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OMC-2 FIR 4: a laboratory to study the formation environment of the Solar System

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Abstract. As part of the IRAM large programme SOLIS (Seeds Of Life In Space), we present NOEMA millimetre observations of OMC-2 FIR 4, a protostellar cluster in Orion likely to be a close analogue of the birth environment of the Solar System. Our results indicate that (i) OMC-2 FIR 4 is the most densely fragmented protocluster observed so far in our Galaxy, and (ii) carbon-chain growth is favoured by the presence of an energetic particle source located within OMC-2 FIR 4.

1. Introduction

The Sun likely formed in a large cluster hosting massive stars (Adams 2010; Pfalzner et al. 2015). Studying low-mass protostellar objects in massive star forming regions can thus help understand the origin of our planetary system. An excellent target for this is the 30 $M_\odot$ protostellar cluster OMC-2 FIR 4, located 2 pc north of the Trapezium OB stellar cluster in Orion. *Herschel*-HIFI observations of N_2H^+ and HCO^+ strongly suggest that this region hosts a source of energetic particles ($\geq$ 10 MeV) whose irradiation field is comparable to that experienced by the young Solar System (Ceccarelli et al. 2014). OMC-2 FIR 4 is therefore a close analogue of what must have been the natal environment of the Sun.

As part of the IRAM large programme SOLIS (Seeds Of Life In Space; Ceccarelli et al. *in prep.*), we used NOEMA (NOrthern Extended Millimeter Array) to map the millimetre continuum emission and several molecular lines in OMC-2 FIR 4 with the aim to investigate (i) what the core population of the protocluster is, and (ii) how the presence of an internal source of energetic particles affects the molecular chemistry of the region.

2. A densely fragmented protocluster

The left panel in Fig. 1 presents the 3 mm continuum map of OMC-2 FIR 4, which reveals numerous fragments in the region. The projected density of cores is approximately 6000 pc^{-2}, which implies a mean projected separation between neighbouring cores of $\sim$ 2600 au. Such a high level of fragmentation has not been observed in any other protocluster so far (e.g. Palau et al. 2013). Possible interpretations to explain this include a low associated magnetic field strength, which favours fragmentation (Commerçon et al. 2011), and

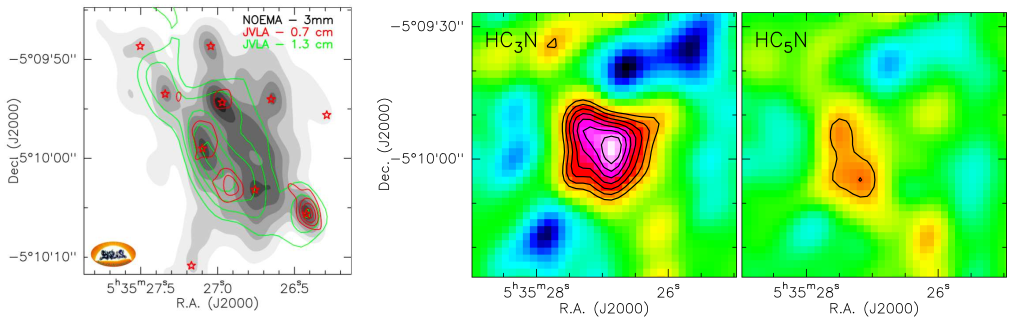

Fig. 1. *Left*: 3 mm continuum map of OMC-2 FIR 4 (grey scale) obtained with NOEMA in CD configuration, resulting in an angular resolution of 3.9″ × 2.1″ (Neri et al. *in prep.*). Each detected core is marked with a red star. JVLA cm continuum maps are overlaid in red and green contours. *Right*: Velocity-integrated HC_3N(J=9–8) and HC_5N(J=31–30) maps of OMC-2 FIR 4 obtained with NOEMA in its D configuration, providing an angular resolution of 9.5″ × 6.1″. Contours for both maps start from 30% of the peak intensity of the HC_3N map and increase by steps of 10% (Fontani et al. 2017).

triggered star formation by an external outflow driven by the nearby protostellar object FIR 3, as proposed by Shimajiri et al. (2008). However, new detailed analysis of SOLIS c-C_3H_2 data does not find clear evidence of such an interaction (Favre et al. *in prep.*).

3. Carbon chain growth

Lower angular resolution maps of the cyanopolyynes HC_3N and HC_5N (Fig. 1) in OMC-2 FIR 4 clearly show that, while HC_3N emits across the whole region, HC_5N is concentrated towards the East of FIR 4. The HC_3N/HC_5N abundance ratio in the Eastern region lies below ∼10, whereas it is in the range 10 – 30 towards the West. We performed gas-phase chemical modelling to constrain the physical conditions leading to this differentiation, and found that the ratios ≤ 10 can only be reproduced if the cosmic-ray ionisation rate is very high, $\zeta \sim 4 \times 10^{-14}\,s^{-1}$, in agreement with previous results (Ceccarelli et al. 2014). Based on these results, we propose that the source of of energetic particles is embedded in the Eastern part of OMC-2 FIR 4. The fact that ionised gas also appears to be present towards the East as evidenced by cm continuum observations obtained with the JVLA (Jansky Very Large Array; Fig. 1, left) lends further support to this interpretation.

Our results support the view that energetic particle irradiation favours carbon chain production. As similar irradiation was also present during the early phases of our Solar System, it is tempting to speculate that such energetic processes have also promoted the production of important carbon reservoirs in the Solar Nebula that could then have been delivered to the early Earth to foster pre-biotic chemistry evolution.

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