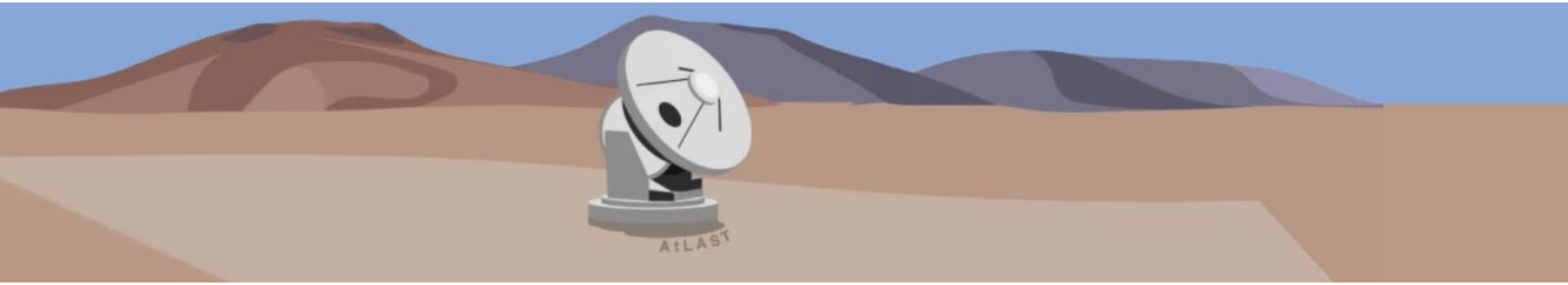
AtLAST as a prebiotic molecule detector



Izaskun Jimenez-Serra

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Iberian AtLAST Days – UCM – 4th June 2026

WG 1-18: The Emergence of Prebiotic Chemistry in Interstellar Space

Coordinators:

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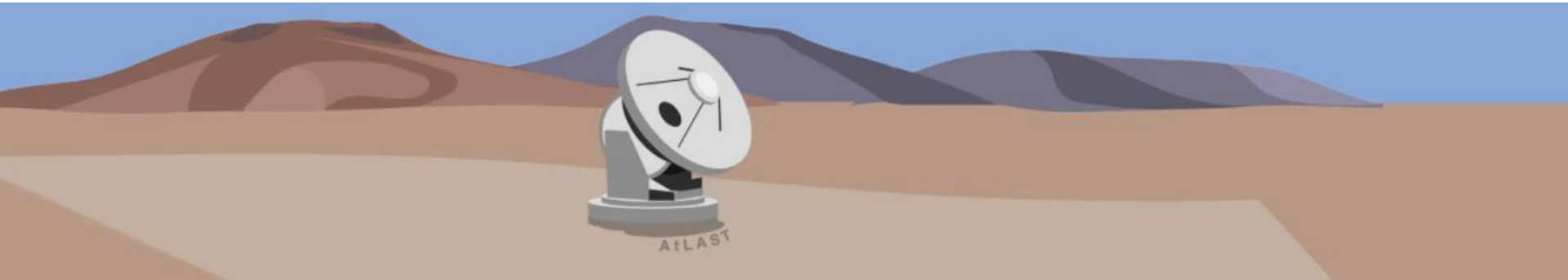


WG 1-18: The Emergence of Prebiotic Chemistry in Interstellar Space

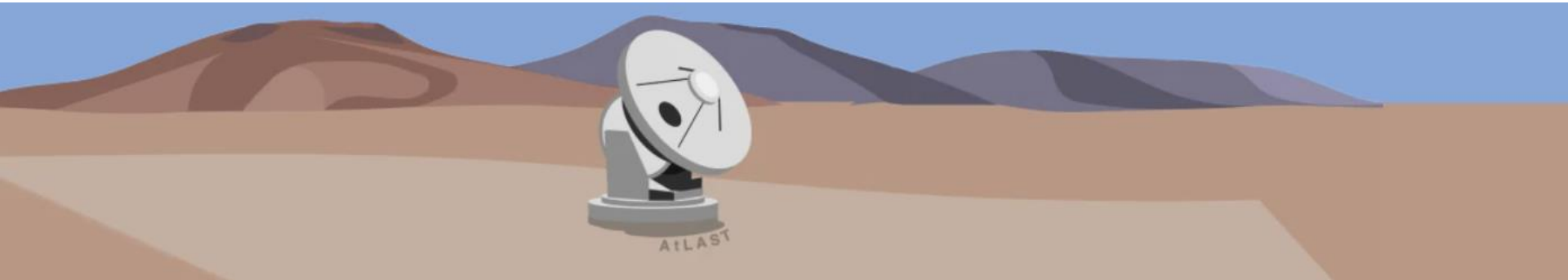
Two ESO Expanding Horizons White Papers in support of AtLAST

The role of supernova remnants for the emergence of pre-biotic chemistry in molecular clouds.

Cosentino et al. 2025, arXiv:2512.14143

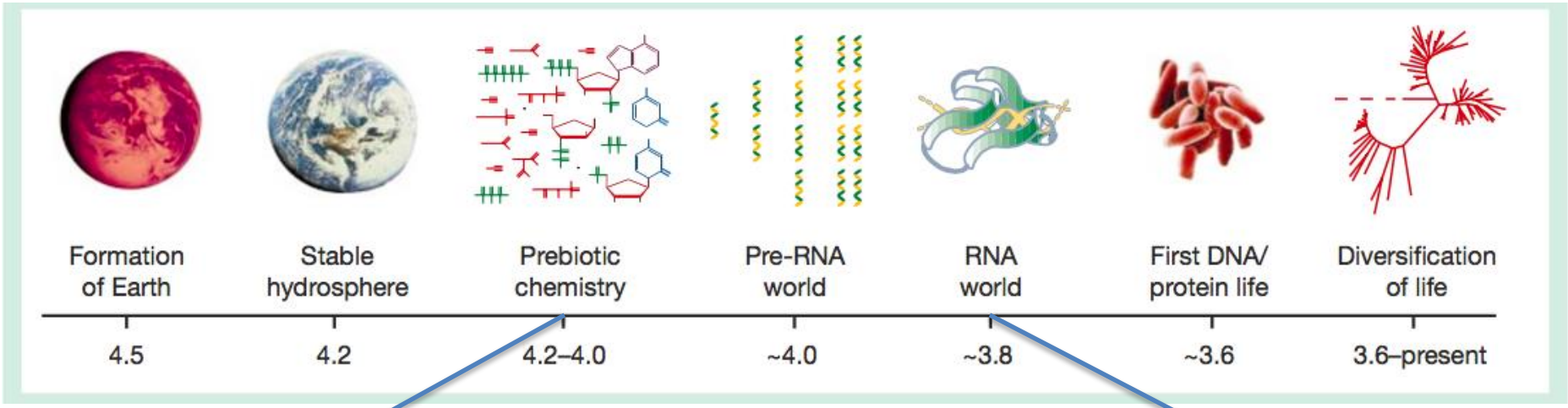
The Emergence of Prebiotic Chemistry in the ISM

Jimenez-Serra et al. 2025, arXiv:2512.14772

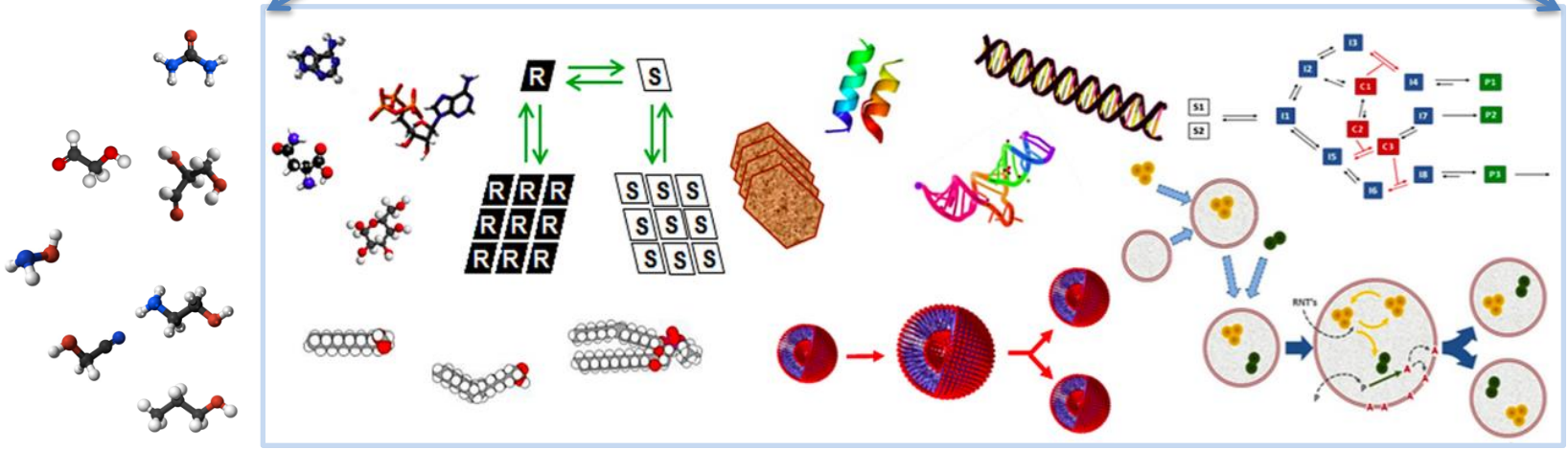


The process of the origin of life

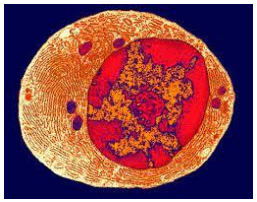
Life emerged ~3.5 Gyrs ago from simple molecular compounds



Joyce 2002, Nature

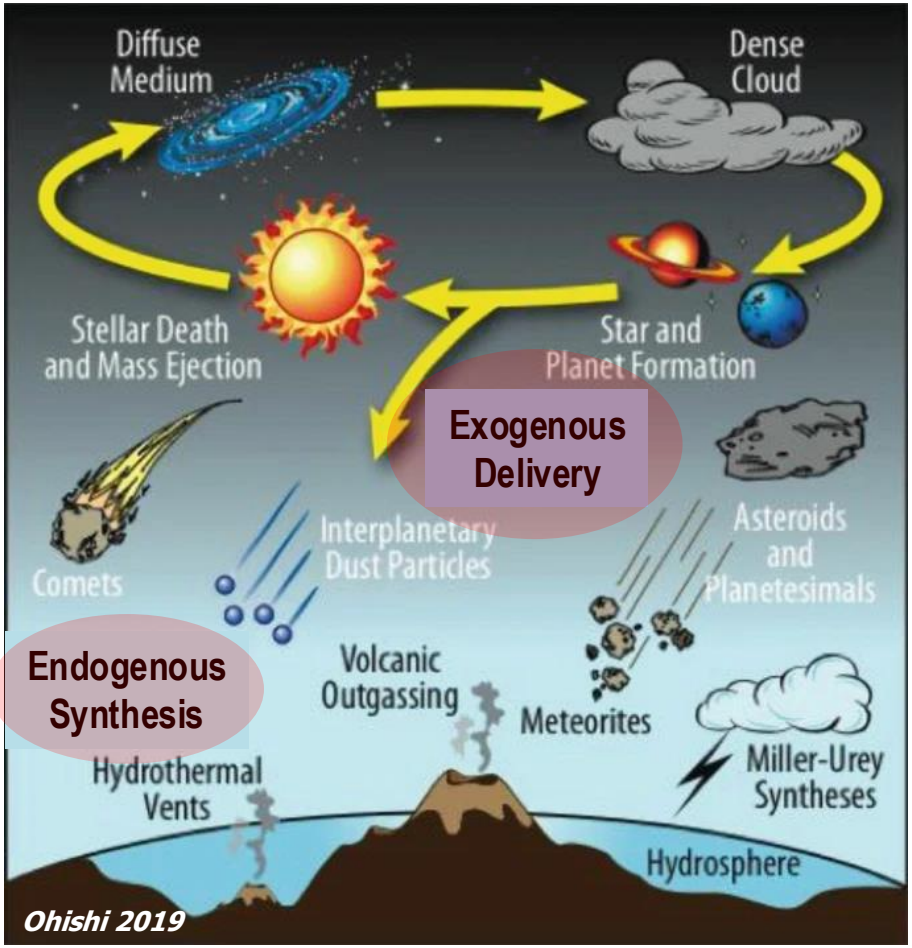


Ruiz-Mirazo, Briones, de la Escosura 2014, Chem. Rev.



LUCA
(Last Universal Common Ancestor)

Exogenous delivery, a decisive step in the origin of life



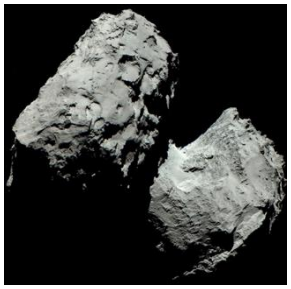
10^{16}-10^{18} kg of exogenous organic matter delivered

vs.

10^{14} kg currently in the biosphere

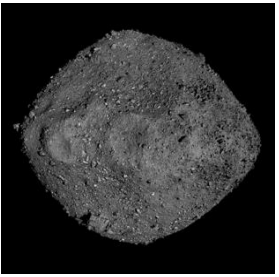
(Chyba & Sagan 1992)

Exogenous delivery, a decisive step in the origin of life

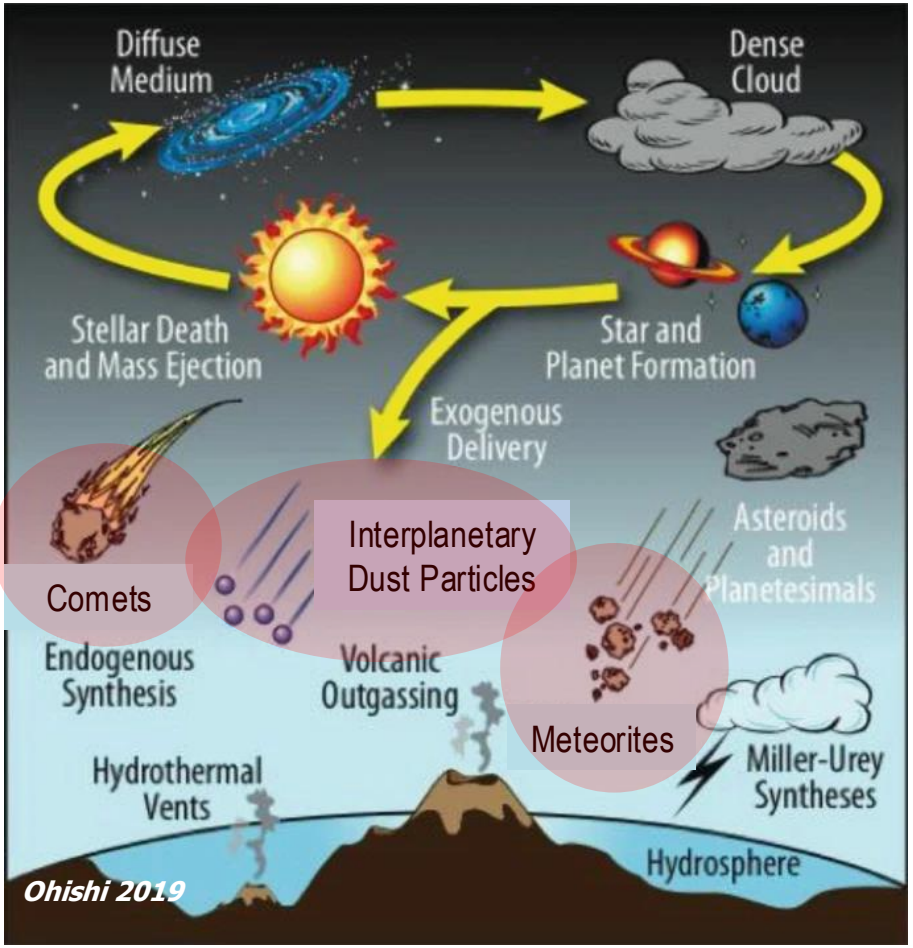


Comet 67P/CG

Ryugu asteroid



Bennu asteroid



Orgueil meteorite

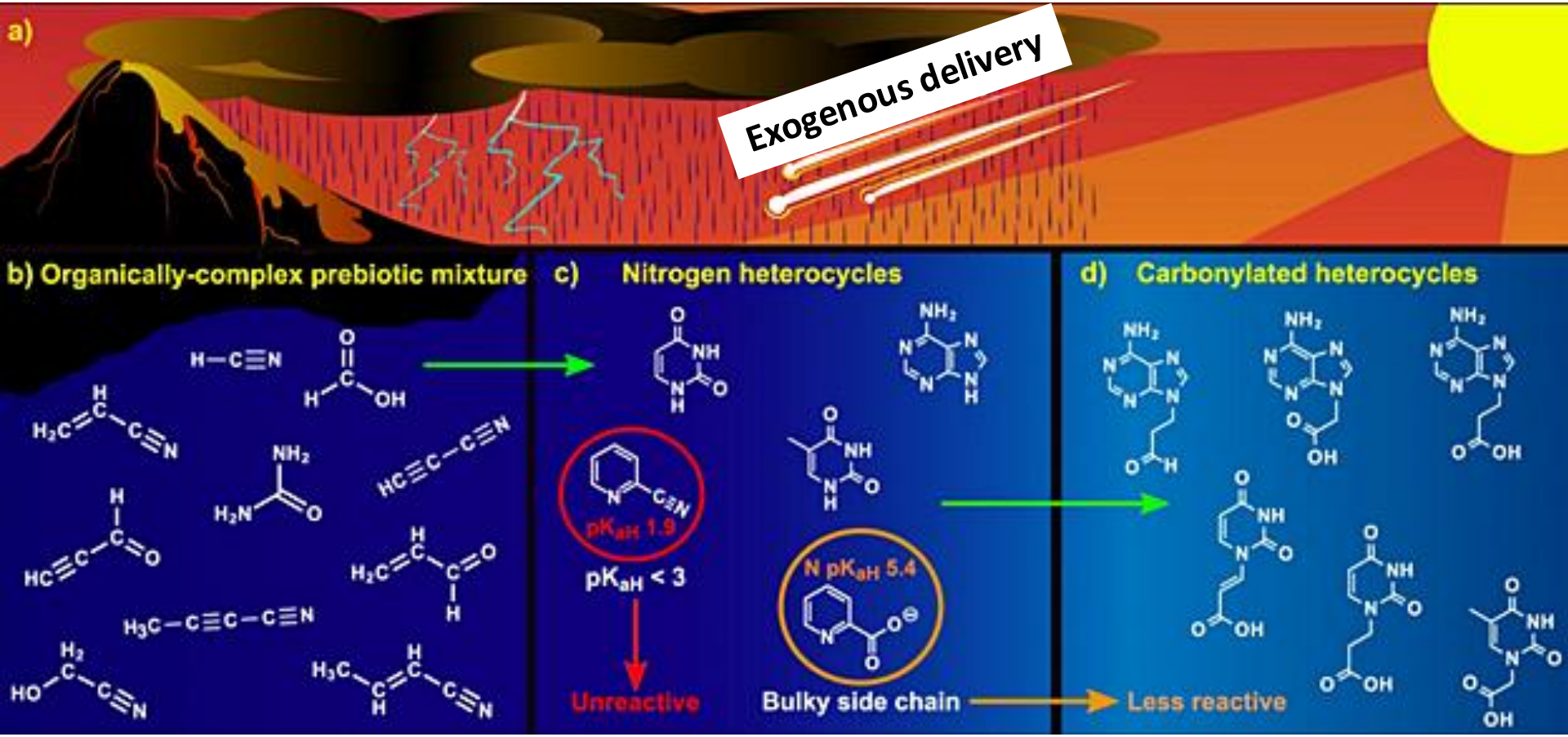
Murchison meteorite

amino acids, sugars & nucleobases found in these objects

organic compounds in comets are pre-solar

Cronin et al. 1971; Meierhenrich et al. 2004; Pizzarello et al. 2006; Burton et al. 2012; Furukawa et al. 2019; Oba et al. 2022; Altwegg et al. 2016, 2019; Hanni et al. 2022; Naraoka et al. 2023; Oba et al. 2023; Glavin et al. 2025

Work hypothesis:
Prebiotic precursors could form already in the ISM



Survival of organic prebiotic material after meteor impact possible

(Chyba & Sagan 1992; Pierazzo & Chyba 2006; McCaffrey et al. 2014)

European Research Council
Established by the European Commission

OPENS

the Onset of Prebiotic chEmistry iN Space

PI: Izaskun Jiménez-Serra

European Research Council
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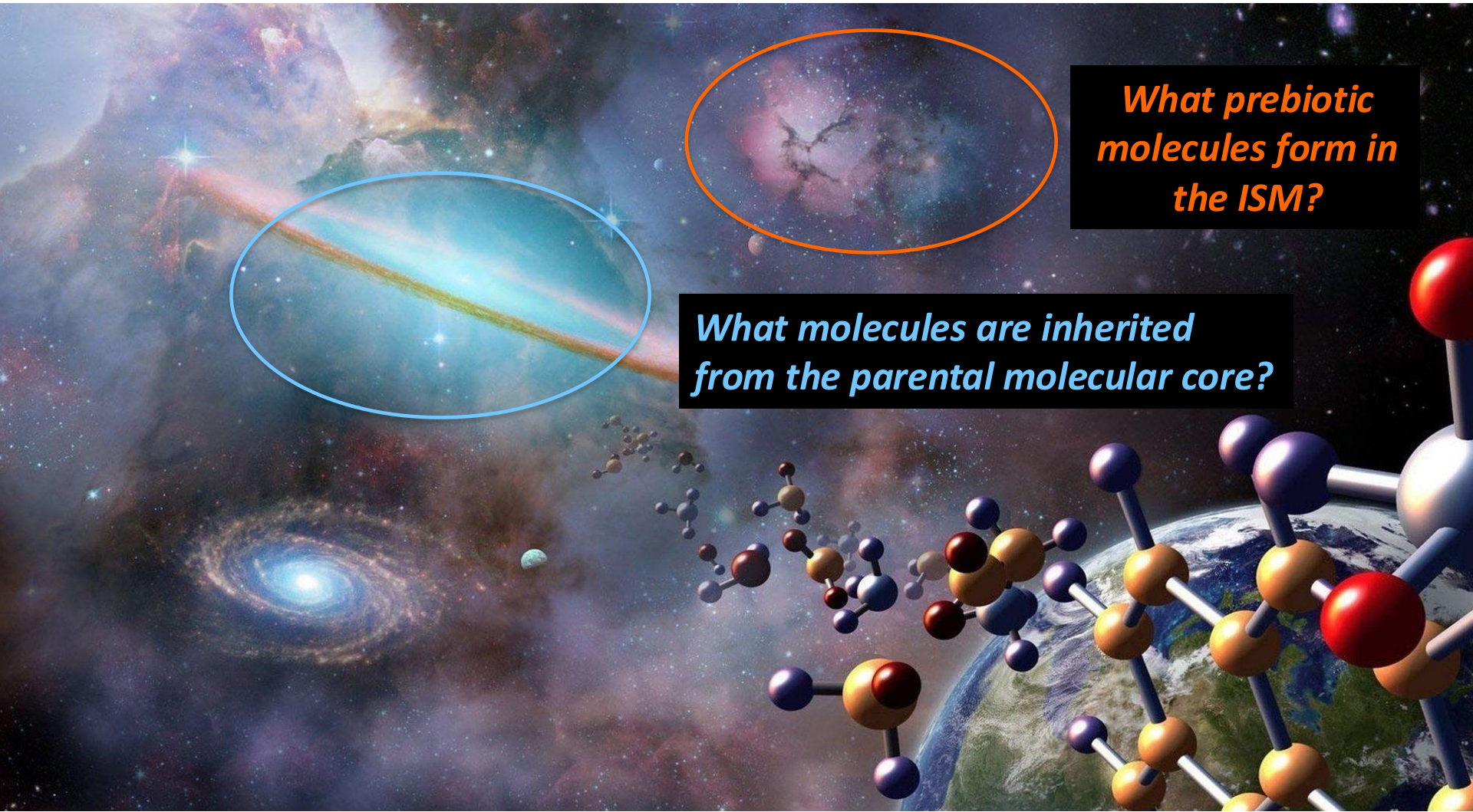

European Research Council
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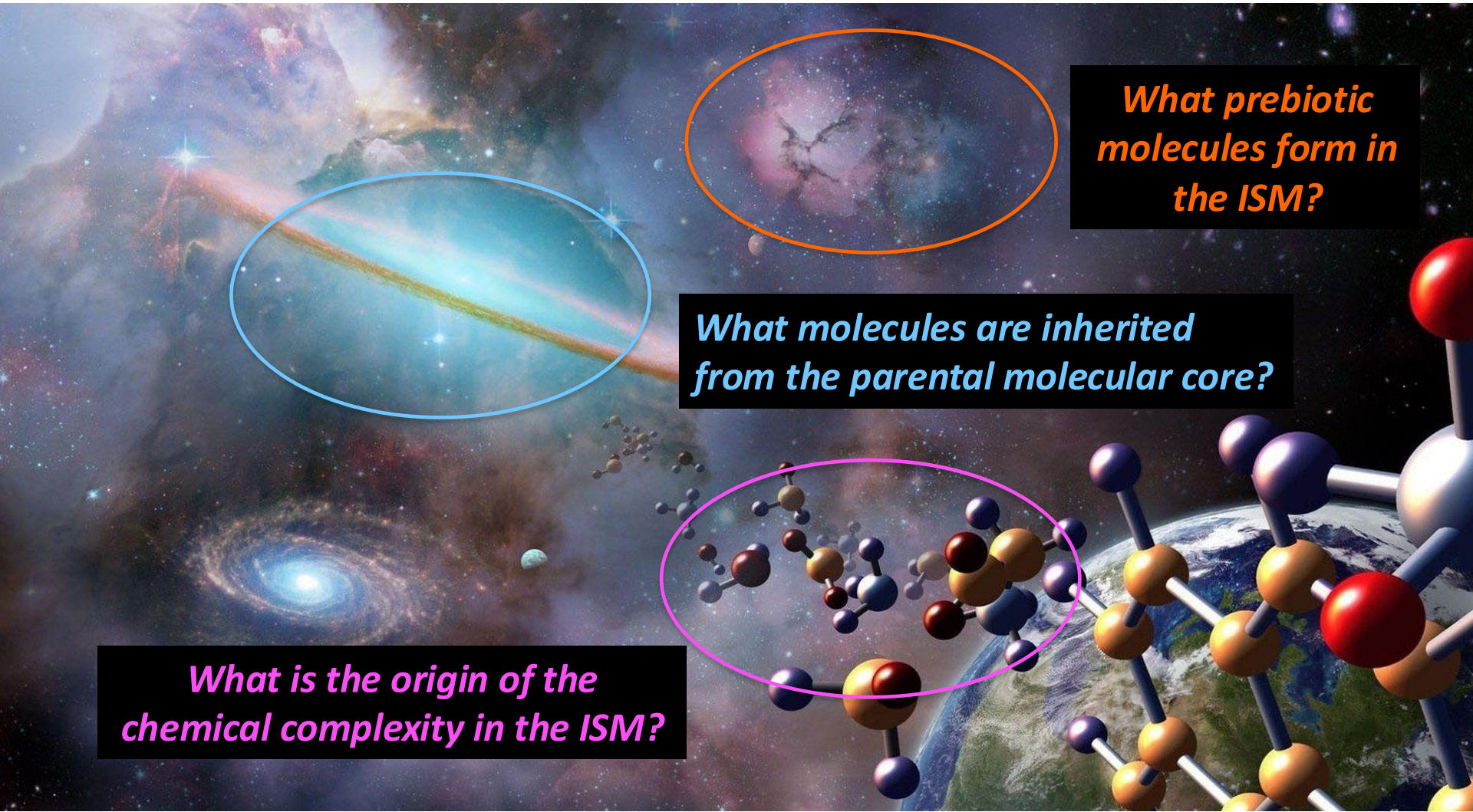
the Onset of Prebiotic chEmistry iN Space



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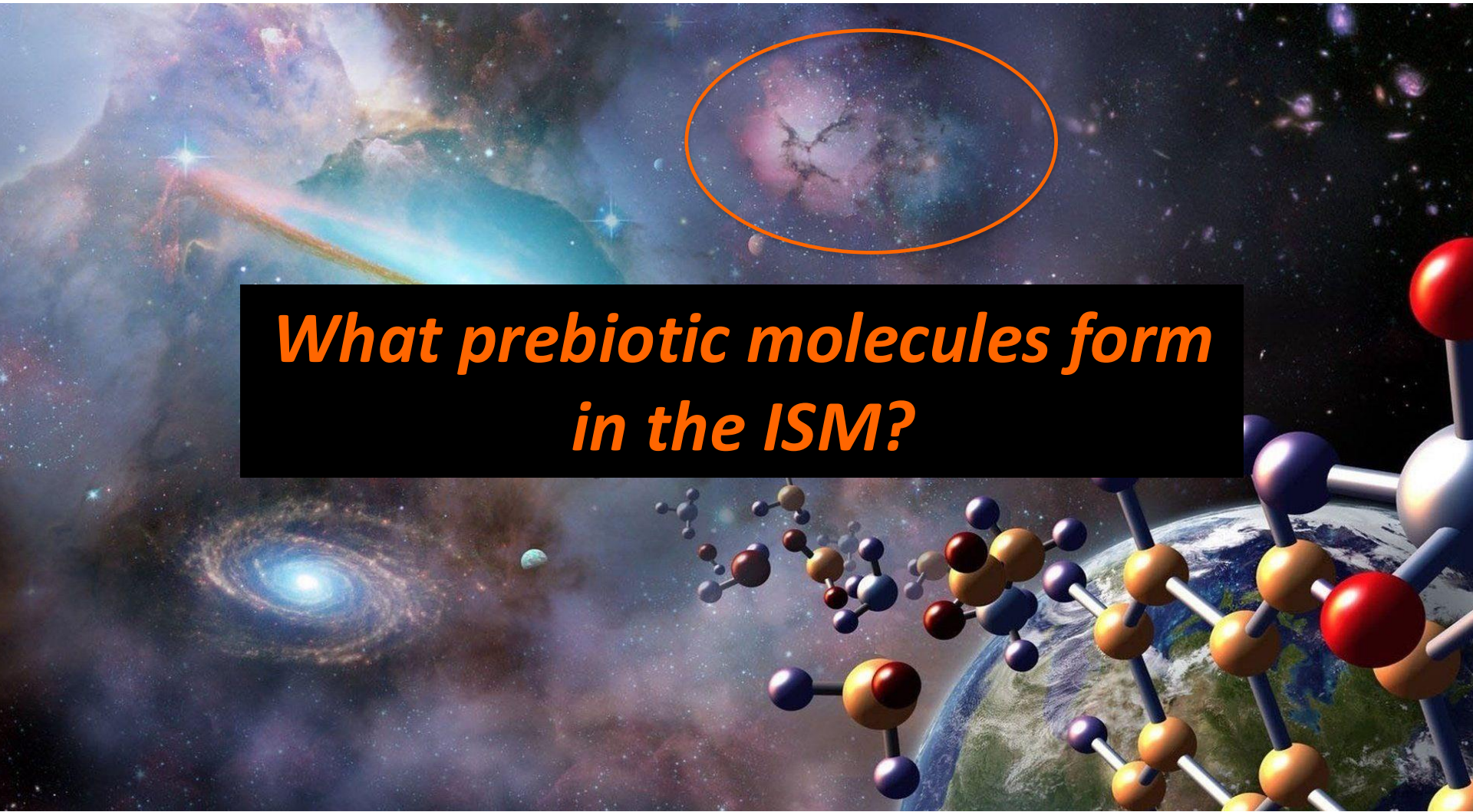
OPENS

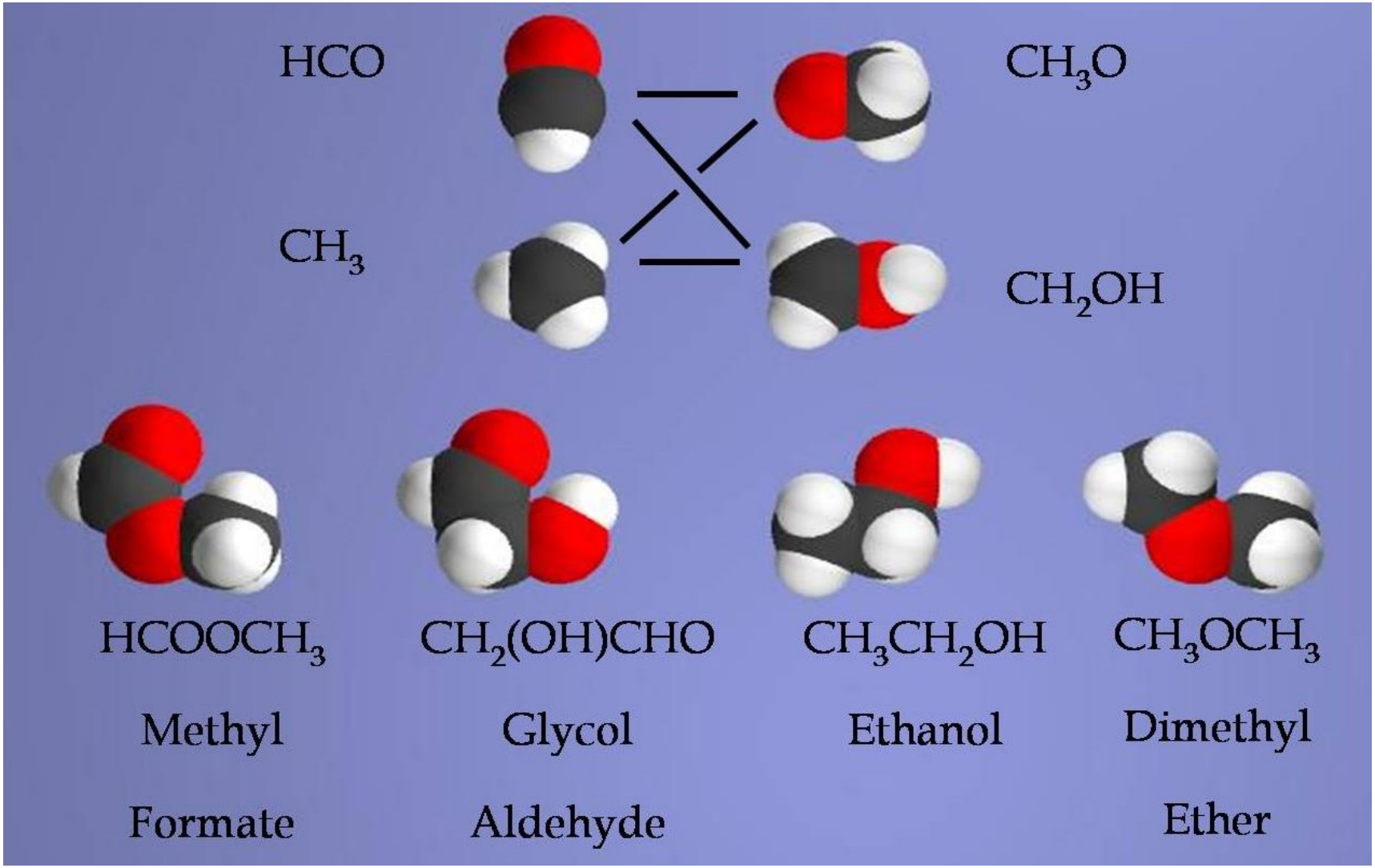
the Onset of Prebiotic chEmistry iN Space



Complex Organic Molecules (COMs)

COMs are carbon-based compounds with ≥6 atoms

(Herbst & van Dishoeck 2009)



COMs are ubiquitous in the ISM

- Star forming regions: Hot Cores and Hot Corinos
  (Hollis+2000,2004; Beltran+2009; Belloche+2016; Jorgensen+2012; Lykke+2017)
- Molecular Outflows and Disks
  (Arce+2008; Codella+2015; 2017; 2020; Walsh+2016; Lee+2019; Podio+2020)
- Photon-Dominated Regions
  (Guzman+2013)
- Cold Clouds Cores and Starless/Pre-stellar Cores
  (Marcelino+2007; Bacmann+2012; Vastel+2014; Jimenez-Serra+2016; Taquet+2017; Agundez+2019;McGuire+2018,2021; Cernicharo+2021)
- Galactic Center GMCs
  (Martin-Pintado+2001;Requena-Torres+2006,2008;Widicus-Weaver+2017;Zeng+2018)

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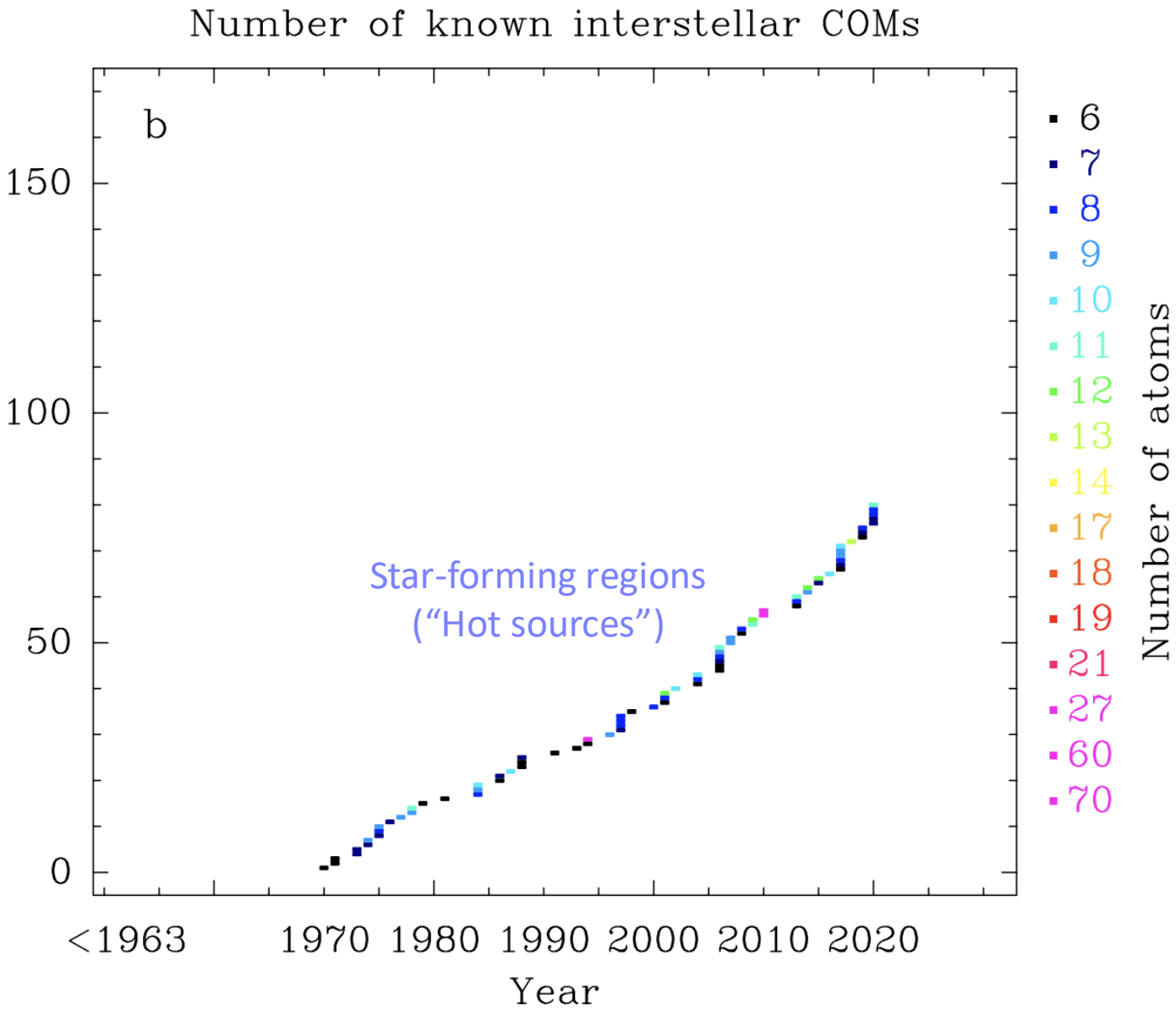
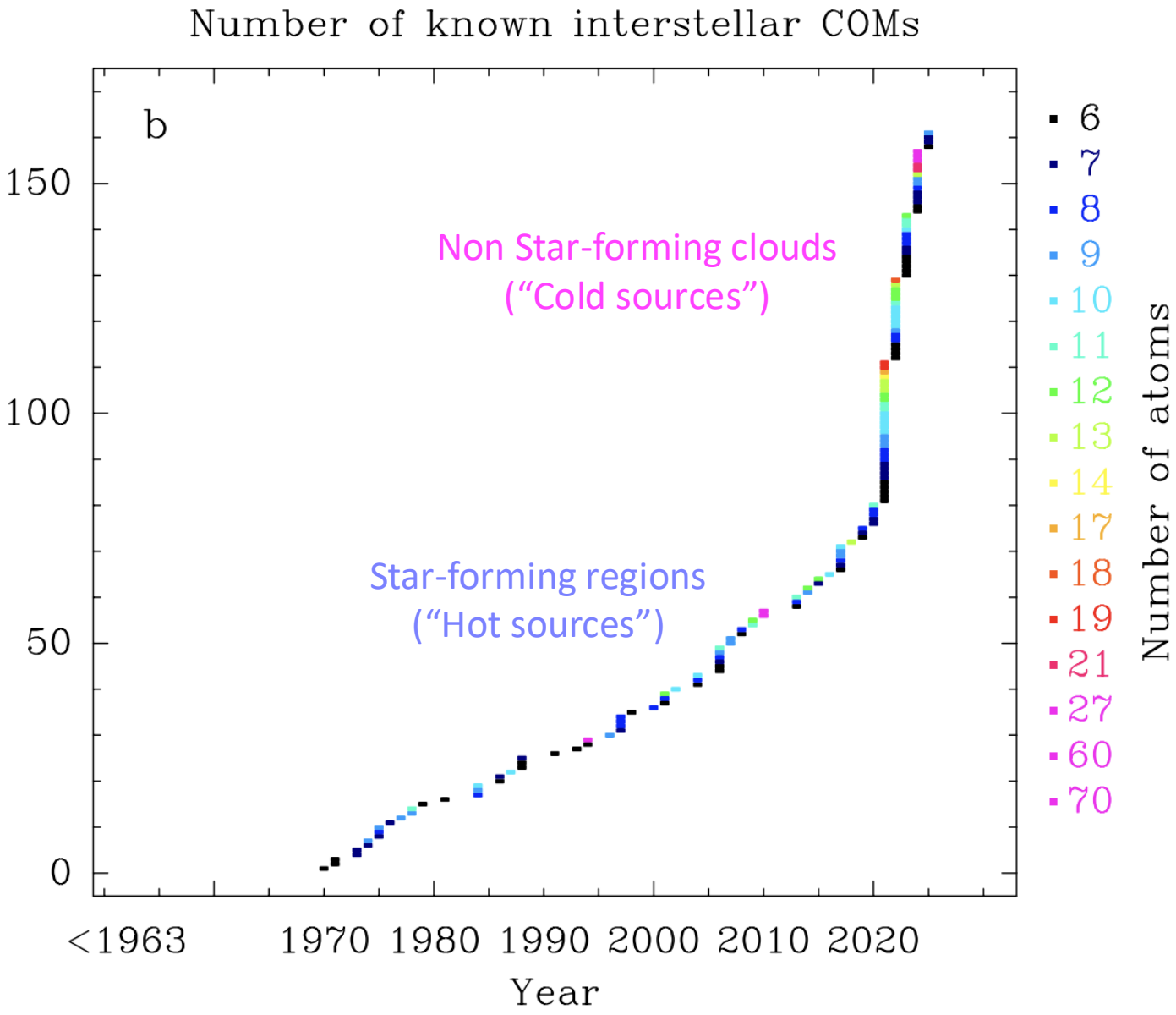
Inventory of COMs in space



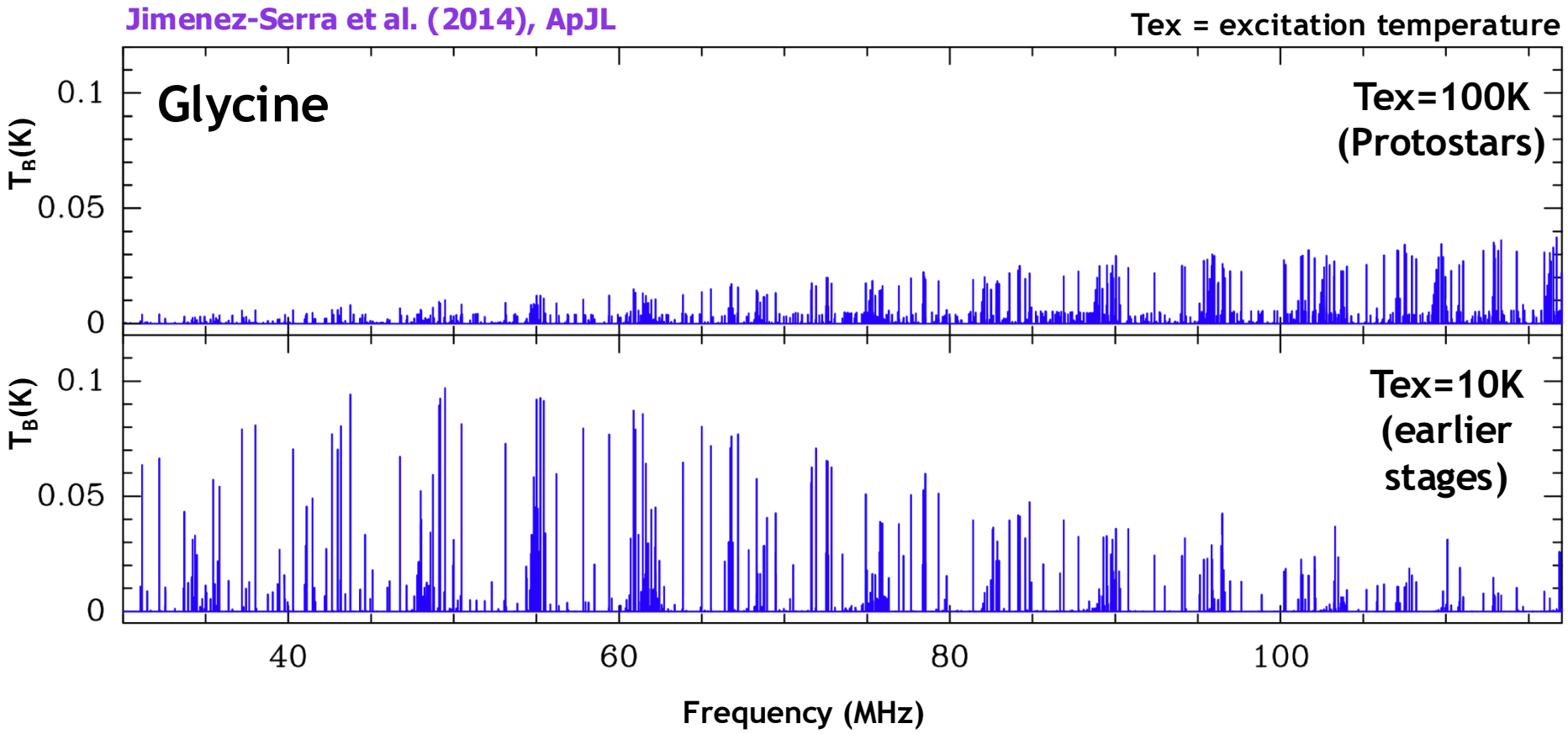
Jiménez-Serra+(2025), to appear in Handbook of Astrochemistry (arXiv:2503.17104)

Inventory of COMs in space



Jiménez-Serra+(2025), to appear in Handbook of Astrochemistry (arXiv:2503.17104)

New methodology for searching large molecules

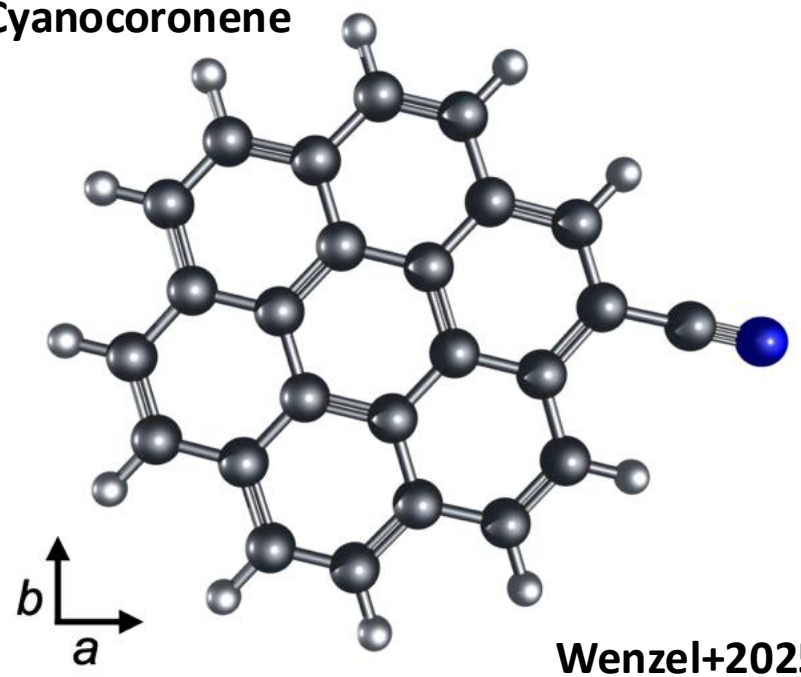


- *Spectrum shifts to lower (cleaner) frequencies*
- *Reduced levels of line blending and line confusion*
- *Line intensities are increased*

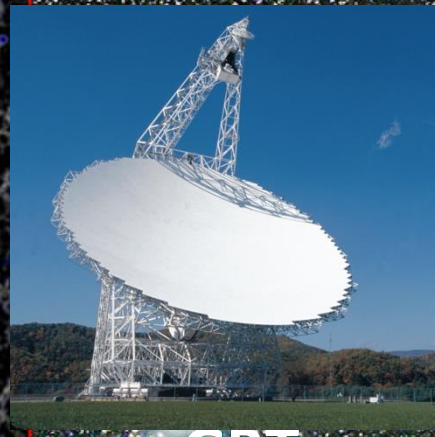
Aromatic Molecules in TMC-1

Yebes 40m
QUIJOTE
(Cernicharo's group)

Cyanocoronene

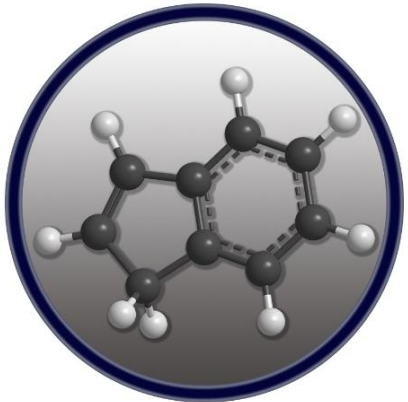


Wenzel+2025

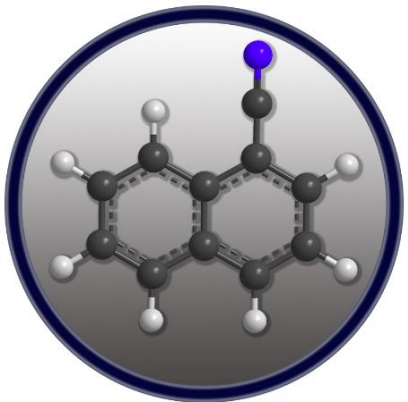


GBT
GOTHAM
(McGuire's group)

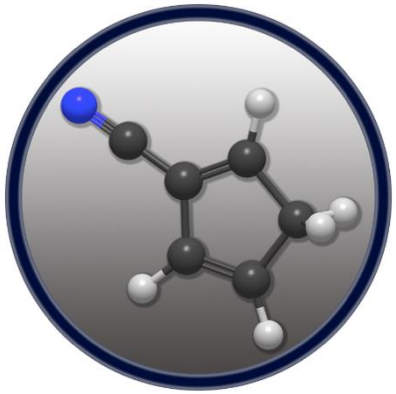
Indene



1,2-cyanonaphtalene



1,2-cyano-cyclopentadiene



Burkhardt+21;
Mcguire+21;
Cernicharo+21a,b,c,d,e;
Lee+21; McCarthy+21;
Agundez+21;
Marcelino+21; Cabezas+21

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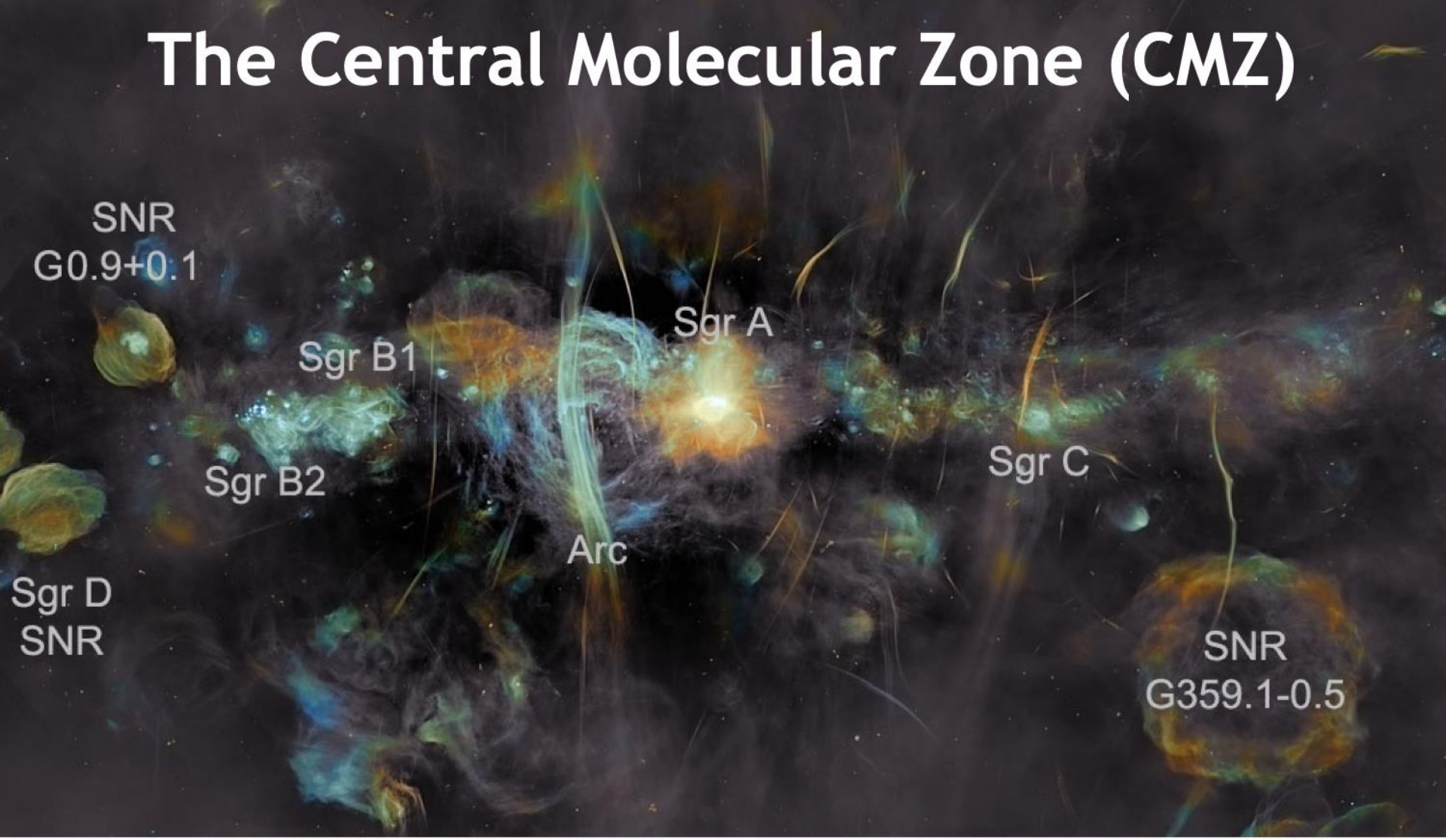
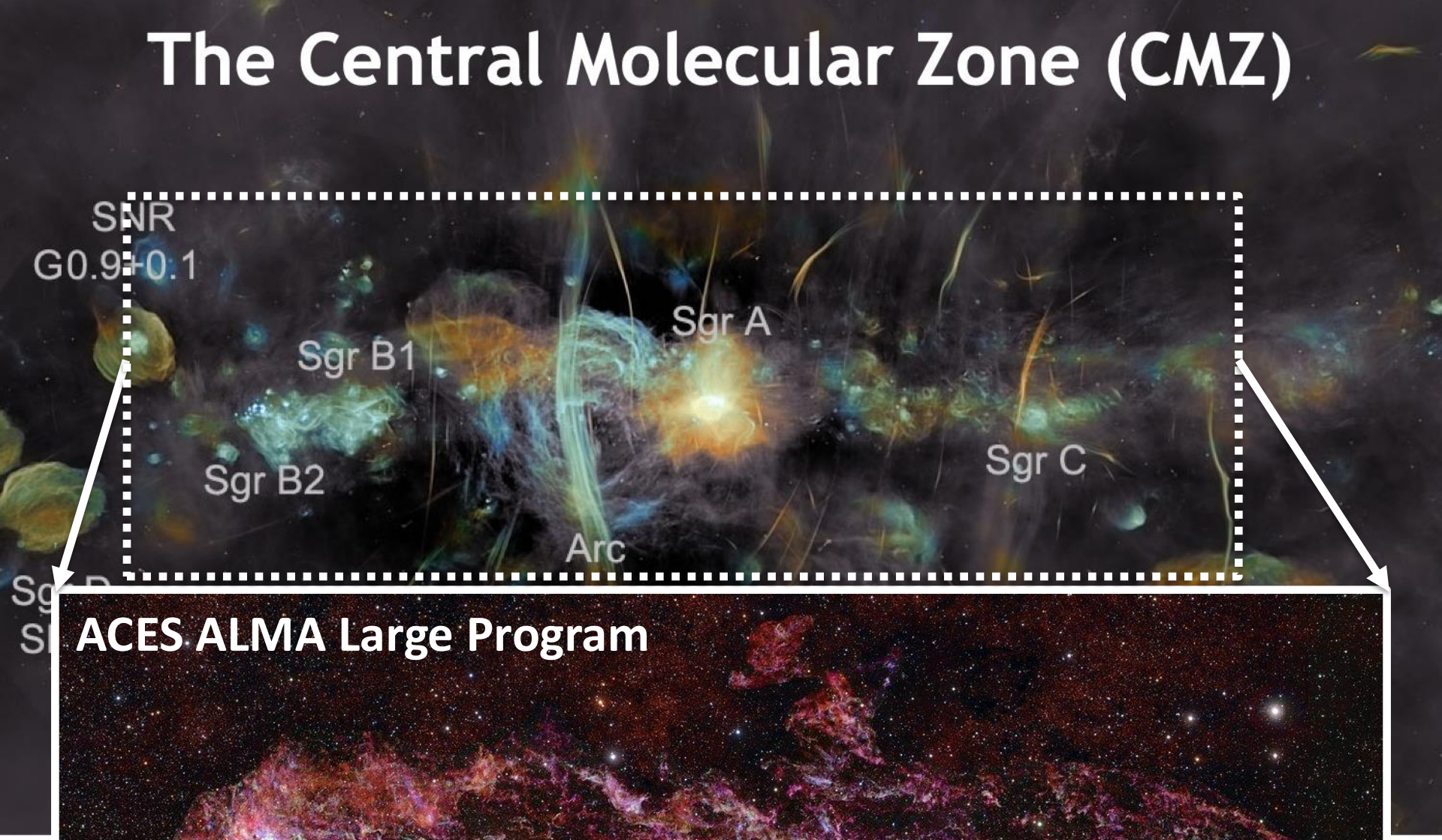
The Central Molecular Zone (CMZ)

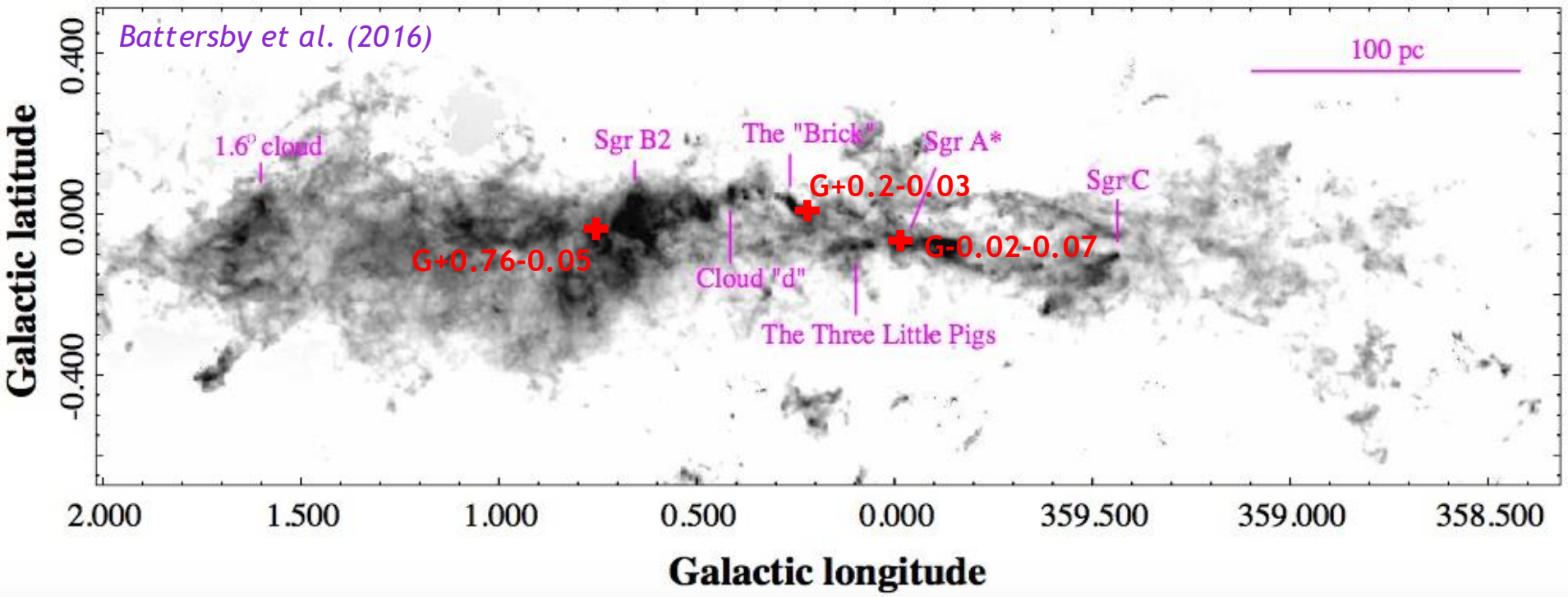


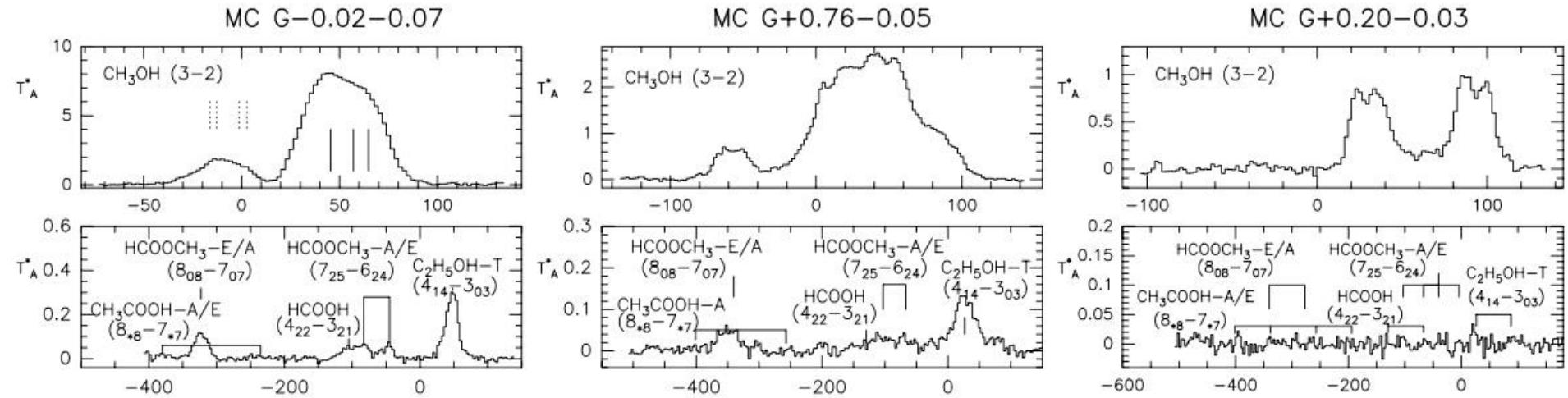
Covers the inner 500 pc of the Milky Way
Hosts >80% of the dense gas in the Galaxy
Closest galactic nucleus to us

The Central Molecular Zone (CMZ)



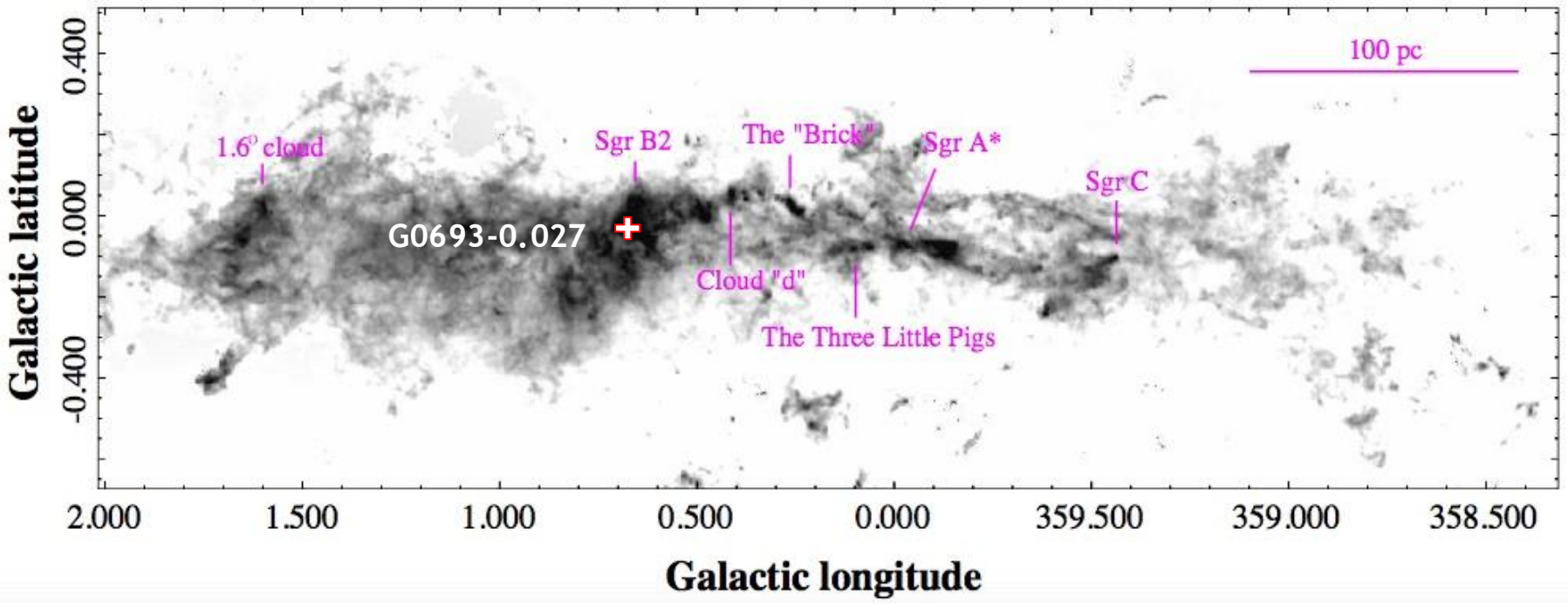
Widespread COM emission in the Galactic Center





Martin-Pintado et al. (2001); Requena-Torres et al. (2006,2008); Zeng et al. (2018); Li et al. (2017,2020)

G+0.693-0.027

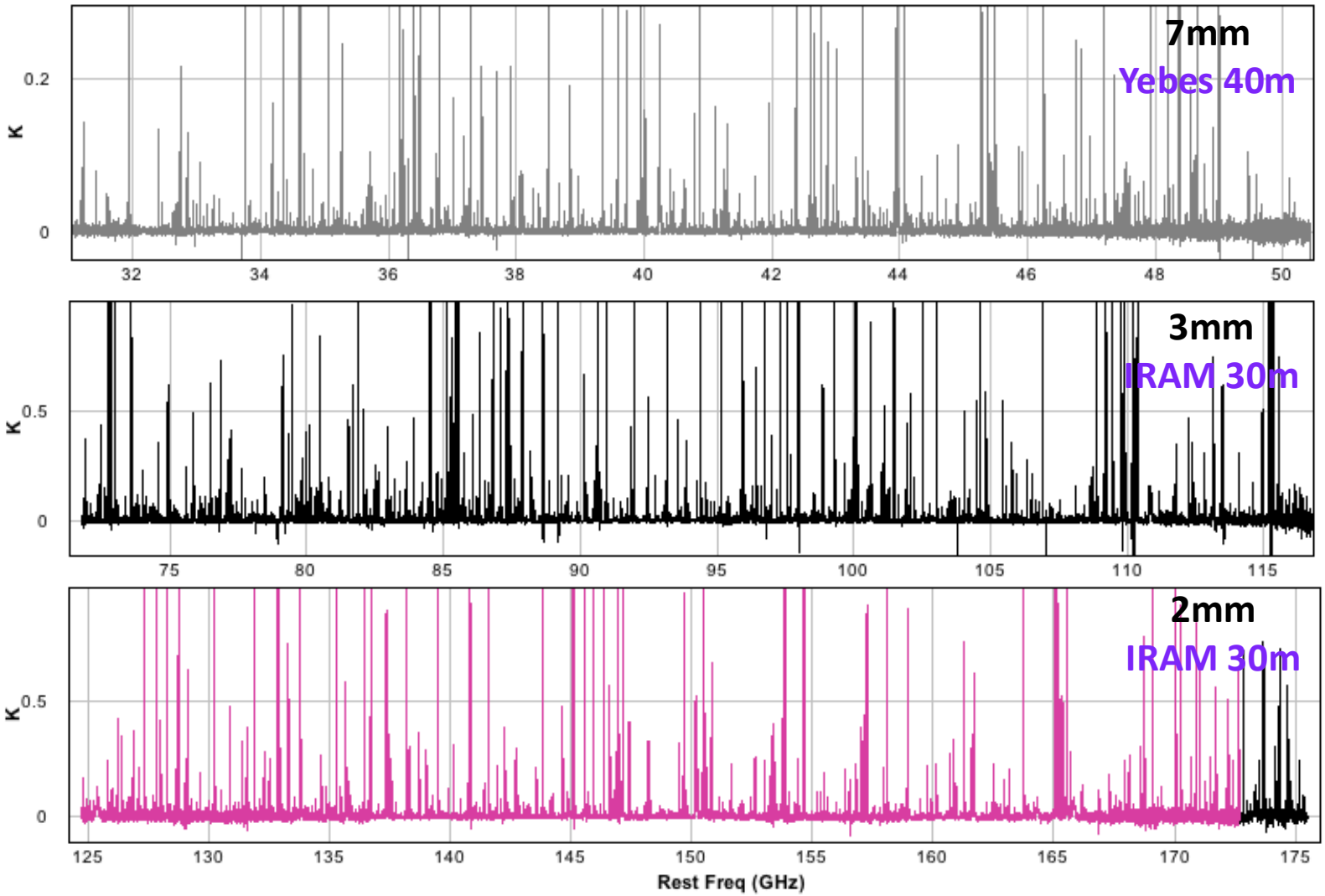


Quiescent cloud (no sign of star-formation)

(Hasegawa+94;Sato+00; Tsuboi+15; Wu+17; Zeng+20; Armijos-Abendaño+20)

- $n(H_2)$~$4x10^4$ cm^{-3}
- T_{dust}<20 K
- T_{gas}>100 K
- Low T_{ex} of the molecular gas (<15 K).
- *Huge advantage for COM searches in "crowded" spectral surveys*

Surveys with GBT, IRAM 30m, Yebes 40m & APEX



>170 species detected --- >50% of them are COMs

One of the most important reservoirs of COMs in the Galaxy

(Requena-Torres et al. 2008; Widicus-Weaver et al. 2017; Zeng et al. 2018)

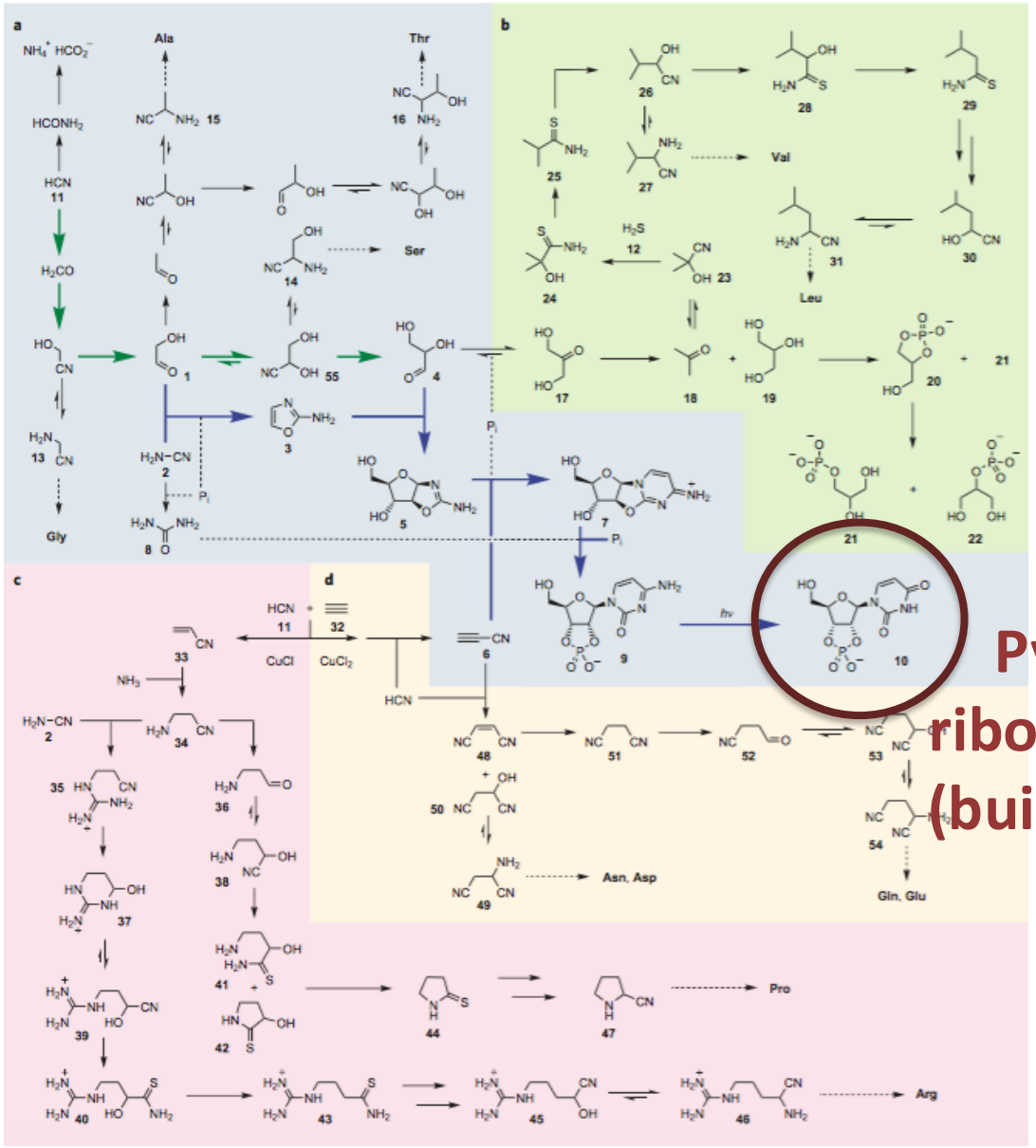
Toward the RNA-world in the ISM

Primordial RNA-world chemical scheme (Powner+2009; Patel+2015)

RNA Precursors

Sugars & Lipid precursors

Amino Acids

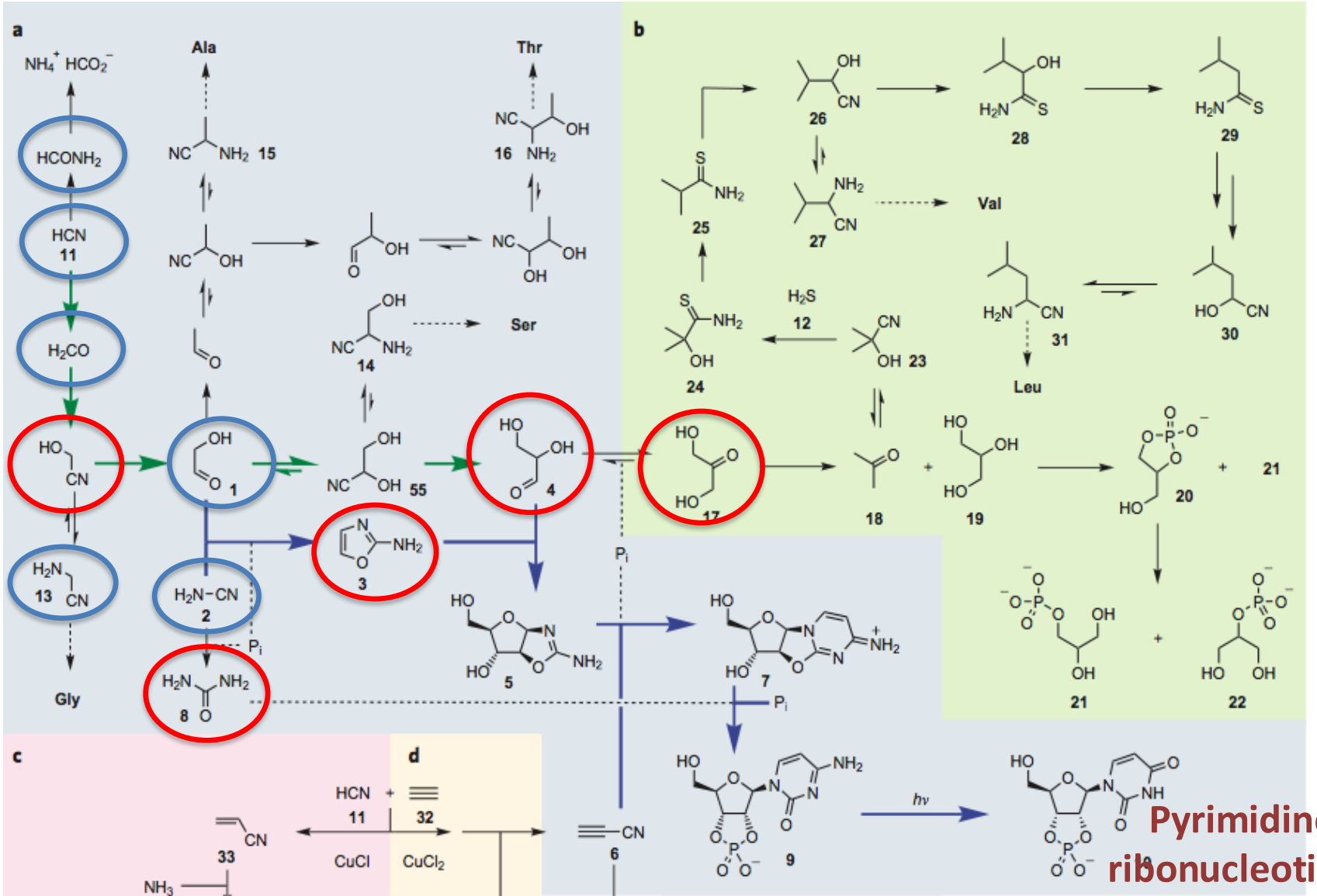


Pyrimidine ribonucleotides (building blocks of RNA)

Toward the RNA world in the ISM

Urea, 2-amino-oxazole, glyceraldehyde & dihydroxyacetone

Patel et al. (2015)



Toward the RNA world in the ISM

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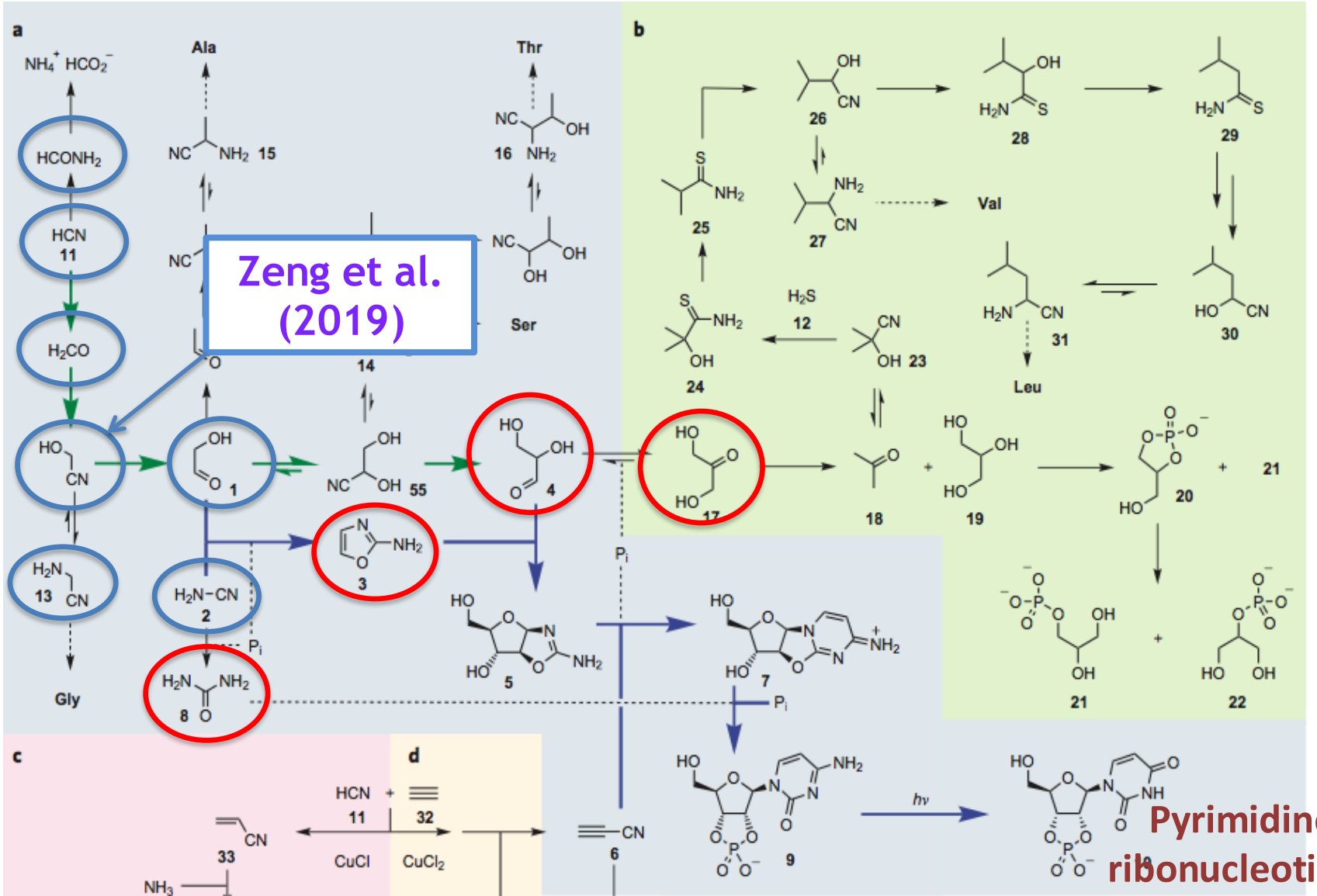
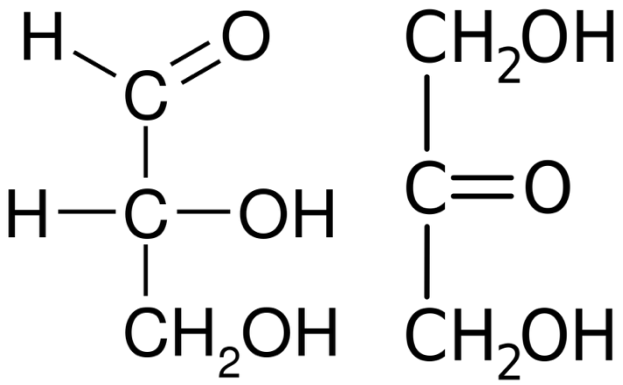
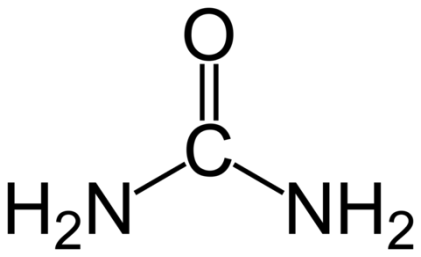


Toward the RNA world in G+0.693

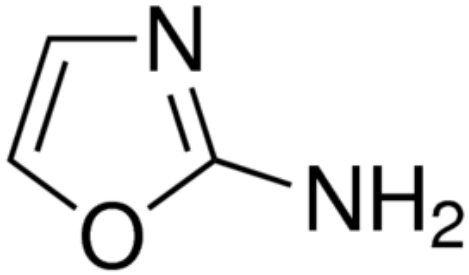
glyceraldehyde
&
dihydroxyacetone



Urea



2-amino-oxazole



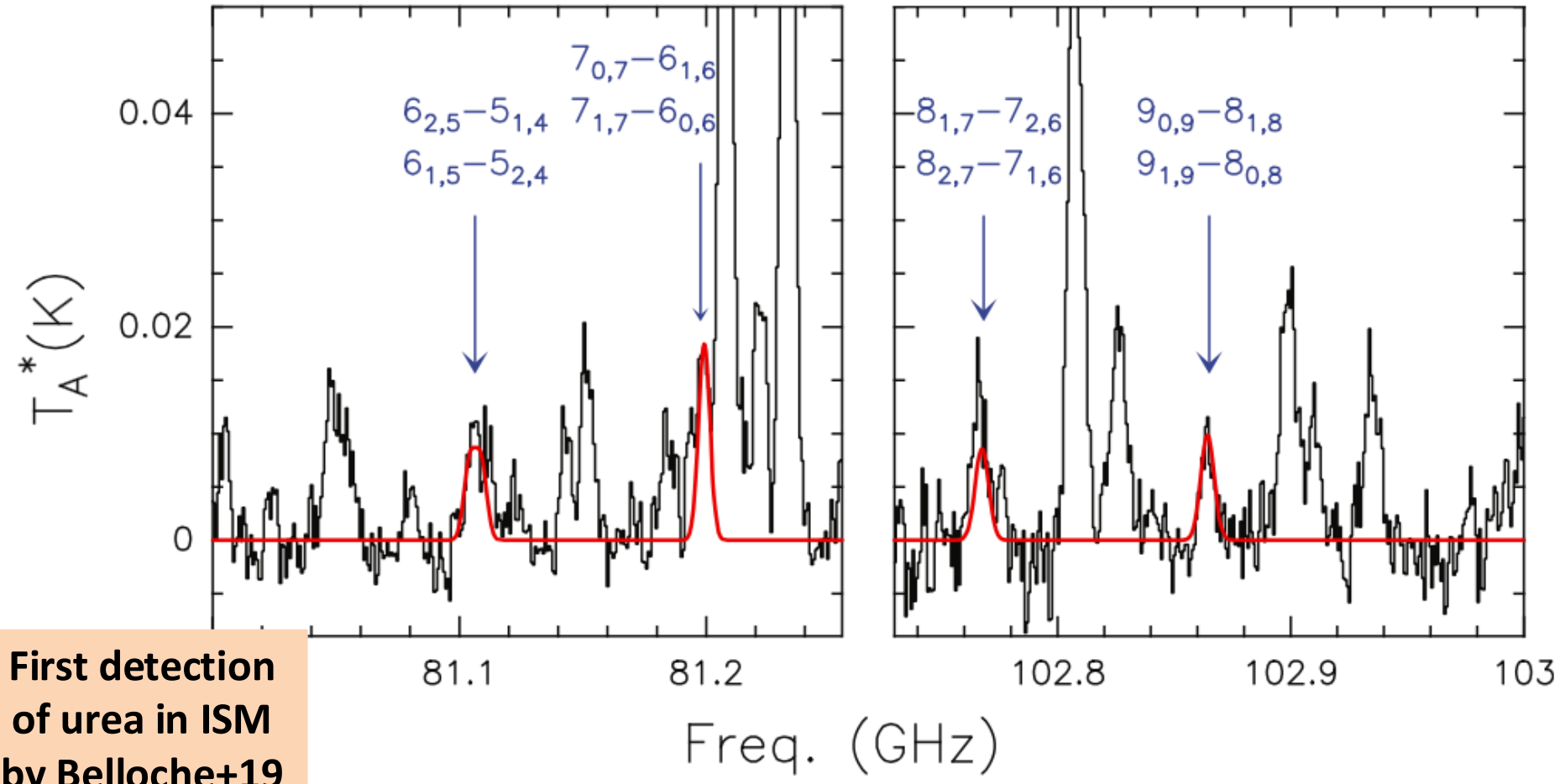
Upper limits
$\chi < (0.5\text{-}1.0)\times10^{-10}$

Consistent with previous searches by Apponi+06

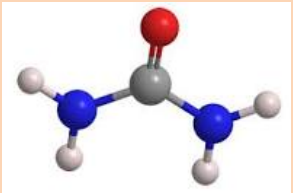
Jimenez-Serra+(2020), Astrobiology, 20, 7

Urea (NH_2CONH_2) in the Galactic Center molecular cloud G+0.693

Jimenez-Serra+(2020)



First detection of urea in ISM by Belloche+19

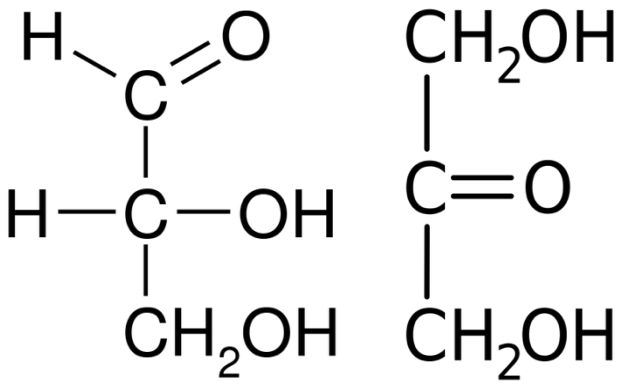


N (NH_2CONH_2) = (6.3±0.1)x10^{12} cm^{-2}

X (NH_2CONH_2) = 4.7x10^{-11} wrt molecular H_2

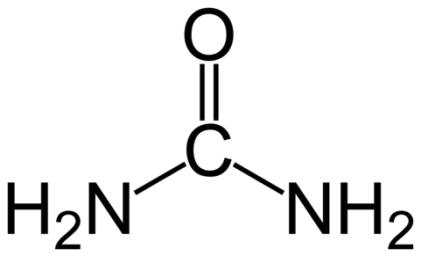
Toward the RNA world in G+0.693

glyceraldehyde
&
dihydroxyacetone



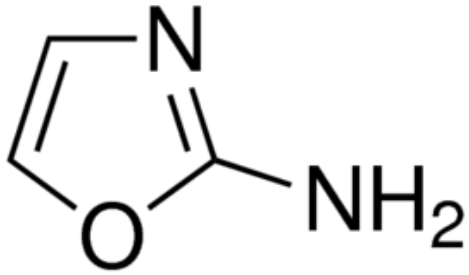
Upper limits
$\chi < (0.5\text{-}1.0)\times10^{-10}$

Urea



Detected
$X \sim 5\times10^{-11}$

2-amino-oxazole

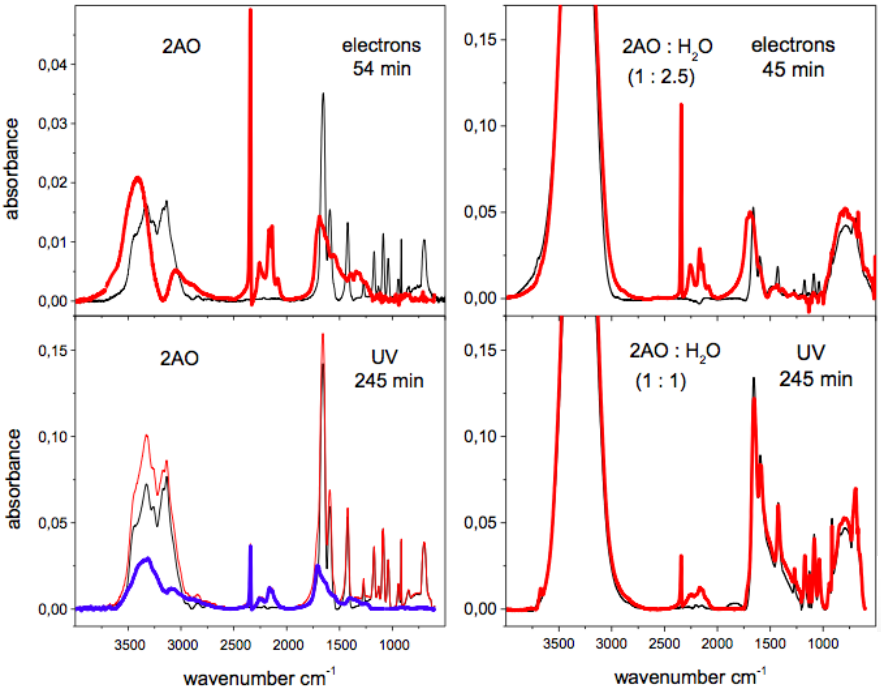


Upper limits
$\chi < 8.0\times10^{-11}$

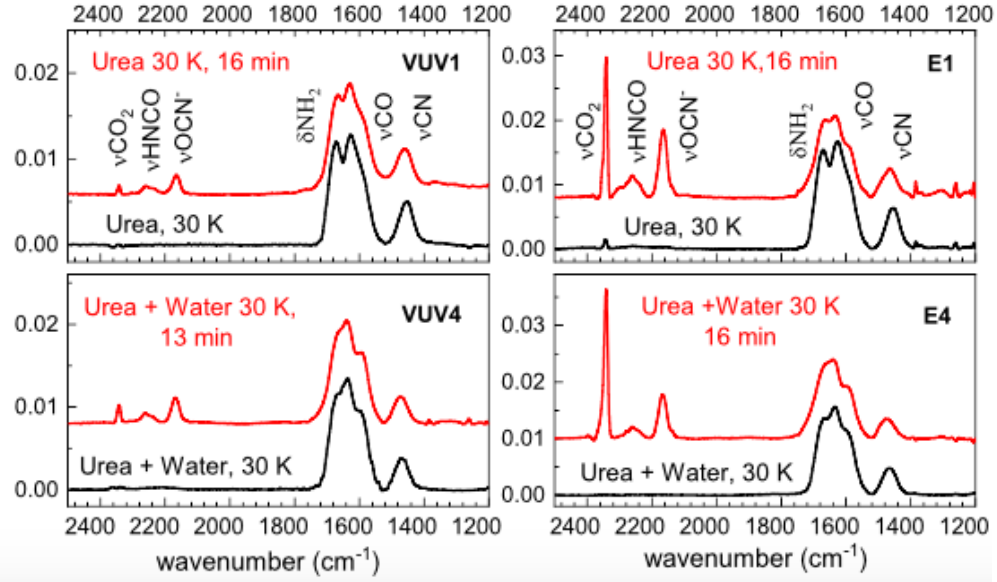
Jimenez-Serra+(2020), Astrobiology, 20, 7

Energetic processing of urea and 2-aminooxazole

2-amino-oxazole (Mate+2021)



Urea (Herrero+2022)

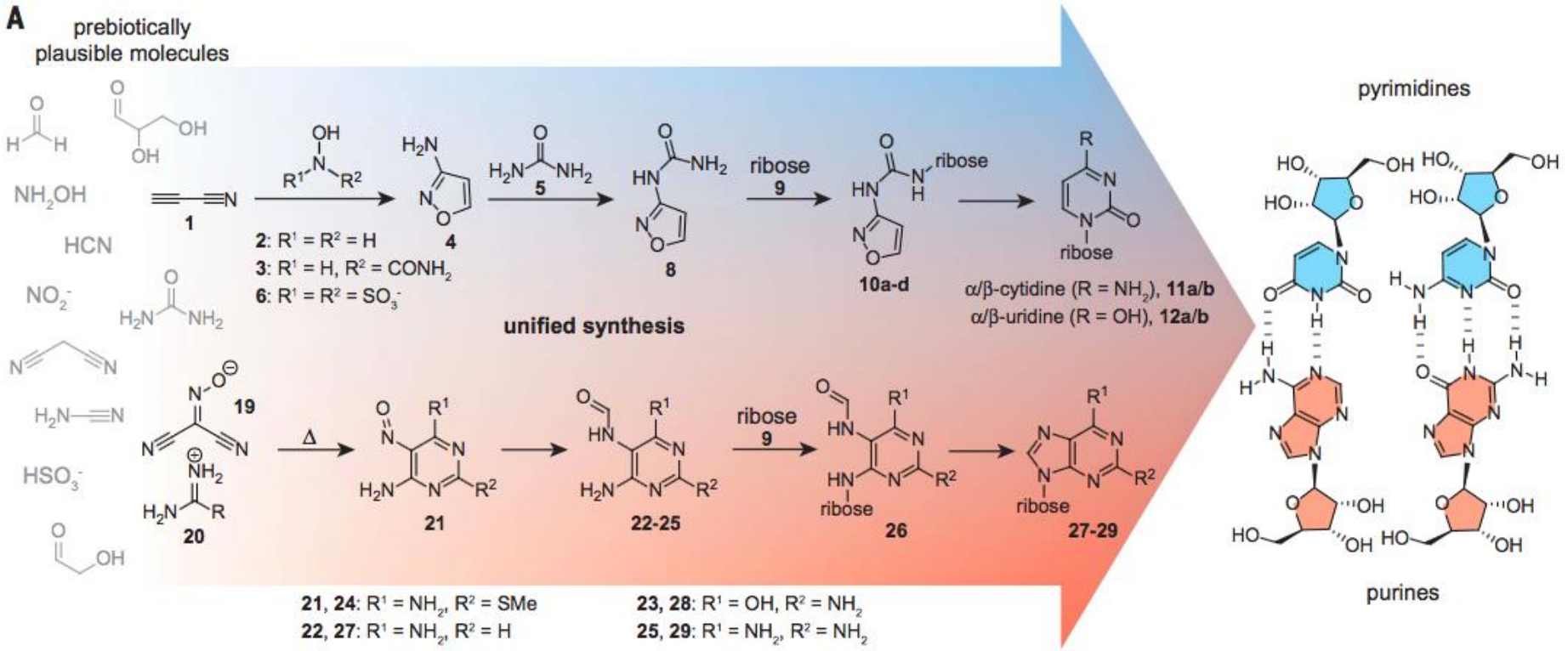


Ices of pure 2AO/urea and of 2AO/urea:H_2O mixes irradiated with UV photons and e-'s simulating CRs

-> *photo-destruction rates*

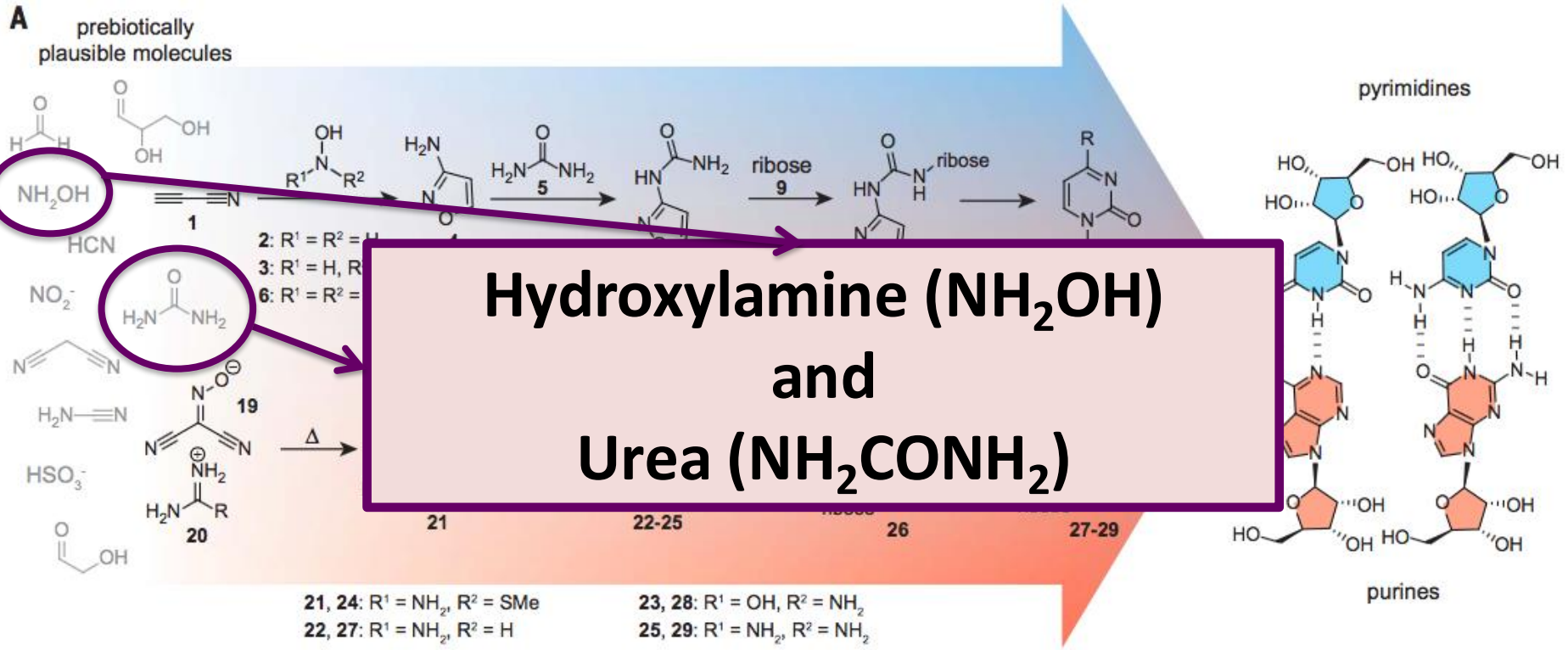
Urea is more resilient to irradiation than 2-amino-oxazole

The primordial RNA-world hypothesis



Concurrent formation of all four RNA ribonucleotides (pyrimidine AND purine)
Becker et al. (2019, Science, 366, 6461)

The primordial RNA-world hypothesis



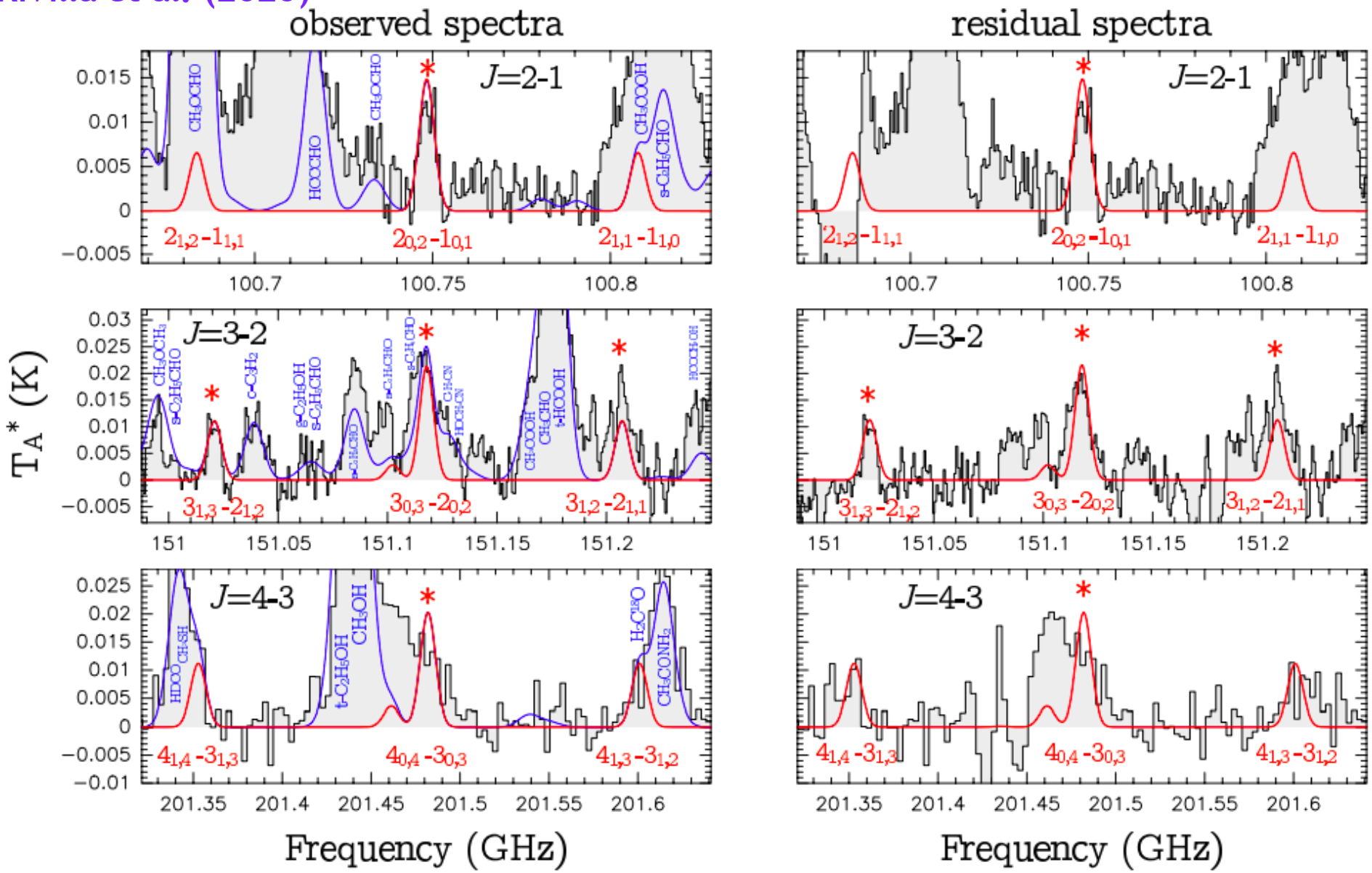
Hydroxylamine (NH_2OH)
and
Urea (NH_2CONH_2)

Concurrent formation of all four RNA ribonucleotides (pyrimidine AND purine)
Becker et al. (2019, Science, 366, 6461)

Prebiotic precursors of the primordial RNA world in space: Detection of NH_2OH

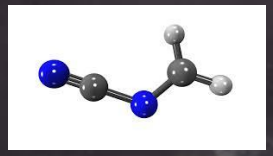
Víctor M. Rivilla,[1,2] Jesús Martín-Pintado,[1] Izaskun Jiménez-Serra,[1] Sergio Martín,[3,4] Lucas F. Rodríguez-Almeida,[1] Miguel A. Requena-Torres,[5,6] Fernando Rico-Villas,[1] Shaoshan Zeng,[7] and Carlos Briones[1]

Rivilla et al. (2020)



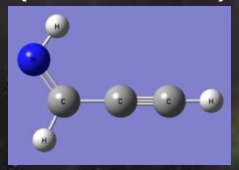
Prebiotic Molecules in G+0.693

Z-cyanomethanimine (Z-HNCHCN)



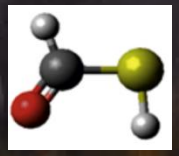
Rivilla et al. (2019b)

Propargylimine (HCCCHNH)



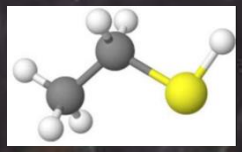
Bizzocchi et al. (2020)

Thio-formic acid (HC(O)SH)



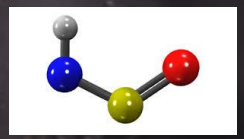
Rodríguez-Almeida et al. (2021a)

Ethanethiol (CH_3CH_2SH)



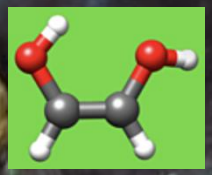
Rodríguez-Almeida et al. (2021a)

Thionylimide (HNSO)



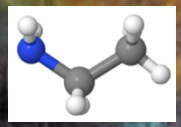
Sanz-Novo et al. (2024)

Z-1,2-ethenediol $(CHOH)_2$



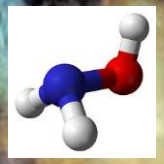
Rivilla et al. (2022a)

Ethyl amine ($C_2H_5NH_2$)



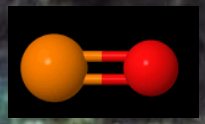
Zeng et al. (2021)

Hydroxylamine (NH_2OH)



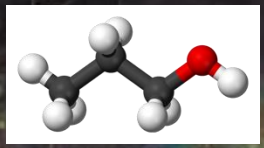
Rivilla et al. (2020)

PO^+



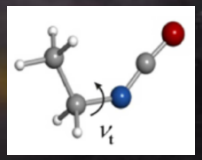
Rivilla et al. (2022)b

n-Propanol ($n\text{-}C_3H_7OH$)



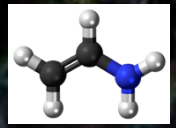
Jimenez-Serra et al. (2022)

Ethyl isocyanate (C_2H_5NCO)

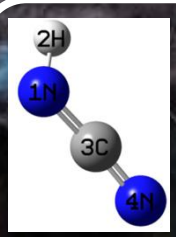


Rodríguez-Almeida et al. (2021b)

Vinyl amine ($C_2H_3NH_2$)



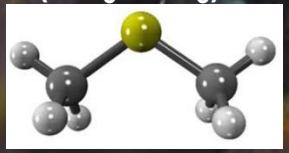
Zeng et al. (2021)



Cyanomydil (HNCH)

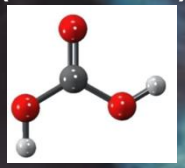
Rivilla et al. (2021b)

di-methyl sulfide (CH_3SCH_3)



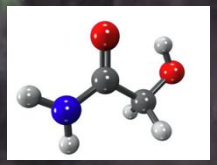
Sanz-Novo et al. (2025)

Carbonic Acid (HOCOOH)



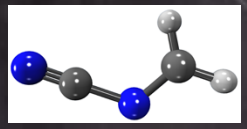
Sanz-Novo et al. (2023)

Glycolamide ($NH_2C(O)CH_2OH$)



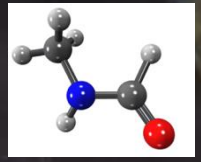
Rivilla et al. (2023)

N-Cyanomethanimine (NH_2CNCN)



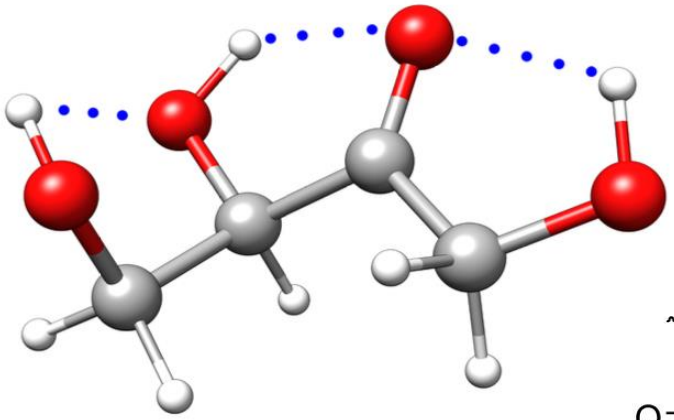
San Andrés et al. (2024)

cis-N-methylformamide (N-CH_3NHCHO)



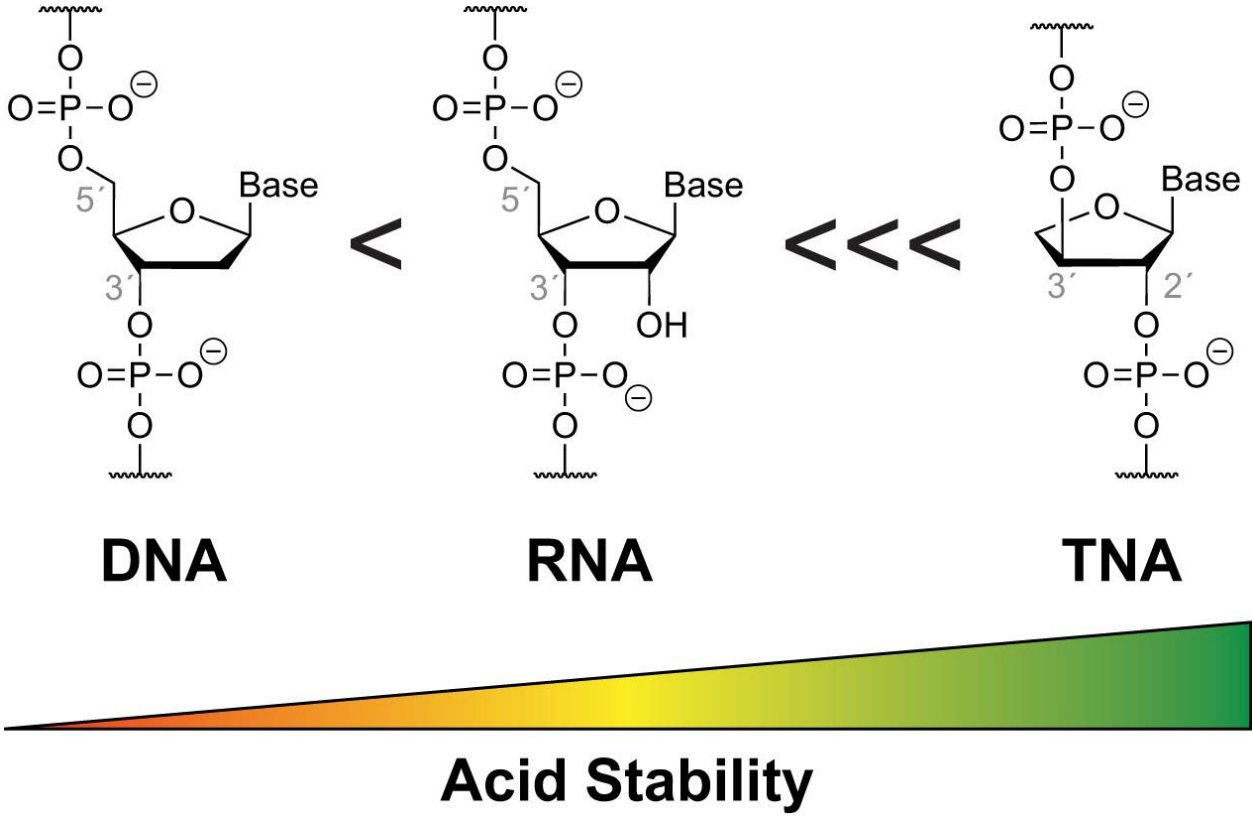
Zeng et al. (2025)

Detection of the first sugar in the ISM: Erythrulose



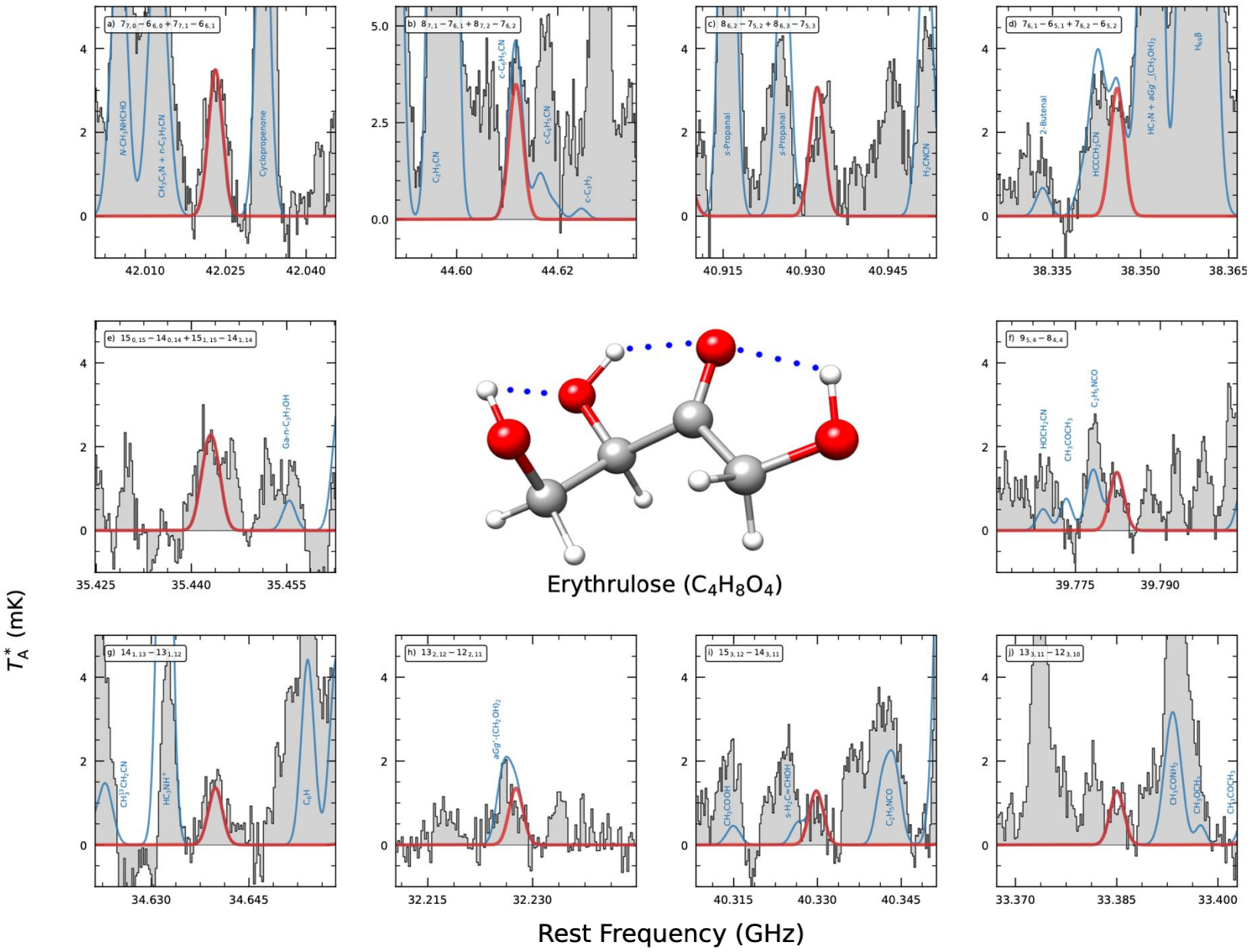
Erythrulose ($C_4H_8O_4$)

Erythrulose is a C4 ketose
It easily isomerizes into threose
(a C4 aldose) in aqueous conditions



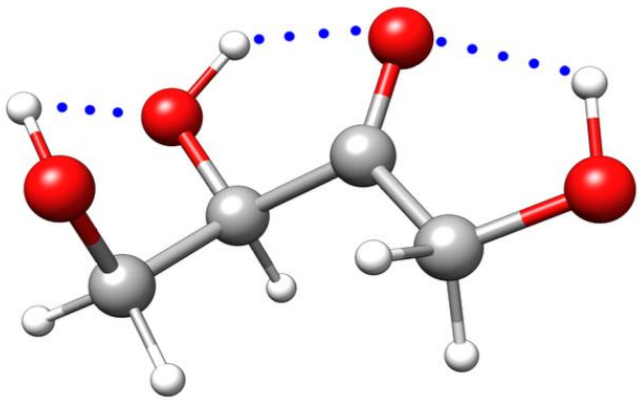
Yu et al. 2012, Nature Chemistry, 4, 183; Lee et al. 2023, Nucleic Acids Research, 51, 9542

Detection of the first sugar in the ISM



Jimenez-Serra et al., Submitted to Nature Astronomy

Detection of the first sugar in the ISM



Erythrulose ($C_4H_8O_4$)

Tex = 11.3 ± 1.8 K

N = (8.7±0.8)×10^{13} cm^{-2}

χ(Erythrulose) ~ 6x10^{-10}

Table 1 Derived physical parameters and modelled abundances of erythrulose and chemically-related species toward the G+0.693 molecular cloud.

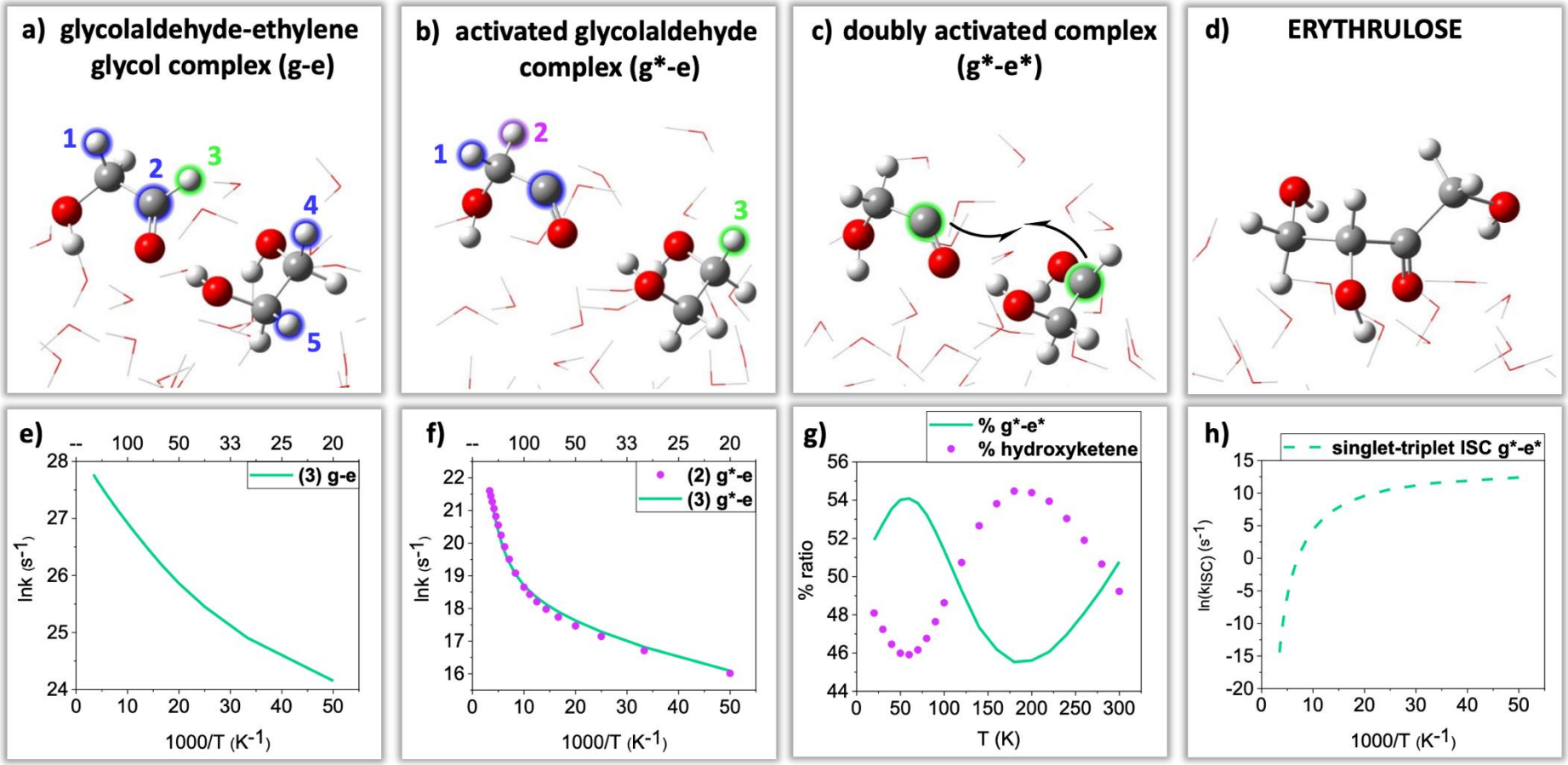
Molecule	N ($\times 10^{13}$ cm^{-2})	T_{ex} (K)	v_{LSR} (km s^{-1})	FWHM (km s^{-1})	χ_{obs} [a] ($\times 10^{-10}$)	χ_{mod} [d] ($\times 10^{-10}$)
Glycolaldehyde ($HOCH_2CHO$)[b]	9.3±0.3	21.8±0.8	68.9±0.2	19.4±0.5	6.9±0.2	∼20
aGg'-Ethylene Glycol [aGg'-$(CH_2OH)_2$]	23.5±5.2	10.3±2.6	67.9±2.8	21[c]	17.4±3.9	∼100
Glyceraldehyde ($HOCH_2CH(OH)CHO$)	≤0.5	10[c]	69[c]	21[c]	≤0.4	∼20
Dihydroxyacetone ($HOCH_2COCH_2OH$)	≤1.0	10[c]	69[c]	21[c]	≤0.7	∼50
Glycerol ($HOCH_2CH(OH)CH_2OH$)	≤2.5	10[c]	69[c]	21[c]	≤1.9	...
Erythrulose ($C_4H_8O_4$)	8.7±0.8	11.3±1.8	69[c]	22[c]	6.4±0.6	∼20

C3 sugars are >8 x less abundant than erythrulose

How can erythrulose form in the ISM?

Jimenez-Serra et al., Submitted to Nature Astronomy

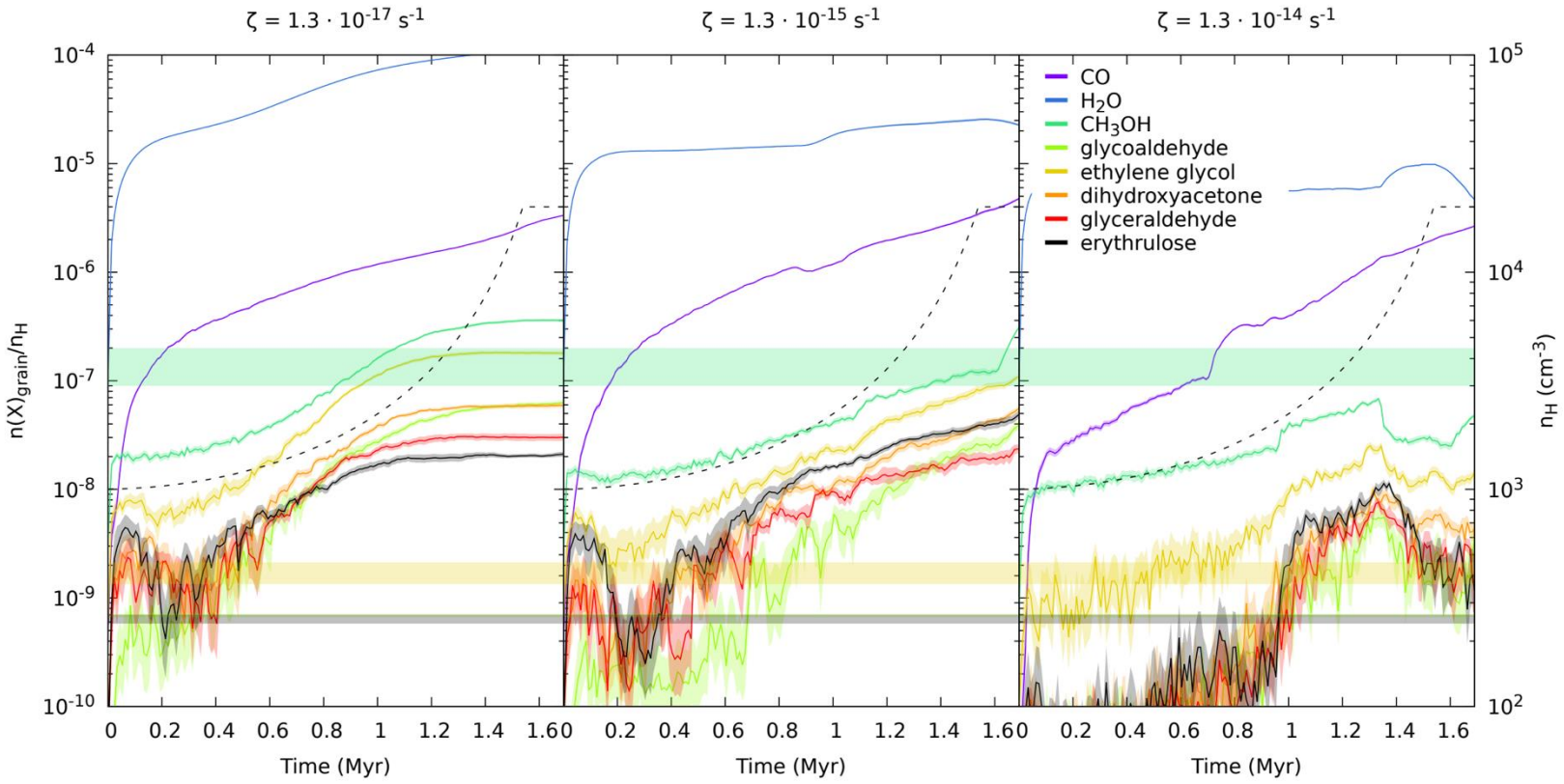
Detection of the first sugar in the ISM



Erythrulose can form on interstellar ices from C2 sugar precursors, glycolaldehyde and ethylene glycol

Jimenez-Serra et al., Submitted to Nature Astronomy

Detection of the first sugar in the ISM



Astrochemical modelling predicts erythrulose abundances consistent with observations

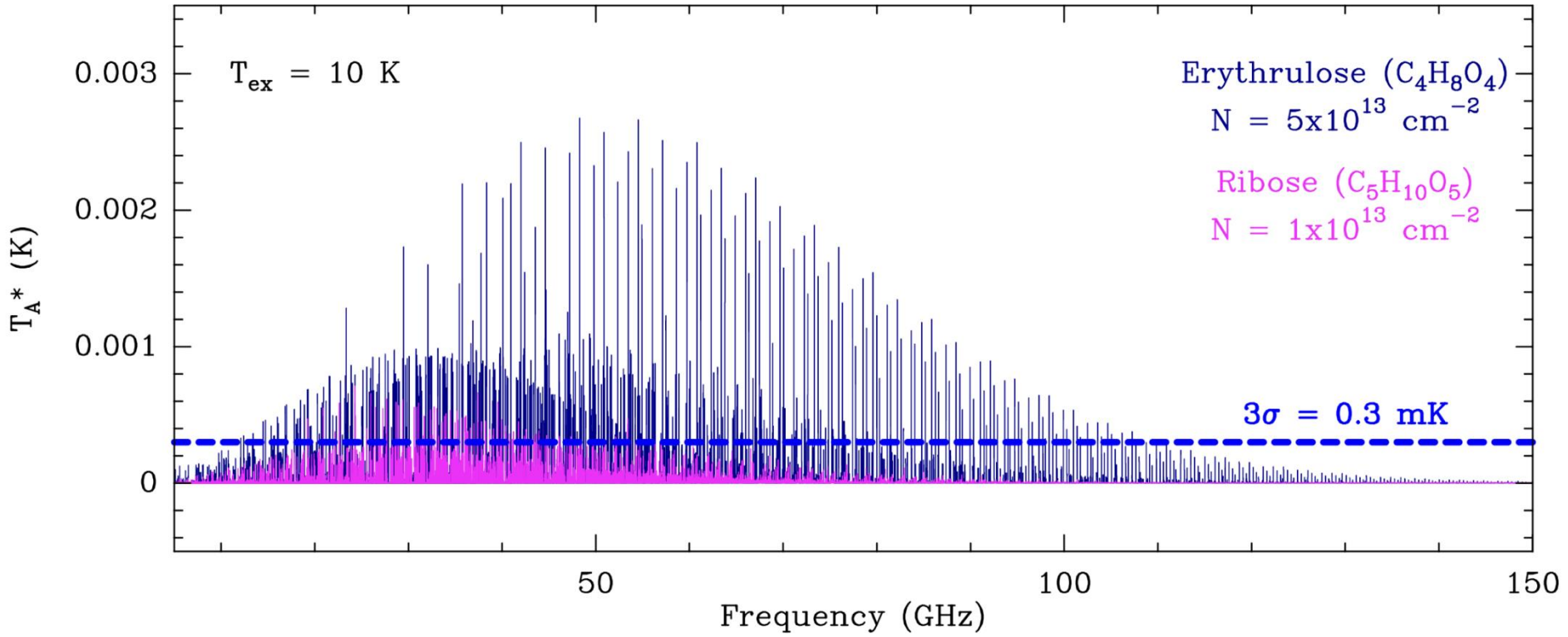
~(0.5-50)×10^9 kg of erythrulose delivered to early Earth

Viable sugar feedstock for early synthesis of nucleic acids

Jimenez-Serra et al., Submitted to Nature Astronomy

Searching for sugars with AtLAST

Feasibility study for the detection of C4 and C5 sugars

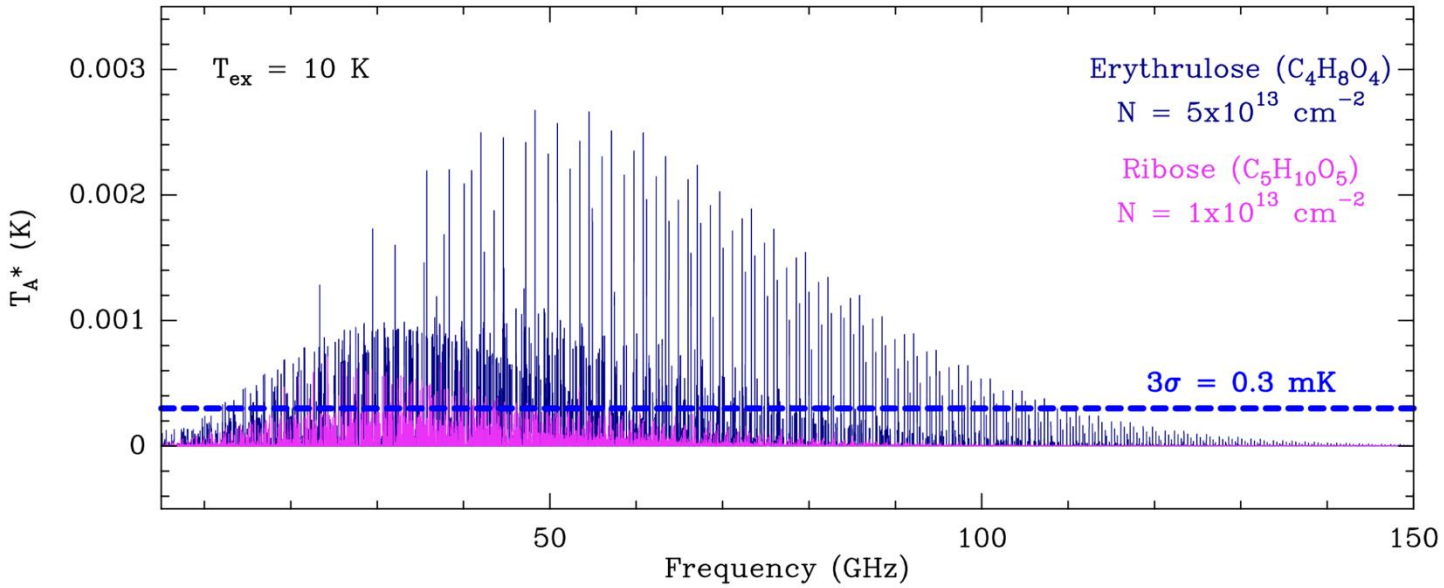


Sensitivity = 0.1 mK (10 x better than in current surveys)

<100 hours of observing time (>1 yr with current facilities)

Jimenez-Serra et al. (2025), AtLAST white paper, arXiv: 2512.14772

Observation Requirements for AtLAST



- *Heterodyne multi-beam receiver*
- *"Sweet spot" between 30-50 GHz*
- *Emission extended -> FoV = 2 deg & beam = 27"-38"*
- *If 10mm-array is "sparse" -> "staring"/"wobbler" obs*
- *If 10mm-array is filled tightly -> fast OTF or daisy pattern*

Jimenez-Serra et al. (2025), AtLAST white paper, arXiv: 2512.14772

CENTRO DE ASTROBIOLOGÍA

CSIC
Consejo Superior de Investigaciones Científicas

INTA Instituto Nacional de Técnica Aeroespacial

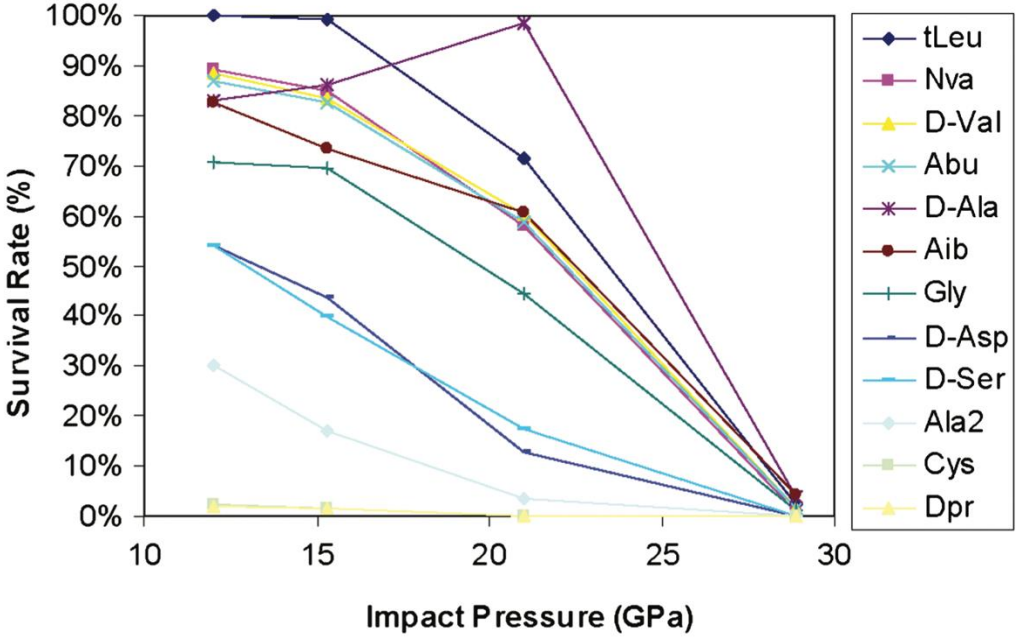
CCISMSF group - https://sites.google.com/view/cab-ccismsf-group/home

UNIÓN EUROPEA
FONDO EUROPEO DE DESARROLLO REGIONAL
"Una manera de hacer Europa"
AGENCIA ESTATAL DE INVESTIGACIÓN
AEI
(PID2022-136814NB-I00)
ILINK CSIC (ILINK23017)
Bilateral CSIC (BIJSP25017)
MINISTERIO DE CIENCIA E INNOVACIÓN
European Research Council
Established by the European Commission
CSIC

Survival of prebiotic molecules through atmospheric entrance and surface impact

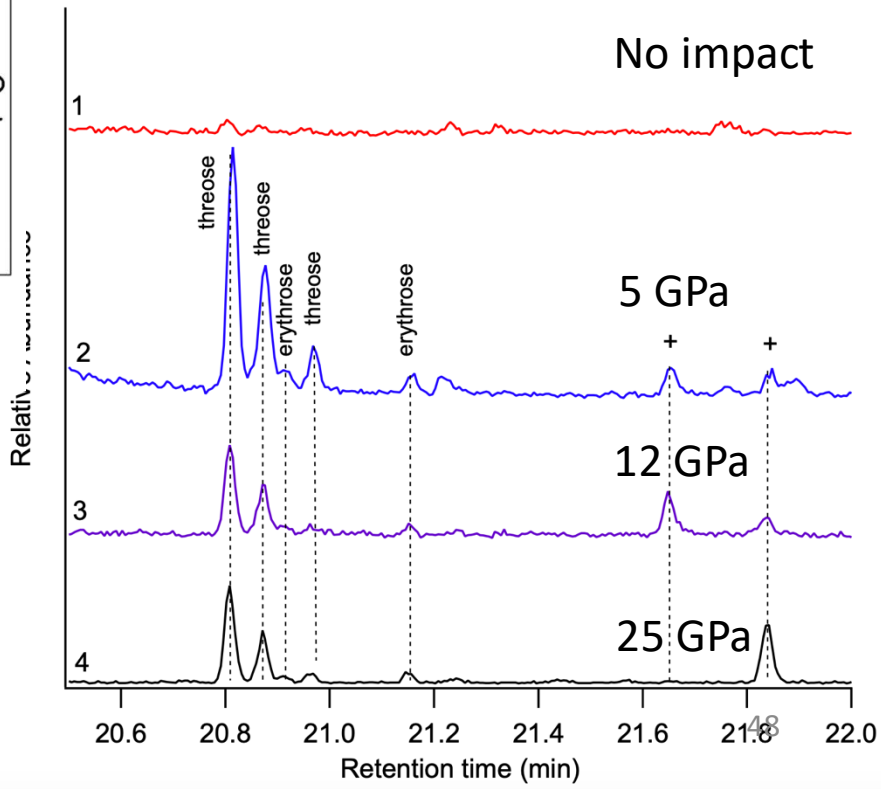
Bertrand et al. (2009), Astrobiology

Amino acid survival rate as a function of impact pressure



McCaffrey et al. (2014), Astrobiology

Glycolaldehyde survival and reactivity in simulated meteor impacts

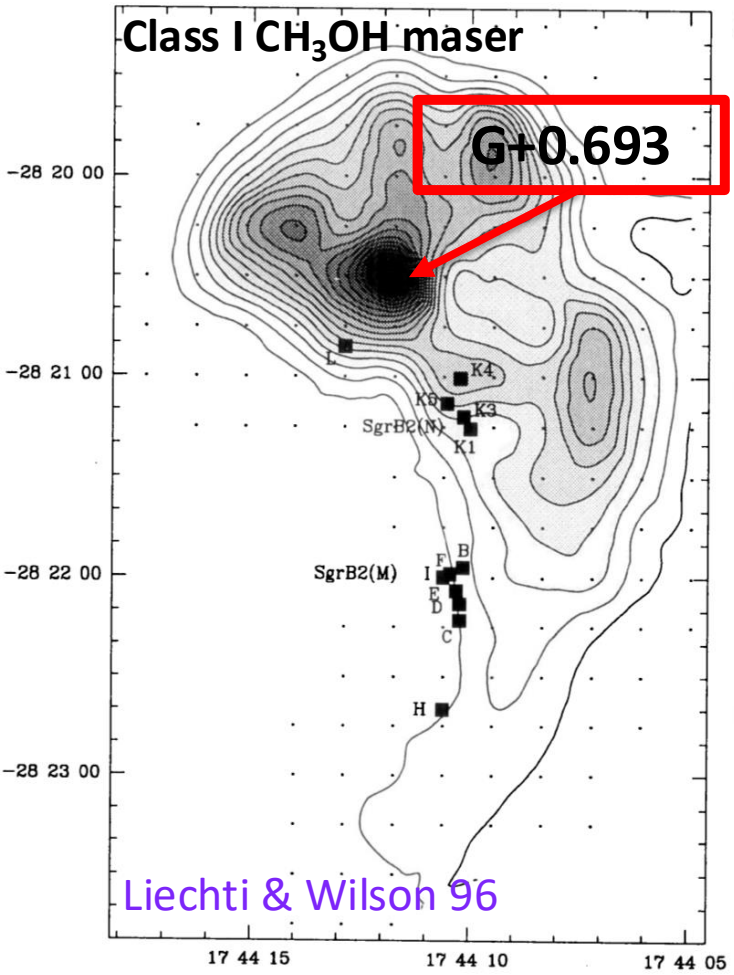


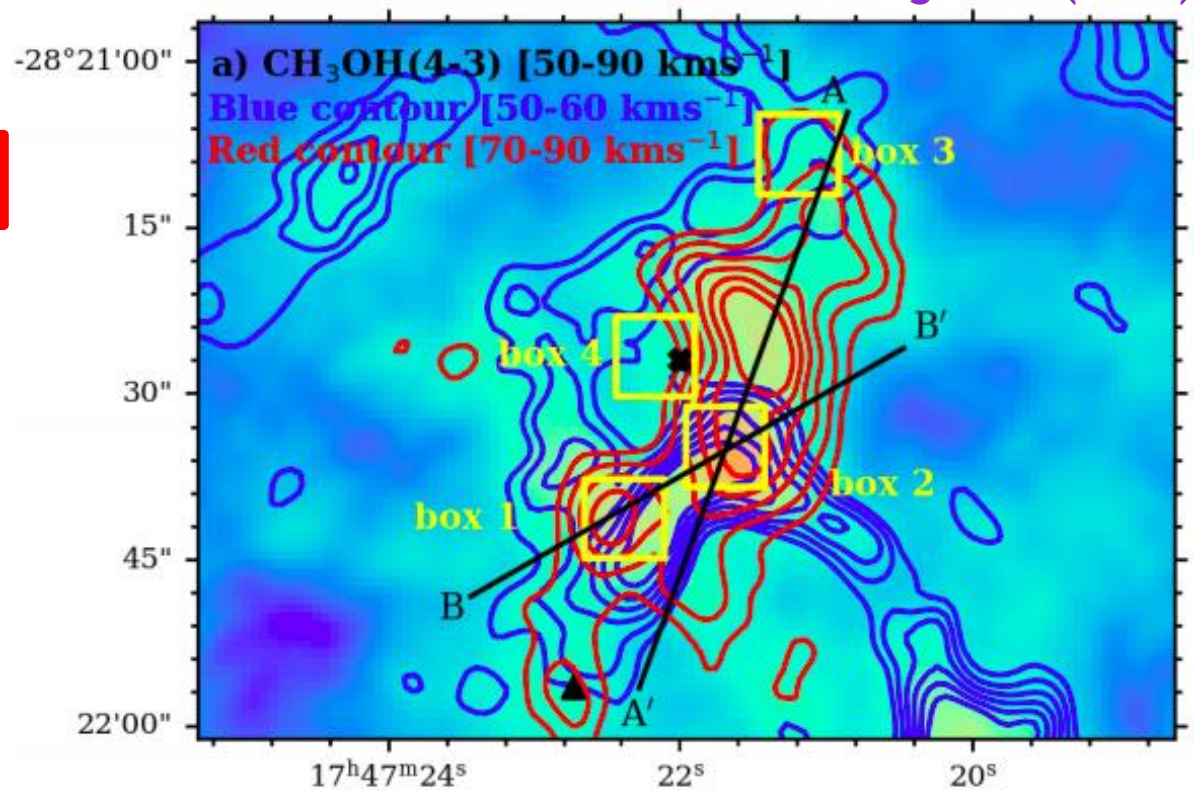
Origin of the chemical richness in G+0.693

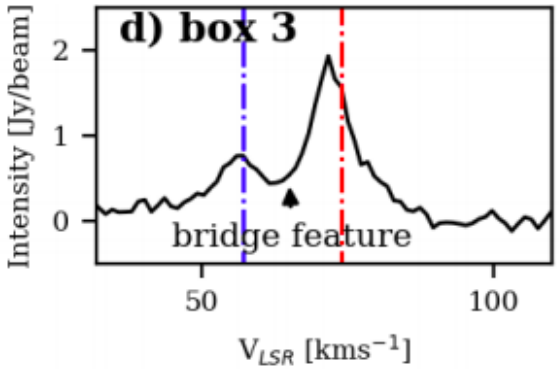
Cloud-cloud collision responsible for large-scale shocks

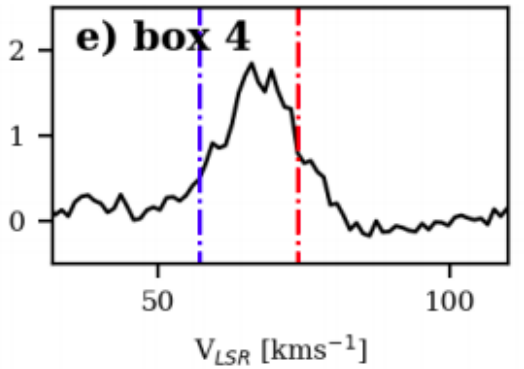
(Hasegawa+94; Sato+00; Tsuboi+15; Wu+17)

Zeng et al. (2020)





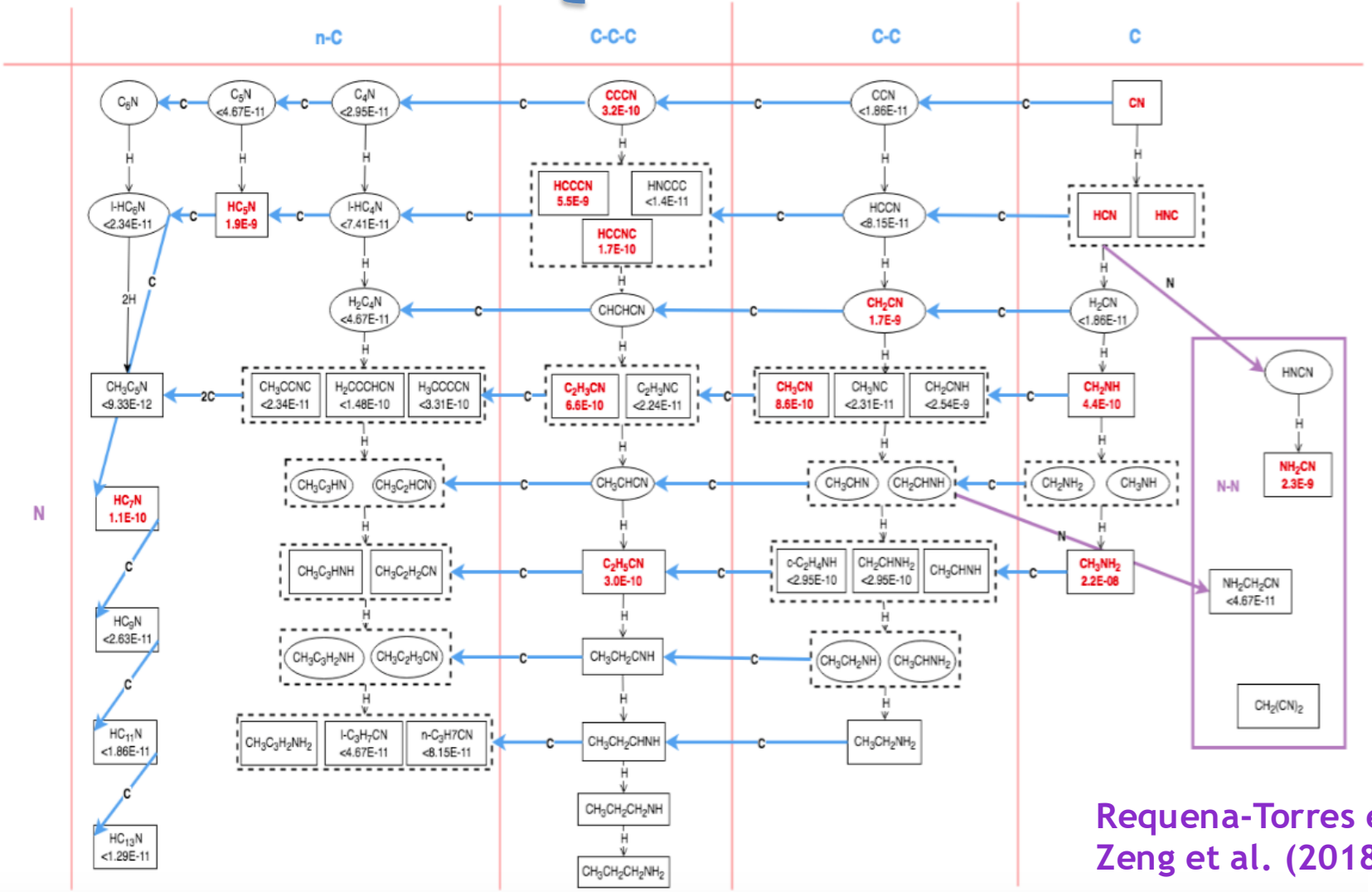




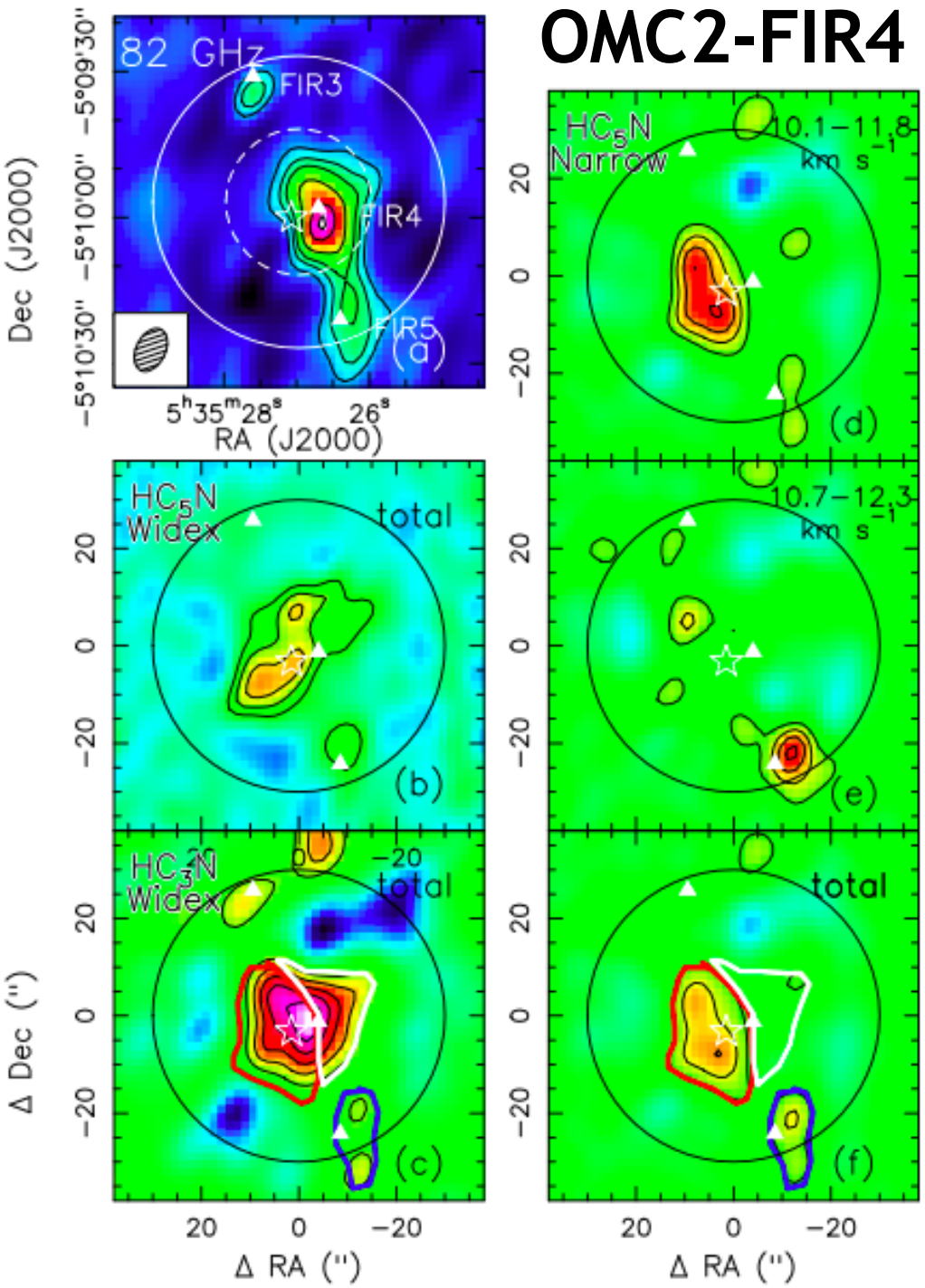
Chemical Inventory in G+0.693

Rich in COMs with:

1) *Oxygen (-OH, -OCHO, -COOH)*
2) *Nitrogen (-CN and -NH/NH_2)*
3) *Sulfur (including -SH)*



Requena-Torres et al. (2008)
Zeng et al. (2018)



Protostars, forges of cosmic rays

Ceccarelli+(2014), Padovani+(2016), Fontani+(2017), Favre+(2018)

Observed chemistry consistent with a high level of cosmic-ray (CR) irradiation

CR field in OMC2
$\zeta \sim 4\times10^{-14}$ s^{-1}

Interstellar CR field
$\zeta \sim 3\times10^{-17}$ s^{-1}

Galactic Center CR field
$\zeta > 3\times10^{-15}$ s^{-1}