ASTR 535 : Observational Techniques

Fall 2023 : class sessions

Light and magnitudes

Logistics

- Syllabus
  - Policies: attendance and ethics
  - APO trip
- Groups
  - A: April, Kevin, Victoria
  - B: Tim, Anna
  - C: Bill, Jessica, Julio
  - D: Maya, Asif, Anokh

Topics 8/22

- Quick student discussion to identify questions
- Questions
- Errata: wavelength in vacuum relative to wavelength in air
- properties of light and quantities astronomers measure
  - Basic quantities
  - Electromagnetic spectrum
- magnitudes

Discussion: flux, surface brightness, and luminosity

- Describe these qualitatively
- What are the dimensions?
- Which quantities are relevant for what astronomical objects?
- How do they depend on distance?

Light and the electromagnetic spectrum

- What are different types of light?
- By what quantities are they characterized?
- How are these quantities related?

Discussion: magnitudes

- Why use magnitudes?
- How are magnitudes defined?
- How does this apply to the relative brightnesses of two objects?
- What is the relative brightness of two objects, m1=2,m2=9.5?
- What is the relative brightness of two objects,m1=12, m2=19.5?
- What is the magnitude difference between two objects that differ in brightness by a factor of a million?
- What does the ratio of two magnitudes indicate?
- What mathematical operations might you expect to use with magnitudes and which ones not)?
- What quantities do apparent and absolute magnitude correspond do (flux, surface brightness, or luminosity?)

Problem : solar flux and surface brightness

- The solar constant is a flux measuring the mean solar radiation at the Earth.
  - What are the dimensions (i.e., in terms of length, mass, time, energy, etc?
  - In MKS/SI, what are the units?
  - In cgs, what are the units?
  - Calculate its value, given the luminosity of the sun is about 3.83×10^{33} ergs/s and the distance to the sun is $(\text{on average})1.496\times10^{13}$cm?
- What is the surface brightness of the sun as seen from Earth (note that the Sun has an angular diameter of about 0.5 degrees)?
  - Give your results per sterradian and per square arcsecond.
- What is the solar constant at Jupiter? How is it related to the solar constant at Earth?
- What is the surface brightness of the Sun as seen from Jupiter? How is it related to the surface brightness of the Sun as seen from Earth?

Problem : monochromatic flux

- The monochromatic flux of Vega at 5500 A is F_λ=3.63x10^{-9} ergs/cm^2/s/A
- Calculate the monochromatic flux F_ν in units of ergs/cm^2/s/Hz?

Problem : binary stars

- A binary star system consists of two stars of equal brightness. If the magnitude of one star is m, what is the combined magnitude of the two stars, i.e., if they were observed as an unresolved system?
- Imagine you are observing a binary star system, but where the stars are so close together that you see them as a single object. If the two stars have magnitudes of 17 and 18 individually, what is the combined observed magnitude?
- Write a (short!) software function that takes as input the apparent magnitude of each of two stars, and computes and returns the apparent magnitude of the two stars combined. Make sure to document the function properly!
- Roughly half of the stars in our Galaxy are in binary systems, and most of these are unresolved. What effect do you think this has on a HR diagram of a star cluster?

Problem: flux and distance

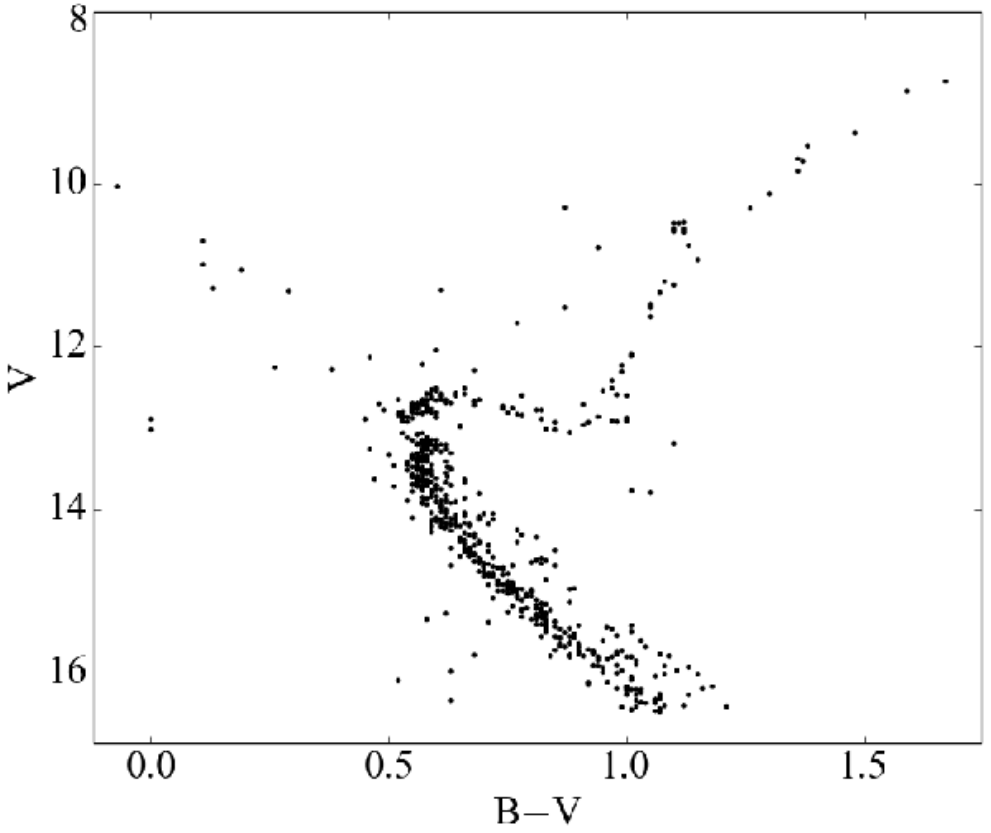
- How does the flux of an object depend on distance? Consider an object at distances d_1 and d_2, what is the ratio of the fluxes?
- What does this relation look like using magnitudes?
- What does the relation look like if one of the distances is 10 pc?
- What is special about the magnitude at 10 pc?

Topics 8/24

- Questions on problems and/or lecture videos
  - Docstrings
  - Binaries and the HR diagram
  - Github accounts
- Quiz
- Errata:
- Magnitude systems
- Magnitude-flux conversion
- colors

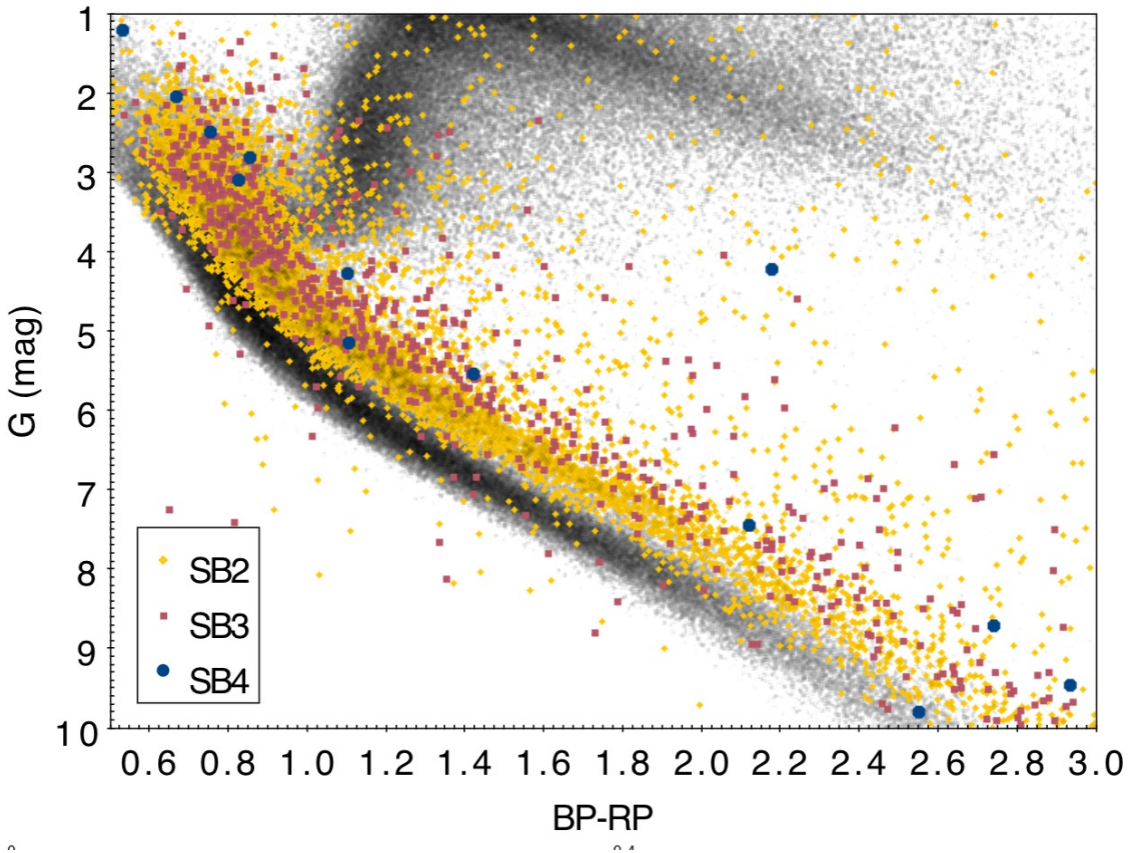
Binaries and the HR diagram

M67



Geller et al 2015

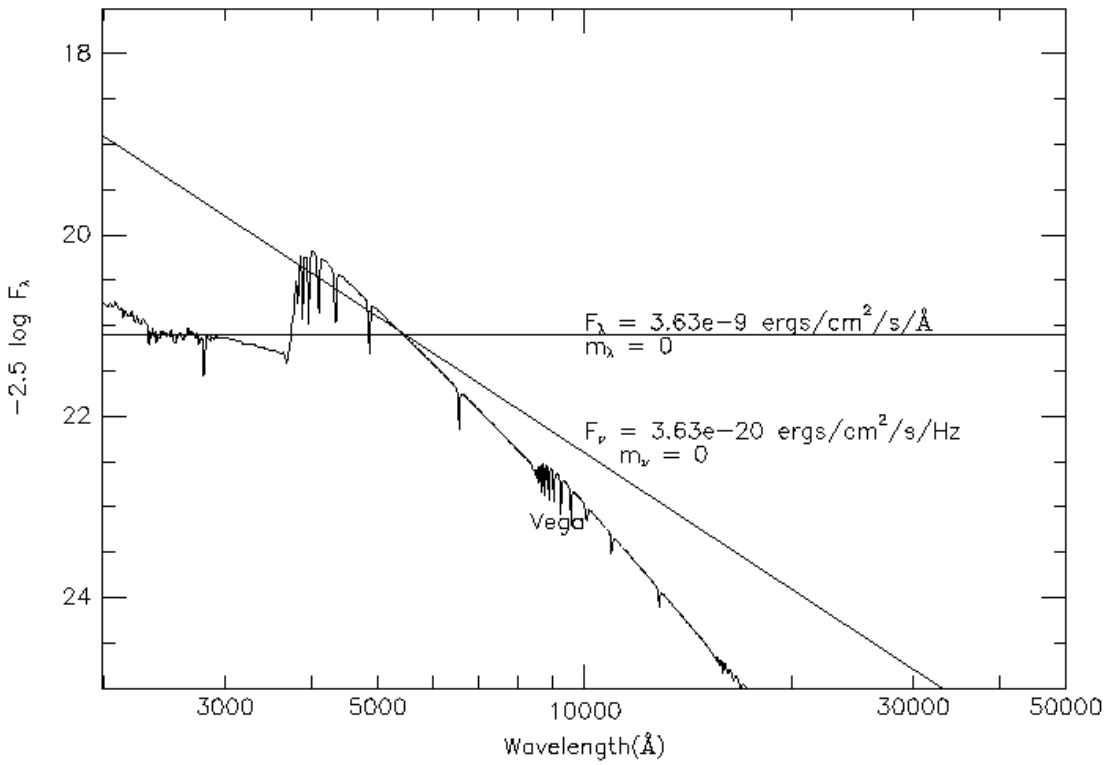
GAIA with APOGEE SB2s



Kounkel et al 2021

Discussion: magnitude systems

- What does it mean to talk about a photometric system?
- What are 3 such systems that are discussed in the notes? How are they different?
- What system does the UBVRI photometric system use (approximately)?
- What system does the SDSS $ugriz$ photometric system use (approximately)?
- Do you need to know what the magnitude system is to interpret the difference in magnitudes of two objects?



STMAG : relative to constant F_λ

- Used by Space Telescope Science Institute
- F_0 = 3.63x10^{-9} ergs / cm^2 / s/ Å

  This is roughly the flux of Vega at 5500 A

$$m_\lambda = -2.5 \log \frac{F_\lambda}{F_0} = -2.5 \log F_\lambda - 21.1$$

(where F_λ is in units of ergs/cm^2/s/Å)

$$F_\lambda = F_0 10^{-0.4\, m_\lambda}$$

- So, Vega will have a magnitude of 0 at 5500 Å, but will deviate from zero at different wavelengths/bandpasses to the extent to which its spectrum deviates from a flat F_λ spectrum

ABNU: relative to a constant F_ν

- Used by many surveys, e.g. SDSS (ugriz), panStarrs, …
- F_0 = 3.63x10^{-20} ergs / cm^2 / s/ Hz

  This is roughly the flux of Vega at 5500 Å

$$m_\nu = -2.5 \log \frac{F}{F_0} = -2.5 \log F_\nu - 48.6$$

(where F_ν is in units of ergs/cm^2/s/Hz)

$$F_\nu = F_0 10^{-0.4\, m_\nu}$$

- So, Vega will have a magnitude of 0 at 5500 Å, but will deviate from zero at different wavelengths/bandpasses to the extent to which its spectrum deviates from a flat F_ν spectrum

From magnitudes to fluxes

- Astrophysics computes fluxes, so to compare to observed magnitudes, need to convert one way or another
  - If astrophysics computes a spectrum, straightforward to derive magnitude
  - Going from magnitude to flux can be done, but note subtlety depending on SED
    - Table with fluxes corresponding to 0 magnitude
    - Note subtlety depending on spectral energy distribution (SED), e.g. WISE
- How would you calculate the apparent V magnitude of the Sun? The absolute magnitude?

Vega Flux Zeropoints

Quantity	U	B	V	R	I	J	H	K	Notes and units
λ_{eff}	0.36	0.438	0.545	0.641	0.798	1.22	1.63	2.19	microns
$\Delta\lambda$	0.06	0.09	0.085	0.15	0.15	0.26	0.29	0.41	microns, UBVRI from Bessell (1990), JHK from AQ
f_ν	1.79	4.063	3.636	3.064	2.416	1.589	1.021	0.64	$x10^{-20}$ erg cm^{-2} s^{-1} Hz^{-1}, from Bessell et al. (1998)
f_λ	417.5	632	363.1	217.7	112.6	31.47	11.38	3.961	$x10^{-11}$ erg cm^{-2} s^{-1} A^{-1}, from Bessell et al. (1998)
Φ_λ	756.1	1392.6	995.5	702.0	452.0	193.1	93.3	43.6	photons cm^{-2} s^{-1} A^{-1}, calculated from above quantities

These are for the Vega magnitude system and the Bessell et al. (1998) Johnson-Cousins-Glass System.

AB Flux Zeropoints

Quantity	u	g	r	i	z	Notes and units
λ_{eff}	0.356	0.483	0.626	0.767	0.910	microns, from Fukugita et al. (1996)
$\Delta\lambda$	0.0463	0.0988	0.0955	0.1064	0.1248	microns, from Fukugita et al. (1996)
f_ν	3631	3631	3631	3.631	3631	Jy or $x10^{-23}$ erg cm^{-2} s^{-1} Hz^{-1}
f_λ	859.5	466.9	278.0	185.2	131.5	$x10^{-11}$ erg cm^{-2} s^{-1} A^{-1}, calculated from above quantities
Φ_λ	1539.3	1134.6	875.4	714.5	602.2	photons cm^{-2} s^{-1} A^{-1}, calculated from above quantities

These are for the SDSS filters on the AB system. Data from Fukugita et al. (1996) repeat their Table 1, rows 1 and 6.

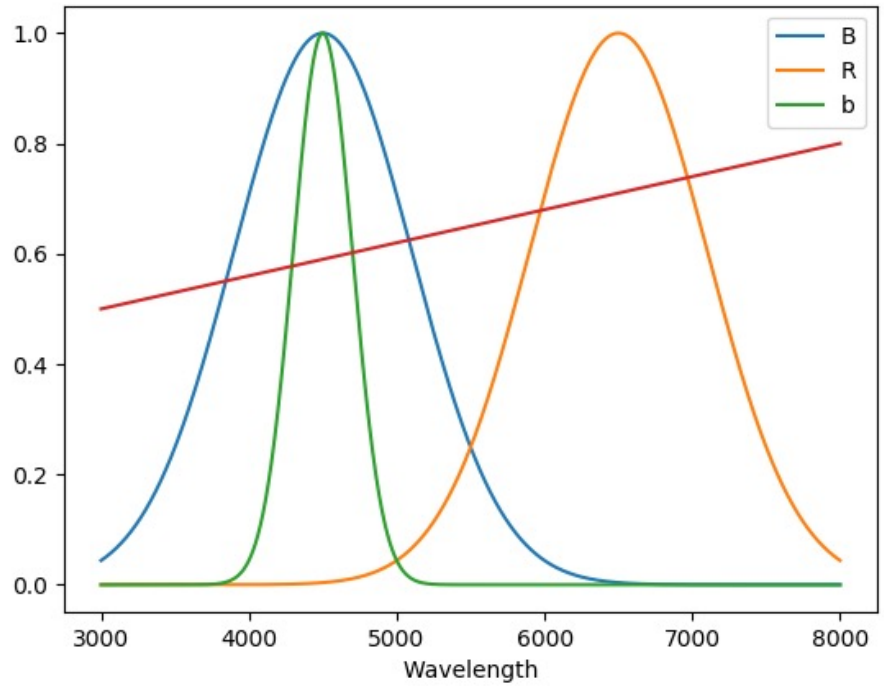
Note that the AB system is defined such that a source with $F_{nu} = 3.63 \times 10^{-20}$ erg cm^{-2} s^{-1} Hz^{-1} has AB mag = 0 in every filter, a

Discussion: colors

- Colors expressed in magnitudes: what do B-V=0, g-r = 0 imply?
  - Do we need to know what the photometric system is to interpret colors, i.e., differences of magnitudes at two wavelengths?
- Narrowband vs broadband:

For the adjacent figure, let's say you do photometry of the star with the red SED through the B(shown in blue) and R (shown in orange) filters, and you find that star has a B-R=1.0

You also make a measurement using the b (shown in green) filter, which uses the same photometric system zeropoint. What approximate value do you expect for b-R?



Questions: STMAG and ABNU systems

See Canvas assignment

Questions: magnitude –flux conversion

See Canvas assignment

Topics 8/29

- How are things going? Videos, level, time, groups?

- Questions on problems and/or lecture videos

- End of module on light! Assignments:
  - Problems from today
  - Module summary by next Tuesday
  - Exposure time calculator : github accounts
- Signal (count) equation
- Photometry: zeropoints and transformation coefficients

Observed fluxes and the signal (count) equation

- How is what we observe related to what objects emit?
- The “signal (count) equation”
  - What are the terms?
  - How well do we know them?
- Can we use the signal equation to measure accurate fluxes?
- What can we use it for?

Signal equation

$$S = \mathrm{Tt} \int F_\lambda \frac{\lambda}{hc} a_\lambda m_\lambda i_\lambda f_\lambda d_\lambda \, d\lambda$$

We can define the observed photon flux, S':

$$S' = \int F_\lambda \frac{\lambda}{hc} a_\lambda m_\lambda i_\lambda f_\lambda d_\lambda \, d\lambda$$

$$S = S' \, T \, t$$

What are the units of S? S'? S'T?

Calibrating observations of brightness

- Photometry: measurement of brightnesses
- Images to counts
- Counts to magnitudes: “instrumental” magnitudes

$$m_{inst} = -2.5 \log counts/s$$

- Differential photometry: compare to other stars in field
  - All terms cancel out (to some “reasonable” level), even in poor conditions!
  - Even if no stars of known brightness, still useful for variability study
- Calibrating photometry
  - If stars of known brightness in field, can determine the zeropoint:

$$m_{apparent} = m_{inst} + z$$

  - Subtlety: zeropoint as a function of SED (transformation): observe stars with range of SED / color
- All sky photometry
  - If no stars of known brightness in field, need to observe stars of known brightness in another field!
  - In this case, transmission of Earth’s atmosphere needs to be considered and characterized: observe stars at range of airmass
  - Extinction, transformation, and zeropoint usually considered simultaneously: observe stars of known brightness at range of airmass and SED/color

Zeropoint

- Two telescope systems have zeropoints of 22 and 24, respectively. Which one would you prefer to use?

Transformation coefficients

- Why?
- How?

Photon flux and signal equation

- See Canvas assignment

Photometric transformations

See Canvas assignment

Examples: photometric data

- Start a browser
- Go to Canvas home page, click on Photometry link
- Download Jupyter notebook phot_fill.ipynb
- Start it:

  jupyter notebook phot_fill.ipynb (--browser=firefox)

Work through the cells one at a time, making sure you understand everything that is happening in the cell. Execute a cell using Shift-Enter

Ask questions!

Some cells require you to add input!

Exposure time calculator: part one

- Let’s design a modular program to apply the count equation
- Given a magnitude and unnormalized SED, or input spectrum and a telescope/instrument, return estimate of observed photons, either as a function of wavelength (spectrograph) or number(s) for given filter(s) (imager)
- What functions do we need?
  - Function to return f(lambda) given input mag, spectrum
  - Function to return collecting area given observatory/telescope
  - function to return telescope transmission: tel(lambda), combine with previous?
  - Function to return atmos(lambda) given observatory
  - Function to return inst(lambda) given instrument
  - Function to return filt(lambda) given instrument/filter(s)
  - Function to return det(lambda) given instrument
  - Function to integrate
- How would we test this?

Other points

- Photon fluxes
- Converting UBVRI magnitudes to fluxes and vice versa
- SDSS and asinh magnitudes