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Activity in main-belt asteroid P/2010 A2

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Abstract

The dust tail of Main-Belt Asteroid P/2010 A2 (LINEAR) has been observed with several telescopes at the at the Observatorio del Roque de los Muchachos on La Palma, Spain. Application of an inverse dust tail Monte Carlo method to the images of the dust ejecta from the object implies a sustained activity over some eight months. The onset of the activity occurred in late March 2009, with a peak dust mass loss rate of about 5 kg s^{-1} in early June 2009, decreasing afterwards to 0.1 kg s^{-1} near perihelion in early December 2009. The total amount of dust released is estimated to be 5×10^7 kg, which represents about 0.3% of the nucleus mass. The nucleus diameter is $D = 220 \pm 40$ m, assuming a bulk albedo of $p = 0.11$, typical of a S-type asteroid. The event could have been triggered by a collision, but this cannot be decided from this dataset alone.

1 Introduction

On January 6, 2010, P/2010 A2 (LINEAR), a comet-like object, was discovered by the LINEAR sky survey. The orbital elements of the object ($a = 2.29$ AU, $e = 0.12$ and $i = 5.26$ deg) are typical of an inner Main-Belt asteroid belonging to the Flora collisional family, and suggest that it is unlikely to have originated in the classical comet source regions (i.e., the Kuiper Belt or the Oort cloud). The object reached perihelion, at a heliocentric distance of $r = 2.0$ AU, on 4 December 2009. Observations taken a few days after discovery [11, 12, 10], showed an inactive nucleus lying outside a dust tail without central condensation. This suggested that the observed dust cloud and the nucleus were the result of an impact between two previously unknown asteroids: the dust cloud is a plume of dust and the nucleus is what remains from the largest of the asteroids that collided.

Owing to its cometary-like aspect and orbital parameters, P/2010 A2 can be classified as a Main-Belt Comet (MBC) [9]. In contrast with the other known MBCs, however, P/2010 A2 has a significantly smaller semi-major axis (2.29 AU versus 2.7 AU and ~ 3.2 AU). Until now, the activity observed in MBCs was found to be compatible with a water-ice driven activation mechanism suggesting that those asteroids retained ice layers below their surface and, under certain conditions, become "activated asteroids". The presence of water-ice on the surface of 24 Themis, the parent asteroid of the Themis family MBCs [3, 16] strongly support this.

In this paper we present and analyze images of P/2010 A2 obtained with three telescopes at the Roque de los Muchachos Observatory (ORM), La Palma, Spain. The analysis of possible ejection scenarios is based on an inverse Monte Carlo dust tail fitting method, e.g., [14, 13].

2 Observations and data reduction

Images of P/2010 A2 were obtained in January 2010 with the Optical System for Imaging and low Resolution Integrated Spectroscopy (OSIRIS) [5, 4] camera-spectrograph at the Gran Telescopio Canarias (GTC), with the Auxiliary camera-spectrograph (ACAM) at the William Herschel Telescope (WHT), and with the Andalucia Faint Object Spectrograph and Camera (ALFOSC) at the Nordic Optical Telescope (NOT) all located at the ORM. Details of the observational ciscumstances, and reduction procedure are given in [15]. Figure 1 depicts some representative images obtained on the different dates with the instruments mentioned above. In this figure one can clearly see the inactive nucleus (marked with an arrow) lying outside the dust cloud that looks like a cometary tail. The absence of a dust cloud surrounding the nucleus indicates that the dust emission has stopped well before the observations. Using aperture photometry, we determined the nucleus R magnitudes for the GTC, WHT, and NOT images, giving $R = 23.4 \pm 0.4$. Using the formalism by [1] with a slope parameter of $G = 0.15$, we obtained a nucleus absolute magnitude of $H = 21.3 \pm 0.3$. Hence, a nucleus diameter of $D = 220 \pm 40$ m can be determined, assuming a bulk albedo of $p = 0.11$, typical of a S-type asteroid. This assumption is based on the fact that the S-type asteroids are the most common objects in the inner Main Asteroid Belt, e.g., [2].

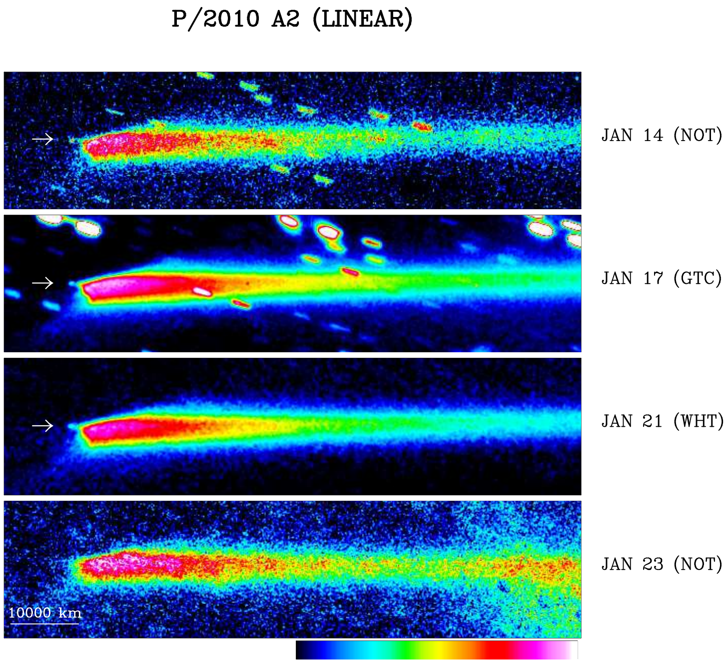

Figure 1: Images of P/2010 A2 (LINEAR) obtained at different dates with different telescopes at the Observatorio del Roque de los Muchachos in La Palma, as described in the text. The telescope abbreviations are NOT = Nordic Optical Telescope, WHT = William Herschel Telescope, and GTC = Gran Telescopio Canarias. The images have been rotated in order to have the tail along the X-axis. The Sun direction is approximately toward $+X$. Whenever the nucleus is visible, it is marked with an arrow.

The combined images from GTC and WHT obtained on the 17th and 21st January show the best S/N ratio (see Fig. 1). These images were rebinned and rotated to the (N, M) coordinate system [6] for analysis.

3 Application of the inverse dust tail model to P/2010 A2

We have performed an analysis of both the WHT and GTC images by the inverse Monte Carlo dust tail fitting code, e.g.,[14, 13], which is based on the same procedures as that developed by Fulle, e.g., [7, 8]. The inverse method involves the inversion of the overdetermined system of equations $AF = I$, where A is the kernel matrix containing the dust tail model, i.e., the surface density of the sample of particles integrated over time and β (the ratio of gravitational to radiation pressure forces), F is the output vector which contains the time-dependent distribution of β, and I is the brightness of the input image in the selected region of the photographic (N, M)-plane.

For a particle density of 1000 kg m^{-3}, the particle radius interval that best fit the observations (Fig. 2) is [0.001,1.0] cm, assuming an isotropic ejection velocity of $v = 1100\beta^{1/2}$ cm s^{-1}, and a particle albedo times phase function of $A_p = 0.04$, i.e., a similar value to that found for comet Halley from in situ observations [15]. The emission speeds agree with typical cometary activity at such heliocentric distance following Whipple's model [17]. The use of anisotropic ejection models [15] results in some improvement on the fits, but the dust mass loss rates are not modified significantly (see Fig. 2). The time variation of the mass loss rate indicates that the onset of the activity occurred in late March 2009, with a maximum of activity around early June 2009, with a peak of dust loss rate of about 5 kg s^{-1}, and decreasing to 0.1 kg s^{-1} near perihelion in early December 2009 (Fig. 2). Thus, the observed brightness distribution is consistent with a sustained cometary-like activity that spanned approximately 8 months. The integrated dust loss is 5.4×10^7 kg. Assuming a spherically-shaped nucleus of diameter of 220 m, and a nucleus bulk density of 3000 kg m^{-3}, the dust mass in the tail corresponds to 0.3% of the total nucleus mass.

Acknowledgments

This work is based on observations made with the Gran Telescopio Canarias (GTC), the William Herschel Telescope (WHT), and the Nordic Optical Telescope (NOT), installed in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias, in the island of La Palma. The William Herschel Telescope is operated by the Isaac Newton Group, and run by the Royal Greenwich Observatory at the Spanish Roque de los Muchachos Observatory in La Palma. The Nordic Optical Telescope is operated on the island of La Palma jointly by Denmark, Finland, Iceland, Norway, and Sweden, in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias. The instrument ALFOSC on the NOT is owned by the Instituto de Astrofísica de Andalucía (IAA) and operated at the Nordic Optical Telescope under agreement between IAA and the NBIfAFG of the Astronomical Observatory of Copenhagen. This work was supported by contracts AYA2007-63670, AYA2008-01720E, AYA2009-08190, and FQM-4555 (Proyecto de Excelencia, Junta de Andalucía). J. Licandro gratefully acknowledges support from the spanish "Ministerio de Ciencia e Innovación" project AYA2008-06202-C03-02. J. L. Ortiz gratefully acknowledges support from the spanish "Ministerio de Ciencia e Innovación" project AYA2008-06202-C03-01.

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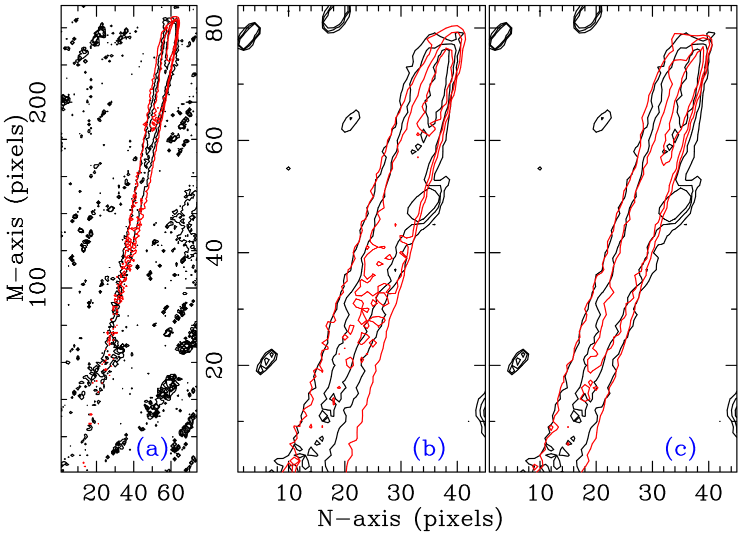

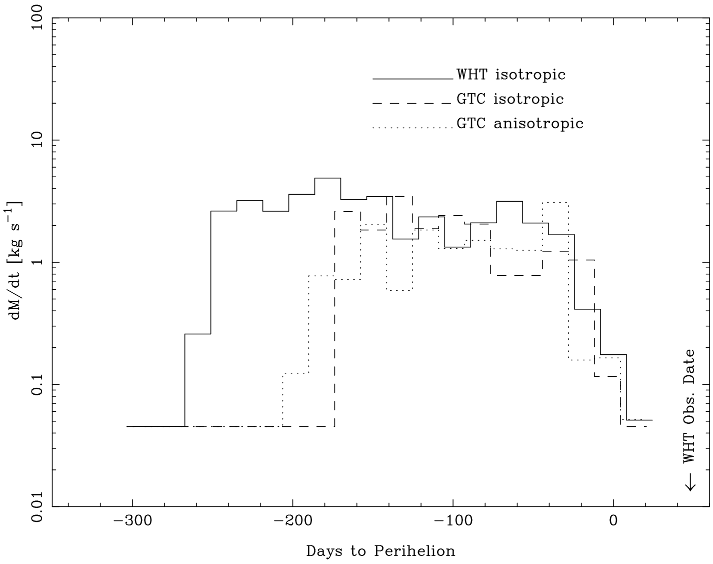

Figure 2: *Upper panels*: Results of the dust model applied to the WHT and GTC images. Coordinate axes correspond to the (N, M) system (see text). Black contours, with isophote levels of 5×10^{-15}, 10^{-14}, and 2×10^{-14} solar disk intensity units, correspond to the observations. Red contours correspond to the model. Panel (a): The isotropic model applied to the WHT image. The physical dimensions of the images are 57154 km × 194632 km. Panel (b): The isotropic model applied to the GTC image. The physical dimensions of the images are 25932 km × 48407 km. Panel (c): The anisotropic model applied to the GTC image, with same physical dimensions as those of panel (b). *Lower panel*: The derived dust mass loss rates for each model. The arrow indicates the observing date of the WHT image.

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