

O meio interestelar



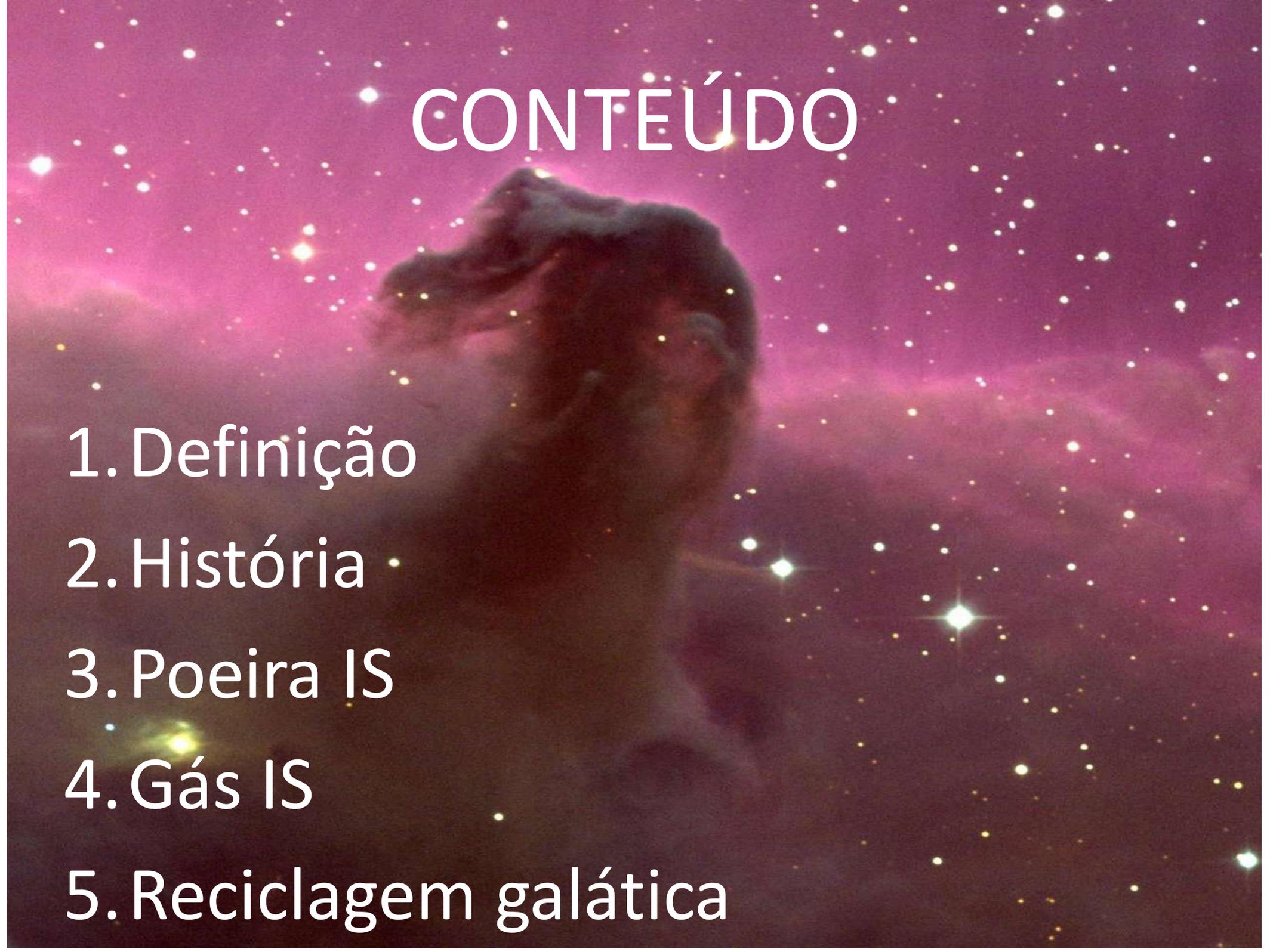
The interstellar (IS) medium

ISM

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21 Jul 2010, IAG-USP

CONTEÚDO



1. Definição

2. História

3. Poeira IS

4. Gás IS

5. Reciclagem galáctica

1. Definição

A região entre as estrelas é chamada de
meio interestelar
(*interstellar medium: ISM*)

1. Definição

As estrelas dominam a luz das galáxias, mas ocupam uma parte minúscula do seu volume.

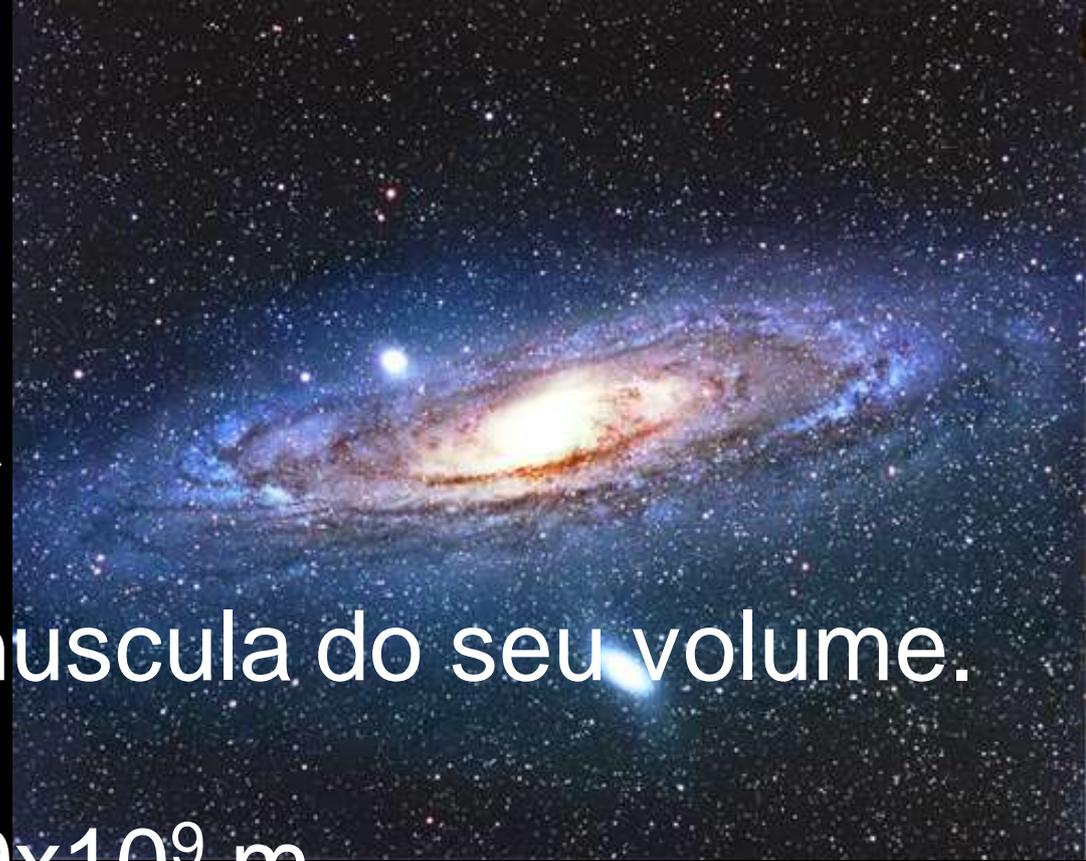
Diâmetro do Sol = 1.39×10^9 m

Distância entre estrelas ~ 3.5 a.l. = 3.3×10^{16} m

Diâmetro/distância = 0.5×10^{-5} , ~ $1/10^{16}$ volume

10^{16} é um número enorme, por exemplo:

- População mundial (2010) = 7×10^9
- Número de estrelas em nossa galáxia ~ 4×10^{11}
- # grãos de areia nas praias do planeta ~ 7×10^{18}



1. Definição

O meio interestelar é composto de poeira (partes escuras) e gás (vermelho)

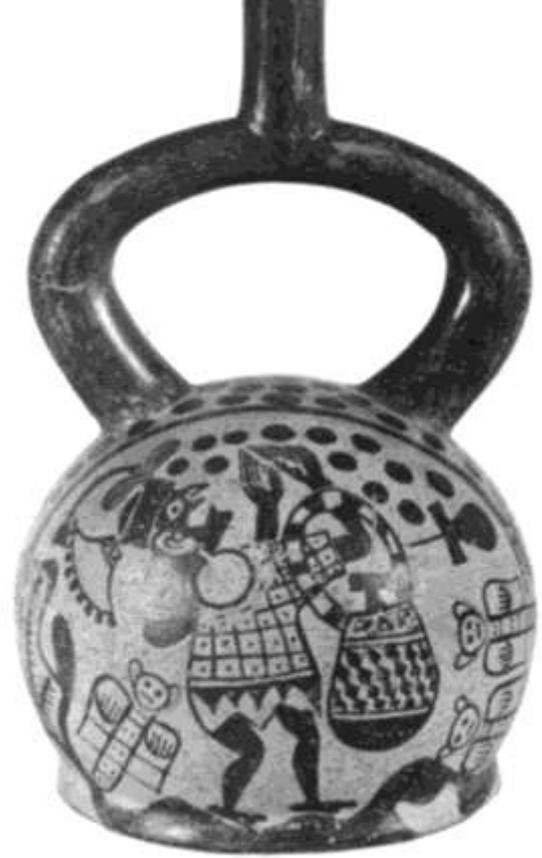


Trifid nebula
© Anglo-Australian Observatory

2. História do meio interestelar

Civilizações europeias
apenas reconheceram
constelações brilhantes
(estrelas)





Inca
empire

2. História do meio interestelar

Civilizações andinas
(2000a.C. – 1542)
identificaram
constelações escuras



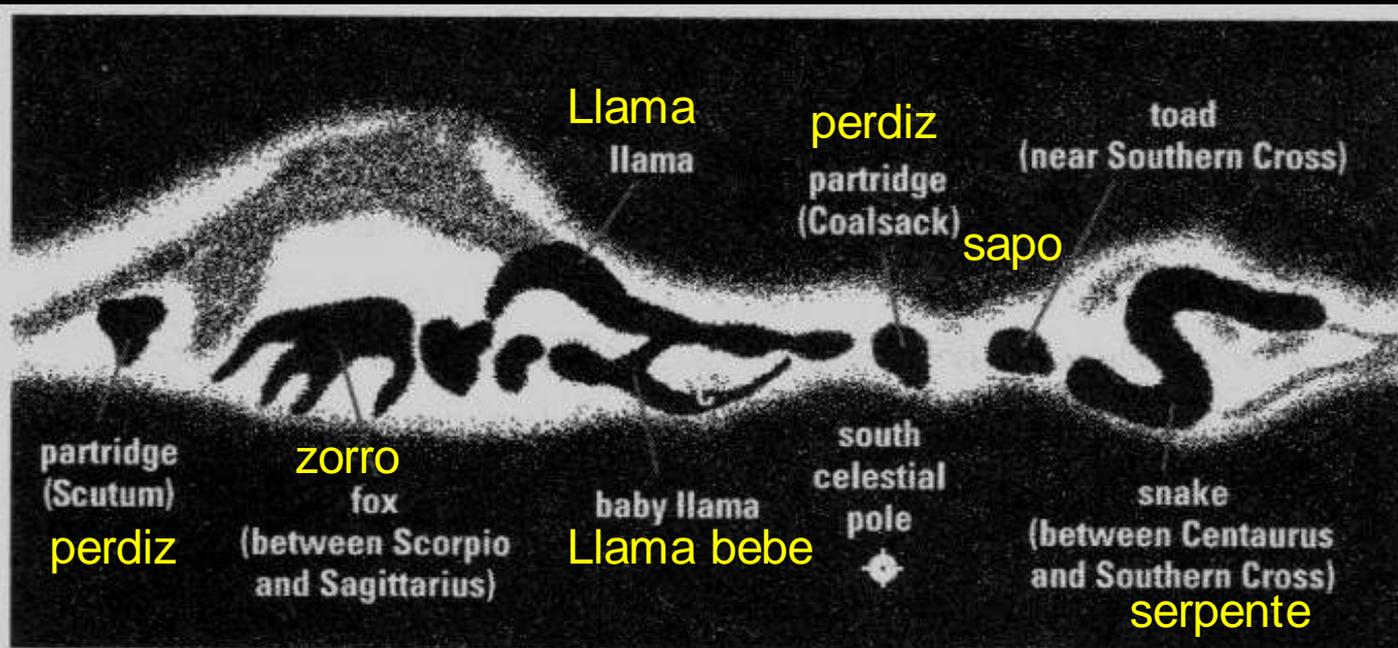
Civilizações andinas observaram em detalhe a via láctea (= mayu, ou rio celestial)

Cronista espanhol: “No hablo sólo de las partes lúcidas y resplandecientes ... sino digo esto por otras partes oscuras y negras que hay en el cielo ... las cuales jamás me acuerdo de haber echado de ver en el cielo cuando estaba en Europa, y acá, en este otro hemisferio, las he visto muy manifiestas ”
José Acosta [1590]

Constelação escura da Llama: Yacana



*α and β Centauri:
Llama Ñahui:
Olhos da Llama*

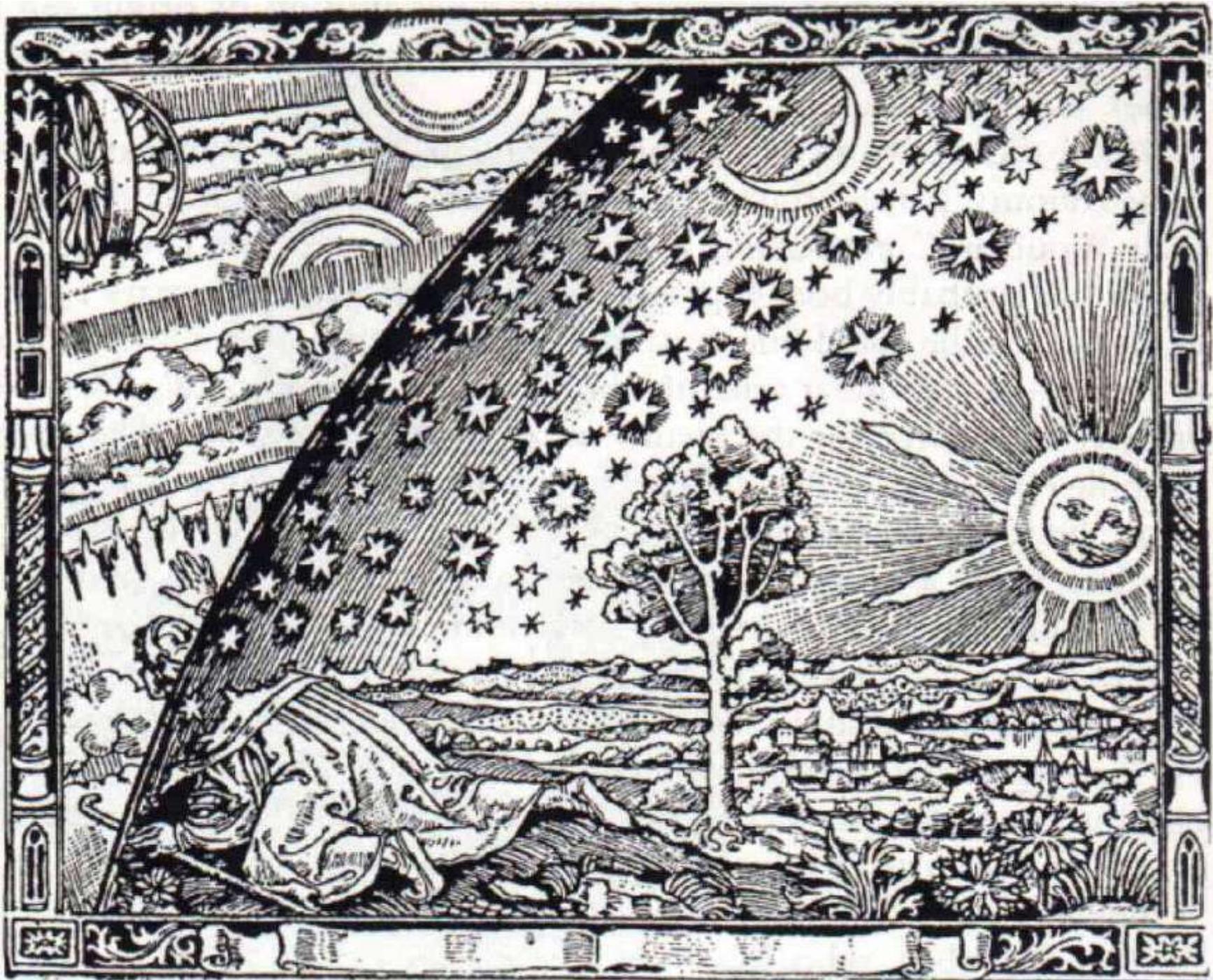


(c)

Figure 2.15 (Continued). (c) Contemporary Andean dark cloud constellations of the southern Milky Way; to the people of Misminay, dark cloud constellations represent animals.

*Aveni,
Stairways to the Stars, 1997*

ISM: o firmamento



Tycho (1546 - 1601) ISM is not solid



Francis Bacon (1561 - 1626)
first coined the term interstellar,
but used it to describe a rigid
and solid structure

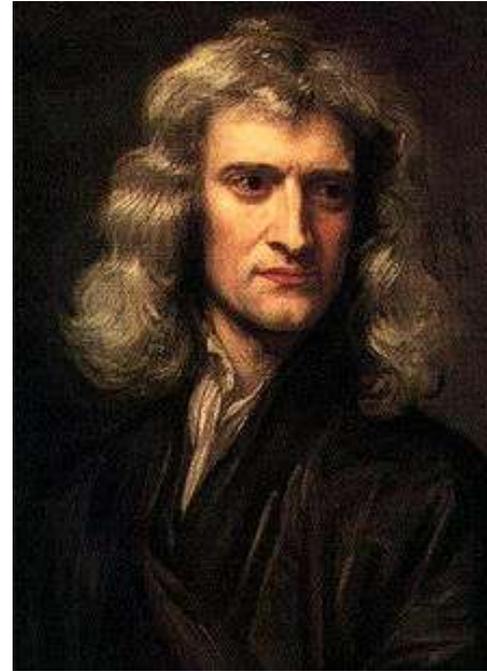
Robert Boyle (1627 - 1691) who decided
that the interstellar medium was empty



Christiaan Huygens (1629 - 1695) hypothesized that light propagating through space required some kind of luminiferous aether



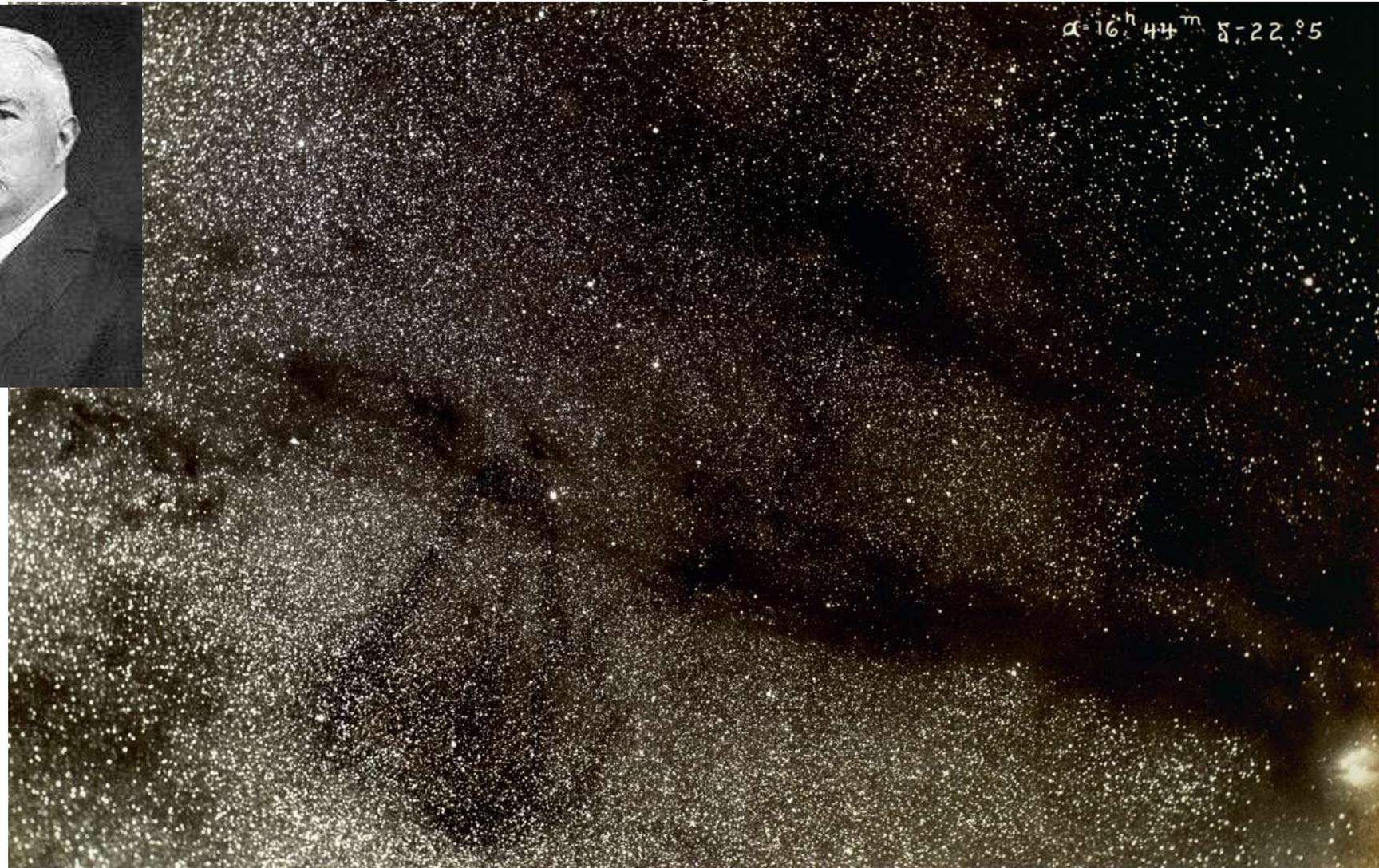
Isaac Newton (1643 - 1727) rejected this idea since such a substance would be seen to retard comets



By the late 19th century - early 20th century, the aether theory was in trouble.

A finais do século XIX e começos do século XX a existencia do meio interestelar foi confirmada

Edward Emerson Barnard (1857 – 1923) produced in 1895 the first images of dark nebulae and came to the conclusion that along with the illuminated gas and dust there was also significant quantities of dust and gas not directly illuminated.

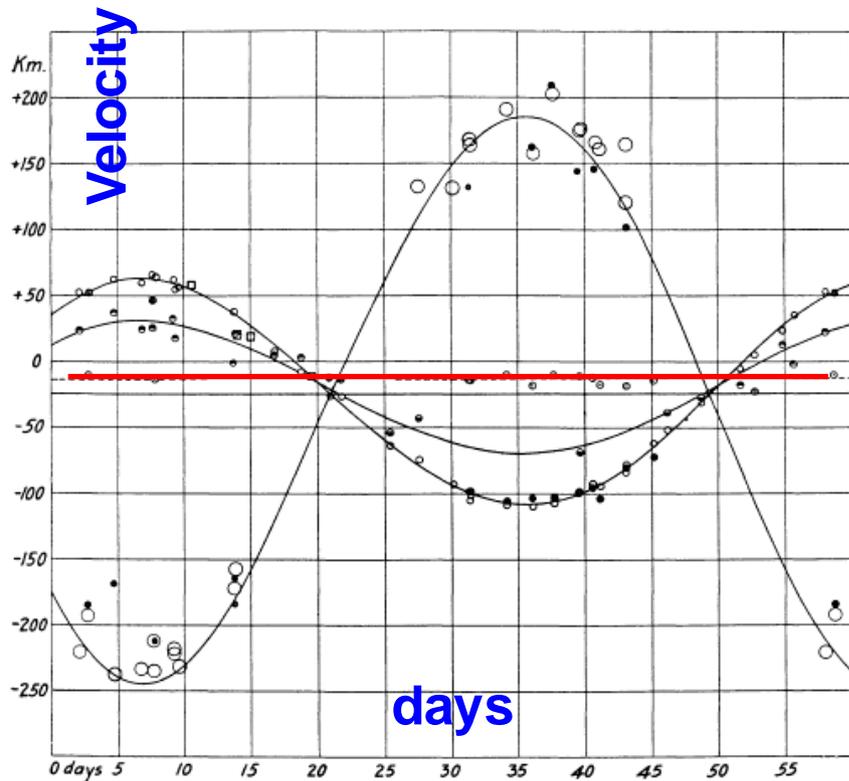


Stationary **interstellar lines** in the spectra of spectroscopic binaries

Hartmann (1904)

Heger (1918)

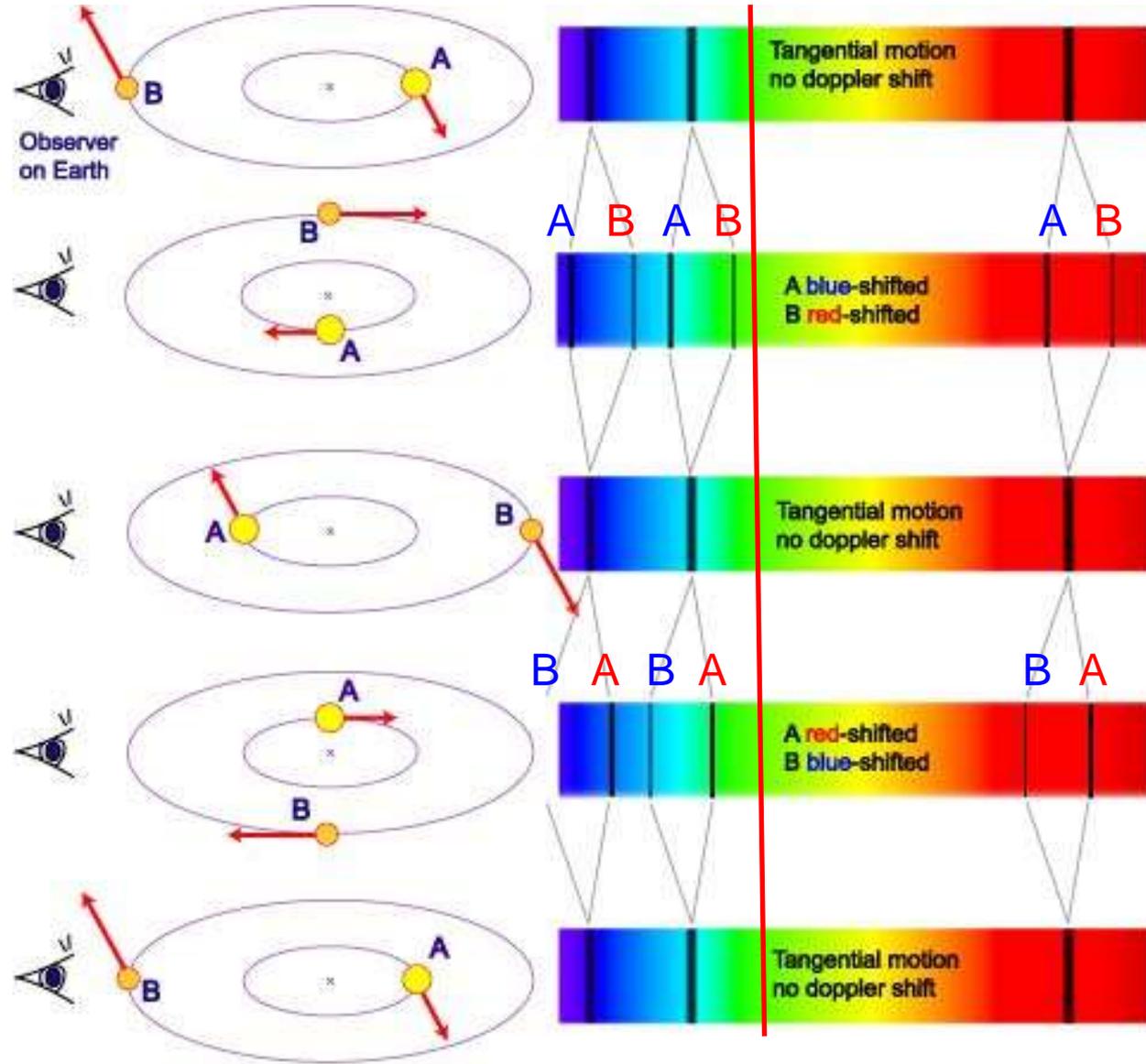
J. A. Pearce (1932)



Primary stellar.....○
 Secondary stellar.....□
 Stellar calcium.....●
 Interstellar calcium.....○
 Blended calcium.....●
 Mt. Wilson.....□

Radial Velocity Curves of H.D. 698

 
Nuven IS

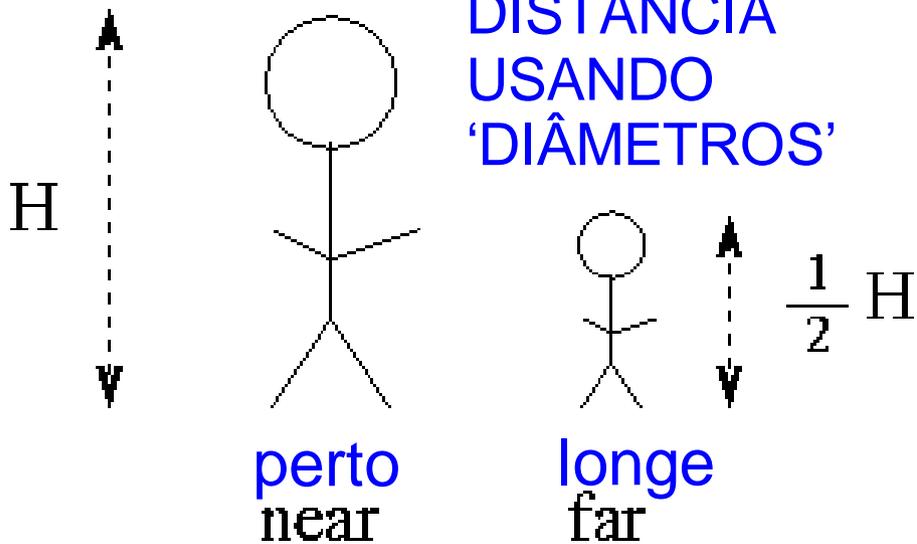


A Spectroscopic Binary System

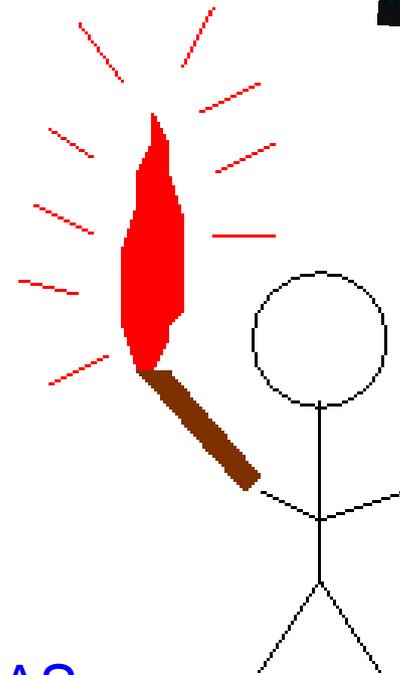
High-mass star A and lower-mass B orbit around a common centre of mass. The observed combined spectrum shows periodic splitting and shifting of spectral lines. The amount of shift is a function of the alignment of the system relative to us and the orbital speed of the stars.

In 1930, Robert Trumpler estimated distances of about 100 open star clusters by measuring:

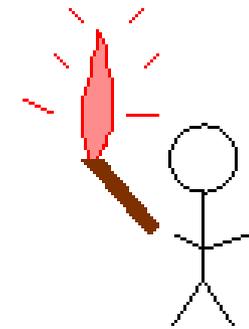
- angular size of the cluster
- central concentration and # of stars
- brightness & spectral class of stars in the OC



DISTÂNCIAS
FOTOMETRICAS



perto
near

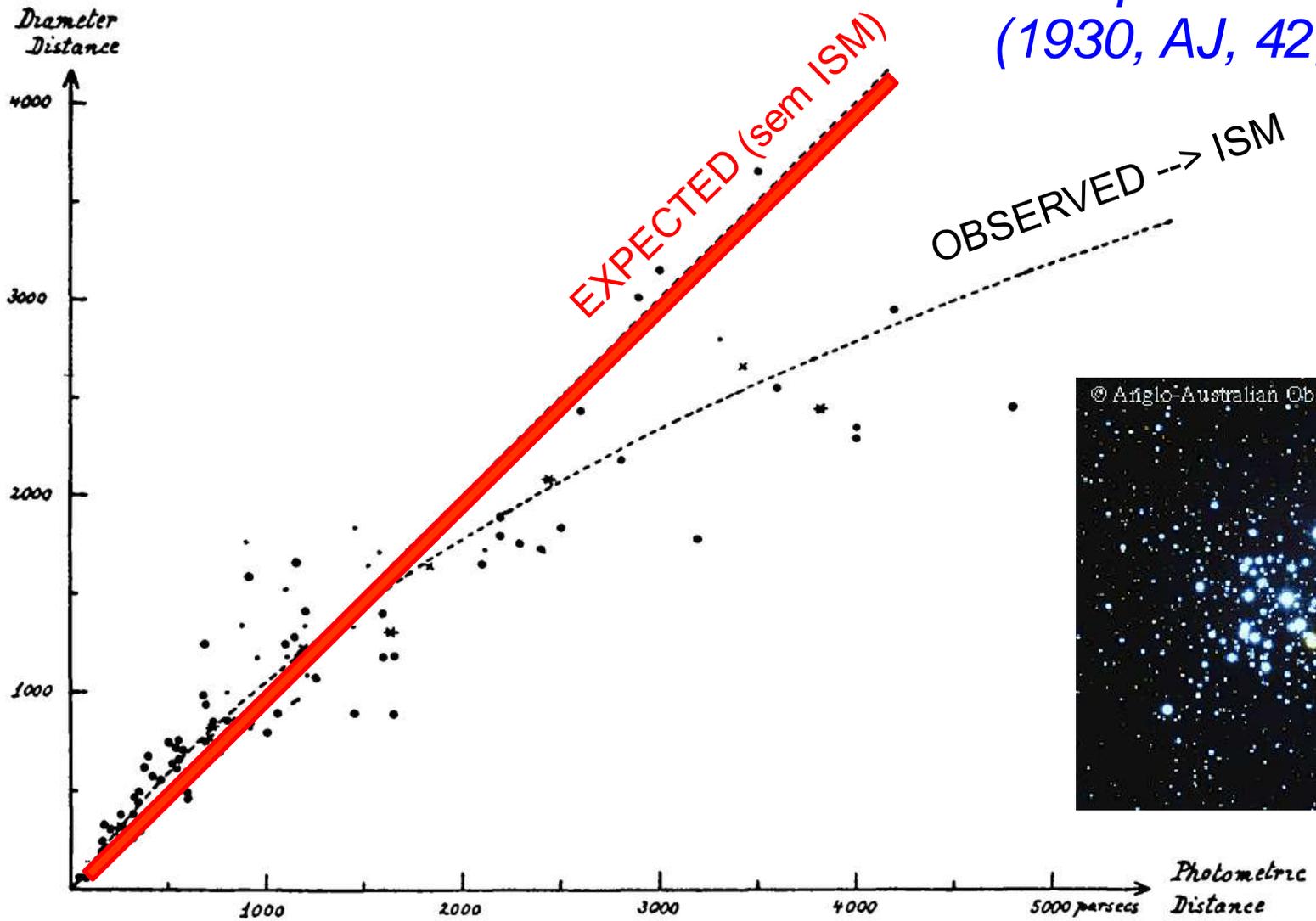


longe
far

Comparação entre distâncias baseadas em 'diâmetros' e em 'fotometria'

Trumpler
(1930, AJ, 42, 214)

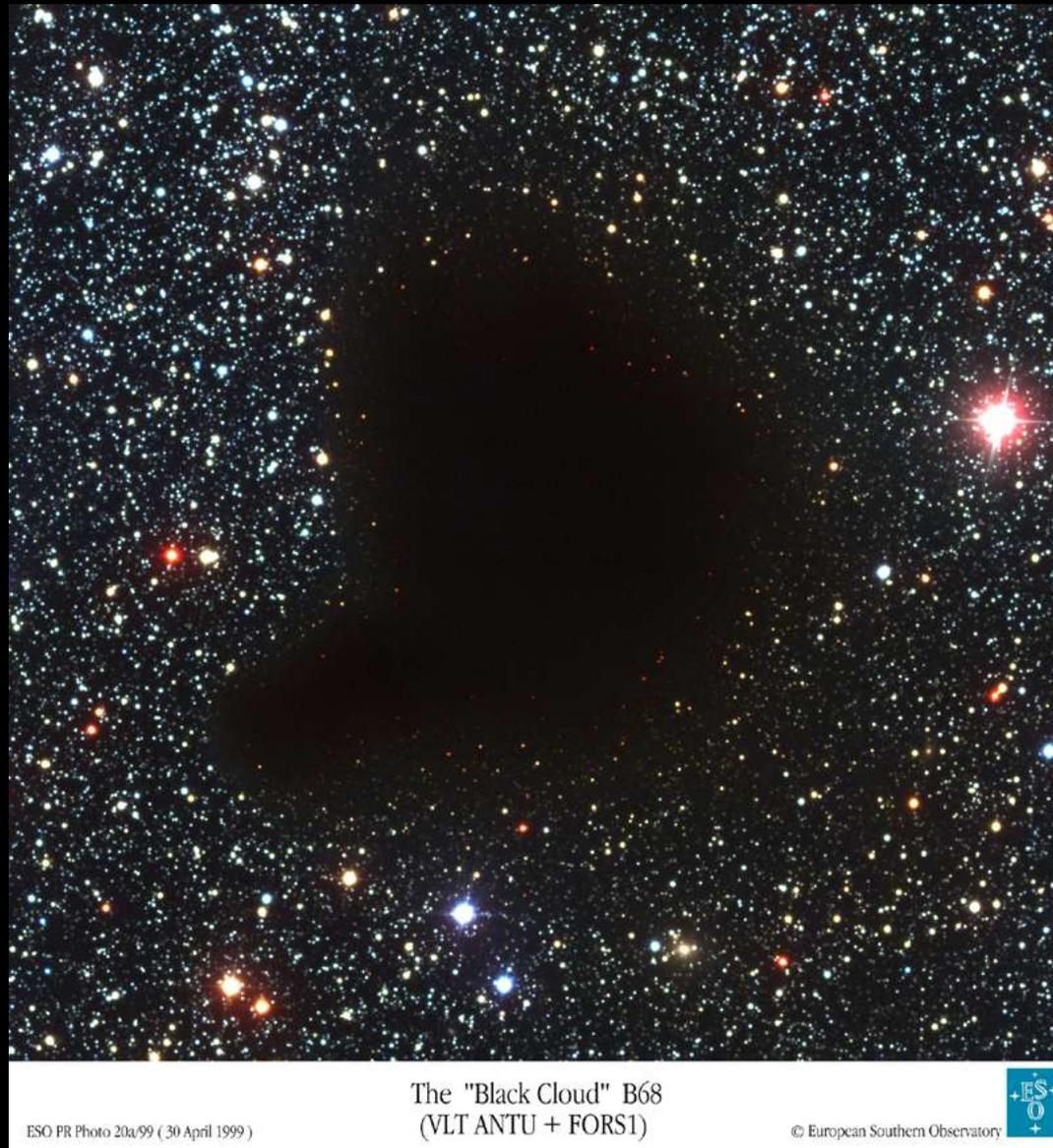
'Diameter' distances



© Anglo-Australian Observatory

'Photometric' distances

3. Componentes do ISM: poeira



Buracos no espaço ou absorção do ISM?

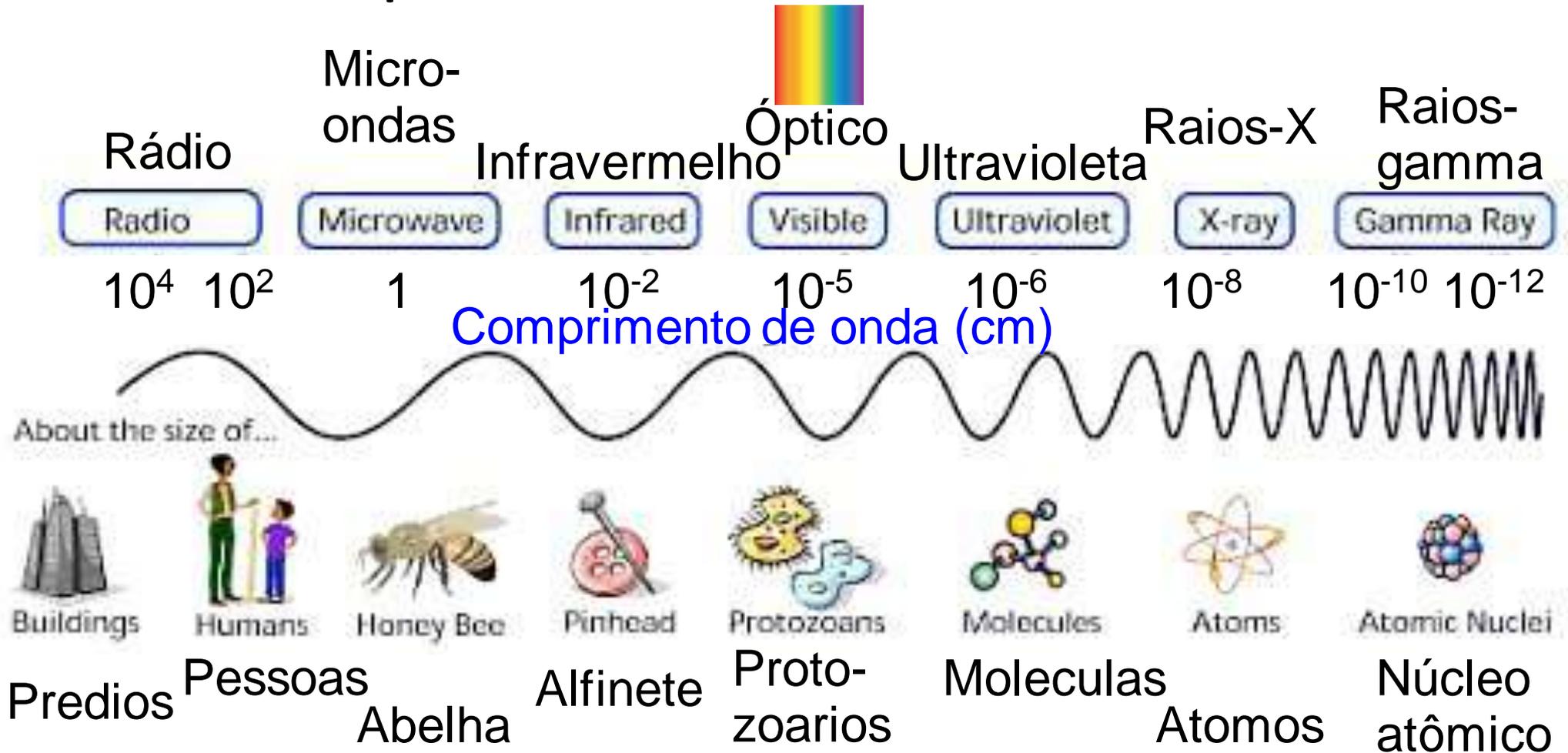
3. Poeira

Via Láctea no óptico

A poeira bloqueia a luz das estrelas
no disco da Via Láctea

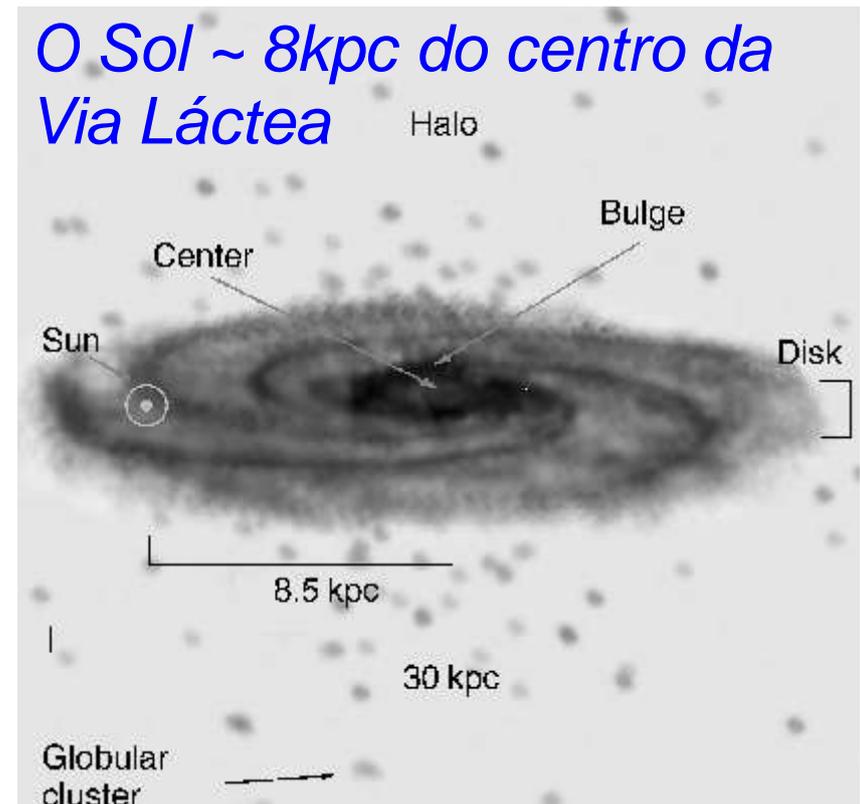
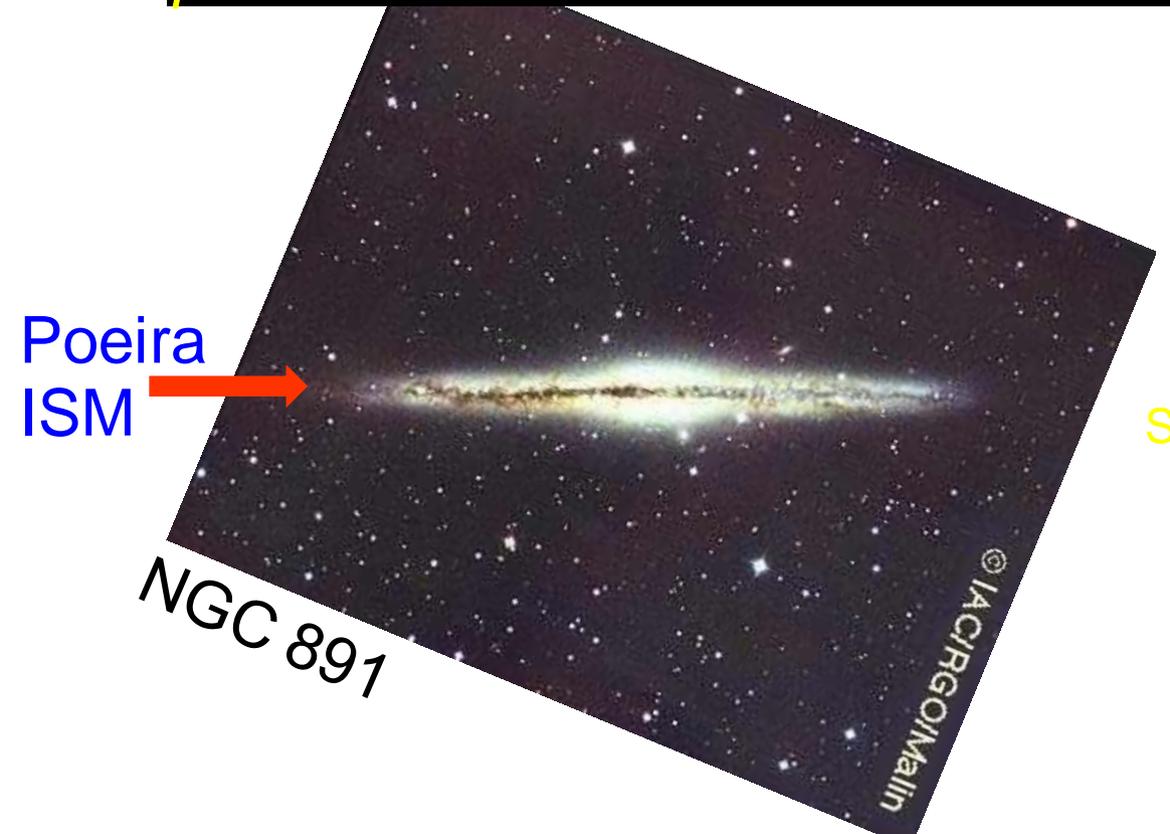
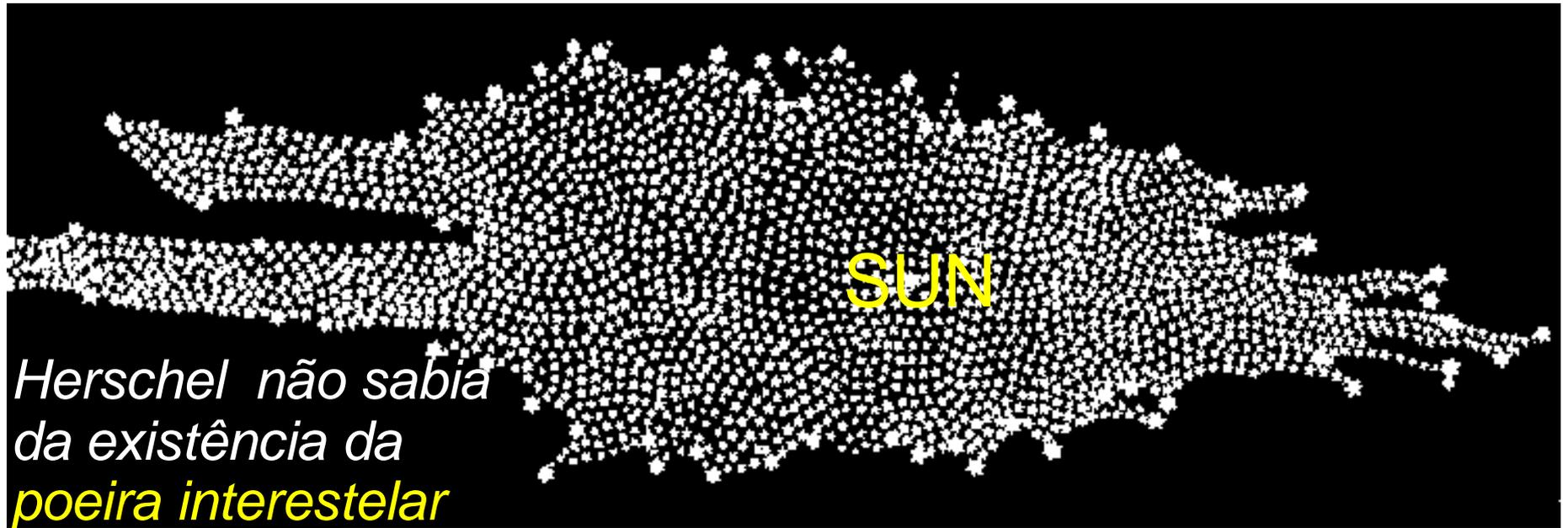
Via Láctea no infravermelho

Todas as formas de 'luz' são radiação electromagnética, mas aparentam ser diferentes pelas **diferentes escalas** envolvidas



A poeira bloqueia a radiação óptica, UV, raio-X, deixando passar a radiação infravermelha e rádio

A Galáxia de acordo ao William Herschel (1780s)

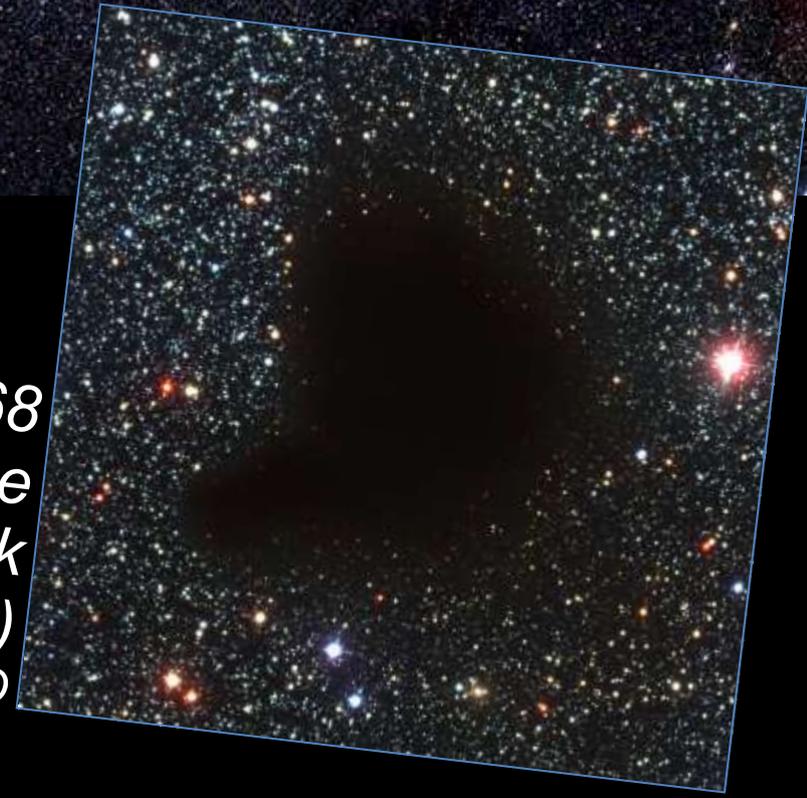


3. Poeira: extinção

Via Láctea no óptico

A atenuação da luz das
estrelas pela poeira
interestelar chama-se
extinção

*B68
(the
black
cloud)
ESO*



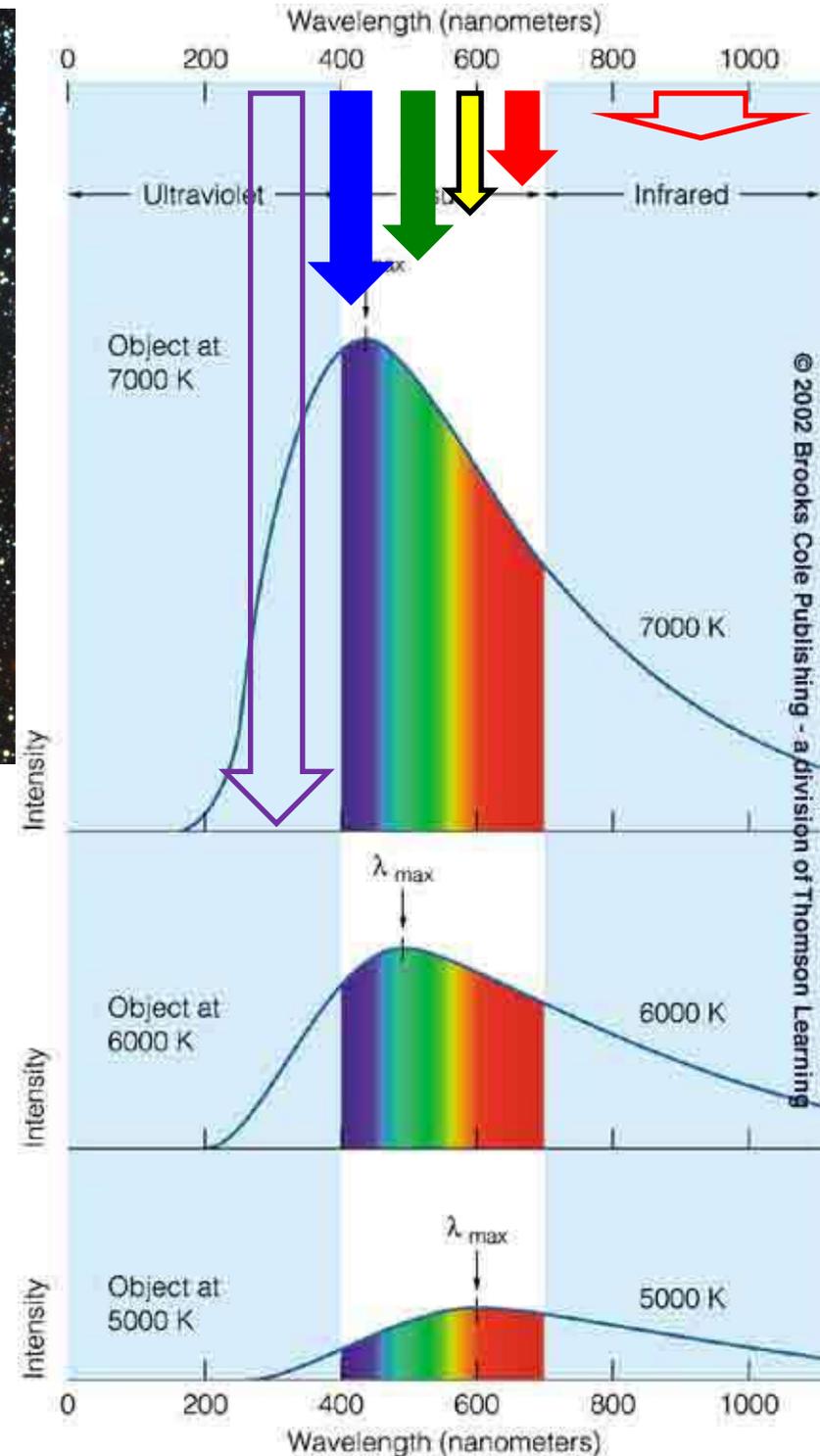
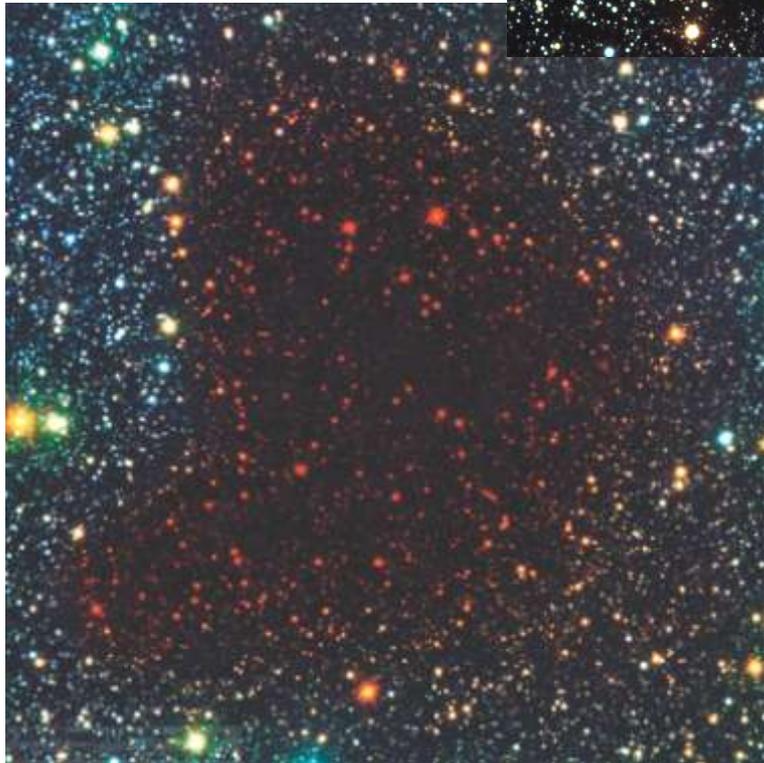
3. Poeira: avermelhamento

A poeira absorve mais a luz azul do que a vermelha, causando o chamado *reddening* ou avermelhamento



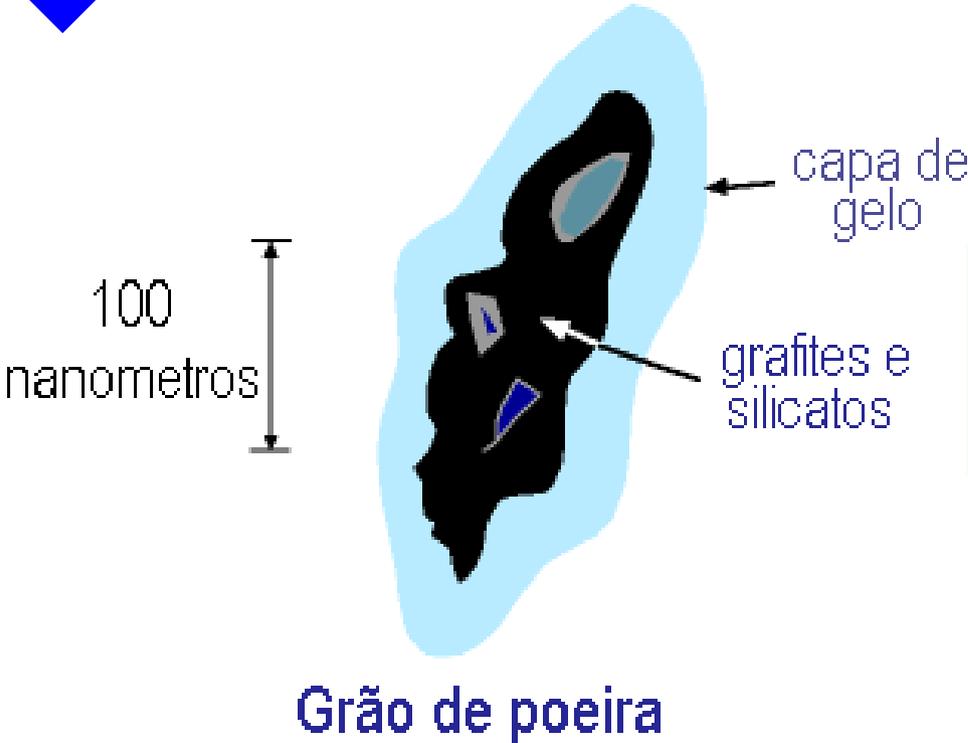
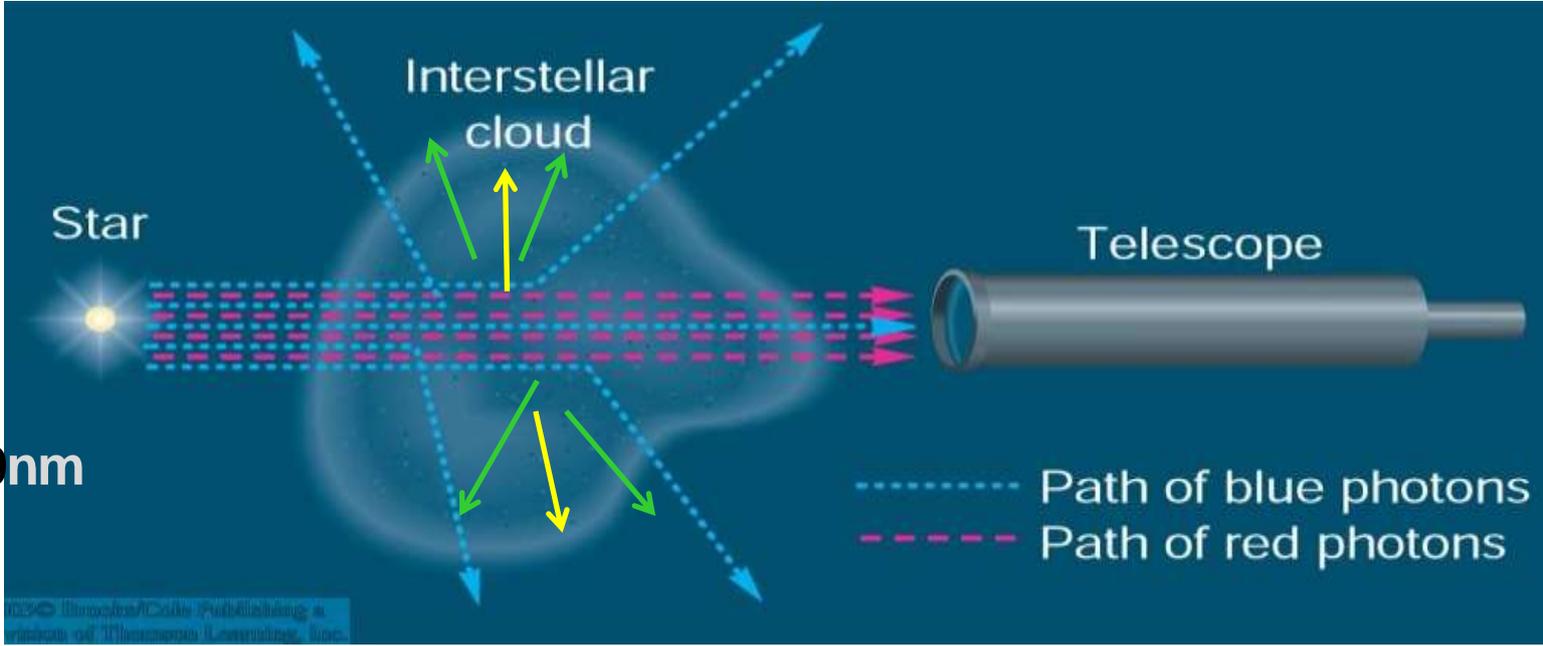
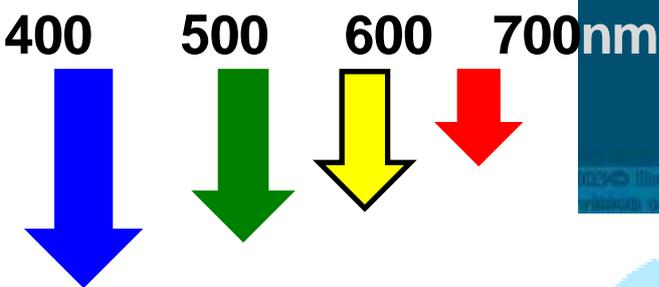
Avermelhamento interestelar

Optical light is strongly scattered and absorbed by interstellar clouds



Extinção e avermelhamento por poeira

Luz de menor λ é mais espalhada e absorvida pela poeira



Probability of scattering $\propto \frac{1}{\lambda}$

Nebulosa de reflexão

A poeira espalha mais a luz azul

Probability of scattering $\propto \frac{1}{\lambda}$



Pleiades

O céu é azul porque as moléculas do ar espalham preferencialmente a luz azul



Hawaii, after observing run ...

$$\sigma_R(\lambda) = \frac{8\pi^3}{3} \frac{(n^2 - 1)^2}{N^2 \lambda^4}$$

Espalhamento Rayleigh

Densidade da poeira IS



Via Láctea no óptico

Apenas 10^{-6} partículas de poeira por m^3
ou 1000 por km^3

Sendo tão pouco densa, como pode a
poeira atenuar a luz vinda das estrelas?

Distância típica entre estrelas ~ 3.5 a.l. = 3.3×10^{16} m

Abundância da poeira



Via Láctea no óptico

A poeira representa apenas 1% do meio interestelar

A componente mais abundante é o gás

A componente mais abundante do meio interestelar é o gás

Em média a densidade do meio interestelar é extremamente baixa: 1 átomo / m³ (10⁶ átomos / m³)

Regiões variam de 10⁴ a 10⁹ átomos/m³

Melhor vácuo conseguido em lab : 10¹⁰ moléculas/m³

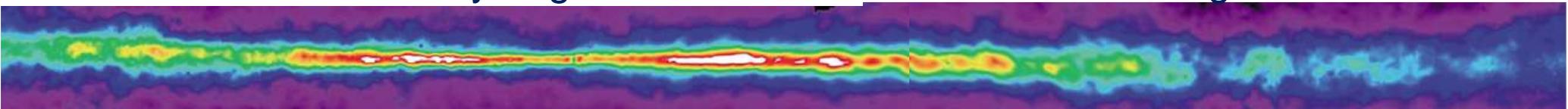
VISIBLE LIGHT (0.4–0.6 micron)

Reveals nearby stars and tenuous ionized gas; dark areas are cold and dense



ATOMIC HYDROGEN (1420 MHz)

Reveals neutral atomic hydrogen in interstellar clouds and diffuse gas



Composição química do gás ISM ~ Sol

Gás interestelar:

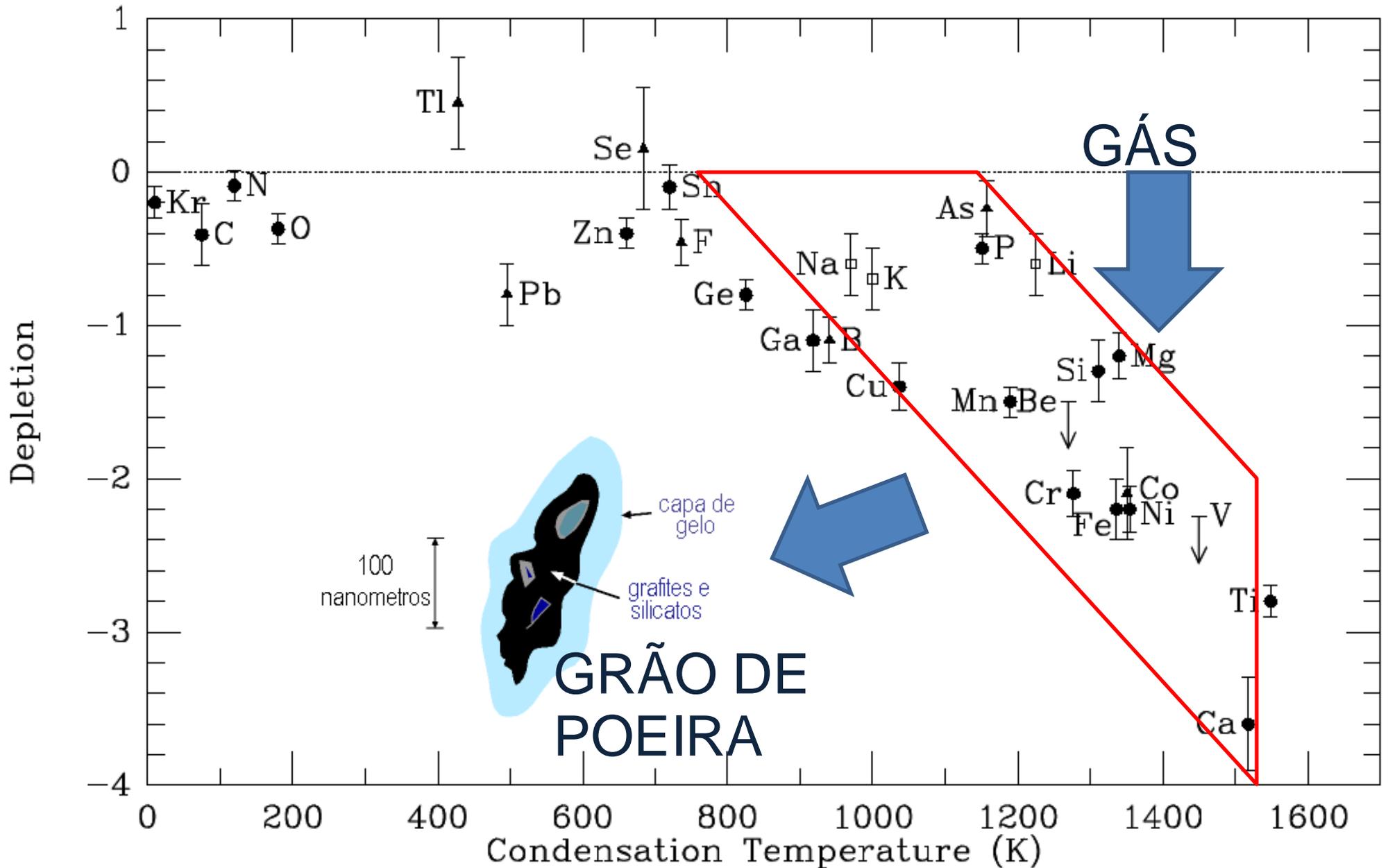
- 90% de H (ionizado, atômico e molecular)
- 9% de He
- 1% de elementos + pesados

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	103 Lr	104 Ku	105 Ha	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

© ESA/NASA/SOHO

Alguns elementos (e.g. C, O, Si, Mg e Fe) são menos abundantes no ISM do que no Sol

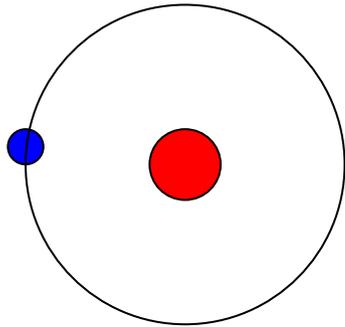
Gás (meio interestelar) - Sun



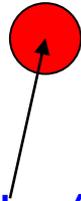
O material 'deficiente' no gás IS está sob forma de grãos

A maior componente do gás IS é o hidrogênio (H I, H II, H₂)

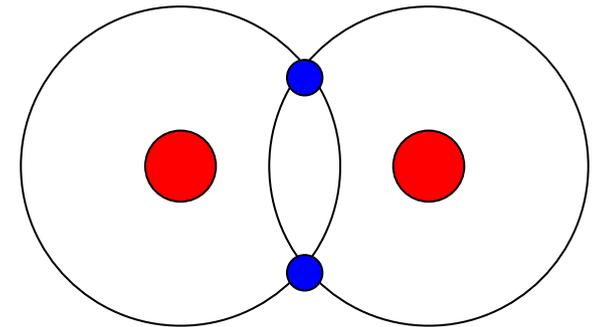
- O hidrogênio pode ser H neutro (HI), H ionizado (HII), e H molecular (H₂)



H neutro tem o e- orbitando o p+.



H ionizado é quando o átomo de H perde o e-



H molecular é quando 2 átomos neutros partilham seus e- para formar uma molécula de H

Tipo de regiões do gás interestelar

As regiões são classificadas de acordo ao estado do H
H é o elemento mais abundante: 90% por #, 75% por massa

Imagem do centro da Nebulosa de Órion obtida com o HST. A imagem cobre 2,5 anos-luz.

- H₂: moleculares (10 K)
- H I: atômica (neutra), nuvens frias (100 K)
- H I: atômica (neutra), nuvens quentes (5000 K)
- H II: H ionizado (10, 000)
- Íons : gás quente (500,000 K)



Interações entre estrelas e gás interestelar

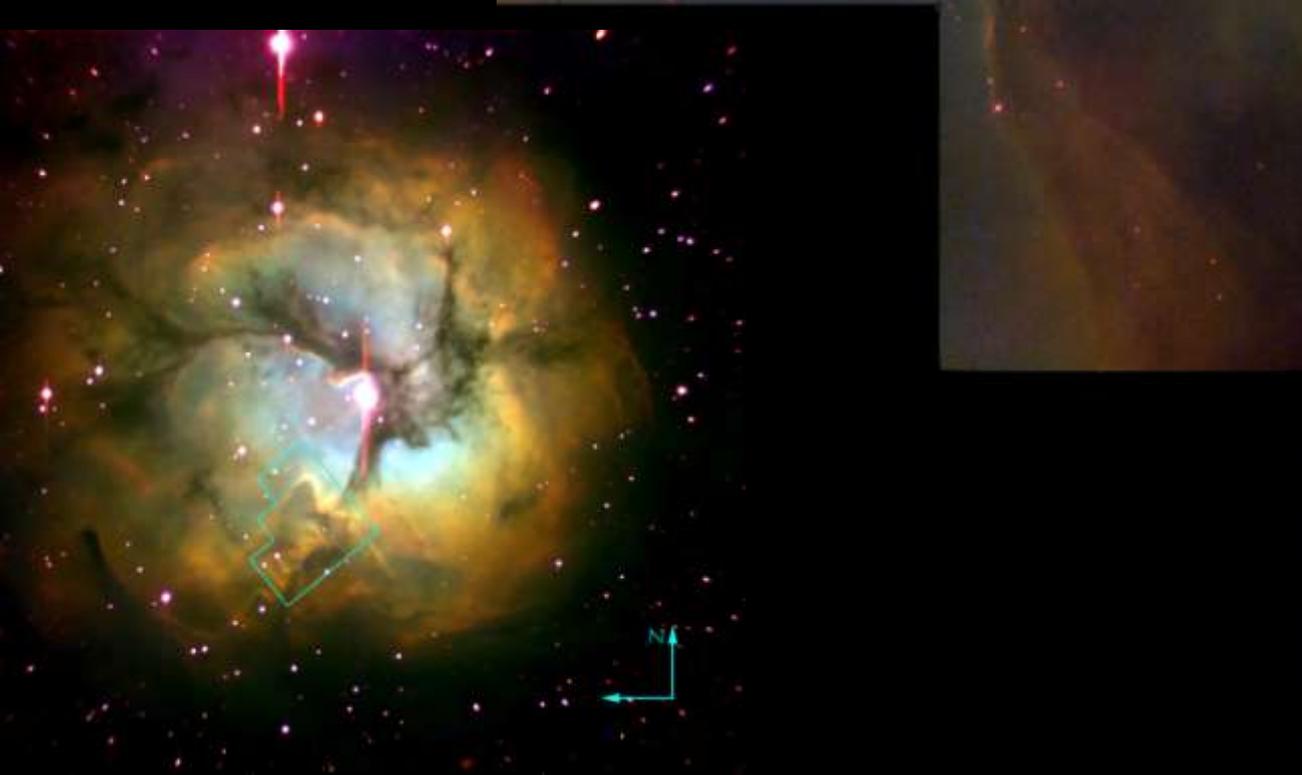
Estrelas quentes do tipo O-B produzem bastante radiação UV ionizam o gás IS ao redor delas criando uma **região HII (H ionizado)**

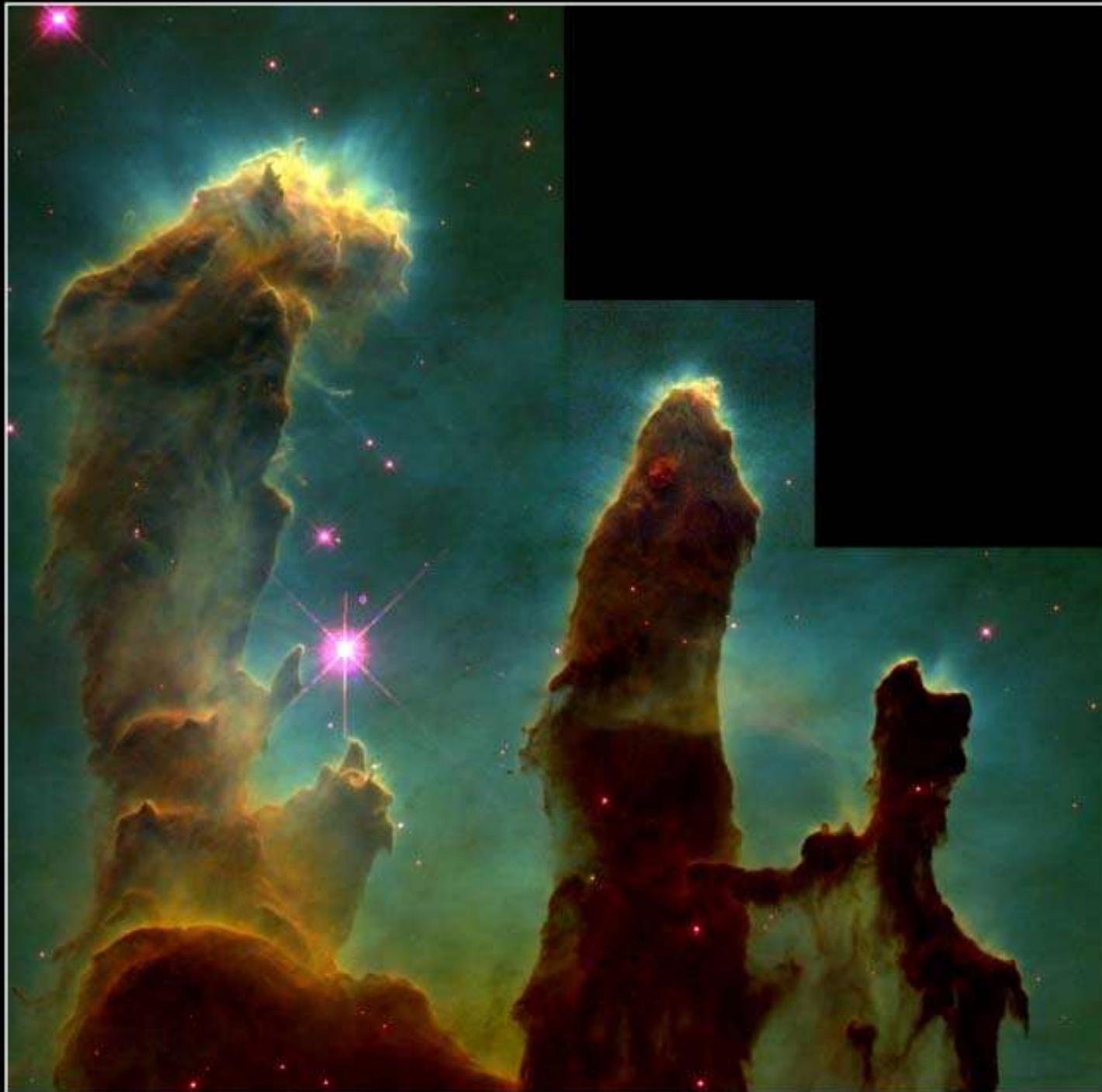


Trapezium cluster in Orion nebula

Coluna de poeira

Estrela brilhante destrói a poeira, criando esta imagem espetacular em um berçário de estrelas





Gaseous Pillars · M16

HST · WFPC2

PRC95-44a · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA



Star-Birth Clouds · M16

HST · WFPC2

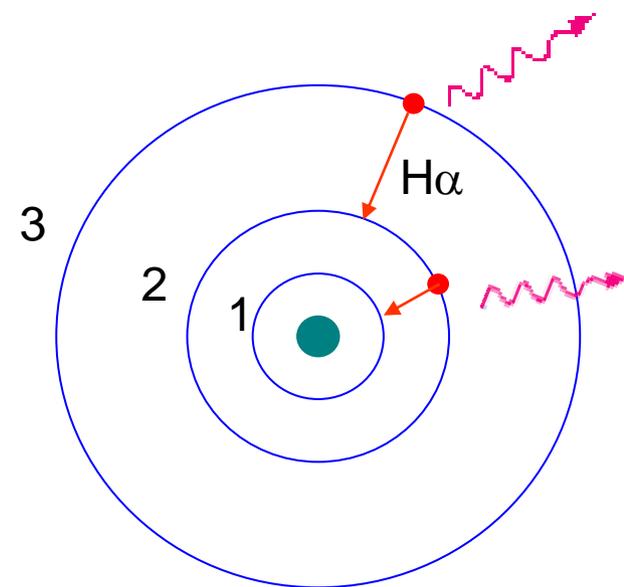
February 14, 2000
PRC95-44b · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

Cabeça de cavalo



Regiões H II

- temperatura $\sim 10^4$ K
 - Luz UV de estrelas quentes O e B
 - Ioniza o gás em volta das estrelas
- Elétrons recombinam formando átomos de H excitados
 - Quando os elétrons decaem a estados de menor energia é emitida radiação visível fazendo com que as nuvens de gás “brilhem”
 - Cor característica é o vermelho (linha de Balmer de H)

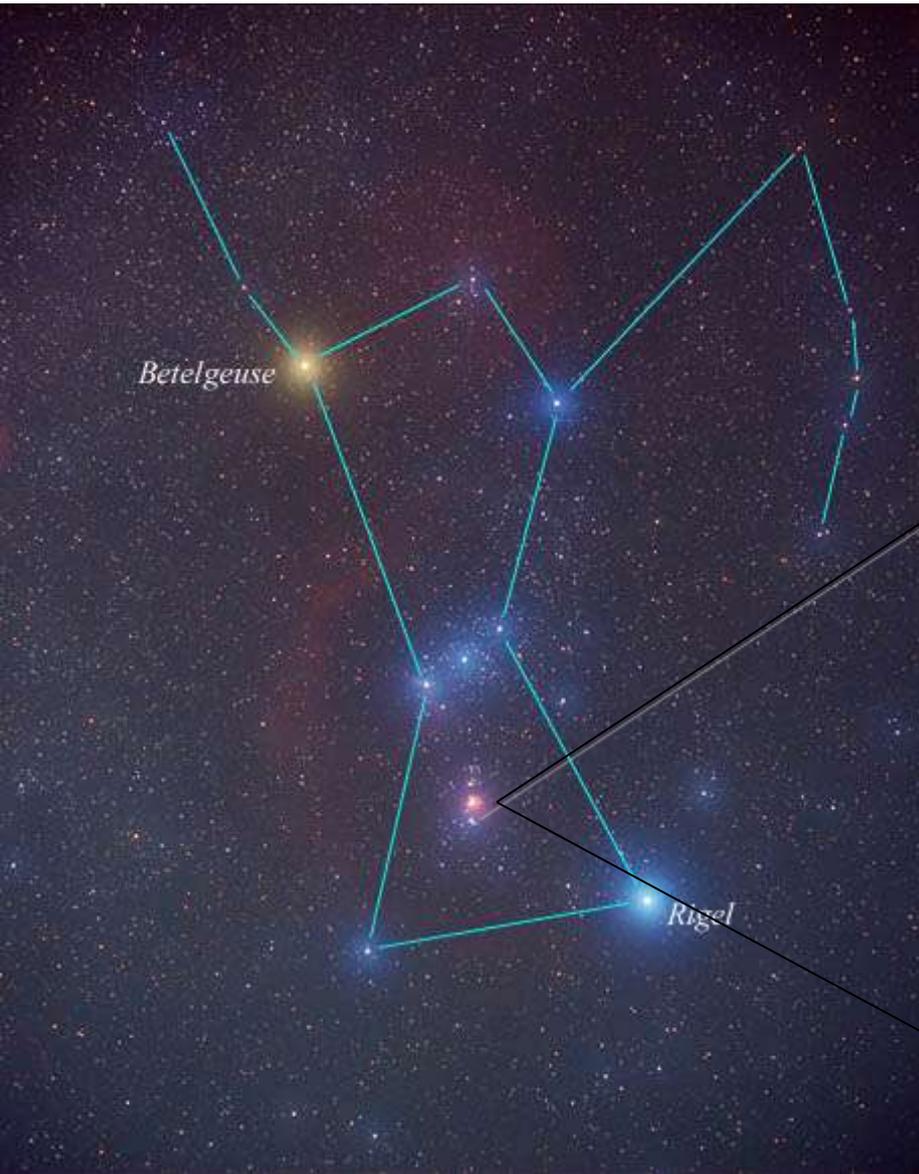
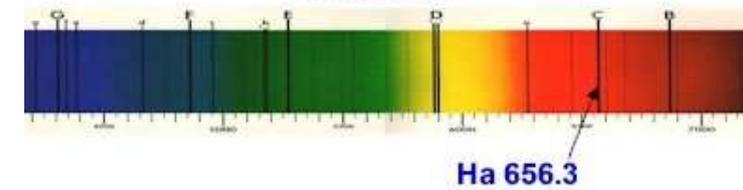
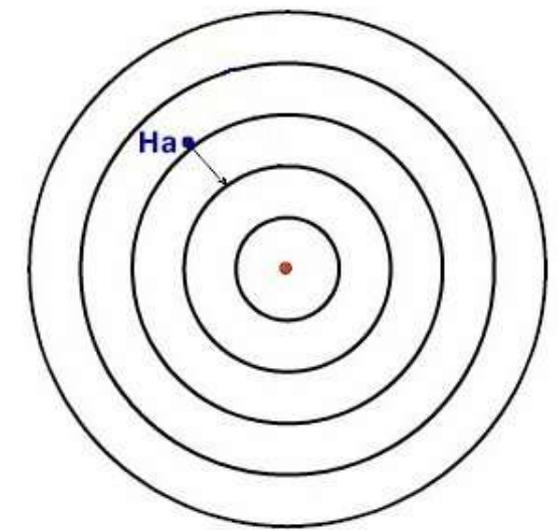


H α
40



Regiões H II: Nebulosa de Órion

- Closest to us, 1,500 LY
- 29x26 anos-luz
- Lugar de formação de estrelas

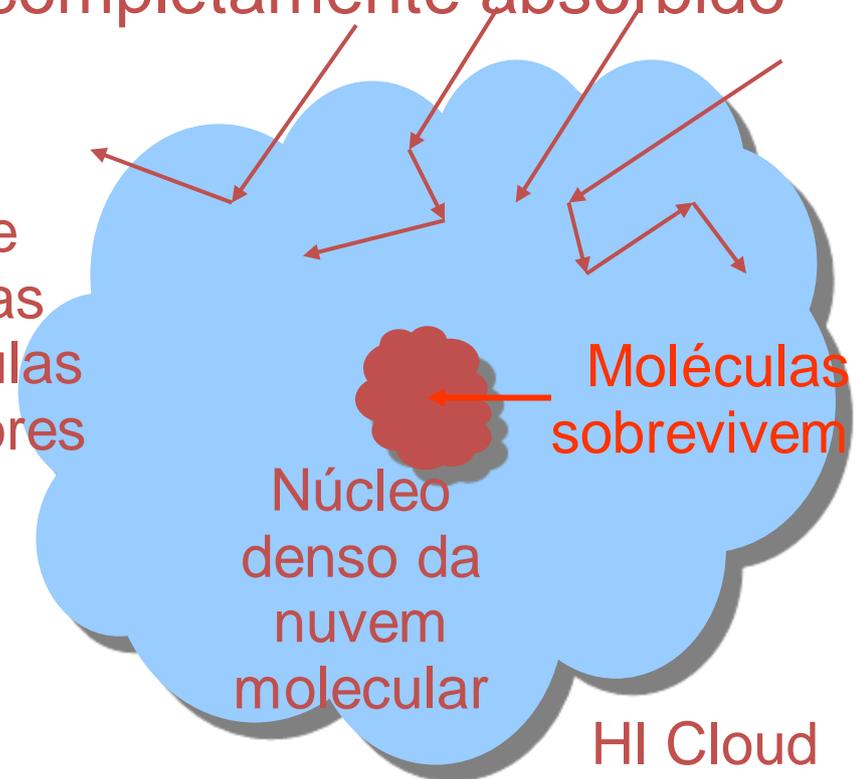


Nuvens Moleculares

Moléculas são facilmente destruídas (dissociadas) por fótons UV de estrelas quentes

- NM só podem sobreviver em nuvens densas, nuvens de poeira, onde a radiação UV é completamente absorvido

Emissão UV de estrelas cercanas destrói as moléculas nas partes exteriores da nuvem



Diâmetro $\approx 15 - 60$ pc

Temperatura ≈ 10 K

Massa total $\approx 100 - 1$ milhão de massas solares

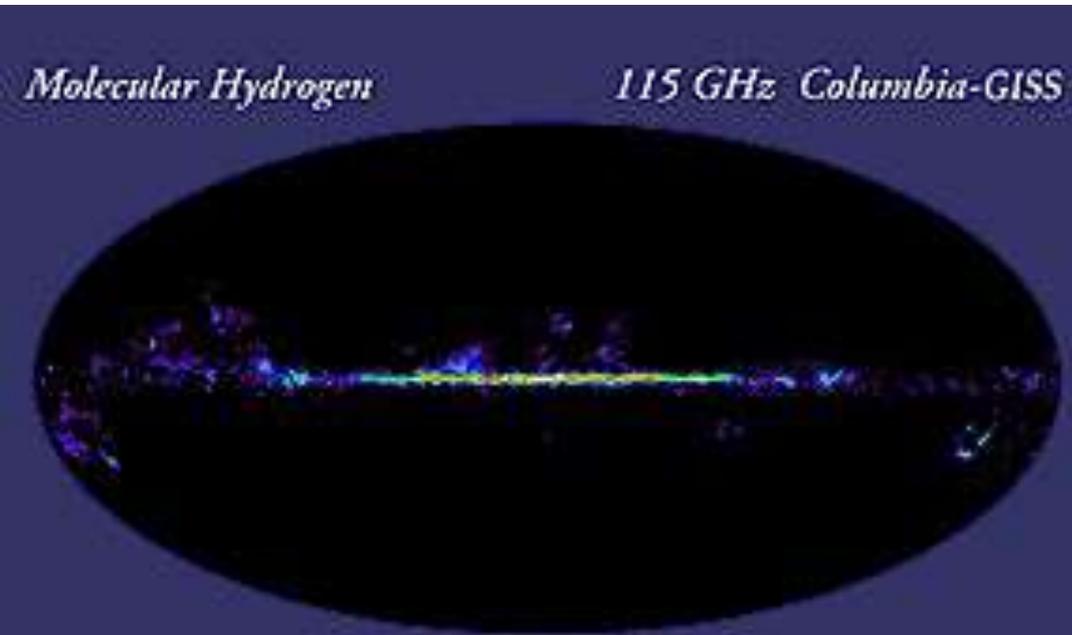
H_2 é difícil de ser detetado, mas onde tem CO tem H_2 , então CO é usado como 'proxy'

- NM são importantes como berçários de estrelas



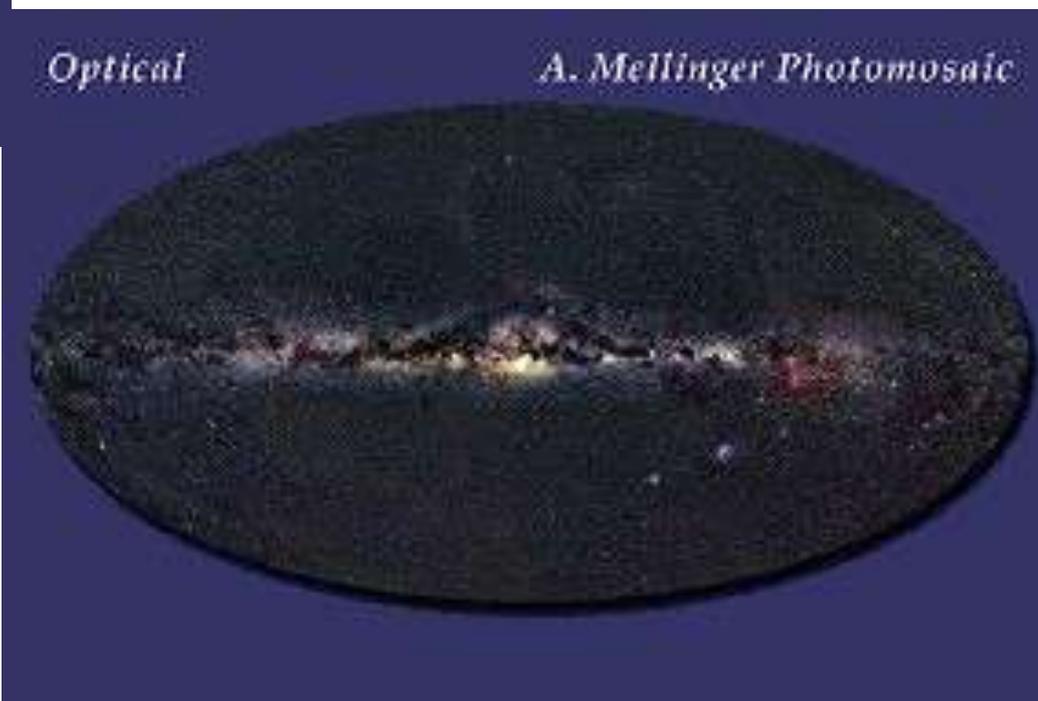
M51: CO contours overlaid on Pa emission + optical

H₂ (CO) em nossa galáxia



- Optical

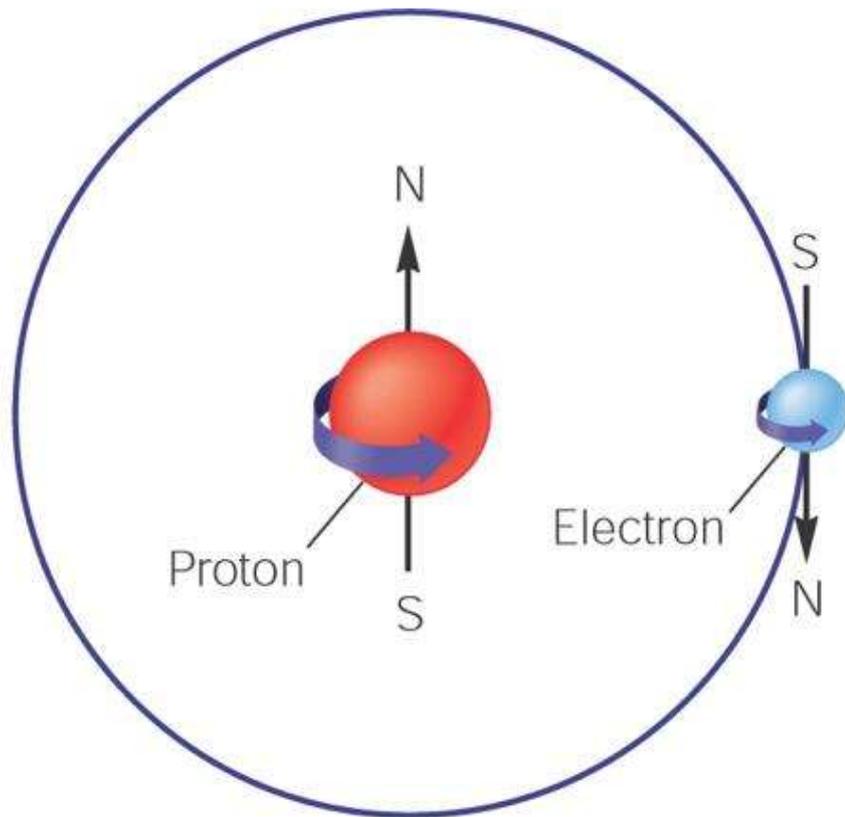
- H₂ (CO)



Regiões H I

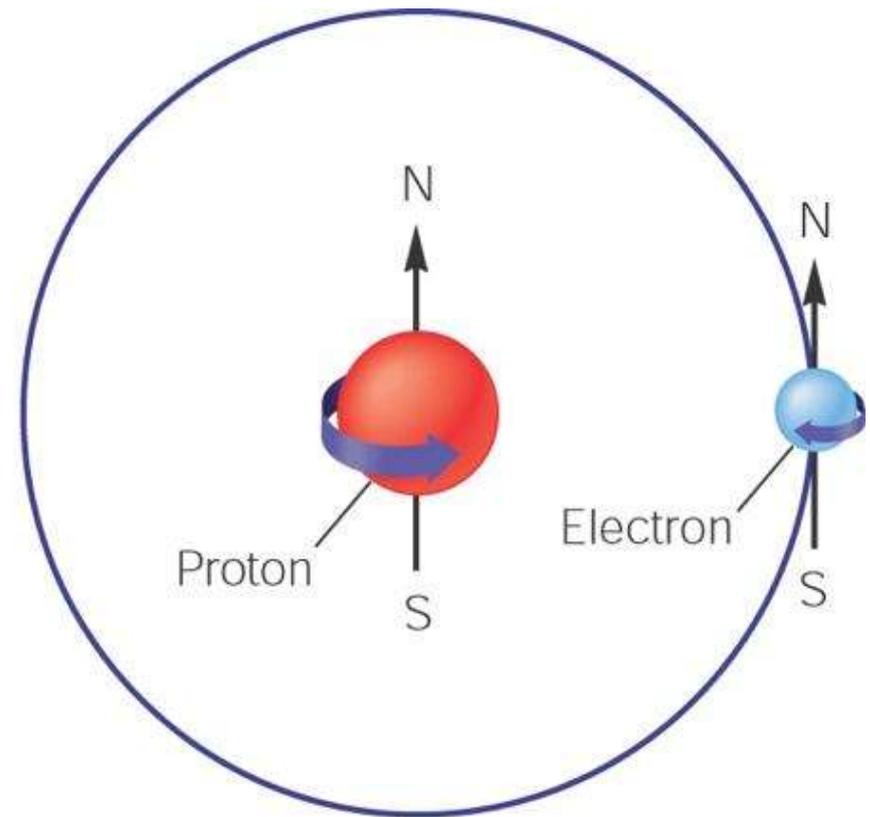
H neutro tb é difícil de ser observado

- Radiação em 21cm (ondas de rádio)



Same spins
Magnetic fields reversed

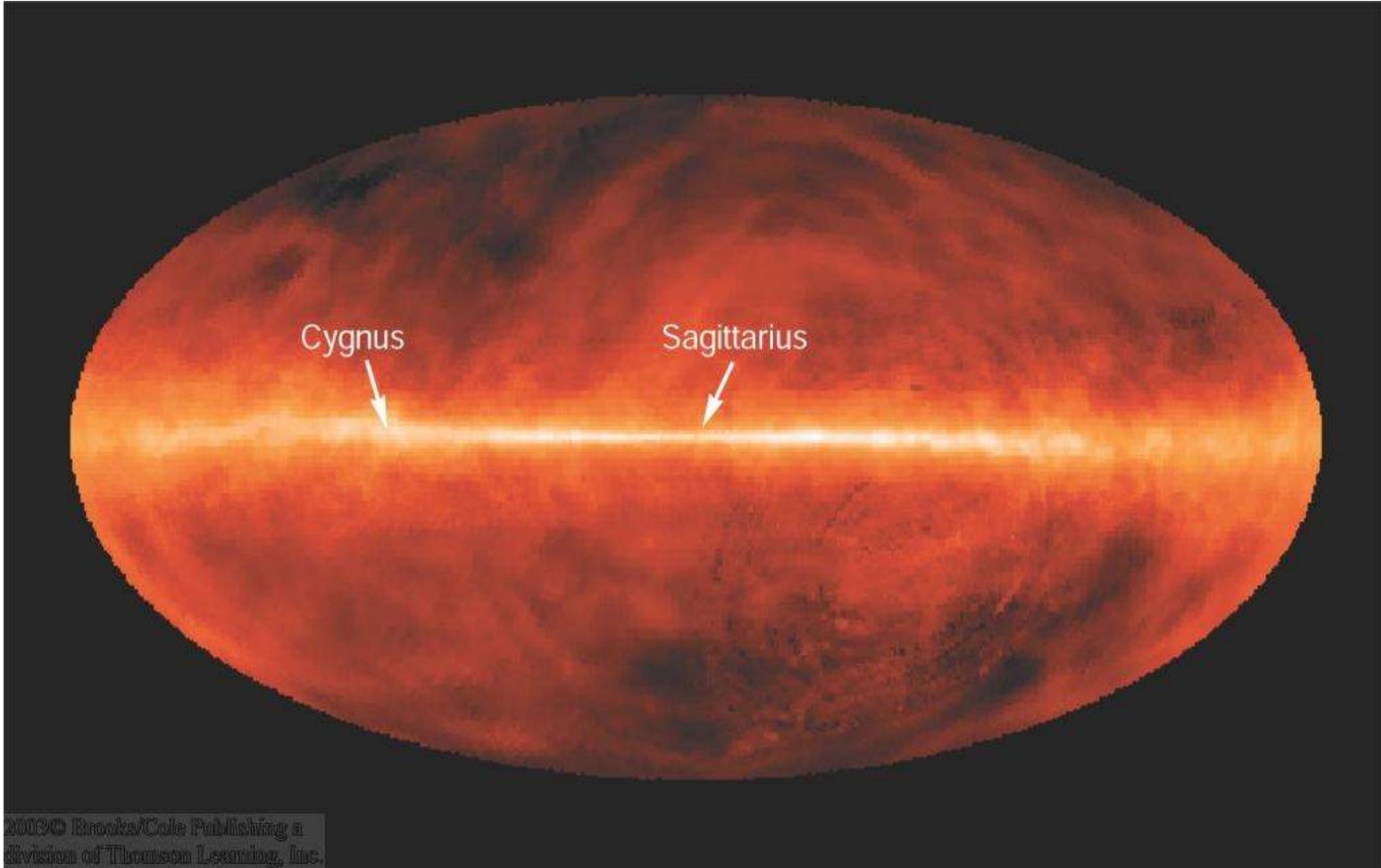
Estado base



Opposite spins
Magnetic fields the same

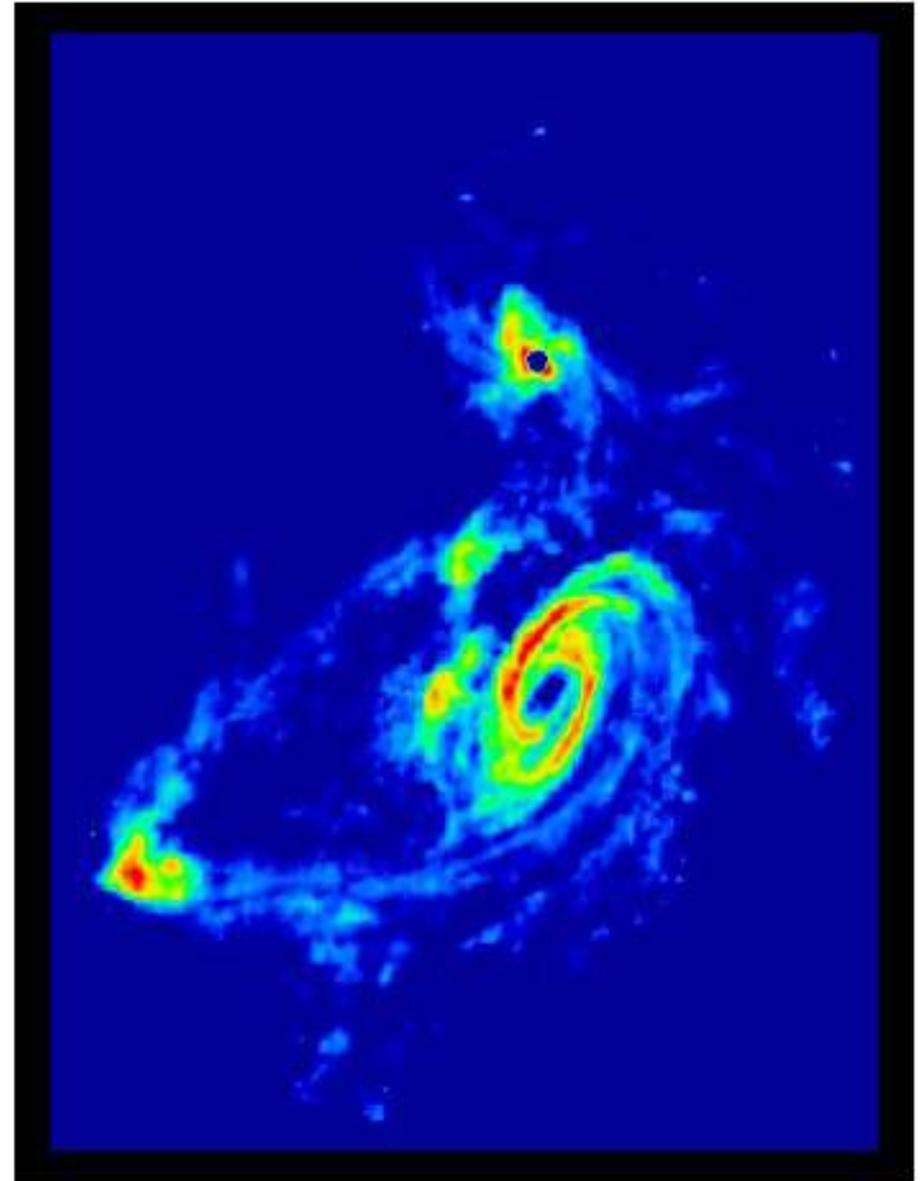
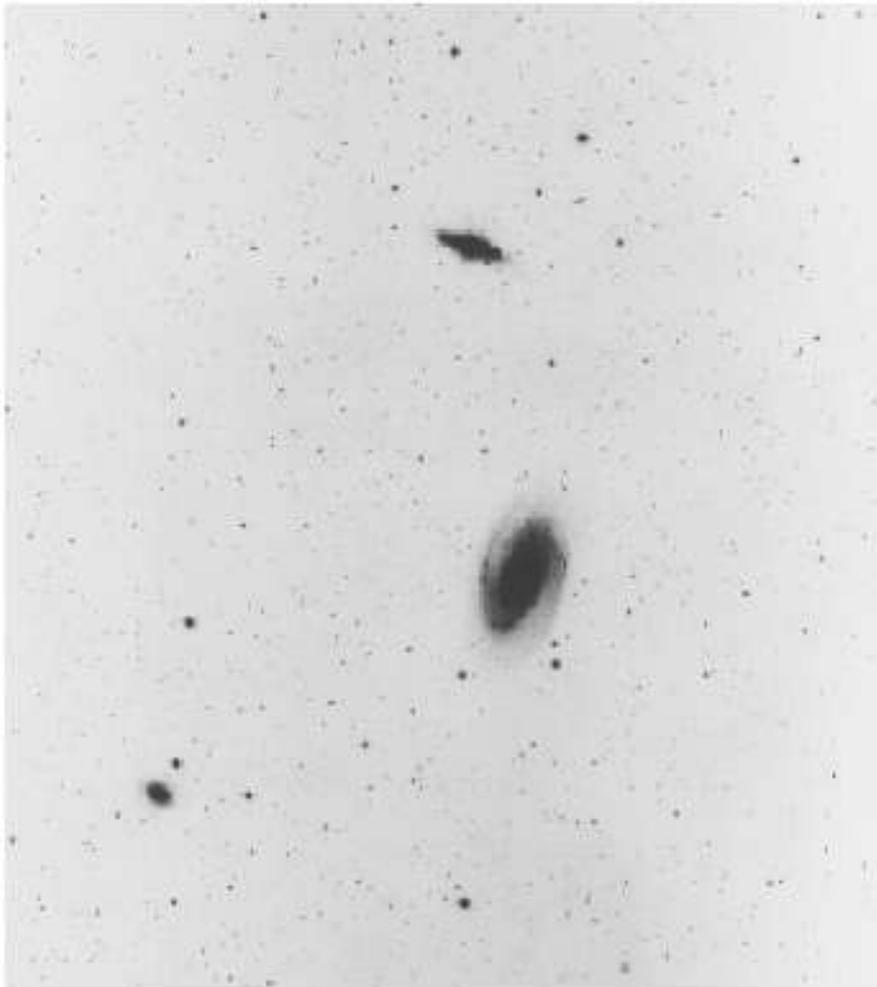
Excitado

Mapa do céu em 21 cm

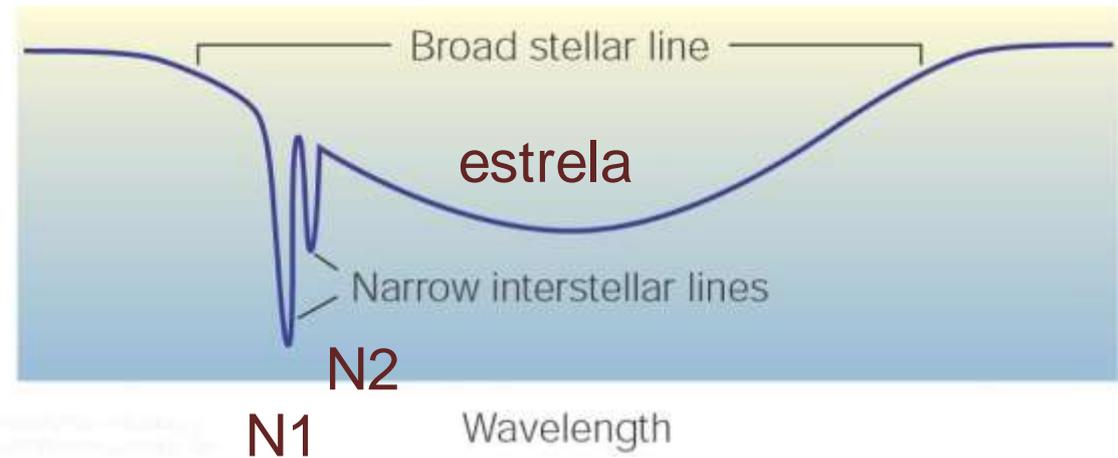
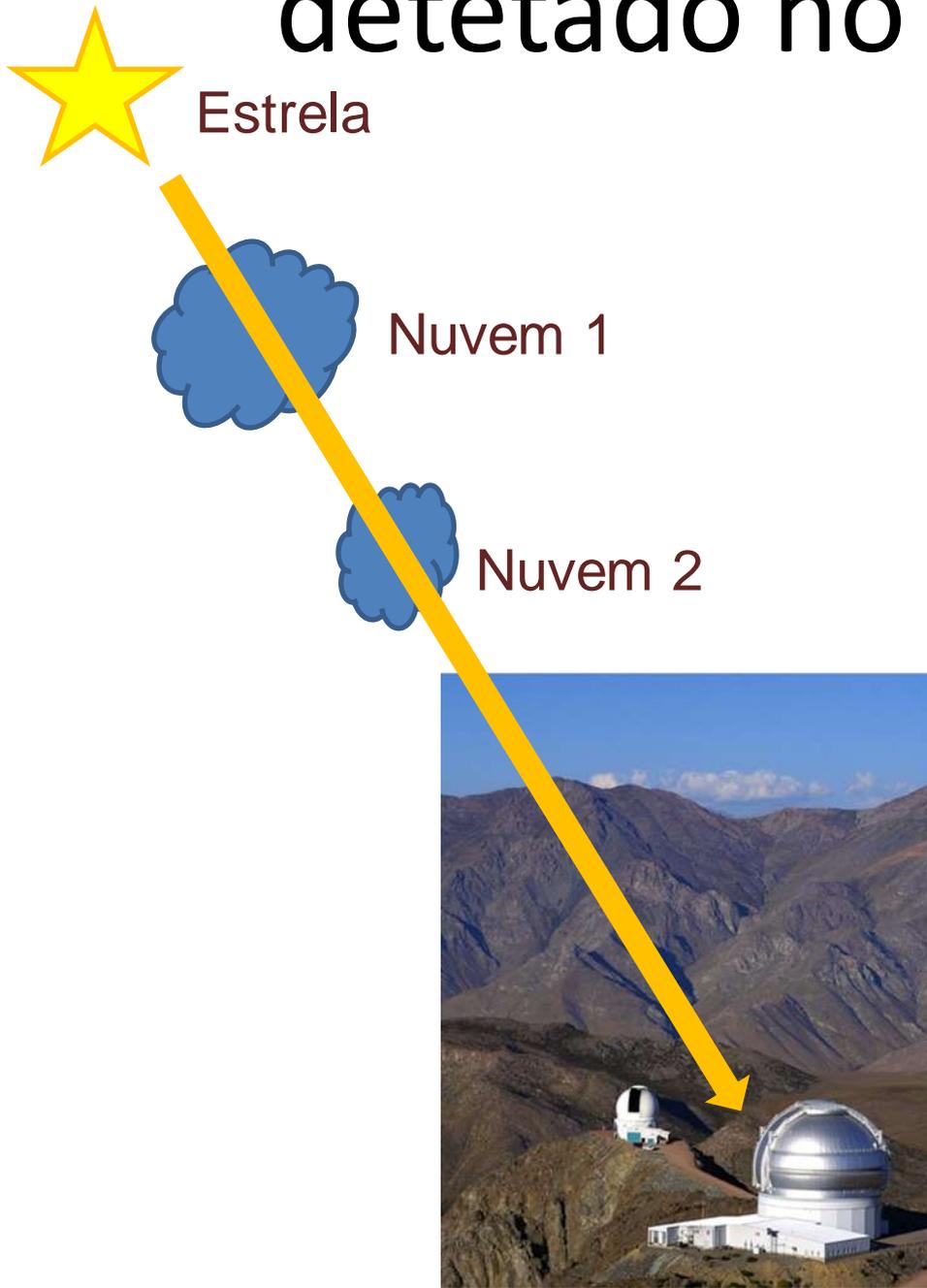


Gás atômico: reserva para formação de estrelas

**M81 group: optical starlight
(left) + VLA HI (right)**

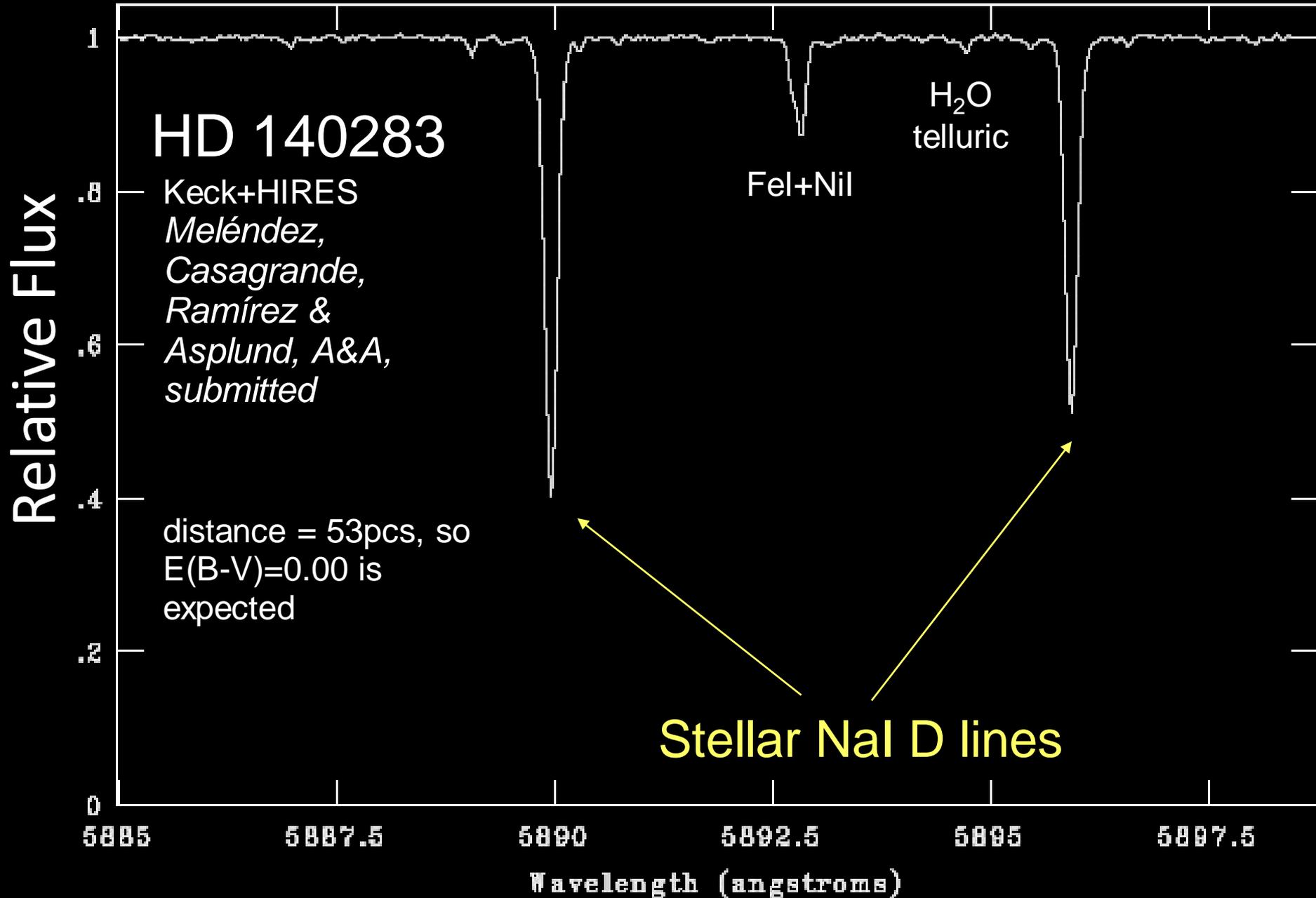


Gás neutro tb é possível de ser detetado no espectro visível



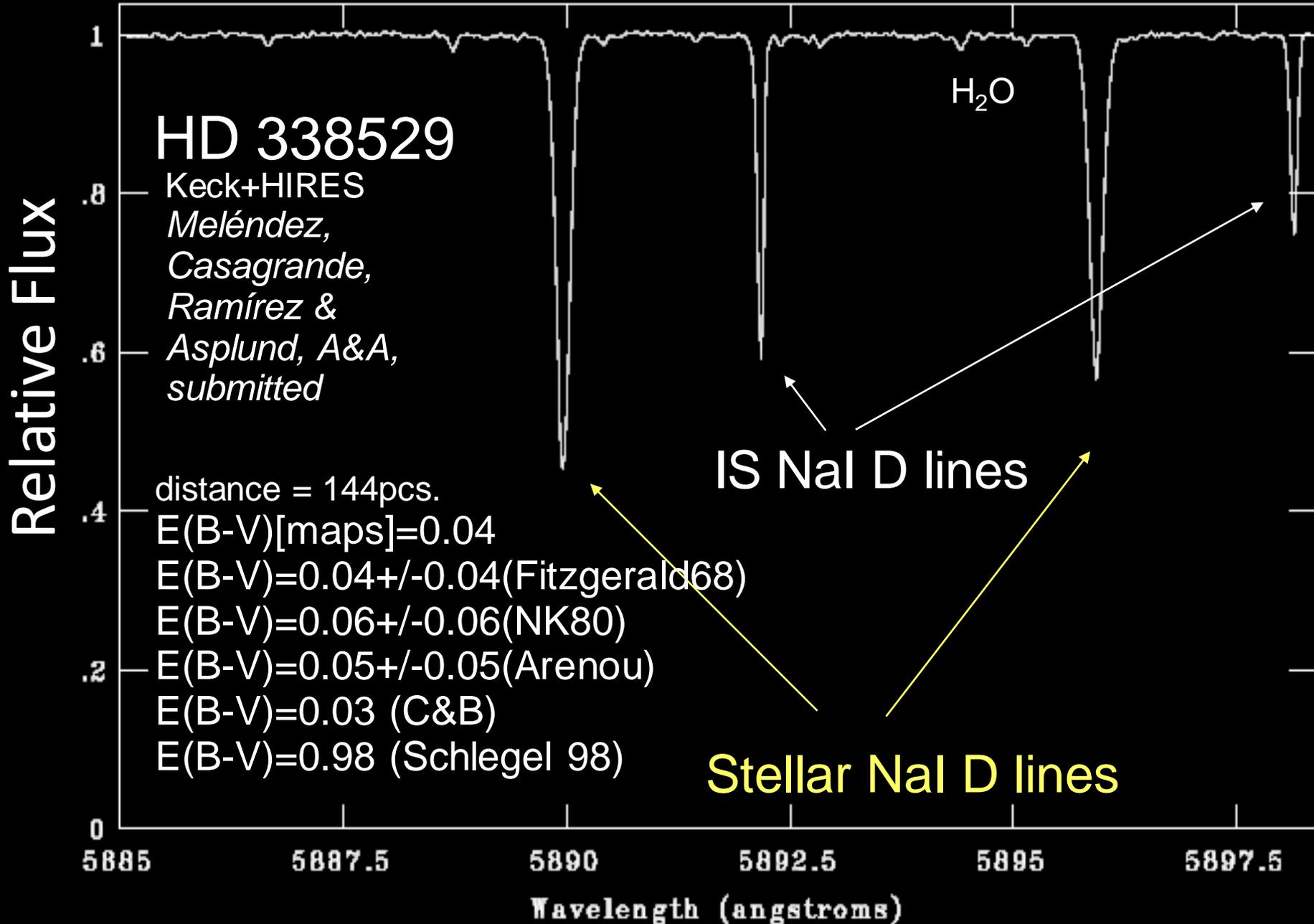
Determining E(B-V) using NaD lines

$$E(B-V) = 0.000 \pm 0.001 \text{ mag}$$



Determining E(B-V) using NaD lines

$$E(B-V) = 0.008 \pm 0.001 \text{ mag}$$



New 3D gas density maps of NaI and CaII interstellar absorption within 300 pc^{★,★★}

Catalog of absorptions towards 1857 early-type stars within 800 pc of the Sun. Using these data we determine the approximate 3-D spatial distribution of neutral and partly ionized IS gas density within a distance-cube of 300 pc from the Sun.

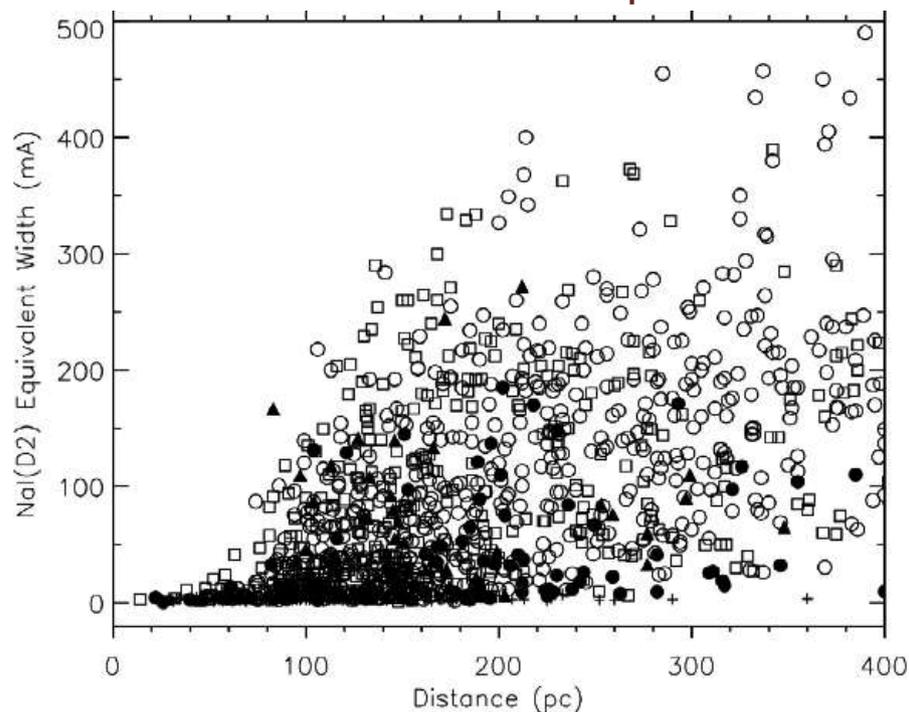


Fig. 7. Plot of the equivalent width ($\text{m}\text{\AA}$) of the interstellar NaI D2-line for stars with distances <400 pc. Filled triangles are for sight-lines with galactic latitude $b > +45^\circ$, open squares for sight-lines with $b = 0$ to 45° , open circles for sight-lines with $b = 0$ to -45° and filled circles for sight-lines with $b < -45^\circ$. Crosses are upper limit values. Note the sharp increase in the level of NaI absorption at ~ 80 pc, which is due to the neutral wall to the Local Cavity.

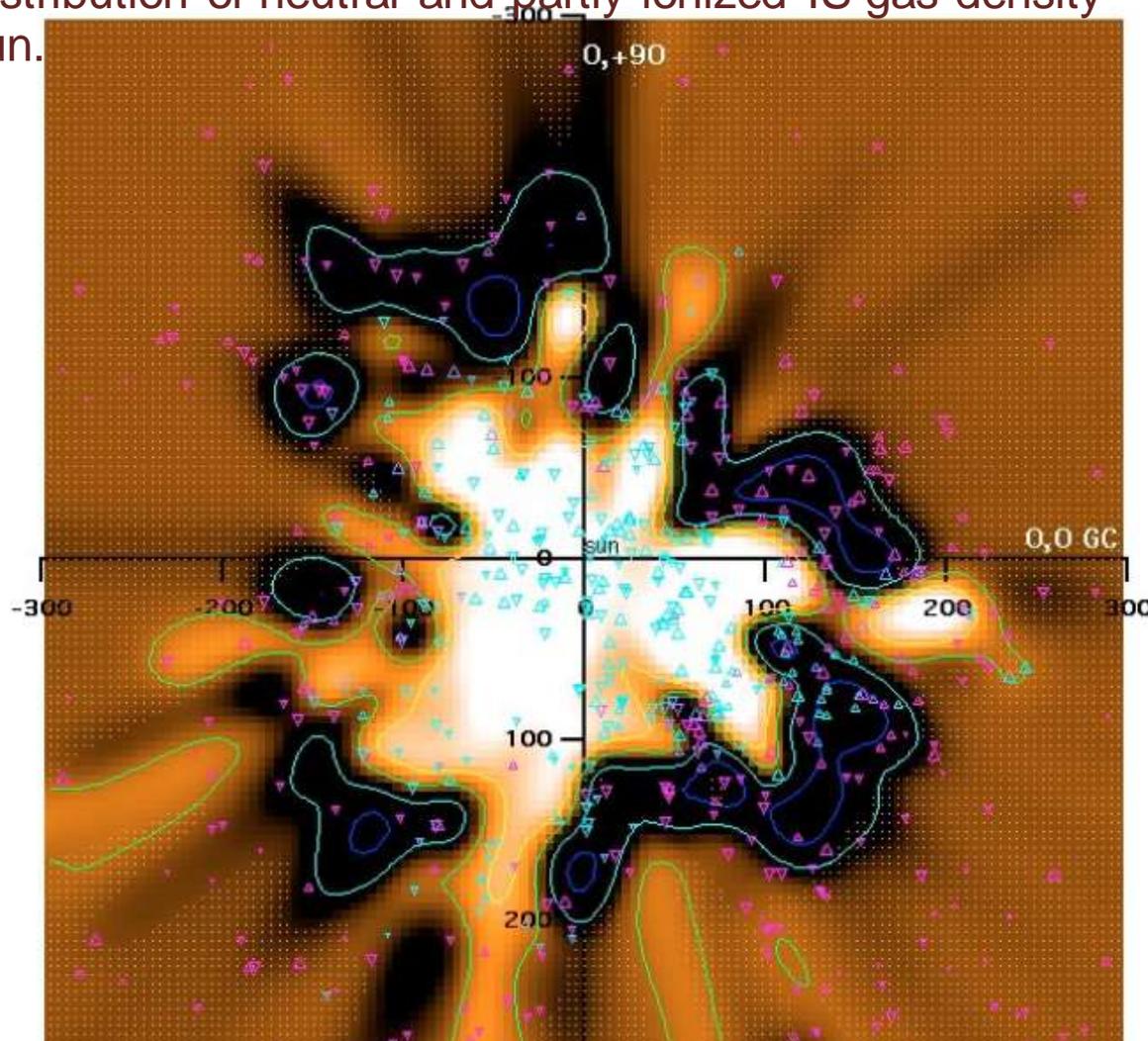


Fig. 12. Plot of 3D spatial distribution of interstellar NaI absorption within 300 pc of the Sun as viewed in the galactic plane projection. Triangles represent the sight-line positions of stars used to produce the map, with the size of the triangle being proportional to the derived NaI column density. Stars plotted with vertex upwards are located above the galactic plane, vertex down are below the plane. White to dark shading represents low to high values of the NaI volume density (n_{NaI}). The corresponding iso-contours (yellow, green, turquoise and blue) for $\log n_{\text{NaI}} = -9.5, -9.1, -8.5$ and -7.8 cm^{-3} are also shown. Regions with a matrix of dots represent areas of uncertain neutral gas density measurement.

Reciclagem galáctica

Stars, gas, and dust are in constant interaction with each other.

Stars are formed from dense molecular cloud cores.

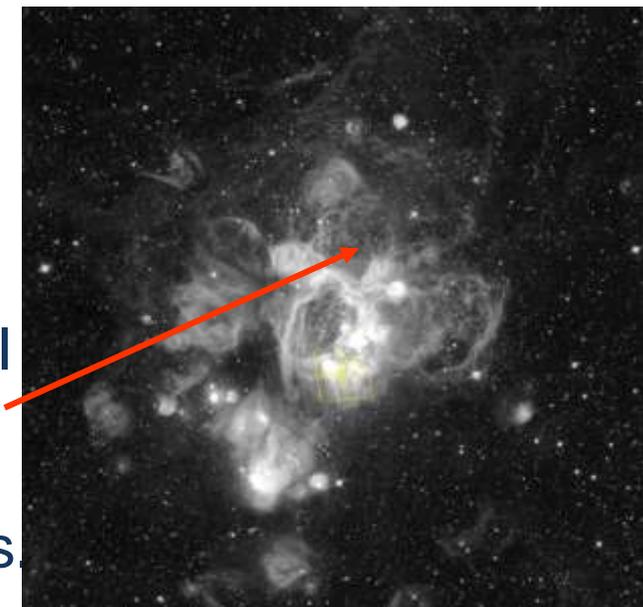
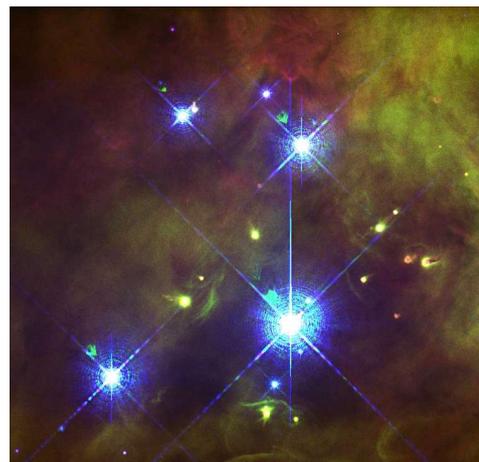
Hot stars ionize gas, producing HII regions.

Young star clusters illuminate the remnants of their “mother” clouds, producing reflection nebulae

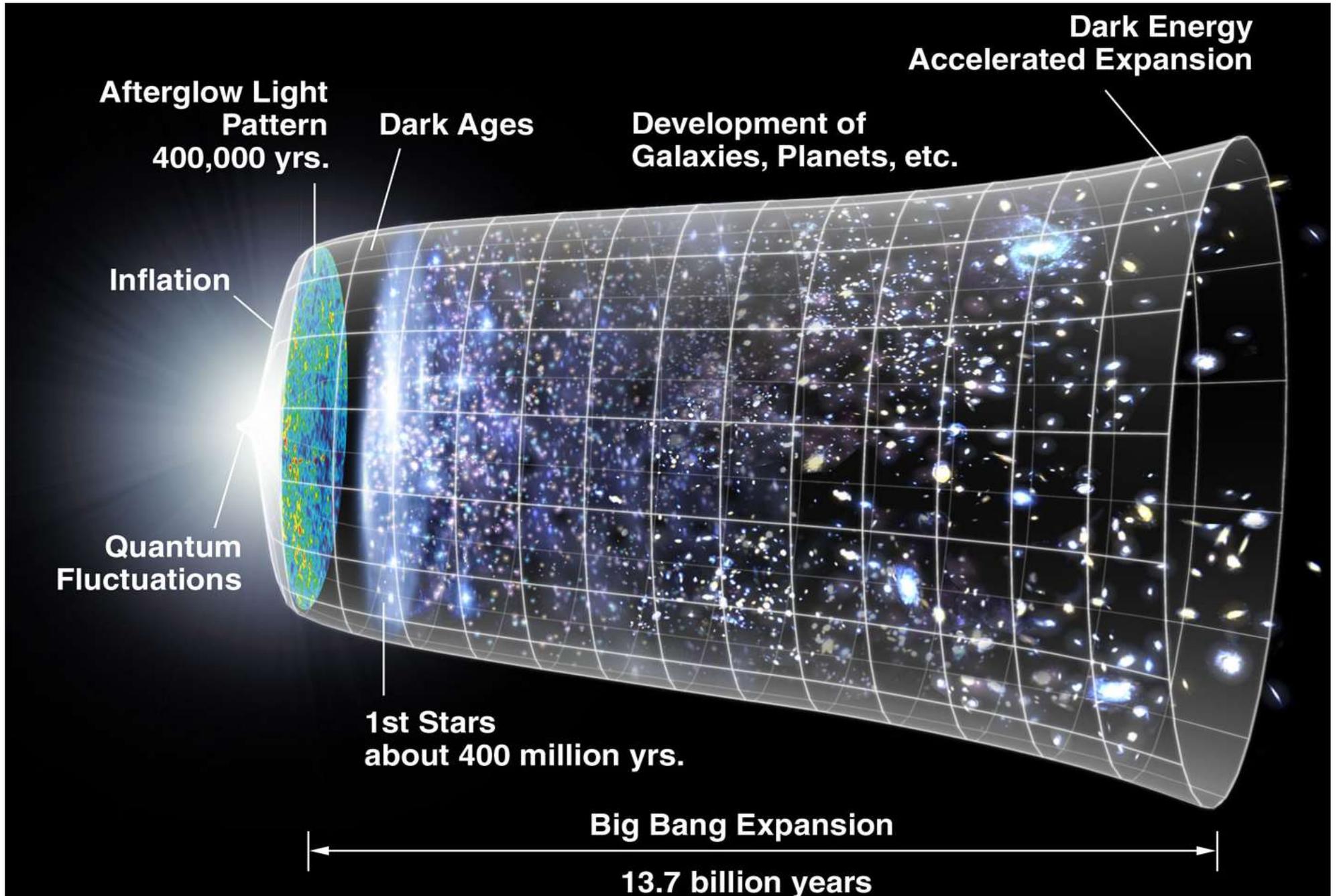
Massive stars will explode as supernovae

Supernovae trigger shock waves in the ISM that lead to the compression of dense clouds and new star formation.

Supernovae of massive stars produce coronal gas and enrich the ISM with heavier elements.



Há 13.7 mil milhões de anos: H, He, ...



Gás -> estrelas -> meio IS -> estrelas

Inner halo and bulge form

Bulge of gas
and first stars

Halo of gas
and first stars

Inner disk forms

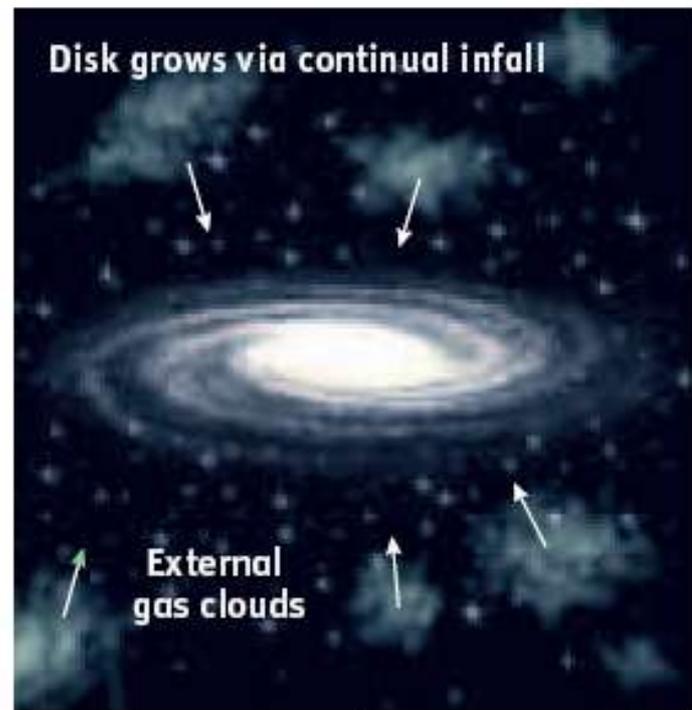
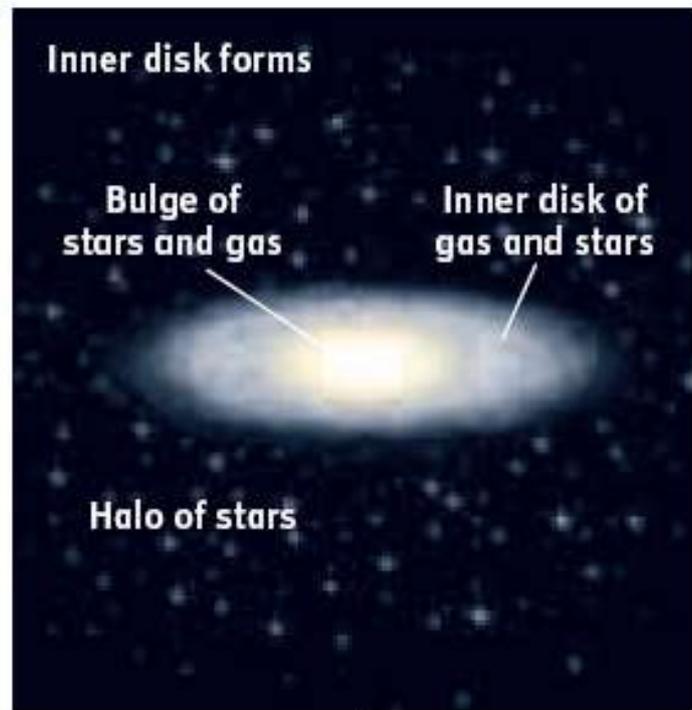
Bulge of
stars and gas

Inner disk of
gas and stars

Halo of stars

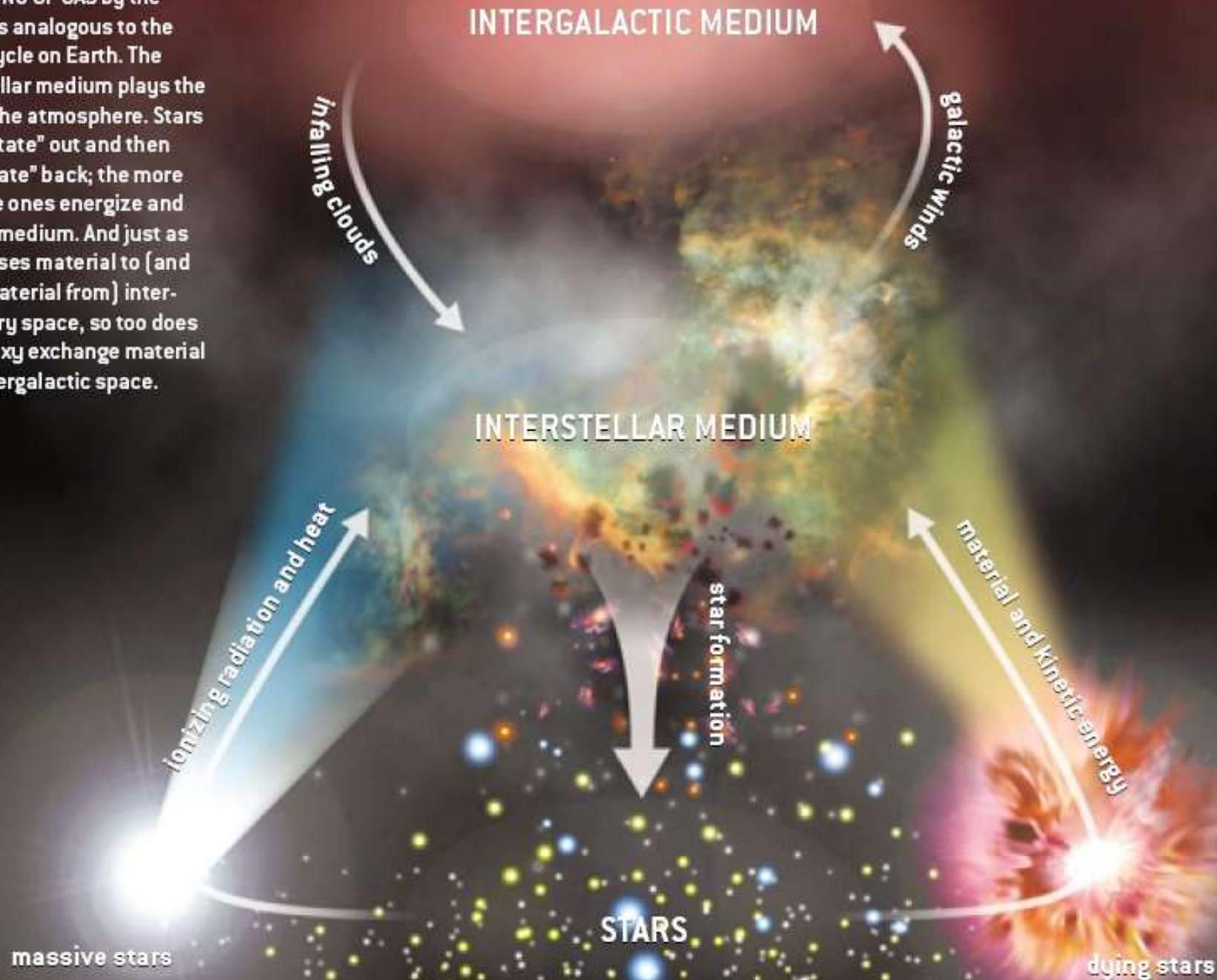
Disk grows via continual infall

External
gas clouds

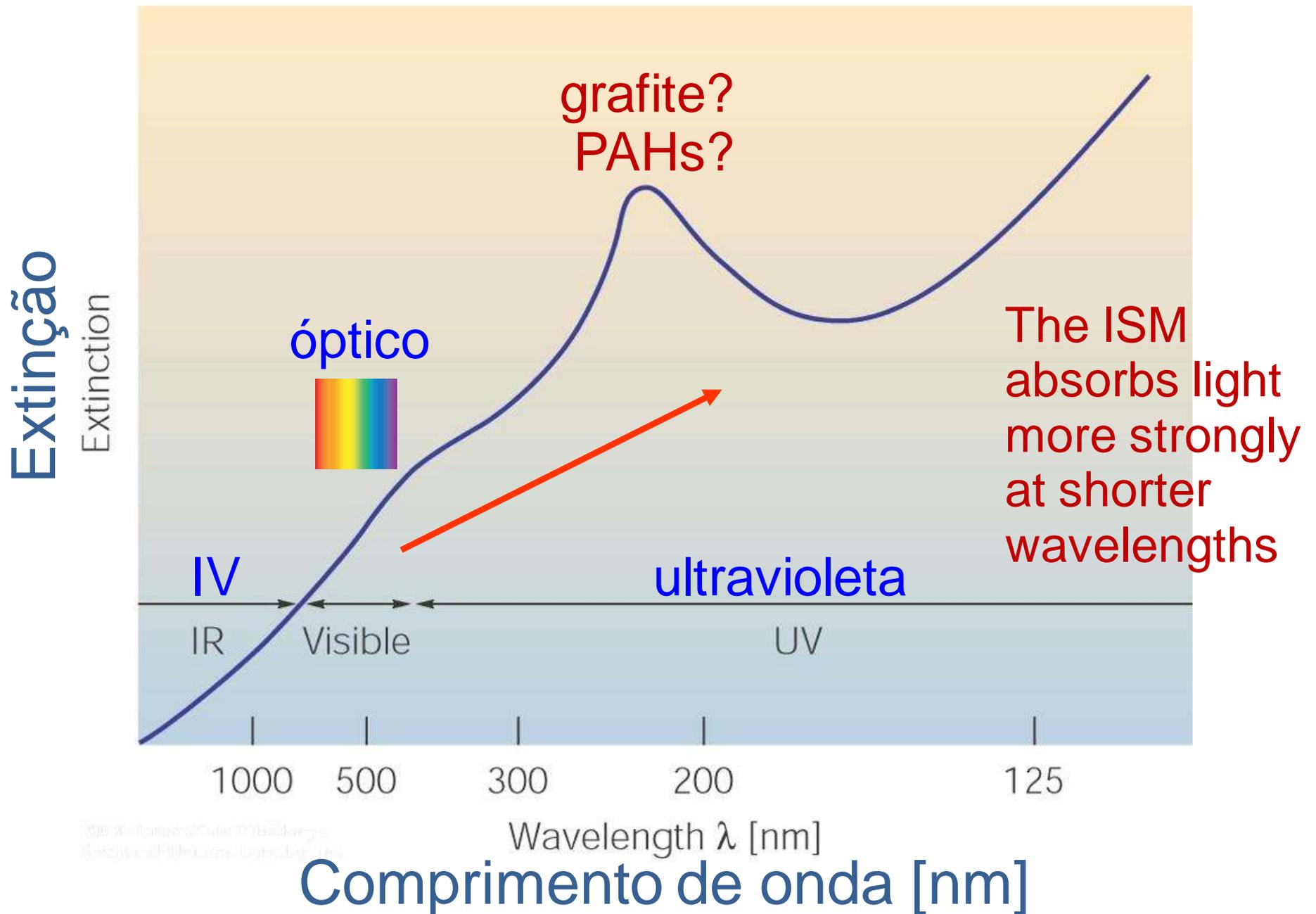


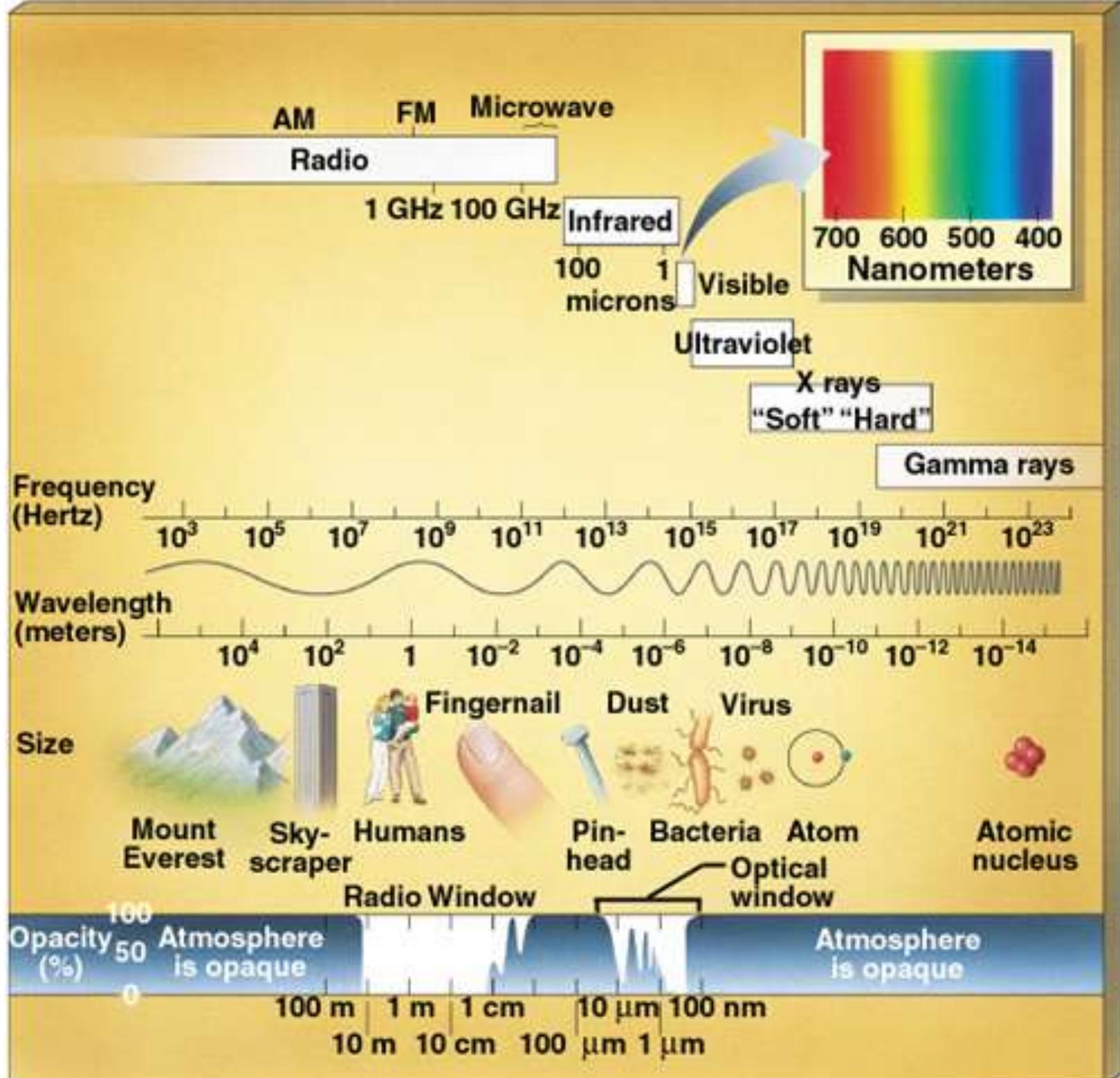
Reciclagem galáctica

RECYCLING OF GAS by the galaxy is analogous to the water cycle on Earth. The interstellar medium plays the part of the atmosphere. Stars "precipitate" out and then "evaporate" back; the more massive ones energize and stir the medium. And just as Earth loses material to (and gains material from) interplanetary space, so too does the galaxy exchange material with intergalactic space.

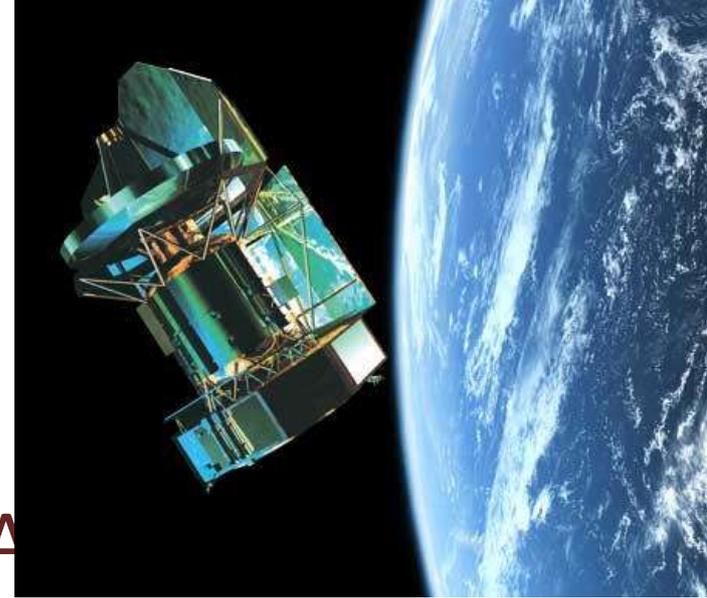


Curva de extinção interestelar





Herschel

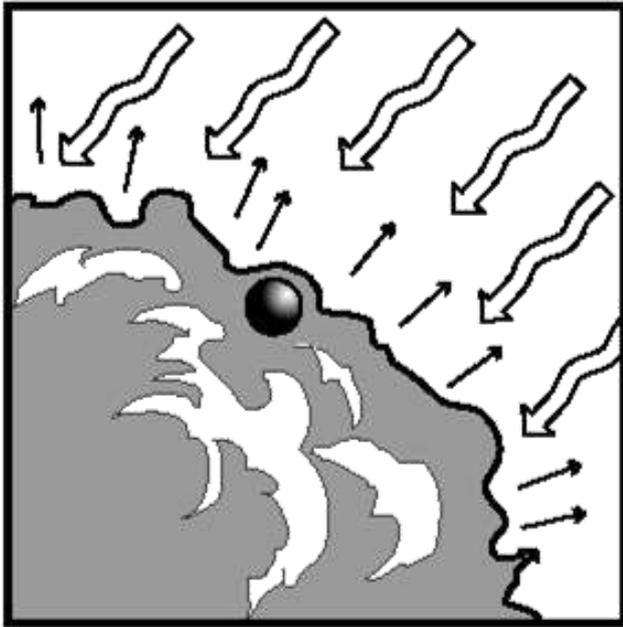


- Primary mirror: 3.5 m in diameter.
- Launch: 14 May 2009 on board an Ariane 5 rocket from ESA's Spaceport in Kourou, French Guiana.
- HIFI (Heterodyne Instrument for the Far Infrared), a high-resolution spectrometer; PACS (Photoconductor Array Camera and Spectrometer) and SPIRE (Spectral and Photometric Imaging REceiver), PACS and SPIRE are both cameras and imaging spectrometers. Together, these instruments cover 55–672 microns. Their detectors will be cooled to temperatures very close to absolute zero.

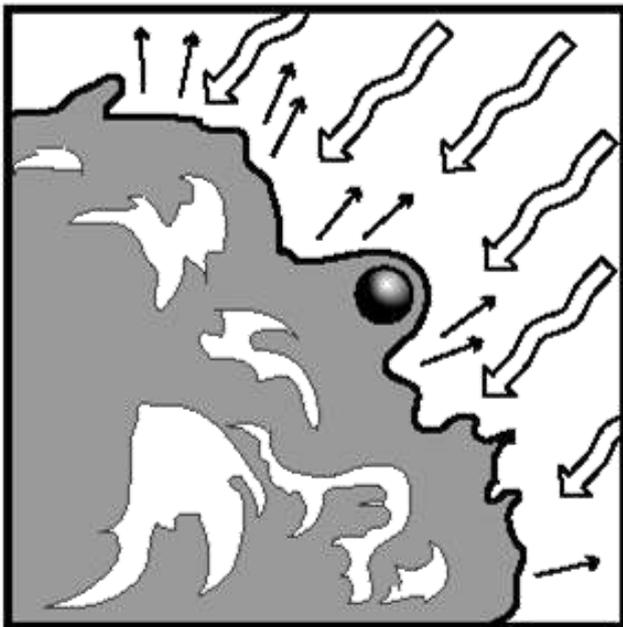


- A cloud of gas and dust called RCW120 as seen by Herschel. The large blue bubble is being blown out by a massive star (unseen) in the centre. This creates the conditions for a giant young star to form on the bubble's bottom edge (white blob)

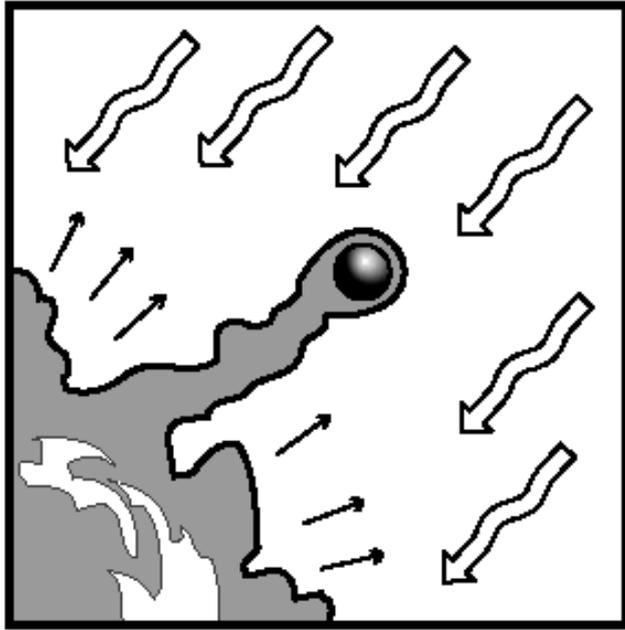
Stellar EGGs in M16



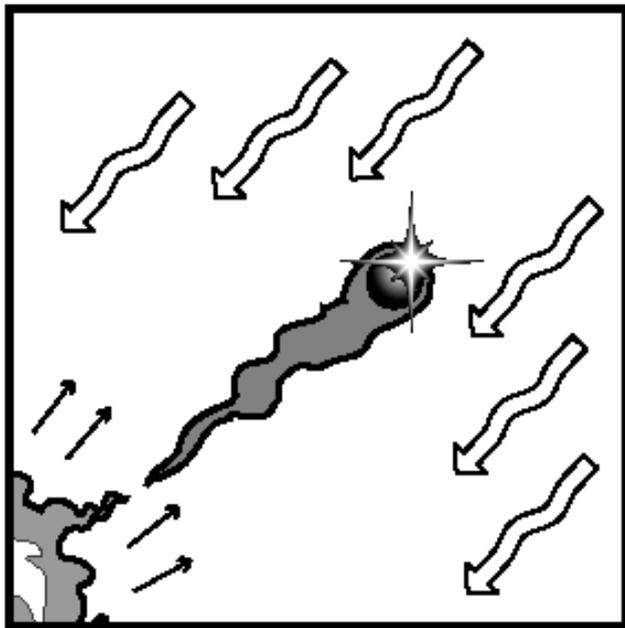
The surface of a molecular cloud is illuminated by intense ultraviolet radiation from nearby hot stars. The radiation evaporates material off of the surface of the cloud.



As the cloud is slowly eaten away by the ultraviolet radiation, a denser than average globule of gas begins to be uncovered



The EGG has now been largely uncovered. The shadow of the EGG protects a column of gas behind it, giving it a finger-like appearance.



Eventually the EGG may become totally separated from the molecular cloud in which it formed. As the EGG itself slowly evaporates, the star within is uncovered and may appear sitting on the front surface of the EGG.