High spatial resolution observations of key hydrocarbon species in the NGC 7023 PDR

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Photo-dissociation regions

Reflection nebulae | Proto-planetary disks | Galaxies starburst

Photon-dominated region

- \( H, C^+, O \)
- \( H_2, C^+, O \)
- \( H_2, CO \)

\( T_{\text{gaz}} = 1000 \) K  \( T_{\text{gaz}} = 200 \) K  \( T_{\text{gaz}} = 50 \) K

\( A_V = 1 \)  \( A_V = 10 \)

Outline

Introduction

Small hydrocarbons in PDRs
Evolutionary scenario of PAHs

The case of a mild-UV irradiated PDR: NGC 7023

The variations of the near-IR features seen by AKARI
The small hydrocarbon emission: CCH and c-C$_3$H$_2$
The evolution of the AIB carriers and small hydrocarbons

Conclusions & perspectives
The abundance of small hydrocarbons in PDRs

The abundances of small hydrocarbons (CCH, c-C$_3$H$_2$, C$_4$H) in low- and mild-UV PDRs are higher than predicted from gas-phase models by 1 or 2 orders of magnitudes.

Teyssier et al., 2004; Fossé et al., 2000; Pety et al., 2005, 2013

The spatial relation between the emission of small hydrocarbons and aromatic infrared bands suggests that the evolution of their carriers (PAHs) is linked.

*Photo-destruction of PAHs can lead to hydrocarbon formation?*
Observations of NGC 7023 NW

A spatially resolved source: NGC 7023 NW, $d = 430$ pc

$G_0 \sim 2600$  \hspace{1cm} nH $\sim 10^4 - 10^5$ cm$^{-3}$  \hspace{1cm} $T_{\text{gas}} \sim 70-120$K

Werner et al., 2004
The evolution of the mid-IR AIB carriers

The mid-IR spectra of PDRs show variation in the shape and intensity of the AIBs, that indicate an evolution of the AIB carriers.

Gas-phase PAHs are produced by destruction of eVSGs by UV photons.

Is there a link with the production of small hydrocarbons?
The differences in the near-IR spectra

Evolution of the 3.4 $\mu$m band relative to the 3.3 $\mu$m band with the physical conditions ($G_0$)

The variation of the near-IR spectral features also indicates an evolution of the AIB carriers

Pilleri et al, to be submitted
Spatial distribution of the 3.3 μm and 3.4 μm bands

Both emissions peak in the filamentary region
No emission of 3.3 μm or 3.4 μm band deeper in the cloud (no UV photons)
The 3.3 μm extends in the low-density, ionized cavity: partly due to ionized PAHs

Absolute intensity comparison is biased by column density and $G_0$
The ratio of the 3.4/3.3 bands as tracer of chemical evolution


Pilleri et al., to be submitted
The evolution of the $I_{3.4}/I_{3.3}$ ratio vs $G_0$

The evolution of the $I_{3.4}/I_{3.3}$ ratio is consistent with a photo-chemical model involving aliphatic methyl and methylene side-groups on PAHs

Adapted from Joblin et al., 1996

Pilleri et al., to be submitted
A link with gas-phase hydrocarbons?

PdBI observations of CCH and c-C$_3$H$_2$ in NGC 7023 NW

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faces the difficulty of the detailed geometry and physical conditions to derive molecular abundances

*Koheler et al., 2014
Joblin et al., in prep.*

needs to include the photo-products of PAHs and eVSGs in chemical networks

*Pilleri et al., in prep.*
Take-home messages

The question of the over-abundance of small hydrocarbons in PDRs needs a detailed study of the photo-processing of the AIB carriers.

Observations reveal a relation between the destruction of eVSG and the production of aliphatic C-H bonds on PAHs and of small hydrocarbons.

The main caveat concerns our poor knowledge on the properties of eVSGs.
Systematic study

3D survey of small hydrocarbons in PDRs

Orion Bar \((G_0 \sim 4 \times 10^4)\)

Cuadrado et al., 2014

Monoceros R2 \((G_0 \sim 4 \times 10^5)\)

Pilleri et al., 2013

NGC 7023 NW / E / S
\((G_0 \sim 2600, 1000, 200)\)

NGC 2023 S / N
\((G_0 \sim 4000, 400)\)

Test the dependence of the hydrocarbons abundance from \(G_0\)

Pilleri et al., in prep.
Perspectives

Constraining the physical conditions and the geometry of NGC 7023 NW

High resolution observations of atomic/molecular lines

Complete census of small hydrocarbons in the PDR

Spectral survey of NGC 7023 NW at 3mm and 2mm

C$_2$H, c/l-C$_3$H$_2$, l-C$_3$H$^+$, c/l-C$_3$H, C$_4$H, …

Application to other galactic PDRs and beyond

Galactic PDRs: 3D mapping of galactic PDRs (Spitzer, IRAM, AKARI)
Galactic (proto-)planetary nebulae, proto-planetary disks (ALMA)
External galaxies

Modeling

Extension of chemical models to include hydrocarbon production