Complex organic chemistry in solar-type protostars : new detections in the framework of the ALMA-PILS survey

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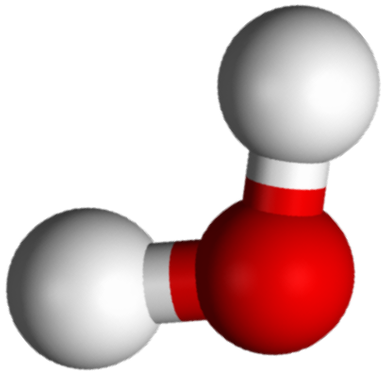
12 July 2018, Quy Nhon, Vietnam

Image credit: ESO/B. Tafreshi

The building blocks of Life

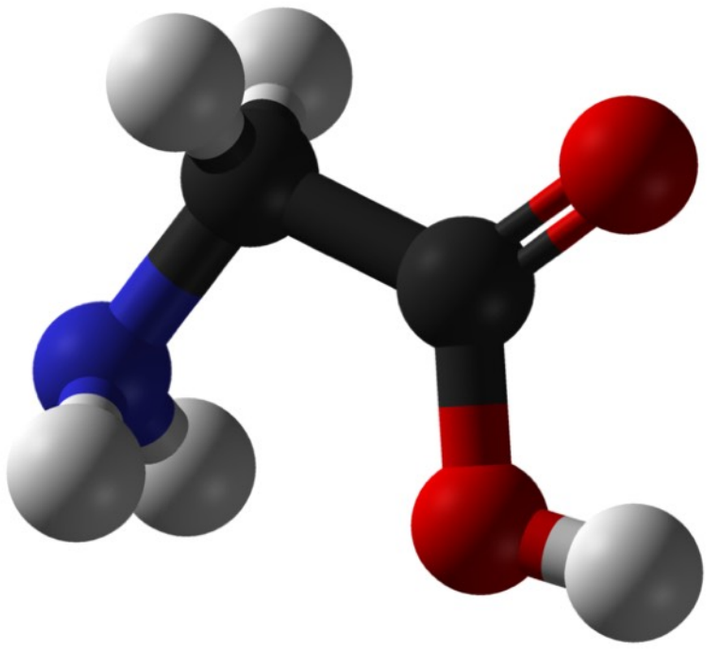
- <u>Water</u>



- <u>Prebiotic molecules</u>

Molecules thought to be involved in the process leading to the origin of Life (Herbst & van Dishoeck 2009)

High interest: amino acids, sugars, nucleobases



Glycine

The building blocks of Life

- Comets and asteroids rich in water and complex organic species such as amino acids and sugars

- Delivery to Earth through bombardments of comets and asteroids

↓

Origin of the molecular complexity of asteroids and comets ?

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Study of other star-forming regions in order to characterize the chemical content available when planets, comets and asteroids form

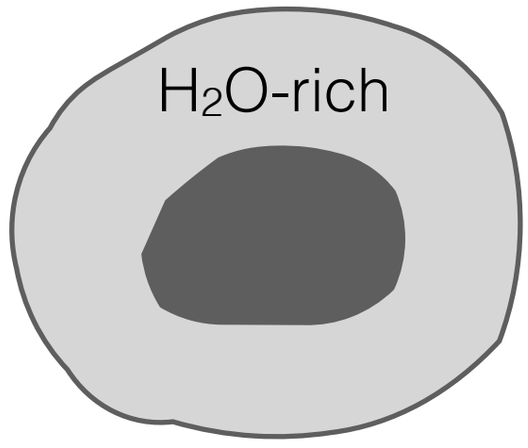
Star formation and chemistry

Stage of star formation

Chemistry

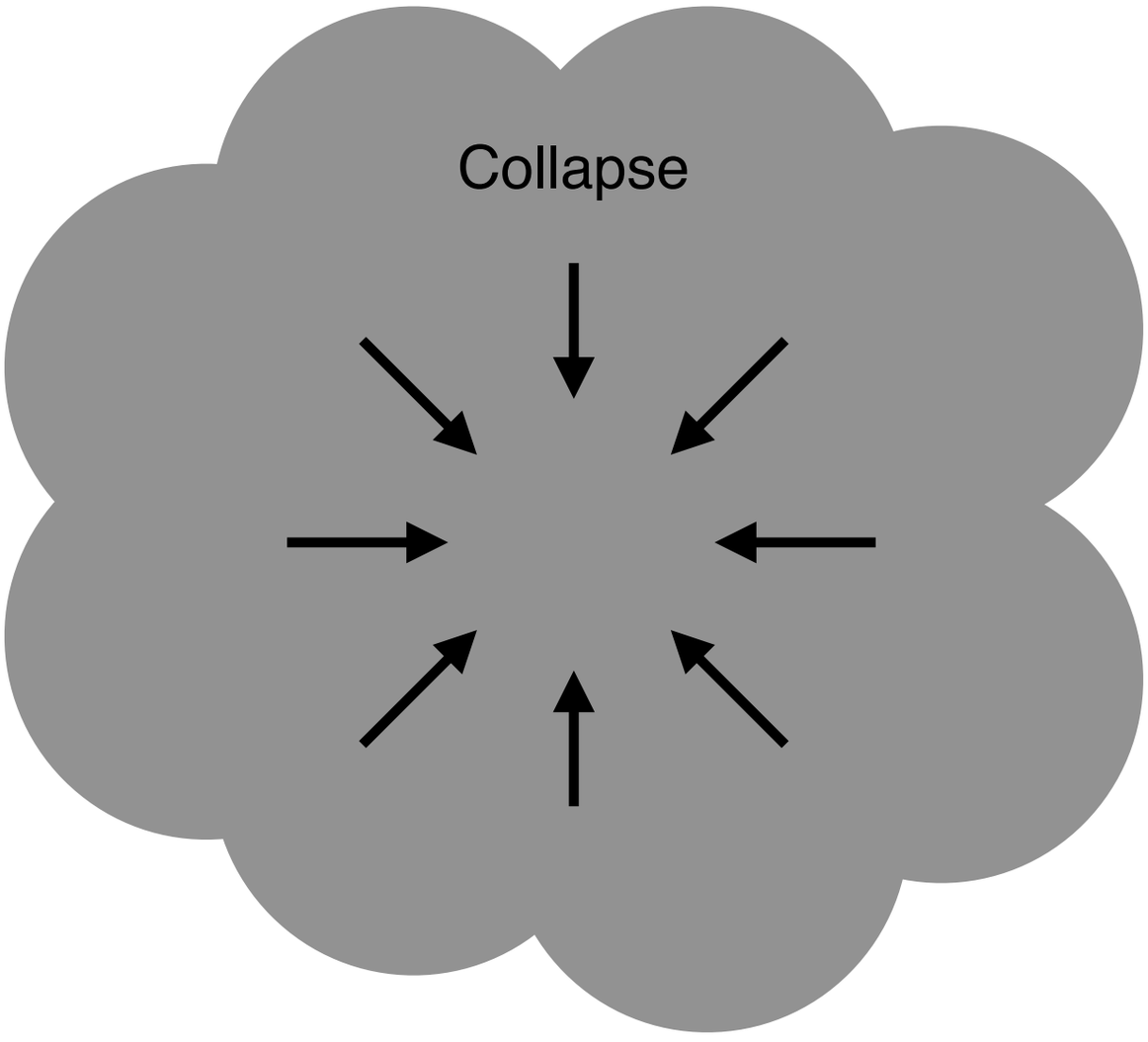
Molecular cloud

Grain

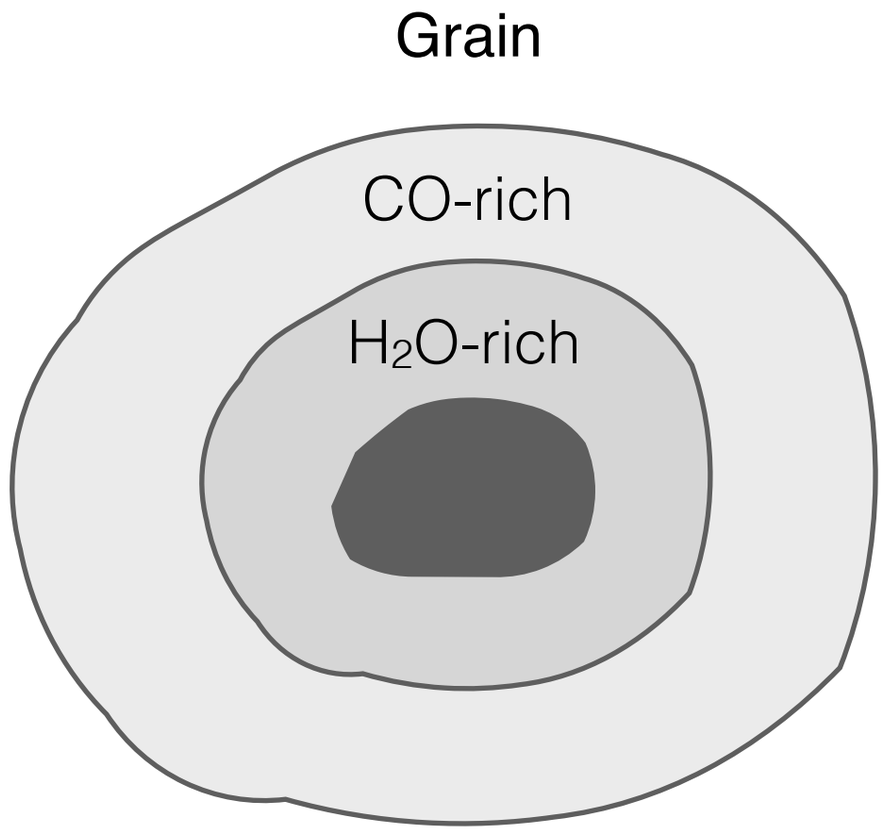


Star formation and chemistry

Stage of star formation

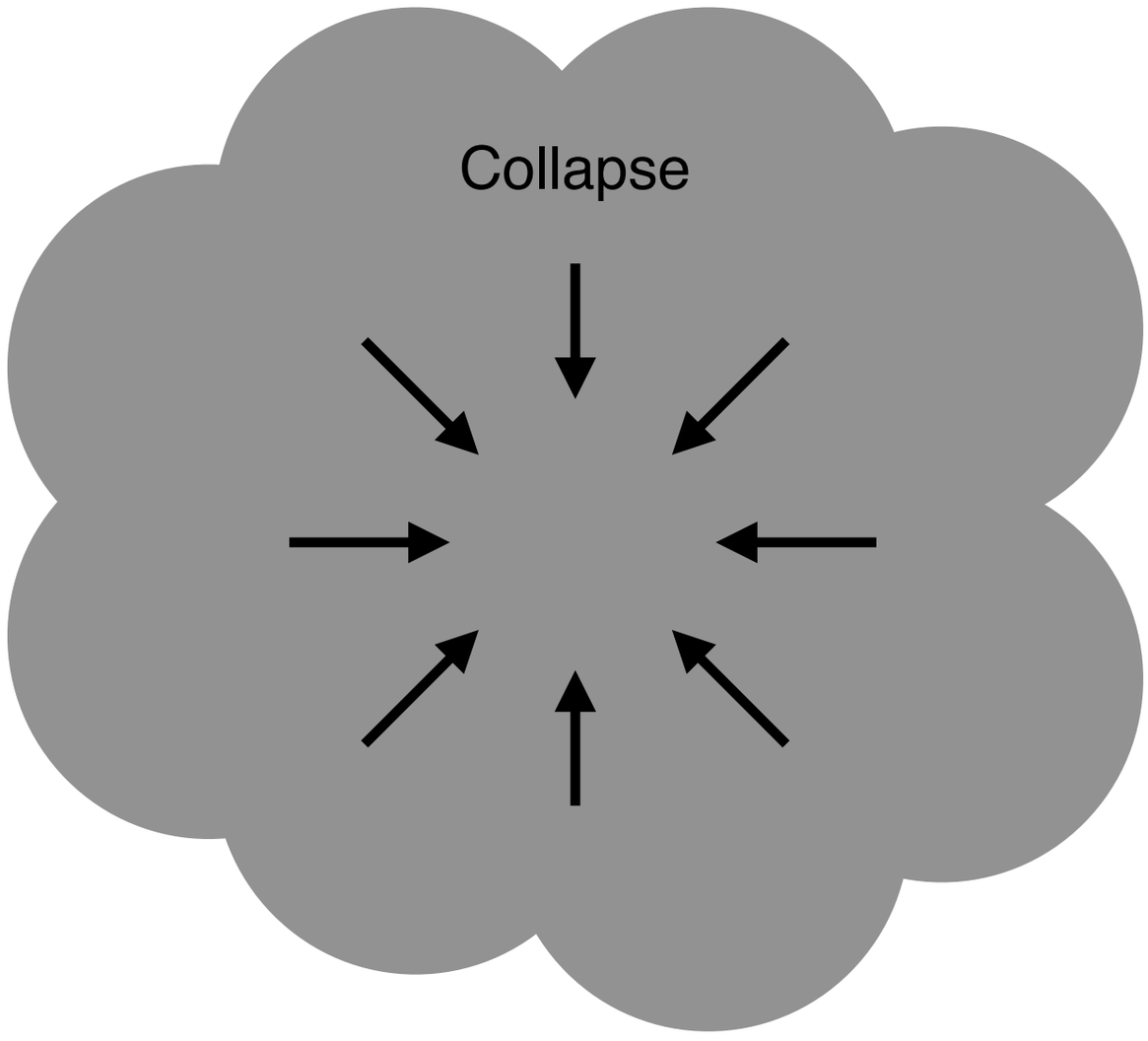


Chemistry



Star formation and chemistry

Stage of star formation



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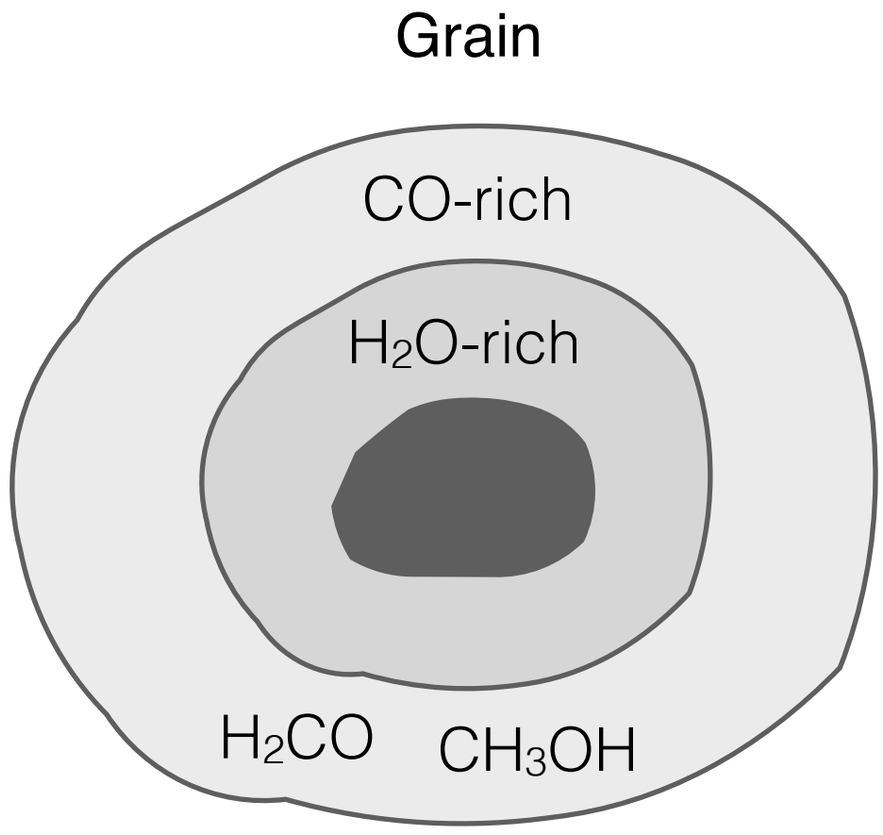
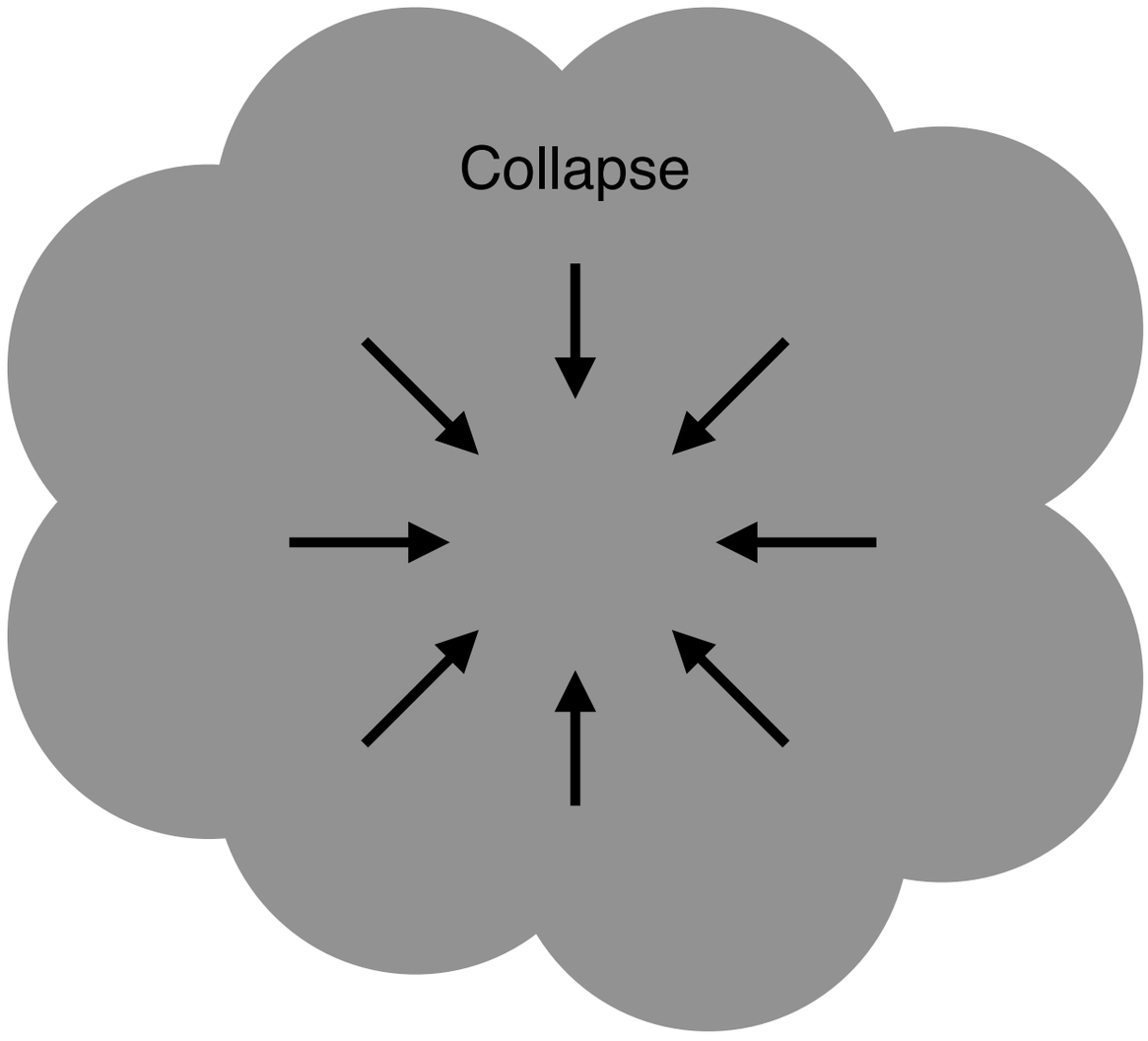


Star formation and chemistry

Stage of star formation



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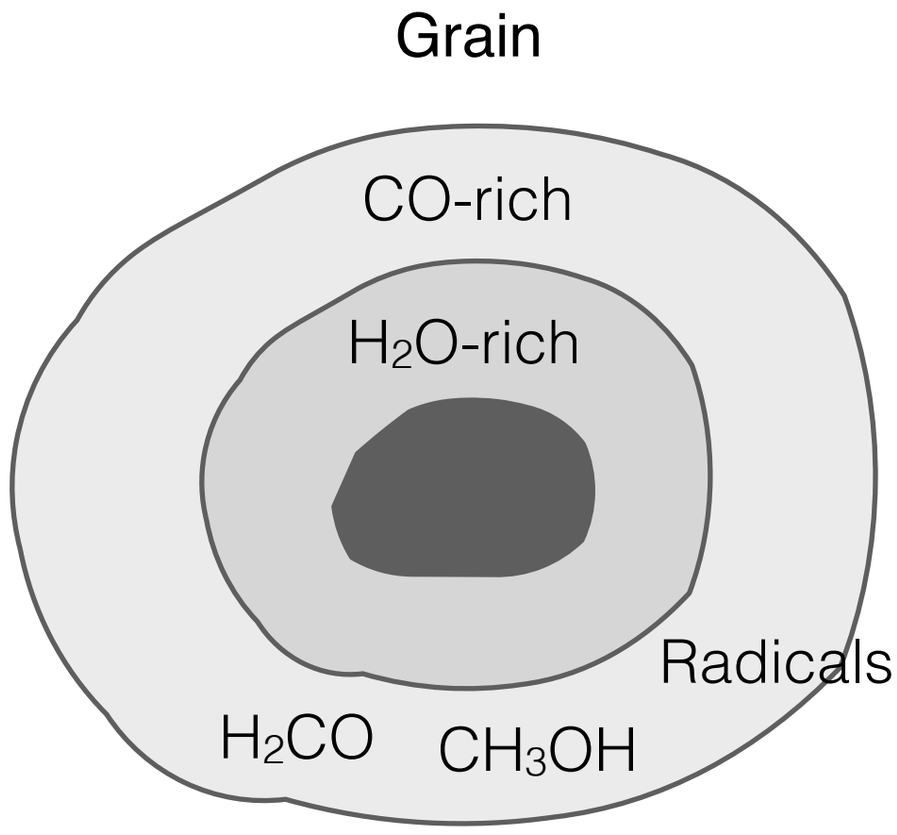
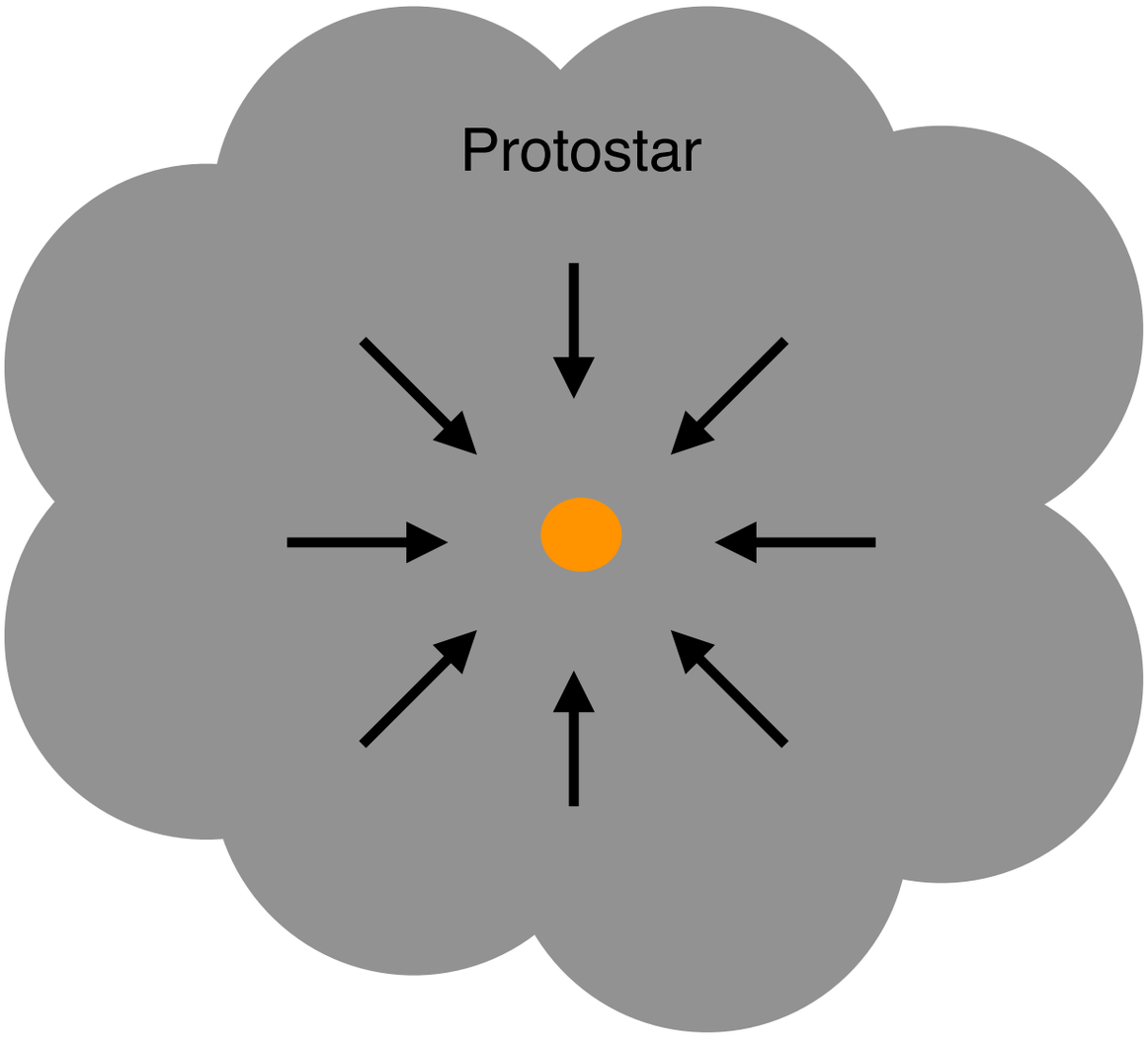


Star formation and chemistry

Stage of star formation



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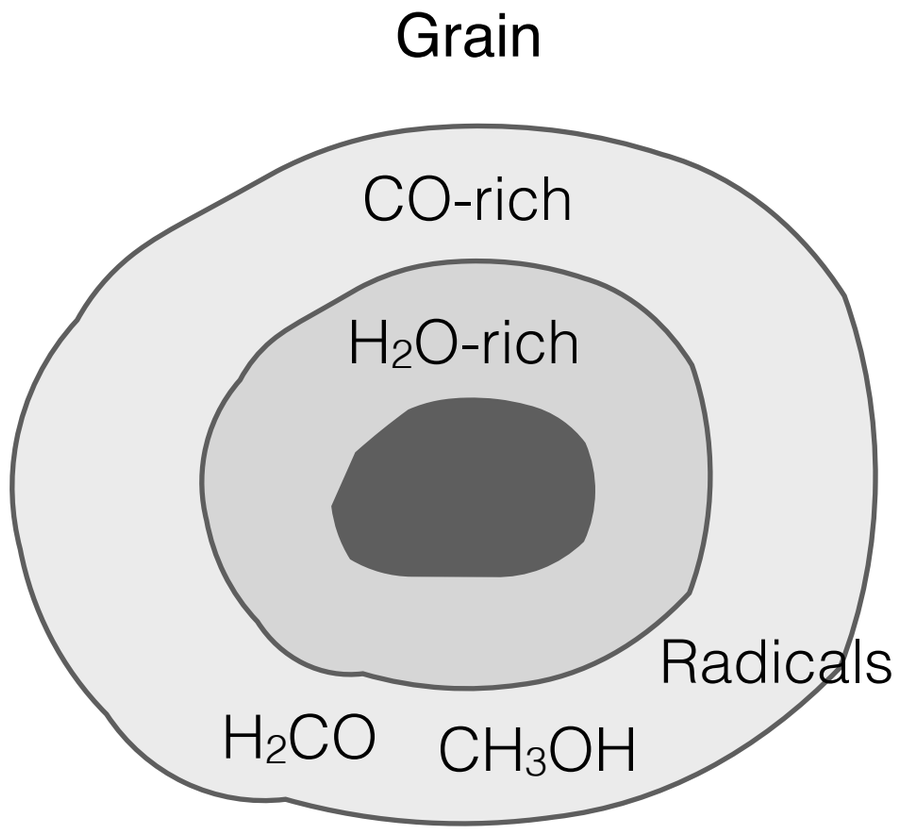

Star formation and chemistry

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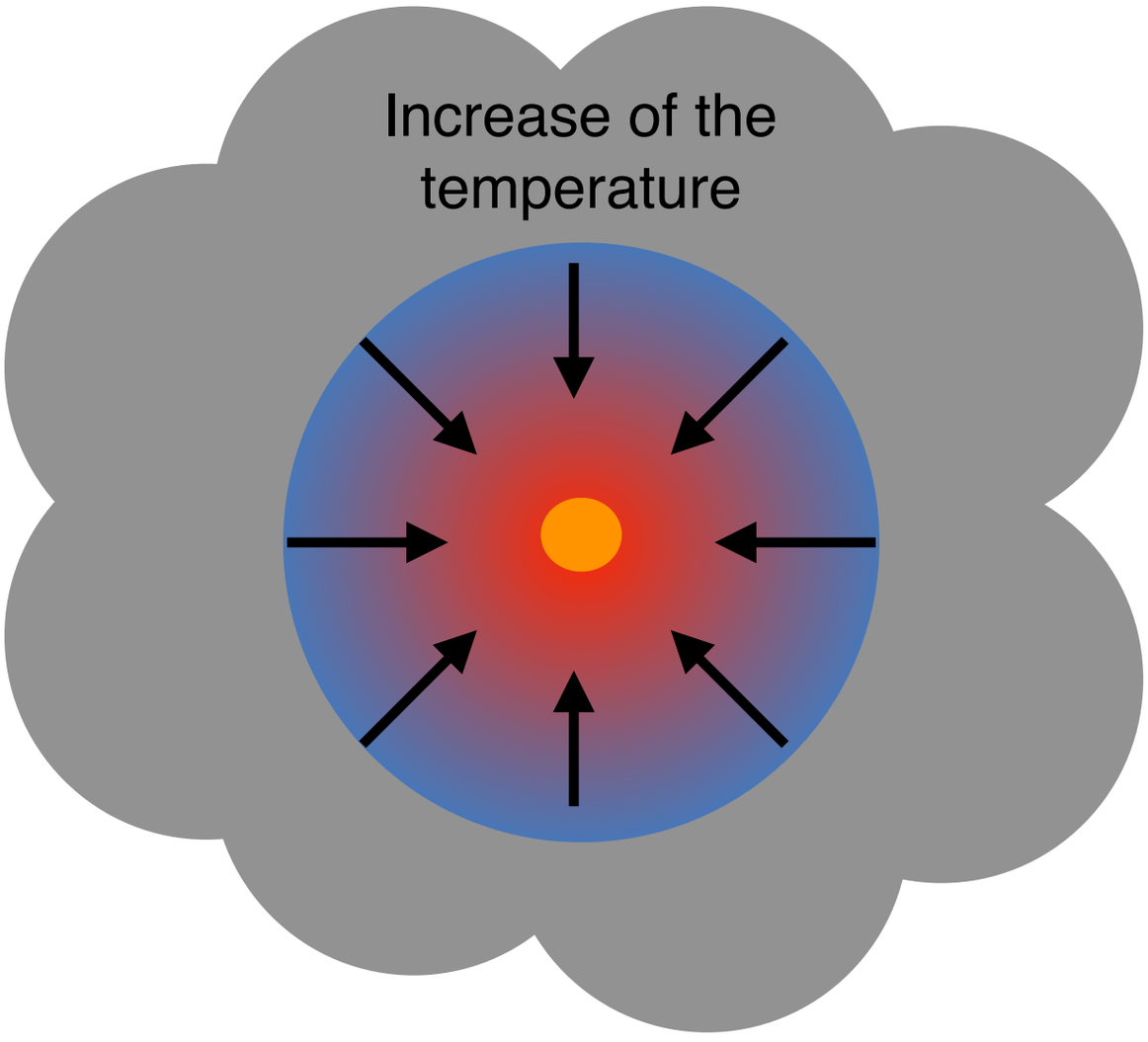
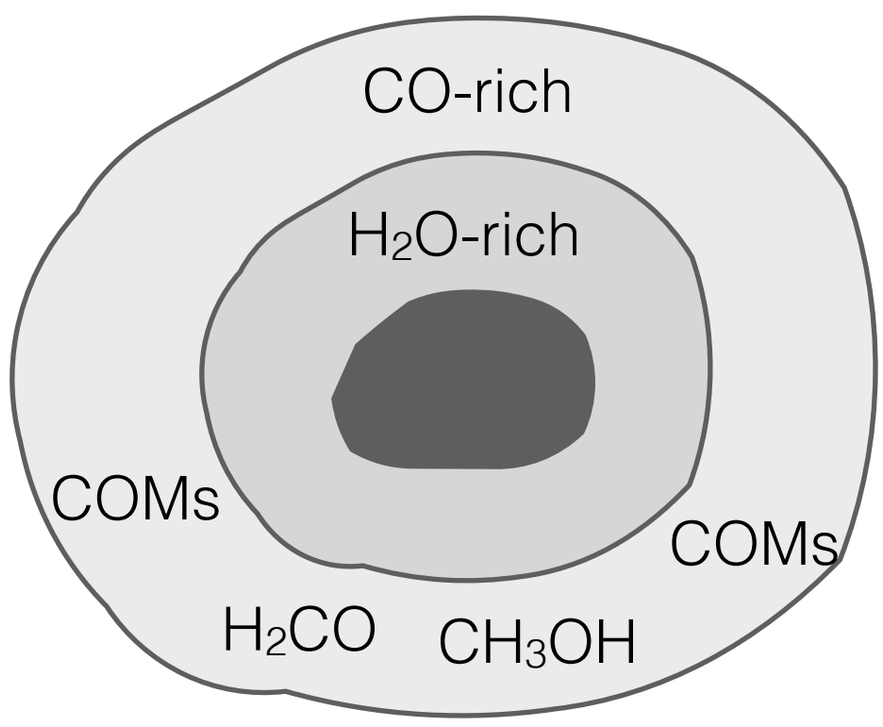
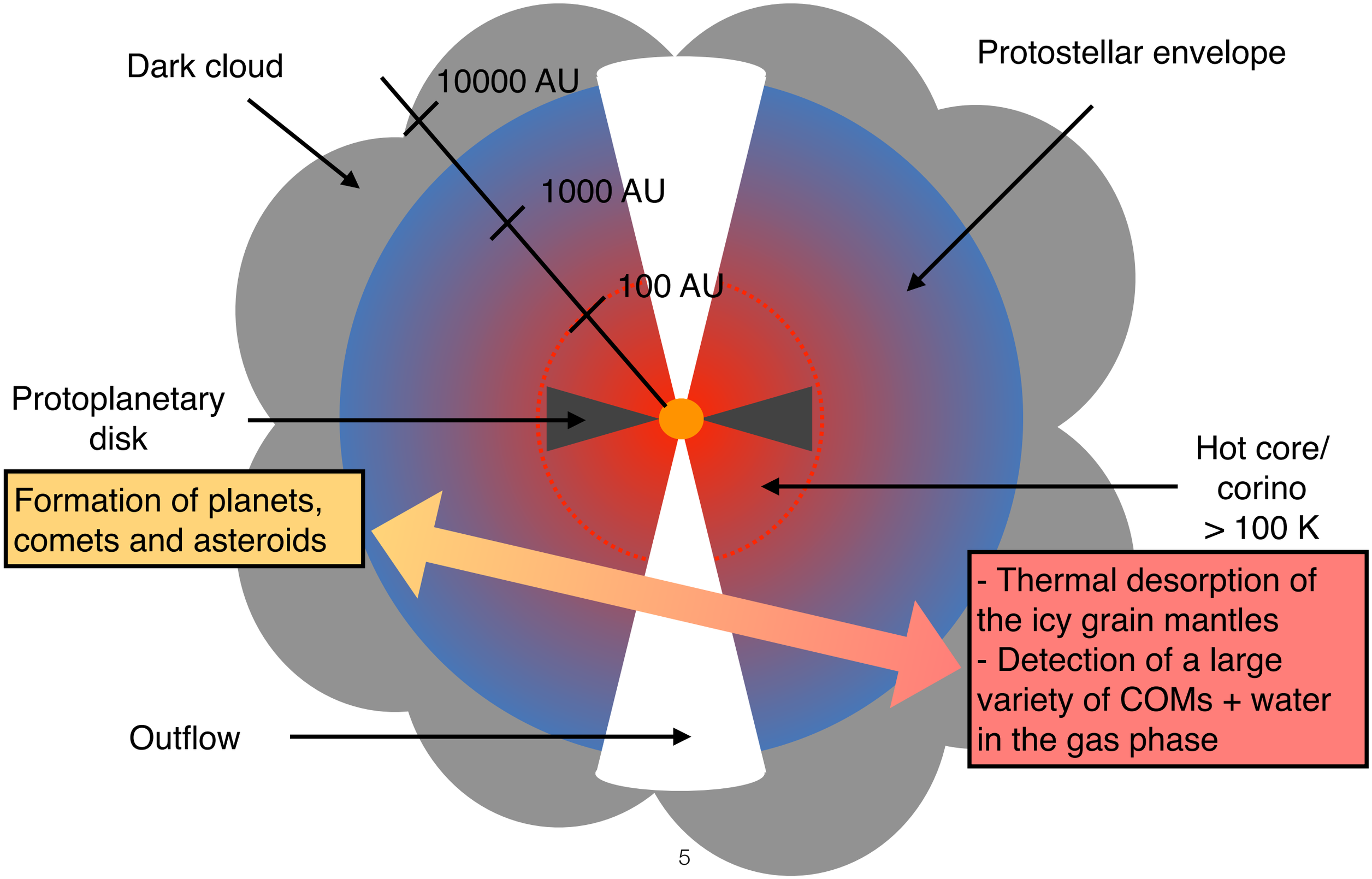


Chemistry



Diffusion of the radicals and formation of the complex organic molecules

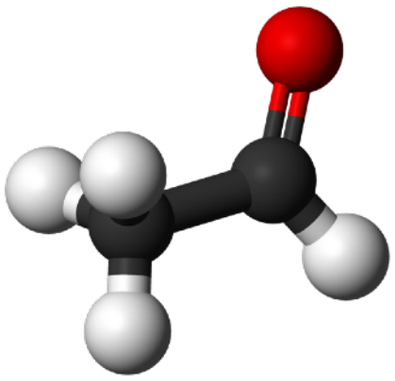
Star formation and chemistry



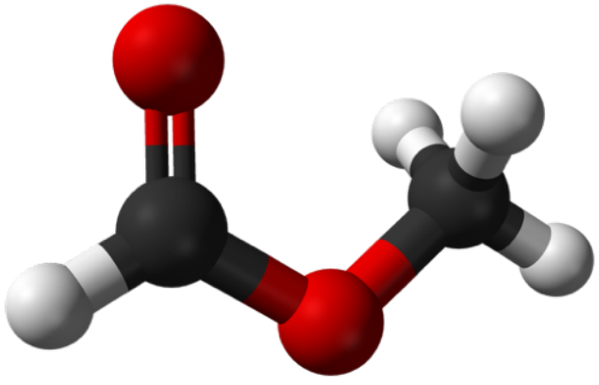
How complex is the chemistry in hot cores and hot corinos ?

- A lot of COMs detected first towards high mass star-forming regions
- First COMs detected in solar-type protostars in 2003 (Cazaux et al.)

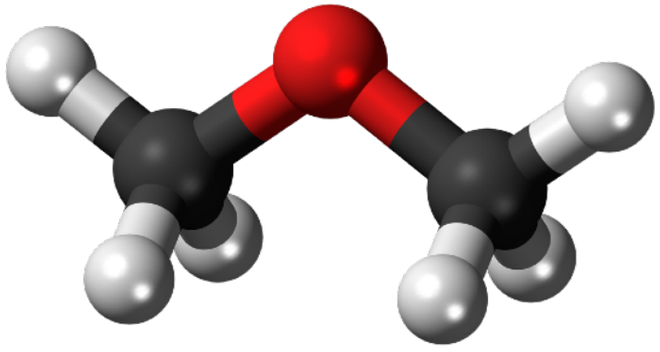
➡ Solar-type protostars can be as rich as the high mass versions



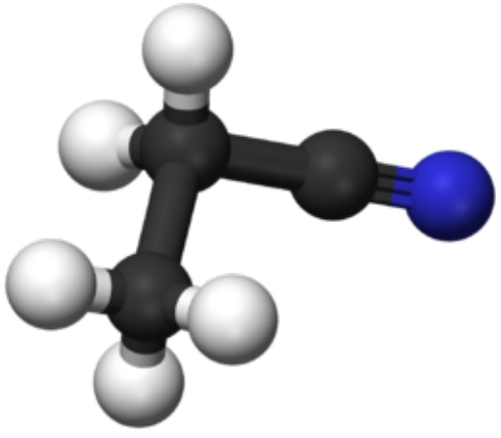
Acetaldehyde



Methyl formate



Dimethyl ether



Ethyl cyanide

New detections with ALMA and NOEMA

- Very high spatial resolution

  Sources spatially resolved

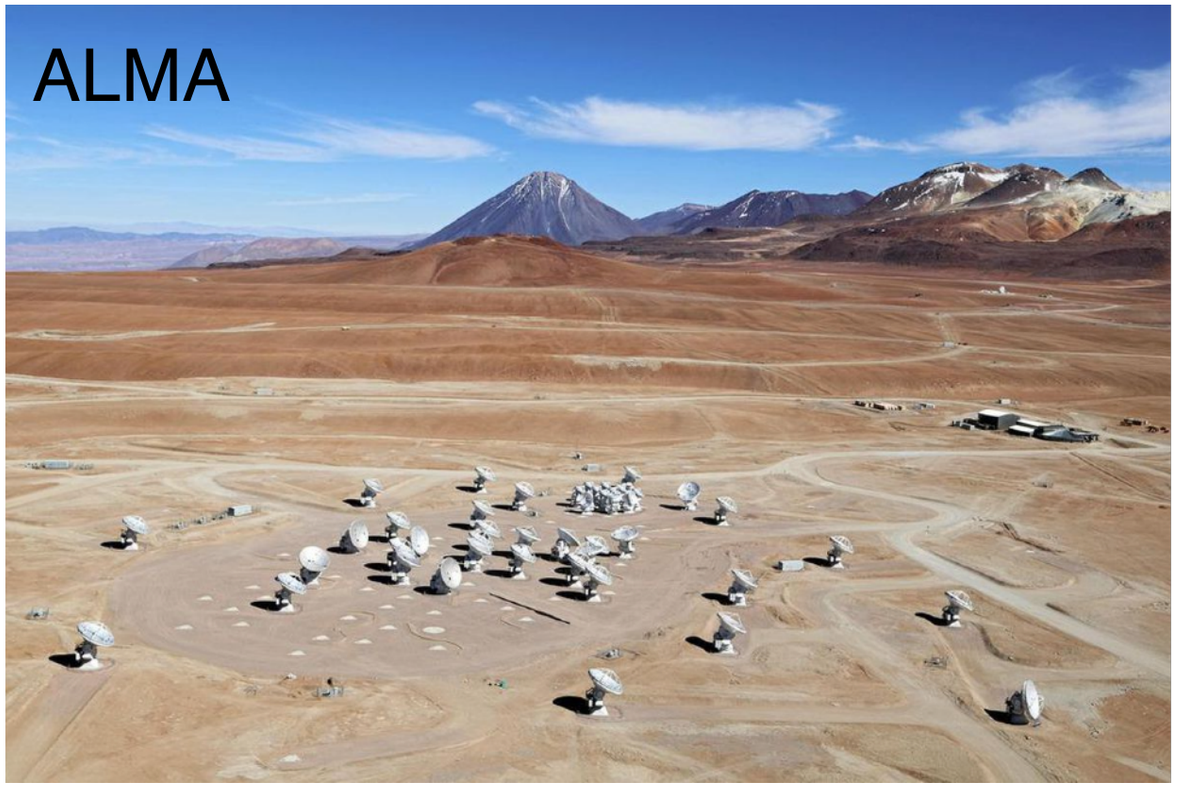
- High sensibility

  Detection of less abundant species

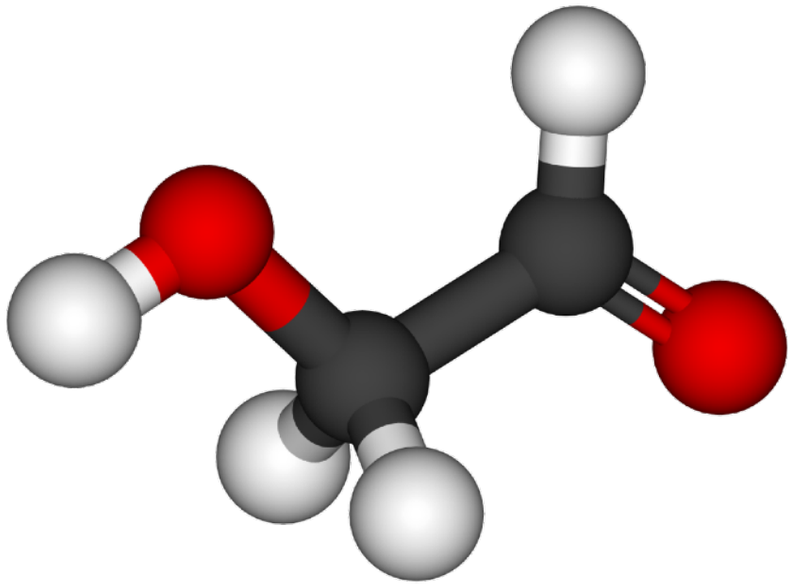
- Broad spectral coverage with high spectral resolution

  More lines to confirm detections

→ Revolutionizing our understanding of the complex chemistry in star-forming regions



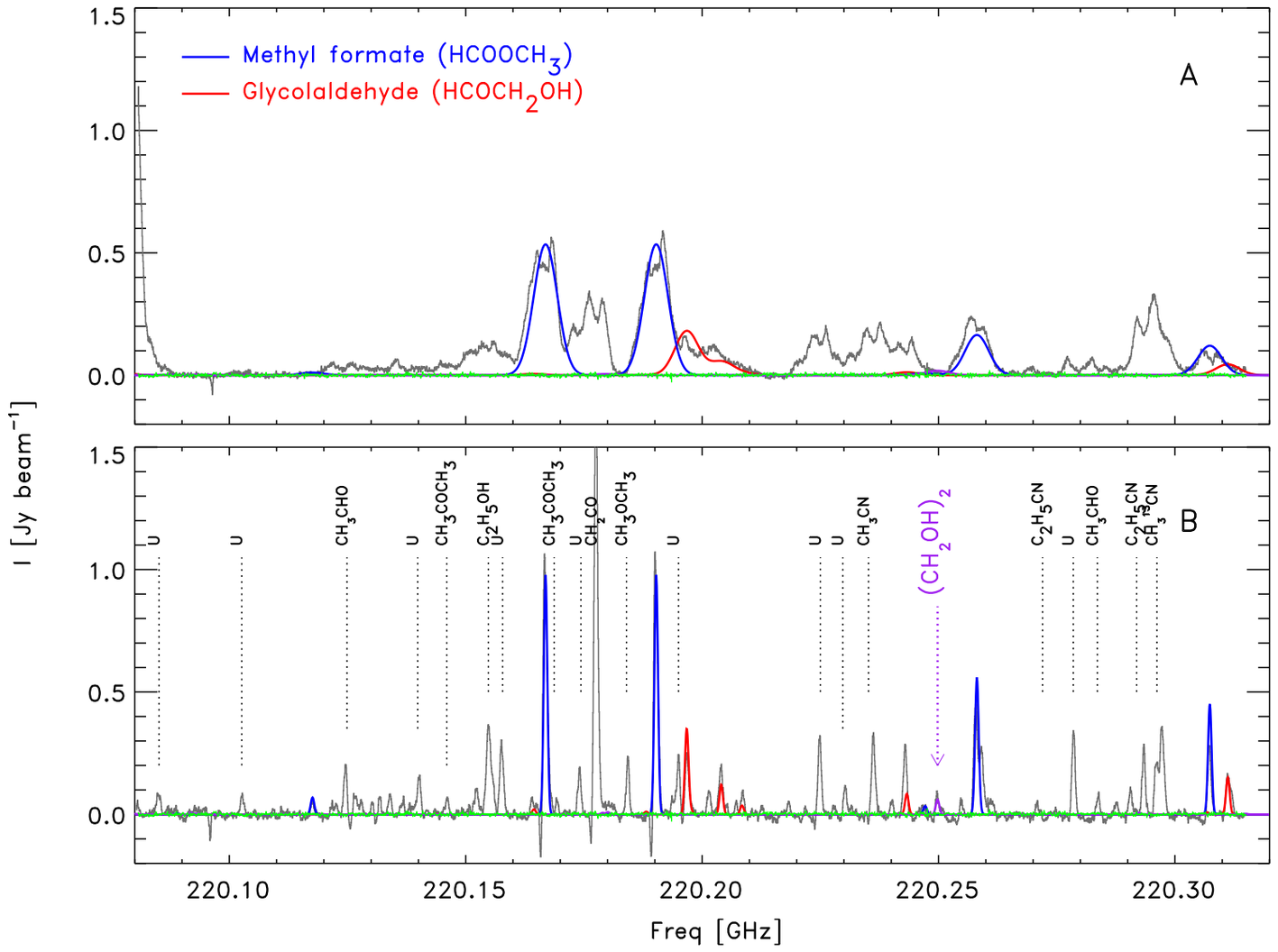
First detection of glycolaldehyde towards a solar-type protostar



CH_2OHCHO Glycolaldehyde

- Prebiotic molecule
- Simplest sugar
- First product in the formation of ribose (essential constituent of RNA)

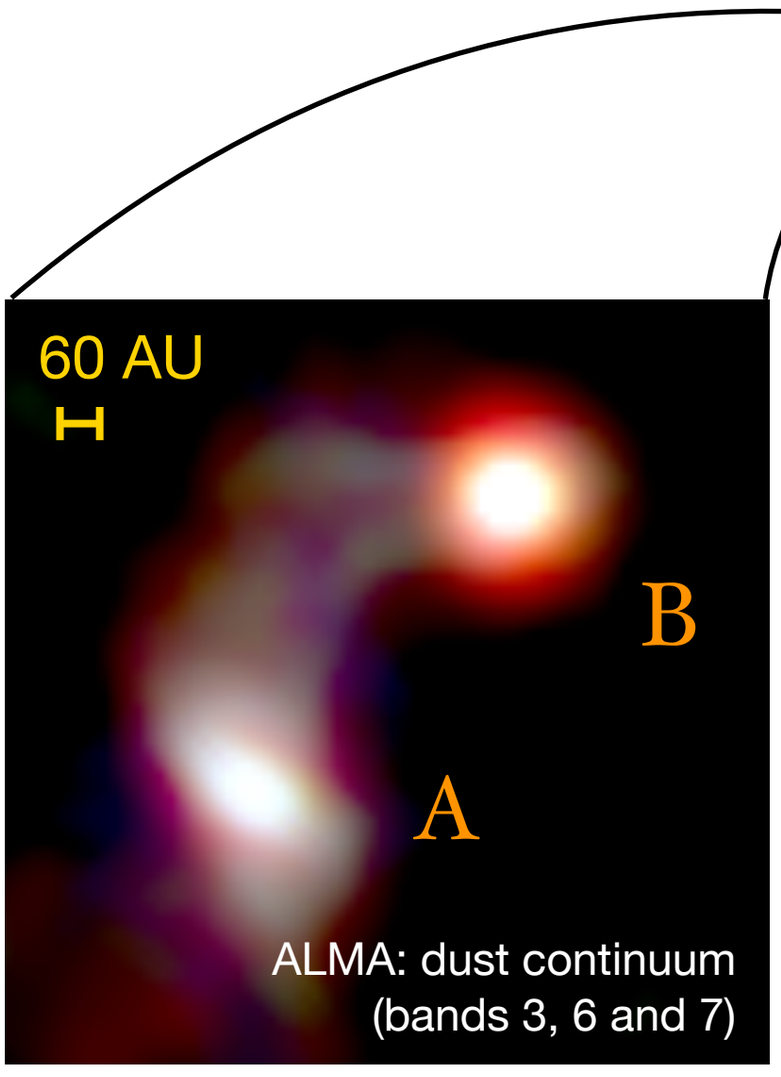
IRAS 16293-2422
ALMA Science verification data



Jørgensen et al. 2012

The ALMA-PILS survey

Solar-type protostar
IRAS 16293-2422
(d = 141 pc)

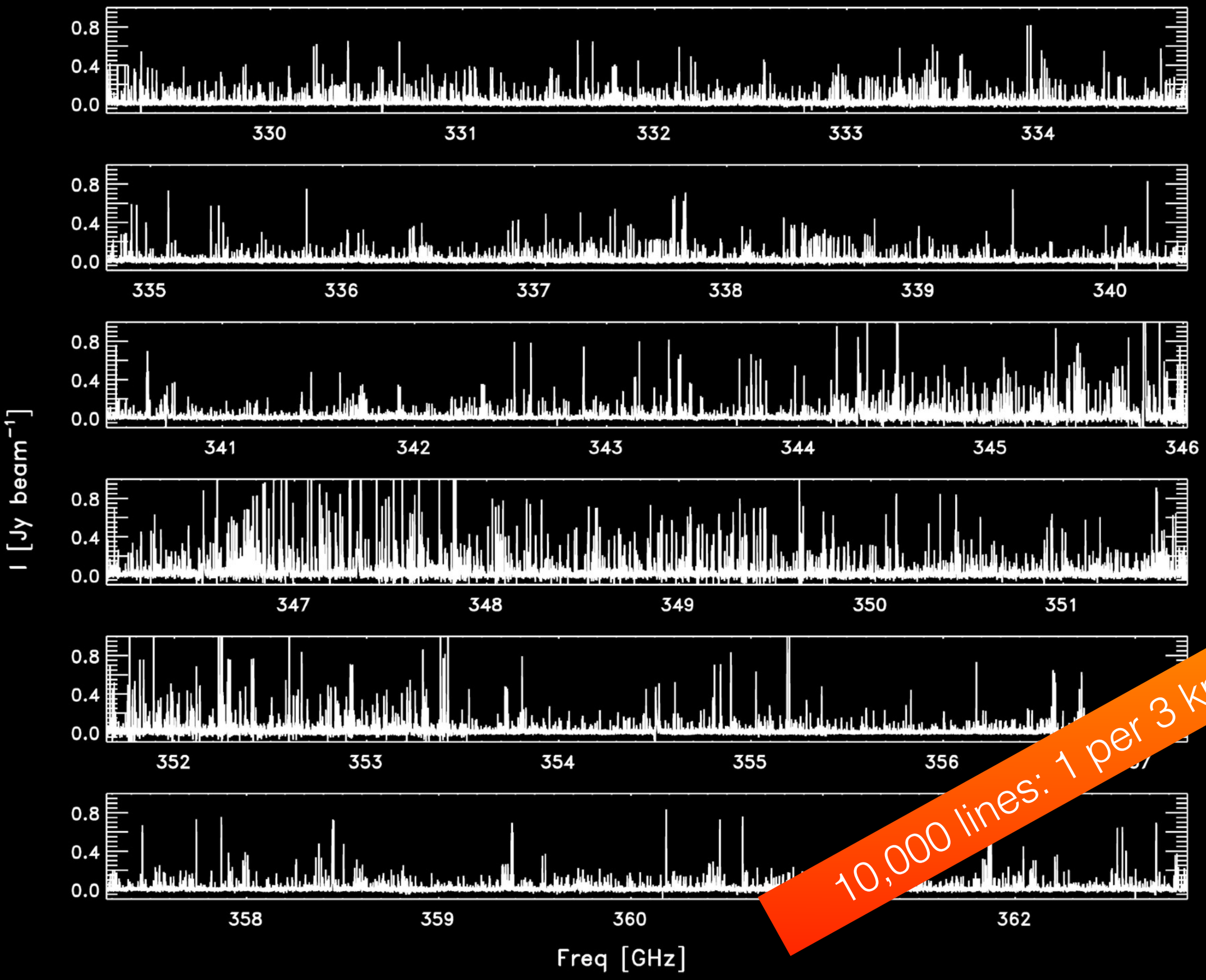


PILS : *Protostellar Interferometric Line Survey*
(Jørgensen et al. 2016)

Spectral survey with ALMA: 329-363 GHz

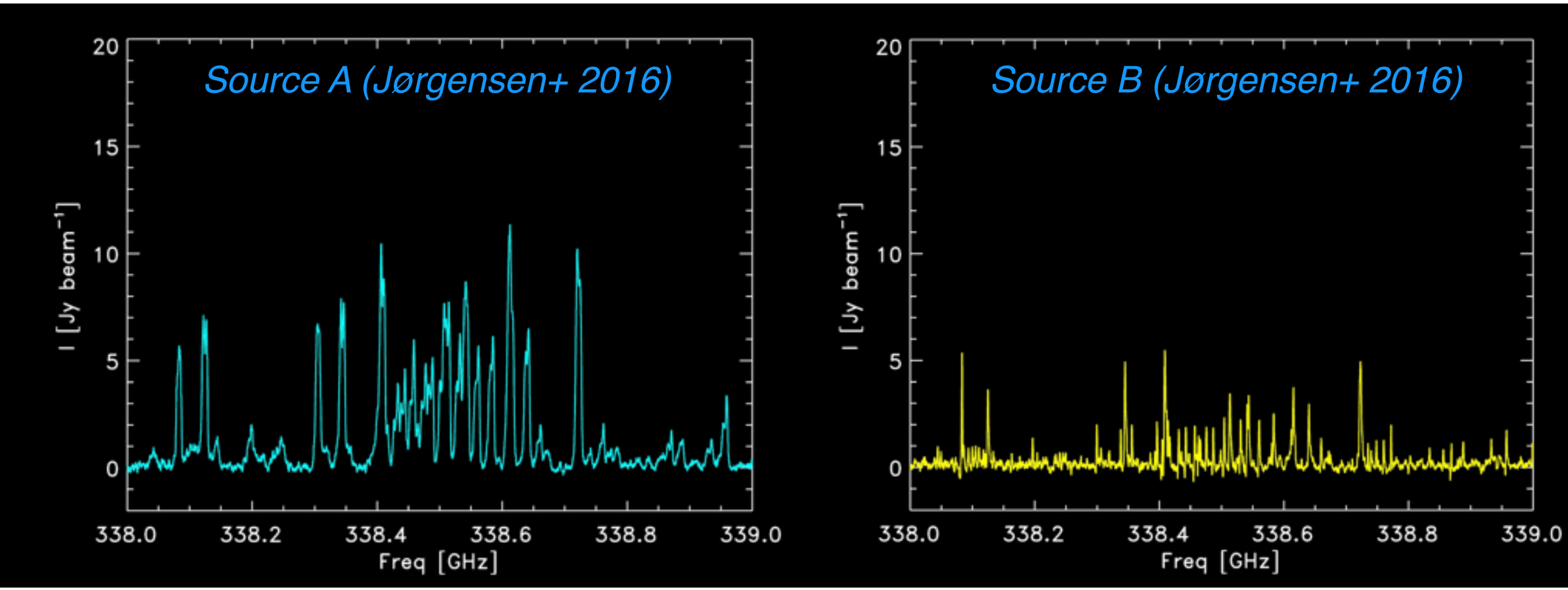
- *Spectral resolution 0.2 km/s*
- *0.5” (60 AU) angular resolution*
- *RMS ~ 5 mJy (1 km/s)*

Spectra of IRAS 16293–2422 (*Jørgensen et al. 2016*)



The ALMA-PILS survey

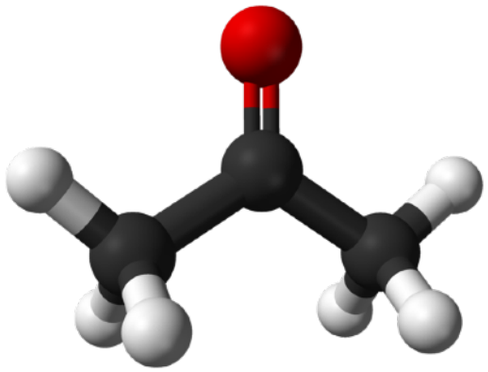
- FWHM ~ 1 km/s towards source B
- FWHM > 3 km/s towards source A
- Less line confusion in source B
- Source B ideal to search for new molecules and isotopologues



PILS : new detections in solar-type protostars

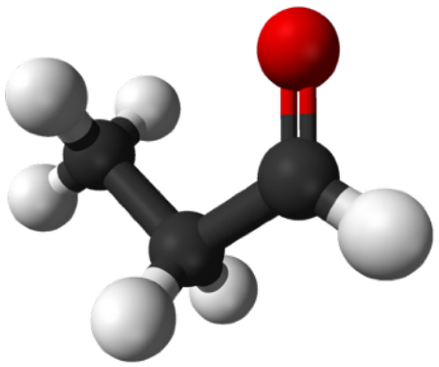
Acetone (CH_3COCH_3)

(detected in comet 67P, Goesmann et al. 2015)

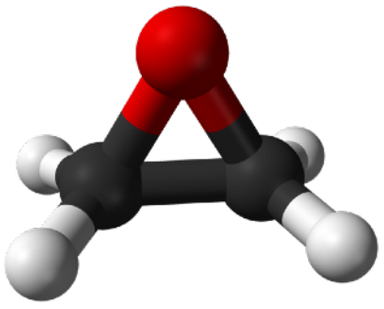


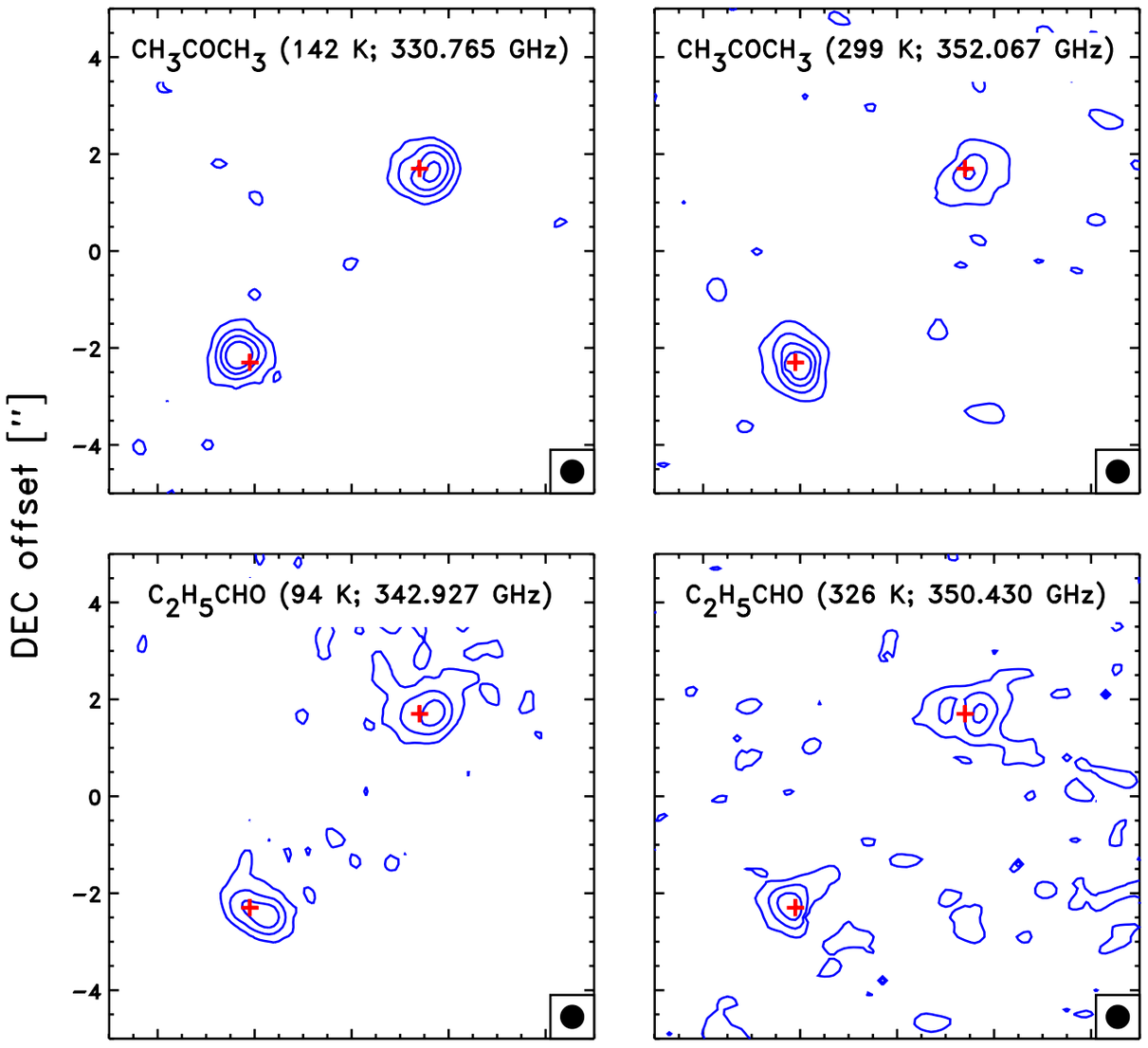
Propanal (CH_3CH_2CHO)

(detected in comet 67P, Goesmann et al. 2015)



Ethylene oxide (C_2H_4O)





Lykke et al. 2017

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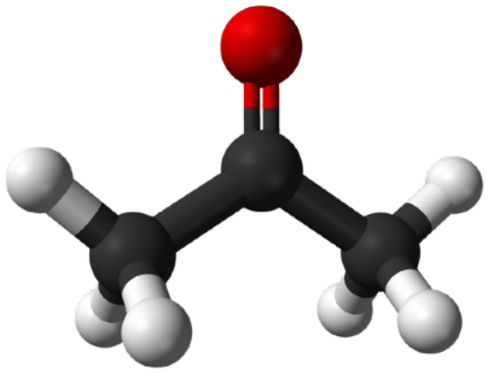

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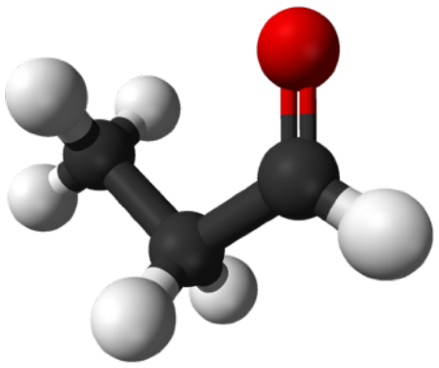

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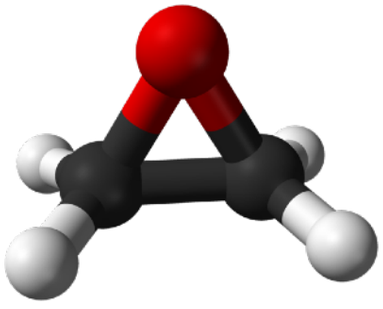
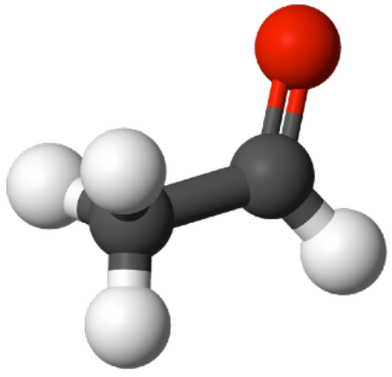
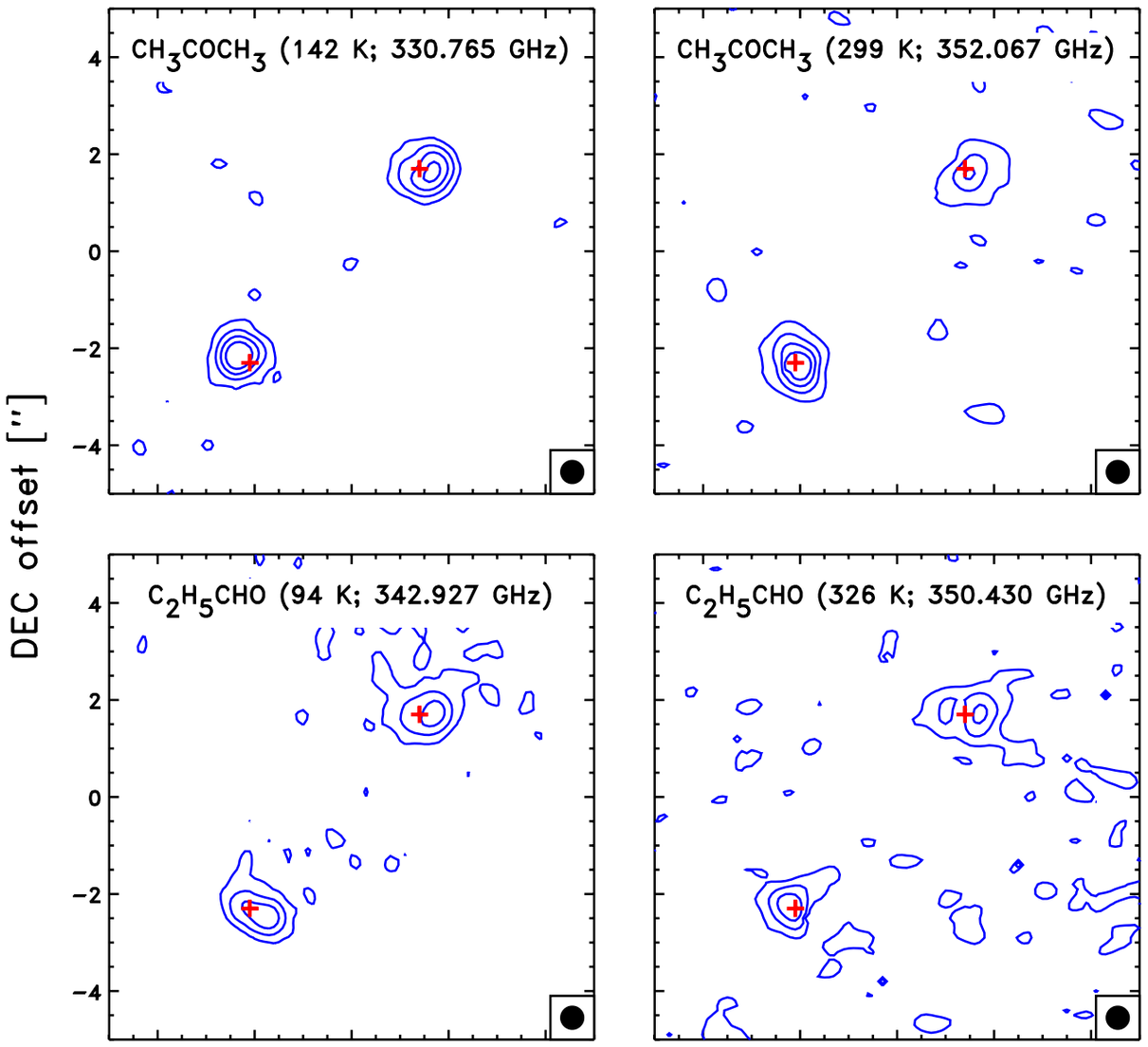


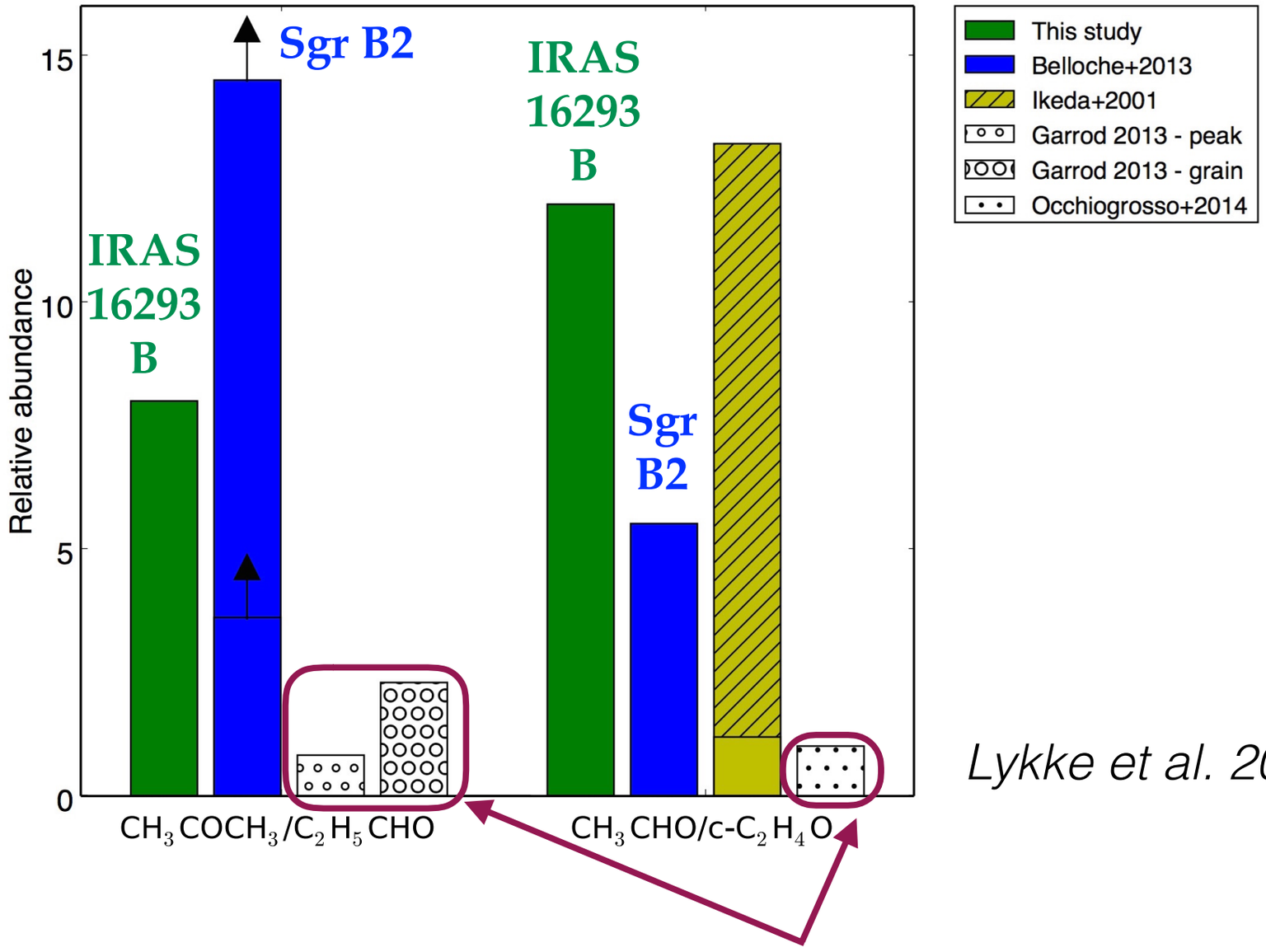
Acetaldehyde (CH_3CHO)





Lykke et al. 2017

PILS : new detections in solar-type protostars



Lykke et al. 2017

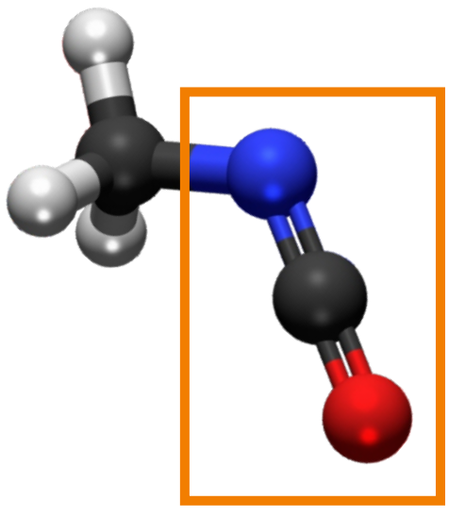
Chemical models

A revision of the formation (and destruction) pathways of these species is needed.

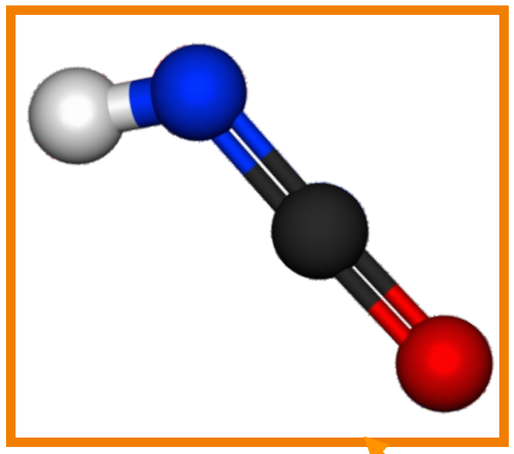
PILS : new detections in solar-type protostars

Methyl isocyanate

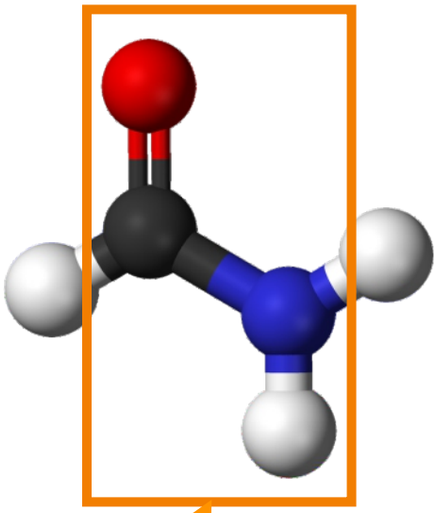
CH_3NCO



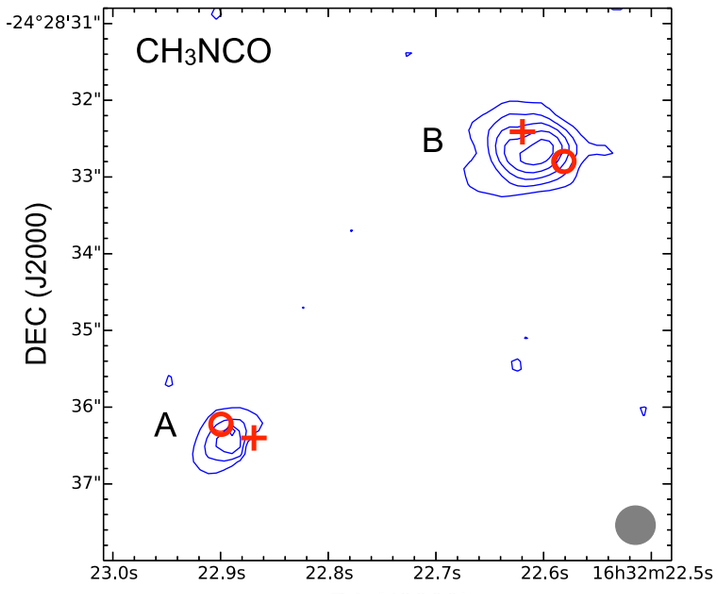
HNCO

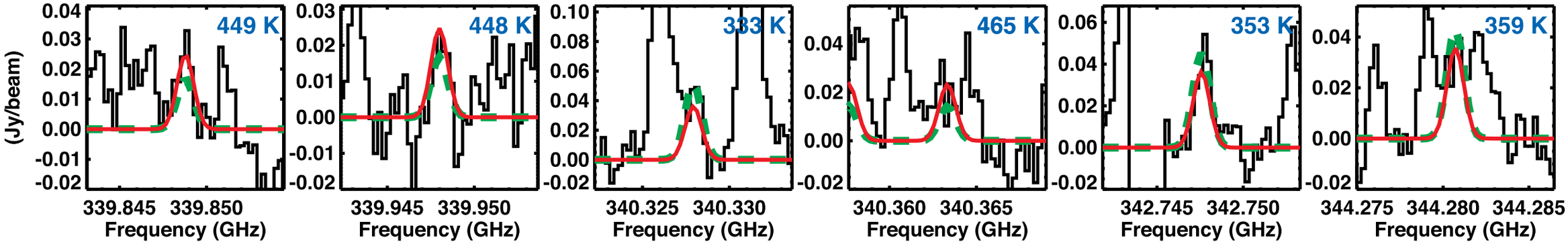


NH_2CHO



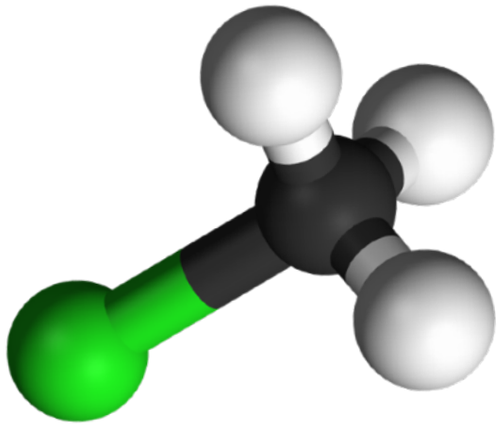
Peptide bond
(synthesis of proteins)





Ligterink et al. 2017

PILS : new detection in the interstellar medium



Methyl chloride (Freon-40)

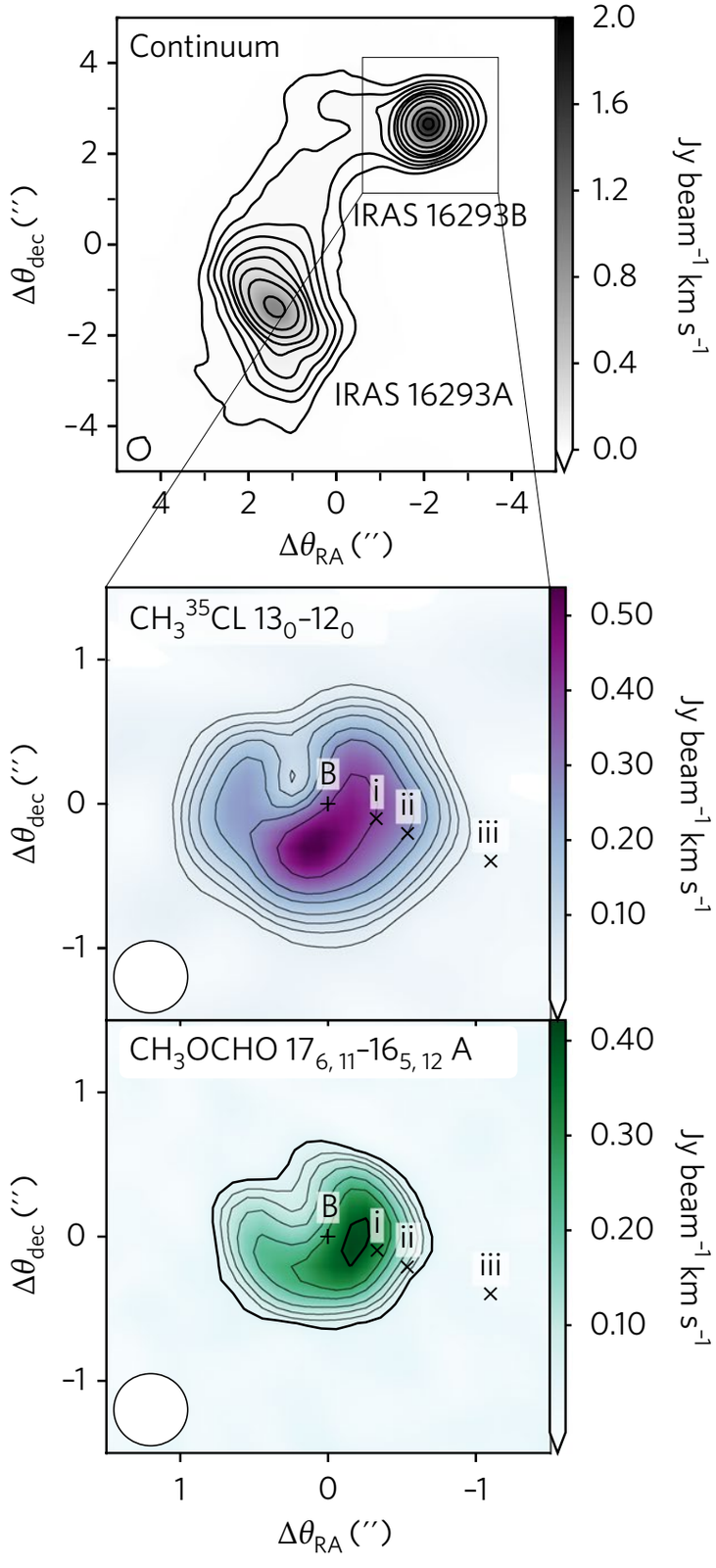
CH_3Cl

- Produced on Earth through biological and industrial processes

- Previously considered as a biomarker in the search for Life on exoplanets

Detection towards both IRAS 16293-2422 and comet 67P (*Fayolle et al. 2017*)

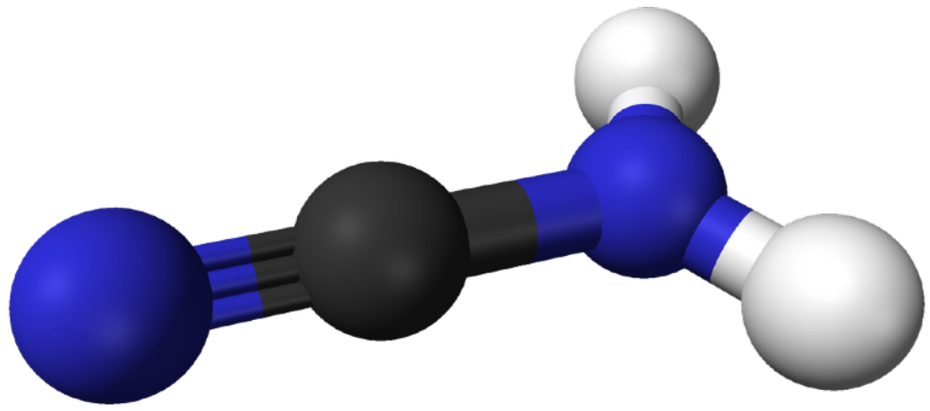
➡ Abiotic formation in the interstellar medium



Cyanamide

Previous detections

- Milky Way : massive star-forming regions Sgr B2 and Orion KL
- Extragalactic medium : NGC 253 and M82



NH_2CN

Prebiotic chemistry

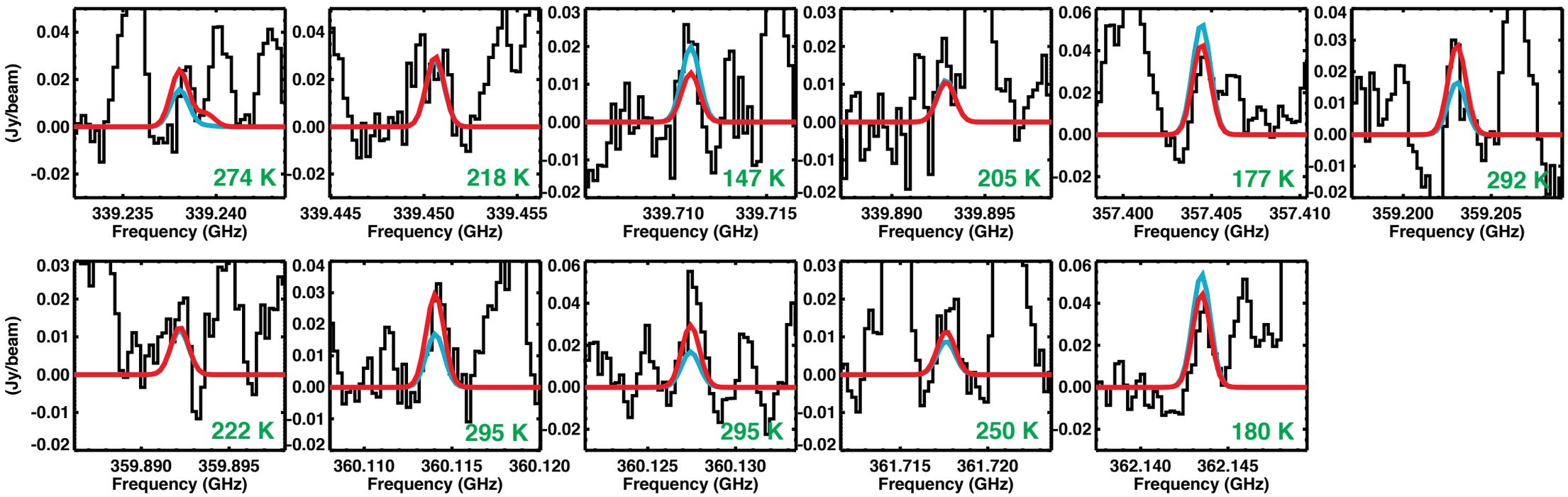
- In liquid water, conversion into **urea**
- Isomerisation into **carbodiimide (HNCNH)** in photochemically and thermally induced reactions in interstellar ice analogs (*Duvernay et al. 2005)*

→ Molecules with the carbodiimide moiety (–NCN–) find use in various biological processes (e.g., assembly of amino acids into peptides)

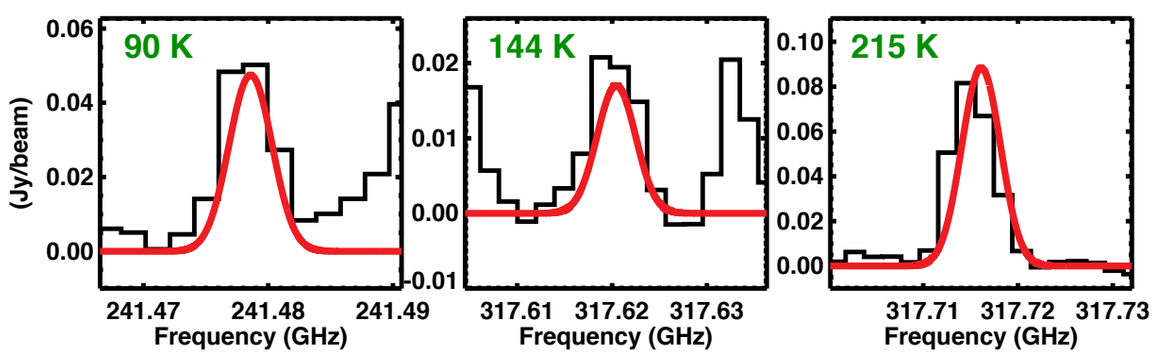
First detection of cyanamide in solar-type protostars

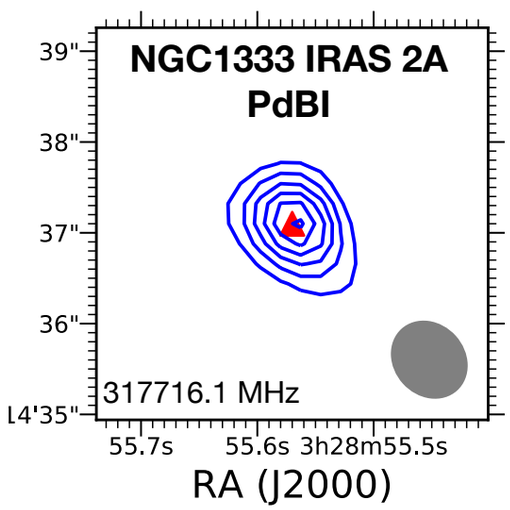
IRAS16293-2422 (ALMA-PILS)

Coutens et al. 2018



NGC1333 IRAS2A





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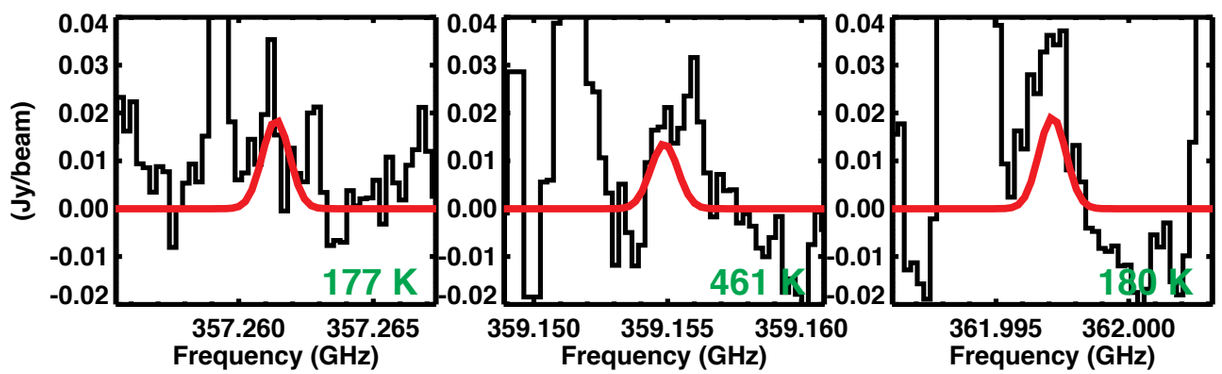
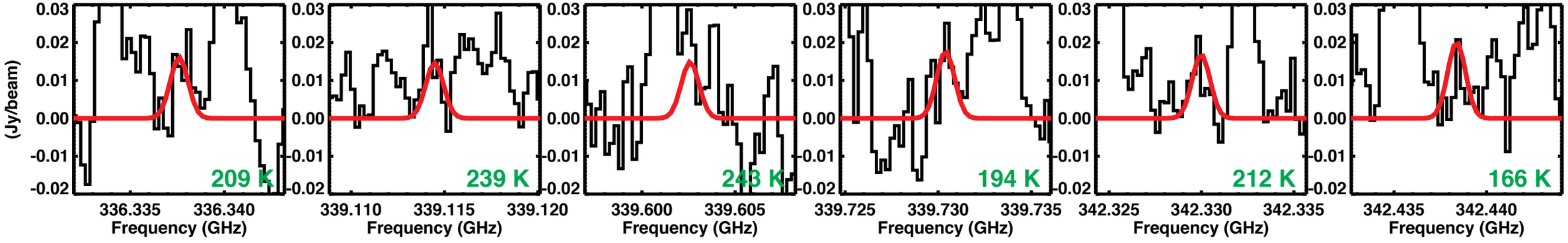
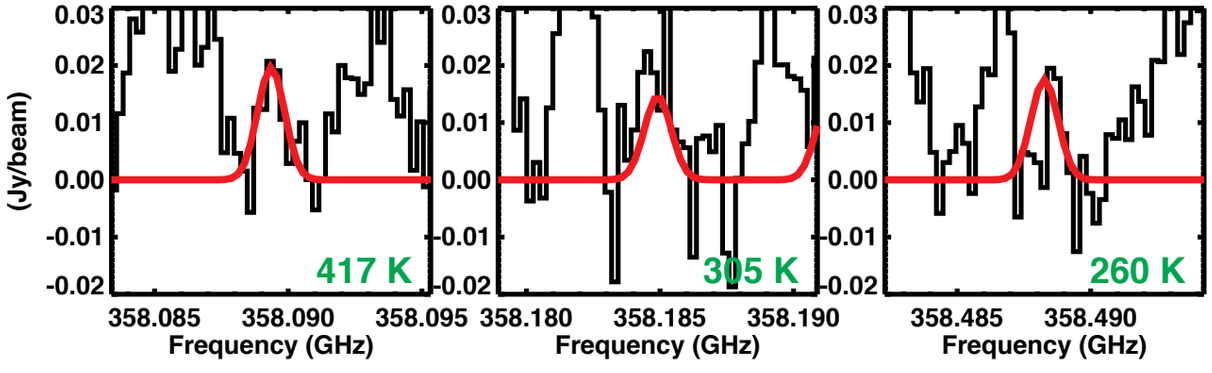


$NH_2{}^{13}CN$



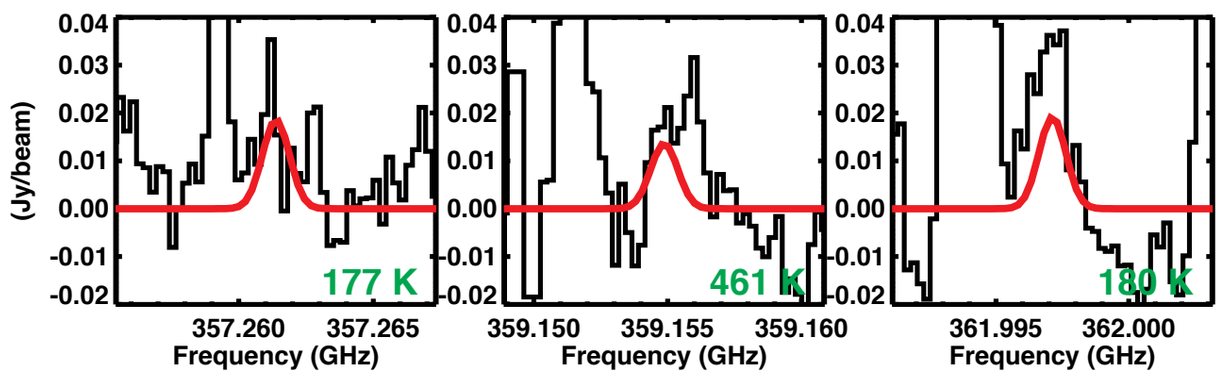


NHDCN (first detection in the ISM)

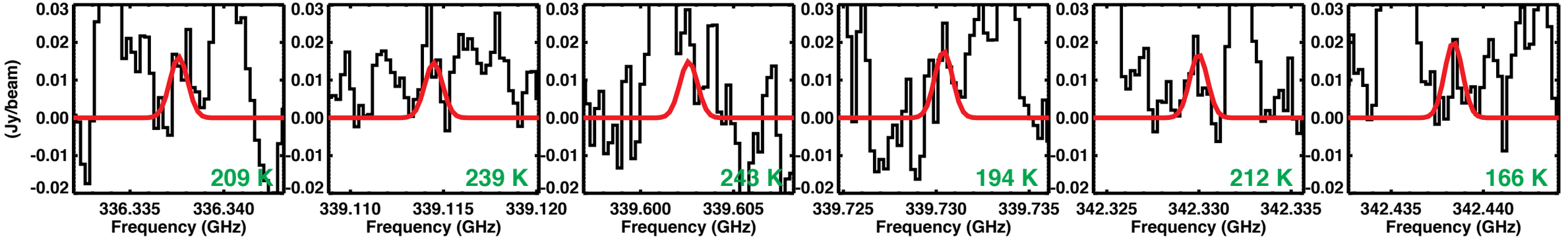
First detection of cyanamide in solar-type protostars

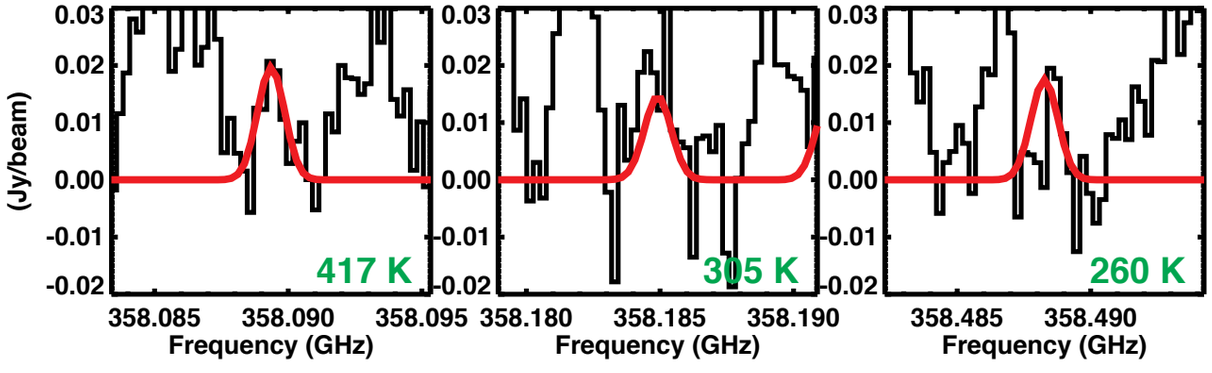
IRAS16293-2422 (ALMA-PILS)

Coutens et al. 2018



$NH_2{}^{13}CN$





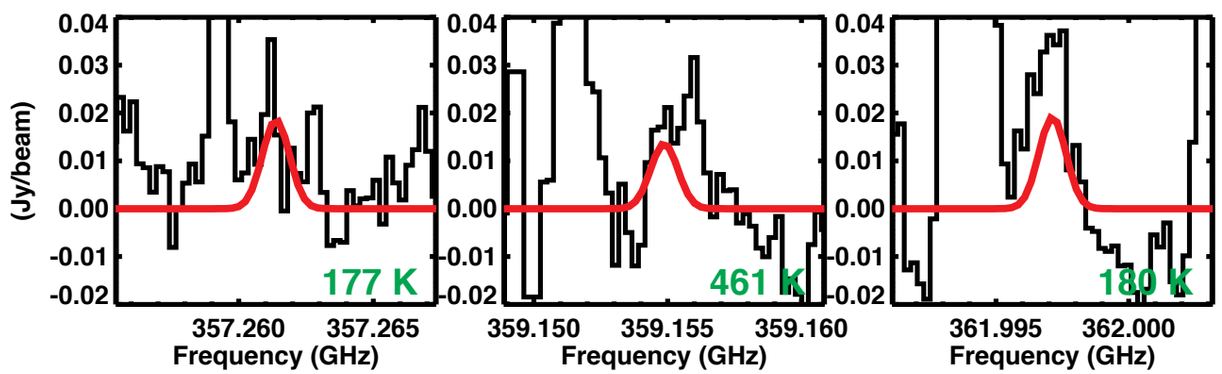
NHDCN (first detection in the ISM)

Other first detections of deuterated COMs in the ALMA-PILS survey :
- Formamide (*Coutens et al. 2016*)
- Glycolaldehyde (*Jørgensen et al. 2016*)

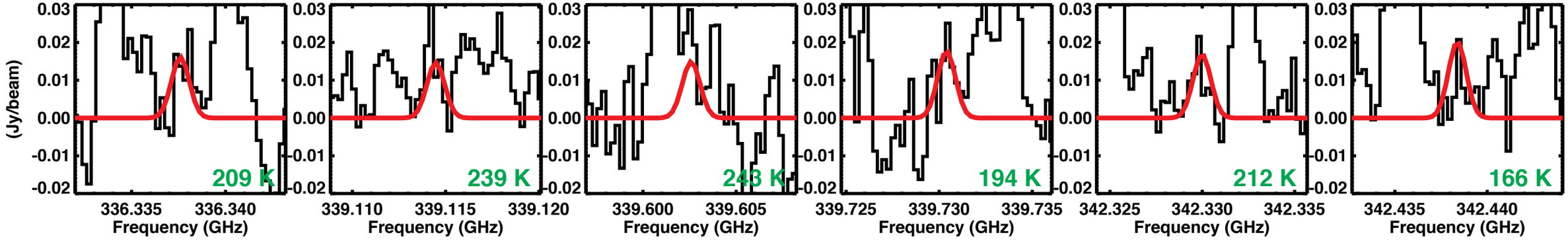
First detection of cyanamide in solar-type protostars

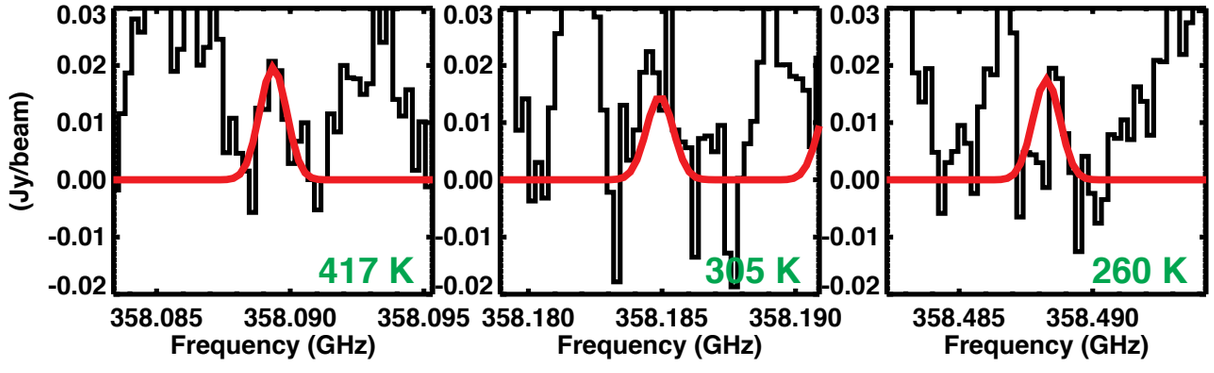
IRAS16293-2422 (ALMA-PILS)

Coutens et al. 2018



$NH_2{}^{13}CN$





NHDCN (first detection in the ISM)

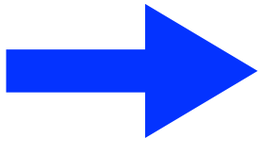
D/H (NH_2CN) ~ 1.7 %
D/H (NH_2CHO) ~ 2 %
D/H (other COMs) ~ 1-8%

Formation pathways of cyanamide

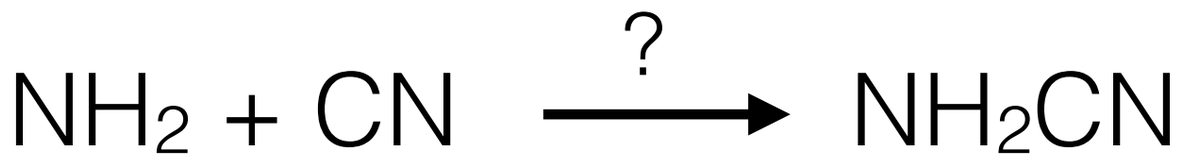
- Gas phase : no formation pathways

- Grain surface : so far not explored

  Observations :
  similar D/H ratio for NH_2CN and NH_2CHO
  + Similar spatial distribution

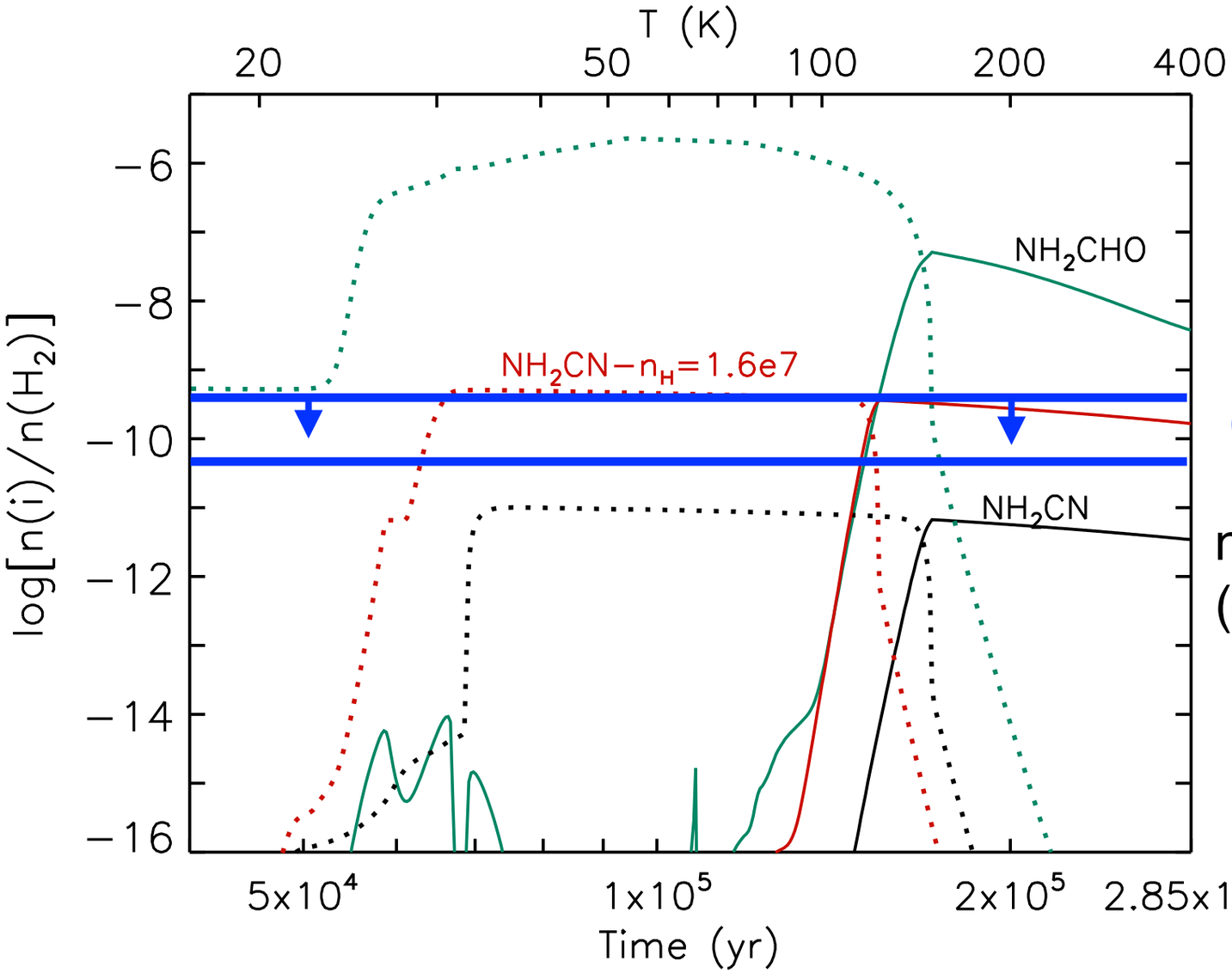


Formation from a same precursor NH_2



Formation pathways of cyanamide

- MAGICKAL gas-grain chemistry code
- Collapse (to n_H) followed by warm-up to 400 K

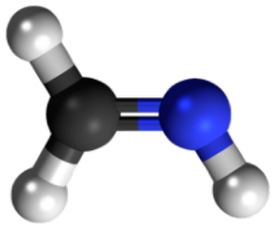


Observations

n_H = 6e10 cm^{-3}
(density IRAS16293B)

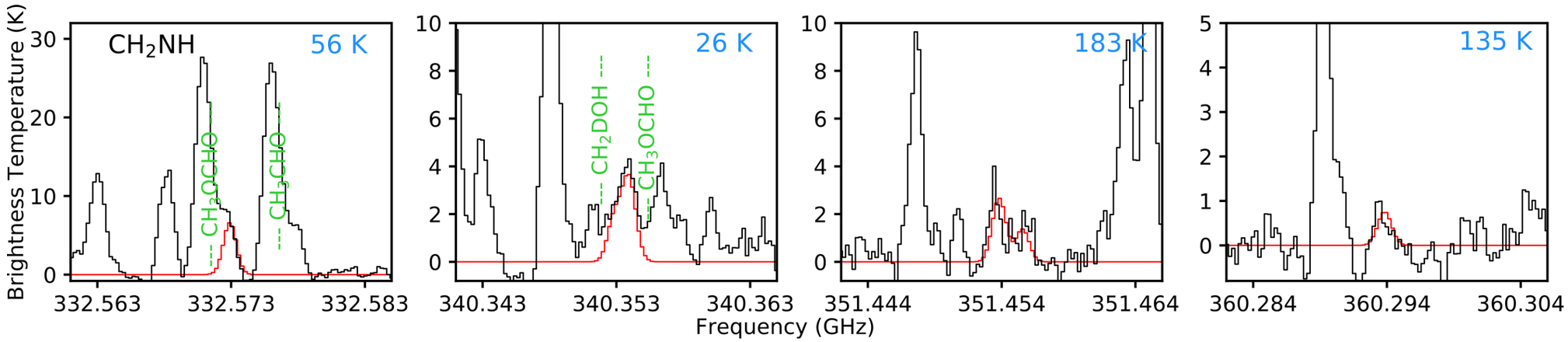
Highlights the necessity for future models of hot cores/corinos to treat the rising density and temperature in such cores concurrently, rather than as a two-stage process

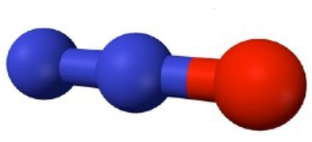
PILS : new detections in solar-type protostars



Methanimine

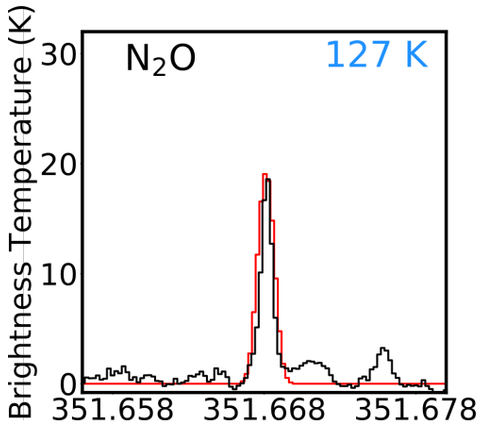
CH_2NH





Nitrous oxide

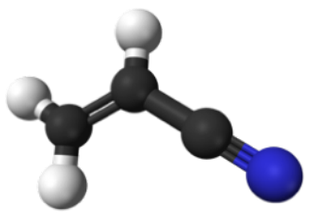
N_2O



CH_3NH_2 and NH_2OH not detected

Ligterink et al. submitted

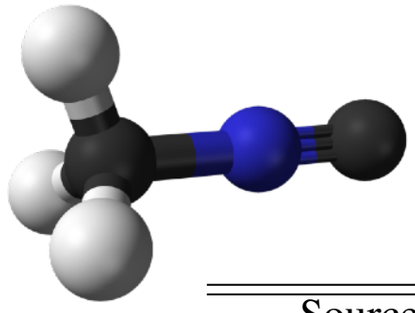
Molecule	Chemical formula	$N_{tot}^{\dagger}$ (cm^{-2})
Nitric oxide	NO	$(1.5-2.5)\times10^{16}$
Nitrous oxide	N_2O	$\geq4.0\times10^{16}$
Hydroxylamine	NH_2OH	$\leq3.7\times10^{14}$
Methanimine	CH_2NH	$(6.0-10.0)\times10^{14}$
Methylamine	CH_3NH_2	$\leq5.3\times10^{14}$



CH_2CHCN

Vinyl cyanide

Calcutt et al. 2018a



CH_3NC

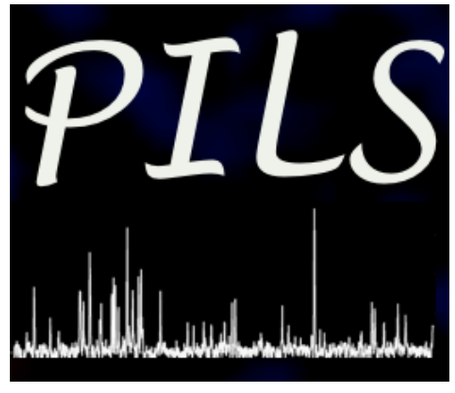
Methyl isocyanide

Source	T_{ex} (K)	N_{tot} (cm^{-2})	$N(CH_3CN)^c / N(CH_3NC)$
IRAS 16293B	150±20	$2.0\pm0.2\times10^{14}$	200
IRAS 16293A	150[a]	$<1.45\times10^{13}$[b]	>5317

Calcutt et al. 2018b

Conclusions

- Very rich chemistry in solar-type protostars
- A lot of things can be learned about their molecular content with ALMA
- ALMA-PILS survey :
    - Detections of acetone, propanal, ethylene oxide, methyl isocyanate, methyl chloride, cyanamide, vinyl cyanide, methanimine, nitrous oxide, methyl isocyanide
    - First detections of deuterated forms of COMs (formamide, glycolaldehyde, cyanamide)
- More to come…



Thanks

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