Interstellar Dust and Gas

The H-R Diagram is a plot of

a) H vs. R
b) apparent magnitudes of stars vs. their spectral types
c) absolute magnitudes of stars vs. their masses
d) luminosities of stars in L_{sun} vs. their photospheric temperatures
e) masses of stars vs. the letters OBAFGKM

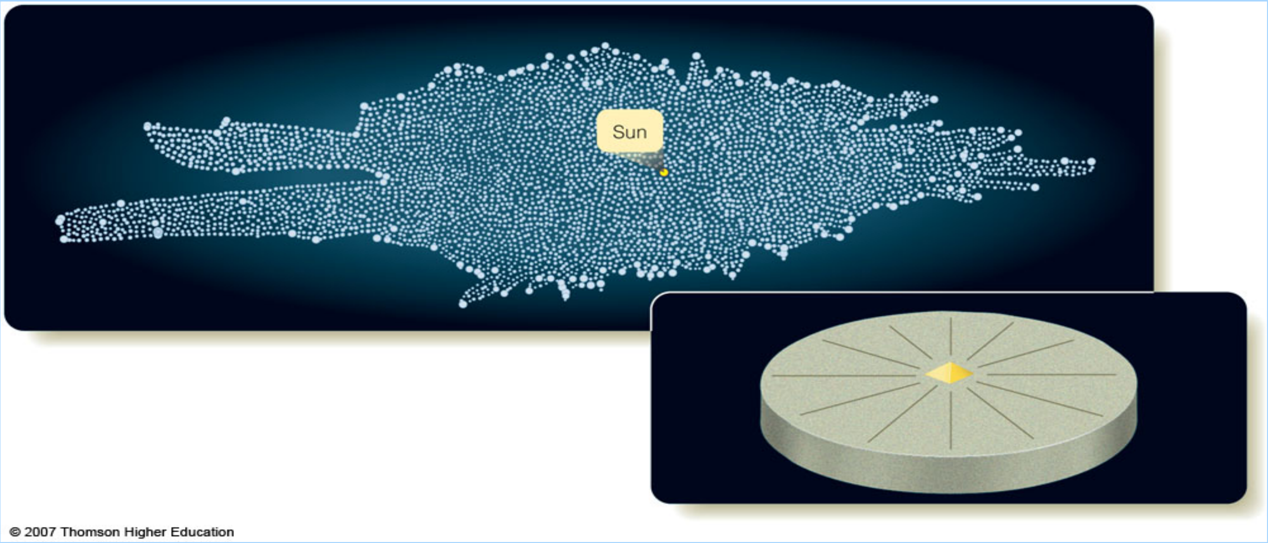
The most important parameter related to how long a star lasts as a main sequence star is

a. its initial composition
b. its mass
c. its rotation rate
d. the depth of its outer convection zone

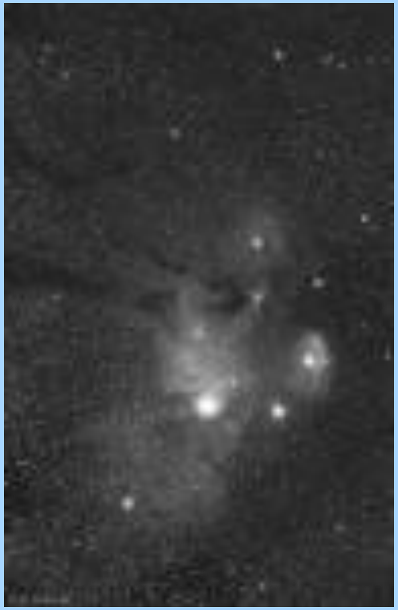
What is the length of the main sequence lifetime of a star with a mass of 2 solar masses?

a. 0.2 billion years
b. 1.7 billion years
c. 20 billion years
d. 56 billion years

In 1783 William Herschel began a survey of the heavens using an 18 ¾ inch reflector of his own construction. His goal was to discover new star clusters, nebulae, and double stars. He made counts of the numbers of stars seen in his 15 arcmin field of view and eventually produced this model of our Galaxy:



To his surprise, when surveying the sky between declination -22 and -24 deg near Scorpius, he found a region devoid of stars. He said to his sister, who was his observing assistant, "Hier ist wahrhaftig ein Loch im Himmel." (Here is indeed a hole in the heavens.) The object he was referring to is known as ρ (rho) Ophiuchi.



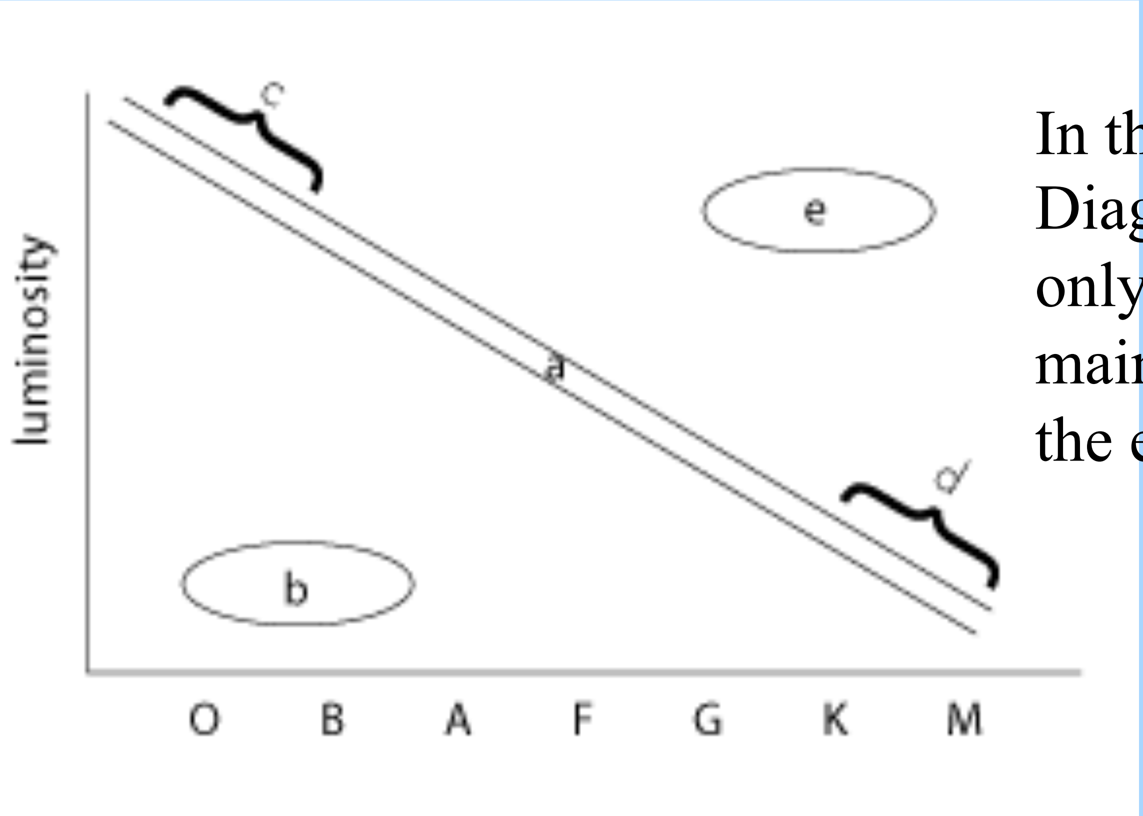
Other discoveries that provided evidence that there was material distributed between the stars:

1847 – W. Struve publishes *Etudes d'Astronomie Stellaire*. From the number of stars per magnitude bin, he concludes that there must be something distributed through space that is dimming starlight

1904 – J. F. Hartmann studied the right hand star in the belt of Orion (δ Ori). It is a spectroscopic binary composed of an O 9.5 bright giant, a much fainter star, plus a visual companion 52 arcsec away. The O-type star is too hot to have calcium lines in its spectrum, but Ca lines are seen nevertheless.

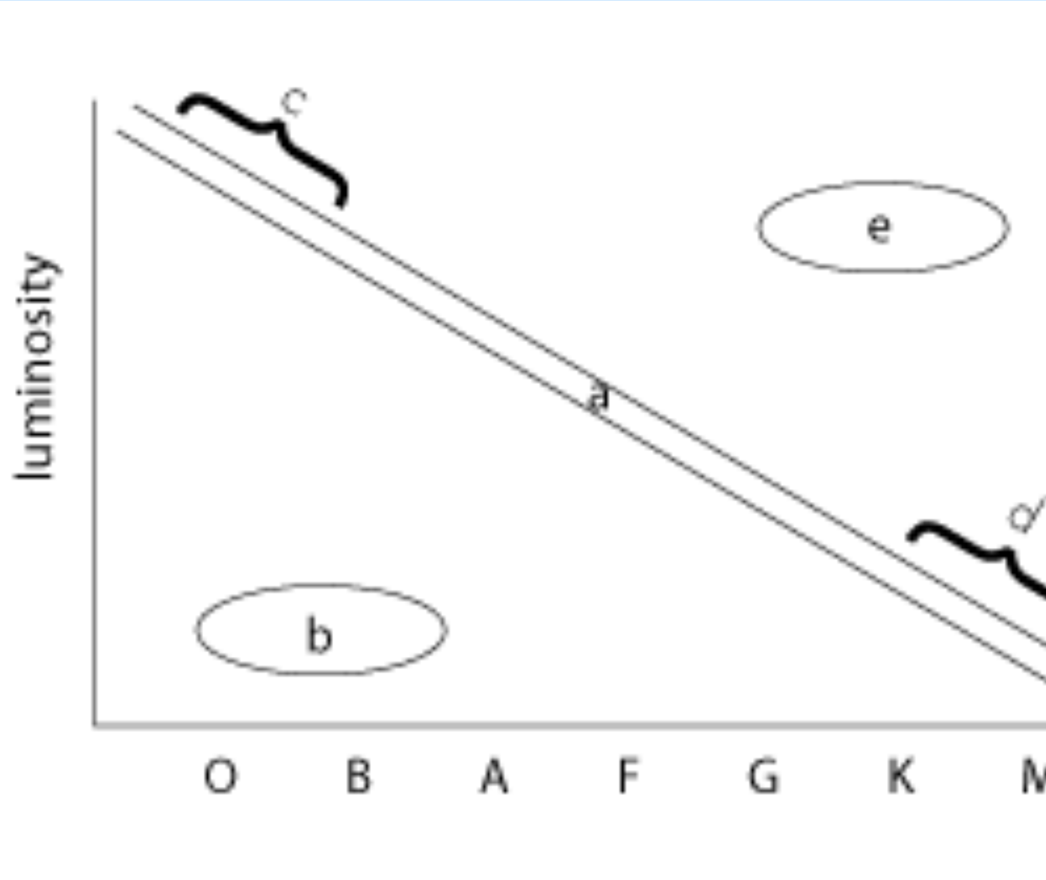
While the spectral lines of the O-type star shift back and forth as the star and its faint companion orbit their center of mass, the Ca lines in the spectrum do not move. The Ca lines are due to interstellar gas along the line of sight.

1930 – R. J. Trumpler's studies of open star clusters involved determining distances from the angular sizes of the clusters and also from the brightness of the stars. As we proceed to further clusters, their photometric distances deviate more and more from the geometric distances. Either the light was falling off faster than the square of the distance, *or* something was dimming the light of the stars.



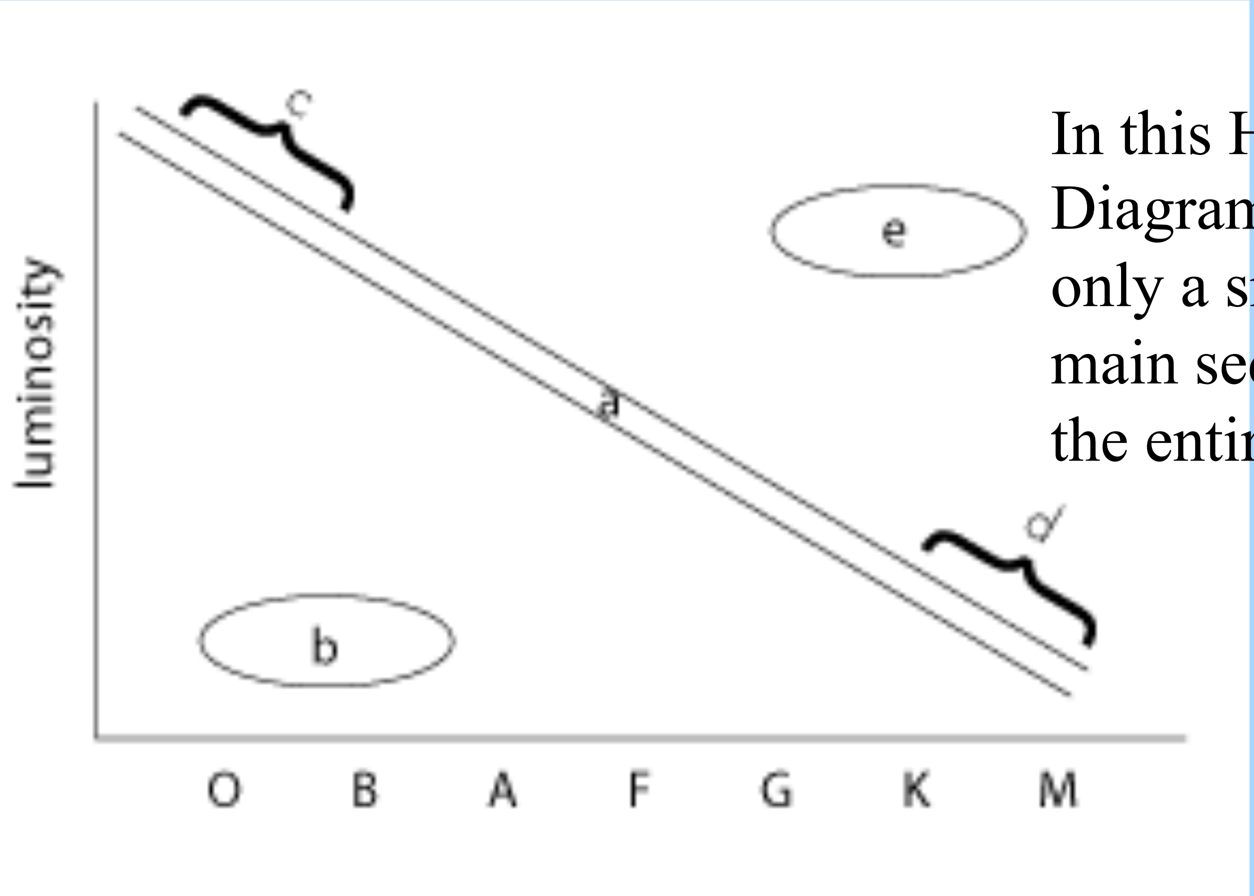
In this Hertzsprung-Russell Diagram c and d represent only a small portion of the main sequence. a represents the entire main sequence.

Stars in which region are converting hydrogen to helium in their cores?



In this Hertzsprung-Russell Diagram c and d represent only a small portion of the main sequence. a represents the entire main sequence.

Of the stars at locations b, c, d, and e
which stars are the most common in the Galaxy today?



In this Hertzsprung-Russell Diagram c and d represent only a small portion of the main sequence. a represents the entire main sequence.

Which stars are the largest?

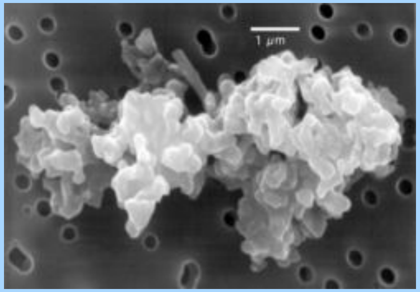
We are now certain that the plane of our Galaxy contains gas and dust. The gas can be detected at a variety of wavelengths.

The dust is detected from its effect on

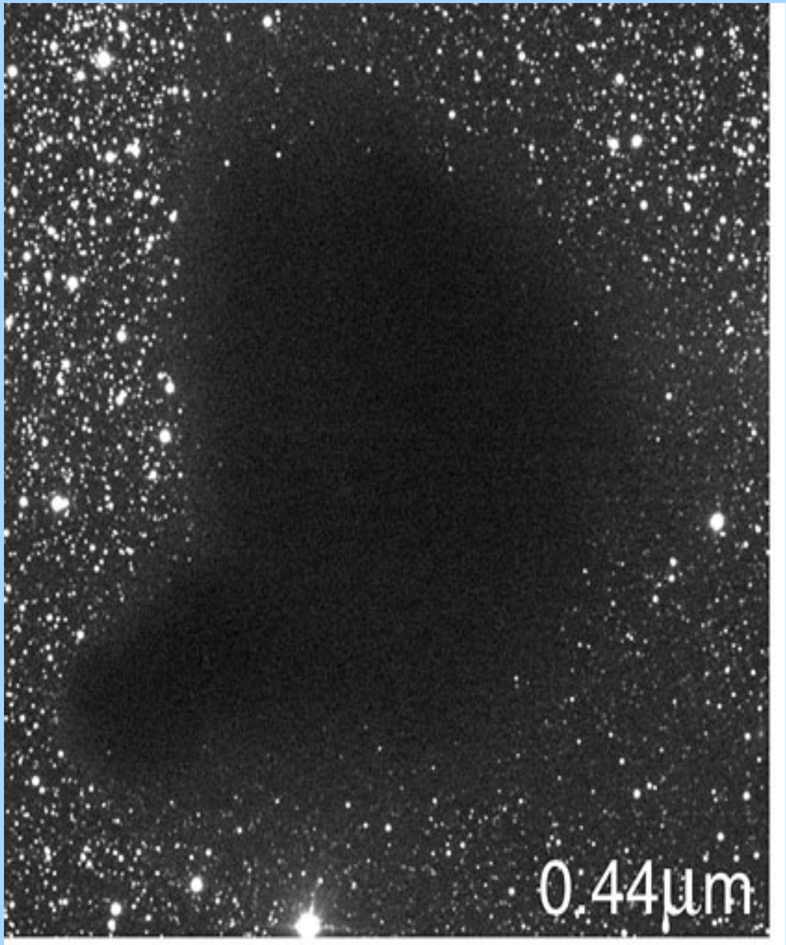
star counts

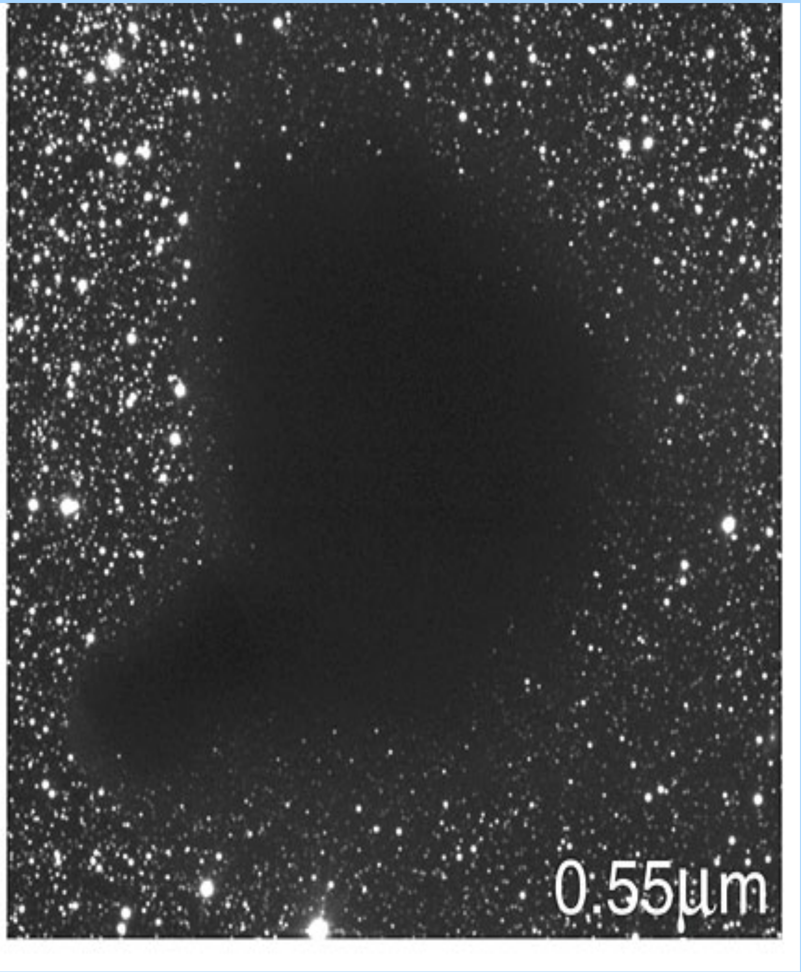
dimming the light of stars

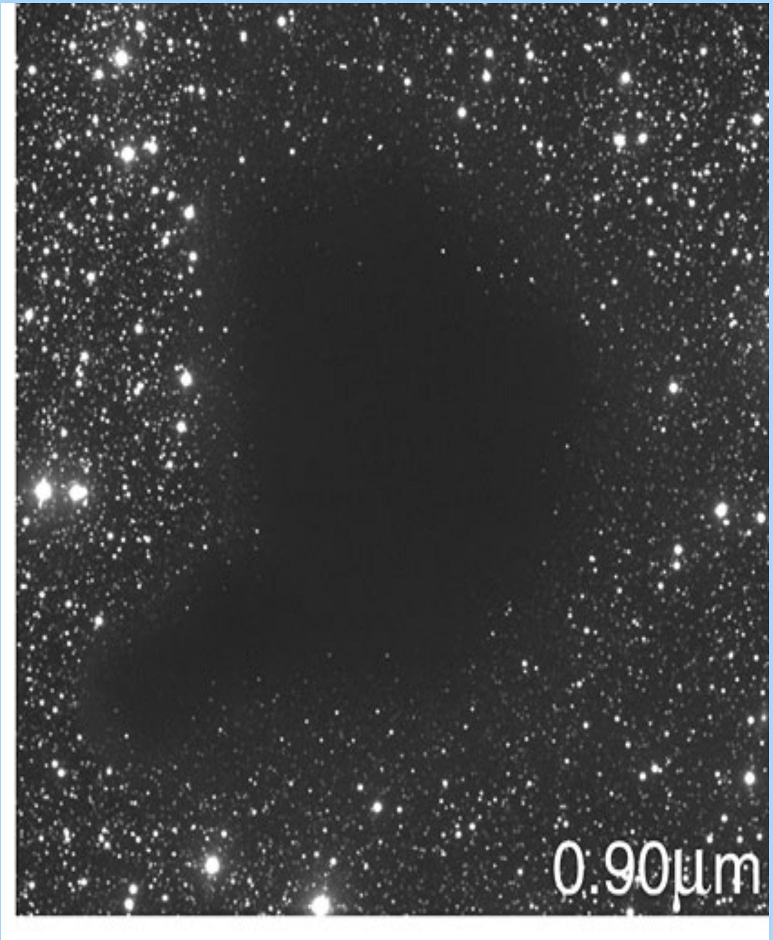
reddening the light of stars

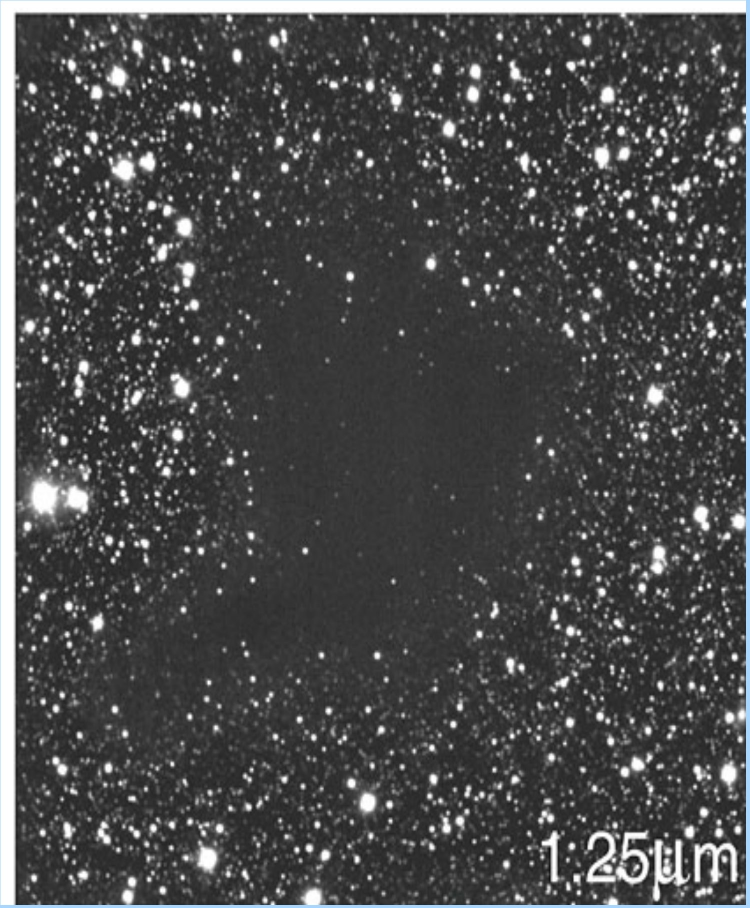


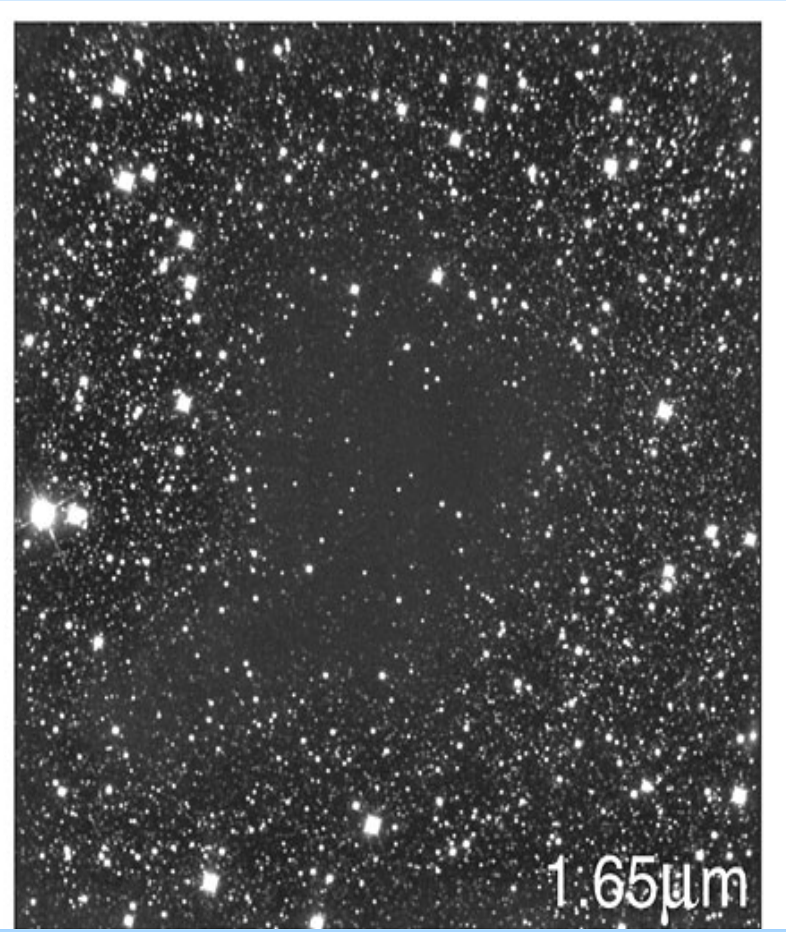
The following sequence of images of the Coal Sack shows that as we proceed from blue, to yellow-green, to near infrared filters, we see more and more stars on the other side of this dense dust cloud.

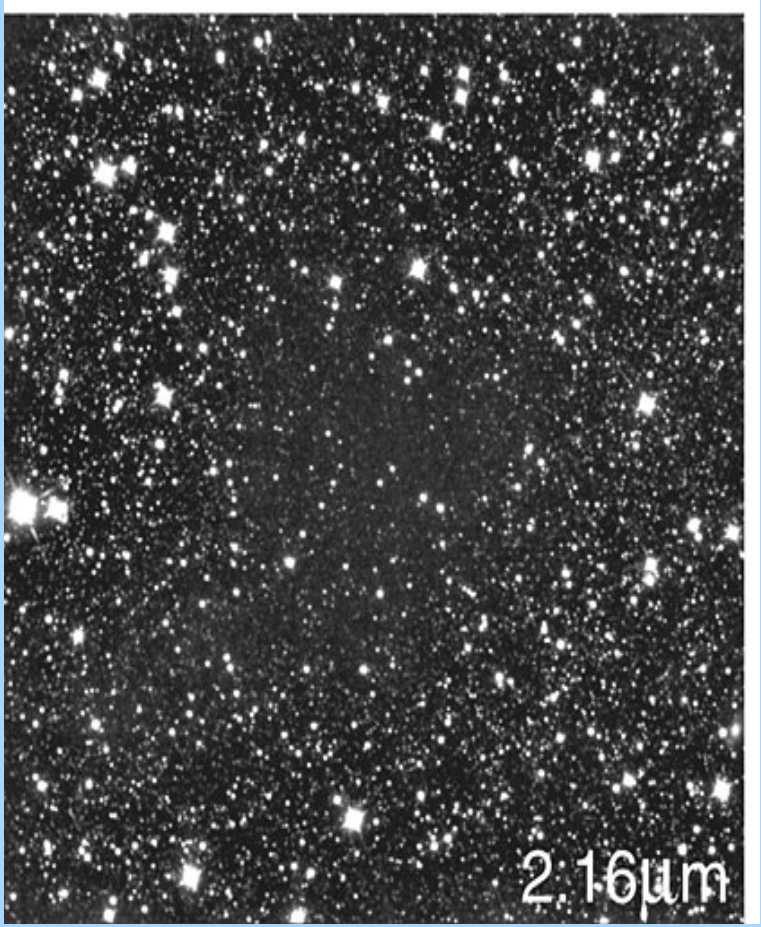

0.44µm

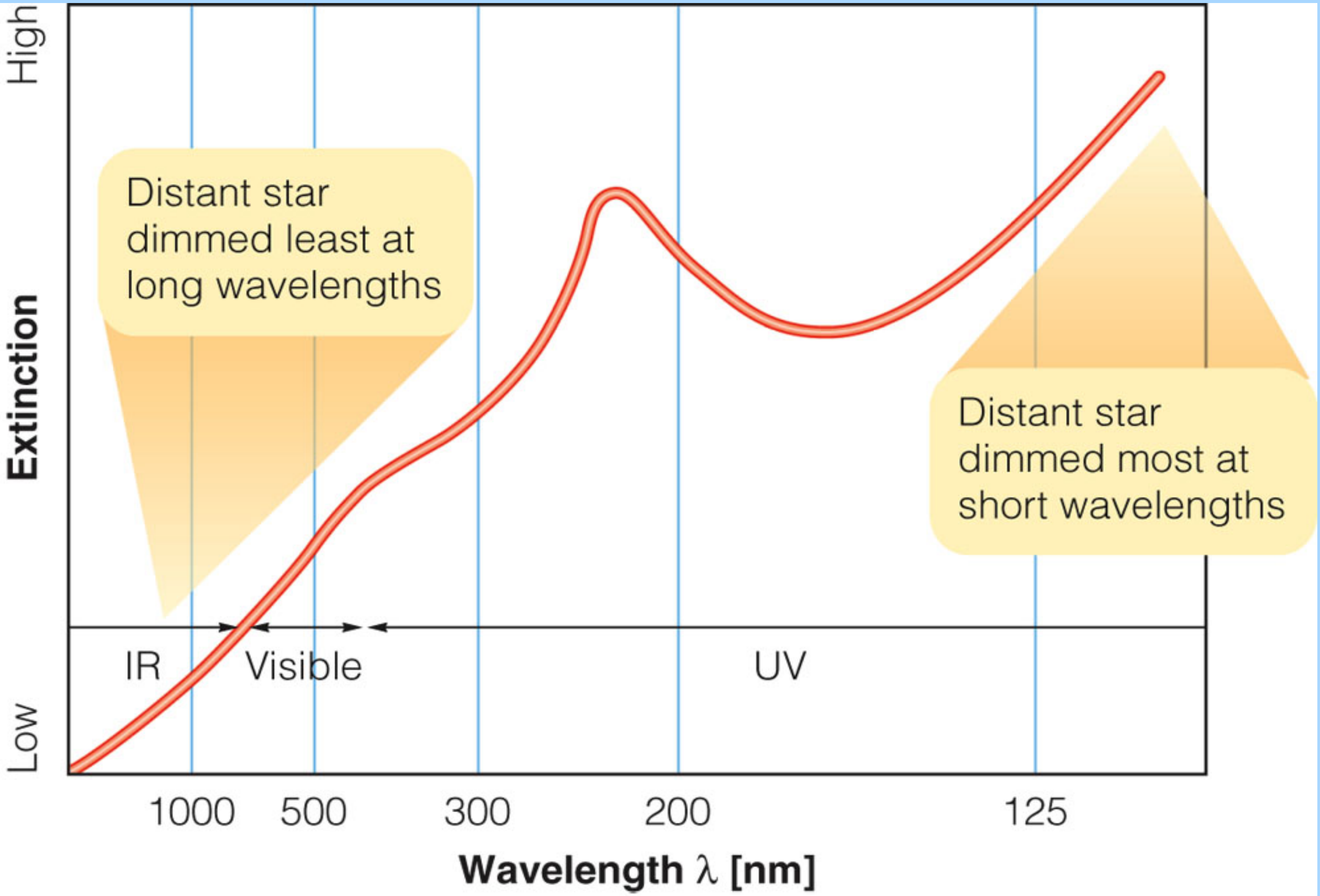

0.55µm


0.90µm


1.25µm


1.65µm


2.16µm


High
Extinction
Low
Distant star dimmed least at long wavelengths
Distant star dimmed most at short wavelengths
IR
Visible
UV
1000
500
300
200
125
Wavelength λ [nm]

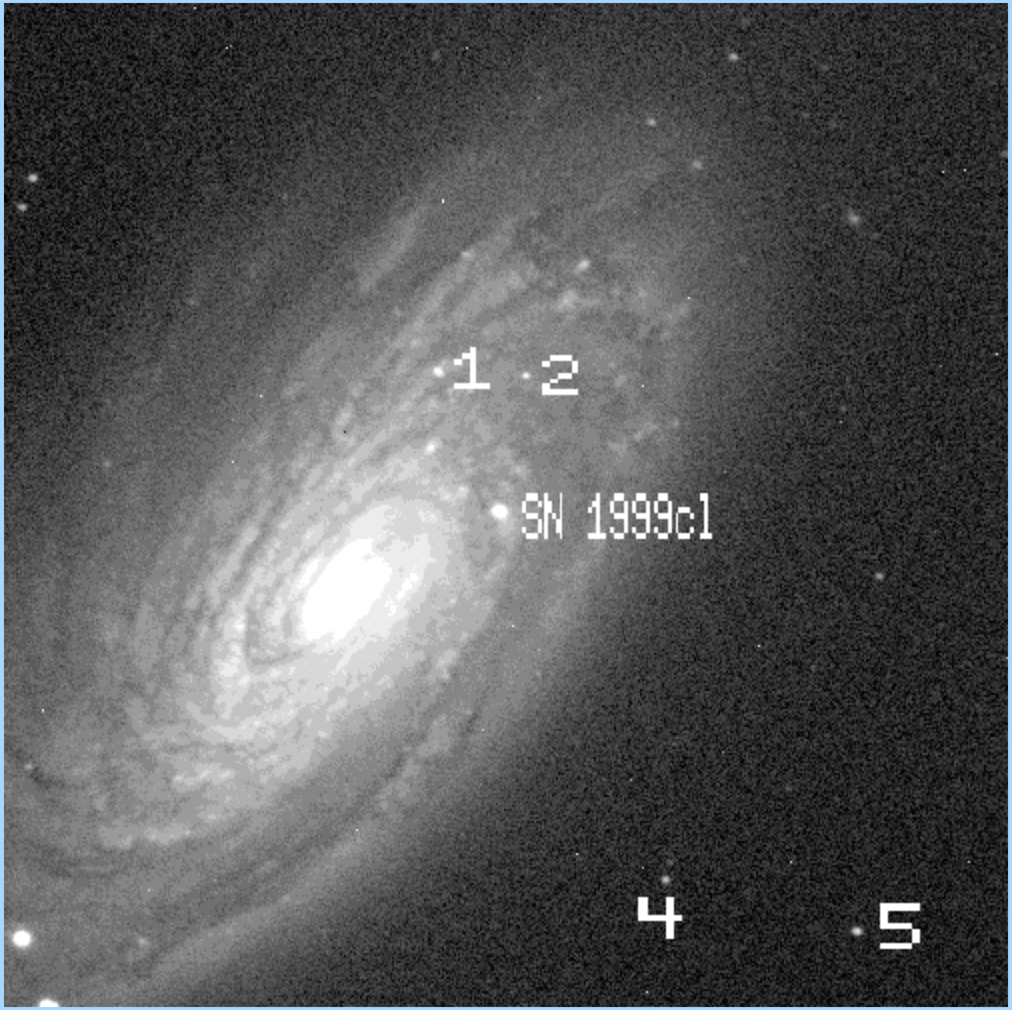
It is possible that a star in our Galactic plane is dimmed 3 magnitudes in the V-band (550nm), and 4 magnitudes in the B-band (440 nm). Say it is an A-type star like Vega. Instead of having a B-V color of 0.00, it will be 1 magnitude redder and will have the *color* of a K-type star like Arcturus.

Such a star would be dimmed by only 0.3 mag in the K-band (2.2 microns in the near-IR). At far infrared wavelengths the interstellar dust would have only a minor effect on the brightness.

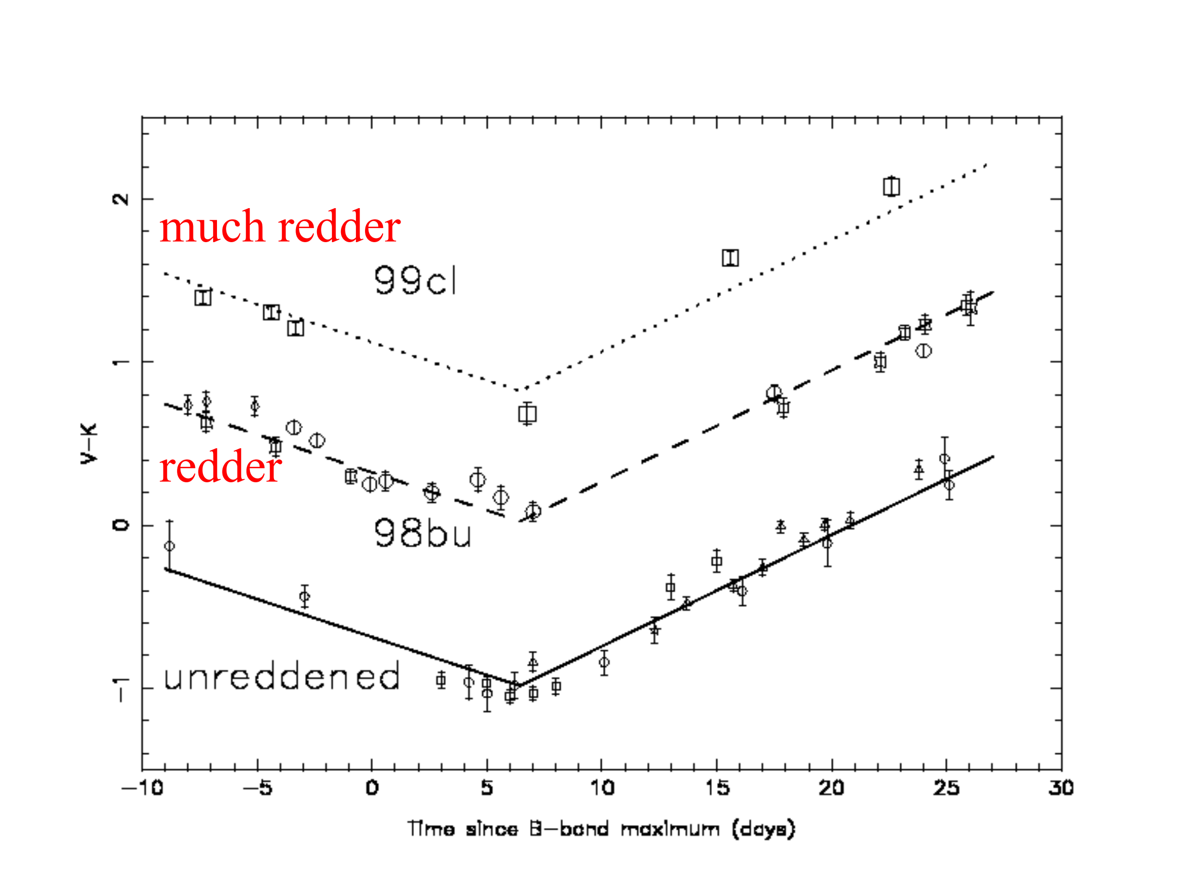
Because interstellar extinction maximizes at wavelengths of 0.2 microns and less, the size of the interstellar grains must be roughly that size.

Interstellar extinction by dust is 10 times less serious at a wavelength of 2.2 microns in the near-infrared compared to extinction in the V-band at 0.55 microns (550 nm).

If we know the intrinsic colors of certain kinds of stars (by spectral type, for example), we can use the observed colors to determine how much they have been reddened by interstellar dust.



SN 1999cl
is dimmed
2 magnitudes
at visual
wavelengths
by dust in
its host
galaxy.



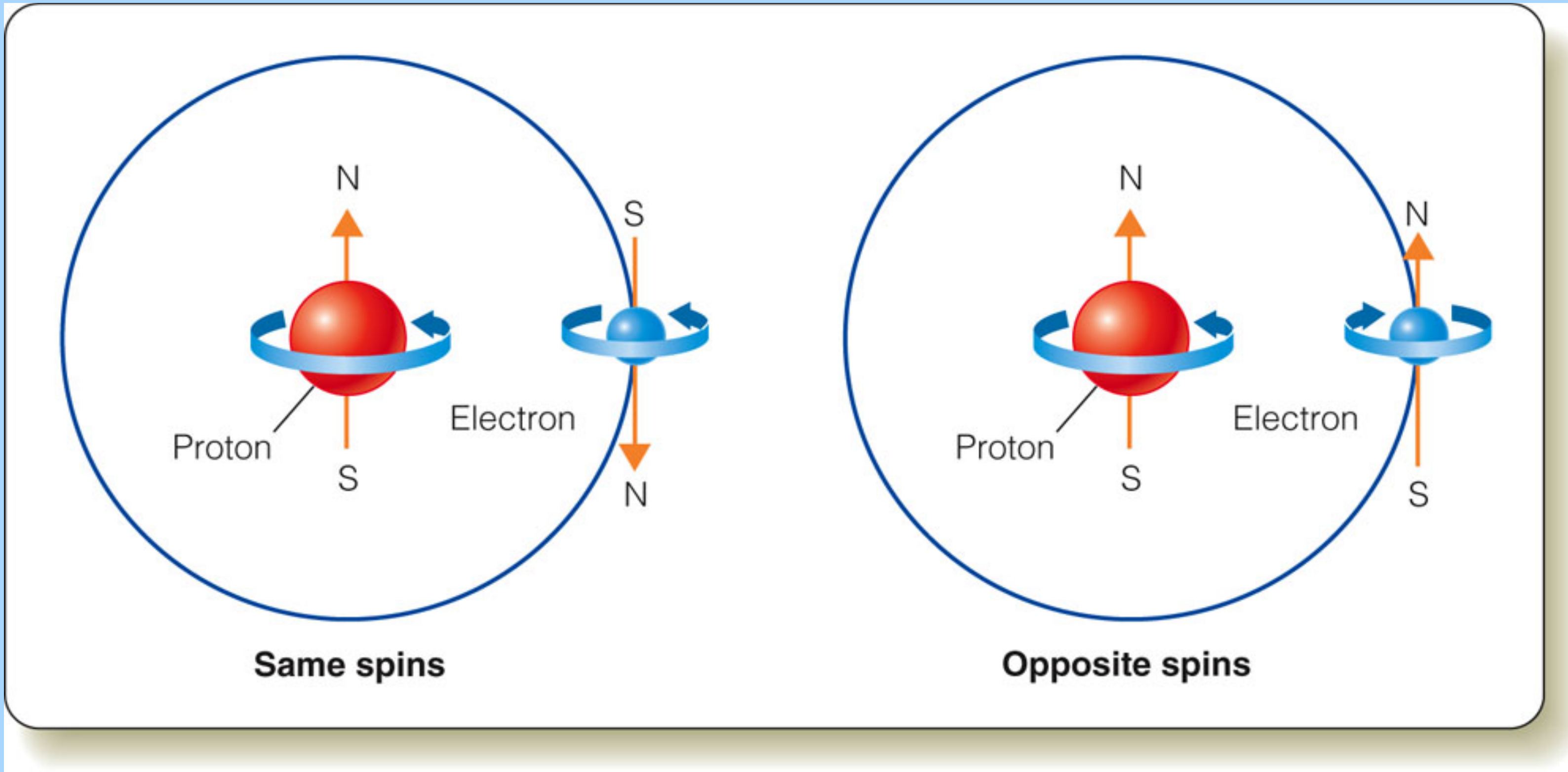
V-K colors of some Type Ia supernovae. 98bu and 99cl have been reddened by dust in their host galaxies

As we will find out shortly, stars are formed from the gravitational collapse of dust and gas clouds. The dust traps the optical and ultraviolet light from any hot stars that form. If we want to see what is happening in a star forming region, we must take images at *infrared* and *radio* wavelengths, because a much higher percentage of longer wavelength light is able to escape from the star forming region.

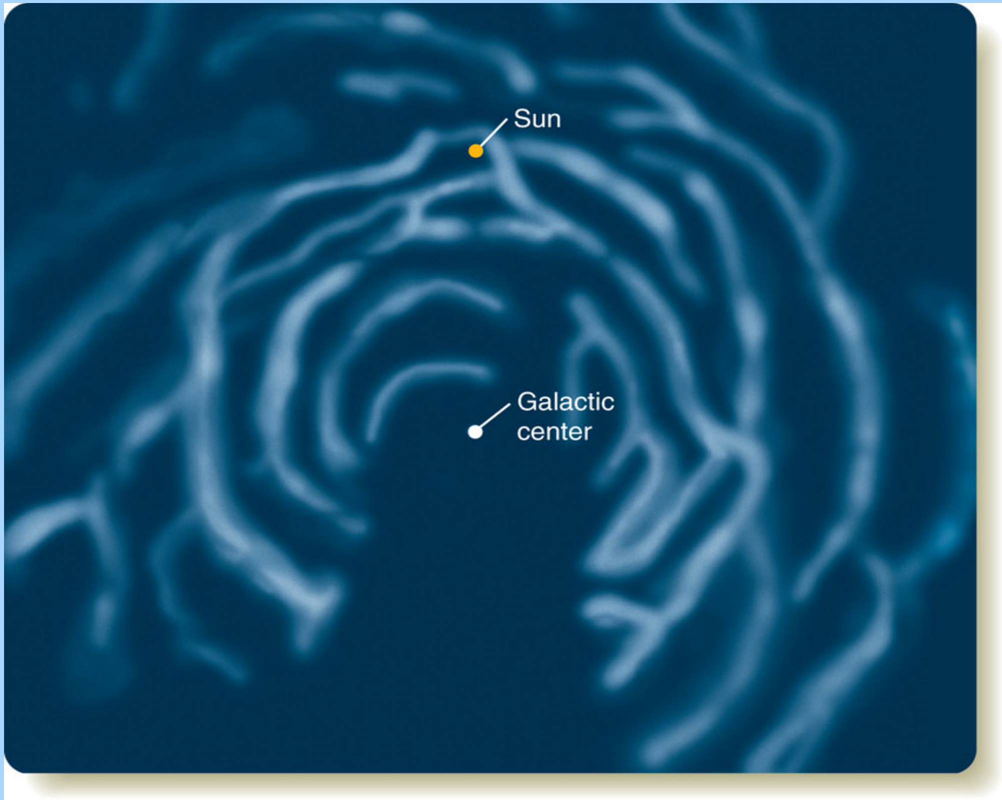
Infrared telescopes such as the United Kingdom Infrared Telescope and the Spitzer Space Telescope are key facilities for studying star formation.

Table 10-2 | Four Components of the Interstellar Medium

Component	Temperature (K)	Density (atoms/cm^3)	Gas
HI clouds	50–150	1–1000	Neutral hydrogen; other atoms ionized
Intercloud medium	10^3–10^4	0.01	Partially ionized
Coronal gas	10^5–10^6	10^{-4}–10^{-3}	Highly ionized
Molecular clouds	20–50	10^3–10^5	Molecules



Radio wave photons at λ = 21 cm are produced when the electrons of atomic hydrogen change their spin. (The labels "Same spins" and "Opposite spins" should be swapped in this graphic.)



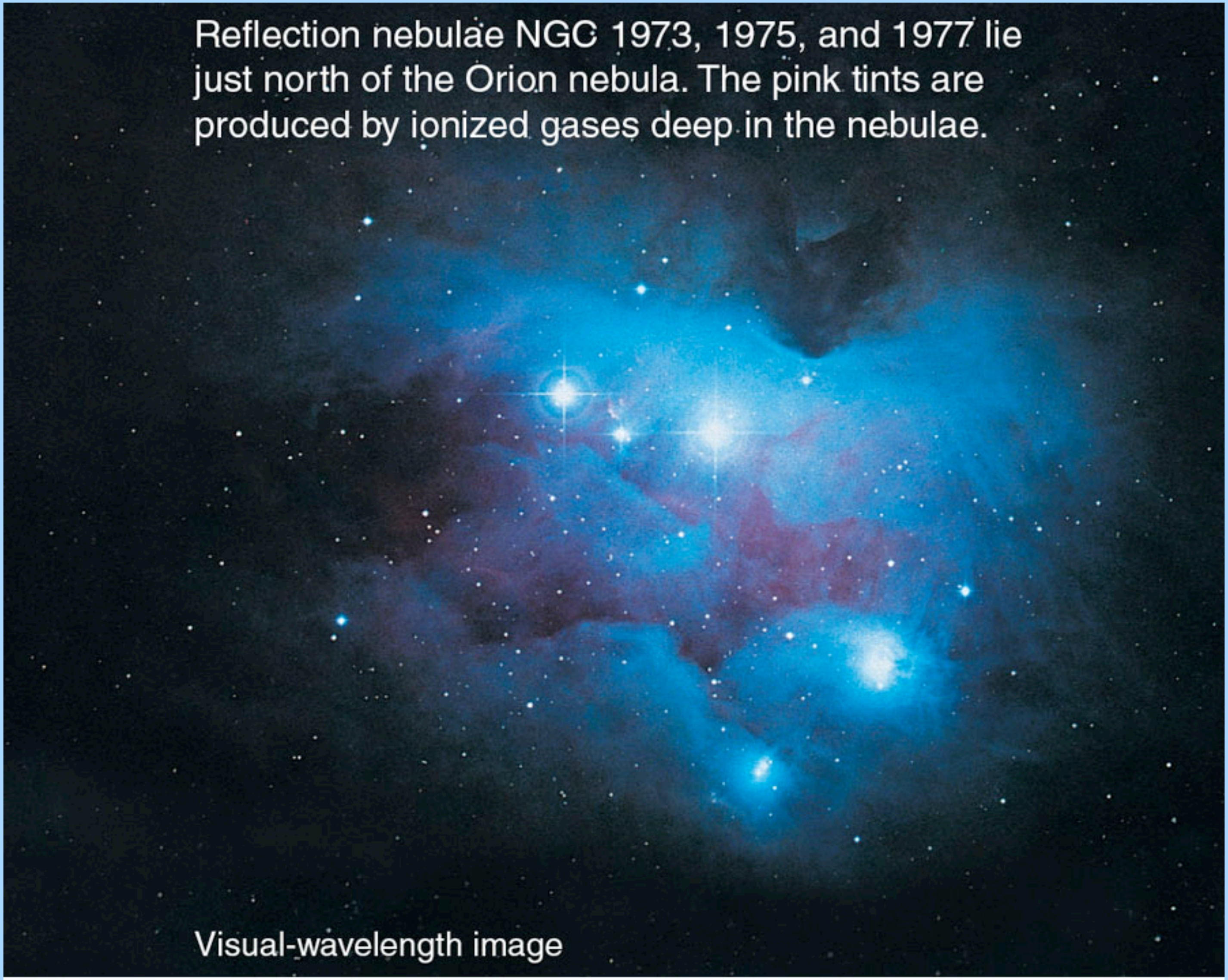
Neutral hydrogen in our Galaxy is found in the plane of the Galaxy and is associated with the spiral arms.

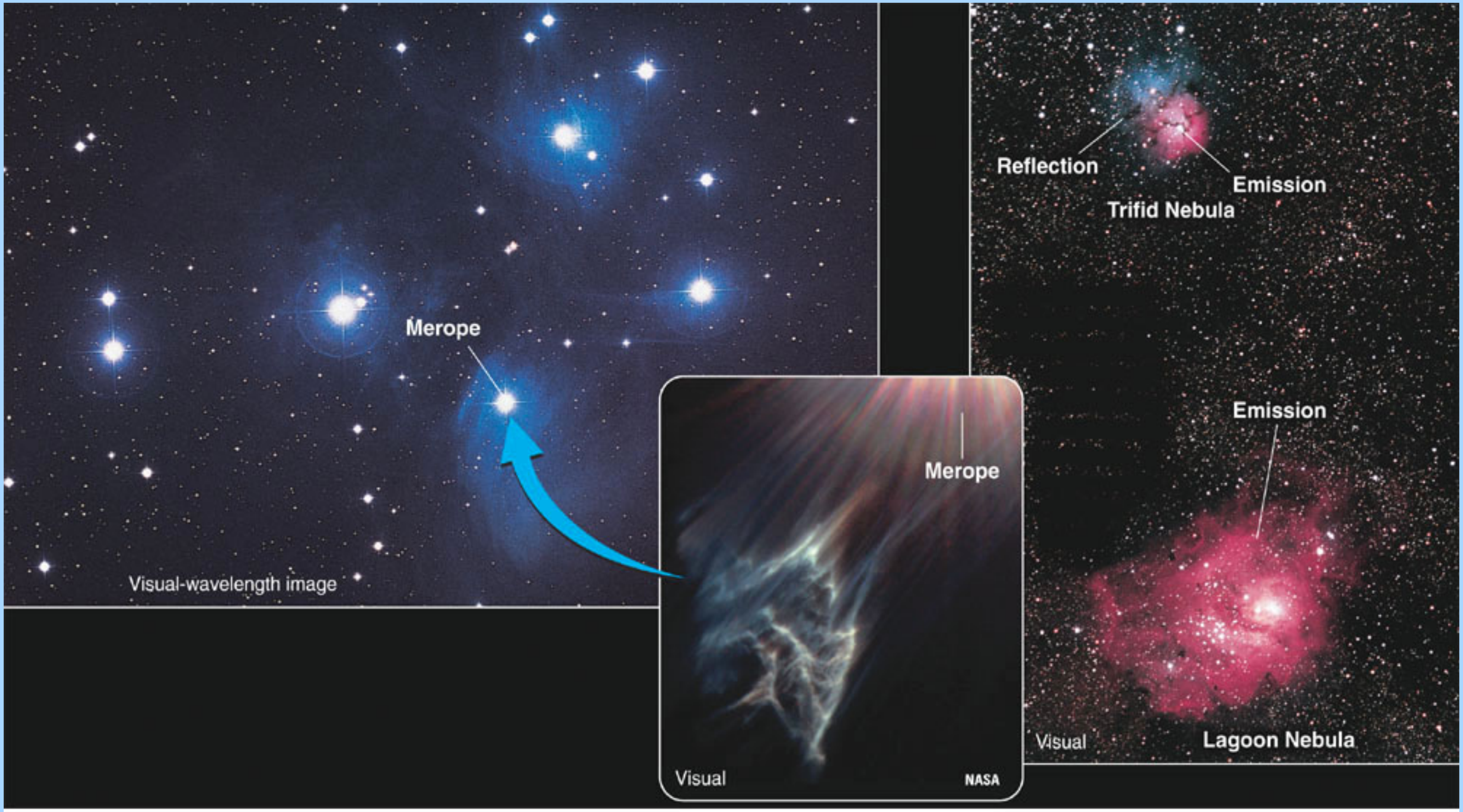
Three Kinds of Nebulae

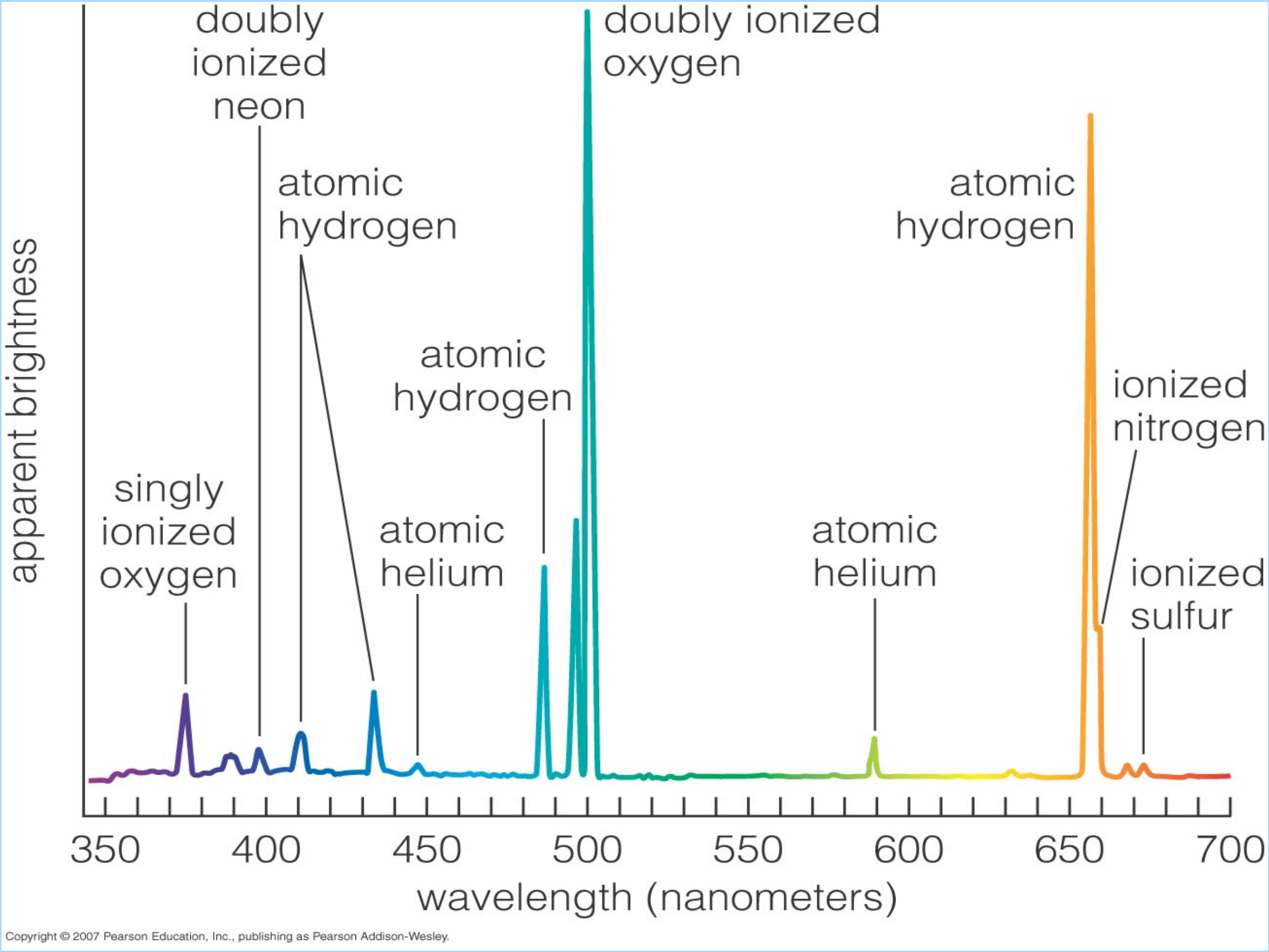
emission nebulae – ionized by stars with temperatures greater than 25,000 K

reflection nebulae – starlight scattered of a dusty nebula

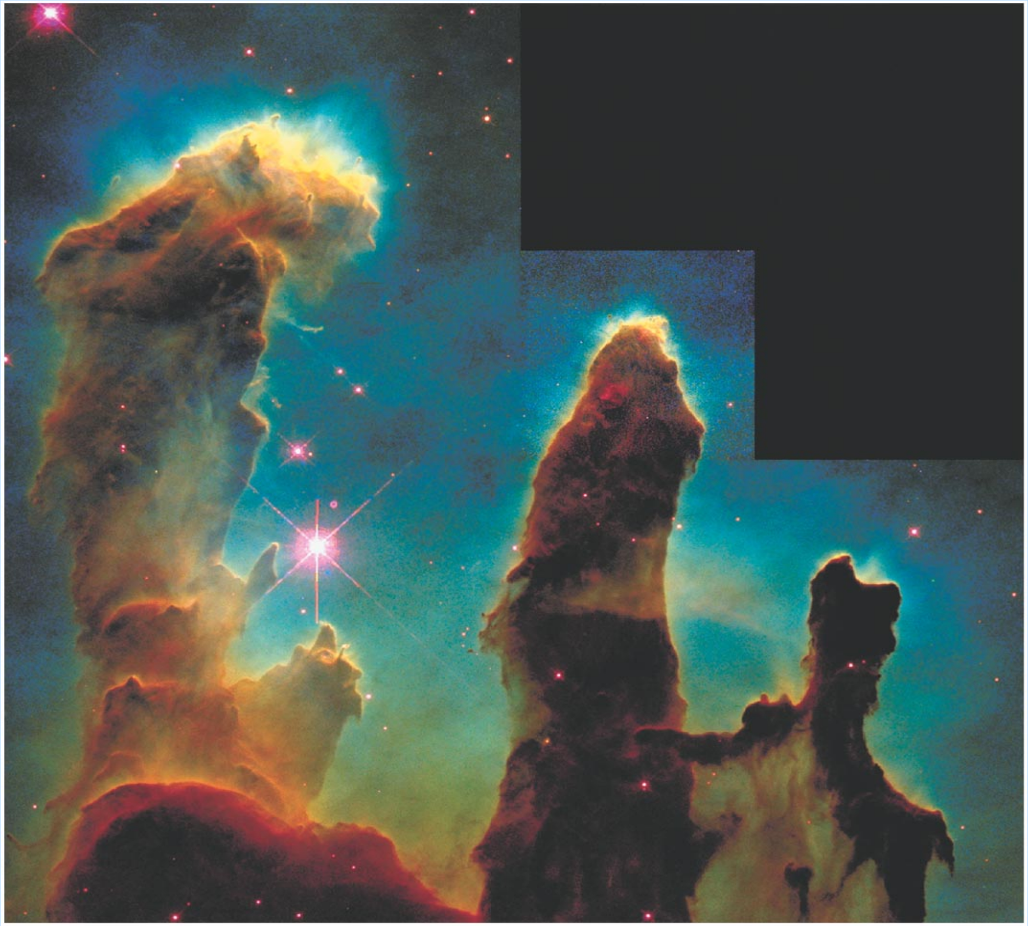
dark nebulae – dense clouds of dust that obscure the light of more distant stars


Reflection nebulae NGC 1973, 1975, and 1977 lie just north of the Orion nebula. The pink tints are produced by ionized gases deep in the nebulae.
Visual-wavelength image


Merope
Visual-wavelength image
Merope
Visual
NASA
Reflection
Emission
Trifid Nebula
Emission
Visual
Lagoon Nebula



A spectrum of the glowing gas between the stars in the Orion Nebula reveals many *emission* lines.



The Eagle Nebula, as imaged with the Hubble Space Telescope.

Table 10-1 | Selected Molecules Detected in the Interstellar Medium

H_2	molecular hydrogen
H_2S	hydrogen sulfide
C_2	diatomic carbon
N_2O	nitrous oxide
CN	cyanogen
H_2CO	formaldehyde
CO	carbon monoxide
C_2H_2	acetylene
NO	nitric oxide
NH_3	ammonia
OH	hydroxyl
HCO_2H	formic acid
$NaCl$	common table salt
CH_4	methane
HCN	hydrogen cyanide
CH_3OH	methyl alcohol
H_2O	water
CH_3CH_2OH	ethyl alcohol

Ethyl alcohol was discovered towards the center of our Galaxy by Zuckerman et al. (1975, *ApJ,* **196**, L99). If all the ethyl alcohol found in Sgr B2 were purged of impurities, it would amount to

A. All the alcohol presently in Las Vegas
B. The amount of alcohol presently in the USA
C. The amount of alcohol presently on Earth
D. More than humans' fermentation efforts since the beginning of recorded history.

DETECTION OF INTERSTELLAR *TRANS*–ETHYL ALCOHOL

B. Zuckerman*
University of Maryland

B. E. Turner
National Radio Astronomy Observatory,† Charlottesville

D. R. Johnson, F. O. Clark,‡ and F. J. Lovas
National Bureau of Standards

et al., ApJ Letters, March 15, 1975

Ethyl alcohol has been of interest to mankind since the dawn of the earliest civilizations (Hallo and Simpson 1971; Seltman 1957). During early October of 1974 we detected a truly astronomical source of ethyl alcohol located in the general direction of the center of our Galaxy. Preliminary estimates indicate that the alcoholic content of this cloud (Sgr B2), if purged of all impurities and condensed, would yield approximately 10^{28} fifths at 200 proof. This exceeds the total amount of all of man's fermentation efforts since the beginning of recorded history.

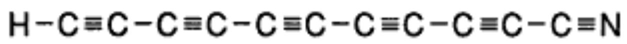
A list of more than 100 interstellar molecules can be found at:

www.cv.nrao.edu/~awootten/allmols.html

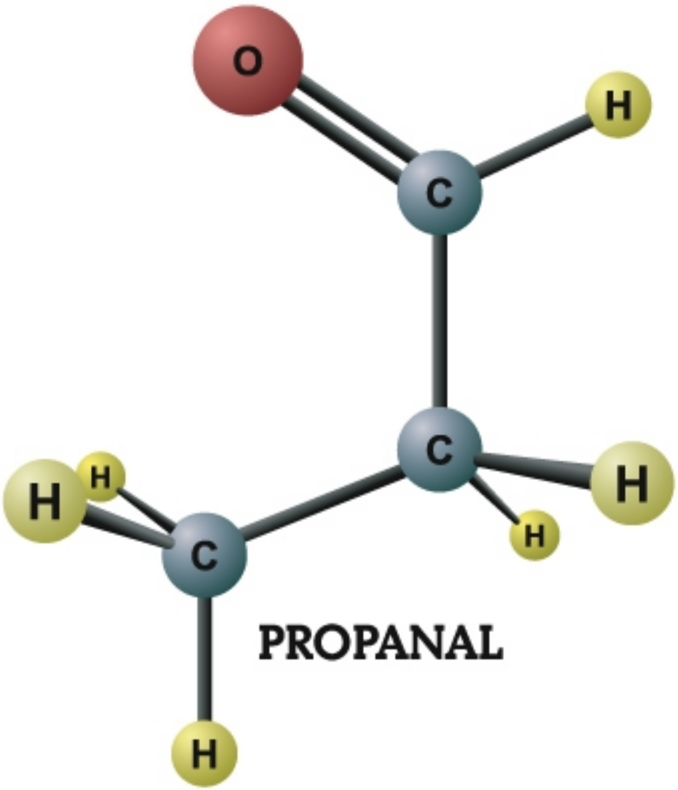
Two examples:

FIG. 1.—Geometry of the C_7H radical. The valence structure shown with alternating single and triple bonds is only approximate.

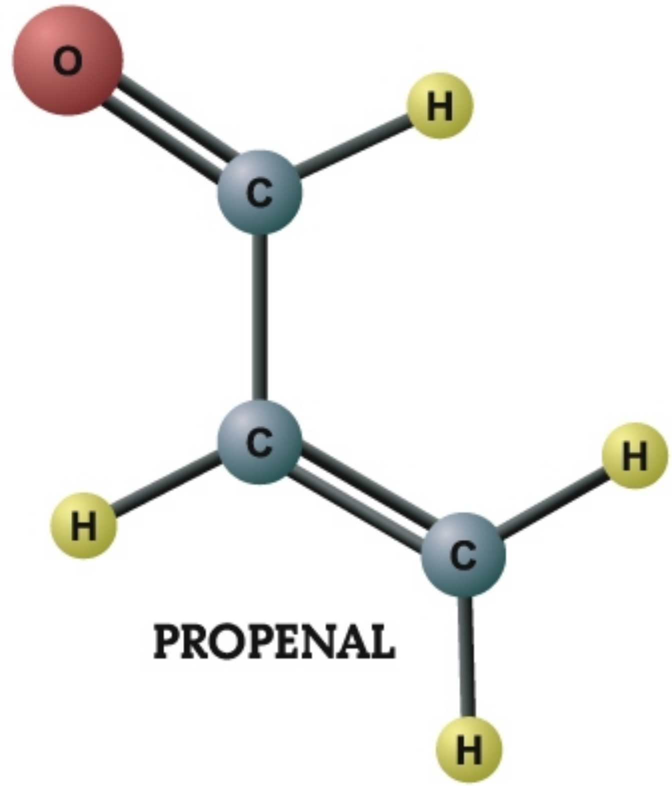
C_7H



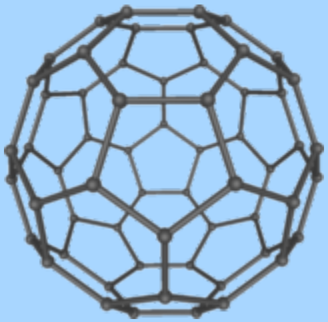
$HC_{11}N$



PROPANAL



PROPENAL



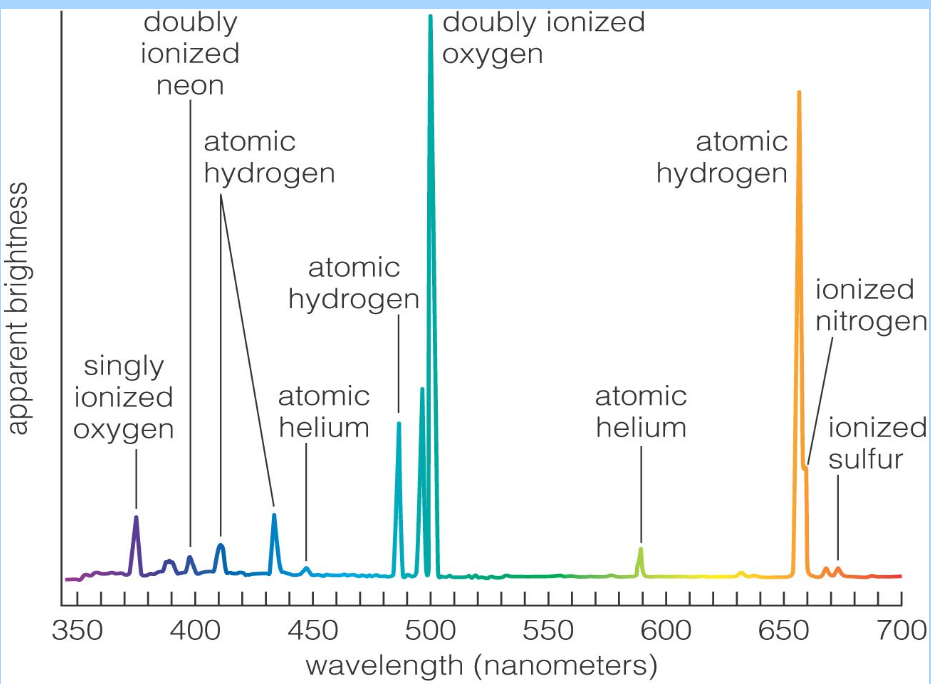
One molecule that might be out there is C_{60}. It is a member of a family of molecules called *fullerenes* after the American architect R. Buckminster Fuller (1895-1983), who advocated that we live in houses in the shape of geodesic domes.

If we aim a radio telescope along the plane of the Milky Way galaxy and tune it to a wavelength of 21 cm we detect the presence of

a. molecular hydrogen
b. cold atomic hydrogen
c. ionized hydrogen
d. interstellar dust

What fraction of the mass of the interstellar medium is made up of interstellar dust?

a. 1 percent
b. 10 percent
c. 50 percent
d. 75 percent



The Orion Nebula (top) is a star forming region visible to the unaided eye. The bottom figure shows a spectrum of the gas *between* the stars there. How might we describe the gas?

a. Hot solid, liquid, or dense gas
b. Low density gas excite to emit
c. Cooler gas between us and a source of continuous radiation
d. degenerate electron gas