Carbon-chain growth in OMC-2 FIR4: the role of cosmic rays

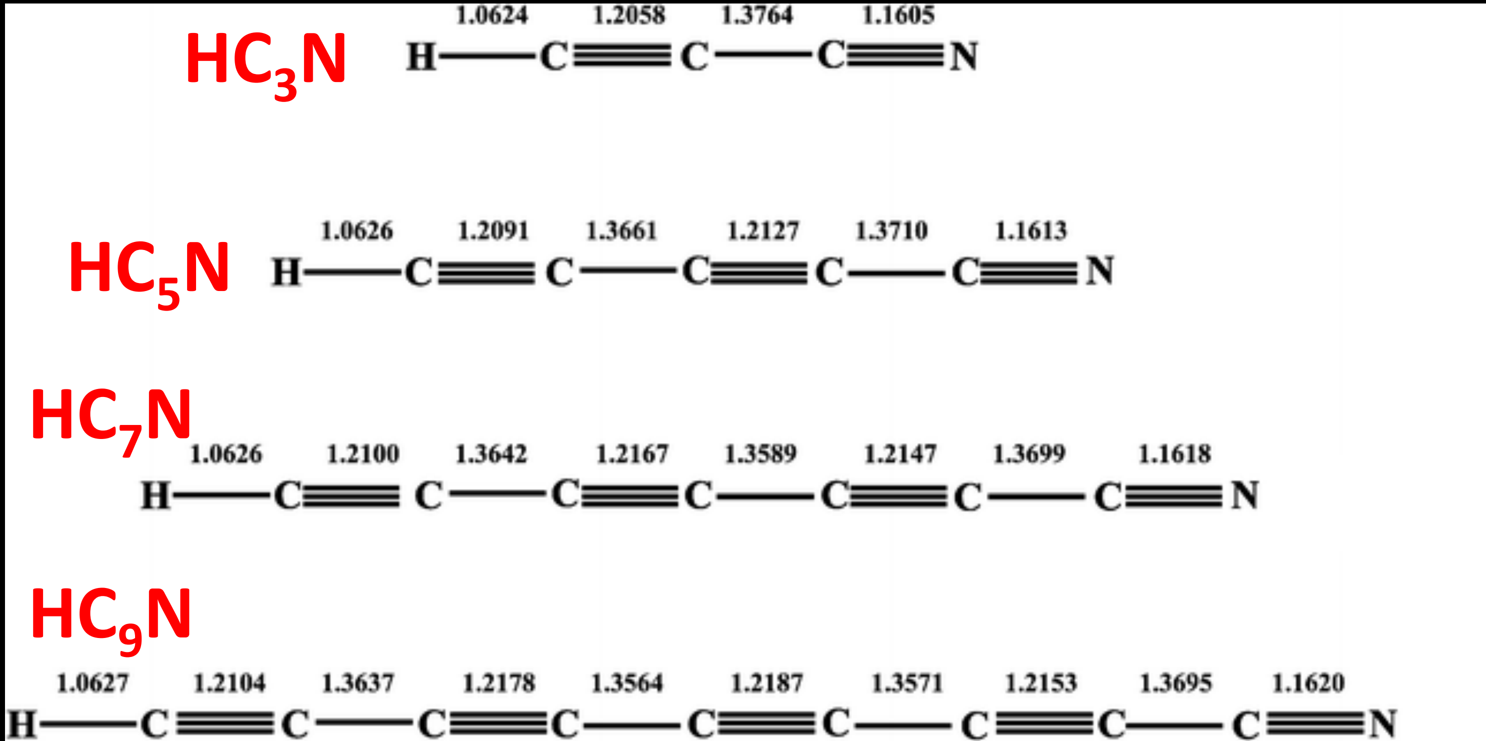
FRANCESCO FONTANI
INAF-Osservatorio Astrofisico di Arcetri

C. Ceccarelli (IPAG), C. Favre (INAF-Arcetri), P. Caselli (MPE), R. Neri (IRAM)
I. Sims (Univ. Rennes), C. Kahane (IPAG), F. Alves (MPE)…and the SOLIS team !

OVERVIEW

- ✓ Cyanopolyynes
- ✓ The source: OMC-2 FIR4
- ✓ Results: HC_3N/HC_5N ratio
- ✓ Implications for ζ

CYANOPOLYYNES



Botschwina2003

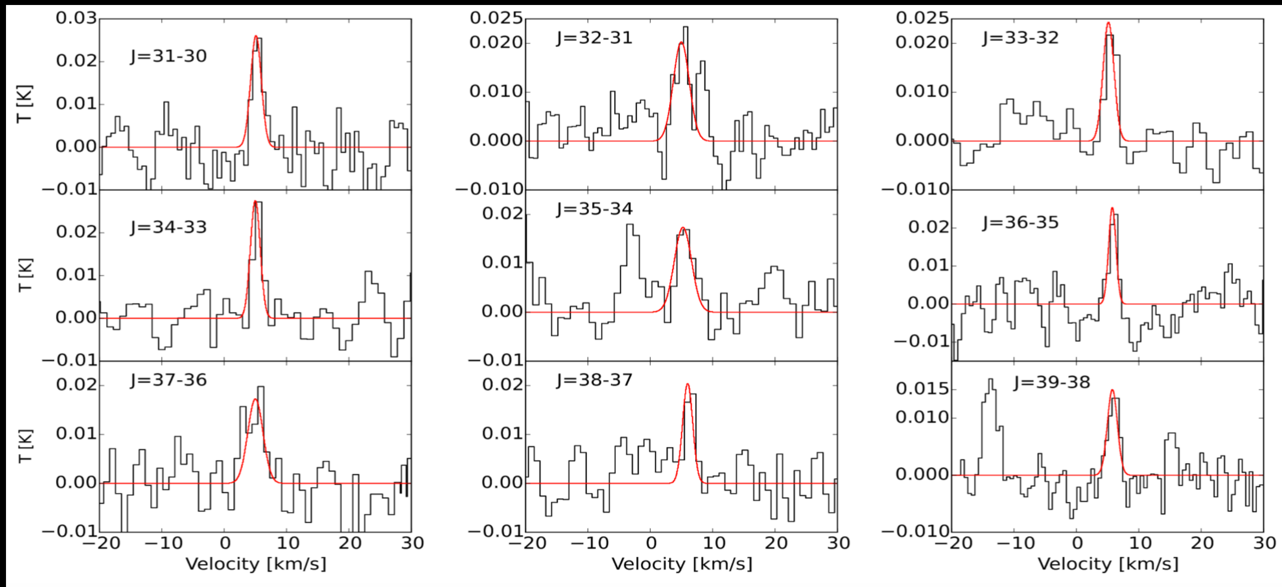
- ✓ Generic formula: $HC_{2n+1}N$
- ✓ Ubiquitous in the ISM
  - → Possible large reservoirs of Carbon

(Clarke & Ferris 1995, Goessmann+2015)

CYANOPOLYYNES

✓ Longest cyanopolyyne in the ISM: HC_9N (Broten et al. 1978)

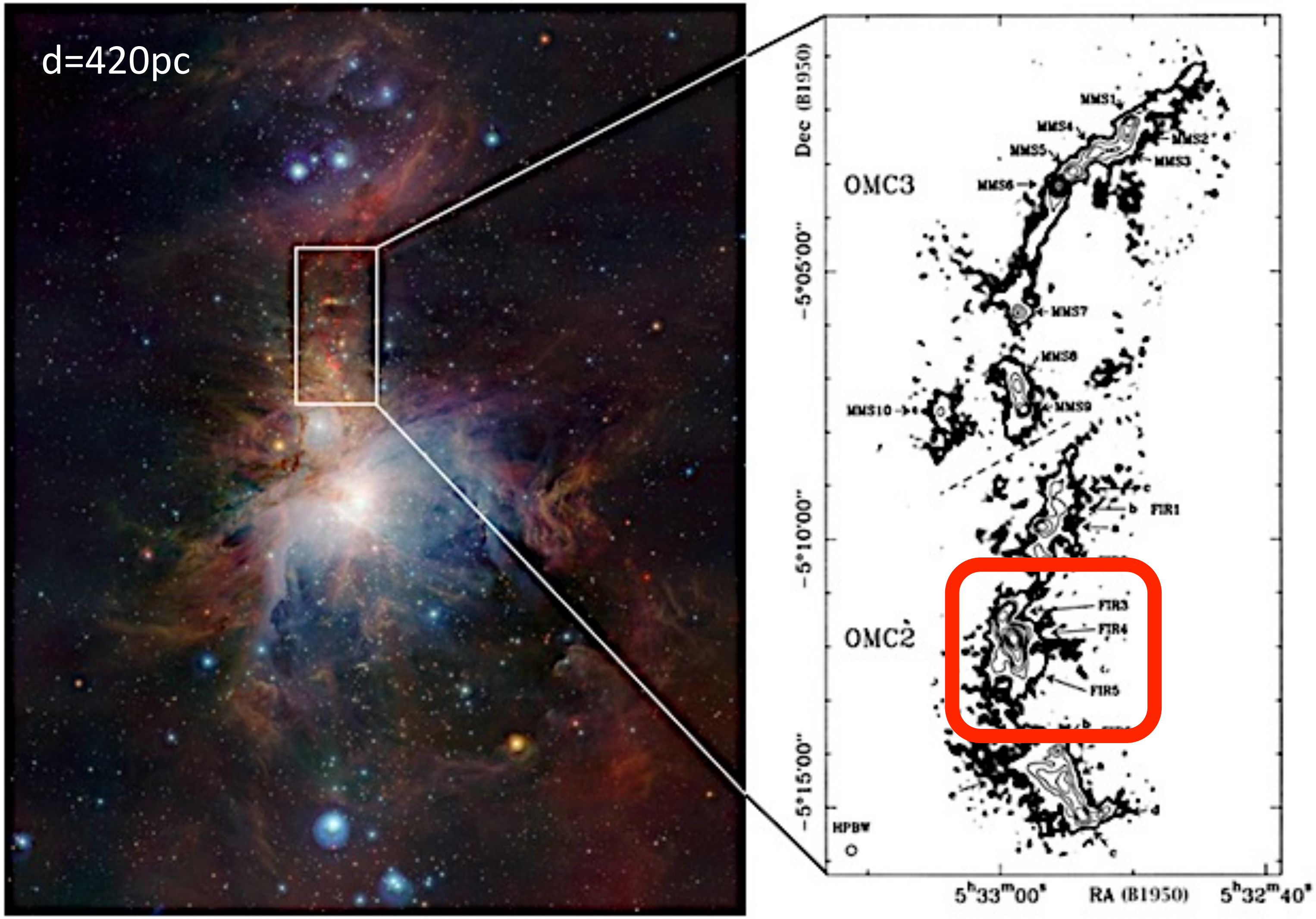
✓ Only up to HC_7N in (few) PROTOSTARS:
L1521E (Hirota+2004); L1527 (Sakai+2008); L1512 (Cordiner+2011); Cha-MMS1 (Cordiner+2012); IRAS16293-2422 (Jaber Al-Edhari+2016)



Jaber Al-Edhari+16

✓ HC_3N in comets and protoplanetary disks:
(Mumma & Charnley 2011, Chapillon+2012, Oberg+2015)

THE SOURCE: OMC-2 FIR 4



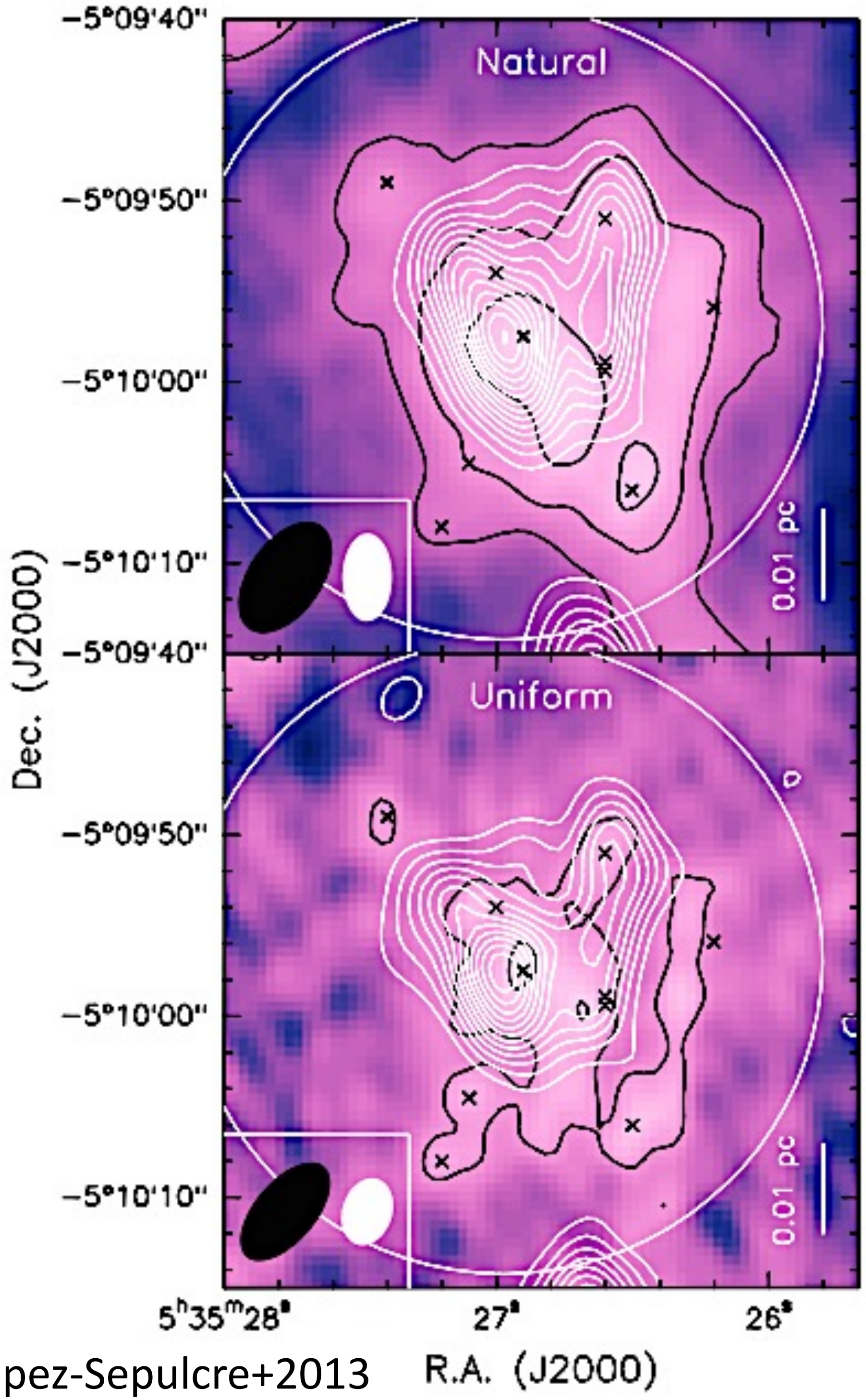
1) In FIR 4, ejection of energetic particles similar to that experienced by the young solar system (Ceccarelli+2014, Herschel measurements)

THE SOURCE: OMC-2 FIR 4

2) Rich and dense protocluster close to OB stars

Shimajiri+2008, Lopez-Sepulcre+2013
Kainulainen+2017

…likely the environment in which the Sun was born
(e.g. Adams10, Taquet+16, Drozdovskaya+18)



Lopez-Sepulcre+2013

RESULTS: HC_3N & HC_5N EMISSION MAPS

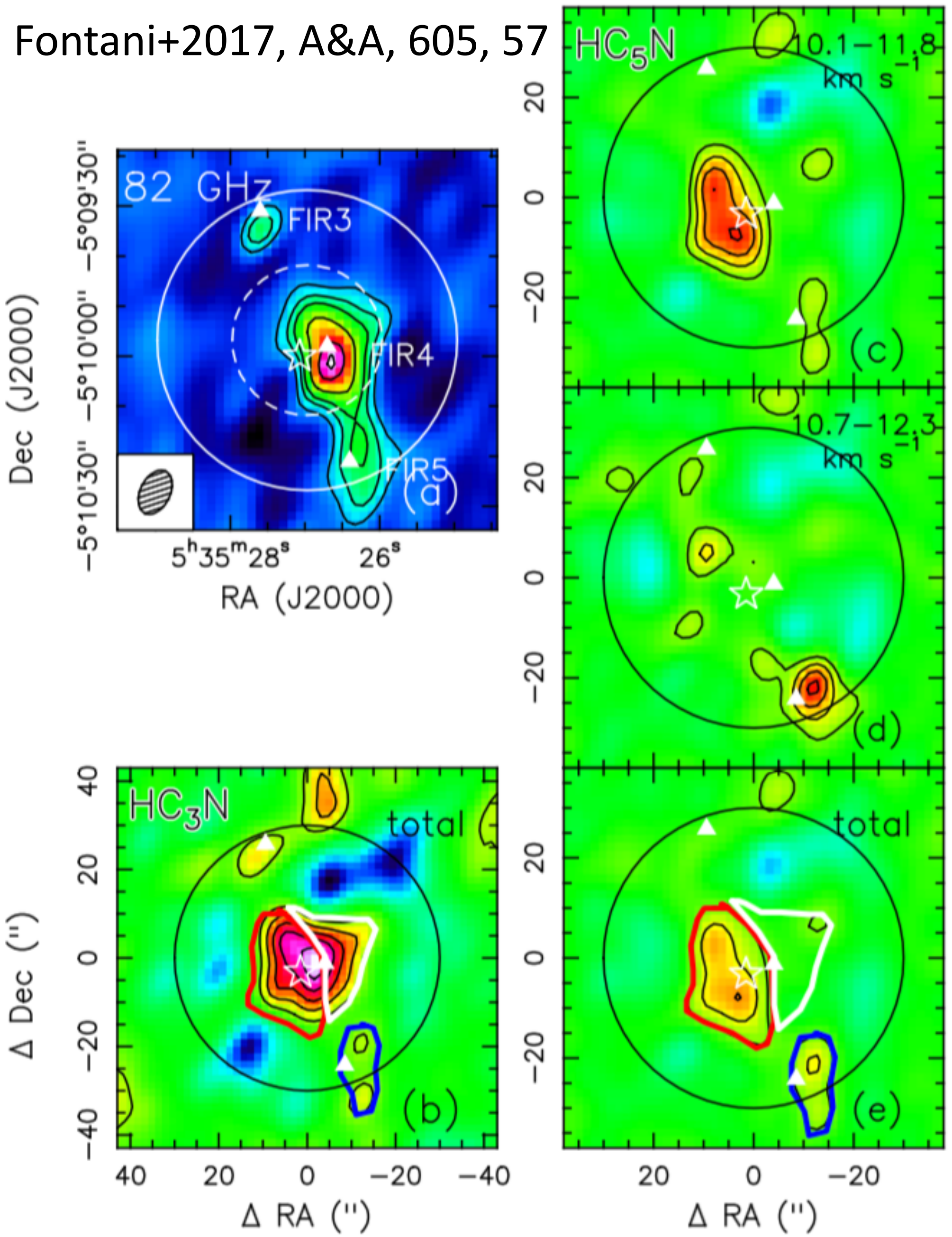
NOEMA D-conf. (~7'')

HC_3N 9-8 E_u ~ 20 K
HC_5N 31-30 E_u ~ 63 K

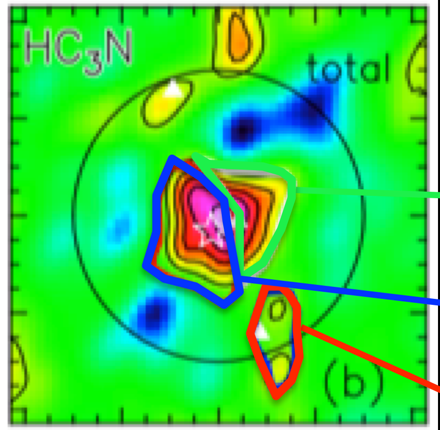
1) HC_3N is strong towards FIR4
weak in FIR3 and FIR5

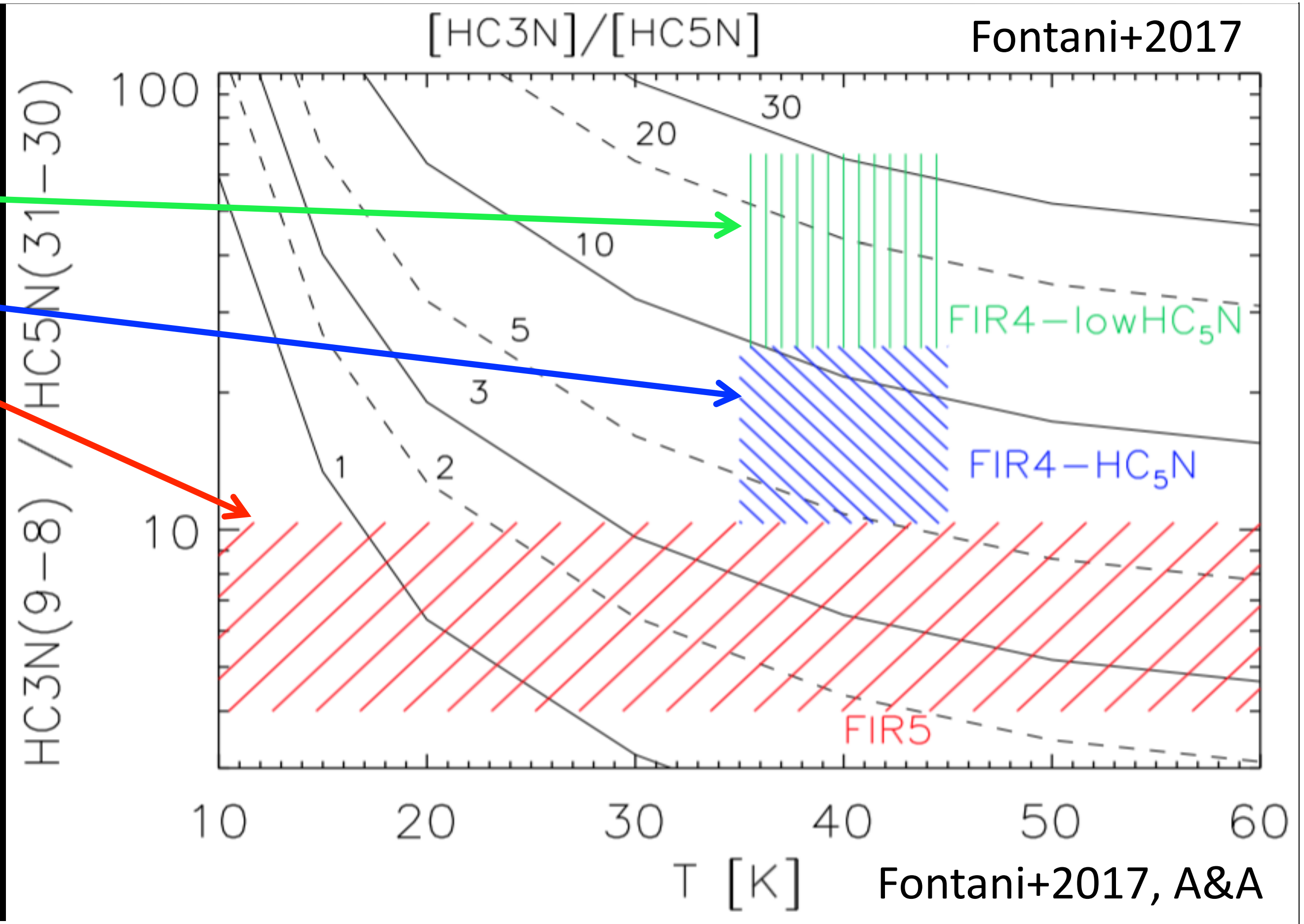
2) HC_5N is strong in FIR4 and FIR5
undetected in FIR3

Fontani+2017, A&A, 605, 57



RESULTS: HC_3N/HC_5N





MODEL: LTE + $\tau \ll 1$

X(HC_3N) = 0.5 – 5 10^{-11}

Line	E_u	$S\mu^2$	Integrated flux density			
			FIR4-total	FIR4-HC_5N (red)	FIR4-lowHC_5N (white)	FIR5 (blue)
	K	D^2	Jy km s^{-1}	Jy km s^{-1}	Jy km s^{-1}	Jy km s^{-1}
HC_3N(9–8)	19.6	124.8	6.0(0.6)	4.0(0.4)	2.0(0.2)	0.46(0.05)
HC_5N(31–30)	63.4	581	0.29(0.03)	0.25(0.03)	0.050(0.007)	0.072(0.009)
HC_3N/HC_5N				4-12	10-30	≤ 6

IMPLICATION 1: C/O ~ 1

CASE 1:

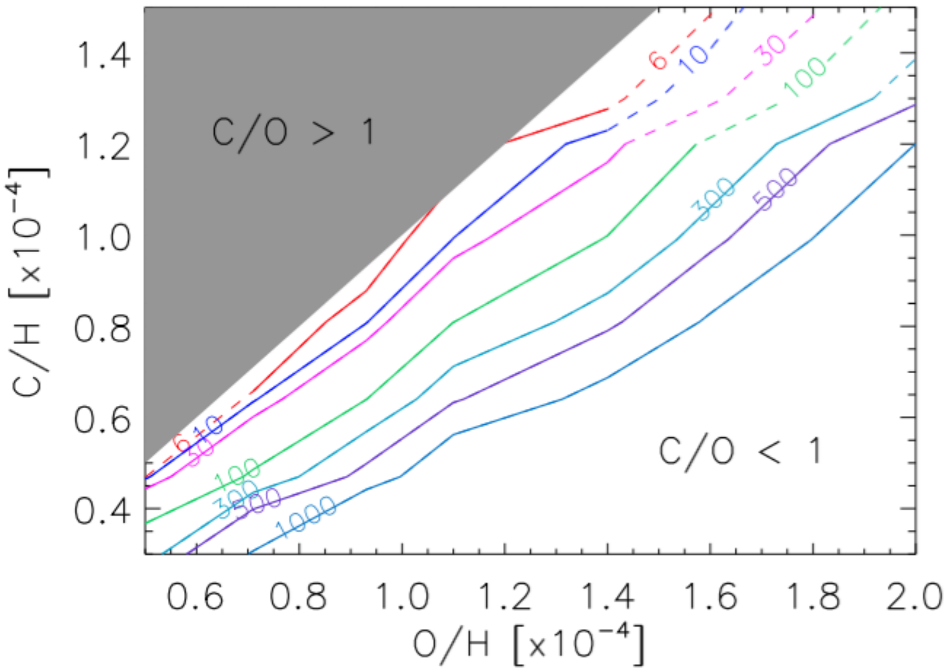
T = 40 K; n(H2) = 1.2 x 10^6 cm^{-3}

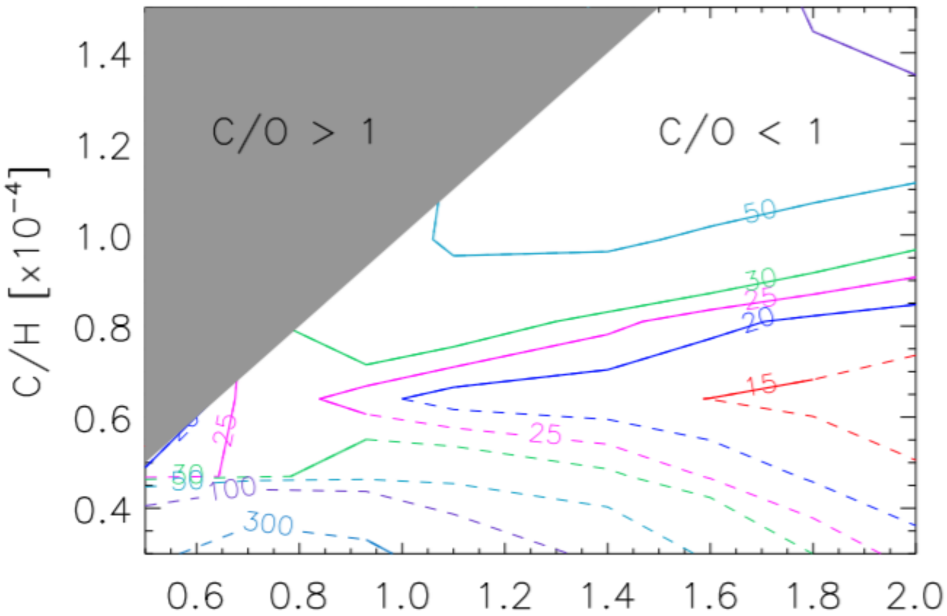
t = 3 x 10^4 yrs; $\zeta = 4 \times 10^{-14}$ s^{-1}

CASE 2:

T = 40 K; n(H2) = 1.2 x 10^6 cm^{-3}

t = 1 x 10^5 yrs; $\zeta = 1 \times 10^{-17}$ s^{-1}





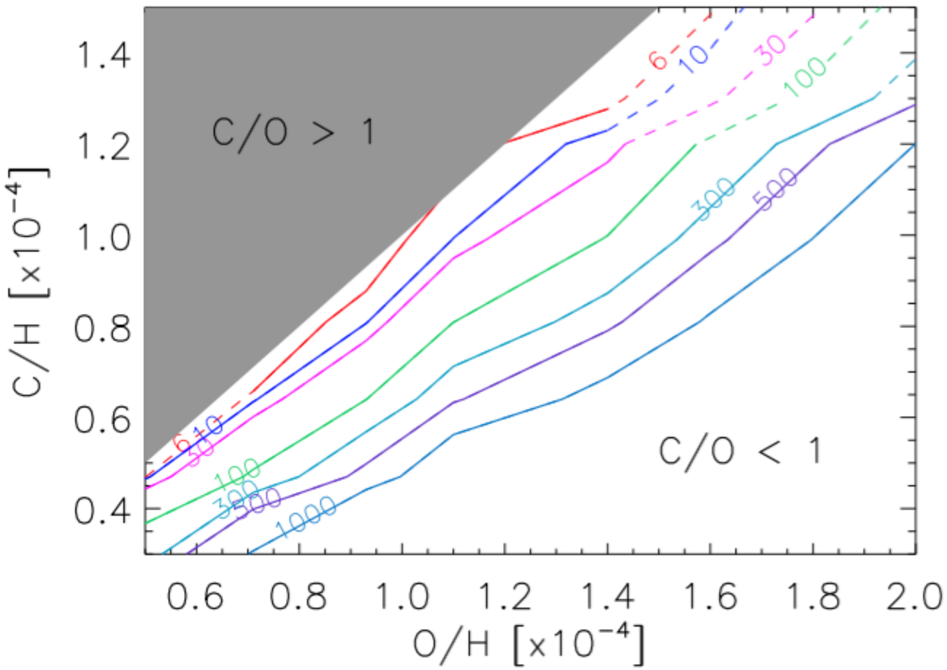
Fontani+2017

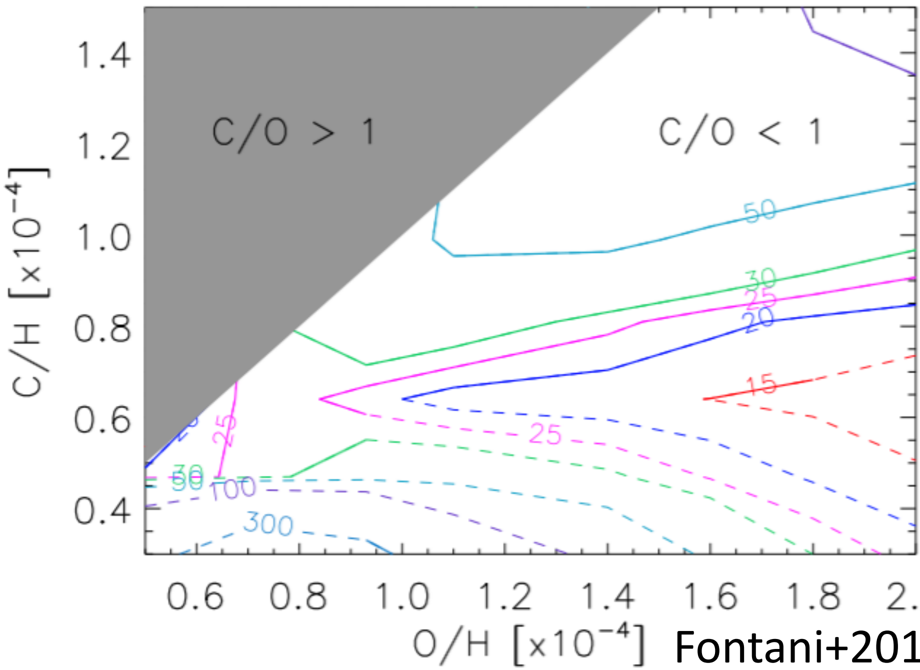
FIR4-HC_5N can be reproduced only if <u>C/O is close to unity</u>

IMPLICATION 2: ζ (CRs ionisation rate) high

CASE 1:
T = 40 K; n(H2) = 1.2 x 10^{6} cm^{-3}
t = 3 x 10^{4} yrs; ζ = 4 x 10^{-14} s^{-1}

CASE 2:
T = 40 K; n(H2) = 1.2 x 10^{6} cm^{-3}
t = 1 x 10^{5} yrs; ζ = 1 x 10^{-17} s^{-1}



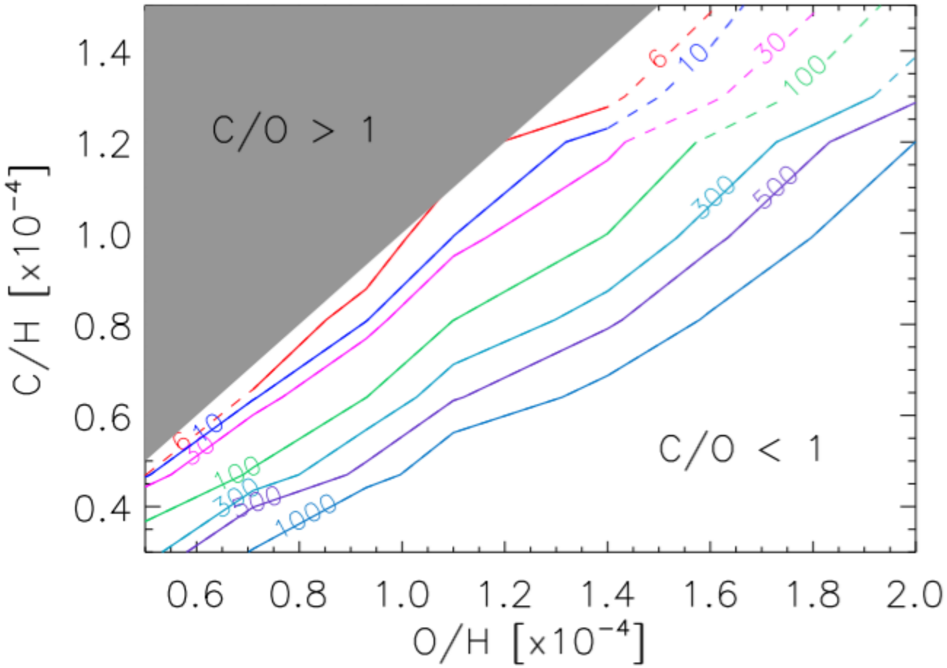


Fontani+2017

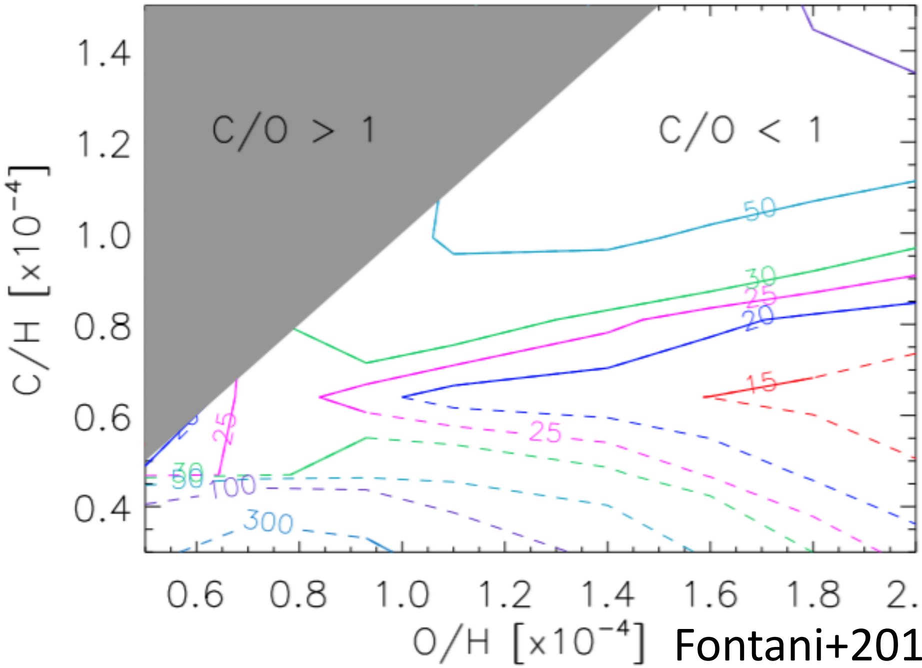
FIR4-HC_5N can be reproduced only if ζ is very high: 4 x 10^{-14} s^{-1}
This value is similar to that found by Ceccarelli+14

IMPLICATION 3: t < 10^5 yrs

CASE 1:
T = 40 K; n(H2) = 1.2 x 10^6 cm^{-3}
t = 3 x 10^4 yrs; ζ = 4 x 10^{-14} s^{-1}

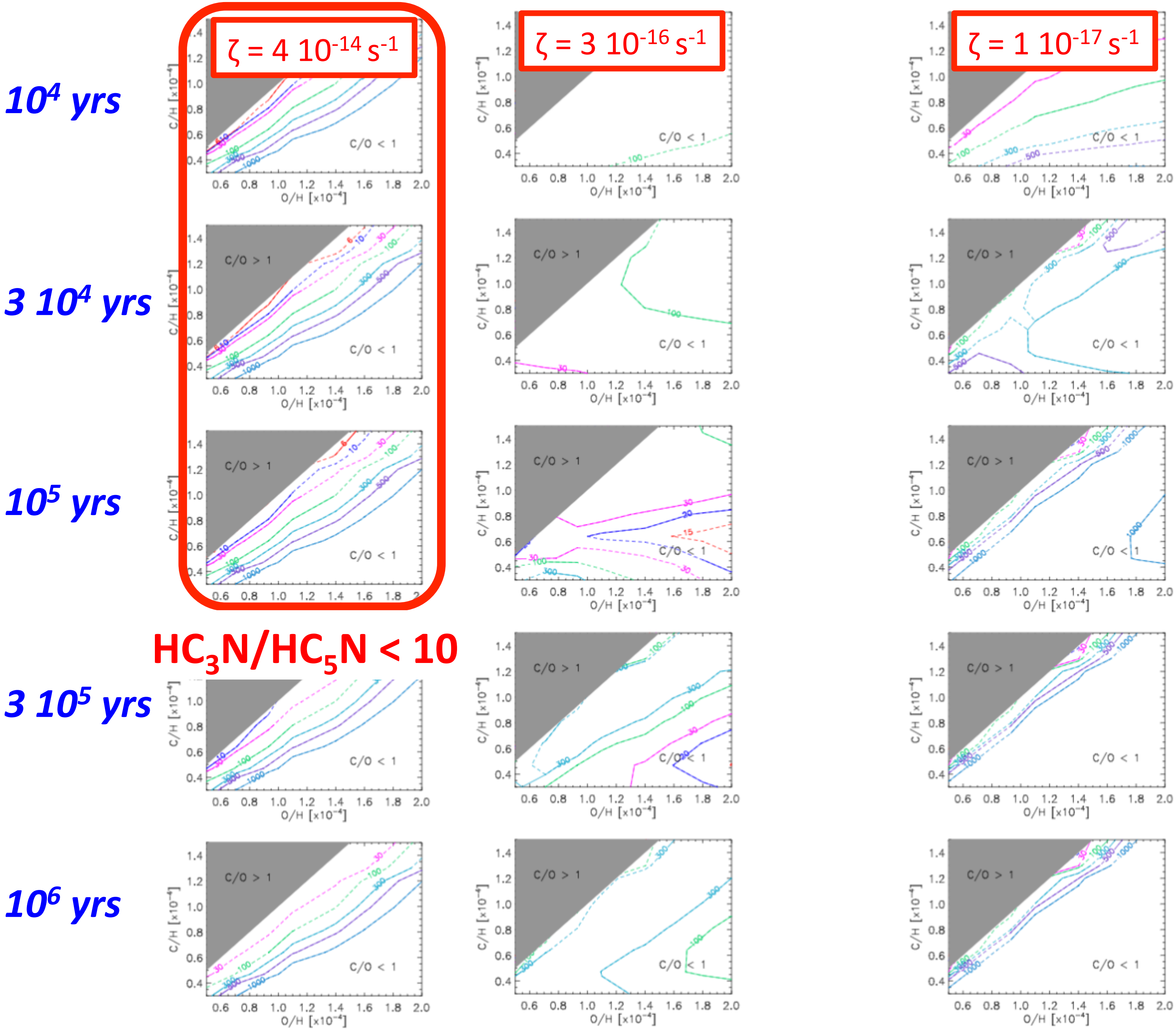


CASE 2:
T = 40 K; n(H2) = 1.2 x 10^6 cm^{-3}
t = 1 x 10^5 yrs; ζ = 1 x 10^{-17} s^{-1}



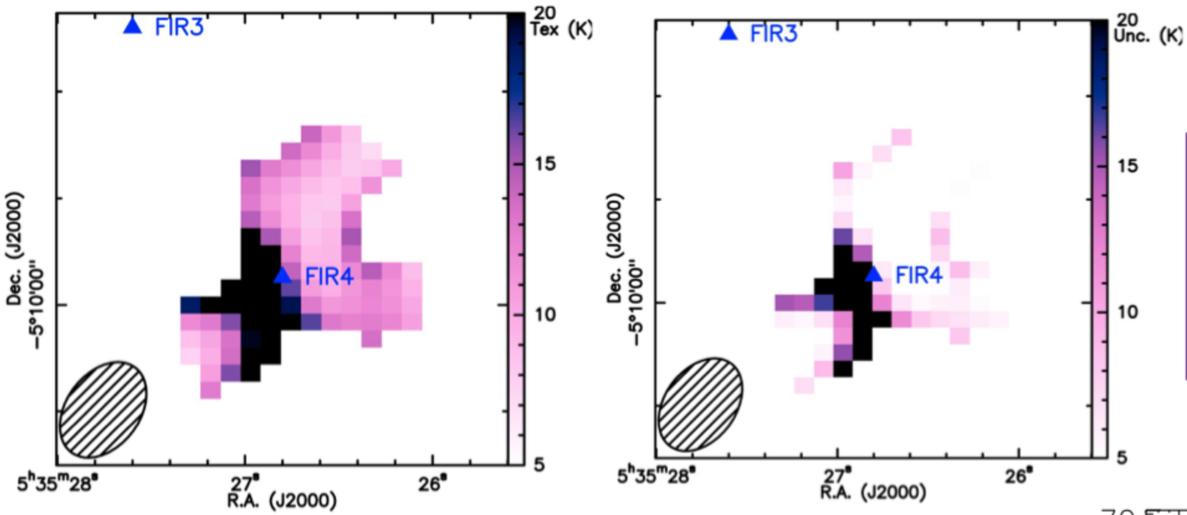
Fontani+2017

FIR4-HC_5N can be reproduced only if <u>t < 10^5 yrs</u>



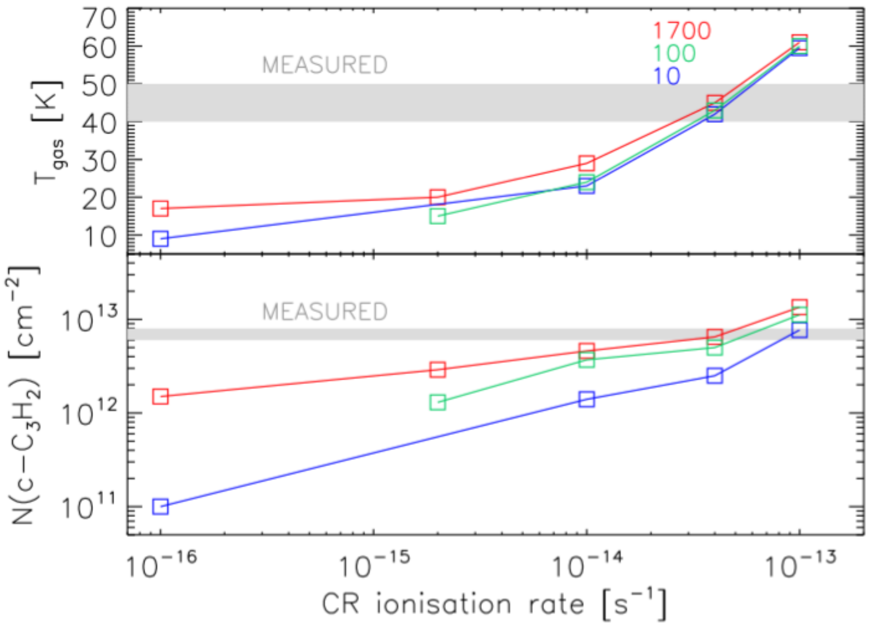
ζ = 4 10-14 s-1
ζ = 3 10-16 s-1
ζ = 1 10-17 s-1
104 yrs
3 104 yrs
105 yrs
3 105 yrs
106 yrs
HC3N/HC5N < 10
C/O > 1
C/O < 1
C/H [x10-4]
O/H [x10-4]

NOEMA SOLIS observations of c-C_3H_2



No significant excitation temperature gradients

Intense FUV field
&
large flux of CR



Chemical modeling via the Meudon PDR code
(Le Petit et al. 2006, Bron et al. 2016)

Favre et al. 2018, ApJ in press

CONCLUSIONS

- ✓ $HC_3N/HC_5N < 10$ can be reproduced only with high ζ → **energetic particles needed**
- ✓ The sources of these particles **promote Carbon chain growth**
- ✓ …then our **Sun**, exposed to a similar dose of energetic particles, **could have experienced a similar Carbon chain growth** (??)