resource for locating potentially interesting or unusual AGN or issues with *Gaia*'s parallax determinations.

Introduction

Proper motion and parallax measurements from the European Space Agency's *Gaia* mission yield some unexpected results where known quasars have measurable proper motions (Souchay et al, 2022). These *Gaia* results are unexpected since only objects within or very near to our galaxy (a few hundred thousand light years) should exhibit a measurable proper motion or parallax during the five-year time frame of *Gaia*'s measurements thus far.

Souchay et al. looked at a subsample of 416,113 objects in the Large Quasar Astrometric Catalogue-5 and identified 41 objects, which exhibited proper motion and are located outside of the Milky Way Galaxy.

The goal of this research project is to compile a list of AGN categorized as having significant parallaxes and cross reference these sources to other AGN characteristics in order to draw conclusions as to what about these particular AGN misled the *Gaia* pipeline into reporting parallaxes when none exist. This analysis may provide a new method by which this unusual subset of AGN could be identified.

Methods & Results

To investigate these AGN candidates, we visually inspected 723 sources. Team members rated each source 1 to 5 based on the presence of confounding environmental factors. Our scale used 5 for the sources with the highest likelihood of being AGN and 1 for with major environmental concerns. We then averaged 15 team members' ratings and produced histograms of these averages, seen as Figure 3. Analysis of the histograms indicates that *Gaia*'s parallax determinations are not confounded by environmental factors for the 419 spectroscopically qualified AGN. The average viability rating is noticeably lower for our set of 304 non-spectroscopically determined AGN candidates that had a similar range of parallaxes to the set of 419 AGN. The known presence of potentially confounding stellar sources would be a possible explanation for the apparent viability shift considering stellar sources are known to be approximately 10% of the WISE R90 catalog.

For the set of 419 AGN, 4% of the sources had a viability rating below a 3 on our scale. This would suggest that approximately 400 of the 419 are reliably AGN with a significant parallax measurement. Approximately 78% of the 304 AGN candidates had a viability rating greater than 3 on our scale. This translates into another 238 objects that are reliably AGN with a significant parallax measurement. There are still 1,858 sources within the original sample of 2,581 AGN candidates that require further analysis. The shift in viability ratings from the 419 to the 304 suggests that spectroscopic confirmation of AGNs should be utilized when trying to ascertain the origin of *Gaia*'s parallax measurements of AGN.
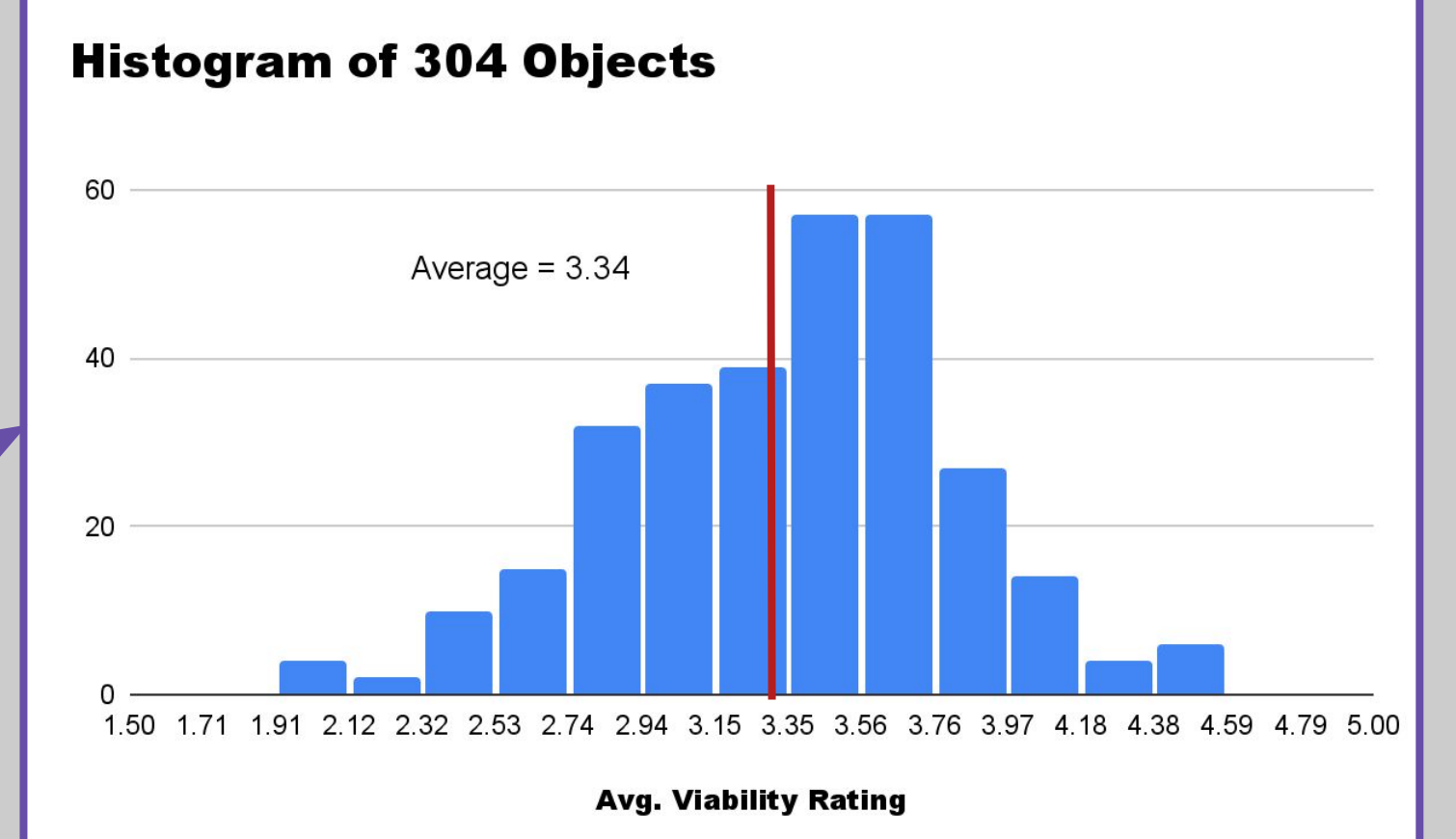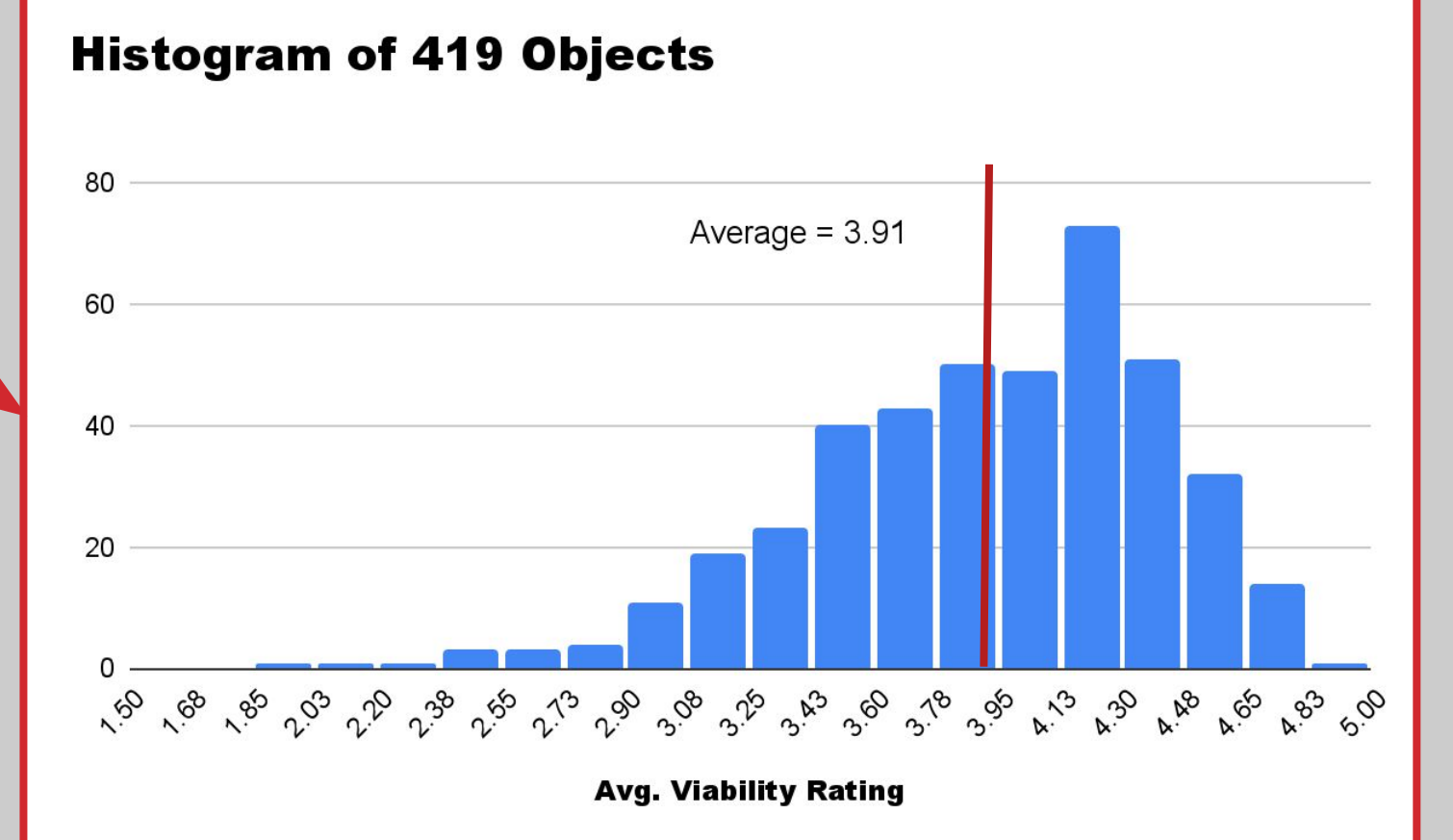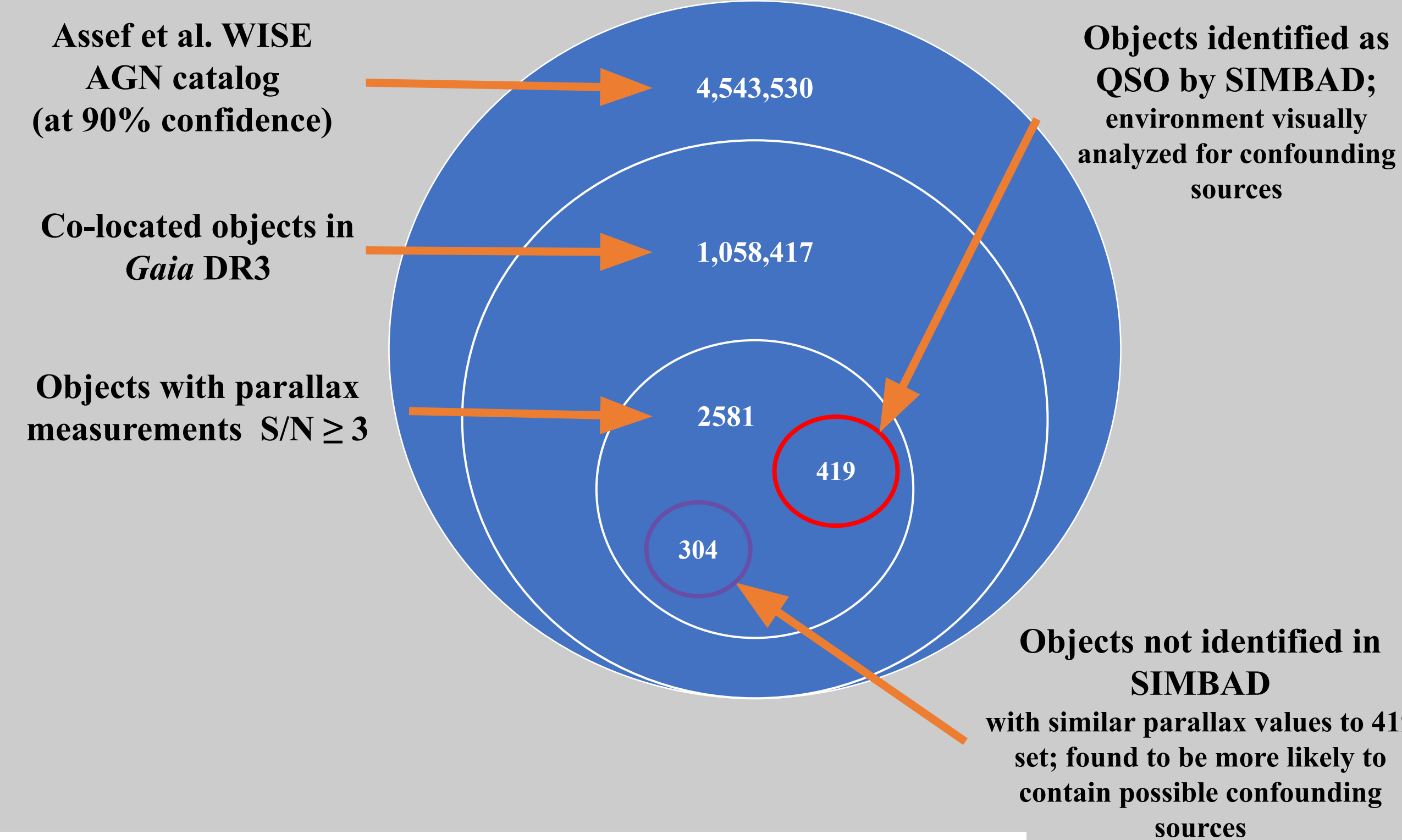
Methodology

Assef et al. WISE AGN catalog (at 90% confidence) → 4,543,530

Co-located objects in *Gaia* DR3 → 1,058,417

Objects with parallax measurements S/N ≥ 3 → 2581

419 — Objects identified as QSO by SIMBAD; environment visually analyzed for confounding sources

304 — Objects not identified in SIMBAD with similar parallax values to 419 set; found to be more likely to contain possible confounding sources

Histogram of 419 Objects
Average = 3.91

Histogram of 304 Objects
Average = 3.34

Figure 3. Histograms of average viability rating for *Gaia* sources with parallax S/N ≥ 3 and identified as AGN candidates by WISE. Both samples have a similar range of parallax measurements. *Top*: 419 AGN with spectroscopic identification in SIMBAD. *Bottom*: 304 AGN candidates not identified in SIMBAD as AGN.
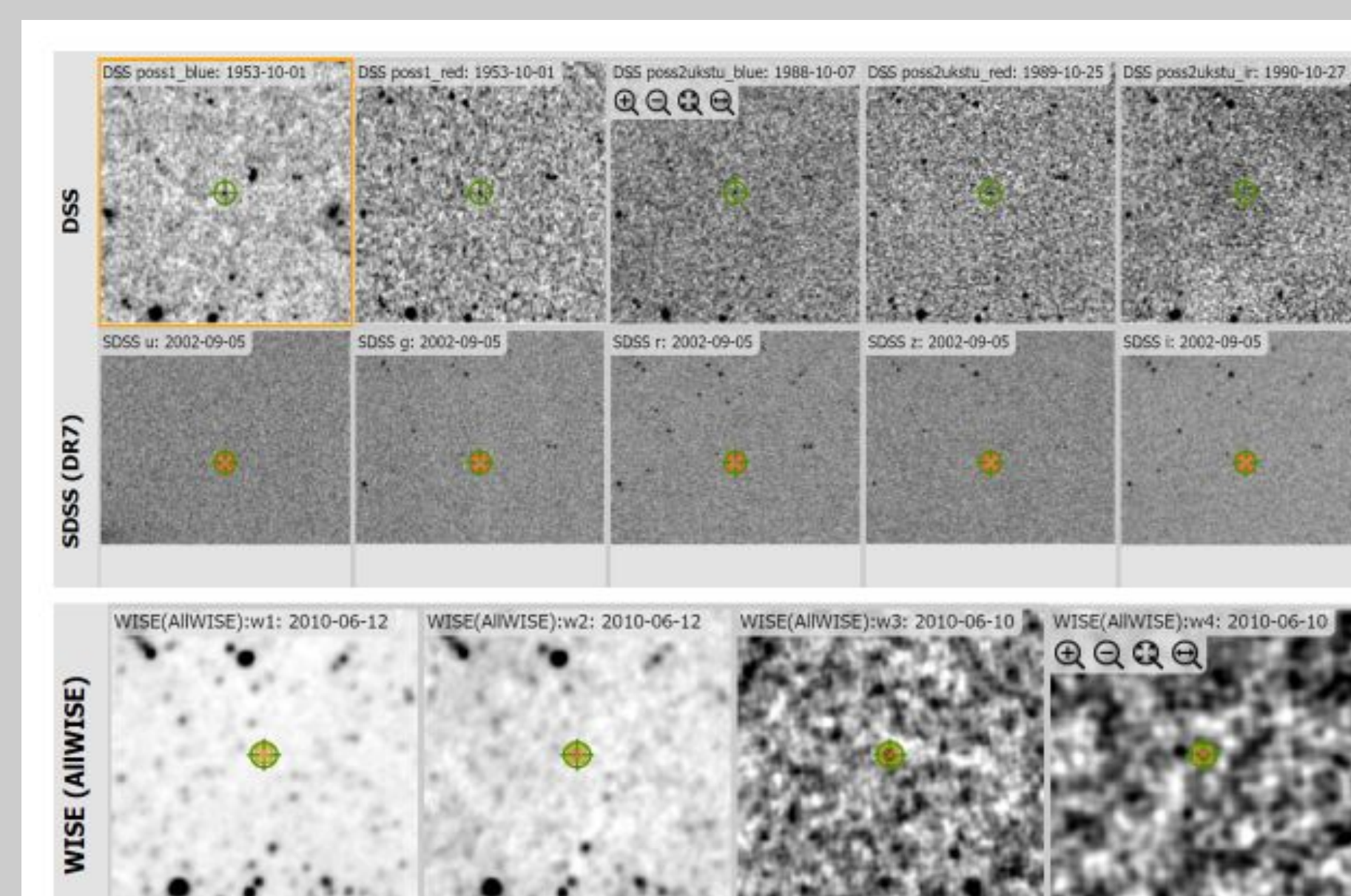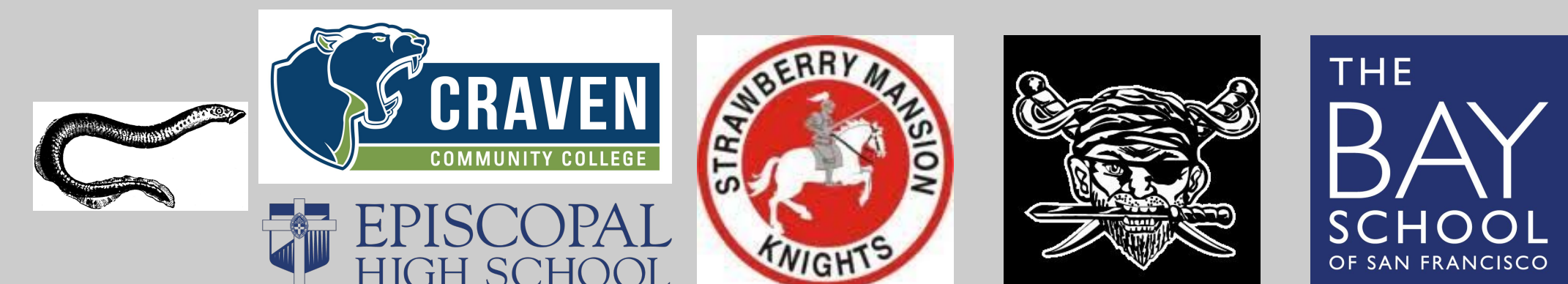

Figure 1. IRSA images of **J231029.77+002600.6**, a high rated source; rating: 4.47. Selected region is not overcrowded with sources in optical or IR and there are no nearby bright stars.
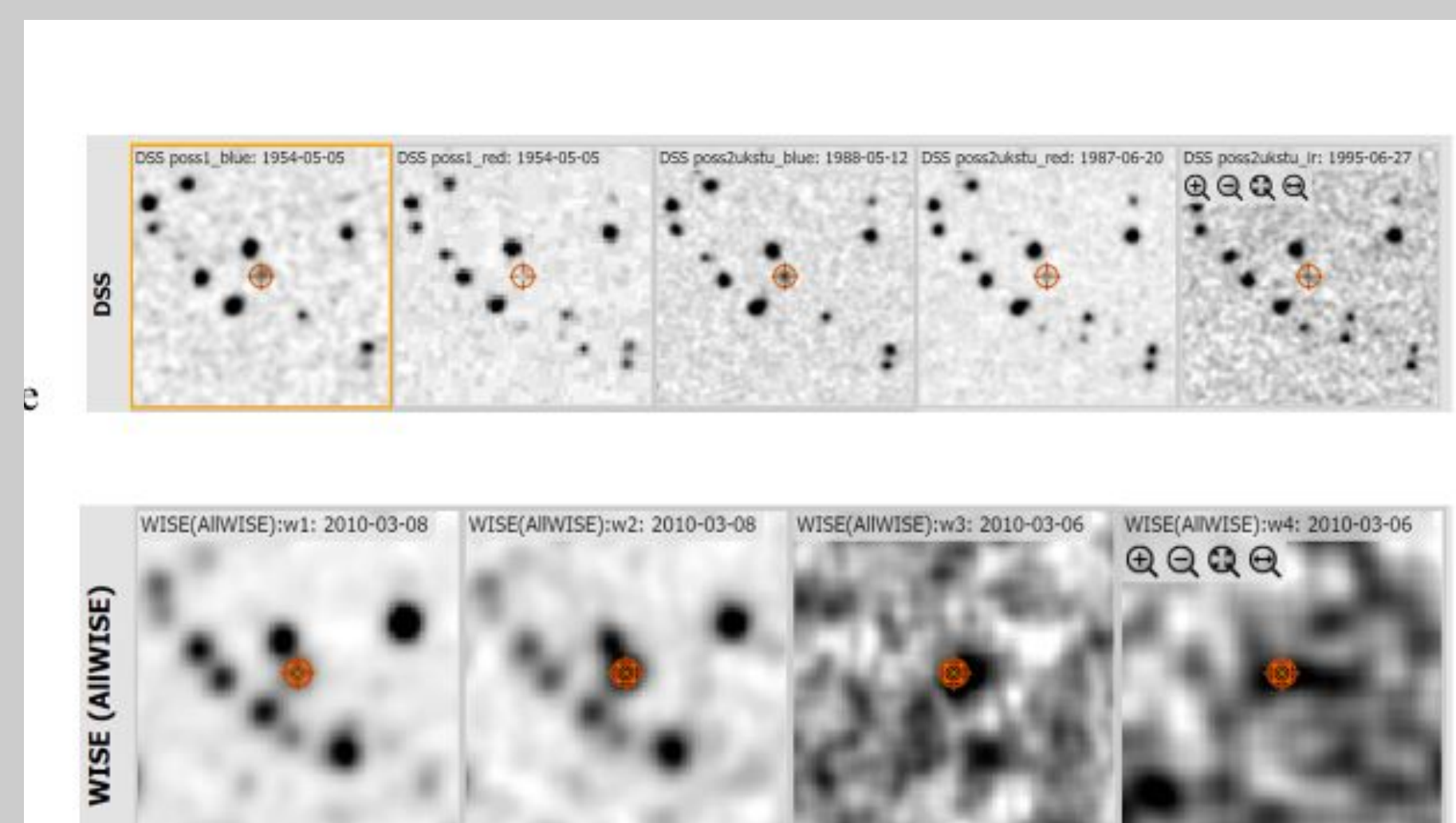

Figure 2. IRSA images of **J170641.12+025832.1**, a low rated source; rating: 2.07. Selected region in crowded with both optical and IR sources and the target appears to grow brighter in longer IR.

Summary & Conclusions

Out of the 1 million AGN identified by WISE and measured by *Gaia*, we found that 2,581 AGN candidates have a *Gaia* parallax with a SNR of ≥3. Out of those, 419 have been spectroscopically verified as AGN and our analysis found no confounding environmental factors for why *Gaia* assigned parallaxes. In addition, 238 out of 304 non-spectroscopically qualified AGN have no confounding environmental factors and high viability ratings. These 2,581 sources and subsets need to be analyzed further to determine why *Gaia* assigned high signal to noise ratio parallaxes to sources that should not have a parallax.

References

Souchay, J., et al. "Quasars with Large Proper Motions: A Selection from the LQAC-5 Catalog Combined with Gaia EDR3-Focusing on Astrometric and Photometric Properties." Astronomy & Astrophysics. 660 (2022): A16.

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