Lecture 1: Astrophysics

Senior Astrophysics

2018-03-06

Outline

Course structure

- 18 sessions — last lecture ADV only
- 14 lectures + 4 computational labs
- From week 2, Friday 12pm lectures will be in SNH Learning Studio 4003
  Need to remember your Matlab!
- **Extra** lab session on Wednesdays at 10 am; SNH Learning Studio. Only need to attend one per week.
- Also: plan to spend 10 minutes each week telling you about important web research tools in astronomy: *Website of the Week* [WOTW]
  - Will be the basis for at least one assignment question, so pay attention!

Timetable

Week	Date	Day		Topic	
week 1	6 Mar	Tue 1pm	Lecture 1	Introduction	
	7 Mar	Wed 9am	Lecture 2	Radiation processes	
	9 Mar	Fri 12pm	Lecture 3	Emission and absorption	
week 2	13 Mar	Tue 1pm	Lecture 4	Sources of radiation	
	14 Mar	Wed 9am	Lecture 5	Stellar structure	
	16 Mar	Fri 12pm/Wed 10am	**Lab 1**	*Lab 1: Line formation*	
week 3	20 Mar	Tue 1pm	Lecture 6	The main sequence	
	21 Mar	Wed 9am	Lecture 7	Stellar evolution 1	
	23 Mar	Fri 12pm/Wed 10am	**Lab 2**	*Lab 2: Stellar evolution 1*	
week 4	27 Mar	Tue 1pm	Lecture 8	Stellar evolution 2	
	28 Mar	Wed 9am	Lecture 9	Supernovae	
Mid-semester break					
week 5	10 Apr	Tue 1pm	Lecture 10	Stellar remnants	**Assignment 1 due 9 Apr**
	11 Apr	Wed 9am	Lecture 11	Binary stars	
	13 Apr	Fri 12pm/Wed 10am	**Lab 3**	*Lab 3: Stellar evolution 2*	
week 6	17 Apr	Tue 1pm	Lecture 12	Accretion energy	
	18 Apr	Wed 9am	Lecture 13	Binary evolution	
	20 Apr	Fri 12pm/Wed 10am	**Lab 4**	*Lab 4: Roche lobes*	
week 7	24 Apr	Tue 1pm	Lecture 14	ADV-only lecture	
week 8	30 Apr	Mon 5pm			**Assignment 2 due 30 April**

Assignments

- Assignments will be released two weeks before the due date.
- All assignments will be submitted through Turnitin.
- Either typeset (LaTeX/Word etc.) or handwritten is acceptable **BUT** quality must be *legible* (no unreadable photos from your phone!)
- Deadline is 11:59 pm on the due date.
- **DO NOT** put your name on the assignment, or in the file name; just your SID. Assignments will be marked anonymously.

Course outline

- **Radiation** — lectures 1–4 + lab 1
  How is radiation produced? How is it affected as it propagates?
- **Stellar structure and evolution** — lectures 5–10 + labs 2 & 3
  Modelling stars; the evolution of stars; stellar remnants
- **Binary stars** – lectures 11–13 + lab 4
  Binary stars; evolution of binaries; applications in modern astronomy
- **Final lecture** (lecture 14): Adv-only: Problems in binary evolution (examinable)

Textbooks

No required text.

Highly recommended:

- Carroll & Ostlie, *An Introduction to Modern Astrophysics*
- Hilditch, *An introduction to close binary stars*

Both on closed reserve in SciTech library.

Astrophysics

Astrophysics is a **big** subject.

- Sometimes will just flag where a whole (possibly large!) field branches off, e.g. won't talk about how stars form
- Sometimes will give qualitative description (with lots of pretty pictures); unless I say otherwise, this is non-examinable
- A few topics are amenable to analysis at our level in time available. I will walk through these in class, and these will most naturally be the subject of assignments and exams.

What is astrophysics?

Application of laws of physics to

- understand the behaviour of astronomical objects
- predict new phenomena that could be observed

Physics used can include electromagnetism, fluid mechanics, plasma physics, general relativity, nuclear physics, and more.

What is astrophysics?

- Main difference between astrophysics and other branches of physics: controlled experiments are (almost) never possible!
- *Observational* science: only information we have is via study of EM radiation from objects (and, very recently, high energy particles and gravitational waves)

What is astrophysics?

Consequences:

- **complex systems**: can't change variables separately to isolate their effects, e.g. galaxies
- **timescales**: often $\gg$ human lifetimes, so can't follow many processes all the way, e.g. stellar evolution
- **rare events**: knowledge is limited, and will usually not occur nearby; e.g. SNe
- best way to add knowledge is to use **new wavelength domains**, e.g. radio, X-ray
- **statistical arguments** vital! more so than in many areas of lab physics, e.g. γ-ray bursts

Physical conditions

Physical conditions we are studying are **very** diverse:

- temperature:

$$\begin{array}{ccccc} 3\mathrm{K} & < & T & < & 10^{12}\ \mathrm{K} \\ \text{(CMB)} & & & & \text{gas near BH} \end{array}$$

- density

$$\begin{array}{ccccc} 10^{-20}\ \mathrm{kg/m^3} & < & \rho & < & 10^{18}\ \mathrm{kg/m^3} \\ \text{(ISM)} & & & & \text{(neutron star)} \end{array}$$

- speeds:

$$v \sim 0.99c \text{ in jets from BH}$$

Units

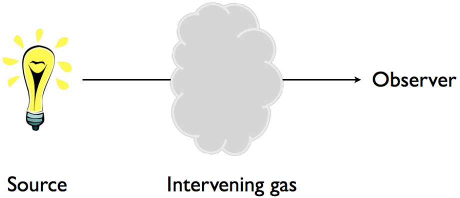
- Astronomers use many non-SI units. Partly historical, like *magnitudes*, but we'll try to avoid those in this course.
- Other main problem is scale of astronomy: inconvenient orders of magnitude involved with using SI units.
- Principal ones we will worry about:
  - distance:
    - parsec (pc); 1 pc = 3.26 ly = 3.086×10^{16} m
      Nearest star is 1.3 pc away
    - solar radius: $1R_\odot = 6.955 \times 10^8$ m
  - mass:
    - solar mass: $1M_\odot = 1.989 \times 10^{30}$ kg
  - luminosity (energy/unit time)
    - solar luminosity: $1\ L_\odot = 3.839 \times 10^{26}$ W

Website of the Week:

APOD: Astronomy Picture of the Day
http://apod.nasa.gov/apod/
Annotated daily astronomical image

Part 1: Radiation

The physics of radiation (4 lectures + 1 lab)



1. How is radiation affected as it propagates to the observer?
2. Mechanisms that produce radiation
   - Blackbody radiation
   - Transitions within atoms
3. Use results to understand spectra of stars, nebulae

Radiation

Because all of astronomy is dependent on electromagnetic radiation, we need to understand radiation itself: how it is produced, how it propagates, and how it is affected as it propagates.

Interstellar gas

Photons escaping star

Basic properties of radiation

- EM radiation: frequency ν, wavelength λ

$$\lambda\nu = c$$

- Individual photons have energy

$$E = h\nu$$

  where $h =$ Planck's constant

- Common to measure energies in eV, where

$$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$$

  (energy of visible light photon $\sim$ few eV)

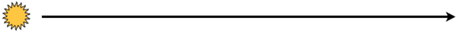
Basic properties of radiation

Simplification: astronomical objects are normally much larger than λ, so

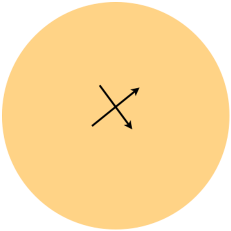
- neglect diffraction
- light travels along straight lines

Need to be careful about *direction* of photon travel:

- Far from source (e.g. light from distant star) can assume radiation is travelling radially



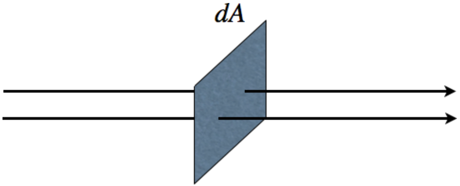
- But e.g. inside a star, photons move in many different directions, so have to worry about angles and how much radiation is moving in each direction



Flux and luminosity

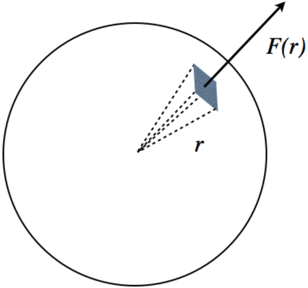
- Define the **radiant flux** F from a source as the total amount of light energy (of all wavelengths) that crosses a (perpendicular) unit area per unit time

$$dE = F\, dA\, dt$$



Flux and luminosity

- For a spherically symmetric steady source with luminosity L ($=$ total amount of energy emitted per unit time): energy conservation means



$$F(r) = \frac{L}{4\pi r^2}$$

inverse square law: measured flux drops off as square of distance

Flux and luminosity

- L is total luminosity emitted at *all wavelengths*, so F is also integrated over all wavelengths.
- In practice, often measure only part of spectrum, so need to consider how radiation is distributed over frequency

$$F = \int F_\nu(\nu) d\nu$$

total energy flux = integral of F_ν over all frequencies
Then

$$dE = F_\nu \, dA \, dt \, d\nu$$

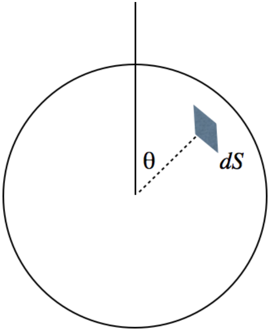
For astronomers only

- Units of F_ν are (energy)/(time) per area per frequency bin so W m^{-2} Hz^{-1}
- Special unit: 1 Jy $= 10^{-26}$ W m^{-2} Hz^{-1}
- F_ν called "flux density" — in order to get power received, need to multiply by the area and by the bandwidth

Solid angle

First we define a **solid angle**

- Consider a sphere of radius r.



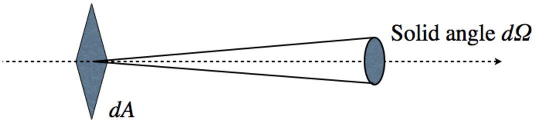
- The area dS of a patch on the surface is

$$dS = r\,d\theta \times r\sin\theta\,d\phi \equiv r^2\,d\Omega$$

  $d\Omega$ is the solid angle subtended by the area dS at the centre of the sphere
- Unit of solid angle is the **steradian** sr
- 4π sr cover the whole sphere

Specific intensity

- Consider an area dA normal to a light ray, and consider all rays that pass through dA which lie within a small solid angle $d\Omega$



- Amount of energy dE passing through dA and into $d\Omega$ in time dt and frequency range $d\nu$ is

$$dE = I_\nu \, dA \, dt \, d\nu \, d\Omega$$

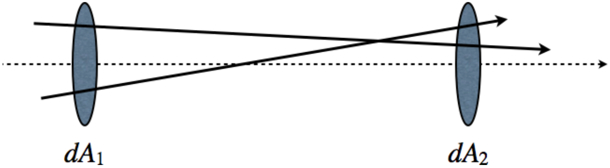
- I_ν is the **specific intensity** of the radiation

Specific intensity

- Units of specific intensity are: W m^{-2} Hz^{-1} sr^{-1}
- Another, more intuitive name for specific intensity is **brightness**

Brightness

- We can show that brightness is **constant** if there is no emission or absorption.
- Consider two points on a ray; construct areas dA_1 and dA_2 perpendicular to the ray at those points. How much energy is carried by those rays that pass through **both** dA_1 and dA_2?



Brightness

- Let $d\Omega_1$ be the solid angle subtended by dA_2 at dA_1; then the energy passing through dA_1 into $d\Omega_1$ is

$$dE_1 = I_{\nu 1}\, dA_1\, dt\, d\nu_1\, d\Omega_1$$

and similarly

$$dE_2 = I_{\nu 2}\, dA_2\, dt\, d\nu_2\, d\Omega_2$$

- No energy loss $\rightarrow dE_1 = dE_2$
- No frequency change $\rightarrow d\nu_1 = d\nu_2$
- Use the definition of solid angle: $d\Omega_1 = dA_2/r^2$
- Find:

$$I_{\nu 1} = I_{\nu 2}$$

Brightness

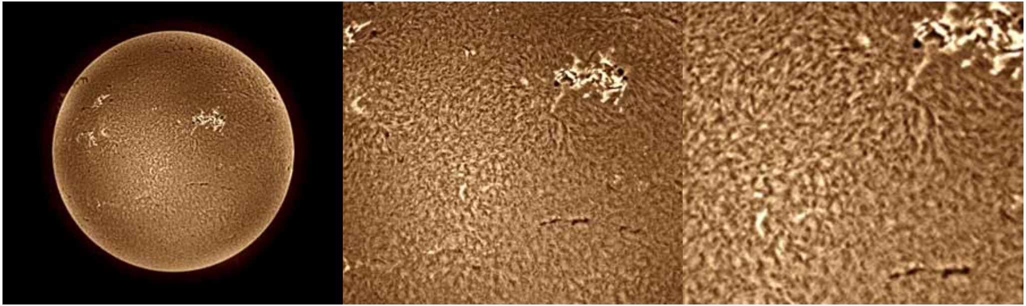
- In other words, specific intensity remains the same as radiation propagates through space.
- The brightness of an object[1] **stays the same** no matter the distance: as it gets further away, amount of flux goes down, but amount of area goes down at same rate.
- If we define the distance along the beam to be s, then we can write

$$\frac{dI_\nu}{ds} = 0$$

i.e. brightness doesn't change along beam

[1]Only matters for *extended* objects (not point sources).

Brightness



The Sun in three imaginary photos taken from a long distance (left), medium distance (center), and short distance (right) would have a constant brightness but increasing angular size (from http://www.cv.nrao.edu/course/astr534/Brightness.html)

Brightness

apod.nasa.gov/apod/ap150102.html

Next lecture

Radiation processes

- Emission
- Absorption
  - Cross-section
  - Optical depth