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A search for main-belt comets with the Palomar Transient Factory

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Abstract

The Palomar Transient Factory (PTF) is a synoptic survey designed to explore the transient and variable optical sky. We search PTF imaging data for observations of known small bodies, catalogue their photometric data and images, and analyze their point spread functions in an attempt to identify cometary activity of the type seen in main-belt comets (MBCs). This project will eventually allow for the study of long-term variability properties using a catalog of a few million asteroid observations.

1. Introduction

The Palomar Transient Factory (PTF; Law et al. 2009; Rau et al. 2009) is a comprehensive automated survey of the optical sky (60-second exposures in g and R bands at ~1 arcsec pixel resolution) using the Palomar Samuel Oschin 1.2m telescope, equipped with the refurbished CFHT12k camera (Rahmer et al. 2008). PTF's original and primary purpose is the detection of non-planetary transient and variable objects, such as supernovae. Two years into data collection, the project has produced about one million images.

In this study we systematically search the survey's database for all occurences of known small Solar System bodies using existing orbital elements. One of the goals of this study is to place limits on the population size of main-belt comets (MBCs). A comprehensive review of all MBC astronomy to date (Berlini 2011) reveals that most previous population studies have considered asteroid sample sizes on the order of hundreds to thousands (Sonnett et al. 2008, Hsieh 2009), or less than 2% of the known main-belt asteroids. Despite the development of careful photometric analysis techniques (Kleyna et al. 2007, Hsieh et al. 2010), the largest sample to date used in looking for MBCs (Gilbert & Wiegert 2009), which contained 11,430 objects, was inspected entirely visually. The forthcoming survey PAN-STARRS (Hodapp et al. 2004) has repeatedly been cited as the next big step in small body observation, and it may fill that role soon. Until then, existing optical surveys such as PTF may have a great deal to contribute to the field.

2. Data Collection Procedure

We use original software to conduct an automated search of fully processed PTF images, which are stored at the Infrared Processing and Analysis Center (IPAC). Associated with each image is a previously-built catalog of point sources found on the image, created using the SExtractor tool (Bertin & Arnouts 1996). This point source catalog lists, for each source, the image and sky coordinates as well as various photometric properties. The ability to search the survey database in catalogued point source space, rather than reading the actual images, allows the pipeline to proceed much faster, since each SExtractor catalog consists of far fewer megabytes of data than the image file itself.

Using the IAU Minor Planet Center (MPC) MPChecker tool, our automated process checks each field for predicted occurrences of any of the more than 500,000 bodies having orbital elements listed by the MPC. This list is overwhelmingly dominated by main-belt asteroids, but also includes near-earth objects, long- and short- period comets and outer Solar System objects (TNOs and KBOs). The cut-off predicted magnitude for queried objects is intentionally several magntiudes dimmer than the m = 21 typical limiting magnitudes of PTF images, with the assumption that unpredictable cometary activity may be seen. All predicted object positions and relative motions are catalogued for each image, and retained regardless of whether a source is eventually confirmed by the automated process.

Confirmed occurrences are automatically cross-checked using the USNO-B1 catalog (Monet et al. 2003) to assure that no known deep-field objects (stars or galaxies) contaminate the object's image. In addition to the object's SExtractor-generated photometric data, small 20x20 pixel cutouts of both the object and a nearby reference star (whose B, R & I magnitudes are found in USNO-B1) are saved to the catalog for later analysis. All uncalibrated magnitudes output by SExtractor are converted into calibrated apparent magnitudes.

The degree to which an object is classified as "extended" depends on its photometric properties relative the population of point sources on the same image. The stars in particular best represent true point sources over the entire range of magnitudes, but they must first be matched to a pre-existing catalog. The Sloan Deep Sky Survey (SDSS), which saw a recent data release (Eisenstein et al. submitted) that includes roughly a quarter of the entire sky, aids in this task. To allow for the use of SDSS's type classification for accurate characterization of stellar photometry, the initial batch of images run through our search pipeline have been selected from a circular region in the Northern Galactic Cap of radius 30° centered on R.A. = 180°, dec. = +30°. This area is completely covered in SDSS Data Release 8, and conveniently samples a large portion of the main asteroid belt.

The key photometric parameter of interest is the difference between the surface brightness of the central pixel (the *mu-max*) and the uncalibrated magnitude (the *mag-auto*). This difference (in units of magnitude), is referred to as the *mu-type*. Stars occupy a relatively narrow distribution of mu-types that broadens slightly with

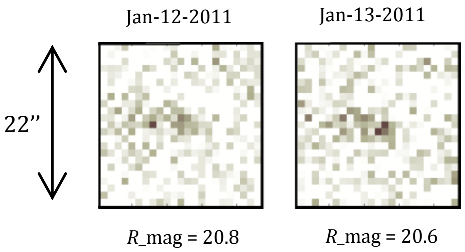

Figure 1 – The known comet C/2009 U5 (Grauer) above was imaged 24h apart in the PTF survey on Jan 12 & 13, 2011, at an orbital distance of 6.3 AU and calibrated apparent *R* magnitude of ~20.7.

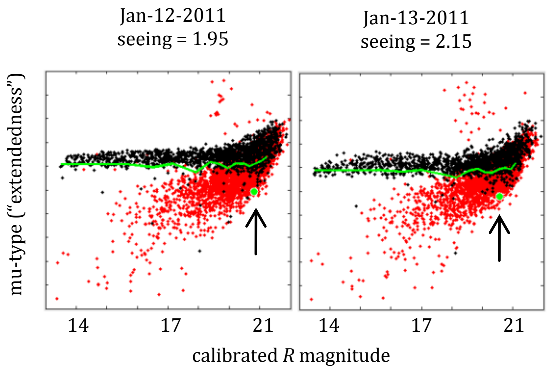

Figure 2 – The same comet C/2009 U5 (Grauer) from Figure 1, here with its mu-type plotted against the other sources in its field. Black dots are stars matched from SDSS, red dots are extended sources (including galaxies). The green dot indicated by the arrow is the comet; the green line shows the minus 1-sigma deviation from the mean stellar mu-type, computed from 100-star bins along the magnitude (horizontal) axis. This figure shows that observations made at different times under different seeing conditions can preserve the mu-type character of even very faint (>20 mag) objects.

increasing magnitude, while galaxies and extended objects fill a much larger portion of this space (see Figure 2 above). By comparing a minor planet's mu-type to the stellar distribution, we compute a probability (p-value) that the object is a point source, and save this p-value to the object's catalog entry.

3. Preliminary Data and Upcoming Science

Our software is currently capable of searching thousands of images per day, with a running average of ~2 minor body observations catalogued per image. Depending on the PTF scheduling and cadences at the time, a given field and hence its included Solar System objects might have been consecutively imaged minutes, days or weeks apart, yielding irregularly spaced points on the light curves of most objects. This makes short period (rotational) light curve analysis difficult most of the time, though high cadence PTF data does exist and is being used for this purpose (Polishook, this volume). Long period (orbital scale) light curves will be of key interest, not only due to this natural sampling timescale but because some main-belt cometary activity is known to have seasonal dependence, as with 133P/Elst-Pizarro (Hsieh et al. 2010).

A statistical algorithm geared toward the careful analysis of point spread functions, currently in development, will eventually serve as another test of the photometric character of catalogued objects. Once our catalog has accumulated a sufficient number of known cometary objects, and we are confident in our ability to distinguish them from other small bodies, we will be able to reassess limits on the population size of main-belt comets.

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