A Precision Two-Epoch Catalog of 44 Million Sources from the USNO-B and SDSS Catalogs

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SUMMARY

We present a new precision, multi-epoch photometric catalog of stars and quasars that spans 60 years by combining the USNO-B and SDSS DR9 catalogs. We recalibrate the photometry of the original USNO-B catalog and create a publicly available catalog with two epochs of photometry in up to five different bands for 43,647,887 optical point sources that lie in the DR9 footprint of the northern sky. The recalibrated objects span a magnitude range $14 \leq m \leq 20$ and are accurate to ≈ 0.1 mag. We minimize the presence of spurious objects and those with inaccurate magnitudes by identifying and removing several sources of systematic errors in the two originating catalogs, with a focus on spurious objects that exhibit large apparent magnitude variations. After accounting for these effects, we find 247,000 stars and quasars that show significant ($>4\sigma$) changes in brightness between the USNO-B and SDSS DR9 epochs ($2 \text{ days} < \Delta t < 60$ years). Most of these variable candidates do not appear in large catalogs of known variables.

MOTIVATION

The next-generation surveys of the time-variable sky will have unprecedented sensitivity and areal coverage, but will be limited in their ability to detect variability on time scales longer than the lifetime of the surveys. The investigation of long-period variable stars, cataclysmic binaries, quasars and the search for rare objects such as novae and R CrB stars all benefit from observations that span decades or more (e.g., Zijlstra et al. 2002; Sesar et al. 2006; Wils et al. 2010; Hudec 2011; Mickaelian et al. 2011). For example, the timing of outbursts from recurrent novae, changes in the periods of Mira variables, and observations of late thermal pulses such as those from FG Sge (Herbig & Boyarchuk 1968) or WISE J1810-3305 (Gandhi et al. 2012) provide insight into the late stages of stellar evolution and mass loss. Measurements of quasar variability over a wide range of time scales are used to constrain physical models for their central engines (e.g., MacLeod et al. 2012). A robust, accurate historical photometric archive can aid in the classification of transient or variable objects discovered through surveys such as those that will be carried out with LSST.

CATALOG ASSEMBLY

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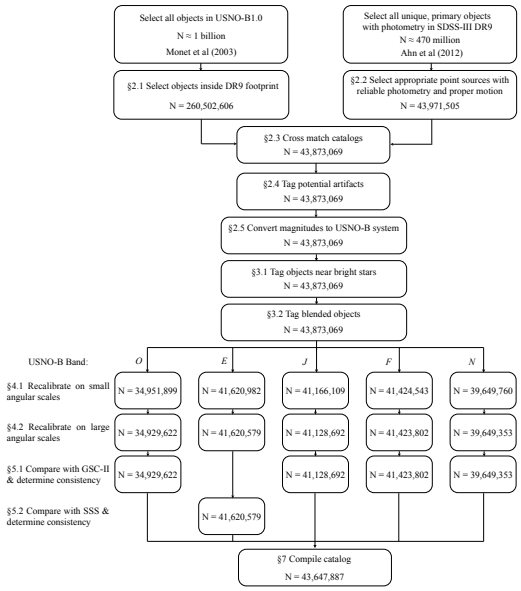
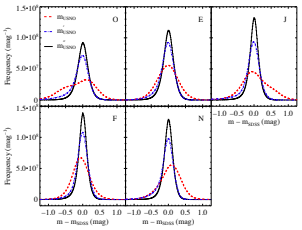


The flowchart above outlines the process by which the catalog was created. For each step, the number of objects that remain after the step was applied is given as *N*. USNO-B suffers from very large photometric errors that can exceed several magnitudes. We carefully cross-match objects in USNO-B to those in DR9 in order to recalibrate USNO-B photometry; the recalibration is based on a scheme described by Sesar et al. (2006). We also compare our results to the Guide Star Catalog 2.3.2 (Lasker et al. 2008) and to the SuperCosmos Survey (Hambly et al. 2001) in order to further minimize the presence of spurious sources.

IMPROVEMENTS TO USNO-B PHOTOMETRY

Our piecewise recalibration, careful flagging of bright/blended objects and consistency checks with other plate surveys have significantly improved the accuracy of USNO-B photometry. The figure at right shows the frequency distribution of the difference between USNO-B and DR9 magnitudes for each of the five USNO-B bands. The dashed red, dotted blue and solid black lines represent the original magnitudes, small-scale recalibrated magnitudes and final recalibrated magnitudes, respectively. For each band, the interquartile range of the distributions has decreased by a factor of 3; the standard deviation has dropped by a factor of 2 down to ≈ 0.1 mag. Note that these improvements can only be made to cross-matched objects between USNO-B and DR9.



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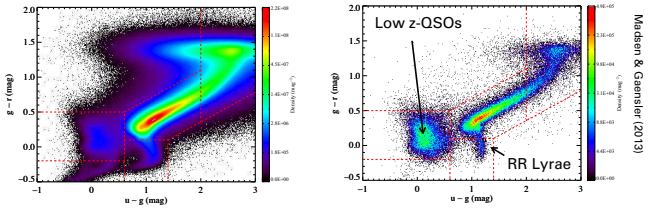
VARIABLE CANDIDATES

Our catalog contains 247,511 unique objects that exhibit significant ($>4\sigma$) changes in brightness between the USNO-B and DR9 epochs, with $0.1 < \Delta m < 5.8$ mag. We visually inspected the photographic plates and DR9 images of a random sample of these variable candidates and found that more than 98% of them appear to be genuine. However, only 4% of these objects appear in the latest version of the AAVSO VSX compiled catalog of variable stars (Watson 2006); many of our identifications may be new discoveries. Classifying these candidates remains a challenge, but this can be aided through cross-matching with other large, deep surveys at other wavelengths; 1.3% of these objects have SDSS spectra that will further aid classification. Another method is to consider the locations of the objects on single-epoch extinction-corrected optical color-color diagrams, as shown below. The panel on the left shows 37 million objects in our catalog with accurate extinction corrections. The panel on the right shows only the ~75,000 objects that are 4σ variables in the USNO-B *J* band. The dashed red lines show the classification boundaries from Richards et al. (2006). The fraction of objects with colors consistent with low-redshift quasars is 35 times higher for the variable population than for the catalog as a whole; quasars are well known to vary in the optical over a range of time scales (e.g., Giveon et al. 1999).



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LARGE-AMPLITUDE VARIABLES

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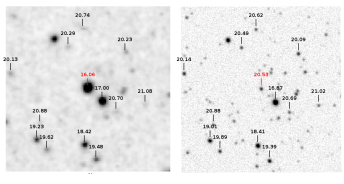

On the left are a photographic plate and DR9 image centered on a previously uncataloged, very large amplitude variable ($\Delta m = 4.5$); the location and magnitude of each object at the given epoch appear as tick marks and labels. The object at the center has an extremely red color and high IR brightness, suggesting that it is a Mira.

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For links to the catalog and a copy of this poster, scan this QR code: