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GROWTH-India Observations of Solar System Objects

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The discovery, characterisation, and monitoring of Near-Earth Objects (NEOs) are critical for understanding and potentially mitigating the long-term threats to our civilisation from Potential Hazardous Asteroids (PHAs). Current survey telescopes have a sensitivity of around 20–21 magnitude, which means PHAs, with absolute magnitude $H > 22$, are typically discovered at distances of a fraction of an astronomical unit (Jedicke et al. 2016). This has two consequences: first, the angular speeds of these objects are often tens of arc-seconds per minute in discovery data, smearing out the faintest objects and making the discovery even more challenging. Second, uncertainties in preliminary orbits calculated from discovery data coupled with the relatively short distance from Earth lead to large uncertainties in the sky positions of these objects: ranging from tens of arc-seconds to a fraction of a degree just half a day after discovery. To confirm such faint objects and refine their orbits, one needs meter class telescopes with relatively wide fields of view.

GROWTH-India Telescope (GIT[1], MPC Observatory Code: N51) is a 70-cm robotic telescope located at the Indian Astronomical Observatory (IAO) site at Hanle, Ladakh. Equipped with a 4k back-illuminated CCD, GIT has a 0.7° field of view at 0.67" resolution and reaches a depth of $r' \approx 21$ in 5-minute exposures. GIT was set up as part of the Global Relay of Observatories Watching Transients Happen (Kasliwal et al. 2019)[2], an international collaboration with NEO studies as one of its key science goals.

GIT began solar system observations in September 2020 and has been used to observe 75 solar system objects as of May 2021 (Figure 1). GIT is broadly used for three types of solar system studies. First, we study NEOs to confirm the discoveries and refine their orbits. The geographic location of GIT — on the opposite side of Earth to the major NEO discovery engines like ZTF (Bellm et al. 2018), CSS (Christensen et al. 2018), ATLAS (Tonry et al. 2018) and PanSTARRs (Chambers et al. 2016) — allows us to observe NEOs before the positional uncertainties blow up to unmanageable scales. Secondly, we undertake coordinated observations of solar system objects with other observatories to obtain continuous coverage over long time spans. An excellent example is the joint study of the episodically active asteroid (6478) Gault (Purdum et al. 2021) where continuous observations were key to reveal the 2.5-hour rotational period. Lastly, we also undertake observations of cometary outbursts - 29P/Schwassmann-Wachmann 1 (Kelley et al. 2021d), 22P/Kopff (Kelley et al. 2021a), C/2020 R4 (ATLAS) (Kelley et al. 2021b) and 99P/Kowal 1 (Kelley et al. 2021c).

Calculating accurate asteroid positions and magnitudes from non-sidereally tracked images poses a unique challenge. All the star images appear as streaks, and standard astrometry software are ill-suited for detecting and extracting such elongated sources. A common approach is to use the start (end) point of each streak as markers for the star positions at the start (end) of the exposure. But this approach needs significant human intervention. We have developed a new automated pipeline to process such images and obtain asteroid positions and photometry. Our pipeline detects streaks in the image and creates a synthetic image with point-like sources that can be solved for astrometry with any software. The final astrometric solutions can be transferred back to the original image, giving a coordinate system for the mid-point of observations. Testing our pipeline on sources with angular speeds as high as 2'/min and stellar streaks up to 5' in length, we have consistently obtained asteroid positions with arc-second residuals (Figure 2). This pipeline is built using open-source python packages like photutils (Bradley et al. 2020), and will soon be released publicly.

The GROWTH-India Telescope (GIT), set up by the Indian Institute of Astrophysics (IIA) and the Indian Institute of Technology Bombay with support from the Indo-US Science and Technology Forum (IUSSTF) and the Science and Engineering Research Board (SERB) of the Department of Science and Technology (DST), Government of India. It is located at IAO (Hanle), operated by IIA.

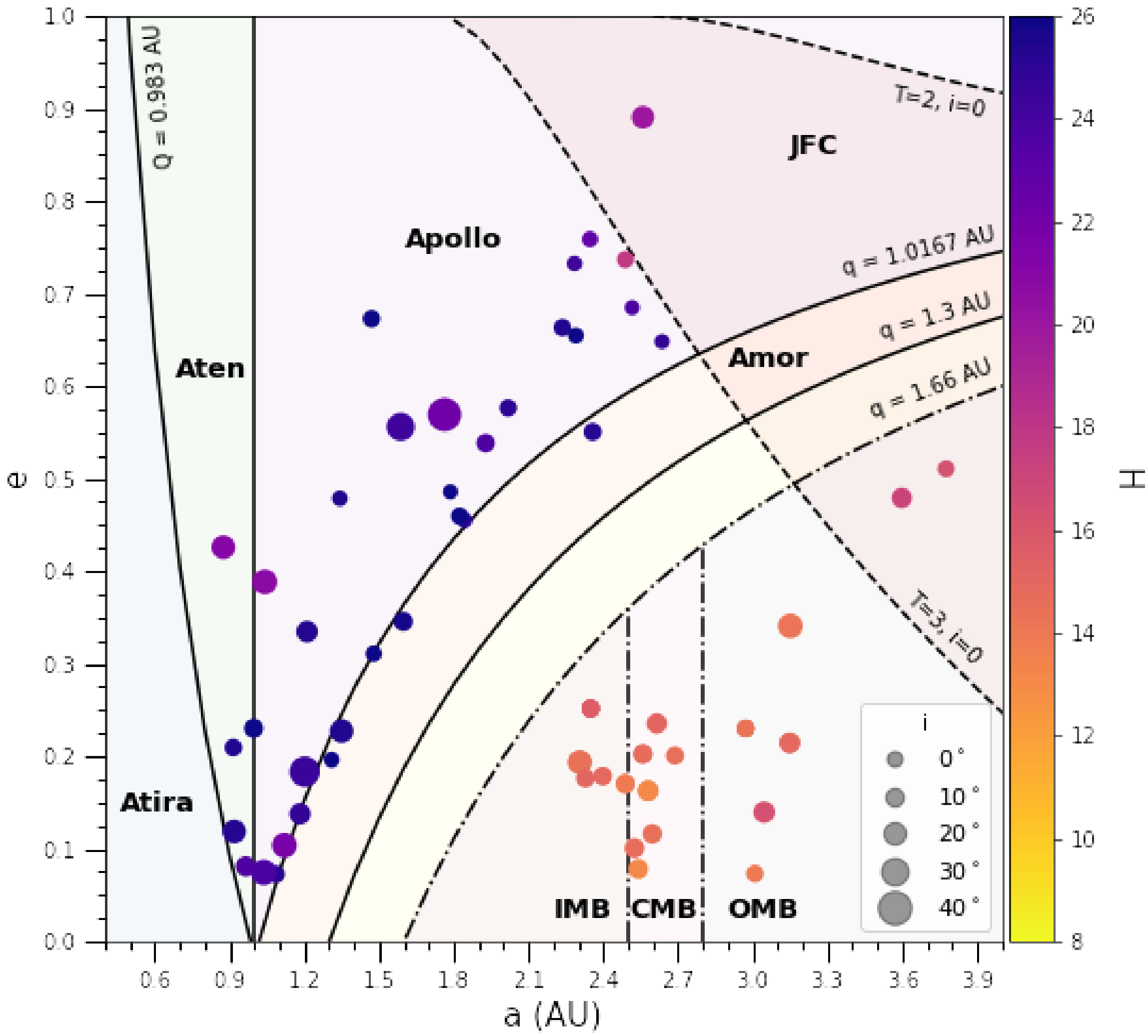

Figure 1: An (a, e, i) orbital distribution of all solar system objects observed with GIT, including 36 NEOs, 15 Main-Belt Asteroids (MBAs), 1 Jupiter Trojan, 7 Periodic Comets and 16 Non-Periodic Comets. The region between perihelion q = 1.3 AU and aphelion Q = 0.983 AU demarcates the NEO regime. We have observed 5 Atens (NEOs with Q ≥ 0.983 AU and a < 1 AU), 21 Apollos (NEOs with a ≥ 1 AU and q ≤ 1.0167 AU) and 9 Amors (NEOs with 1.0167 AU < q ≤ 1.3 AU). The orbital parameters of periodic comets with a > 4 AU and non-periodic comets are not included in this figure. We have also observed 5 Inner MBAs (a ≤ 2.5 AU and q ≥ 1.66 AU), 5 Central MBAs (2.5 < a ≤ 2.8 AU and q ≥ 1.66 AU) and 7 Outer MBAs (a > 2.8 AU and q ≥ 1.66 AU).

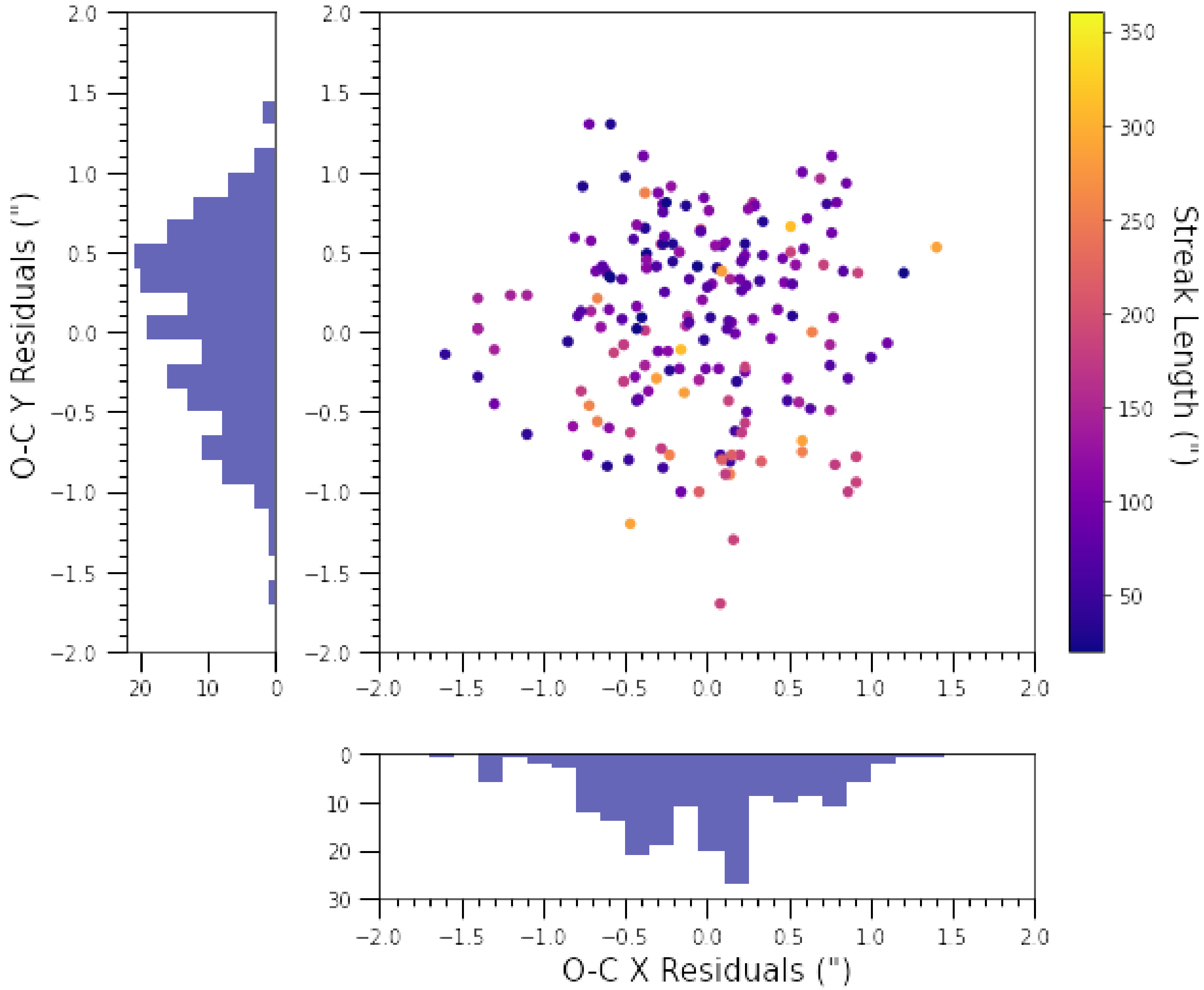

Figure 2. Observed-minus-Computed (O-C) residuals in the X and Y directions of all positions of NEOs observed with GIT. The NEOs tracked had a proper motion in the range of 4 − 120"/min. The exposures of 40 − 500 s were taken, resulting in streaking reference stars of lengths in the range 22 − 310". Astrometry on this data was performed using the GROWTH-India Astrometry Pipeline with a standard deviation of 0.57", which is fairly good for faint and fast-moving NEOs.

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