Study of the Surface of 2003 EL_{61}: the largest carbon-depleted object in the trans-neptunian belt

N. Pinilla-Alonso\(^1\), R. Brunetto\(^2,3\), J. Licandro\(^4\), R. Gil-Hutton\(^5\), T. L. Roush\(^6\), and G. Strazzulla\(^3\)

\(^1\) Fundación Galileo Galilei & Telescopio Nazionale Galileo, P.O.Box 565, E-38700, S/C de La Palma, Tenerife, Spain.  
e-mail: npinilla@tng.iac.es  
\(^2\) Institut d’Astrophysique Spatiale, Université Paris-Sud, bâtiment 121, 91405 Orsay Cedex, France.  
\(^3\) INAF-Osservatorio Astrofisico di Catania, Via S. Sofia 78, I-95123, Catania, Italy.  
\(^4\) Instituto de Astrofísica de Canarias, c/Via Láctea s/n, E38205, La Laguna, Tenerife, Spain.  
\(^5\) Complejo Astronómico El Leoncito (Casleo) and San Juan National University, Av. España 1512 sur,J5402DSP, San Juan, Argentina  
\(^6\) NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035-1000, USA

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ABSTRACT

Context. 2003 EL\(_{61}\) is the largest member of a group of trans-neptunian objects (TNOs) with similar orbits and ‘unique’ spectral characteristics: neutral slope in the visible and the deepest water ice absorption bands ever observed in the trans-neptunian belt (TNb). Studying the surface of 2003 EL\(_{61}\) provides useful constrains on the origin of this particular group of TNOs and on the outer Solar System’s history.

Aims. To study the composition of the surface of 2003 EL\(_{61}\).

Methods. We present visible and near-infrared spectra of 2003 EL\(_{61}\) obtained with the 4.2m WHT and the 3.6m TNG telescopes at the Roque de los Muchachos Observatory (Canary Islands, Spain). Near infrared spectra were obtained at different rotational phases covering almost one complete rotational period. Spectra are fitted using scattering models based on Hapke theory and constraints on the surface composition are derived.

Results. The observations confirm previous results: 2003 EL\(_{61}\) spectrum is neutral in color and presents very deep water ice absorption bands. Meanwhile, they provide us with some new facts about the surface of this object, no significant variations in the spectral slope (in the near-infrared) and in the depth of the water ice absorption bands at different rotational phases are evident within the S/N suggesting that the surface of 2003 EL\(_{61}\) is homogeneous. The scattering models show that a 1:1 intimate mixture of crystalline and amorphous water ice is the most probable composition for the surface of this big TNO, and constrain the presence of other minor constituents to a maximum of 8%.

Conclusions. The derived composition suggests that: a) cryovolcanism is unlikely to be the resurfacing process that keeps the surface of this TNO, and the other members of this population, covered mainly by water ice; b) the surface is older than 10\(^8\) yr. This constrains the time scale of any catastrophic event, like the collision suggested to be the origin of this population, to at least 10\(^8\) yr; c) the surface of 2003 EL\(_{61}\) is depleted of carbon bearing species. According to the orbital parameters of the population, this makes it a possible source of carbon-depleted Jupiter family comets.

Key words. Kuiper Belt — Solar system: formation — techniques: spectroscopic — Astrochemistry

1. Introduction

2003 EL\(_{61}\) is the fourth largest known TNO and one of the most peculiar ones. It is the largest member of a group of TNOs with surfaces composed of almost pure water ice and moving around the Sun in a narrow region of the orbital parameters space (41.6 < a < 43.6 AU, 25.8 < i < 28.2 deg., 0.10 < e < 0.19) (Pinilla-Alonso et al., 2007). Brown et al. (2007) claim that this group is a family of fragments produced by a giant collision that happened in the trans-neptunian belt (TNb). The spectra of all these objects show the same characteristics, they are dominated by neutral slopes in the visible and large water ice absorption bands in the near-infrared (the deepest ever observed in the TNb, Pinilla-Alonso et al., 2007).

The study of the surface composition of these TNOs could provide important clues to understand the origin of this group, the role of collisions in sculpting the TNb, and the resurfacing processes that take place in this region of the Solar System. In particular, since 2003 EL\(_{61}\) is the brightest one, it is the best candidate for such a study. Some works have been done with this purpose since the discovery of this object.

Rabinowitz et al. (2005) show a photometric study of 2003 EL\(_{61}\) revealing that this body has an unambiguous double-peak light curve. They discuss two different explanations for this curve, assuming this body is an homogeneous elongated ellipsoid whose shape determines the light curve variations and assuming it is a flattened spheroid where light variations are related with albedo patterns on its surface.

Tegler et al. (2007) obtain a visible spectrum of 2003 EL\(_{61}\) and show that it is featureless, with a neutral slope, they also
report the possible existence of a band at 5773 Å probably due to O2-ice, anyway this feature has not yet been confirmed as its confirmation requires a higher signal precision of the continuum in the spectrum.

Trujillo et al. (2007) present a near-infrared spectrum of 2003 EL61 and using Hapke models (Hapke 1981) they claim that it can be modeled considering crystalline water ice and a blue component necessary to fit the spectrum above 2.35μm like HCN or hydrated tholins. Merlin et al. (2007) present a new visible and near-infrared spectrum of 2003 EL61 and fit them with Skhuratov models that suggest that the surface of the TNO is essentially composed of water ice, mainly in crystalline state, but in a small fraction of the surface the water ice could be amorphous.

In this paper we present new spectroscopic observations from 2003 EL61 in the visible and near-infrared (Section 2). In Section 3, we present a collection of near-infrared spectra of 2003 EL61 taken at different rotational phases and study the homogeneity of its surface. In Section 4 we model the spectrum of 2003 EL61 and detail the physical implications for the object composition. We discuss previous results in Section 5 and summarize the conclusions in Section 6.

2. Observations

We observed 2003 EL61 on 2005 August 1.92 UT simultaneously with two telescopes at the “Roque de los Muchachos Observatory” (ORM, Canary Islands, Spain), namely the 4.2m William Herschel (WHT) and the Italian 3.6m Telescopio Nazionale Galileo (TNG), and only in the near-infrared with the TNG on 2006 February 25, from 01:21 to 04:33 UT. Both nights were photometric.

2.1. Visible Spectrum

The visible spectrum (0.35-0.98 μm) was obtained using the low resolution gratings (R300B and R158R with dispersions of 0.86 and 1.63 Å/pixel, respectively) of the double-armed spectrograph ISIS at WHT, and a 5″ slit width oriented at the parallactic angle (the position angle for which the slit is perpendicular to the horizon) to minimize problems with differential atmospheric refraction. The tracking was at the TNO proper motion. Three 30s spectra were obtained by shifting the object by 10″ in the slit to better correct the fringing. Calibration and extraction of the spectra were done using IRAF and following standard procedures (Massey et al., 1992).

The three spectra of the TNO were averaged. Spectra of the solar-analogue star BS4486 and the G2 Landolt (SA) 107+998 (Landlot, 1992) were obtained the same night at a similar airmass just before and after the TNO spectrum, and used to obtain the final reflectance spectrum of the TNO, normalized at 0.5μm shown in Fig.1.

2.2. Infrared Spectrum

The near-infrared spectra were obtained using the high through-put, low resolution spectroscopic mode of the Near-Infrared Camera and Spectrometer (NICS) at the TNG, with an Amici prism disperser. This mode yields a complete 0.8-2.5μm spectrum. We used a 1.5″ and a 0.75″ wide slit in 2005 and 2006 observations respectively, corresponding to a spectral resolving power R~34 and R~70 along the spectrum. The identification of the TNO was done by taking a series of images through the J, H, K filters (A_cerr=1.25μm). 2003 EL61 was identified as a moving object at the predicted position and with the predicted proper motion. The slit was oriented at the parallactic angle and the tracking was at the TNO proper motion. We used the observing and reduction procedure described by Licandro et al. (2001).

The acquisition consisted of a series of images (3 in 2005 and 1 in 2006 observations respectively) of 90 seconds exposure time in one slit position (position A) and then offsetting the telescope by 10″ in the direction of the slit (position B). This process was repeated obtaining several AB cycles up to a total exposure time of 1080 and 5220 seconds in 2005 and 2006, respectively.

To correct for telluric absorption and to obtain the relative reflectance, the G stars Landolt (SA) 98-978, Landolt (SA) 102-1081, Landolt (SA) 107-998 (Landlot, 1992) were observed at different airmasses along the night, before and after the TNO observations, and used as solar analogue stars.

The spectra of 2003 EL61 were divided by the spectra of the solar analogue stars, and then normalized to unity around 1.0μm thus obtaining the scaled reflectance. In Fig.1 The resulting spectra obtained by combining all the extracted AB of each night and normalized to join the visible spectrum around 0.9μm are presented.

Around the two large telluric water band absorptions the S/N of the spectrum is very low. Even in a rather stable atmosphere, the telluric absorption can vary between the object and solar analogue observations introducing false features. Therefore, any spectral structure in the 1.35-1.46 and 1.82-1.96μm regions must be carefully checked.

3. Analysis of the spectrum

The spectrum of 2003 EL61 shows the characteristics described in previous papers (Merlin et al., 2007 and references therein) (a) The visible is featureless within the S/N and neutral (the spectral slope, computed between 0.53 and 1.00μm, is S′_vis = 0.0 ± 2%/1000Å), such a neutral slope together with the high albedo estimated for this TNO (ρ_v = 0.6-0.8, Rabinowitz et al.,...
The depth of the bands,
the normalized infrared reflectivity gradient
and the five combined spectra from the series obtained on 2006
February 25 (see text).

2006) is indicative of the lack of complex organics (typically red
in color produced by the irradiation of hydrocarbons and/or al-
cohols) on its surface; (b) The slope of the continuum is blue in
the near-infrared; (c) It presents two deep absorption bands cen-
tered at 1.52 and 2.02 µm, indicative of water ice; (d) The band at
1.65 µm, typical of crystalline water ice, appears in all our spectra
in the near-infrared; (e) There is a clear absorption above 2.2 µm;
(f) There is no absorption band in the 0.6-0.8 µm spectral region
indicative of phyllosilicates (Formasier et al., 2004).

Due to the S/N of our spectrum in the visible we cannot con-
firm the presence of a feature at 0.58 µm that has been suggested
by Tegler et al., (2007) and would be related to the presence of
O2-ice in the surface.

### 3.1. Rotational variation

On 2006 February 25, we obtained a series of near-infrared spec-
tra of 2003 EL61 from 01:21 to 04:33 UT. The rotation period
of this TNO is 3.9 hrs. (Rabinowitz et al., 2006), so our obser-
vations cover about 80% of the rotation of 2003 EL61 and allow us
to study possible surface inhomogeneities. To do that we com-
bined five sub-samples of this series to produce five spectra cov-
ering different rotational phases (see Table 1 for details). Fig 2
shows these five spectra and the spectrum obtained in 2005.

There is no evidence of large inhomogeneities on the sur-
face of the TNO. Every single spectrum shows the same fea-
tures within the S/N. Fig 3 shows the ratio between these spectra
and the spectrum of 2003 EL61 represented in Fig 1 (labelled sp2006all). Notice that there is no systematic deviation within
the limit of the noise for none of the spectra obtained at differ-
ent phases, neither in the slope nor in the spectral bands.

Finally, to quantify any possible variation in the slope and/or
band depths of the spectra we computed two parameters:

(a) The normalized infrared reflectivity gradient \( S' \) over the 0.85-1.3µm range. To compute it we fit the contin-
um between 0.85 and 1.3µm with a straight line. This fit is
sensitive to the first and last points of the spectrum but the
error introduced by this factor is negligible compared to the
systematic errors.

(b) The depth of the bands, \( D \), with respect to the continuum
of the spectrum (fitted in the infrared using a cubic spline) as:
\[ D = 1 - R_b/R_c \]
where \( R_b \) is the reflectance in the center of the band (1.52 or 2.02 µm) and \( R_c \) is the reflectance of the continuum in the same points (1.52 or 2.02 µm, respectively).

Table 2 presents the values of these parameters obtained
from each spectrum. The mean \( S'_\mu = -0.9 \pm 1.8 \). The largest devi-
ation from this mean value corresponds to the spectrum obtained
at phase 1 and it is 2.5%/1000Å. Considering that, due to sys-
tematic errors (e.g. centering uncertainties of the TNO and/or
solar analogues in the slit...) uncertainties of 2%/1000Å in the
slope are usual, we should conclude that the spectral slope is
similar at all rotational phases. Lacerda et al. (2008) found a
small variation of 0.035 magnitudes in the B-R color of 2003
EL61 correlated with the rotation of the TNO. They suggest that
this is produced by a region of the surface with lower albedo and
redder in color. This change in color corresponds to a reddening
of \( S' \) of about 1-2%/1000Å which is smaller than the uncertain-
ties of our measurements so we cannot confirm Lacerda et al.
results from the study of the spectra.

In the same way, the mean depth of the water absorption
bands \( D_{1.52} \) and \( D_{2.02} \) are 33.7±2.5 and 53.5±4.0 respectively.
The errors of the measured band depths for each spectrum are
larger than the deviation from the mean, so we can conclude
that there are no variations of the depths of the water absorption
bands larger than %. We conclude that the surface of 2003 EL61 is
homogeneous in a large scale. This reinforces the hypothesis
that its shape is like a very elongated ellipsoid.

### 4. Spectral Models

In this section, we use the Hapke scattering model (Hapke, 1981,
Hapke, 1993) to fit the spectrum of 2003 EL61 and derive conclu-
sions about its surface composition. In particular we test whether
the spectrum is consistent with the presence of amorphous ice
and investigate the presence of other minor components.
To fit the model we use our best S/N spectrum named sp2006all, obtained by combining all the spectra acquired in the 2006 run as explained in Section 2. To increase the S/N, we merge our spectrum of 2003 EL61 with that of Trujillo et al., 2007. Notice that there are no significant differences between our spectrum and the already published data. 

Table 2. Normalized reflectivity gradient $S'_{\nu}$ and depth of the 1.52 and 2.02 $\mu$m bands $D$, as defined in the text, for the all the considered infrared spectra. Uncertainties of 2%/1000Å in the slope are typical due to systematic errors (see text for details). $\epsilon$ are the associated errors of $D$.

| name         | $S'_{\nu}$ | $D_{1.52}$ | $\epsilon_{1.52}$ | $D_{2.02}$ | $\epsilon_{2.02}$ |
|--------------|------------|------------|--------------------|------------|--------------------|
| Aug. 2005    | 1.07       | 31.13      | 7.2                | 49.7       | 13.5               |
| sp2006all    | 1.40       | 34.0       | 4.8                | 53.8       | 6.6                |
| 2006 phase1  | 1.61       | 33.9       | 6.7                | 55.8       | 10.0               |
| 2006 phase2  | -1.77      | 33.3       | 5.6                | 51.3       | 10.2               |
| 2006 phase3  | -2.12      | 38.3       | 7.0                | 54.6       | 10.6               |
| 2006 phase4  | -2.32      | 32.4       | 9.2                | 49.5       | 13.0               |
| 2006 phase5  | -1.97      | 33.1       | 7.8                | 59.8       | 10.6               |

Fig. 3. Ratio between the spectra shown in Fig[2] and the sp2006all spectrum. Uncertainties are given by the point of point variation. Notice that there is no systematic deviation within the limit of the noise for none of the spectra obtained at different phases.

4.1. Crystalline and amorphous water ice spatial mixtures

We first tried to fit the spectrum with pure crystalline water ice (Fig[4] upper panel), the fit fails mainly at reproducing the 1.52$\mu$m and 2.02$\mu$m bands at the same time and at reproducing the depth of the 2.2$\mu$m band. We investigate the possibility of reproducing the spectrum with only pure amorphous water ice (Fig[4] upper panel). Amorphous water ice is bluer at the longer wavelengths ($\geq 2.2\mu$m) than crystalline water ice but it does not reproduce the spectrum well either. This is chiefly because the 1.65$\mu$m feature is absent in amorphous ice and the 1.5 and 2.0$\mu$m are at too short a wavelength compared to the observational data.

Then, we investigated a model of a mixture of amorphous and crystalline ice. A first approach is to assume that crystalline and amorphous ice are spatially segregated on the surface. Thus, we applied a spatial mixture. The results are shown in the lower panel of Fig[4]. The best fit is a model of two segregated components: 37.5% of crystalline water ice (with grain size of 7$\mu$m) and 62.5% of amorphous water ice (with grain size of 50$\mu$m). In the visible range the mixture produces a flat spectrum and a geometric albedo of about 0.7, which is in agreement with previous results.

The fit curve is not satisfactory because, even if several features of the spectrum are well reproduced it fails to reproduce the depth of the 1.65$\mu$m band.

Table 2. Normalized reflectivity gradient $S'_{\nu}$. and depth of the 1.52 and 2.02 $\mu$m bands $D$. Notice that there is no systematic deviation within the limit of the noise for none of the spectra obtained at different phases.
4.2. Crystalline and amorphous water ice intimate mixtures

Since the spatial mixture was not satisfactory, we tested an intimate mixture of amorphous and crystalline ice. The results are shown in the upper panel of Fig. 5; the model corresponds to a 54.5% of amorphous ice (grain size of 10 μm) and a 45.5% of crystalline ice (grain size of 31 μm). This model produces slightly different grain sizes for amorphous and crystalline ice but considering the errors in the optical constants the differences in size may not be significant. In the visible range, our model produces a flat spectrum and a geometric albedo of about 0.7.

This fit reproduces the data better than the spatial mixture in particular the 1.65μm absorption band (Fig. 5 lower panel), but it reduces the quality of the fit in the 1.7-1.85μm range. However, the uncertainties of the optical constants in the 1.7-1.85μm range are larger than in the 1.65μm spectral band as the transmittance of the water ice is almost zero in this region. Some discrepancies are still present in the 2.2μm shoulder and in the 1.45μm and 2.4μm region. These discrepancies appear systematically in all our models and can be attributed to the uncertainties of the optical constants and observations.

Despite these discrepancies, this model reproduces better the most important features of the spectrum. Notice that an intimate mixture of crystalline and amorphous would imply a rather homogenous surface, in agreement with our results based upon the study of the rotational variation.

A model that considers an intimate mixture of amorphous and crystalline water ice was also proposed by Merlin et al., (2007). Comparing our fit with that of Merlin et al., we find a much higher percentage of amorphous ice, which would indicate a longer exposure to ion irradiation, i.e. an older surface. Merlin et al. used very different grain size for amorphous and crystalline ice (more than a factor of 10), which is very hard to be explained, while in our model the difference is reduced to a factor of 3. Also they used a contribution from an amorphous carbon that is not included in our model. Considering that a small amount of amorphous carbon (3%) would reduce considerably the geometric albedo, and that the albedo we derived from the model is $p_V = 0.7$ consistent with the observations (Rabinowitz et al. 2006) we constrain the amount of amorphous carbon to a very small fraction less than a few percent.

We conclude we achieved a good fit of the spectrum of 2003 EL61 that has stronger physical meaning, with an amorphous/crystalline ratio of 1:1 that indicates a competition between different physical processes on the surface.
irradiation would affect the icy layers gradually, and a sudden transition from amorphous to crystalline is not expected.

4.4. Minor components

One of the aims of this paper is to put constraints on the presence of minor components on the surface of 2003 EL₆₁. In this step we investigated the contribution of some species, using them as minor components in an intimate mixtures with amorphous and crystalline water ice. We consequently estimated upper limits for these species, and results are included in Table 3.

We put special attention to materials that have been proposed to be on the surface of this object. We found that none of the investigated components help to improve the fit quality (see Fig. 7), furthermore, even small amounts of these materials change the shape of the model adding spurious features or reddening the slope, and impoverishing the quality of the fits.

The presence of ammonia and methane is discarded in a proportion larger than 5% as we see from features introduced in the 2.2-2.3µm region (models A and C respectively).

The serpentine (not shown) and kaolinite contribution could help to produce a blue slope in the long wavelength region, but using percentages higher that 5-10% introduces other features (especially in the visible, model D in Fig. 7) that are not present in the observations. A simple 5% contribution of poly-HCN (model B in Fig. 7) is enough to produce non-neutral slopes in the visible range, which is in complete disagreement with the observations. Thus, the hypothesis of Trujillo et al. (2007) of a strong contribution of these species has to be discarded. A large contribution of pyroxenes (model E in Fig. 7) is discarded also as a small percentage of 7% is enough to introduce an broad feature in the visible spectrum from 0.8 to 1.1µm.

In the case of hydrated ammonia (model F in Fig. 7), the study is particularly interesting as it has been related to cryovolcanism. We find that a 8% of hydrated ammonia impoverishes the quality of the fit as the reduced chi square value is 3.7, for the whole spectral range, and 2.3, if we restrict to the region around the 1.65µm, (far from the 3.0 and 1.8 values found for models with only water ice). In spite of this, adding hydrated ammonia is interesting when a feature around 2.2 microns is detected (Cook et al. 2007). Unfortunately, the relatively poor S/N of our spectrum does not allow us to clearly detect this feature, so we discard the presence of hydrated ammonia with an upper limit of 8% but we condition this to the obtention of a better spectrum that confirms the presence or the absence of a feature around 2.2 microns.

In conclusion, we discard the presence of other component on the surface but water to a high level of confidence. We stress that none of the components investigated helped us to improve the fit quality. In particular, the main discrepancies mentioned above remain. We think that discrepancies at 2.0 and 2.2µm can be attributed to uncertainties in the optical constants.

| Species | Upper limit |
|---------|-------------|
| NH₃     | 5%          |
| poly-HCN| 5%          |
| CH₄     | 5%          |
| CO₂     | 6%          |
| NH₄OH   | 8%          |

Table 3. Upper limits for possible minor components of the surface of 2003 EL₆₁.

4.3. Multi-layer models

Next step was to test a multi-layer system. This is an option that Hapke model offers, although not yet deeply explored (Brunetto & Roush, 2008). It consists on considering that from the moment that incident sun light reaches the surface of the body to the moment it leaves and is reflected to Earth, it travels through layers composed of different materials characterized by different physical properties. Here we model a simple layered configuration using equations 7.45c, 8.89, 9.14, and 11.24 from Hapke (1993): the model calculates the reflectance from a system where a layer overlies an infinitely thick substrate.

This physical model arises from the consideration that 2003 EL₆₁ is homogeneously irradiated by solar wind and cosmic ions. Given this situation, it is reasonable to imagine that different layers close to the surface have suffered a dose of irradiation that decreases with increasing depth causing the amorphization of water ice.

We initially considered a configuration where an amorphous mantle is on top of a crystalline substrate (Fig 6 dotted curve), but the result was unsatisfactory as using an upper layer of only 10µm amorphous ice is enough to mask the 1.65µm band of the underlying crystalline ice, in contrast to the observations of 2003 EL₆₁.

We then considered a configuration where the upper layer is composed of an intimate mixture of amorphous and crystalline water ice (Fig 6 solid curve). This model consists of an intimate mixture of 60% amorphous and 40% crystalline ice on top of an infinite crystalline ice substrate.

Although there are some remaining differences between the model and the spectrum this second model is closer to the spectrum of 2003 EL₆₁. Actually, we find that all three major models (spatial mixture, intimate mixture, two-layers model) produce reduced chi square of about 3. This would not allow to discriminate among them. Nevertheless, if we restrict to the region of the 1.65µm feature, we find values of: 3 for the spatial mixture; 2.4 for the intimate mixture; and 1.8 for the two-layers model.

These simple tests indicate that multi-layer models can be a useful tool to interpret TNOs spectra. Future efforts should focus on the possibility to model several layers, since ion
The effects of including minor components in the fit of 2003 EL₆₁ spectrum.

5. Discussion

In the previous Sections we find a surface composition for 2003 EL₆₁ of >92% of pure water ice, and we discard the presence of a significant fraction of complex organics on its surface. In spite that this is not the first object showing a large fraction of water ice on its surface, TNOs with no traces of organics should not be common assuming that the original chemical composition of all TNOs is very similar i.e. objects composed of abundant water ice, some molecular ices like CO, CO₂, CH₄, N₂.

Laboratory experiments with astrophysical ice mixtures show that long term processing by high energy particles and solar radiation induces the loss of hydrogen and the formation of complex organic species, resulting in a dark and usually red mantle that covers the unprocessed original ices (Moore et al., 1983; Johnson et al., 1984; Strazzulla & Johnson, 1991). In the case of a TNO, Gil-Hutton (2002) shows that the time scale required to form this mantle of carbon residues, even when there is a competition between darkening by cosmic-rays and resurfacing due to impacts, is ~ 10⁸ years. If we consider this timescale for the development of a mantle, it is expected that a normal TNO begins to show the reddening of its spectrum, due to the presence of these organics species, in shorter periods.

In the particular case of 2003 EL₆₁ its spectrum does not show the expected presence of complex organic species on the surface, and this is an interesting fact that needs an explanation. As it has been already proposed for 2005 RR₄₃ (Pinilla-Alonso et al. 2007) different scenarios are possible: the surface has been recently replenished with fresh material (e.g. due to cryovolcanism, multiple collisions or a recent huge collision), or these objects are originally carbon depleted.

An increase of fresh material on the surfaces of icy bodies in the Solar System can be explained by processes of replenishment with fresh and unaltered material from the interior. Subsurface material could be exposed by outgassing onto the surface or by flows from the interior as a result of cryovolcanism. This process would produce a surface composed of patches of fresh water ice covering partially an older surface of processed ices. Cryovolcanism has already been proposed as a mechanism of continuous resurfacing of the surface of medium-size TNOs as (50000) Quaoar (Jewitt & Luu, 2004) or Charon (Cook et al., 2007) but it has always been related to ammonia hydrate. Ammonia hydrate is an expected product of condensation in the high-density protoplanetary disk and evidence from the comets composition show that this molecule is also trapped from the solar nebula (Kawakita & Watanabe, 2002). For TNOs greater than 400 km in diameter, an ice mixture of ammonia and water would be melted at temperatures typical of the interiors of these bodies. This melted mixture could propagate through cracks until it reaches the surface in a similar way that basaltic volcanism propagates on Earth (Stevenson, 2004). In this case, the surface would show patches of fresh crystalline water ice with traces of ammonia hydrate covering partially older amorphous water ice. In the spectrum, we should see signs of ammonia hydrate clearly evidenced by an absorption band at 2.2µm. This band is not present in the spectrum of 2003 EL₆₁. Also our fits favour an intimate mixture instead of an areal one, so cryovolcanism is not a scenario compatible with the observations. Furthermore, as the surface properties of the group of TNOs related to 2003 EL₆₁ are similar, we should conclude that resurfacing mechanism acting on them is similar. But as several of them have diameters smaller than 400 km, we can discard cryovolcanism.

Another scenario is that of resurfacing produced by collisions. One collisional event has been proposed by Brown et al. (2007) as the origin of the group of TNOs with similar orbital and spectral properties to those of 2003 EL₆₁’s. Such an energetic impact would release a large amount of energy that could partially be converted into heat and that would produce a significant increase of the temperature (above 100-130 K) leading to the crystallization of a large amount of water ice. The eroded material would be sublimated and globally distributed over the TNO surface on a timescale of tens of hours (Stern 2002). The result of this process would be a fresh surface covered with crystalline water ice as proposed for 2002 TX₃₉₀ (Licandro et al. 2006), another member of the group. After the event the temperature of the ice cools down to about 40 K and irradiation process starts to transform crystalline into amorphous water ice. From the analysis of the spectrum of 2003 EL₆₁ and the models presented in Sec 4., we find a percentage of crystalline and amorphous water ice on the surface in a ratio of 1:1, and this can be used to constrain the age the surface of 2003 EL₆₁. Leto & Baratta (2003) found from laboratory experiments that a 1:1 mixture of crystalline and amorphous water ice is obtained by irradiating crystalline water ice with a dose of at least 1eV/molecule. Taking also into account the percentage of crystalline and amor-
phous ice in our model and the results of Strazzulla et al. (2003) about the time needed to produce a radyolitic change in irradiated water ice, we can infer a timescale for this process of about $10^6$ yr at an heliocentric distance of 40 AU (the error in this estimate is of a factor of 5). Moreover, we have to consider the effect of collisions with smaller particles in the TNb, these continuous events recrystallize water ice on the surface and compete with that of amorphization by irradiation. So, the timescale needed to produce a 1:1 crystalline/amorphous surface is probably longer than $10^8$ yr.

This estimation puts a constraint on the age of the surface of 2003 $EL_{61}$, since a recent (< $10^8$ yr) impact that rejuvenated and recrystallized the whole surface has to be excluded. It is important to note that this result agrees with recent calculations indicating that the large impact that most probably originated the family of 2003 $EL_{61}$ should be primordial (Ragazzine & Brown, 2007).

In any case, the surface of 2003 $EL_{61}$ should be older than $10^8$ yr, i.e. it is old enough to show on its surface the signal of complex organics, but this is not the case for this object. The only reasonable explanation for the lack of organics on the surface of the members of this population is that they have a composition depleted of carbon chains (as already suggested for 2005 $RR_{43}$ (Pinilla-Alonso et al.2007)). This carbon depleted population turns into the first group whose surface properties can only be explained by a different original composition, and this needs to be further investigated. Either the depletion of carbon chains is related to the hypothetic giant collision or alternatively these TNOs were formed in an heterogeneous region of the solar nebula.

All the members of this group have similar orbital parameters (41.6 $\leq a$< 43.6 AU, 25.8 $< e < 28.2$ degr., 0.10 $< i < 0.19$) and lie in an unstable region of the TNb crossed by Neptune resonances. This suggests some of these objects could be injected to inner regions of the TNb finishing their lives as Jupiter family comets. Consequently this group could be a source (not necessarily unique) of the carbon depleted comets in the Jupiter family already noticed by A’Hearn et al. (1995).

6. Conclusions

We observed 2003 $EL_{61}$ on 2005 August 1.92 UT simultaneously in the visible and near infrared with two telescopes, the 4.2m WHT and the 3.6m TNG at the ORM (Canary Islands, Spain); and only in the near-infrared with the TNG on 2006 February 25, from 01:21 to 04:33 UT. We present the low-resolution spectra obtained in both nights. The similarities between near infrared spectra obtained at different rotational phases (covering almost 80 % of the rotational period) let us conclude that the surface of this TNO is almost homogeneous. Fitting 2003 $EL_{61}$ spectrum using Hapke (1981) models we concluded that it is composed of almost pure water ice. We reproduce the spectrum with an intimate mixture of crystalline and amorphous water ice in a proportion 1:1. We also obtain a good fit with a multi-layer model representing a thin cap of an intimate mixture of crystalline and amorphous water ice in a proportion of 4:6 over an infinite layer of crystalline water ice. Both configurations are physically consistent with the homogeneity of the surface and with the processing of water ice under cosmic irradiation.

If the present surface of 2003 $EL_{61}$ is the product of a large collision, the relative percentage of amorphous and crystalline ice we obtain from the models, implies that this collision should have happened more than $10^8$ years ago, in agreement with dynamical models.

Furthermore, these models evidence that adding other constituents in a percentage over 8% impoverishes the fit of the spectrum introducing new features or reddening the slope in the visible range. So we discard the presence of a significant amount of other components on the surface but water to a high level of confidence. In particular we discard the presence of complex organics.

Considering that our models favor an intimate 1:1 mixture of amorphous/crystalline water ice, and that there is no signature of ammonia hydrate in the spectrum, we conclude that cryovolcanism is unlikely the main resurfacing mechanisms on 2003 $EL_{61}$.

Given the estimation of the age and the lack of an evolved mantle of complex organics on the surface of 2003 $EL_{61}$, we conclude that, as for 2005 $RR_{43}$, and probably the other members of the $EL_{61}$ group of TNOs identified by Pinilla et al. (2007) this body has a significant smaller fraction of carbon chains on its surface. This group is a carbon-depleted population of TNOs that, considering their orbital parameters, could be the origin of some of the carbon-depleted comets already noticed by A’Hearn et al. (1995).

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