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(596) Scheila in outburst: A probable collision event in the Main Asteroid Belt

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Abstract

Images of asteroid (596) Scheila have been acquired at various dates after the detection of the 2010 outburst. Assuming a short-duration event scenario, as suggested by the quick vanishing of the dust tail brightness with time, and integrating numerically the equation of motion of individual particles ejected from the surface, we have developed a tail model from which we estimate the parameters associated to the geometry of the ejection, the size distribution, and the velocity distribution of the ejected particles, as well as the total mass ejected. We found a weak inverse power-law dependence of ejection velocity versus particle radius, with velocities ranging from 50 to 80 m s^{-1} for particle radii in the range 5 cm to 8×10^{-5} cm, respectively. These velocities are very different from those expected from ice sublimation at the asteroid heliocentric distance ($\sim$3 AU), and suggest a collision scenario as a likely cause of the outburst. We found that the ejected particles are distributed in size following a power law of index –3, and, based on the ejecta mass and scaling laws, the impactor size is estimated at 30–90 m in radius, assuming an impact velocity of $\sim$5 km s^{-1}, and the same density (1500 kg m^{-3}) for the asteroid as for the projectile. We have inferred an asymmetry in the ejecta along the axis normal to the asteroid orbit plane, a likely indicator of an oblique impact. The impact is estimated to have occurred on November 27th, with an accuracy not better than $\pm$3 days.

1. Introduction

(596) Scheila is a large Main-Belt Asteroid (MAB) (113 km in diameter) with very low geometric albedo (p_v=0.038) [9]. It has been classified as a D-type asteroid based on its visible and near-ir spectroscopy [7]. On December 11.4 2010, the asteroid displayed a surprising comet-like appearance. The outburst was detected by Larson [6] from Catalina Sky Survey (CSS), who reported the object as having a total magnitude $V = 13.4$. By inspection of the CSS archive images, it was determined that the outburst must have occurred sometime between November 11th and December 3rd, 2010 [6]. Right after the outburst detection many amateur and professional astronomers performed observations of the object, which displayed a well-defined bifid tail in the anti-sunward direction, consisting, in principle, of dust grains being blown away by radiation pressure. The tail was clearly seen since detection, but the brightness tend to vanish quickly after a few days, becoming undetectable after some three weeks after discovery. This scenario could be compatible with a short-duration event, such as a collision with another body, but other possibilities, such as a "regular", short-term, cometary-like outburst, or a sudden mass loss from rotational instability cannot be ruled out in principle. This object constitutes the seventh of the so-called Main-Belt Comets [5].

In this paper we report images of the asteroid at acquired at different dates and observatories (Calar Alto, La Palma, Izaña, and New Mexico Skies Observatory [8], and make an interpretation on the basis of a short-term event using a forward Monte Carlo dust tail code, in order to provide estimates of (i) timing, and geographic location of the event on the asteroid surface, (ii) particle ejection velocity law, (iii) particle size distribution, and (iv) total ejected mass. A complete analysis is provided in [8].

2. The Model

The asteroid is assumed to be a spherical body of radius R_n=56.67 km with a density of 1500 kg m^{-3}. In a heliocentric system, the equation governing the motion of the particles can be written as:

$$\frac{\mathrm{d}^2\mathbf{r_s}}{\mathrm{d}t^2} = -GM_a\frac{\mathbf{r_a}}{r_a^3} - \mu GM_s\frac{\mathbf{r_s}}{r_s^3} \quad (1)$$

where G is the gravitational constant, M_a is the asteroid mass, M_s is the mass of the Sun, $\mathbf{r_s}$ is the position vector of the particle, $\mathbf{r_a}$ is the vector from the asteroid to the particle, and t is time. The parameter $\beta = 1 - \mu$ is the ratio of the solar gravity force to the pressure radiation force and is given by $\beta = C_{pr}Q_{pr}/(2\rho_d r_d)$, where C_{pr}=1.19× 10^{-3} kg m^{-2}, and ρ_d is the particle density, assumed at ρ_d=1000 kg m^{-3} . For absorbing particles of radii $r_d > 0.25$ μm, the radiation pressure coefficient is $Q_{pr} \sim 1$ [1].

3. Results

The integration of the equation of motion (1) for a large number of particles gives a map of particle positions in the sky that, after projection on the photographic (N,M) plane, and taking into account the brightness of each individual particle, provides us with a synthetic image of the dust ejecta. The best solution found (see Figure 1) corresponds to an impact latitude θ=–10°, and an event time around November 27th, 2010. The particle ejection velocities we have found range from ∼50 m s^{-1} to ∼80 m s^{-1}, for the particle size domain 5 cm to 8×10^{-5} cm, respectively. The derived particle velocity law is of the form $v \propto \beta^\gamma$, with γ ∼0.05, i.e., a weak dependence of v on the inverse radius. This velocity law is in marked contrast with typical cometary ejection velocities at such heliocentric distances (e.g. [2]). Based on these velocity arguments, and the quick vanishing of the ejecta, we conclude that a collision event is a likely cause of the Scheila's outburst. If the impact took place at the mean velocity in the MAB of ∼ 5 km s^{-1}, an estimate of the impactor mass can be obtained from scaling laws [3]. The ejected mass having velocity higher than a certain value $M(v)$ divided by the impactor mass m_i can be related to the ratio v/U, depending on the target strength [4]. Thus, experiments show that for v/U ∼0.01, $M(v)/m_i$ ∼4 for weakly cemented basalt and $M(v)/m_i$ ∼100 for solid basalt [4]. As the model predicts a total ejected mass of 2×10^{10} kg, we would get m_i in the range 5×10^9 kg to 2×10^8 kg. Converting these masses to sizes, with ρ_i=1500 kg m^{-3}, we get a spherical projectile in the range ∼30–90 m in radius.

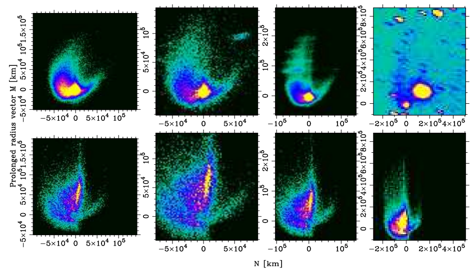

Figure 1: Left to right: Images of (596) Scheila corresponding to 13th, 14th, 17th, and 29th December, 2010 (Izaña 0.80-m, CAHA 1.23-m, and NMS 0.10-m telescopes). The upper row corresponds to the observations, while the lower row to the models. The tails show clearly a bifid pattern with a central spike in the sunward direction, although it not detectable in the 29 December image. Except for this latter case, the modeled images are rendered using the same color code for the intensities as the corresponding observed images at the top row.

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