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Interpretation of polarimetric observations of hyperbolic comets

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Abstract. Polarimetric observations of comet C/2013 X1 (PANSTARRS) were compared with polarimetric data taken from the Polarimetric Comet Observations Database. To obtain a synthetic phase dependence of the degree of linear polarization of hyperbolic comets, the data were interpreted using computer simulations. In this case, computer simulation means calculating the characteristics of light scattered by particles of irregular shape and a certain chemical composition. Simulations showed that the dust ball would have to be 74 % amorphous carbon, 25 % magnesium-rich silicates, and 1 % water ice to reproduce the observed linear polarization values.

Keywords: comets: polarimetry; computer simulation

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1 Introduction

Hyperbolic comets of the Solar System are comets with parabolic and hyperbolic orbits, i.e., the eccentricity of their orbits is greater than or equal to 1. Many of these comets may originate from the Oort cloud or from interstellar space. There are currently 468 known hyperbolic comets.

One of the newly discovered hyperbolic comets, named C/2013 X1 (PANSTARRS), was discovered on December 4, 2013 at Haleakala Observatory in Haleakala National Park on Maui, Hawaii, when the comet was at a distance of 8.9 AU. from the Sun. The eccentricity of its orbit is 1.001026±0.000002. Polarimetric observations of this comet were carried out in a broadband filter R (6400/1580 Å) on the 6-m BTA telescope of the Special Astrophysical Observatory (SAO) and on the 2.6-m Shain telescope of the Crimean Astrophysical Observatory (CrAO).

2 Comparison with other hyperbolic comets

The polarimetric observation data for comet C/2013 X1 (PANSTARRS) were compared with polarimetric data taken from the database of polarimetric observations of comets, as well as from the works (Ivanova et al. 2017; Zhuzhulina et al. 2022; Shubina et al. 2024).

It turned out that the results of polarimetric observations for comet C/2013 X1 (PANSTARRS) are in good agreement with data obtained for other hyperbolic comets in the red passband. In this regard, data interpretation was carried out using computer modeling for the synthetic phase dependence of the degree of linear polarization of hyperbolic comets. We calculated the characteristics of light scattered by model particles of irregular shape and a certain chemical composition.

3 Interpretation of observations

To interpret the observed dependence of linear polarization on phase angle, we applied the shape matrix method, and conjugate Gaussian random particles were used as model particles (see Fig. 1). A mixture of three types of particles was considered: amorphous carbon (refractive index m = 1.993 + 0.259i (Scott & Duley 1996)), high-magnesium silicates (m = 1.674 + 0.002224i (Li & Greenberg 1997)) and ice. These refractive index values are widely used to interpret cometary observations (e.g., Halder & Ganesh 2021). Particle sizes were taken from 0.49 μm (carbon), 0.83 μm (silicates), 0.39 μm (ice) to 3 μm. Averaging of particles by orientation and size was carried out according to a power law with an exponent n = 3 for all types of particles.

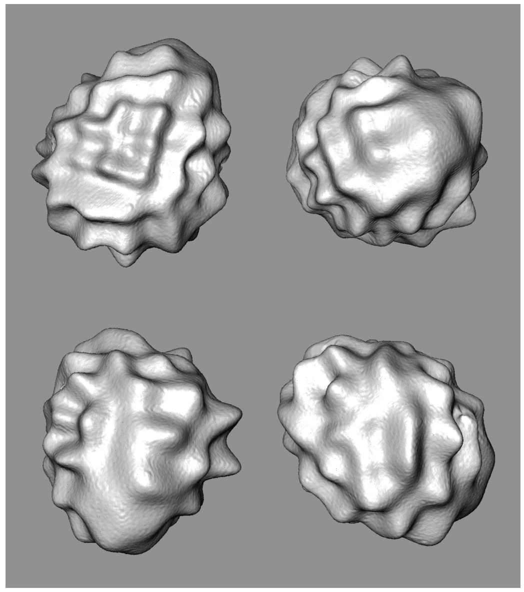

Fig. 1. Examples of conjugate Gaussian random particles.

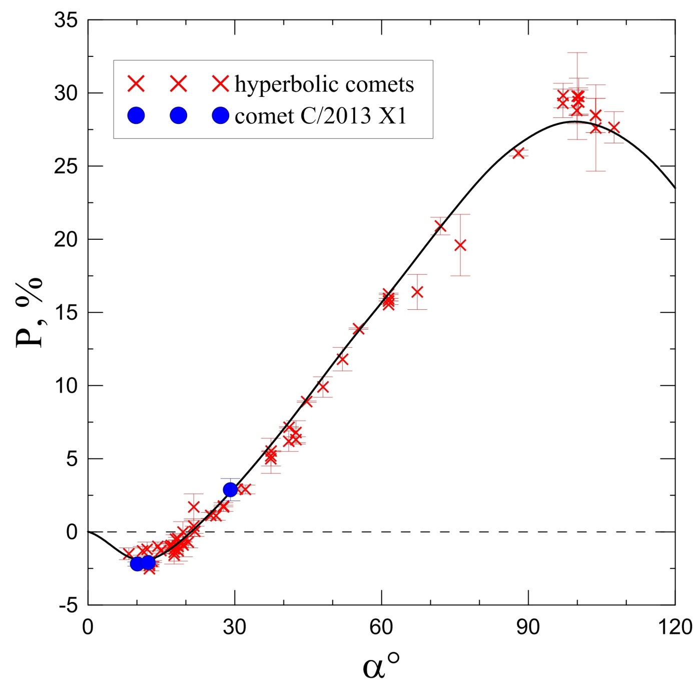

Fig. 2. Phase dependence of comet C/2013 X1 (PANSTARRS) (circles), other hyperbolic comets (crosses) and result of interpretation (line).

4 Summary

Simulations showed that the best fit between observation data and computer simulations is reached when dust coma consists of 74 % amorphous carbon, 25 % magnesium-rich silicates, and 1 % water ice (see Fig. 2). These results are in good agreement with Woodward et al. (2021) and are based on the analysis of IR spectral observations and thermal modeling.

Indeed, Woodward et al. (2021) determined that the dust composition of comet C/2013 X1 is dominated by dark dust particles (assumed as amorphous carbon) with an atomic ratio of carbon to silicon (C/Si) of 7.781 ± 6.091, much higher than it is in carbonaceous chondrites. Thus, taking into account the best fit between the results of polarimetry and computer modeling, it can be concluded that the solid material that makes up the dust particles of comet C/2013 X1 is rich in carbon.

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