Signatures of UV radiation around low-mass protostars in Serpens

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A new-born protostar forms in dense core deep inside a molecular cloud. Molecular cloud is characterised by high extinction in the optical range so observations at long wavelengths are necessary. In particular, submillimetre spectra include rotational lines of key molecules which are useful tracers of physics and chemistry around low-mass protostars. HCN, CN, and CS emission is modelled using radiative transfer code RADEX to determine the gas physical conditions and molecular abundances. This information provides input parameters to use an astrochemical model in order to characterise the strength of the UV radiation. Thus, we gain new understandings of chemical and physical processes around low-mass protostars.

Key words: stars: formation, ISM: individual objects: Serpens Main, ISM: molecules

INTRODUCTION

New discoveries of extrasolar planets trigger questions about star and planet formation and composition. Detailed studies on the earliest stages of stellar evolution are necessary in order to understand these phenomena. Protostars are formed in dense cores inside a moleculars cloud. The earliers phases of star formation is characterised by gas and dust accretion from an envelope and bipolar, collimated outflows which carry out molecular gas from the dense core ([1]). Protostars interact with their sourrondings changing chemical and physical properties of the matter that the stars and planets are formed from. In this turbulent einviroment an energetic electromagnetic radiation, such as ultraviolet radiation or X-rays, is produced that causes the ionisation of young stellar objects' environment ([8]). The UV radiation around massive protostars is estimated at 20-600 times higher than average in the interstellar medium ([2]). The strength of the UV radiation around less massive young stellar objects is still a matter of debates.

The Serpens molecular cloud is characterized by a large sample of known protostars ([4]). With the distance of 436 ± 9 pc ([6]) it is one of the largest clouds containing low-mass protostars in within 500 pc. The Serpens Main region is situated in the northern part of the cloud. There are several low-mass protostars at the very early stage of their evolution. The initial identification of the protostars was obtained in the submillimetre range, hence the objects got numbered by their submillimetre luminosity with the SMM prefix.

OBSERVATIONS

The observation was obtained with IRAM 30 submillimetre telescope. It is equipped with a high resolution and broad band EMIR receiver that has provided high quality spectra of targeted lines: HCN, CN, CS and their isotopologues. Observations were divided into two regions of the Ser-SMM1 (centered at $\alpha_{\rm J2000} = 18^h29^m49.6^s$, $\delta_{\rm J2000} = +01^\circ15'20.5''$) and the Ser-SMM3/Ser-SMM4 (centered at $\alpha_{\rm J2000} = 18^h29^m56.6^s$, $\delta_{\rm J2000} = +01^\circ14'00.3''$). The beam size varies from 14 arcsec for $H^{13}CN$ $J = 2-1$ to 29 arcsec for $H^{13}CN$ $J = 1-0$. The observation summary is shown in Tab. 1.

Table 1: Overview of the observations

Mol.	Trans.	ν (GHz)	Beam size ($''$)	Beam eff. $\eta_{\rm MB}$
HCN	1-0	88.631602	28	0.81
CN	1-0	113.494921	22	0.78
CS	3-2	146.969029	16	0.74
$C^{34}S$	3-2	144.617109	16	0.74
$H^{13}CN$	1-0	86.342274	29	0.81
$H^{13}CN$	2-1	172.677881	14	0.68

Beam sizes and efficiencies are taken from `http://www.iram.es/IRAMES/mainWiki/Iram30mEfficiencies`

RESULTS AND CONCLUSIONS

HCN molecule photodissociates into CN radical in the presence of the UV radiation while CN itself is less sensitive to the photodissociation. Thus, CN/HCN ratio is widely used as a tracer of the ultraviolet radiation (e.g. [5], [3], [7]). Fig. 1 shows CN $J = 1-0$ and HCN $J = 1-0$ integrated intensities ratio. The integration was performed above 3 σ level. In the studied region the highest CN/HCN ratio is co-spatial with more evolved protostars: SMM5 and SMM6. The HCN molecule dominates in molecular outflow positions as well as in the denser regions of large concentration of protostars, where the energetic radiation is highly absorbed by a dust. This results show that CN/HCN ratio can be a good tracer of more evolved protostars independently of the SED analysis.

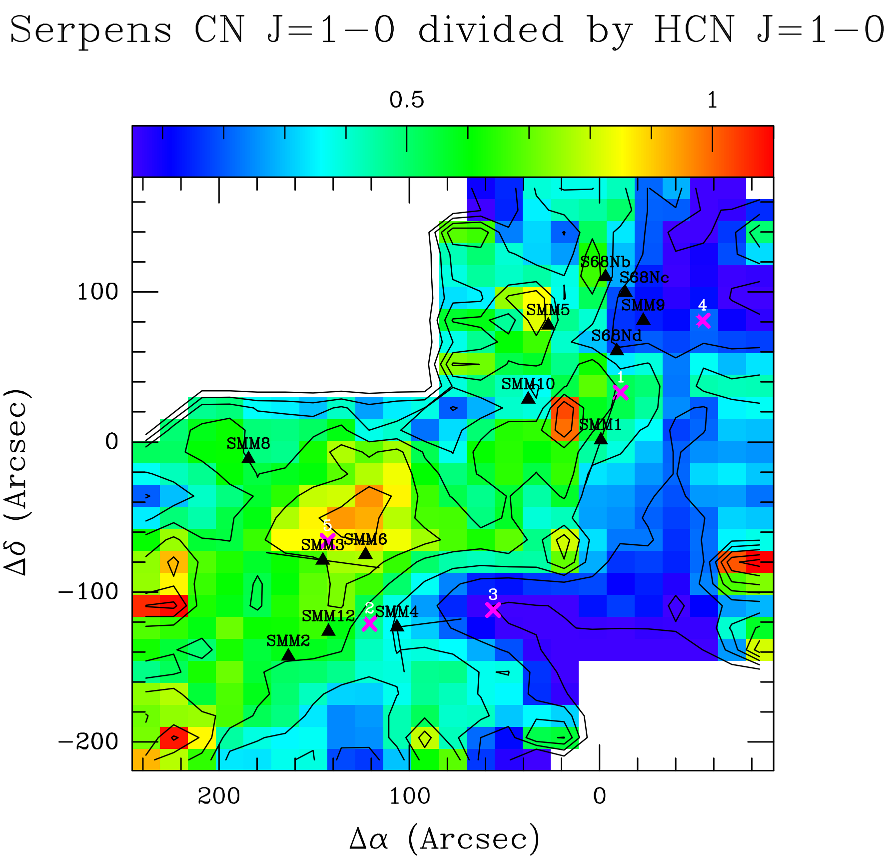

Fig. 1: Emission of the CN/HCN in the Serpens Main region. Black triangles show the positions of the protostars, whereas black lines show the associated outflow directions. Outflow positions are displayed as purple crosses.

CN, HCN and CS abundances can be calculated based on intensities of the observed molecular lines using RADEX radiative transfer code ([9]). We prepared the sets of RADEX models with kinetic temperature of 30 K and hydrogen densities varying from 10^3 to 10^5 cm^{-3}. The CN/HCN ratio around low-mass protostars varies between 1-10 regardless of molecular hydrogen densities. CN/CS ratio varies between 10 and 30 for the all protostars positions, while CS/HCN ratio is in order of 0.1-0.3. An example sets of models are shown in Fig. 2.

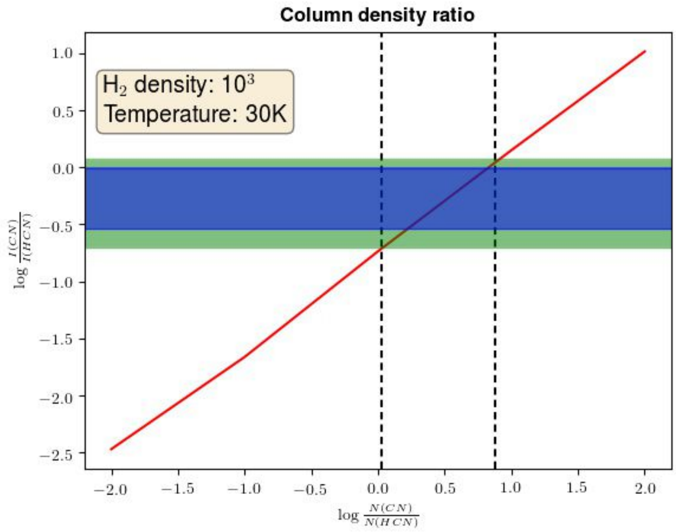

Fig. 2: CN/HCN column density ratio for hydrogen densities of $n_{\mathrm{H_2}} = 10^3$ cm^{-3} and kinetic temperatures of $T_{\mathrm{kin}} = 30$ K (red line). The observed line intensity ratio is plotted in blue (protostars positions) and green (all positions).

The astrochemical model Nahoon ([10]) was applied for calculating chemical network of HCN, CN and CS. A reaction probability depends on various parameters such as UV radiation flux, the cloud temperature or dust grains size. The abundances ratio does not change dynamically in low temperatures what allowed fixing the temperature parameter at 50K. Comparing CN/HCN results with similar plots of CN/CS (Fig. 3 and Fig. 4) restricts the parameter space to very low-density and weakly irradiated gas. Astrochemical models computed for CS/HCN ratio show similar behaviour. At the protostars positions high hydrogen densities can be assumed $\approx 10^6$ cm^{-3}. The models allow to estimate the strength of needed UV radiation field of $G_0 \approx 0.03$.

Astronomical models show that there is non-zero UV radiation in the gas of 50 K at the positions of low-mass protostars. An additional radiation source of few hundredth of the average interstellar UV radiation field is required to explain the observational ratios.

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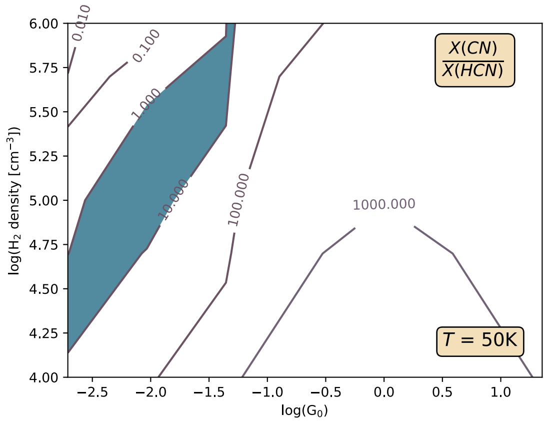

Fig. 3: Contour plot of Nahoon sets of models of CN/HCN abundances ratios with fixed temperature T = 50 K against UV radiation flux (G0 parameter) and hydrogen densities. The observational abundances ratio is marked with blue colour. G0 parameter describes the average UV flux in the interstellar medium. An additional UV radiation of few hundredth of the average interstellar UV radiation flux is enough to cover the observations in wide range of total hydrogen densities.

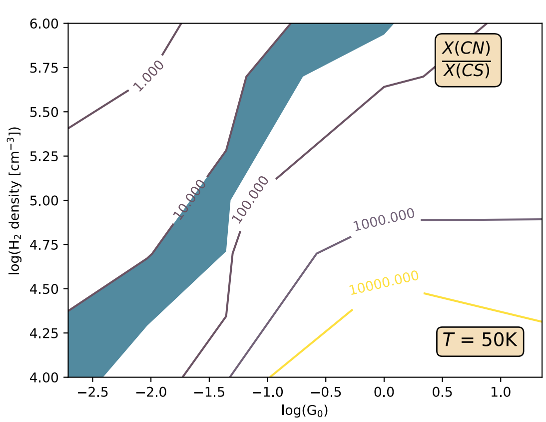

Fig. 4: Similar to Fig. 3 but for CN/CS abundances ratios.

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