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Constraining the Rotational and Shape Properties of Highly Inclined Centaur 2015 KZ120 Using Sky Survey Data

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ABSTRACT

Trans-neptunian objects and centaurs are widely studied distant objects that provide us with insights about the activities and evolution of our solar system. In this research, 48 TNOs and 16 CENs were studied from wide-field sky astronomical surveys from ground-based telescopes ZTF and ATLAS. From the data collected and using the Lomb-Scargle periodogram algorithm, best fit rotational periods are derived for all objects. Additionally we derive 7 g-r colours from the ZTF telescope and 15 c-o colours from the ATLAS telescope. Additionally, a new and not previously found rotational period for object 517717 (designated as 2015 KZ120) is found, $P = 0.44 \pm 0.02$ days. A provisional shape model for this object was constructed using the light curve inversion methods.

Keywords: minor planets, asteroids: general - methods: observational - techniques: photometric.

1. INTRODUCTION

The planet Earth is located exactly one astronomical unit away from the Sun, but Trans-Neptunian objects (TNOs) are minor planets located beyond Neptune's orbit at approximately 30 astronomical units away from the Sun. Even though Pluto was discovered in 1930 and classified as a planet then, in 1992, it was reclassified as the first TNO. Today, there are at least 70,000 TNOs in space presumably, but roughly 2500 of them have been identified. TNOs are diversely spread out between the Kuiper Belt and the Scattered Disk, and according to their orbital parameters and distance from the Sun they are classified as KBOs and SDOs respectively (Levison & Morbidelli 2005). KBOs' semi-major axis is approximately at 55 AU and are subdivided into the resonant TNOs and classical KBOs (called "cubewanos"). Resonant TNOs are fixed near Neptune's orbit while cubewanos are not, both presenting elliptic and near circular orbits due to a synchronization of their orbits. SDOs on the other hand, are more eccentric and inclined objects (their orbits are not circular) that are further classified as extreme TNOs (eTNOs), typical scattered disk objects, and detached objects. Overall, TNOs are believed to be primitive because of their gravitational stability and little collisions experienced. This preserves their structural composition and rotation providing great insight about the history and evolution of our solar system (Perna et al. 2010)

Unlike TNO's, Centaurs (CENs) are small icy bodies that have intercepted the orbits of bigger planets making their own orbits unstable. The composition and origin of Centaurs can be investigated through the observations of the color indices of their surfaces and the spectra. However, colours of Centaurs vary greatly making it a big challenge while developing models to explore their composition (Perna et al. 2010). A Centaur can have a diameter up to hundred of kilometers (km) but the largest Centaur to date is Chariklo. Discovered in early 1997, Chariklo is an elongated Centaur with a diameter of approximately 260 km. The first Centaur was discovered in 1920, as defined by the Jet Propulsion Laboratory, was named Hidalgo (944). Many years after the discovery of Chiron in 1977, more objects alike were discovered and Centaurs were recognized as a separate population of asteroids (Stern & Campins

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1996). Centaurs have a perihelion greater than 5.2 AU and a a semi-major axis less than 30.1 AU, according to the Jet Propulsion Laboratory (JPL Solar System Dynamics, https://ssd.jpl.nasa.gov/).

In this work, 48 TNOs and 16 CENs were studied from wide-field sky astronomical survey from ground-based telescopes. Rotation periods, light curves, g-r and c-o colours, and a possible shape for object 517717, designated as 2015 KZ120, are derived.

2. OBSERVATIONS

We present analysis of ZTF and ATLAS data for 48 TNOs and 16 Centaurs. Of these the most interesting was 2015 KZ120 (517717), a distant minor planet on a highly eccentric orbit with an orbital period of 319.44 ± 0.02 years. This object was discovered on May, 20th of 2015 by Pan-STARRS 1 at Haleakala. 517717 has a semi-major axis a = 46.73 ± 0.002 AU, a perihelion of q = 8.37 AU, an absolute magnitude H = 9.99 mag, and inclination i = 85.5 degrees. This object was observed 83 times over a duration of around 1.2 years with the ZTF telescope and 53 times over a duration of almost five months with ATLAS telescope.

2.1 ZTF data

The Zwicky Transient Facility (ZTF) is a wide-field sky survey using a camera attached to the Samuel Oschin Telescope at the Palomar Observatory in California. Designed to achieve the maximum signal-to-noise ratio and minimum beam obstruction, the ZTF telescope uses three filters; ZTF-g (blue), ZTF-r (orange), and ZTF-i (red) (Bellm et al. 2019). This telescope provides 47 square degrees of instantaneous field of view with a very fast read-out time. Using the ZTF-g and ZTF-r filter, it collects imagery data every three nights and it can take 30 seconds exposure pictures while scanning 3750 squared degrees per hour up to a magnitude of 20.5 of the entire Northern Sky (Duev et al. 2019). Our entire data contained 1405 detections in total over a period of about 1.2 years. From which 467 were ZTF-g filter detections and 938 were ZTF-r filter detections. These detections correspond to a total of 48 TNOs and 16 CENs observed. The data obtained for 2015 KZ120 (517717) from the ZTF telescope corresponds to 14 photometric detections using the ZTF-g filter and 69 photometric data points using the ZTF-r over a duration of around 1.2 years.

2.2 ATLAS data

Originally designed to detect any object that could collision with and endanger the Earth, the Asteroid Terrestrial-impact Last Alert System (ATLAS) is a two unit telescope located in Hawaii. While using a 110 megapixels CCD, ATLAS' system provides a 30 seconds exposure per picture and a 5 seconds readout of 25 percent of the sky four times during one night (Tonry 2011). Observations on a normal night can reach the 900 pictures from all cameras combined. ATLAS uses three main filters for normal asteroid search but only two of them are relevant to this work, the c (cyan) and o (orange) filters (Tonry et al. 2018). The c filter has a broad band from 420-650 nm and the o filter has a broad band from 560-820 nm (Erasmus et al. 2020). Using the list of TNOs and CENs that we extracted from the ZTF telescope, we obtained 4782 detections of 22 TNOs and 1492 detections of 7 CENs over the time span of around 3.1 years. Particularly regarding 517717, we obtained 44 photometric detections using the o-filter and 9 photometric detections using the c-filter over a duration of approximately four months.

3. RESULTS

3.1 Rotational Period and Light Curves

Given the richness of the photometric data using the ZTF-r filter, we considered viable to use it as the data set to extract a rotational period for 517717. Using the Lomb-Scargle periodogram algorithm (Lomb 1976; Scargle 1982), a best fit period was found at $P_r = 0.4485$ (± 0.02) days (see periodogram plot in **Figure 1**). This period was then folded to the light curve of 517717 using photometric data from the ZTF-r filter and is given in **Figure 2**. Consequently, light curves of remaining filters ZTF-g, c, and o were derived using the same period of $P_r = 0.4485$ (± 0.02) days.

3.2 Colors

Since finding the colours of an asteroid can inform us about their possible composition we derived colours of 2015 KZ120 (517717) from the data obtained from ZTF and ATLAS telescopes. The g-r and c-o colours were found by obtaining the difference in the average of the absolute magnitudes of each filter and removing the sun's g-r and the c-o color from each. The solar corrected g-r colour obtained for 517717 is 0.2163 (± 0.02) and it is presented in **Figure**

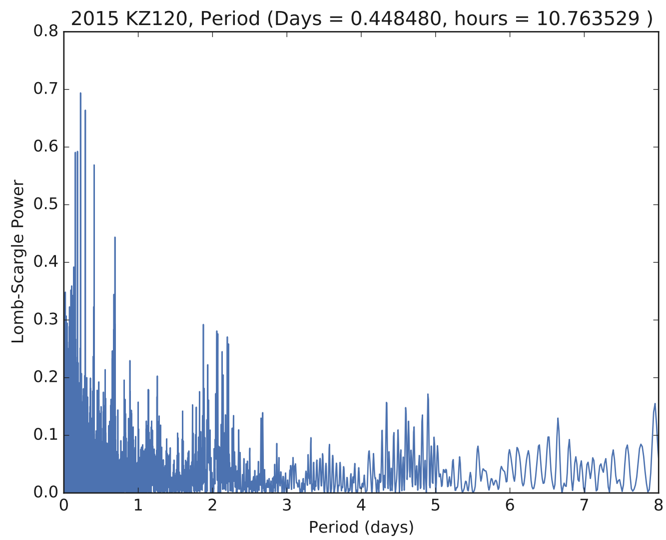

Figure 1. Lomb-Scargle periodogram showing the rotational period of 2015 KZ120 (517717) showing a period of 0.4485 days.

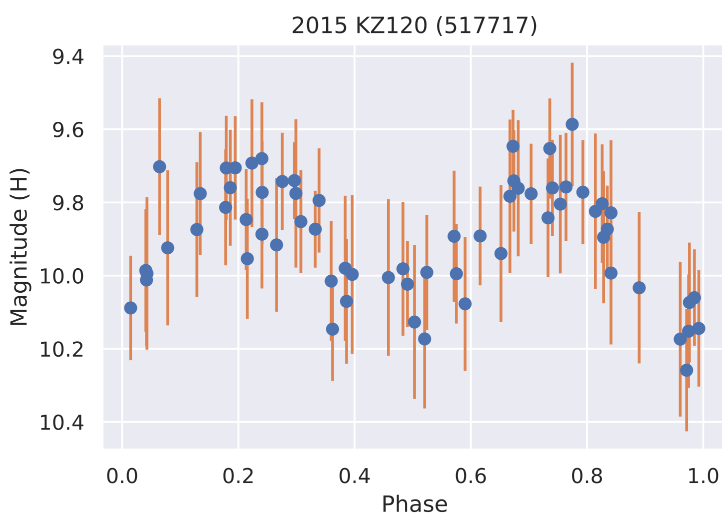

Figure 2. Light Curve of 2015 KZ120 (517717) folded to a rotational period of $P_r = 0.4485$ ($\pm$ 0.02) days.

3. The solar-corrected c-o colour obtained is 0.1965 ($\pm$ 0.02) and it is displayed in **Figure 4**. Periods, 4 g-r colours and 8 c-o colours for TNOs are listed in **Table 1**. As well as periods, 3 g-r colours and 7 c-o colours for CENs are listed in **Table 2**.

3.3 Shape Model

With the sparse data that we obtained from the ZTF and ATLAS telescopes, deriving a provisional shape model for KZ120 was possible through light curve inversion techniques. The model for light curve inversions used was taken from the Database of Asteroid Models from Inversion Techniques (DAMIT; Durech et al. 2010). This model derives the spin pole rotations, scattering parameters, and the rotational period of an object, then it uses these values to determine an approximate shape (Durech et al. 2010). The best fit light curve inversion for 2015 KZ120 (517717) using ZTF photometric data is presented in **Figure 5**. The spin pole parameters derived were longitude $\lambda = 220°$ and $\beta = -15°$. Views from the north, south, east, and west poles are presented in **Figure 6**.

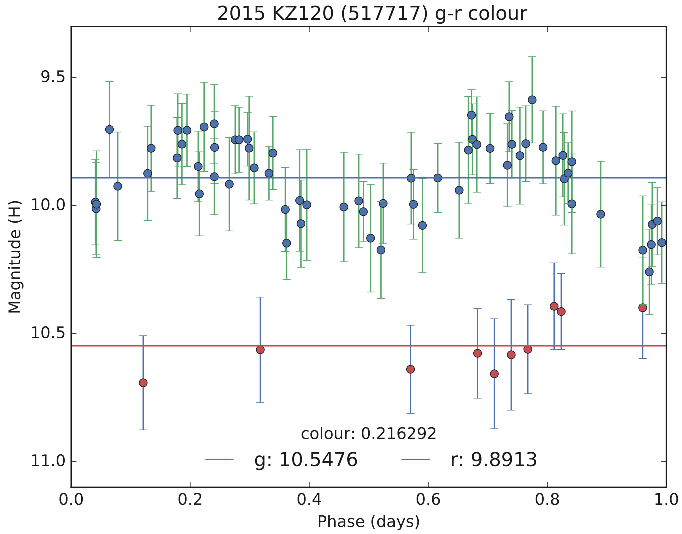

Figure 3. ZTF g-r colour of 2015 KZ120 (517717). The red circles are 14 detections and the horizontal red line represents the average absolute magnitude, both from ZTF g filter. The blue circles are 69 detections and the horizontal blue line represents the average absolute magnitude, both from ZTF r filter.

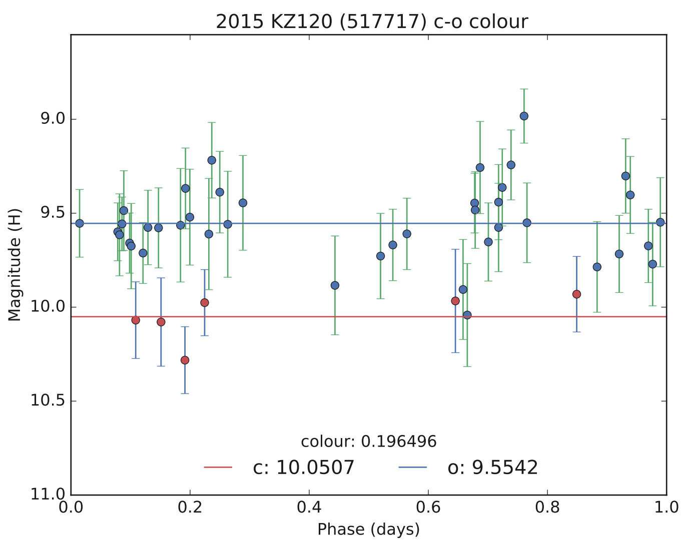

Figure 4. ATLAS c-o colour of 2015 KZ120 (517717). The red circles are 9 detections and the horizontal red line represents the average absolute magnitude, both from ATLAS c filter. The blue circles are 44 detections and the horizontal blue line represents the average absolute magnitude, both from ATLAS o filter.

DISCUSSION

As of the date that this paper was written, there are 12 known Centaurs with highly inclined orbits within 30° perpendicular to the plane of the solar system. Previous research suggests that high inclination objects must have been formed closer to the sun. (Brown et al. 2005). However, more recent research is suggesting that such objects have their origin in the Oort cloud due to their long-period comet-like orbits (Volk & Malhotra 2013). There are newer discussions suggesting that they might have originated from another star, however, these have largely been debunked (Morais & Namouni 2017; Morbidelli et al. 2020).

Table 1: Trans-Neptunian Objects

ID	Name	Diameter (km)	LCBD Period (d)	Period (d)	g-r colour	c-o colour
136108	Haumea	1303.09	0.1631	0.1631	-0.0217	0.1385
136199	Eris	2700	1.0792	1.105	0.1119	0.1039
136472	Makemake	1523.97	0.9511	0.9978	0.1719	0.2061
55636	2002 TX300	286	0.3383	0.3619	0.0102	-0.2983
38628	Huya	410.7	0.22	0.22	-	0.3381
90482	Orcus	1525.9	0.5495	0.544	-	0.1370
134340	Pluto	2339	6.3872	6.3153	-	0.2061
50000	Quaoar	908	0.3683	0.3644	-	0.5963

Table 2: Centaurs

ID	Name	Diameter (km)	LCBD Period (d)	Period (d)	g-r colour	c-o colour
2060	Chiron	271.37	0.2466	0.2188	-0.013	-0.0138
517717	2015 KZ120	44	-	0.4485	0.2163	0.1965
54598	Bienor	161.27	0.3821	0.4039	0.1175	-0.2324
95626	2002 GZ32	185.17	0.2417	0.2405	-	0.3878
281371	2008 FC76	76.84	-	-	-	0.1735
349933	2009 YF7	36.78	-	-	-	0.0320
10199	Chariklo	260.35	0.2918	0.29801	-	-0.1614

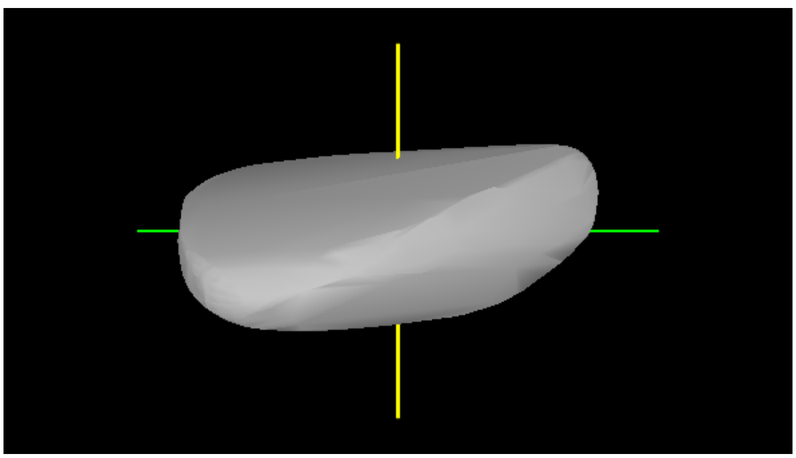

Figure 5. 3-dimensional shape model of 2015 KZ120 derived using light curve inversion. Frontal view.

The typical rotation of a Centaur usually ranges between 0.25 to 0.5 days according to the Light Curve Database (LCDB; Warner et al. 2009). With a rotational period of almost half a day, the rotation of 2015 KZ120 (517717) is typical of a Centaur. This object has a large orbital period, which makes it a challenge to derive spectral data for taxonomic classification. With the limited data available, the colours derived could give us a potential insight as to its composition. The g-r and c-o colours both indicate that this object could be classified as an S-type (Erasmus et al. 2020). If that is the case, we are looking at an highly inclined object with a possible stony-like composition. Currently, we have been able to learn only a small portion of what we could learn if we had a larger data sample. Therefore, a much larger sample is required to produce further and more meaningful results, but this is not feasible until the object's next perihelion in the 2300s.

CONCLUSION

We have analyzed photometric data from ZTF and ATLAS telescopes for 48 TNOs and 16 Centaurs. Of these objects, we present rotation periods for 8 TNOs and 5 CENs and 15 c-o/g-r colours. We also present a new rotational

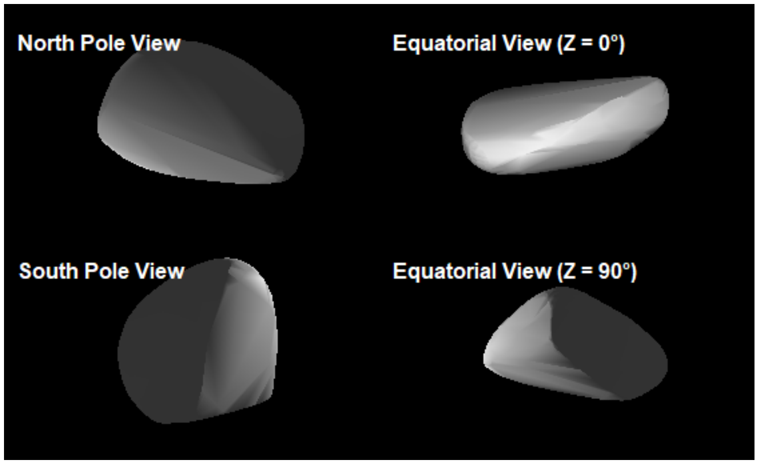

Figure 6. 3-dimensional shape model of 2015 KZ120 derived using light curve inversion. Views: North, South, Equatorial (Z = 0 degrees), and Equatorial (Z = 90 degrees).

period for object 2015 KZ120 (517717) $P_r = 0.4485$ days. Light curves are folded to the rotational period found allowing the extraction of Solar-corrected ZTF g-r and ATLAS c-o colours. Light curve inversion techniques were used to derive a provisional shape model for object 2015 KZ120 (517717). The colour values obtained suggest this object may have a stony composition, however, further observations would be needed to confirm this though no spectral data exists from this orbit.

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