New near-infrared spectra of (594913) 'Aylo'chaxnim, the first known asteroid orbiting inside Venus orbit

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Abstract

The asteroid (594913) 'Aylo'chaxnim, formerly designated as 2020 AV2, is the only one known to go around the Sun inside Venus orbit. Because of its orbit, the surface of this asteroid is being constantly modified by the high temperature, by the strong solar wind irradiation that characterizes the innermost region of the Solar system, and by high-energy micrometeorite impacts. Thus, it represents an extreme case when compared with typical near-Earth asteroids.

We obtained near-infrared spectral observation using NASA's Infrared Telescope Facility (IRTF) equipped with the SpeX instrument. The spectra show a band minimum at **BI_{min} = 1. 05 ± 0.03 μm.** This new result is consistent with our previous results (obtained with NOT and WHT telescopes) and **confirms an olivine rich or an olivine dominated composition.** We did not detect the 2 μm feature corresponding to pyroxene (up to the level of our error bars). There is a **strong variation of the near-infrared spectral slope** between the spectra observed on different nights that can be caused by the large phase angle and the shape of the object.

Introduction

Numerical simulations [1,2] predicted the existence of a population of small bodies that is orbiting entirely inside Venus orbit. They could represent about 0.22% of the steady-state near-Earth asteroids (NEAs). These asteroids are called Vatiras (in analogy with Atira-class NEAs) or Interior to Venus Orbit Objects. The only one known up to now was discovered on January 4, 2020 at Zwicky Transient Facility [3] and it was called (594913) 'Aylo'chaxnim.

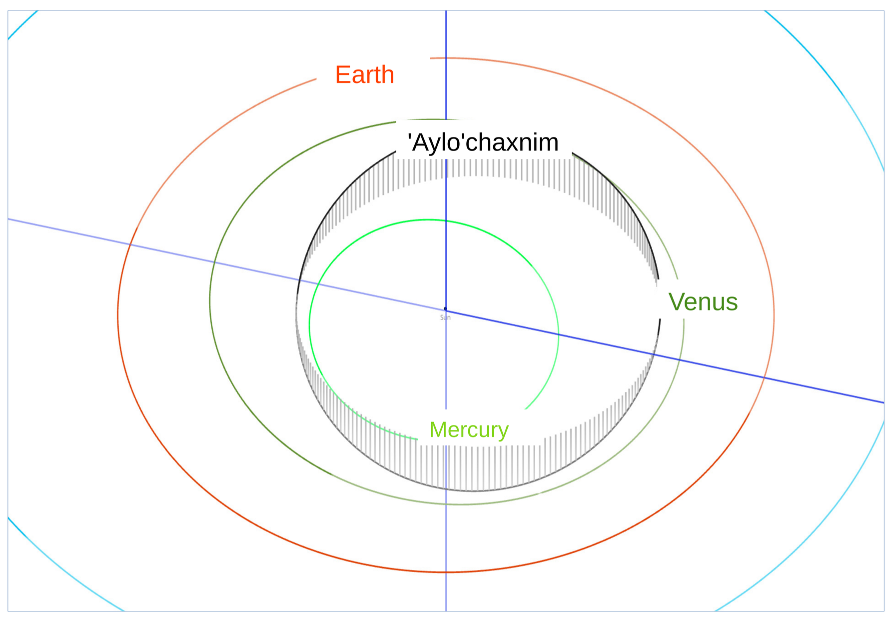


Fig. 1 Orbit of 2020 AV2 (black) compared with the orbit of inner planets.
Diagram generated with JPL Small-Body Database Browser

Orbital parameter		value±1σ uncertainty
Semimajor axis, a (au)	=	0.55541670±5.7E-8
Eccentricity, e	=	0.17707297±9.0E-7
Inclination, i (°)	=	15.86857312±6.1E-5
Longitude of the ascending node, Ω (°)	=	6.7024±0.00026
Argument of perihelion, ω (°)	=	187.3290±0.00031
Mean anomaly, M (°)	=	327.2155±0.00045
Perihelion, q (au)	=	0.45706742±5.1E-7
Aphelion, Q (au)	=	0.65376597±6.7E-8
Absolute magnitude, H (mag)	=	16.21±0.775

Table 1. Heliocentric Keplerian orbital elements of 2020 AV2 and their 1σ uncertainties. The orbit determination is referred to epoch Epoch 2459800.5 (2022-Aug-09.0) TDB (Barycentric Dynamical Time, J2000.0 ecliptic and equinox). Source: JPL Small-Body Database (solution date, 2022-Feb-14 04:50:02).

The aim of our studies is to characterize this body spectroscopically in order to understand its compositional properties, the extreme phase angle effect on the observations, and the consequences of the environment (strong solar wind and micro-meteorites bombardment) on its surface.

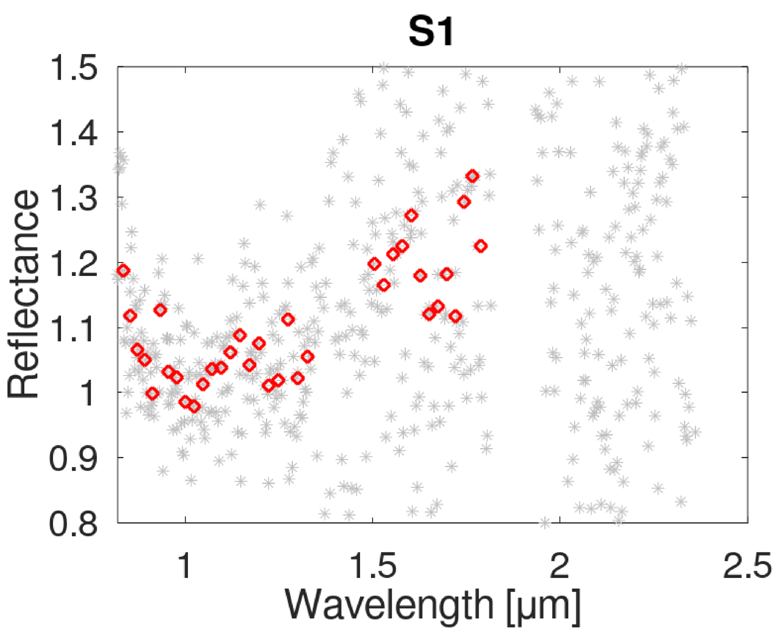
New near-infrared spectra

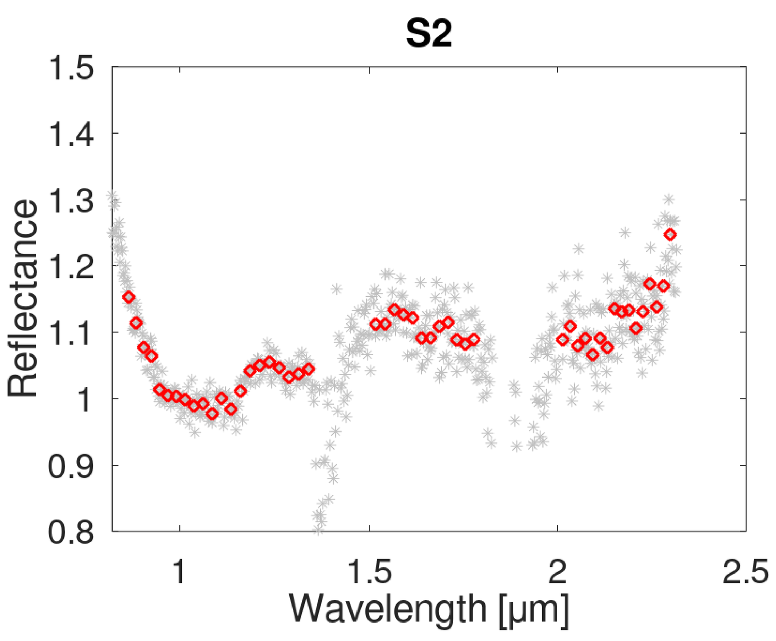
The ground-based observations for this object are difficult because of its orbit so close to the Sun. The best time to observe it is when the object is at the **maximum solar elongation, which is about 40°.** It can only be observed for ~30 min at an **airmass of 2 to 3.5, and a phase angle around 80°.**

Observational circumstances

Spec. ID	Elon.[°]	r [A.U.]	Δ[A.U.]	α[°]	V [mag.]
S1	39.7	0.654	0.867	82.3	17.9
S2	39.6	0.653	0.874	81.7	17.9
S3	39.4	0.652	0.889	80.6	17.8

Spec. ID	Average UT	Average airmass	Total exp. [sec]	Number of exp.
S1	2021-08-11T14:38:38	2.8	1912	16
S2	2021-08-12T14:37:21	2.9	1793	15
S3	2021-08-14T15:05:12	3.0	836	7





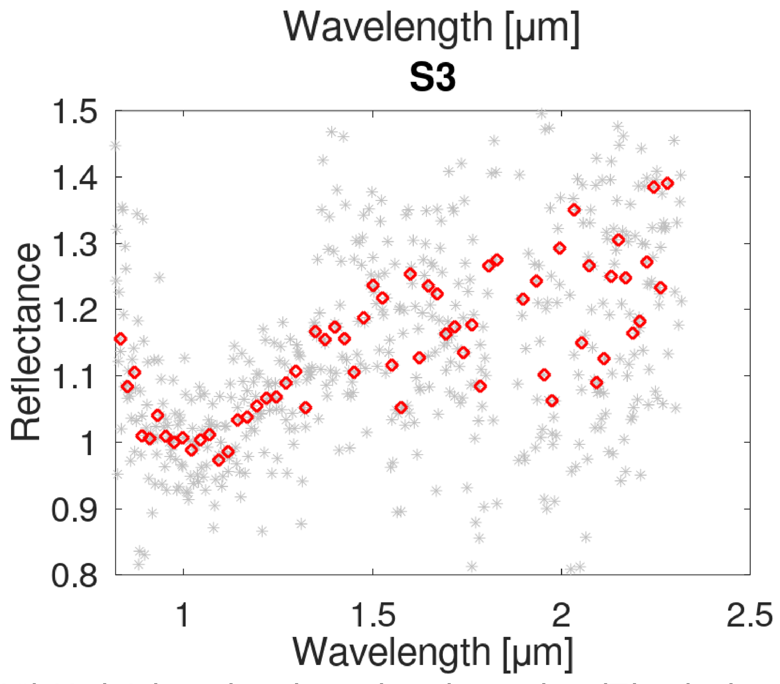


Fig 2. (Top Left) Observational circumstances for (594913) 'Aylo'chaxnim, the solar elongation (Elon.), the heliocentric distance (r), the geocentric distance (Δ), the phase angle (α), and the apparent magnitude (V) of (59413) 'Aylo'chaxnim during the observations. The remaining plots are the spectral curves S1, S2, S3 obtained with IRTF/SpeX during August 2021. The gray points represent the data obtained after Spextool (the pipeline used to reduced the spectral images). The red ed points were obtained by binning every 9 points from the original data (the gray ones). The data is normalized at 1 μm.

We used the **NASA-IRTF/SpeX instrument**, with the PRISM mode and a slit of 0.8 x 15 arcsec. This configuration allowed us to cover **the 0.82 – 2.5 μm spectral interval.** The spectral images were acquired in the ABBA mode. The data reduction was performed using Spextool [4]. We could observe only one solar analog, a G2V star, namely GSC 01881-01236, which was the best suited in terms of apparent vicinity and time constraints.

The object was observable **before the start of the morning twilight.** We noticed a **wide apparent magnitude variation between the nights**, thus the signal to noise ratio for the spectra S1 and S3 is lower compared with the one for S2.

Results

All three ner-infrared spectral curves show the wide feature characteristic of olivine at 1 μm. The observations obtained during the three nights are identical up to 1.3 μm. They also match with the s

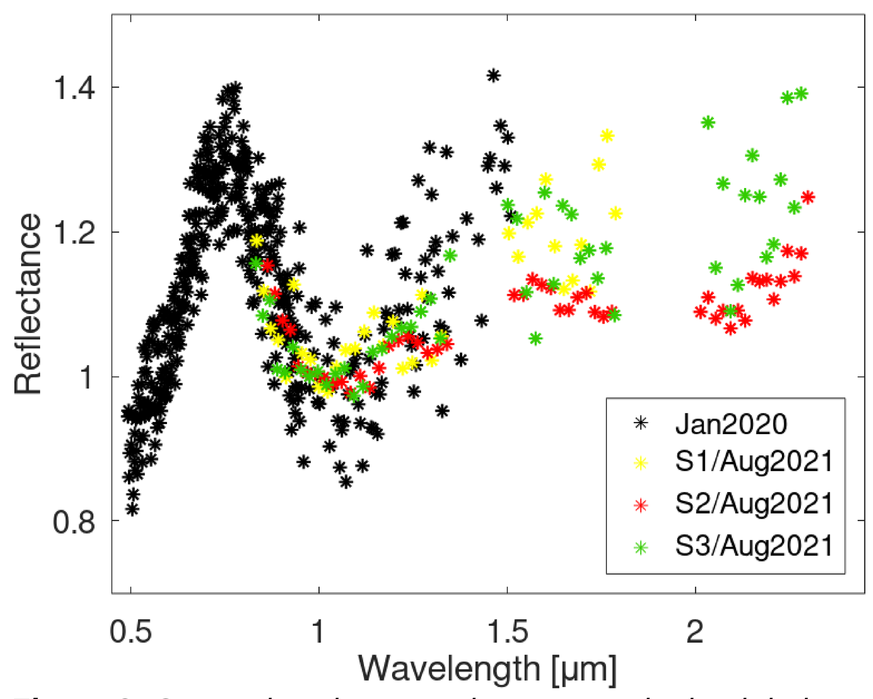


***Figure 3:** Comparison between the spectra obtained during January 2020 [5], and those obtained during August 2021. All spectra are normalized to 1 μm.*

- The S1 and S3 spectra are redder compared to the S2, for wavelengths longer than 1.3 μm. This can be quantified in terms of slopes over 1 – 2 μm spectral range:
  - $Slope_{S1}$ = 0.32 **± 0.04 μm^{-1},**
  - $Slope_{S2}$ = 0.17 **± 0.02 μm^{-1}**
  - $Slope_{S3}$ = 0.26 **± 0.04 μm^{-1}**

  This can be due to phase angle effect (~80°) and the orientation of different asteroid surface features toward the observer. We also note that the effect is correlated with the apparent magnitude of the object (the brightest magnitude correspond to the smallest slope)

- A thermal tail is identifiable for S2. As shown in [5], the surface temperature at aphelion is 330 ± 10 K (computed using an average albedo of p_v = 0.23).

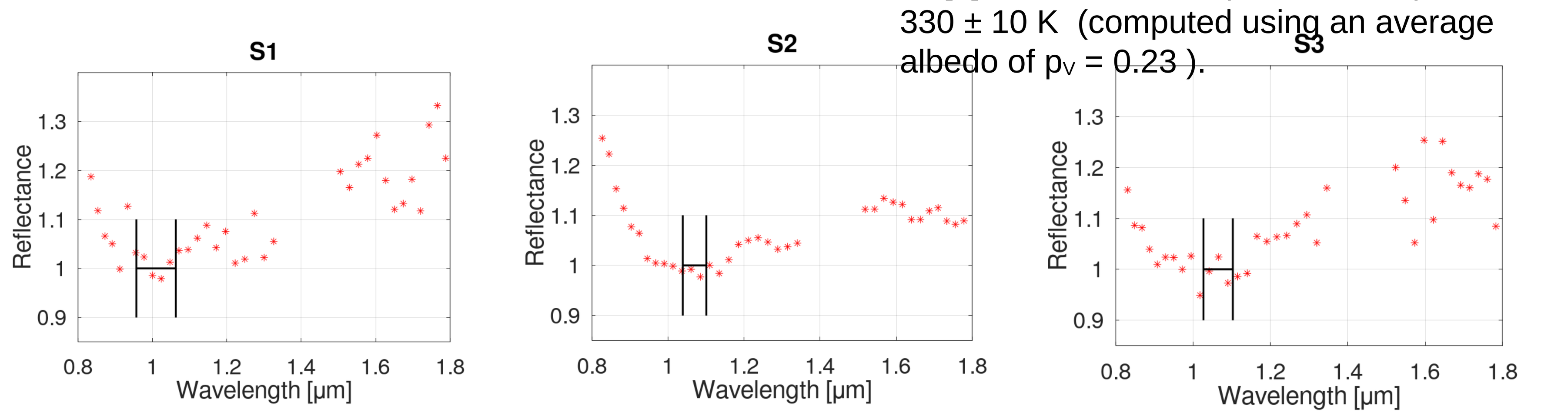


***Figure 4:** The band minima found for the three spectra:*
BI_{min}^{S1} = 1. 010± 0.53 μm, BI_{min}^{S2} = 1. 070± 0.031 μm, BI_{min}^{S3} = 1. 065± 0.038 μm

The position for BImin (band I minimum) is shown in Fig. 4. Altough this computation is affected by the low signal to noise ratio of the spectra, the average **BI_{min} = 1. 05 ± 0.03 μm** is consistent throughout the set of three spectra.

The value of **BI_{min}** is consistent with the olivine rich composition proposed based on 2020 observations [5]. The S2, which has the best signal to noise ratio shows **a possible feature at 1.25-1.30 μm**, which can be attributed to olivine

We noticed that S2 does not show the 0.9 μm feature which corresponds to the complex wide 1 μm band of olivine. This feature tends to disappear at high temperatures [6].

Comparison with other published results

- Bolin et al. (2022) [7] published the visible spectrum and color indexes obtained with the Keck telescope. Their results are compatible with an S-type asteroid, and the visible spectrum shows a BI_{min} around 0.95.
- While **all reported spectral results agree on the presence of 1 μm band**, there is a mismatch between the position of the band minimum.
- Nevertheless, the presence of the 1 μm band suggests an albedo p_v = 0.23, which is the average for an S or A-types asteroids. Thus**, the estimated size for this object is 1.6 ± 0.6 km**.

Conclusions

Methods:

- We performed spectral observations of (594913) 'Aylo'chaxnim using NASA-IRTF/SpeX instrument over the 0.82 – 2.5 μm spectral interval
- The observations were performed under extreme conditions at an airmass of 2 to 3.5 and a phase angle around 80°. This is due to the fact that the maximum solar elongation of this object is 40°.

Findings:

- ✓All three near-infrared spectral curves show the wide feature characteristic of olivine at 1 μm. This result agrees with the previously published data.
- ✓There is a strong spectral slope variation between the spectra observed on different nights. This can be accounted by the observing geometry.
- ✓The spectra show a band minimum at BI_{min} = 1. 05 ± 0.03 μm. This new result is consistent with the previous result and confirms an olivine rich or an olivine dominated composition.
- ✓We did not detect the 2 μm feature corresponding to pyroxene (up to the level of our error bars).
- ✓Both our results and the results available in the literature indicate an object with an equivalent size of 1.6 ± 0.6 km with olivine on its surface.

References: [1] Greenstreet et al.; Greenstreet et al.; Icarus, 217, Issue 1, p. 355-366, (2012) [2] Granvik et al. Icarus, 312, p. 181-207, 2018; [3] Bolin et al. MPEC (2020); [4] Cushing et al. PASP (2004); [5] Popescu et al. MNRAS (2020); [6] R. Burns, Cambridge University Press 1993; [7] Bolin et al. MNRAS (2022); Ip, Wing-Huen et al. The Astrophysical Journal Letters, 935, 1, id.L6, 4 pp., 2022

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