The Metallicity Ladder in Resolved Stellar Populations

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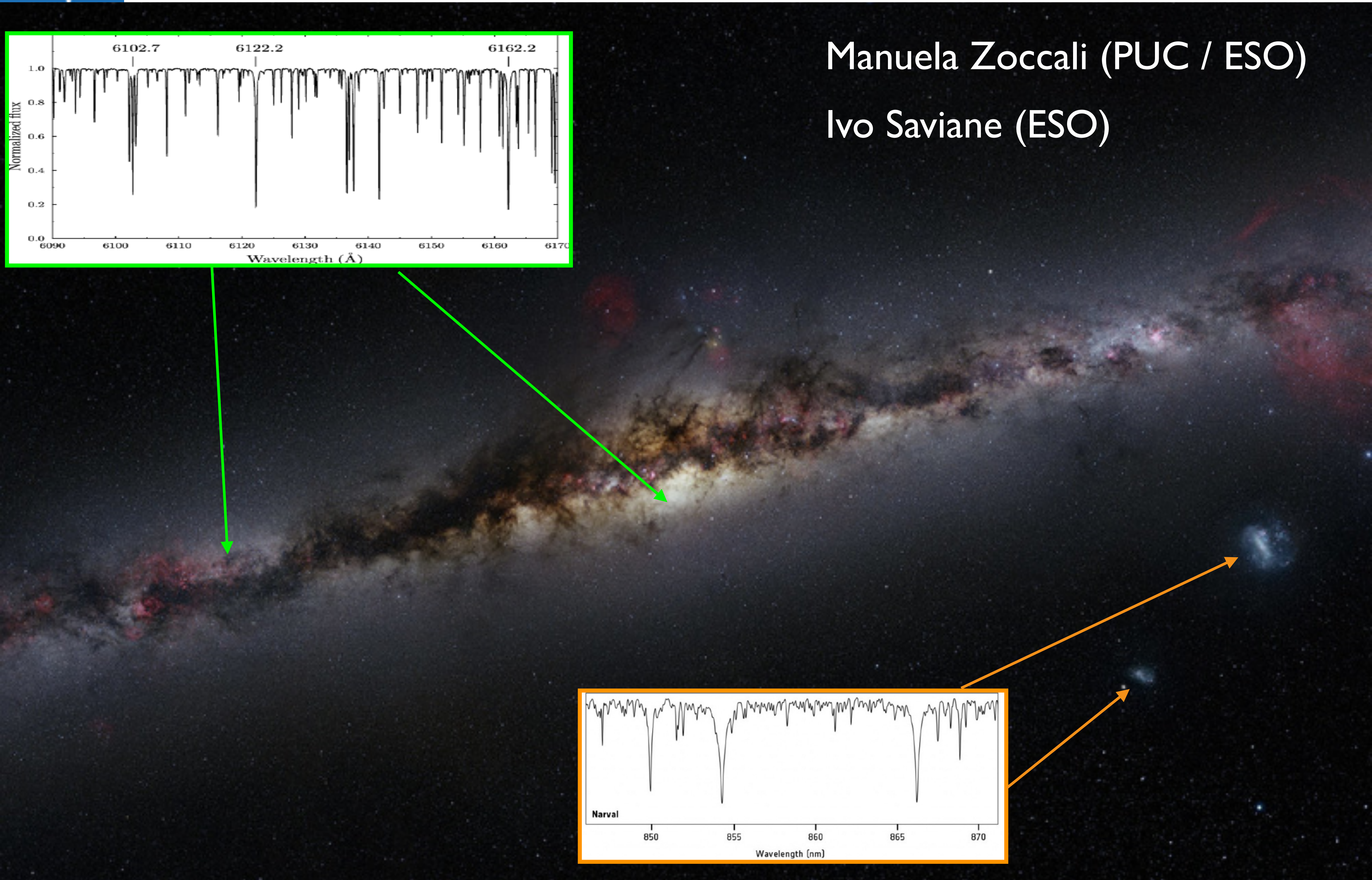

The (surface) chemical composition of a star

Theoretical scale:

Mass Fraction normalized to unity: $X + Y + Z = 1$

$\uparrow$ H $\uparrow$ He $\uparrow$ Metals

	X		Y		Z
First stars in the Universe:	0.75	+	0.25	+	0
Sun	0.71	+	0.27	+	0.02

Observational scale:

$$[Fe/H] = \log \frac{A(Fe)}{A(Fe)_\odot}$$

with A(Fe) = N_{Fe} / N_H = Nr of Fe atoms / Nr of H atoms

Conversion:

$$[M/H] = \log \frac{Z}{Z_\odot} \boxed{= [Fe/H]}$$

only **if** Fe traces all the metals

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Sun	Z = 0.02	[M/H] = 0.0	[Fe/H]=0.0
	Z = 0.002	[M/H] = –1	
	Z = 0.0002	[M/H] = –2	
	Z = 0.04	[M/H] = 0.3	

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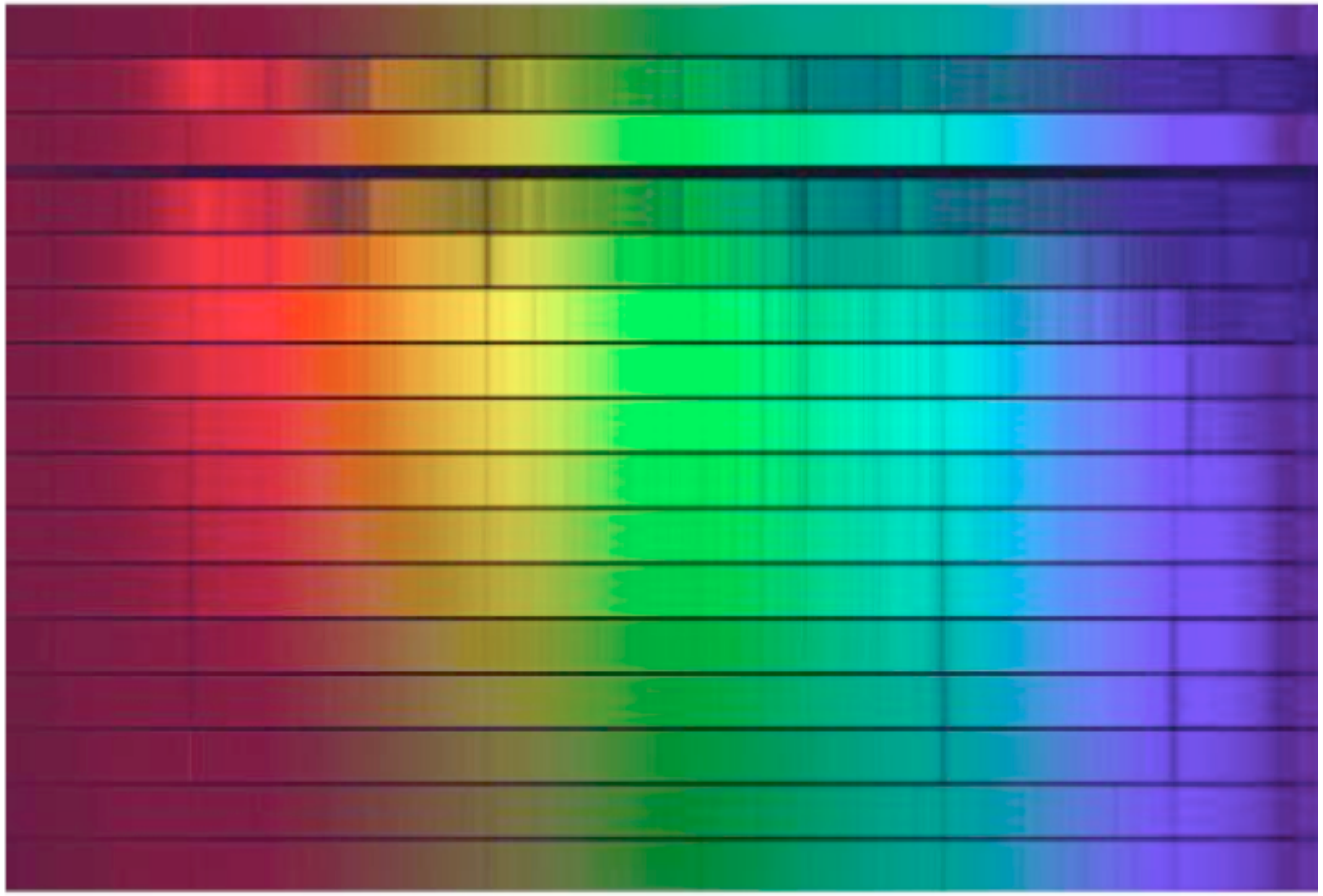
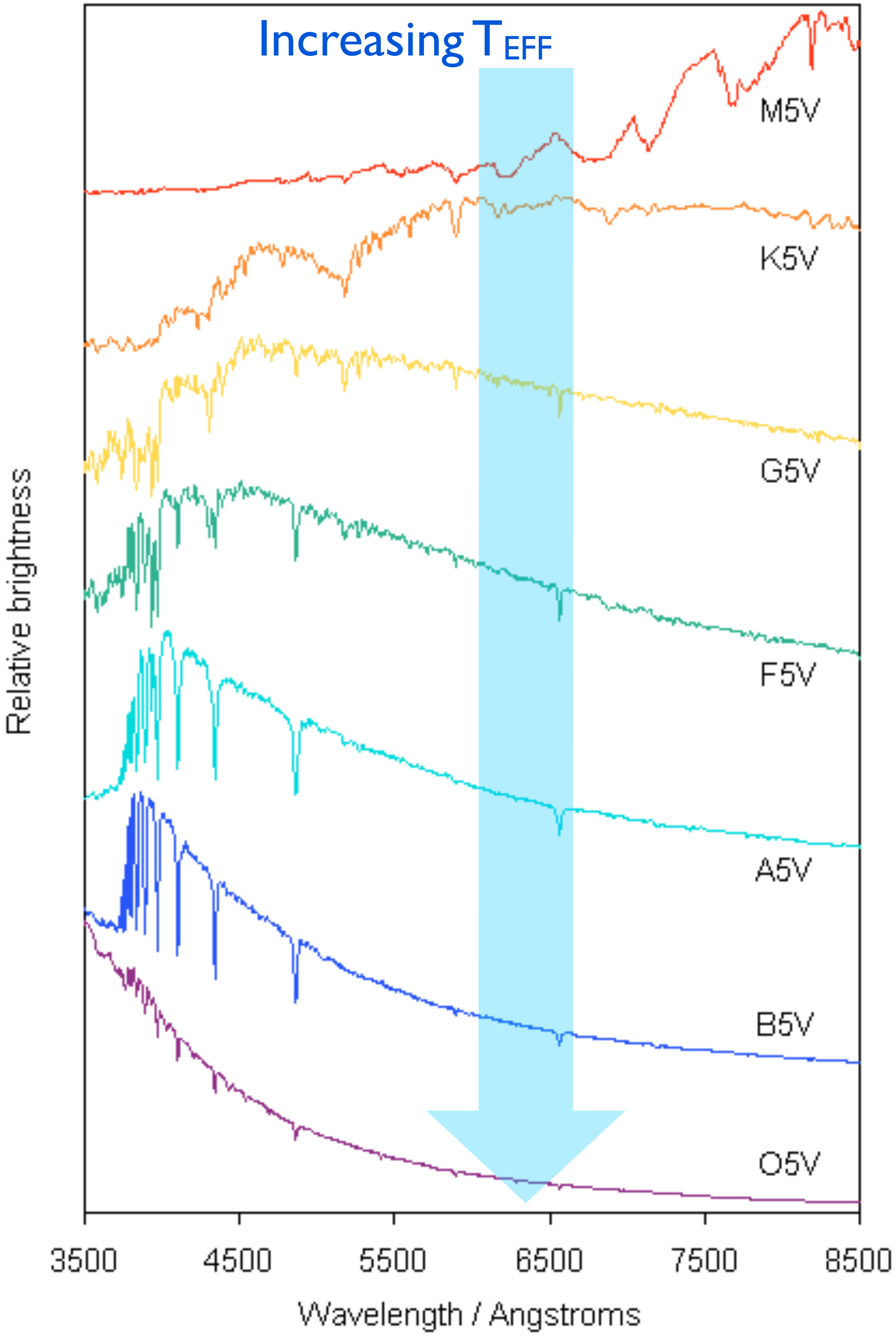
The spectrum of a star

Continuum (Black Body) + Fraunhofer Lines





What is a blackbody?

DEFINITION:
A container that is completely closed except for a very small hole in one wall. Any light entering the hole has a very small probability of finding its way out again, and eventually will be absorbed by the walls or the gas inside the container: this is a perfect absorber - all light that enters the hole is absorbed inside.

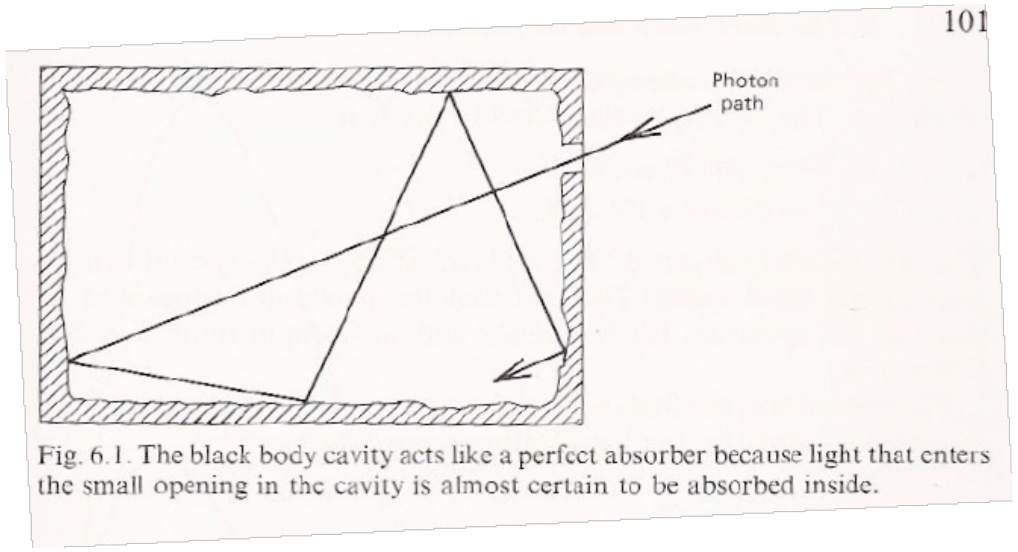


Fig. 6.1. The black body cavity acts like a perfect absorber because light that enters the small opening in the cavity is almost certain to be absorbed inside.

Eventually the photon finds the hole again and gets out, but this happens only after a lot of bouncing against the walls, i.e., after many interactions with the box material. This is the definition of "thermodynamic equilibrium", a condition that is also fulfilled in (most of) the stellar atmospheres.
By heating the box, one "heats" also the photons in it, and the resulting energy (=frequency) distribution of the outcoming photons also changes, according to the following laws:

Wien Law

$$\boxed{\lambda_{max} = \frac{2.9\times10^{-3}}{T}}$$

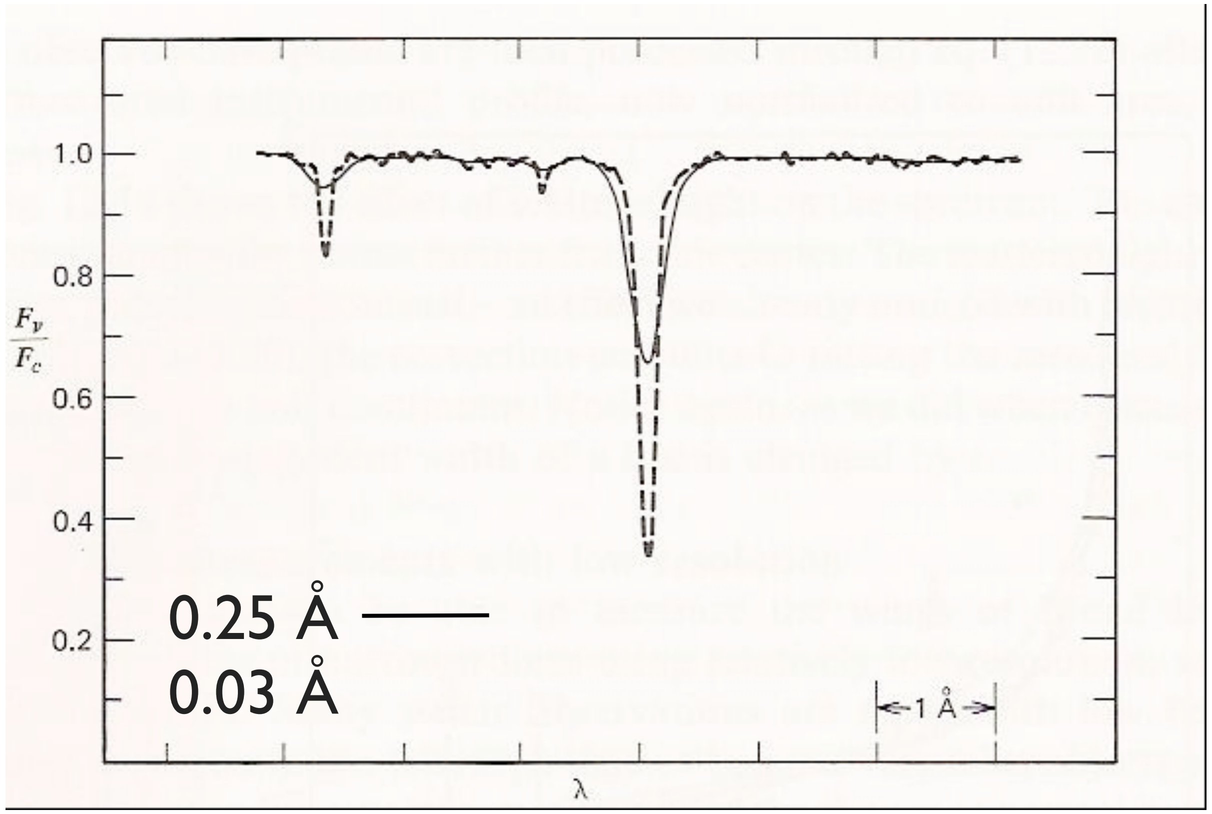
Stefan-Boltzmann Law

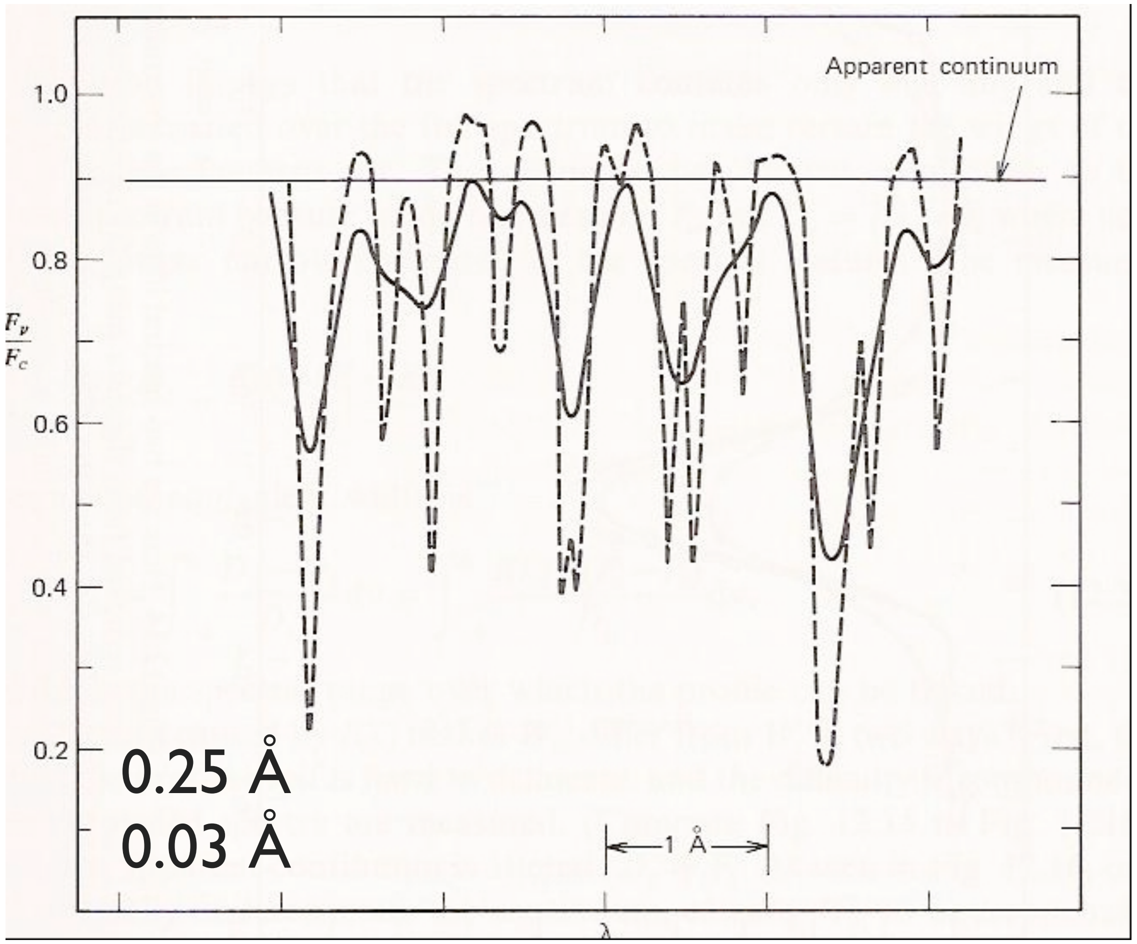
$$\boxed{F = \sigma T^4}$$

Spectral Resolution

$$R = \frac{\lambda}{\Delta\lambda}$$

Resolution is crucial in spectroscopy, not only to separate (resolve) individual spectral lines, but also to define continuum in crowded spectra (=metal rich stars, cold stars)





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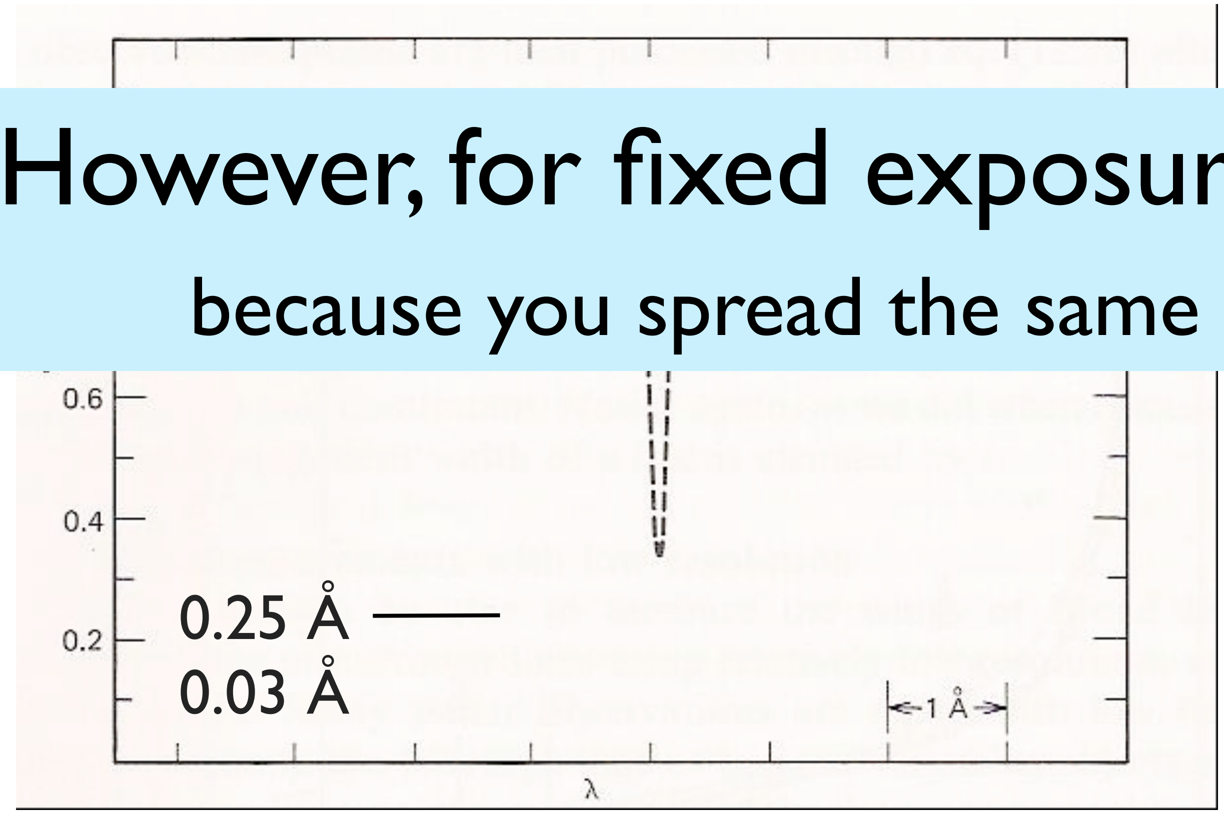

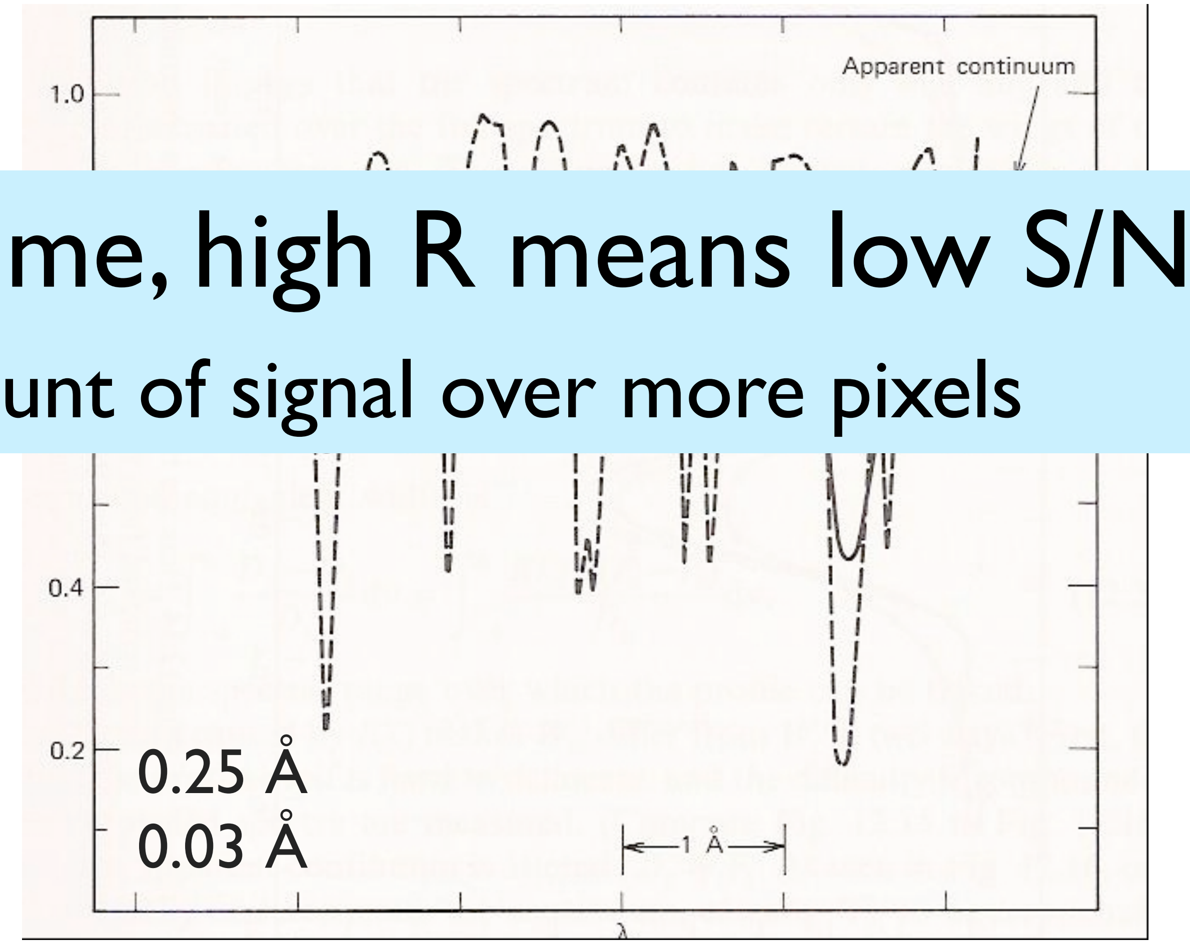

However, for fixed exposure time, high R means low S/N,

because you spread the same amount of signal over more pixels

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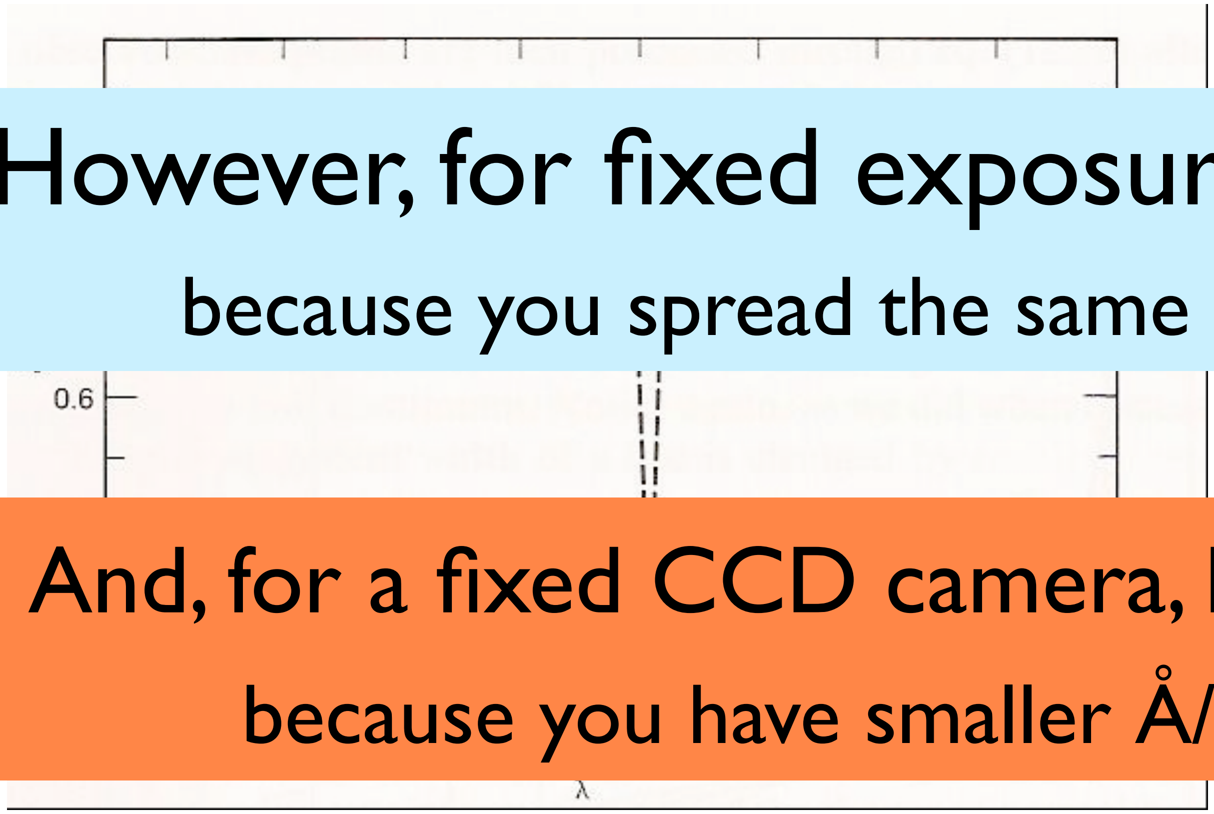
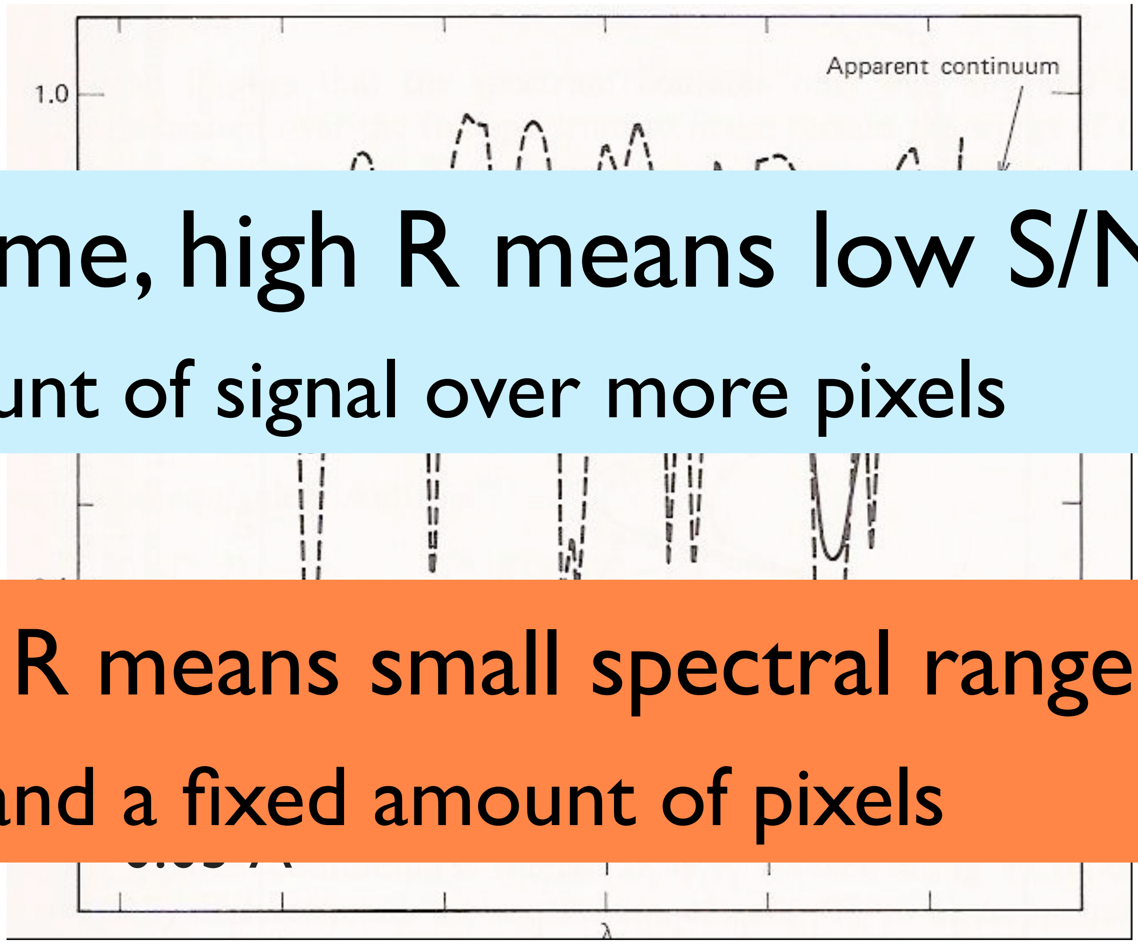




However, for fixed exposure time, high R means low S/N,

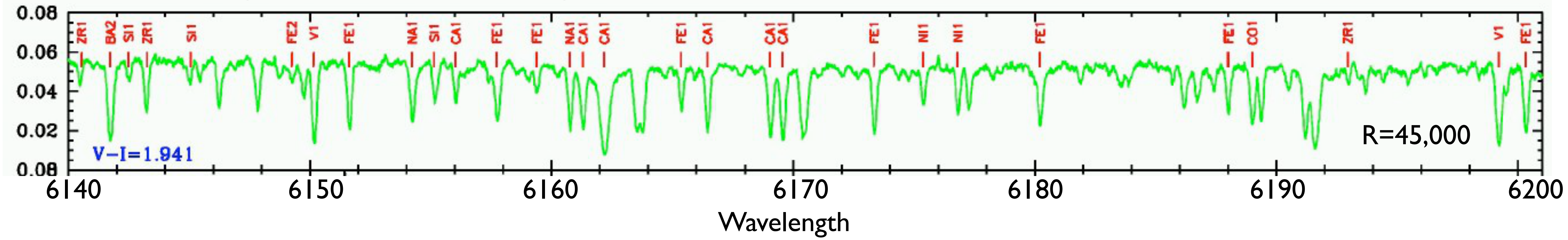
because you spread the same amount of signal over more pixels

And, for a fixed CCD camera, high R means small spectral range,

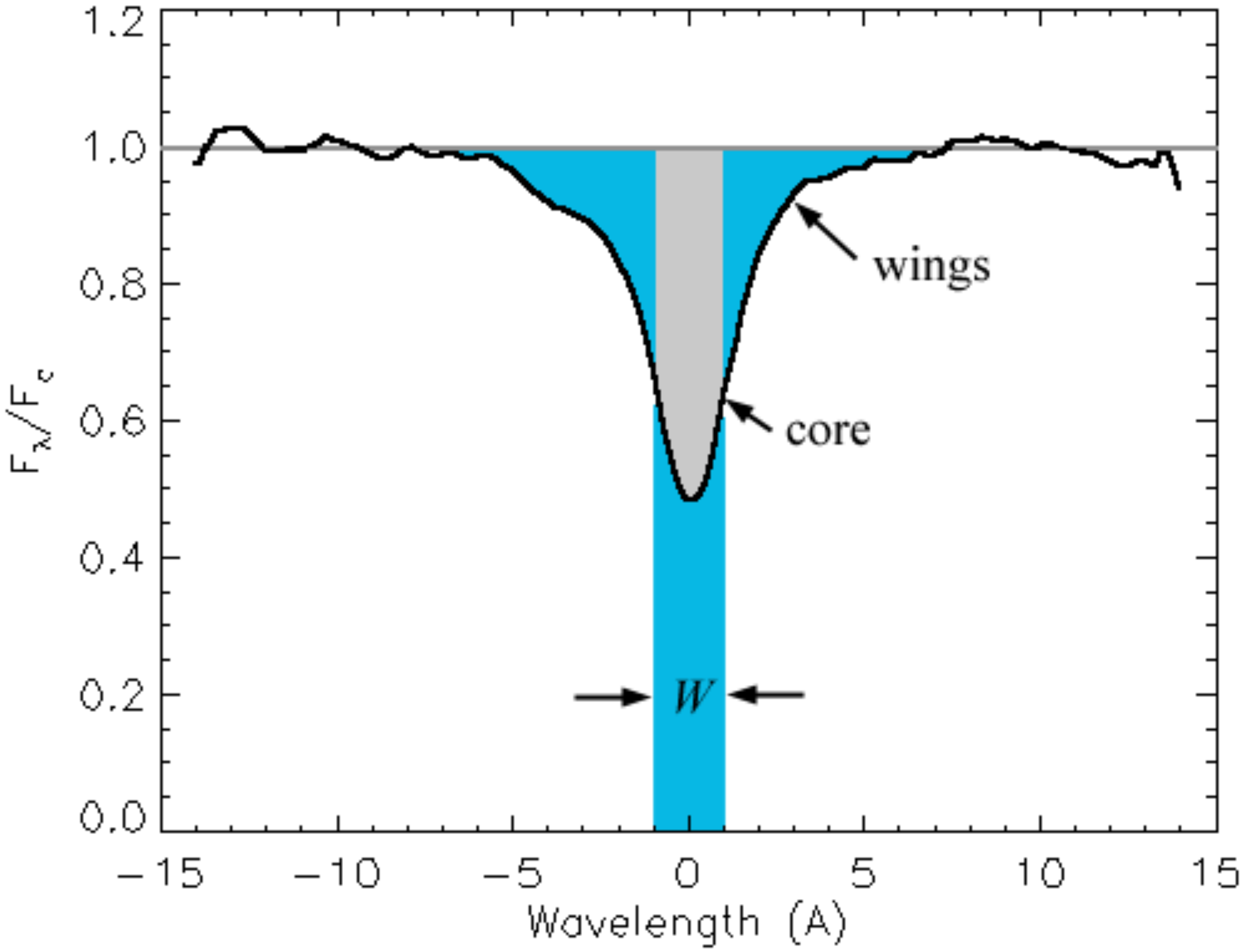
because you have smaller Å/pix, and a fixed amount of pixels

Chemical Abundance determination from HR spectra

a red giant star in the Galactic bulge



Equivalent width (W or sometimes EW)



the width that the line would have if it were a rectangle.

EW (or W) is measured in mÅ

Line profiles and curves of growth

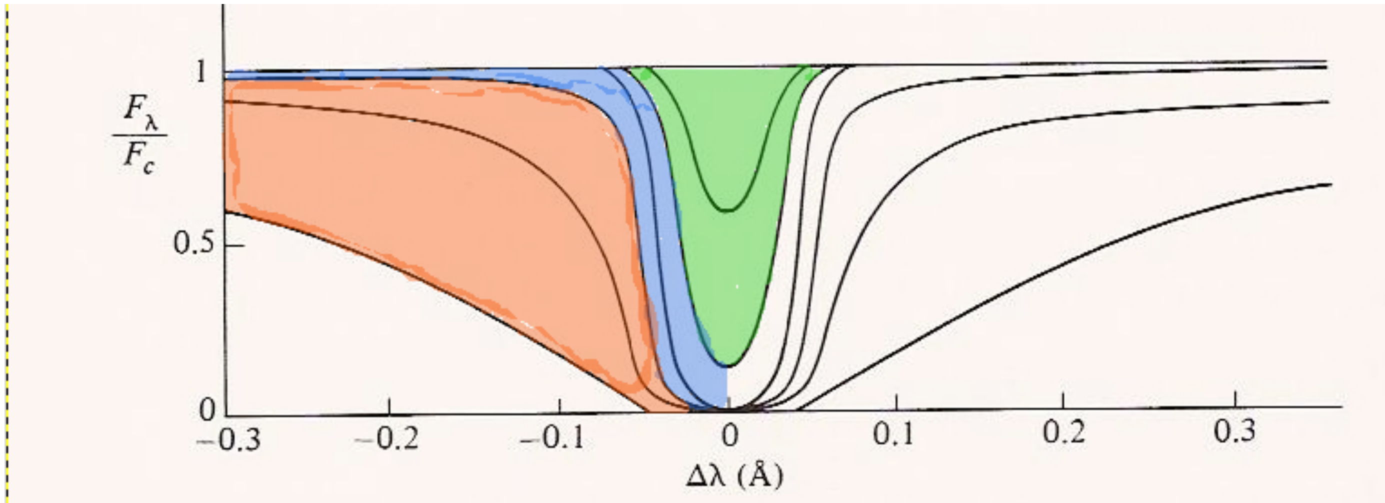


Figure 9.20 Voigt profiles of the K line of Ca II. The shallowest line is produced by $N_a = 3.4 \times 10^{11}$ ions cm^{-2}, and the ions are ten times more abundant for each successively broader line. (Adapted from Novotny, *Introduction to Stellar Atmospheres and Interiors*, Oxford University Press, New York, 1973.)

For small optical depths (τ_υ<<1) it can be demonstrated that:

$$W/\lambda = 8.85\times10^{-13}\, N_i\, f_\lambda\, \lambda$$

where:

Ni = column density of element

f_λ = oscillator strength (sort of a transition probability for that line)

[pag. 206 “Atomic Astrophysics and Spectroscopy” Pradhan & Nahar]

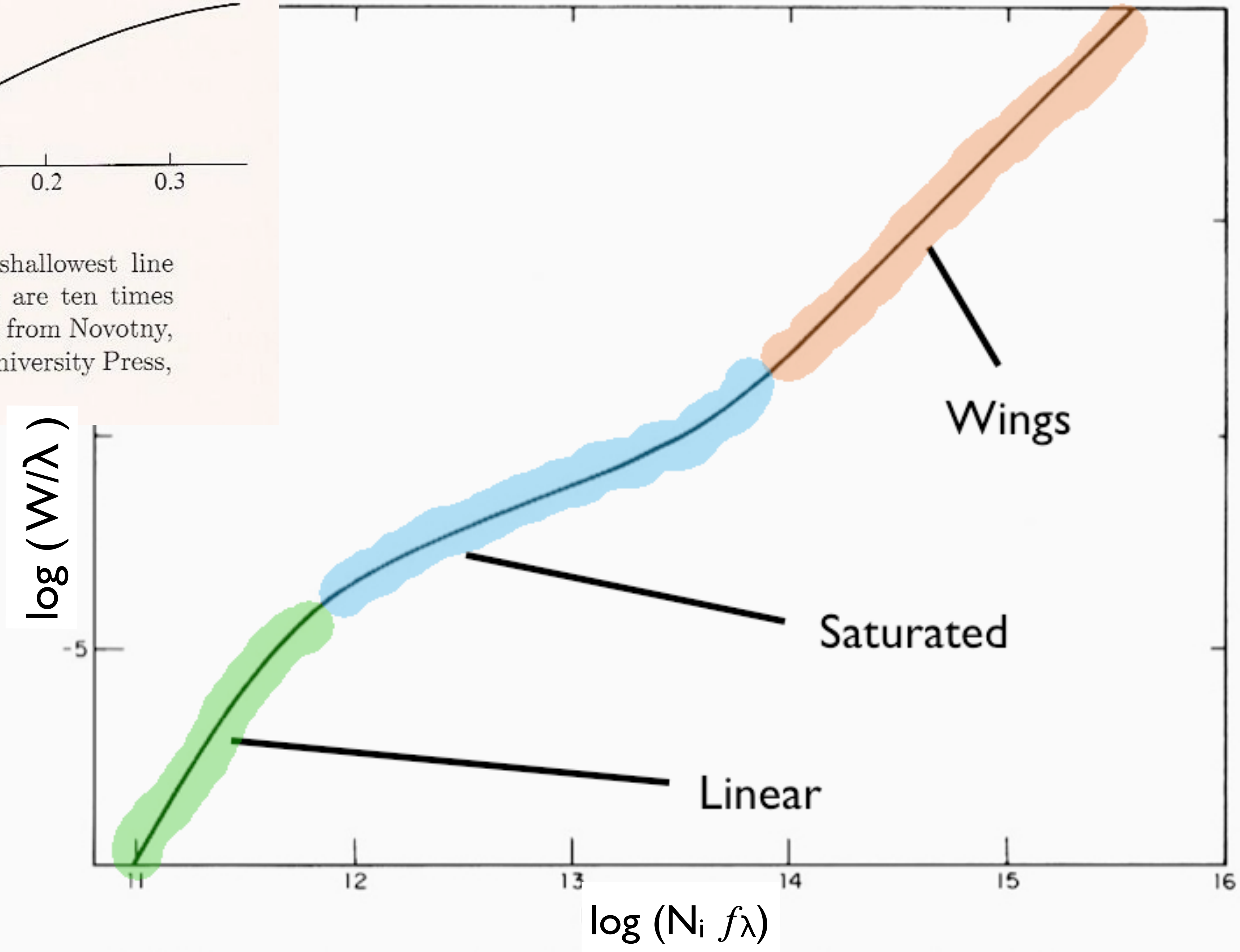


Figure 9.22 A general curve of growth for the Sun. (Figure from Aller, *Atoms, Stars, and Nebulae*, Revised Edition, Harvard University Press, Cambridge, MA, 1971.)

From EWs to Abundances

How many atoms of a given element can contribute to a given line?

From EWs to Abundances

How many atoms of a given element can contribute to a given line?

The problem is greatly simplified by the assumption of **Local Thermodynamical Equilibrum**:

1) The distribution of kinetic energies follows the **Maxwell law**

this tells you how many atoms change level due to collisions [they do not produce a line]

$$\boxed{f(v) = 4\pi v^2 \left(\frac{m}{2\pi KT}\right)^{3/2} \exp\left(\frac{-mv^2}{2KT}\right)}$$

2) The distribution of photon energy follows the **Planck's law**

this tells you how photons of a given λ (or ν) are available

$$\boxed{B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/kT}-1}}$$

3) The distribution of electrons among different excitation states follows the **Boltzman equation**

this tells you how many electrons there are in different atomic levels

$$\boxed{\frac{N_i}{N_j} = \left(\frac{g_i}{g_j}\right)\exp\left(\frac{-(Ei-Ej)}{KT}\right)}$$

4) The distribution of atoms among different ionization states follows the **Saha equation**

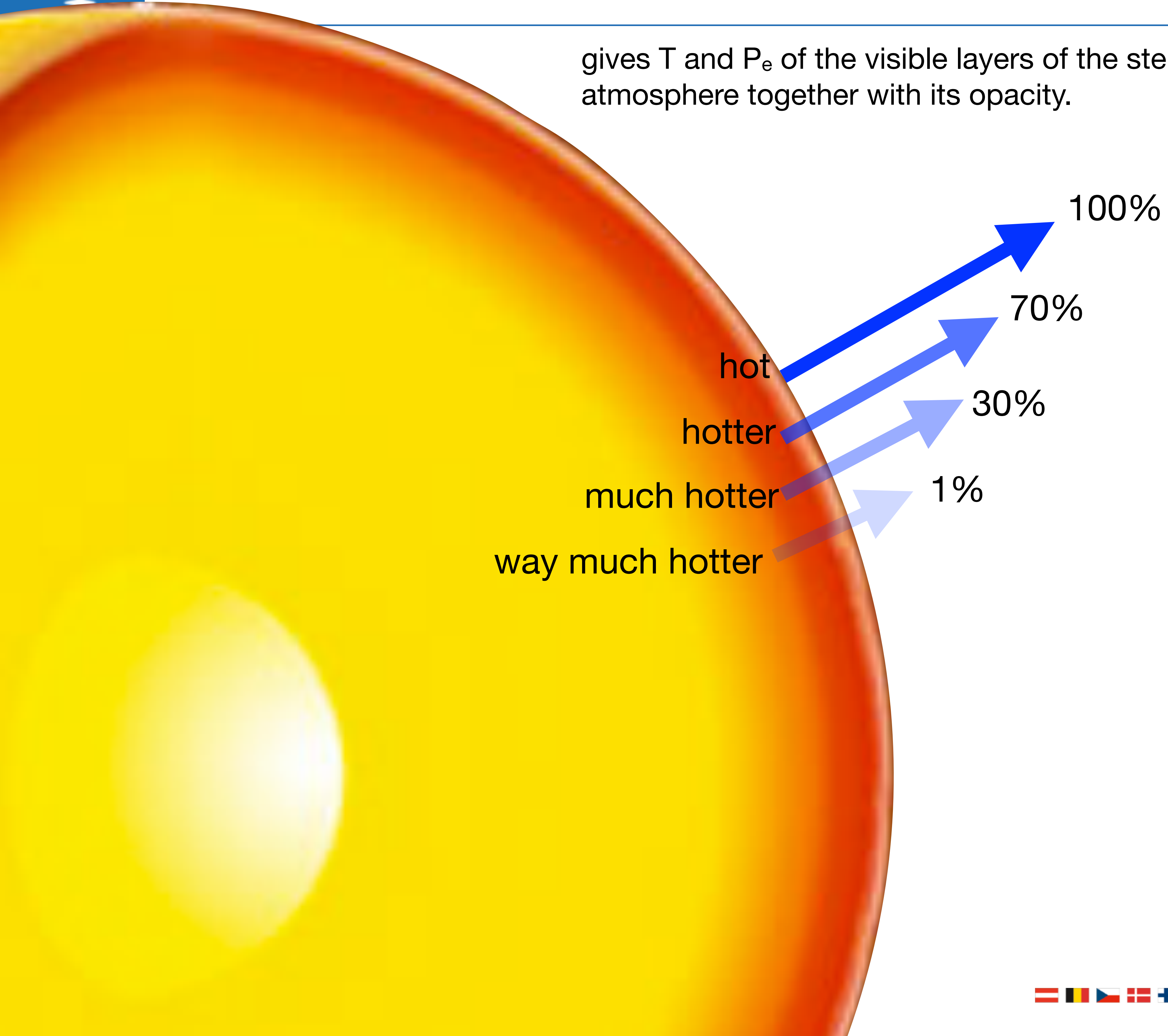
this tells you how many atoms are ionized

$$\boxed{\log\frac{N^I}{N_0} = \log\frac{u^I}{u^0} + 2.5\log T - \frac{5040}{T}\chi_{\text{ion}} - \log P_e - 0.176}$$

The model atmosphere

what is it? why do we need one?

gives T and P_e of the visible layers of the stellar atmosphere together with its opacity.



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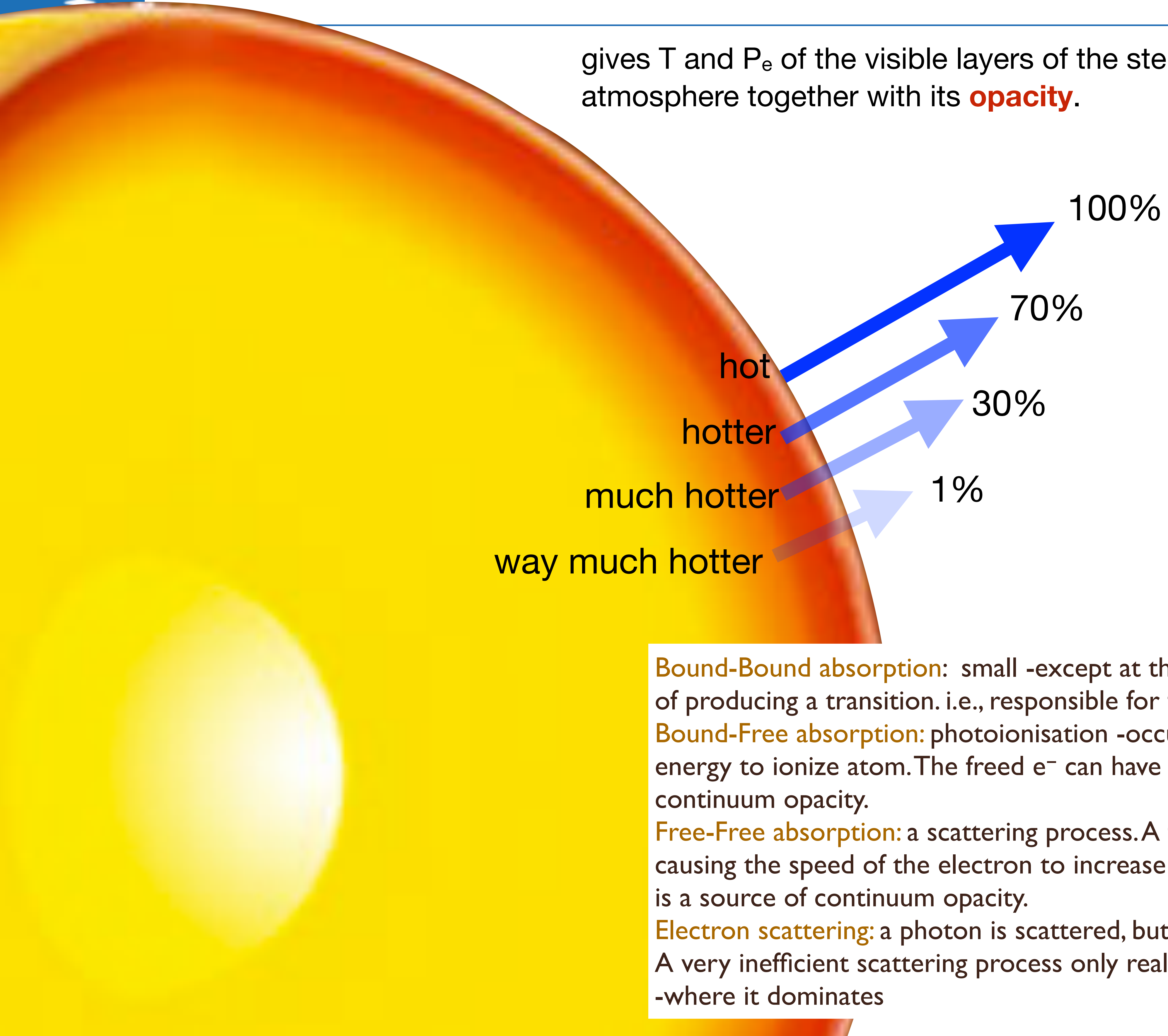


Bound-Bound absorption: small -except at those discrete wavelengths capable of producing a transition. i.e., responsible for forming absorption lines

Bound-Free absorption: photoionisation -occurs when a photon has sufficient energy to ionize atom. The freed e^- can have any energy, thus this is a source of continuum opacity.

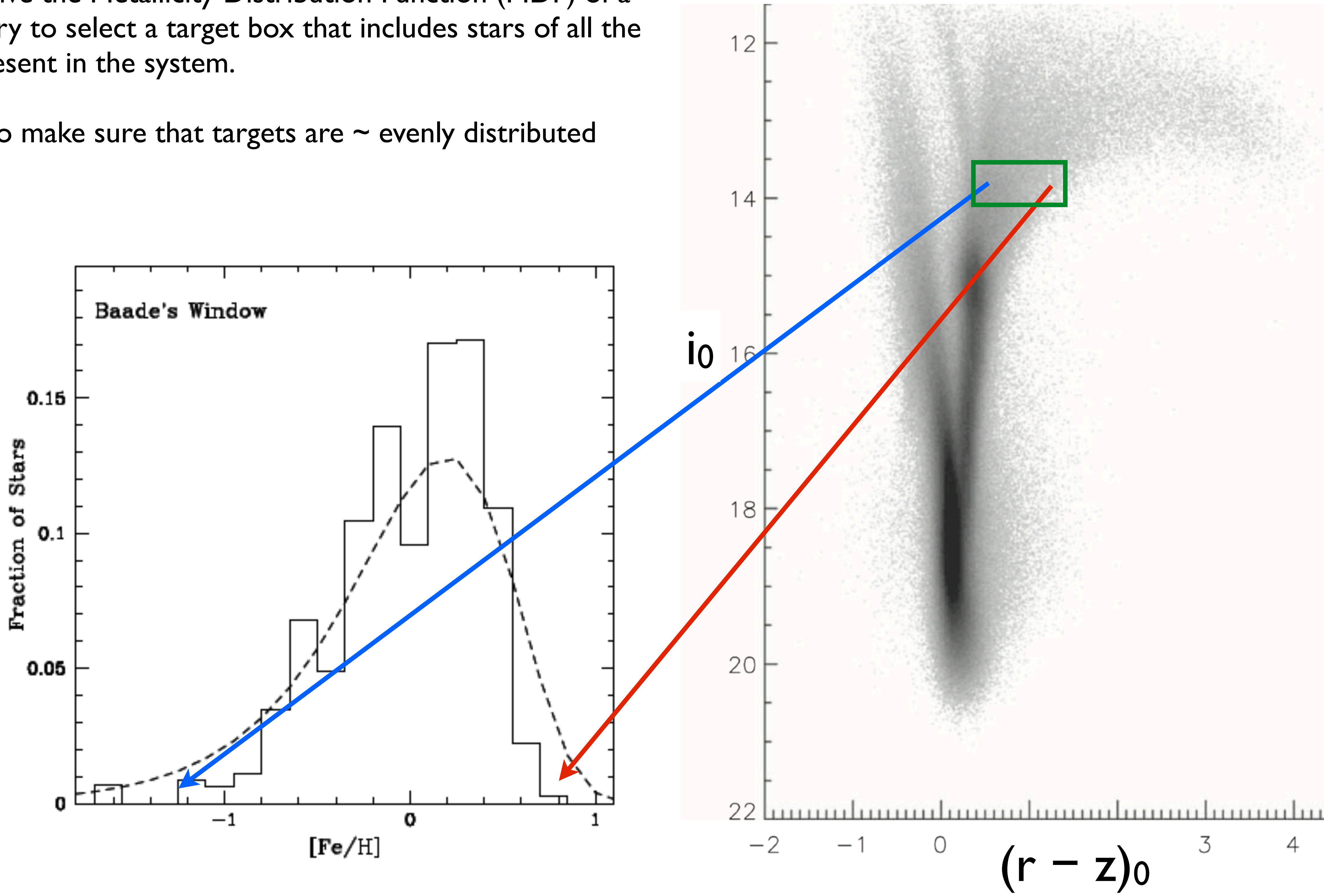
Free-Free absorption: a scattering process. A free electron absorbs a photon, causing the speed of the electron to increase. Can occur for a range of λ, so it is a source of continuum opacity.

Electron scattering: a photon is scattered, but not absorbed by a free electron. A very inefficient scattering process only really important at high temperatures -where it dominates

The iron distribution of a complex stellar population

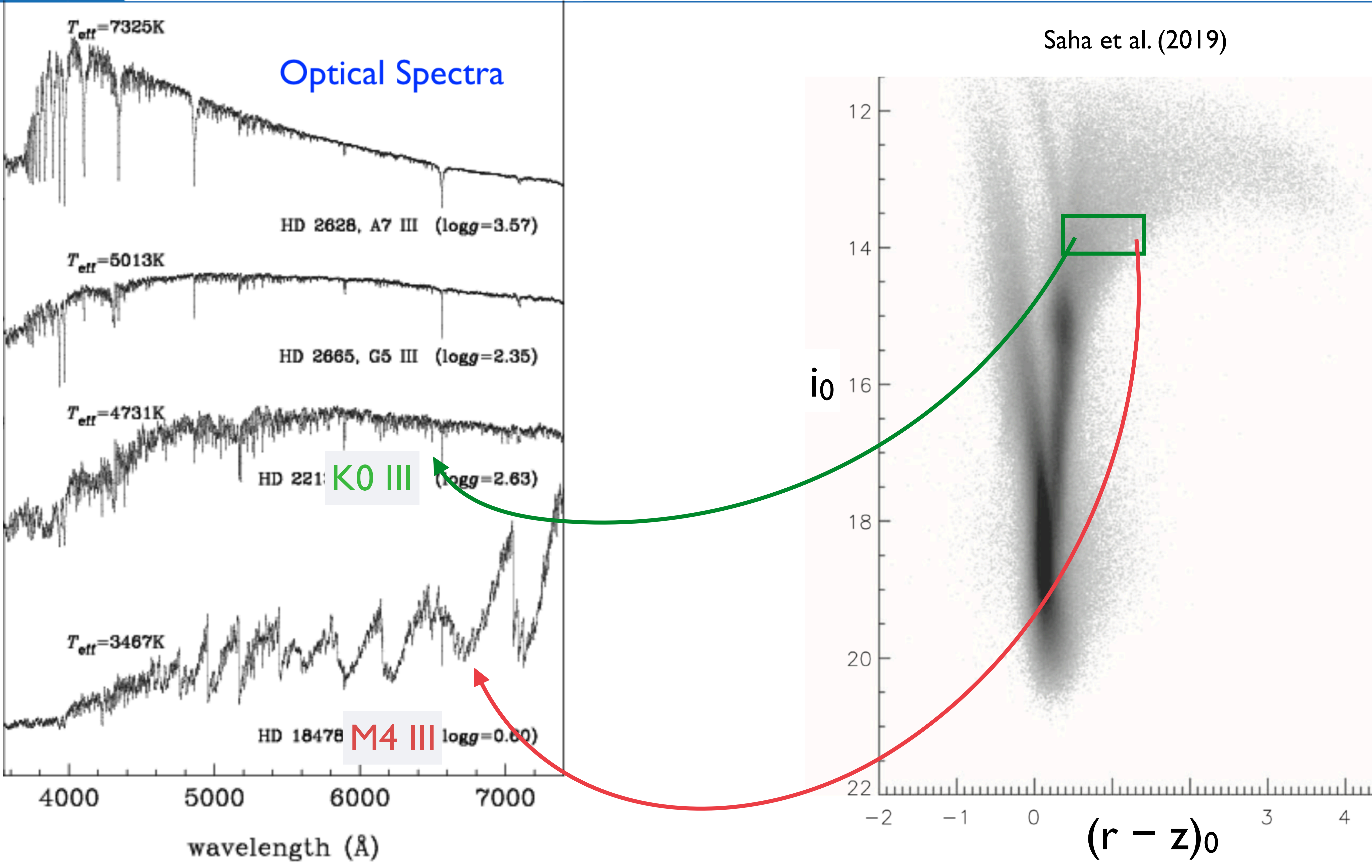
In order to derive the Metallicity Distribution Function (MDF) of a SP it is necessary to select a target box that includes stars of all the metallicities present in the system.

One should also make sure that targets are ~ evenly distributed within the box.



Saha et al. (2019)

The iron distribution of a complex stellar population



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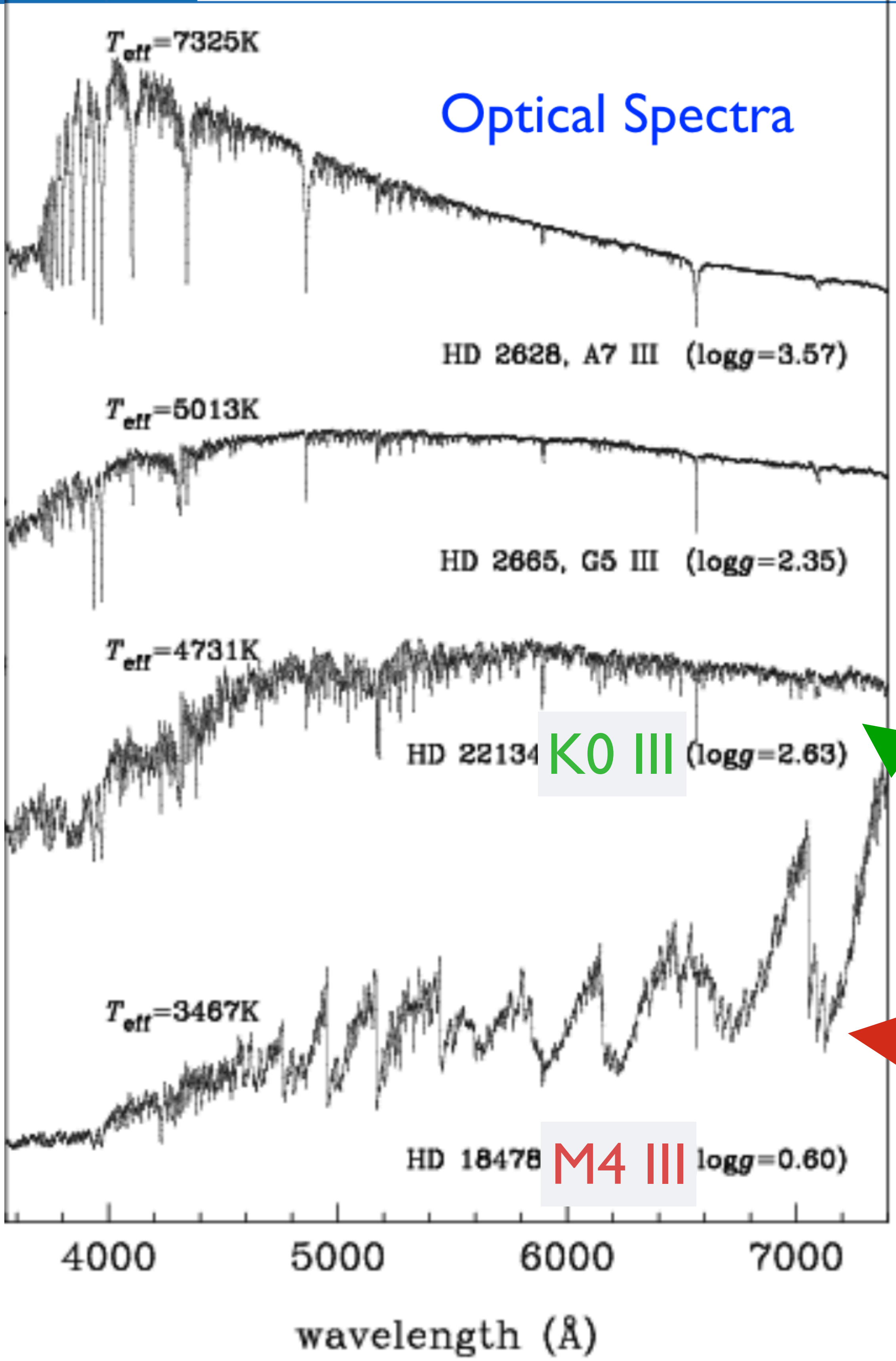

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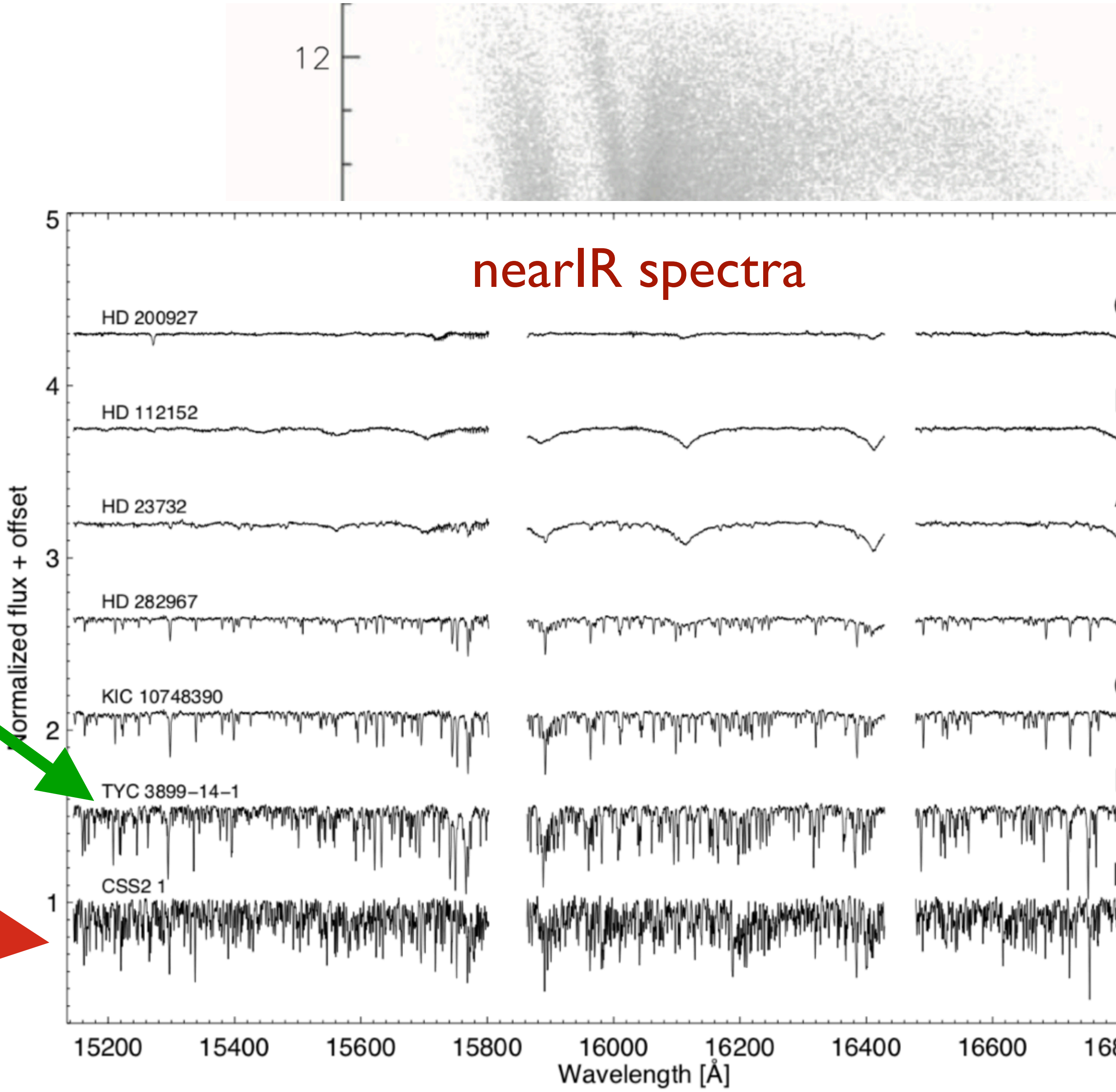
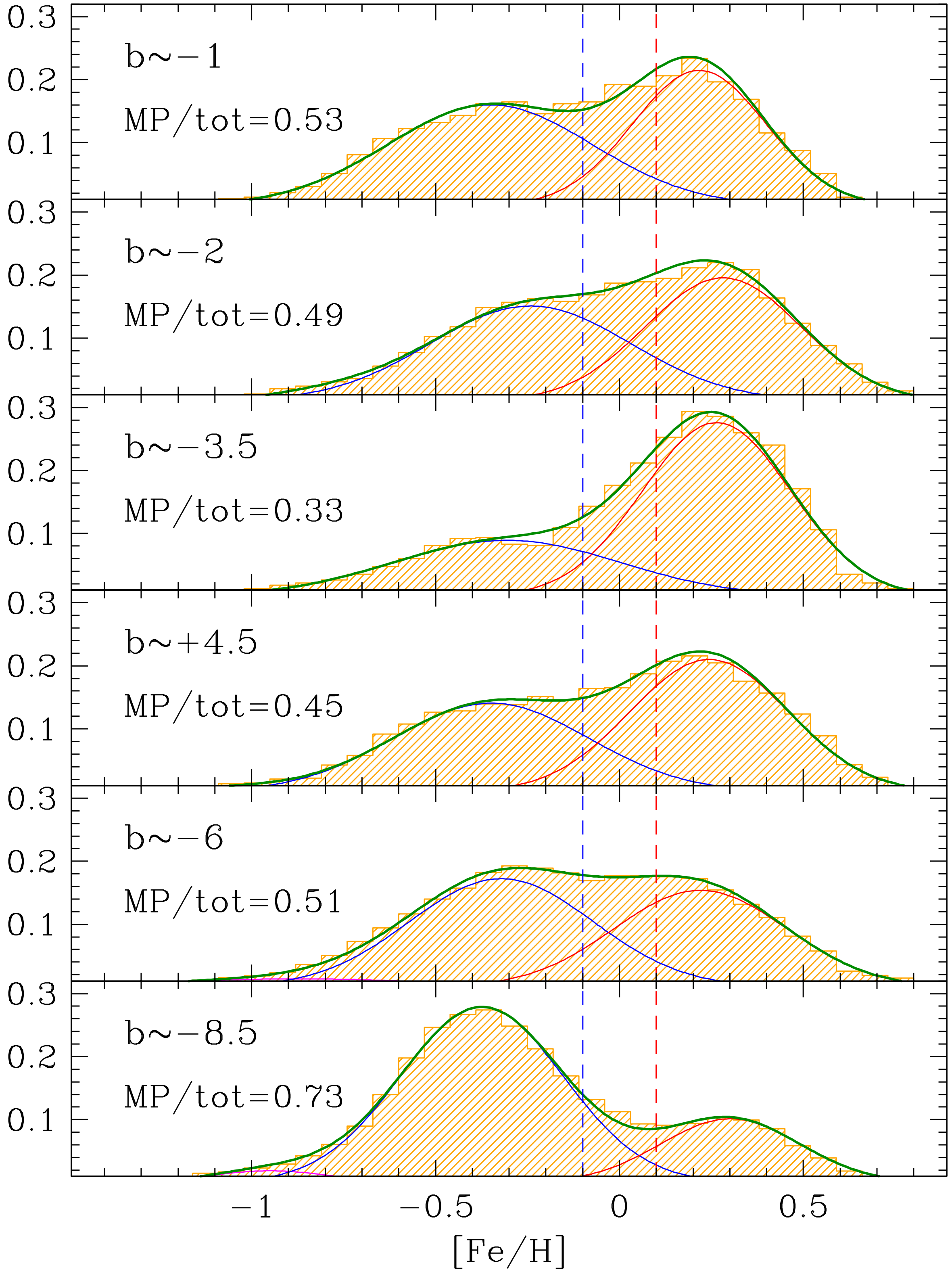


FIG. 6.— An image showing continuum normalized APC spectra as a function of stellar spectral type. The earlier sp

The Metallicity Distribution of the Galactic bulge

GIBS: MZ et al. (2017)

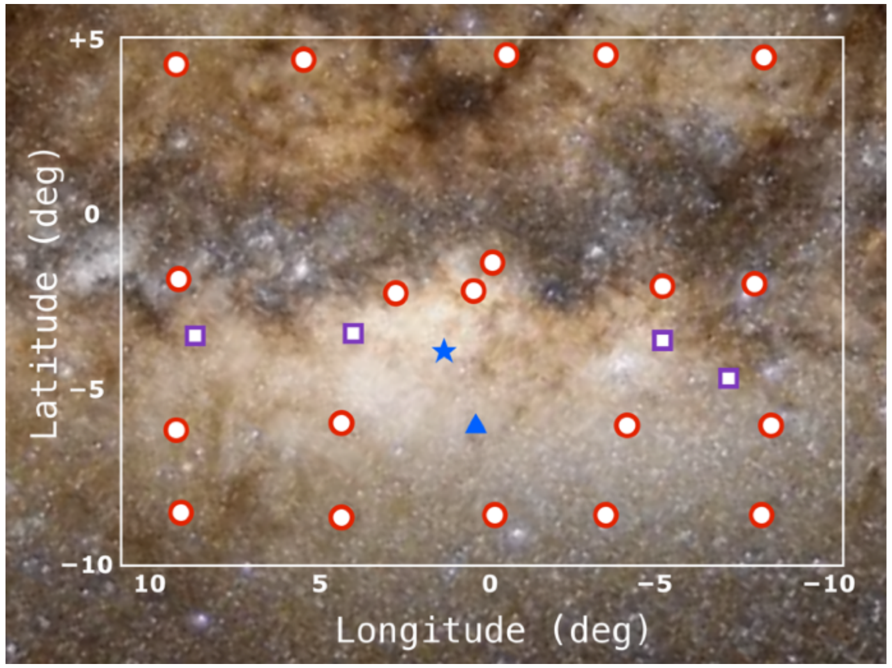


inner

outer

GaiaESO:
Rojas-Arriagada et al. (2014, 2017)

ARGOS:
Ness et al. (2013)



The Metallicity Distribution of the Galactic bulge

MUSE @ VLT

2 hours exposure 1500 stars