Laboratório de Astrofísica

Simulação de ambientes extraterrestres (Cometas, Atmosferas planetárias/lunares, Meio interestelar)

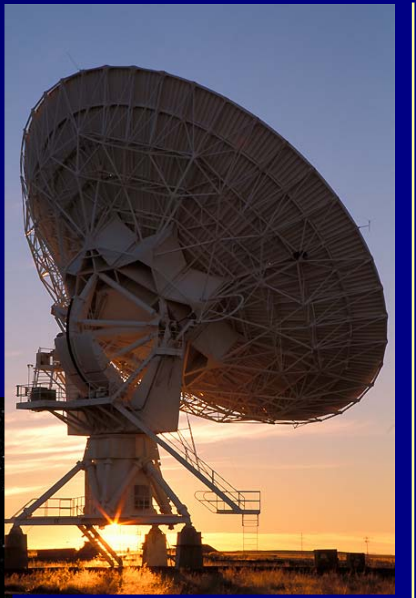
Sergio Pilling
sergiopilling@yahoo.com.br

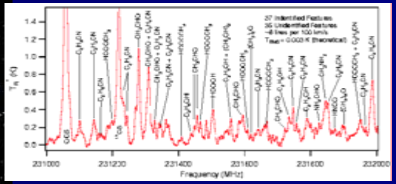
PUC RIO

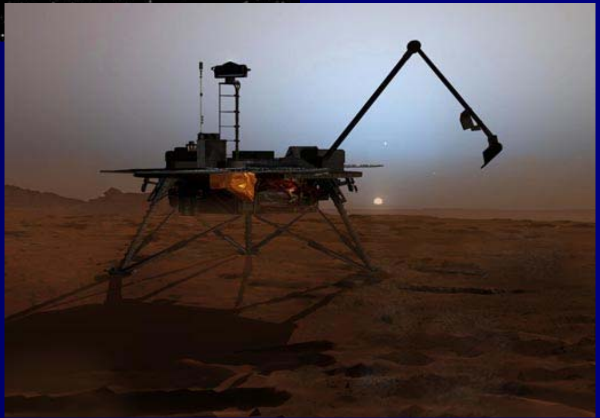
INPE
31/07/2009

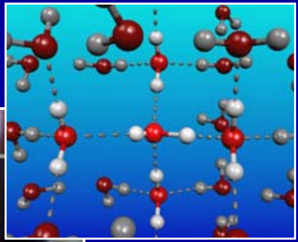
Astroquímica

Ciência multidisciplinar + Observacional + Teórica + Experimental









Astroquímica

Ciência multidisciplinar + Observacional + Teórica + Experimental

Interesses científicos:

- Estudar os processos físicos, químicos e físico-químicos envolvendo átomos e moléculas no espaço.

- Moléculas na fase gasosa e fase condensada (gelos astrofísicos)

- Abundâncias, reações químicas, interações com a radiação (fótons + partículas rápidas), seções de choque, taxas de reações, tempos de meia vida.

- Determinar parâmetros físicos e físico-químicas (temperatura, densidade, velocidades, etc.) de ambientes astrofísicos a partir das observações de átomos e moléculas.

- Fornecer vínculos para o estudo da evolução química do Universo.

- Astroquímica + Geologia espacial: Rochas e minerais, space weathering

- Astroquímica + Astrobiologia: Moléculas pré-bióticas (açucares, aminoácidos, bases de DNA), reações catalíticas, Ambientes líquidos, etc.

Moléculas encontradas no cosmos (radio e infravermelho)

Detected cosmic molecules in interstellar and circumstellar environments (adapted from Wootten 2001).

Diatomic	Triatomic	4 atoms	5 atoms	6 atoms	7 atoms	8 atoms	9 atoms	10 atoms	11 atoms	13 atoms
H_2	C_3	c-C_3H	C_5	C_5H	C_6H	CH_3C_3N	CH_3C_4H	CH_3C_5N	HC_9N	$HC_{11}N$
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN	$HCOOCH_3$	CH_3CH_2CN	$(CH_3)_2CO$		
AlCl	C_2O	C_3N	C_4Si	C_2H_4	CH_3C_2H	CH_3COOH	$(CH_3)_2O$	NH_2CH_2COOH		
C_2	C_2S	C_3O	l-C_3H_2	CH_3CN	HC_5N	C_7H	CH_3CH_2OH			
CH	CH_2	C_3S	c-C_3H_2	CH_3NC	$HCOCH_3$	CH_2OHCHO	HC_7N			
CH^+	HCN	C_2H_2	CH_2CN	CH_3OH	NH_2CH_3		C_8H			
CN	HCO	CH_2D^+	CH_4	CH_3SH	c-C_2H_4O					
CO	HCO^+	HCCN	HC_3N	HC_3NH^+	CH_2CHOH					
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO						
CP	HOC^+	HNCO	HCOOH	NH_2CHO						
CSi	H_2O	HNCS	H_2CHN	C_5N						
HCl	H_2S	$HOCO^+$	H_2C_2O							
KCl	HNC	H_2CO	H_2NCN							
NH	HNO	H_2CN	HNC_3							
NO	MgCN	H_2CS	SiH_4							
NS	MgNC	H_3O^+	H_2COH^+							
NaCl	N_2H^+	NH_3								
OH	N_2O	SiC_3								
PN	NaCN									
SO	OCS									
SO^+	SO_2									
SiN	c-SiC_2									
SiO	CO_2									
SiS	NH_2									
CS	H_3^+									
HF	SiCN									
SH										

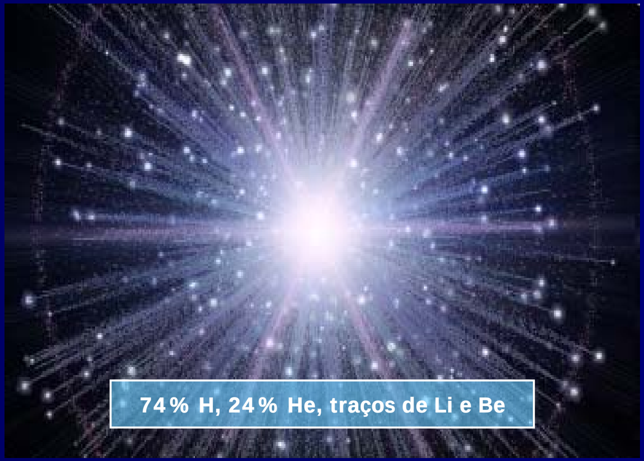
Alcoóis, cetonas, ácidos carboxílicos, aminas, nitrilas, ésteres, ...

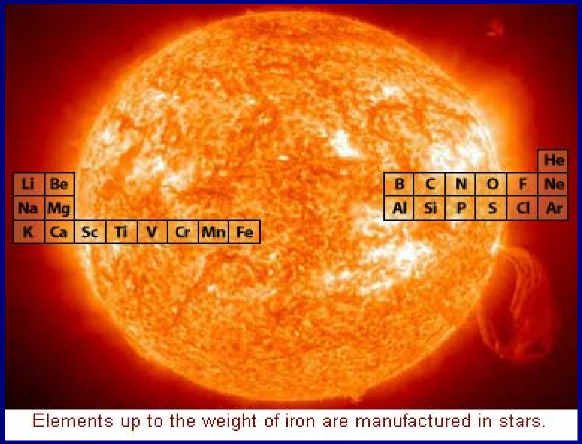
Hidrocarbonetos, PAHs, ...

Nos meteoritos também foram encontrados aminoácidos, bases nitrogenadas e açúcares!

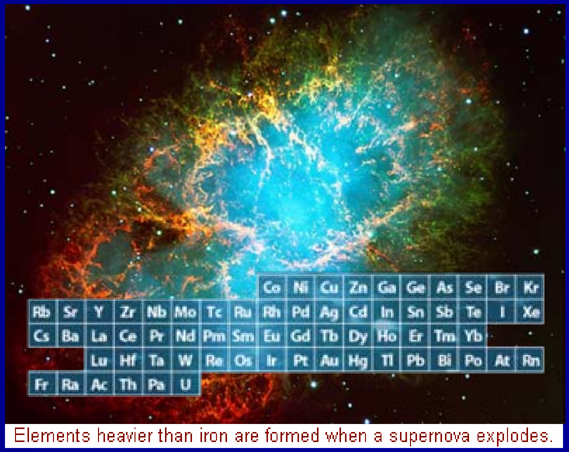
Origem dos átomos:

Nucleossíntese primordial (big bang) + estelar + supernovas.





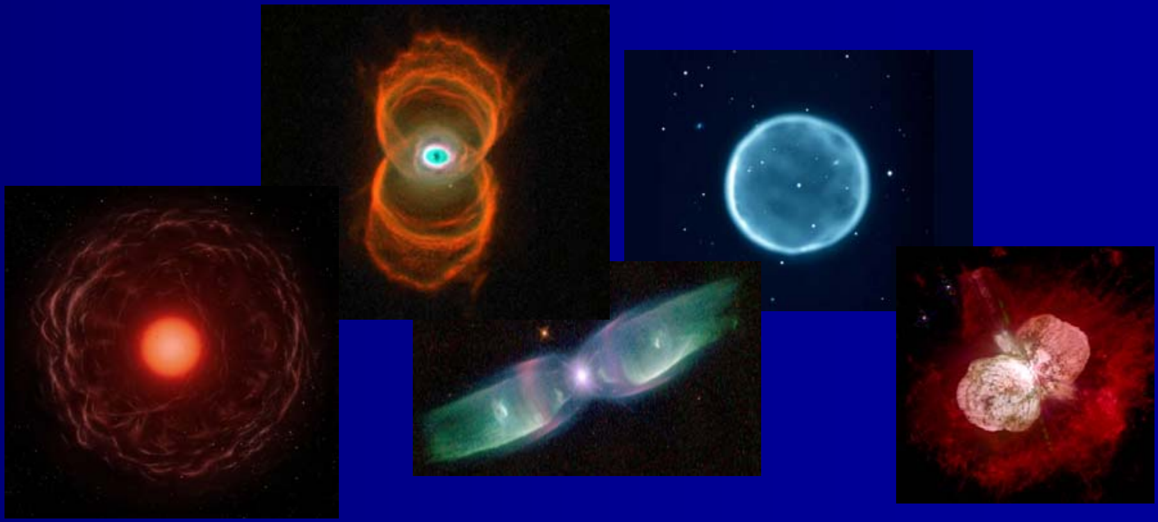
Elements up to the weight of iron are manufactured in stars.

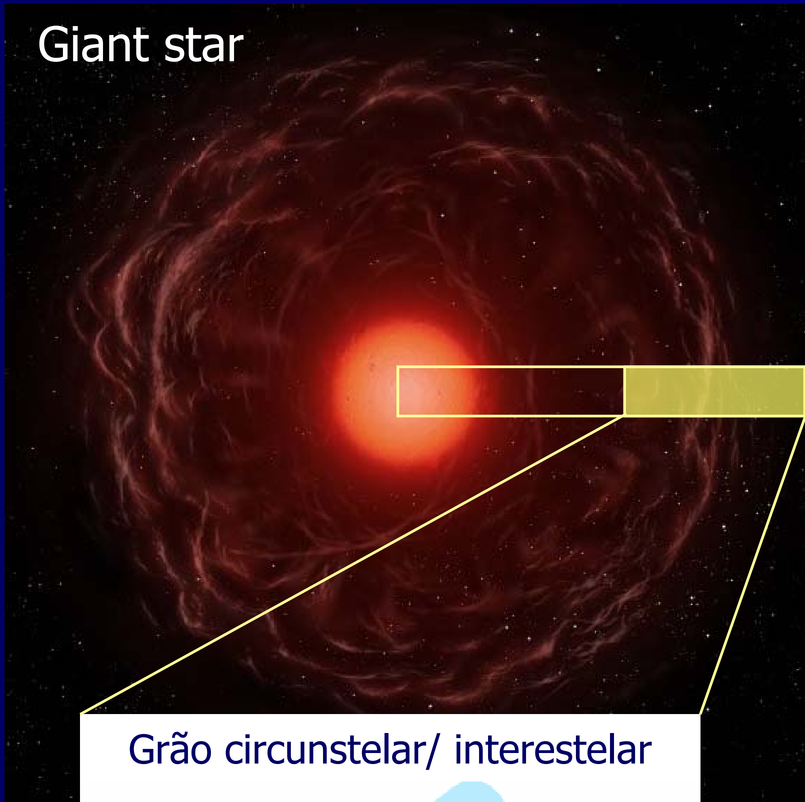


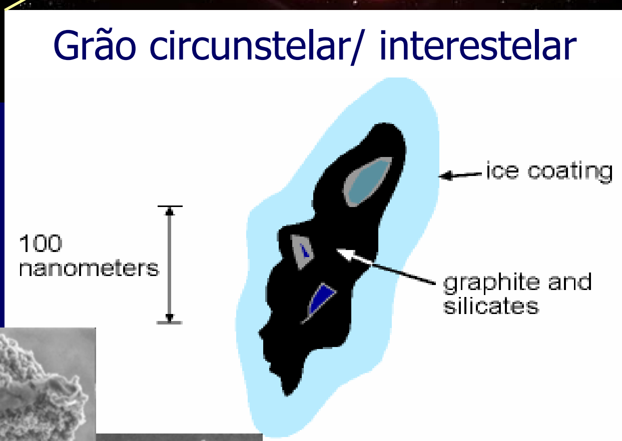
Elements heavier than iron are formed when a supernova explodes.

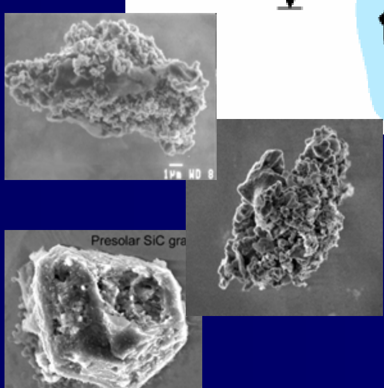
Origem das moléculas:

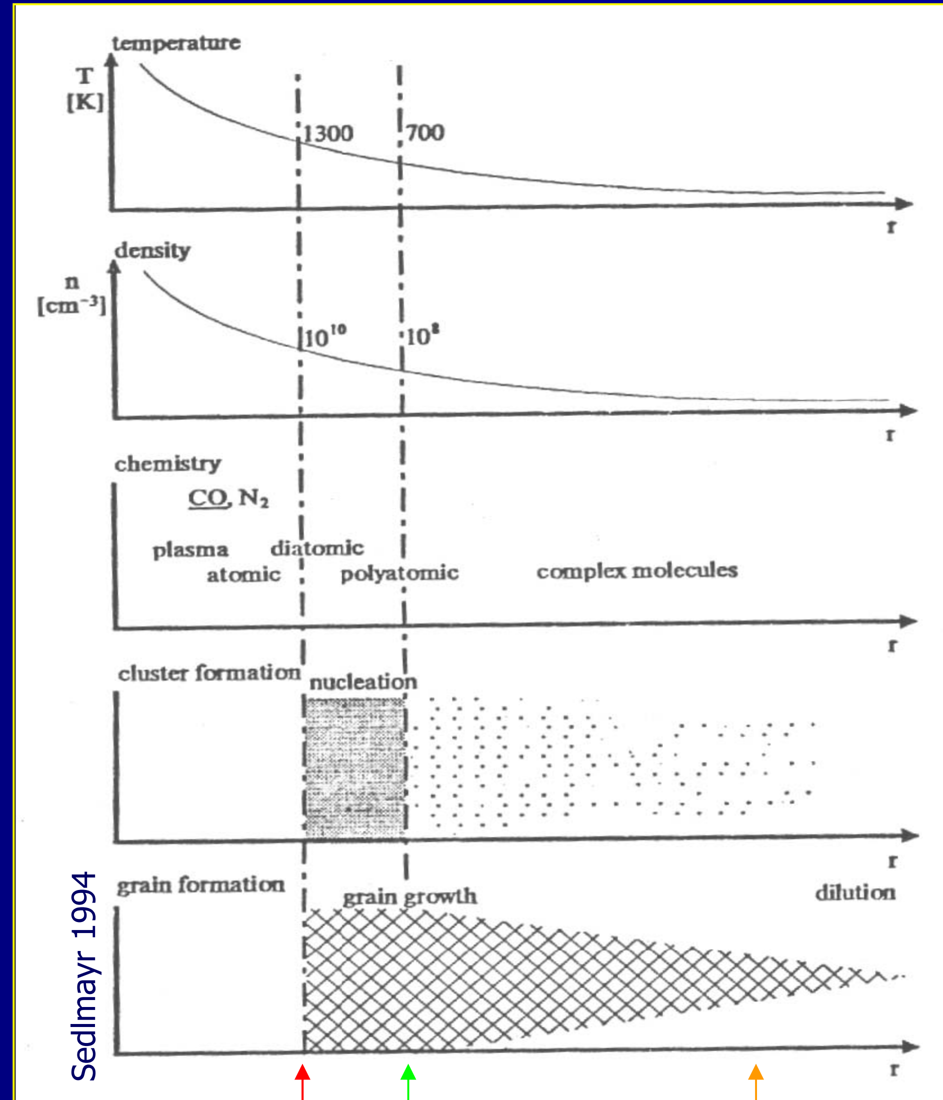
Ventos estelares, reações químicas (gás e superfície), regiões de baixa temperatura.











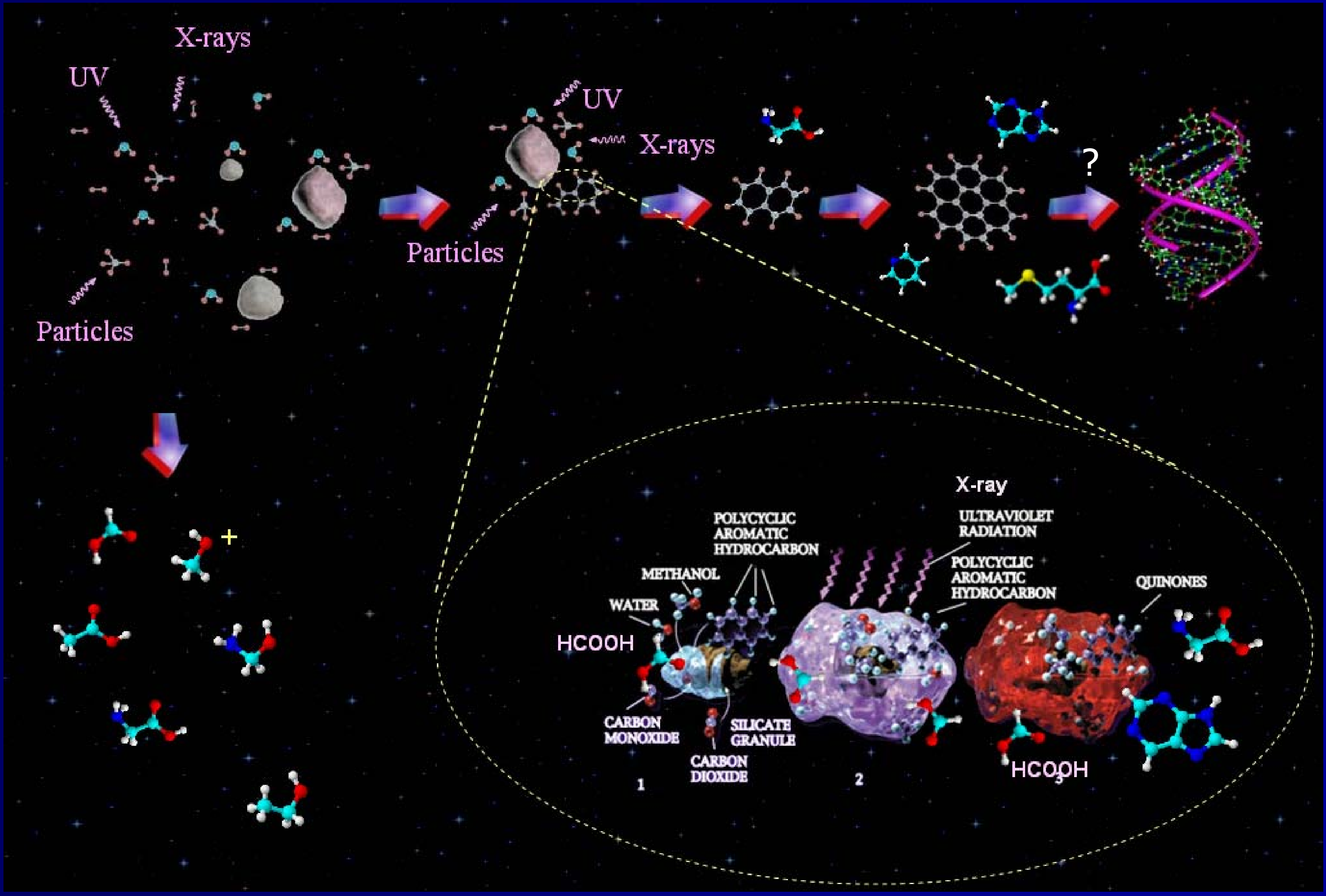
Al_2O_4 (temp ~ 1700K); silicatos (temp ~ 1400K)

Moléculas carbonáceas (C, PAHs, SiC)

Moléculas voláteis – mantos (H_2O, CH_4...)

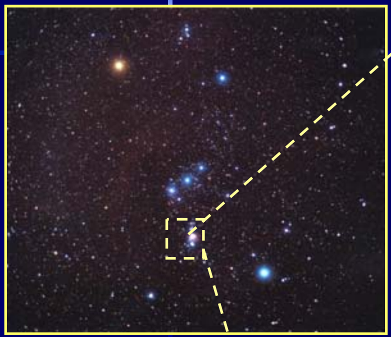
Origem das moléculas maiores:

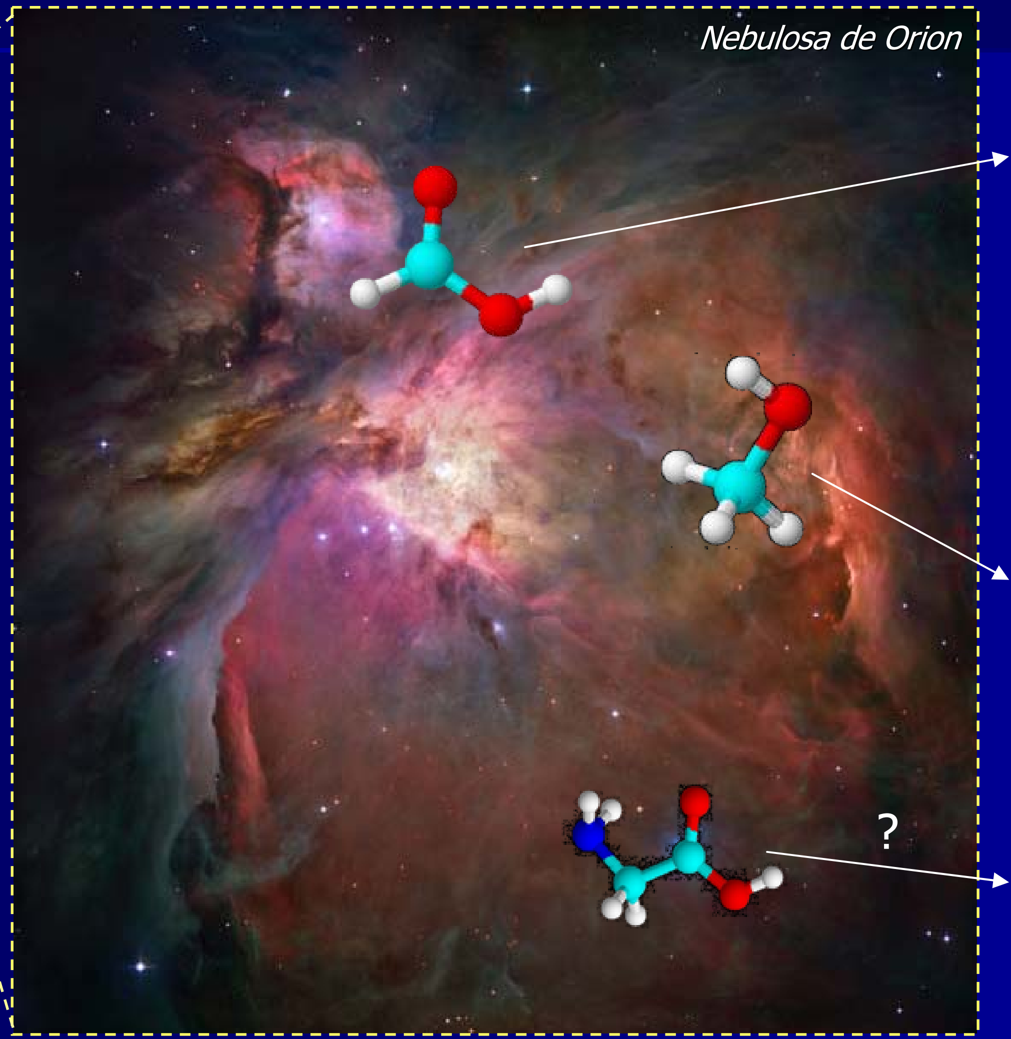
- Reações na fase gasosa e na superfícies dos grãos (catálise heterogênea)
- Fotólise e radiólise

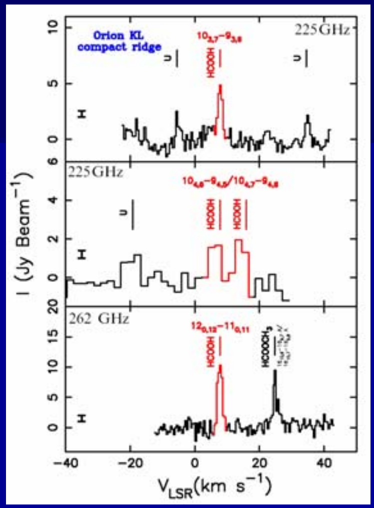


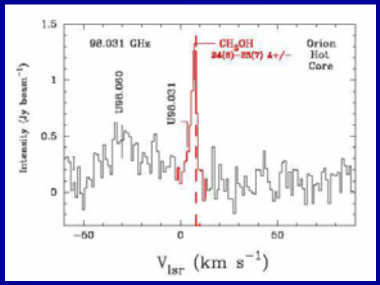
Moléculas na fase gasosa:

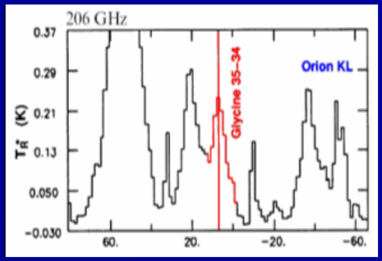
Evidências observacionais (Envoltórios de estrelas, MI, nuvens moleculares, atmosferas planetárias, etc.)

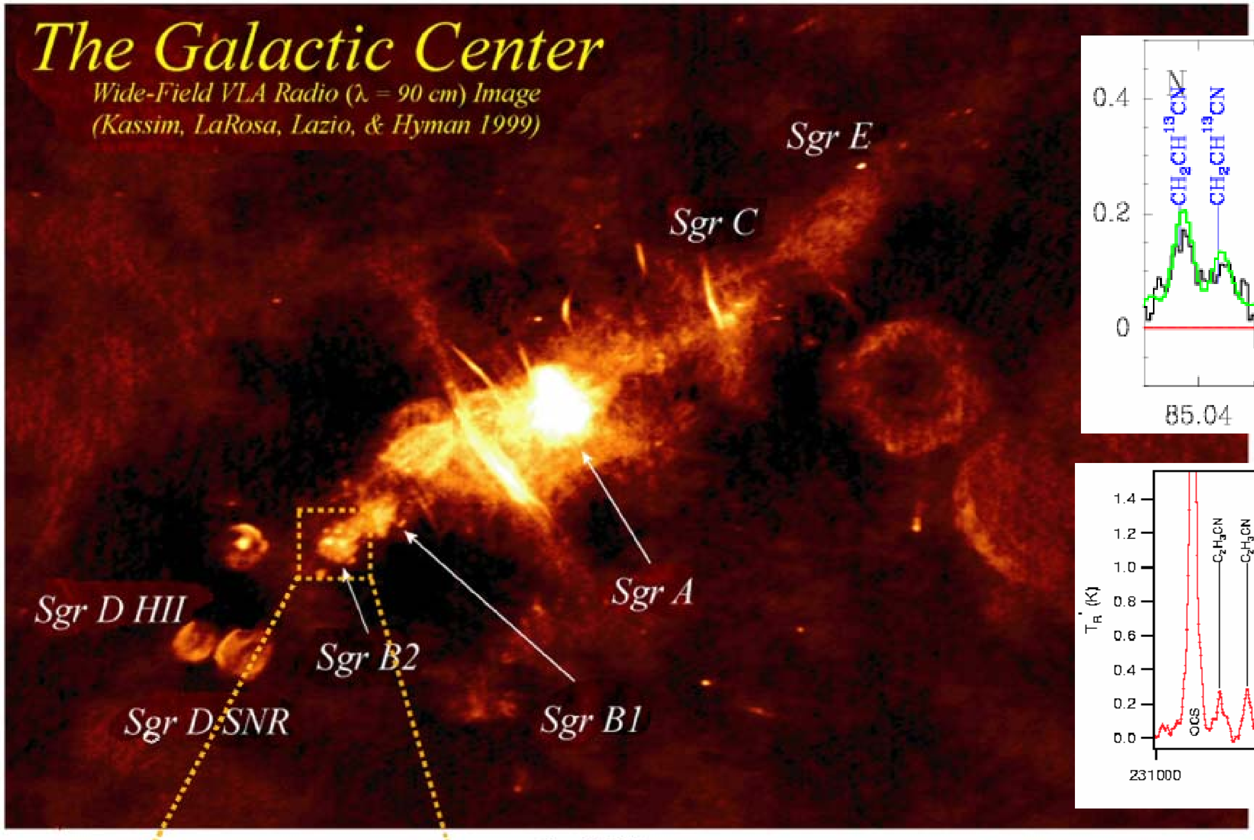




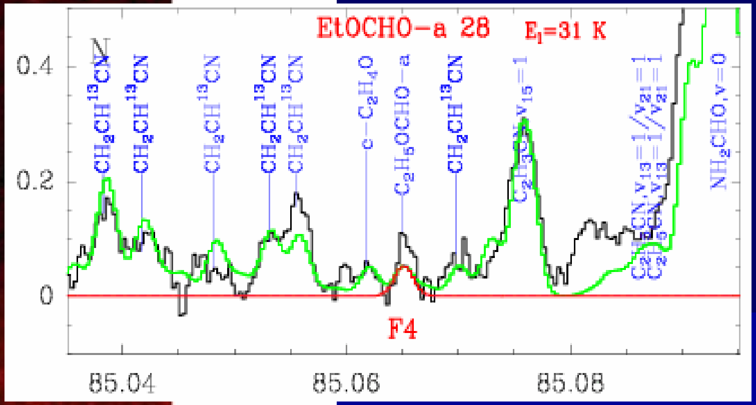




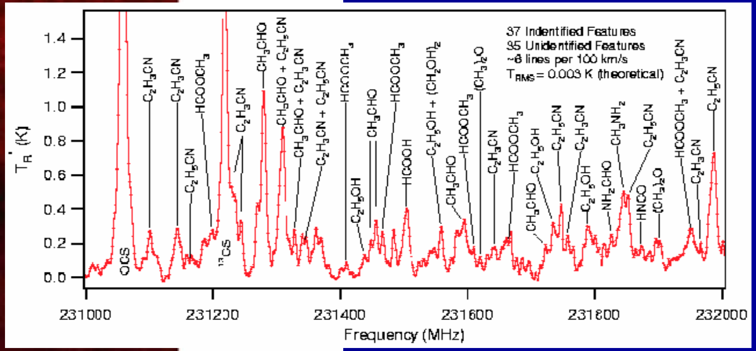




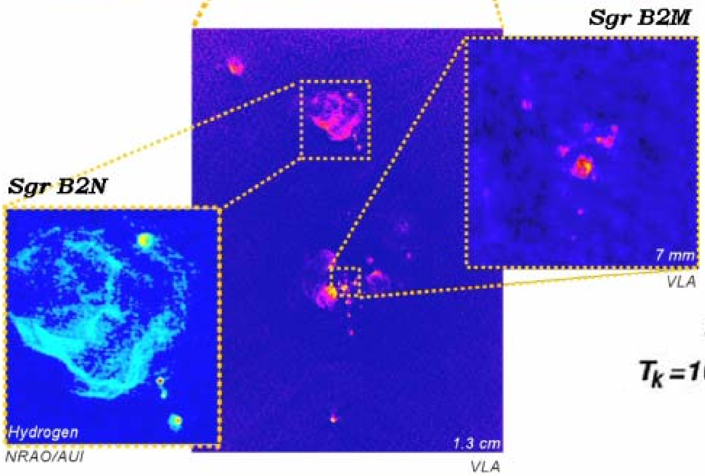
The Galactic Center
Wide-Field VLA Radio (λ = 90 cm) Image
(Kassim, LaRosa, Lazio, & Hyman 1999)
Sgr E
Sgr C
Sgr A
Sgr D HII
Sgr B2
Sgr B1
Sgr D SNR



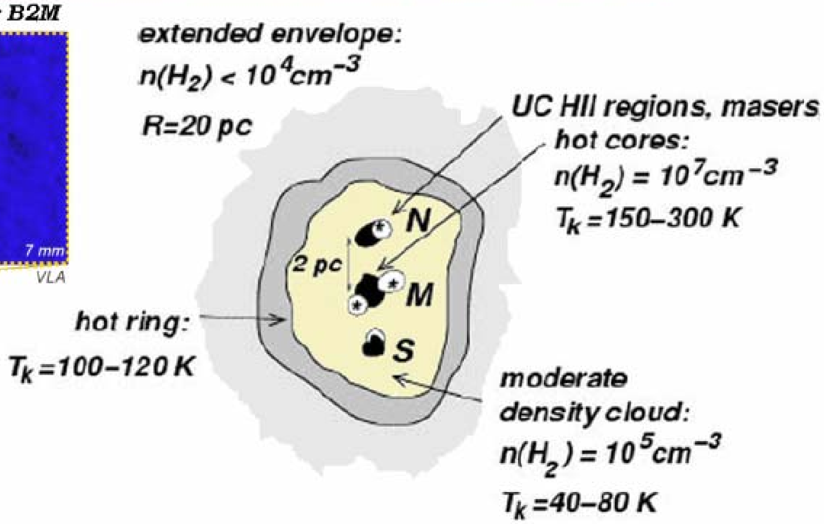
EtOCHO-a 28
E_l=31 K
F4
0.4
0.2
0
85.04
85.06
85.08



37 Indentified Features
35 Unidentified Features
~8 lines per 100 km/s
T_RMS = 0.003 K (theoretical)
T_R' (K)
Frequency (MHz)
231000
231200
231400
231600
231800
232000



Sgr B2M
Sgr B2N
7 mm
VLA
Hydrogen
NRAO/AUI
1.3 cm
VLA



extended envelope:
n(H2) < 10^4 cm^-3
R=20 pc
UC HII regions, masers
hot cores:
n(H2) = 10^7 cm^-3
Tk =150–300 K
N
2 pc
M
S
hot ring:
Tk =100–120 K
moderate
density cloud:
n(H2) = 10^5 cm^-3
Tk =40–80 K

Horse head nebula

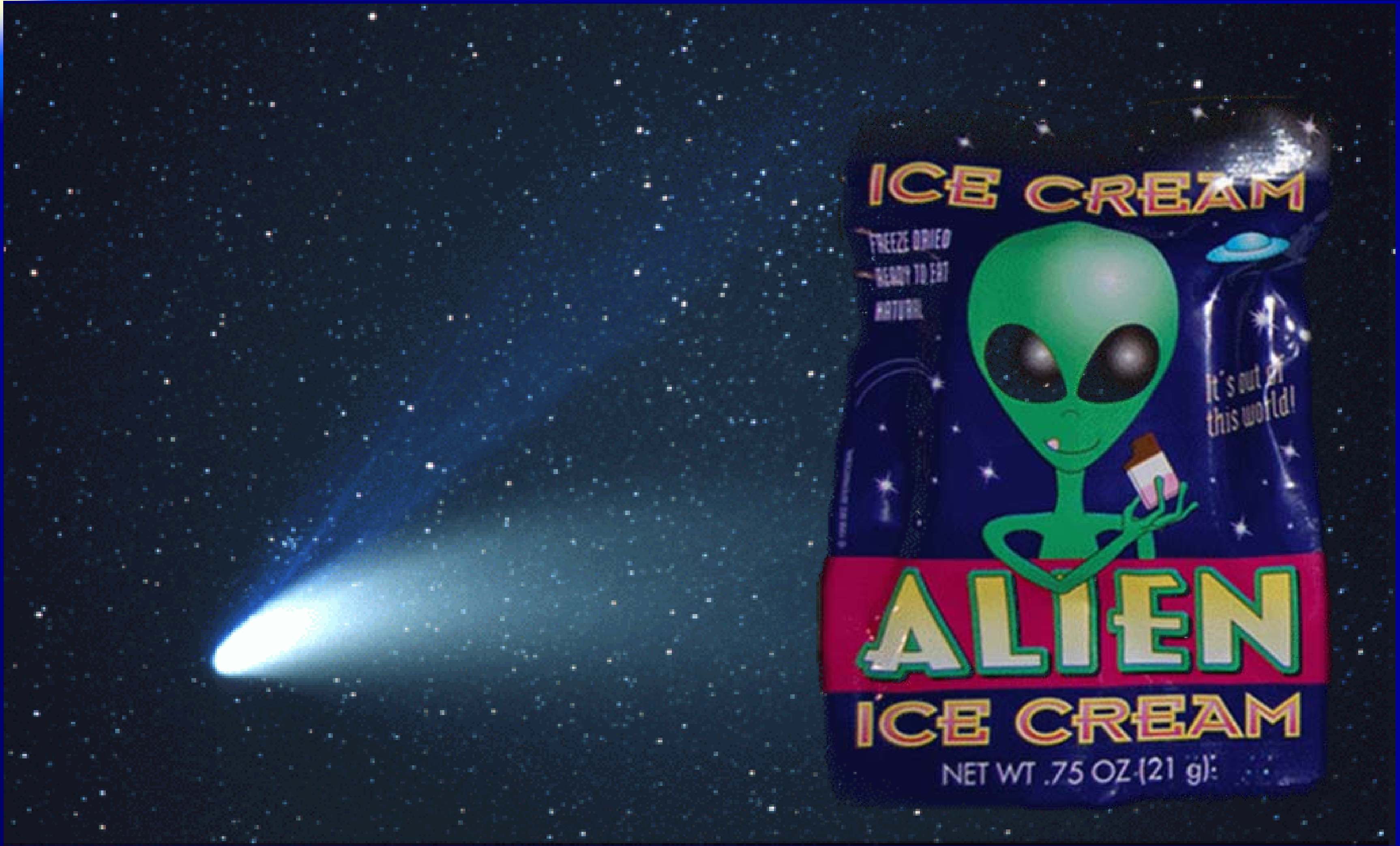
Black cloud Nebuloa (B68)

N ~ 10^4 cm^{-3}

T~10-50K!

Cruzeiro do Sul e a nebulosa do saco de carvão

Moléculas na fase condensada (gelos astrofísicos):
Evidências observacionais (MI, Nuvens moleculares, cometas, etc.)

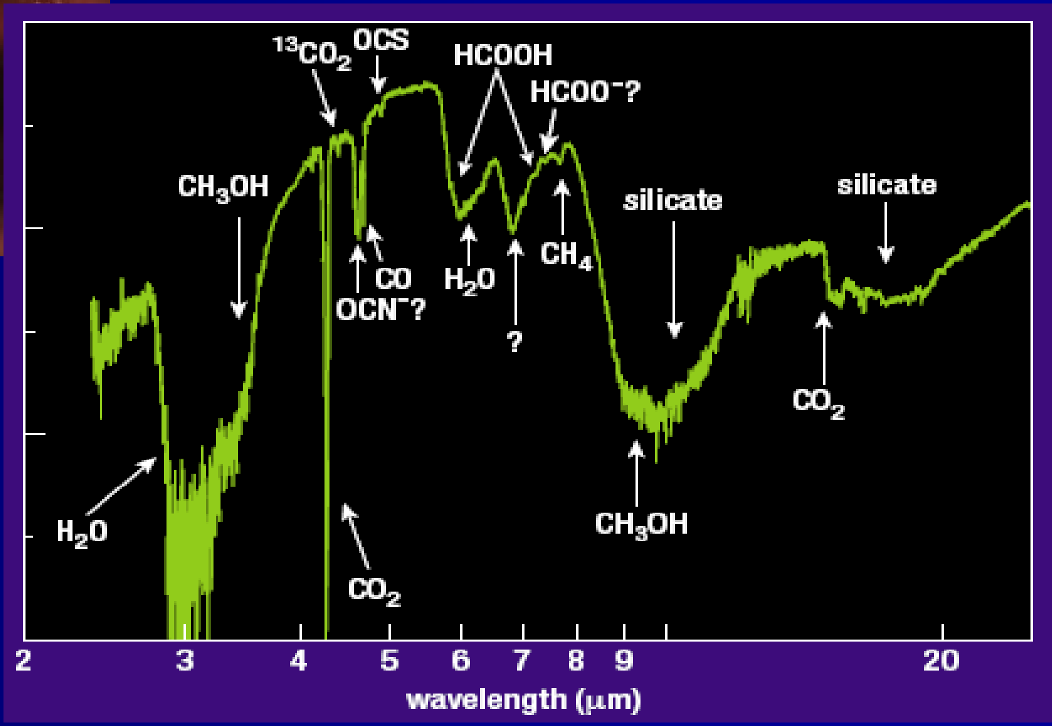


Gelos astrofísicos

Objetos estelares jovens (YSOs) e discos proto planetários

N~ 10^4-10^8 cm^{-3}

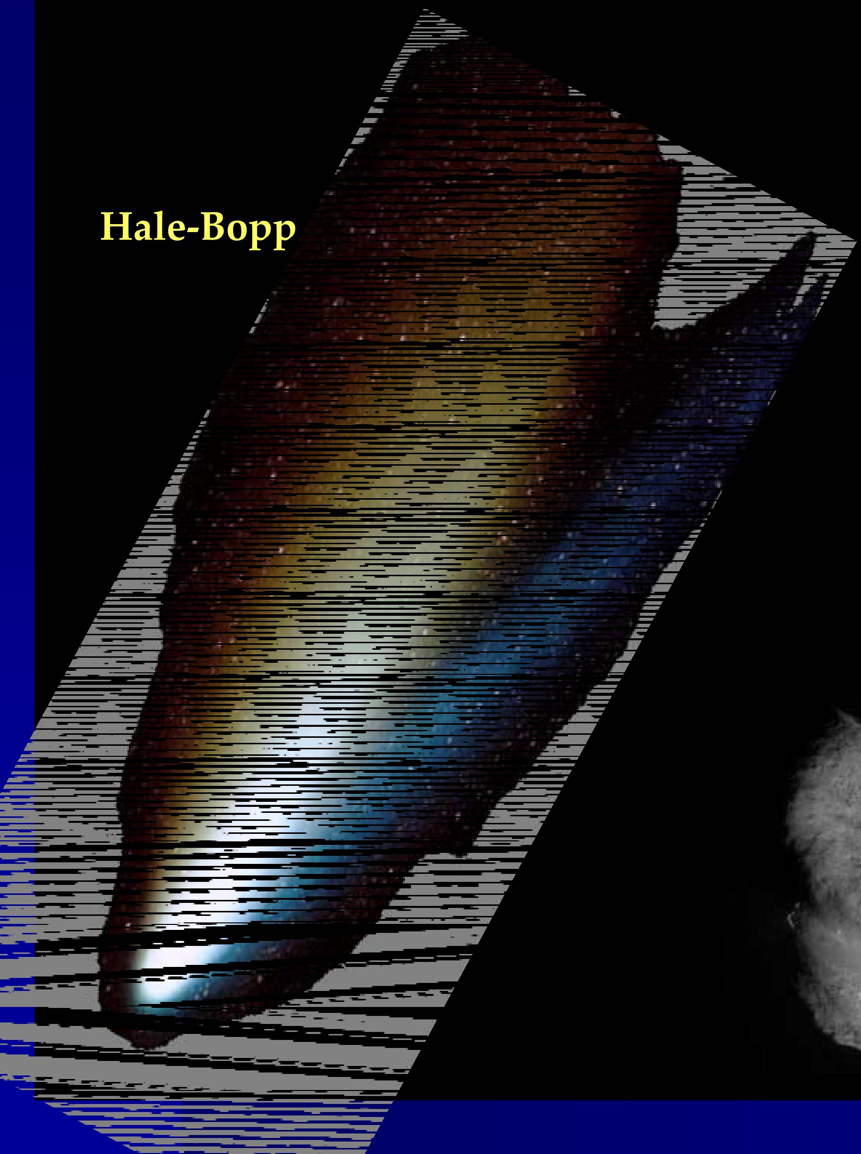
T ~ 10-50 K



W33a, Protstar (Gibb etal 2000)

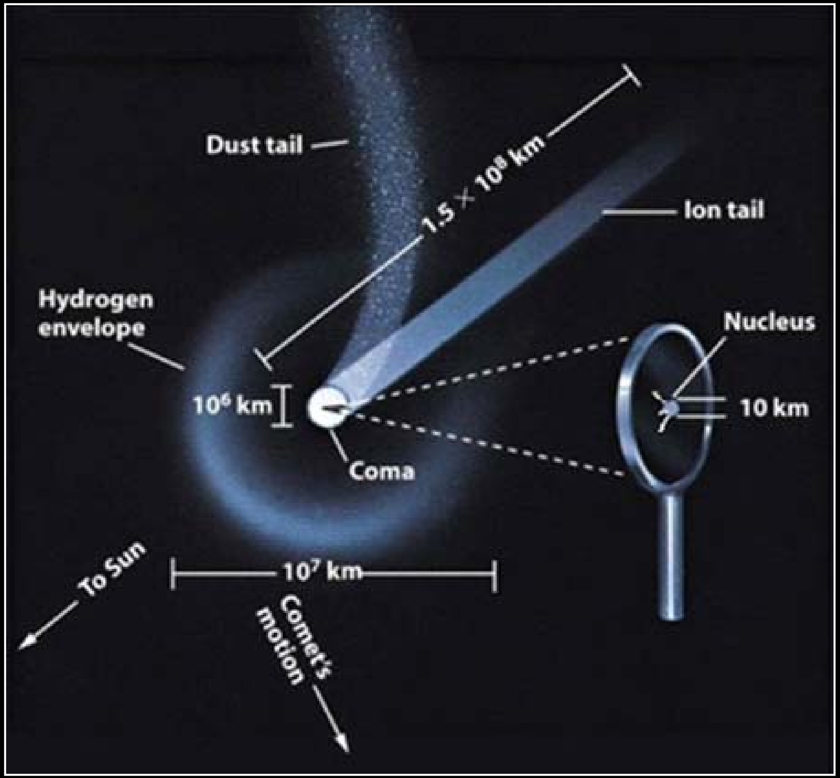
Gelos astrofísicos

Cometas (~80% água. CO, CO_2, CH_4, ….)



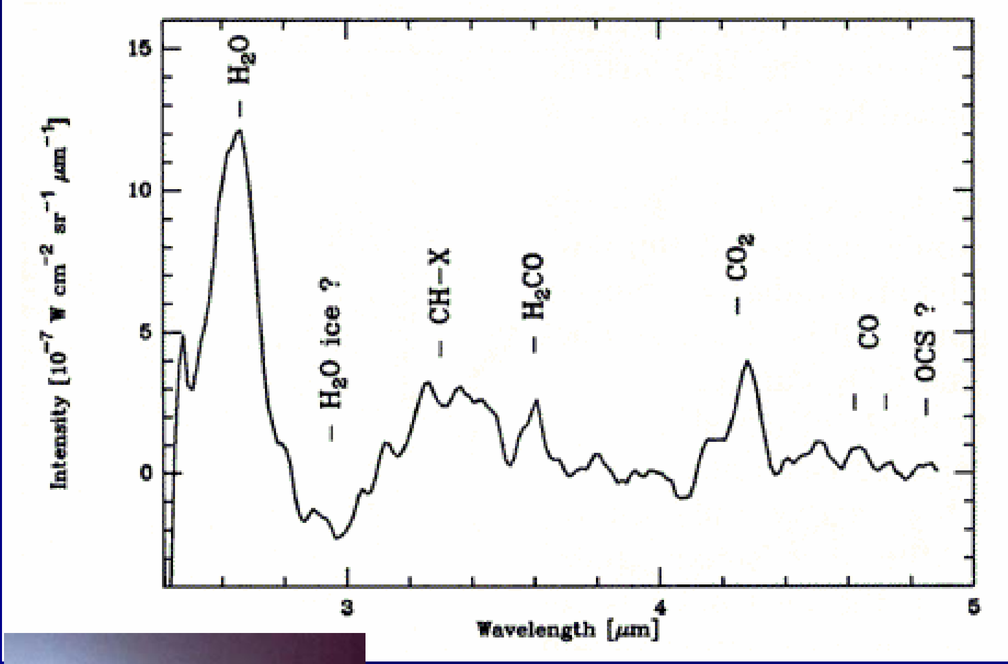
Hale-Bopp

Tempel 1

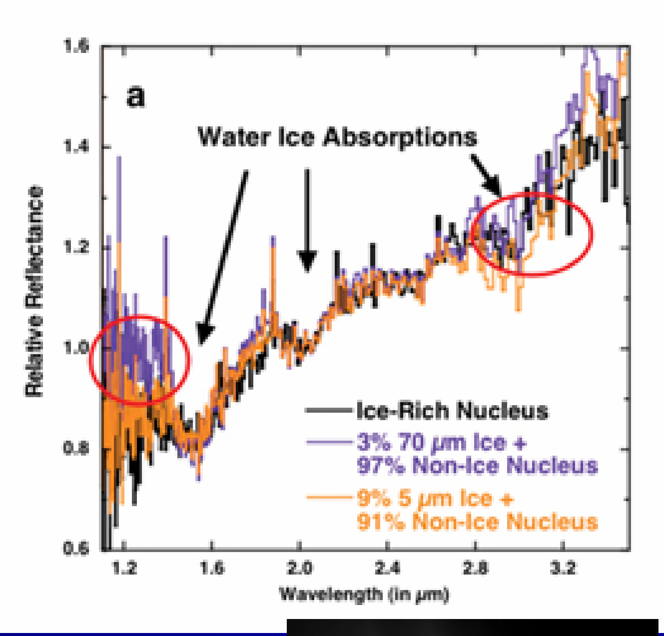


Gelos astrofísicos

Comet Halley (Combes etal 1988)



Tempel 1 (NASA)



Deep impact Mission

Gelos astrofísicos

- Luas e Planetas.

Artist impressions of Enceladus

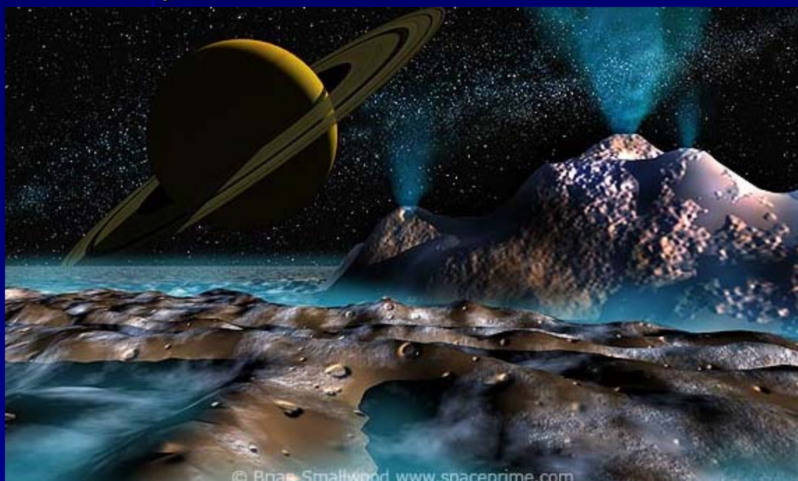


Table 1. Ices in the Solar System.

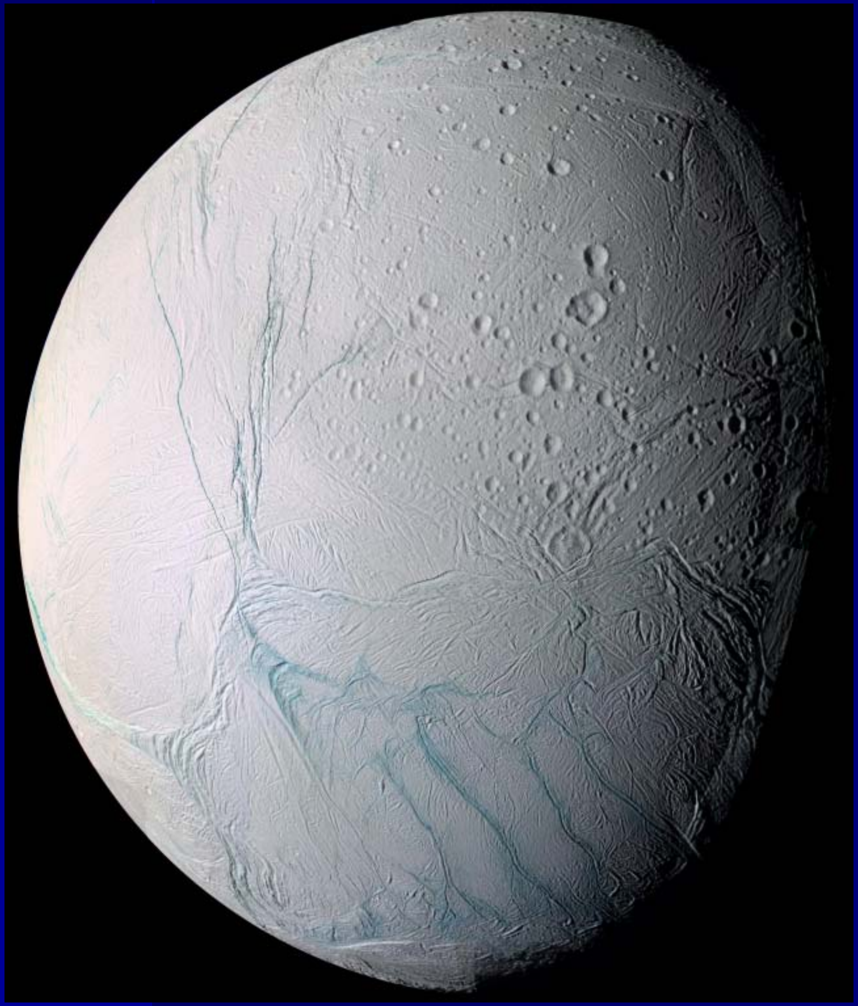
Planet Satellite *(Ref.)*	Observed Species
Jupiter	
Io	SO_2, H_2S, H_2O
Europa	H_2O, SO_2, CO_2, H_2O_2
Ganimede	H_2O, O_2, O_3, CO_2
Callisto	H_2O, SO_2, CO_2
(Calvin et al. 1995; Nash and Betts 1995)	
Saturn	
Mimas	H_2O
Enceladus	H_2O
Tetis	H_2O
Dione	H_2O, O_3
Rhea	H_2O, O_3
Hyperion	H_2O
Iapetus	H_2O
(Morrison et al. 1984; Cruikshank et al. 1984; Thomas et al. 1986)	
Uran	
Miranda	H_2O
Ariel	H_2O
Umbriel	H_2O
Titania	H_2O
Oberon	H_2O
(Cruikshank et al. 1995)	
Neptune	
Triton	N_2, CH_4, CO, CO_2, H_2O
(Brown et al. 1995)	
Pluto*	N_2, CH_4, CO, H_2O
Charon	H_2O
(Cruikshank et al. 1995)	

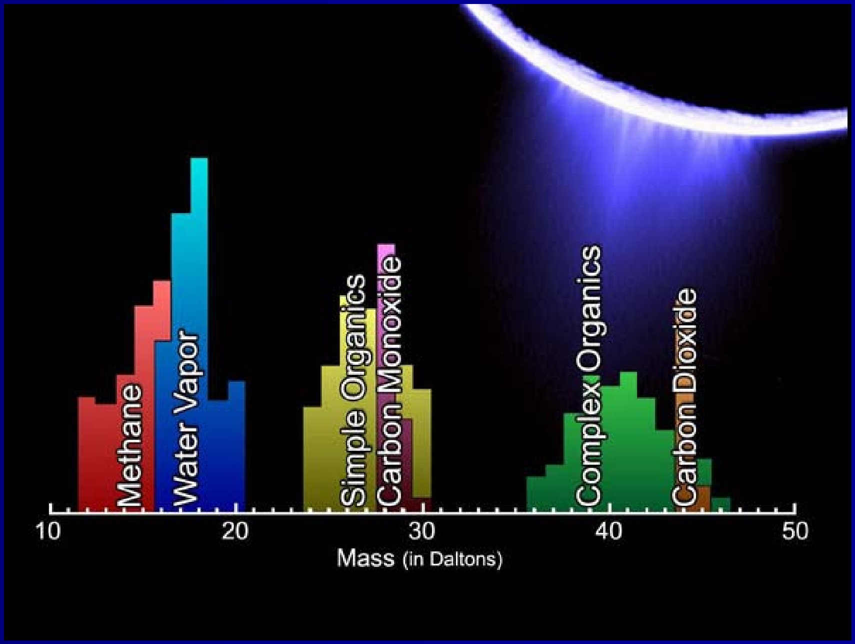
* After IAU resolution, in 2006, Pluto is a *dwarf planet* and is recognized as the prototype of trans-Neptunian objects.

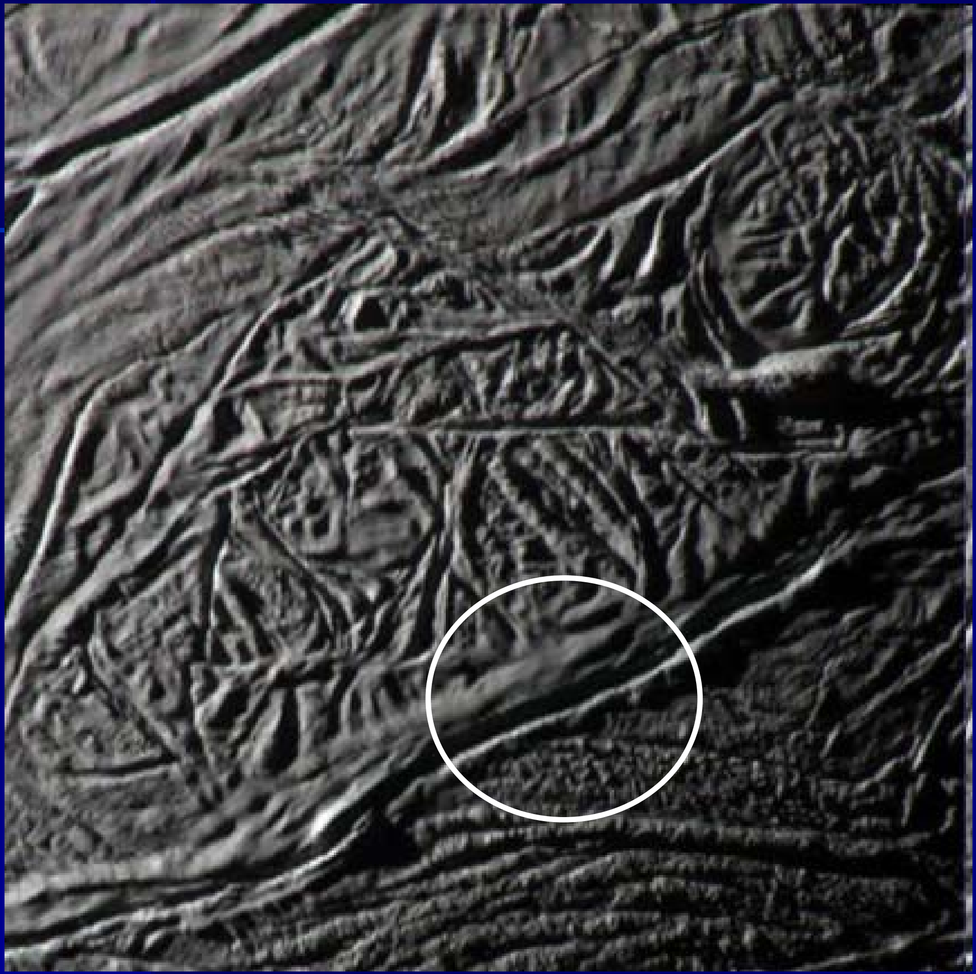
Gelos astrofísicos

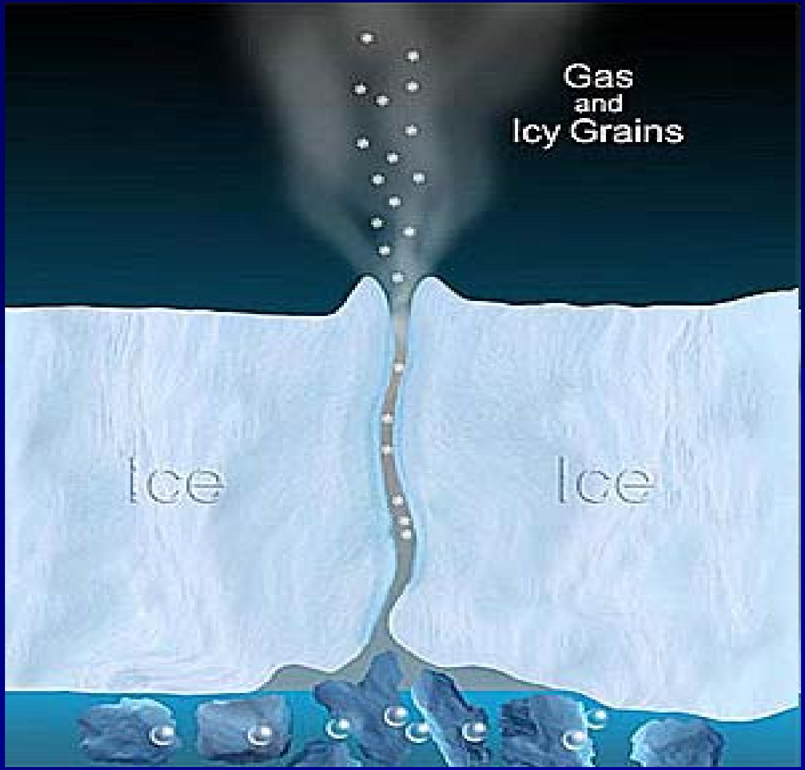
Luas e Planetas.

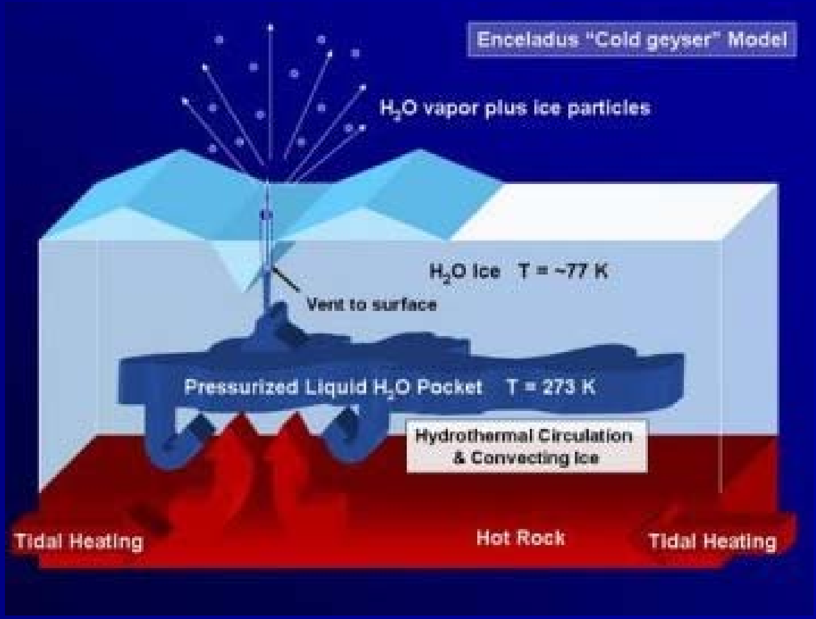
Ex. Enceladus (lua de Saturno).

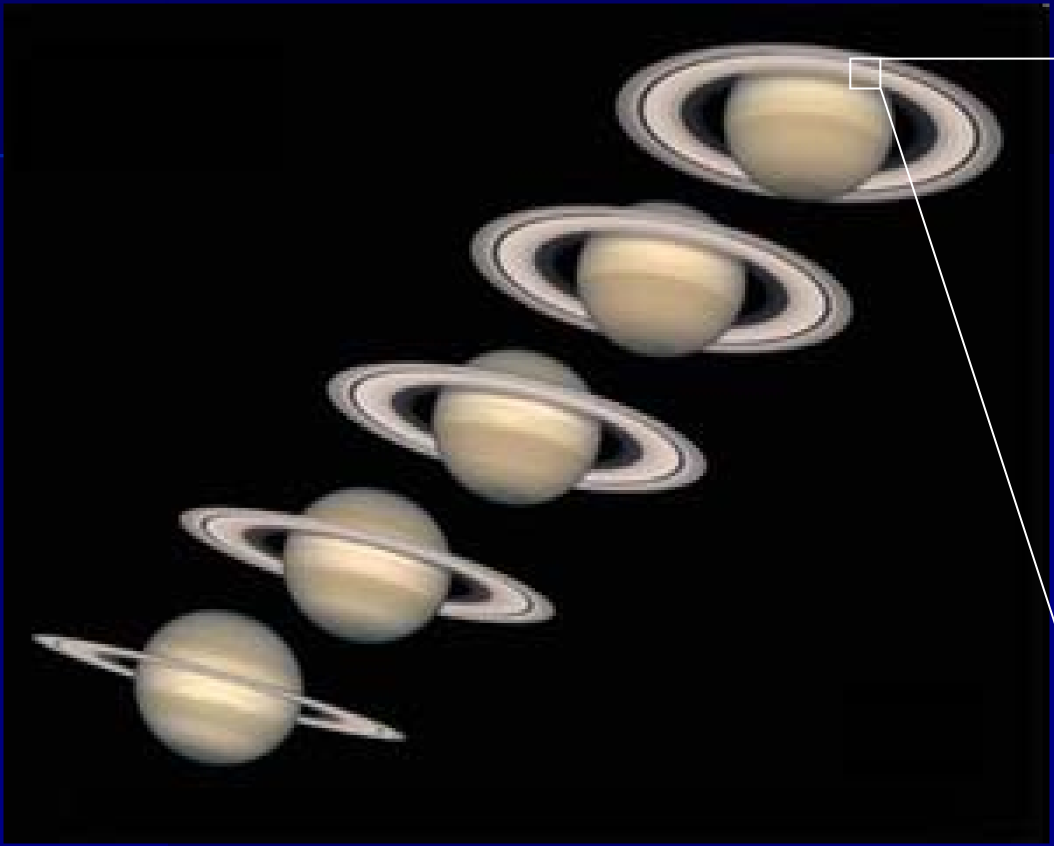


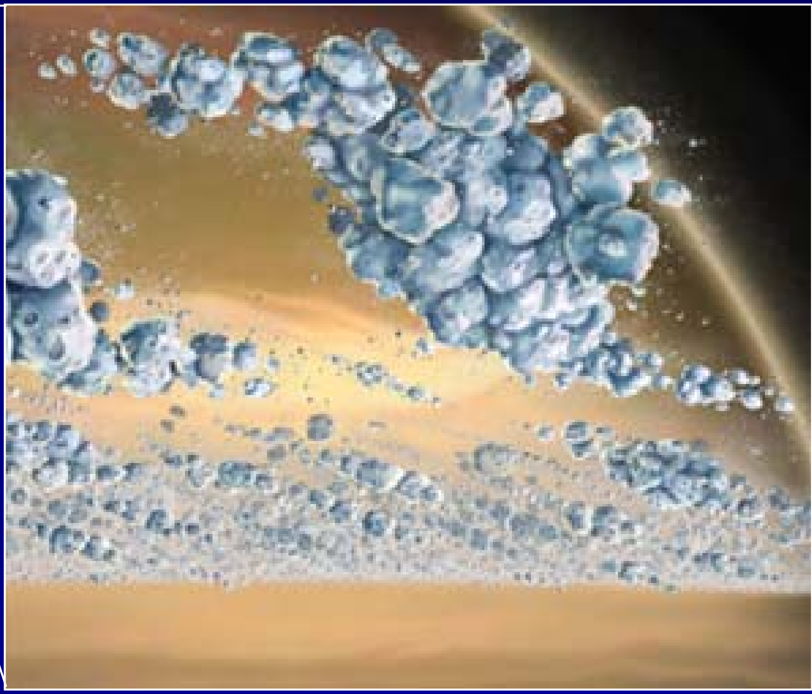




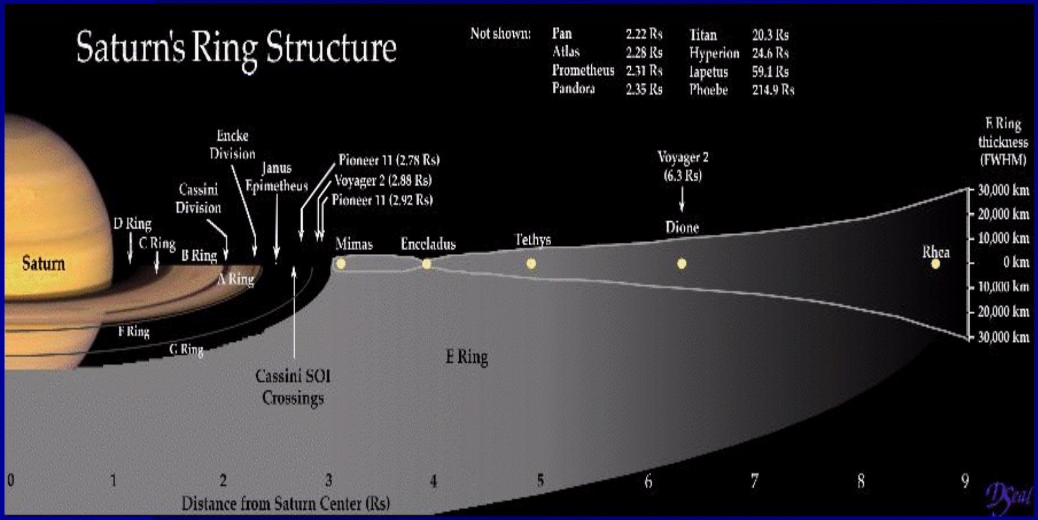

Gas
and
Icy Grains
Ice
Ice


Enceladus "Cold geyser" Model
H_2O vapor plus ice particles
H_2O Ice T = ~77 K
Vent to surface
Pressurized Liquid H_2O Pocket T = 273 K
Hydrothermal Circulation
& Convecting Ice
Tidal Heating
Hot Rock
Tidal Heating





Gelo de água ~ 99% + silicatos
1 cm - 10 mt.
Enceladus?

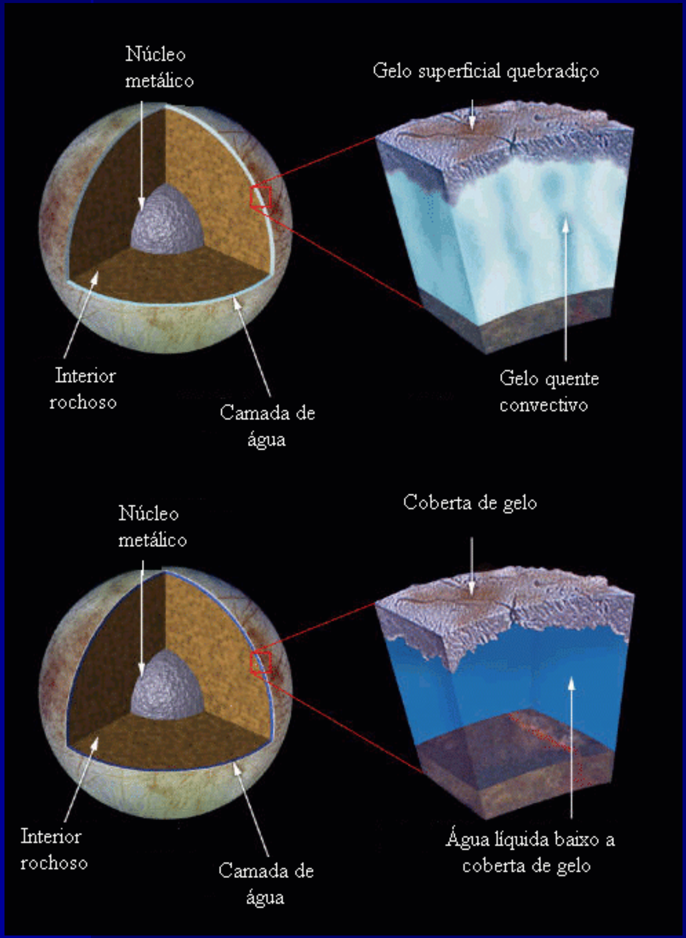


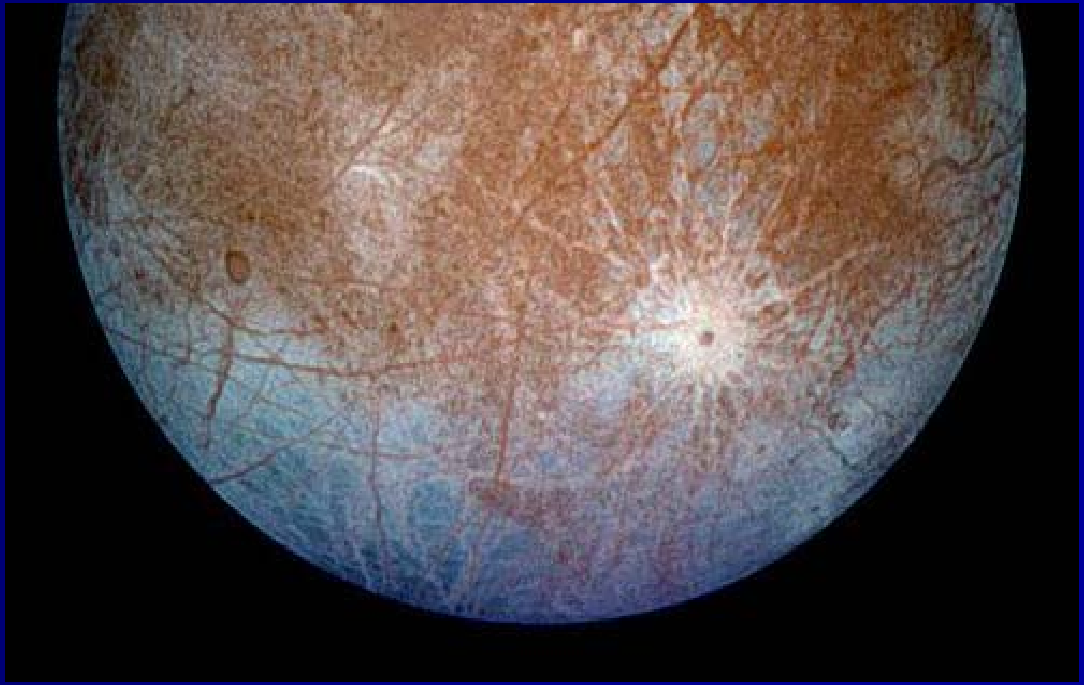
Ex. Anéis de Saturno

Gelos astrofísicos

Luas e Planetas.

Ex. Europa (lua de Jupiter).





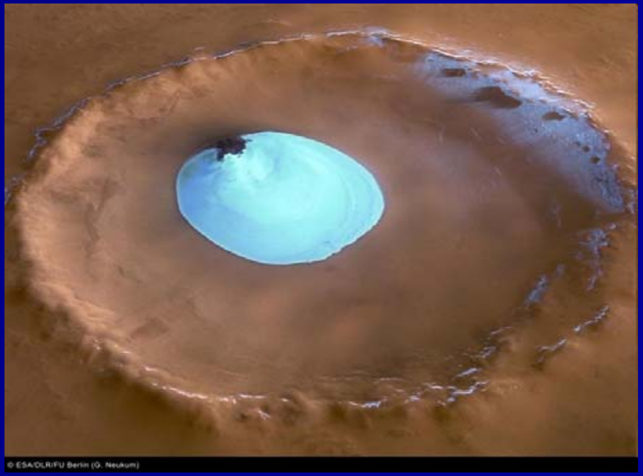
Modelos propostos

Gelos astrofísicos

- Luas e Planetas

Ex. Marte (T~ −46 °C)

Efeito sazonal

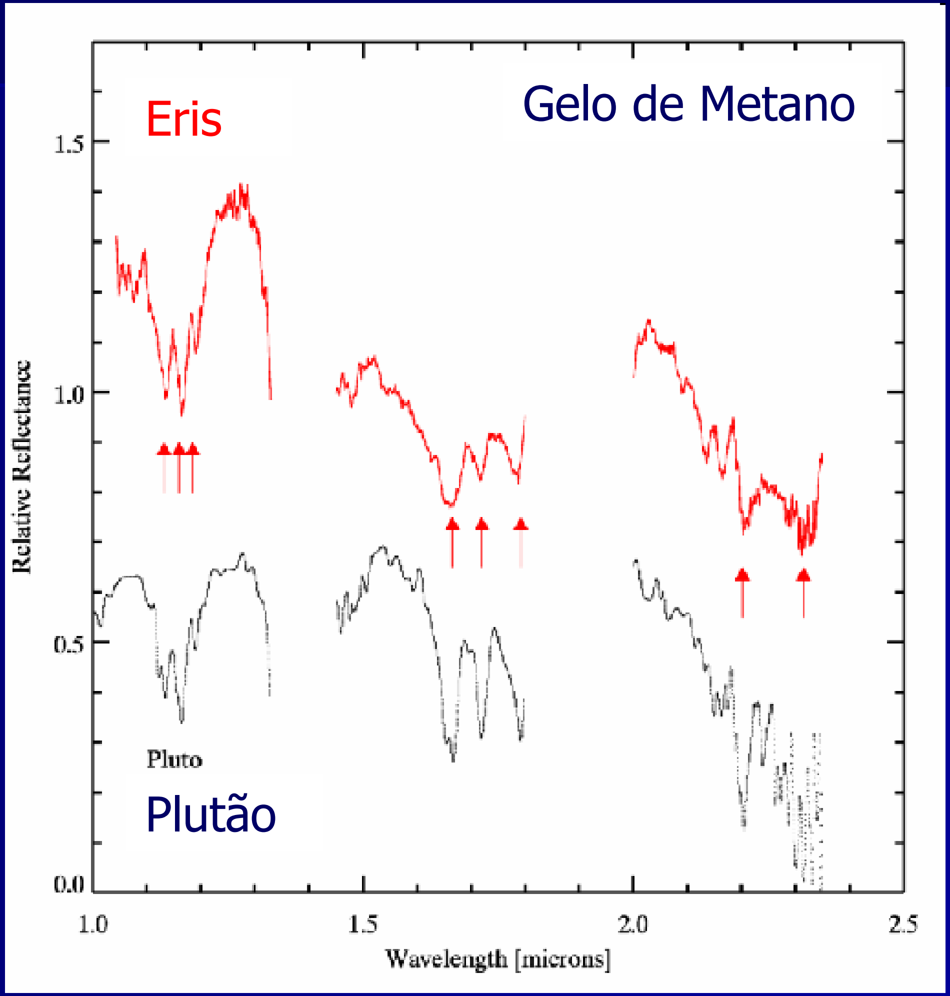


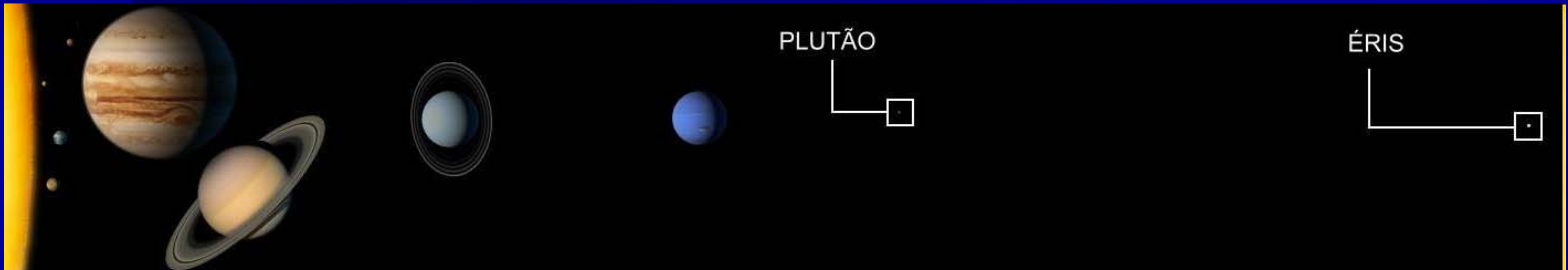
gelo de CO_2 na cratera Vastitas Borealis.

Gelos astrofísicos

Planetas anões

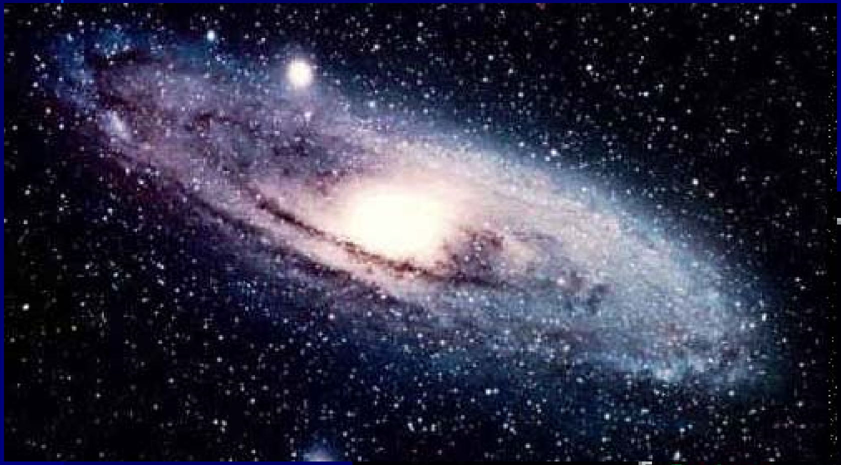
Ex. Plutão e Eris

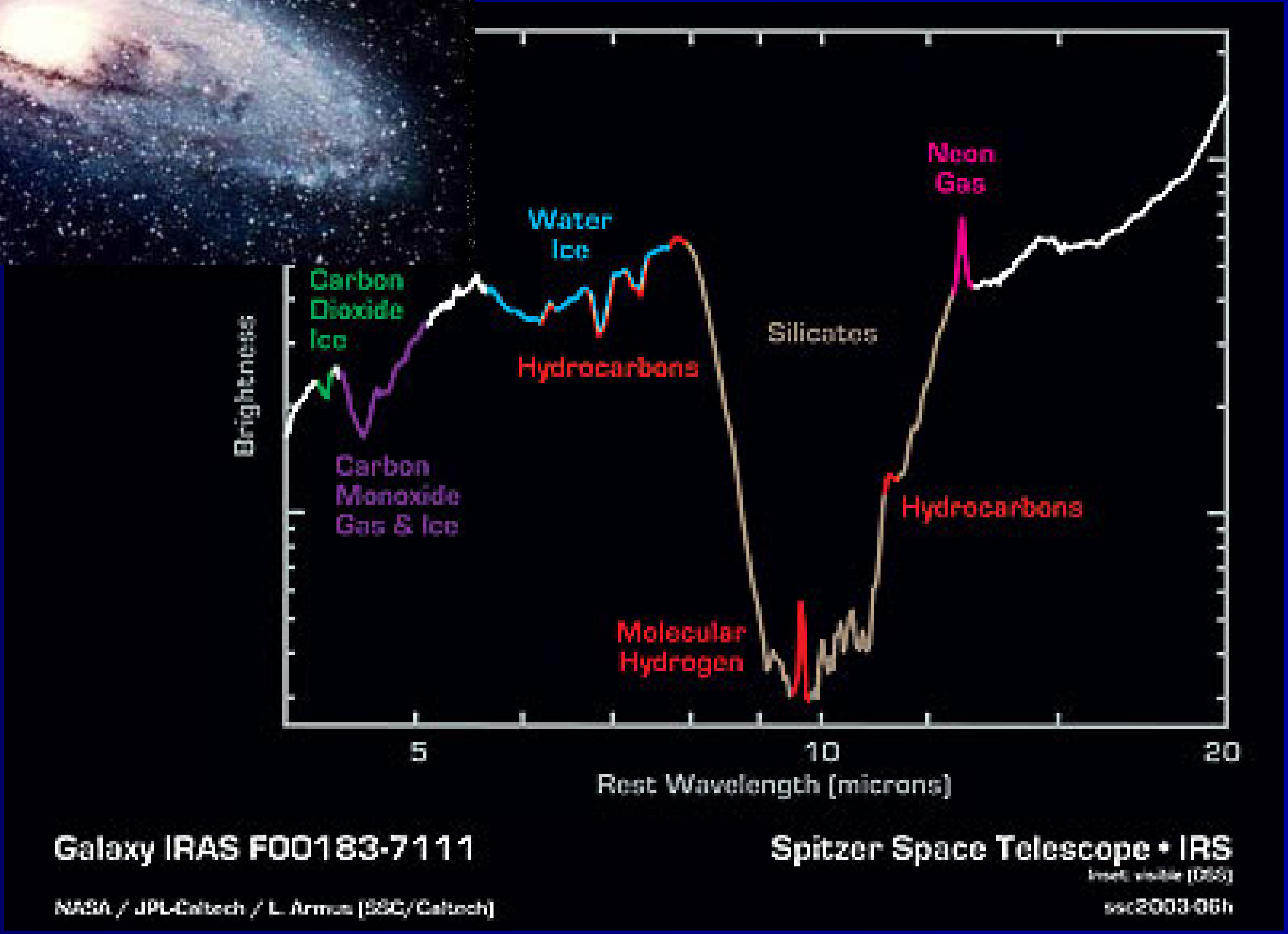




Gelos astrofísicos

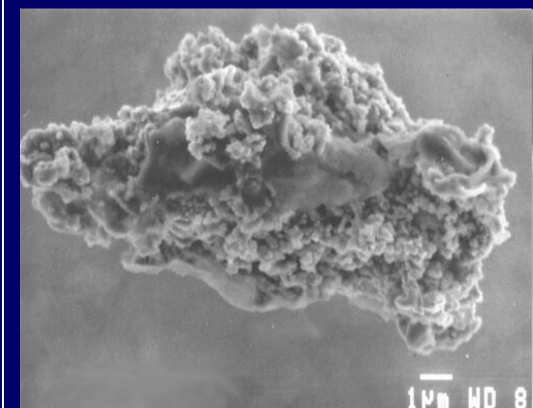
- Outras galáxias

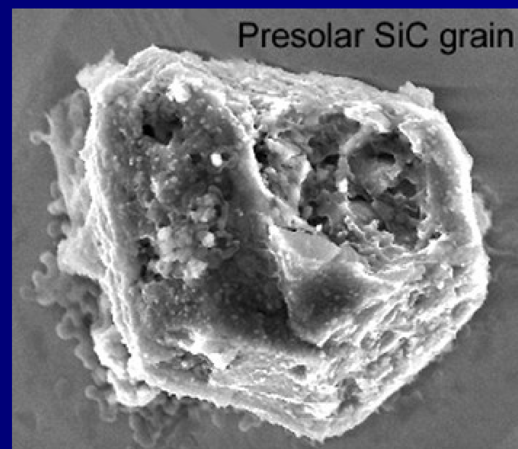


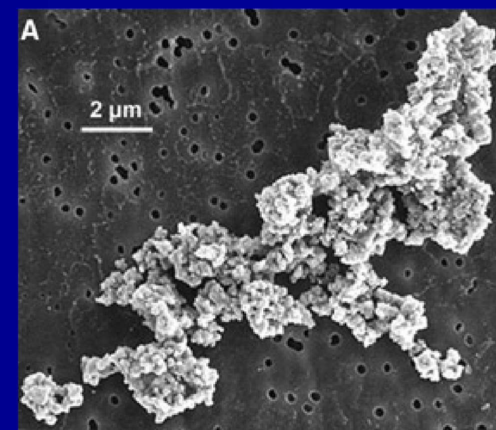


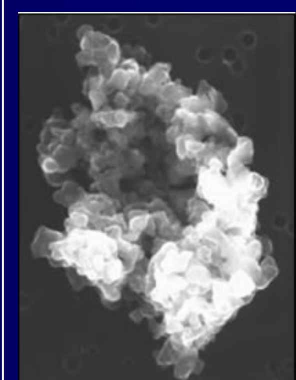
Processos de crescimento, alteração e destruição dos gelos astrofísicos e experimentos de laboratório

Ex. Grãos interplanetários

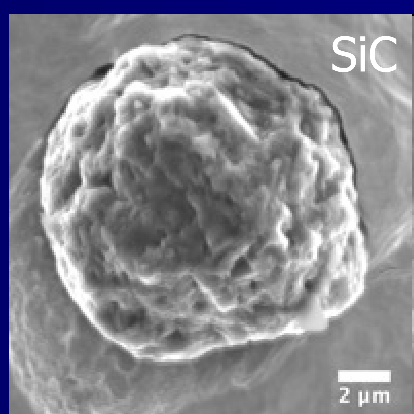


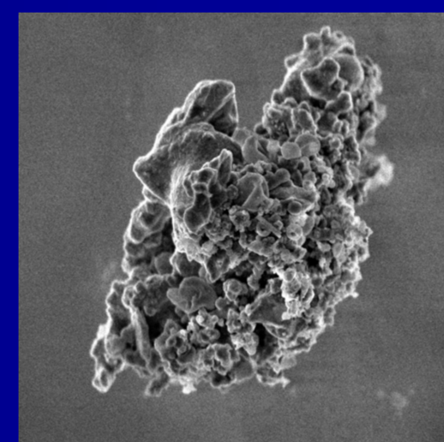






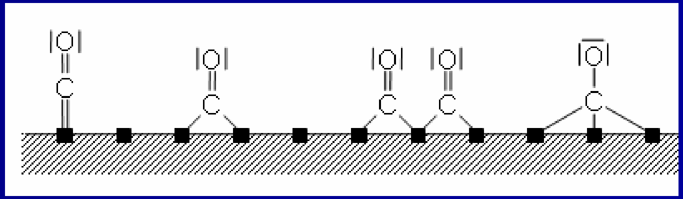
Cosmic dust grain 11 micrometers in diameter.





1) Processos de crescimento: adsorção

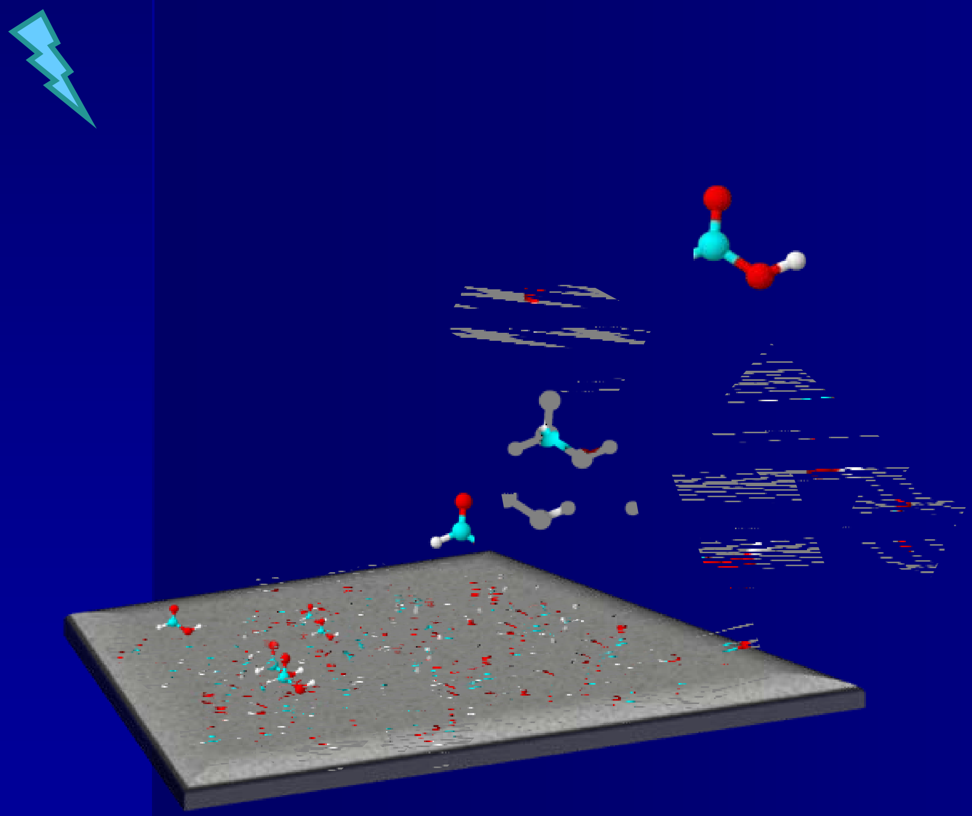
- Quimissorção (Chemisorption)
  - Ligações químicas entre superfície-adsorbato (~eV)
  - Sítios específicos de absorção.
  - Envolve energia de ativação.
  - 1ª monocamada,



- Fisissorção (Fisisorption)
  - Forcas intermoleculares (Ligações fracas): Pontes de hidrogênio, dipolo, dipolo induzido, van der Walls, … (~ meV)
  - Não envolve sítios específicos: Toda a superfície!
  - Não envolve energia de ativação.
  - Moléculas podem caminhar bastante na superfície (difusão alta)
  - Multicamadas; Preenchimento de microporos.
  - Em equilíbrio: o n de moléculas que “colam” na superfície é igual ao numero de moléculas que “descolam” superfície.

2) Processos de Alteração e Destruição:

- FOTÓLISE: Fótons (UV, Raios X)
- RADIÓLISE: Partículas (e^-, íons, CRs); Vento solar.
- AQUECIMENTO: Colisão entre os grãos



Reações químicas
Desorção
Aquecimento e Evaporação
Sputtering (erosão)
Compactacao

3) Experimentos de Laboratório

- Diferentes domínios de energia (alta, intermediária, media e baixa) envolvendo fótons, elétrons, íons e átomos neutros.
- Estudos de superfície ou volume

3.1) Energias Altas (ex. > 1 keV) → Sputtering, dissociação

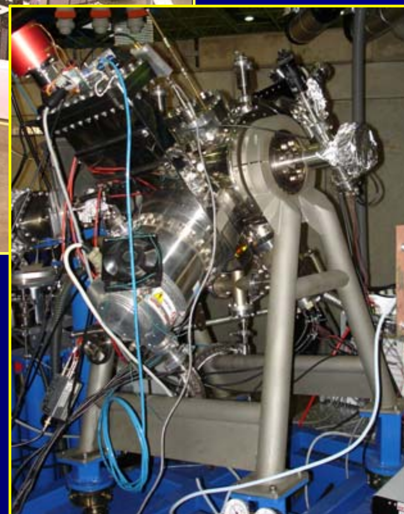
Fótons (X-ray): ionização e dissociação molecular, reações químicas (radicais, espécies iônicas), Sputtering (para energias altas), Seções de choque de absorção (camada interna).

Íons rápidos: compactação, clusters, Grande Sputtering, reações, seções de choque diss.

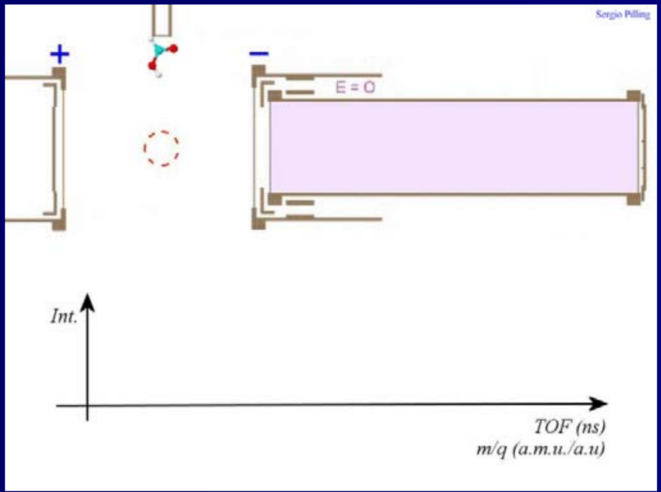
OBS: A penetrabilidade os íons é maior do q a dos fótons e elétrons. Stopping power: Energia depositada.

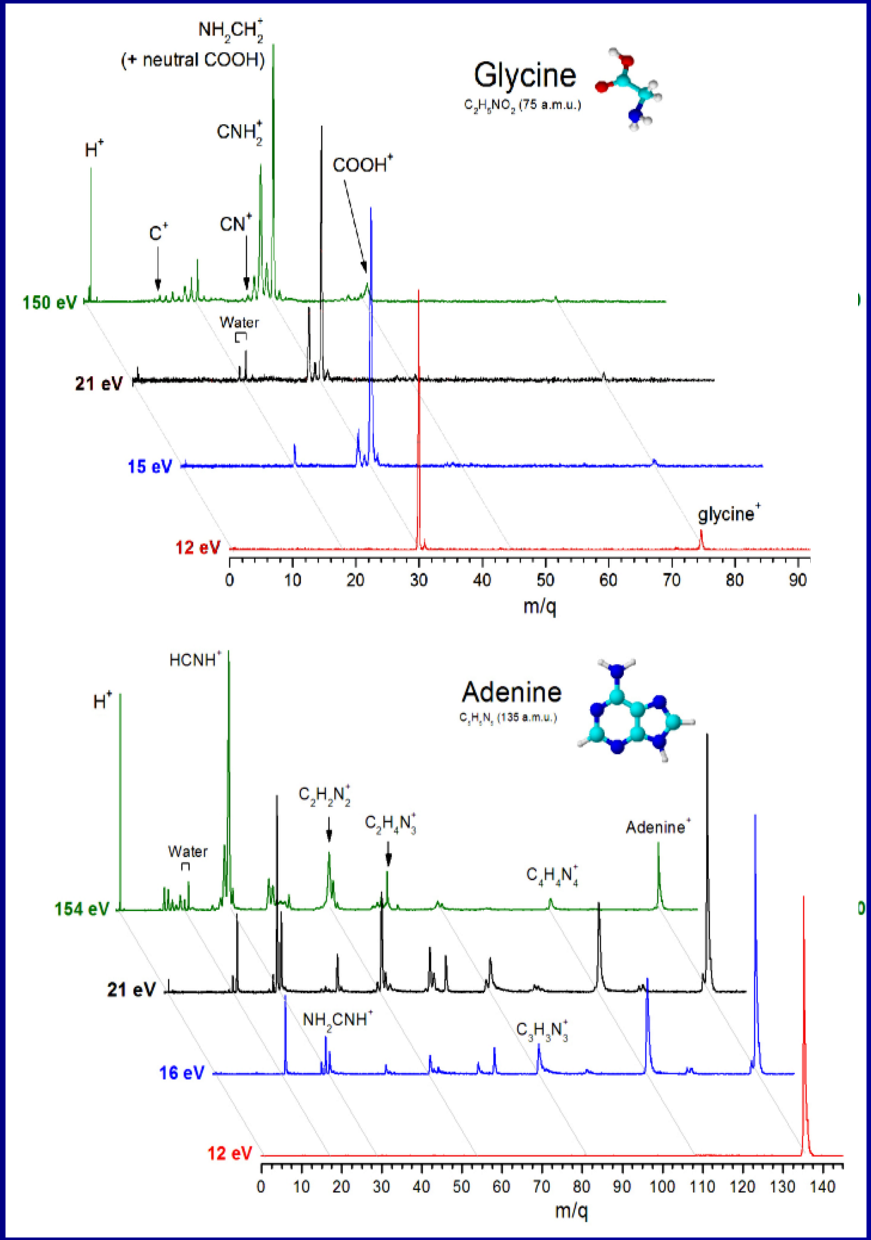
Técnicas investigativas: PDMS, PSID, TOF-MS, FTIR, QMS.

Ex. Experimentos de interação com fótons energéticos (fase gasosa)

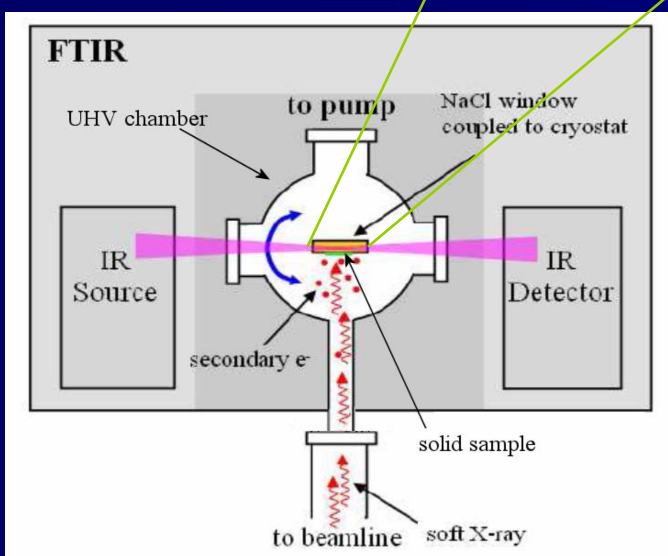


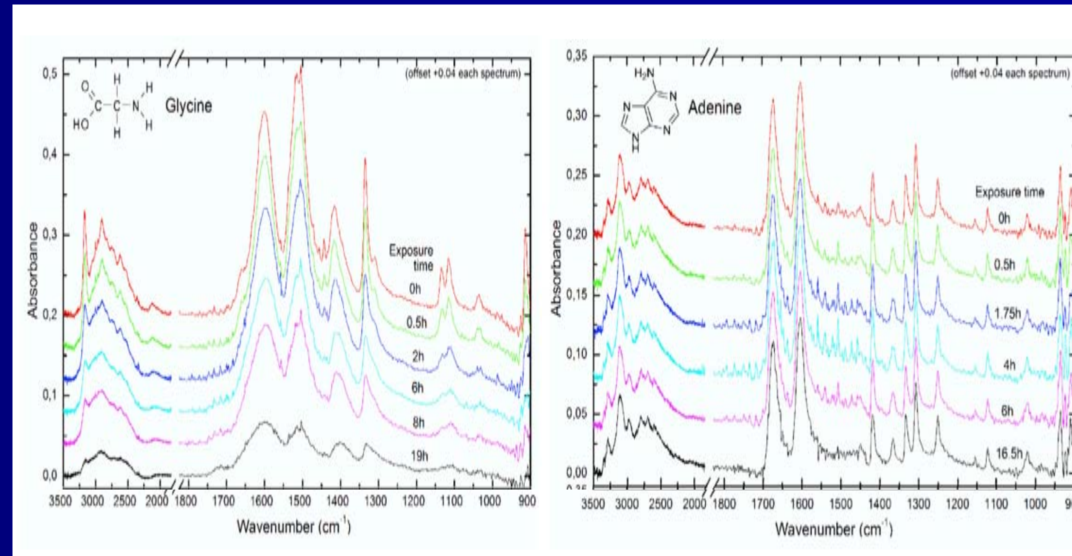
- -LNLS (raios X moles)
- -TOF-MS
- -Br. ratio e Seções de choque.

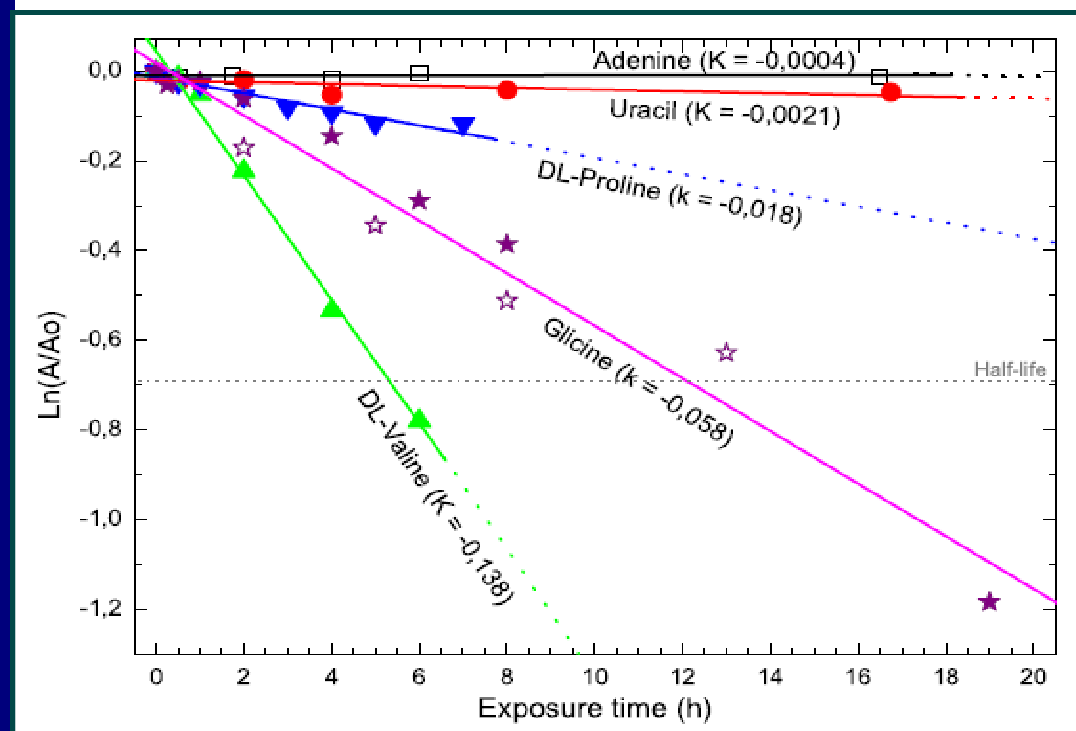




Ex. Experimentos de interação com fótons energéticos (fase condensada)





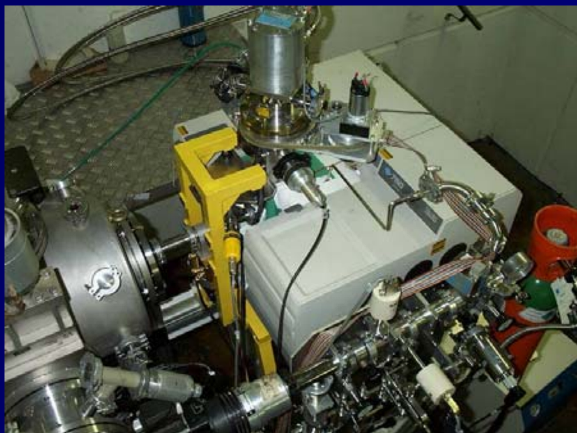


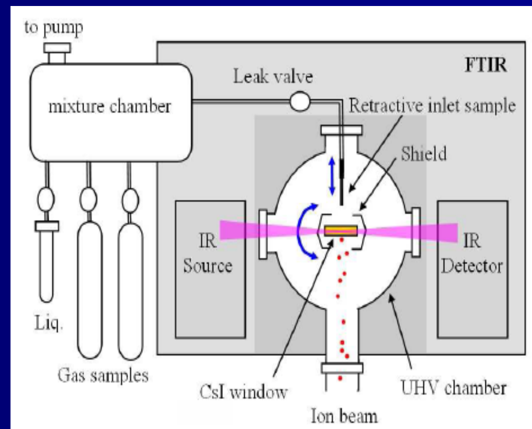
Ex. Experimentos de interação com ions energéticos (fase condensada)

- Simulação do efeitos de raios cósmicos em gelos astrofísicos.

S. Pilling, et al. 2009 A&A, Submt

GANIL
GRAND ACCELERATEUR NATIONAL D'IONS LOURDS





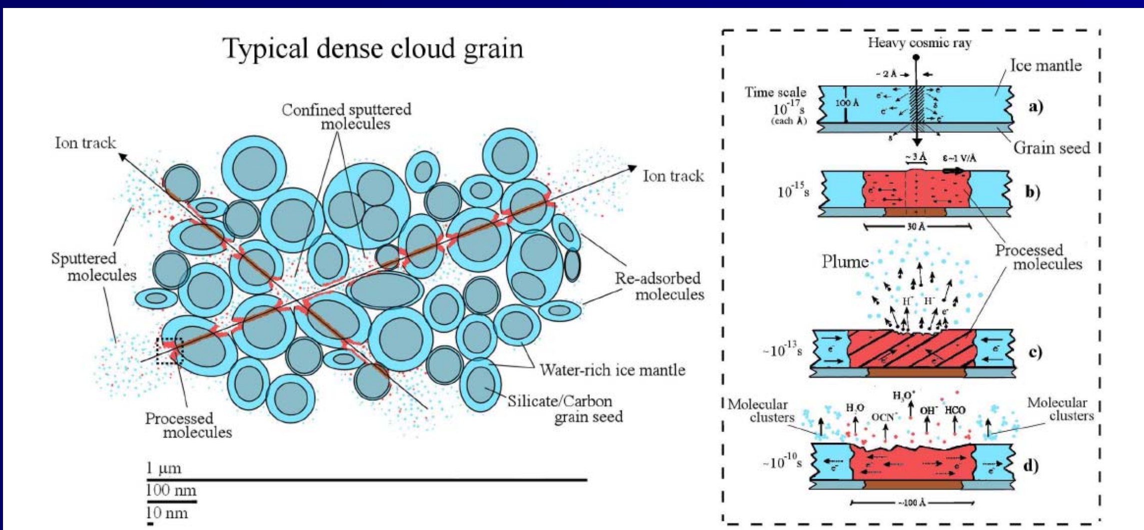
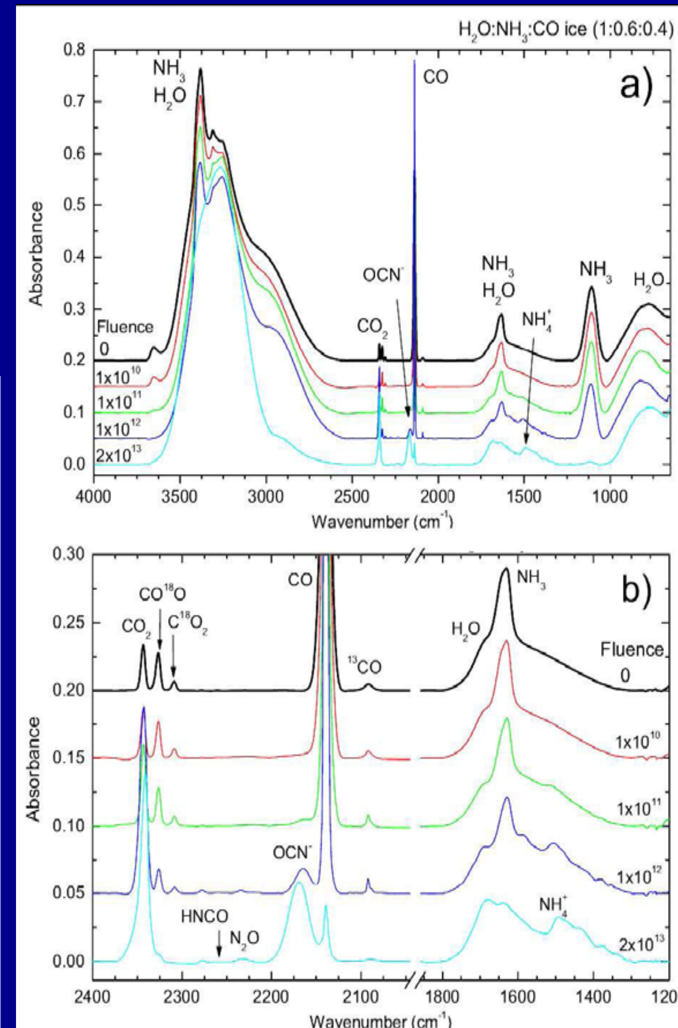


Fig. 7. Schematic view showing the interaction between heavy ion cosmic ray with a typical interstellar grain inside dense clouds. The ion track along the coagulate sub-micron size grains, the grain mantles, the processed and the sputtered molecules are indicated. Figure insets were adapted from Andrade et al. (2008) and indicate the physical-chemical changes on the grain mantel due to the impact with heavy ion. See details in text.



Sputtering e seção de choque de dissociação

Compactação

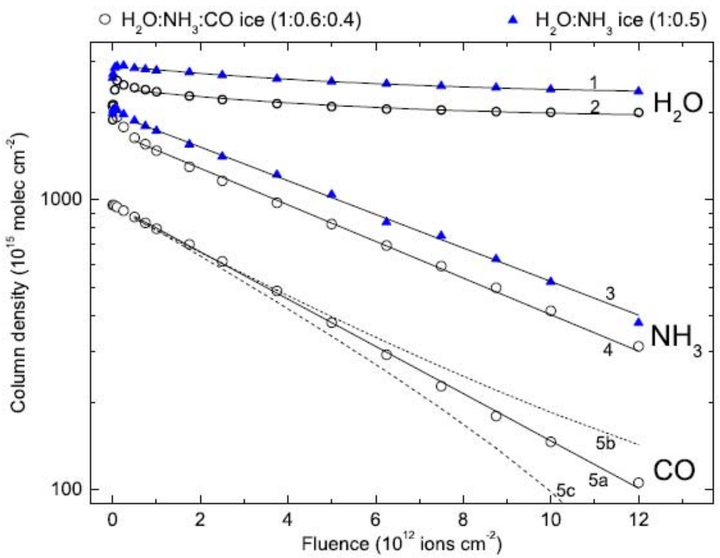


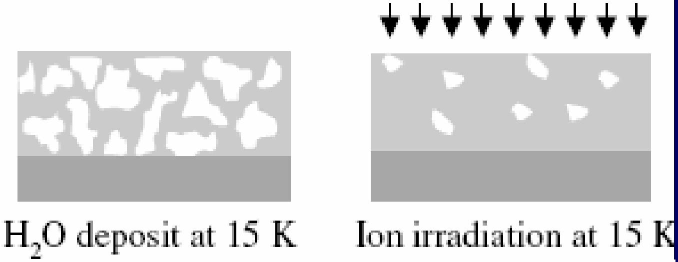
Fig. 3. Variation of the column density of water, ammonia and CO as a function of fluence. The solid lines are the fittings using Eq. 6 and Eq. 7. Triangles and circles correspond to different ice samples. The model parameters are listed in Table 3. See details in text.

$$N_i = N_{0i} \exp(-\sigma_{d,i} F) \quad \text{for } i \neq 1 \text{ species}$$

and

$$N_1 = (N_{01} - N_{\infty,1}) \exp(-\sigma_{d,1} F) + N_{\infty,1}$$

where $N_{\infty,1} = (L_1 - Y_1)/\sigma_{d,1}$ is the asymptotic value of column density at higher fluences due to the presence of layering. N_i and N_{0i} are the column density of species i at a given fluence and at the beginning of experiment, respectively.



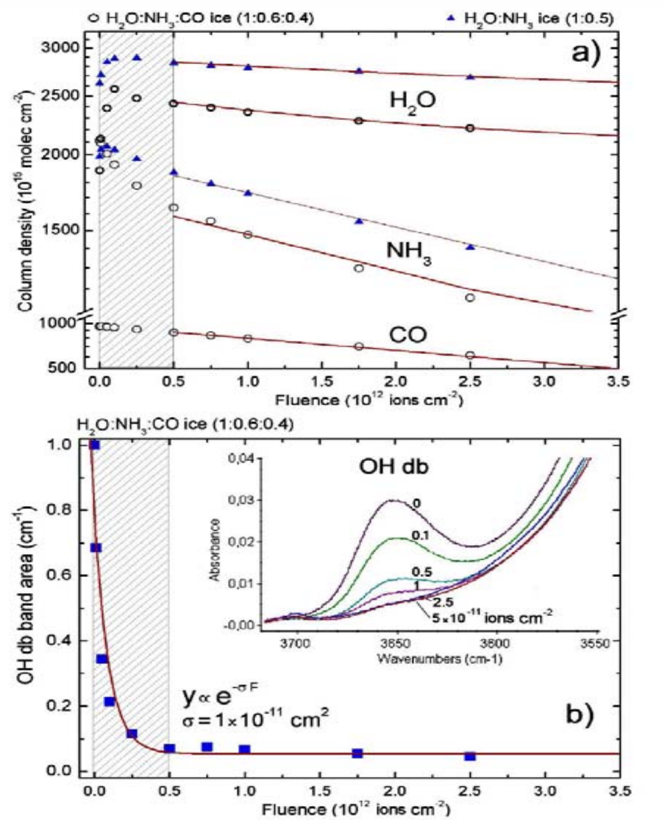


Fig. 4. a) Expanded view of Fig. 3 at the begining of irradiation. Note the drastic changes in column density of water and ammonia up to fluence of 5×10^{11} ions cm^{-2}. The hachured strip indicates the regions where the compaction is occurring. b) OH dangling bond feature area (cm^{-1}) in the $H_2O:NH_3:CO$ ice (1:0.6:0.4) as a function of fluence. Figure inset is the OH db feature from non irradiated ice and at fluences 0.1, 0.5, 1, 2.5 and 5×10^{11} ions cm^{-2}.

Formação de espécies novas (OCN-; Glicina?)

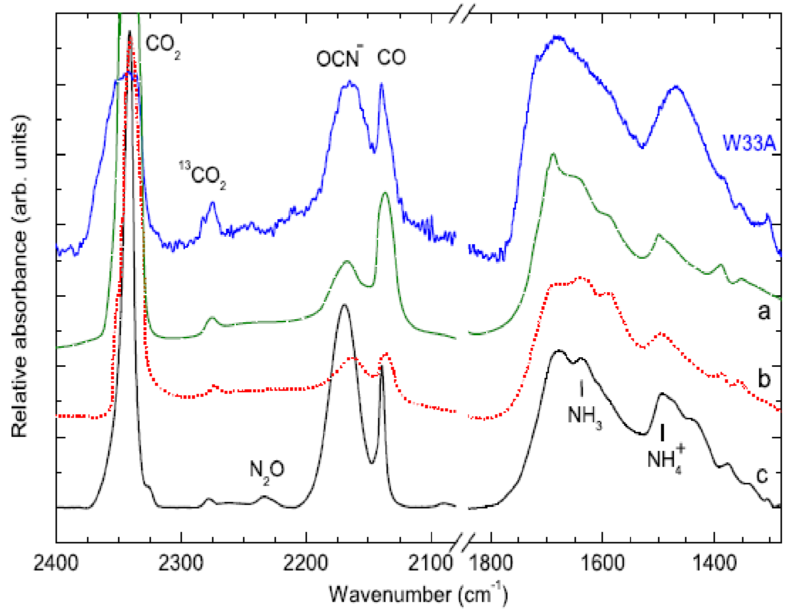
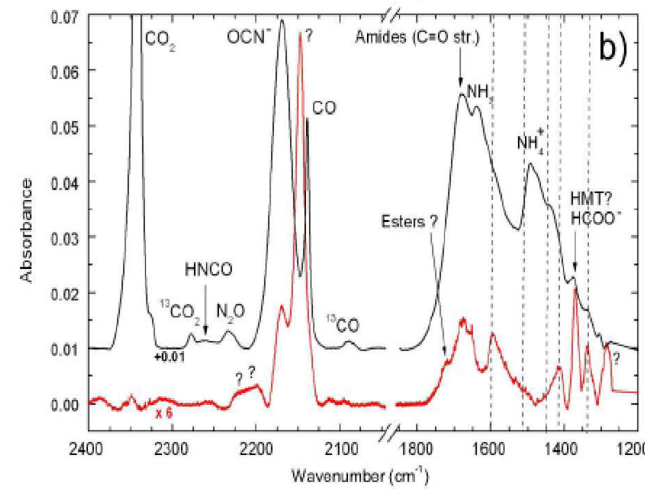


Fig. 5. Comparison between IR spectra of interstellar and laboratory ices. The upper trace is the infrared spectra of protostellar source W33A obtained by Infrared Space Observatory (ISO). Lower traces indicates lab spectra of $H_2O:NH_3:CO$ ices at 13-15 K after processing by ionizing radiation. a) $H_2O:NH_3:CO$ (1:0.2:0.2) ice processed by UV photons (Hudson & Moore 2000); b) $H_2O:NH_3:CO$ (1:0.2:0.2) ice bombarded by 0.8 MeV protons (Hudson & Moore 2000); c) $H_2O:NH_3:CO$ ice (1:0.6:0.4) irradiated by 46 MeV Ni ions simulating heavy and energetic cosmic rays (this work).



b) Comparison between the organic residue at 13 K and 300 K. Vertical dashed lines indicate the frequencies of some vibration modes of zwitterionic glycine ($NH_3^+CH_2COO^-$).

Table 4. Infrared absorption features produced by the radiolysis of the $H_2O:NH_3:CO$ ice (1:0.6:0.4) by heavy, charged and energetic ions and the assignment of the observed bands at 13 K and 300 K.

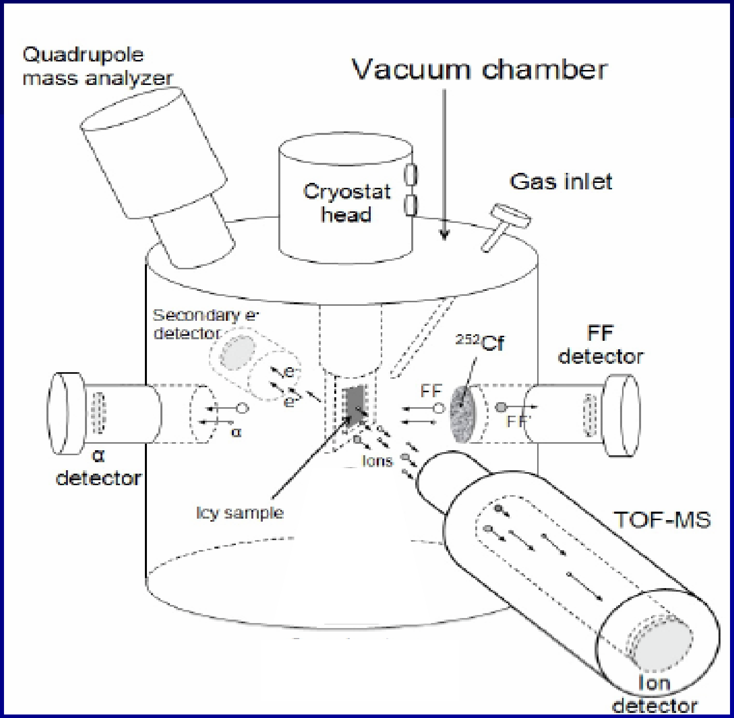
Frequency (cm^{-1})	Wavelength (μm)	Temp. (K)	Molecule	Vibration mode (cm^{-1})	Notes
~2280	4.38	13	HNCO	(~2265)	[1,3,7]
2233	4.48	13	N_2O	N-N str.(2235)	[1,2]
2218[d]	4.51	300	aryl nitriles	Ar-C≡N (2210)	[8]
2200	4.54	300	conjug. nitriles	(~2180)	[8]
2168	4.61	13, 300	OCN^-	(~2165)	[1,3,4,7]
2147[d]	4.66	300	aliph. isocyanide	R-N≡C (2150)	[8]
~ 2112	4.73	300	NCO_2	ν_1 (2115)	[2]
1725[d]	5.80	300	ester[a]	C=O str. (~1742)	[5]
1683	5.94	300	amides[b]	C=O str. (~1680)	[5]
1652[d]	6.05	300	N_3; asym-N_2O_3	(1652)	[2]
1637	6.11	13	?		
1593[d]	6.28	300	$NH_3^+CH_2COO^-$	COO ν_{as} (1596)	[6]
1558	6.42	300	?		
1533	6.52	300	?		
1506[d]	6.64	300	$NH_3^+CH_2COO^-$	NH_3 δ_s (1505)	[6]
~1490	6.71	13	NH_4^+	ν_4 (~1485)	[1,3,7]
1474	6.78	13	NO_3?	(1471)	[2]
1440[d]	6.94	13	$NH_3^+CH_2COO^-$	NH_3 δ (1444)	[6]
1415[d]	7.07	300	$NH_3^+CH_2COO^-$	COO ν_s (1415)	[6]
~ 1370[d]	7.30	13, 300	HMT[c]	CH scis (1375)	[5]
			HCOO–	CH scis	[5]
1338[d]	7.47	13, 300	$NH_3^+CH_2COO^-$	CH_2 ω (1342)	[6]
			$NH_2CH_2COO^-$	ν_9 (1342)	[6]
1305	7.66	13	N_2O_3; N_2O_4; N_2O_5	ν_1; ν_3; ν_2(1303)	[2]
1283[d]	7.80	300	N_2O	N-O str. (1288)	[2]

[a] amides, $H_2NC(=O)-R$; [b] esters, R−C(=O)-O-R; [c] HMT - hexamethylenetetramine, $(CH_2)_6N_4$; [d] tentative assignment. [1] Proton bombardment of several ices (Hudson et al. 2001); [2] Electron bombardment of $N_2:CO_2$ (Jamieson et al. 2005); [3] Hudson & Moore 2000; [4] van Broekhuizen et al. 2005; [5] UV photolysis of $H_2O:NH_3:CH_3OH:CO:CO_2$ ice (Munoz Caro and Shutte 2003); [6] Electron bombardment of $CH_3NH_2:CO_2$ ice (Holtom et al. 2005); [7] UV photolysis of ammonia-rich ices (Demyk et al. 1998); [8] UV photolysis of $N_2:CH_4$ ices at various pressures (Imanaka et al. 2004).

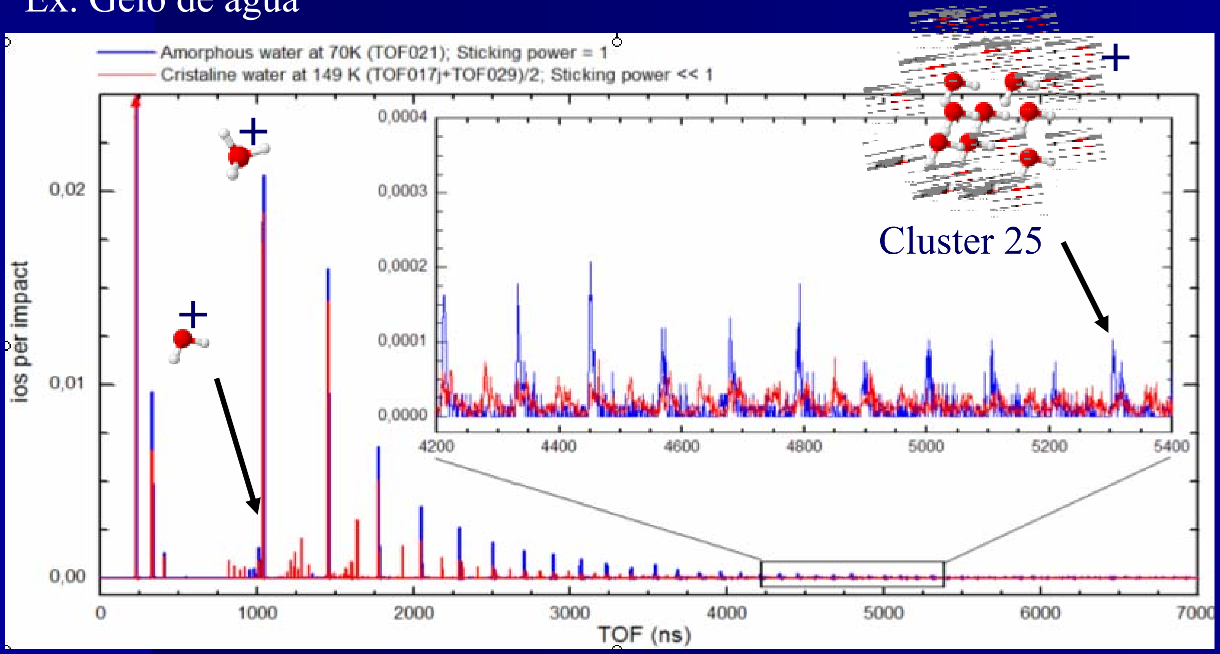
Ex. Investigações da superfície pelo impacto de íons rápidos

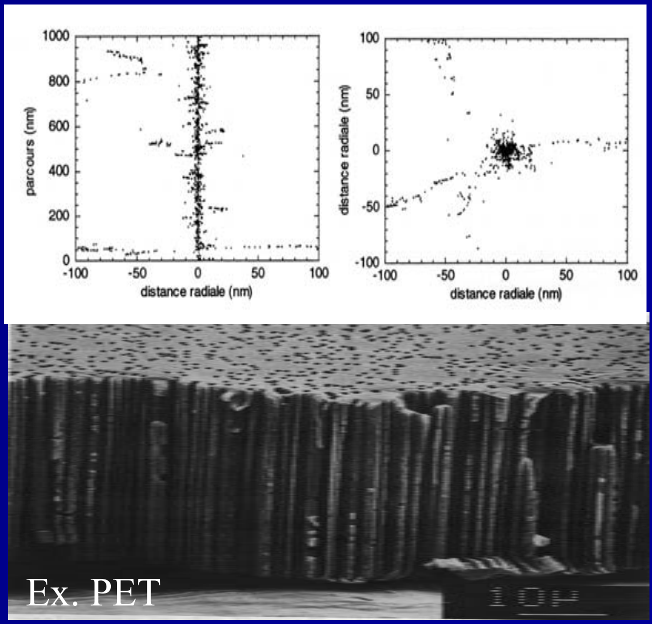
PDMS – Cf: Plasma Desorption Mass spectrometry by ^{252}Cf fission frag.
- E~ 65MeV; (Regime eletrônico)
- Baixo fluxo ~ 1000 cm^{-2} s^{-1}.

UVH + TOF-MS
- Track: Atomização e molecularização
- Dissociação molecular (via secondary e^-).
- Novas espécies (via secondary e^-).
- Clusters; íons positivos e negativos.



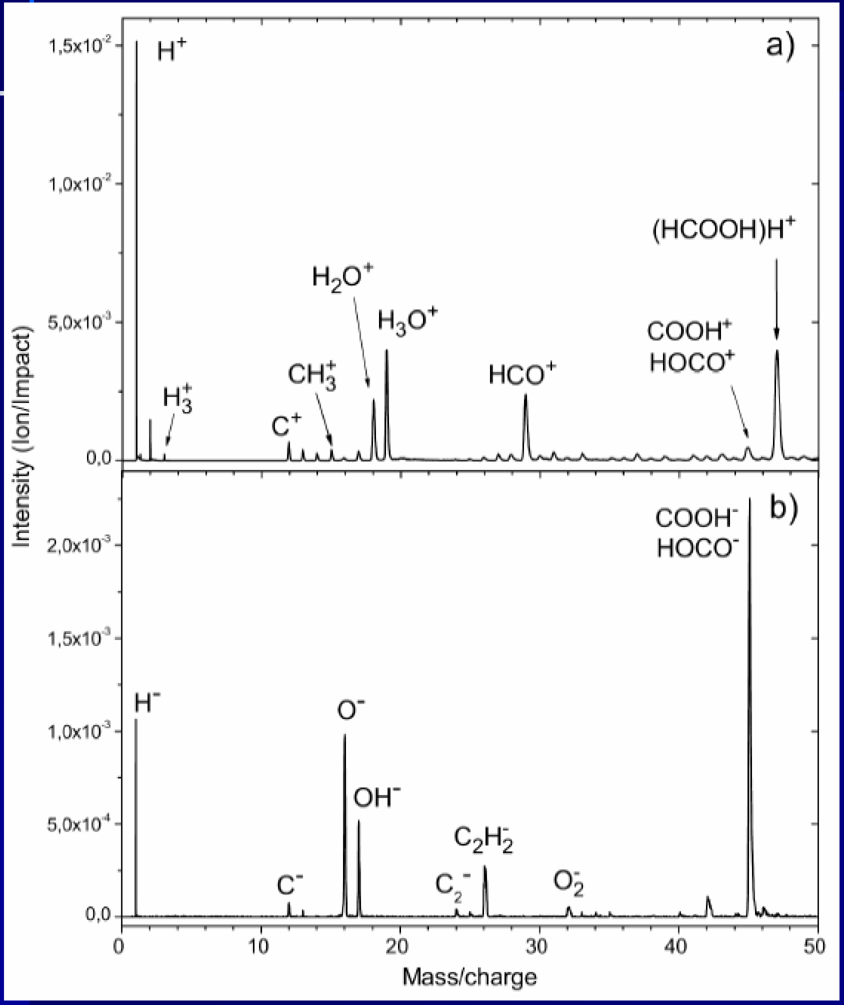
Ex. Gelo de água

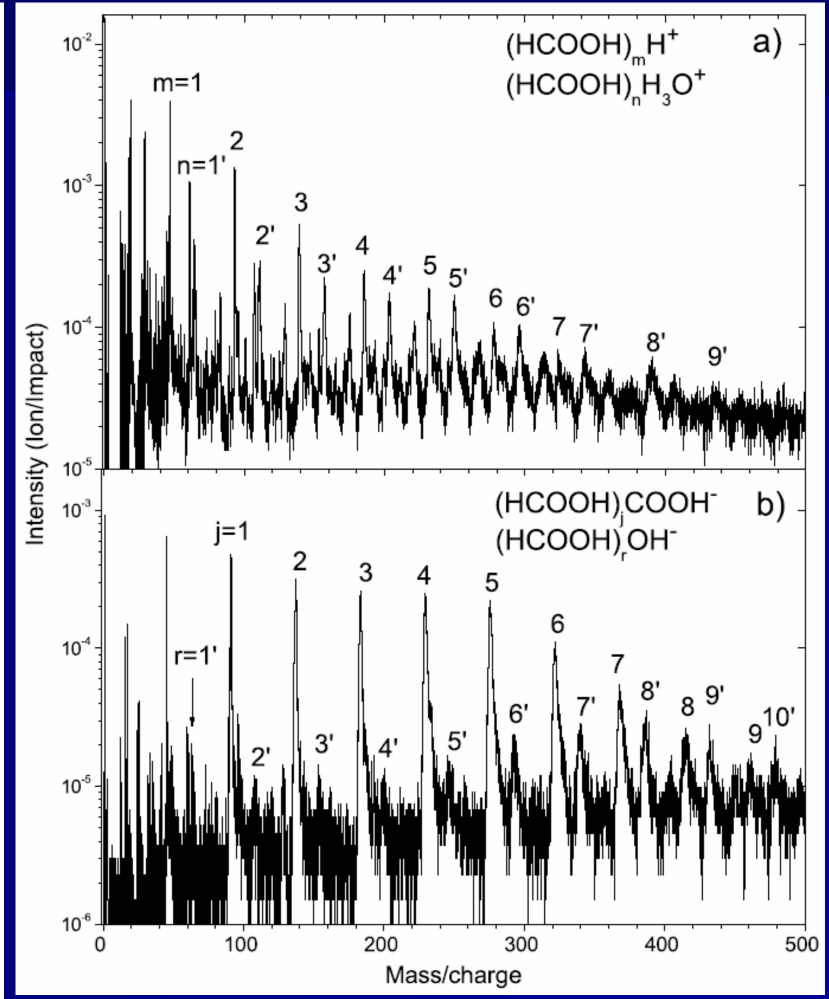




Ex. PET

Ex. Gelo de acido Fórmico (HCOOH) à 55K





Andrade et al. 2008

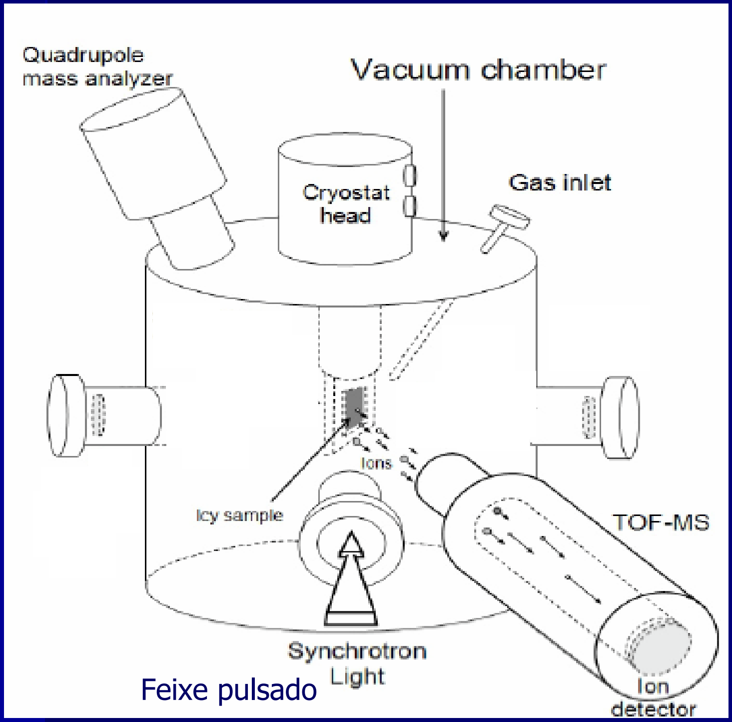
Ex. Investigações da superfície pelo impacto de fótons energéticos

PSID – Photon Stimulation Ion Desorption

- Raios X; Feixe Pulsado (LNLS)

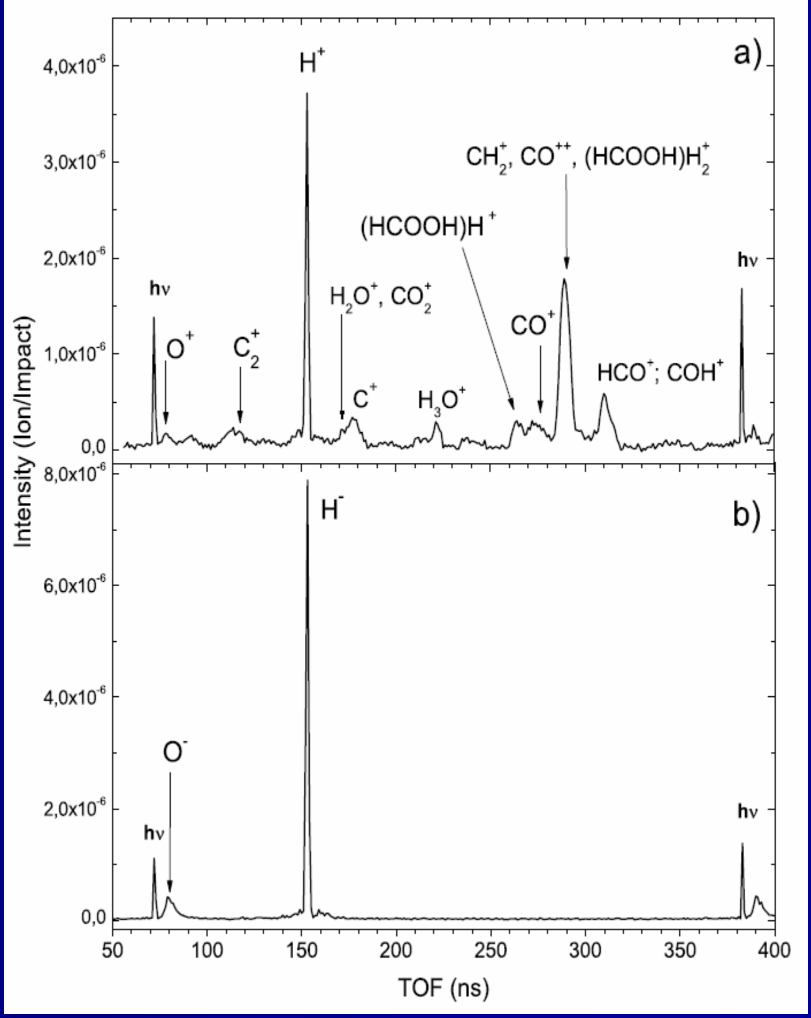
UVH + TOF-MS

- Dissociação molecular.
- Desorção estimulada.
- Íons positivos e negativos.
- NÃO produz Clusters



Feixe pulsado

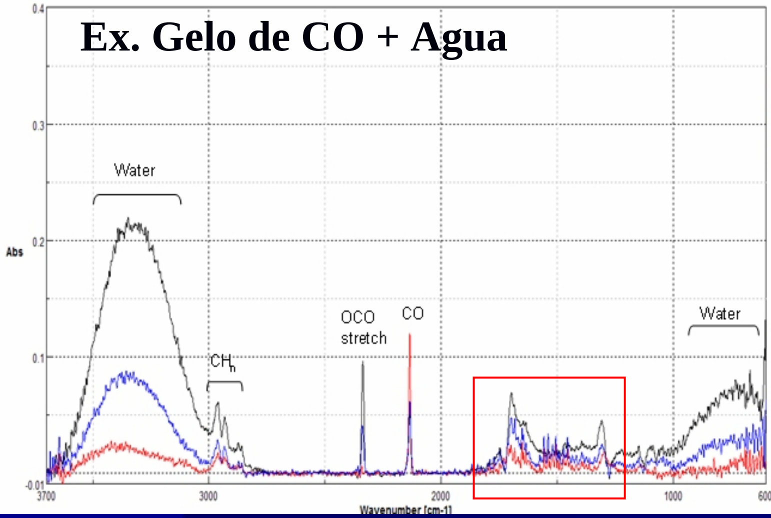
Ex. Gelo de acido Fórmico (HCOOH) à 55K

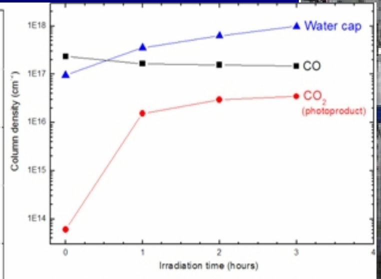


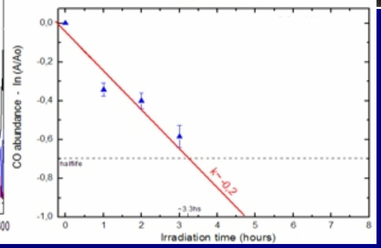
Andrade et al. 2008

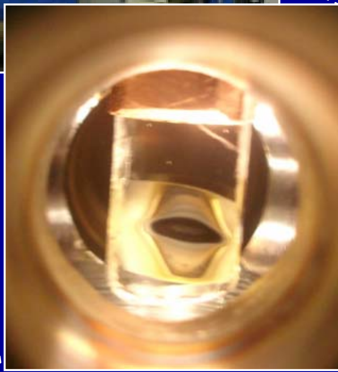
Ex. Fotoquímica de gelos de CO e CO_2 dentro de nuvens moleculares simuladas

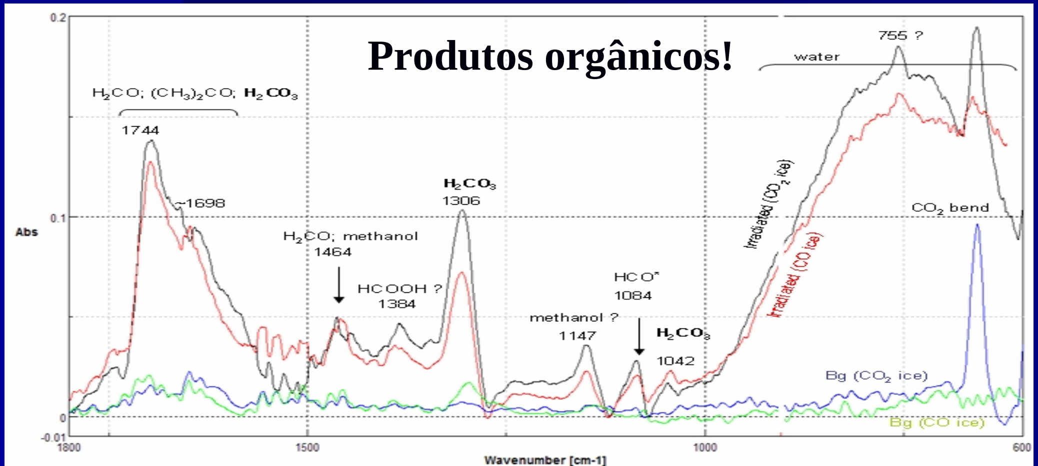
- Cryo-IR_{β} (NaCl; 12 K; 10^{-7} mbar)
- SXS (white beam; 0.5-3 keV)
- k, σ, $\tau_{1/2}$







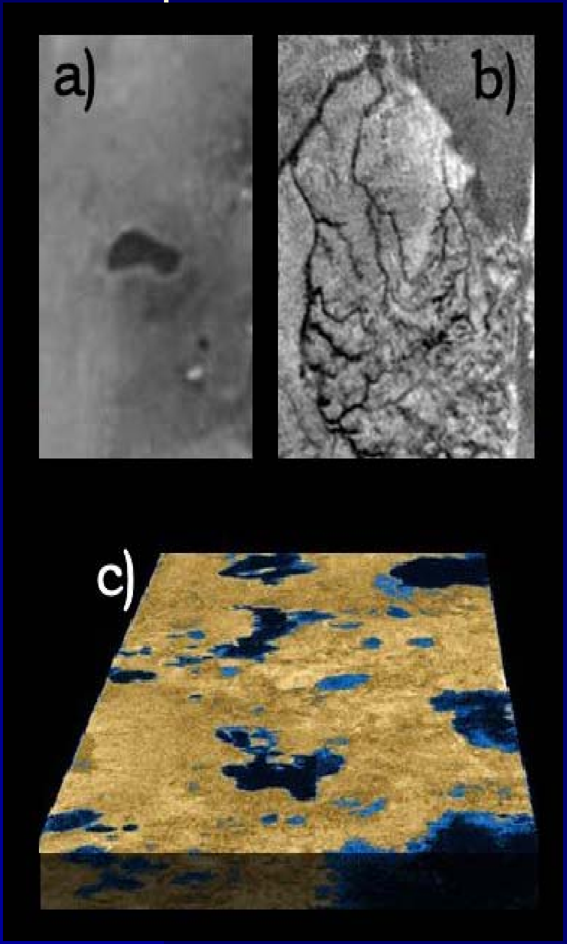


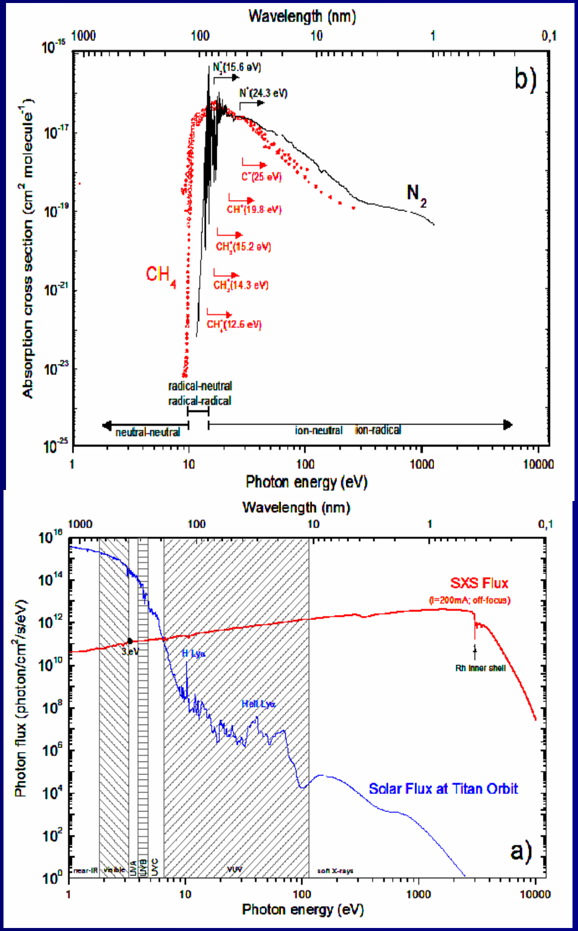


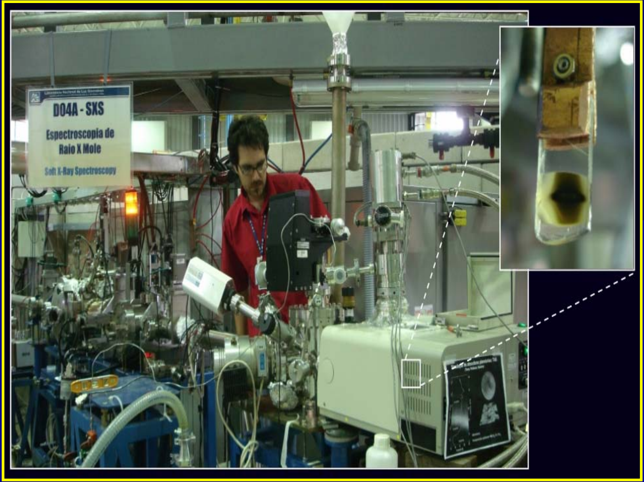
	Photon flux at soft X-ray range	Half life of CO	Half life of CO_2
Experimental	$2x10^4$ erg/cm^2 s	3.4 hs	6.7 hs
Typical XDR	10 erg/cm^2 s	~ 4 x 10^3 hs	~ 7 x 10^3 hs
Dense Cloud (AFLGL 2591)	10^{-2} erg/cm^2 s	~ 5 x 10^3 years	~ 10^4 years

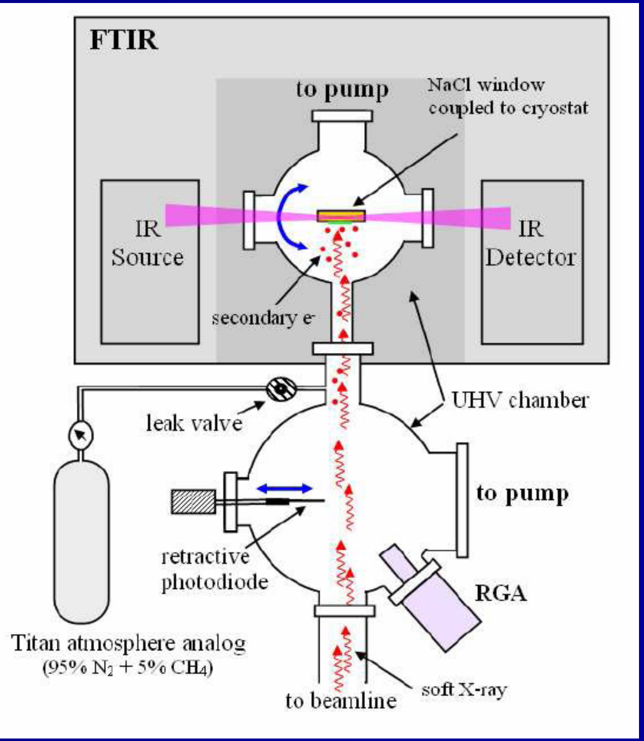
Ex. Fotoprodução de biomoléculas na atmosfera de Titã por raios X

- Cryo-IR$_{\beta}$ (NaCl; 12 K; 10^{-8} mbar)
- N_2 95% + CH_4 5% (+ traços H_2O): 10^{-6} mbar
- SXS (white beam; 0.5-3kev; ~10^{12} fótons/cm s)
- *In-situ* FTIR, *in-situ* Q-MS, GC-TOFMS, RMN: ADENINA

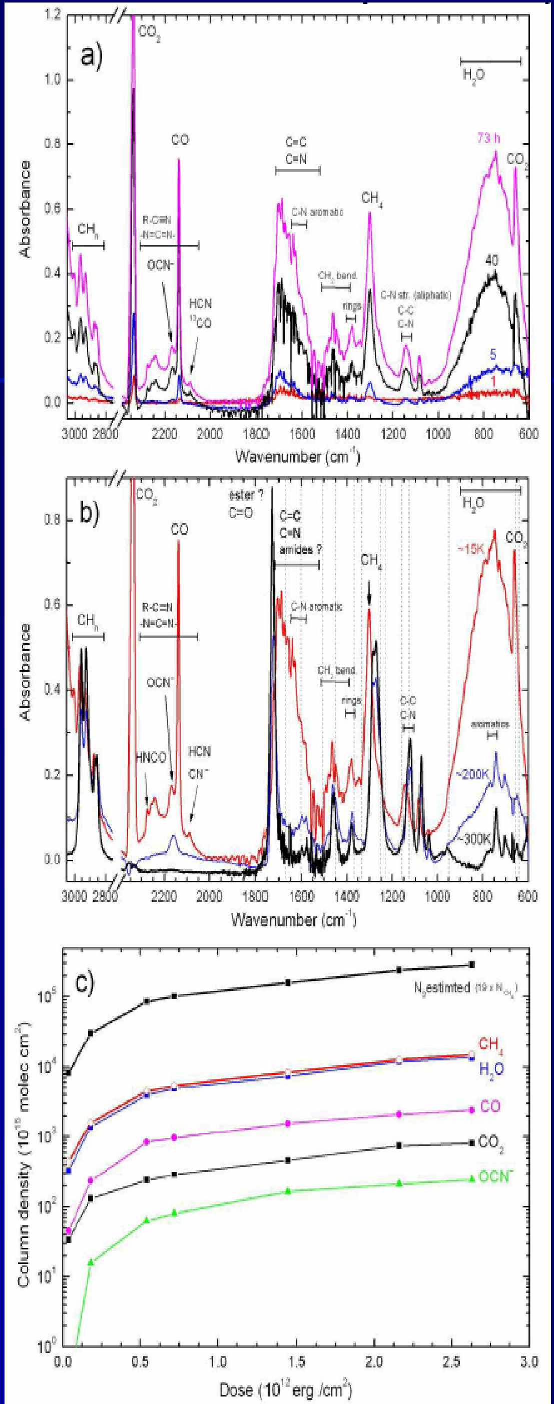


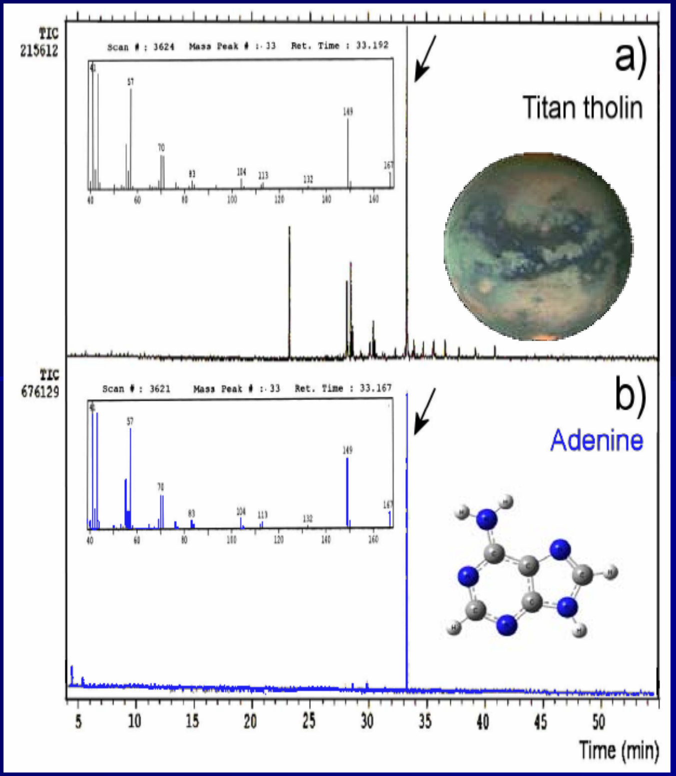


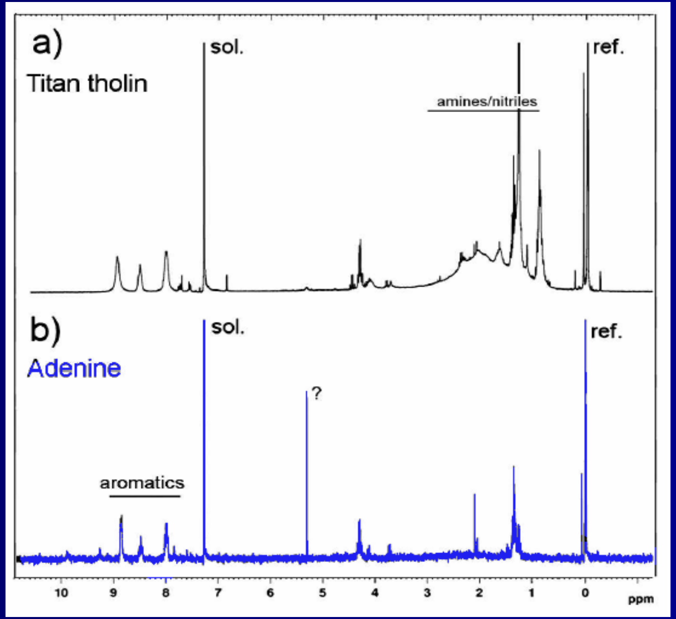




S. Pilling, D. Andrade, L. Ducati, R. Rittner, A. Naves de Brito. JCP, 2009.

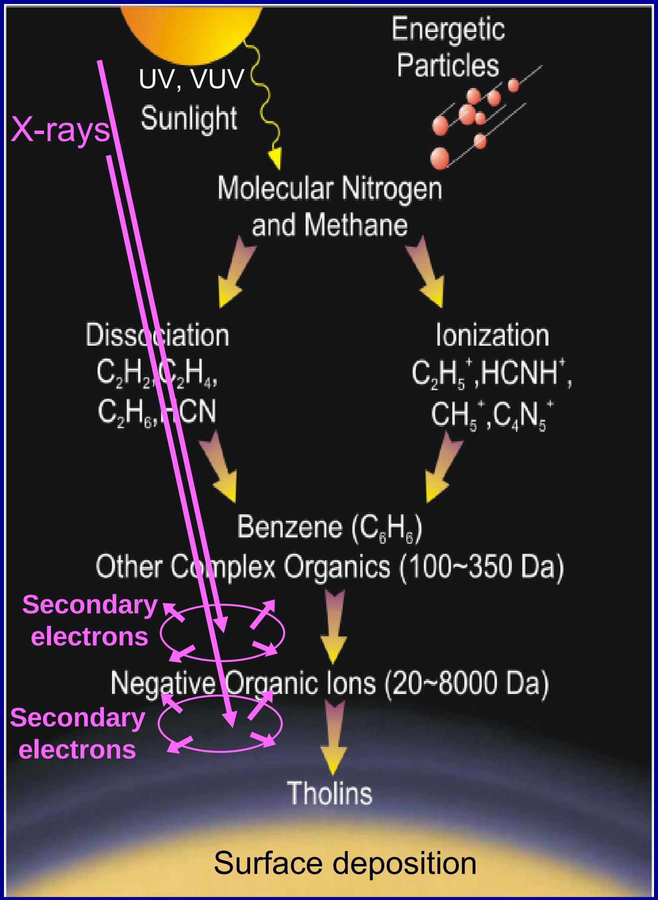






In-situ FTIR

- 73 hs de irradiação com luz sincrotron!
- ~ 7 milhões de anos de raios X solares em Titã
- Adenina: formação promovida por elétrons secundários produzido a partir da dissociação de moléculas por fótons de raios X.



Ex. Amorfização da estrutura cristalina (alta energia e energia intermediária)

Leto 2003 A&A

UV

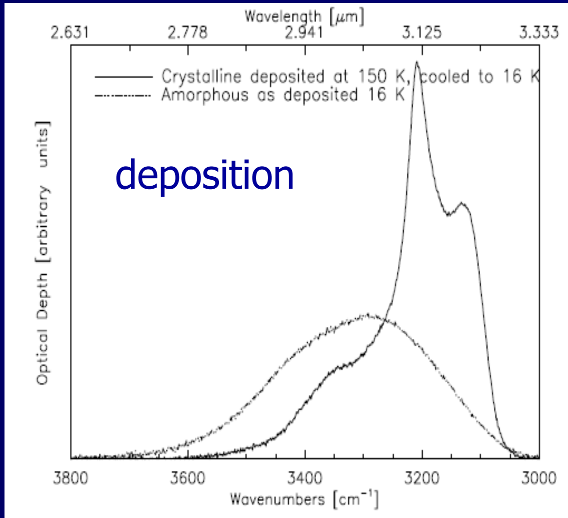


Fig. 1. The 3-micron OH band in the case of crystalline and amorphous water ice.

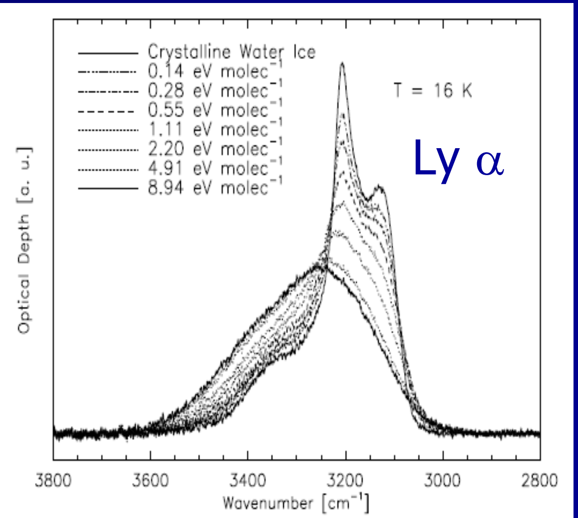
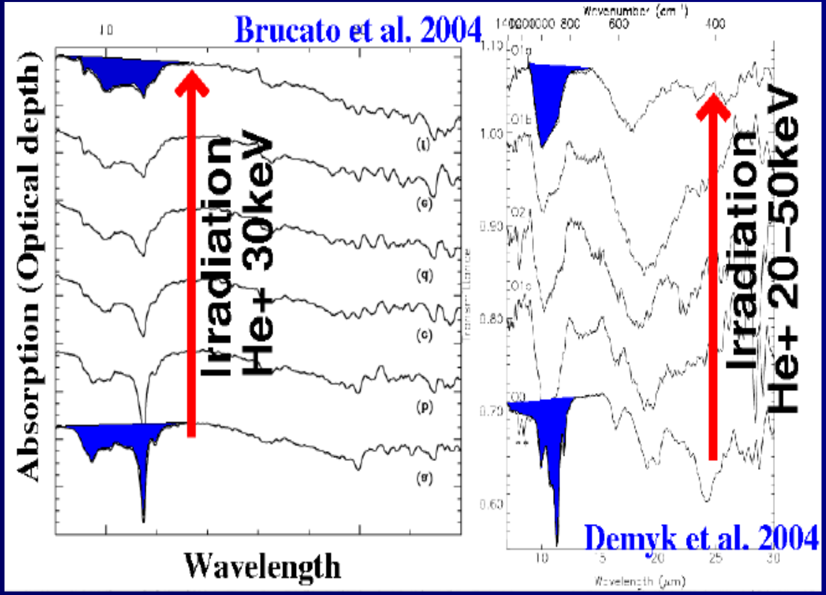
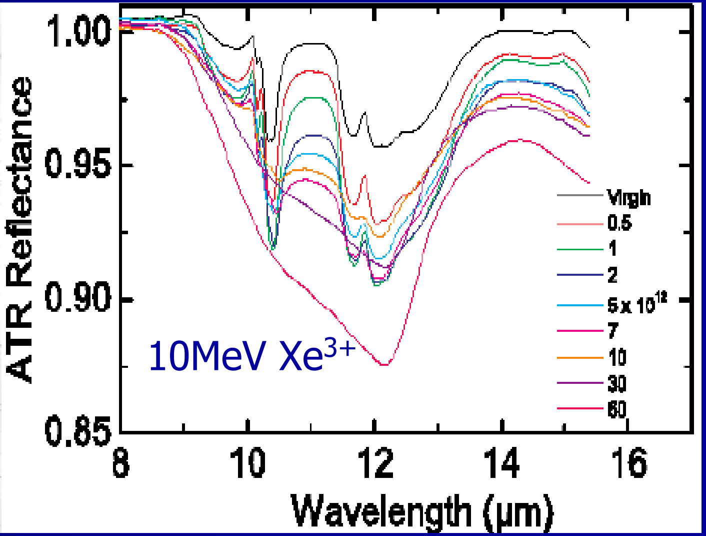


Fig. 3. Evolution of the crystalline water ice band under UV photolysis.

CRs



Bringa etal 2007 A&A



3.2) Energias intermediárias (ex. ~ 1-10 eV) → Ionização, Dissociação, Rearranjos moleculares, Reações químicas.

Fótons (UV) e elétrons: ionização e dissociação molecular, reações químicas (radicais, espécies iônicas), Sputtering (para energias altas) Seções de choque de absorção (valência), dissociação iônica, dissociação neutra, dissociação por captura eletrônica.

Íons lentos: Implantação, aquecimento, reações.

Técnicas investigativas: Low energy ion/eletrom beam, TOF, FTIR, QMS.

Ex. Produção de aminoácidos a partir do processamento de gelos astrofísicos simulados

- Misturas: $H_2O+NH_3+CH_4$ ou $H_2O+CH_3OH+N_2$ .....
- UHV, Fonte de ionização (fótons, e-, íons)
- Monitoramento *in-situ*: FTIR
- Análise *ex-situ*: Cromatografia Liquida (HPLC) e gasosa (GC-MS)

Mon. Not. R. Astron. Soc. 384, 605–610 (2008) doi:10.1111/j.1365-2966.2007.12687.x

Amino acids produced from the ultraviolet/extreme-ultraviolet irradiation of naphthalene in a H_2O+NH_3 ice mixture

Y.-J. Chen,[1] M. Nuevo,[1★] T.-S. Yih,[1] W.-H. Ip,[2] H.-S. Fung,[3] C.-Y. Cheng,[4] H.-R. Tsai[4] and C.-Y. R. Wu[5]

The Astrophysical Journal, 660:911–918, 2007 May 1
© 2007. The American Astronomical Society. All rights reserved. Printed in U.S.A.

MECHANISMS OF AMINO ACID FORMATION IN INTERSTELLAR ICE ANALOGS

Jamie E. Elsila,[1,2] Jason P. Dworkin,[3] Max P. Bernstein,[1] Mildred P. Martin,[3,4] and Scott A. Sandford[1]

ELSEVIER
Available online at www.sciencedirect.com
SCIENCE DIRECT®
Advances in Space Research 36 (2005) 190–194
Advances in Space Research (a COSPAR publication)
www.elsevier.com/locate/asr

Abiogenic photochemical synthesis on surface of meteorites and other small space bodies

Michael B. Simakov *, Eugenia A. Kuzicheva

A&A 457, 741–751 (2006)
DOI: 10.1051/0004-6361:20042018
© ESO 2006
Astronomy & Astrophysics

The effects of circularly polarized light on amino acid enantiomers produced by the UV irradiation of interstellar ice analogs

M. Nuevo[1,2], U. J. Meierhenrich[3,4], G. M. Muñoz Caro[1,5], E. Dartois[1], L. d'Hendecourt[1], D. Deboffle[1], G. Auger[6], D. Blanot[6], J.-H. Bredehöft[3], and L. Nahon[7,8,9]

NATURE | VOL 416 | 28 MARCH 2002
letters to nature

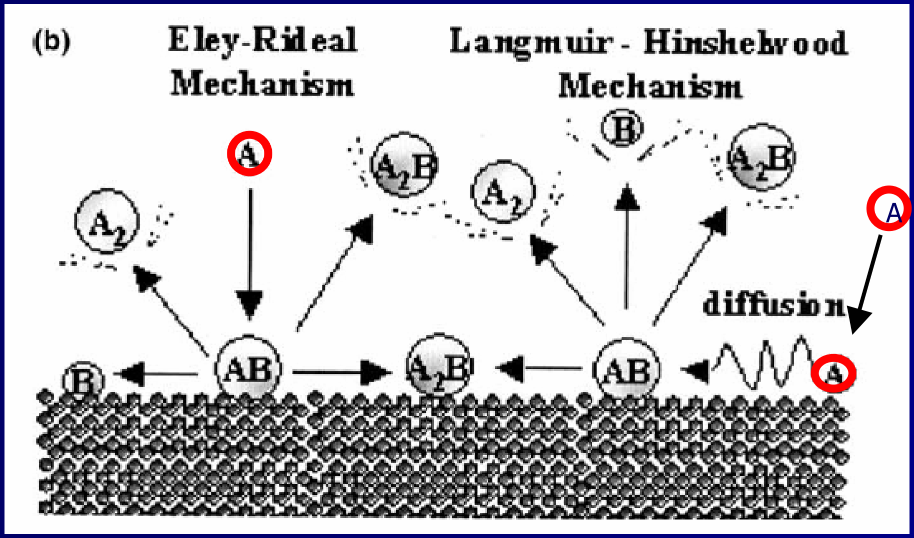
Racemic amino acids from the ultraviolet photolysis of interstellar ice analogues

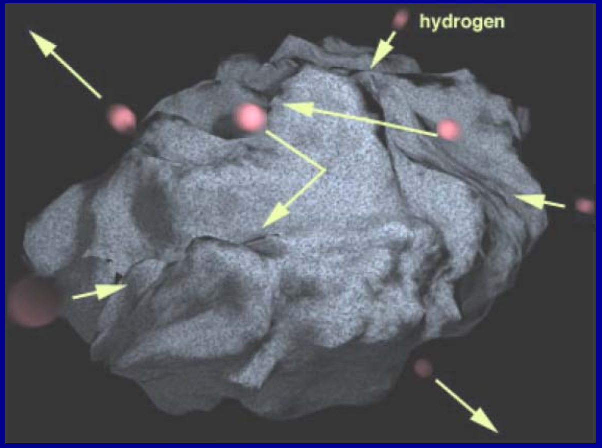
Max P. Bernstein*†, Jason P. Dworkin*†, Scott A. Sandford†, George W. Cooper† & Louis J. Allamandola†

3.3) Energias baixas (ex. ~ 0.1-1 eV) → Reações seguidas por evaporação

- Sticking → difusion → reaction → evaporation
  - Eley-Rideal/hot –atom reaction
  - Langmuir-Hnshelwood reaction
  - Experimentos de Formacão do H_2,
  - Formação de H_2O a partir de O_2 +H_2, etc.
- Técnicas investigativas: TPD, FTIR, QMS.
- Dissociation by electron association

Exemplos.





Ex. Formação do H_2

(catalise heterogênea)

3.4) Energias muito baixas (ex < 0,01 eV) → Aquecimento - evaporação

- Fótons de IR, Visível, colisões entre grãos.
- Técnicas investigativas: TPD, FTIR, QMS.

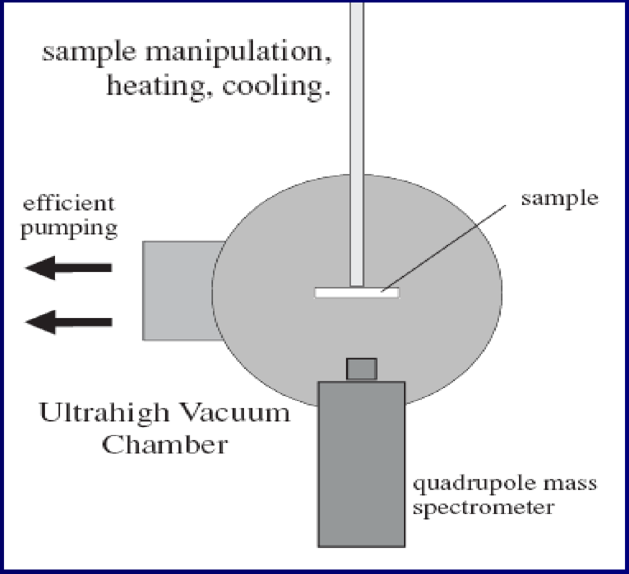
Ex. Experimentos para o estudo da evaporação de gases em gelos astrofísicos (TPD)

TPD – Thermal Programed Desorption

UHV + Aquecimento controlado + QMS

UHV (10^{-9} mbar → ~ 1 monolayer per hour ~ 10^{12} mols/cm^2 s); Bombeamento eficiente para prevenir acumulação de gás na câmara; Rampa de aquecimento constante (ex. β=1K/s); estudar o aprisionamento de gases; "Anelamento" de gelos astrofísicos.

Esquema experimental típico



Polanyi-Wigner equation

Taxa de desorção, R(T)

Fator pré-exponencial

$$R(T) = -\frac{dN_s}{dT} = \frac{A}{\beta} N_s^m \exp^{-E_d / k_B T}$$

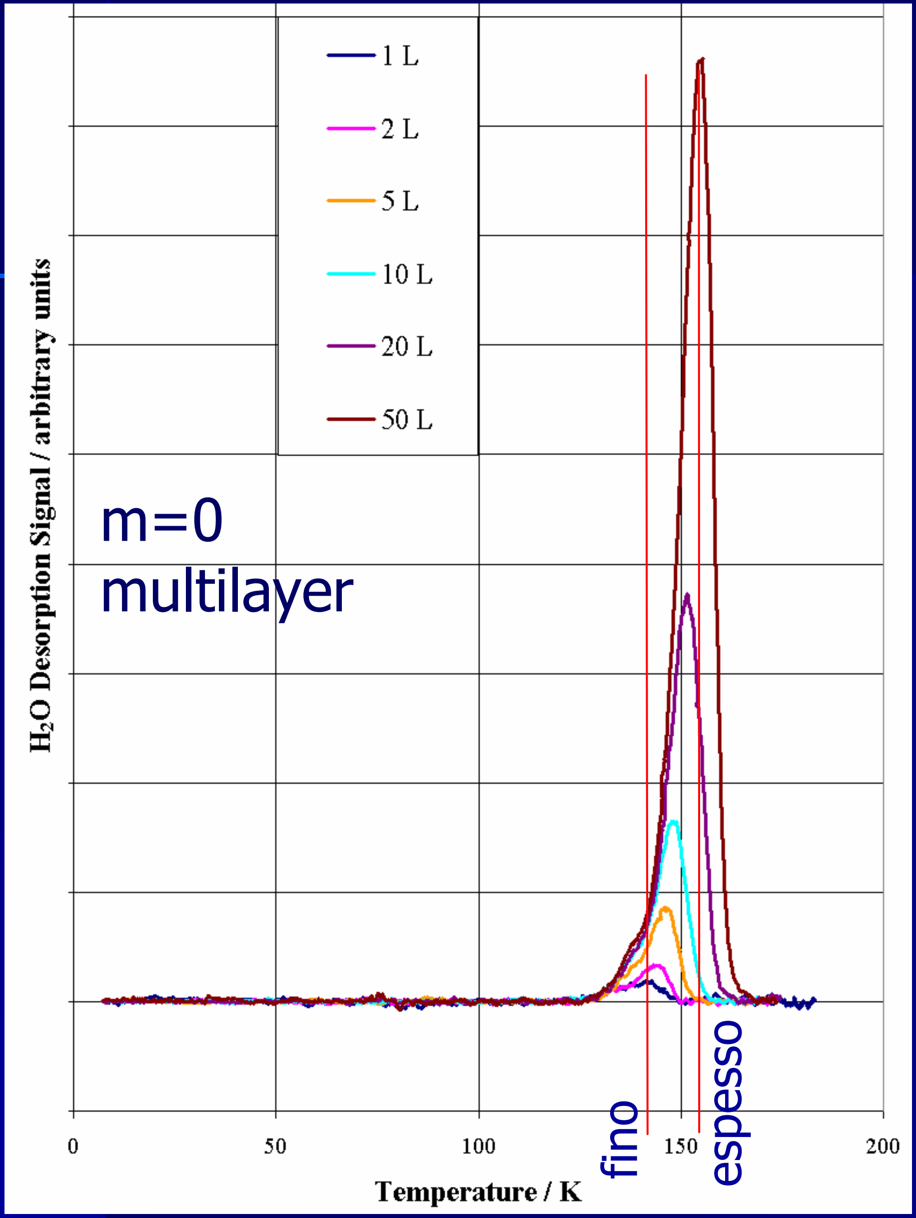
Rampa de aquecimento

m=0 → multilayer ices (bulk of solid ices)

m=1 → monolayer (molecule-surface region)

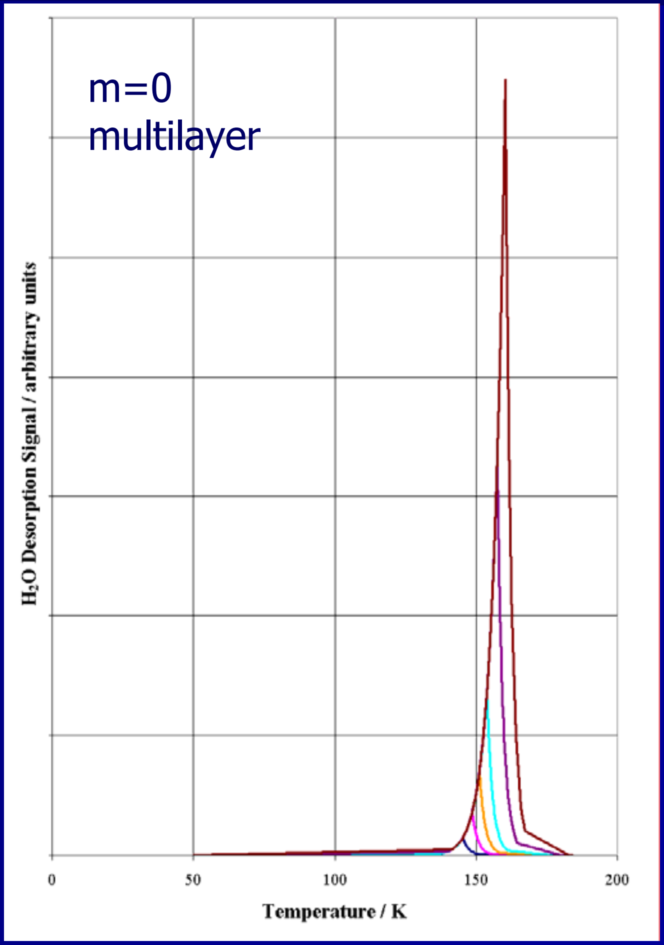
$E_d \approx \Delta_{sub} H$

TPD da Agua Pura (sobre Au)



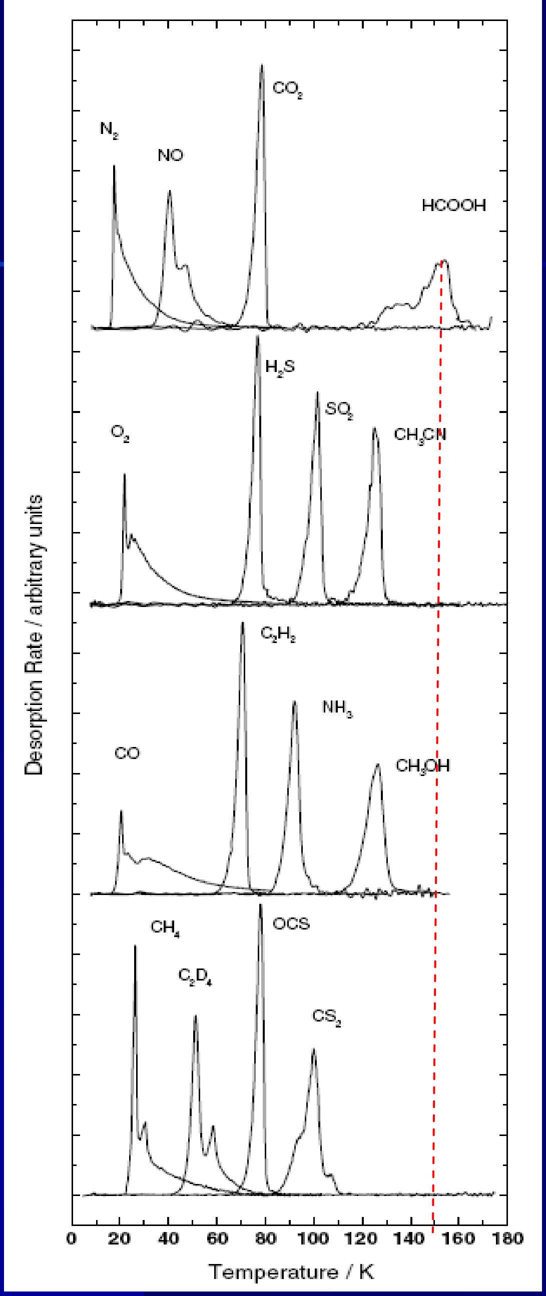
$$-\frac{dn_{H_2O(bulk)}}{dt} = 10^{30\pm2} e^{-48,000\pm500/RT} \ \text{molec cm}^{-2}\ \text{s}^{-1}$$

Ajuste

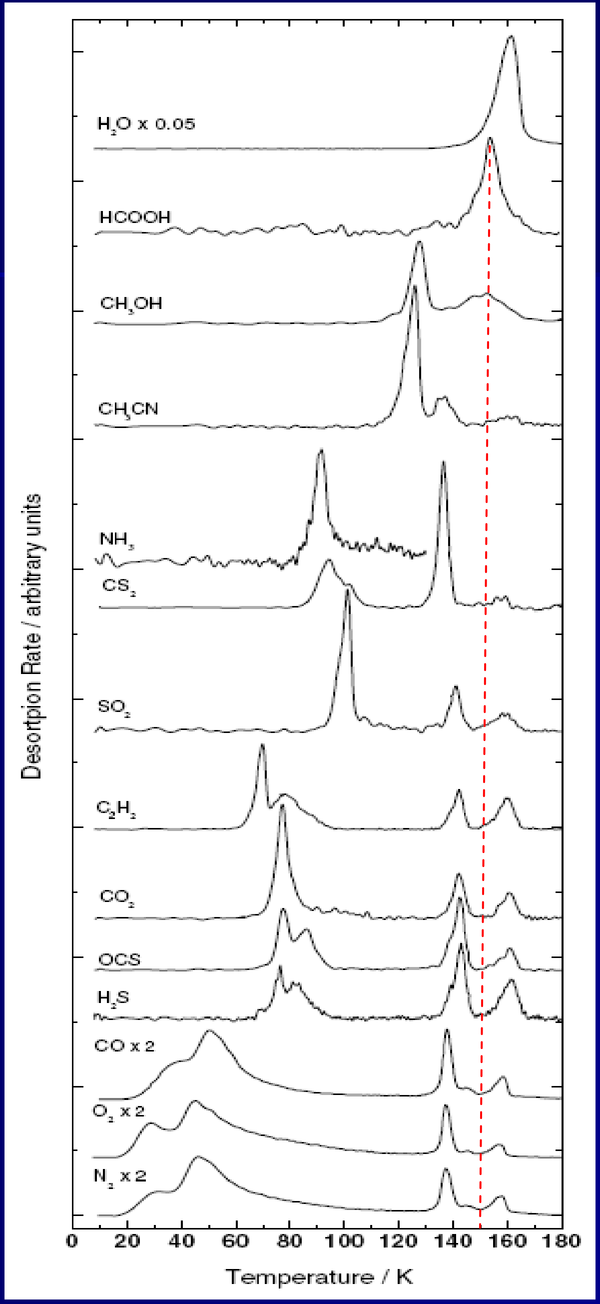


Fraser *et al* 2001, *MRNAS*.

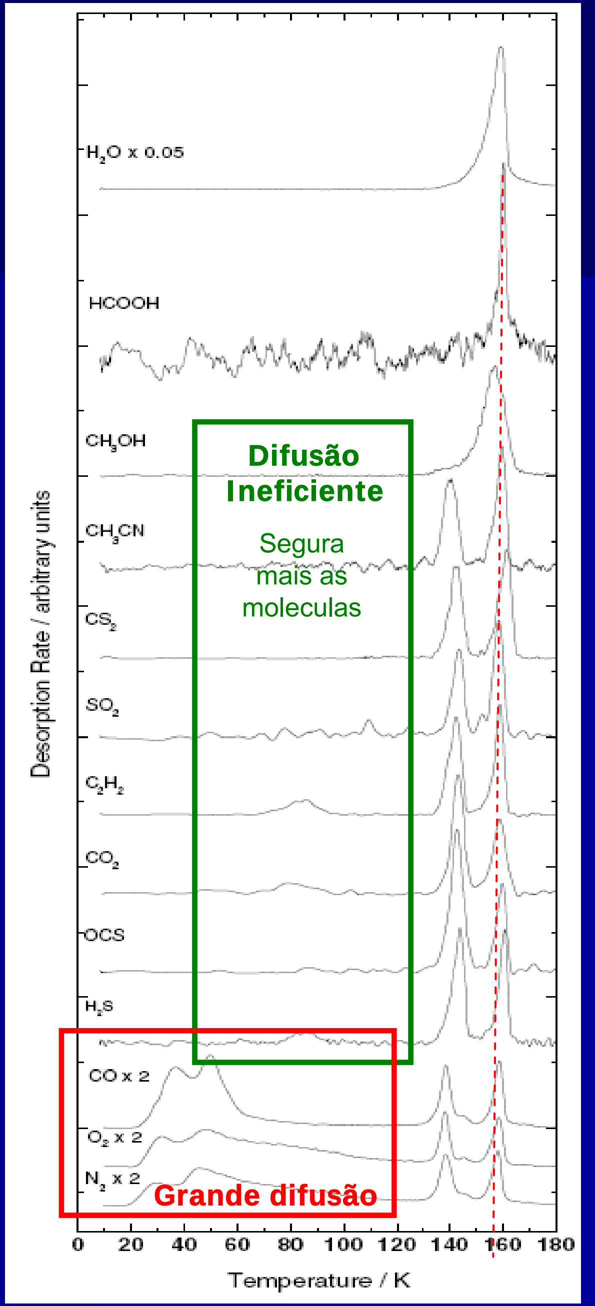
Amostras puras (sobre Au)



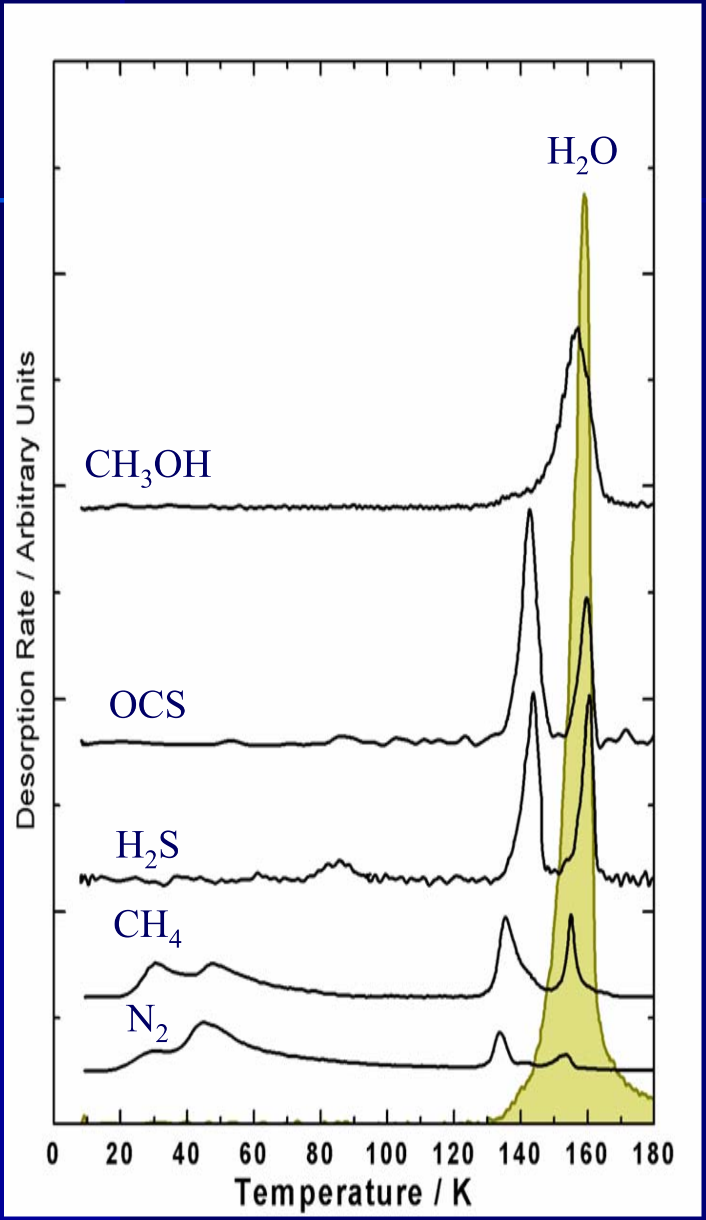
Amostras puras (sobre Gelo Agua)



Amostras misturadas com Água



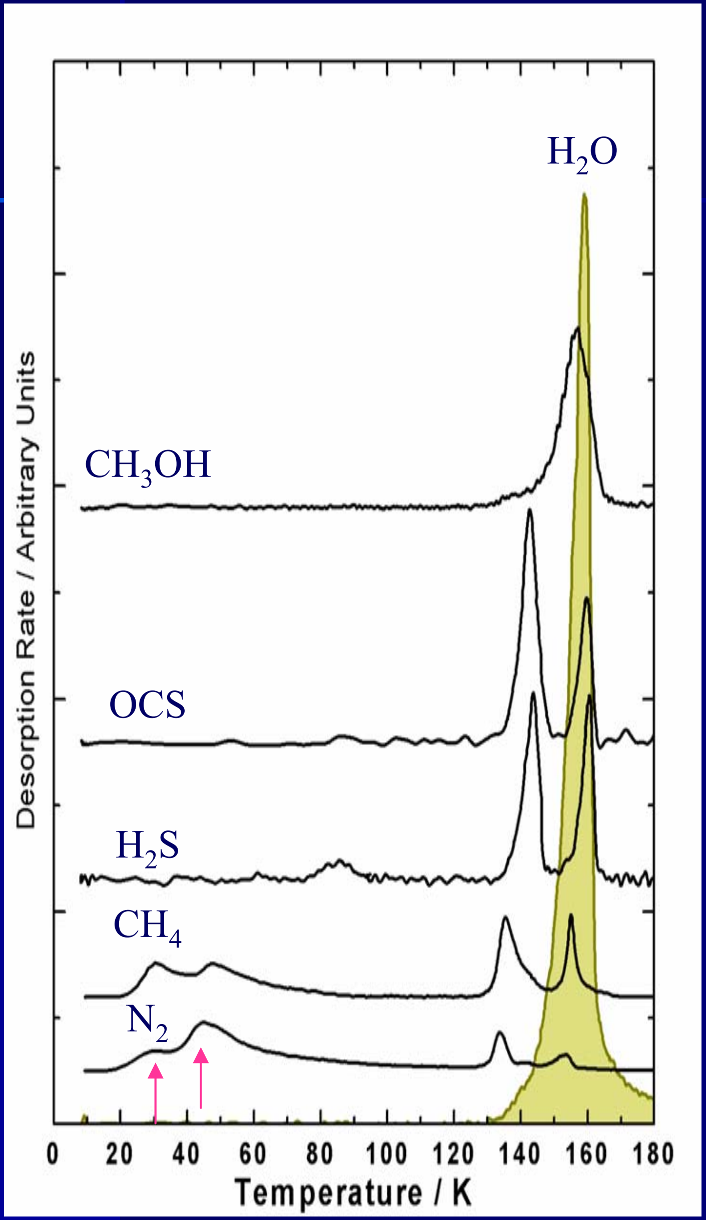
TPD de misturas contendo água (Caso real dos gelos astrofísicos)



TIPO 1 – Moléculas que fazem pontes de hidrogênio (ex. NH_3, CH_3OH, ...). Desorvem quando o gelo de água desorve.

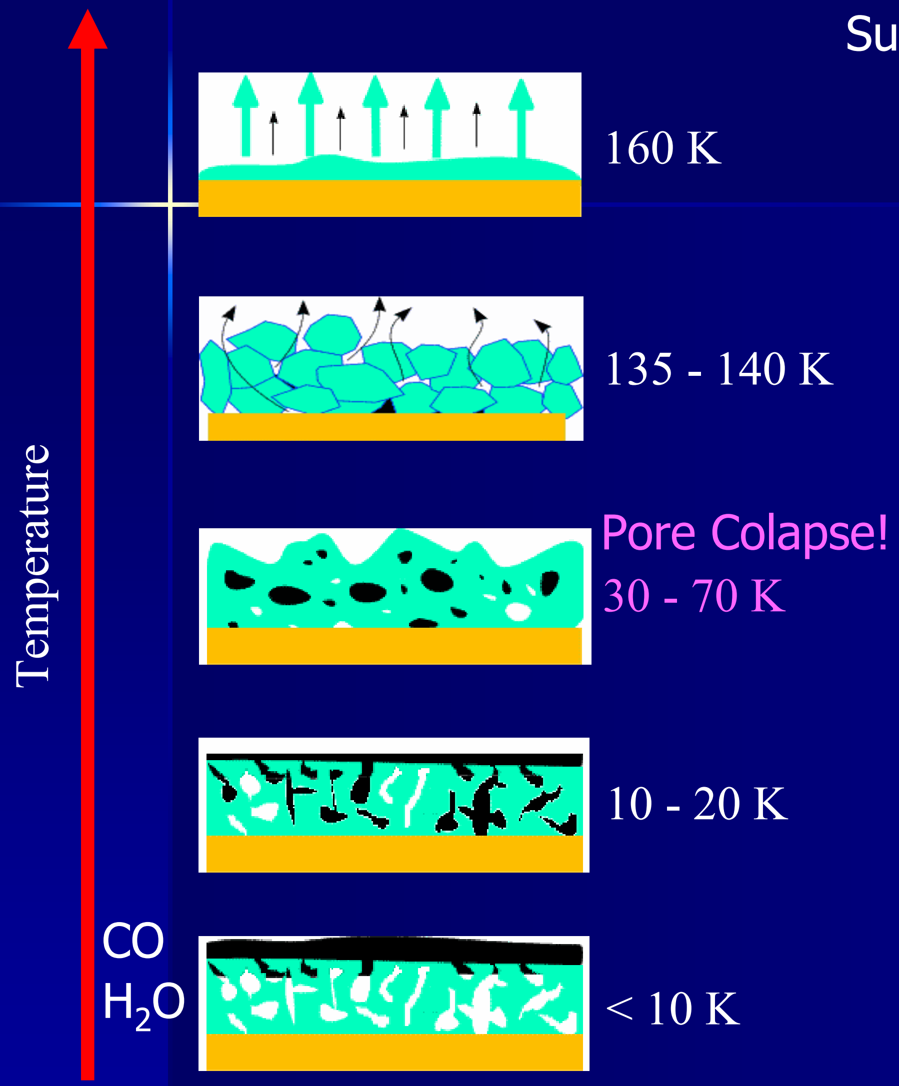
TIPO 2 - Espécies que tem $T_{sub}>T_{pore\text{-}colapse}$ (Ex. H_2S, CH3CN, ...) Apresentam uma habilidade limitada de difusão não sendo aprisionadas (trap) quando sobrepostas pelo gelo de água mas possuem um grande potencial de aprizionamento em situações de misturas gasosas.

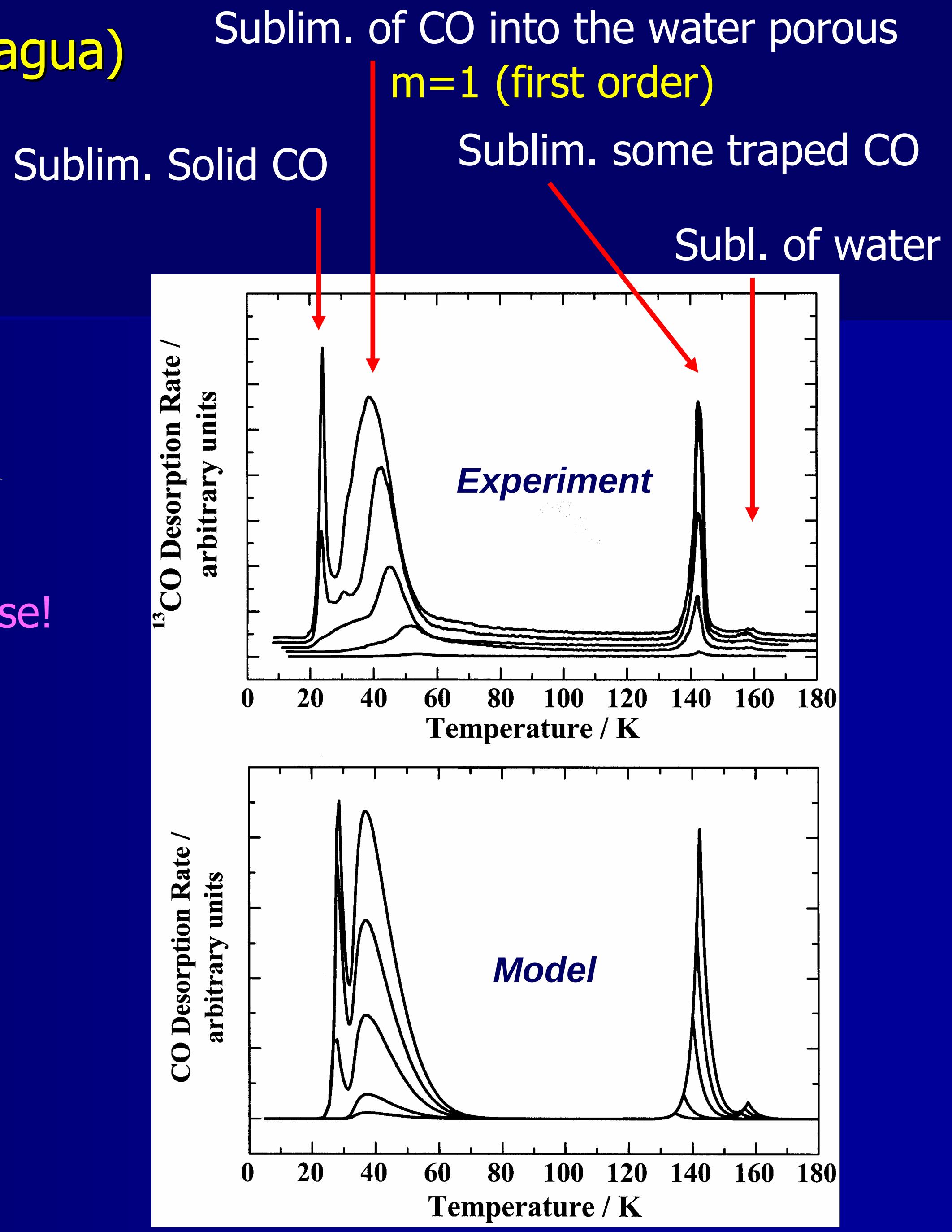
TPD de misturas contendo água (Caso real dos gelos astrofísicos)



TIPO 3 – Espécies que tem $T_{sub}<T_{pore\text{-}collapse}$ (ex. N_2, O_2, CH_4, CO…). Difundem rapidamente e se comportam como CO exibindo quatro características no espectro TPD quando em misturas. Espécies muito voláteis! Os dois picos da esquerda são da desorção das multi-camadas e da monocamada.

MIXTURA (CO sobre gelo de agua)

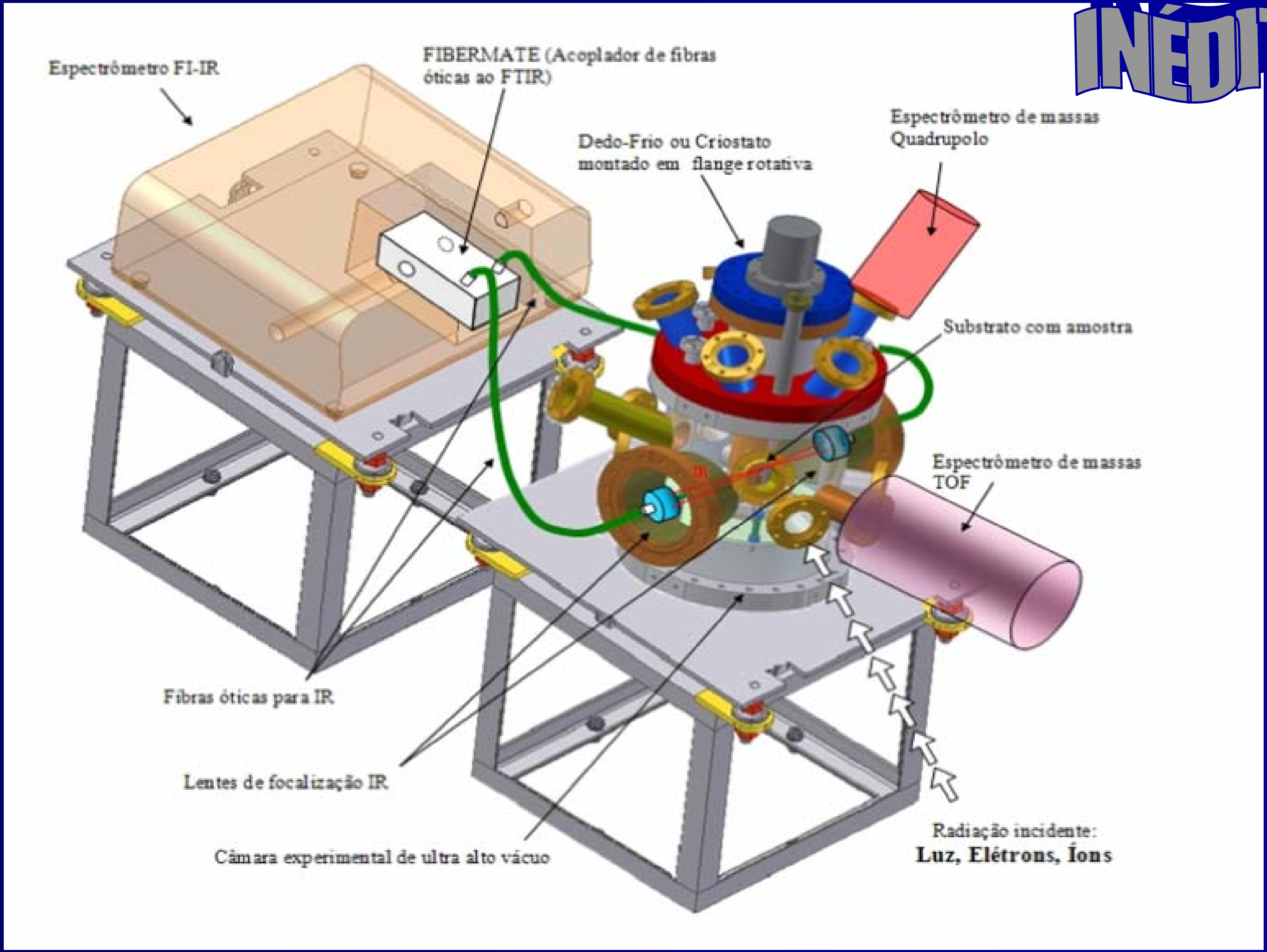




M. P. Collings, *Ap. J.*, 2003, **583**, 1058
M. P. Collings, *MRNAS*, 2004, **354**, 1133

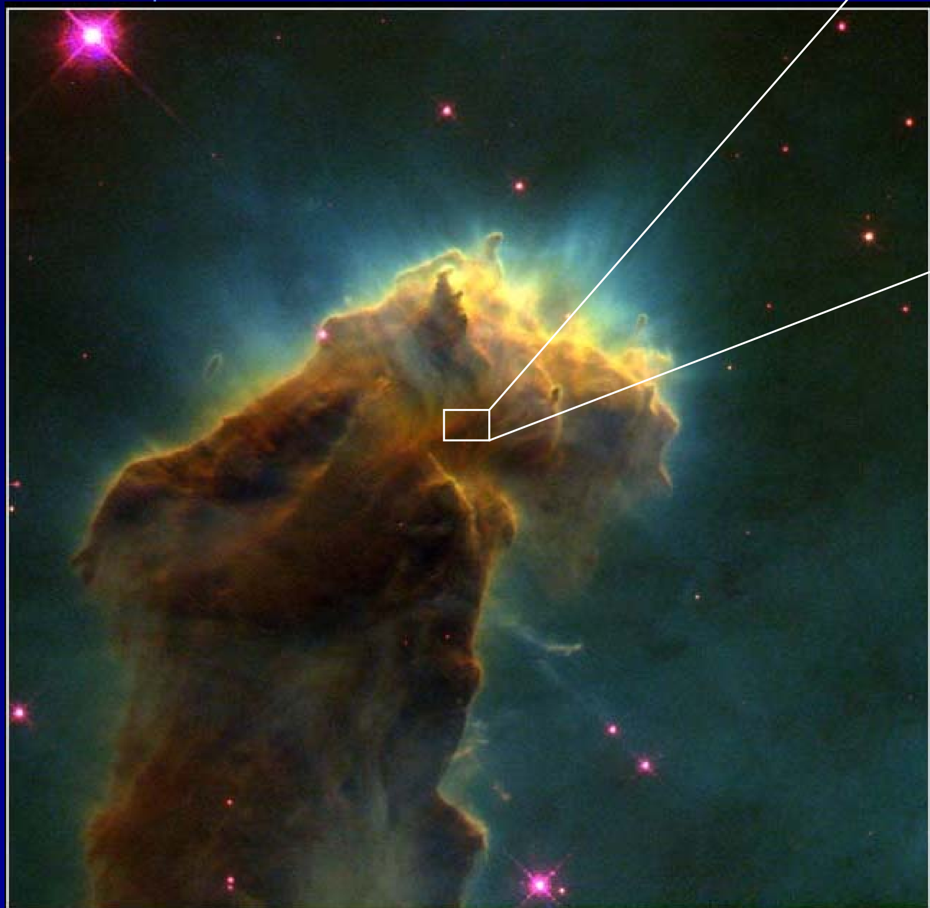
FUTURO: Investigações da superfície e bulk ao mesmo tempo pelo impacto de fótons ou íons energéticos

INÉDITO!

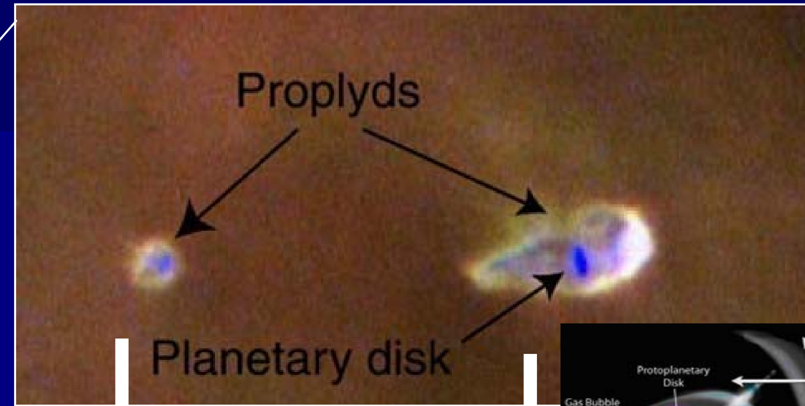


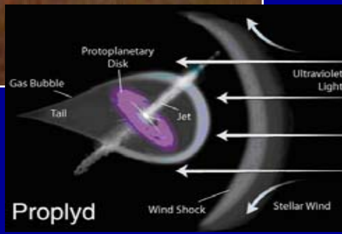
Obrigado pela atenção.

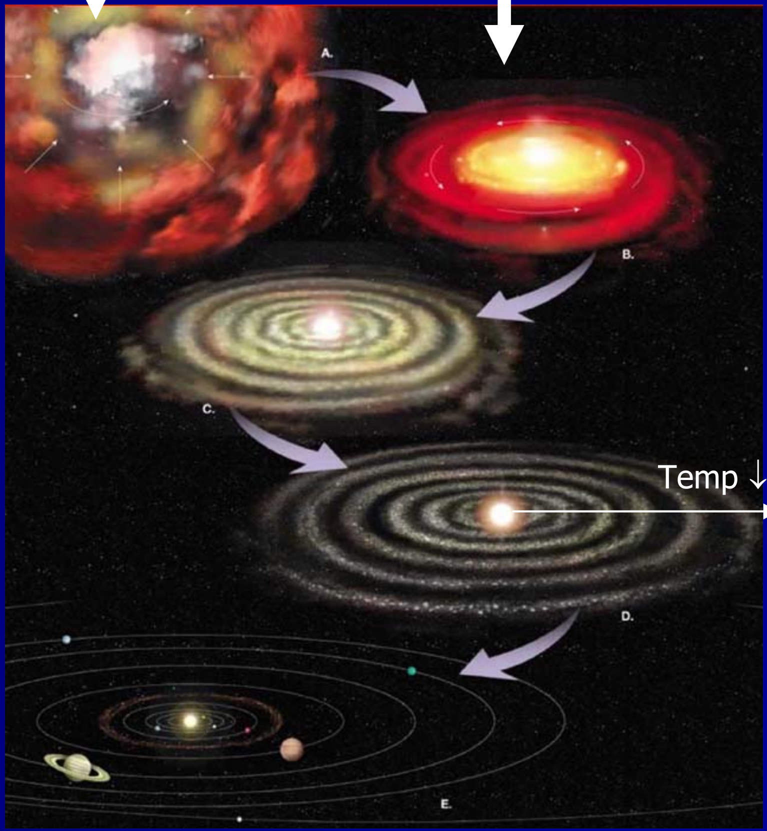
Gelos interestelares vs Gelos interplanetários



Star-Birth Clouds · M16 HST · WFPC2
PRC95-44b · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA







Gelos interplanetários são os resquícios da nuvem protosolar