Cutting-Edge Telescopes in the Quest for Space Molecules

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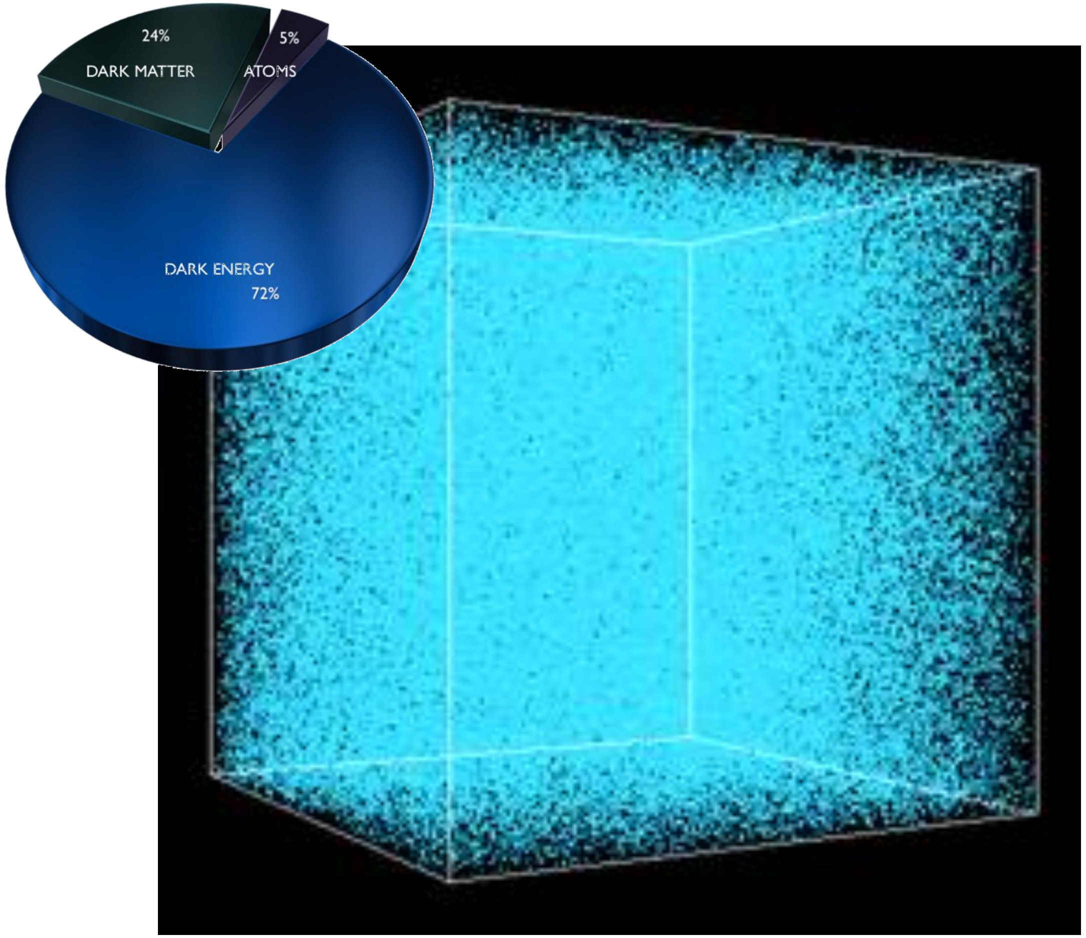
Introduction



- Only 5% is baryonic matter;
- Atoms (blocks);
- Molecules (Buildings)!

Identification of space molecules

- **CH** (1937) *P. Swings, et al., ApJ 86:483-486* – Electronic transitions
- **CN** (1940) *A. McKellar, Publ Astron Soc Pac 52:187-192*– Electronic t.
- **OH** (1963) *S. Weinreb, A. et al., Nature 200:829-831* – **Rotational**
- **NH_3** (1968) A. C. Cheung, et al., Phys Rev Lett 25:1701-1705 – **Rotational**
- **H_2O** (**1969**) A. C. Cheung, et al., Nature 221:626– **Rotational**
- **H_2CO** (**1969**) L. E. Snyder, et al., Phys Rev Lett 22:679-681– **Rotational**

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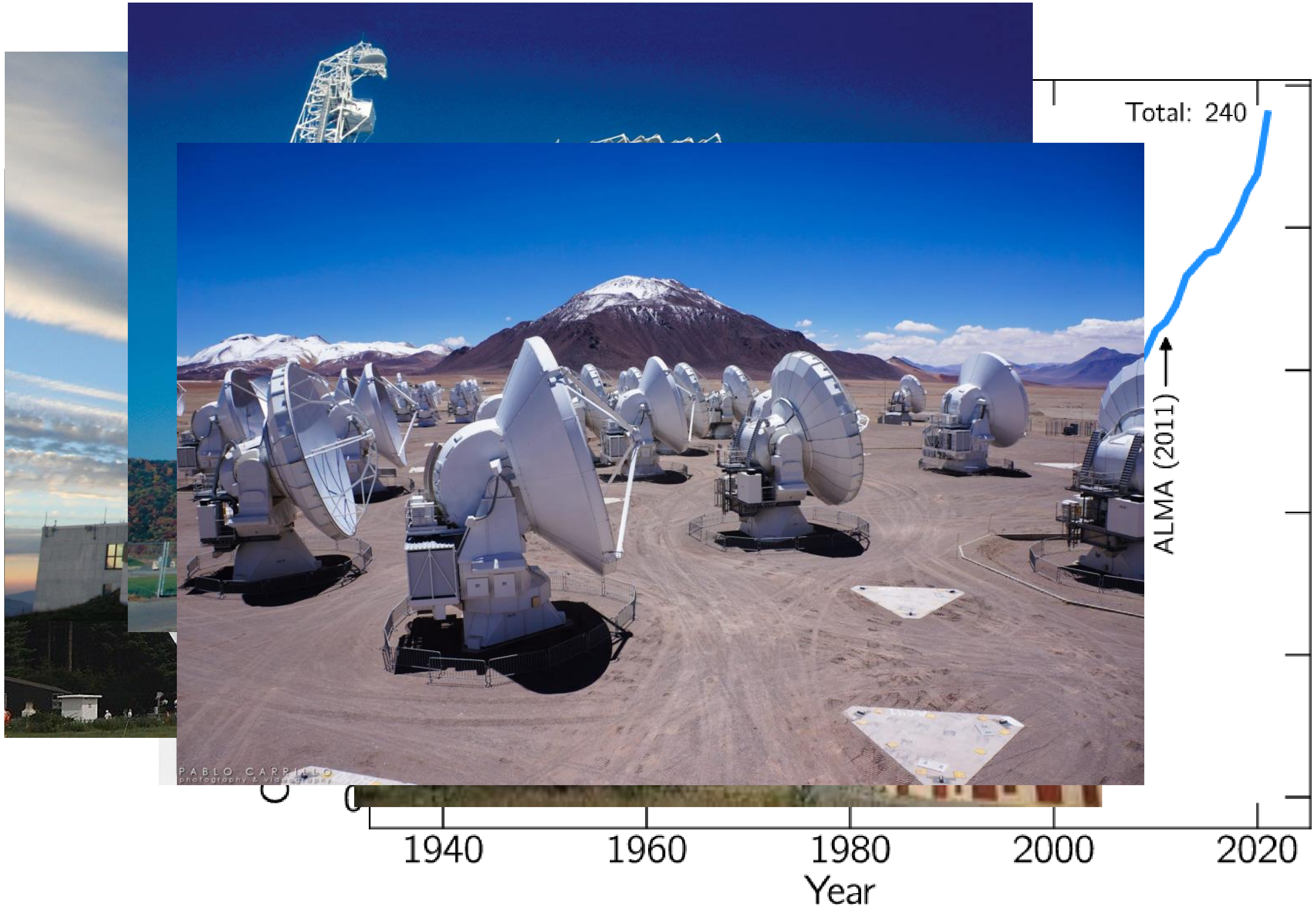
Molecules in ISM Identified over time



Brett A. McGuire 2022 *ApJS* **259** 30

Interstellar molecules

2 atoms	3 atoms	4 atoms	5 atoms	6 atoms	7 atoms	8 atoms	9 atoms	10 atoms	11 atoms	12 atoms	>12 atoms
H_2	C_3 *	c-C_3H	C_5 *	C_5H	C_6H	CH_3C_3N	CH_3C_4H	CH_3C_5N	HC_9N	c-C_6H_6 *	C_{60} *
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN	$HC(O)OCH_3$	CH_3CH_2CN	$(CH_3)_2CO$	CH_3C_6H	n-C_3H_7CN	C_{70} *
AlCl	C_2O	C_3N	C_4Si	C_2H_4*	CH_3C_2H	CH_3COOH	$(CH_3)_2O$	$(CH_2OH)_2$	C_2H_5OCHO	i-C_3H_7CN	C_{60}^+ *
C_2**	C_2S	C_3O	l-C_3H_2	CH_3CN	HC_5N	C_7H	CH_3CH_2OH	CH_3CH_2CHO	$CH_3OC(O)CH_3$	$C_2H_5OCH_3$?	c-C_6H_5CN 2018
CH	CH_2	C_3S	c-C_3H_2	CH_3NC	CH_3CHO	C_6H_2	HC_7N	CH_3CHCH_2O			
CH^+	HCN	C_2H_2*	H_2CCN	CH_3OH	CH_3NH_2	CH_2OHCHO	C_8H	CH_3OCH_2OH 2017			
CN	HCO	NH_3	CH_4 *	CH_3SH	c-C_2H_4O	l-HC_6H *	$CH_3C(O)NH_2$				
CO	HCO^+	HCCN	HC_3N	HC_3NH^+	H_2CCHOH	CH_2CHCHO (?)	C_8H^-				
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO	C_6H^-	CH_2CCHCN	C_3H_6				
CP	HOC^+	HNCO	HCOOH	NH_2CHO	CH_3NCO	H_2NCH_2CN	CH_3CH_2SH (?)				
SiC	H_2O	HNCS	H_2CNH	C_5N	HC_5O 2017	CH_3CHNH	CH_3NHCHO ? 2017				
HCl	H_2S	$HOCO^+$	H_2C_2O	l-HC_4H *	$HOCH_2CN$ 2019	CH_3SiH_3 2017	HC_7O 2017				
KCl	HNC	H_2CO	H_2NCN	l-HC_4N							

2022, around 300 **molecules** have been **detected** in the **interstellar medium** or **circumstellar shells** and **around 73** in **extragalactic sources**

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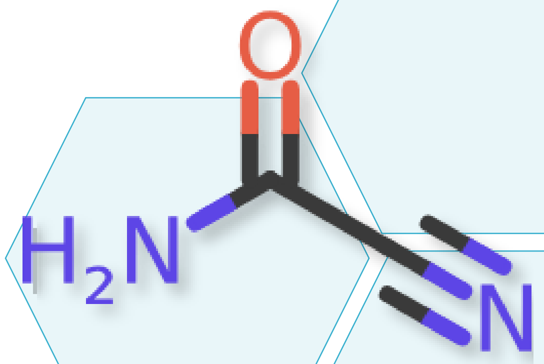
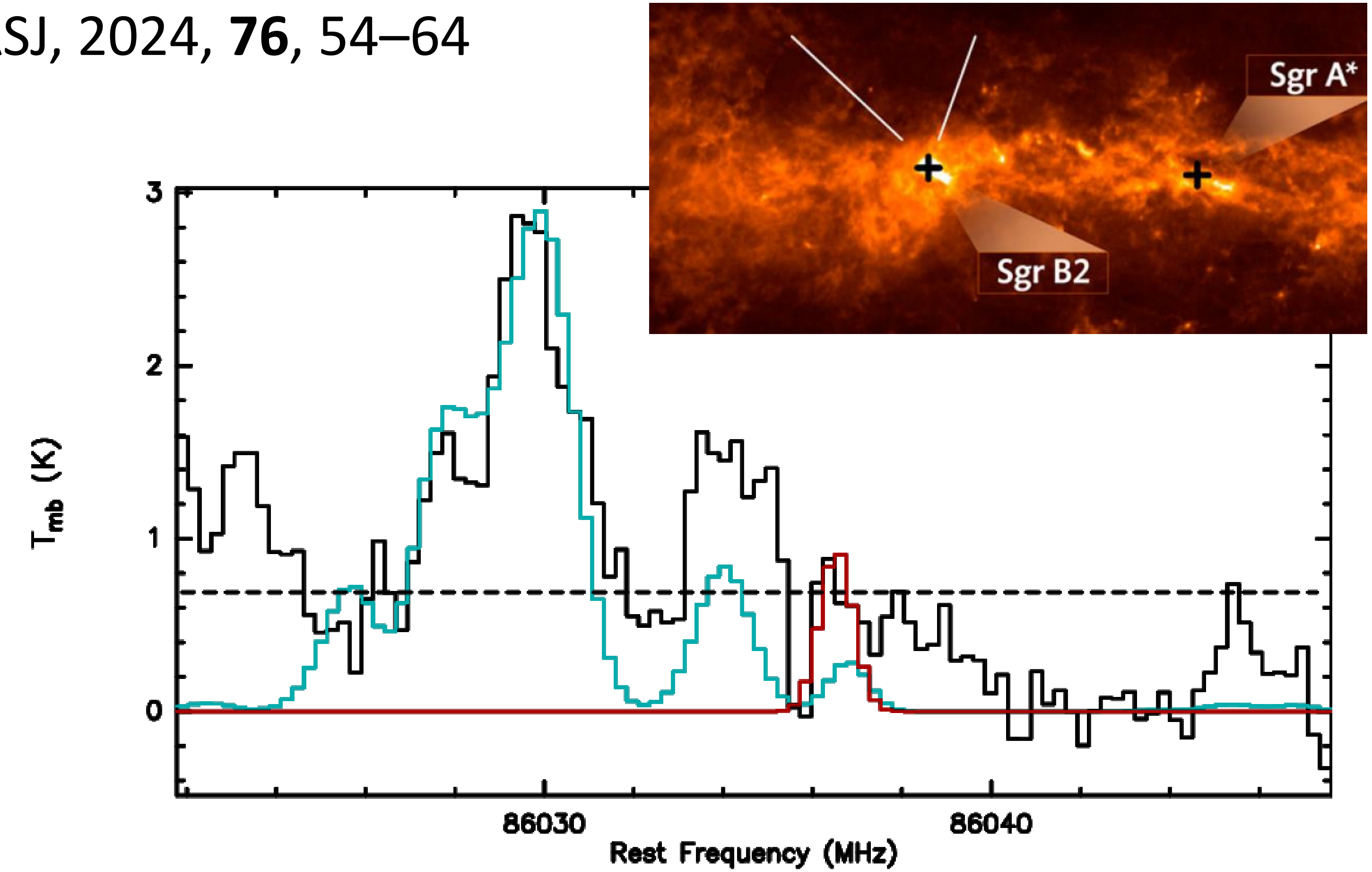


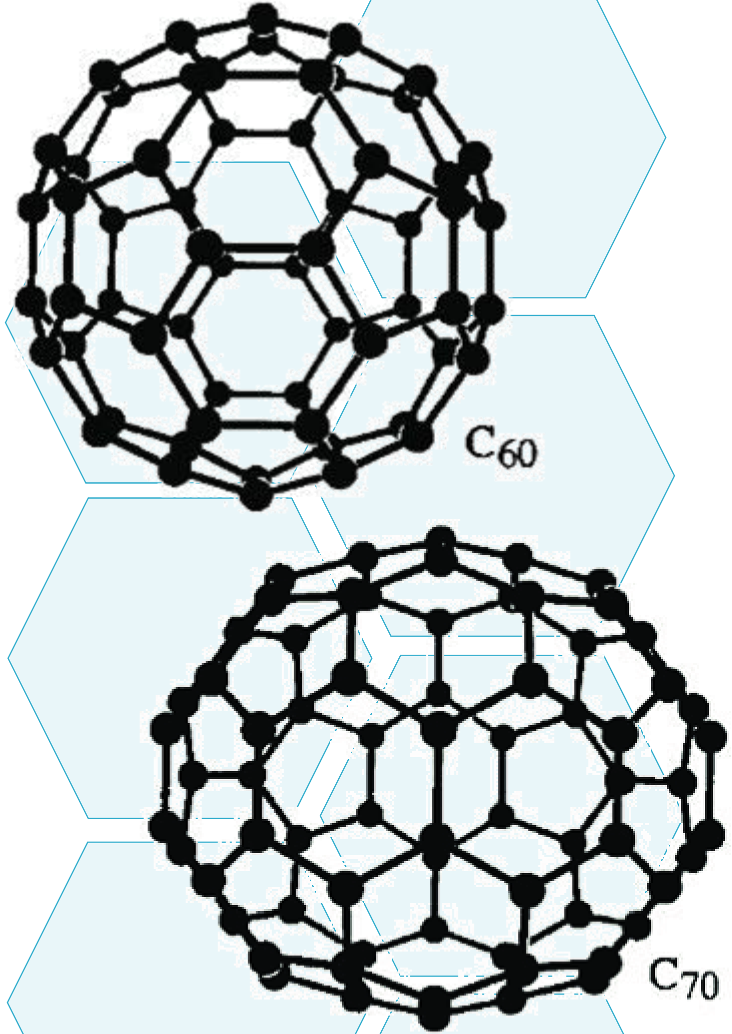
Cyanoformamide ($NCCONH_2$)

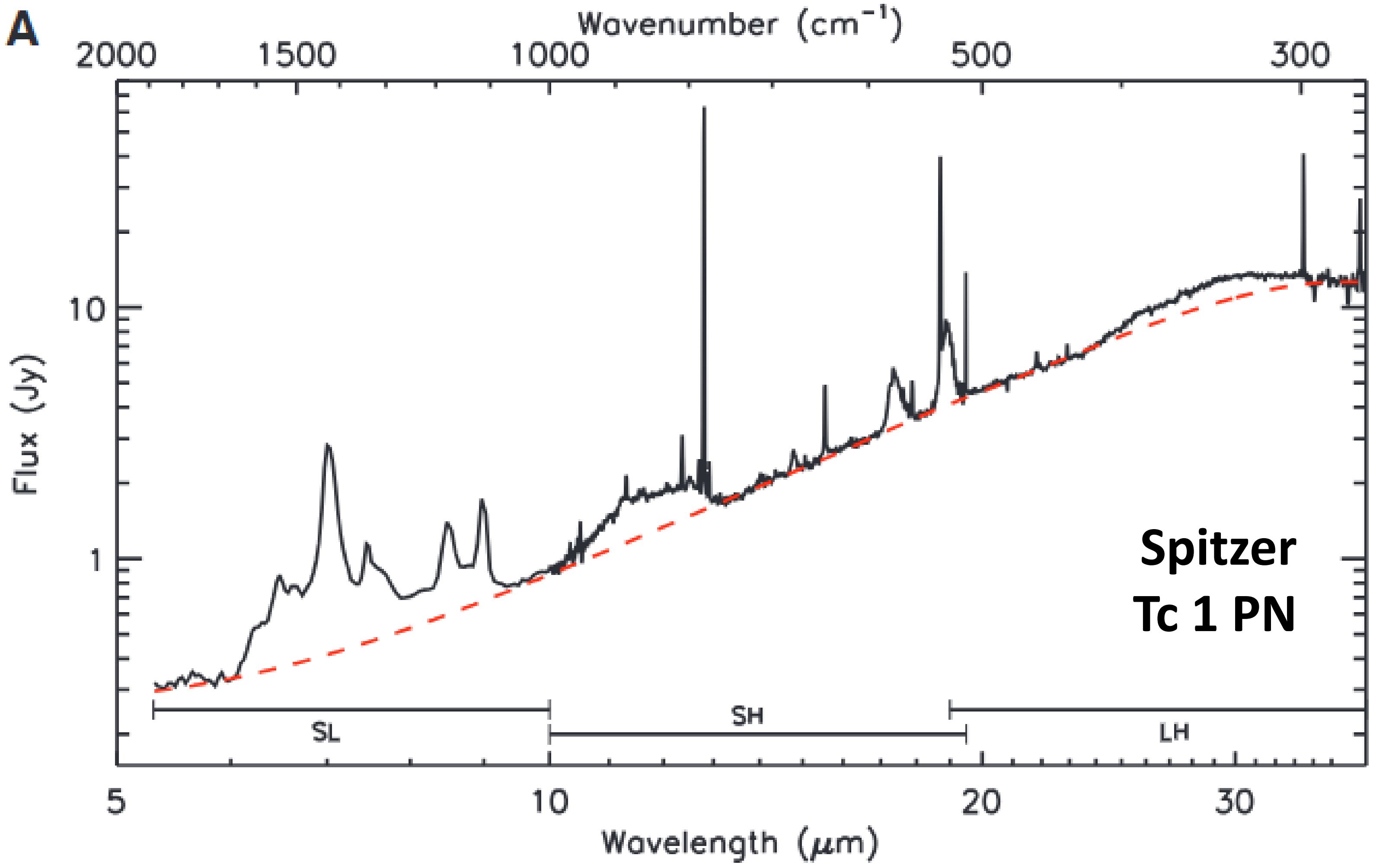
Li et al. PASJ, 2024, **76**, 54–64



- Tentative detection
- Using ALMA
- 10 spectral lines
- Ratio abundance with respect to formamide (NH_2CHO): 1%

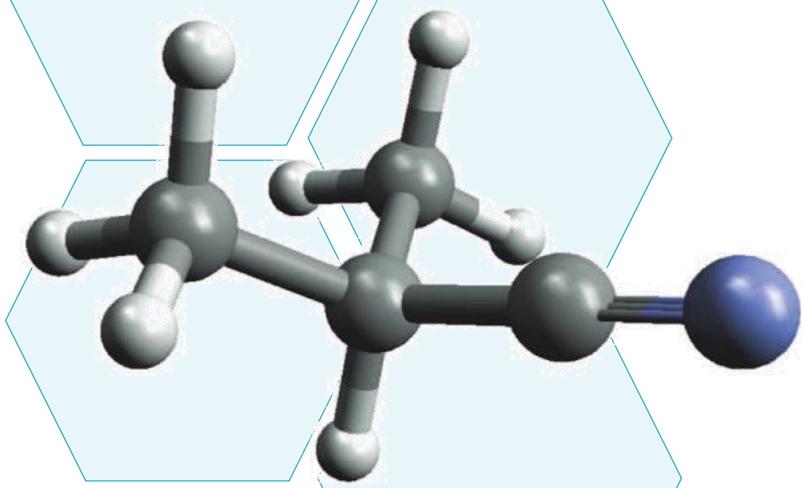
Fullerenes C_{60} and C_{70}

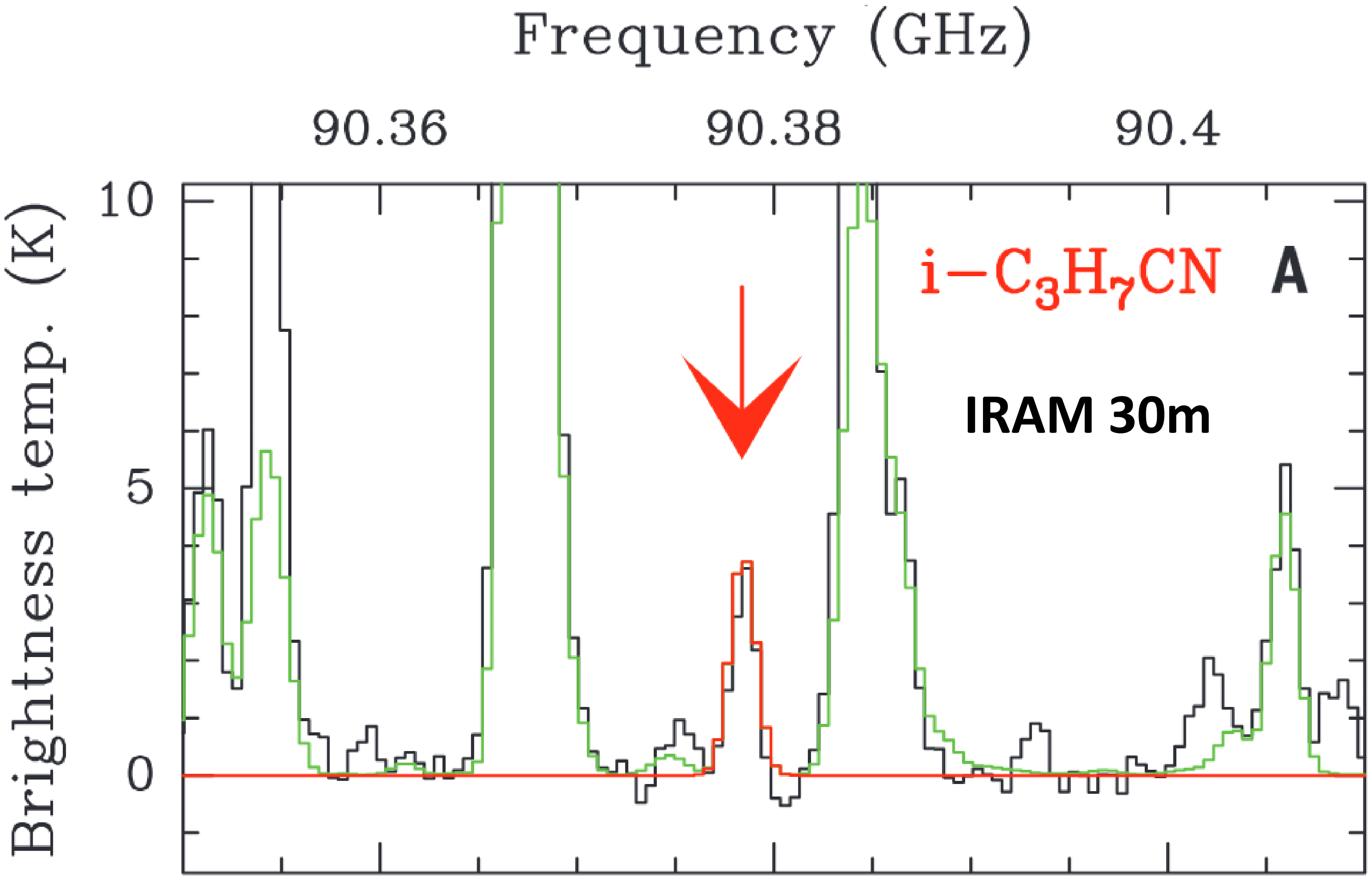




Cami et al. Science 2010, **329**, 180-182

Isopropyl cyanide (*i*-C_3H_5CN): first branched ISM molecule





Belloche et al. Science 2014, **345**, 1584-1587.

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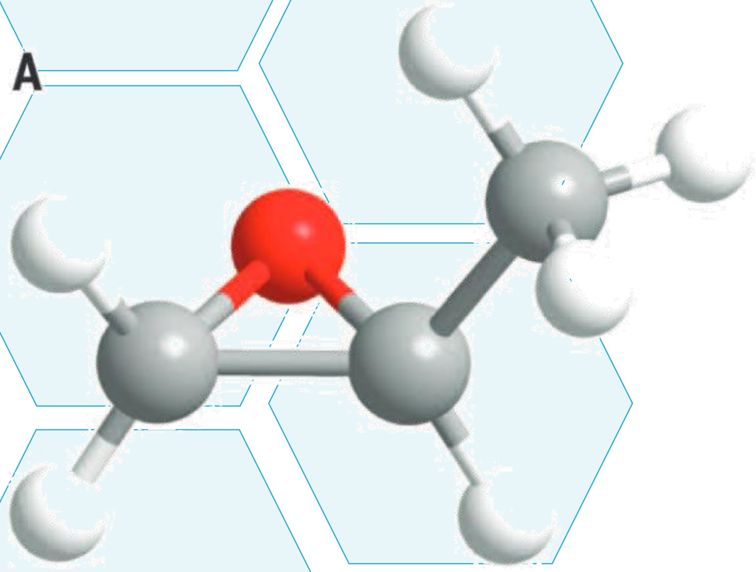
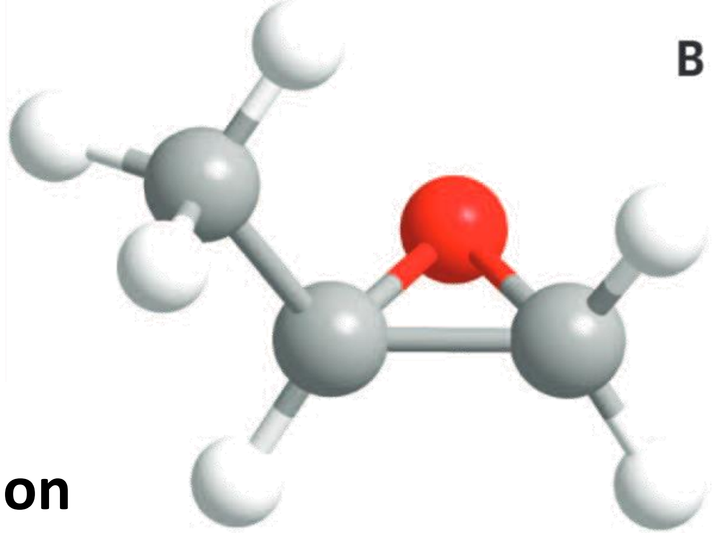
Propylene oxide (CH_3CHCH_2O) a chiral ISM molecule

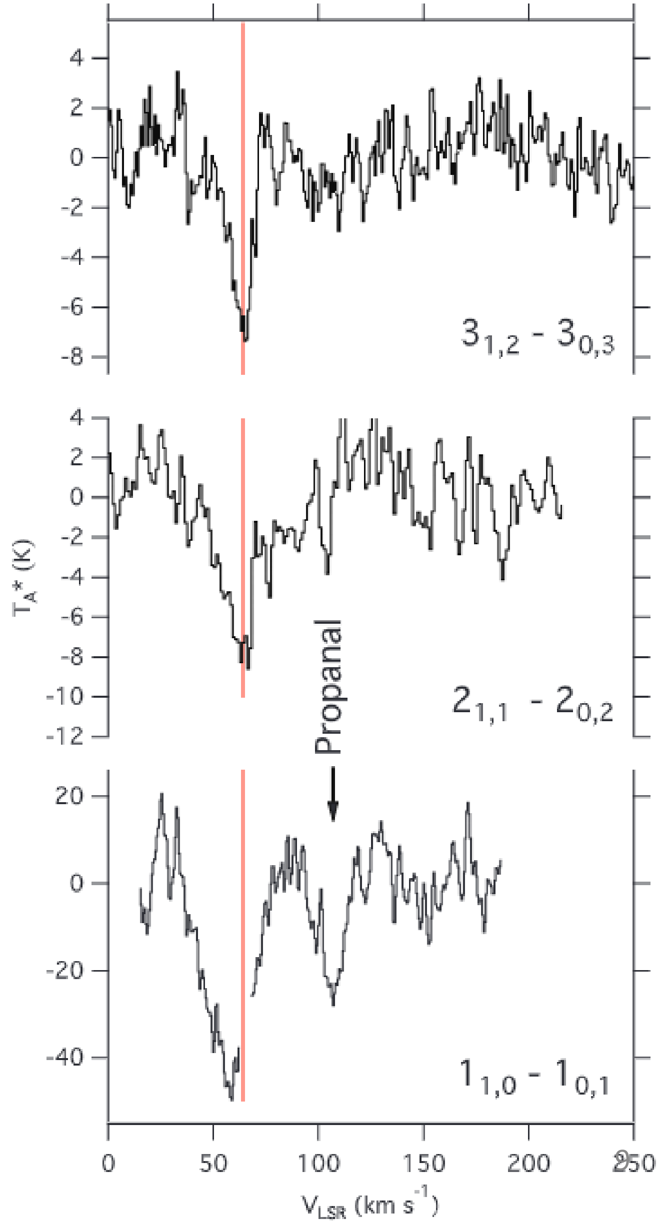
McGuire et al. Science 2016, **352**, 1449-1452.

A



B





Sagittarius B2 star-forming region
GBT observations

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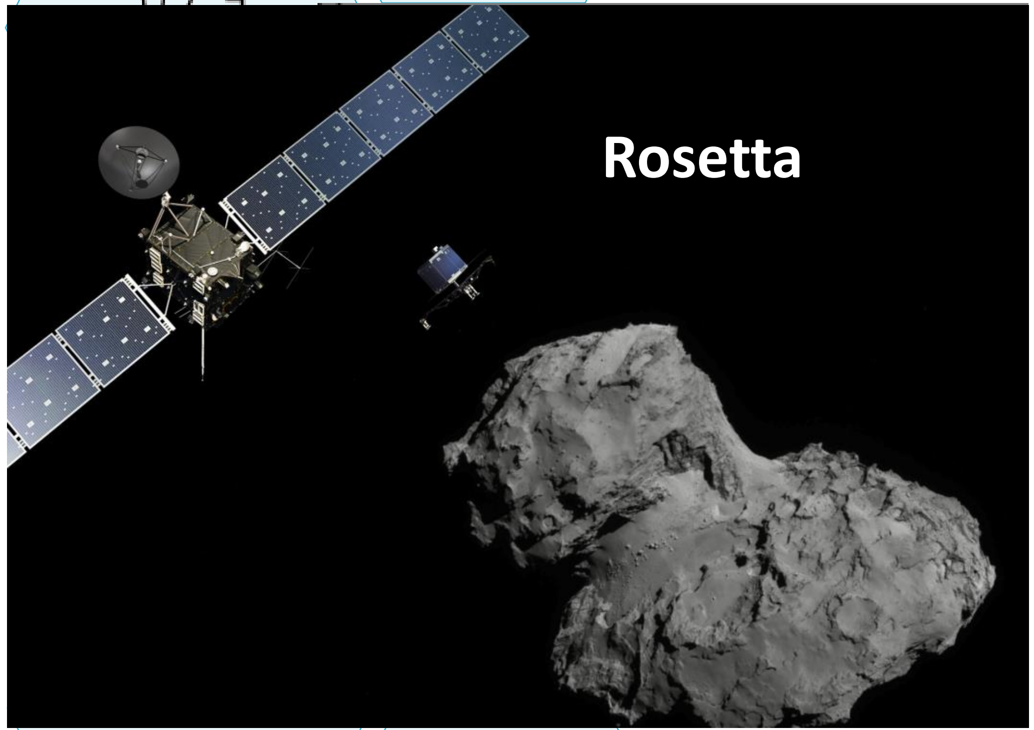
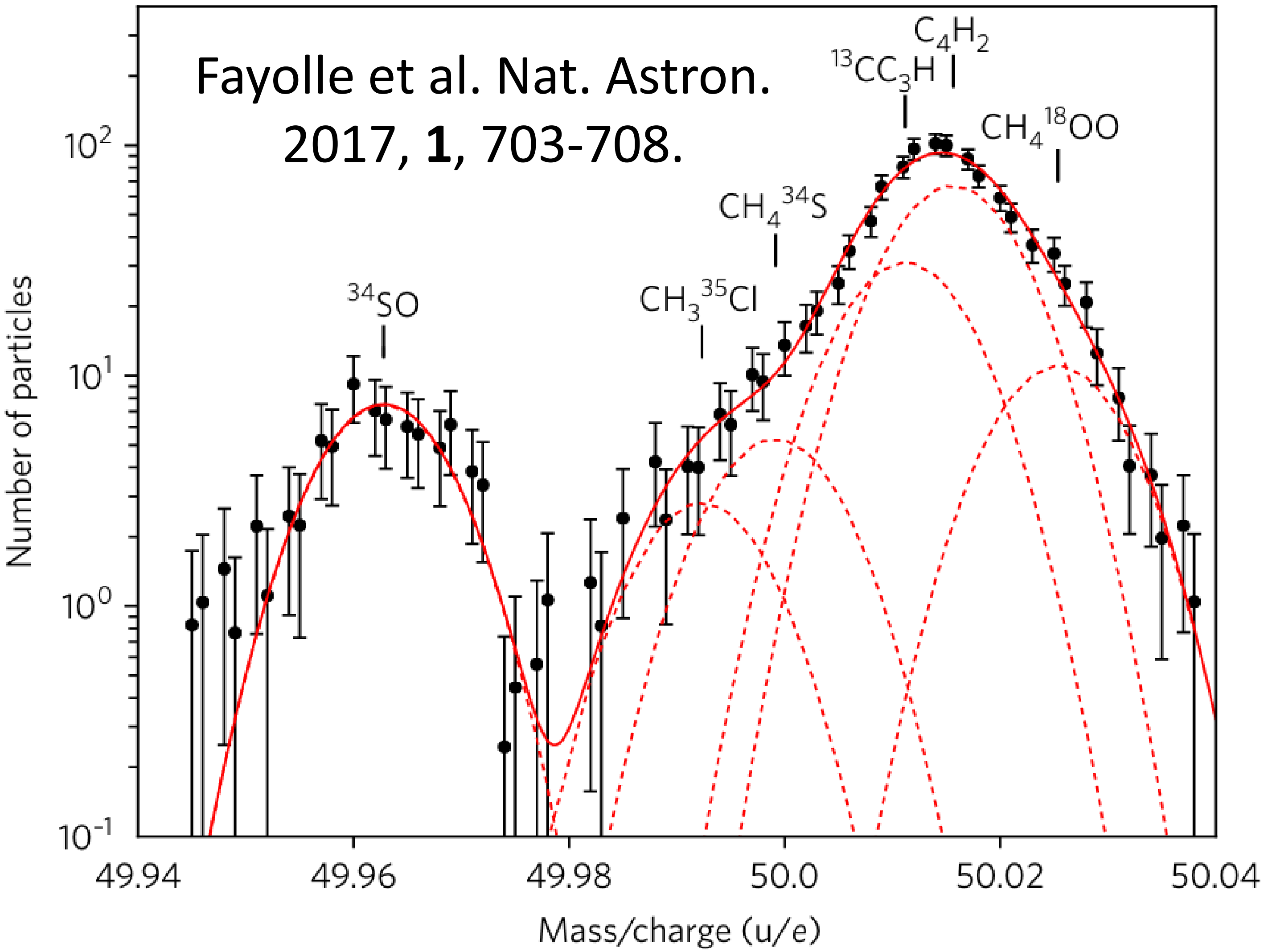
Organohalogens in protostars and comets

0.8
0.7 4





ALMA

Fayolle et

Benzonitrile (C_6H_5CN)

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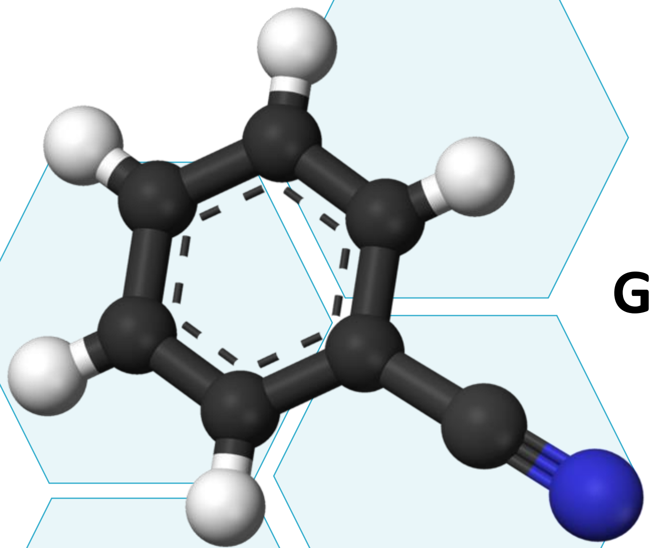
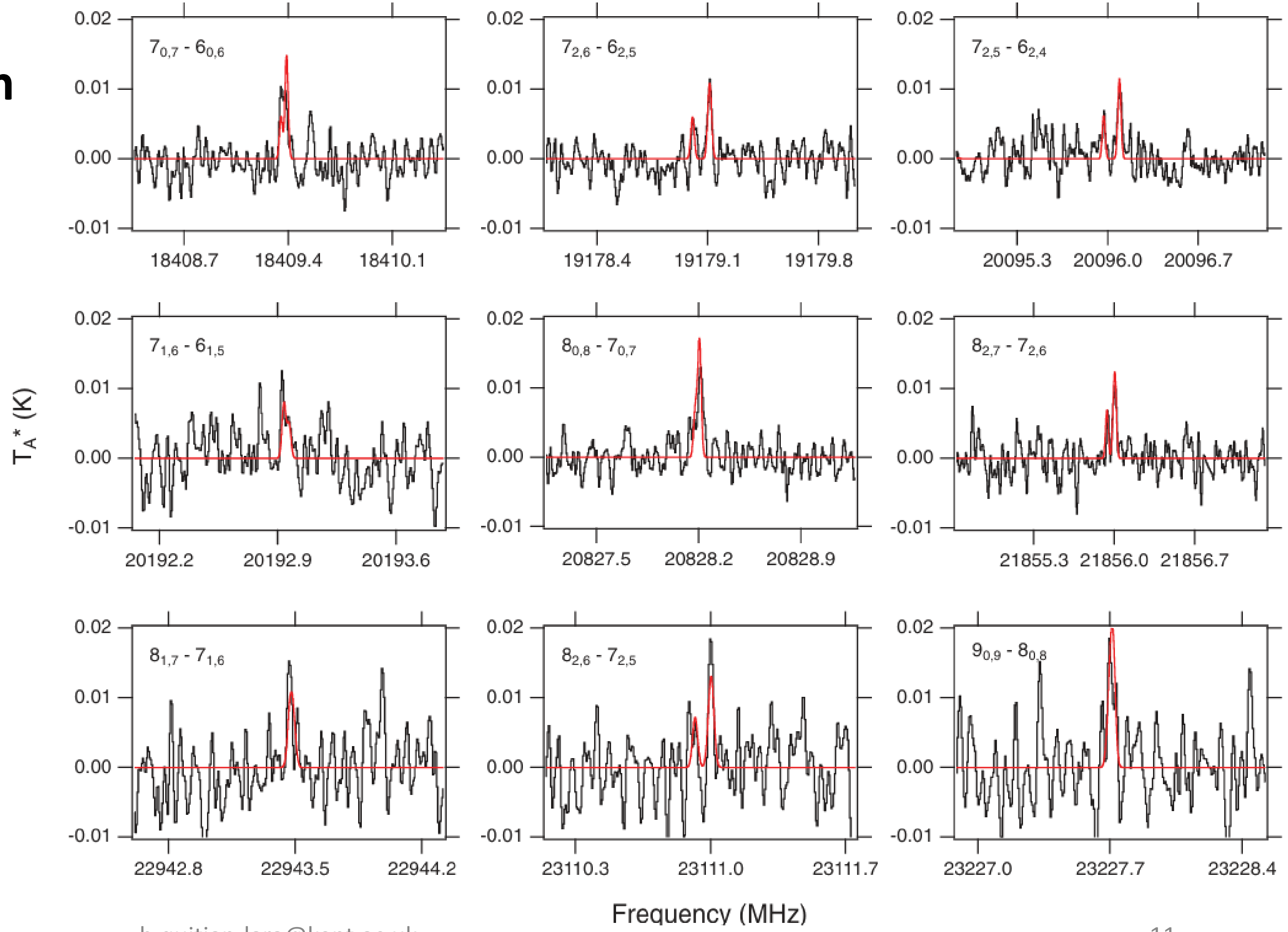
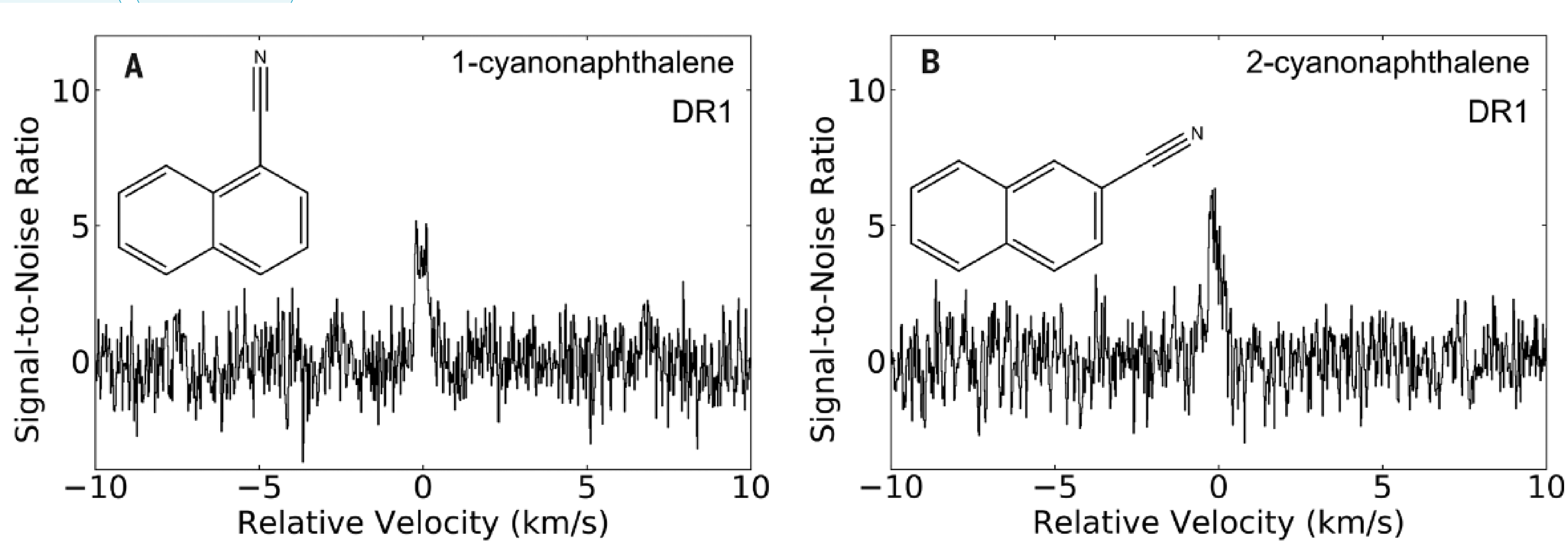


GBT 100m
TMC1



McGuire et al. Science **359**, 202–205 (2018)

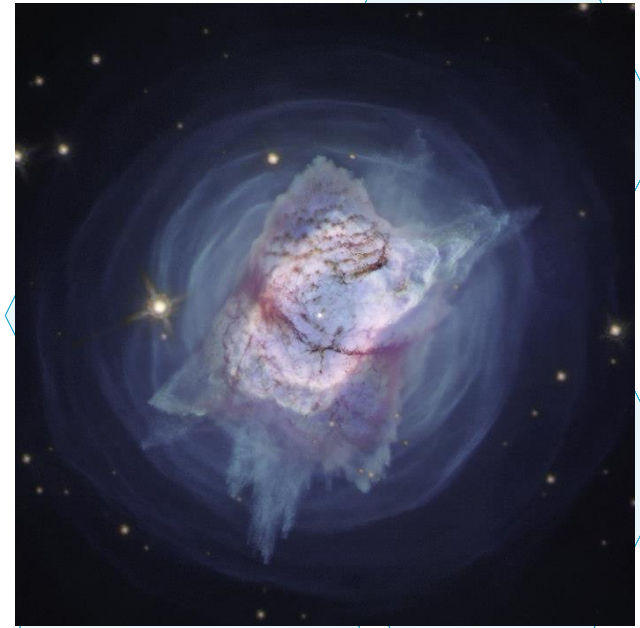
Polycyclic aromatic hydrocarbons



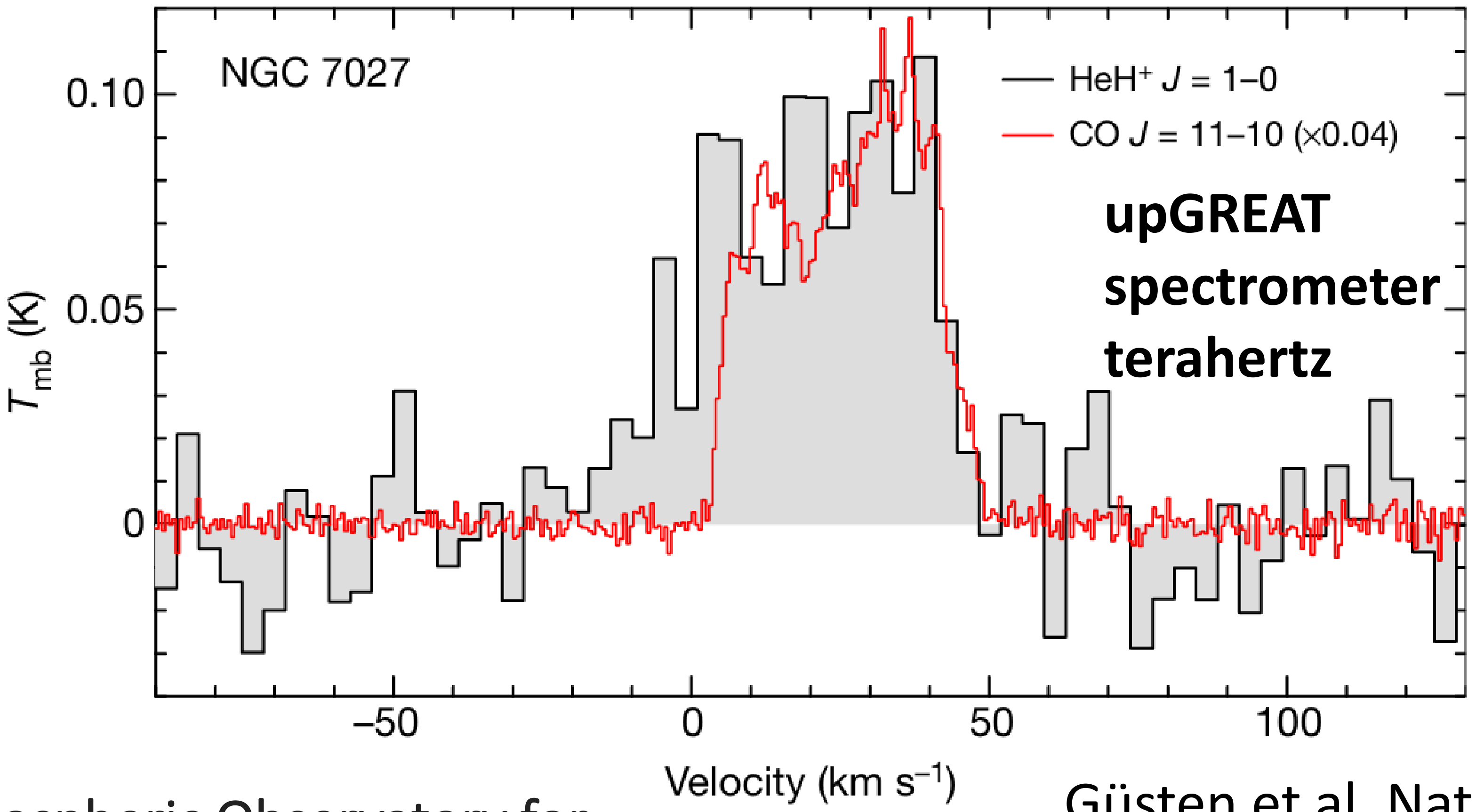
McGuire et al. Science 2021, **371**, 1265-1269.

GBT
TMC1

HeH^+, the first molecule formed after Big Bang



NGC 7027



upGREAT spectrometer terahertz

Stratospheric Observatory for Infrared Astronomy (SOFIA)

Güsten et al. Nature **568**, 357–359 (2019)

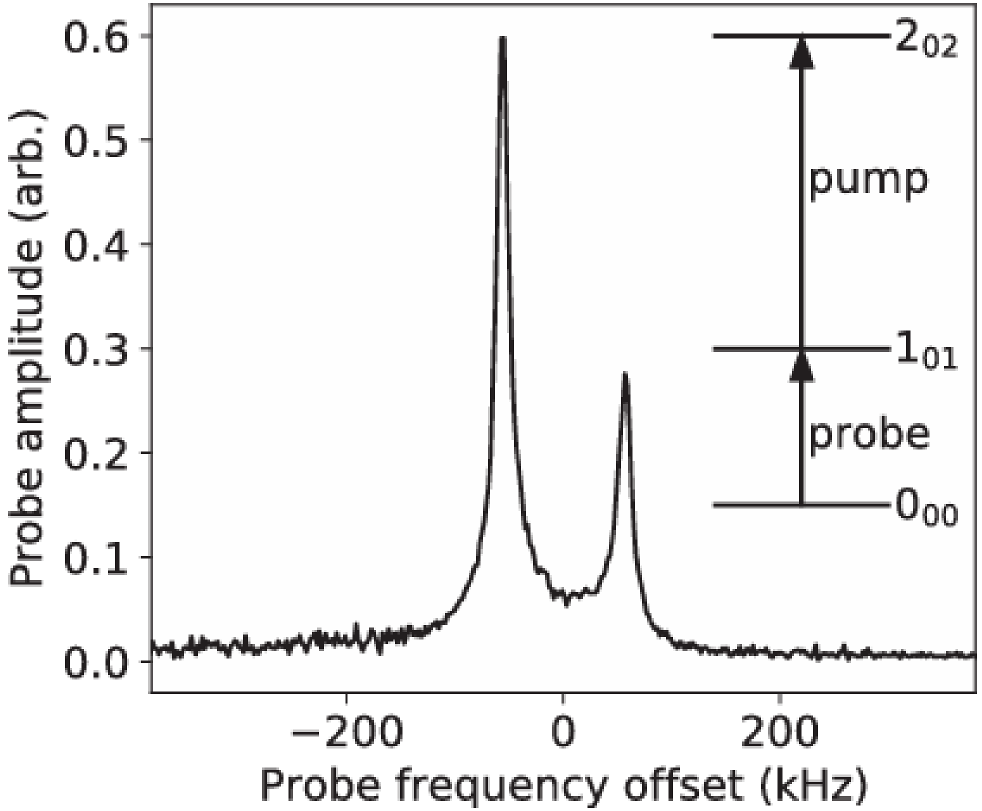
Radio telescopes - Interferometers

- Detection of molecules in the gas phase;
- Large-scale or 0.05”resolution spectra and images;
- Synergy of experiments and observations

Magnesium containing molecules in IRC +10216

Yebes + IRAM 30m

MgC_2: P. B. Changala, et al. ApJL 2022, **940**, L42



Laboratory measurements: Fourier transform microwave spectrometer coupled to a laser ablation supersonic expansion.

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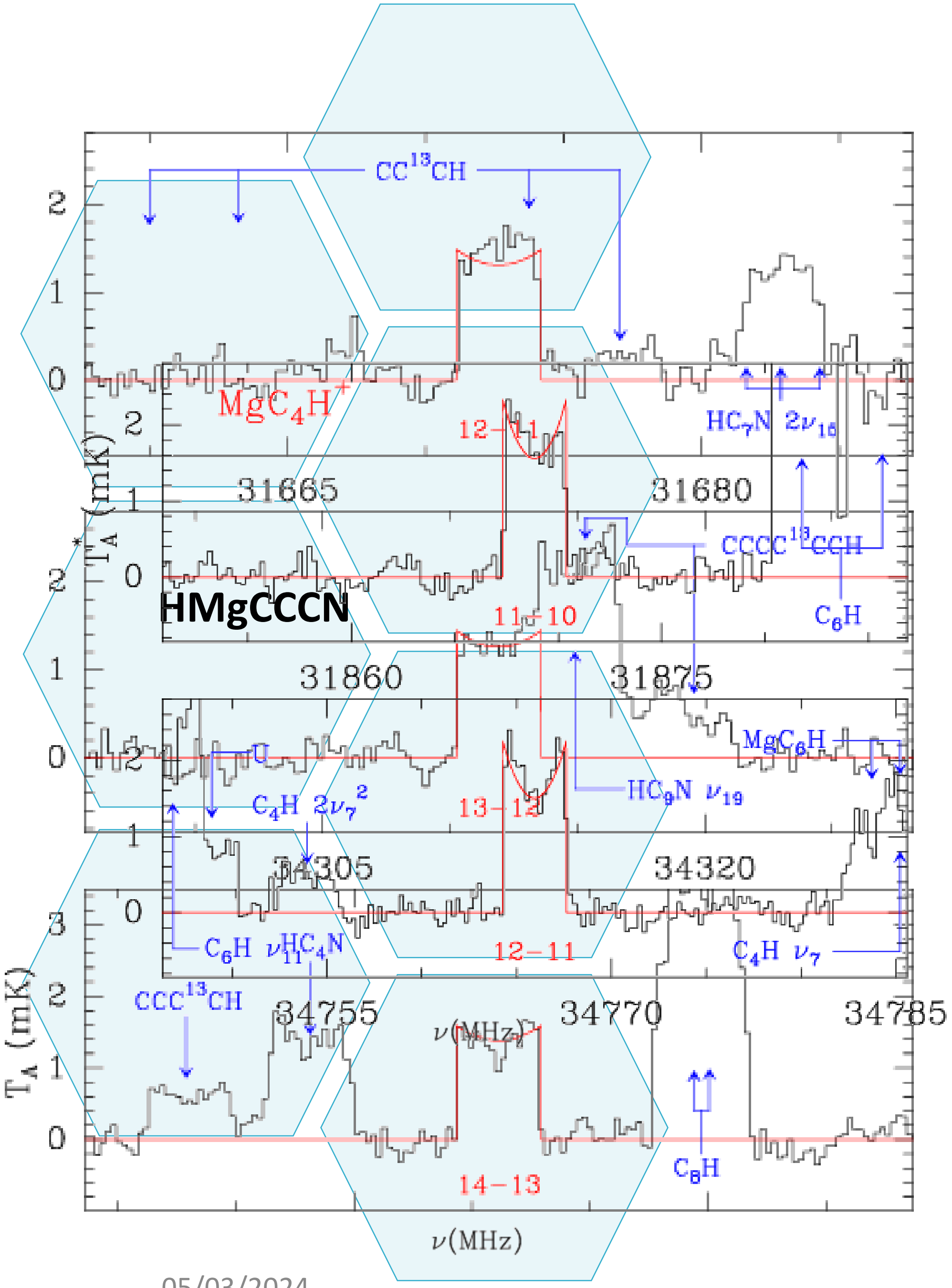


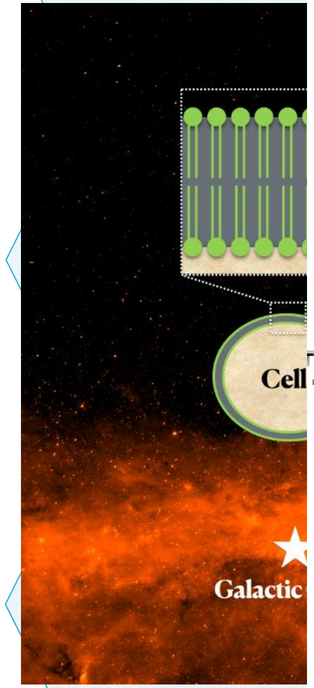
Magnesium containing molecules in IRC +10216

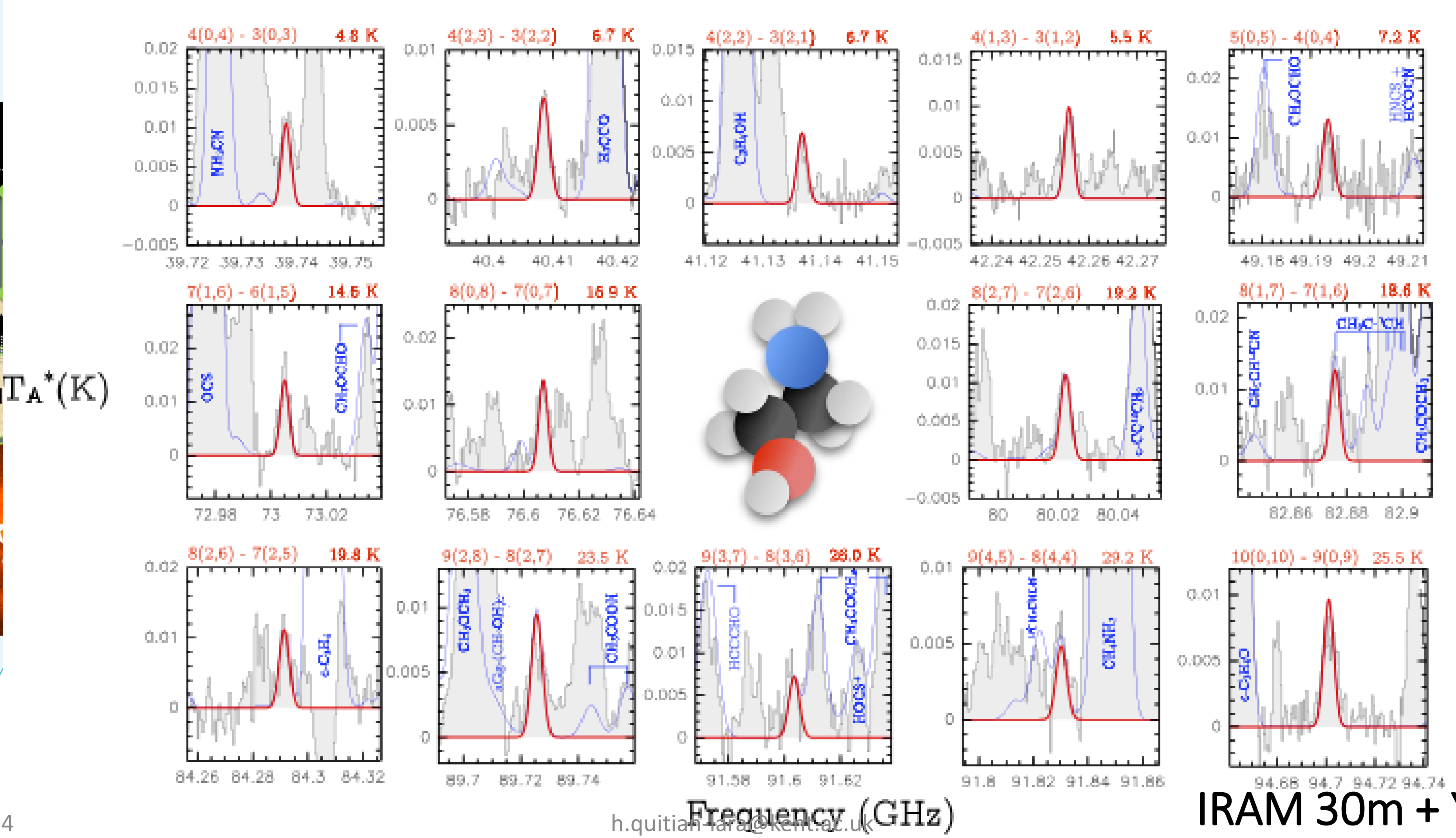
- **HMgCCCN:** C. Cabezas, et al., 2023, A&A **672**, L12;
- **MgC_4H^+, MgC_3N^+, MgC_6H^+,** and **MgC_5N^+**
  J. Cernicharo, et al. A&A, 2023, **672**, L13.

Yebes + IRAM 30m

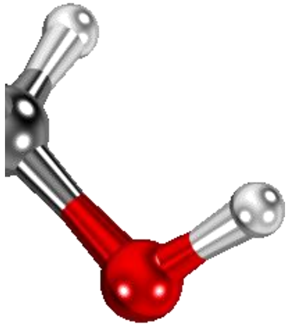
Experimental/theoretical frequencies FTMW

Ethanolamine $NH_2CH_2CH_2OH$
Molecular cloud G+0.693 - 0.027



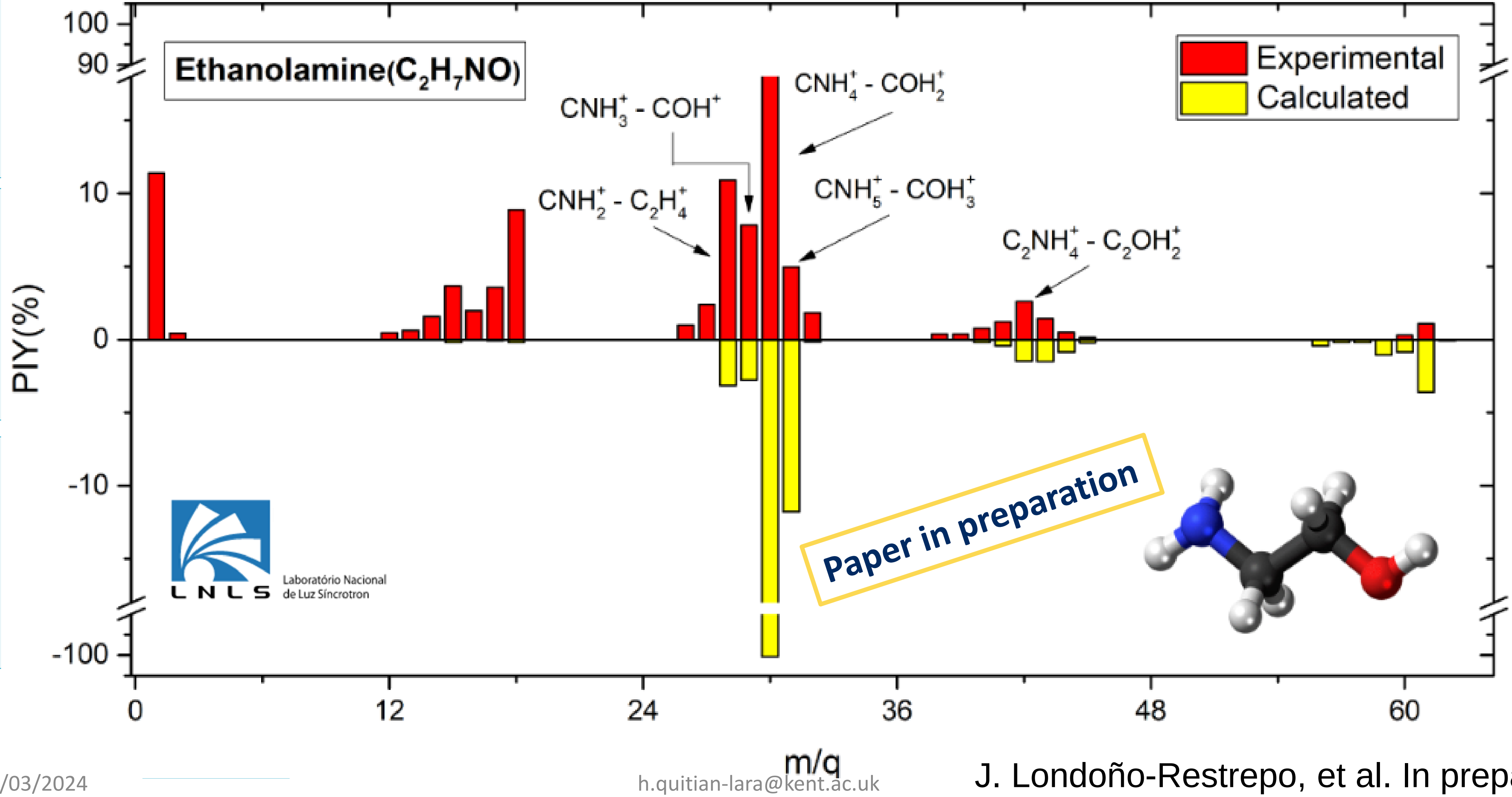


...1, **118**.



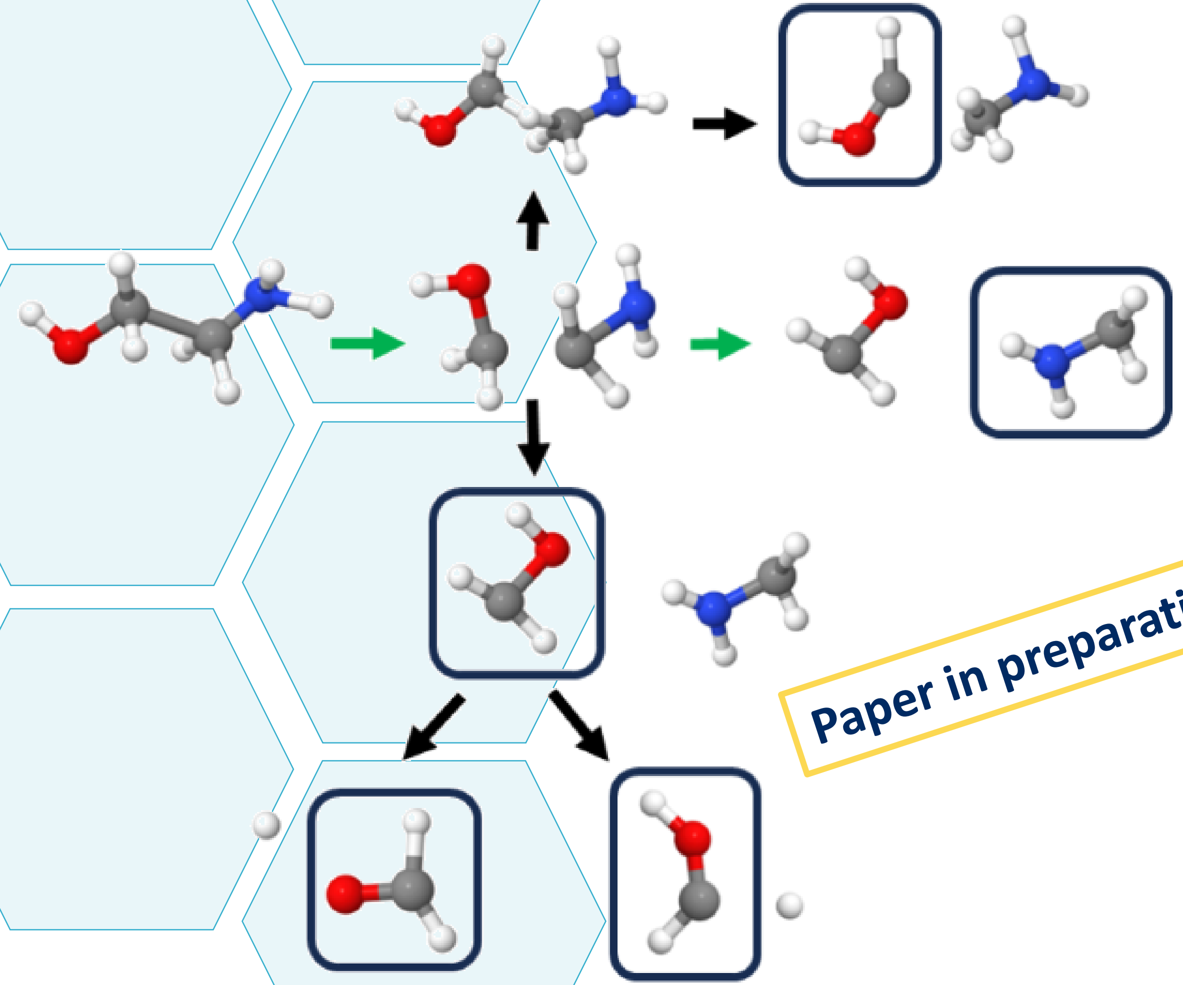
IRAM 30m + Yebes 40m

Ethanolamine, C_2H_7NO X-rays

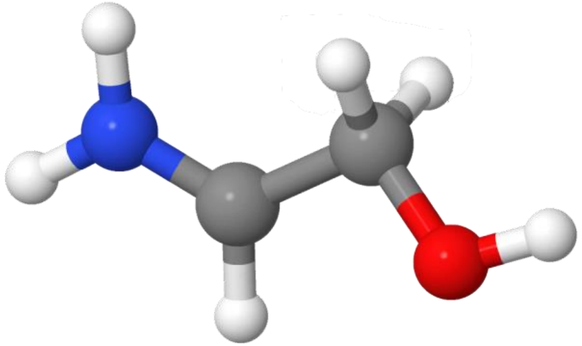


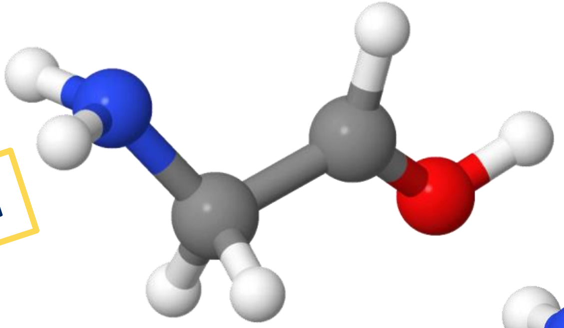
J. Londoño-Restrepo, et al. In preparation

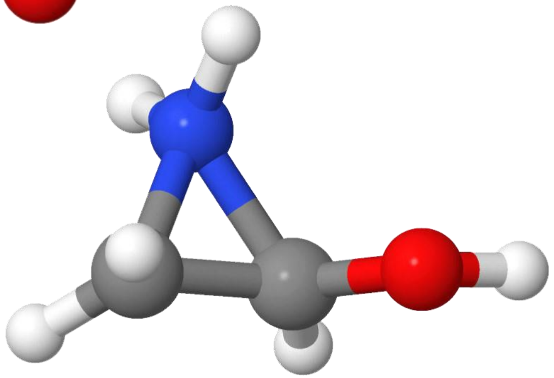
Ethanolamine, C_2H_7NO X-rays



Paper in preparation





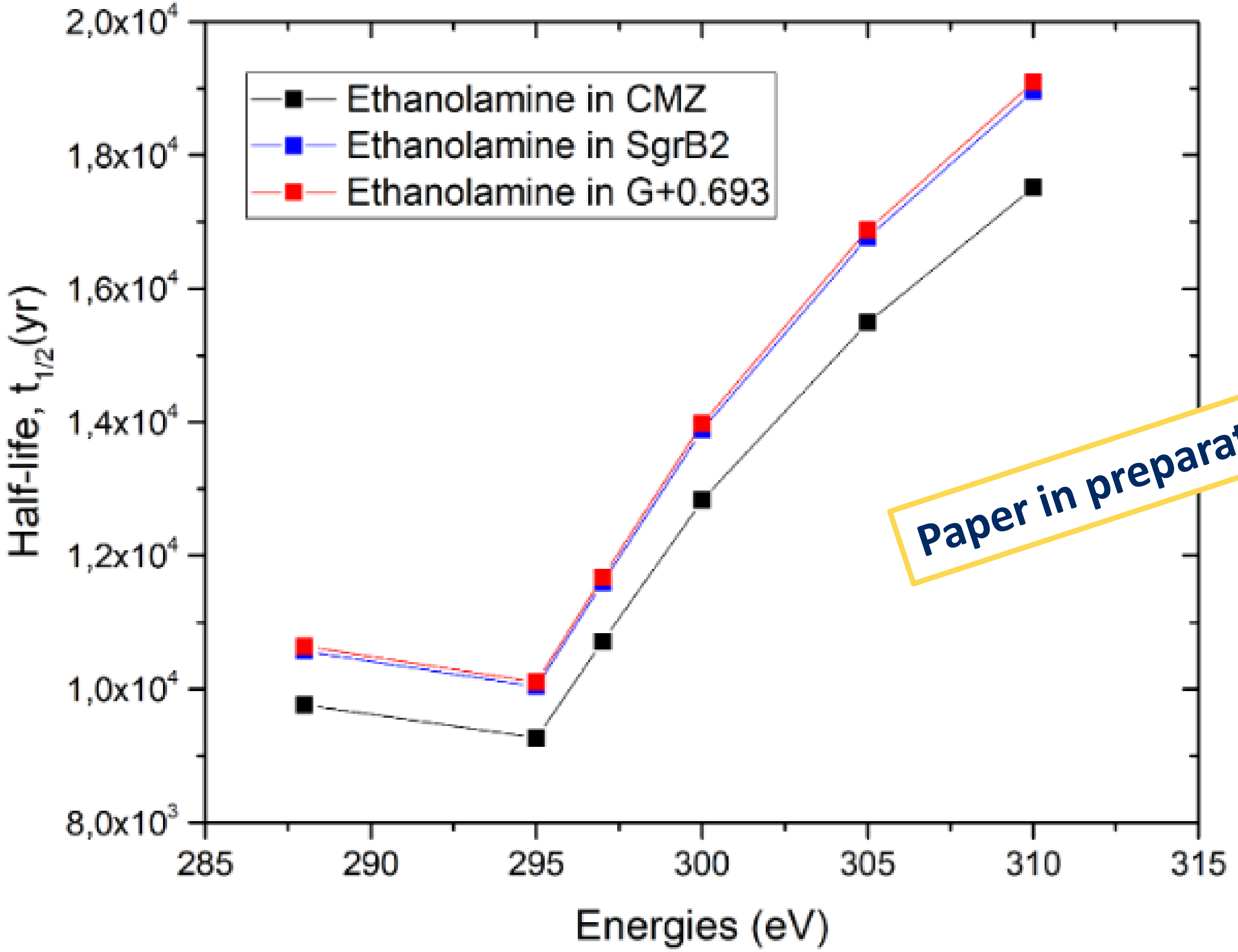


$C_2H_6NO^+$
Cation isomers

Fragmentation route leading to m/q = 30 fragments.

J. Londoño-Restrepo, et al. In preparation

Ethanolamine, C_2H_7NO X-rays

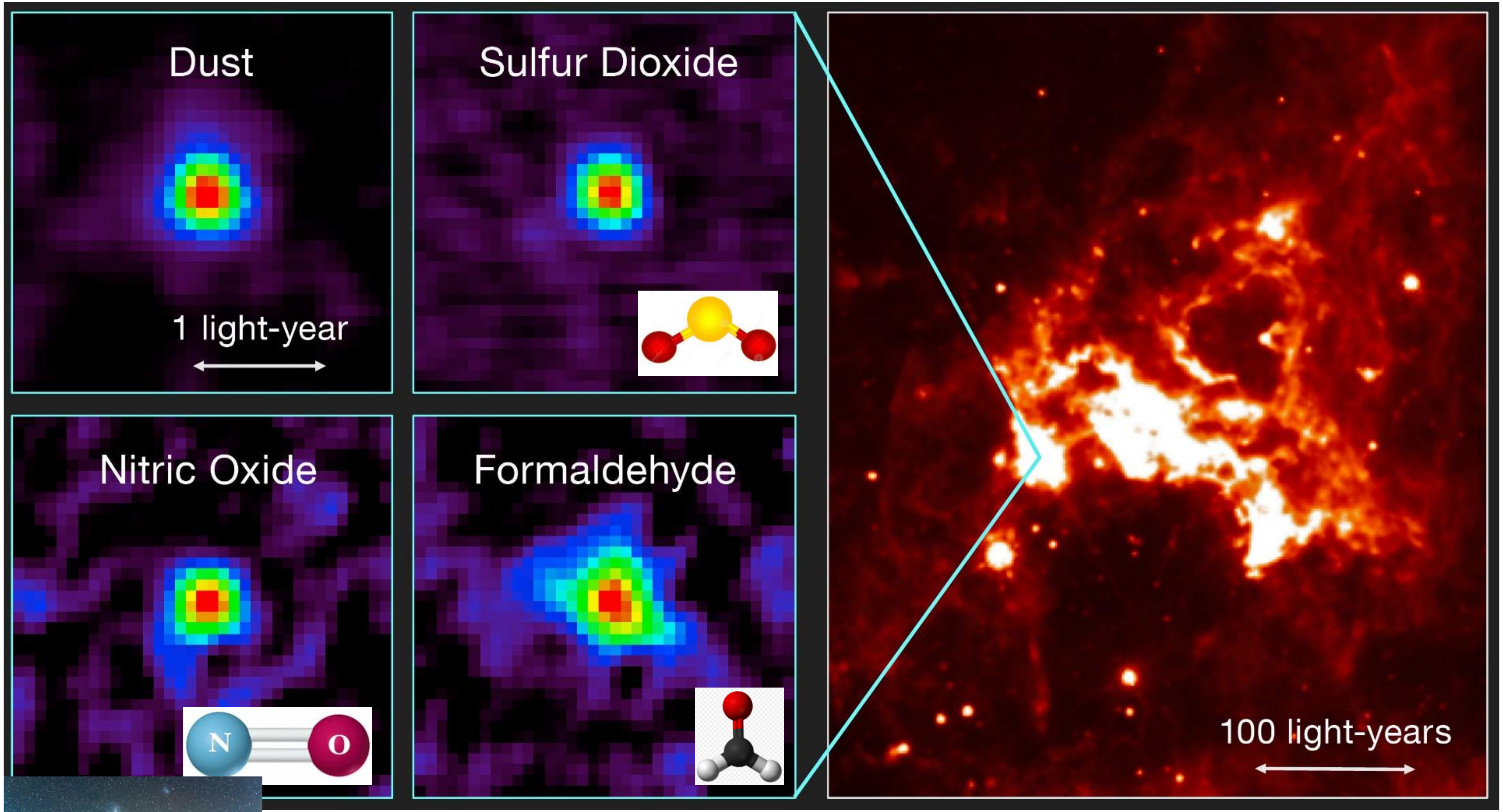


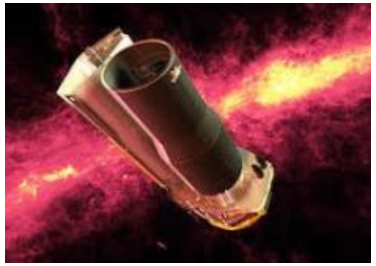
Paper in preparation

Jhoan Londoño

MSc. Sergio Guerrero

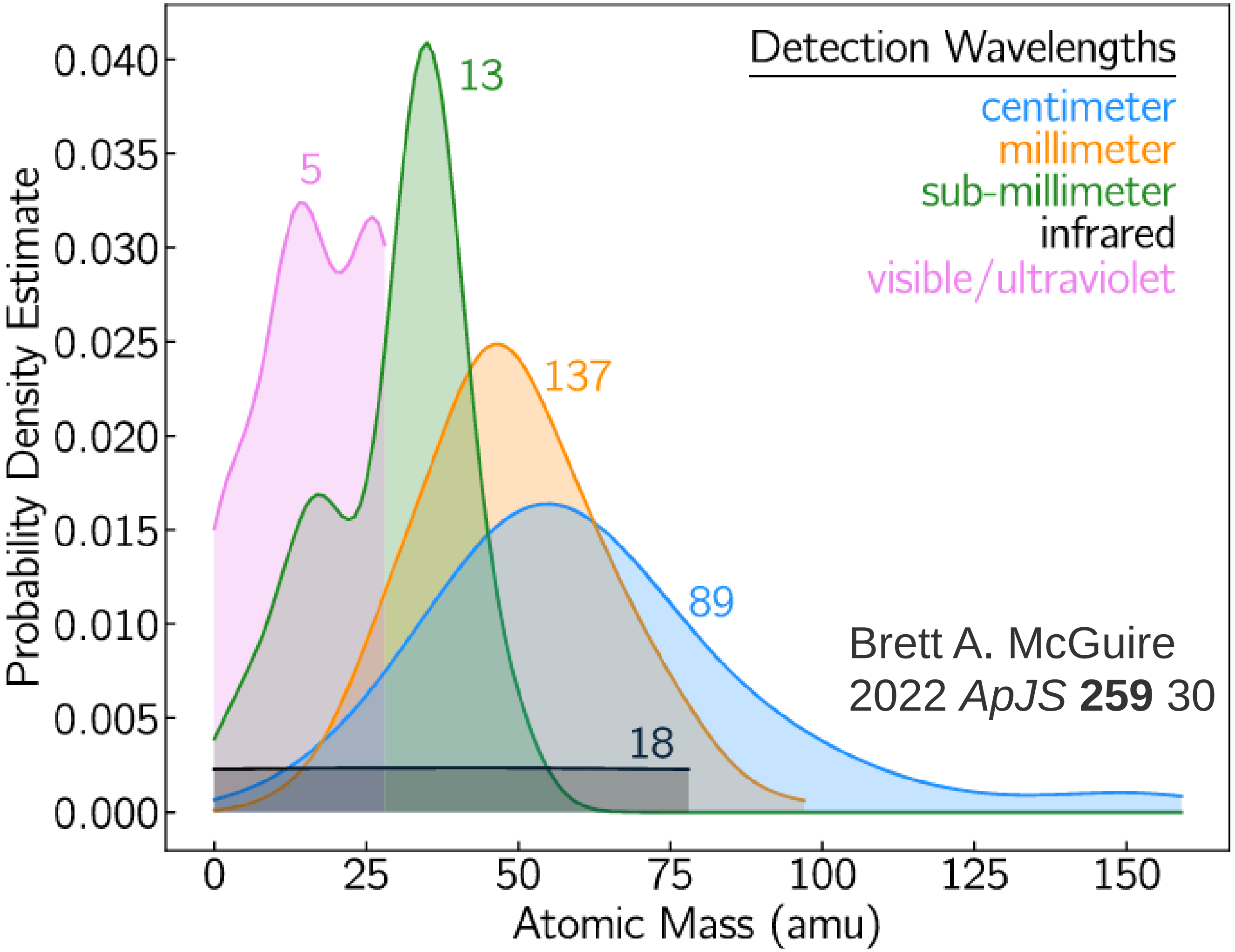
J. Londoño-Restrepo, et al. In preparation



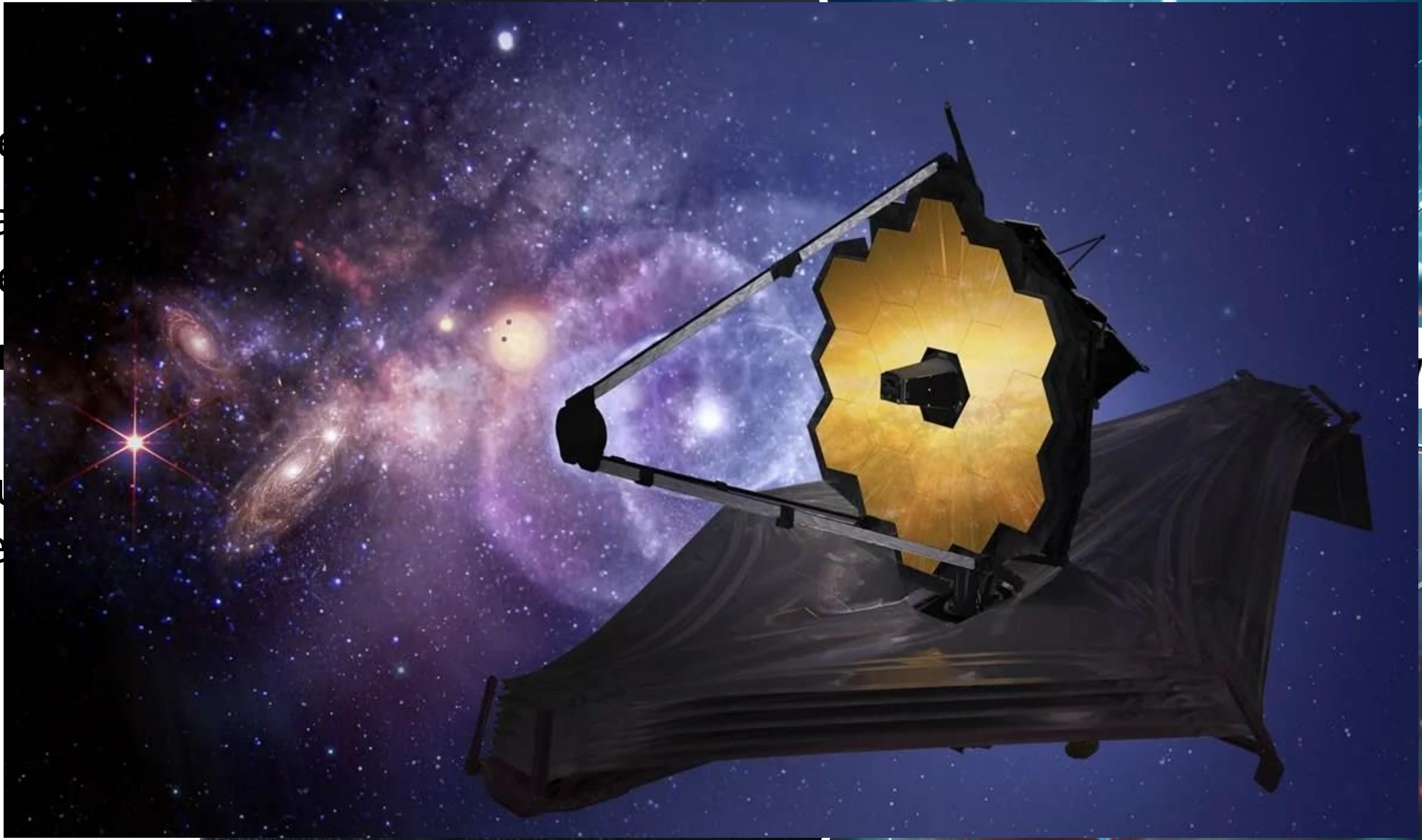


Observations of the first hot core found outside the Milky Way .
ALMA (2016). Object ST11 , Large Magellanic Cloud (LMC)

Molecules detected at different wavelengths

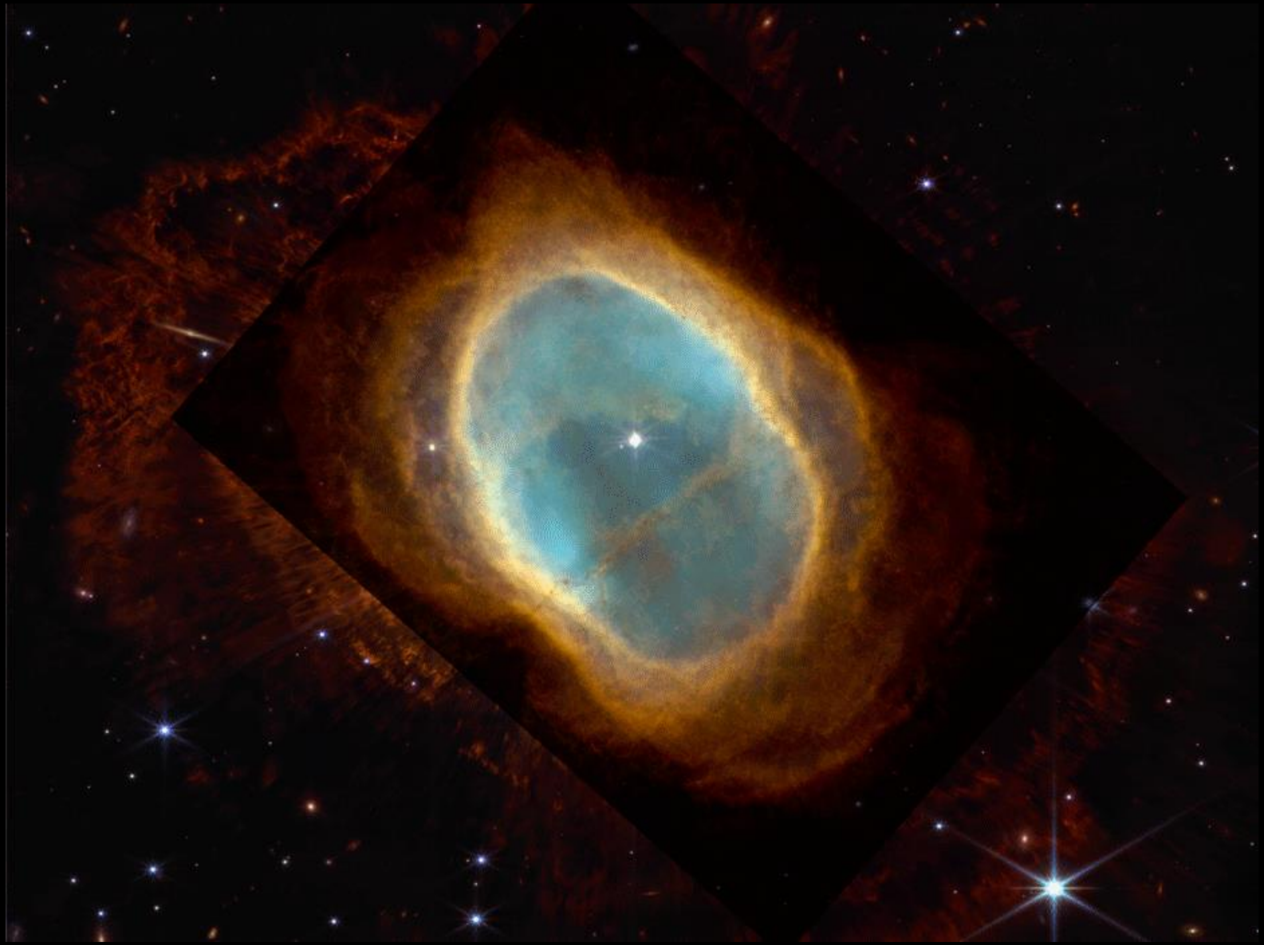


- Rotationa
  frequenci
- Vibrationa
  frequenci
- Pure and r
  samples
- Amorphou
  crystalline
- JWST



JWST

- Greater sensitivity and higher spatial resolution in the infrared compared to Hubble
- Higher spectral resolution in the mid-infrared compared to Spitzer.
- R > 2000 over a 3''x3'' field and with 0.1'' spatial resolution.
- Near-simultaneous mapping and spectroscopy of gas and dust from 0.6 – 28.8 µm.



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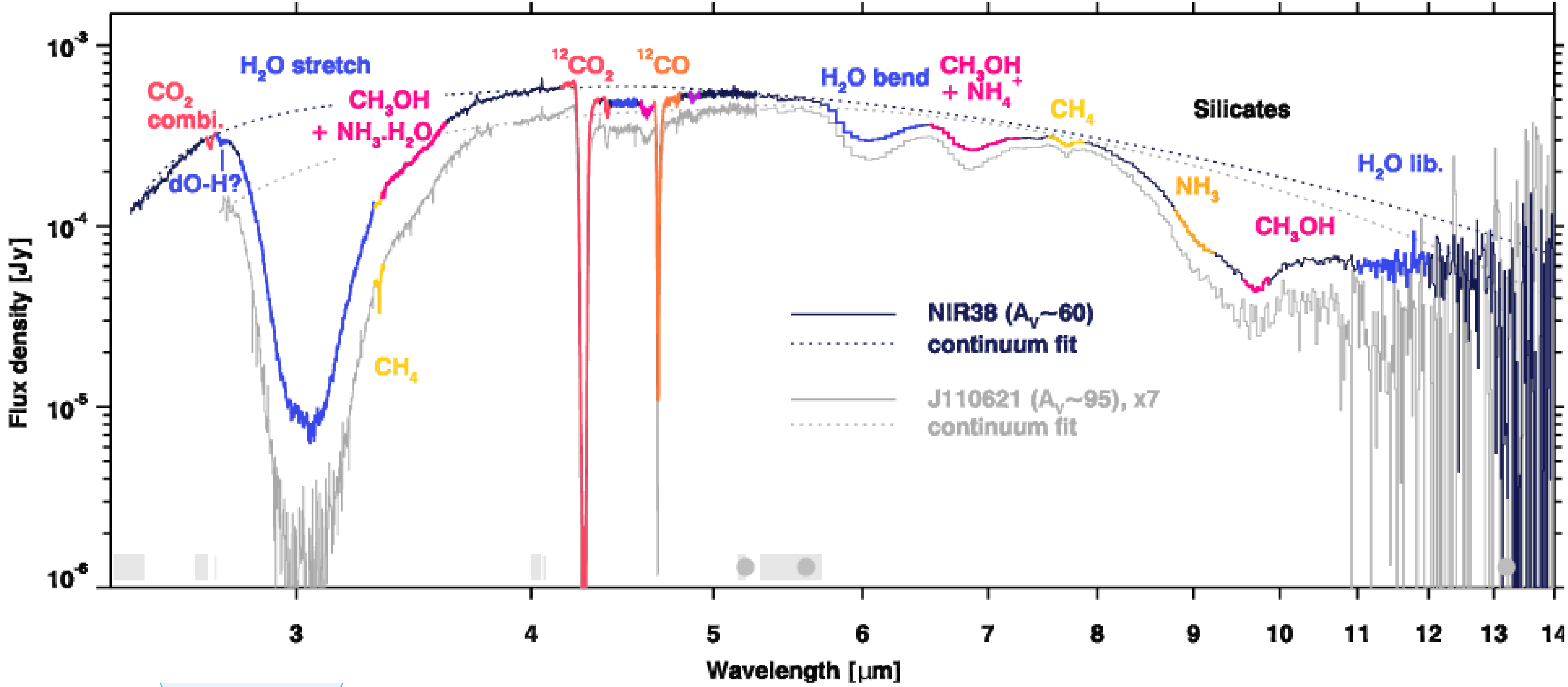
Dense molecular cloud ices

M.K. McClure, et al., *Nature astronomy*, **2023**, 1-13.



Protostellar Object
NGC 1333 IRAS 4A

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2024 *MNRAS* **527,** 10294-10308

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NGC 1333 IRAS 4A

O-bearing group				
CO	^{13}CO	$C^{17}O$	$C^{18}O$	$^{13}C^{17}O$
$^{13}C^{18}O$	NO	SiO	^{29}SiO	SO
SO^+	$S^{18}O$	^{33}SO	^{34}SO	HDO
HCO	HCO^+	DCO^+	$H^{13}CO^+$	$HC^{17}O^+$
$HC^{18}O^+$	OCS	$O^{13}CS$	$OC^{34}S$	SO_2
$^{34}SO_2$	H_2CO	HDCO	D_2CO	$H_2{}^{13}CO$
$H_2C^{18}O$	HCNO	HNCO	HOCN	DNCO
$HOCO^+$	H_2COH^+	H_2CCO	HCOOH	CH_3OH
CH_2DOH	$^{13}CH_3OH$	NH_2CHO	CH_3CHO	HCCCHO
CH_3OCHO	$CH_2(OH)CHO$	C_2H_5OH	CH_3OCH_3	
S-bearing group				
CS	^{13}CS	$C^{33}S$	$C^{34}S$	NS
NS^+	SO	SO^+	$S^{18}O$	^{33}SO
^{34}SO	H_2S	HDS	D_2S	$H_2{}^{33}S$
$H_2{}^{34}S$	HCS^+	CCS	OCS	$O^{13}CS$
$OC^{34}S$	SO_2	$^{34}SO_2$	H_2CS	HDCS
D_2CS	$H_2C^{34}S$	HSCN	CCCS	CH_3SH
N-bearing group				
CN	^{13}CN	NO	NS	NS^+
PN	HCN	DCN	$H^{13}CN$	$HC^{15}N$
HNC	DNC	$HN^{13}C$	$H^{15}NC$	N_2H^+
N_2D^+	$^{15}NNH^+$	$N^{15}NH^+$	$HCNH^+$	HCNO
HNCO	DNCO	HOCN	HSCN	NH_2D
HC_3N	DC_3N	CH_3CN	NH_2CHO	
C-chains group				
CCH	CCD	CCS	$l\text{-}C_3H$	$c\text{-}C_3H$
CCCS	$c\text{-}C_3H_2$	$c\text{-}C_3HD$	C_4H	HC_3N
DC_3N	H_2CCO	HCCCHO	CH_3CCH	

- Identification of 1474 spectral lines;
- 97 different molecular species;

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NGC 1333 IRAS 4A

2	3	4	5
CO	HCO	H_2CO	H_2CCO
CN	HCN	$HCNH^+$	HCOOH
CS	HNC	HCNO	H_2COH^+
SiO	HCO^+	HNCO	HC_3N
NO	CCH	HOCN	c-C_3H_2
SO^+	H_2S	c-C_3H	C_4H
SO	SO_2	l-C_3H	
NS	N_2H^+	CCCS	
NS^+	OCS	$HOCO^+$	
PN	CCS	H_2CS	
	HCS^+	HSCN	
6	7	8	9
CH_3OH	CH_3CHO	CH_3OCHO	C_2H_5OH
CH_3CN	CH_3CCH	$CH_2(OH)CHO$	CH_3OCH_3
NH_2CHO			
CH_3SH			
HCCCHO			

- Identification of 1474 spectral lines;
- 97 different molecular species;
- C-O-N-S-P-Si;

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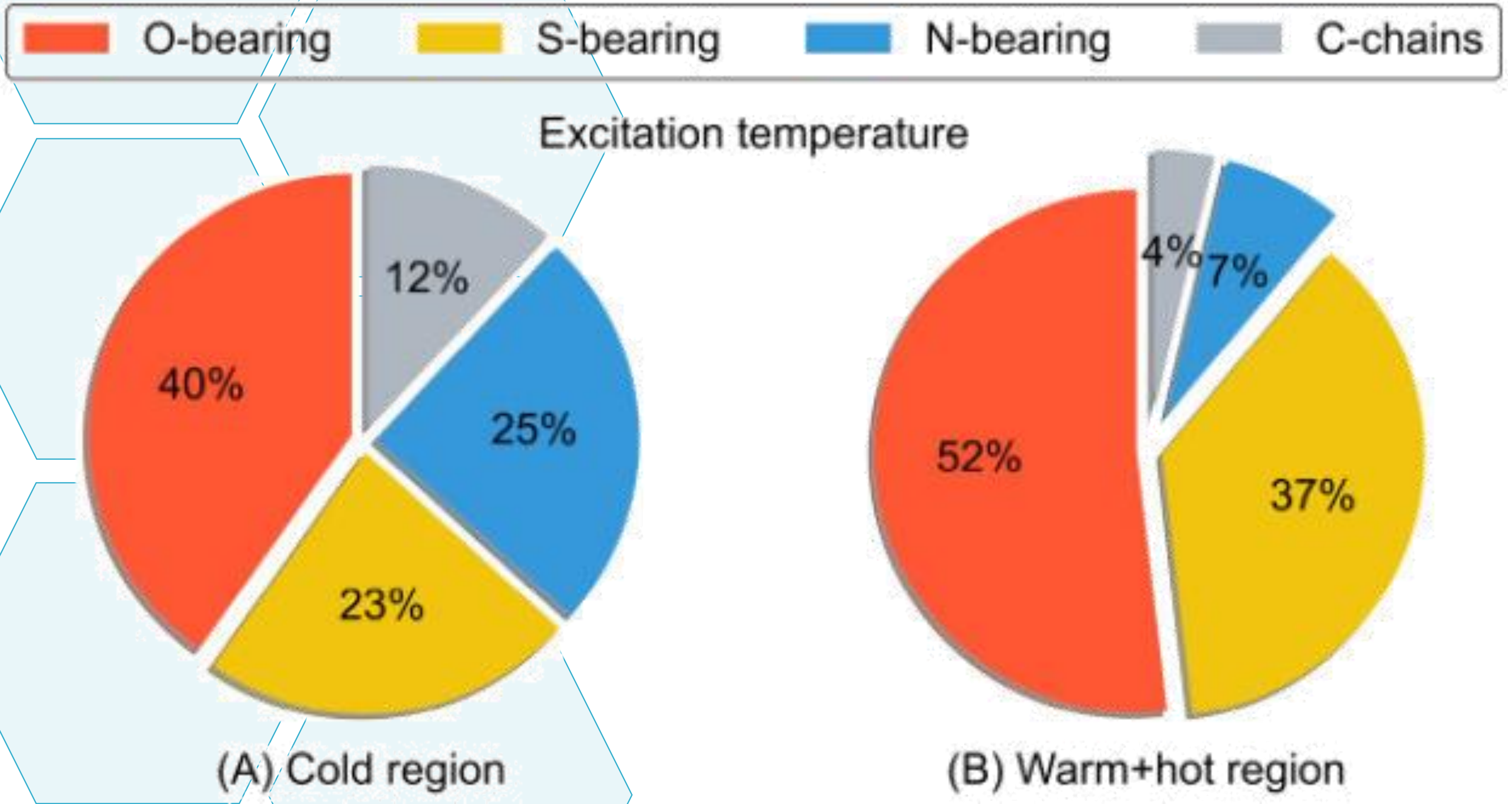
2024 *MNRAS* **527,** 10294-10308

NGC 1333 IRAS 4A



- Identification of 1474 spectral lines;
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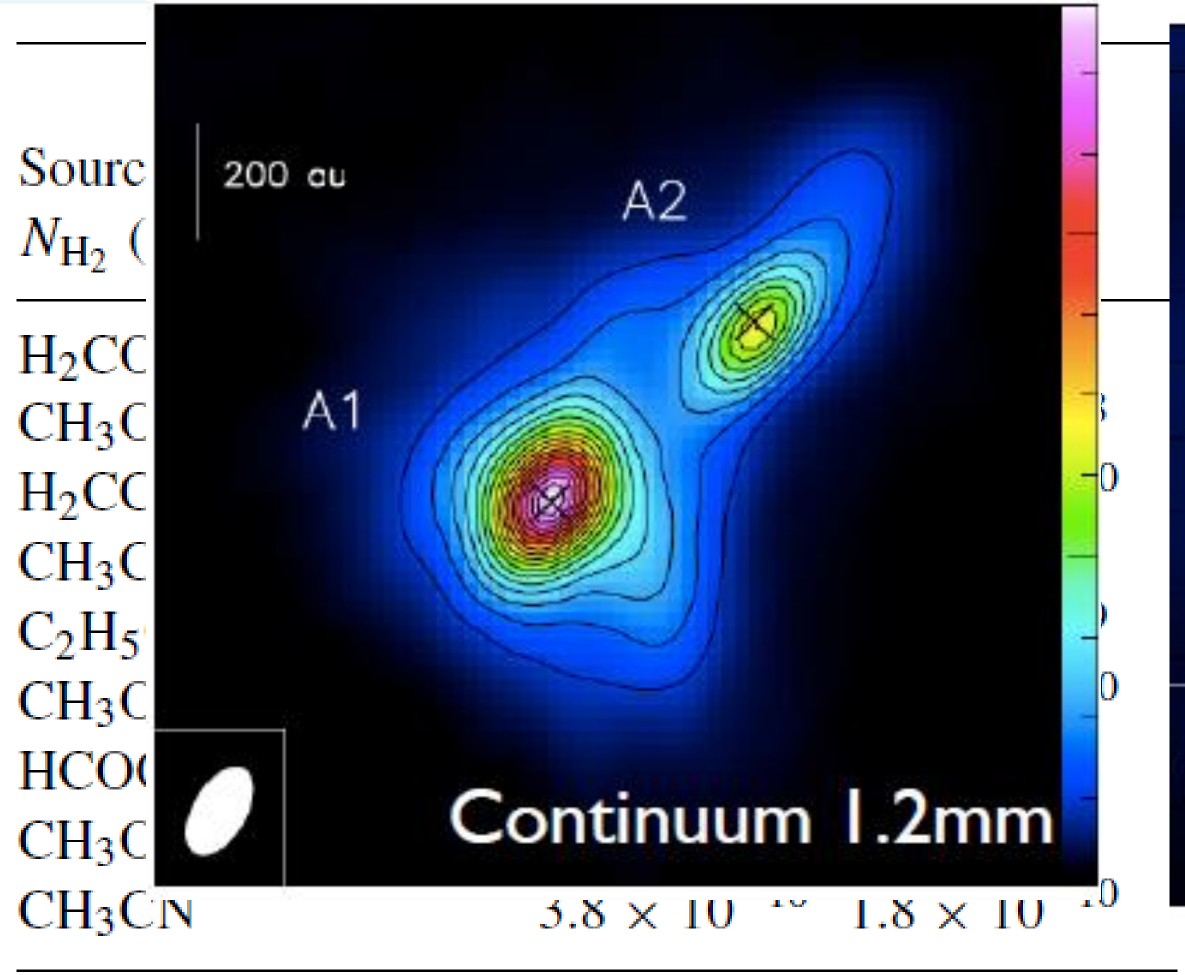
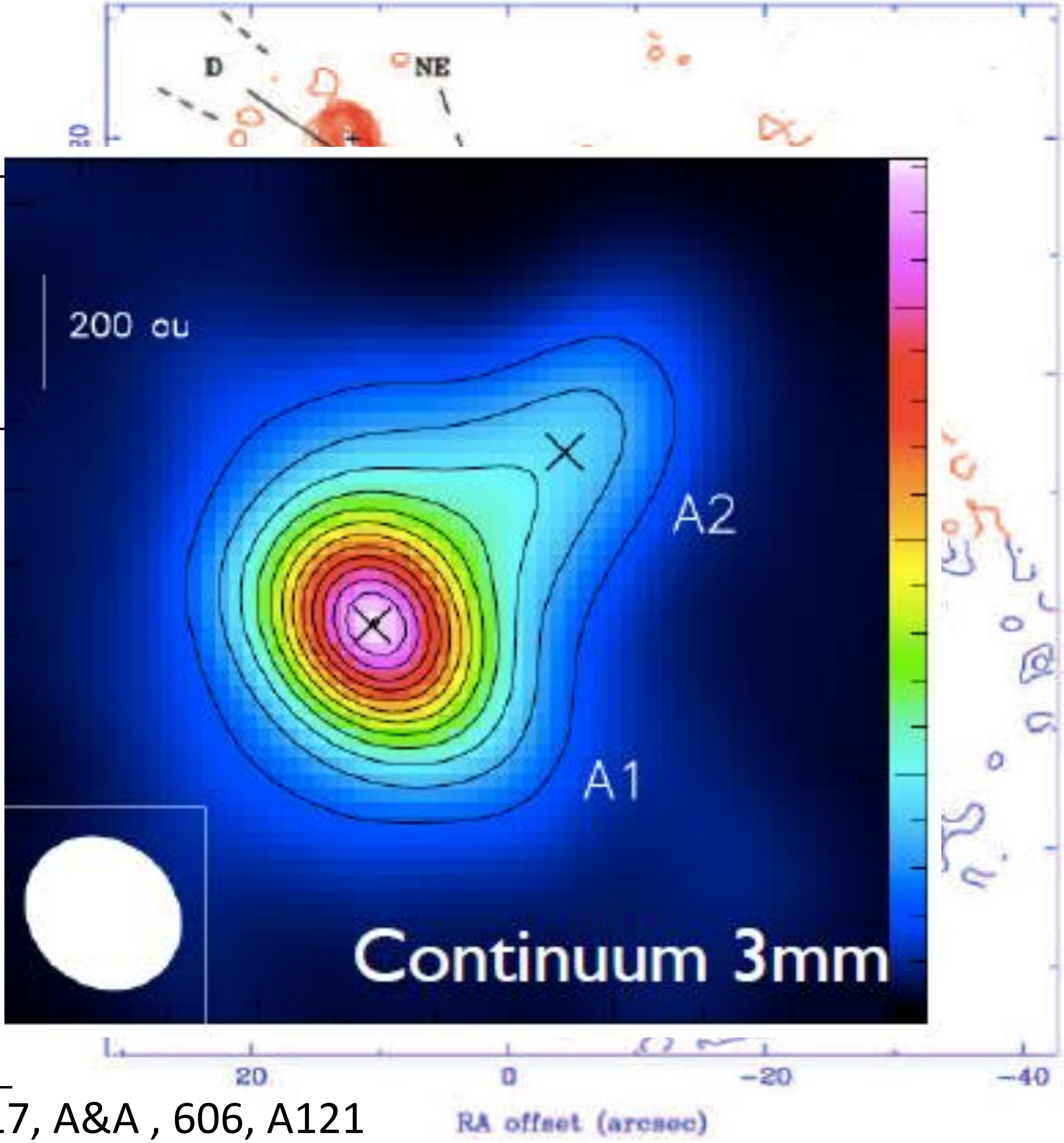
NGC 1333 IRAS 4A

Santangelo G. et al., 2015, A&A , 584, A126

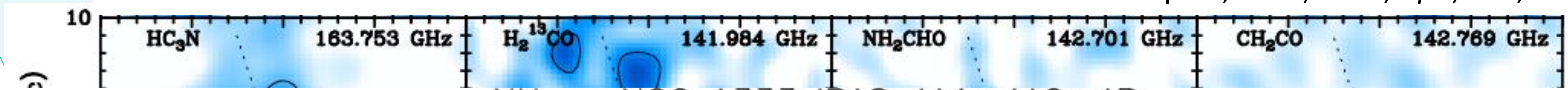


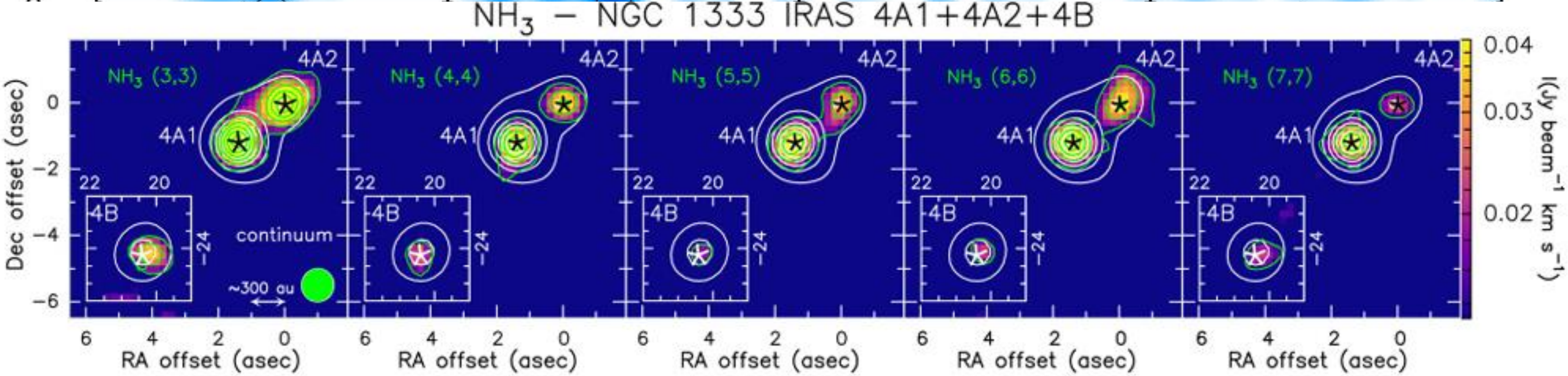


López-Sepulcre A. et al., 2017, A&A , 606, A121

NGC 1333 IRAS 4A

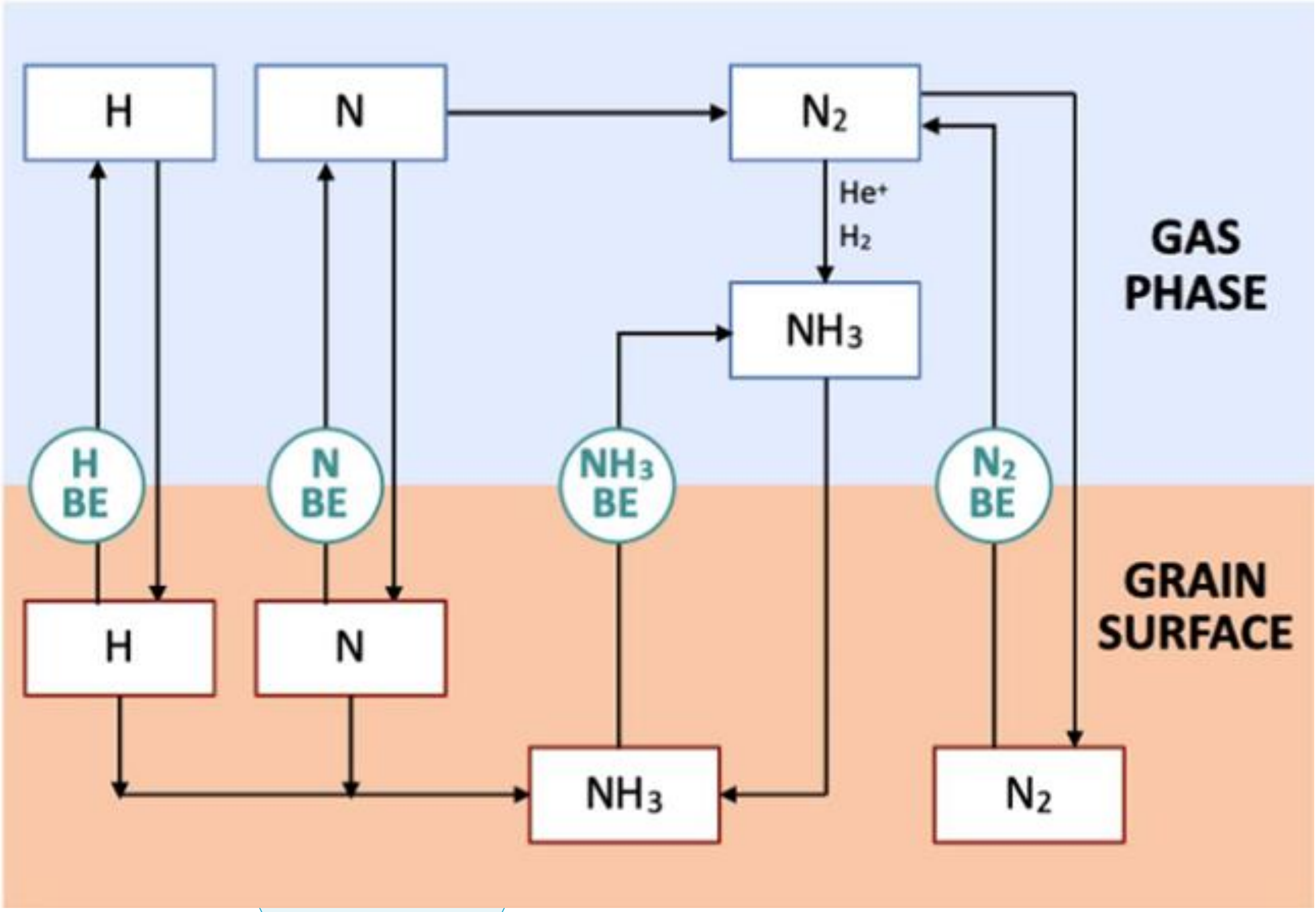
V. Taquet , et al., **2015**, *ApJ* , 804, 81





M. De Simone, et al., **2022,** *ApJL* , 935:L14

NGC 1333 IRAS 4A



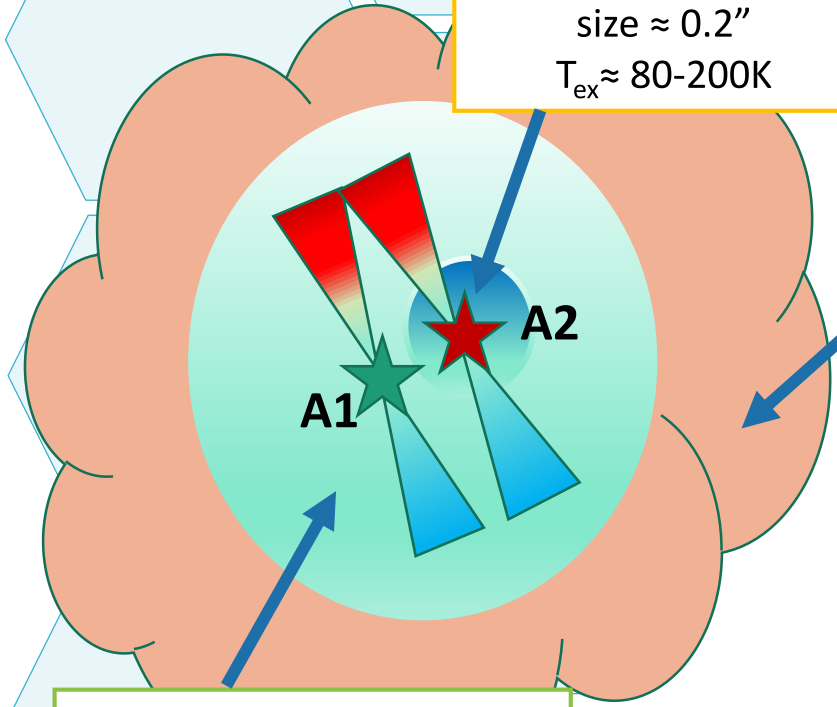
Composition of **the icy mantle** along the line of sight of **protostars and protoplanetary discs** will be crucial for characterising the chemical and physical evolution of the early stages of **planetary system formation**.

M. De Simone, et al., **2022,** *ApJL* , 935:L14

Morphological representation of IRAS 4A

Hot corino
of high-excitation gas
size ≈ 0.2”
T_{ex}≈ 80-200K

Traced by the CH_3OH molecule.

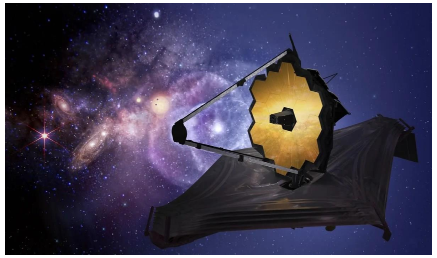


Cold outer envelope
of low-excitation gas
size ≈ 100”
T_{ex} ≈ 10-20K

Rich in **simple molecules**.
More than **80%** of total species were **identified here including hydrocarbons, polyynes**;

Warm medium envelope
of moderate-excitation gas
size ≈ 20”
T_{ex} ≈ 40-60K

Complex organic molecules are identified
CH_3OH, H_2CCO, CH_3CHO, NH_2CHO.
Evaporating Ice mantle Region



Conclusions

- Specialised **telescopes** allowed the **identification** of a broad variety of **molecules**;
- Gas phase shows a **large molecular richness**;
- More information is needed on **ice mantles** and the effects of evaporation in modifying the physical-chemical properties of astrophysical objects;
- **Collaboration** with **experimental** and **theoretical** groups is needed.
- **Telescopes** and **astronomy** are powerful platforms for **scientific outreach**.

STEM Outreach Programmes in Colombia

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She's an Astronaut: Colombian girls at NASA

Date: Thursday, 10 February 2022

No dream is impossible to fulfill. That is what Mariana Ospina and Ingrid Guacheta repeat when they remember that, at just 16 and 15 years old, respectively, they visited NASA. This is thanks to the fact that in October 2019, the NASA Space Center signed an alliance for the development of the She's an Astronaut program, whose objective is to impact the lives of 31 Colombian girls between the ages of 9 and 16, who live in vulnerable situations, in rural areas of the country and who have mostly been affected by the armed conflict such as Putumayo, Cauca, Chocó, Bolívar, Meta, Santander, Magdalena and Cundinamarca.

Since 2019, **more than 500 girls** have participated!

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2024

1st Colombian Symposium on Astrochemistry (23-26/10/24)

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OBSERVATORIO ASTRONÓMICO NACIONAL DE COLOMBIA

Bogotá, Colombia

Chairs: Prof Dr Mario Higuera (Colombian National Observatory);
Dr Heidy Quitián-Lara (University of Kent)

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Thank you!