Extinción interestelar (absorción interestelar)

¿Están distribuidas homogéneamente las estrellas o existe algo que las oculta?

Extinción interestelar
(absorción interestelar)

Se debe a la dispersión y absorción
de la luz de las estrellas

Antes que nada:
extinción interestelar ≠ extinción atmosférica

Extinción interestelar

"Zone of avoidance" (a evitar)

Medio Interestelar (ISM)

- El medio interestelar es una de las componentes más importantes de las galaxias, ya que es el responsable de la formación de estrellas, quienes a su su vez son las fuentes de energía dominantes.

- Importante componente de las galaxias.
- Responsable de Formación Estelar (F.E.)

Medio Interestelar (ISM)

- Materia

  - Oscura (~ 25% de la materia total)

  - **Bariónica** (~ 5% de la materia total)

    - Determina la apariencia de las galaxias.

    - Responsable de la energía emitida de las gx.

    - Del 100% de bariones, el 10% pertenece al ISM.

Medio Interestelar (ISM)

- Materia
  - **Bariónica** (10% pertenece al ISM)
  - Determina la apariencia de las galaxias.

Primeros tiempos.

- La materia bariónica estaba contenida en el gas del MI. A medida que las galaxias evolucionaron (estrellas evolucionaron), el MI se convirtió en forma gradual en estrellas.
- Una fracción del MI puede ser eyectado en forma de vientos galácticos o en algunos casos removido de la galaxia por el medio intergaláctico. Por otro lado, el gas del medio intergaláctico puede agregar masa al MI.

Medio Interestelar (ISM)

Composición

1. Gas interestelar

• Iones. Átomos. Moléculas

2. Polvo interestelar: Partículas pequeñas (< 1μm) → el polvo no sobrevive.

3. Radiación E-M

• Diversas fuentes

– Fondo de radiación de microondas (CMB).

– Fotosferas estelares.

– Radiación emitida por gas interestelar.

- Radiación emitida por polvo interestelar

– Radiación Libre-Libre (L-L) de plasma interestelar.

– Radiación sincrotrónica de e - .

– Rayos γ

Medio Interestelar (ISM)

Composición

4. Rayos cósmicos: Iones y electrones con energías cinéticas muy altas ("relativistas").

Campo magnético interestelar

5. Campo gravitatorio interestelar

6. Materia oscura

No existen bordes definidos en las galaxias. Los constituyentes mencionados también se pueden hallar en el Medio Intergaláctico.

Vía Láctea

- Disco fino $\rightarrow$ Gas + polvo

  Masa (a 15 Kpc del C.G.) $\rightarrow 10^{11}\ M_\odot$

  – Estrellas $\rightarrow \sim 5 \times 10^{10}\ M_\odot$

  – Gas $\rightarrow \sim 7 \times 10^{9}\ M_\odot$

Vía Láctea

- Disco fino → Gas + polvo

  Masa (a 15 Kpc del C.G.) → 10^{11} M$\odot$

  – Estrellas → ~ 5×10^{10} M$\odot$

  – Gas → ~ 7×10^{9} M$\odot$

Gas Interestelar

- H ~ 70%

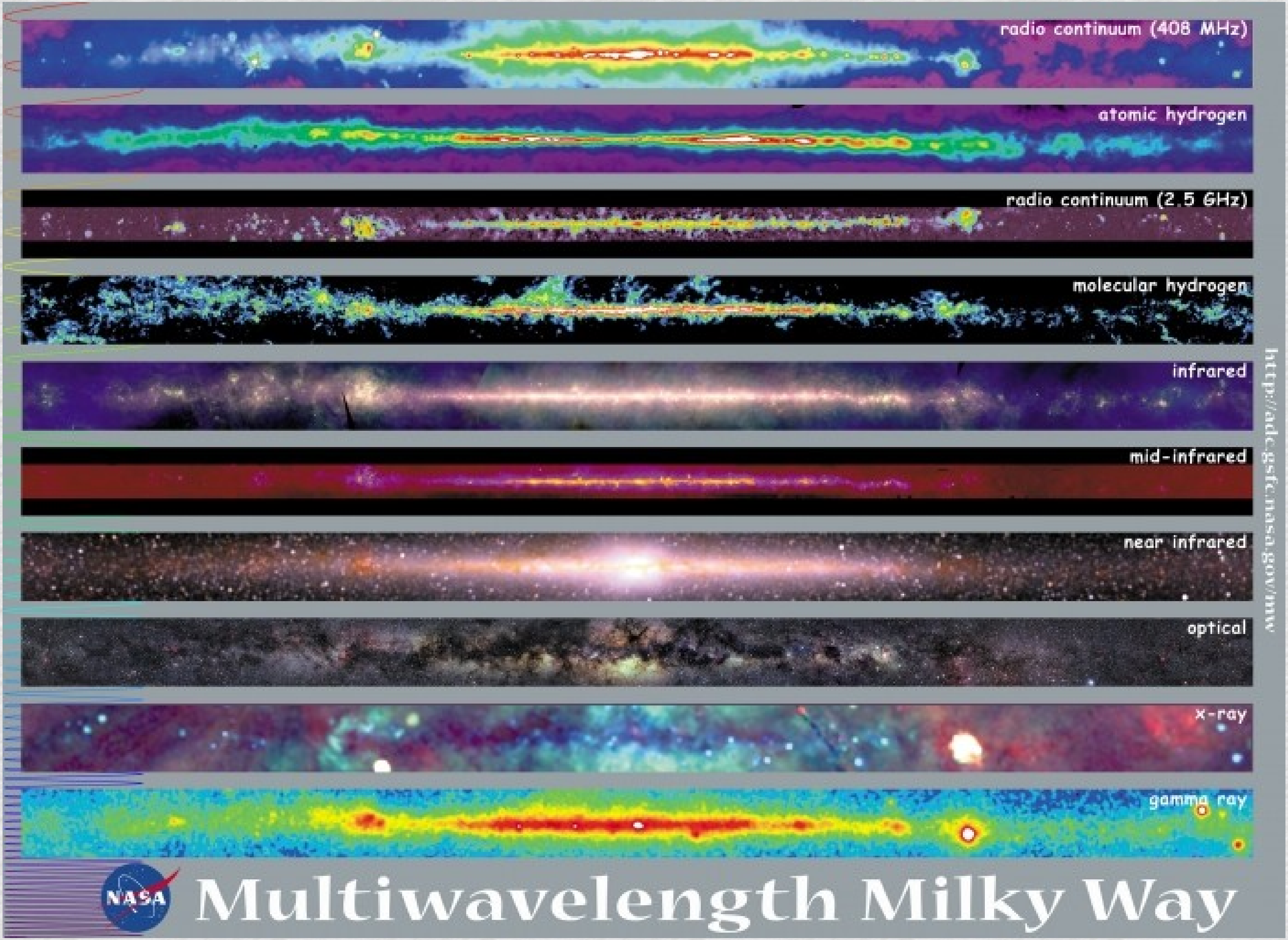
~ 60% Atómico

~ 20% Molecular

~ 20% Ionizado

- He ~ 27%

- O, N, C, Ne, Si, ... ~ 3%


radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
http://adc.gsfc.nasa.gov/mw
NASA
Multiwavelength Milky Way


Radio
Microwave
Infrared
UV
X-Ray
Gamma Ray
Radio
60,000 nm
600 K
Infrared
1200-800 nm (10-3.6 um)
4,500 K
Optical
450-750 nm
6,000 K
Ultraviolet
400-200 nm
10,000 K
X-ray
100-10 nm
10,000,000 K
Multiwavelength Whirlpool Galaxy
COLD GAS: Radio waves reveal regions of gas cool enough for CO_2 molecules to exist.
COOL STARS: Infrared shows smaller cool red stars that make up most of the galaxy.
SOLAR STARS: Optical light comes from stars around the size of the Sun.
HOT STARS: Ultraviolet shows the larger hot blue stars that are less frequent in galaxies.
HOT GAS: X-rays are emitted from the hottest regions of gas where atoms are ionized.
COOL LOW ENERGY RADIATION
VISIBLE LIGHT
HOT HIGH ENERGY RADIATION

M51

Estados/Fases del MI

- Gas coronal (HIM): Gas calentado por "Shocks" $\rightarrow$ Causado por onda expansiva de explosiones de supernovas.
  - Gas ionizado colisionalmente.
  - $T_{emp} \gtrsim 3 \times 10^5\ K$
  - Posee densidades muy bajas $\sim$ 0.004 cm^{-3}.
  - Llena una fracción apreciable del volumen de la Galaxia.
  - Dimensiones características $\sim$ 20 pc (conectado a otras regiones de gas coronal). Volumen por arriba y debajo del disco posee contiene gas coronal. $\rightarrow$ Se expande hasta un punto, y se frena debido a la atracción gravitatoria.
  - Emite en X, UV, radiación de sincrotrón.
- Gas HII $\rightarrow$ Fotoionización de HI por estrellas calientes (tipo O).
  - $T_{emp} \sim 10^4\ K$
  - Tamaño $\rightarrow$ Unos pocos pc (ejemplo: Nebulosa de Orión)
  - Tiempo de vida $\rightarrow$ Estelar $\sim$ ($3 - 10\ Myrs$)

Estados/Fases del MI

- Masa (en la Galaxia) $\rightarrow 1.1 \times 10^9 \ M_\odot$ de H ionizado

  $\rightarrow$ Nebulosas Planetarias (NP)
- Generadas por estrellas de $0.8 \ M_\odot < M < 6 \ M_\odot$
- Tiempo de vida $\rightarrow \sim 10^4$ años

• Medio interestelar [neutro] tibio (WNM)

- $T_{emp} \sim 5000 \ K$
- $\rho \sim 0.6 \ cm^{-3}$
- Fracción $\rightarrow \sim \ 40\%$
- Observado en HI 21 cm. En óptico, UV, en lineas de absorción

• Medio interestelar [neutro] frío (CNM)

- $T_{emp} \sim 100 \ K$
- $\rho \sim 30 \ cm^{-3}$
- Fracción $\rightarrow \sim \ 1\%$
- Observado en HI 21 cm. En óptico, UV, en lineas de absorción

Estados/Fases del MI

- Gas molecular difuso: Similar a las nubes de HI frío, pero con densidades suficientemente grandes como para que sobreviva (self-shielding) H_2 y sean abundantes en su interior.
  - $T_{emp} \sim 50\ K$
  - $\rho \sim 100\ cm^{-3}$
- Gas molecular denso: Nubes autogravitantes oscuras [$A_v \geq 3$]. A partir de él se forman las estrellas.
  - $T_{emp} \sim 10 - 50\ K$
  - $\rho \sim 10^3 - 10^6\ cm^{-3}$
- Flujos estelares: Las estrellas evolucionan y pierden masa.

  Estrellas evolucionadas frías:
  - $\sim\ 10^{-4}\ M_\odot/año$
  - $v \leq 30\ Km/s$ Presentan flujos salientes de alta densidad

  Estrellas más calientes: flujos de mayor velocidad, aunque de densidades mucho menores.

MEDIO INTERESTELAR

- Medio interestelar (gas y polvo): 10% de la masa de la galaxia
- Frio, denso, estado molecular, vinculado a la formacion de estrellas
- Caliente, tenue, en el espacio inter-nubes moleculares
- De acuerdo a la fase en que se encuentre puede emitir desde radio hasta X
- Polvo: es el 1% del medio interestelar, 100 particulas por km cubico, granos de hasta 300 nm, absorbe visible y reemite en infrarrojo. Hidrocarbonos. Origen: condensacion en atmosferas K M o estrellas de carbono (convectivas con ciclo CNO)
- Gas: es el 99% del medio interestelar, 1 atomo por cc, puede ser calentado, excitado, ionizado por estrellas proximas. Basicamente H y He.
- Rayos cosmicos acelerados por campos magneticos.
- Gas de la corona de la galaxia

Nebulosa oscura

Barnard 68 is a large molecular cloud that is so thick, it blocks out the light from stars that we normally would be able to see.
Credit: ESO

Nebulosa oscura

Nebulosa oscura

Nebulosa de reflexión (dispersa la luz de las estrellas)

Nebulosa de reflexión

THE ASTROPHYSICAL JOURNAL, 589:347–361, 2003 May 20

THE PLEIADES REFLECTION NEBULA. I. ULTRAVIOLET, OPTICAL, AND FAR-INFRARED IMAGING PHOTOMETRY

STEVEN J. GIBSON[1] AND KENNETH H. NORDSIECK[2]
Received 2002 July 16; accepted 2002 September 20

ABSTRACT

We present new wide-field optical and ultraviolet images of the Pleiades reflection nebula that allow a more thorough evaluation of the dust scattering than any prior data set. Vacuum-UV images were taken at 1650 and 2200 Å during the first flight of the Wide-Field Imaging Survey Polarimeter (WISP), a sounding rocket–borne telescope. WISP captured the brighter parts of the nebula at both wavelengths, with 3 σ sensitivities of 22.5 and 23.4 UV mag arcsec^{-2}, respectively. The 5°0 × 1°7 WISP field was also mapped at 4400 Å with a mosaic of 40 Burrell Schmidt CCD frames using a broadband B_J filter. The Schmidt mosaic shows extensive and intricate nebulosity down to a 5 σ sensitivity limit of 27.6 B mag arcsec^{-2}, including features undetected by photographic surveys. We explore the intensity and color behavior of the nebula in our UV and optical images and far-infrared *IRAS* data. We find that the photometric structure near bright stars is more complex than previous studies have implied, but general trends are still apparent. The color gradients around the stars are caused by phase function effects rather than internal reddening. The greater concentration of scattered light versus thermal emission indicates that most of the observed scattering is from foreground dust. A somewhat greater concentration of UV versus optical light suggests grain scattering is more forward-directed at shorter wavelengths. The UV nebula is much fainter than expected from the stellar photometry and interstellar reddening. Explaining this UV faintness requires either more reddening than is measured or significant alterations to current dust property estimates.

THE ASTRONOMICAL JOURNAL, 121:3138–3148, 2001 June

BARNARD'S MEROPE NEBULA REVISITED: NEW OBSERVATIONAL RESULTS

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Received 2000 November 10; accepted 2001 March 1

ABSTRACT

IC 349 is a small, fan-shaped reflection nebula located only 30″ from 23 Tau; its nucleus is, by a factor 15, the brightest area of the Pleiades nebulosity. We propose that IC 349 is a fragment of the Taurus-Auriga molecular cloud that has been encountered by the Pleiades in that cluster's southward motion and is being illuminated and shaped by the radiation field of 23 Tau. New *Hubble Space Telescope* multicolor imagery and the structure, colors, and surface brightness of IC 349 are discussed in terms of that hypothesis. What is known of the proper motion of the nebula, what can be inferred of the properties of the nebula from its color, and what is expected from radiation pressure theory appear to be compatible with this cloudlet-encounter hypothesis.

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The 3D geometry of reflection nebulae IC 59 and IC 63 with their illuminating star gamma Cas

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[3]*IPAC, California Institute of*

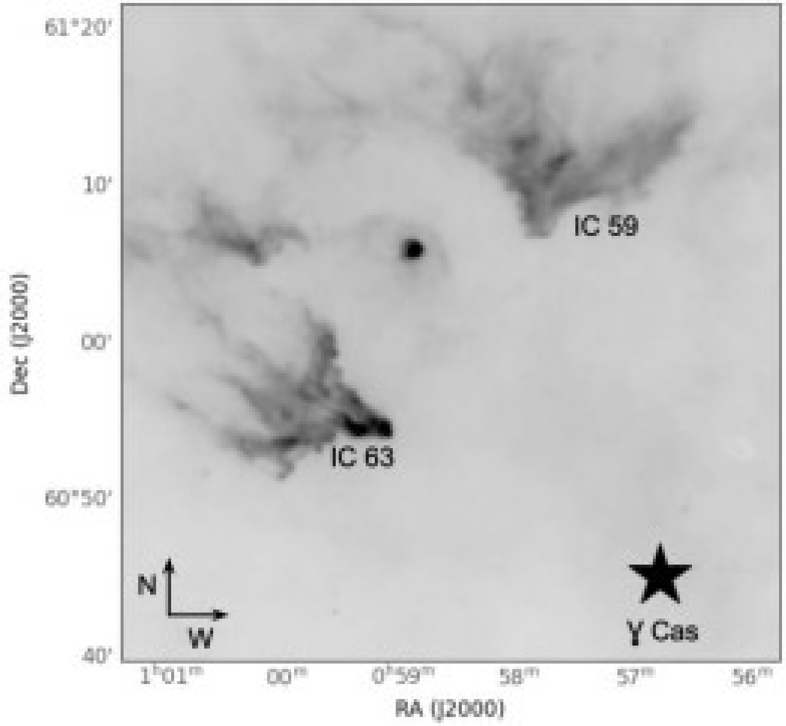


Figure 1. *WISE* Band 3 (12 μm) cutout of region containing gamma Cas with IC 59 and IC 63.

Diferentes tipos de MI ...

The reddish nebulae glow with light emitted by hydrogen atoms.

The darkest areas are clouds of dust that block the light from stars behind them.

The upper part of the picture is filled with the bluish glow of light reflected from hot stars embedded in the outskirts of a huge, cool cloud of dust and gas.

The cool supergiant star Antares can be seen as a big, reddish patch in the lower-left part of the picture. The star is shedding some of its outer atmosphere and is surrounded by a cloud of its own making that reflects the red light of the star.

Polvo interestelar

Las nebulosas gaseosas, además del gas, contienen polvo y debemos tener en cuenta que sus efectos sobre las propiedades de las nebulosas no son despreciables.

11.1 Extinción interestelar

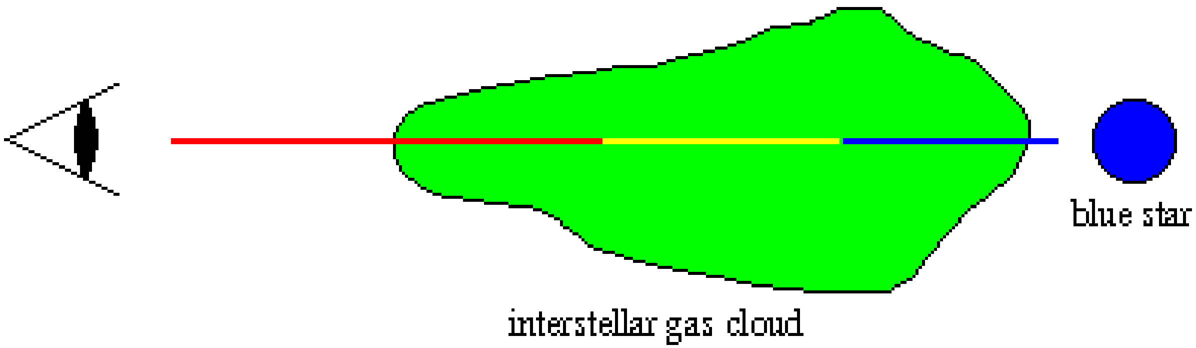
El efecto más obvio del polvo interestelar es la extinción de la luz que proviene de las estrellas y nebulosas.

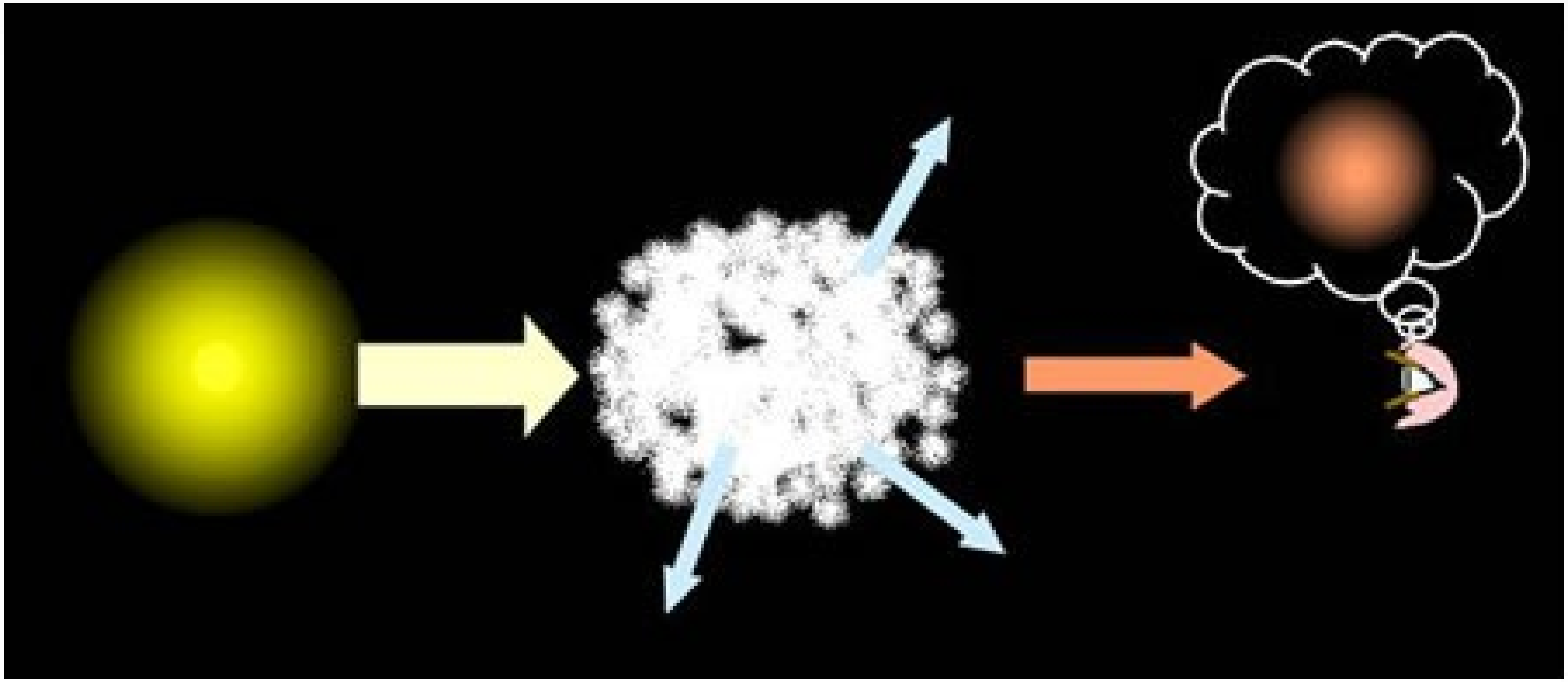
Extinción interestelar:

- Dispersión
- Absorción

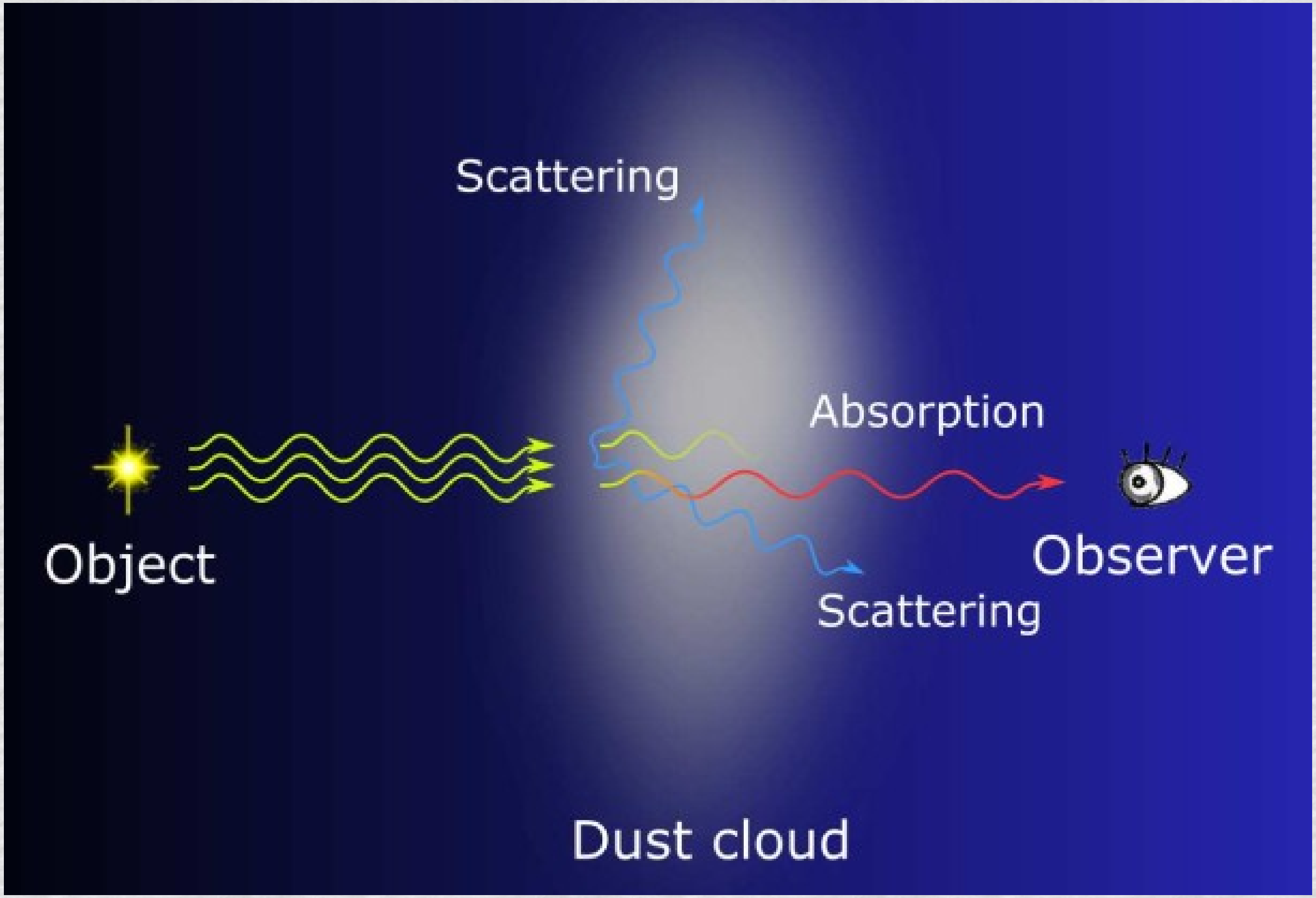
En el rango óptico, la extinción se debe pricipalmente a la dispersión, aunque también hay contribución de la absorción.

Light from a remote star has part of its blue component removed by interfering gas clouds. The result is a redder color for the star.

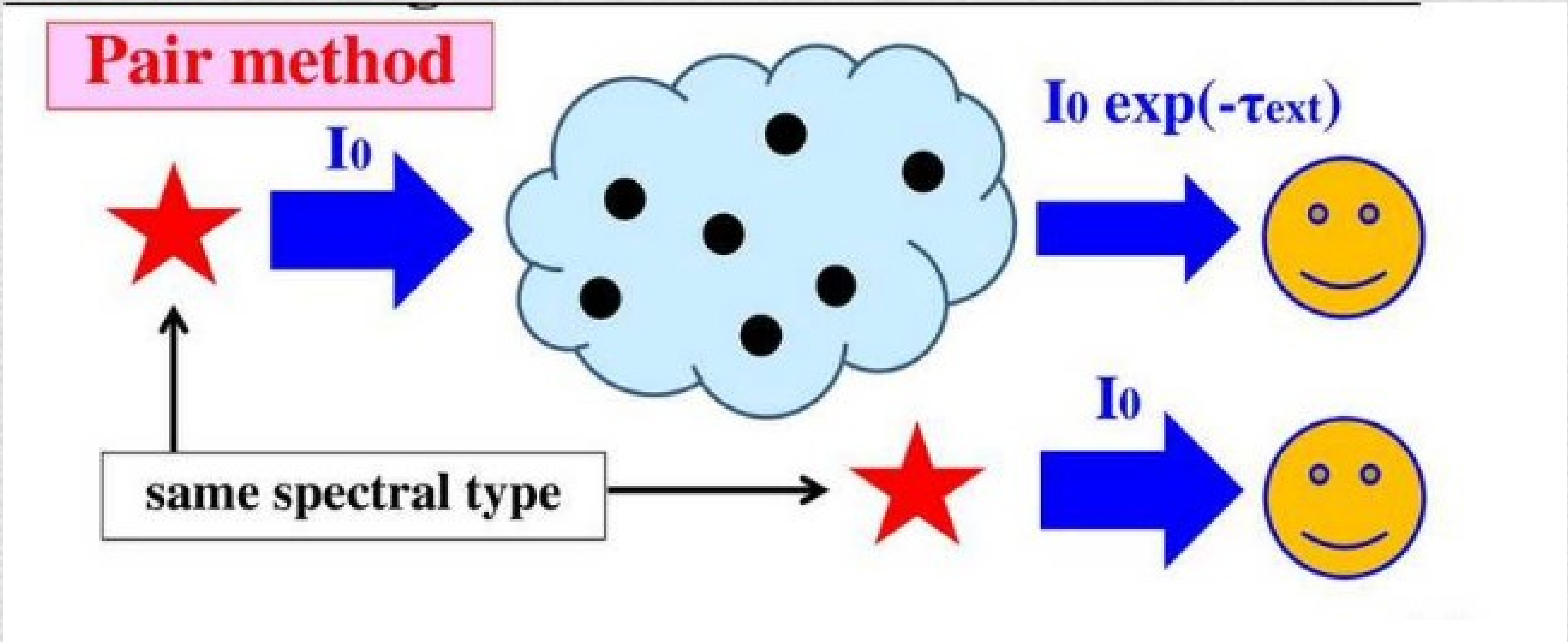




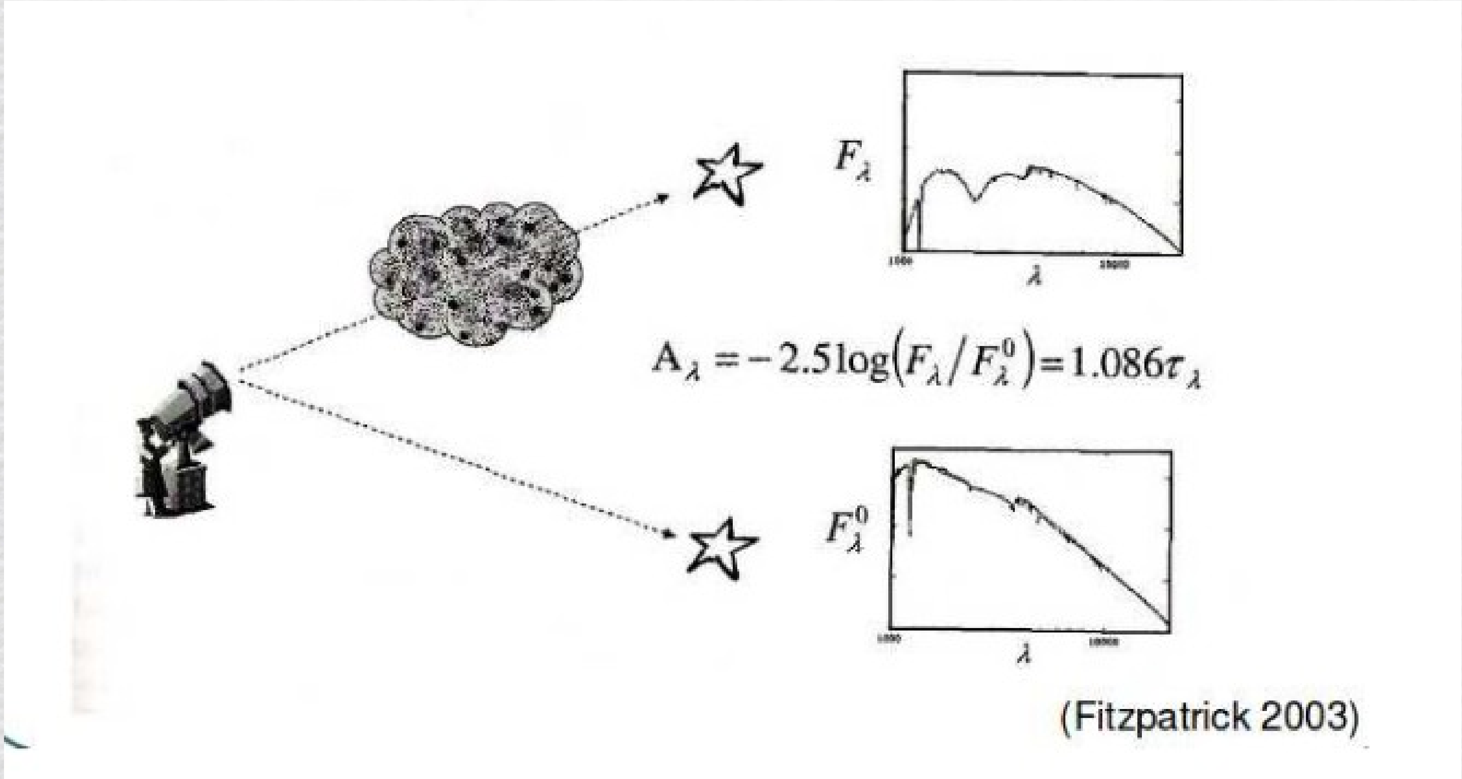
Dust grains along the line of sight scatter and absorb **light** coming from distant objects. We therefore see these objects as dimmer and redder than they really are. These effects are known as **extinction** and **interstellar reddening** respectively.


Scattering
Absorption
Object
Observer
Scattering
Dust cloud

Derivando la curva de extinción

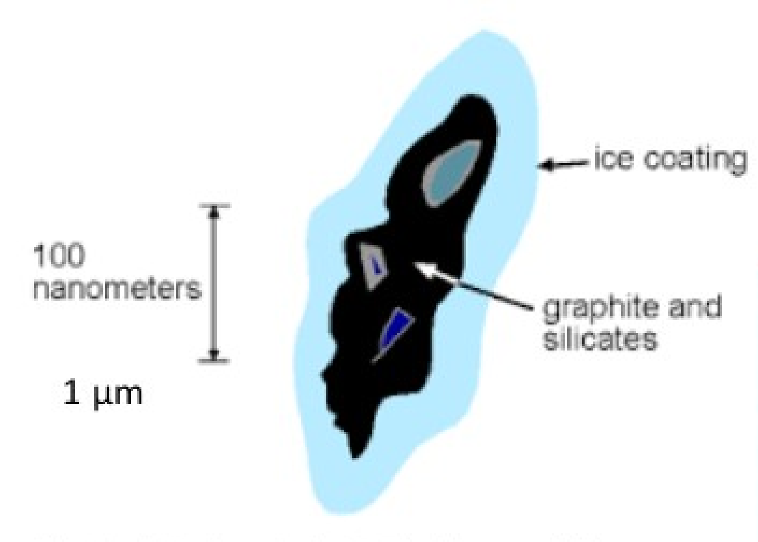


Derivando la curva de extinción

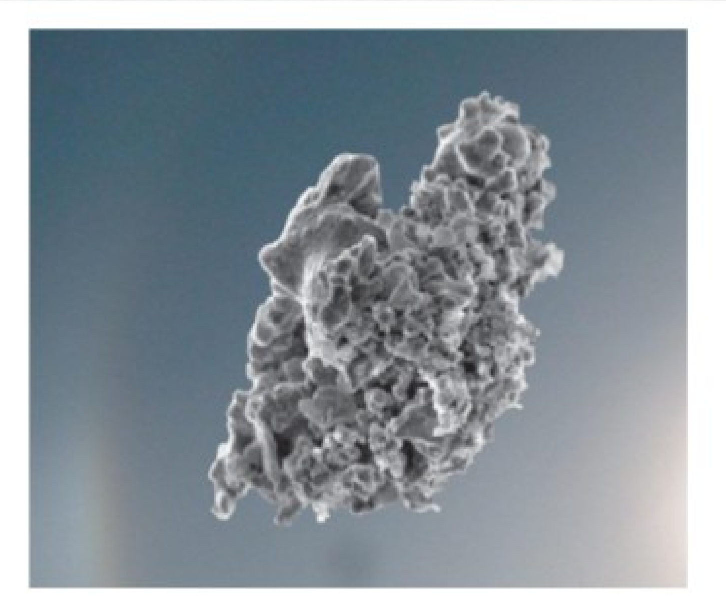


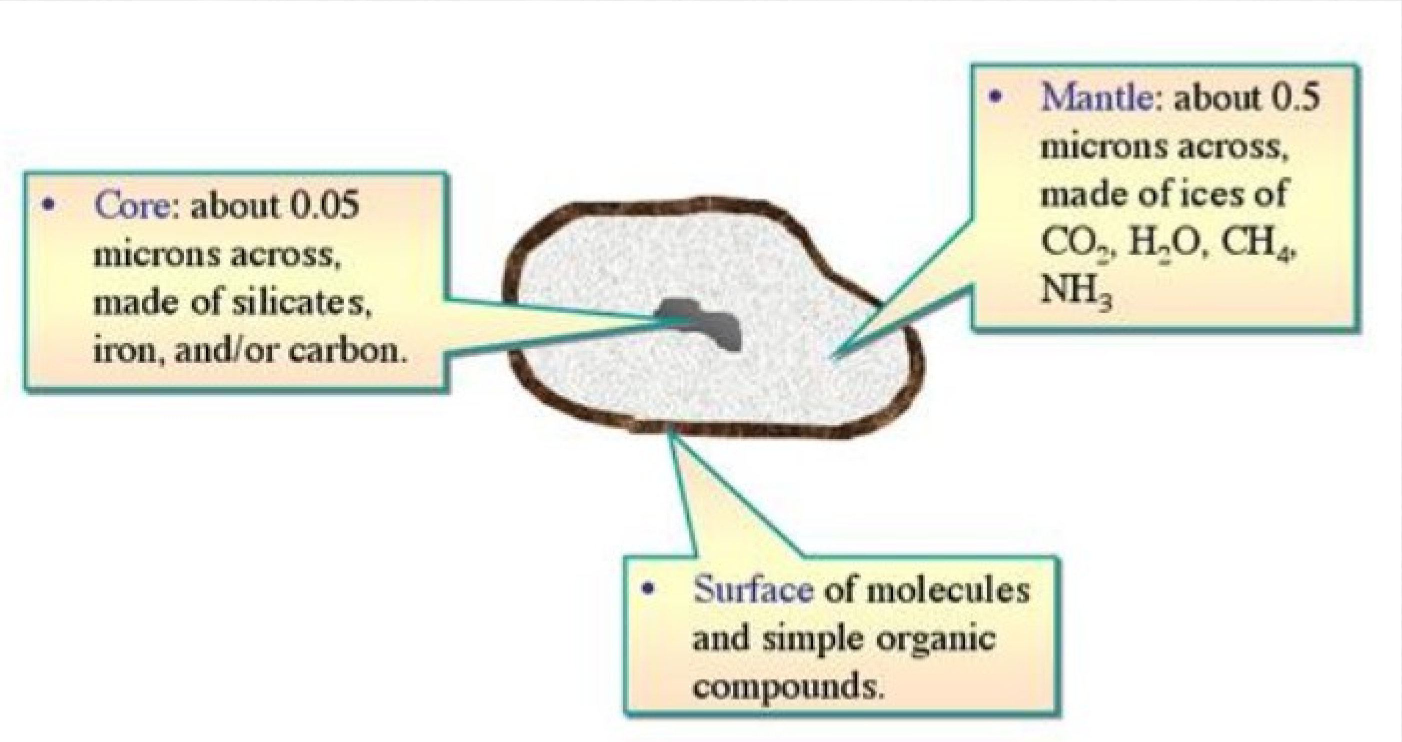
(Fitzpatrick 2003)

Grano de polvo interestelar



A typical dust grain (note the tiny scale!).





Disminución del flujo

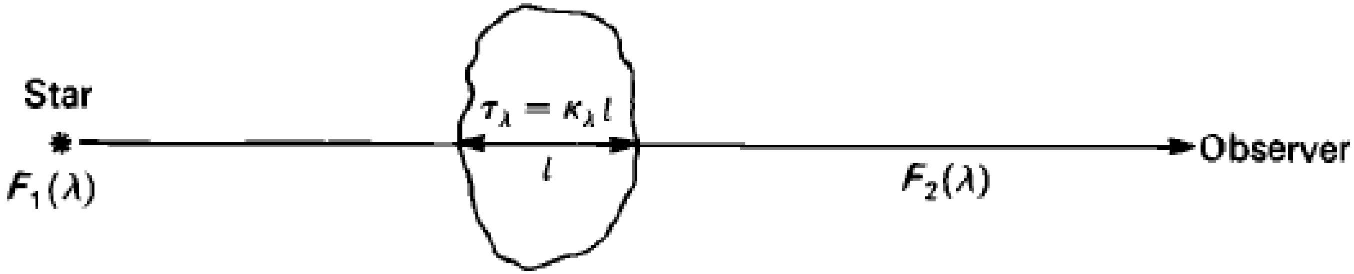


Fig. 19.10. The radiative flux $F(\lambda)$ from a star passes through an interstellar gas cloud and is reduced by the absorption in the cloud. The observed flux $F_2(\lambda) = F_1(\lambda) \cdot e^{-\tau_\lambda}$, where $F_1(\lambda)$ is the flux we would have received without the absorption in the cloud.

Absorción ...

The change in the intensity, dI_λ, of a ray of wavelength λ as it travels through a gas is proportional to its intensity, I_λ, the distance traveled, ds, and the density of the gas, ρ. That is,

$$\boxed{dI_\lambda = -\kappa_\lambda \rho I_\lambda \, ds.} \tag{9.13}$$

The distance s is measured along the path traveled by the beam and increases in the direction that the beam travels; the minus sign in Eq. (9.13) shows that the intensity *decreases* with distance due to the absorption of photons. The quantity κ_λ is called the **absorption coefficient**, or **opacity**, with the λ subscript implicitly indicating that the opacity is wavelength-dependent (κ_λ is sometimes referred to as a *monochromatic opacity*). The opacity is the cross section for absorbing photons of wavelength λ per unit mass of stellar material and has units of $m^2\ kg^{-1}$. In general, the opacity of a gas is a function of its composition, density, and temperature.[11]

Enrojecimiento interestelar y absorción (extinción)

- $U = U_o + A_U$
- $B = B_o + A_B$
- $V = V_o + A_V$

A_V es la absorción o extinción en V. Análogamente para los filtros B, U, etc.

Enrojecimiento interestelar y absorción (extinción)

- $U = U_o + A_U$
- $B = B_o + A_B$
- $V = V_o + A_V$

A_V es la absorción o extinción en V. Análogamente para los filtros B, U, etc.

$$(B\text{-}V)_o = (B - V) - (A_B - A_V)$$

$$(B\text{-}V)_o = (B\text{-}V) - \boxed{E(B\text{-}V)}$$

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

Enrojecimiento interestelar y absorción (extinción)

- $U = U_o + \boxed{A_U}$
- $B = B_o + \boxed{A_B}$
- $V = V_o + \boxed{A_V}$

A_V es la absorción o extinción en V. Análogamente para los filtros B, U, etc.

$$(B\text{-}V)_o = (B - V) - (A_B - A_V)$$

$$(B\text{-}V)_o = (B\text{-}V) - \boxed{E(B\text{-}V)}$$

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

$$\boxed{E(U\text{-}B) = A_U - A_B}$$

Enrojecimiento interestelar y absorción (extinción)

- $U = U_o + A_U$
- $B = B_o + A_B$
- $V = V_o + A_V$

A_V es la absorción o extinción en V. Análogamente para los filtros B, U, etc.

$$(B\text{-}V)_o = (B - V) - (A_B - A_V)$$

$$(B\text{-}V)_o = (B\text{-}V) - \boxed{E(B\text{-}V)}$$

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

$$\boxed{E(U\text{-}B) = A_U - A_B}$$

- Definición Enrojecimiento o Exceso de Color:

$$\boxed{\begin{array}{l} E(B\text{-}V) = (B\text{-}V) - (B\text{-}V)_o \\ E(U\text{-}B) = (U\text{-}B) - (U\text{-}B)_o \end{array}}$$

Curva de extinción interestelar

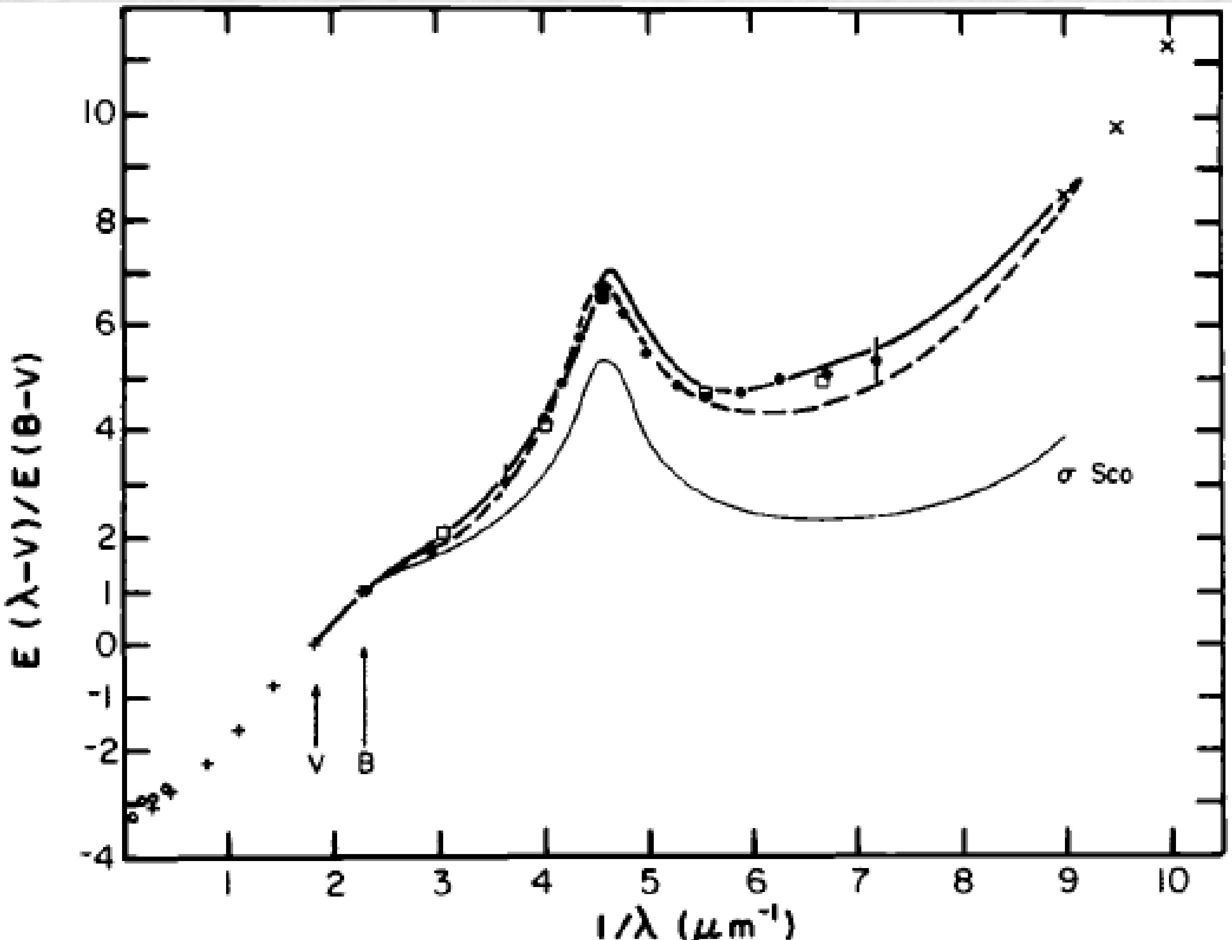
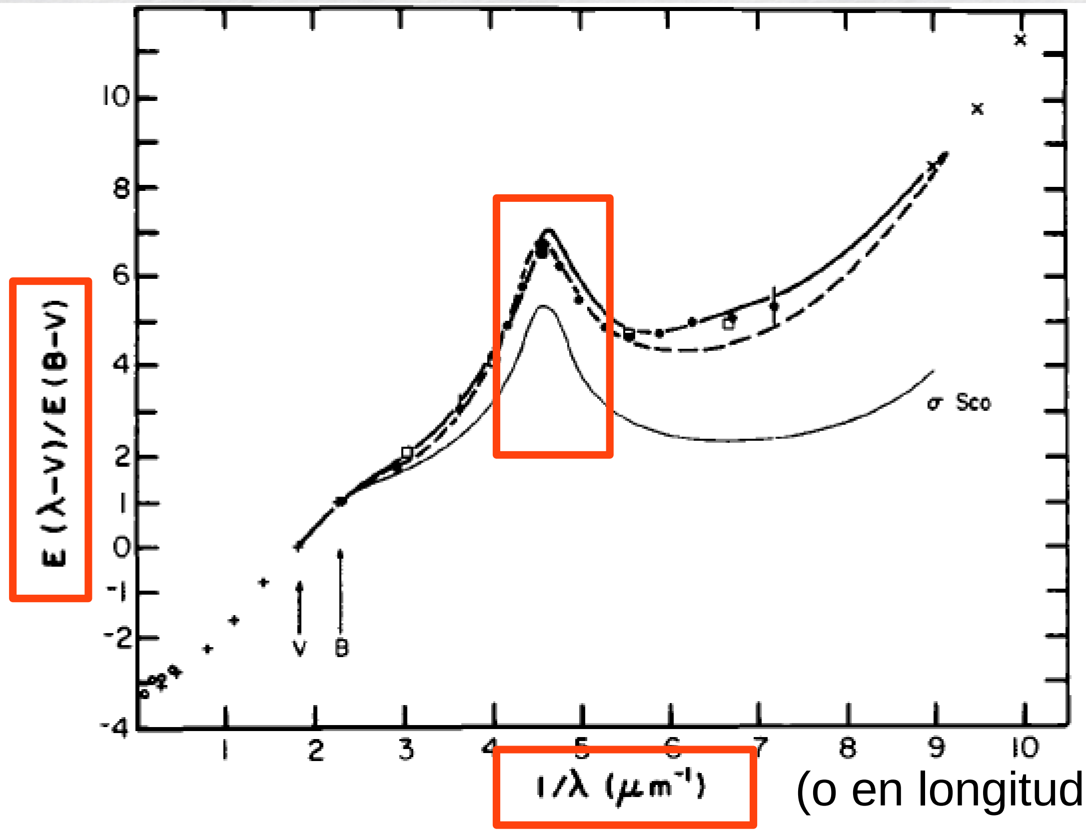


Fig. 19.12. Interstellar extinction curves, $m_\lambda - m_V$, per $E(B-V) = 1$, also written as $(A_\lambda - A_V)/E(B-V)$, or $E(\lambda - V)/E(B-V)$, are shown as a function of $1/\lambda$, where λ is the wavelength of the light measured in μ. ($1\mu = 10^4$ Å). The bump occurs at 2200 Å. The average extinction curve is shown as the dashed line. Low extinctions in the ultraviolet are relatively rare and do not influence the average very much.

Curva de extinción interestelar

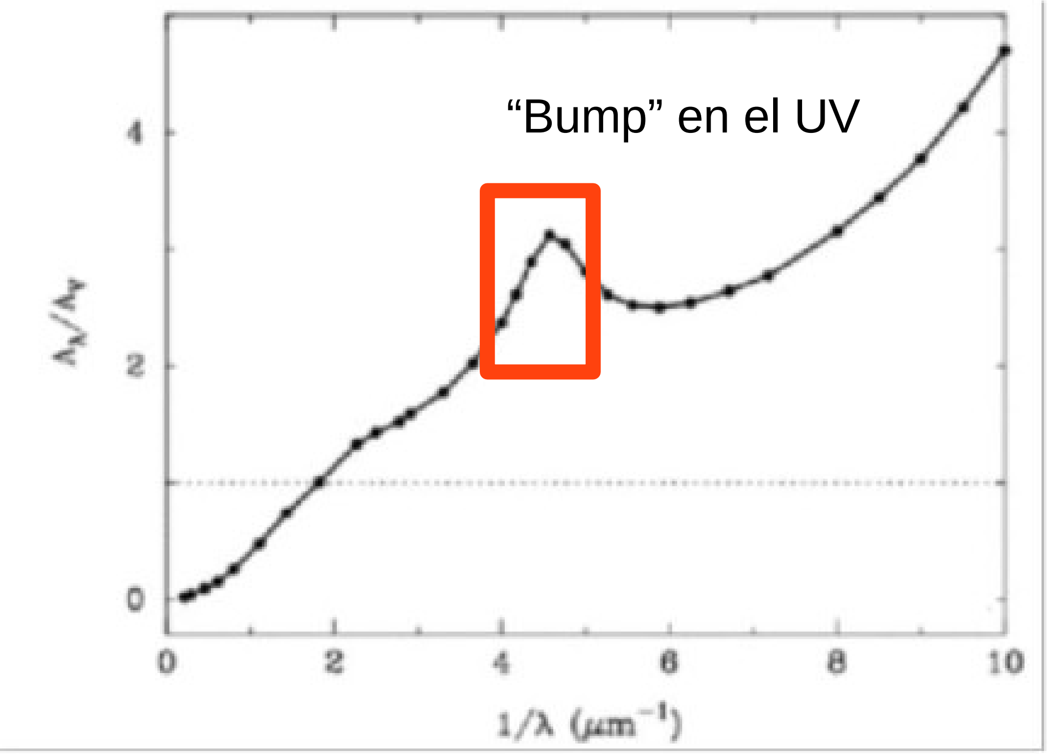
Normalizada



(o en longitud de onda)

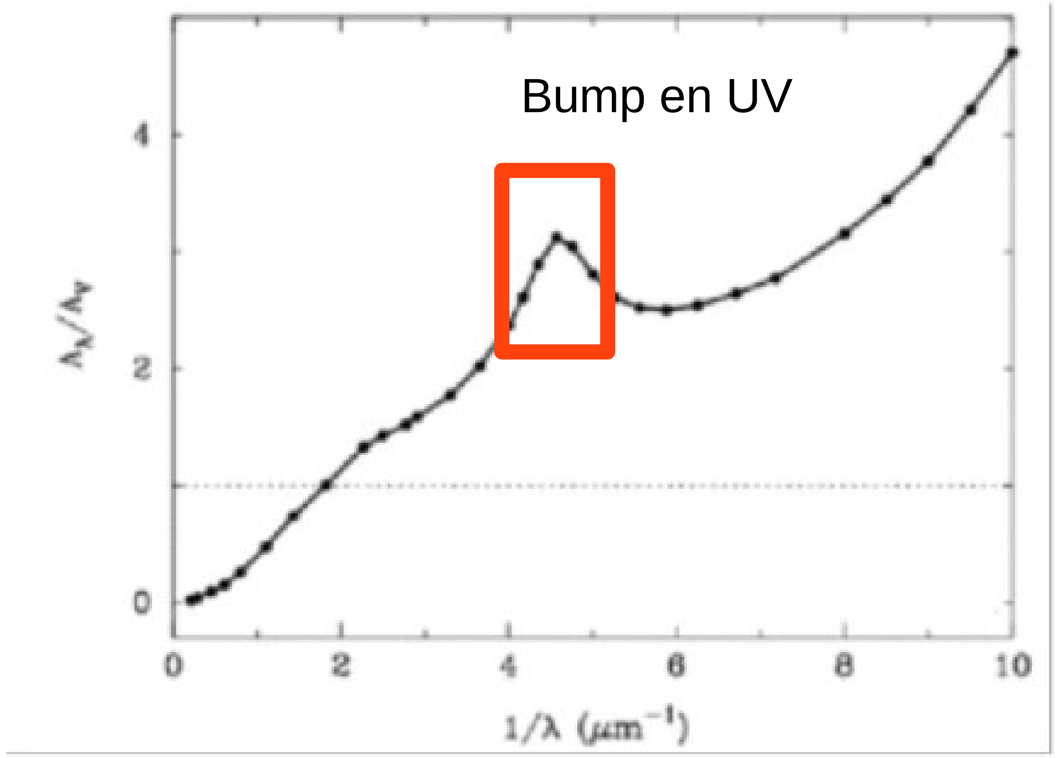
Fig. 19.12. Interstellar extinction curves, $m_\lambda - m_V$, per $E(B-V) = 1$, also written as $(A_\lambda - A_V)/E(B-V)$, or $E(\lambda - V)/E(B-V)$, are shown as a function of $1/\lambda$, where λ is the wavelength of the light measured in μ. ($1\mu = 10^4$ Å). The bump occurs at 2200 Å. The average extinction curve is shown as the dashed line. Low extinctions in the ultraviolet are relatively rare and do not influence the average very much.

The interstellar extinction for the short wavelengths does not look like Mie curves seen in Fig. 9.10. (From Dyson & Williams 1980.)



Band	λ [nm]	A_λ/A_V
U	360	1.531
B	450	1.324
V	550	1
R	660	0.748
I	800	0.482
J	1250	0.282
H	1650	0.175
K	2200	0.112
L	3500	0.058
M	4800	0.023

$A_{\lambda 1}$, $A_{\lambda 2}$ la extinción en $\lambda 1$ y $\lambda 2$.



Band	λ [nm]	A_λ/A_V
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R	660	0.748
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J	1250	0.282
H	1650	0.175
K	2200	0.112
L	3500	0.058
M	4800	0.023

En el caso del sistema UBV, la razón entre la absorción total en la banda V (A_V) y la selectiva en el intervalo (λ_B,λ_V) se define como:

$$\boxed{R = \frac{A_V}{A_B - A_V} = \frac{A_V}{E(B-V)}}$$

$$\boxed{R = 3.1 \pm 0.2}$$

Curva de extinción interestelar MW

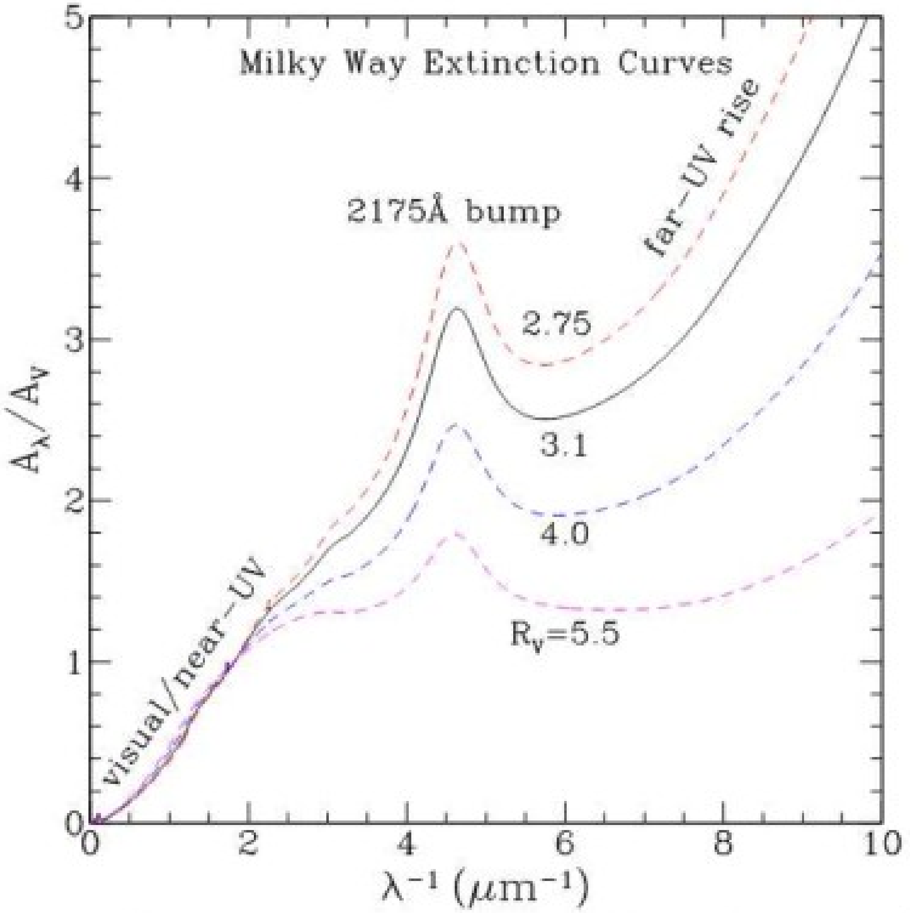


Figure 1. Interstellar extinction curves of the Milky Way ($R_V = 2.75$, 3.1, 4.0, 5.5). There exist considerable regional variations in the Galactic optical/UV extinction curves, as characterized by the total-to-selective extinction ratio R_V, indicating that dust grains on different sightlines have different size distributions.

Curva de extinción interestelar MW, LMC, SMC y AGN

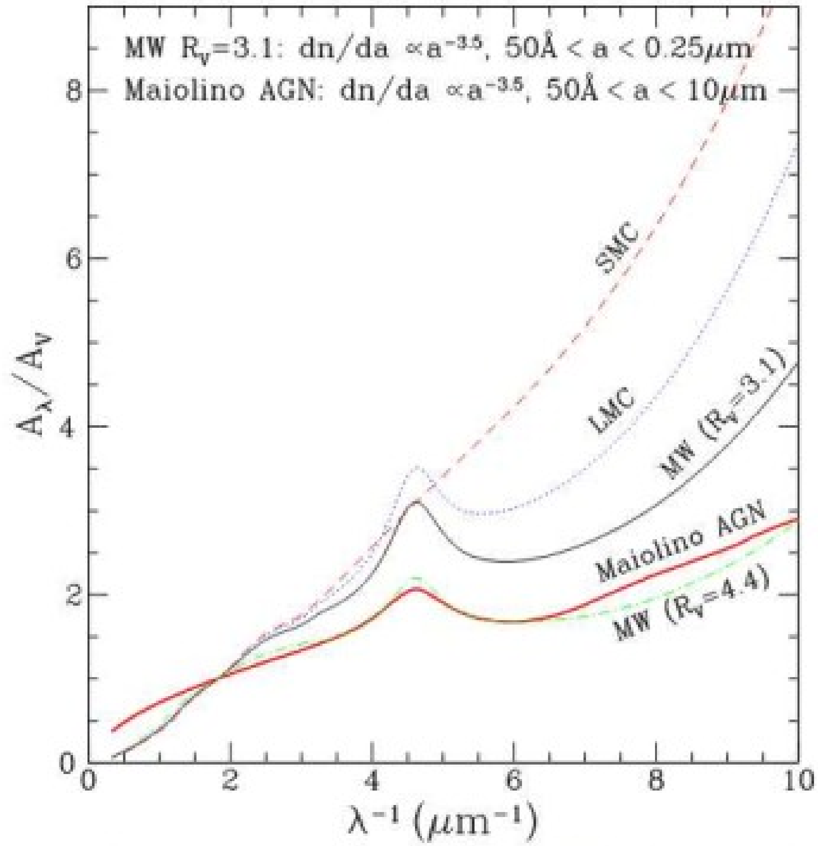
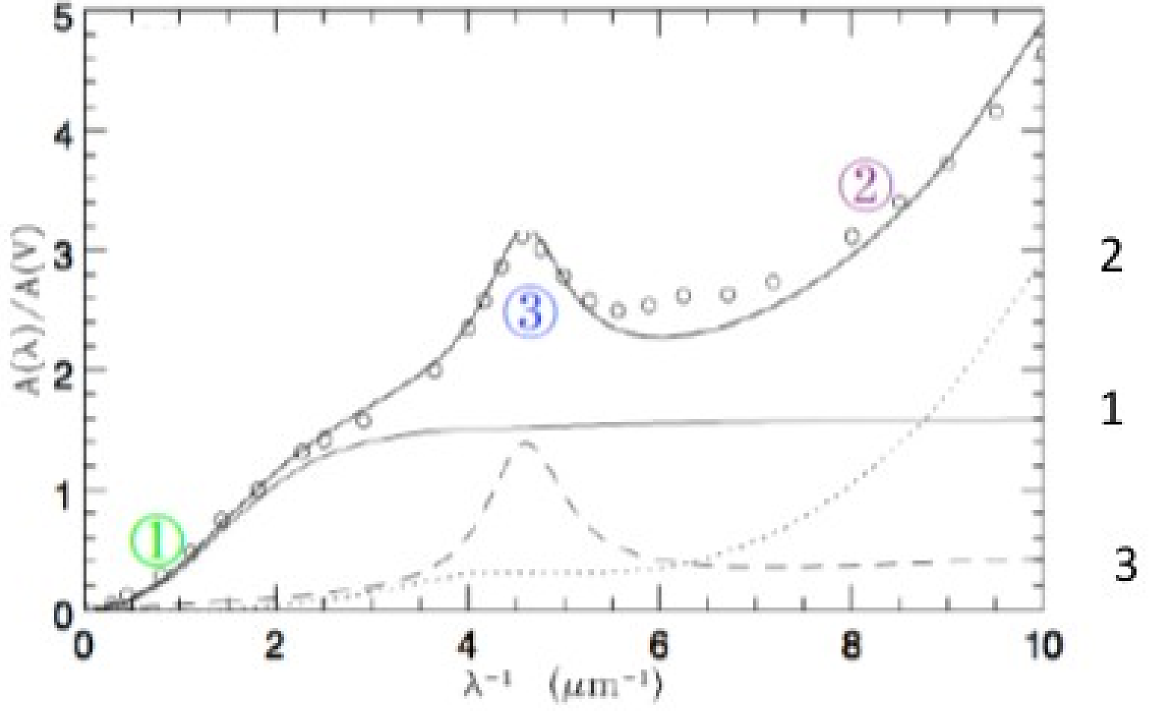
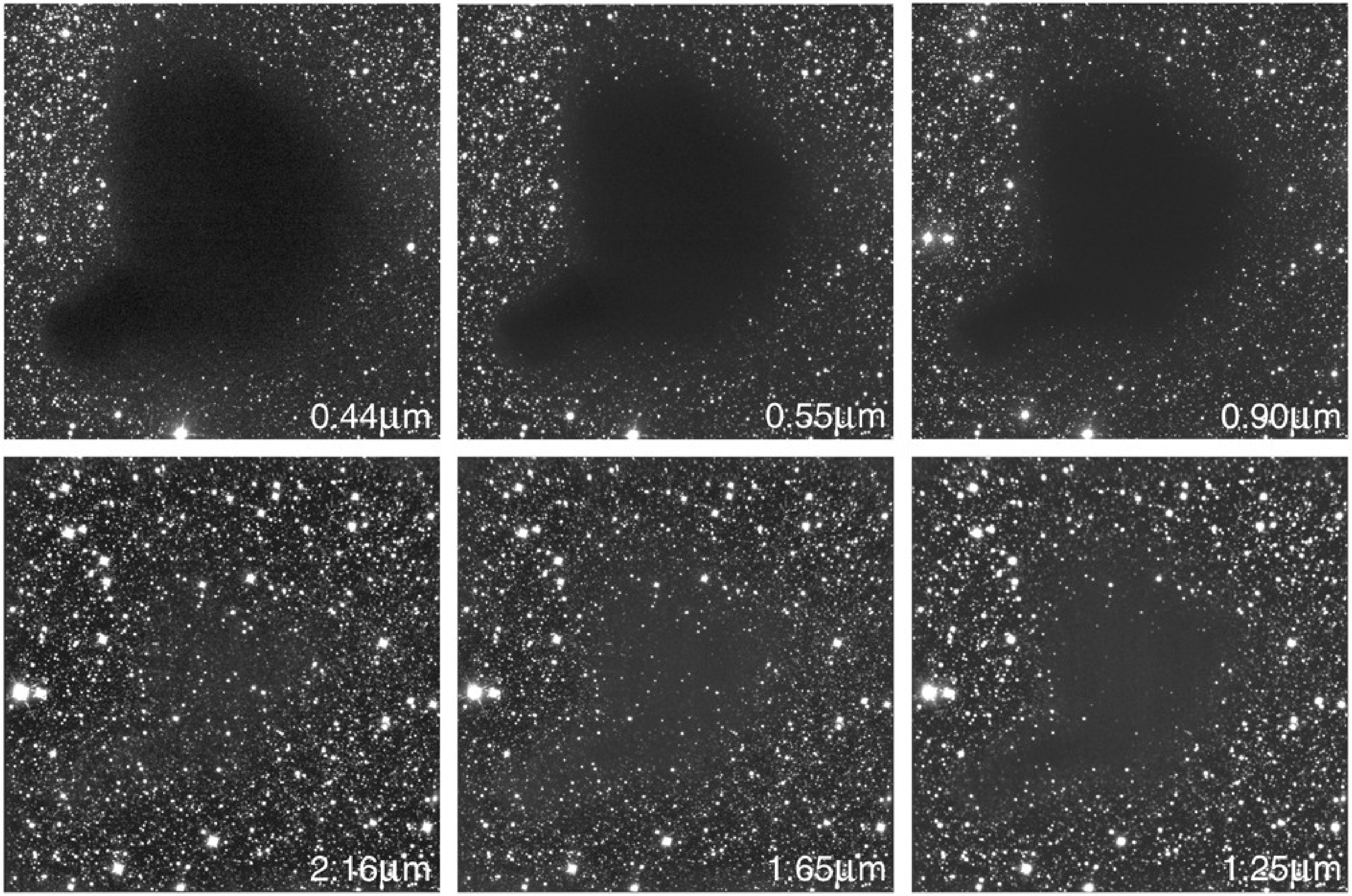


Figure 2. Interstellar extinction curves of the Milky Way ($R_V = 3.1$, 4.4), SMC, and LMC. Also plotted is the "Maiolino"-type extinction curve for AGNs (similar to the Galactic $R_V = 4.4$ curve) produced by a mixture of interstellar silicate and graphite grains with a size distribution of $dn/da \sim a^{-3.5}$ ($50\,\text{Å} < a < 10\,\mu\text{m}$), the same as that for the Galactic average $R_V = 3.1$ except with a smaller upper cutoff for the latter ($50\,\text{Å} < a < 0.25\,\mu\text{m}$).

Observable	Interpretación
Continua extinción de la luz estelar	Presencia de partículas sólidas
1 - Extinción prop 1/λ en el Visible	Partículas con tamaño de 0.3 µm
2 - Rápido aumento en el UV	Partículas con tamaño < 0.1 m
3 - Incremento local en 2175 Å	Partículas pequeñas ricas en C



Absorción “selectiva”



The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

ESO PR Photo 29b/99 (2 July 1999)

PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC, **111**:63–75, 1999 January

Correcting for the Effects of Interstellar Extinction

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ABSTRACT. This paper addresses the issue of how best to correct astronomical data for the wavelength-dependent effects of Galactic interstellar extinction. The main general features of extinction from the IR through the UV are reviewed, along with the nature of observed spatial variations. The enormous range of extinction properties found in the Galaxy, particularly in the UV spectral region, is illustrated. Fortunately, there are some tight constraints on the wavelength dependence of extinction and some general correlations between extinction curve shape and interstellar environment. These relationships provide some guidance for correcting data for the effects of extinction. Several strategies for dereddening are discussed along with estimates of the uncertainties inherent in each method. In the Appendix, a new derivation of the wavelength dependence of an average Galactic extinction curve from the IR through the UV is presented, along with a new estimate of how this extinction law varies with the parameter $R \equiv A(V)/E(B-V)$. These curves represent the true monochromatic wavelength dependence of extinction and, as such, are suitable for dereddening IR–UV spectrophotometric data of any resolution and can be used to derive extinction relations for any photometry system.

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A precise knowledge of the wavelength dependence of interstellar extinction (i.e., the absorption and scattering of light by interstellar dust grains) and of any spatial variability in this dependence is important for two distinct reasons. First, the extinction depends on the optical properties of the dust grains along a line of sight and potentially can reveal information about the composition and size distribution of the grains. Further, changes in the extinction from place to place may reveal the degree and nature of dust grain processing occurring in the ISM. Second, the wavelength dependence of extinction is required to remove the effects of dust obscuration from observed energy distributions, since most astronomical objects are viewed through at least some small amount of interstellar dust. Spatial variations in the extinction potentially limit the accuracy to which energy distributions can be "dereddened." Such uncertainties might be acceptably small for very lightly reddened objects but quickly can become debilitating along modestly reddened sight lines.

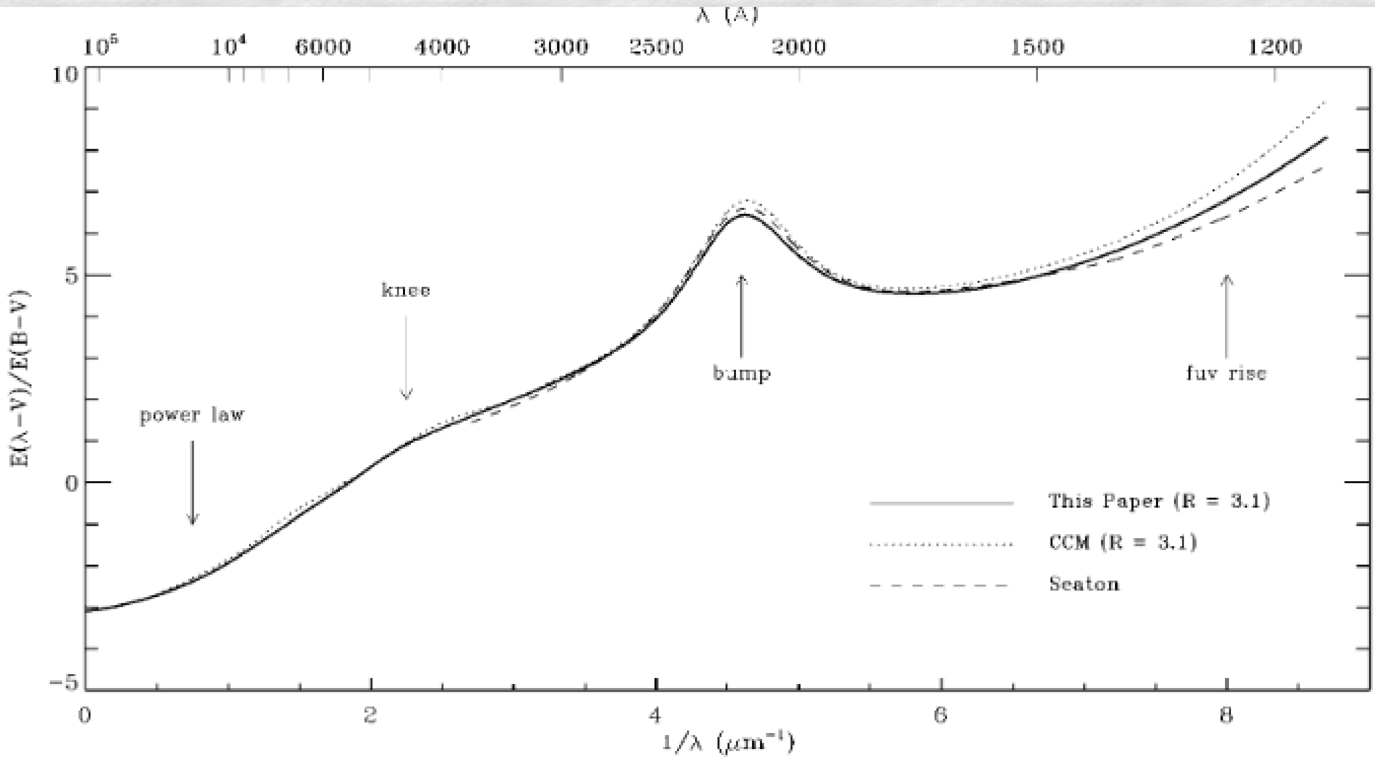


FIG. 1.—Normalized interstellar extinction curves from the far-IR through the UV. Several general features of the curves are noted. The solid and dotted curves are estimates for the case $R \equiv A(V)/E(B-V) = 3.1$ derived in the Appendix of this paper and by Cardelli et al. (1989), respectively. The dashed curve shows the average Galactic UV extinction curve from Seaton (1979).

Diagrama color-color (DCC-CCD): el vector enrojecimiento

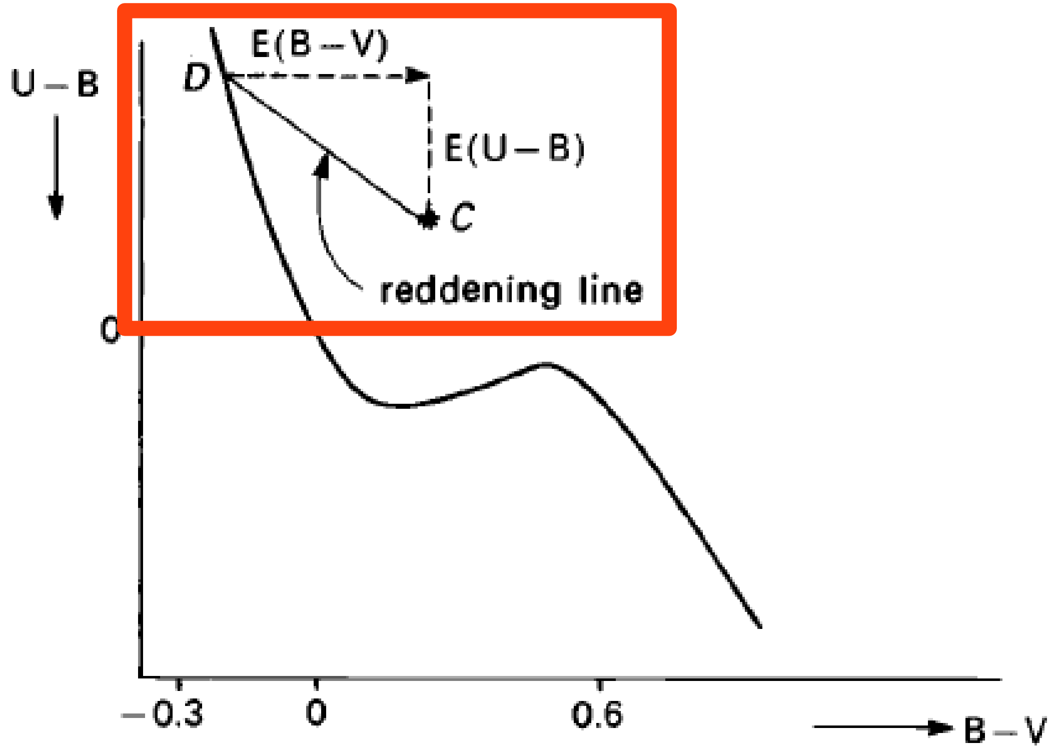
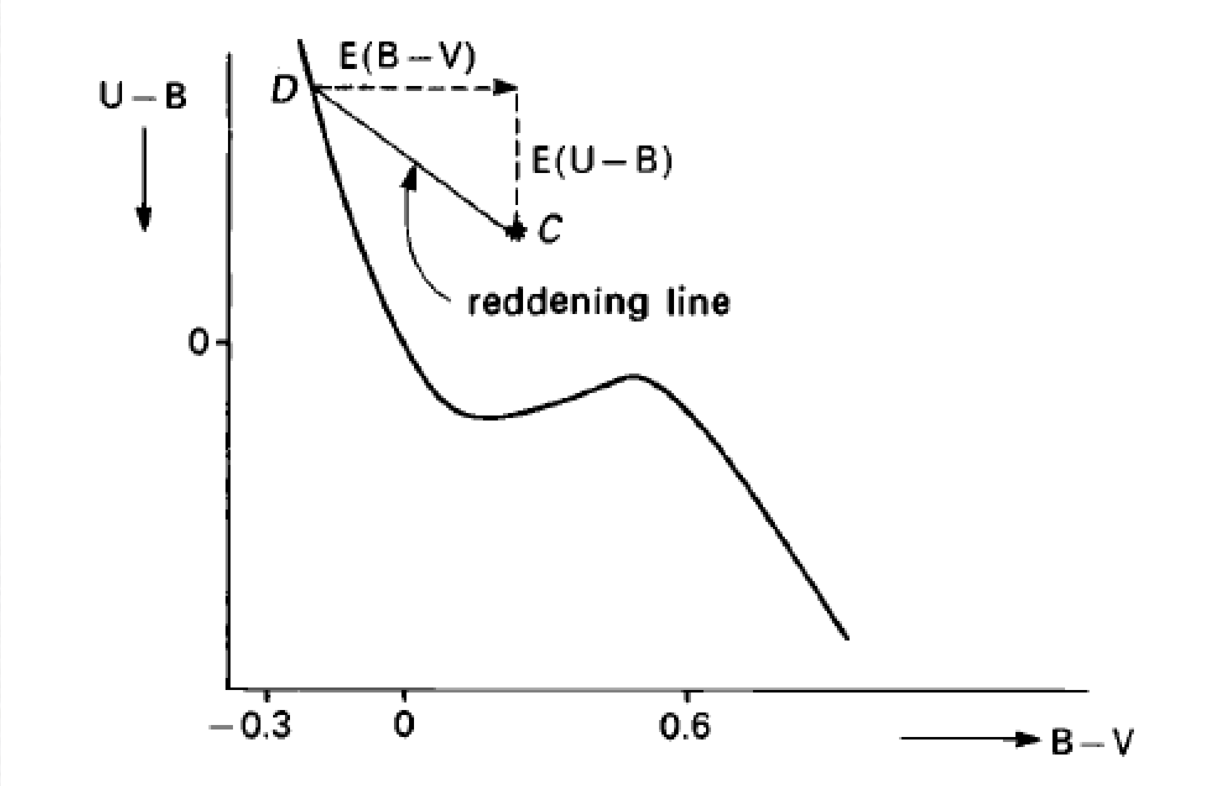


Fig. 19.7. The two-color diagram for the true colors of the stars is shown schematically by the solid line. Also shown is a point (*) for the observed colors of a star *C*. The direction of the reddening line E(U − B)/E(B − V) = 0.72 is also drawn in. Following the direction to the 'true' color line of normal stars tells us what the unreddened colors are of the observed star (point *D*).

- La línea continua indica los colores reales (~~enrojecimiento~~) de las estrellas (secuencia principal).
- C indica los colores observados de la estrella.
- Se indica el vector de enrojecimiento E(U-B)/E(B-V) = 0.72.
- Siguiendo al vector de enrojecimiento se lleva al punto C a la posición D, sobre la secuencia principal “desenrojecida”, lo cual permite determinar los índice de color intrínsecos de la estrella.



UNIVERSITY OF CALIFORNIA PUBLICATIONS

ASTRONOMY

LICK OBSERVATORY BULLETIN

NUMBER 420

PRELIMINARY RESULTS ON THE DISTANCES, DIMENSIONS AND SPACE DISTRIBUTION OF OPEN STAR CLUSTERS

BY

ROBERT J. TRUMPLER

Although the observations of magnitudes and spectral types in open star clusters of the Milky Way undertaken by the writer are still far from being complete, it seemed of interest to utilize the data at present available for a preliminary investigation of the distances and diameters of these clusters and for a study of their space distribution.

The mean absolute magnitudes of the spectral subdivisions have been determined by various observers from trigonometric and moving cluster parallaxes or statistically from proper-motions. The values used are given in Table 1 and are mainly based on the determinations of Adams & Joy[1], Lundmark[2], Malmquist[3], and Hess[4]:

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11. The Apparent Distribution of Open Star Clusters

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distances and diamet … , Lundmark[2], Malm-
study of their space di …

TABLE 18

Apparent Distribution of Open Clusters According to Galactic Longitude

Galactic longitude	Number of clusters	Constellations
0°– 20°	5	Aquila.
20 – 40	7	Vulp.-Cygn.
40 – 60	15	Cygnus.
60 – 80	19	Cygn.-Ceph.-Lac.
80 –100	21	Cassiop.
100 –120	19	Camel.-Perseus
120 –140	11	Pers.-Auriga
140 –160	17	Auriga-Taur.-Gem.
160 –180	19	Monoceros.
180 –200	27	Monoc.-Can. Major
200 –220	27	Puppis
220 –240	14	Puppis-Vela.
240 –260	29	Vela-Carina
260 –280	22	Crux-Cent.
280 –300	19	Circin.-Norm.
300 –320	22	Norma-Scorp.
320 –340	22	Scorp.-Sag.-Ophiuch.
340 –360	19	Sagittar.-Scutum.
	334	

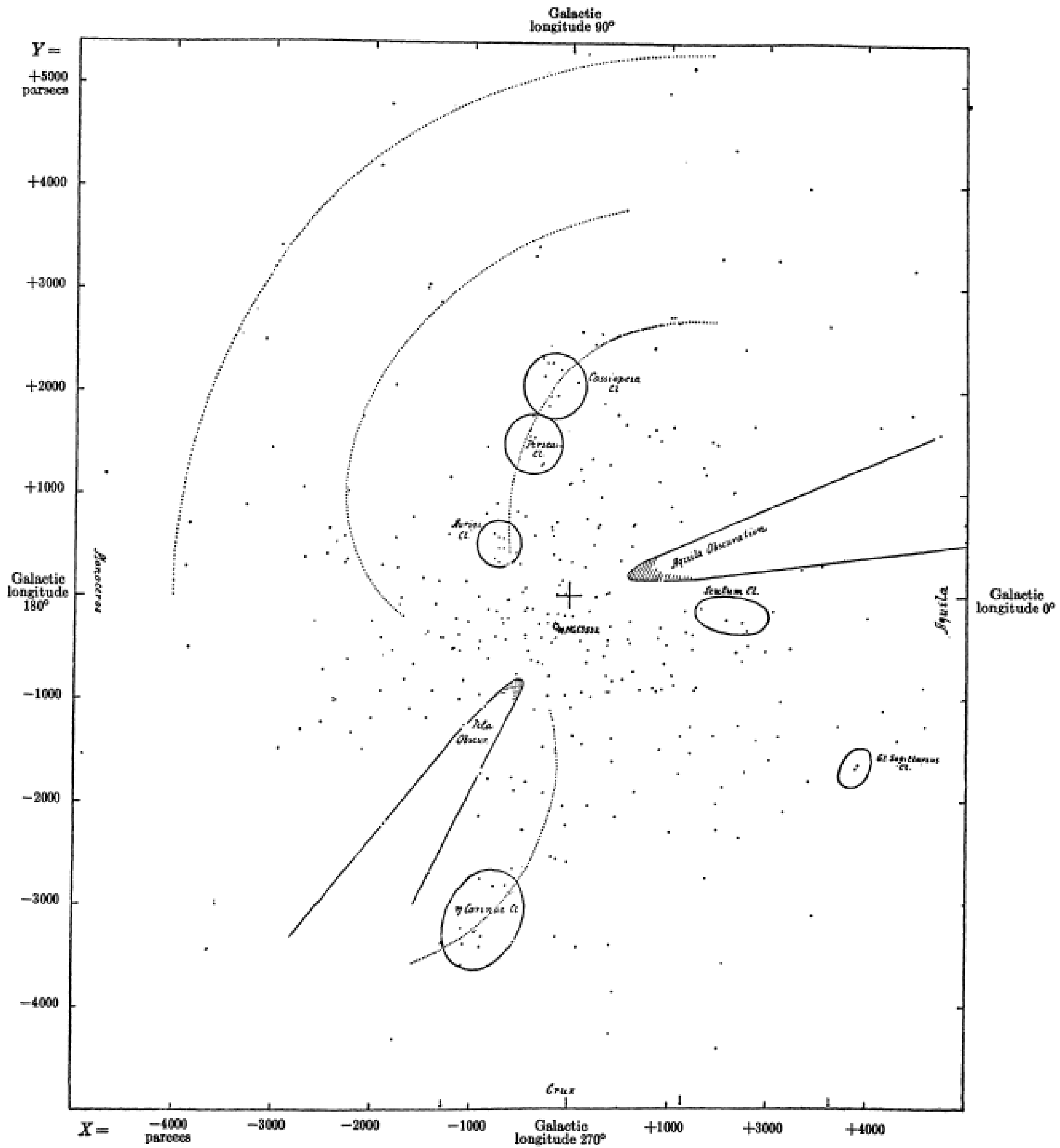

Fig. 8. Special features of the cluster system.

This figure gives a projection of the clusters on the galactic plane like Fig. 4. The position of the Sun is marked by a cross, that of the median point of the system by an open circle, the cluster NGC 3532 by an asterisk. Some traces of spiral structure are indicated by the dotted lines; the large open circles or ovals represent the probable location of cluster groups or star clouds, the shaded areas, dark clouds of absorbing material with their sectors of obscuration.

7. Absorption of Light in the Milky Way System

Our method of deriving cluster distances from magnitudes and spectral types was based on formula (1) which expresses the law that the apparent brightness of a star diminishes with the square of the distance from the observer. If interstellar space is not perfectly transparent this law does not hold; the apparent brightness decreases more rapidly, our distance results are too large, and the error increases with the distance of the cluster. The linear diameters computed with these distance results are then also too large, and the error also progresses with distance, just like the residuals in column 3 of Table 10.

It is natural to interpose here the question why such an absorption of light should not have been discovered in the discussion of the diameters of globular clusters which are much more distant, and how it is possible that we still find small color-indices in some globular clusters (such as Messier 13) despite of their great distances. There is only one way which seems to lead out of the dilemma: the hypothesis that the absorbing medium, like the open clusters, is very much concentrated toward the galactic plane. We

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THE OPTICAL–INFRARED EXTINCTION CURVE AND ITS VARIATION IN THE MILKY WAY

E. F. Schlafly[1,2,14], A. M. Meisner[2,3], A. M. Stutz[1], J. Kainulainen[1], J. E. G. Peek[4], K. Tchernyshyov[5], H.-W. Rix[1], D. P. Finkbeiner[6,7], K. R. Covey[8], G. M. Green[6], E. F. Bell[9], W. S. Burgett[10], K. C. Chambers[11], P. W. Draper[12], H. Flewelling[11], K. W. Hodapp[11], N. Kaiser[11], E. A. Magnier[11], N. F. Martin[1,13], N. Metcalfe[12], R. J. Wainscoat[11], and C. Waters[11]

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The dust extinction curve is a critical component of many observational programs and an important diagnostic of the physics of the interstellar medium. Here we present new measurements of the dust extinction curve and its variation toward tens of thousands of stars, a hundred-fold larger sample than in existing detailed studies. We use data from the APOGEE spectroscopic survey in combination with ten-band photometry from Pan-STARRS1, the Two Micron All-Sky Survey, and *Wide-field Infrared Survey Explorer*. We find that the extinction curve in the optical through infrared is well characterized by a one-parameter family of curves described by $R(V)$. The extinction curve is more uniform than suggested in past works, with $\sigma(R(V)) = 0.18$, and with less than one percent of sight lines having $R(V) > 4$. Our data and analysis have revealed two new aspects of Galactic extinction: first, we find significant, wide-area variations in $R(V)$ throughout the Galactic plane. These variations are on scales much larger than individual molecular clouds, indicating that $R(V)$ variations must trace much more than just grain growth in dense molecular environments. Indeed, we find no correlation between $R(V)$ and dust column density up to $E(B-V) \approx 2$. Second, we discover a strong relationship between $R(V)$ and the far-infrared dust emissivity.

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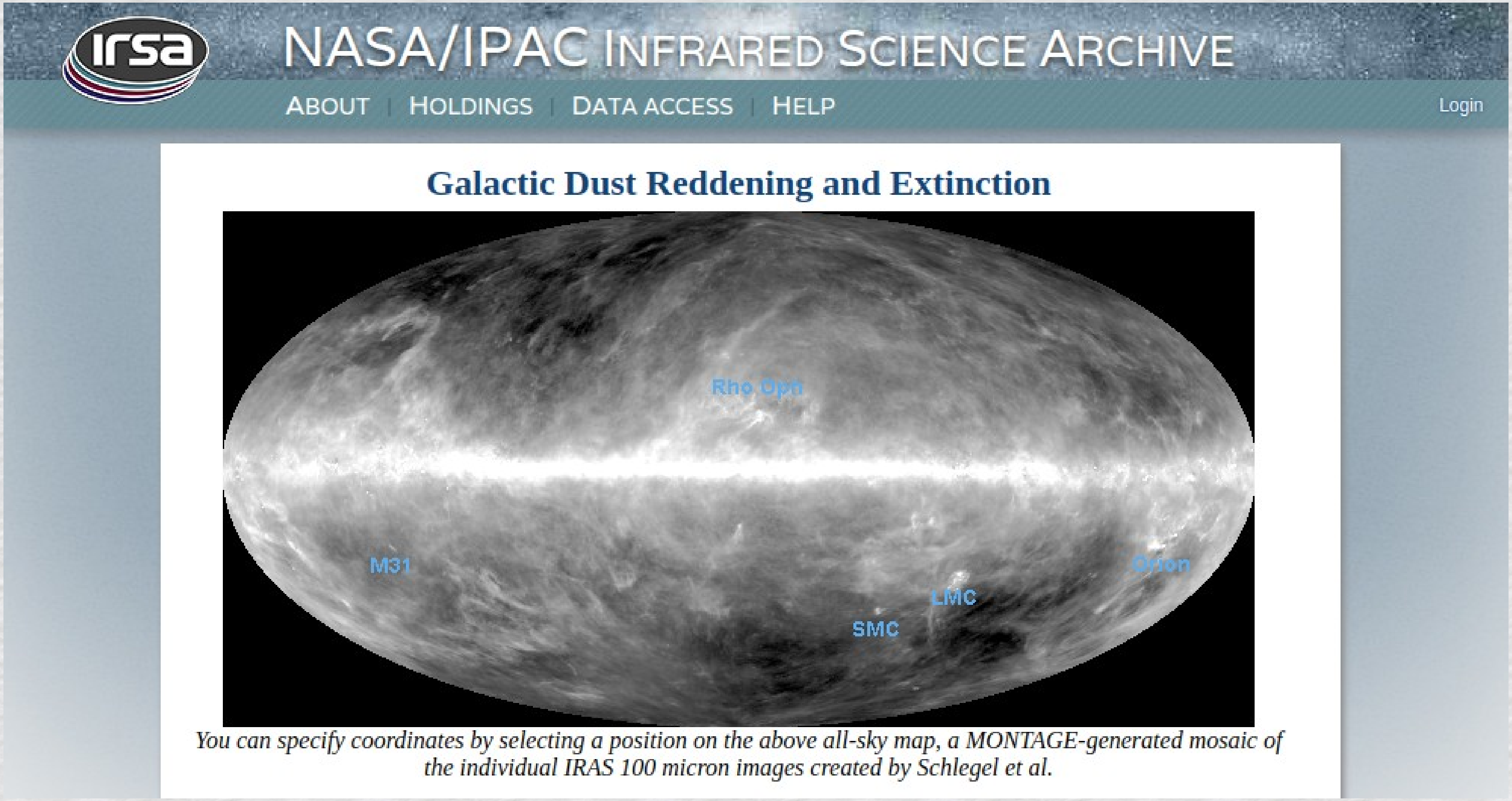
Dust is composed of small, solid grains of material. These grains are made of heavy elements formed from nuclear fusion in stars, blown into the interstellar medium (ISM) by stellar winds and explosions. The dust grains scatter and absorb light. Owing to the small size of the grains, dust preferentially scatters and absorbs blue light relative to red light in the optical through infrared. The resulting extinction as a function of wavelength is called the dust extinction curve (Draine 2003).

Effective parameterizations of the dust extinction curve in the ultraviolet (UV) and optical were developed by Fitzpatrick & Massa (1986, 1988). The work of Cardelli et al. (1989, CCM) showed that much of the variation could be described by a single parameter, $R(V) = A(V)/E(B - V)$, the total-to-selective extinction ratio, though especially in the UV this description is far from complete.

The shape of the extinction curve is a valuable diagnostic of the properties of the dust. Variation in $R(V)$ is sometimes attributed to variation in the size distribution of dust grains;

NED NASA/IPAC Extragalactic Database

https://ned.ipac.caltech.edu/extinction_calculator



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