EPSC Abstracts
Vol. 11, EPSC2017-849, 2017
European Planetary Science Congress 2017

3D radiative transfer code for polarized scattered light with aligned grains

V.-M. Pelkonen (1), A. Penttilä (1), M. Juvela (1), and K. Muinonen (1,2)
(1) Department of Physics, University of Helsinki, Helsinki, Finland (veli-matti.pelkonen@helsinki.fi), (2) Finnish Geospatial Research Institute FGI, Masala, Finland

Abstract

We are working on a 3D Monte Carlo radiative transfer code which incorporates hierarchical grid structure (*octree*) and the full Stokes vector for both the incoming radiation and the radiation scattered by dust grains. The dust model can include different populations of dust, differing in composition, size distribution, shapes, and orientation. The non-spherical dust grains can be randomly aligned, or a fraction of them can be aligned with the magnetic fields (in particular, by the radiation field via radiative torques, RATs). The code will be a valuable tool in studying polarized scattered light from cometary comae in the solar system and from protoplanetary disks in the exoplanetary context.

1. Introduction

Polarized scattered light has been observed in cometary comae [1] and in circumstellar disks [9]. An example of a cometary coma is given in Figure 1. Polarized scattered light carries information about the grains from which the light scattered. However, modelling polarized scattered light is a complicated problem. So far, most scattering codes consider either optically thin cases, where radiative transfer is not necessary, or only do one-dimensional (1D) radiative transfer. Three-dimensional (3D) radiative transfer is mainly focused on unpolarized radiation, which is easier to calculate.

We are in the process of developing a 3D radiative transfer code, which will calculate the full Stokes vector of the scattered light, not just the intensity. In addition, we will be able to have grains aligned in the magnetic field, and calculate their effect on the arising polarization of the scattered light.

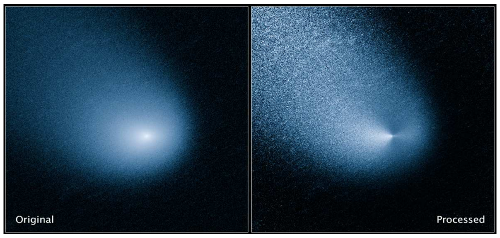

Figure 1: Comet C/2013 A1 coma captured by Wide Field Camera 3 on Nasa's Hubble Space Telescope. Processed image (right) shows jets coming from the comet's nucleus, which is too small to be seen in the images. The coma is about 20000 km across.[7]

2. Radiative transfer code

2.1 CRT code

The radiative transfer code is based on the CRT code [6][5], which was originally developed to study continuum dust emission from interstellar clouds. However, in order to do so, the radiation field impinging on the dust grains within the optically thick cloud has to be solved. While the code allows for internal sources as well, usually the radiation source is outside.

The 3D model cloud is divided into cubic cells, each with constant density. The optical depths for absorption and scattering, as well as the parameters of the scattering function are calculated for each cell. The Henyey-Greenstein formula [2] and the asymmetry parameter g are used to define the scattering function. The radiation field is calculated with Monte Carlo methods. Model rays are initiated at random locations at the cloud boundary in order to simulate the background radiation, and within the cloud to simulate emission from the dust and possible internal sources. The path of the model ray is traced in the cloud. A model ray represents a number of real rays. Absorbed intensity is counted in each cell that is crossed, and from time to time, the model ray is scattered towards a new direction as determined by the dust model. Because of the frequency dependence of the scattering probability, the simulation has to be carried out separately for each frequency.

2.2 The new code

In the code under development, we take the framework provided by the CRT code, but add the *octree* hierarchical grids, the full Stokes vector rather than just intensity for the model ray, and non-spherical grains which may or may not be aligned with the magnetic field. In *octree* grid format an upper level cell can be divided into 8 subcells by halving the cell in each of the three axis. Levels of further refinement of the grid may be added, as shown in Figure 2.

Due to the non-spherical grains and the polarization, the scattering problem will be the main issue for the code and most time consuming. The scattering parameters will be taken from the models for individual grains. We can introduce populations of different grain shapes into the dust model, and randomly select, based on their amounts, from which shape the model ray scatters. Similarly, we can include aligned and non-aligned subpopulations of these grains, based on the grain alignment calculations (such as using RATs[4][3]), to see which grains should be oriented with the magnetic field, or, in the absence of a magnetic field close to the comet nucleus, with another axis of alignment (e.g., the radiation direction[4]). The 3D nature of the grid allows us to assign these values for each computational cell, to model phenomena like e.g., cometary jets, such as seen in Figure 1.

The code will record polarized scattered light towards the observer, and it is possible to add multiple observer directions to calculate scattering at different phase angles within a single simulation run. These results can then be compared with the observations of comets, or, in the case of other star systems, of circumstellar disks, to help us study these objects.

Acknowledgements

VMP, AP, and KM acknowledge the financial support from the European Research Council, Advanced Grant No. 320773 entitled Scattering and Absorption of Electromagnetic Waves in Particulate Media (SAEMPL). VMP and MJ acknowledge the support of the Academy of Finland Grant No. 285769.

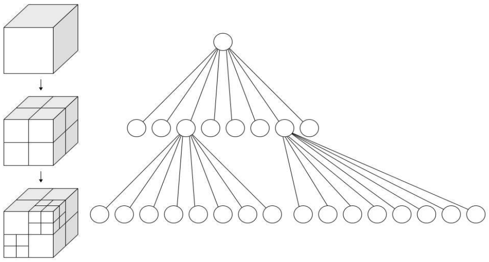

Figure 2: Subdivision of the calculation cube into octants, and the resulting *octree* structure.[8]

References

[1] Hadamcik, E., Levasseur-Regourd, A.C., Hines, D.C., Sen, A.K., Lasue, J., and Renard, J.-B.: Properties of dust particles in comets from photometric and polarimetric observations of 67P, MNRAS, Vo. 462, pp. 507-515, 2016.

[2] Henyey, L.G. and Greenstein, J.L.: Diffuse radiation in the Galaxy, ApJ, Vol. 93, pp. 70-83, 1941.

[3] Herranen, J., Markkanen, J., and Muinonen, K.: Dynamics of interstellar dust particles in electromagnetic radiation fields, Radio Science, submitted.

[4] Hoang, T., Lazarian, A.: Grain alignment by radiative torques in special conditions and implications, MNRAS, Vol. 438, pp. 680-703, 2014.

[5] Juvela, M.: Efficient Monte Carlo methods for continuum radiative transfer, A&A, Vol. 440, pp. 531-546, 2005.

[6] Juvela, M. and Padoan, P.: Dust emission from inhomogeneous interstellar clouds: Radiative transfer in 3D with transiently heated particles, A&A, Vol. 397, pp. 201-212, 2003.

[7] NASA, ESA, and J.-Y. Li (Planetary Science Institute) - https://www.nasa.gov/press/2014/march/nasas-hubble-space-telescope-spots-mars-bound-comet-sprout-multiple-jets/

[8] WhiteTimberwolf, PNG version: Nü - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=9851485

[9] Wolff, S.G., Perrin, M., Millar-Blanchaer, M.A. et al.: The PDS 66 circumstellar disk as seen in polarized light with the Gemini Planet Imager, arXiv:1601.07248