Revision: Sun, Stars (and Planets)

See web slides of Dr Clements for Planets revision

Juliet Pickering   Office: Huxley 706

Office hour (Pickering):

Thursday 22nd May 12-1 pm

Outline overview of first part of the course

The Sun: its structure and energy generation

Stars: putting the Sun into context

Solar structure and energy generation:

What is a star?

Stellar structure equations
Estimates of ρ, P, T etc

energy generation – nuclear burning

convection vs radiation

Interior structure

Timescales (thermal, dynamical)

Solar Atmosphere , Solar activity
Solar spectrum

Equations of stellar structure

$$\frac{dp}{dr} = \frac{-Gm\rho}{r^2}$$ Hydrostatic equilibrium

$$\frac{dm}{dr} = 4\pi\rho r^2$$ Mass continuity

$$\frac{dL}{dr} = 4\pi\rho r^2\varepsilon$$ Energy generation

$$\varepsilon = \varepsilon_o \rho T^{\eta}$$

$$\kappa = \kappa_o \rho^{\alpha} T^{-\beta}$$

$$\frac{dT}{dr} = \frac{-3\kappa\rho L}{16\pi a c r^2 T^3}$$ if heat transport is radiative

$$\frac{dT}{dr} = \left(1 - \frac{1}{\gamma}\right)\frac{T}{p}\frac{dp}{dr}$$ if heat transport is convective

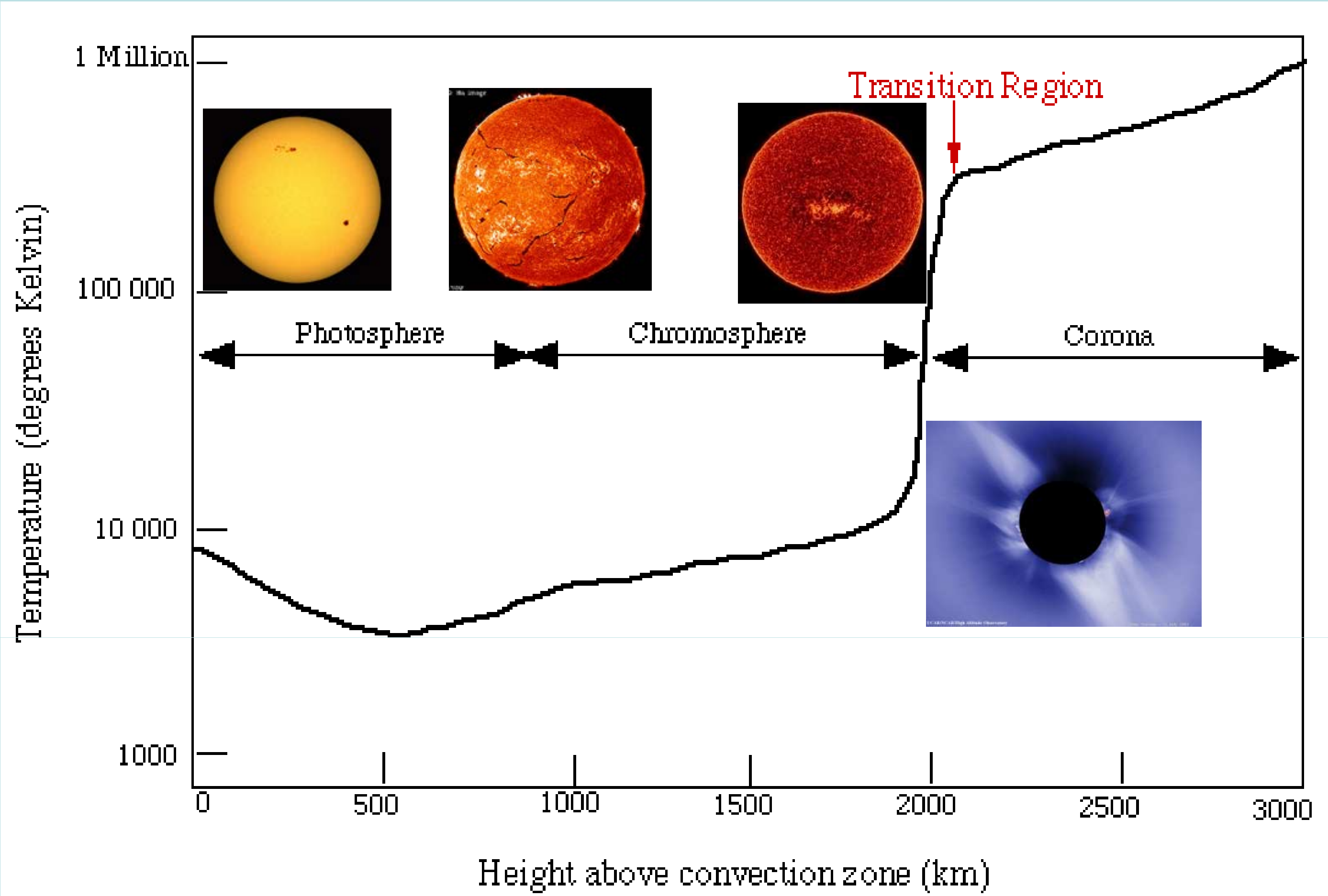
Equation of state

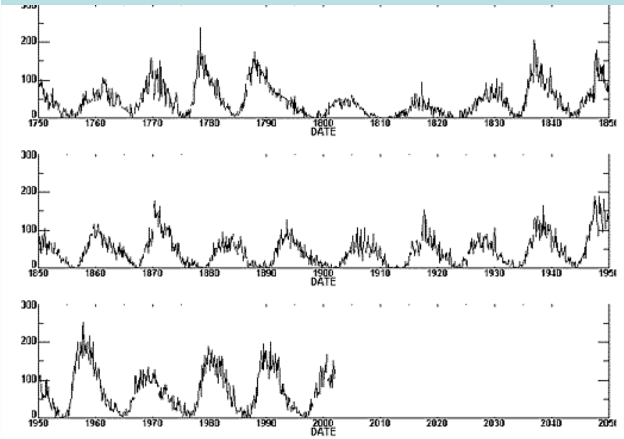
$$P_{gas} = \frac{\rho \mathcal{R} T}{\mu}$$

You need to know this!

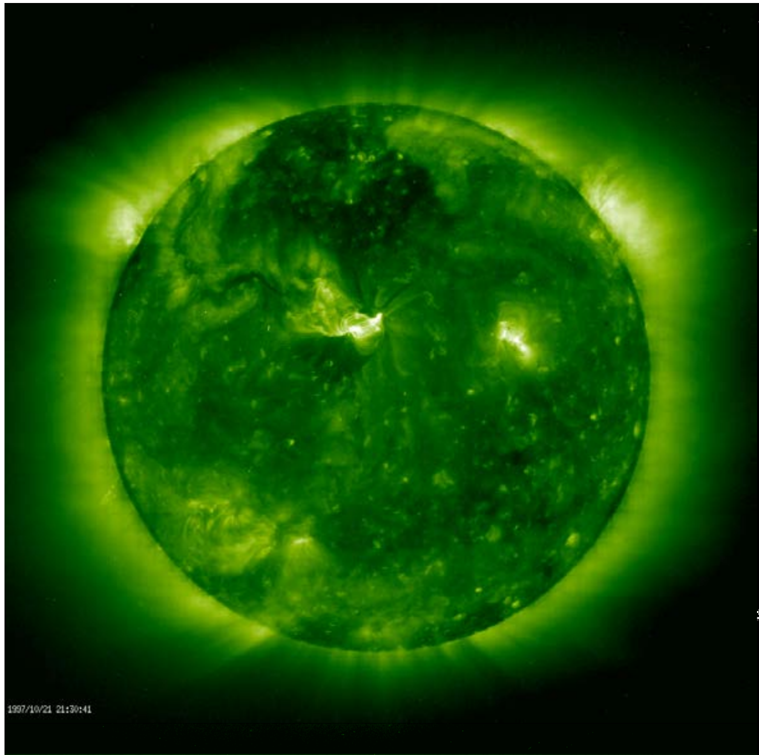
Solar atmosphere

- Photosphere
- Chromosphere
- Transition region
- Corona
- Solar wind





Magnetic Activity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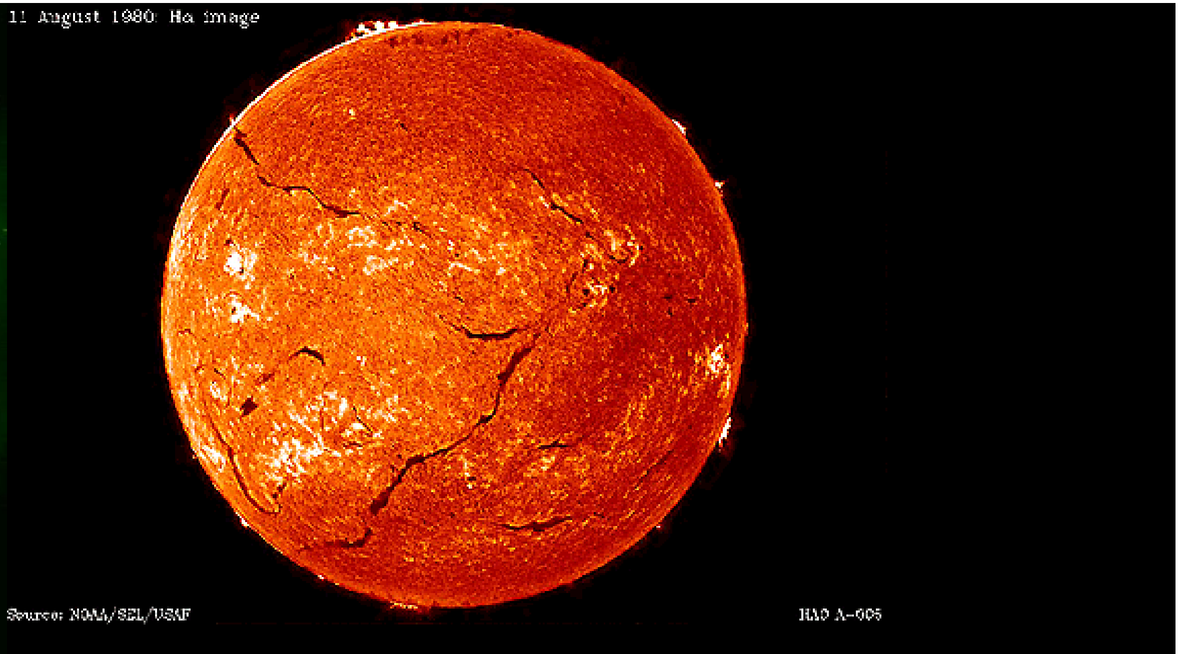
11 August 1980: Hα image
Source: NOAA/SEL/USAF
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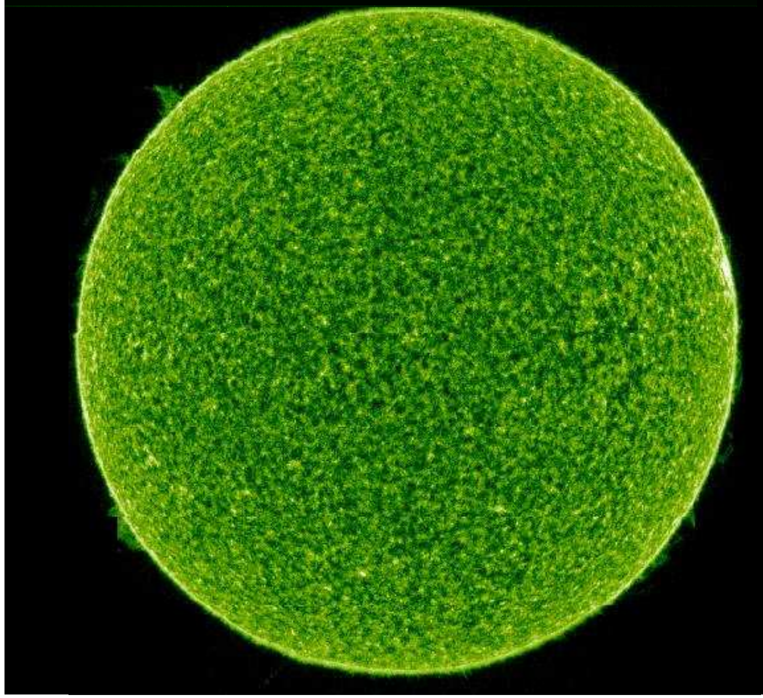
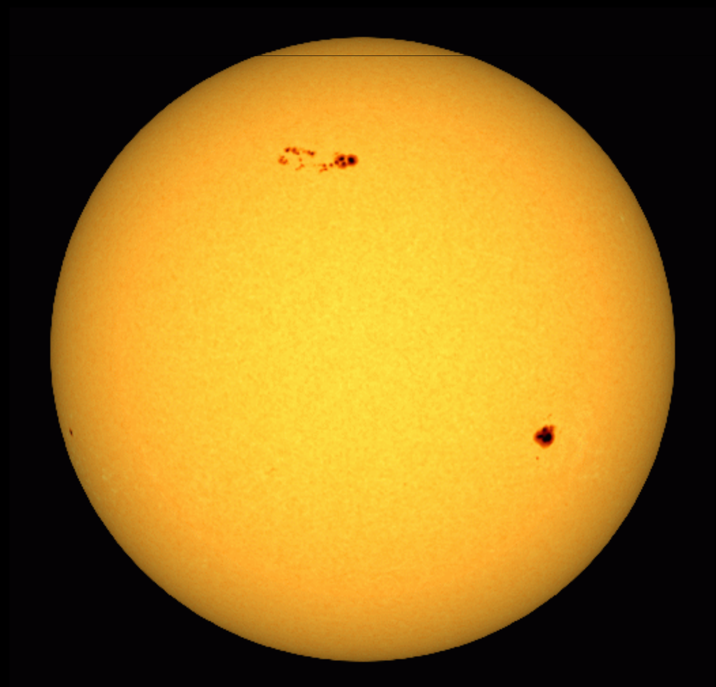
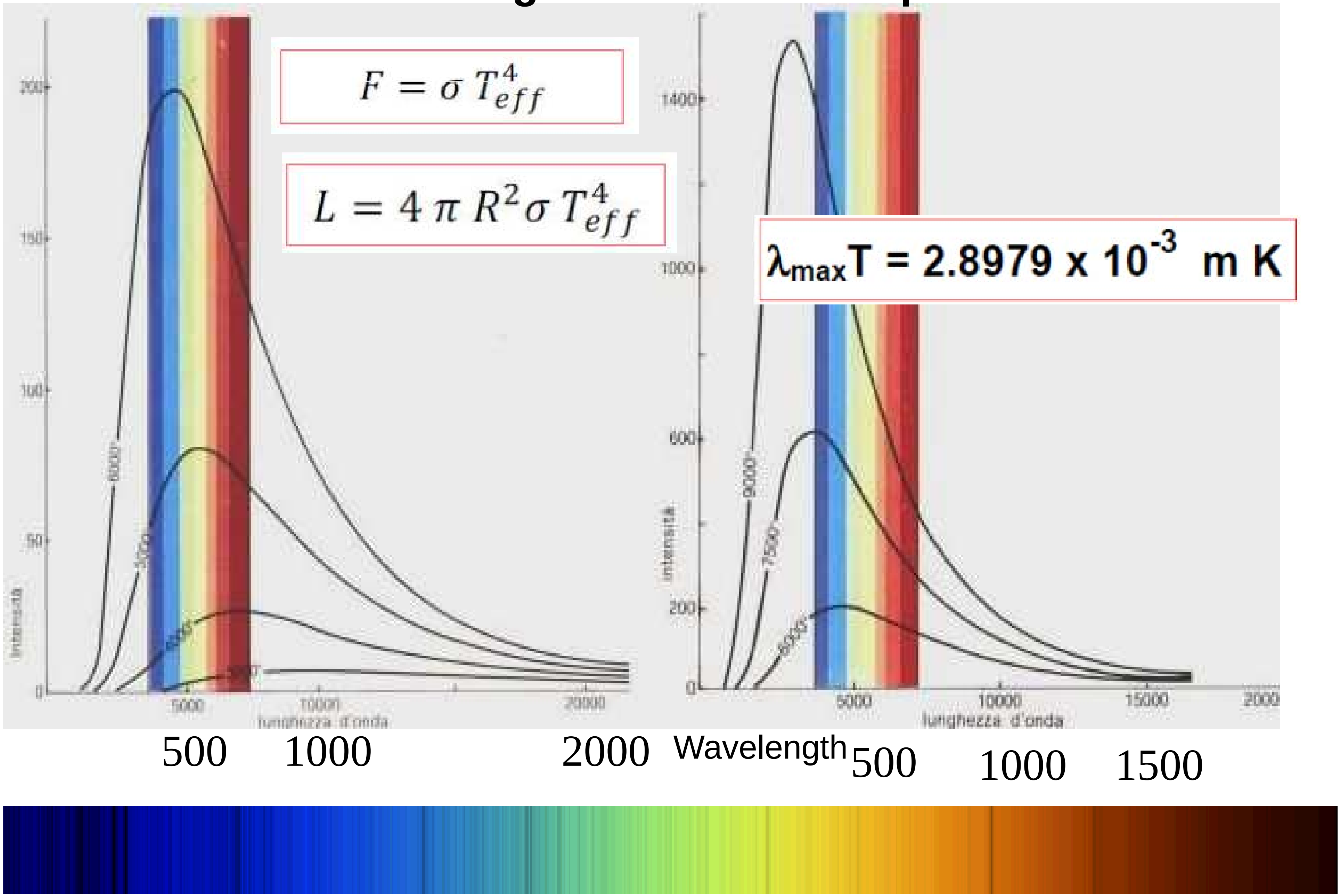
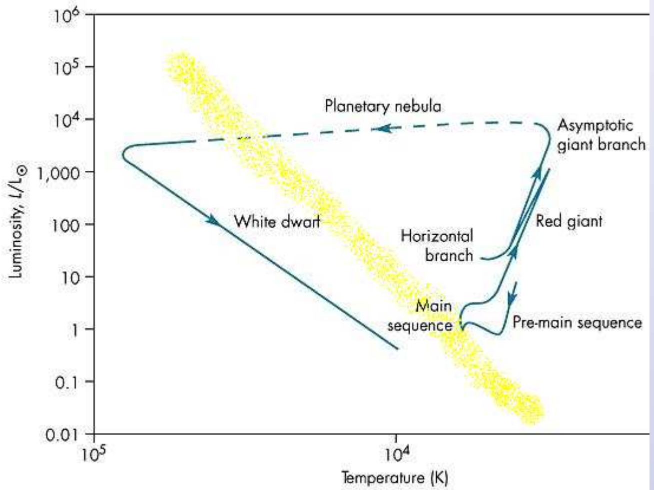
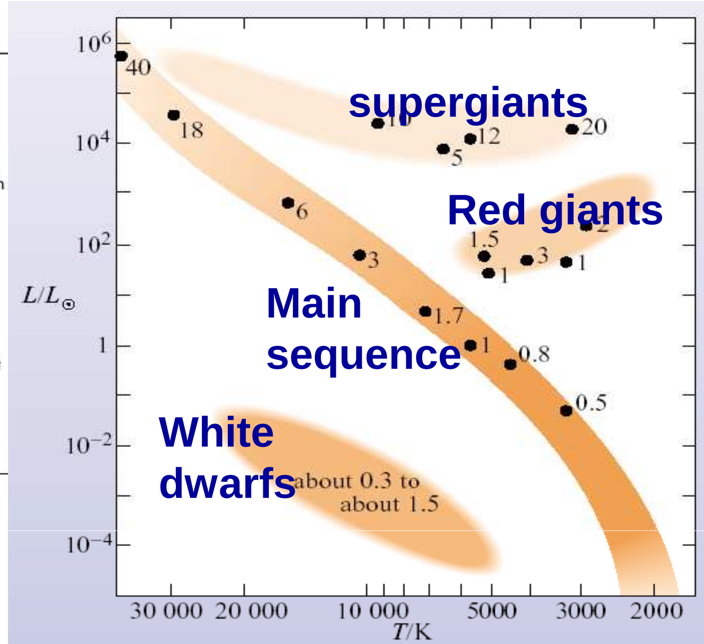



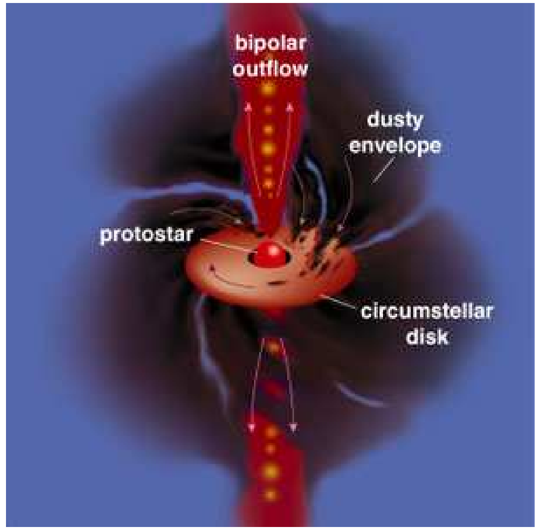
Intensity vs wavelength, Planck curves for blackbodies at a range of different temperatures

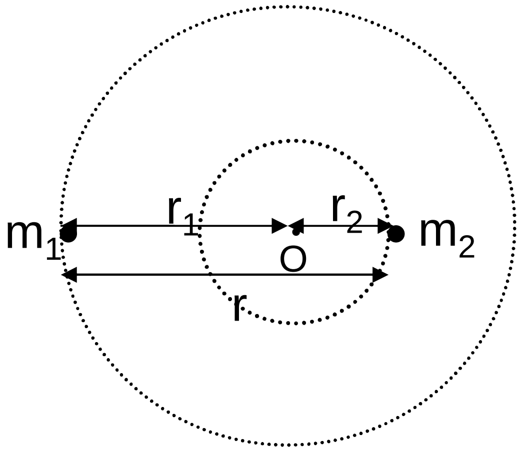


Stars: putting the Sun into context –









Physical parameters and their measurement: egs

L,

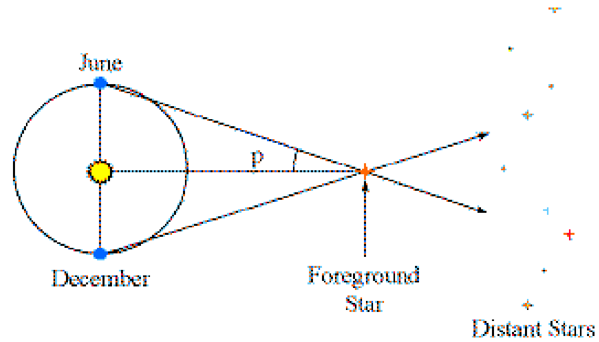
$$m = -2.5 \log_{10} f + K$$

$$M = m - 5 \log_{10} d + 5$$

magnitude – absolute and apparent

distance (parsec pc, light years, AU)

parallax, proper motion



effective T, colour index

age

radius, mass, composition (stellar spectrum, spectral type, spectral classification, opacity)

Units (arc sec, parsec, light year, solar units etc)

Spectral classification of stars

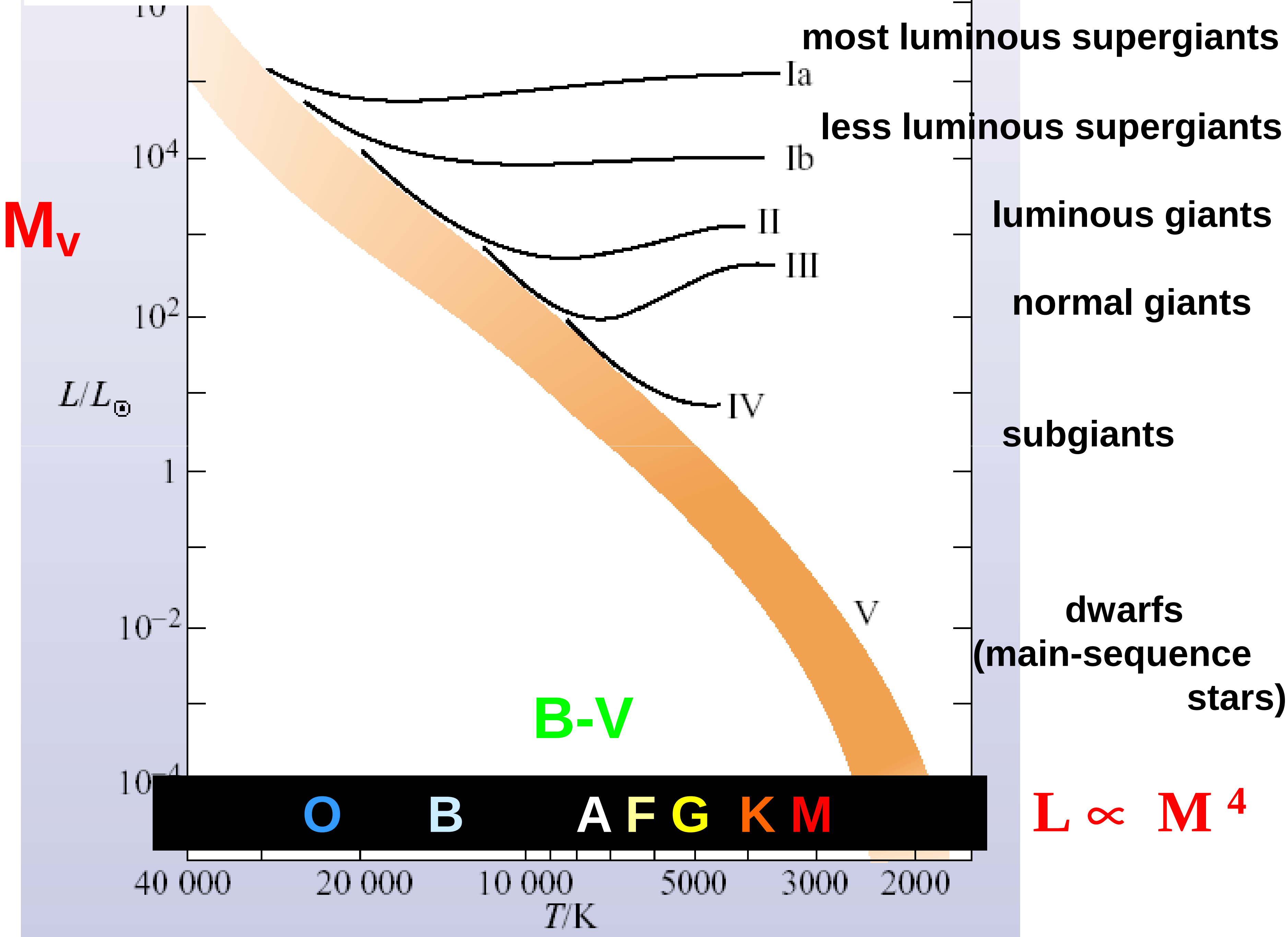
Type	Colour	Teff (K)	Main characteristics	Examples
O	Blue	> 25000	He+ lines; strong UV	Mintaka (δ Orionis)
B	Blue-white	11000 – 25000	Neutral He lines	Rigel, Spica
A	White	7500 – 11000	Strong H lines	Sirius, Vega
F	Yellow-white	6000 – 7500	Weak metal lines	Procyon
G	Yellow	5000 – 6000	Solar-like spectrum	Sun, Capella
K	Orange	3500 – 5000	Metal lines dominate	Arcturus, Aldebaran
M	Red	< 3500	Molecular bands noticeable	Betelgeuse, Antares

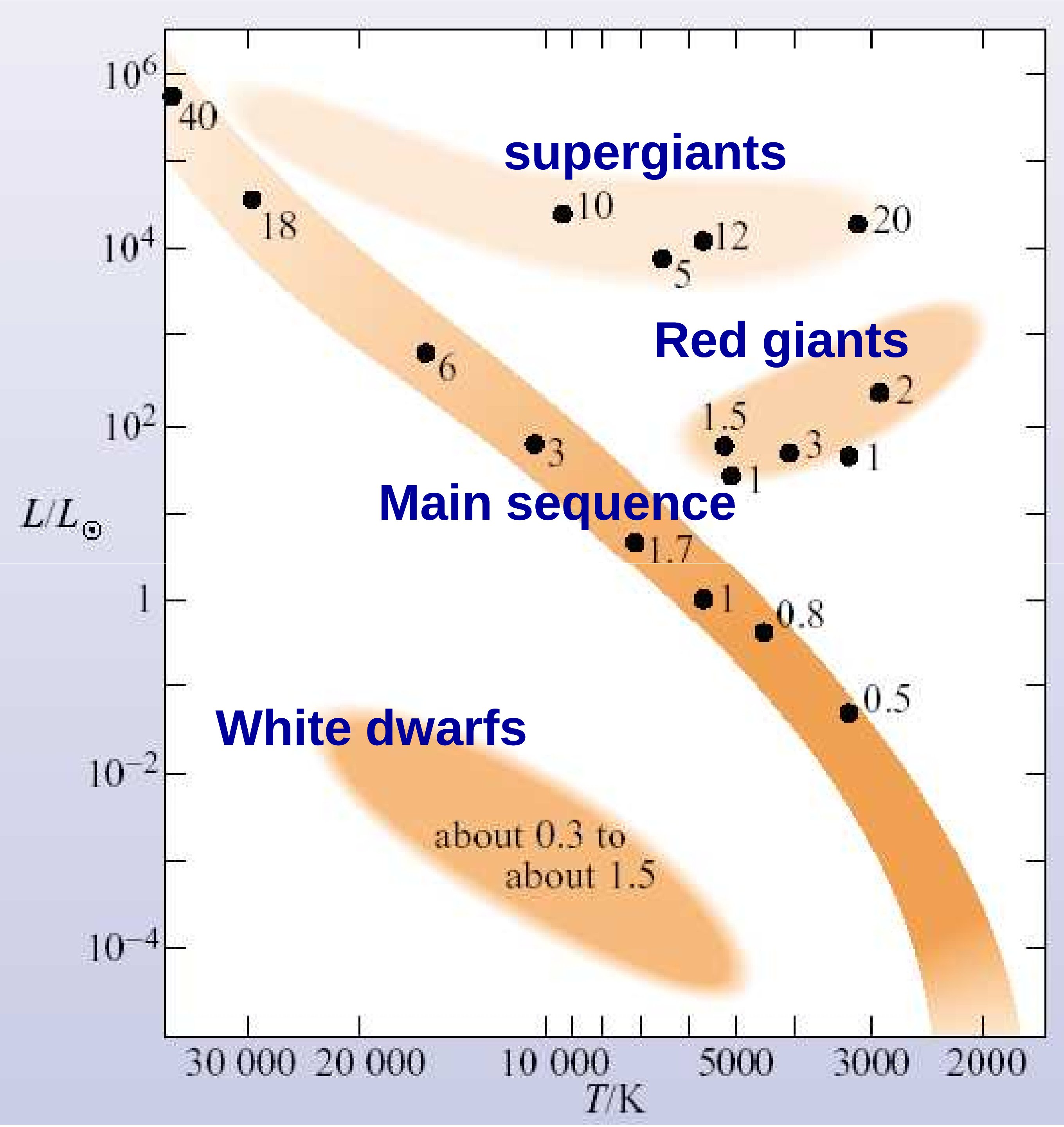
Each class also divided into 10 subdivisions, so e.g.
…, B8, B9, A0, A1, A2, … A9, F0, F1, …
0 being hottest, so F9 and G0 are very similar stars

HR diagram and stellar evolution

- dependence on stellar mass,
- types of stars
- time spent in different stages
- explanations
- Evolutionary tracks
- homologous series,
- Age of star clusters

HR diagrams


most luminous supergiants
less luminous supergiants
luminous giants
normal giants
subgiants
dwarfs
(main-sequence
stars)
Ia
Ib
II
III
IV
V
M_V
$L/L_\odot$
10^4
10^2
1
10^{-2}
10^{-4}
B-V
O B A F G K M
40 000
20 000
10 000
5000
3000
2000
T/K
$L \propto M^4$

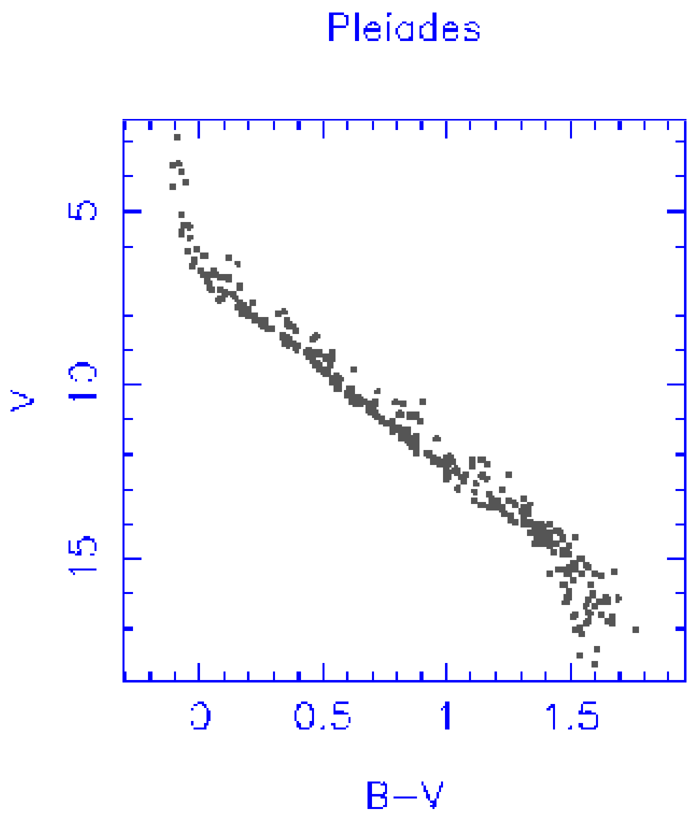


supergiants
Red giants
Main sequence
White dwarfs
about 0.3 to
about 1.5
40
18
6
3
1.7
1
0.8
0.5
10
5
12
20
2
1.5
3
1
1
10^6
10^4
10^2
1
10^{-2}
10^{-4}
$L/L_\odot$
30 000
20 000
10 000
5000
3000
2000
T/K

Homology transformation

Consider set of stars of homogeneous composition, burning hydrogen.

Stars differ only because of their mass.



Derived many relations, egs:

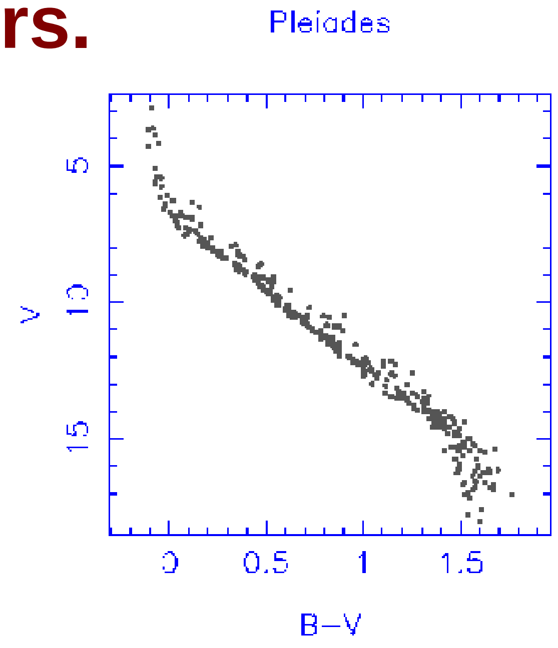
$$\rho_c \propto M / R^3$$

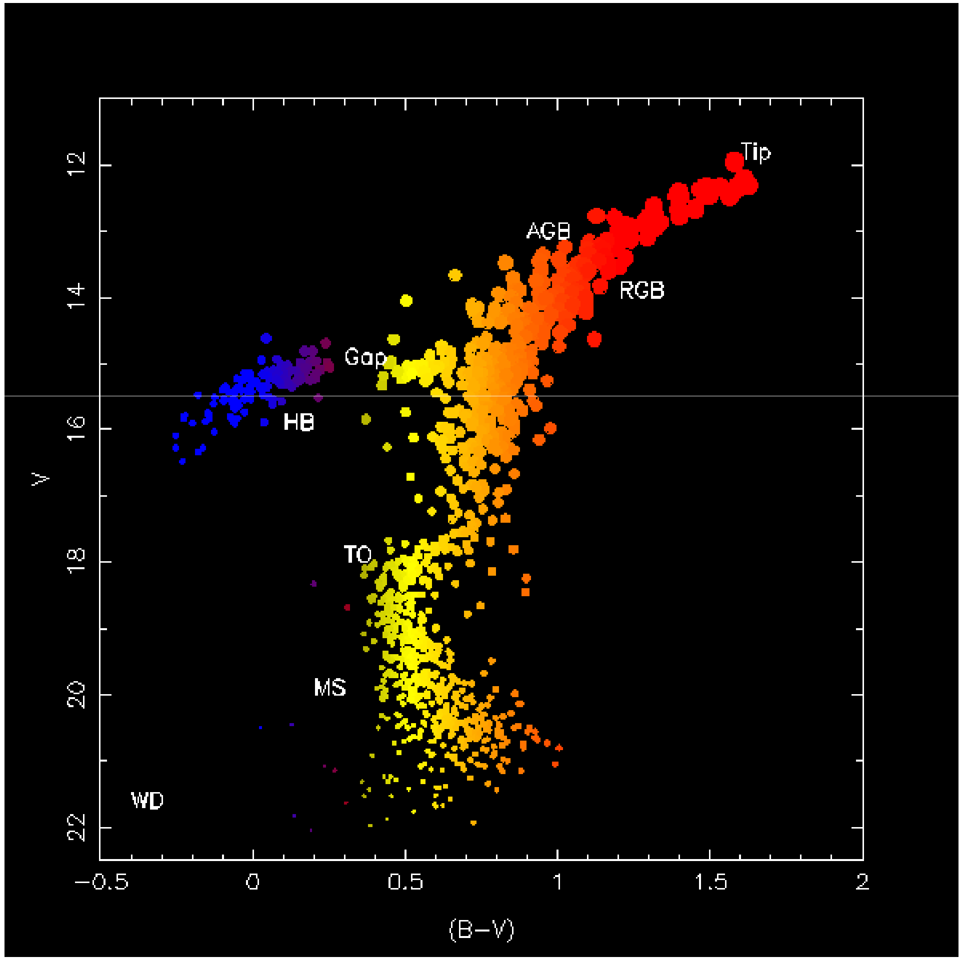
$$Pc \propto M^2 / R^4$$

$$T_c \propto M / R$$ ***etc etc***

Main sequence lifetime $$t \propto \frac{1}{M^3}$$

So massive stars (at top of main sequence) exhaust their hydrogen quickest -- explains **turn-off point** in **clusters.**





Estimating cluster age

$$\text{Cluster age } \tau = \frac{\text{Total energy released on MS}(E_{\text{ms}})}{\text{Luminosity}}$$

$$E_{MS} = \text{mass H "burnt"} \times \text{Nuclear energy released/Kg } (E_{NKg})$$

$$= f\, X_H\, M \times E_{NKg}$$

Use a relevant M-L relation:

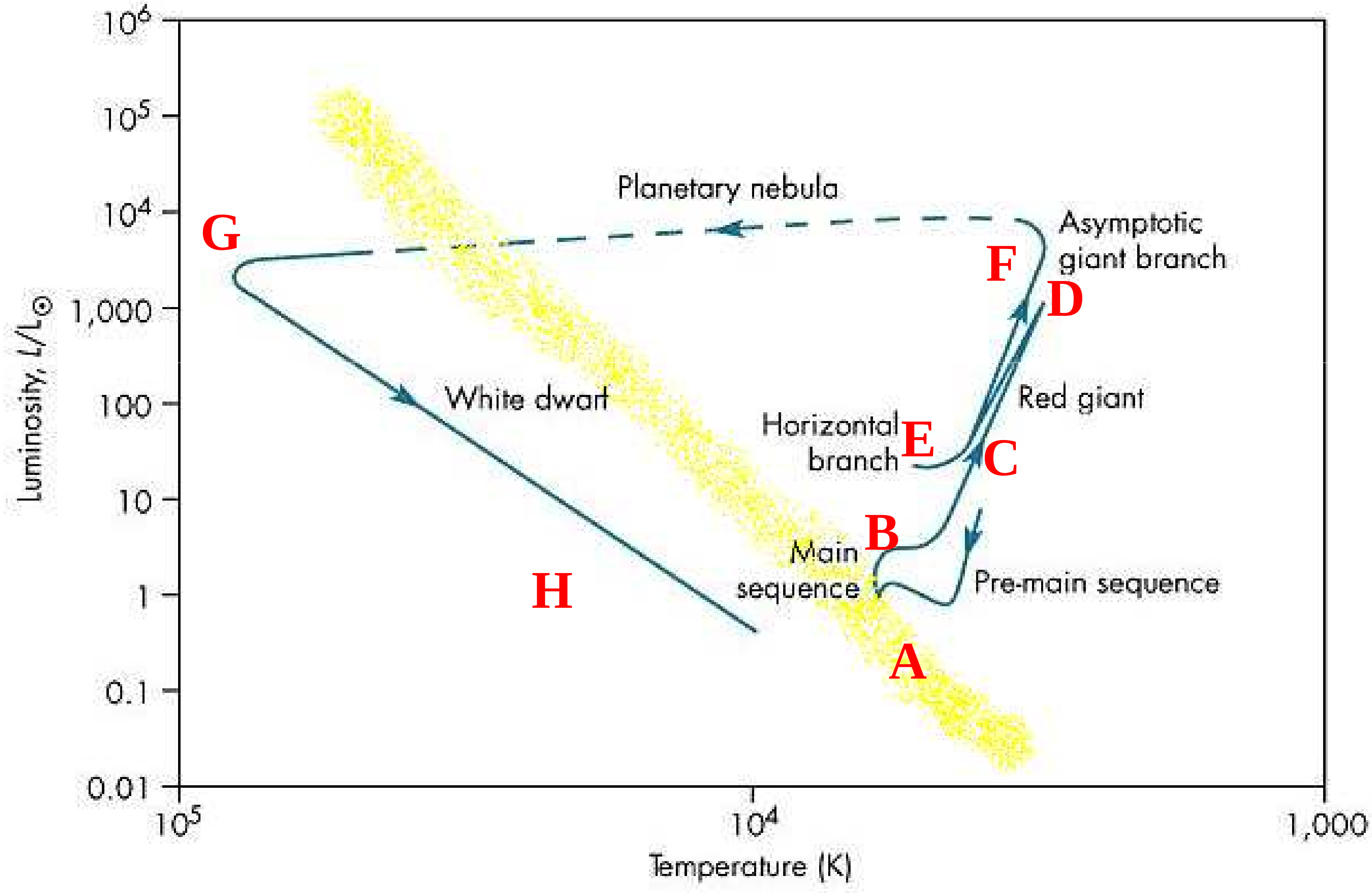
$$L \propto M^4 \longrightarrow M \propto L^{1/4} \longrightarrow M = M_\odot \left(\frac{L}{L_\odot}\right)^{1/4}$$

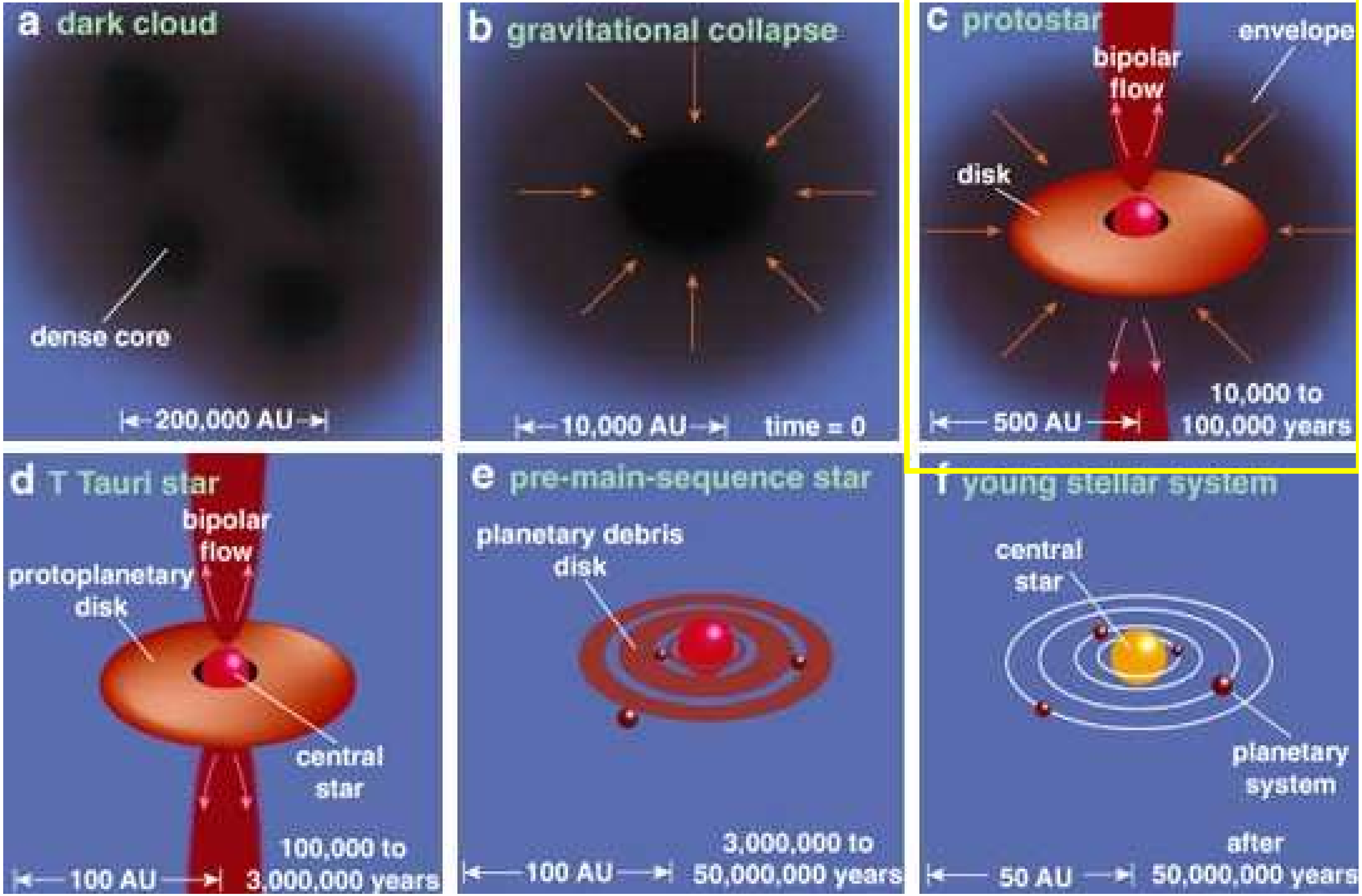
$$\tau = \frac{E_{MS}}{L} = \frac{f\, X_H\, M_\odot}{L} \left(\frac{L}{L_\odot}\right)^{1/4} E_{NKg}$$

$$\boxed{\tau = f\, X_H \frac{M_\odot}{L_\odot} \left(\frac{L}{L_\odot}\right)^{-3/4} E_{NKg}}$$

Or even simpler : see problem sheet 3 for rough estimate

Stellar evolutionary tracks on an HR diagram

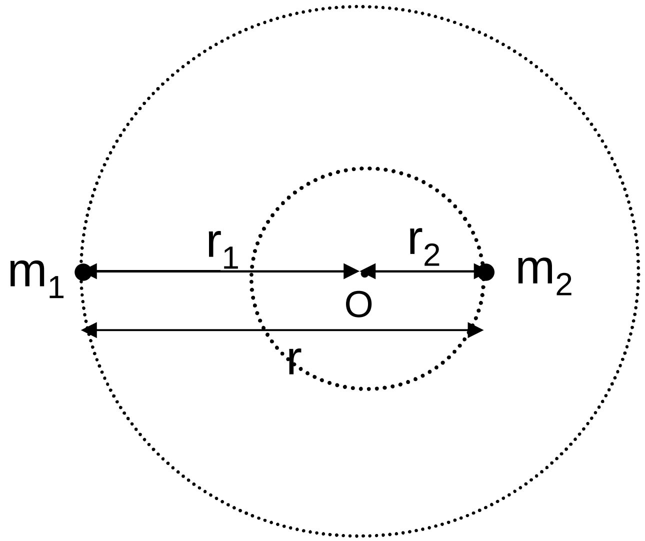




a dark cloud
dense core
200,000 AU
b gravitational collapse
10,000 AU
time = 0
c protostar
bipolar flow
envelope
disk
500 AU
10,000 to 100,000 years
d T Tauri star
bipolar flow
protoplanetary disk
central star
100 AU
100,000 to 3,000,000 years
e pre-main-sequence star
planetary debris disk
100 AU
3,000,000 to 50,000,000 years
f young stellar system
central star
planetary system
50 AU
after 50,000,000 years

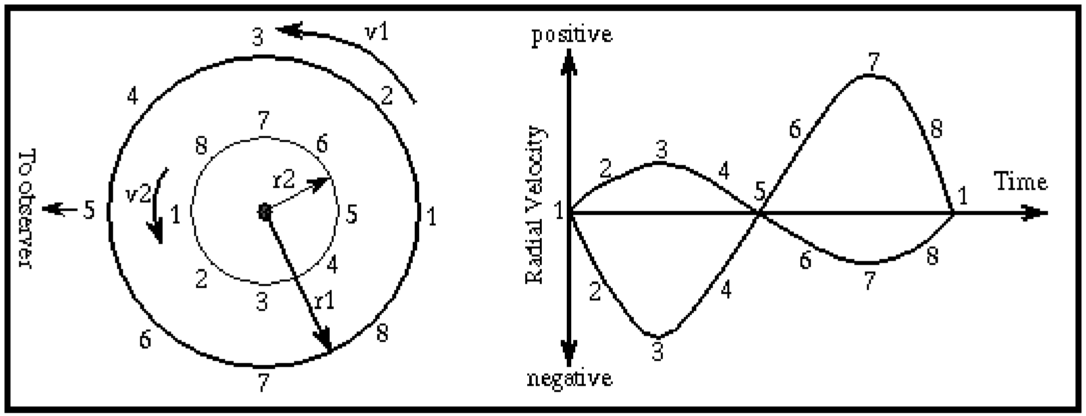
- **Binary Stars**

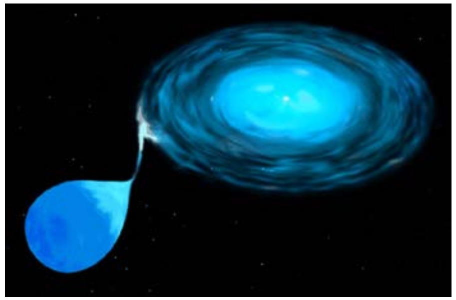
-Visual
-Spectroscopic
-Eclipsing



$$\frac{M_1}{M_2} = \frac{r_2}{r_1}$$

$$M_1 + M_2 = \frac{4\pi^2}{G}\frac{r^3}{P^2}$$





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Good luck !
Any
questions?

Sun, Stars & Planets Revision Lecture

Dave Clements & Juliet Pickering

Overview

- The Exam & Exam advice
- Stars Summary
- Planets Summary
- Questions

The Exam

- Format same as previous years:
  - Section A: compulsory [40 marks]
    - Will include a question on stars & a question on planets
  - Section B
    - Choose 2 questions out of 4 [30 marks each]
    - Will include an ‘essay’ type question

What you are Given

- List of constants
- Equations of Stellar structure

Fundamental physical constants

a	radiation density constant	7.6×10^{-16} J m^{-1} K^{-4}
c	speed of light	3.0×10^{8} m s^{-1}
G	Gravitational constant	6.7×10^{-11} N m^{2} kg^{-2}
h	Planck's constant	6.6×10^{-34} J s
k	Boltzmann's constant	1.4×10^{-23} J K^{-1}
e	electron charge	1.6×10^{-19} C
m_e	mass of electron	9.1×10^{-31} kg
m_H	mass of hydrogen atom	1.7×10^{-27} kg
N_A	Avogadro's number	6.0×10^{23} mol^{-1}
σ	Stefan-Boltzmann constant	5.7×10^{-8} W m^{-2} K^{-4}
ϵ_0	permittivity of free space	8.9×10^{-12} F m^{-1}
μ_0	permeability of free space	$4\pi \times 10^{-7}$ H m^{-1}
$\mathcal{R}$	Gas constant	8.3×10^{3} J K^{-1} kg^{-1}

Astrophysical quantities

$L_\odot$	solar luminosity	3.8×10^{26} W
$M_\odot$	solar mass	2.0×10^{30} kg
$R_\odot$	solar radius	7.0×10^{8} m
$T_{\mathrm{eff}\odot}$	effective temperature of Sun	5780 K
AU	astronomical unit	1.5×10^{11} m
pc	parsec	3.1×10^{16} m

Equations of Stellar Structure

$$\frac{dm}{dr} = 4\pi r^2 \rho$$

$$\frac{dP}{dr} = -\frac{Gm\rho}{r^2}$$

$$\frac{dT}{dr} = -\frac{3\kappa \rho L}{16\pi a c r^2 T^3}$$ if heat transport is radiative

$$\frac{dT}{dr} = \left(1 - \frac{1}{\gamma}\right) \frac{T}{P} \frac{dP}{dr}$$ if heat transport is convective

$$\frac{dL}{dr} = 4\pi r^2 \rho \epsilon$$

Exam Advice: I

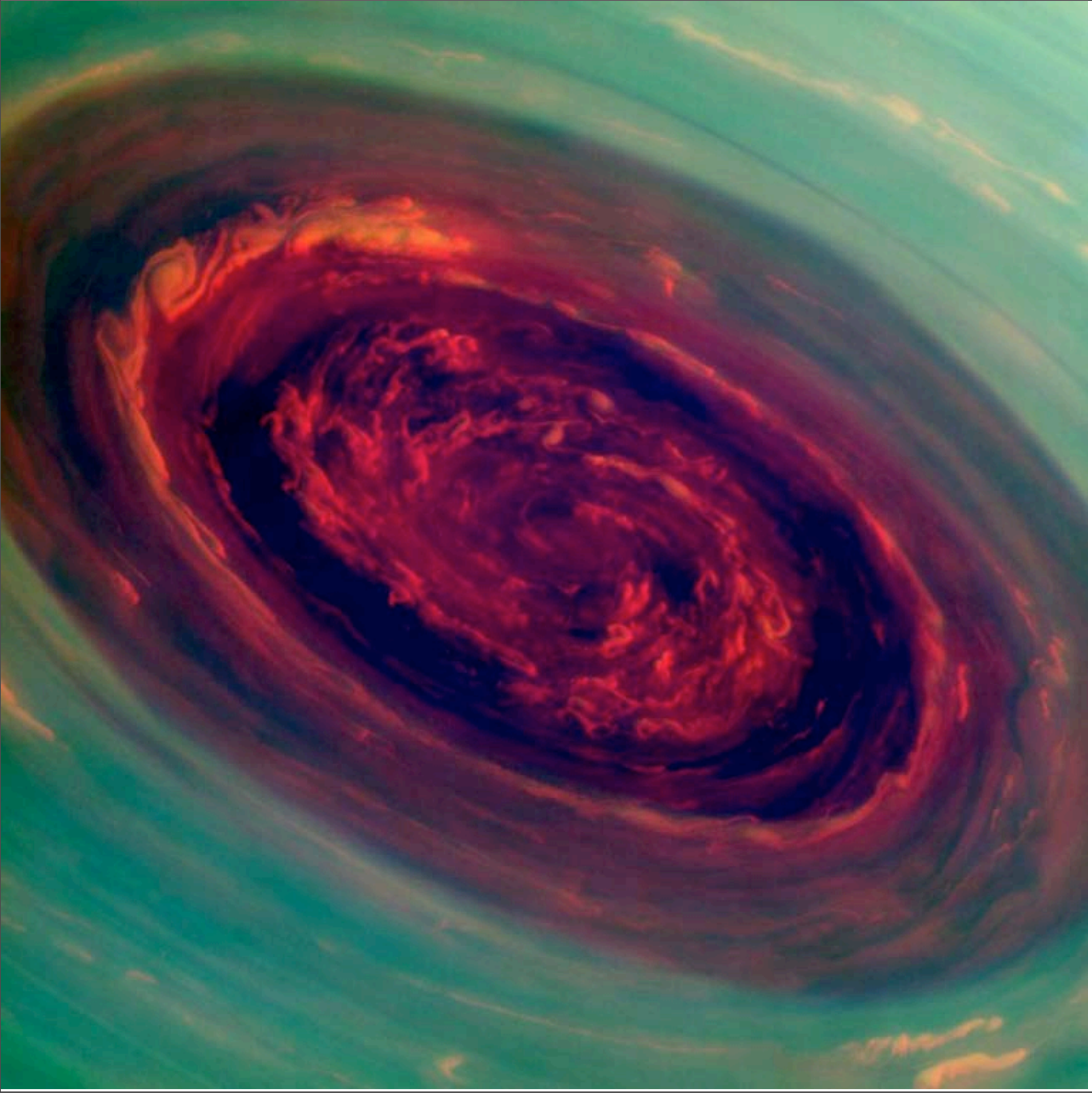
- Read all questions before choosing which to do
- Read them carefully: eg. sketch does not mean plot exactly, estimate does not mean make a precise calculation
- Check units: astronomical units are not SI
  - angles - arcsec vs. radians
  - distances - m, AU, pc

Exam Advice: 2

- Remember: one answer book for each question
- Write legibly!!!!
- Give intermediate steps so we can follow what you're doing and give credit if things go wrong half way
- If you reach an answer you know is wrong but can't fix it, tell us it is wrong and why it is wrong

Resources

- On Blackboard
  - Lecture notes
  - Problem sheets
  - Handouts
  - Slides from lectures
  - Past papers
- Office hours
  - Come and see us or email us!
  - But not at the last minute ie. weekend before the exam



A storm on Saturn

Solar System: Key Points

- Structure of the Solar System: Planets, Ecliptic, Nebular Hypothesis
- Kepler's Laws
  - 1)The orbit of a planet forms an ellipse with the Sun at one focus
  - 2)The Sun-planet vector sweeps out equal areas in equal time
  - 3)The square of the orbital period of the planet is proportional to the cube of the orbit's semi-major axis
- Know & explain all 3
- Show 3rd law in the context of a circular orbit

Planets: Key Points

- Terrestrial Planets:
  - atmospheric & interior structure
  - cooling & heating
  - shaping of surfaces
  - no-atmosphere temperature, Greenhouse Effect & Carbon cycle
- Gas Giants:
  - structure & atmospheres
  - ring systems and moons
  - Roche limit
- Asteroids, KBOs and Comets
- Orbital resonances & tidal locking
- Comet reservoirs (Oort cloud & KBOs) and implications for comets

Exoplanets: Key Points

- Detection methods:
  - astrometry
  - transits
  - radial velocities
    - equations simplified version of binaries with $M_p << M_s$
  - appreciate selection effects, explain quantities being measured
- Exoplanet characteristics
  - not rare, systems being found, range of eccentricities, many short-period planets including hot Jupiters
- Possibility of life outside the Solar System
  - Habitable zone, Drake Equation & Fermi Paradox