

Statistical analysis of observatory performances



Introduction

We present a preliminary statistical analysis of astrometric post-fit residuals based on a dataset of observations of more than 260,000 numbered minor planet submitted to the Minor Planet Center (MPC).

This study focuses on evaluating the performance of the most active surveys contributing to the MPC.

The precision of astrometric measurements depends on various factors, including the observation epoch, apparent magnitude, choice of reference star catalog, the target's rate of motion, and specific characteristics of the observational survey. For example, although widely acknowledged, it has not yet been rigorously demonstrated that adopting a more accurate stellar catalog, such as Gaia DR3 [1], directly improves observational performance.

Our goal is to analyze the performance of all known observatories listed at <https://minorplanetcenter.net/iau/lists/ObsCodesF.html>, focusing on the post-fit astrometric residuals, which are the difference between observed and computed sky positions—based on a computed orbit.

The analysis represents the first step to create a new reliable weighting scheme [2, 3], which is key to improve the accuracy of the orbit catalog and reduce the need of manual intervention on orbit-computers.

Methodology

Advances in observational methods, from visual and photographic techniques to modern CCD-based surveys, have significantly increased both the volume and quality of asteroid astrometry.

This study presents the results obtained analyzing the residuals of astrometric data for **numbered minor planets**, as archived by the Minor Planet Center (MPC), the international authority responsible for small body observations and orbit data (<https://minorplanetcenter.net/>). The dataset used for this study contains over **215 million astrometric measurements** spanning multiple decades. As shown in Figure 1, the majority of the observations originate from modern wide-field surveys such as Pan-STARRS, ATLAS, and the Catalina Sky Survey.

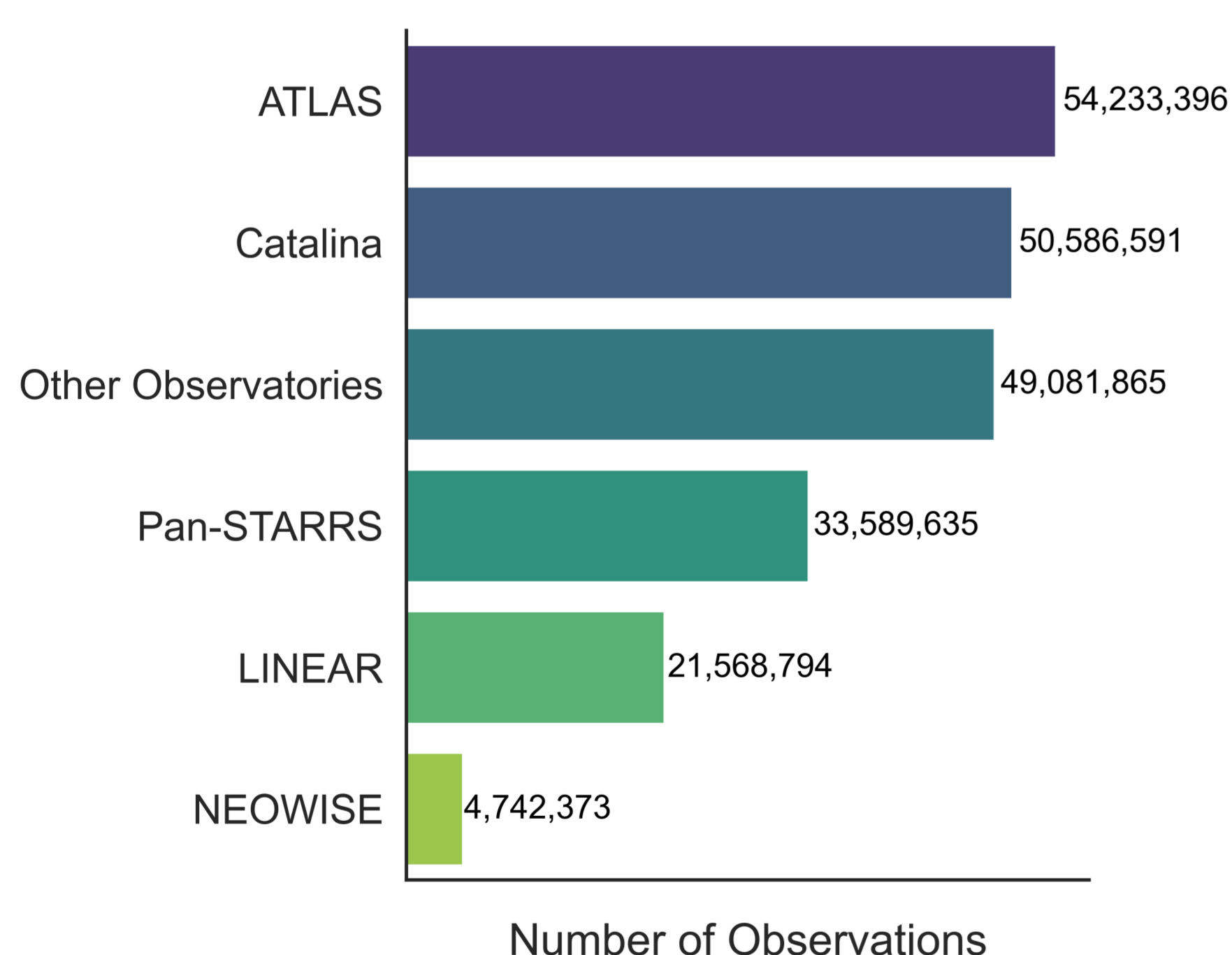


Figure 1. Number of astrometric observations by survey (numbered objects only) used for this study. Data: MPC (<https://minorplanetcenter.net/data>).

We use *post-fit astrometric residuals*, the difference between observed and computed sky positions—based on orbits computed with the `OrbFit` package. We discarded the observations rejected by the fit and we only considered the observations accepted in the final orbit solutions. We examined the residuals as functions of observatory code, epoch, and stellar catalog to analyze the performance of the large surveys. As part of the analysis, we are also able to identify systematic biases and instrument-specific effects.

Results

Here we present results for a few selected surveys. Figure 2 shows the post-fit astrometric residuals as a function of observation epoch for two large surveys: the result is based on more than 10 million measurements from one of the Pan-STARRS telescopes and over 240,000 from NEOWISE.

Pan-STARRS (F52) is a 1.8-meter ground-based optical telescope with a 7 deg² field of view and 1.1" resolution. A stable pipeline enables sub-arcsecond astrometric accuracy. NEOWISE (C51), in contrast is a 40-cm space-based infrared telescope with a ~0.78 deg² field of view and 6.1" resolution. Despite being above the atmosphere, its lower resolution limits its astrometric precision, therefore residuals are larger than as the ones in F52. In addition, we were able to notice a systematic bias in the declination residuals for NEOWISE, which is still to be understood.

Moreover, we investigated astrometric residuals in right ascension and declination for the F51 Pan-STARRS telescope, based on over 23 million observations of 272,747 unique numbered objects. These measurements were reduced using 12 different stellar catalogs over the years. This is a common feature among observatories that tend to use the most up-to-date and accurate stellar catalogs. Figure 3 presents the distribution of post-fit residuals across all catalogs used in F51 data. The dataset is dominated by reductions employing the 2MASS catalog (over 11 million observations) and multiple Gaia data releases (over 12 million observations). As expected, Gaia-based reductions, particularly those using Gaia EDR3 [1], result in significantly improved residual statistics, with reduced scatter, fewer outliers, and notably smaller systematic biases compared to reductions using other catalogs.

Figure 4 focuses on the five most frequently used catalogs, illustrating the temporal evolution of their residual distributions. The impact of Gaia EDR3 is especially evident, with consistently lower residuals and improved stability over time, underscoring its value for high-precision astrometric reductions.

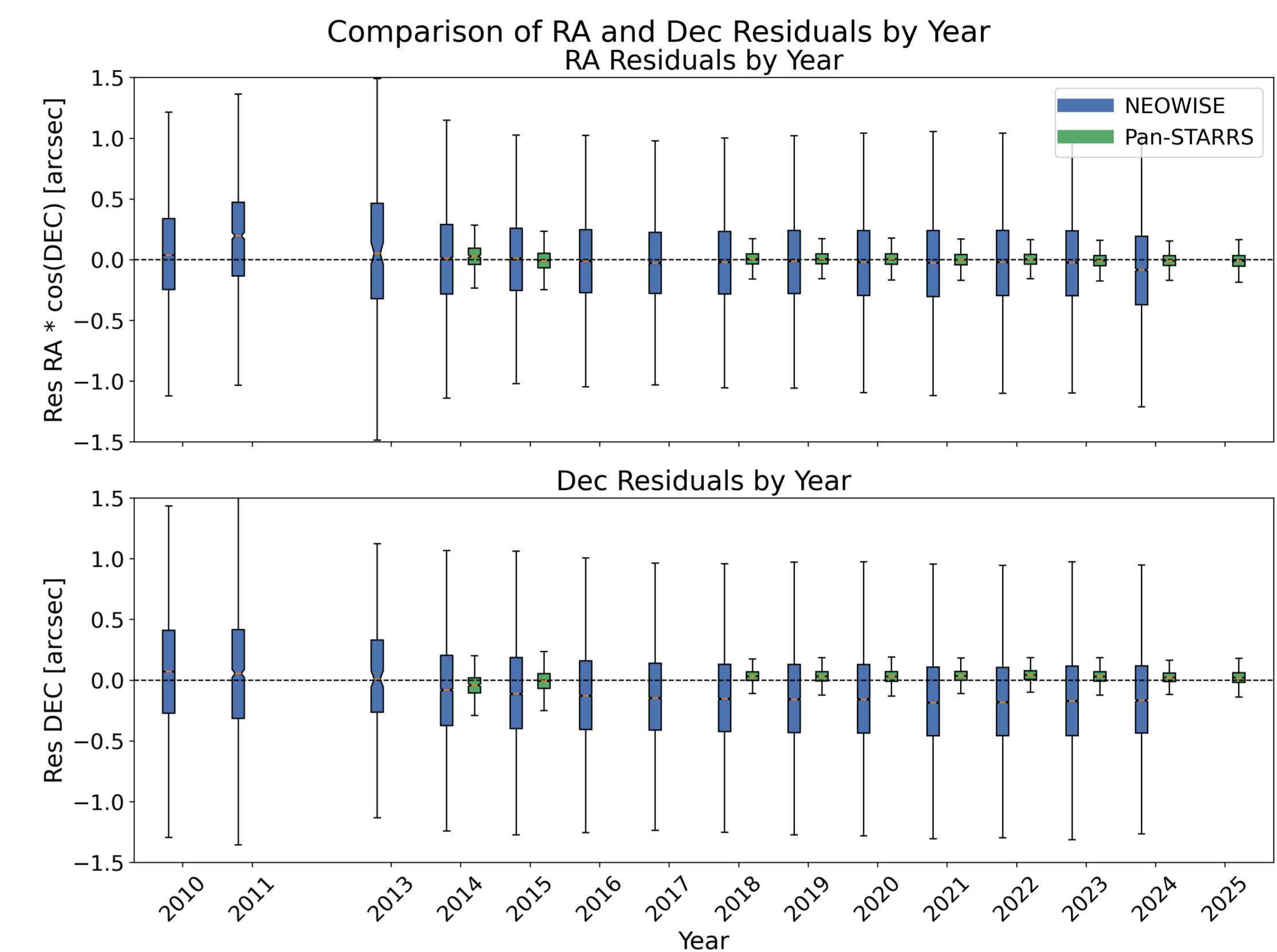


Figure 2. Post-fit residuals of over 10M observations as a function of time for the Pan-STARRS telescope (code F52 [4]) and NEOWISE space telescope (code C51 [5]).

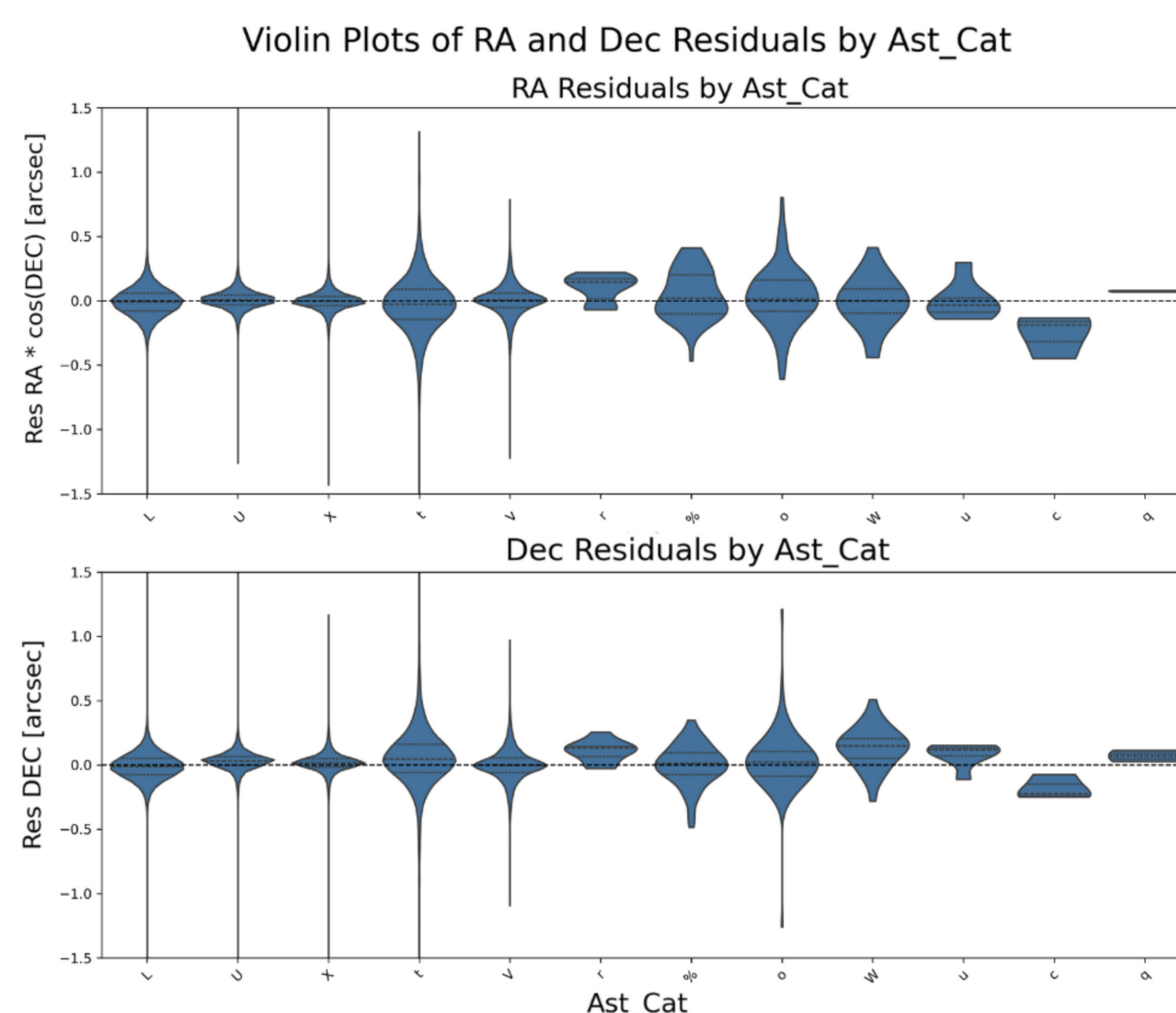


Figure 3. Post-fit residual distributions for all catalogs used in F51 Pan-STARRS station data.

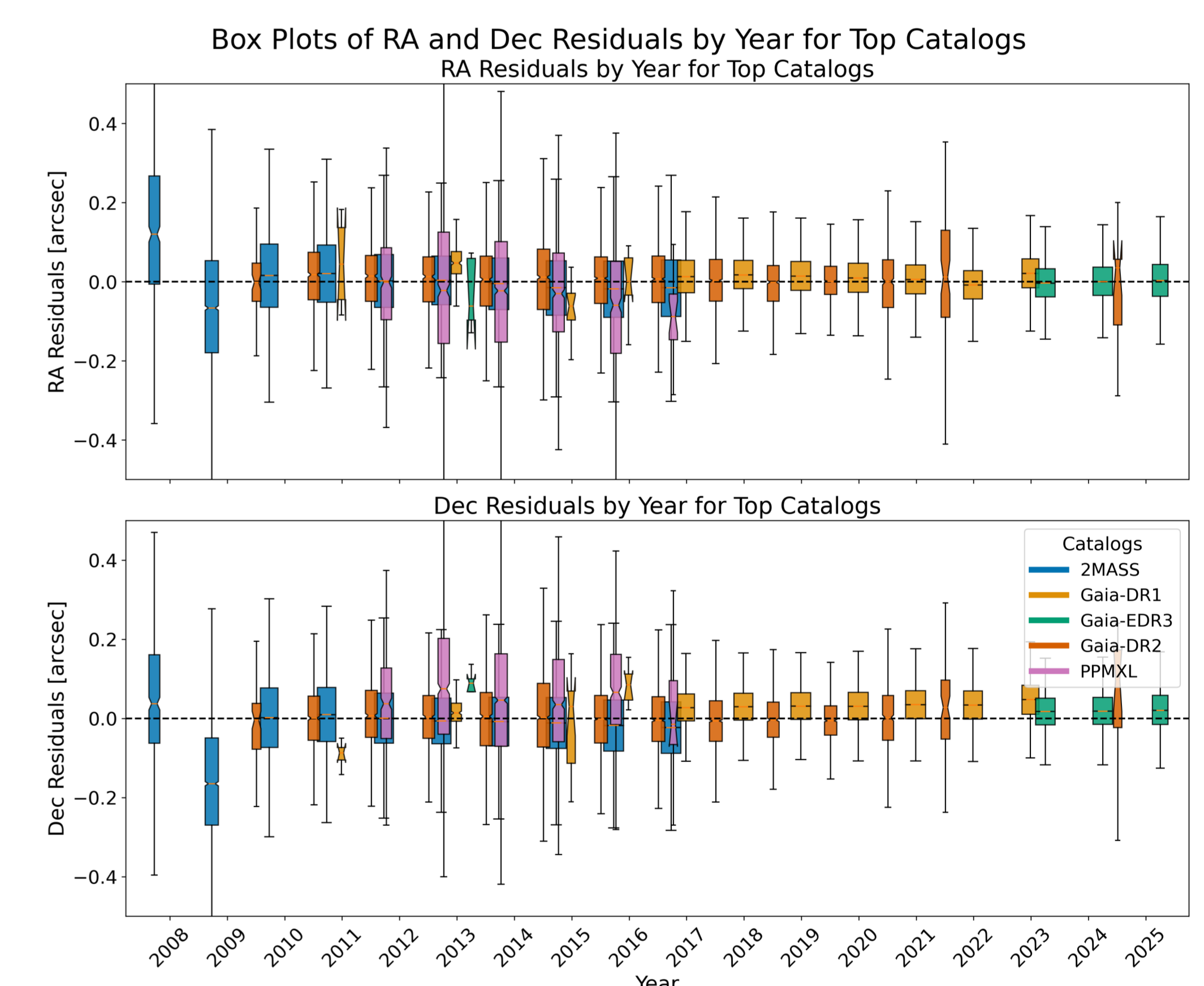


Figure 4. Post-fit residual distributions for the five most frequently used catalogs in F51 Pan-STARRS station data.

Conclusions

- We presented just a few examples, but we find that astrometric residuals vary significantly over time and between observatories, reflecting differences in instrumentation, observing conditions, and reduction pipelines. We found systematic offsets in declination, in particular for the space-based infrared telescope NEOWISE.
- Gaia-based stellar catalogs shows improved astrometric precision, but small systematic biases persist. Further evaluation is required to quantify catalog-dependent effects more robustly.
- Future work will include a full analysis of the performance including:
 - Analysis of residuals vs. magnitude and motion rate;
 - Full statistical assessment per observatory and epoch;
 - Evaluation of observatory productivity and data quality;
 - Development of survey-specific weighting models;
 - Prediction tests to assess weighting quality with the goal to achieve normally distributed predictions.

References

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Acknowledgements: This research was supported by the NASA YORP23 grant. Data from the MPC's database is made freely available to the public. Funding for this data and the MPC's operations comes from a NASA PDCO grant (80NSSC22M0024), administered via a University of Maryland - SAO subaward (106075-Z6415201). The MPC's computing equipment is funded in part by the above award, and in part by funding from the Tamkin Foundation. Part of this research was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004).