Dark cloud such as TMC-1

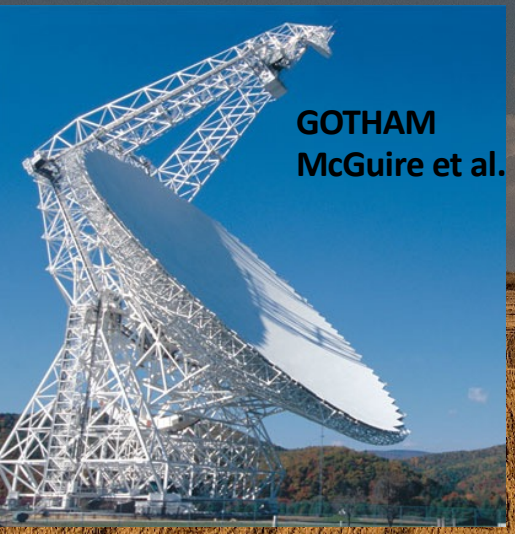
But at 10 K and
N~10^4 cm-3

QUIJOTE

Q-band Ultrasensitive Inspection Journey to the Obscure TMC-1 Environment

Chemical complexity in TMC-1

A line survey with an unprecedented sensitivity (≈0.06 mK)



Windmills in La Mancha.
The land of Don QUIXOTE

Spectroscopy in space and in the laboratory: searching for new molecules
in the interstellar and circumstellar media.

NANOCOSMOS & RADIO ASTRONOMY: QUIJOTE

QUIJOTE: The limits of sensitivity

- **Building new and novel ultrasensitive broadband receivers for the Yebes 40m radio telescope (NANOCOSMOS)**

- **Exploring the sub milliKelvin chemical work**
- **Reaching unexplored limits of sensitivity**

- **To see what radio astronomers have never seen before !**

σ = 0.06 mK = 60 μK = 0.00006 K (never done before)

- **To identify molecules through classical techniques of line by line detection**
- **SANCHO : Fidel companion of QUIJOTE. High sensitivity maps of the molecular emission at the milli Kelvin level**

GOTHAM line survey of TMC-1 (a cold dark cloud in Taurus)

- **Green Bank 100 m telescope observations 1-50 GHz (cm wavelengths)**
- **Most molecules detected through statistical analysis of the noise trough spectral stacking. Very powerful technique but you have to believe in the results !!!**
- **Discovery of CN derivatives of PAHs in a cold dark cloud**
- **C_6H_5CN (benzonitrile) and $C_{10}H_7CN$ (cyano-naphthalene, 2 isomers)**
- **Several cyanide derivatives of hydrocarbons**
- **McGuire et al. 2018, Science, 359, 202**
- **McGuire et al. 2021, Science, 371, 1265**
- **How, and where, these PAHs are formed ?**

Yebes 40m telescope observing TMC-1 in January 2021

The Yebes observatory is located in the region of La Mancha, the land of Don Quixote, at 950 m of altitude. It is around 60 km away from Madrid

The radio telescope was built and equipped for VLBI observations

Table 4. Estimated efficiencies for Yebes 40 m telescope from differen contributions at four observing frequencies.

Component	32 GHz	50 GHz	72 GHz	90 GHz
η_{m1}	0.95	0.87	0.75	0.65
η_{m2}	0.99	0.97	0.94	0.91
η_{mn}	1.00	0.97	0.97	0.95
η_{ohm}	1.00	1.00	1.00	1.00
η_{block}	0.92	0.92	0.92	0.92
η_{mbr}	0.98	0.98	0.97	0.97
η_i	0.80	0.80	0.82	0.82
Total $\eta_A{}^{(a)}$	0.67	0.59	0.50	0.41

Data analysis and data interpretation

- **Data analysis:** very tedious data analysis procedure with 2560 spectral windows per run (x 19 runs x 2 polarizations). Always performed by myself to keep homogeneity of the data products. Each run takes near one full month of work to reduce data . ALL systematics removed !!!

- **Data interpretation:** Use of the best spectral catalogues (CDMS and JPL) is not enough to interpret the data and to get the molecular content included in QUIJOTE (MADEX is needed). ML is not really necessary, a very simple routine can perform this task for >90% molecules. However, ML could help in identifying and interpreting peculiar cases. Pure astrophysical problem.

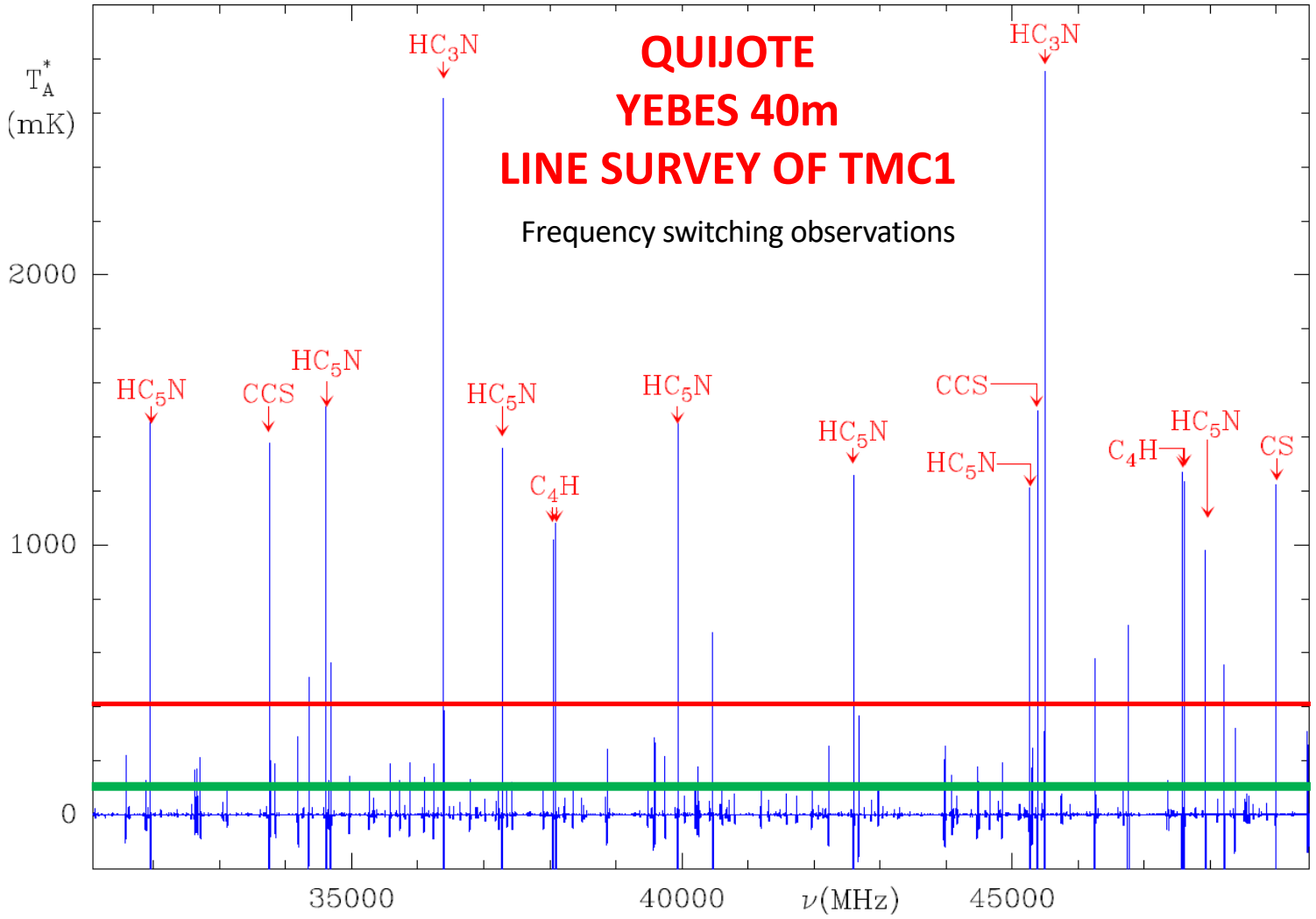
- **MADEX Catalogue:** 6700 spectral entries with laboratory information. Maintained by JC since 1985. Automatic identification of the molecules in QUIJOTE using a simple assignment code and automatic identification of unknown spectral features (U-lines). 40 years of work (MADEX, CDMS, JPL).

- Elaborated analysis of spectral patterns within the U-features. TMC-1 as a laboratory for molecular spectroscopy. The analysis needs of a multidisciplinary team (quantum chemistry, spectroscopy, molecular physics, astrophysics, numerical modelling,…)

SPECTRAL PURITY

- Looking for new molecules requires to perform line surveys or frequency sweeps around expected frequencies.
- Several lines have to be detected to claim for a new molecule
- The number of lines depends on the source and its physical properties. The criteria is not well stablished and journals often publish **very** doubtful detections.
- SPECTRAL PURITY (NO GHOSTS) is mandatory. This an instrumental requirement. Interaction between astronomers and engineers is absolutely necessary. **How many lines could be spurious in a line survey? My own experience is that depends on the sensitivity of the data. ML is possible in this context but each instrument will require specific criteria and local inputs.**
- If lines are broad, then statistical techniques are not well suited for the search of new molecules

QUIJOTE : Q-band Ultrasensitive Inspection Journey to the Obscure Tmc-1 Environment

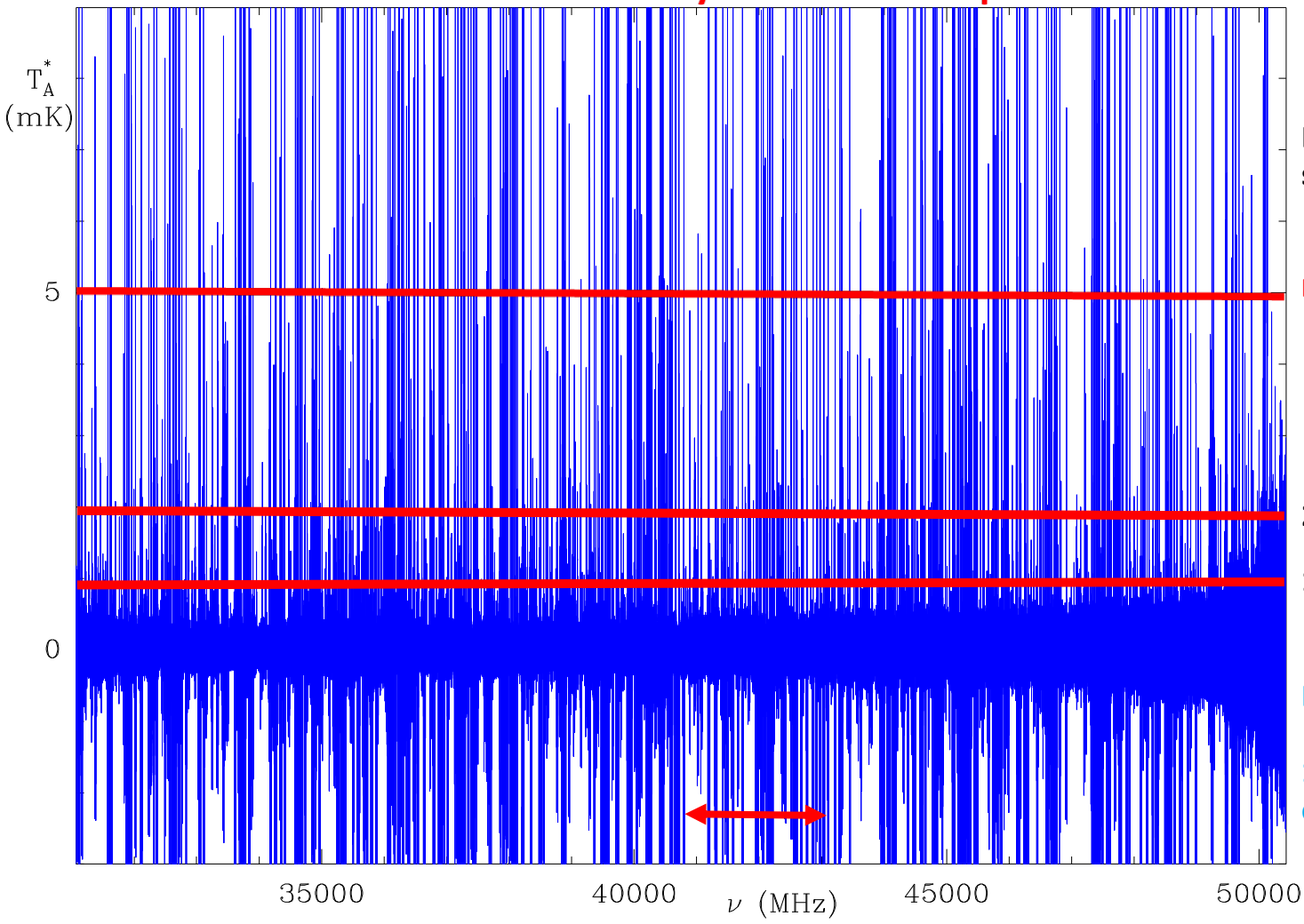


only 22 lines above 400mK

A few more above 200 mK

First problem : all isotopologues of the carriers of the strong lines could be easily detected with QUIJOTE, but also those of the lines above the green line (100 mK). ^{13}C. D, ^{15}N, ^{34}S, ^{33}S

TMC-1 can not be considered any more as a line poor source



Between 5-50 mK several new species

Below 5 mK:
A forest of lines from isotopologues and unknown species

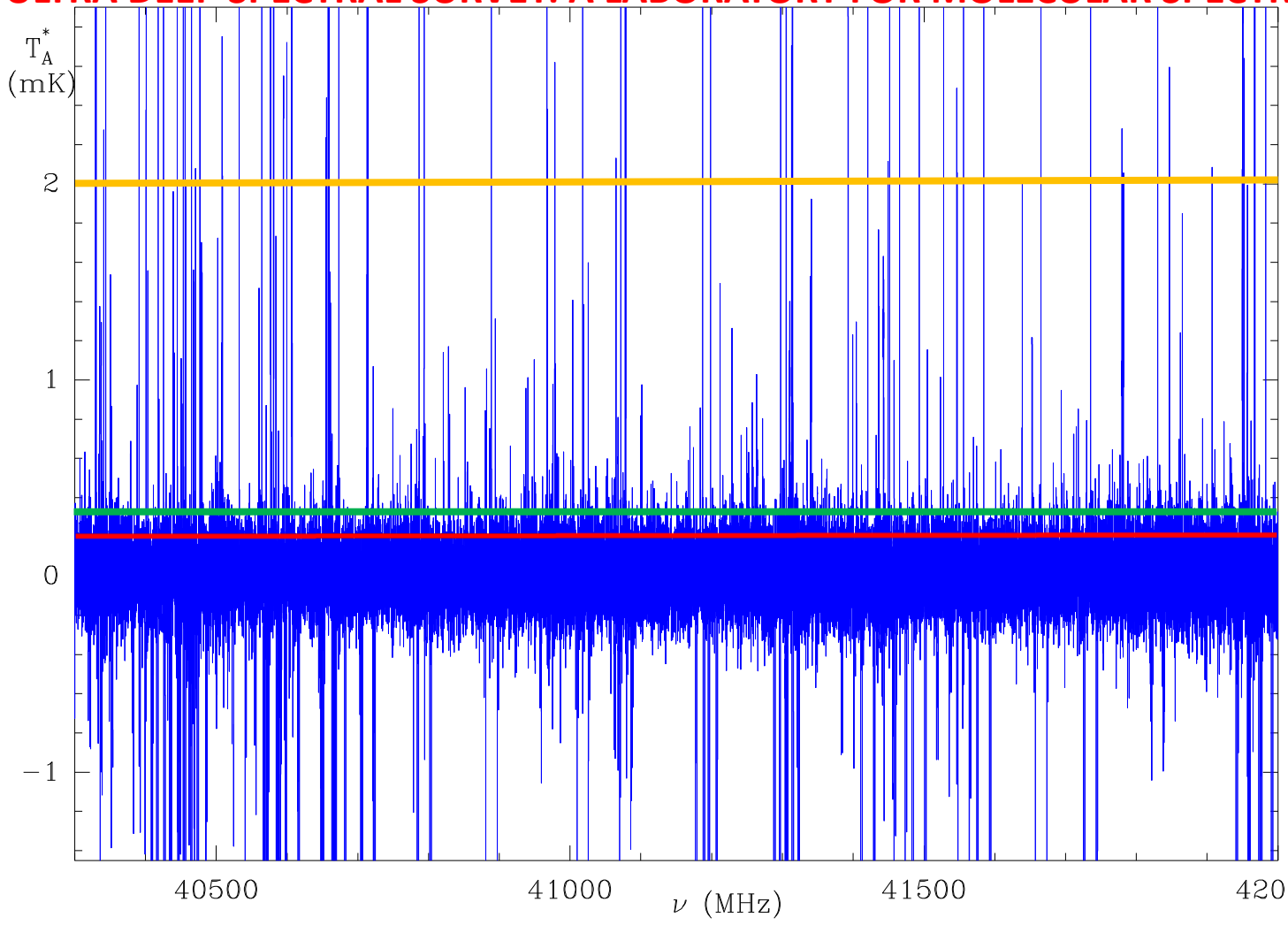
2 mK

1 mK

Data by Sept 2024

1500 hours of observing time

ULTRA DEEP SPECTRAL SURVEY: A LABORATORY FOR MOLECULAR SPECTROSCOPY



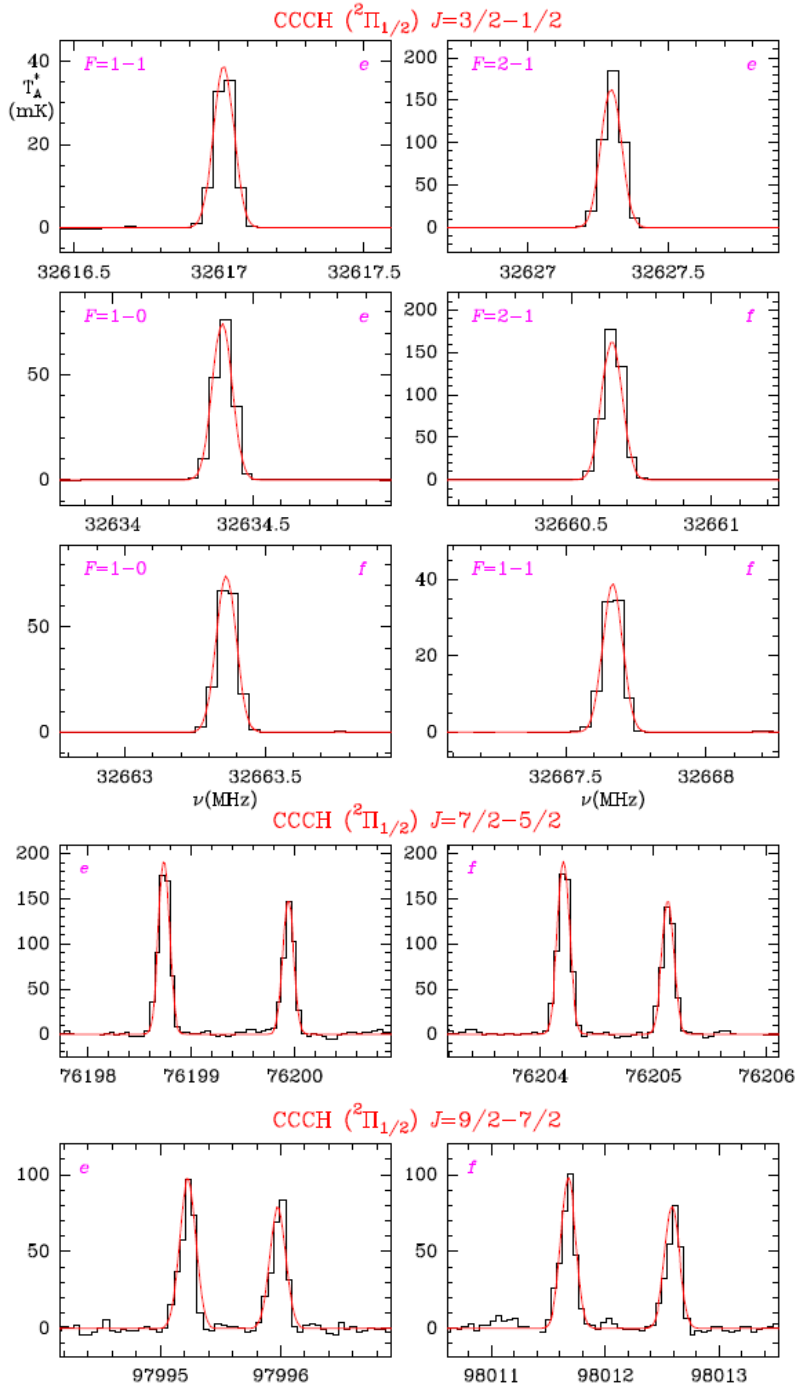
Above 2 mK most lines have been assigned (many new molecules)

Below 2 mK most lines are unidentified

Sensitivity by Sept. 2024 of 0.30 mK (5σ)

FINAL GOAL to detect lines of 0.20 mK at 5σ (σ=0.04 mK)

On-going project; goal to be reached by 2028
$X > 10^{-12}$
for very polar species


CCCH ($^2\Pi_{1/2}$) J=3/2−1/2
F=1−1
e
F=2−1
e
F=1−0
e
F=2−1
f
F=1−0
f
F=1−1
f
T_A^* (mK)
ν(MHz)
ν(MHz)
CCCH ($^2\Pi_{1/2}$) J=7/2−5/2
e
f
CCCH ($^2\Pi_{1/2}$) J=9/2−7/2
e
f

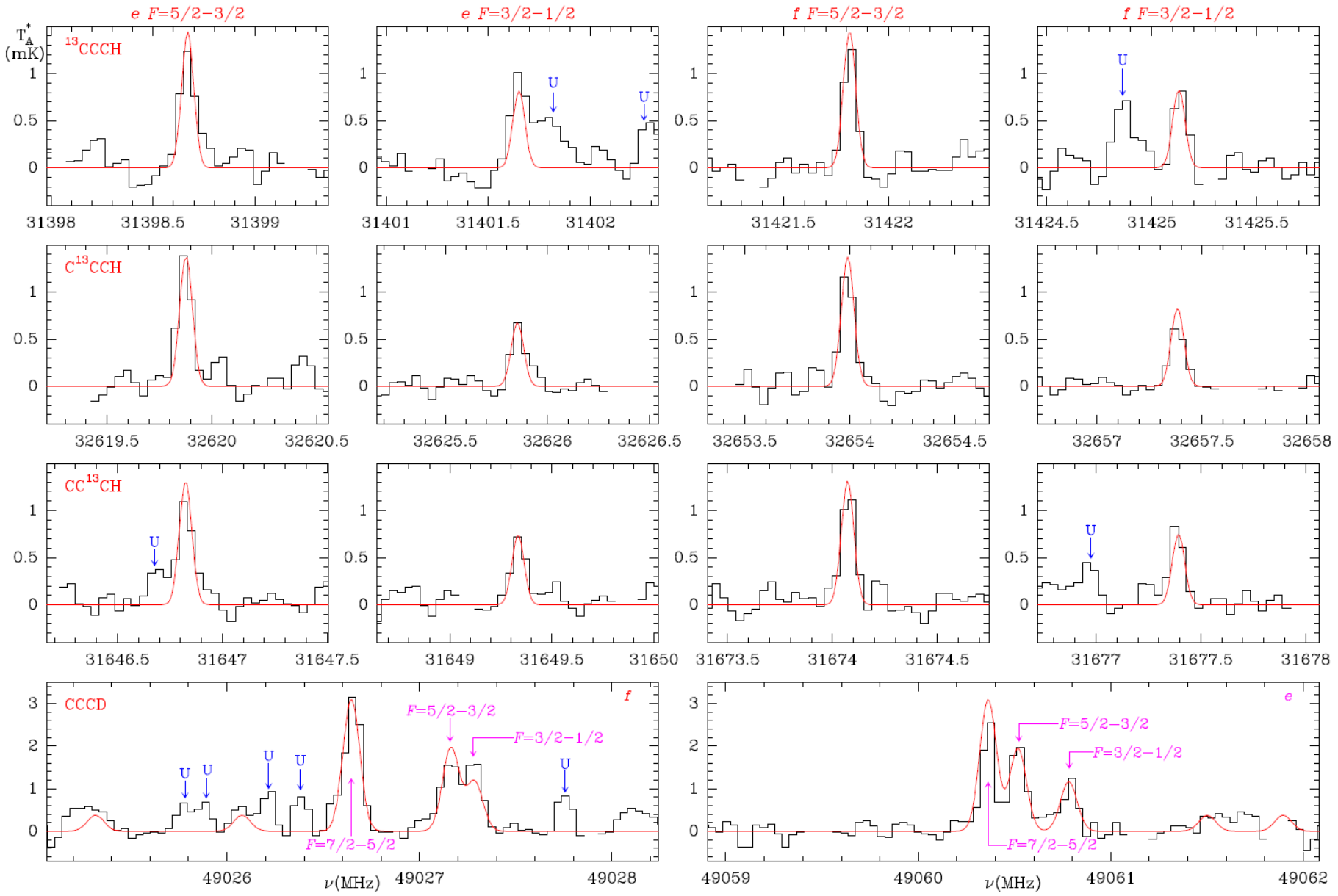


Fig. 3. Observed lines of the ^{13}C and D isotopologues of CCCH. Line parameters are given in Table A.1. The abscissa corresponds to the rest frequency assuming a velocity for the source of 5.83 km s^{-1} (Cernicharo et al. 2020). The ordinate is the antenna temperature corrected for atmospheric and telescope losses in mK. Species and quantum numbers are indicated at the top-right of each panel. The red line corresponds to the synthetic spectrum derived from the models described in Sect. 3.2. Blanked channels correspond to negative features produced in the folding of the frequency switching data.

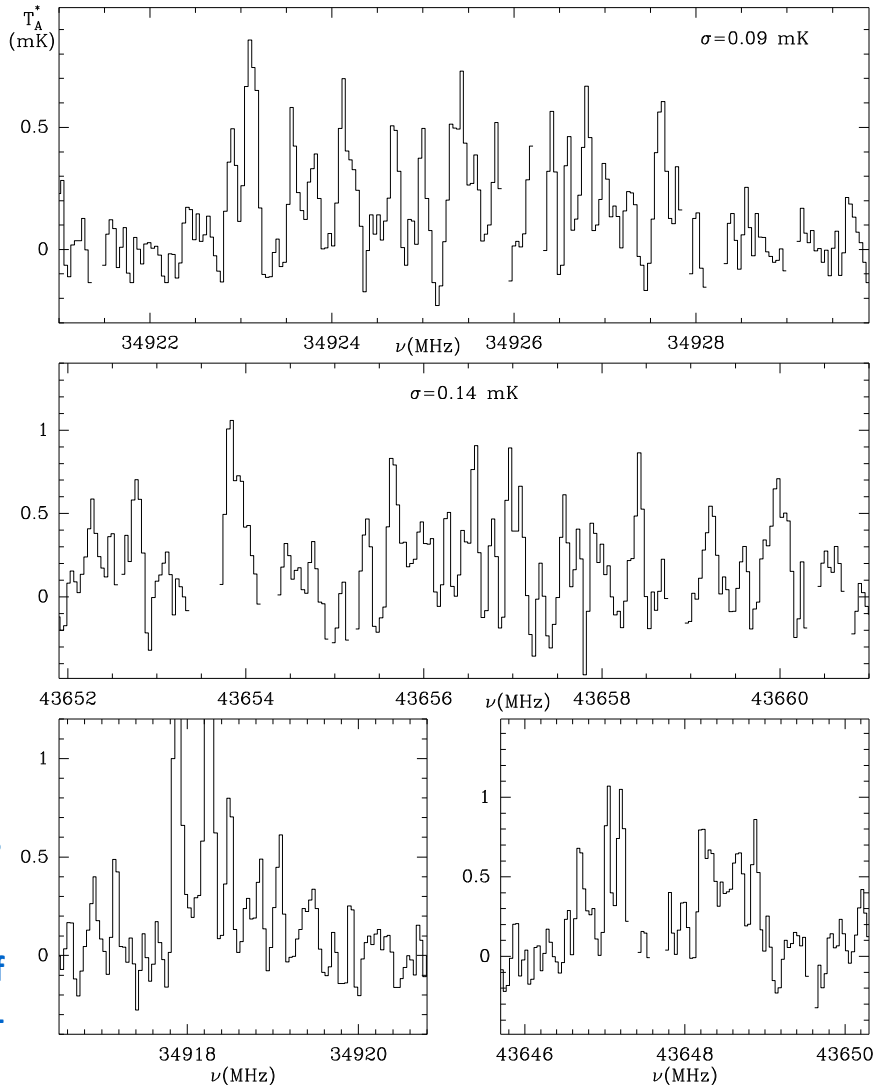
SPECTRAL PURITY

TMC-1 can not be considered as a poor line source at the QUIJOTE's sub mK level

Looking for specific spectroscopic patterns it is possible to discover new molecular species without any previous information on the frequencies.

TMC-1 is a chemical laboratory for molecular spectroscopy thanks to QUIJOTE and NANOCOSMOS.

QUIJOTE can now fight against the giant windmills of the forest of U-lines of TMC-1



ν_2/ν_1=1.249993 ≈ 5/4

Transitions N=5-4 and N=4-3 of a new radical ???

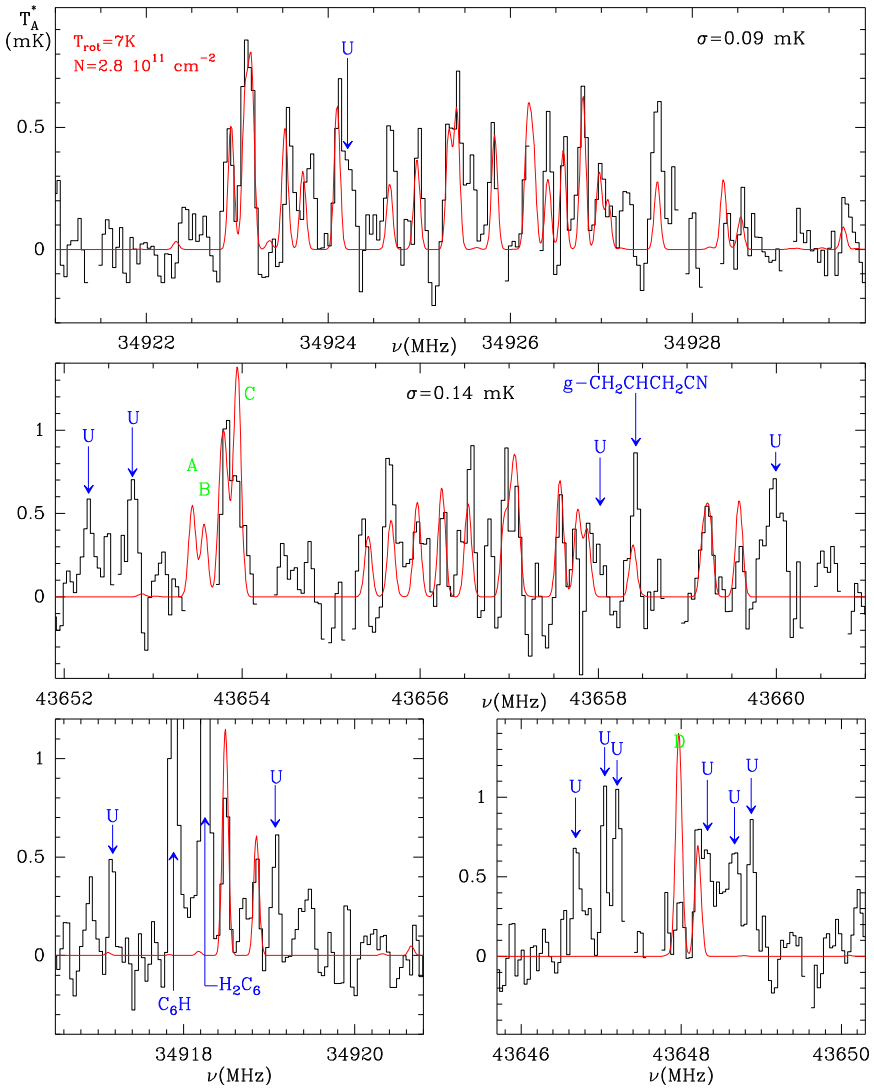
B or (B+C)/2 ≈ 4365 MHz

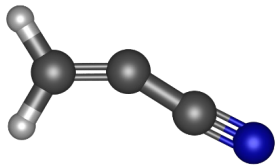
HCCCN has B=4549.1 MHz

H_2CCCN ???

Excellent data quality
All features are real.
Sensitivity continues
to increase with time.

Systematic instrumental
effects removed and
uncerstood





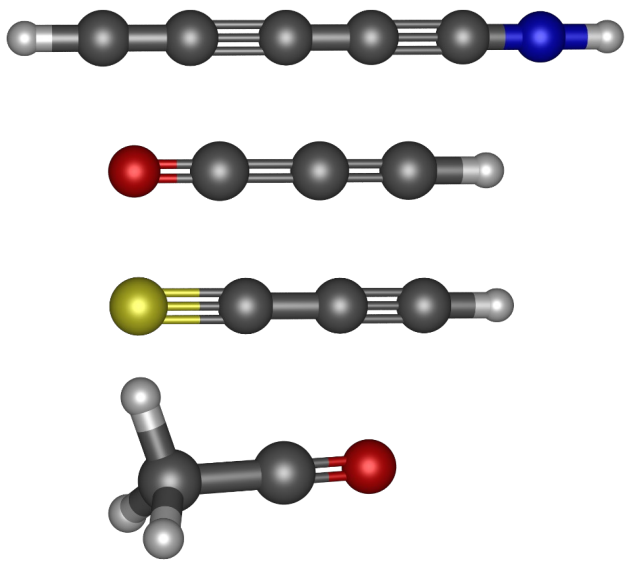
H_2CCCN radical
Cabezas et al. 2023, A&A, 676, L5

Laboratory data from Endo's team

RESUME OF PREVIOUS RESULTS FROM QUIJOTE: TMC-1 as a spectroscopic laboratory

- **Detection of species WITHOUT previous laboratory data**. Searching for systematic spectral patterns in the data. Confirming assignments in the laboratory when possible and through ab initio calculations

- **HC_5NH^+** Marcelino et al., 2020, A&A, 643, L6
- **HC_3O^+** * Cernicharo et al., 2020, A&A, 642, L17
- **HC_3S^+** * Cernicharo et al., 2021, A&A, 646, L3
- **CH_3CO^+** * Cernicharo et al., 2021, A&A, 646, L7
- **C_5H^+** Cernicharo et al., 2022, A&A, 657, L16
- **HC_7NH^+** Cabezas et al., 2022, A&A, 659, L8
- **$HCCNCH^+$** Agúndez et al., 2022, A&A, 659, L9
- **$HCCS^+$** Cabezas et al., 2022, A&A, 657, L4
- **C_7N^-** Cernicharo et al. 2023, A&A, 670, L19
- **NC_4NH^+** Agúndez et al. 2023, A&A, 669, L1
- **$C_{10}H^-$** GOTHAM, Remijan et al. 2023, ApJ, 944, L45



- **HC_3N^+, HC_5N^+, HC_7N^+** Cernicharo et al. 2024 A&A 686, L15, Cabezas et al. 2024. A&A, 687, L22
- **And isotopologues such as HDCCN, Cabezas et al., 2021, A&A, 646, L1; CH_2DC_3N, Cabezas et al, 2021**

- Additionally, QUIJOTE has confirmed the previous detection of C_5N^- in IRC+10216 by detection of six narrow lines of this species in TMC-1 (**together with C_3N^-**). Rotational constants for these species have been improved.

A&A 657, L16 (2022)
https://doi.org/10.1051/0004-6361/202142992

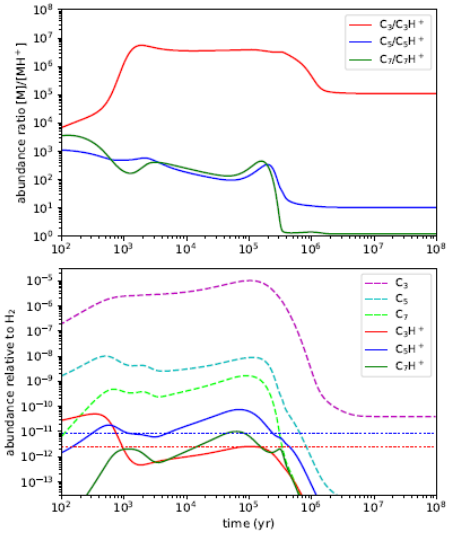
LETTER TO THE EDITOR

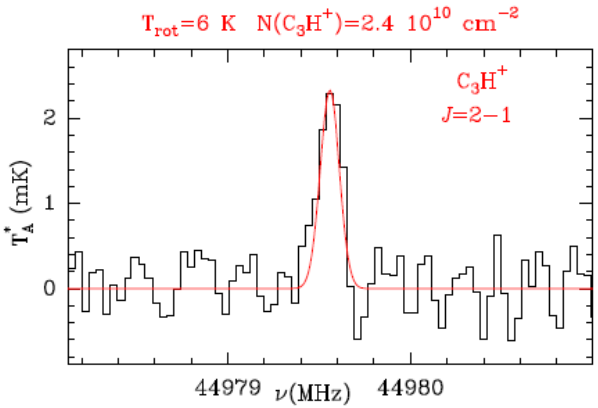
Discovery of C_5H^+ and detection of C_3H^+ in TMC-1 with the QUIJOTE line survey★

J. Cernicharo[1], M. Agúndez[1], C. Cabezas[1], R. Fuentetaja[1], B. Tercero[2,3], N. Marcelino[2], Y. Endo[4], J. R. Pardo[1], and P. de Vicente[3]

Table 2. Theoretical spectroscopic parameters for the different molecular candidates for the observed lines in TMC-1 (all in MHz).

		C_5H^+ ($^1\Sigma$)		l-C_5H^- ($^3\Sigma$)		ql-C_5H^- (^1A)		C_5H ($^2\Pi$)	
Parameter	TMC-1 (a)	Calc. (b)	Scaled (c)	Calc. (b)	Scaled (c)	Calc. (b)	Scaled (c)	Exp. (d)	Calc. (b)
B_e	2411.94397(55)	2404.2	2410.3	2366.4	2372.4	2389.5	2395.5 (e)	2395.131(1)	2389.1
$D \times 10^{-6}$	138(3)	102	127	97.9	121	101	126	127.41(3)	103





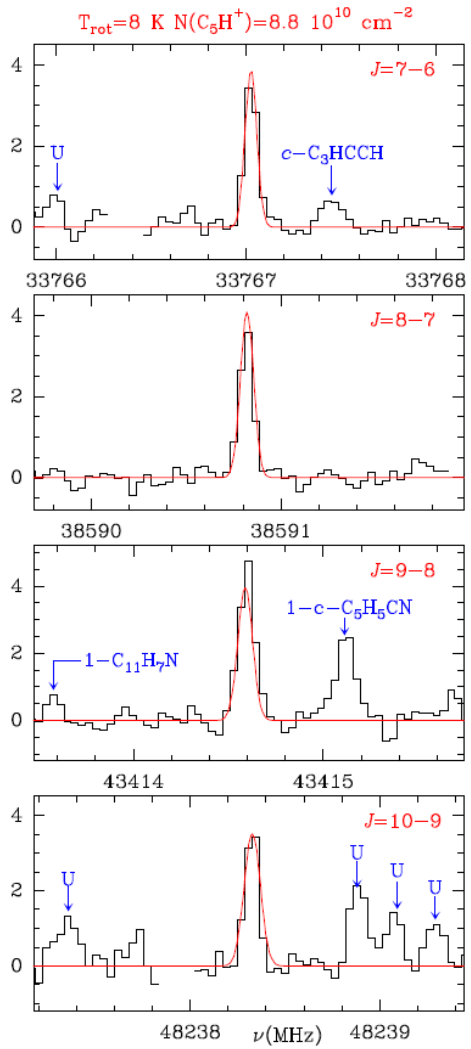


Fig. 1. Observed lines of C_5H^+ toward TMC-1. Line parameters given in Table 1. The abscissa corresponds to the rest frequency assuming a local standard of rest velocity of 5.83 km s^{-1}. The ordinate is antenna temperature corrected for atmospheric and telescope losses mK. The red line shows the synthetic spectrum derived for T_{rot} = 8 and $N(C_5H^+) = 8.8 \times 10^{10}$ cm^{-2}. Blank channels correspond to negat features produced in the folding of the frequency-switching data.

A&A 657, L4 (2022)
https://doi.org/10.1051/0004-6361/202142815

LETTER TO THE EDITOR

Discovery of the elusive thioketenylium, HCCS$^+$, in TMC-1

C. Cabezas[1], M. Agúndez[1], N. Marcelino[2,3], B. Tercero[2,3], Y. Endo[4], R. Fuentetaja[1], J. R. Pa
P. de Vicente[3], and J. Cernicharo[1]

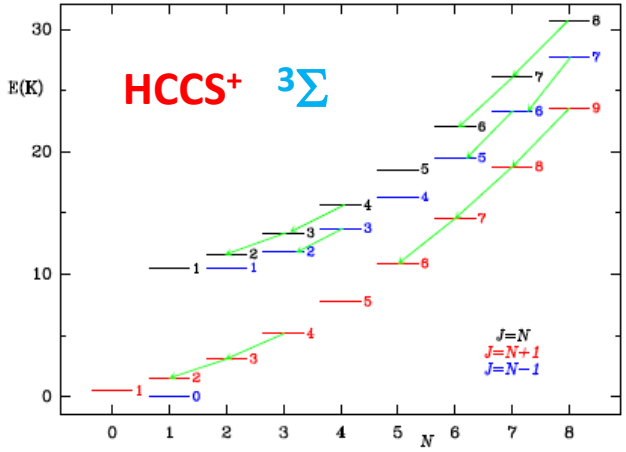
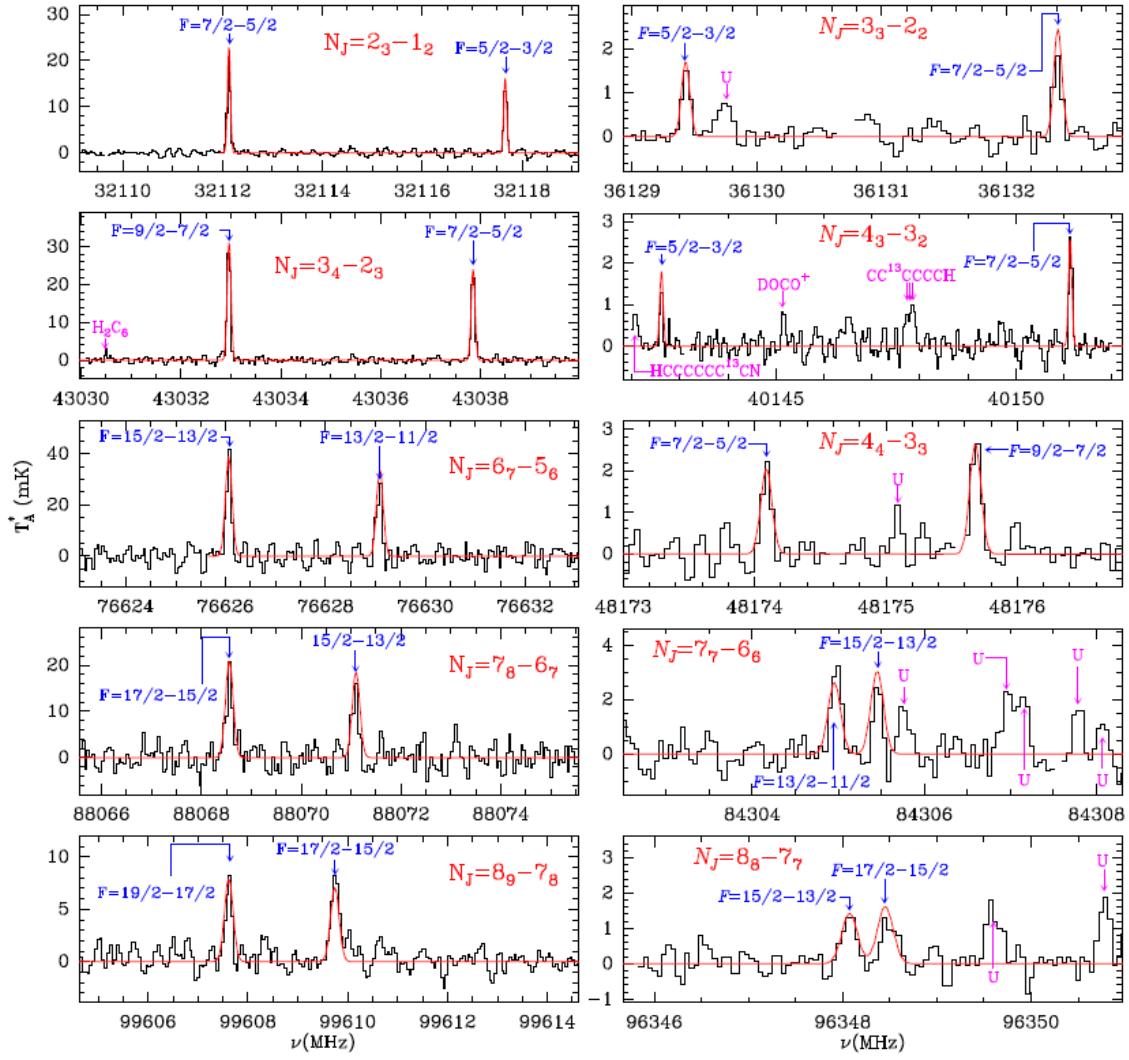


Table 1. Spectroscopic parameters of HCCS$^+$, in MHz.

Parameter	TMC-1 fit	Theoretical	CCS [a]
B	6021.89878(55) [b]	6021.2 [c],[d]	6477.75036(71)
D	0.0012543(72)	0.00120 [e]	0.00172796(95)
λ	108970.78(83)	–	97196.07(77)
λ_D	0.04060(65)	–	0.02700(67)
γ	−41.776(46)	−18.4 [e]	−14.737(49)
b_F (H)	−44.961(23)	−47.6 [f]	–
c (H)	31.663(70)	71.6 [f]	–
σ [g]	26.1	–	18
N	26	–	31



$HCC^{34}S^+$

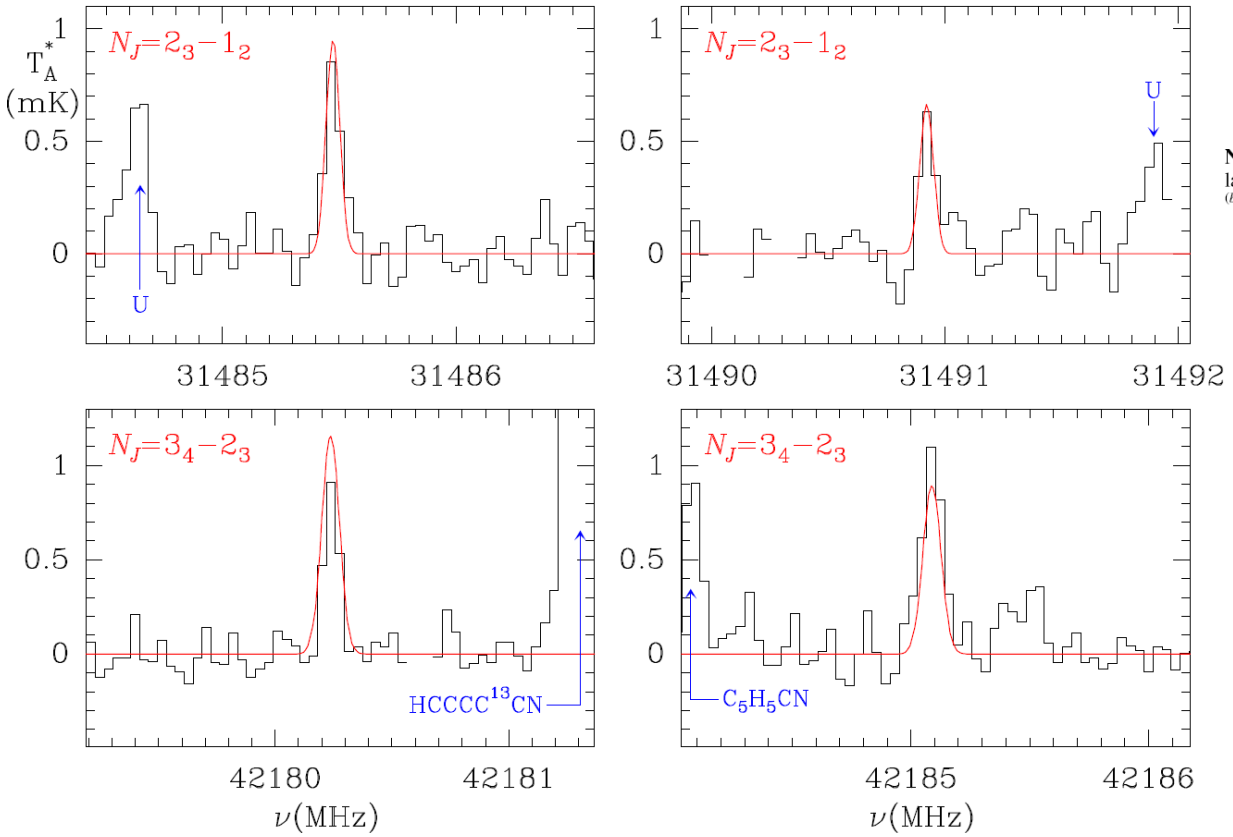


Table A.8. Spectroscopic parameters of $HCC^{34}S^+$

Parameter	$HCC^{34}S^+$
B (MHz)	5889.02214(82) [a]
D (KHz)	[1.2543] [b]
λ (MHz)	[108970.78] [b]
λ_D (kHz)	[40.60] [b]
γ (MHz)	[−41.776] [b]
$b_F^{(H)}$ (MHz)	−45.024(99)
$c^{(H)}$ (MHz)	[31.663] [b]
σ (kHz)	8.0
N_{lines}	4

Notes. [(a)] Numbers in parentheses are 1σ uncertainties in units of the last digits.
[(b)] Fixed to the value reported by Cabezas et al. (2022a) for $HCCS^+$.

Fuentetaja et al. 2024, in prep.

$HCCS^+$ fully confirmed from space data

TMC-1 : The sulfur factory (frequencies in the catalog)

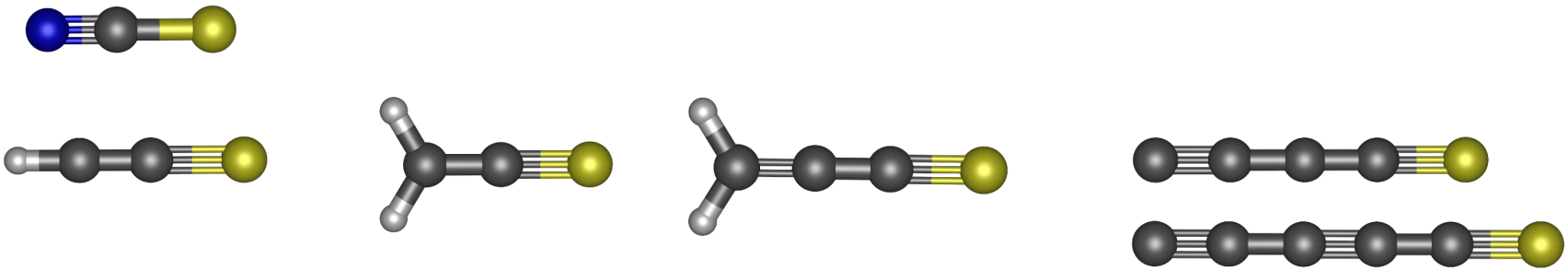
A&A 648, L3 (2021)
https://doi.org/10.1051/0004-6361/202140642

Astronomy & Astrophysics

LETTER TO THE EDITOR

TMC-1, the starless core sulfur factory: Discovery of NCS, HCCS, H_2CCS, H_2CCCS, and C_4S and detection of C_5S★

J. Cernicharo[1], C. Cabezas[1], M. Agúndez[1], B. Tercero[2,3], J. R. Pardo[1], N. Marcelino[1], J. D. Gallego[3], F. Tercero[3], J. A. López-Pérez[3], and P. de Vicente[3]



16 new sulphur-bearing species by Oct 2024

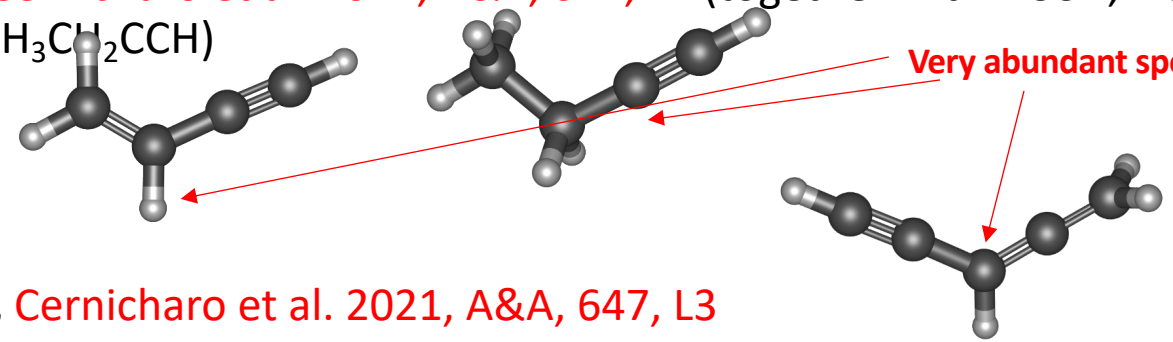
RESUME OF PREVIOUS RESULTS FROM QUIJOTE: Pure hydrocarbons in TMC-1

arXiv:2106.00635

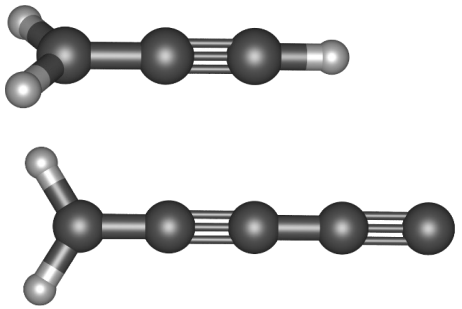
- **Discovery of several high abundant pure hydrocarbons, including three cycles (species with low dipole moment)**

FREQUENCIES ARE KNOWN

- **CH_2CHCCH**, Cernicharo et al. 2021, A&A, 647, L2 (together with HCCN, HC_4N, CH_3CH_2CN and tentatively CH_3CH_2CCH)



- **$H_2CCCHCCH$,** Cernicharo et al. 2021, A&A, 647, L3
- **$H_2CCCHCCCCH$**, Fuentetaja et al. 2022, A&A, 663, L3
- **HCCCHCCC,** Fuentetaja et al., 2022, 667, L4
- **H_2CCCH,** Agúndez et al., 2021, 647, L10 **(extremely abundant !!!)**
- **c-C_5H,** Cabezas et al. 2022, A&A, 663, L2
- **H_2C_5,** Cabezas et al., 2021, A&A, 650, L9



A&A 649, L15 (2021)
https://doi.org/10.1051/0004-6361/202141156

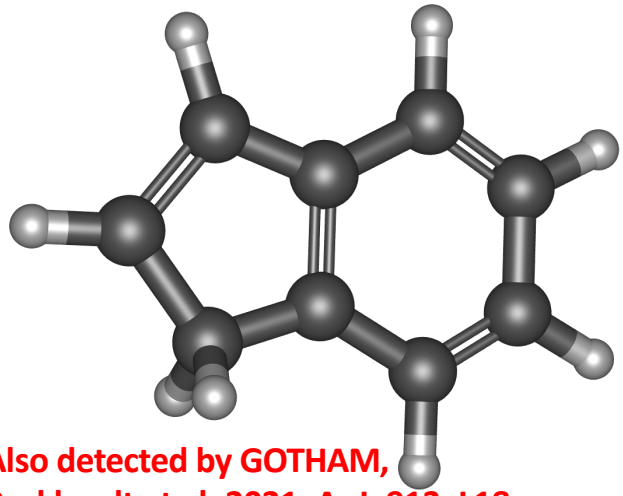
Astronomy & Astrophysics

LETTER TO THE EDITOR

Pure hydrocarbon cycles in TMC-1: Discovery of ethynyl cyclopropenylidene, cyclopentadiene, and indene★

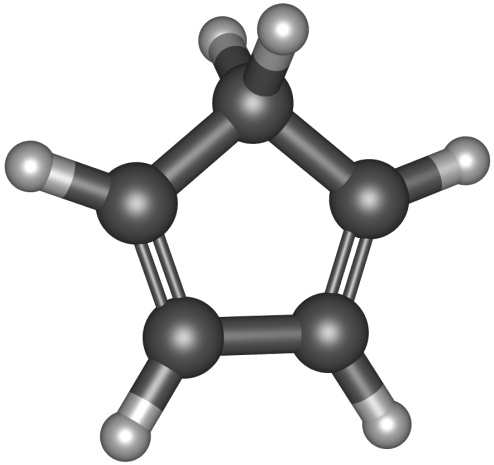
J. Cernicharo[1], M. Agúndez[1], C. Cabezas[1], B. Tercero[2,3], N. Marcelino[1], J. R. Pardo[1], and P. de Vicente[2]

Indene c-C_9H_8

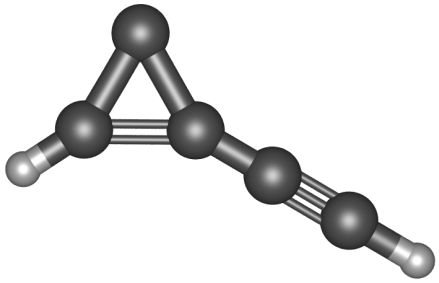


Also detected by GOTHAM, Burkhardt et al. 2021, ApJ, 913, L18

Cyclopentadiene c-C_5H_6



CN derivatives of cyclopentadiene detected by GOTHAM



Ethynyl cyclopropenylidene c-C_5H_2

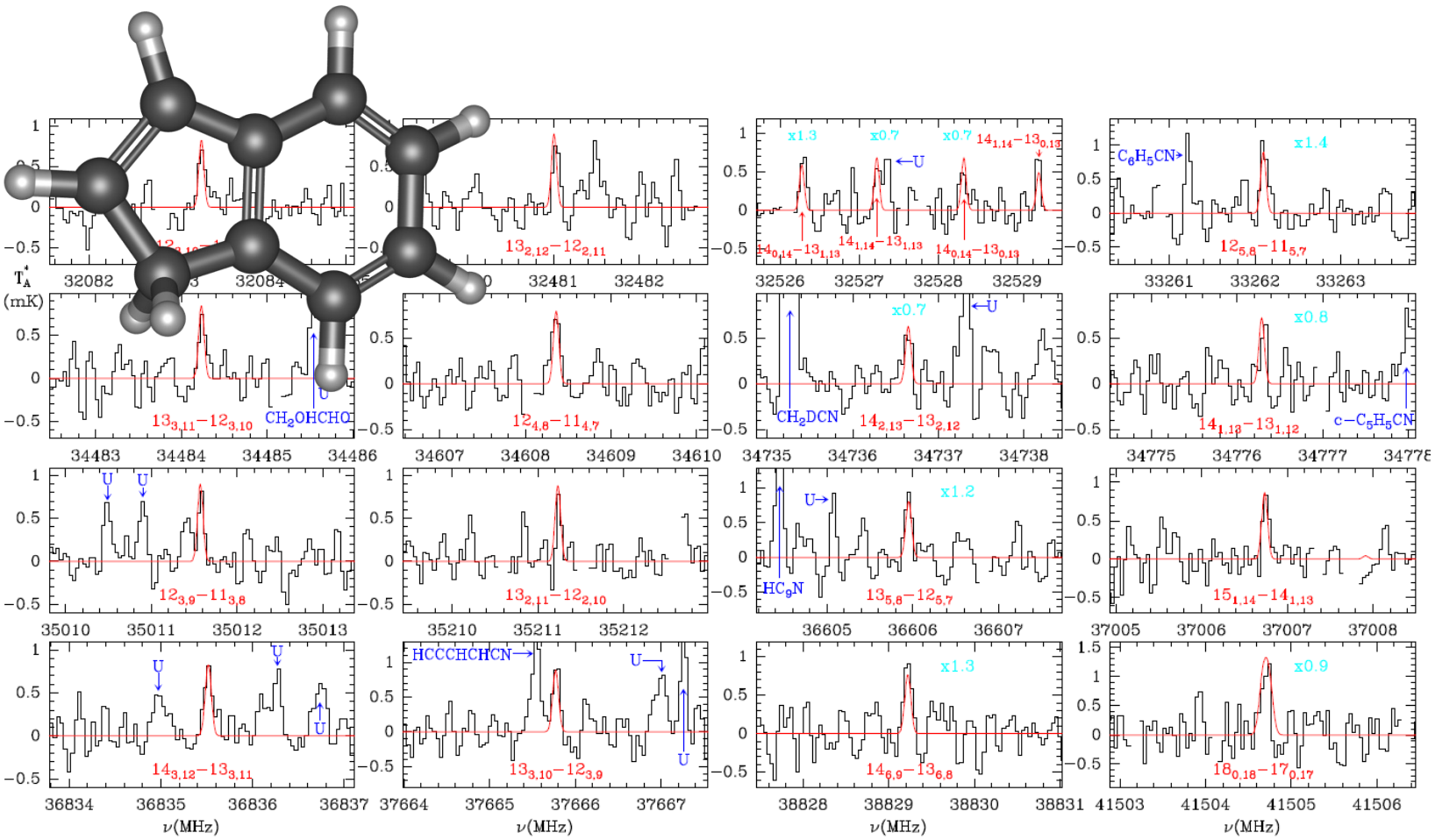


Fig. 4. Same as Fig. 2 but for the selected transitions of c-C_9H_8 observed towards TMC-1. The red line shows the computed synthetic spectrum for indene assuming $T_r = 10$ K and $N(c\text{-}C_9H_8) = 1.6 \times 10^{13}$ cm^{-2}. Cyan labels, when present, indicate the multiplicative factor applied to the best fit model to match the observations.

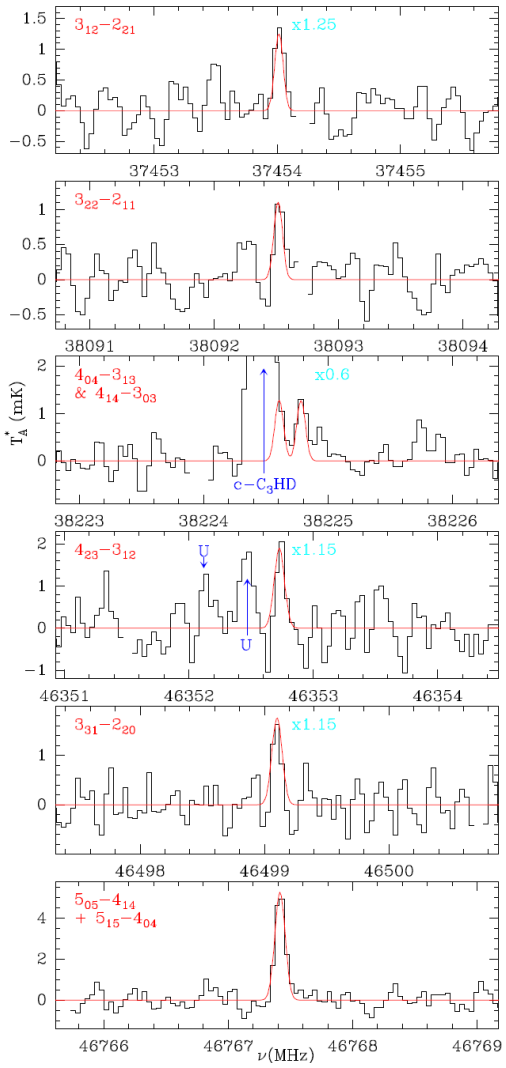
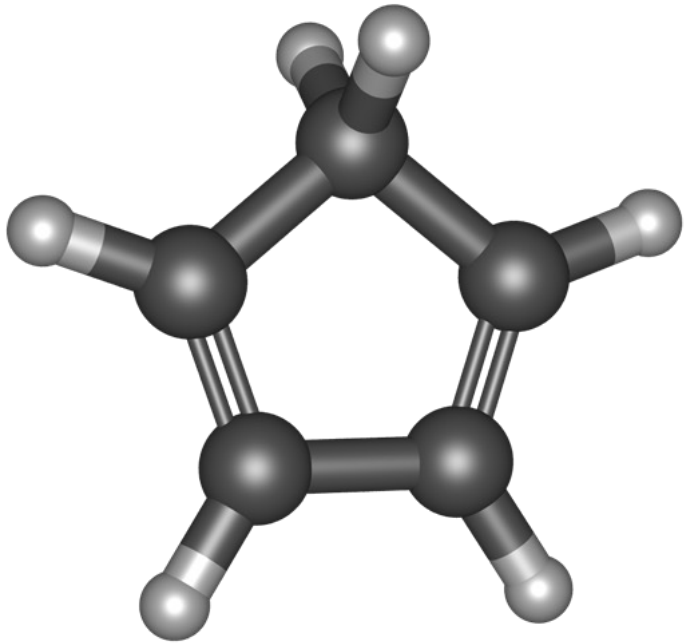


Fig. 3. Same as Fig. 2 but for the observed transitions of c-C_5H_6 towards TMC-1. The red line shows the computed synthetic spectrum for cyclopentadiene assuming $T_r = 10$ K and $N(c\text{-}C_5H_6) = 1.2 \times 10^{13}$ cm^{-2}. Cyan labels, when present, indicate the multiplicative factor applied to the best fit model to match the observations.



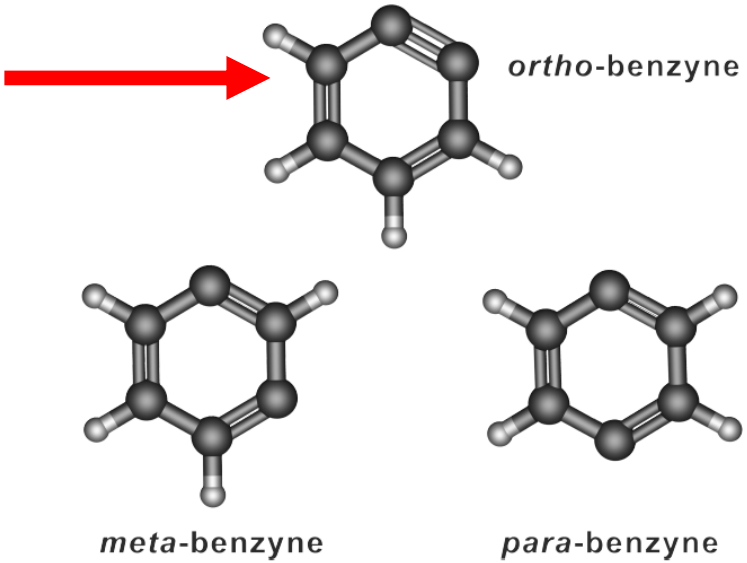
A&A 652, L9 (2021)
https://doi.org/10.1051/0004-6361/202141660

Astronomy & Astrophysics

LETTER TO THE EDITOR

Discovery of benzyne, *o*-C_6H_4, in TMC-1 with the QUIJOTE line survey*

J. Cernicharo[1], M. Agúndez[1], R. I. Kaiser[2], C. Cabezas[1], B. Tercero[3,4], N. Marcelino[1], J. R. Pardo[1], and P. de Vicente[3]



A&A 655, L1 (2021)
https://doi.org/10.1051/0004-6361/202142226

Discovery of two isomers of ethynyl cyclopentadiene in TMC-1: Abundances of CCH and CN derivatives of hydrocarbon cycles★

J. Cernicharo[1], M. Agúndez[1], R. I. Kaiser[2], C. Cabezas[1], B. Tercero[3,4], N. Marcelino[4], J. R. Pardo[1], and P. de Vicente[3]

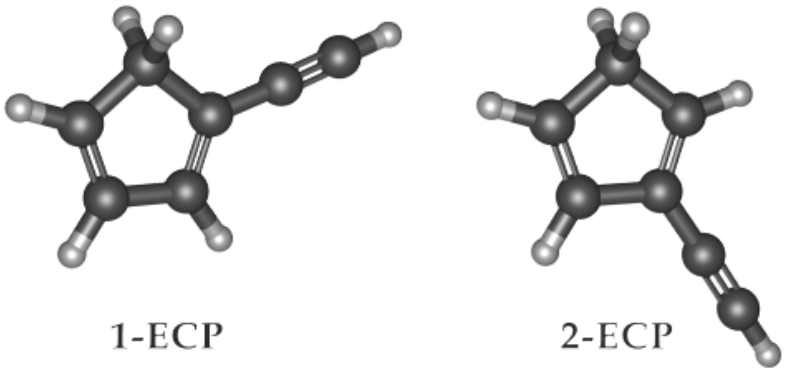


Fig. 1. Scheme of the two lowest energy isomers of ethynyl cyclopentadiene.

Cyano derivatives of cyclopentadiene detected by GOTHAM team by stacking techniques.

Table 1. Abundances of ethynyl and cyano species in TMC-1.

Molecule	N (cm^{-2})	Abundance[a]	Comments
c-C_5H_6	1.3×10^{13}	1.3×10^{-09}	1
1-*c*-C_5H_5CCH	1.4×10^{12}	1.4×10^{-10}	2
2-*c*-C_5H_5CCH	2.0×10^{12}	2.0×10^{-10}	2
1-*c*-C_5H_5CN	3.1×10^{11}	3.1×10^{-11}	2,A
2-*c*-C_5H_5CN	1.3×10^{11}	1.3×10^{-11}	2,B
C_6H_5CCH	$\sim2.5\times10^{12}$	2.5×10^{-10}	2,C
C_6H_5CN	1.2×10^{12}	1.2×10^{-10}	2,D
c-C_9H_8	1.6×10^{13}	1.6×10^{-09}	1,E

Notes.
[(a)] Assuming a column density of molecular hydrogen of 10^{22} cm^{-2} (Cernicharo & Guélin 1987). [(1)] Cernicharo et al. (2021c). [(2)] This work. [(A)] A value of 1.44×10^{12} cm^{-2}, has been reported by McCarthy et al. (2021) and of 8.3×10^{11} cm^{-2} by Lee et al. (2021). [(B)] A value of 1.9×10^{11} cm^{-2} has been derived by Lee et al. (2021). [(C)] Tentative detection. [(D)] A value of 4.0×10^{11} cm^{-2} has been derived by McGuire et al. (2018). This value has been revised to 1.6×10^{11} cm^{-2} by Burkhardt et al. (2021b). [(E)] A value of 9.6×10^{12} cm^{-2} has been reported by Burkhardt et al. (2021b).

QUIJOTE results during 2024:

- HNC_5, Fuentetaja et al. 2024, A&A, 688, L29
- HC_3N^+. HC_5N^+, HC_7N^+, Cernicharo et al. 2024 A&A 686, L15, Cabezas et al. 2024. A&A, 687, L22
- $NCCH_2CN$ (malononitrile) Agúndez et al. 2024, A&A, 688, L31
- NCCHCHCN (maleonitrile) Agúndez et al. 2024, A&A, 688, L31
- HCCCH2CCH, Fuentetaja et al. 2024, A&A, 688, L15
- NCCCS and HCCCS, Cernicharo et al. 2024, A&A, 688, L13
- NCCHCS, Cabezas et al. 2024, A&A, 686, L3
- 1- and 5- cyano acenaphthylene, Cernicharo et al. 2024, A&A, 690, L13

- **12 new molecules between January-October 2024**

- Isotopologues ^{13}C, ^{15}N, D, and double ^{13}C, $^{13}C/^{15}N$, $D/^{13}C$ and $D/^{15}N$ of HC_3N, Tercero et al. 2024, A&A, 682, L12
- Isotopologies ^{13}C, ^{15}N, D of HNCCC and HCCNC, Cernicharo et al. 682, L13
- Several papers coming on the isotopologues of all carbon chain molecules up to 7 carbons

A&A, 686, L15 (2024)
https://doi.org/10.1051/0004-6361/202450801

Astronomy & Astrophysics

LETTER TO THE EDITOR

QUIJOTE discovery of the cation radicals HC_5N^+ and HC_7N^+ ★

J. Cernicharo[1], C. Cabezas[1], M. Agúndez[1], Y. Endo[2], B. Tercero[3,4], N. Marcelino[3,4], and P. de Vicente[4]

Table A.1. Estimated frequency centroid of the observed lines of HC_5N^+.

$J_u - J_l$	ν_{obs} [a] (MHz)	$\int T_A^* dv$ [b] (mK km s^{-1})	$< v_{LSR} >$ [c]	Δv [d]
25/2-23/2	33416.338±0.040	4.3±0.4	5.8	2.8
27/2-25/2	36089.623±0.040	4.4±0.4	5.8	2.3
29/2-27/2	38762.821±0.040	3.7±0.4	5.9	1.9
31/2-29/2	41436.111±0.040	3.0±0.3	5.8	1.7
33/2-31/2	44109.381±0.040	1.7±0.2	5.6	1.0
35/2-33/2	46782.597±0.040	2.2±0.2	5.7	1.4
37/2-35/2	49455.783±0.040	0.6±0.1	5.8	0.7

Notes. [a]Frequency centroid of the line. We have adopted a v_{LSR} of 5.83 km s^{-1} for the source (Cernicharo et al. 2020c). [b]Integrated line intensity in mK km s^{-1}. [c]Averaged velocity (in km s^{-1}). [d]Equivalent line width (in km s^{-1}).

Table A.2. Observed line parameters of HC_7N^+.

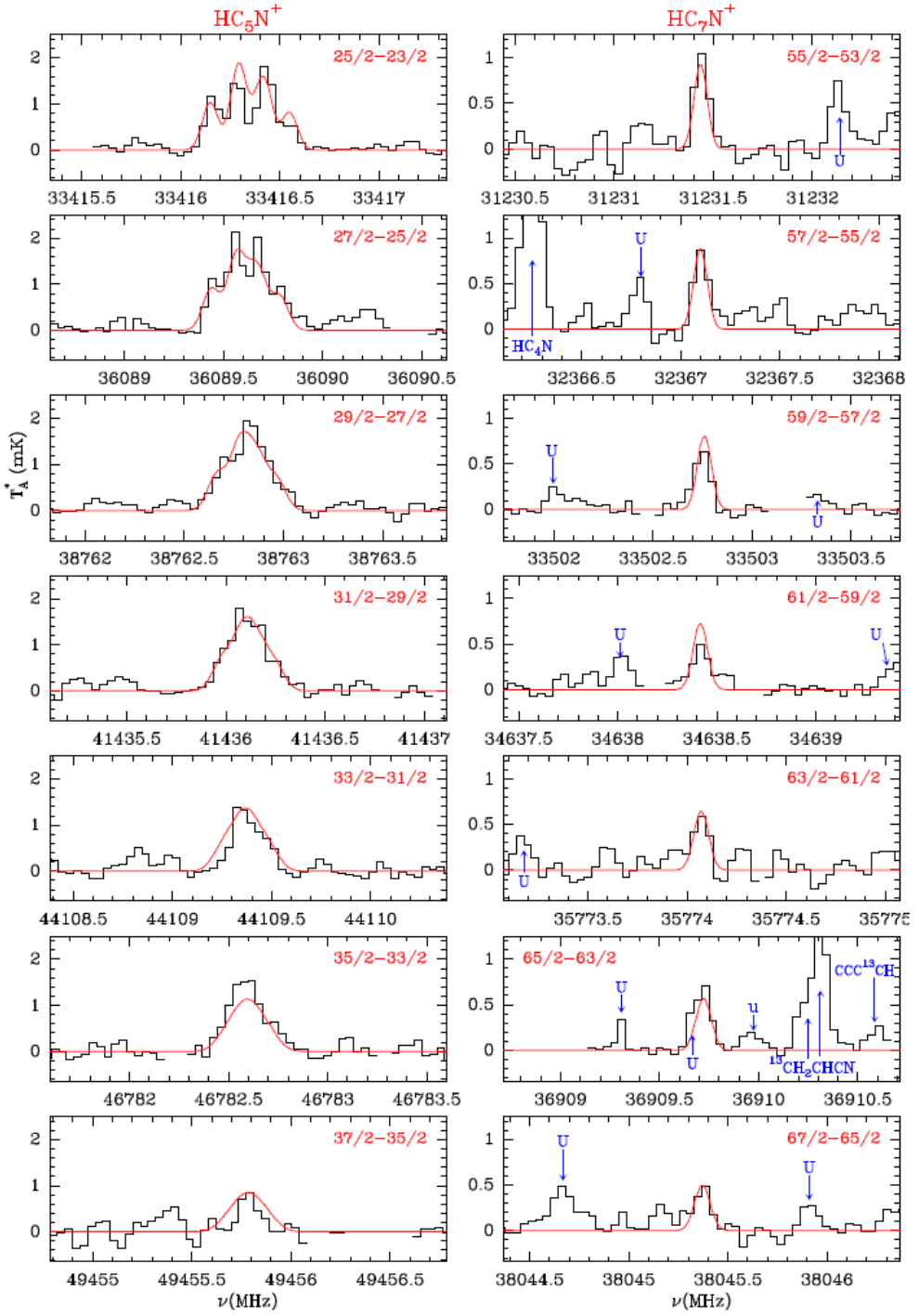
$J_u - J_l$	ν_{obs} [a] (MHz)	(o-c) [b] (kHz)	$\int T_A^* dv$ [c] (mK km s^{-1})	Δv [d]	T_A^* [e] (mK)
55/2-53/2	31231.441	5.0	0.90±0.12	0.79±0.12	1.07±0.14
57/2-55/2	32367.105	6.0	0.76±0.12	0.83±0.15	0.87±0.07
59/2-57/2	33502.745	-14.2	0.59±0.06	0.86±0.09	0.65±0.05
61/2-59/2	34638.423	6.4	0.43±0.04	0.96±0.10	0.41±0.07
63/2-61/2	35774.073	2.0	0.40±0.12	0.65±0.13	0.57±0.08
65/2-63/2	36909.712	-10.5	0.56±0.03	0.72±0.05	0.73±0.05
67/2-65/2	38045.367	-3.8	0.44±0.10	0.93±0.25	0.45±0.08
69/2-67/2	39181.025	9.2	0.21±0.05	0.46±0.19	0.43±0.09

Notes. [a]Measured frequency of the line. The uncertitude is 10 kHz for all lines. We have adopted a v_{LSR} of 5.83 km s^{-1} for the source (Cernicharo et al. 2020c). [b]Observed minus calculated frequencies (in kHz). [c]Integrated line intensity in mK km s^{-1}. [d]Line width (in km s^{-1}). [e]Antenna temperature (mK).

Rotational constants close to those of HC_5N and HC_7N

For one of them significant hyperfine structure : HC_5N^+

Ab initio calculations perfectly reproduce the observed line profiles for HC_5N^+ and rotational constant of HC_7N^+



A&A, 687, L22 (2024)
https://doi.org/10.1051/0004-6361/202451081

Astronomy & Astrophysics

LETTER TO THE EDITOR

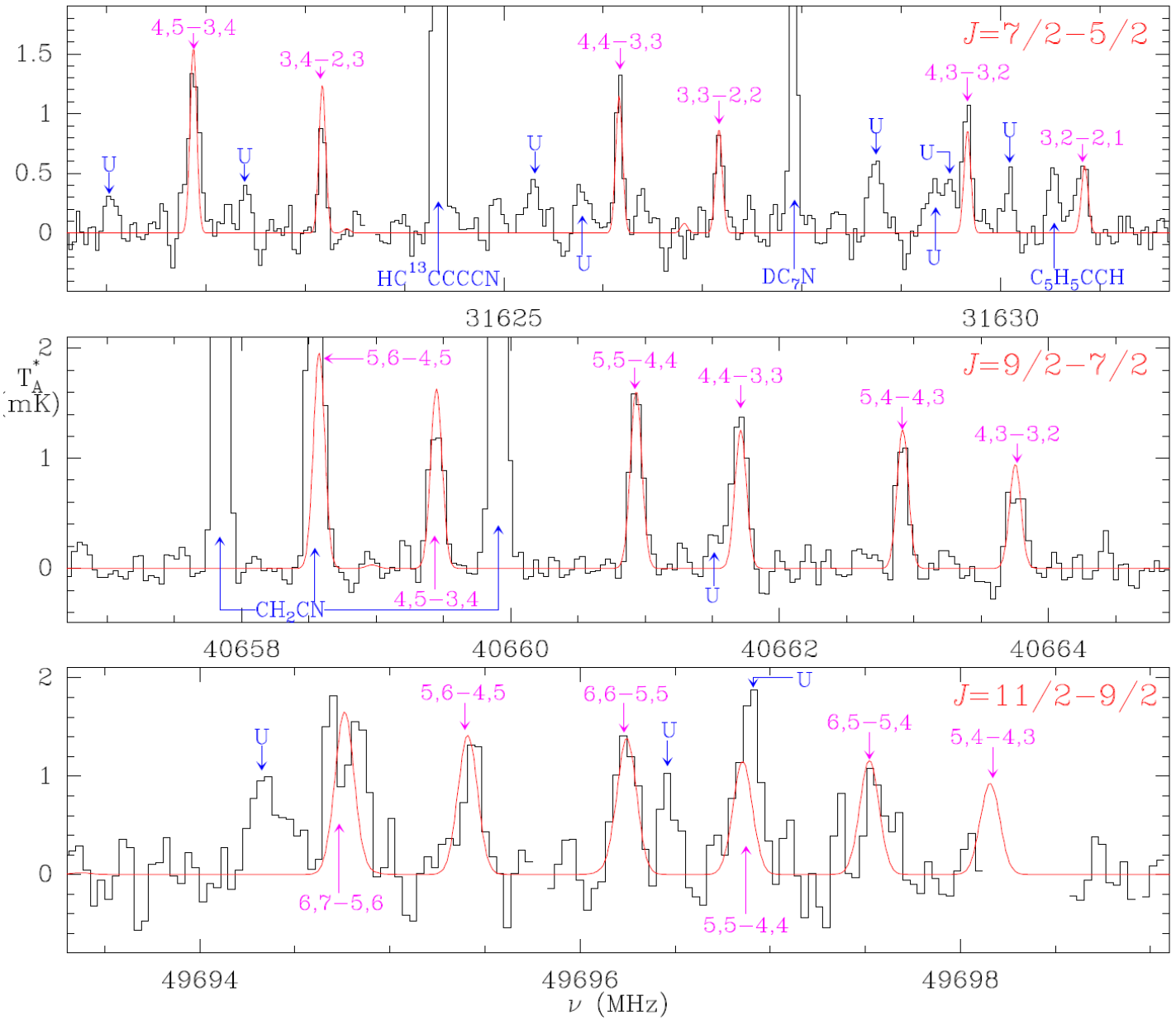
Discovery of the interstellar cyanoacetylene radical cation HC_3N^+ ★

C. Cabezas[1], M. Agúndez[1], Y. Endo[2], B. Tercero[3,4], N. Marcelino[3,4], P. de Vicente[4], and J. Cernicharo[1]

Table 1. Molecular constants (all in megahertz) of HC_3N^+ in $\tilde{X}\ ^2\Pi_{3/2}$.

Constant	TMC-1	Theoretical [a]
B	4533.31711(148) [b]	4535
D	0.000456(36)	0.000469
b_F(H)	−39.9(36)	−36.37
T_{aa}(H)	–	22.20
T_{bb}(H)	–	−3.87
a(H)	18.53(160)	25.55
c(H)	[33.3] [c]	33.3
b_F(N)	9.52(276)	0.13
T_{aa}(N)	–	−20.55
T_{bb}(N)	–	38.01
a(N)	33.67(129)	45.18
c(N)	[−30.82] [c]	−30.82
eQq(N)	−5.442(62)	−6.21
$\|\mu\|$/D	–	5.5

Notes. [a]These values have been obtained from quantum chemical calculations at different levels of theory. (See text for details.) [b]The uncertainties (in parentheses) are in units of the last significant digits. [c]Values in brackets have been kept fixed to those obtained theoretically.



These species could be the protonated forms of C_3N, C_5N and C_7N.
HC_7N^+ and C_7N^- detected !!!! Where is C_7N ???

Searching for C_7N…….

C_7N should be in TMC-1. Depending on its electronic ground state it could be detectable or not. If $^2\Sigma$ then little chances (μ too low). However, if $^2\Pi$ then yes (μ high).

We found a significant number of lines in harmonic relation with half integer quantum numbers and B close to the expected value . We though we had detected C_7N. But ...

All lines are arising from 1-cyano naphthalene with J integer and Ka=0,1

Table A.1. Fit of the K_a=0 lines of 1-cyanonaphthalene in the Q-band.

Transition [a]	J^* [b]	ν_{calc} [c] (MHz)	ν_{lin} [d] (MHz)	$\nu_{calc} - \nu_{lin}$ [e] (kHz)
$27_{0,27} - 26_{0,26}$	55/2	31953.900	31953.897	3.0
$28_{0,28} - 27_{0,27}$	57/2	33115.827	33115.826	1.0
$29_{0,29} - 28_{0,28}$	59/2	34277.751	34277.751	0.0
$30_{0,30} - 29_{0,29}$	61/2	35439.672	35439.672	0.0
$31_{0,31} - 30_{0,30}$	63/2	36601.589	36601.590	−1.0
$32_{0,32} - 31_{0,31}$	65/2	37763.503	37763.504	−1.0
$33_{0,33} - 32_{0,32}$	67/2	38925.413	38925.414	−1.0
$34_{0,34} - 33_{0,33}$	69/2	40087.320	40087.321	−1.0
$35_{0,35} - 34_{0,34}$	71/2	41249.222	41249.223	−1.0
$36_{0,36} - 35_{0,35}$	73/2	42411.120	42411.121	−1.0
$37_{0,37} - 36_{0,36}$	75/2	43573.014	43573.015	−1.0
$38_{0,38} - 37_{0,37}$	77/2	44734.904	44734.904	0.0
$39_{0,39} - 38_{0,38}$	79/2	45896.789	45896.789	0.0
$40_{0,40} - 39_{0,39}$	81/2	47058.669	47058.669	0.0
$41_{0,41} - 40_{0,40}$	83/2	48220.545	48220.544	1.0
$42_{0,42} - 41_{0,41}$	85/2	49382.416	49382.415	1.0

Notes. [a]Rotational quantum numbers of a-type $K_a = 0$ transitions of 1-cyanonaphthalene with $K_c = J_u$. [b]Effective rotational quantum number ($J^* = J_u + 1/2$). [c]Predicted frequencies using an A-reduced Hamiltonian (representation I^r) and the rotational constants determined by McNaughton et al. (2018). [d]Fitted frequencies using the relation $\nu = 2\,B_{eff}\,J^* - 4\,D_{eff}\,J^{*3}$. The results of the fit are $B_{eff} = 580.987413 \pm 0.000015$ MHz and $D_{eff} = 4.9354 \pm 0.0057$ Hz. The standard deviation of the fit is 1 kHz. [e]Difference between the predicted frequencies using an A-reduced Hamiltonian (representation I^r) and those obtained through the linear fit with half integer quantum numbers.

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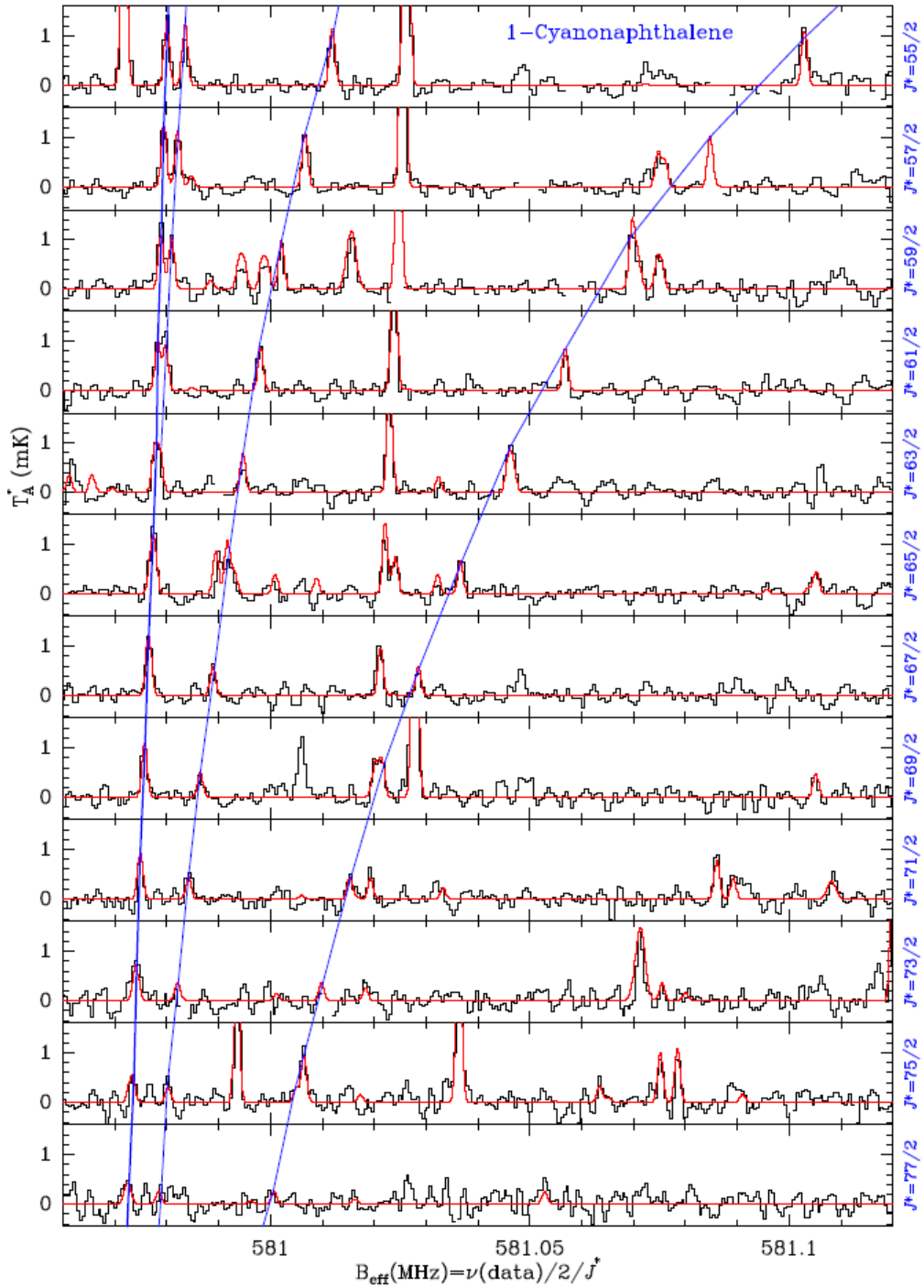

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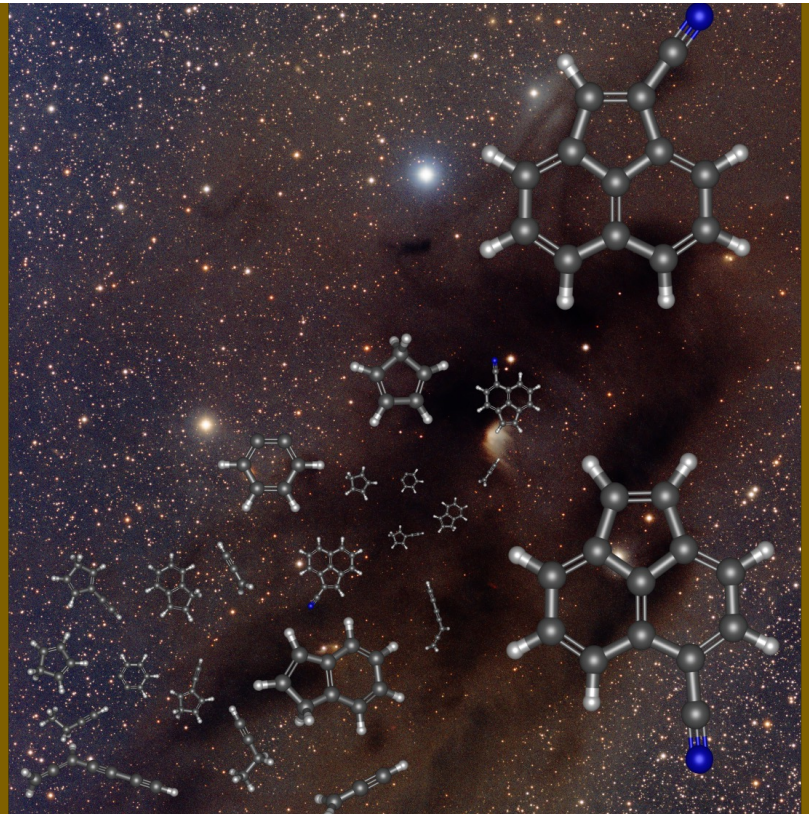
Astronomy & Astrophysics

LETTER TO THE EDITOR

Discovery of two cyano derivatives of acenaphthylene ($C_{12}H_8$) in TMC-1 with the QUIJOTE line survey★

J. Cernicharo[1,★★], C. Cabezas[1], R. Fuentetaja[1], M. Agúndez[1], B. Tercero[2,3], J. Janeiro[4], M. Juanes[5], R. I. Kaiser[6], Y. Endo[7], A. L. Steber[5], D. Pérez[4], C. Pérez[5], A. Lesarri[5], N. Marcelino[2,3], and P. de Vicente[2]

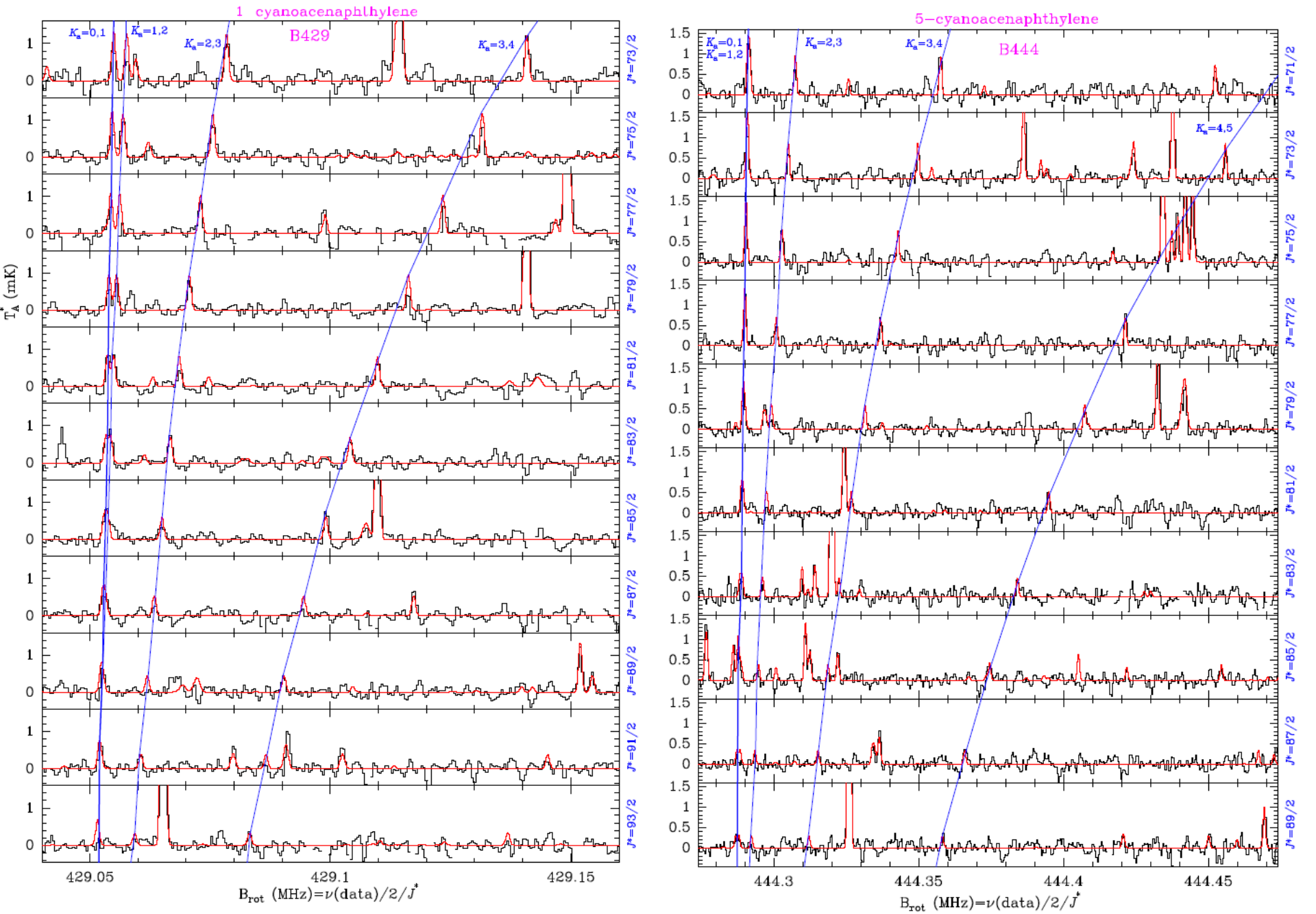


Detected and fully characterized in TMC-1

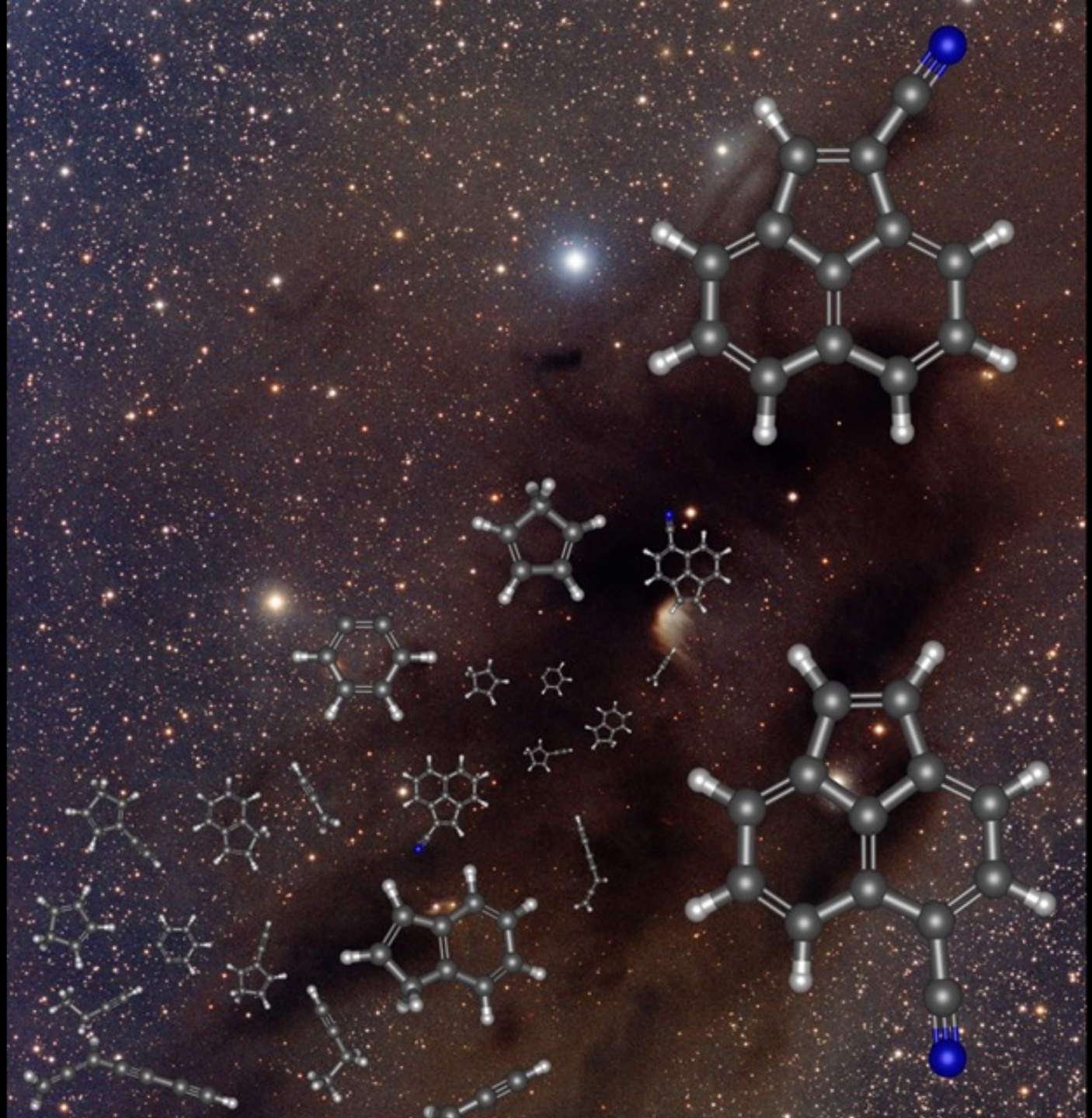
Synthetised in the chemical lab

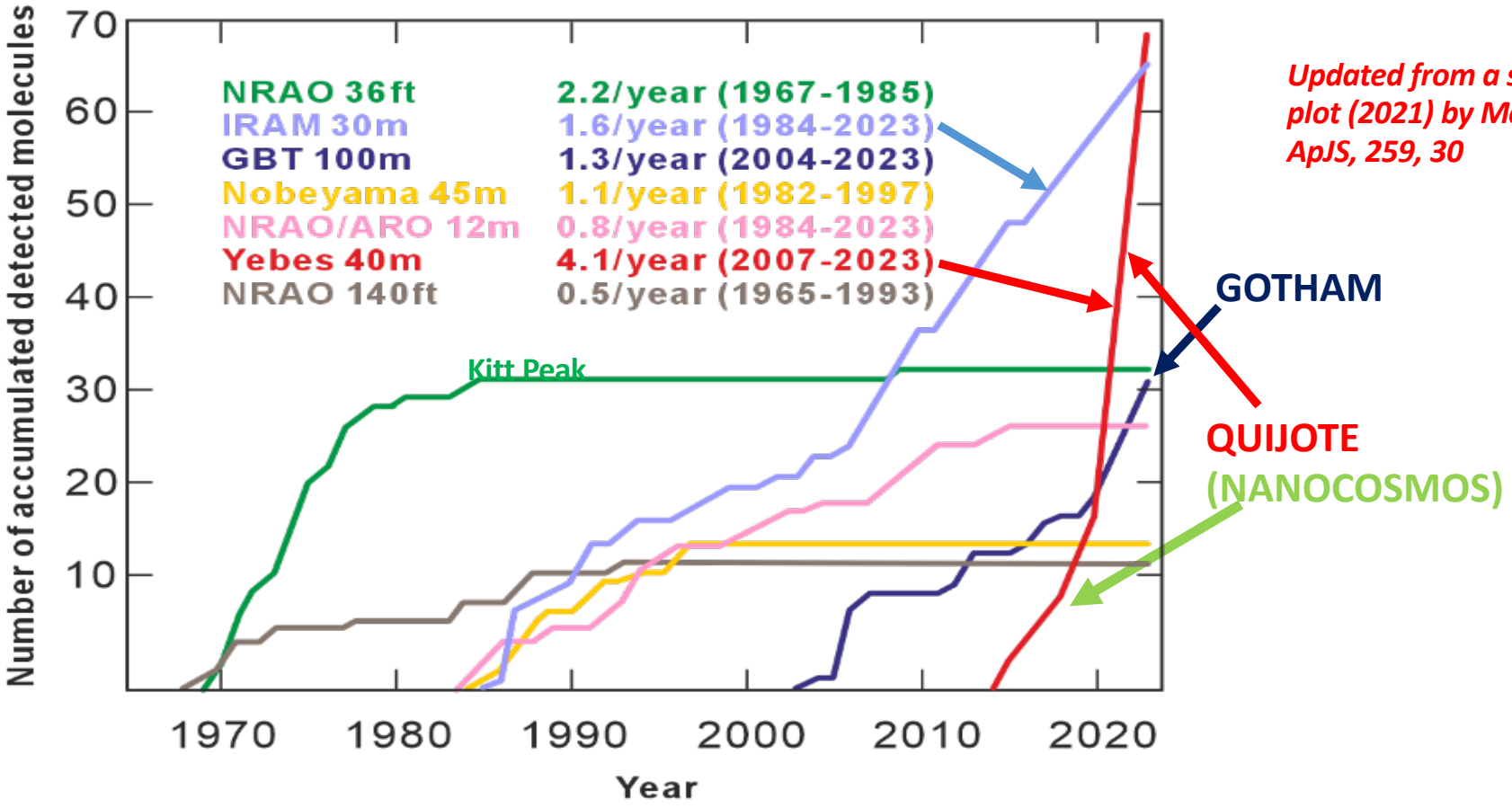
Observed in the microwave laboratory

Space and laboratory rotational constants differ by less than 2 kHz



107 AND 56 INDIVIDUAL LINES. Identification without the shadow of a doubt !!!!!!





Updated from a similar plot (2021) by McGuire, ApJS, 259, 30

The Yebes 40m telescope (Spain) is the instrument with the largest number of molecular discoveries in space !!!!