Stars

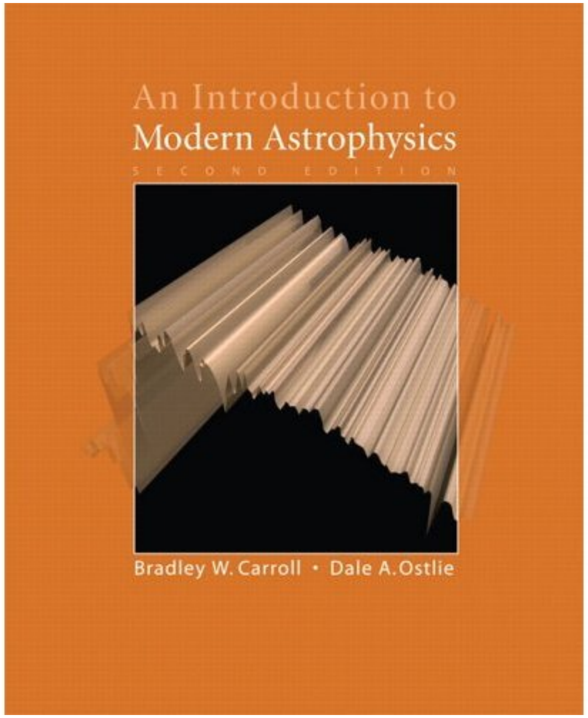
Lecturer: Professor David Alexander
Office: Ogden Centre West 119

Components: 17 lectures on Mon (12am) and Fri (11am) over 4th Nov-31st Jan;
8 workshops, 7 weekly problems, and a mid-term progress test

Stars course overview

Lecture components (in order):

Observed properties… 3 lectures
Stellar power source… 4 lectures
Stellar structure… 5 lectures
Stellar evolution… 5 lectures



Lecture slides are loaded onto DUO:
http://duo.dur.ac.uk

Lecture slides are handed out for each lecture
- Key equations are *numbered*
- We will go through examples and derivations in class

Summary of the key equations and all 17 lectures (including relevant chapters of the book) are on DUO

Text book: Carroll & Ostlie

Relevant material: chapters 3, 5, and 7-18

Course summaries for stars on DUO:

Stars Level 2, Durham University Physics
David Alexander

Part 1: Observed Properties

Lecture 1: Luminosity, distance, colour, temperature, radius
[chapter 3 of Carroll and Ostlie]

Lecture 2: Spectral properties, classification, HR diagram
[chapter 8 (some of chapters 5 & 7) of Carroll and Ostlie]

Lecture 3: Binaries, orbits, masses
[chapter 7 of Carroll and Ostlie]

Part 2: Stellar Power Source

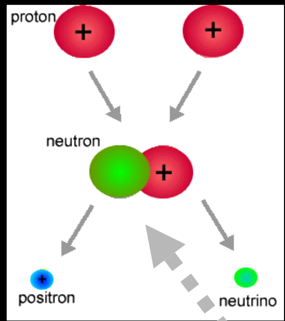
Lecture 4: Hydrostatic equilibrium and conditions in the stellar c
[chapter 10 (some of chapter 9) of Carroll and C

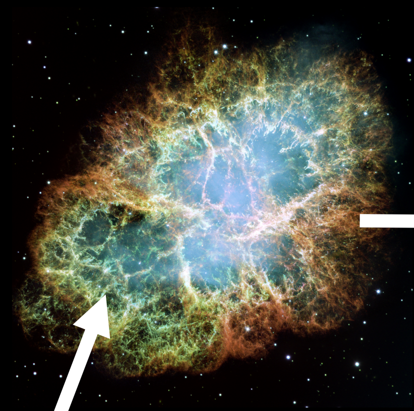
Note: that these may get updated throughout the duration of the course

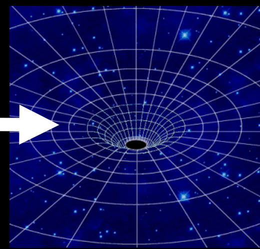
Stars overview:
Aims of each lecture

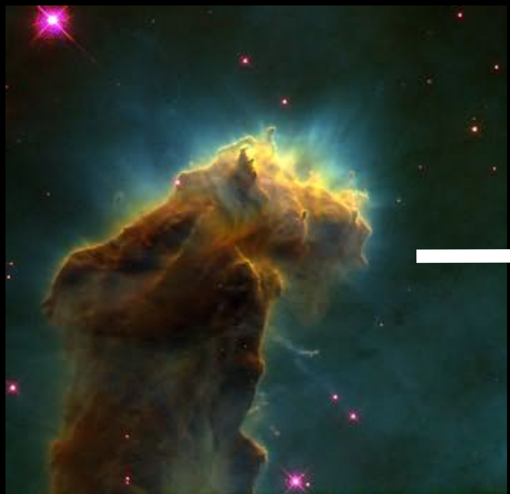
1

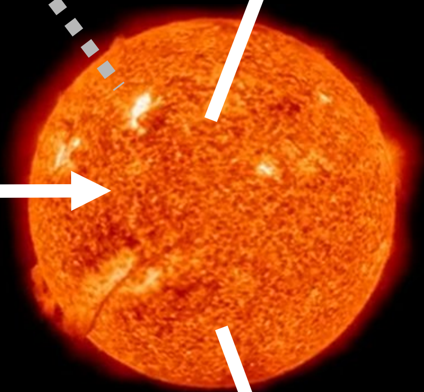
Astrophysics from the birth to the death of stars

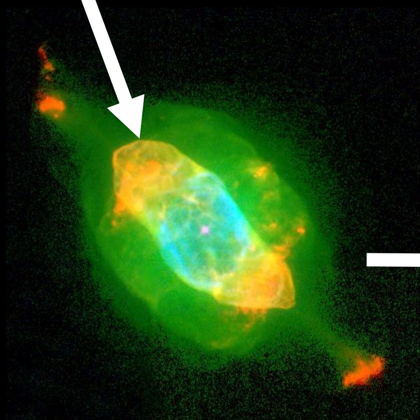


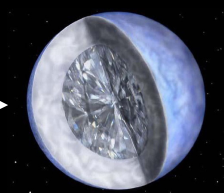










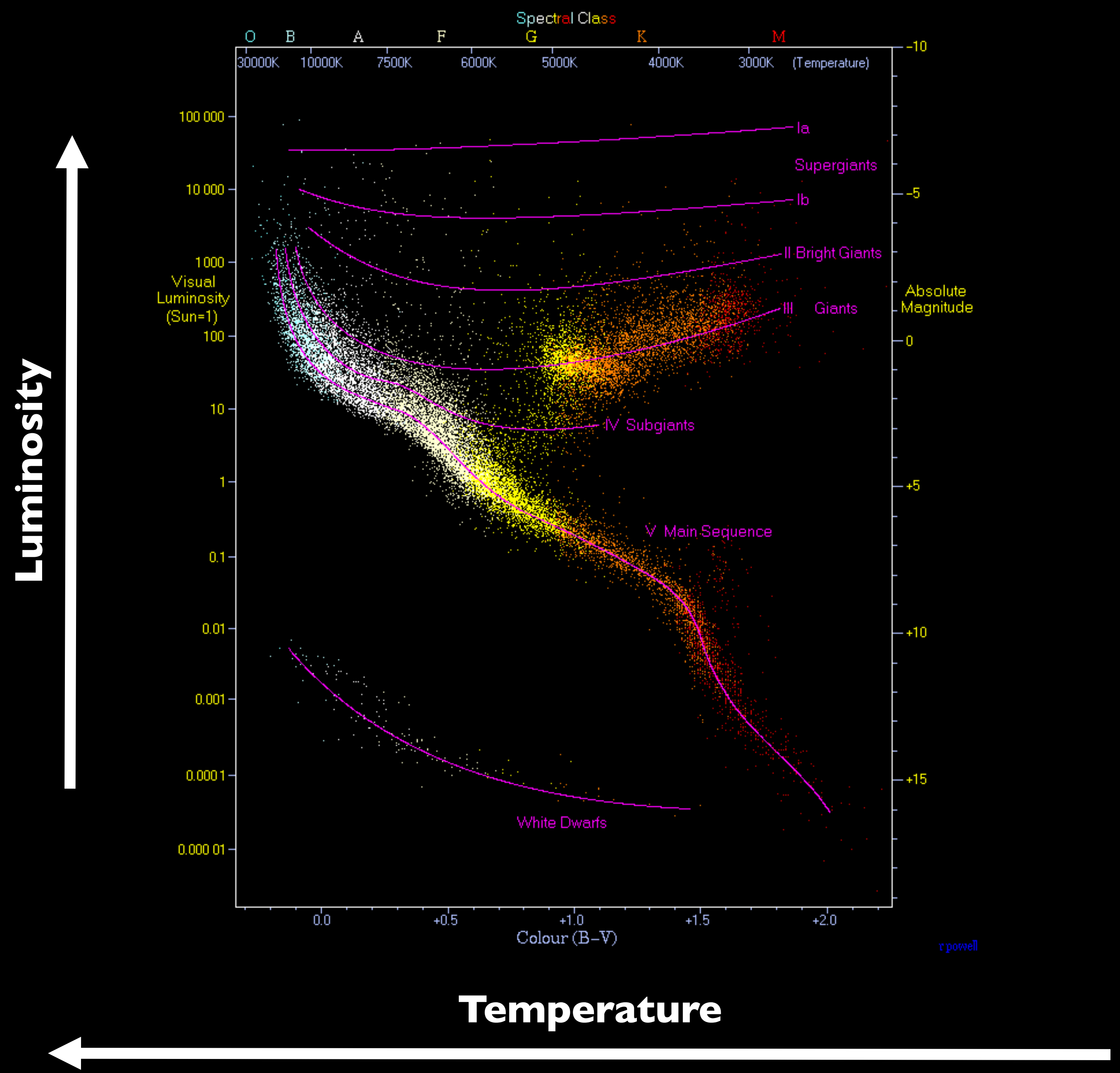


Key aims:

(1) Overview of the observational properties of stars and how these relate to the physics and conditions within stars

(2) Qualitative and quantitative understanding of stars from their formation to their power source, evolution, and destruction

Key observational diagrams



Stars are important because…

… they produce the heavier elements from Carbon onwards, which we need for planets, people, living organisms, food etc

… they provide the light and heat that living organisms require

ASTROPHYSICIST

WHO WANTS TO BE A

50:50

15 £1 MILLION
14 £500,000
13 £250,000
12 £125,000
11 £64,000
10 £32,000
9 £16,000
8 £8,000
7 £4,000
6 £2,000
5 £1,000
4 £500
3 £300
2 £200
1 £100

Where does the Sun’s energy come from?

A: Glow of molten rocks

B: Majority of the general public voted for D

C: Combining light elements to form heavier elements

D: Breaking apart of heavy elements into lighter elements

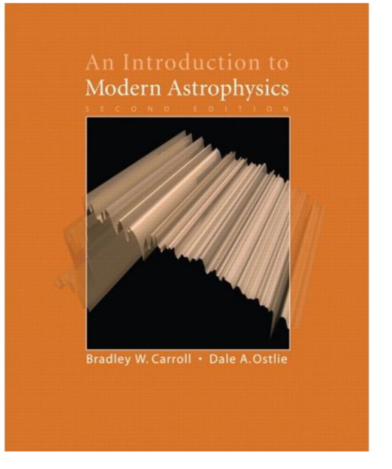
Lecture 1: Observed properties –

Luminosity, distance, colour, temperature, radius

A lot of this lecture is a review of relevant observational techniques lectures

Professor David Alexander
Ogden Centre West 119

Chapter 3 of Carroll and Ostlie

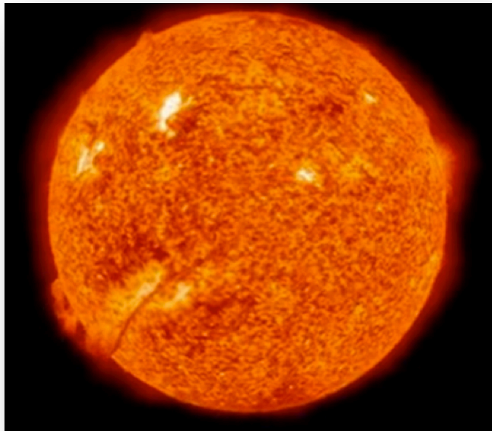


What can we observe of stars?

Basic observable properties:

(1) Brightness (lecture 1)
magnitude, flux, distance, and luminosity

(2) Colour (lecture 1)
temperature and black-body emission



(3) Radius (lecture 1)

(4) Spectral properties (lecture 2)

(5) Mass: stellar binaries (lecture 3)

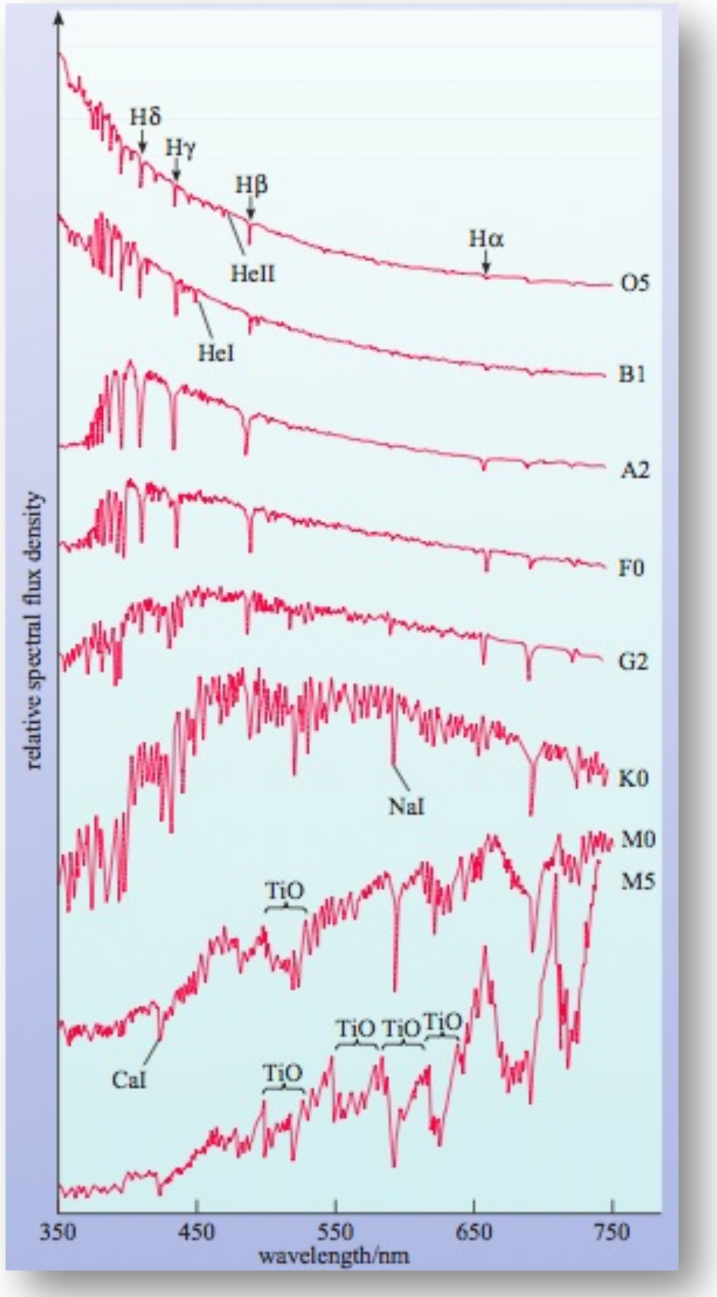
(6) Orbital motions: stellar binaries (lecture 3)

And how these properties are related… this sets the scene for later lectures

What can we observe of stars?

We won't dwell long on the brightness of stars (this is more observational techniques)

But over the next 2 lectures we will understand why the spectra of stars look like this



Aims of lecture

Key concept: black-body emission

Aims:

- Know what stellar properties can be measured
- Understand the connection between stellar colours and temperature
- Know and be able to use:

$$L = 4\pi R^2 \sigma T_e^4$$

Stefan-Boltzmann luminosity equation (for a black body)

$$\lambda_{\max} = \frac{2.9 \times 10^{-3}}{T}$$

Peak wavelength for black-body emission

$L = 3.84 \times 10^{26}$ W
$R = 6.96 \times 10^{8}$ m (~100 x radius of Earth)
$T_e = 5800$ K (surface)

Some of the key measurable properties of stars

Stellar property	Range of observed properties
Luminosity	$\sim10^{-6}$—10^{6} solar luminosities
Radius	~0.1—2000 solar radii
Surface temperature	~2,500—50,000 K
Mass	~0.08—200 solar masses
Lifetime	$\sim10^{6}$—10^{12} years

These properties are for fusion-powered stars – degenerate stars (we explore at the end of the course) can be substantially smaller, hotter, and have longer lifetimes… counter intuitively, the most massive stars have the shortest lifetimes!

The majority of fusion-powered stars are mostly composed of Hydrogen (~71%) and Helium (~27%), with few heavier elements; however, as we will learn, the cores of stars can be more rich in heavy elements

Magnitude: apparent and absolute [brief review]

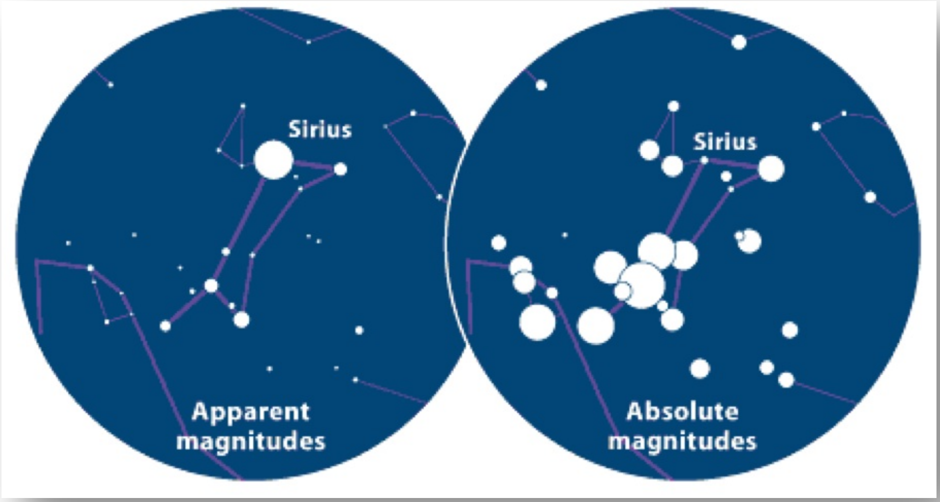
Apparent magnitude (flux):

$$m = const - 2.5\log(f)$$

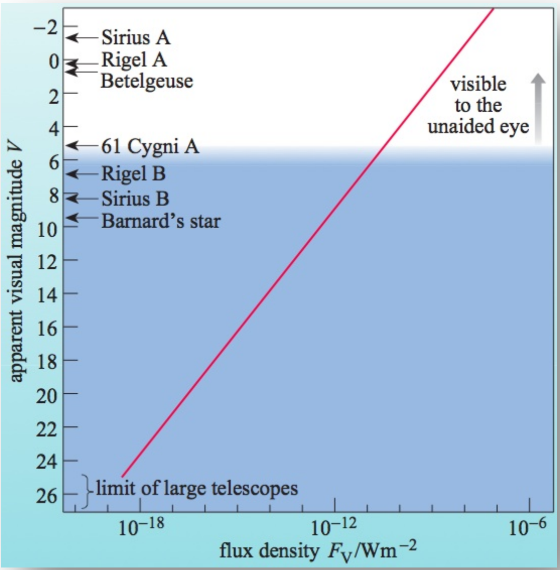
Absolute magnitude (luminosity):

$$M = const - 2.5\log(L)$$

$$m - M = 5\log(d_{pc}) - 5$$



Absolute magnitude: the magnitude a star would have if it was placed at 10pc



Luminosity (L), flux (f), distance (d) relationship in normal units (inverse square law):

$$L = 4\pi d^2 f$$

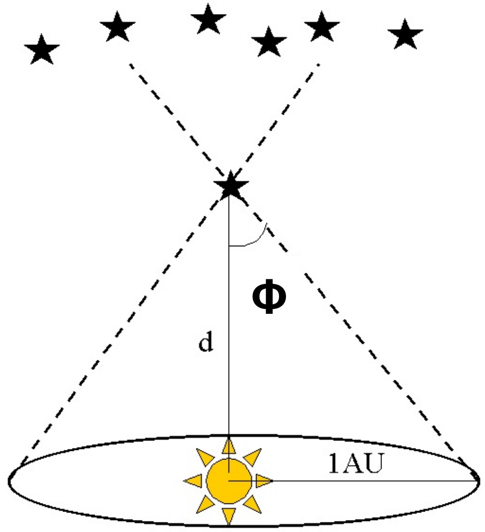
Stellar distances: parallax and Cepheid stars

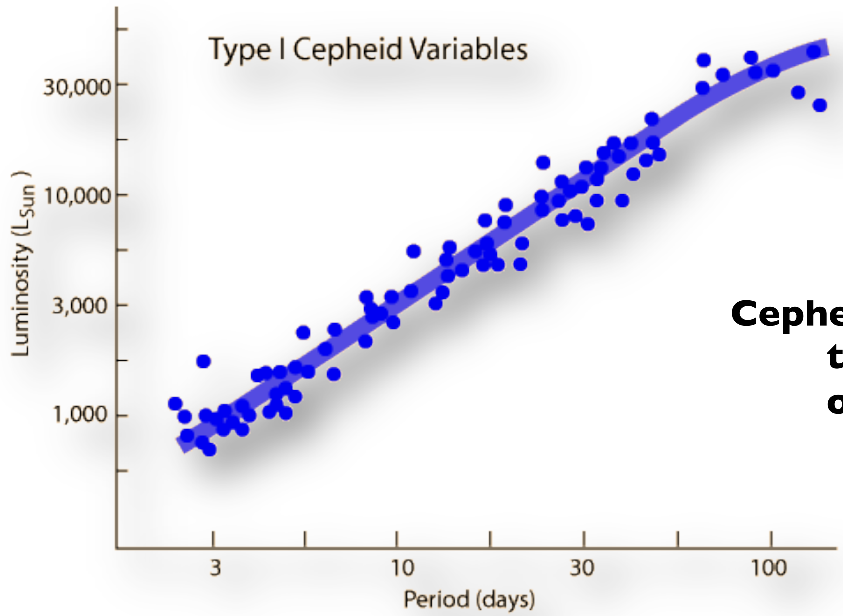
Parallax (see obs techniques lectures)

For small angles:

$$d(pc) = \frac{1}{\phi(arc\sec)}$$

1 parsec = distance of a star with a parallax of 1 arcsec





Cepheid variable stars: these can also be used to measure distances, particularly to other galaxies (more in lecture 12)

Key fact: stars are (near) black-body emitters

Black-body emission

The emission from a non-reflective body in thermodynamic equilibrium produces a distinctive spectrum:

The amount of radiant energy crossing unit area, in a unit solid angle in unit frequency range and in unit time is given by:

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$

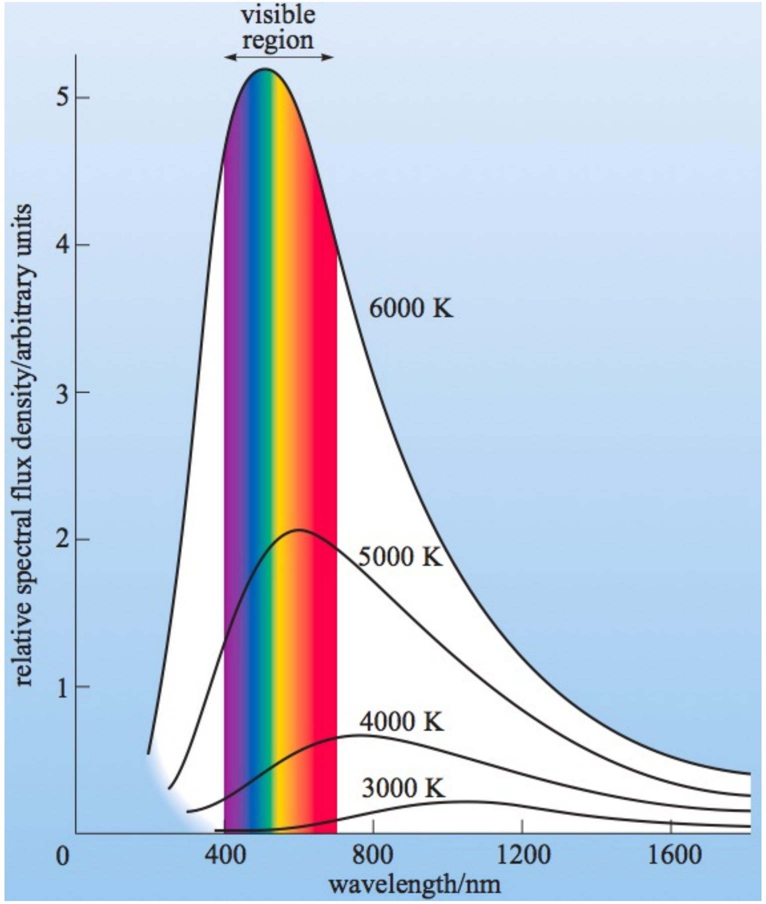
$B_\lambda(T)$ = Planck distribution at temperature T

λ = wavelength of light

c = velocity of light

h = Planck's constant = 6.62×10^{-34} Js

k_B = Boltzmann's constant = 1.38×10^{-23} JK^{-1}

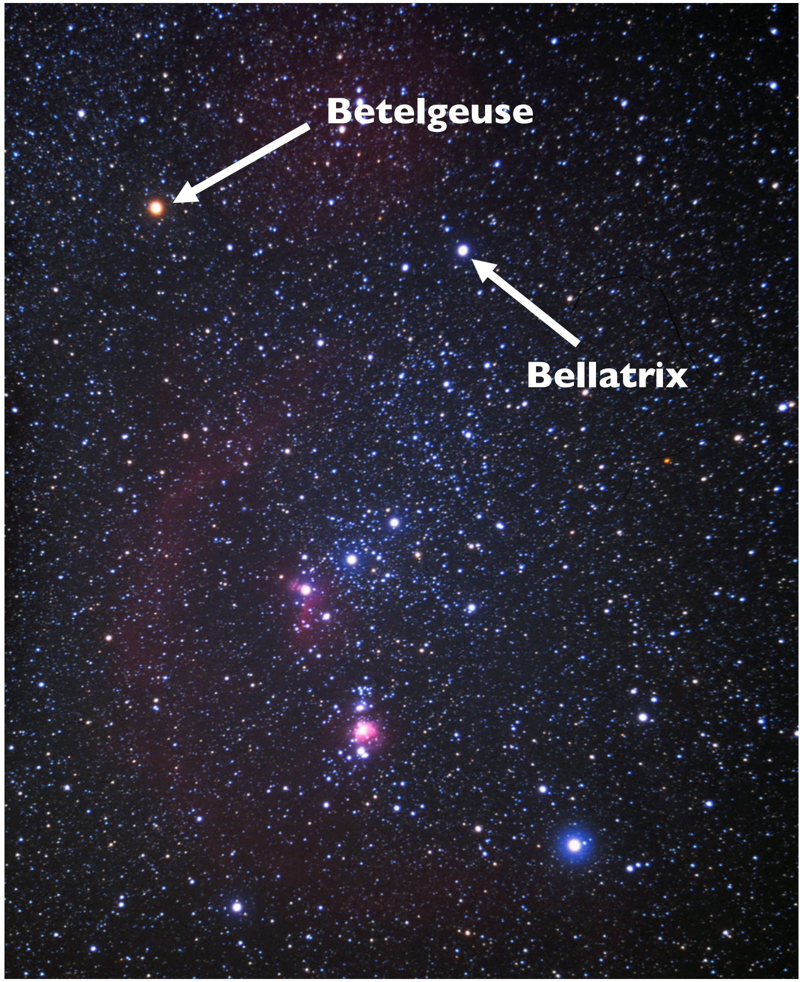


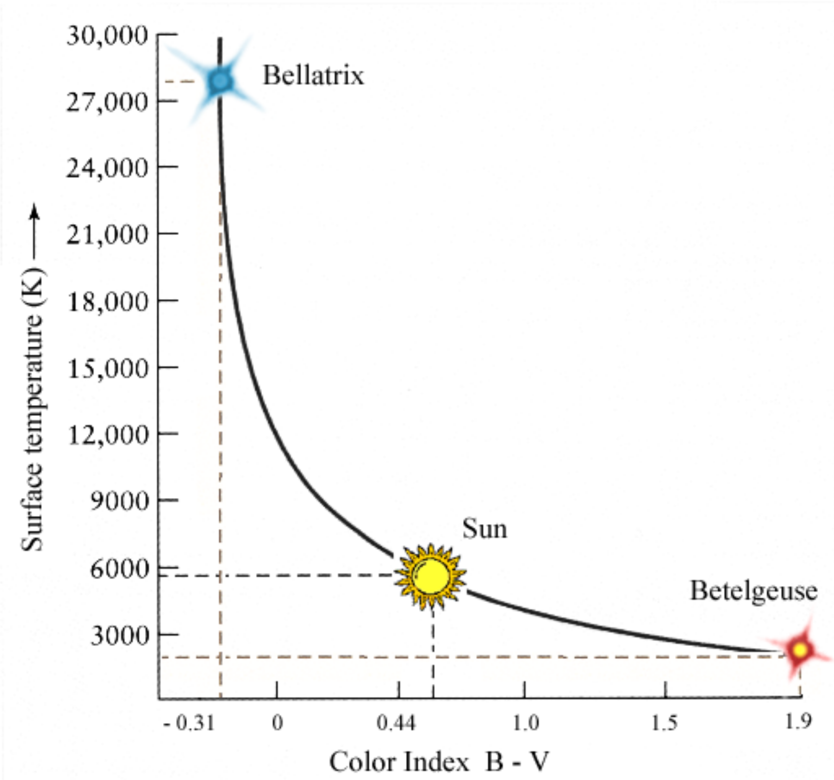
Wien displacement law:

$$\lambda_{max} = \frac{2.9 \times 10^{-3}}{T}$$

Stellar colours: observations

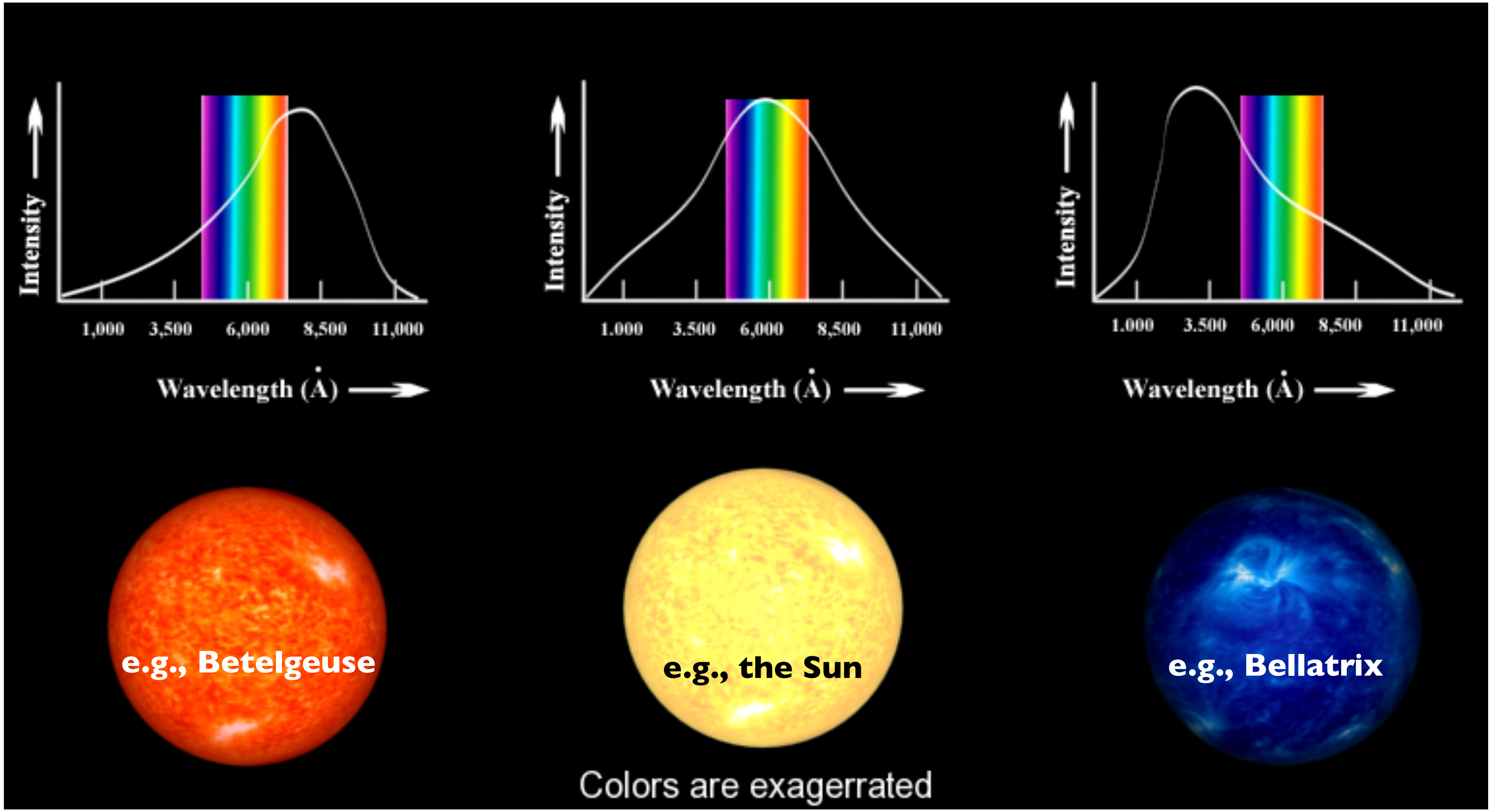
Stars are (near) black-body emitters





Stellar colours due to surface temperature: B = filter at 440nm; V = filter at 550nm

Stellar colours: black-body emission



Which star is the hottest? What are the surface temperatures of these stars?

Luminosity: from black-body emission

Effective temperature:

Stars are not quite perfect black-body emitters. We therefore define an effective temperature (T_e); this is defined in such a way that a black body of temperature T_e with the same radius as the star would radiate the same amount of energy.

Stefans law:

$$F = \sigma T^4 \qquad \text{(W m}^{-2}\text{)}$$

F = radiation emitted per square metre of surface

σ = Stefan-Boltzmann constant = 5.67×10^{-8} W m^{-2} K^{-4}

Stefan-Boltzmann luminosity equation (definition for a black body):

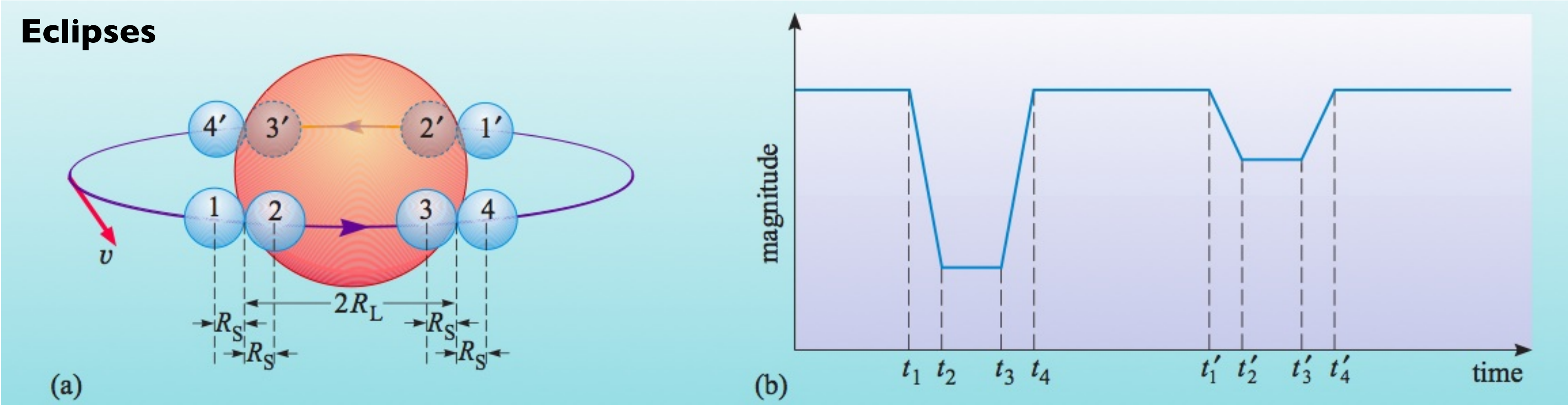
$$L = 4\pi R^2 \sigma T_e^4 \qquad \textbf{Equation 1}$$

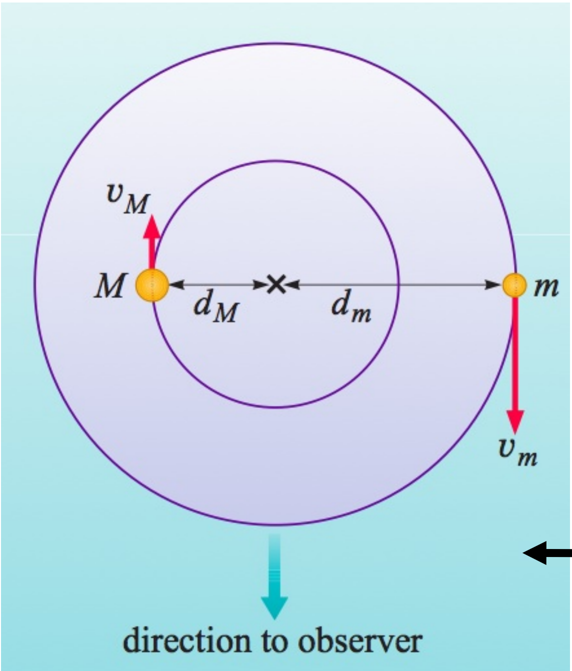
R = radius of the star

σ = Stefan-Boltzmann constant

Stellar radius: eclipses

Radii of stars can be measured using an interferometer (obs techniques) and also eclipses

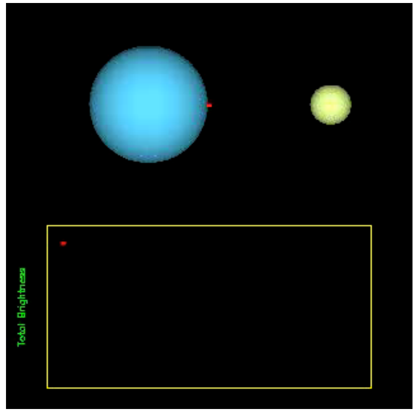




$$2R_S = v \times (t_2 - t_1)$$

$$2R_L = v \times (t_4 - t_2)$$

$$2R_S + 2R_L = v \times (t_4 - t_1)$$

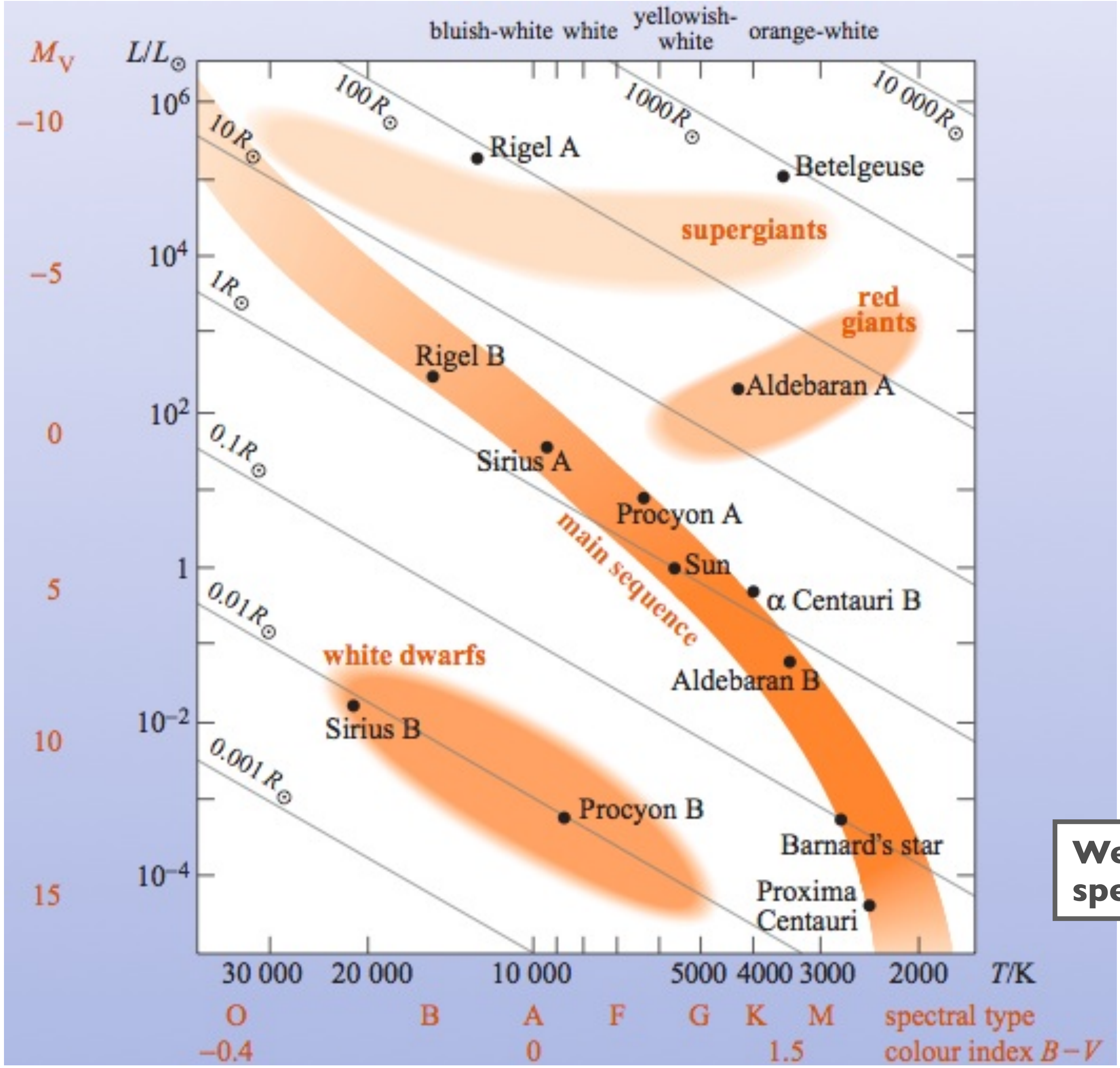


v can be measured using the maximum doppler (velocity) shift of the stellar component:

$$v = v_M + v_m \text{ or } v = v_L + v_S$$

We explore eclipses more in lecture 3

The key plot: the Hertzsprung-Russell diagram



With this black-body luminosity equation

$$L = 4\pi R^2 \sigma T_e^4$$

If we know two out of L, R, and T we can plot the star on the HR diagram

We will learn about the spectral types in lecture 2

Progress test on Friday 15th November at 11am

- Formative and is aimed to give you experience of answering relevant exam questions.
- Based on the observational techniques lectures (you will have a similar test for the stars lectures next term).
- Consist of 1 long question and 4 short questions (questions will be similar to those in May/June exam).
- Take place in the normal lecture slot in Ph8; for concession students the room is PCL57.
- 40 mins to answer all questions (students on concessions can take more time).