Introduction to Stellar Astrophysics

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Lecture 1:

- Stellar Structure (very briefly!)
- Observational Properties / stellar parameters
- Homework !

Lecture 2:

- Structure and Evolution presentations
- Stellar Atmospheres
- Cool Stars

Big missing chunks:

- Stellar Evolution proper (esp star formation)
- Mass accretion and Outflows
- Radiative Transfer … and lots more!

Text books:

Roger Tayler (CUP)

The Stars: their structure and evolution

Dina Prialnik (CUP)

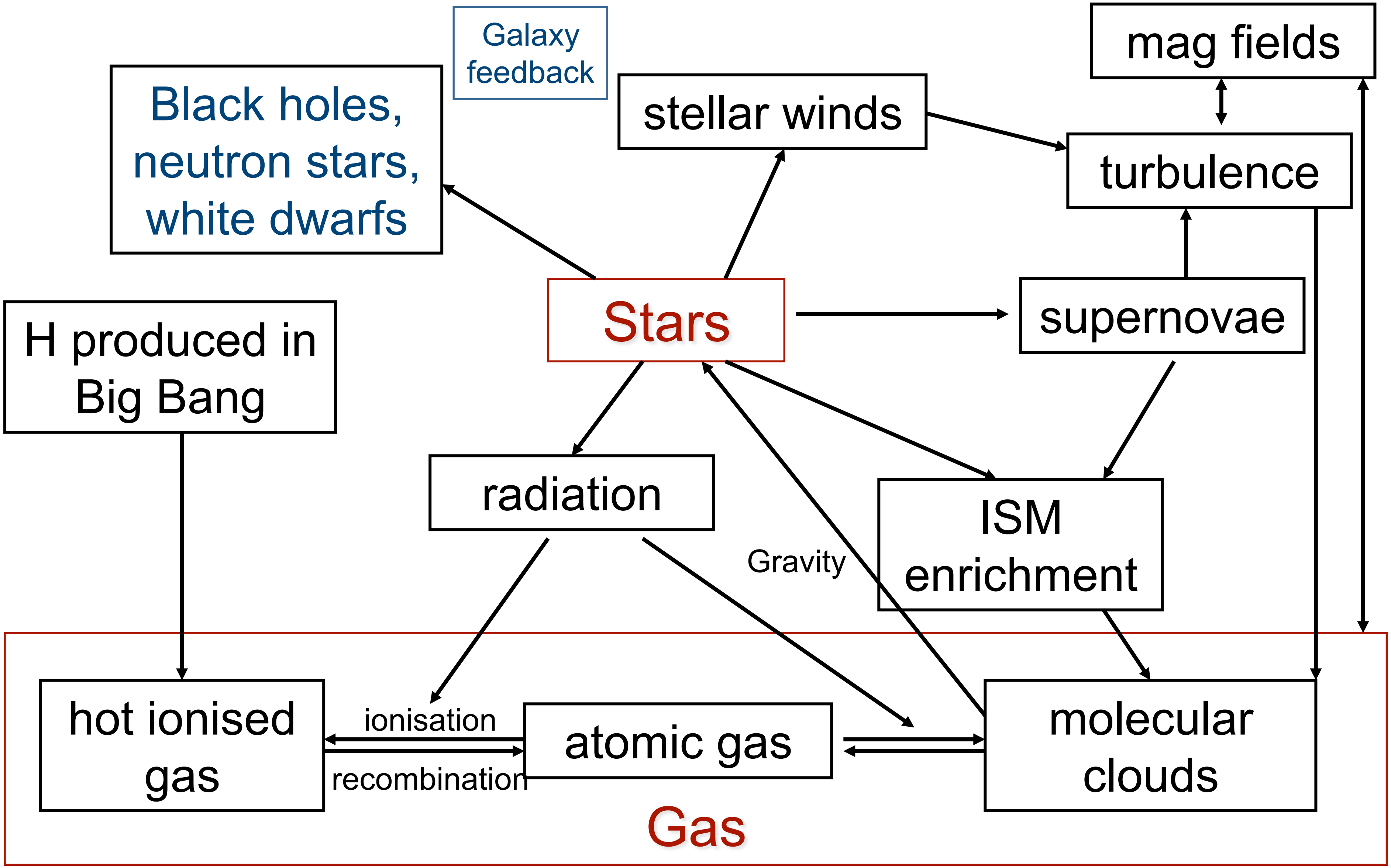
An Introduction to the Theory of Stellar Evolution and Structure

Dimitri Mihalas (Freeman)

Stellar Atmospheres

& many more: Böhm-Vitense, Phillips, Bowers & Deeming, …

Why bother about stars?



Thanks to Raman Prinja

What is a star?

bound by self-gravity; radiating energy supplied by internal energy source …

… though… WD, BD..

Can often assume:

- sphericity (mostly fine, except for rotation)
- static (though see time-scale discussion)
- isolated (though 50% are in binaries!)
- uniform initial composition

Important timescales $\tau = \phi / \dot{\phi}$

Dynamical timescale

characteristic timescale when grav and pressure forces are not balanced ($\phi \rightarrow$ distance)

$$t_d \approx R / v_{esc} \approx (R^3/GM)^{1/2} \qquad (\approx 1000\text{s for Sun})$$

Thermal timescale:

linked to internal processes ($\phi \rightarrow$ internal E $\rightarrow$ grav E);
time star can radiate by energy from contraction alone

$$t_{th} = E_{grav} / L \approx G M^2 / R L \quad (\approx 30 \text{ Mio yrs for Sun})$$

Nuclear timescale:

thermal equilib

time to exhaust nuclear energy ($\phi \rightarrow$ nuclear E, $L_n = L$)

$$t_n = \varepsilon M c^2 / L \quad (\approx 10 \text{ Bio yrs for Sun})$$

Timescales…

$$t_d \ll t_{th} \ll t_n$$

• dynamical timescale is extremely short; if collapse occurs it is observable in its entirety (supernova!)

• most dynamical processes do not involve whole star

• quasi-static evolution

• thermal timescale is shorter than stellar lifetime, but too long for us to observe evolution of thermal processes

• star is in thermal equilibrium during most of its life time

• rates of nuclear processes determine stellar evolution

… you might want to swot up on nuclear burning…

Stellar structure equations

	r as independent var	*m* as independent var	
mass continuity	$\frac{dm}{dr} = 4\pi\,\rho\,r^2$	$\frac{dr}{dm} = \frac{1}{4\pi\,\rho\,r^2}$	
hydrostatic equilibrium	$\frac{dP}{dr} = -\frac{Gm\rho}{r^2}$	$\frac{dP}{dm} = -\frac{Gm}{4\pi\,r^4}$	
energy conservation	$\frac{dL}{dr} = 4\pi\,\rho\,r^2\,\epsilon$	$\frac{dL}{dm} = \epsilon$	
energy transport	$\frac{dT}{dr} = -\frac{3\kappa\,\rho L}{16\pi\,a\,c\,r^2\,T^3}$	$\frac{dT}{dm} = -\frac{3\kappa\,L}{64\pi^2 a\,c\,r^4\,T^3}$	radiative
	$\frac{dT}{dr} = \left(1-\frac{1}{\gamma}\right)\frac{T}{P}\frac{dP}{dr}$	$\frac{dT}{dm} = \left(1-\frac{1}{\gamma}\right)\frac{T}{P}\frac{dP}{dm}$	convec-tive

7 unknowns: m (or r), ρ, P, T, L (luminosity), ε (energy gen.), κ (opacity)

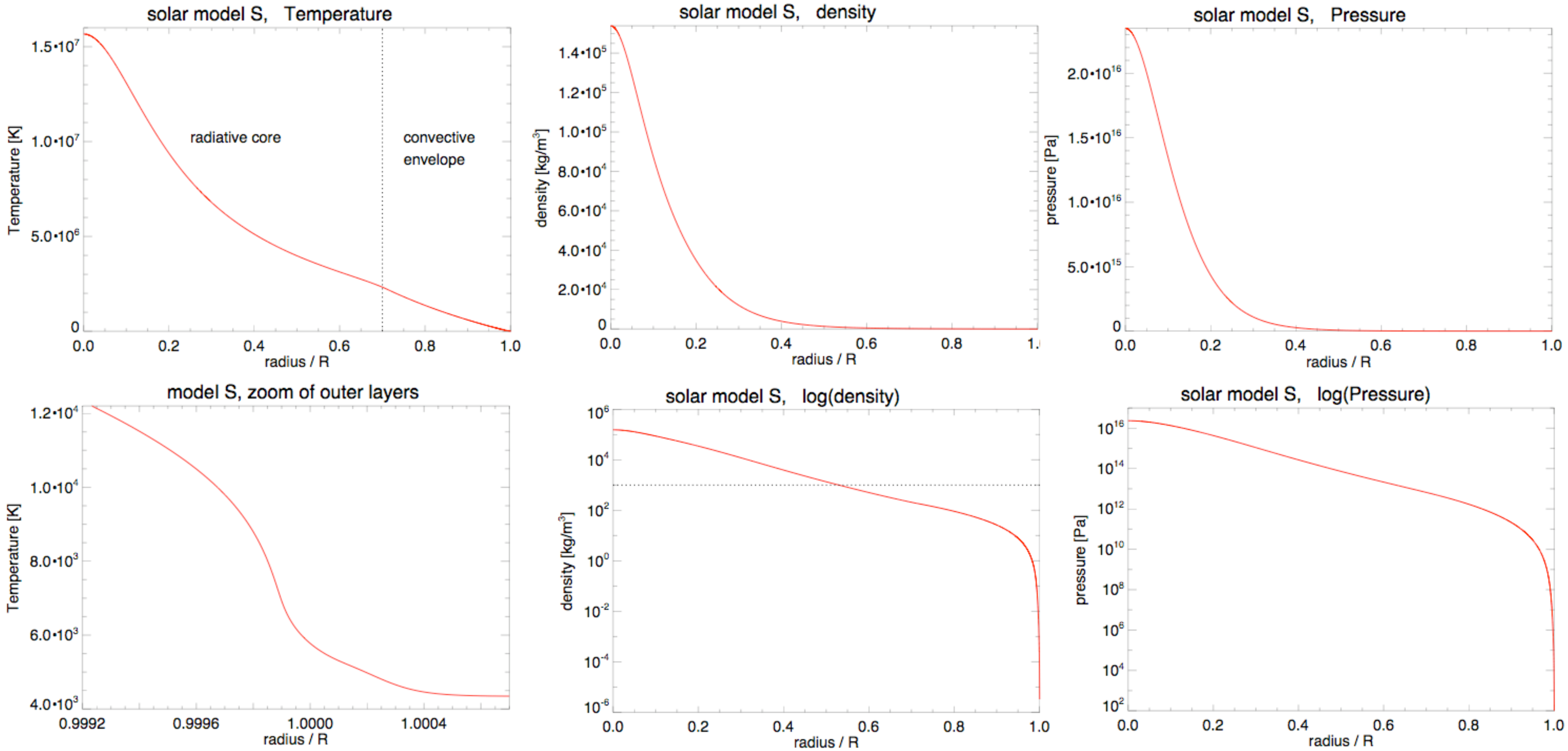
need equations of state: P, ε, κ = f (ρ, T, comp)

$$P = \frac{\rho \mathcal{R} T}{\mu}$$

$$\kappa = \kappa_0\,\rho^\alpha\,T^\beta$$

$$\epsilon = \epsilon_0\,\rho\,T^\eta$$

Example: solar structure



Model S from Christensen-Dalsgaard et al. 1996, Science 272, 1286

For stars of same composition (assuming same EoS)

→ homologous models: stellar structure (P, T, R, L, ρ) prescribed as function of fractional mass

→ scaling laws … useful, but not quite correct → comp models

Scaling laws? Or at least some comments regarding the main sequence…

For stars of same composition (assuming same EoS)

→ homologous models: stellar structure (P, T, R, L, ρ) prescribed as function of fractional mass

→ scaling laws … useful, but not quite correct → comp models

Stellar structure equations are reasonably easy to solve on the **main sequence,** this is when stars burn H in their cores. Typically a stable process, and the longest stage in the evolution of a star.

Give scaling laws here… or do them on the board??

Once H is exhausted, life becomes more complicated (see next lecture)

Parameters that theoreticians would like to know:

- **Mass** — difficult, unless in binary
- **Composition**
- **Age** — mostly through radius (composition)

These should allow determination of all other parameters

… well almost …

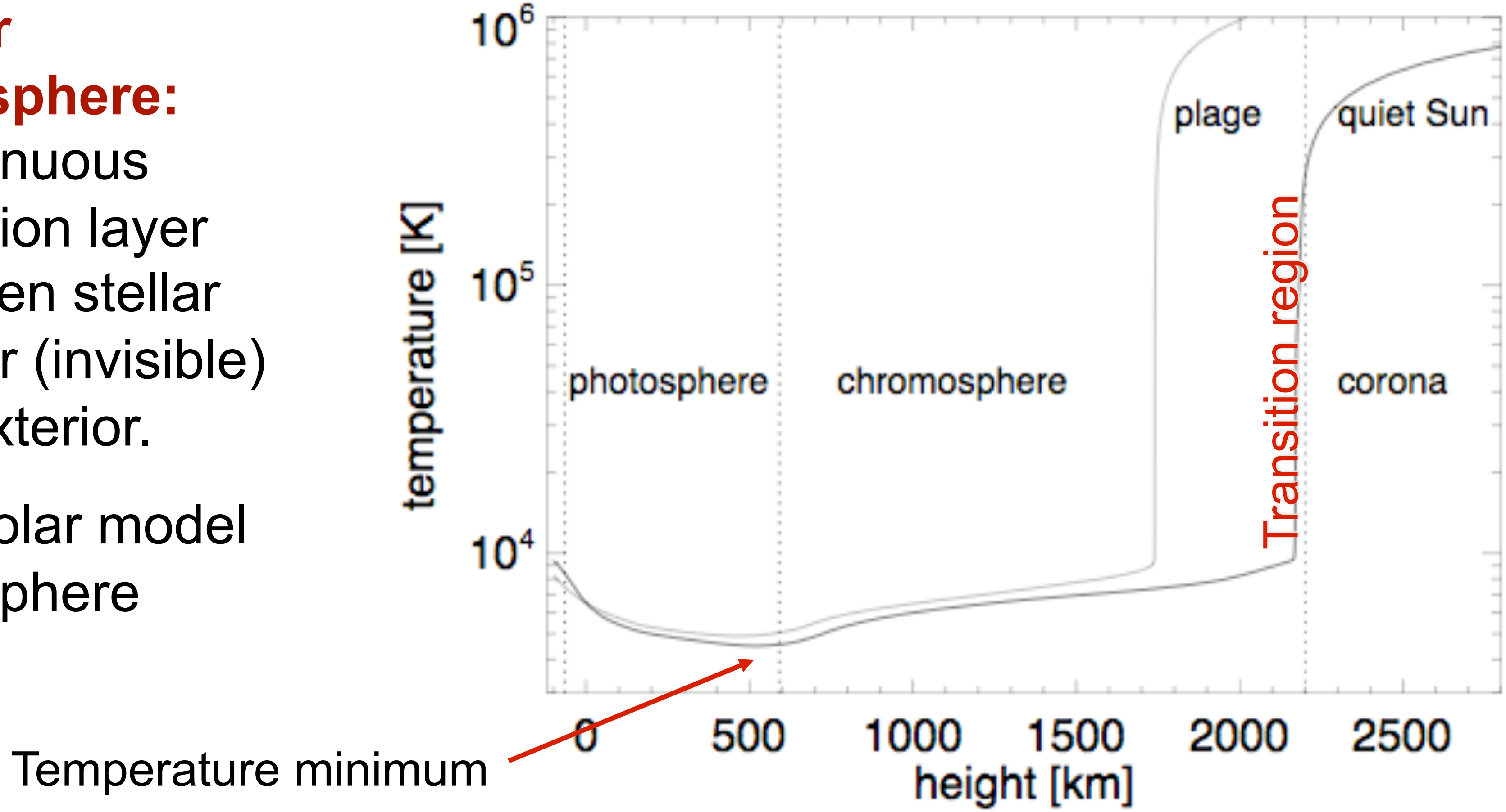
- magnetism
- rotation
- environment
- ?

What mostly see: stellar parameters and observables

Most of the visible radiation is emitted by the **photosphere,** this is what we usually consider as the stellar surface. It is part of the

stellar atmosphere: thin tenuous transition layer between stellar interior (invisible) and exterior.

E.g: solar model atmosphere



Atmospheres primarily characterised by

- o Temperature
- o gravity ($\log g = f(R,M)$)

Recall:	$L = 4\pi R^2 F$
For BB:	$F = \sigma T^4$

Next lecture: a bit more detail on emergent radiation

- radiative transfer (very very briefly!)
- characteristic emission from various atmospheric layers (in the solar case)

For now, consider parameters we can determine from analysis of photometry and spectroscopy

NB: Radiation gets attenuated; distance to source matters!