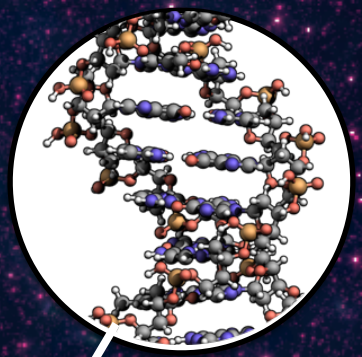
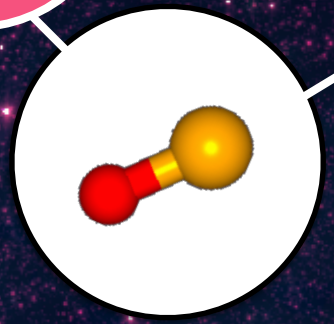
# BIOSFERA

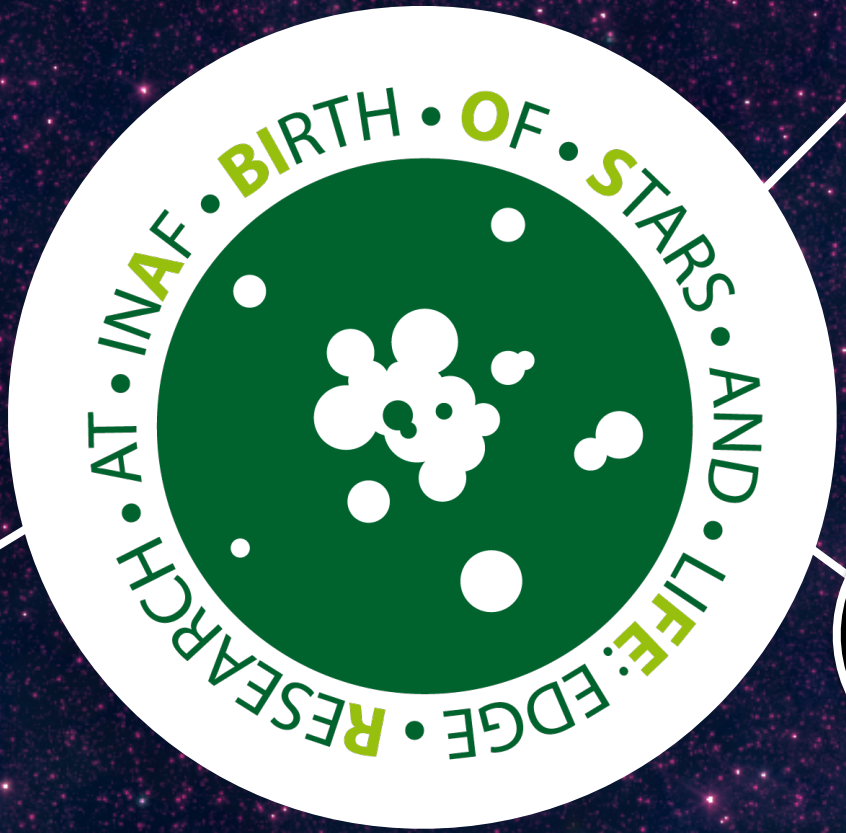
## BIrth Of Stars and LiFE: Edge Research at INAF

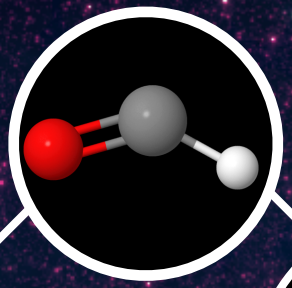

Víctor M. Rivilla

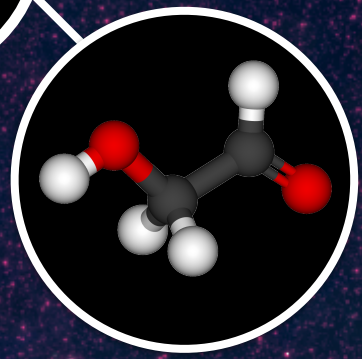
INAF - Osservatorio Astrofisico di Arcetri

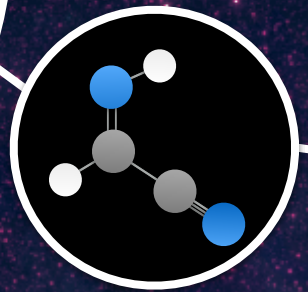



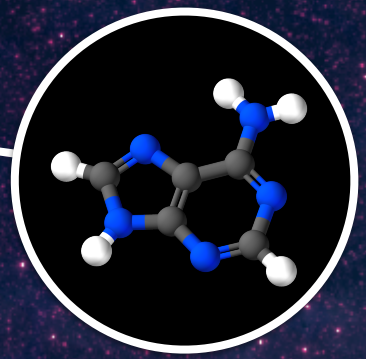










AstroFIt 2

**3rd ASTROFIT2 annual meeting**

**Rome, Italy, October 16 2019**


This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 664931.

# From atoms & Simple molecules to … LIFE

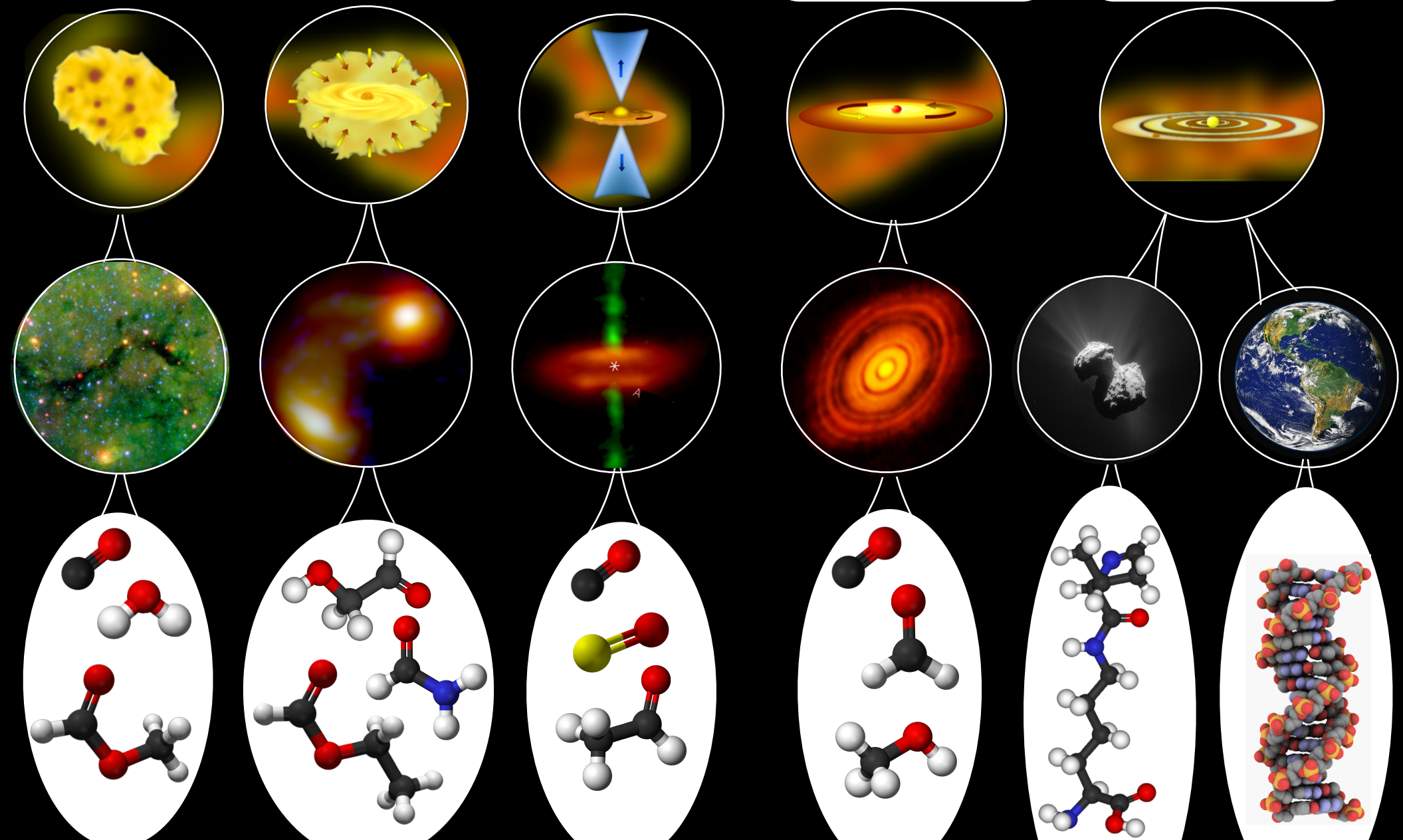
prestellar cores

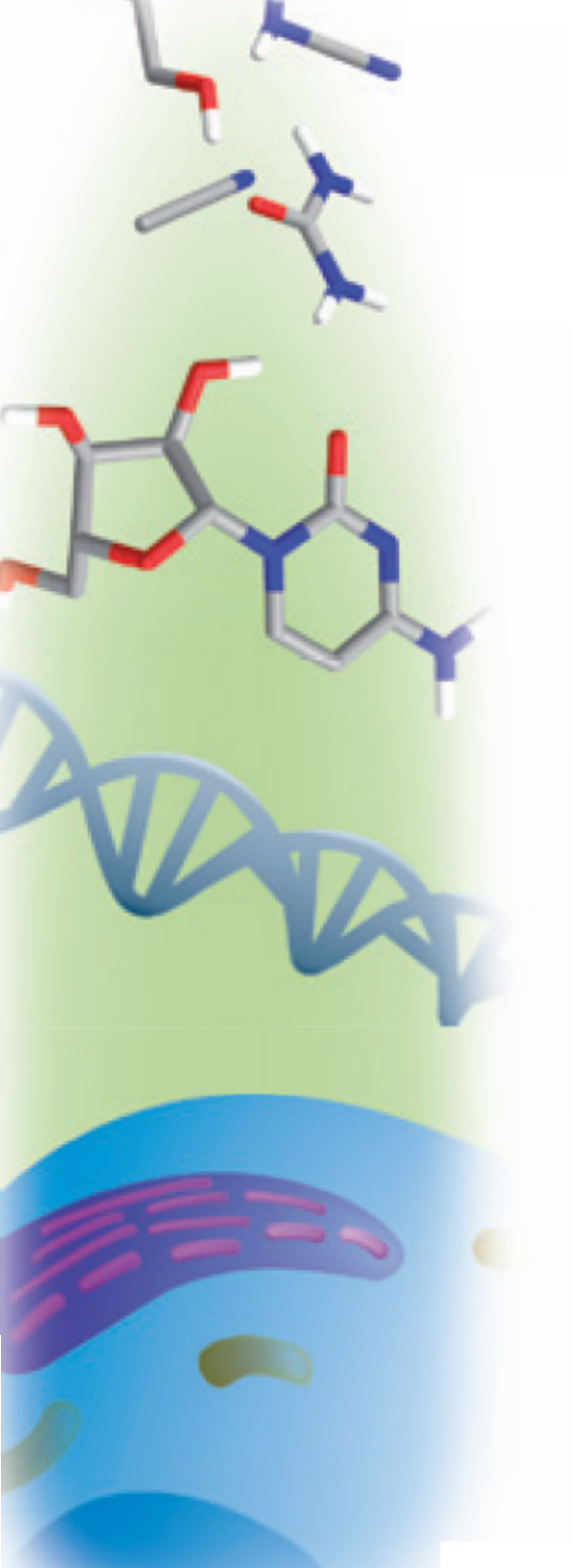
protostar envelope

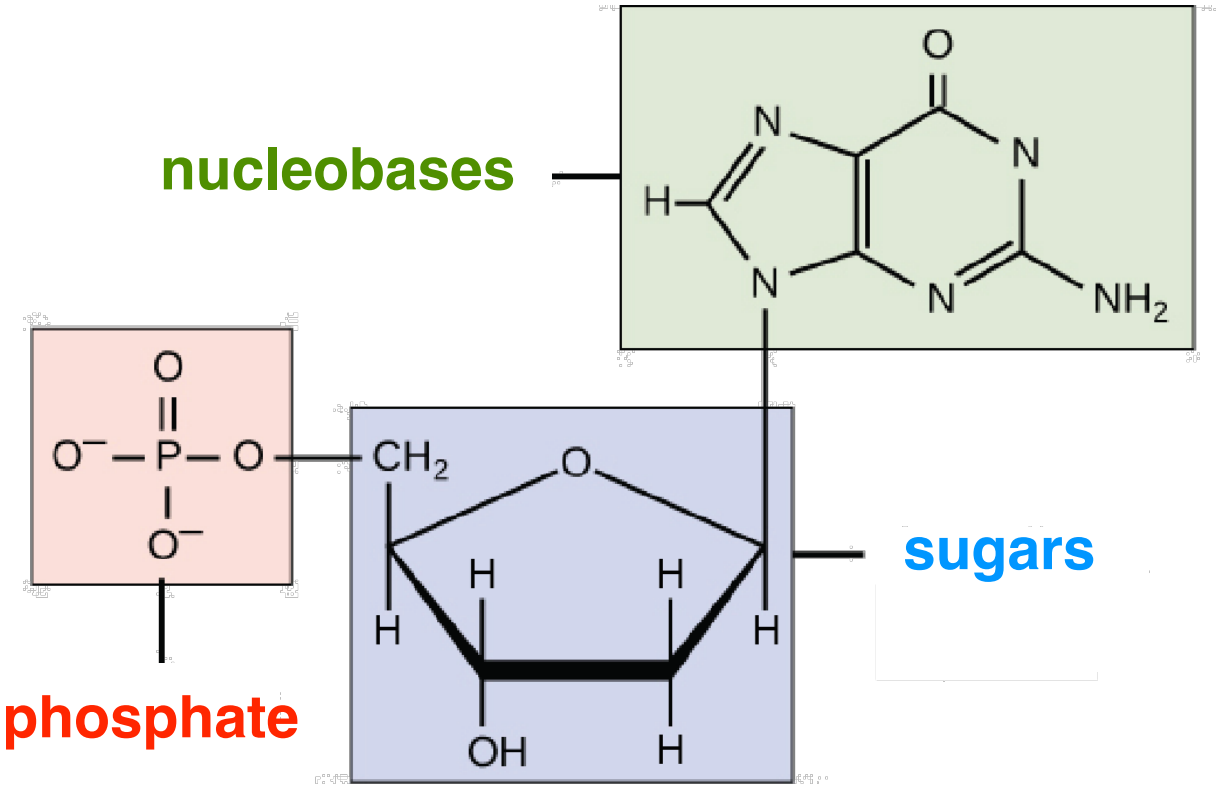
circumstellar disk and jet

protoplanetary disk

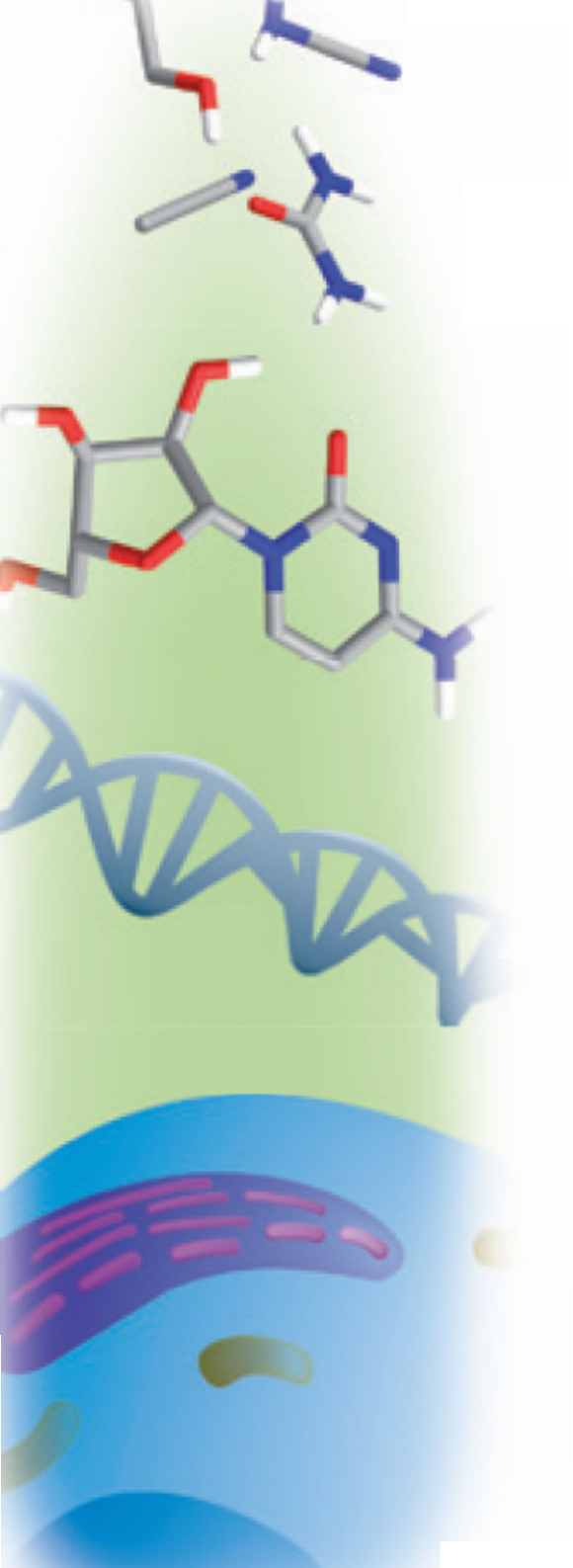
planets, comets & life

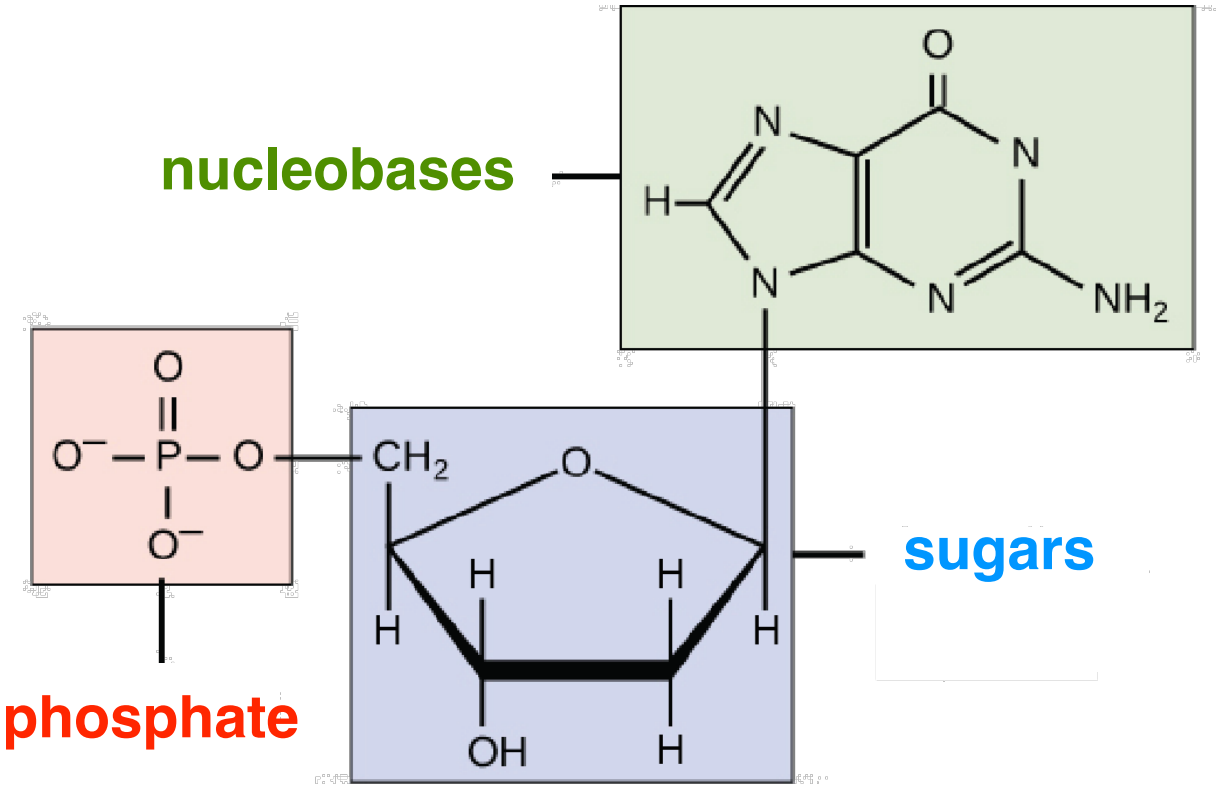






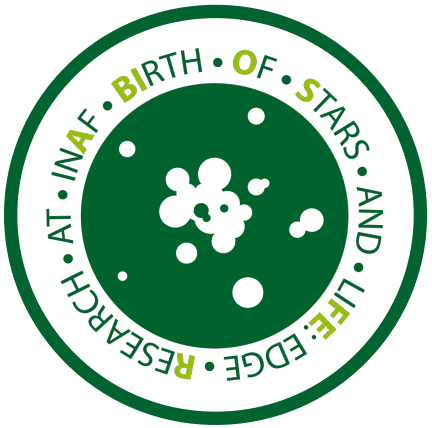

# Nucleotides: the building blocks of Life

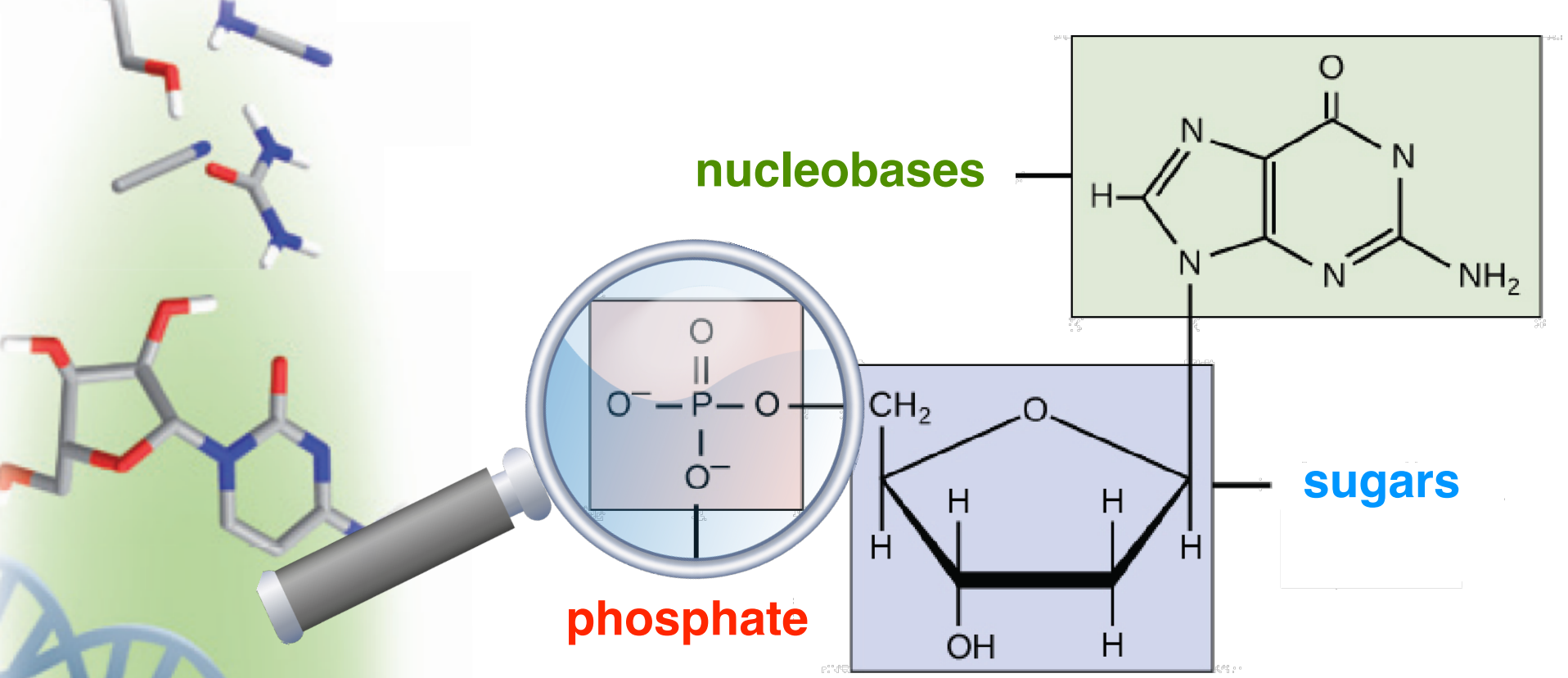





# BIOSFERA

**BIrth Of Stars and LiFE: Edge Research at INAF**





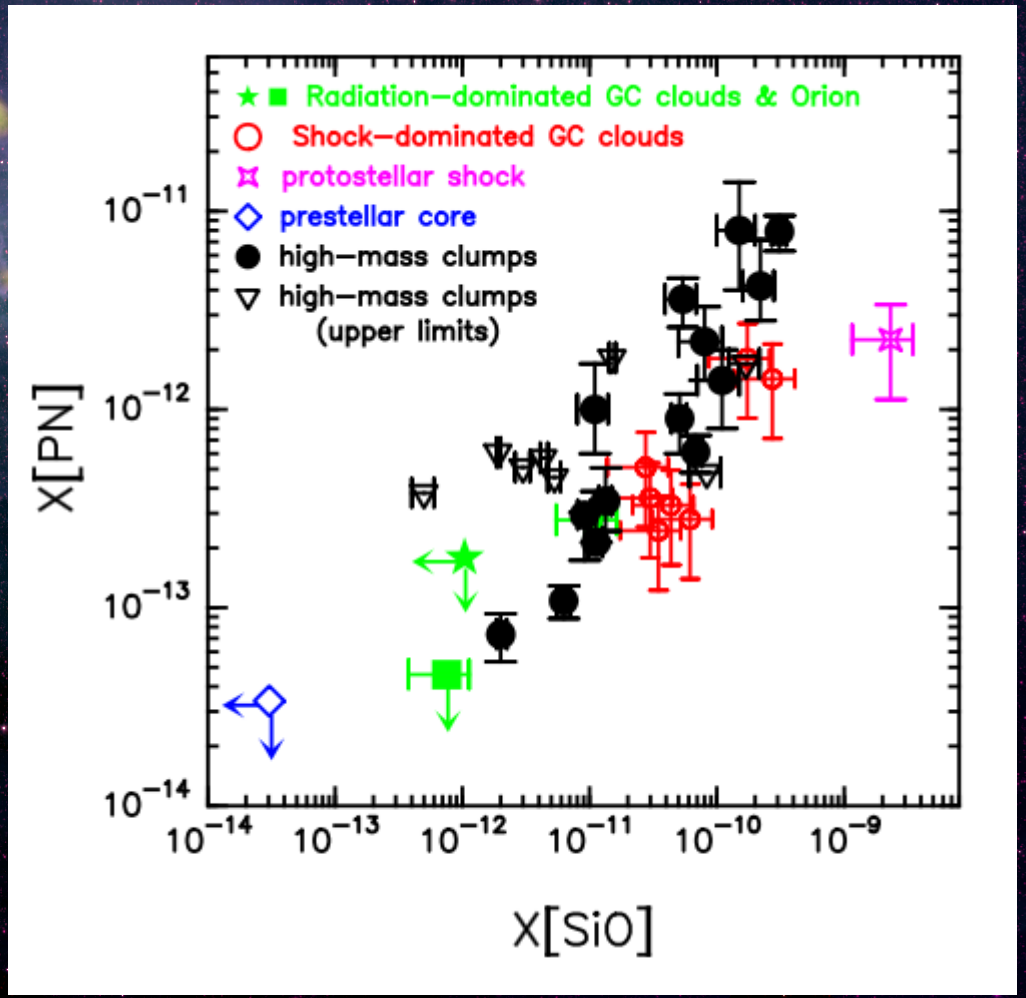

# BIOSFERA

**BIrth Of Stars and LiFE: Edge Research at INAF**

# PN in the Galaxy

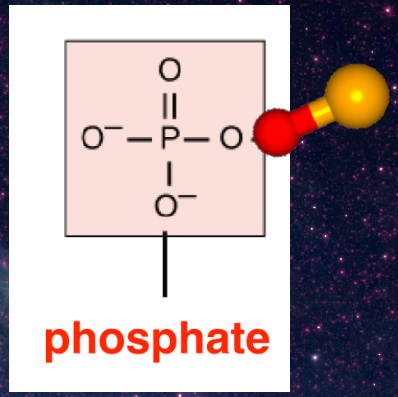
Fontani, Rivilla et al. (2016)
Rivilla et al. (2018)
Mininni, Fontani, Rivilla et al. (2018)

Survey of PN towards a large sample of massive star forming regions and Galactic Center clouds

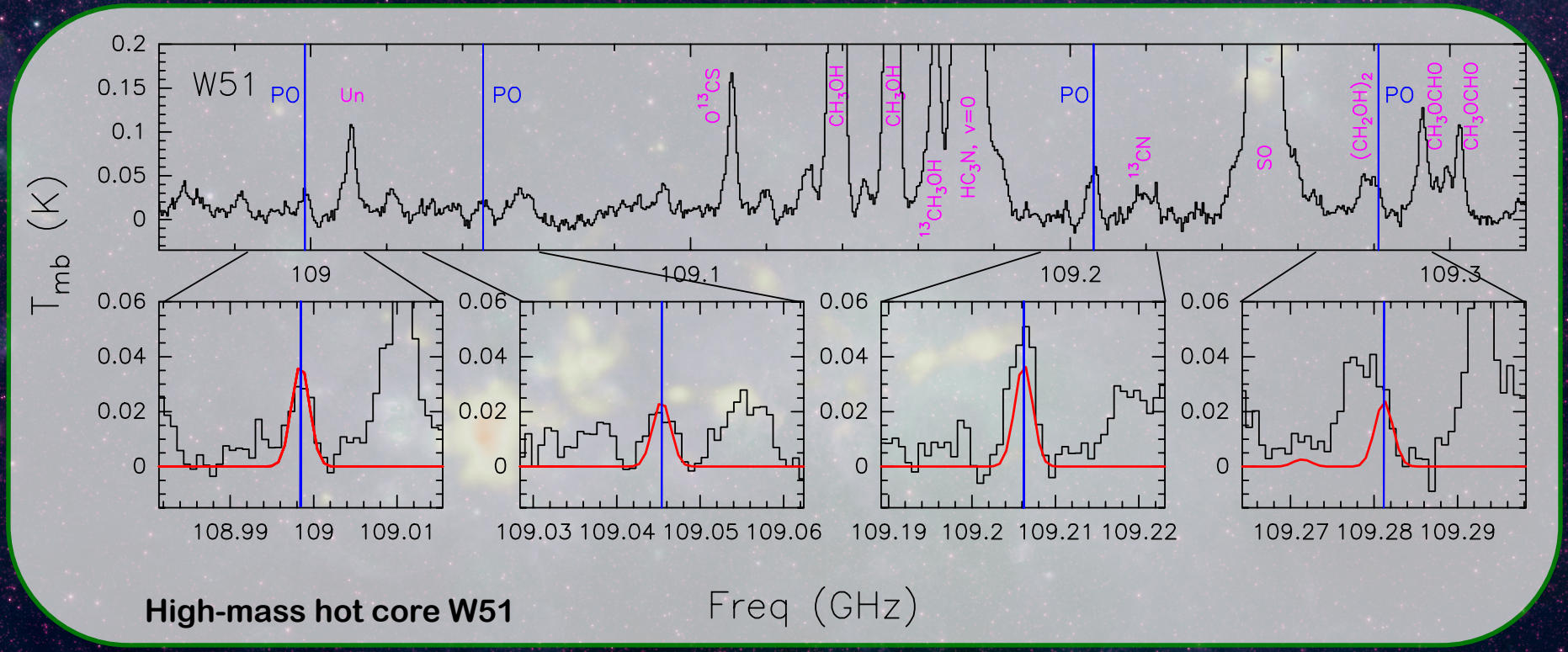


# First detections of PO in star-forming regions

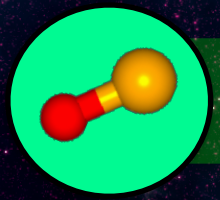
Rivilla et al. (2016)



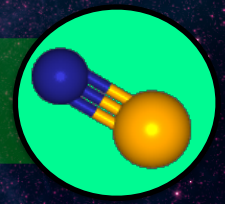

Rivilla et al. 2016




**High-mass hot core W51**

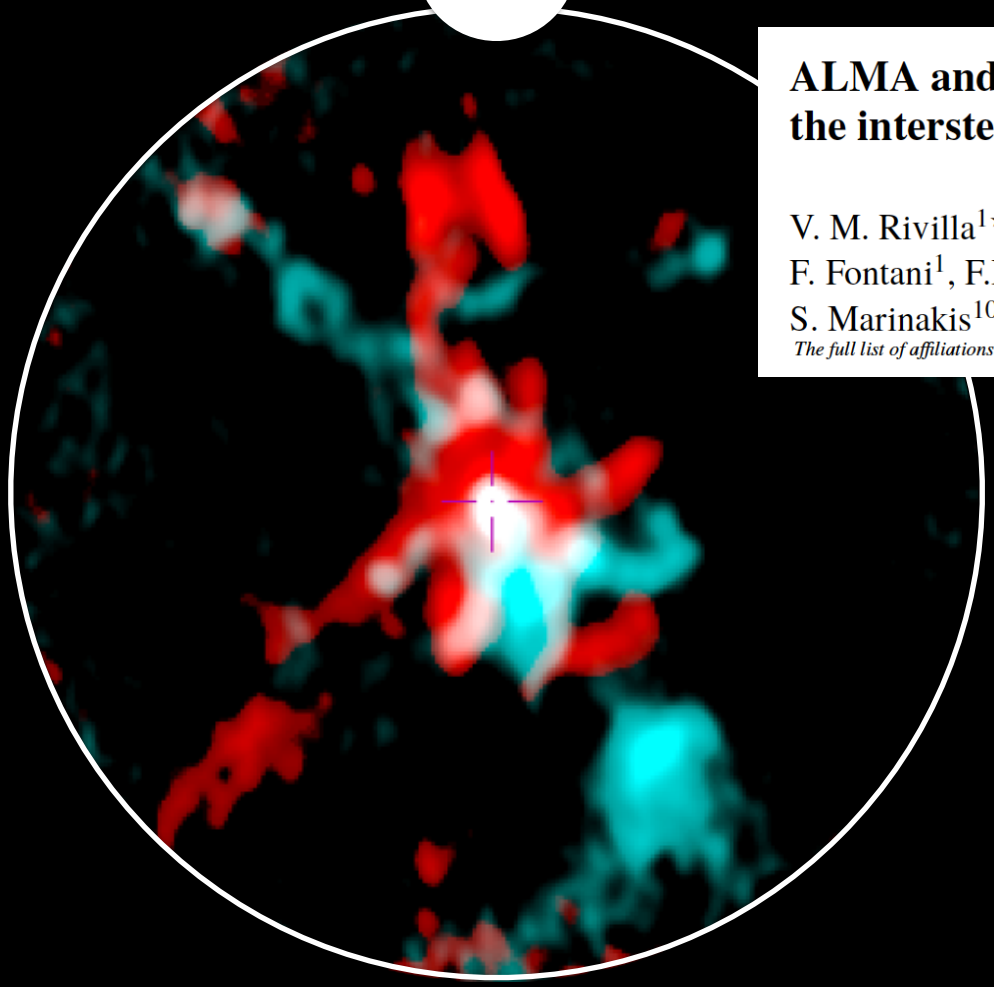


**PO is a factor 2-3 more abundant than PN !**



# AFGL 5142 star-forming region

SO



Rivilla et al. (2019c)

**ALMA and ROSINA detections of phosphorus-bearing molecules: the interstellar thread between star-forming regions and comets**

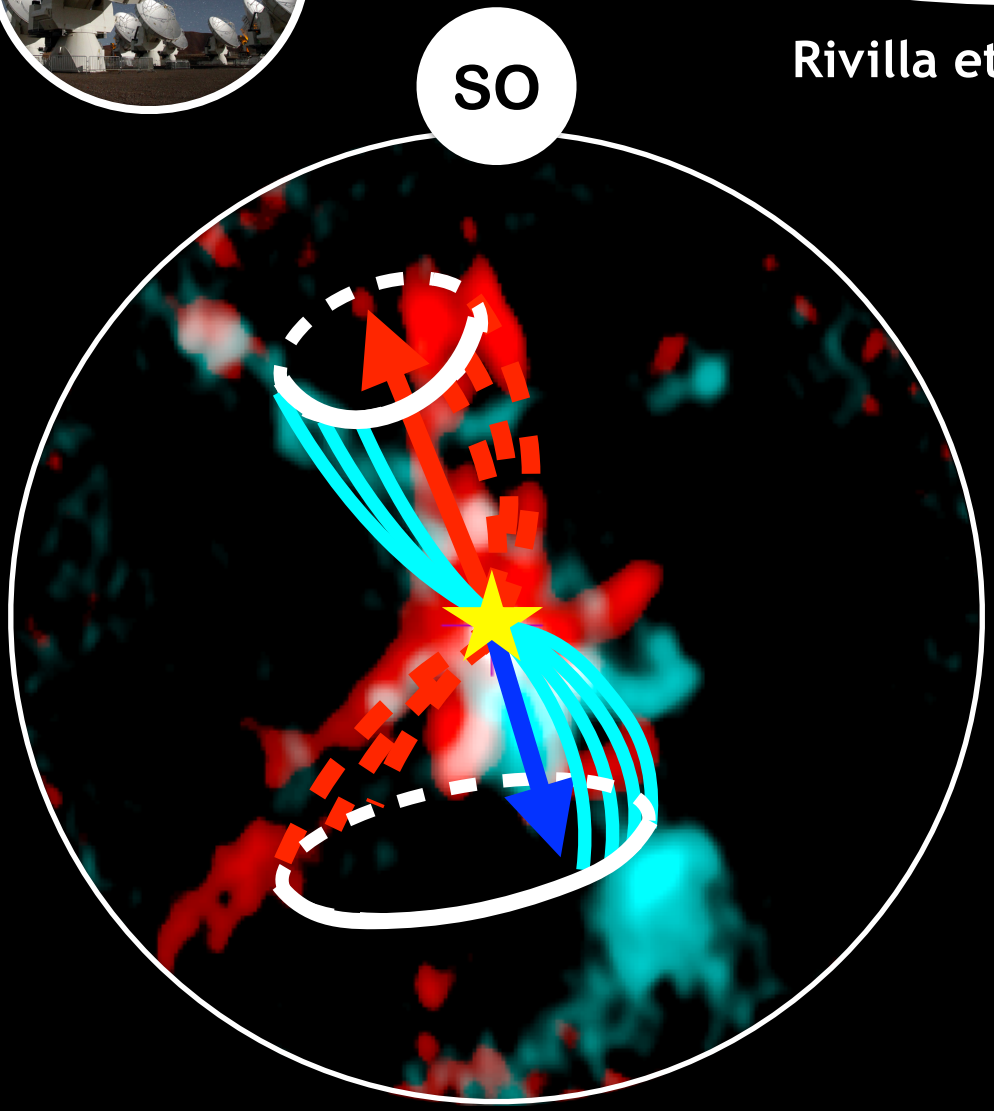
V. M. Rivilla[1]⋆, M. N. Drozdovskaya[2], K. Altwegg[3], P. Caselli[4], M. T. Beltrán[1], F. Fontani[1], F.F.S. van der Tak[5,6], R. Cesaroni[1], A. Vasyunin[7,8], M. Rubin[2], F. Lique[9], S. Marinakis[10,11], L. Testi[1,12,13], and the ROSINA team[14]

*The full list of affiliations appears at the end of the paper in Appendix A.*

[-12, -4.1] km/s $v_{sys}$=3.8 km/s [-3.5, 6.0] km/s

# AFGL 5142 star-forming region

Rivilla et al. (2019c)

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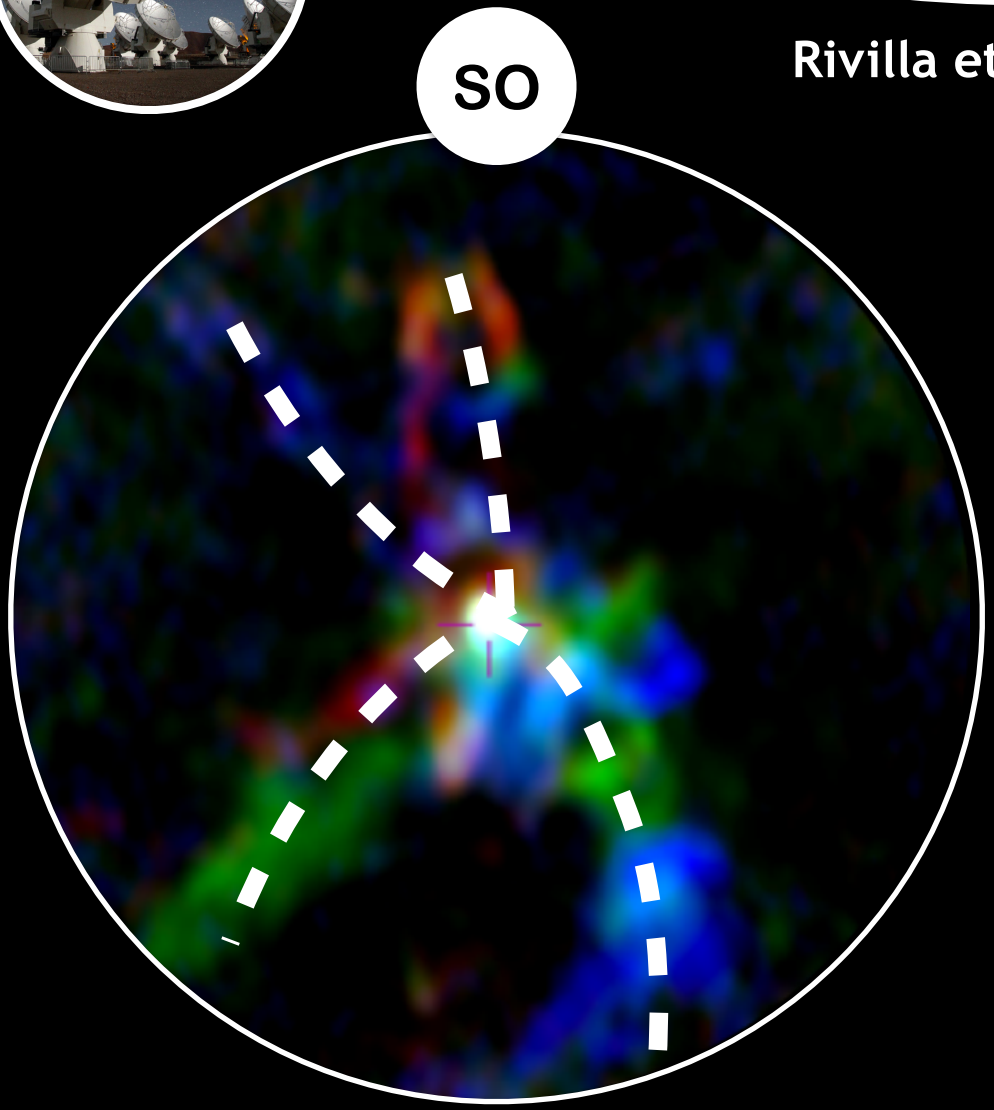
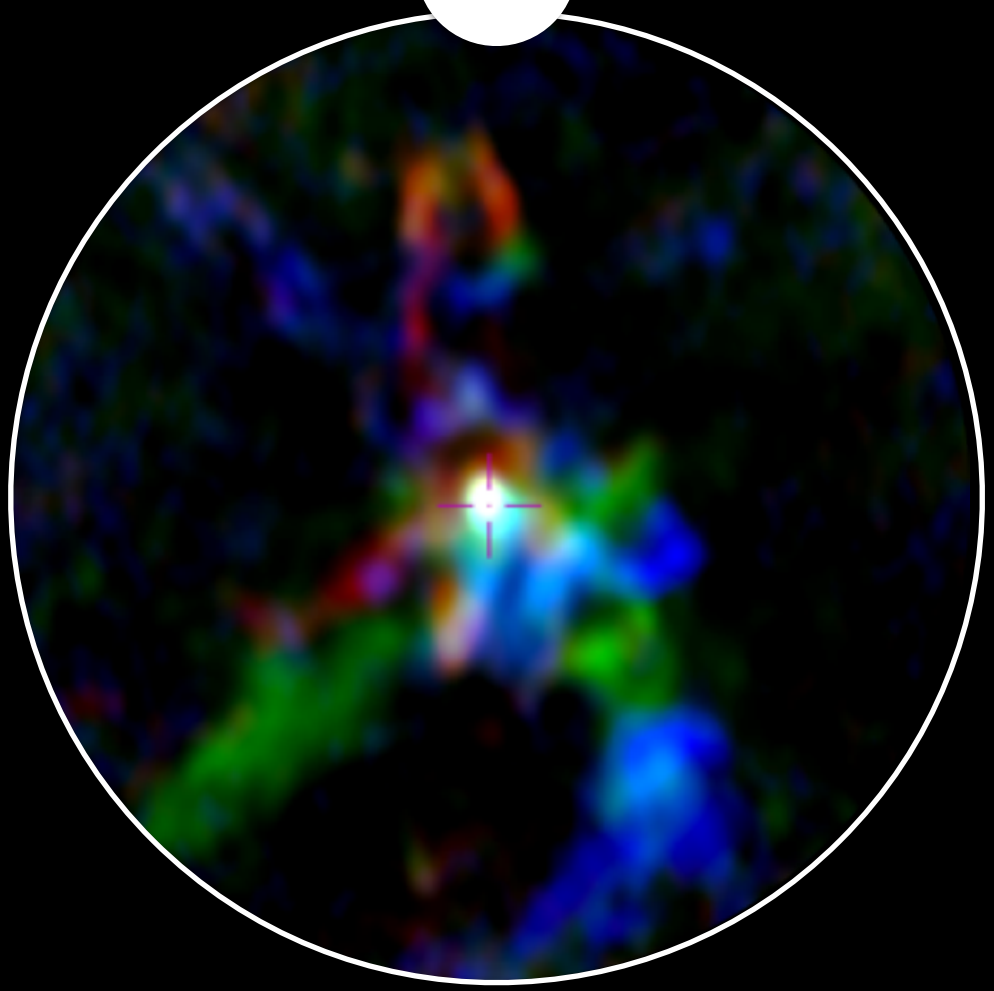



[-6.5, -4.5] km/s [-4.5, -2.0] km/s [-2.0, 0.0] km/s

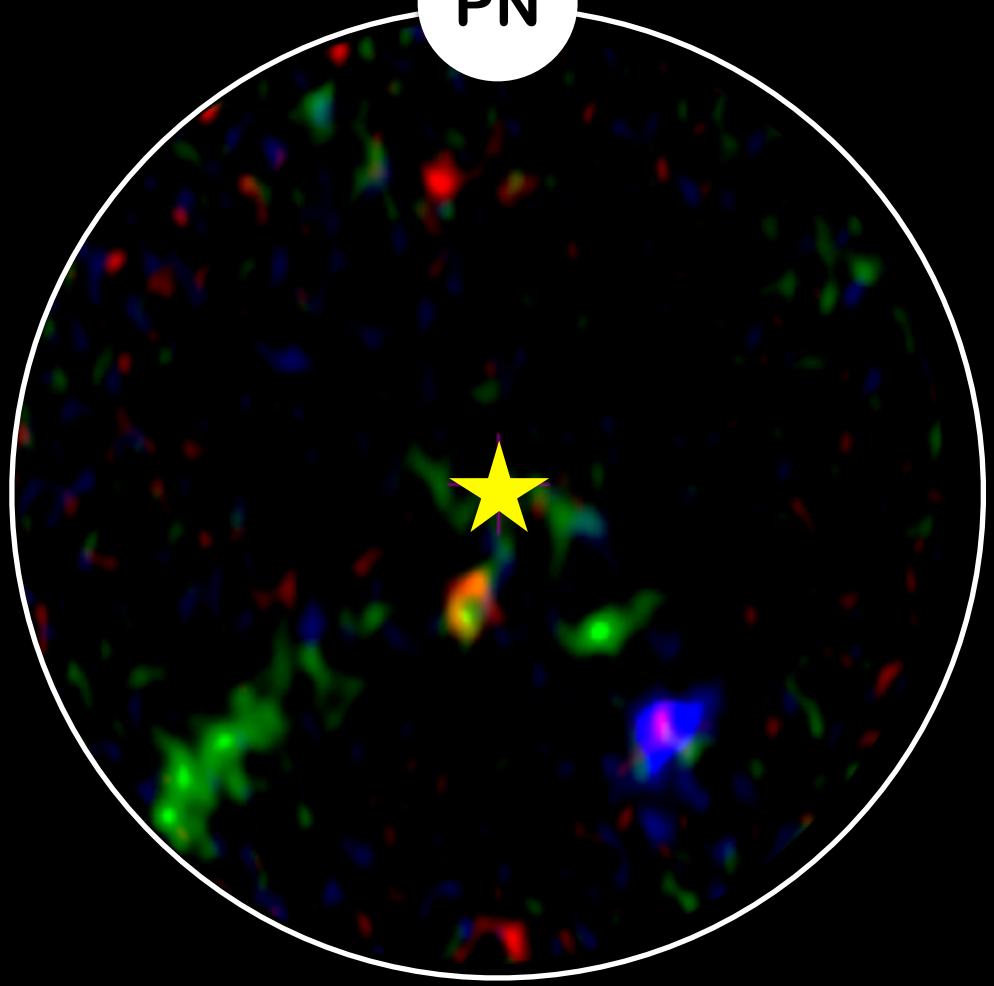
# AFGL 5142 star-forming region

Rivilla et al. (2019c)

SO



PN



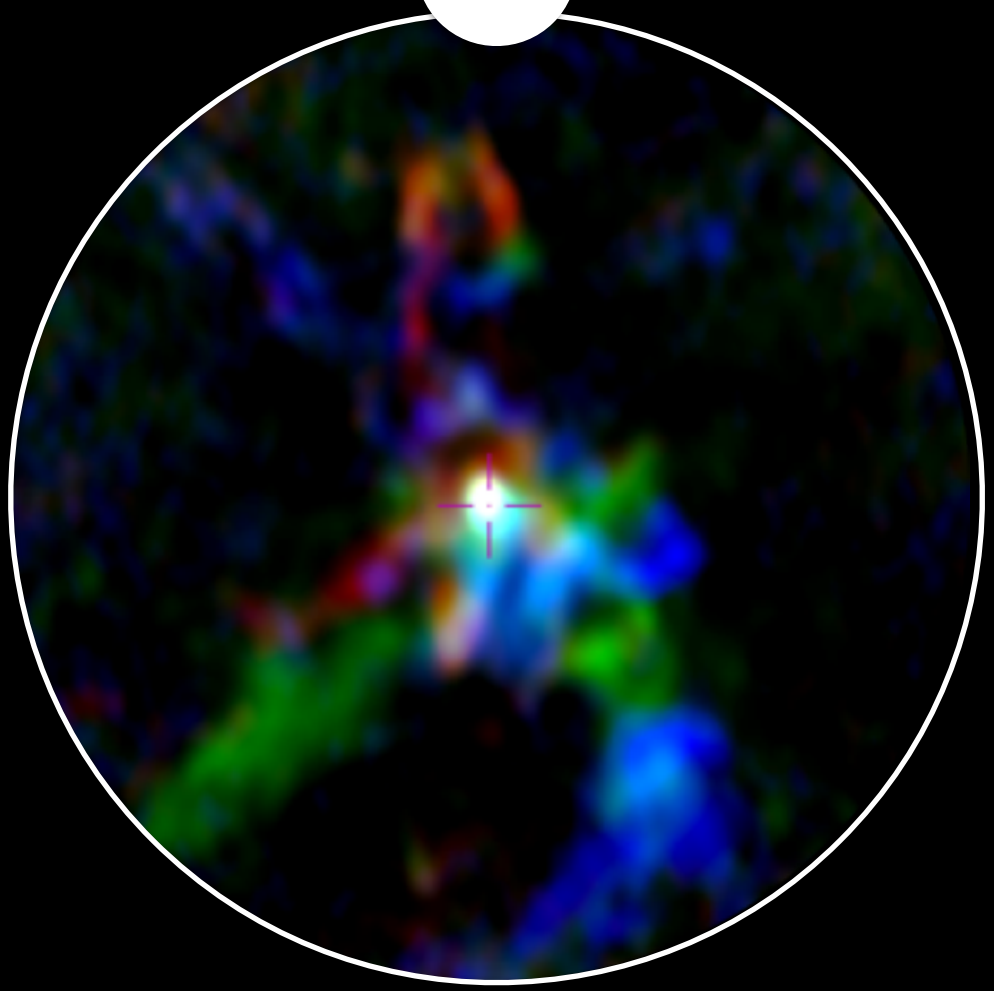
[-6.5, -4.5] km/s [-4.5, -2.0] km/s [-2.0, 0.0] km/s

[-6.5, -4.5] km/s [-4.5, -2.0] km/s [-2.0, 0.0] km/s

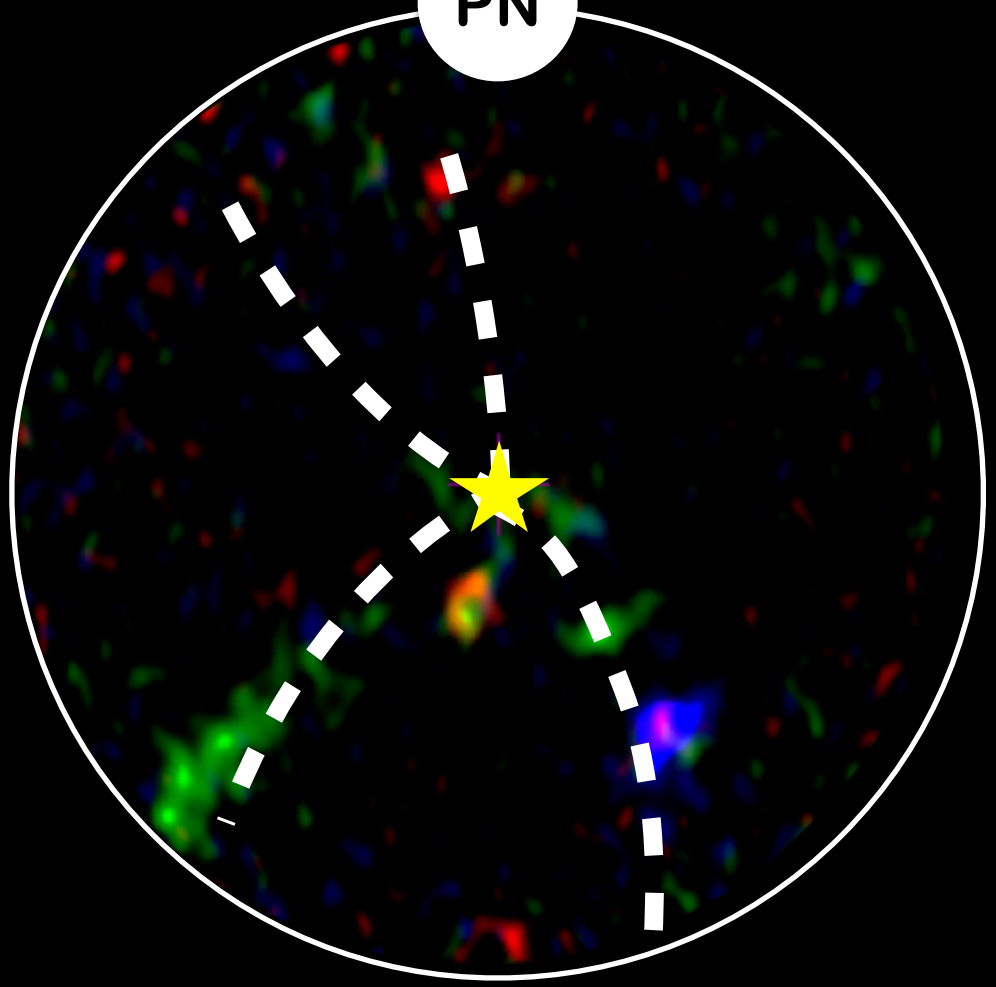
# AFGL 5142 star-forming region

Rivilla et al. (2019c)

SO



PN



[-6.5, -4.5] km/s [-4.5, -2.0] km/s [-2.0, 0.0] km/s

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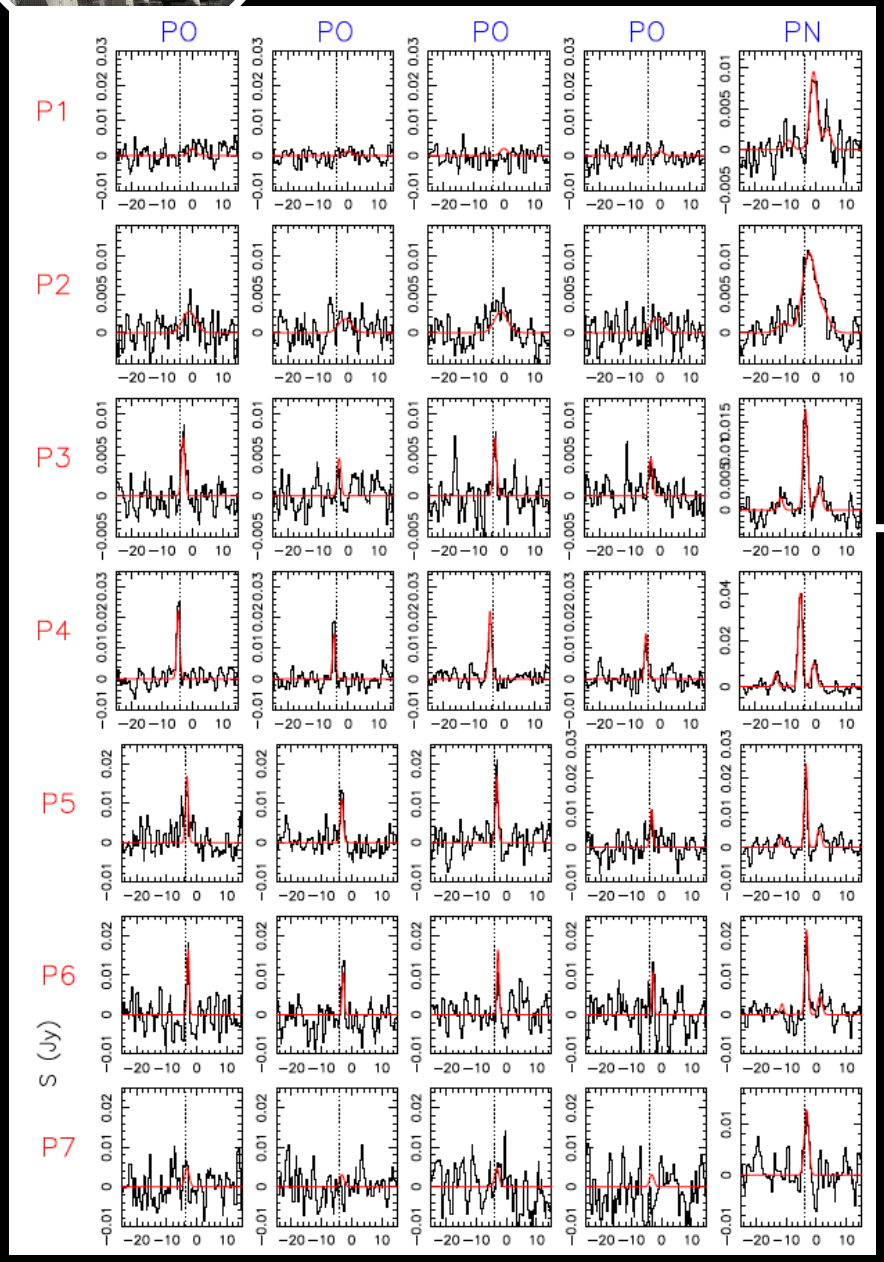
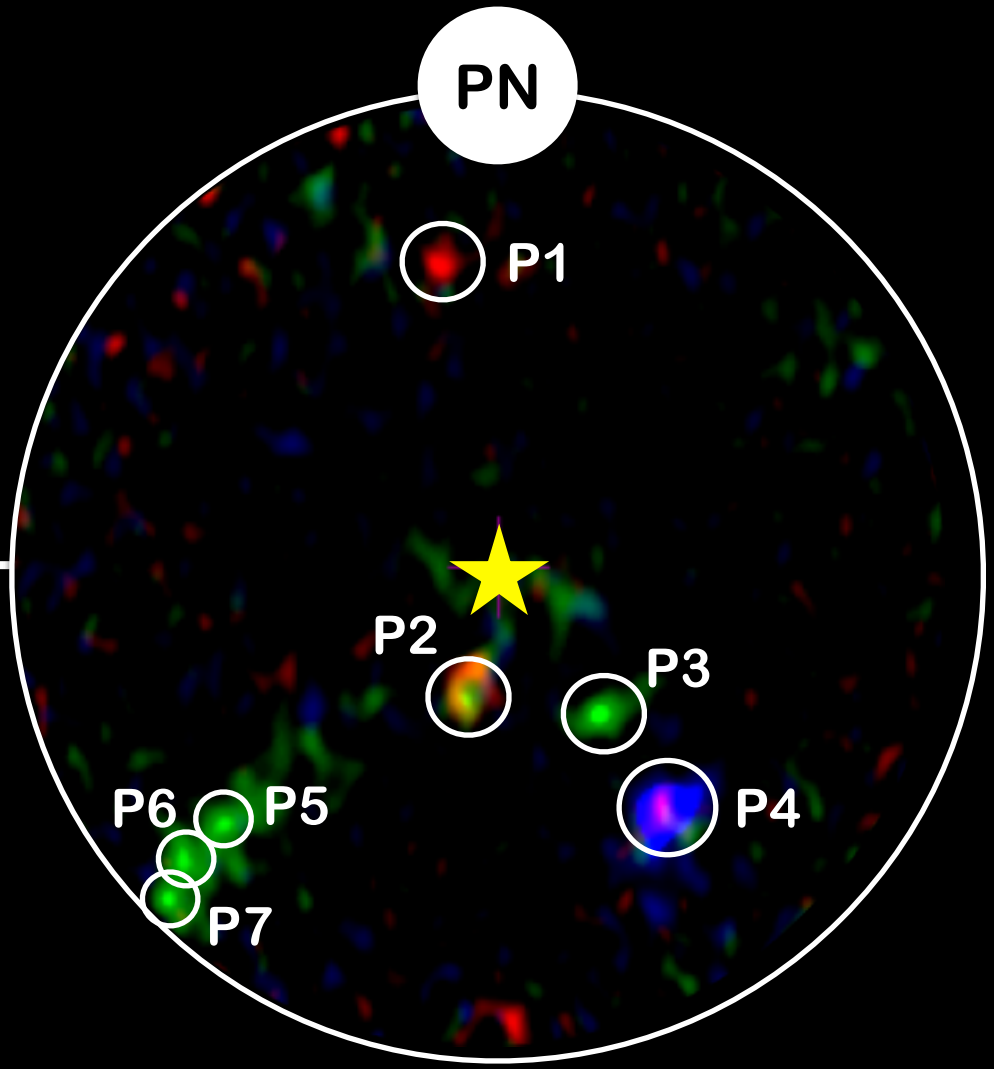
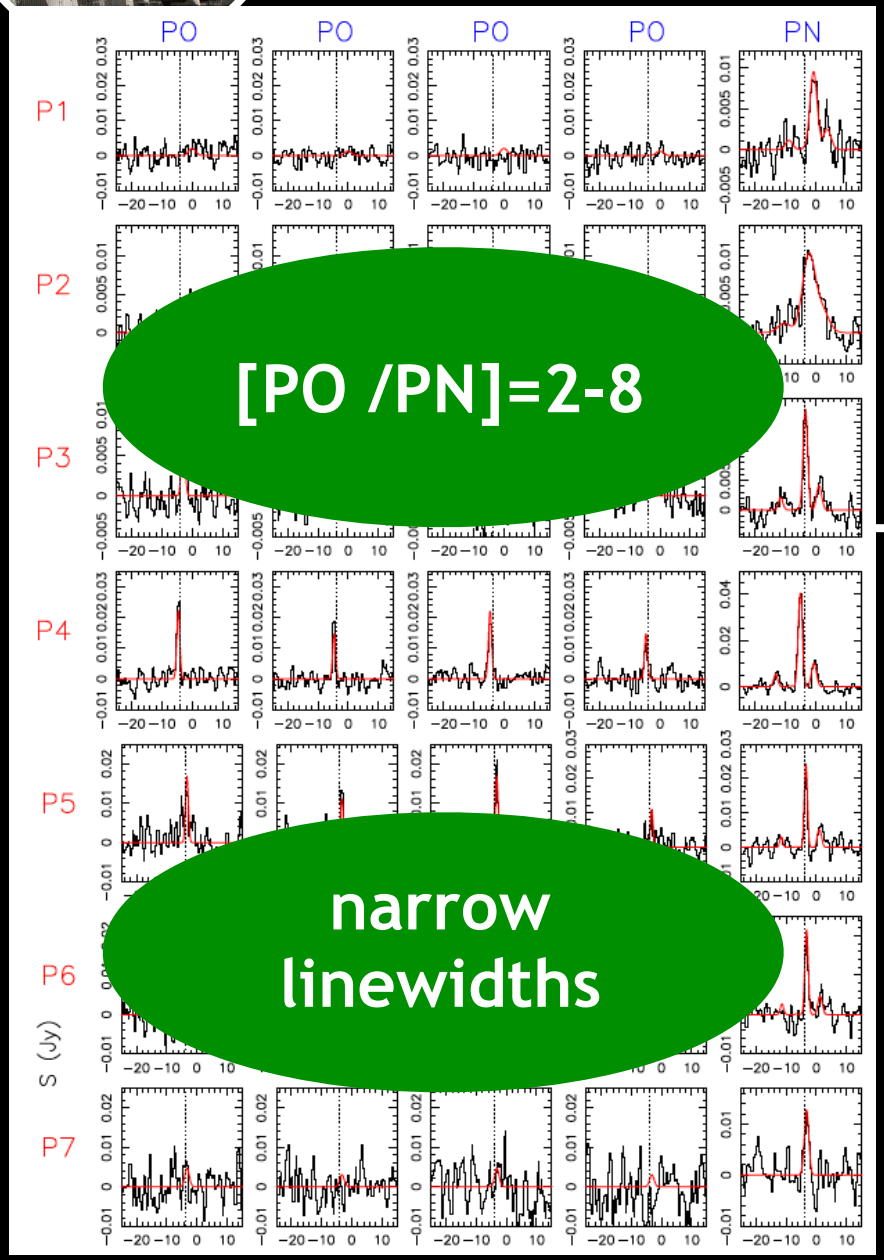
# AFGL 5142 star-forming region



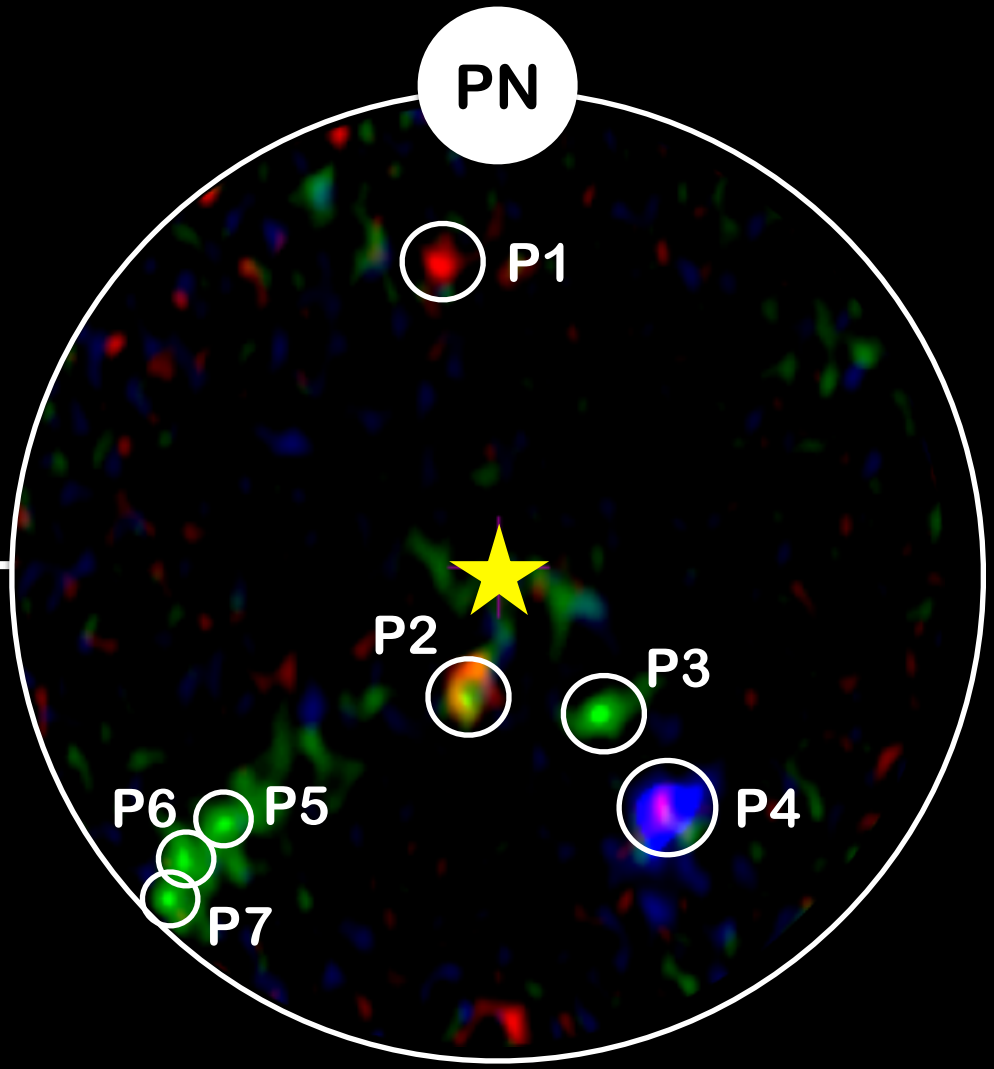

[-6.5, -4.5] km/s [-4.5, -2.0] km/s [-2.0, 0.0] km/s

# AFGL 5142 star-forming region




[PO /PN]=2-8

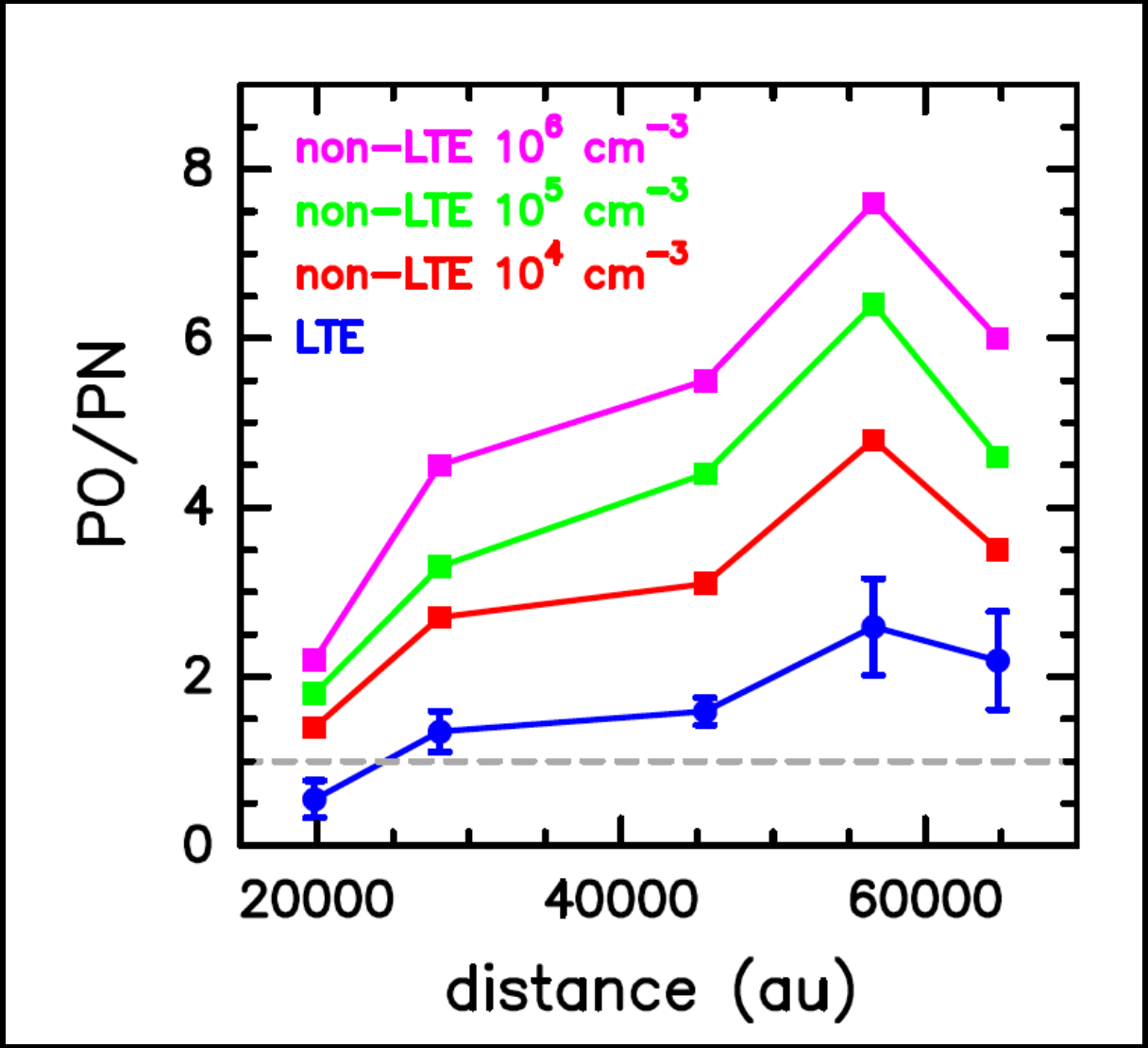
narrow linewidths




[-6.5, -4.5] km/s [-4.5, -2.0] km/s [-2.0, 0.0] km/s

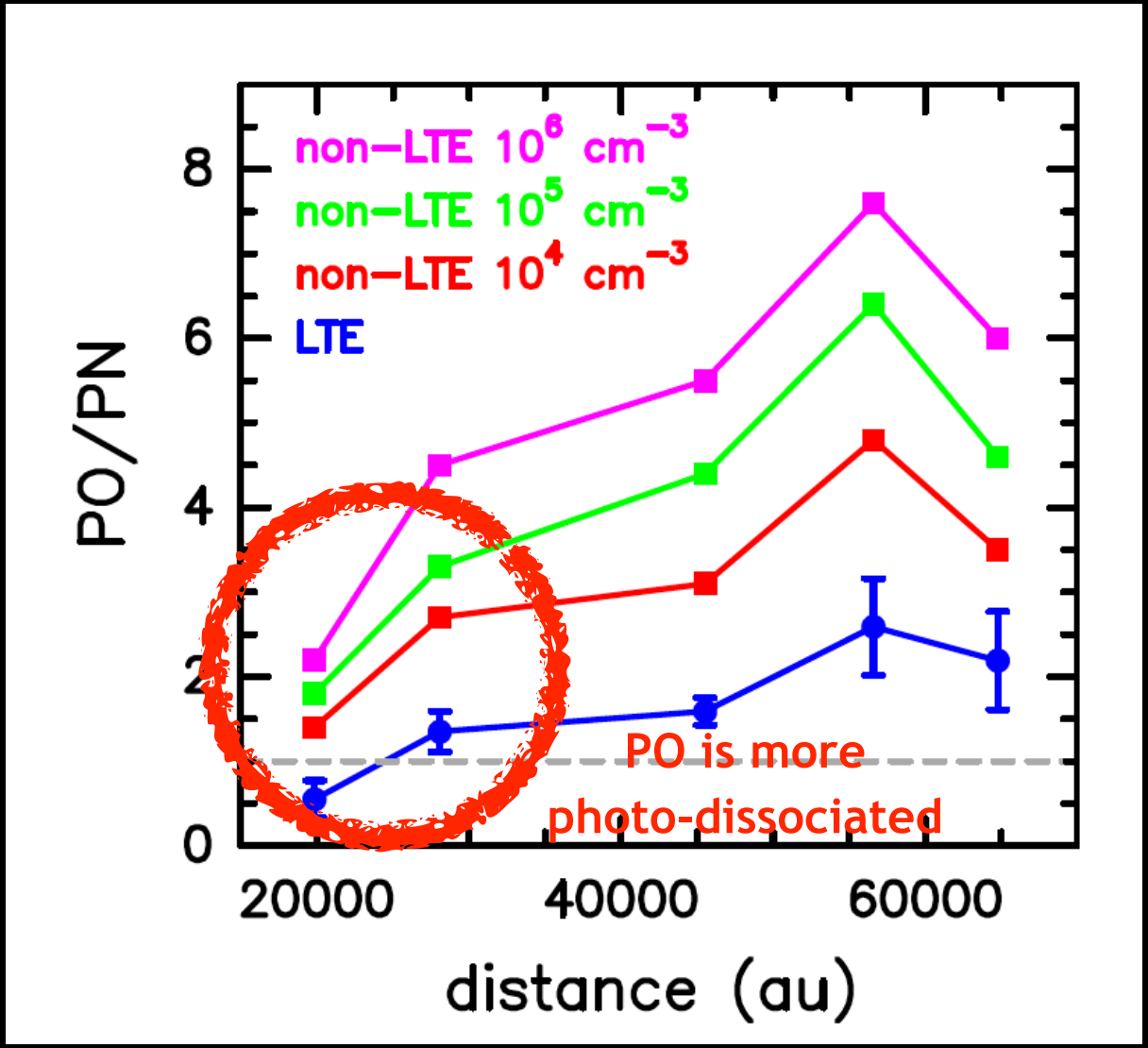
# PO/PN ratio

Rivilla et al. (2019c)



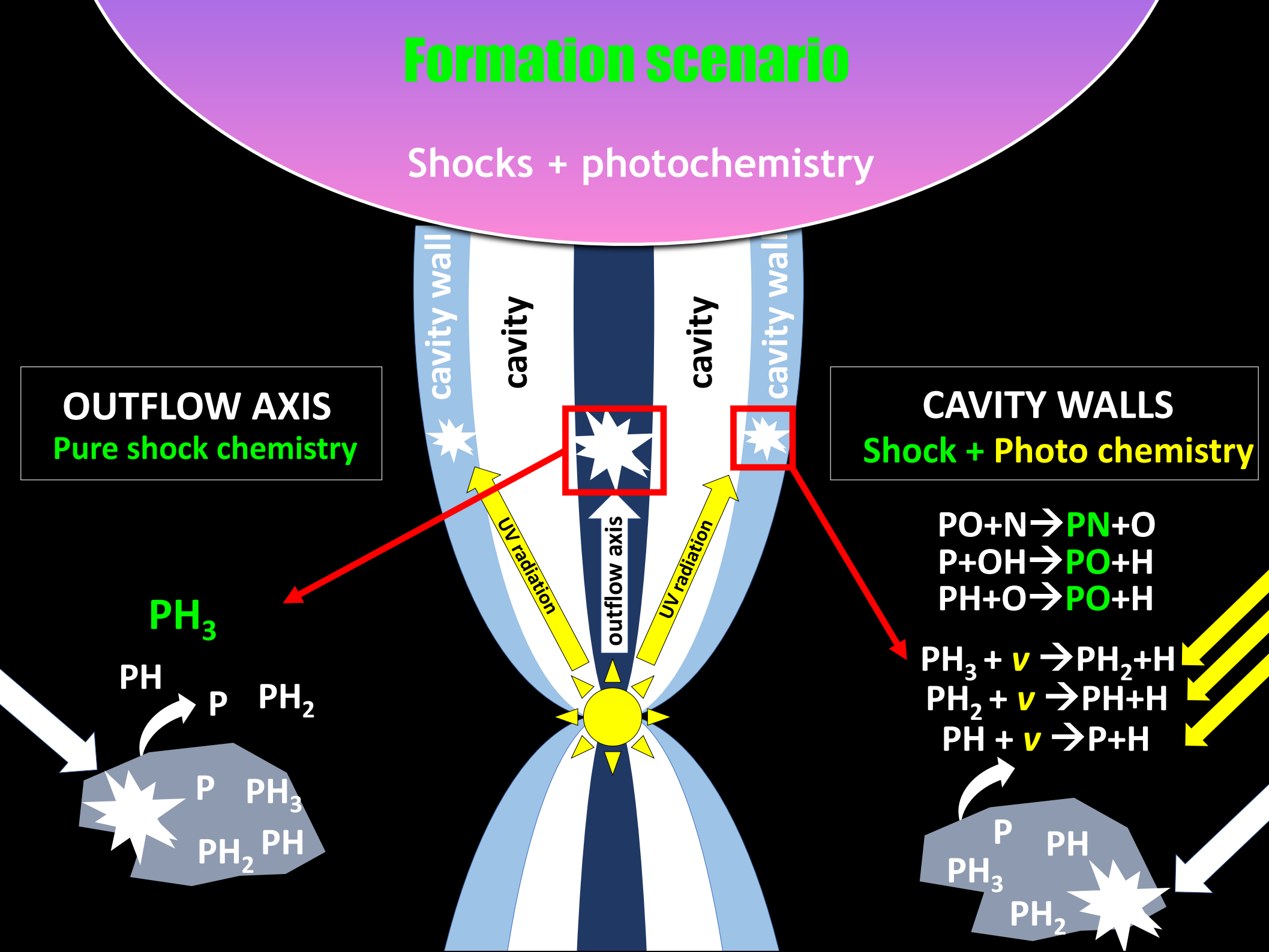
# PO/PN ratio

Rivilla et al. (2019c)



# Formation scenario

Shocks + photochemistry




**OUTFLOW AXIS**
Pure shock chemistry

$PH_3$

PH P $PH_2$

P $PH_3$ $PH_2$ PH

**CAVITY WALLS**
Shock + Photo chemistry

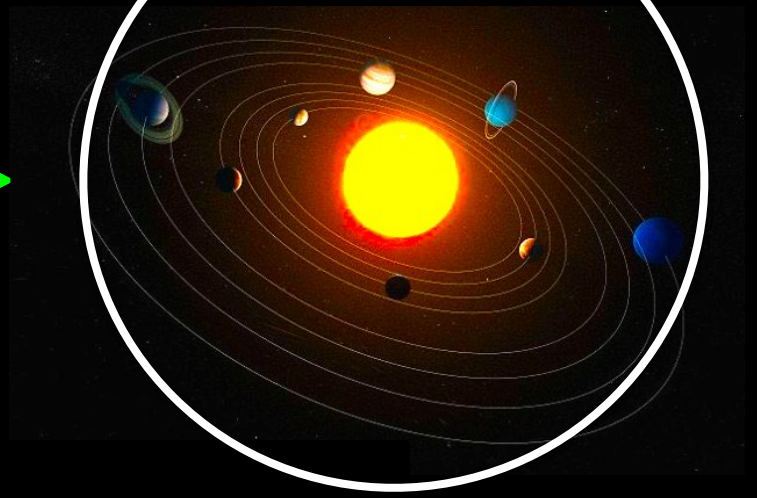
$PO+N \rightarrow PN+O$
$P+OH \rightarrow PO+H$
$PH+O \rightarrow PO+H$

$PH_3 + \nu \rightarrow PH_2+H$
$PH_2 + \nu \rightarrow PH+H$
$PH + \nu \rightarrow P+H$

P PH $PH_3$ $PH_2$

# The Phosphorus connection between protostars and comets

Rivilla et al. (2019c)

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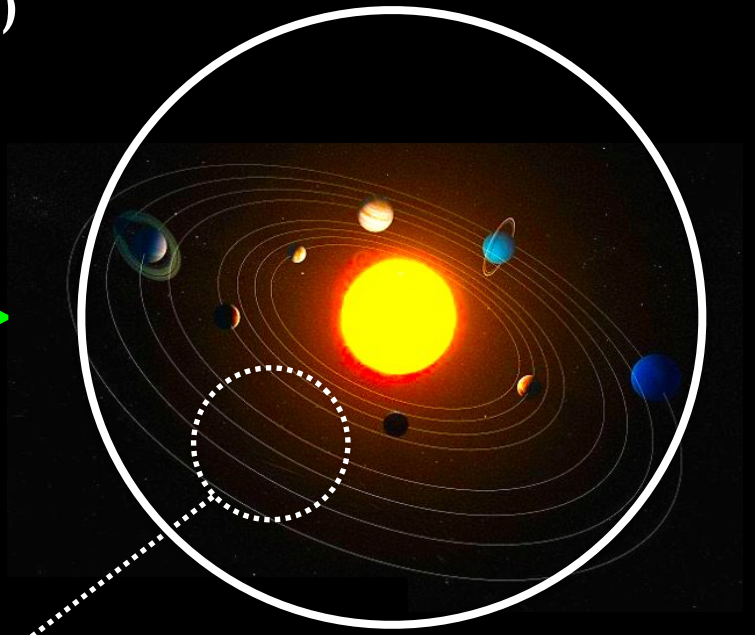
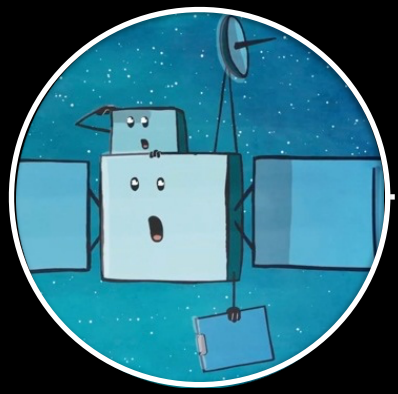
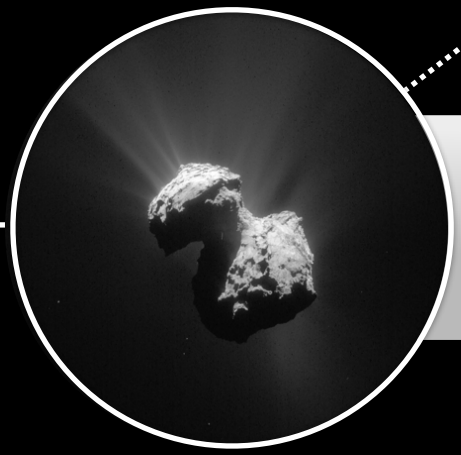
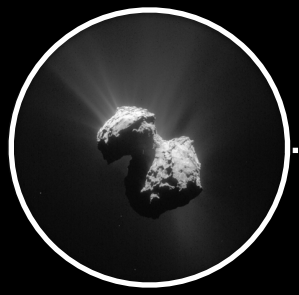


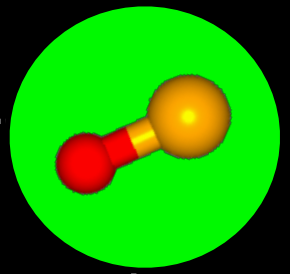




Pristine material from the early Solar System.

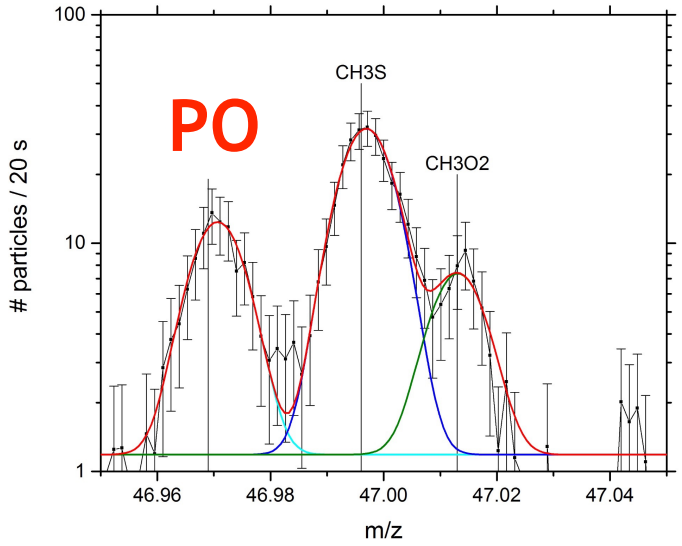
67P Churyumov-Gerasimenko comet





# Phosphorus in 67P

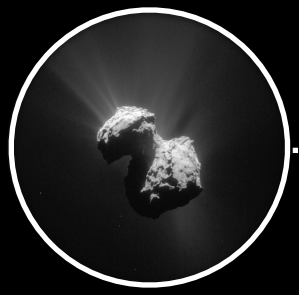
## Rivilla et al. (2019c)

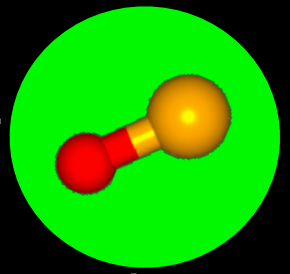



PO is present in the comet.

- Upper limits for PN, $PH_3$ and CP.

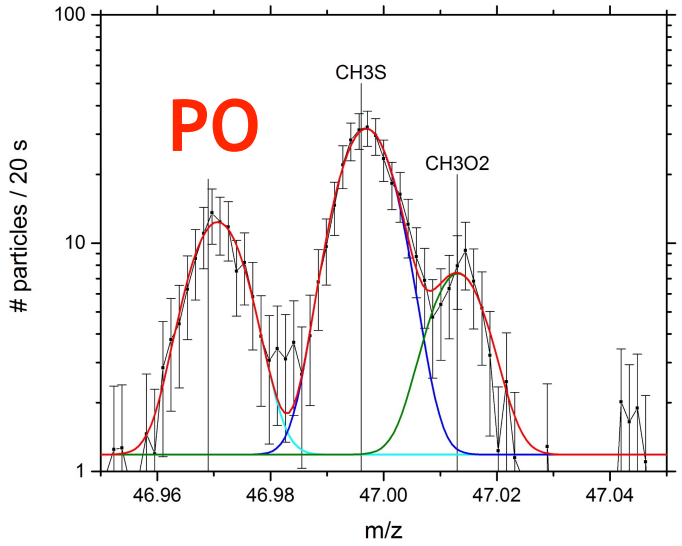
[PO/PN]>10





# Phosphorus in 67P

## Rivilla et al. (2019c)

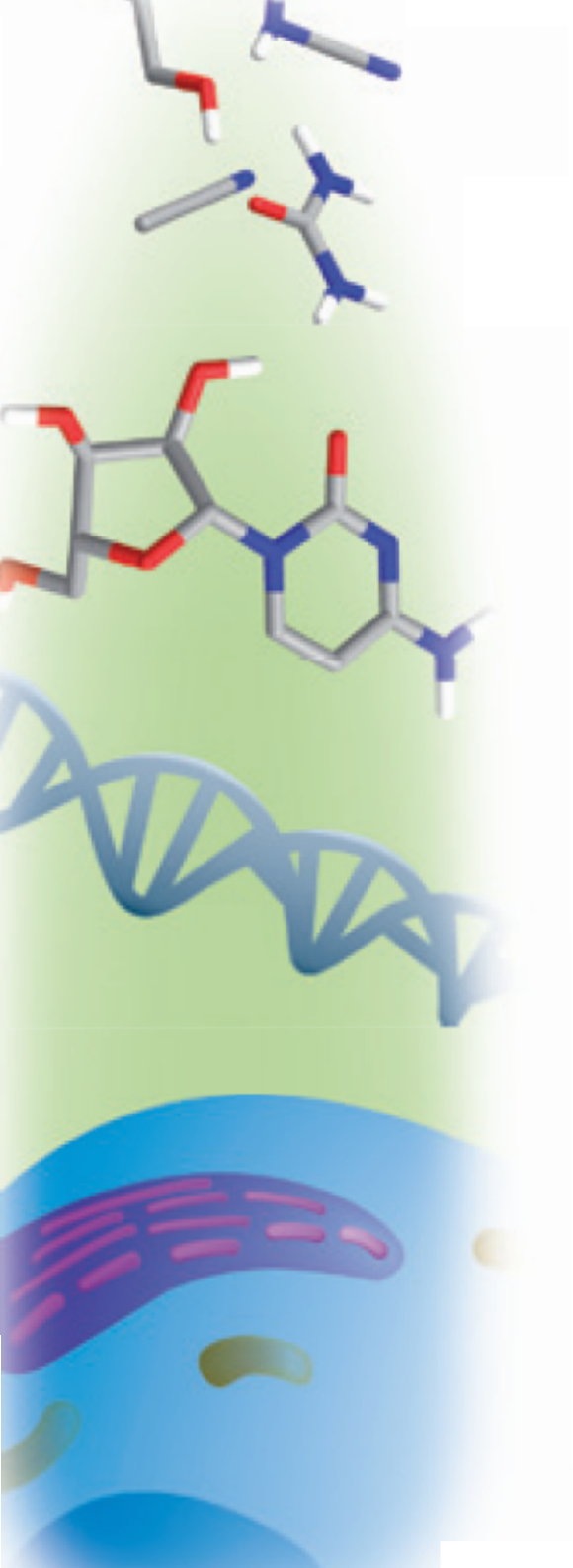


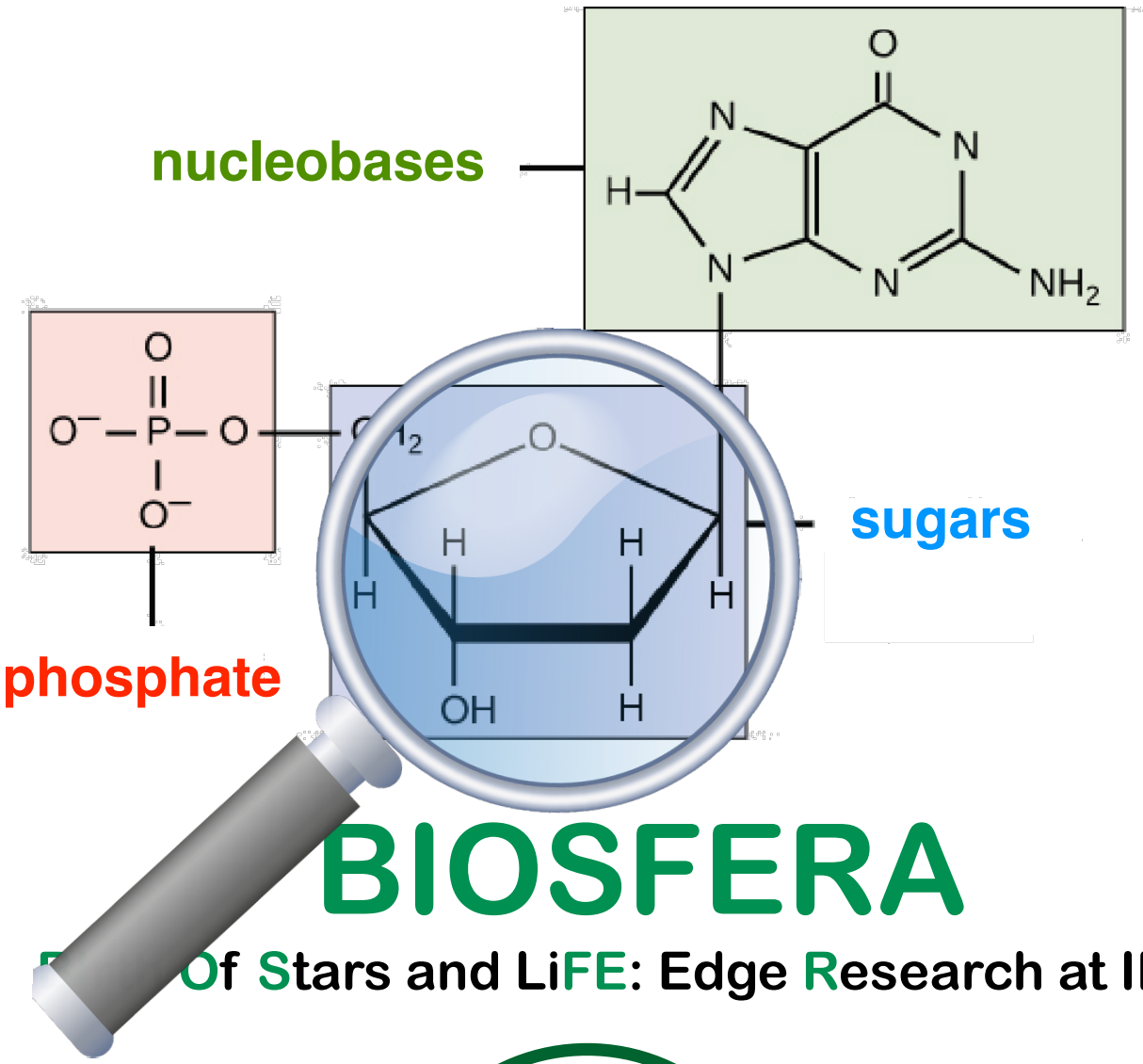

**PO is present in the comet.**

- Upper limits for PN, $PH_3$ and CP.

**[PO/PN]>10**

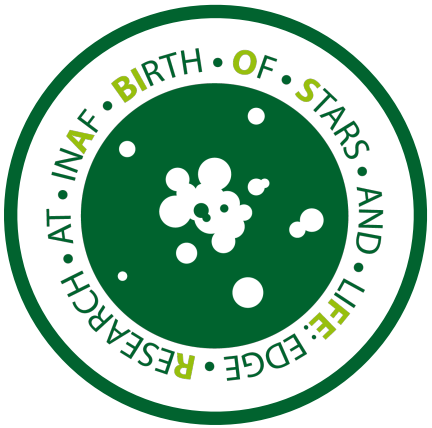
**PO is more abundant than PN both in star-forming regions and the comet.**





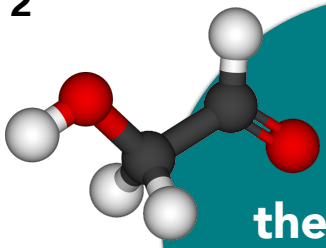

# BIOSFERA

**B**irth **O**f **S**tars and Li**FE**: Edge **R**esearch at IN**A**F



# The formation of complex organic molecules: a complex problem

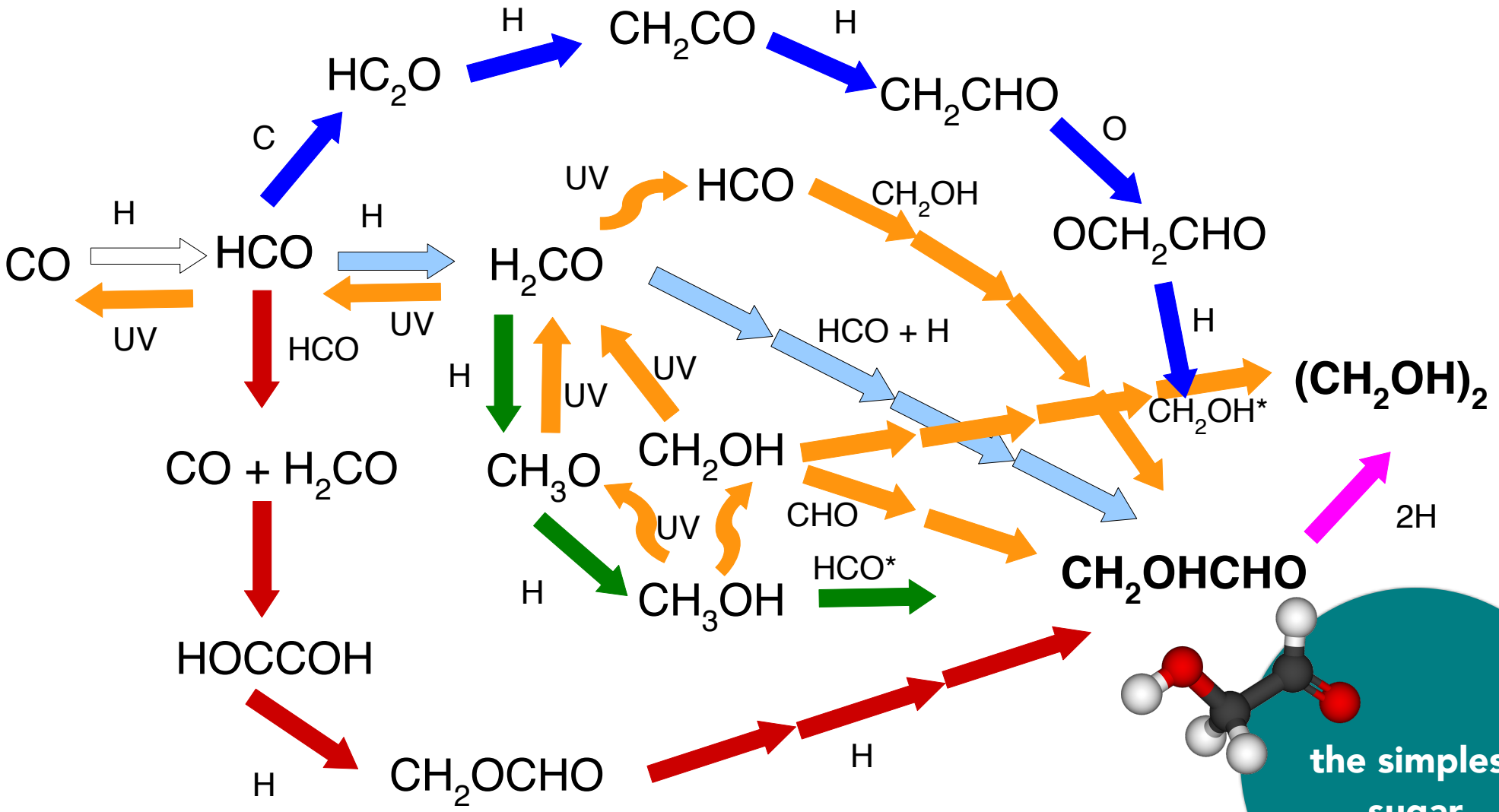
$CH_2OHCHO$

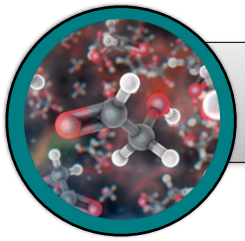


the simplest sugar

# The formation of complex organic molecules: a complex problem

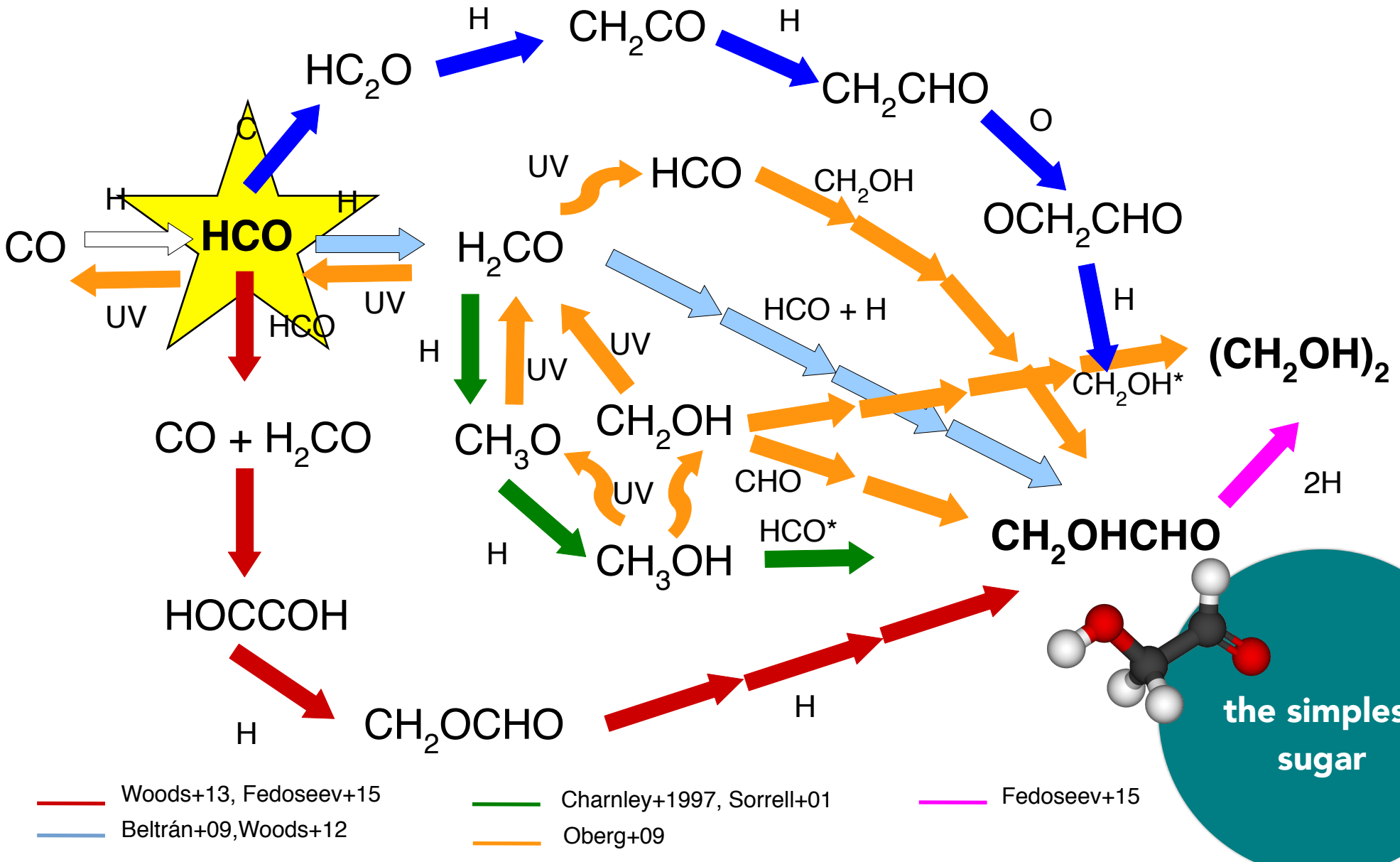
## Game of Reactions





# The formation of complex organic molecules: a complex problem

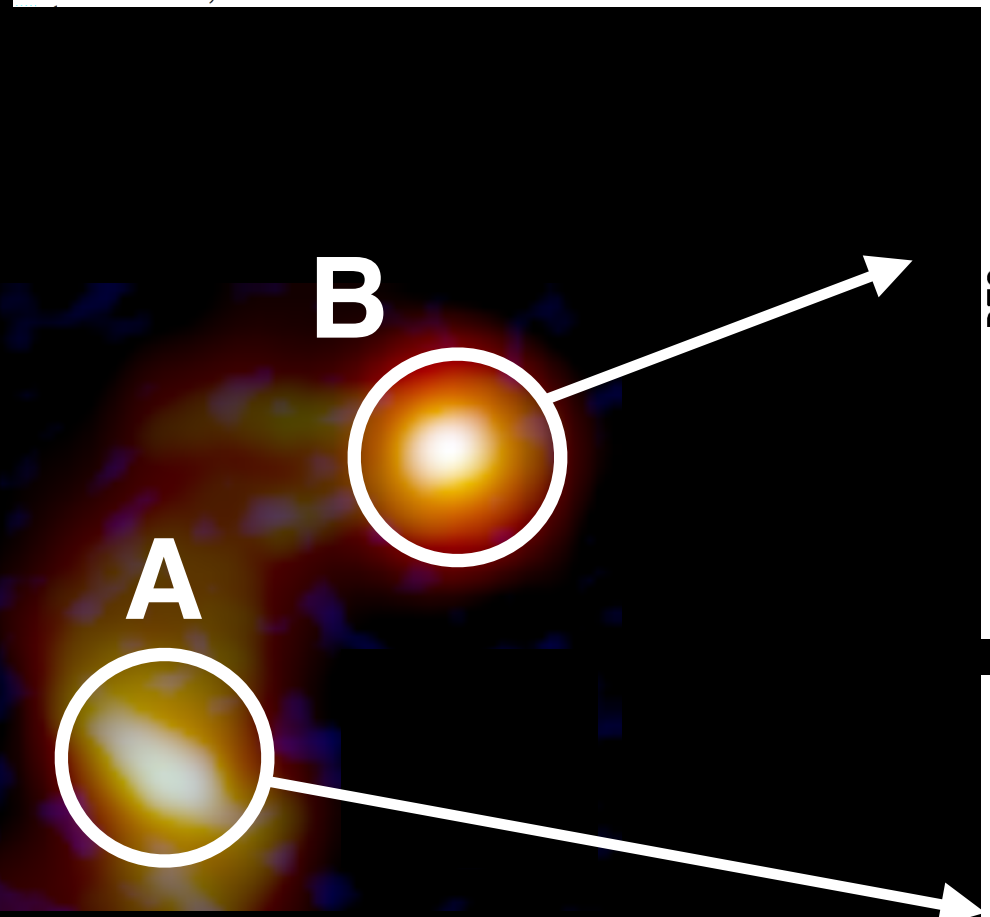
## Game of Reactions

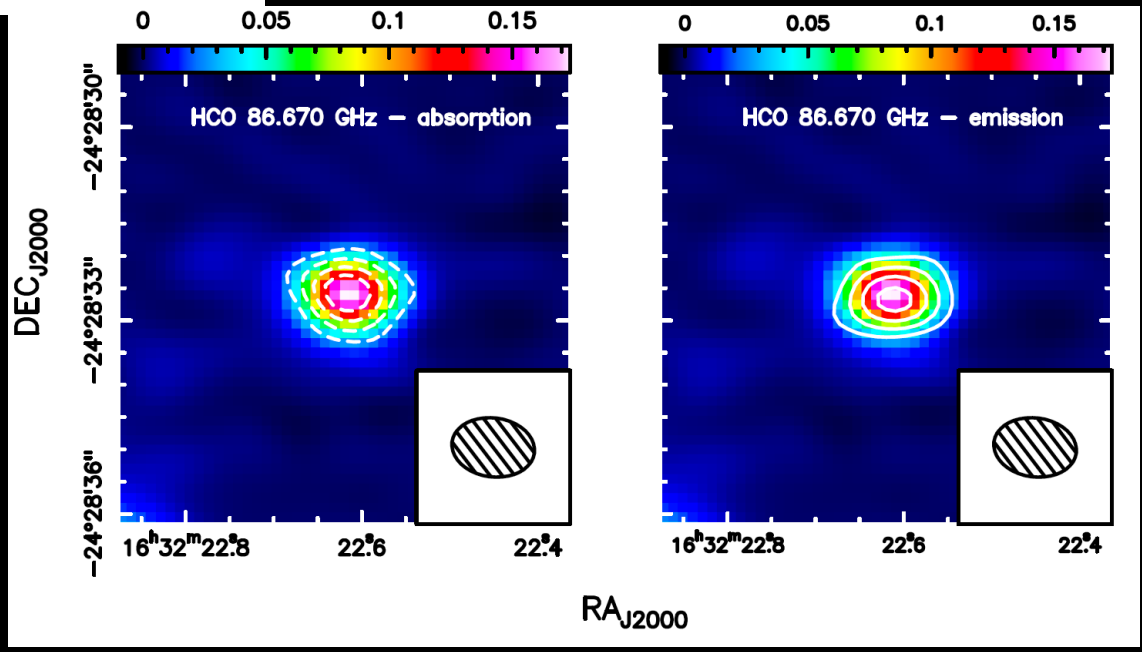


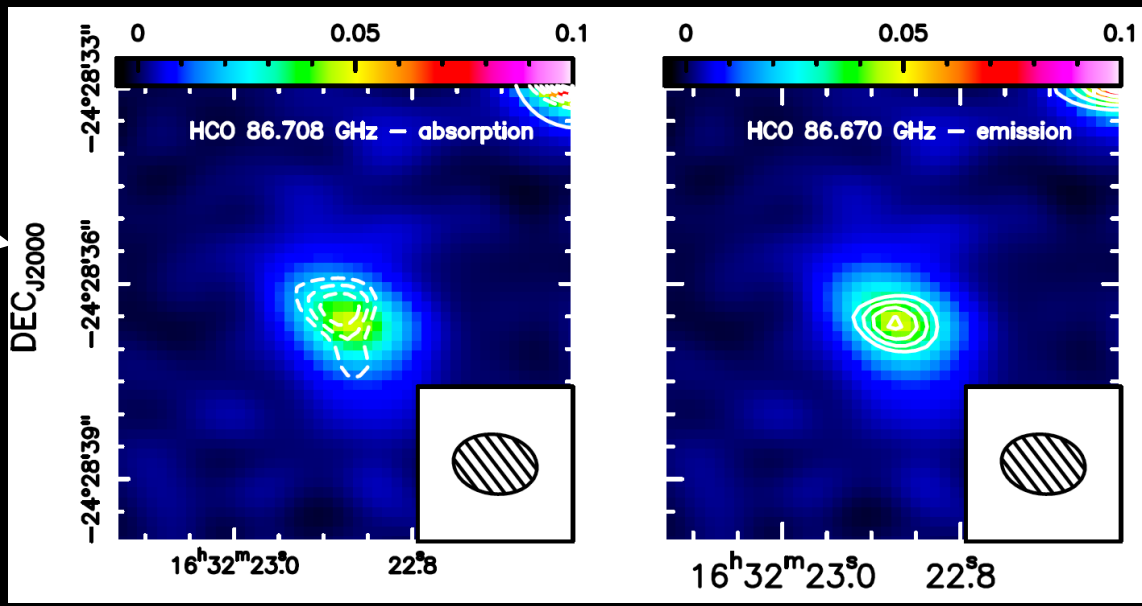
**First ALMA maps of HCO, an important precursor of complex organic molecules, towards IRAS 16293−2422**

V. M. Rivilla[1]*, M. T. Beltrán[1], A. Vasyunin[2,3,4], P. Caselli[2], S. Viti[5], F. Fontani[1], and R. Cesaroni[1]

Rivilla et al., 2019a



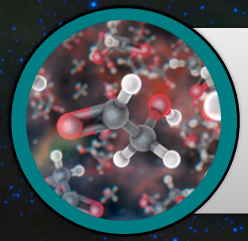



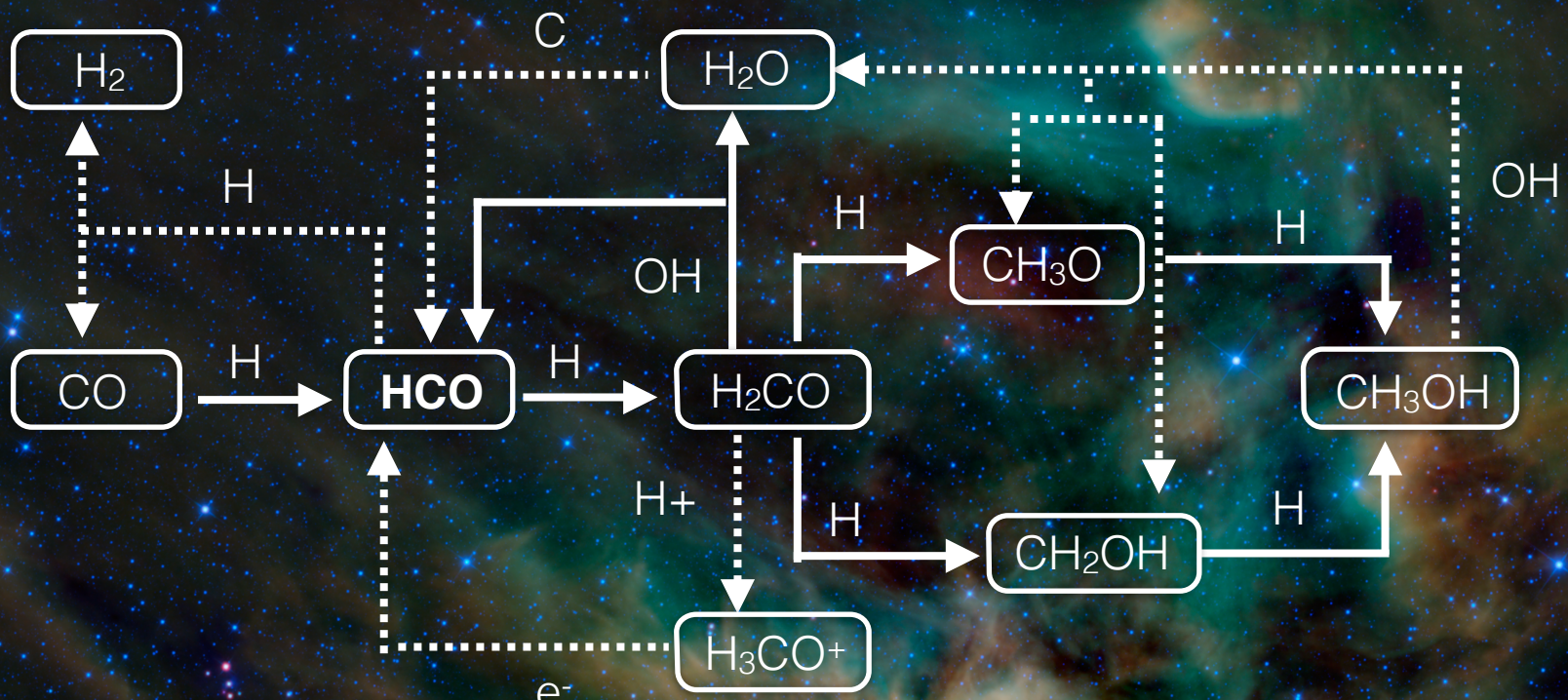

**ALMA MAPS**

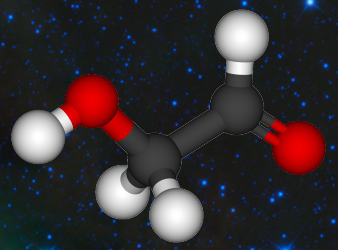
1”-1.5” resolution

150 - 225 au



# The formation of glycolaldehyde $CH_2OHCHO$



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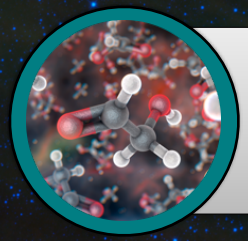

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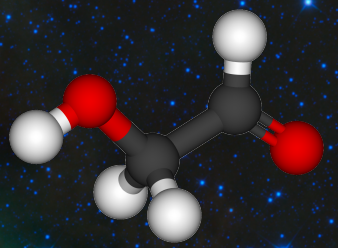

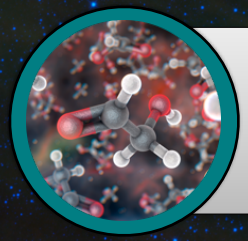

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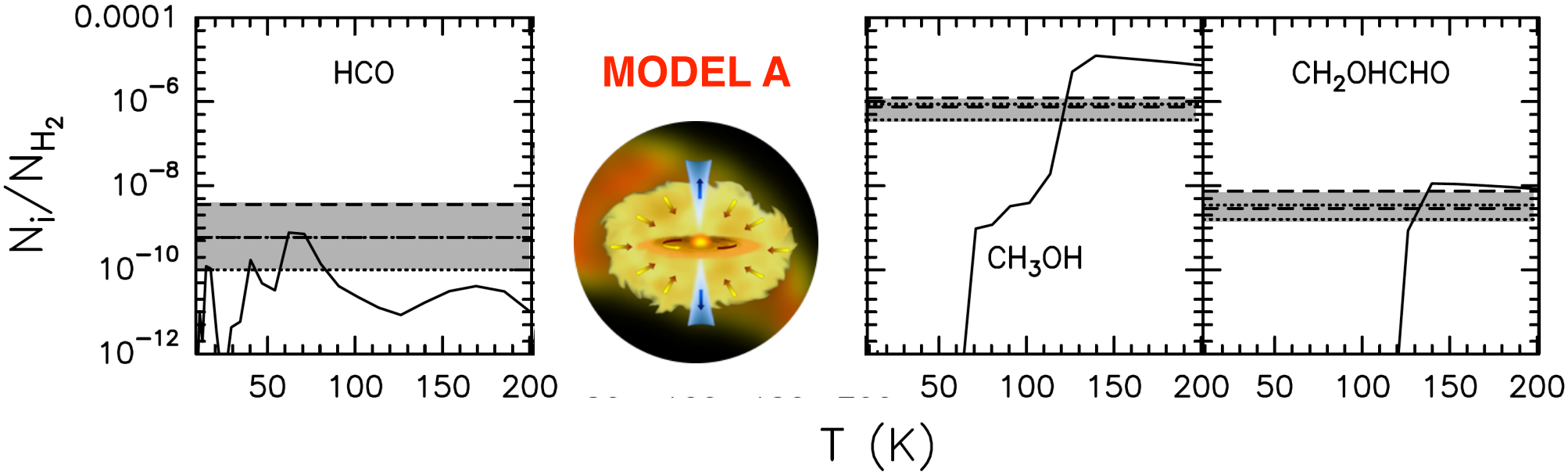
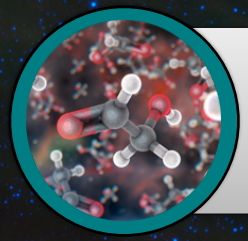
**$CH_2OH + HCO \rightarrow CH_2OHCHO$**





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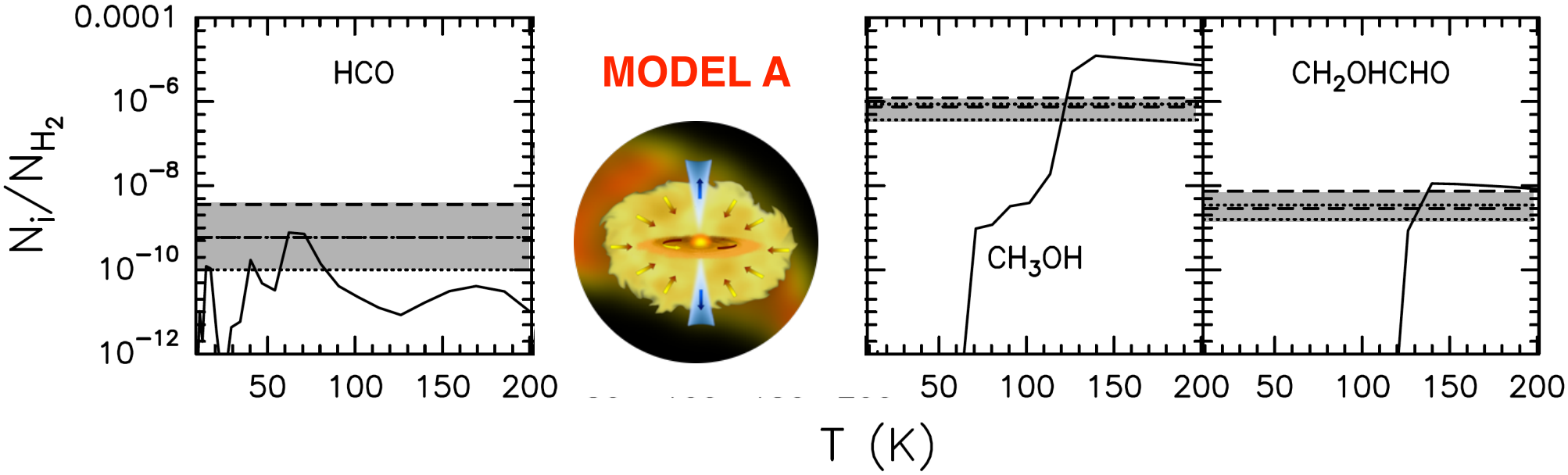
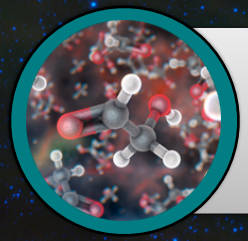



but MODEL C (recombination of two HCO radicals) cannot be ruled out



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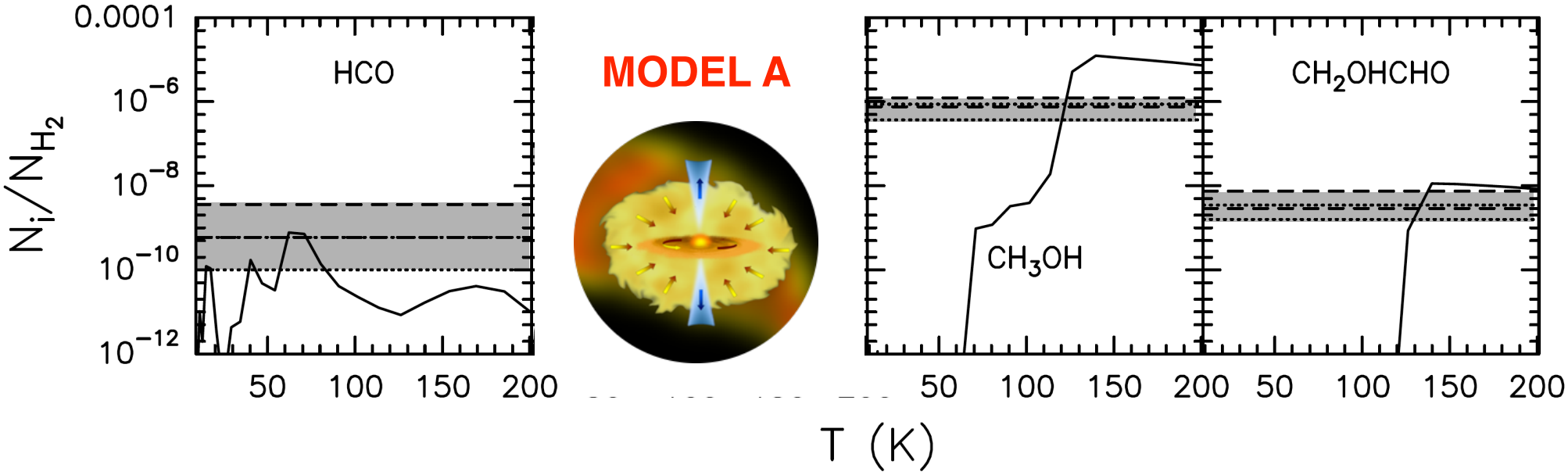
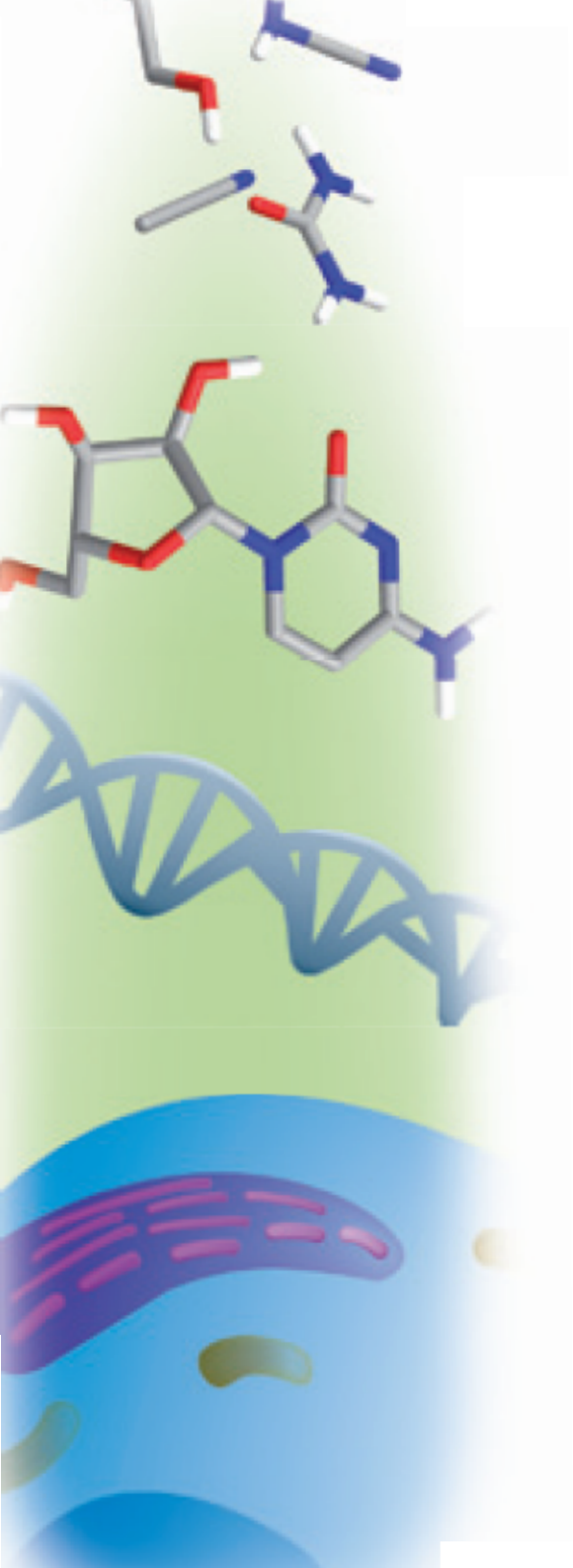
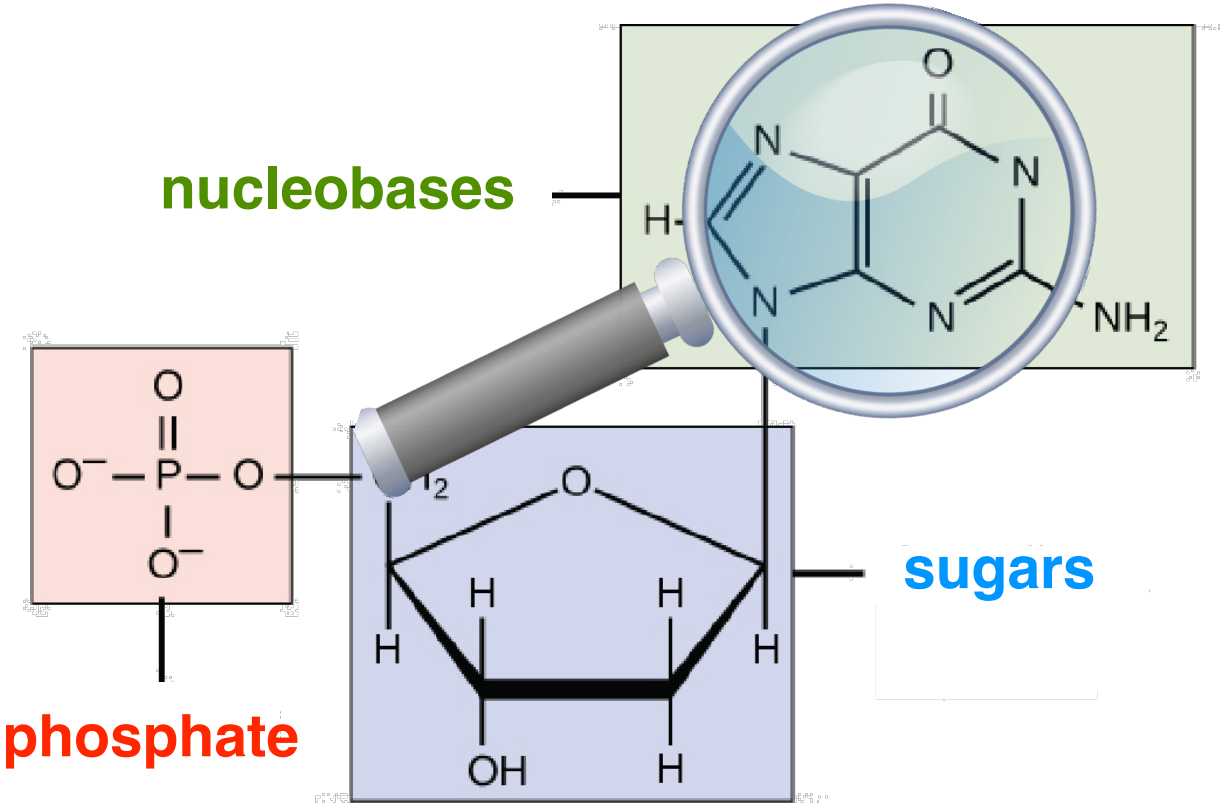



**but MODEL C (recombination of two HCO radicals) cannot be ruled out**

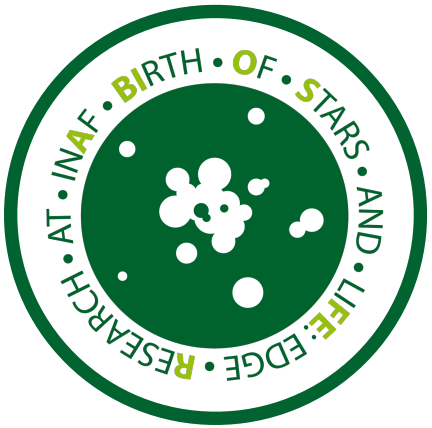
Good agreement with laboratory works (Fedoseev et al. 2015, Chuang et al. 2016) and chemical modeling (Coutens et al. 2018)

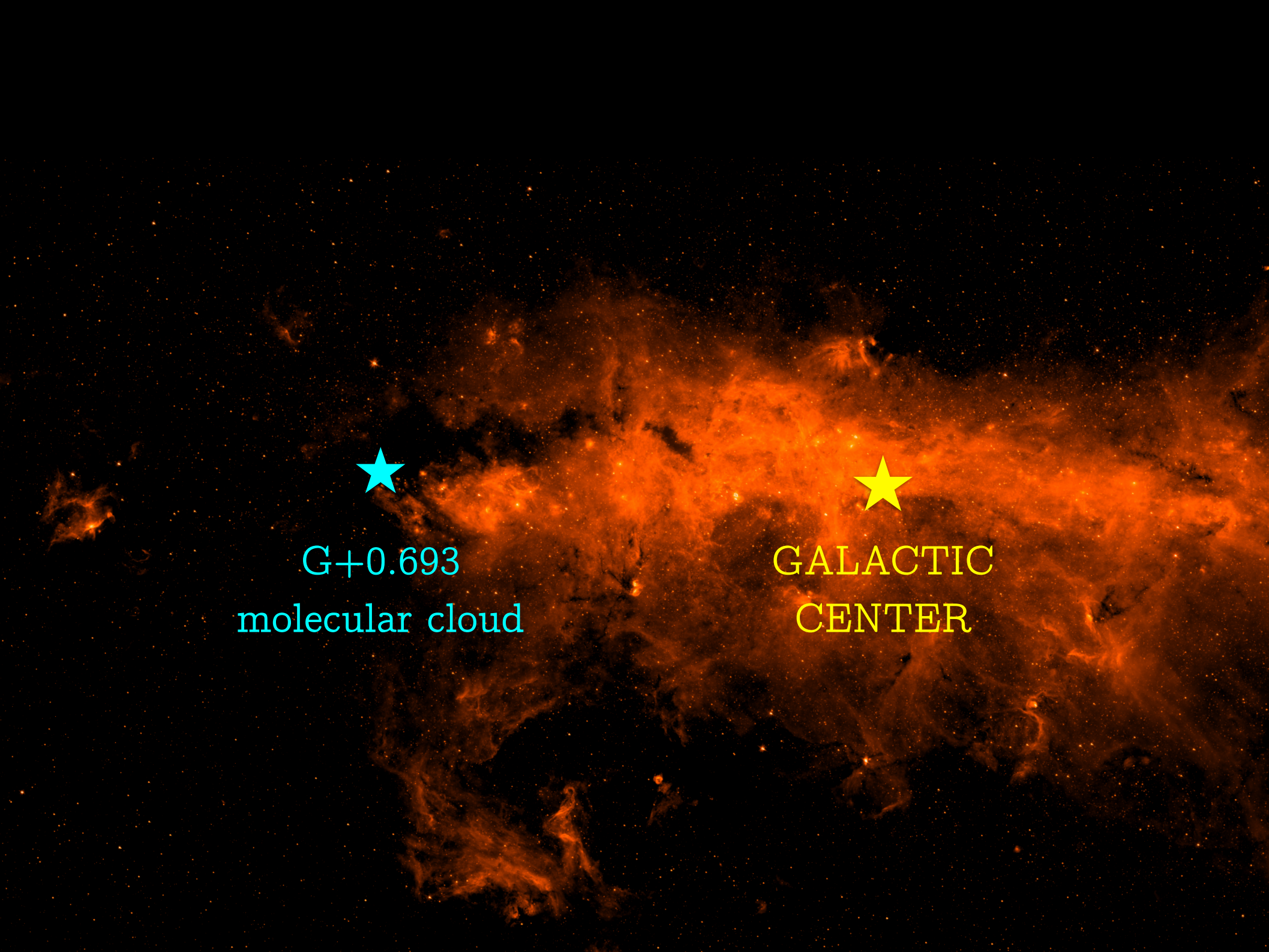




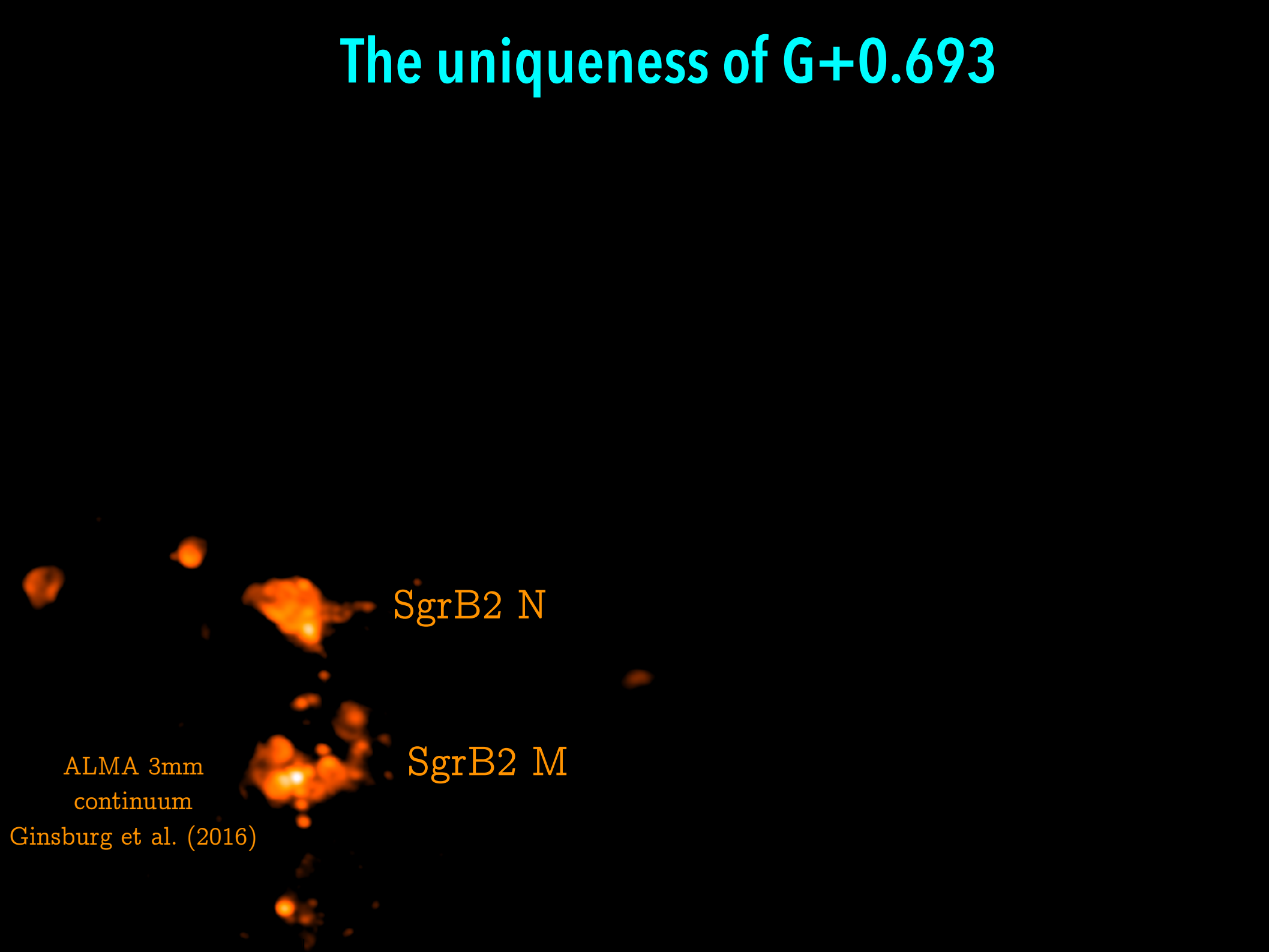

# BIOSFERA

**BIrth Of Stars and LiFE: Edge Research at INAF**




G+0.693
molecular cloud
GALACTIC
CENTER

# The uniqueness of G+0.693



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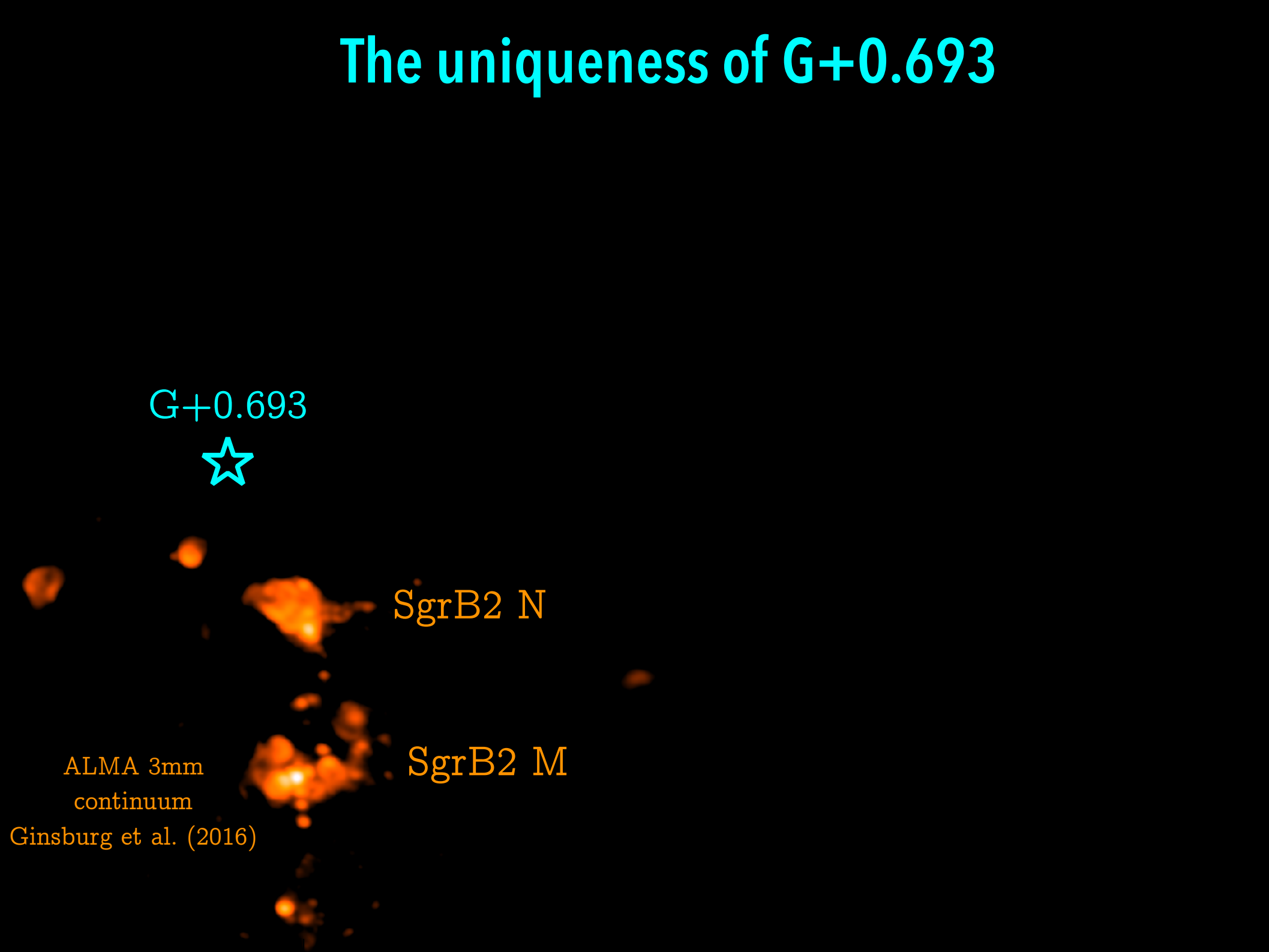
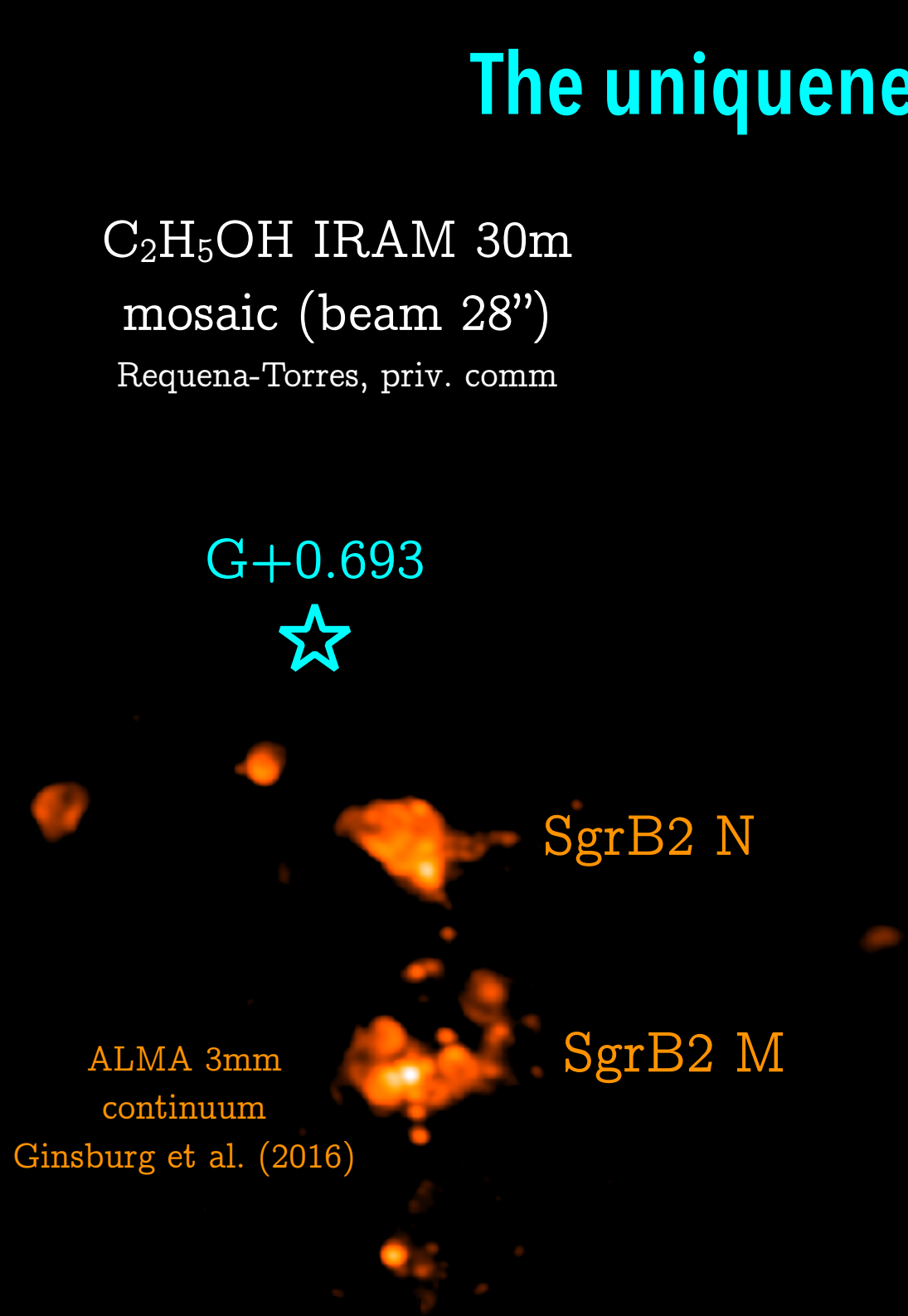


# The uniqueness of G+0.693

$C_2H_5OH$ IRAM 30m
mosaic (beam 28")
Requena-Torres, priv. comm

G+0.693
☆



SgrB2 N

SgrB2 M

ALMA 3mm
continuum
Ginsburg et al. (2016)

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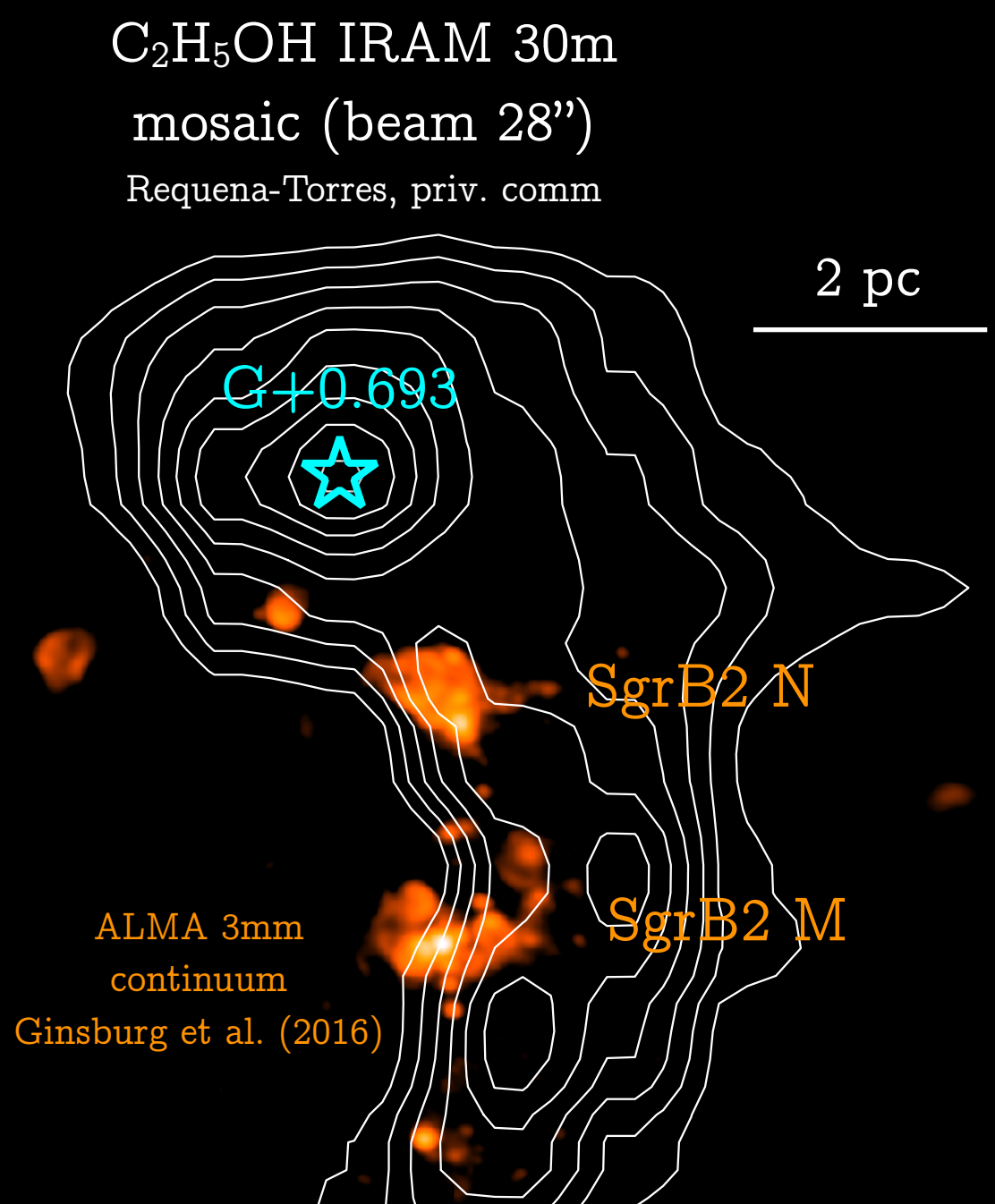

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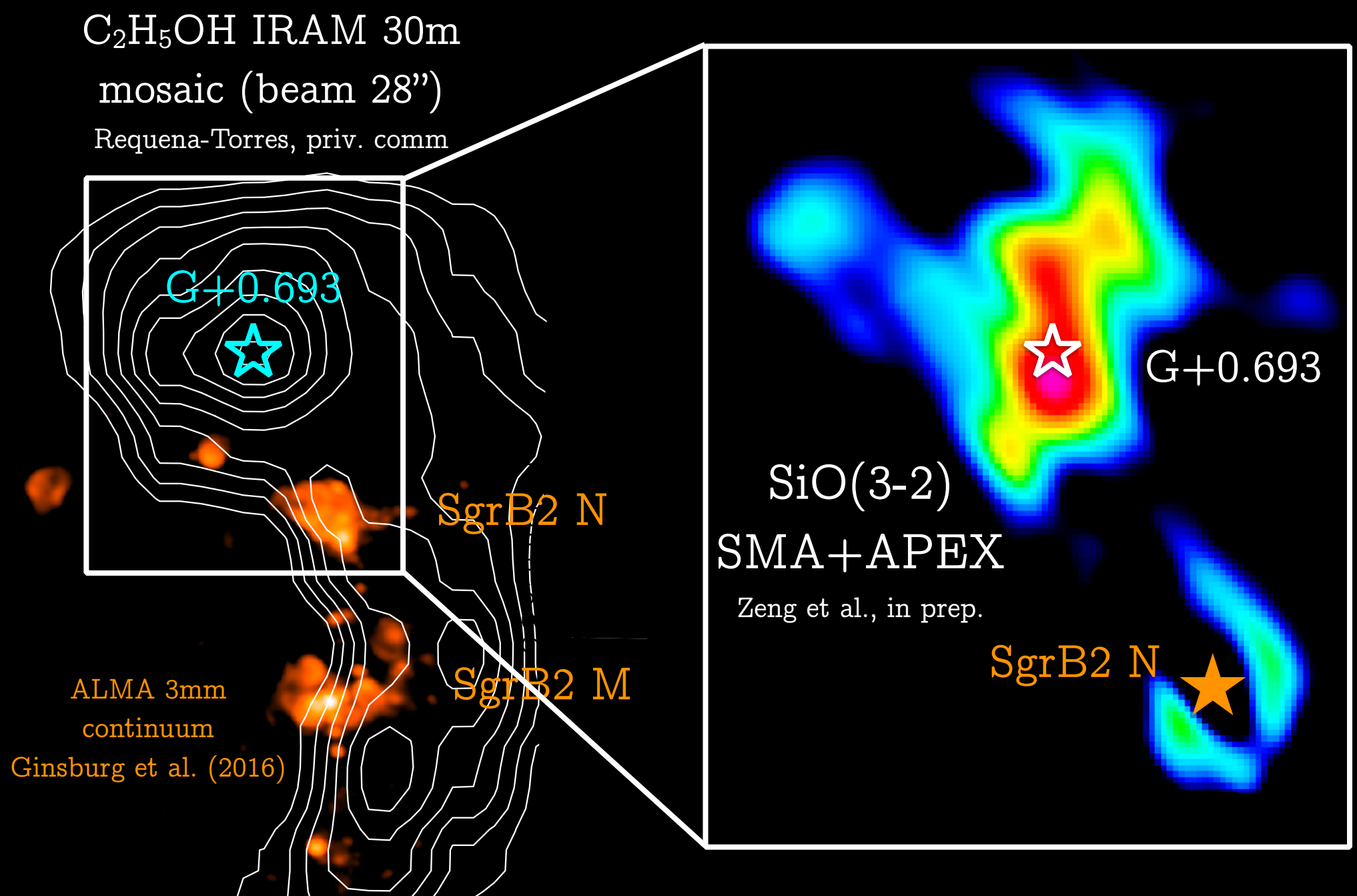

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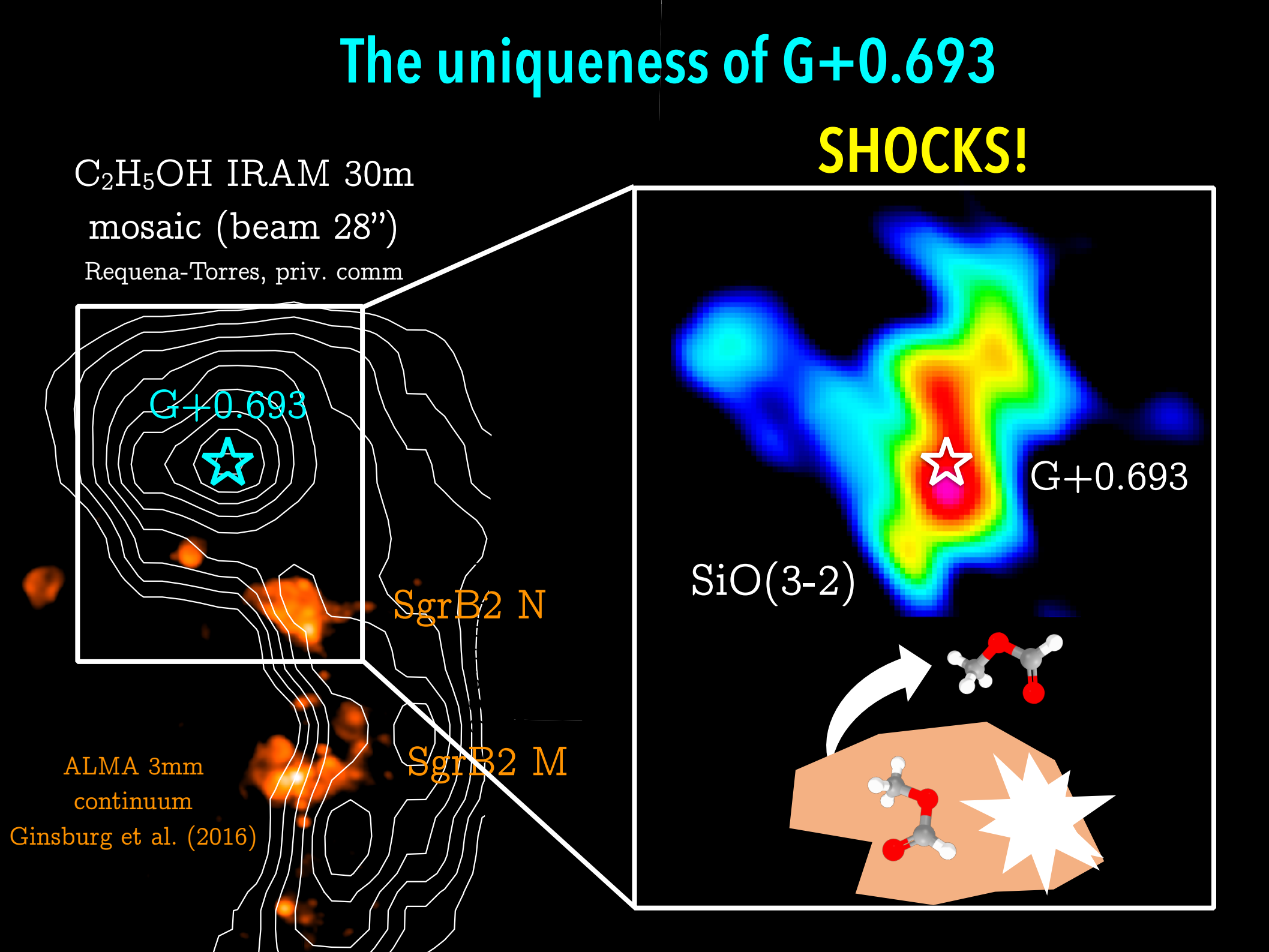
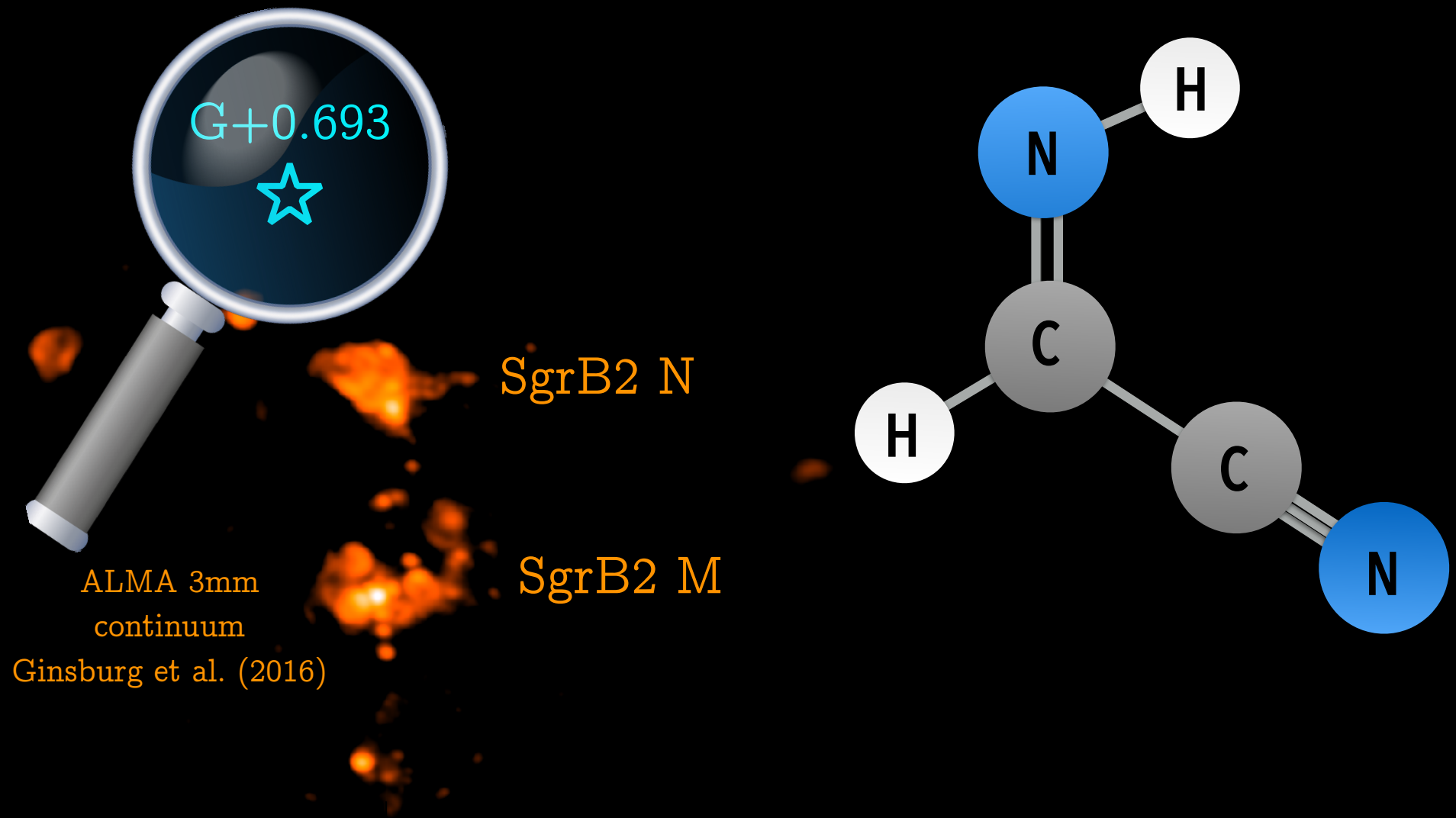


# Search for cynomethanimine HNCHCN



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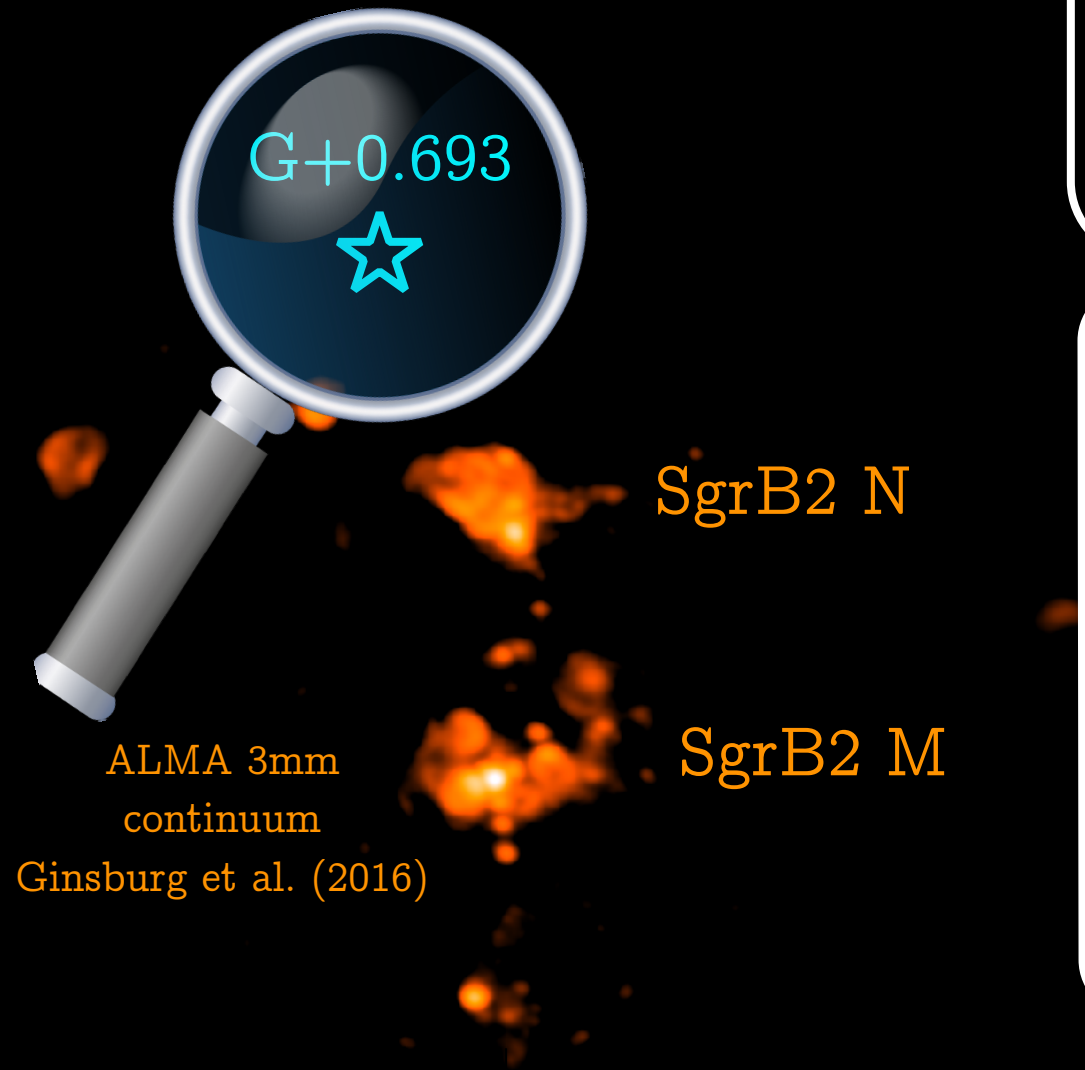
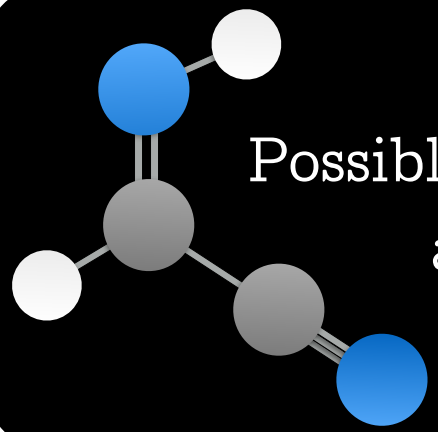
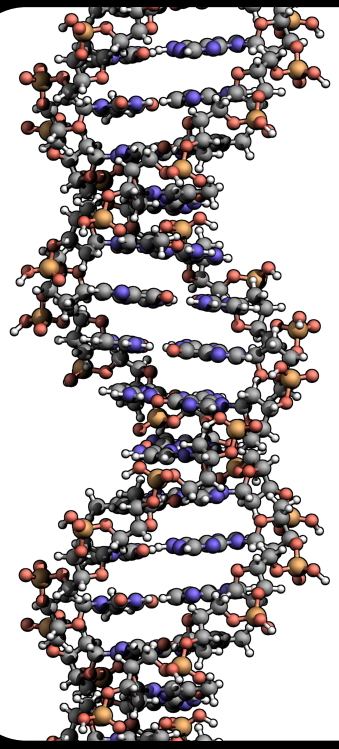


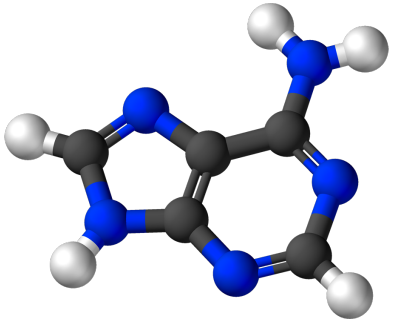

ALMA 3mm continuum
Ginsburg et al. (2016)



Possible precursor of adenine



Adenine

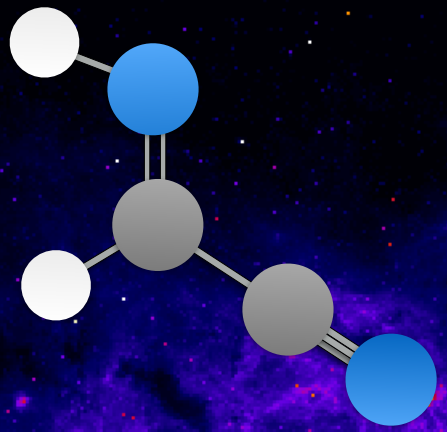


DNA and RNA nucleobase

# Cynomethanimine HNCHCN

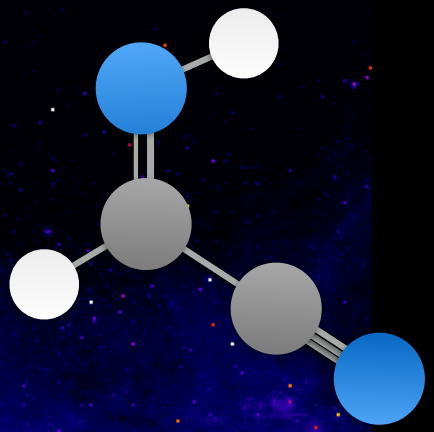
The most stable dimer of HCN is C-cyanomethanimine, which presents two isomers:

## E-isomer

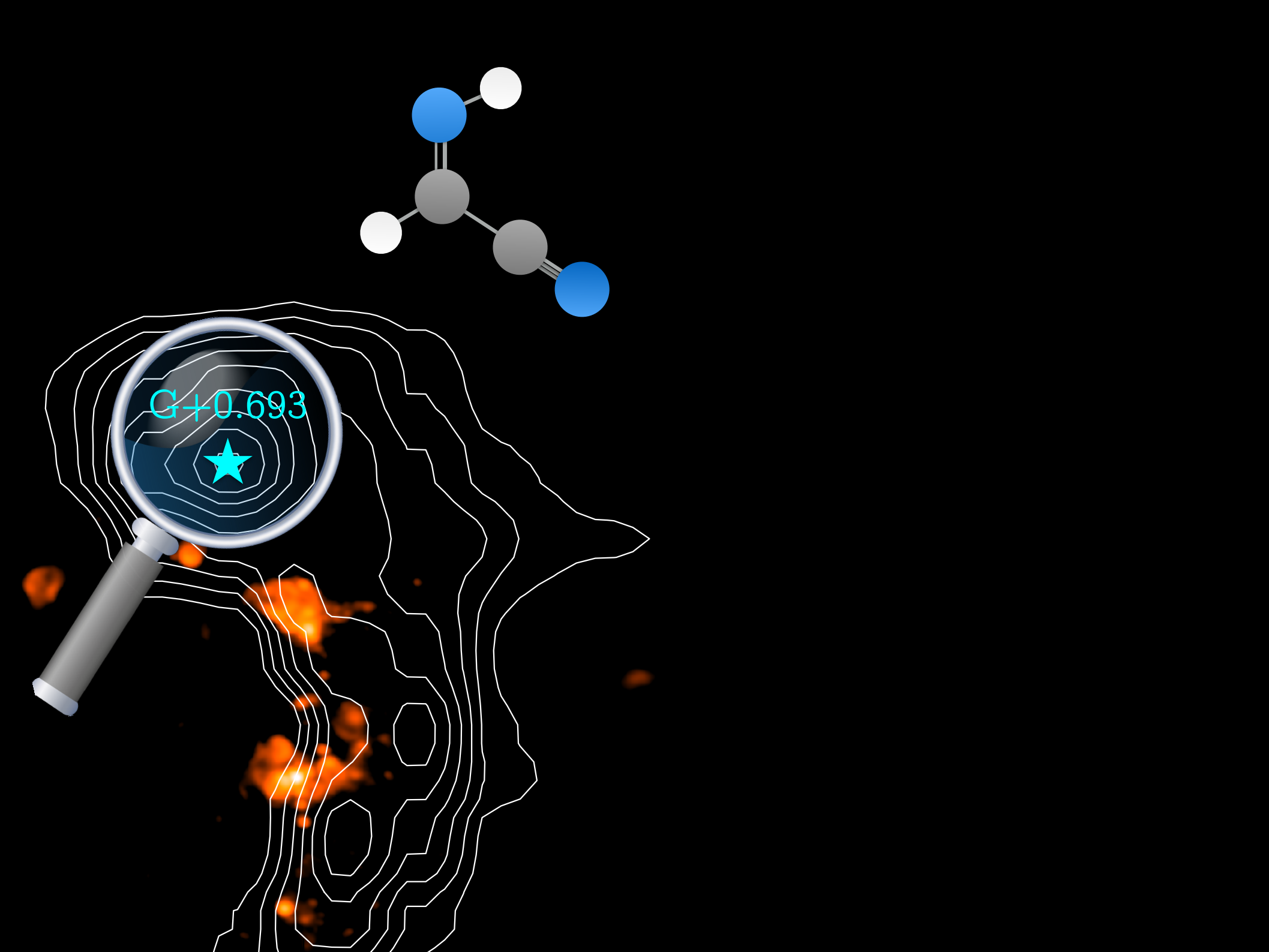


- Higher energy isomer
- Previously detected only in SgrB2 N (Zaleski et al. 2013)

## Z-isomer



- Lower energy isomer
- Never detected in the ISM, despite observational efforts (Melli et al. 2018)

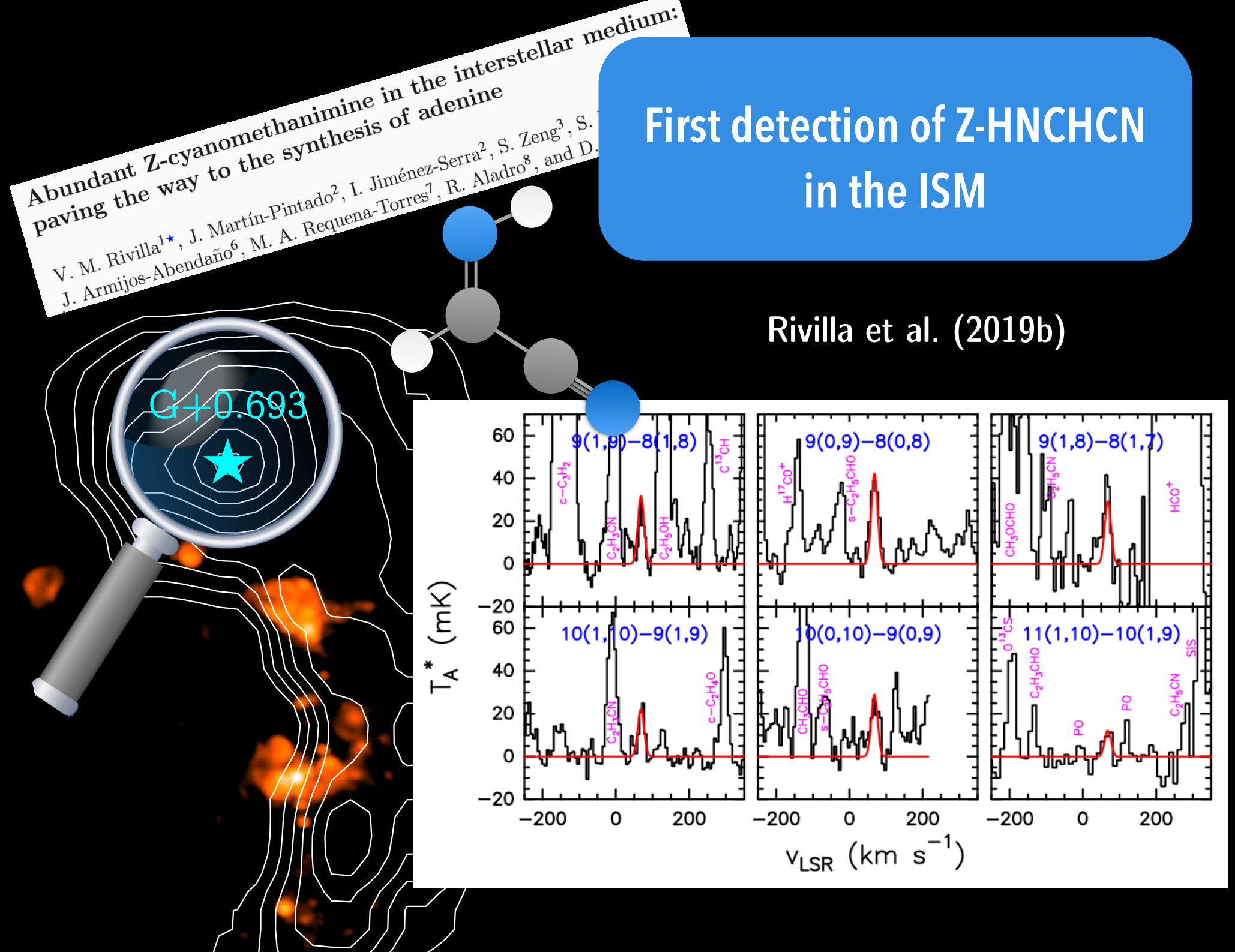

G+0.693

**Abundant Z-cyanomethanimine in the interstellar medium: paving the way to the synthesis of adenine**

V. M. Rivilla[1⋆], J. Martín-Pintado[2], I. Jiménez-Serra[2], S. Zeng[3], S. …
J. Armijos-Abendaño[6], M. A. Requena-Torres[7], R. Aladro[8], and D. …

# First detection of Z-HNCHCN in the ISM

Rivilla et al. (2019b)



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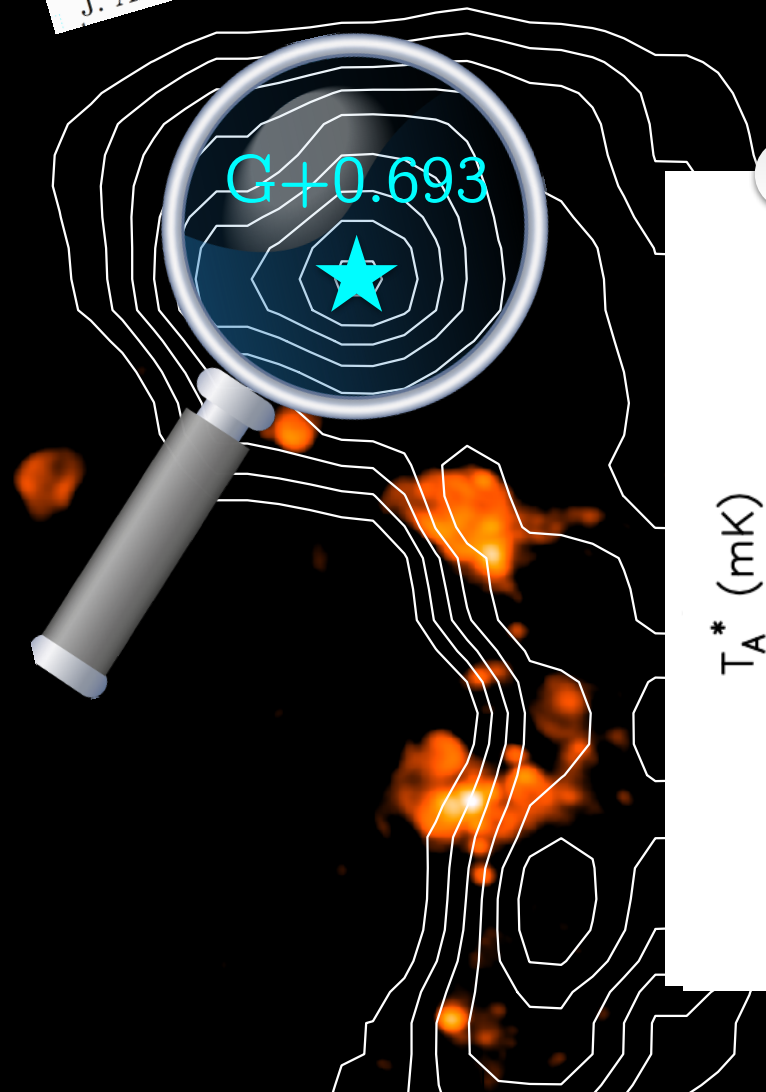
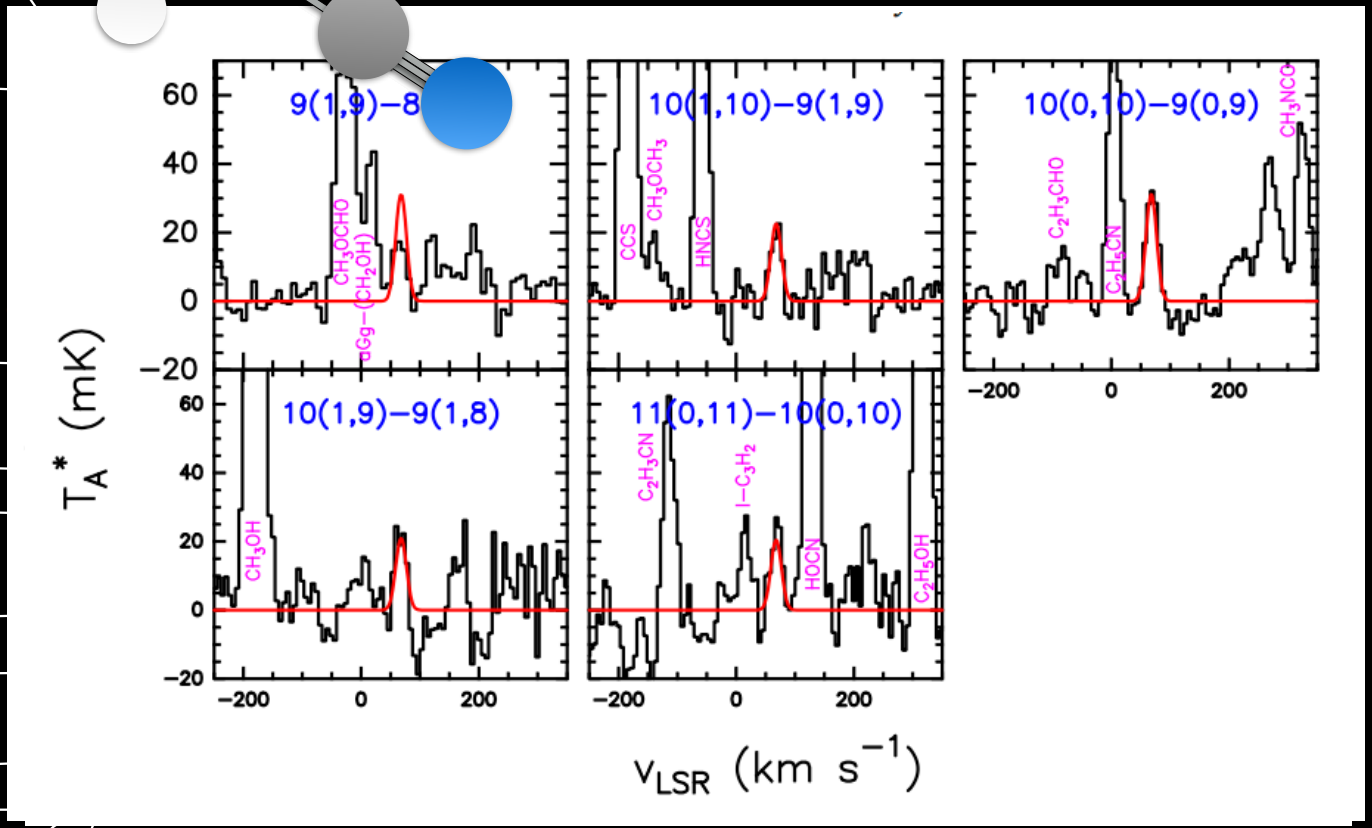
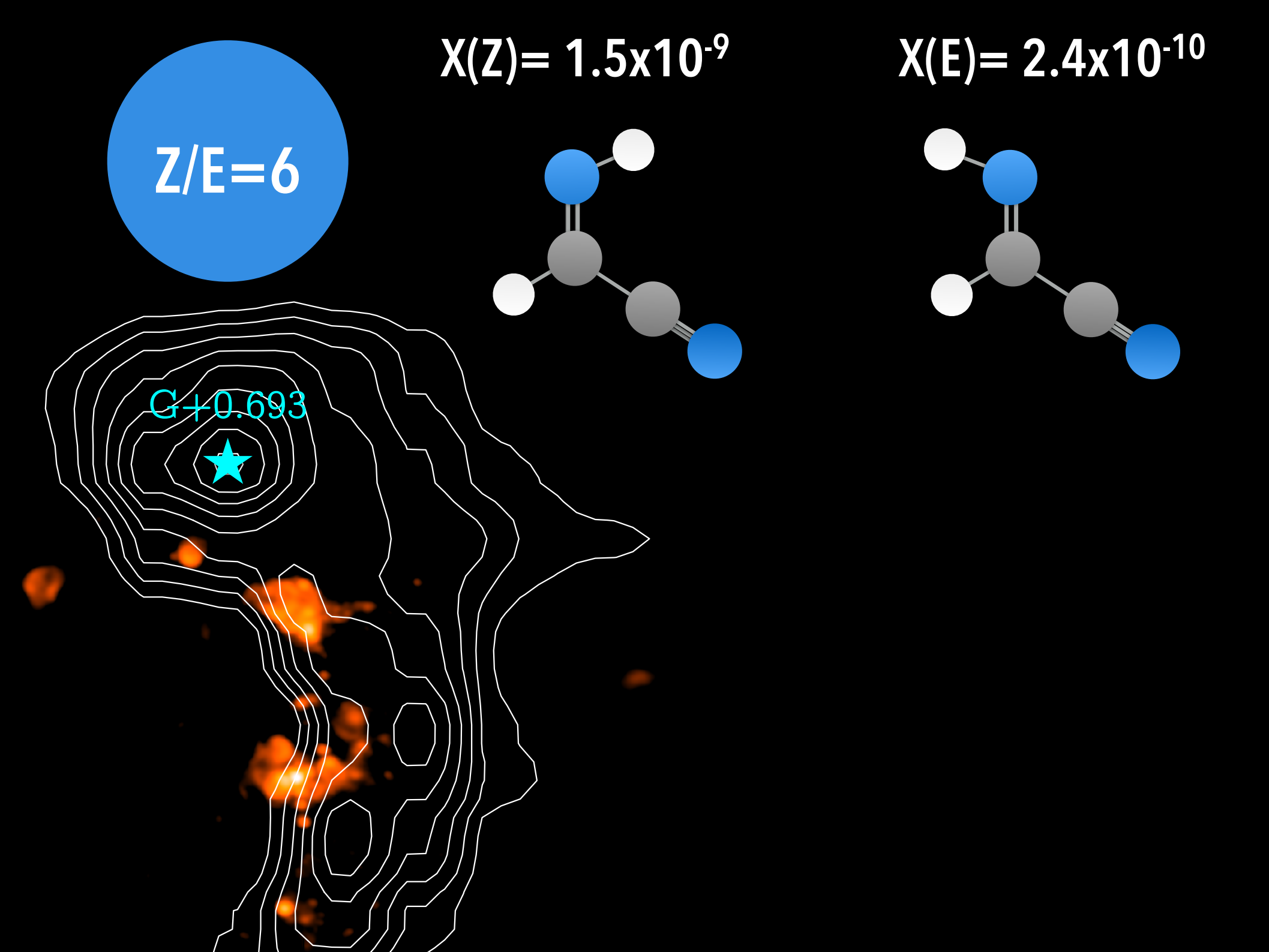
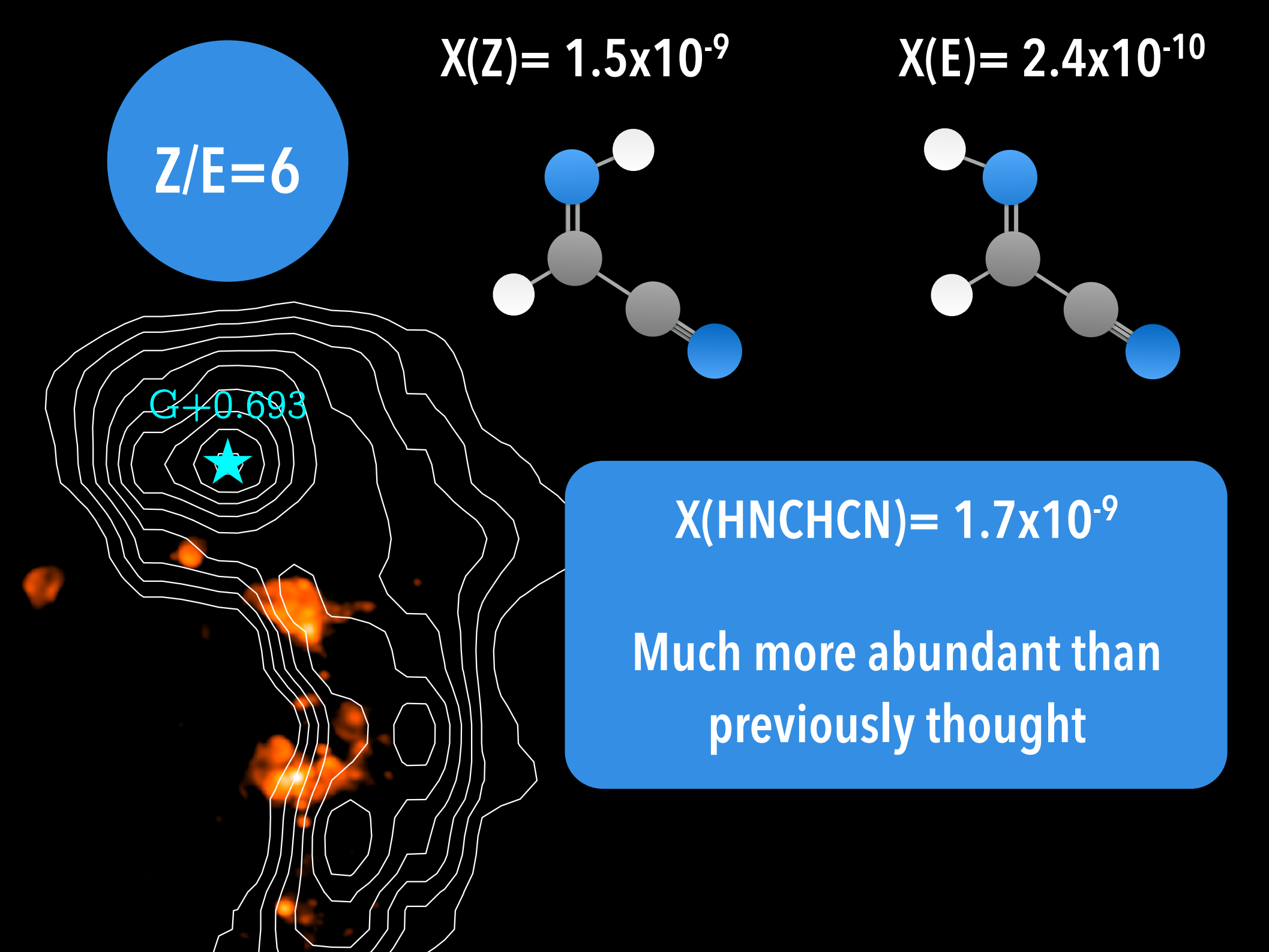
# E-isomer also detected

Rivilla et al. (2019b)



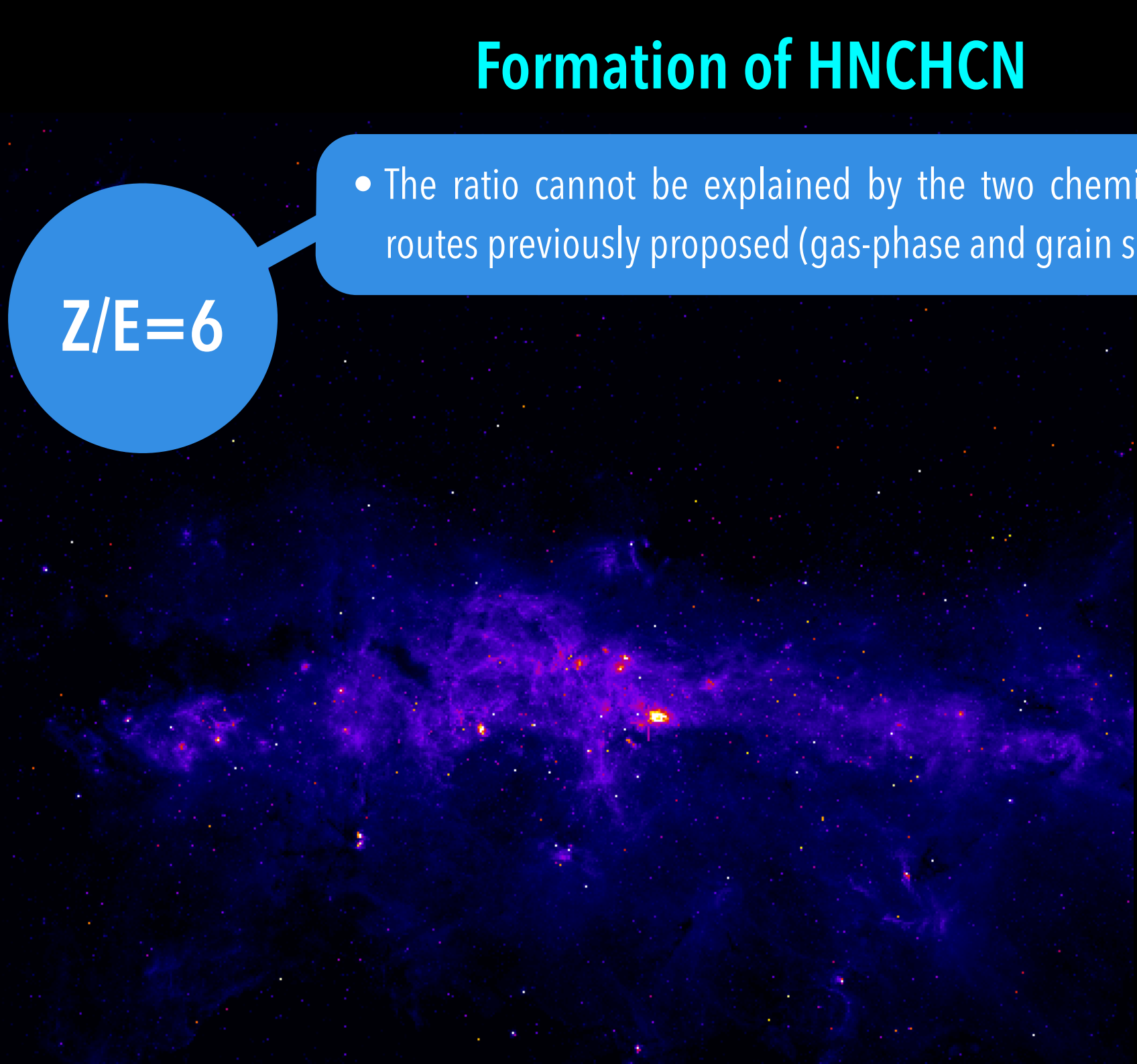

X(Z)= 1.5x10-9
X(E)= 2.4x10-10
Z/E=6
G+0.693


X(Z)= 1.5x10-9
X(E)= 2.4x10-10
Z/E=6
G+0.693
X(HNCHCN)= 1.7x10-9
Much more abundant than previously thought

# Formation of HNCHCN

Z/E=6

- The ratio cannot be explained by the two chemical formation routes previously proposed (gas-phase and grain surface)



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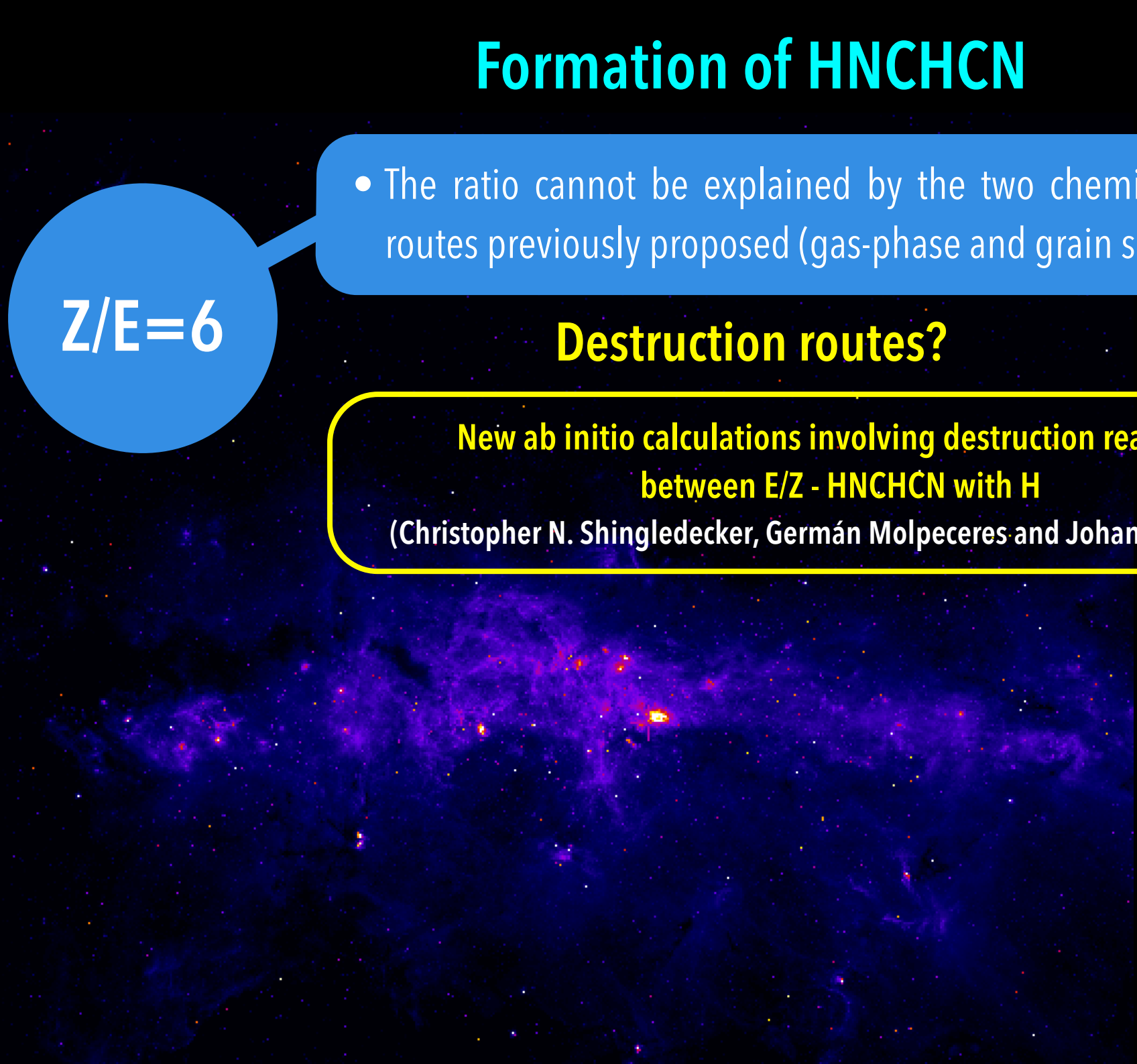
**New ab initio calculations involving destruction reactions between E/Z - HNCHCN with H**

**(Christopher N. Shingledecker, Germán Molpeceres and Johannes Kästner)**



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- **Chemical models need to be run to see of this explains Z/E ~ 6**

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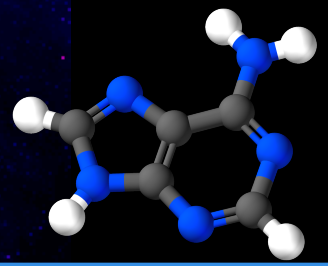
**Whatever the formation/destruction mechanism(s), the high abundance of Z-HNCHCN shows that possible precursors of adenine are efficiently formed in the ISM.**



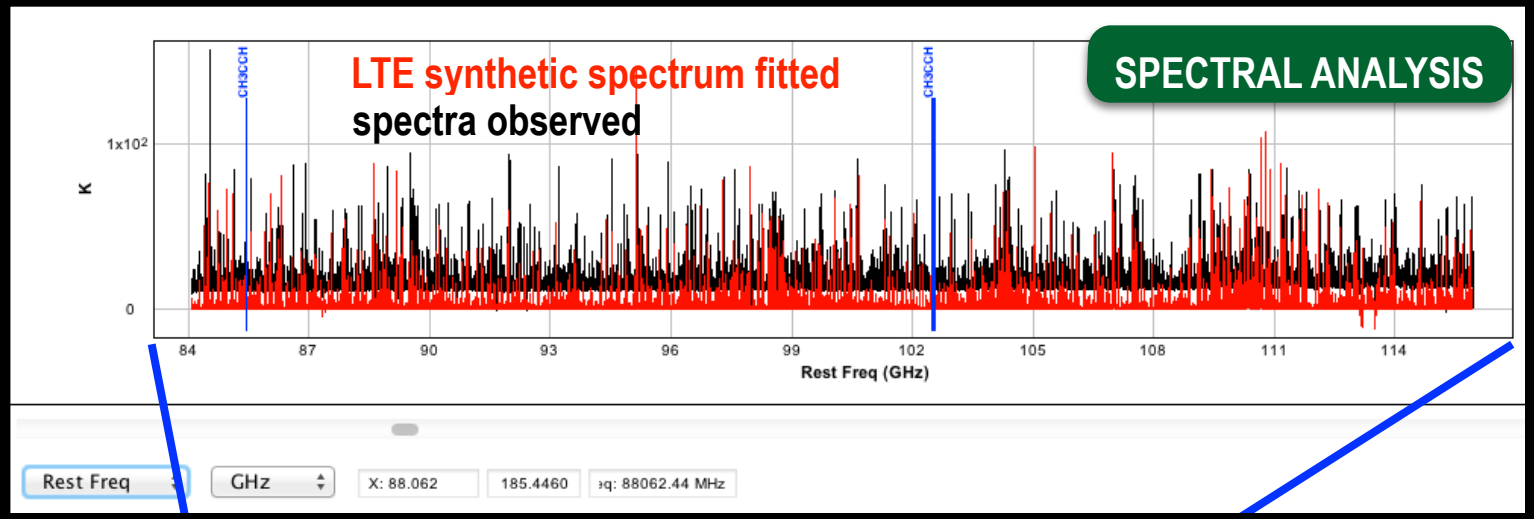
# Software development


**Spectral Line Identification and Modelling (SLIM) in the MAdrid Data CUBe Analysis (MADCUBA) package**

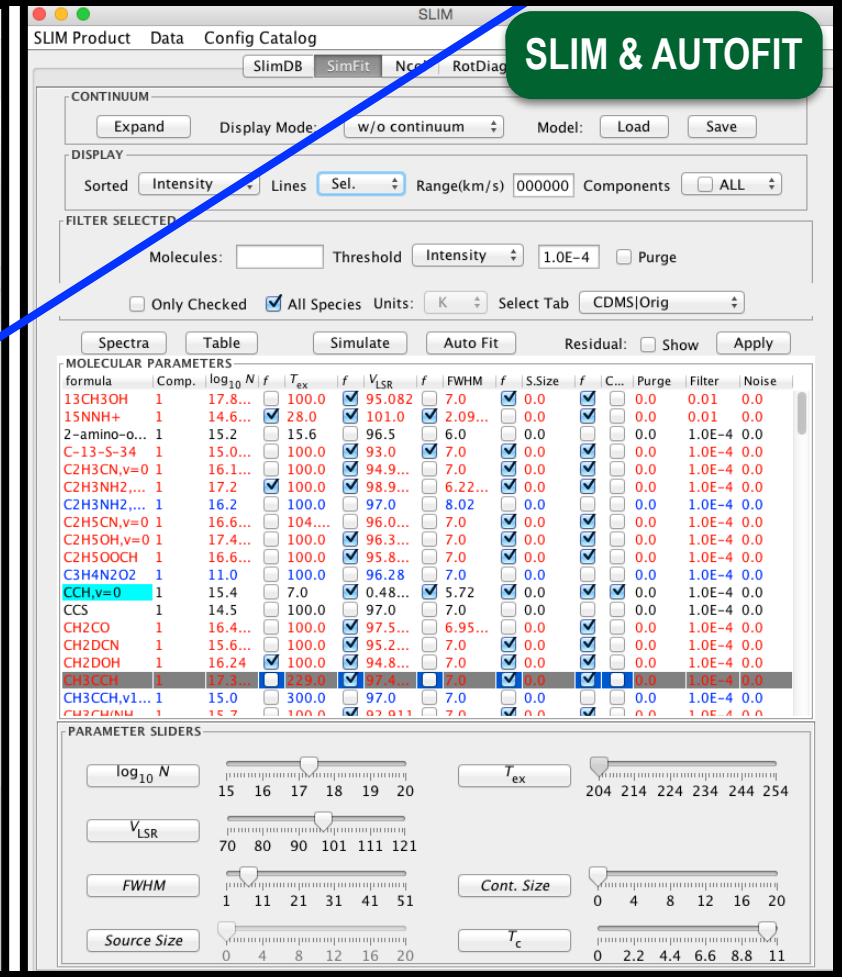
**An interactive software for data cube analysis**

S. Martín[1,2], J. Martín-Pintado[3], C. Blanco-Sánchez[3], V. M. Rivilla[4], A. Rodríguez-Franco[5], and F. Rico-Villas[3]

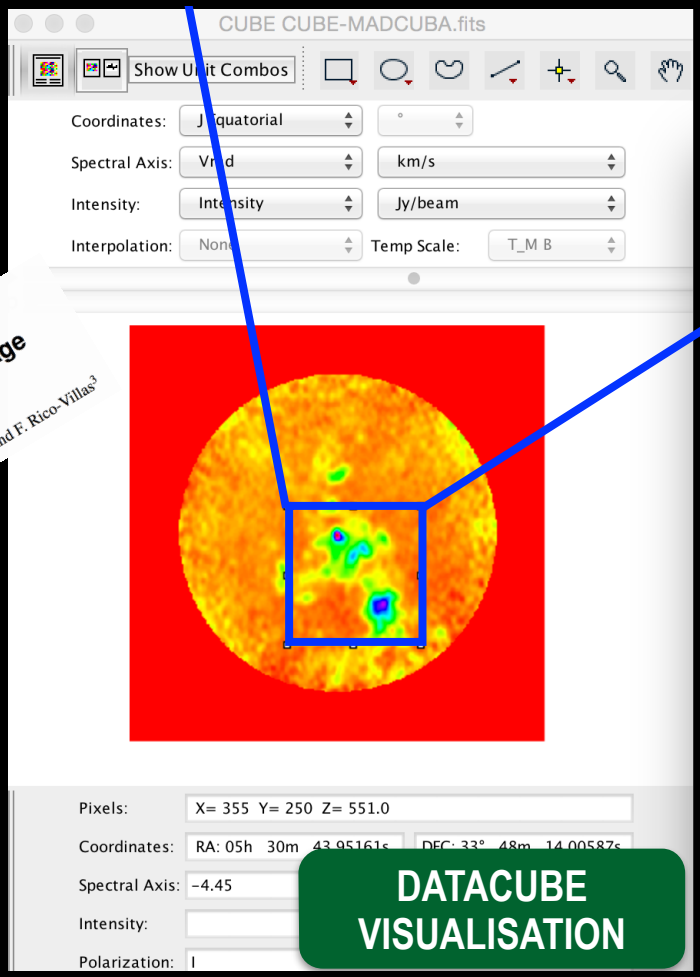
## SPECTRAL ANALYSIS




## SLIM & AUTOFIT




## DATACUBE VISUALISATION



Astro FIt 2

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- 2 invited talks and 8 contributed talks at conferences
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**PRESS RELEASES**

8 Press releases in different institutions (Media INAF, ESO, ALMA, NRAO, Leiden University, Queen Mary University)

**TRANSDISCIPLINARY IMPACT**

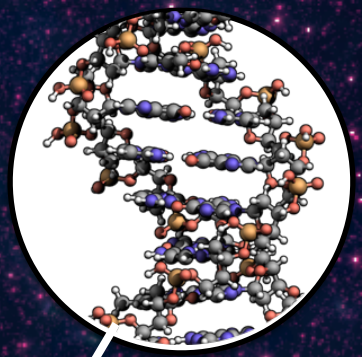
My research has been cited by publications in other fields (astrobiology, chemistry, spectroscopy), such as *Life, Nature Chemistry, Physical Chemistry Chemical Physics, Journal of Physical Chemistry, Chemical Communications and Journal of Quantitative Spectroscopy* and *Radiative Transfer.*

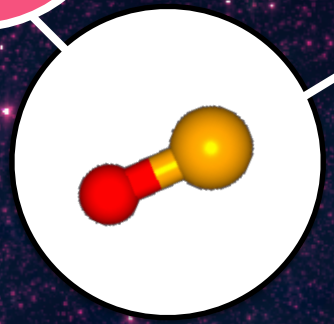
# BIOSFERA

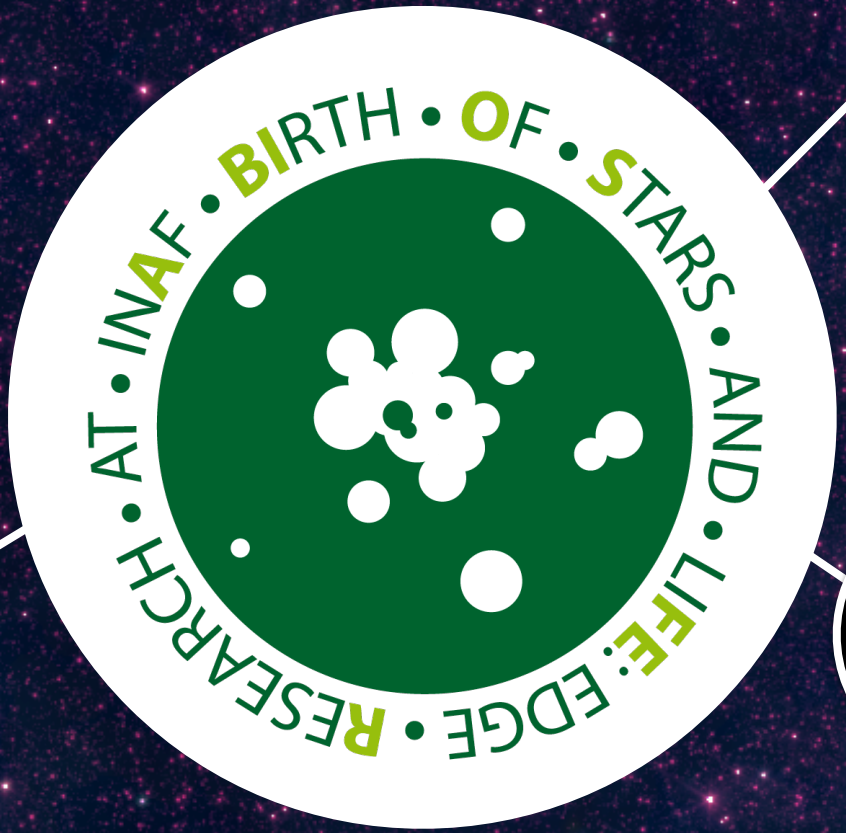
## BIrth Of Stars and LiFE: Edge Research at INAF

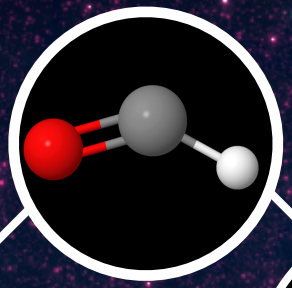

Víctor M. Rivilla

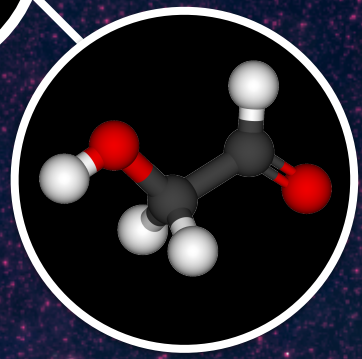
INAF - Osservatorio Astrofisico di Arcetri

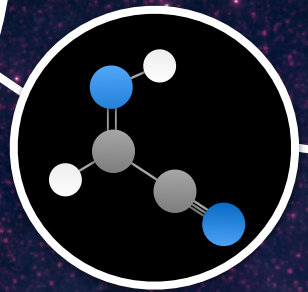



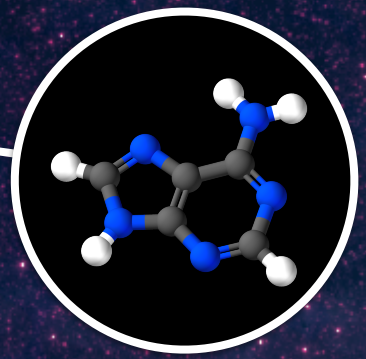











Astro FIt 2

**3rd ASTROFIT2 annual meeting**

**Rome, Italy, October 16 2019**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