



Spectroscopic and photometric properties of (98943) 2001 CC21, the target of Hayabusa2# space mission



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Abstract

The near-Earth asteroid (98943) 2001 CC21 is the flyby target of Hayabusa2 extended mission, nicknamed Hayabusa2# (SHARP: Small Hazardous Asteroid Reconnaissance Probe). The observations performed with ground-based telescopes are a key science input for the scientific investigation of this object. We obtained a detailed characterization during the 2022, and 2023 when this object came to apparent magnitudes as bright as 16.5. We report the average colors $(g-r) = 0.662 \pm 0.033$ mag, $(i-r) = 0.182 \pm 0.054$ mag and $(i-z_s) = -0.044 \pm 0.060$ which are compatible with an S-complex classification. The detailed visible to near infrared spectrum we obtained show a Sq type. We also found a mineralogy similar with LL ordinary chondrite meteorites and estimate the surface composition.

Introduction

The Hayabusa2 spacecraft has completed the nominal mission operation of returning samples from the asteroid (162173) Ryugu. The near-Earth asteroid (98943) 2001 CC21 is the Hayabusa2 extended mission (nicknamed Hayabusa2#) flyby target during 2026 [1]. In this context, the observations performed with ground-based telescopes are a key science input for the scientific investigation of this object. They are also important for designing the engineering approach of spacecraft to this near-Earth object. The acquired data will contribute to the scientific results, allowing a direct comparison between ground-based telescopic observations and in-situ measurements obtained by the onboard instruments of Hayabusa2, the multi-band imager ONC-T and the near-infrared spectrometer.

The visible spectrum of 2001 CC21 was first reported in 2004 by [2]. On this first observation, the reflectance spectrum of asteroid was classified as a L-type (Bus taxonomy), which has a red slope and it is relatively flat around 1 μ m. The L-type is a peculiar class of asteroids, and only 2% among all spectrally observed asteroids belong to it. During the same observational window, [3] reported a visible to near-infrared spectrum of this asteroid. Based on their spectral curve, they classified it as an Sk-type (Bus taxonomy), less red spectral slope and a stronger 1- μ m absorption band characteristic of olivine-pyroxene compositions.

A detailed characterization of the photometric and spectroscopic properties was made during its favorable observational window during 2022 and 2023, when the asteroid was at the brightness apparent magnitude of 16.5. Our objectives were: 1) to classify this asteroid based on high signal to noise (SNR) spectrum; 2) to estimate the surface composition; 3) to characterize the space-weathering effects on its surface; 4) to check for possible large-scale inhomogeneity; 5) to determine its rotational properties. The observations were performed using various telescopes from Observatorio del Roque de los Muchachos, including the 10.4m Gran Telescopio Canarias (GTC), and the NASA 3.0 Infrared Telescope Facility (IRTF).

Observations

Spectroscopy:

The visible spectrum of (98943) 2001 CC21 was obtained on the night of December 1, 2021, using the OSIRIS camera-spectrograph at the (GTC). We used the 1.2" slit and the R300R grism (dispersion of 7.74 $\text{\AA}/\text{pixel}$ for a 0.6" slit) covering the 0.48 - 0.92 μ m wavelength range.

The near-infrared spectrum was obtained with the IRTF SpeX instrument, with the 1.6" x 15" slit, in the low resolution mode (prism). The setup covered the spectral interval 0.8-2.5 μ m.

The following well known spectroscopic solar analog stars were used: a) SA 98-978 and SA 102-1081 for the visible wavelengths; b) HD 75488 and Hyades 64 for the NIR region. They were in the apparent vicinity of the asteroid at the observing time (the reason for which we did not use the same ones for the visible and NIR data calibration).

Spectro - photometry

We used the 1.52 m Telescopio Carlos Sánchez equipped with the MuSCAT2 instrument for obtaining simultaneous photometric observations in four visible broad-band filters, namely g (400 - 550), r (550 - 700), i (700 - 820) and z_s (820 - 920) nm. At the end of each of the four channels there is an independently controllable CCD (charge couple device) camera (1024 x 1024 pixels), having a pixel size of ~ 0.44 "/pixel and a FoV of $7.4' \times 7.4'$.

The data reduction was made using the PHOTOMETRYPIPELINE - PP (Mommert 2017). For astrometric registration we used the GAIA - DR2 catalog. The PanSTARRS catalog was used for all photometric calibration. The accuracy of these calibrations was dependent of the number of stars imaged by each exposure.

Designation	UT_start	V mag	r_helioc[a.u.]	Δ_{geo} [a.u.]	α [°]	Total time [h]
98943	2022-02-08T03:21:51	18.0	1.0347	0.2416	71.8	0.3871
98943	2022-02-17T04:03:07	18.0	1.0009	0.2247	80.3	2.331
98943	2022-02-24T05:04:20	18.2	0.9741	0.2219	87.5	0.7654
98943	2022-12-23T00:15:07	18.3	1.2203	0.3234	37.5	6.9258

Table 1: TCS observations circumstances

Light - curves

Besides the observations obtained with TCS, we carried out an extensive campaign for the photometry of (98943) 2001 CC21.

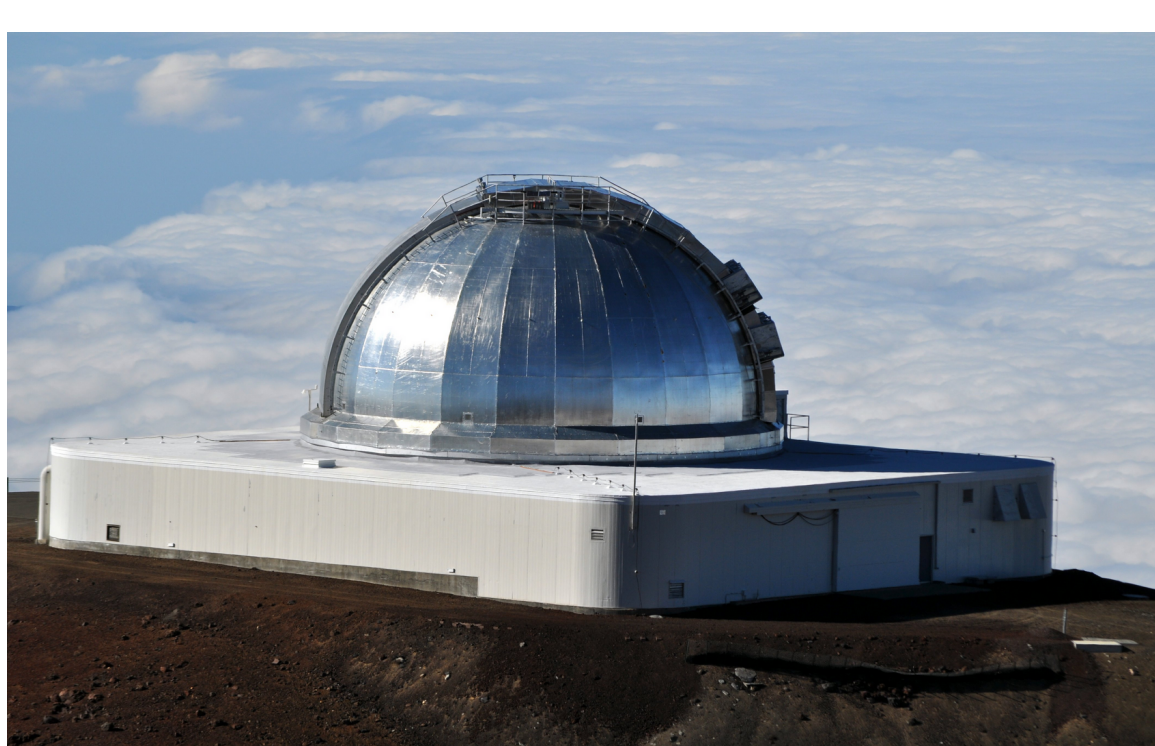
The object has been observed with the TTT1 and TTT2, the two telescopes with an aperture of 0.80-m located at the Teide Observatory, during 15 nights between 08/02/2023 and 06/03/2023, with a total observing time of more than 60 hours. A set of u'g'r'i'z' images has been obtained for some of these nights also.

We also used IAC 80 (an 80 cm aperture telescope) during seven nights between November 25, 2022 and March 1, 2023. Some lightcurves were also gathered as a professional -amateur collaboration during February 2023 using a 25 cm aperture telescope.

The telescopes



The 10.4m Gran Telescopio Canarias (GTC, GRANTECAN)



The 3.0m NASA/IRTF (Infrared Telescope Facility)



The 1.52m Telescopio Carlos Sánchez

Results

Spectro - photometry:

The average colors shown in Table 2 are compatible with an S-type asteroid. This classification was also obtained using machine learning algorithms with a well known training sample.

During the four nights of observations the colors varied only within the photometric uncertainty. No other variation was noted.

On the night of December 23, 2022 we observed the object for 6.9 hrs. The simultaneous lightcurves obtained with g, r, i, and z_s broad band filters doesn't indicate any large scale heterogeneity.

Night	(g-r) [mag]	(g-r)_err [mag]	(r-i) [mag]	(r-i)_err [mag]	(i-z_s) [mag]	(i-z_s)_err [mag]	(r-z_s) [mag]	(r-z_s)_err [mag]
220207	0.662	0.05	-	-	-	-	0.083	0.047
220216	0.638	0.051	-	-	-	-	0.128	0.055
220223	0.661	0.093	-	-	-	-	0.141	0.099
221222	0.686	0.059	0.182	0.054	-0.044	0.06	0.135	0.058
Average	0.662	0.033	0.182	0.054	-0.044	0.06	0.122	0.034

Table 2: The median colors obtained during each night of observations performed with Muscat2/TCS

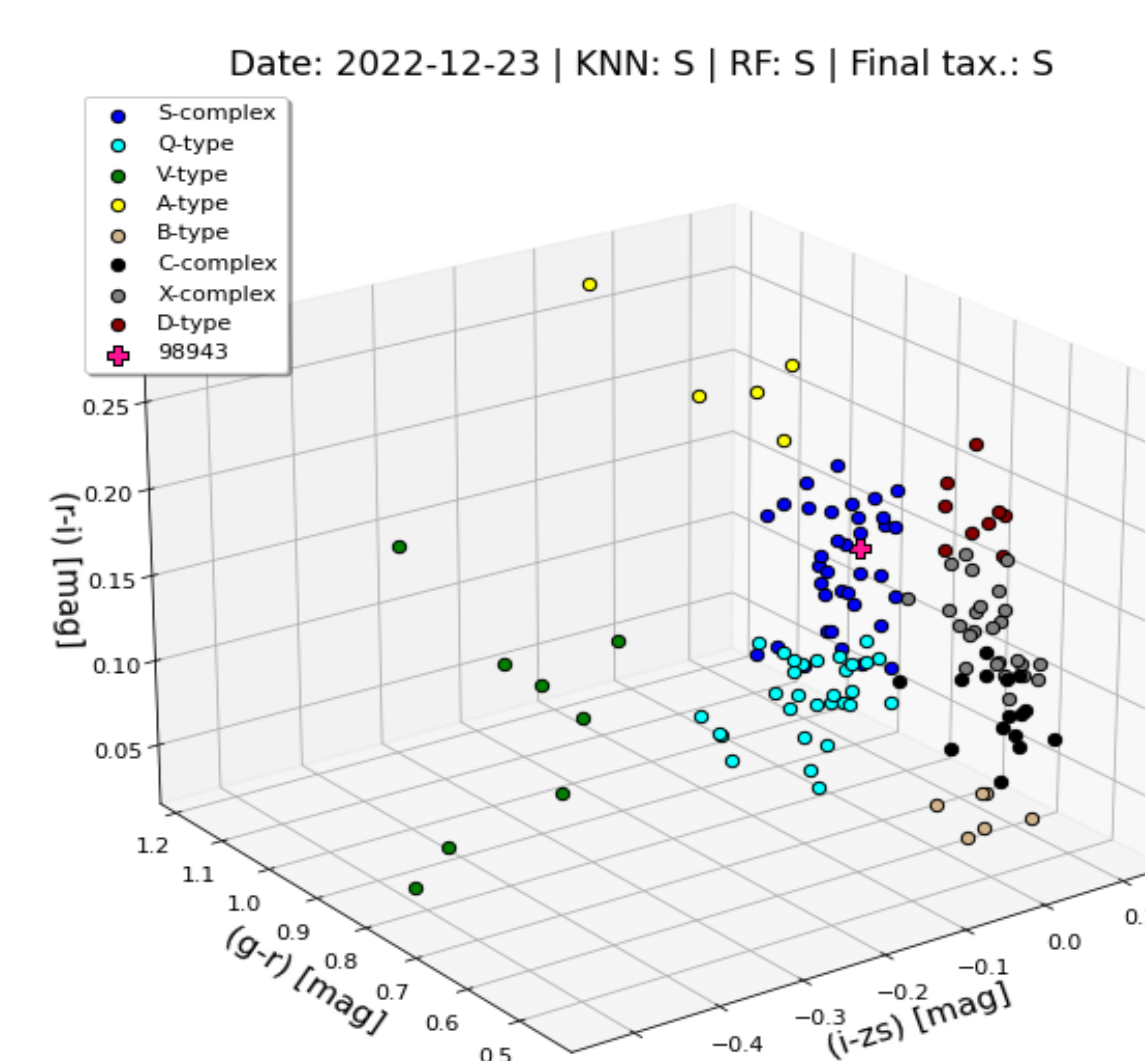


Fig. 2 The (g-r) vs. (r-i) vs. (i-z_s) (right panel) color-color diagram of the 155 objects with known spectral classification, used as training data. The value corresponding to (98943) 2001 CC21 are shown with magenta. The title shows the classification according to the K nearest neighbors (KNN) and Random Forest (RF) algorithm.

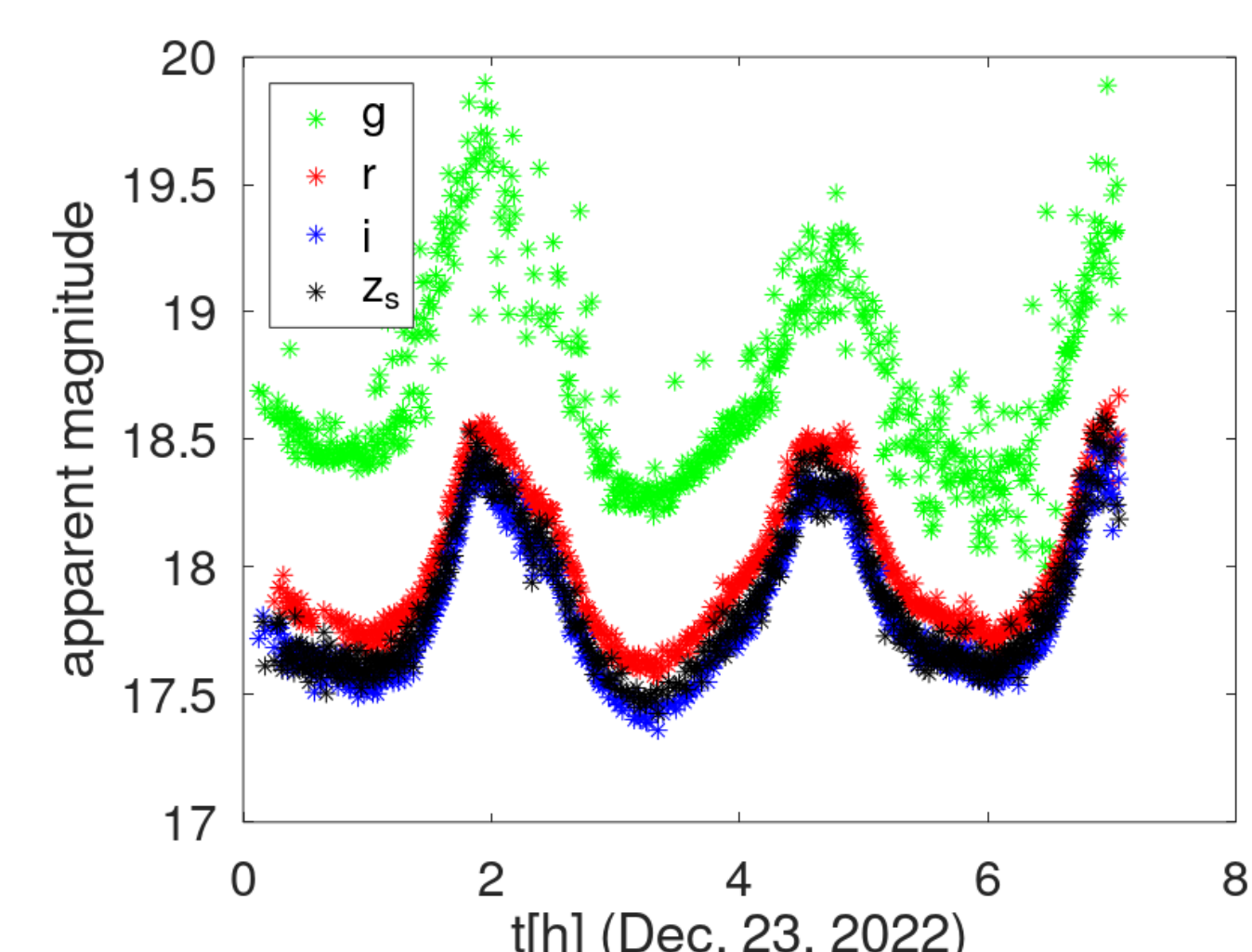


Fig. 3 The simultaneous lightcurves obtained with g, r, i, z_s filters. The data corresponding to the g band has a low SNR due to the magnitude limit of the instrument.

We also determined the B-V = 1.142 mag, and V-R = 0.461 mag by using 2.5m Isaac Newton Telescope at La Palma, Spain.

Spectroscopy:

The visible and the near-infrared part of the spectrum were merged together based on normalization over the common wavelength region. We notice that the curve shapes overlap.

The obtained visible to near-infrared spectrum is classified undoubtedly as an Sq type. This classification agrees also with the broad one obtained from colors (S-complex)

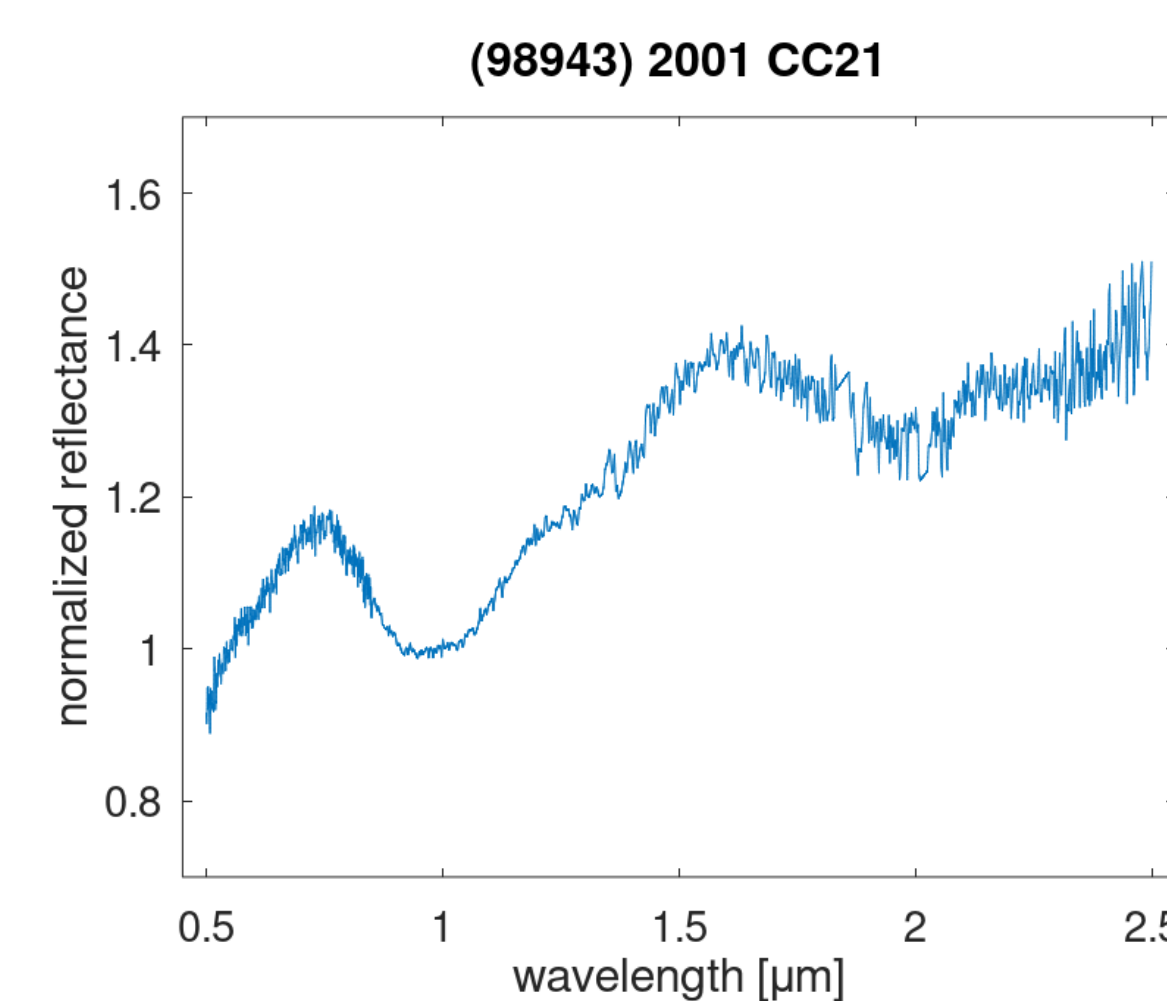


Fig. 4 The merged visible to near-infrared spectrum of (98943) 2001 CC21.

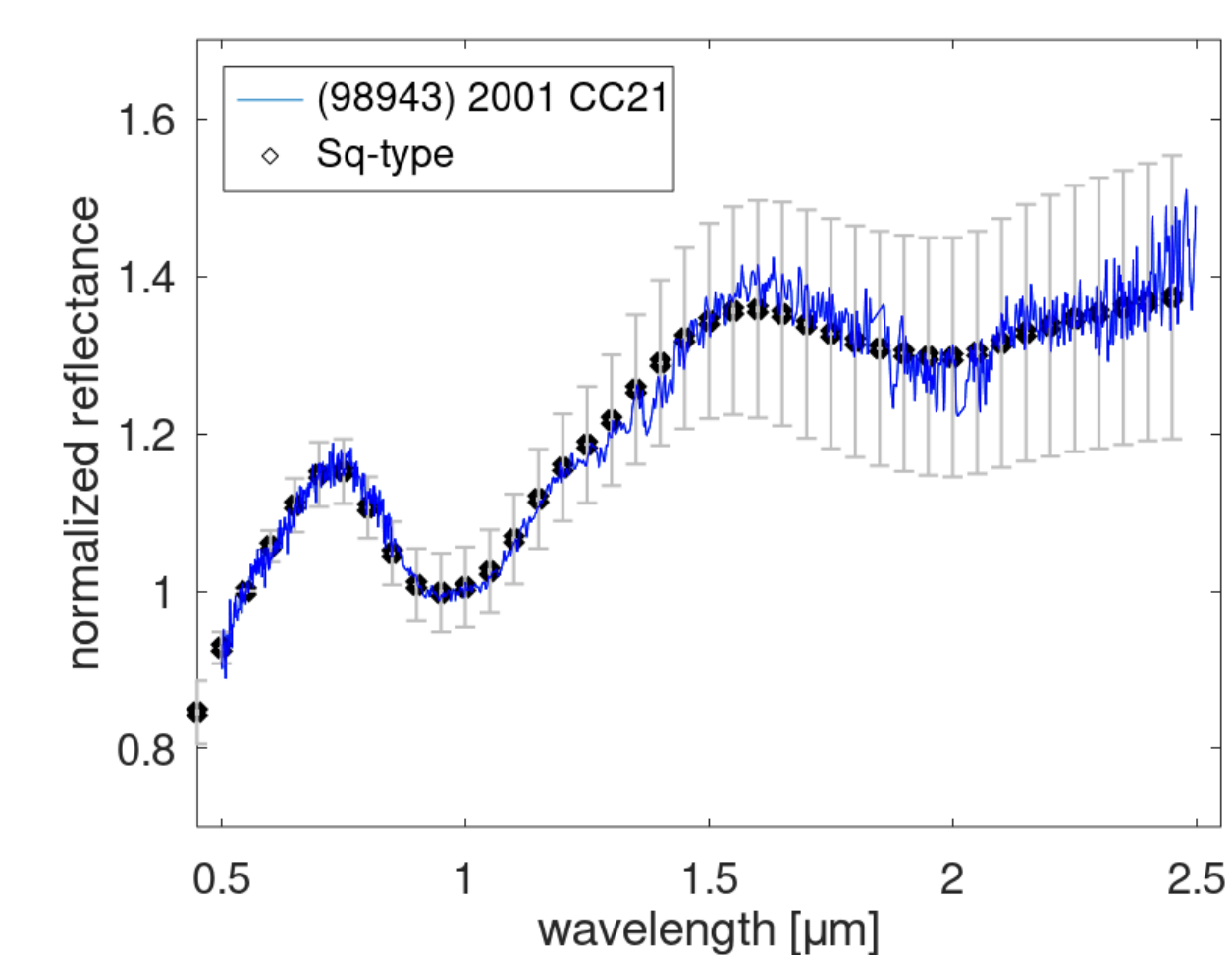


Fig. 5 The comparison between Sq-type and the spectrum normalized at 1.25 μ m.

Mineralogical models:

The mafic mineral abundances can be derived using the absorption features of olivine and pyroxene. Thus we applied the models summarized by Reddy et al. 2015 (see reference there in) to compute the band minima (Blmin, Bllmin), band centers (BIC, BllC), band area ratio (BAR) and band depths. Consequently, we are able to infer the olivine - pyroxene ratio, and percentages of fayalite and festerite.

Blmin [μ m]	0.9559 ± 0.0087
Bllmin [μ m]	1.9962 ± 0.0073
BIC [μ m]	0.9911 ± 0.0087
BllC [μ m]	1.9996 ± 0.0148
BAR	0.5196 ± 0.1629
ol/(ol + px)	0.60
Fa[mol %]	28.5
Es[mol %]	23.4

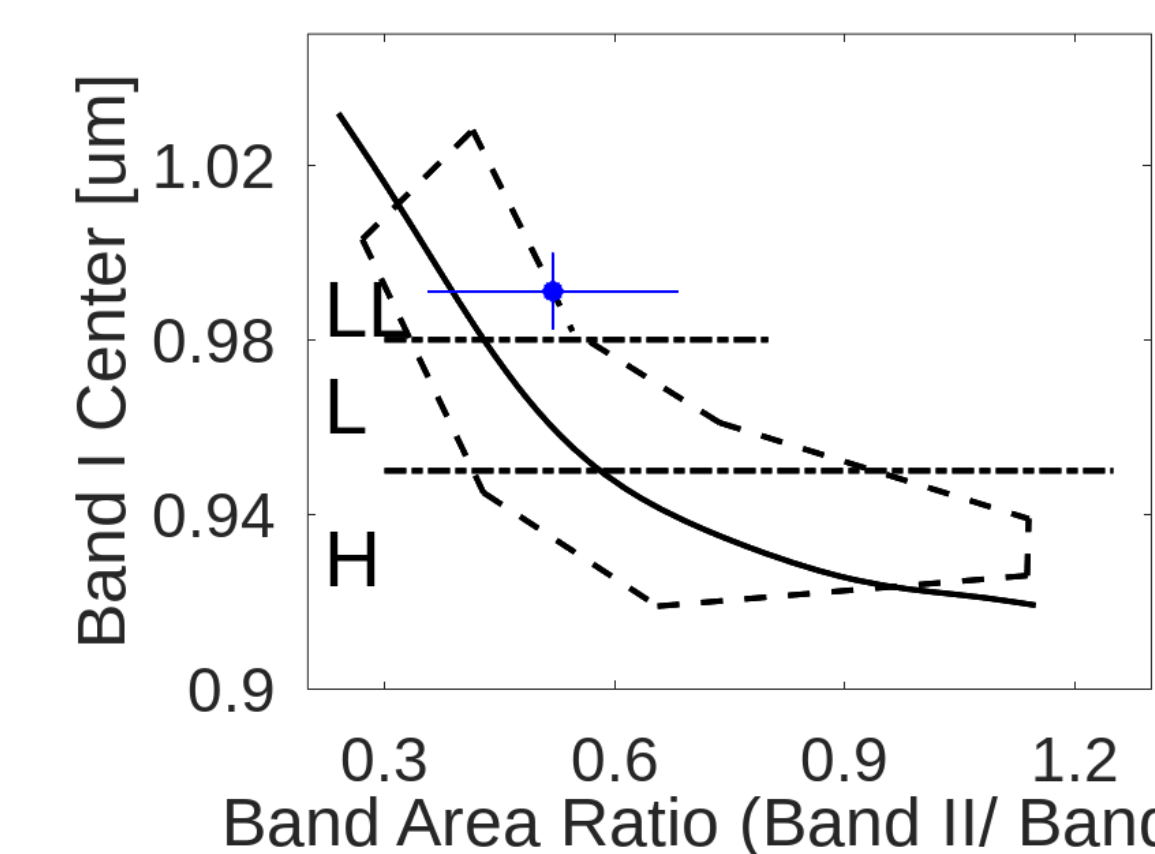


Fig. 6 The position of (98943) 2001 CC21 spectral features in BAR versus Band Center I space. The enclosed regions are taken from Dunn et al. (2013) which follow the results of Gaffey et al. (1993); Burbine et al. (2001b); Cloutis et al. (2010b).

References: [1] Hirabayashi, M et al. (2021). Hayabusa2 extended mission: New voyage to rendezvous with a small asteroid rotating with a short period. Advances in Space Research 68, 1533. [2] Binzel, R.P. et al. (2004). Observed spectral properties of near-Earth objects: results for population distribution, source regions, and space weathering processes. Icarus 170, 259. [3] Lazzarin, M. et al. (2005). Spectroscopic investigation of near-Earth objects at Telescopio Nazionale Galileo. Monthly Notices of the Royal Astronomical Society 359, 1575. [4] Narita, N., Fukui, A., Kusakabe, N. et al. (2018). MuSCAT2: four-color simultaneous camera for the 1.52-m Telescopio Carlos Sánchez. Journal of Astronomical