PROSPECTS:
Prebiotic mOlecules from SPacE to ComeTS

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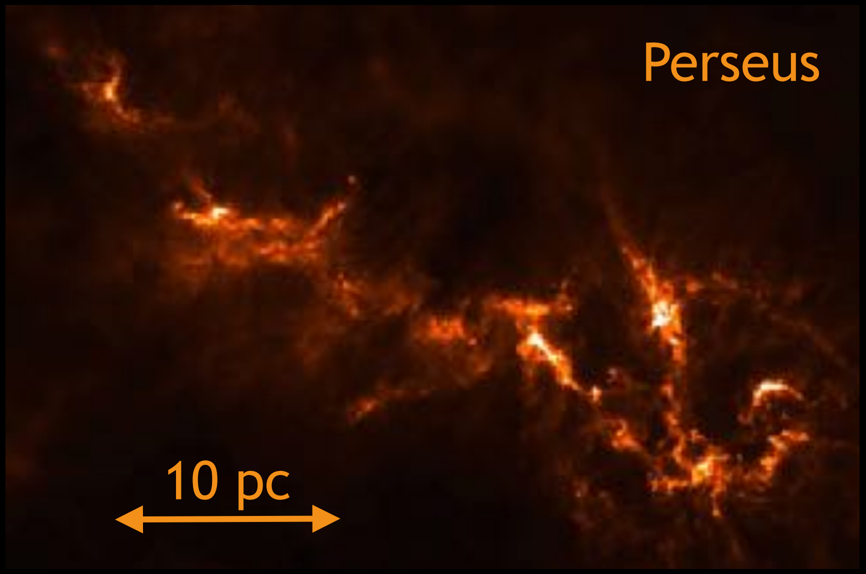
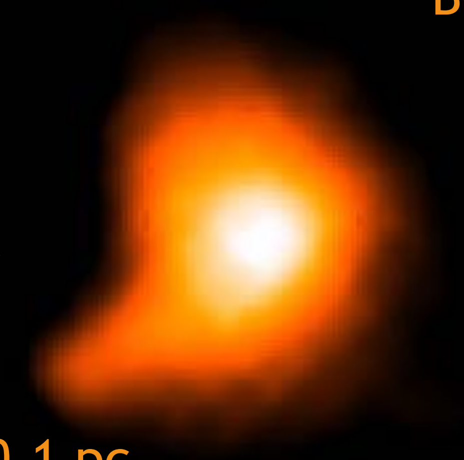
AstroFIt 2 Fellowship

The formation of low-mass stars

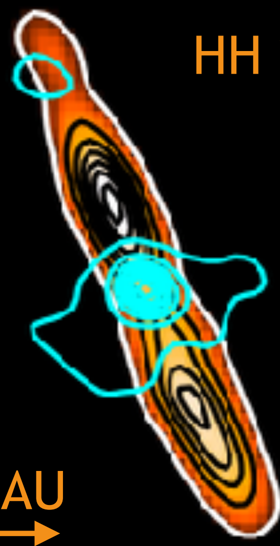
Molecular cloud



Prestellar core

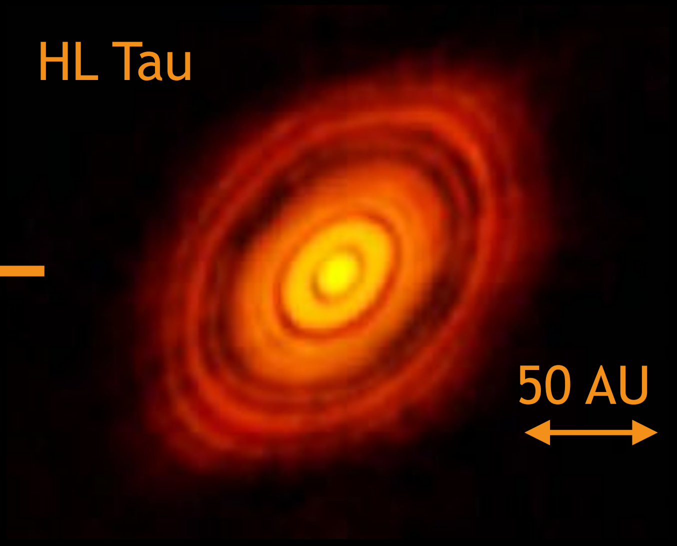


Protostar



Planetary system

Protoplanetary disk

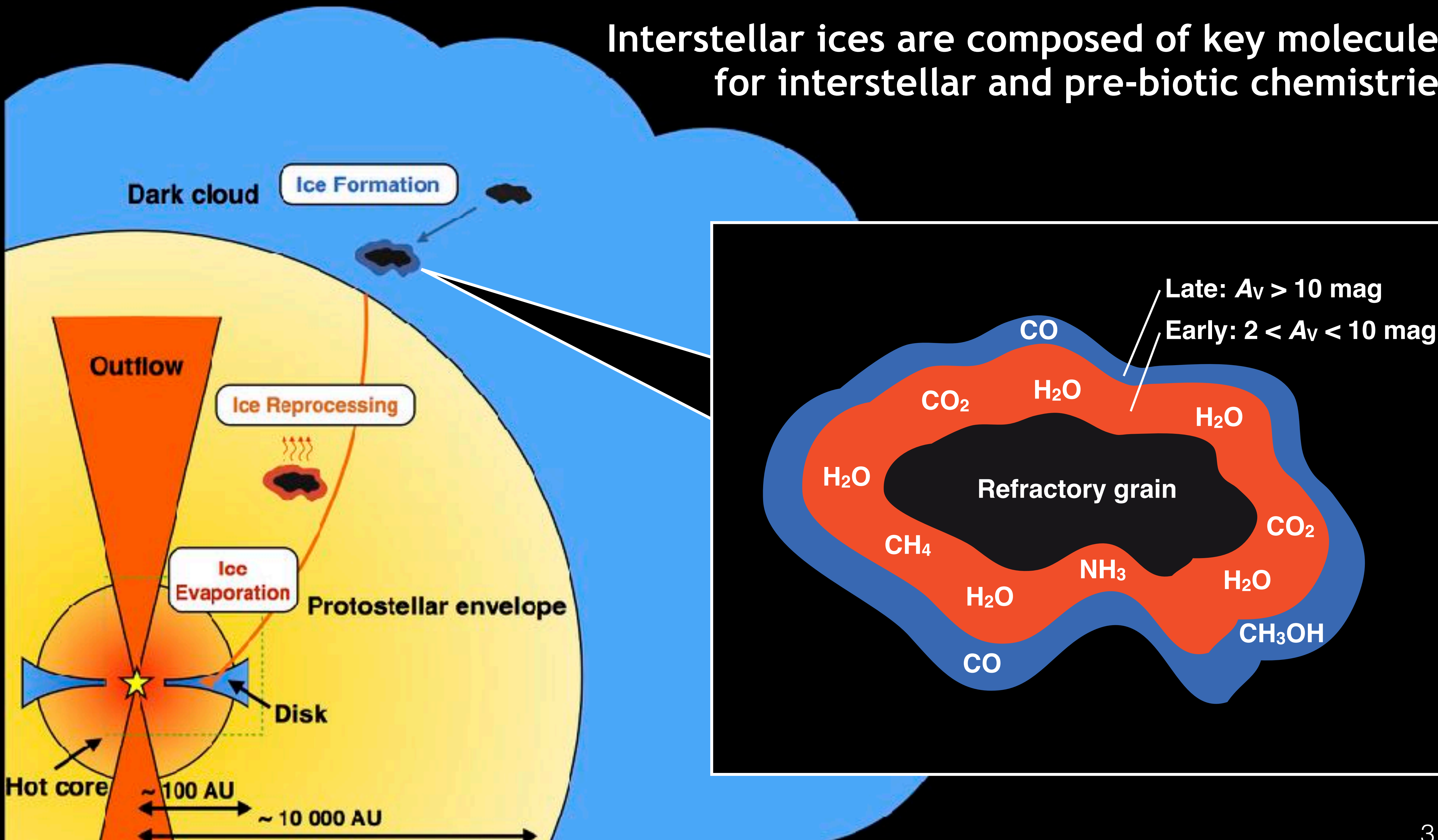


Zari et al. (2016), Roy et al. (2014),
Codella et al. (2014), ALMA et al. (2015)

How to observe molecules in star-forming regions ?

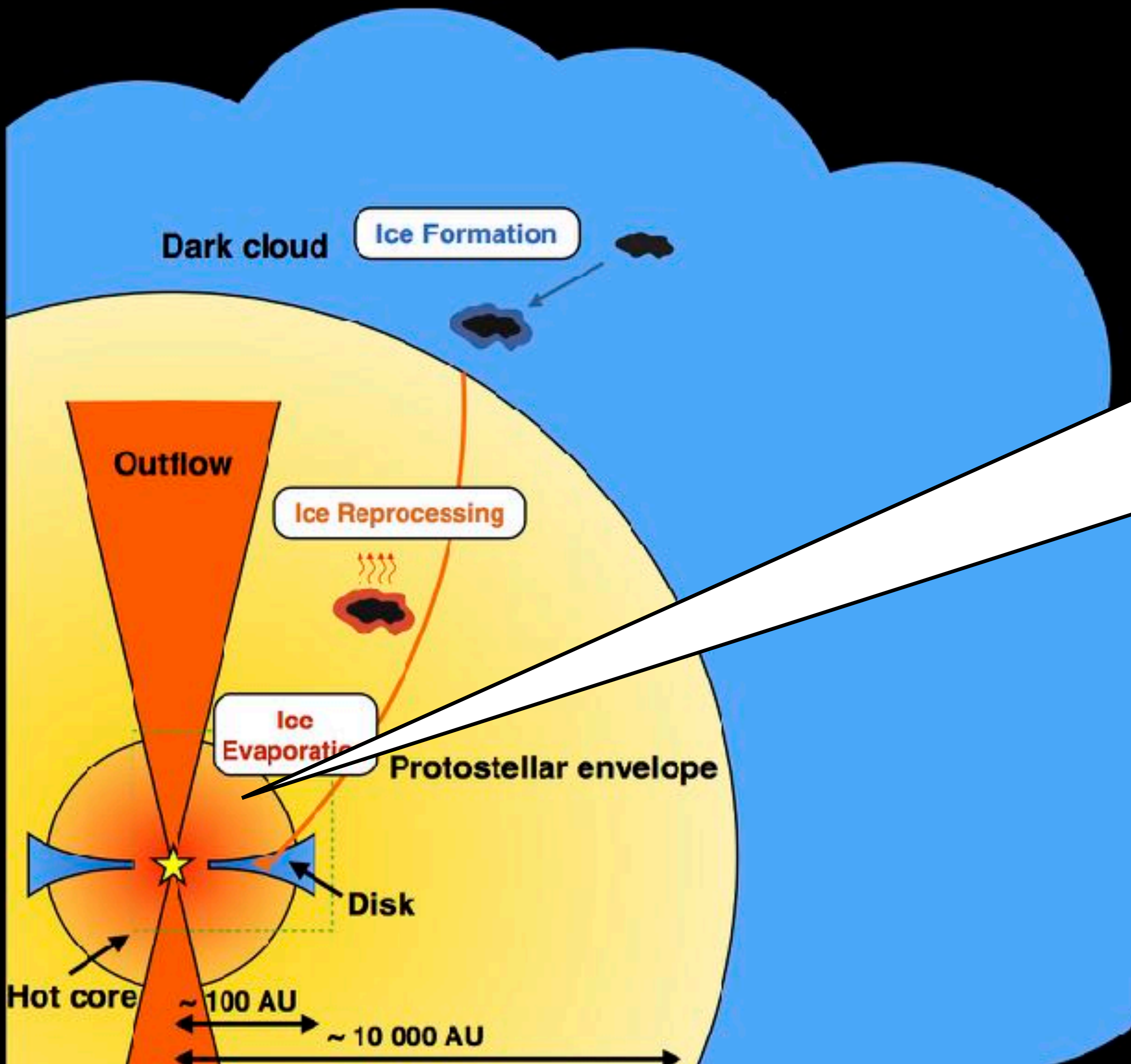
1. Infrared spectroscopy in absorption to study interstellar ices

Interstellar ices are composed of key molecules for interstellar and pre-biotic chemistries

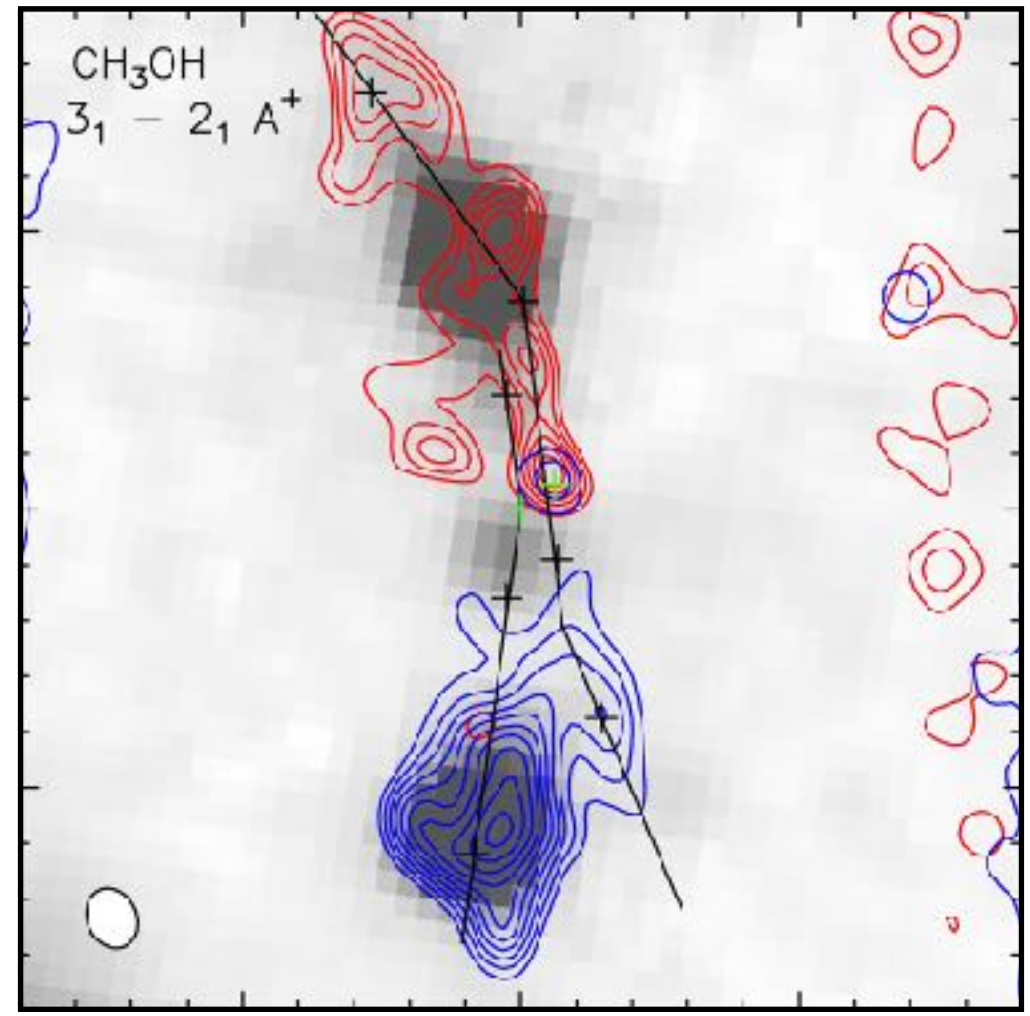


How to observe molecules in star-forming regions ?

2. Millimetric spectroscopy in emission to study the molecular gas



Gas: sub-mm/mm



Taquet et al. (en prep.)

New observatories:
NOEMA, ALMA

How to observe molecules in star-forming regions ?

2. Millimetric spectroscopy in emission to study the molecular gas

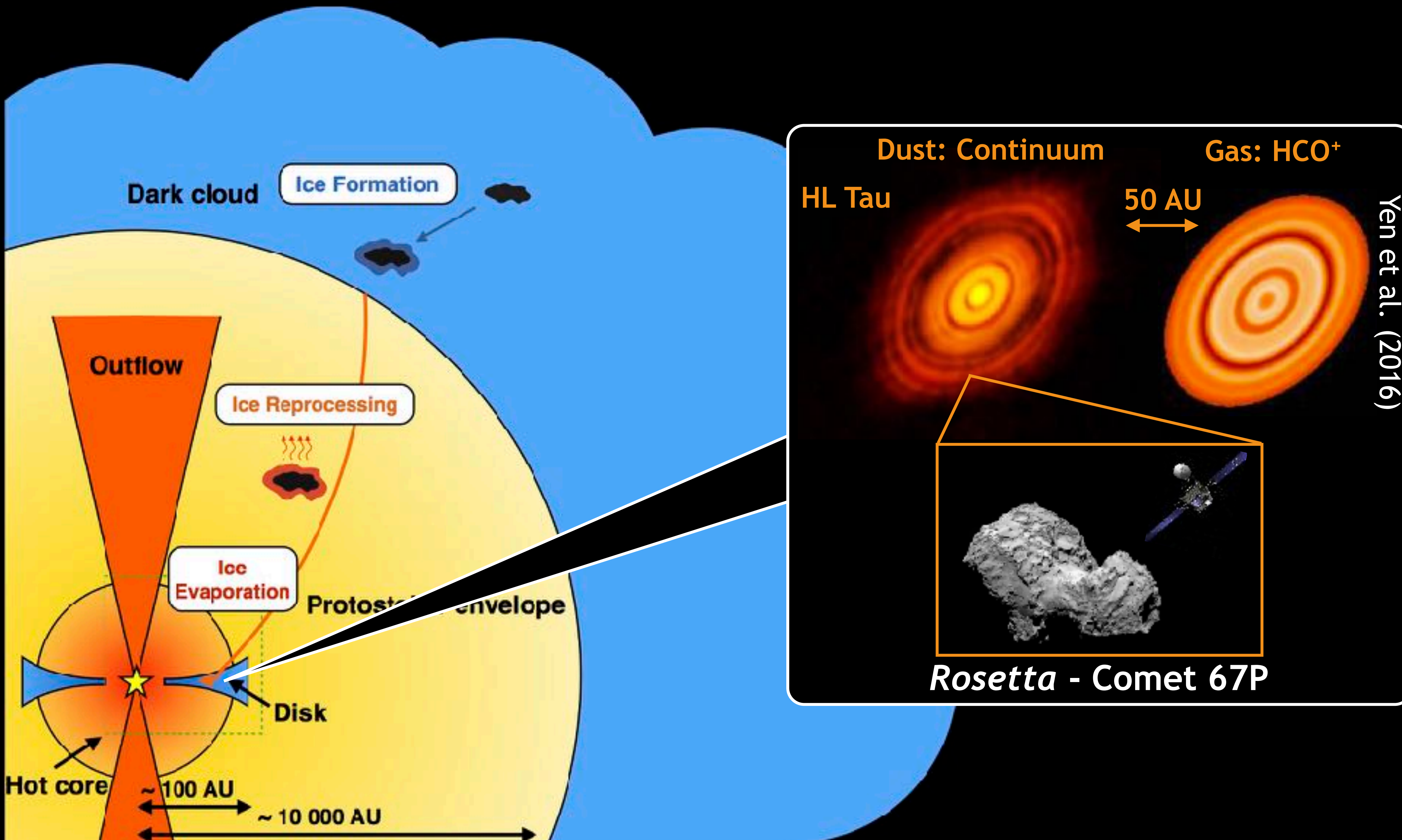
Star formation is accompanied by a chemical complexity process

- **60** of the 175 detected interstellar species are complex organic molecules (COMs)
- Importance for the formation of amino- and hydroxy-acids ?

6 atoms	7 atoms	8 atoms	9 atoms	10 atoms	11 atoms	12 atoms	>12 atoms
C_5H	C_6H	CH_3C_3N	CH_3C_4H	CH_3C_5N	HC_9N	$c\text{-}C_6H_6$ *	$HC_{11}N$?
$l\text{-}H_2C_4$	CH_2CHCN	$HC(O)OCH_3$	CH_3CH_2CN	$(CH_3)_2CO$	CH_3C_6H	$n\text{-}C_3H_7CN$	C_{60} *
C_2H_4*	CH_3C_2H	CH_3COCH	$(CH_3)_2O$	$(CH_2OH)_2$	C_2H_5OCHO	$i\text{-}C_3H_7CN$	C_{70} *
CH_3CN	HC_5N	C_7H	CH_3CH_2OH	CH_3CH_2CHO	$CH_3OC(O)CH_3$	$C_2H_5OCH_3$?	C_{60}^{+}*
CH_3NC	CH_3CHO	C_6H_2	HC_7N	CH_3CHCH_2O 2016			
CH_3OH	CH_3NH_2	CH_2OHCHO	C_8H				
CH_3SH	$c\text{-}C_2H_4O$	$l\text{-}HC_6H$*	$CH_3C(O)NH_2$				
HC_3NH^+	H_2CCHOH	CH_2CHCHO (?)	C_8H^-				
HC_2CHO	C_6H^-	CH_2CCHCN	C_3H_6				
NH_2CHO	CH_3NCO 2015	H_2NCH_2CN	CH_3CH_2SH (?)				
C_5N		CH_3CHNH					
$l\text{-}HC_4H$*							
$l\text{-}HC_4N$							
$c\text{-}H_2C_3O$							
H_2CCNH (?)							
C_5N^-							
$HNCHCN$							

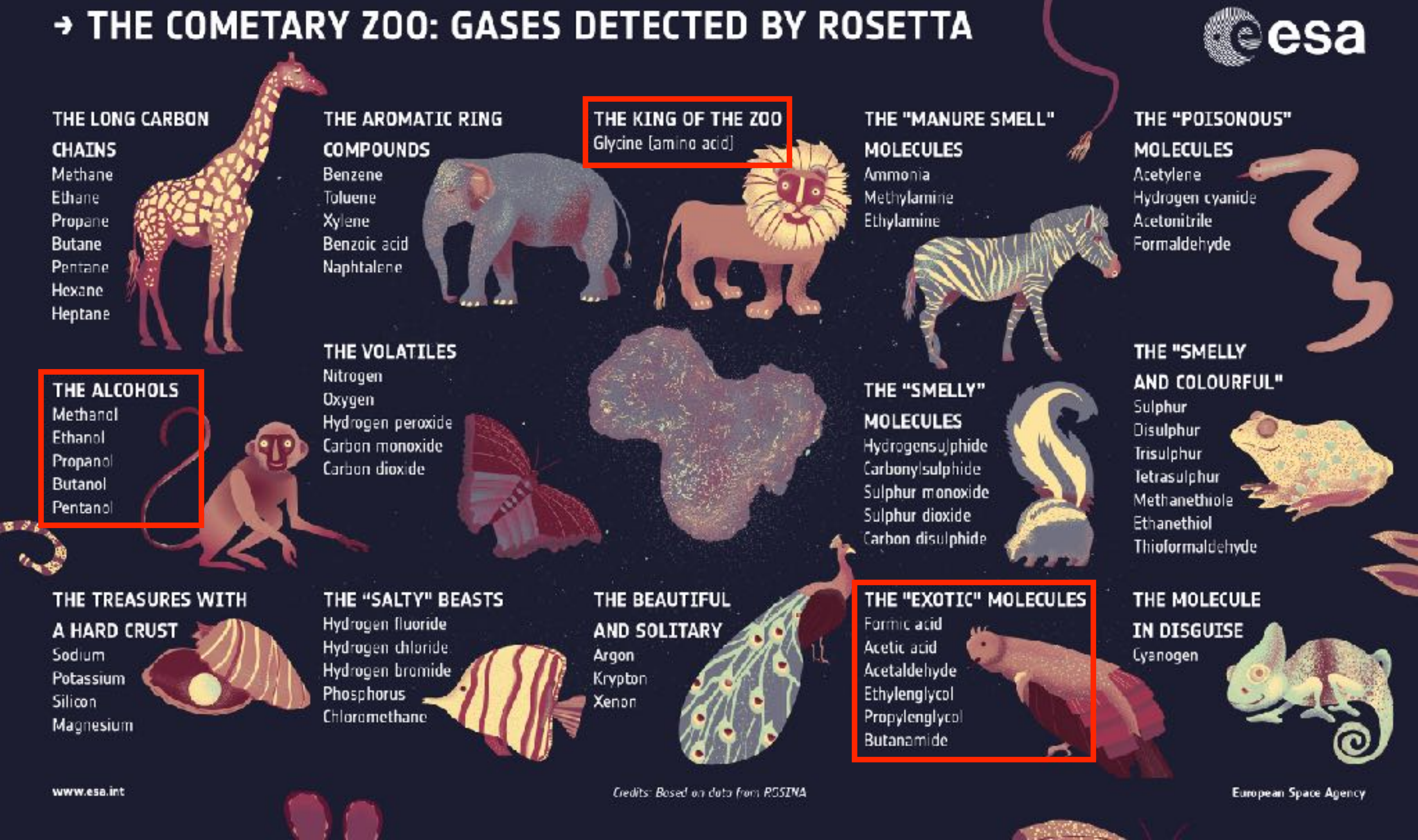
How to observe molecules in star-forming regions ?

3. Space missions: final composition of the Solar Nebula

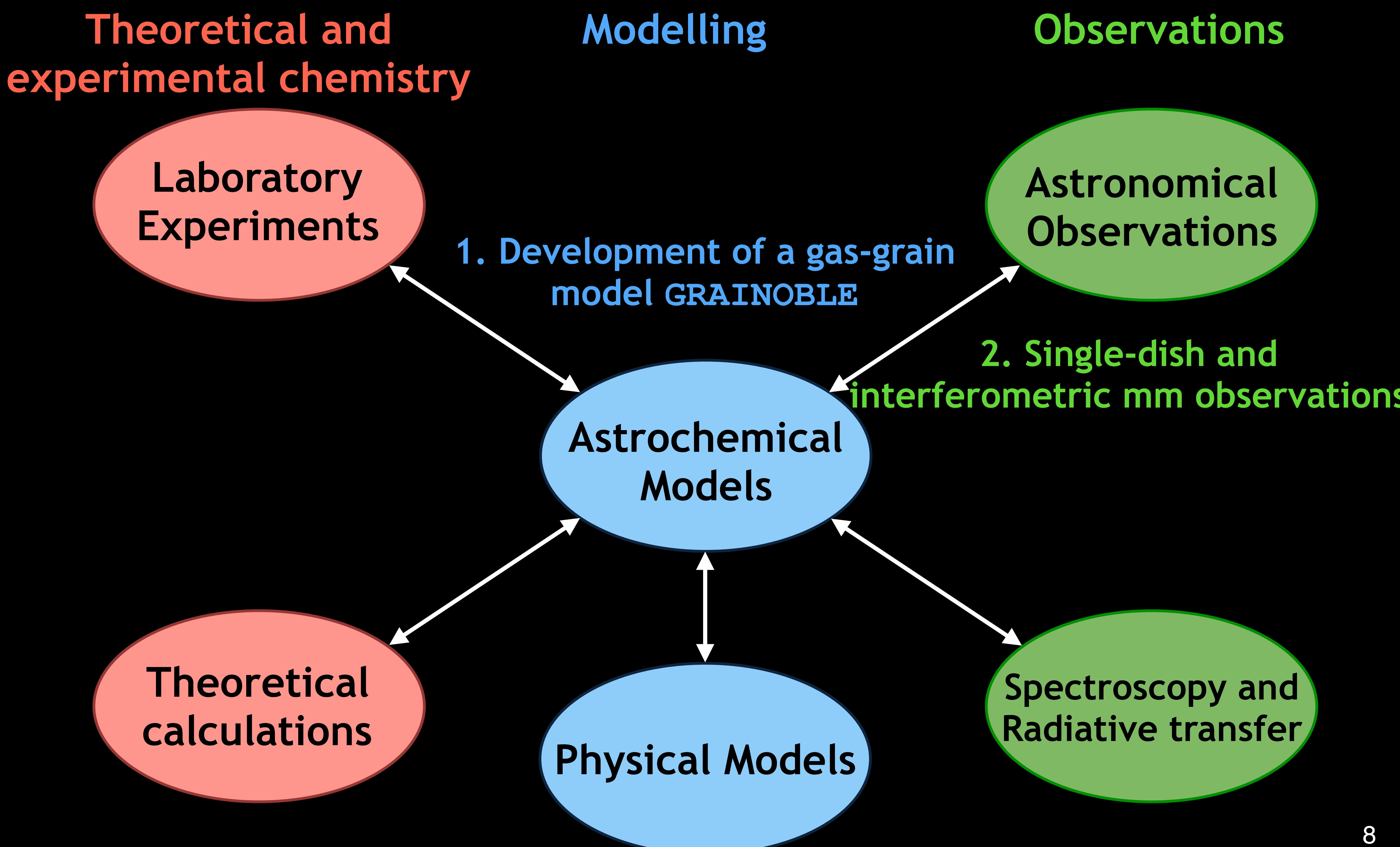


How to observe molecules in star-forming regions ?

Chemical census of a comet:



Expertises in Astrochemistry

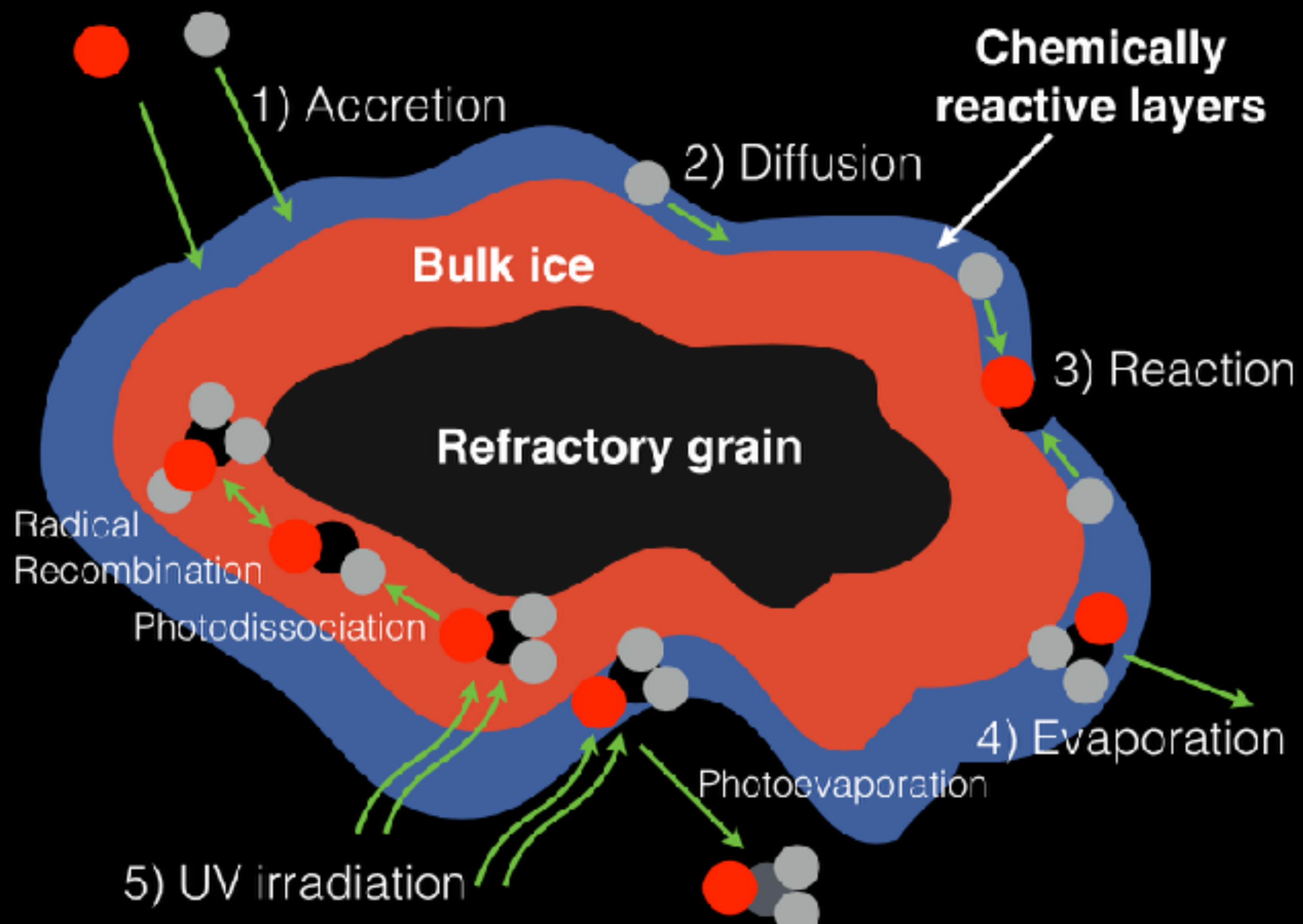


Gas-grain astrochemical models

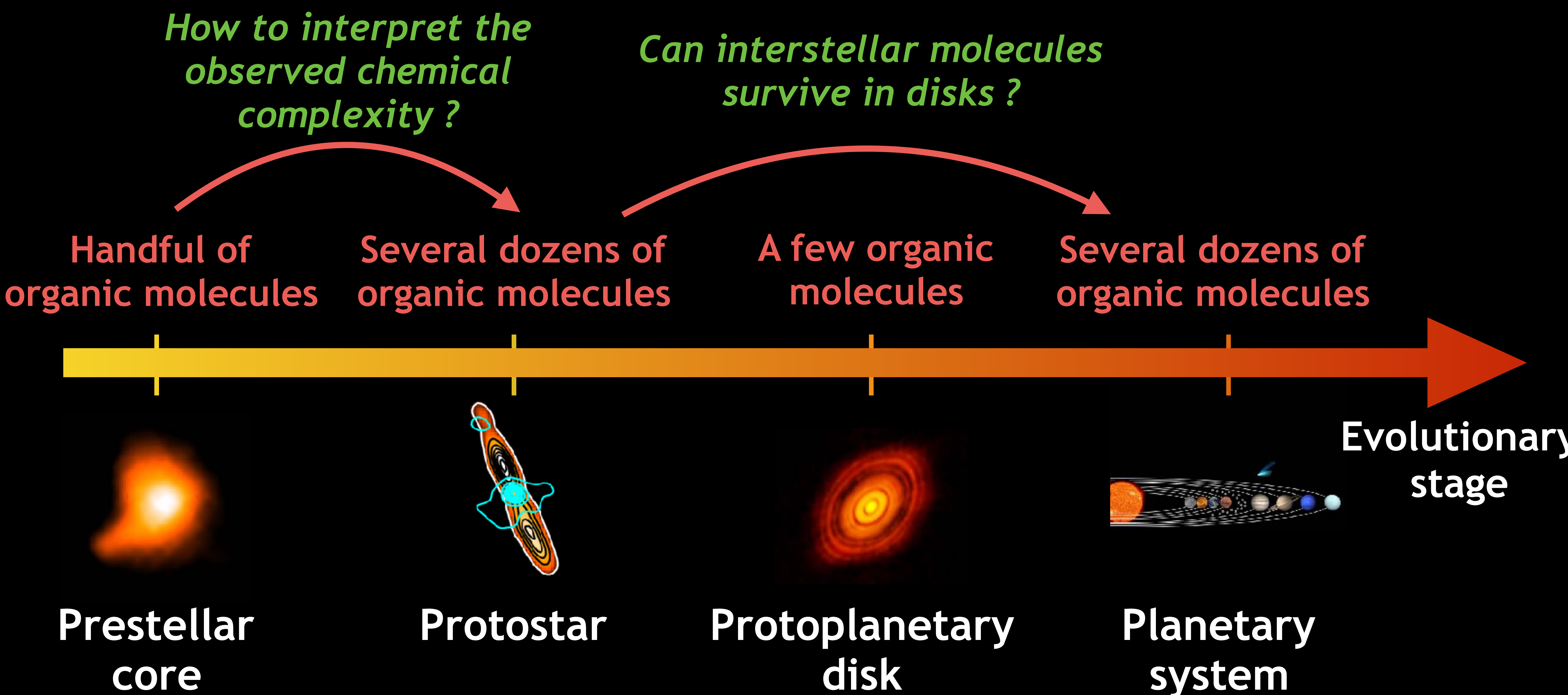
Gas phase chemistry

Dissociation, ionisation, ion-neutral, neutral-neutral reactions
(KIDA, or UMIST chemical databases)
~ 10,000 reactions, 1,000 species

Gas-grain processes



Main objectives of the AstroFIt 2 project



Have cometary (and Solar System) molecules an interstellar origin ?

Main objectives of the AstroFlt 2 project

1 - Chemical complexity pathways

What is the degree of chemical complexity reached in the ISM ?

A) Constrain the physical and chemical processes in ices with a modelling of laboratory experiments IN PROGRESS (collaboration with F. Dulieu)

B) Study the effect of new types of gas phase reactions
IN PROGRESS (collaboration with S. Charnley)

2 - Physical evolution and chemistry

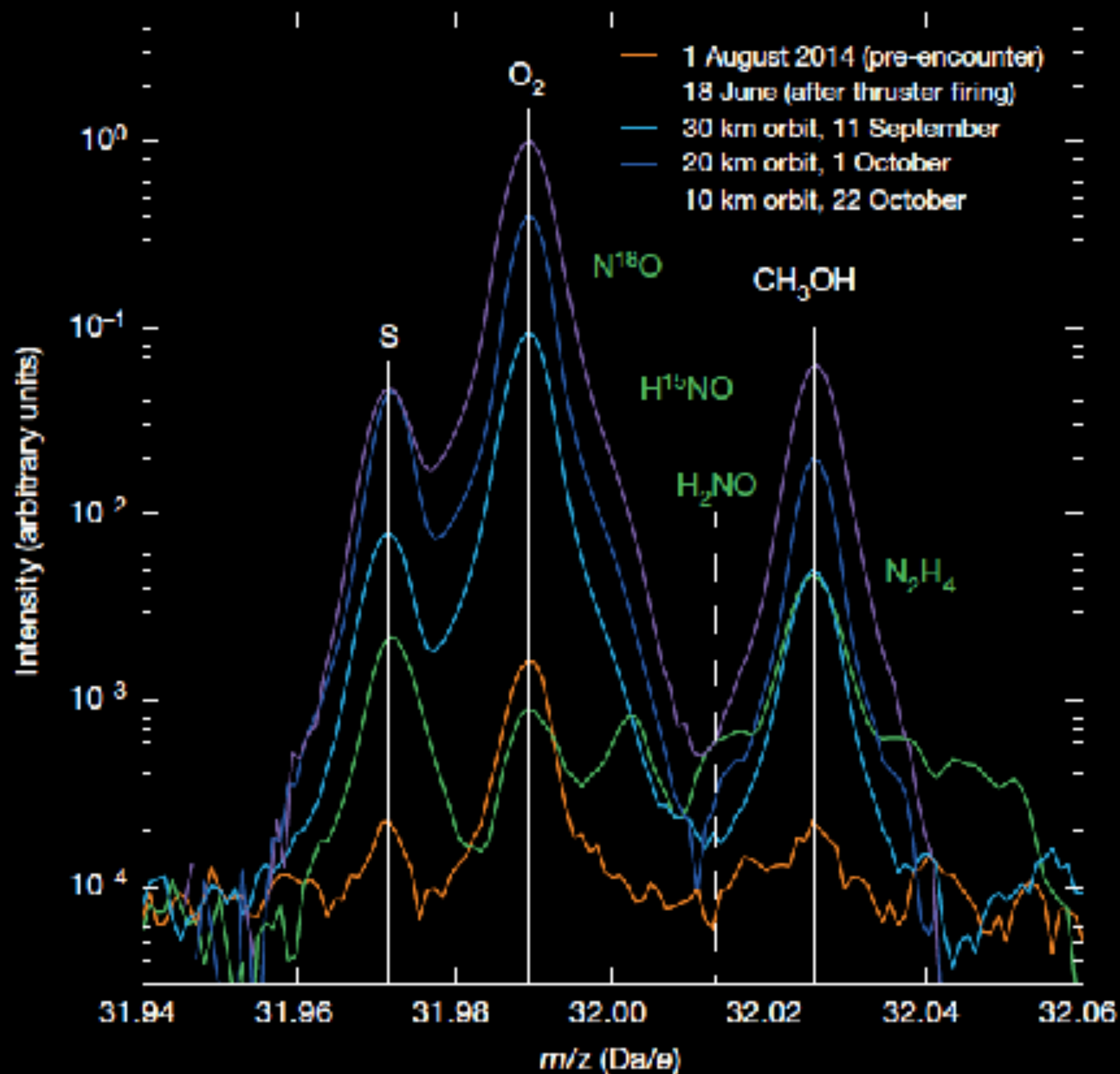
Have the cometary and meteoritic molecules an interstellar origin ?

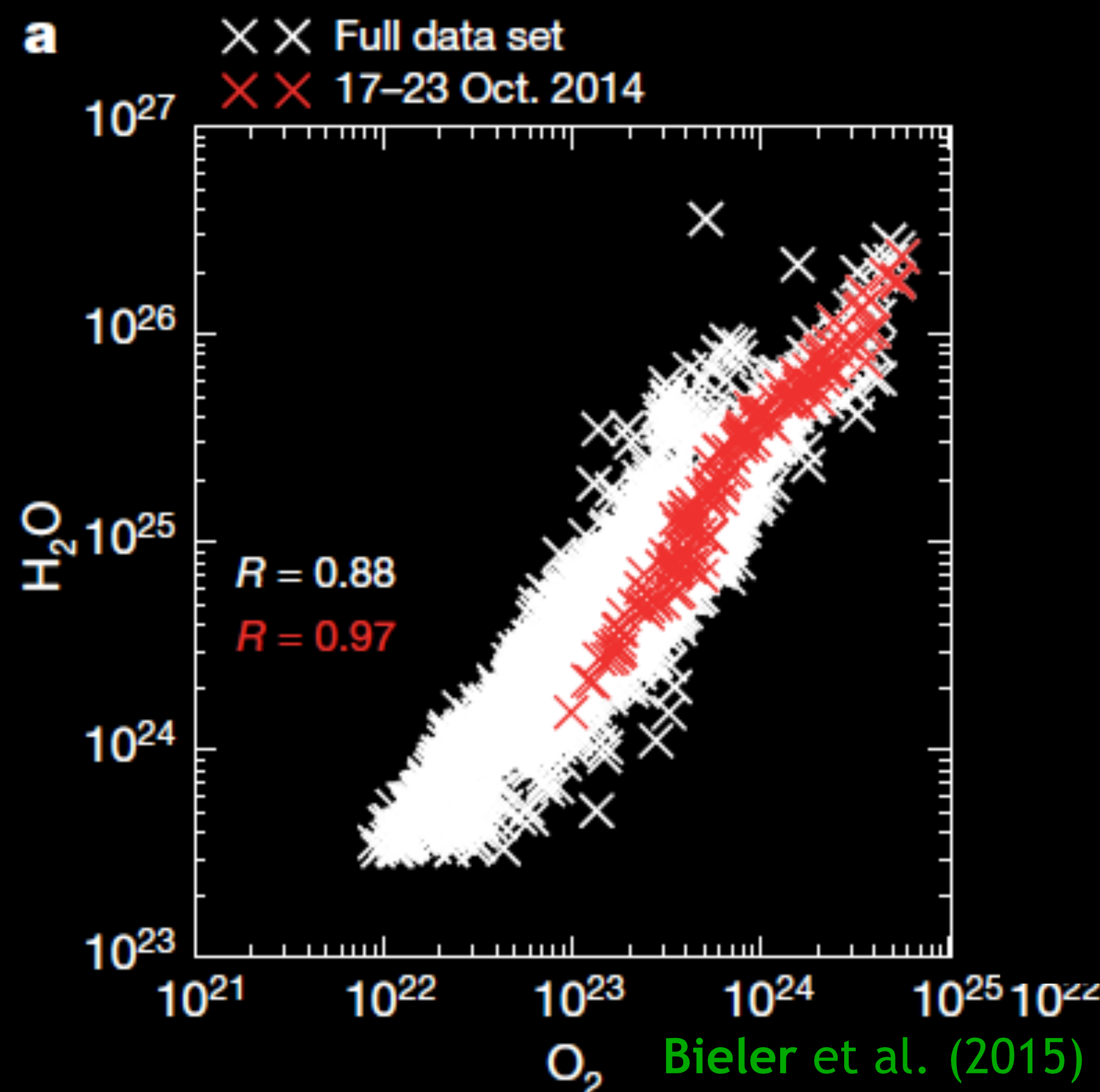
A) Follow the chemical evolution from dark clouds to disks with dynamical models TO BE STARTED (collaboration with M. Padovani?)

B) Interpret interferometric observations of star-forming regions
IN PROGRESS (collaboration with C. Codella, C. Ceccarelli, …)

High abundance of O_2 in comets

First detection of O_2 in a comet by Rosetta:





Bieler et al. (2015)

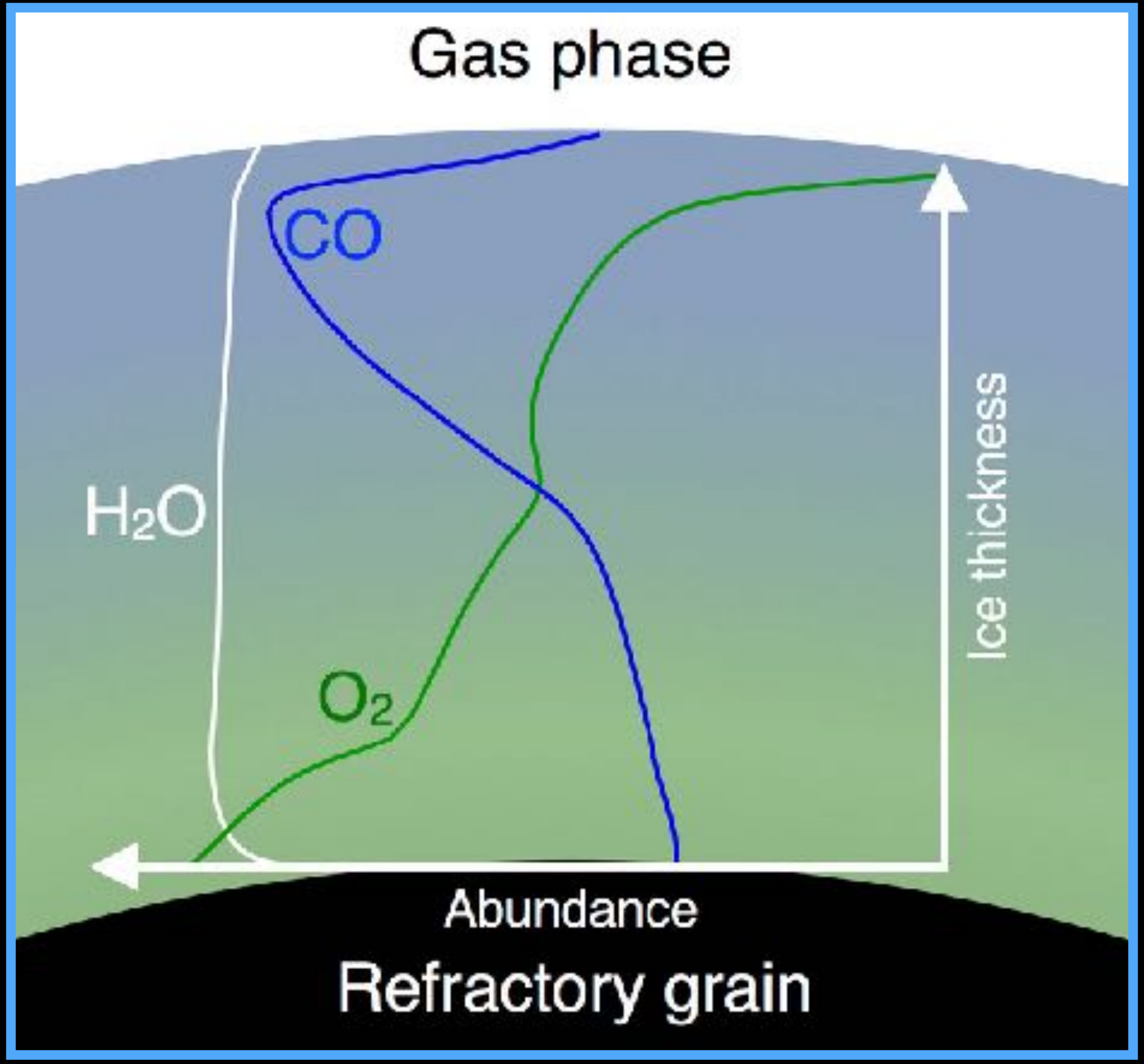
$X(O_2) / X(H_2O) = 3.8 \pm 0.9$ % with strong correlation between O_2 and H_2O

O_2 is elusive in space, but can O_2 be detected around young stars ?

A primordial origin for cometary O_2

1) O_2 formation in molecular clouds ?

- High observed abundance reproduced for **"dense" and "warm" physical conditions** ($n_H \sim 10^5 - 10^6$ cm^{-3}; T ~ 20 K)
- **O_2 trapped in water ice** → in agreement with *Rosetta* observations



Taquet et al. (2016)

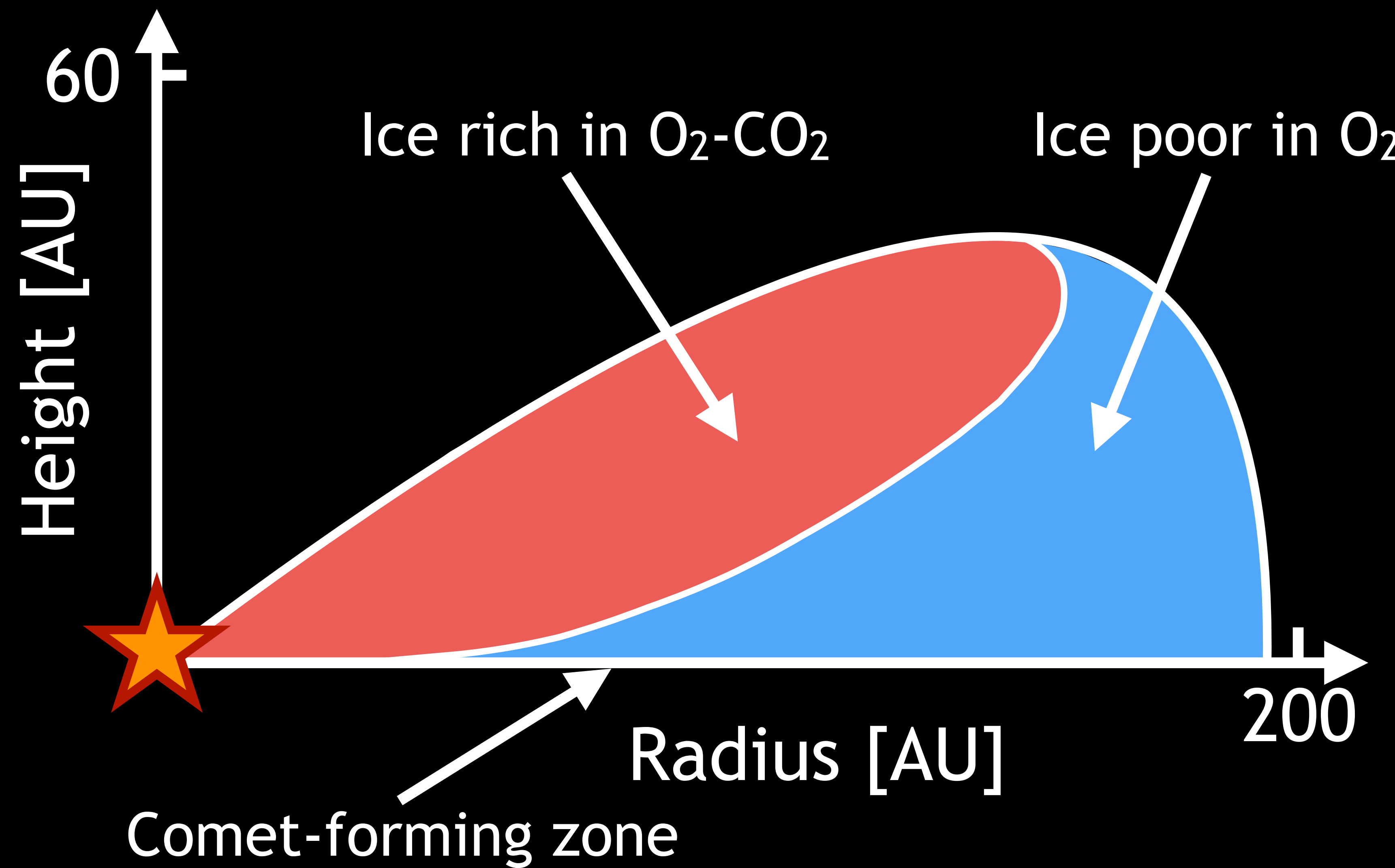
A primordial origin for cometary O_2

2) O_2 formation during protostellar collapse? NO

3) O_2 formation in protoplanetary disks? NO

- O_2 formation with CO_2 in external disk layers

→ Non efficient formation in cometary formation zones



Taquet et al. (2016)

A deep search of $^{16}O^{18}O$ towards IRAS 16293

ALMA observations of the $^{16}O^{18}O$ 2_1-0_1 transition at 233.946 GHz towards IRAS 16293 located in the Ophiuchus cloud:

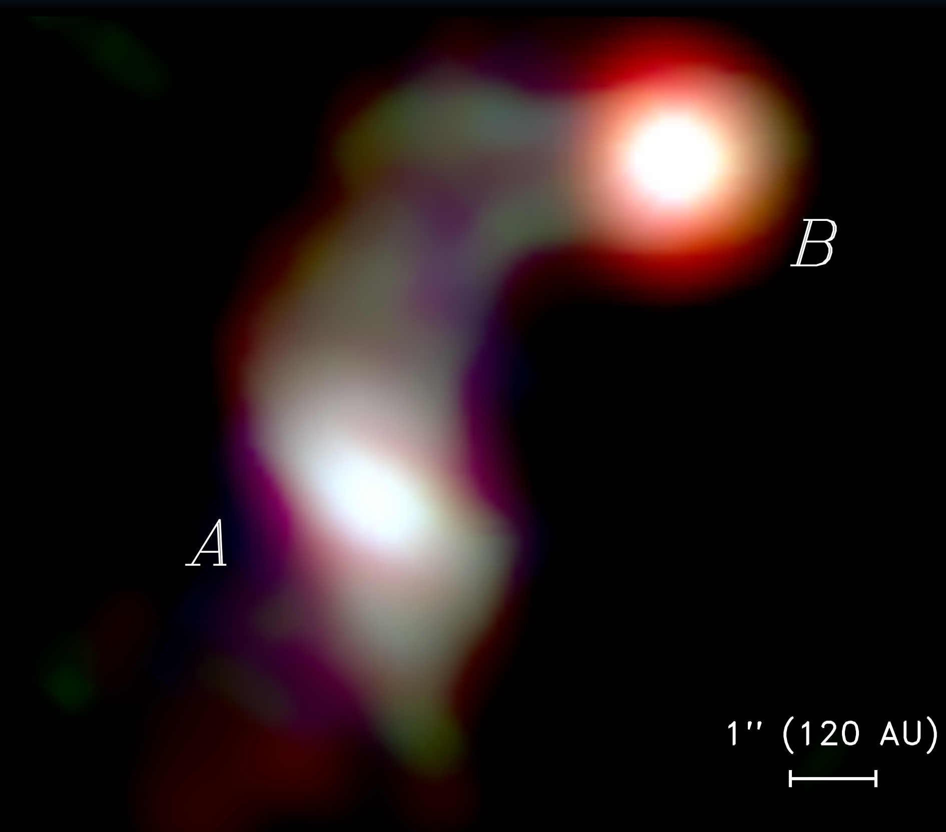
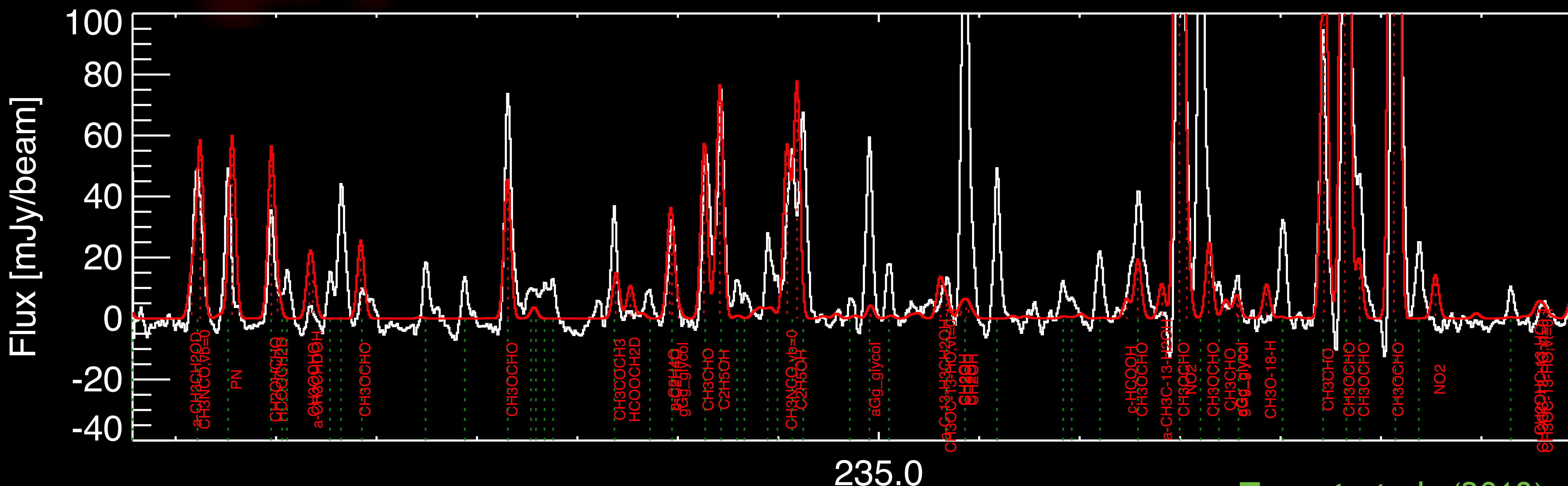
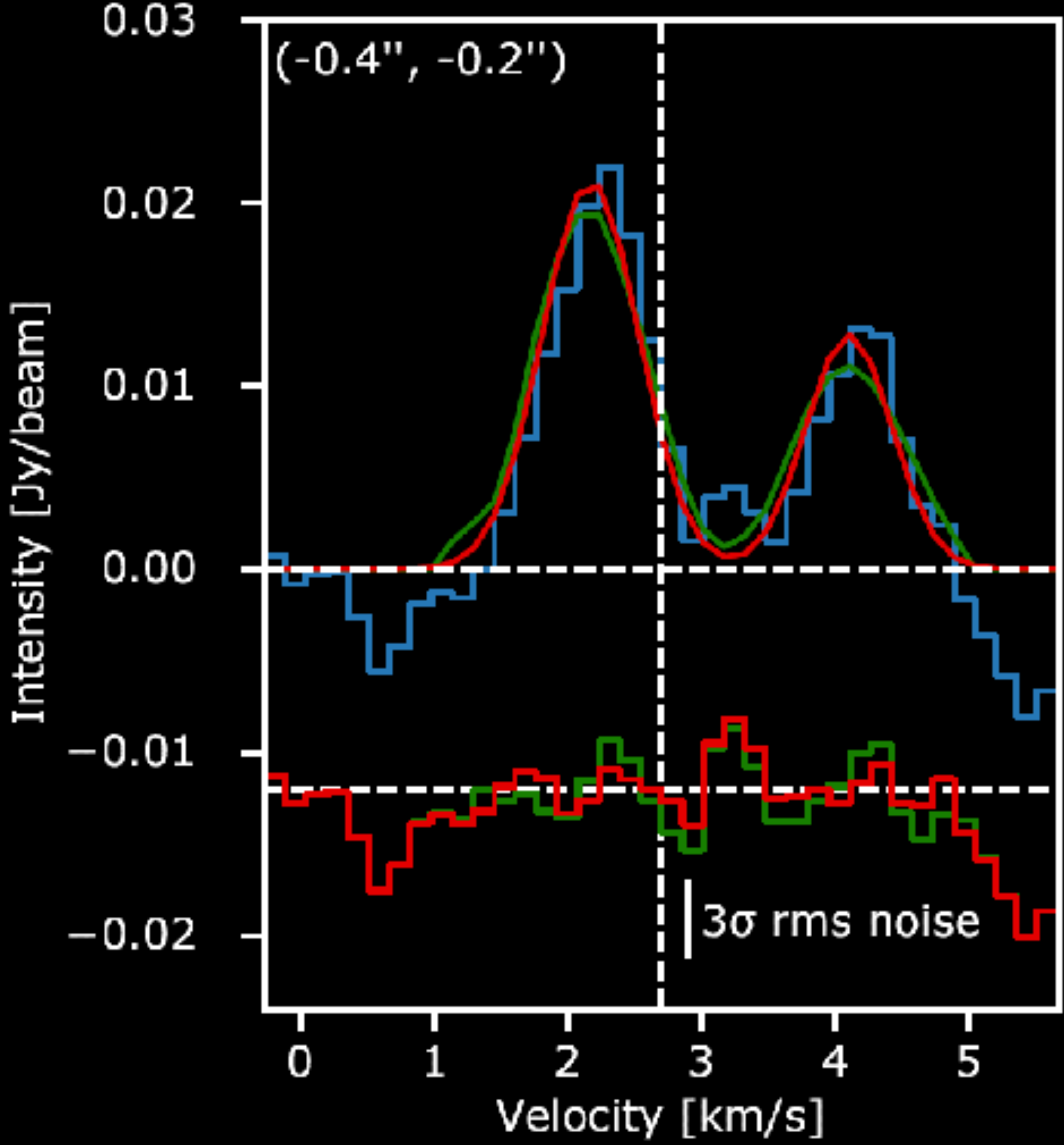


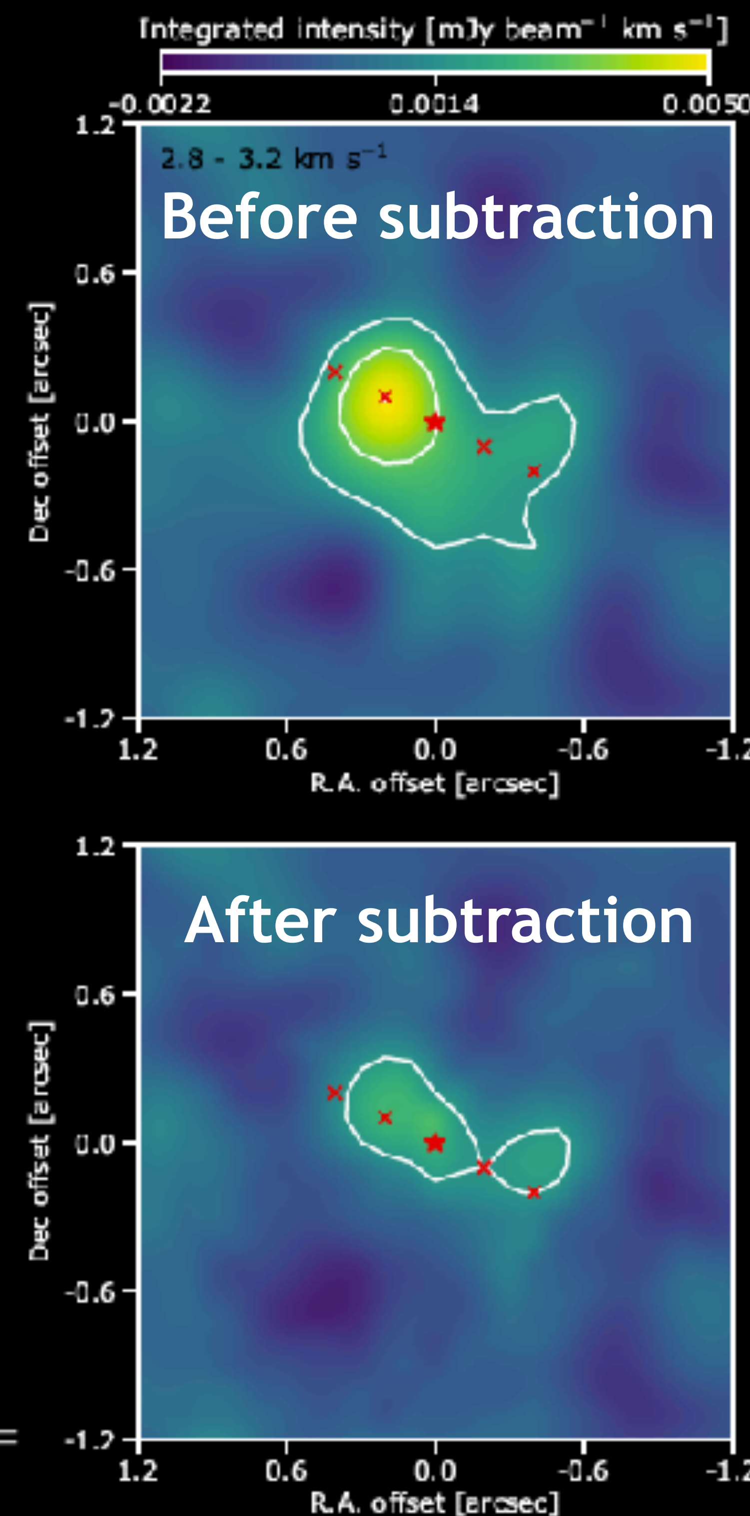
Image credit: Jørgensen et al. (2016)



Taquet et al. (2018)

Analysis of the $^{16}O^{18}O$ transition





Molecule	N (cm^{-2})	$N/N(CH_3OH)$ (%) IRAS 16293	Comet 67P/C-G [c]
O_2	$\leq (4.2 - 9.0) \times 10^{19}$	$\leq 2.1 - 4.5$ [a]	5 – 15
	$(9.9 - 21) \times 10^{19}$.	$5.0 - 10.5$ [b]	5 – 15

Taquet et al. (2018)

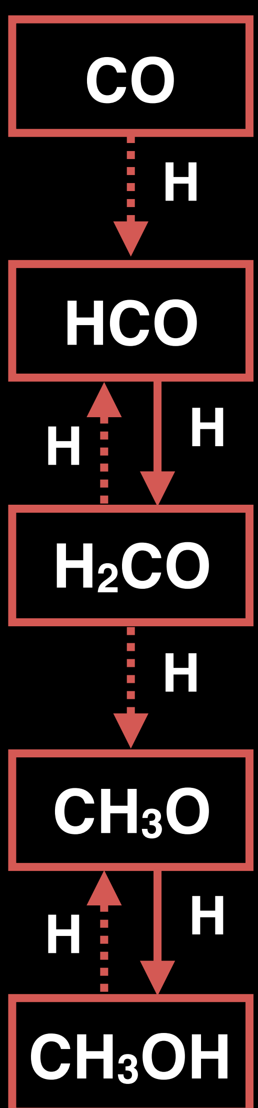
Modelling of laboratory experiments

Constrain the physical and chemical processes in ices with a modelling of laboratory experiments focusing on cold surface chemistry:

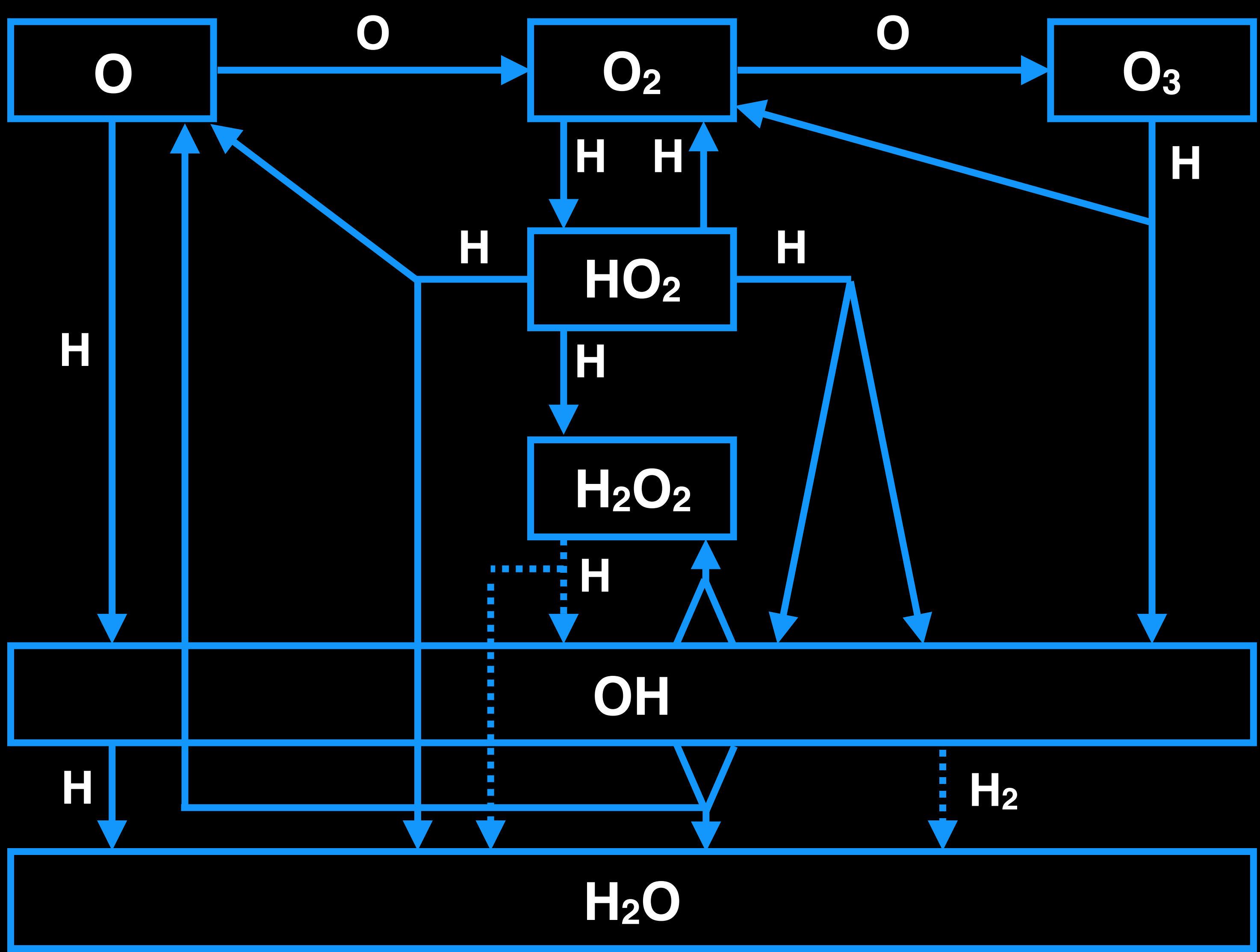
- Validate the formalism used in interstellar models with “in-situ” data

- Constrain key physical and chemical parameters

Methanol network



Water network



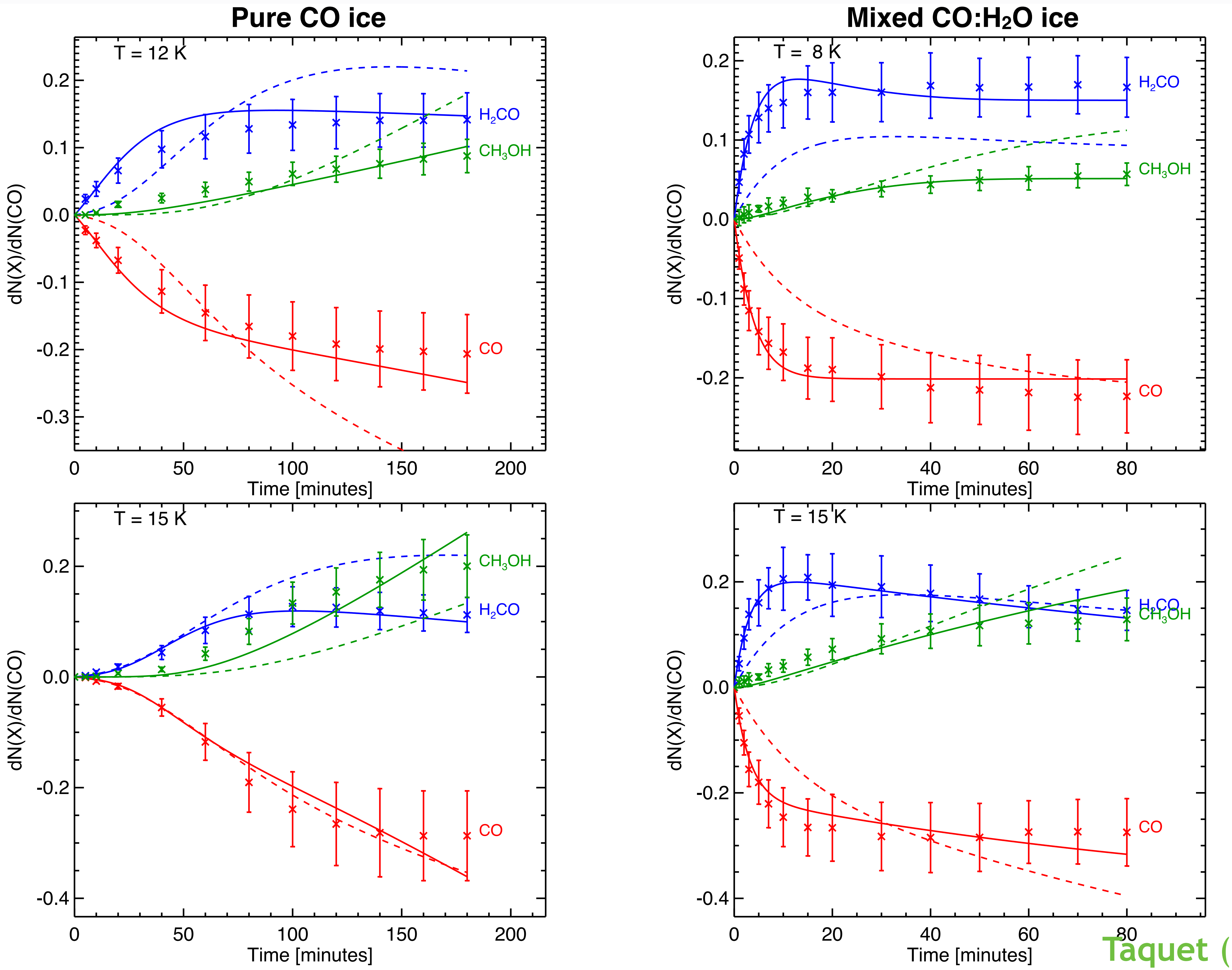
Modelling of laboratory experiments

Constrain the physical and chemical processes in ices with a modelling of laboratory experiments focusing on cold surface chemistry:

Experiment properties			Ice sample		Irradiation		Ref.
Name	Network	Temperature (K)	Species	Thickness (MLs)	Species	Flux (mol cm^{-2} s^{-1})	
CO-1	CO+H	10	H_2CO on H_2O	1 on 10	H	1.0(+15)	H04
CO-2	CO+H	8-10-12	CO	10	H	5.0(+14)	W04
CO-3	CO+H	12-13.5-15-16.5	CO	8	H	5.0(+13)	F09
CO-4	CO+H	8-10-12-15-20	CO:H_2O	6:24	H	5.0(+14)	W04
O_2-1	O_2	12-15-18-20-23-28	O_2	30	H	5.0(+13)	I08
O_2-2	O_2	12-15-18-20-23-25-26-27	O_2	35	H	2.5(+13)	I10
O_2-3	O_2	25	O_2	1-3-5-8-12-25	H	2.5(+13)	I08
CO:O_2-1	CO+O_2	15-20	CO:O_2	28:7	H	2.5(+13)	I11
CO:O_2-2	CO+O_2	15-20	CO:O_2	14:14	H	2.5(+13)	I11
CO:O_2-3	CO+O_2	15-20	CO:O_2	7:28	H	2.5(+13)	I11

Taquet (in prep.)

Modelling of laboratory experiments

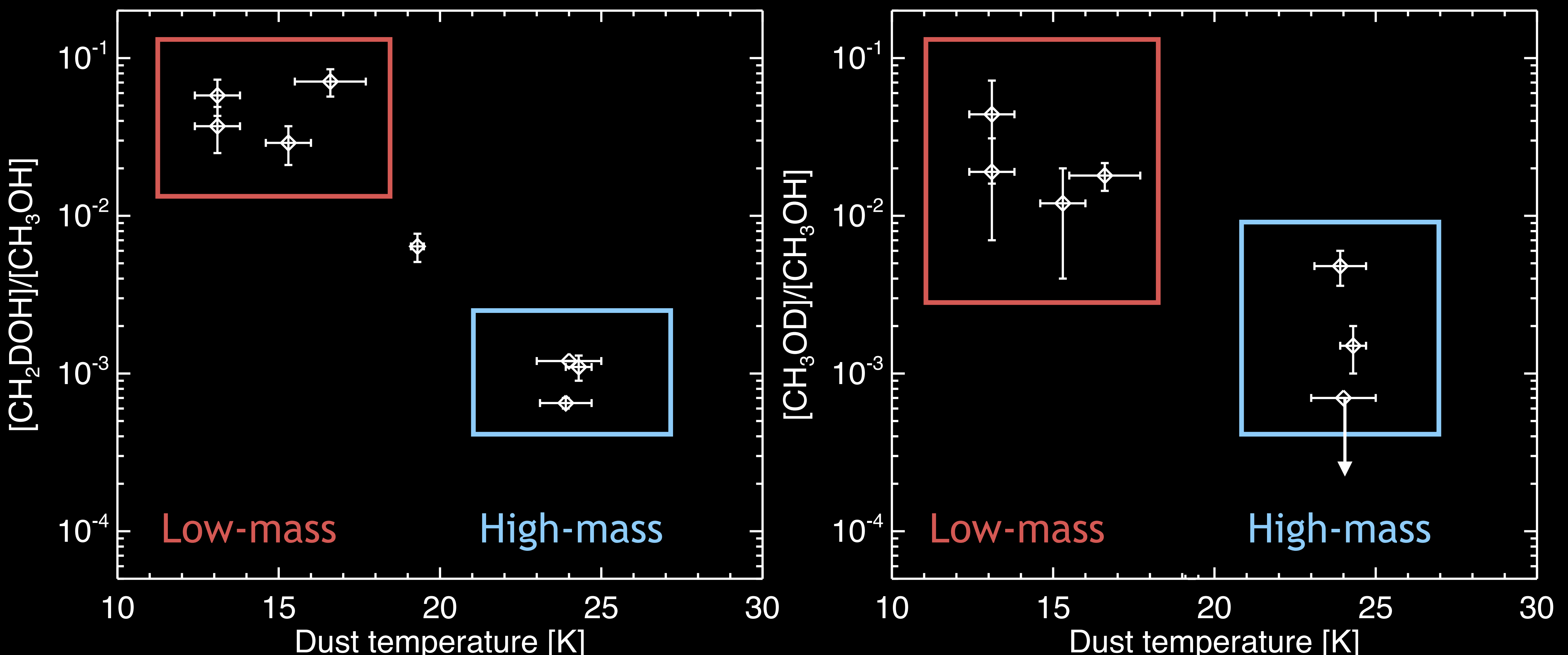


Taquet (in prep.)

Methanol deuteration from low-mass to high-mass hot cores

Methanol deuteration observed towards hot cores mostly regulated by the temperature of the progenitor cloud

+ Other processes (time, gas phase chemistry) at work ?



From Taquet et al. (2018, submitted); IRAS16293: Jørgensen et al. (2018), IRAS2A/IRAS4A: Taquet et al. (2018), HH212: Bianchi et al. (2017), NGC7129: Fuente et al. (2014), SgrB2(N2): Belloche et al. (2016), Orion KL: Peng et al. (2012), NNGC6334: Bøgelund et al. (2018)

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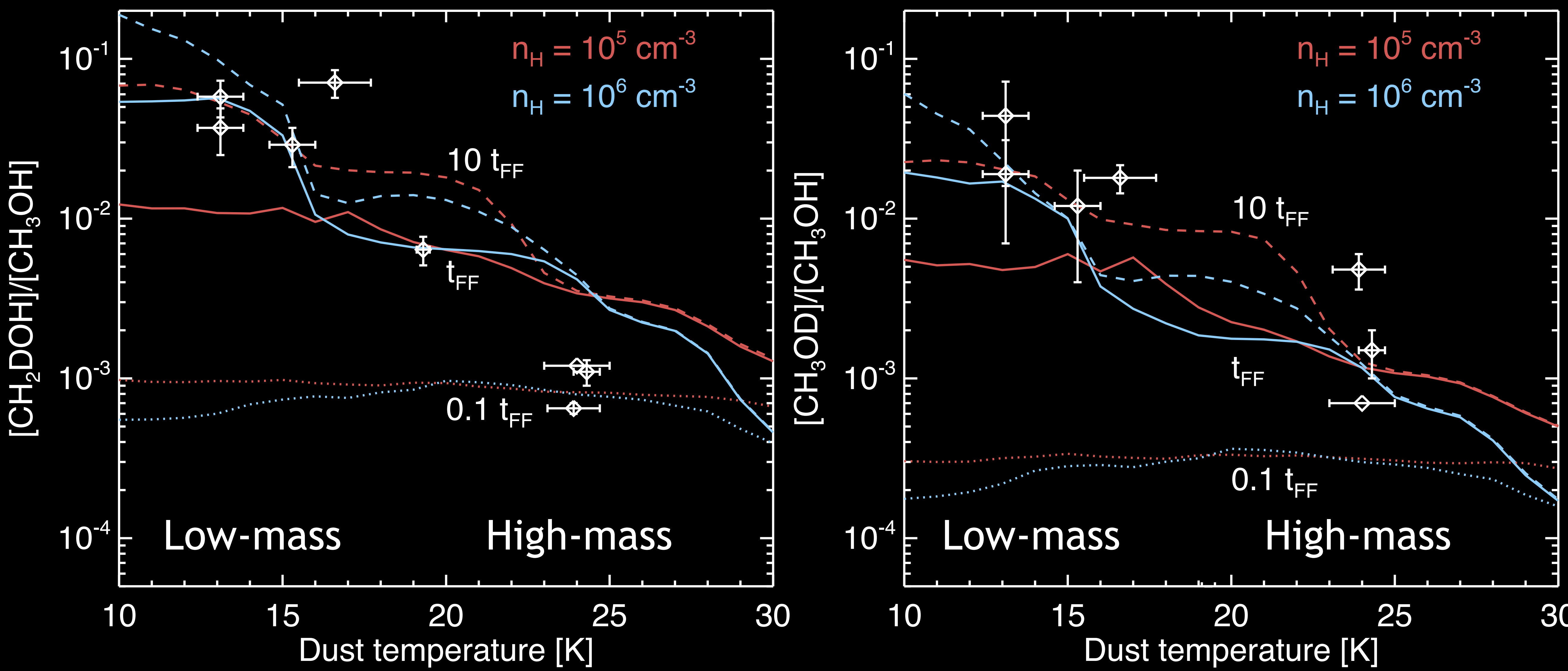

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Main activities

- 14 Publications:

Models:

Ceccarelli, Viti, Balucani, **Taquet** 2018, *MNRAS*

Observations:

Taquet, van Dishoeck, Swayne et al. 2018, *A&A*
Taquet, Bianchi, Codella et al. 2018, submitted to *A&A*

Support to astronomers:

Bianchi, Codella, Ceccarelli, **Taquet** et al. 2017, *A&A*
Persson, …, **Taquet** et al. 2017, *A&A*
Bøgelund, McGuire, Ligterink, **Taquet** et al. 2018, *A&A*
Jørgensen, …, **Taquet** et al. 2018, *A&A*
Manigand, Calcutt, Jørgensen, **Taquet** et al. 2018, *A&A*
Van't Hoff, Persson, Harsono, **Taquet** et al. 2018, *A&A*
Bøgelund, Barr, **Taquet** et al. 2018, submitted to *A&A*

Support to chemists:

Rimola, …, **Taquet** et al. 2018, *Earth and Space Chemistry*
Ligterink, Terwisscha, **Taquet** et al. 2018, MNRAS
Dulieu, Nguyen, Congiu, Baouche, **Taquet** 2018, submitted to *MNRAS*
Qasim, Fedoseev, Chuang, **Taquet** et al. 2018, submitted to *MNRAS*

Main activities

- **14 Publications:**

2 first-author publications, 12 others with significant contributions

- **Two Invited talks since September 2017**

  Ciudad Real, “Gas phase cold chemistry of COMs”, December 2017

  Paris, “Oxygen in Space”, October 2018

- **Two visits at Paris Observatory with F. Dulieu’s group**

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- One visit at the Ospedale !