ASTROFISICA MOLECULAR
ASTROQUÍMICA :
COMPLEJIDAD
QUÍMICA EN EL ESPACIO

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Outline of the talk:

Introduction to the physical properties of our “laboratories”

THE ROLE OF MOLECULAR PHYSICS IN ASTROPHYSICS

The interstellar and circumstellar media

Gas, dust and PAHs

Evolved stars and Planetary Nebulae (AGBs and post-AGBs)

Our Tools, our needs, our observing machines

THE NANOCOSMOS PROJECT

Far-infrared spectral range (Space)

(λ ~30-350 μm) (1/λ ~ 330-30 cm^{-1}) (ν~ 10 THz- 1000 GHz)

Submillimeter spectral range

(λ ~300-1000 μm) (ν~ 1000 GHz- 300 GHz) ALMA

Millimeter spectral range

(λ ~1mm-10 mm) (ν~ 300 GHz- 30 GHz) ALMA & single dish

The radio spectral range (microwaves)

(λ ~10mm-1 cm) (ν~ 30 GHz- 3 GHz) Most ground based RT

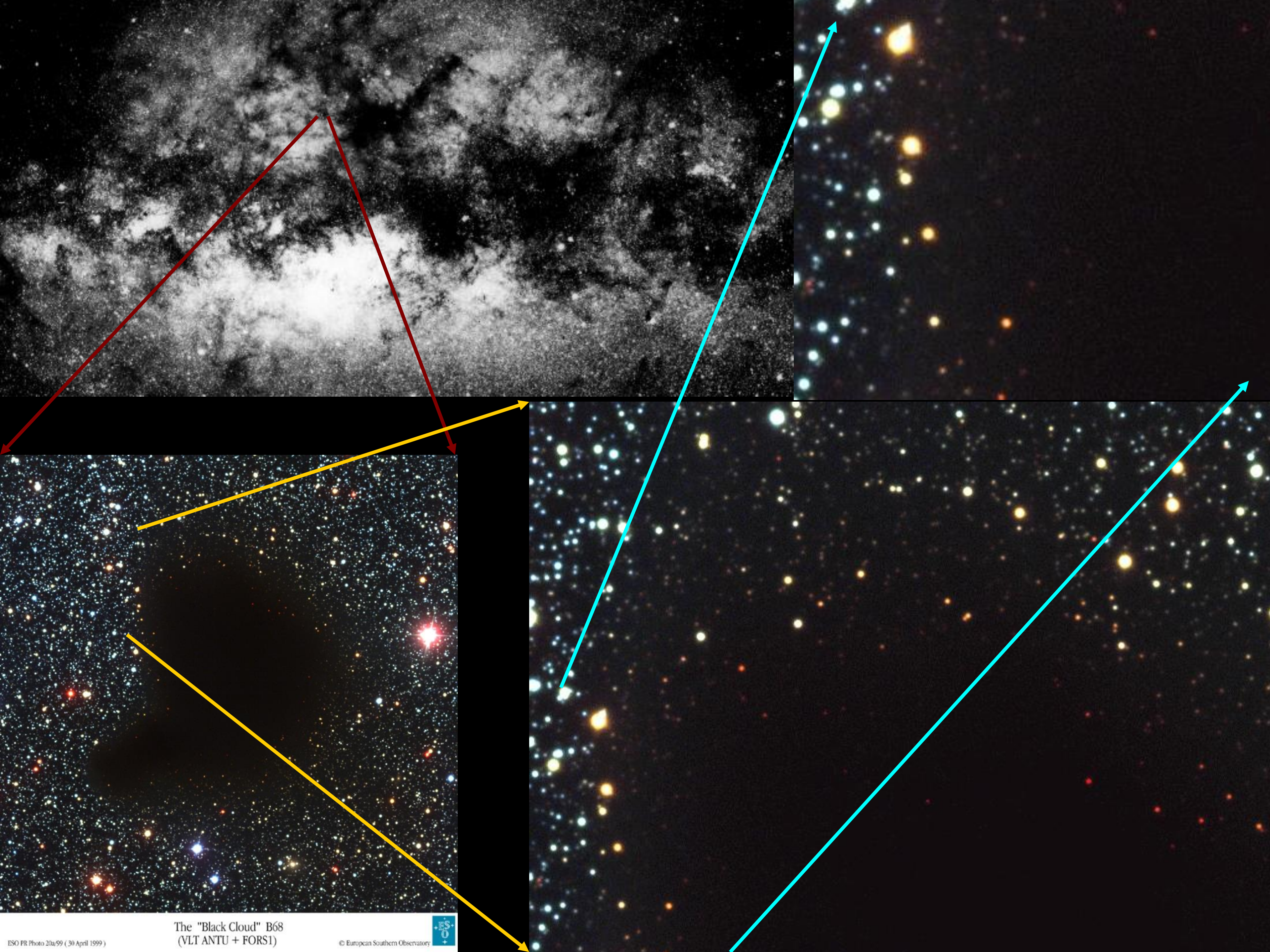
⇒ "Transparent to dust" ⇒ Obscured dusty objects

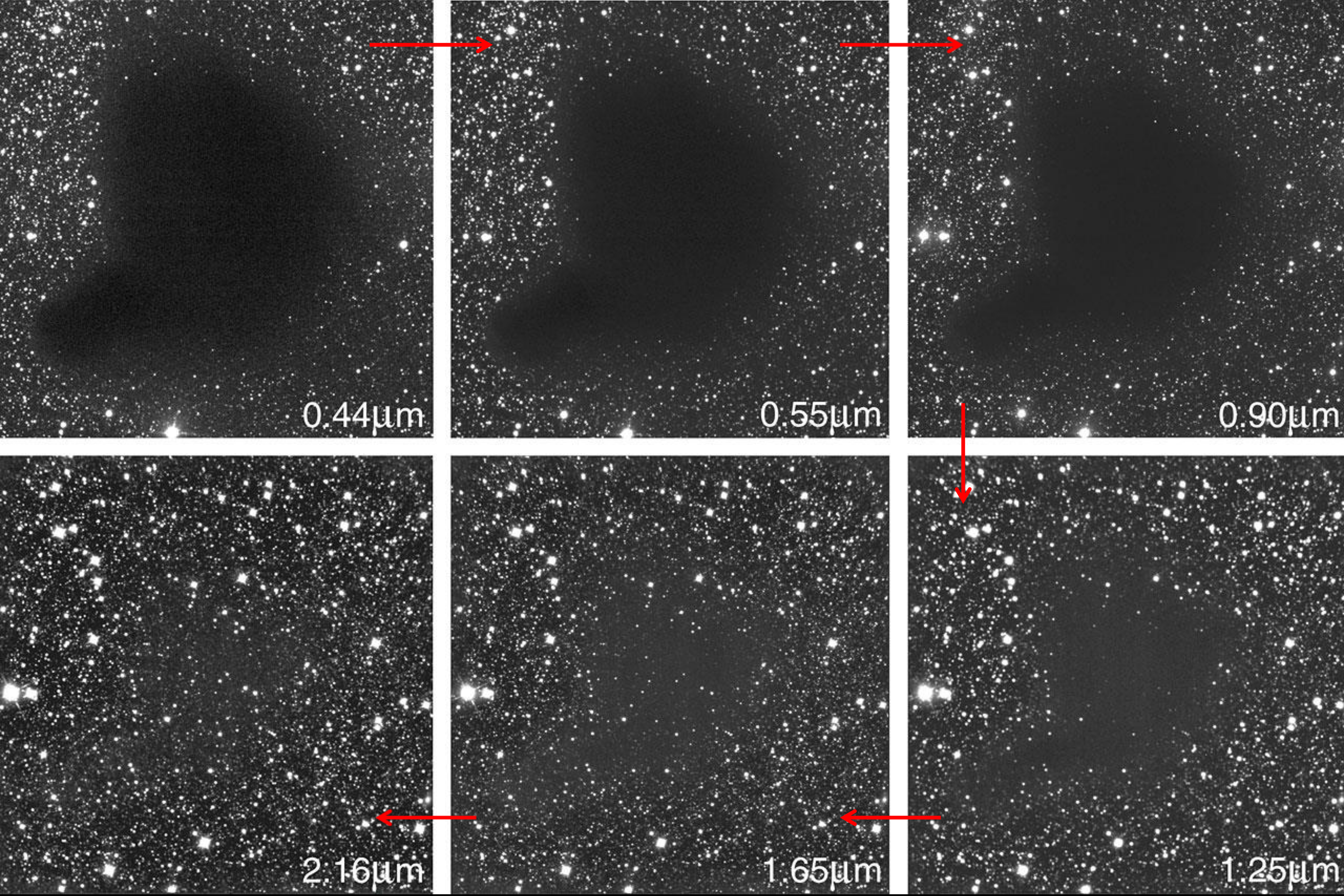
(n, T_K) ⇒ Molecular Universe ⇒ Gas and dust life-cycle

Properties of the different phases of the interstellar medium

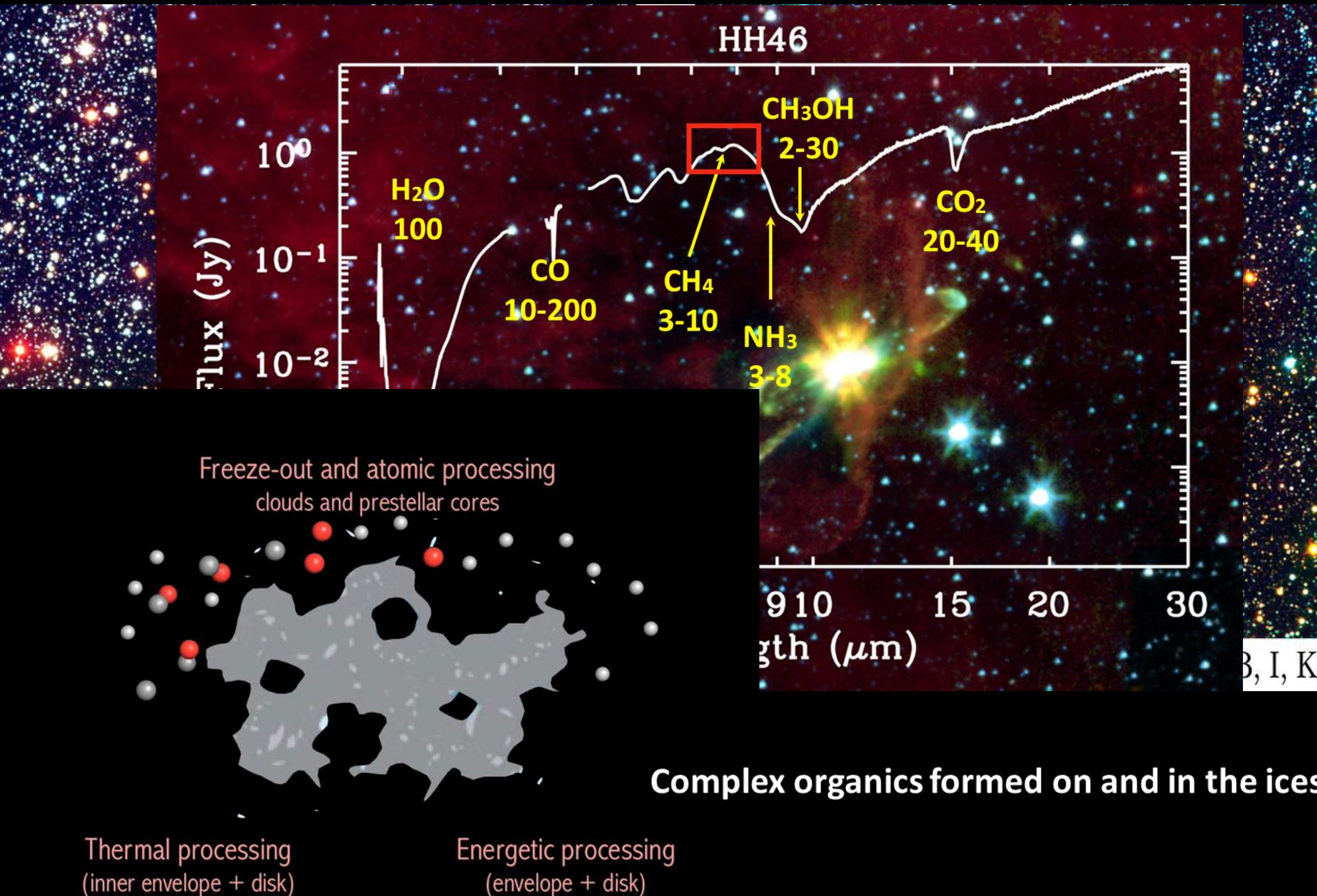
Phase	n [cm^{-3}]	T [K]	f	M [$10^9 M_\odot$]
Hot ionised Medium	0.003	10^6	0.5	-
Hot Neutral Medium	0.5	8000	0.4	1.4
Warm Ionized Medium	0.3	8000	0.1	1.0
Diffuse Clouds (HI)	50	80	-	2.5
Molecular Clouds	>300	10	-	2.5
HII Regions	$1 - 10^5$	10^4	-	-
Protoplanetary Systems	10^4-10^{12}	10-1000	-	-
Evolved Stars	10^2-10^{14}	10-2000	-	-
Earth Surface	$2\ 10^{19}$	300		

f = Fraction of the galactic disk filled by each phase

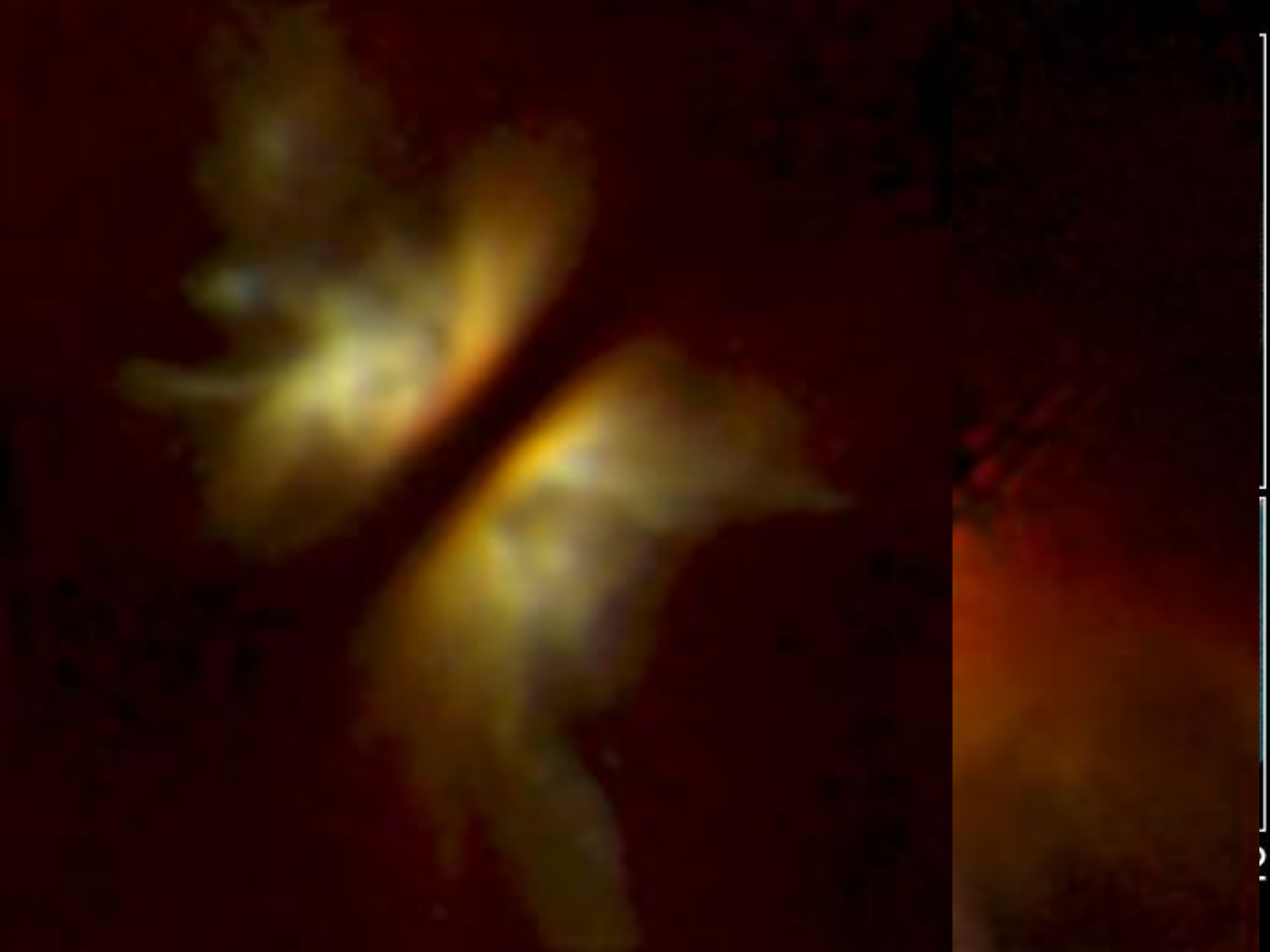

The "Black Cloud" B68
(VLT ANTU + FORS1)
ESO PR Photo 20a/99 (30 April 1999)
© European Southern Observatory

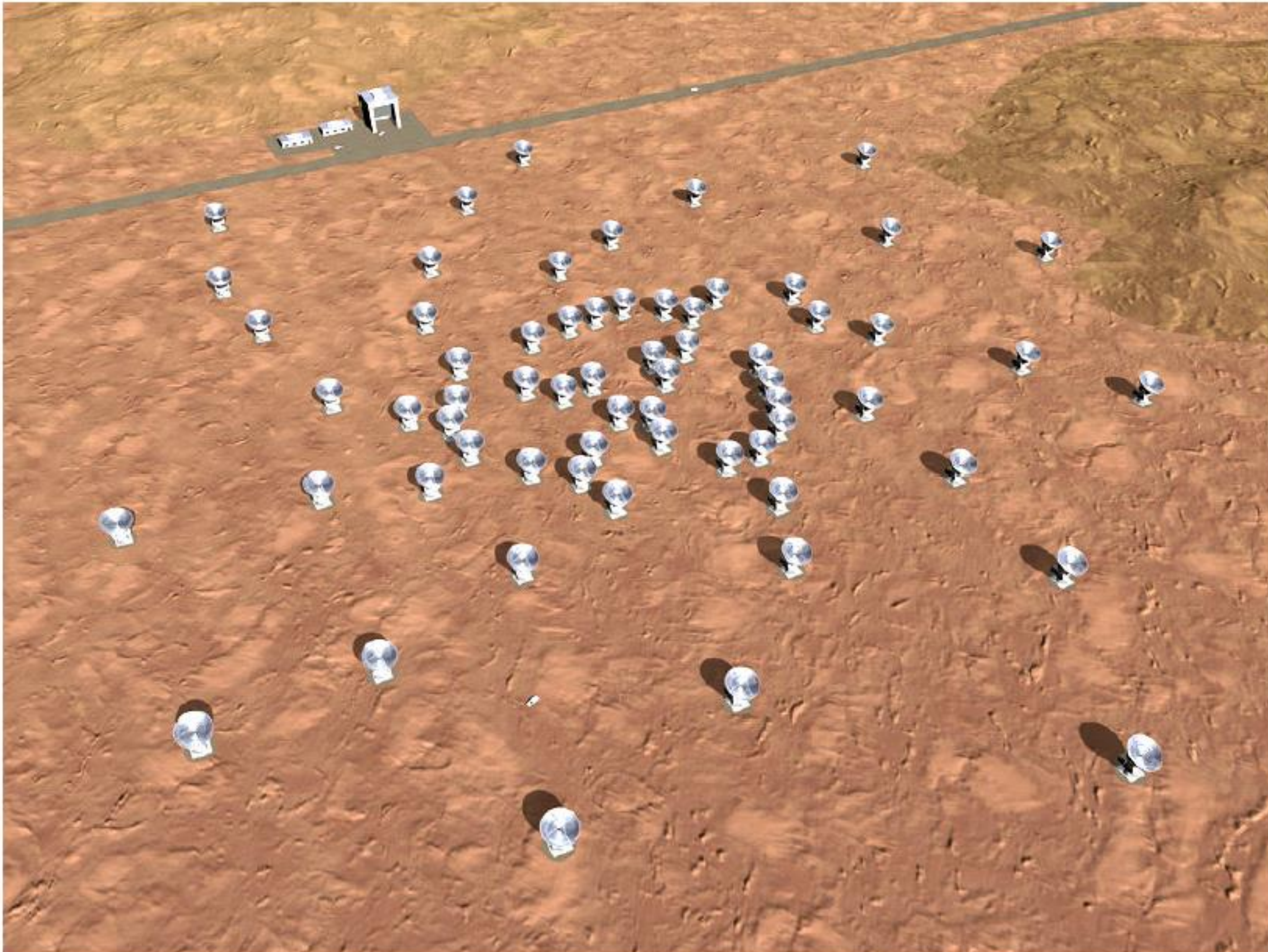


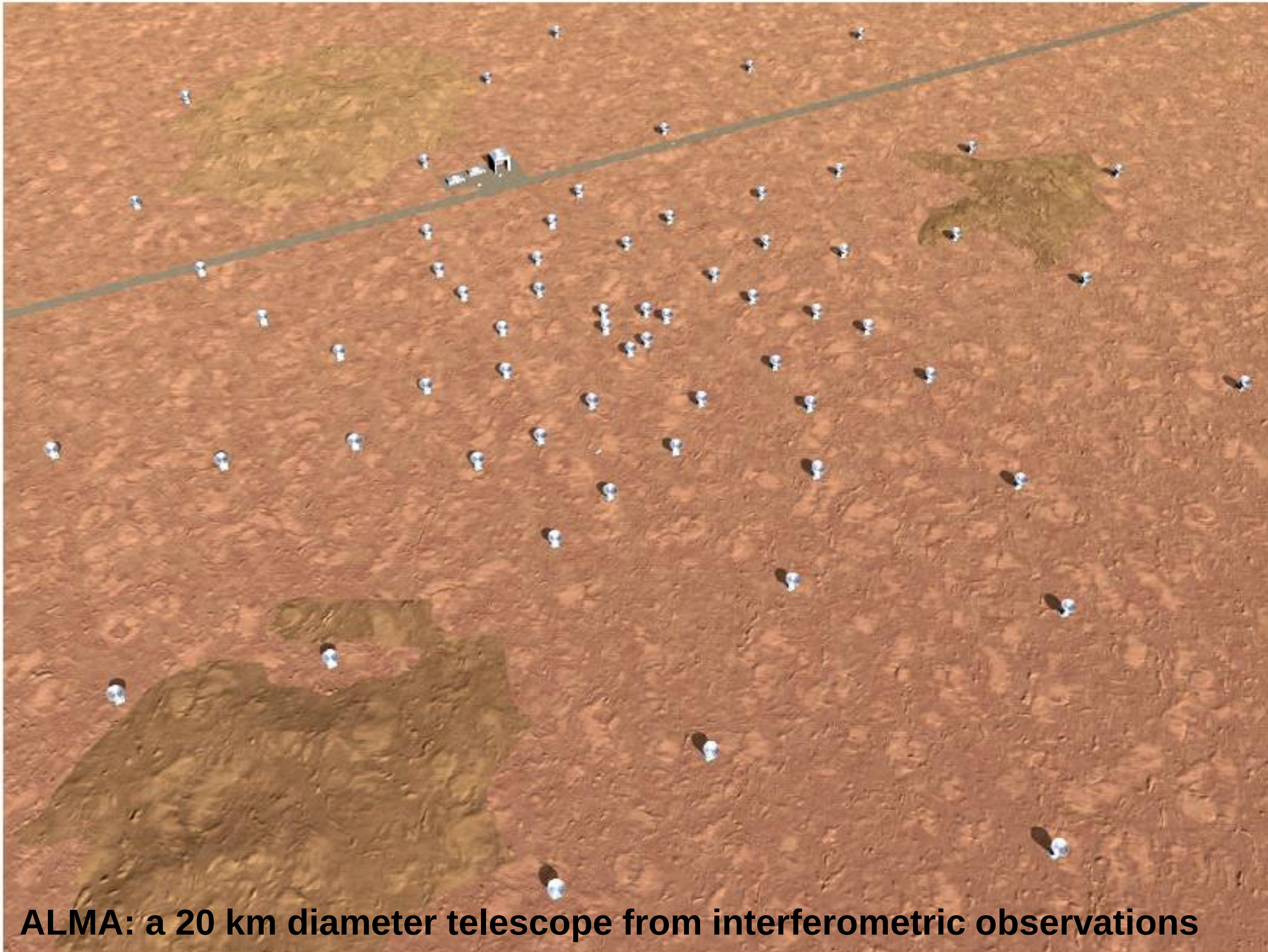
Molecular clouds are filled with submicron dust grains (≈0.5 µm)



Complex organics formed on and in the ices

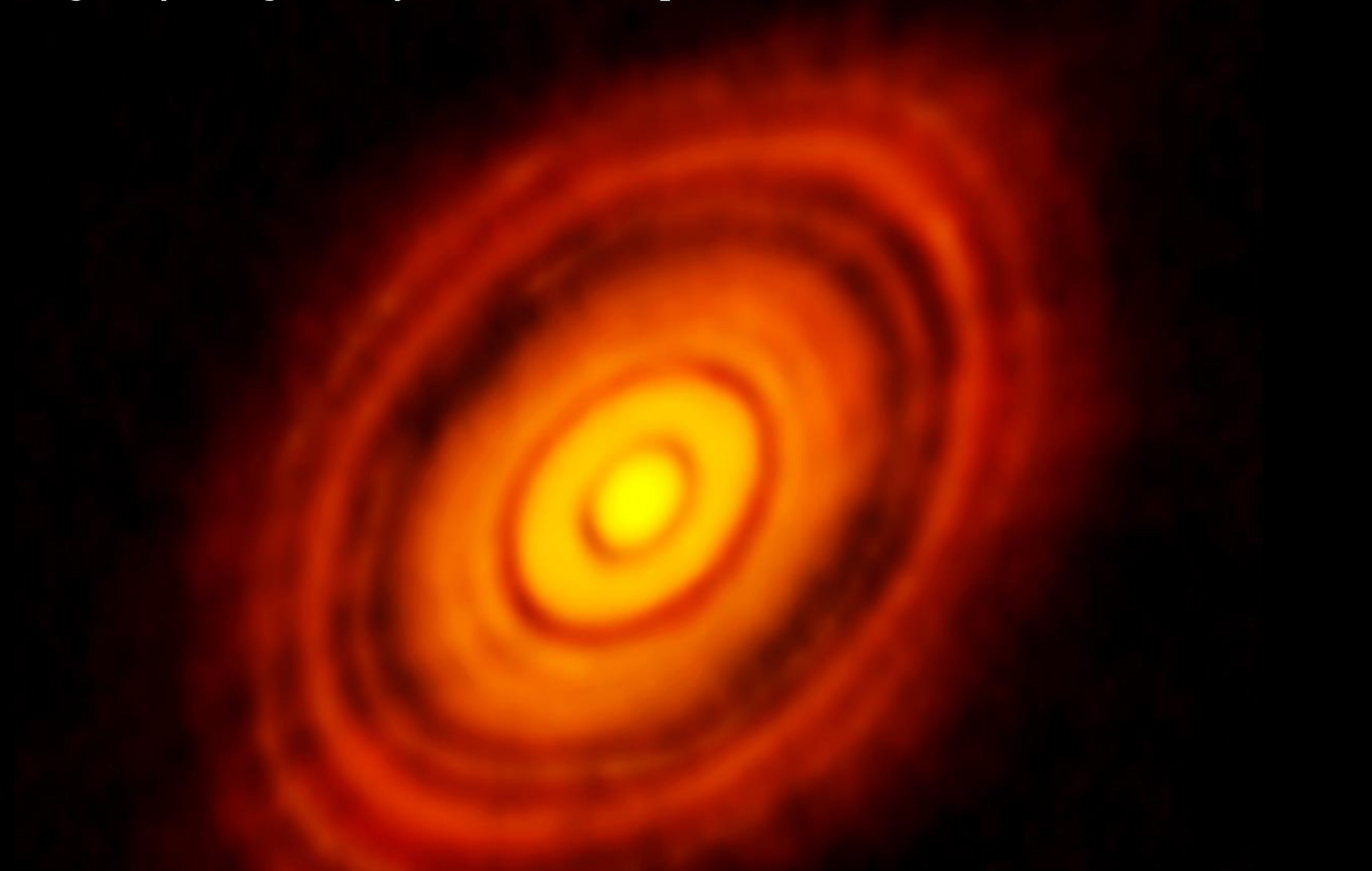






ALMA: a 20 km diameter telescope from interferometric observations

Image of a planetary disk as observed with ALMA in the continuum emission at submm wavelenghts of dust grains. Synthetized telescope = 15 km.



The dust grains that will made rocky planets have been formed in evolved stars and SNe
They have been processed (covered by ices) during several millions years in the evolution of molecular clouds. Learning about their formation is a crucial and key step in astrophysics

Why observing molecules in Space

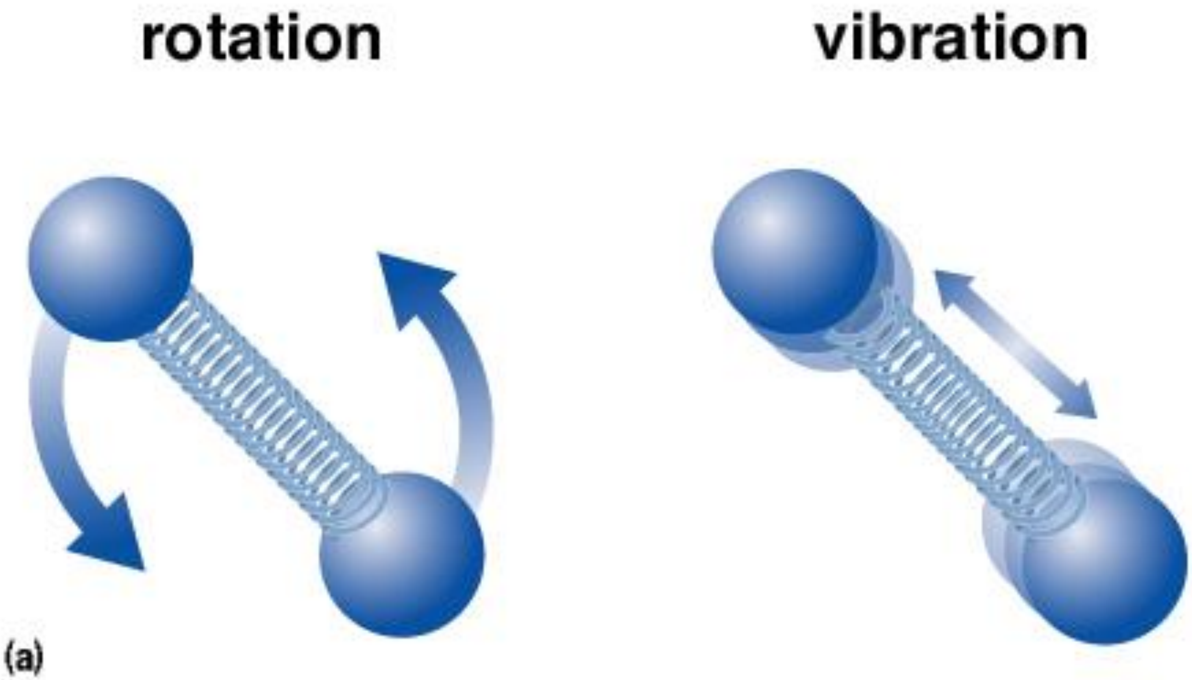
Molecular clouds are dark !! They contain H_2 and dust (gas/dust mass ratio ≈200 (all metals in grains !!)

Dust grains protect the inner part of molecular clouds against molecular photodissociation. Rich gas phase chemistry
H_2 + cosmic ray=H_2^+ followed by $H_2^+ + H_2 = H_3^+$ and H_3^++O ….

Molecules are cooling agents=>dynamics=>star formation

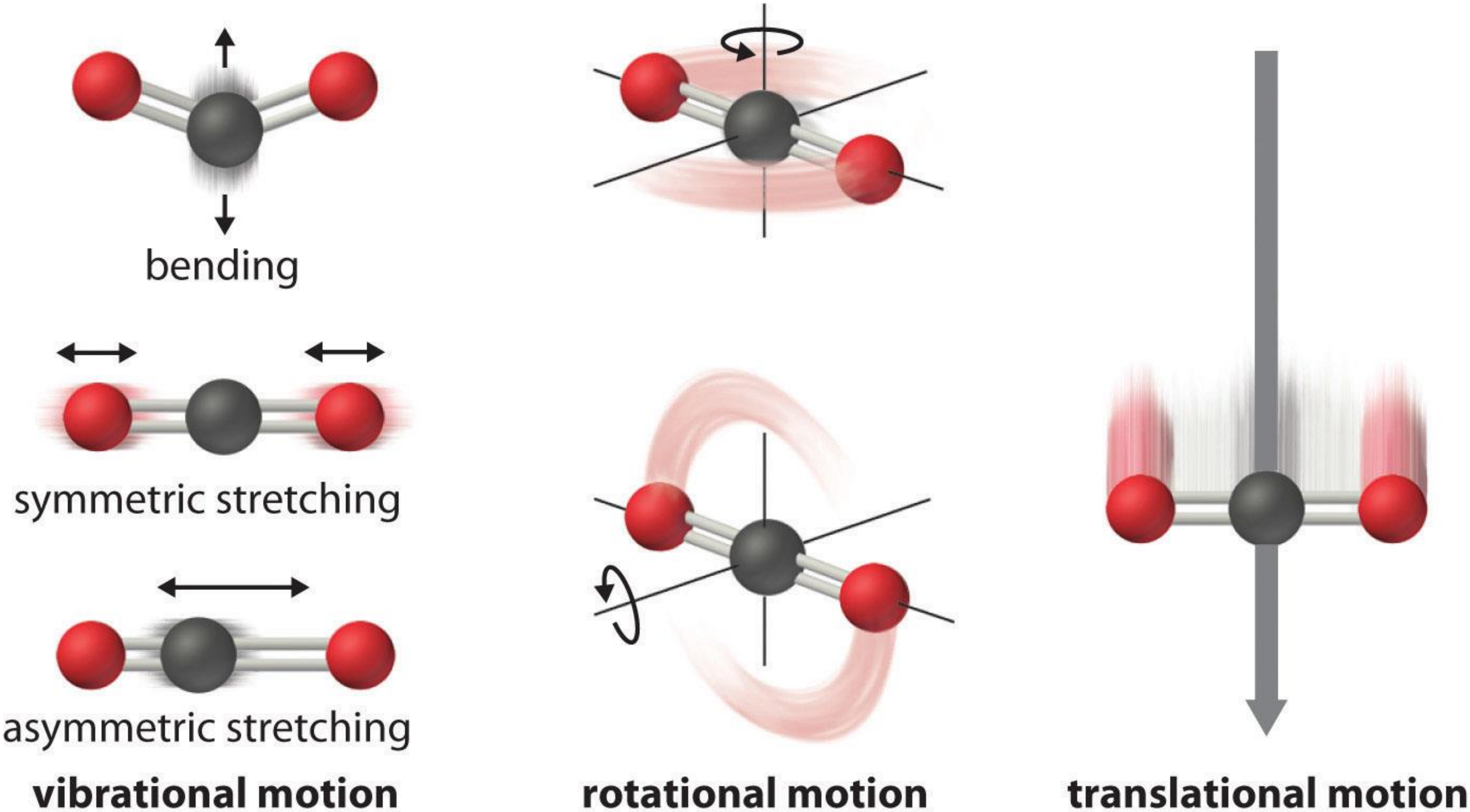
Molecules aggregate on dust grains during gravitational collapse =>rich surface chemistry=>preparing the initial conditions for the composition of surface and atmosphere of rocky planets

Molecules => getting volume densities, kinematics, dynamics, and kinetic temperatures from their line profile and intensity

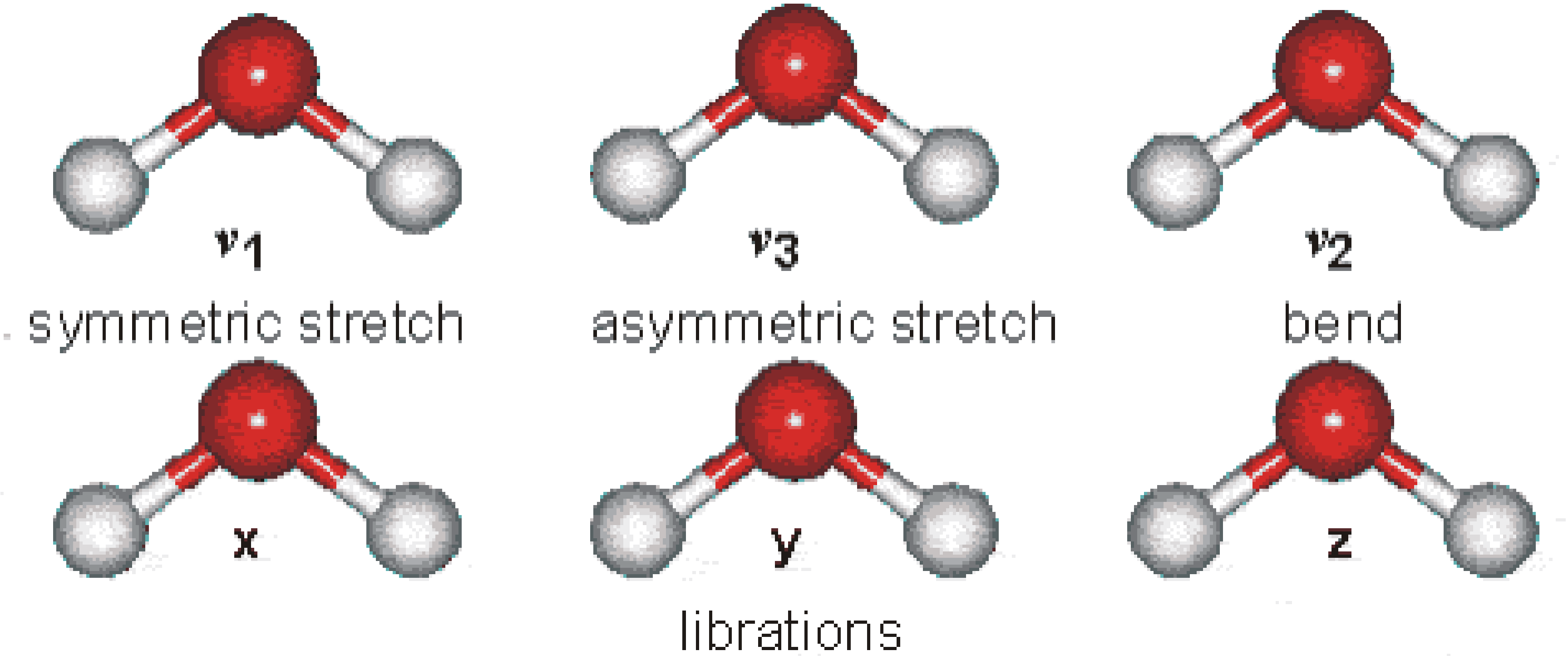


Microwave/millimeter/submillimeter/far IR

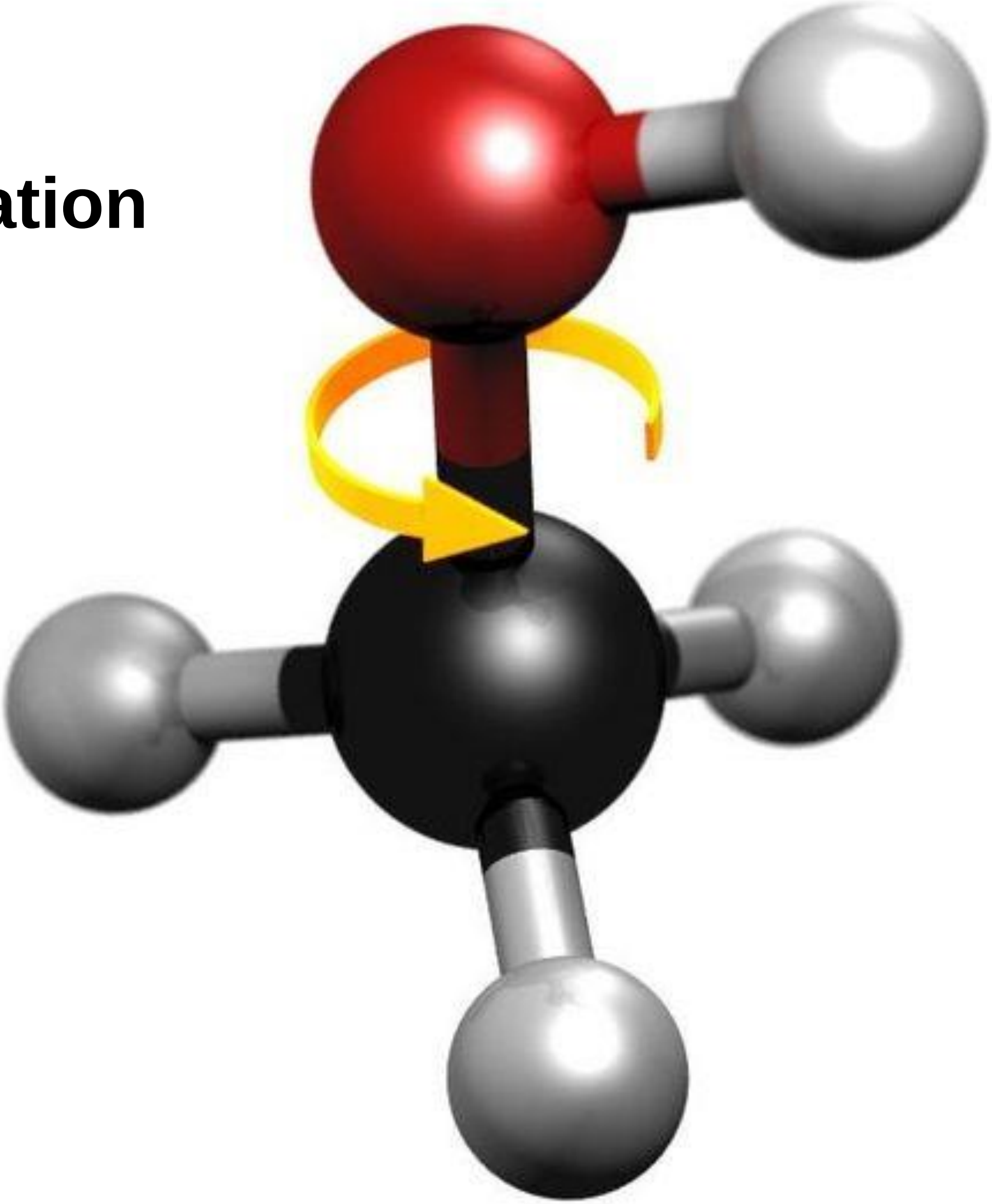
mid/near-Infrared

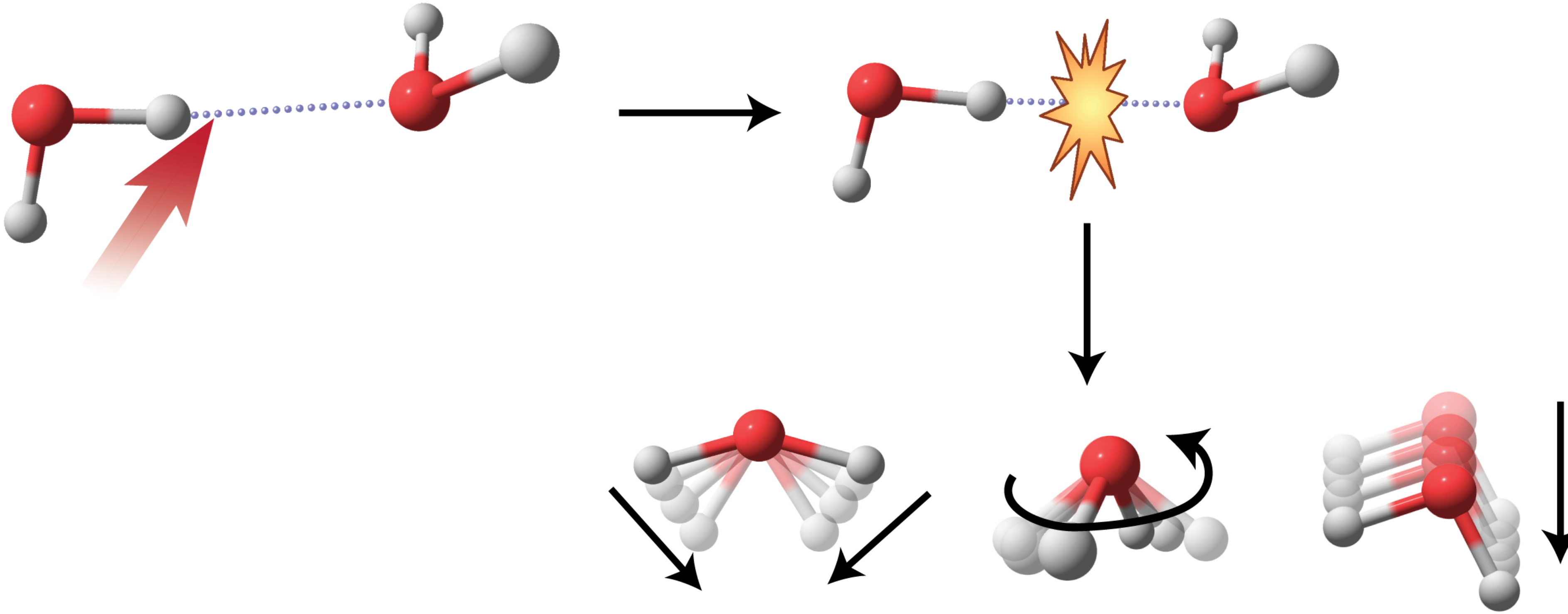

bending
symmetric stretching
asymmetric stretching
vibrational motion
rotational motion
translational motion

Absorption of EM radiation



CH_3OH
Internal rotation





MODELING ASTROPHYSICAL DATA: PRACTICALLY ALWAYS OUT OF EQUILIBRIUM

Lines arise from a region where temperature, abundance, and density can vary very fast

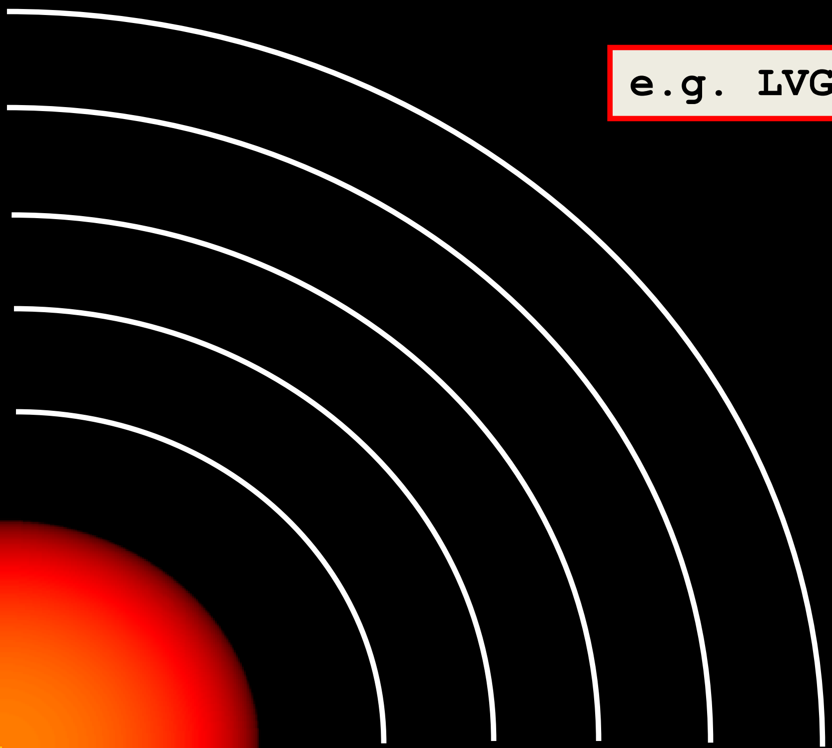
↓

The medium is not homogeneous

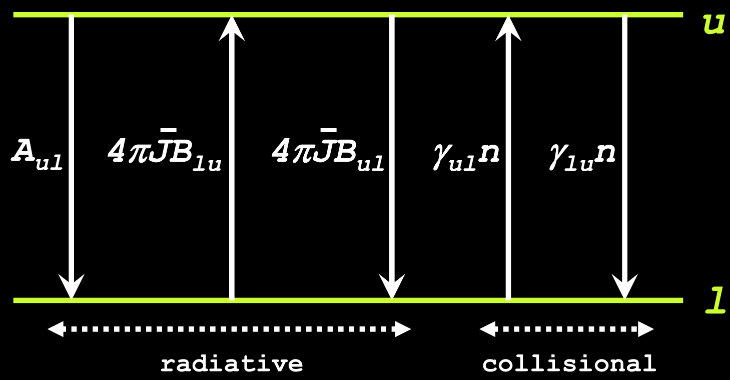
It is necessary to use sophisticated methods

↓

e.g. LVG multishell or non-local codes

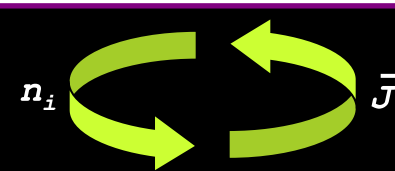


METHODS: Non LTE radiative transfer (LVG and non Local Codes)



Statistical Equilibrium

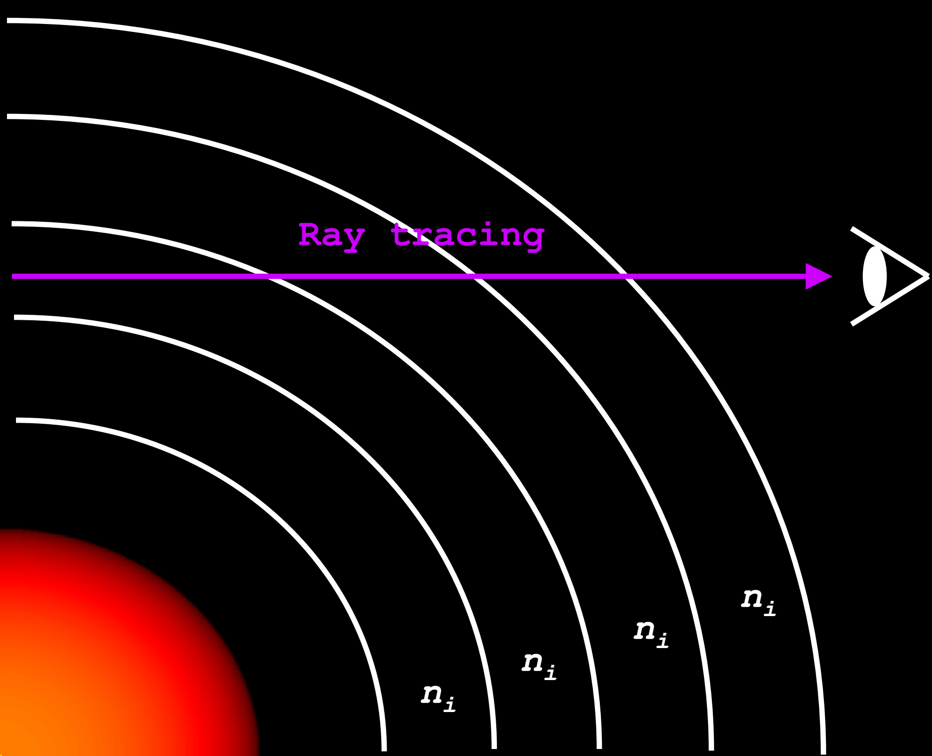
$$\frac{dn_i}{dt} = \sum_{j\neq i} n_j (4\pi \bar{J} B_{ji} + \gamma_{ji} n) + \sum_{j>i} n_j A_{ji} - n_i \sum_{j\neq i} (4\pi \bar{J} B_{ij} + \gamma_{ij} n) - n_i \sum_{j<i} A_{ij}$$

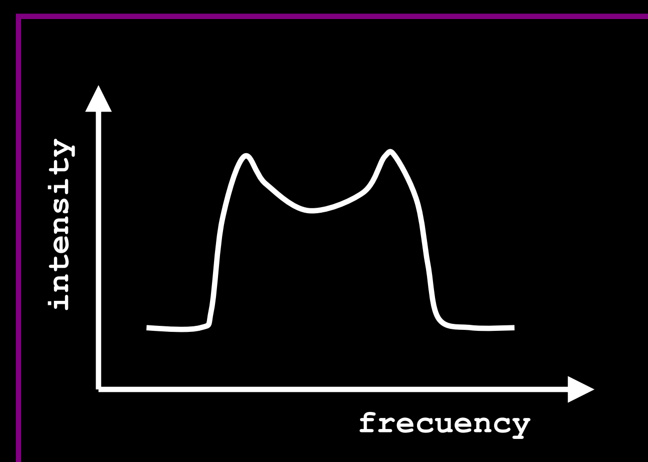


$$\bar{J} = (1-\beta) S_\nu + \beta I_\nu^{bg}$$

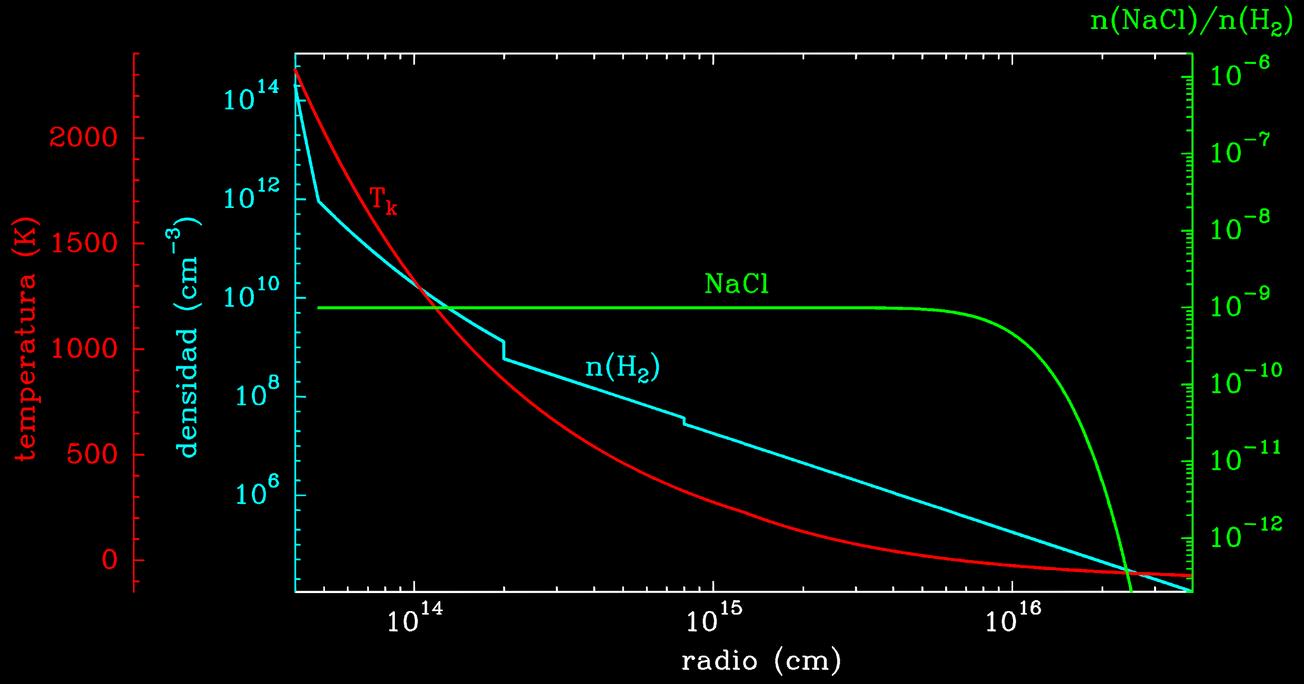
LVG codes

n_i population

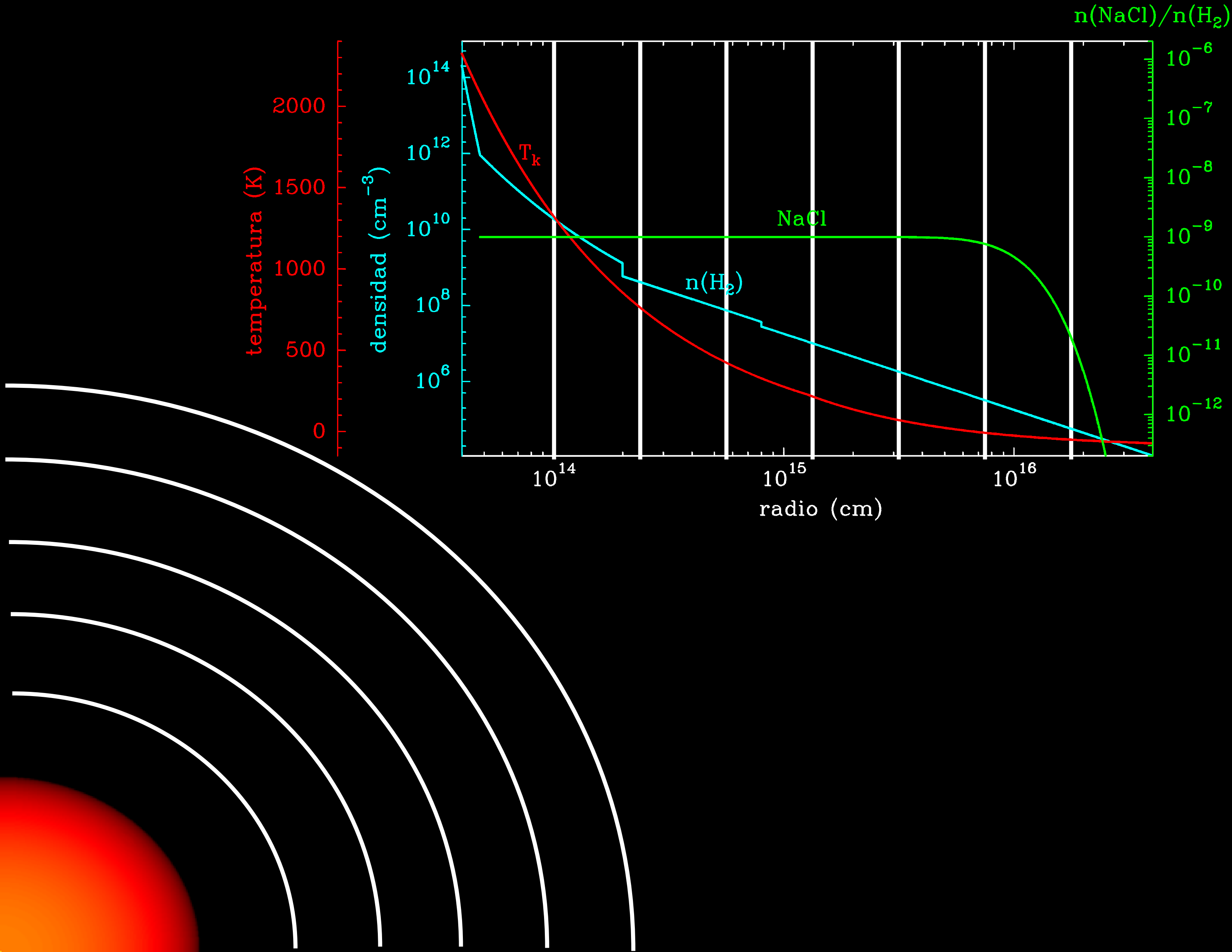




LVG multishell models

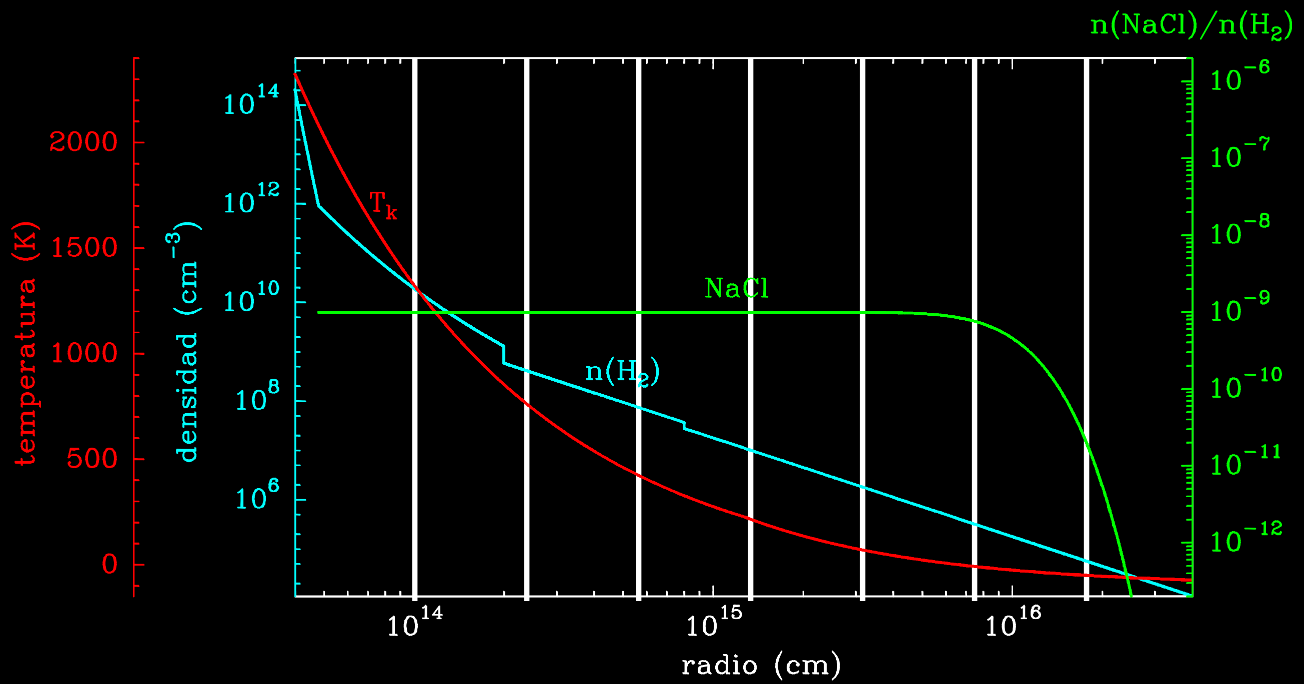


LVG multishell models



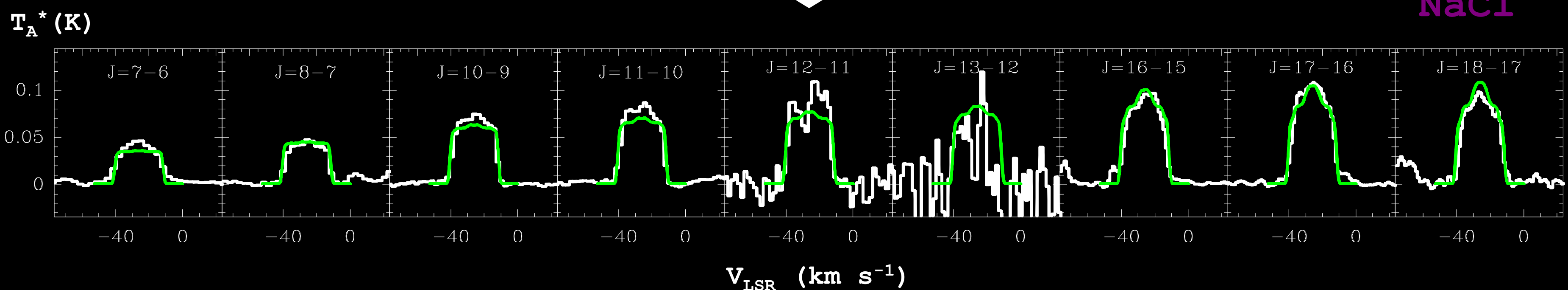
MODELING

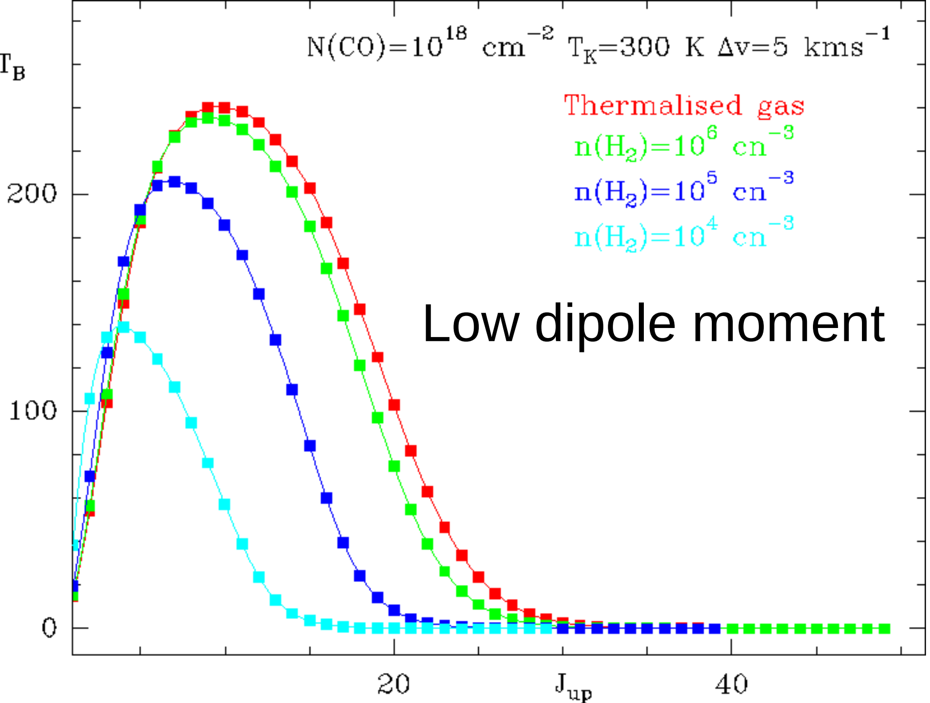
LVG multishell models



Results

NaCl

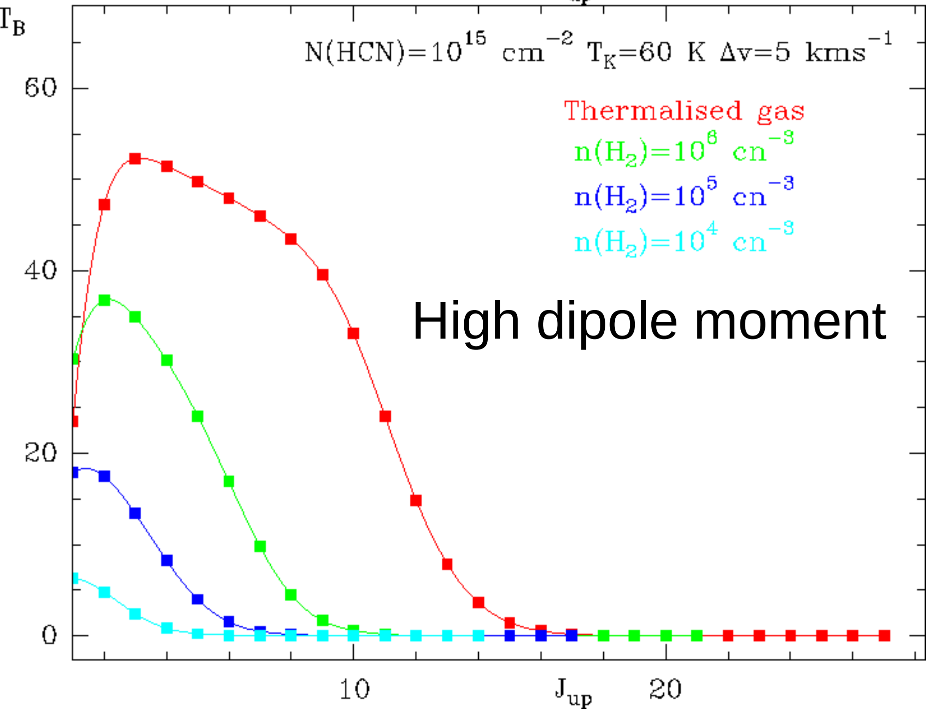




By selecting the appropiate molecule we can trace different physical parameters.

Low dipole moment molecules are easily thermalized, even at moderate densities. These molecules can be used to trace the kinetic temperature.

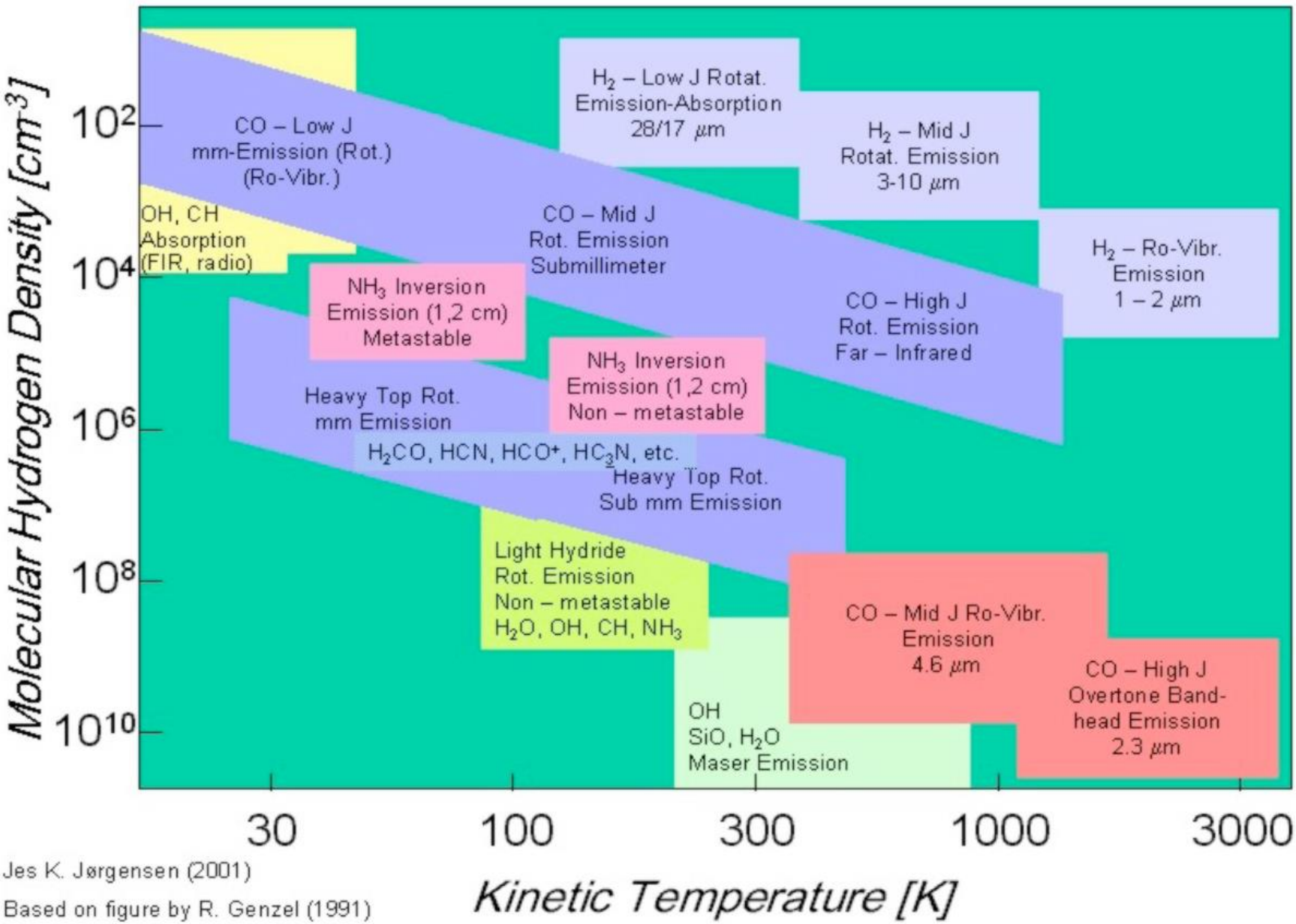
High dipole moment molecules trace the gas density.



However, state to state collisional rates between the molecule and H_2 must be known in order to model the observed emission.

These collisional rates are only available for a few species (CO, HCN, HCO^+, H_2CO, CH_3CN, SiO, NH_3, N_2H^+, CS, HC_3N,...) and often they have been calculated with He rather than with molecular hydrogen as collider.

Molecules as probes of T and n_H



Jes K. Jørgensen (2001)

Based on figure by R. Genzel (1991)

MOLECULAR ASTROPHYSICS AS A MULTISDICIPLINARY FIELD

LABORATORY SPECTROSCOPY (all λs)
& *ab initio* CALCULATIONS

DATA

PUBLIC CDMS & JPL CATALOGS
OR PRIVATE SPECTRAL CATALOG
(The MADEX code:
5247 spectral entries all them included
in the RT codes)

COLLISIONAL
RATES (theory)
H_2, He, H, e^-

RADIATIVE TRANSFER
LVG
NON LOCAL
LTE

CHEMICAL MODELS

REACTION RATES (lab and theory)
GAS AND GRAIN CHEMISTY

MOLECULAR ABUNDANCES

New Species | Source Structure | Chemistry | Physical Conditions

Number of Atoms

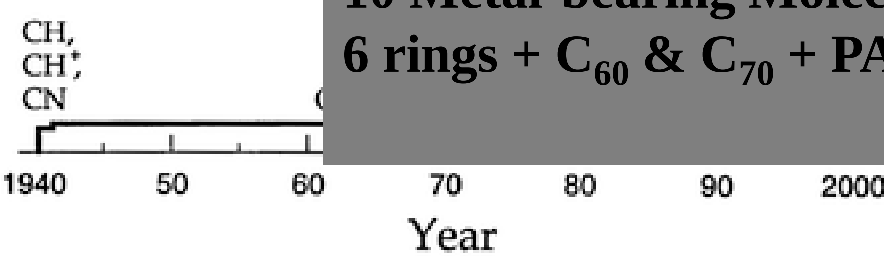
2	3	4	5	6	7	8	9
H_2	H_2O	NH_3	SiH_4	CH_3OH	CH_3CHO	CH_3CO_2H	CH_3CH_2OH
OH	H_2S	H_3O^+	CH_4	NH_2CHO	CH_3NH_2	HCO_2CH_3	$(CH_3)_2O$
SO	SO_2	H_2CO	CHOOH	CH_3CN	CH_3CCH	CH_3C_2CN	CH_3CH_2CN
SO^+	HN_2^+	H_2CS	$HC{\equiv}CCN$	CH_3NC	CH_2CHCN	C_7H	$H(C{\equiv}C)_3CN$
SiO	HNO	HNCO	CH_2NH	CH_3SH	HC_4CN	H_2C_6	$H(C{\equiv}C)_2CH_3$
SiS	SiH_2?	HNCS	NH_2CN	C_5H	C_6H		C_8H
NO	NH_2	CCCN	H_2CCO	HC_2CHO	c-CH_2OCH_2		
NS	H_3^+	HCO_2^+	C_4H	$CH_2{=}CH_2$	C_7^-?		**10**
HCl	NNO	CCCH	c-C_3H_2	H_2CCCC			
NaCl	HCO	c-CCCH	CH_2CN	HC_3NH^+			CH_3COCH_3
KCl	HCO^+	CCCO	C_5				$CH_3(C{\equiv}C)_2CN$?
AlCl	OCS	CCCS	SiC_4				
AlF	CCH	HCCH	H_2CCC				**11**
PN	HCS^+	$HCNH^+$	HCCNC				
SiN	c-SiCC	HCCN	HNCCC				$H(C{\equiv}C)_4CN$
NH	CCO	H_2CN	H_3CO^+				
CH	CCS	c-SiC_3					**13**
CH^+	C_3	CH_3					
CN	MgNC	CH_2D^+?					$H(C{\equiv}C)_5CN$
CO	NaCN						
CS	CH_2						
C_2	MgCN						
SiC	HOC^+						C_{60}^+
CP	HCN						
CO^+	HNC						
HF	SiCN						
	KCN?						

Recent detection of anions:
CN^-, C_3N^-, C_5N^-,
C_4H^-,C_6H^-.C_8H^-

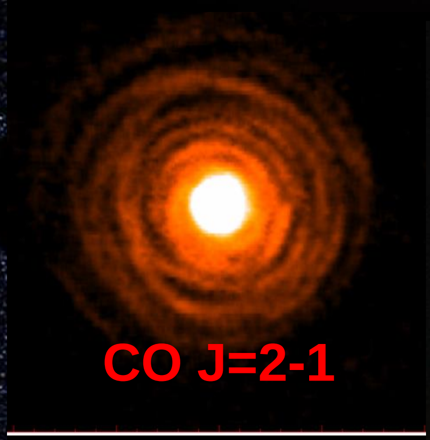
>15 cations

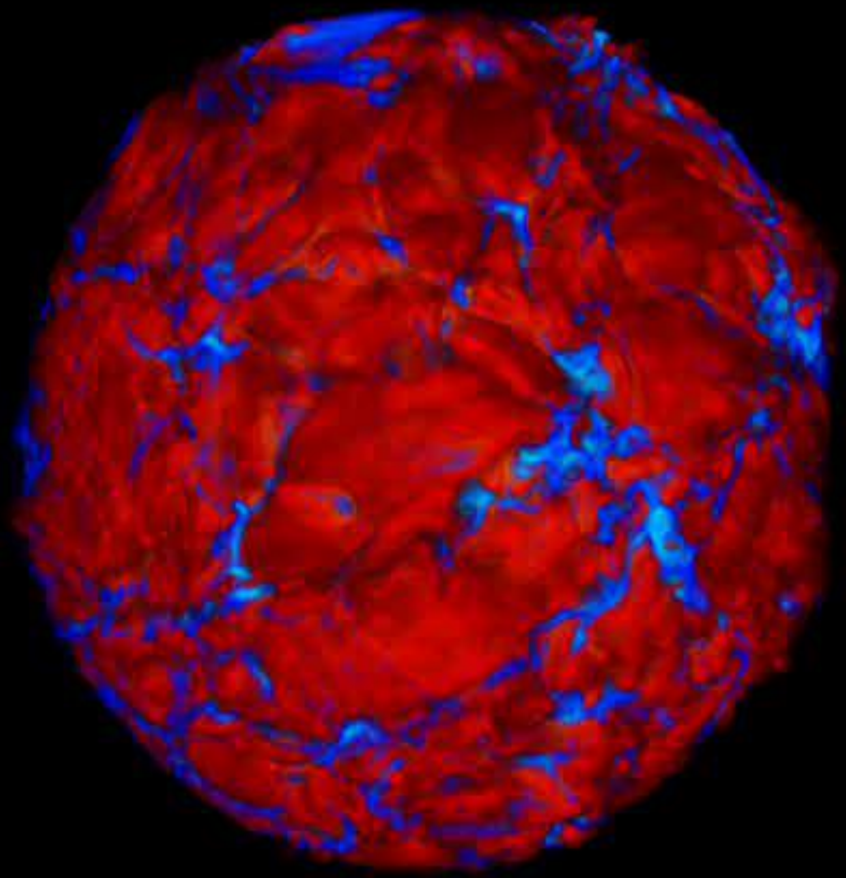
>100 Carbon Molecules

10 Metal-bearing Molecules
6 rings + C_{60} & C_{70} + PAHs

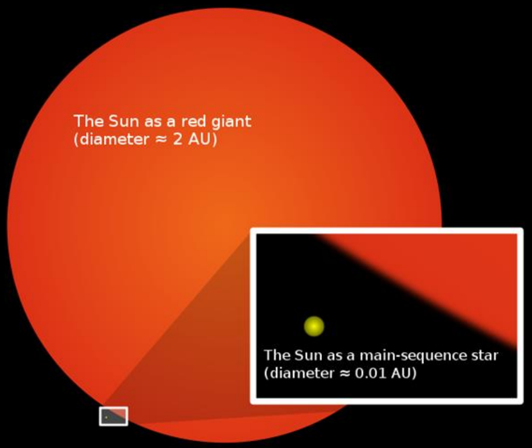


AGBs and post-AGBs





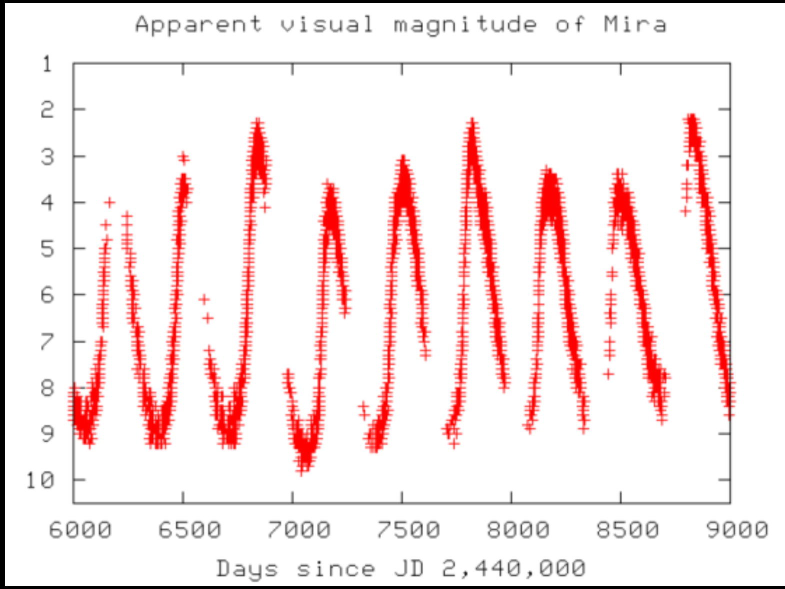
Relative temperature fluctuations, with different amounts of transparency at different stages of the movie, showing either the surface features or the interior global dipole flow pattern.

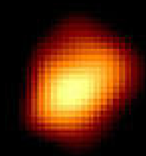


http://www.lcse.umn.edu/research/RedGiant/

What is the structure of an AGB star ?

Parameters for some well known AGB stars	Max Magnitud	Min Magnitud	Period days
Mira (o Ceti)	2	10,1	331,996
χ Cygni	3,3	14,2	408,5
R Hydrae	3,5	10,9	388,87
R Carianae	3,9	10,5	308,71
R Leonis	4,4	11,3	309,95
S Carinae	4,5	9,9	149,9
R Cassiopeiae	4,7	13,5	430,46
R Horologii	4,7	14,3	407,6
U Orionis	4,8	13	368,3
RR Scorpii	5,0	12,4	281,45
R Serpentis	5,16	14,4	356,41
R Centauri	5,3	11,8	546,2
R. Trianguli	5,4	12,6	266,9
R Leporis	5,5	11,7	427,1
R Aquilae	5,5	12	284,2
R Aquarii	5,8	12,4	386,96
U Cygni	5,9	12,1	463,24





Many AGBs are optically visible : low mass loss rate (10^{-7} solar masses /year)
others are very dusty : high mass loss rate (10^{-4} solar masses/year)
All them are pulsating

CHEMISTRY IN SPACE

How Molecules are formed ?

Physical conditions very different from those in the Earth Laboratories

Interstellar gas is far from thermodynamical equilibrium

MODELS UNDER THERMAL EQUILIBRIUM

Reaction rates and the path to form molecules are not important. Molecular abundances are determined by their value at thermo-dinamical equilibrium.

That means that two and three body reactions must be much faster that the time scale for dinamic evolution.

Of course, these models will provide reasonable results only for the most dense and warm regions. In the external layers of the envelope molecular abundances will be strongly dependent on the chemical kinetics and on the UV photons entering the envelope.

The formation rate of the molecule AB, assuming that the activated complex reaches an equilibrium between formation and destruction is given by

$$dn(AB)/dt = n(AB^*) \times n(M)k_2$$

$$dn(AB^*)/dt = n(A) \times n(B) \times k_1 - n(AB^*) \times n(M) \times k_2 - n(AB^*) \times k_3$$

$$dn(AB^*)/dt = 0$$

$$n(AB^*) = \frac{n(A)\ n(B)\ k_1}{(k_3 + k_2\ n(M))}$$

and

$$dn(AB)/dt = \frac{k_1\ k_2\ n(A)\ n(B)\ n(M)}{k_3 + k_2\ n(M)}$$

If A, B y M are neutral species then $k_1 \approx 10^{-11}$ cm^3s^{-1} and $k_2 \approx 10^{-10}$ cm^3s^{-1} , but k_3 10^{+11} s^{-1}, and

$$dn(AB)/dt \approx 10^{-32}\ n(A)\ \ n(B)\ \ \ n(M)\ \ cm^{-3}s^{-1}$$

The best case in the ISM/CSM occurs for A=B=M= H

$$H + H + H \Leftrightarrow H_2 + H$$

For hydrides (BH) the optimal case will correspond to A=H, M=H and $B \in (C,N,O)$, i.e., $n(B) \approx 10^{-4}\ n(H)$ and

$$dn(BH)/dt \approx 10^{-36}\ n^3(H)\ cm^{-3}\ s^{-1} \quad B \in (C,N,O)$$

EXAMPLE:

Let us consider an atomic cloud without dust grains and without radiation field. For t=0 the density of atomic hydrogen is n and that of molecular hydrogen is 0. The formation of H_2 occurs through the reaction

$$H + H + H = H_2 + H$$

with a rate $K = 10^{-32}\ \mathrm{cm}^6\ \mathrm{s}^{-1}$

The formation rate of H_2 is given by

$$\frac{dn(H_2)}{dt} = K\, n^3_H(t); \qquad f(t) = \frac{2\, n_{H2}(t)}{n_H(t) + 2\, n_{H2}(t)} = \frac{2\, n_{H2}(t)}{n}$$

$$\frac{df(t)}{dt} = K\, n^2\, (1 - f(t))^3 \qquad f(t) = 0.5 \text{ for which time ?}$$

EXAMPLE

f(t)=0.5

n(cm^{-3})	**10^5**	**10^{10}**	**10^{12}**	**10^{15}**	**10^{16}**	**10^{18}**
t(years)	**$6\ 10^{14}$**	**$6\ 10^4$**	**6**	**$6\ 10^{-6}$**	**$6\ 10^{-8}$**	**$6\ 10^{-10}$**
				(600 s)	**(6s)**	**(0.0006s)**

The three body mechanisms is only efficient for densities larger than 10^{10} cm^{-3}. Even in this case, the density is not enough taken into account the dynamical time scale of evolution of the object.

For a density of 10^{14} cm^{-3}, i.e., the photosphere of an AGB star, the time necessary to transform H into H_2 is $6\ 10^{-4}$ yr = 5.3 hours !!!!

Interstellar and Circumstellar chemistry require very different Chemical reactions to produce significant molecular abundances !

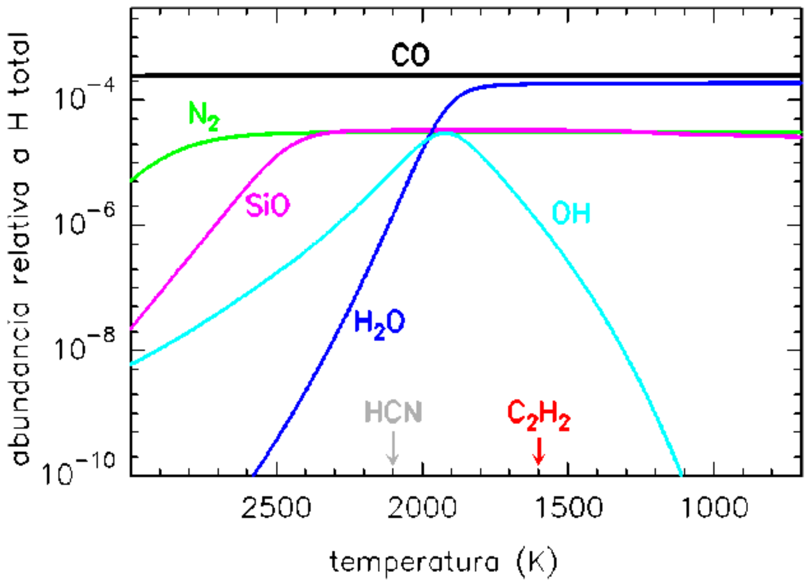
Dust grains

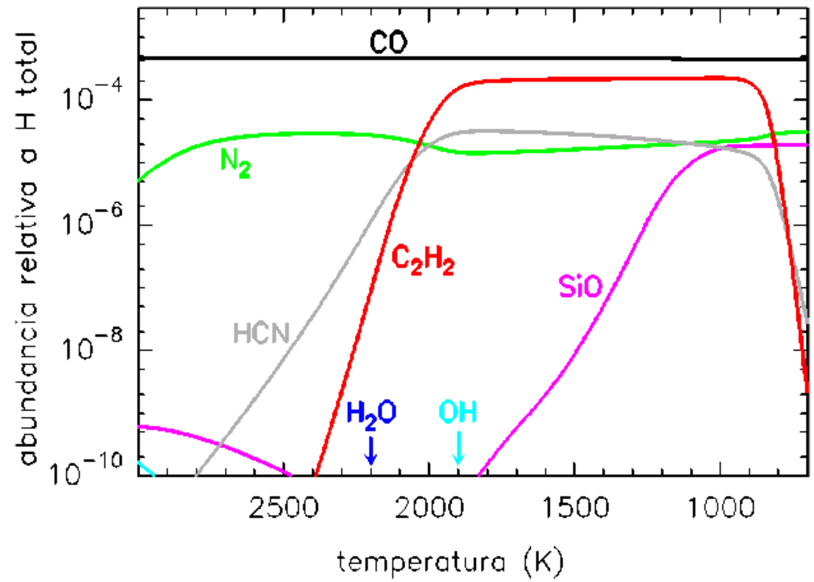
Formation
Evolution
Processing
Carbon material (PAHs)
Chemistry on their surfaces

The role of C/O ratio on the gas

O-rich or C-rich, that is the question

O-rich star	C-rich star
[C]/[O] < 1	[C]/[O] > 1

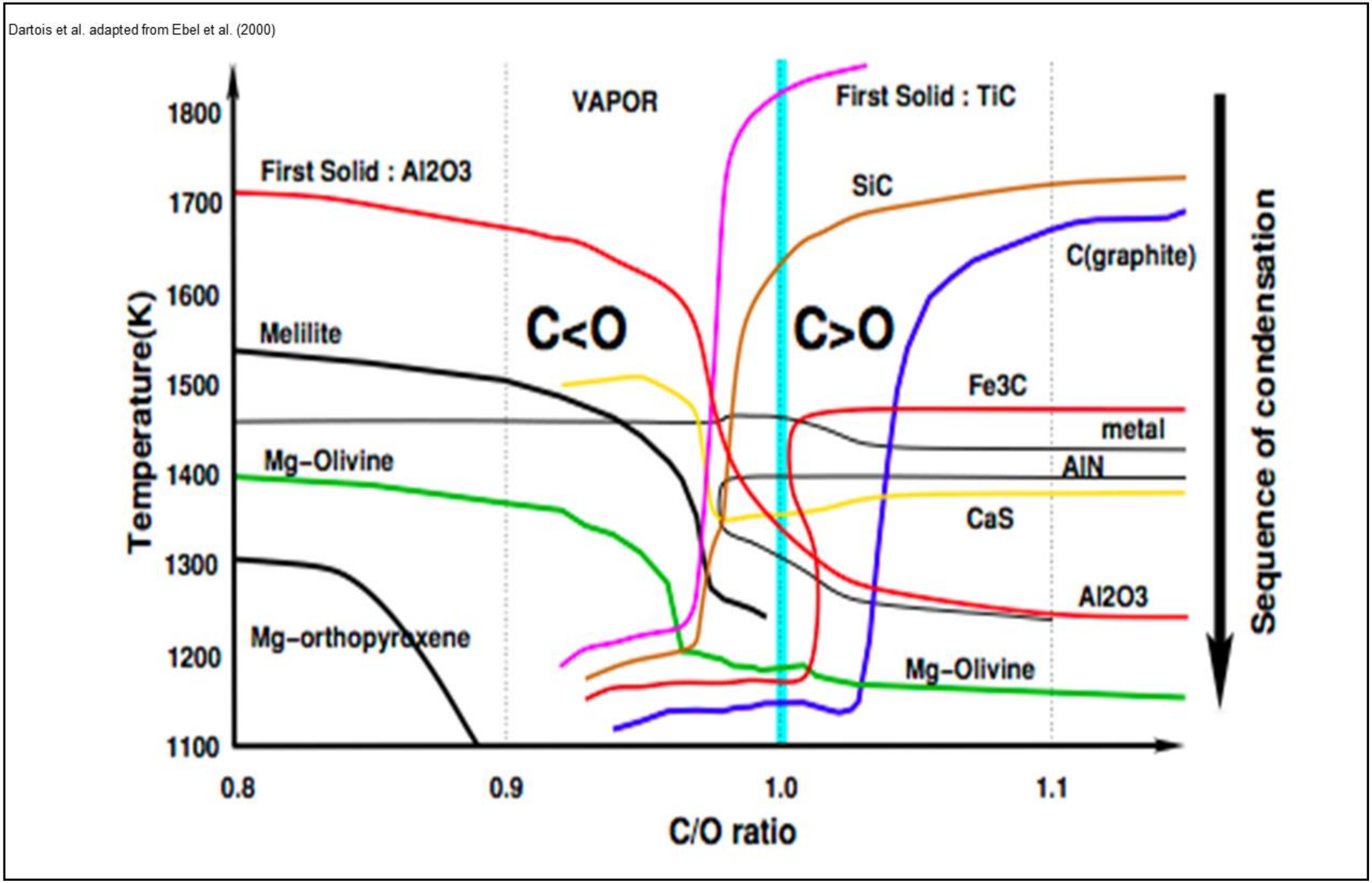




O-bearing molecules:
CO, H_2O, SiO, OH, …

C-bearing molecules:
CO, C_2H_2, HCN, CS, …

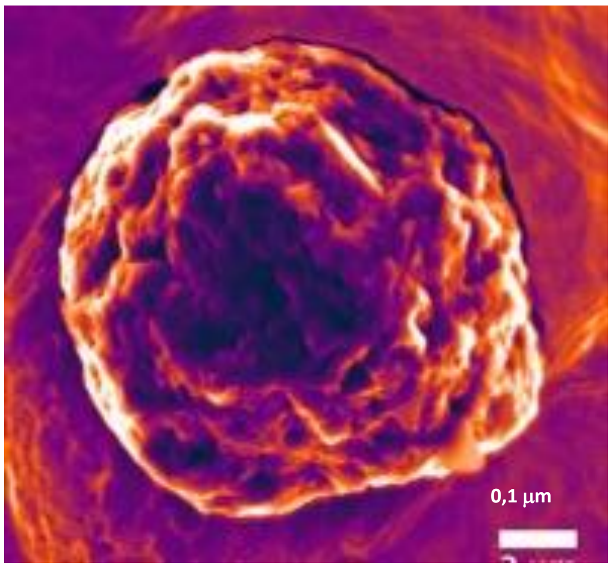
The role of C/O on the nucleation seeds

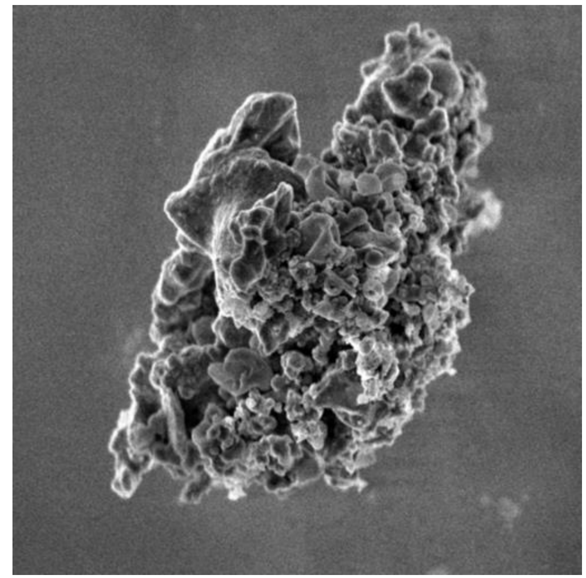


The challenge of dust growth modelling

A dust grain of 0.1µm contains ~ billion atoms

Several billion chemical reactions to form it from H, C, N, S, Si, Ti, Fe, Al, Mg, …..





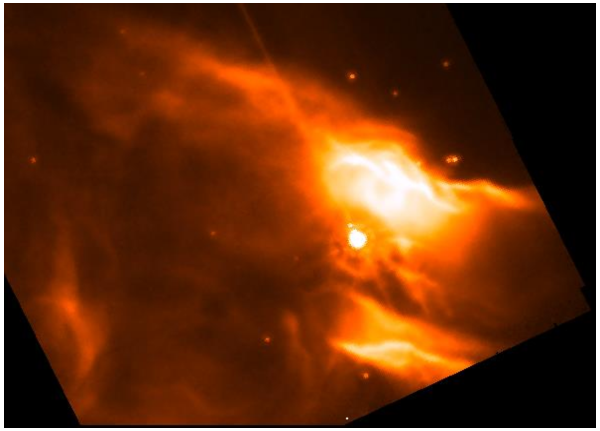
Impossible to study all the reactions individually : making circumstellar grains analogs in the laboratory

The Aromatic Infrared Bands (AIBs)

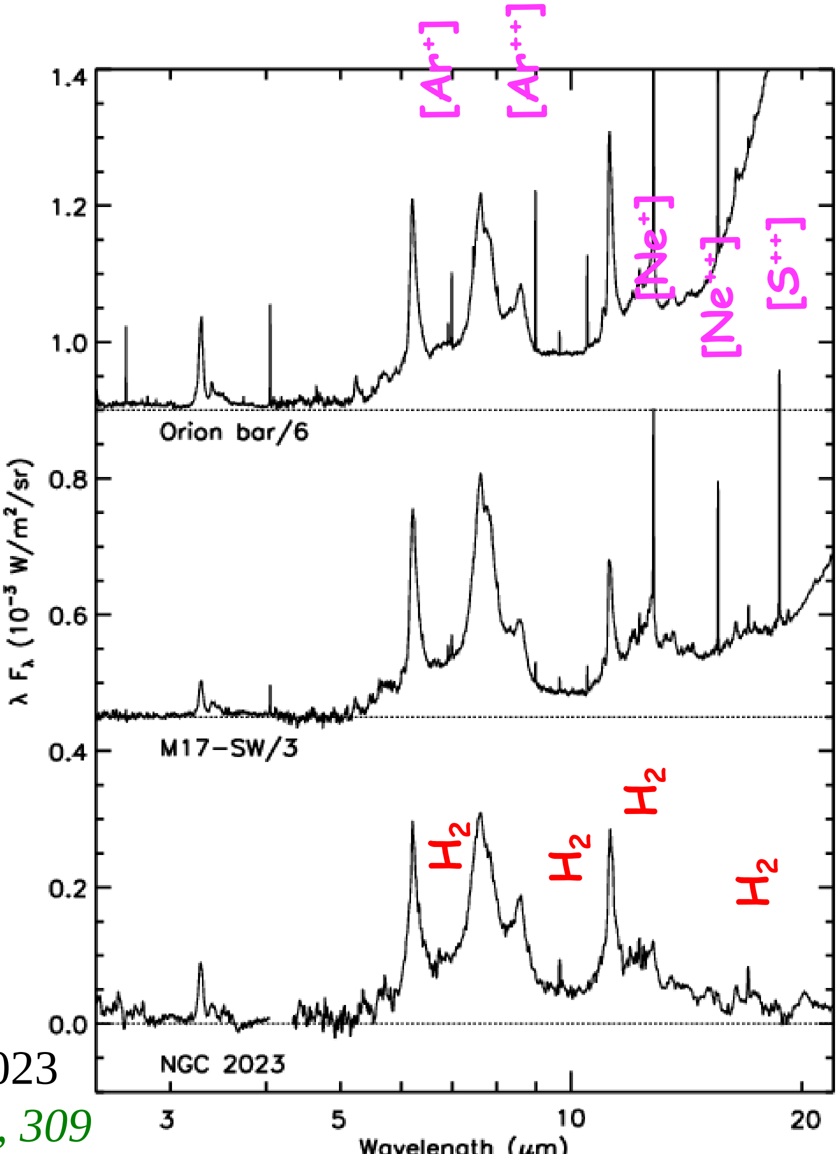
Infrared Space Observatory
ESA; 1995-1998

Spitzer Space Telescope
NASA; 2003-2009

AKARI
JAXA; 2006-2011

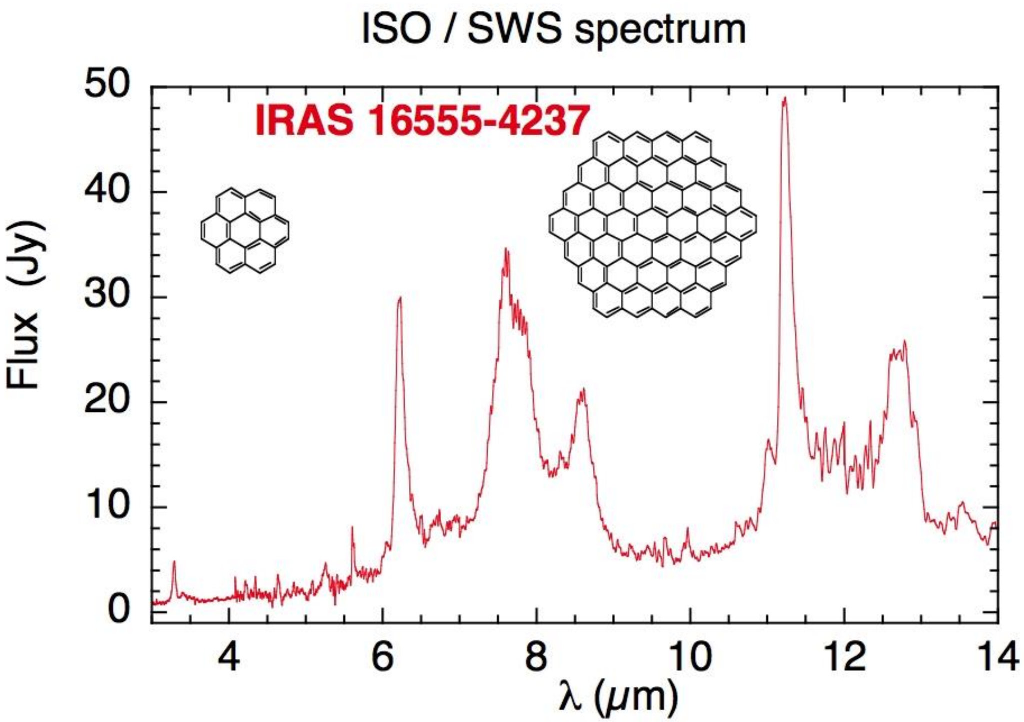


SST IRAC 8 μm image – NGC 7023
Werner et al. 2004, ApJ Supp 154, 309



ISO SWS spectra
Vertratete et al. 2001, A&A 372, 981

The PAH model



3.3 μm (3050 cm^{-1}); 6.2 μm (1610 cm^{-1});
‘’ 7.7 ‘’ μm (1300 cm^{-1}); 8.6 μm (1160 cm^{-1});
11.3 μm (890 cm^{-1}); 12.7 μm (785 cm^{-1})

CH and CC aromatic modes

- Stochastic heating – absorption of a single UV photon

N~50 ; T~1000 K

Sellgren 1984, ApJ 277, 623

- Candidates: PAH molecules

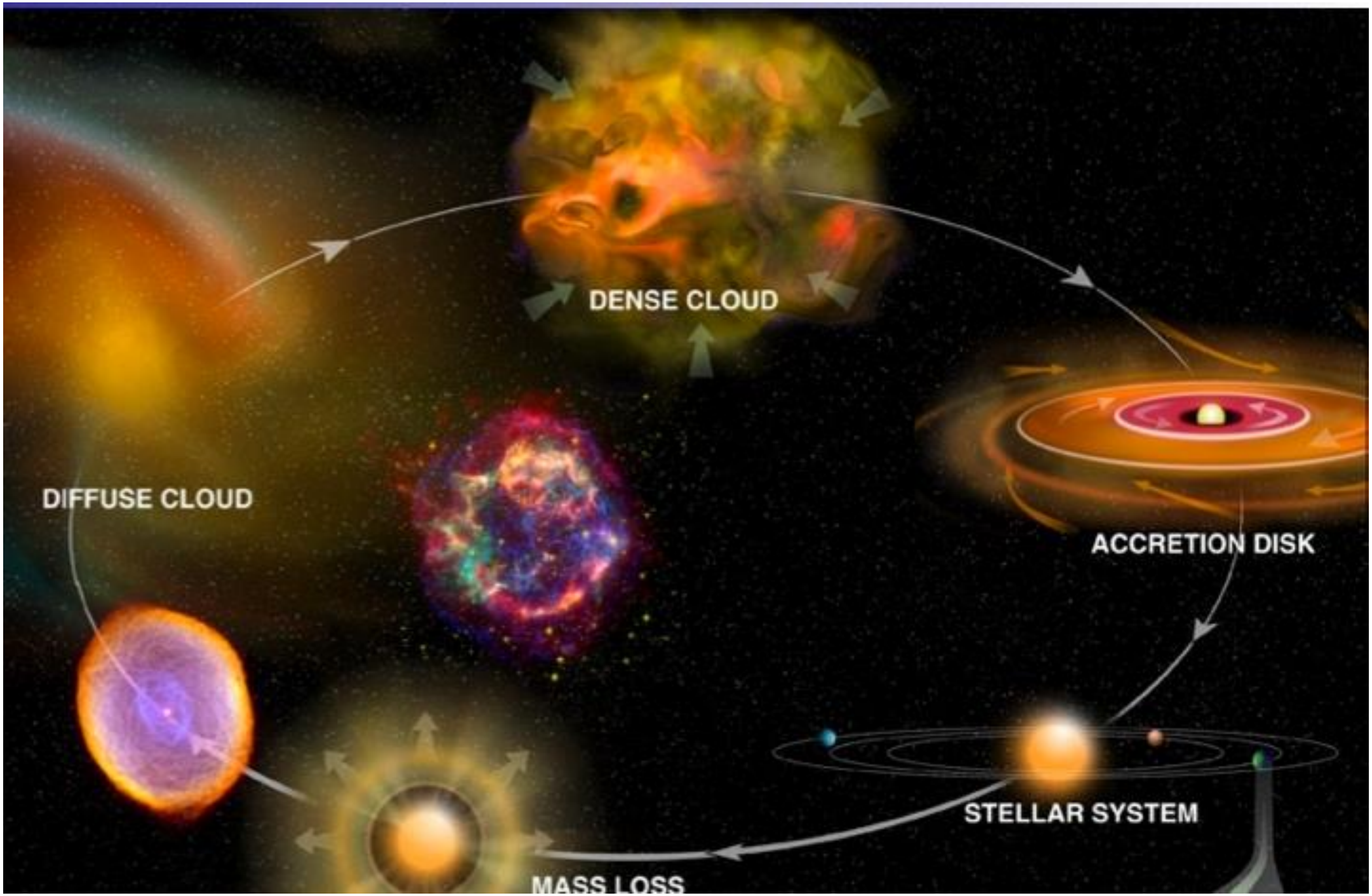
Léger & Puget 1984, A&A 137, L5
Allamandola, Tielens & Barker 1985, ApJ 290, L25

➢ Energetic budget: 10 to 20% of total carbon in PAHs

Joblin et al. 1992, ApJ 393, L79
Li & Draine 2001, ApJ, 554, 778
Draine & Li 2007, ApJ 657, 810

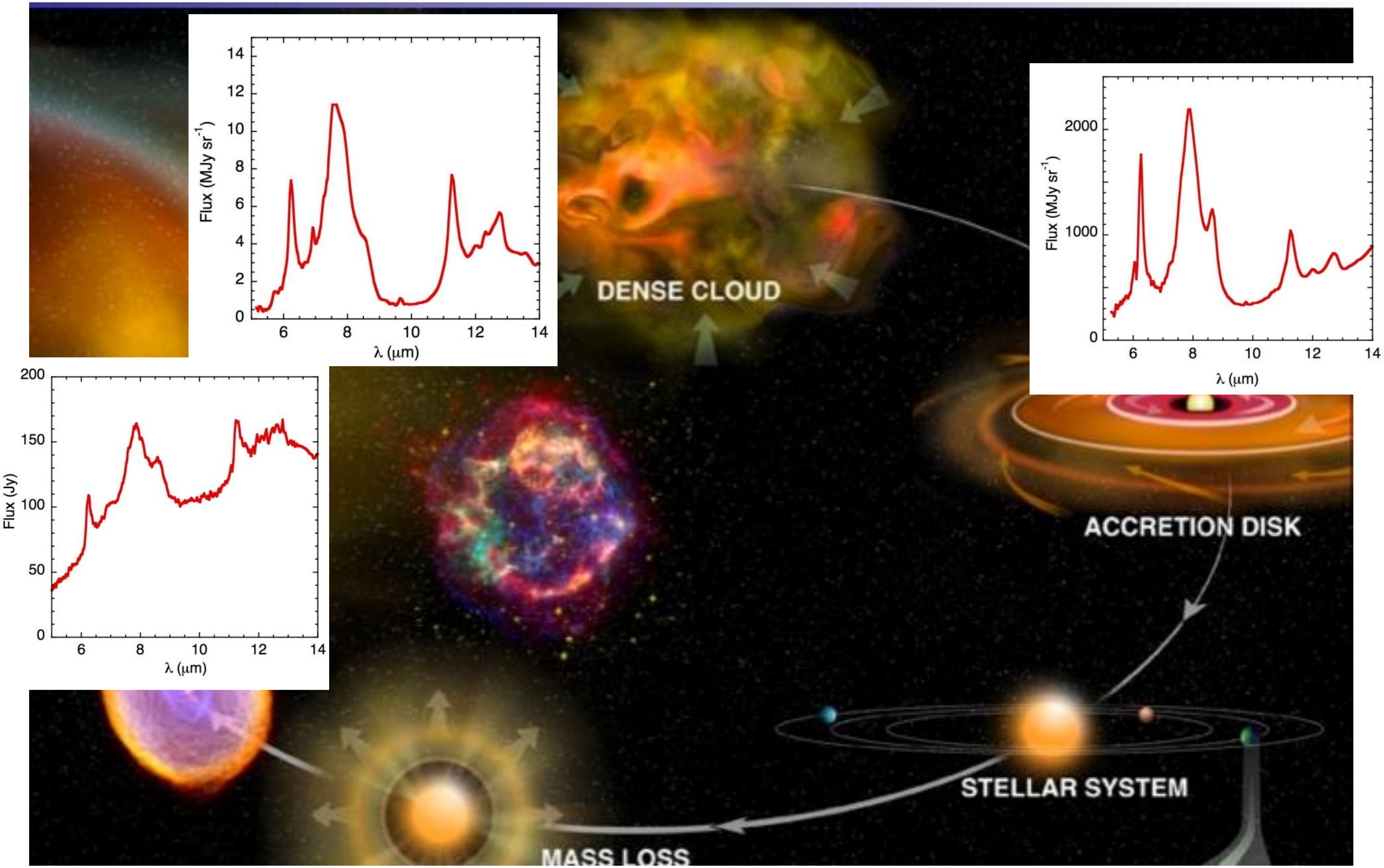
X_{PAH}~ 10^{-7} (N_C~50)

The AIBs in the galactic dust cycle



Adapted from *http://www.nrao.edu/pr/2006/gbtmolecules/* *Bill Saxton, NRAO/AUI/NSF*

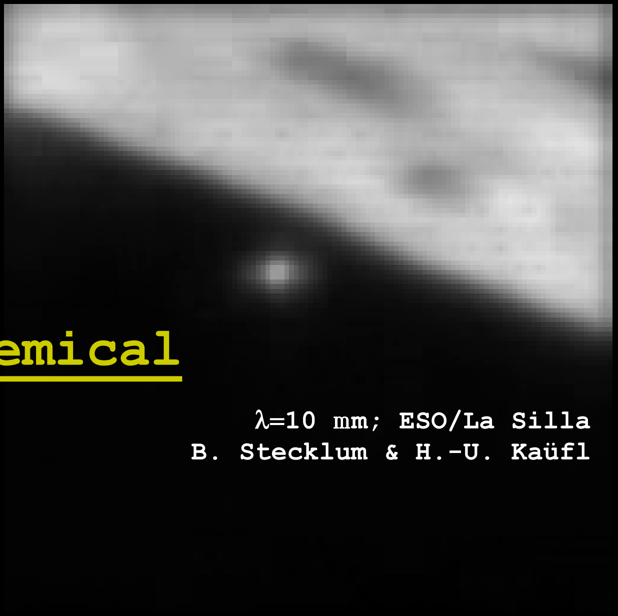
The AIBs in the galactic dust cycle



Adapted from *http://www.nrao.edu/pr/2006/gbtmolecules/* *Bill Saxton, NRAO/AUI/NSF*

AGBs ➔ IRC +10216:

Chemical study of the envelope

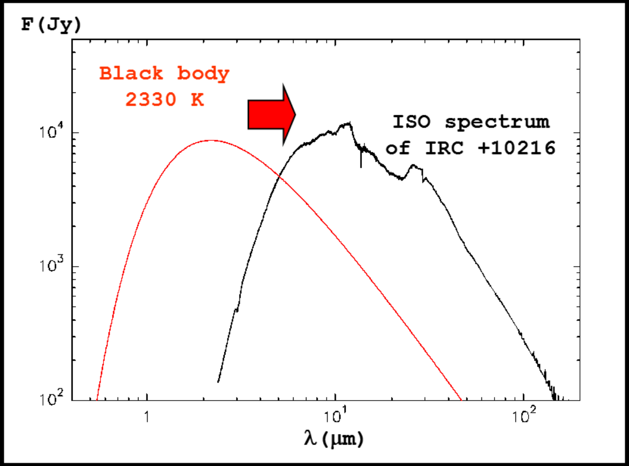


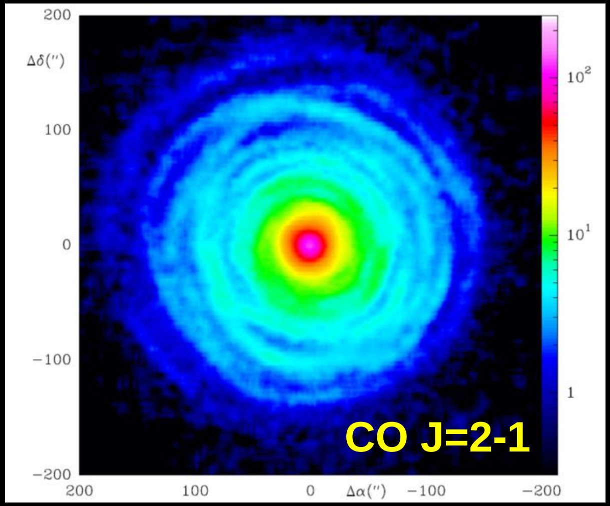
λ=10 mm; ESO/La Silla
B. Stecklum & H.-U. Käufl

¿Why is so interesting the study of chemical composition of IRC +10216?

- IRC+10216 is a prototype of C-rich stars

- 50% of the molecules known in space have been detected in its CSE





Cernicharo et al, 2015,
Leao et al., 2006

METHODS : Astronomical observations at all frequencies Radiative transfer modelling, Dynamical Evolution, Chemical modelling,….

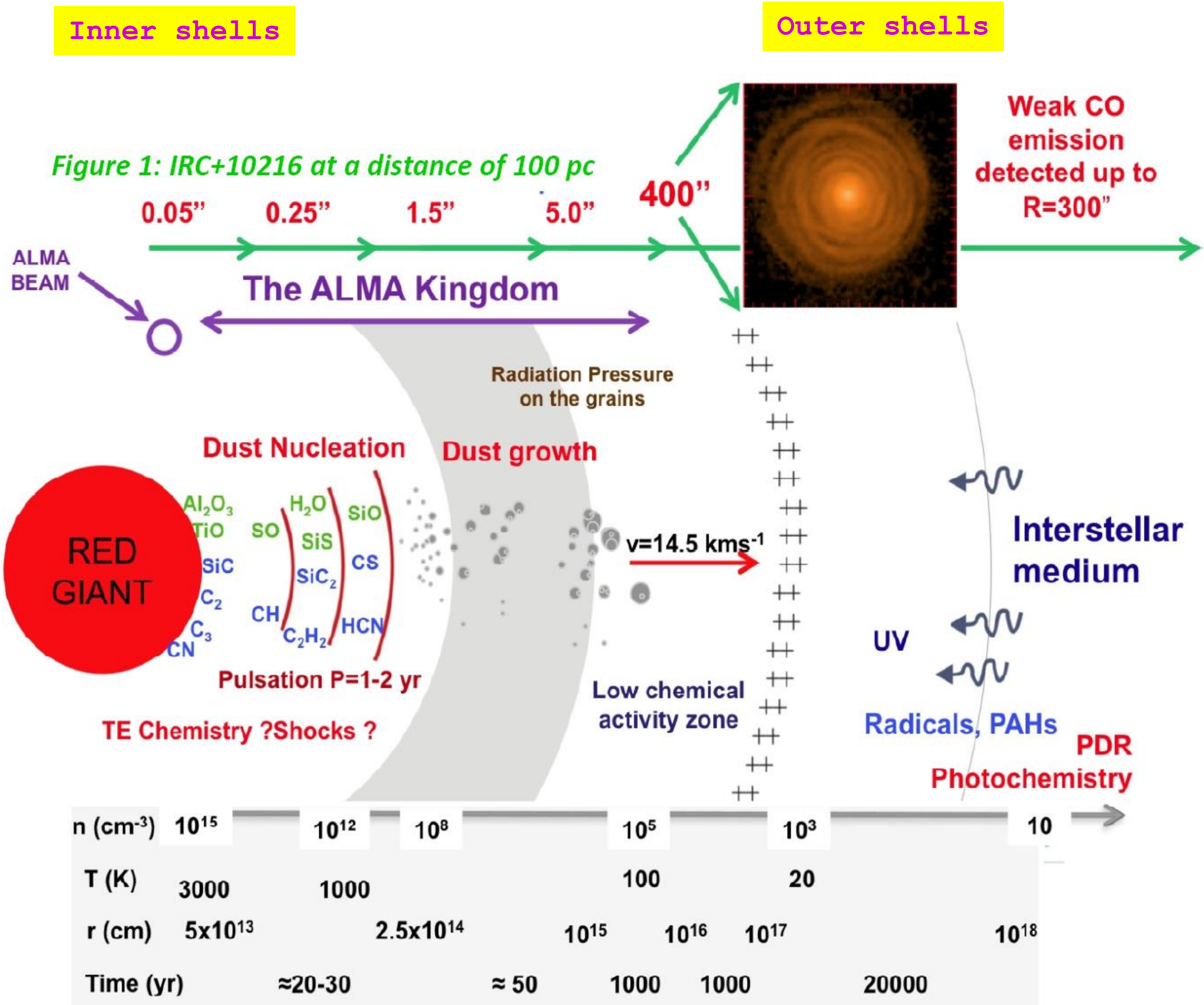


Figure 1: IRC+10216 at a distance of 100 pc

Dust grain formation is an out of equilibrium process

Three zones can be defined

I) Dust seeds formed in the photosphere?

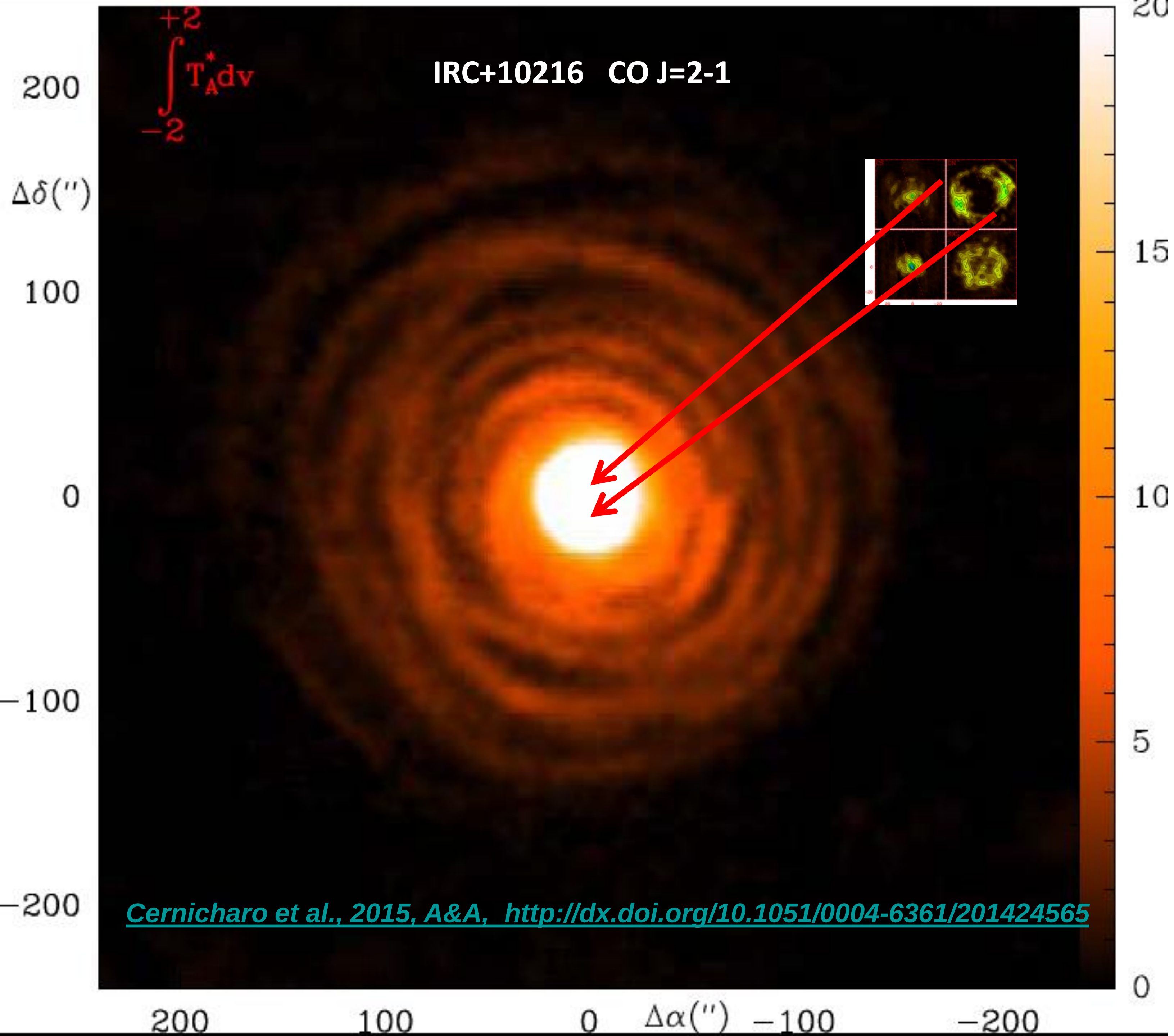
T_K=2500 K, n(H)=10^{14} -10^{15} cm^{-3} , p=0.03-0.3 mbar
Gas phase thermodynamical equilibrium applies for H_2, CO, HCN, H_2O, etc.
Time to reach equilibrium from a few minutes (p=0.3 mbar) to a few hours (p=0.03 mbar). H_2/H~10^4 at T_K ~ 1000 K

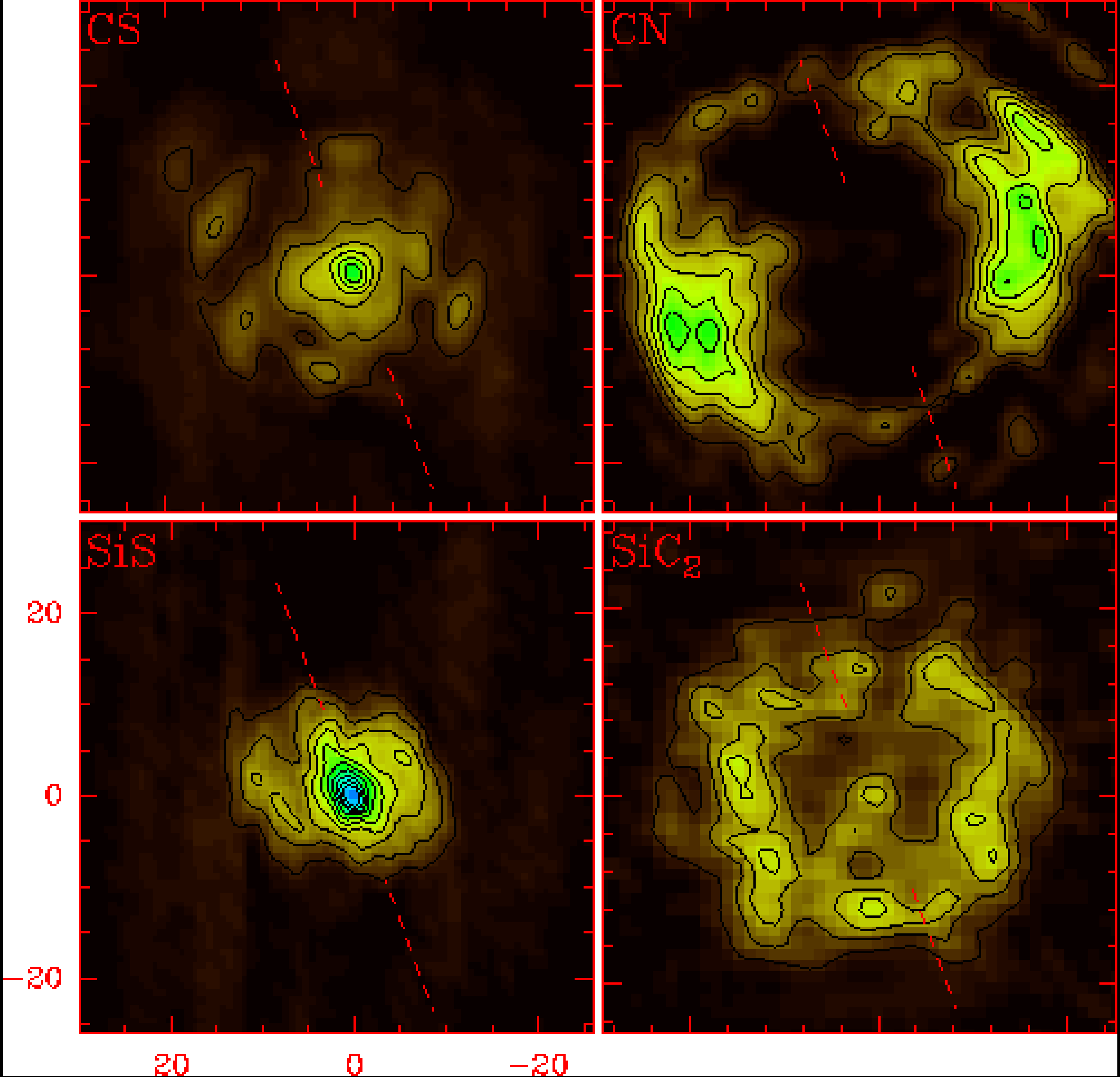
II) Seeds are accelerated by radiation pressure, density decreases as r^{-2}, temperature also decreases very fast. Dust nucleation

Region 1-5 R_* (T_K=2500-1000 K, density decreases by a factor 25 at r=5R_*).
Pressure decreases from 0.03-0.3 mbar down to <0.001-0.01 mbar

III) *Dust grain growth in the region 5-20 R_* (3 10^{14}-1.5 10^{15} cm)*

- **Seeds formed in the region 1-5 R_* travel through a region ~10^{15} cm in size during ~ 50- 100 yr. At the end of this region gas and dust are decoupled.**
- **Dust-dust collisions are very rare and "chemical vapor deposition" is the main growth process. Pressures are very low, accreation rates are also low.**
- **In this zone most abundant (observed) gas species are H_2, CO, C_2H_2, CH_4, HCN, H_2O, SiC_2, SiO, SiS, CS, OH,… but H still an abundant species**


IRC+10216 CO J=2-1
$\int_{-2}^{+2} T_A^* dv$
Δδ('')
200
100
0
−100
−200
200
100
0
Δα('')
−100
−200
20
15
10
5
0
Cernicharo et al., 2015, A&A, http://dx.doi.org/10.1051/0004-6361/201424565

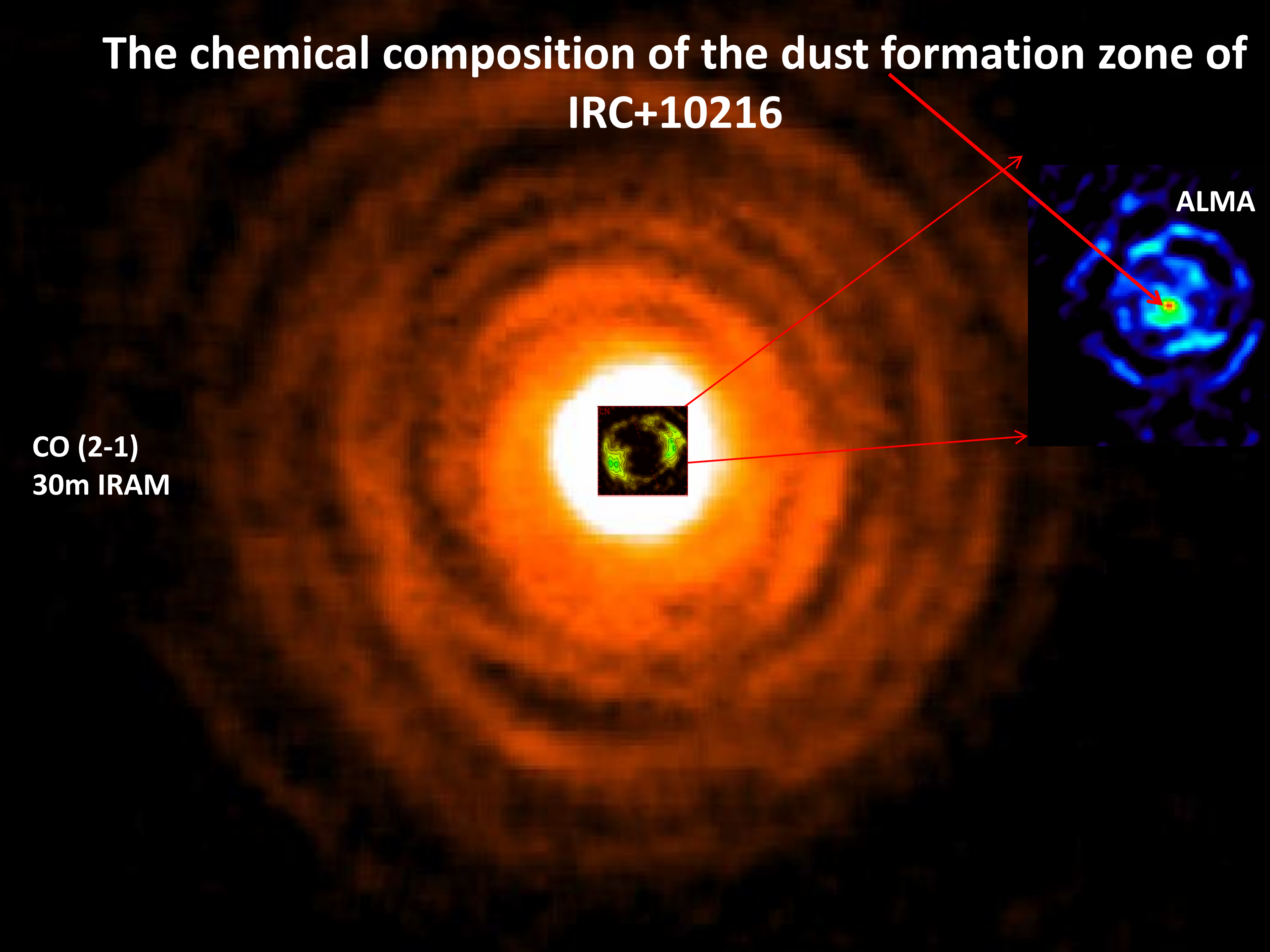


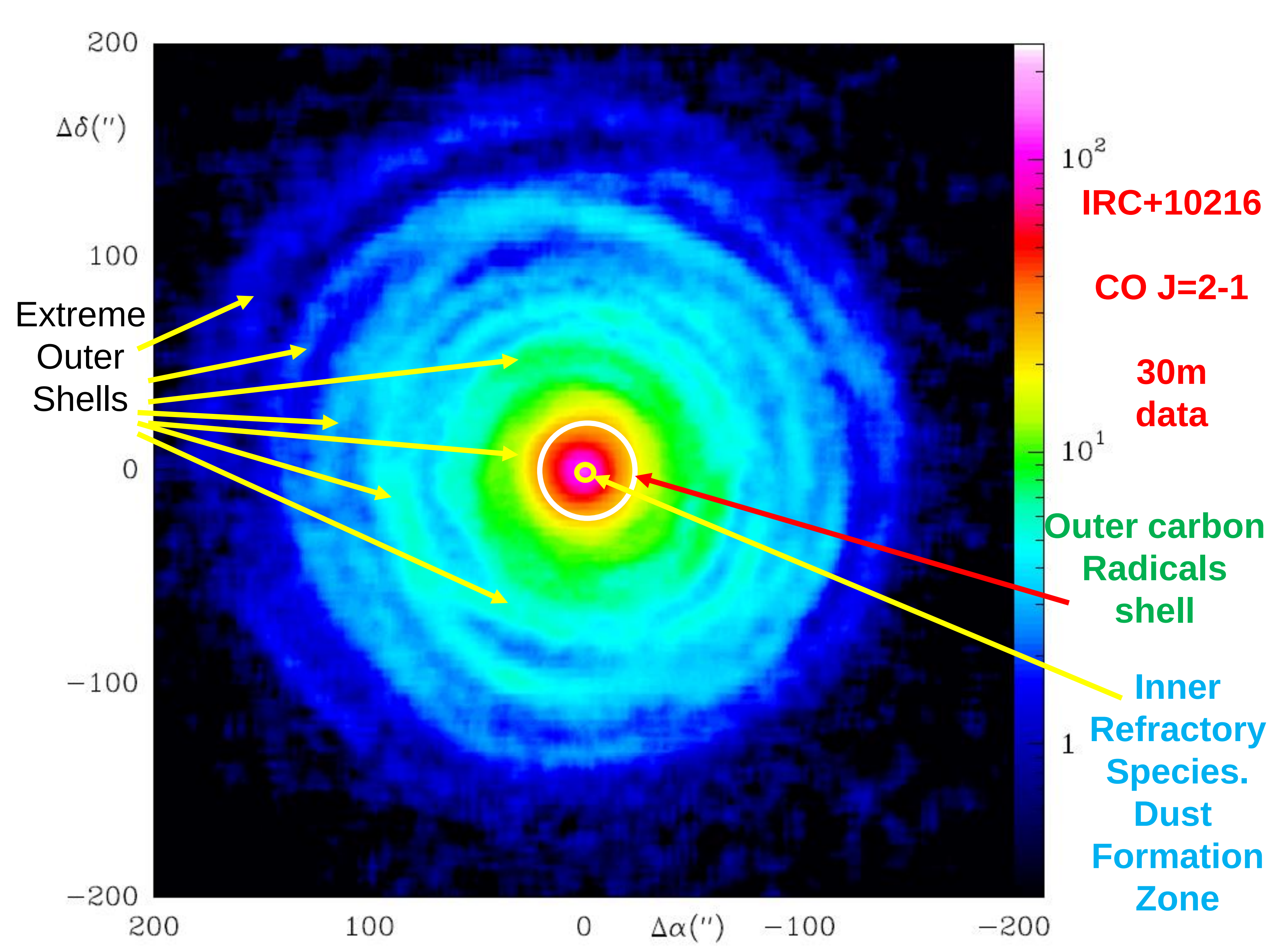
Guélin & Coworkers

PdBI data
3” resolution

Radicals C_nH and C_nN are found in the molecular ring at 14” from CW Leo

The chemical composition of the dust formation zone of IRC+10216





200
Δδ('')
100
0
−100
−200
200
100
0
Δα('')
−100
−200
10^2
10^1
1
Extreme
Outer
Shells
IRC+10216
CO J=2-1
30m
data
Outer carbon
Radicals
shell
Inner
Refractory
Species.
Dust
Formation
Zone

Leao et al., 2006, (B-V)

Astrochemistry:
Observation of molecules and dust in space

1) Molecular Astrophysics:
Interpretation of the observations involving emission/absorption of molecules

2) Laboratory Astrophysics:
Gathering data from laboratory to help in the interpretation of Astrophysical data

Using theoretical methods in quantum chemistry to get properties Of molecules observed by astrophysicists

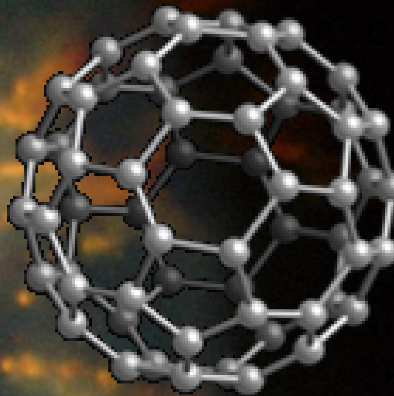
What kind of laboratory experiments are of interest for astrophysics?
NANOCOSMOS: A synergy project of the European Research Council

NANOCOSMOS

José Cernicharo
ICMM, CSIC, Spain

Christine Joblin,
IRAP, CNRS, France

José A. Martin-Gago,
ICMM, CSIC, Spain



Astronomers, Chemists, Physicists, and Engineers working together at the frontiers of knowledge.

Understanding the formation of cosmic dust and chemical complexity in Space and on Earth

NANOCOSMOS A complementary and multidisciplinary team

Ultra-high vacuum
Technologies
NanoSciences

Laboratory Astrophysics
Carbonaceous macromolecules
& nanograins
Photodissociation regions

Radioastronomy
Molecular spectroscopy
Evolved Stars

erc
European Research Council
Established by the European Commission

+15 MEuros

Beyond the current frontiers

OBSERVATIONS

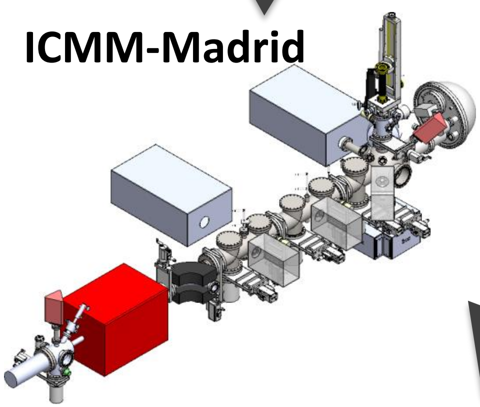
MODELLING

Stars, as factories of molecular complexity and dust

Understanding formation of dust in space

Impact on our vision of the origin of planets and life

ICMM-Madrid



IRAP-Toulouse

EXPERIMENTS

Technical and scientific innovation through synergy

Dust formation in evolved stars:

- Investigating chemical and physical conditions in the dust formation zone
- Characterizing dust properties

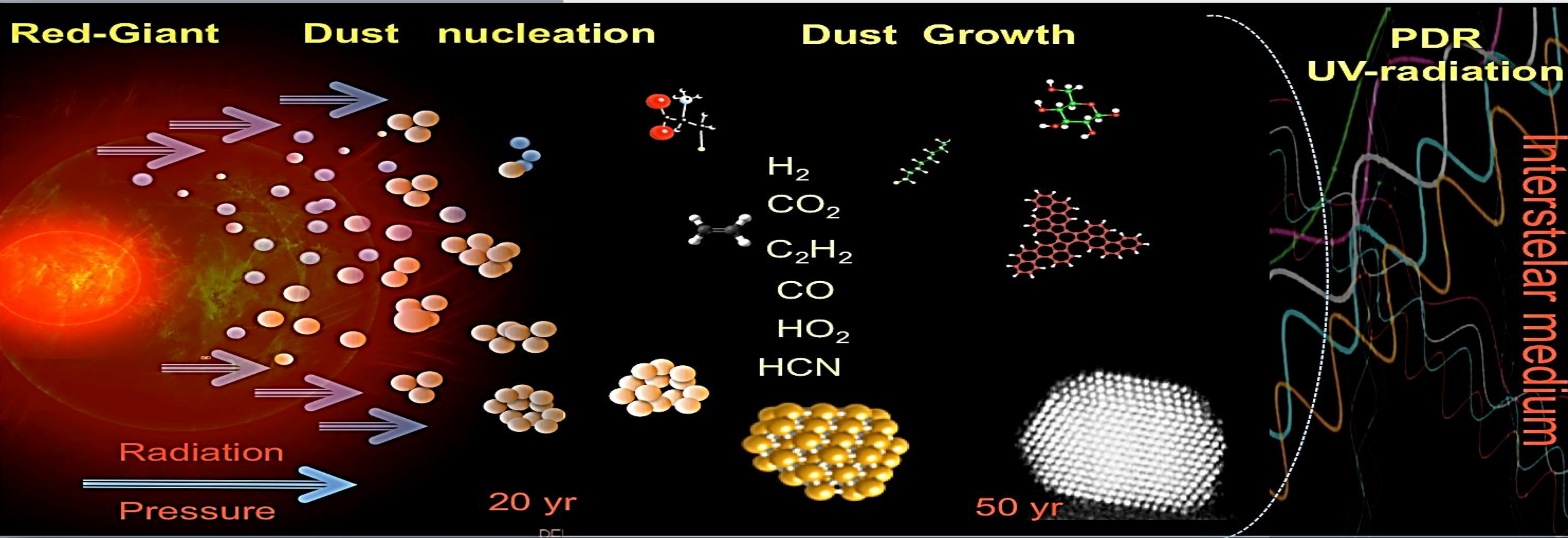
Dust formation: laboratory approach

- Producing analogues of circumstellar dust
- Investigating formation mechanims

Dust properties in cosmic (circumstellar and interstellar) conditions

- Spectroscopy from 10 to ~1000 K
- Processing (UV, thermal, electrons, high-energy ions, H,....)
- Gas-grain interactions: Atomistic view and grain size effects. Reactivity of dust analogues

→ PAHs = one of the dust populations

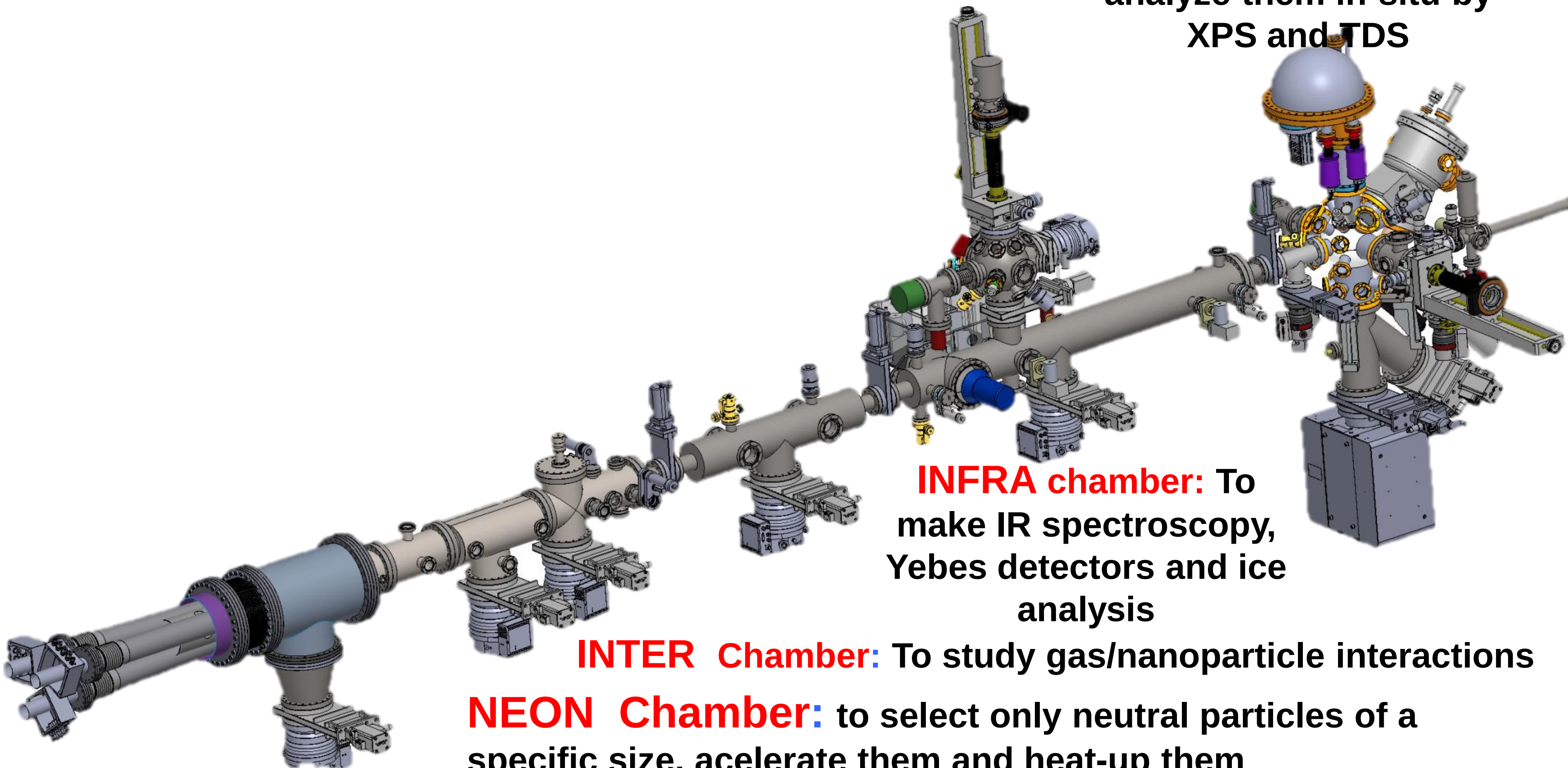


A challenge: The Stardust chamber

Nanocosmos: The StarDust chamber in Madrid (design v3)

PI: J.-A. Martín-Gago

ANA Chamber: to collect them and to analyze them in-situ by XPS and TDS



INFRA chamber: To make IR spectroscopy, Yebes detectors and ice analysis

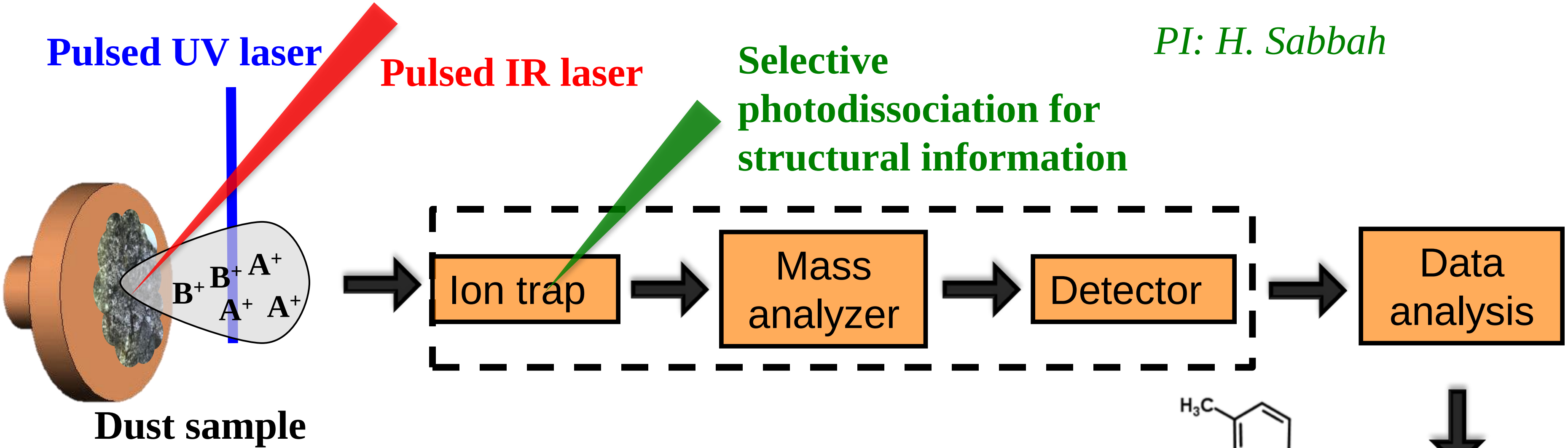
INTER Chamber: To study gas/nanoparticle interactions

NEON Chamber: to select only neutral particles of a specific size, acelerate them and heat-up them

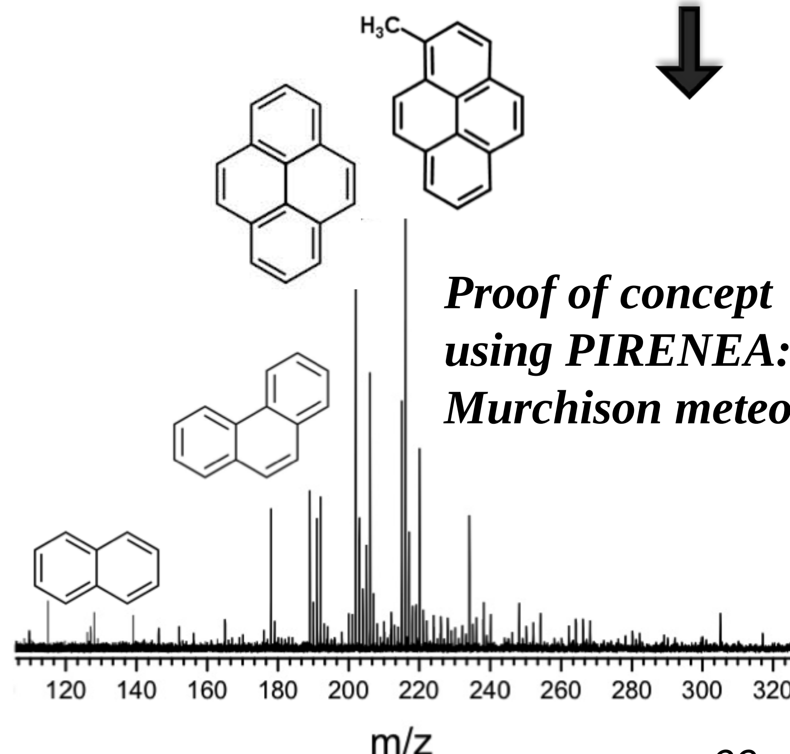
MICS Chamber: to produce nanoparticles from atoms

The Stardust molecular analyzer in Toulouse

PI: H. Sabbah



- Extraction of the molecular part by laser desorption
- High spatial resolution (5-10 µm) and sensitivity (subfemtomole level)
- *In situ* analysis with minimal sample preparation (molecular mass and structure)



Proof of concept using PIRENEA: Murchison meteorite

Working activities and Goals

Technical Activities

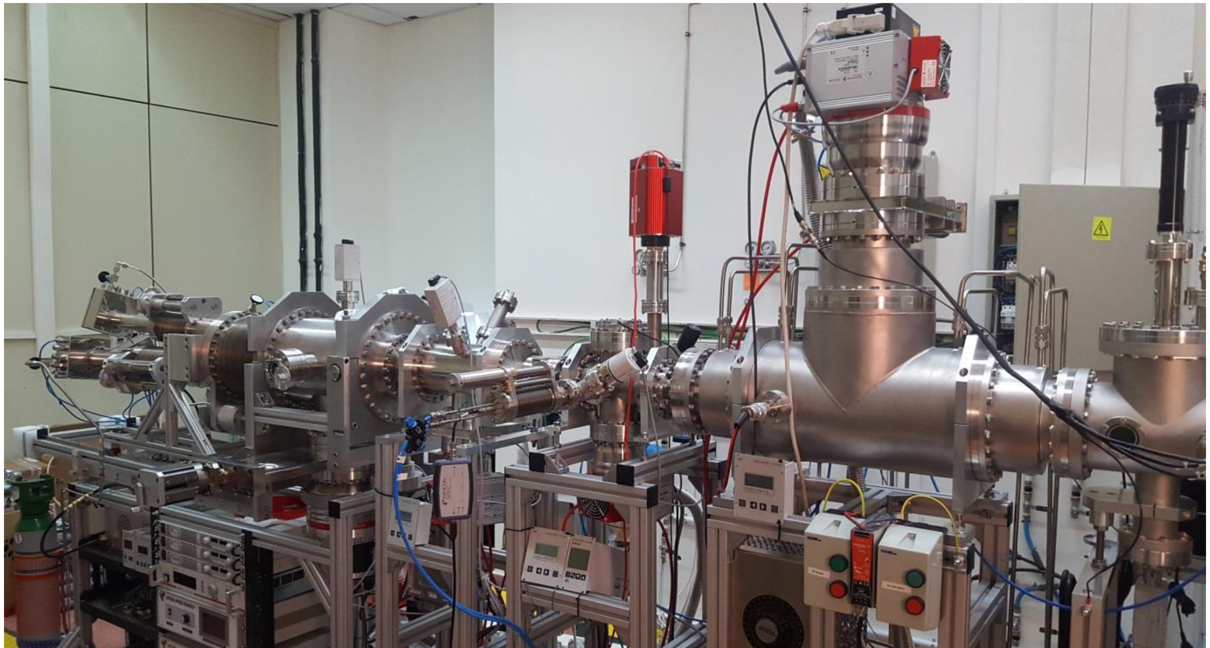
- HEMT RECEIVERS
- STARDUST chamber
- GAS EVOLUTION chamber
- PIRENEA/ESPOIRS Upgrades
- MOLECULAR ANALYZER

Scientific Activities

- OBSERVATIONS
  High-res: ALMA, VLT
  Surveys: 40m OAN
- LABORATORY EXPERIMENTS
  Spectroscopy
  Dust formation & processing
- THEORY- Quantum chemistry
  Structure, energetics
  Dynamics
- MODELLING
  Radiative transfer
  Chemical models

GOALS

- Determine gas composition at the dust formation zone
- Identify dust nucleation seeds & key processes
- Create cosmic dust in the laboratory
- Identify dust growth processes
- Identify some key catalytic reactions in molecular formation



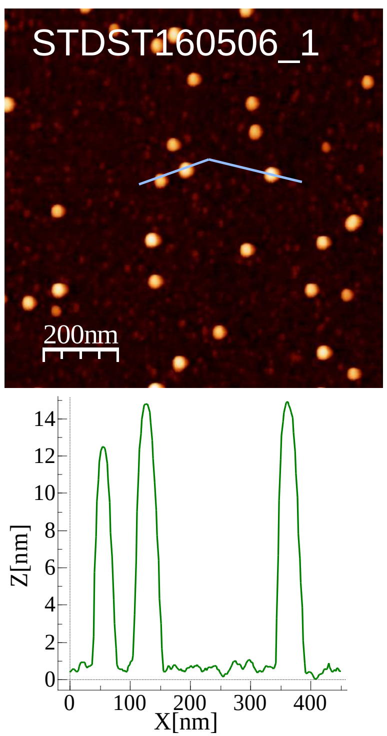
June 2016

Tests with two mangetrons M1 + M2

Φtotal = 100 sccm
ϕ1 = ϕ2 =50 sccm
L1 = L2 = 192mm (also L1=242mm)
L3 = 242mm
Lbb = fully extended
P1 = P2 = 30W

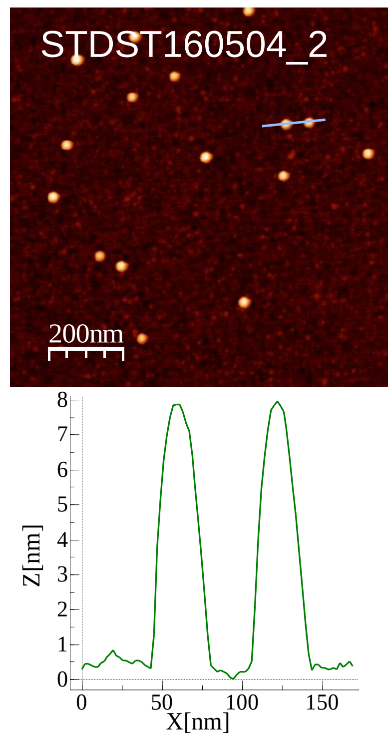
Rates (ng*s/cm2):
M1 = 120 ng*s/cm2
M2 = 2 ng*s/cm2
M1+M2 = 204 ng*s/cm2 (L1=L2)
M1+M2 = 221 ng*s/cm2 (L1=242mm)

M1



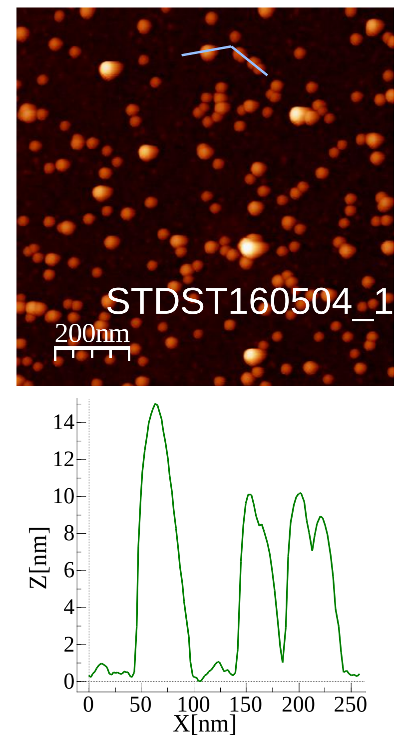
13 nm
25 NPs/um2
~1 s

M2



8 nm
16 NPs/um2
5 s

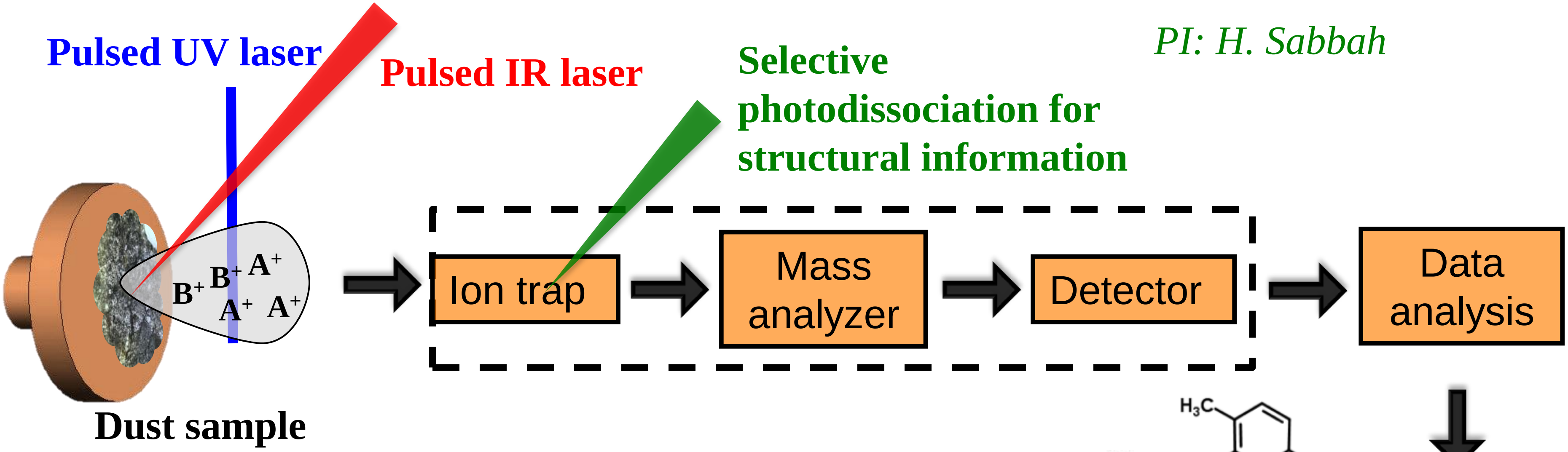
M1+M2



9 nm
(14-20nm)
170 NPs/um2
~1 s

The Stardust molecular analyzer in Toulouse

PI: H. Sabbah



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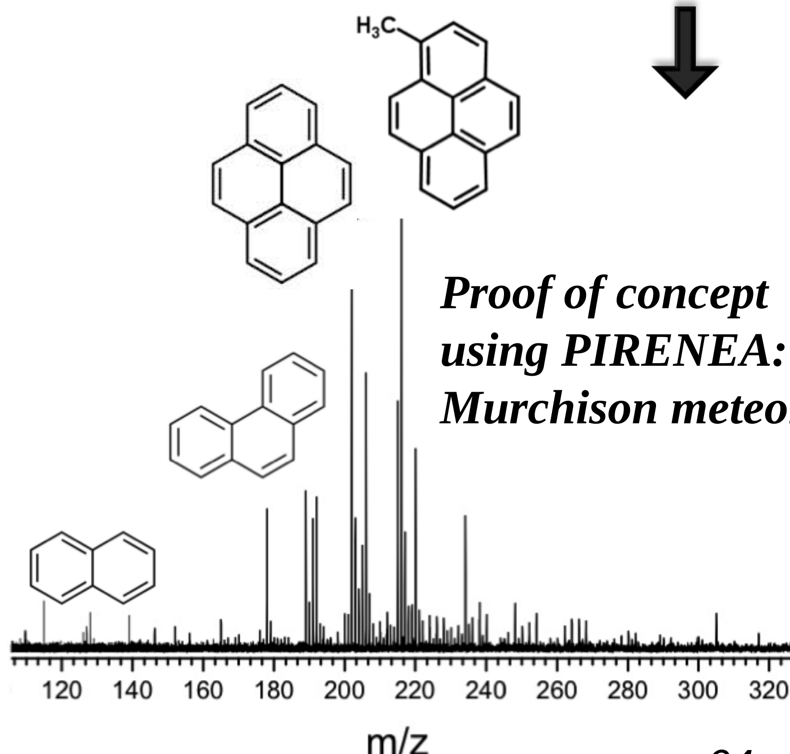


Proof of concept using PIRENEA: Murchison meteorite

The Gas Cell Simulator Chamber

- A gas cell equipped with HEMT receivers covering 30-50 & 70-116 GHz. Instantaneous bandwidth 20x3 GHz with FFTs and spectral resolution of 0.19 MHz for broadband spectroscopy. 24 x 1.5 GHz bands with 20 KHz spectral resolution for high spectral resolution spectroscopy. Observing thermal emission
- A molecular cloud with 10^{22} cm^{-2} molecules of H_2 in the line of sight will contain 10^{18} cm^{-2} molecules of CO and 10^{14} molecules of HCN, HCO^+, HNC, CCH, CN, CS, ….

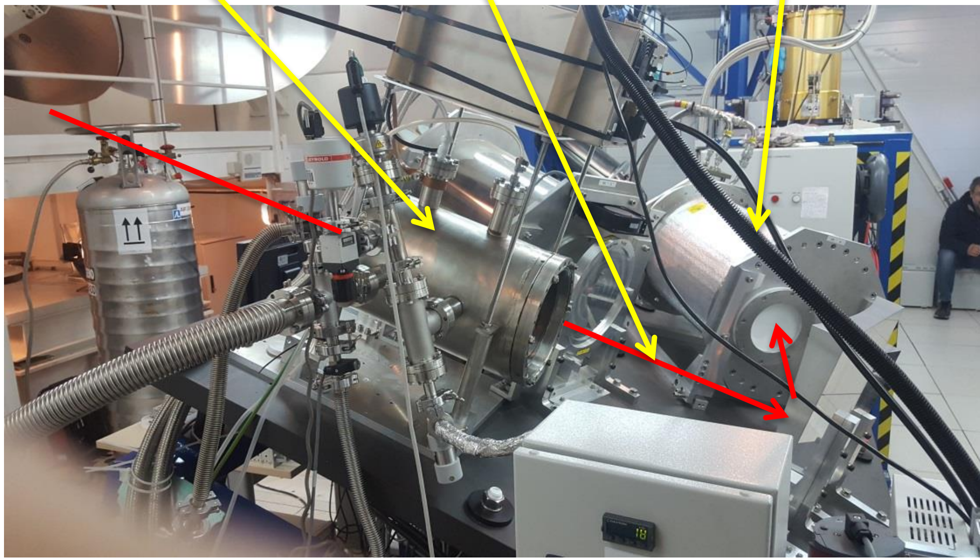
Molecular cloud
Size 10^{19} cm
Density ~ 10^4-10^5 cm^{-3}

Molecular abundances
~ 10^{-8}-10^{-11}

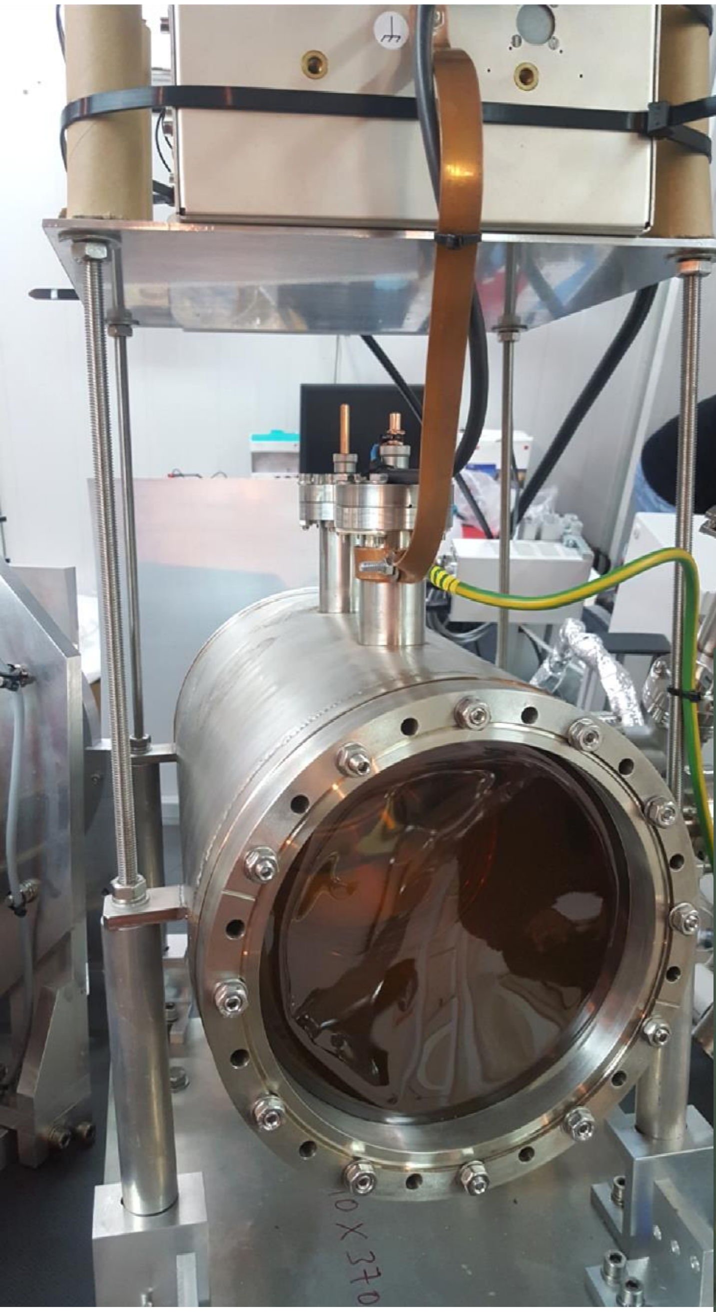
Prototype Gas Cell (40 cm)

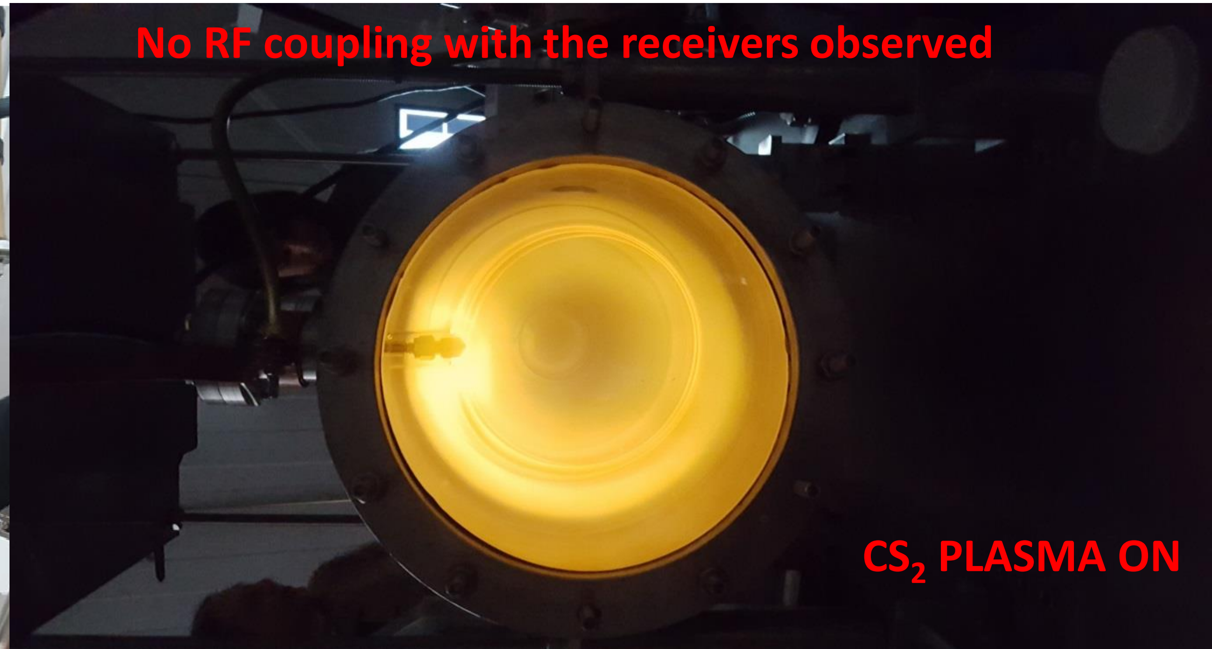
Telescope Beam

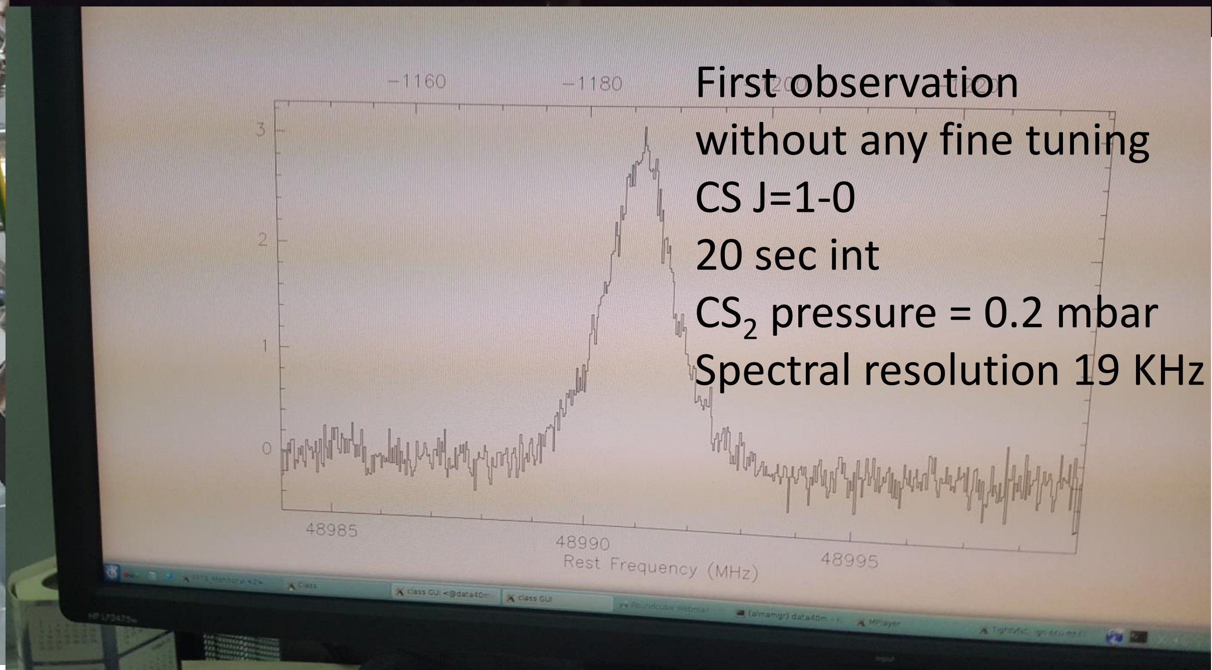
HEMT 45 GHz receiver



The prototype installed in the electrical path of a 40 m radiotelescope







The Stardust machine from scratch

Main institutes involved in Spain

PIs: J. Cernicharo , J. A. Martín-Gago

- Instituto de Ciencia de Materiales de Madrid (CSIC)
- OAN and Centro Tecnológico de Yebes (IGN)
- Universidad de Castilla la Mancha (chemistry)
- Instituto de Estructura de la Materia (CSIC)
- Universidad de Valladolid (microwave, millimeter and submillimeter spectroscopy)

Involved teams at CNRS/ Univ. Toulouse

PI: C. Joblin

- *Milieu Interstellaire, Cycle de la Matière, Astro-Chimie* at IRAP
- *Matériaux et Procédés Plasmas* at LAPLACE
- *Interactions Ions-Matière* at LCAR-IRSAMC
- *Modélisation, agrégats, dynamique* at LCPQ-IRSAMC

SUMMARY

- The study of dust formation requires a good understanding of gas phase processes leading to the formation of the nucleation seeds
- Laboratory experiments are mandatory to understand the growth processes (coagulation, molecular condensation)
- Observations at all lambdas are needed to fully characterize the chemistry of dust formation
- A good, close and fruitfull collaboration with teams of many areas are needed to address this fundamental problem
- NANOCOSMOS project is open to collaborate with other teams interested in the physical and chemical studies we are going to perform

NANOCOSMOS

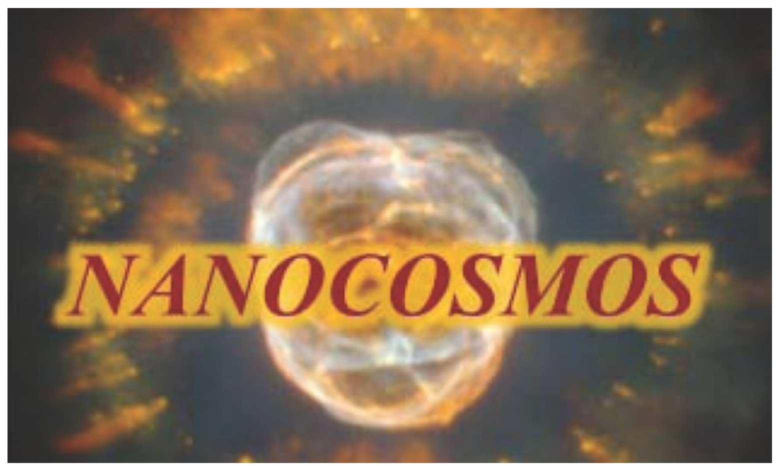
Nanocosmos puts stardust into your hands

A synergetic multidisciplinary project
at the frontiers of technology and knowledge

erc

Astronomers, chemists, physicists, and engineers working together to understand the formation of cosmic dust and chemical complexity in Space and on Earth

CSIC
CONSEJO SUPERIOR
DE INVESTIGACIONES
CIENTÍFICAS



cnrs
CENTRE NATIONAL DE LA
RECHERCHE SCIENTIFIQUE

We know that human beings are made from stardust
NANOCOSMOS will show us how cosmic dust is made

MUCHAS GRACIAS POR SU ATENCIÓN