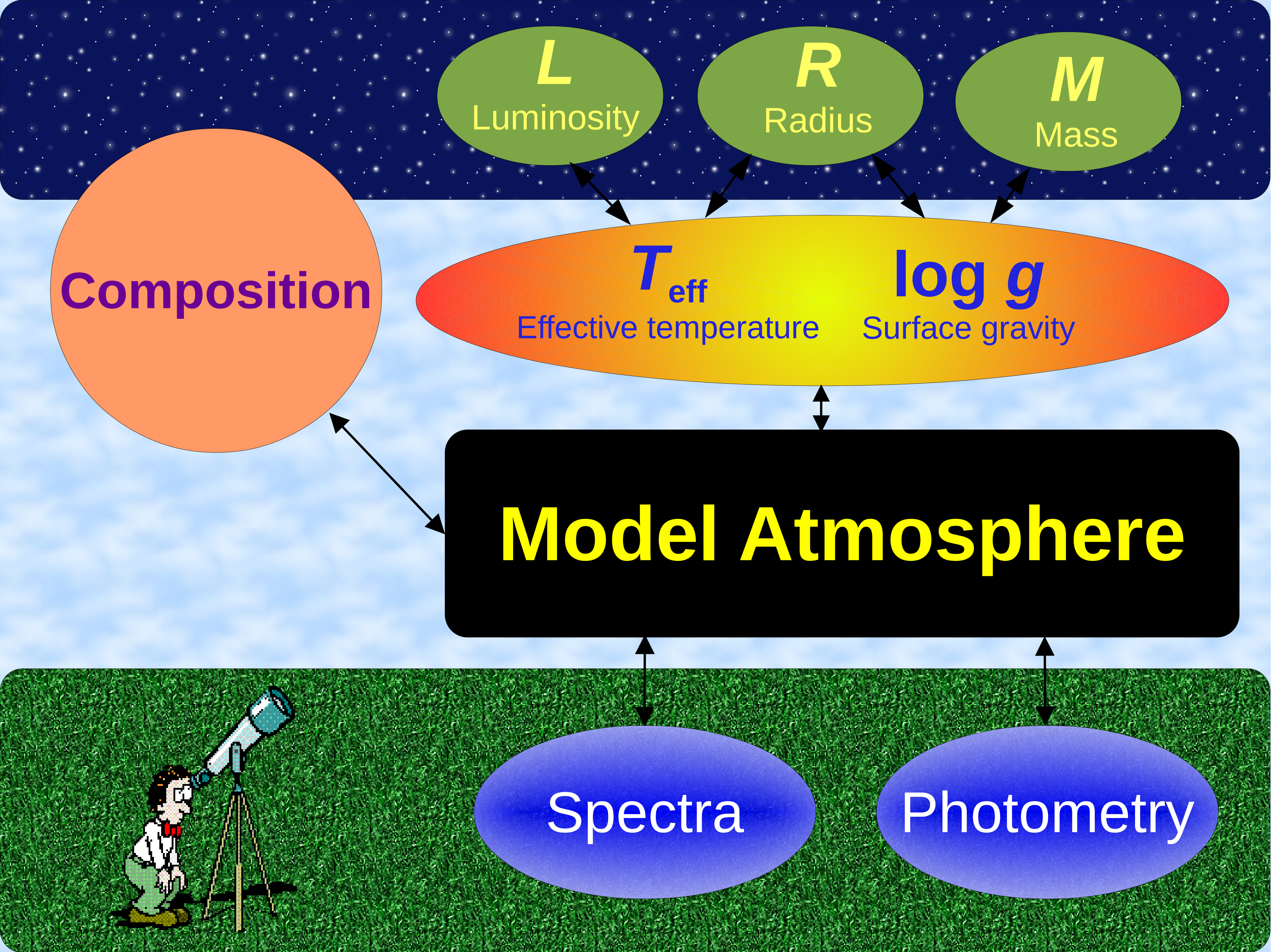
Atmospheric Parameters

Barry Smalley

Astrophysics Group
Keele University
Staffordshire ST5 5BG
United Kingdom

b.smalley@keele.ac.uk

Keele University



L
Luminosity
R
Radius
M
Mass
Composition
Teff
Effective temperature
log g
Surface gravity
Model Atmosphere
Spectra
Photometry

Effective Temperature

$$\sigma T_{eff}^4 \equiv \int_0^\infty F_\nu \, d\nu = F_* = \frac{L}{4\pi R^2}$$

- It is the temperature of a black body that gives the same total power per unit area.
- Physically related to F_* total radiant power per unit area at stellar surface.
- T_{eff} of star is temperature of blackbody with same luminosity and radius as the star.

T_{eff}: Observable quantities

$$F_{*} = \frac{\theta^2}{4} f_{\oplus}$$

- $f_{\oplus}$ total flux at earth (UV, optical, IR)
  - **Corrected for interstellar reddening.**
- θ is angular diameter
  - Directly: interferometry, lunar occultations
    - **Use limb-darkening corrected values**
  - Indirectly from eclipsing binary systems with known distances (parallaxes): $\theta \propto R/d \propto R\,\pi$

Surface Gravity

$$g = g_{\odot} M / R^2$$

- <u>Directly</u> given by stellar mass and radius.
  - An *indirect* measure of photospheric pressure
- Direct measurement from
  - eclipsing spectroscopic binaries
  - asteroseismology

Parallaxes DO NOT give log *g*

Stellar Density

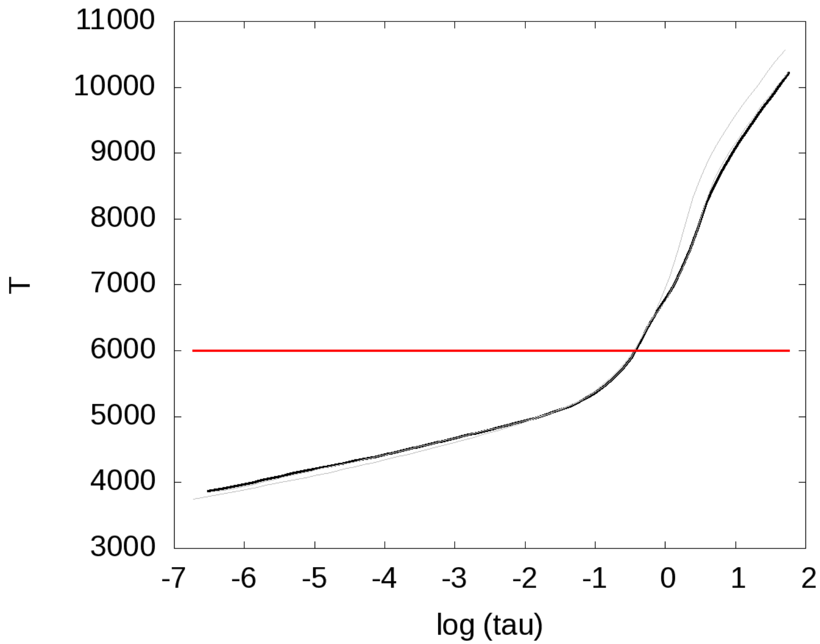
- Stellar density and log *g* equations

$$g = g_\odot M/R^2, \rho = \rho_\odot M/R^3, g = R\rho$$

- Density and Radius give log *g*
- Obtainable from:
  - Pairs (binary stars) R and M directly
  - Planets (transits) Just ρ
  - Pulsations (astereoseismology) ρ and R

Depth Dependence

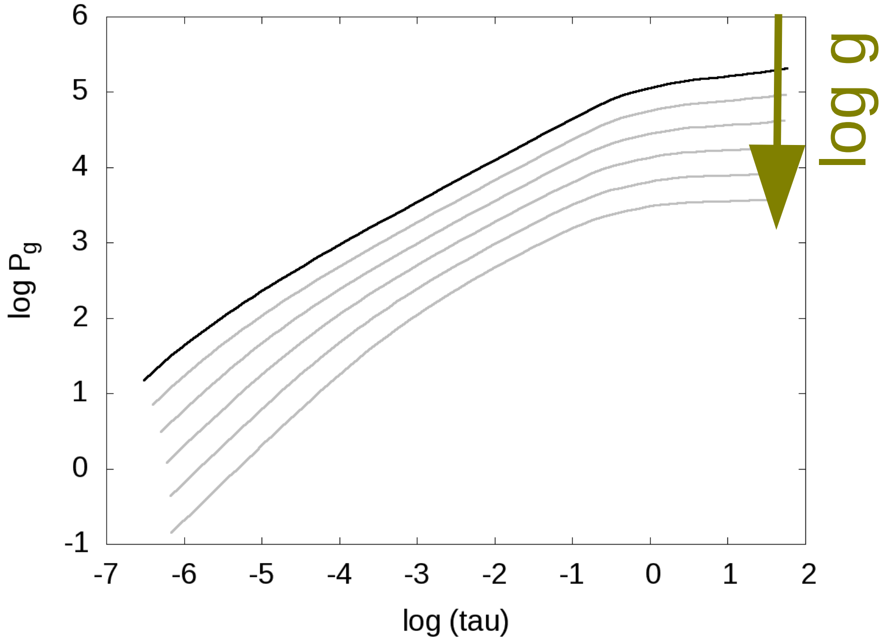
- Continuum is at/near temperature T_{eff}
- Temperature of line forming region is lower than T_{eff}
- Spectral lines are formed at different depths and temperatures.
    - ➔ Spectral diagnostics



T_{eff} 6000, log g 4.5

Pressure Dependence

- Scale height of atmosphere proportional to surface gravity
- Increasing surface gravity compresses atmosphere, increasing pressure:
  - $\log P_g \propto \log g$
  - $\log P_e \propto \log g$



T_{eff} 6000, log g 4.5 → 2.0

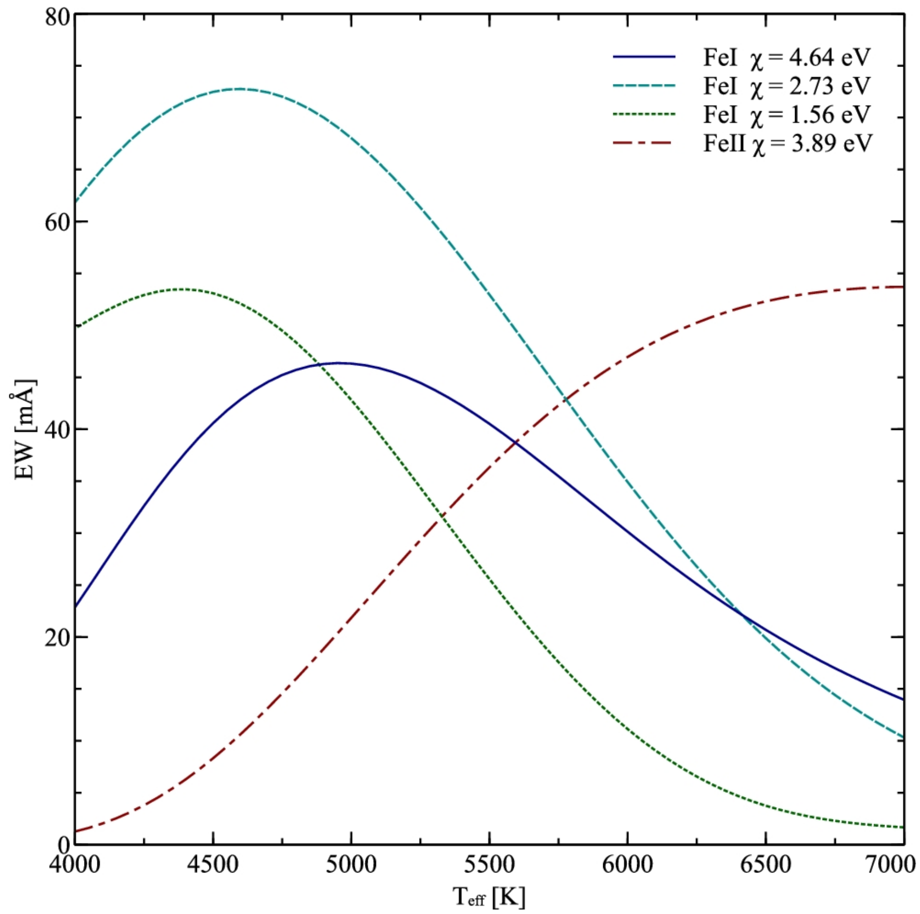
Obtain log *g* from pressure sensitive spectral lines

Temperature sensitivity of spectral lines

Spectral Line	Element	Weak Lines	
		Low Excitation	High Excitation
Neutral	Mostly neutral	Weak negative dependence	Strong positive dependence
Neutral	Mostly ionized	Strong negative dependence	Negative dependence
Ion	Mostly neutral	Strong positive dependence	Very strong positive dependence
Ion	Mostly ionized	Weak negative dependence	Strong positive dependence

Based on Eqs 13.21-13.24 in D.F. Gray (2008)

Line Strength variations with T_{eff}



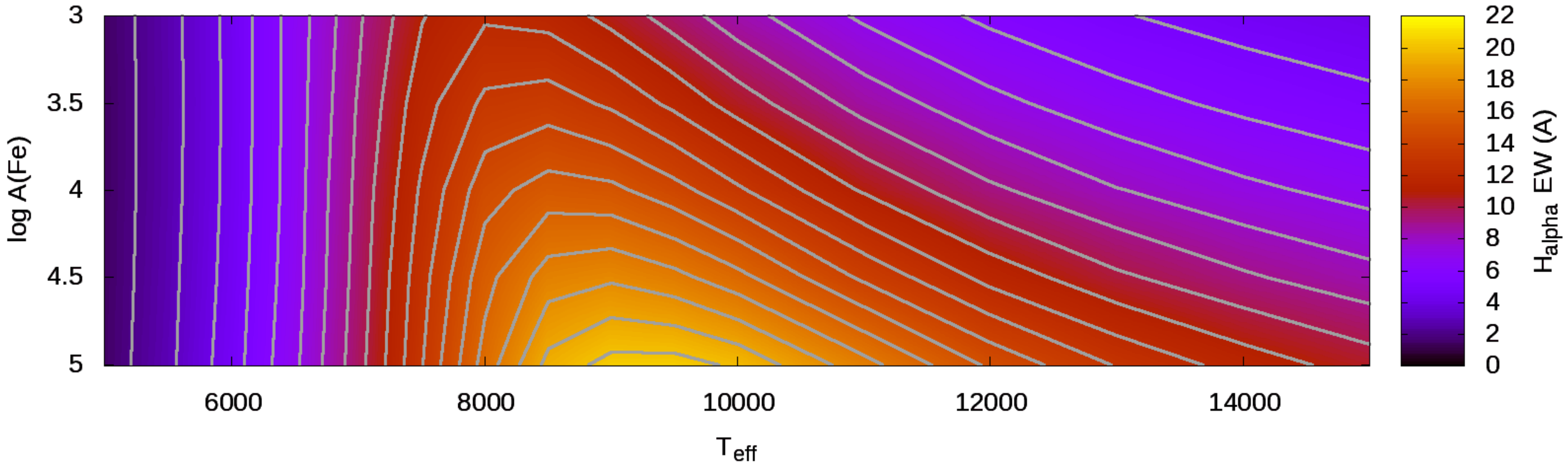
2017MNRAS.469.3965M

Pressure sensitivity of spectral lines

Spectral Line	Element	Weak Lines	Strong Lines
Neutral	Mostly neutral	sensitive	
Neutral	Mostly ionized	Insensitive	Positive dependence (e.g. Na D)
Ion	Mostly neutral	very sensitive	
Ion	Mostly ionized	insensitive	Negative dependence (e.g. Ca H & K)

For weak lines lower pressure leads to stronger lines

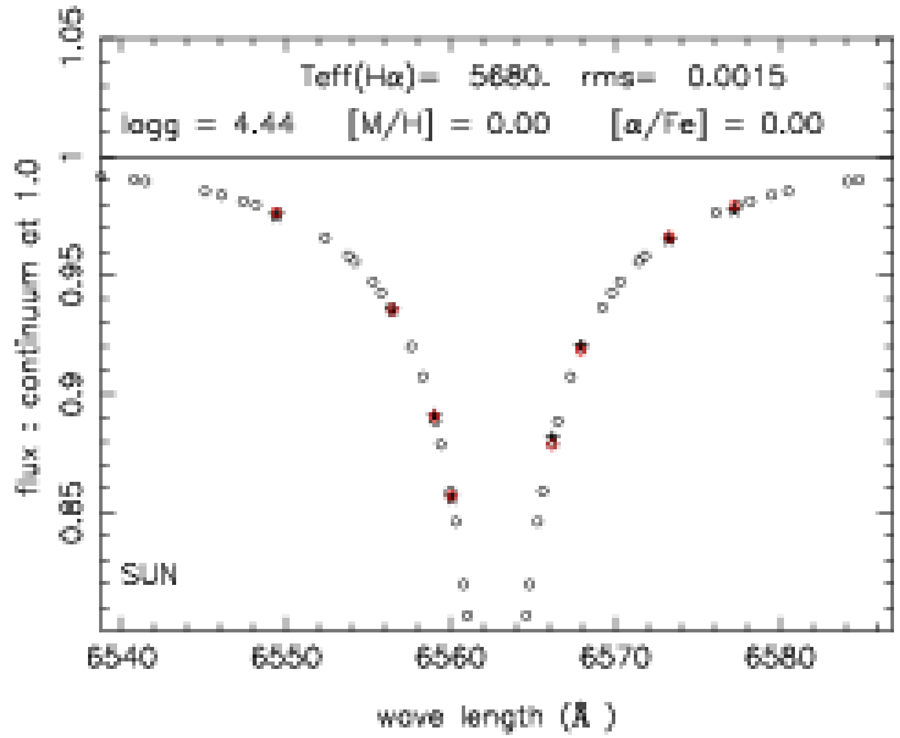
Balmer Profiles



- The Balmer lines provide good T_{eff} diagnostic below around 8000K due to low sensitivity to surface gravity.
- For hotter stars sensitivity to both T_{eff} and log g.

Effective Temperature from H_α

- Least number of metal lines.
- **Beware**
  - Telluric lines
  - Emission in core
  - Convection
    2004IAUS..224..131S



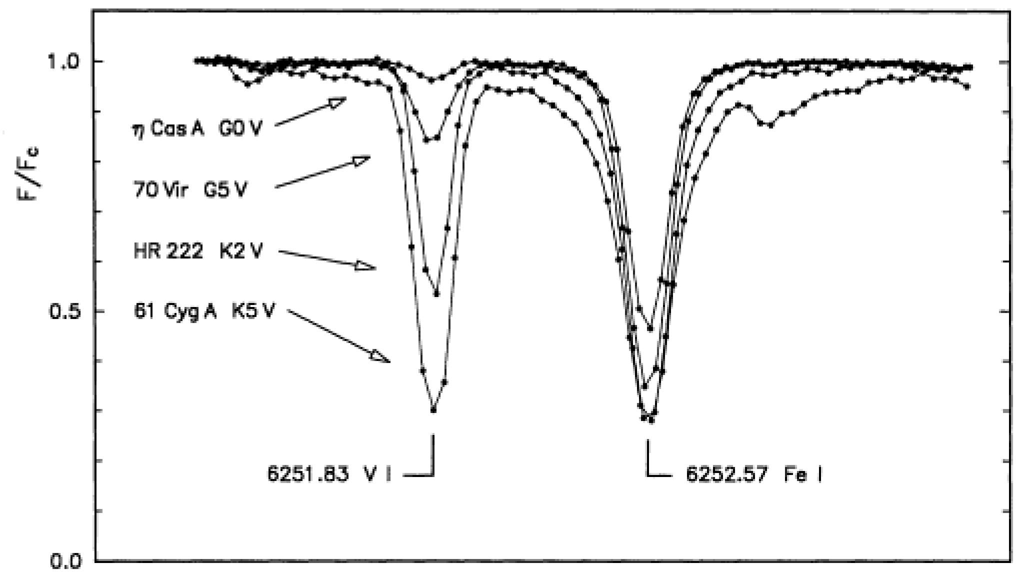
2011A&A...531A..83C

Empirical calibration:

$$T_{\rm eff}({\rm direct}) = 20.3 + 1.014 \times T_{\rm eff}({\rm H}\alpha).$$

rms only 30K

Spectral Line depth ratios



Gray & Johanson, 1991, PASP, 103, 439

Good for looking for T_{eff} variations in a given star

- Line depth ratios
  - Differing excitation potentials
  - Precise to ±10K
- A measure of temperature in line forming regions
  - Model dependent

Tied to T_{eff} scale by empirical calibrations.

Log g variation: Na I D lines

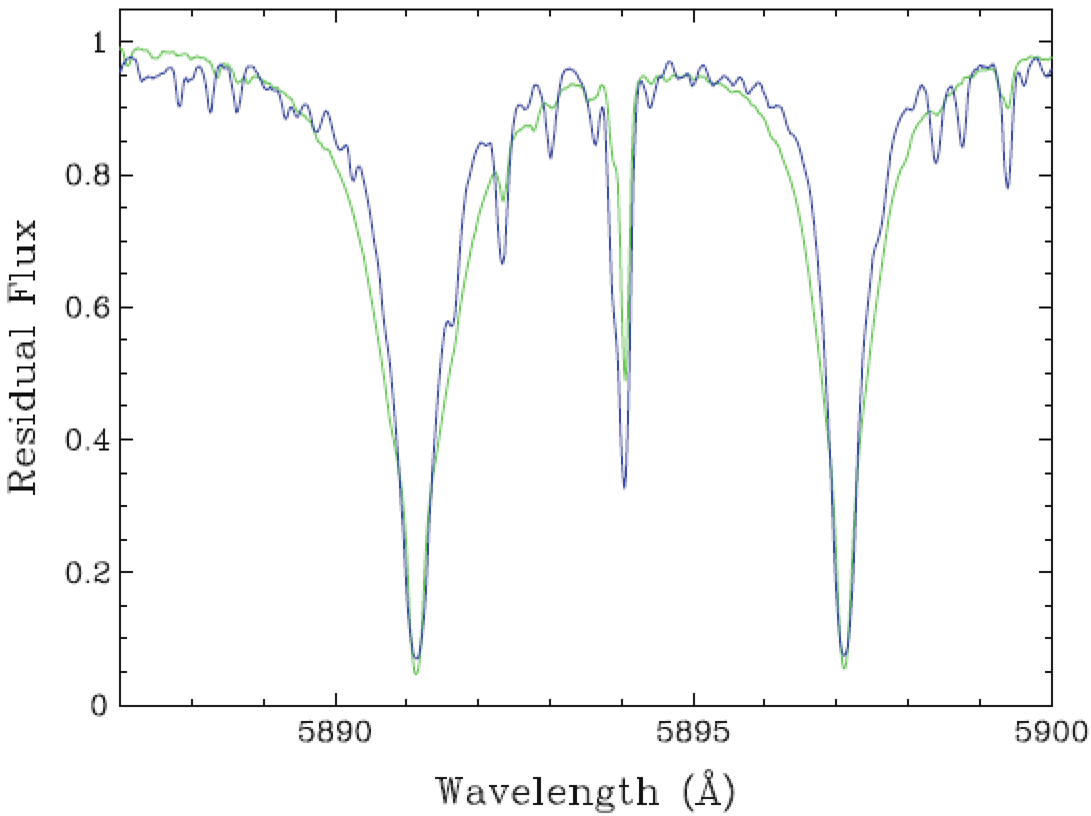


Fig. 1 Profiles of the Na D lines of HD 100623 (K0 V, *green*) and HD 99322 (K0 III, *blue*) taken from the UVES-POP database (Bagnulo et al. 2003). The effect of different gravity can clearly be seen, the lines of the giant are narrower than the lines of the dwarf

Positive dependence

2014dapb.book...97C

Log g variation: Ca II H line

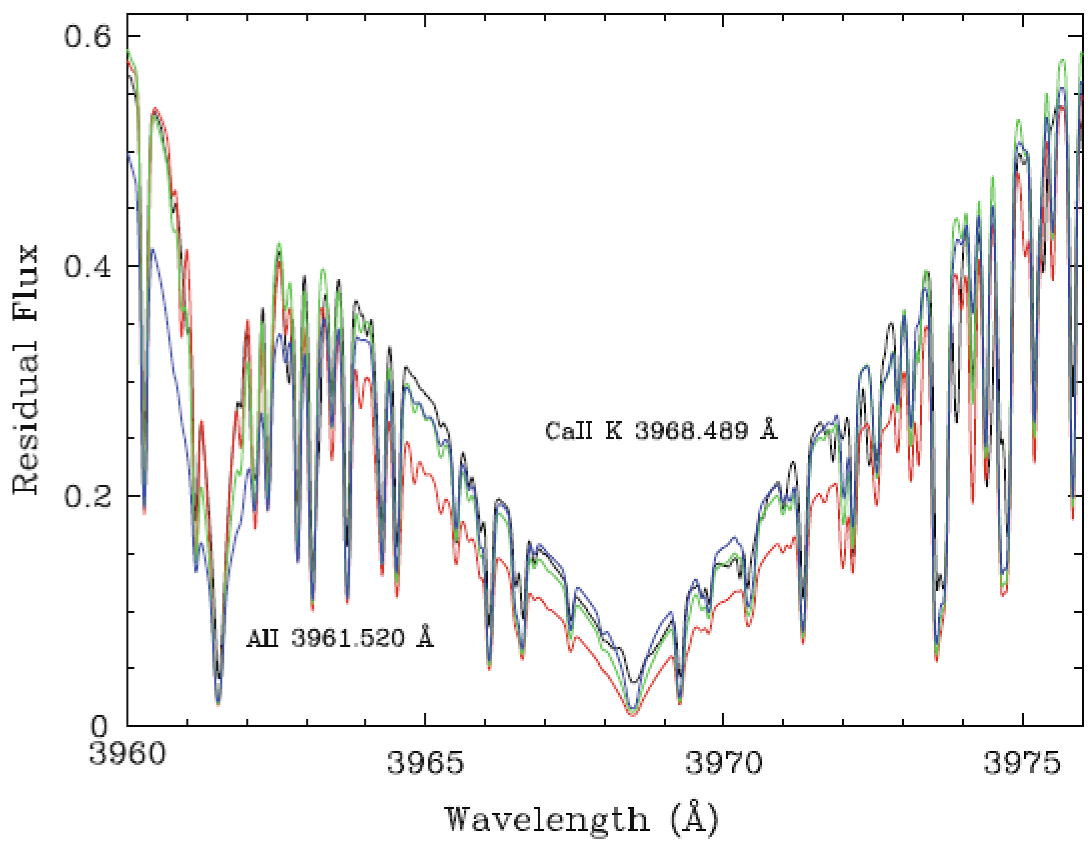


Fig. 3 *Black line* is the observed Ca II H line in HD 152311, the *red*, *green*, and *blue lines* are the computed ones for log g = 3.0, 4.0, and 5.0, respectively

Negative dependence

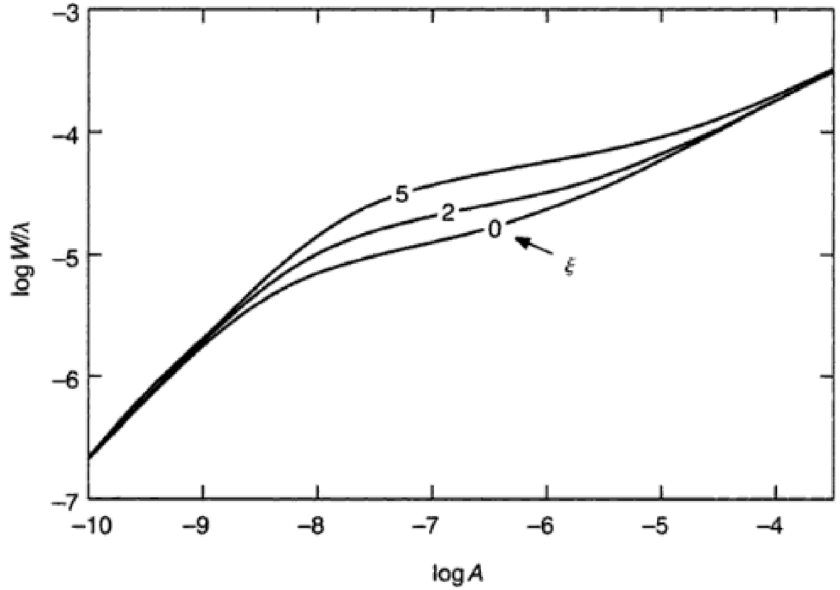
2014dapb.book...97C

Metal Line Diagnostics

- **Excitation Potential**
  - Abundances from the same element should agree for all excitation potentials
- **Ionization Balance**
  - The abundances obtained from differing ionization stages of the same element ***must*** agree
  - Fe I/Fe II ratio can be used as a T_{eff} – log g diagnostic

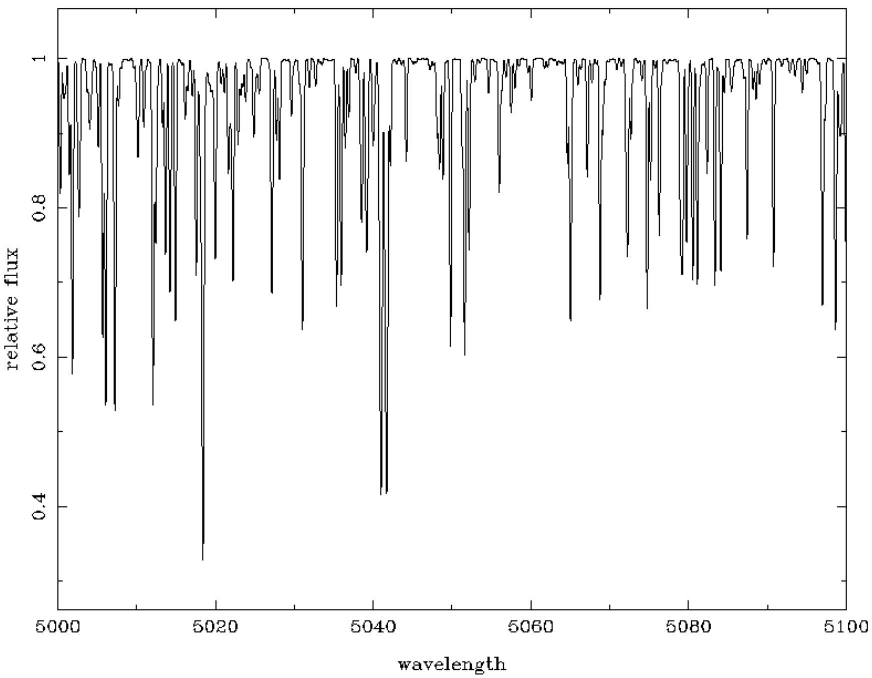
Microturbulence

- Another parameter that ***must*** be considered.
  - free parameter (ξ_{turb})
- Varied to ensure that there is no trend in abundance with equivalent width.



Gray (2008) Book

An Example

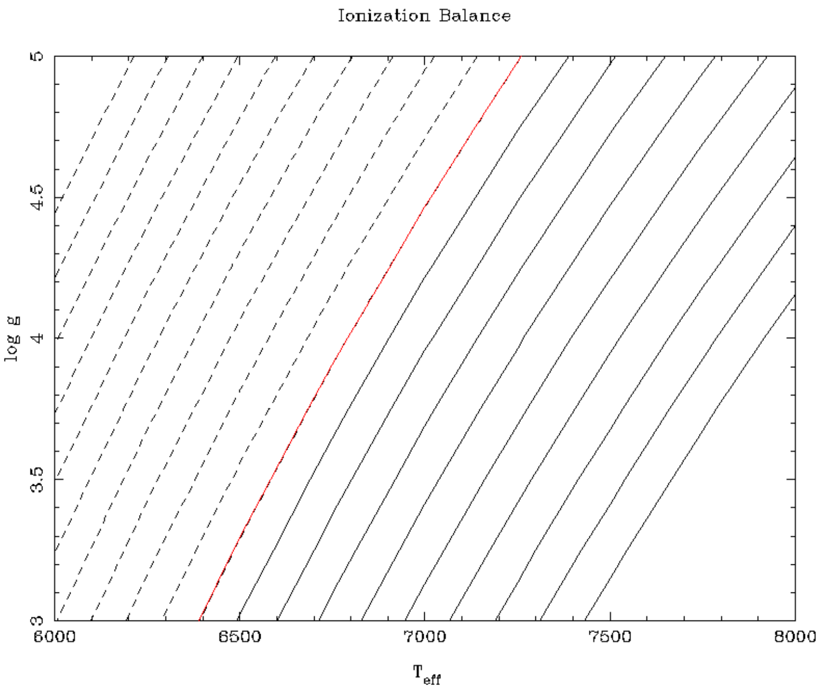


- What are the T_{eff} and log g of this synthesis?
  - "measured" all Fe lines stronger than 1mÅ
    - 29 Fe II
    - 103 Fe I

Let us begin...

An Example: Step 1

- Initial estimation of parameters
  - T_{eff} and log g
    - *approximate*!
  - $\xi_{\mathrm{turb}} = 0.0$
  - [Fe/H] = 0.0
- Fe Ionization balance
  - T_{eff} = ~7000K
  - log g = 4.5 [assumed]



It is the red line!

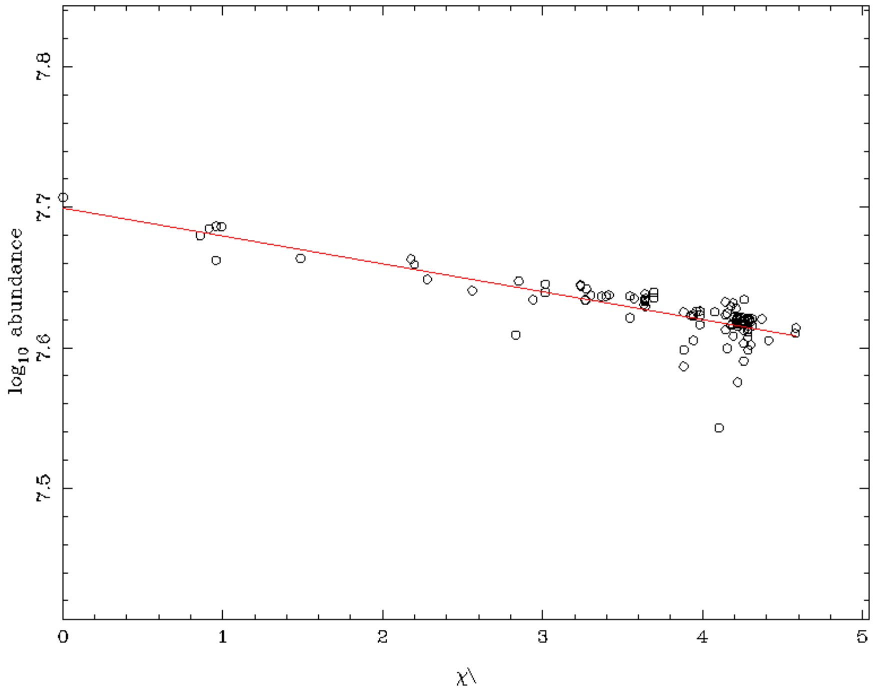
An Example: Step 2

- Initial estimation of ξ_{turb} using Fe I
  - For 7000K, 4.5 we get ~2 km/s
- Re-determine ionization balance for this ξ_{turb}
  - For log g = 4.5 we now get T_{eff} ~ 7200K
- Iterate once more...
  - For log g = 4.5 we now get T_{eff} ~ 7230K
  - ξ_{turb} ~2.08 km/s for Fe I.

BUT...

An Example: Step 3

- What about log *g*?
  - Plot abundance against excitation potential for Fe I lines
    - *should all give same abundance*
- Our initial assumed log *g* was not correct!



An Example: Step 4

- To get surface gravity
  - Vary log *g* until there is no trend of abundance with excitation potential.
  - Determine ξ_{turb} from Fe I and Fe II lines, independently
    - For log g = 5.0, Teff = 7440, ξ_{turb} Fe I: 2.06 Fe II: 2.30
    - For log g = 4.5, Teff = 7230, ξ_{turb} Fe I: 2.08 Fe II: 2.24
    - For log g = 4.0, Teff = 7020, ξ_{turb} Fe I: 2.05 Fe II: 2.02
- Solution: 7020, 4.0, 2.04 and [Fe/H] = 0 [assumed]
- Answer: 7040, 4.05, 2.05, [Fe/H] = 0.0

Global Spectral Fitting

- Take a large grid of synthetic spectra with varying Teff, log g, ξ_{turb} , [Fe/H]
  - Locate the best-fitting synthesis
  - Hence obtain Teff, log g, ξ_{turb} , [Fe/H]
- Issues to consider
  - How reliable are these parameters?
  - What are the hidden dangers?
  - What are realistic error estimates, over and above the internal precision?

Metallicity

Do not neglect metallicity when determining T_{eff} and log g.

An incorrect metallicity can have a significant effect on perceived values of these parameters.

T_{eff}-log g Diagram

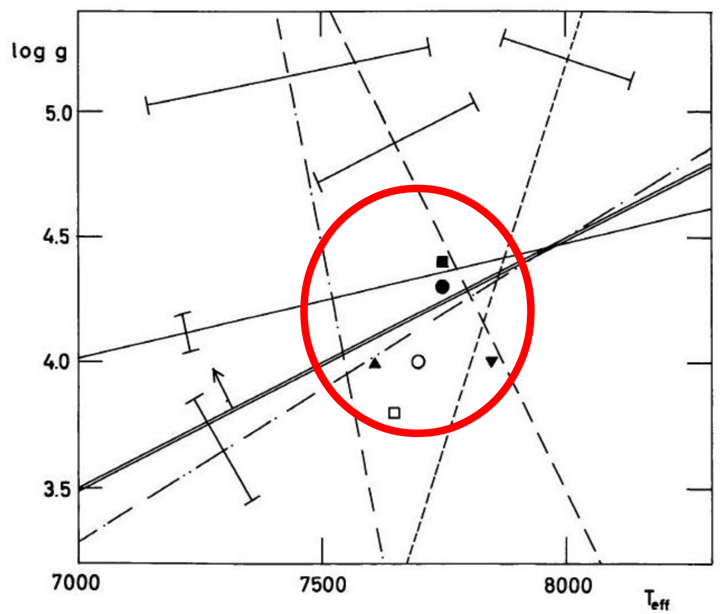


Fig. 2. T_{eff}-log g-diagram for the evaluation of the model parameters from ═══ balmer jump, —— absolute magnitude, – – – Hα, –·–·– Hγ, –··– ionization equilibrium of iron, - - - - - flux gradient (5450–8206 Å); ● adopted model. For comparison other models for 63 Tau are indicated: ■ van't Veer, 1963; ▼ Baschek and Oke, 1965; ▲ Oke and Conti, 1966; □ Conti, 1965; ○ Smith, 1971

63 Tau (Hundt, 1973, A&A, 21, 413)

- Very useful diagnostic
- In theory all diagnostics should give *unique* T_{eff} and log g solution.
- In practice there is a *region* in T_{eff} and log g space that contains the solution and its uncertainty.

T_{eff} - log g diagram is **not** the same as a HR Diagram
log g is **not** directly related to luminosity

“Laws”

- T_{eff} and log *g* pairs are not unique spectra
  - Metallicity, rotation, velocity fields, etc.
- **Law 1**: Two stars with same T_{eff} and log *g* do not necessarily have same spectrum.
- **Law 2**: Two stars with same spectrum *<u>must</u>* have same T_{eff} and log *g*.

Do we care about T_{eff} and log g?

- The effective temperature of a star is not important, it is the $T(\tau_0)$ relationship that determines the spectral characteristics.
  Gray's Book (2005)
- The parameters obtained from spectroscopic methods alone ***may not*** be consistent with the true values
  - Not necessarily important for abundances
  - Important when interested in stellar properties

A Recipe for Solar-type Stars

1) Obtain T_{eff} from H_α

2) Use Na D lines to determine log g

3) Assume microturbulence based on T_{eff}

4) Measure several (~10) unblended Fe I lines and fit to get average [Fe/H]

5) Possibly iterate, if [Fe/H] ≠ 0

Precision:

Teff ±100 K, log g ±0.2 dex and [Fe/H] ±0.1 dex

Conclusion

T_{eff} and log g are:

A. Free parameters that can be adjusted at will to provide best model fit to observations

B. Fixed parameters dictated by the physical properties of the star

C. "Random" numbers found in the literature

D. All of the above

Please select one option