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THE TERMINAL VELOCITY OF THE DEEP IMPACT DUST EJECTA

M. Rengel,[1] M. Küppers,[1,2] H. U. Keller,[1] P. Gutierrez,[3] and S. F. Hviid[1]

RESUMEN

La colisión entre el proyectil liberado por la nave Impacto Profundo y el núcleo del cometa 9P/Tempel 1 generó una columna caliente de gas y polvo. Posteriormente se creó una eyección y el material se movió lentamente en la forma de una nube de polvo, la cual se disipó días después del impacto. Aquí reportamos un estudio sobre la distribución de velocidades terminales de las partículas eyectadas por el impacto, el cual se ha realizado por medio del desarrollo y aplicación del método del problema inverso mal condicionado. Modelamos las curvas de brillo observadas por la cámara NAC de OSIRIS a bordo de la nave espacial Rosetta y las comparamos con las observaciones de OSIRIS. Las velocidades terminales las derivamos usando el estimador de la máxima verosimilitud. La distribución de velocidad del polvo está bien definida y tiene su máximo alrededor de 220 m s^{-1}. Esta velocidad concuerda con otros valores publicados de la velocidad de expansión de la nube de polvo. La comparación entre la velocidad medida y observada sugiere que el la eyección fué rápidamente acelerada por el gas en la coma cometaria. Este análisis proporciona una mejor comprensión de las propiedades (la velocidad y la masa de polvo) de la nube de polvo generada por el Impacto Profundo.

ABSTRACT

The collision of the projectile released from NASA Deep Impact spacecraft on the nucleus of comet 9P/Tempel 1 generated a hot plume. Afterwards ejecta were created, and material moved slowly in a form of a dust cloud, which dissipated during several days after the impact. Here we report a study about the distribution of terminal velocities of the particles ejected by the impact. This is performed by the development and application of an ill-conditioned inverse problem approach. We model the light-curves as seen by the Narrow Angle Camera (NAC) of OSIRIS onboard the ESA spacecraft Rosetta, and we compare them with the OSIRIS observations. Terminal velocities are derived using a maximum likelihood estimator. The dust velocity distribution is well constrained, and peaks at around 220 m s^{-1}, which is in good agreement with published estimates of the expansion velocities of the dust cloud. Measured and modeled velocity of the dust cloud suggests that the impact ejecta were quickly accelerated by the gas in the cometary coma. This analysis provides a more thorough understanding of the properties (velocity and mass of dust) of the Deep Impact dust cloud.

Key Words: comets: individual — methods: miscellaneous

1. INTRODUCTION

In order to investigate the comet's interior, on 4 July 2004 the NASA mission Deep Impact (DI) fired a projectile of 364 kg into the nucleus of 9P/Tempel 1 (Tempel 1). A crater was formed and material was ejected from the comet, which moved afterwards in a form of a dust cloud (A'Hearn et al. 2005). One of the challenges of the DI experiment's physics is to characterize the cloud (e.g. structure, morphology, number of water molecules produced in the impact, abundance ratio between the CN parent molecules and water). Several of these property estimations are already reported in the literature. A problem of special interest is to find a reliable estimate for the terminal velocity distribution of the ejected dust after any acceleration process on the basis of the observations of the DI event. Reconstruction methods like the regularized inverse problem approach can be valuable tools for obtaining such a parameter characterization. On the other hand, the Narrow Angle Camera (NAC) of OSIRIS onboard Rosetta spacecraft (Keller et al. 2007b) monitored Tempel 1 from 5 days before to 10 days after the DI experiment (Küppers et al. 2005), and this data represent a well suited one to this kind of analysis.

2. OBSERVED AND MODELLED LIGHT CURVES

Between 28 June and 14 July 2005 Tempel 1 was observed nearly continuously with the OSIRIS cameras (Keller et al. 2007a). By cometocentric circu-

[1]Max-Planck-Institut für Sonnensystemforschung, Max-Planck-Strasse 2, Katlenburg-Lindau, D-37191 Deutschland (rengel@mps.mpg.de).

[2]European Space Agency, European Space Astronomy Centre, P.O. Box 50727, 28080 Madrid, Spain.

[3]Instituto de Astrofísica de Andalucia-CSIC, Camino Bajo de Huétor, 50, 18008 Granada, Spain.

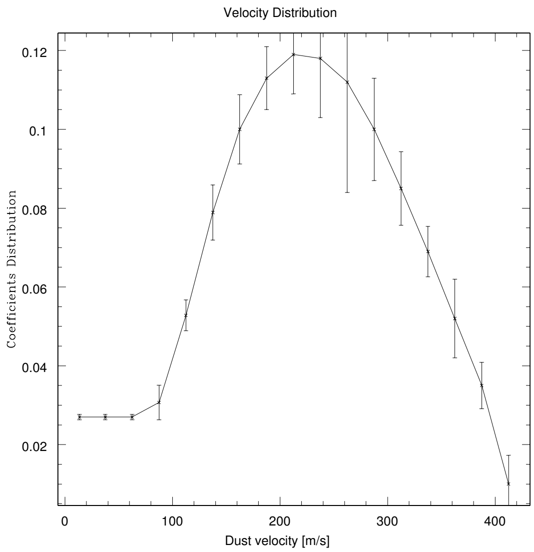

Fig. 1. Retrieved coefficients c versus dust terminal velocity. Error bars represent the standard deviation.

lar aperture photometry on the images of Tempel 1 taken with the NAC, the brightness of the cometary dust is integrated over a set of nine apertures of different radii (from 3000 to 15000 km, 1 pixel = 1500 km). Several hours after the impact collision, the expanding dust cloud started to leave the photometric apertures. Therefore the flux in each aperture decreases. By using the decay of the flux when the material leaves these different circular fields we compute the expansion of the dust ejecta plume. As a first approximation, in our model the material moves progressively outward in an expanding sphere. We compute the fluxes of the dust ejecta plume for different projected ejecta velocities v (from 1 to 600 m s^{-1}, with a velocity interval i of 25 m s^{-1}), and for different apertures (radii from 3000 to 15000 km). Figure 1 in Keller et al. (2007a) shows: (1) the light curves of the cometary dust in the clear filter, for the nine circular fields from 2 to 10 pixels, and (2) model profiles for velocities of 110, 160, and 300 m s^{-1}.

3. INVERSE APPROACH

Linear regression as a parameter estimation is used, and to solving the systems of linear equations (equation 2) –so-called normal equations of the least-squares problem– the Singular Value decomposition (SVD) (Press et al. 1992) is employed. Furthermore, to stabilize the inversion process, regularization was applied by a truncated SVD (TSVD) method. We fit simultaneously the observed flux O (which have associated error σ) by minimizing the sum of the chi-squared differences between all the data-points O (603 points[4]), and linear combinations of the modeled fluxes M (constructed for 25 different velocities):

$$\chi^2 = \sum_{k=1}^{603} \frac{1}{\sigma_k^2} \left(\sum_{j=1}^{25} [a(j)]_k - O_k \right)^2 , \qquad (1)$$

where $[a(j)]_k$ is defined as $c_j M_{jk}$ and c, a set of positive dimensionless coefficients to be determined, as $(c_1, c_2, ..., c_{25})$. The solution of equation 2 provides an estimate of the coefficients c:

$$\frac{\partial \chi^2}{\partial c_j} = 2 \sum_{k=1}^{603} \frac{1}{\sigma_k^2} \left(\sum_{j=1}^{25} c_j M_{jk} - O_k \right) M_{jk} = 0 . \qquad (2)$$

4. RETRIEVAL OF THE VELOCITY DISTRIBUTION

In Figure 1 we show the velocity distribution, it peaks at around 220 m s^{-1}. This velocity is in good agreement with the projected speed values derived from other authors.

5. CONCLUSIONS

We developed a discrete linear inverse problem approach which allows to simultaneously fit modelled light-curves to a set of observed ones of cometary dust of Tempel 1 acquired by NAC onboard Rosetta spacecraft. We derived a broad accurate velocity distribution of the dust particles (between 1 and 600 m s^{-1}) which peaks around 220 m s^{-1}. The velocities of the dust seen in the light curve in the first minutes after the impact suggest early acceleration of the ejected material close to the cometary surface. In the following days, the impact created cloud was accelerated in anti-solar direction by solar radiation pressure. There was no long-term effect of the impact. The ejecta cloud had dispersed after about a week.

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[4] 67 images per aperture, they correspond to early times (13 hours), where the effect of the radiation force is almost insignificant.