Aerosol formation and the entrainment of organic biosignatures within cryovolcanic plumes at Enceladus and other icy ocean worlds

Supervision team: Dr Mark Fox-Powell, Dr Toni Gladding, Dr Vic Pearson

Lead contact: Dr Mark Fox-Powell

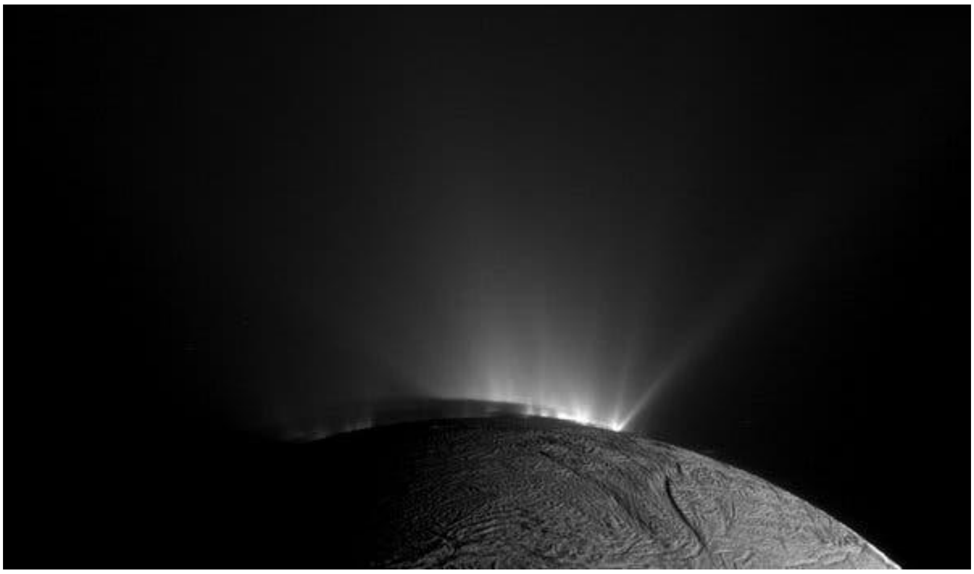

Figure 1: An image of the south polar region of Enceladus captured by the Cassini spacecraft, with the plumes clearly visible. Credit NASA JPL/Caltech/Space Science Institute

Project highlights:

- Conduct pioneering aerosol simulation experiments investigating the formation of cryovolcanic plumes at Enceladus and other icy ocean worlds
- Develop a strongly interdisciplinary skillset with elements of low-temperature aqueous geochemistry, organic chemistry and microbiology (bioaerosols)
- Join a large interdisciplinary group (AstrobiologyOU) with involvement in many aspects of the search for life beyond Earth

Project description:

Cryovolcanic plumes, such as those emanating from the south pole of Saturn's moon Enceladus, represent some of our best opportunities for searching for life beyond Earth [1]. Enceladus harbours a global subsurface ocean that is known to possess favourable conditions for microbial metabolisms such as methanogenesis [2]. But while the likely habitable ocean is locked under kilometres of solid ice, cryovolcanic plumes eject ocean aerosols into space, where they can be captured by spacecraft.

The Cassini spacecraft encountered microscopic icy particles within the plumes of Enceladus that contained salts and macromolecular organics [3,4]. These were interpreted as rapidly frozen droplets of ocean spray, and hint at a richly complex mechanism of aerosol generation by vigorous bubbling deep within cracks in the ice shell [5]. While it has been recently shown how droplets of ocean fluid behave during rapid freezing [6], the mechanisms governing cryovolcanic aerosol formation are not well understood.

Seawater aerosols on Earth, also formed via bubble bursting, exhibit a diverse range of sizes and compositions and frequently contain microorganisms and biological organics [7]. However, at Enceladus only the smallest aerosol droplets are accessible to spacecraft, as larger droplets do not achieve escape velocity and quickly fall back to the surface. In order to relate measurements made by Cassini to the ocean below, it is vital to understand the processes by which materials are transferred from the ocean into the plumes, and ultimately ejected into space.

The aim of this project is to establish the potential for biosignatures to become entrained within cryovolcanic aerosols and thus be ejected into space. The student will use bioaerosol monitoring techniques and bespoke experimental facilities at the OU to study the production of aerosols under a range of experimental conditions relevant to Enceladus's plumes, using fluid compositions guided by other work within the group. The candidate will then apply detailed analytical techniques (including ion chromatography and gas chromatography-mass spectrometry) to investigate how the inorganic composition and organic content of experimental cryovolcanic aerosols varies across a range of particle sizes relevant to those encountered by Cassini. The efficiency of aerosol formation for capturing biosignatures (including diagnostic low and high-molecular weight organic compounds as well as intact microbial cells) from the liquid phase will be determined.

Results from this project will help build a mechanistic understanding of how biosignatures become entrained within cryovolcanic plumes and will be applicable to other ocean worlds such as Jupiter's moon Europa, which will be visited by spacecraft in the coming decade.

References:

1. Spencer & Nimmo (2013). Enceladus: An active ice world in the Saturn System. *Ann. Rev. Earth Planet. Sci.* 41, 693
2. Waite, J.H., Glein, C.R., Perryman, R.S., Teolis, B.D., Magee, B.A., Miller, G., Grimes, J., Perry, M.E., Miller, K.E., Bouquet, A. and Lunine, J.I. (2017). Cassini finds molecular hydrogen in the Enceladus plume: evidence for hydrothermal processes. *Science*, 356(6334), pp.155-159.
3. Postberg, F., Khawaja, N., Abel, B., Choblet, G., Glein, C.R., Gudipati, M.S., Henderson, B.L., Hsu, H.W., Kempf, S., Klenner, F. and Moragas-Klostermeyer, G., 2018. Macromolecular organic compounds from the depths of Enceladus. (2018) *Nature*, *558*(7711), pp.564-568.
4. Postberg, F., Kempf, S., Schmidt, J., Brilliantov, N., Beinsen, A., Abel, B., Buck, U. and Srama, R., (2009). Sodium salts in E-ring ice grains from an ocean below the surface of Enceladus. *Nature*, 459(7250), pp.1098-1101
5. Porco, C.C., Dones, L. and Mitchell, C., (2017). Could it be snowing microbes on Enceladus? Assessing conditions in its plume and implications for future missions. *Astrobiology*, 17(9), pp.876-901.
6. Fox-Powell, M. G. & Cousins, C. R. (2021) Partitioning of crystalline and amorphous phases during freezing of simulated Enceladus ocean fluids. *Journal of Geophysical Research: Planets* 126, e2020JE006628
7. Rastelli, E., Corinaldesi, C., Dell'Anno, A., Martire, M.L., Greco, S., Facchini, M.C., Rinaldi, M., O'Dowd, C., Ceburnis, D. and Danovaro, R., (2017). Transfer of labile organic matter and microbes from the ocean surface to the marine aerosol: an experimental approach. *Scientific Reports* 7, 11475

Qualifications required:

At least a 2:1 BSc or a MSc in geosciences, chemistry, or a relevant discipline. Specialism in planetary geochemistry or organic geochemistry is advantageous, as is laboratory experience.