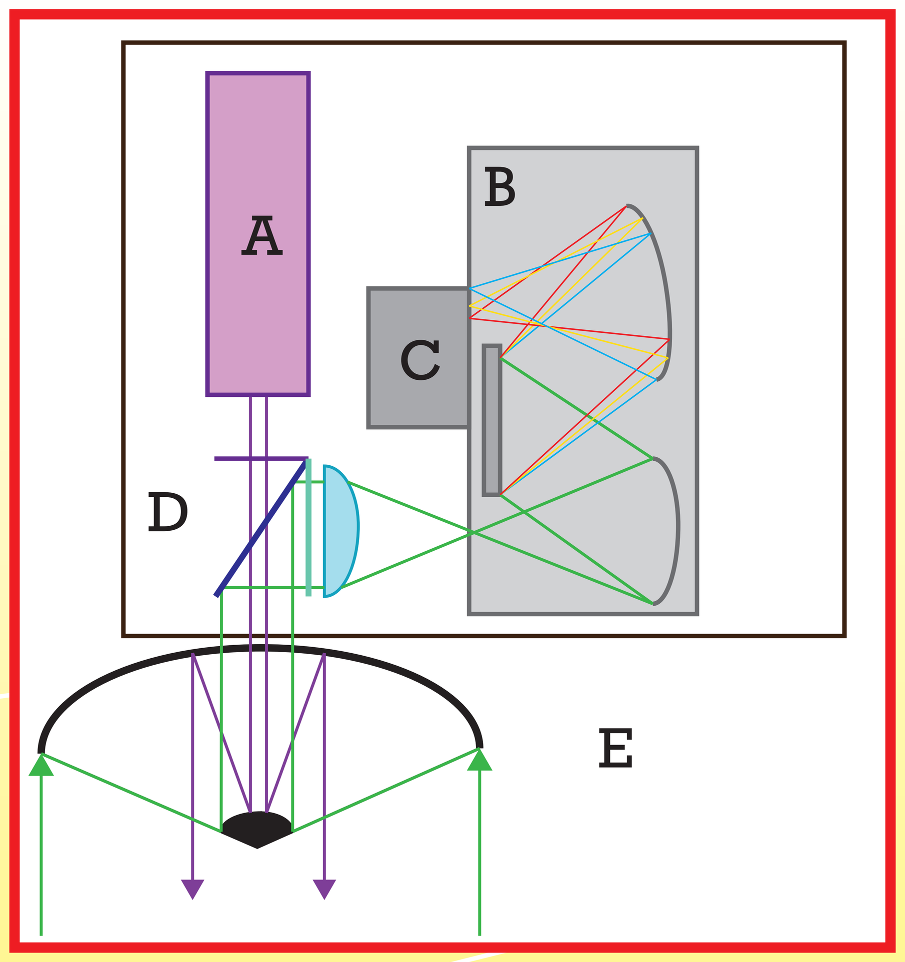
Determining the viability of fluorescent spectroscopy for detecting tryptophan at the plume of Enceladus

Erin Redwing[1], Christopher McKay[2], Francesca Scipioni[2], Tony Colaprete[2], Nathan Bramall[3], Steve Benner[4], Lee Cronin[5], Imke de Pater[1]
[1]UC Berkeley, [2]NASA-Ames, [3]Leiden Instruments, [4]Foundation for Applied Molecular Evolution, [5]University of Glasgow

ABSTRACT:

This project sought to assess the viability of using laser fluorescence spectroscopy to detect the presence of tryptophan in and around the plume of Enceladus during a fly-by mission. Enceladus is a target of astrobiological interest due to the potential for habitability in its subsurface liquid water ocean. Though the ocean sits beneath a layer of ice, it is possible to gain insight into its contents by observing Enceladus' south polar plumes, which spew water vapor from the ocean to the surface[1]. Tryptophan, an amino acid essential to many common proteins in Earth-life, was chosen as a representative biomolecule in this experiment due to its fluorescence when excited by UV photons. The detection of tryptophan, and therefore confirmation of complex biomolecules on Enceladus, could be possible using active remote sensing on a spacecraft equipped with a UV laser and receiver for collecting re-emitted visible photons.



Instrumentation:

A: Ultraviolet laser

B: Spectrograph

C: Multi-anode PMT

D: Dichroic filter

E: Telescope

Fluorescence Spectroscopy:

involves using a beam of light to excite electrons in certain molecules, causing them to emit a light spectrum which can be analyzed to determine the unique identification of the molecule. This technique is widely used in biomedical and chemical research fields for identifying organic compounds[2], as several complex amino acids have strongly fluorescent properties, including tryptophan, tyrosene, and phenylalanine. Of all amino acids found in proteins, tryptophan has the strongest fluorescent properties, making it an excellent candidate for studying the viability of fluorescence spectroscopy for astrobiological purposes.

Fig 1: Characteristic emission spectra of tryptophan, tyrosine, and phenylalanine.

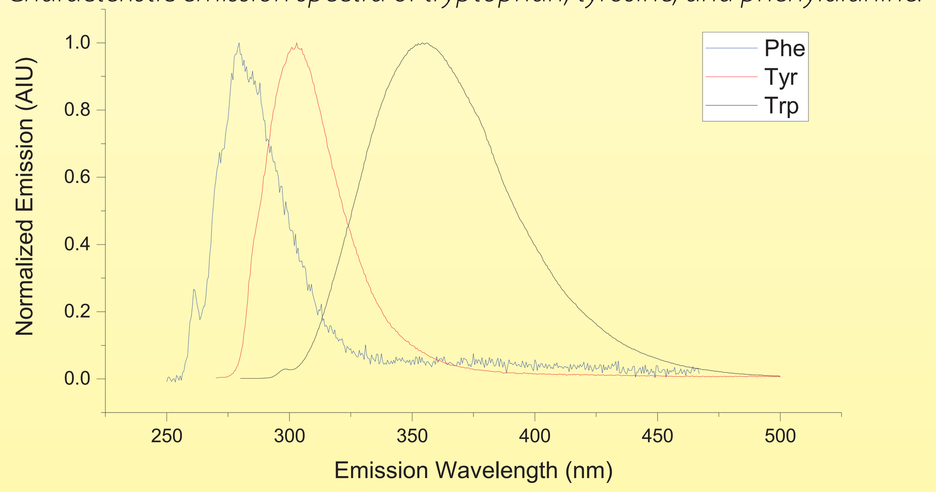
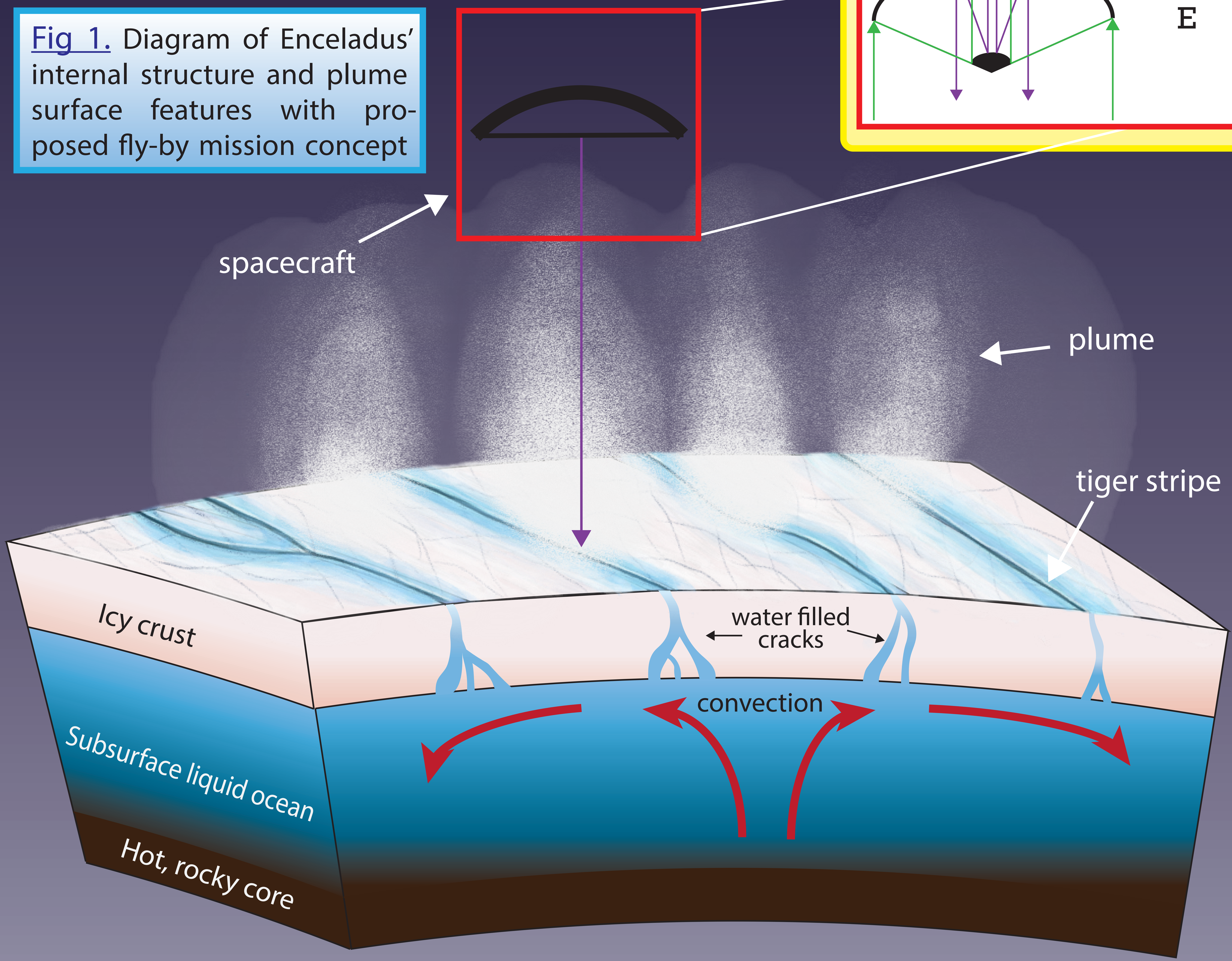


Fig 1. Diagram of Enceladus' internal structure and plume surface features with proposed fly-by mission concept



Conclusions:

The calculations suggest that detecting tryptophan in the optically thin case (in the plume of Enceladus) would require too large a laser power to be reasonable for a fly-by mission. However, it is possible that the optically thick tiger stripes and surrounding plume material could prove a more promising target, with limiting scattering noise being the primary constraint. The laser power required for probing the surface of Enceladus seems to be around the order of magnitude of other space based UV-laser remote sensing systems[4], but this cannot be conclusively stated until further in depth calculations have been completed.

More in depth work must be done in order to conclusively determine the viability of using fluorescence spectroscopy for astrobiological applications. In addition to more comprehensive radiative transfer calculations and modeling, other fluorescent amino acids such as tyrosine and phenylalanine should be studied, as well as varying material substrates such as rocks and other ices.

Tryptophan:

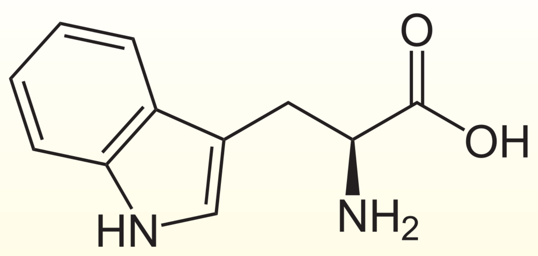


Fig 2: Molecular structure of tryptophan

an aromatic amino acid essential to proteins in Earth-life. It is the most complex amino acid used in protein synthesis[3], and as such its presence could be an indicator of biotic processes (as opposed to simpler "building block" amino acids, whose formation can be explained through abiotic chemical processes). Simple amino acids were detected on Enceladus during Cassini's flyby, but the presence of complex amino acids have not yet been discovered on Enceladus or anywhere outside of Earth.

Methods:

The viability of a fly-by detection of tryptophan fluorescence was assessed using back of the envelope radiative transfer calculations. These calculations were performed by solving for the total number of visible photons which reach the spacecraft as a function of the number of ultraviolet photons emitted by the laser:

$$\frac{E_f}{I_0} = \frac{\eta \sigma s D^2}{4\delta(\delta + s)}$$

where E_f/I_0 = ratio of visible photons received to UV photons emitted, η = number density, σ = laser cross section, s = thickness of the source, D = telescope diameter, and δ = distance from spacecraft to source

These simple calculations sought to begin placing physical limitations on the laser power, distance, and tryptophan concentration required for detection, as well as address the viability of detecting tryptophan at low optical density (i.e. plume vapor) verses high optical density (i.e. tiger stripes, surface material surrounding the plumes).

References:

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2: Held, Paul. "Peptide and Amino Acid Quantification Using UV Fluorescence in Synergy HT Multi-Mode Microplate Reader." Biotek. Apr (2003).
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4: Reitebuch et al. "The airborne demonstrator for the direct-detection Doppler wind lidar ALADIN on ADM-Aeolus." Journal of Atmospheric and Oceanic Technology26.12 (2009): 2501-2515.