A480 Notes

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1 Things to Check

The named asteroids in Harris (1994) (most notably 4179 Toutatis) should be checked for TESS observations. As these should tumble.

288 Glauke Harris (2015)

2 Background writing

The Transiting Exoplanet Survey Satellite (TESS) Ricker et al. (2014) is a large area, high imaging cadence, space telescope. TESS is tasked with observing one piece of sky for 27 d at a time (a sector), delivering $96° \times 24°$ full frame images (FFIs) at regular intervals. These FFIs are built from stacked 2 s exposures, leveraging the short readout times of the 16 CCD cameras on-board. With the initial cadence for these full frame images set to 30 min, the time resolution of TESS is unparalleled. This does come at the cost of spatial resolution, as the pixels are each $21''$ square. A Nyquist frequency of h^{-1} is well sampled enough to characterise most variable stars, as well as find the orbital periods of exoplanets to a high precision. After the initial mission had mapped the entire sky, TESS started to reduce the time of the full frame images, down to 10 min and then down to only 200 s.

Of interest here is what such a high sampling rate can do for statistic on the asteroid population. For bright asteroids the rotation periods should be able to be easily determined from this vast dataset. The shortest FFIs will be able to accurately determine the rotation periods of all but the fastest rotating asteroids, most of which will be too dim to see in the TESS data. There have been attempts before to find and classify the asteroids in TESS data before by Pál et al. (2018, 2020). This work aims to extend their study to more sectors, and to use a different data reduction method, using the `TESSreduce` package (Ridden-Harper et al., 2021). As part of a full sky transient survey using TESS, `TESSELLATE` (Ridden-Harper and Roxburgh et al., in prep), asteroids pop out as transient objects that are spikes in brightness of pixels for only a few frames. They can confuse pipelines looking for short time stellar transients such as flare stars and supernova. As such, a way of filtering them out is required, as well as this filtering will get the properties of the light curves, such as the rotation periods and amplitude variation of these small solar system bodies. A full sky, self-consistent catalogue of these properties is important for many reasons. The asteroid population statistics are useful in their own right, understanding the orbits of near earth objects is useful for planetary defence, and these bodies ...

The first interstellar object (ISO) was discovered in late 2017, it has come to be called 1I/'Oumuamua(see Bannister et al., 2019, for a review). 'Oumuamuawas determined to be spectroscopically red (Fitzsimmons et al., 2017; Meech et al., 2017), and having a photometric colour in the neutral end of the solar system range (Bannister et al., 2017). It appeared to be tumbling (e.g. Drahus et al., 2018; Fraser et al., 2018), the double peaked light curve was found to have a rotation period of 8.67 ± 0.34 h (Belton et al., 2018).

Peak to peak LC of 2.5 mag (Meech et al., 2017)

Combing the tumbling with an elongation ratio of up to 6 ± 1:1 (McNeill et al., 2018), 1I is said to have a cigar shape (Belton et al., 2018).

1I was classed as asteroid due to lack of a coma, and no noticable activity

3 Method Notes

To check for asteroids in the TESS data, the positions of the asteroids with time are required. For most asteroids, their orbital elements are well known, so it is a matter of looking them up and cross-matching with transients in the TESS data. However, querying APIs for timesteps of 30 min or shorter is prohibitively expensive, especially when they rate limit their calls. Python was used to make API calls to Skybot[1] to get positions of asteroids in a cone search box in RA and Dec space. As TESS sectors are 27days long, querying every 12 h is manageable. These positions are still very sparsely spaced in time compared to the TESS data, so an interpolation is needed to bridge

[1] Skybot

the gap. With TESS data coming in $\frac{1}{2}$h chunks, 24 interpolated points are needed between each API call. Assuming this is fine is justified, as asteroids move at close to a TESS pixel per TESS frame (Pál et al., 2018, 2020). For the faster TESS data, more interpolated points are needed, but a smaller the change in position between each point.

In another series of API calls, this time querying JPL Horizons[2] by object name, the orbital elements of the asteroids can be found. From these elements the type of asteroids (i.e. main belt, NEOs, Jupiter Trojan etc.) can be determined by plotting the semi-major axis, a, against the inclination, i, and the eccentricity, e, of the body. Osculating elements, such as the heliocentric distance, r_h and the distance to the observer, delta δcan also be found from Horizons. Plotting inclination against a change in these distances with time can give an idea of the motion of the bodies. The JPL queries can also be used to check the validity of the interpolation from Skybot. By geting the RA and Dec values of a named asteroid for all the timesteps interpolated, a ΔRA against ΔDec plot can be made. This was heavily rate limited, as the epoch querying did not want to play ball with date formats, but what was produced showed that the interpolation was accurate to within an arcsecond most of the time, the earliest points were the most astray, but this was still within three or four arcseconds, much smaller than the $21''$ TESS pixels.

Having interpolated these positions, there was a well sampled set of RA, Dec and time values of where these asteroids should be in the TESS data. They should show up in a pixel for a small number of frames, of order ~ 1. This is the same as a lot of other transient events, a sharp rise in brightness and then disapering quickly again. The number of frames do change, type Ia supernova will brighten is a matter of a few hours and then dim for days, while stellar flares are of similar profile by a smaller max brightness and a corrsependingly shorter decay time. Asteroids are very short, however detection pipelines are robust. These pipelines have already found the aforementioned supernova and stellar flares, the job of this work is to catch all the asteroids in the set of all the transients. To do this, catelogue matching is in order. Using the `KDTree` algorithm (Maneewongvatana and Mount, 1999) as implemented in `SciPy` (Virtanen et al., 2020) , the RA and Dec values of the interpolated asteroid positions can be queried for each of the unknown detections in the small cut of a TESS sector of interest. The largest time gap between any match is 0.1 d, this is to stop any matches that are coincident

[2]JPL Horizons

spatialy but very far apart in time and is intentionally longer than one TESS FFI. Then, if multiple detection match to the same interpolated point, a cut is made by smallest distance, in coordinate space, and any distance must be smaller than $0.01°$ ($36''$), which is within 2 TESS pixels.

From these matches, the flux of the detection can be plotted against the time of the event, this is a textbook lightcurve. Using the `Lightkurve` package (Lightkurve Collaboration et al., 2018), a Lomb-Scargle periodigram can be formed, and the most likely period can be determined. `Lightkurve` was built for TESS data (as well as for the Kepler mission), so it is the best fit for the analysis here.

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