OCS line emission: a new method for measuring the luminosity of embedded protostars in binary systems

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I. Context

To measure the luminosity of embedded protostars, the common way is to derive it **from the spectral energy distribution** from millimeter to infrared wavelengths. However, **we cannot obtain the luminosity of each protostar** for binary systems due to the lack of telescope with the spatial resolution needed to resolve each protostar.

To overcome the problem, we propose here a new method using the gaseous emission of the OCS molecule. Using **new quantum mechanics calculations of OCS binding energy distribution**, we analyzed the size of the desorption zone from the grain mantle of this molecule to estimate a luminosity for each protostar.

II. Source and observations

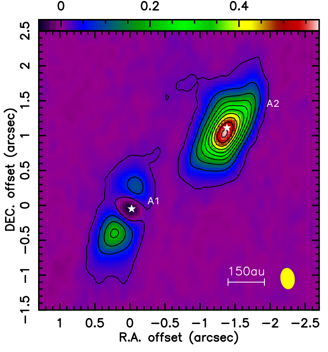

Figure 1: *Moment 0 emission of the OCS molecule around IRAS4A*

We used observations of IRAS4A from FAUST ALMA large program [1]. We used the **OCS (J=19–18) line at 231.060 GHz**, where the Moment 0 emission is presented in *Fig. 1*. The source IRAS4A is composed of two objects, IRAS4A1 and IR4SA2 (south-east and north-west, respectively), both **Class 0 protostars**.

Due to the proximity of the two sources, **we do not have observations available separating them below 800 μm**. We only know the total luminosity, estimated to **14.5 ± 1.5 L_{sol} at 299 ± 15 pc** [2], [3].

III. OCS and binding energy

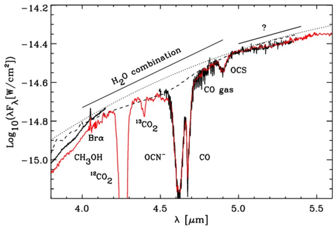

Figure 2: *Ice components observations of W33A (from [5])*

Why OCS? For now it is the **only S-bearing molecule surely detected in interstellar ices** in both low- [4] and high- [5] mass stars forming regions. Because OCS **is inefficiently formed in the gas-phase** [6], we consider the formation on the grains. The gas phase abundance is then **due to the desorption**.

The binding energy **(BE)** represents the capacity of a molecule to be **thermally desorbed from the grain surface to the gas phase**. It is directly linked to the **sublimation temperature** and depends **on the molecule** we consider. A scheme of OCS desorption with increasing ice temperature is represented in *Fig. 3*.

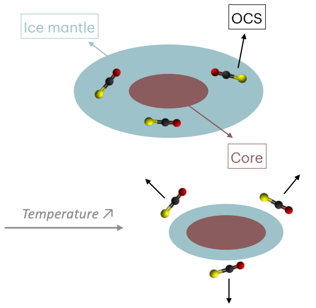

Figure 3: *Desorption of OCS molecule from ice grain*

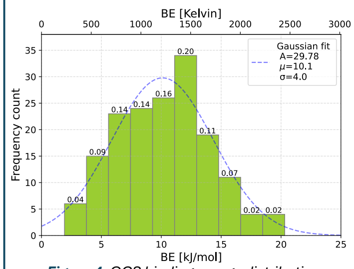

Figure 4: *OCS binding energy distribution*

Each molecule is more or less bounded to the grain **depending on its orientation or position**. The BE value is then estimated **with a gaussian distribution and not a mean value. The new calculation of the OCS BE distribution** used in this study, computed by **Vittorio Bariosco**, is shown in *Fig.4*.

The OCS BE is relatively low compared to that of other molecules (1215 K compared to 4255 K for methanol [7]), **implying that desorption can occur at low temperatures.** Given the formation on grain surfaces, we expect an extended emission due to grain desorption.

IV. Modelling

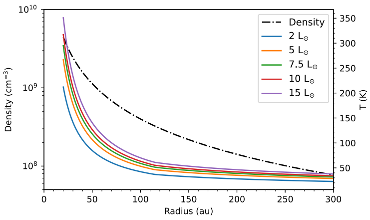

Figure 5: *Density (dash) and temperature (full) profiles*

$$n_{gas}(r) = 4.3 \times 10^8 \left(\frac{r}{100\,\mathrm{au}}\right)^{-1.5} \mathrm{cm}^{-3}$$ [2], [8]

Opt. thick region

$$T_{dust}(r) = 31 \left(\frac{L_{A_2}}{L_\odot}\right)^{1/4} \left(\frac{r}{115\,\mathrm{au}}\right)^{-1} \mathrm{K}$$

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[8], [9], [10]

Equilibrium between adsorption and desorption:

$$k_{des} x_{ice}(OCS) = k_{ads} x_{gas}(OCS)$$

$$x_{ice}(OCS) + x_{gas}(OCS) = x_{tot}(OCS)$$

With:

$$k_{des} = \nu_{des} \exp\left[-\frac{BE}{T_{dust}}\right]$$

$$k_{ads} = S\,\pi\,a_{dust}^2\,n_{dust}\,v_{th}$$

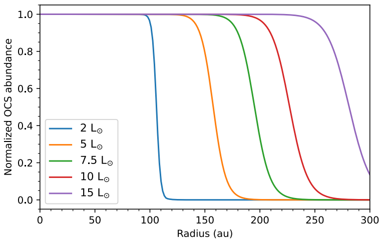

Figure 6: *Gas phase abundance profile*

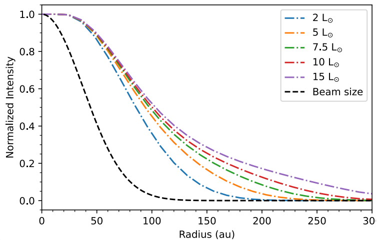

Figure 7: *Theoretical intensity profile*

To reproduce the observations, the intensity profile **is convolved by the synthetized beam size**.

$$I_{OCS}(s) = \int_{LOS} x_{gas}(OCS)(s,s')\, n_{gas}(s,s') \times h\nu\, A_\nu \exp\left[-\frac{h\nu}{k_B\, T_{gas}(s,s')}\right] ds'$$

V. Results

The **study is made only for IRAS4A2**, because **of the important dust absorption around IRAS4A1** the molecular emission is too weak.

The observed profile is made is the envelope direction of the source at a **PA = 120°** [11].

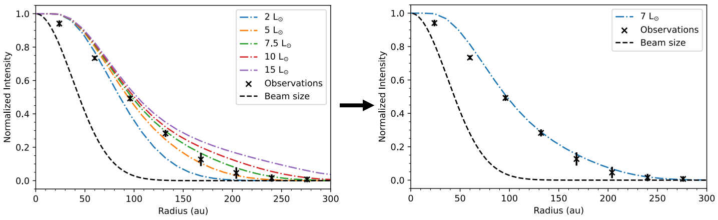

Figure 8: *Best luminosity fit between theoretical and observed OCS emission profile*

The best fit between model and observations gives a luminosity of **7 ± 1 L_{sol} for IRAS4A2**.

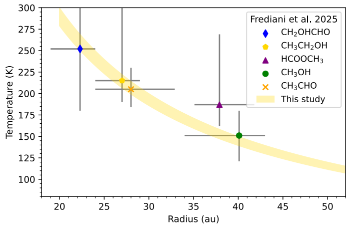

Figure 9: *Comparison with [12] temperature points*

The luminosity-based temperature profile of IRAS4A2 was computed and then compared with the results of [12].

The luminosity of IRAS4A1 is obtained using the total bolometric luminosity (14.5 ± 1.5 L_{sol}) and the luminosity of IRAS4A2 (7 ± 1 L_{sol}), giving **a luminosity of 7.5 ± 2.5 L_{sol}**.

VI. Conclusion

We present here a new method to estimate the luminosity of embedded protostars in binary systems using molecular emission. By using new quantum mechanics calculation of OCS binding energy, we obtain an estimation of the luminosity of IRAS4A1 and IRAS4A2 without using the spectral energy distribution. **The bolometric luminosities for IRAS4A1 and IRAS4A2 are 7.5 ± 2.5 and 7 ± 1 L_{sol}, respectively.**

References

[1] Codella et al. 2021
[2] Kristensen et al. 2012
[3] Zucker et al. 2018
[4] McClure et al. 2023
[5] Boogert et al. 2022
[6] Loison et al. 2012
[7] Bariosco et al. 2025
[8] Jorgensen et al. 2002
[9] Adams & Shu 1986
[10] Ceccarelli et al. 2000
[11] Chahine et al. 2024
[12] Frediani et al. 2025