9. Astronomical Photometry and Colors

The light from stars and stellar systems is typically measured through filters of known bandpasses. By using standardized filters, one can compare photometric measurements of different sources - independent of the observer and observatory. The following table summarizes the popular Johnson system of wide-band filters. Other frequently used wide-band filter systems include the UBVRI Mould system used at Kitt Peak National Observatory, the uvbby Stromgren system configured to avoid specific emission lines, and the Hubble Space Telescope’s own system. At optical wavelengths, filter bandpasses are often expressed in nanometers (1 nm = 10⁻⁹ m) or in Angstroms (1 Å = 10⁻¹⁰ m). At the longer infrared wavelengths, microns (μm) are the preferred units (1 μm = 10⁻⁶ m). The bandwidth of a filter is usually expressed as the full-width at half-maximum (FWHM) of the filter’s transmissivity function. Wide-band filters such as those tabulated below are used to characterize the continuum emission from an astronomical source in terms of its overall brightness and color. Narrow-band filters (bandwidths less than 10 nm) are used for the isolation of particular spectral features such as emission lines and discontinuities (“jumps”) in the stellar continuum emission.

<table>
<thead>
<tr>
<th>Johnson Filter</th>
<th>Central Wavelength</th>
<th>Bandwidth (FWHM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U (far-violet)</td>
<td>365 nm (3650 Å)</td>
<td>70 nm (700 Å)</td>
</tr>
<tr>
<td>B (blue)</td>
<td>440 nm (4400 Å)</td>
<td>100 nm (1000 Å)</td>
</tr>
<tr>
<td>V (yellow) (“visual”)</td>
<td>550 nm (5500 Å)</td>
<td>90 nm (900 Å)</td>
</tr>
<tr>
<td>R (red)</td>
<td>700 nm (7000 Å)</td>
<td>220 nm (2200 Å)</td>
</tr>
<tr>
<td>I (far-red)</td>
<td>880 nm (8800 Å)</td>
<td>240 nm (2400 Å)</td>
</tr>
<tr>
<td>J (near-infrared)</td>
<td>1250 nm (1.25 μm)</td>
<td>380 nm (0.38 μm)</td>
</tr>
<tr>
<td>K (near-infrared)</td>
<td>2200 nm (2.2 μm)</td>
<td>480 nm (0.48 μm)</td>
</tr>
<tr>
<td>L (near-infrared)</td>
<td>3400 nm (3.4 μm)</td>
<td>700 nm (0.70 μm)</td>
</tr>
<tr>
<td>M (mid-infrared)</td>
<td>5000 nm (5.0 μm)</td>
<td>1200 nm (1.2 μm)</td>
</tr>
<tr>
<td>N (mid-infrared)</td>
<td>10,400 nm (10.4 μm)</td>
<td>5700 nm (5.7 μm)</td>
</tr>
</tbody>
</table>

Astronomical colors involve flux measurements through two different filters, and are often expressed as a difference between the two measured magnitudes, whereby

\[ m(\lambda_2) - m(\lambda_1) = -2.5 \log \left( \frac{f(\lambda_2)}{f(\lambda_1)} \right). \]

For example, the \((B - V)\) color index is obtained from
\[(B - V) = m(B) - m(V) = -2.5 \log \left( \frac{f(B)}{f(V)} \right),\]

where \(f(B)\) and \(f(V)\) are respective measurements of the flux per unit wavelength through the \(B\) and \(V\)-band filters. The characteristic \((B - V)\) colors of main-sequence stars are tabulated in the Endnote 11.

10. Radiative Properties of Black Bodies

Black Bodies are perfect radiators, such that their spectral energy distributions (SEDs) depend only on the body’s surface temperature. The flux per unit frequency interval (\(dv\)), unit area of emitting surface (\(dS\)), and unit solid angle of direction (\(d\omega\)) is known as the Planck function, after the German physicist Max Planck (1858 - 1947) who first explained the observed emission from hot bodies in terms of quantum processes. It is expressed as follows

\[B_\nu(T) = \frac{2\pi^3}{c^2} \frac{1}{e^{\frac{\nu}{kT}} - 1},\]

where \((h)\) is Planck’s constant \((h = 6.62 \times 10^{-27}\text{\ erg-s})\), \((k)\) is Boltzmann’s constant \((k = 1.38 \times 10^{-16}\text{\ erg/Kelvin})\), \((c)\) is the speed of light \((c = 3.00 \times 10^{10}\text{\ cm/s})\), and \((B_\nu)\) is in units of \(\text{ergs/}[\text{s cm}^2\text{ Hertz steradian}]\). Sometimes it is more convenient to re-write this function in terms of wavelength \((\lambda)\), where \(\lambda = c/\nu\), and \(|d\lambda| = cdv/\nu^2\), so that

\[B_\lambda(T) = \frac{2\pi^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}.\]

The maximum of this function occurs where its slope goes to zero, i.e. where \(dB_\lambda/d\lambda = 0\). The corresponding wavelength of peak emissivity is thus found to be inversely proportional to the temperature, whereby

\[\lambda(\text{peak}) = C/T.\]

For instance, a doubling of the temperature results in the wavelength of peak emissivity being reduced by 1/2 (see Figure 3.1). This relation is known as Wein’s Displacement Law. The constant \(C\) depends on the particular unit of wavelength. In units of meters, \(C = 2.898 \times 10^{-3}\text{\ K-m}\); in cm, \(C = 2.898 \times 10^{-4}\text{\ K-cm}\); in microns, \(C = 2.898 \times 10^{3}\text{\ K-microns}\); in nanometers, \(C = 2.898 \times 10^{6}\text{\ K-nanometers}\); and in Angstroms, \(C = 2.898 \times 10^{7}\text{\ K-Angstroms}\).

Integrating the Planck function over all possible solid angles (in steradians) outward from the unit area of emitting surface produces what is known as the monochromatic flux \(F_\nu(T) = \pi B_\nu(T)\), or \(F_\lambda(T) = \pi B_\lambda(T)\). Further integrating the monochromatic flux over all frequencies (or wavelengths) produces the so-called bolometric surface flux

\[F(T) = \pi T^4,\]

where \(\sigma\) is the Stefan-Boltzmann constant \((\sigma = 5.67 \times 10^{-5}\text{\ ergs/}[\text{s cm}^2\text{ Kelvin}^4])\). Note the high power in the exponent of the temperature, and correspondingly high sensitivity of the surface flux to any changes in the temperature. For example, if the temperature doubles, the surface flux will increase by a factor of \(2^4 = 16\)! By assuming spherical symmetry (as in a star), one can integrate over the total spherical surface area and so obtain the total (bolometric) luminosity

\[L(R,T) = (4\pi R^2) \pi T^4.\]

Simple comparisons between stars can be made by assuming black-body emissivities and taking ratios, such that
\[
\frac{L_2}{L_1} = \left( \frac{R_2}{R_1} \right)^2 \left( \frac{T_2}{T_1} \right)^4.
\]

For example, the red supergiant star Betelgeuse is about 800 times larger than the Sun, but with a surface temperature that is roughly half that of the Sun. Its bolometric luminosity is then approximately \((800)^2 \left(\frac{1}{2}\right)^4 = 40,000\) times greater than the Sun’s total power output.

11. Main Sequence Stars

The following table summarizes the basic properties of main sequence stars. This table is based on having established reliable distances to a large enough number of representative stars - no easy task. The recent results of the Hipparcos astrometric satellite has helped tremendously in this regard (see Endnote 1).

<table>
<thead>
<tr>
<th>Type (1)</th>
<th>( (B - V) ) (mags) (2)</th>
<th>( T_{\text{eff}} ) (°K) (3)</th>
<th>( M_V ) (mags) (4)</th>
<th>( L_{\text{bol}} ) ((L_{\odot})) (5)</th>
<th>( M ) ((M_{\odot})) (6)</th>
<th>( \tau ) (years) (7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O5</td>
<td>–0.32</td>
<td>50,000</td>
<td>–6.0</td>
<td>( 1.1 \times 10^6 )</td>
<td>40</td>
<td>( 6.3 \times 10^6 )</td>
</tr>
<tr>
<td>B0</td>
<td>–0.30</td>
<td>27,000</td>
<td>–4.1</td>
<td>( 6.5 \times 10^4 )</td>
<td>17</td>
<td>( 1.2 \times 10^7 )</td>
</tr>
<tr>
<td>B5</td>
<td>–0.16</td>
<td>16,000</td>
<td>–1.1</td>
<td>( 8.0 \times 10^2 )</td>
<td>7</td>
<td>( 4.7 \times 10^7 )</td>
</tr>
<tr>
<td>A0</td>
<td>0.00</td>
<td>10,400</td>
<td>+0.6</td>
<td>( 6.7 \times 10^1 )</td>
<td>3.6</td>
<td>( 2.0 \times 10^8 )</td>
</tr>
<tr>
<td>A5</td>
<td>+0.15</td>
<td>8,200</td>
<td>+2.1</td>
<td>( 1.3 \times 10^1 )</td>
<td>2.2</td>
<td>( 7.7 \times 10^8 )</td>
</tr>
<tr>
<td>F0</td>
<td>+0.30</td>
<td>7,200</td>
<td>+2.6</td>
<td>7.9</td>
<td>1.8</td>
<td>( 1.4 \times 10^9 )</td>
</tr>
<tr>
<td>F5</td>
<td>+0.45</td>
<td>6,700</td>
<td>+3.4</td>
<td>3.7</td>
<td>1.4</td>
<td>( 3.1 \times 10^9 )</td>
</tr>
<tr>
<td>G0</td>
<td>+0.60</td>
<td>6,000</td>
<td>+4.4</td>
<td>1.5</td>
<td>1.1</td>
<td>( 7.1 \times 10^9 )</td>
</tr>
<tr>
<td>G5</td>
<td>+0.65</td>
<td>5,500</td>
<td>+5.2</td>
<td>( 7.4 \times 10^{-1} )</td>
<td>0.9</td>
<td>( 1.5 \times 10^{10} )</td>
</tr>
<tr>
<td>K0</td>
<td>+0.81</td>
<td>5,100</td>
<td>+5.9</td>
<td>( 4.2 \times 10^{-1} )</td>
<td>0.8</td>
<td>( 2.3 \times 10^{10} )</td>
</tr>
<tr>
<td>K5</td>
<td>+1.18</td>
<td>4,300</td>
<td>+8.0</td>
<td>( 9.8 \times 10^{-2} )</td>
<td>0.7</td>
<td>( 3.8 \times 10^{10} )</td>
</tr>
<tr>
<td>M0</td>
<td>+1.39</td>
<td>3,700</td>
<td>+9.2</td>
<td>( 5.1 \times 10^{-2} )</td>
<td>0.5</td>
<td>( 1.5 \times 10^{11} )</td>
</tr>
<tr>
<td>M5</td>
<td>+1.69</td>
<td>3,000</td>
<td>+12.3</td>
<td>( 6.7 \times 10^{-3} )</td>
<td>0.2</td>
<td>( 1.0 \times 10^{13} )</td>
</tr>
</tbody>
</table>

**Notes to table:**

(1) Spectral type, based on spectral absorption-line features.

(2) \((B - V)\) color index in magnitudes.
(3) Surface effective temperature in Kelvins, assuming a blackbody emissivity spectrum.
(4) Absolute visual magnitude, based on apparent magnitude $m_V$ and distance $d$ (see Technical Notes 1 and 3).
(5) Bolometric (total) luminosity, based on absolute visual magnitude $M_V$ and bolometric correction B.C., which in turn is based on the stellar surface temperature. $L_{bol}$ is expressed in units of solar luminosities \{L_{bol\odot} = 4 \times 10^{33} \text{ ergs/s}\}, such that $L/L_{\odot} = 10^{-0.4(M - M_{\odot})}$, where the absolute bolometric magnitude of the Sun is $M_{bol\odot} = 4.77$ mag.
(6) Mass in units of solar masses \{M_{\odot} = 2 \times 10^{33} \text{ g}\}, based (mostly) on the orbital behavior of stars in binary star systems. For the highest mass stars \{M > 20 M_{\odot}\}, nearby (resolvable) binary systems are lacking, and so stellar models are used.
(7) Total main-sequence lifetime, based on theoretical mass-lifetime relations.

From this table, empirical relations can be drawn. Most notably for main sequence stars, the mass and luminosity are directly related by power laws

$$\frac{L}{L_{sun}} = \left(\frac{M}{M_{sun}}\right)^n$$

For intermediate-to-high masses of $0.5 \ M_{sun} < M < 20 \ M_{sun}$, the exponent $n \approx 3.5$. A crude idea of the total stellar lifetime can be obtained by dividing the “fuel” (M) by the available “fire” (L). More specifically,

$$\frac{\tau}{\tau_{sun}} = \frac{M}{M_{sun}} \frac{L}{L_{sun}}$$

which reduces to

$$\frac{\tau}{\tau_{sun}} = \left(\frac{M}{M_{sun}}\right)^{1-n}.$$

Therefore, the stellar lifetime goes as $\tau \approx 10^{10} \left(M / M_{sun}\right)^{-2.5}$ years, a reasonable approximation to what the more sophisticated stellar models indicate. For example, a 10 solar-mass B3 main-sequence star has a predicted lifetime that is only 30 million years, while a 0.7 solar-mass K5 star should last more than 20 billion years.

12. Star Groups

There are basically three kinds of star groups that have been found in galaxies. Stellar associations are loose, young groupings of recently formed stars, conspicuous because of their very high luminosity and temperature. They are typically larger than 100 light years across. Open clusters are smaller, more compact groups, relatively stable and with a variety of ages. Globular clusters are large, with total diameters of 100 to 300 light years, populous, containing $10^4$ to $10^6$ stars, and bright, with luminosities of $10^2$ to $10^4$ Suns. In our Milky Way galaxy, they are uniformly very old, generally including the oldest known stars known. In the neighboring Magellanic Clouds, however, a much wider range of globular cluster ages is found.

13. Phases of Interstellar Gas
Up until the 1970’s, the interstellar medium was thought to contain two phases of interstellar gas. The cool atomic hydrogen gas, first detected in the 1950’s, was the densest phase. It had a temperature of about 100K and occurred in massive clouds. The warm ionized phase was 100 times hotter and 100 times less dense, comprising a tenuous intercloud medium. The resulting energy densities (and pressures) of the two phases were in rough equilibrium. Moreover, sufficient compression of the warm tenuous gas could drive thermal instabilities that would result in the gas switching its phase to the cool atomic state. This “two-phase” model provided one of the first cogent galactic ecosystems, in which clouds and subsequent star formation could develop in regions of gas compression (e.g. spiral arms).

Since the 1970’s, we have learned that the interstellar medium contains a far more complex stew of gaseous phases. The following table summarizes these various phases. The tabulated temperatures and densities are rounded off to the nearest power of ten. That is because these quantities vary by factors of 2-3 within each phase, and so any further specification would be more confusing than accurate.

The product (nT) is directly proportional to the thermal energy density (u = nkT), where k is Boltzmann’s constant. The thermal energy density also corresponds to the thermal gas pressure. From the table, we see that the cold molecular, cool atomic, warm atomic, warm diffuse ionized and hot coronal phases are in rough pressure equilibrium. Some evidence exists to support the idea that transitions can occur between some of these phases - driven by compressive dynamics along with radiative cooling. By contrast, the H II regions and supernova remnants (SNRs) are overpressurized - indicating expansive dynamics. The high-density molecular phase also appears overpressurized. However, gravitational binding plays an important role at these densities, thus preventing any expansion.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Temperature (°K)</th>
<th>Number Density n (cm⁻³)</th>
<th>Pressure/k (= nT) (cm⁻³K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Molecular</td>
<td>10¹</td>
<td>10³ - 10⁶</td>
<td>10⁴ - 10⁷</td>
</tr>
<tr>
<td>Cool Atomic</td>
<td>10²</td>
<td>10²</td>
<td>10⁴</td>
</tr>
<tr>
<td>Warm Atomic</td>
<td>10³</td>
<td>10¹</td>
<td>10⁴</td>
</tr>
<tr>
<td>Warm Ionized (H II Regions)</td>
<td>10⁴</td>
<td>10², 10⁰</td>
<td>10⁶</td>
</tr>
<tr>
<td>(Diffuse H II)</td>
<td>10⁴</td>
<td></td>
<td>10⁴</td>
</tr>
<tr>
<td>Hot Ionized (SNRs)</td>
<td>10⁶</td>
<td>10¹, 10⁻²</td>
<td>10⁷</td>
</tr>
<tr>
<td>(Coronal)</td>
<td>10⁶</td>
<td></td>
<td>10⁴</td>
</tr>
</tbody>
</table>

14. Doppler Shifts

As Christian Doppler showed in the early 1800’s, the line-of-sight motion between a source of propagating waves and an observer ends up shifting the observed wavelength by a predictable
amount. This so-called Doppler shifting applies to all types of propagating energy that can be described in terms of waves - from the siren wail of a speeding ambulance to the nebular line emission from a swirling galaxy.

When the source and observer are in relative motion toward one another, the wavefronts emanating from the source scrunched up in the direction of motion, shortening the wavelength and so producing a blueward shift, or “blueshift.” When the source and observer are in relative motion away from one another, the emanating wavefronts are stretched out in the receding direction, producing a redward shift in wavelength, or “redshift.”

The amount of shifting is denoted by $z$, and is directly proportional to the relative velocity along the line of sight between source and observer. This is quantified as

$$z = \frac{\Delta \lambda}{\lambda_o} = \frac{\lambda - \lambda_o}{\lambda_o} = \frac{v}{c},$$

where $\lambda$ and $\lambda_o$ are, respectively, the observed and emitted wavelengths, $v$ is the component of velocity along the line of sight, and $c$ is the speed of the propagating wave.

For light in a vacuum, $c = 3 \times 10^{10}$ cm/s. By convention, approaching motions have negative velocities and hence negative (blue) shifts in wavelength. Receding motions have positive velocities and positive (red) shifts. The shifting of frequency $v$ has the same dependence but of opposite sign, ie. $\Delta v/v = -v/c$.

When the line-of-sight velocity is a significant fraction of light speed, relativistic time-dilation effects alter the relation to

$$z = \frac{\Delta \lambda}{\lambda_o} = \frac{\left(1 + \frac{v}{c}\right)}{\left(1 - \frac{v^2}{c^2}\right)^{1/2}} - 1.$$

Unlike the non-relativistic relation, the redshift $z$ can exceed unity without the relative velocity surpassing light speed and so violating the fundamental premise of Einstein’s theory of special relativity.

The redshifts of galaxies are often discussed in terms of Doppler recession velocities. Indeed, the Hubble constant $H_0$ that describes the expansion of the galaxian Universe is most commonly expressed as

$$H_0 = v/d,$$

where $v$ is found from the redshift $z$. However, the cosmological redshifts of galaxies are more closely related to the scale of the Universe than to any measurements of velocity. As our space-time expands, all propagating light waves stretch accordingly. The interpretation of galaxian redshifts as Doppler recession velocities no longer makes sense, because the galaxies are not moving relative to our space-time. It is our space-time that is expanding.

15. Reddening and Extinction by Dust
Microscopic grains of cosmic dust interact with light in three basic ways. They absorb light with an efficiency that increases at shorter wavelengths. They scatter light with a similar wavelength-dependent efficiency. And they emit light with a spectral energy distribution that depends on their temperature. Here, we will concentrate on their absorbing properties and consequences.

The most directly observable consequence of cosmic dust is the extinction of starlight that is produced by absorbing dust along the line of sight to the star. In the magnitude system (see Endnote 3), the extinction $A(\lambda)$ is defined as follows

$$A(\lambda) = m(\lambda) - m_0(\lambda) = -2.5 \log \left( \frac{f(\lambda)}{f_0(\lambda)} \right),$$

where $m_0$ and $f_0$ respectively refer to the apparent magnitude and flux in the absence of extinction. Solving for the observed flux yields

$$f(\lambda) = f_0(\lambda)10^{-0.4A(\lambda)},$$

which is the same as

$$f(\lambda) = f_0(\lambda)e^{-\tau(\lambda)},$$

where the extinction $A(\lambda)$ and optical depth $\tau(\lambda)$ are related by

$$A(\lambda) = 1.086 \tau(\lambda).$$

The optical depth refers to the actual amount of dust along the line of sight, such that

$$\tau(\lambda) = \kappa(\lambda) N_d,$$

where $\kappa(\lambda)$ is the absorption efficiency of the dust grains, and $N_d$ is the column density of dust along the line of sight (in units of grains per unit projected area). Extinctions are determined from observations, while optical depths are typically derived from theoretical models. So it is handy to know how these two measures of dust are related.

The dependence of extinction on wavelength varies with galactic locale. Key influences include the abundance of heavy elements (the metallicity) necessary to make dust grains, the density of the clouds containing the dust, and the intensity of ultraviolet light from hot stars. All of these factors can change the distribution of grain sizes as well as the grain geometries and chemical compositions. In the Milky Way, the average extinction is more or less inversely proportional to the wavelength, ie.

$$\frac{A(\lambda_2)}{A(\lambda_1)} = \frac{\tau(\lambda_2)}{\tau(\lambda_1)} = \frac{\kappa(\lambda_2)}{\kappa(\lambda_1)} = \frac{\lambda_1}{\lambda_2},$$

with the biggest exception occurring near the ultraviolet wavelength of 215 nm, where carbonaceous grains are thought to produce the excess absorption that is observed. Curiously, this UV absorption feature is not observed in the Magellanic Clouds, nor in several other galaxies, where measurements of sufficient accuracy have been made.

Because the wavelength-dependent extinction passes the redder light at the expense of the blue light, it is often termed reddening. In the magnitude system, it is expressed as a color excess, where

$$E(\lambda_2 - \lambda_1) = A(\lambda_2) - A(\lambda_1).$$

For example, through the Johnson blue $(B)$ and visible $(V)$ filters, the color excess goes as

$$E(B - V) = A(B) - A(V).$$

Determinations of the $E(B - V)$ color excess from observations of nearby star clusters have shown that the color excess (reddening) is directly proportional to the total amount of visual extinction. This relationship is simply expressed as

$$A(V) = R_v E(B - V),$$
where the constant of selective extinction $R_v$ has an average value of 3.2 in our Milky Way galaxy. Based on this relationship, one can obtain a reasonable estimate of a star’s visual extinction (and corresponding dust column density to that star) by measuring the reddening of the star’s light. For star clusters, this is often done by plotting the $(B - V)$ colors with respect to the $(U - B)$ colors of the stars and comparing the resulting distribution with the predicted color-color “tracks” of main-sequence and giant stars. By measuring the offset in the $(B - V)$ and $(U - B)$ colors relative to the theoretical tracks, one obtains a good estimate of the $E(B - V)$ reddening and corresponding visual extinction $A(V)$.

Another method for determining the extinction to a source is by measuring the hydrogen line emission from the nebulae associated with hot stars (H II regions). The key is to measure two or more different hydrogen lines from the same source, and then to compare the resulting line ratios with those predicted by atomic theory. For example, in an H II region with a typical nebular temperature of $10^4$ K, the nominal ratio of fluxes between the Balmer series Hα line at 656.3 nm wavelength and the shorter wavelength Hβ (486.1 nm) line is $f_\text{H}\alpha/f_\text{H}\beta = 2.86$. Measurements of higher flux ratios would then indicate the presence of reddening, whose quantification would provide the ingredients necessary to compute the nebular extinction.

All of these methods for determining and compensating for the extinction rendered by dust assume that the dust is foreground to the source and is uniformly distributed - as in a hazy slab. However, nature is often far more complicated and interesting than our naive assumptions allow. Mixing the emitting sources with the absorbing dust, or altering the geometry of the slab into a shell, or merely organizing the dust into clumps can have varying effects on the emergent radiation which are difficult to model.

Sometimes, we find that our estimates of visual extinction based on hydrogen-line ratios systematically increase when we use lines of greater wavelength (e.g. the infrared Brackett series Brα and Brγ lines at 4.05 μm and 2.16 μm, respectively). This behavior can be understood, if the sources and dust are co-mixed - producing a “skin-depth” effect that is wavelength dependent. Simply put, the longer-wavelength emission is seen to greater depths in a dense emitting and absorbing cloud, so we sample more dust and measure greater extinctions at these wavelengths. That is why longer-wavelength infrared and radio observations are often preferred in studies of especially dusty systems.

Other times, we find that our stellar and nebular measures of visual extinction towards the same source can differ. Most likely, geometric factors are to blame. In young star-forming regions, the stars are often more localized than the gas. Moreover, the stellar winds can evacuate their immediate surroundings - reducing the extinction toward them compared to that found in the neighboring nebulae. In older stellar systems, the gas is frequently more localized than the stars - producing entirely different effects. Given the many possible arrangements of stars, gas, and dust in galaxies, we must regard our estimates of reddening and extinction with a good bit of caution.