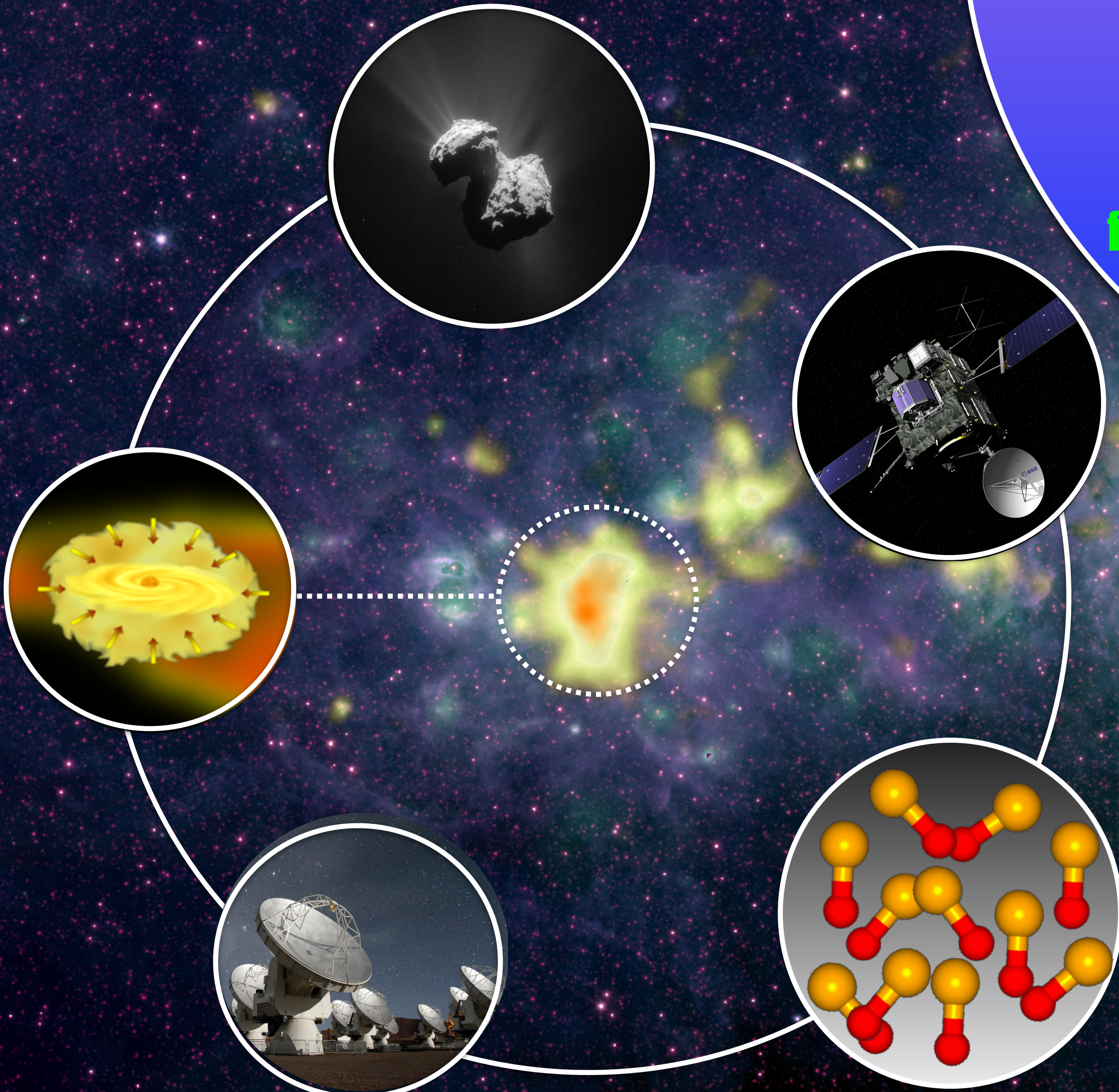
Phosphorus:

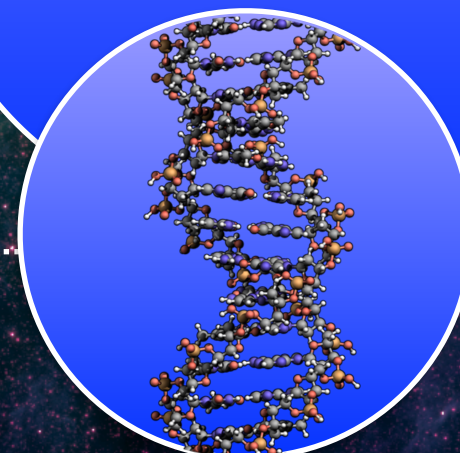
the missing prebiotic element... found in star-forming regions and comets



Víctor M. Rivilla

Marie Skłodowska-Curie Fellow

Osservatorio Astrofisico di Arcetri

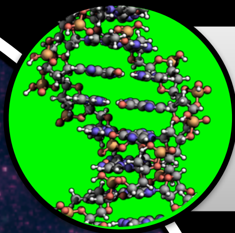


Nitrogen

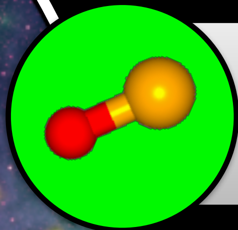
F. Fontani, M. Beltrán, P. Caselli, A. Vasyunin, C. Mininni, J. Martín-Pintado, I. Jiménez-Serra, R. Cesaroni, M. Drozdovskaya, K. Altwegg and the ROSINA team...and more

Prebiotic molecules in Space and Origins of Life on Earth
Bad Honnef, March 19-23 2018

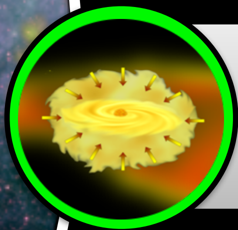
Outline



The prebiotic importance of Phosphorus



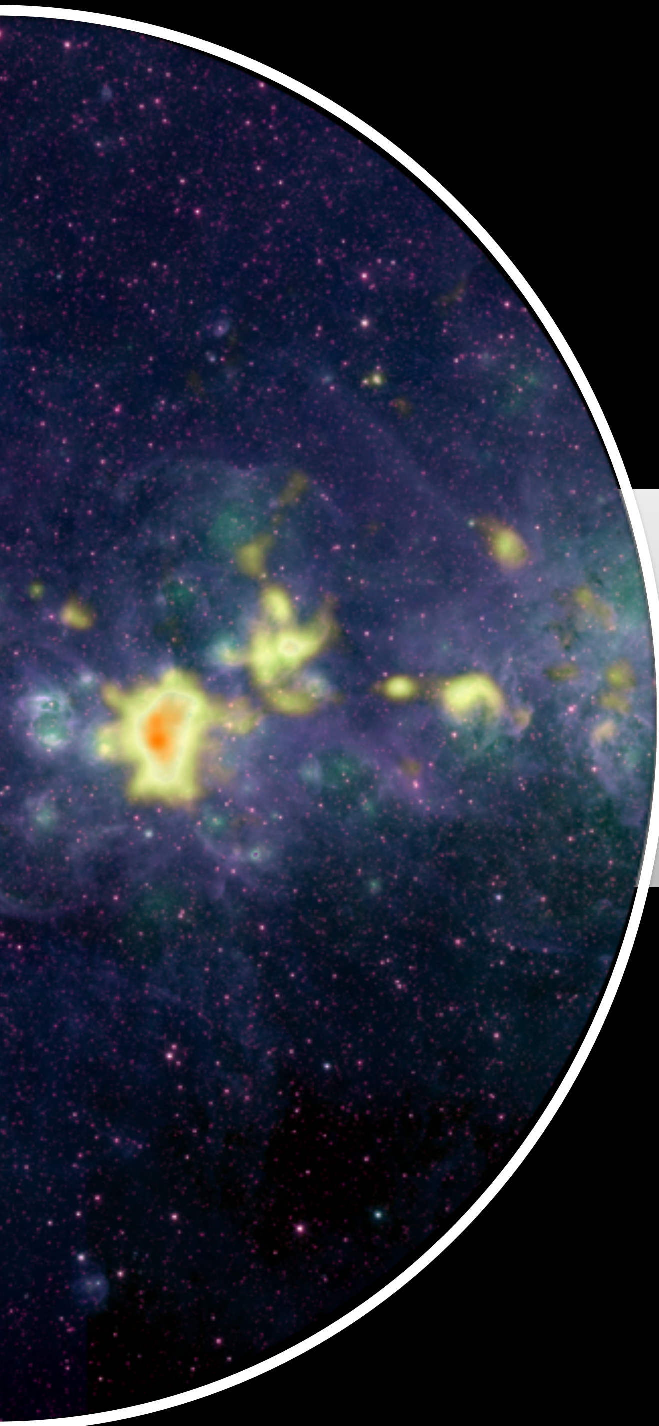
P-bearing molecules in the ISM:
a missing element?



Search for P-bearing molecules in
star-forming regions and the Galactic Center

Phosphorus in the
67P Churyumov-Gerasimenko comet

Conclusions

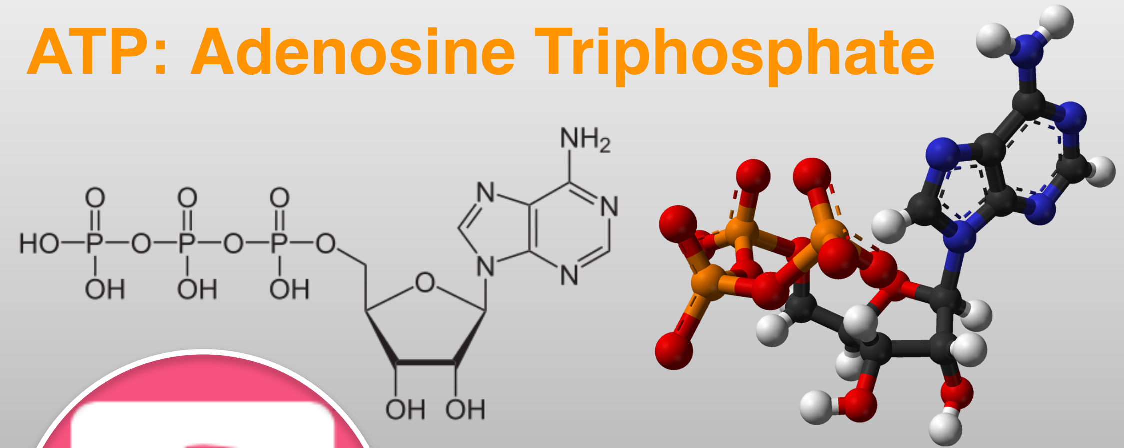


The prebiotic importance of Phosphorus

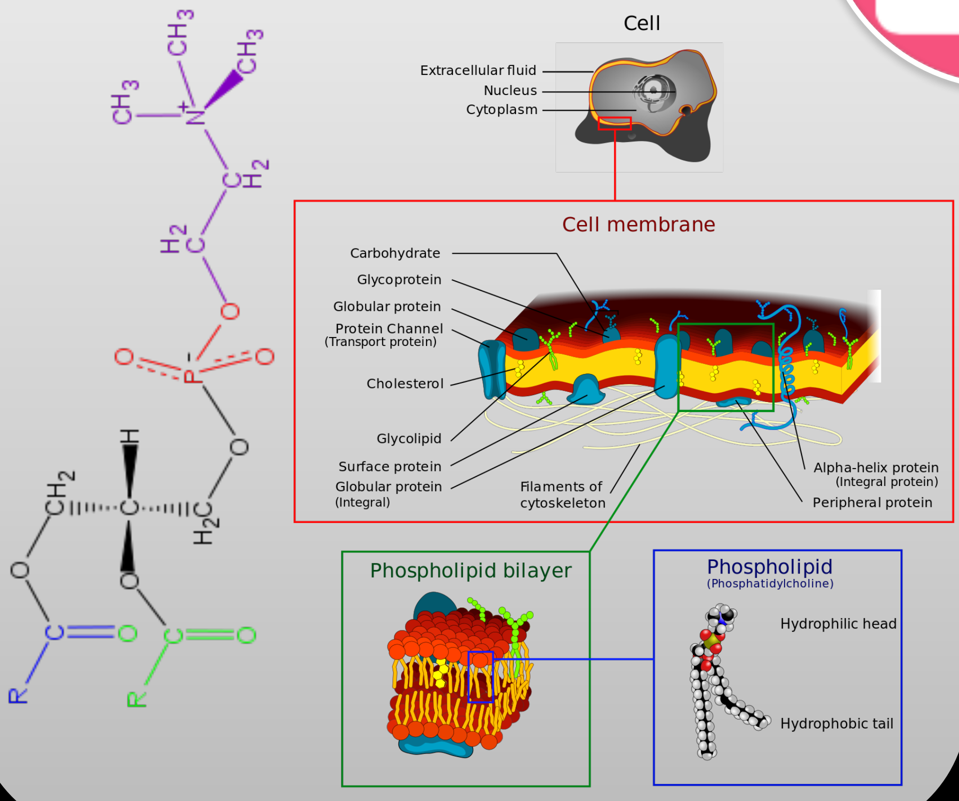
Phosphorus: key to Life

Chemical reactivity
Structural stability

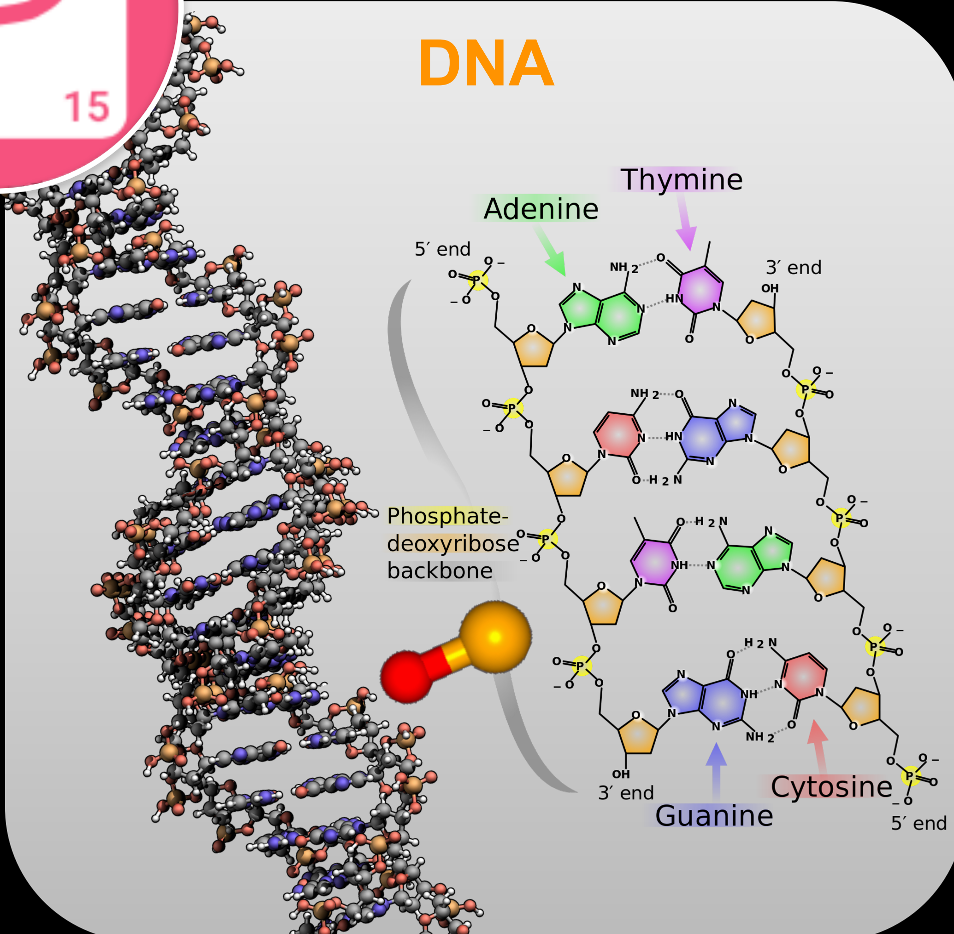
ATP: Adenosine Triphosphate



Phospholipids

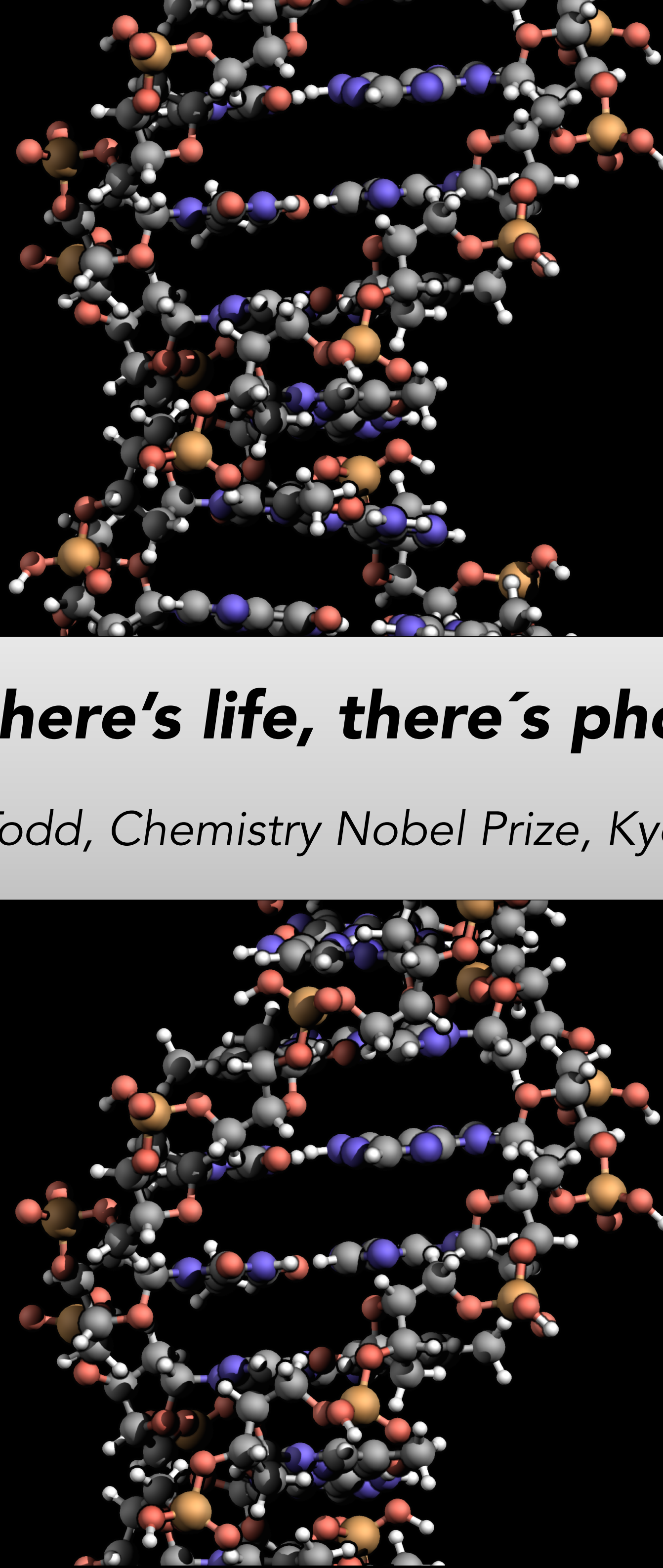


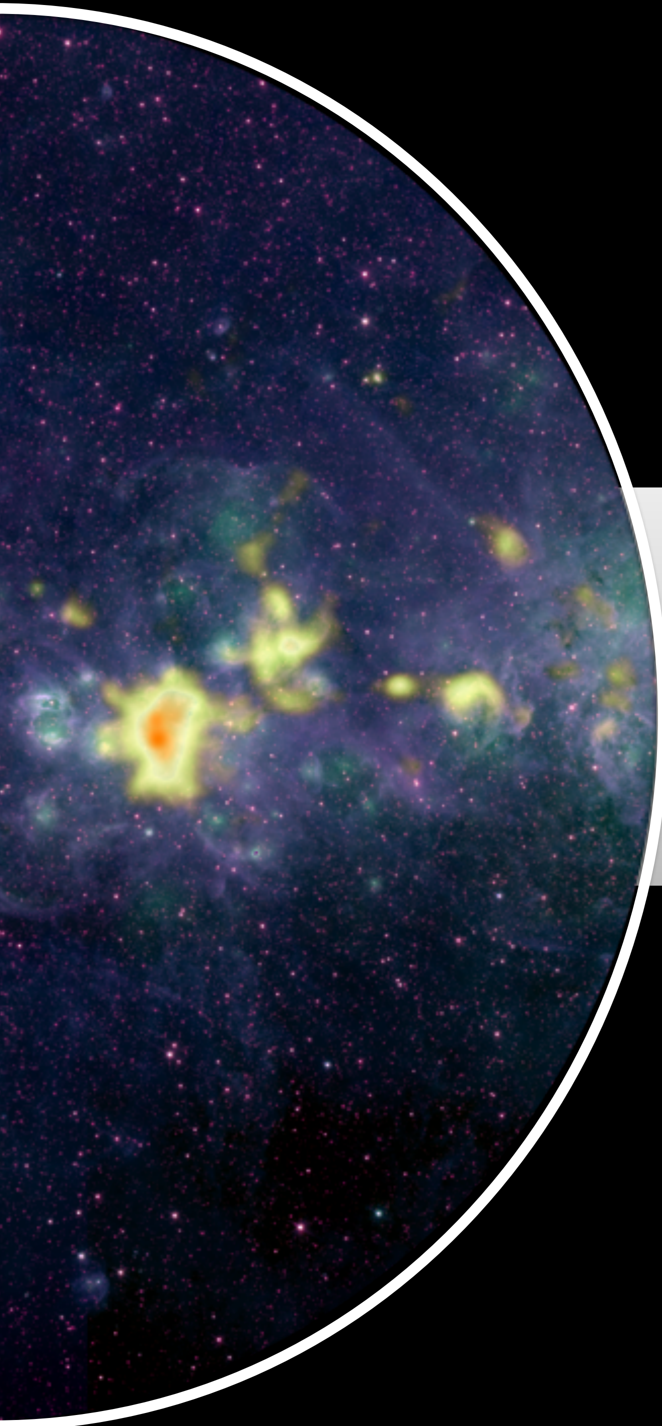
DNA



"Where there's life, there´s phosphorus

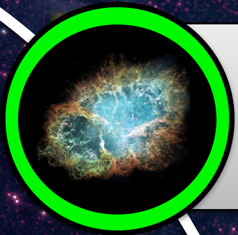
Sir Alexander Todd, Chemistry Nobel Prize, Kyoto Lecture 1982





P-bearing molecules in the ISM: a missing element?

P-bearing molecules in the ISM



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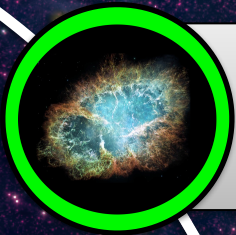

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It is barely detected in space:

- **P^+** in several diffuse clouds (Jura & York 1978)
- **PN**, **PO**, **CP**, **HCP**, **C_3P** and **PH_3** in circumstellar envelopes of evolved stars.
- PH_3 has been observed in the atmospheres of Jupiter and Saturn.

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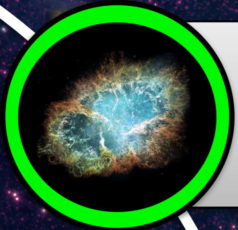

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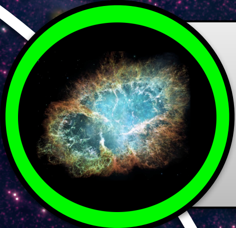
Low cosmic abundance: 3×10^{-7} (Grevesse & Sauval 1998)

Element	Cosmic abundance
C	**~10^{-4}**
O	**~10^{-4}**
N	**~10^{-5}**
P	**~10^{-7}**

P-bearing molecules in the ISM



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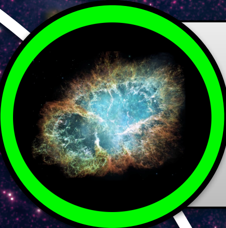

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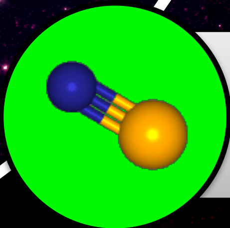
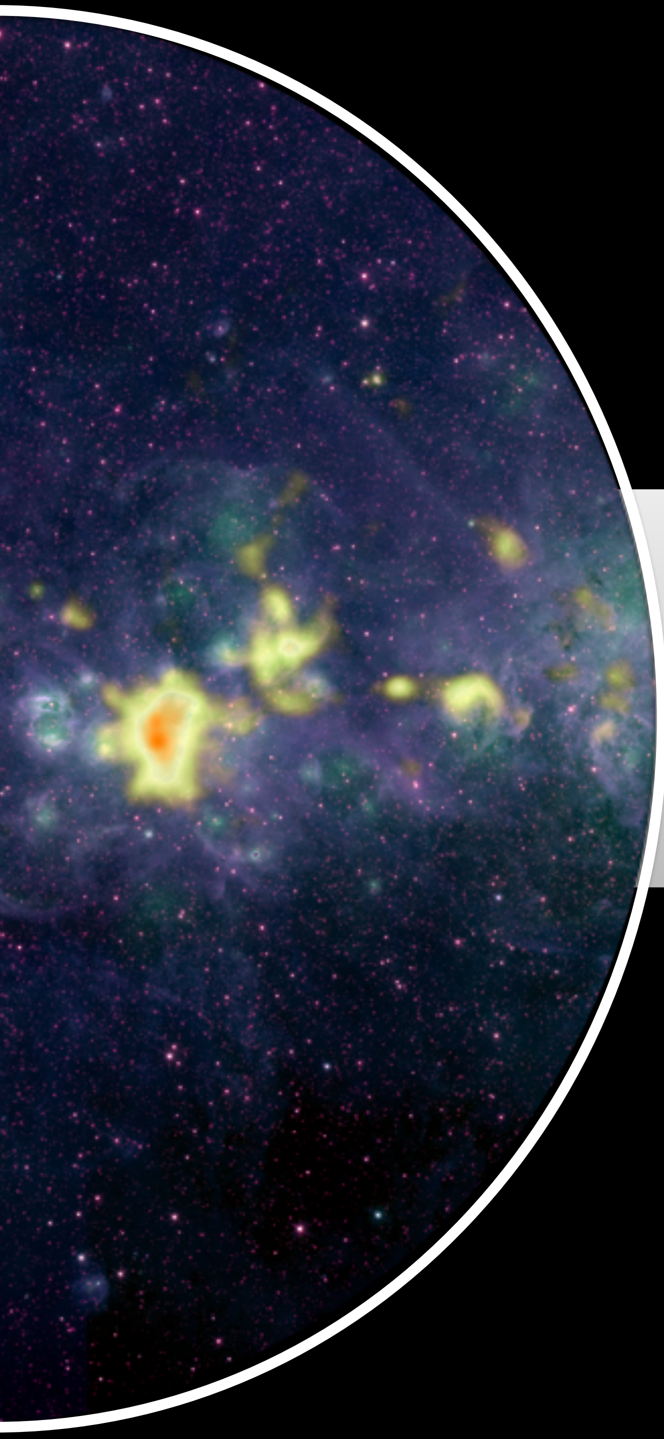


Little is known about the chemistry of Phosphorus



P-bearing molecules in star-forming regions

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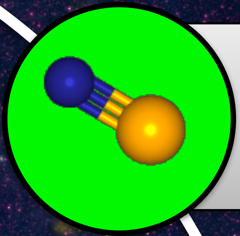
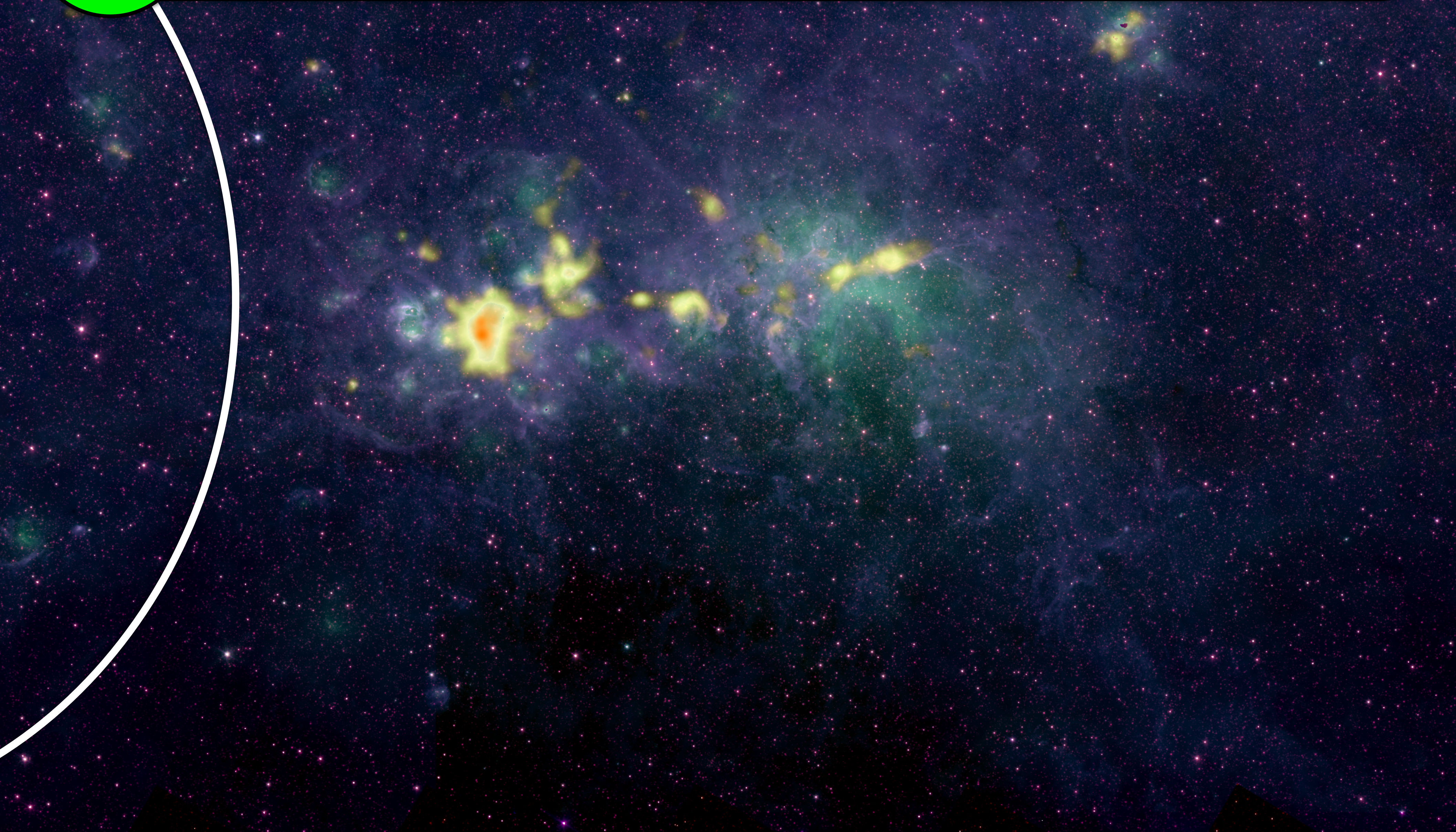


Only a very few detections of PN towards hot cores before 2016

(Turner&Bally 1987, Ziurys & Friberg 1987, Turner et al.1990)



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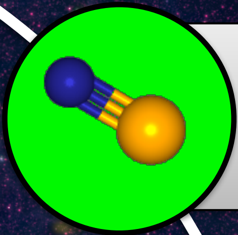

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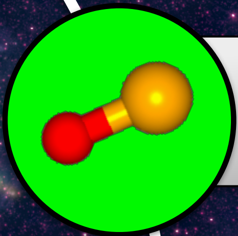

Previous searches of PO were unsuccessful

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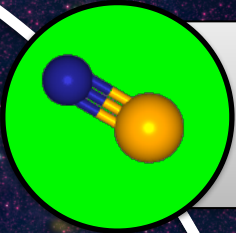

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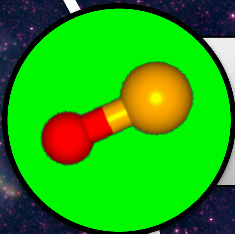

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Our group started several projects to study
P-bearing molecules in star-forming regions

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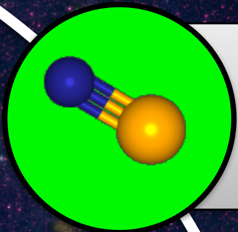

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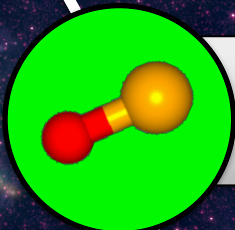

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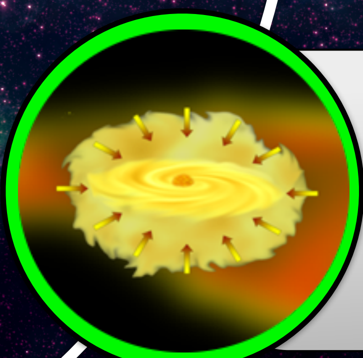
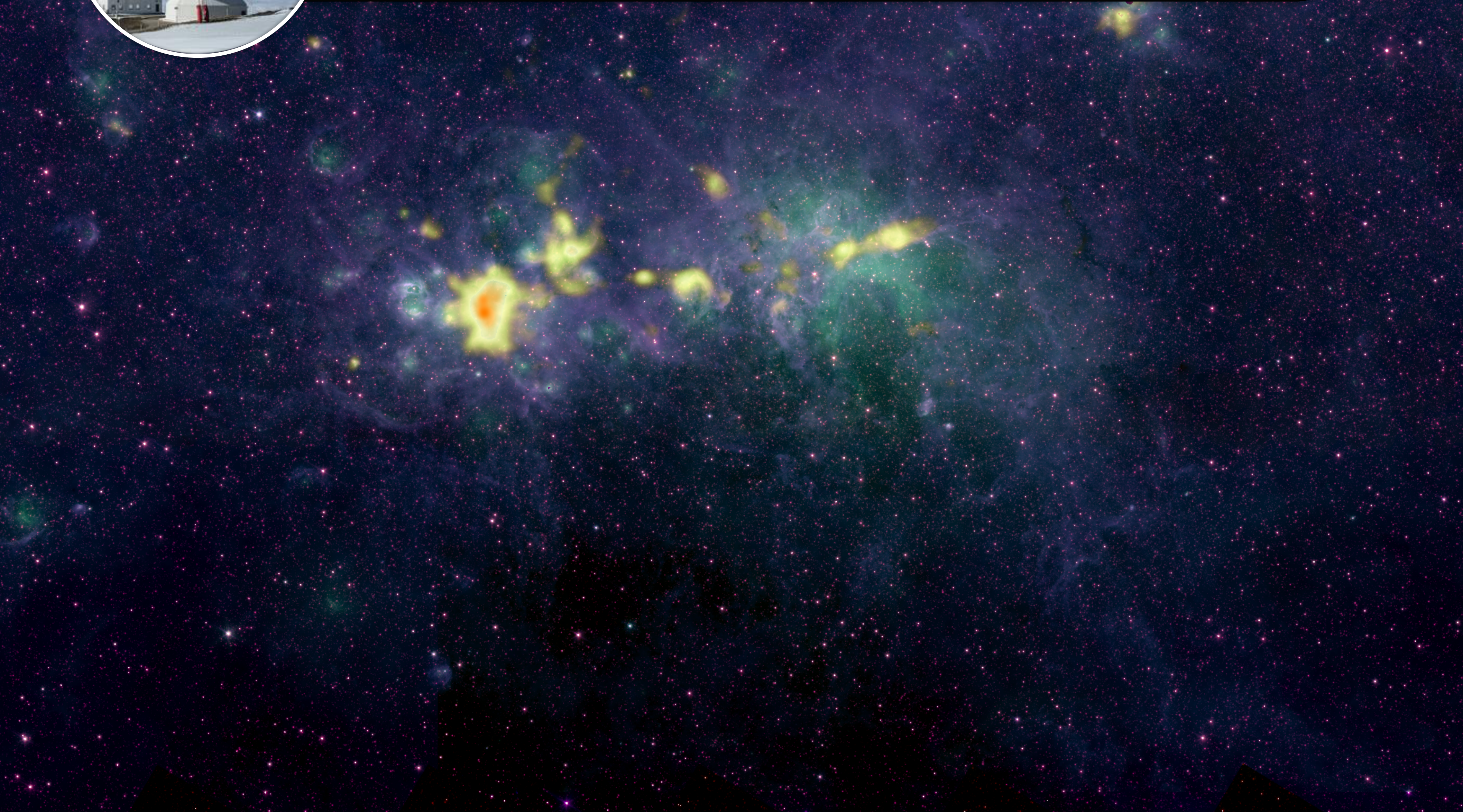


- ***Where***: sample of molecular dense ($n(H_2) > 10^4$ cm^{-3}) clouds with large masses (> 100 M_{sun}) and $T > 20$ K.
- ***Why***: they are the birthplaces of most stars, **including our Sun** (e.g. Adams 2010,Taquet+2016, Drozdovskaya+2018)

PN in a sample of star-forming regions

- IRAM 30m telecope (Sierra Nevada, Spain).
- PN(2-1) at 93.9 GHz in a sample of **27 massive dense cores**
(Fontani et al. 2011; Fontani et al. 2015; Colzi et al. 2018 - POSTER 01)



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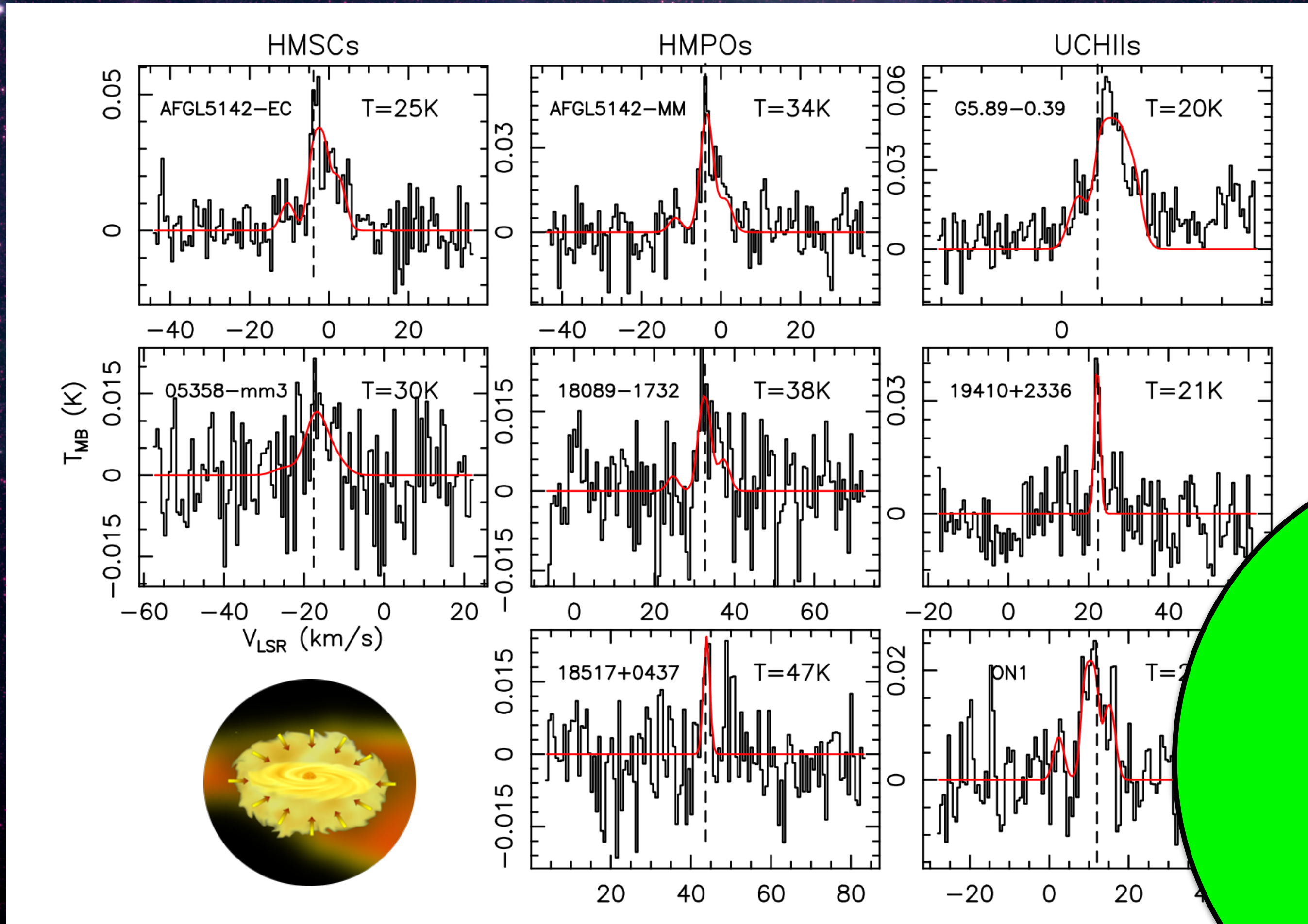
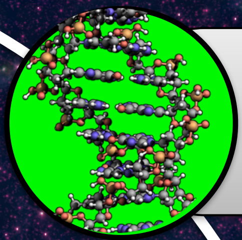
Fontani, Rivilla et al. (2016)



8 new PN detections

What about PO?



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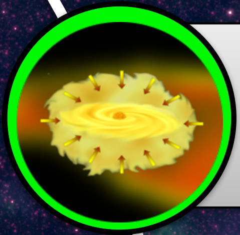
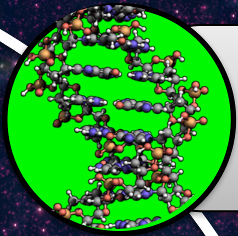


Not detected in any source

Good constraints on upper limits



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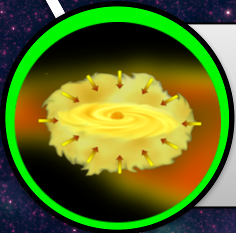

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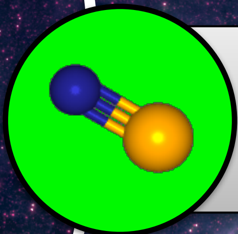

$N_{PO}^{upper} > N_{PN}$

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PO could be as abundant as PN

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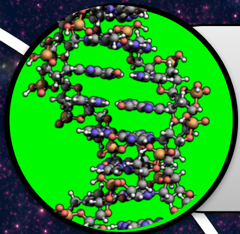

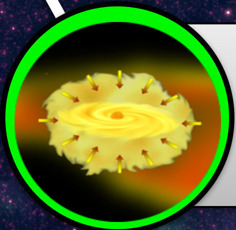

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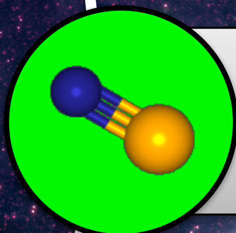

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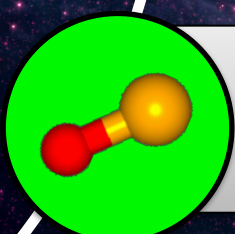
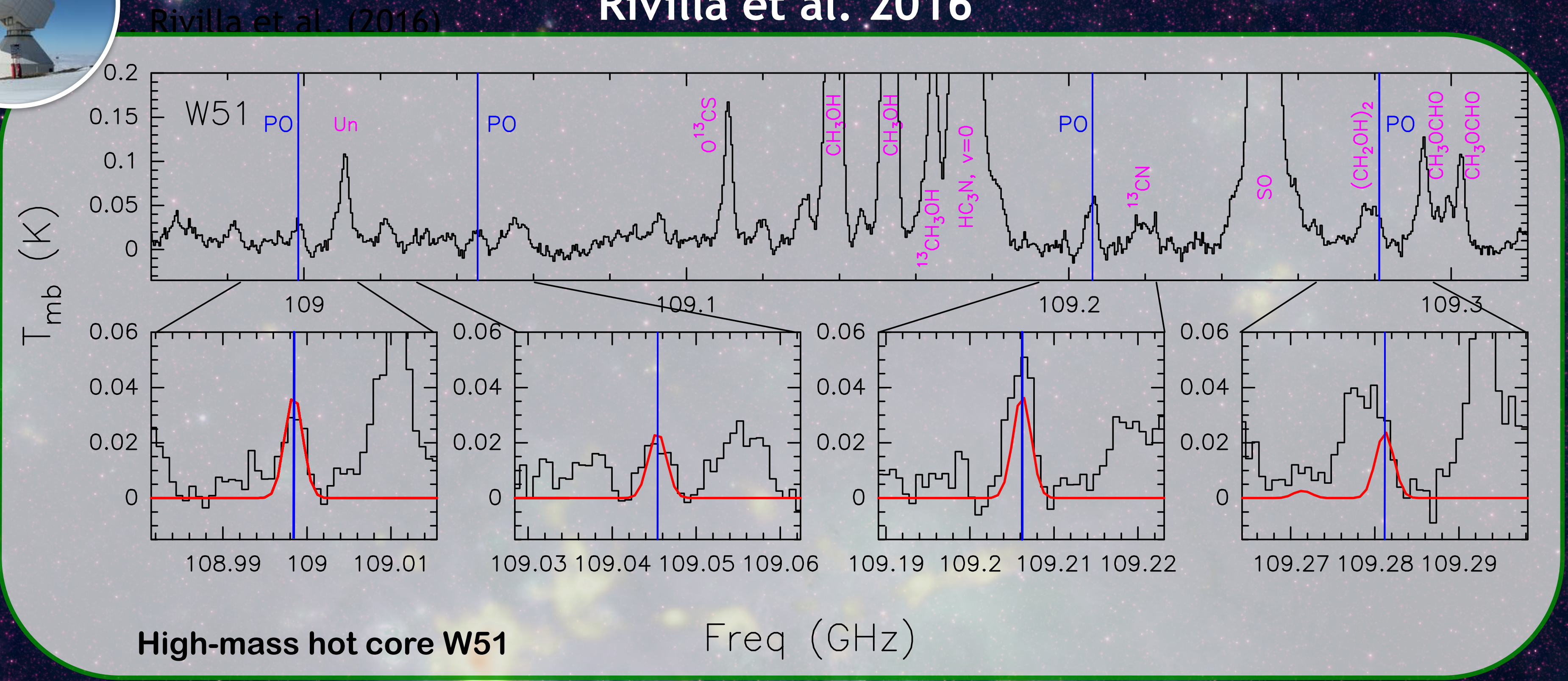


PO could be as abundant as PN

Search in the two brightest cores in PN with the IRAM 30m telescope

First detections of PO in star-forming regions

Rivilla et al. 2016



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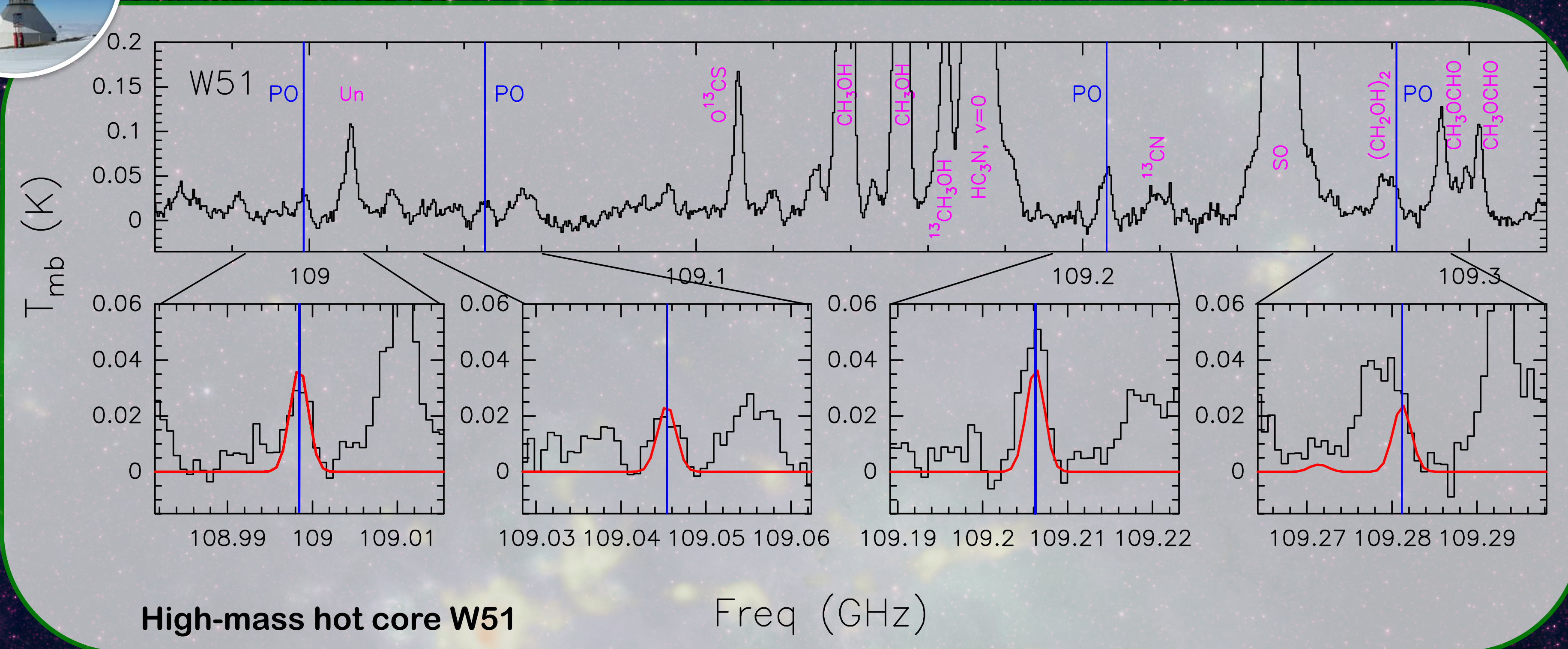
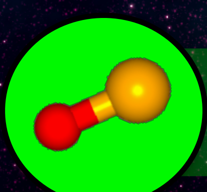
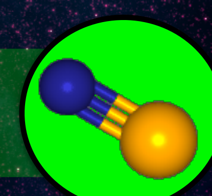


	Abundance (10^{-10})
PN	0.4-1.1
PO	1.2-2.0



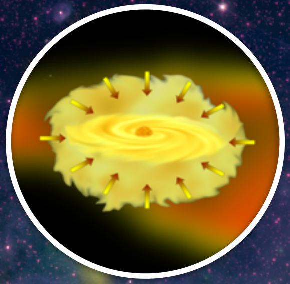
PO is a factor 2-3 more abundant than PN !



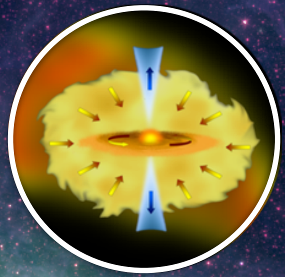
Chemical modeling

- Our theoretical team at MPE (Vasyunin, Caselli) included the chemical network of P in a 2-phase physical model to mimic the evolution of a star-forming region.

Cold starless phase



Warm-up protostellar phase



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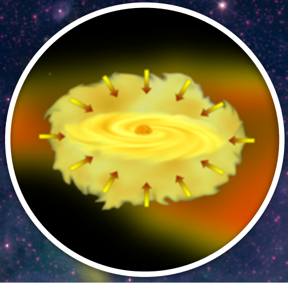

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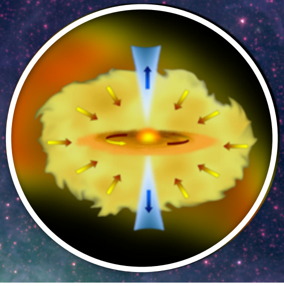

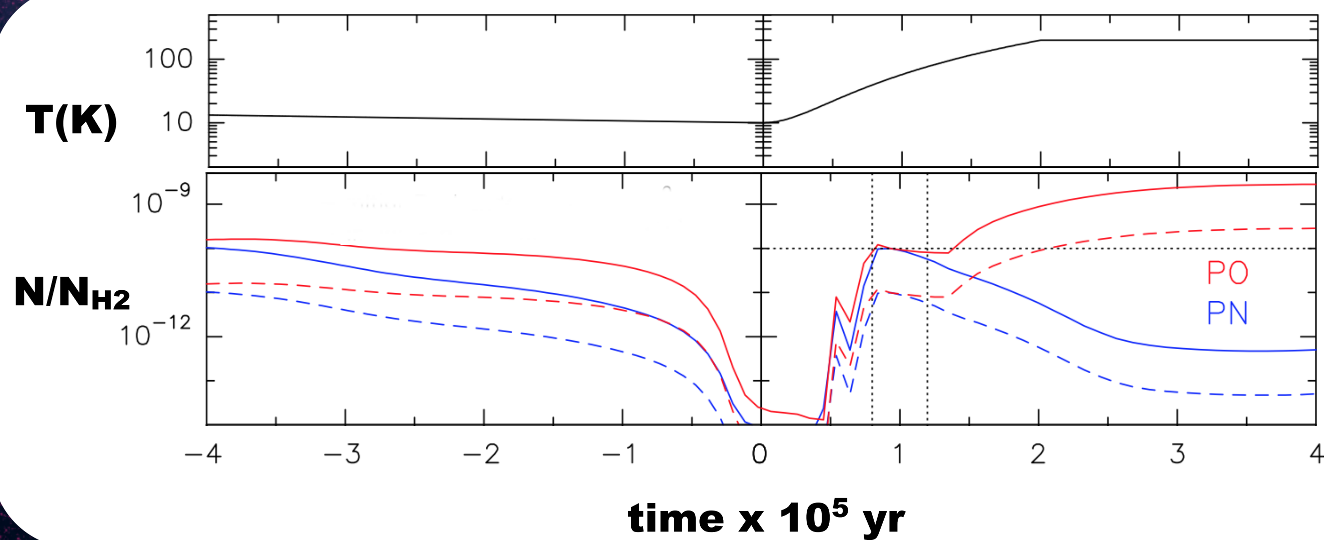

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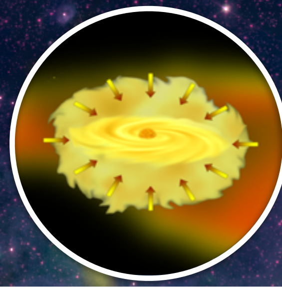

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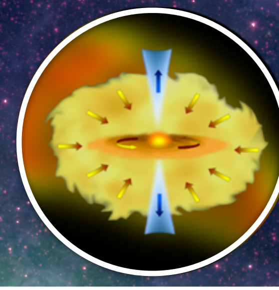

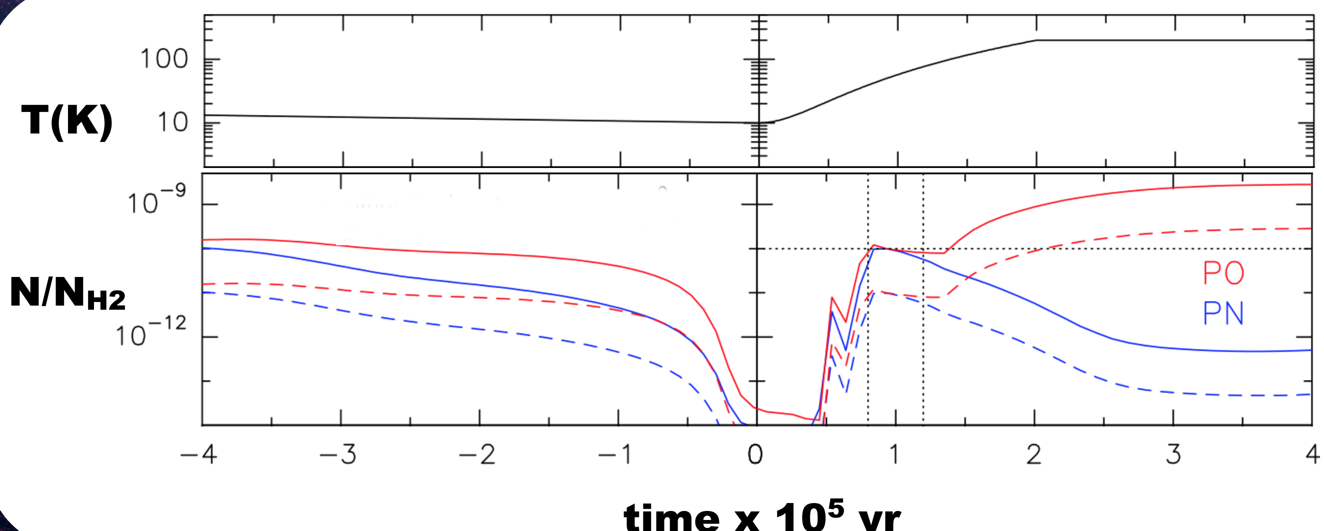

The two P-bearing molecules form in a sequence of **gas-phase** ion-molecule and neutral-neutral reactions during the cold collapse phase.

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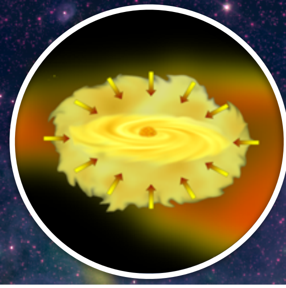
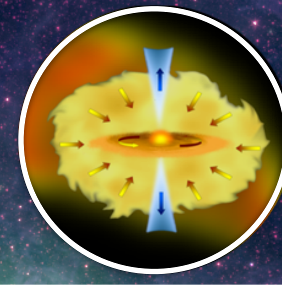
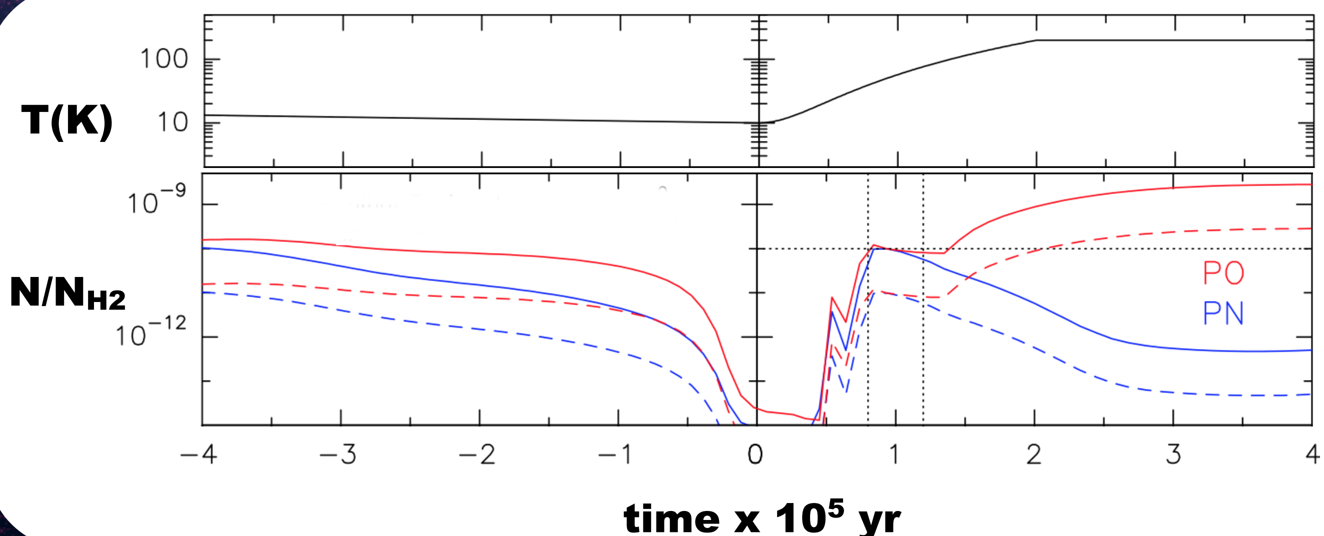


Warm-up protostellar phase





The two P-bearing molecules form in a sequence of **gas-phase** **ion-molecule** and **neutral-neutral** reactions during the cold collapse phase.

- The heating from the protostar produces the **thermal desorption** of the P-bearing species.
- **Hot chemistry** can explain the observed abundances.

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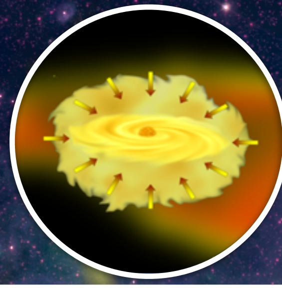

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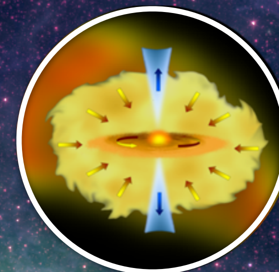
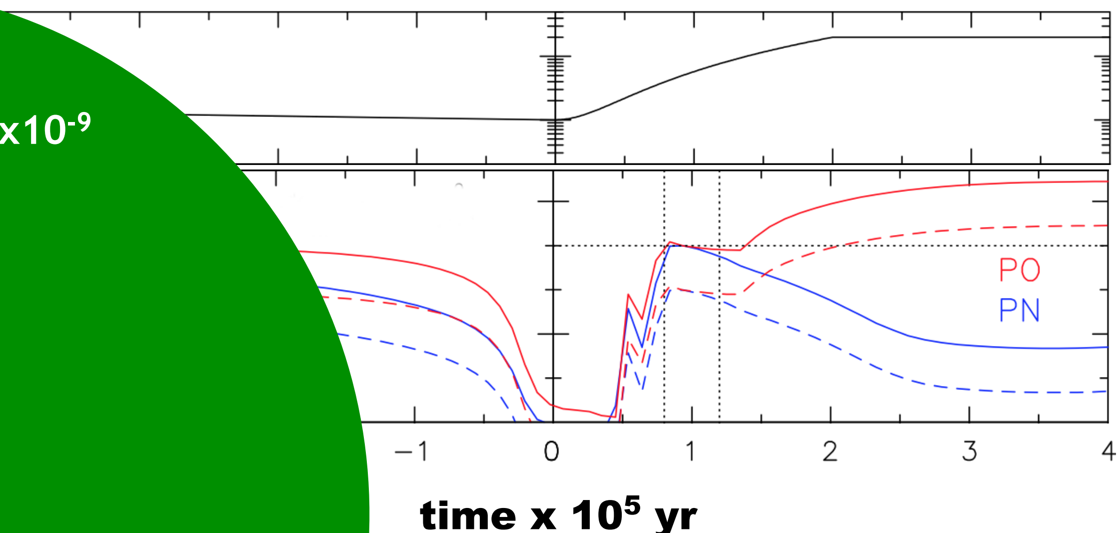


P initial abundance = 5×10^{-9}



m in a
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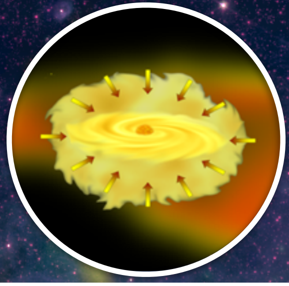
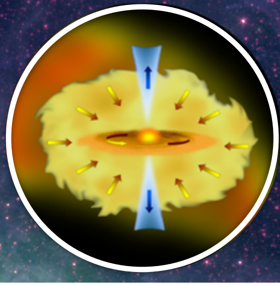
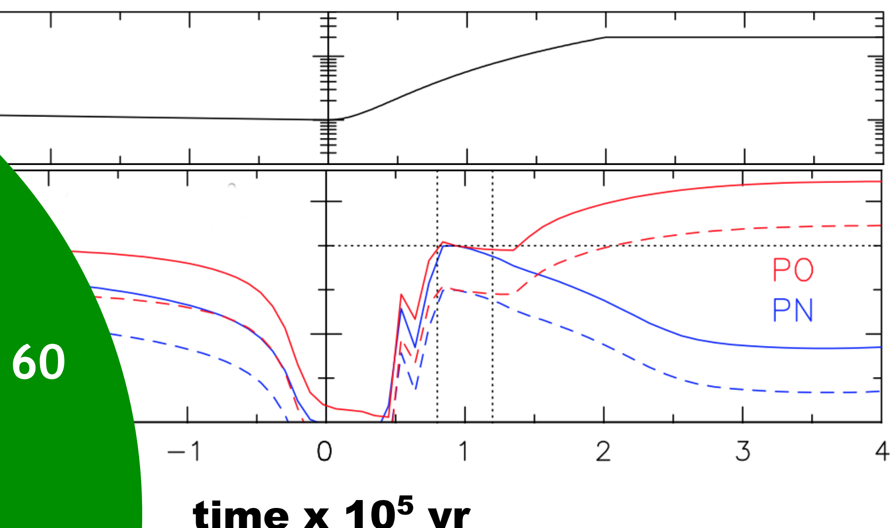
Cold starless phase



Warm-up protostellar phase





P initial abundance = 5×10^{-9}

depletion factor = $P_{cosmic} / P_{gas} \sim 60$

m in a
olecule
during

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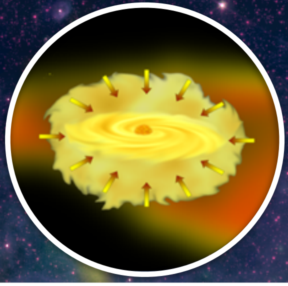

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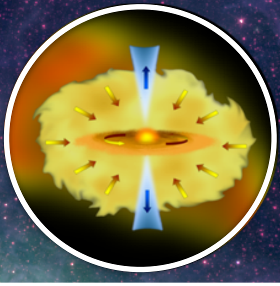

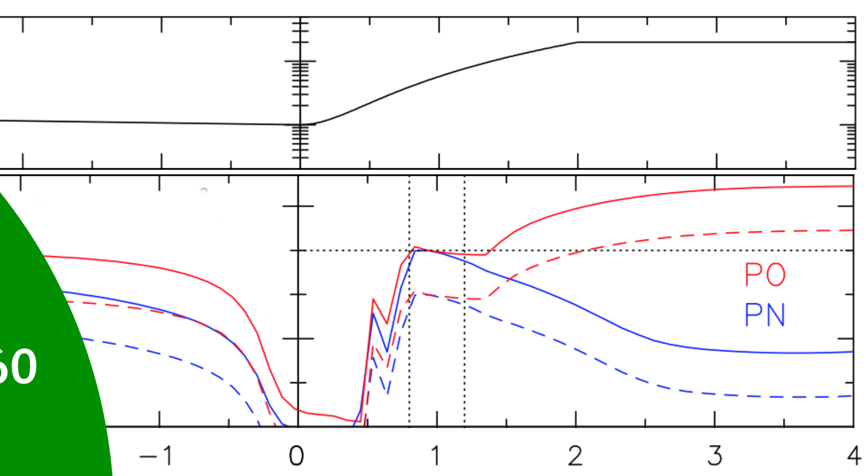

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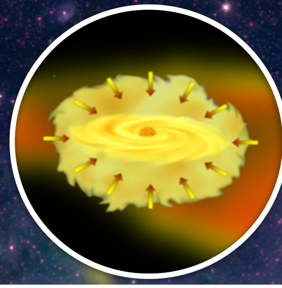

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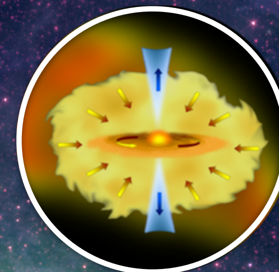

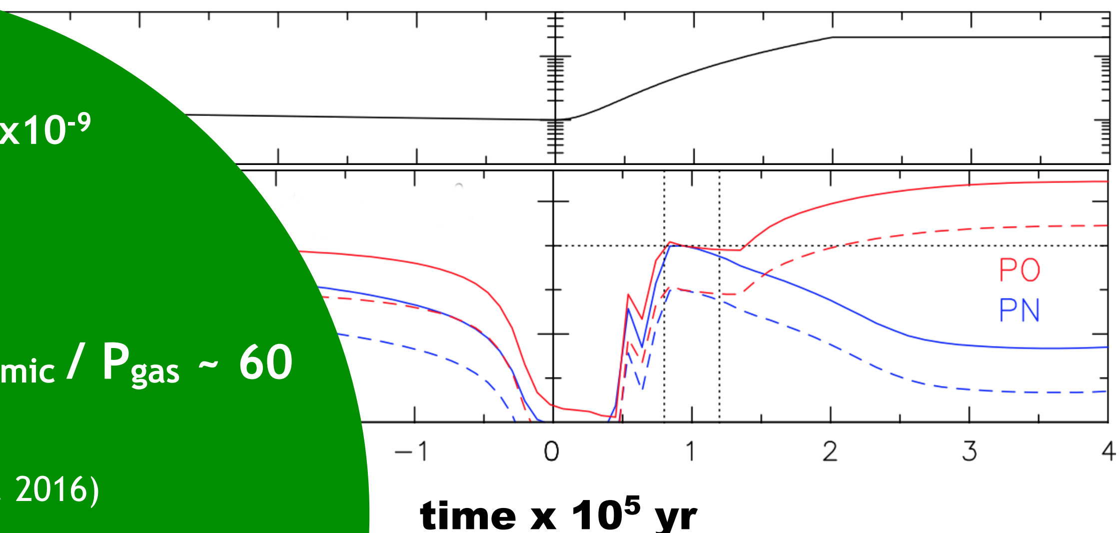

P initial abundance = 5×10^{-9}

depletion factor = P_{cosmic} / P_{gas} ~ 60

~100 (Lefloch et al. 2016)

Significantly lower than the value previously thought: **600-10^4**

(Turner et al. 1990, Wakelam & Herbst 2008)

m in a
olecule
during

- The heating from the protostar produces the **thermal desorption** of the P-bearing species.
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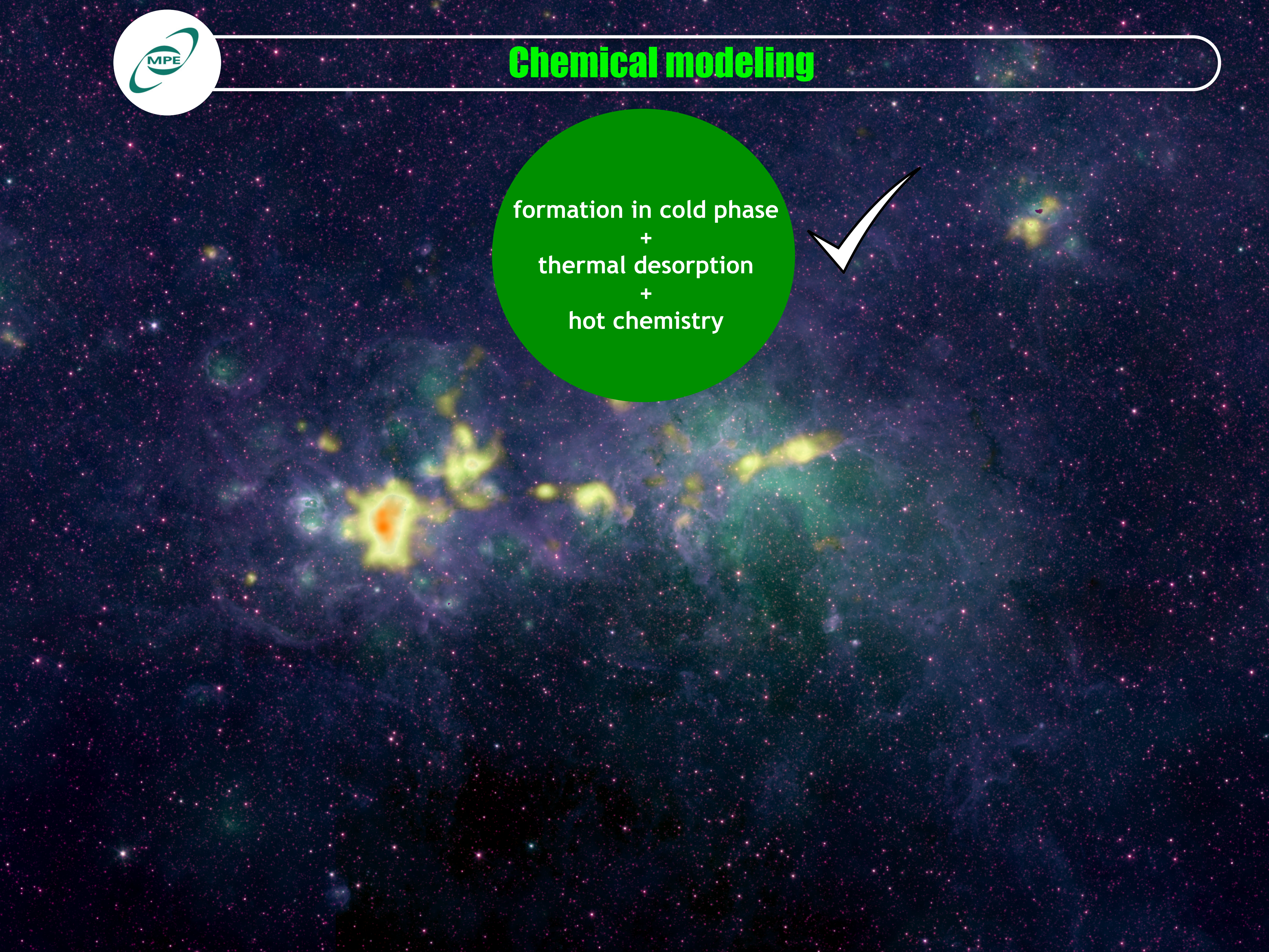
MPE
Chemical modeling
formation in cold phase
+
thermal desorption
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hot chemistry

Chemical modeling

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G5.89-0.39
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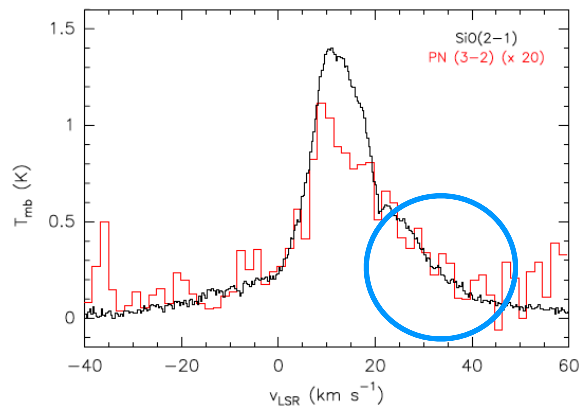

Mininni et al. (2018)

POSTER 14!

Chemical modeling

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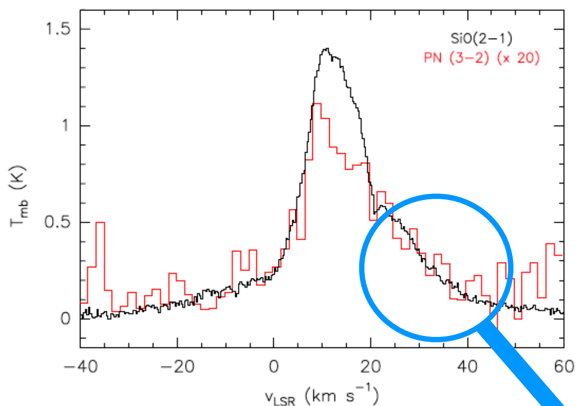
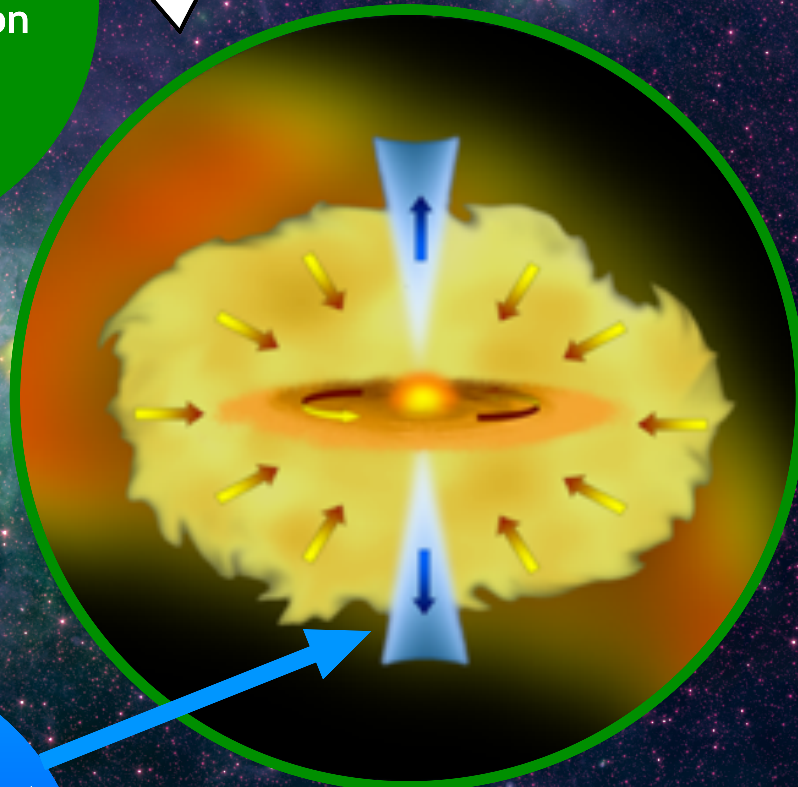


Mininni et al. (2018)

POSTER 14!

Shocked material at high velocities



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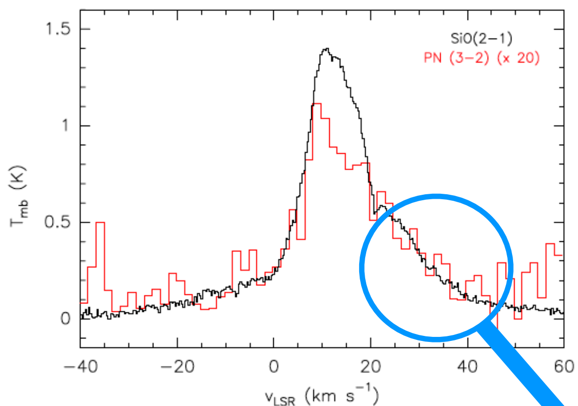
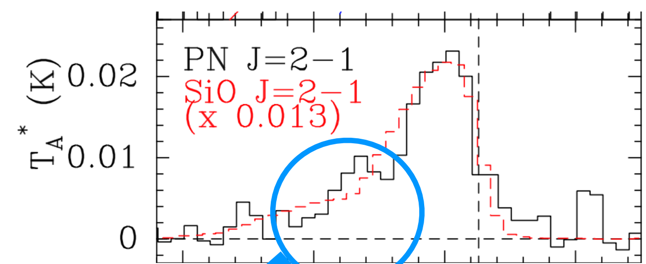


Mininni et al. (2018)

POSTER 14!

L1157-B1 shock



Lefloch et al. (2016)

Talk tomorrow

Shocked material at high velocities

Chemical modeling

formation in cold phase
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+
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G5.89-0.39
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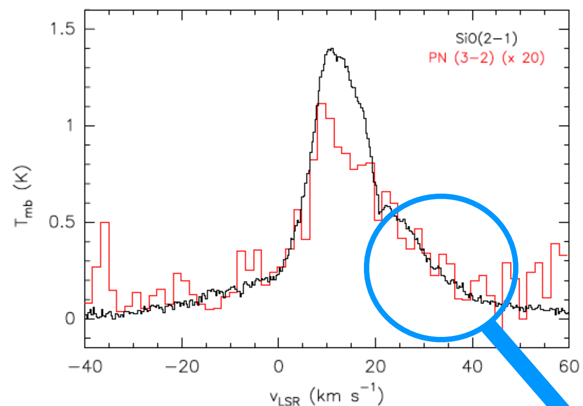

Mininni et al. (2018)

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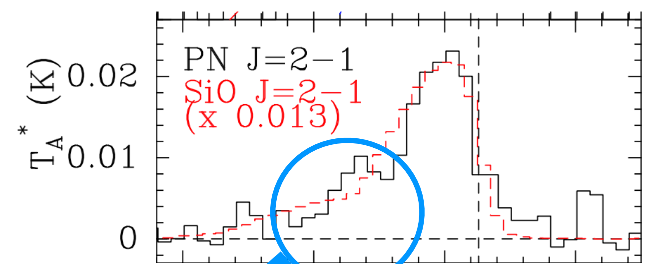


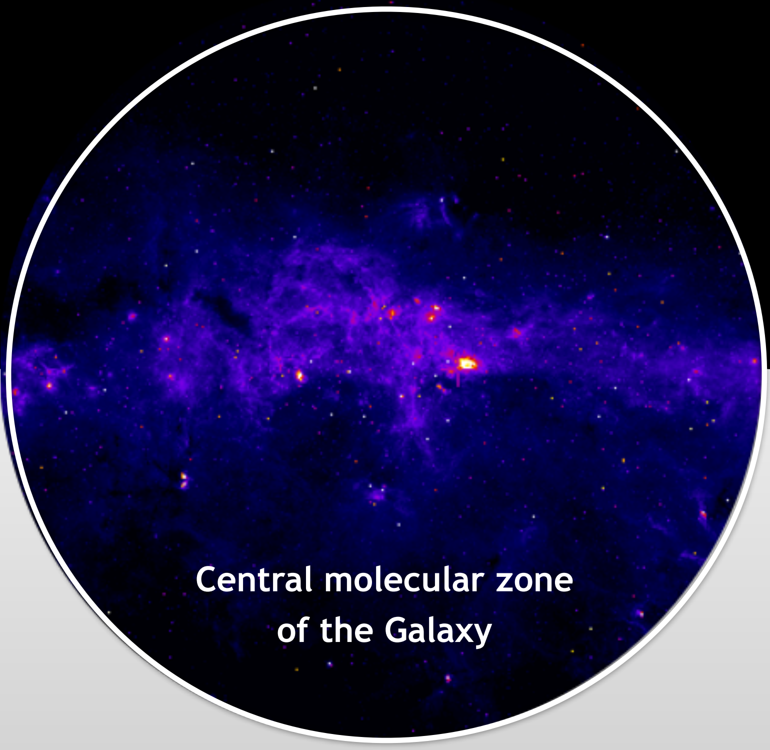
Lefloch et al. (2018)

Talk tomorrow

Shocked material at high velocities

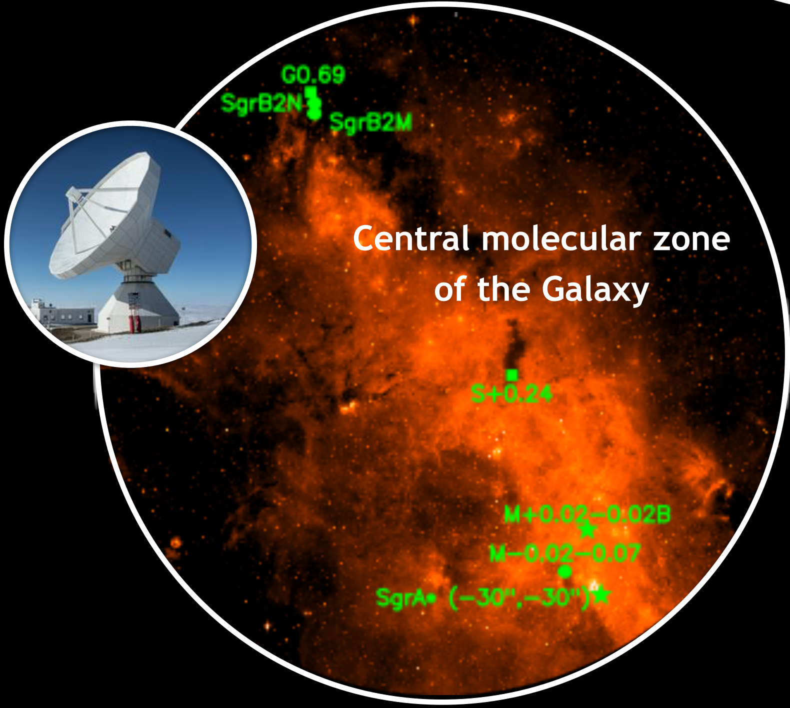
?

Galactic Center



- Dust grain sputtering by widespread large-scale low-velocity shocks.

Galactic Center



THE SAMPLE

Shock-dominated regions

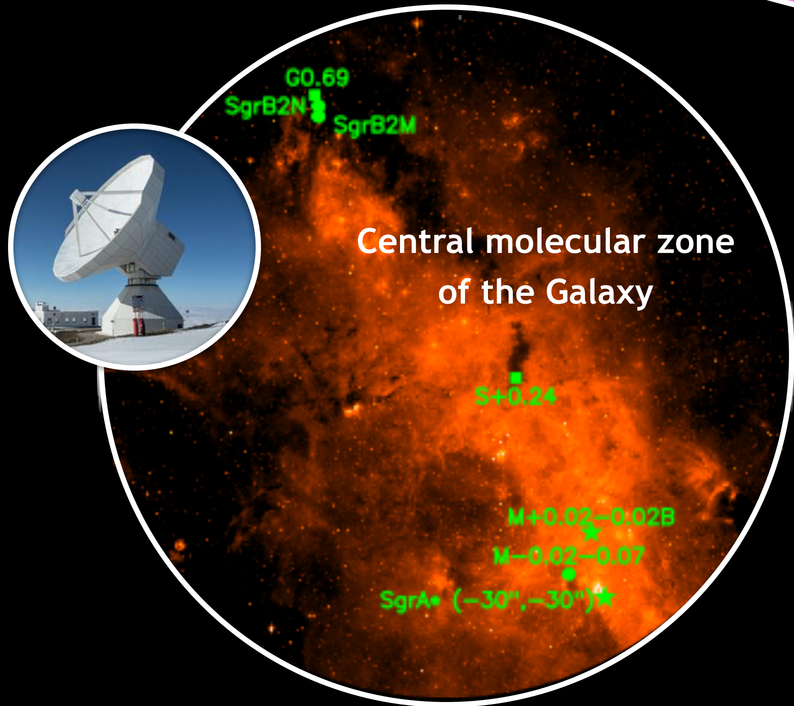
COMs-rich

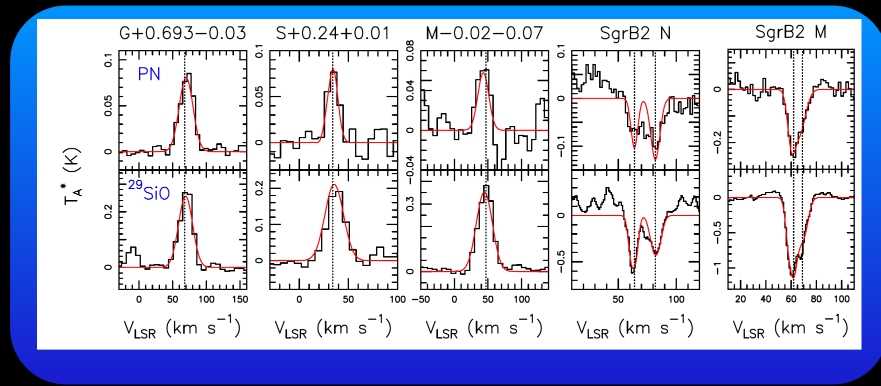
Radiation-dominated regions

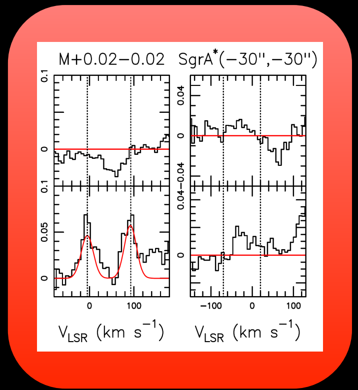
Cosmic rays
X-rays
UV

Rivilla et al. (2018)

Galactic Center







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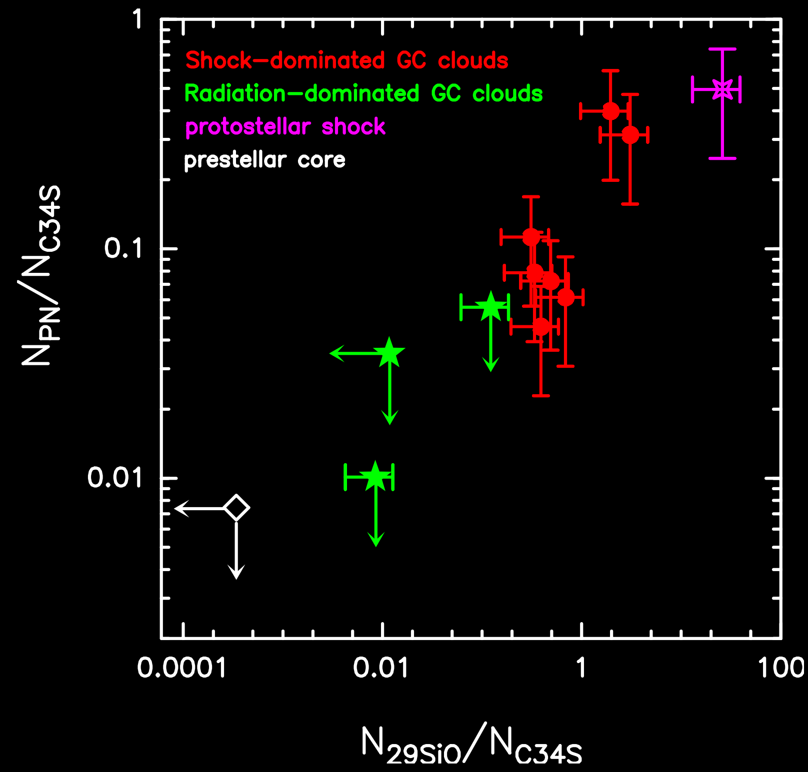
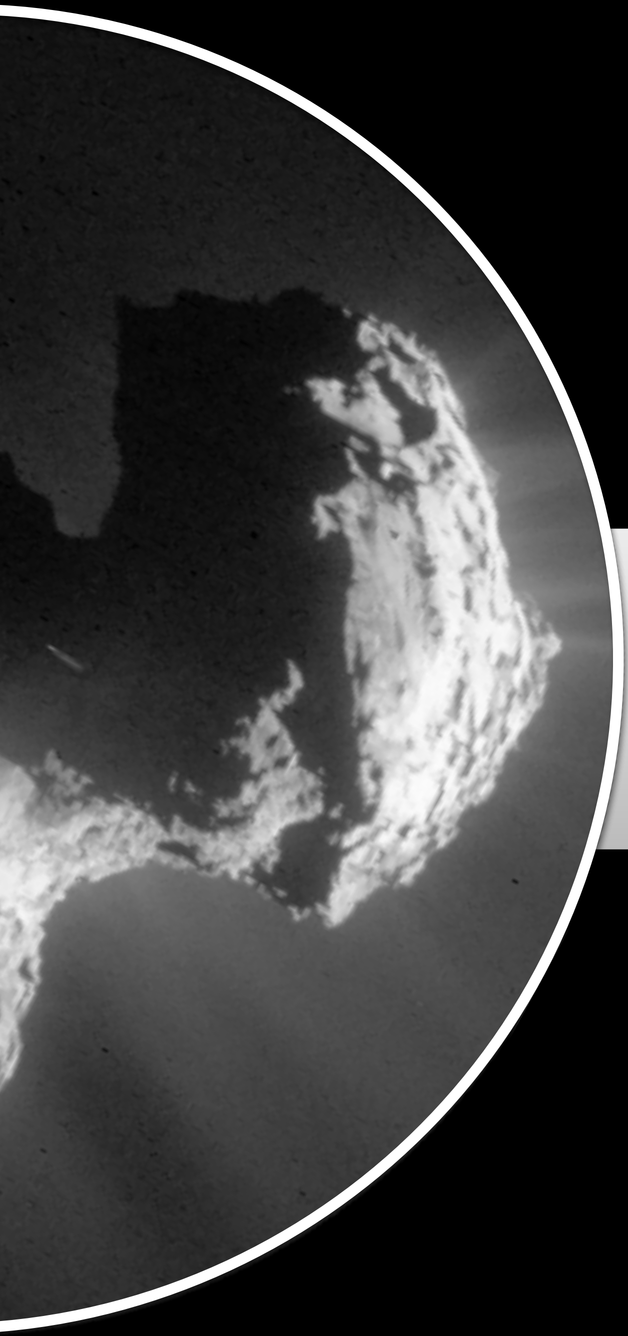


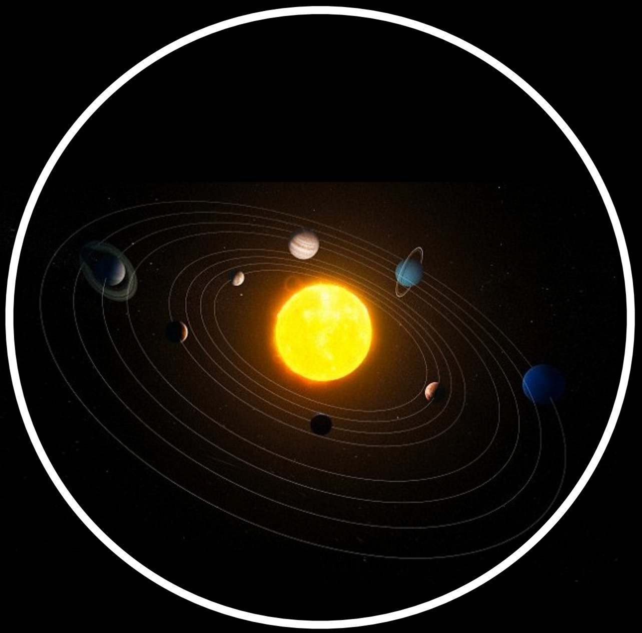
Rivilla et al. (2018)



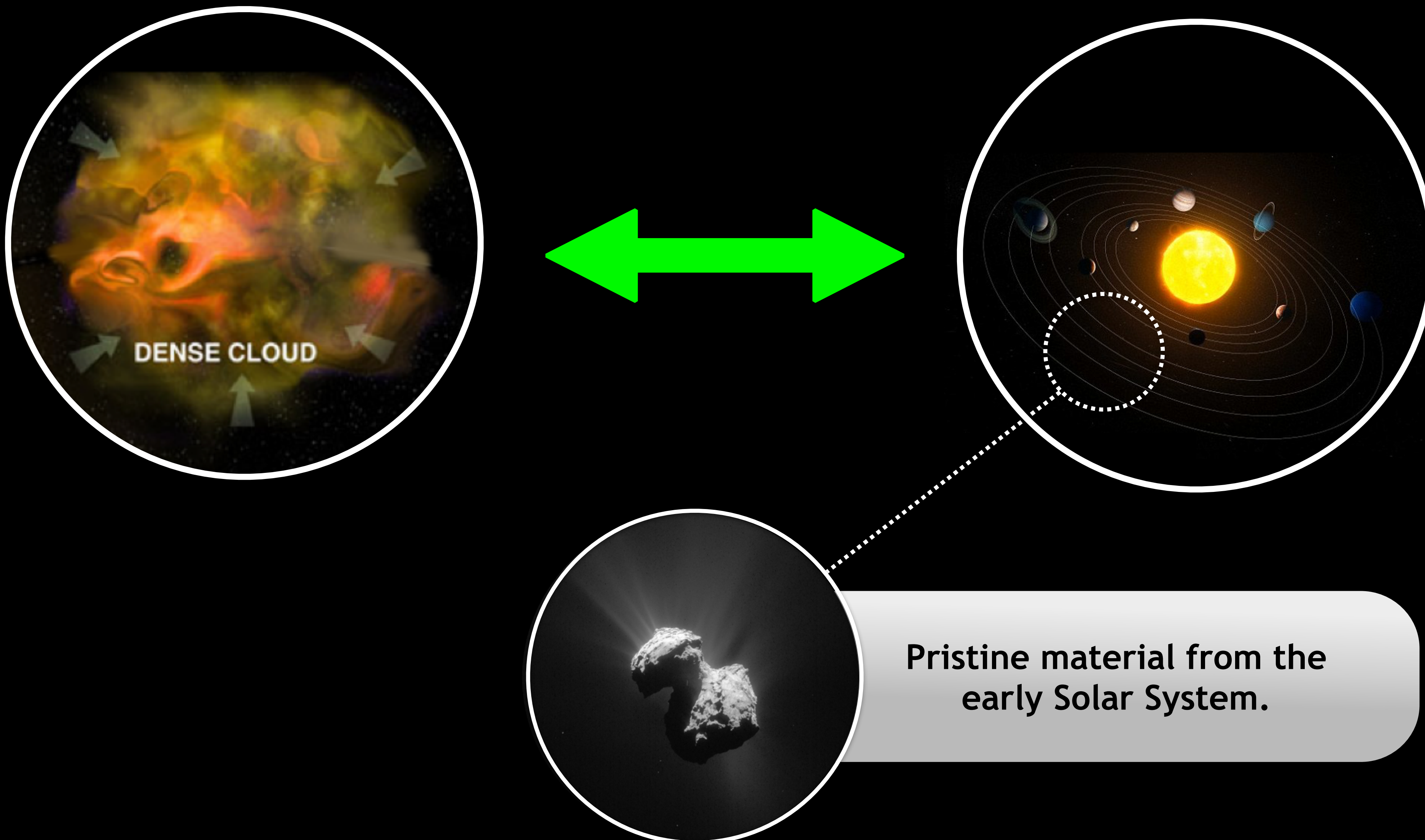
Phosphorus in the 67P Churyumov-Gerasimenko comet

Collaboration with Maria Drozdozvskaya, Kathrin Altwegg, and the ROSINA team

The Phosphorus connection between protostars and comets



The Phosphorus connection between protostars and comets



67P Churyumov-Gerasimenko comet

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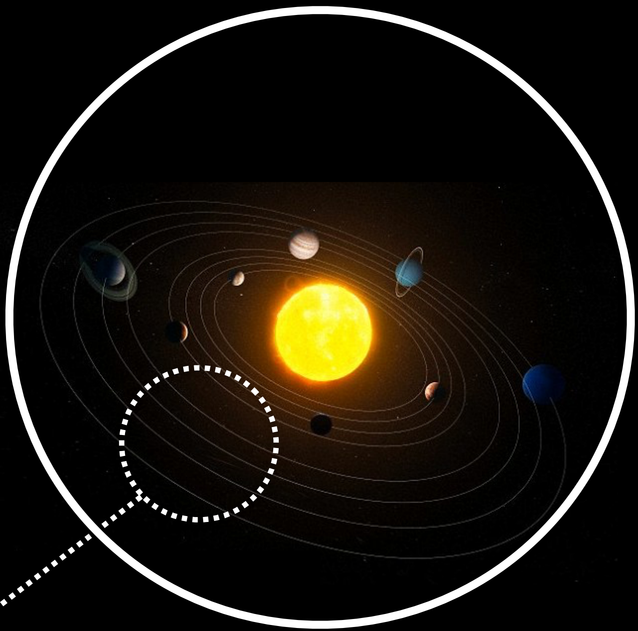
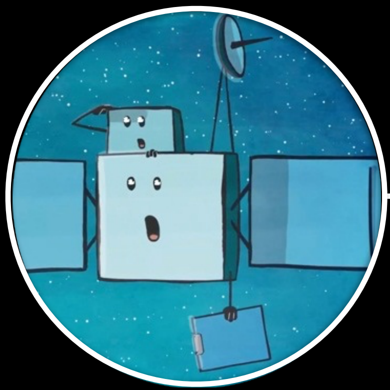
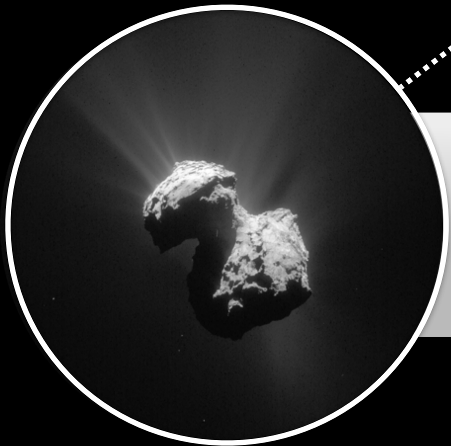


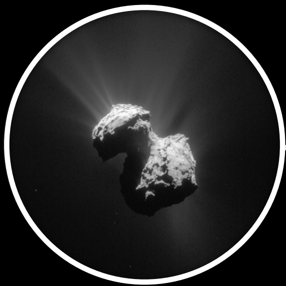


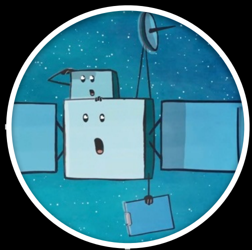


Pristine material from the early Solar System.

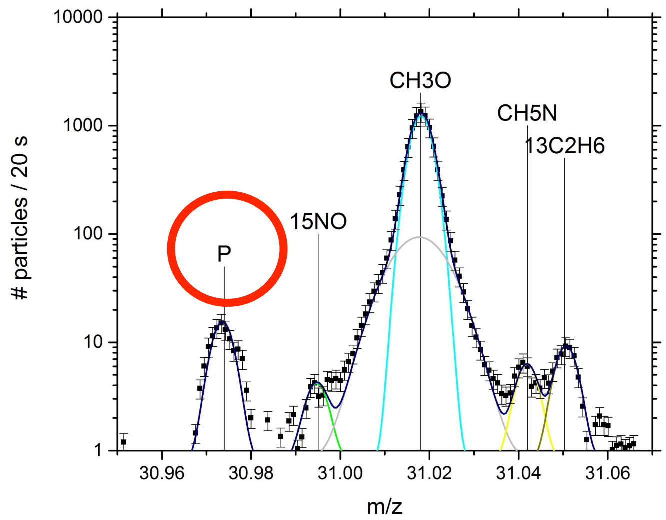
67P Churyumov-Gerasimenko comet

Phosphorus in 67 P



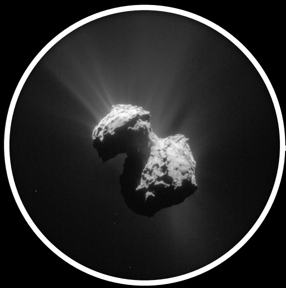


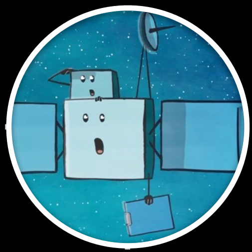
Altwegg et al. (2016)



Clear mass peak at the location of P (30.9737 Da)

Phosphorus in 67 P





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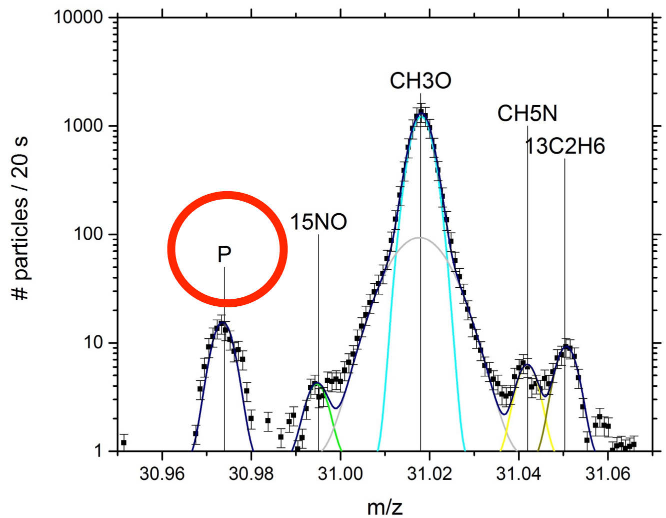

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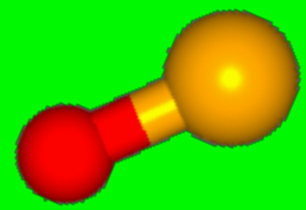
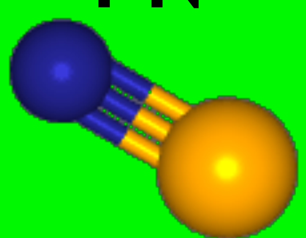
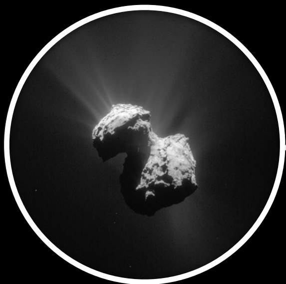
PO

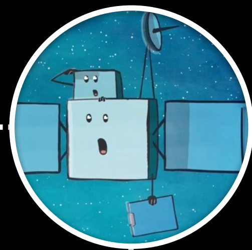


PN



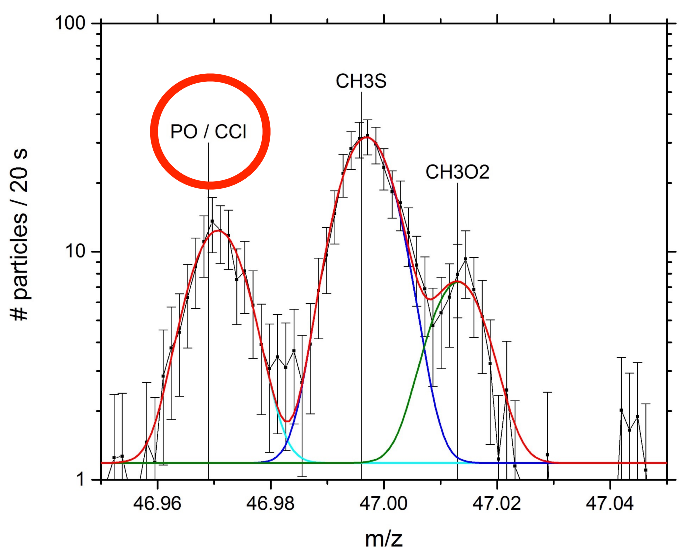
?



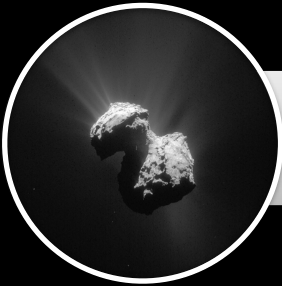


Phosphorus in 67 P

Rivilla et al. (in prep.)



- Clear mass peak at the location of PO (mass 46.9681 Da).
- Possible contamination from CCl (same mass).

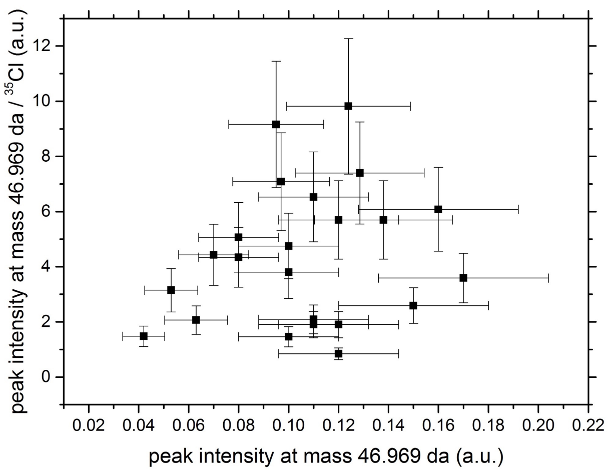


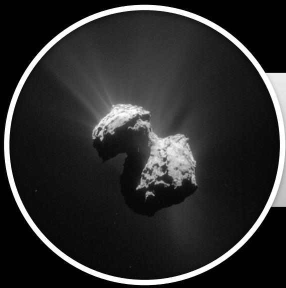
Correlation between the peak at 46.969 and the P peak (mass 31) and ^{35}Cl (mass 35)

Rivilla et al. (in prep.)

CCl?

No Correlation with ^{35}Cl peak





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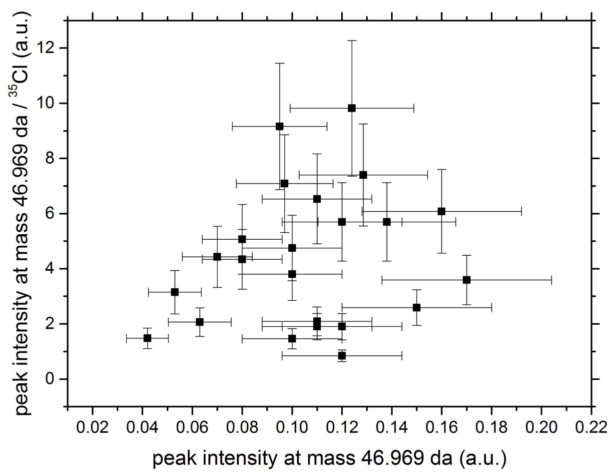
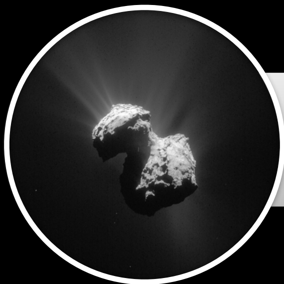


CH_3Cl (possible precursor of CCl) not detected at that measurement period



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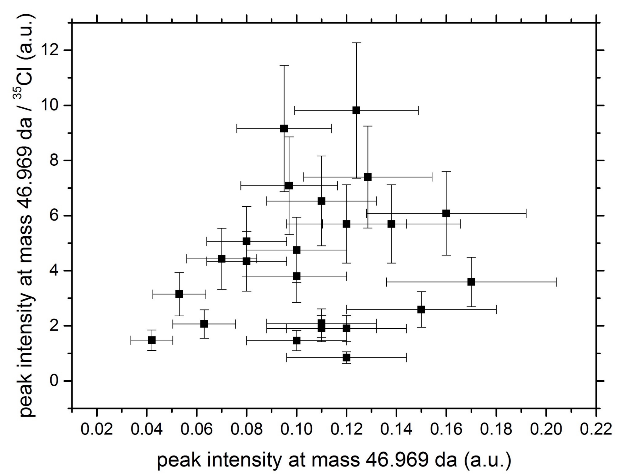

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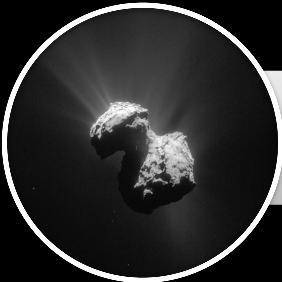

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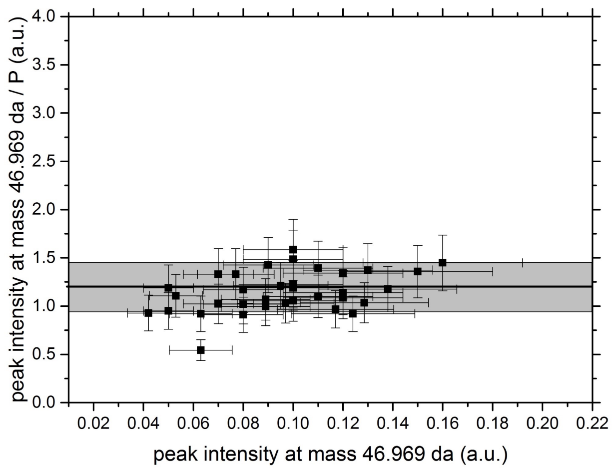
Rivilla et al. (in prep.)

PO?

Correlation with P peak



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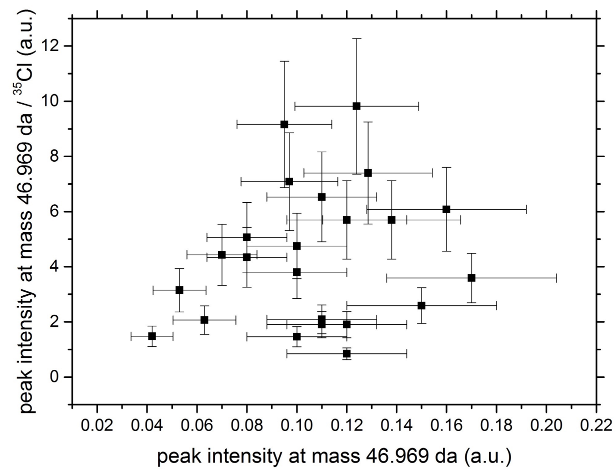

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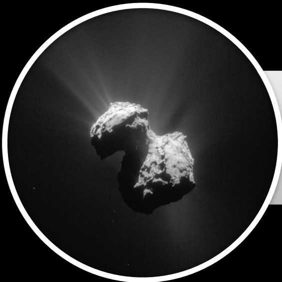

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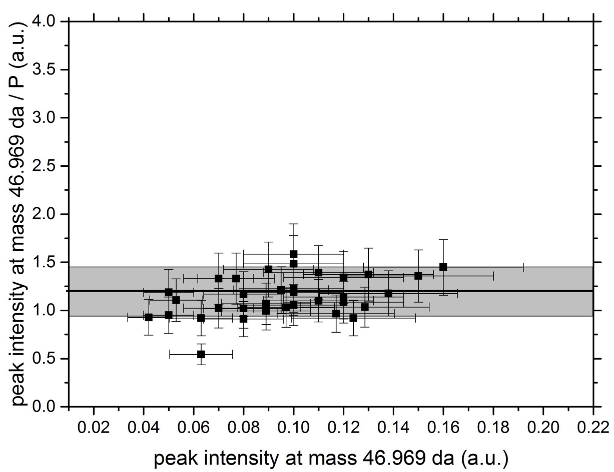

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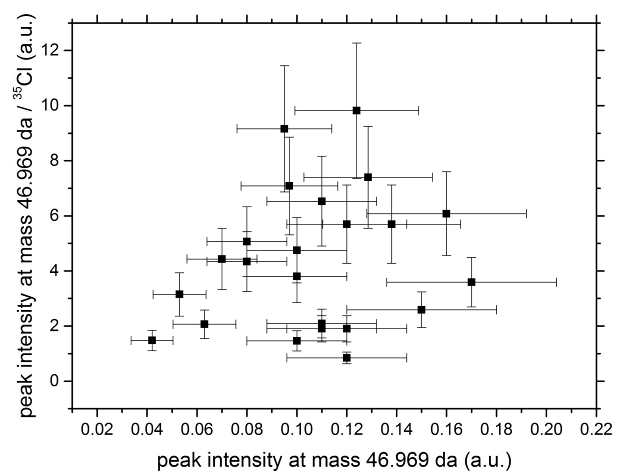

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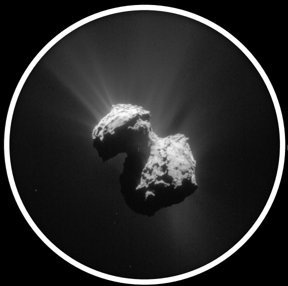
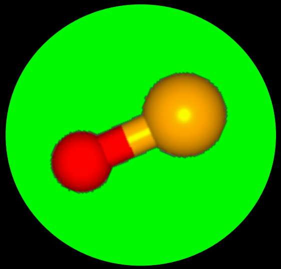
Phosphorus in 67 P





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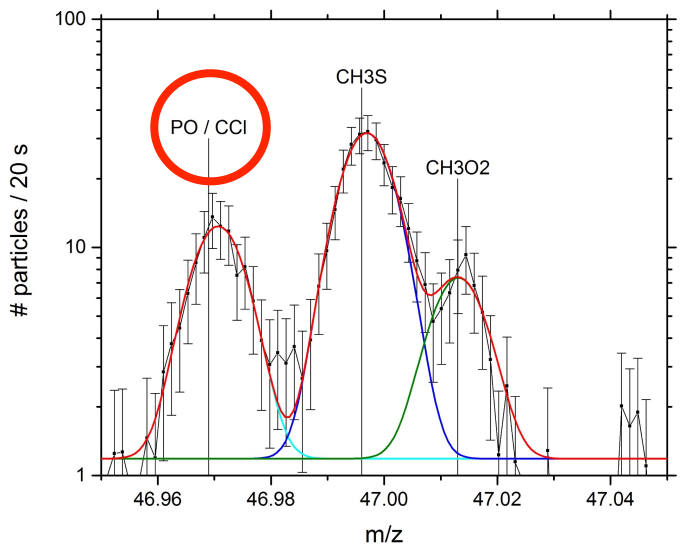
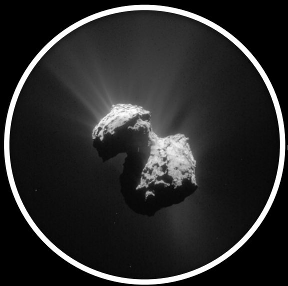
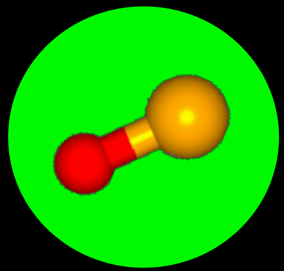


PO is present in the comet.

Phosphorus in 67 P





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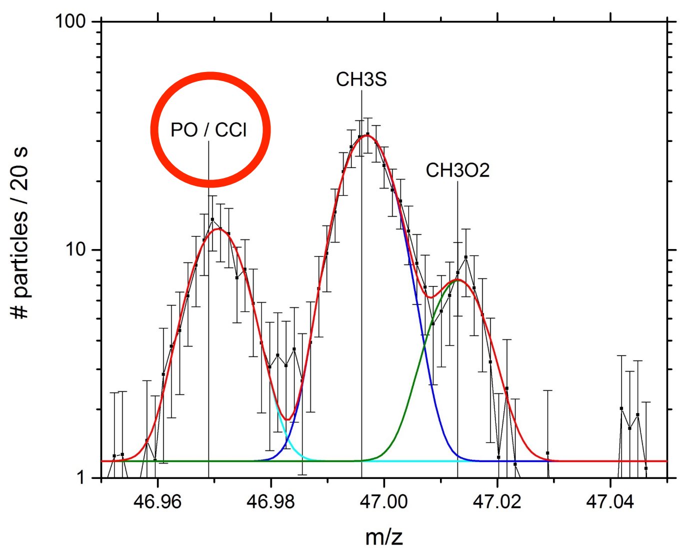
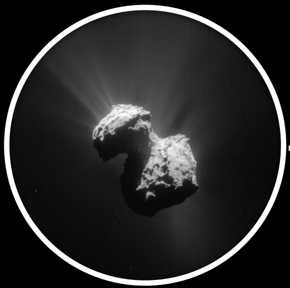
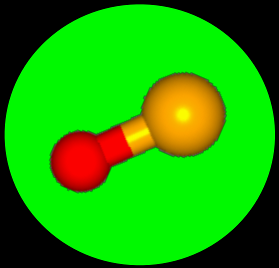


PO is present in the comet.

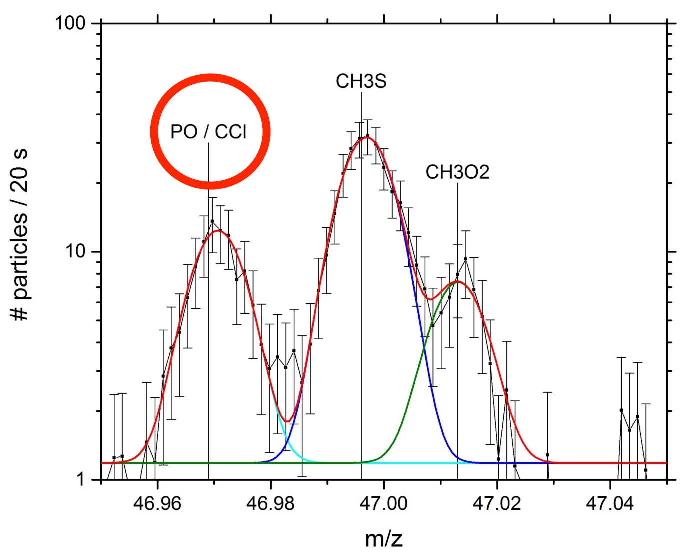
- Upper limits for PN, PH_3 and CP.

Phosphorus in 67 P





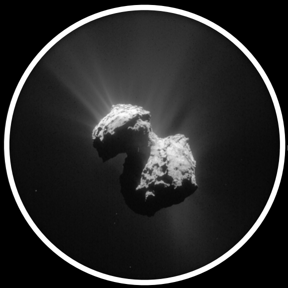
Rivilla et al. (in prep.)

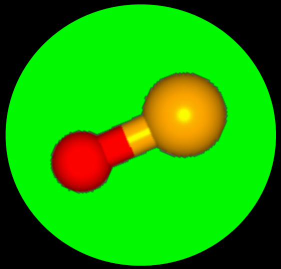


PO is present in the comet.

- Upper limits for PN, PH_3 and CP.

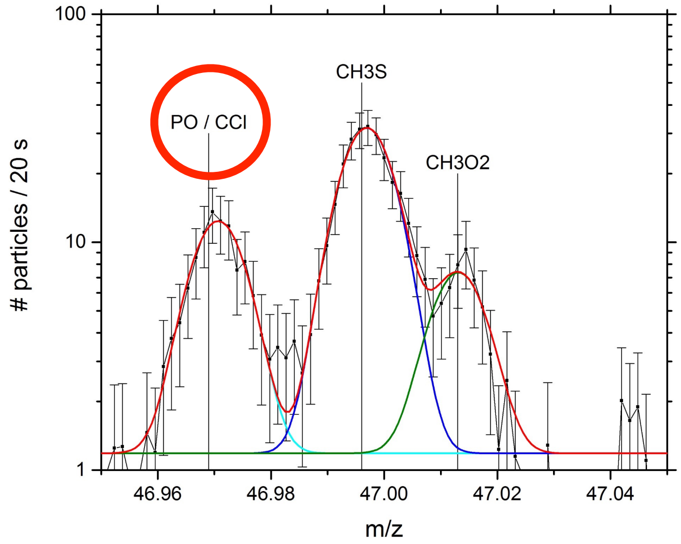
[PO/PN]>10





Phosphorus in 67 P

Rivilla et al. (in prep.)



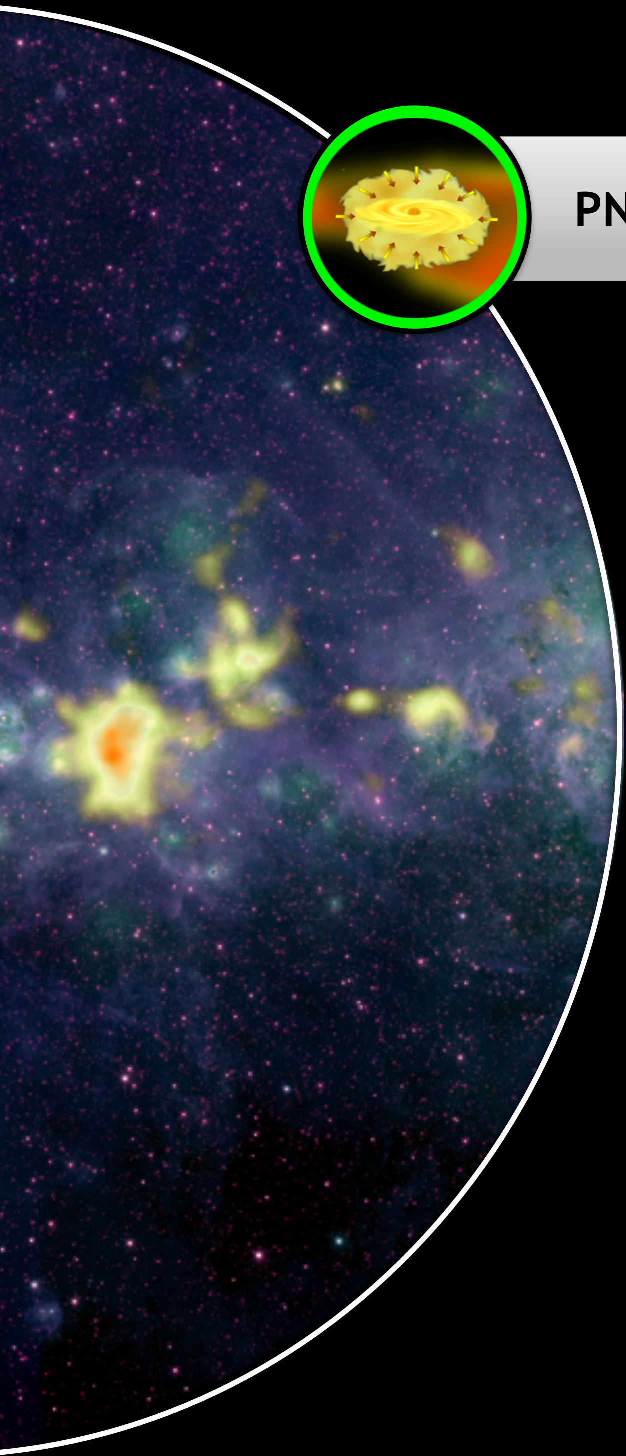
PO is present in the comet.

- Upper limits for PN, PH_3 and CP.

[PO/PN]>10

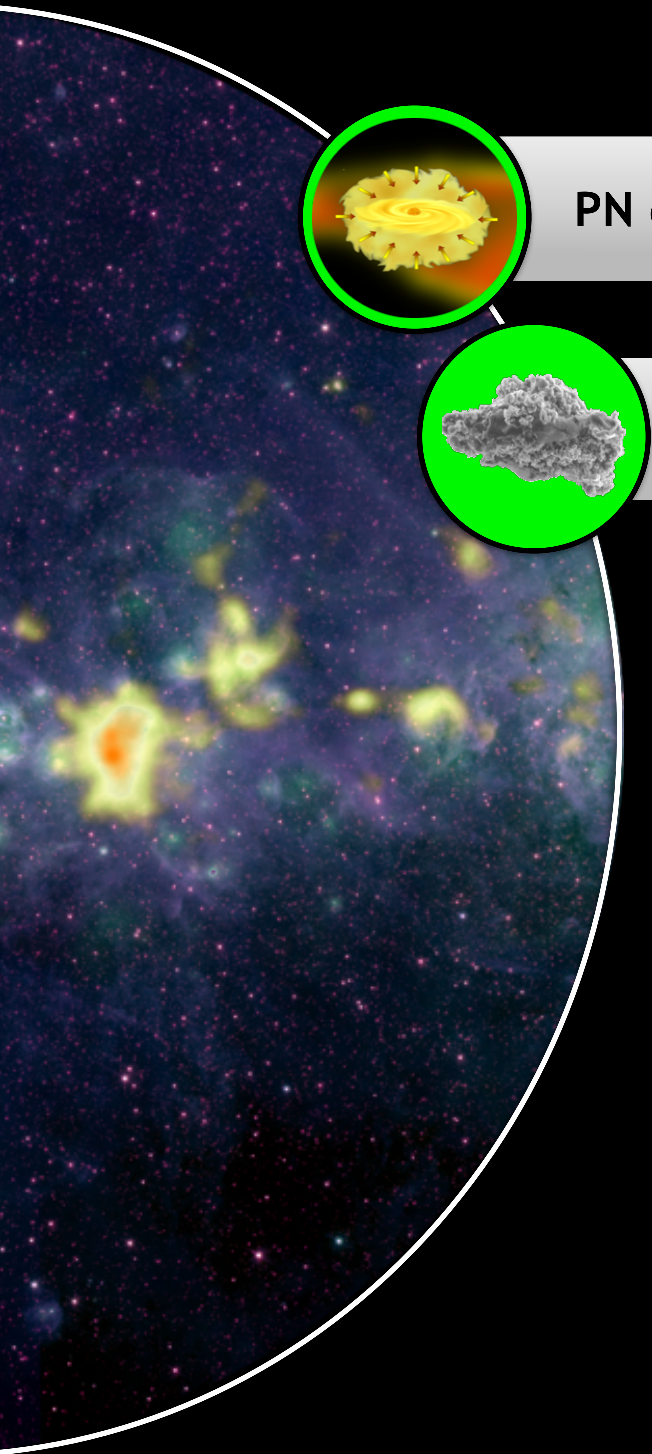
PO is more abundant than PN both in star-forming regions and the comet.

Conclusions



PN detected in a sample of massive dense star-forming cores

Conclusions



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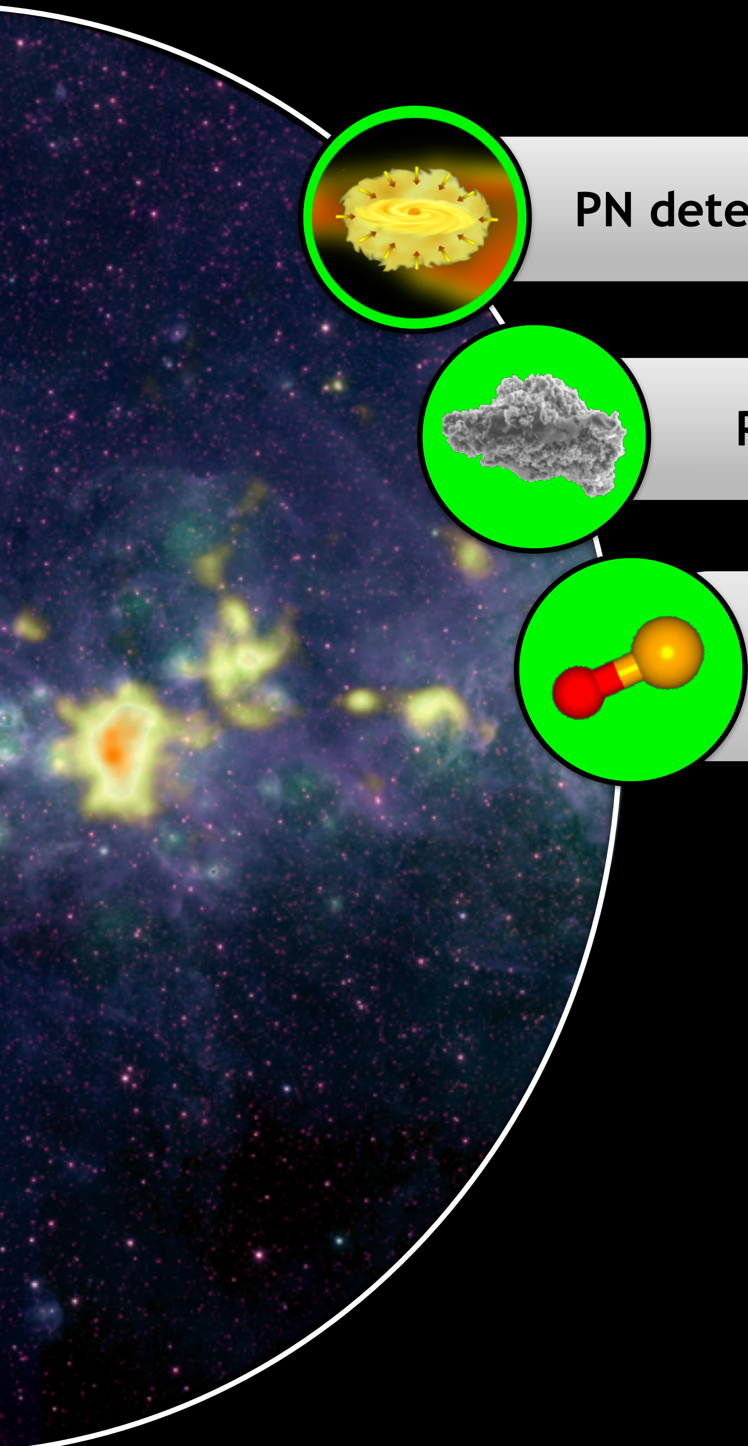
P is less depleted in SF regions than previously thought.

Conclusions



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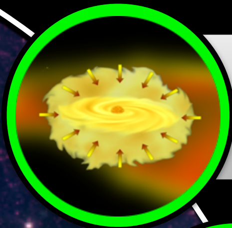
PO detected for the first time in 3 star-forming regions and in a quiescent cloud in the Galactic Center.

Conclusions



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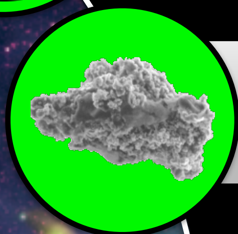

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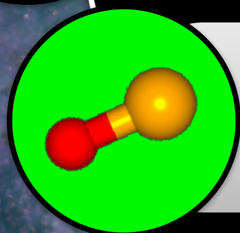

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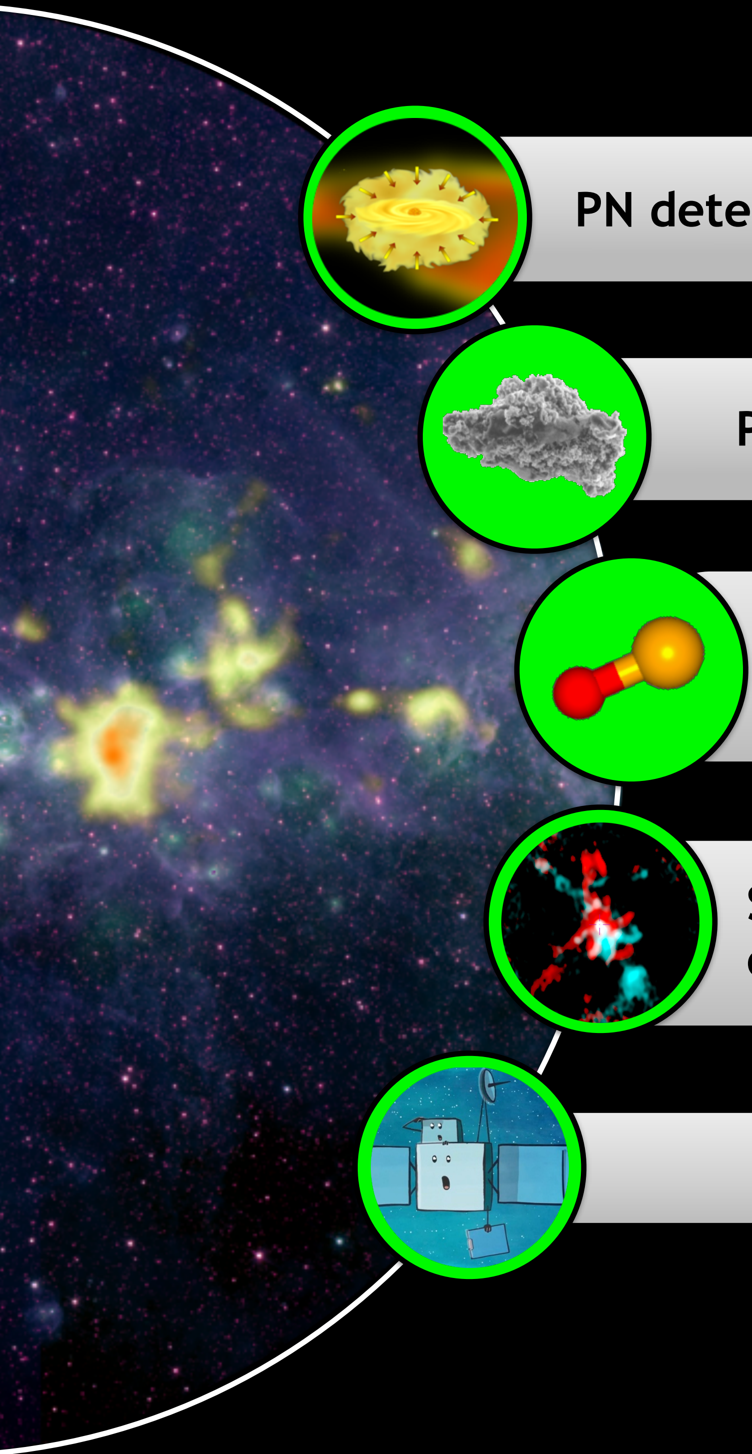
Several observations point towards a shocked origin of P-bearing molecules.

Conclusions



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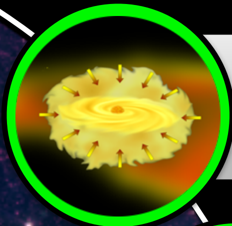
Confirmation of PO in the comet 67-P.

Conclusions



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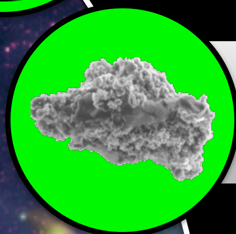

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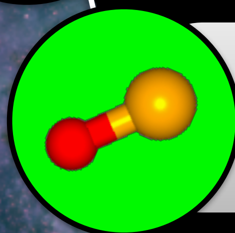

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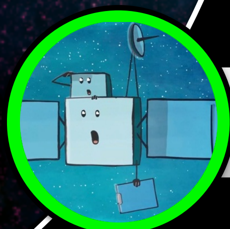
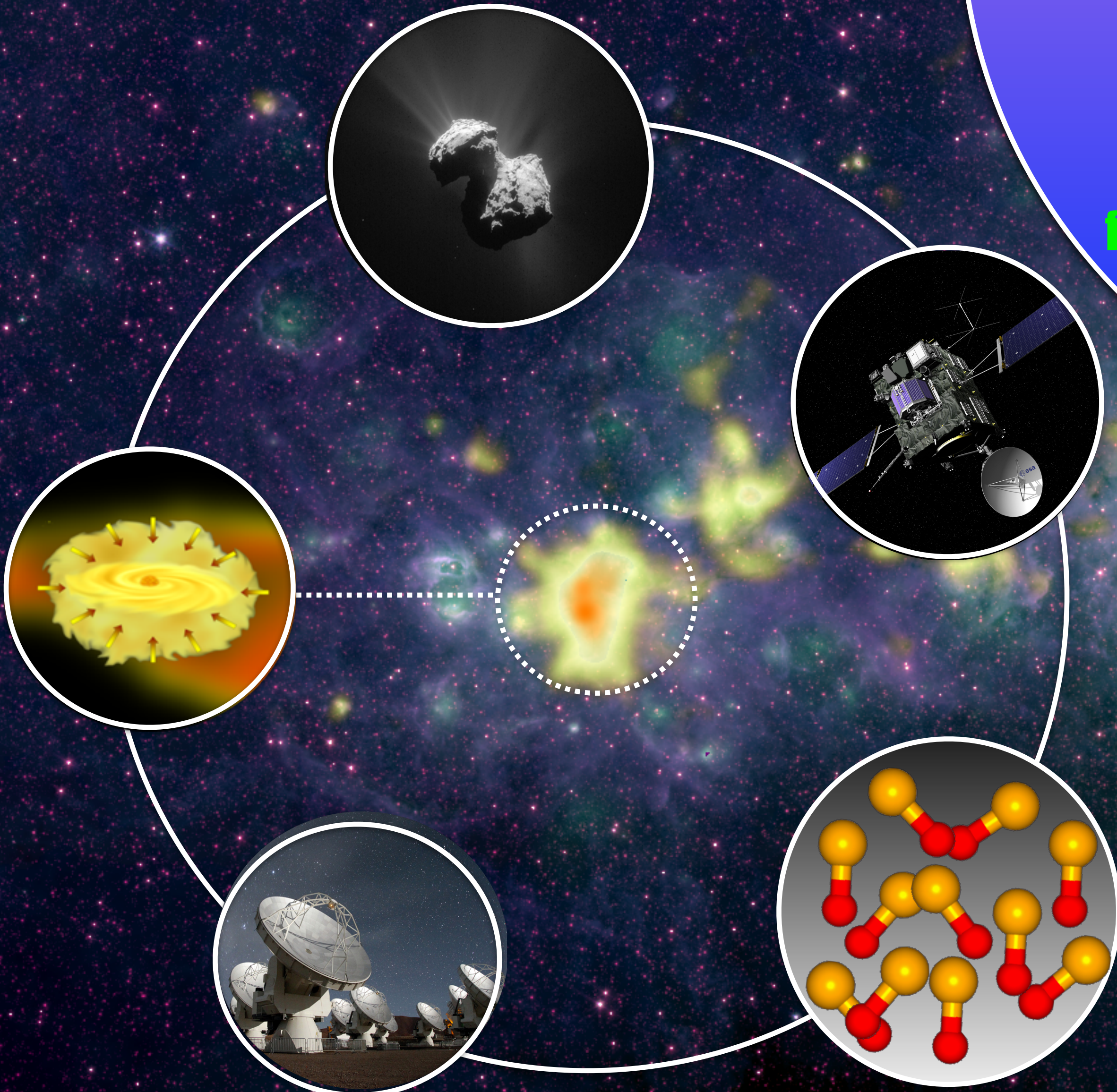


Confirmation of PO in the comet 67-P.

Chemical connection between SF regions and comet:
PO is always more abundant than PN.

Phosphorus:

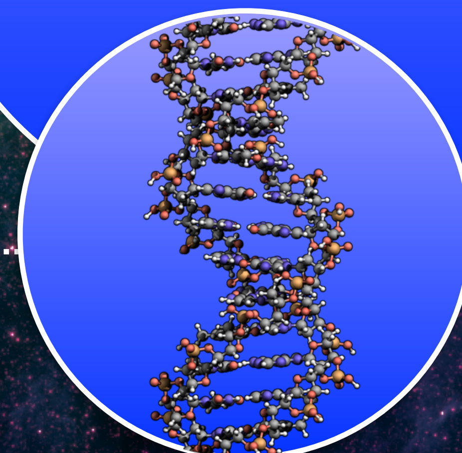
the missing prebiotic element... found in star-forming regions and comets



Víctor M. Rivilla

Marie Skłodowska-Curie Fellow

Osservatorio Astrofisico di Arcetri



F. Fontani, M. Beltrán, P. Caselli, A. Vasyunin, C. Mininni, J. Martín-Pintado, I. Jiménez-Serra, R. Cesaroni, M. Drozdovskaya, K. Altwegg and the ROSINA team...and more

Prebiotic molecules in Space and Origins of Life on Earth
Bad Honnef, March 19-23 2018