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Letter to the Editor

An R-type asteroid within near-Earth objects?*

S. Marchi, M. Lazzarin, and S. Magrin

Dipartimento di Astronomia, Università di Padova, Vicolo dell'Osservatorio 2, 35122 Padova, Italy
e-mail: [marchi;lazzarin;magrin]@pd.astro.it

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Abstract. We present visible and near-infrared spectroscopy of 2001 XR31, a previously unclassified small near-Earth object (NEOs). Its spectrum resembles that of basaltic body, with the distinctive 1 and 2 μm pyroxene absorption bands, similar to those found on V-type bodies. However, the spectrum of 2001 XR31 is somewhat peculiar and we discuss whether it can belong to another class of basaltic bodies, namely the rare R-class.
If confirmed, this object would be the only R-type detected among NEOs so far. In the light of this possibility, we also discuss the relationships of 2001 XR31 with other main belt R-types and a possible explanation of its origin.

Key words. minor planet – asteroids – near-Earth objects

1. Introduction

The physical properties of near-Earth objects (NEOs) are still vaguely known. However, this is one of the most important task to be performed in the near future in order to have a global view of this population of asteroids. The knowledge of the physical properties of NEOs will allow us to obtain information about their surface composition, as well as about their origin, evolution, and their link with other small bodies.

So far, many of the taxonomic classes introduced for the main belt asteroids (see Bus 1999; Bus & Binzel 2002) have been already detected among NEOs (see Lazzarin et al. 2004; Binzel et al. 2002), indicating a great compositional variety. A variety which is also reflected by other quantities like spin states, shapes, dimensions, dynamical behavior and so on. All the available information are suggesting for a big heterogeneity among NEOs, which of course reflects their complex history.

The best way for studying physical properties of minor bodies is through spectroscopy. In this letter we present the visible and near-infrared spectroscopy of 2001 XR31, a previously unclassified small NEO. Although its spectrum resembles that of a basaltic body (V-like), it is somewhat peculiar and we discuss whether it can be a R-type instead of a V-type. If confirmed, this object would be the only R-type detected among NEOs so far. This would be very important because the R-class is very rare among minor bodies: only other 4 bodies (all main belt asteroids (MBAs)) have been classified as R-types. A reason which would allow us to track or, at least constraint, the evolution of this NEO.

Send offprint requests to: S. Marchi, e-mail: marchi@pd.astro.it
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2. The spectra

We recorded the visible and near-infrared (NIR) spectra of 2001 XR31 on 5th (visible) and 7th (NIR) May 2003, with the ESO New Technology Telescope (NTT) at La Silla, Chile. For the visible observations, the NTT was equipped with EMMI (ESO Multi-Mode Instrument), used in the low resolution mode with the Grism #1 and a slit width of 5″ (the resolution was about 250). For the NIR, SOFI (Son OF Isaac) was used in the low resolution mode equipped with the Grism Blue that in the range 0.95−1.64 μm gives a resolution of 1000 with a slit of 0.6″. For a more detailed description of the instruments, the observational strategy and the reduction techniques see Lazzarin et al. (2004), Marchi et al. (2003).

In Fig. 1 the visible spectrum of 2001 XR31 is shown. Its spectrum presents the overall behavior of igneous, V-like, objects. However its visible spectrum also presents many common aspects with another group of igneous bodies, those belonging to the R-class. Tholen (1989) introduced the distinction between V- and R-class on the basis of the spectra of two peculiar MBAs, (4) Vesta and (349) Dembowska, respectively (for further details, see Gaffey et al. 1993). Recently Bus (1999), which proposed a new taxonomy obtained through the visible data of SMASSII, still kept this distinction, although he provided new spectra in both classes increasing the spreading between each class. In particular he found 3 more objects similar to (349) Dembowska, and hence classified as R-types. However, a detailed inspection of all the visible spectra of V- and R-types show that this division is somewhat weaker than that introduced by Tholen. This is because many asteroids classified as V-type have spectra similar to those of the R-types. Following the classification of Bus, the spectra are discriminated between V and R by a complex analysis which

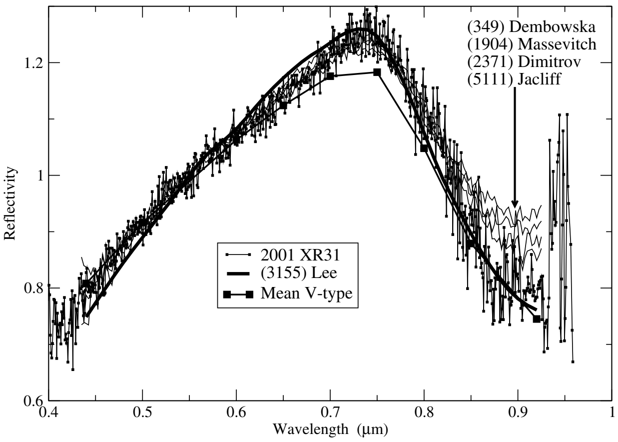

Fig. 1. Comparison of 2001 XR31 with R-type MBAs (taken from Bus 1999) in the visible region. The mean V-type and (3155) Lee are also shown (both from Bus 1999).

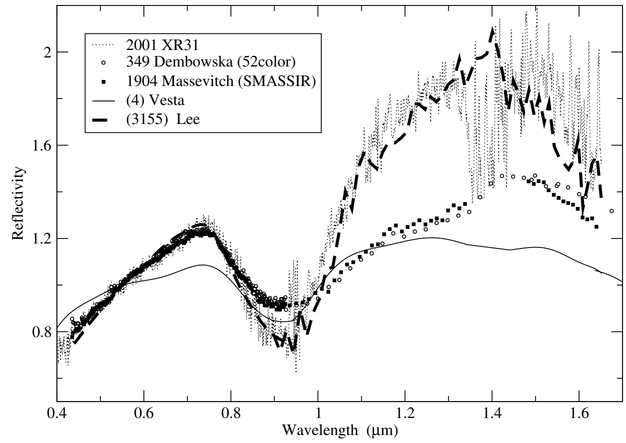

Fig. 2. Comparison of 2001 XR31 with R-type asteroids. On the same plot, (4) Vesta and (3155) Lee are also shown. The NIR of (1904) Massevitch and (3155) Lee are from SMASSIR (Burbine et al. 1997), while the NIR of (349) Dembowska is from 52-Color survey (Bell et al. 1988).

involves the value of the reflectivity at 0.75 μm and 0.92 μm, and in particular the latter has to be less than 0.82, for the V-type. According to this classification, 2001 XR31 would be at the border between V- and R-class (see Fig. 1). However, we underline also that the spectrum of 2001 XR31 surprisingly overplots exactly the R-types in the range 0.4−0.85 μm. Moreover, we point out another similarity between the R-types and our NEO, namely on the basis of their behavior within the range 0.86−0.95 μm. In fact, the reflectivity of all the R-type objects in this interval is noticeably constant (see Fig. 1) while for the V-types it is generally slightly decreasing. In other words, the bottom of the 1 μm band is almost flat. Now, it is difficult to understand the origin of this behavior, but it is believed to be significant for compositional differences. We point out that it could be due to mixture of compounds which have the peak of the 1 μm band at slightly different wavelengths, for example by a mixture of olivine and pyroxene or a mixture of pyroxenes with different contents of Fe (e.g. see Gaffey 1997). To better show the differences between V-types and R-types, in Fig. 1 we also report the object (3155) Lee which, among the V-types, is the one which closer resembles 2001 XR31. Figure 1 clearly shows that although the overall behavior of these two objects is quite similar, there are differences in slope and the shape of the 1 μm band, reasons for which the spectrum of 2001 XR31 is best fitted by the R-types, instead of V-types.

However, the NIR (see Fig. 2) of 2001 XR31 does not resemble those of the only two available R-types. Anyway, the 2001 XR31 high values of reflectivity in the range 1.3−1.5 μm with respect to (349) Dembowska is likely the same kind of discrepancy shown by the V-types and Vesta. For the latter a possible explanation has been found in grain size effects (Burbine et al. 2001): smaller particle sizes produce higher values of reflectivity. Other possible reasons able to increase the reflectivity could be compositional differences or space weathering. As shown by Hiroi & Sasake (2001), the spectrum of (349) Dembowska is well fitted by a mixture of space-weathered olivine (55%), space-weathered orthopyroxene (44%), and fresh olivine (1%). If 2001 XR31 is a fragment of (349) Dembowska, their differences could be affected by different degree of space weathering. Finally, the steep right-hand limb of the 2 μm band of 2001 XR31 would indicate a greater concentration of pyroxene on 2001 XR31 with respect to (349) Dembowska.

3. Dynamical implications

Concerning the intriguing possibility that 2001 XR31 (having an estimated diameter of about 1.3 km) is related to R-type instead of V-type, notice that the only possible known parent body is (349) Dembowska. This is because it has a diameter of about 140 km, while the other main belt R-types have diameter in the range 6−12 km, unless they are remnants of a larger R-type body which suffered a collision, but there is no evidence for that at the moment. Nevertheless other sources cannot be excluded.

The surface of (349) Dembowska is still poorly known. The only information about its shape comes from the analysis of the light curves (e.g. see Zappalà et al. 1979). As pointed out by Abell & Gaffey (2000), the light curves and spectral variations seem to indicate the presence of an albedo spot near the equator. Possibly it could be a trace of a cratering event, as also noted by Abell and Gaffey. If so, the differences observed in the NEOs spectra with respect to the R-types can results from NEOs being fragments of deepen layers which should have different composition considering the spot albedo variation.

However, (349) Dembowska is placed far from the strong ν_6 and 3:1 resonances, which are thought to be the main sources for near-Earth objects, and the delivery of its fragments into near-Earth space would have followed other routes. It has a proper semi-major axis of 2.925 AU which falls inside the 5:2 and 7:3 mean motion resonances. These resonances are probably not too efficient to produce NEOs, because they tend to push objects into high eccentricity orbits and eventually, when they reach a critical eccentricity for becoming Jupiter crosser, the objects are subsequently removed from the inner solar system by close encounters with Jupiter

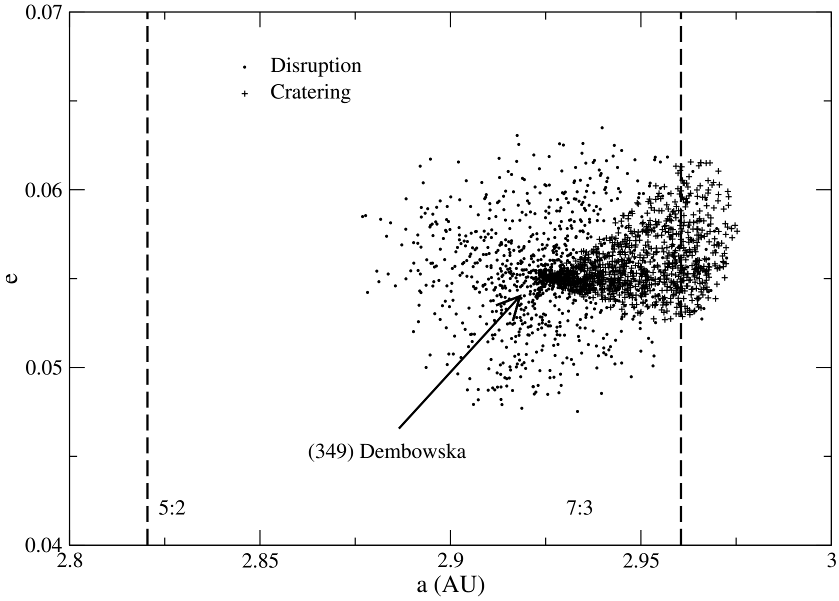

Fig. 3. Distribution of ejecta from (349) Dembowska in the (a, e) plane, for catastrophic disruption and cratering event. In the latter case, the ejection cone is oriented along the direction of motion of (349) Dembowska. In both cases, the fragments are generated with a uniform distribution of velocity modules between 0 and 0.15 km s^{-1}, and for (349) Dembowska's true anomaly of 90 deg (see text).

(see Moons & Morbidelli 1995; Gladman et al. 1997; Morbidelli & Gladman 1998). However this possibility cannot be ruled out, because for eccentricity lower than the critical value, some objects can have close encounter with Mars and the Earth (see Moons & Morbidelli 1995; Morbidelli & Gladman 1998), and eventually, they can be trapped in near-Earth space, as maybe indirectly prove by the presence of many C-types among NEOs. Concerning the inclinations, hypothetical (349) Dembowska's fragments would have values within few tenths of that of (349) Dembowska itself (i.e. about 8 deg). For a comparison the present inclination of 2001 XR31 is 22.7 deg. Notice that, the dynamical behavior of such fragments would be quite similar to that of Eos-like objects which have been investigated recently by Tsiganis et al. (2003). They found a mean resident-time in the 7:3 of 12.4 Myr, and that such Eos-like objects can reach inclination of about 16 deg, before being ejected from the resonance by close encounter with Jupiter. The variation of the inclination due to the evolution driven by the resonances alone can be of a few degree at most (see Fig. 3b in Tsiganis et al. 2003; Yoshikawa 1989). A similar increase in inclination can probably also be achieved by close encounters with Earth and/or Venus, as shown for the Alinda class by Milani et al. (1989). Moreover, notice that at the present time, the orbit of 2001 XR31 is such that it can have "strong" close encounter with the Earth and with Mars, and for this reason it is difficult to get constraints of its origin (see `http://newton.dm.unipi.it/cgi-bin/neodys/neoibo`). Concerning the possibility that (349) Dembowska's fragments can reach any resonance, we show in Fig. 3 the distribution of fragments generated by (349) Dembowska after both a catastrophic collision and a cratering event. The fragments have been considered to be ejected isotropically (suitable for a catastrophic collision) or in a cone of semi aperture of 40 deg (suitable for a cratering event), with uniform distribution of velocity modules between 0 and 0.15 km s^{-1}, which is roughly the escape velocity of (349) Dembowska (for more details of the model used see Marchi et al. 2001, 2002). The figure shows that fragments can easily reach the 7:3 resonance, for which a velocity of about 0.1 km s^{-1} is sufficient; while higher velocity (~0.5 km s^{-1}) are needed to reach the 5:2 resonance. Also taking into account possible semi-major axis mobility, i.e. the Yarkovsky effect (see Farinella & Vokrouhlicky 1999), it seems unlikely that the 5:2 has played a role in delivering fragments from (349) Dembowska.

4. Conclusion

In this paper we analysed the visible and NIR spectrum of a small NEO, namely 2001 XR31. Our findings can be summarize as:

– 2001 XR31 resembles V-type bodies, but we point out its possible link with the R-class. If this would be confirmed by other observations, it will be the first R-type discovered among NEO so far.
– Considering the possibility that 2001 XR31 is R-type, we point out that it could have been injected in near-Earth space by the 7:3 mean motion resonance with Jupiter.

References

Abell, P. A., & Gaffey, M. J. 2000, LPI XXXI, abstract No. 1291
Bell, J. F., Owensby, P. D., Hawke, B. R., & Gaffey, M. J. 1988, abstract of the Lunar and Planetary Science Conf., 19, 57
Binzel, R. P., Lupishko, D., di Martino, M., Whiteley, R. J., & Hahn, G. J. 2002, in Asteroids III, ed. W. F. Bottke, A. Cellino, P. Paolicchi, & R. P. Binzel (Tucson: Univ. of Arizona Press)
Burbine, T. H., Buchanan, P. C., Binzel, R. P., et al. 2001, M&PS, 36, 761

Burbine, T. H., Binzel, R. P., & Bus, S. J. 1997, 28th Annual Lunar and Planetary Science Conf., 179
Bus, S. J. 1999, Ph.D. Thesis, Boston, MIT
Bus, S. J., & Binzel, R. P. 2002, Icarus, 158, 146
Farinella, P., & Vokrouhlicky, D. 1999, Science, 283, 1507
Gaffey, M. J. 1997, Icarus, 127, 130
Gaffey, M. J., Burbine, T. H., & Binzel, R. P. 1993, Meteoritics, 28, 161
Gladman, B. J., Migliorini, F., Morbidelli, A., et al. 1997, Science, 277, 197
Hiroi, T., & Sasaki, S. 2001, M&PS, 36, 1587
Lazzarin, M., Marchi, S., Barucci, A. M., Di Martino, M., & Barbieri, C. 2004, Icarus, in press
Marchi, S., Lazzarin, M., Magrin, S., & Barbieri, C. 2003, A&A, 408, L17
Marchi, S., Barbieri, C., Dell'Oro, A., & Paolicchi, P. 2002, A&A, 381, 1059
Marchi, S., Dell'Oro, A., Paolicchi, P., & Barbieri, C. 2001, A&A, 374, 1135
Milani, A., Carpino, M., Hahn, G., & Nobili, A. M. 1989, Icarus, 78, 212
Moons, M., & Morbidelli, A. 1995, Icarus, 114, 33
Morbidelli, A., & Gladman, B. 1998, M&PS, 33(5), 999
Tholen, D. J., & Barucci, M. A. 1989, in Asteroids II (University of Arizona Press), 298
Tsiganis, K., Varvoglis, H., & Morbidelli, A. 2003, Icarus, 166, 131
Yoshikawa, M. 1989, A&A, 213, 436
Zappala, V., van Houten-Groeneveld, I., & van Houten, C. J. 1979, A&AS, 35, 213