Interstellar reddening and extinction

Milky Way above the VLT/ESO

AGA5802, Jorge Meléndez

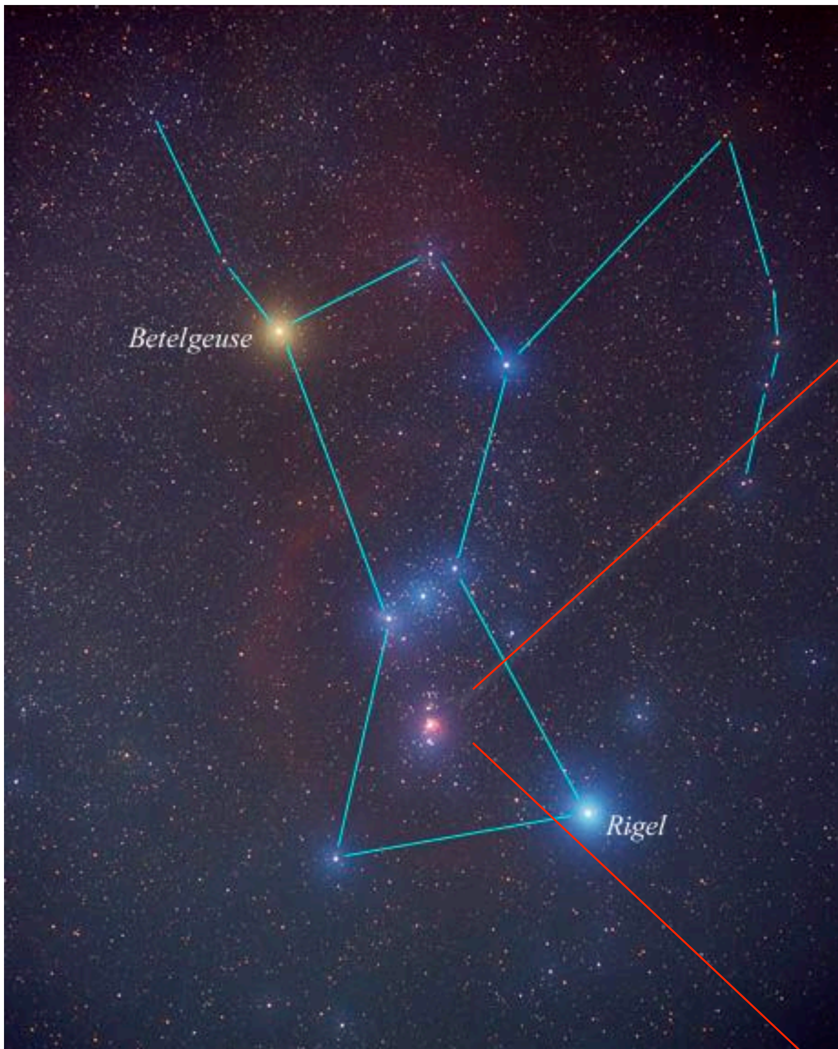
Discuss at the beginning of the class

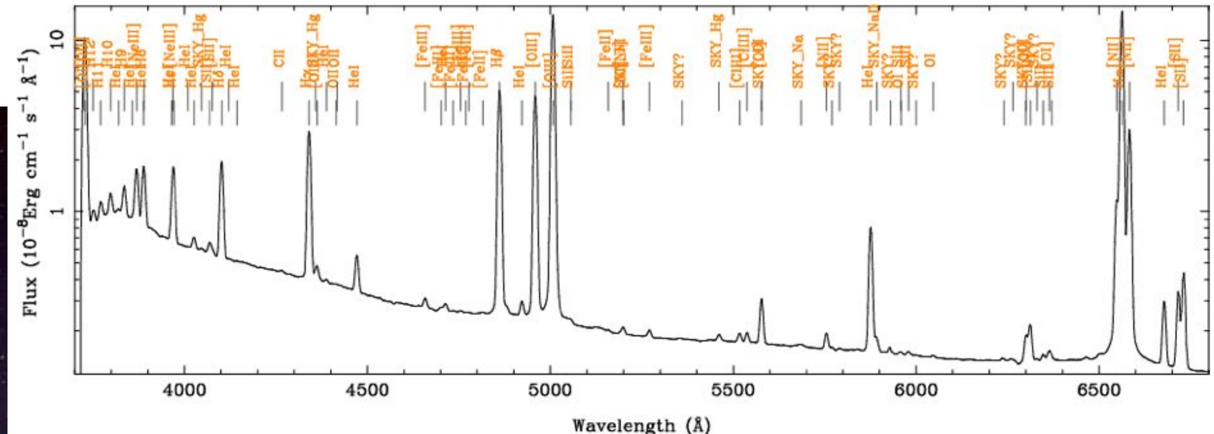
- Have you seen the Milky Way from a dark site?
- Draw Milky Way as seen from the "side"
- How do we see clusters at different distances
- Angular size? Brightness? How many stars?
- What do black regions in the Milky Way mean?
- How to verify that a interstellar spectral line is not actually a stellar line?
- What region of the spectrum is more affected by the interstellar medium?

The interstellar medium is composed of dust (**dark** & blue regions) and gas (red).

At the end of the XIX century & beginning of the XX century, the existence of the interstellar medium was confirmed

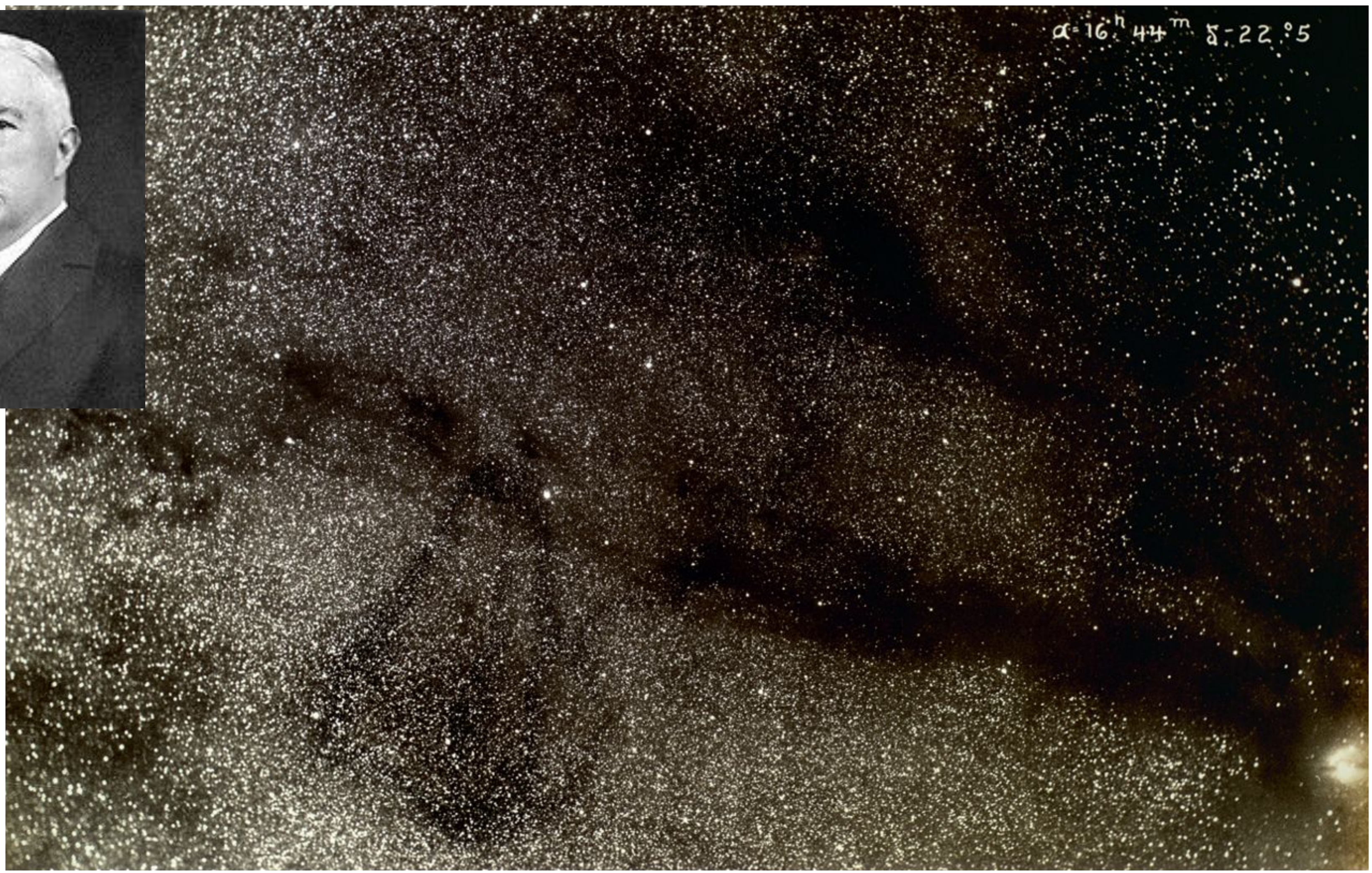
Huggins & Miller (1863) observed the spectrum of the Orion nebula and found that is was characteristic of a emitting gas





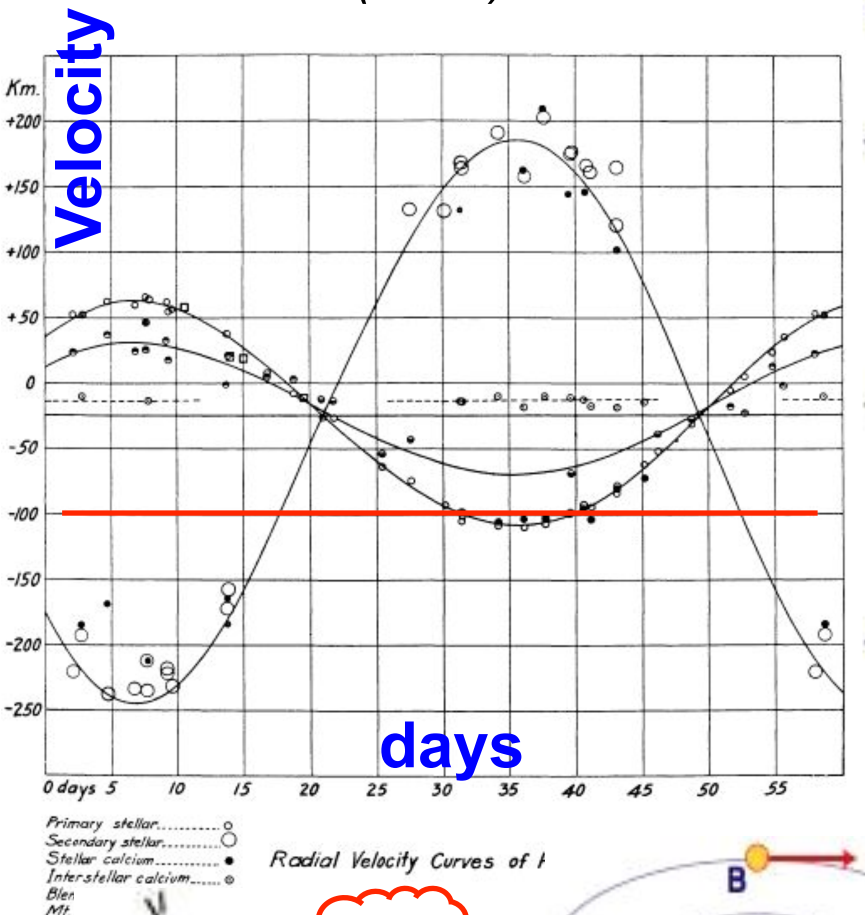
At the end of the XIX century & beginning of the XX century, the existence of the interstellar medium was confirmed

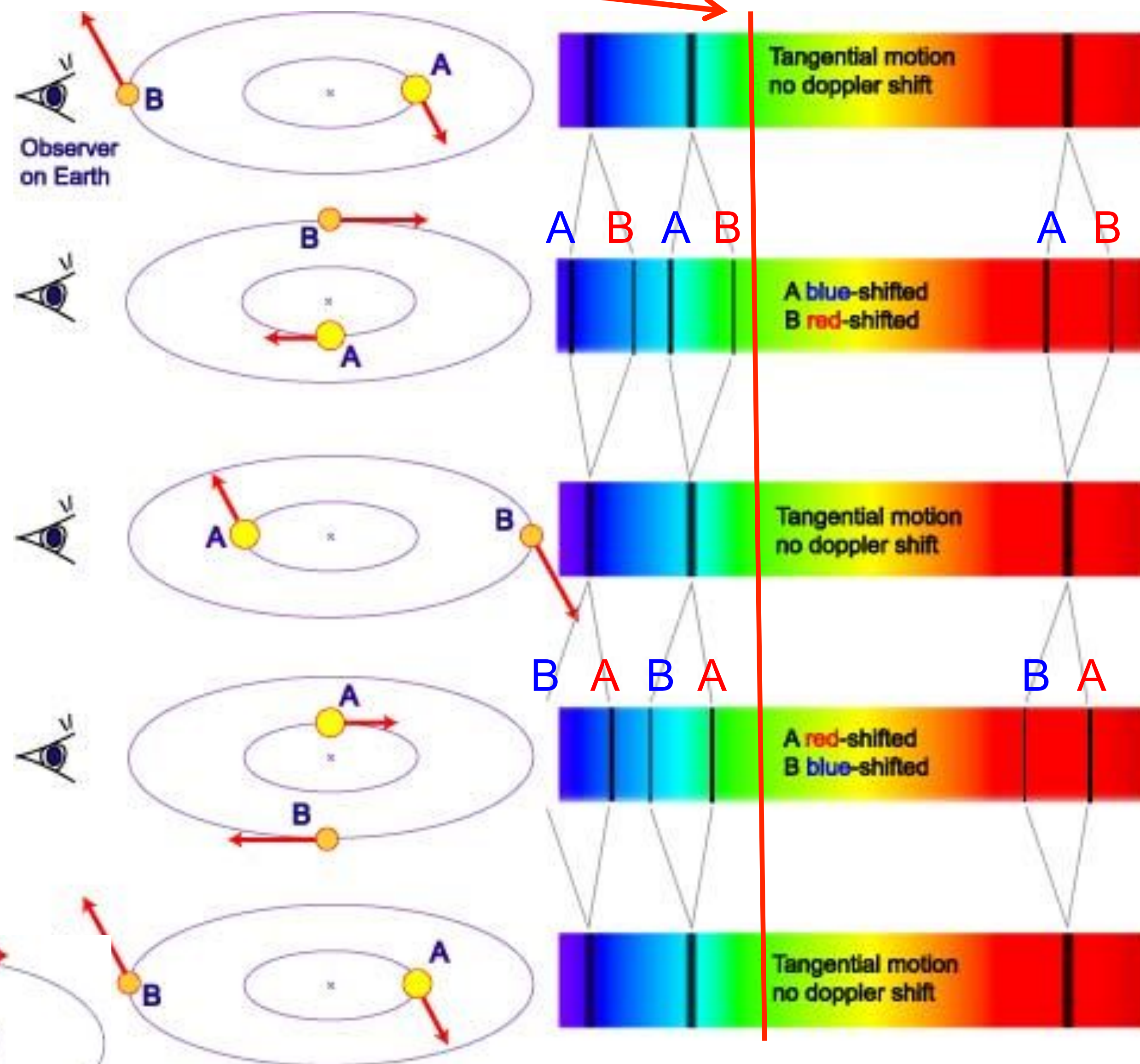
Edward Emerson Barnard (1857 – 1923) produced in 1895 the first images of dark nebulae and concluded that along with the illuminated gas and dust there was also significant quantities of dust and gas not directly illuminated.

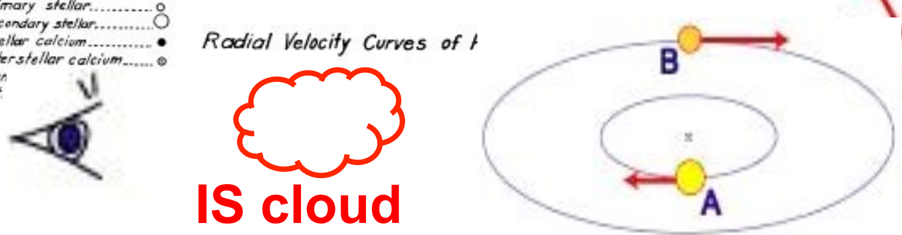


Stationary interstellar lines in the spectra of spectroscopic binaries

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



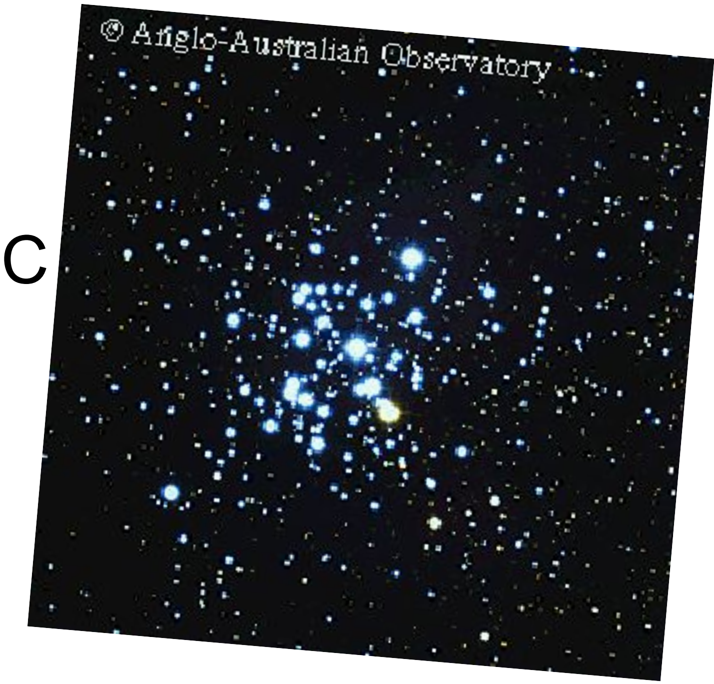




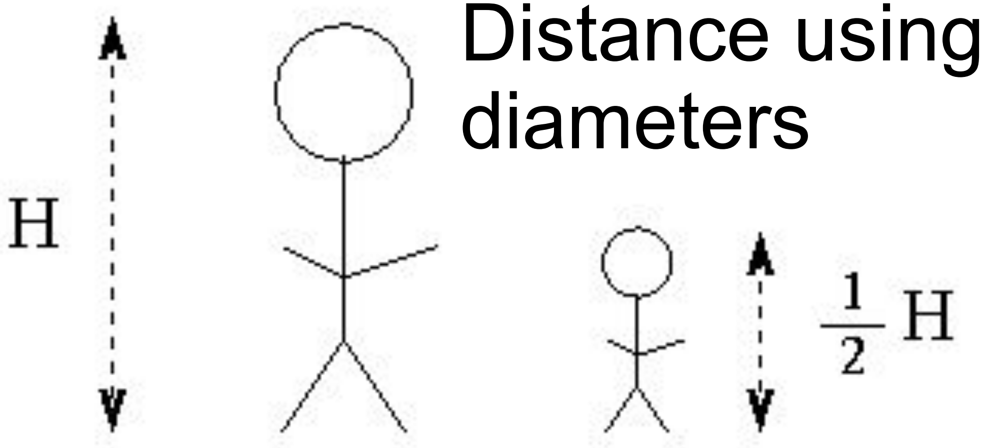
A Spectroscopic Binary System
High-mass star A and lower-mass B orbit around a common centre of mass. The observed combined spectrum shows periodic splitting and shifting of spectral lines. The amount of shift is a function of the alignment of the system relative to us and the orbital speed of the stars.

In 1930, Robert Trumpler estimated distances of ~ 100 open clusters (OC) by measuring:

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

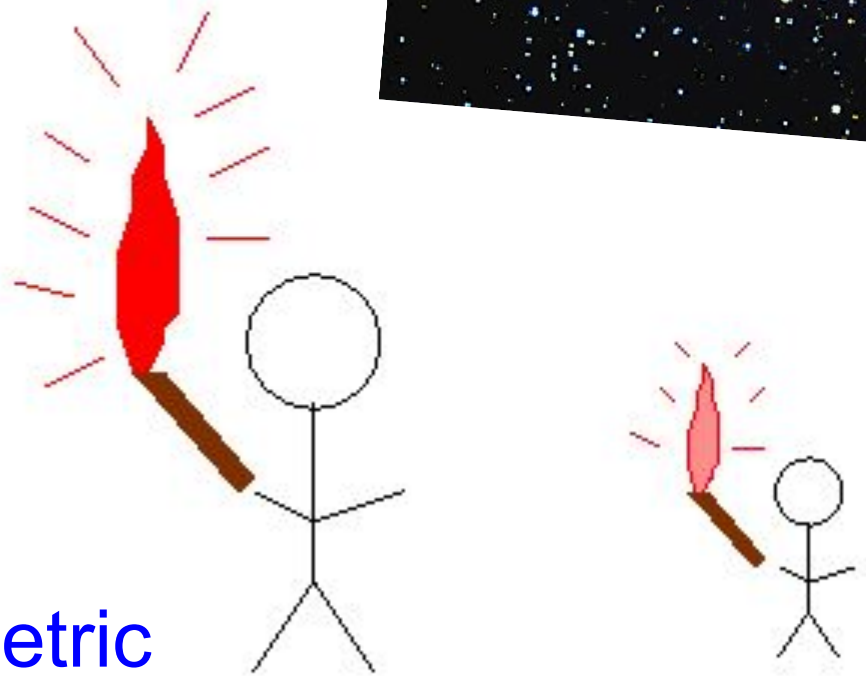


Distance using diameters



near far

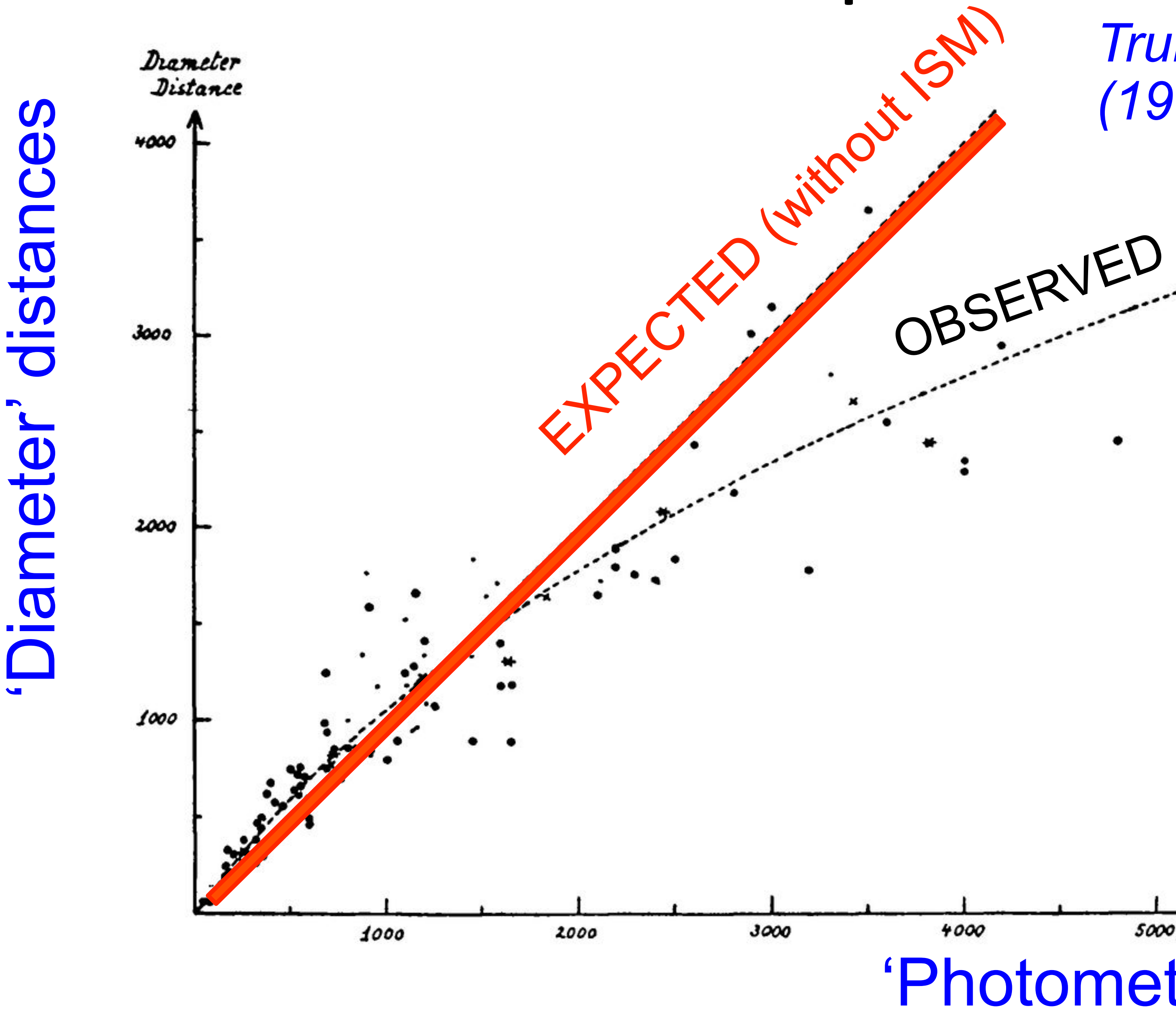
Photometric distances



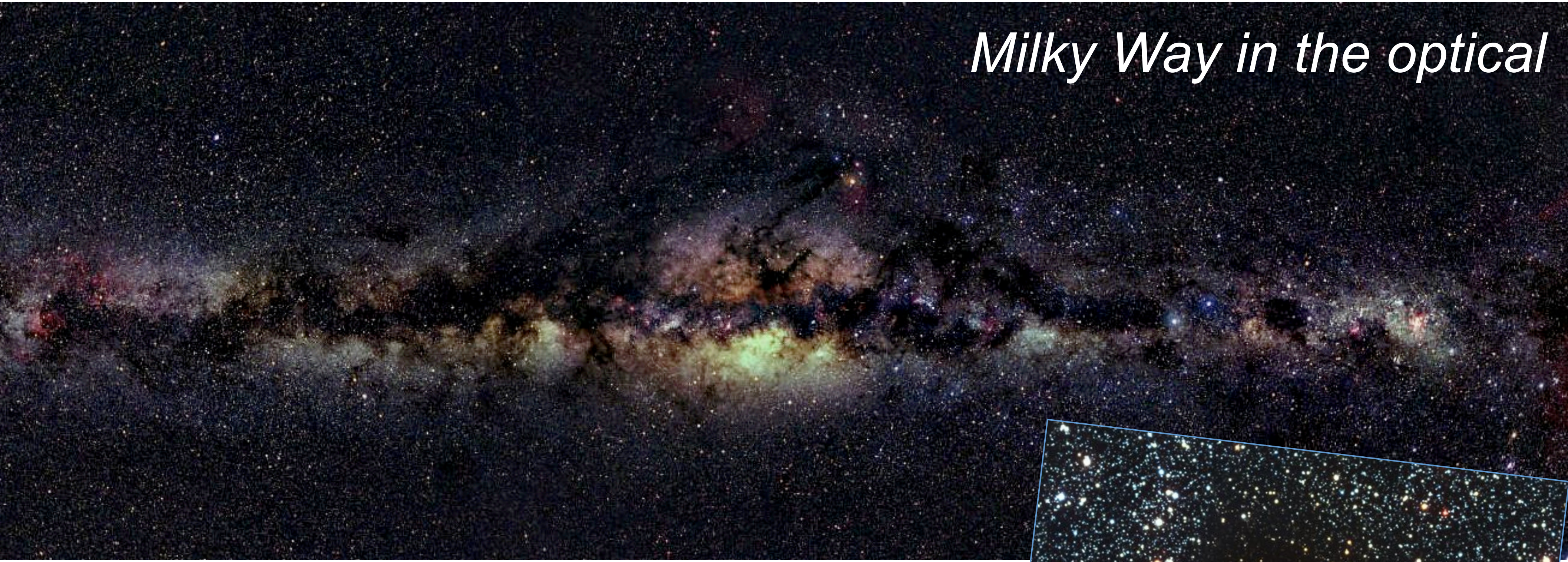
near far

Comparison between distances based on 'diameters' and 'photometry'

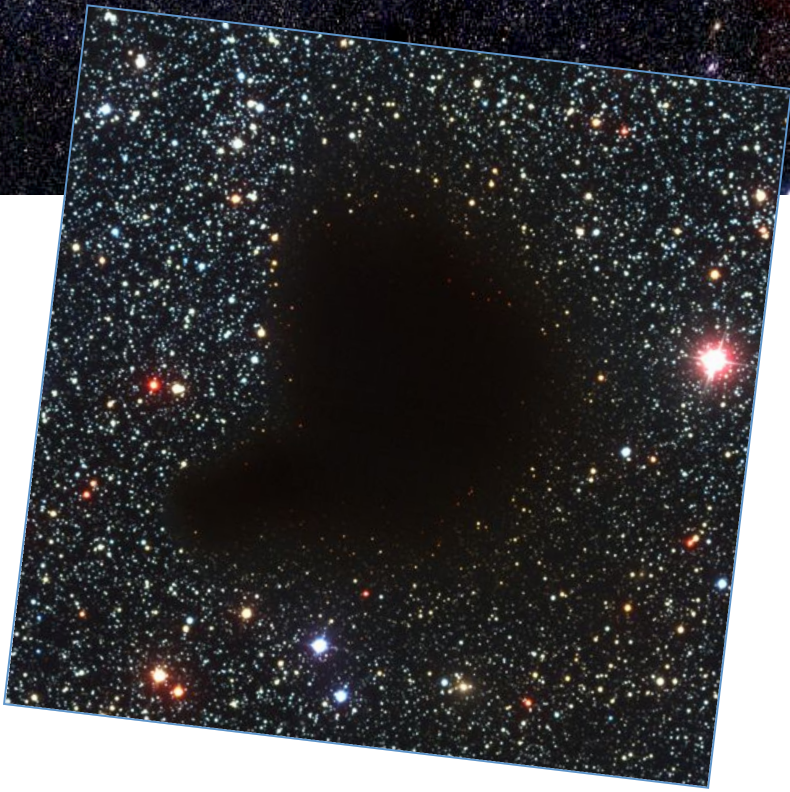
Trumpler (1930, AJ, 42, 214)



Effects of dust: extinction

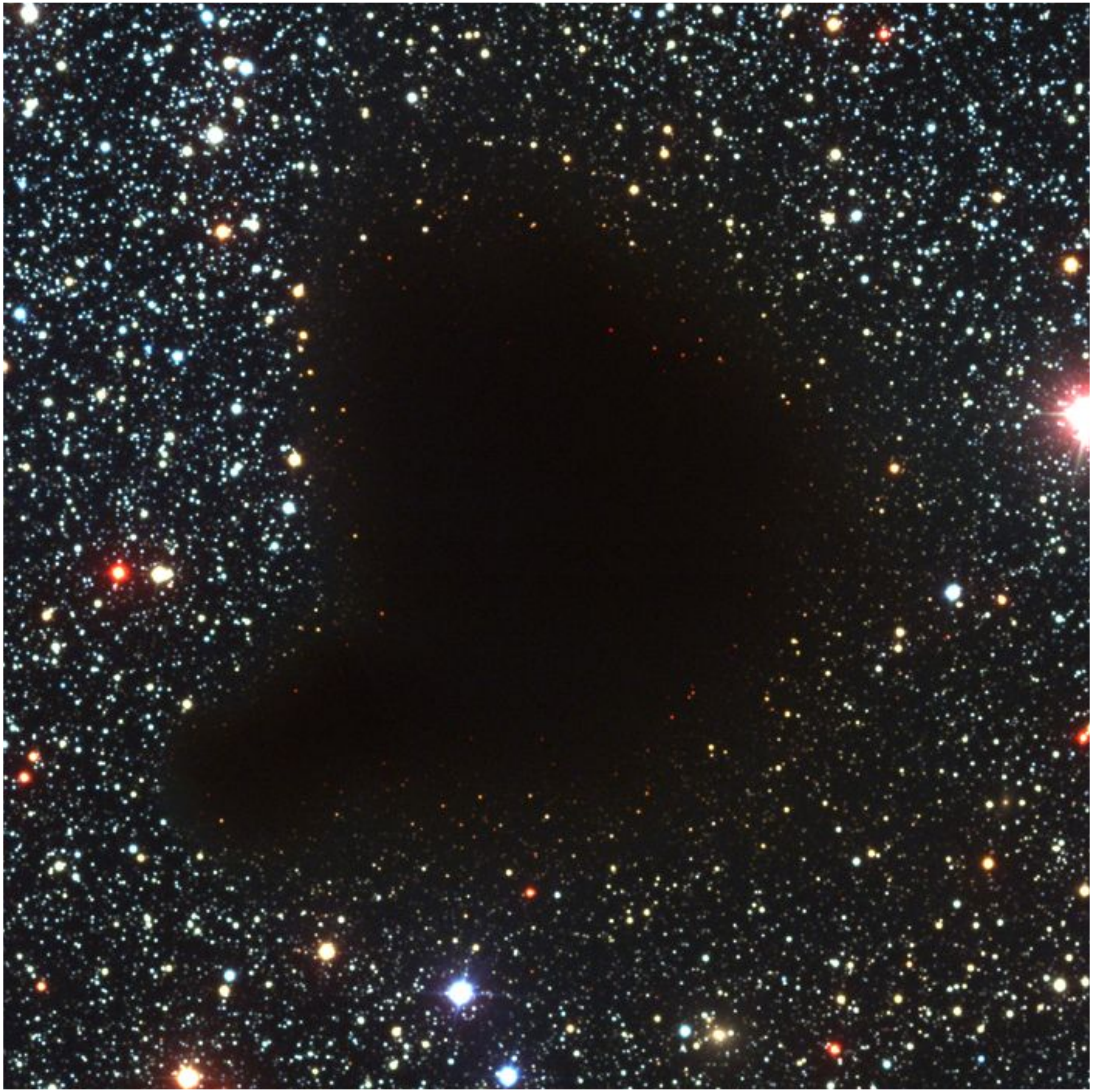


The attenuation of stellar light by interstellar dust is called **extinction**



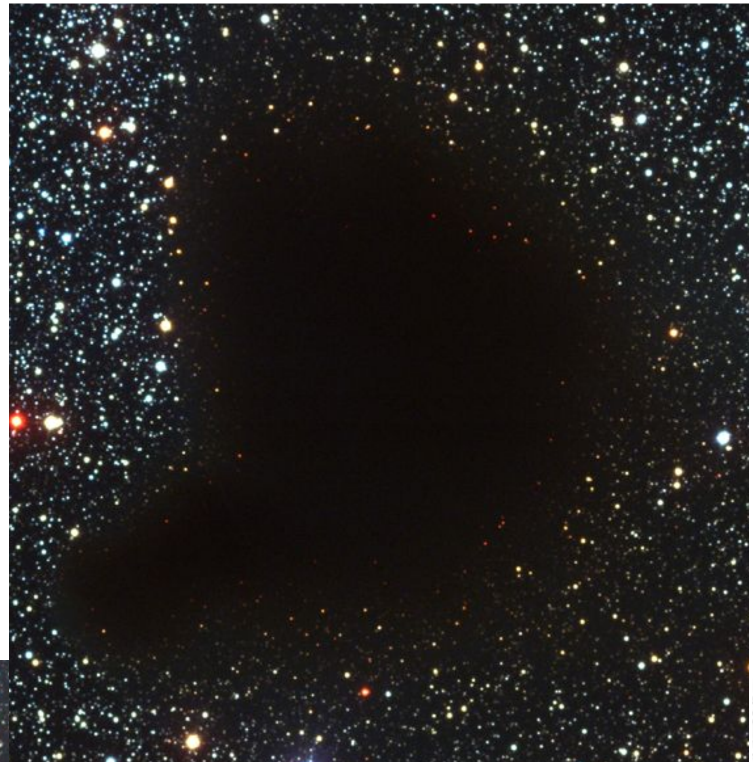
Effects of dust: reddening

Dust absorbs more blue than red light, causing the so called *reddening*

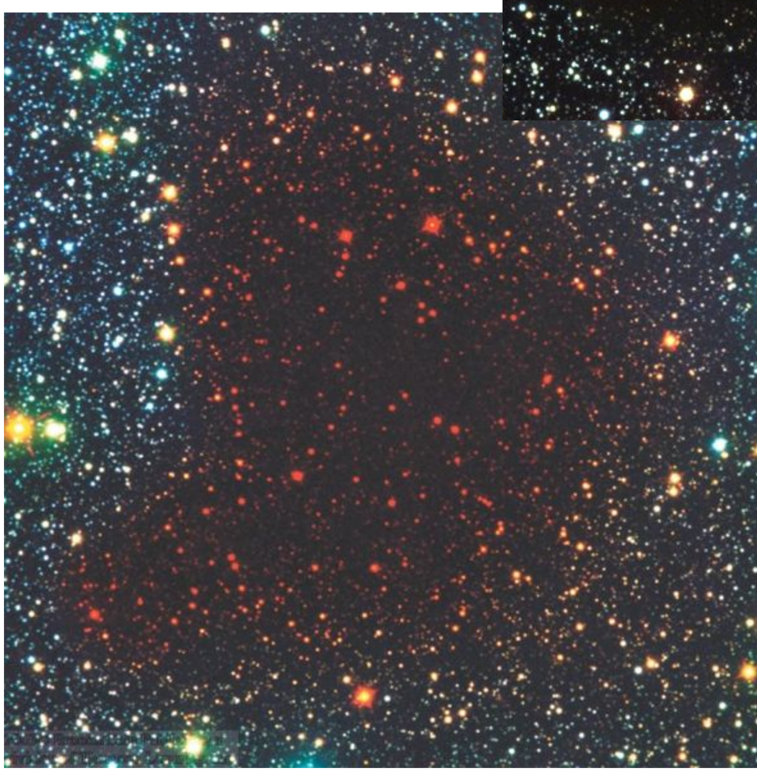


Interstellar reddening

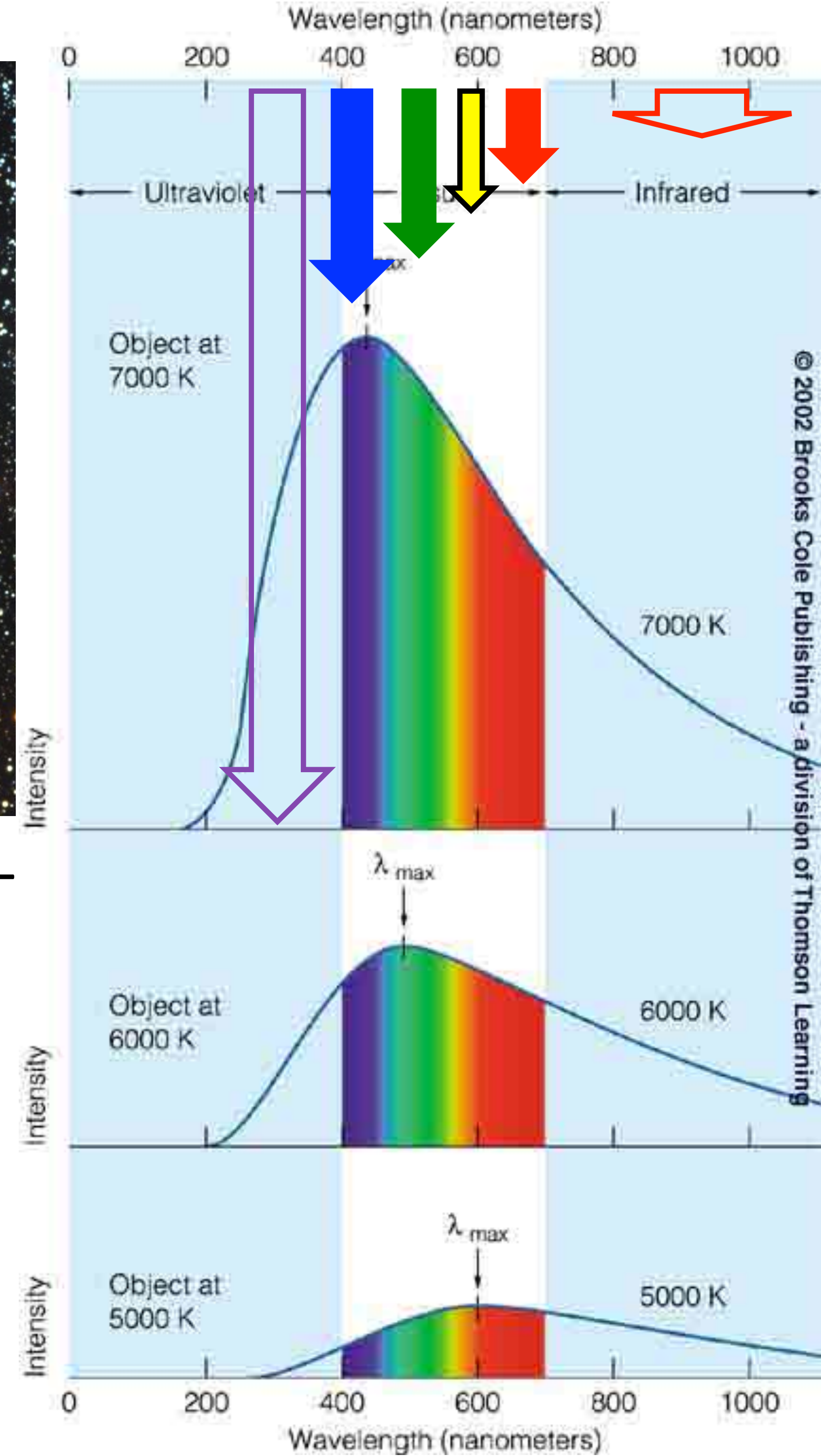
Optical light is strongly scattered and absorbed by interstellar clouds



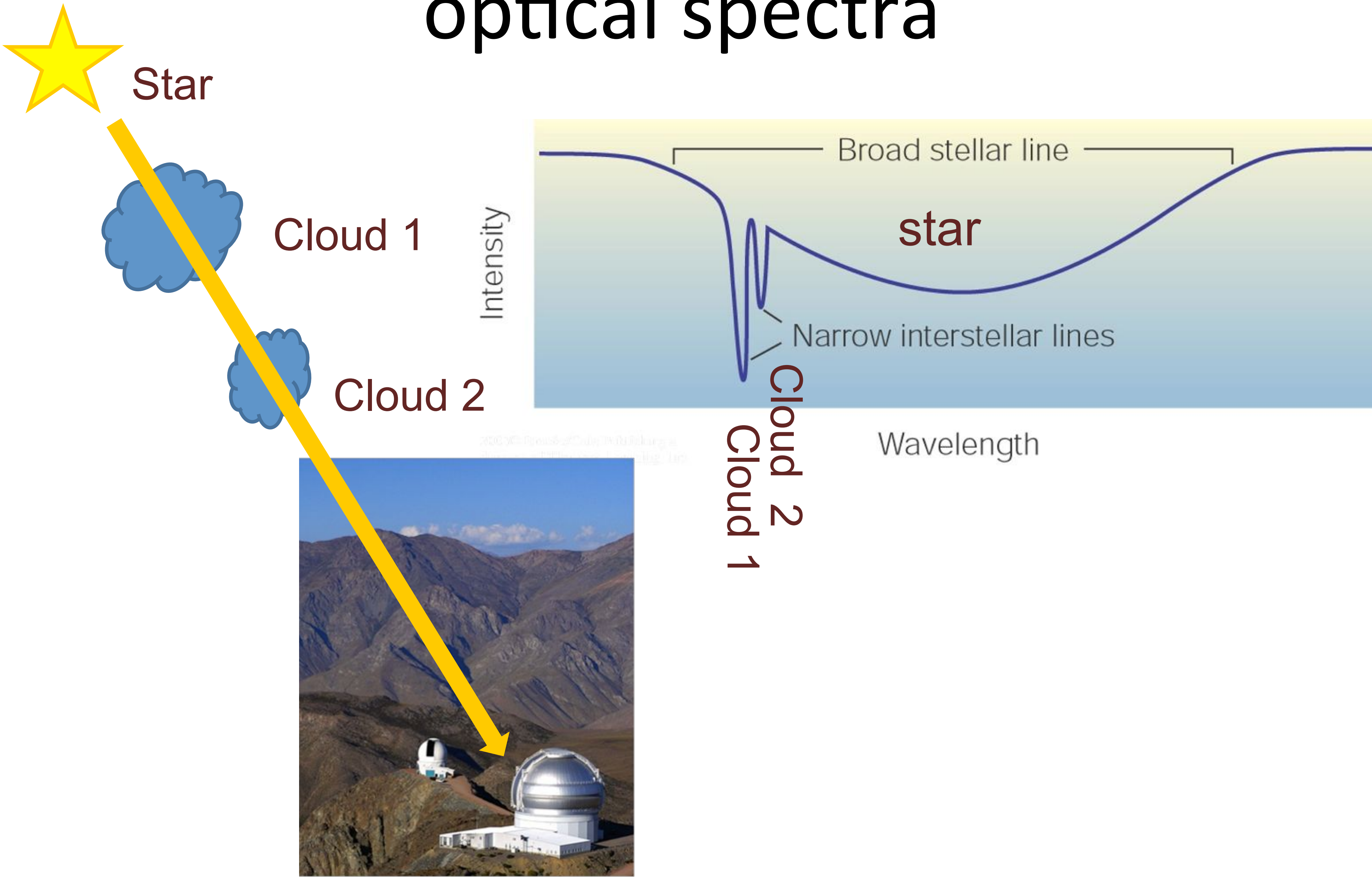
OPTICAL



INFRARED

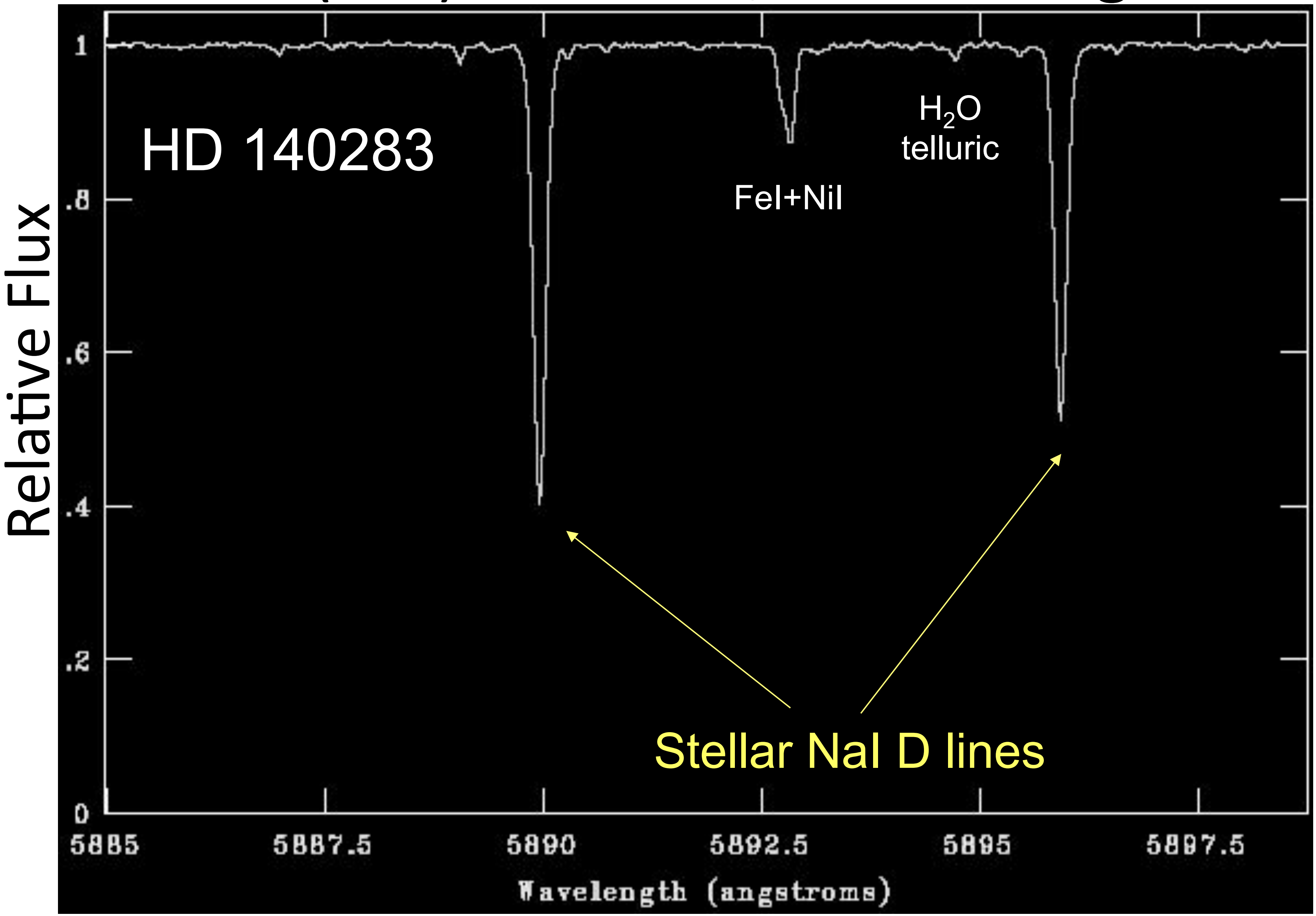


Neutral gas could be detected in optical spectra



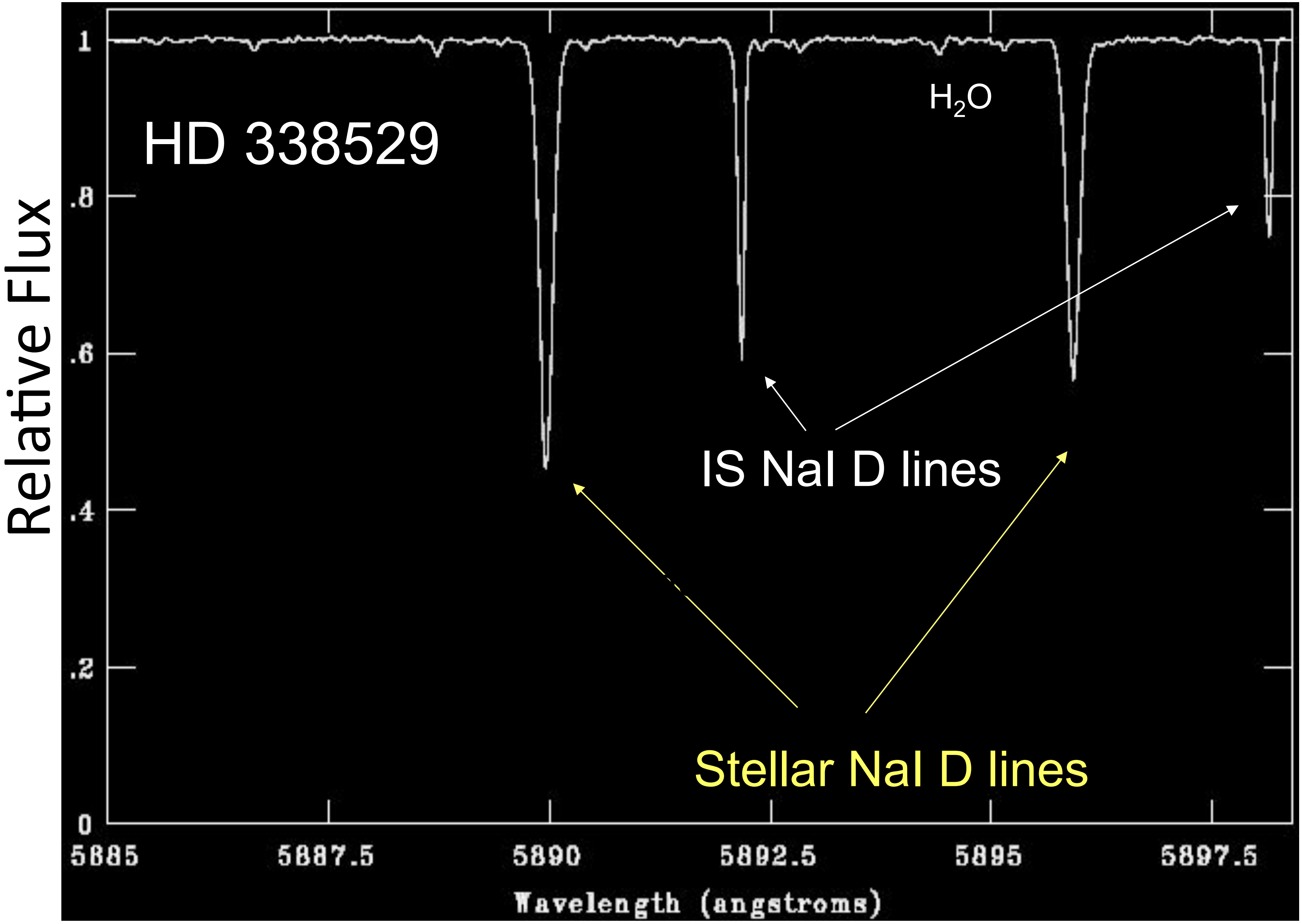
Star without lines from the ISM

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



Star with lines from the ISM

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



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

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

Astronomy & Astrophysics

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.

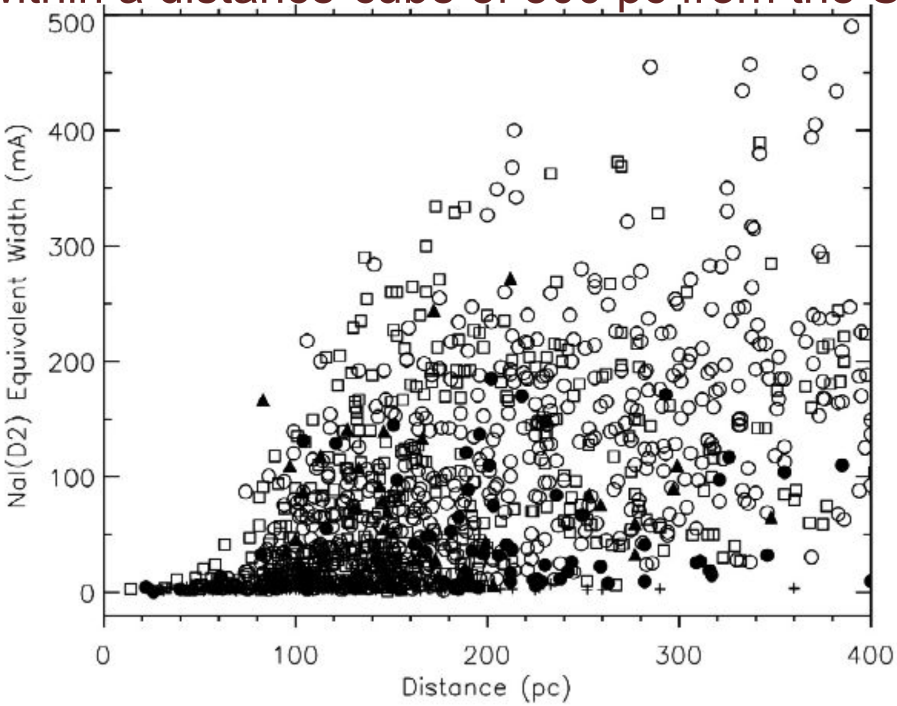


Fig. 7. Plot of the equivalent width (mÅ) of the interstellar NaI D2-line for stars with distances <400 pc. Filled triangles are for sight-lines with galactic latitude $b > +45°$, open squares for sight-lines with $b = 0$ to 45°, open circles for sight-lines with $b = 0$ to $-45°$ and filled circles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

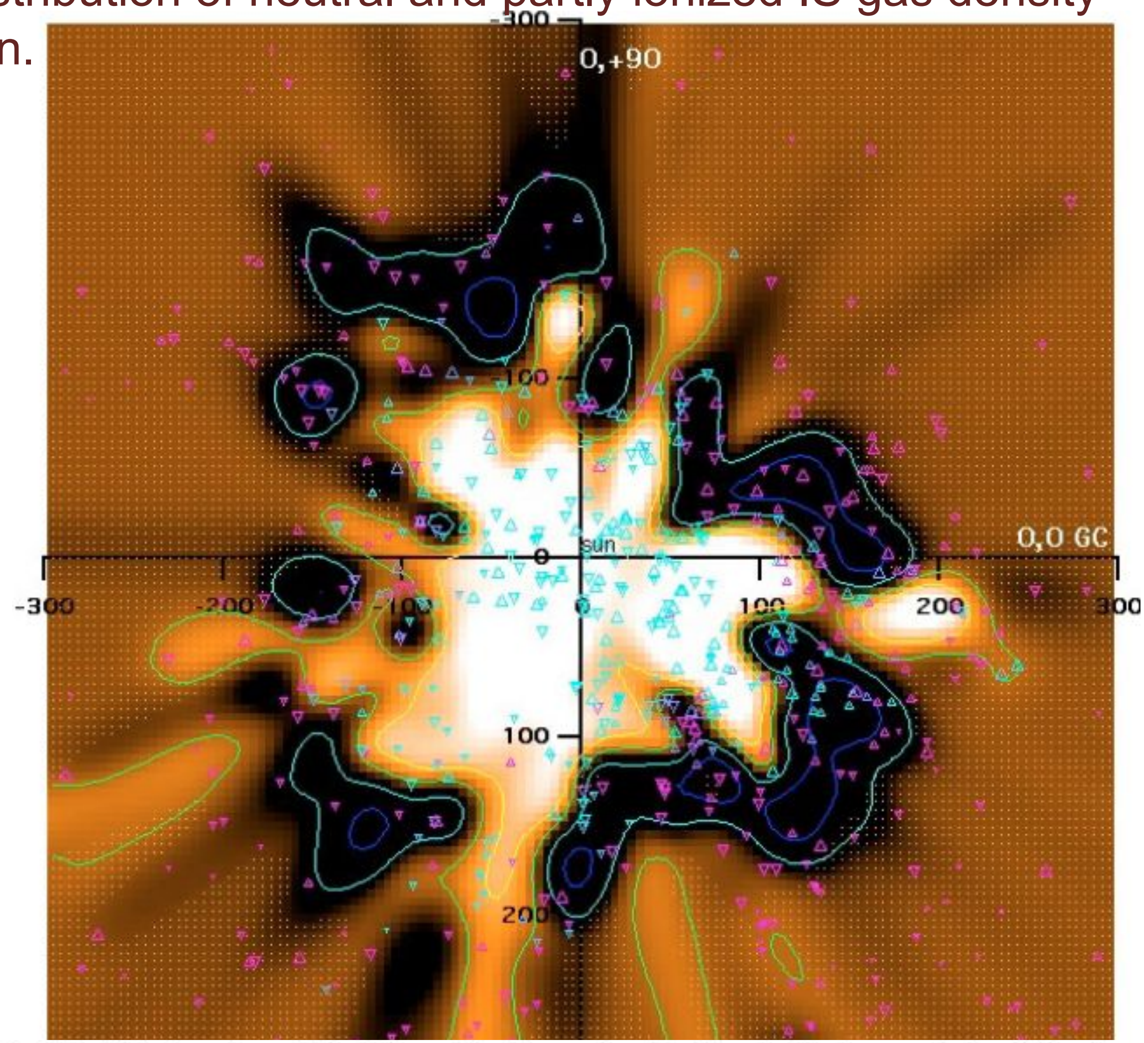


Fig. 12. Plot of 3D spatial distribution of interstellar NaI absorption within 300 pc of the Sun as viewed in the galactic plane projection. Triangles represent the sight-line positions of stars used to produce the map, with the size of the triangle being proportional to the derived NaI column density. 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.

Interstellar extinction curve

Mon. Not. R. astr. Soc. (1979) 187, *Short Communication*, 73P–76P

Interstellar extinction in the UV

M. J. Seaton

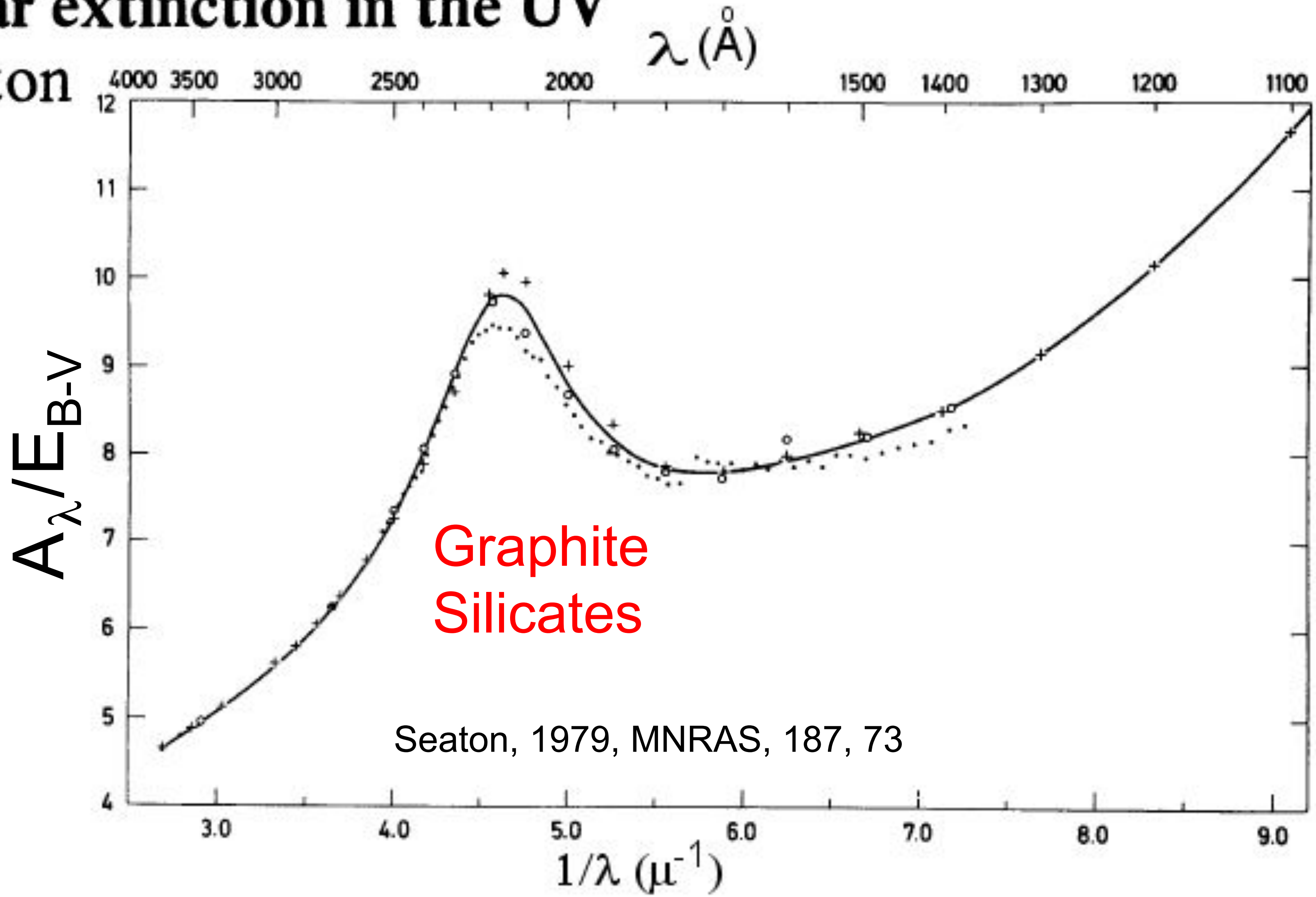


Figure 1. The UV extinction $X(x) = A_\lambda / E_{B-V}$ against $x = 1/\lambda$ with λ in microns. + *OAO-2* data of C76 (Code *et al.* 1976); · *TD-1* data of N75 (Nandy *et al.* 1975); ○ *TD-1* data of N76 (Nandy *et al.* 1976). The full line curve is from the fits of Table 2.

Interstellar extinction curve

Savage & Mathis
1979, ARA&A 17, 73

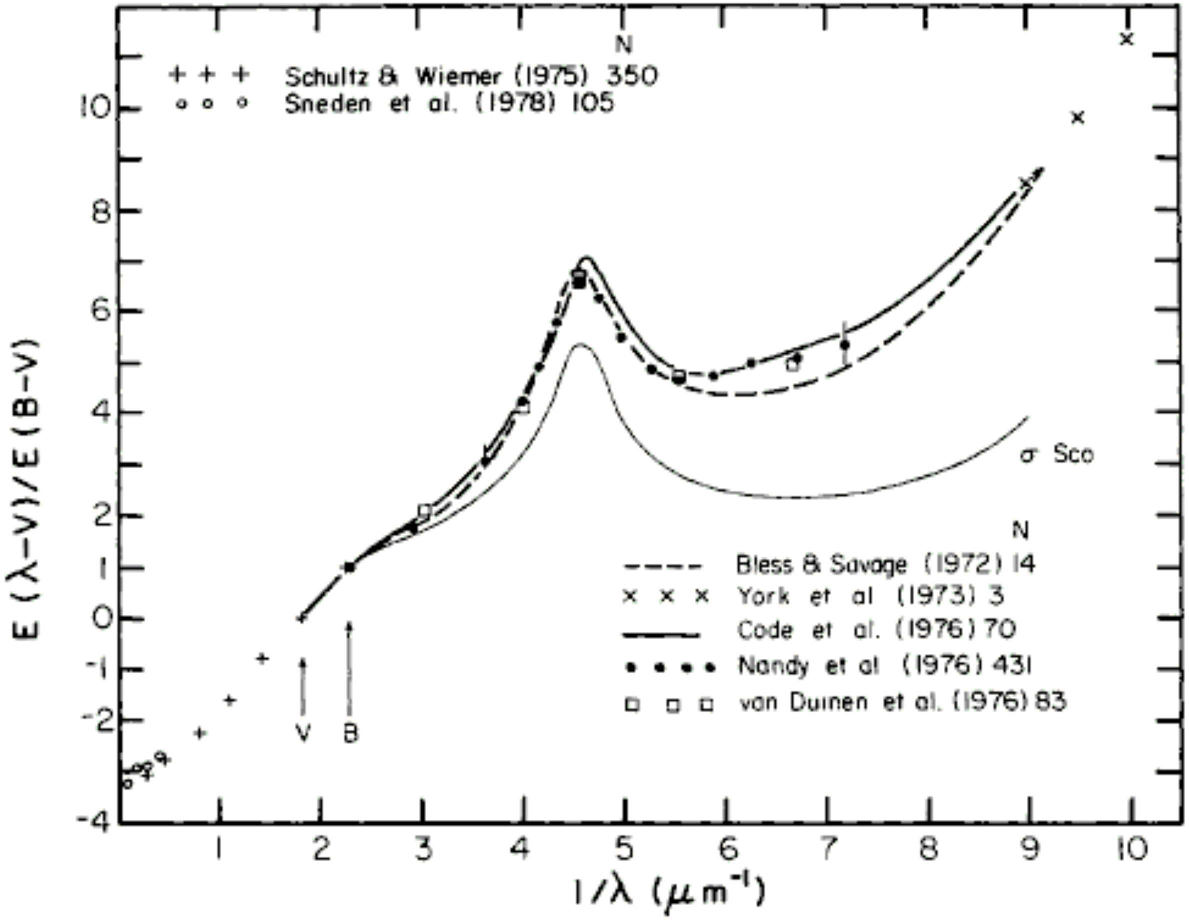


Figure 1 Average normalized interstellar extinction is plotted versus $1/\lambda$ in μm^{-1}. $E(\lambda{-}V)$ refers to the extinction in magnitudes between a wavelength λ and the photoelectric V band. The references for the various curves are provided along with an indication of how many stars were 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.

Interstellar extinction A_X

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

- A_X: extinction
- m_X: observed magnitude
- m_{X0}: intrinsic magnitude (observed in absence of interstellar absorption)

$$\mathbf{A_V = V - V_0 \quad \Rightarrow V_0 = V - A_V}$$

Example

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

- $A_V = 1,5$ mag
- $V = 11,6$ mag
- $V_0 = V - A_V = 10,1$ (intrinsic magnitude, i.e., the magnitude that would be observed in absence of interstellar dust)

Color excess E(X-Y)

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

- E(X-Y): color excess
- $m_X - m_Y$: observed color
- $m_{X0} - m_{X0}$: intrinsic color

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

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

Color excess E(X-Y)

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

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

$$E(X-Y) \equiv A_X - A_Y$$

Example: $E(B-V) = A_B - A_V$

Example

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

V = 10,1 & B = 10,9. Find $(B-V)_0$

E(B-V) = 1,05 – 0,90 = 0,15

B-V = 10,9 – 10,1 = 0,80

$(B-V)_0$ = (B-V) - E(B-V) = 0,80 – 0,15

$(B-V)_0$ = 0,65

Table 2 An average interstellar extinction curve

	$\lambda(\mu m)$	$\lambda^{-1}(\mu m^{-1})$	$E(\lambda-V)/E(B-V)$	$A_\lambda/E(B-V)$
	∞	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

Savage & Mathis 1979, ARA&A 17, 73

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

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

Rough A_V and 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* within 30° Galactic North Pole: E(B-V) = 0.00
- *b* within 30° Galactic South Pole: E(B-V) = 0.03
- |*b*| < 60° from the plane:

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

EXTINCT

Hakkila et al. 1997, AJ 114, 2043

A_v : *EXTINCT.FOR*

l,b,d(kpc)

ftp.mankato.msus.edu/pub/astro

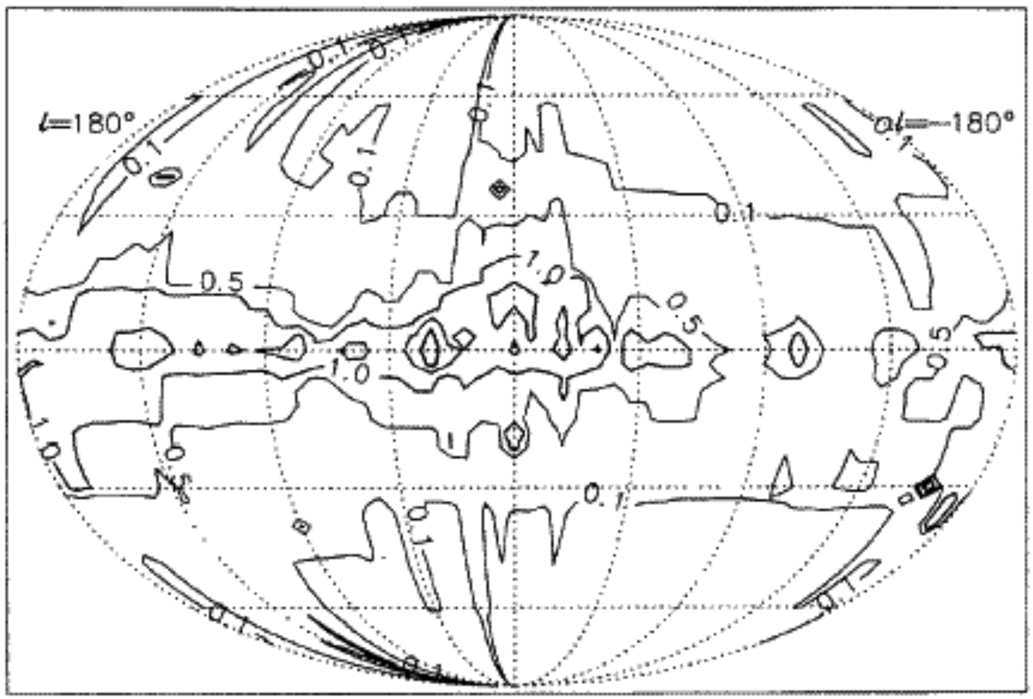


FIG. 11. Total visual extinction A_v (mag) in Galactic coordinates to a distance of 1 kpc as obtained from combining the results of all studies. When available, extinction from individual clouds identified in the high-latitude study is used. Otherwise, the results represent an average of available subroutines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

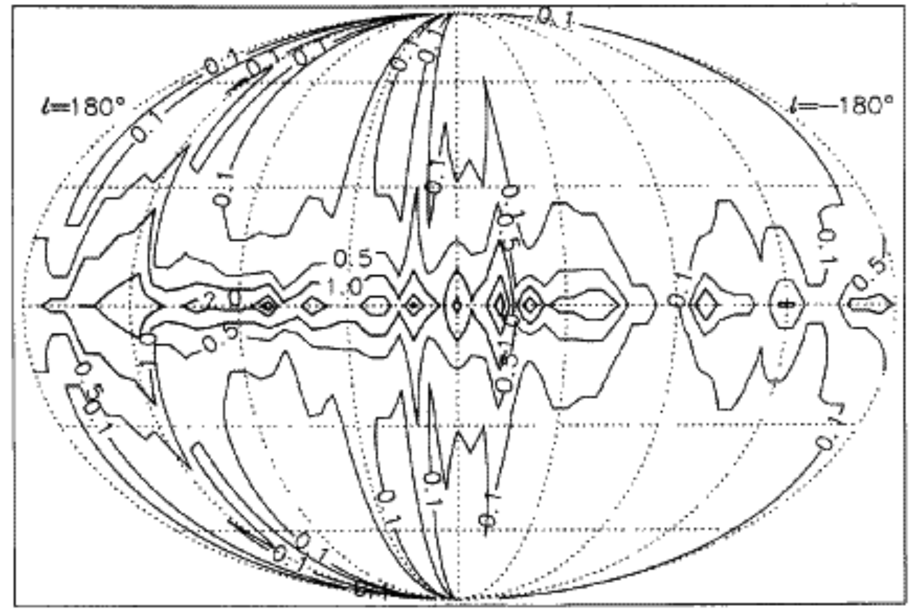


FIG. 2. Total visual extinction A_v (magnitudes) in Galactic coordinates to a distance of 1 kpc as obtained from the FitzGerald (1968) study. Plot contours are 0.1, 0.5, 1.0, 2.0, and 3.0 mag.

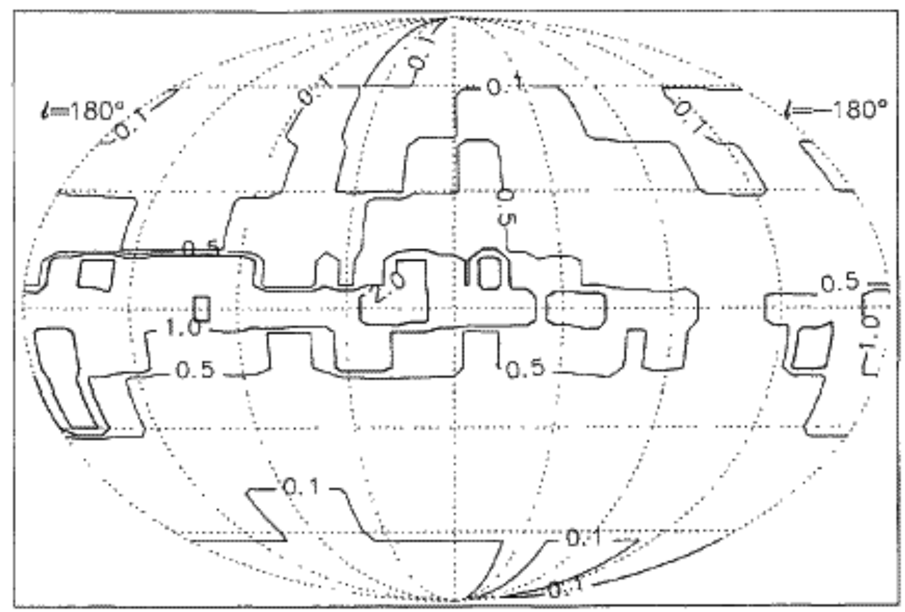


FIG. 7. Total visual extinction A_v (magnitudes) in Galactic coordinates to a distance of 1 kpc as obtained from the Arenou *et al.* (1992) study. Plot contours are 0.1, 0.5, 1.0, 2.0, and 3.0 mag.

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

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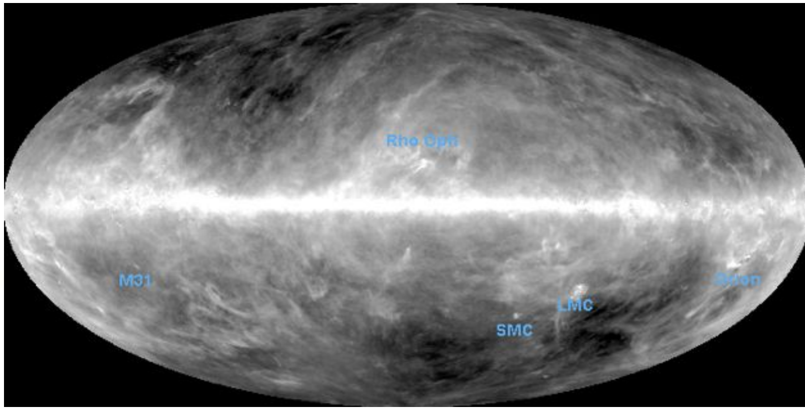


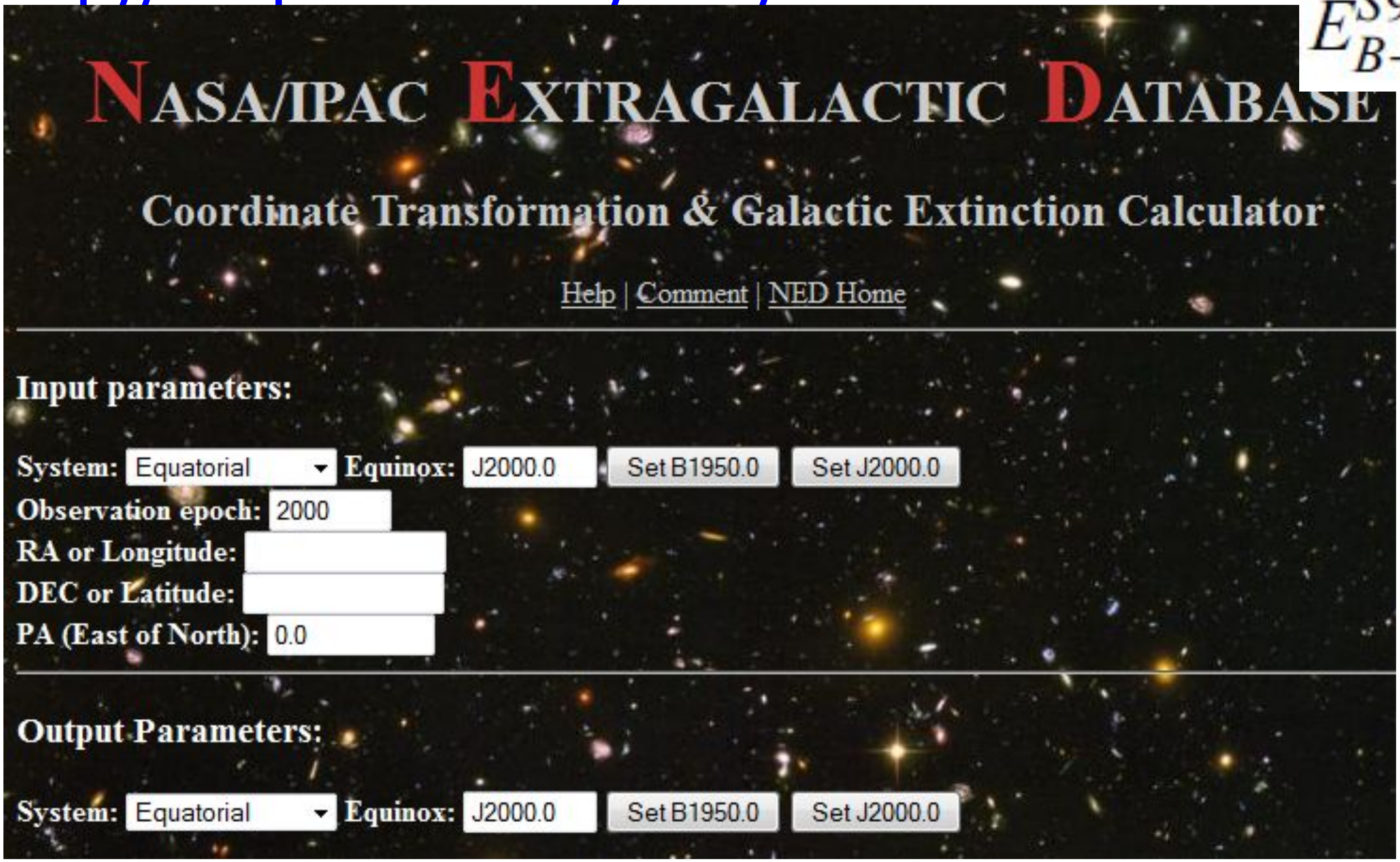
http://astro.berkeley.edu/~marc/dust/

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

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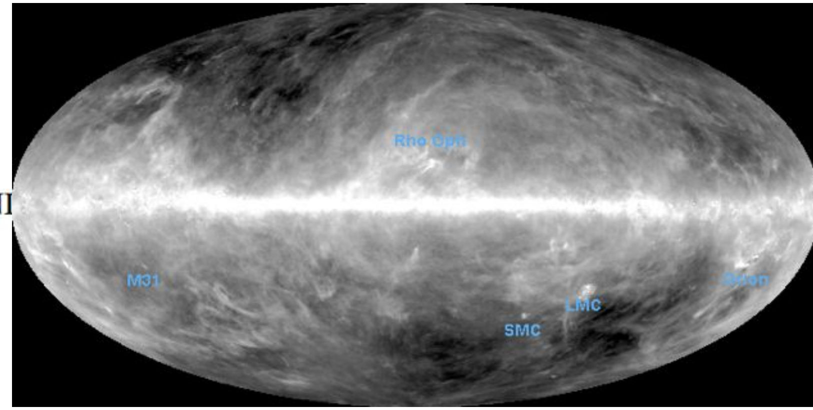


TABLE 6

RELATIVE EXTINCTION FOR SELECTED BANDPASSES

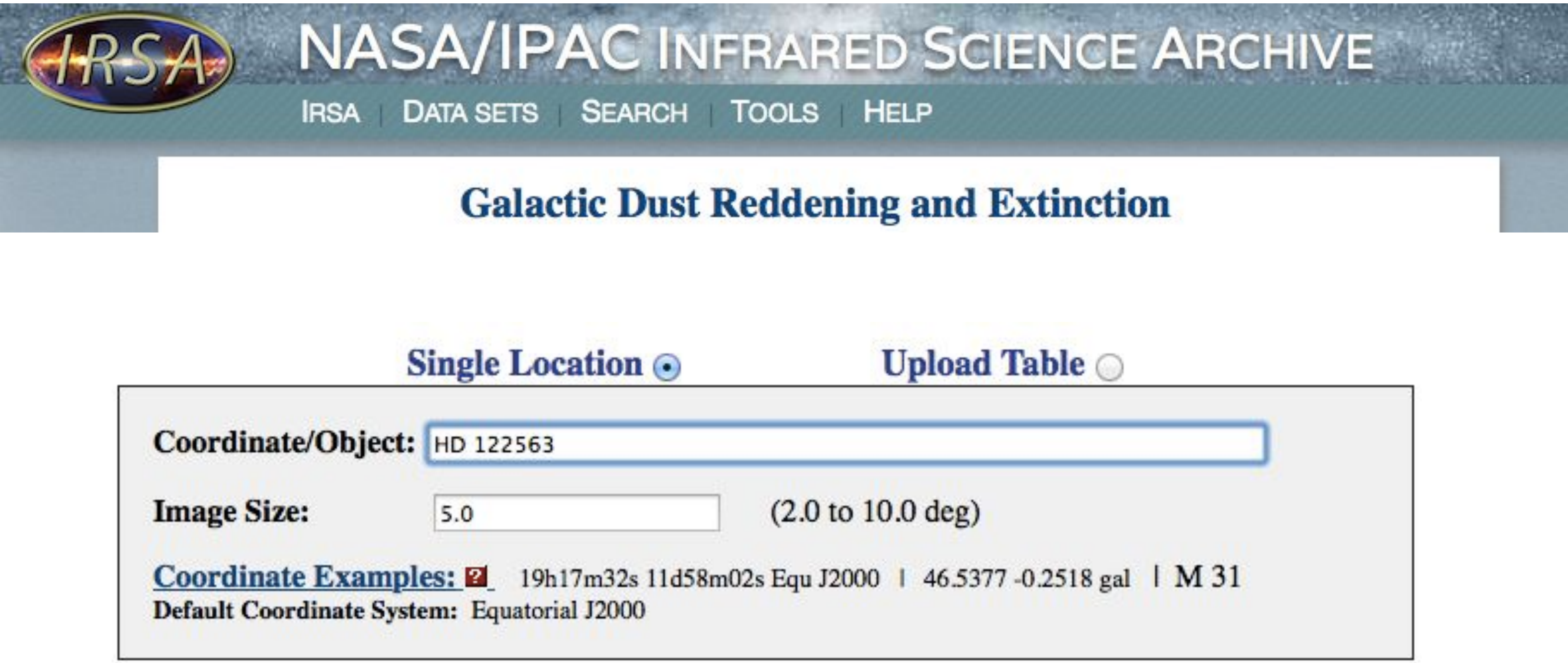
Filter	λ_{eff} (Å)	$A/A(V)$	$A/E(B-V)$	Filter	λ_{eff} Å	$A/A(V)$	$A/E(B-V)$
Landolt *U*	3372	1.664	5.434	Strömgren *u*	3502	1.602	5.231
Landolt *B*	4404	1.321	4.315	Strömgren *b*	4676	1.240	4.049
Landolt *V*	5428	1.015	3.315	Stromgren *v*	4127	1.394	4.552
Landolt *R*	6509	0.819	2.673	Strömgren *β*	4861	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 $E(B-V)$.

R, I are both in the Cousin system

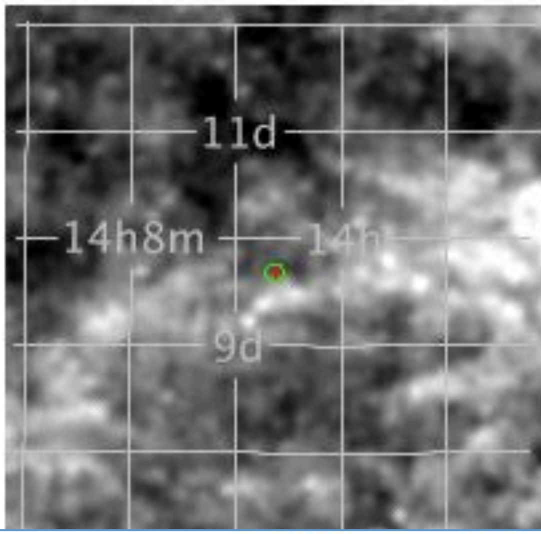
Schlegel maps with correction

http://irsa.ipac.caltech.edu/applications/DUST/



Data Tag: ADS/IRSA.Dust#2016/0405/143812_17720

HD 122563	210.63269 +9.68610 equ J2000



E(B-V) Reddening (mag)

	S & F (2011)	SFD (1998)
Reference Pixel(red '+')	0.0213	0.0248
Max	0.0242	0.0281
Min	0.0201	0.0233
Mean	0.0218 +/- 0.0012	0.0254 +/- 0.0014
Extinction by Bandpass		

$E(B-V)_{S\ \&\ F} = 0.86 \times E(B-V)_{SFD}$

S & F = Schlafly & Finkbeiner 2011 (ApJ 737, 103)
SFD = Schlegel et al. 1998 (ApJ 500, 525)

Assuming a visual extinction to reddening ratio Av / E(B-V) = 3.1, then:

$Av_{S\ \&\ F} = 0.0661$ (mag)
$Av_{SFD} = 0.0768$ (mag)

$E(B-V)_{SFD} = 0.025$ (mag)
$Av_{SFD} = 0.077$ (mag)
(Assuming an extinction to reddening ratio Av / E(B-V) = 3.1)

Extinction in Different Bandpasses Download

Filter	LamEff[a] (um)	A/E(B-V)[b]	A[c] (mag)	A/E(B-V)[b]	A[c] (mag)
		S and F (2011)		SFD (1998)	
CTIO U	0.3734	4.107	0.102	4.968	0.123
CTIO B	0.4309	3.641	0.090	4.325	0.107
CTIO V	0.5517	2.682	0.066	3.240	0.080

Example

Observed data: V = 9,831; B-V = 0,750; V-R =0,464

Adopting E(B-V) = 0,10, which are the magnitudes (V) and colors (B-V, V-R) corrected by interstellar extinction? Use table of Schlegel (slide 26).

Adopting 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 → A_V – A_R = 0,642 E(B-V).

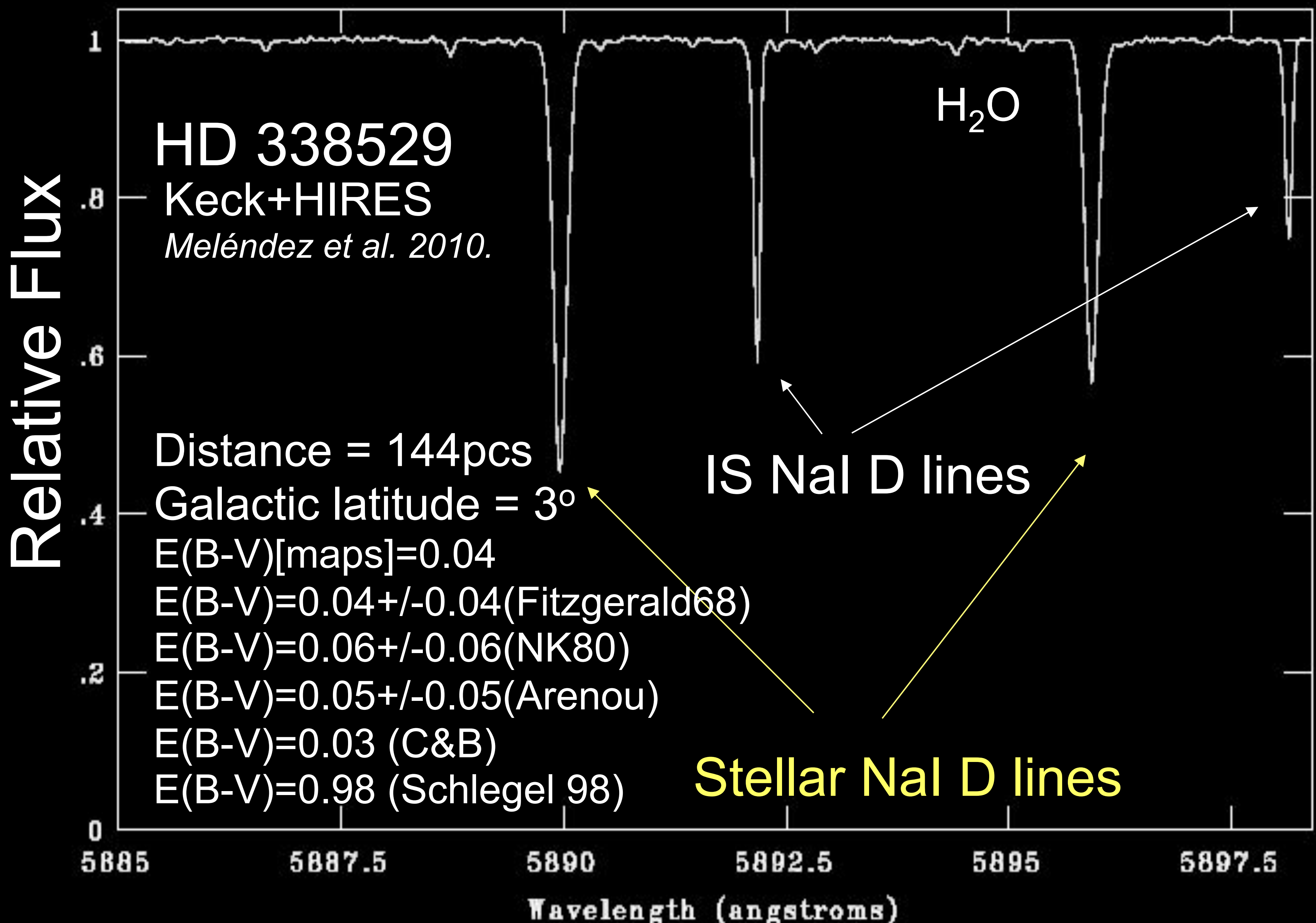
E(V-R) = A_V – A_R → E(V-R) = 0,642E(B-V) = 0,064

Note: we suggested previously that E(V-R) ~ 0,6 E(B-V), which is close to the value from Schlegel table

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

E(B-V) can also be obtained using NaD lines

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



How to estimate E(B-V)?

For nearby objects (d < 80 pc): E(B-V) = 0.00, independent of galactic latitude

Away from the Galactic plane (latitudes $b < -20^0$ & $b > +20^0$) you can use the Schegel et al. (1998) maps:

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

At low Galactic latitudes ($-20^0 < b < +20^0$) you could use:

$$E(B-V)_{star} = [1 - \exp(-|d \sin b|/h)] \cdot E(B-V)_{S98}$$

- $E(B\text{-}V)S_{98}$ is the full extinction from the Schlegel et al. (1998), which could be corrected (or not).
- *d* is the distance
- *b* is the galactic latitude
- *h* is the scale-height of the thin dust disk (125 pc)

Árnadóttir, A. S.; Feltzing, S.; Lundström, I. 2010, A&A, 521, A40