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Codella, C.; Bachiller, R.; Viti, S.

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C. Codella[1,2], R. Bachiller[3], and S. Viti[4,5]

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claudio.codella@inaf.it

[1] INAF, Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125, Firenze, Italy; claudio.codella@inaf.it

[2] Univ. Grenoble Alpes, CNRS, IPAG, F-38000 Grenoble, France

[3] Observatorio Astronómico Nacional (OAN), Alfonso XII, 3, E-28014, Madrid, Spain

[4] Leiden Observatory, Leiden University, P.O. Box 9513, NL-2300 RA Leiden, The Netherlands

[5] Department of Physics and Astronomy, UCL, Gower Street, London WC1E 6BT, UK

C. Codella https://orcid.org/0000-0003-1514-3074

R. Bachiller https://orcid.org/0000-0002-5331-5386

S. Viti https://orcid.org/0000-0001-8504-8844

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Abstract

The Cepheus A East high-mass star-forming region has been mapped at 1.4 mm using the OCS(17–16) and (18–17) lines observed with the IRAM 30 m antenna. Contour maps and high-resolution line profiles reveal the association of OCS with both (i) the hot-core region, and (ii) with the NE, SE, and S outflows driven by the young stellar objects. This confirms that OCS is among the main S-molecules observed in the gas-phase after thermal evaporation due to protostellar heating or shocks due to propagation of protostellar jets. Adopting Local Thermodynamic Equilibrium conditions, optically thin emission, and a temperature of 100 K, the total OCS column density (after correction for beam dilution) of the hot-core component is $\sim 10^{16}$ cm^{-2}. For the outflow component, assuming a temperature range of 20–100 K, and extended emission, the OCS column density is $\leq 5 \times 10^{14}$ cm^{-2} for a temperature $\geq$ 20 K.

1. Introduction

Star formation occurs in high density and low temperature conditions in molecular cores located in filaments (Pineda et al. 2023). The earliest star-forming stages are characterized by fast ($\sim$100 km s^{-1}) jets removing angular momentum, to allow the prostotar to accrete further material (Frank et al. 2014). Jets strike the ambient medium driving shocks, where the species frozen onto the grain mantles are injected into the gas-phase either because of sputtering (gas-grain collisions) or shattering (grain-grain) (Ceccarelli et al. 2023, and references therein). Shocks also trigger high-temperature gas-chemistry, thus dramatically enhancing the abundance of a large number of species (Bachiller et al. 2001) such e.g. the Sulfur-bearing molecules.

In star-forming regions, [S]/[H] is lower by 1–2 orders of magnitude (e.g. Fuente et al. 2019) with respect what measured in our Solar System (1.8 $\times 10^{-5}$). In the grains, 90% of Sulfur is refractory, (e.g. Kama et al. 2019), while it is still debated what are the main S-species on mantles. It has been predicted that OCS, along with with H_2S, should be the solution (Wakelam et al. 2004). Only very recently, Boogert et al. (2022) reported convincing OCS features in ices in star-forming regions, followed by the first results of the JWST [6] observations revealing icy OCS in dense clouds and protoplanetary disks (McClure et al. 2023; Sturm et al. 2023).

We present IRAM 30 m maps in CepA-East ($d = 700$ pc), an archetypical star-forming region used to study how high-mass star formation alter the surrounding medium. When traced at spatial scale ≥ 0.1 pc, CepA-East is associated with 3 main outflows along the SW. SE, NE directions, outlined by 15 ionized sources (Garay et al. 1996) aligned in three strings (HW1, HW4-5-6 and HW7) plausibly produced by shocks driven by the HW2 and HW3 prototars. A fourth flow is flowing toward South (Codella et al. 2003). A rich chemistry is observed along the outflows confirming that shocks alter the chemical abundances in the gas phase. In this context, also OCS(7–6) emission has been detected at 85 GHz with the IRAM 30 m antenna in the inner 30" around HW2 (Codella et al. 2005), but no map has been produced.

2. Observations

The observations of CepA-East were performed with the IRAM 30 m telescope in 2006 June. Two OCS lines have been observed using spectral units of 0.11 km s^{-1} resolution, successively smoothed to 1 km s^{-1} to increase sensitivity: (i) OCS(17–16) line [7] at 206745.156 MHz ($E_u = 89$ K), and OCS(18–17) at 218903.356 MHz ($E_u = 100$ K). The HPBW was 12" ($J = 17$–16), and 11" ($J = 17$–16). The spectra are reported in units of main-beam brightness temperature (T_{MB}). The r.m.s. noise was 20–30 mK. We obtained maps of 40" $\times$40" with a sampling of 10", centered at the coordinates of the HW2 object: $\alpha_{2000} = 22^h56^m17^s\!.9$, $\delta_{2000} = +62°01'49''\!.7$.

3. Results

Figure 1 (Left panels) shows the OCS(17–16) and (18–17) contour maps, indicating the association of the molecule with the central region of CepA-East, known to host hot-cores, i.e. regions heated by the young stellar objects at temperatures larger than 100 K, where the mantle of dust sublimates (Brogan et al. 2007). In addition, two main elongated structures are observed, one along NE, and an additional component pointing toward SE. Finally, emission toward the southern direction is also revealed.

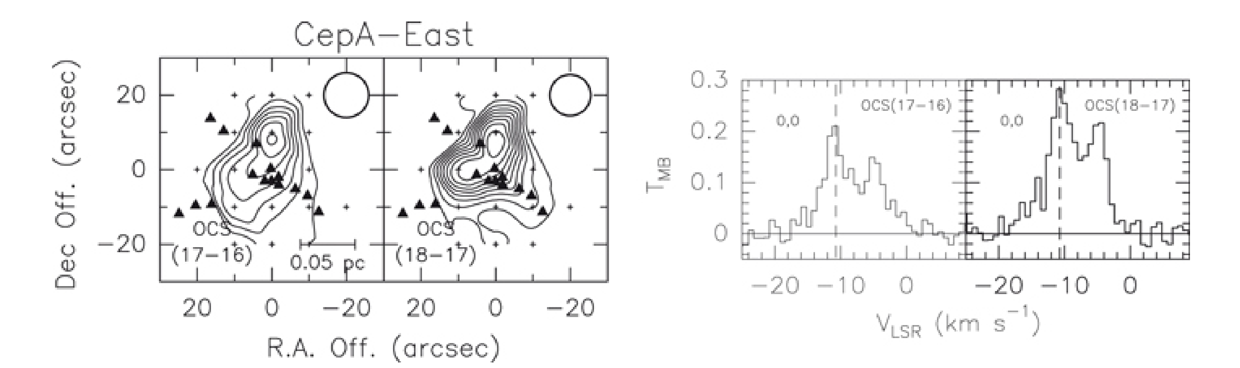

Figure 1. Left: Countour maps of the integrated emission (in the −20, +5 km s^{-1} range) of the OCS(17–16), and OCS(18–17) emission toward CepA-East. The triangles stand for the VLA 2 cm continuum components which trace strings of shocked regions (Garay et al. 1996). The maps are centered at the HW2 position (see text). The circles show the beam (HPBW), while the crosses mark the observed positions. The first contours and steps correspond to 3σ (0.30 K km s^{-1}). Right: OCS spectra ($T_{\rm MB}$ scale) observed at the map center. The dashed lines stand for the LSR velocity (–10.7 km s^{-1}, Codella et al. 2005).

The line profiles (Right panels) confirm this picture, showing a peak (with a FWHM $\simeq$ 5 km s^{-1}) at the systemic velocity of –10.7 km s^{-1} (hot-core component), revealing in addition bright red-shifted emission up to $\sim$0 km s^{-1} (outflow component). This bright emission is consistent with kinematics of the SE, NE, and S outflows, which indeed mainly show red-shifted emission (Codella et al. 2003). Note that the present OCS spatial distribution and the spectra are in agreement with the $H_2S(1_{10}$–$1_{01})$ contour map reported by Codella et al. (2003), considered that the H_2S emission has been mapped with a beam of 29".

Adopting Local Thermodinamic Equilibrium (LTE) conditions, optically thin emission and a temperature of 100 K, the total beam-averaged (10") OCS column density of the component associated with the hot-core is $\sim$10^{14} cm^{-2}. Assuming a hot core size of less than 1" (Brogan et al. 2007), and consequently applying the filling factor correction then $N_{\rm OCS}$ increases up to $\sim$10^{16} cm^{-2}. For the red-shifted outflows component, using again LTE and optically thin conditions, the beam-averaged OCS column density is 5 ×10^{14} cm^{-2} for a temperature of 20 K, while it decreases of about an order of magnitude if the temperature raises to 100 K.

The present results confirm that both OCS and H_2S are among the main S-molecules observed in the gas-phase after thermal evaporation due to protostellar heating as well as shocks due to propagation of jets.

Footnotes

6 James Webb Space Telescope.

7 Spectral parameters extracted from the Cologne Database for Molecular Spectroscopy.