Universidade Federal Fluminense
Campus Volta Redonda

Semana acadêmica
18-19/out/2016

Minicurso:
Astroquímica e Astrobiologia

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UNIVERSIDADE DO VALE DO PARAÍBA
São José dos Campos - SP

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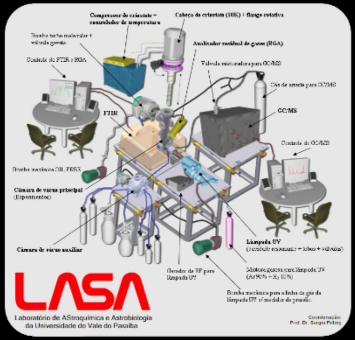
- -39 cursos de Graduação
- -3 Doutorados
(Física e Astronomia – nota 4 CAPES)
- -6 Mestrados
- -23 Especialização Lato-Sensu

Instituto de pesquisa (IP&D)

LASA

Laboratório de AStroquímica e Astrobiologia
da Universidade do Vale do Paraíba



- Produção de amostras de interesse astrobiológico e ambientes astrofísicos simulados de baixa temperatura (gelos astrofísicos)

- Degradação de espécies químicas em ambientes gelos astrofísicos simulados.

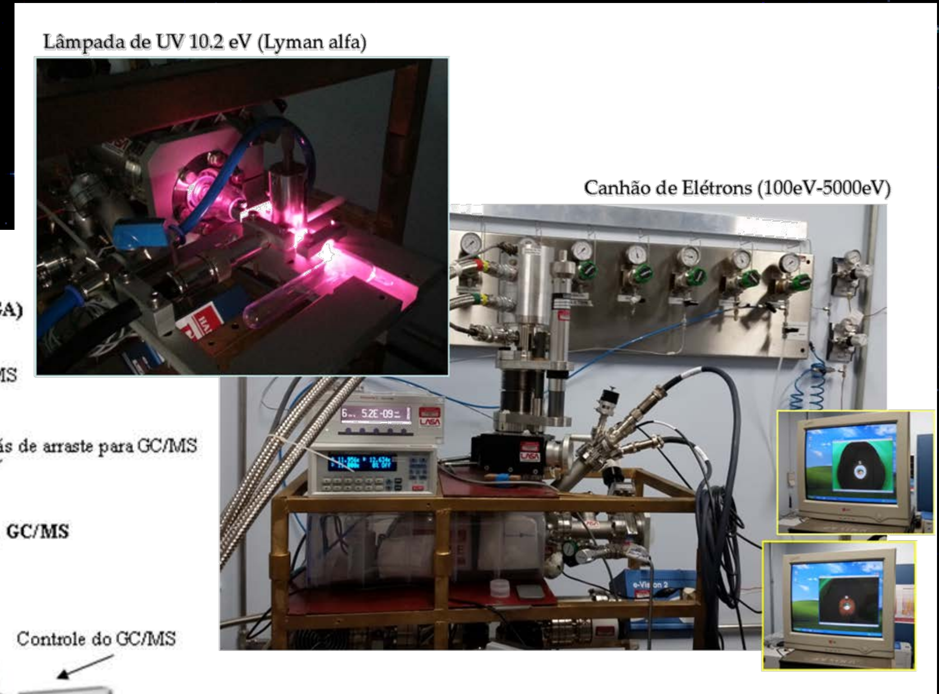
- Determinação de seções de choque e tempos de meia vida em ambientes astrofísicos via via FTIR /QMS.

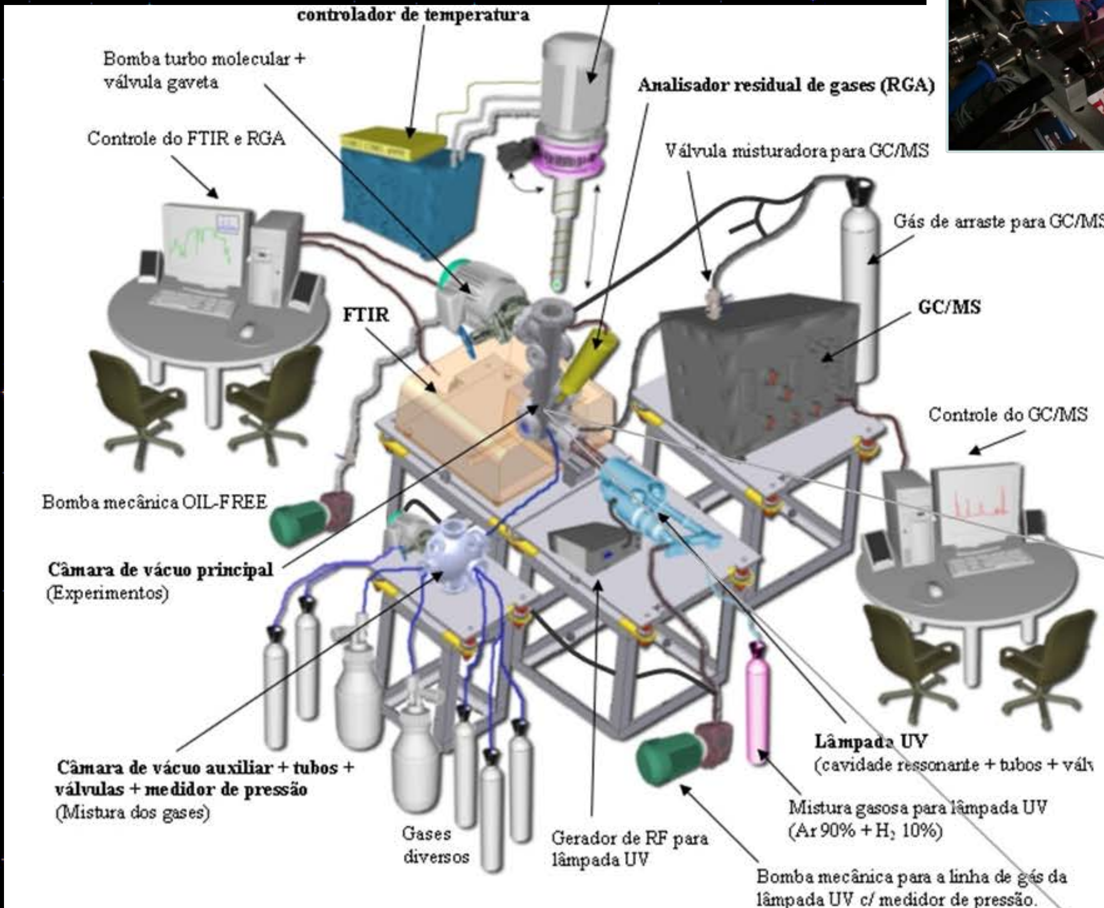
- Comparação de espectros IR de laboratório com observações astronômicas (ex. ISO, GEMINI,Spitzer).

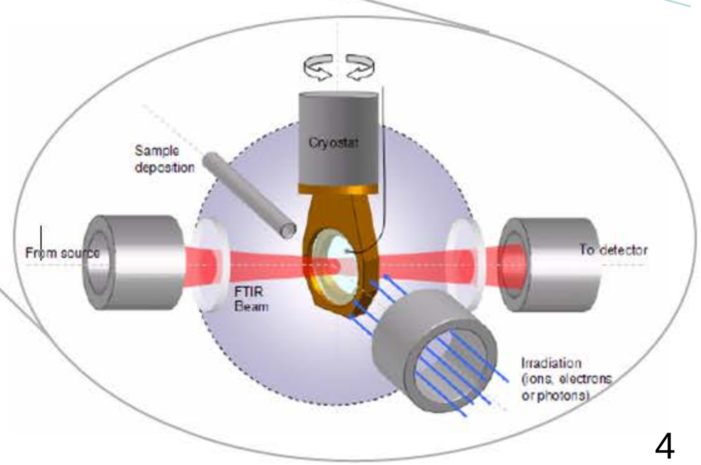
- Identificação de espécies novas em observações em Radio (ROI, ALMA) previstas de serem produzidas nas simulações experimentais de ambientes astrofísicos.

- Simulações realistas do efeito do sol/estrelas - SpaceWeathering (UV+elétrons simultaneamente) em amostras frias/sólidas no meio interplanetário (superfície de luas, cometas, asteroides, equipamentos aeroespaciais).

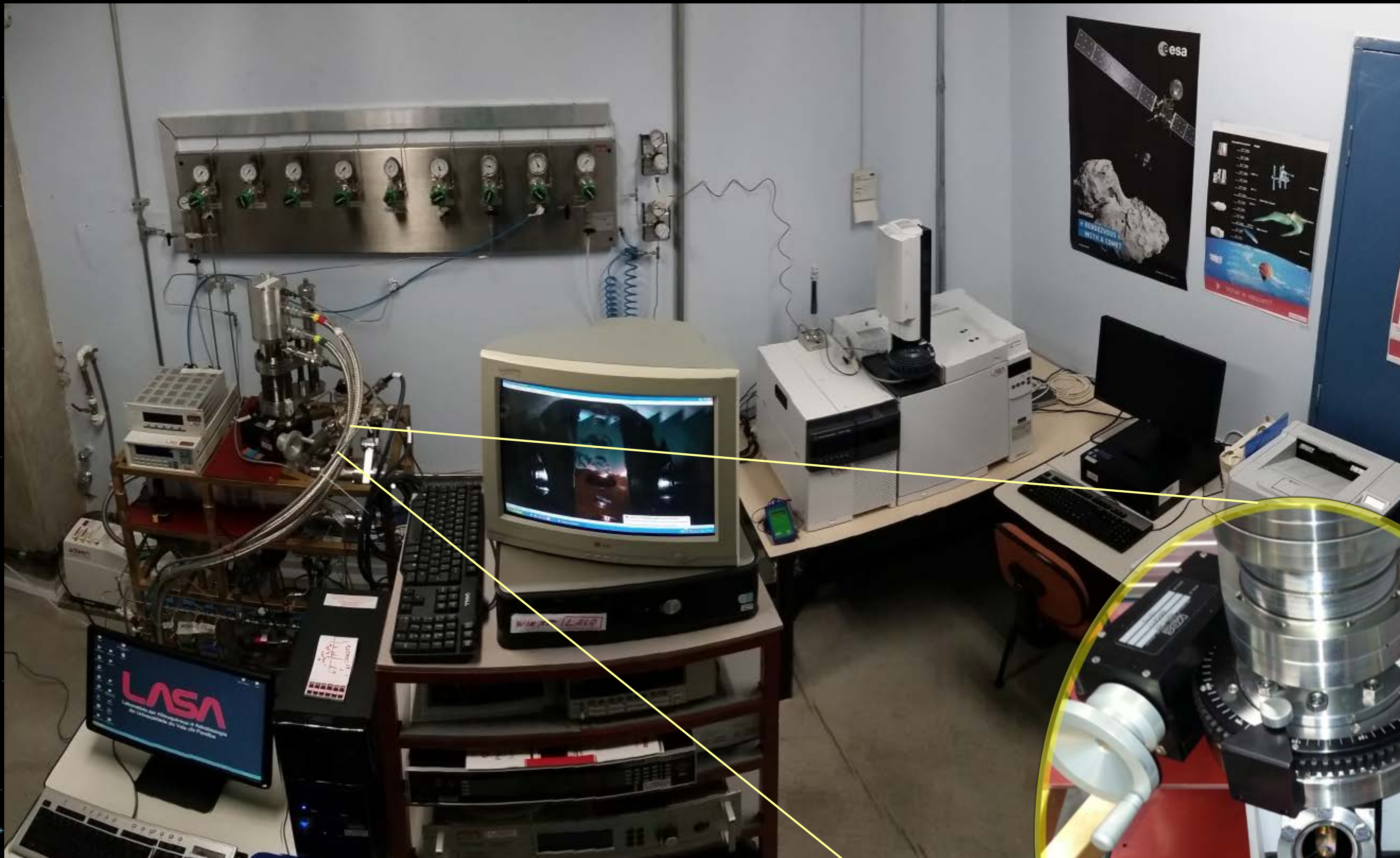
~1milhão reais
(FAPESP, CNPQ, FINEP, FVE/UNIVAP)

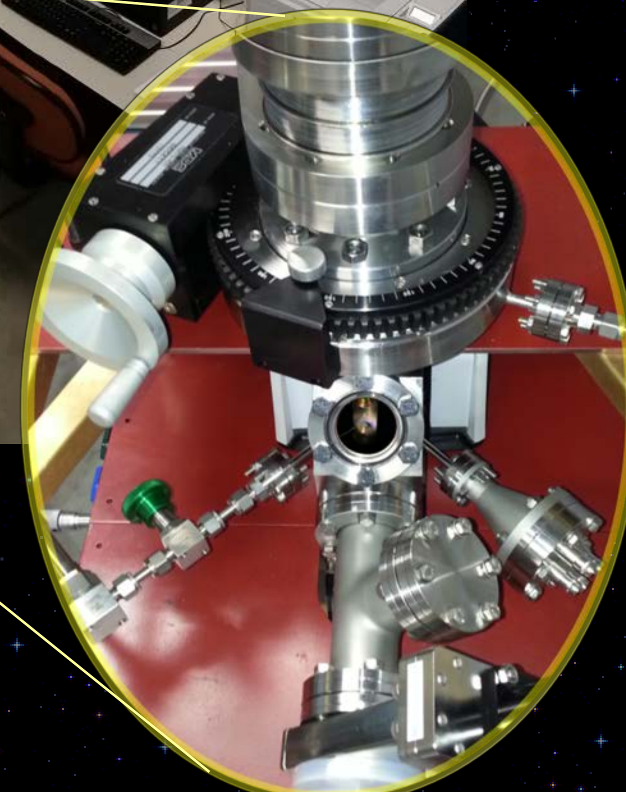






LASA
Laboratório de Astroquímica e Astrobiologia





LAB ~90m^2

GAA – Grupo de Astroquímica e Astrobiologia da Univap (out/2016)

1 posdoc
3 doutorandos
3 mestrandos
3 IC/TCC

Aula 1:

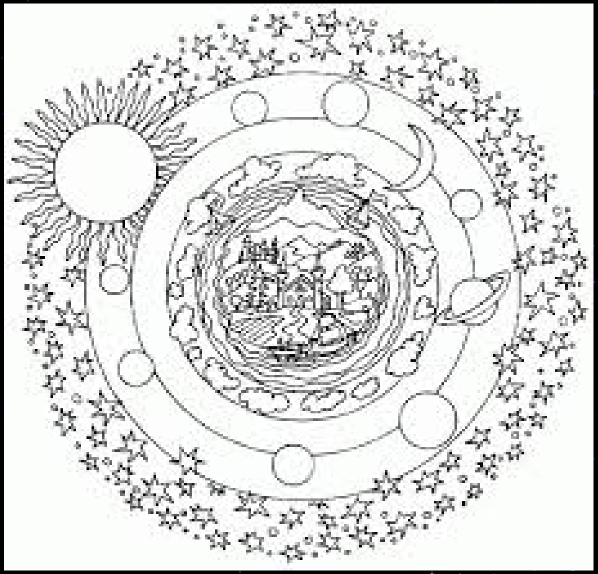
Introdução a Astroquímica e a evolução química do Universo

Nucleossínteses, evolução estelar, meio interestelar, Formação de moléculas nos Cósmos, Observações (IR e Rádio) e experimentos.

Aula 2:

Introdução a Astrobiologia e vida no contexto cósmico

Exoplanetas, habitabilidade, panspermia, extremofilos.
Experimentos de astrobio.



Aula 1:

Introdução a Astroquímica e evolução química do Universo

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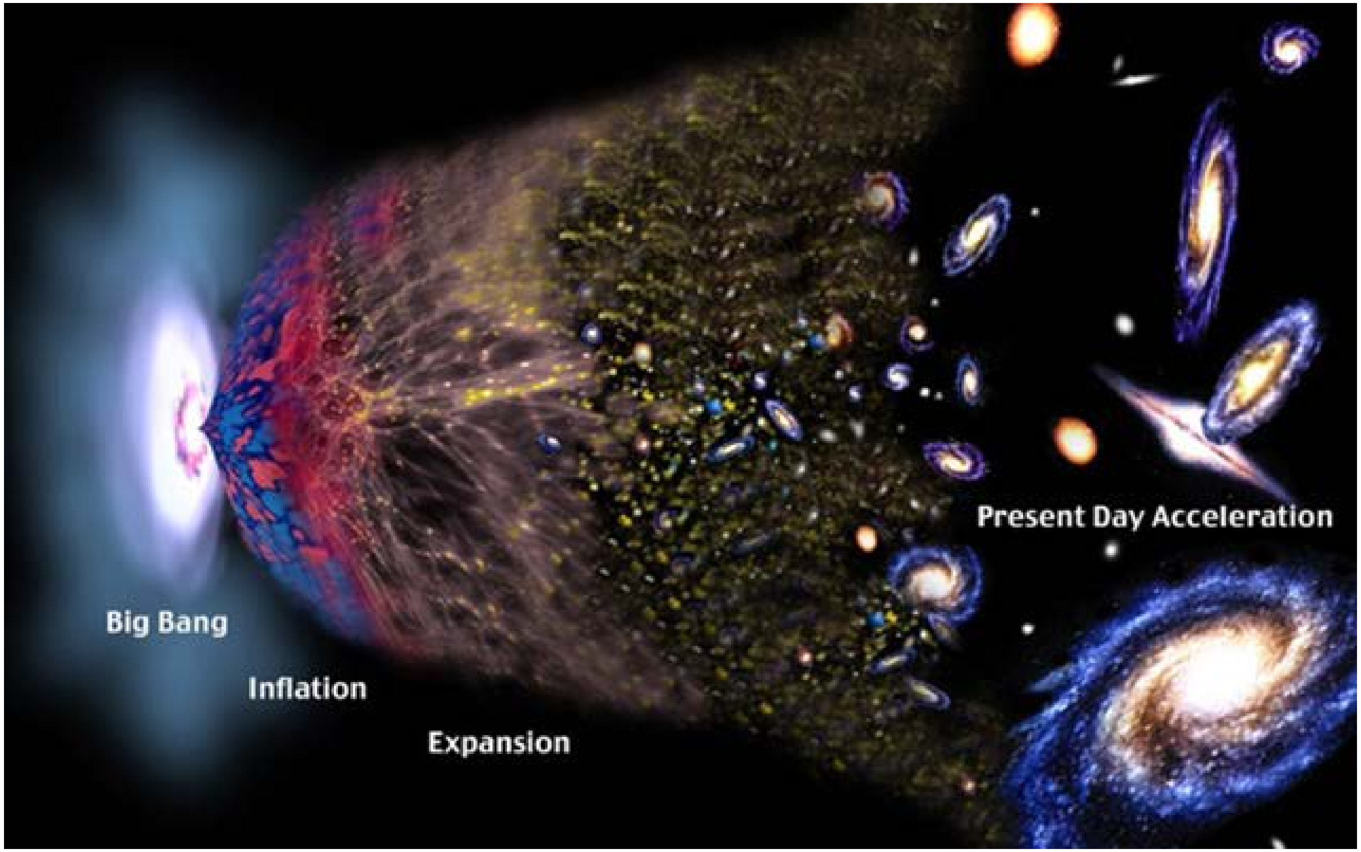
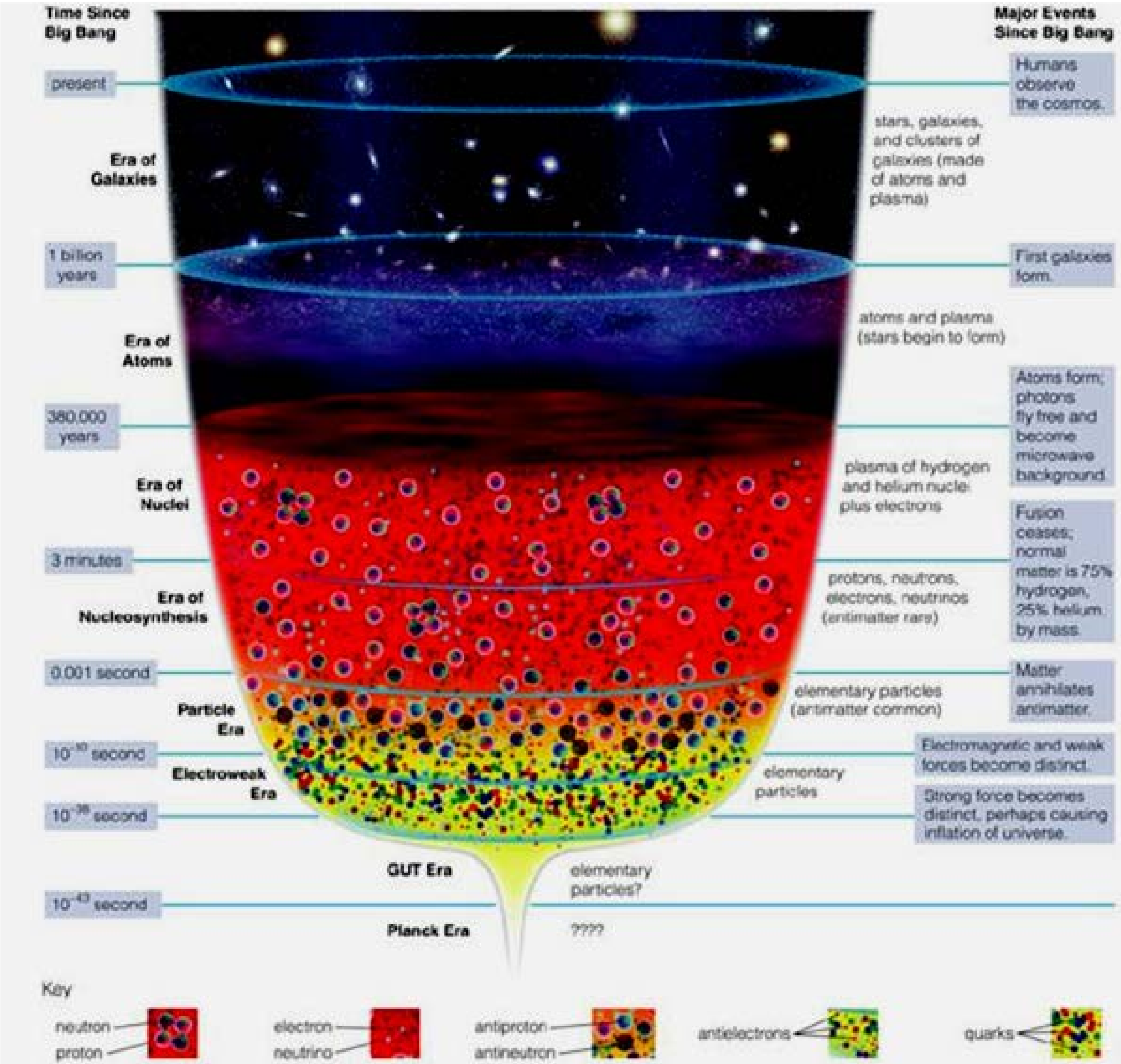
A) Formação dos primeiros átomos e aumento da complexidade elementar no Universo

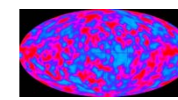



BigBang

A1) A teoria do BigBang



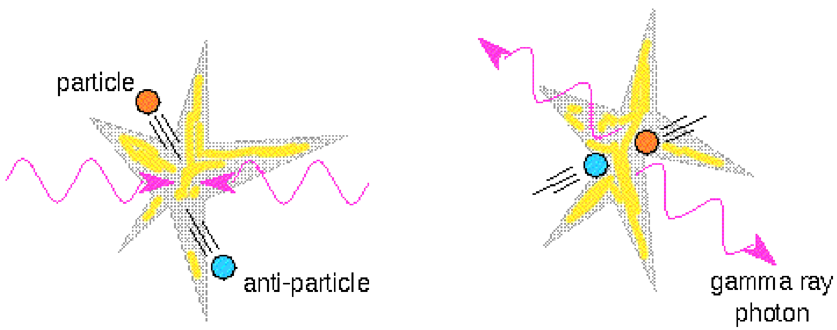
- ← Hoje
- ← Surgimento da vida
- ← 1ªs moléculas orgânicas
- ← 1ªs moléculas
- ...
- ← 2ª geração de estrelas
- ← 1ª geração de estrelas
- ← 1ºs Átomos (**H, He,** Li, Be)
- ← RCF ~ 2.7 K



- ← 1ºs Núcleos
- ← 1ºs prótons e nêutrons
- ← Partículas elementares
- ← Big bang

A2) Universo primitivo (até ~ 1 seg)
Formação das partículas elementares e hadrons

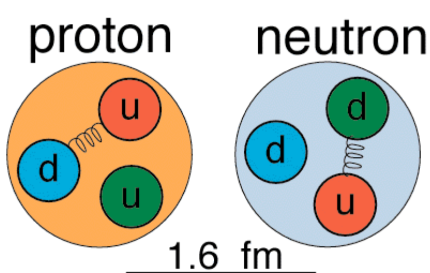
Energia radiante (raios gama) é convertida em matéria e anti-matéria.
(Eq Einstein, $E = m.c^2$)

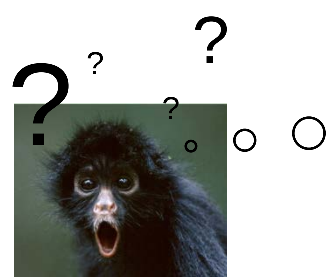


Partículas elementares
$\sim 10^{-32}$ até 10^{-6} segundos

	LÉPTONS		QUARKS	
1ª Família	Elétron	Neutrino do elétron	*Up*	*Down*
2ª Família	Múon	Neutrino do múon	*Charm*	*Strange*
3ª Família	Tau	Neutrino do tau	*Top*	*Botton*

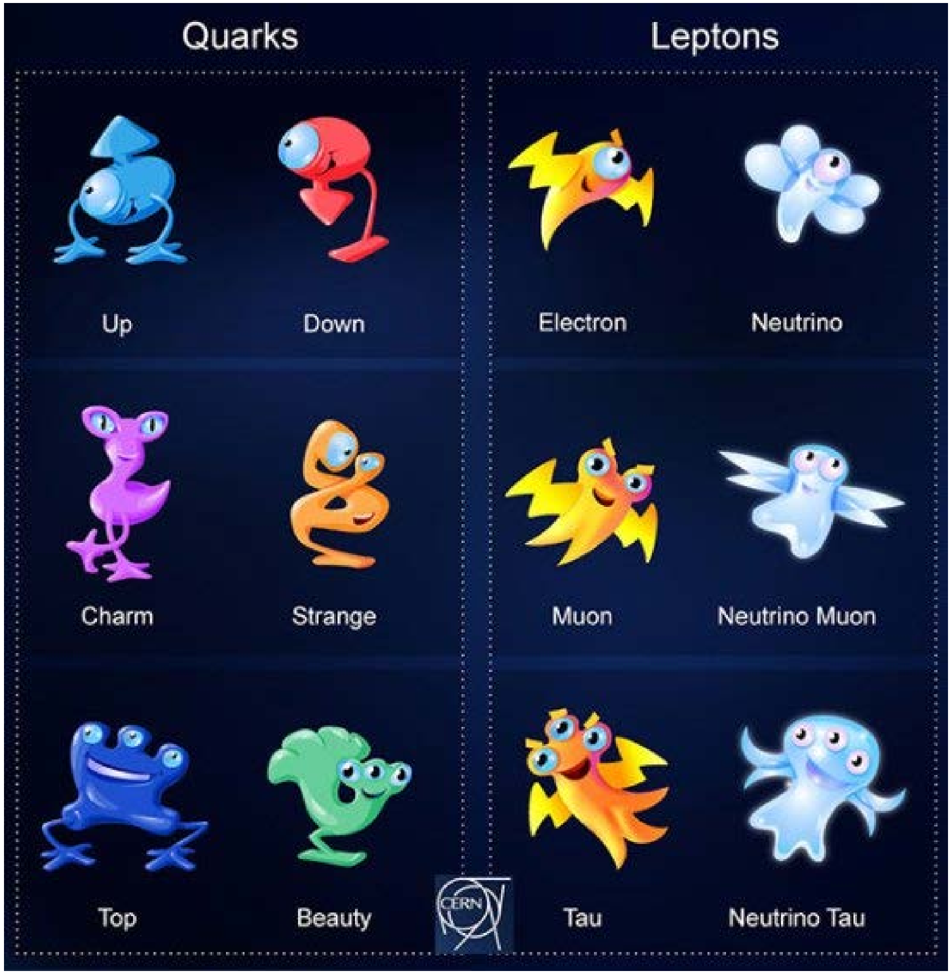
Formação dos hadrons
10^{-5} seg até ~1 seg



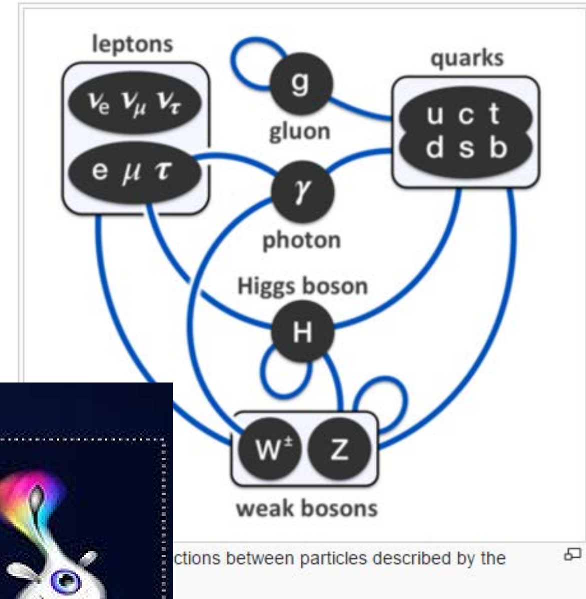


Anti-partículas (1/1bi)?
Ex. anti-elétron (pósitron)

1ª Grande festa Cósmica (Menos de 1 s após Bigbang)

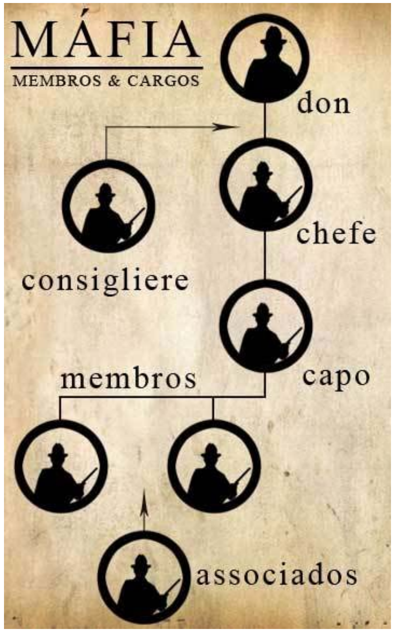


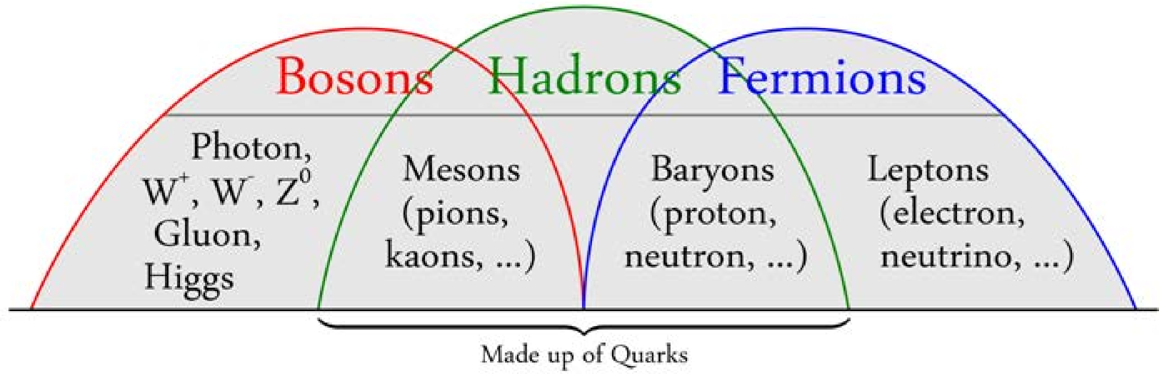
Panelinhas e Dialetos.

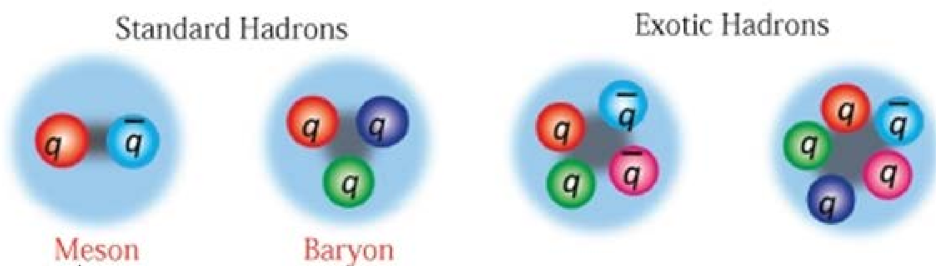


Local do Evento (Início do Universo)

As primeiras Famílias!

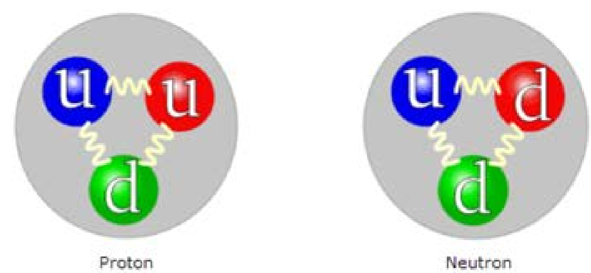






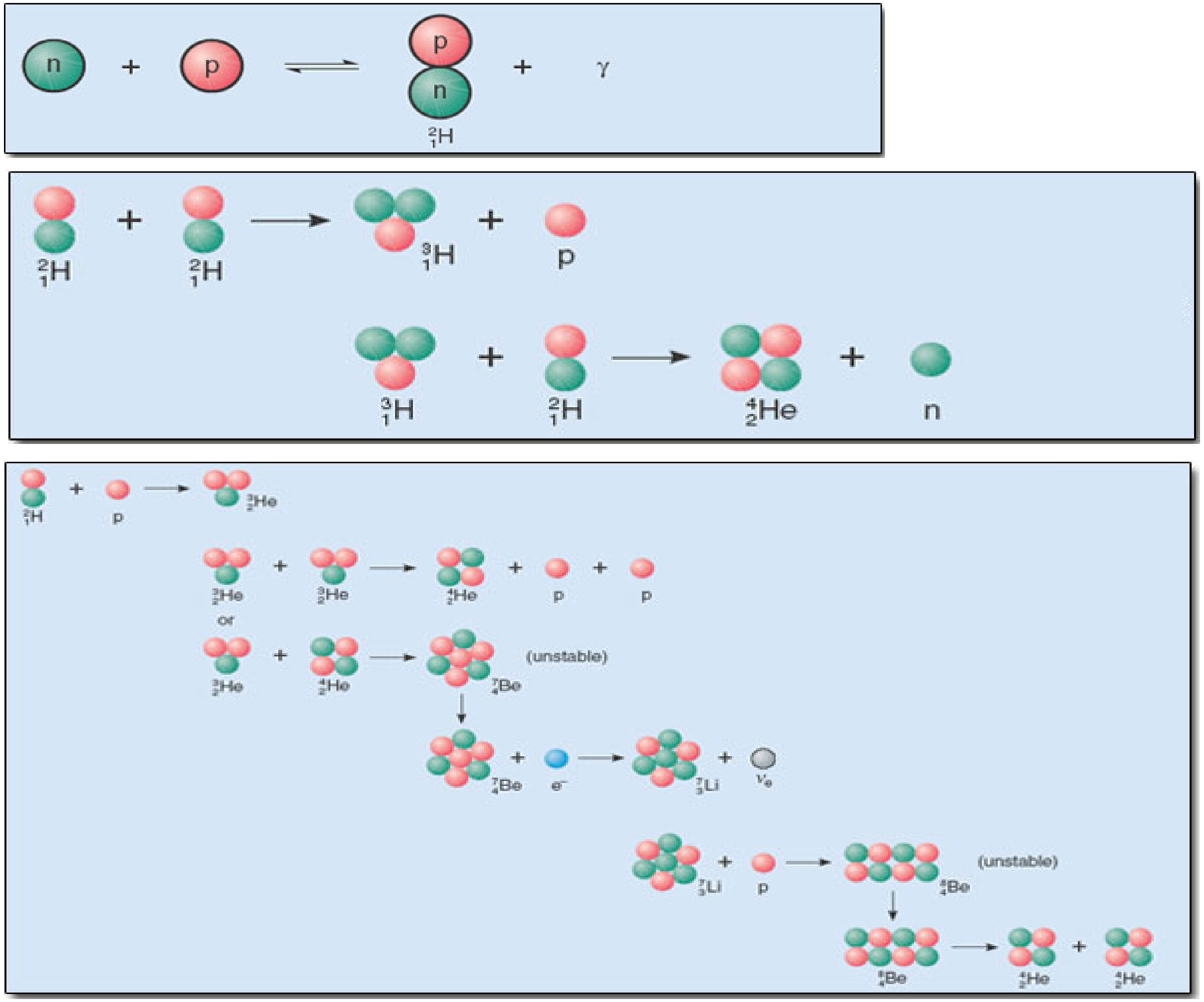
ex.

Mesons $q\bar{q}$ Mesons are bosonic hadrons. There are about 140 types of mesons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

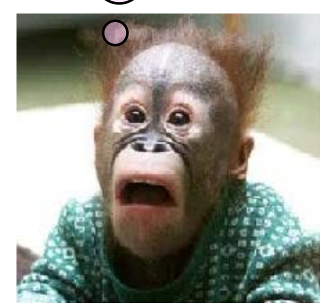


Quark composition of a proton and a neutron (diagrams from *Wikipedia*)

A3) Nucleossíntese primordial (~10 seg até ~ 5 min)



Nessa época o Universo era parecido com o núcleo do Sol. Uma sopa de partículas ionizadas (PLASMA)

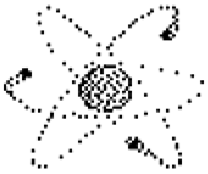


No fim da era da nucleossíntese a composição da matéria bariônica do universo era de 74% prótons, 24% núcleos de hélio e traços de núcleos de outros elementos leves como Lítio, Deutério e Berílio.

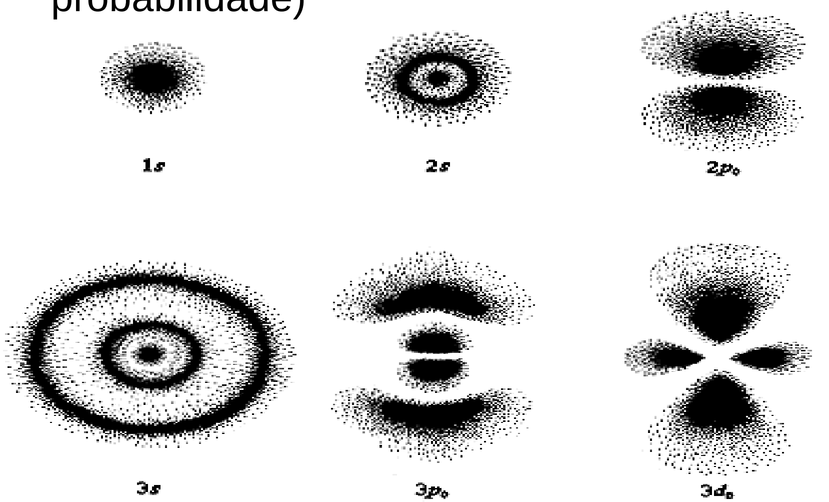
A4) Atomossíntese primordial (de 5 min até ~ 380 000 anos)

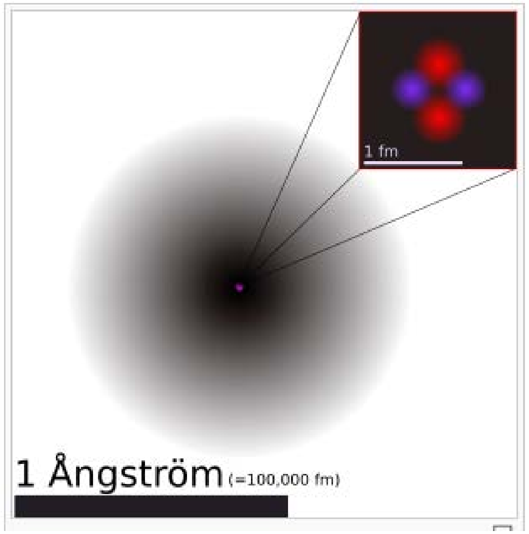
Ao longo dos primeiros 380 mil anos a temperatura do universo decresceu bastante chegando ate cerca de 3000 K, permitindo que os núcleos formados (prótons e nêutrons) combinassem com os elétrons errantes resultando em átomos neutros (recombinação).

Visão clássica (órbitas)

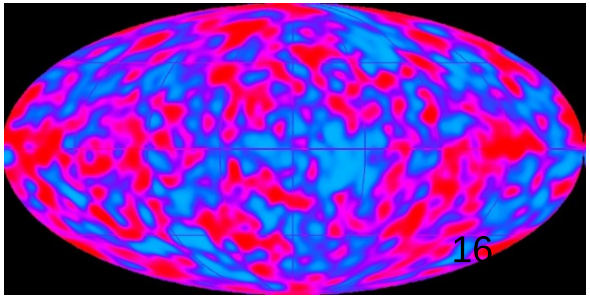


Visão quântica (orbitais = distribuição de probabilidade)



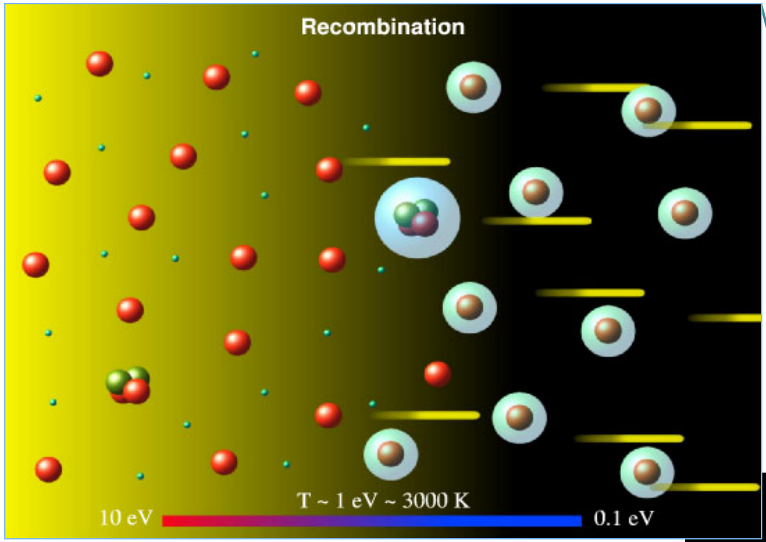


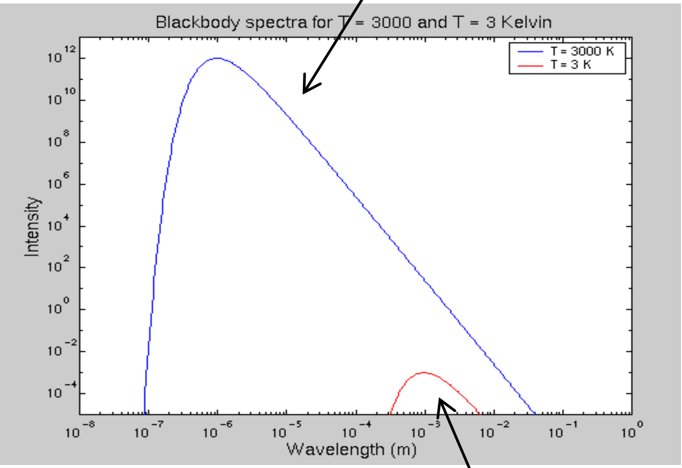
Nessa época o universo deixou de ser opaco a radiação como (o interior solar; espalhamento da luz pelos elétrons livres) e começou a ser transparente. Podendo ser observado nos dias de hoje como a radiação cósmica de fundo (2.7K)

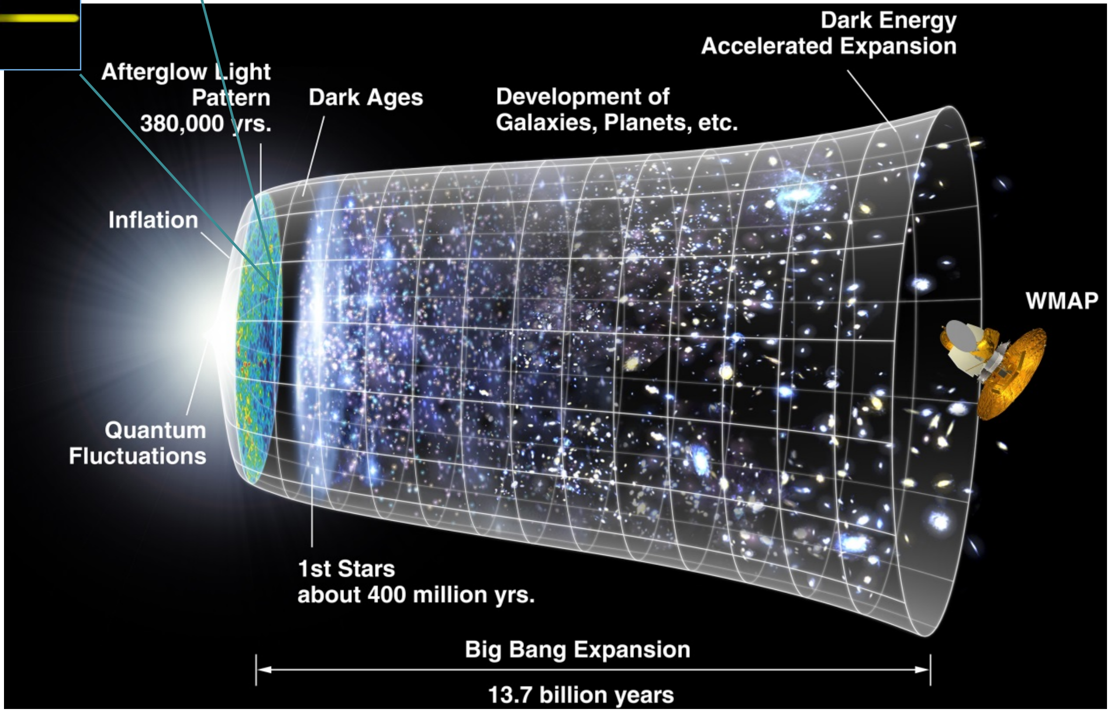


Mais sobre a radiação cósmica de fundo (RCF).

- Recombinação (3000K); Expansão do Universo + Efeito Doppler (2.7 K - Ondas de rádio (mm)); RCF (Flutuações; galáxias iniciais, Topologia do Universo).

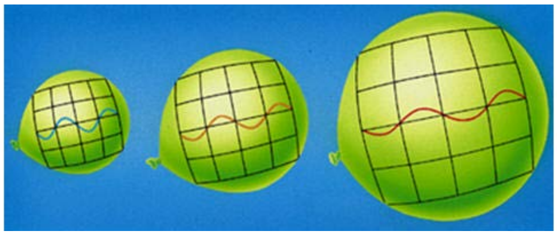


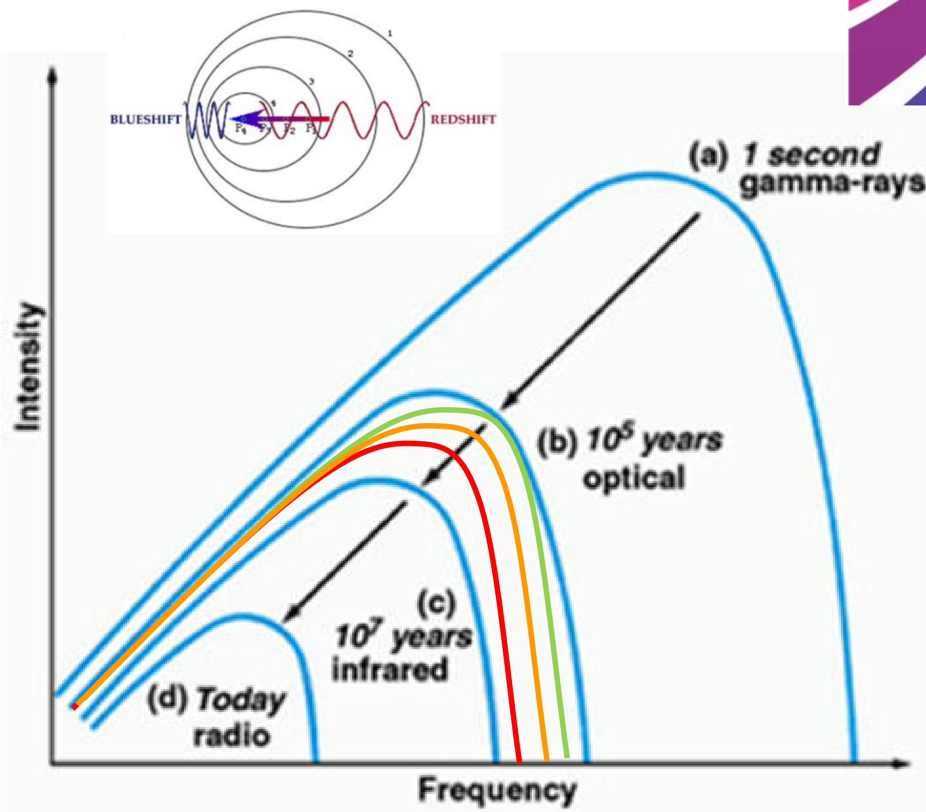




Devido a expansão do universo
(efeito Doppler)Hoje

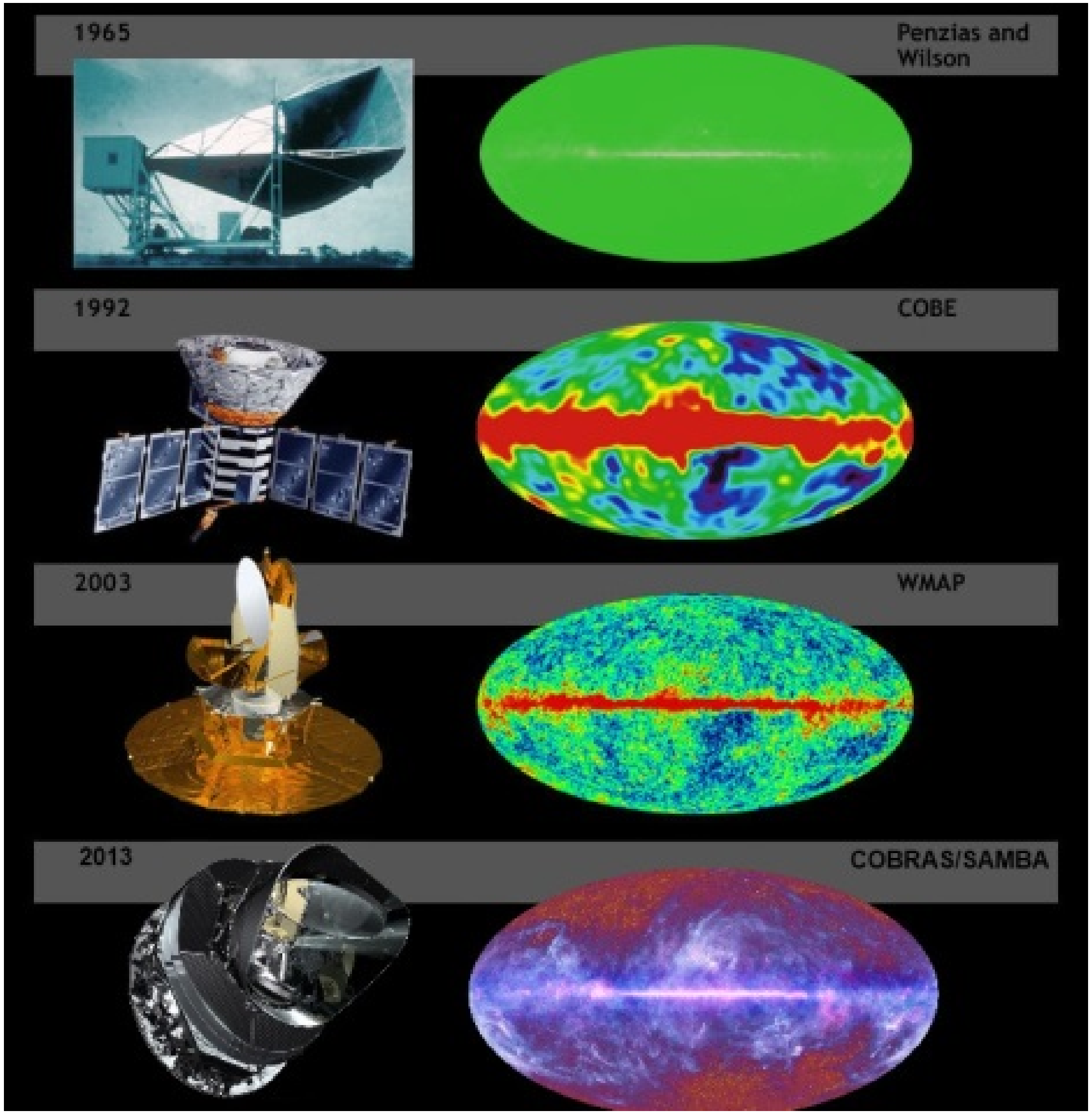
O universo foi “mudando de cor” a medida que evoluiu (expandiu).

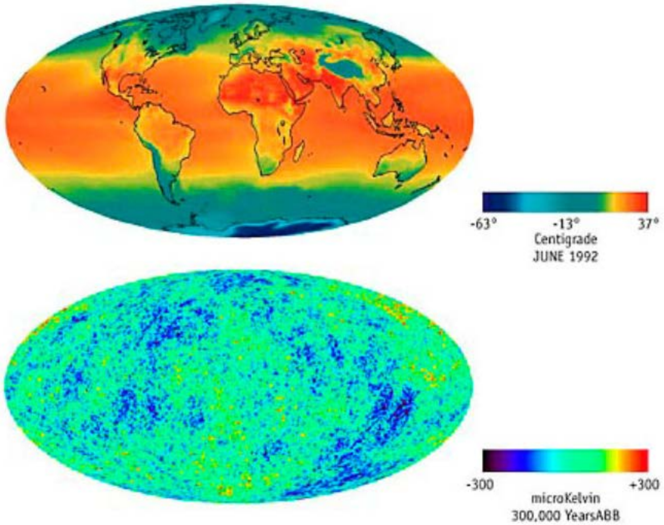


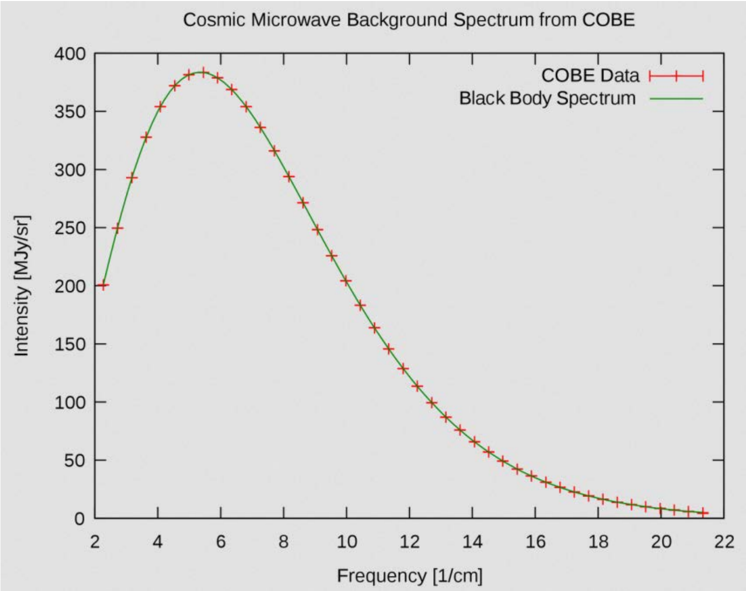


Temperature	peak wavelength
3 K	1mm (radio waves)
300 K (room temperature)	10 microns (infrared)
6000K (surface of sun)	0.5 micron (visible light)
3,000,000 K	1 nanometer (x-rays, gamma-rays)

Mais sobre a radiação cósmica de fundo.

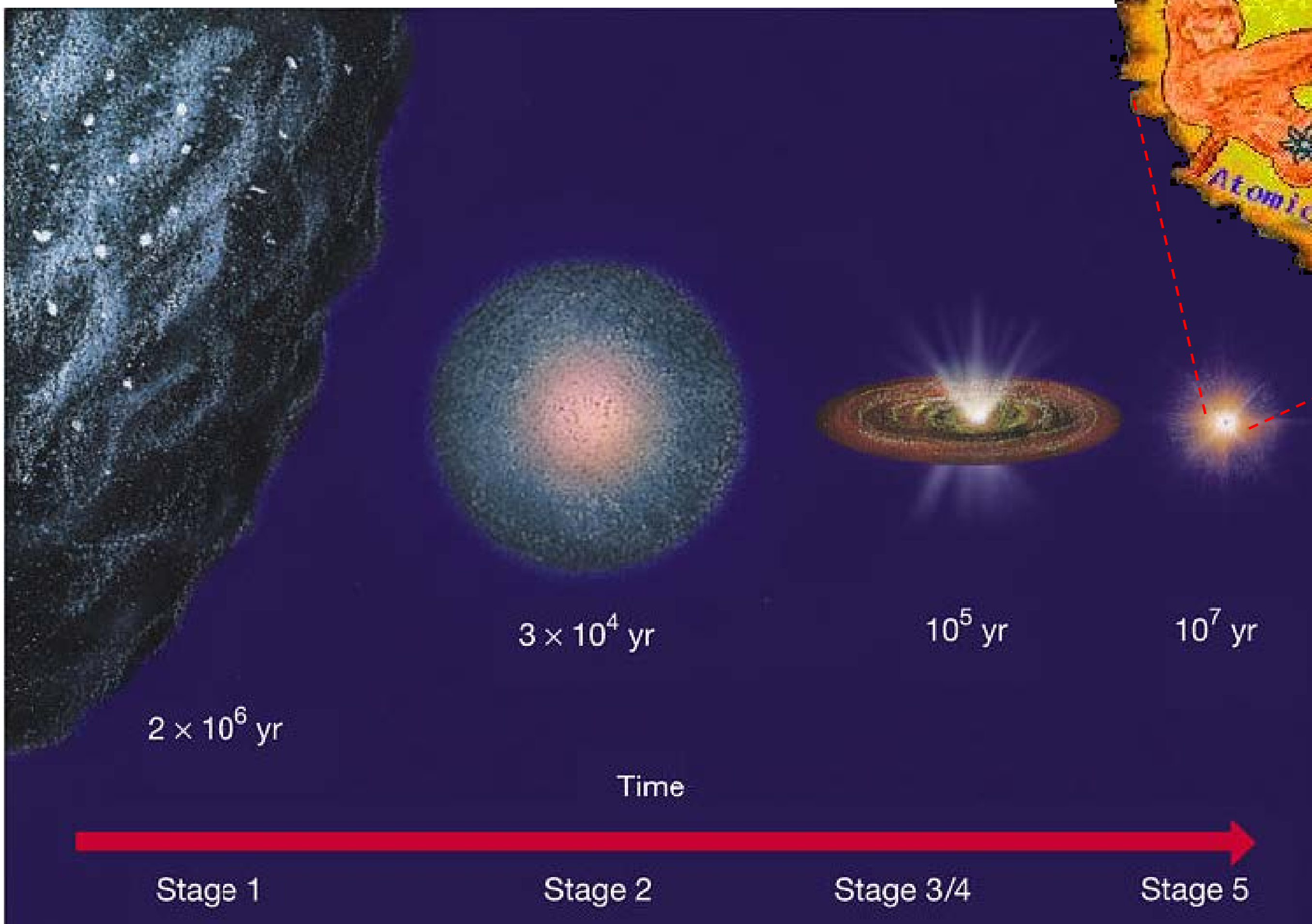


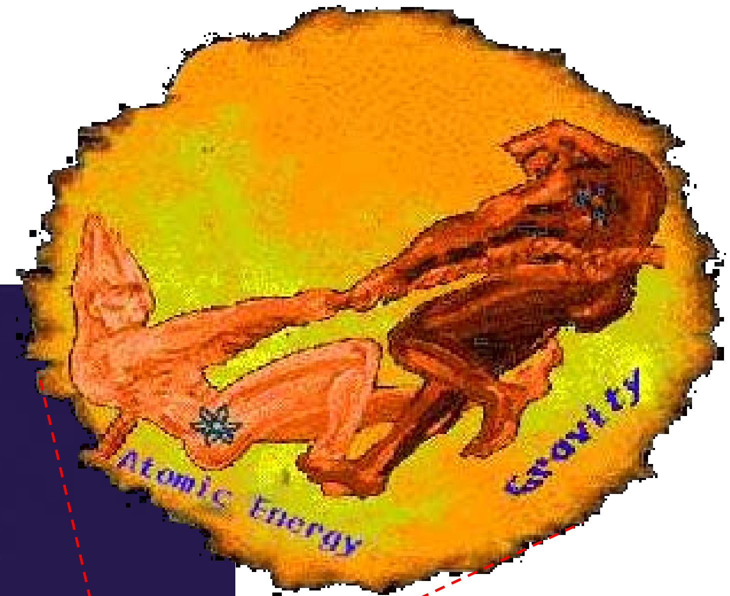




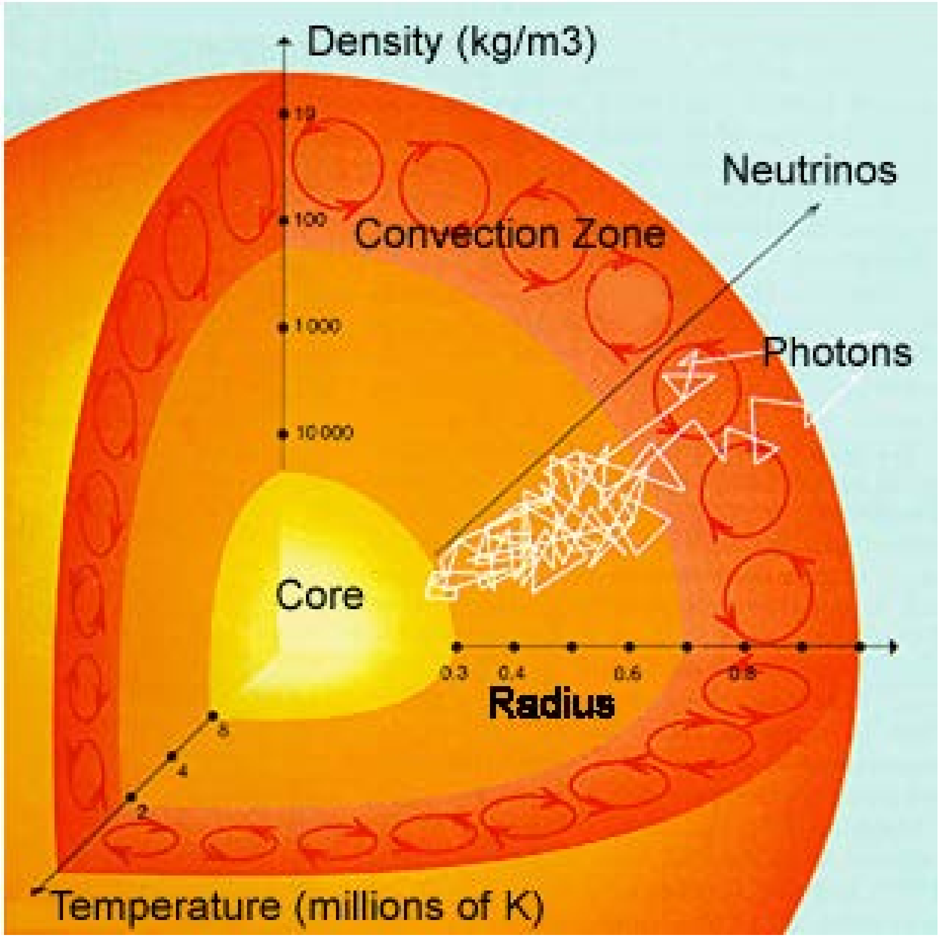
A5) 1as estrelas e nucleossíntese estelar (~ 1bi ano)

Nuvem de
átomos de H, He

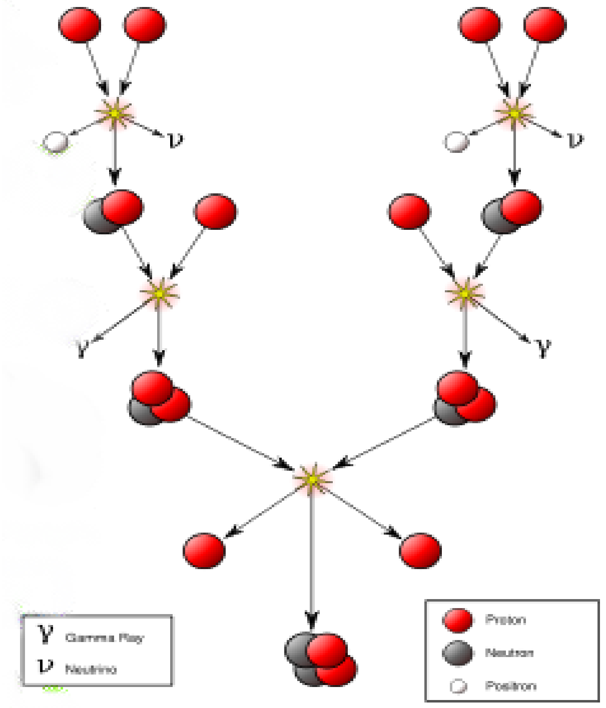


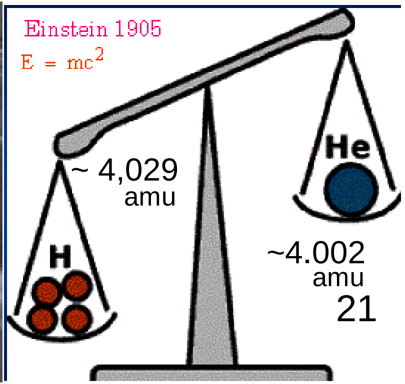


- Estrelas do tipo solar

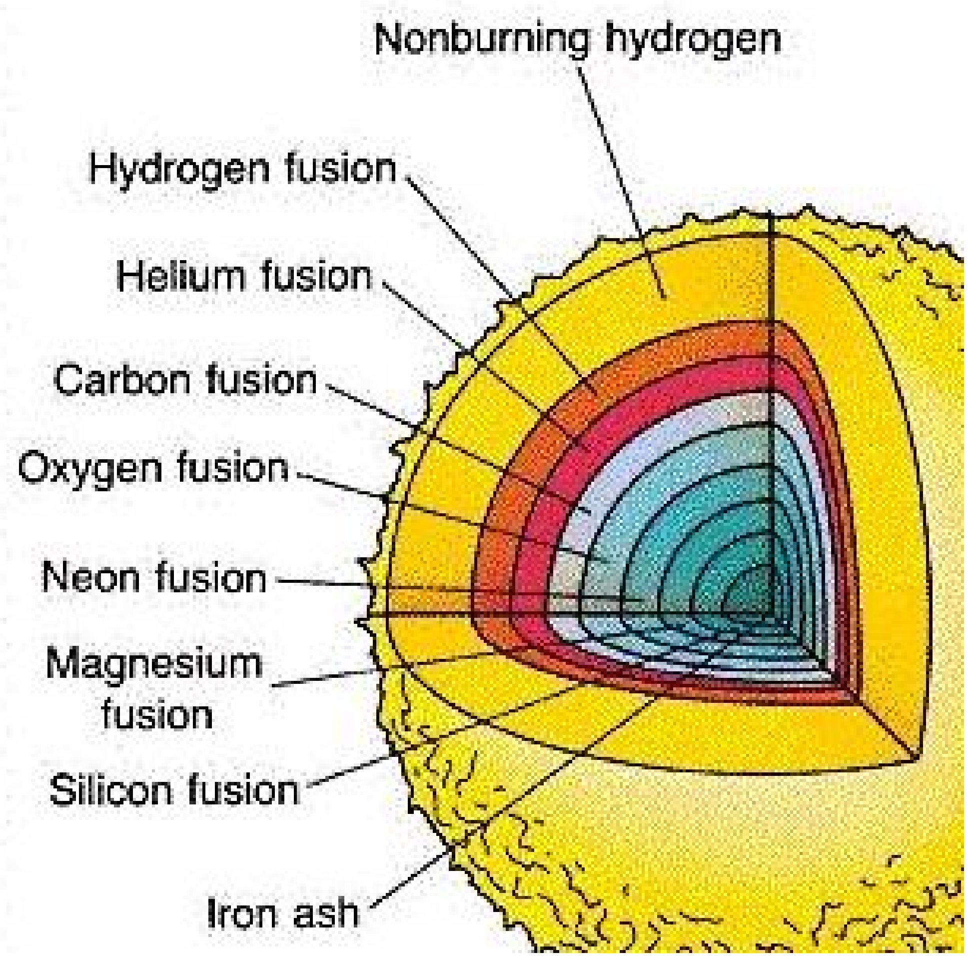


Queima do hidrogênio (cadeia p-p)





- Estrelas do grade massa



Exemplo de reações

$^{12}C + {}^{4}He \rightarrow {}^{16}O + \gamma$

$^{16}O + {}^{4}He \rightarrow {}^{20}Ne + \gamma$

$^{20}Ne + {}^{4}He \rightarrow {}^{24}Mg + \gamma$

$^{36}Ar + {}^{4}He \rightarrow {}^{40}Ca + \gamma$

$^{24}Mg + {}^{4}He \rightarrow {}^{28}Si + \gamma$

$^{28}Si + {}^{4}He \rightarrow {}^{32}S + \gamma$

$^{32}S + {}^{4}He \rightarrow {}^{36}Ar + \gamma$

$^{36}Ar + {}^{4}He \rightarrow {}^{40}Ca + \gamma$

$^{12}C + {}^{12}C \rightarrow {}^{24}Mg + \gamma$

$^{12}C + {}^{12}C \rightarrow {}^{23}Mg + n$

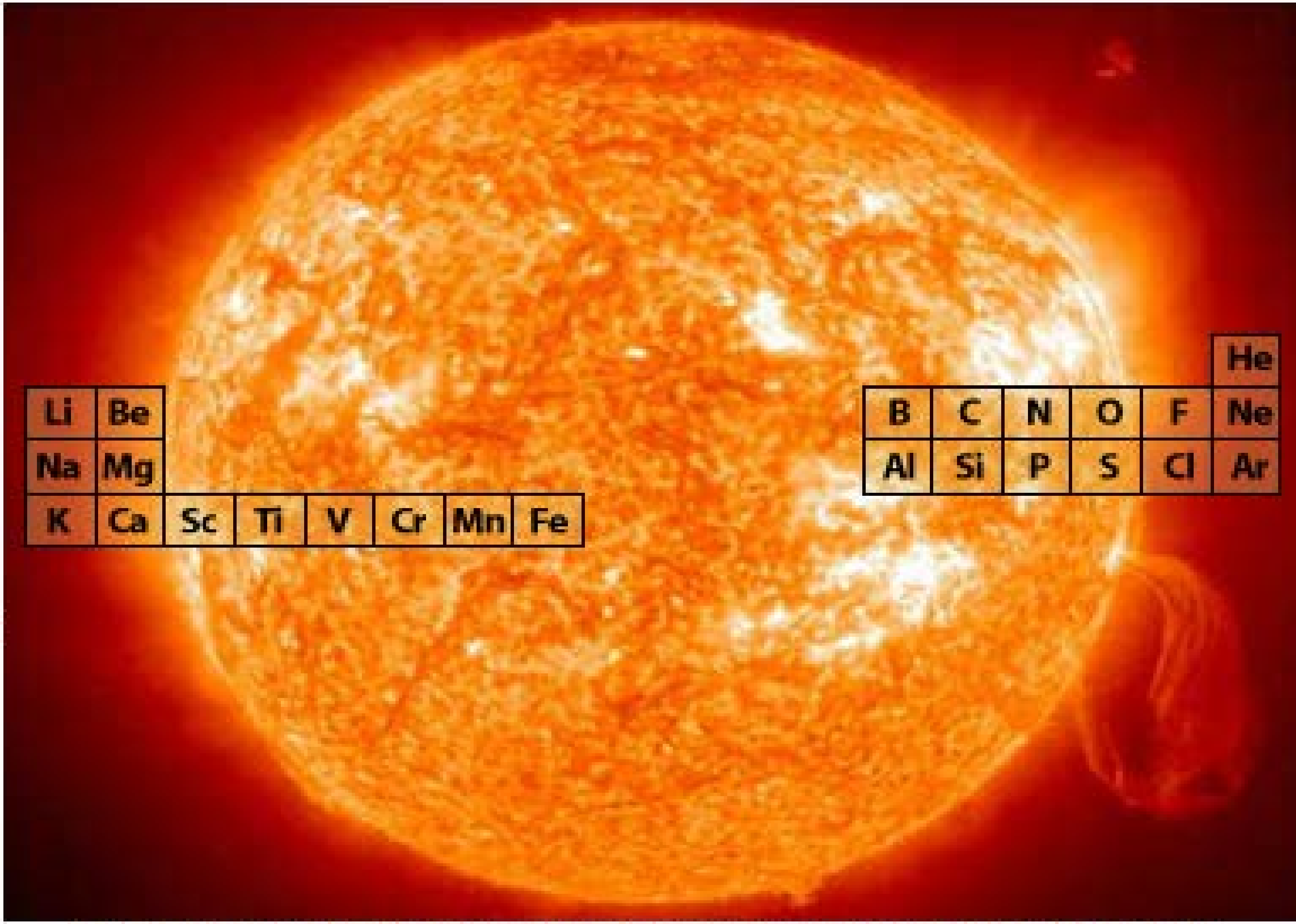
$^{12}C + {}^{12}C \rightarrow {}^{23}Na + p$

$^{16}O + {}^{16}O \rightarrow {}^{32}S + \gamma$

$^{16}O + {}^{16}O \rightarrow {}^{31}S + n$

$^{16}O + {}^{16}O \rightarrow {}^{31}P + p$

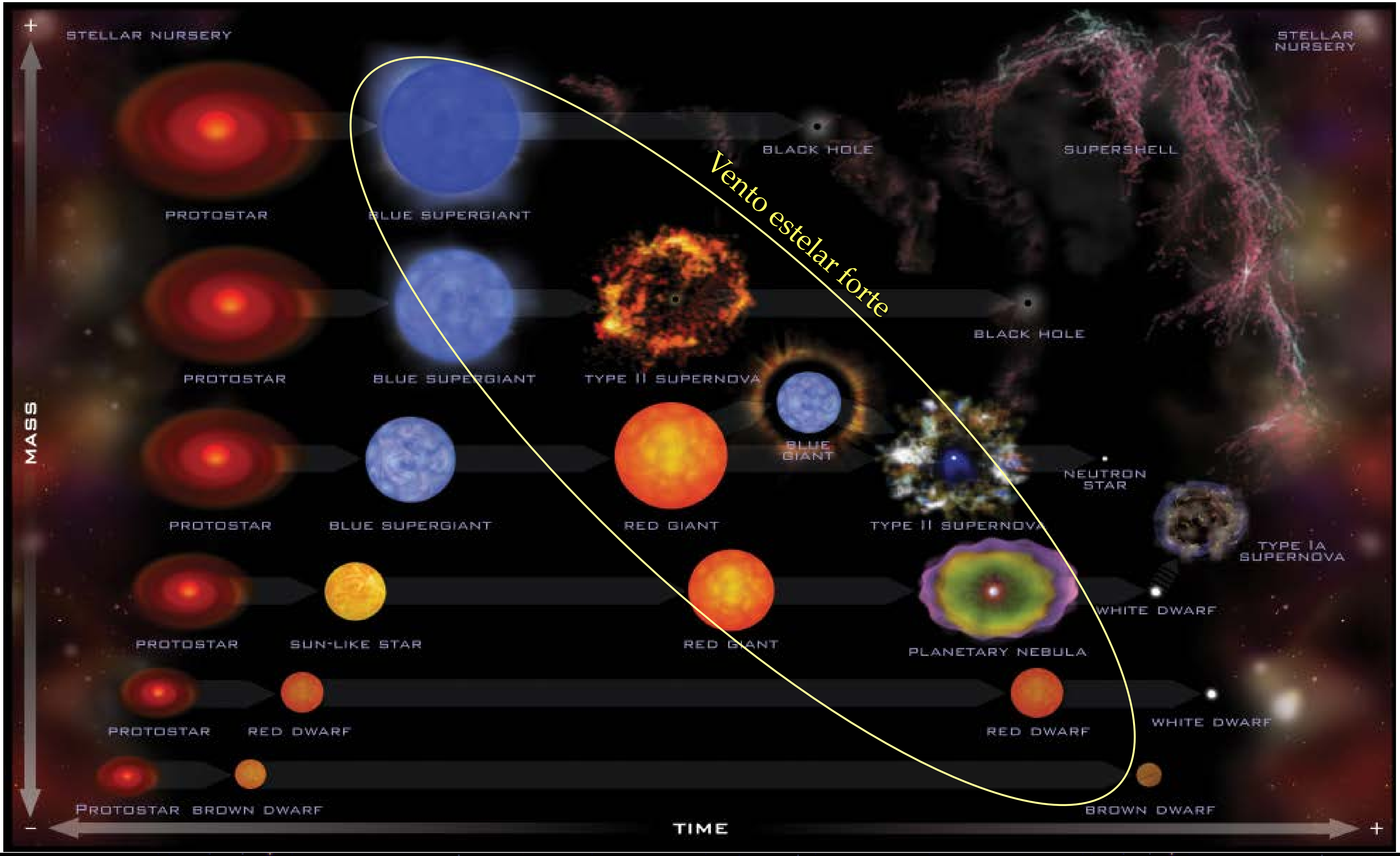
1as estrelas e nucleossíntese estelar (~ 1bi ano)



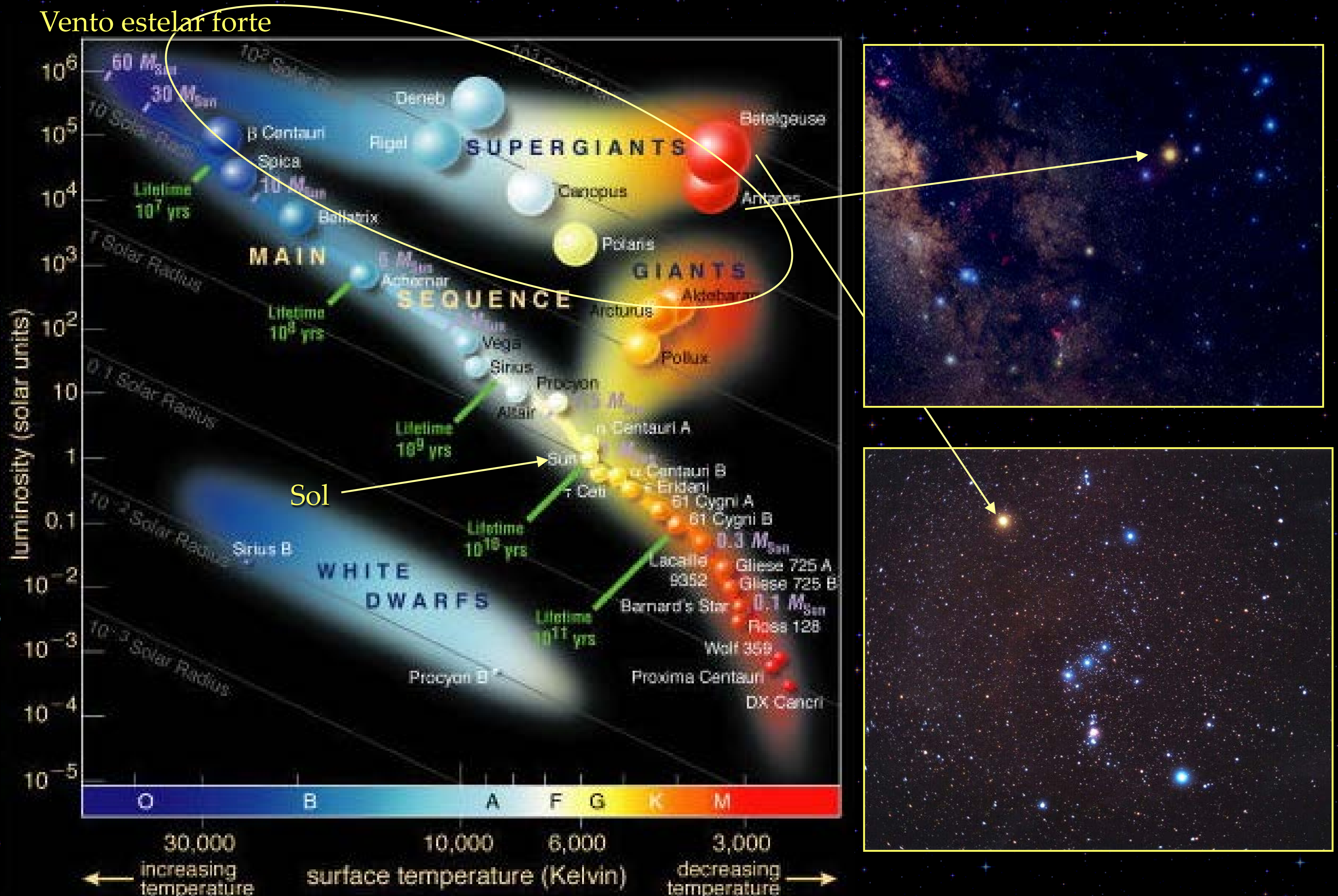
Elements up to the weight of iron are manufactured in stars.

A6) Um pouquinho sobre Evolução estelar

Biografia estelar



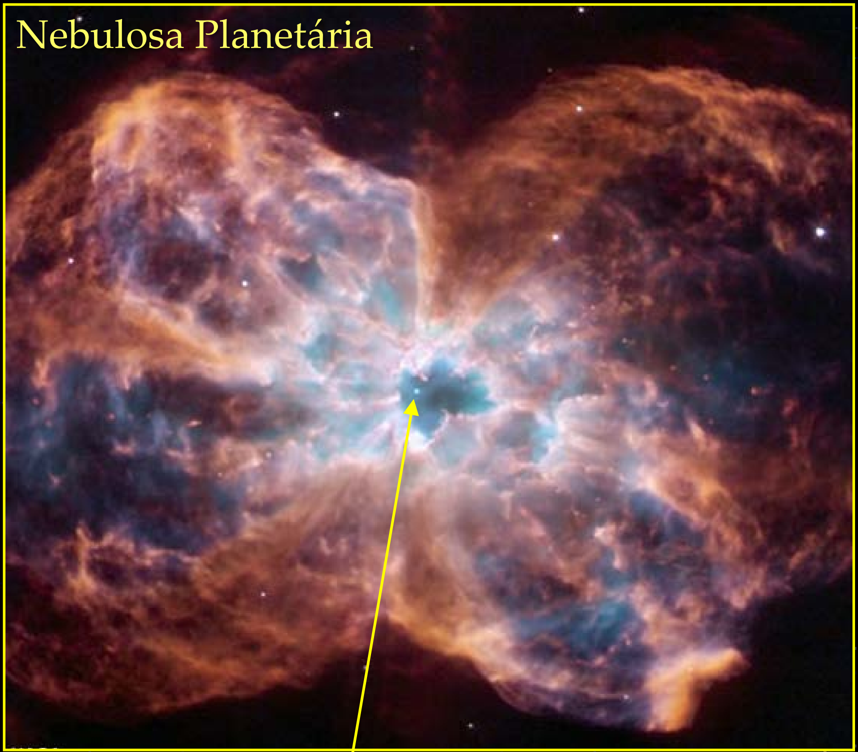
O Diagrama HR (Hertzprung-Russel)



Estágios finais e Ventos

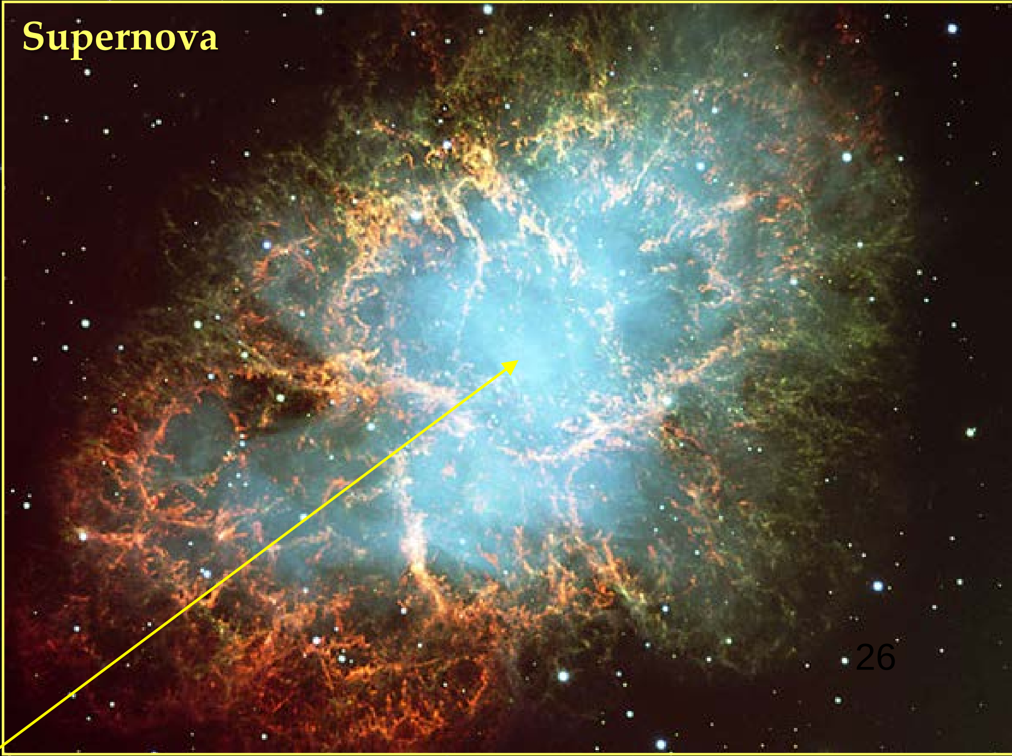
Estágios finais de estrelas do tipo solar

Nebulosa Planetária

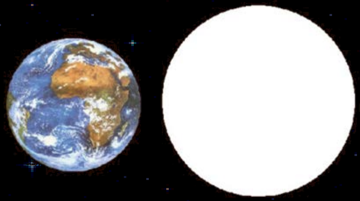


Estagio finais de estrelas do grade massa

Supernova



Comparação de tamanhos!!

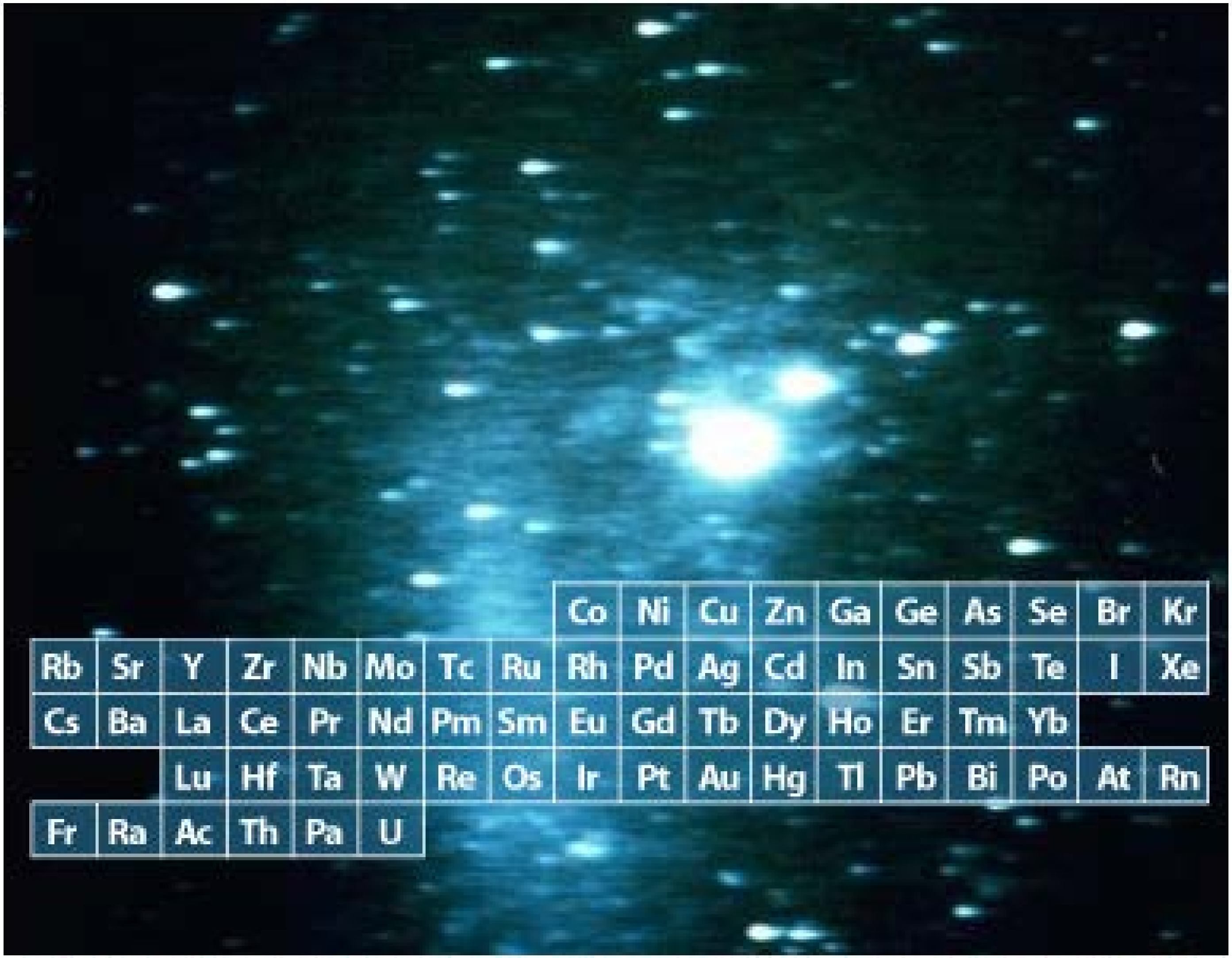


anã branca

Estrelas de nêutrons, buraco negro

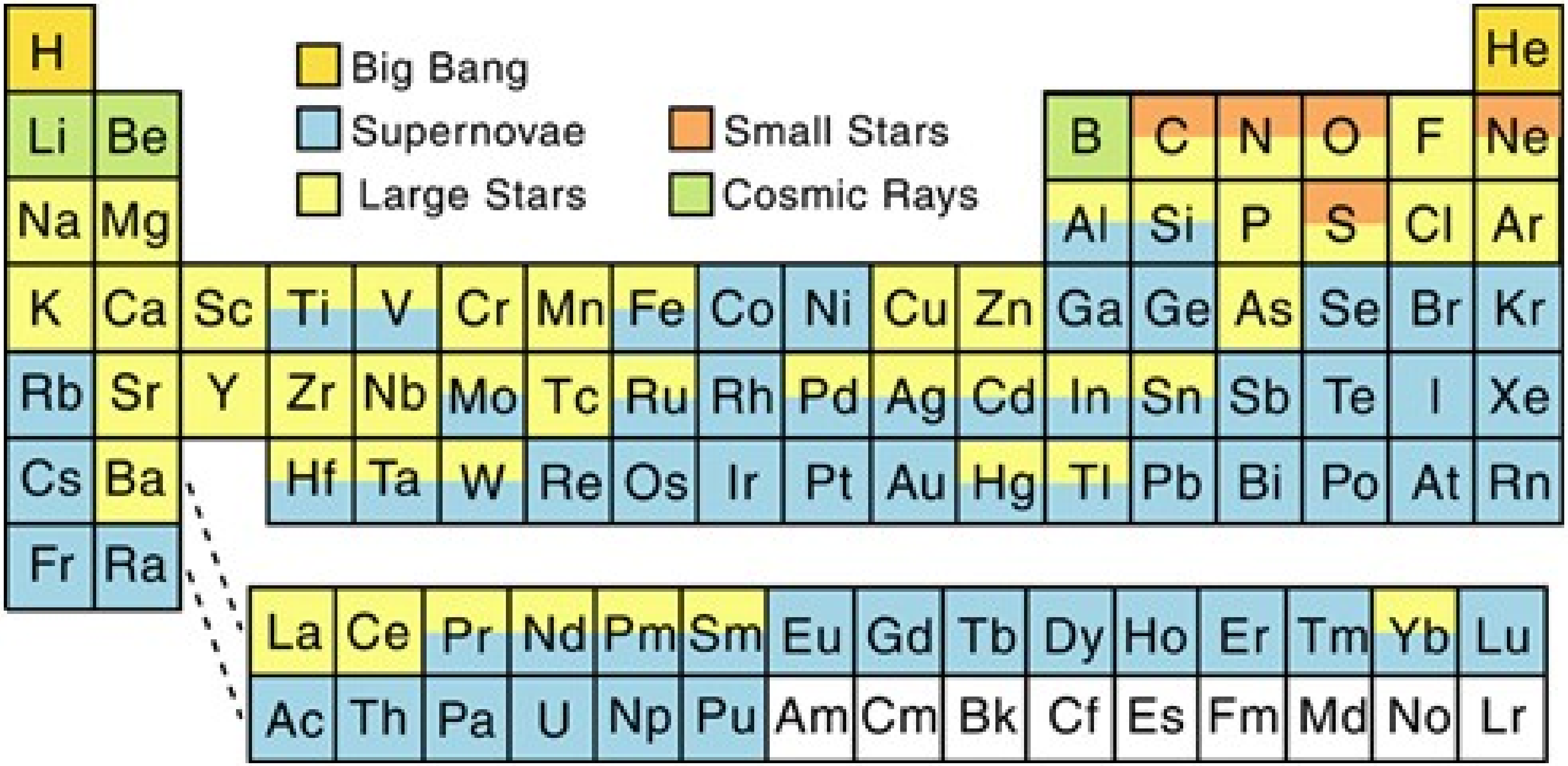
Vetos estelares: Enriquecem o Meio interestelar átomos novos!!

1as estrelas e nucleossíntese estelar (~ 1bi ano)



Elements heavier than iron are formed when a supernova explodes.

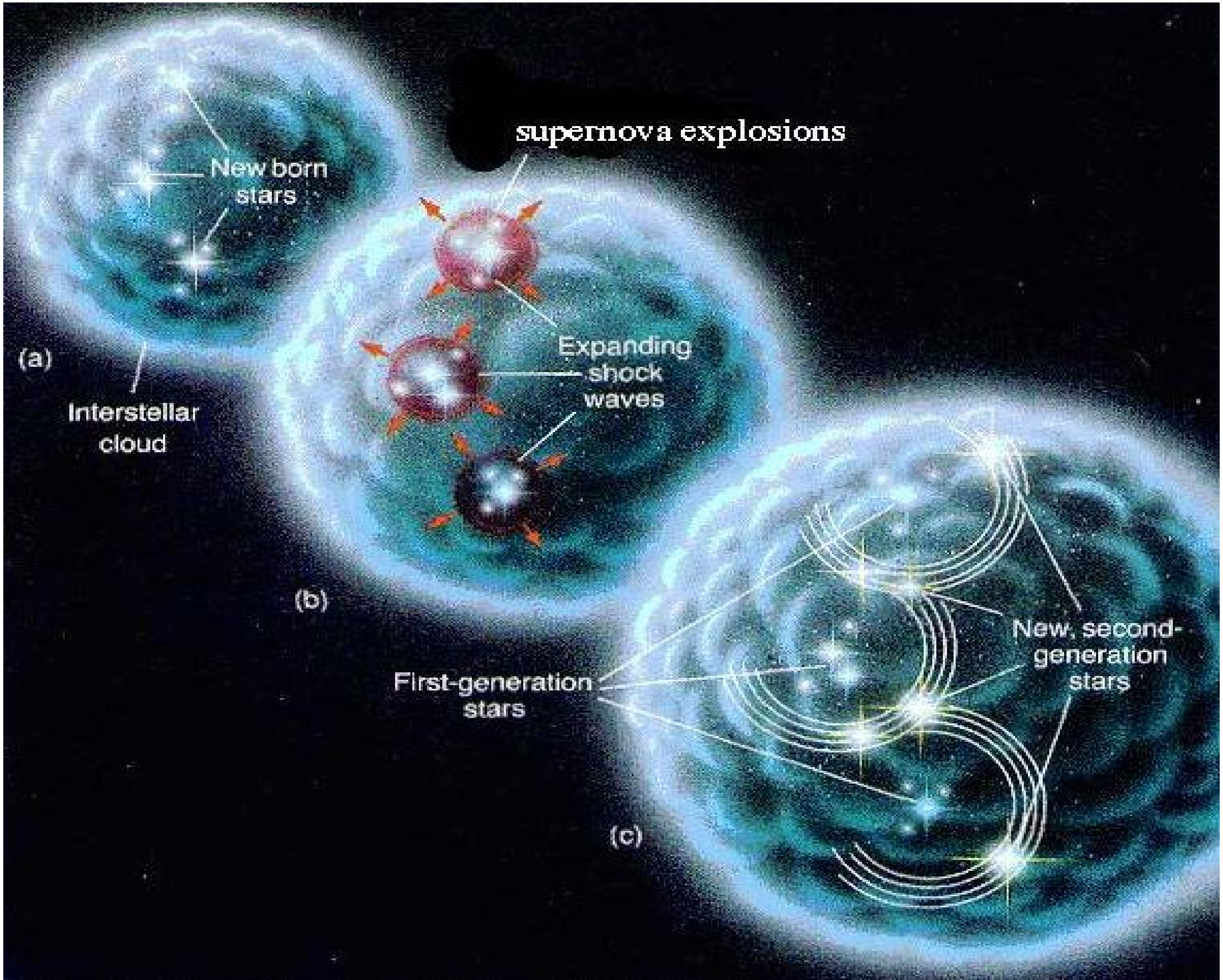
Tabela Periódica com os átomos e sua origem



Estrelas -> supernovas -> estrelas -> ....

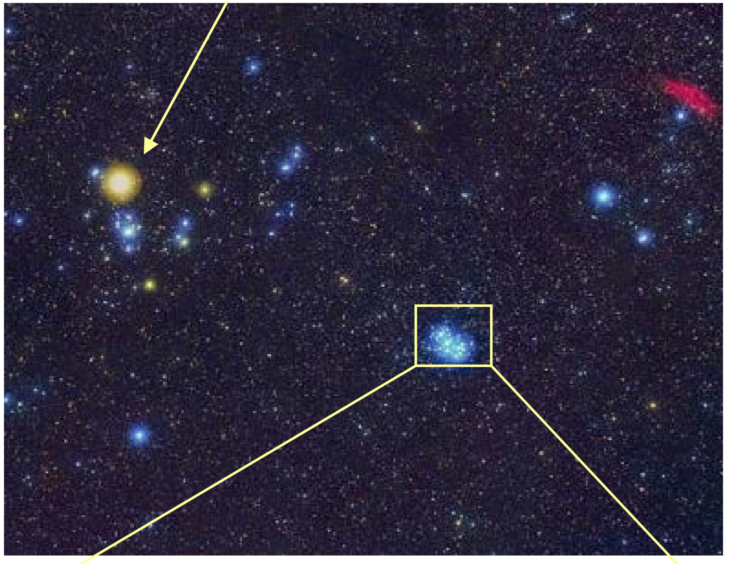
Tempo

Enriquecimento químico



Com as estrelas, apareceram os aglomerados de estrelas ....

Aldebaran (gigante vermelha)



M22, um aglomerado globular

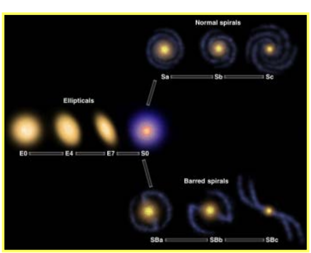
aglomerado aberto Pleiades

.... as galáxias e aglomerados de galáxias

Andromeda (nossa vizinha)

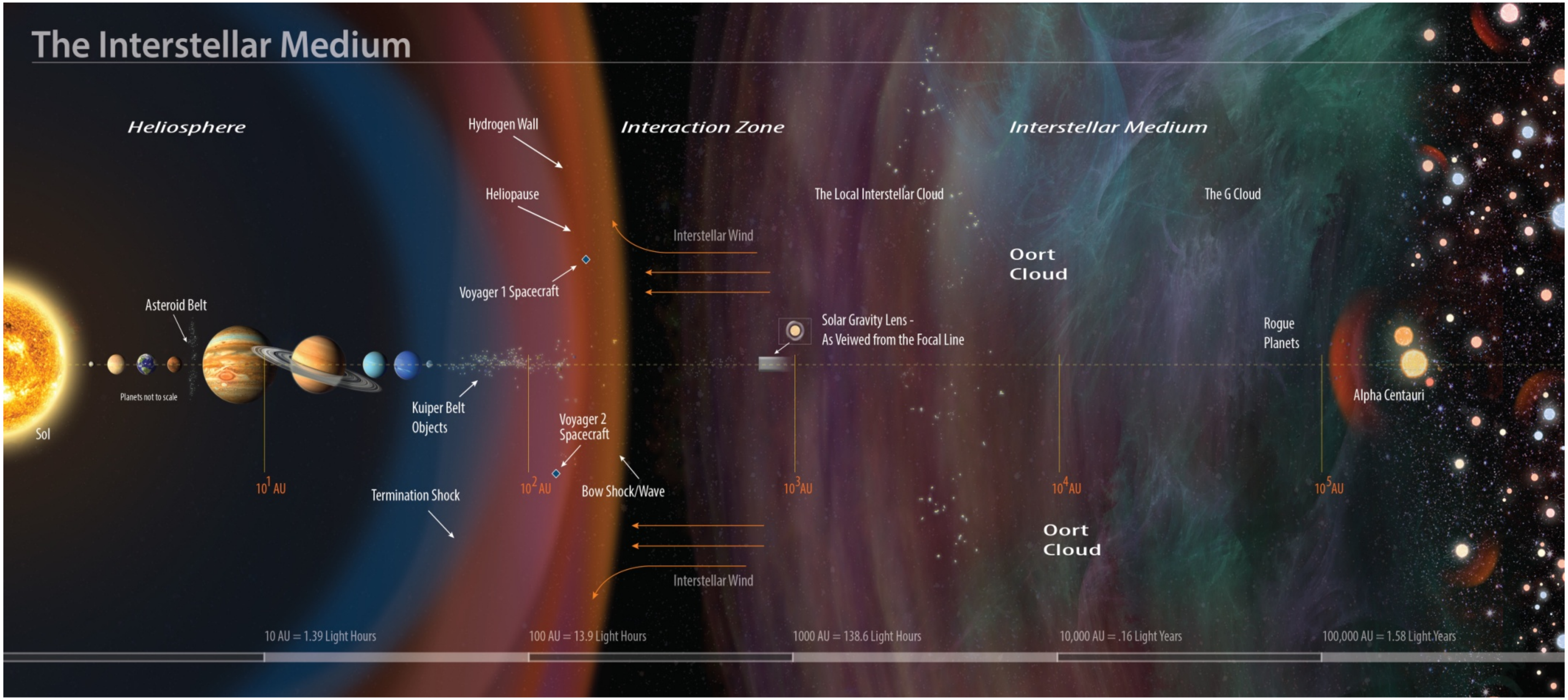
Colisões de galáxias

Galaxy Cluster Abell 2218
(Gravitational Lensing)



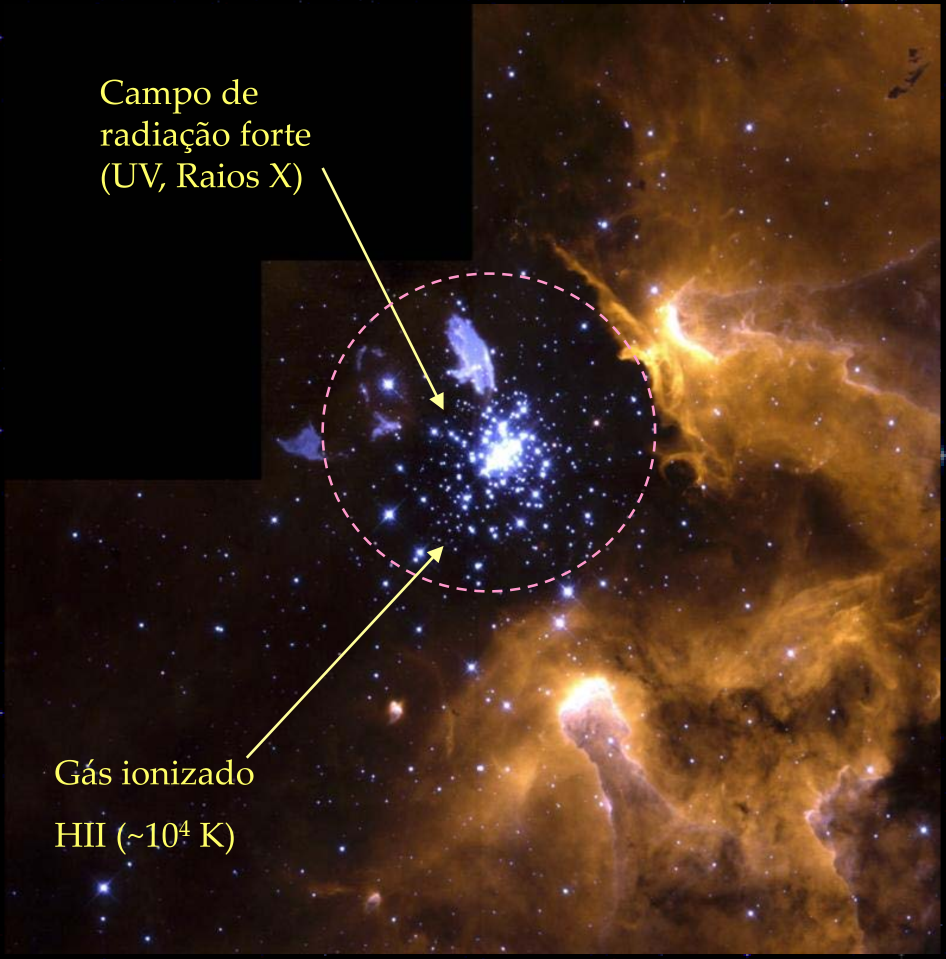
B) O meio interestelar

O espaço entre as estrelas esta cheio de coisas (radiação, partículas, campo magnéticos, poeira cósmica , moléculas, etc...)

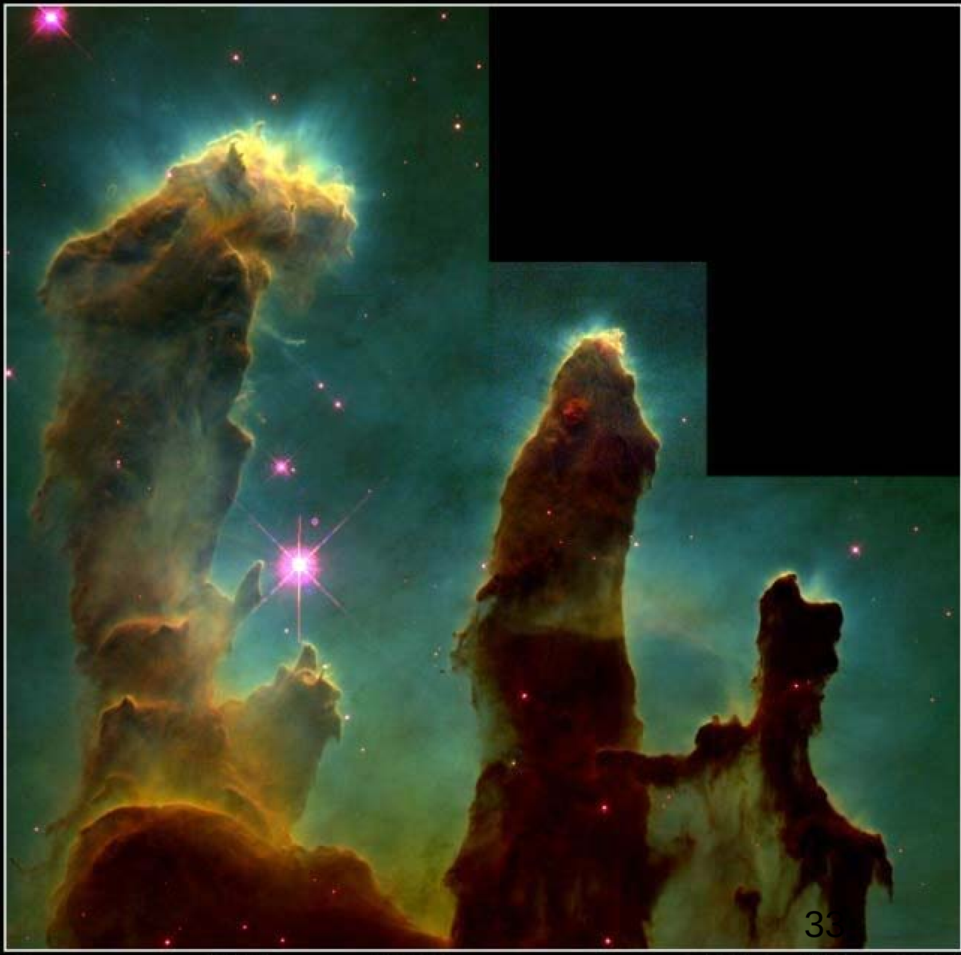


O meio interestelar (o espaço entre as estrelas)

- Evolução estelar → ventos → Enriquecimento do meio interestelar (elemento e moléculas)
- Formação de novas estrelas (+ ricas em metais)



NGC 3603



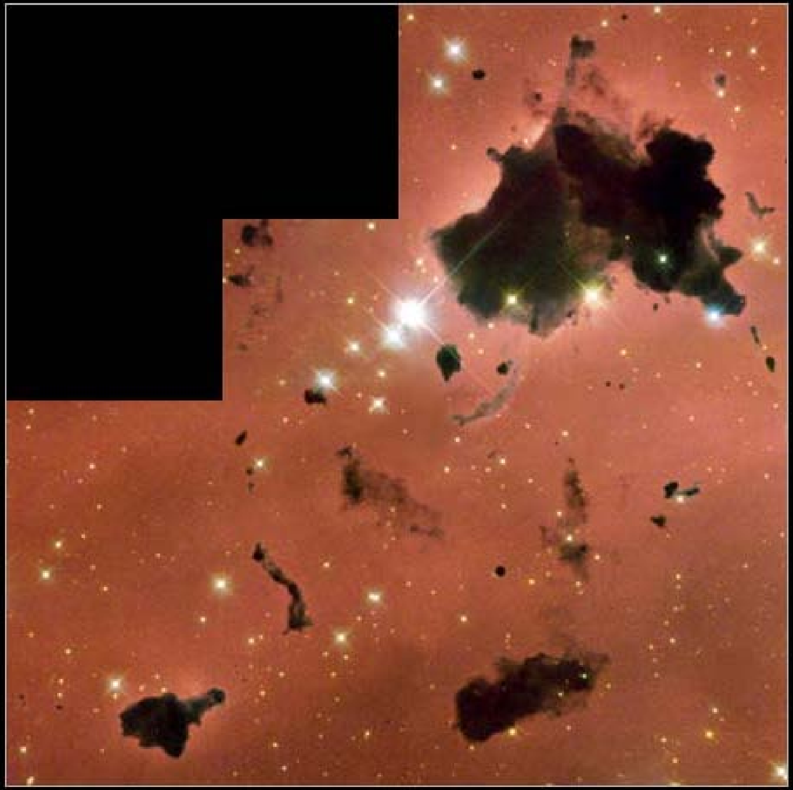
Gaseous Pillars • M16 HST • WFPC2

Propriedades do meio interestelar

- Composição: Átomos, Moléculas, Agregados moleculares, grãos de poeira (agregados de moléculas refratarias. Carbono, Silicatos) e radiação (fotons, eletrons, íons e raios cósmicos)

• Regiões do MI: Nebulosas, Nuvens difusas (quente e rarefeitas N<1); Regiões ionizadas (HII, T~10^4K); Nuvens densas (N~10^5), Nuvens Moleculares (T~10K); Glóbulos de bock; Discos proto-planetários, Envoltórios circunstelares, Nebulosas planetárias e outros.

Thackeray's Globules in IC 2944



Hubble Heritage

Reflection Nebula in the Pleiades • IC 349

Hubble Heritage

O gás interestelar

Cerca de 99% da matéria interestelar é composta de gás. A poeira constitui cerca de 1%.

Destes 99% temos que cerca de 90% é formado por H ou H_2, cerca de 9% é He e apenas 1% é formado por elementos mais pesados do que o hélio.

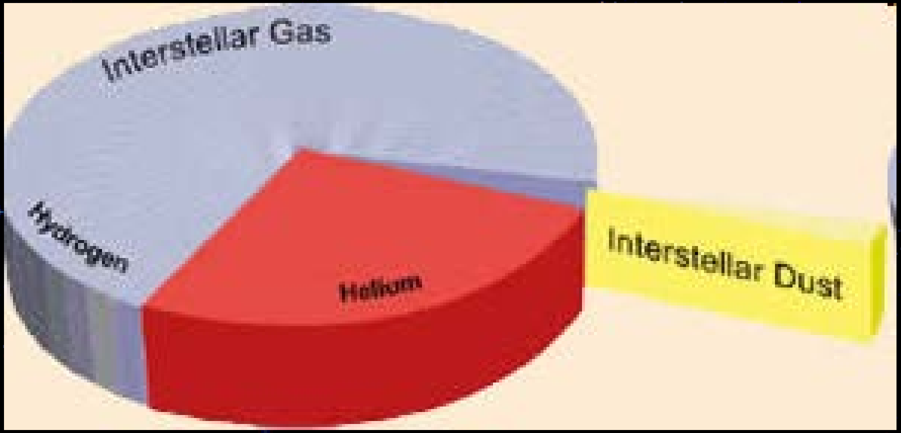
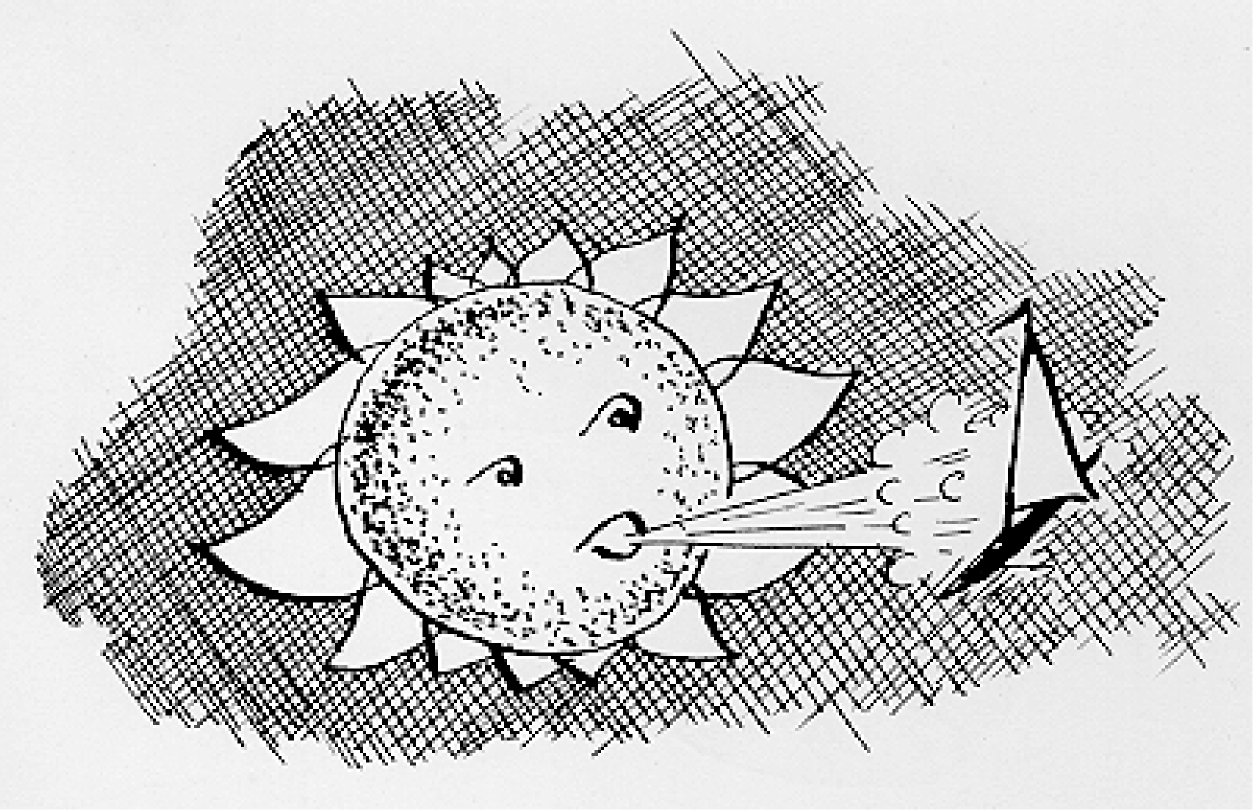


Table 1: Components of the interstellar medium

Component	Fractional Volume	Scale Height (pc)	Temperature (K)	Density (atoms/cm³)	State of hydrogen	Primary observational techniques
Molecular clouds	< 1%	70	10—20	10^2—10^6	molecular	Radio and infrared molecular emission and absorption lines
Cold Neutral Medium (CNM)	1—5%	100—300	50—100	20—50	neutral atomic	H I 21 cm line absorption
Warm Neutral Medium (WNM)	10—20%	300—400	6000—10000	0.2—0.5	neutral atomic	H I 21 cm line emission
Warm Ionized Medium (WIM)	20—50%	1000	8000	0.2—0.5	ionized	Hα emission and pulsar dispersion
H II regions	< 1%	70	8000	10^2—10^4	ionized	Hα emission and pulsar dispersion
Coronal gas Hot Ionized Medium (HIM)	30—70%	1000—3000	10^6—10^7	10^{-4}—10^{-2}	ionized (metals also highly ionized)	X-ray emission; absorption lines of highly ionized metals, primarily in the ultraviolet

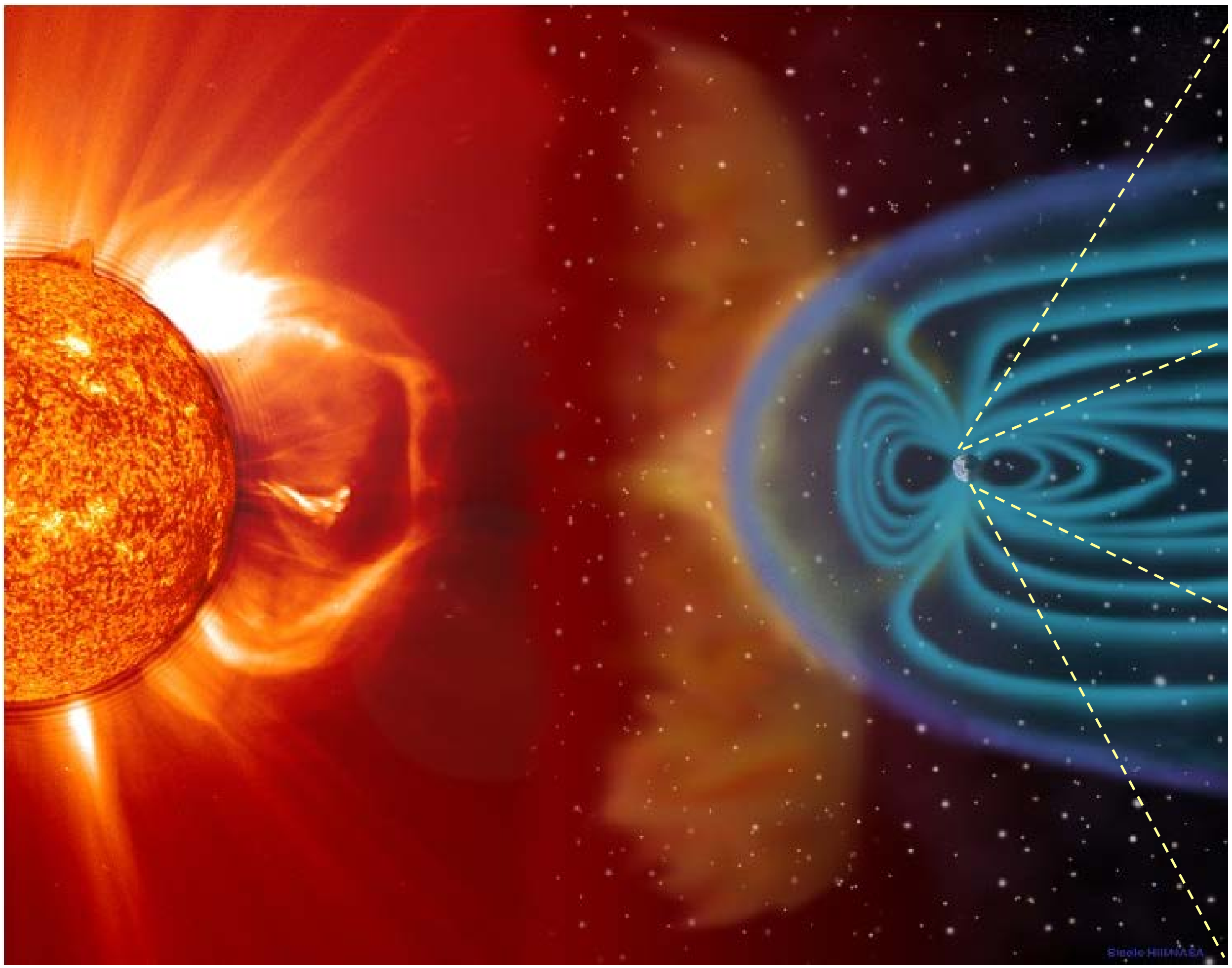
C) O vento estelar e formação das moléculas

O vento estelar tem é essencial para a formação de moléculas circunstelares e interetelares e aumento da complexidade química do meio ionterestelar.



•Vento solar (auroras, tempestades solares,...)

•Vento estelar → formação envoltório circunstelar. Concluinte do meio interplanetário.



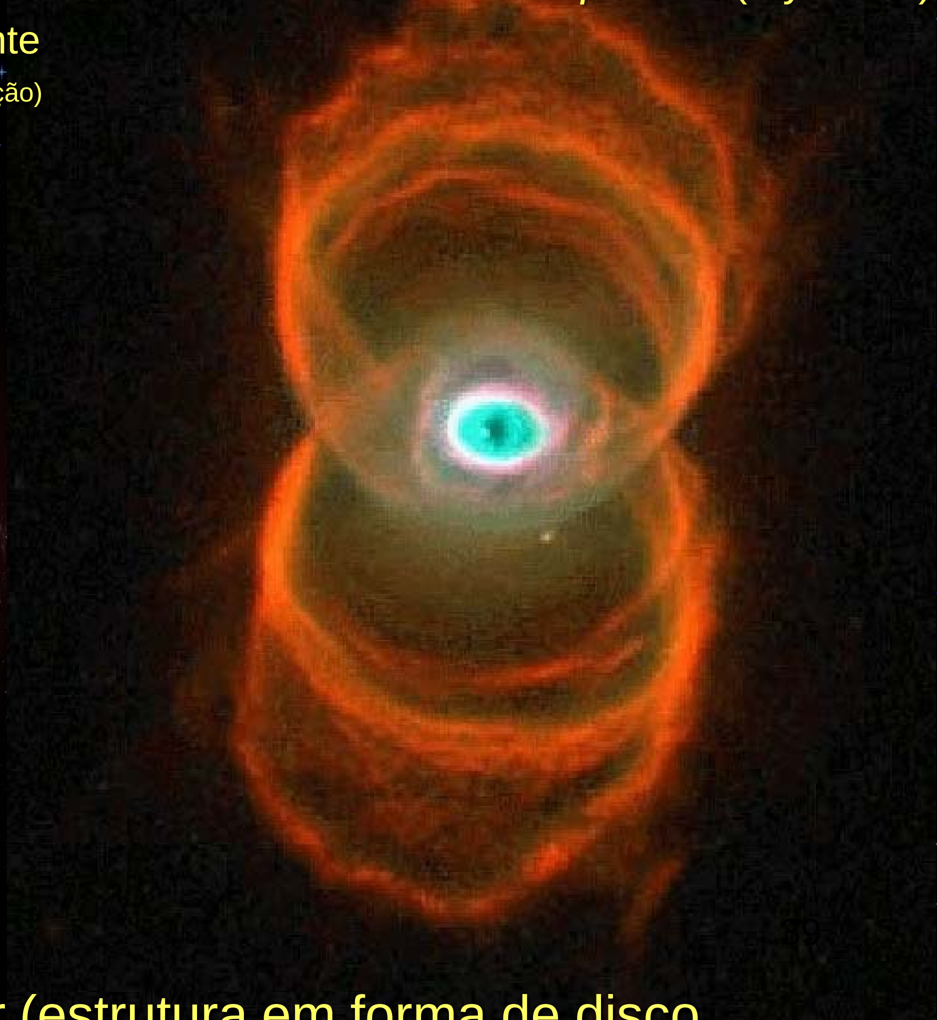
Evolução temporal, aumento da fase de ventos →

Nebulosa Planetária

Nebulosa da Ampulheta (MyCn 18)

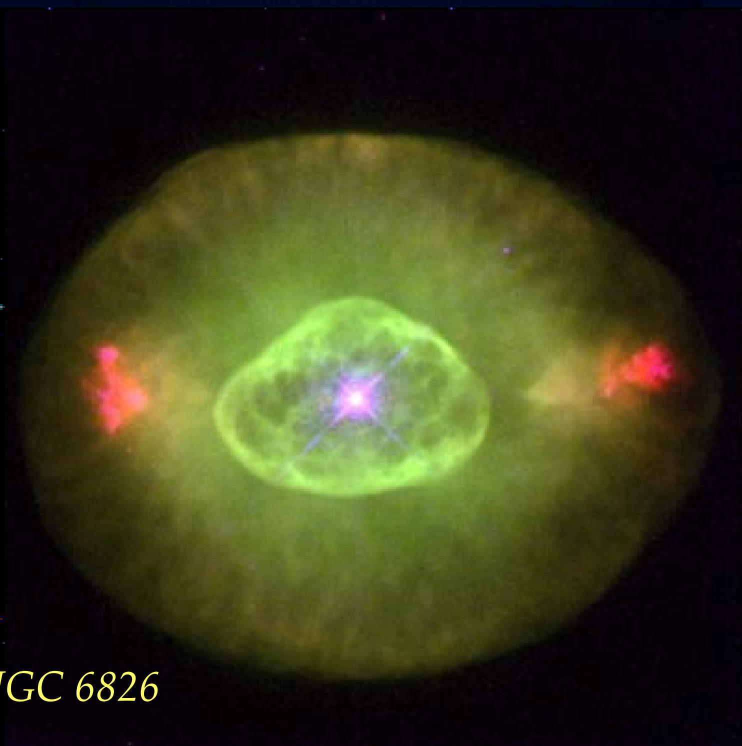
Envoltório de Estrela gigante vermelha M < 8 Msol (ilustração)

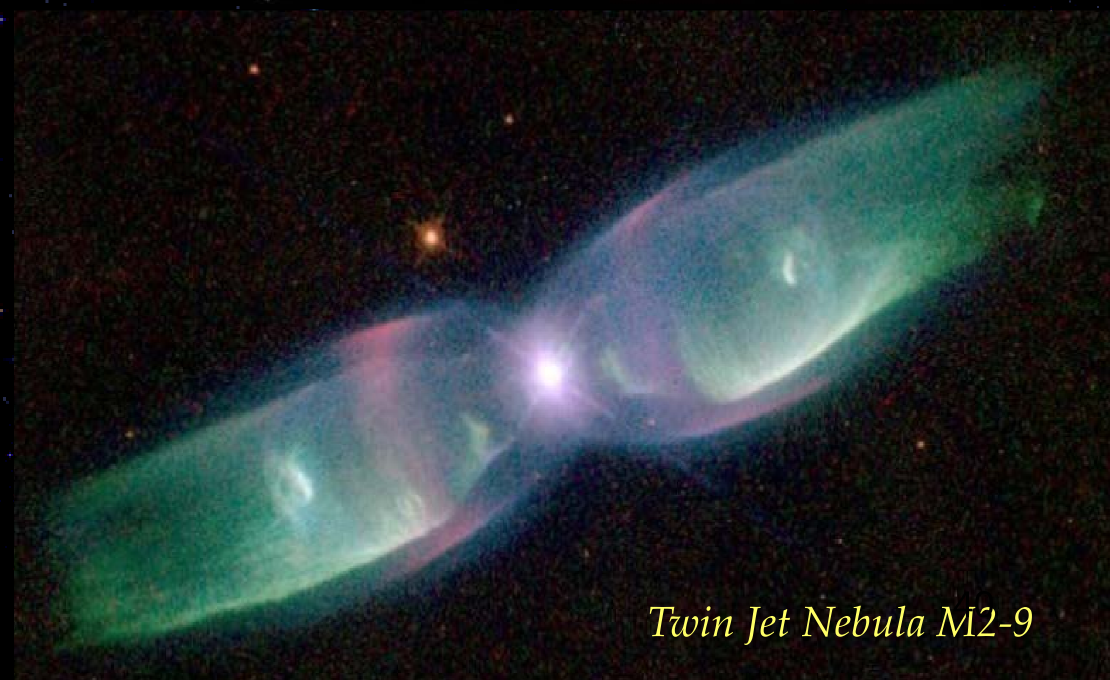
sol



Vento estelar → material circunstelar (estrutura em forma de disco, esférica, bipolar, jatos polares) → meio interestelar

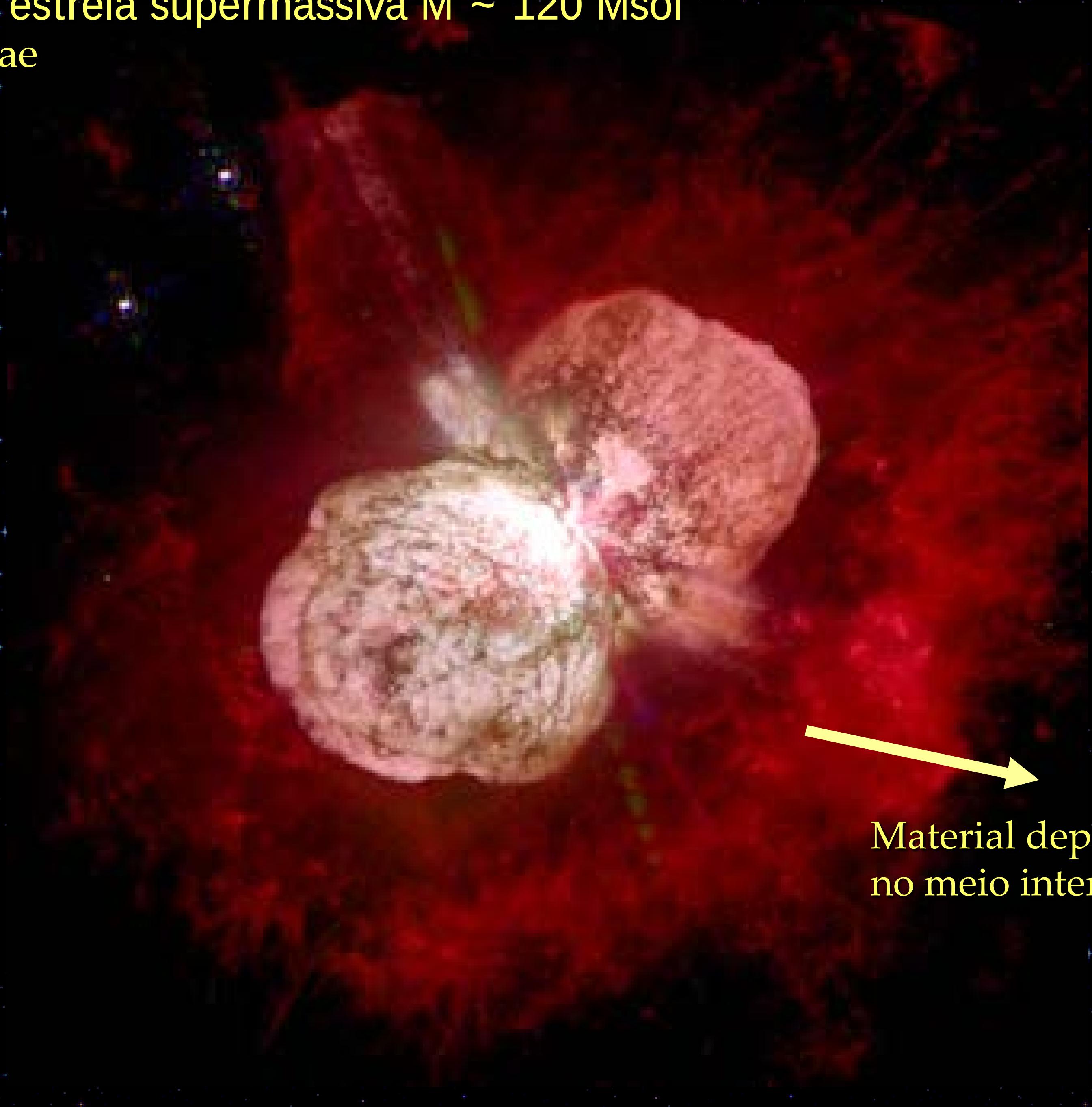
Mais ventos de nebulosa Planetárias





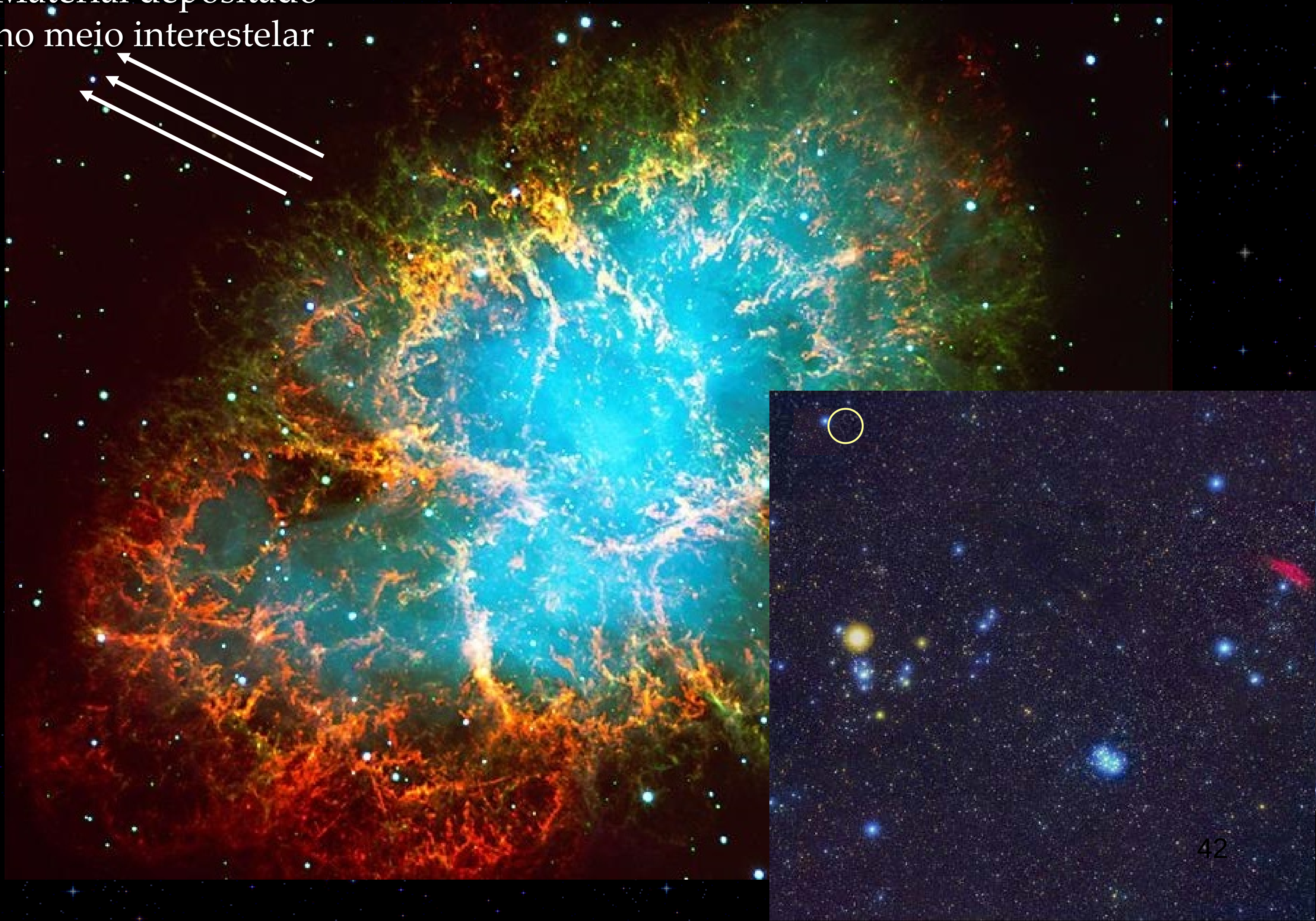
Vento de estrela supermassiva M ~ 120 Msol

Eta Carinae

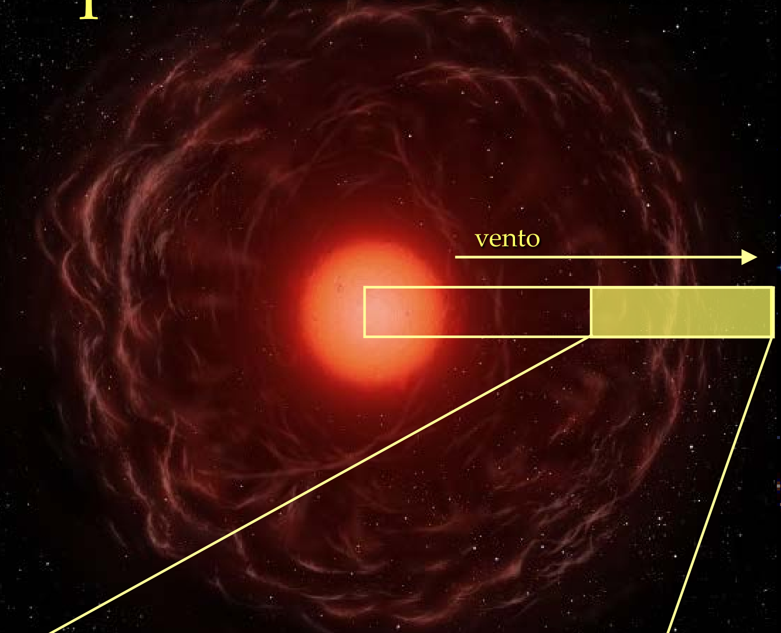


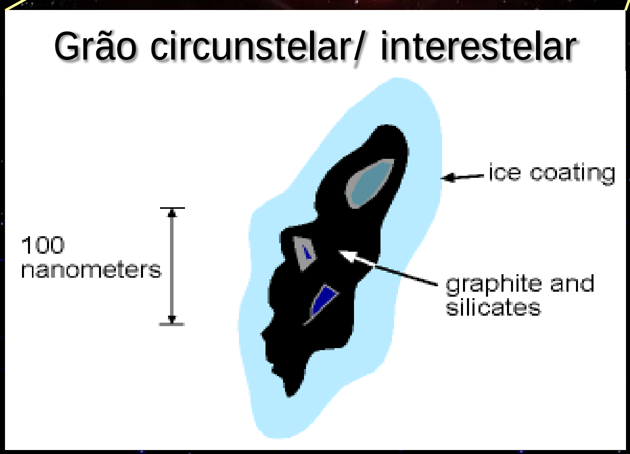
Ventos de uma remanescentes de supernova
nebulosa do caranguejo

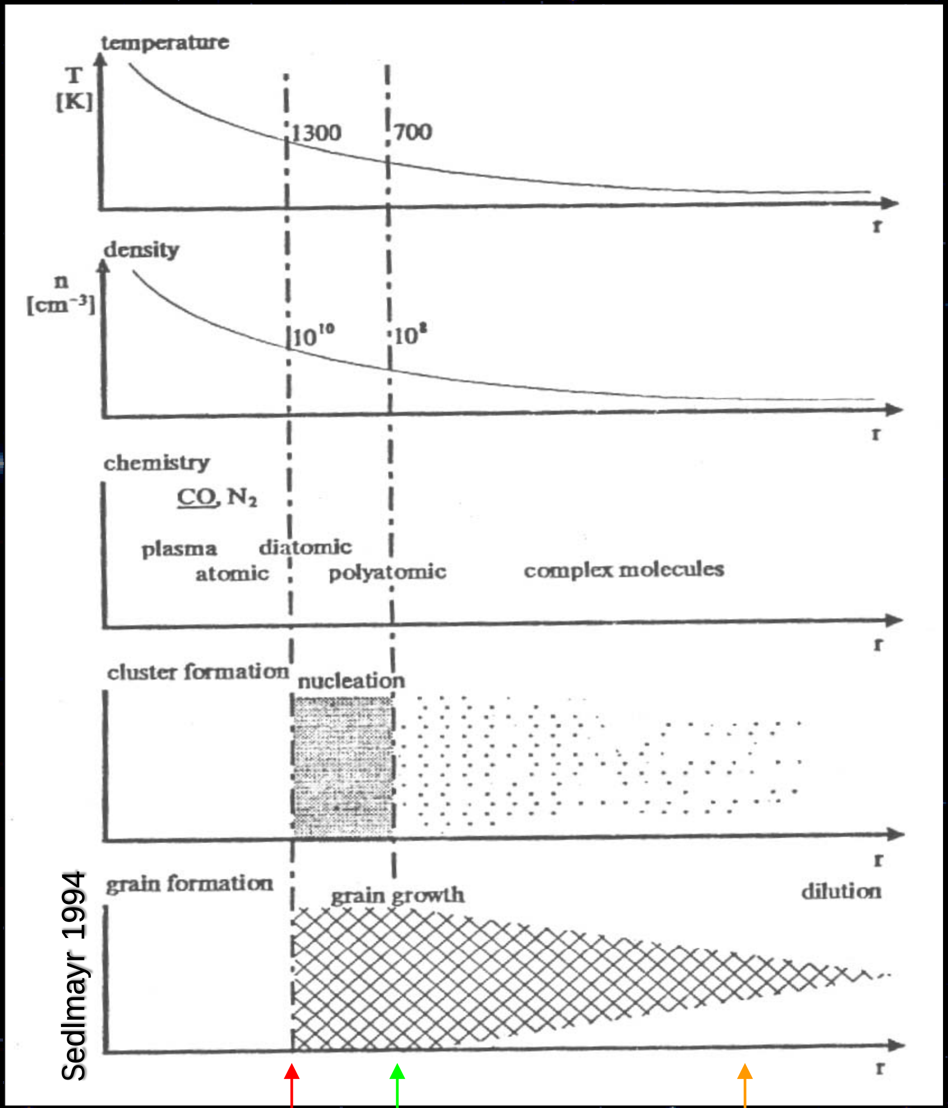
Material depositado
no meio interestelar

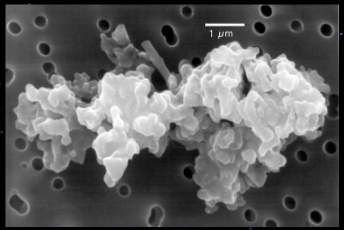


A poeira interestelar





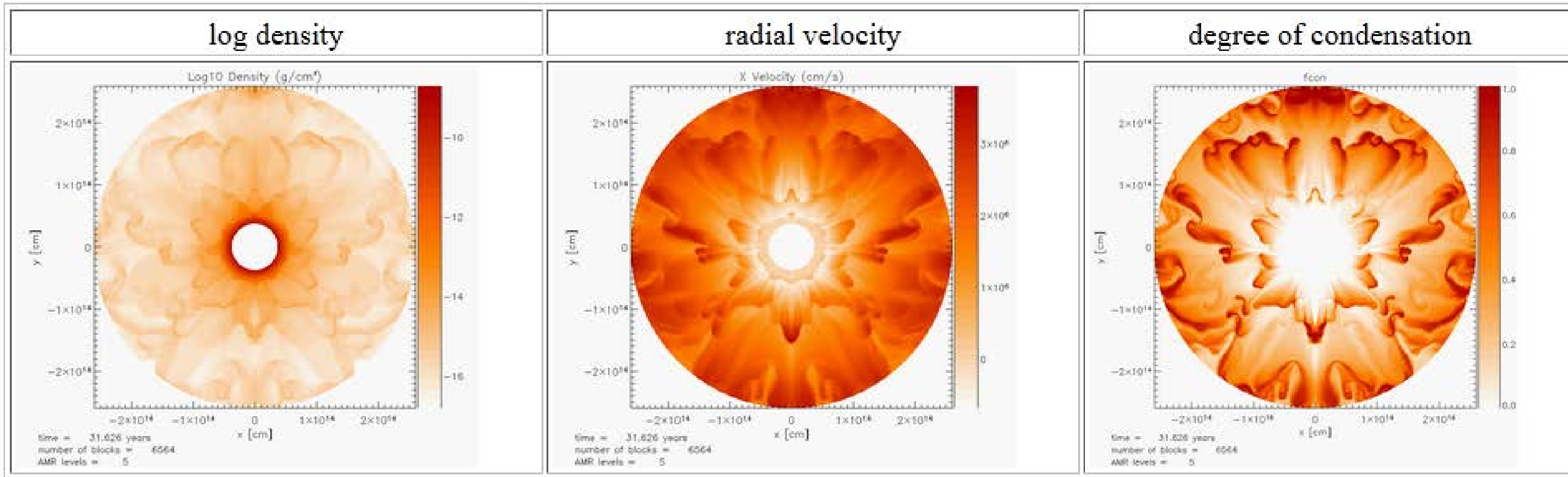


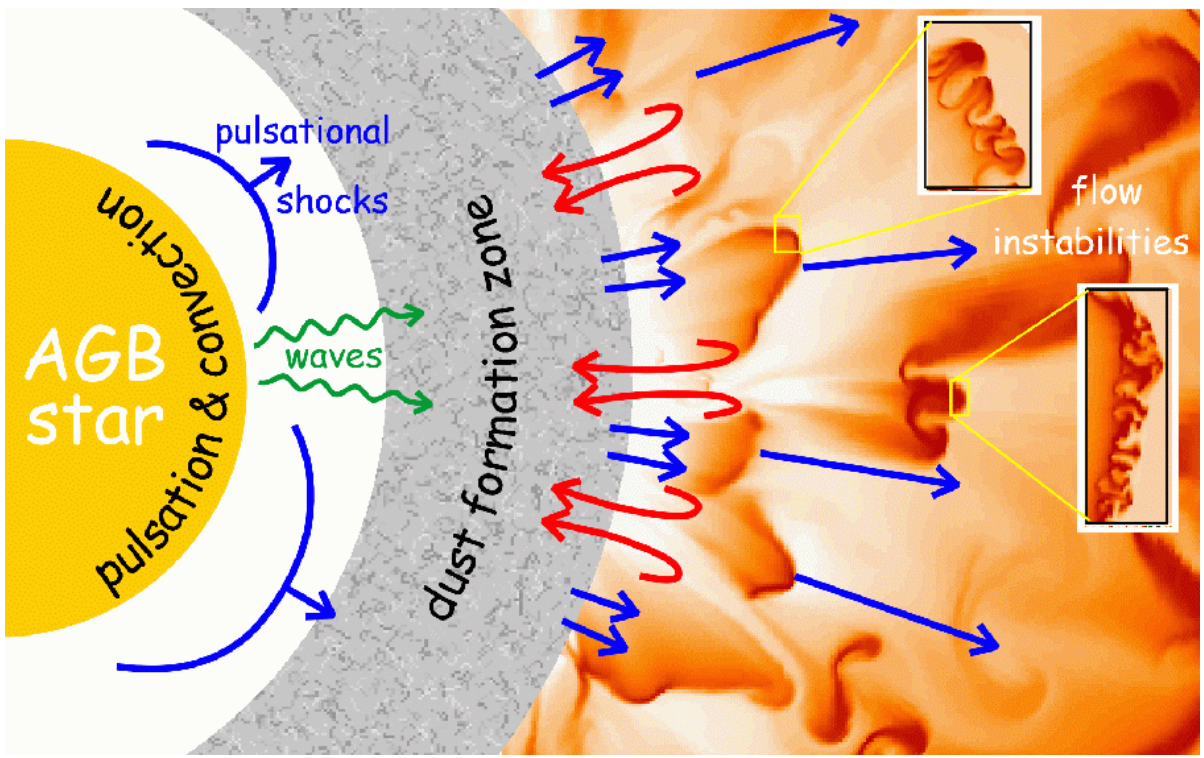


Al_2O_4 (temp ~ 1700K); silicatos (temp ~ 1400K)

Moléculas carbonaceas (C, PAHs, SiC)

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

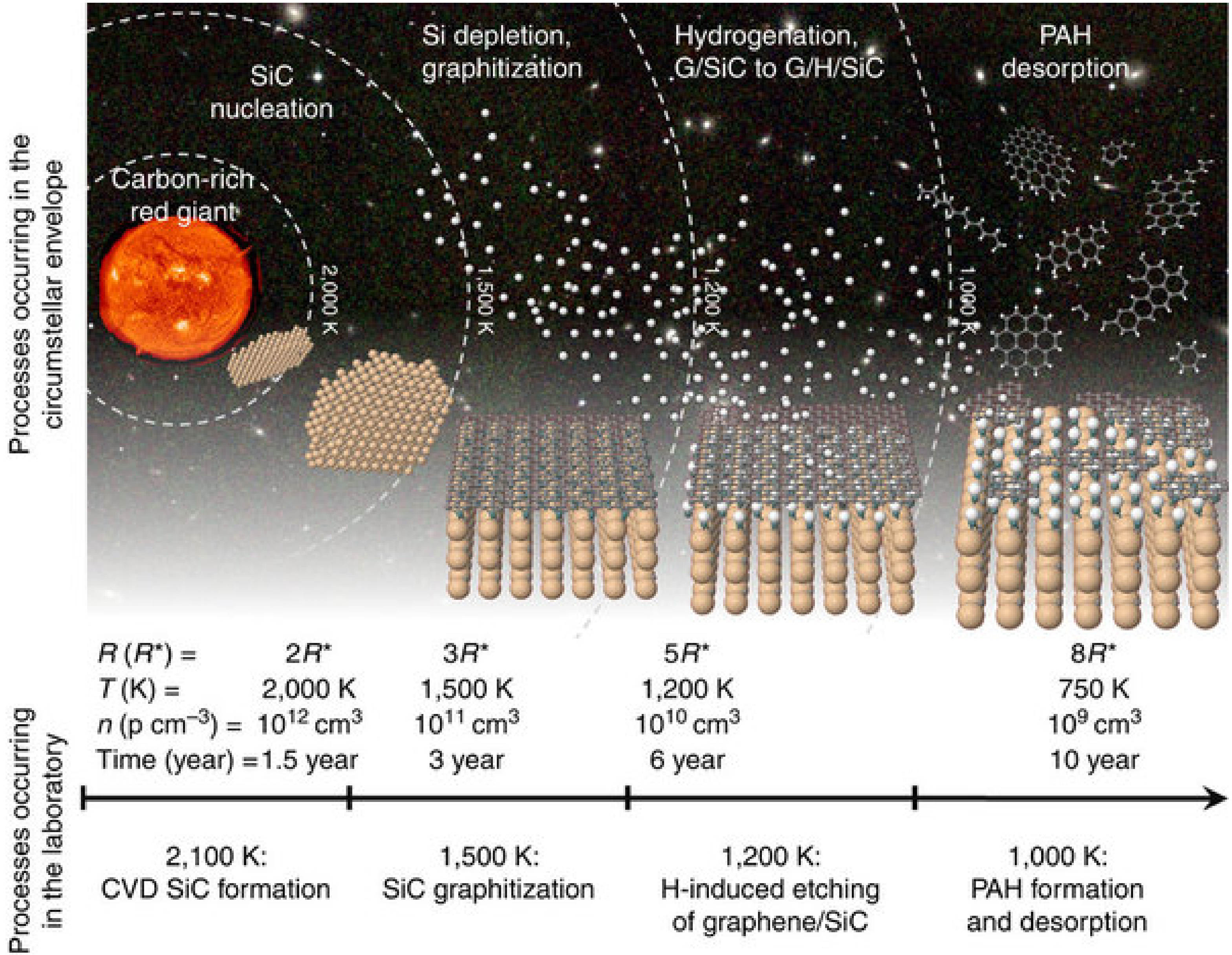




Ver vídeos:

http://homepage.univie.ac.at/peter.woitke/AGB_popular.html

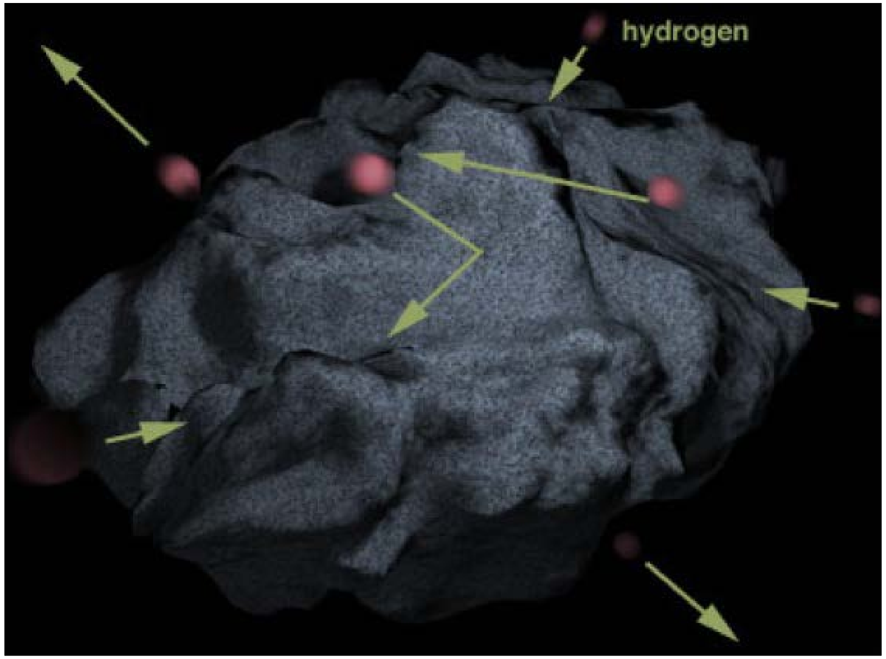
Merino et al. Nature 2013

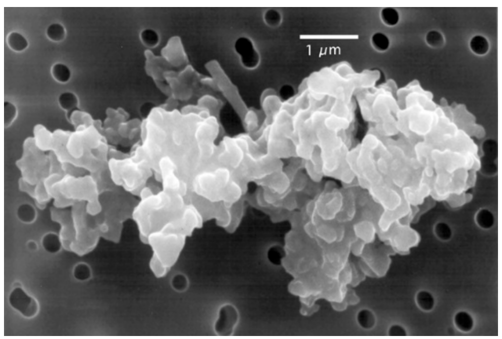


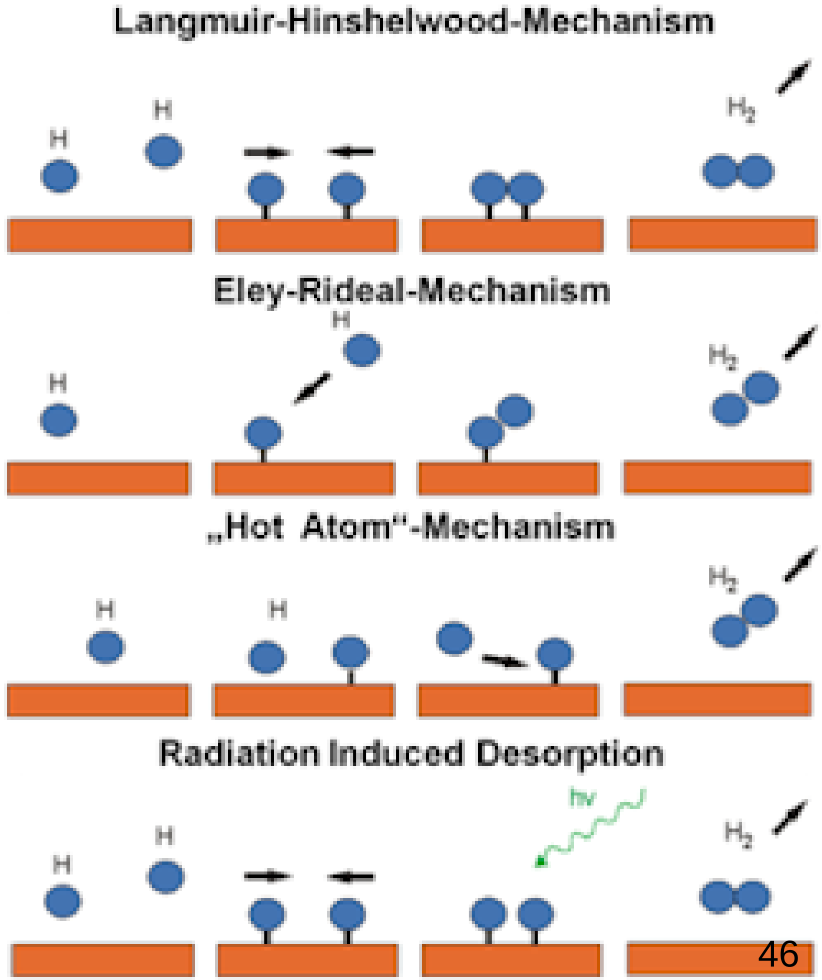
Grãos interestelares e a formação do H_2

-Probabilidade de reação na fase gasosa baixa.

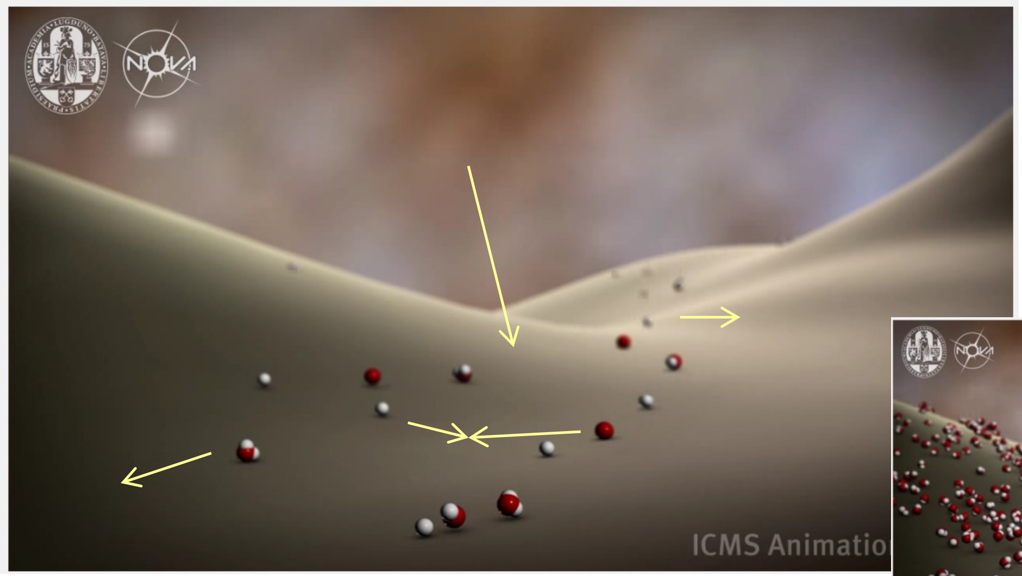
- Grãos (T~10K) agem como catalisadores.

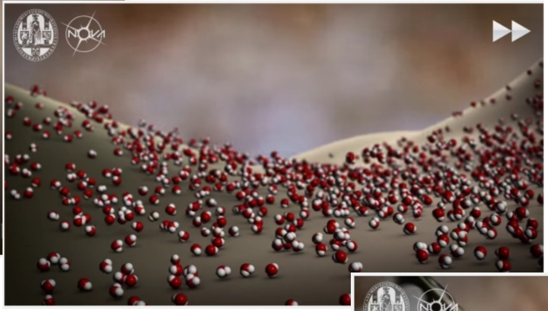






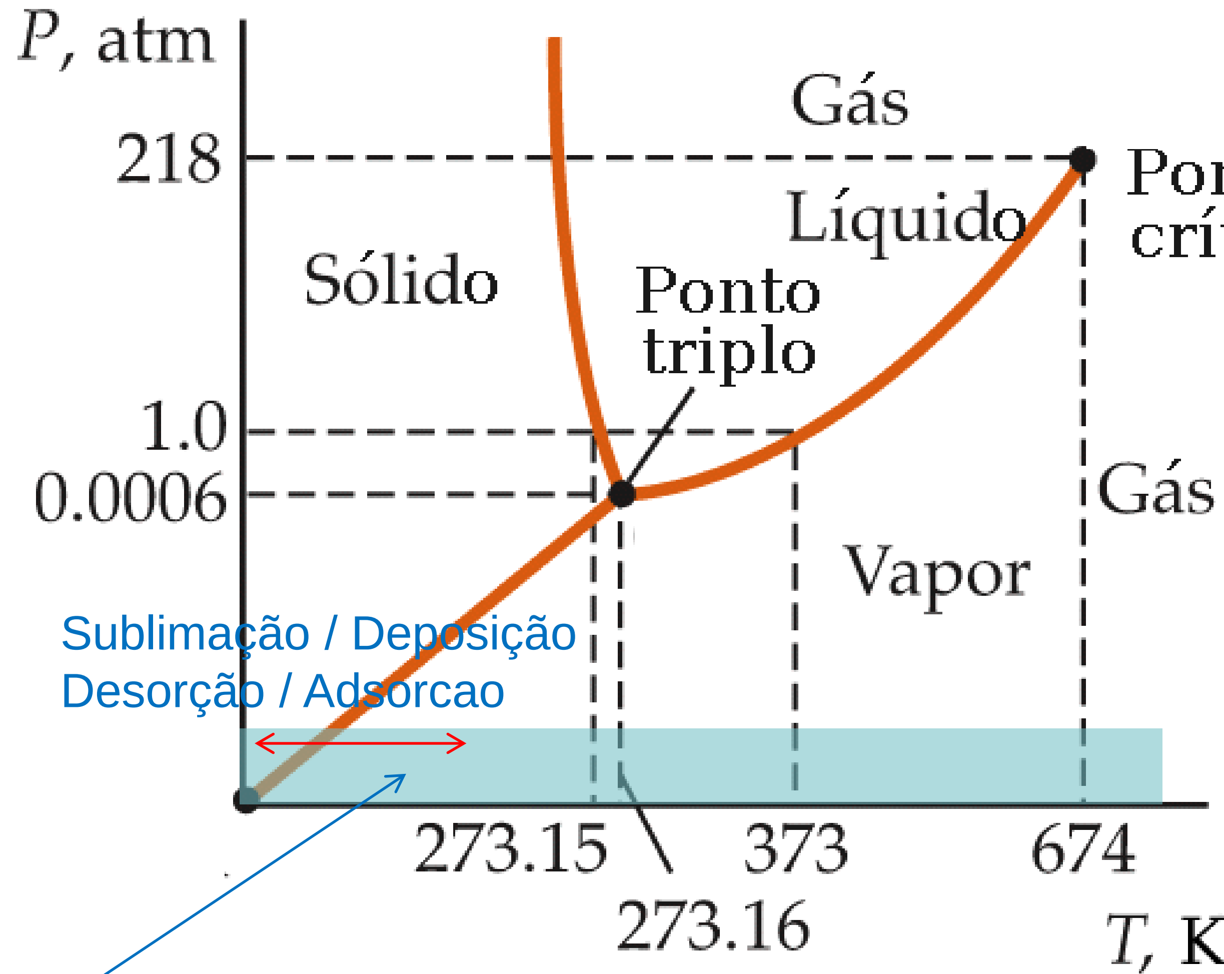
Formação de gelos de água no espaço





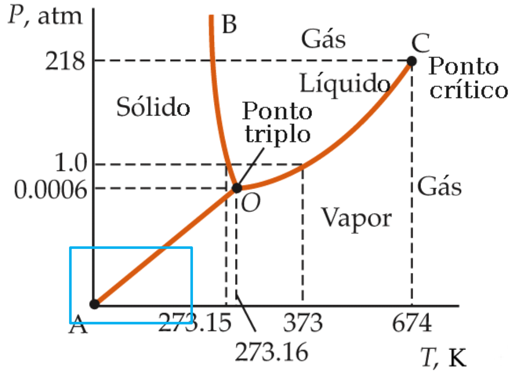
Ver vídeo:

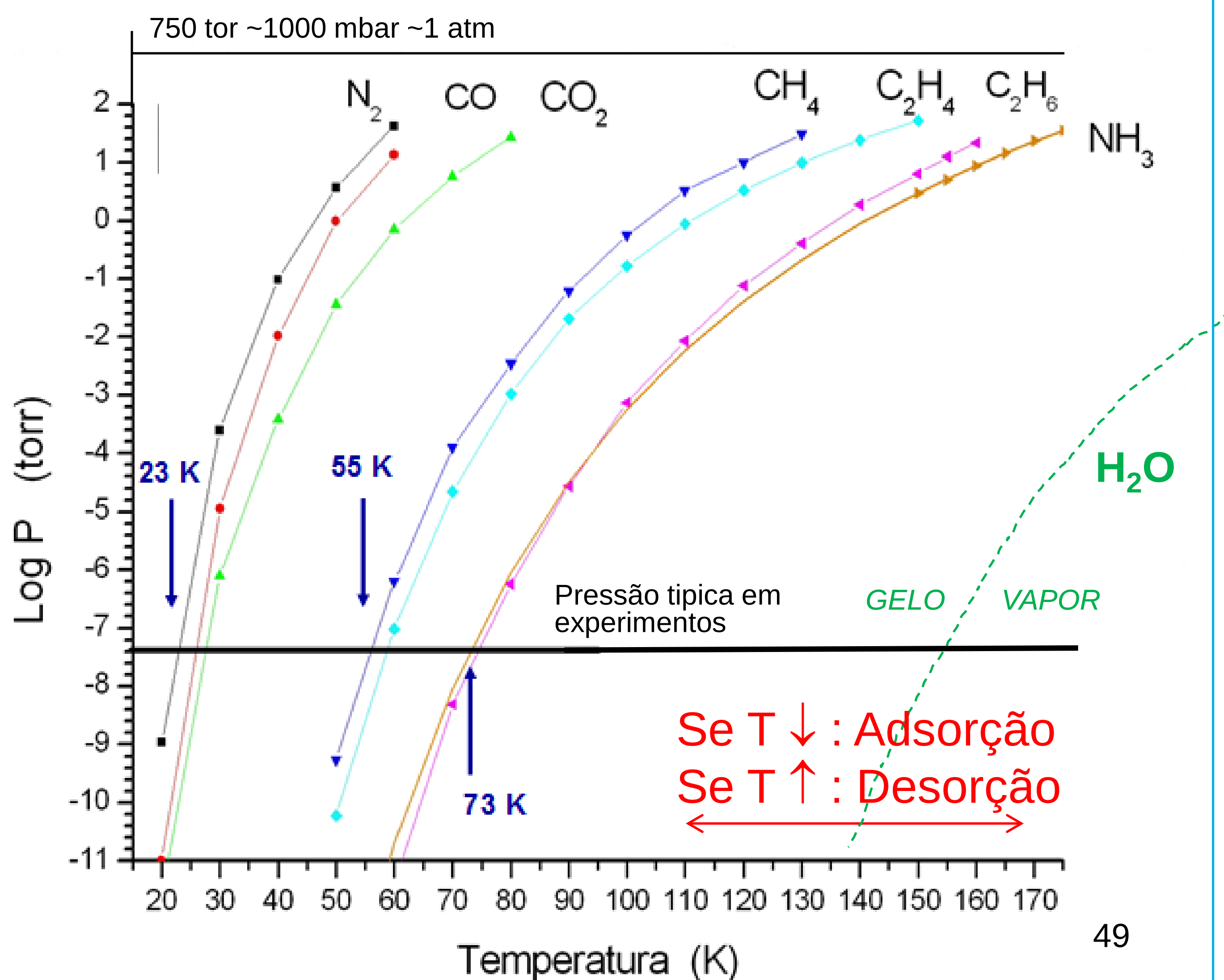
Diagrama de Fase e Pressão de Vapor



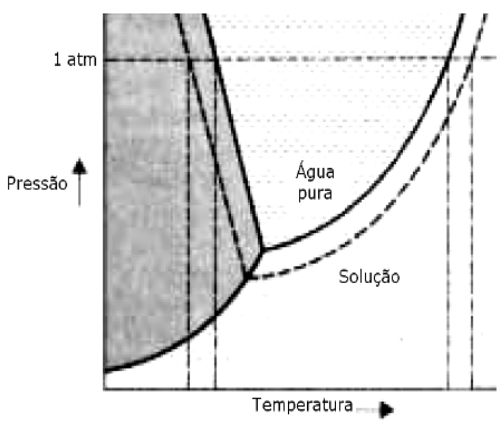
No espaço!!!

Diagrama de Fase e Pressão de Vapor





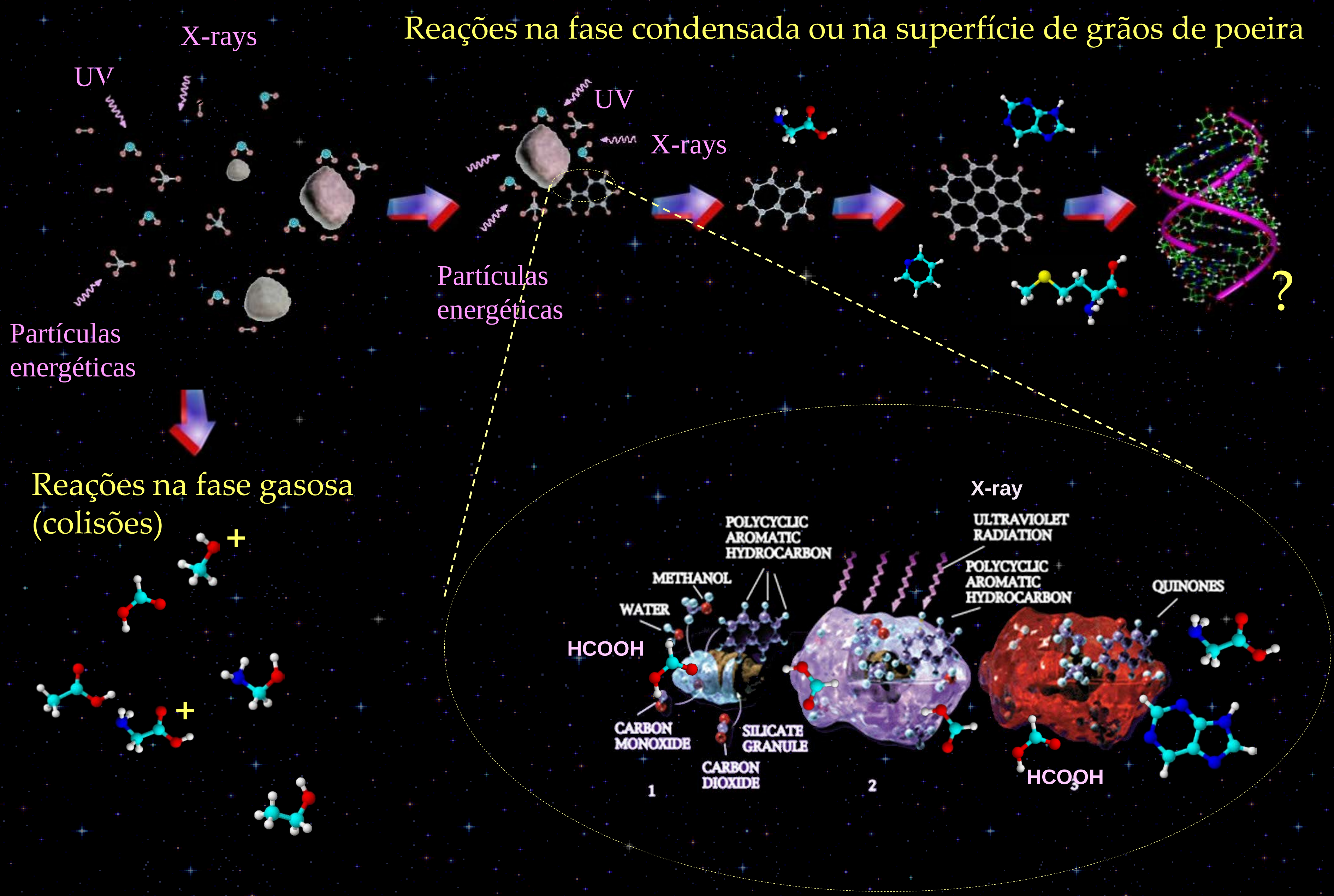
Obs: Soluções



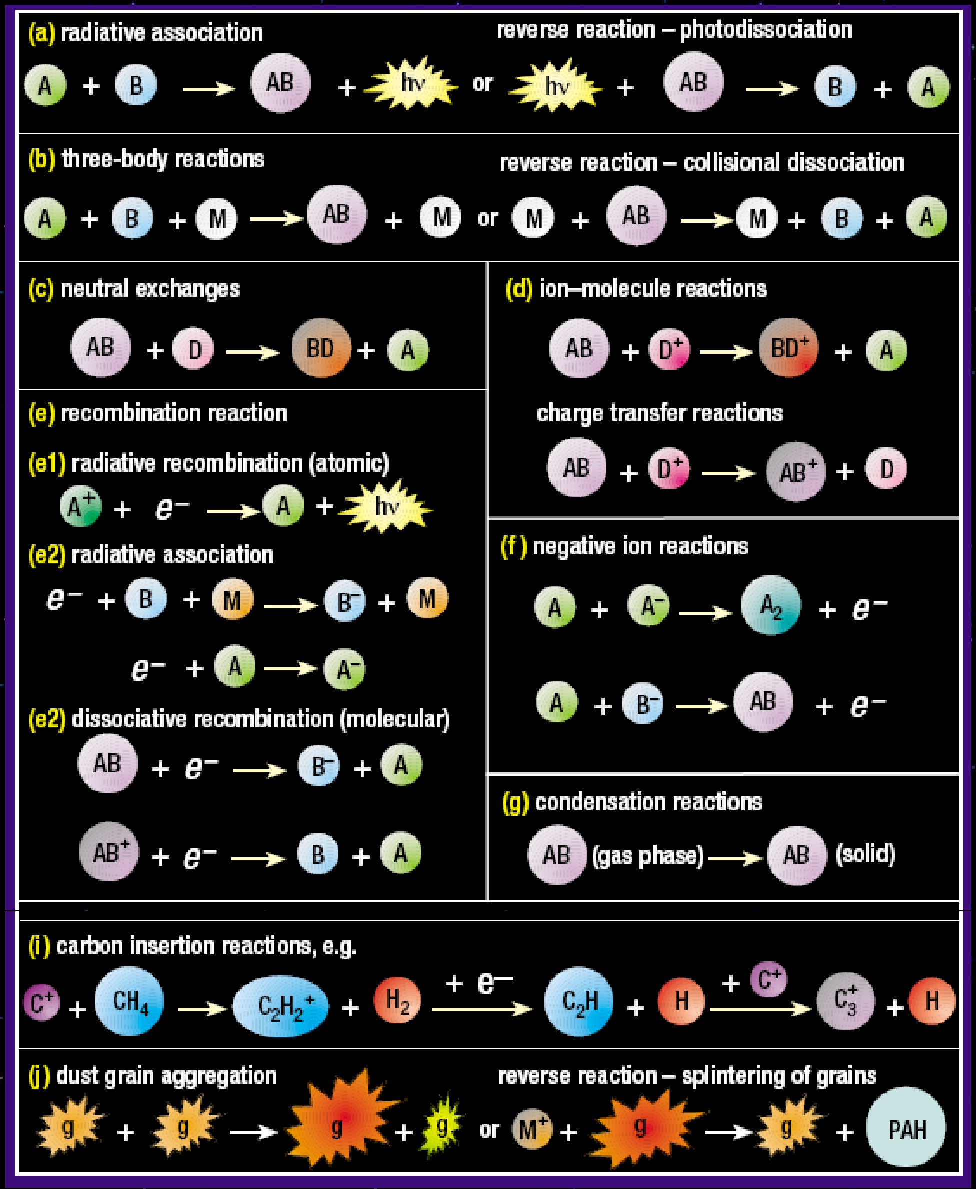
Faixas de Pressão

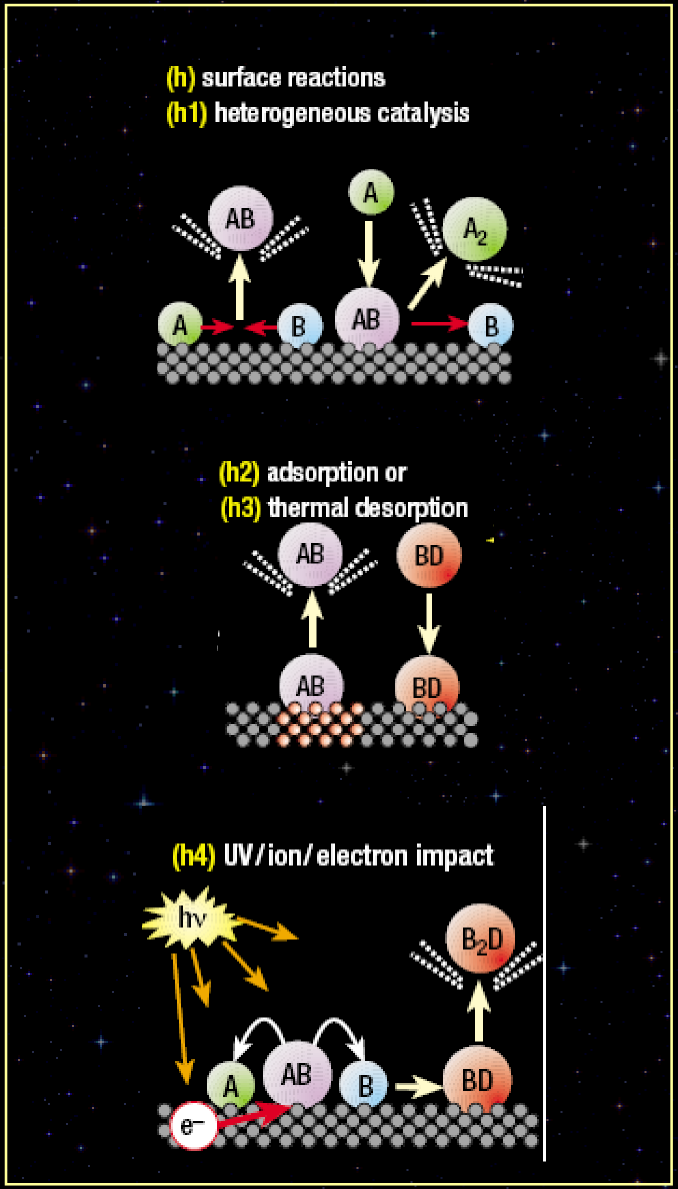
Meio interestelar
10^{-12} a 10^{-18} mbar
10^{4} a 10^{-2} cm^{-3}

Formação de outras moléculas no espaço

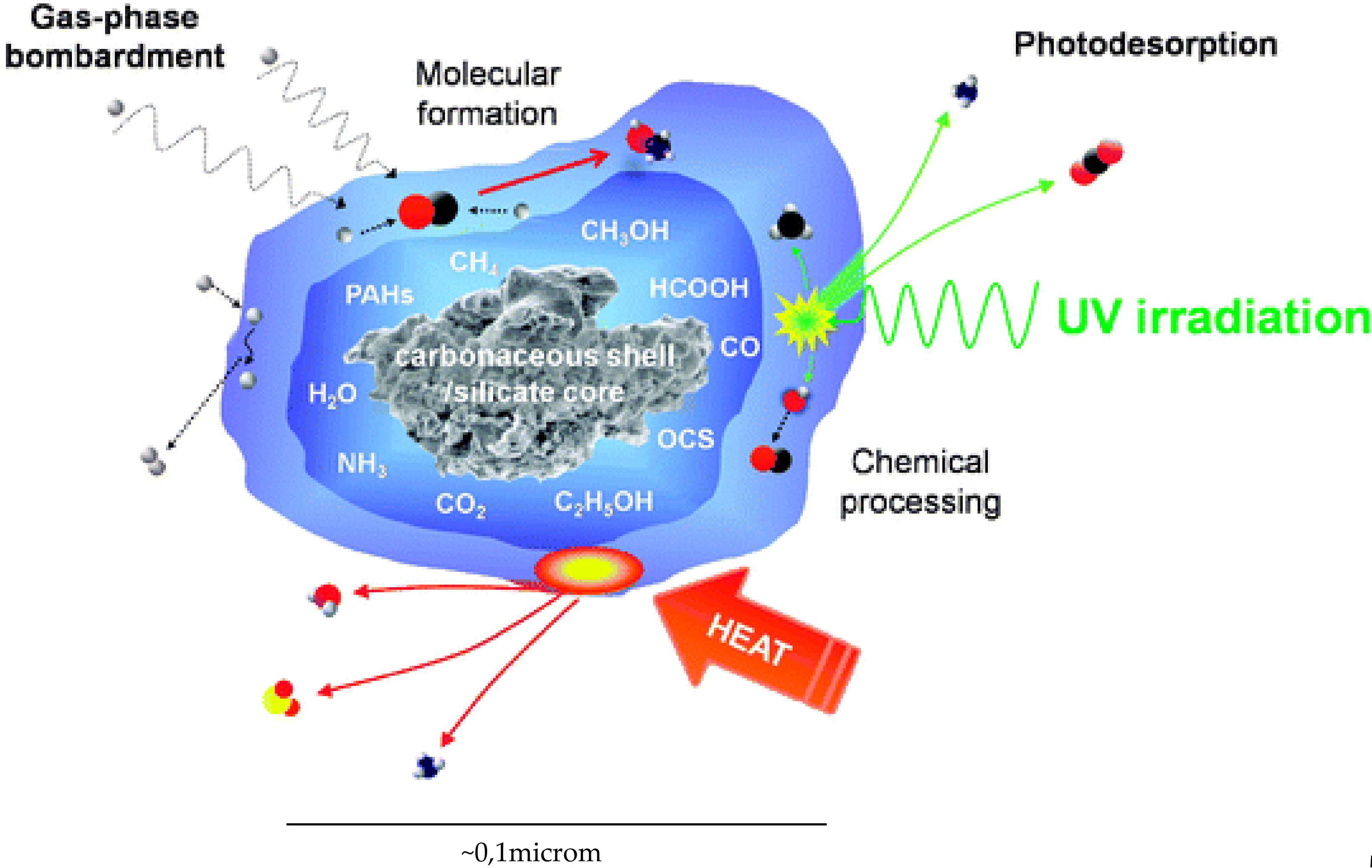


Algumas reações típicas na fase gasosa e fase condensada.



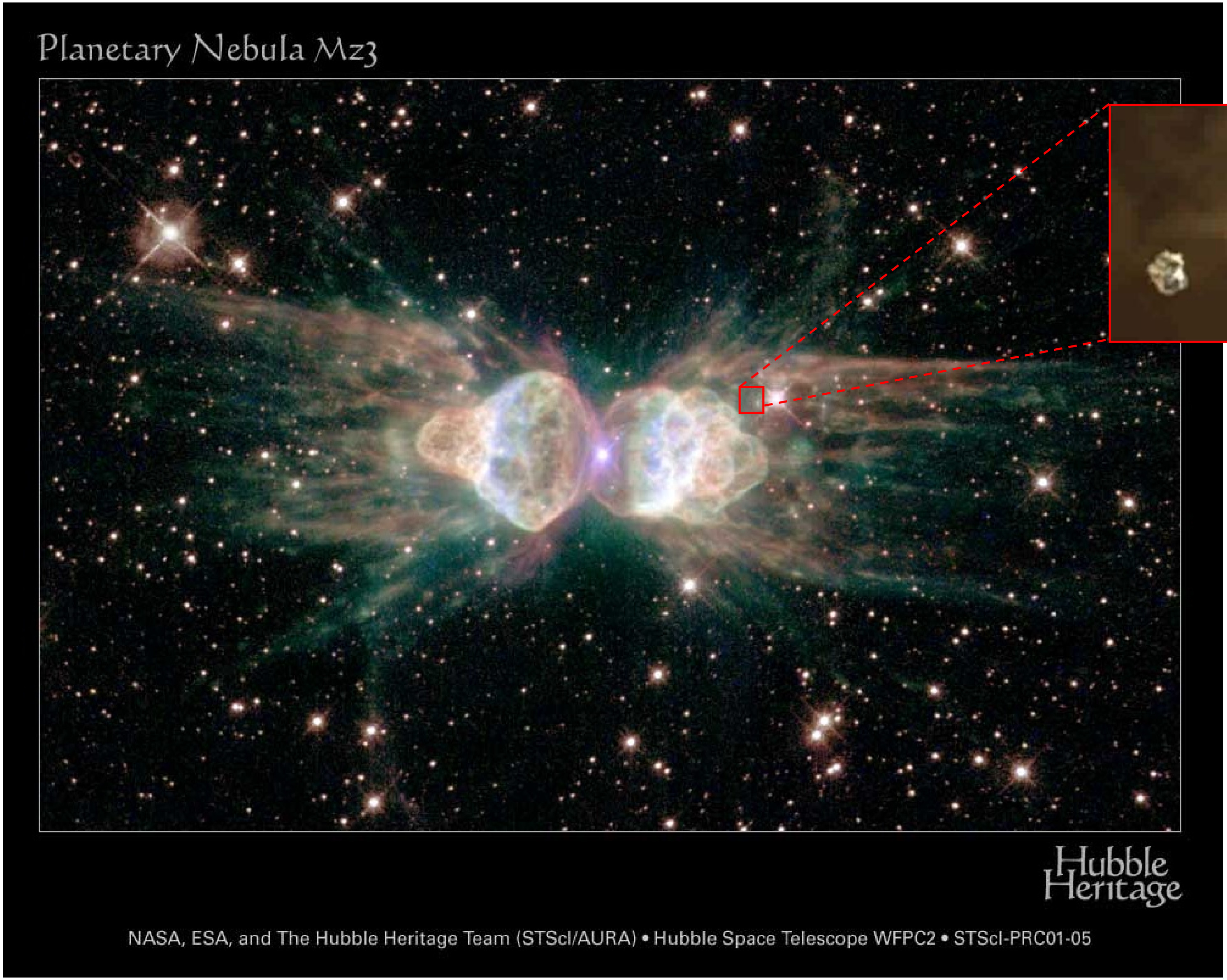


Grão interestelar típico (coberto por um manto de gelo)



Mais sobre gelos astrofísicos

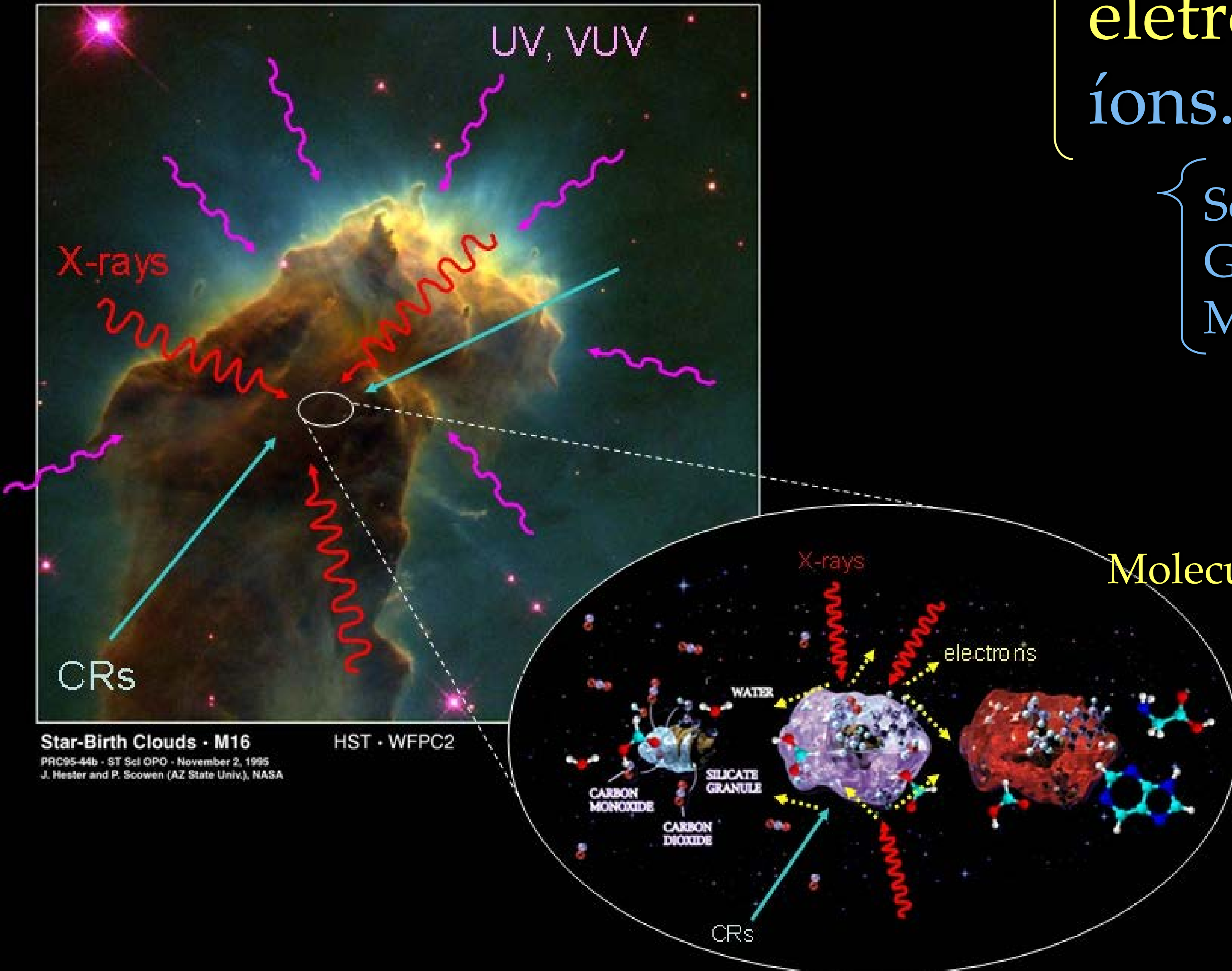
- Grãos de poeira fria: núcleos de silicatos/carbono + cobertura de moléculas voláteis condensadas (H_2O, CO, N_2, NH_3, etc...)


Planetary Nebula Mz3
Hubble Heritage
NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope WFPC2 • STScI-PRC01-05

Processamento pela Radiação:

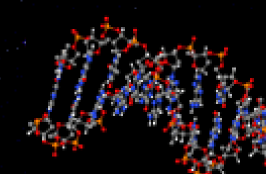
Fótons,
eletrons,
íons.

Sol,
Galáxia,
Magnetosfera.

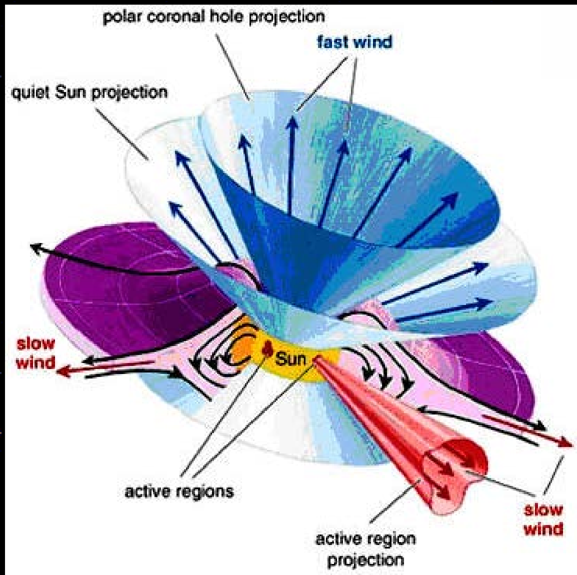


Moleculas complexas!
- Aminoácidos.

Peptídeos,
RNA, DNA?



Vento solar (íons baixa energia)



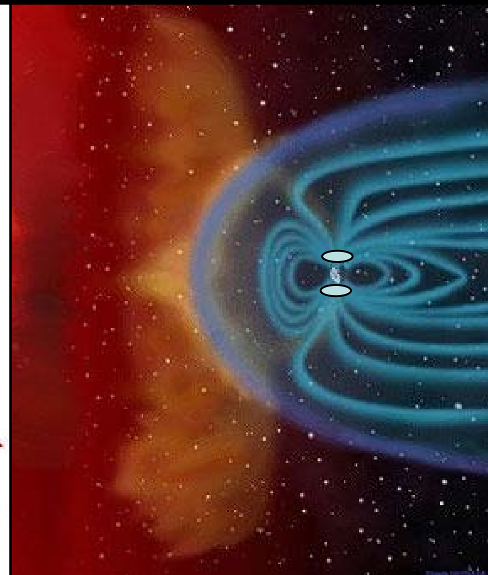


Table 1. Averaged properties of solar wind at 1 au (adapted from Kroll & Trivelpiece 1973, Toptygin 1985 and Zirin 1988).

Properties	Quiet times	Disturbed times
Density[a]	$\sim$10 ions cm^{-3}	20–40 ions cm^{-3}
Bulk speed	$\sim$450 km s^{-1} (100–600 km s^{-1})	$\sim$750 km s^{-1} (700–900 km s^{-1})
Ion temperature	$\sim 8 \times 10^4$ K	$\sim 3 \times 10^5$ K
Proton energy	$\sim$0.6 keV	$\sim$3 keV (1–10^4 keV)
Electron energy	$\sim$0.3 eV (0.1–10^4 eV)	$\sim$1.5 eV (0.1–10^4 eV)
Magnetic field	$3–8 \times 10^{-5}$ G	$10–30 \times 10^{-5}$ G
Energy flux	$\sim$0.5 erg cm^{-2}	$\sim$15 erg cm^{-2}

[a]95 per cent H^+, 4 per cent He^{++} and traces of C, N, O, Ne, Mg, Si and Fe ions.

Pilling et al. 2006, MNRAS, 372, 1379,

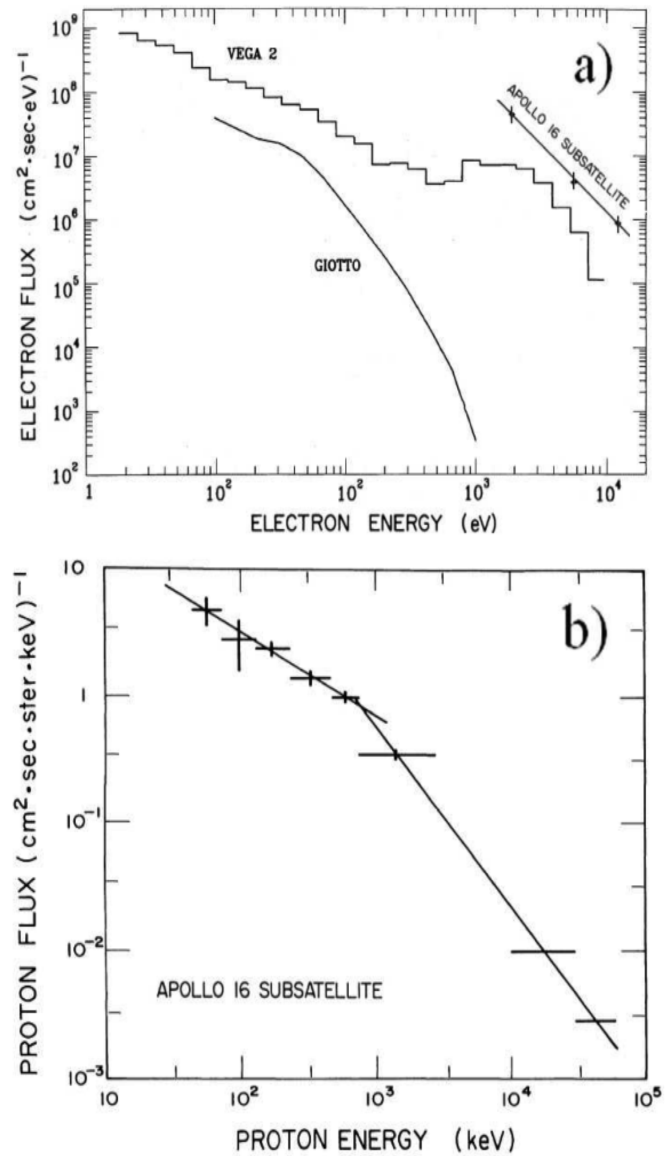
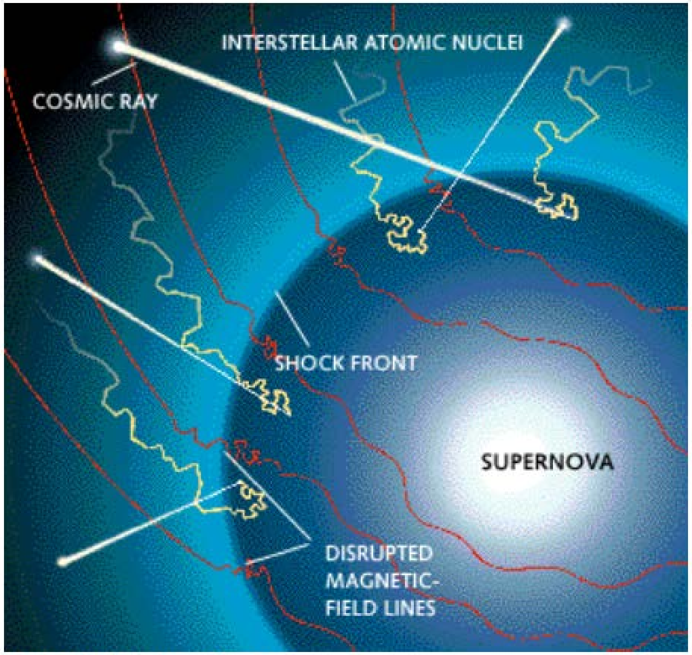
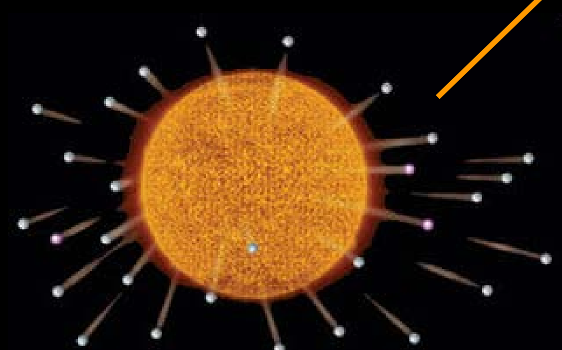


Figure 1. (a) Electron fluxes in comet Halley measured by the Vega 2 (Gringauz et al. 1986), Giotto (D'Uston et al. 1989) and at lunar orbit measured by APOLLO 16 subsatellite (adapted from Lin et al. 1974). (b) The proton energy spectrum due to solar wind at lunar orbit measured by APOLLO 16 subsatellite (Lin et al. 1974).

Raios cósmicos e partículas enérgicas do vento solar



Credit: George Kelvin



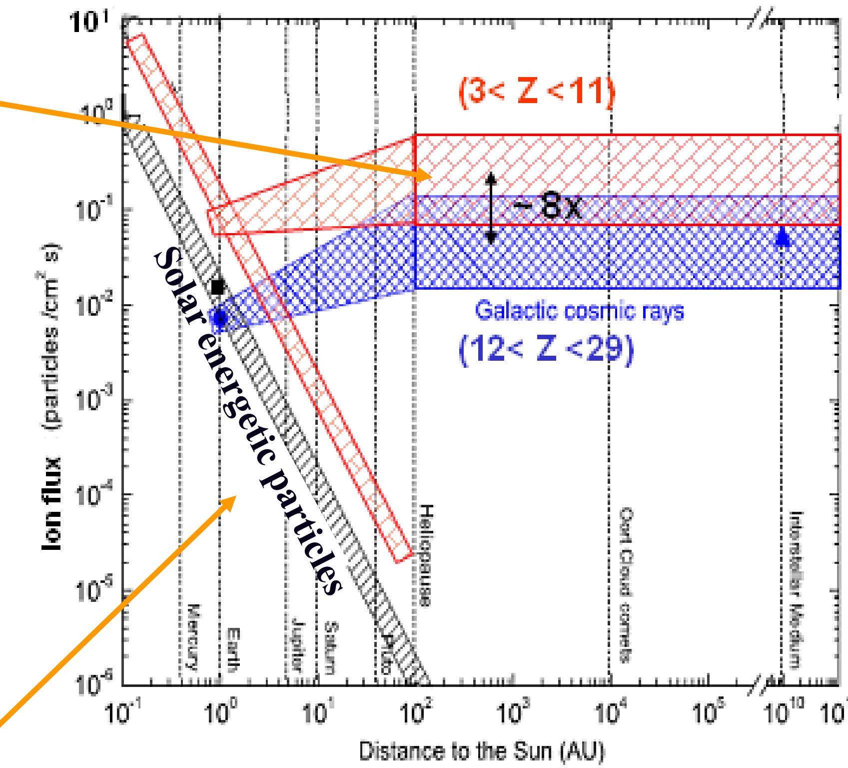


Fig. Estimated value of the integrated ion flux **(3< Z<11)** and (12 ≲ Z ≲ 29) with energy between 0.1-10 MeV/u inside solar system and at interstellar medium as a function of distance to the Sun. Both Galactic cosmic rays and solar wind particles are displayed. Square: integrated flux of solar wind ions. Circle and triangle: integrated flux of cosmic rays.

Pilling et al. 2011, PCCP

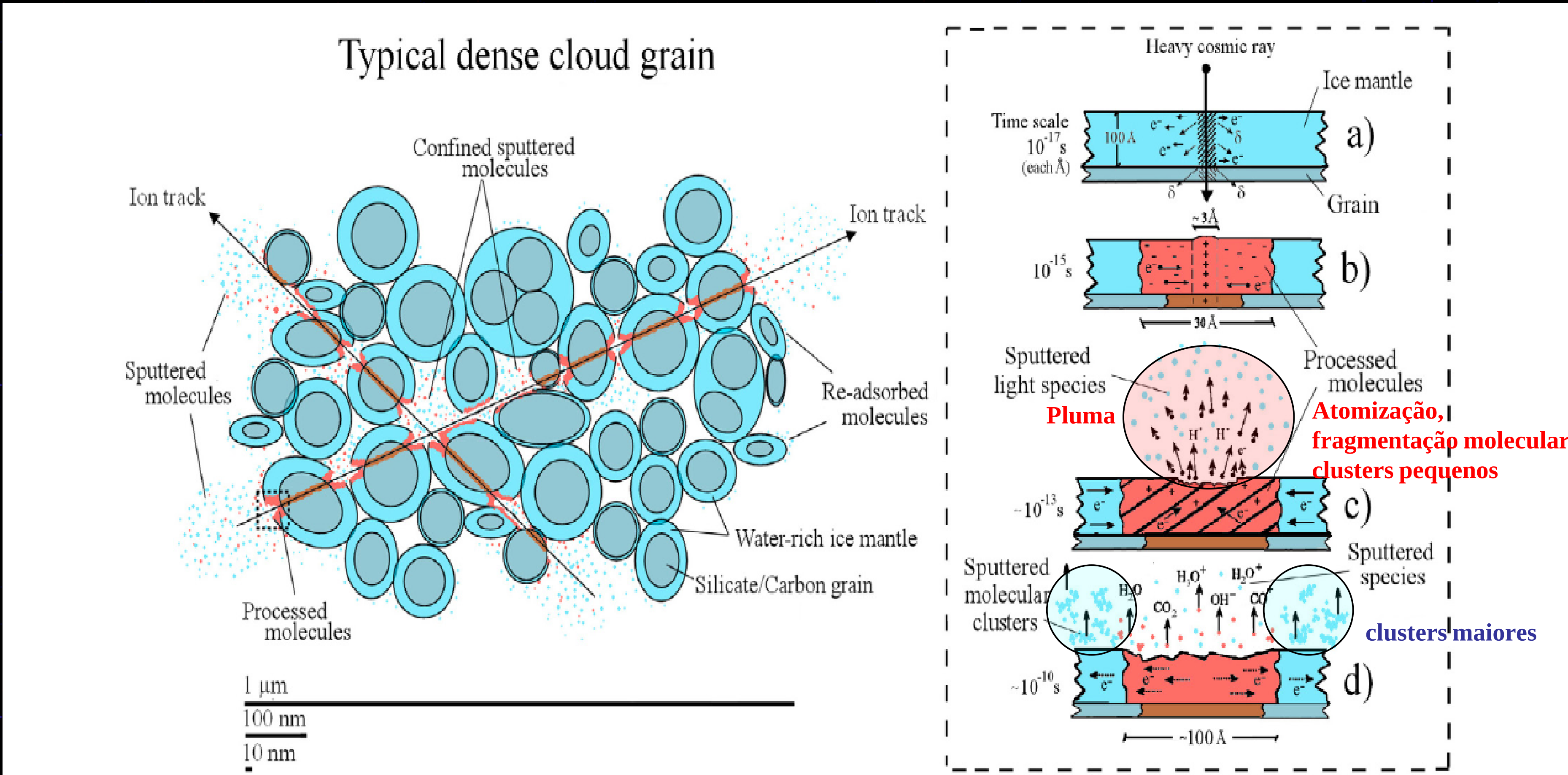
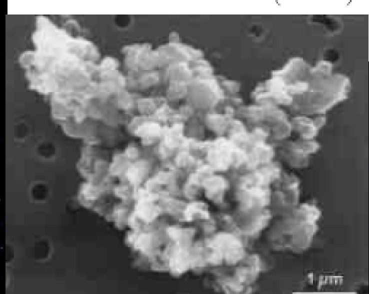


Fig. 7. Schematic view showing the interaction between a heavy-ion cosmic ray and a typical interstellar grain inside dense clouds. The ion track along the coagulate sub-micron size grains, the grain mantles, the processed and the sputtered molecules are indicated. Figure insets were adapted from Andrade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



Dust grain or IDP, interstellar dust particle
Credit: UWSTL, NASA Hubble

Pilling et al. 2010, A&A

Radiólise → Elétrons secundários → Energia extra no sistema.

Atomizacão, moléculas novas, sputtering, clusters

D) Como essas moléculas são detectadas?

Telescopios Infravermelhos
(bandas vibracionais)

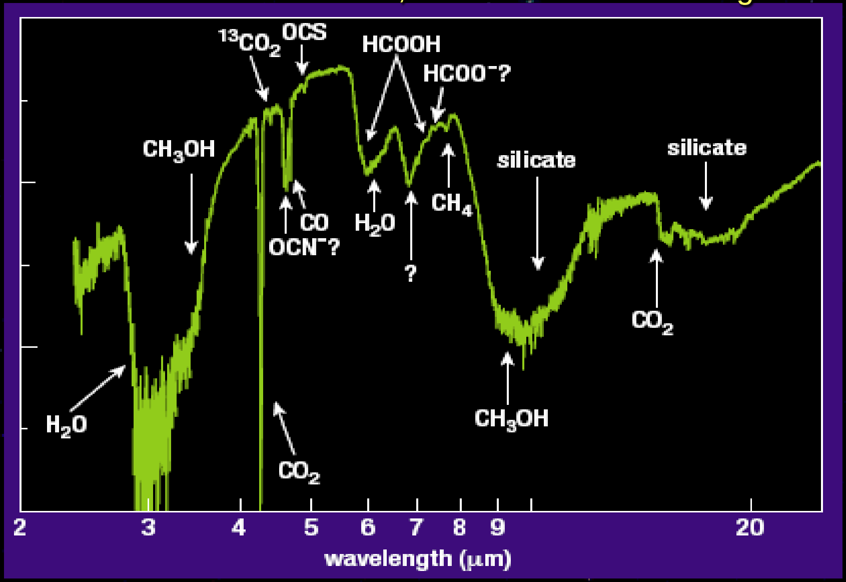
GEMINI Sul (8.1m)

ISO

SPITZER

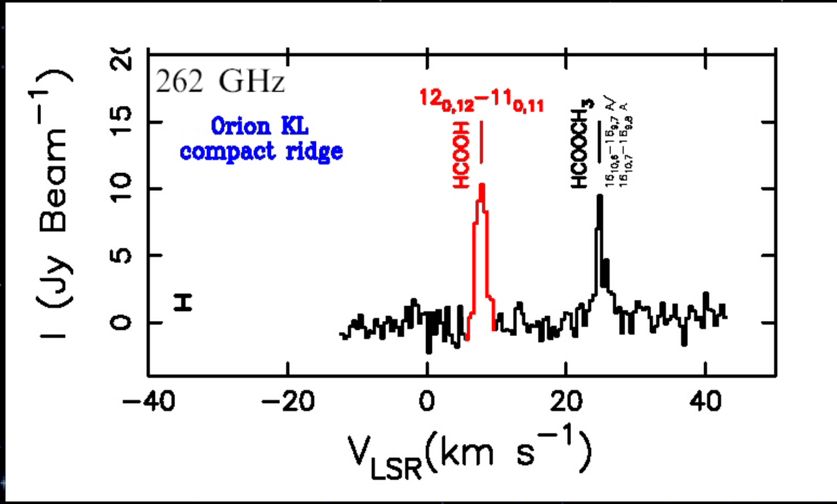
SOAR (4.2m)

W33a, Proto estrela – Gelo orgânico!

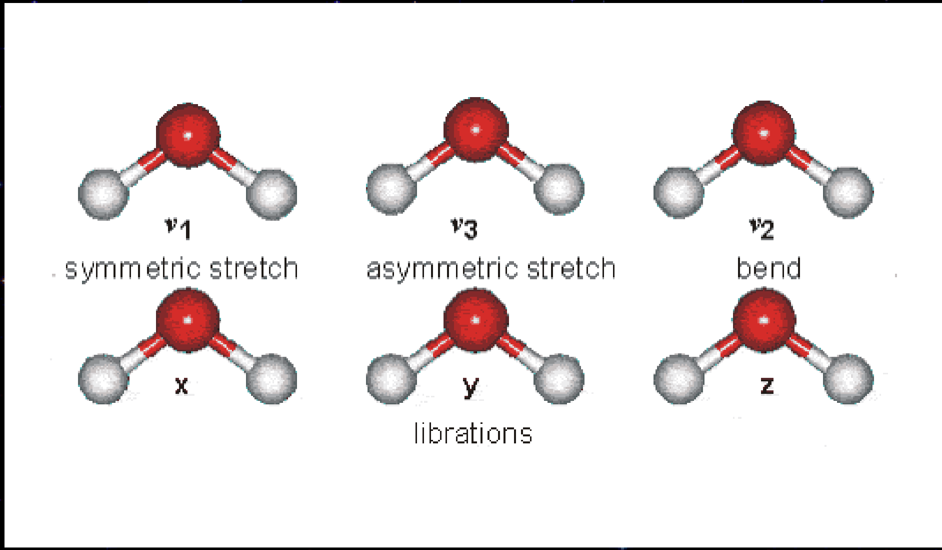


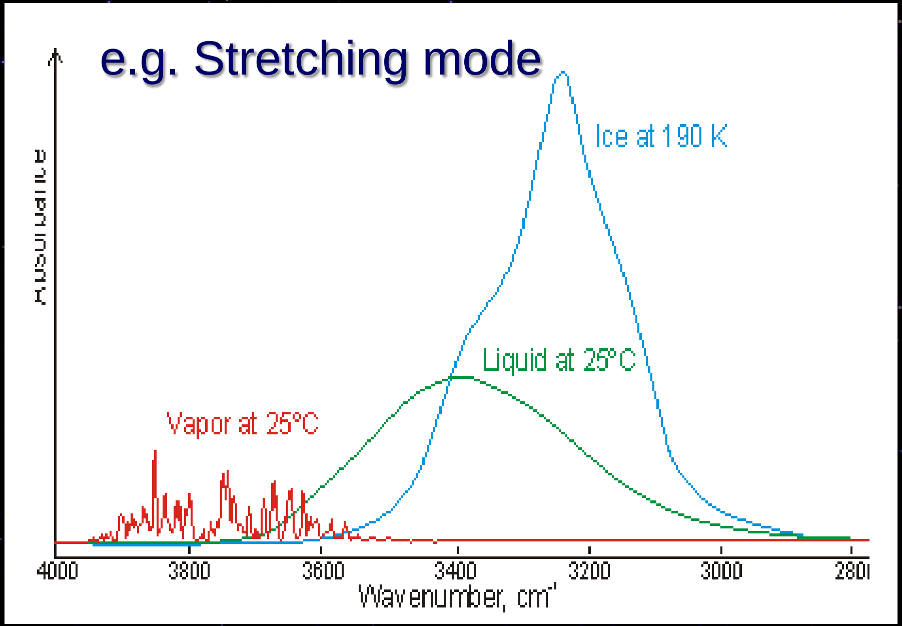
Radiotelescopios
(linhas rotacionais e
ro-vibracionais)

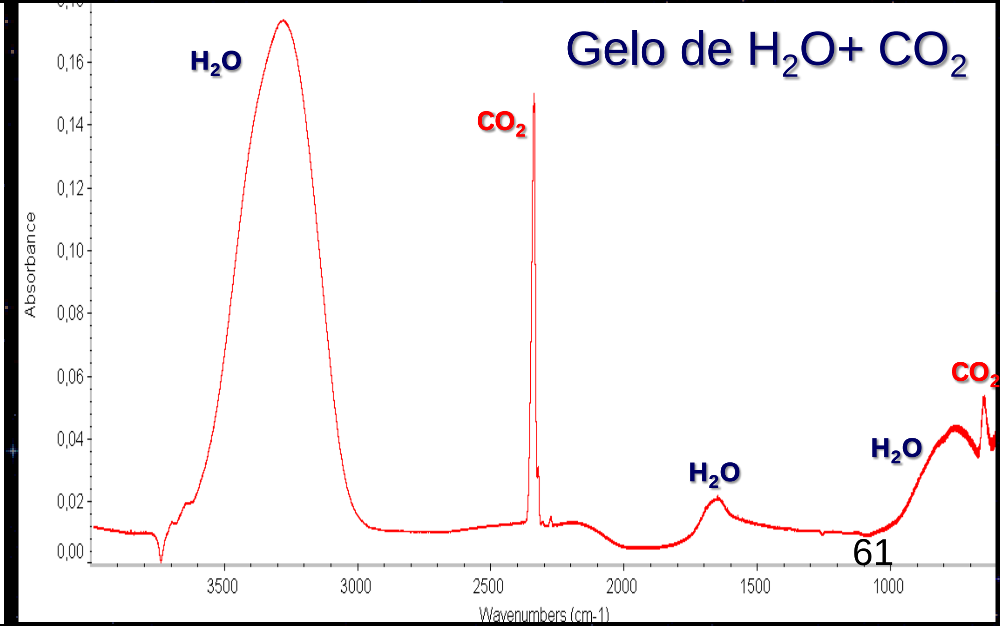
Itapetinga, SP



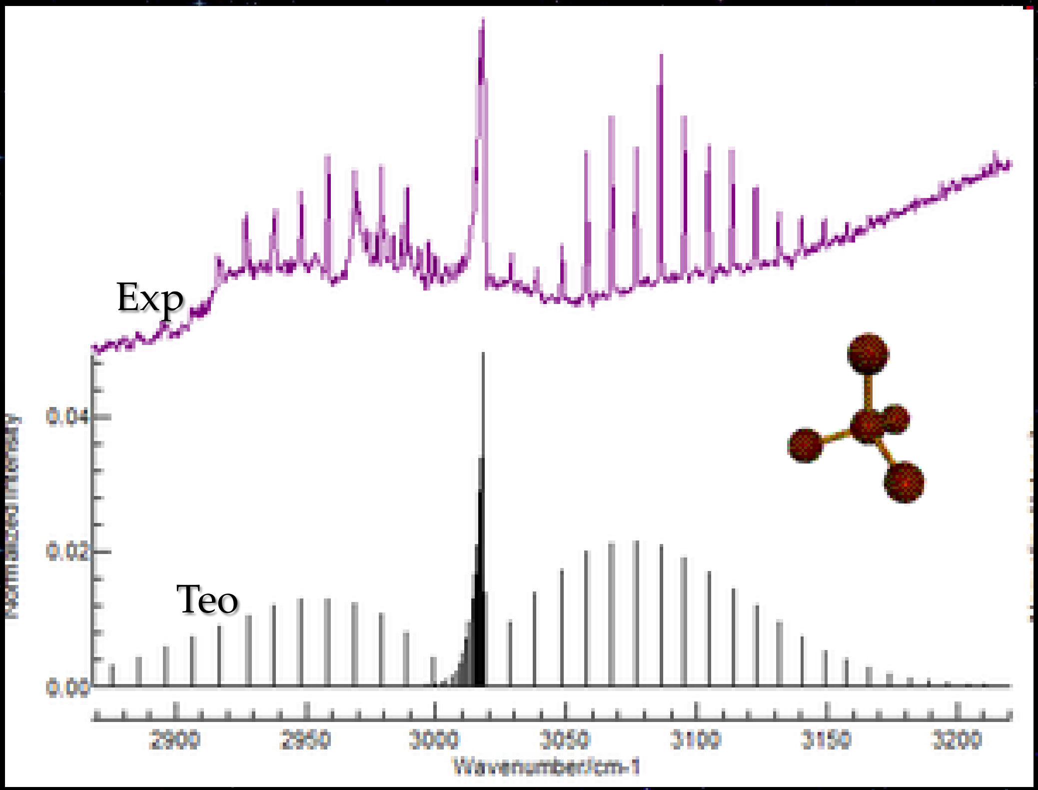
Espectroscopia Molecular no IR – Bandas vibracionais (GELO)

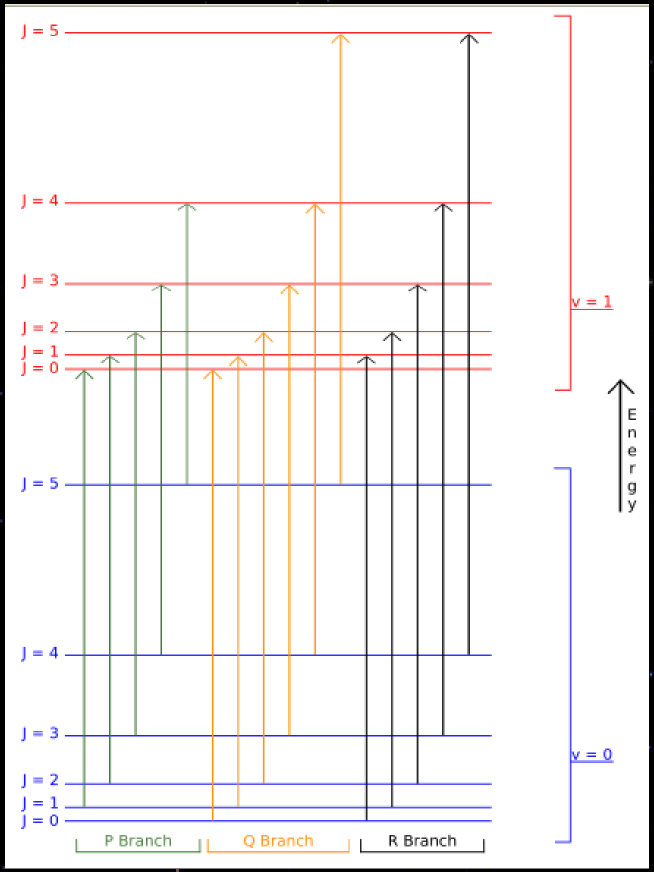




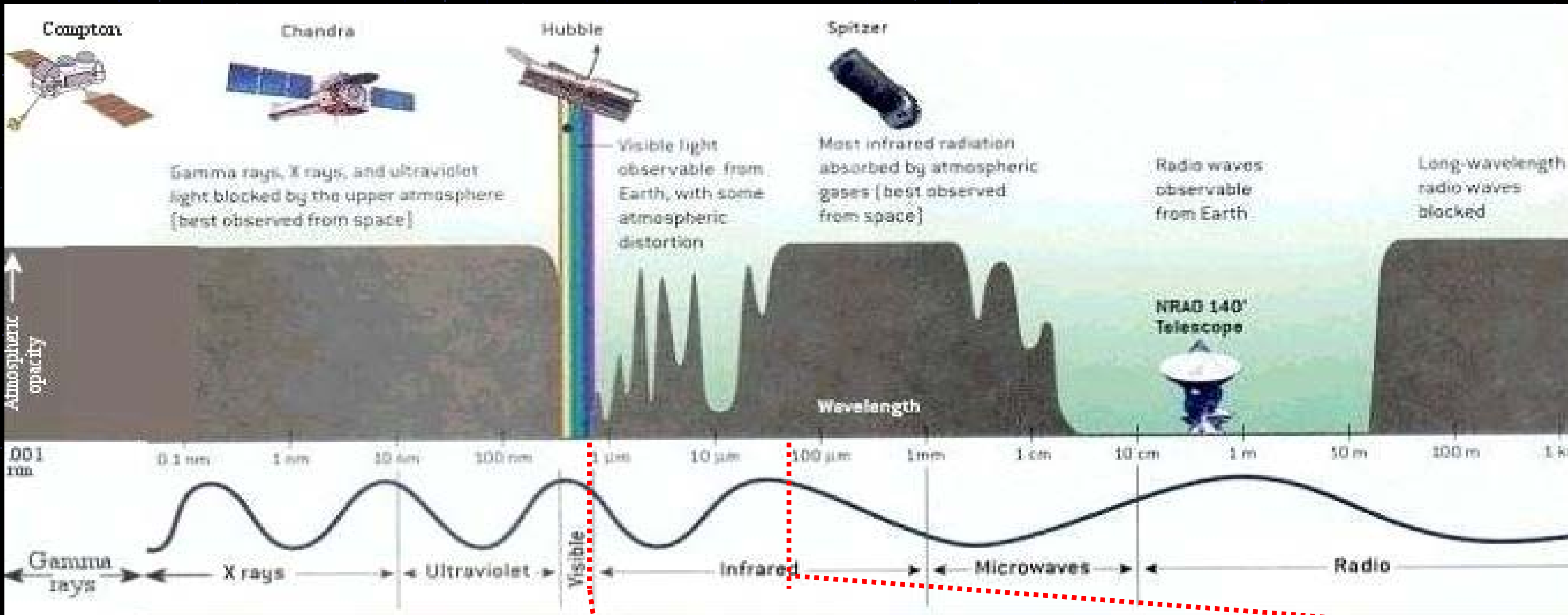


Espectroscopia Molecular no microondas/rádio – Bandas rotacionais-vibracioanis e bandas rotacionais **(FASE GASOSA)**

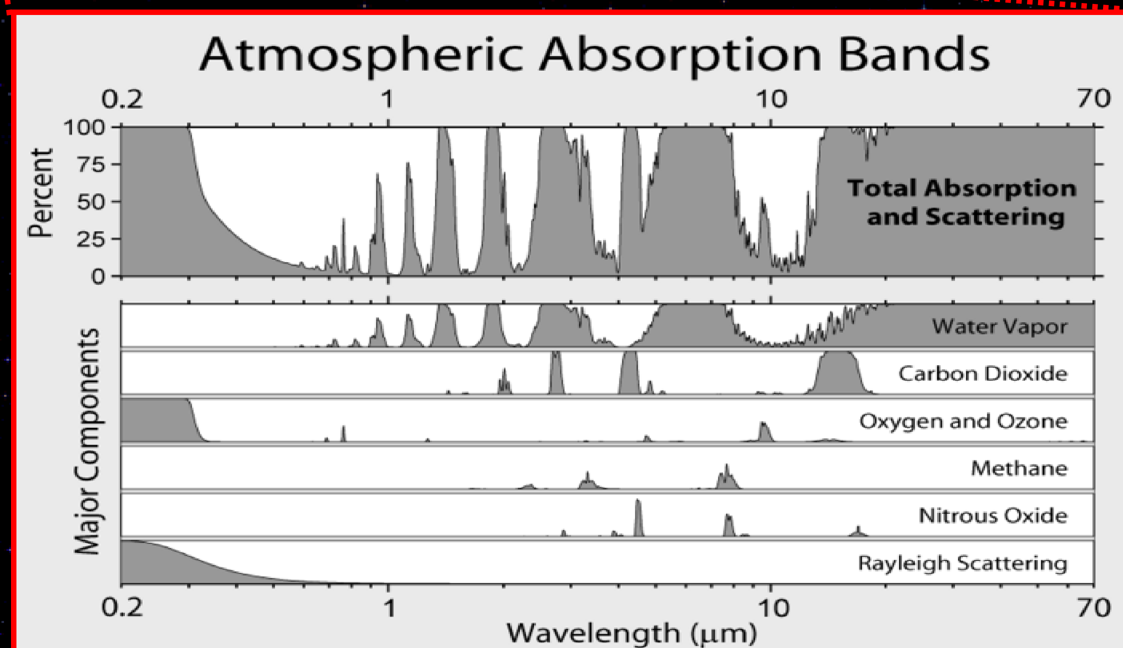




http://web.mit.edu/5.33/www/lec/spec5.pdf
http://www.ias.ac.in/initiat/sci_ed/resources/chemistry/rotational.pdf



Absorção da radiação pela atmosfera

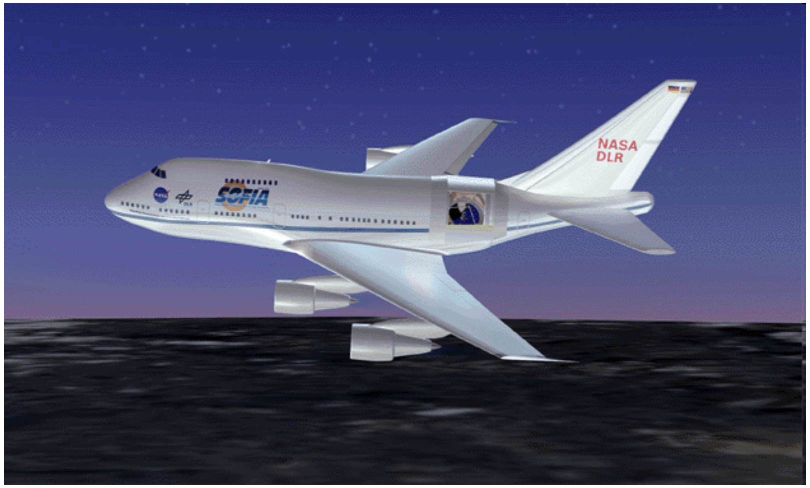


Observatórios IR

Gemini (Hawai e Chile)

SOAR (Chile)

UKIRT – Hawai



SOFIA (nasa)

VLT (Chile) – Interferometria

Coisa em comum?

Grandes altitudes.

Telescópios espaciais e Sondas

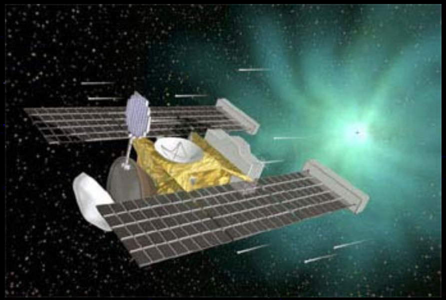
IRAS (1983)

ISO (1995-1998)

Spitzer (2003-2009)

Spacecrafts

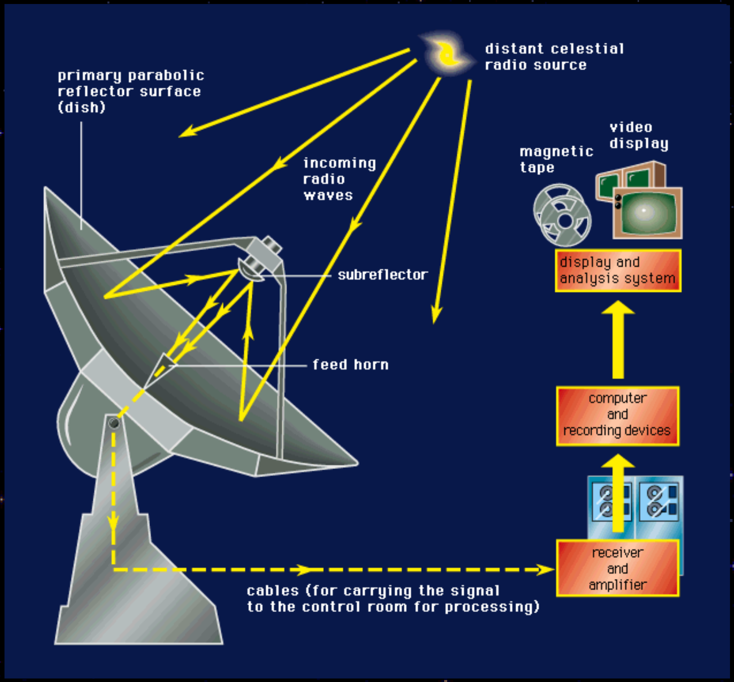
HST(1999, ...)



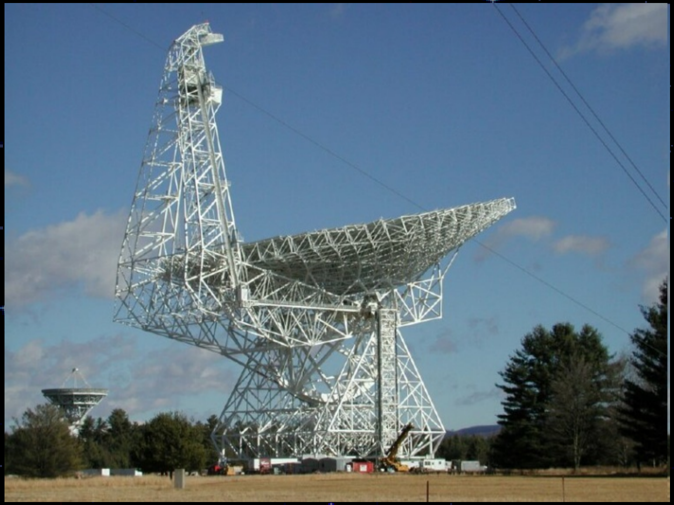
Ex. Stardust, Cassini, Mars Rovers

Observatórios na faixa de microondas e rádio

Single Dishes



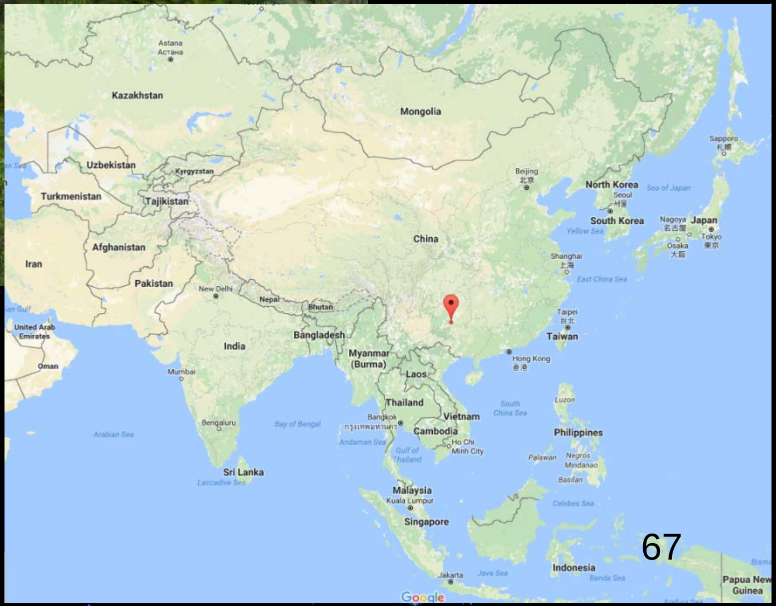
305-meter Arecibo



100-Meter Green Bank Radio Telescope

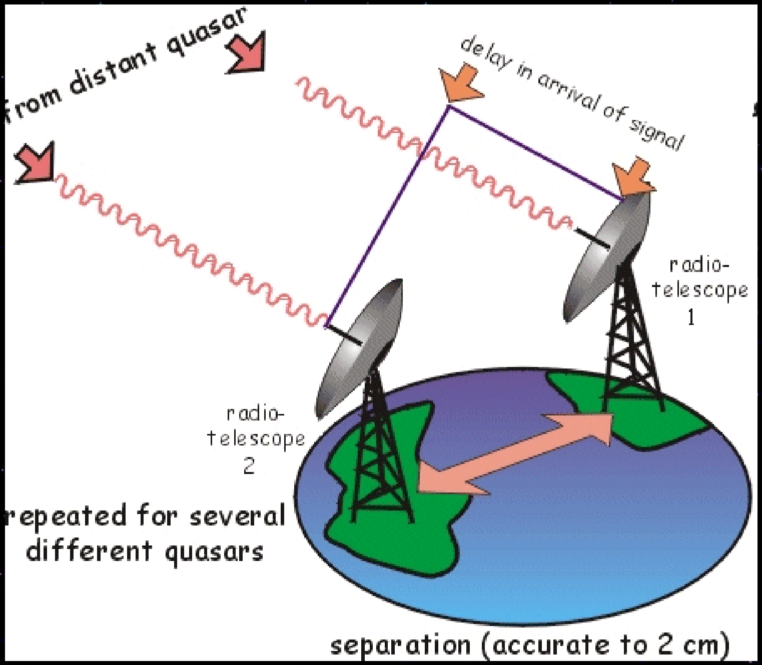
Radio telescópio FAST, China (Maior do mundo, 500m diâmetro)

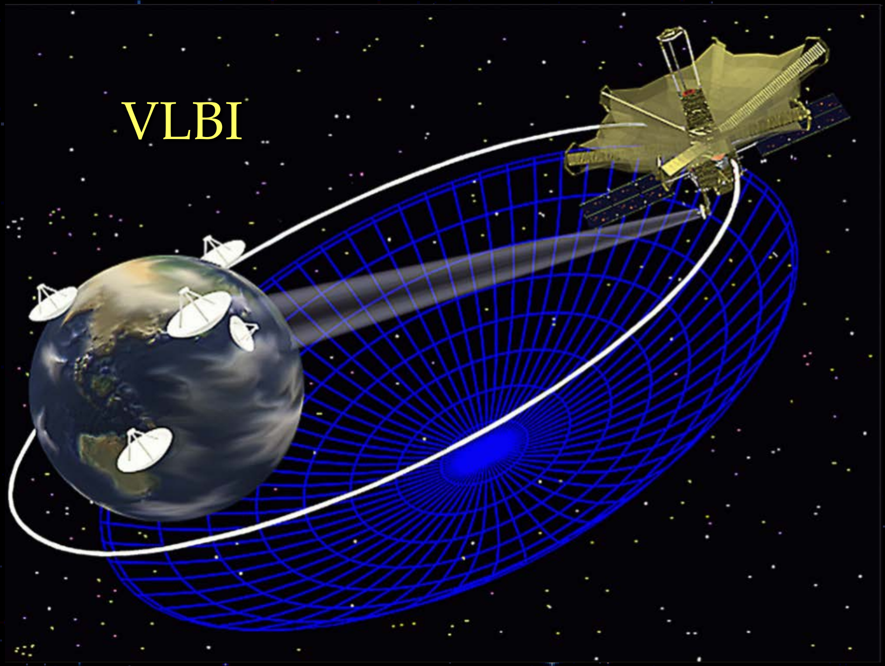
FAST's surface is made of 4450 triangular panels (11 m side)
Pointing: anywhere within ±40° from the zenith
Working frequency range: 70 MHz to 3.0 GHz.



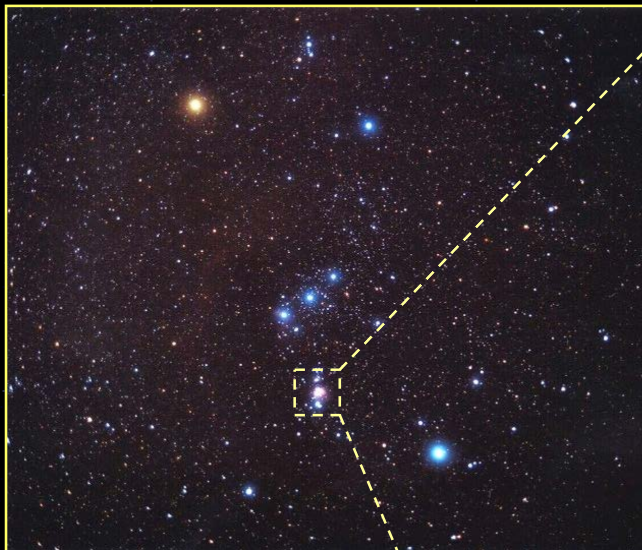
Observatórios na faixa de microondas e rádio

Multi-dishes Inferferometry

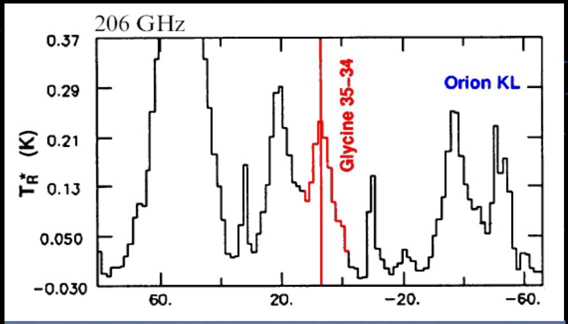


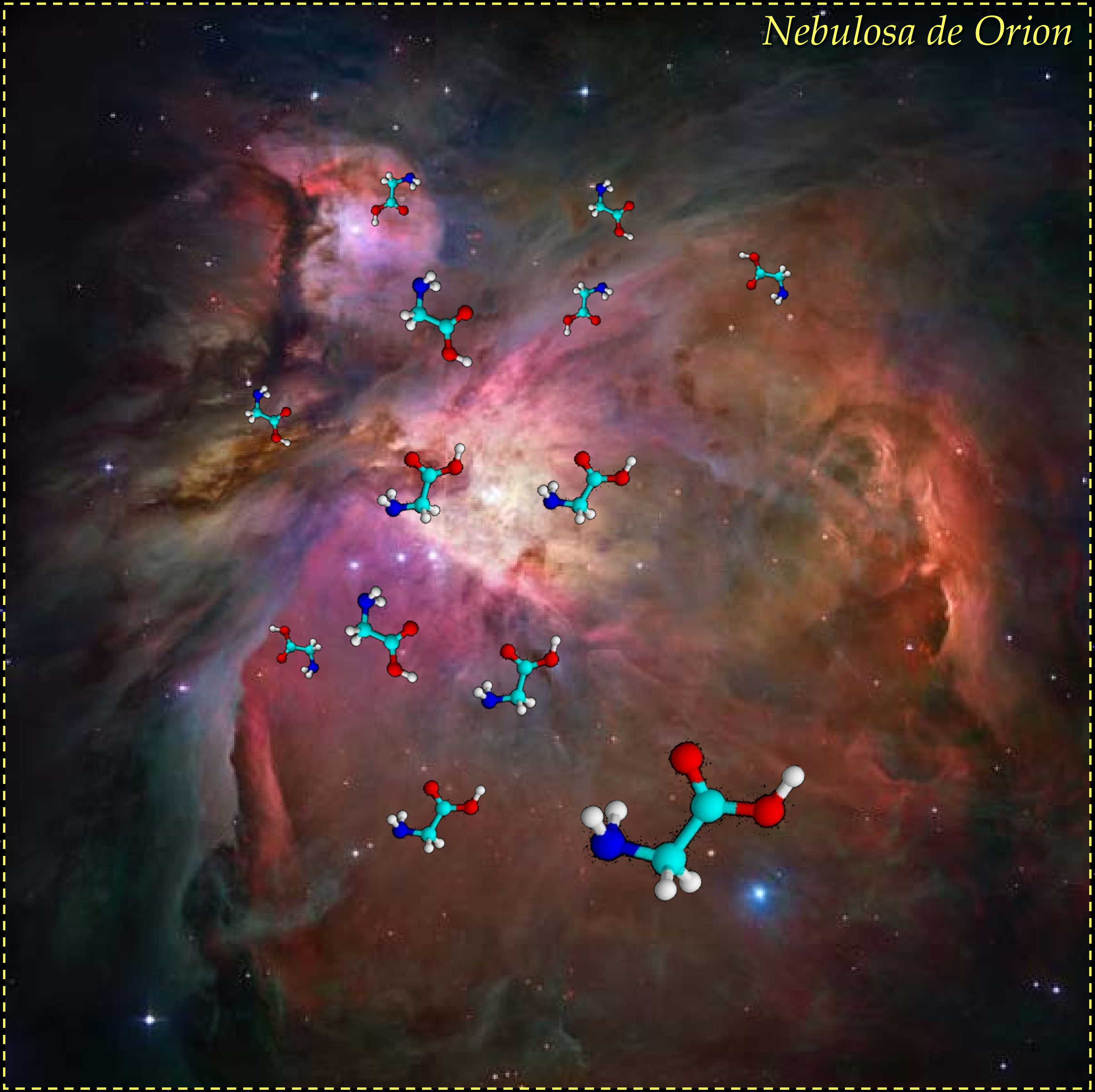


Nuvens moleculares: berçário estelar



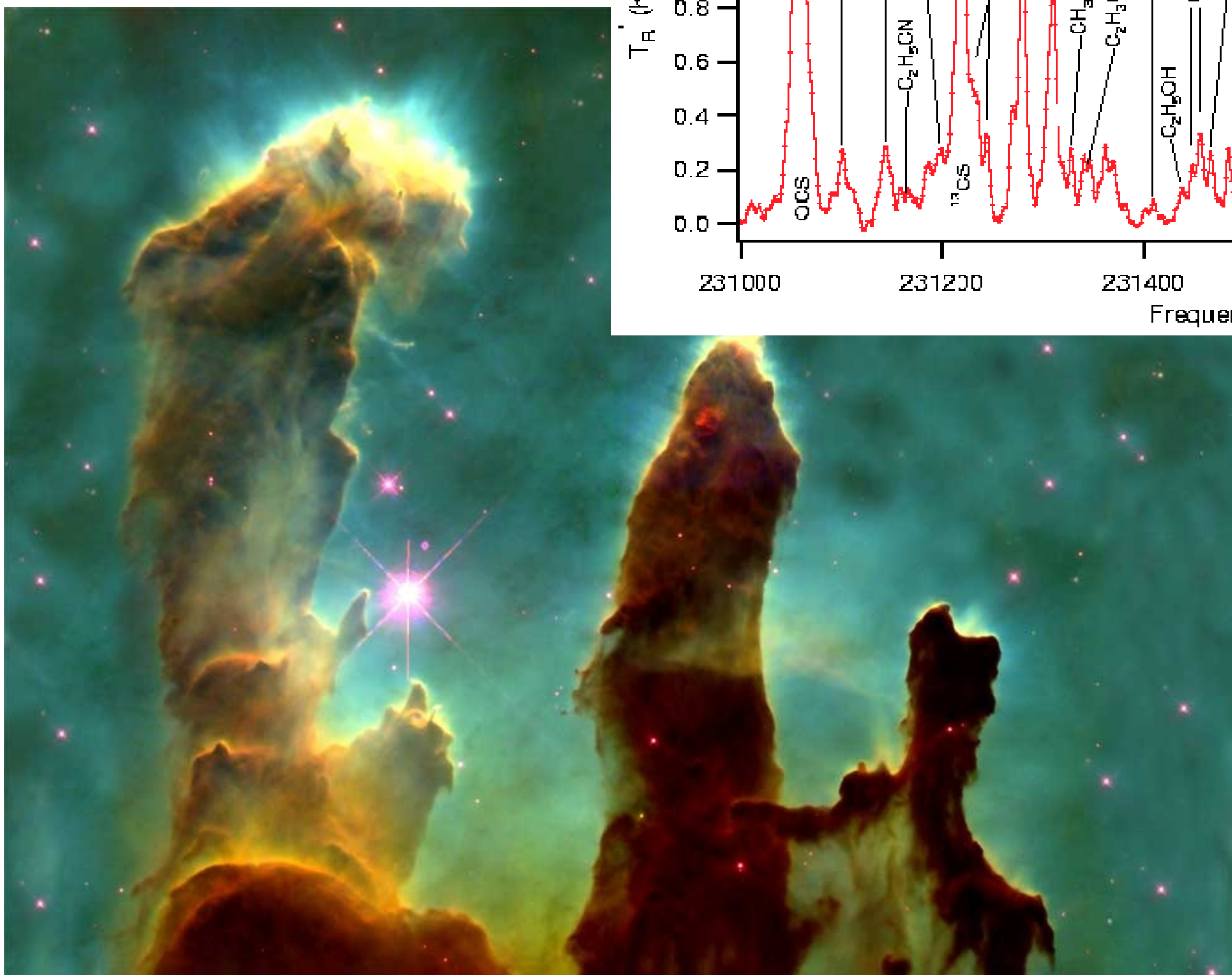
Nuvens moleculares: berçário estelar

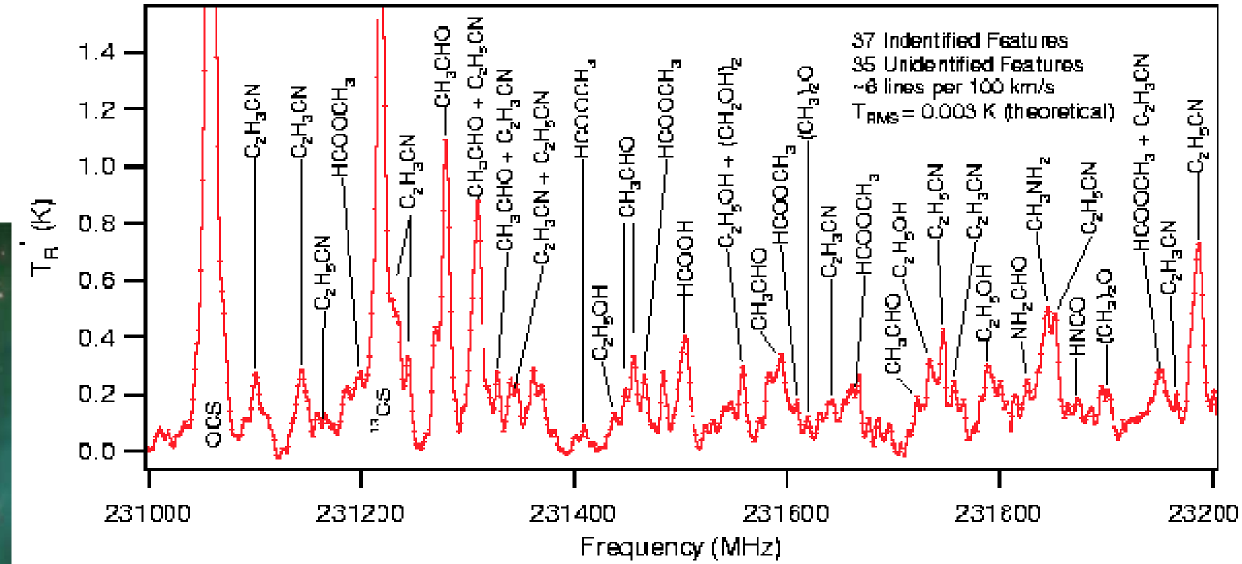




Aonde mais essas moléculas são encontradas?

Gaseous Pillars – Eagle Nebula



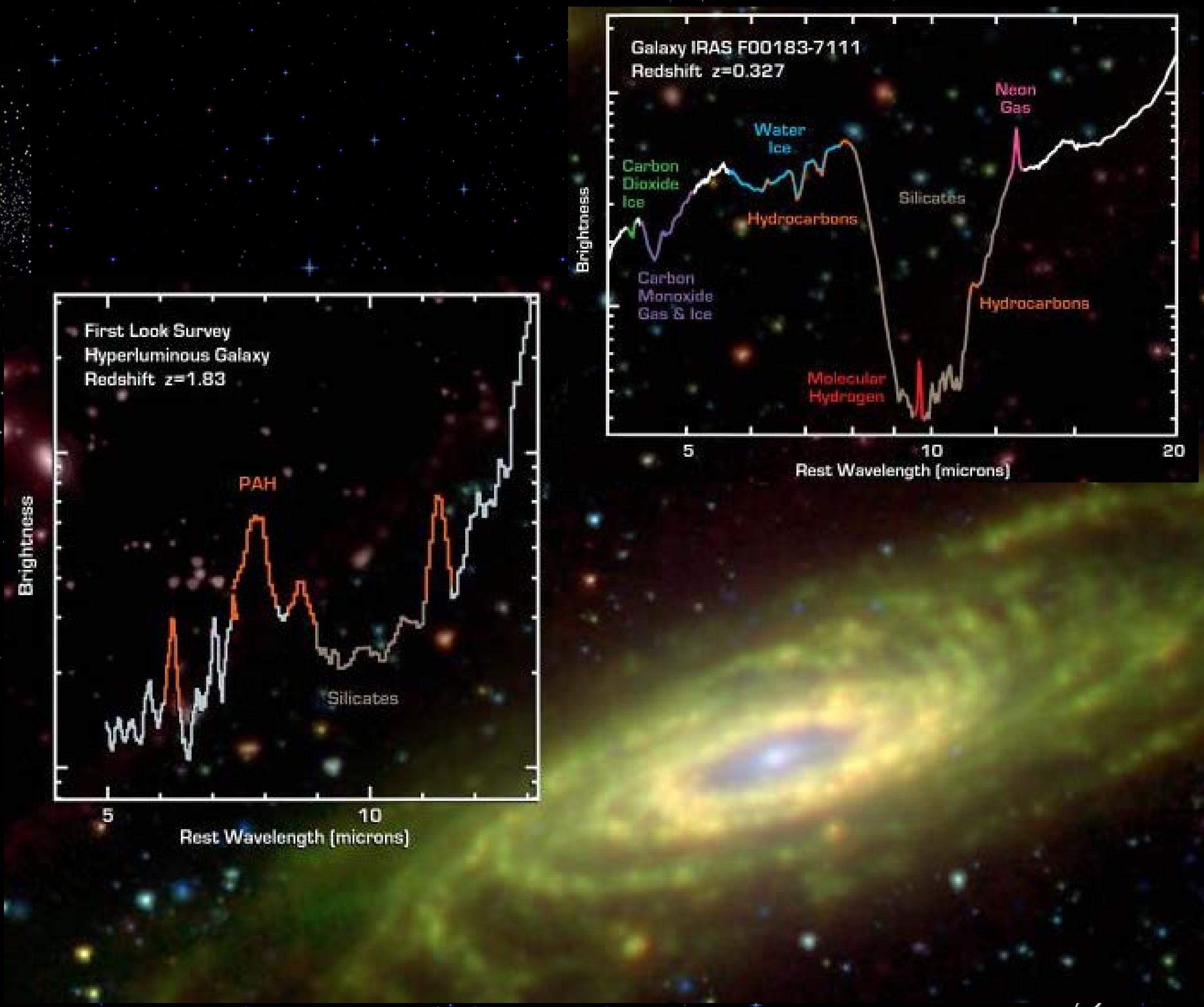


Sgr B2 with ALMA

Moléculas em Galáxias distantes.

1ª moléculas orgânicas (idade do universo ~2 -3 bi anos)

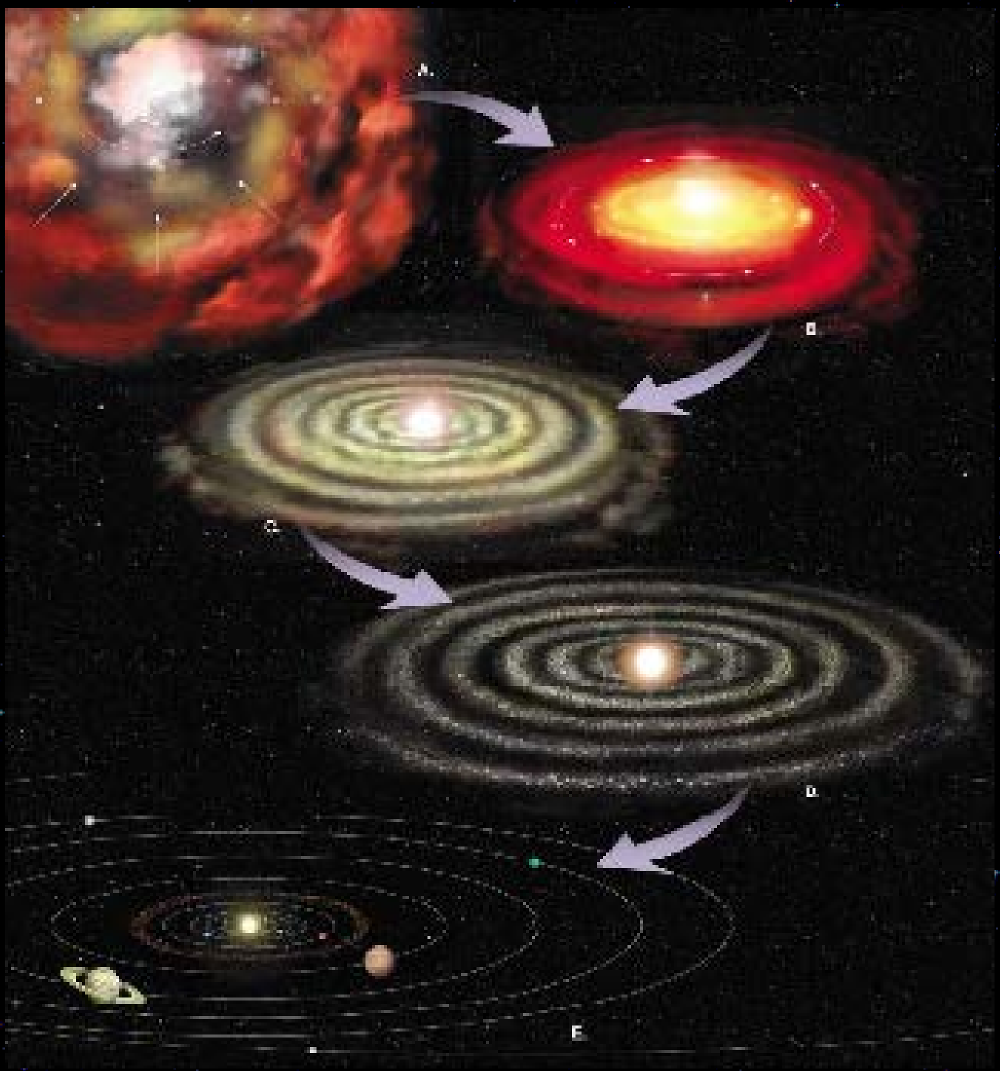
Telescópio espacial SPITZER



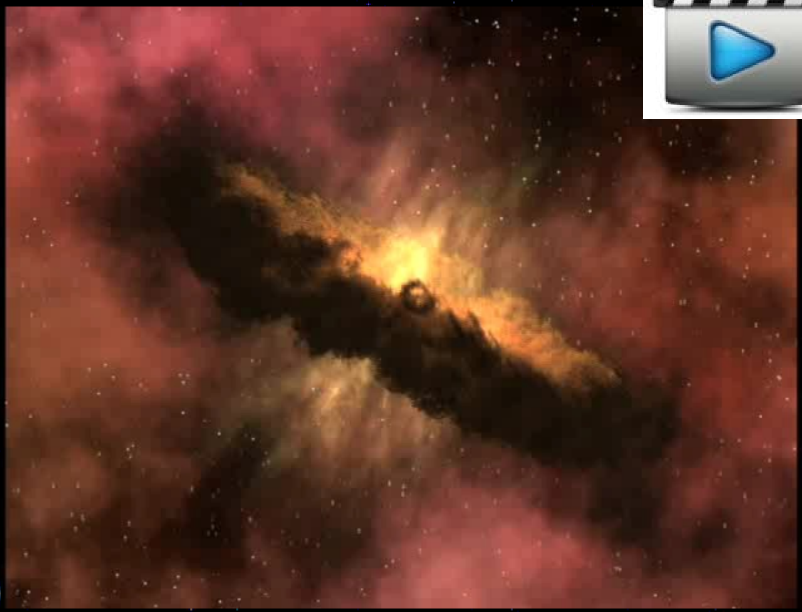
Moléculas orgânicas em galáxias distantes!

Moléculas em discos protoestelares (gás e gelos)

Nuvem de átomos (ex. H, He, C, N, O, ...) e moléculas (ex. H_2, silicatos, água, CO, CO_2, etanol, acetona, amônia, ...)



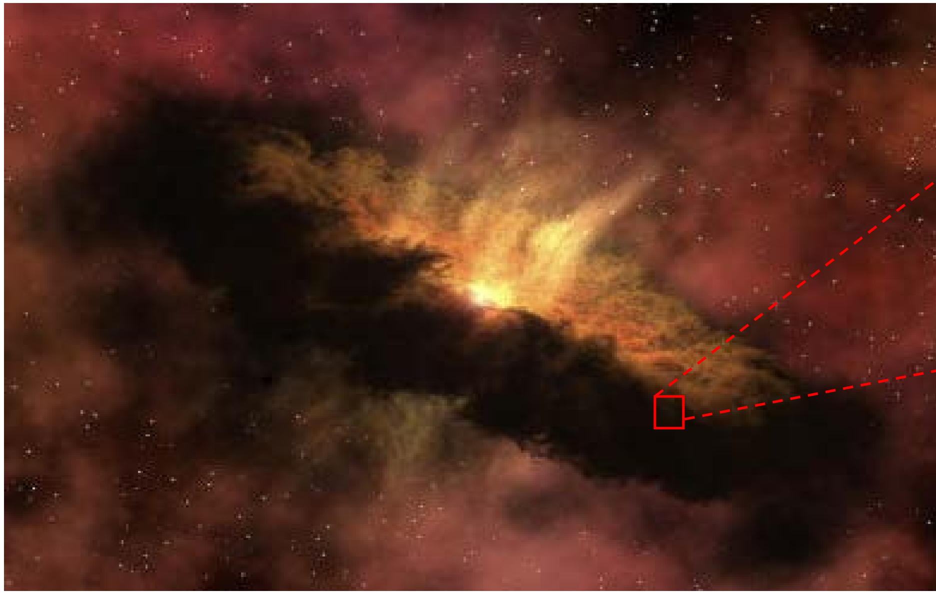
Ver



Sistemas planetários, cometas, etcs.

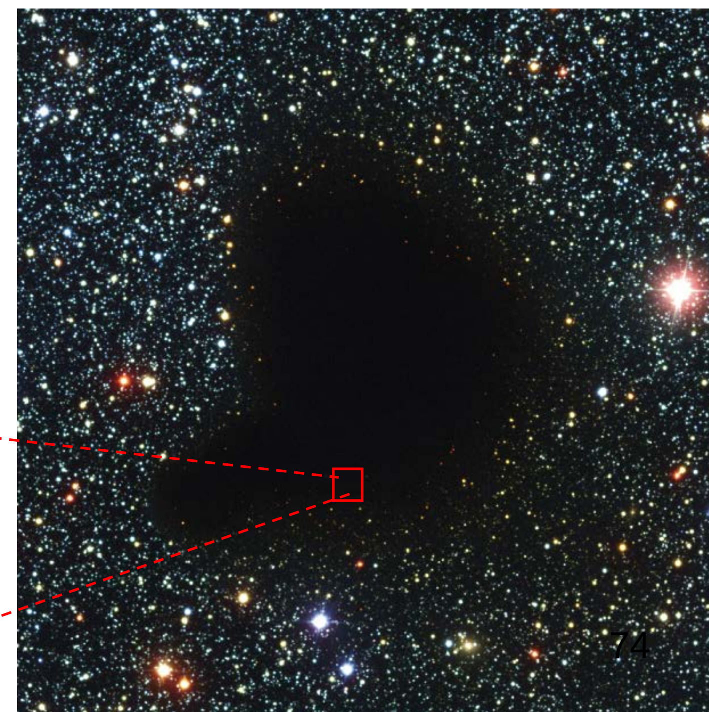
Moléculas em discos protoestelares e nuvens densas

- Grãos de poeira fria: núcleos de silicatos/carbono + cobetura de moléculas volateis condensadas (H_2O, CO, N_2, NH_3, etc...)



Objetos estelares jovens (YSOs) e discos proto planetários (N~ 10^4-10^8 cm^{-3}; T ~ 10-50 K)

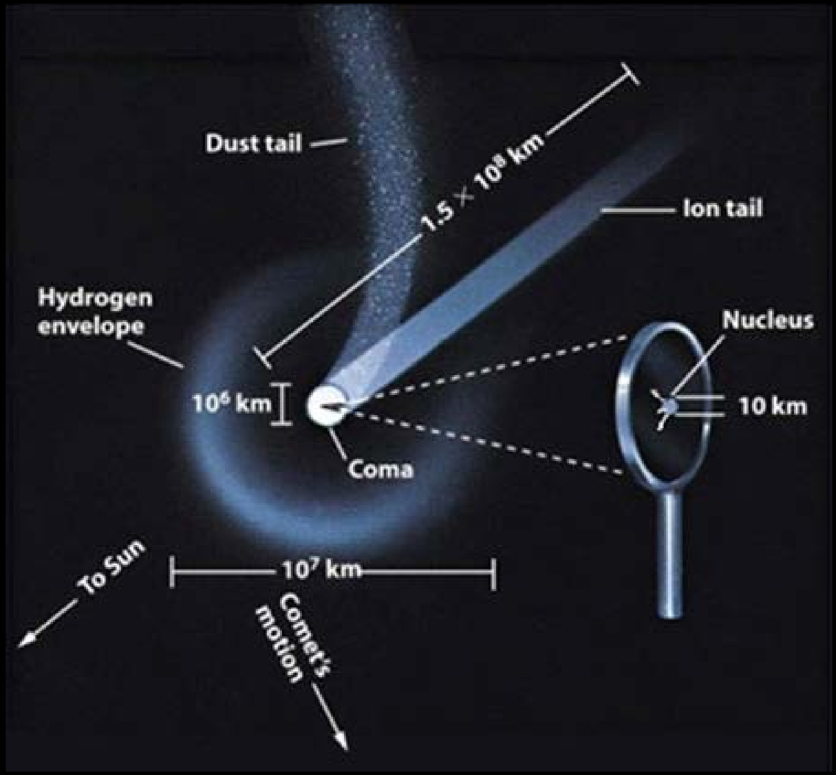
Ver vídeos:



Moléculas em cometas

Composição básica dos cometas:
(~80% água. CO, CO_2, CH_{4}, ...)

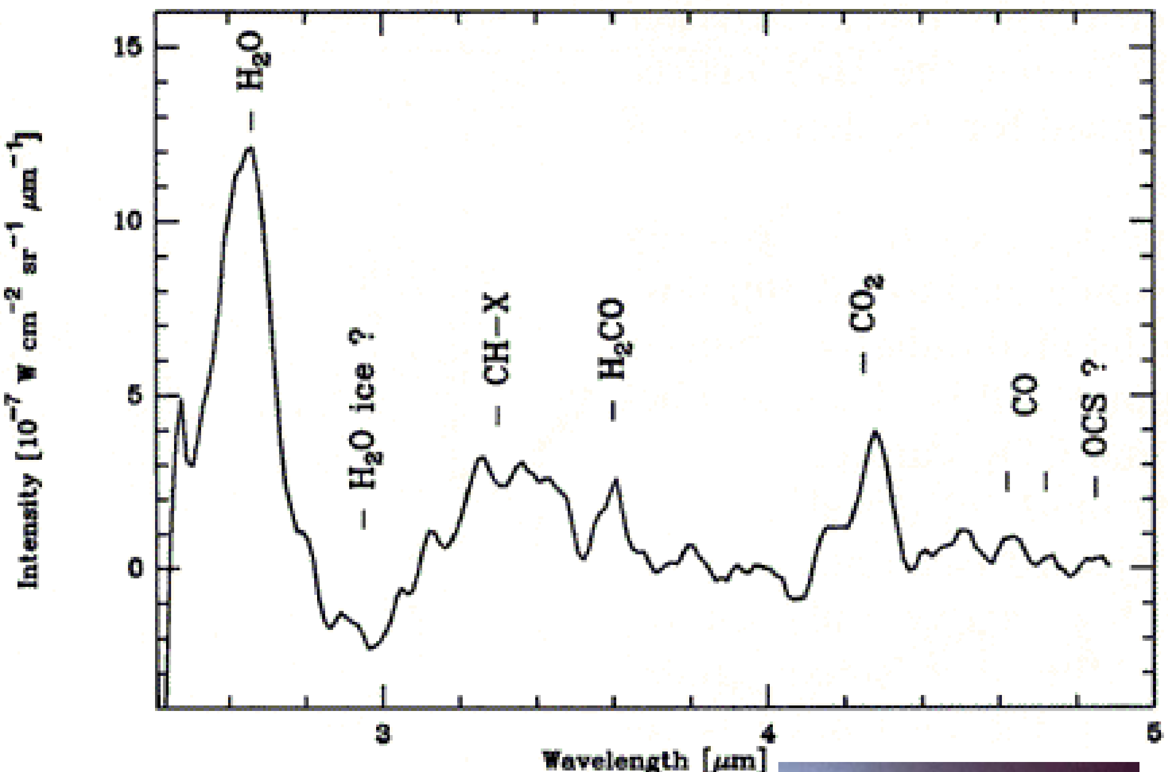
Hale-Bopp



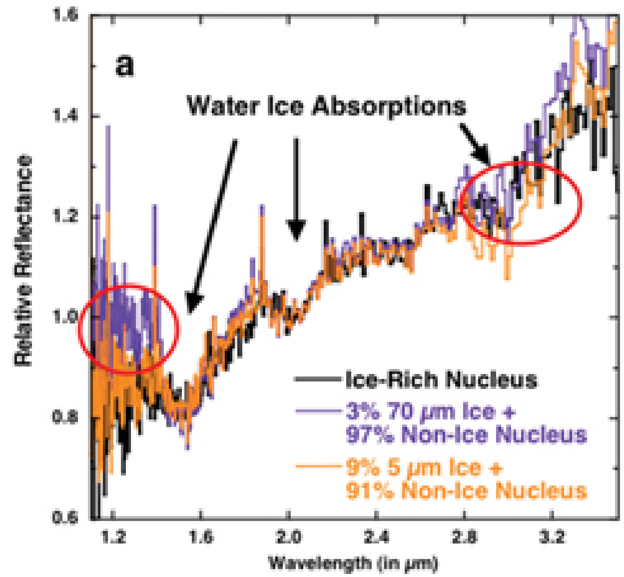
Tempel 1

Exemplo de Espectroscopia de Cometas no IR

Comet Halley (Combes etal 1988)



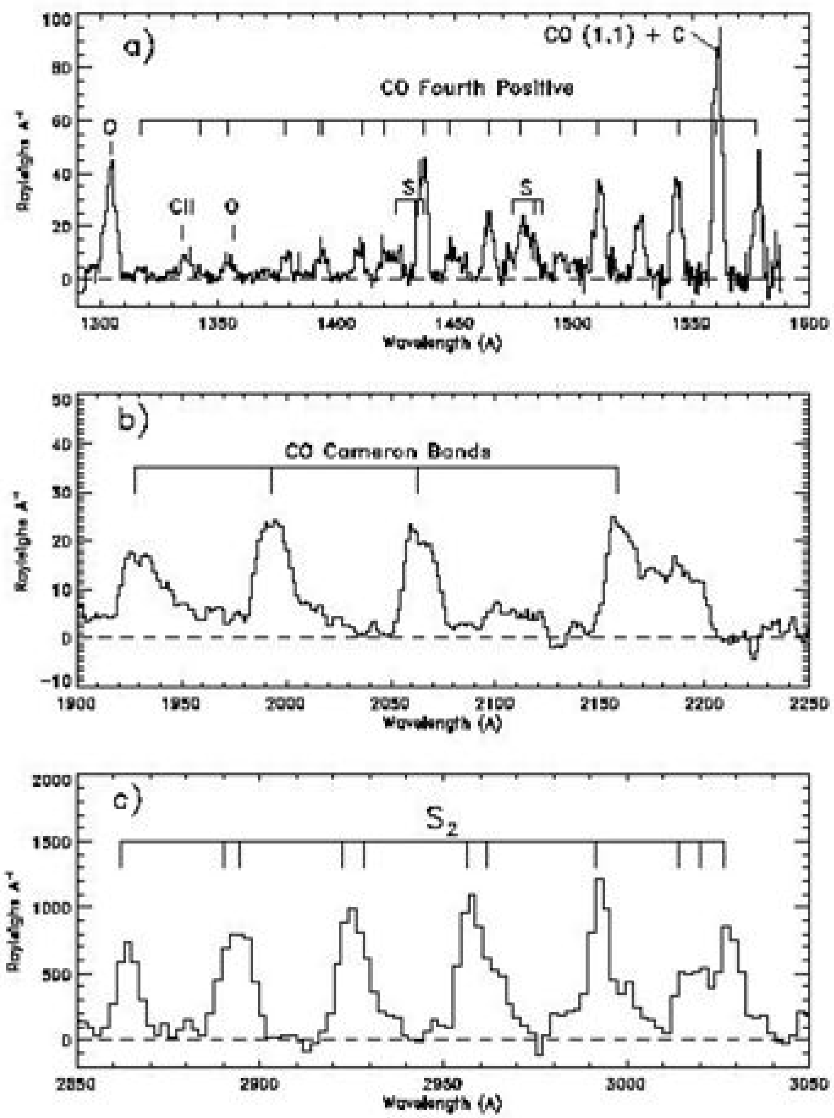
Tempel 1 (NASA)
Deep impact Mission



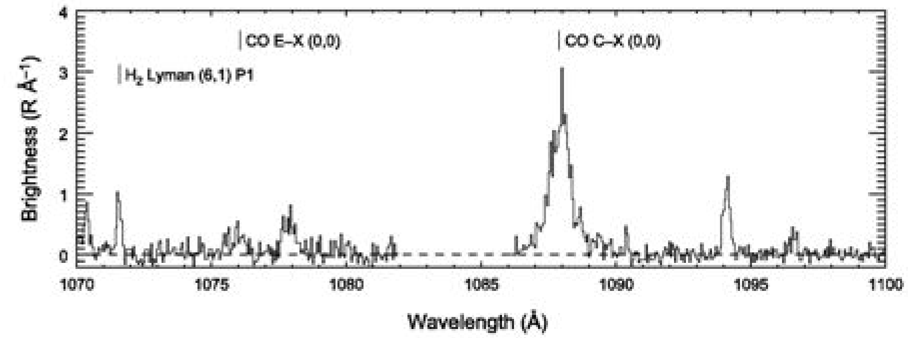
Comet Halley

Tempel 1

Exemplo de Espectroscopia de Cometas no UV



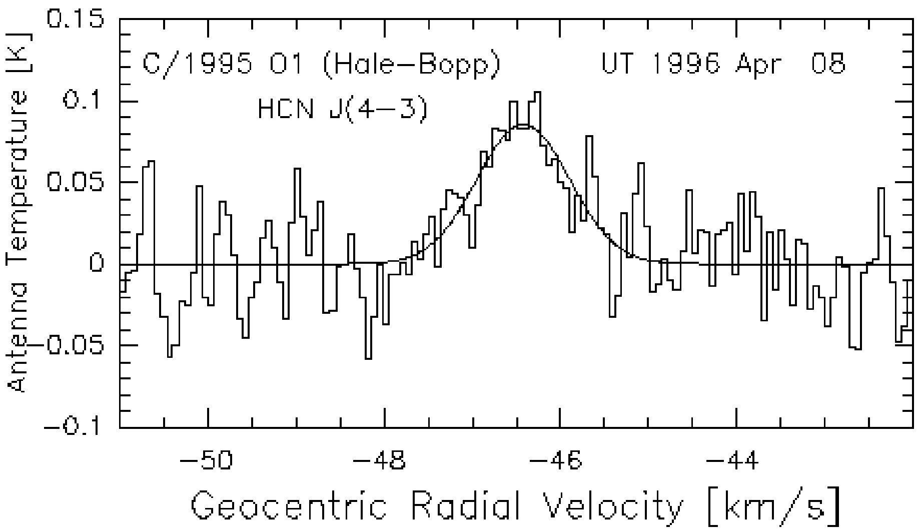
HST Espectro do Hyakutake (C/1996 B2)

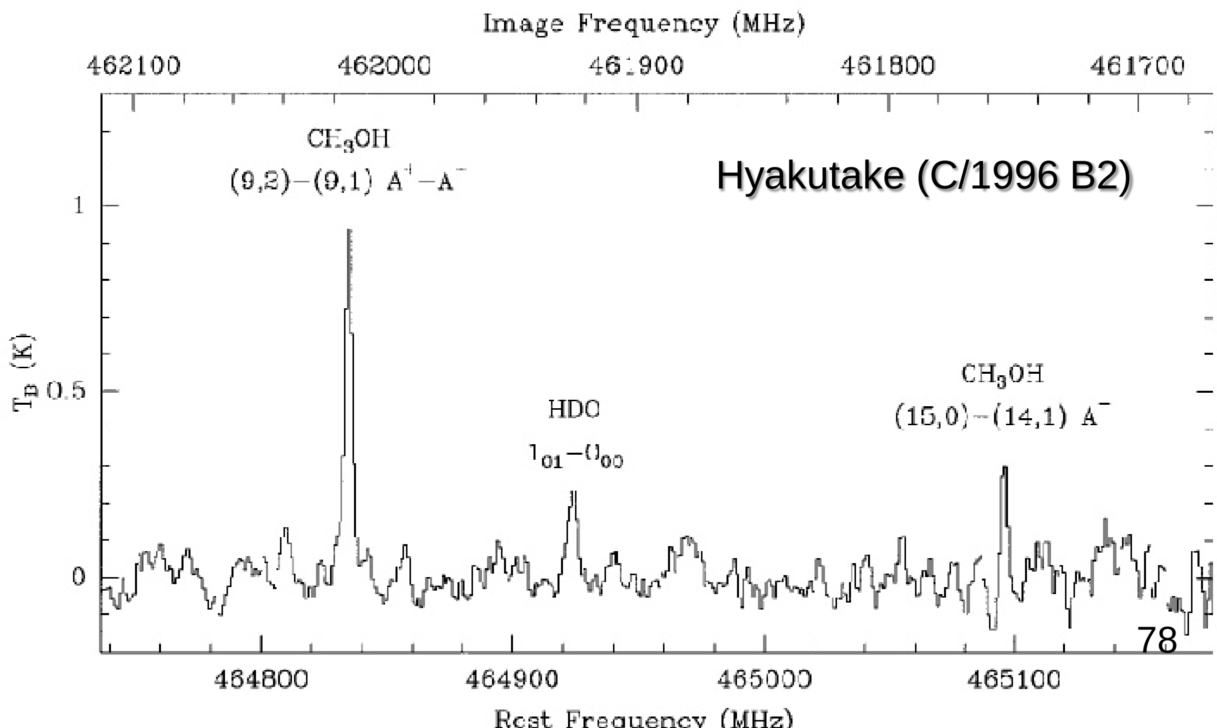


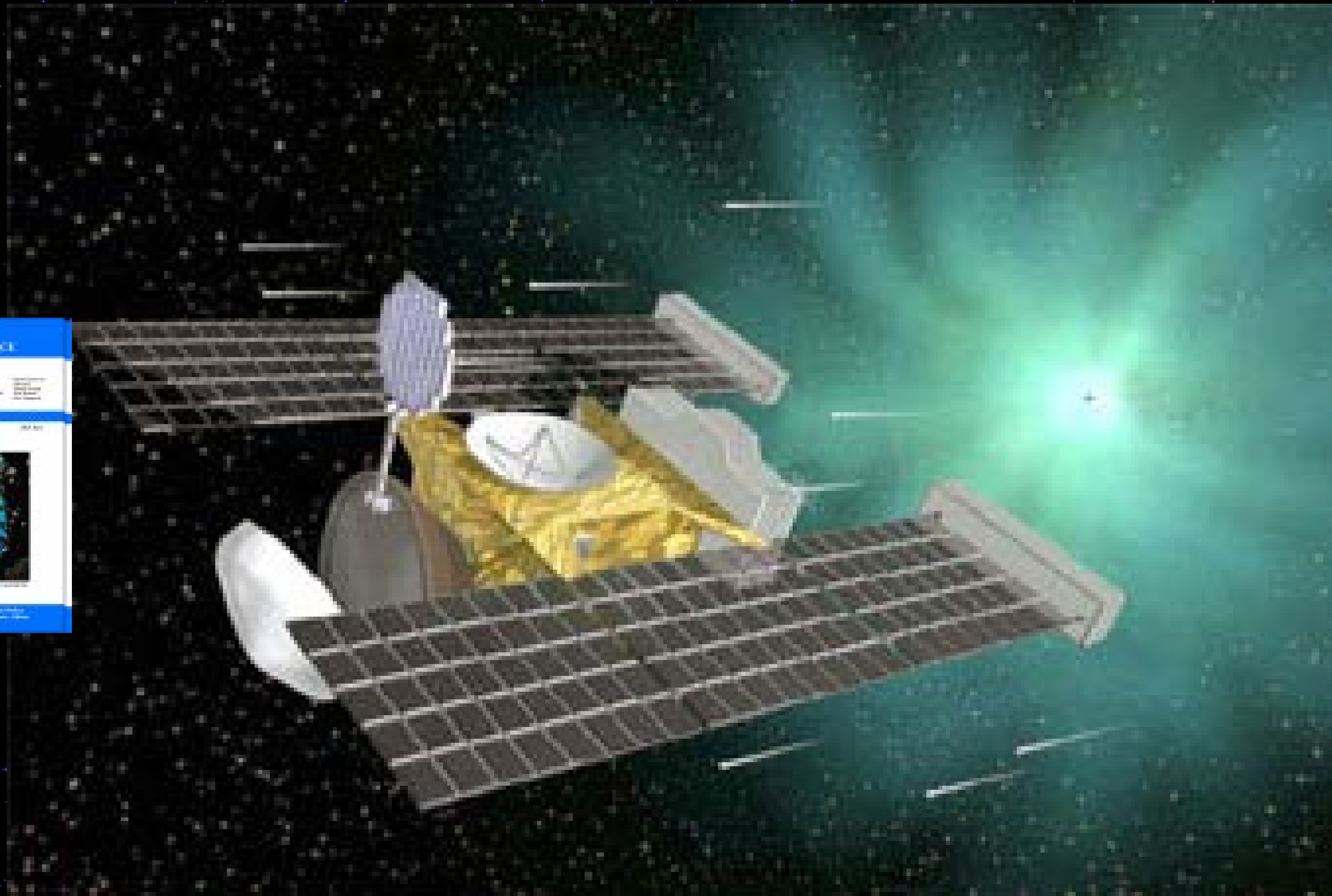
FUSE Espectro do cometa Linear (C/2001 A2)

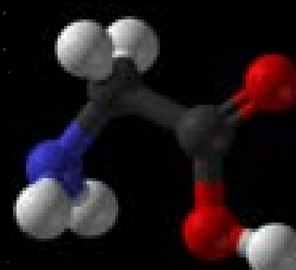
Hyakutake (C/1996 B2)

Exemplo de Espectroscopia de Cometas na faixa radio









Glicina

Elsila etal. 2010, Met. Plant Science

Moléculas em gelos extraterrestres: outras evidências observacionais

- Luas e Planetas

Artist impressions of Enceladus

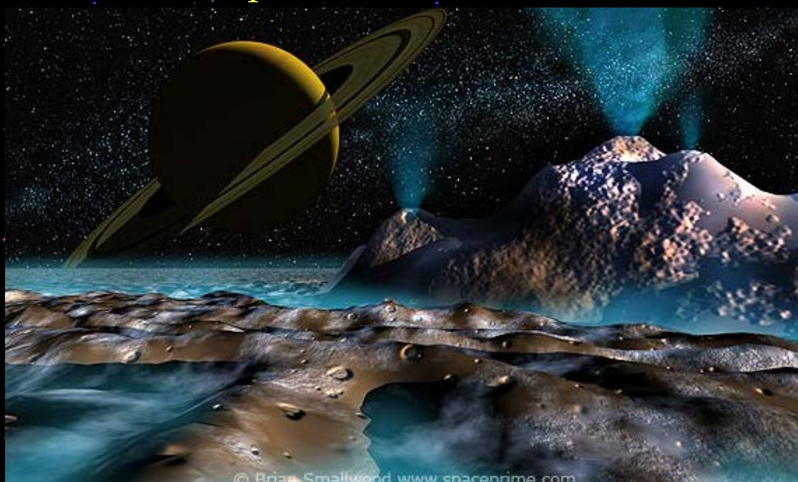


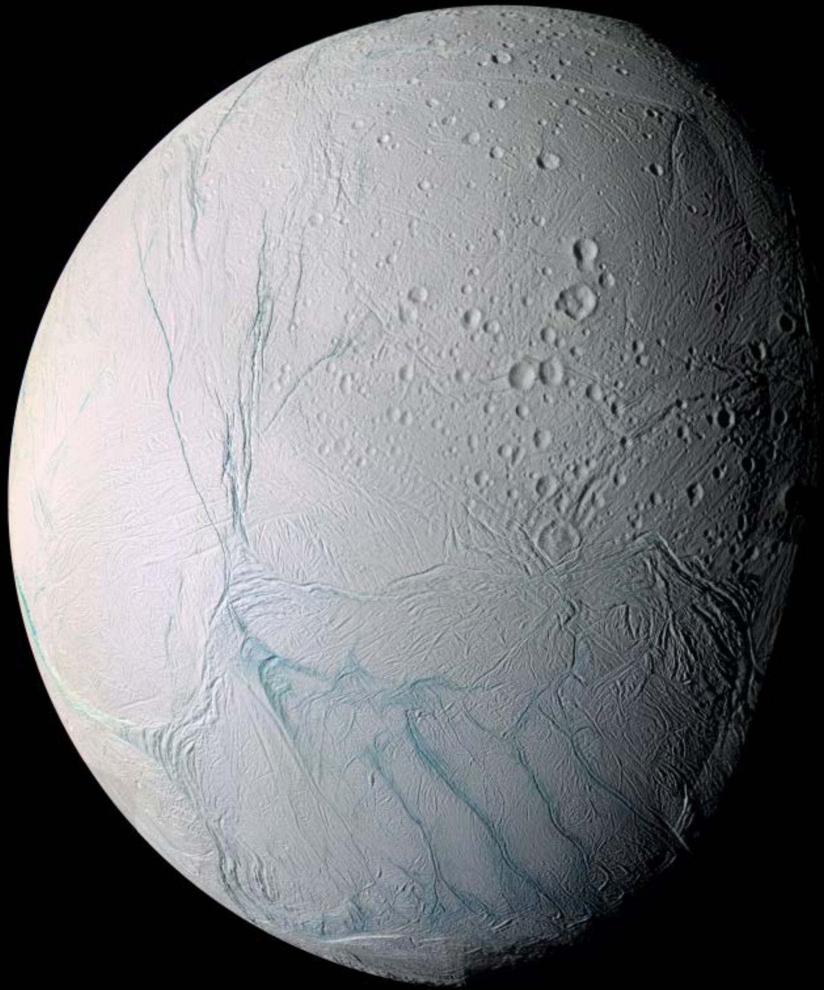
Table 1. Ices in the Solar System.

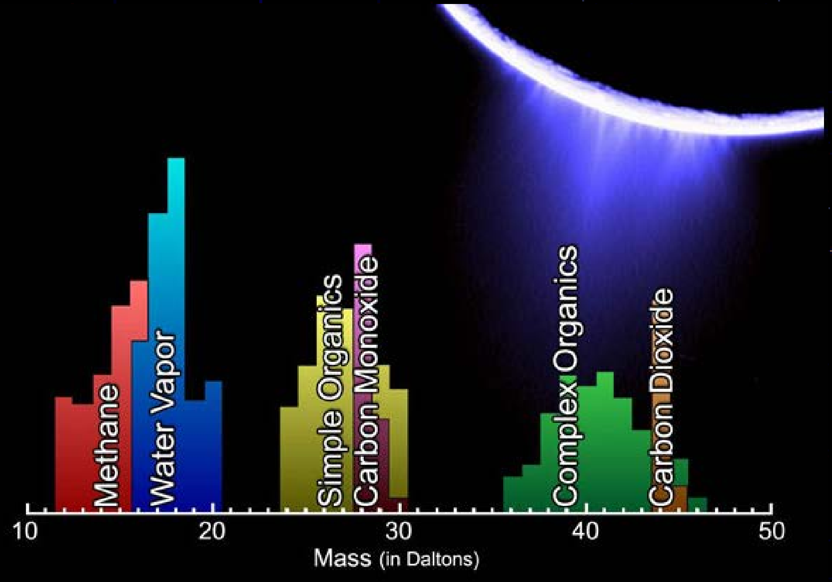
Planet / Satellite / (*Ref.*)	Observed Species
Jupiter	
Io	SO_2, H_2S, H_2O
Europa	H_2O, SO_2, CO_2, H_2O_2
Ganimede	H_2O, O_2, O_3, CO_2
Callisto	H_2O, SO_2, CO_2
(*Calvin et al. 1995; Nash and Betts 1995*)	
Saturn	
Mimas	H_2O
Enceladus	H_2O
Tetis	H_2O
Dione	H_2O, O_3
Rhea	H_2O, O_3
Hyperion	H_2O
Iapetus	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.

• Luas e Planetas

Enceladus (lua de Saturno).

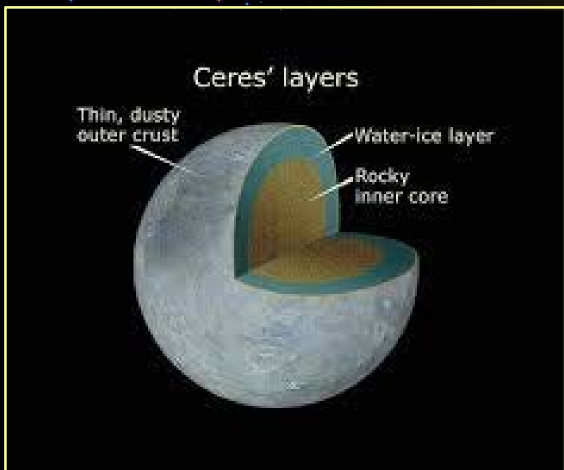


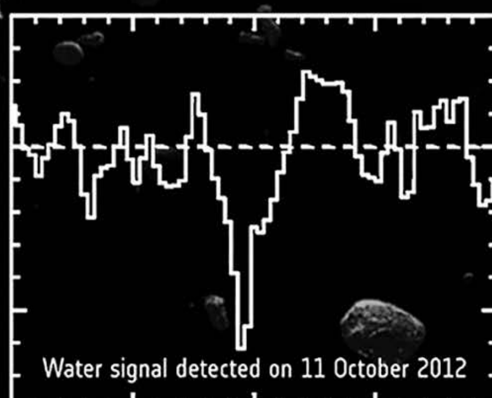


- Planetas anões

Detecção de água em Ceres (atmosfera tênue de vapor de agua)

ESA's Herschel space observatory between 2011 and 2013

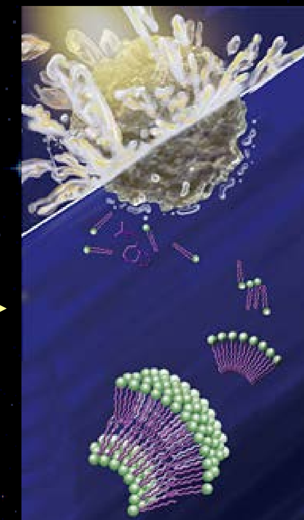


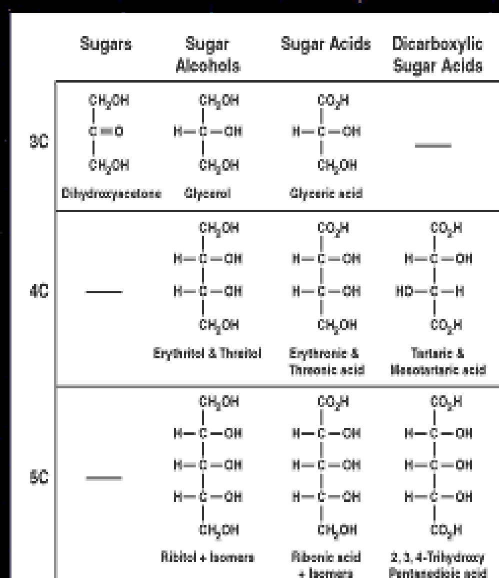


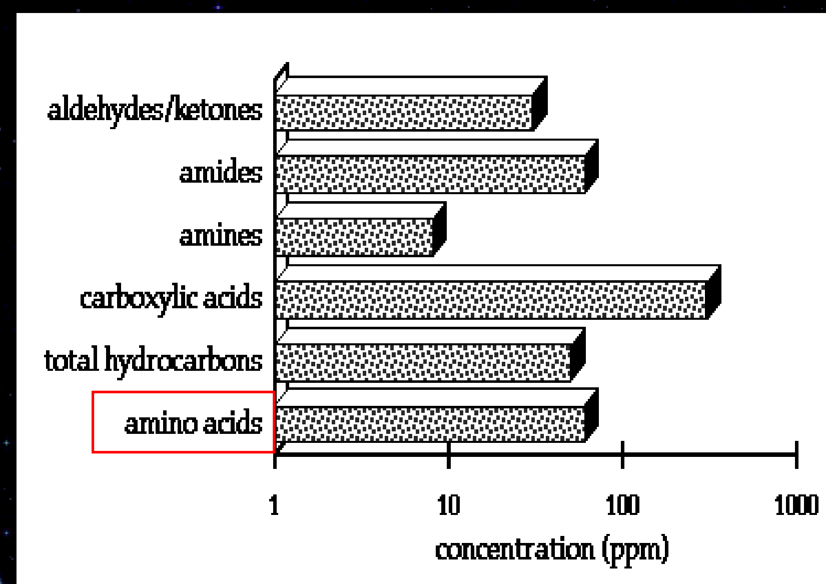
Aonde mais essas moléculas são encontradas?

Murchison meteorite

- Aminoácidos
- Bases de DNA.
- Açúcares
- Precursores de Fosfolipídios →

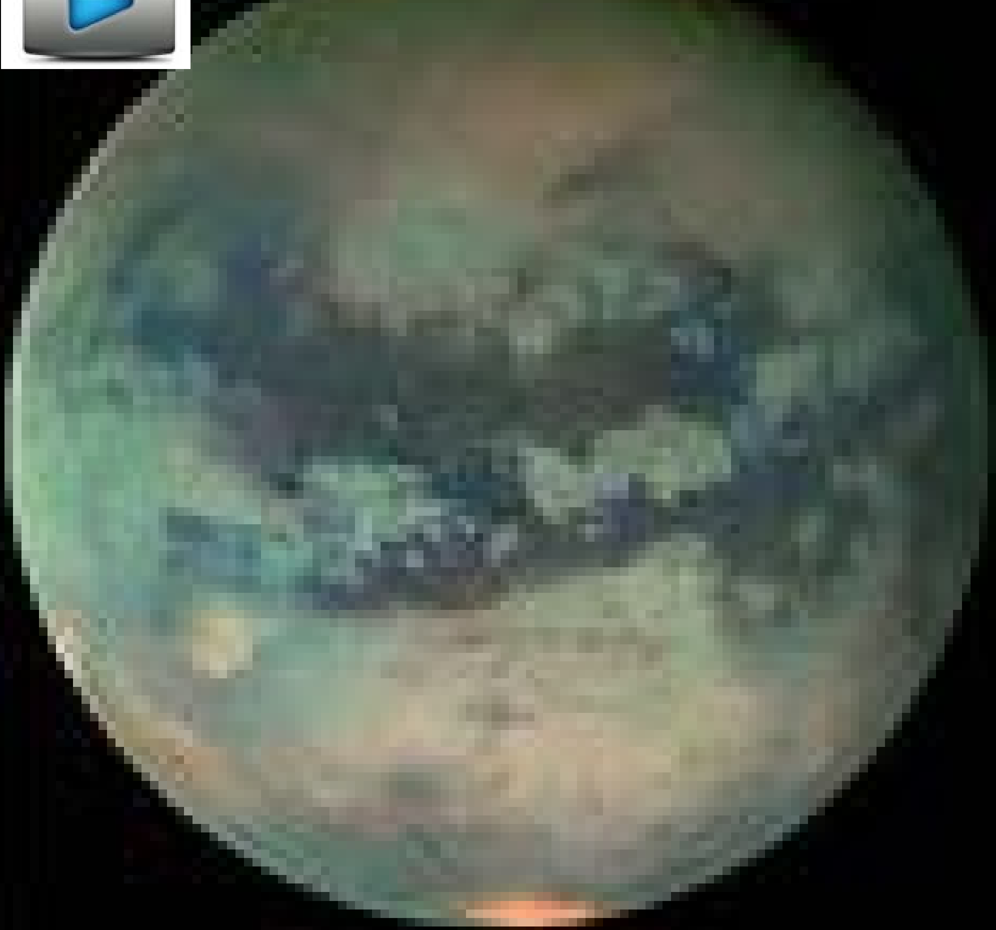




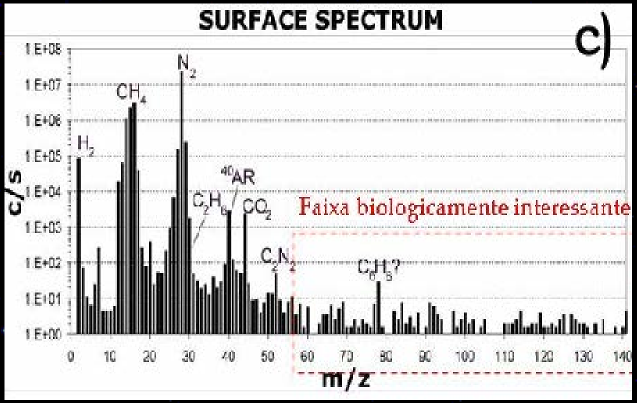


Moléculas em outros planetas

Ver vídeos:



Cassini-Huygens spacecraft, 2004



Titã

Metano e gelo de água fazem o papel da água e silicatos na terra.

T_{sup} ~ 100K, P_{sup} ~1.5 atm.

Universo Molecular!

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

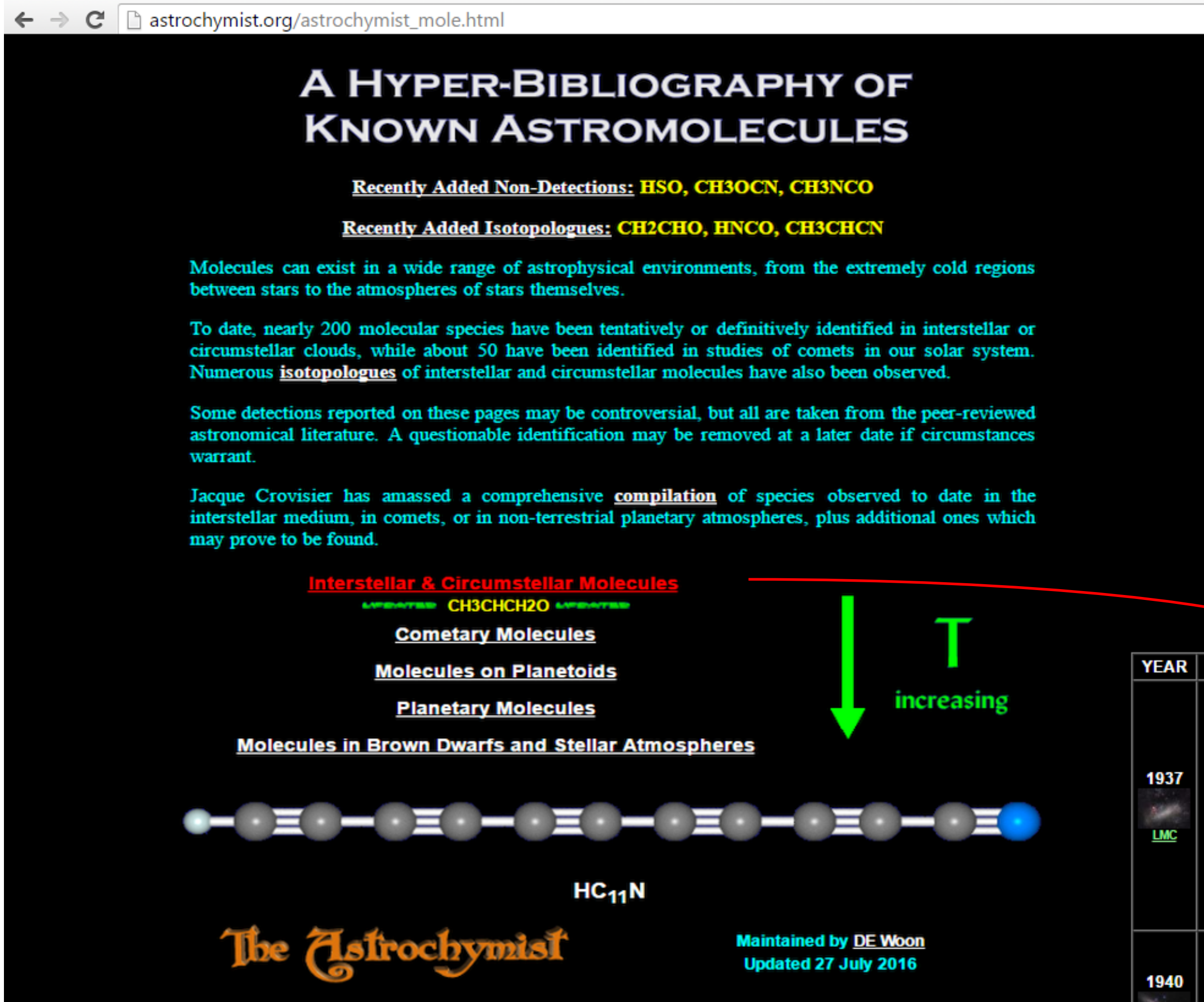
Diatomic	Triatomic	4 atoms	5 atoms	6 atoms	7 atoms	8 atoms	9 atoms	10 atoms	11 atoms	13 atoms
H_2	C_3	c-C_3H	C_5	C_5H	C_6H	CH_3C_3N	CH_3C_4H	CH_3C_5N	HC_9N	$HC_{11}N$
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN	$HCOOCH_3$	CH_3CH_2CN	$(CH_3)_2CO$		
AlCl	C_2O	C_3N	C_4Si	C_2H_4	CH_3C_2H	CH_3COOH	$(CH_3)_2O$	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!

http://astrochymist.org/



astrochymist.org/astrochymist_mole.html

A Hyper-Bibliography of Known Astromolecules

Recently Added Non-Detections: HSO, CH3OCN, CH3NCO

Recently Added Isotopologues: CH2CHO, HNCO, CH3CHCN

Molecules can exist in a wide range of astrophysical environments, from the extremely cold regions between stars to the atmospheres of stars themselves.

To date, nearly 200 molecular species have been tentatively or definitively identified in interstellar or circumstellar clouds, while about 50 have been identified in studies of comets in our solar system. Numerous isotopologues of interstellar and circumstellar molecules have also been observed.

Some detections reported on these pages may be controversial, but all are taken from the peer-reviewed astronomical literature. A questionable identification may be removed at a later date if circumstances warrant.

Jacque Crovisier has amassed a comprehensive compilation of species observed to date in the interstellar medium, in comets, or in non-terrestrial planetary atmospheres, plus additional ones which may prove to be found.

Interstellar & Circumstellar Molecules
UPDATED CH3CHCH2O UPDATED

Cometary Molecules

Molecules on Planetoids

Planetary Molecules

Molecules in Brown Dwarfs and Stellar Atmospheres

T increasing

$HC_{11}N$

The Astrochymist

Maintained by DE Woon
Updated 27 July 2016

Linha do tempo das Descobertas

YEAR	SPECIES	CITATION	SOURCE(S)/LINES
1937 LMC	CH methylidyne Astromolecule of the Month	Considerations Regarding Interstellar Molecules P. Swings and L. Rosenfeld, ApJ 86:483-486 (1937) Evidence for the Molecular Origin of Some Hitherto Unidentified Interstellar Lines A. McKellar, Publ Astron Soc Pac 52:187-192 (1940) Some Results with the COUDÉ Spectrograph of the Mount Wilson Observatory W. S. Adams, ApJ 93:11-23 (1941) Radio Detection of Interstellar CH O. E. H. Rydbeck, J. Elldér, and W. M. Irvine, Nature 246:246-248 (1973) *Hubble Space Telescope* Measurements of Vacuum Ultraviolet Lines of Interstellar CH Y. Sheffer and S. R. Federman, ApJ 659:1353-1359 (2007)	ζ Oph vis lines at 3878.8, 3886.4, 3890.2, & 4300.3 Å; uv lines near 1271, 1368, 1369, 1370, 1549, & 1694 Å; Cas A and 4 dark clouds $J = 1/2$, v_{01} (3263.794 MHz) $J = 1/2$, v_{11} (3335.481 MHz) $J = 1/2$, v_{10} (3349.193 MHz)
1940 NGC253	CN cyano radical Astromolecule of the Month	Evidence for the Molecular Origin of Some Hitherto Unidentified Interstellar Lines A. McKellar, Publ Astron Soc Pac 52:187-192 (1940) Some Results with the COUDÉ Spectrograph of the Mount Wilson Observatory W. S. Adams, ApJ 93:11-23 (1941) Observation of the CN Radical in the Orion Nebula and W51 K. B. Jefferts, A. A. Penzias, and R. W. Wilson, ApJ 161:L87-L89 (1970)	ζ Oph lines at 3874.02 & 3874.61 Å Orion nebula, W51 $J = 1 \rightarrow 0$ (113492 MHz)
1941 LMC	CH^+ methylidyne cation Astromolecule of the Month	Note on CH+ in Interstellar Space and in the Laboratory A. E. Douglas and G. Herzberg, ApJ 94:381 (1941) OBSERVATIONS Interstellar Neutral Potassium and Neutral Calcium T. Dunham, Jr., Pub Astron Soc Pac 49:26-28 (1937) Some Results with the COUDÉ Spectrograph of the Mount Wilson Observatory W. S. Adams, ApJ 93:11-23 (1941)	ζ Oph, ξ Per, χ^2 Ori, 55 Cyg (0,0), (1,0), and (2,0) bands of the $A\ ^1\Pi - X\ ^1\Sigma$ system at 4232.6, 3957.7, & 3745.3 Å
1963 M82	OH hydroxyl radical Astromolecule of the Month	Radio Observations of OH in the Interstellar Medium S. Weinreb, A. H. Barrett, M. L. Meeks, and J. C. Henry, Nature 200:829-831 (1963)	Cas A $F=2 \rightarrow 2$ (166[illegible] MHz) $F=1 \rightarrow 1$ (1665.402 MHz)

• • •

http://astrochymist.org/

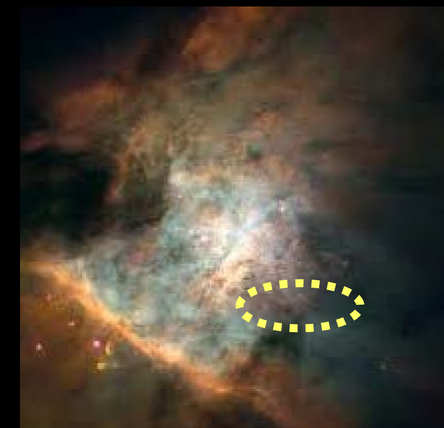
E) Alguns experimentos de astroquímica

1 Fase gasosa

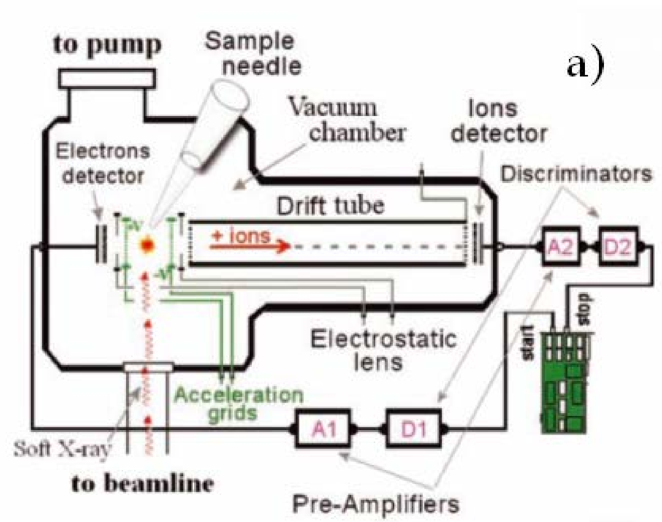
2 Fase condensada (gelos)

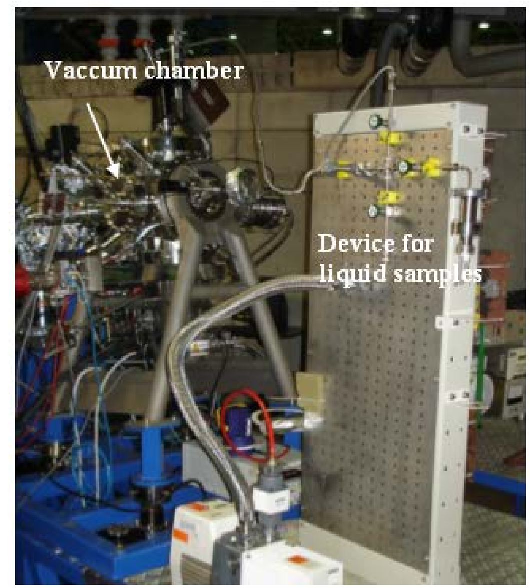
1 - Experimentos envolvendo a interação da radiação (fótons, elétrons, íons) com moléculas na fase gasosa.

Resultados: Fragmentação, Canais de dissociação, σ, τ1/2

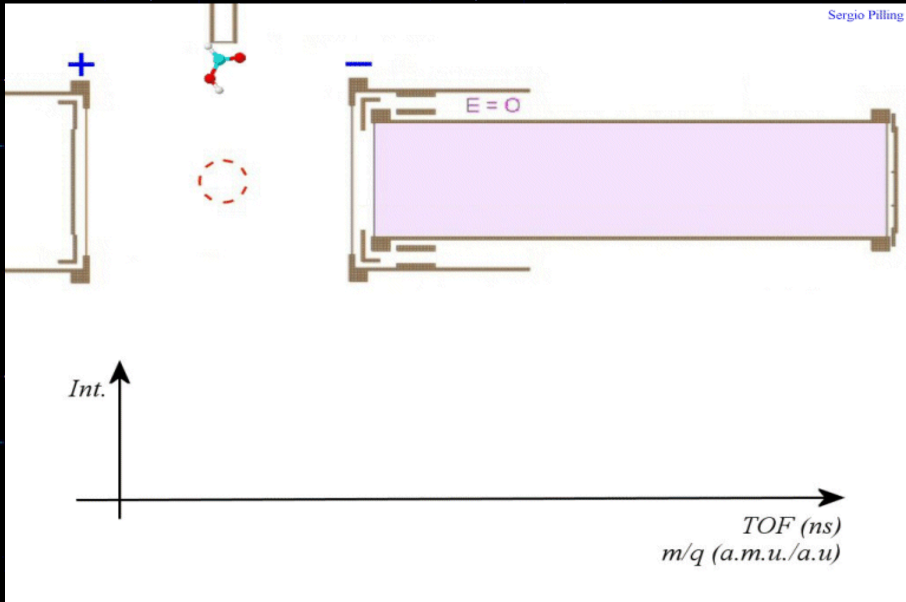


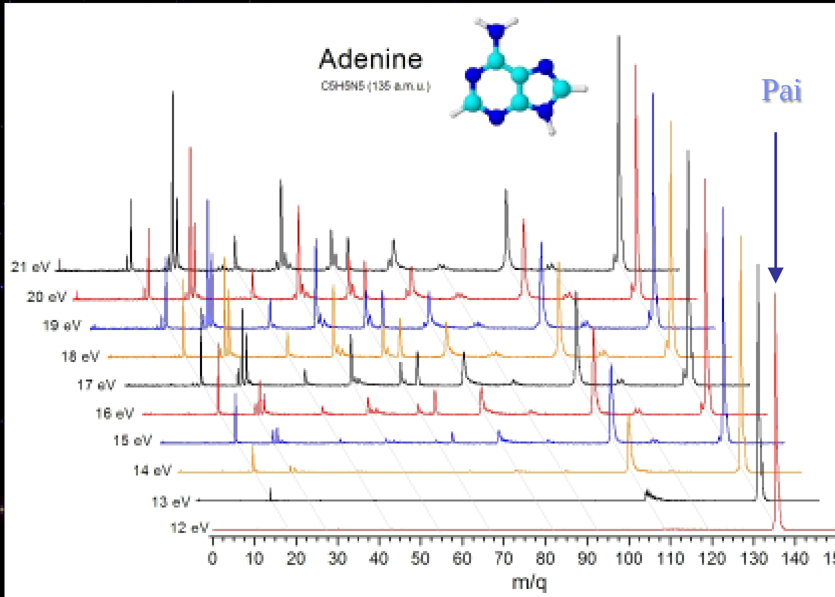
Ex. Fótons (LNLS)

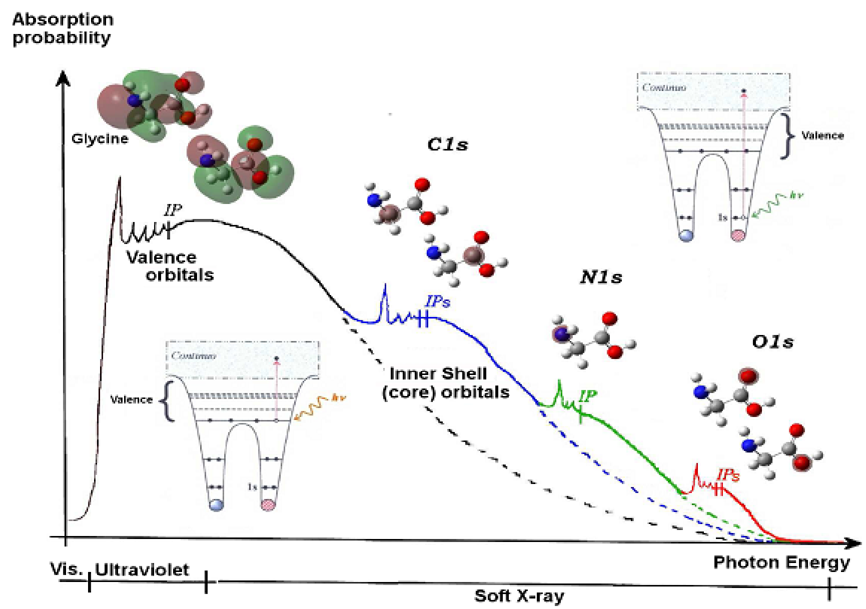




a) Schematic diagram of the experimental set-up employed in gas-phase experiments.
b) Photography of equipment employed at the soft X-ray beamline of LNLS.

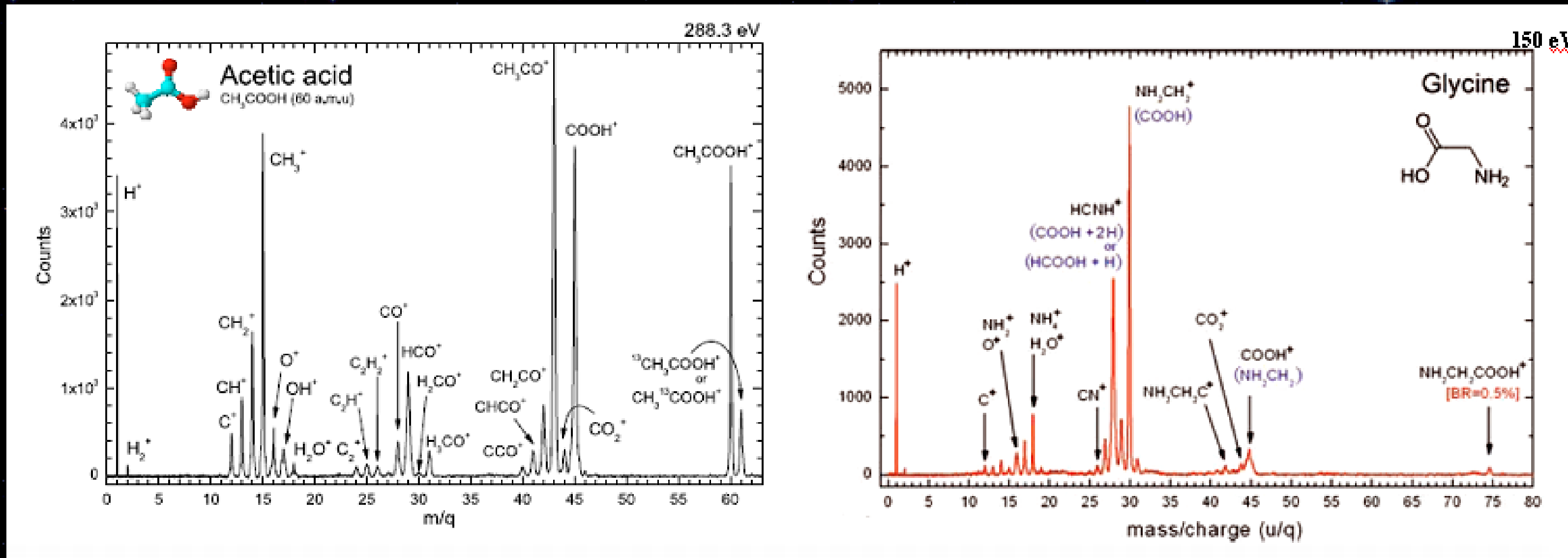


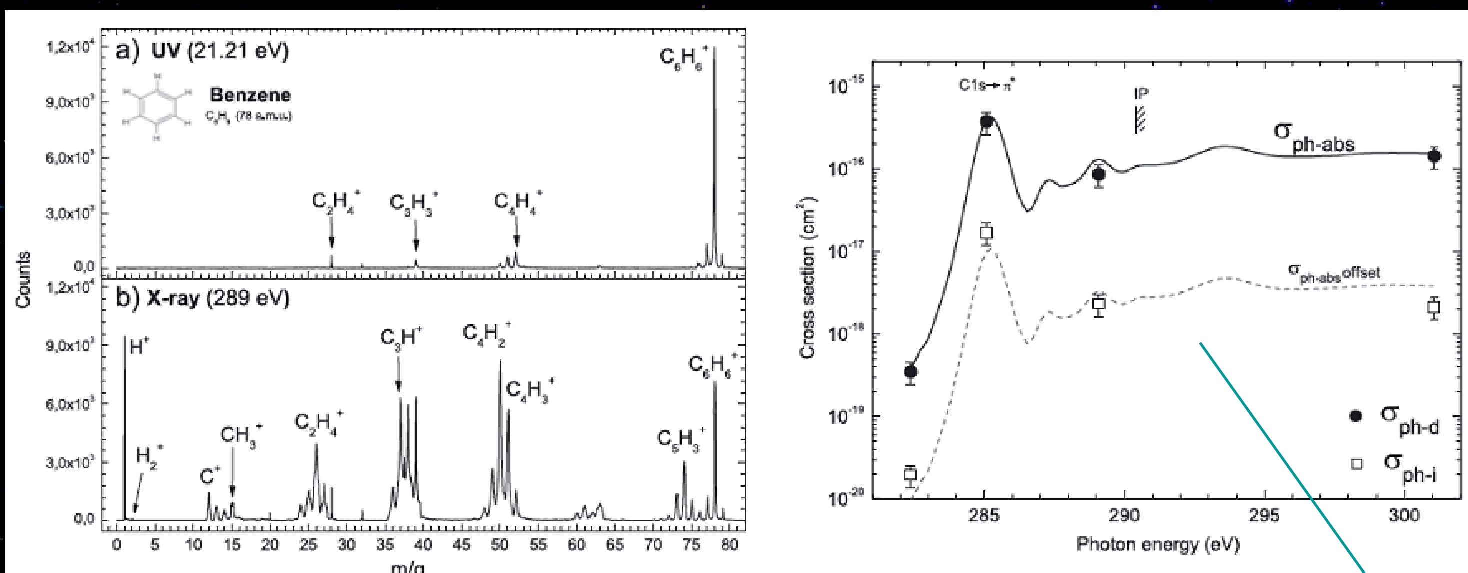




Schematic view of absorption probability as a function of photon energy for polyatomic molecule (e.g. glycine). IP indicates the ionization potential of a given orbital.

Outros exemplos



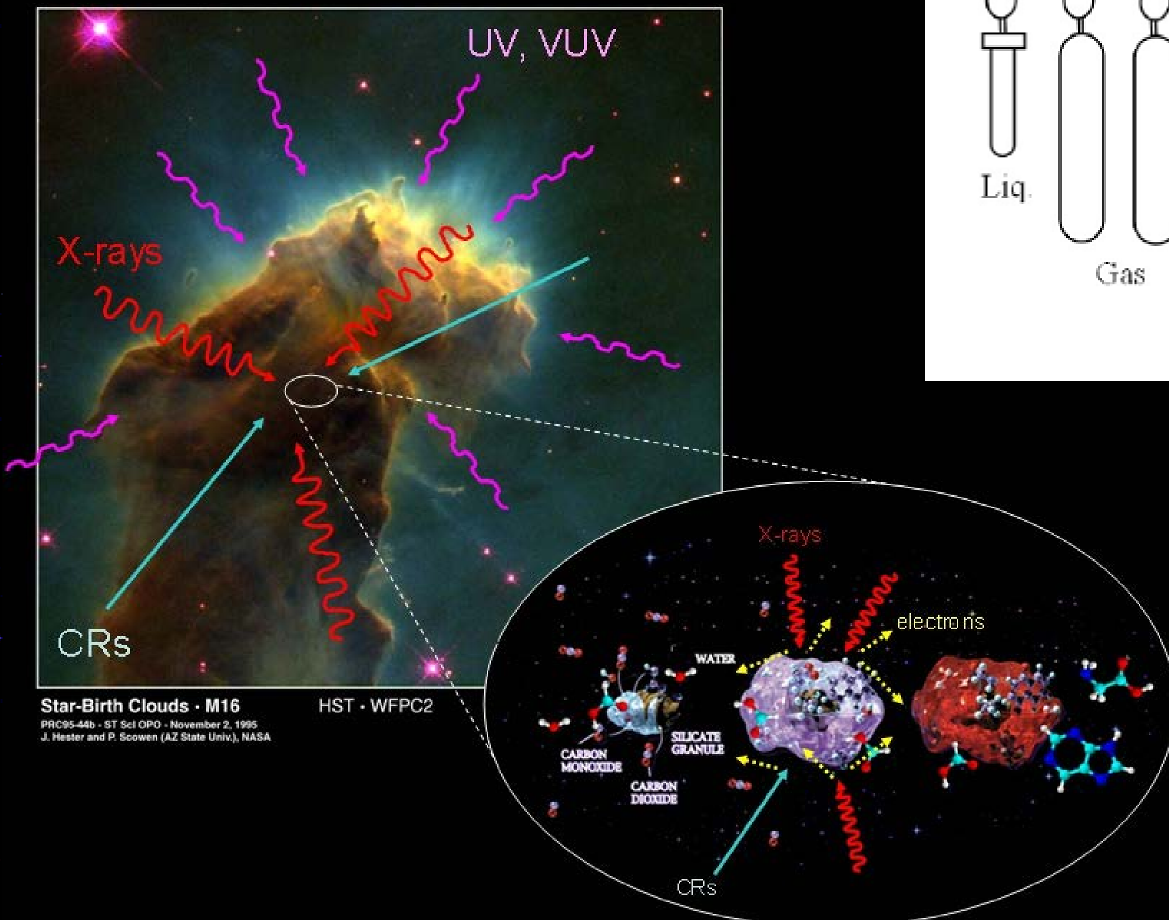


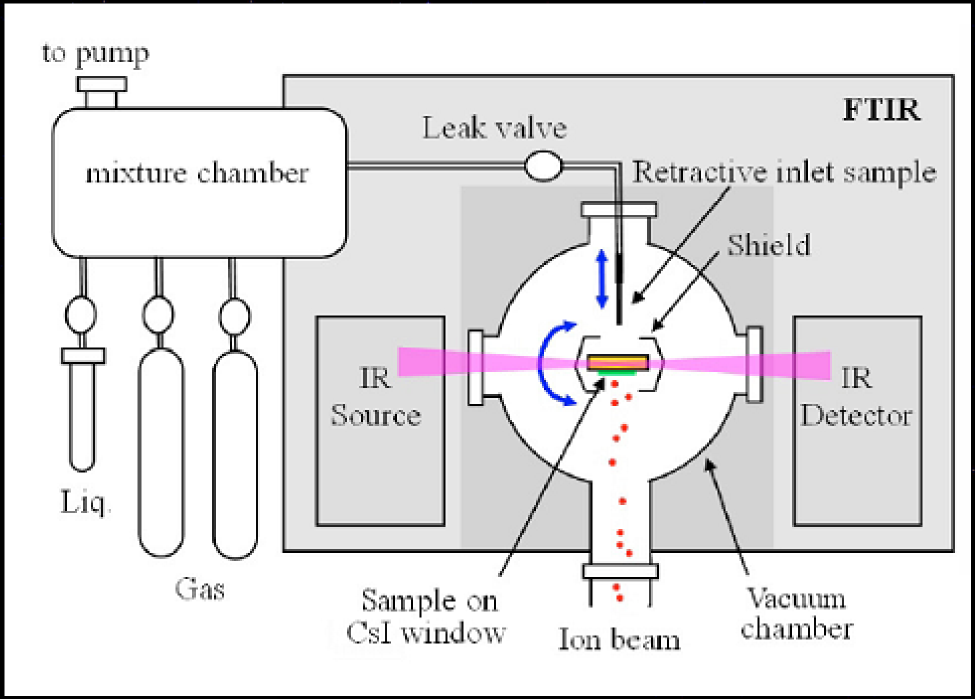
Taxa de Dissociação e tempo de meia-vida

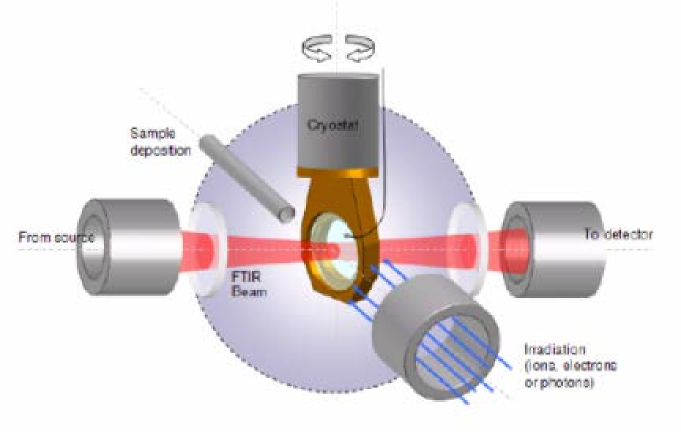
$$R_i \approx \phi \times \sigma_{d,i} \quad [s^{-1}], \qquad t_{1/2,i} = \frac{\ln 2}{R_i} \quad [s]$$

2- Experimentos de Radiólise/Fotólise de Gelos astrofísicos

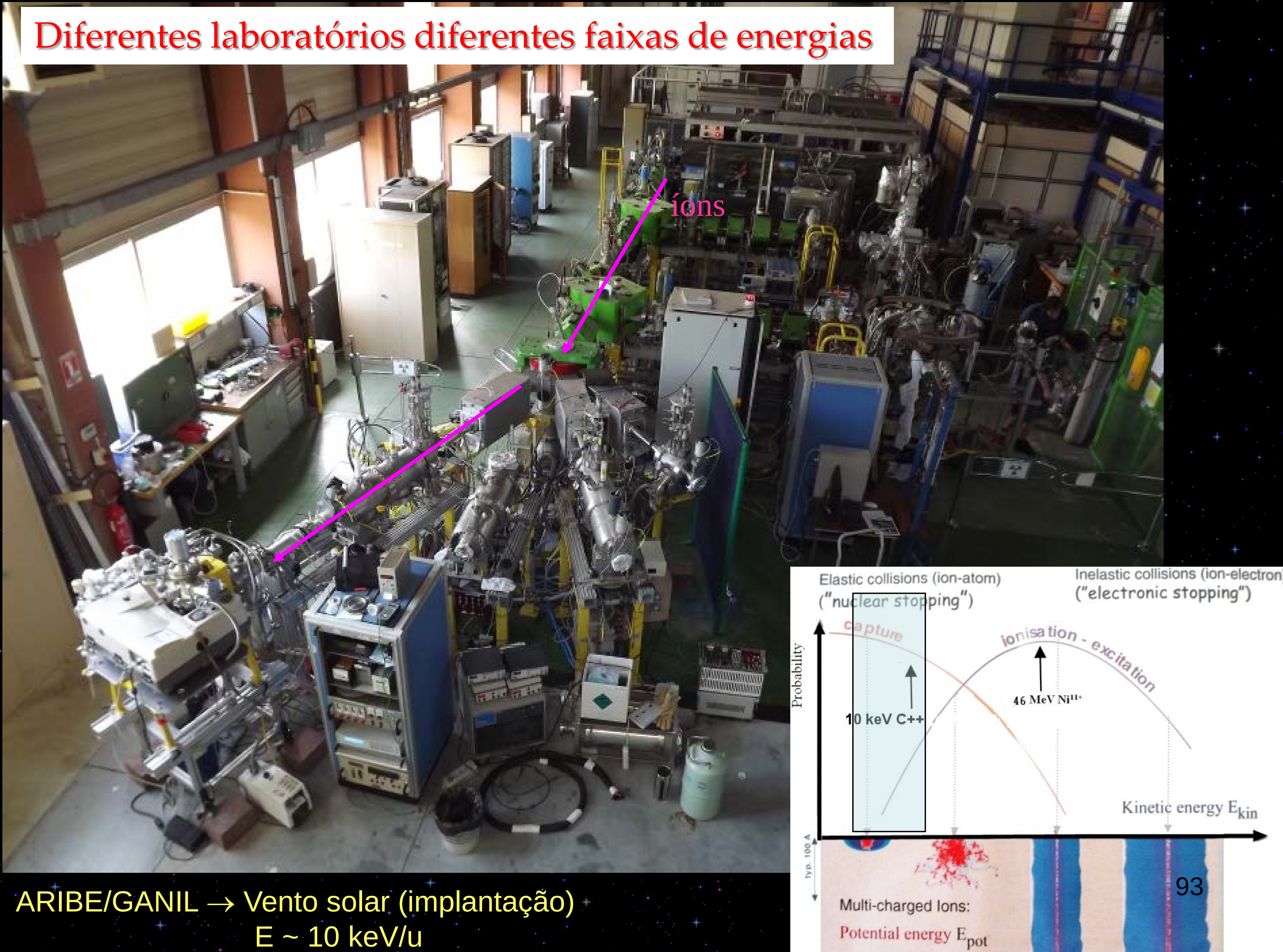
- Criostato (10K);
- Câmara UHV (< 10^{-8} mbar);
- Agente ionizante (PUC-Rio, GANIL, LNLS)
- FTIR e QMS



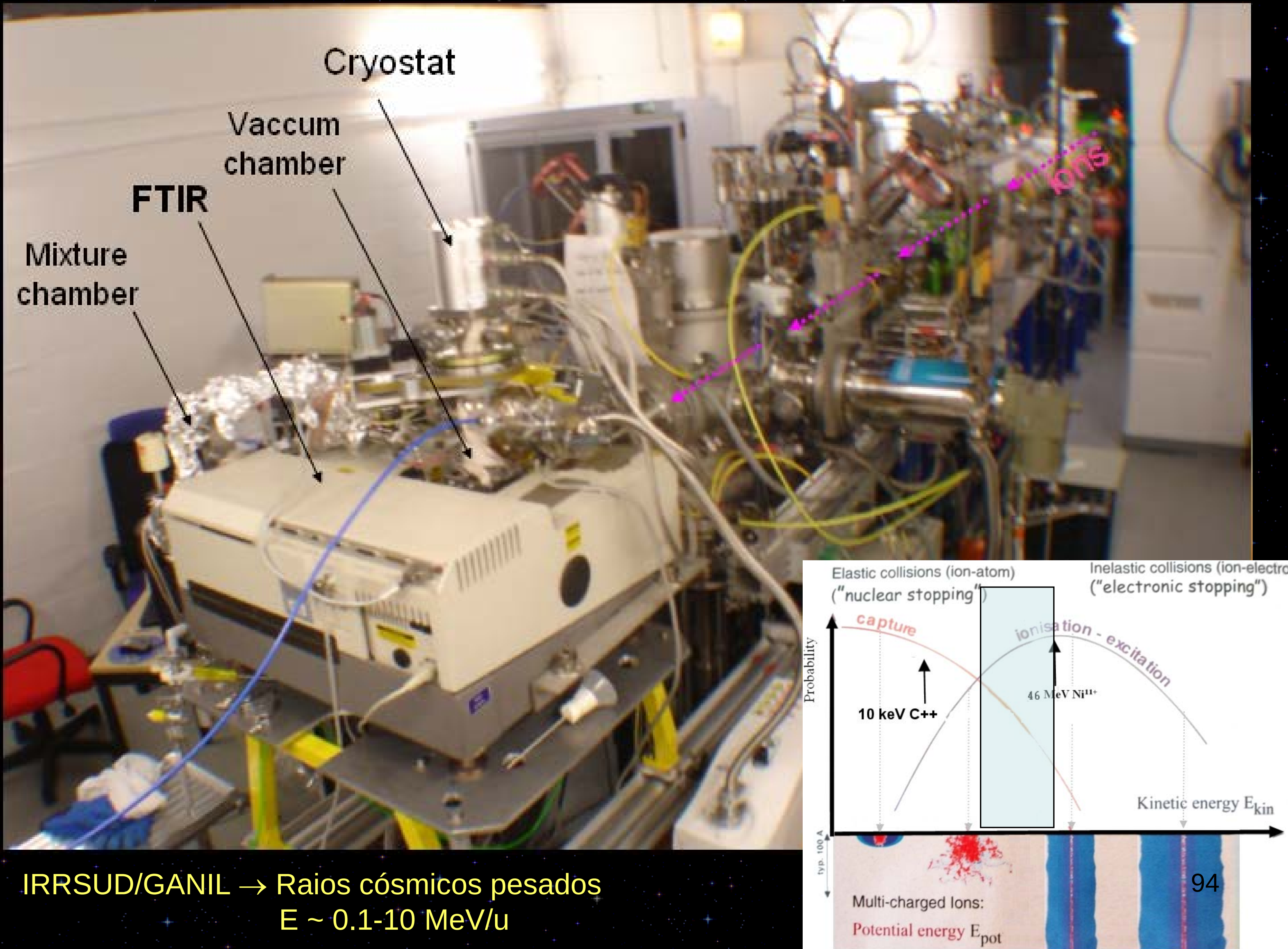




Diferentes laboratórios diferentes faixas de energias



ARIBE/GANIL → Vento solar (implantação)
E ~ 10 keV/u



IRRSUD/GANIL → Raios cósmicos pesados
E ~ 0.1-10 MeV/u

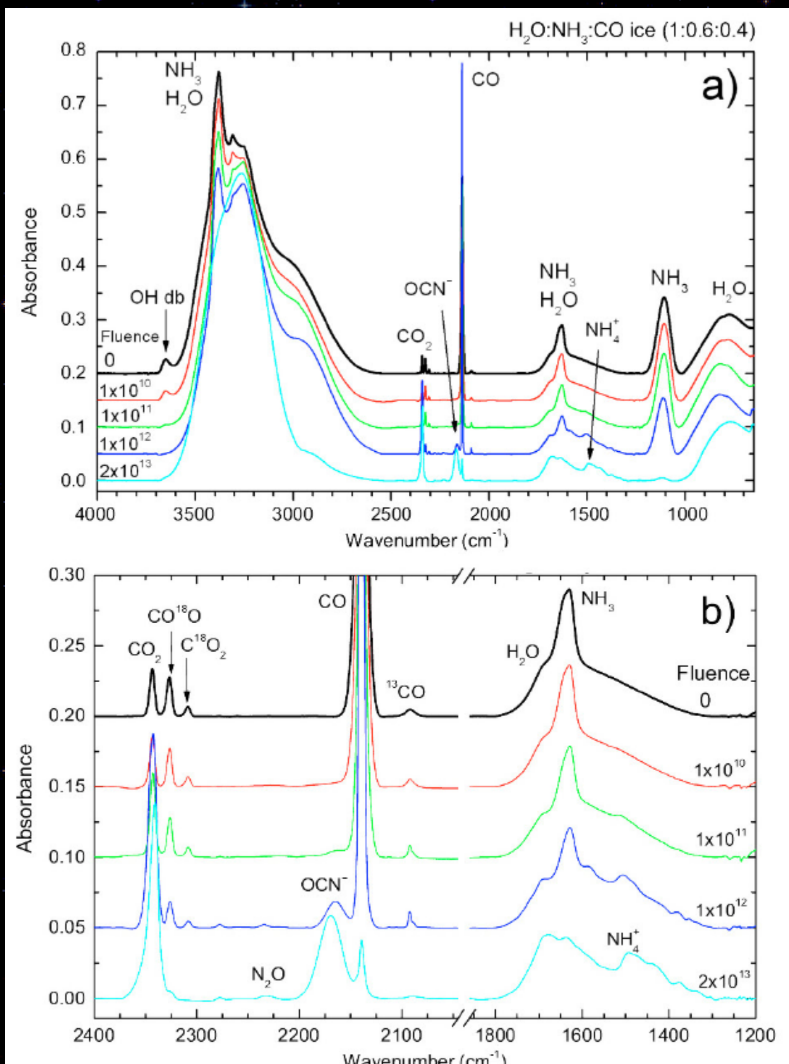
2.1: Bombardeamento de gelo interestelar contendo ammonia com raios cósmicos

A&A 509, A87 (2010)
DOI: 10.1051/0004-6361/200912274

Astronomy & Astrophysics

Radiolysis of ammonia-containing ices by energetic, heavy, and highly charged ions inside dense astrophysical environments

S. Pilling[1,2], E. Seperuelo Duarte[1,3,4], E. F. da Silveira[1], E. Balanzat[3], H. Rothard[3], A. Domaracka[3], and P. Boduch[3]



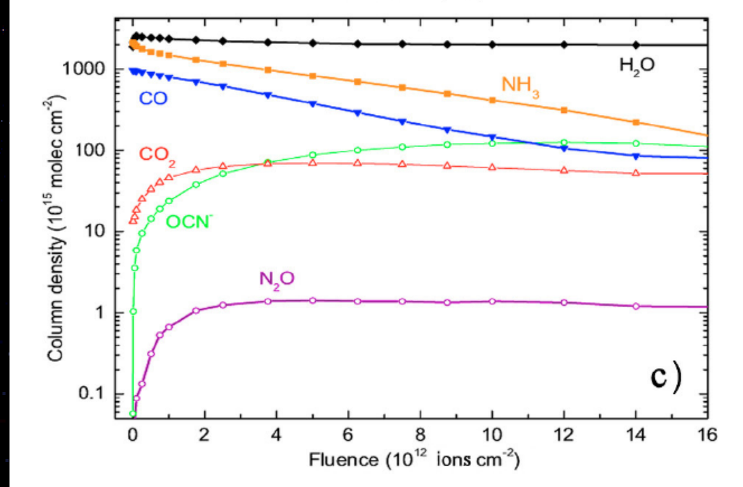


Fig. 2. **a)** Infrared spectra of $H_2O:NH_3:CO$ ice (1:0.6:0.4) before (top dark line) and after different irradiation fluences. **b)** Expanded view from 2400 to 1200 cm^{-1}. Each spectrum has an offset of 0.05 for better visualization. **c)** Molecular column density derived from the infrared spectra during the experiment.

$$\frac{dN_i}{dF} = \sum_{j \neq i} \sigma_{f,ij} N_j + L_i - \sigma_{d,i} N_i - Y_i \Omega_i(F),$$

Table 3. Dissociation cross-sections of the studied molecular species for radiolysis of ammonia-containing ices by 46 MeV Ni ions

Species	Mixture ($H_2O:NH_3:CO$)	σ_d (10^{-13} cm^2)	N_∞ (10^{17} molec cm^{-2})	Y (10^4 molec ion^{-1})	L^f (10^4 molec ion^{-1})	N_0 (10^{17} molec cm^{-2})
H_2O	(1:0.5:0)	~2	23	1^a	38	29
	(1:0.6:0.4)	~2	19	1^a	35	24
NH_3	(1:0.5:0)	1.3	NA^e	0^b	0	2.0
	(1:0.6:0.4)	1.4	NA	0^b	0	1.7
CO	(1:0.6:0.4)	1.9	NA	0^b	0	1.0
	(1:0.6:0.4)	1.9	NA	0^b	1^d	1.0
	(1:0.6:0.4)	1.9	NA	1^c	0	1.0

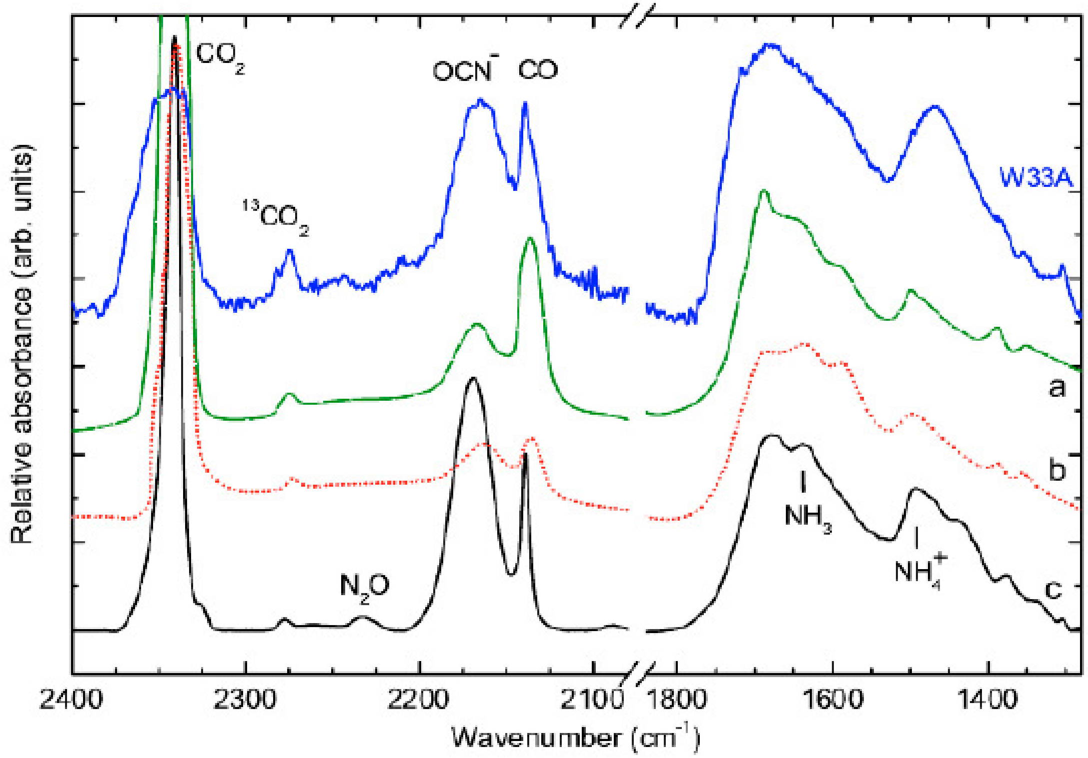
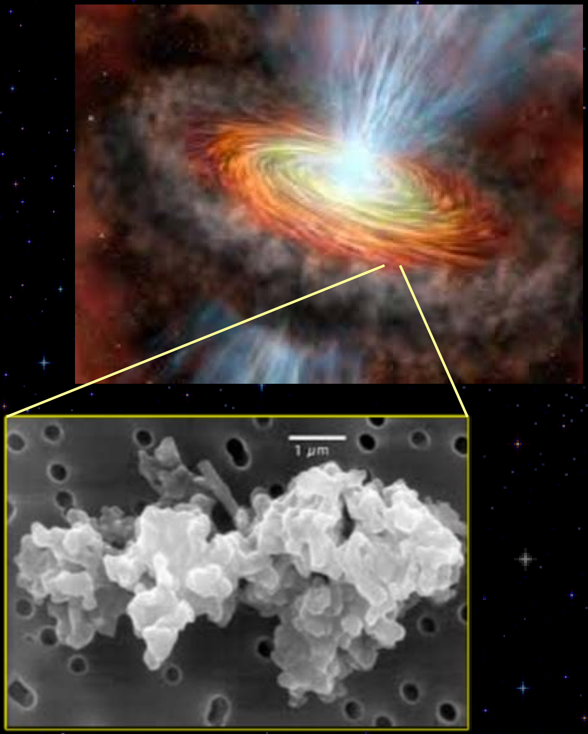


Fig. 5. Comparison between IR spectra of interstellar and laboratory ices. The highest curve is the infrared spectra of protostellar source W33A obtained by the Infrared Space Observatory (ISO). Lower traces indicate laboratory spectra of H_2O:NH_3:CO ices after processing by: **a**) UV photons (Hudson & Moore 2000); **b**) 0.8 MeV protons (Hudson & Moore 2000), and **c**) 46 MeV Ni ions (this work).



Seção de Choque de Destruição e Sputtering

$$N = \left(N_0 + \frac{Y}{\sigma_d}\right)\exp(-\sigma_d F) - \frac{Y}{\sigma_d}$$

$$N_k \approx N_0 \sigma_{f,k}\left[F - \frac{\sigma_d + \sigma_{d,k}}{2} F^2 \exp(-\sigma_d F)\right]$$

Radiochemical yield

$$G_f = 100\frac{\sigma_f}{S} \text{ molecule per 100 eV.}$$

Taxa de Dissociação e tempo de meia-vida

$$R_i \approx \phi_{\mathrm{HCR}} \times \sigma_{\mathrm{d},i} \quad [\mathrm{s}^{-1}], \qquad t_{1/2,i} = \frac{\ln 2}{R_i} \quad [\mathrm{s}]$$

Valores médios empregando íons pesados (E =0.1-10 MeV/u)

σ_d ~ 10^{-13} cm^2 ; G~ 5-10; Y ~ 10^4;
$t_{1/2}$ (MI) ~ 10^6 anos
σ_f ~ 10^{-14} cm^2 ;

Exemplos de reações induzidas por CR

$$H_2O \xrightarrow{CR} H_2O^* \longrightarrow H_2O^+ + e^-$$
$$\searrow OH + H$$
$$\searrow OH + H^+ + e^-$$

$$CO_2 \xrightarrow{CR} CO_2^* \longrightarrow CO_2^+ + e^-$$
$$\searrow CO + O$$
$$\searrow CO + O^+ + e^-$$

$$CO + OH \longrightarrow CO_2 + H$$
$$CO_2 + e^- \longrightarrow CO_2^-$$

$$CO \xrightarrow{H} HCO \xrightarrow{H} H_2CO \xrightarrow{H} CH_3O$$
$$HCO \xrightarrow{OH} HCOOH$$
$$H_2CO \searrow CH_2OH \xrightarrow{H} CH_3OH$$

$$CO_2^- + OH \searrow$$
$$CO_2 + OH^- \longrightarrow HCO_3^- \xrightarrow{H^+} H_2CO_3$$

2.2 Destruição de aminoácidos em ambientes espaciais com raios cósmicos

ASTROBIOLOGY
Volume 13, Number 1, 2013

DOI: 10.1089/ast.2012.0877

The Influence of Crystallinity Degree on the Glycine Decomposition Induced by 1 MeV Proton Bombardment in Space Analog Conditions

Sergio Pilling[1] Luiz A.V. Mendes[2] Vinicius Bordalo[3] Christian F.M. Guaman[3] Cássia R. Ponciano[3] and Enio F. da Silveira[3]

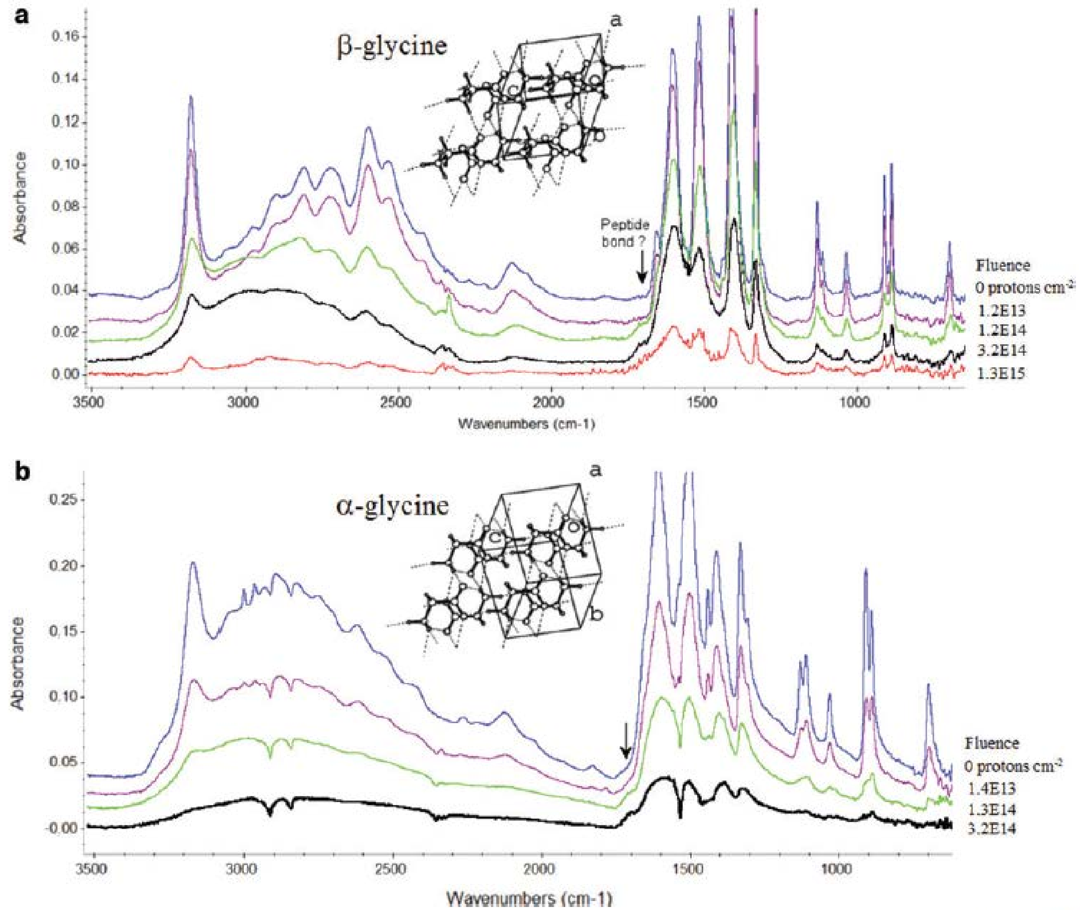


FIG. 4. Evolution of IR spectra of (**a**) β-glycine (from β2 experiment) as a function of proton fluence (0, 1.2×10^{13}, 1.2×10^{14}, 3.2×10^{14}, and 1.3×10^{15} ions cm^{-2}); (**b**) α-glycine (from α1 experiment) as a function of proton fluence (0, 1.4×10^{13}, 1.3×10^{14}, and 3.2×10^{14} ions cm^{-2}). The absorption peaks around 2910, 2850, and 1550 cm^{-1} are artifacts from background subtraction. Crystal structures of glycine polymorphs were taken from Fábián and Kálmán (2004). Arrows indicate the position of an amide functional group around 1650–1700 cm^{-1}, suggesting the formation of peptide bonds in the sample. Color images available online at www.liebertonline.com/ast

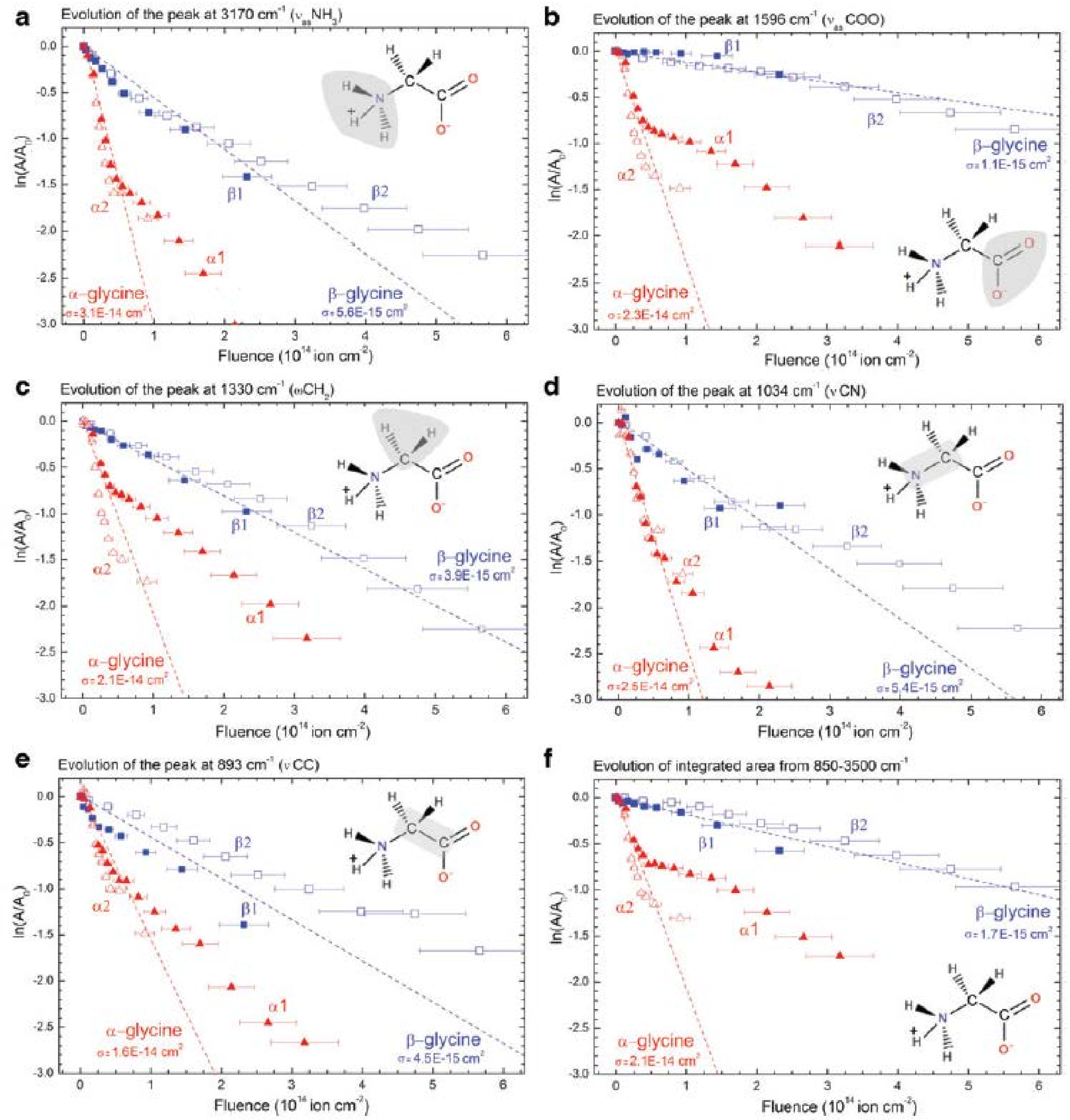


FIG. 5. Evolution of the normalized peak areas as a function of the proton fluence. The selected glycine IR bands are (**a**) 3170 cm^{-1} (v_{as} NH_3), (**b**) 1596 cm^{-1} (v_{as} COO^-), (**c**) 1330 cm^{-1} (ω CH_2), (**d**) 1034 cm^{-1} (v CN), (**e**) 893 cm^{-1} (v CC), and (**f**) whole molecule using integrated area of IR spectra from 850 to 3500 cm^{-1}. The hatched site over zwitterionic glycine structural formulae shows the chemical bonds studied in each figure. The obtained values of the dissociation cross sections

2.3: Formação de aminoácidos, Hidrocarbonetos aromaticos e ligacões peptidicas do espaço.

A&A 509, A87 (2010)
DOI: 10.1051/0004-6361/200912274

Astronomy & Astrophysics

Radiolysis of ammonia-containing ices by energetic, heavy, and highly charged ions inside dense astrophysical environments

S. Pilling[1,2], E. Seperuelo Duarte[1,3,4], E. F. da Silveira[1], E. Balanzat[3], H. Rothard[3], A. Domaracka[3], and P. Boduch[3]

Table 4. Assignment of infrared absorption features produced by the radiolysis of the H_2O:NH_3:CO ice (1:0.6:0.4) by 46 MeV Ni ions at 13 K and after warming to 300 K.

Frequency (cm^{-1})	Wavelength (μm)	Temp. (K)	Molecule	Notes
2233	4.48	13	N_2O	[1,2]
2218–2200	4.51–4.54	300	nitriles†	[8]
2168	4.61	13, 300	OCN^-	[1,3,4,7]
2147	4.66	300	aliph. isocyanide†	[8]
~2112	4.73	300	$NCO_2^†$	[2]
1725	5.80	300	ester†	[5]
1683	5.94	300	amides†	[5]
1652	6.05	300	asym-$N_2O_3^†$	[2]
1637	6.11	13	?	
1593	6.28	300	$NH_3^+CH_2COO^{-†}$	[6]
1558	6.42	300	?	
1533	6.52	300	?	
1506	6.64	300	$NH_3^+CH_2COO^{-†}$	[6]
~1490	6.71	13	NH_4^+	[1,3,7]
1474	6.78	13	$NO_3^†$	[2]
1440	6.94	13	$NH_3^+CH_2COO^{-†}$	[6]
1415	7.07	300	$NH_3^+CH_2COO^{-†}$	[6]
~1370	7.30	13, 300	HMT†	[5]
			$HCOO^-$	[5,9]
~1338	7.47	13, 300	$NH_3^+CH_2COO^{-†}$	[6]
			$NH_2CH_2COO^{-†}$	[6]
			$HCOO^-$	[9]
1305	7.66	13	$N_2O_3^†$; $N_2O_4^†$	[2]
1283	7.80	300	$N_2O^†$	[2]

† 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 & Shutte 2003); [6] electron bombardment of CH_3NH_2:CO_2 ice (Holtom et al. 2005); [7] UV photolysis of ammonia-containing ices (Demyk et al. 1998); [8] UV photolysis of N_2:CH_4 ices at various pressures (Imanaka et al. 2004); [9] proton bombardment of H_2O:NH_3:CO ice (Hudson & Moore 2001).

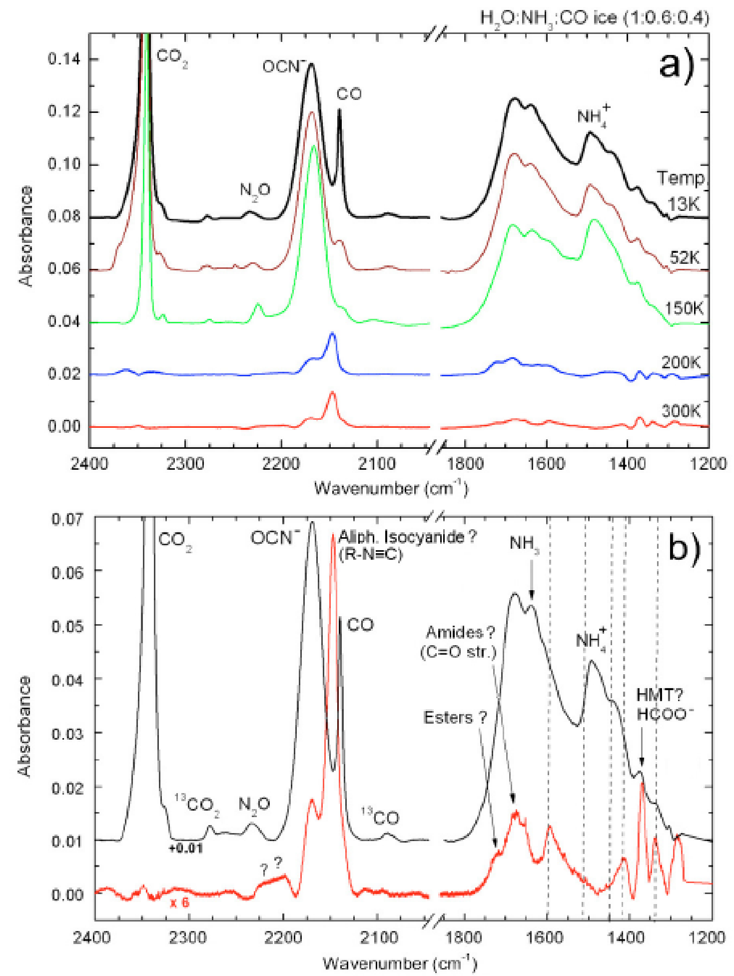


Fig. 6. a) Infrared spectra of H_2O:NH_3:CO ice (1:0.6:0.4) from 2400 to 1200 cm^{-1} during heating to room temperature. The sample temperature of each spectrum is given. Each spectrum has an offset of 0.02 for clearer visualization. **b)** Comparison between the irradiated ice at 13 K (top spectrum) and the 300 K residue (bottom spectrum). Vertical dashed lines indicate the frequencies of some vibration modes of zwitterionic glycine ($NH_3^+CH_2COO^-$).

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
Mon. Not. R. Astron. Soc. 423, 2209–2221 (2012)
doi:10.1111/j.1365-2966.2012.21031.x

Formation of unsaturated hydrocarbons in interstellar ice analogues by cosmic rays

S. Pilling,[1★] D. P. P. Andrade,[1] E. F. da Silveira,[2] H. Rothard,[3] A. Domaracka[3] and P. Boduch[3]

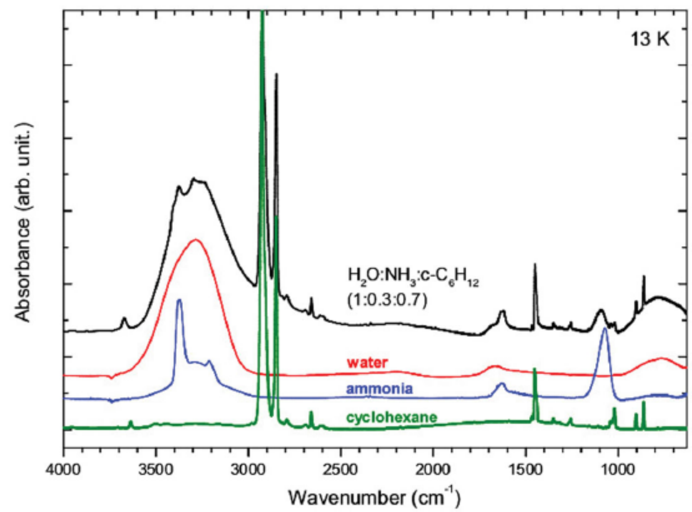


Figure 2. FTIR spectra from 4000 to 600 cm^{-1} of non-irradiated ices at 13 K: mixed H_2O:NH_3:c-C_6H_{12} (1:0.3:0.7) ice (top) and pure c-C_6H_{12} ice (bottom). For comparison, spectra of pure H_2O ice and pure NH_3 ice are also shown.

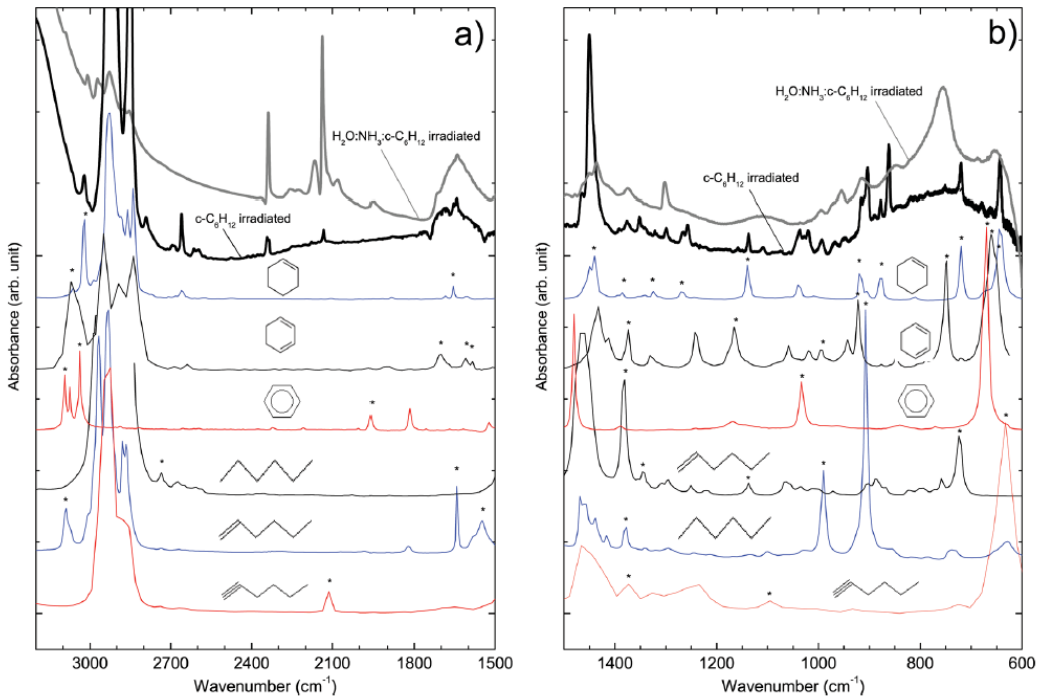


Figure 5. Comparison between the IR spectra of the two irradiated ices at highest fluences (this work) with IR spectra of different non-irradiated cyclic and aliphatic hydrocarbons from the NIST database (Lindstrom & Mallard 2005). Skeletal formulae of each species (cyclohexene, 1,3-cyclohexadiene, benzene, hexane, 1-hexene and 1-hexyne) are shown. Asterisks indicate the peaks that have possible identification in the spectra of irradiated ices. (a) From 3200 to 1500 cm^{-1}. (b) From 1600 to 600 cm^{-1}.

No Lab.

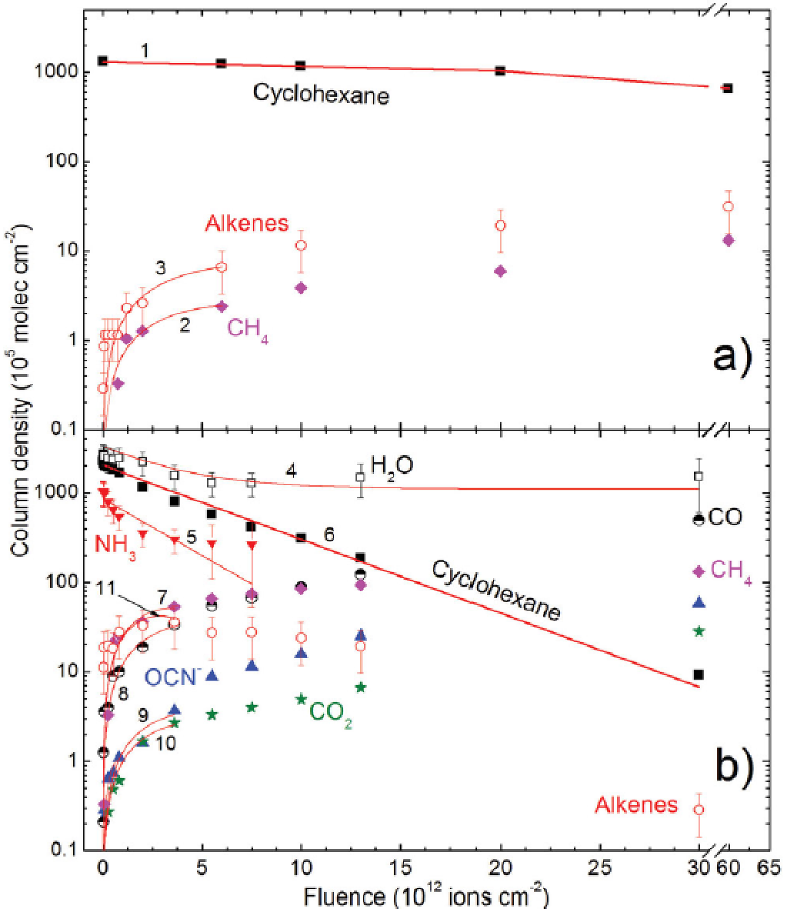


Figure 6. (a) Variation of the column density of cyclohexane and selected daughter species (CH_4) in pure ice experiment as function of ion (219-MeV O) fluence. (b) Variation of the column density of cyclohexane, water and ammonia and selected daughter species (CO, CO_2, CH_4 and OCN^-) in mixed ice experiment as a function of ion (632-MeV Ni) fluence. The lines indicate the fittings using equation (4) (pure cyclohexane), equation (5) (cyclohexane and ammonia in mixed ice), equation (6) (water in mixed ice) and equation (7) (products). The model parameters are given in Table 3.

→

No espaço

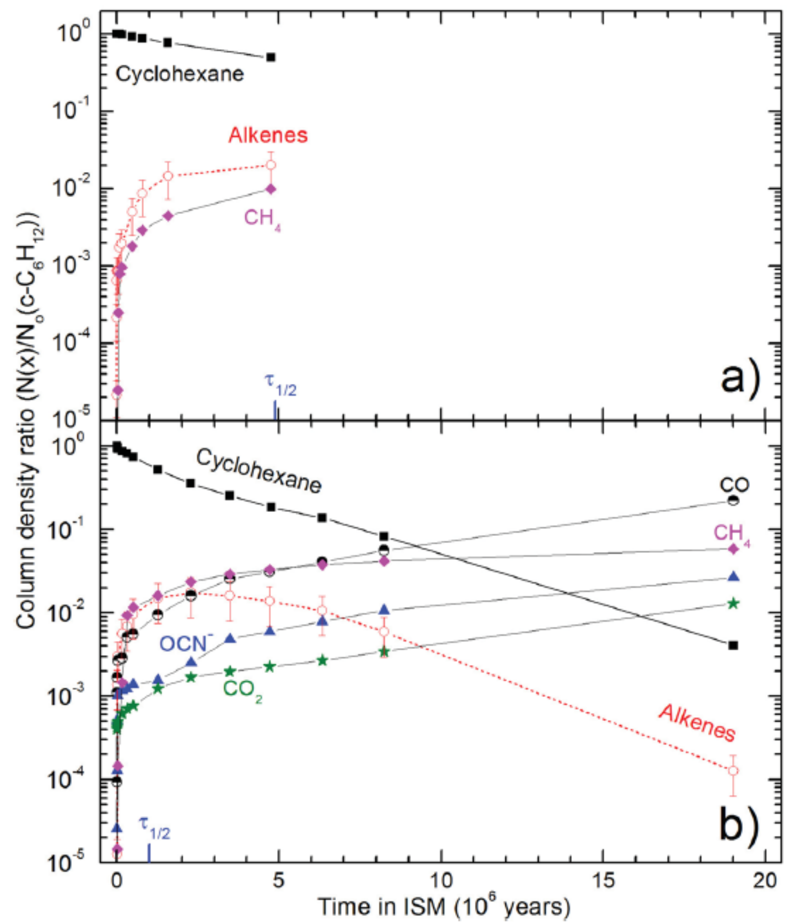


Figure 7. Column density ratios of cyclohexane and some radiolysis products over initial cyclohexane column density as function of equivalent cosmic ray exposure time at ISM. (a) Pure c-C_6H_{12} ice at 13 K irradiated by 219-MeV O ions (medium-mass cosmic ray analogue). (b) Mixed H_2O:NH_3:c-C_6H_{12} (1:0.3:0.7) ice at 13 K irradiated by 632-MeV Ni ions (heavy cosmic ray analogue). In each figure, the half-life of cyclohexane ($t_{1/2}$) in ISM as a result of cosmic ray bombardment is indicated. Lines are only to guide the eyes.

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **441**, 3209–3225 (2014) doi:10.1093/mnras/stu656

Radiolysis of amino acids by heavy and energetic cosmic ray analogues in simulated space environments: α-glycine zwitterion form

Williamary Portugal,[1] Sergio Pilling,[1★] Philippe Boduch,[2] Hermann Rothard[2] and Diana P. P. Andrade[1,2]

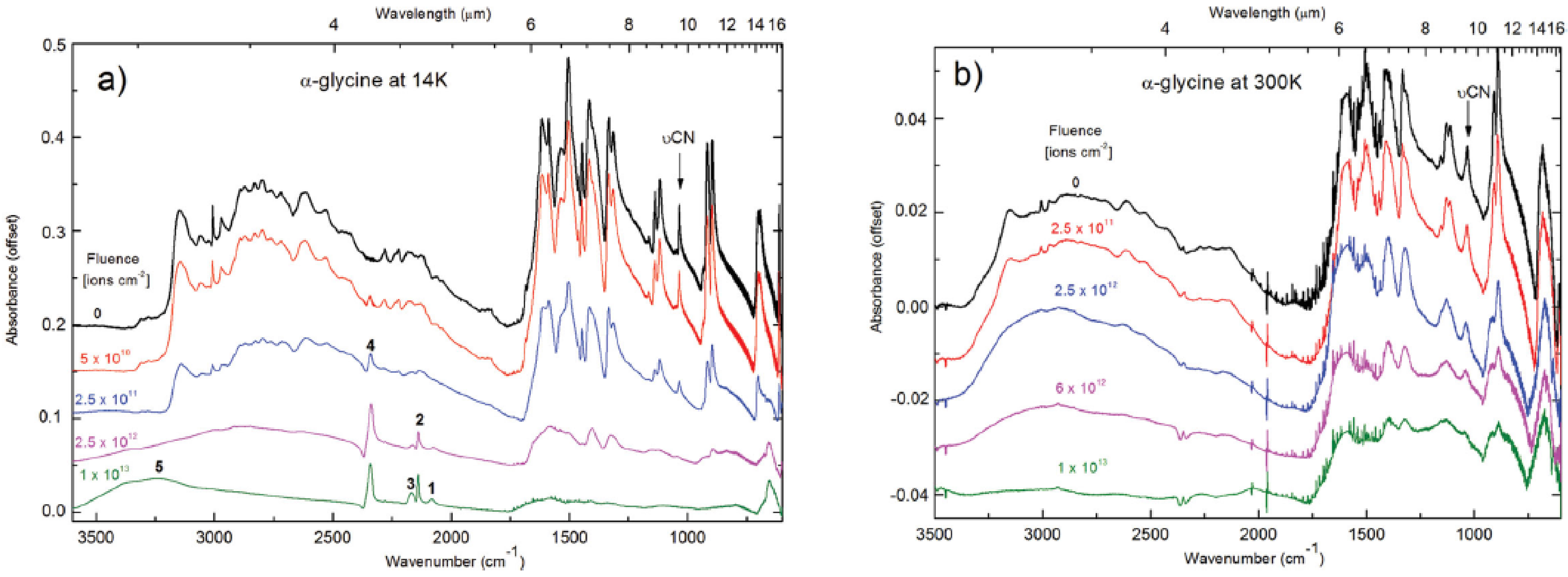


Figure 2. Infrared spectra of α-glycine ($^{+}NH_3CH_2COO^{-}$) before (top dark line) and after different irradiation fluences. The arrow on the peak at 1034 cm^{-1} indicates the location of the CN stretching mode employed to quantify the sample. The peaks of daughter species formed on the irradiated sample at 14 K are indicated by numbers: (1) CN^- (2080 cm^{-1}); (2) CO (2137 cm^{-1}); (3) OCN^- (2165 cm^{-1}); (4) CO_2 (2336 cm^{-1}); (5) H_2O (3280 cm^{-1}). Samples at (a) 14 K and (b) 300 K.

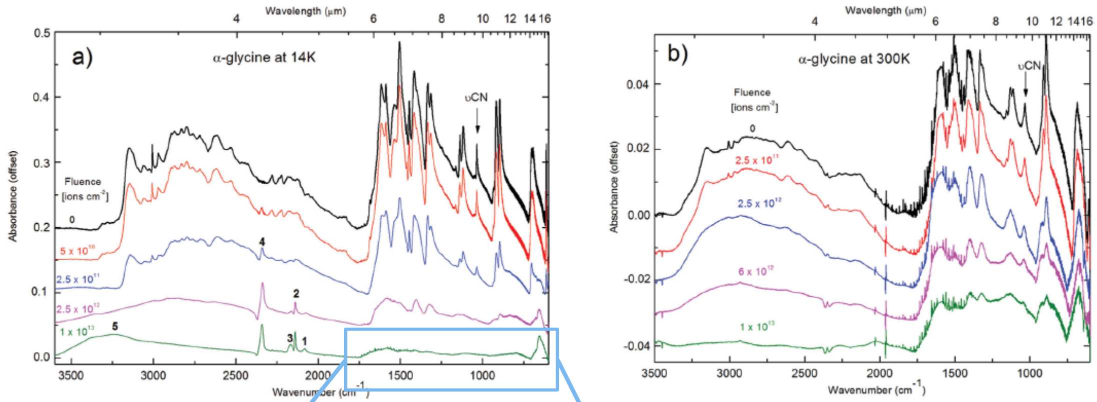


Figure 2. Infrared spectra of α-glycine ($^{+}NH_3CH_2COO^{-}$) before (top dark line) and after different irradiation fluences. The arrow on the peak at 1034 cm^{-1} indicates the location of the CN stretching mode employed to quantify the sample. The peaks of daughter species formed on the irradiated sample at 14 K are indicated by numbers: (1) CN^{-} (2080 cm^{-1}); (2) CO (2137 cm^{-1}); (3) OCN^{-} (2165 cm^{-1}); (4) CO_2 (2336 cm^{-1}); (5) H_2O (3280 cm^{-1}). Samples at (a) 14 K and (b) 300 K.

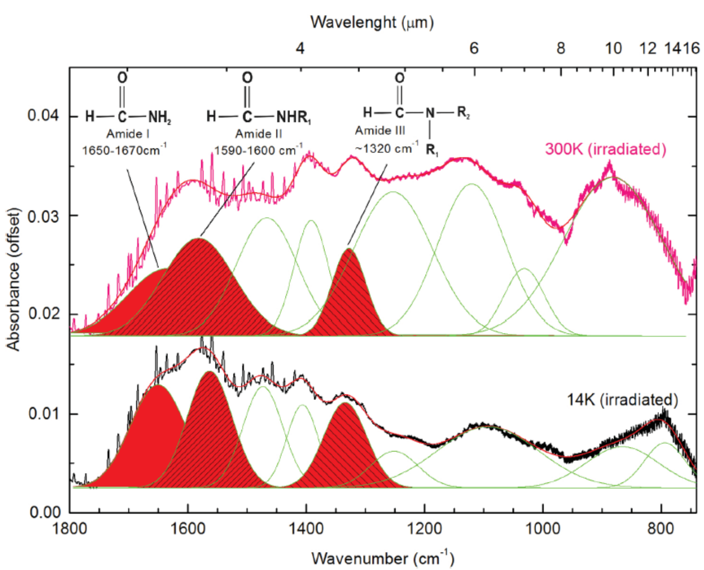


Figure 8. Expanded view of infrared spectra of the residues produced after the bombardment employing 1×10^{13} Ni ion cm^{2}. Filled curves present tentative assignments of amide bands obtained from a spectral deconvolution employing nine Gaussian profiles, in the range 1800–750 cm^{-1}.

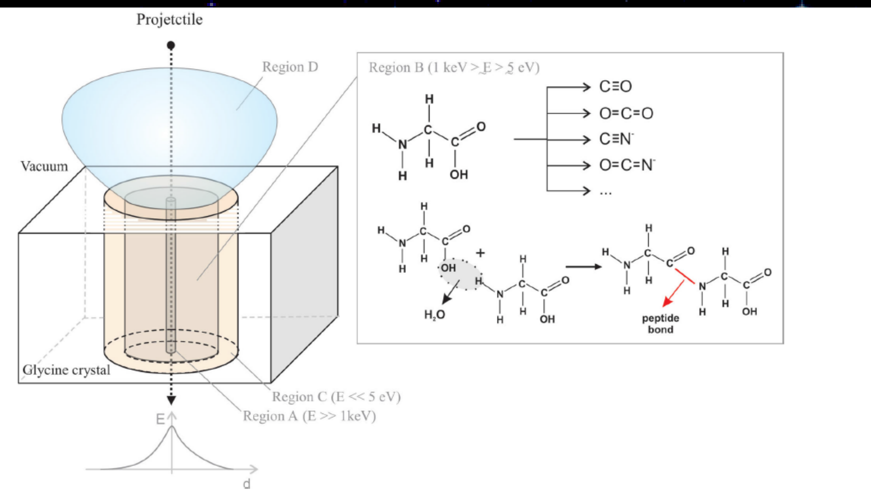
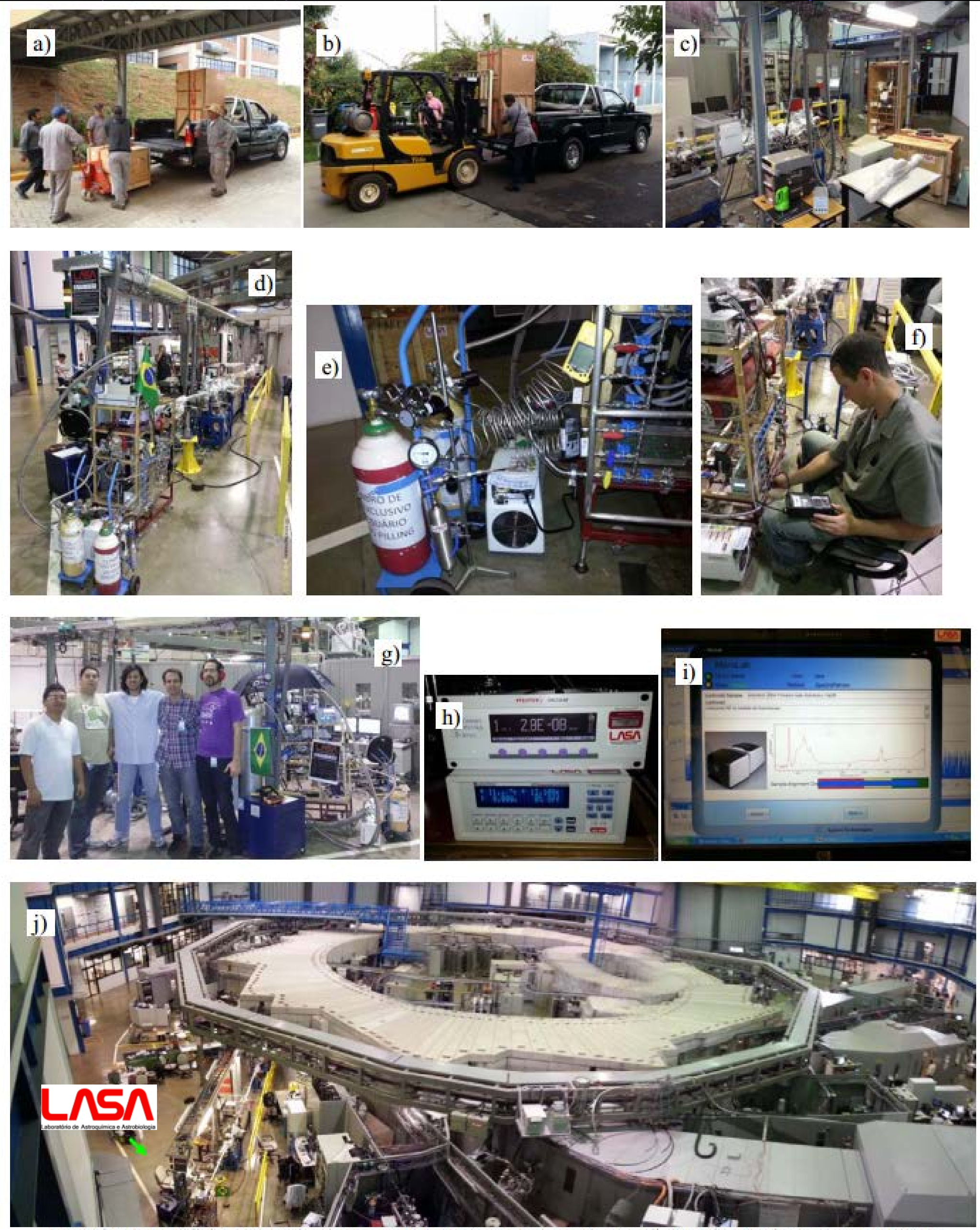


Figure 7. Schematic diagram of the three different physical–chemical regions surrounding the ion track during the bombardment of the glycine sample (named as regions A, B, C and D). Selected reaction pathways for some daughter species that can occur in region B and a schematic plot of the energy delivered within the sample as a function of the distance of the ion track are also shown. A tentative reaction for eventual production of the peptide bond is also illustrated. See details in the text.

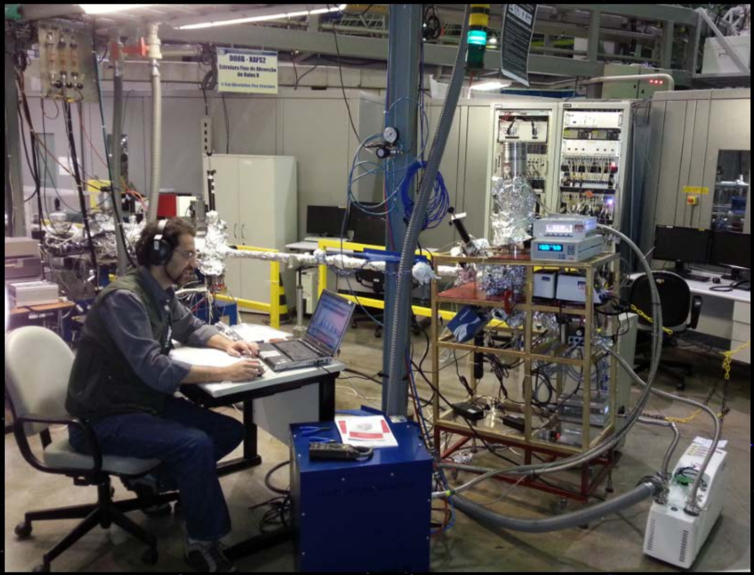
2.4 - Experimentos de fotólise com luz Síncrotron (UV, Raios X)

The measurements were performed inside a high vacuum chamber from Astrochemistry and Astrobiology Univap´s laboratory (LASA) coupled to SGM beamline at the Brazilian Synchrotron light Source LNLS at Campinas in june of 2013.



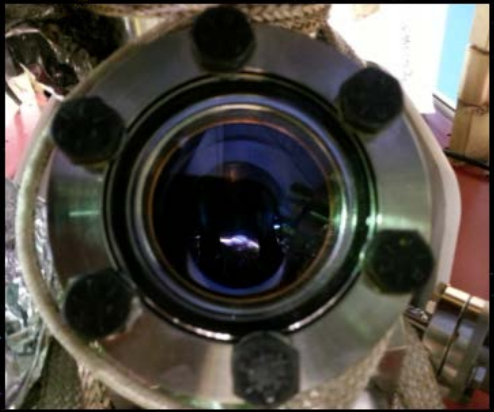
Legenda: a) Acondicionamento da câmara STARK para seu transporte para realização de experimentos no LNLS em Campinas, SP; b) Chegada dos equipamentos no LNLS; c) Desempacotamento da câmara STARK dentro do Hall experimental do LNLS, d) Câmara STARK montada na linha SGM do LNLS pronta para início dos experimentos; e) Cilindros de amostras e detectores de gases do LASA acoplados a câmara STARK; f) Teste da linha de gás da câmara STARK; g) Equipe do LASA realizando os experimentos no LNLS; h) Eletrônica dos controladores de pressão e temperatura da câmara

2.4.1 Simulação da lua Europa



Sample preparation

Sample irradiation



The gas samples were deposited onto a ZnSe substrate at 13 K and then heated (when was the case) to specific temperatures to be irradiated. *In-situ* analysis were performed by a Fourier transform infrared (FTIR) spectrometer at different photon fluences. Cross section, photolysis yield and half-lives of the produced species were quantified.

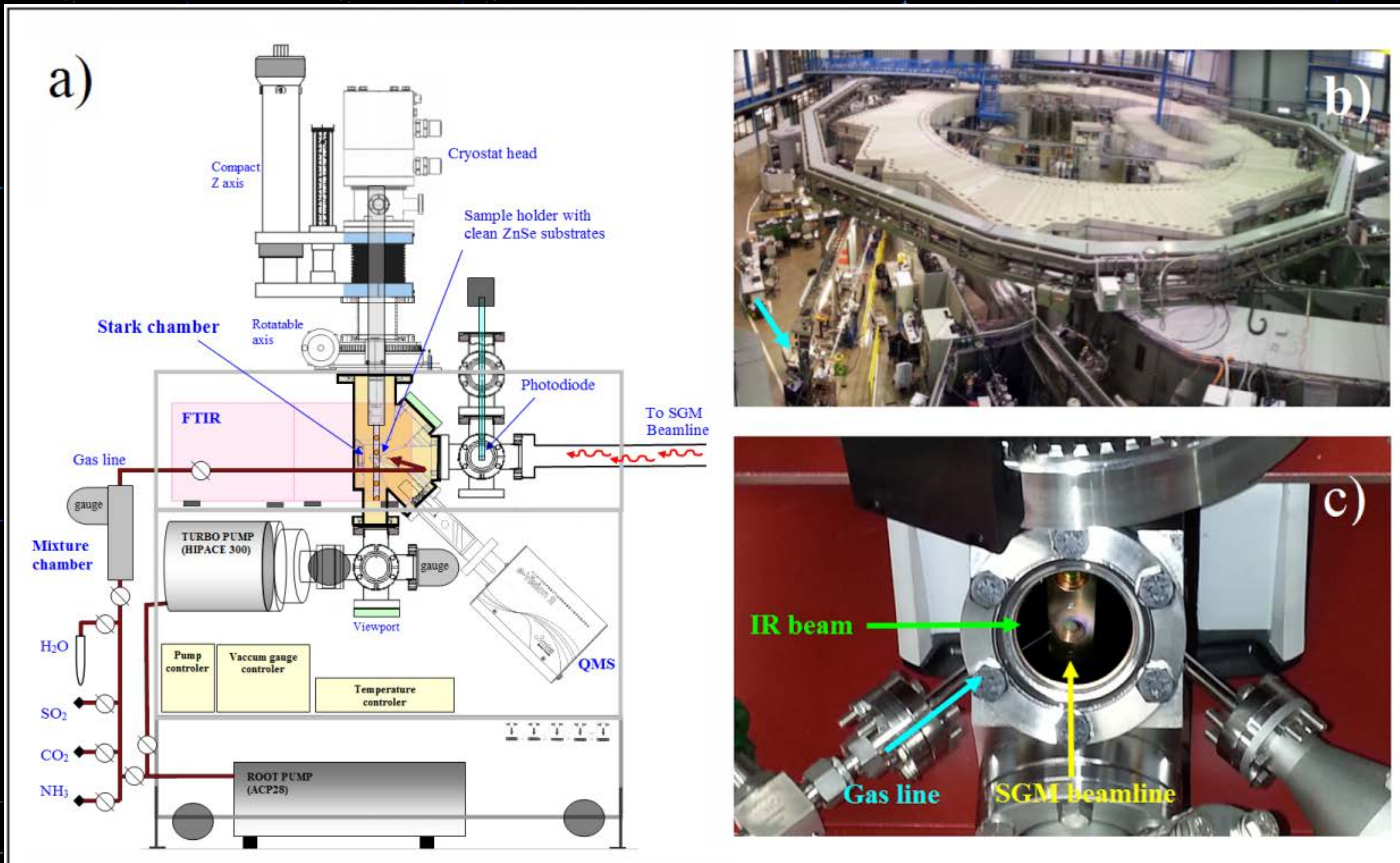
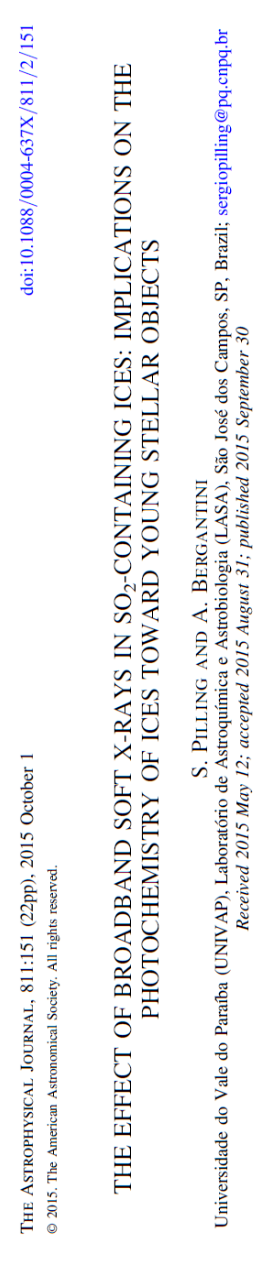


Figure 1. a) Diagram of the experimental setup (Stark chamber). b) Picture of the experimental hall of the Brazilian synchrotron source (LNLS) with the experimental chamber coupled at the SGM beam line (arrow). c) Picture showing the Europa surface analog inside the chamber ready to be irradiated by synchrotron light.

Pilling and Bergantini, MNRAS, 2015, APJ.

Irradiation of the Europa surface analog by X-rays.


THE ASTROPHYSICAL JOURNAL, 811:151 (22pp), 2015 October 1
doi:10.1088/0004-637X/811/2/151

THE EFFECT OF BROADBAND SOFT X-RAYS IN SO_2-CONTAINING ICES: IMPLICATIONS ON THE PHOTOCHEMISTRY OF ICES TOWARD YOUNG STELLAR OBJECTS

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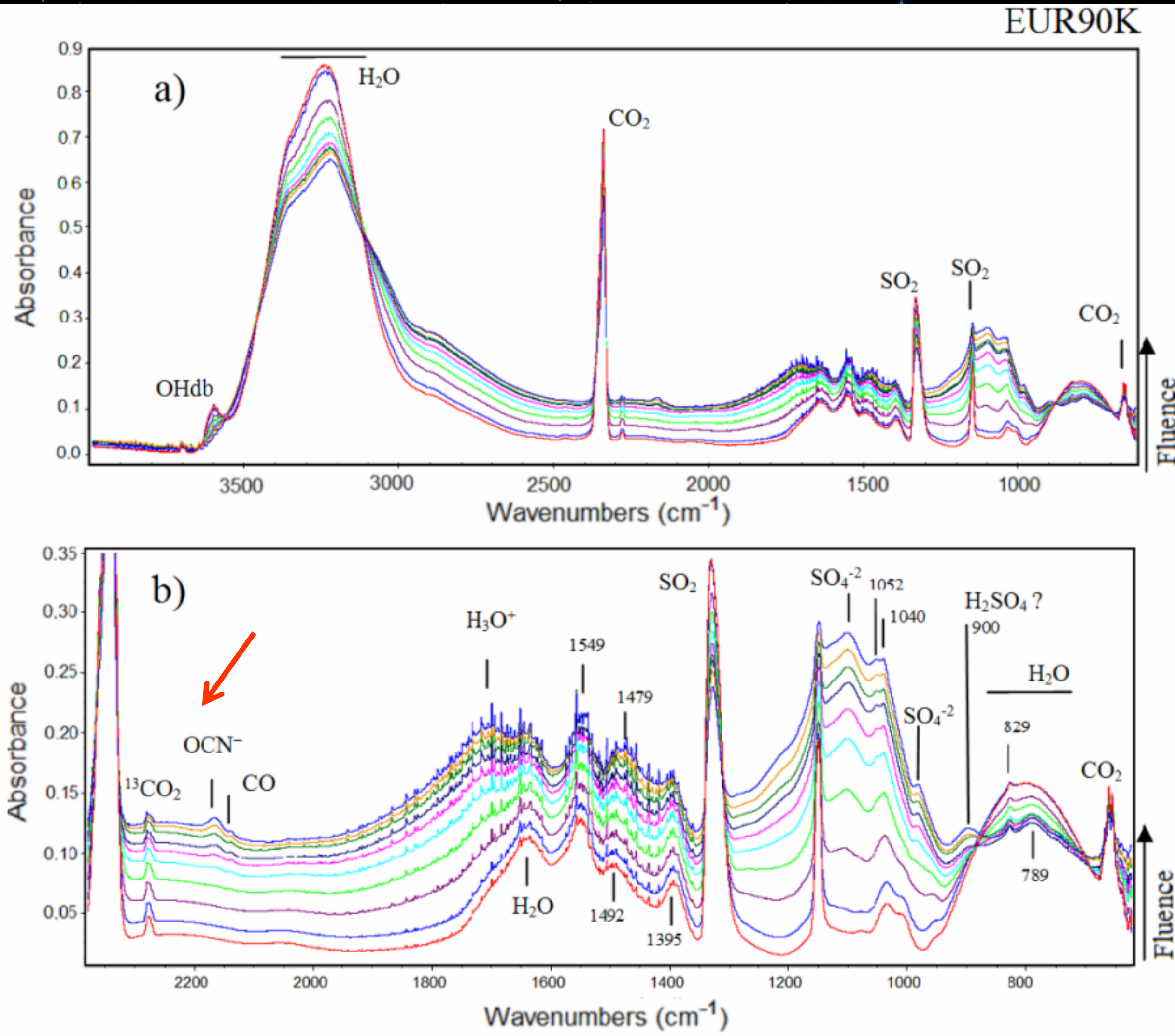
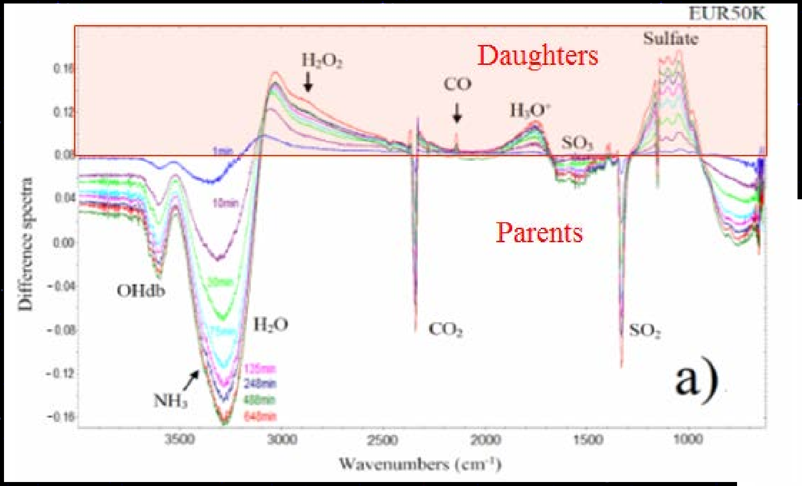
Received 2015 May 12; accepted 2015 August 31; published 2015 September 30

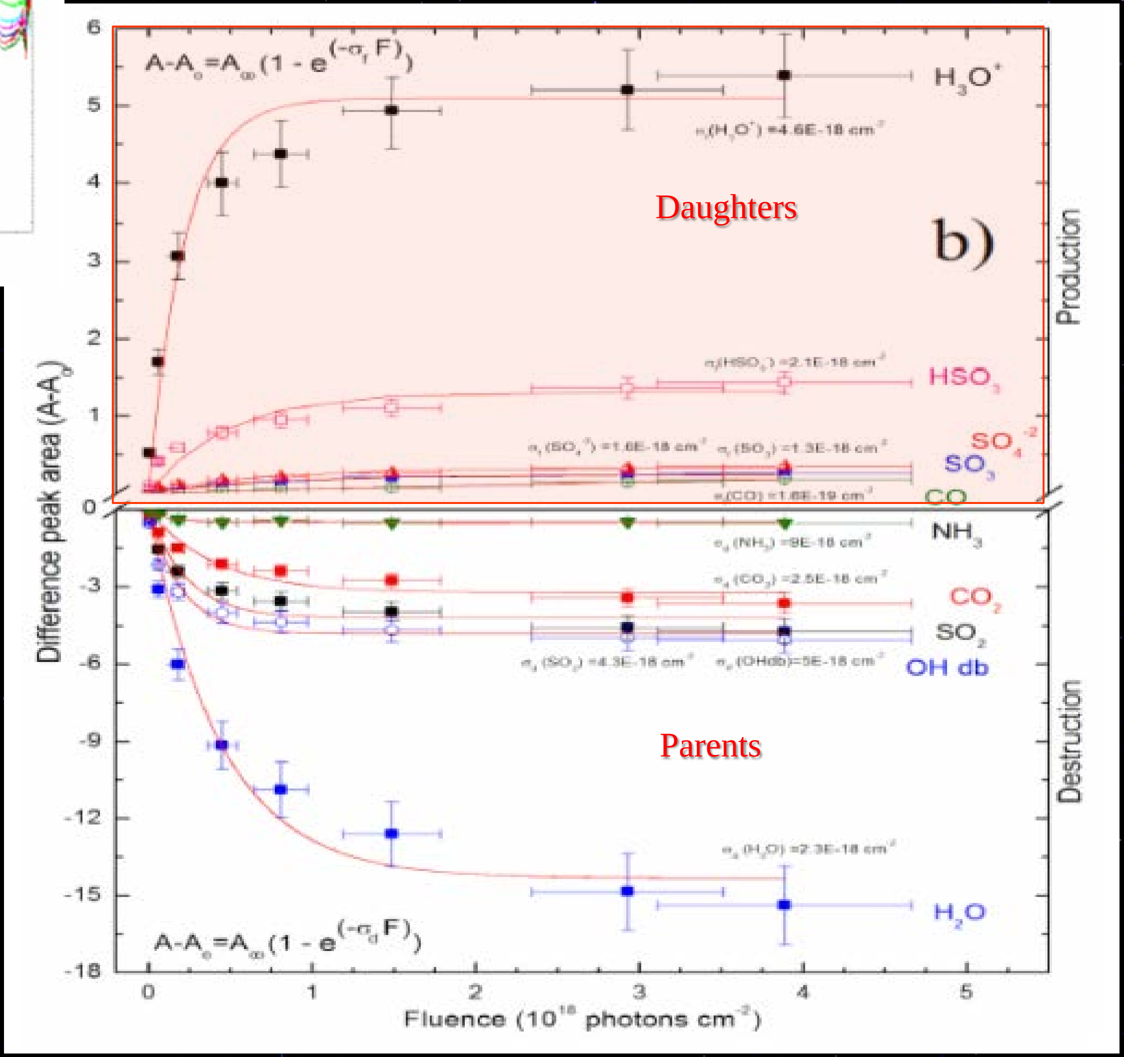


Fluence up to 3.6×10^{18} photons cm^{-2}

Figure 6 - a) Evolution of infrared spectrum of Europa analog at 90 K (equatorial regions) during the irradiation employing VUV and soft X-rays. The bottom spectrum is the unirradiated ice and the uppermost spectrum is the one obtained at the highest photon fluence. b) Expanded view from 2380 to 610 cm^{-1}. Each spectrum has an offset for better visualization.

Absolute formation and dissociation cross sections (e.g. EUR 50K).





Absolute formation and dissociation cross sections.

Table 4 - Dissociation cross sections and dissociation rate for parental species in Europa surfaces simulation considering photons between 6 to 1200 eV (mostly soft X-rays). Half-life obtained in the lab are also given. The uncertainty was estimated to be around 20%

	EUR50K			EUR90K		
	σ_d (cm^2)	k_{lab} (s^{-1})	$t_{1/2}$ (lab)[a] [10^3 s]	σ_d (cm^2)	k_{lab} (s^{-1})	$t_{1/2}$ (lab)[a] [10^3 s]
H_2O[b]	3E-18	3E-4	2.3	7.0E-18	7.0E-4	9.9
CO_2	2.2E-18	2.2E-4	3.1	3.0E-18	3.0E-4	2.3
NH_3	~6E-18	~6E-4	~1	~2E-18	~2E-4	~3
SO_2	4.3E-18	4.3E-4	1.6	4.0E-18	4.0E-4	1.7

[a]Considering the half-life $t_{1/2} = \ln(2)/k$, where k is the photodissociation rate in units of s^{-1} (see Table 4).
[b]For OHdb the destruction cross sections are 5 $\times 10^{-18}$ cm^2 and 8 $\times 10^{-18}$ cm^2 for exp EUR50K and EUR90K, respectively.

Table 5 - Formation cross sections and formation rate for selected parental species in Europa surfaces simulation considering photons between 6 to 1200 eV. The uncertainty was estimated to be around 20%.

$k = \sigma \times \phi$ [s^{-1}]

	EUR50K		EUR90K	
	σ_f (cm^2)	k_{lab} (s^{-1})	σ_f (cm^2)	k_{lab} (s^{-1})
H_3O^+	4.6E-18	4.6E-04	4E-18	4E-04
H_2O_2	-	-	9E-19	9E-05
HSO_3^-	2.1E-18	2.1E-04	4E-18	4E-04
SO_3	1.3E-18	1.3E-04	-	
SO_4^{-2}	1.6E-18	1.6E-04	2E-17	2E-03
CO	1.6E-19	1.6E-05	9E-19	9E-05
OCN^-	-	-	7E-20	7E-06
1470 cm^{-1}	-	-	9E-19	9E-05

2.4.2 Destruição de aminoáacidos e bases nitrogenadas em ambientes espaciais

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Photostability of gas- and solid-phase biomolecules within dense molecular clouds due to soft X-rays

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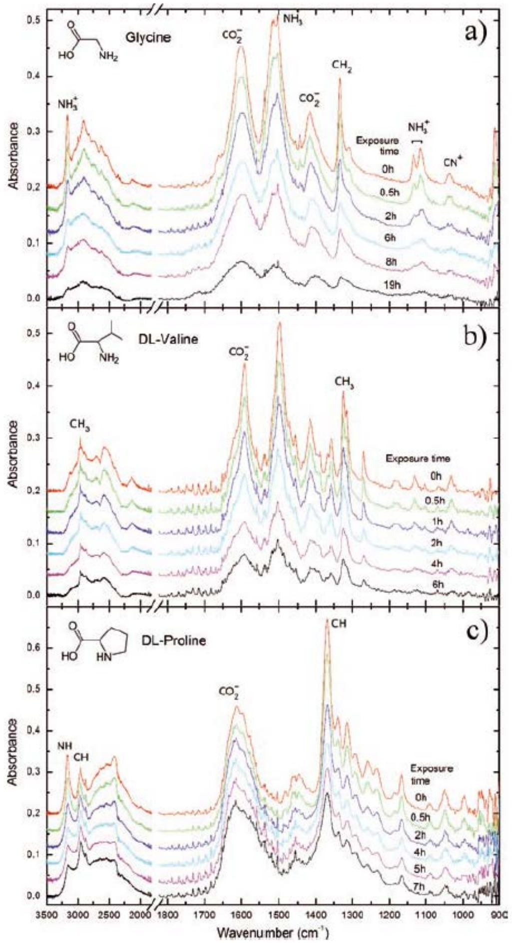


Figure 3. Photostability of the solid-phase amino acids due to the exposure of 150-eV soft X-rays photons as a function of time.

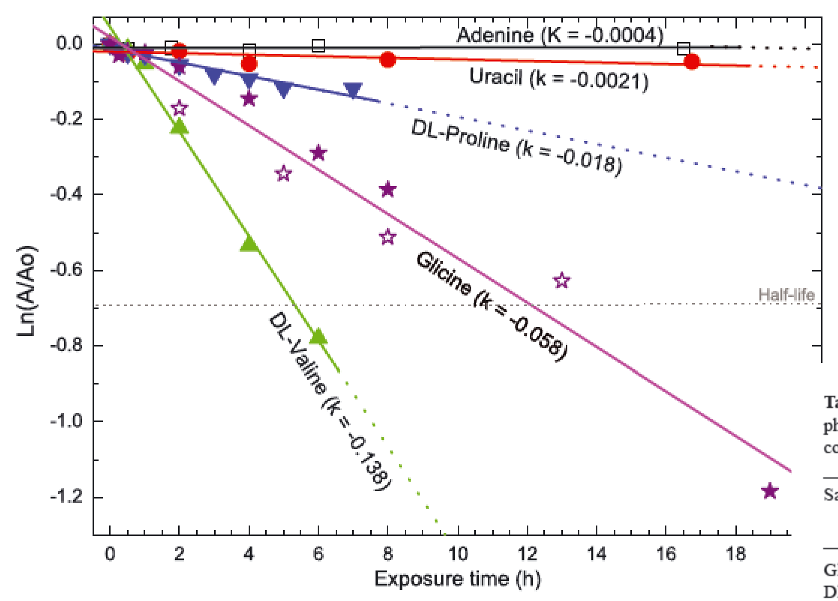


Figure 5. Integrated absorbance spectra of the solid-phase samples a function of irradiation time. For each compound, the photodissociation r *k*, is also indicated.

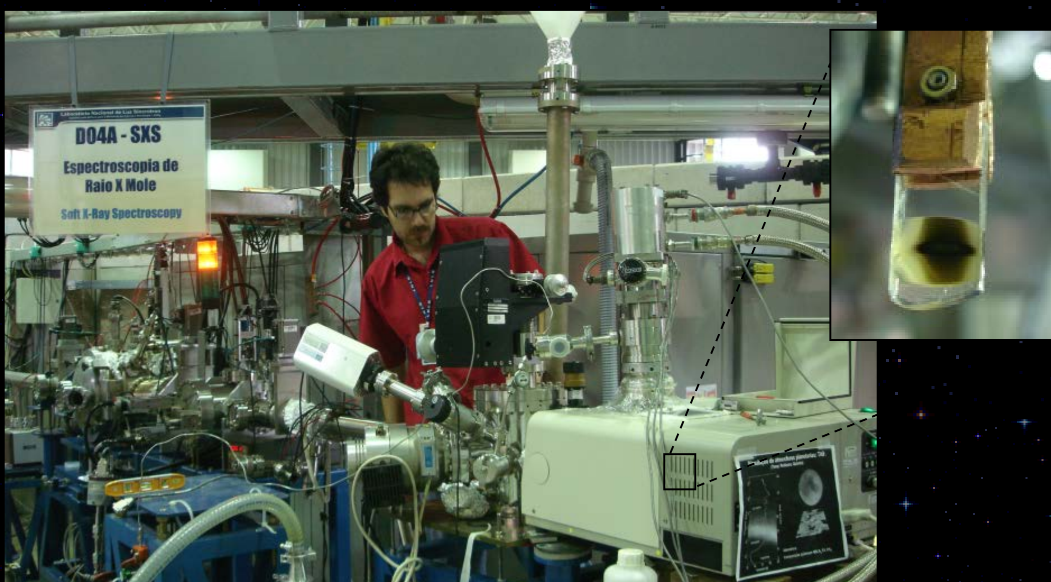
Table 2. Comparison between the half-lives values of solid-phase amino acids and nucleobases in dense clouds due to UV cosmic ray induced flux and soft X-ray flux.

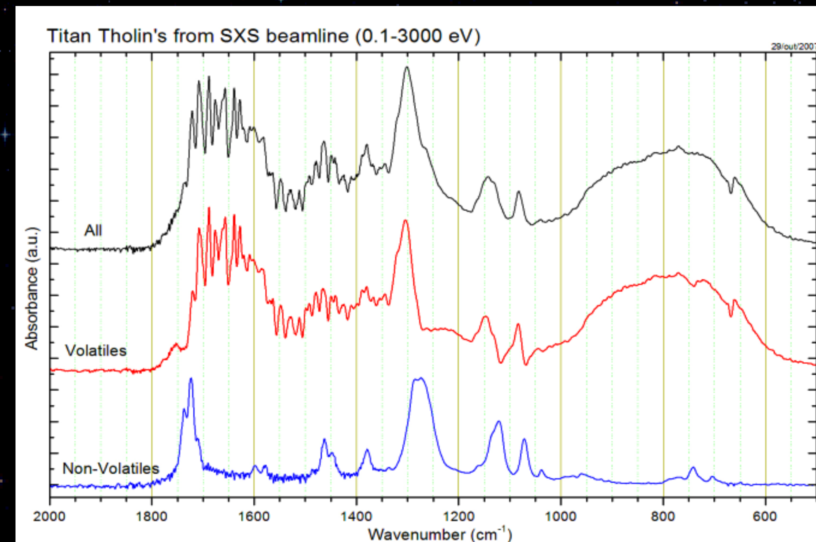
Samples	Half-life in dense clouds (Myr)	
	UV[a]	Soft X-rays[b]
Glycine	1.84[c]	0.7[d]
Dl-Valine	–	0.3
DL-Proline	–	2
Adenine	8.27[c]	90[d]
Uracil	2.03[c]	20[d]

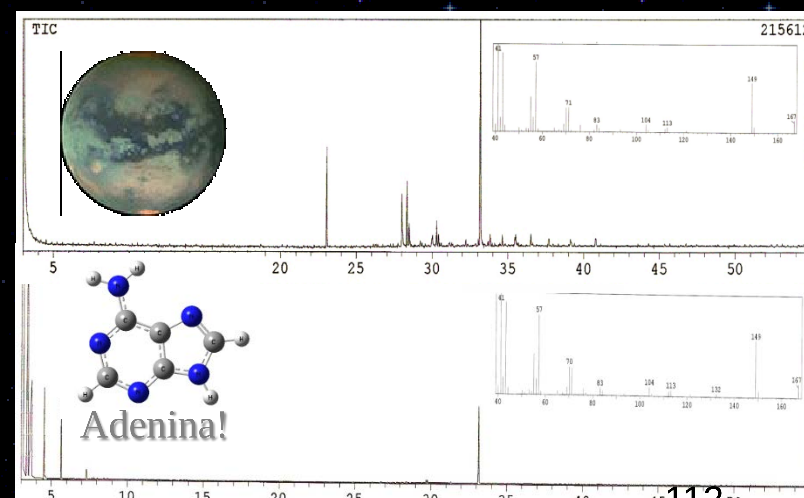
[a] Assuming a cosmic ray induced UV flux of 10^3 photons $cm^{-2}\ s^{-1}$ (Prasad & Tarafdar 1983).
[b] Assuming a 150 eV photon flux of 3×10^6 photon $cm^{-2}s^{-1}$ (for AFGL 2591, at 200 au from the X-ray source; Staüber et al. 2005).
[c] Pure compounds at 12 K in Argon matrix; Peeters et al. (2003).
[d] Pure compounds at room temperature; this work.

2.4.3 - Produção de Adenina em ambientes extraterrestres simulados (Lua Titã)

- Simulação de Aerossóis na atmosfera de Titã.
- N_2 95% + CH_4 5% (+ traços H_2O): 10^{-6} mbar
- SXS (white beam; 0.5-3kev; ~10^{12} fótons/cm s)
- Cryo-IR_β (NaCl; 12 K 10^{-8} mbar)
- *In-situ* FTIR, *in-situ* Q-MS, GC-TOFMS, RMN
- Adenina via elétrons secundários.







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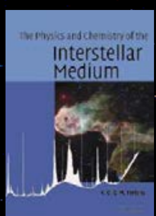

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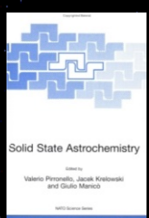

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Continuamos na próxima aula.