

Variability of Enceladus' plumes reflectance as a function of the potentially occurrence of microbes

Introduction

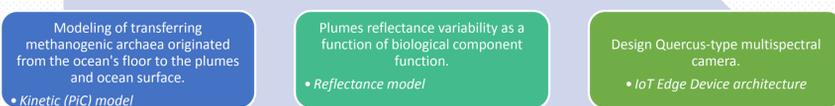
Enceladus is particularly attractive environment in the outer Solar System where life can thrive because of liquid water and energy availability. Concepts of life finding mission were proposed, analyzed and discussed in recent years. Temporal variations in the plume's gas content and matter fluxes from individual sources were observed. Main component of plume's is water in two states: solid and vapor. Organic and biologically compounds were detected during previous missions. Cassini spacecraft during its closest approach to Enceladus' surface in July 2005 collected data using the Ion and Neutral Mass Spectrometer and provided the best estimation of the plumes composition: 91 (± 3)% H₂O, 3.2 (± 0.6)% CO₂, 4.0 (± 1.0)% N₂ or CO and 1.6 (± 0.4)% CH₄. Hydrogen (H₂) was detected in the plume's vapor. Multiple stellar and solar occultation measurements of the plumes vapor column density performed by ultraviolet spectrograph (UVIS) and INMS data suggests multiple gas jets of different gas emissions: high-speed gas emission and low-speed thermal emission.

The occultation data suggests quite homogenous total plume H₂O output between 180 kg/s and 250 kg/s. INMS data, in the contrast, suggests spatially more variable H₂O stream ranging from 200 kg/s to 1000 kg/s.

The structure of the plume itself and the structure of geological formation from which the plume originates, may be varied. Detection of sodium-salt-rich ice grains led some researchers to hypothesized that the plumes may contain, among others, seafloor matter.

In recent years, many researchers have been interested in the possibility of the existence of habitat suitable for microorganisms in their diverse forms. It is possible to distinguish four main types of theoretically habitable areas near Enceladus' south pole: bottom of the ocean in the area of volcanic activity and around it, the surface of the ocean inside rifts, an ice surface around the rifts where the heavier particles fall from the interior of the subsurface ocean and finally geysers themselves.

Objectives



Materials and methods

Particle-in-Cell model and boundary parameters: according to Porco et al. (2017) we assumed oceans bottom heat flux similar to the Lost City Hydrothermal Field $\Phi \sim 0.1 \text{ W m}^{-2}$, salinity $\sim 1.0\%$, microbes concentrations at hydrothermal vents on Enceladus $\sim 10^7$ cells/mL, oceans density dependence on three main factors: temperature, salinity and pressure.

The basic ocean temperature was set on value We also set basic ocean temperature 276.15 K and surface gravity $g = 0.114 \text{ m s}^{-2}$. We assumed that there are four main forces acting on water and biological component particles described by the following parameters: mass m , velocity vector v , temperature T , volume V and density ρ : Enceladus' gravity, buoyancy force, water resistance and pressure-gradient force.

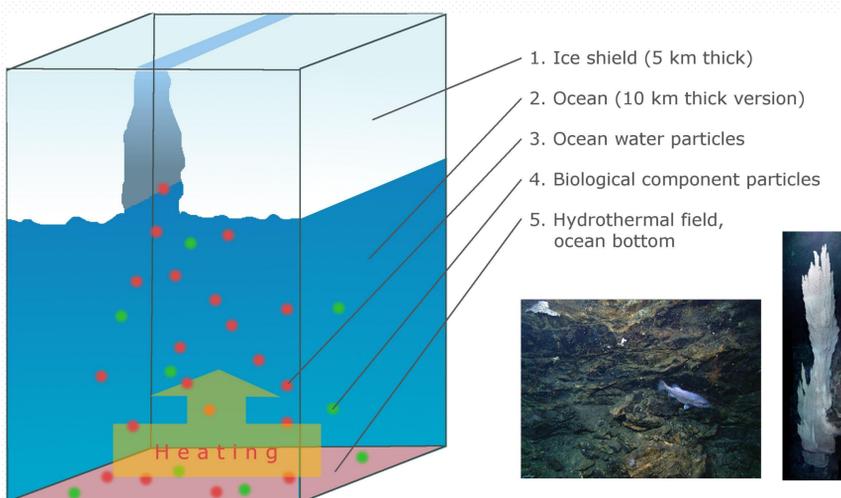


Fig.1. EMMA Particle-In-Cell model.

Selected methanogenic archaea spectral data acquisition in the range of visible light and near infrared in concentrations according to the work of Porco et al. (2017) was prepared spectrometer and QUERCUS 6 multispectral camera (designed and built in the Institute of Aviation in Warsaw, see Mazur et al. 2018). We used pure methanogenic archaea strains isolated from mine biofilm in the Department of Biochemistry of Microbes of the Institute of Biochemistry and Biophysics PAS in Warsaw by prof. Urszula Zielenkiewicz research team. For spectral measurements, the suspension of each methanogen in distilled water was prepared. All reflectance measurements were carried out at temperature 21 °C using a) Evolution 220 spectrometer in the range of 500 - 1100 nm with a sampling frequency 1 nm and b) QUERCUS 6 multispectral camera with six optical bands in the optical bands: 532 nm, 570 nm, 660 nm, 740 nm, 810 nm and 880 nm.

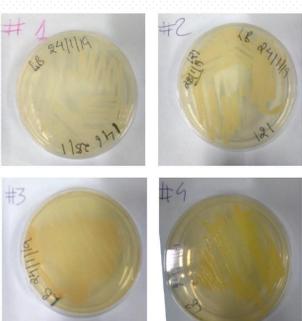


Fig.2. Methanogenic archaea strains used for spectral data measurement.

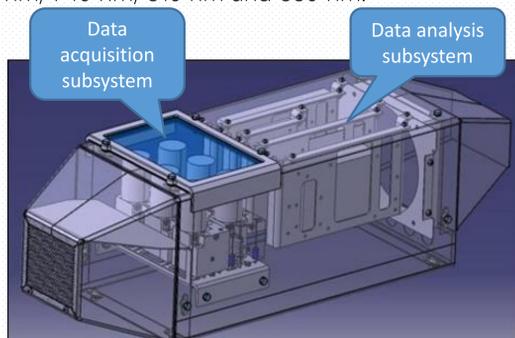


Fig.3. QUERCUS 6 multispectral camera developed in the Institute of Aviation (EC LIFE11 ENV/PL/000459 project).

Results

Kinetic model: We found two classes of "microbe - type" particles:
a) main class with temperature $\sim 40 - 80 \text{ }^\circ\text{C}$ near ocean bottom and $\sim 5 - 10 \text{ }^\circ\text{C}$ near surface and
b) with temperature $\sim 0 - 10 \text{ }^\circ\text{C}$ near oceans bottom.
For $z > 0.0$ an average particles vertical velocity = $2.43 (\pm 1.05) \text{ m/s}$ and temperature $3.99 (\pm 0.99) \text{ }^\circ\text{C}$. This implies potential particle velocity in plume about $1.072 (\pm 0.002) \text{ km/s}$ what is consistent with the Cassini in-situ observations. An average available biological mass escaping flux rate was estimated as is $1.547 \cdot 10^{-7} \text{ kg s}^{-1} \text{ m}^{-2}$ ($\sim 0.5 \%$ of microbes concentration on the ocean bottom, 20 times less than in Porco at al. (2017).

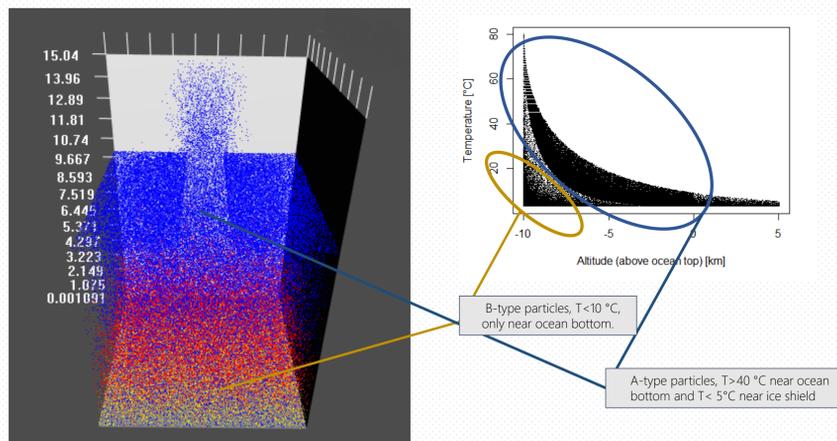


Fig.4. Left: Kinetic model result. Colors represent particles temperatures: Yellow $> 60 \text{ }^\circ\text{C}$ > Orange $> 40 \text{ }^\circ\text{C}$ > Red $> 20 \text{ }^\circ\text{C}$ > Blue. Right: Particles temperature vs altitude. Two particle classes marked.

Spectral measurements: All samples containing a suspension of each of the four strains of microorganisms were characterized by higher reflectance compared to the #Zero sample. The effect of the suspension on the reflectance of the sample was below 5% for visible light and in the range of 5-10% for near infrared.

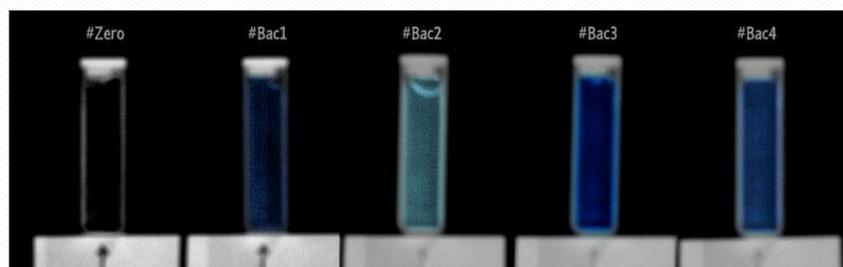


Fig. 5. Comparison of reflectance images of methanogenic strains acquired by QUERCUS 6 multispectral camera in optical channels: 660 nm (red), 720 nm ('red edge') and 810 nm (NIR). DN values (0-255) were strengthened (multiplied) by factor 28.

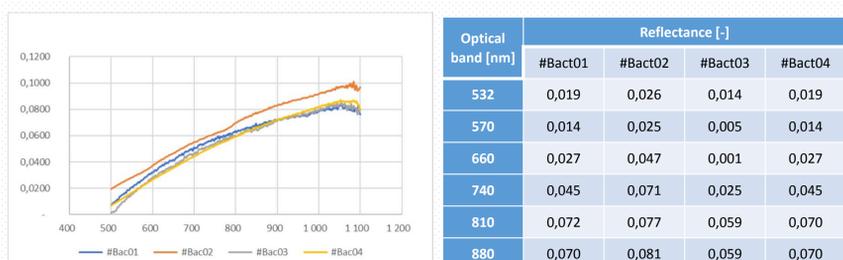


Fig. 6. Spectral reflectance of methanogenic archaea strains in concentrations \sim about 10^7 cells / mL, according to Porco et al. (2018). Reflectance data measurements from: Left - Evolution 220 spectrometer, Right - QUERCUS 6 multispectral camera.

Conclusions

The spectral characteristics of all four tested suspensions implies methanogenic archaea detection methodology based on normalized differential indices using optical channels: Infrared ($> 800 \text{ nm}$) and green or yellow ($< 600 \text{ nm}$).

The red and 'red edge' range differentiates all four samples and could potentially be used to detect a particular type of bacteria. On the basis of these results, it is possible to postulate the separation of two functionalities in the image processing algorithm of the multispectral camera (see fig. 7): (1) detection of the presence of methanogenic microbes using the green, yellow and NIR bands, (2) distinguish of a specific microbial taxon using red and / or 'red edge' bands.

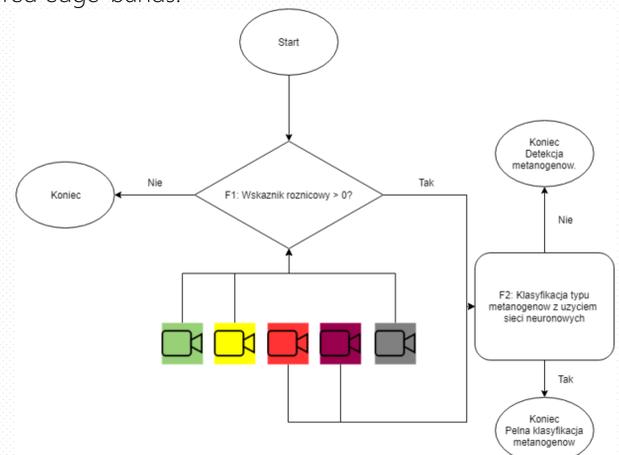


Fig.7. Image processing algorithm architecture proposed for archaea detection and classification.

This methodology should be applied for concentrations comparable to the model of the geyser plume. This model is currently being developed in the Institute of Aviation in Warsaw.

References: Porco, C. C., et al. (2017). Could it be snowing microbes on Enceladus? *Astrobiology*, 17(9), 876-901.; Mazur, Anna, et al. "The influence of atmospheric light scattering on reflectance measurements during photogrammetric survey flights.....", *Leśne Prace Badawcze* 79.1 (2018).