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New candidates for active asteroids: Main-belt (145) Adeona, (704) Interamnia, (779) Nina, (1474) Beira, and near-Earth (162,173) Ryugu

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ABSTRACT

For the first time, spectral signs of subtle coma activity were observed for four main-belt primitive asteroids (145) Adeona, (704) Interamnia, (779) Nina, and (1474) Beira around their perihelion distances in September 2012, which were interpreted as manifestations of the sublimation of H_2O ice in/under the surface matter (Busarev et al., 2015a, 2015b). We confirm the phenomenon for Nina when it approached perihelion in September 2016. At the same time, based on results of spectral observations of near-Earth asteroid (162,173) Ryugu (Vilas, 2008) being a target of Japan's *Hayabusa 2* space mission, we suspected a periodic similar transient activity on the Cg-type asteroid. However, unlike the main-belt primitive asteroids demonstrating sublimation of ices close to their perihelion distances, the effect on Ryugu was apparently registered near aphelion. To explain the difference, we calculated the subsolar temperature depending on heliocentric distance of the asteroids, considered qualitative models of internal structure of main-belt and near-Earth primitive asteroids including ice and performed some analytical estimations. Presumed temporal sublimation/degassing activity of Ryugu is a sign of a residual frozen core in its interior. This could be an indication of a relatively recent transition of the asteroid from the main asteroid belt to the near-Earth area.

1. Introduction

As follows from the mineralogy of carbonaceous chondrites (e.g., Dodd, 1981; Brearley, 2006) being along with other meteorites the oldest solids in the Solar System (e.g., Connelly et al., 2008; Amelin, Krot, 2007) and possible fragments of primitive asteroids (C-type and others), these asteroids are the least geologically changed solid celestial bodies. Thus, they could preserve fingerprints of the first physical, chemical and dynamical processes that formed all of the planets. Widespread condensation and accumulation of volatile compounds (H_2O, CO_2, CO, etc.) in the internal Solar System beyond the "snow-line" obviously was one of the key processes that influenced the formation of not only proto-Jupiter and other giant planets, but also a swarm of smaller planetary bodies, including asteroids. Models of the early Solar System (ESS) (e.g., Safronov, 1969; Lewis, 1974; Makalkin, Dorofeeva, 2009; Bitsch et al., 2015) as well as taxonomic classifications of asteroids based on their spectral observations (Tholen, 1984; Bell et al., 1989; Bus, Binzel, 2002a, b) show that the snow-line at the stage of planetesimal formation was somewhere between the outer edge of the Main asteroid belt (or MAB, ~3.3 AU) and Jupiter's orbit (5.2 AU). However, the boundary could not stabilize in the ESS because of probable luminosity changes in the young Sun and decreasing turbulent viscous dissipation (e.g., Baraffe et al., 2015; Bitsch et al., 2015). Besides, due to intense ejection of residual stone-ice bodies by Jupiter from its formation zone to the inner region (Safronov, 1969; Safronov, Ziglina, 1991), it might has been possible to deliver icy material to the MAB (Busarev, 2002, 2011, 2012, 2016). For the two last plausible factors, it could result in mixing substances of silicate and ice composition in the MAB. Another important process, as follows from investigations of chondritic meteorites, was the early thermal evolution of silicate planetary bodies due to decay of short-lived isotopes (predominately ^{26}Al with $T_{1/2}$ = 0.72 My) (e.g., Grimm, McSween, 1993; Srinivasan et al., 1999). According to our analytical estimations (Busarev et al., 2003), for the first few million years after formation of calcium-aluminum inclusions

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(CAIs) in the silicate fraction of matter, internal water oceans (at an average temperature of ~4 °C) could form into big enough stone-ice bodies ($R > 100$ km) everywhere beyond the snow-line including the formation zone of proto-Jupiter. The main consequences of the processes would be aqueous differentiation of such bodies and accumulation of a silicate-organic core (up to ~0.7 R) saturated with liquid water and heavy organics (of kerogen or bitumen type with density > 1 g/cm^3) (Busarev et al., 2003, 2005). According to numeric modeling, important related processes in the water-rock system of the bodies were likely the exothermic reaction of serpentinization (hydration) of silicates and intense release of H_2 and CH_4 gases (Wilson et al., 1999; Rosenberg et al., 2001). These processes resulted in layered, microporous, and fragile internal structures of the bodies, and therefore, their low mechanical strength. It could be one of the main reasons for the predominant crushing rock-ice bodies from Jupiter's zone in collisions with asteroid parent bodies. Thus, all the above processes could lead to formation of a broad heliocentric distribution of the most abundant primitive type asteroids (C-type and similar) with a maximum near ~3 AU (Bell et al., 1989; Bus, Binzel, 2002b; Busarev, 2011, 2012; Alexander et al., 2012). It suggests that most, if not all, main-belt primitive asteroids include a considerable icy component.

Previous findings of cometary-like bodies among main-belt asteroids were interpreted in most cases as random events connected with "dynamical" contamination of the asteroid family with atypical icy objects (for instance, extinct comet nucleus) which become active only due to sporadic collisions or impacts (e.g., Hsieh, Jewitt, 2006; Hsieh, Haghighipour, 2016). Another point of view based on modeling and observations is that free water ice is widespread originally in the subsurface interiors of primitive main-belt asteroids themselves (e.g., Schorghofer, 2008; Rivkin, A. S., Emery, J. P., 2010). Our discovering simultaneous sublimation activity on several main-belt primitive asteroids at shortest heliocentric distances supports the last opinion and points likely to the same or similar physical and chemical conditions of origin of the bodies corresponding to the outer edge of the main-belt and beyond.

2. Observations, data reduction and asteroid reflectance calculation

Observational data on the asteroids were already described in more details in our previous publication (Busarev et al., 2015b) along with a comparison with previously obtained data by other authors. It is discussed here only briefly. Spectra of the main-belt asteroids (145) Adeona, (704) Interamnia, (779) Nina, and (1474) Beira were obtained in September 2012 using a 2-m telescope with a low-resolution (R ≈ 100) CCD-spectrophotometer in the wavelength range 0.35–0.90 μm at Terskol Observatory (Mt. Terskol, 3150 m above sea level, Russia) operated by IA RAS. Ephemerides and some observational parameters of Adeona, Interamnia, Nina, and Beira (calculated with on-line service of IAU Minor Planet Center http://www.minorplanetcenter.net/iau/MPEph/MPEph.html) are given in Table 1 at the times (UT) corresponding to averaged reflectance spectra of the asteroids on each night (Figs. 1–5). DECH spectral package (Galazutdinov, 1992) was used to reduce CCD observations by means of standard reduction procedures (flat-field correction, bias and dark subtraction, etc.) and to extract asteroid spectra. Wavelength calibration of the spectra was done using the positions of hydrogen Balmer lines in the spectrum of α Peg (B9III) observed in a repeated mode. The obtained spectra were corrected for the difference in air mass by applying a conventional method based on observations of a standard star being, as well, a solar analog (e.g., Hardorp, 1980). Its spectrum was also taken (instead of that for the Sun) for calculation of asteroid reflectance spectra (e.g., McCord et al., 1970). Observational data on the same star were used to determine the running spectral extinction func-

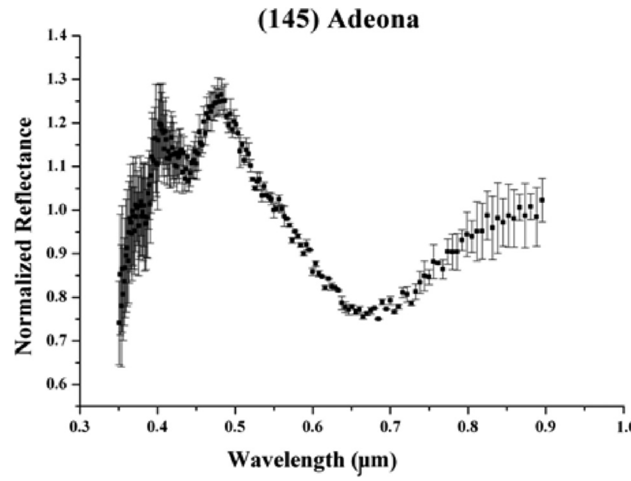

Fig. 1. Averaged and normalized ($R = 1.0$ at 0.55 μm) reflectance spectrum of (145) Adeona on 19 September 2012. Error bars represent the standard deviation.

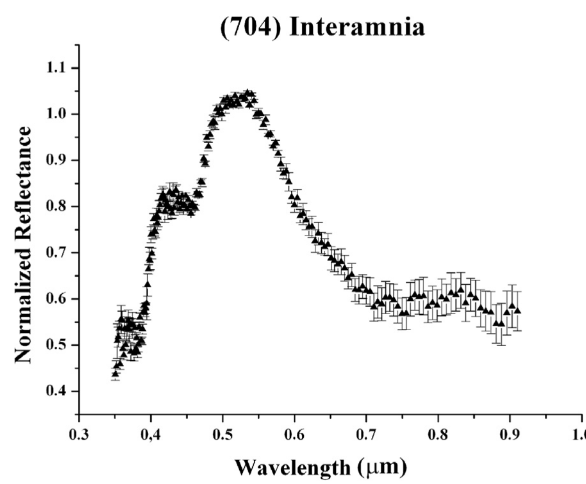

Fig. 2. Averaged and normalized ($R = 1.0$ at 0.55 μm) reflectance spectrum of (704) Interamnia on 13 September 2012. Error bars represent the standard deviation.

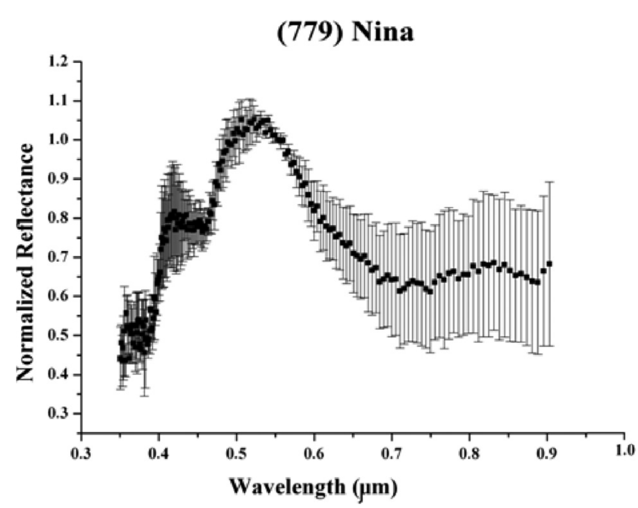

Fig. 3. Averaged and normalized ($R = 1.0$ at 0.55 μm) reflectance spectrum of (779) Nina on 13 September 2012. Error bars represent the standard deviation.