Mem. S.A.It. Vol. 90, 636
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Memorie della

Exploring the Enceladus molecular environment with the LMT

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Abstract. Enceladus is one of the most promising "ocean world" of the Solar System for detecting molecular precursors to life, as it ejects into space a large quantity of material from a series of geysers. This material is thought to arise from an underground ocean. We present a spectroscopic monitoring program in the millimeter regime that will make use of the SEQUOIA spectrometer attached to the single-dish 50 m Large Millimeter Telescope. We expect to detect many molecular species (e.g., HCN, H_2CO, NH_2CHO, CH_3OH, and CO) in the Enceladus' torus and, through recurrent observations, explore their time variability.

Key words. instrumentation: spectrographs – planets and satellites: individual (Enceladus) – planets and satellites: composition – radio lines: planetary systems

1. Introduction

The Saturn satellite Enceladus is a primary target for life-searching studies in the solar system, ever since the *Cassini* probe discovered, in 2005, a complex of geysers near the south pole of the satellite (Porco et al. 2006), ejecting

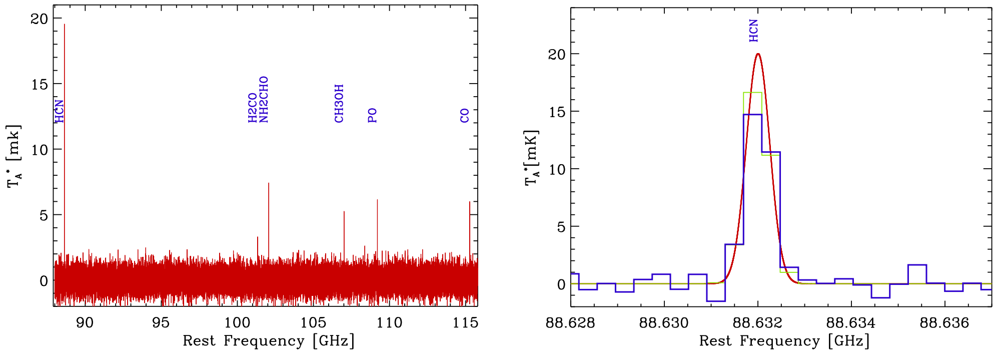

Fig. 1. Synthetic spectra of the Enceladus observations in the SEQUOIA frequency range, at a spectral resolution of 391 kHz. Left panel: the spectrum of the whole interval, where a Gaussian noise is included, assuming a total exposure time of 16 hours. Right panel: a zoom of the HCN line; the theoretical spectrum (red curve) has been binned in the SEQUOIA channels (green) and a Gaussian noise is added (blue).

into space gas and dust from fractures of the icy crust. The source of this material is a subsurface ocean (Thomas et al. 2016; Van Hoolst et al. 2016). The chemical composition of the ejected material, that creates the Saturn E ring, has been measured by the *Cassini*'s Neutral and Ion Mass Spectrometer (INMS) and the Ultraviolet Imaging Spectrograph (UVIS): it allowed to infer the properties of the ocean, that is salty (Postberg et al. 2011), warm (Matson et al. 2012; Travis & Schubert 2015) and mostly composed of liquid water and other organic compounds (Waite et al. 2009). The full set of chemical species so far detected (Waite et al. 2009) includes virtually all life related elements (C, N, H, O, S), with the exception of phosphorus, in a number of molecular species such as H_2O, CO, CO_2, HCN, H_2S, C_3H_4, C_4H_4, C_2H_2, NH_3, and CH_3OH. The *Herschel* space telescope confirmed the dominant presence of water vapor in the vicinity of Enceladus (Hartogh et al. 2011). Drabek-Maunder et al. (2019) also claimed the detection of methanol, in the torus of Enceladus, measured from ground with the 30m IRAM telescope at 1.2 mm. Therefore, the global conditions for life appear to be present in this moon: organic-related elements, liquid water and a probable source of energy other than solar light, like serpentinization of ultramafic rocks.

The exciting possibility of discovering complex life's precursor molecules in this Saturnine world already fomented the proposal of several robotic space missions envisaged to explore Enceladus in the next decades (e.g., Konstantinidis et al. 2014; Lunine et al. 2015; MacKenzie et al. 2016; Mitri et al. 2018). It is, therefore, of fundamental importance to start monitoring the satellite from the ground to fully characterize the chemical composition of the material being ejected from its interior, including organic species. In this project, we propose to use the largest single-dish mm telescope, the 50m Large Millimeter Telescope (LMT), equipped with the high-resolution spectrometer SEQUOIA, to answer the still many open questions related to Enceladus and its evolution, which will help us to understand if life is or was present in this fascinating exoworld.

2. The proposed observations

Observations of Enceladus and its torus of material will be conducted at the LMT with the spectrometer SEQUOIA in the 3mm band (12 arcsec beam diameter), at the most suitable resolution, when this moon is at its maximum elongation with respect to Saturn. We calculated the expected line intensities for the main molecular species that can be observed with SEQUOIA, assuming a gas temperature

Table 1. Expected line intensities of molecular species in the Enceladus torus: columns indicate the molecular species, the transition frequency, the column density, the integrated brightness temperature (Tb), the Tb peak and its error, and the exposure time.

Molecule	Frequency GHz	N_{mol} cm^{-2}	Tb mK km s^{-1}	Tb_{peak} mK	rms mK	Exp. time hr
HCN	88.631602	2×10^{12}	31	20	1.3	16
H_2CO	101.33299	2×10^{12}	7.4	4.7	1.3	16
NH_2CHO	102.06431	2×10^{12}	12.3	8.0	1.3	16
CH_3OH	107.01377	1.8×10^{13}	9.2	5.9	1.3	16
CO	115.27120	3×10^{13}	9.1	5.9	1.3	16

of 100 K (Hartogh et al. 2011) and a conservative line widths of 2 km/s. The calculations are based on the molecular line list of the Cologne Database for Molecular Spectroscopy (CDMS) database(2) and we derived the expected column densities considering the mass fractions of Waite et al. (2009) with respect to water and assuming a $N_{H_2O} = 1 \times 10^{16}$ cm^{-2} according to Hansen et al. (2006) (derived with UVIS). The results are shown in Table 1 and were used to produce a sinthetic spectrum, in the SEQUOIA frequency interval, that we show in Figure 1. The interval includes a PO transition at 109.20620 GHz, that we added in our simulation (with a column density of 5×10^{12} cm^{-2}): a possible phosphorus detection will be of great importance for reconsidering the chemistry of Enceladus' ocean.

Taking into account that the millimeter wavelength region is very rich in molecular lines, the LMT, with its large aperture, will undoubtedly provide an unprecedented chance to verify the presence of organic species in the Enceladus torus and collect information on fainter transitions never seen before, either by detecting chemical networks leading to more complex molecules, but also direct evidence of complex organics. We foresee a great potential of discovery that will deliver valuable information of the environment of Enceladus and, in general, on the precursors and conditions that allows for life to emerge in planetary systems.

In the near future, the new set of LMT instruments (for instance, B4R) will allow the investigation of the gas contents of Enceladus environment at other wavelengths (1 and 2 mm), increasing the number of molecular species that can be detected. The LMT observations of Enceladus will be periodically repeated in order to monitoring the possible variability of the geysers activity both in time and in chemical composition.

Acknowledgements. EB, OV, and MC acknowledge the financial support by Mexican CONACyT, through grant CB-2015-256961.

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