Ground Recovery of Periodic SOHO Comets

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INTRODUCTION

The Solar and Heliospheric Observatory (SOHO) has discovered nearly 5,000 comets since it began operation in 1995, including about a dozen possible short-period comets. However, SOHO's low spatial resolution (~1') makes it difficult to confidently constrain the orbits of these objects. Thus, even though several of them have relatively well-defined orbits, only two of them (322P/SOHO and 323P/SOHO; Knight et al. 2016, Hui et al. 2022) have been recovered and characterized with ground-based telescopes.

Following the successful recovery of 322P/SOHO by Knight et al. (2016), we have been attempting to recover other SOHO periodic comets from the ground. Here we present our analysis of several campaigns conducted between 2017 and 2021, focusing on comets 321P/SOHO, 323P/SOHO, 342P/SOHO, and P/1999 J6 (SOHO).

DATA

We used an array of telescopes ranging from 0.6 to 5.1 m for our campaigns. The observations are summarized in Table 1.

Target	Telescope	Dates	Elong	r_H	LM (V)
321P	P200	2019-12-16/17	43°	1.01 to 0.99 au	18.0 (bad seeing)
321P	31in	2020-01-01/03	34° to 31°	0.63 to 0.57 au	18.0, 16.0 (clouds)
321P	NEXT	2020-01-02	32°	0.60 au	18.5
321P	LDT	2020-02-22	100°	1.10 au	19.0 (clouds)
323P	INT	2017-01-24/25/26/27	171° to 167°	1.57 to 1.61 au	23.5
342P	DECam	2021-09-30, 2021-10-01	44° to 42°	0.71 to 0.66 au	22.0
P/1999 J6	LDT	2021-03-03	31°	0.59 au	16.5

Table 1. Summary of the observations and observing circumstances. Abbrevations: P200 - 5.1 m Palomar Hale Telescope; 31in - Lowell NURO 31-inch telescope; NEXT - 0.6 m Ningbo Education Xinjiang Observatory Telescope; LDT - 4.3 m Lowell Discovery Telescope; INT - 2.5 m Isaac Newton Telescope; DECam - Blanco 4 m Telescope.

Most of these observations were made at small solar elongations in twilight. Substantial challenges arose from bright and uneven backgrounds as well as (for larger telescopes) worsen instrumental seeing due to the mirror's weight.

Images are bias-subtracted and flat-corrected, and are then astrometrically calibrated using the Gaia DR3 catalog (Gaia Collaboration et al. 2023), with the exception being the DECam images which robust astrometric solution is supplied with the released images (Valdes et al. 2014). Limiting magnitudes (LM) are estimated using the PANSTARRS DR1 catalog (Magnier et al. 2013). We then blink the images to look for moving objects matching the predicted motion direction and rate of the objects of interest.

ANALYSIS

321P

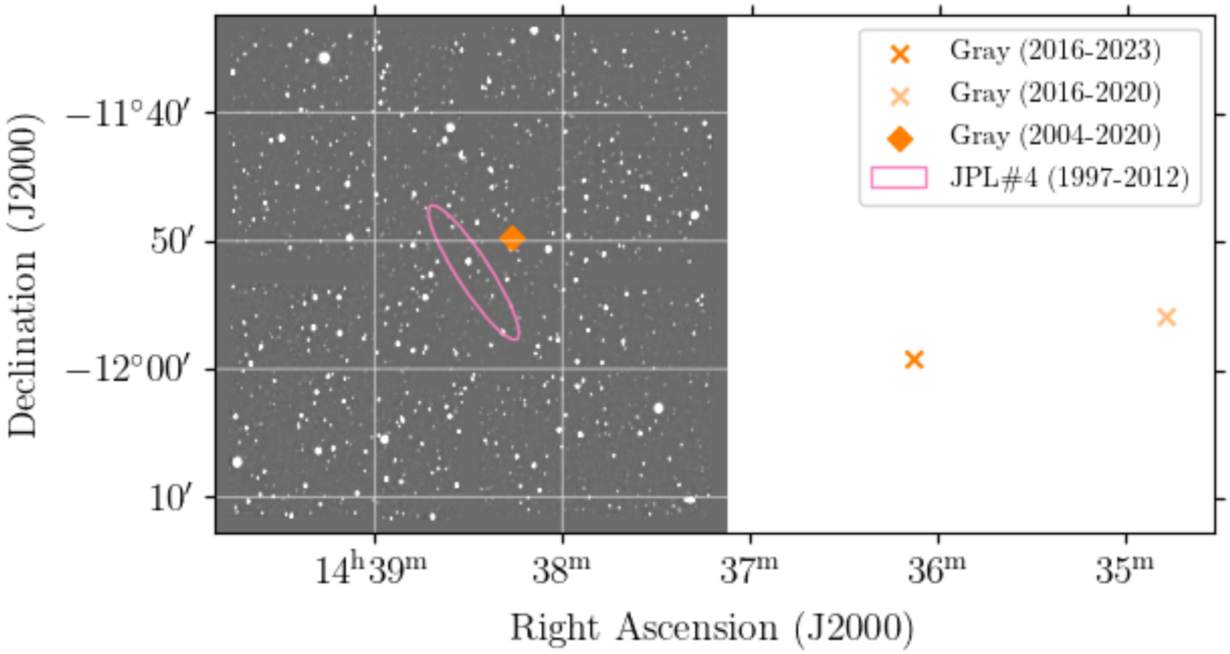

Figure 1. Search fields of 321P/SOHO taken by P200 on Dec 16, 2019. Also shown are the 3-sigma position error ellipse using JPL#4 (computed using data from 1997-2012) as well as the positions calculated by B. Gray using data from 2004-2020, 2016-2020, and 2016-2023 (Gray, private comm.)

Observations were guided using orbit solution JPL#4 (computed using SOHO data between 1997-2012) and covered the 10-sigma ellipse. Independent calculations using different data arcs by B. Gray (Gray, private comm.) found that while the orbit calculated using the 2004-2020 arc yielded a similar on-sky position, the ones calculated using the more recent, 2016-2020 and 2016-2023 arcs yielded positions about 1º to the west (Figure 1). Curiously, even these two orbits show a ~0.4º difference even though they use largely the same data (2016 and 2020). Similar ephemeris disparity also impacts later attempts using the Lowell 31-inch, NEXT and LDT.

Significant mirror deformation due to the high airmass at the time of the observation also led to very poor seeing (~20") and low limiting magnitude (*V*~18). This is far from the predicted brightness of 321P (V~24) assuming an absolute magnitude comparable to the well-measured 323P. The observations made by the Lowell 31-inch and NEXT, conducted roughly two weeks later, also did not have the sensitivity to reach the prediction (up to V~18.5 compared to V~23). The LDT observations, conducted in February 2020, would benefit from the improved phase angle in which 321P was expected to be around V~21.5, but the observations suffered from clouds and only reached V~19.5.

323P

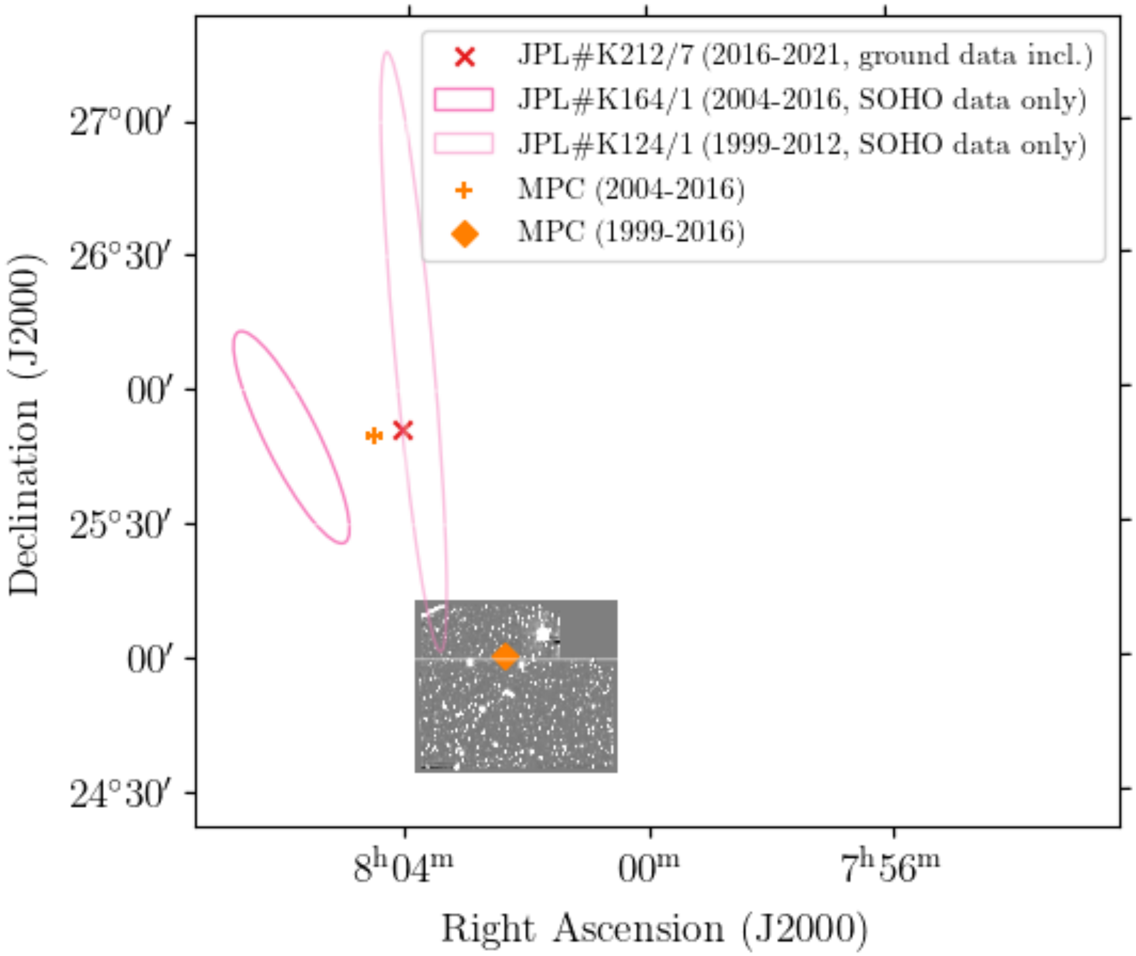

Figure 2. Search fields of 323P/SOHO taken by INT on Jan 25, 2017. Also shown are the position error ellipses calculated using JPL#K124/1 (computed using SOHO-only data from 1999-2012), JPL#K164/1 (computed using SOHO-only data from 2004-2016), JPL#K212/7 (computed using SOHO and ground-based data from 2016-2021, ellipse too small to be shown), as well as the positions calculated the two orbit solutions published by the Minor Planet Center (MPC) in Minor Planet Electronic Circular (MPEC) 2016-Y36.

323P was recovered from ground by Hui et al. 2022 and the orbit is now well constrained. Nevertheless, we reanalyze our data taken back in 2017 in which we (Fitzsimmons et al. 2017) previously reported a negative detection. The search was guided by the orbit with the longest observational arc available back then, and covered a ~0.6º area approximately centered at the predicted nominal. Nominals of all published orbits, including the "ground truth" orbit that contains high-precision (compared to SOHO), ground-based data, are shown in Figure 2. Similar to what we found on 321P, the nominals scattered over a ~1º region. They have no obvious correlation with the time or length of the arc, and do not seem to align with the orientation of the error ellipses in the JPL solutions (which also show some level of disagreement among themselves). The ones that are closest to the "ground truth" are neither longest in arc nor the latest, suggesting that this proximity is likely by chance.

Using the absolute magnitude derived by Hui et al. (2022), 323P would be *V*~21.5 at the time of the INT observation, which is well within the range of the images.

342P

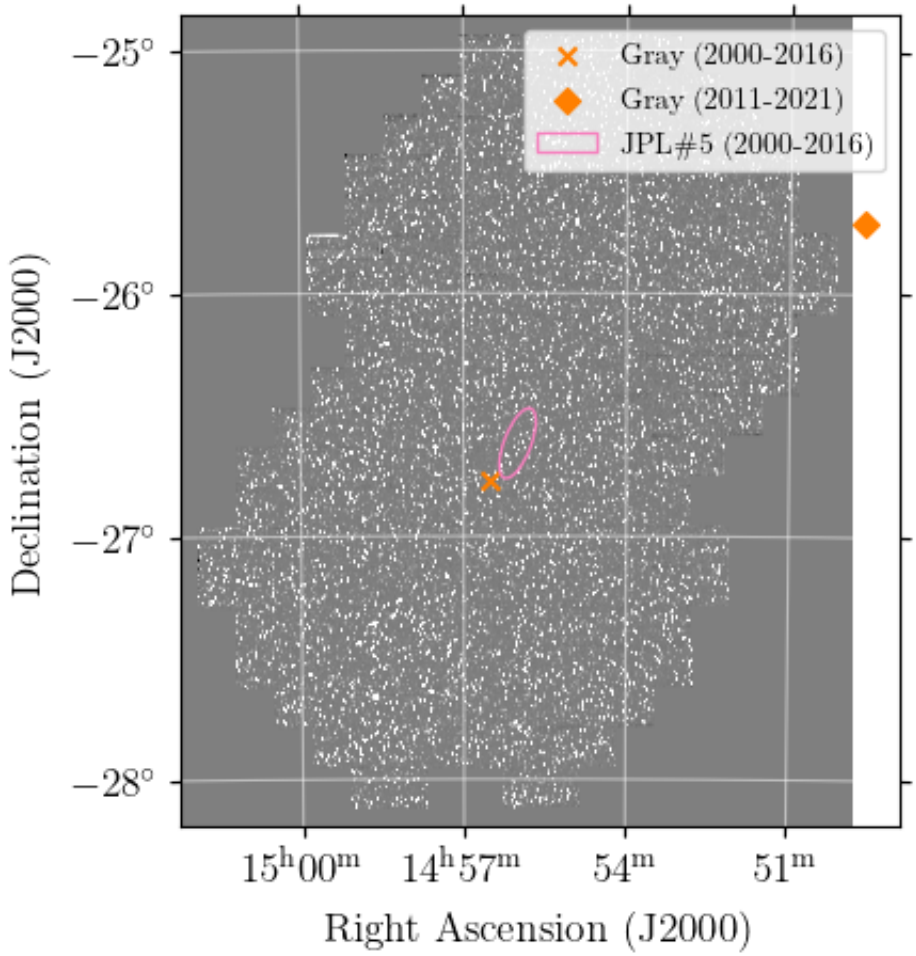

Figure 3. Search fields of 342P/SOHO taken by DECam on Sep 30, 2021. Also shown are the position error ellipse calculated using JPL#5 (computed using SOHO data from 2000-2016) as well as the positions calculated by B. Gray using data from 2000-2016 and 2011-2021 (Gray, private comm.)

We observed an area covering a 30-sigma error ellipse calculated by orbit solution JPL#5 on Sep 30 and Oct 1, 2021, using the Dark Energy Camera (DECam) on the 4 m Blanco telescope. The images reached *V*~22.0 and fell short of the predicted brightness of 342P (*V*~23.0). No object matching 342P was found.

Independent calculations by B. Gray showed that orbit calculated using the SOHO data taken between 2000-2016 was largely in line with the JPL orbit (which used the same dataset), but the one derived from 2011-2021 data (which only become available after the DECam observation, since DECam observed before 342P's perihelion passage) showed a nominal that was ~2º northwest of the other two nominals, and was beyond the images.

SUMMARY

- The on-sky nominals calculated from SOHO astrometry appear to have an uncertainty of ~1º. The size and orientation of error ellipses computed from SOHO astrometry can be dictated by numerical artifacts. Using more recent data or data with longer observational arcs do not significantly reduce the uncertainty.
- Phase effect strongly affects the apparent brightness of periodic SOHO objects; the best windows for recovery are controlled by the combination of distance to the Sun and phase angles, and often do not coincide with smaller heliocentric distances.

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TRANSCRIPT

ABSTRACT

The Solar and Heliospheric Observatory (SOHO) has discovered over 4,000 comets since it began operation in 1995, including about a dozen comets on short-period orbits. Several of these comets have relatively well-defined orbits, but only two of them (322P/SOHO and 323P/SOHO; Knight et al. 2016, Hui et al. 2022) have been recovered and characterized with ground-based telescopes. As these comets periodically venture into the extreme solar environment they undergo major changes, which can provide unique information on their compositions and internal structure. Here we present our analysis of a series of ground-based images collected between 2017 and 2021, focusing on recovering periodic SOHO comets: 321P/SOHO, 323P/SOHO, 342P/SOHO, and P/1999 J6 (SOHO). These images were bias-subtracted, flat-corrected, and combined to produce clean, deeply-stacked images for object searches. We then search for the comets using the updated orbits based on most recent SOHO observations. The results, implications, and lessons learned from collecting and interpreting data taken in the challenging twilight conditions will be presented and discussed at the conference.

This work is supported by NASA programs NNX17AK15G and 80NSSC22K0772.

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