Spectral Characterization of 2020 SO

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1. Abstract

2020 SO was discovered by the Pan-STARRS planetary defense survey and originally designated as a near-Earth object (NEO). Based on its low relative velocity to the Earth, 2020 SO was reclassified as an artificial object. We

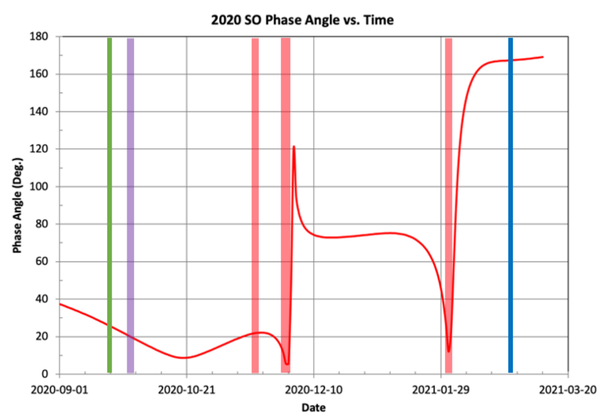
present the results of our characterization of 2020 SO to verify its true nature. Three different telescopes were used to spectrally characterize the object in visible and near-infrared wavelengths. Our results show that 2020 SO is indeed an artificial object associated with the Surveyor 2 mission to the Moon.

2. Introduction

2020 SO was discovered by the Pan-STARRS planetary defense survey on September 17, 2020 [1]. Originally classified as a near-Earth object, the object's artificial nature became evident due to its low velocity relative to Earth and changes to its orbit about the Sun [2]. 2020 SO is thought to be a Centaur rocket body (R/B) from the launch of the Surveyor 2 mission to the Moon based on a backward propagation of its orbit. We characterized 2020 SO using a range of ground-based optical and near-infrared telescopes to constrain its true nature.

3. Observations

We used three different telescopes to characterize 2020 SO. When the object was faint (V~21.5), we used the twin 8.2-meter Large Binocular Telescope (LBT) located on Mt. Graham, Arizona, to obtain Sloan photometric color data. To compare these color spectra with other Centaur R/Bs in Earth orbit, we obtained visible wavelength spectra (0.35-0.9 µm) using RAPTORS 1 0.6-meter telescope located on the University of Arizona campus [3]. The last telescope we used was the NASA IRTF to characterize on three epochs 2020 SO in the near-infrared wavelength (0.7-2.5 µm) when it was brighter than V. Mag. ~19.5 [4]. Figure 1 shows the observation dates for various telescopes along with phase angle and visual magnitude. Table 1 shows observational circumstances for the campaign.



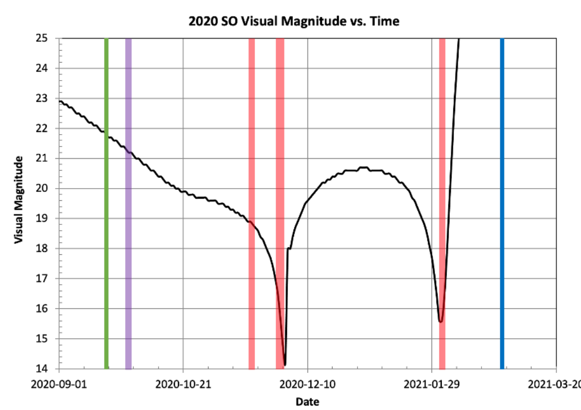


Figure 1. (Left) Plots of Phase Angle (Sun-Target-Earth angle) vs. Time and (Right) Visual Magnitude vs. Time for 2020 SO. The green line indicates the approximate date when the object was capture into the Earth-Moon system and the blue line indicates the date of its departure. The purple line indicates the date of LBT observations, and the red lines indicate the dates of observations with the NASA IRTF.

Date (UTC)	Target	V. Mag.	Phase Angle	Range (km)	Range (LD)	Telescope	Aperture	Instrument	Type of Observations	Wavelength Range	Spec. Res.
28-Sep-20	2020 SO	21.5	20.5	3420234	8.898	LBT	8.2-m	LBC	Sloan griz colors	0.464-0.90 µm	R=4
10-Oct-20	NORAD ID: 3598	~6-8	76.8	745	0.002	RAPTORS I	0.6-m	FLI 4220	Visible spectroscopy	0.438-0.950 µm	R~30
22-Oct-20	NORAD ID: 6155	~6-8	15.5	1300	0.003	RAPTORS I	0.6-m	FLI 4220	Visible spectroscopy	0.438-0.950 µm	R~30
17-Nov-20	NORAD ID: 4882	~6-8	80.6	4900	0.013	RAPTORS I	0.6-m	FLI 4220	Visible spectroscopy	0.438-0.950 µm	R~30
17-Nov-20	2020 SO	19.3	21.9	1160736	3.020	NASA IRTF	3.0-m	SpeX	Near-IR spectroscopy	0.69-2.54 µm	R~100
29-Nov-20	2020 SO	15.7	5.4	300896	0.783	NASA IRTF	3.0-m	SpeX	Near-IR spectroscopy	0.69-2.54 µm	R~100
30-Nov-20	2020 SO	14.9	5.5	152894	0.398	NASA IRTF	3.0-m	SpeX	Near-IR spectroscopy	0.69-2.54 µm	R~100
30-Nov-20	NORAD ID: 4882	~6-8	62.4	34000	0.088	NASA IRTF	3.0-m	SpeX	Near-IR spectroscopy	0.69-2.54 µm	R~100
2-Feb-21	2020 SO	15.8	23.8	221541	0.576	NASA IRTF	3.0-m	SpeX	Near-IR spectroscopy	0.69-2.54 µm	R~100

Table 1. Table of observational circumstances for characterizing 2020 SO

4. Results

Due to the relative faintness of the target (V~21.5), initial characterization observations following its discovery were made with the twin 8.4-meter Large Binocular Telescope (LBT). We obtained Sloan (g'r'i'z') broadband colors of

2020 SO using the Large Binocular Camera to constrain its rotational properties and visible spectral slope. The color 'spectrum' shows a red spectral slope distinct from those of S- and C-type asteroids [5]. We compared the color spectrum of 2020 SO with low resolution (R~30) visible wavelength (0.45-0.95 µm) spectra of two Centaur R/Bs (NORAD IDs 3598 and 6155) obtained using the RAPTORS 0.6-meter telescope. The two datasets are consistent with slight differences in spectra slope. 2020 SO is redder than the Centaur R/Bs. These spectral slope differences could be due to phase angle difference between the two observations, the different orbital environments to which they have been exposed, time on orbit, or differences of their physical characteristics.

Diagnostic absorption bands in the near infrared (0.75-2.5 µm) have traditionally been used to characterize surface properties of solid surfaces. The SpeX instrument on the NASA Infrared Telescope Facility (IRTF) was used to obtain a low-resolution (R~100) near-IR spectrum (0.70-2.5 µm) of 2020 SO. The object was observed on three dates as it moved closer to the Earth. The spectra show a general rise in reflectance in the range of ~0.70-1.63 µm and a neutral spectral slope beyond that. The visible colors obtained by the LBT are consistent with the near-IR data. Three spectrally dominant materials are identified on the Centaur R/B consistent with those used for the Surveyor 2 mission. These include: a stainless-steel R/B body; white polyvinyl fluoride (PVF) which covered the aft bulkhead radiation shield; and aluminized mylar which insulated the forward bulkhead of the R/B. The red spectral slope between 0.69-1.63 µm is consistent with the spectrum of stainless steel. Also detected were three absorption features in the near-IR spectrum of 2020 SO centered at 1.43±0.02 µm, 1.72±0.01 µm, and 2.29±0.01 µm. The laboratory spectrum of pure PVF obtained by the USGS was used to verify its presence on 2020 SO. The PVF lab spectrum shows a sharp rise in reflectance <0.5 µm and a negative spectral slope beyond that. Also detected are four absorption bands between 1.0-2.5 µm. The band centers of three of the deepest absorption bands are 1.43±0.02 µm, 1.71±0.01 µm, and 2.30±0.01 µm, consistent with those seen on 2020 SO. The lab spectra of aluminized mylar are still under investigation to look for affinities to 2020 SO. Our goal is to create a mixing model using these three spectrally significant components as a next step. As part of our final characterization efforts, we observed Centaur R/B (NORAD ID: 04882) with the NASA IRTF, which is broadly consistent with 2020 SO.

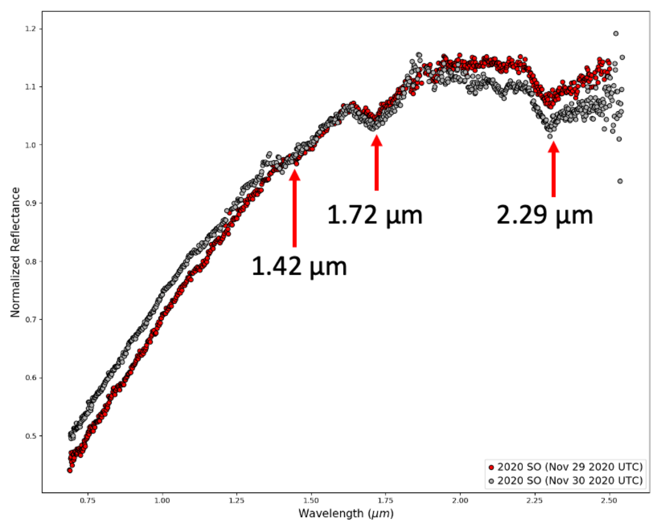


Figure 2. Near-IR (0.7-2.5 µm) spectrum of 2020 SO obtained on Nov. 29, 2020 (red) and Nov. 30, 2020 (gray) showing a sharp rise in reflectance between 0.7-1.75 µm and three weak absorption bands superimposed on this red continuum. The location of these three absorption bands is indicated by the red arrows.

Object/ Material	Band I Center (µm)	Band II Center (µm)	Band III Center (µm)
PVF (Lab)	1.432±0.001	1.716±0.001	2.307±0.001
2020 SO	1.430±0.02	1.720±0.01	2.290±0.01

Table 2. Band centers of the three absorption bands detected on telescopic near-IR spectrum of 2020 SO along with those on laboratory spectrum of polyvinyl fluoride (PVF).

5. ACKNOWLEDGMENTS

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6. REFERENCES

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