# The role of external UV irradiation for the survival of astrophysical ices in protostellar envelopes

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## ABSTRACT

The survival of astrophysical ices in star-forming regions depends of suitable conditions of temperature, density and of the radiation field. In this work, the role of Interstellar Radiation Field (ISRF) on ices in Elias 29 is addressed. This object is the most luminous protostar in ρ Oph E molecular cloud, and is surrounded by many Young Stellar Objects distant only a few arcminutes. In addition, other two brightness B2V stars (S1 and HD 147889) enhance the external irradiation in Elias 29. This study was carried out by using the Monte Carlo radiative transfer code RADMC-3D assuming an internal and external irradiation. As result, we found that HD 147889 dominates the ISRF, instead of the closest protostars, and contributes to enhance the external irradiation in 44 times the standard flux of Interstellar Medium. Furthermore, remarkable effects are observed in FIR spectrum, as well as in near-IR image. Additionally, the snowline positions of volatile compounds are redefined to a toroidal-shaped morphology in the envelope, with low FUV flux ($10^{-7}$ ergs cm$^{-2}$ s$^{-1}$). Such region would host Complex Organic Molecules (COMs) such as $CH_3OH$ and $C_2H_4O_2$ isomers (methyl formate, acetic acid and glycolaldehyde) for a lifetime larger than $10^4$ years as shown in Figure below. In more evolved stages, it is expected that such COMs will be assimilated by planets and cometary bodies, once their lifetimes in the disk region is larger than $10^5$ years. More details are shown in Rocha & Pilling (submitted).

## 1. INTRODUCTION AND MOTIVATION

Protostellar envelopes are some places of the interstellar medium that host several frozen molecules (also called astrophysical ices). The chemical evolution and survival of these ices, however, depends of the intensity of internal and external Interstellar Radiation Field (ISRF). Once early-type protostars are surrounded by several other Young Stellar Objects, the influence of ISRF on $C_2H_4O_2$ isomers in Elias 29 is addressed, by combining computational simulation and laboratory data to reproduce the whole spectrum and images in near-IR.

## 2. METHODOLOGY

### 2.1 External irradiation and Temperature

In order to estimate the ISRF on Elias 29 coming from YSOs+stars (S1 and HD 147889), a WISE image and $A_V$ map were used (Fig. 1), + the relative distances ($R_i$) in Fig. 2. The total flux ($F_{tot}$) and optical depth ($\bar{\tau}_i^{UV}$) were calculated using the equations (1) and (2). The external flux was estimated in 44 the standard flux for ISM.

$$F_{tot} = \sum_i^n \left(\frac{L_i^{UV}}{4\pi R_i^2}\right) \exp[\bar{\tau}_i^{UV}] \quad (1)$$

$$\bar{\tau}_i^{UV} = \left(\frac{2}{m}\sum_j^m A_V^{ij} - A_V^{foreground}\right) \rho_d^{rel} \frac{R_i}{d_i} \quad (2)$$

The spectrum, near-IR images, outer temperature and survival line of ices are shown, respectively in Figs 3, 4, 5 and 6.

### 2.2 Laboratory data ($\sigma^{photodissociation}$ [$cm^2$])

- 2.2(-19) for $CH_3OH$-$H_2O$: Bertin et al. (2016)
- 4.2(-18) for $HCOOCH_3$: Rachid et al. (2017)
- 4.8(-18) for CH3COOH: Rachid et al. (2017)

### 2.3 RADMC-3D code

This code (see References) was used to calculate the radiative transfer inside the solid blue circle as shown in the Astrophysical scenario.

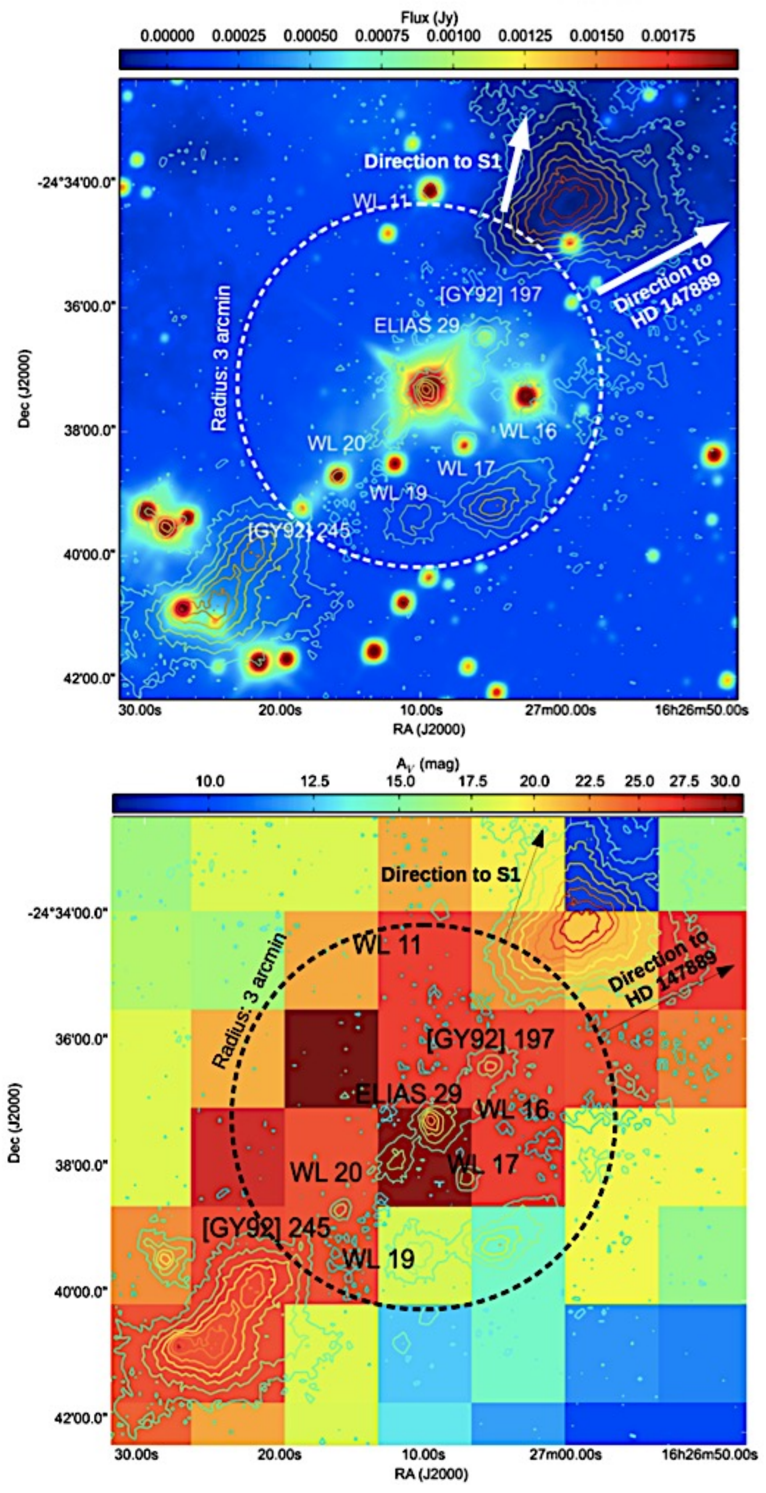
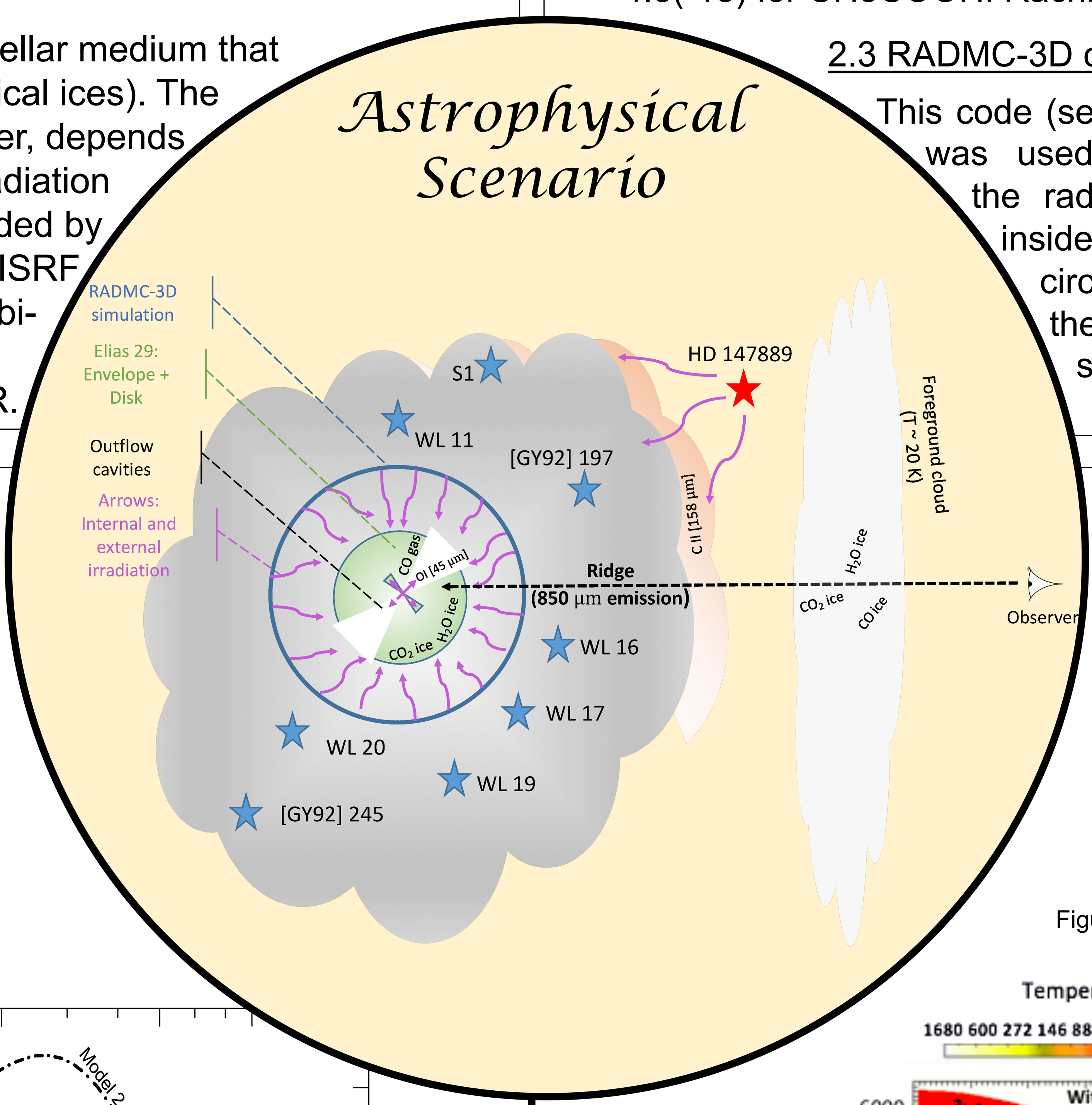



Figure 1: (a) WISE image at 3.2 $\mu$m superposed by the dust emission at 850 $\mu$m from SUBARU/JCMT. The objects inside the circle plus S1 and HD147889 were used in this work. Elias 29 is placed at center. (b) $A_V$ extinction map from COMPLETE database (Ridge et al. 2006). Labels are the same of (a).




## 3. RESULTS AND DISCUSSION

PHYSICS

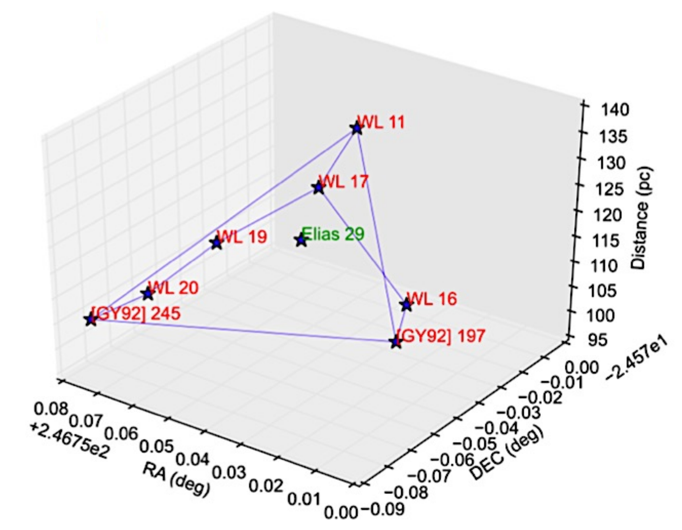


Figure 2: Relative distances ($R_i$) between each YSO and Elias 29 shown by the liks. The absolute distances ($d_i$) are shown in the z axis.

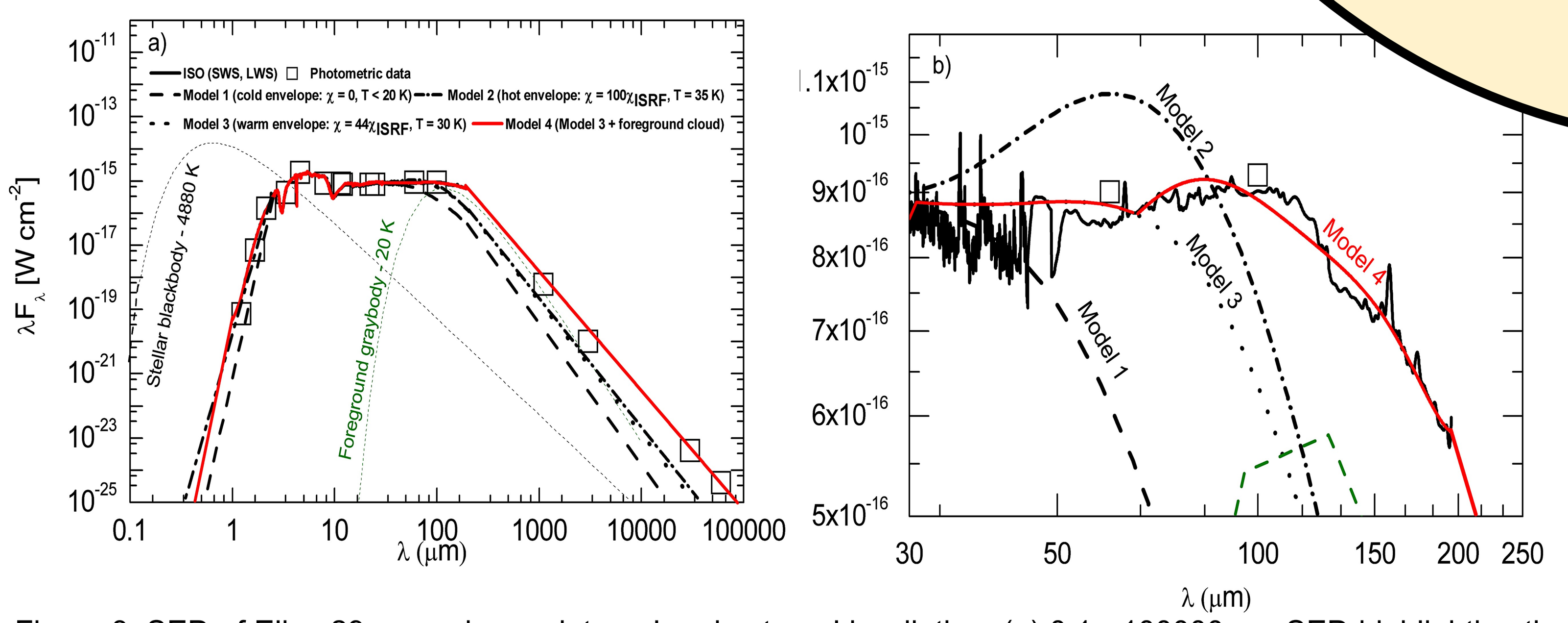


Figure 3: SED of Elias 29 assuming an internal and external irradiation. (a) 0.1 - 100000 μm SED highlighting the Models 1 - 4 and the photometric data taken from literature (2MASS, WISE, Spitzer, IRAS, SMA and ATCA). (b) Zoom of panel (a) showing details of the Models 1 - 4.

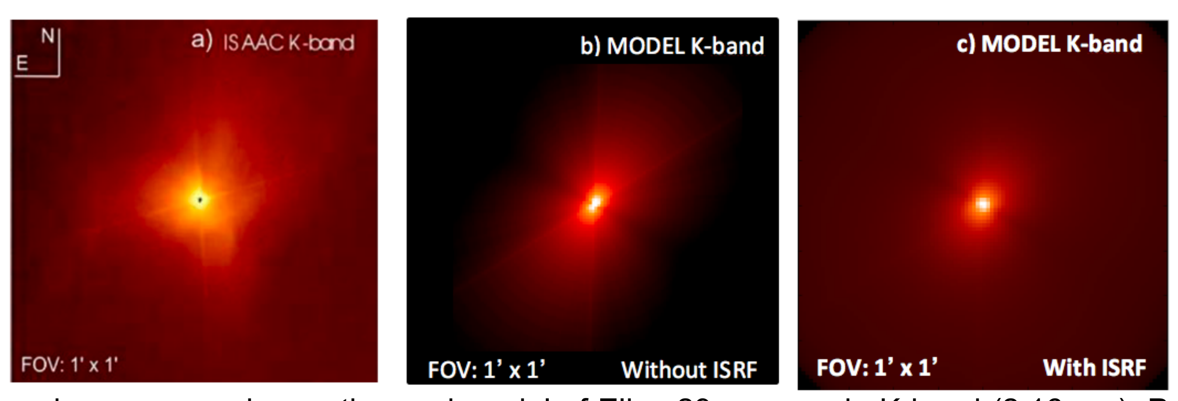



Figure 4: Comparison among observation and model of Elias 29 as seen in K-band (2.16 μm). Panel (a) shows Elias 29 as observed with ISAAC/VLT in polarimetric mode (adapted from Huélamo et al. 2005). Panels (b) and (c) show Elias 29 simulated with RADMC-3D assuming a scenario without and with external irradiation, respectively. No polarization is calculated in the models.

CHEMISTRY

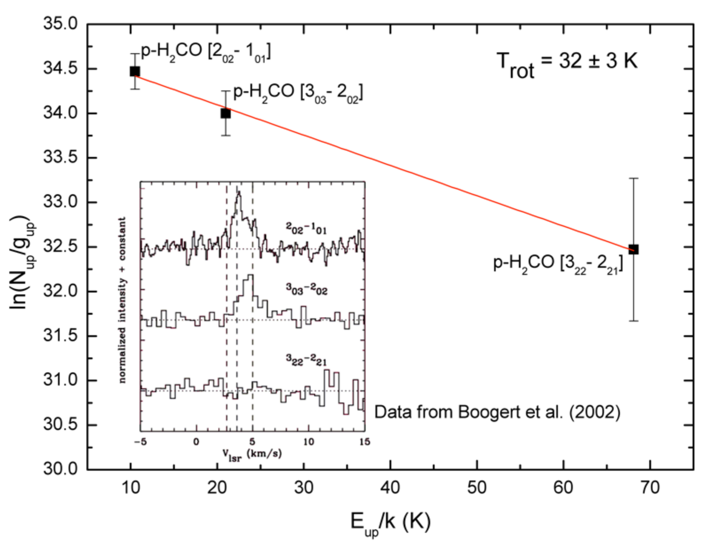


Figure 5: Rotational diagram for three transitions of para-$H_2CO$ molecule.

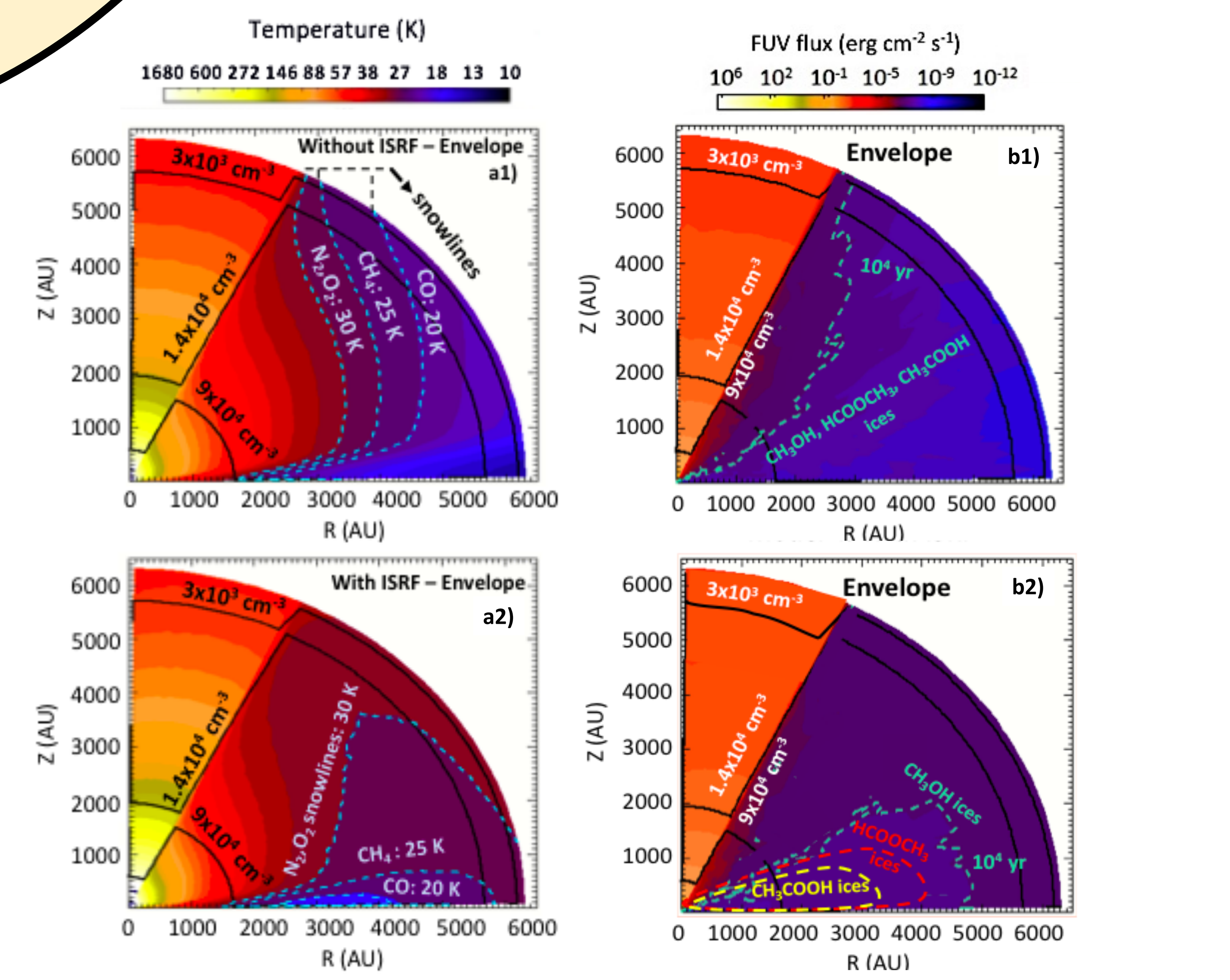



Figure 6: Temperature (a1 and a2) and flux map (b1 and b2) at Elias 29 calculated with RADMC-3D for the models with and without ISRF. The snowlines and survival lines are shown by dashed lines.

## 4. CONCLUSIONS

This work was focused in showing effect of the ISRF on survival of ices in Elias 29, The conclusions are summarized below:

- The outer envelope of Elias 29 is more warm (T ~ 30K) than what is expected for protostars illuminated only by a central source and HD147889 contributes in 93% with the ISRF;
- The FUV external irradiation penetrates in the envelope and redefine the snowline position of volatile molecules such as $N_2$, $O_2$, $CH_4$ and CO and create a toroidal-shaped distribution of $T_d$.
- Besides redefine the snowline position of volatile compounds, the FUV irradiation might create a toroidal-shaped region of COMs ($CH_3OH$, $HCOOCH_3$, $CH_3COOH$ and $HOCH_2CHO$) in the envelope with a half-life time of around $10^4$ years.

## REFERENCES

NOTE 1: Work based on Rocha & Pilling (submitted)
NOTE 2: RADMC-3D available in:
http://www.ita.uni-heidelberg.de/~dullemond/software/radmc-3d/

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Huélamo N., Brandner W., Wolf S., Khanzadyan T., 2005, in Protostars and Planets V Posters. p. 8209
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