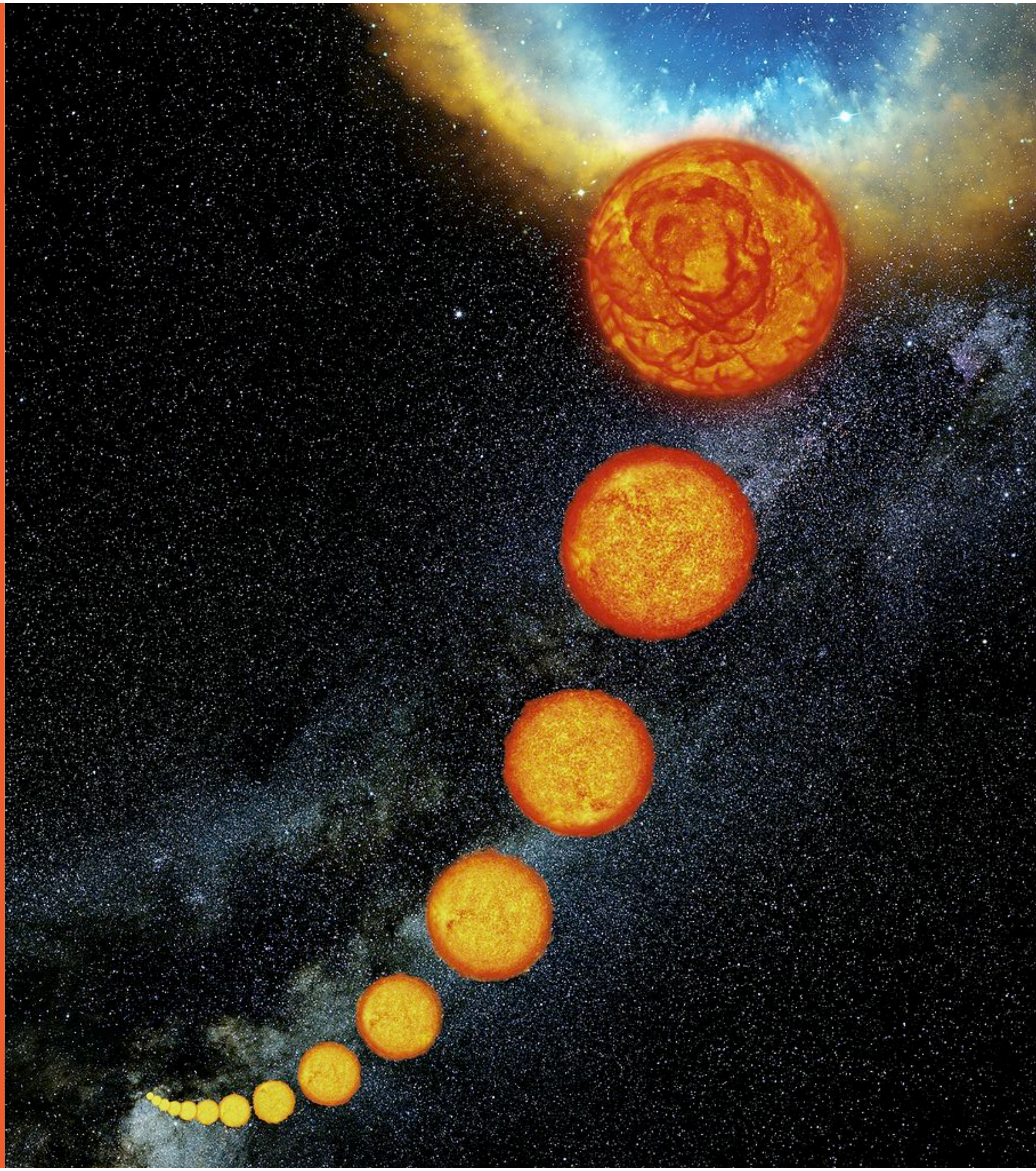
PHYS3xxx Astrophysics Review

22 June 2018

THE UNIVERSITY OF SYDNEY



Exam

Three sections to the course:

- Radiation
- Stellar evolution
- Binaries

Exam consists of three questions: one question on each topic.

Two common questions, one split Advanced/Normal

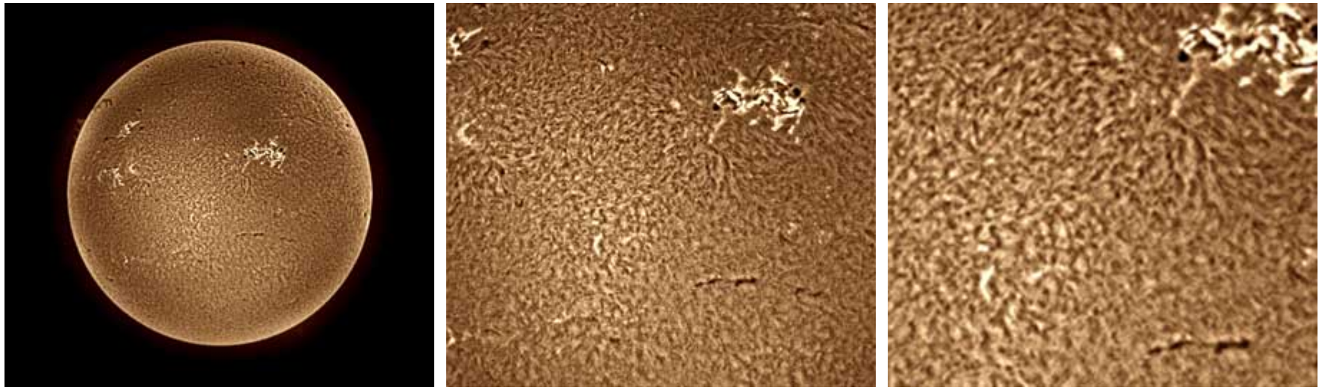
(1 hr per option = 20 min per question)

Note **TWO** constants lists

1. Radiation

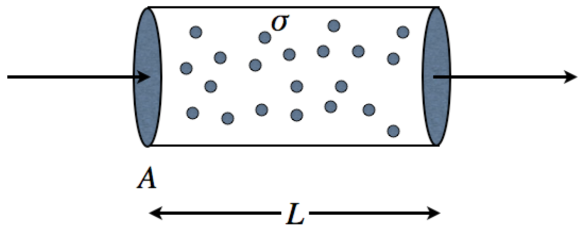
Major topics:

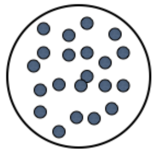
- **Brightness** (specific intensity)
  – amount of light per unit solid angle (per pixel)



1. Radiation

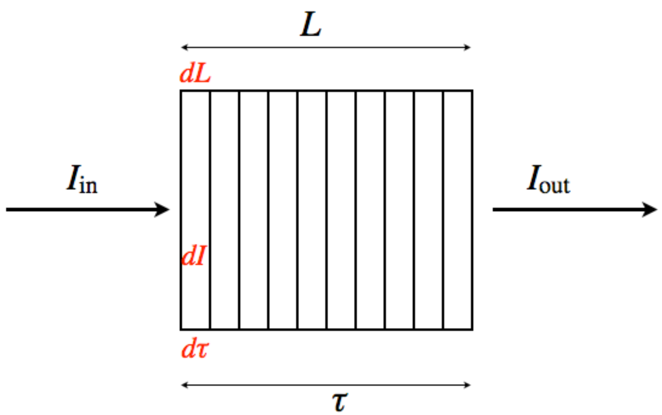
- **Optical depth**: distance over which light decreases by 1/e





$$\tau = nL\sigma \qquad \text{for small } \tau$$

$$I_{\rm out} = I_{\rm in}(1-\tau)$$



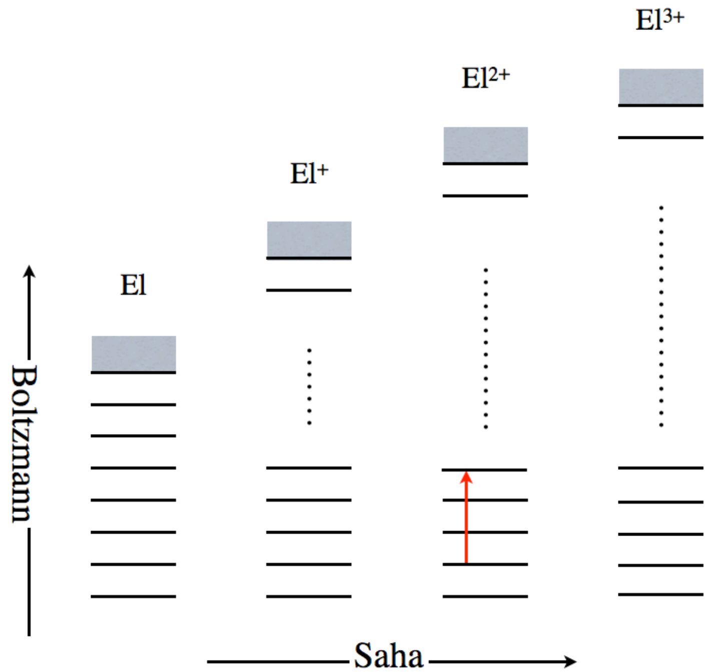
For large τ (optically thick)

$$I_{\rm out} = I_{\rm in}e^{-\tau}$$

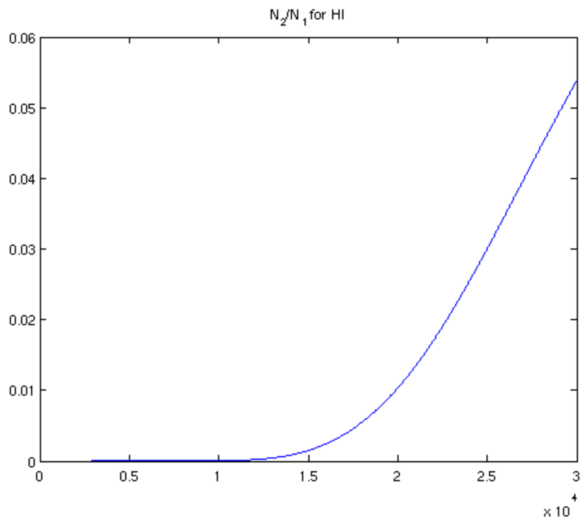
Typically see to a depth $\tau \sim 1$ into an atmosphere

1. Radiation

- **Saha-Boltzmann equations**
  - Boltzmann equation ⇒ distribution of electrons in different energy levels
  - Saha equation ⇒ distribution of atoms in different ionisation states



1. Radiation



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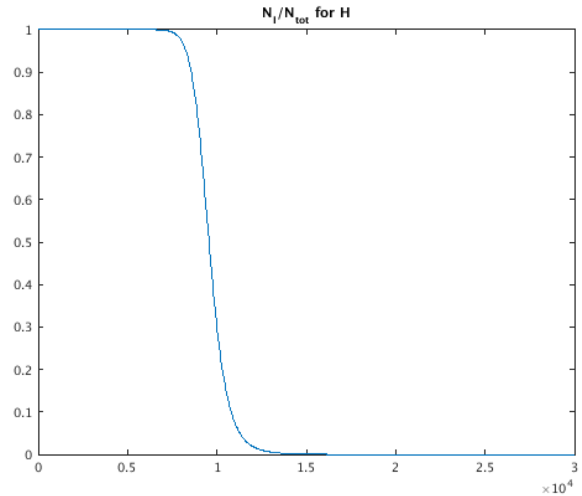

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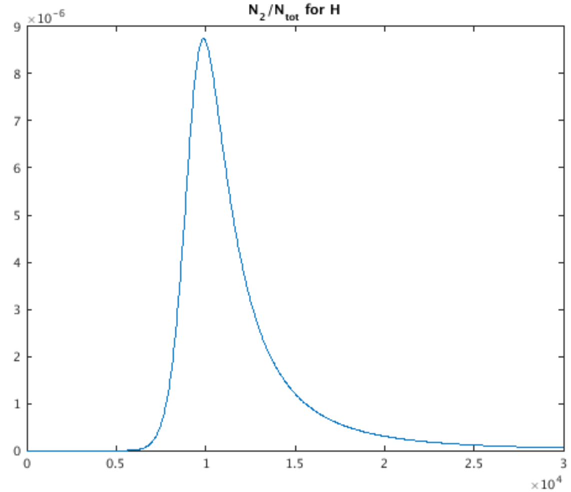


Boltzmann:

N in correct energy level ↑ with *T*

Saha:

N in correct ionisation state ↓ with *T*

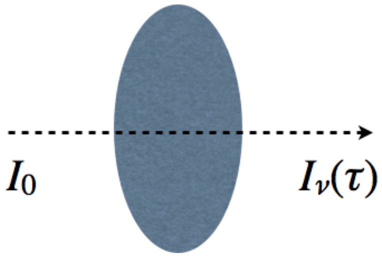
Result:

line strength peaks at particular *T*

(What determines T?)

1. Radiation

- **Emission/absorption lines**

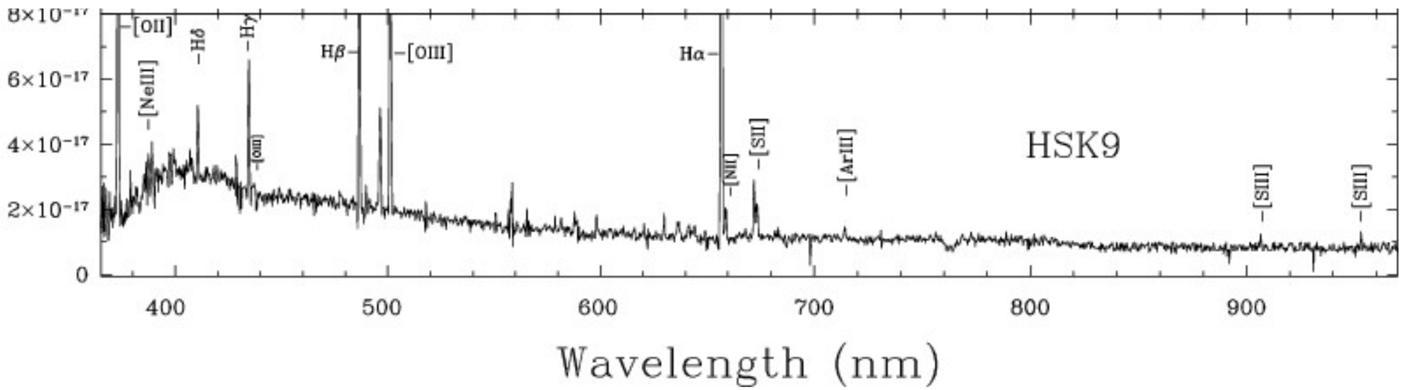


$$I_\nu = I_0 e^{-\tau_\nu} + B_\nu(1 - e^{-\tau_\nu})$$

1. Optically thin, τ small: $I_0 = 0 \qquad I_\nu \approx B_\nu(1 - 1 + \tau_\nu) = \tau_\nu B_\nu$

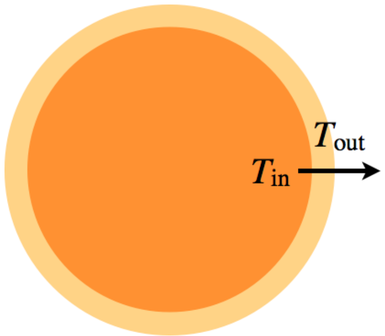
   – large intensity where absorption coefficient is large

   ⇒ emission lines



1. Radiation

2. Optically thick, τ large: spectrum is blackbody in LTE with gas until the outer layer

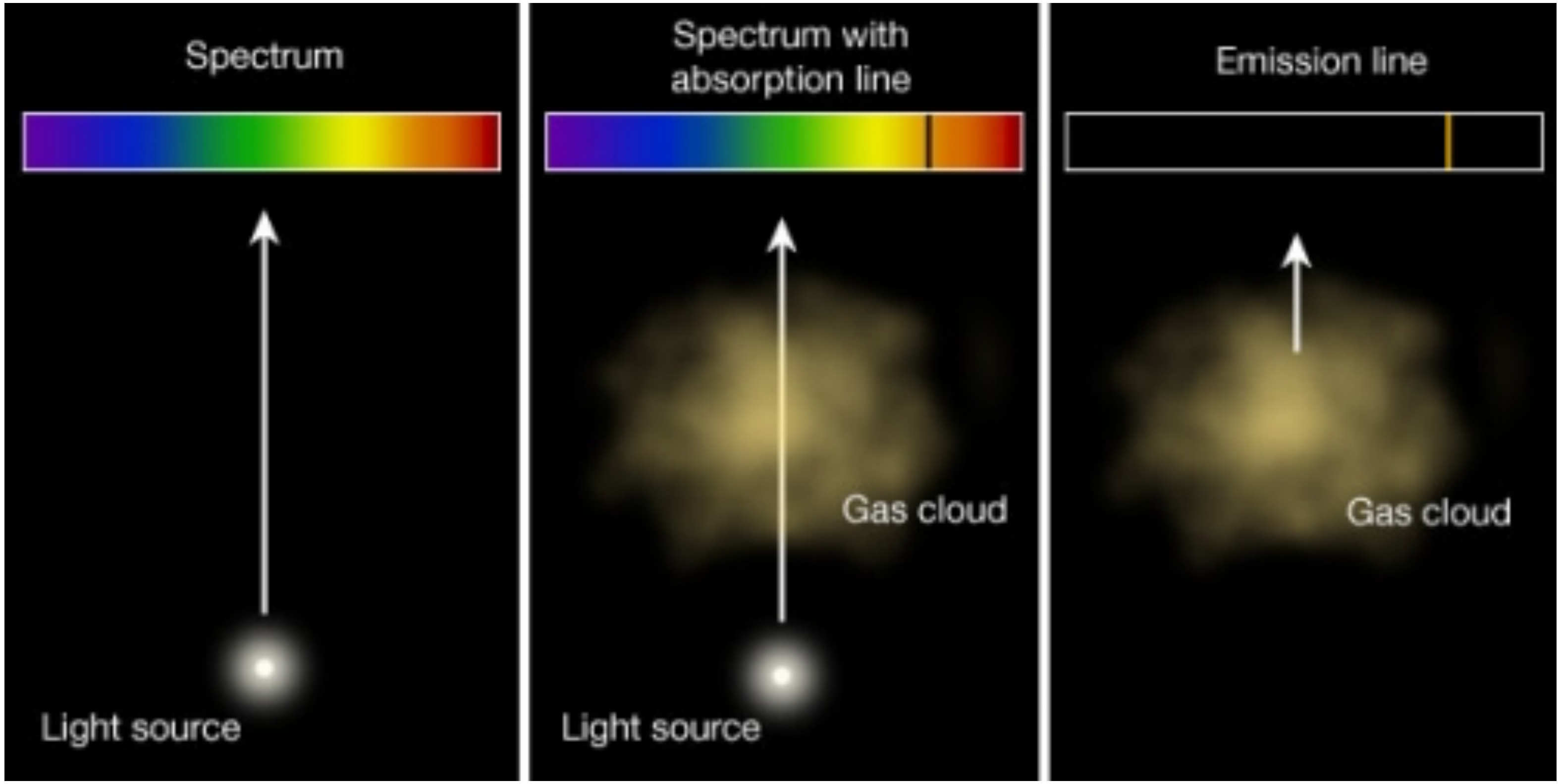


$$I_\nu = B_\nu(T_{\rm in}) + \tau_\nu \left[B_\nu(T_{\rm out}) - B_\nu(T_{\rm in})\right]$$

sign depends on whether $T_{\rm out} > T_{\rm in}$

$\Rightarrow$ continuum + absorption lines if $T_{\rm out} < T_{\rm in}$

continuum + emission lines if $T_{\rm out} > T_{\rm in}$



Spectrum
Light source
Spectrum with
absorption line
Gas cloud
Light source
Emission line
Gas cloud

2. Stellar evolution

Major topics:

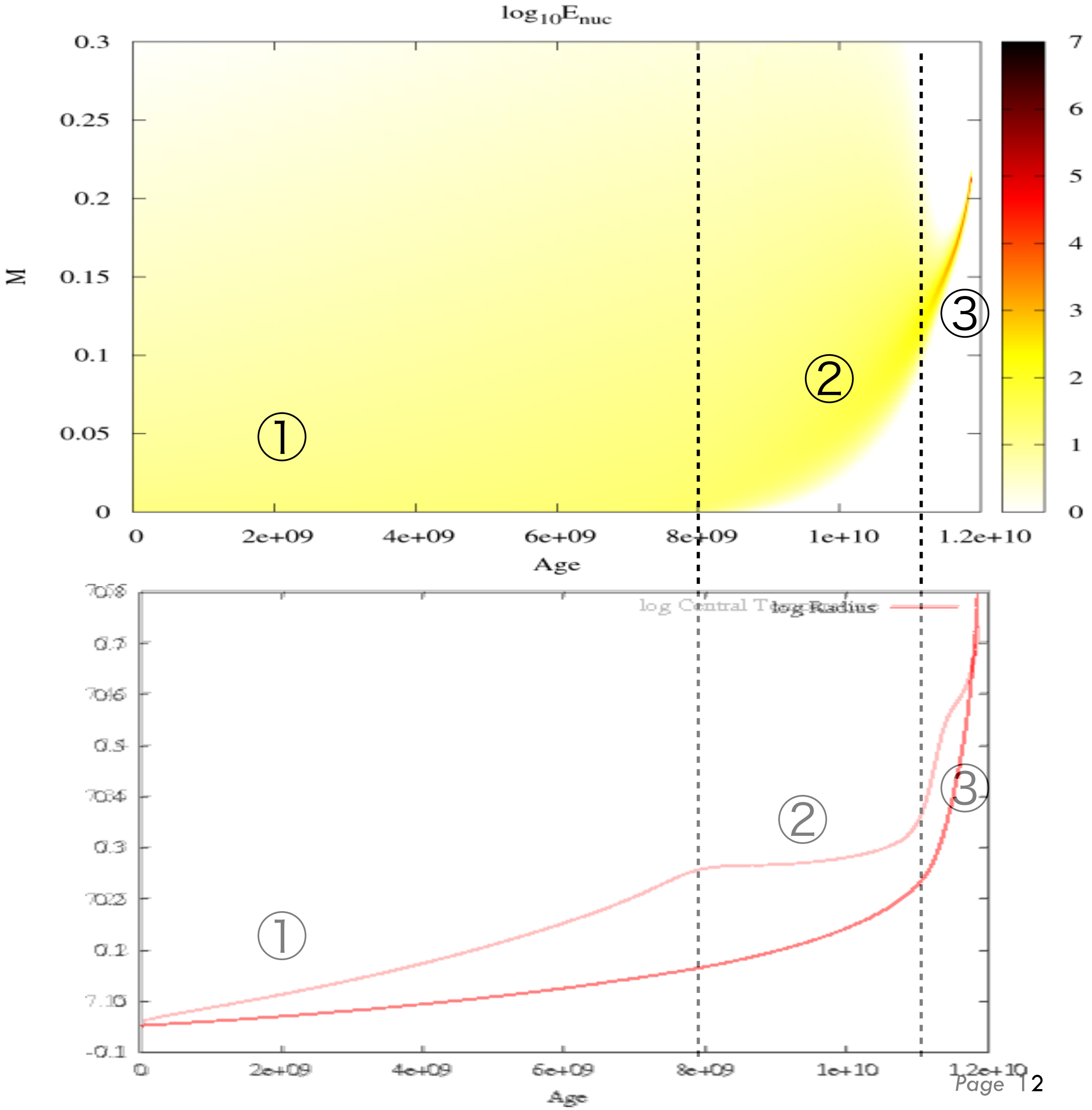
- *Structure* of star: at any time, the structure of a star is the result of balance between inward gravitational pull and outward pressure produced by energy generation in interior
- Stars *evolve* with time as nuclear fuel is consumed
- *Reactions*: H $\rightarrow$ He, He $\rightarrow$ C, C $\rightarrow$ N etc. These reactions need higher and higher temperatures $\Rightarrow$ take place sequentially in cores of stars.
- *Timescales*: estimate 3 timescales:
  - dynamical
  - thermal
  - nuclear

2. Stellar evolution

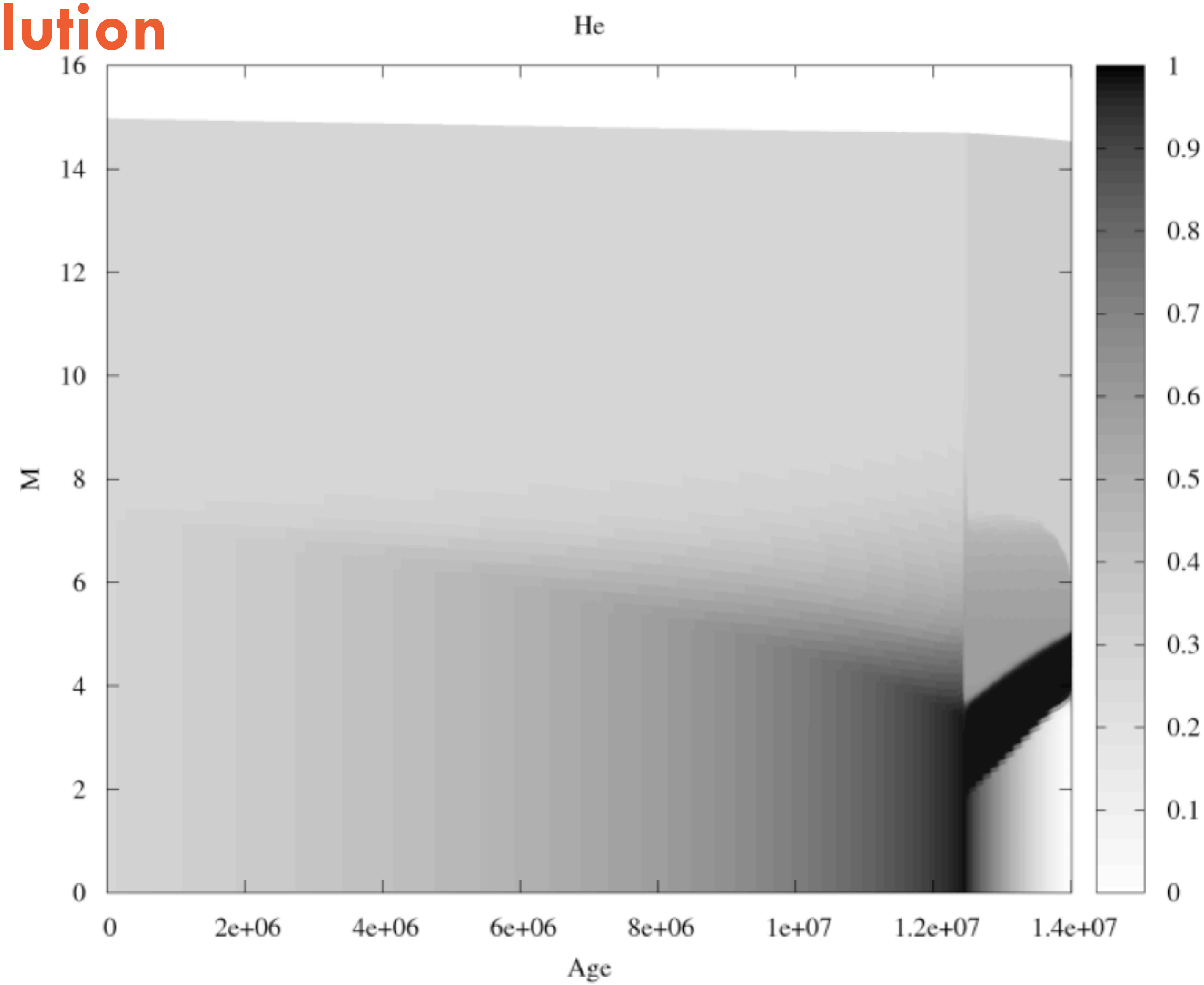
- Four regions of the H-R diagram with different evolution:
  - red dwarfs: $M_\odot < 0.7M$ $\tau_{ms} >$ age of Universe
  - low-mass: $0.7M_\odot < M < 2M_\odot$. Ends as WD.
  - intermediate-mass: $2M_\odot < M < 8$–$10M_\odot$; ends as higher mass WD.
  - massive: $M > 8$–$10M$. Ends as supernova, leaving neutron star or black hole
- Boundaries are uncertain, mass ranges are approximate.
- Be able to discuss the evolutionary tracks of these stars and the internal changes which cause them; remember your WTTS.

2. Stellar evolution

1. MS: core H fusion → He
2. Core fusion stops, T_c plateaus, He core continues to grow
3. Core begins to collapse and heat up. Shell H → He burning starts.
4. Next: threshold T for He burning is reached (not shown).



2. Stellar evolution



2. Stellar evolution

- Stellar remnants (white dwarfs, neutron stars, black holes)
- WD and NS supported by *degeneracy pressure* (quantum)
- Maximum possible mass for WD = Chandrasekhar mass, ~1.4 $M_\odot$
  - *electron degeneracy pressure*
- Maximum neutron star mass not well known, ~3 $M_\odot$
  - *neutron degeneracy pressure*

3. Binaries

- Two stars born together, orbiting according to Kepler's law

$$\left(\frac{P}{2\pi}\right)^2 = \frac{a^3}{G(M_1 + M_2)}$$

- Consider rotating reference frame:

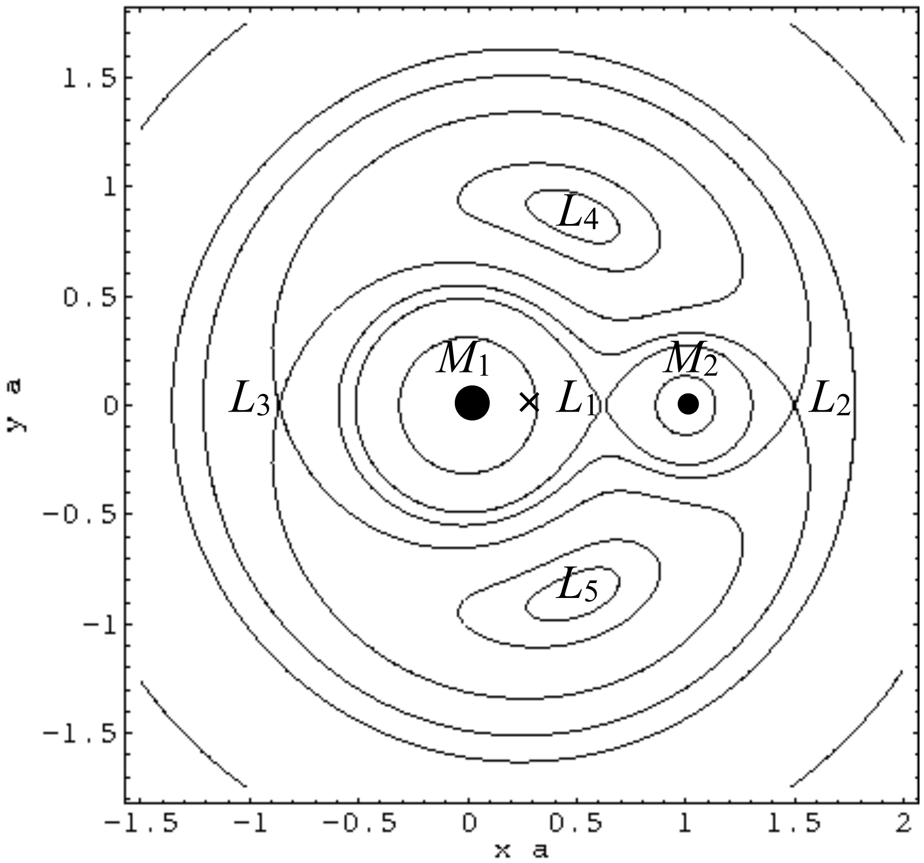
$$\Phi = -G\left(\frac{M_1}{s_1} + \frac{M_2}{s_2}\right) - \frac{1}{2}\omega^2 r^2$$

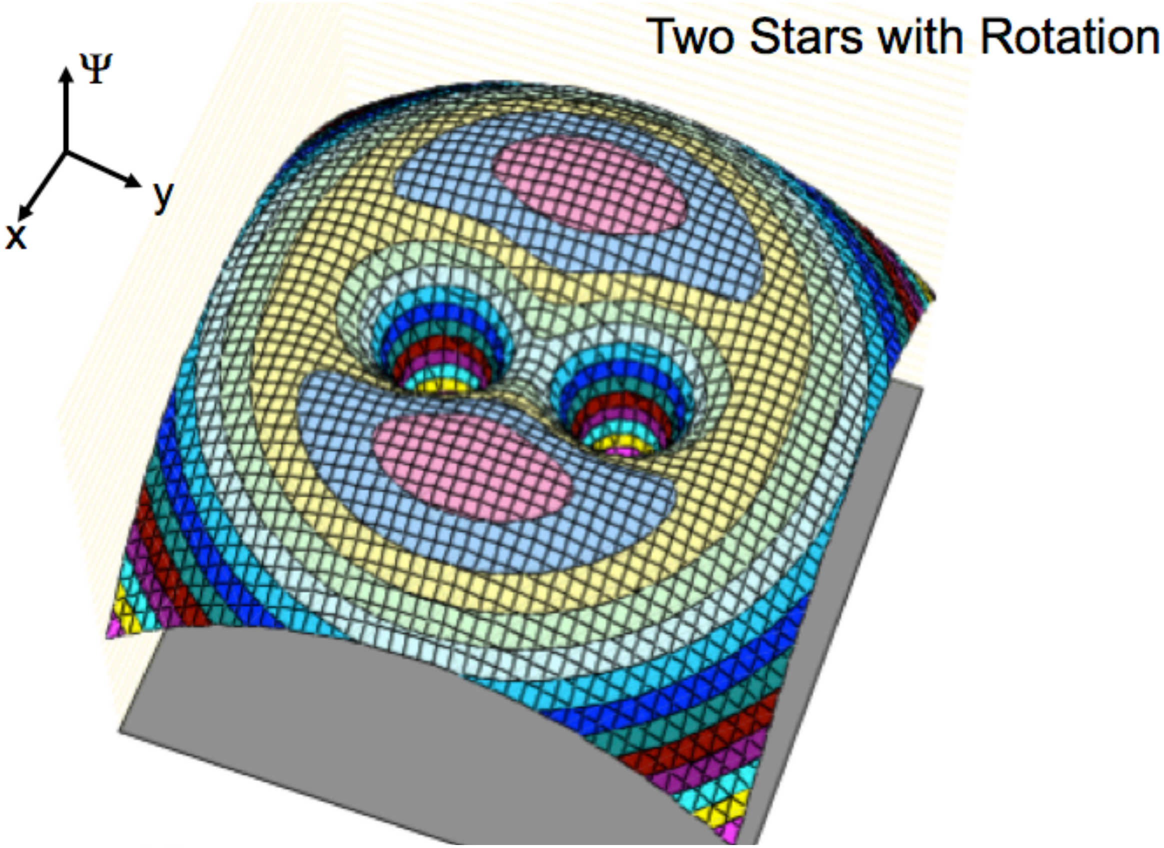
gravity star 1

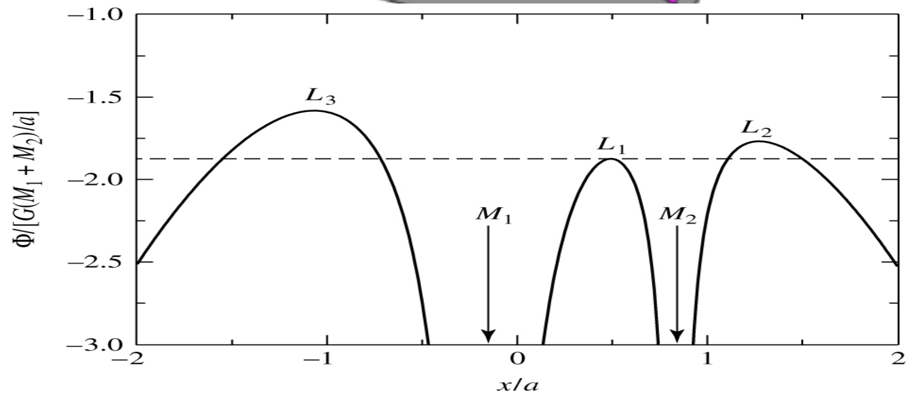
gravity star 2

centrifugal term

3. Binaries

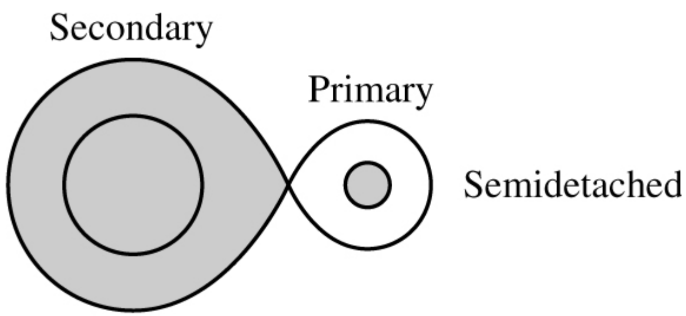

M1
M2
L1
L2
L3
L4
L5
1.5
1
0.5
0
−0.5
−1
−1.5
2
y a
x a


Two Stars with Rotation
Ψ
y
x


−1.0
−1.5
−2.0
−2.5
−3.0
−2
−1
0
1
2
L3
L1
L2
M1
M2
Φ/[G(M1 + M2)/a]
x/a

3. Binaries

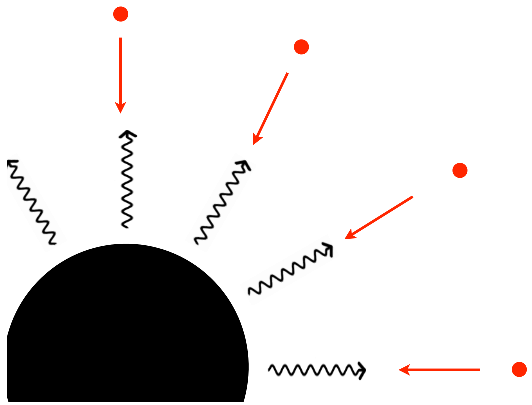
- L_1 is the inner Lagrange point: if one star expands to fill its Roche lobe (= region defined by potential through L_1), matter will cross this point and transfer to companion ⇒ *accretion*.



- Accretion liberates energy: turns GPE into radiation.
- $E \propto \dot{M}$: the more mass is accreted, the more energy is produced ⇒ there is a limit to the rate which mass can be accreted

3. Binaries

- Eddington limit: balance outward force of radiation with the inward force of gravity.



$$L_{\mathrm{Edd}} = \frac{4\pi c G m_p M}{\sigma_{\mathrm{T}}} = 1.26 \times 10^{31} \left(\frac{M}{M_\odot} \right) \ \mathrm{W}$$

L_{Edd} depends *only* on the mass of the accretor

Assumptions?

3. Binaries

- Mass transfer can lead to changes in the orbit of the two stars. If star 1 transfers mass to star 2, angular momentum is conserved, and all mass lost by star 1 is gained by star 2, then the change in the orbital separation depends on the mass ratio

$$\frac{\dot{a}}{a} = -\frac{2\dot{M}_1}{M_1}\left(1 - \frac{M_1}{M_2}\right)$$

- $M_1 < M_2 \quad \Rightarrow \quad \frac{\dot{a}}{a} > 0$ orbit *widens*
- $M_1 > M_2 \quad \Rightarrow \quad \frac{\dot{a}}{a} < 0$ orbit *shrinks*; get *runaway mass transfer*

3. Binaries

- Types of binaries you should be able to describe/explain:
  - ultra-compact binaries, with orbital separations much less than original star sizes
  - Algol-like systems, where less massive star is more evolved
  - cataclysmic variables
  - (ADV only) Type Ia supernovae and GW binaries