Pluto surface composition from spectral model inversion with metaheuristics

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Abstract

The New Horizons mission has returned hyperspectral data for Pluto's surface consisting of complex, not directly modelisable spectra. A radiative transfer model that accurately represents the complexity of the putative surface structure and mix of components poses a high-dimensional inverse problem, with 50-60 independent variables. We develop an efficient resolution method using progressive metaheuristics, and present the most accurate quantitative data on Pluto's surface composition to date.

1 Background

Since arriving at Pluto in 2015, New Horizons has sent back vast quantities of data, including high-resolution hyperspectral cubes from the LEISA instrument. Data reduction and PCA has allowed us to identify the major types of surface material and to qualitatively map their composition [1]. These types of material can interact in multiple ways, including molecular, granular and areal mixing as well as vertical stratification (Fig. 1). A first quantitative map based on a pixel-by-pixel model inversion has also been created, but the model used is simplified, only taking into account sub-pixel areal mixing [2].

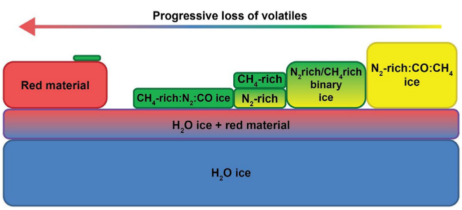

Figure 1: Schematic representation of the various materials present on Pluto and their possible mixing states [1]

2 Methods

We are working with multiple radiative transfer models (RTMs) to accurately represent the potential complexity of Pluto's surface. This representation brings into play a multitude of independent free parameters, such as the surface components' grain size, porosity, proportions, and anisotropic factor. The result is a high-dimensional inversion problem that resists conventional solving via exhaustive calculation of a spectral library or via simple algorithms such as gradient descent.

A promising path towards the resolution of this problem lies through metaheuristics, a class of higher-level optimisation strategies that sample from a large set of solutions to find a sufficiently good global solution. In particular, simulated annealing is a method that combines gradient descent with stochastic perturbations to escape local minima (see Fig 2 for application to simulating spectra).

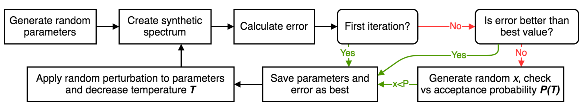

Figure 2: Flowchart showing an application of simulated annealing to optimising the fit of a synthetic spectrum.

Our application of simulated annealing integrates a stochastic ranking of the parameters by magnitude of effect: the progressive addition of parameters to the model in order of decreasing importance allows us to more efficiently search the complex or "rugged" parameter space. The method's validation via synthetic spectra has obtained excellent accuracy (convergence to RMSE<0.25% in under 20000 iterations).

3 Preliminary results

We are presenting quantitative spectral fits for several compositional endmembers — locations on Pluto's surface with relatively pure compositions — as well as first results for more complex terrains that consist of two or more components. We will discuss the implications of these fits as regards Pluto's geology and topography during the congress, as well as present methodology for eventual pixel-by-pixel mapping and segmentation of the entire surface.

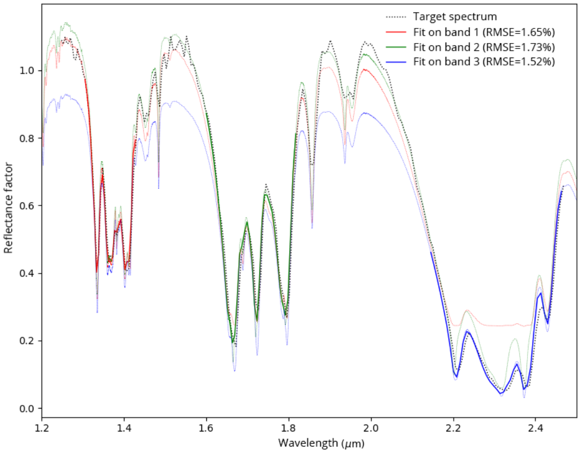

Figure 3: Example of synthetic spectra fitted to real Pluto spectrum representing the typical North pole terrain

References

[1] Schmitt, B., et al. Physical state and distribution of materials at the surface of Pluto from New Horizons LEISA imaging spectrometer. Icarus 287 (2017): 229-260.

[2] Protopapa, S., et al. Pluto's global surface composition through pixel-by-pixel Hapke modeling of New Horizons Ralph/LEISA data. Icarus 287 (2017): 218-228.