# Line Blanketing and Line Veiling

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## 1. Introduction

Stars can be approximated reasonably well by perfect black bodies. The dense gas and plasma in a star is an optically thick material that both emits radiation outwards and absorbs radiation from the core, where the photon production occurs. This balance of energy results in thermodynamic equilibrium of the optically thick material, making it nearly a black body. This black body radiation produces the ”continuum” level of radiation that we see in stellar spectra. Deviations from pure black body-like radiation comes from characteristics of the gas that makes up the stellar atmosphere. These deviations can result in absorption and emission lines. Additionally, further complications arise when we consider how intervening material can affect the height of emission lines and the depth of absorption lines. Therefore we will explore two of these deviations from black body radiation in stellar spectra in Sections 2 and 3. First, we will discuss absorption lines, as they are the common deviation that we're interested here.

### 1.1. Absorption Lines

Absorption and emission of photons by a medium depends on the properties of the medium. If there is material that has a high absorption coefficient at a certain frequency, then the photons with that frequency will be absorbed by that material. By the radiative transfer equation (1), for a high value of $\alpha_\nu$ and a constant or negligible value of $j_\nu$, $\frac{dI_\nu}{ds}$ will decrease and there will be an absorption line at that frequency, $\nu$.

$$\frac{dI_\nu}{ds} = -\alpha_\nu I_\nu + j_\nu \tag{1}$$

Absorption lines are used frequently in many aspects of astronomy and space physics to understand systems of observation. They are often used to determine chemical compositions by determining what materials are causing the absorption lines at certain frequencies. They can be used to measure relative velocities when we can identify a line, whose rest wavelength we know, that is shifted due to the Doppler effect. They can also be used to obtain properties of a star, such as surface gravity determinations determined by the pressure broadening effects when a star's high surface gravity, and thus high density, results in a broadened absorption line. In order to properly interpret absorption lines, it is important to understand how these lines both affect our observations and how they can be affected by processes intermediate between their source and our detector.

## 2. Line Blanketing

### 2.1. Introduction

As photons are emitted from the stellar photosphere, they can interact with the gases of the stellar atmosphere. For metal-rich stars, this can result in extreme observational features, namely absorption lines resulting from photons of certain wavelengths being absorbed by metallic atoms and molecules. Because of the diversity and multitude of metal species in some stellar atmospheres, there can be large portions of the stellar spectrum that contain these absorption lines. This can result in line blanketing, where the lines blend together and effectively reduce the continuum level of the stellar photosphere. See Figure 1.

Milne (1928) was the first to use the term ”blanketing” when referring to this problem. He referred to the metal-rich atmosphere producing these lines as the ”reversing-layer” where the continuum would be ”darkened” by absorption lines. Thus it can easily be said that this is not a new problem in astrophysics. The abundance of lines resulting from metals makes it difficult to understand observationally and difficult to model due to computationally extensive methods needed.

### 2.2. Derivations

As discussed in Section 1.1, absorption lines arise when materials in the stellar atmosphere absorb photons of particular frequencies. To understand why this results in a dip in the intensity or flux at that frequency, we can also think of it in terms of optical depth. Say that a specific ”metal” molecule ($H_2O$ for instance) which forms at a radius of $0.9R_\star$ (again, for instance), absorbs photons with frequency $\nu_{H_2O}$. The optical depth, $\tau_{\nu H_2O}$, is given by integrating $d\tau_{\nu_{H_2O}} = \alpha_{\nu_{H_2O}} ds$ from some $s_0$ to s:

$$\tau_{\nu_{H_2O}}(s) = \int_{s_0}^{s} \alpha_{\nu_{H_2O}}(s')ds'. \tag{2}$$

The only region where this $\alpha_{\nu_{H_2O}}$ is applicable is where water molecules can form and survive, which we've said is from $0.9R_\star$ to the surface, $R_\star$. This means that we can reach a $\tau_{\nu_{H_2O}}$=1 at $0.9R_\star$. If we ignore coronal heating and assume hydrostatic equilibrium, the temperature

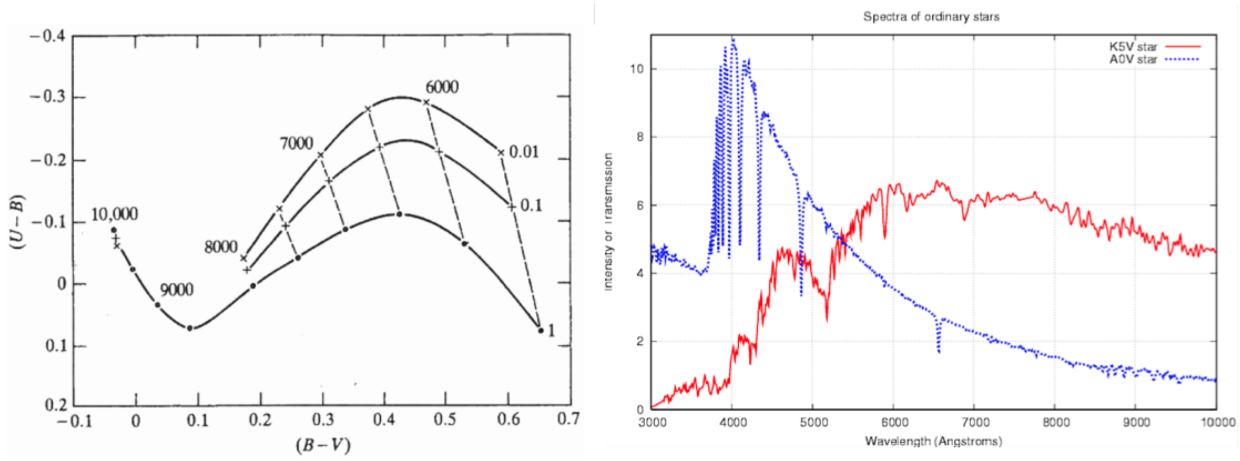

Fig. 1.— Right: Figure from Mihalas & Binney (1981), showing the effects of line blanketing. Solid points show theoretical solar (U-B) and (B-V) colors for different effective temperatures. The plus signs are 0.1 $Z_\odot$ and the crosses are 0.01 $Z_\odot$. The dashed lines show how line blanketing will affect the colors, namely making them redder. Left: Example spectra of a hot, early-type star (blue) and a cool, late-type star (red). The cooler star lacks a clear continuum due to the blending of the many absorption lines (AstroBetter).

of a star decreases with radius as

$$\frac{dT}{dr} = -\frac{3}{4ac}\frac{\kappa\rho}{T^3}\frac{F}{4\pi r^2} \tag{3}$$

from Prialnik (2010) which we can with use boundary conditions and Taylor expansion to derive a temperature profile for the star. The important aspect here is that the temperature decreases with radius. Thus when $\tau_{\nu_{H_2O}}$=1 at $0.9R_\star$, the temperature is cooler than that of the continuum core, *so the line is probing a cooler region of the star and we see an absorption line down to what the continuum would be at that temperature.*

In these cool stellar atmospheres, the abundance of complex metal molecules can mean that many, many lines form and begin to overlap and blend. This is when we see line blanketing diminishing the stellar continuum.

### 2.3. Implications

Line blanketing can make it difficult to know precisely what lines are being observed in cool stellar atmospheres and how deep those lines are (it's difficult to tell where the ”top” of the line is when there is no continuum to use as a baseline level). Current work often requires high-resolution spectroscopy to observe as many lines as possible and the use of extensive stellar modeling that includes the long list of molecular lines that can form in cool atmospheres.

# 3. Line Veiling

## 3.1. Introduction

If we consider a cool star that has absorption lines as discussed for line blanketing (and less extreme cases), then line veiling is the ”shallowing” (veiling) of those absorption lines due to additional continuum sources in the system. For example, hot dust near the star can add this extra continuum source as could a hot shocked region on the stellar photosphere as material accretes onto the central star; we will discuss only the former here (Hartigan et al. 1989). This can occur in observations of protoplanetary disks where dust orbits the star at a close orbital radius. As discussed in Section 2, molecules can form in cool stellar atmospheres, creating absorption lines in the observed spectra. Adding hot dust to the system, adds another continuum source. The dust captures stellar radiation and re-emits it at longer wavelengths as a rough black body. This dust continuum will be observed with the stellar spectra and stellar absorption lines will be ”shallowed,” relative to a system without dust; see Figure 2.

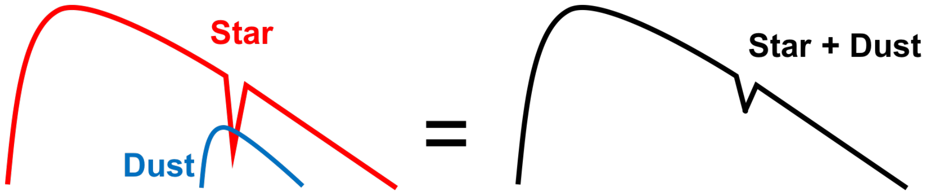

Fig. 2.— A schematic view of how hot dust orbiting a star can add a continuum source that makes stellar absorption lines appear ”shallowed,” relative to what they would otherwise be observed as.

## 3.2. Implications

If we understand veiling and how it affects our observations, we can use it to characterize how much hot dust exists in the regions close to the star. This is important in protoplanetary disks as newly formed planets can impact the dust distributions in these systems and dust can also act as a shield for gas molecules that would otherwise be dissociated by stellar radiation.

For a given system, if we know the spectral type of the central star and have a spectral standard (an observation of a star of the same spectral type but with no dust), we can subtract the spectral standard from the observed system to get what is added by the dust, see Figure 3. When we fit the dust continuum with a blackbody, that can tell us how hot the dust is and we can infer from this where the dust is located in the disk. This method requires a proper characterization of spectral standards, especially if they are cool stars with the line blanketing complexities discussed in Section 2. Without an understanding of absorption line causes and depths, this work would not be possible.

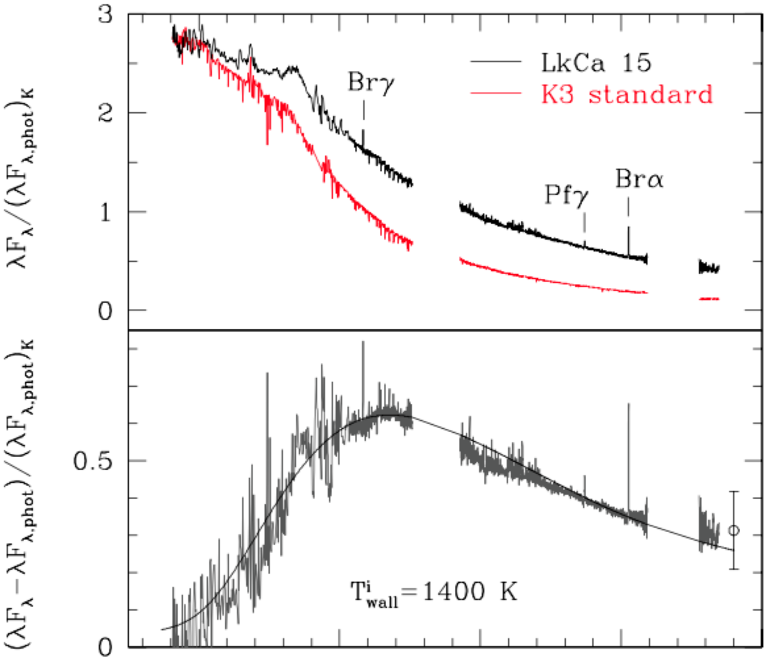

Fig. 3.— Example of a system where we can characterize the dust content around this young star, LkCa 15. Top: the spectra of LkCa 15 (black) and a spectral standard of the same spectral type (red). In a system without dust (the standard), the absorption lines are deeper than in a system with an added dust continuum (LkCa 15). Bottom: the residual when we subtract the standard from the observation of LkCa 15, which we can fit a 1400 K blackbody curve to for the hot dust continuum. Figure from Espaillat et al. (2010).

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