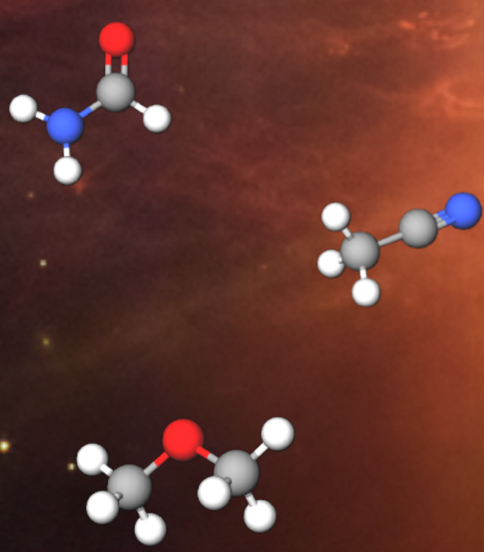
Astrochemistry: perspectives for the SKAO



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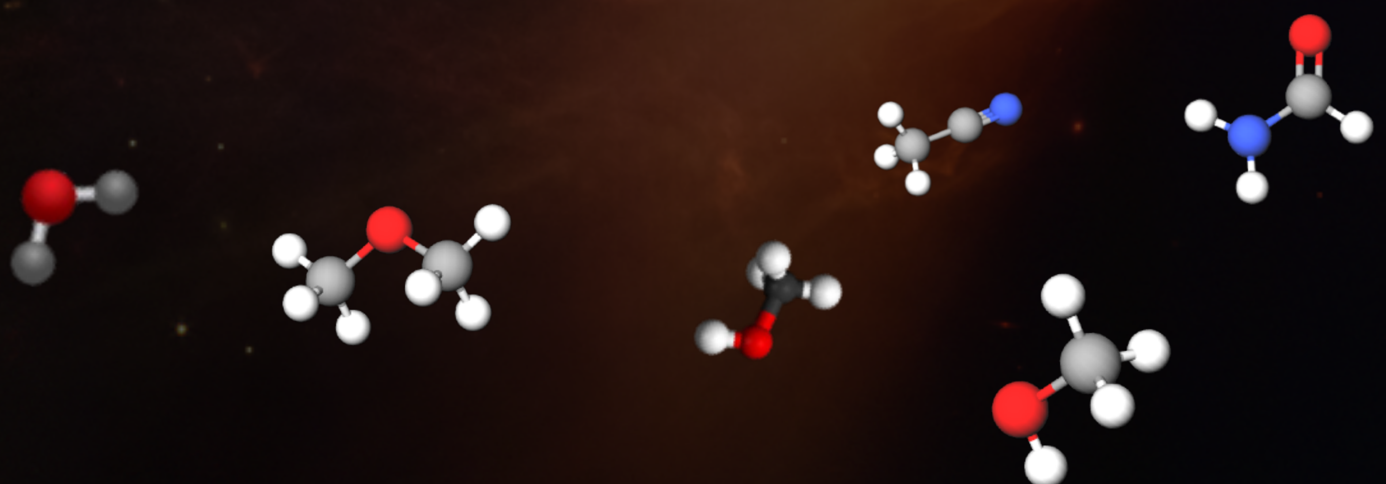
Astrochemistry with the SKA

- From a diffuse cloud to a solar-like planetary system
- Chemical diversity: hot corino vs WCCC
- Radio observations of complex carbon chemistry
- Astrochemistry of planet-forming disks
- Future perspectives with a new generation of instruments: science case for SKA-MID



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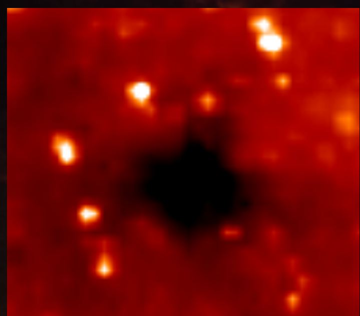
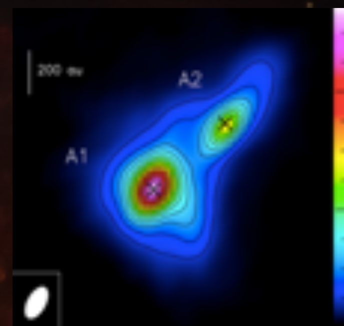
From a diffuse cloud to a solar-like planetary system

1) Prestellar phase



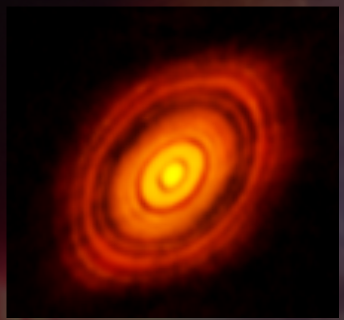
t=0
gravitational collapse

2) Protostellar phase



~10^4 yr
envelope,disk, jets/outflows

3) Protoplanetary disk phase

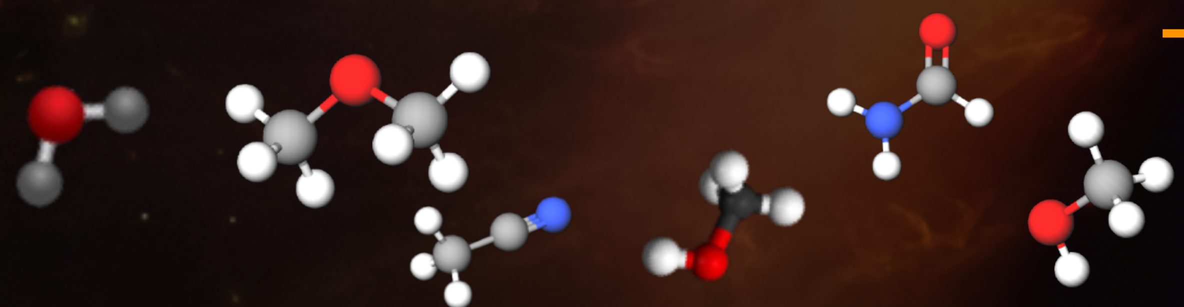


~10^5 yr
disk, jets/outflows

4) Planetesimals & planets formation

~10^6–10^7 yr
dust growth & settling
planetes formation

Time



?

Astrochemistry is a powerful tool to reconstruct this history

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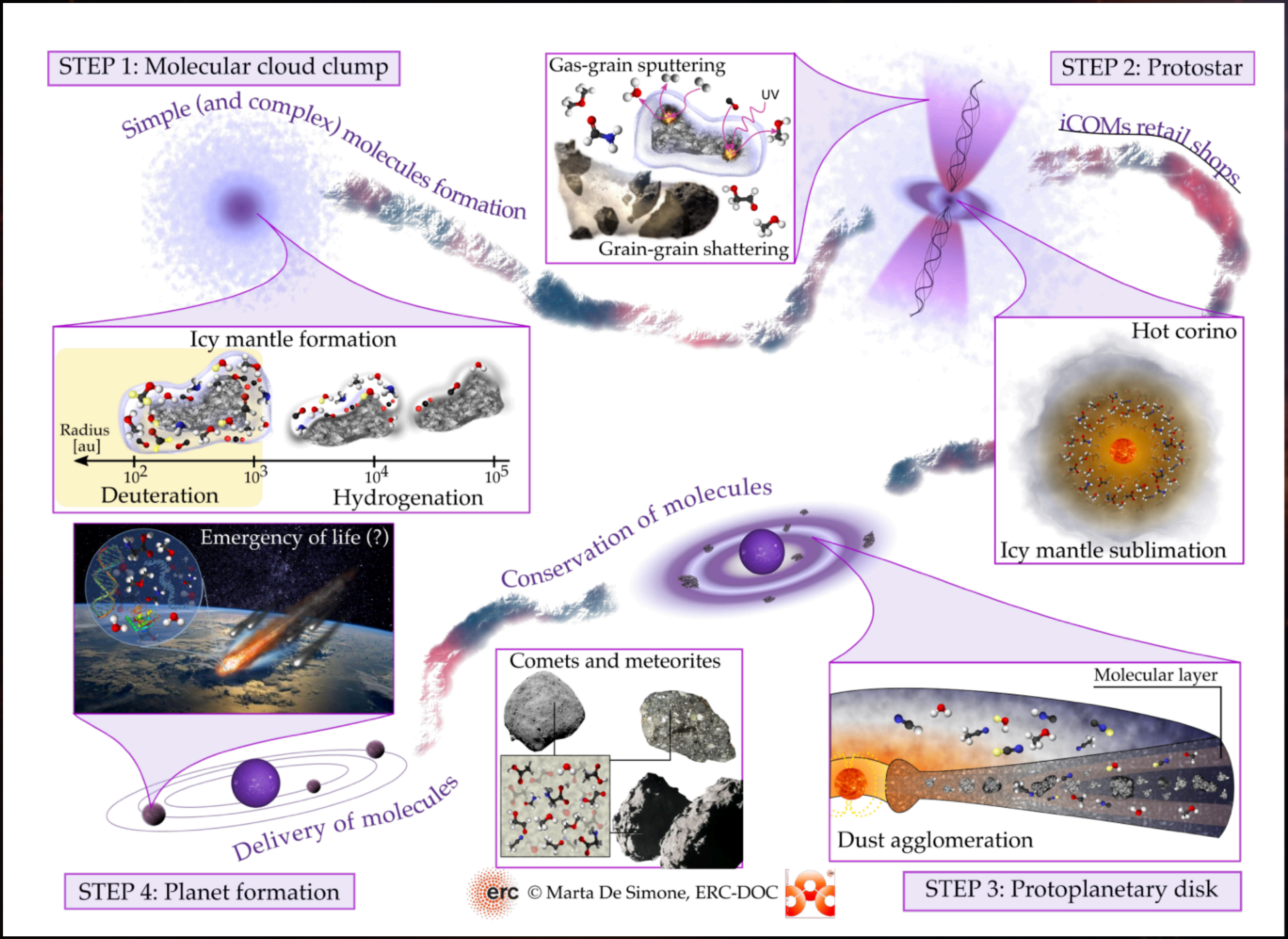
From a diffuse cloud to a solar-like planetary system



Planetary composition: disk chemical reset or inheritance ?

e.g., Caselli & Ceccarelli 2012; Ceccarelli et al. 2023, PPVII

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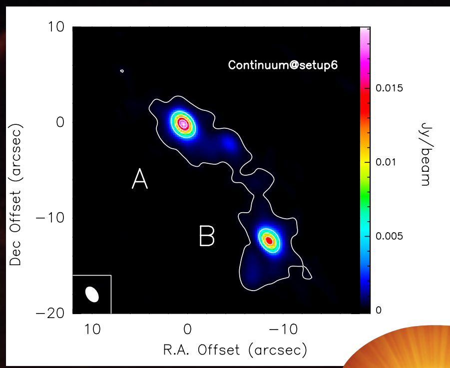
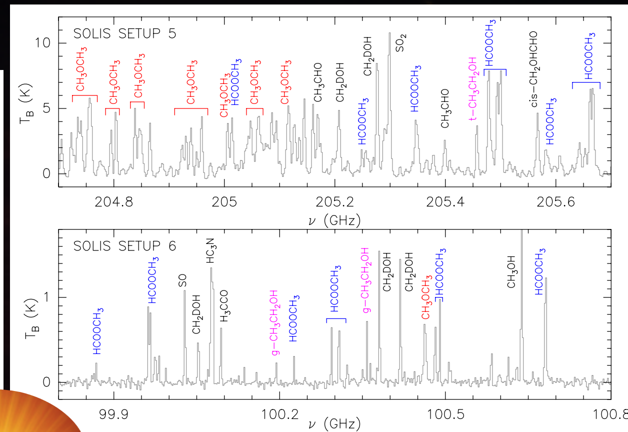
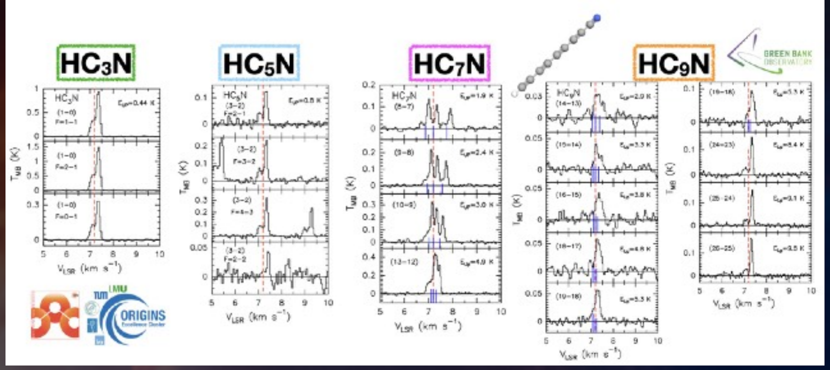
Multi-wavelength observations of Solar-System analogs

Ceccarelli et al. 2022
Bianchi et al. 2022a





Bianchi et al. 2023

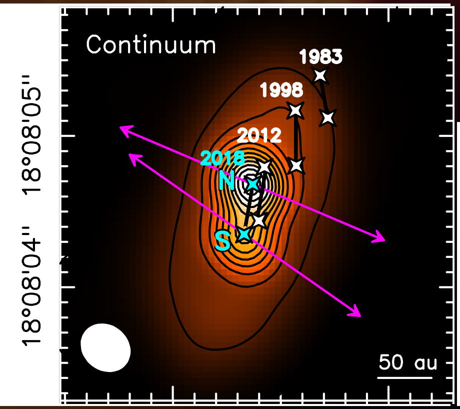


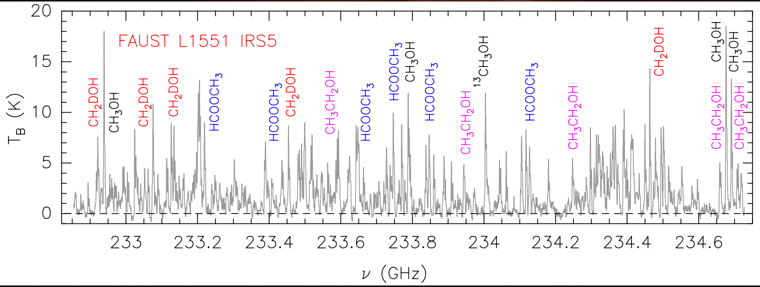
GBT pilot survey

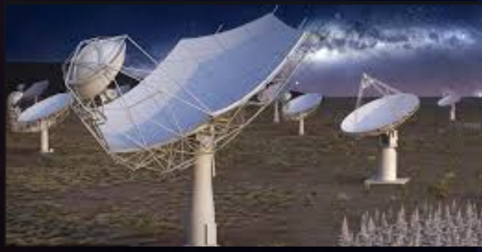
IRAM NOEMA LP

ALMA LP

Bianchi et al. 2020

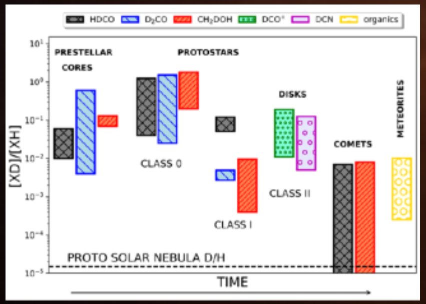






Coming....

IRAM 30m LP



Bianchi et al. 2017, 2019a, 2019b

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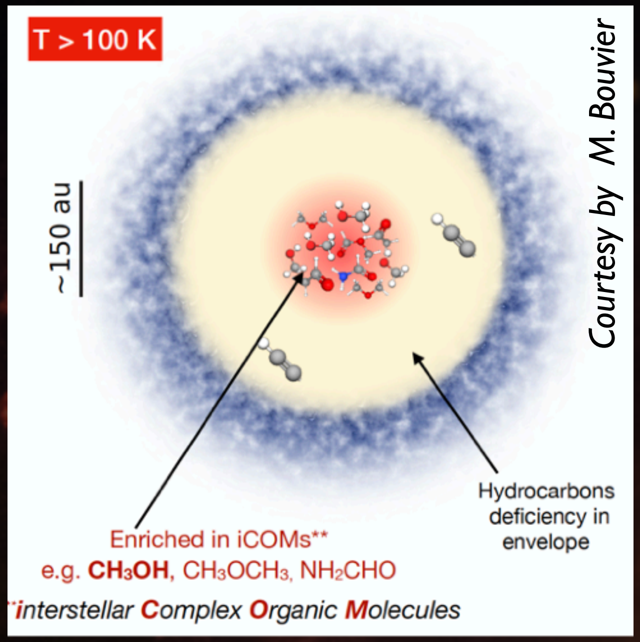
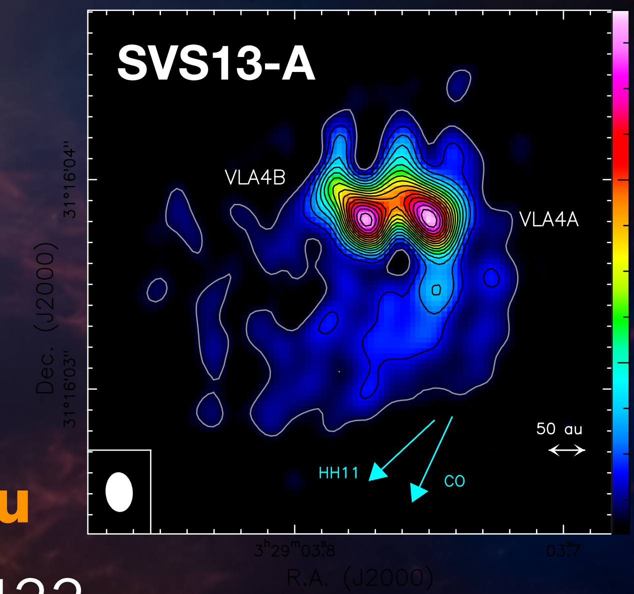
Chemical diversity



Hot corino

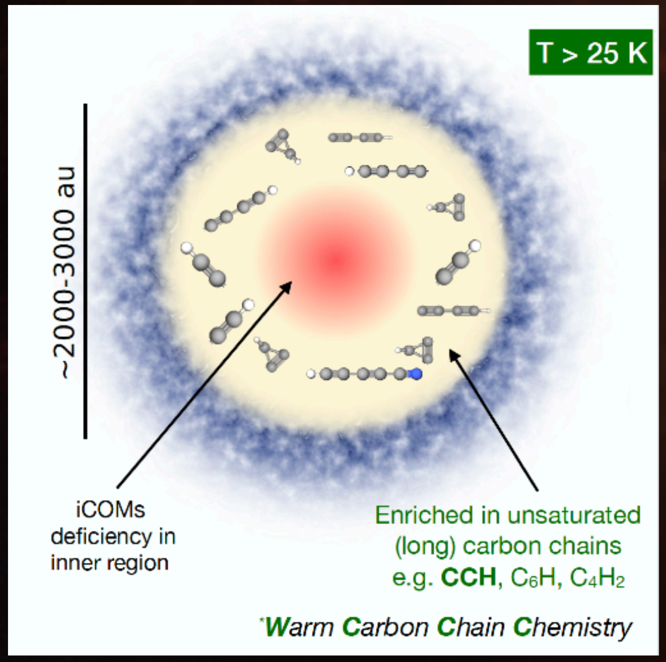
interstellar complex organic molecules (iCOMs) e.g. $HCOOCH_3$, CH_3OCH_3, CH_3CH_2OH, NH_2CHO…



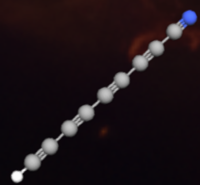
Bianchi et al. 2022b

Abundances ~100x WCCCs **size < 100 au**

Examples: SVS13-A, IRAS4A, IRAS16293-2422..



Warm Carbon Chains Chemistry (WCCC)



Unsaturated (long) carbon chains e.g. C_4H_2, C_4H, C_6H, HC_7N, HC_9N…

Abundances ~10x those in hot corinos

Examples: L1527 **size ~ 2000 au**

Tobin/NASA/JPL-Caltech

Ceccarelli et al. 2004, 2022, Sakai & Yamamoto 2013, Yoshida et al. 2019, Bouvier et al. 2020

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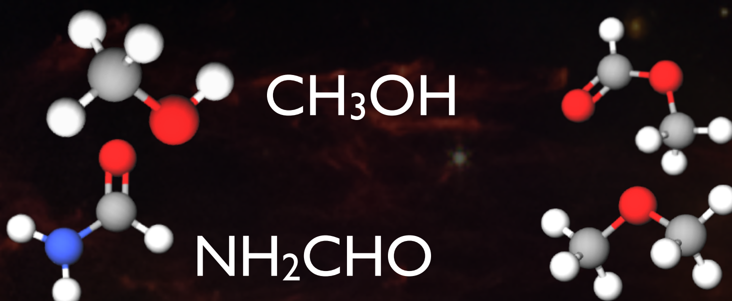
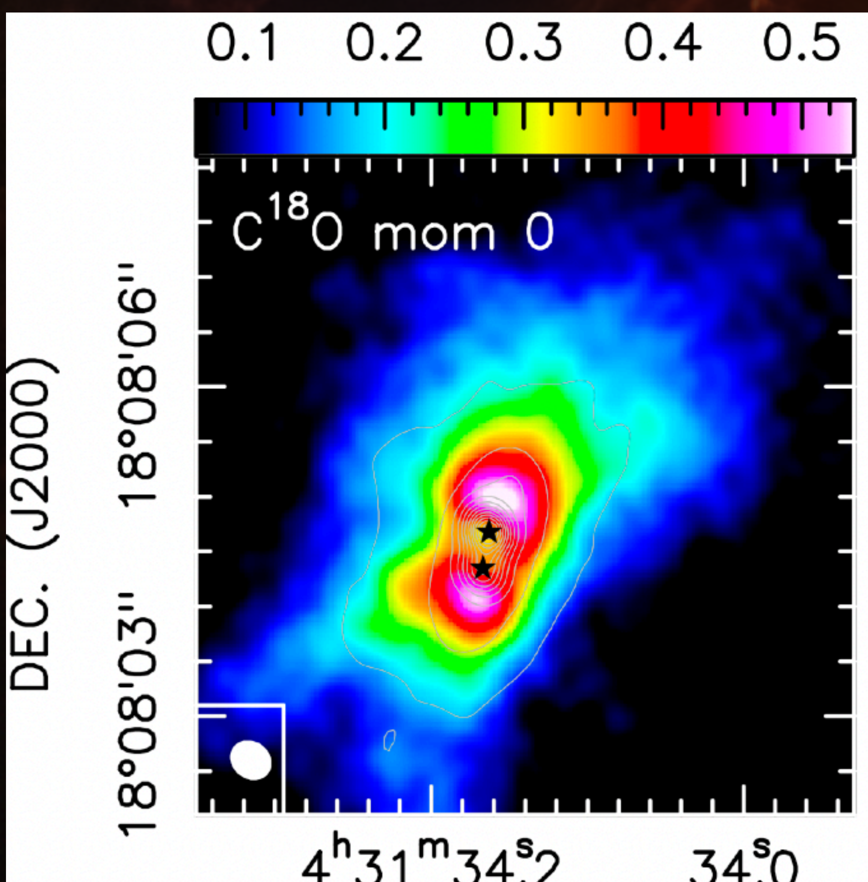
Hot corinos in the (sub-)mm

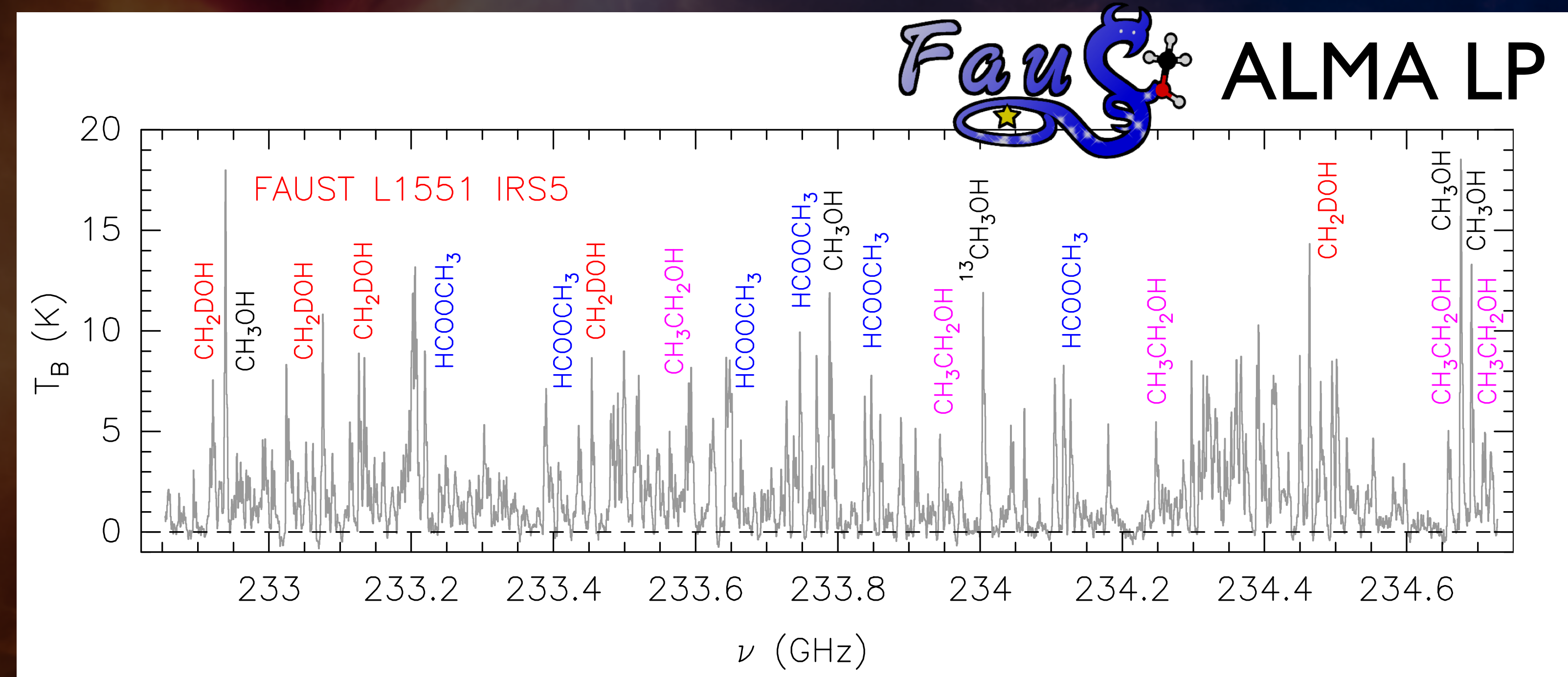
Interstellar Complex Organic Molecules (iCOMs, > 6 atoms)



CH_3OH $HCOOCH_3$ NH_2CHO CH_3OCH_3

Bricks of prebiotic molecules abundant in young protostars!





Bianchi et al. 2020, FAUST I

50 au scale: in the planet-formation region

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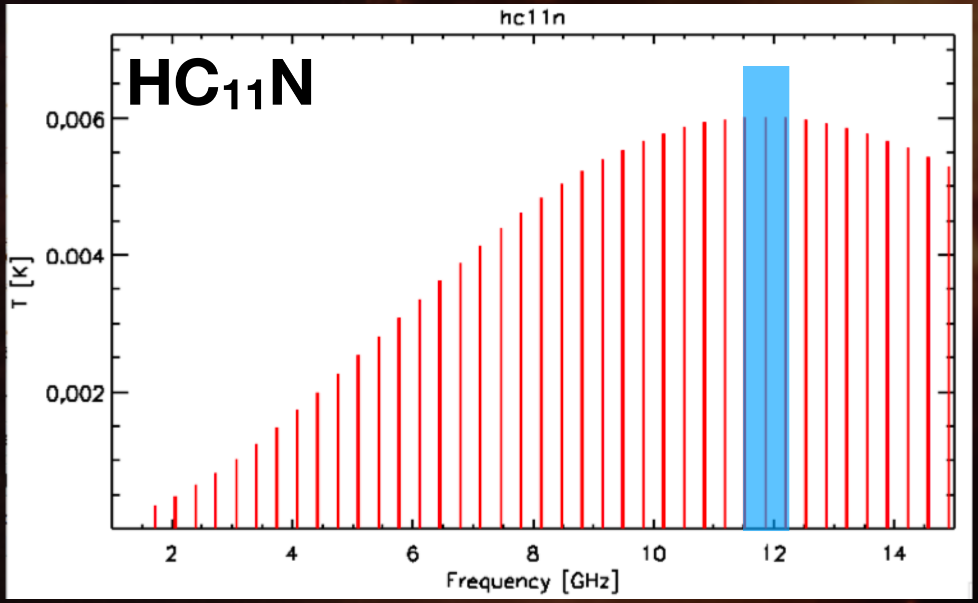
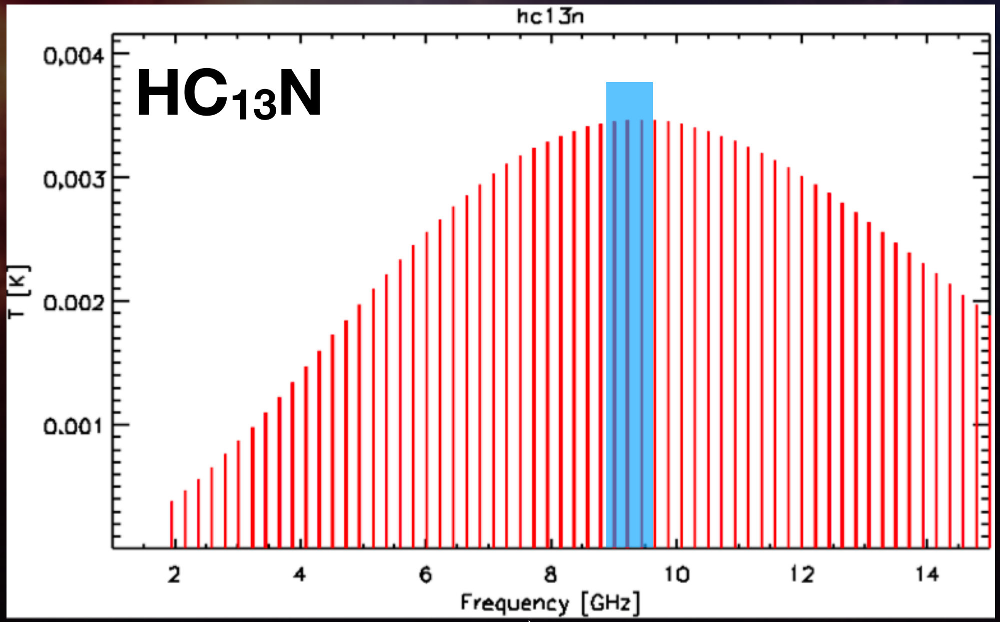
Astrochemistry at radio frequencies

Large molecules peak at lower Frequencies

Rotational transitions–> the line frequencies depend on the moment of inertia of the molecule

Predicted LTE spectrum





Increasing complexity

Simple prestellar core simulation with T=10 K, N=10^{11} cm^{-2} FWHM=0.2 km/s and extended source size

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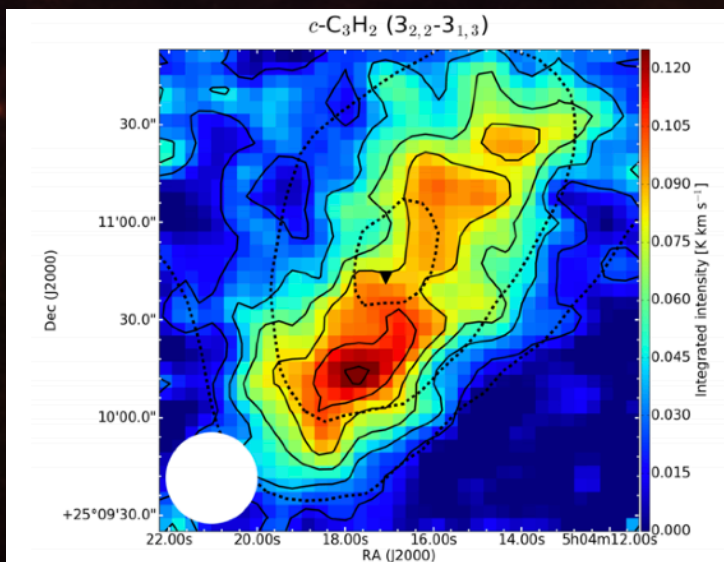
Complex carbon chemistry

GBT observations 53 hours

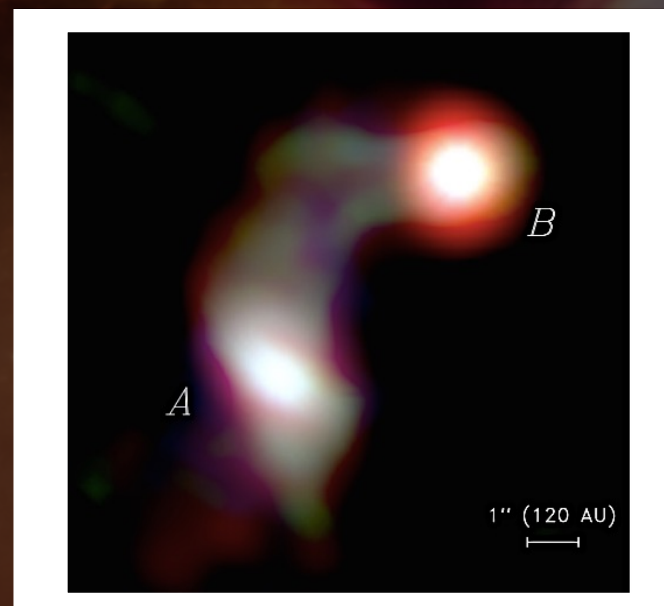
L1544 prestellar core



Low density shell rich in iCOMs and Carbon Chains

Vastel et al. 2014, Jiménez-Serra et al. 2016, Spezzano et al. 2017 , Urso et al. 2019

IRAS 16293-2422 protostar



Hot corino rich in iCOMs

Cazaux et al. 2003, Bottinelli et al. 2004 , Jaber et al. 2017, Jørgensen et al. 2016

Survey of
Ku-band ~ 13.9-15.4 GHz
+
follow up of L1544 in
X-band ~ 8-11.5 GHZ
rms ~ 1-2 mK

SKA Band 5 frequencies

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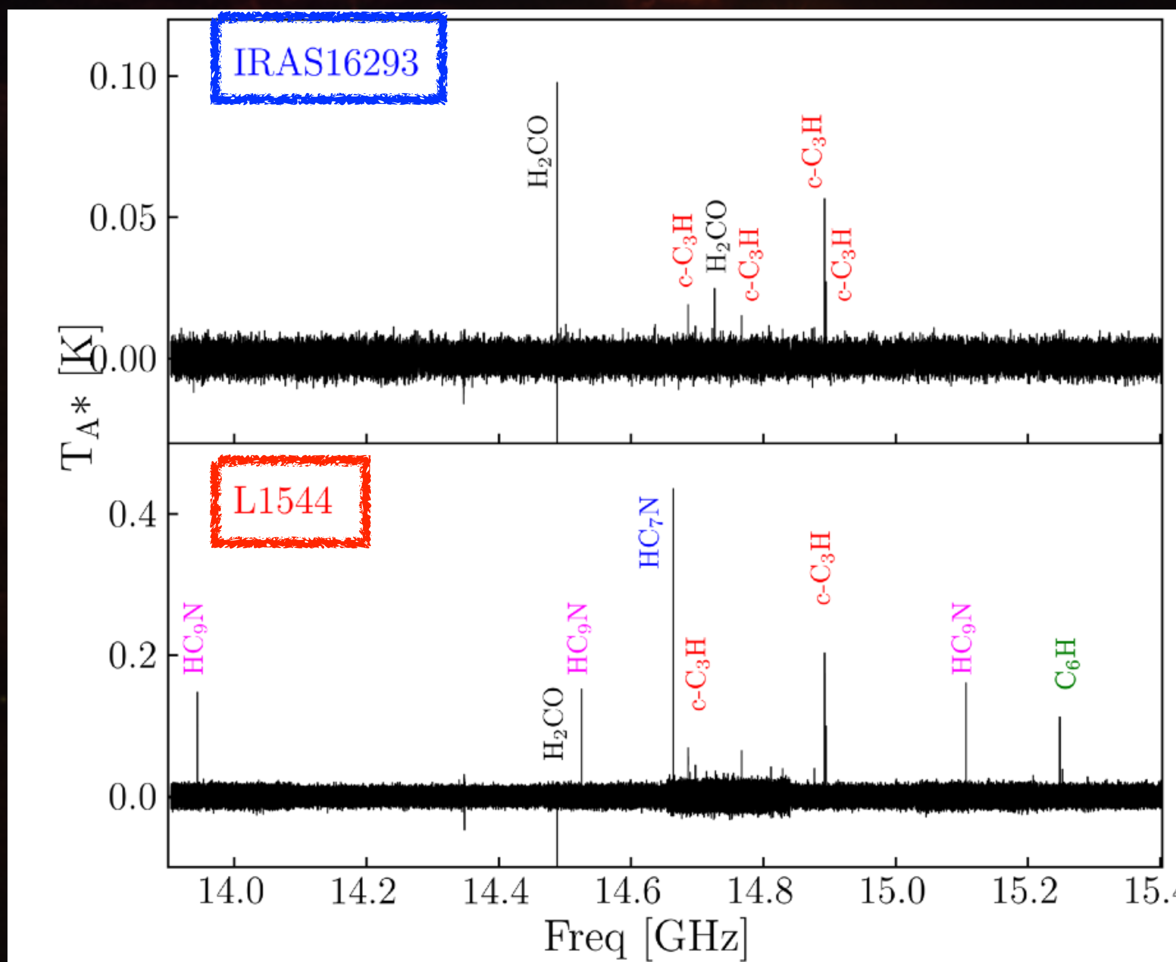
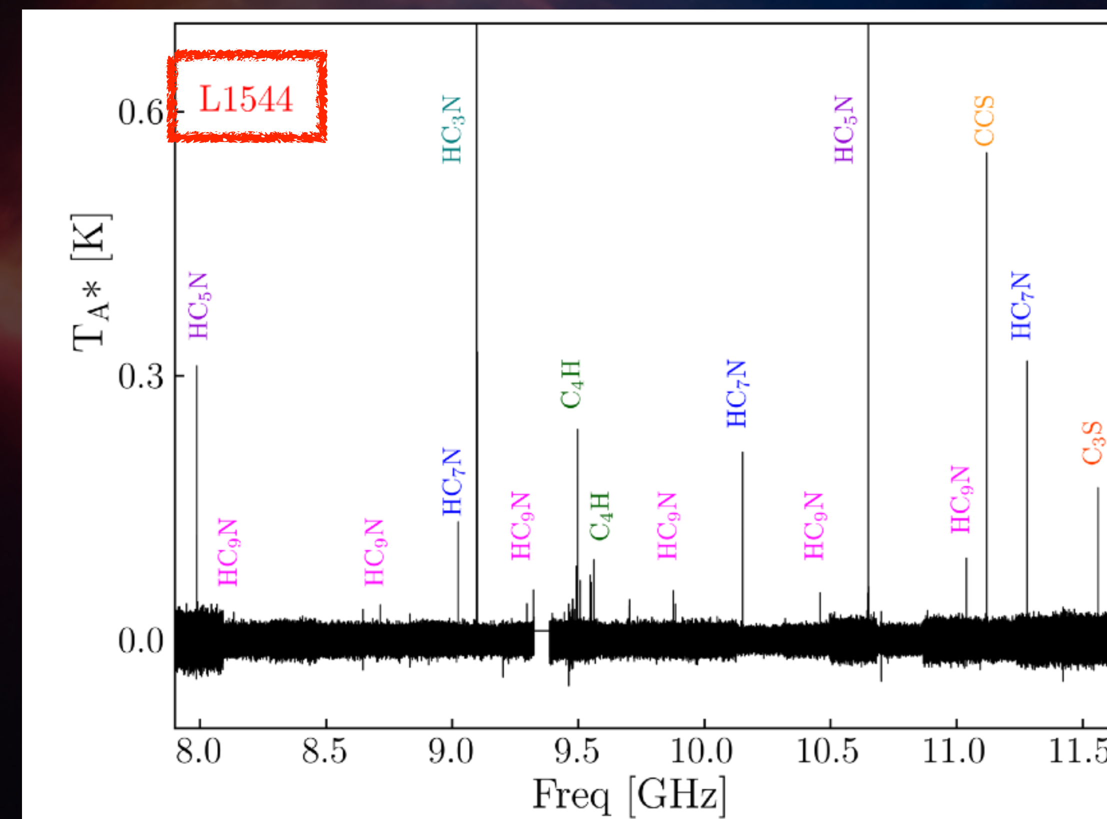
Complex carbon chemistry

Ku-band



X-band



Bianchi et al. 2023

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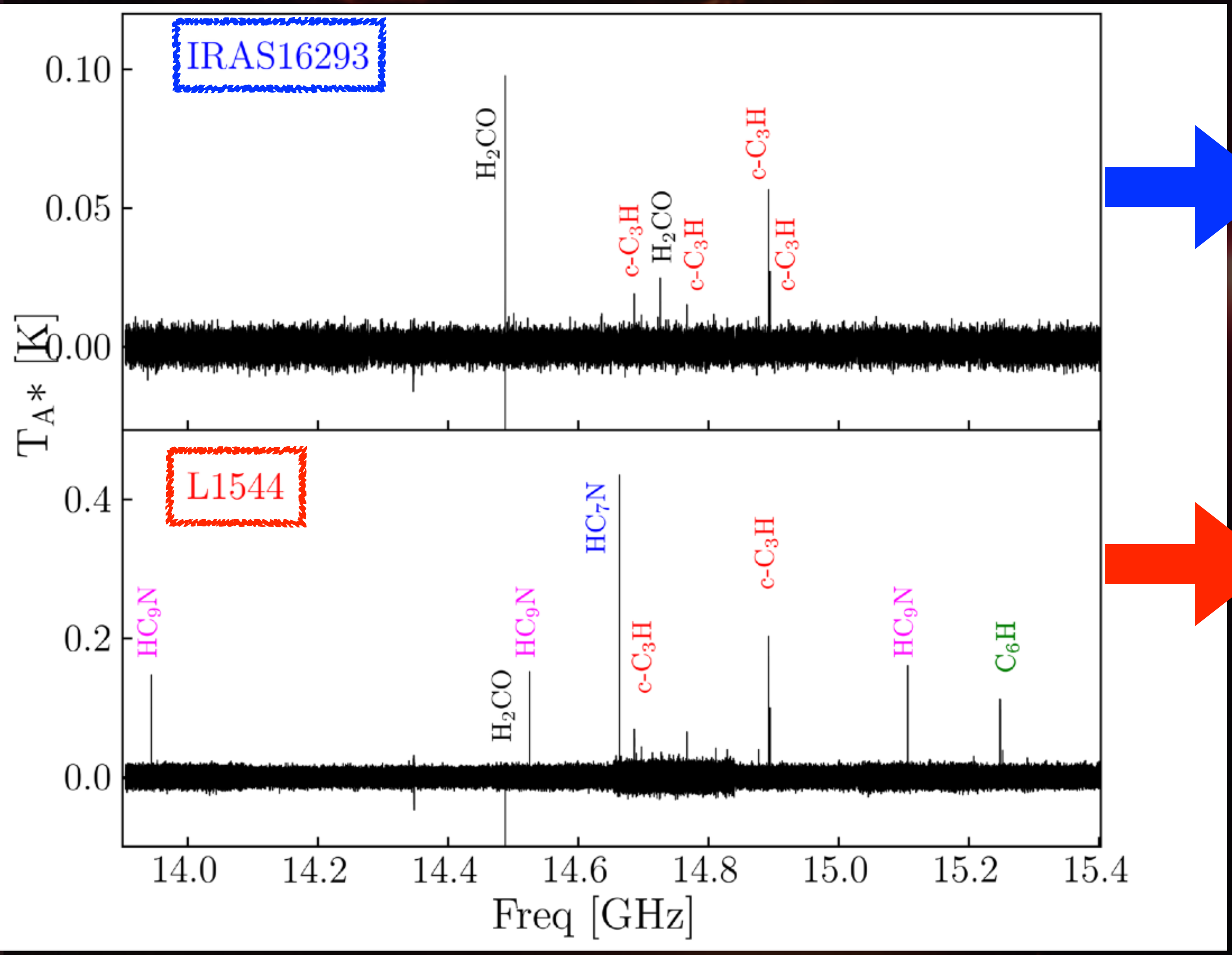
Complex carbon chemistry

Chemical diverse?



Bianchi et al. 2023

Detected
H_2CO IRAS16293 B
c-C_3H envelope/parental cloud

Detected
H_2CO
c-C_3H, C_4H, C_6H,
HC_3N, HC_5N, HC_7N, HC_9N,
CCS, C_3S

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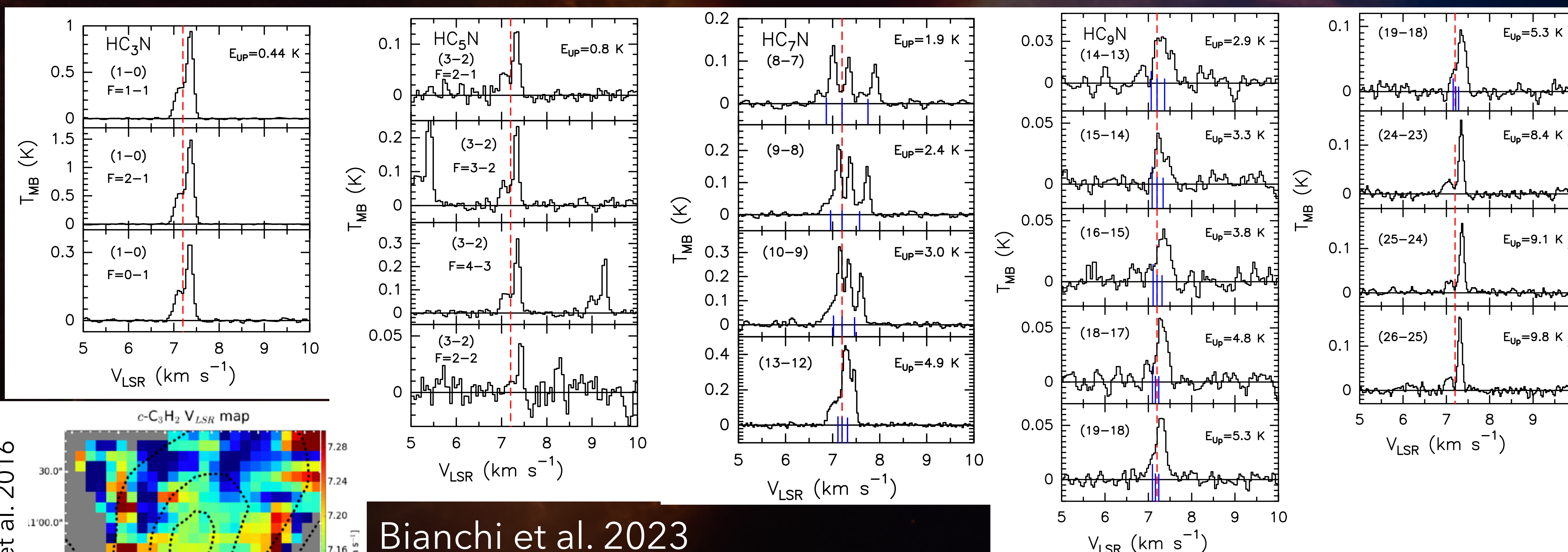
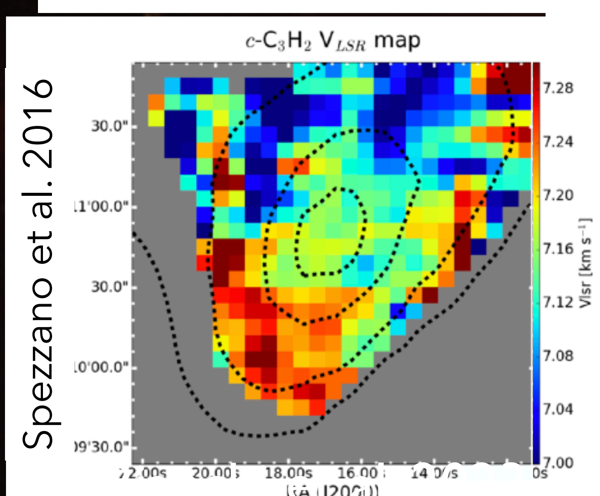
Complex carbon chemistry

From HC_3N to HC_9N

HC_3N  HC_5N HC_7N HC_9N





Spezzano et al. 2016

Bianchi et al. 2023

Cyanopolyyne emission is dominant in the outer layers of the core

LVG analysis

T_{kin} = 7.5 K

$n_{H2} \geq 100$ cm^{-3}

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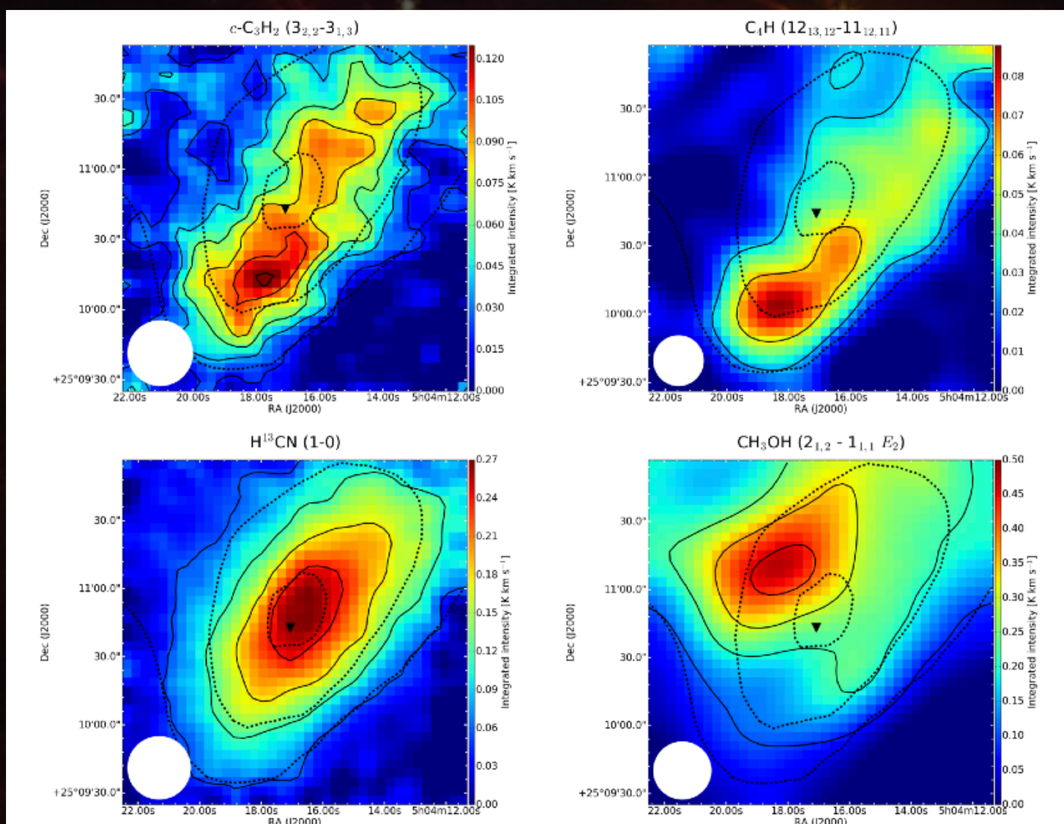
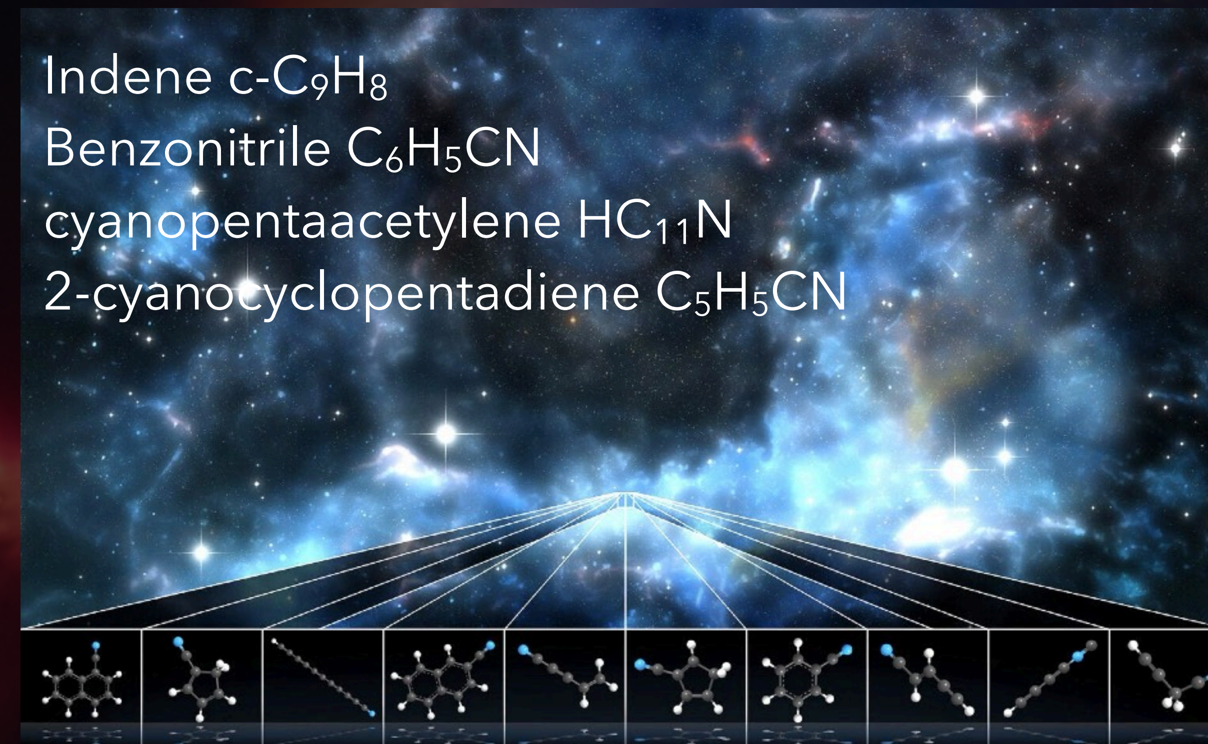
Complex carbon chemistry

cyanopolyyne chemistry depends on the gaseous C abundance



Spezzano et al. 2016, 2017

Age or UV illumination?



GBT GOTHAM: TMC-1; McGuire et al. 2020
GBT ARKHAM: 4 sources; Burkhardt et al. 2021
YEBES 40m QUIJOTE: TMC-1; Cernicharo et al. 2021

Synergy between (sub-)mm and radio observations

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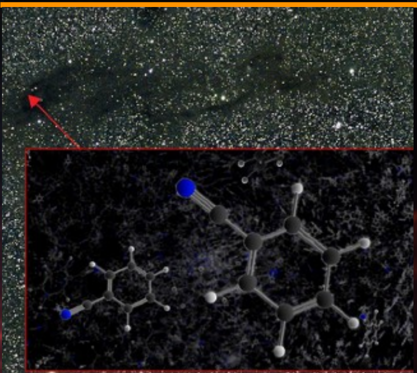
Complex carbon chemistry



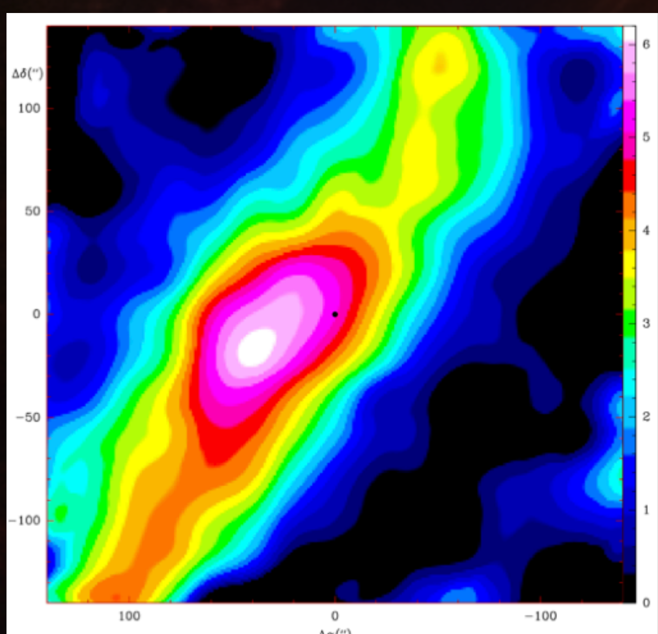
Rich carbon chemistry

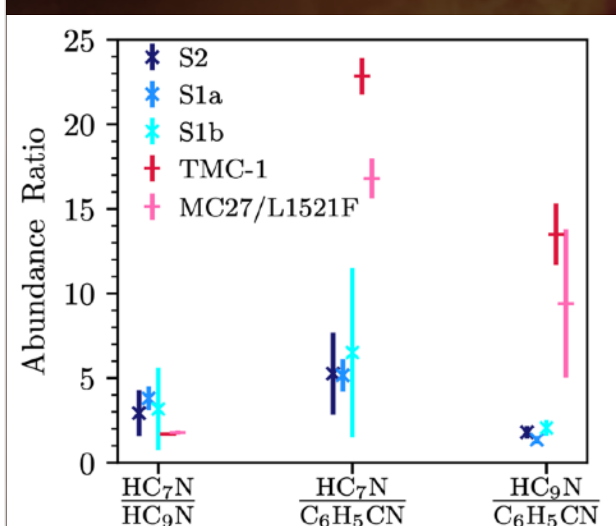
Indene c-C_9H_8
cyanopentaacetylene $HC_{11}N$
2-cyanocyclopentadiene C_5H_5CN

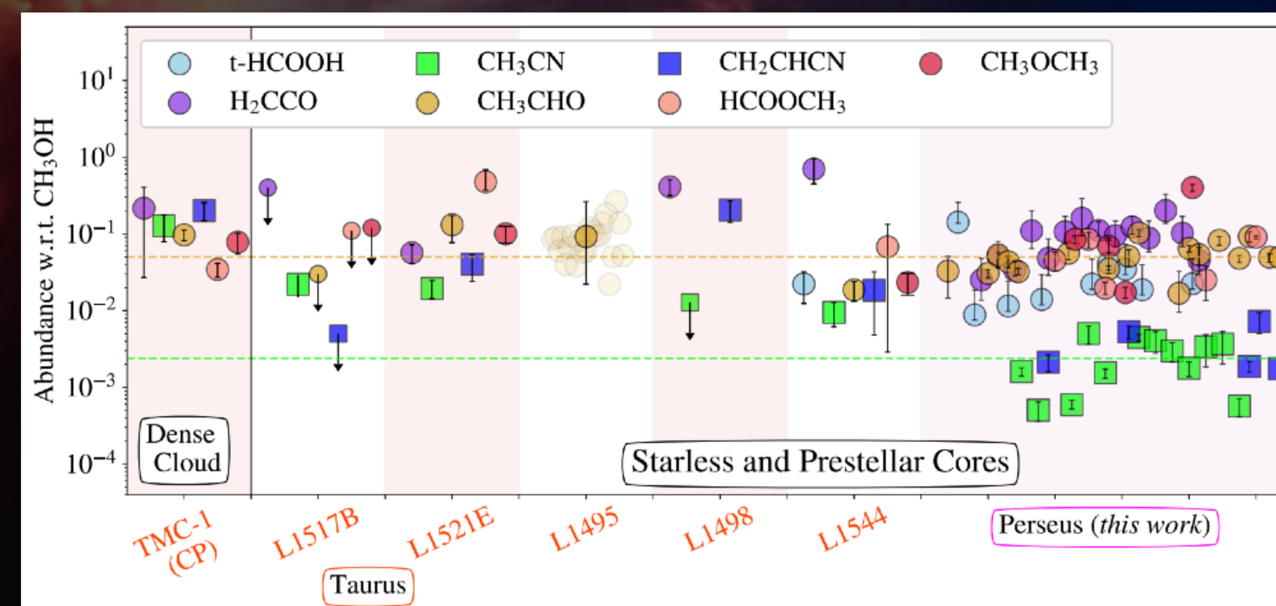
Interstellar complex organic molecules

Taurus 31 cores
CH_3OH ~100%
CH_3CHO~70%

C_6H_5CN benzonitrile in TMC-1







Cernicharo et al. 2023, Burkhardt et al. 2021
McGuire et al. 2018, Agúndez et al. 2023, Fuente et al. 2023,
Cernicharo et al. 2021a, 2021b, 2022, Bianchi et al. 2023a

Scibelli et al. 2020, 2024

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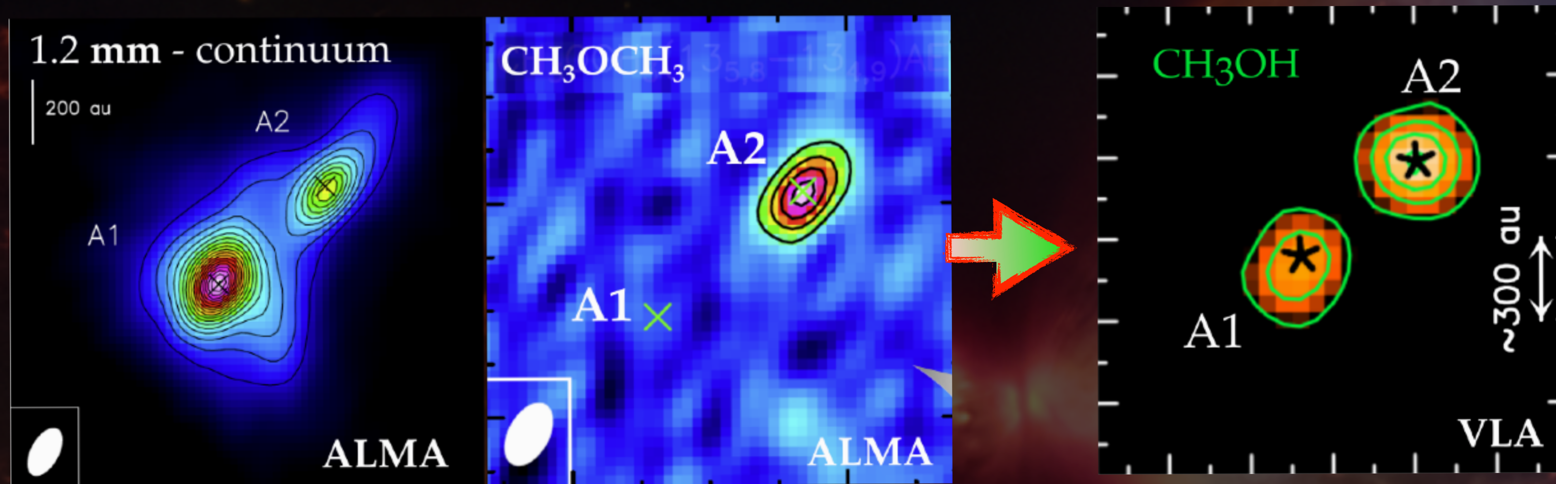
Astrochemistry of planet-forming disks

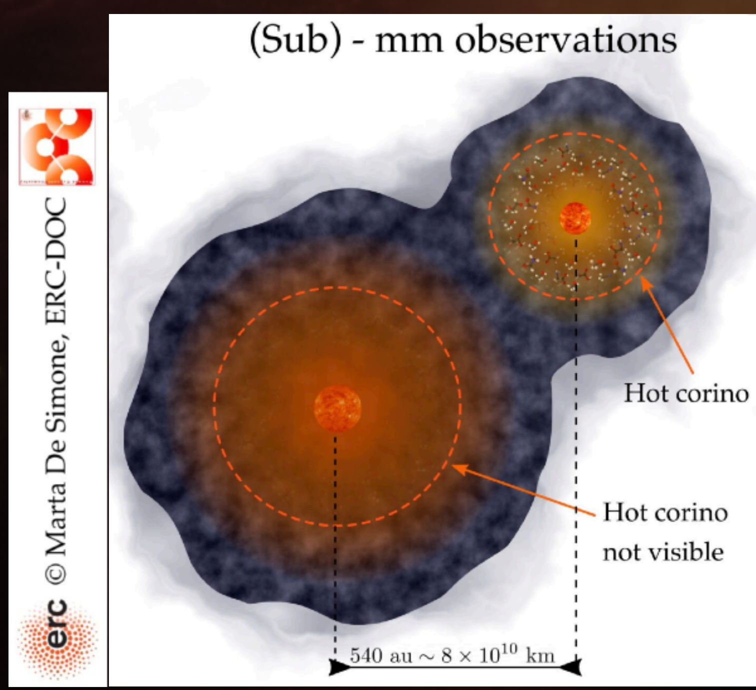
Dust opacity problem in the (sub-) mm

López-Sepulcre et al. 2017

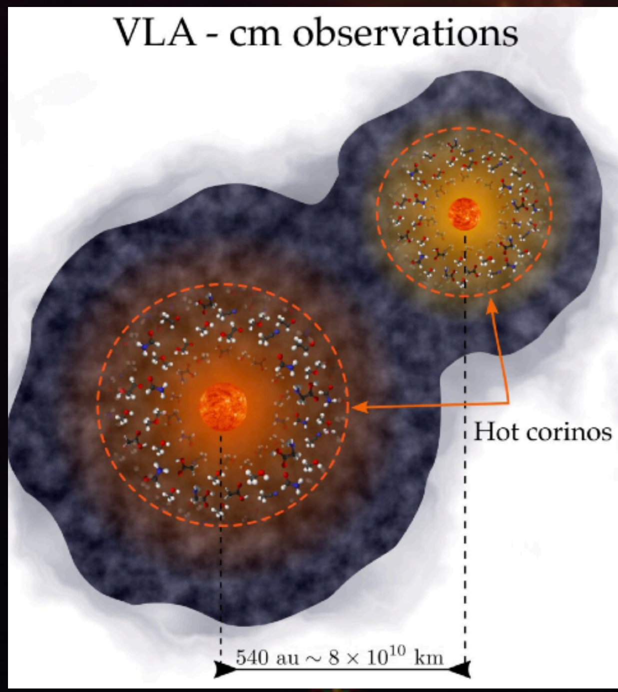


Dust hides molecules

Moving from millimetre to centimetre wavelengths



IRAS4A



De Simone et al. 2020

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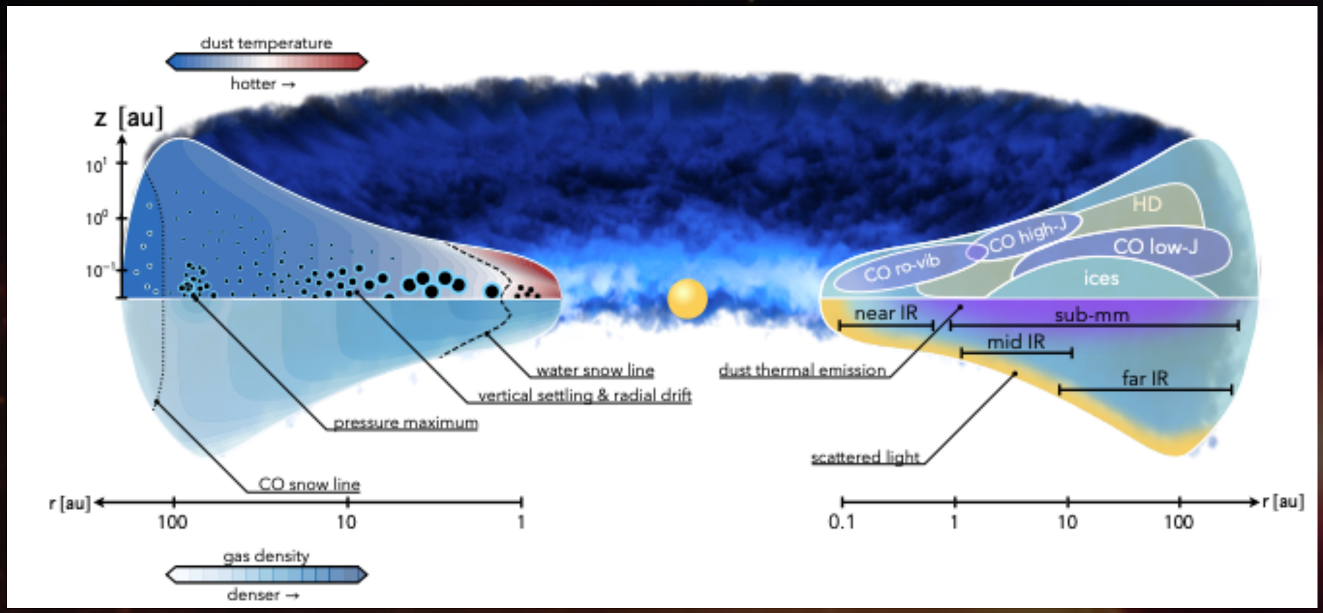
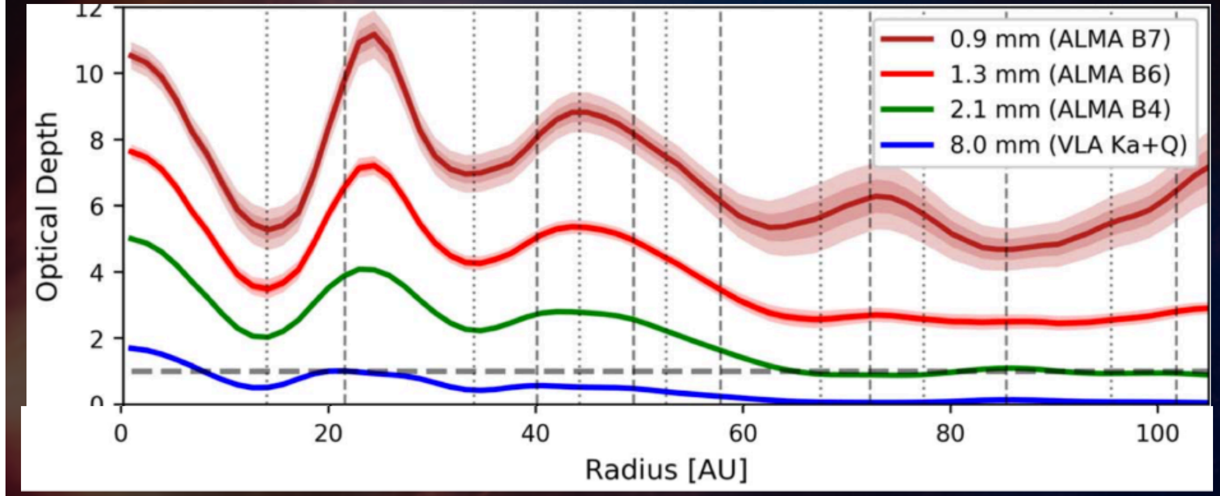
Astrochemistry of planet-forming disks

Dust opacity problem in the (sub-) mm

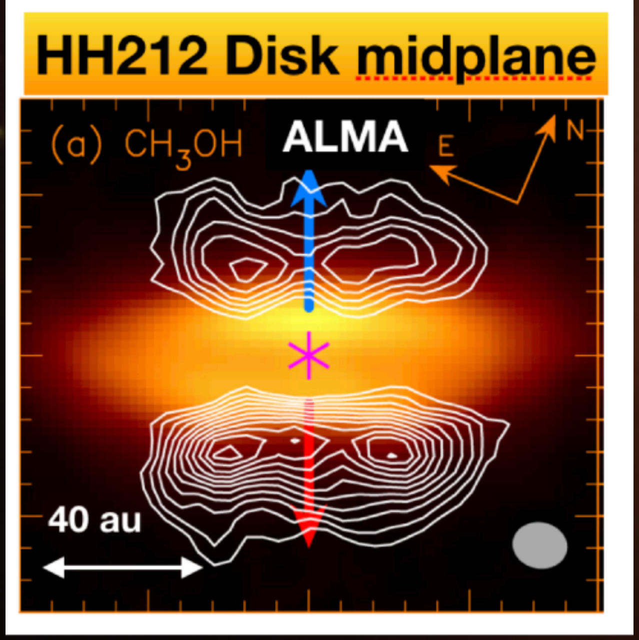
Miotello et al. 2022

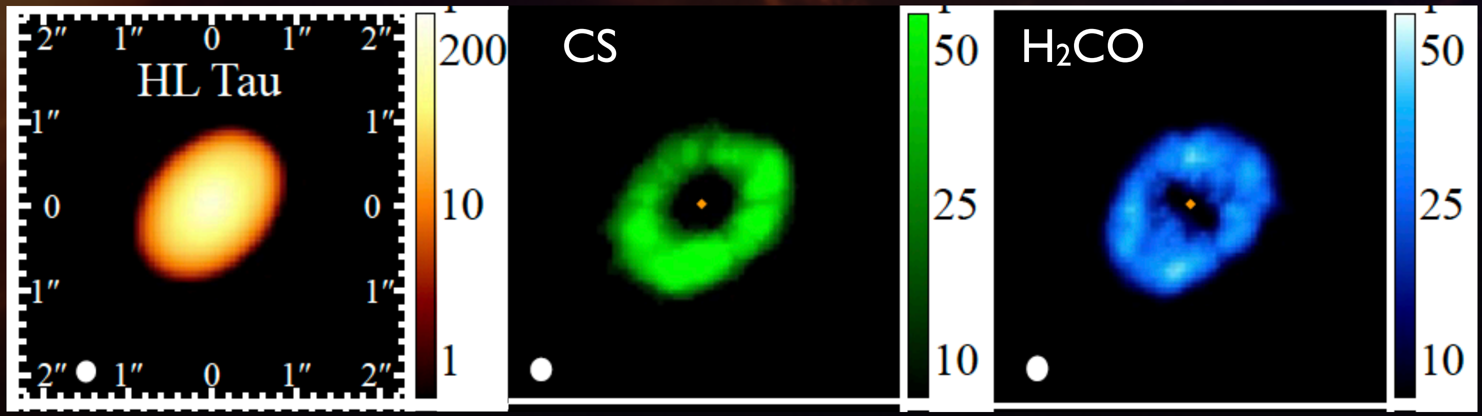




HL Tau - ALMA & VLA obs Carrasco Gonzalez et al. 2019

Codella et al. 2019, Lee et al. 2019





ALMA-DOT disks, Garufi et al. 2020

Dust hides the disk's planet-forming region

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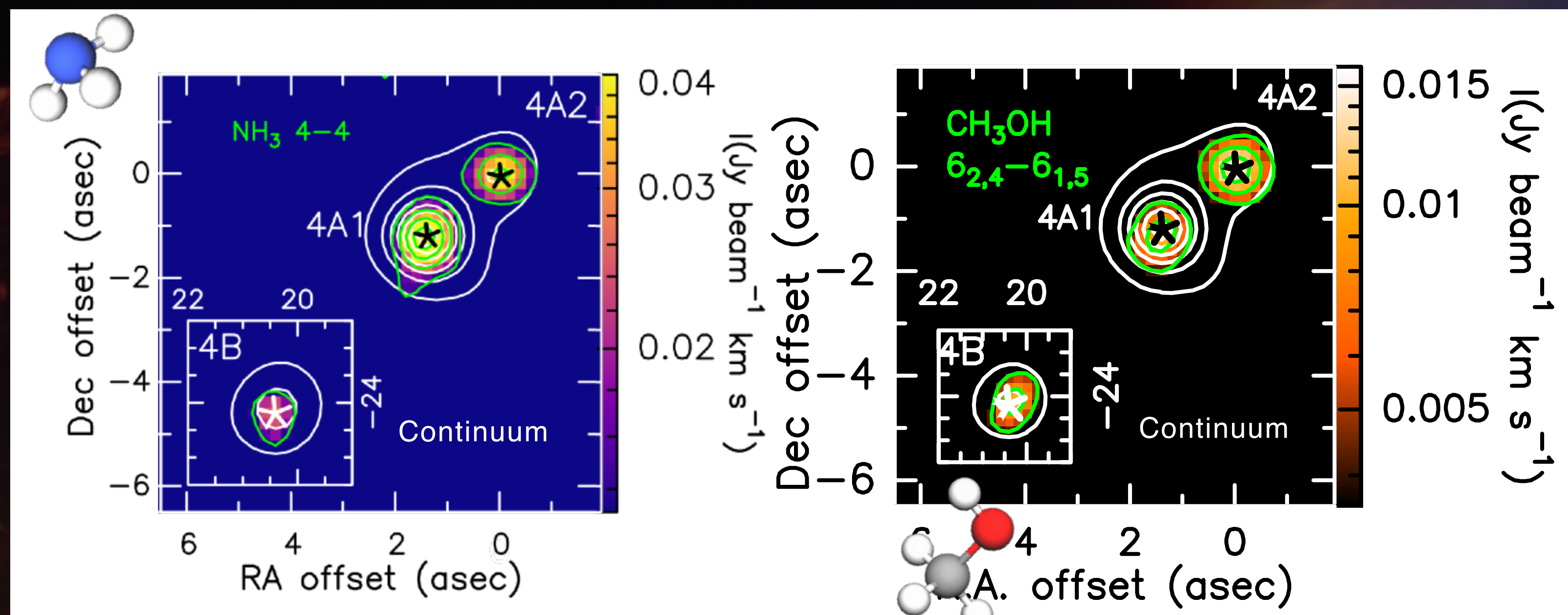
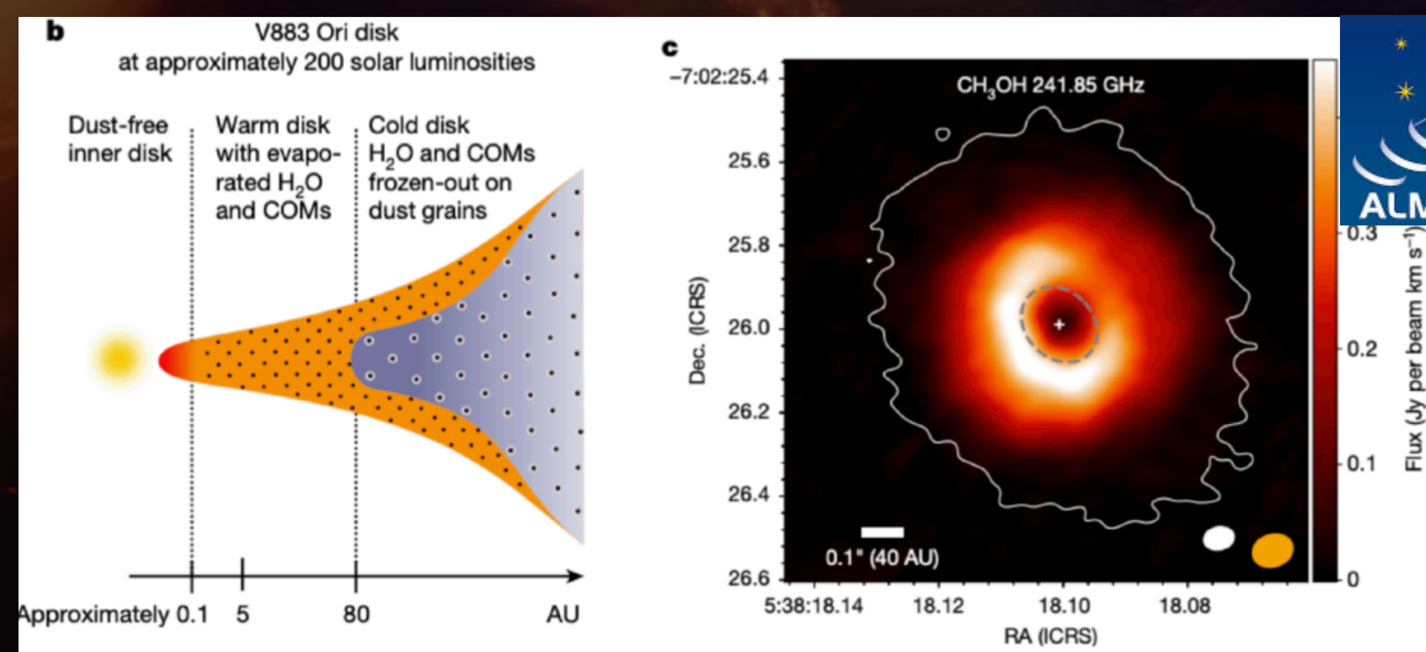
Astrochemistry of planet-forming disks

IRAS 4A



De Simone et al. 2022

V883 17h



JVLA can detect CH_3OH and NH_3 in young and bright or outbursting sources

Tobin et al. 2023, Podio et al. in prep

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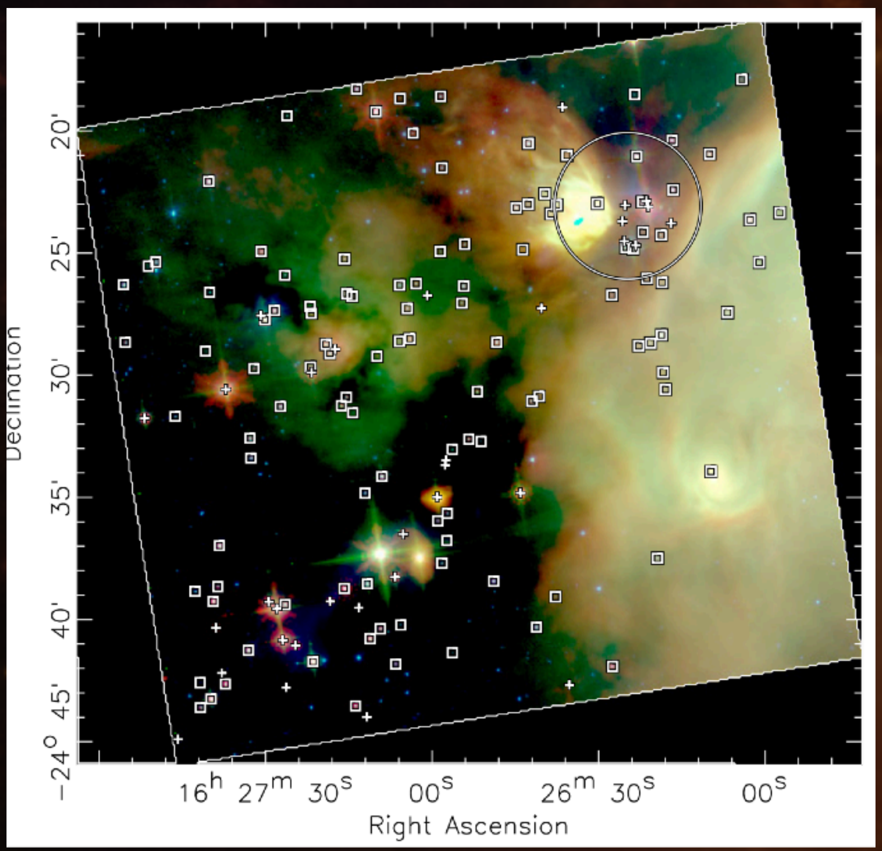
The Cradle of Life

Cradle of Life
Science Working Group

SKAO

Join us!



L1688 in ρ Oph

Hoare et al. 2015, Ilee et al. 2020

- Grain growth in disks
- Complex molecules in the planet forming regions
- Origin of the Solar System

Radio 2024, Erlangen, 12-15 Nov. 2024

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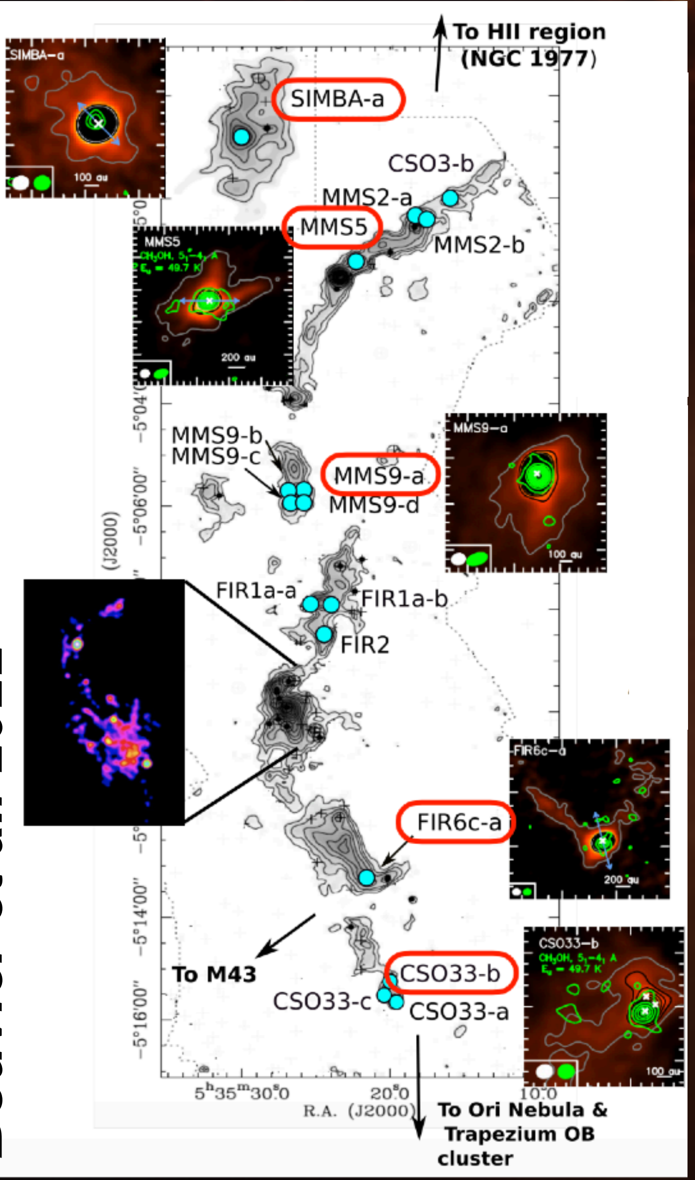
SKA unveiling heavy carbon chains chemistry

Use case for **SKA1-MID** PI: Bianchi, E & The Cradle of Life WG

Orion Molecular Cloud 2, the closest analogue to our Sun's birth environment



Bouvier et al. 2022

SKA MID Band 5 ~ 1000 hr

9.0-11.5 GHz + 13.0-15.5 GHZ

spectral resolution ~ 1.9 km/s

+

4 narrow zoom windows

on selected lines

angular resolution <0.5" (< 200 au)

OMC2-FIR4 protocluster

a similar chemistry than that

of our early Solar System

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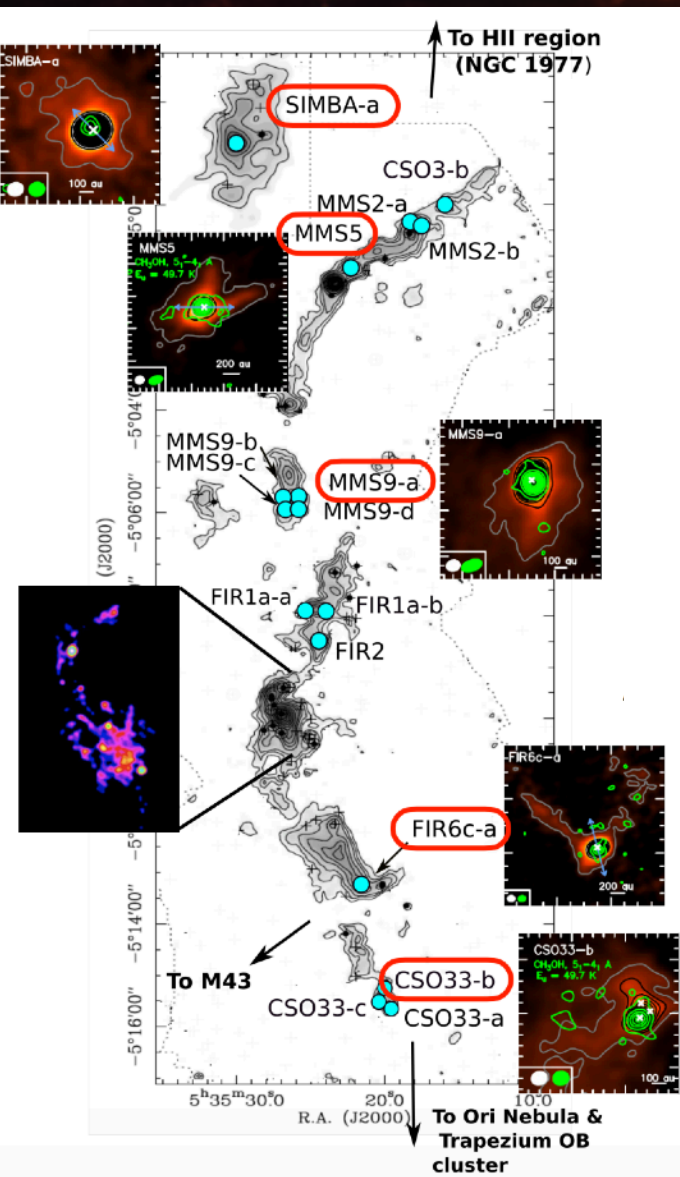

Bouvier et al. 2022

Preparatory work in the (sub-)mm

- ORANGES are different from PEACHES
Unbiased survey ALMA Band 6 –> less hot corino than Perseus (30% vs >50%)

- CCH and c-C_3H_2 not good tracers for WCCC, need for longer chains and rings

30m NOEMA

Bouvier et al. 2020, 2021, 2022

Fontani et al. 2017, Lattanzi et al. 2023, Chahine et al. 2022, Favre et al. 2018, Ceccarelli et al. 2014

And in the radio

JVLA 22h PI Bouvier K-band 18-26.5 GHz

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SKAO Science Activities

up-to-date coverage of the science questions that will be addressed by the full design baseline (and beyond)

Cradle of Life
Science Working Group
SKAO

Join us!

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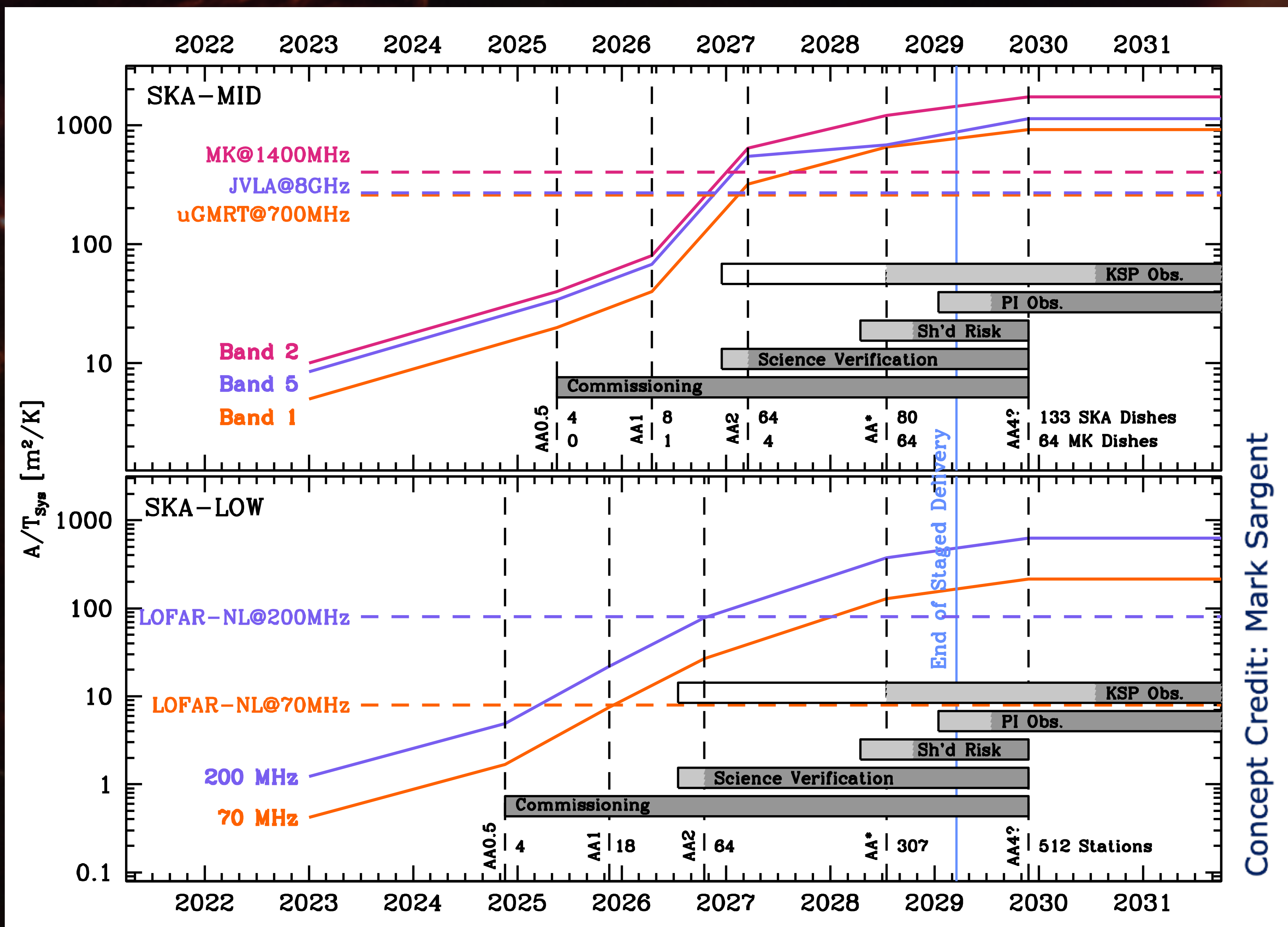
SKAO Timeline

Timeline



Late 2026

AA2 Science verification

End of 2028

AA* SKA-MID 80 dishes+
64 MeerKAT dishes
Full BW, zooms
Shared Risk Cycle 0
PI (and KSP) Proposals!

Join us!

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Take home

- Observations of Solar System analogs show a **complex chemistry** rich in **iCOMs** and **complex carbon species** since the early evolutionary phases
- Planet-forming disks are difficult to observe in the (sub-)mm because of dust opacity, especially the mid-plane region
- The new generation of radio interferometers are fundamental to obtain a complete census of the prebiotic molecules in the planet-forming region
- SKA Use Case for **Cradle of Life** WG: SKA will explore the complex carbon chemistry in a nearby star forming region

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Thanks!

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