X-shooter Science Verification Proposal

Tracking ices in the trans-Neptunian belt. High resolution spectroscopy with X-shooter.

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Abstract:

Trans-Neptunian objects (TNOs) are a fundamental piece of the puzzle in the understanding of the outer Solar System. Because of their location and physical properties they are thought to be made of mostly unprocessed material, close in composition to that of the primordial planetesimals. However, space weathering, collisions, and their own physical properties including distance from the Sun, can evolve the surface of these objects probably resulting in the actual observed variety of surface properties in the TNb (Gil-Hutton, 2002). Determining their present composition can shed light upon the initial conditions in the early Solar System and on its physical and chemical evolution.

Here we propose to study the composition of the binary trans-Neptunian object (47171) 1999 TC_{36}. Previous studies of the surface of this body give different results but most of them indicate its surface has a high concentration of evolved organic materials and a certain amount of ices as water ice could still be present. Recent colors obtained with IRAC-Spitzer reinforces this hypothesis indicating the presence of CH4 and, possibly, H2O ices. In order to shed some light on the controversial composition of 1999 TC_{36} more data are needed at higher signal to noise.

Scientific Case:

Due to their faintness, compositional information for these distant objects is extremely limited (see Barucci et al. 2008 and references therein for a picture of our knowledge of the trans-Neptunian region and its inhabitants as of mid-2006). The surface properties of TNOs and Centaurs were first assessed from optical and near-infrared broadband photometry. Spectroscopy is possible only with the largest telescopes, and is limited to the brightest objects and wavelengths between 0.3 and 2.5 μm. These studies show a wide range of colors (from slightly blue to very red) and spectral reflectance. Some objects have very low albedo surfaces with no diagnostic spectral bands, while others have spectra showing signatures of various ices (such as water, methane, methanol, and nitrogen) and higher geometric albedos. In particular, the biggest TNOs (Plutoids) have visible and near-infrared spectra dominated by methane or water-ice bands, as they are big enough to retain some of the original volatiles on their surfaces. On the other hand, some medium-size TNOs, are supposed to have lost almost all the volatiles on their surfaces, but some of them have spectra compatible with the presence of ices, as water ice or methane ice (e.g. (50000) Quaoar, Jewitt & Luu, 2004. Schaller & Brown 2007; and (20000) Varuna, Licandro et al. 2002 & Dalle Ore *Personal Communication*). All this variety suggests a substantial range of original compositions, and/or different evolutionary states.

The existence of ices on the surface of medium-size objects is under study and needs to be explained, some processes proposed to be related with it could be cryovulcanism and collisions. The extension of available data at wavelengths longer than 2.5 μm, thanks to the Spitzer Space Telescope, provides greater leverage on the modeling effort because plausible surface materials, particularly complex organic species and ices of light hydrocarbons have strong absorption bands beyond 2.5 μm. In this sense, new photometric measurements at 3.6 and 4.5 μm (with the IRAC camera), together with spectroscopic observations from 0.4 to 2.5 μm, have yielded new information about the surface composition of (90377) Sedna and (50000) Quaoar (Emery et al. 2007, Dalle Ore et al. 2009).

We propose here a study of the composition of the multiple system (47171) 1999 TC_{36} (V=19.9, K=18.5). Spitzer observations of this system yielded an effective diameter of the binary is of 405 km and an effective visible geometric albedo for the system is 0.079 (Stansberry et al. 2006). The binary orbit, magnitude contrast between the components, and system mass have been determined from HST data studied by Margot et al. (2004).

Spectroscopic observations and fits of the data with Hapke scattering models(Gilbert et al. 2009 and Protopapa et al. 2009, and references therein) show different compositions for the surface of this body. All of them include high amounts of evolved organics (tholins) and different amounts of water ice. But the quality of the data does not lead to strong conclusive results, even with the highest available quality in the near-infrared. This is the case of SINFONI data from Protopapa et al. (2009), where they get good fits either with a 35% or with a 5% of water ice.

Therefore, recent observations of this body with IRAC (Spitzer) reveal it as a good candidate for containing some amount of ices that could be visible in the near infrared. The observations indicate the existence of CH4 on its surface, along with organics and H2O. This object, lies in a region in color-color plot together with other objects that have been probed to contain ices, as (50000) Quaoar and (20000) Varuna (Fig.1). These ices could be visible in a high-quality spectrum.

It is in this sense that X-shooter appears promising, its full spectral range is sensitive to the detection of the three materials aforementioned. One single hour of exposure time will provide us with high signal data even in the near-infrared. Spectroscopic data in the visible could uncover the presence of the 0.74 and 0.89 μm methane bands, and the bands of aqueously altered materials at 0.6 and 0.73 μm. More data in the H and K band could show, if present, the 1.5 and 2.0 μm water ice as well as the 2.4 μm methane line: the new data would confirm or refute the presence of these ices, present on the surface of TNOs with similar colors.

The aim of this work is to obtain simultaneously a complete spectrum of 1999 TC_{36} from the UV to the near-infrared. This spectrum, with a high signal to noise ratio in the whole range and a high resolution, will provide us with good quality data that will help us to confirm or reject the presence of proposed materials on the surface of this TNO and to decipher its intriguing surface composition.

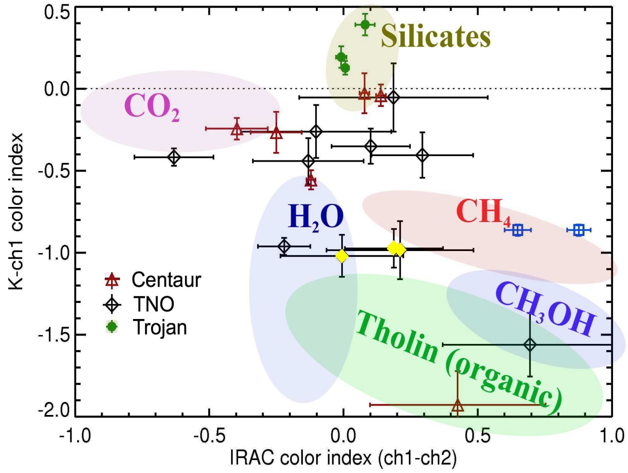

Figure 1: Fig.1 Colors of some objects in the outer Solar System On the abscissa is the color calculated from the ratio of the two IRAC bands (ch1 [3.6 μm] and ch2 [4.5 μm]). On the ordinate is the color calculated from the ratio of the K band [2.2 μm] and ch1 [3.6 μm]. The over-plotted regions are calculated by getting colors from synthetic reflectance of pure ices modeled with the Hapke theory. The three yellow objects in the middle are (50000) Quaoar, (20000) Varuna and (47171) 1999 TC_{36}. Note that in the last case, the data fall near the regions spanned by CH4, H2O ices and organic materials.

Calibration strategy:

The reduction will be carried out using the data provided by ESO accordingly: bias and dark subtraction, flat-fielding, and wavelength calibration. The total exposure time will be split in the UVB and VIS arms in two exposures (see below) in order to avoid possible systematic problems introduced by the CCD. The exposure in NIR arm will be split in 6 integrations, taken with an offset following the ABBA pattern in order to better extract the sky.

The observations will be carried using the slit mode of X-Shooter, in particular using the NODDING ALONG SLIT template. The slits selected are $1.0'' \times 11''$, $0.9'' \times 11''$, and $0.9'' \times 11''$ for the UVB, VIS, and NIR arms respectively.

The reduction will be performed using standard astronomical software (e.g., IDL, IRAF). To obtain the final spectrum of 1999 TC_{36} we need to observe a solar analogue star, diving the spectrum of our target by that of the star we remove the solar spectrum, as well as the telluric lines of the sky.

The high resolution offered by X-Shooter will allow to re-bin the spectrum increasing the already good SNR. We expect to be able to resolve any possible band that might be present in the spectrum of 1999 TC_{36} and that escaped detection due to the low SNR of the current data. The obtained results will provide the benchmark for the future study of TNOs using X-shooter.

We would like to remark that it will be the first time that the whole spectrum between 0.4 and 2.5 μm will be obtained at once for a TNO. All previous studies rely on photometric calibrations to put together all the pieces (usually VIS + J + H-K spectra) therefore introducing errors in the resulting combined spectrum making the further modeling and interpretation of the data challenging.

Targets and number of visibility measurements

Target	**RA**	**DEC**	**V** mag	**Mode** (slit/IFU)	**Remarks**
(47171) 1999 TC_{36}	01 27 52.7	+00 10 46	19.9	slit	moving object[a]
HD 2966	00 32 50.1	-13 15 28	8.3	slit	solar analogue

[a] Ephemeris taken for 2009 Aug. 15 at 0 UTC.

Time Justification:

We are requesting for 1.38 h to obtain the spectrum of 1999 TC_{36} and that of a solar analogue star with a good SNR over most of the spectral coverage of X-Shooter. The chosen read out is slow mode, high gain with 2×2 binning for the UBV and VIS arms.

For 1999 TC_{36} the block will be separated as follows:
- UVB arm: 2 exposures of 1800 s with an offset. - VIS arm: 2 exposures of 1800 s with an offset (minimize the fringing at the red end of the detector) - NIR arm: 6 exposures of 600 s, following an ABBA pattern to perform the sky-subtraction.
The expected SNR in each arm ranges from 10 to 50 in UVB arm, 20 to 30 in the VIS arm, and 3 to 40 in NIR arm. The total exposure time including the overheads, as indicated in X-shooter manual, is 1.2 h.

The spectrum of the solar analogue star will be taken in a similar fashion and using the same setup as for 1999 TC_{36}:
- UVB arm: 2 exposures of 2 s with an offset. - VIS arm: 2 exposures of 2 s with an offset. - NIR arm: 2 exposures of 2 s, with an offset.
The total exposure time (plus overheads) is 0.18 h.

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