

2011 HP: A Potentially Water-Rich Near-Earth Asteroid.

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Abstract

Broadband photometry was obtained to provide data on 2011 HP, a Near-Earth Object (NEO) discovered April 24, 2011. Our data was collected over a series of three nights using the 0.6 m telescope located at Table Mountain Observatory (TMO) in Wrightwood, California. The data was used to construct a solar phase curve for the object which, along with our measured broadband colors, allowed us to determine that the object most likely has a low albedo and a surface composition similar to the carbonaceous chondrite meteorites, which tend to be water-rich. 2011 HP appears to have a Xc type spectral classification, determined by comparison of our rotationally averaged colors (B-R=1.110 \pm 0.031 mag; V-R=0.393 \pm 0.030 mag; R-I=0.367 \pm 0.045 mag) against the 1341 asteroid spectra in the SMASS II database. We assumed a double-peaked lightcurve and were able to determine a period of 3.95 \pm 0.01 hr. Assuming a low albedo as suggested by the solar phase curve, we estimate the diameter of the object to be ~250 meters, and given that the minimum orbital intersection distance (MOID) equals 0.0274 AU, we recommend that this particular meteorite be re-classified as a Potentially Hazardous Asteroid by the Minor Planet Center.

Introduction

Asteroid impact craters dot the surface of our Earth as a visual reminder of the ever-present possibility of collisions of space debris with our home planet. These collisions, though rare, are a very real occurrence, and the tracking of these NEOs, or Near-Earth Objects is an essential component in the security of human civilization as a whole. Currently, astronomers are not only observing objects that are very large in size, but are also focusing on asteroids that older technology was unable to track and detect, but that still pose a very real danger. The 'National Aeronautics and Space Administration Authorization Act of 2005' revised the size parameter of space objects that should be detected, tracked, and cataloged to determine their danger to the Earth to objects 140 meters and greater, equivalent to roughly one and one-half football fields (Hutchison and Bailey, 2005). These space objects are tracked and the data is analyzed in order to determine their threat to the Earth, as the first line of defense against possible collisions. The summer 2011 photometry team did just that. In addition to the subject of this report, 2011 HP, over the course of the summer, our team observed, imaged, and analyzed data from asteroids that all pose a potential hazard to life as we know it.

Near Earth Objects are comprised of two main types, asteroids and comets. A Near Earth Object is defined as having a perihelion distance of less than 1.3 AU, and if the object happens to be a comet, its' period of orbit must be less than 200 years. Perihelion distance refers to the point in the object's orbit in which it is closest to the sun. An AU, or Astronomical Unit is equal to 149,598,000 kilometers, or roughly the distance from the Earth to the Sun. There are two main groups of Near Earth Objects that distinguish between Near Earth Comets, or NECs, and Near Earth Asteroids, or NEAs. There are then three different sub-groups of NEAs, dependent not only on the perihelion distance, but also on the aphelion distance, or the point in the object's orbit in which it is furthest from the Sun. These three sub-groups of NEAs are referred to as the Atens, Apollo, and Amor asteroids. The Atens and Apollo families orbits' cross the orbit of the Earth, which makes them a threat. The Amor asteroids do not currently cross the orbit of the Earth, but may someday, so they are not considered an immediate threat. Finally, there is one last group of Near Earth Asteroids, potentially hazardous asteroids, or PHAs.

To qualify as a potentially hazardous asteroid, the Earth minimum orbital intersection distance, or Earth MOID, must be less than 0.05 AU. The MOID refers to the distance between the two objects at the closest point between each bodies' respective orbit. MOID is used to determine the risk of collision, and is also measured for other planets. In addition to the MOID being less than 0.05 AU, to be classified as a potentially hazardous asteroid, it must also have an absolute magnitude of less than 22.0. We shall return to the concept of absolute magnitude later. As of August 11, 2011, there are 1243 NEOs classified as Potentially Hazardous Asteroids (NASA).

Taxonomy

Taxonomy is the science of classifications, and for our purposes, we use taxonomy to physically characterize the surface composition of asteroids. One of the parameters that we use to define the asteroids is their spectral profile. We use the spectrum of light reflected from the surface of the asteroid to assign a classification. Currently, there are two widely used asteroid spectral classification systems, the Tholen classification and the SMASS classification.

Tholen Spectral Classification

The Tholen classification system depends on the wavelength of the spectra reflected from the asteroid, and on the albedo of the object (Tholen, 1989). Albedo is, put simply, the reflectivity of the asteroid, which directly corresponds to how bright the asteroid appears. The Tholen classification is a database containing broadband spectral data from 978 asteroids, all collected during the Eight Color Asteroid Survey in the 1980's. Spectra obtained from unclassified objects is compared to the 978 asteroids in the Tholen taxonomy database. The Tholen system of classification established 14 types of asteroids, however, the vast majority fall into three main groups: S-group, C-group, and X-group. The S-group asteroids are composed of siliceous, or “stony” magnesium and iron silicates. The majority of the S-group asteroids exhibit a medium albedo. The C-group are dark, carbon-rich asteroids, and as such, their albedo tends to be lower. The dark surface reflects less light, so the objects appear dimmer. The C-group asteroids are the most common of all of the asteroid groups. The C-group also includes several smaller sub-types, including the B, F, G, and C-types. In addition, the X-group of asteroids also contains several smaller sub-classes, the E-type, M-type, and P-types. Unlike the other two main divisions of S-group and C-group, the X-group asteroids do not share similar compositions, only similar spectra. Also, these sub-classes have varying albedos, with the E-type exhibiting the highest mean albedo of all asteroid types, and the P-type exhibiting a lower albedo. Furthermore, some asteroids that do not have albedo data available are assigned the X-group classification. Lastly, there are six smaller, rarer classes, the A, D, T, Q, R, and V-types (Binzel et al. 2002).

SMASS Spectral Classification

SMASS taxonomy is a more recent and more expansive classification system. SMASS, or Small Main Belt Asteroid Spectroscopy Survey, started in 1990 on 1447 asteroids utilizing higher resolution than the previous Eight Color Asteroid Survey used for Tholen taxonomy. Phase two of the survey was conducted on 1341 asteroids in 2002, which is the current database we use for comparison of unknown taxonomy. While the SMASS system generally keeps asteroid classifications similar to Tholen taxonomy, the major difference between the two is that the SMASS system is independent of albedo. The three major groups, S, C, and X from Tholen taxonomy remain, but each of the main groups include several sub-groups, and transition groups. The S-group in SMASS taxonomy includes A, Q, R, K, L, and S-types, in addition to several transition types, Sl, Sk, Sr, Sq, Sa, which are asteroids that belong to the main S-group, but also exhibit characteristics of the other letter types. The C-group includes the B and C-type asteroids, but also includes transition types Cg, Ch, Cgh, and Cb. The X-group is comprised of X-type asteroids and transition types Xc, Xe, and Xk. Finally, there are five additional types that do not fall under the main three groups: T, D, Ld, O, and V-types (Binzel et al. 2002).

Phase Angle

Phase angle refers to the angle from the light incident on the asteroid to the light reflected from the object, which in our case is the Sun to the object to the observer on Earth. The phase angle can vary between 0 degrees, in which the sun and the Earth are both on the same side of the object and each is linear with the asteroid, and 180 degrees, in which the Sun and the Earth are on opposite sides of the object. The phase angle directly affects the magnitude, or brightness of the asteroid.

Asteroid Brightness

There are three main ways to describe the magnitude of the asteroid: apparent magnitude, reduced magnitude, and absolute magnitude. One important fact is that the lower the value of the magnitude of the object, the brighter the object. Apparent magnitude (parameter M) is just that—how bright the asteroid appears to be to the observer, taking into account

the effects of the distance of the asteroid to the Sun (parameter r) and to Earth (parameter Δ), and the phase angle of the asteroid (parameter α). Parameters F_x and F_x^0 refer to the flux observed and a reference flux, respectively, in the passband the measurements are taken. Reduced magnitude (parameter $H(\alpha)$) is the brightness of the asteroid assuming the distance of the asteroid to the Sun and to the asteroid to the Earth are each 1 AU, and only taking into account the phase angle. Absolute magnitude (parameter H) is the brightness of the asteroid if the object was 1 AU from both the Sun and the Earth, and if the phase angle was zero. We can use absolute magnitude to estimate the diameter of the asteroid. The absolute magnitude equation introduces one more parameter into the equation, G , which is a slope parameter, describing the steepness or shallowness of the phase curve (British Astronomical Society).

$$M = -2.5 \log_{10} (F_x / F_x^0) \quad (1)$$

Apparent Magnitude Equation

$$H(\alpha) + M - 5 \log(r\Delta) \quad (2)$$

Reduced Magnitude Equation

$$H = H(\alpha) + 2.5 \log[(1-G)\Phi_1(\alpha) + G\Phi_2(\alpha)] \quad (3)$$

$$\Phi = \exp[-A_i(\tan 0.5(\alpha))^{B_i}], \text{ where } i=1 \text{ or } 2$$

$$A_1 = 3.33 \quad B_1 = 0.63$$

$$A_2 = 1.87 \quad B_2 = 1.22$$

Absolute Magnitude Equation

Phase and Light Curves

The final bit of background I would like to offer is regarding the two different types of curves plotted for asteroids, phase curves and light curves. Both curves are plots of brightness of the asteroid, but each plots brightness with respect to different parameters. Phase curves plot the brightness of the object with respect to time. Our phase curve plots the reduced magnitude of the asteroid with respect to the phase angle. The phase curve is used in determination of the albedo of the object and gives clues to the surface composition of the asteroid. Light curves also plot the brightness of the asteroid, but the brightness is plotted as a function of time. Light curves are used in the determination of the period of rotation of the asteroid. Our light curves plot the absolute magnitude of the asteroid against the rotational phase. We analyze the variance of absolute magnitude over time in order to find a pattern of the minimum and maximum magnitude variation in order to determine a period of rotation.

Procedure

Our group operates the 0.6 meter telescope, a specialized Cassegrain reflector (Richey-Chretien reflector). We use a 1K CCD camera, which we cryo-cool with liquid nitrogen. The CCD, or charge-coupled device, converts light captured at the shutter after passing through Bessel BVRI filters and transmits that light into electrons, which are then read and translated into an image we can evaluate. The Bessel BVRI passbands filter photons during our imaging of asteroid targets. BVRI refers to the wavelengths of light and their respective colors that each filter allows through, with B representing blue, V representing visual, R representing red, and I for infrared. We use these to determine color of the asteroid, which we describe with three different colors, B-R, V-R, and R-I. All of the bandwidths of these filters, or passbands are between 30 and 100 nanometers, thus they are referred to as broadband filters. The entire procedure is known as broadband photometry.

Broadband Spectral Analysis of 2011 HP

We conducted three nights of broadband photometry on a NEO called 2011 HP. 2011 HP was discovered on April 24, 2011. We obtained two nights of Bessel BVRI broadband photometry at Table Mountain Observatory on May 27 and 28, and one night of broadband photometry strictly in the Bessel R-band on June 1, 2011. Our imaging of 2011 HP on the first two nights utilizing the BVRI filters produced spectral color values for each of the filters. In order to compare our colors to the SMASS II spectral classification system database, we performed a rotational average on each of the colors, which means we took the mean of the color values during the course of the asteroid's rotation (*Table 1*). These colors were then compared to colors of cataloged asteroids contained in the SMASS II database in order to find objects analogous to 2011 HP. Out of the data for the two nights, there were 5 close fit asteroids selected to plot their relative reflectance against 2011 HP (*Table 2*). All of the asteroids selected for comparison belong to the X-group spectral classification, with a mixture of X-types and Xc-types. Figure 1 presents the spectral color comparison of 2011 HP against the 5 analogous asteroids. The red dot and lines represent our results for 2011 HP, with a solid dot at the wavelength respective to the R-passband because we normalize our results respective to the R-band. The red lines are representative of the magnitude of the B-R, V-R, and R-I colors, including the standard deviation in our rotationally averaged results. All of the analogs are a close fit, however, the Xc-type was the most compatible of the two types of analogs considered. Thus, we feel that we can say with a fair amount of certainty, according to our comparison of spectral color data, 2011 HP appears to belong to the Xc-type asteroid spectral class (Hicks et al. 2011).

UT Date	B-R [mag]	V-R [mag]	R-I [mag]
2011 05 27	1.129+/-0.012	0.400+/-0.011	0.387+/-0.064
2011 05 28	1.073+/-0.019	0.388+/-0.041	0.355+/-0.033
mean:	1.110+/-0.031	0.393+/-0.030	0.367+/-0.045

Table 1: Rotationally Averaged Colors

MISFIT	OBJECT NAME	TAXONOMIC CLASS (THOLEN)	CLASS (BUS)
0.288	92 Undina	X	Xc
0.337	261 Prymno	B	X
0.383	413 Edburga	M	X
0.399	409 Aspasia	CX	Xc
0.410	348 May		X

Table 2: Best-fit SMASS II Spectral Analogs to 2011 HP

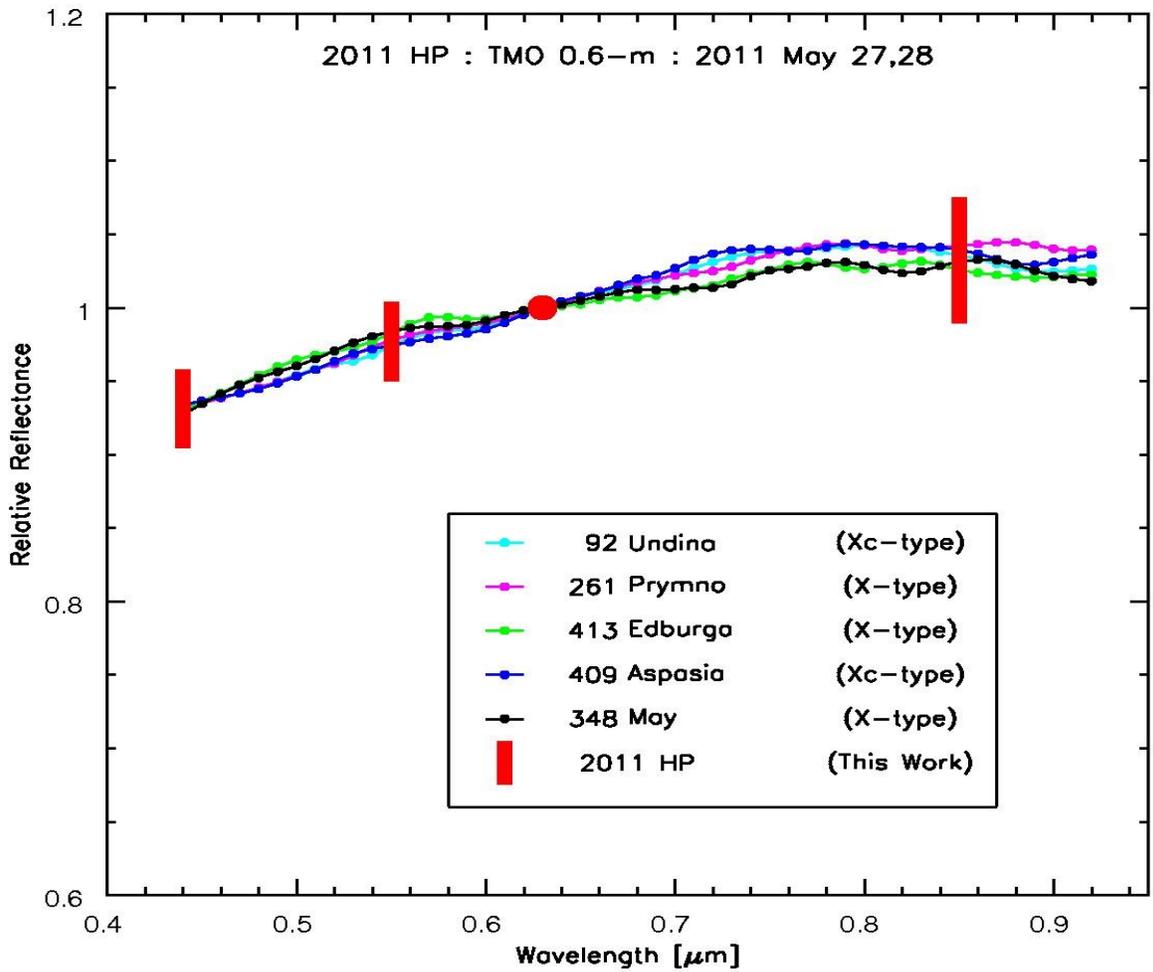


Figure 1: Spectral Color Comparison of 2011 HP

Solar Phase Curve Data

Our data allowed us to construct a solar phase curve for 2011 HP (Figure 2). The solar phase curve plots the reduced magnitude of the asteroid with respect to the corresponding observed solar phase angle. We plotted a best fit for the target at an absolute magnitude relative to the R-passband (H_R —Figure 2) of 21.39, and a phase parameter, G, of -0.07. The phase parameter is consistent with a low albedo. In addition, our spectral profile of 2011 HP is quite similar to spectral profiles of meteorites belonging to the carbonaceous chondrite classification. The low albedo and spectral profile suggest that 2011HP may be analogous to carbonaceous chondrites. Several classes of carbonaceous chondrites are thought to be water-rich, thus we theorize that 2011 HP may be a water-rich asteroid. This is also in line with our assertion that 2011 HP belongs to the transition Xc-type spectral class—with the Xc-types being a transition of the carbon-rich C-type asteroids.

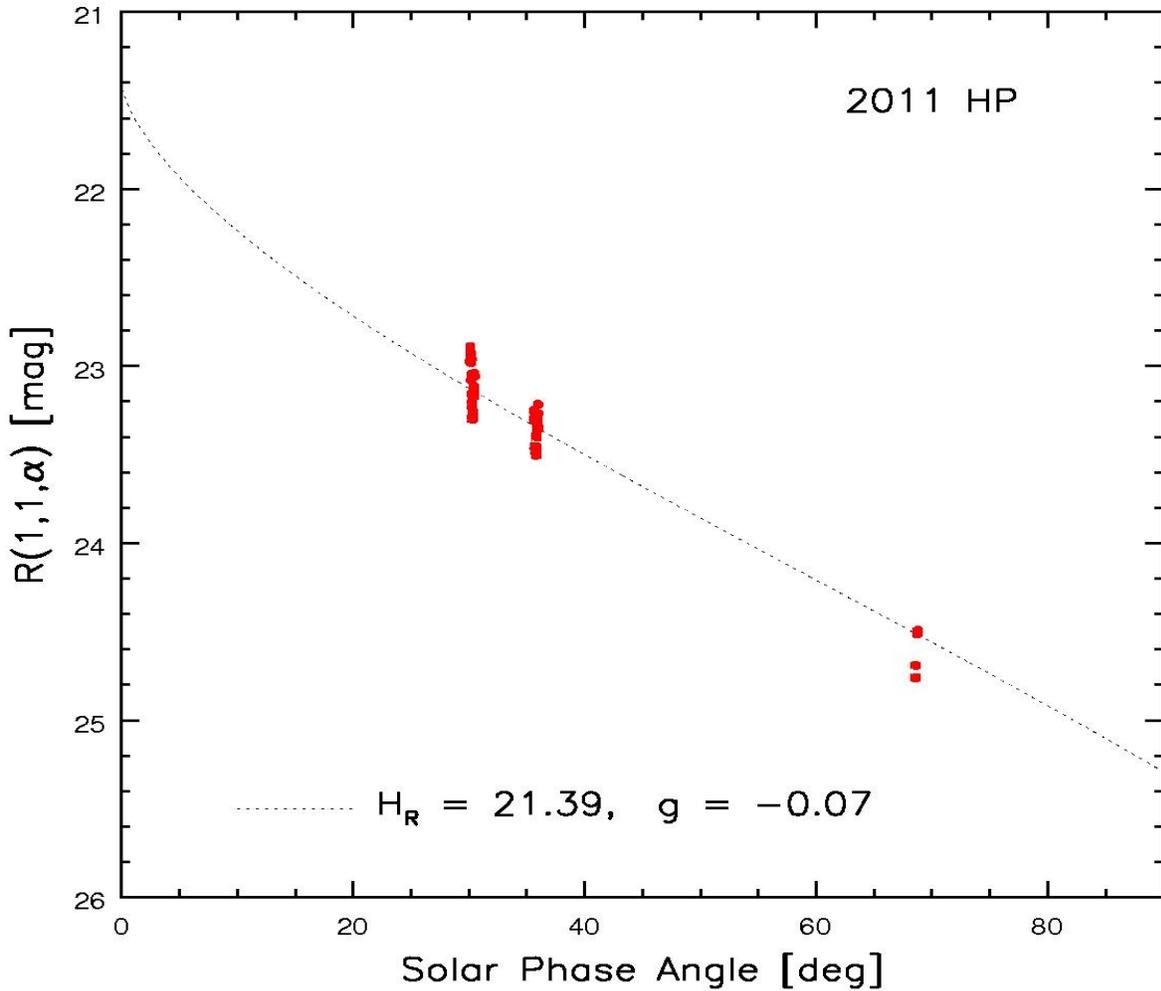


Figure 2: Phase Curve for 2011 HP

Light Curve for 2011 HP

The data we obtained from our three nights of observations also allowed us to plot a light curve for 2011 HP (Figure 3). This plots absolute magnitude with respect to time. We found a period of rotation of 3.95 hours, plus or minus 0.01 hours was the best fit for our data, as determined by the deterioration of the fit curve in other graphs with varying period of rotation selections. A slight modification of 0.01 hours breaks the fit of the curve, so we are able to present our result for 2011 HP's period of rotation with a fair amount of certainty. This period of rotation, however, is slower than expected given the absolute magnitude with relative to the V-passband of 21.8 mag, for which we expect a median period of 13.7 minutes. This, in combination with a given MOID of 0.0274 AU, and an estimated calculated diameter of approximately 250 meters, leads to our recommendation that 2011 HP be re-classified as a potentially hazardous asteroid.

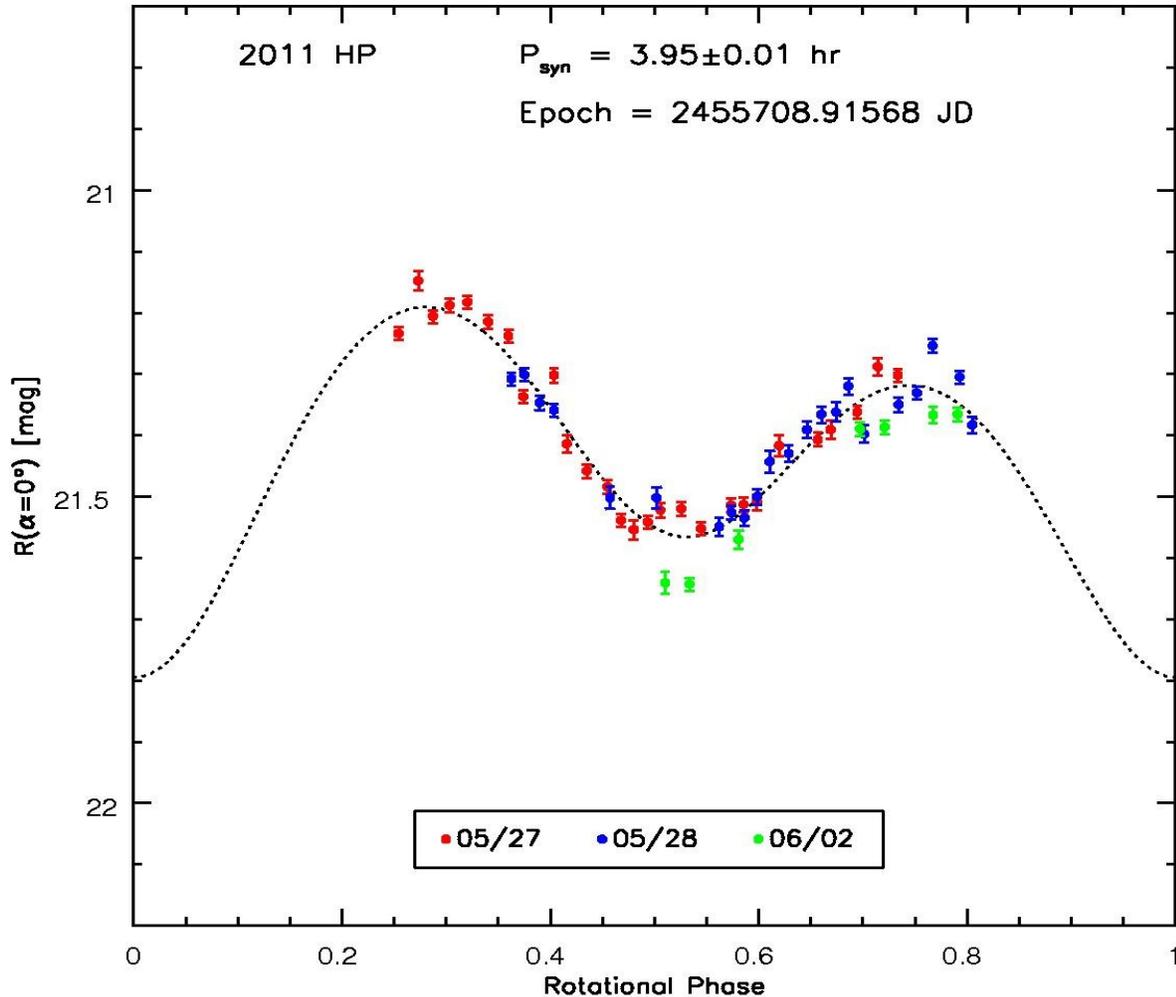


Figure 3: Light Curve for 2011 HP

Future Research

As for the future of research on 2011 HP, it appears that the data we collected over this three day period, along with the other astronomers' data from this short observational window is all we will have for several years to come. 2011 HP will not be considered an observable target again for Table Mountain Observatory until May of 2019.

Acknowledgments

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