Detection of cyanopolyynes in the protostellar shock L1157-B1

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International Symposium and Workshop on Astrochemistry
Campinas
07/07/2016

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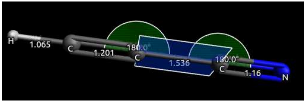
Cyanopolyynes in interstellar conditions

ASAI: Line identification

Formation of HC_3N in L1157-B1

Summarizing

Cyanopolyynes in interstellar conditions



1971: HC3N, Sgr 1971

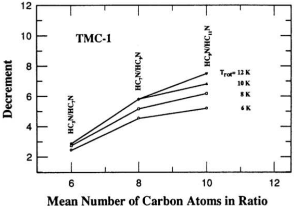
1976: HC5N, Sgr B2

1978: HC7N, TMC-2

1978, HC9N ISM

1997, HC11N, TMC-1

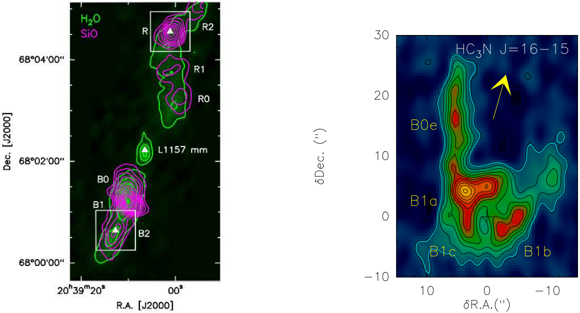
Bell et al. (1997) determined a decrement between successive cyanopolyynes in TMC-1



Synthesis starting with small precursors $C_2H_2^+$, HCN, C_2H, HNC Freeman et al. (1978) →→ 20

The source: L1157-B1

L1157-mm is a low-mass Class 0 protostar (∼ 250 pc)



(left) Santangelo et al. 2013 (right) Map of L1157-B1 with HC$_3$N J=16-15

L1157-B1, the brightest shock, is located at the second cavity in the south hemisphere

L1157-B1 is a young object, its dynamical age is ∼ 4000 yr

Several chemical species have been observed at mm wavelengths: H_2CO, CH_3OH, NH_2CHO, CH_3CN, H_2S...

Interferometric image of L1157-B1

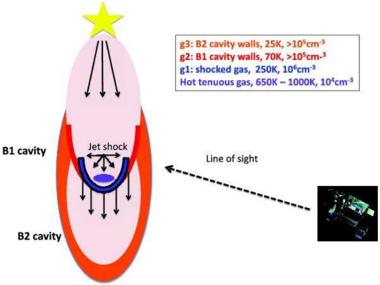
HC$_3$N J=16-15 (3.5 × 2.3 arcsec)

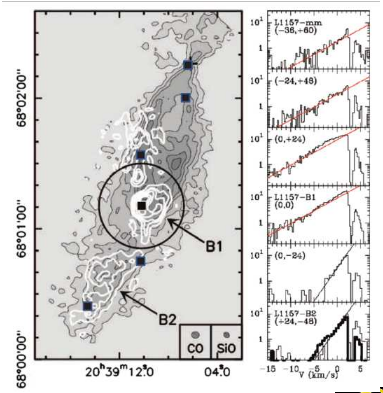
Bachiller et al. (2001); Lefloch et al. (2012); Benedettini et al. (2013); Podio et al. (2014)

The source: L1157-B1

Physical components in B1

- g_1: $T_{kin} \approx 250$ K
- g_2: $T_{kin} \approx 70$ K
- g_3: $T_{kin} \approx 25$ K





Busquet et al. (2014) and Lefloch et al. (2012)

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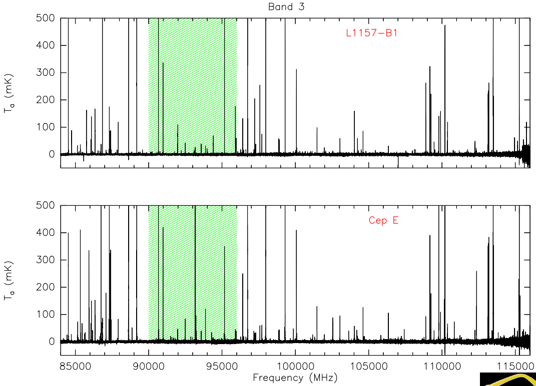
The ASAI large program

Astrochemical Surveys At Iram: 350 hours of observation at IRAM-30m (PIs: Lefloch & Bachiller 2014)

Sources: Samples that cover all the evolutionary phases of solar type protostars



Frequencies observed through ASAI:

3 mm: 80 - 116 GHz

2 mm: 130 - 170 GHz

1.3 mm: 200 - 320 GHz

0.8 mm: 329 - 350 GHz

Data reduction: Systematic study of HCN, HC_3N and HC_5N

The data reduction was performed using the GILDAS/CLASS90 package.

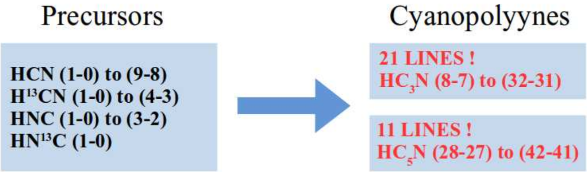
http://www.iram.fr/IRAMFR/GILDAS/

The CDMS and JPL spectroscopy databases were used to identify lines

http://www.astro-uni-koel.de/cgi-bin/cdmssearch
http://spec.jpl.nasa.gov/ftp/pub/catalog/catform.html

The telescope and receiver paramenters:

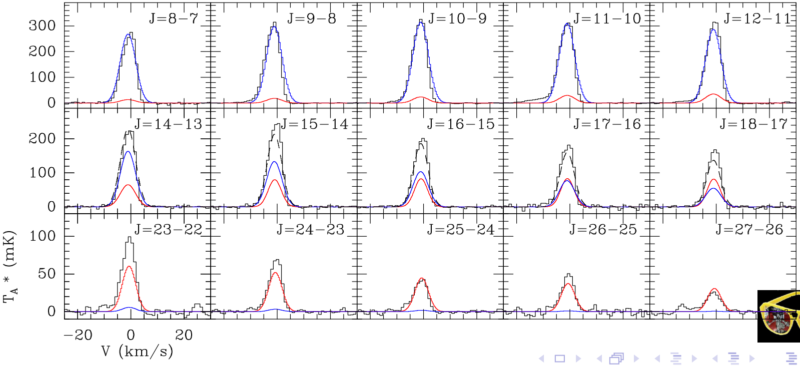
http://www.iram.es/IRAMES/mainWiki/Iram30mEfficiencies



Detection of HC_3N and HC_5N

HC_3N

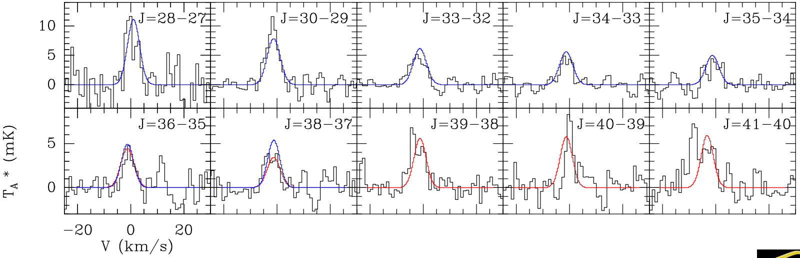
- Cold component
  from HC_3N J=8-7 to J=19-18
  T_{rot} = 16 K
  N = 3 $\pm$ 1 $\times$ 10^{13} cm^{-2}
- Hot component
  from HC_3N J=23-22 to J=32-31
  T_{rot} = 48 K
  N = 6 $\pm$ 2 $\times$ 10^{12} cm^{-2}



Detection of HC_3N and HC_5N

HC_5N

- Cold component
  from HC_3N J=8-7 to J=19-18
  $T_{rot} = 16$ K
  $N = 3 \pm 1 \times 10^{13}$ cm^{-2}
- Hot component
  from HC_5N J=36-35 to J=42-41
  $T_{rot} \approx 110$ K $N = 9 \times 10^{11}$ cm^{-2}



Spectral line profile

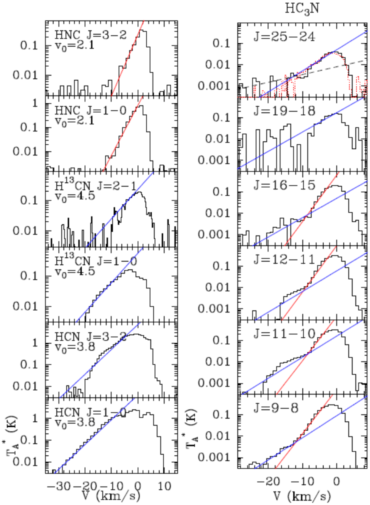
The high sensitivity of ASAI allowed to analyse the line profiles of HCN J=3-2, HCN J=1-0 and H^{13}CN J=2-1

$$I(v) \propto \exp\left(\left|\frac{v}{v_0}\right|\right)$$

$v_0 \simeq$ 12 km/s
$v_0 \simeq$ 4 km/s
$v_0 \simeq$ 2 km/s
Lefloch et al. (2012)
Gómez-Ruiz et al. (2015)

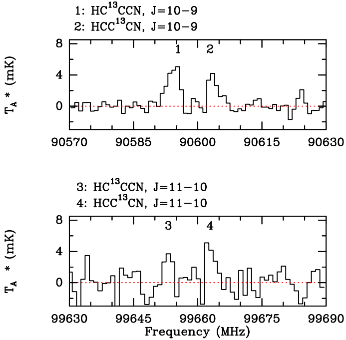
Physical components

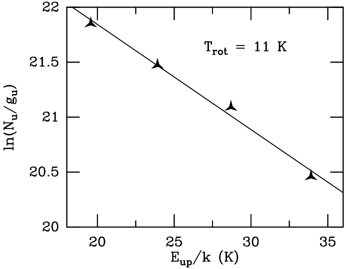
1. Component g1: T_k = 210 K, N(CO)= 9 × 10^{15} cm^{-2}, size ≈10″
2. Component g2: T_k = 64 K, N(CO)= 9 × 10^{16} cm^{-2}, size ≈20″
3. Component g3: T_k = 23 K, N(CO)= 1 × 10^{17} cm^{-2}, size ≈25″



HC_3N isotopologues in B1: a subtle evidence

$H^{13}CCCN$ J	Freq MHz	$HC^{13}CCN$ J	Freq MHz	$HCC^{13}CN$ J	Freq MHz
10–9	88166	9–8	81534	10–9	90601
11–10	96983	10–9	90593	11–10	99661
12–11	105799	11–10	99651	12–11	108720
		12–11	108710		





- ✓ Rotational temperatures around 15 K
- ✓ $N(H^{13}CCCN) \approx N(H^{13}CCCN) \approx 1 \times 10^{12}$ cm^{-2}; $N(HCC^{13}CN) \approx 5 \times 10^{11}$ cm^{-2}

Molecular abundances (preliminary results)

Abundances derived from LTE and LVG calculations

Component	T_{kin} (K)	$n(H_2)$ 10^6 cm^{-3}	N(CO) 10^{16} cm^{-2}	[HCN] 10^{-8}	[HNC] 10^{-8}	[HC_3N] 10^{-8}	[HC_5N] 10^{-8}
g1	200-300	0.8-1.5	0.48	42	-	-	-
g2	50-70	0.1-1	7.0	69	0.19	1.3	0.13
g3	$\lesssim$30	0.2-0.3	8.8	3.4	1.7	3.8	0.34

Next step: chemistry

1. What kind of processes govern the HC_3N formation?
2. Can we find a match between the observations and chemical models?
3. Task: Chemical modelling of the physical components of B1

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Chemical modelling: Formation of HC$_3$N

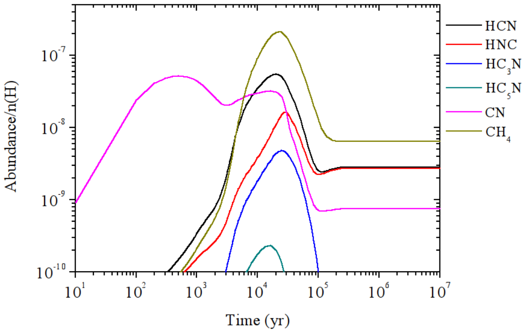
Phases

Nahoon (Wakelam et al. 2012) was employed to compute the chemical abundances of HC3N and its precursors as a function of time.

- Dark-cloud conditions: $T = 10$ K, $A_v \geq$ 10 mag, $n(H_2) \simeq 10^4$ cm^{-3}, $\zeta = 3 \times 10^{-16}$ s^{-1}
- High temperature phase: $T \leq 3000$ K, $A_v \geq$ 5-10 mag, $n(H_2) \simeq 10^5$ cm^{-3}
- Physical conditions of g2: $T \leq 70$ K and $A_v \geq$ 5-10 mag

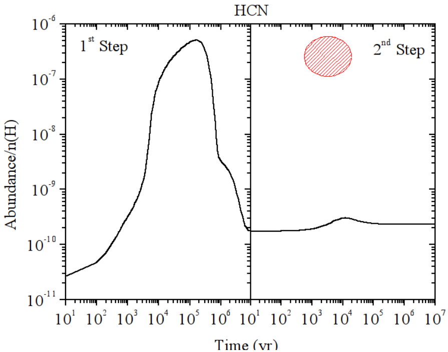
Initial abundances

Specie	Abundance
He	0.14
N	7.4×10^{-5}
O	3.52×10^{-4}
C^+	1.46×10^{-4}
S^+	1.60×10^{-7}
Si^+	1.60×10^{-8}
Fe^+	6.0×10^{-9}
Na^+	4.0×10^{-9}
Mg^+	1.4×10^{-8}



Chemistry in the physical component g_2

1^{st} Step	2^{nd} Step
Chemistry Elemental abundances e.g. Podio et al. 2014; Wakelam & Herbst 2008	Abundanes in steady-state ($t = 1 \times 10^6$ yr)
Physics n(H) = 2×10^4 cm^{-3} T = 10 K A_v = 10 mag ξ = 1-3 $\times$ 10^{-17} s^{-1} ...	n(H) = 1×10^5 cm^{-3} T = 70 K A_v = 10 mag ξ = 1-3 $\times$ 10^{-16} s^{-1} ...



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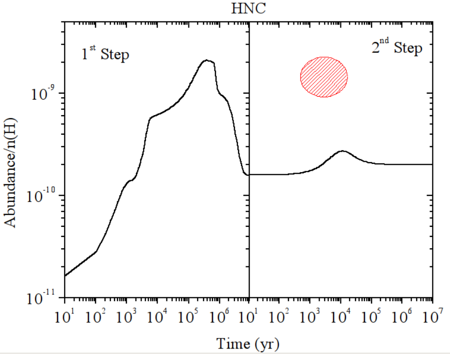

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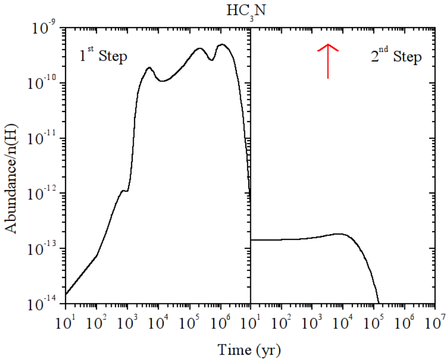

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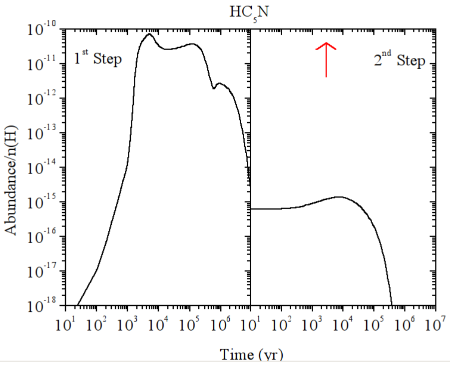

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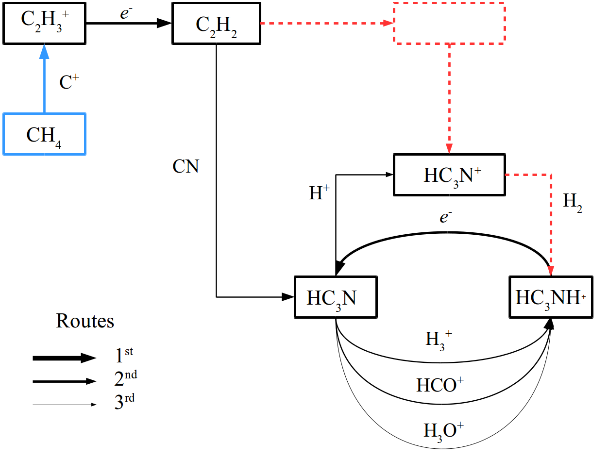
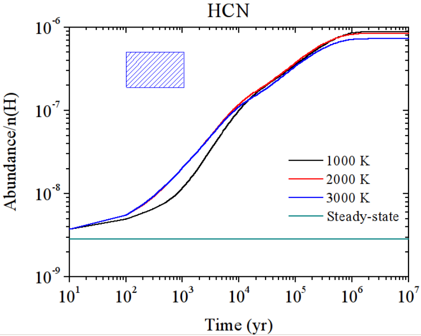
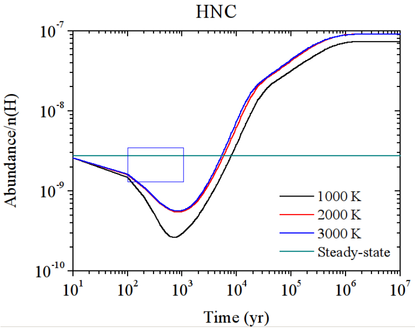


High temperature phase

We kept the physical conditions **except** temperature.
Models including:

T =1000 K
T =2000 K
T =3000 K





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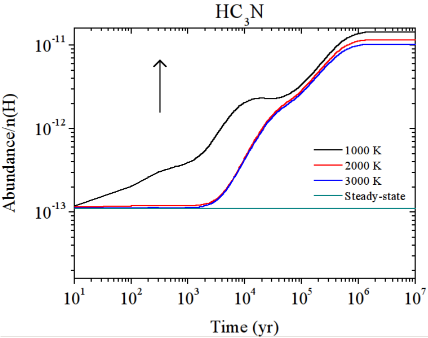
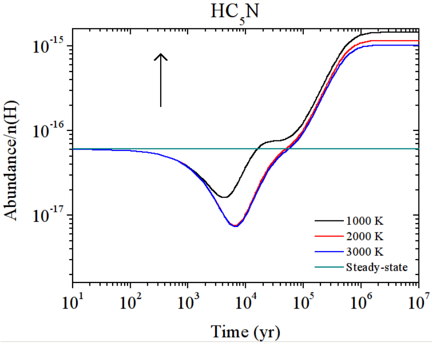
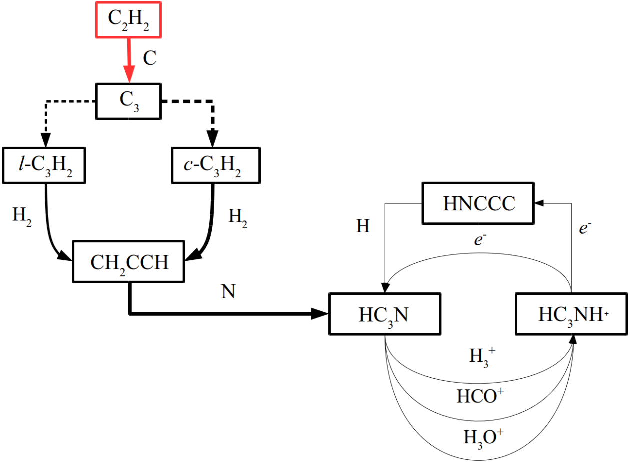




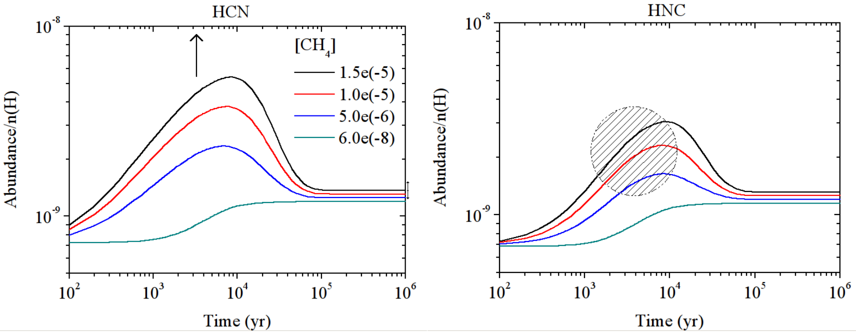
Reactions working at high temperature



Sputtering of CH_4

Sakai et al. 2012; Codella et al. 2015
Large quantities of CH4 have been found around L1157-mm
X(CH4) $\simeq$ 0.4-1.5$\times$ 10^{-5}

What is the influence on the abundances when is injected CH4?



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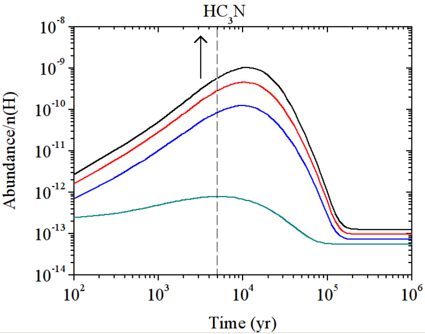

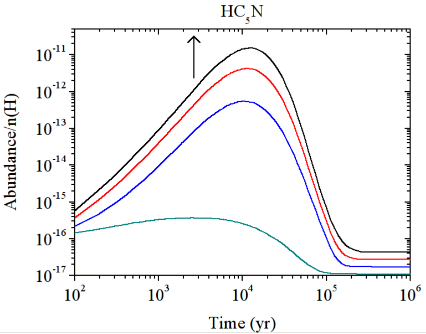

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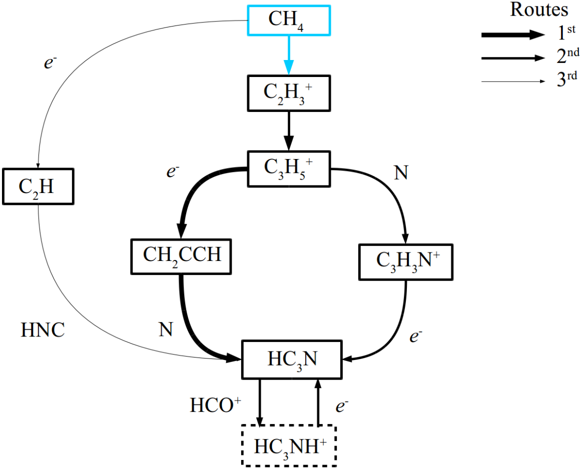

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- ✓ Detection of HC_3N from J=9-8 to J=32-31, HC_5N from J=32-31 to J=43-42.
- ✓ The spectral line profiles of HNC J=1-0, HCN J=1-0 and HC_3N = 9-8 evidenced the contribution of the g2 and g3 physical components, as reported by Lefloch et al. 2012 and Gómez-Ruiz et al. 2015

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g1	200-300	0.48	42	--	--	--
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THANKS!

Universidade do Vale do Paraíba