Laboratory simulations of cosmic-ray processing of N_2-containing ices at dark cloud conditions

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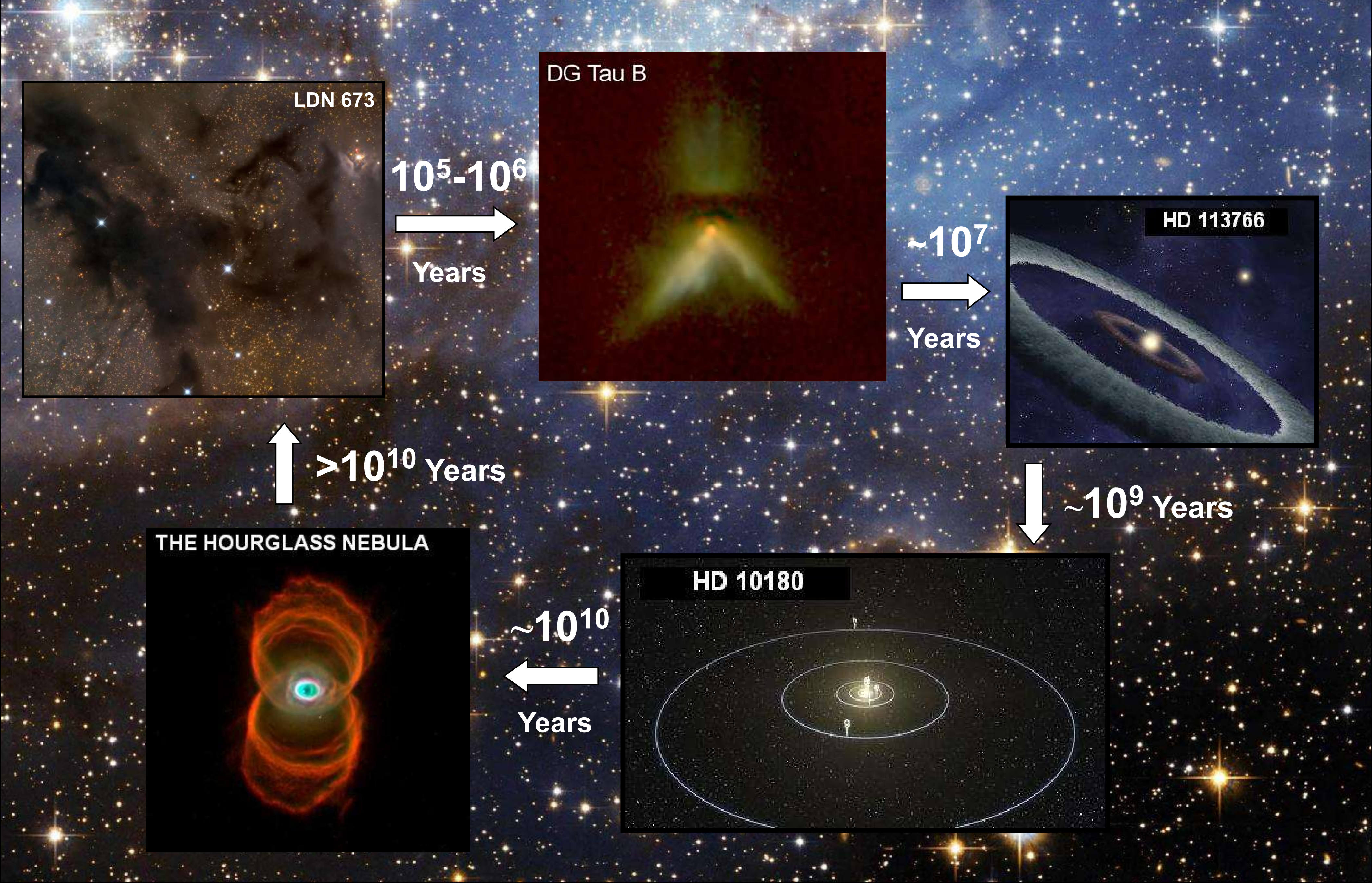
Outline

- Introduction and Research Project Goals
- Analysis and Methods
- Results and Discussion
  - Examples of the acquired IR spectra
  - Examples of the obtained kinetic curves
  - HNCO, OCN^- and HCN formation yields
- Conclusions and Outlooks

Molecular forges of the Interstellar Medium

Different Stages of Star Formation



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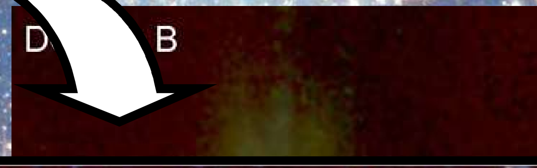
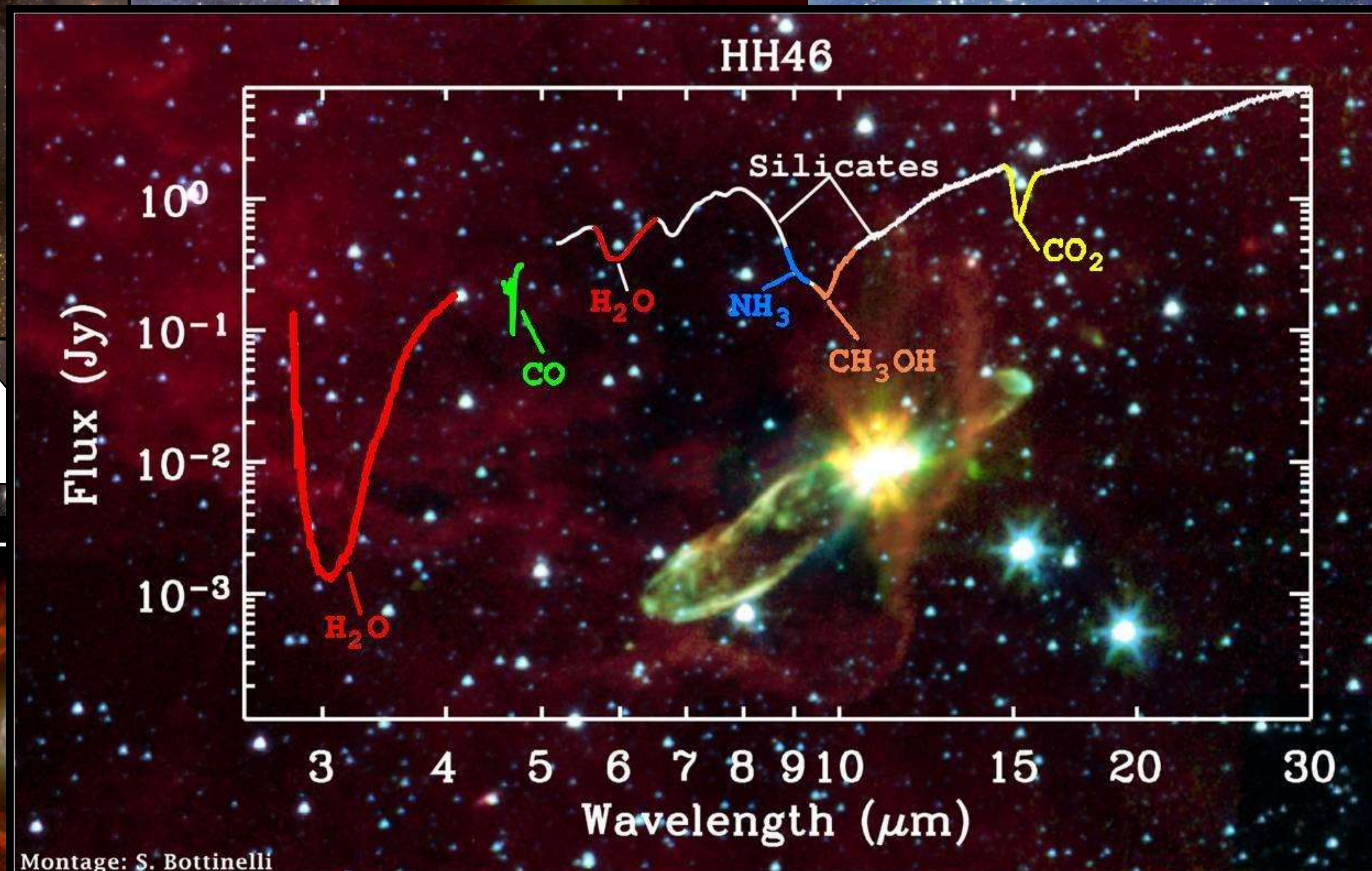
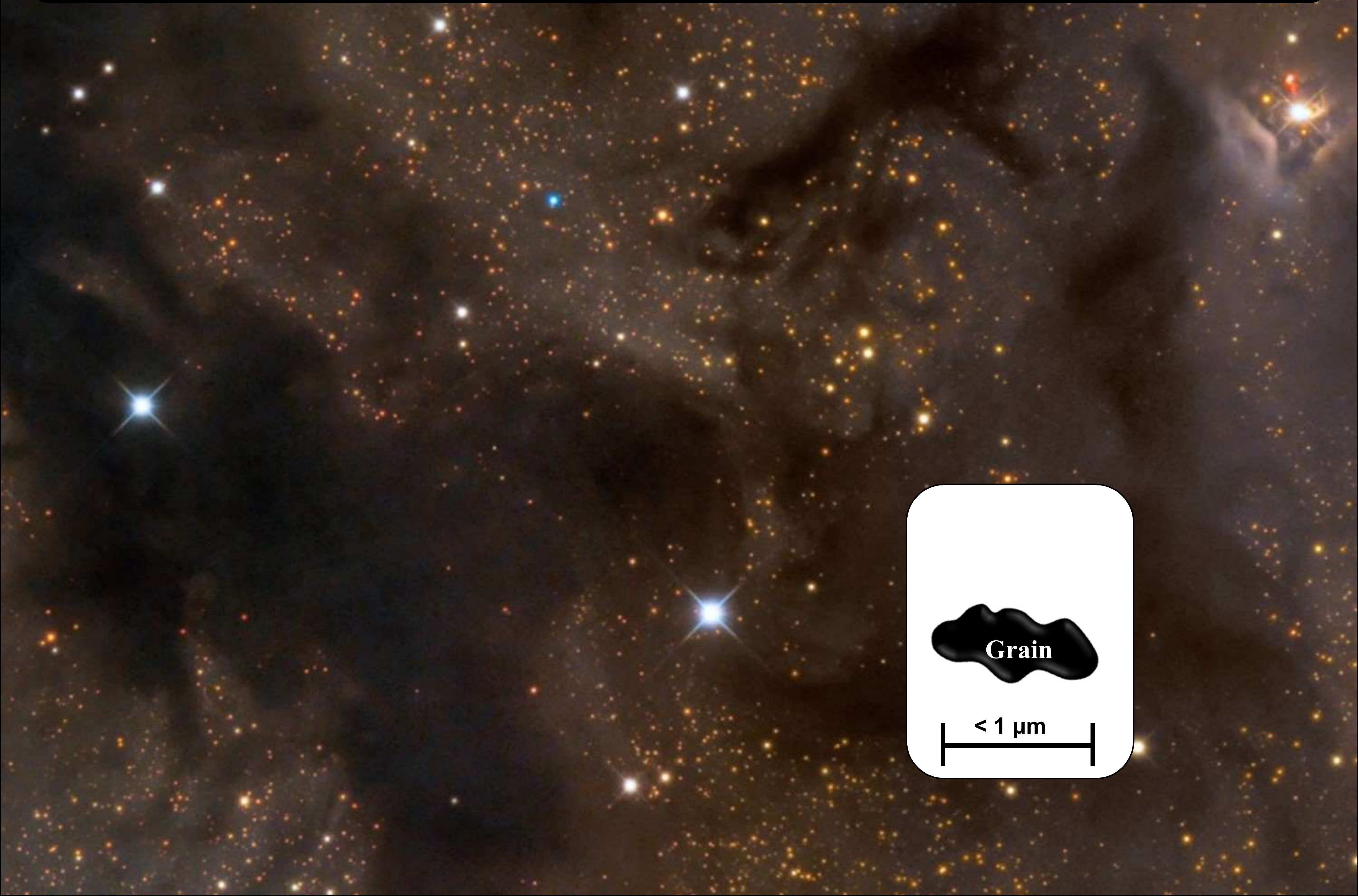




Chemistry on the Surface of Interstellar Grains



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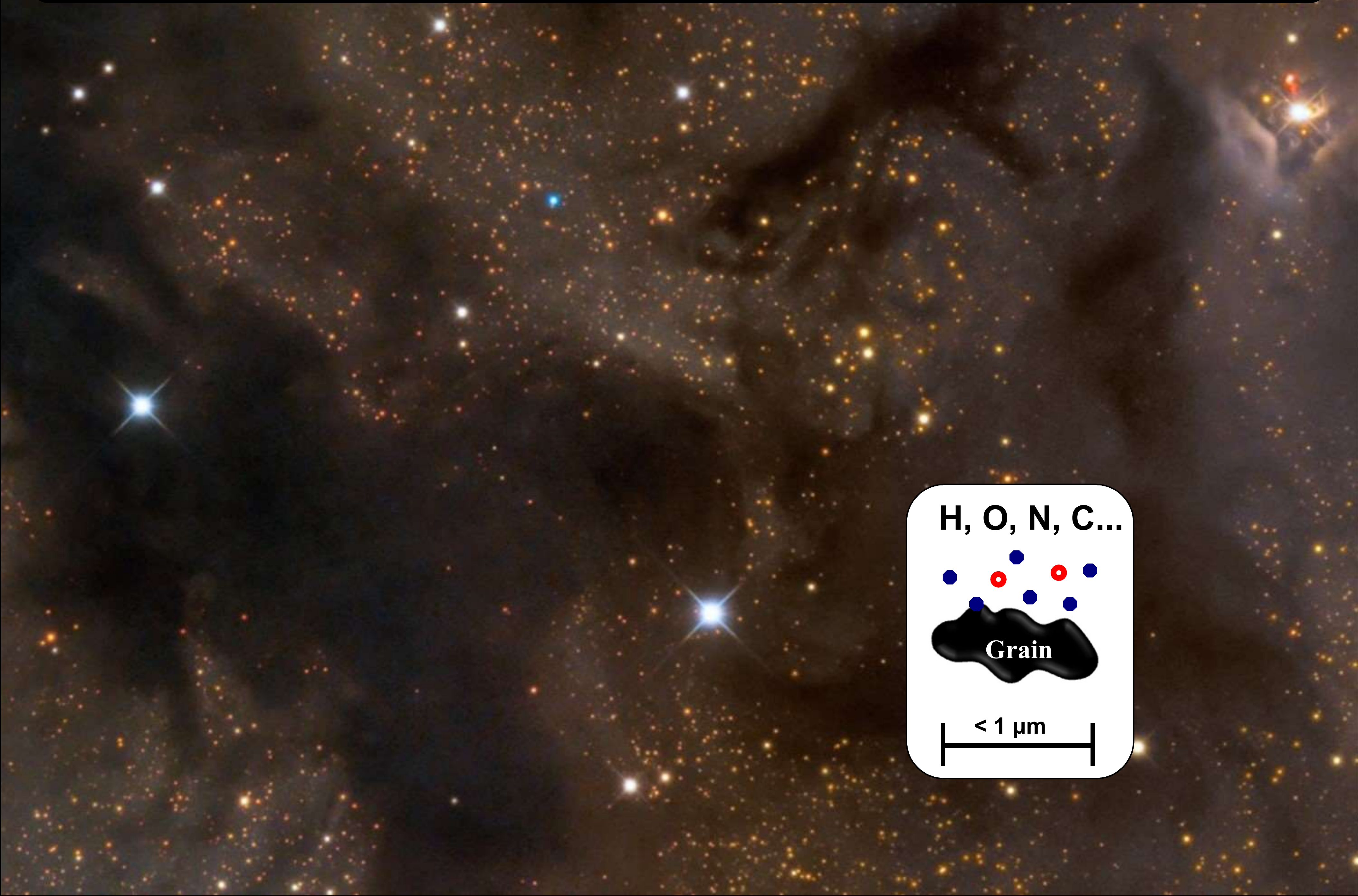

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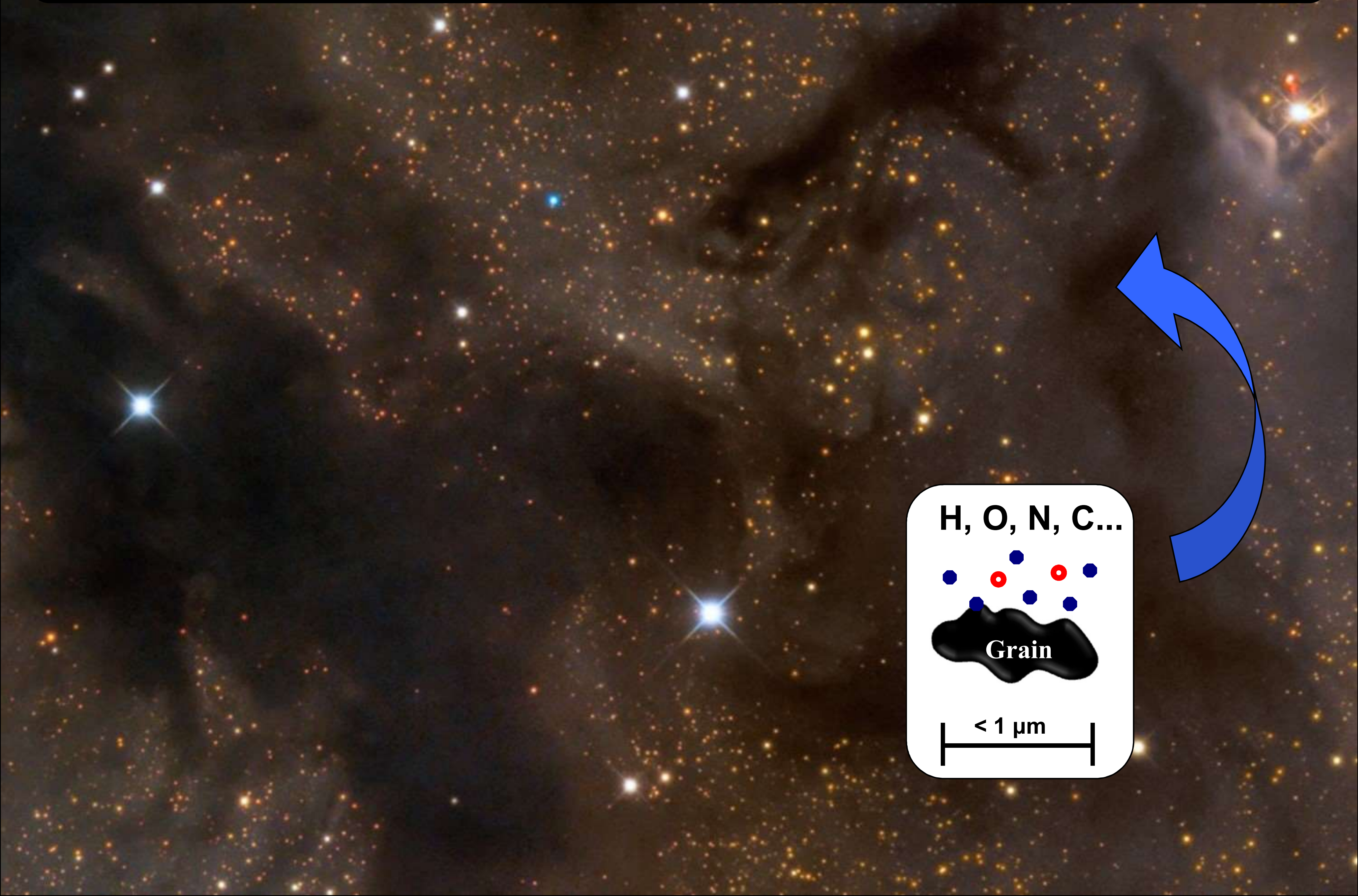

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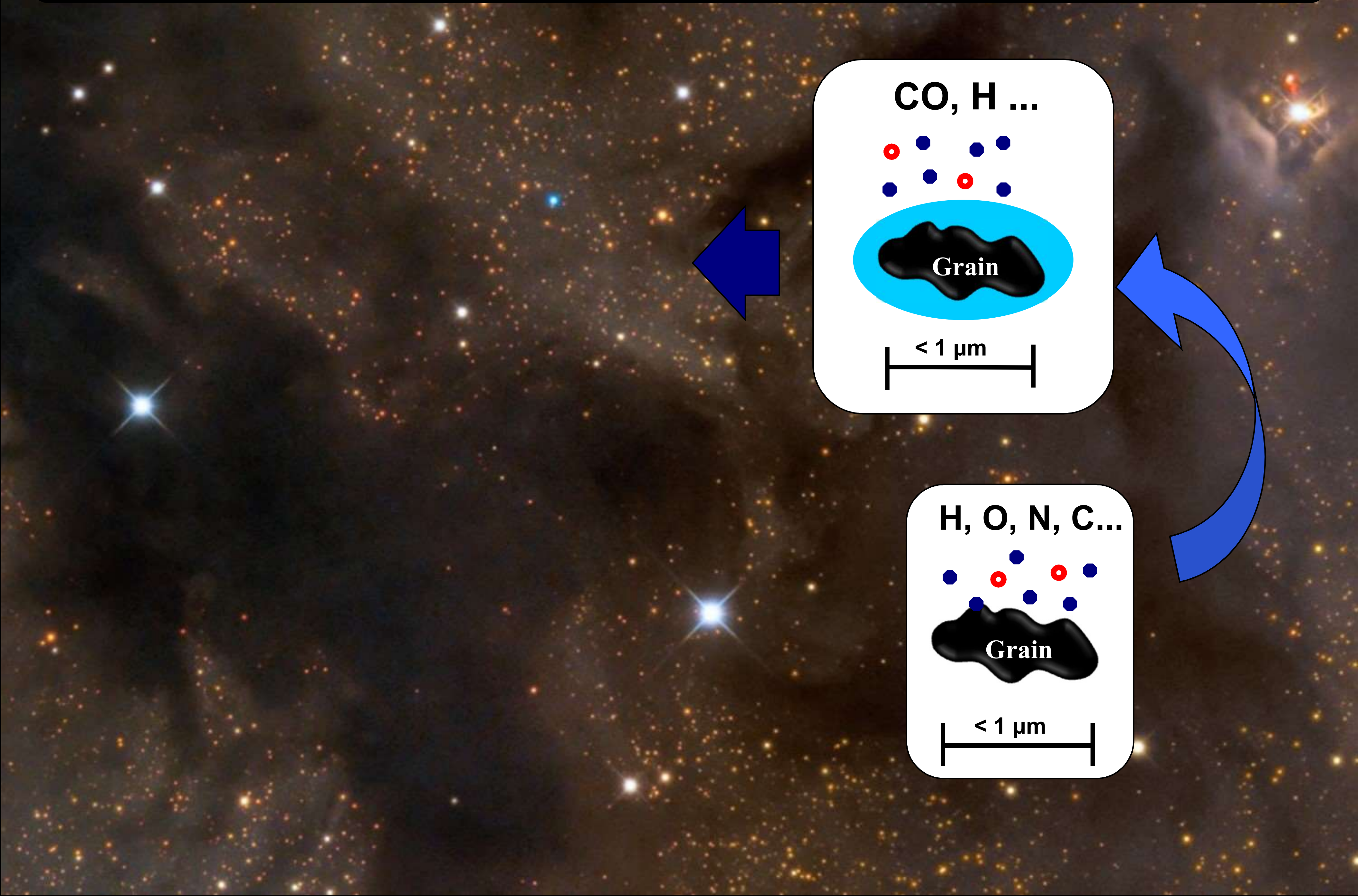

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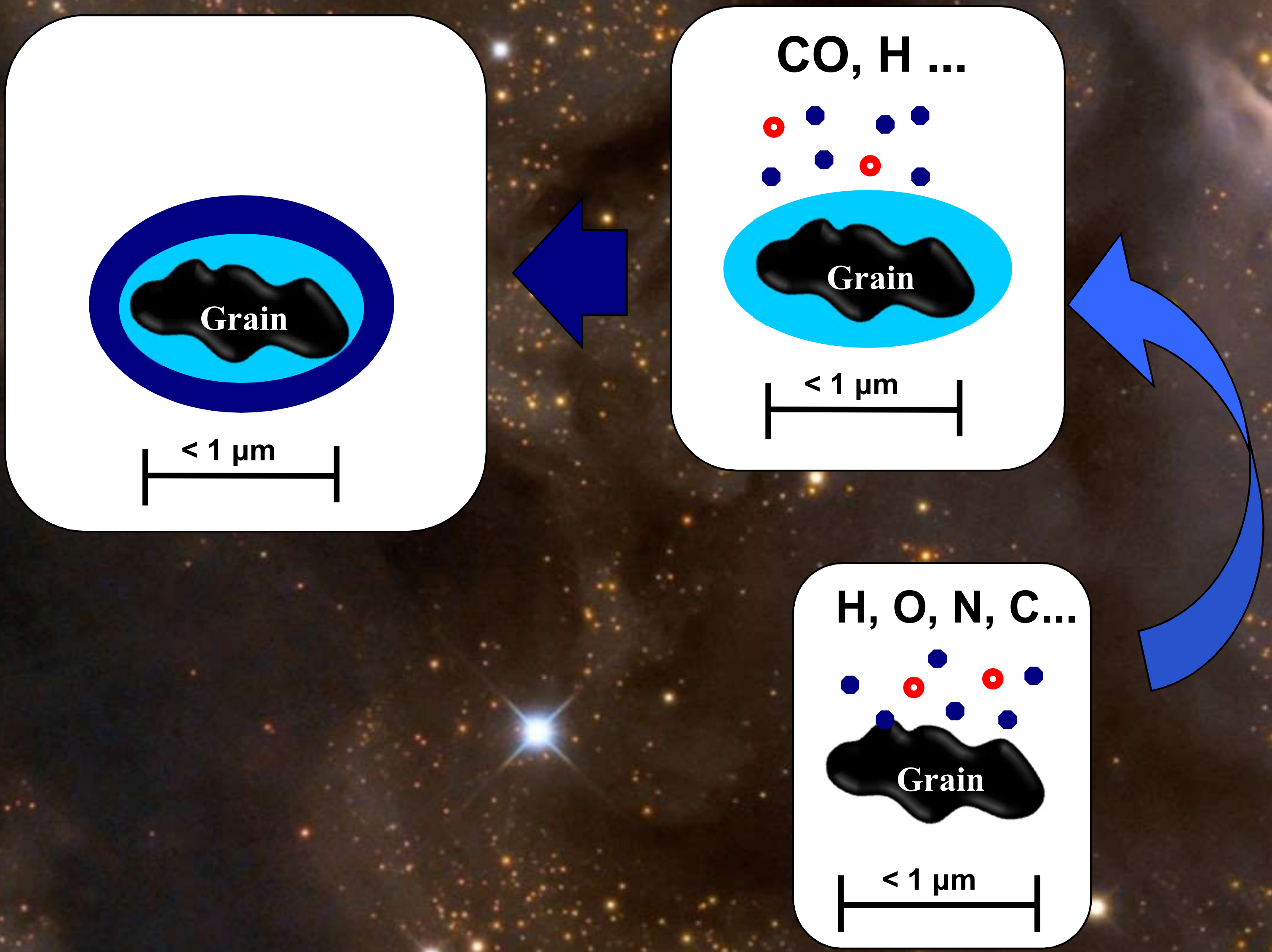

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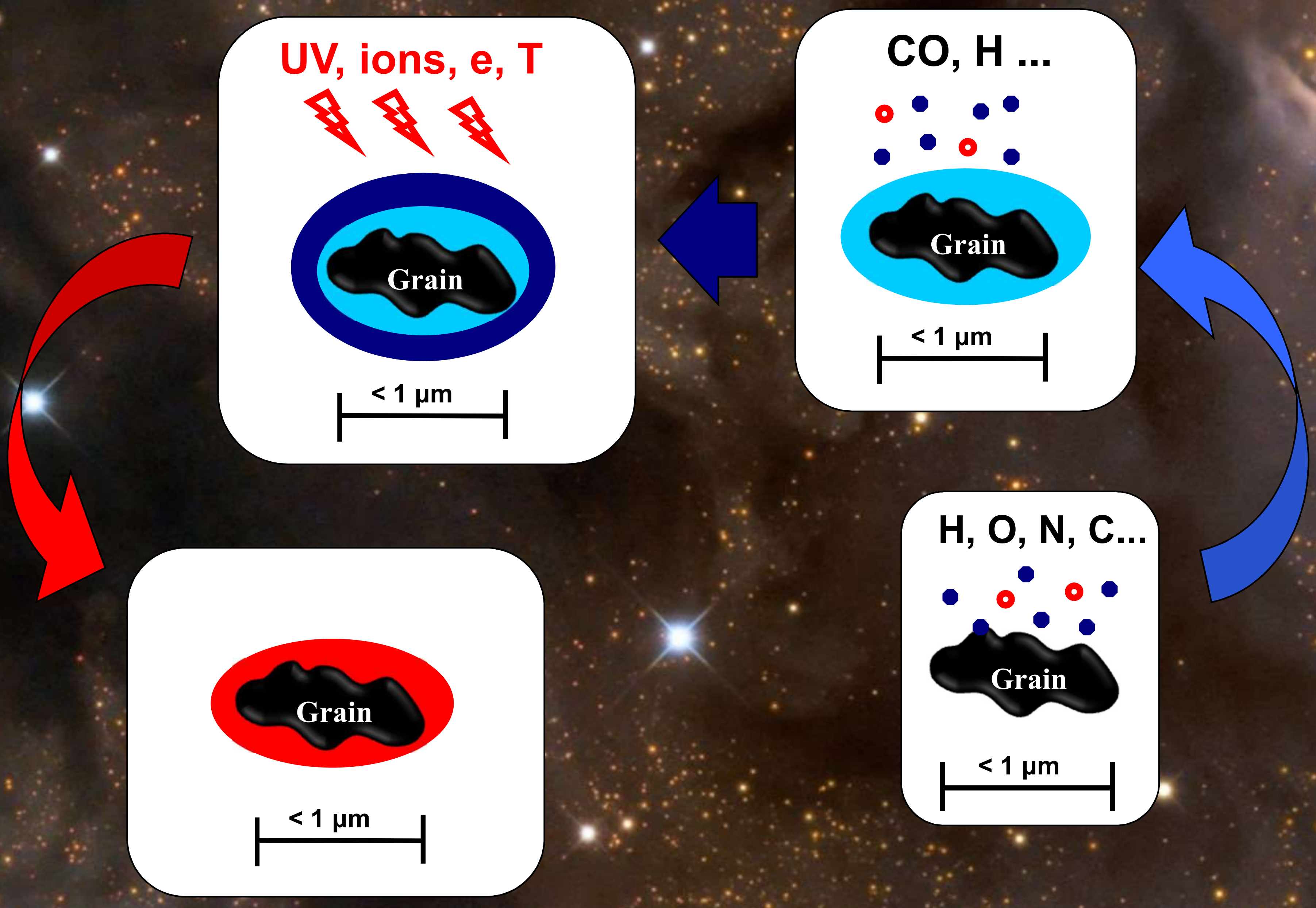


Chemistry on the Surface of Interstellar Grains

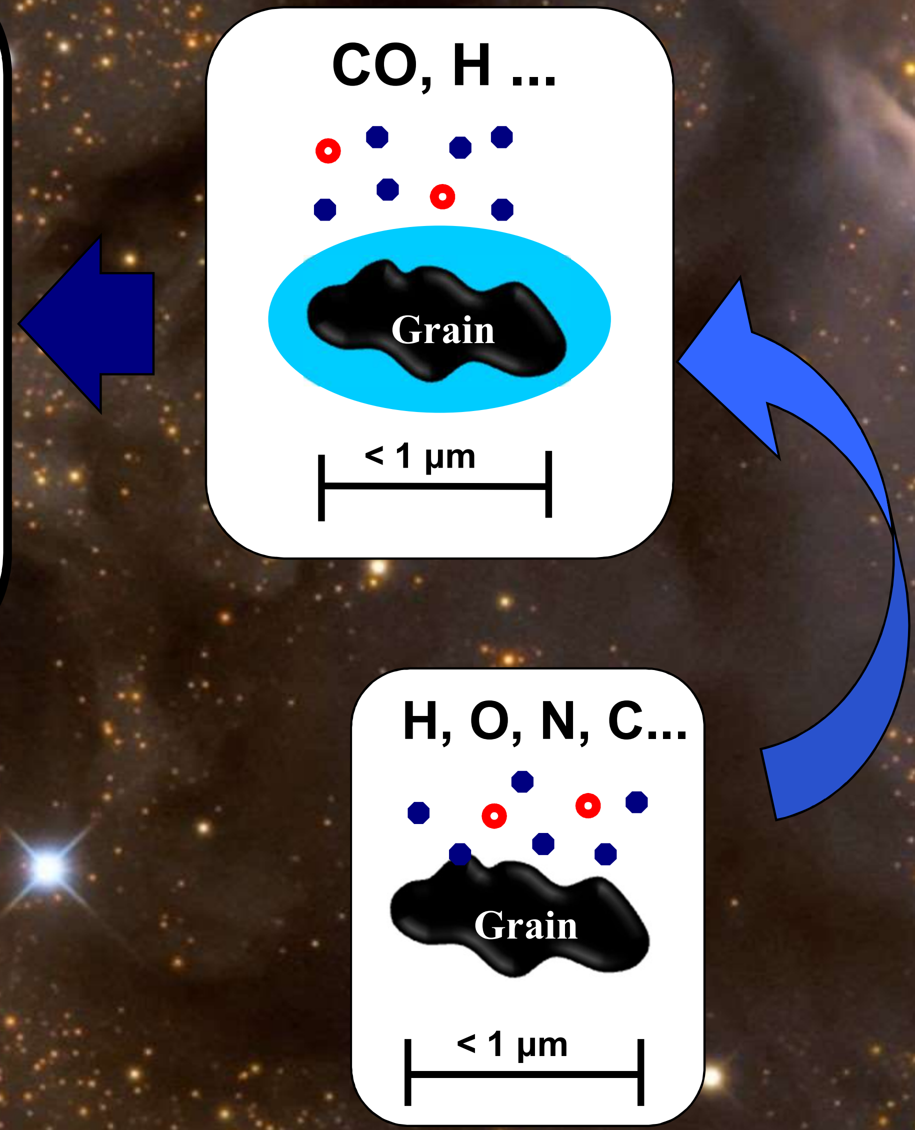
H_2O,

CO, CO_2,

CH_3OH, NH_3, CH_4,

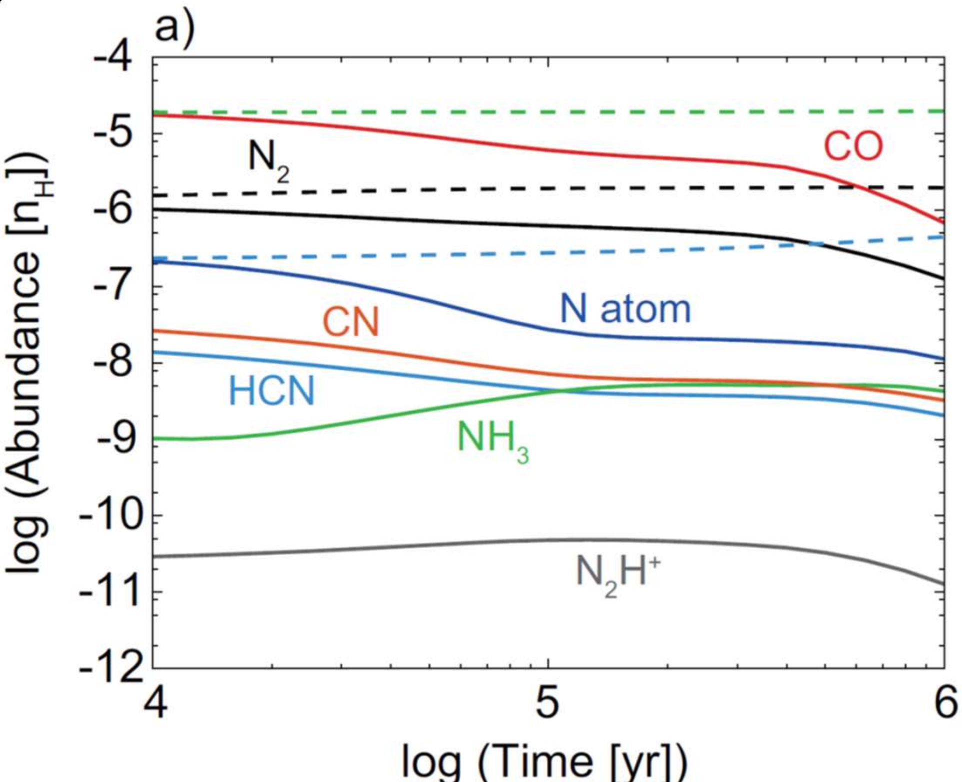
XCN (OCN^-)

Öberg et al. 2011, Boogert et al. 2015



Chemistry on the Surface of Interstellar Grains

Furuya & Aikawa, 2018



Gas-phase:

1) **N + OH/CH → <u>NO/CN</u> + H**

2) **N + <u>NO/CN</u> → N_2 + O/C**

Solid-state (Vasyunin & Herbst 2013):

1) **N + NH → N_2 + H**

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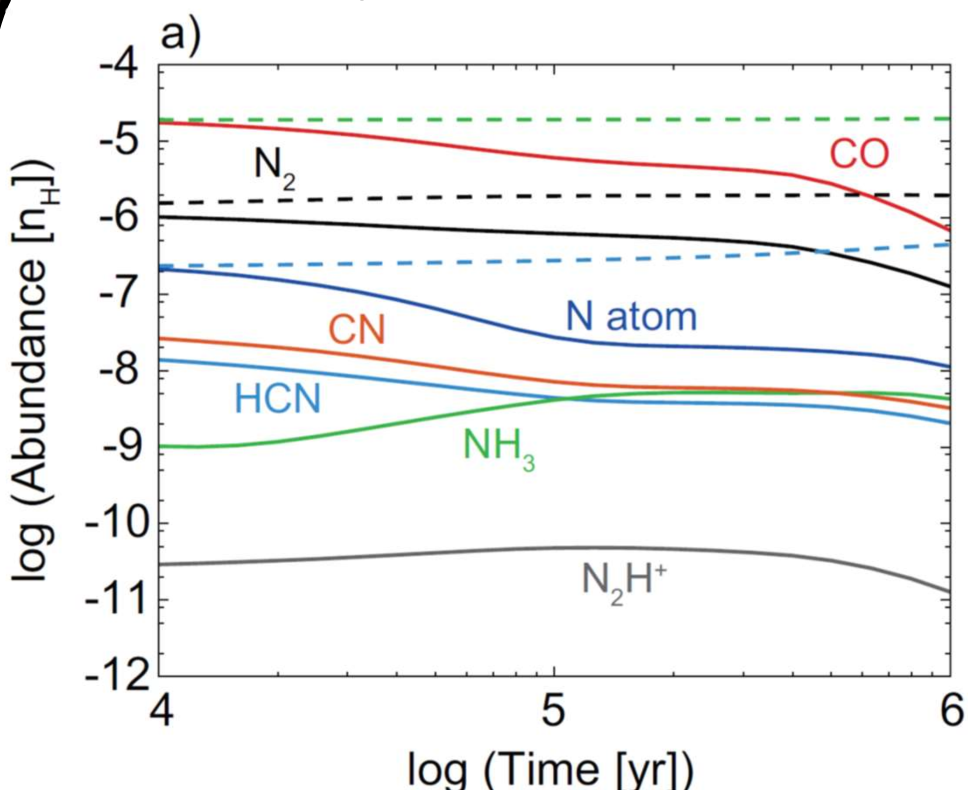

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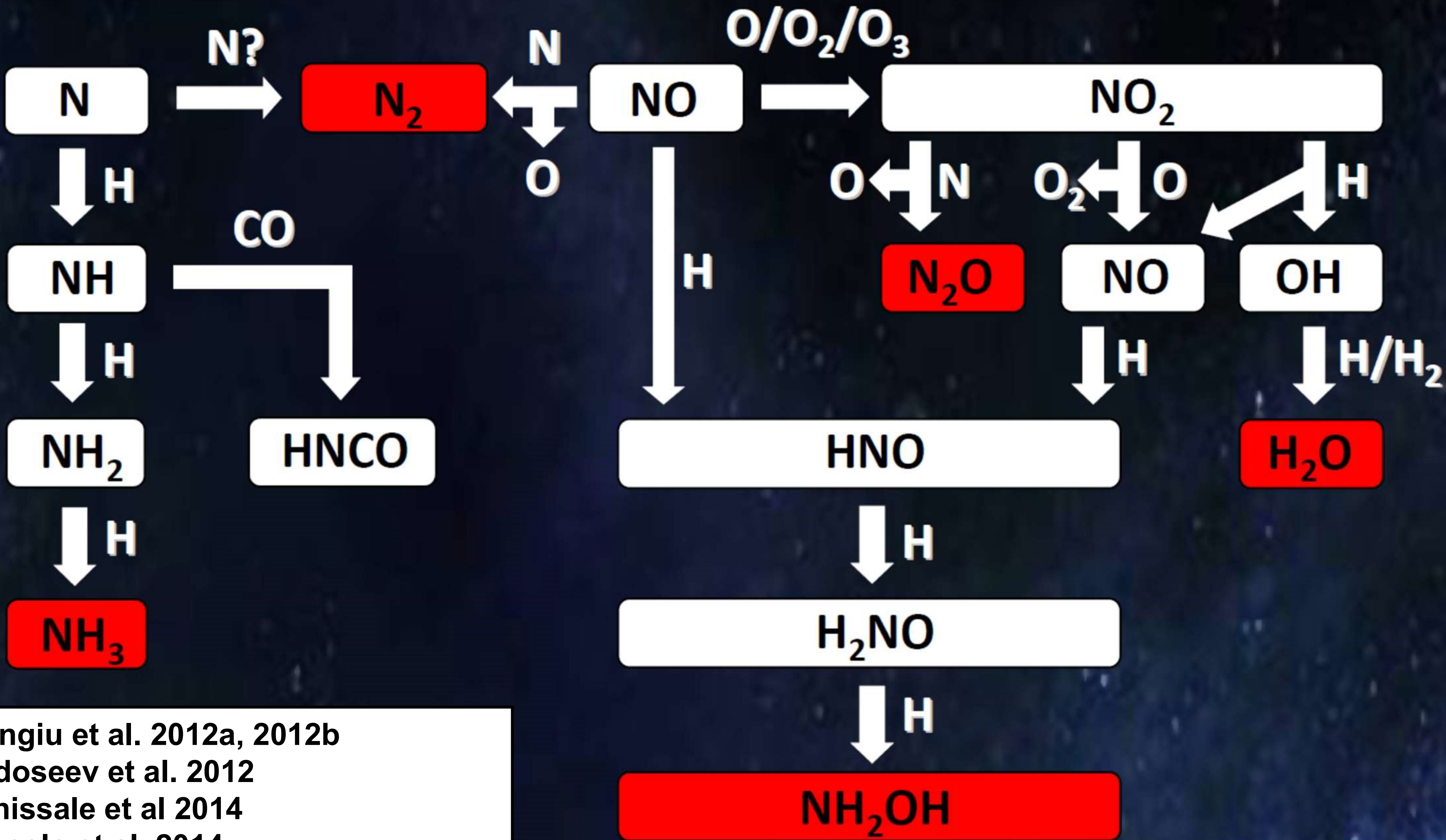
- To guide future JWST observations

- By investigating the possibility of utilizing future OCN^- and possible HNCO observations as an indicator for N_2 presence in the solid-state

- Or utilizing other possible indicators

What do we know about solid-state N-network?



Congiu et al. 2012a, 2012b
Fedoseev et al. 2012
Minissale et al 2014
Ioppolo et al. 2014
Fedoseev et al 2015a,b

Why N_2 chemistry is interesting for Us?

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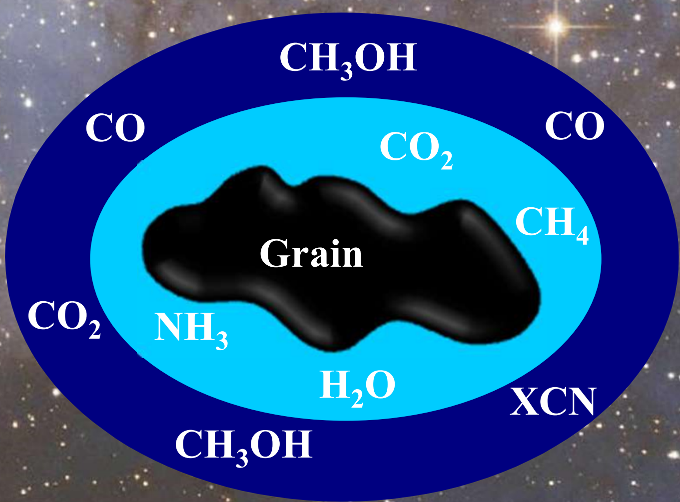
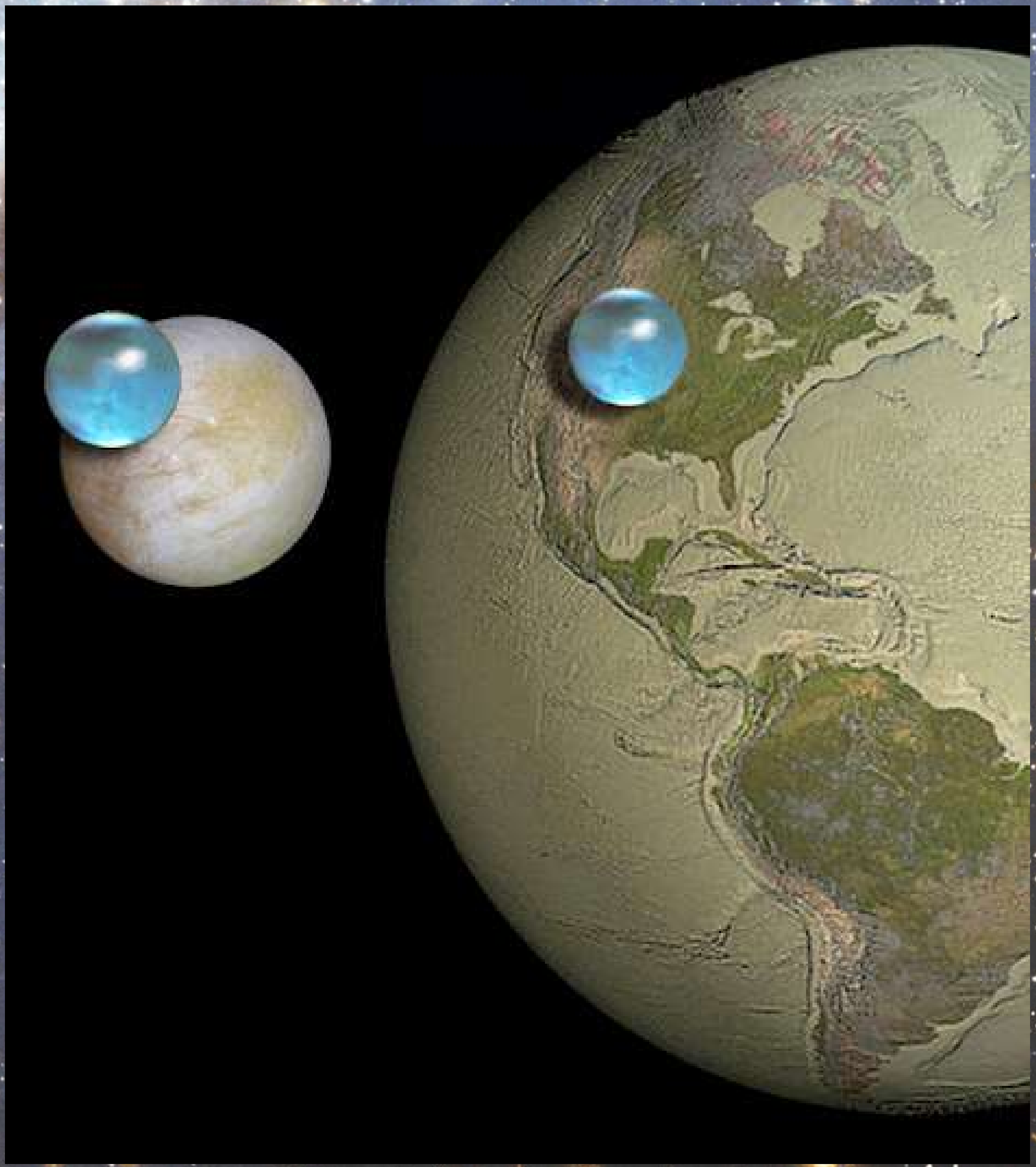
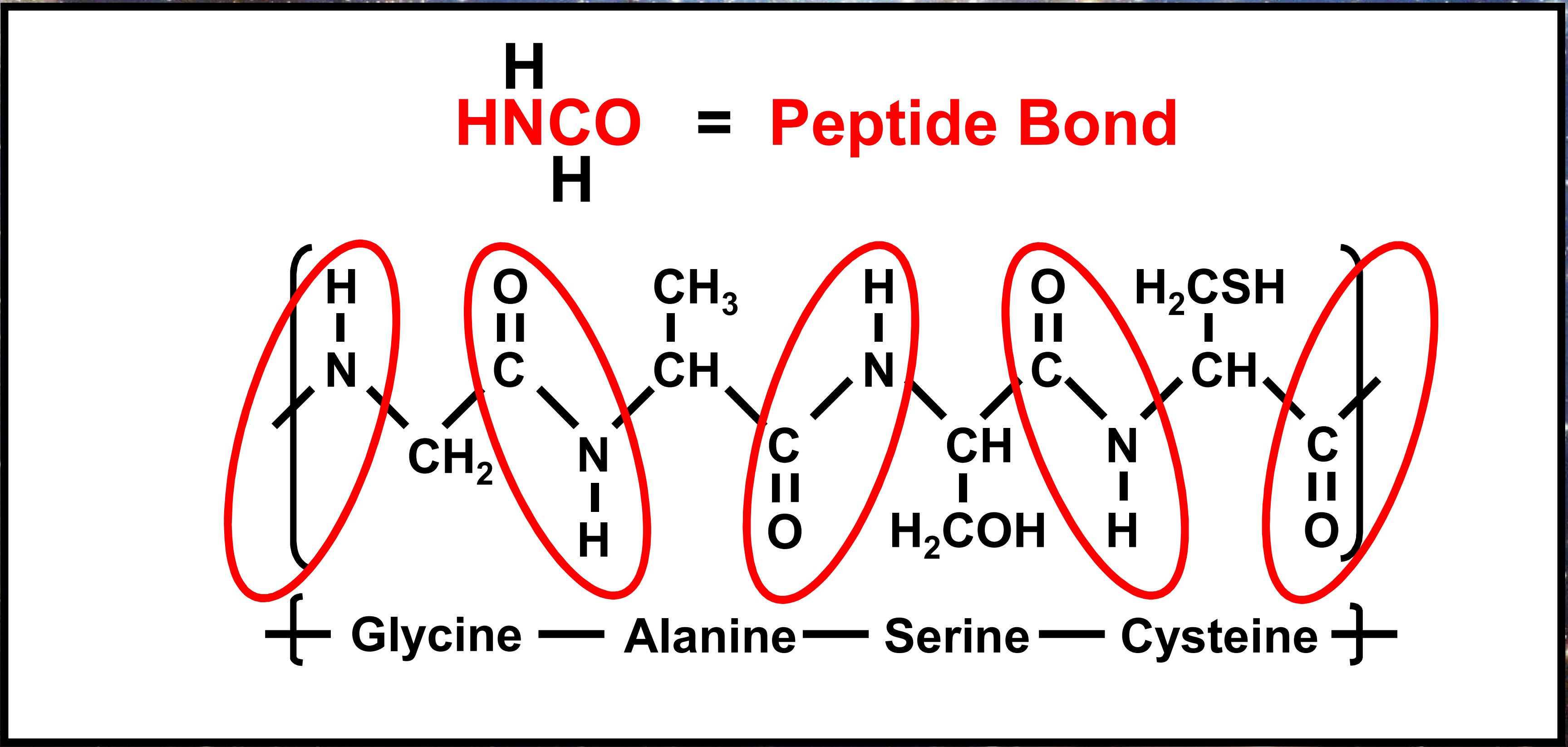
Icy Grain





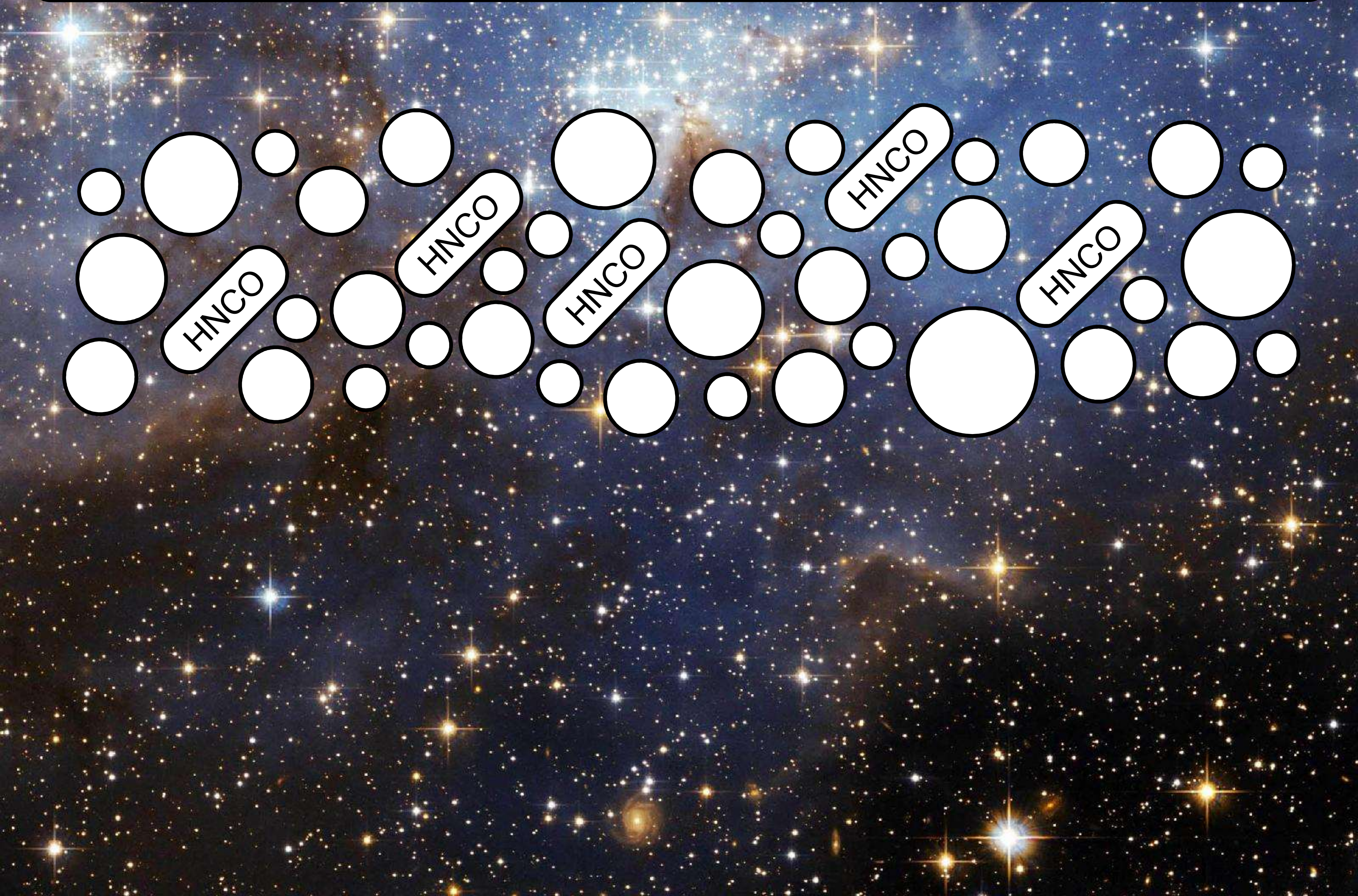
Kevin Hand (JPL/Caltech)

HNCO and NH_2CHO importance for Astrobiology



Isocyanic acid and formamide are often suggested to play a role in the formation of prebiotic molecules, *i.e.* peptides

HNCO and NH_2CHO importance for Astrobiology



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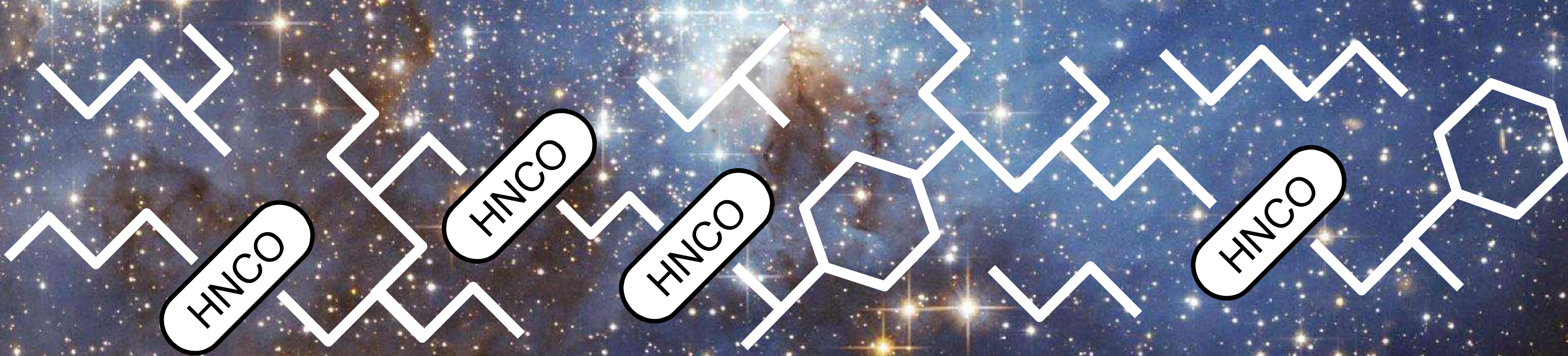
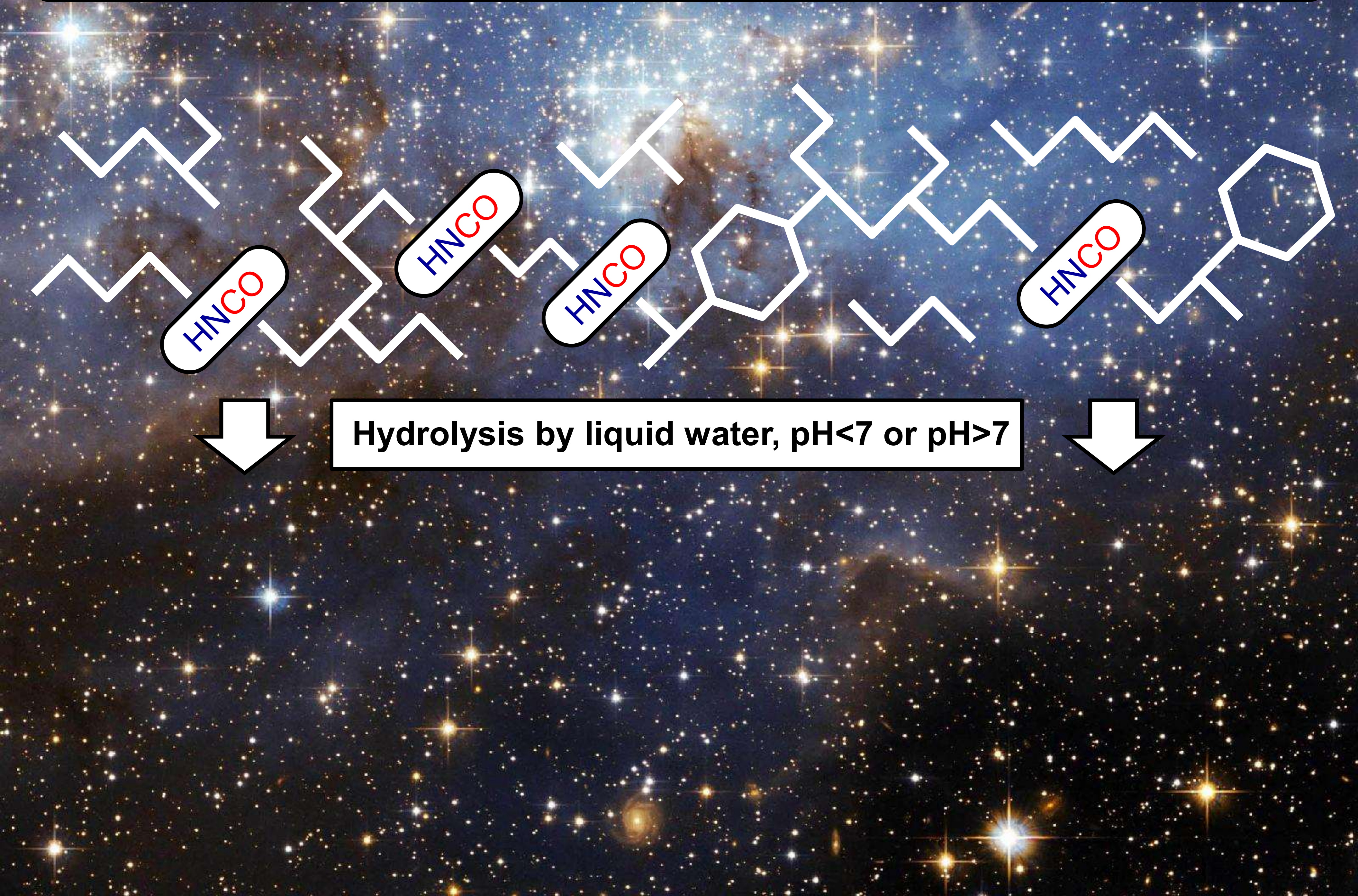


Energetic processing creating insolubale residues!

HNCO and NH_2CHO importance for Astrobiology



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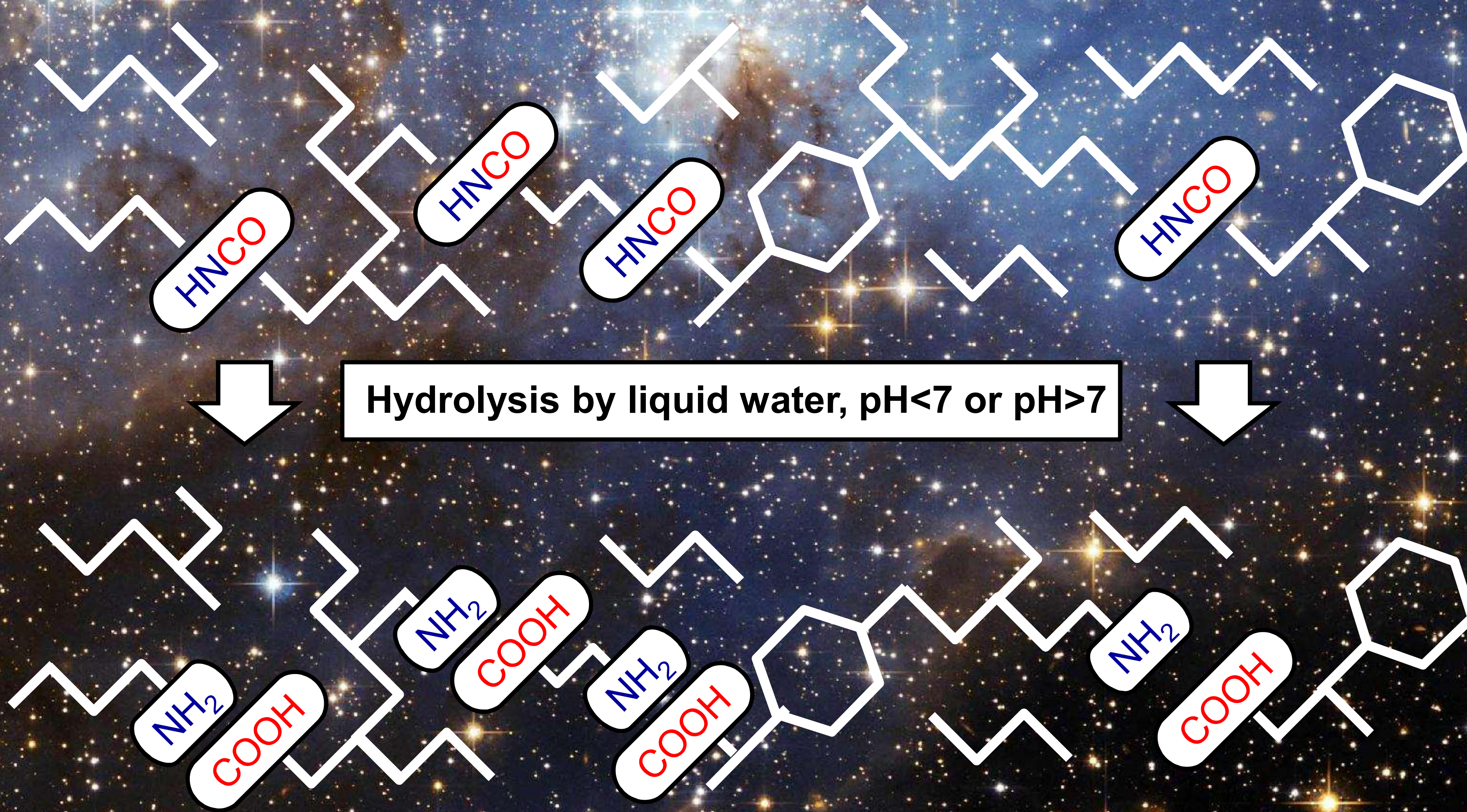
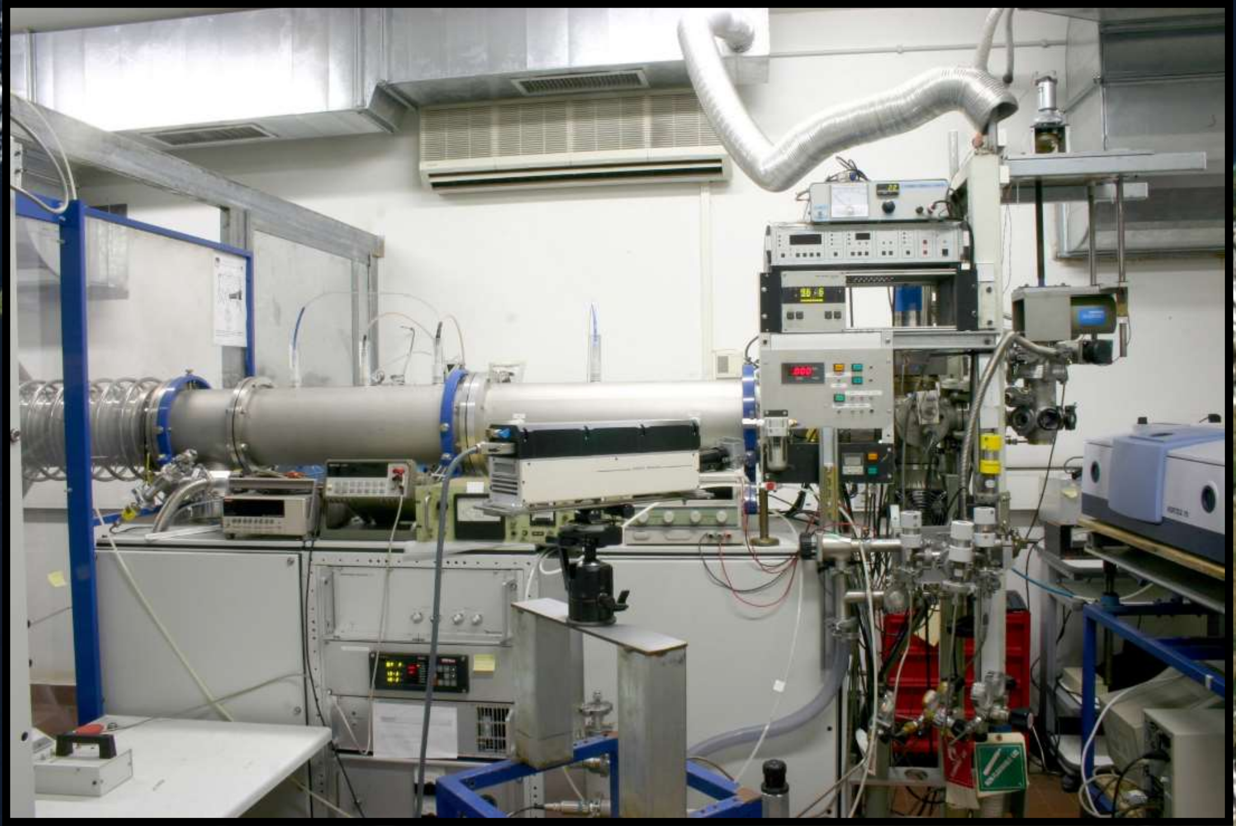


Urso et al. 2017, Accolla et al. (in prep)

Analysis and Method

Experimental Astrophysics Laboratory (LASP)



Pressure: ~10^{-9} mbar
Temperature: 15-300 K
Ion beams: 200 keV H^+, He^+, D^+ *etc.*

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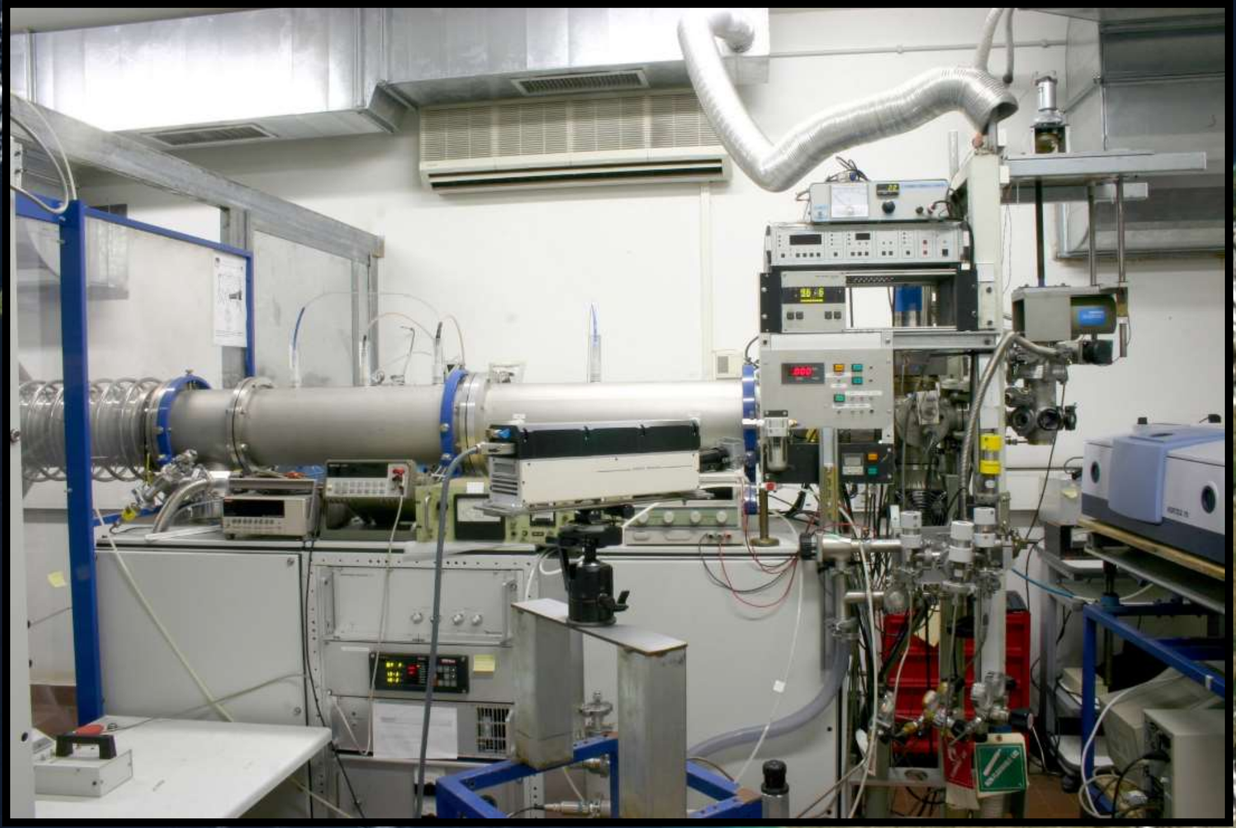

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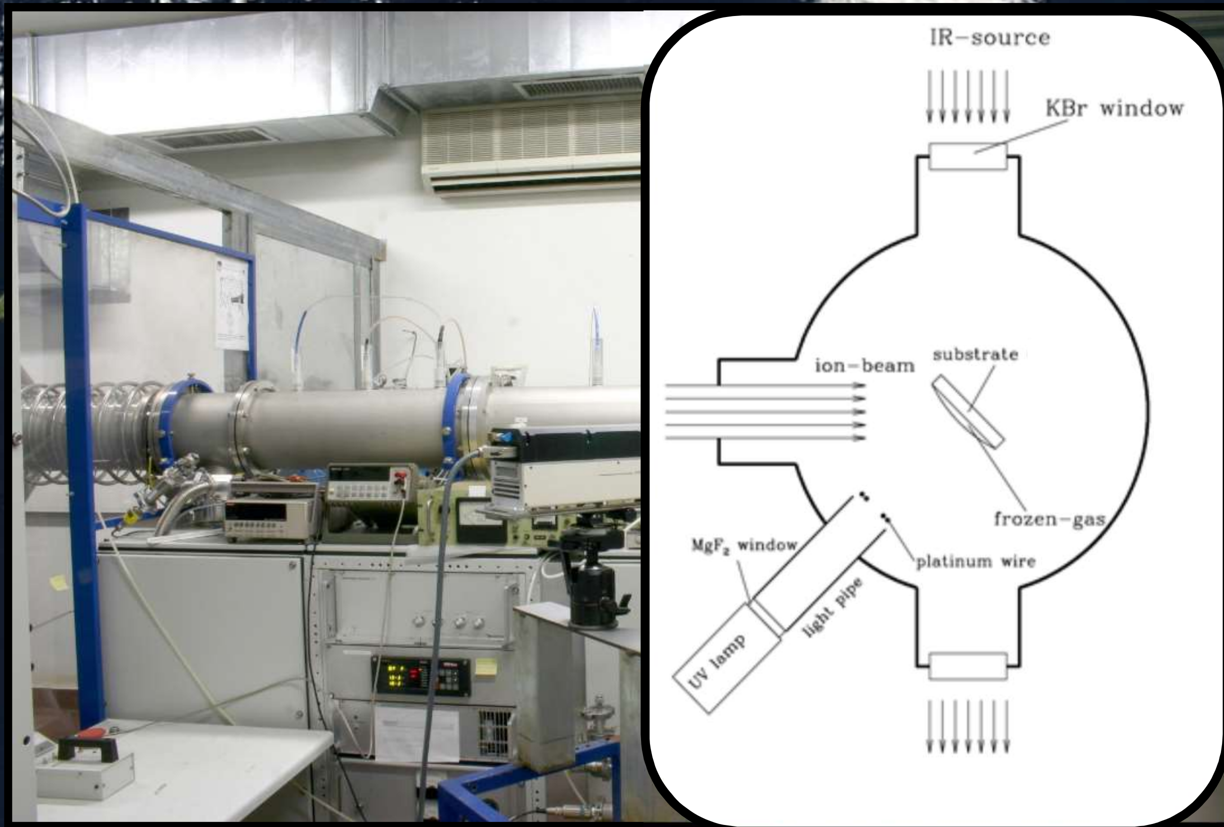

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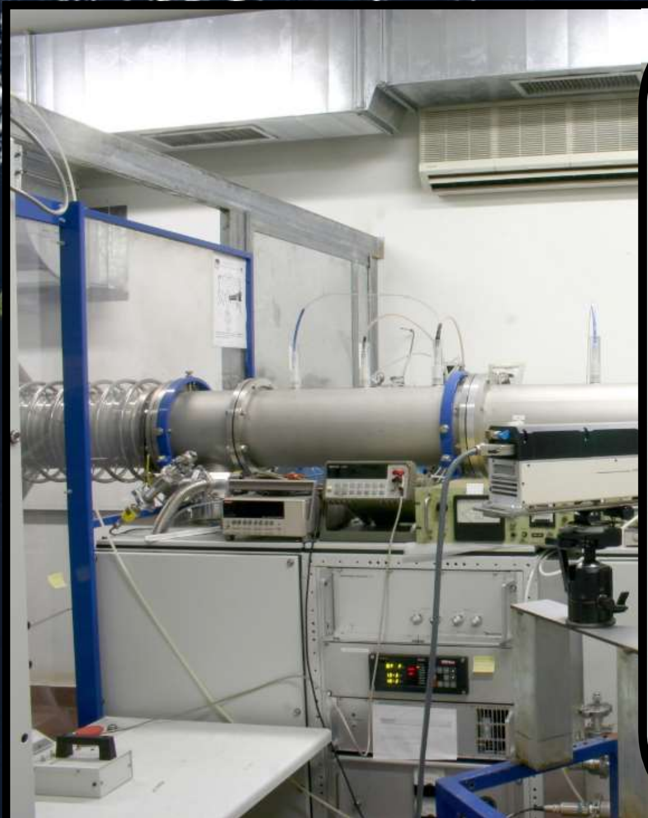

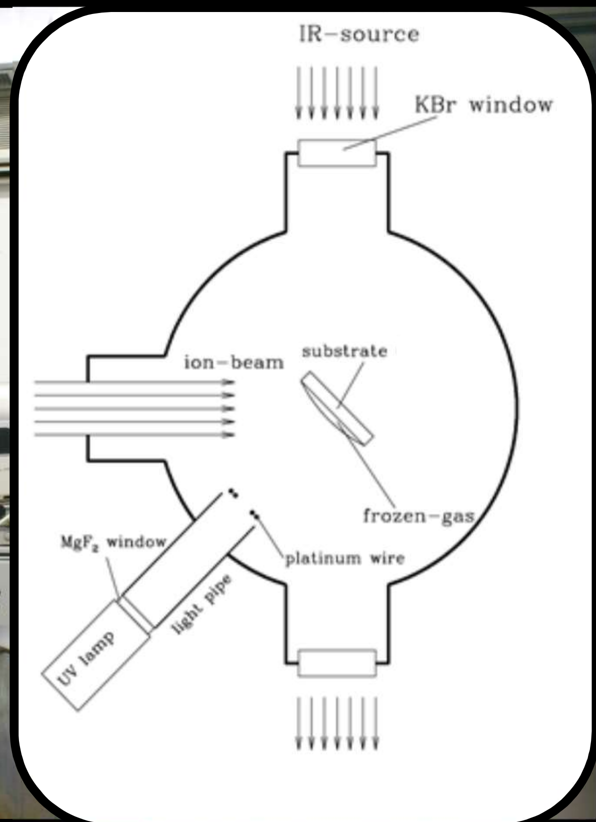

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IR spectroscopy:
- "in situ" ice analysis
- does not damage the ice
- provides kinetic data!

Typical examples of acquired IR spectra

Ion irradiation of $CH_3OH:N_2$ (1:1) ice at 17 K with 200 keV H^+ beam

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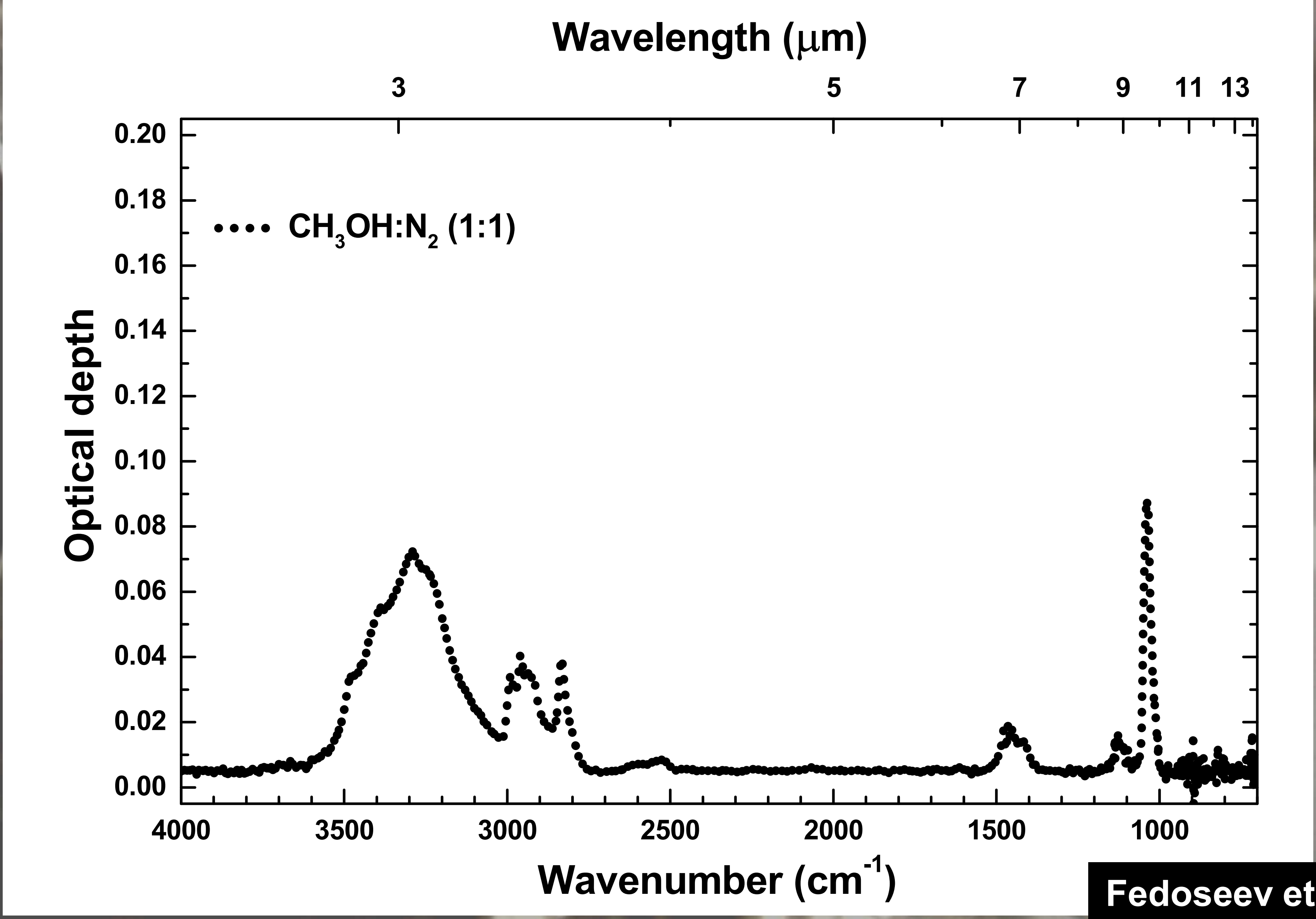

Fedoseev et al. 2018

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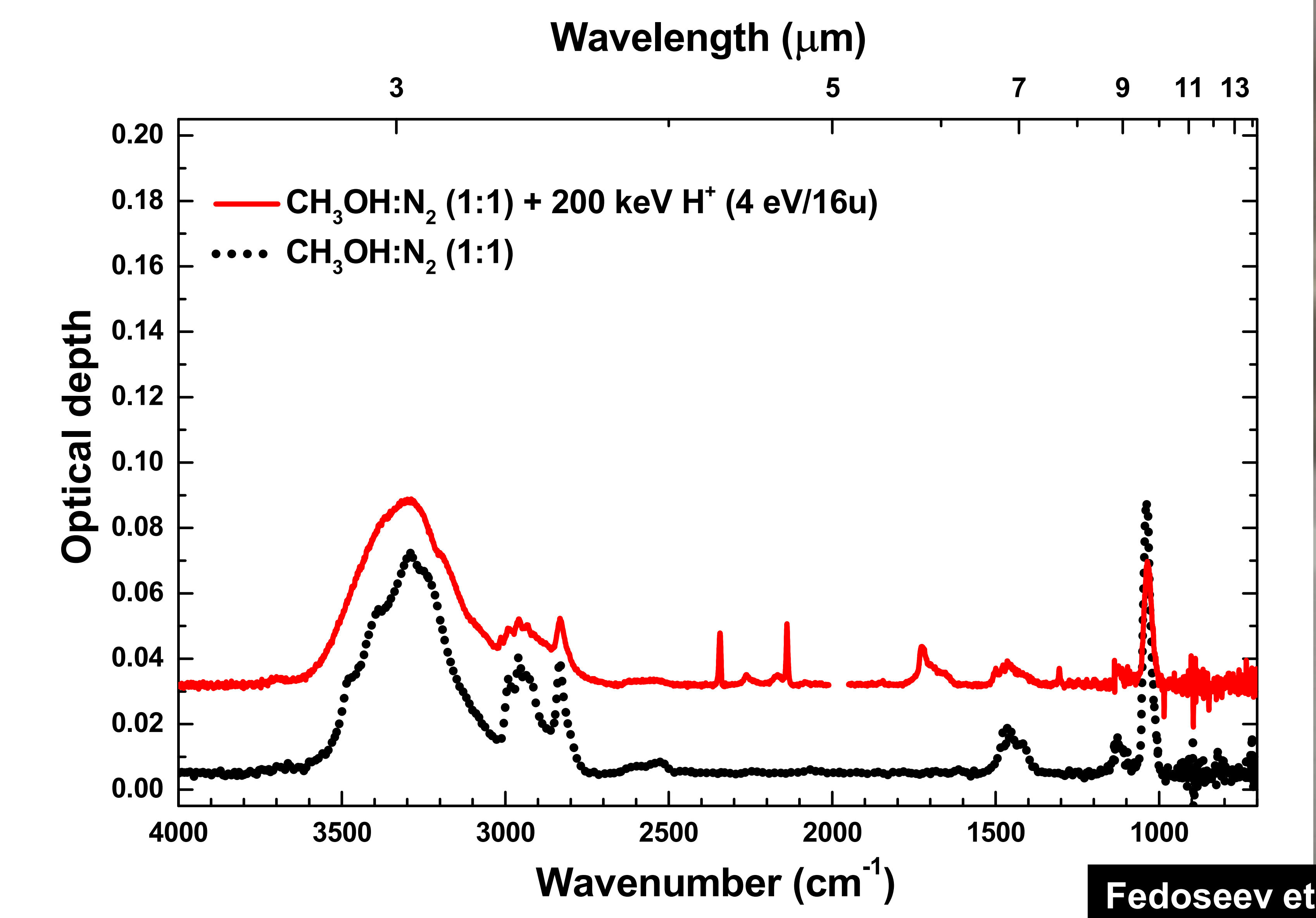

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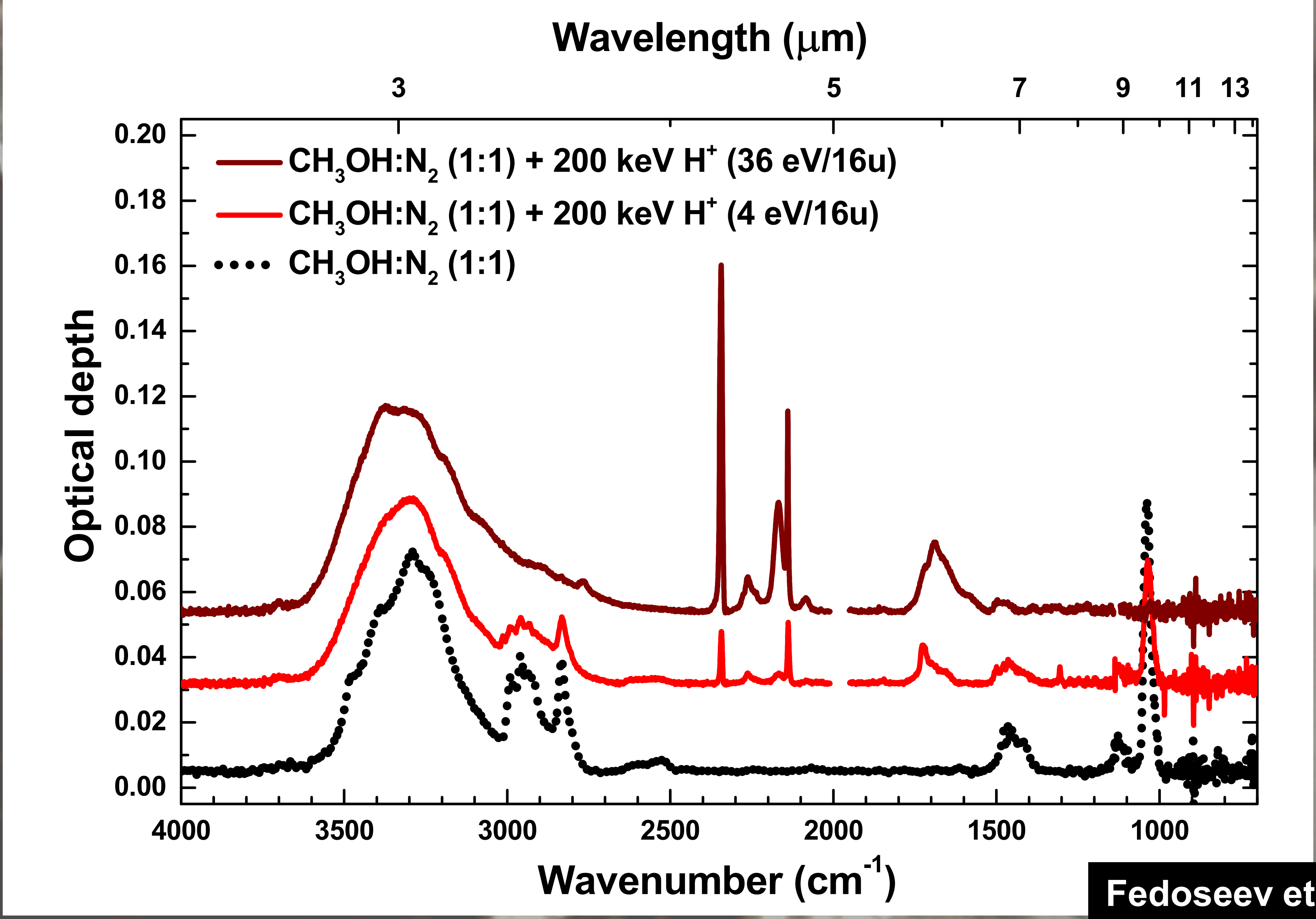

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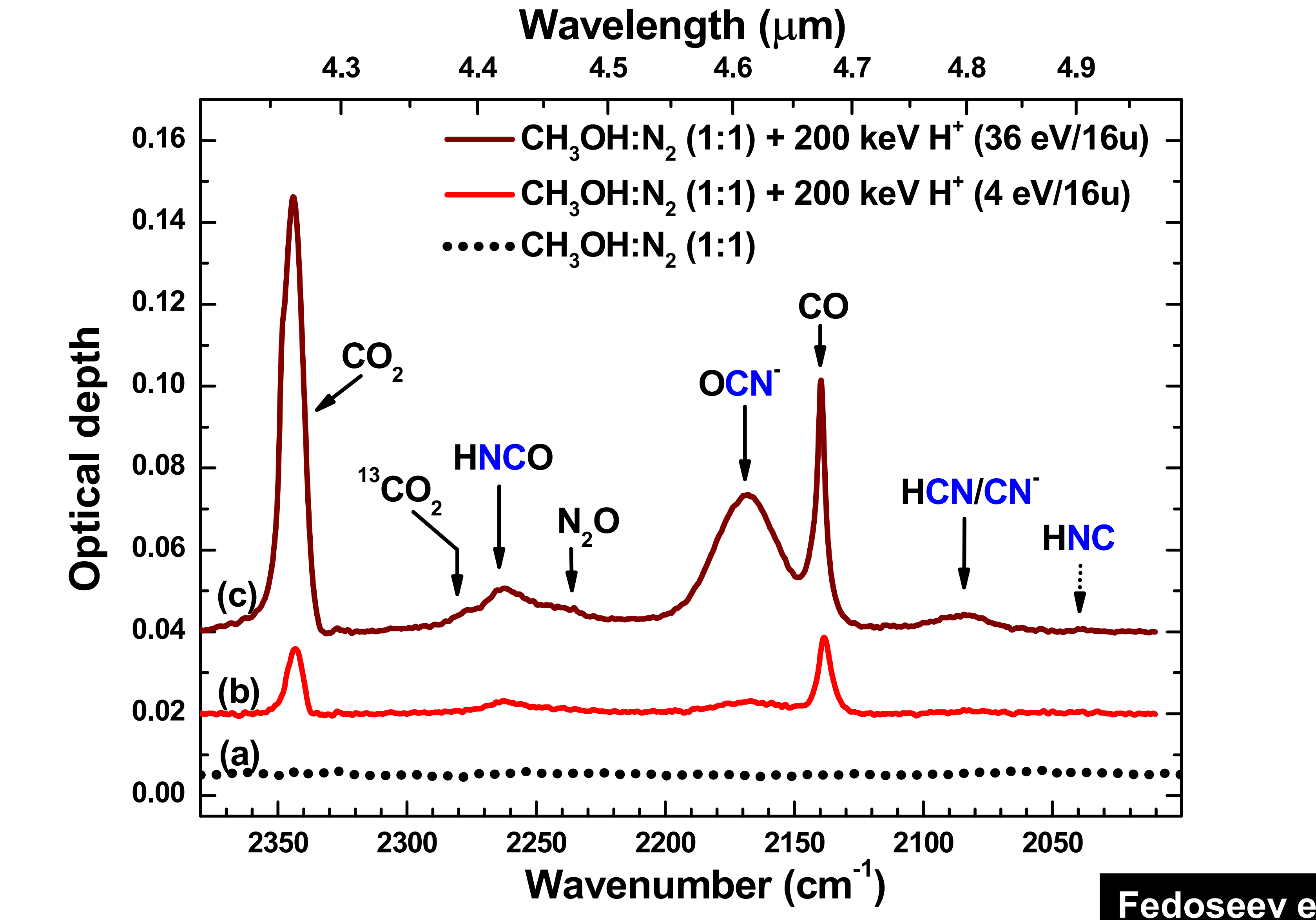

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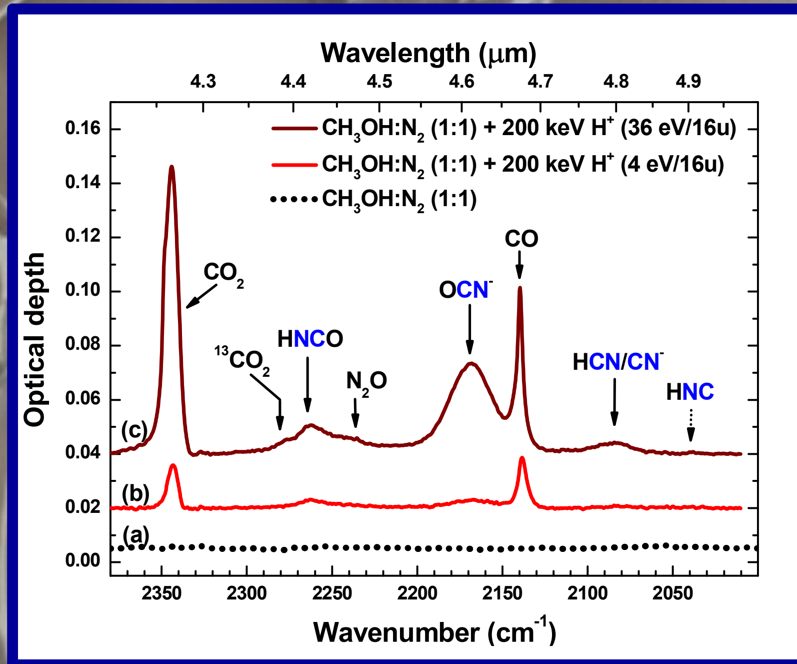

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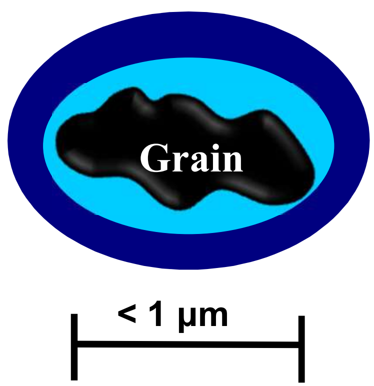

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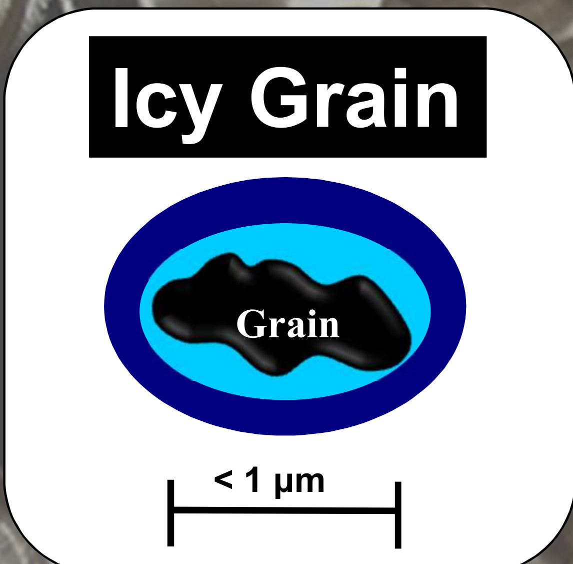

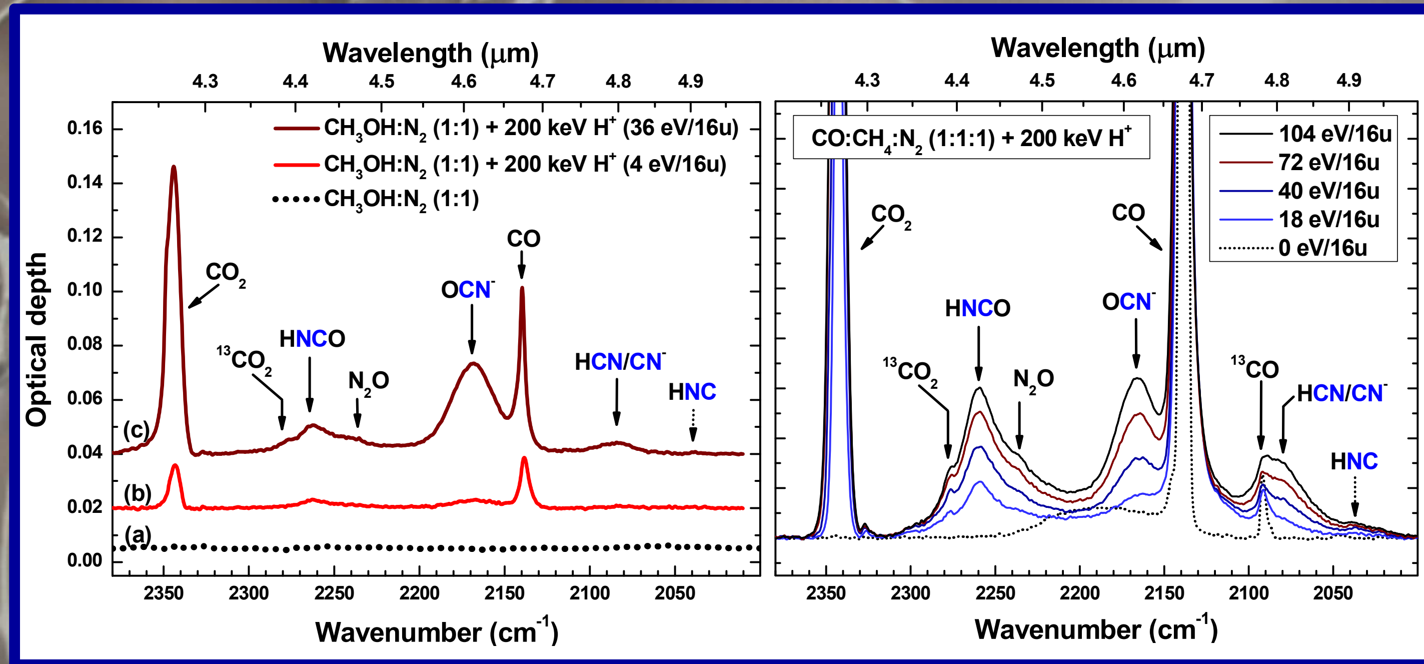

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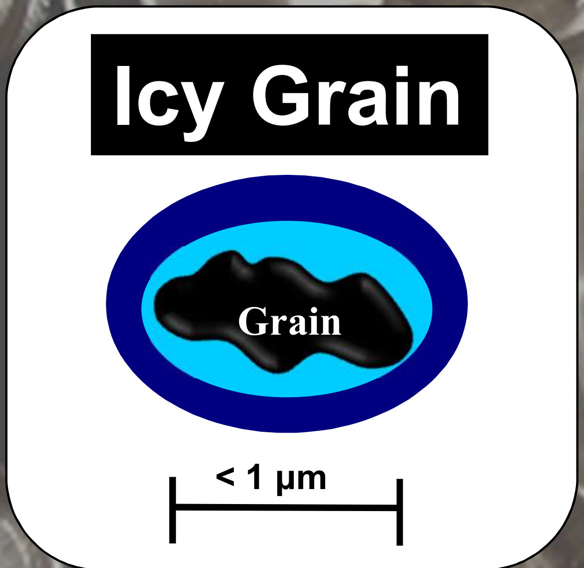

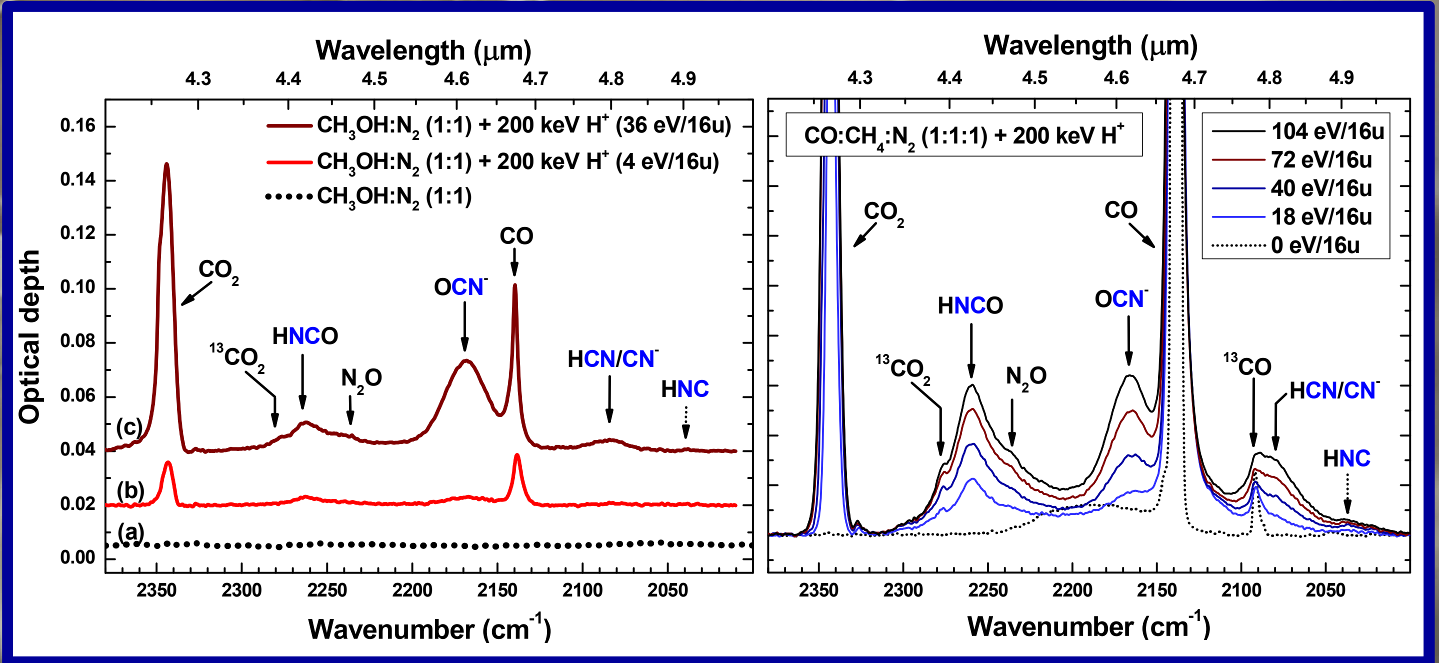

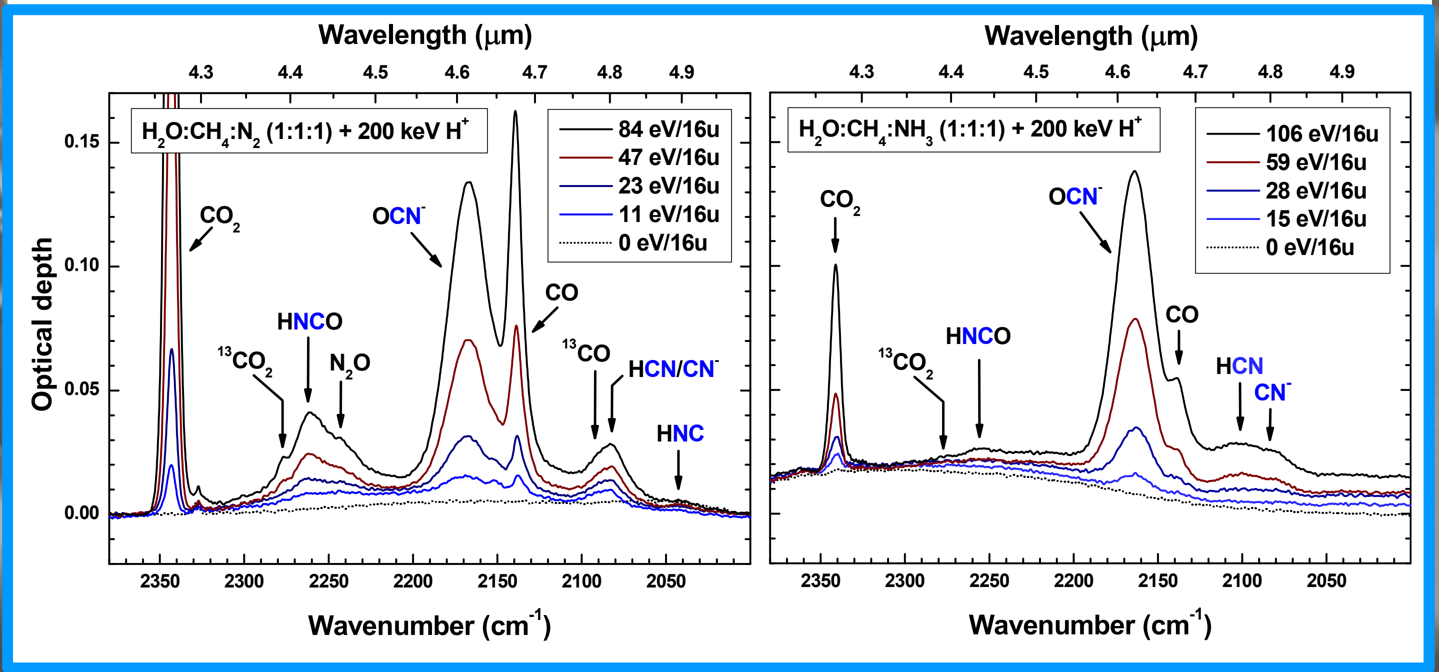

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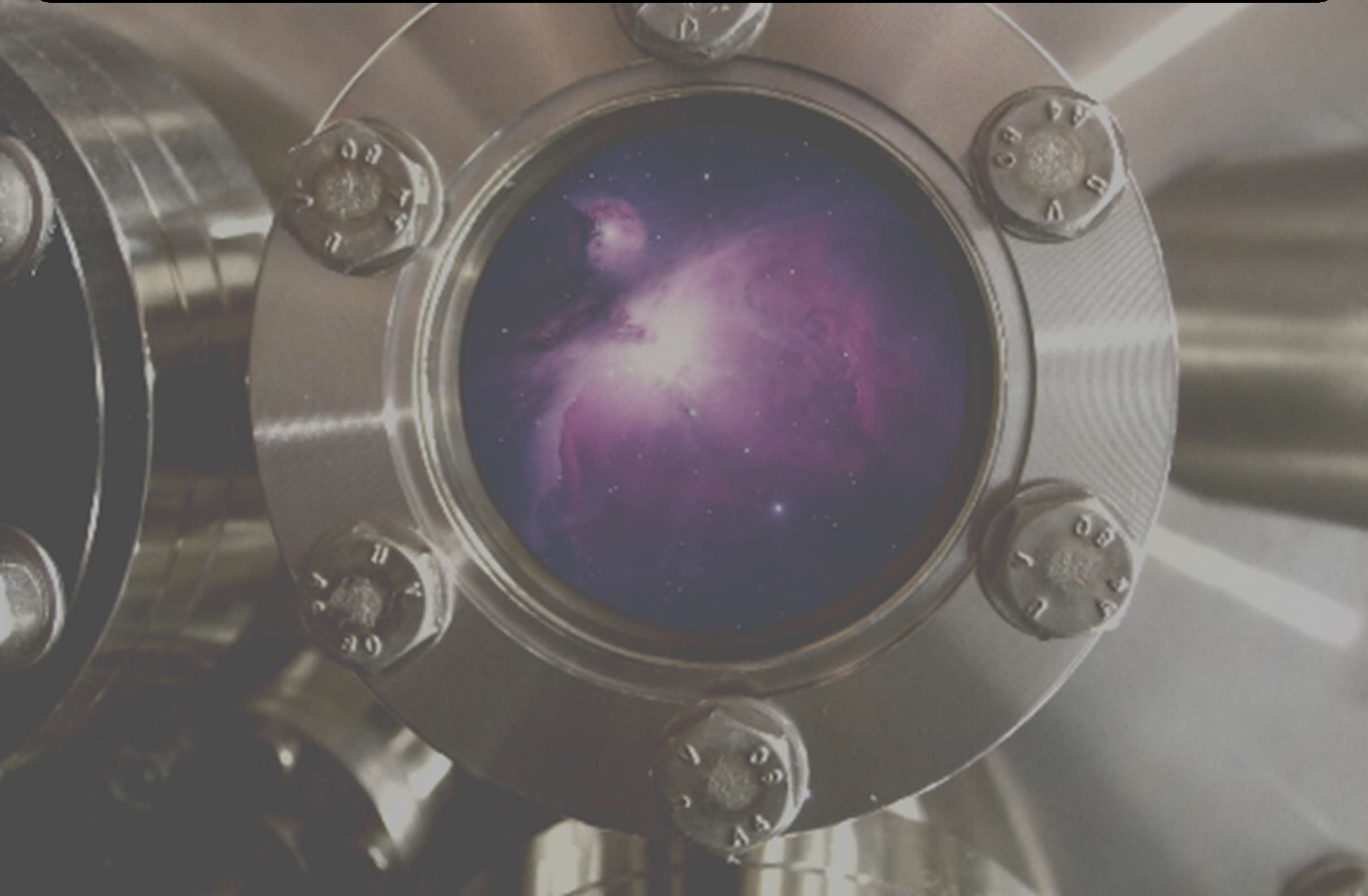
Examples of the obtained kinetic curves



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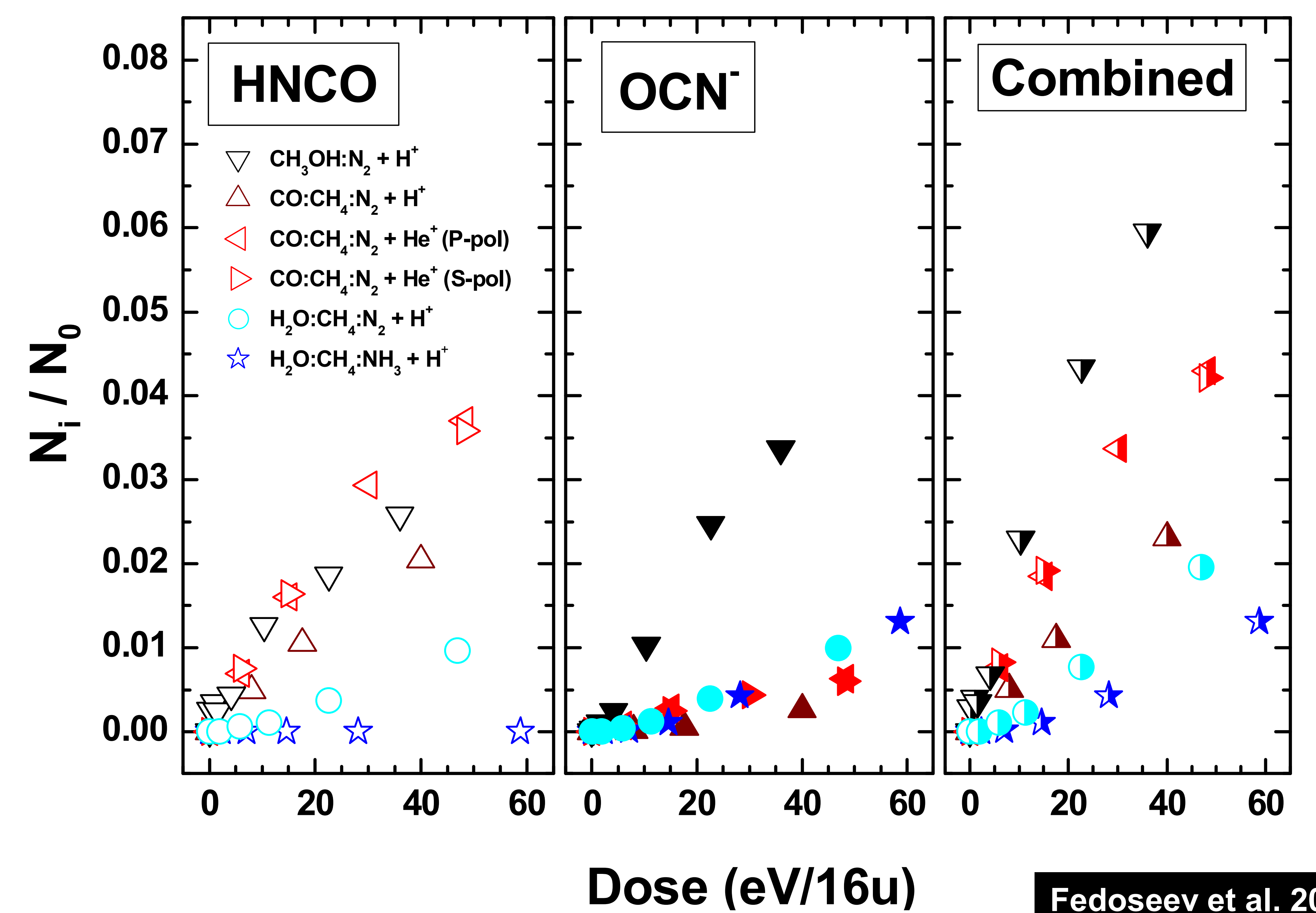

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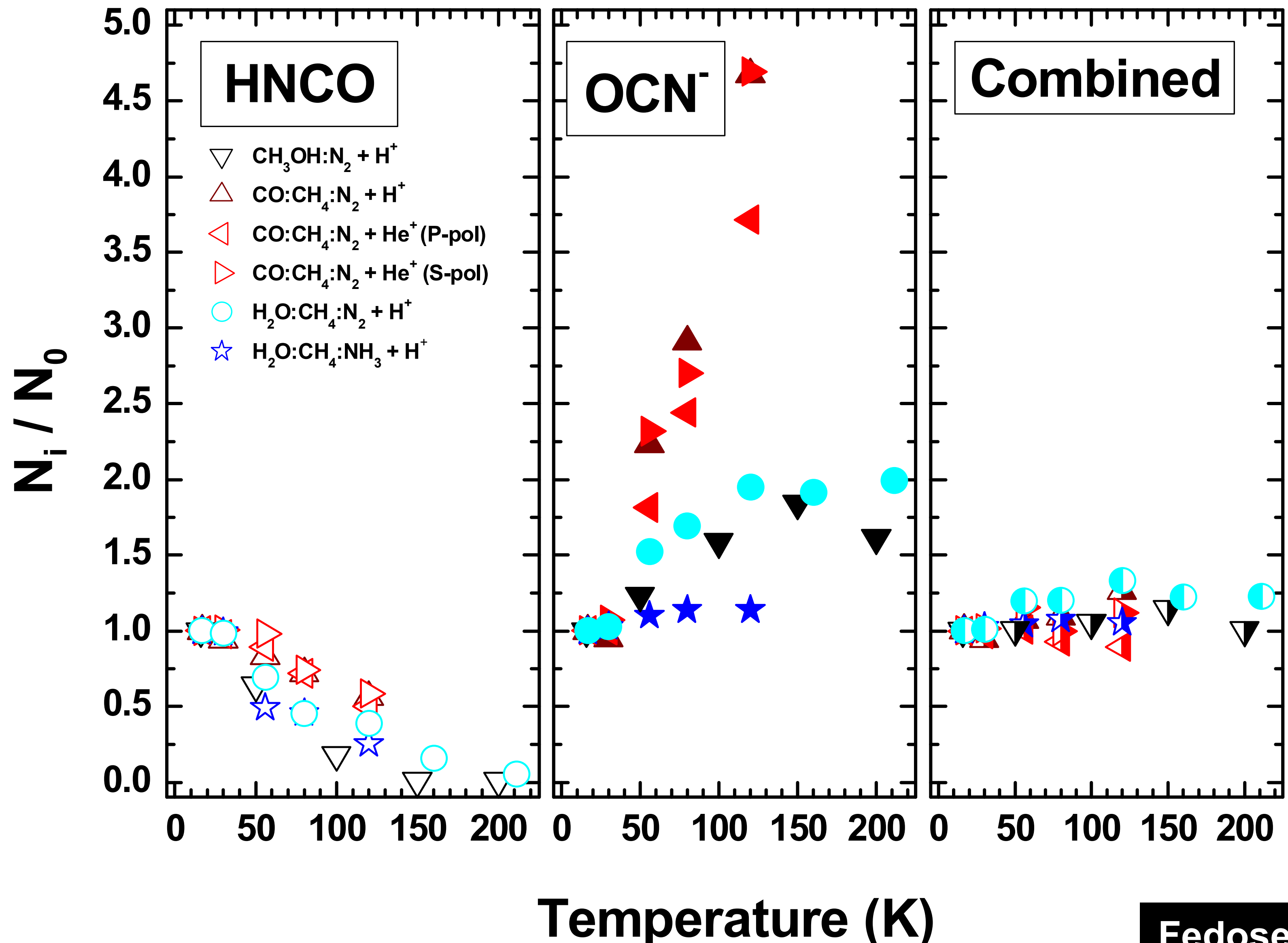
Examples of the obtained kinetic curves

HNCO + M → $OCN^- M^+$ (acid-base interaction)



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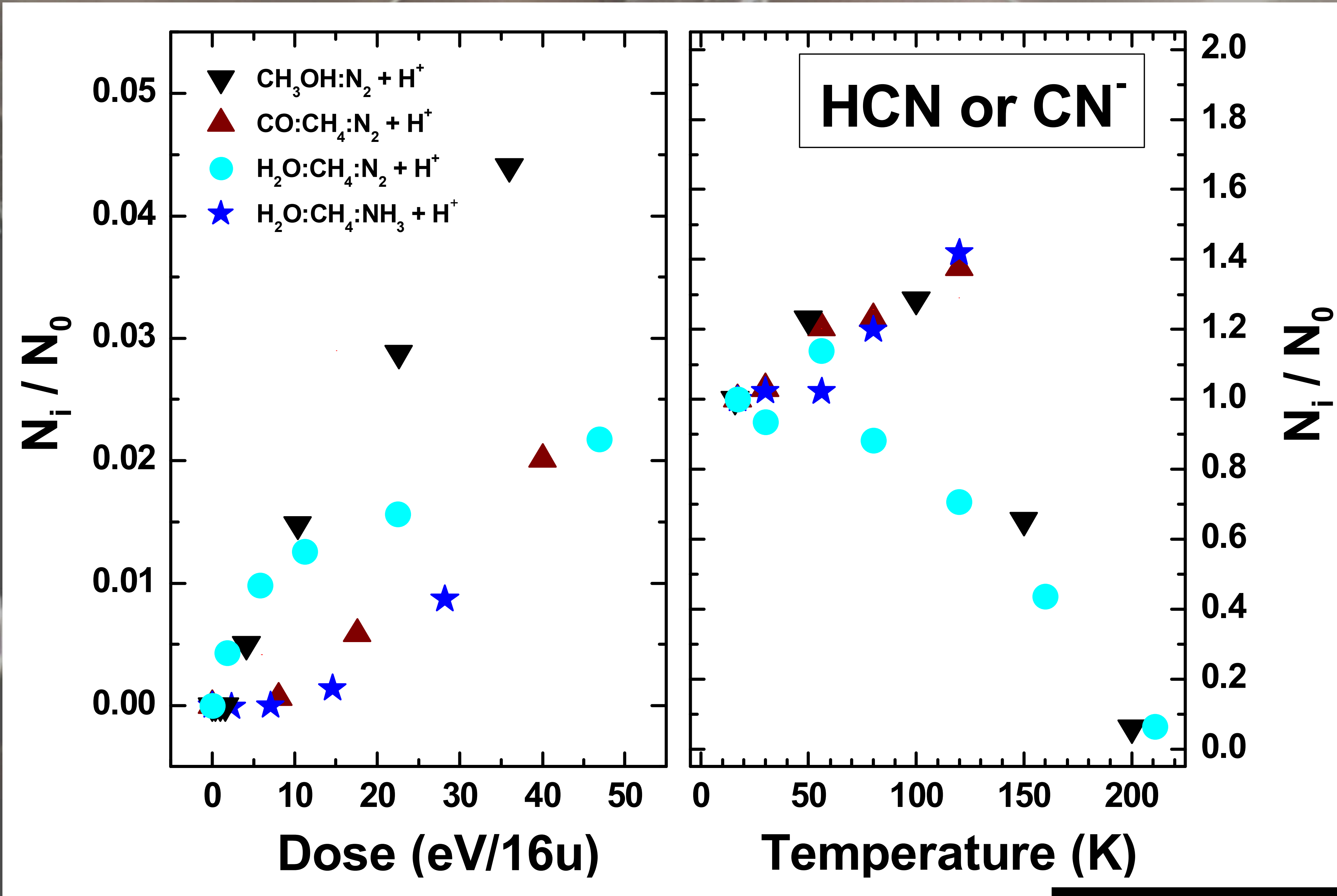

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Interpolation to dark cloud conditions

Interpolation to dark cloud conditions

Normalized formation yields obtained by interpolation

	$CH_3OH:N_2$ (1:1)	$CO:CH_4:N_2$ (1:1:1)	$H_2O:CH_4:N_2$ (1:1:1)	$H_2O:CH_4:NH_3$ (1:1:1)
Dose eV/16u	0.05	0.05	0.05	0.05
HNCO	$5x10^{-5}$	$3x10^{-5}$	$5x10^{-6}$	-
OCN^-	$3x10^{-5}$	$2x10^{-6}$	$4x10^{-6}$	$2x10^{-6}$
HCN/CN^-	$7x10^{-5}$	$1x10^{-5}$	$1x10^{-4}$	$3x10^{-6}$

Ionization rate: $3x10^{-17}$ s^{-1}
Time = $2x10^5$ years

Ion irradiation by 1 MeV H^+
Flux: ~ 1 cm^{-2} s^{-1}
(20 nm ice mantle)

Fedoseev et al. 2018

Interpolation to dark cloud conditions

Normalized formation yields obtained by interpolation

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Dose eV/16u	5	5	5	5
HNCO	5×10^{-3}	3×10^{-3}	5×10^{-4}	-
OCN^-	3×10^{-3}	2×10^{-4}	4×10^{-4}	2×10^{-4}
HCN/CN^-	7×10^{-3}	1×10^{-3}	1×10^{-2}	3×10^{-4}

Ionization rate: 3×10^{-17} s^{-1}
Time = 2×10^7 years

OR

Ionization rate: 1.3×10^{-15} s^{-1}
Time = 2×10^5 years

Ion irradiation by 1 MeV H^+
Flux: ~ 1 cm^{-2} s^{-1}
(20 nm ice mantle)

Fedoseev et al. 2018

Astrochemical Implications and Conclusions

- The obtained $HNCO/OCN^-$ ratios (see Table **5**) can be used as the tracers of N_2 presence

- Co-formation of N_2O in N_2-containg ices serves as the discriminator between N_2 and NH_3 precursors for OCN^- formation.

- Unless formation of OCN^- occurs in 'H_2O-rich' ice layer of icy grain mantle, HNCO should always be observed simultaneously with OCN^-.

Acknowledgments

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Dr. M. Accolla
Dr. G. A. Baratta
Dr. P. Modica
Msc. R. G. Urso

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