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Light scattering from a cometary coma by means of Monte Carlo methods: application to 67/P Churyumov-Gerasimenko

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1. Introduction

In this paper we present simulations of the radiance coming from the coma of 67/P Churyumov-Gerasimenko, that are meant to support the scientific investigation of VIRTIS (Visible and Infrared Thermal Imaging Spectrometer) instrument onboard of the Rosetta spacecraft, working in the 0.25-5 μm spectral range. During the observation plan phase such simulations drive the selection of the integration times and spacecraft's pointing while during the post-processing phase the same model shall be used to retrieve the physical properties of the coma. Cometary coma spectra are strongly affected by the dynamical processes involving dust and ice grains present in the coma. The solar light illuminates the grains that can scatter, absorb and emit radiation. Radiative transfer in the coma can be modeled by means of Monte Carlo methods. Here we show results from two different routines: SCATRD 06.10 code (Vasilyev et al., 2006) and 3D Monte Carlo code developed by (Ciarniello et al., 2014).

2. Comet model

The simulations we show are performed on the following model of comet. The nucleus is a Lambert sphere with R=2 km and A_L=0.04. The coma has the following properties: 1) optical spectral properties calculate using Mie Theory; 2) density profile n(r) from ICES (http://ices.engin.umich.edu/) at 1.3 AU, adapted to radial symmetry; 3) composition: Titan tholin (McDonald et al. 1994); 4) grain size distribution: log-normal with r_{eff}=3 μm, ν_{eff}=10 μm and power law (q=-4); 5) p(g) = Heyney-Greenstein.

3. Monte Carlo model: SCATRD

The SCATRD 06.10 code (Vasilyev et al., 2006) is a Monte Carlo code and calculates the multiple scattered solar radiation for each wavelength in the VIRTIS spectral range. The atmosphere is modeled in spherical geometry allowing us to simulate both limb and nadir (for various zenith angles) viewing geometries. The simulations have been performed at 1.3 AU heliocentric distances and using different dust grains models in which size distribution, composition and vertical distribution are changed. All spectra are computed in limb and nadir mode with a spacecraft distance of 100 km, incidence i=50°, emission e=88°, phase g=40° angles, and a tangent altitude above the surface of 0.1,1,2,5,10 km.

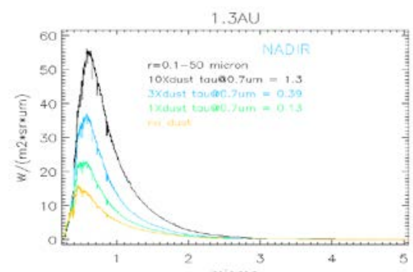

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Figure 1: Effect of dust content observing in NADIR mode. The Dust content affects the continuum and increases the radiance; The composition of the dust affects the shape of the spectral radiance introducing a shift of the peak due to absorption in the UV range; In nadir mode the absorption bands become detectable if dust content increases.

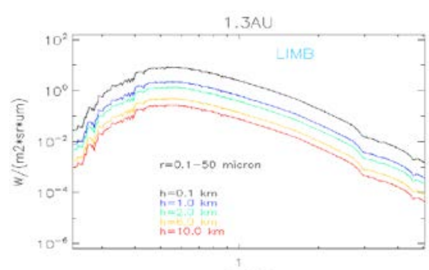

Figure 2: Coma intensity evaluated at different altitudes from the surface

4. 3D Monte Carlo code

We developed a Monte Carlo routine in IDL language that simulates 3D light scattering in a cometary coma, accounting only for dust contribution. The coma is modeled as a box and at each position the particles numerical density **n(r)** and the optical properties of the dust (single scattering albedo **w**, average particle phase function **p(g)** and extinction cross section **σ(E)** are defined. Photons are propagated from the top of the box downward where they interacts with the dust in the coma. Photons that reach the nucleus undergo lambertian scattering. When the photons escape from a face of the box their propagation direction and position are stored. The number of photons escaping in a given position and with a direction Ω is proportional to the power measured by an instrument placed in that position and observing in that direction. This routine is able to simulate light scattering for any distribution of dust. Below (fig.) we show results obtained with a model of coma as described in sec. ?, in which a jet of particles has been added, whose density is 100 times the density of the surrounding coma, observed at 0.7 µm.

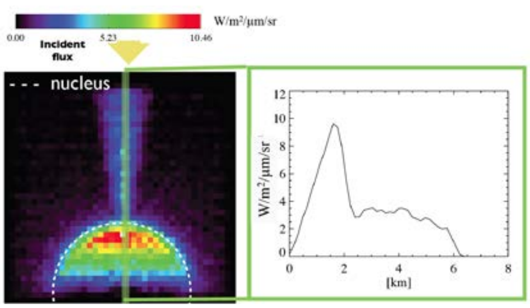

Figure 3: Left panel: simulated image of light scattered by a jet in a cometary coma. Right panel: radiance profile along the green line in the left panel.

It is possible to note that most of the signal comes from the nucleus but also the structure of the jet is clearly visible.

5. Comparison between SCATRD and the 3D Monte Carlo code

In fig. 4 we show a simulations performed at 0.7µm with the 3D Monte Carlo code on the comet model of sec. 2. We show two different observation geometries with phase angle ***g*=*0*°** and ***g*=*90*°**. In the radiance profile plot we report simulations carried out with SCATRD at the same geometries (we recall that SCATRD produce punctual radiance spectra at a given position).

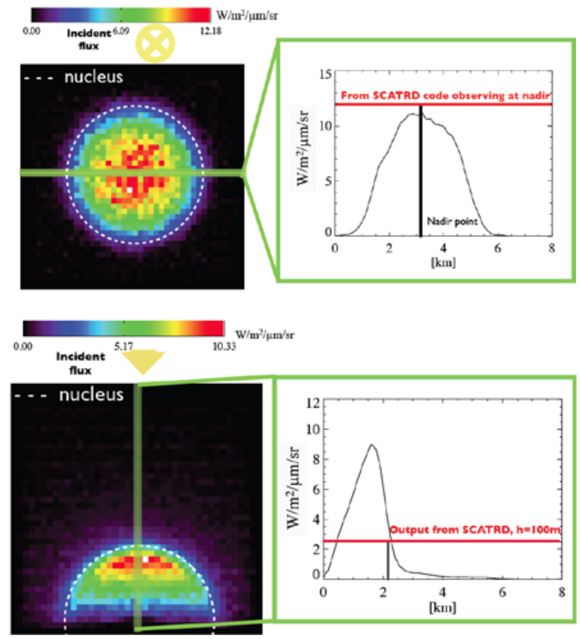

Figure 4: Top panel (***g*=*0*°**): simulated image of the comet (left) and radiance profile along the green line in the left panel (right). Bottom panel (***g*=*90*°**): simulated image of the comet (left) and radiance profile along the green line in the left panel (right). The output produced, in the same geometric conditions, by SCATRD is shown by the red line). demonstrating good correlation between the two models.

6. Summary and Conclusions

SCATRD is able to simulate punctual radiance spectra from a spherical symmetric coma considering single and multiple scattering as well as nucleus contribution. The 3D Monte Carlo code produces monochromatic images of the comet assuming any distribution of dust. We applied these two routines to simulate observations of C-G 67/P as seen by VIRTIS. We also compared the two codes simulating the photometric output of the coma at the same observation geometries.