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Optical spectra of near-Earth asteroids (381906) 2010 CL19 and (453778) 2011 JK

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Abstract. In the framework of the *Observational Astrophysics: from proposals to publication program* (which is an OPTICON and ERASMUS+ school), we report the spectral characterization of two near-Earth asteroids, namely (381906) 2010 CL19 and (453778) 2011 JK. The data were obtained with the 2.56 m Nordic Optical Telescope equipped with ALFOSC instrument. The spectral data reduction and the methods for analyzing the results are shown in detail. We found that (381906) 2010 CL19 is a K-type asteroid, and (453778) 2011 JK is an Sq type asteroid. The comparison with laboratory spectra of meteorites revealed spectral similarities with ordinary chondrites for both objects. Considering the average albedo corresponding to the assigned types, we estimated the size of (381906) 2010 CL19 to be in the order of 1 km, and the size of (453778) 2011 JK to be about 550 m.

Key words: minor planets; techniques: spectroscopic; methods: observations

1. Introduction

The spectral signature of asteroids is determined by the properties of their surface. In the optical and near-infrared wavelength region, the radiation that comes from these bodies corresponds mostly to the reflected Sun light. The reflectance spectra obtained from ground based observatories can be used to determine the compositional information. This is usually done by comparing the telescopic measurements with the laboratory data of meteorites and of various kind of minerals. The spectral features are explained by crystal field theory (Burns, 1993).

All authors contributed equally to the work

The reasons that motive the studies of the small celestial bodies cover both practical and scientific aspects. The asteroids are fragments of the planetesimals that once formed the planets. Because most of them didn't suffer significant geological transformations they are the pieces of the puzzle for understanding the formation and evolution of the Solar System. On the other hand, the practical reasons are the exploitation of small bodies for the space exploration and for planetary defense (e.g. Binzel et al., 2015).

Table 1. Known properties of the observed asteroids. The Δv budget (the total change in velocity required for a space mission), the Tisserand parameter (T_J) with respect to Jupiter, the absolute magnitude (H), the Minimum Orbit Intersection Distance with Earth - MOID, the rotation period - P_{syn}, and the maximum lightcurve amplitude - A_{max} (mag) are shown. The data was obtained from the JPL Small-Body Database, the Minor Planet Ceneter, Warner (2014), and Warner et al. (2009).

Target	Orbit	Δv km/s	T_J	MOID AU	H mag	P_{syn} hrs	A_{max} mag
381906	Apollo	8.389	4.198	0.0115306	17.8	3.5197±0.0005	0.39±0.03
453778	Amor	5.802	3.790	0.0247028	18.5	≈2.5	< 0.37

The aim of our article is to outline the methods for obtaining and analyzing optical spectral data of minor planets. To exemplify these, we present new spectra for two near-Earth asteroids, namely (381906) 2010 CL19 and (453778) 2011 JK. These were selected due to their proximity to Earth orbit, thus in the future they can be space-mission targets. Furthermore, they are catalogued as potentially hazardous asteroids, which means that on a long time scale they may pose a threat to Earth. Some of the known properties of these bodies are shown in Table 1.

Based on the albedo value, $p_V = 0.451 \pm 0.224$, obtained by NEOWISE (Nugent et al., 2016), the diameter of (381906) 2010 CL19 can be estimated to be 0.520 ± 0.111 km. The size of (453778) 2011 JK can be approximated only based on the absolute magnitude and it can range between 0.4 - 1.4 km depending on its albedo. The correlation between albedo and the spectral type allowed us to constrain significantly the dimensions of these objects.

The article is organized as follows: the Section 2 describes the observations and the steps performed for the data reduction. The obtained spectra are analyzed in Section 3. Section 4 discuss the results and summarize the paper.

2. The observing procedure and data reduction

The observations were performed using the 2.56 m Nordic Optical Telescope, located at El Roque de los Muchachos Observatory in La Palma, Canary Islands.

The instrument was the Alhambra Faint Object Spectrograph and Camera (ALFOSC). Low resolution spectroscopy is sufficient to characterize the asteroids because they show spectral bands (as they are solid bodies). Thus, the Grism_#4 was used in conjunction with a slit having a width of 1.8 arcsec. The second order blocking filter GG475 was used to avoid contamination. This setup allows us to cover the optical interval 0.48 - 0.92 μm with a resolution of $\sim$ 300.

Table 2. Log of of observations for the night of 2019 April, 24. The designation of the targets, the observation time (UT_{start}), the total exposure time, the apparent magnitude (V_{mag}) and the airmass are shown.

Target	UT_{start} $hh:mm$	Exp. time *sec.*	V_{mag} *mag*	Airmass
SA98-978	20:43	3x15	10.6	1.548
381906	21:28	3x600	17.5	1.346
SA102-1081	22:16	3x15	9.9	1.146
453778	22:25	3x600	17.7	1.295

The observing log is shown in Table 2. Calibration images were obtained at the beginning of the night. These include biases, internal flats, and lamp (with He, Ne, ArTh) exposures for wavelength calibration. The well known solar analogues from Landolt catalogue, SA102-1081 and SA102-1081 were observed for calibrating the observed asteroids spectra.

The raw data from the telescope need to be prepared and calibrated for subsequent spectrum extraction. The preliminary step for data reduction implies the inspection of the image headers and generation of a log. The log contains the essential information about each image including the type of file (flats, biases, source spectra etc.), the coordinates, the exposure time, the instrument information, and the atmospheric conditions at the time and of the data acquisition.

The preparation of the images include the trimming of the over-scan and non-target regions. The next step is to combine an average of the bias frames which show the digital readout flaws, using standard routines in `IRAF`. The raw images are then de-biased using the final master bias. In much the same way we produce a master flat which corrects for flaws in the optical instrumentation. All these tasks are automatized using additional `python` scripts.

The extraction of the asteroid spectra is achieved with the help of the *apall* package, available through `IRAF` software (*noao* $\rightarrow$ *onedspec* $\rightarrow$ *apextract*). The *apall* package combines all the spectrum extraction utilities into one and is a handy tool for simple spectrum extraction. The outline of the extraction procedure using this package is the following: 1) find the spectrum on the CCD image; 2) define the extraction and background windows in pixels; 3) trace the center of spatial profile along the dispersion axis; 4) sum the spectrum within the extraction window, subtracting sky background at each step. At this step, the extracted spectrum is in units of signal (ADU - Analog to Digital Unit) per pixel of the CCD. The Ox-axis is represented by the pixel number. We used `IRAF` again and lamp flats to fit our wavelength to known emission lines from the Calibration lamps.

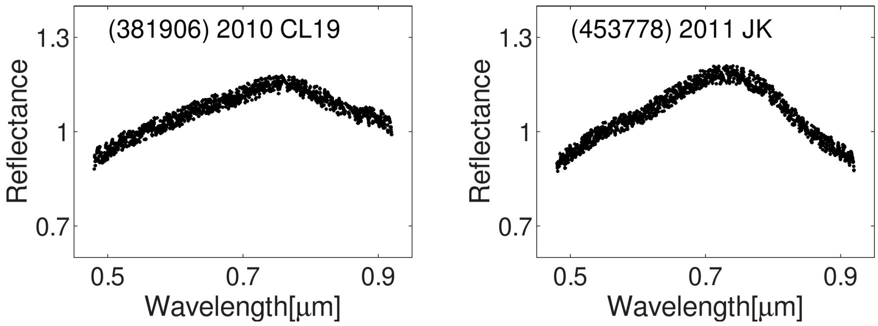

Figure 1. The optical reflectance spectra of the NEAs studied in this work. The spectra were normalized to be 1 at 0.55 μm.

The final step is to obtain the reflectance spectrum. This is done by dividing the observed asteroid spectrum with the spectra of the two solar analogue stars. Both solar analogues give similar results in terms of spectral shape. This validates the observations and the data reduction process (we note that both stars are well known solar analogues used for calibrating asteroid reflectance spectra). The final reflectance spectra, shown in Fig. 1, are obtained relative to SA102-1081. This has been selected because is closer in terms of airmass.

3. Results

The spectra we obtained are analyzed to determine their taxonomic classification and compared to the spectra of meteorites obtained in laboratory. Considering the correlation between the spectral classes and albedo we can compute the diameter of the asteroids.

The taxonomic classification provides a general characterization of asteroid spectra and a common language for their comparison. Among the most used taxonomies is the one of Bus & Binzel (2002), which covers optical wavelengths. The updated version proposed by DeMeo et al. (2009) covers the entire 0.45 - 2.45 μm interval. To classify our spectra we used a χ^2 minimization between the various spectral templates of DeMeo et al. (2009) and our observed asteroid reflectances. We found that (381906) 2010 CL19 belongs to the K-type asteroid class and (453778) 2011 JK is an Sq-type. These results are shown in Fig. 2.

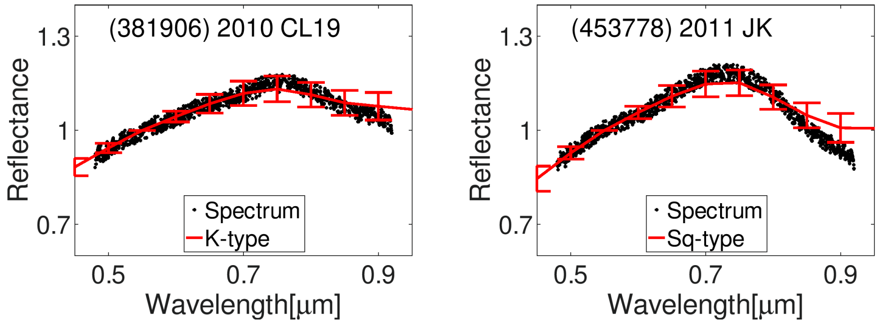

Figure 2. Comparison between the observed asteroid spectra and the assigned taxonomic classes.

Besides sorting our asteroids into classes according to DeMeo et al. (2009) taxonomic scheme, we can also use our spectra to determine what meteorite sample found on Earth resembles the asteroid the closest. This connects the laboratory data with the spectral properties of celestial objects providing the basis for interpreting the composition of these small bodies of the Solar System. This algorithm was implemented in `python` and it applies χ^2 test to find the meteorite spectrum from the Relab database that best fits our data.

We found that (381906) 2010 CL19 shows similarities with ordinary chondrite meteorites. However, the spectrum that best matched it corresponds to a sample of Divnoe meteorite (Sample ID: MB-CMP-015-L), which is categorized as a primitive achondrite. This ambiguity is due to the fact that the presence of 0.9 μm band is not sufficient to distinguish between various olivine-pyroxene compositions.

The spectral curve of (453778) 2011 JK is matched by several ordinary chondrite meteorites. The best fit corresponds to a sample from Knyahina meteorite (Sample ID: MR-MJG-049), which is an L5 ordinary chondrite.

We note that these results give an indication to certain types of compositions, but the solution is not unique and observations in other wavelength regions can improve it. Mineralogical models can be applied for spectra covering the optical to near-infrared interval.

4. Discussions and conclusions

The results of Mainzer et al. (2011) show a direct relation between the spectral type and the albedo. They provide the average value of visual geometric albedo p_V for each taxonomic class defined by DeMeo et al. (2009). Furthermore, the geometric albedo p_V, the absolute magnitude H, and the diameter

D are associated by the well-known formula (e.g. Harris & Lagerros, 2002): $D = 1329 \times 10^{-0.2H}/\sqrt{p_V}$.

We classified (453778) 2011 JK as Sq type. Therefore, using the absolute magnitudes H (shown in Table 1) and the average S-class value of the albedo $p_V = 0.23 \pm 0.02$ we can estimate for the first time the diameter for (453778) 2011 JK as $D \approx 550m$. The K-type assigned to the asteroid (381906) 2010 CL19, has an associated albedo ($p_V = 0.13 \pm 0.058$). Based on this value we can estimate its size to 1 km. This value is significantly larger compared to the one estimated based on the measured albedo, $p_V = 0.451 \pm 0.224$ (Nugent et al., 2016), which gives about 0.55 km.

The fact that the spectrum of (453778) 2011 JK is very similar to the spectra of the ordinary chondrites suggests that it may be the remnant of a much more primitive, and therefore, an ancient object of the Solar System.

Complementary observations using various techniques (polarimetry, near-infrared spectra, radar) can further constrain the physical and the dynamical properties of these asteroids. Altogether, these will allow to trace and predict the evolutionary path of these celestial bodies.

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The following databases and web-resources were used in this work: JPL Small-Body Database[1], IAU Minor Planet Center[2], NEA Delta-V for Spacecraft Rendezvous[3], Relab database[4], Asteroid Lightcurve Photometry Database-ALCDEF[5].

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