APPARENT AND ABSOLUTE MAGNITUDE

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Reference: Carroll, Bradley W. & Ostlie, Dale A. (2007), *An Introduction to Modern Astrophysics*, 2nd Edition; Pearson Education - Chapter 3, Problem 3.3.

The ancient Greek astronomer Hipparchus was the first known person to classify stars by their apparent brightness. He introduced a 6-point scale with the brightest stars being of first magnitude and the faintest stars visible with the naked eye being of sixth magnitude. An decrease in the magnitude number by -1 was taken to be equivalent to a doubling of brightness.

When more sophisticated methods of measuring the actual intensity of light received from a star became available, it was found that the difference in flux between stars of first and sixth magnitude was roughly a factor of 100. In 1856, the English astronomer Norman Robert Pogson made the magnitude scale precise by defining a difference of 5 magnitudes to be exactly a factor of 100, so that each change of magnitude by 1 corresponds to a difference in brightness of $100^{1/5} \approx 2.512$.

Pogson's scale defines the *differences* between magnitudes, but a zero point is still needed. It is now generally accepted that the star Vega is the reference zero magnitude star, even though at some wavelengths, Vega is slightly variable. It was noticed that Vega's spectrum closely approximates that of a black body with a temperature of $T = 11,000$ K, so to make things precise, it is this black body that is used as the definition of zero magnitude at all wavelengths.

The apparent magnitude m of a star (that is, how bright a star *looks* to us on Earth) obviously depends on how far away it is, so m on its own can't be used to deduce the actual luminosity of a star. To provide such a measure, we define the *absolute magnitude* M, which is the apparent magnitude a star would have if it were 10 parsecs away. The flux received from a star depends on its apparent magnitude, so since each magnitude represents a brightness factor of $100^{1/5}$ and a higher magnitude represents a fainter star, we can write

$$F = A\left(100^{1/5}\right)^{-m} \tag{1}$$

where A is a constant, and is the flux received from a star of magnitude zero (such as Vega).

The ratio of fluxes from a star at its actual distance and at the standard distance of 10 pc is therefore

$$\frac{F_{10}}{F} = 100^{(m-M)/5} \tag{2}$$

From the inverse square law for flux, we have

$$\frac{F_{10}}{F} = \frac{d^2}{10^2} = 100^{(m-M)/5} \tag{3}$$

where d is the distance to the star measured in parsecs. Therefore

$$\begin{aligned} d &= \sqrt{100^{(m-M+5)/5}} && (4) \\ &= 10^{(m-M+5)/5} && (5) \end{aligned}$$

Example. Sirius has a parallax of $0.379''$ so its distance is

$$d = \frac{1}{0.379} = 2.639 \text{ pc} = 8.6 \text{ ly} = 5.44 \times 10^5 \text{ AU} = 8.14 \times 10^{16} \text{ m} \tag{6}$$

The apparent magnitude of Sirius is -1.47, so the absolute magnitude of Sirius is therefore

$$\begin{aligned} M &= m + 5 - 5 \log d && (7) \\ &= -1.47 + 5 - 5 \times \log 2.639 && (8) \\ &= +1.42 && (9) \end{aligned}$$

The difference between apparent and absolute magnitudes is called the *distance modulus*. For Sirius

$$m - M = -2.89 \tag{10}$$

Since $m = M$ when $d = 10$ pc a negative distance modulus indicates that the star is closer than 10 pc and a positive distance modulus that it is further than 10 pc.

The Sun's absolute magnitude is only $+4.74$, so if it were 10 pc away, it would be one of the fainter stars visible to the naked eye.

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