SPA613M: Introduction to Celestial Observational Techniques

Lecture 4

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Summary

- Blackbody Radiation.
- Intensity, Flux, Luminosity.
- Filter system.
- Magnitude system: Apparent, Absolute, Bolometric.
- Color indices and Bolometric correction.

Wien's law and Stefan Boltzmann law

- He saw the relationship between Temperature and wavelength coming out of a heated box.

$$T = \frac{0.0029Km}{\lambda} \tag{1}$$

- The amount of radiation emitted by a star not only depend on the temperature but also on the size.

$$L = 4\pi R_\star^2 F \tag{2}$$

$$\frac{dQ}{dt} \propto AT^4 \tag{3}$$

Classification based on Luminosity

Table 1.3. *Modern spectral classes in order of decreasing temperature. The L and T classes are recent additions. Some objects of class L and all of class T are not true stars but brown dwarves. Temperatures marked with a colon are uncertain*

Type	Temperature range, K	Main characteristic of absorption line spectra
O	$>$ 30 000	Ionized He lines
B	30 000–9800	Neutral He lines, strengthening neutral H
A	9800–7200	Strong neutral H, weak ionized metals
F	7200–6000	H weaker, ionized Ca strong, strong ionized and neutral metals
G	6000–5200	Ionized Ca strong, very strong neutral and ionized metals
K	5200–3900	Very strong neutral metals, CH and CN bands
M	3900–2100:	Strong TiO bands, some neutral Ca
L	2100:–1500:	Strong metal hydride molecules, neutral Na, K, Cs
T	$<$ 1500:	Methane bands, neutral K, weak water

Distance Using Luminosity

- Flux decreases as we get farther from the star – like $1/distance^2$.
- Mathematically, if we have two stars A and B.

$$\frac{Flux_A}{Flux_B} = \frac{Luminosity_A}{Luminosity_B}\left(\frac{Distance_B}{Distance_A}\right)^2 \tag{4}$$

Example: Which star would appear brightest?
A) Star A - 10 pc away, 1 solar luminosity
B) Star B - 30 pc away, 3 solar luminosities
C) Star C - 5 pc away, 0.5 solar luminosities

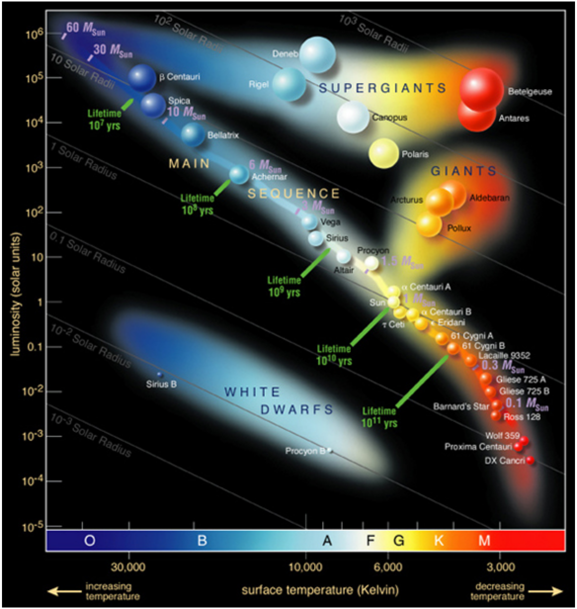
Relationship between Distance, Temperature and Luminosity

- Stephan Boltzmann Law.
- Temperature from Wien's law.
- Distance using parallax.

Spectroscopic Parallax

- Two very smart astronomers Ejnar Hertzsprung and Henry Norris Russell in 1913.
- Plotted Luminosity vs Temperature (color).
- From 100 star's to million of star's.

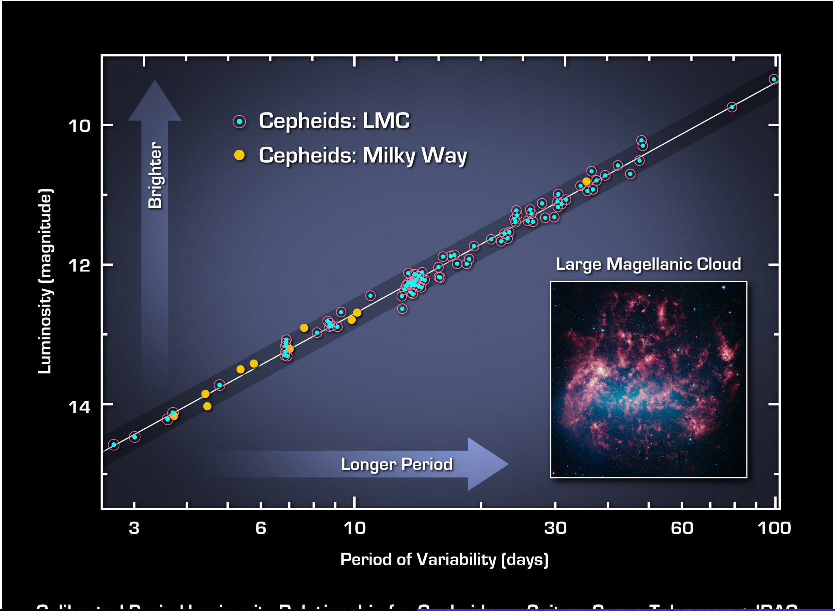
Hertzsprung–Russell diagram



Cepheid Variable Stars

- While stellar parallax can only be used to measure distances to stars within hundreds of parsecs.
- Cepheid variable stars can be used to measure larger distances such as the distances between galaxies.
- Cepheids was discovered in 1908 by Henrietta Leavitt after studying thousands of variable stars in the Magellanic Clouds.
- A strong direct relationship exists between a Cepheid variable's luminosity and its pulsation period.
- Due to burning of Helium the outer layer of the star contracts, heating due to compression until the helium doubly ionizes, becoming much more opaque. This causes it to accumulate heat, causing a build-up of pressure that forces the layer back out again until it cools enough to become singly ionized again.

Cepheid Variable Stars



Cepheid: Standard Candles

- The term standard candle applies to celestial objects with well-defined absolute magnitudes which are assumed to not vary with age or distance.
- Measuring the apparent magnitude of a Cepheid then allows us to determine its distance using the period-luminosity relationship.
- Example: A Cepheid variable star has a period of 3.7 days, and from this we know its absolute magnitude is -3.1. Its apparent magnitude is 5.5. How far away is this Cepheid variable star?

Type Ia Supernovae

- Type Ia supernovae are all caused by exploding white dwarfs which have companion stars.
- They can be distinguished from other supernovae because they do not have hydrogen lines in their spectra and have a strong Si II line at 615 nm.
- All type Ia supernovae reach nearly the same brightness at the peak of their outburst with an absolute magnitude of -19.3 ± 0.03.
- Type Ia supernovae can be used to measure distances from about 1 Mpc to over 1000 Mpc.

Counting Photons

- Most modern detectors that work in the in ultraviolet through near infrared parts of the spectrum are photon counters—they don't measure power.

$$Flux = 10^{-0.4 \times m(apparentmagnitude)} \times flux_{m=0} \tag{5}$$

Johnson Filter	Central Wavelength (nm)	Width (nm)	Flux at m=0 (Jy)	Reference
U	360	54	1810	Bessel
B	440	97	4260	Bessel
V	550	88	3640	Bessel
R	640	147	3080	Bessel
I	790	150	2550	Bessel
J	1260	202	1600	Campins
H	1600	368	1080	Campins
K	2220	511	670	Campins
g	520	73	3730	Schneider
r	670	94	4490	Schneider
i	790	126	4760	Schneider
z	910	118	4810	Schneider

Counting Photons

- Example: How many V-band photons are incident per second on an area of $1m^2$ at the top of the atmosphere from a $V = 23.90$ star?
- From the table, the flux at $V = 0$ is 3640 Jy.
- $1\ Jy = 10^{-23} ergsec^{-1} cm^{-2} Hz^{-1}$.
- $1\ Jy = 1.51 \times 10^{7}\ photonssec^{-1} m^{-2} (d\lambda/\lambda)$

Signal to Noise: SNR

- Even with a perfect, noise-free detector we cannot measure the brightness of a star with absolute certainty.
- The reason for this is that the emission and detection of photons is probabilistic.
- A different number of counts arises because each measurement is a single sample drawn from a Poisson distribution.
- If we measure a star and get $n = 10000$ then $\delta n = 100$ and the fractional uncertainty in our measurement is $\delta n/n = 0.01$ or 1%.
- We define the signal-to-noise ratio to be the inverse of the fractional uncertainty,

$$SNR = \frac{N}{\sqrt{N}} \tag{6}$$

Astronomical Optics

Astronomy relies heavily on observation of light emitted by distant objects with limited ability to perform experiments.

Astronomical instruments measure:

- Flux (stellar pulsations, exoplanet transits).
- Position (astrometry $\rightarrow$ masses)
- Spectra (temperature, light emission process, chemical composition, velocimetry)
- Polarization (magnetic fields, optical scattering of light)

Astronomical Optics & Technology

- Astronomy relies on optics, and is largely driven by (and driving) technology advances in optics, with ripple effects in other fields.
- The largest optical imaging systems are built for astronomy, but telescopes are also used for Earth sciences & defense.
- Advances in interferometry and adaptive optics are partially driven by astronomy, but are also used for medical imaging, defense, telecommunications etc.

Astronomical Telescopes: History

- Before there were telescopes, there were eyeglasses.
- Oldest surviving pair of eyeglasses date back to 13th centaury Italy (1285).
- First Telescope: probably in the 16th Cen, using two lenses, could create a magnified image.
- Hans Lippershey, applied for Dutch patent in the year 1608.
- Early telescopes were primarily used for making Earth-bound observations, such as surveying and military tactics.
- Early Dutch telescopes magnified only 3x.

Astronomical Telescopes: History

- Galileo, on hearing rumors of Lippershey's device, constructs one for himself in 1609.
- Credited with being the 1st to use telescopes for astronomy.
- He uses subsequent models to observe the night sky.
- 1st one was 3x and later 30x
- Chromatic aberrations.

Telescope

- Purpose of a telescope: gather light over a large area and focus it onto a small area.
- Method 1: Refraction (using a convex lens)
- Disadvantages: Hard to make a large lens with two perfect surfaces; hard to support a large lens by edges; different colors are focused at slightly different distances