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Temperature and reflectance derivation from VIRTIS-H observations of 67P

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Abstract

A specific thermal emission model is applied to observations of 67P/Churyumov-Gerasimenko surface by the high-resolution channel of VIRTIS. Signal inversion provides both an effective surface temperature (averaged inside the FoV) and a reflectance spectrum corrected from thermal emission. Details of the organic material band at 3.2 µm [1] and longer wavelengths can then be studied at resolution R ~ 1500-3000 with increased contrast and accuracy.

1. Introduction

We use a basic radiance model in which reflectance and emissivity are related through a photometric function, and a single temperature is used for each pixel – this actually represents an average of sub-pixel temperatures weighted by area and black body radiance, and is therefore usually slightly less than the highest temperature present in the pixel. However, inversions of such models are known to be numerically instable. A regularization scheme is used here.

2. Radiance model

The method is adapted from that described in [2]. Radiance reads:

$$L(\lambda) = r_F(i,e,\varphi)\,\frac{E_s(\lambda)}{\pi R^2} + B_\lambda\,\varepsilon(e)$$

where B_λ is the black body radiance at the effective surface temperature T, $\frac{E_s(\lambda)}{R^2}$ is the solar irradiance at the target distance R, $r_F(\lambda)$ and $\varepsilon(\lambda)$ are the radiance factor and the directional emissivity of the surface at the same wavelength.

In a particulate medium at thermal equilibrium, directional emissivity is related to hemispherical-directional reflectance at each wavelength by Kirchhoff's law:

$$\varepsilon(e) = 1 - r_{hd}(e) = 1 - \int_{2\pi} r_F\, d\Omega_i$$

where reflectance is integrated over incidence angles in the free half-space. This strongly depends on the phase function of the material. If the photometric function can be assumed Lambertian (a reasonable assumption for bright materials) Kirchhoff's law simply reads:

$$\varepsilon(e) = 1 - r_F / (\cos i)$$

This quantity does not depend on incidence in the Lambertian case, and emission is isotropic. For dark materials such as the 67P surface, the Lommel-Seeliger model is however a better assumption. In this case, a similar, more complicated formulation of Kirchhoff's law can be derived, where emissivity is no longer isotropic. The photometric functions used in the present formulation mostly account for the influence of sub-pixel roughness, which is often modeled using a "beaming factor" [e.g., 3].

3. Inversion method

The above equation can be inverted to provide temperature and spectral reflectance from measurements. In practice, the inversion process is extremely sensitive to the noise and subject to numerical divergences, in particular near the crossover point between solar reflected light and thermal emission. On 67P, this is located between 3 and 5 µm and migrates towards shorter wavelengths as the comet approaches the Sun. A simple inversion therefore results in a correct estimate of temperature but in large spectral oscillations, sometimes with large negative values. It is therefore not applicable to recover a reflectance spectrum to be compared with experimental measurements.

The procedure used here consists in including a continuity constraint, i.e. to minimize the difference in retrieved reflectance between any two consecutive channels. This constraint prevents large oscillations to alter the reflectance spectrum, and acts as a smoothing function. As opposed to the Bayesian methods used for VIRTIS-M [4] no assumption is made on the expected spectrum, which could conceal minor absorptions. A practical drawback is the large increase in computing time (currently a factor of ~20), but it does provide reasonable estimates of spectral reflectance.

4. Application

The method presented here is applied to the inversion of VIRTIS-H / Rosetta observations of the nucleus of 67P and gives satisfying results when applied at a certain distance from the limb (e < 60°). Accuracy is assessed using spectra of similar areas at different temperatures. Reflectance estimates will be compared with laboratory measurements of relevant materials.

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