Systematic search for phosphorus-bearing molecules in low-mass protostars

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Context

Phosphorus plays a crucial role in the origin of life as we know it. Indeed, this element plays an important role in biochemistry (e.g., through P-O bonds in DNA and ATP molecules) and is part of the well-known CHNOPS, the key elements for life on Earth. Thus, understanding its interstellar journey from its initial carriers is important. However, only a few detections are reported, but they reveal two important insights: first, this element is mostly detected toward shock regions, and second, its observed abundance is systematically lower than what we expect. These insights highlight the need for more detections to constrain physico-chemical conditions necessary for phosphorus chemistry and to understand the origin of this depletion. In this work, we use data from the ALMA large program COMPASS [1] to search for phosphorus-bearing molecules with a high angular resolution.

I. Observations

Complex Organic Molecules in Protostars with ALMA Spectral Surveys **(COMPASS)**

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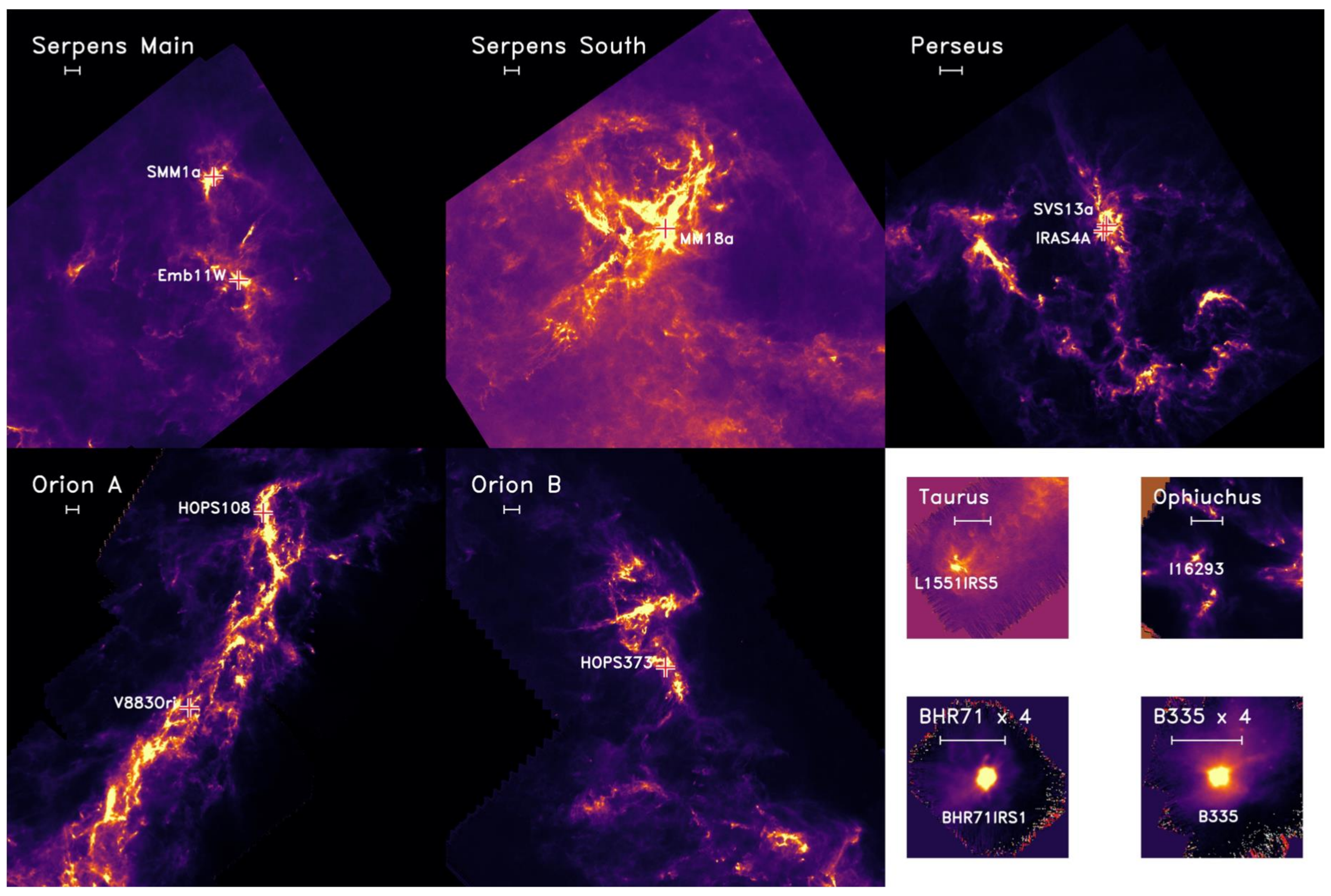
- ALMA Large Program, Band 7, **125h of observing time** (12m array)
- **11 low-mass protostars**: to probe the influence of different environments and evolutionary stages
- **Large spectral surveys** covering the range 279.0 - 311.7 GHz
- **High angular resolution**: 0.3”- 0.5” (up to 0.15” – 0.25” for two binary sources)
- Spectral resolution: 0.4 - 0.5 km s^{-1}
- Sensitivity: 2.2 - 2.7 mJy beam^{-1}
- **19 P-bearing species covered** in the COMPASS range

Check our website!



Column density maps for the different COMPASS targets as well as IRAS16293 (observed with the PILS survey) [1].

II. Warm inner regions

- **LTE models on the 19 P-bearing species at the continuum peak position**

↳ no detection, **3σ upper limits on column densities** derived using the CASSIS software [2]

Species	BHR71 IRS1 N(species) (cm^{-2})	BHR71 IRS1 X(species/CH_3OH)	BHR71 IRS1 X(species/H)	IRAS4A N(species) (cm^{-2})	IRAS4A X(species/CH_3OH)	IRAS4A X(species/H)
PN	$< 1.50 \times 10^{14}$	$< 3.00 \times 10^{-6}$	$< 3.00 \times 10^{-11}$	$< 1.00 \times 10^{14}$	$< 1.79 \times 10^{-6}$	$< 1.79 \times 10^{-11}$
PO	$< 6.60 \times 10^{14}$	$< 1.32 \times 10^{-5}$	$< 1.32 \times 10^{-10}$	$< 1.15 \times 10^{14}$	$< 2.05 \times 10^{-6}$	$< 2.05 \times 10^{-11}$
PO^+	$< 1.90 \times 10^{14}$	$< 3.80 \times 10^{-6}$	$< 3.80 \times 10^{-11}$	$< 7.00 \times 10^{13}$	$< 1.25 \times 10^{-6}$	$< 1.25 \times 10^{-11}$
CP	$< 7.20 \times 10^{14}$	$< 1.44 \times 10^{-5}$	$< 1.44 \times 10^{-10}$	$< 7.00 \times 10^{14}$	$< 1.25 \times 10^{-5}$	$< 1.25 \times 10^{-10}$
PS	$< 3.30 \times 10^{14}$	$< 6.60 \times 10^{-6}$	$< 6.60 \times 10^{-11}$	$< 7.60 \times 10^{13}$	$< 1.36 \times 10^{-6}$	$< 1.36 \times 10^{-11}$
PNO	$< 2.50 \times 10^{14}$	$< 5.00 \times 10^{-6}$	$< 5.00 \times 10^{-11}$	$< 4.90 \times 10^{13}$	$< 8.75 \times 10^{-7}$	$< 8.75 \times 10^{-12}$
CCP	$< 1.90 \times 10^{14}$	$< 3.80 \times 10^{-6}$	$< 3.80 \times 10^{-11}$	$< 3.95 \times 10^{13}$	$< 7.05 \times 10^{-7}$	$< 7.05 \times 10^{-12}$
HPO	$< 5.00 \times 10^{14}$	$< 1.00 \times 10^{-5}$	$< 1.00 \times 10^{-10}$	$< 2.17 \times 10^{14}$	$< 3.88 \times 10^{-6}$	$< 3.88 \times 10^{-11}$
PH_2	$< 1.80 \times 10^{18}$	$< 3.60 \times 10^{-2}$	$< 3.60 \times 10^{-7}$	$< 3.00 \times 10^{17}$	$< 5.36 \times 10^{-3}$	$< 5.36 \times 10^{-8}$
HCP	$< 6.50 \times 10^{15}$	$< 1.30 \times 10^{-4}$	$< 1.30 \times 10^{-9}$	$< 4.00 \times 10^{15}$	$< 7.14 \times 10^{-5}$	$< 7.14 \times 10^{-10}$
PO_2	$< 5.40 \times 10^{16}$	$< 1.08 \times 10^{-3}$	$< 1.08 \times 10^{-8}$	$< 2.00 \times 10^{16}$	$< 3.57 \times 10^{-4}$	$< 3.57 \times 10^{-9}$
PCN	$< 4.00 \times 10^{14}$	$< 8.00 \times 10^{-6}$	$< 8.00 \times 10^{-11}$	$< 7.60 \times 10^{13}$	$< 1.36 \times 10^{-6}$	$< 1.36 \times 10^{-11}$
H_2CP	$< 8.60 \times 10^{15}$	$< 1.72 \times 10^{-4}$	$< 1.72 \times 10^{-9}$	$< 3.85 \times 10^{15}$	$< 6.88 \times 10^{-5}$	$< 6.88 \times 10^{-10}$
NC_2P	$< 2.70 \times 10^{14}$	$< 5.40 \times 10^{-6}$	$< 5.40 \times 10^{-11}$	$< 6.00 \times 10^{13}$	$< 1.07 \times 10^{-6}$	$< 1.07 \times 10^{-11}$
HCCP	$< 2.80 \times 10^{15}$	$< 5.60 \times 10^{-5}$	$< 5.60 \times 10^{-10}$	$< 6.60 \times 10^{14}$	$< 1.18 \times 10^{-5}$	$< 1.18 \times 10^{-10}$
H_2PCN	$< 7.00 \times 10^{14}$	$< 1.40 \times 10^{-5}$	$< 1.40 \times 10^{-10}$	$< 1.25 \times 10^{14}$	$< 2.23 \times 10^{-6}$	$< 2.23 \times 10^{-11}$
HC_3P	$< 7.00 \times 10^{15}$	$< 1.40 \times 10^{-4}$	$< 1.40 \times 10^{-9}$	$< 2.00 \times 10^{15}$	$< 3.57 \times 10^{-5}$	$< 3.57 \times 10^{-10}$
CH_3CP	$< 2.10 \times 10^{15}$	$< 4.20 \times 10^{-5}$	$< 4.20 \times 10^{-10}$	$< 3.90 \times 10^{14}$	$< 6.96 \times 10^{-6}$	$< 6.96 \times 10^{-11}$
C_2H_5CP	$< 1.90 \times 10^{16}$	$< 3.80 \times 10^{-4}$	$< 3.80 \times 10^{-9}$	$< 2.90 \times 10^{15}$	$< 5.18 \times 10^{-5}$	$< 5.18 \times 10^{-10}$

Chadourne et al. in prep.

Upper limits on X(species/H) using:

- $N(CH_3OH)_{BHR71\ IRS1} = 5 \times 10^{19}$ cm^{-2} [3]
- $N(CH_3OH)_{IRAS4A} = 5.6 \times 10^{19}$ cm^{-2} [4]
- $X(CH_3OH/H) \simeq 1 \times 10^{-5}$ [5]
- $X(P_{total}/H) \simeq 2.6 \times 10^{-7}$ in the ISM [6]
- $X(P_{gas}/H) \simeq 2.6 \times 10^{-9}$ in the ISM [7,8]

Real constraints X(species/H) < $X(P_{gas}/H)$

No constraint derived X(species/H) > $X(P_{gas}/H)$

III. Beyond the warm inner regions

Species focused: PN, PO, and PO^+ as they are the only P-bearing molecules detected in the ISM so far [9].

Methodology: search for emission above 5σ in all positions of the data cubes.

Work in progress, stay tuned for the results! (Chadourne et al. in prep.)

References: **[1] Jørgensen et al. 2026**, A&A, in press • **[2] Vastel et al. 2015**, SF2A-2015: Proceedings, 313-316, https://cassis.irap.omp.eu • **[3] Coutens et al. 2026**, A&A, in press • **[4] Belloche et al. 2026**, A&A, in press • **[5] Espagnet et al.**, A&A, submitted • **[6] Asplund et al. 2009**, ARA&A, 47, 481-522 • **[7] Lefloch et al. 2016**, MNRAS, 462, 3937-3944 • **[8] Rivilla et al. 2018**, Proc. Int. Astron., S332, 409-414 • **[9] Fontani 2024**, Front. Astron. Space Sci., 11, 1451127

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