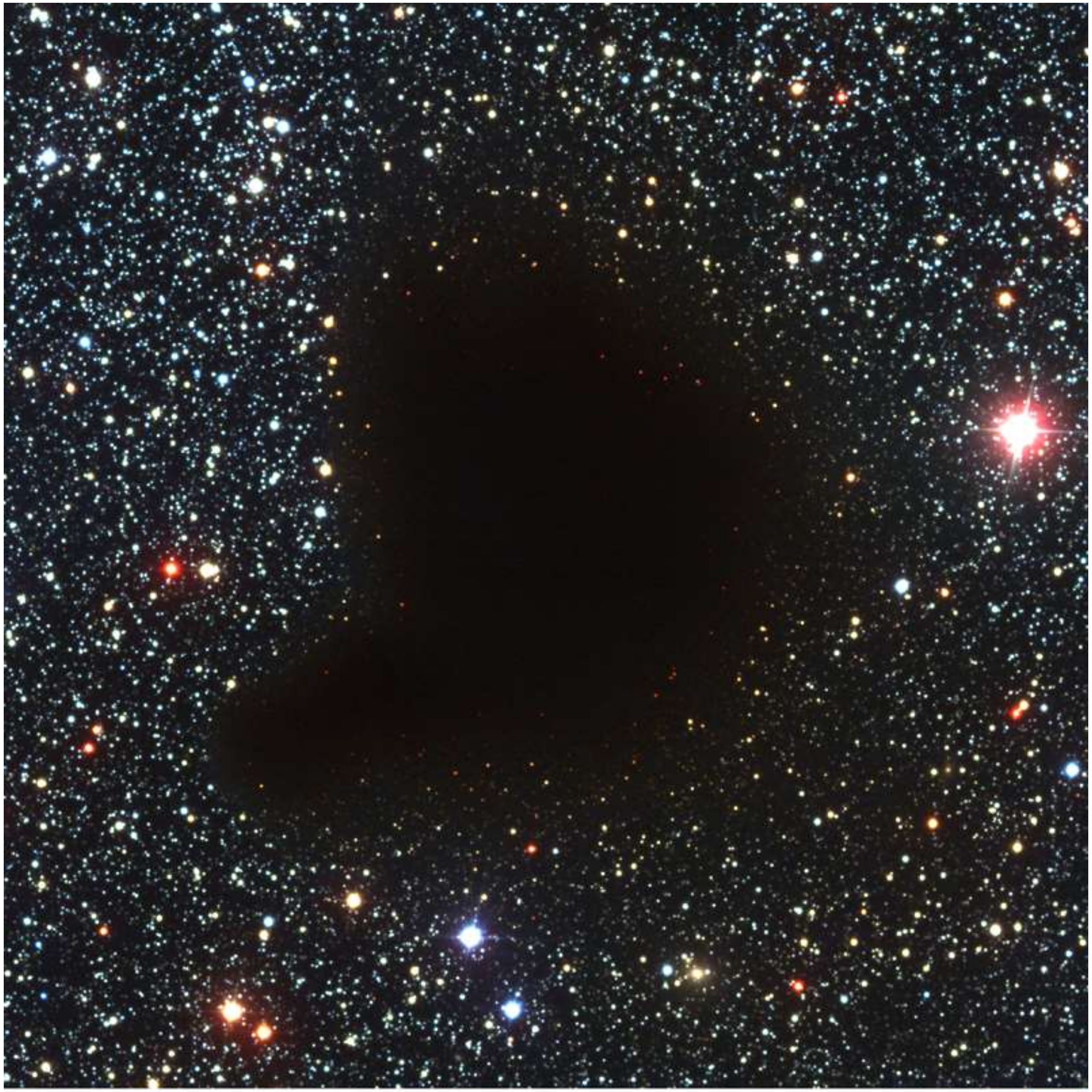
Fotometria III
Extinção e Avermelhamento Interestelar

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

Nuvens escuras de poeira



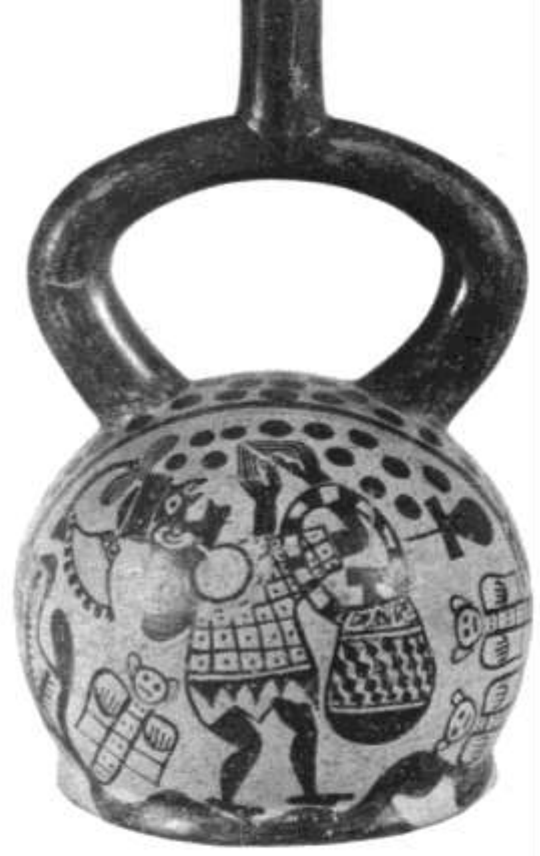
The "Black Cloud" B68
(VLT ANTU + FORS1)

ESO PR Photo 20a/99 (30 April 1999)

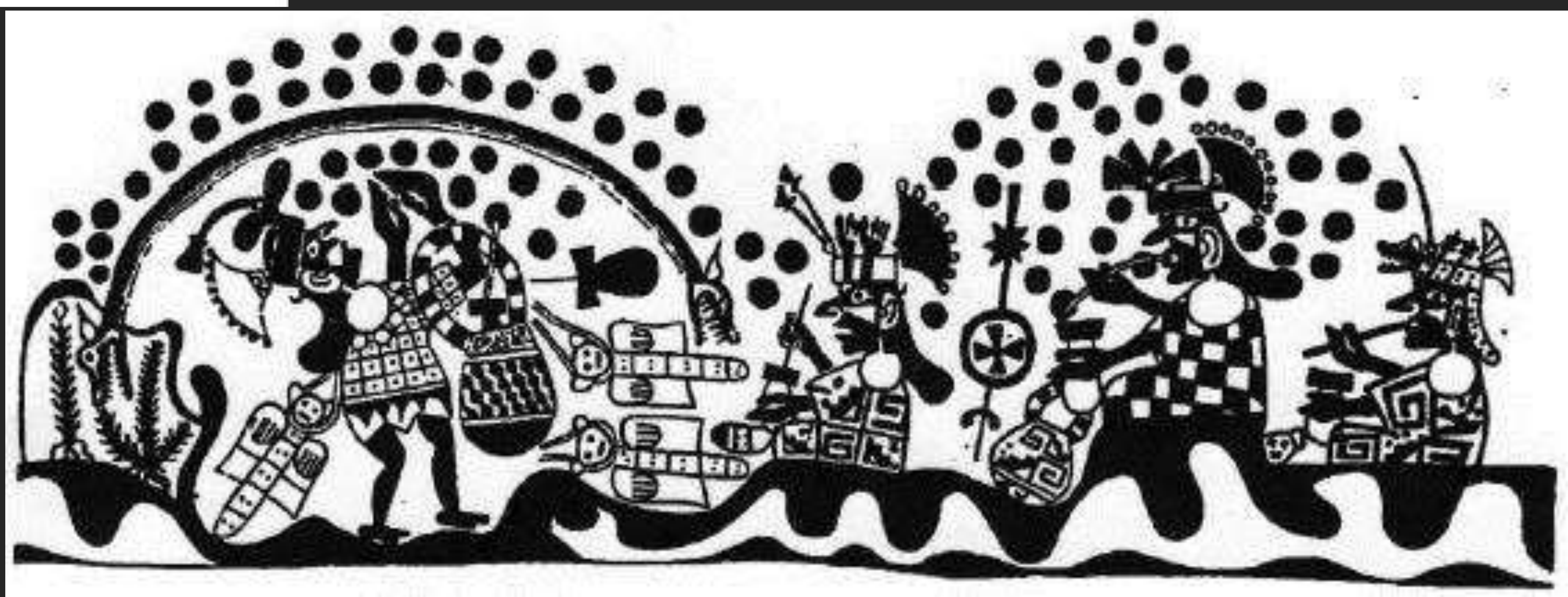
Primeiras observações do meio interestelar

Civilizações europeias apenas reconheceram constelações brilhantes (estrelas)

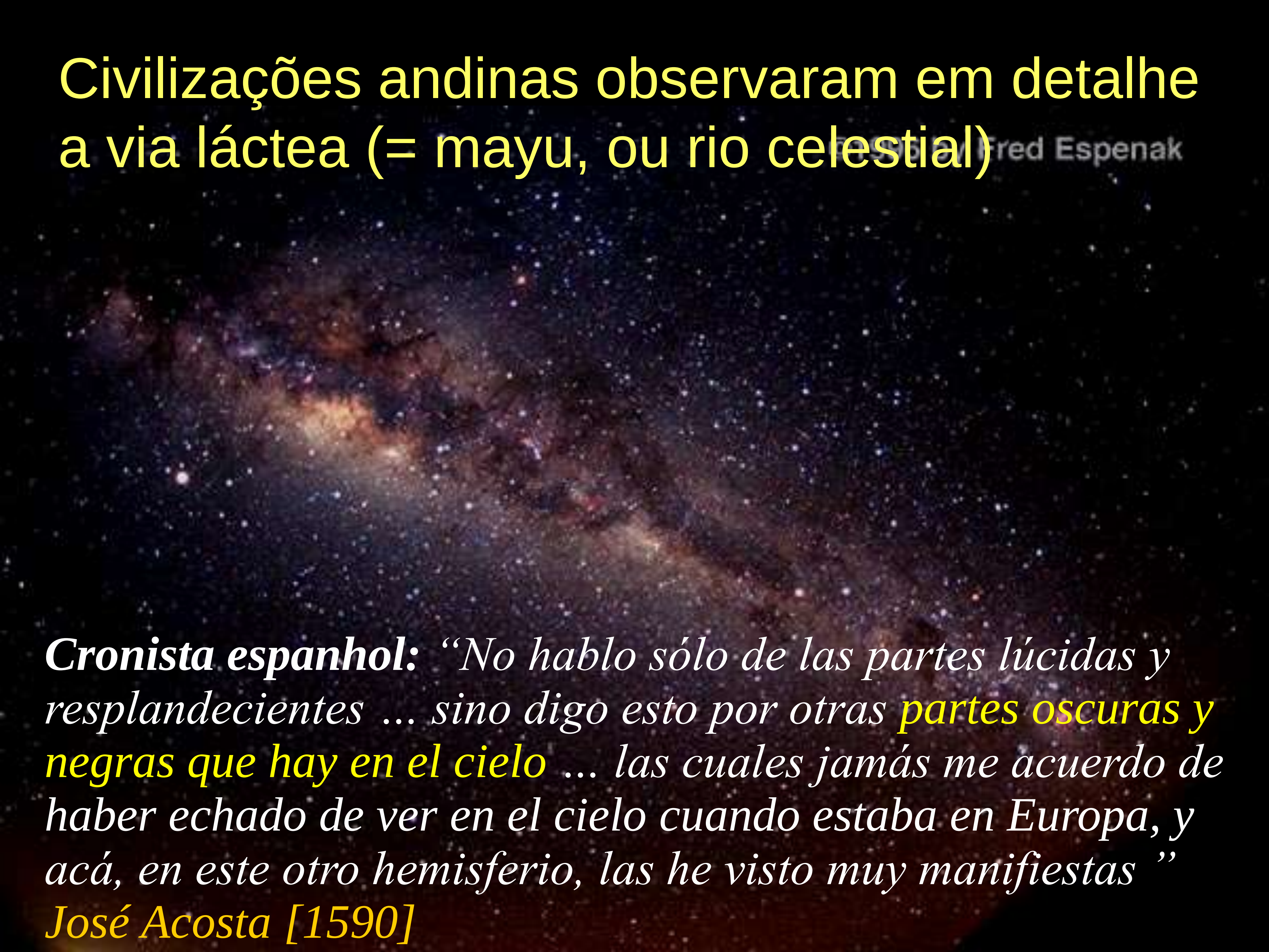
No hemisfério Sul foram reconhecidas constelações escuras



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



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



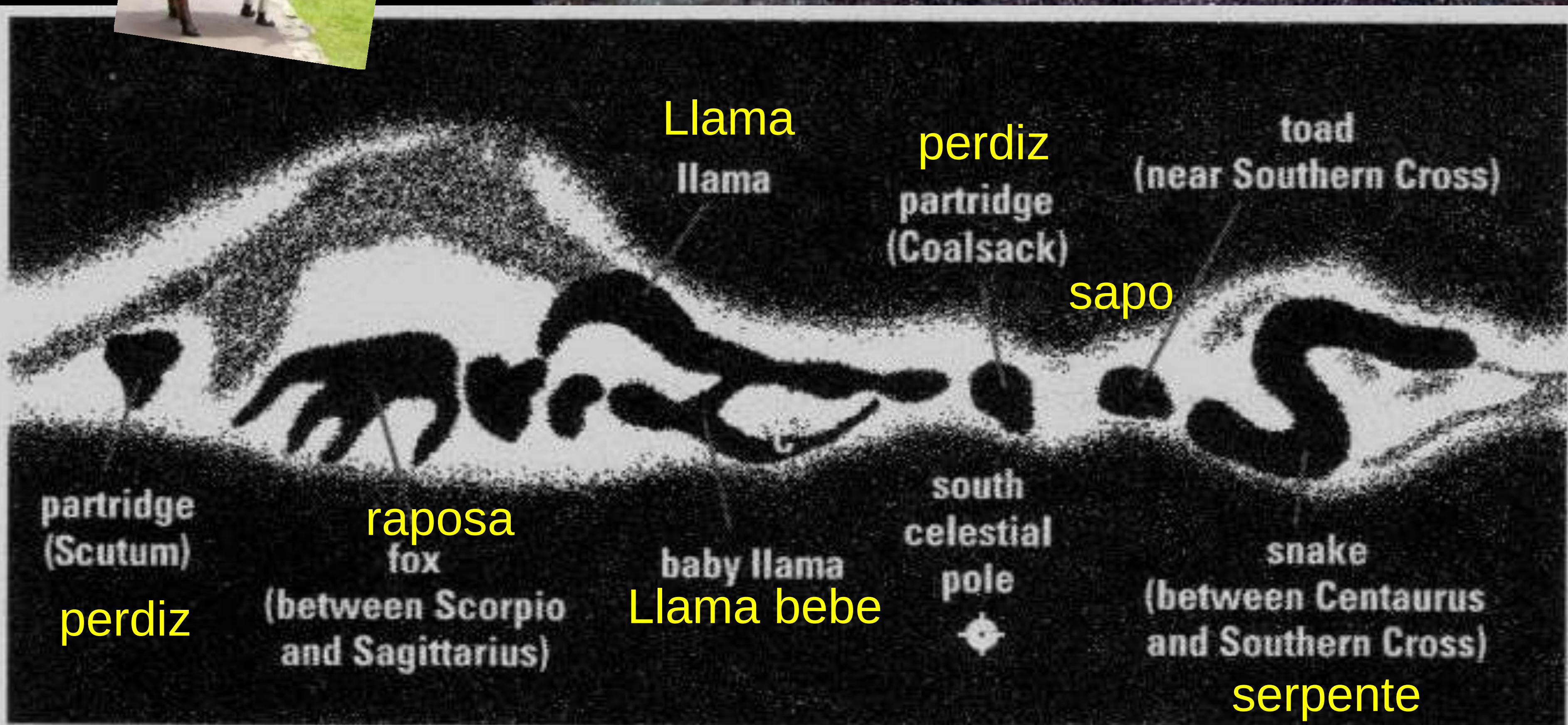
Cronista espanhol: *"No hablo sólo de las partes lúcidas y resplandecientes … sino digo esto por otras partes oscuras y negras que hay en el cielo … las cuales jamás me acuerdo de haber echado de ver en el cielo cuando estaba en Europa, y acá, en este otro hemisferio, las he visto muy manifiestas "*

José Acosta [1590]

Constelação escura da Llama: Yacana

α, β Centauri:
Llama Ñahui:
Olhos da Llama

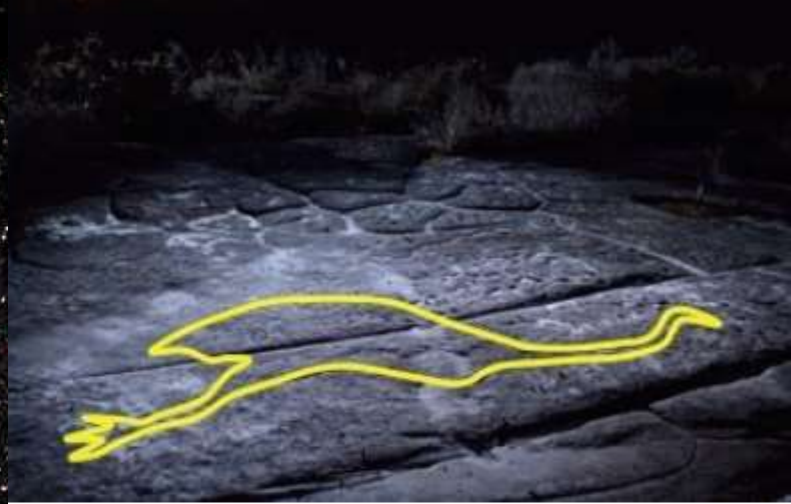
Constelação escura da Llama: Yacana



(c)

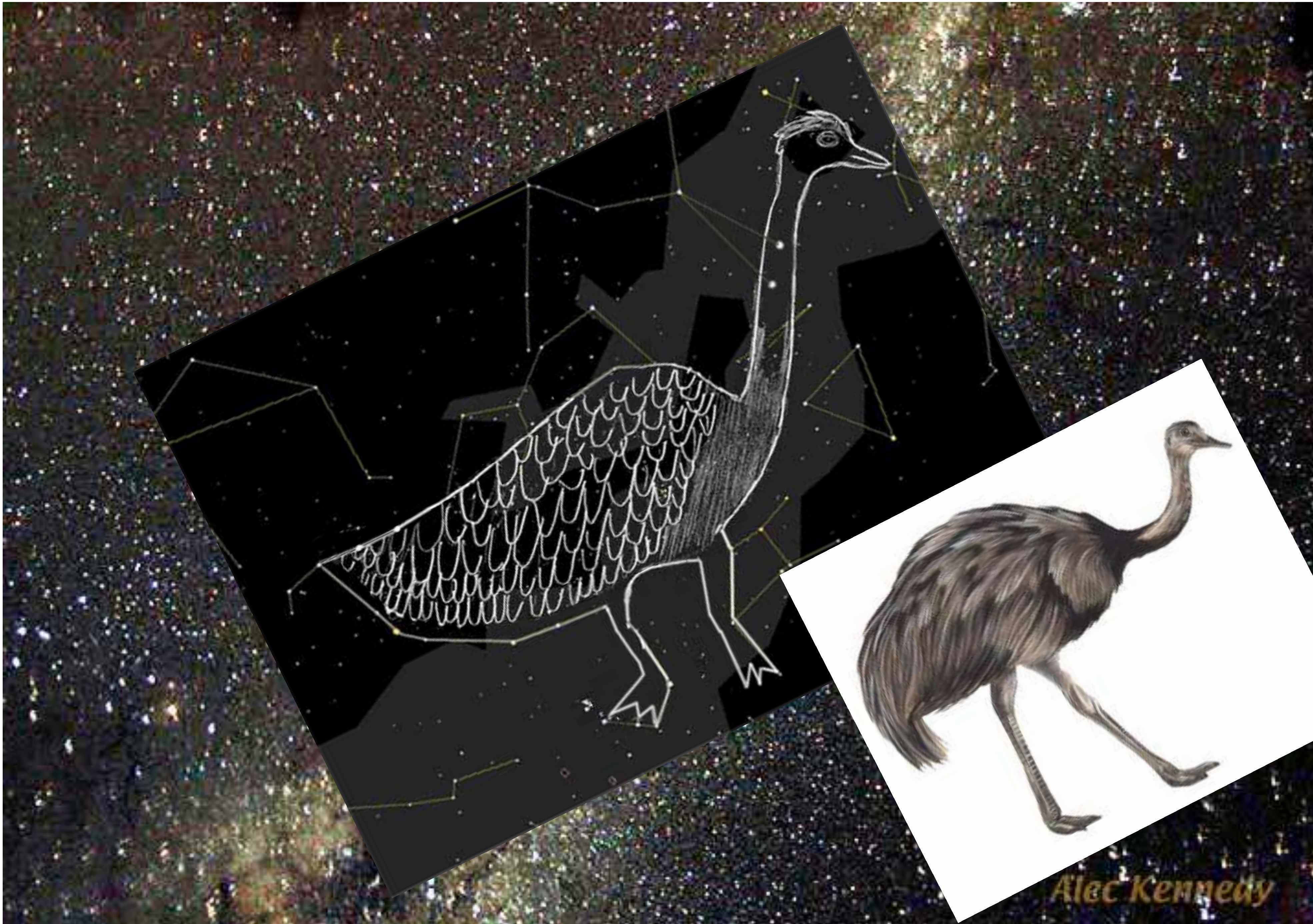
Figure 2.15 (*Continued*). (c) Contemporary Andean dark cloud constellations of the southern Milky Way; to the people of Misminay, dark cloud constellations represent animals.

Aveni, Stairways to the Stars, 1997



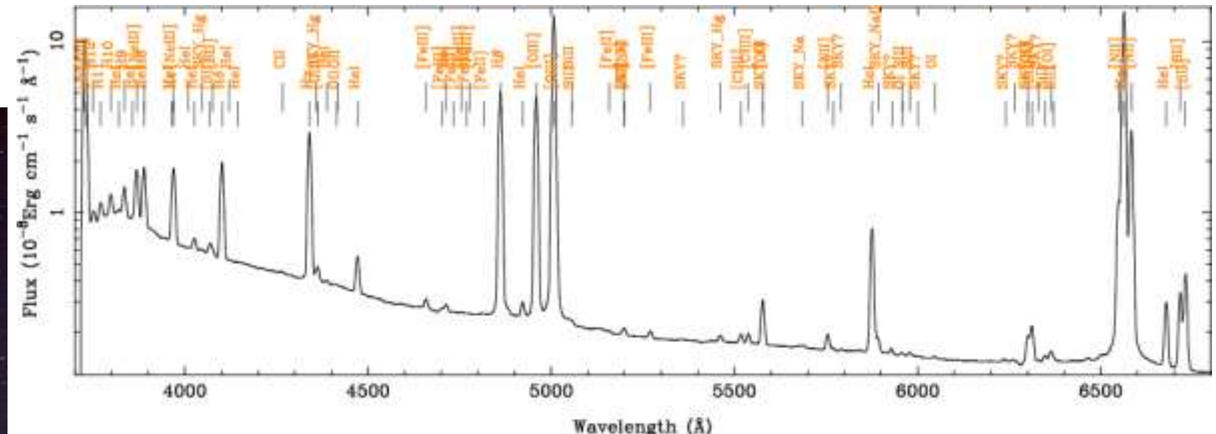
Austrália: Emu

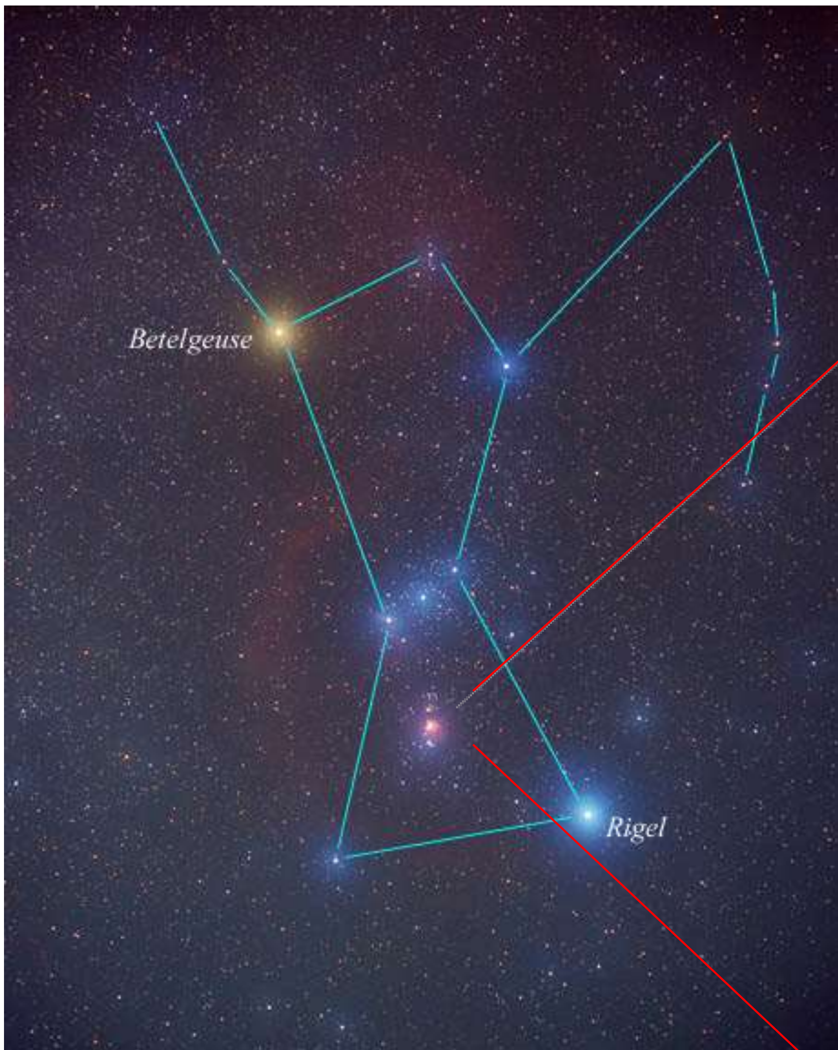
Brasil: Ema



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

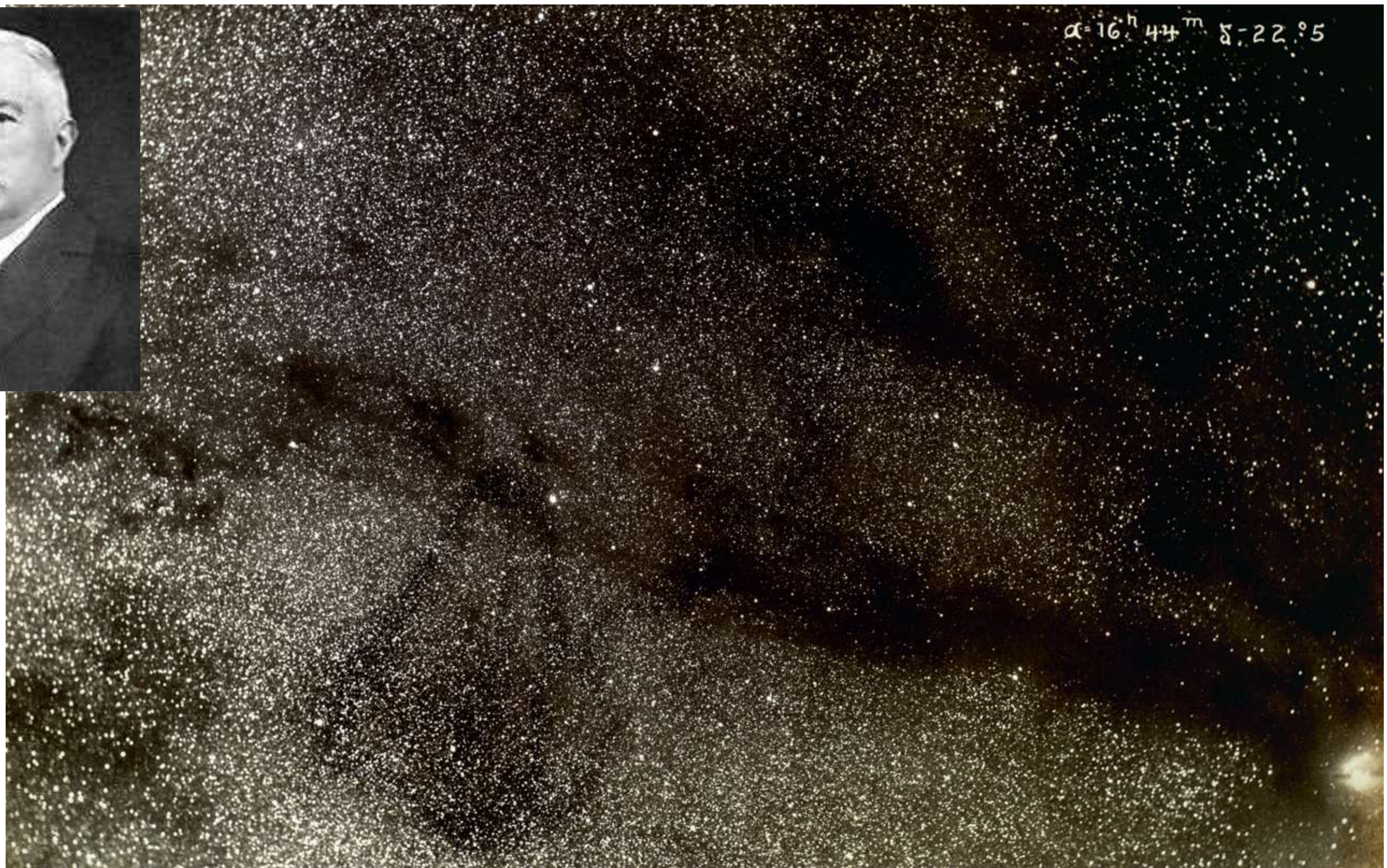
Huggins & Miller (1863) observaram o espectro da nebulosa de Órion e encontraram que o espectro de emissão era caraterístico de gás.





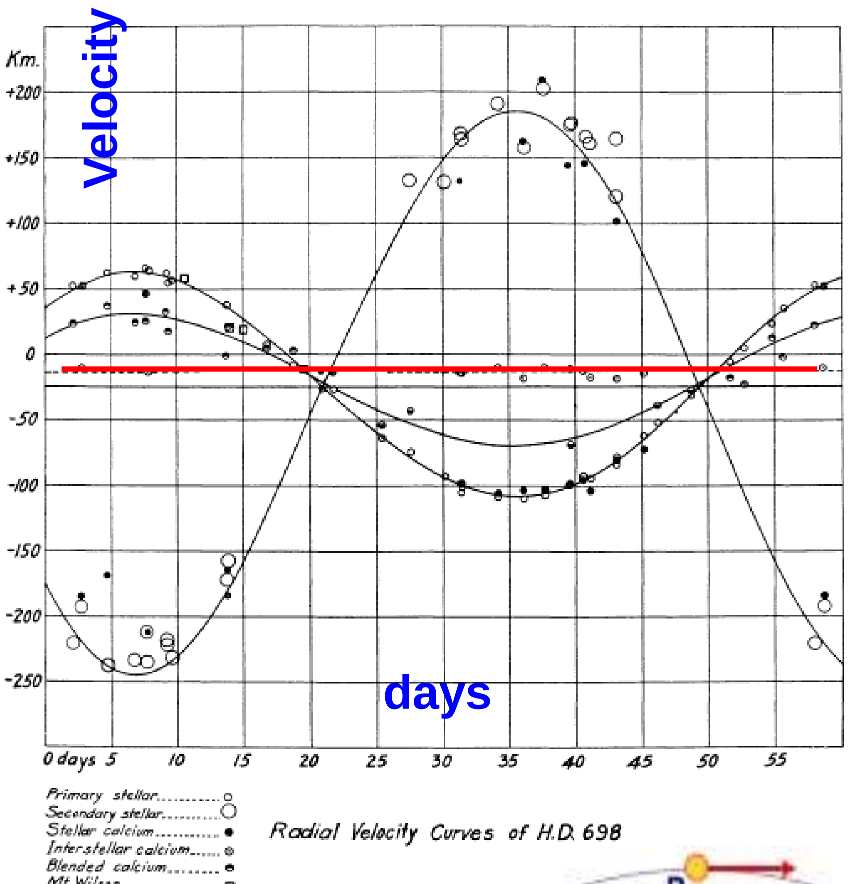
A finais do século XIX e começos do século XX a existencia do meio interestelar foi confirmada

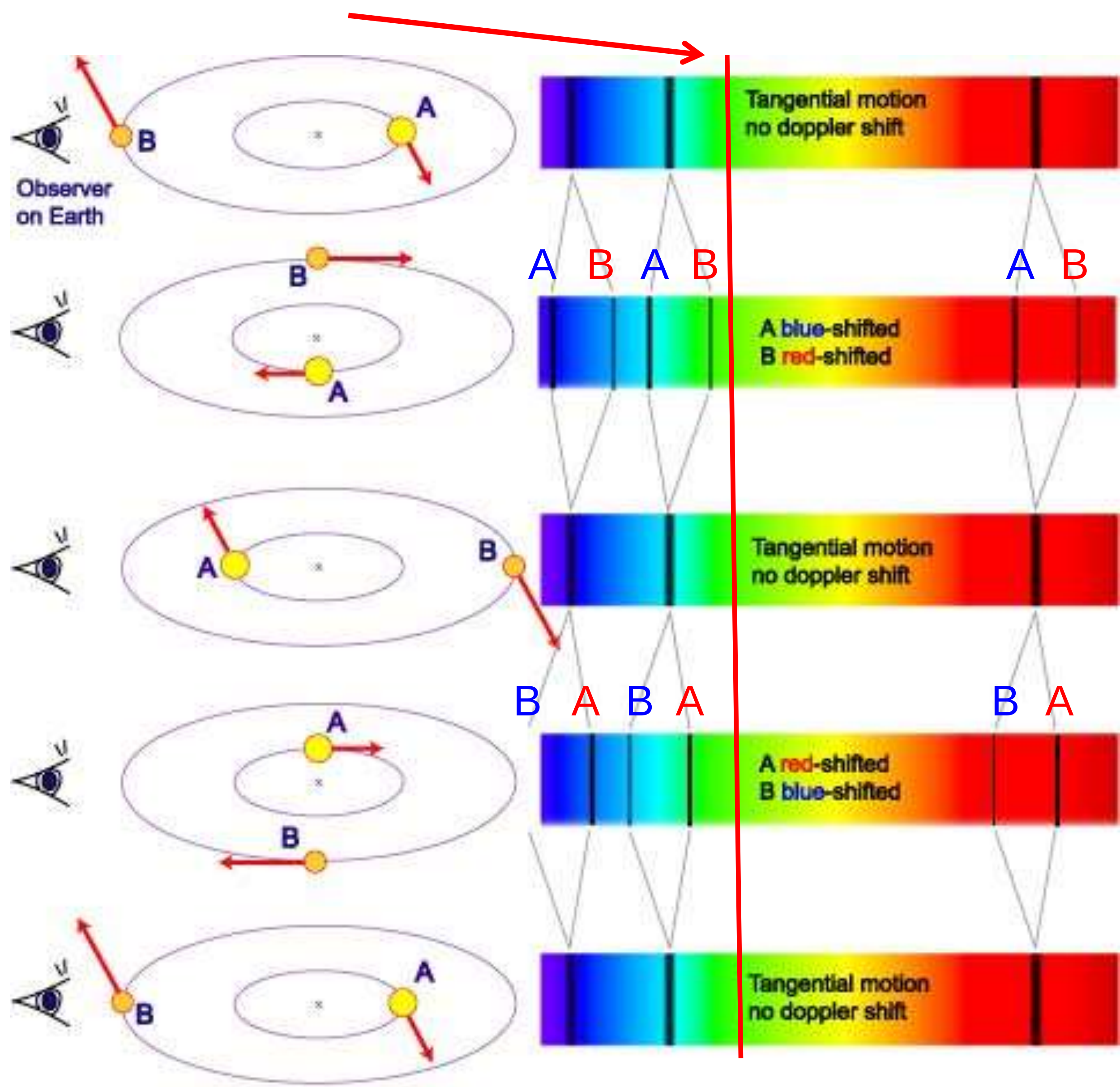
Edward Emerson Barnard (1857 – 1923) produced in 1895 the first images of dark nebulae and came to the conclusion that along with the illuminated gas and dust there was also significant quantities of dust and gas not directly illuminated.

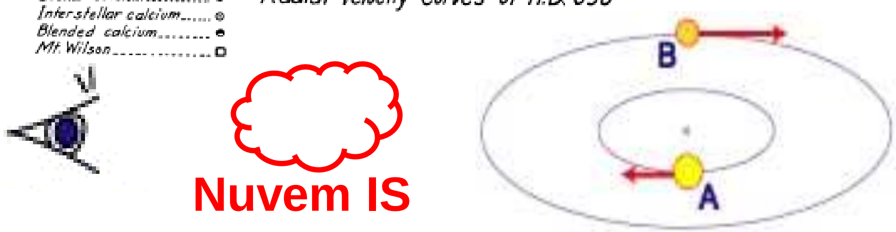


Linhas interestelares estacionárias in the spectra of spectroscopic binaries

Hartmann (1904)
Heger (1918)
J. A. Pearce (1932)





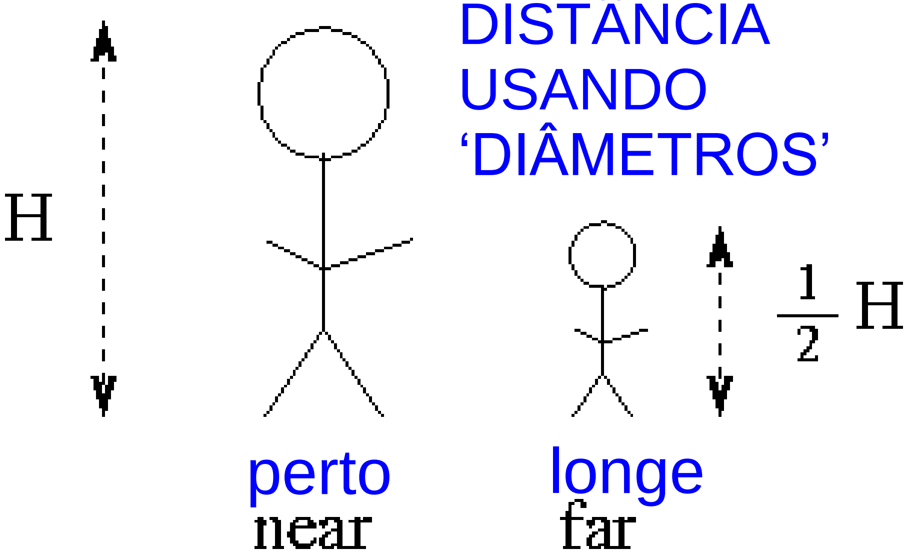


A Spectroscopic Binary System
High-mass star A and lower-mass B orbit around a common centre of mass. The observed combined spectrum shows periodic splitting and shifting of spectral lines. The amount of shift is a function of the alignment of the system relative to us and the orbital speed of the stars.

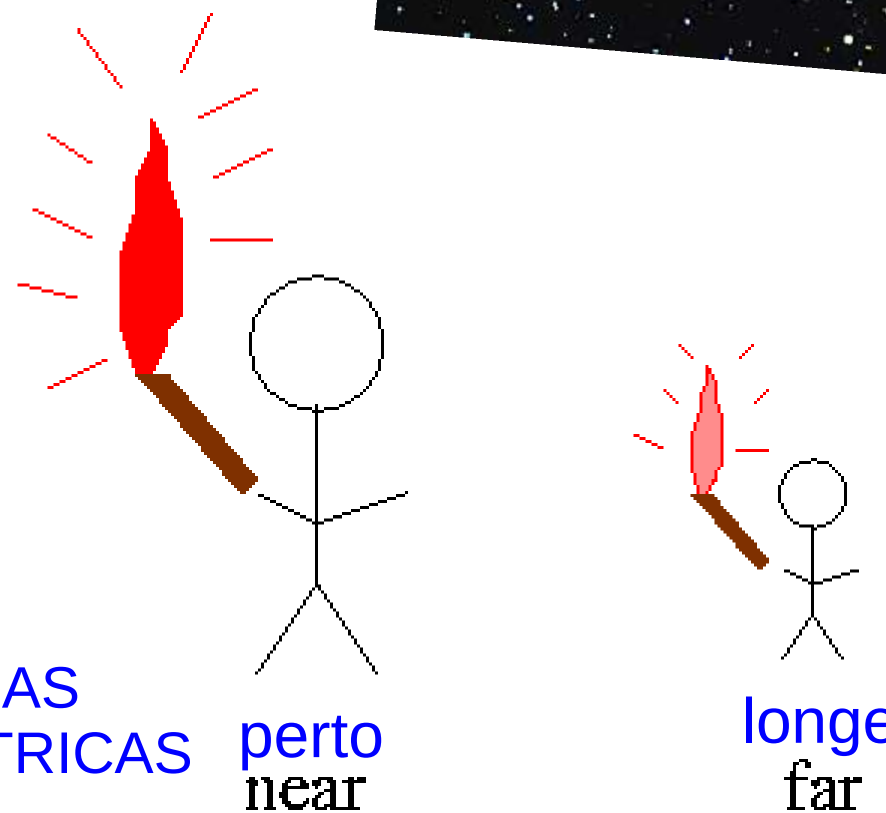
In 1930, Robert Trumpler estimated distances of about 100 open star clusters by measuring:

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

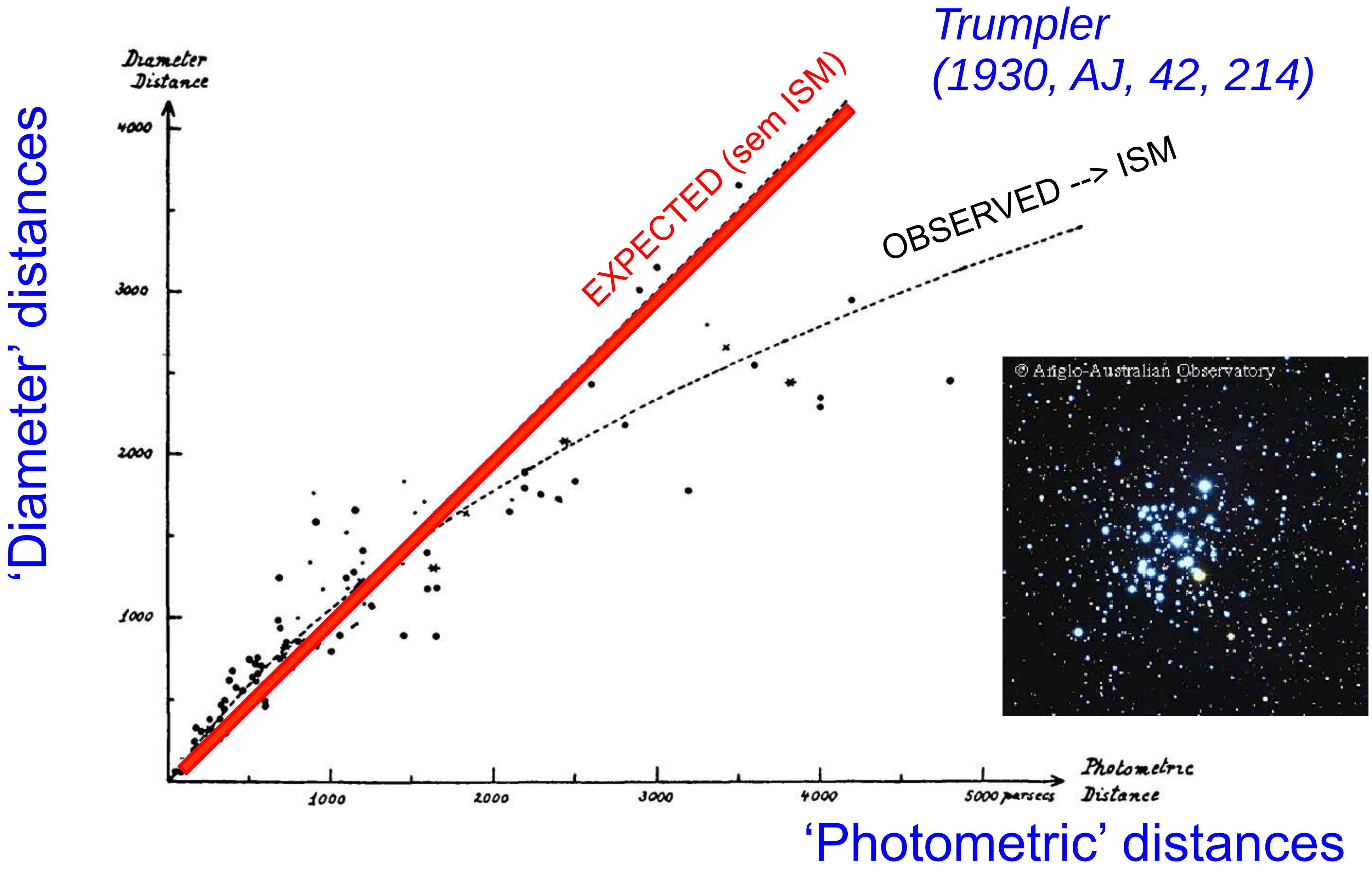
DISTÂNCIA USANDO 'DIÂMETROS'



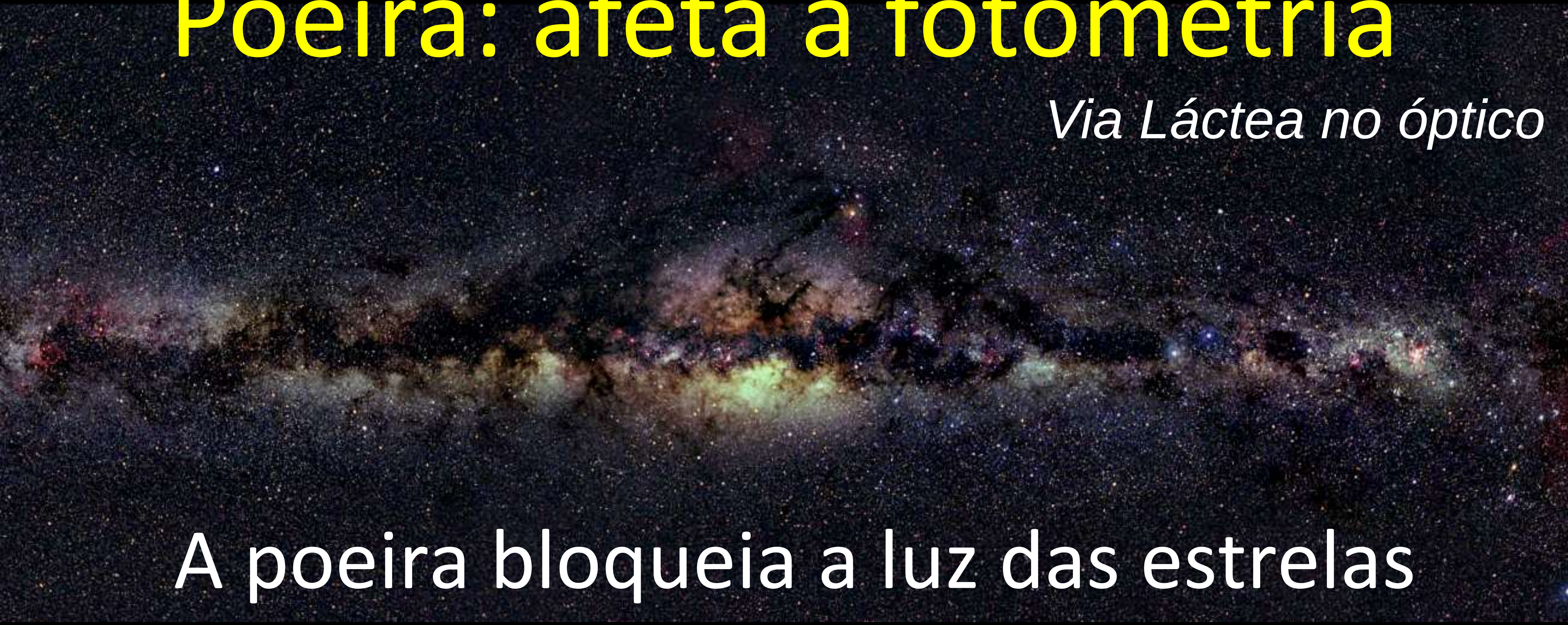
DISTÂNCIAS FOTOMETRICAS



Comparação entre distâncias baseadas em ‘diâmetros’ e em ‘fotometria’



Poeira: afeta a fotometria

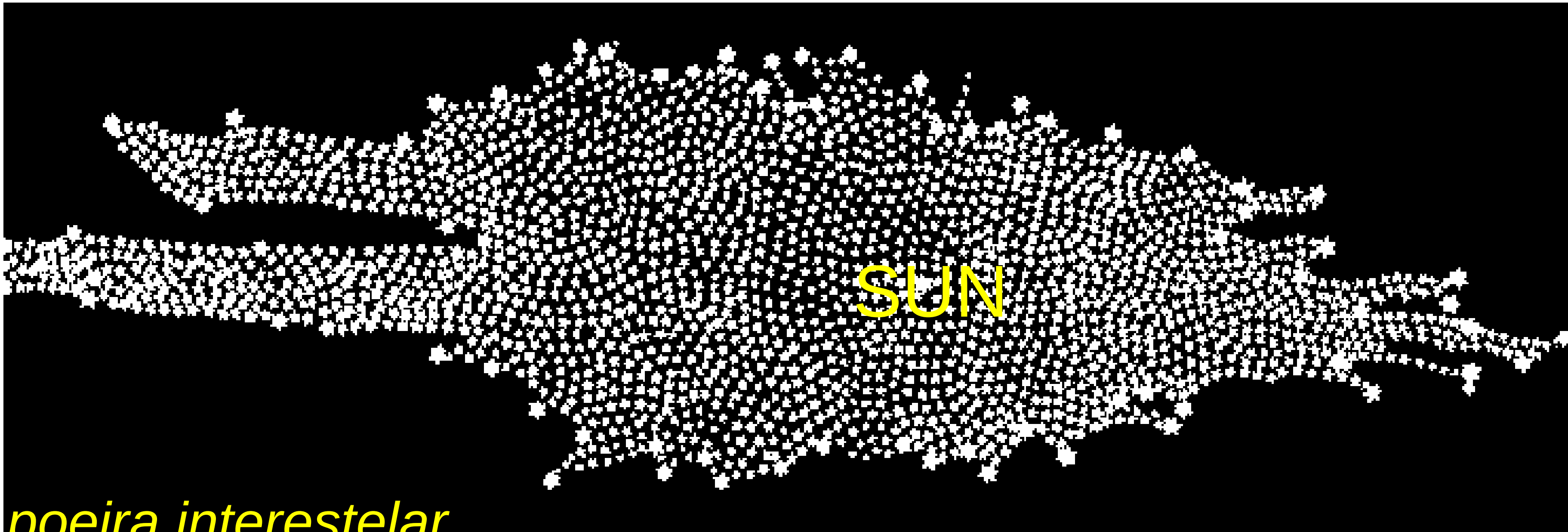


Via Láctea no óptico

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

Via Láctea no infravermelho

A Galáxia de acordo ao William Herschel (1780s)



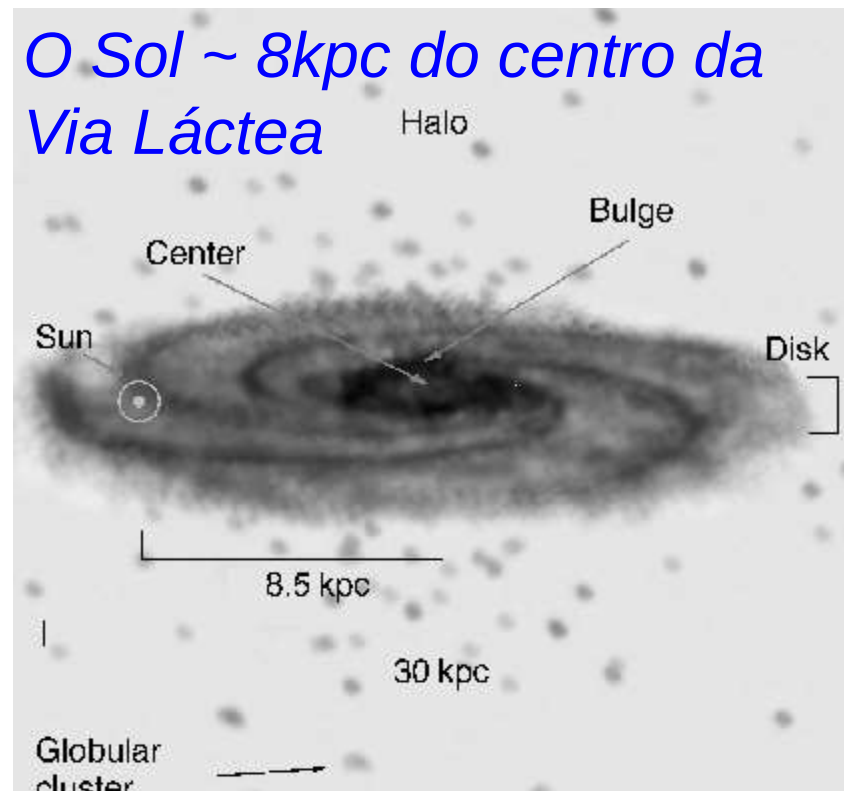
poeira interestelar

Poeira
ISM

NGC 891

S

O Sol ~ 8kpc do centro da Via Láctea



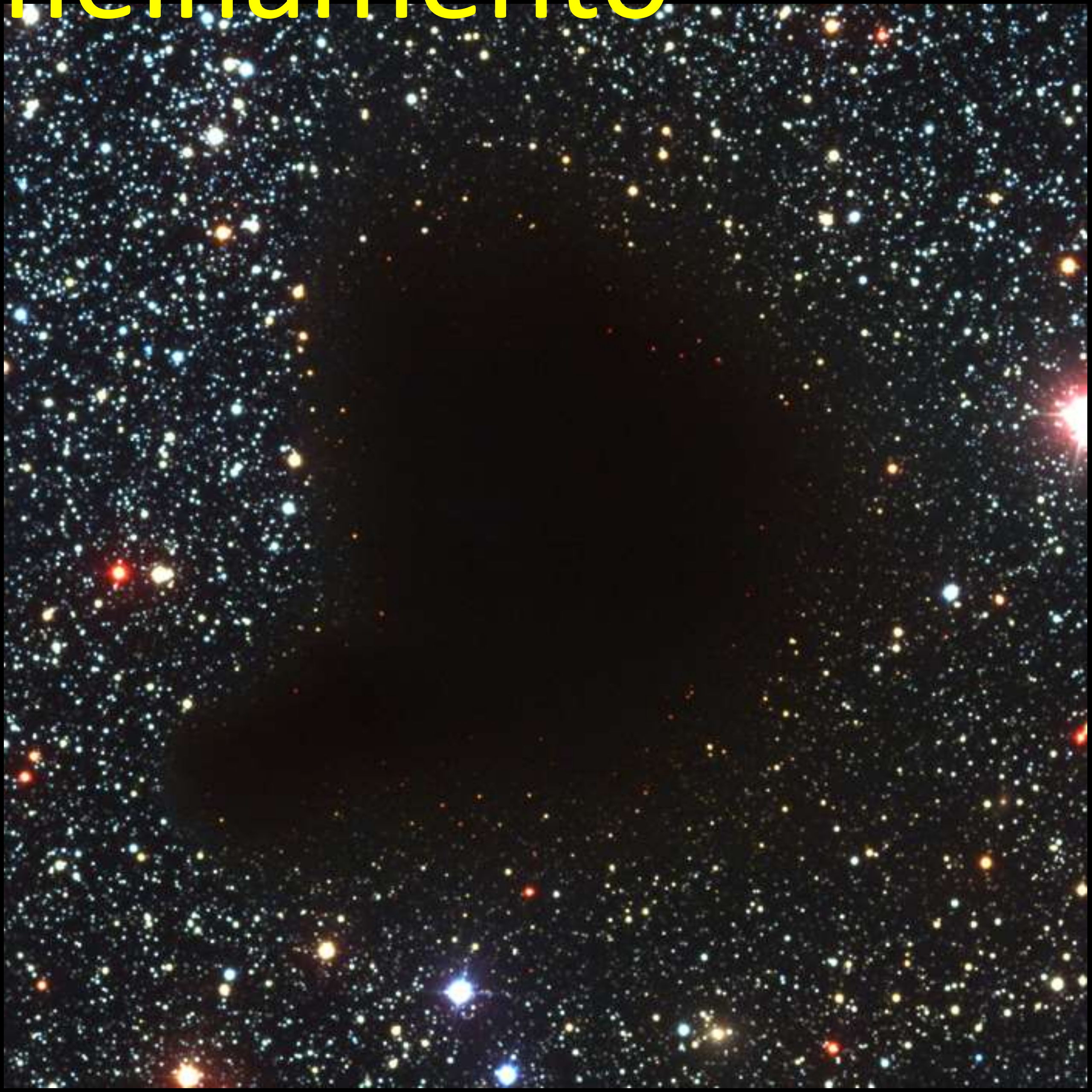
Efeitos da poeira: extinção

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

B68 (the black cloud) ESO

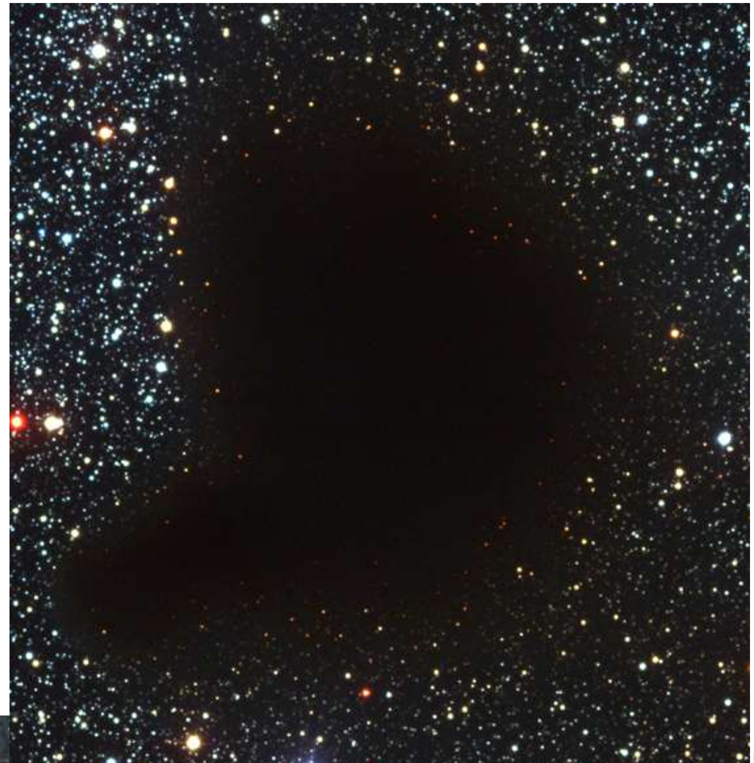
Efeitos da poeira: avermelhamento

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

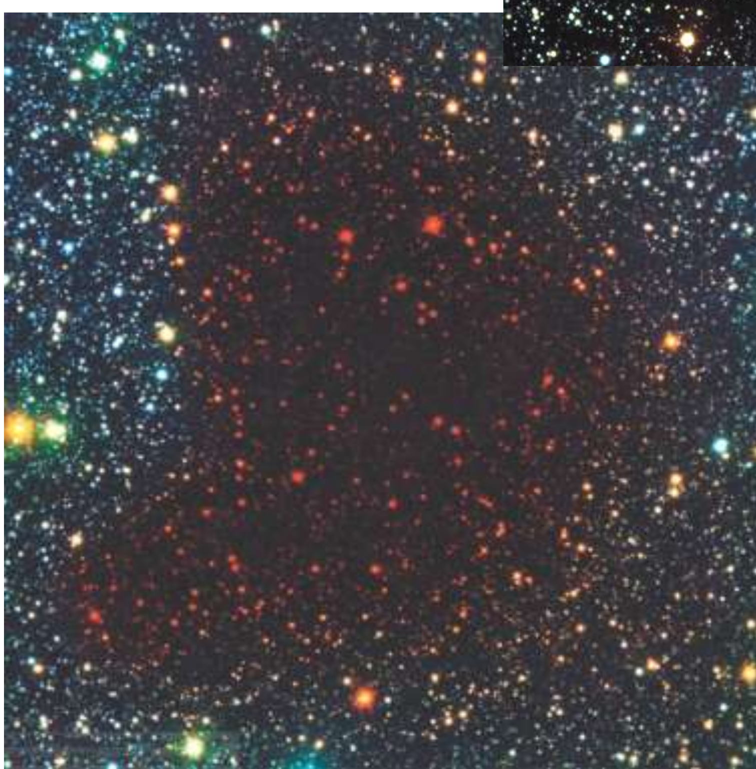


Avermelhamento interestelar

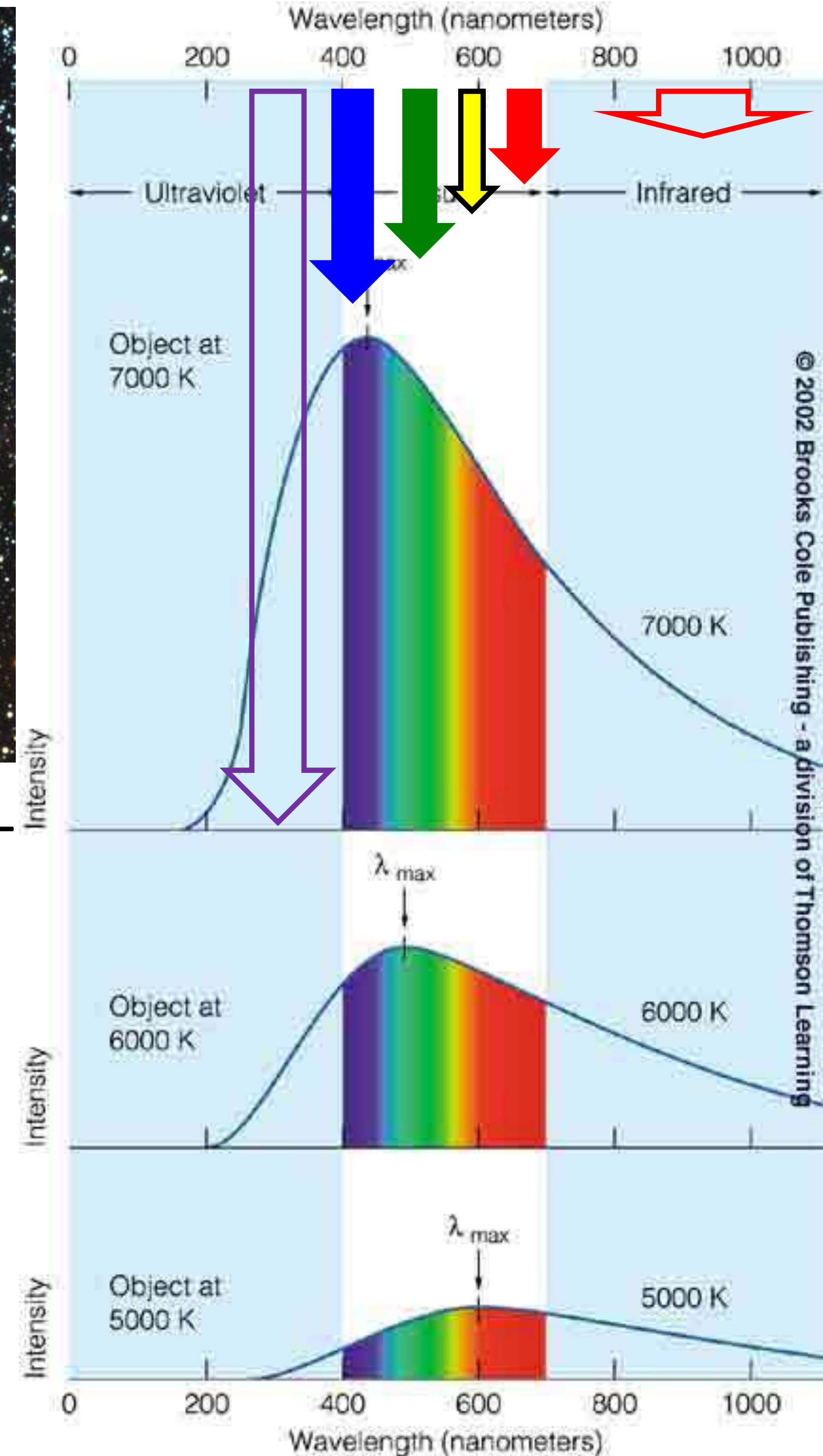
Optical light is strongly scattered and absorbed by interstellar clouds



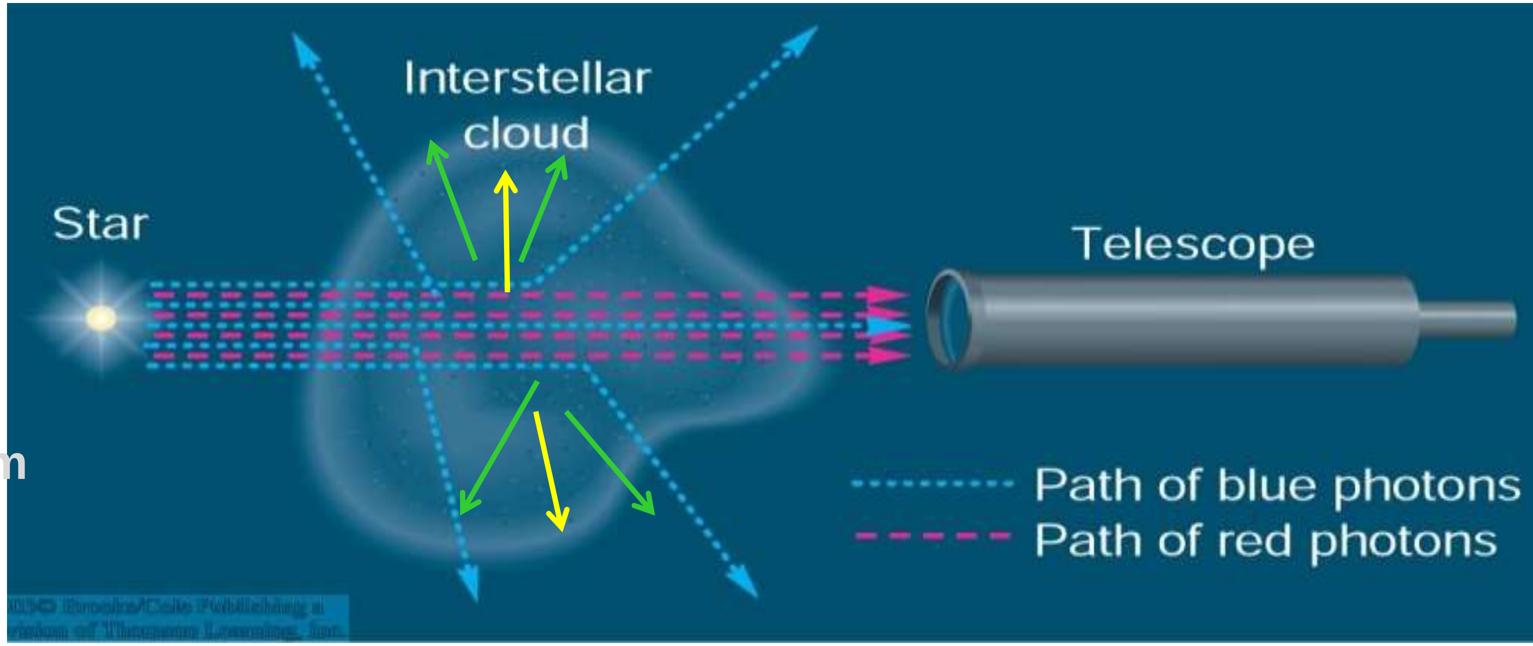
OPTICAL

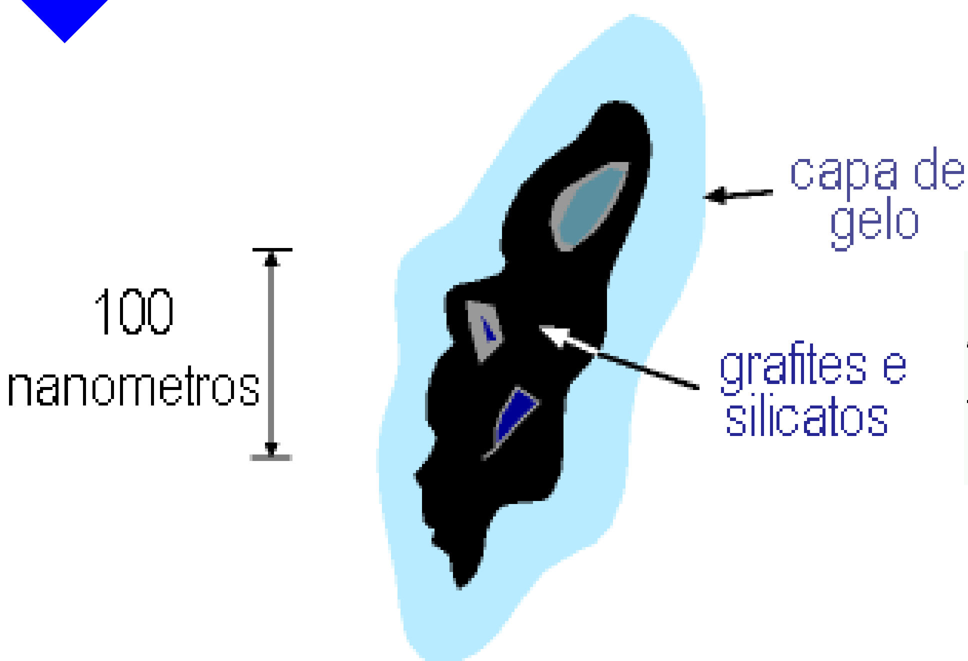


INFRARED



Extinção e avermelhamento por poeira





Grão de poeira

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

Nebulosa de reflexão

A poeira espalha mais a luz azul

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

Pleiades

Densidade da poeira IS

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

A componente mais abundante do meio interestelar é o gás

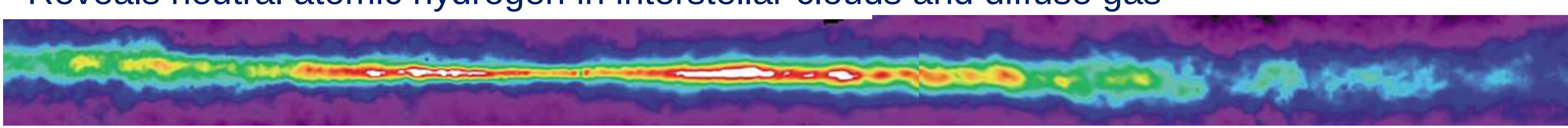
Em média a densidade do meio interestelar é extremamente baixa: 1 átomo / m^3 (10^6 átomos / m^3)

Regiões variam de 10^4 a 10^9 átomos/m3

Melhor vácuo conseguido em lab : 10^{10} moléculas/m^3

VISIBLE LIGHT (0.4–0.6 micron)
Reveals nearby stars and tenuous ionized gas; dark areas are cold and dense

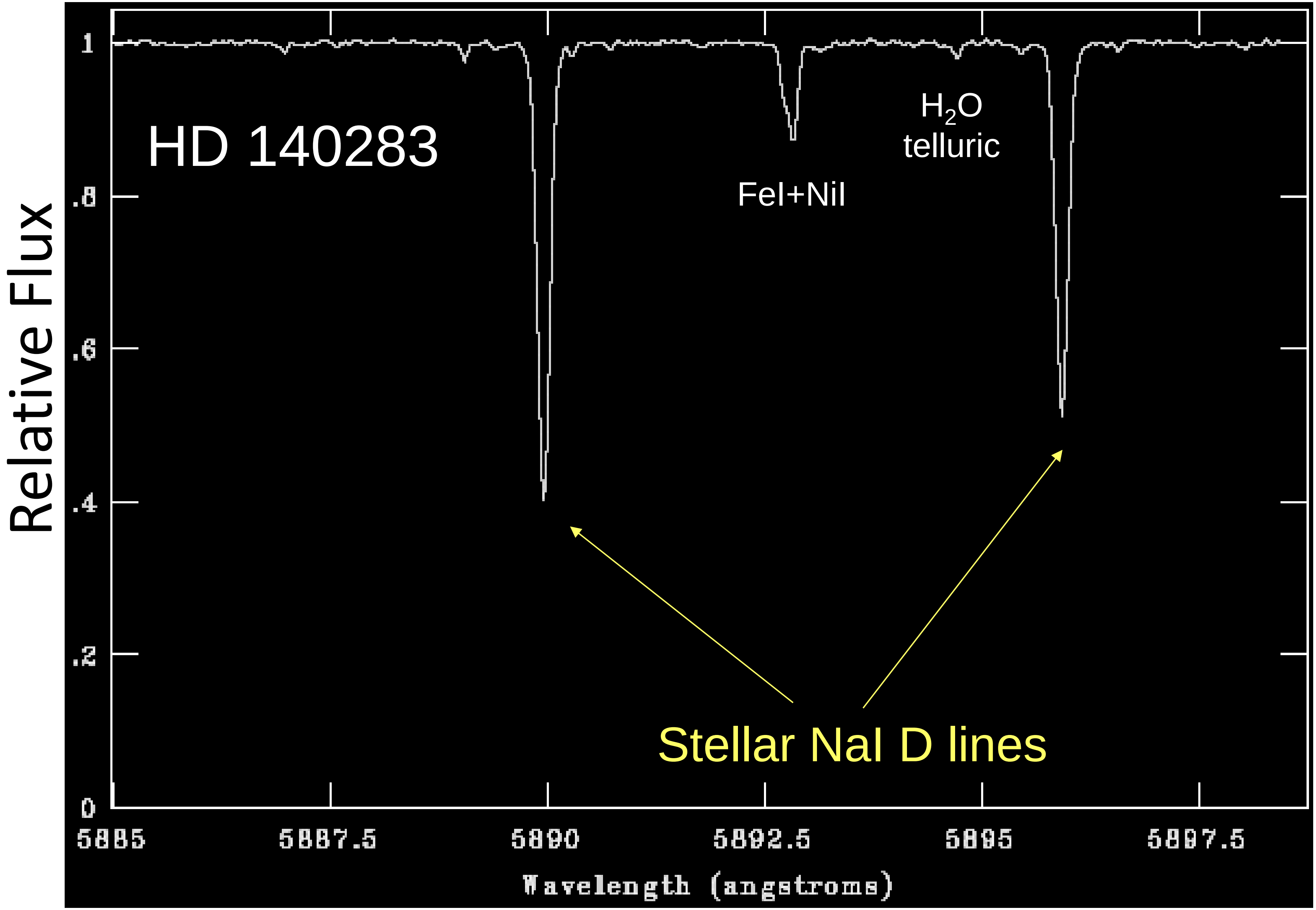
ATOMIC HYDROGEN (1420 MHz)
Reveals neutral atomic hydrogen in interstellar clouds and diffuse gas



Gás neutro tb é possível de ser detetado no espectro visível

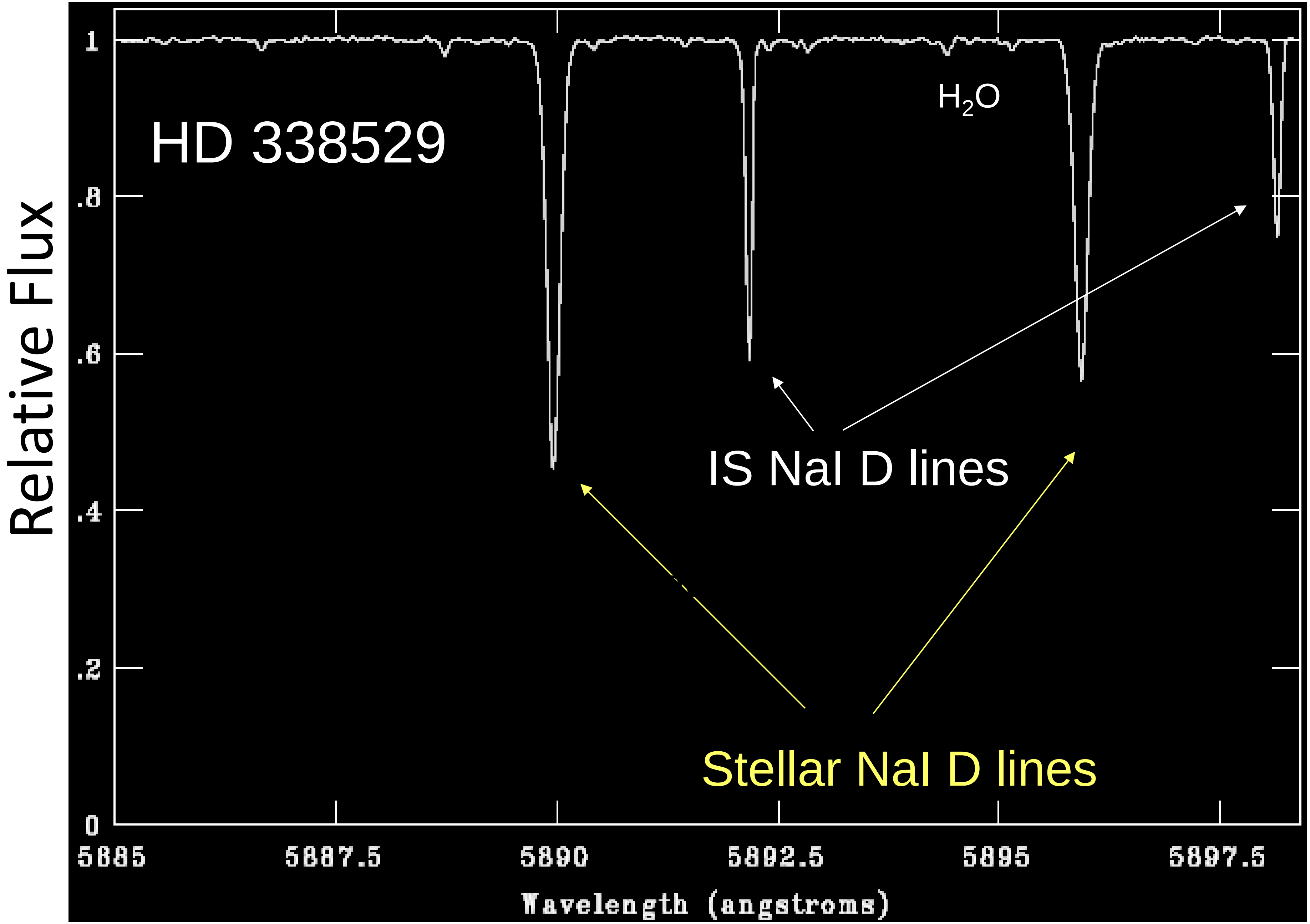
Estrela sem linhas de absorção do MIS

E(B-V) = 0.000 +/- 0.001 mag



Estrela com linhas de absorção do MIS

E(B-V) = 0.008 +/- 0.001 mag



A&A 510, A54 (2010)
DOI: 10.1051/0004-6361/200913202

Astronomy & Astrophysics

B. Y. Welsh[1], R. Lallement[2], J.-L. Vergely[3], and S. Raimond[2]

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.

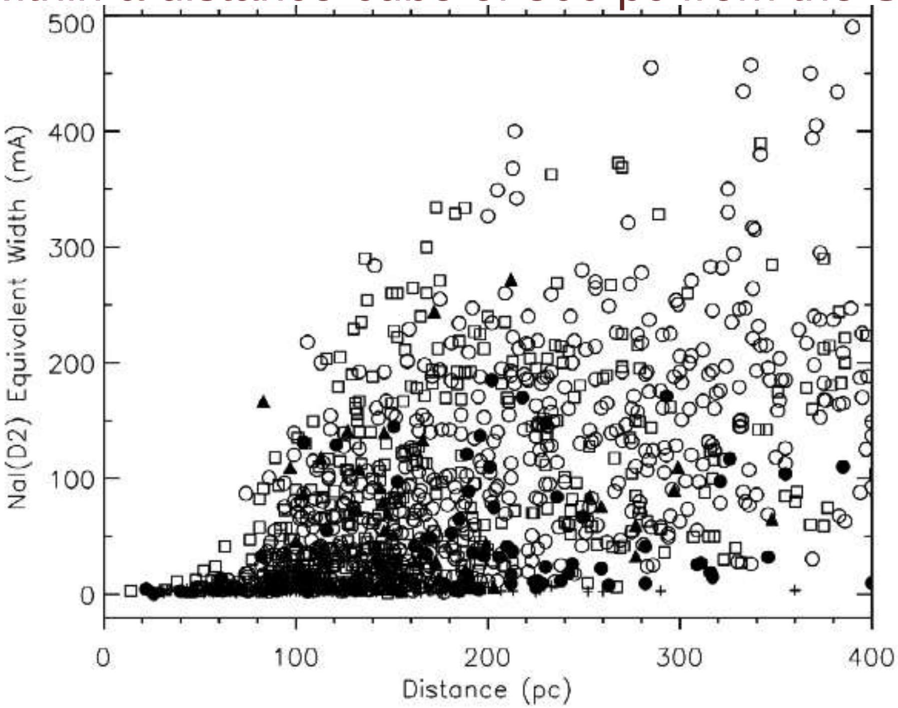


Fig. 7. Plot of the equivalent width (mÅ) of the interstellar NaI D2-line for stars with distances <400 pc. Filled triangles are for sight-lines with galactic latitude $b > +45°$, open squares for sight-lines with $b = 0$ to 45°, open circles for sight-lines with $b = 0$ to $-45°$ and filled circles for sight-lines with $b < -45°$. 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.

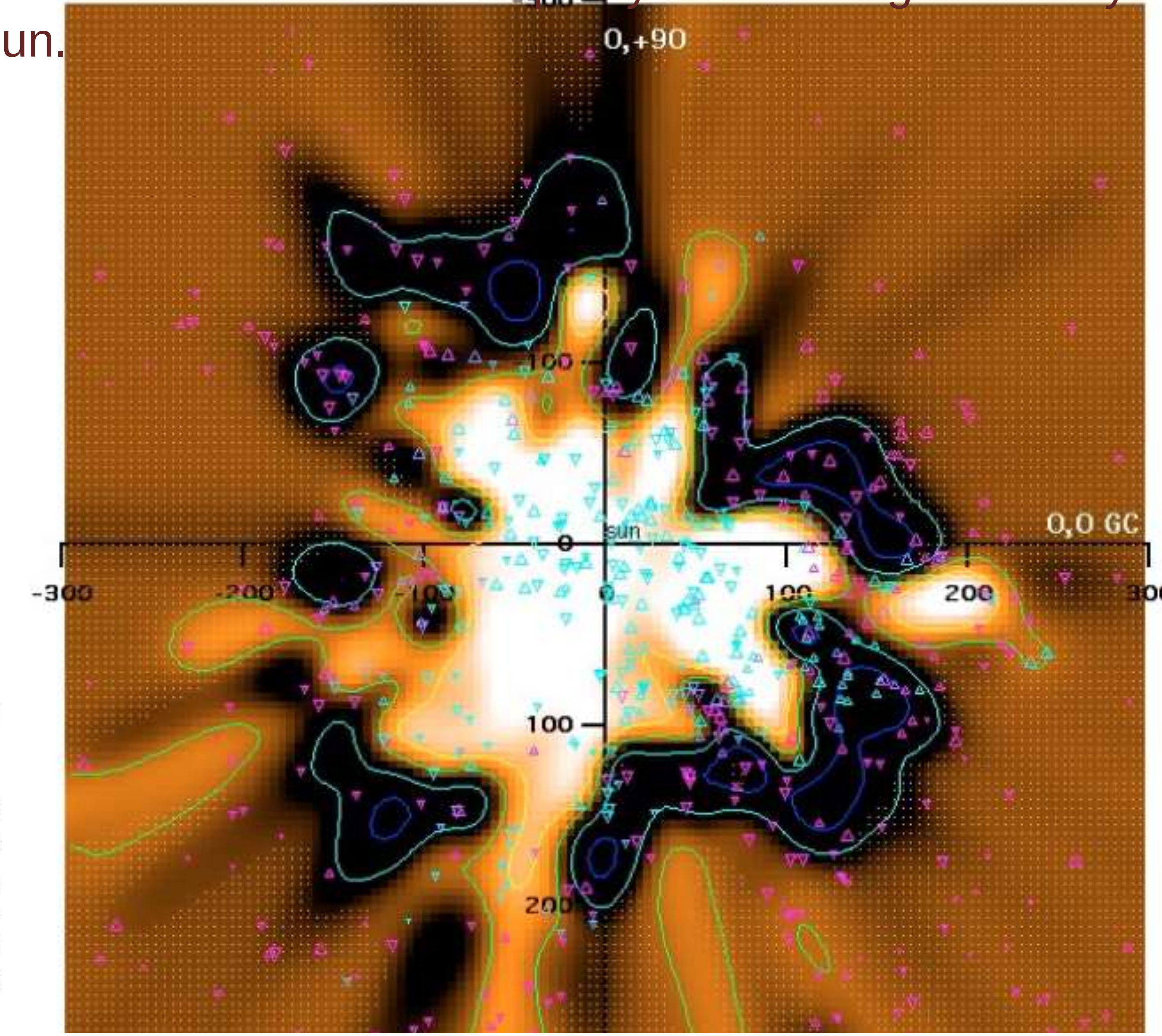
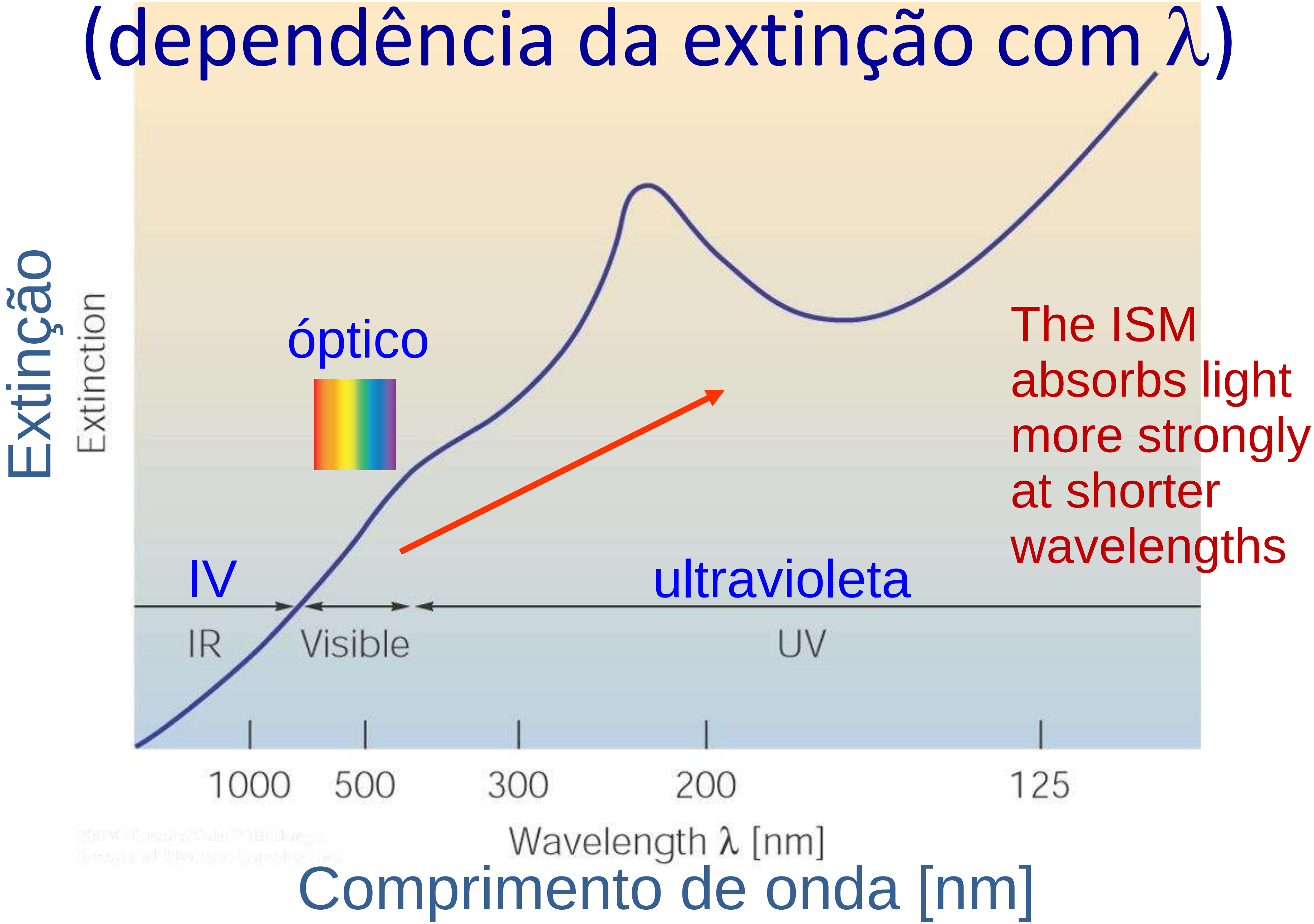


Fig. 12. Plot of 3D spatial distribution of interstellar NaI absorption within 300 pc of the Sun as viewed in the galactic plane projection. Triangles represent the sight-line positions of stars used to produce the map, with the size of the triangle being proportional to the derived NaI column density. 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 $n_{NaI} = -9.5, -9.1, -8.5$ and -7.8 cm^{-3} are also shown. Regions with a matrix of dots represent areas of uncertain neutral gas density measurement.

Curva de extinção interestelar

(dependência da extinção com λ)



Curva de Extinción Interestelar

Savage & Mathis 1979, ARA&A 17, 73

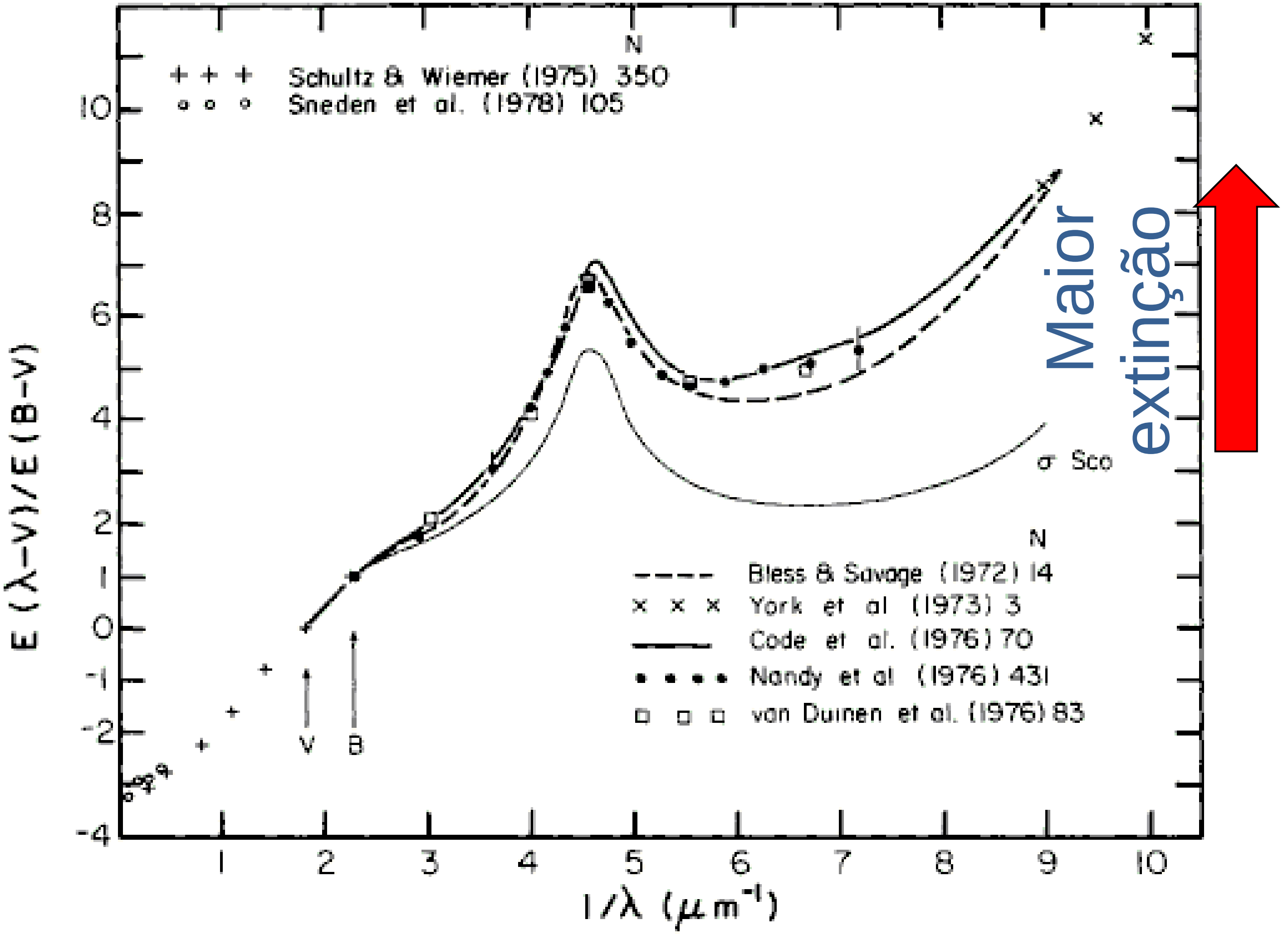
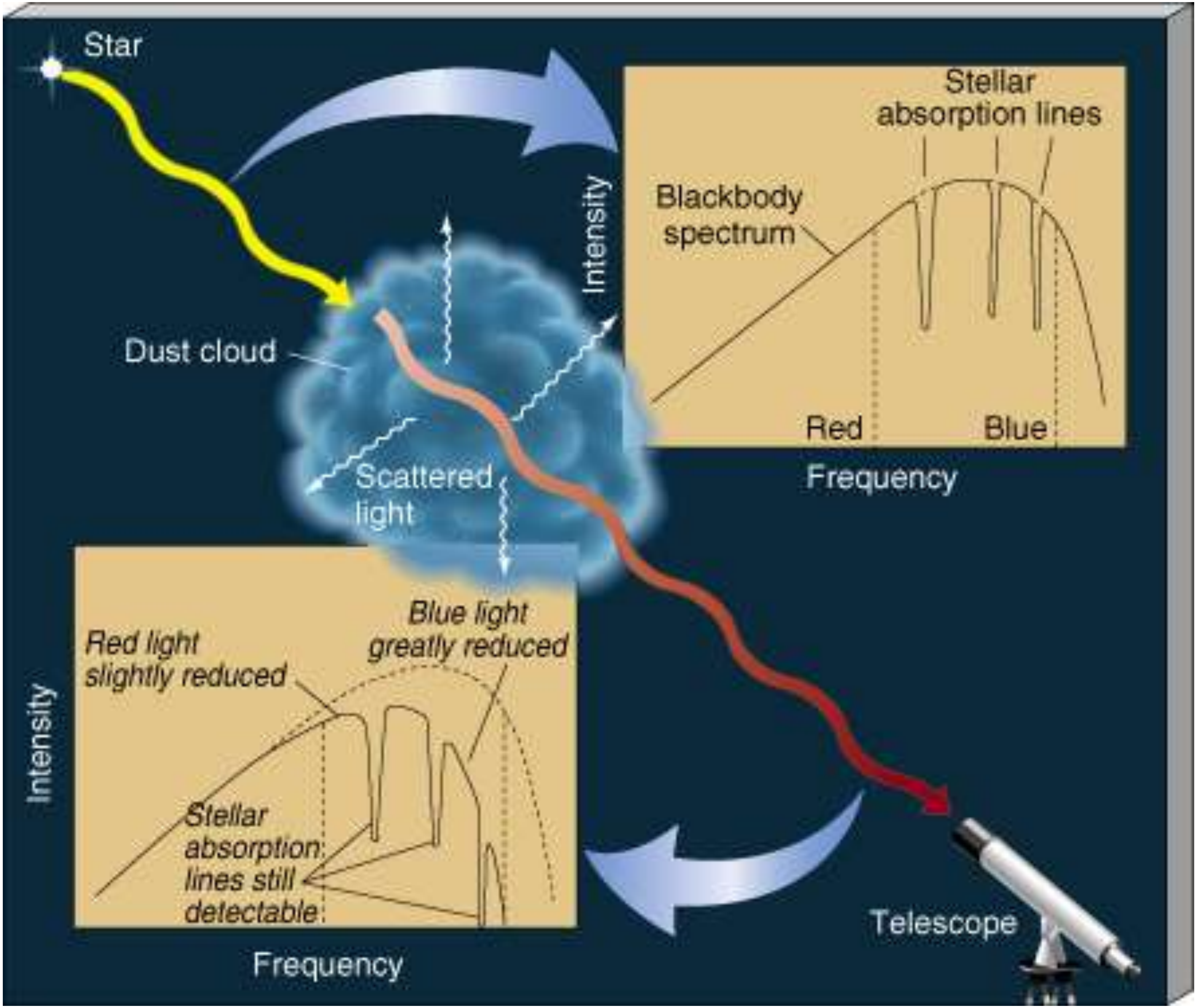


Figure 1 Average normalized interstellar extinction is plotted versus $1/\lambda$ in μm^{-1}. $E(\lambda - V)$ refers to the extinction in magnitudes between a wavelength λ and the photoelectric V band. The references for the various curves are provided along with an indication of how many stars were used to derive each average curve. One abnormal ultraviolet curve for σ Sco from Bless & Savage (1972) is also shown. The average curves plotted can be converted to total normalized extinction, $A_\lambda/E(B-V)$, by adding $R = 3.1$ to the quantity plotted. Note that the normalization to $E(B-V) = 1$ implies a corresponding hydrogen column density of $N(HI + H_2) = 5.8 \times 10^{21}$ atoms cm^{-2} (see Section 2). The error bars on two of the TD-1 points (Nandy et al. 1976) give an indication of the maximum observed variation in the *average* extinction curves derived for different galactic regions.

Efeitos da extinção pela poeira interestelar



Extinção Interestelar A_X

$$A_X \equiv m_X - m_{X0} \Rightarrow m_{X0} = m_X - A_X$$

- A_X: extinção
- m_X: magnitude observada
- m_{X0}: magnitude intrínseca (o que seria observado em ausência de poeira IS)

Exemplo: $A_V = V - V_0 \Rightarrow V_0 = V - A_V$

Exemplo

$$A_X \equiv m_X - m_{X0} \Rightarrow m_{X0} = m_X - A_X$$

- $A_V = 1{,}5$ mag
- $V = 11{,}6$ mag
- $V_0 = V - A_V = 10{,}1$ (magnitude intrínseca, ou seja, a que seria observada em ausência de poeira IS)

Excesso de cor E(X-Y)

$E(X\text{-}Y) \equiv (m_X - m_Y) - (m_{X0} - m_{Y0})$

- $E(X\text{-}Y)$: excesso de cor
- $m_X - m_Y$: cor observada
- $m_{X0} - m_{X0}$: cor intrínseca

Exemplo: $E(B\text{-}V) = (B\text{-}V) - (B_0\text{-}V_0)$

$\Rightarrow$ $(B\text{-}V)_0 = (B\text{-}V) - E(B\text{-}V)$

Excesso de cor E(X-Y)

$$E(X\text{-}Y) \equiv (m_X - m_Y) - (m_{X0} - m_{Y0})$$

$$E(X\text{-}Y) \equiv (m_X - m_{X0}) - (m_Y - m_{Y0})$$

$$E(X\text{-}Y) \equiv A_X - A_Y$$

Exemplo: $E(B\text{-}V) = A_B - A_V$

Exemplo

A_B = 1,05 mag, A_V = 0,90 mag

V = 10,1 e B = 10,9, qual o valor de $(B\text{-}V)_0$?

E(B-V) = 1,05 – 0,90 = 0,15

B-V = 10,9 – 10,1 = 0,80

$(B\text{-}V)_0$ = (B-V) - E(B-V) = 0,80 – 0,15

$(B\text{-}V)_0$ = 0,65

Exemplo

$E(B-V) = 0{,}15$

$B-V = 0{,}80$ e $V-R = 0{,}5$, qual o valor de $(V-R)_0$?

$(V-R)_0 = (V-R) - E(V-R) = \ldots$

Table 2 An average interstellar extinction curve

Savage & Mathis 1979, ARA&A 17, 73

	$\lambda(\mu m)$	$\lambda^{-1}(\mu m^{-1})$	$E(\lambda-V)/E(B-V)$	$A_\lambda/E(B-V)$
	∞	0	−3.10	0.00
L	3.4	0.29	−2.94	0.16
K	2.2	0.45	−2.72	0.38
J	1.25	0.80	−2.23	0.87
I	0.90	1.11	−1.60	1.50
R	0.70	1.43	−0.78	2.32
V	0.55	1.82	0	3.10
B	0.44	2.27	1.00	4.10
	0.40	2.50	1.30	4.40
	0.344	2.91	1.80	4.90
	0.274	3.65	3.10	6.20
	0.250	4.00	4.19	7.29
	0.240	4.17	4.90	8.00
	0.230	4.35	5.77	8.87

Careful: this is for R, I in the Johnson (J) system. Now most people use R, I in the Cousin (C) system.

- $E(V-R)^J = 0.78\,E(B-V)$ $\quad$ *$E(V-R)^C = 0.60\,E(B-V)$*
- $E(V-I)^J = 1.60\,E(B-V)$ $\quad$ *$E(V-I)^C = 1.25\,E(B-V)$*
- $E(V-K)^J = 2.72\,E(B-V)$
- $E(J-K)^J = 0.22\,E(B-V)$
- $E(b-y) = 0.73\,E(B-V)$
- $E(m_1) = -0.33E(b-y) = -0.24\,E(B-V)$
- $E(c_1) = 0.17\,E(b-y) = 0.12\,E(B-V)$

Valores de A_V, E(B-V)

$$R = \frac{A_V}{E(B-V)} \approx 3{,}1$$

- d < 80-100 pc (0.1 kpc) $\Rightarrow$ E(B-V) ~ 0
- E(B-V) $\approx$ 0.53 d (kpc)
- $A_V \approx$ 1,6 d (kpc) magnitudes

Bond (1980, ApJS 44,517):

- *b* dentro de 30° polo norte Gal.: E(B-V) = 0.00
- *b* dentro de 30° polo sur Gal.: E(B-V) = 0.03
- $|b| < 60°$ do plano:

$$E(B-V) = 0.03 \csc b [1 - \exp(-0.008\, d(\mathrm{pc}) \sin|b|)]$$

EXTINCT

Hakkila et al. 1997, AJ 114, 2043

A_v : *EXTINCT.FOR*

l,b,d(kpc)

ftp.mankato.msus.edu/pub/astro

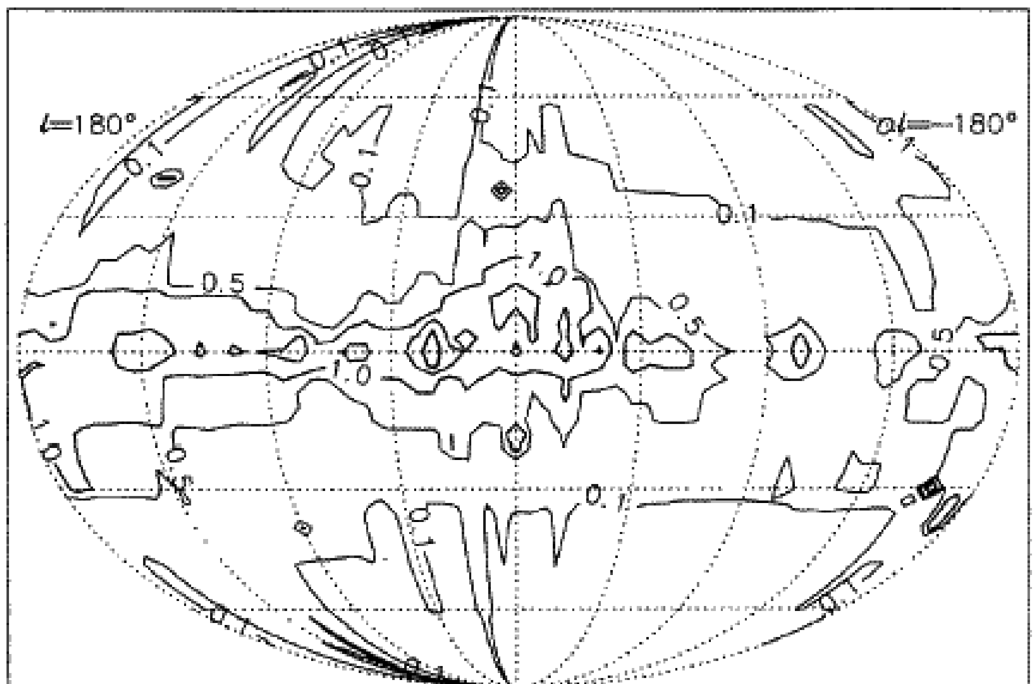


FIG. 11. Total visual extinction A_v (mag) in Galactic coordinates to a distance of 1 kpc as obtained from combining the results of all studies. When available, extinction from individual clouds identified in the high-latitude study is used. Otherwise, the results represent an average of available subroutines weighted equally. Contours in this plot are 0.1, 0.5, 1.0, 2.0, and 3.0 mag.

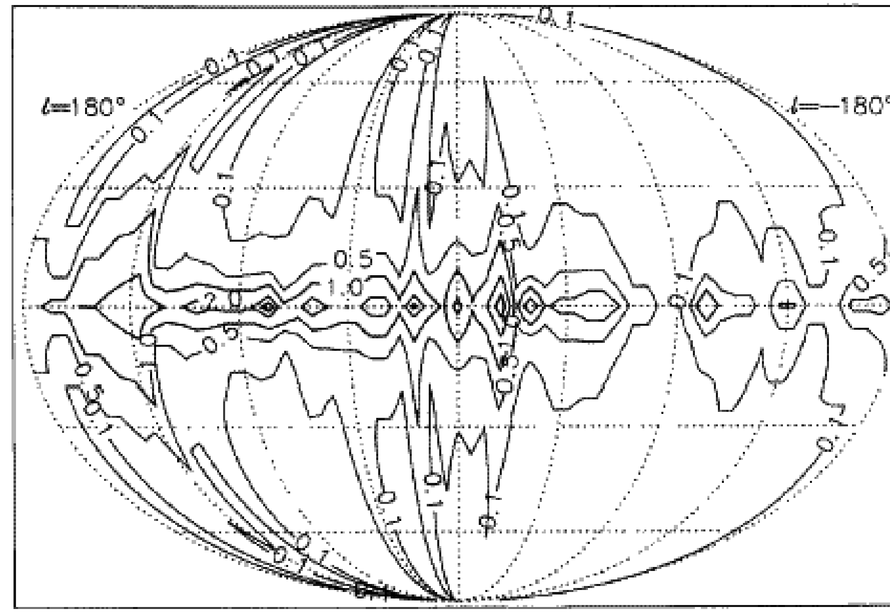


FIG. 2. Total visual extinction A_v (magnitudes) in Galactic coordinates to a distance of 1 kpc as obtained from the FitzGerald (1968) study. Plot contours are 0.1, 0.5, 1.0, 2.0, and 3.0 mag.

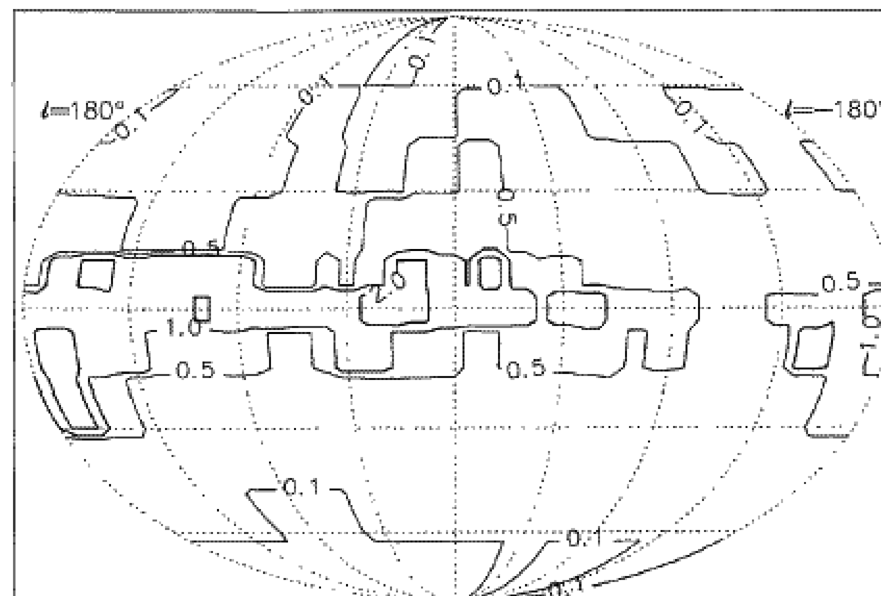


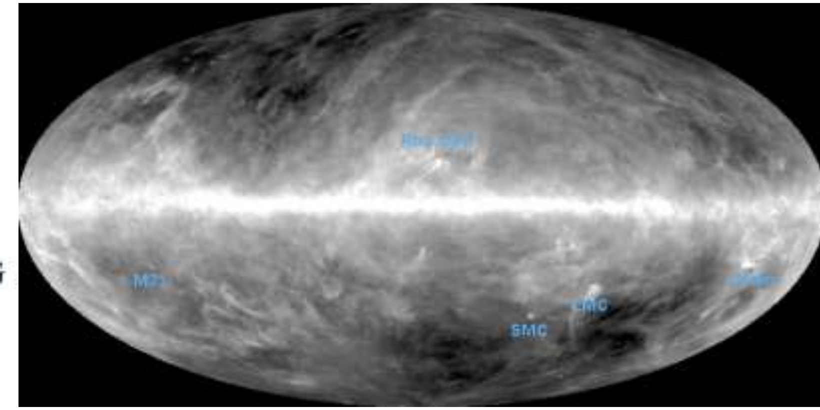
FIG. 7. Total visual extinction A_v (magnitudes) in Galactic coordinates to a distance of 1 kpc as obtained from the Arenou *et al.* (1992) study. Plot contours are 0.1, 0.5, 1.0, 2.0, and 3.0 mag.

Schlegel et al. maps

THE ASTROPHYSICAL JOURNAL, 500:525–553, 1998 June 20

MAPS OF DUST INFRARED EMISSION FOR USE IN ESTIMATION OF REDDENING COSMIC MICROWAVE BACKGROUND RADIATION FOREGROUNDS

DAVID J. SCHLEGEL
University of Durham, Department of Physics, South Road, Durham DH1 3LE, UK; D.J.Schlegel@durham.ac.uk
AND
DOUGLAS P. FINKBEINER AND MARC DAVIS



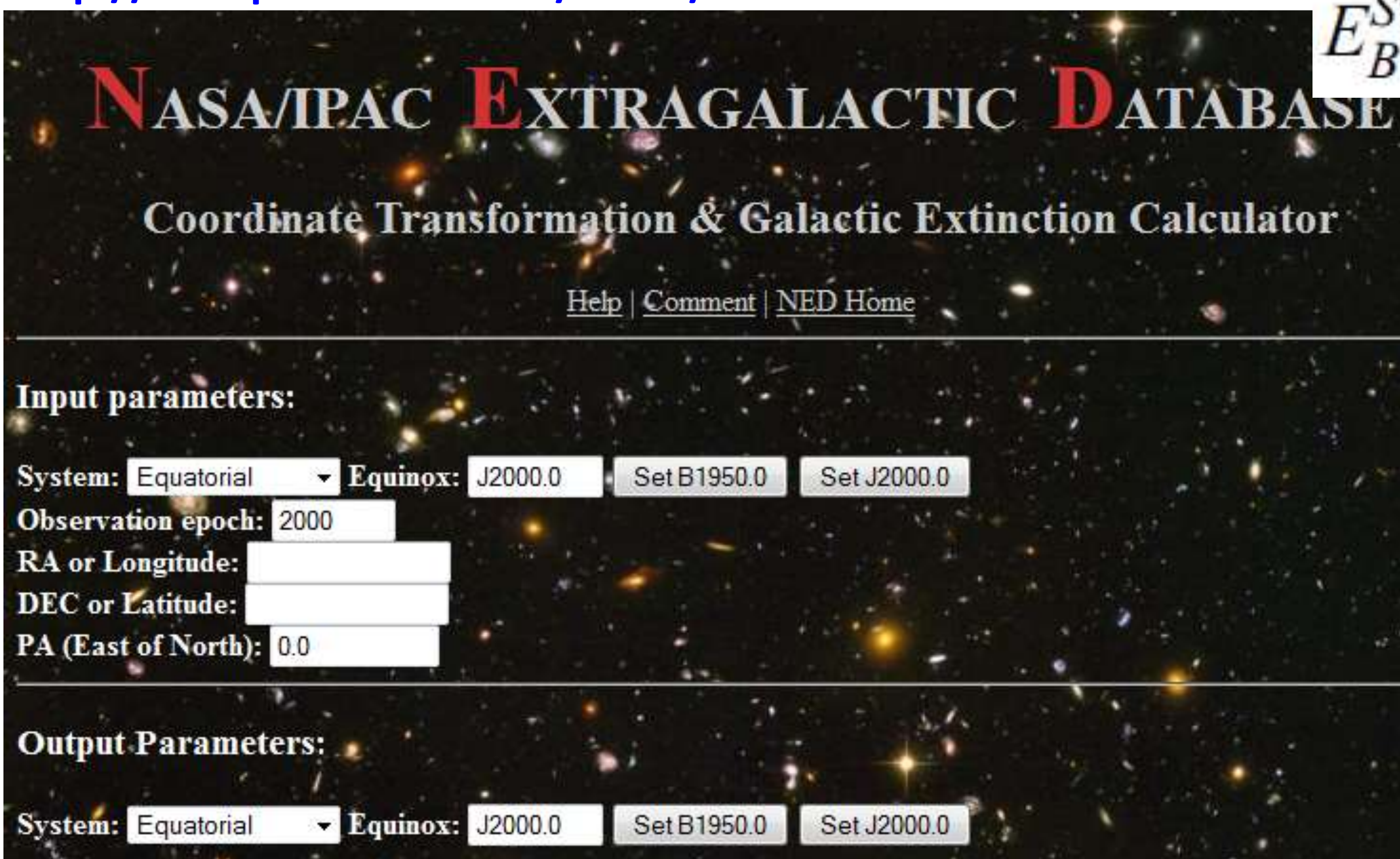
http://astro.berkeley.edu/~marc/dust/

Melendez et al. 2006, ApJ, 642, 1082

We adopted the following correction for the S98 maps:

$$E_{B-V}^{S98c} = 0.9E_{B-V}^{S98} - 0.01$$

http://ned.ipac.caltech.edu/forms/calculator.html



Schlegel et al. maps

THE ASTROPHYSICAL JOURNAL, 500:525–553, 1998 June 20

MAPS OF DUST INFRARED EMISSION FOR USE IN ESTIMATION OF REDDENING AND COSMIC MICROWAVE BACKGROUND RADIATION FOREGROUNDS

DAVID J. SCHLEGEL
University of Durham, Department of Physics, South Road, Durham DH1 3LE, UK; D.J.Schlegel@durham.ac.uk
AND
DOUGLAS P. FINKBEINER AND MARC DAVIS

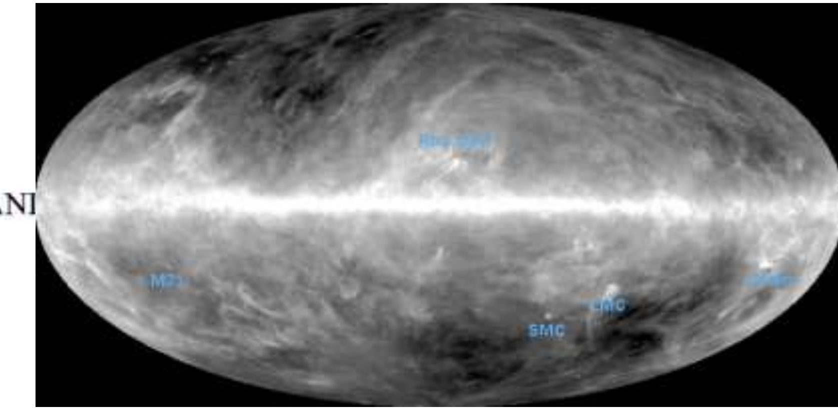


TABLE 6

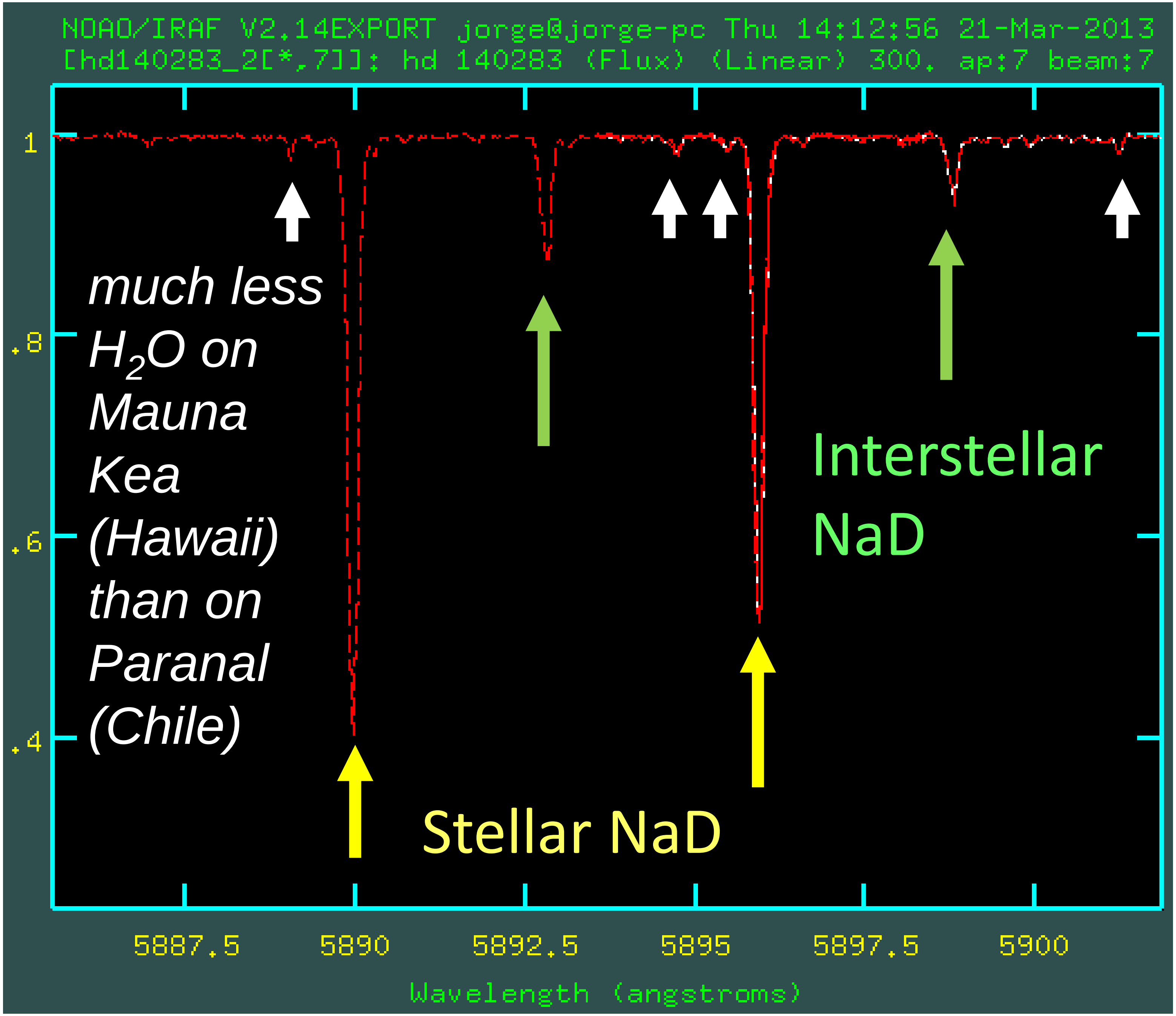
RELATIVE EXTINCTION FOR SELECTED BANDPASSES

R, I are both in the Cousin system

Filter	λ_{eff} (Å)	$A/A(V)$	$A/E(B-V)$	Filter	λ_{eff} Å	$A/A(V)$	$A/E(B-V)$
Landolt U	3372	1.664	5.434	Strömgren u	3502	1.602	5.231
Landolt B	4404	1.321	4.315	Strömgren b	4676	1.240	4.049
Landolt V	5428	1.015	3.315	Stromgren v	4127	1.394	4.552
Landolt R	6509	0.819	2.673	Strömgren β	4861	1.182	3.858
Landolt I	8090	0.594	1.940	Strömgren y	5479	1.004	3.277
CTIO U	3683	1.521	4.968	Sloan u'	3546	1.579	5.155
CTIO B.........	4393	1.324	4.325	Sloan g'	4925	1.161	3.793
CTIO V	5519	0.992	3.240	Sloan r'	6335	0.843	2.751
CTIO R.........	6602	0.807	2.634	Sloan i'	7799	0.639	2.086
CTIO I	8046	0.601	1.962	Sloan z'	9294	0.453	1.479
UKIRT J	12660	0.276	0.902	WFPC2 F300W......	3047	1.791	5.849
UKIRT H	16732	0.176	0.576	WFPC2 F450W......	4711	1.229	4.015
UKIRT K	22152	0.112	0.367	WFPC2 F555W......	5498	0.996	3.252
UKIRT L'	38079	0.047	0.153	WFPC2 F606W......	6042	0.885	2.889
Gunn g	5244	1.065	3.476	WFPC2 F702W......	7068	0.746	2.435
Gunn r..........	6707	0.793	2.590	WFPC2 F814W......	8066	0.597	1.948
Gunn i	7985	0.610	1.991	DSS-II g	4814	1.197	3.907
Gunn z..........	9055	0.472	1.540	DSS-II r	6571	0.811	2.649
Spinrad R_S......	6993	0.755	2.467	DSS-II i...............	8183	0.580	1.893
APM b_J.........	4690	1.236	4.035				

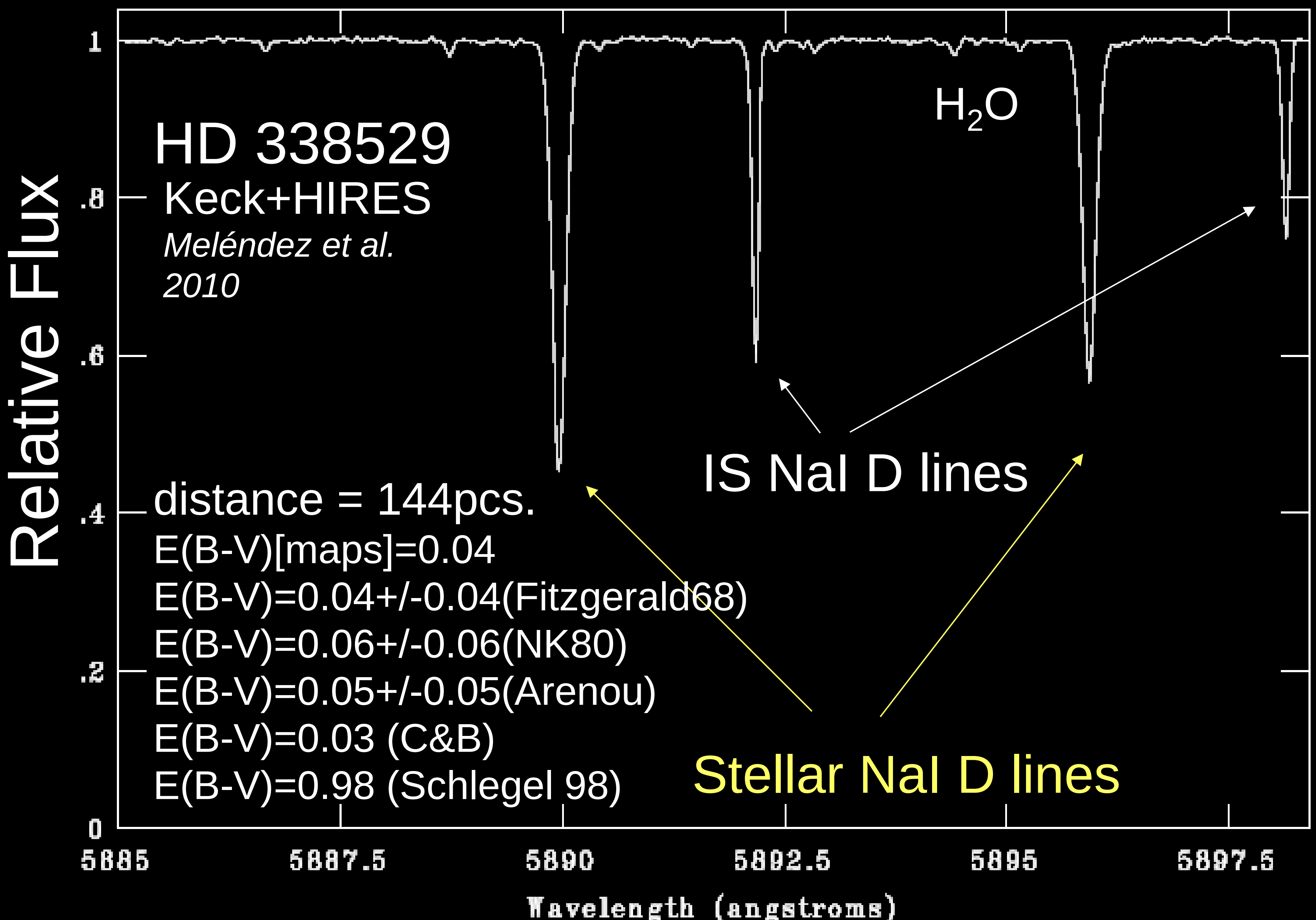
NOTE.—Magnitudes of extinction evaluated in different passbands using the $R_V = 3.1$ extinction laws of Cardelli et al. 1989 and O'Donnell 1994. The final column normalizes the extinction to photoelectric measurements of $E(B-V)$.

Keck (4.2km) spectrum of HD140283



E(B-V): using NaD lines

E(B-V) = 0.008 +/- 0.001 mag



Como calcular E(B-V)?

- Longe do plano da Galáxia (latitudes $b < -20^0$ e latitudes $b > +20^0$) o mais simples é utilizar os mapas do Schegel et al. (1998)

http://ned.ipac.caltech.edu/forms/calculator.html

- Para latitudes próximas ao plano, podem usar a receita apresentada no slide a seguir

How to deal with IS reddening : maps

The Astrophysical Journal, 642:1082–1097, 2006 May 10

Jorge Meléndez[1] Nataliya G. Shchukina and Irina E. Vasiljeva Iván Ramírez[1]

1. $E_{B-V}^{\rm maps} = 0.0$ for stars within 75 pc.
2. For stars with 75 pc $< d \leq 100$ pc, $E_{B-V}^{\rm maps} = (E_{B-V}^{H97} + (E_{B-V}^{B80} + E_{B-V}^{C98})/2 + 2 \times 0.0)/4$. The factor 2×0.0 considers a 50% chance of zero reddening.
3. If a star has $d > 100$ pc and $|b| > 45°$, $E_{B-V}^{\rm maps} = (nE_{B-V}^{H97} + mE_{B-V}^{S98c})/(n + m)$, where n is the square root of the number of maps used in H97 and $m = (d + 1.5)(\sin|b|)^{1.5}$, with d in kpc. This empirical parameterization gives a high weight to the S98 map for high-latitude and/or distant objects, and a weight essentially zero for low-latitude stars.
4. Stars with $d > 100$ pc and $|b| \leq 45°$, $E_{B-V}^{\rm maps} = (nE_{B-V}^{H97} + mE_{B-V}^{S98c} + (E_{B-V}^{B80} + E_{B-V}^{C98})/2)/(n + m + 1)$. The weights n and m are equal to the previous case, except that $m = 0$ if $E_{B-V}^{S98c} > 2E_{B-V}^{H97}$ (in some cases this restriction was relaxed, especially for very distant objects with $|b| > 30°$).
5. If after applying the above criteria $E_{B-V}^{\rm maps} > E_{B-V}^{S98c}$, then we adopted $E_{B-V}^{\rm maps} = E_{B-V}^{S98c}$.

How to deal with IS reddening : Na D

A&A 513, A35 (2010)

A. Alves-Brito[1,2], J. Meléndez[3], M. Asplund[4], I. Ramírez[4], and D. Yong[5]

tion lines were used. The $E(B-V)$ values based on the D lines were obtained as follows. In the optical thin case the relation between column density N (units cm^{-2}) and equivalent width EW (units mÅ) is

$$N = 1.13 \times 10^{17} EW/(f \lambda^2) \quad (1)$$

The N(Na I) density was transformed to N(H) with the relation found by Ferlet et al. (1985):

$$\log N(\mathrm{HI} + \mathrm{H}_2) = (\log N(\mathrm{NaI}) + 9.09)/1.04, \quad (2)$$

where both N(Na I) and N(H) are in cm^{-2}. Finally, $E(B-V)$ was computed from the total hydrogen density (Bohlin et al. 1978)

$$E(B-V) = N(\mathrm{HI} + \mathrm{H}_2)/5.8 \times 10^{21}, \quad (3)$$

where N(H) is in cm^{-2} and $E(B-V)$ in magnitudes. Although this relation seems not well established for $E(B-V) < 0.1$, Ramirez et al. (2006) have shown it to be very accurate for a $E(B-V) = 0.01$ star.

Exemplo

Valores observados: V = 9,831; B-V = 0,750; V-R =0,464

Se E(B-V) = 0,10, quais os valores corregidos da extinção interestelar para a magnitude V e as cores B-V e V-R? Usar a tabela de Schlegel (slide 42).

Adotando A_V / E(B-V) = 3,315 → A_V = 0,331

V_0 = V – A_V = **9,500**

$(B\text{-}V)_0$ = (B-V) – E(B-V) = **0,650**

A_V/E(B-V) = 3,315, A_R/E(B-V) = 2,673, ou seja $A_V - A_R$ = 0,642 E(B-V). Como E(V-R) = $A_V - A_R$ → E(V-R) = 0,642E(B-V) = 0,064

Nota: no slide 38 já tinhamos sugerido que E(V-R) ~ 0,6 E(B-V), mas agora verificamos usando a tabela do Schlegel que de fato esse é o caso.

$(V\text{-}R)_0$ = (V-R) – E(V-R) = **0,400**