A New Approach to Synthetic Stellar Spectra: The STARDIS Radiative Transfer Code

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STARDIS is an extension of the TARDIS radiative transfer code (which generates synthetic spectra for supernovae) for generating stellar spectra. These spectra can be compared to observations to determine key facts about the stars we see, such as their temperature or elemental composition.

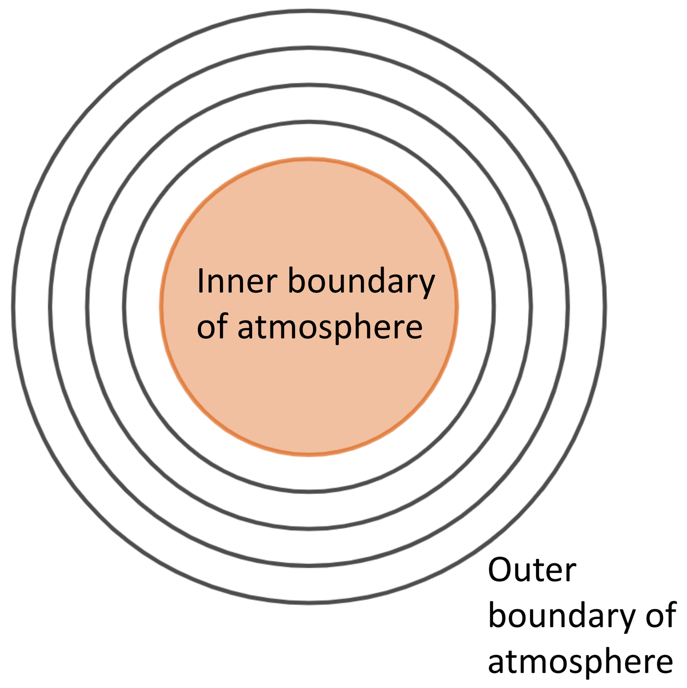
The code is designed to give researchers as many options as possible to generate spectra, and it can incorporate new research on atomic physics and stellar atmospheres without any changes to the code through reading atomic or opacity data files. STARDIS is unique in that it is open science, which will allow it to be used and developed across the astrophysics community.

Scan to check out the code!

The Physics of STARDIS

Model and Plasma

STARDIS breaks down the stellar atmosphere into spherical shells as shown below and approximates that the plasma state is uniform throughout each shell. We rely on the MARCS code, a code that generates models of stellar atmospheres, to determine the temperatures, elemental abundances, and densities in each shell. The existing TARDIS plasma infrastructure determines the rest of the plasma state, namely the excitation and ionization properties and transition rates.

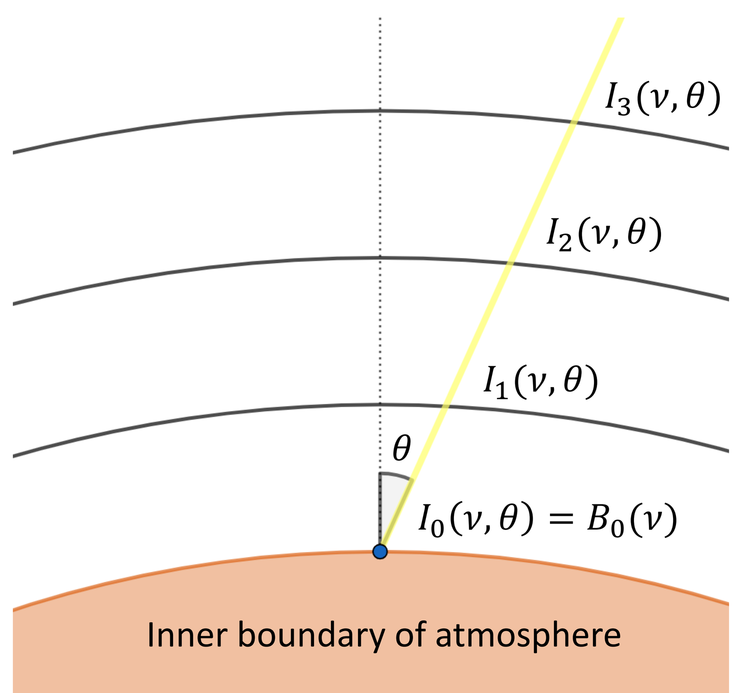


Opacities

To determine an output spectrum, we need to understand how photons of light move through the atmosphere and what interactions they experience. Opacity is a measure of how likely it is that light will be scattered or absorbed by some material, like the stellar plasma, per unit distance it travels. This is contributed to by several mechanisms, which are described to the right.

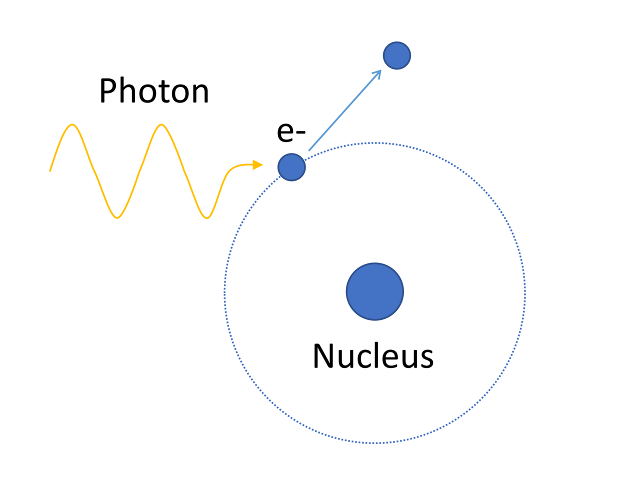
Transport

Finally, we use the opacity information to trace beams of light coming from the photosphere at different angles and frequencies to find the final intensity. Light comes out of the photosphere in a blackbody distribution $B_0(\nu)$. At each shell boundary, we compute the intensity of the beam based on the opacity in the shell it traveled through. The intensity at the outer boundary of the atmosphere is then integrated over every angle to give us the flux density, which is the desired spectrum.

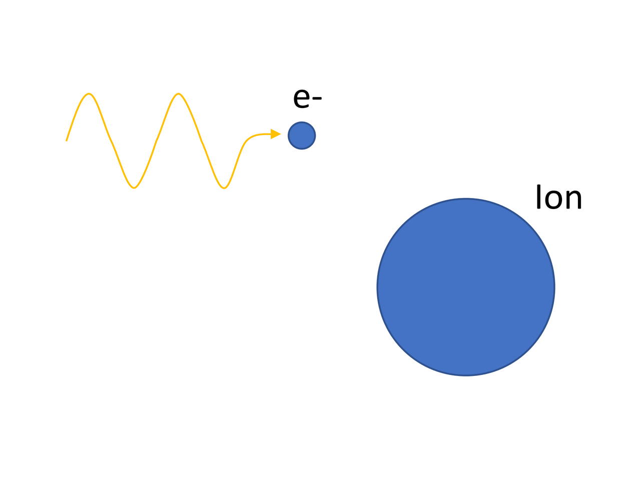


Light-Matter Interactions

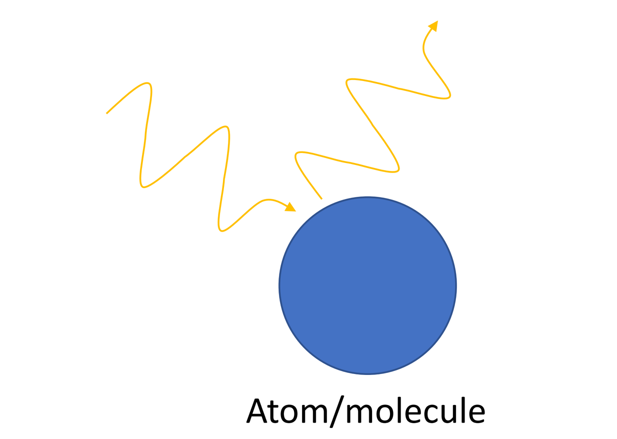
Bound-free absorption:



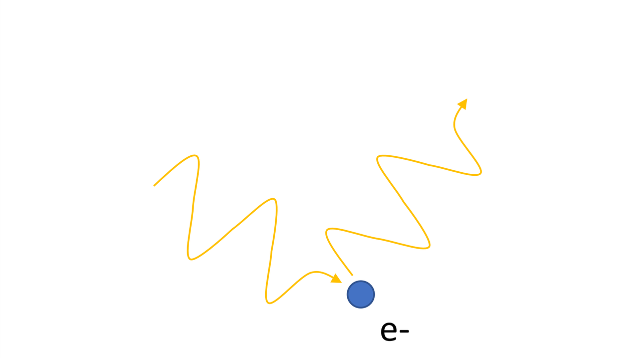
Free-free absorption:



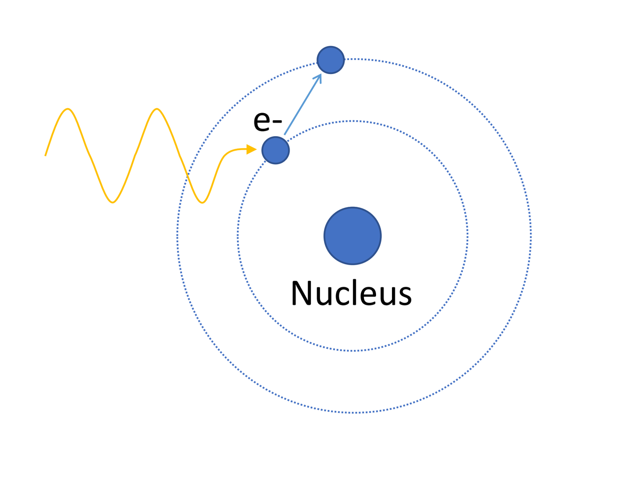
Rayleigh scattering:



Electron scattering:



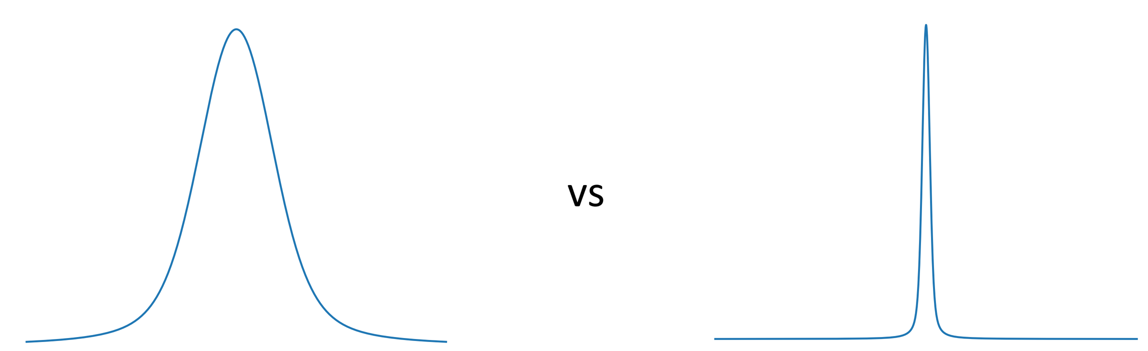
Line interaction:



The first four of these interactions are *continuum interactions*, as they affect light at a large range of frequencies. Line interactions, on the other hand, only occur with light around specific frequencies, corresponding to the electron's jump in energy. These are called *resonant frequencies*.

Line Broadening

Line interaction opacity does not occur only at the exact resonant frequencies; lines are broadened to reach other nearby frequencies. Thus, the line interaction opacity is the total line opacity times the *line profile* which describes the broadening.

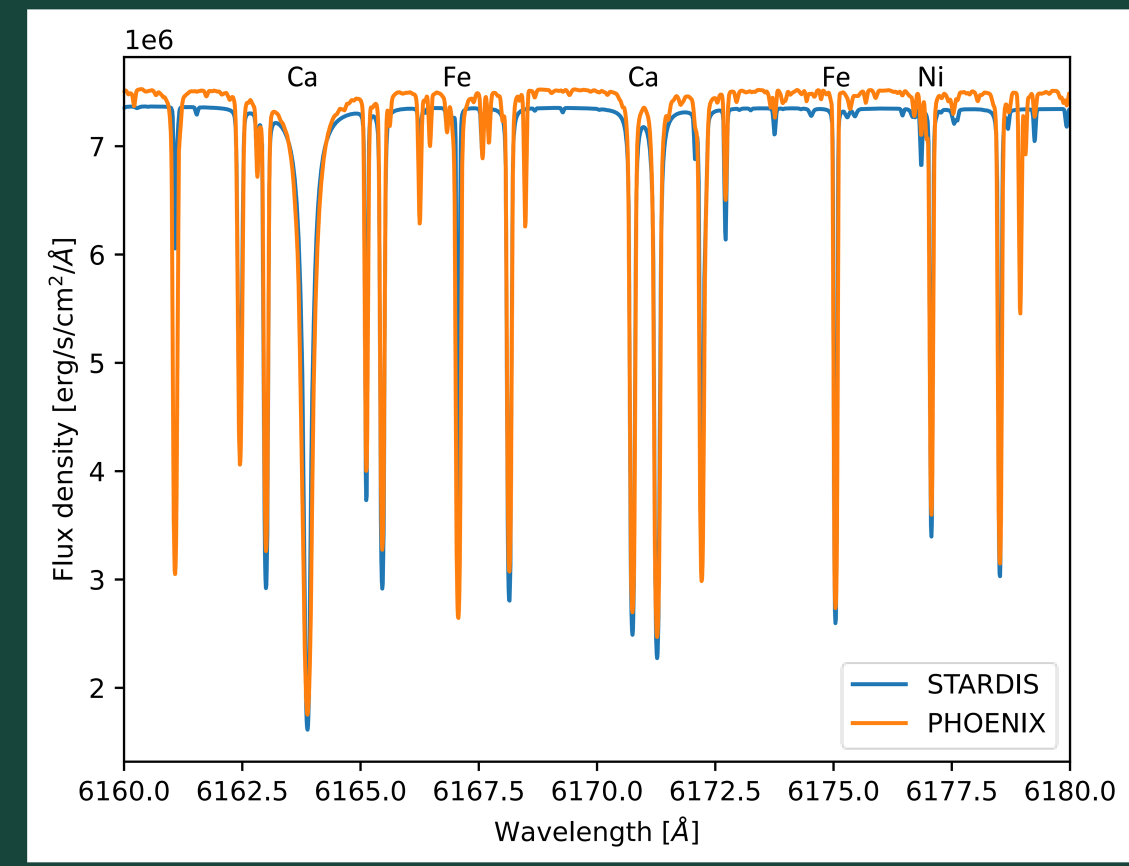


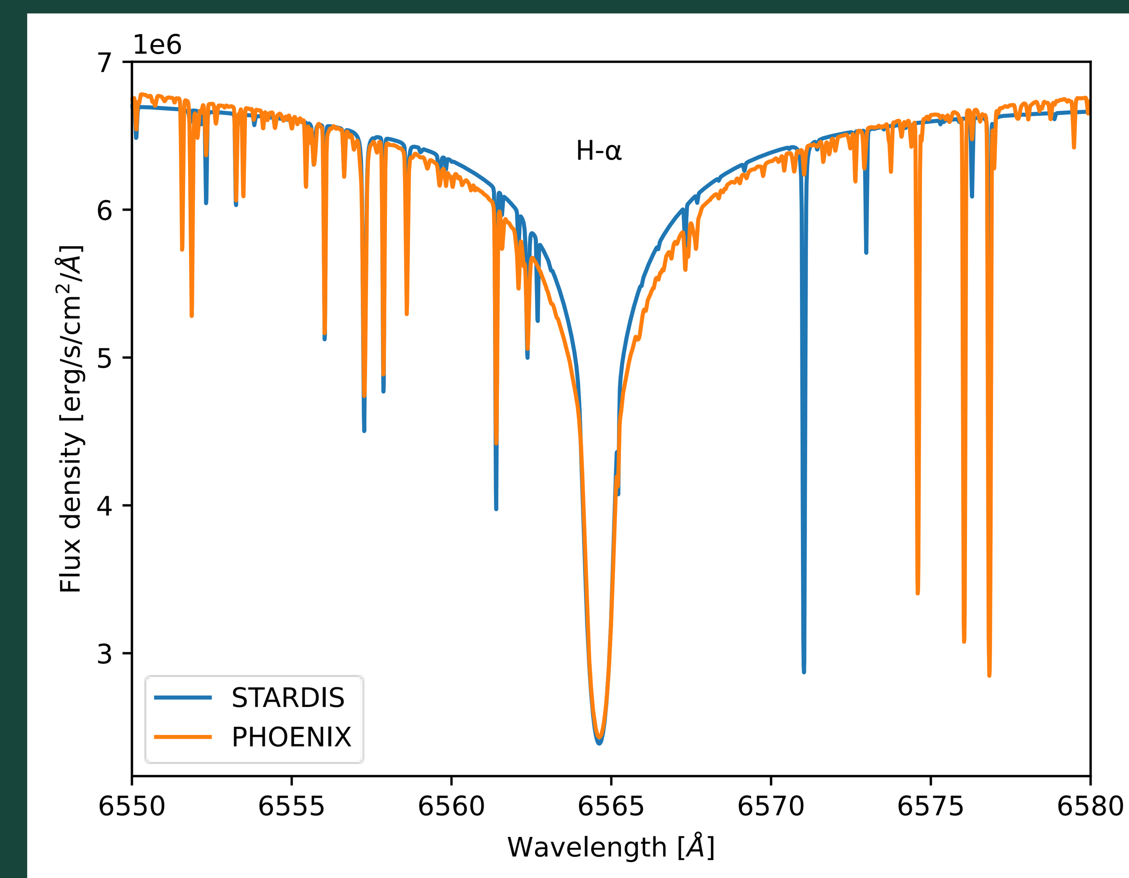
Above are examples of line profiles, the left being very broadened and the right being less broadened. Both are centered at the resonant frequency. The line profile is a Voigt distribution which uses the following parameters for determining how much the line is broadened:

- The Einstein coefficient, which describes the line's natural acceptance of non-resonant frequencies.
- The doppler width, which is the range of frequencies that are red- or blueshifted to be the resonant frequency due to the rapid movement of ions in the plasma.
- The collisional broadening parameter, describing the effects of forces between ions, or between ions and electrons, which shift the resonant frequency.

Solar Spectra Examples

We compare STARDIS solar spectra to those produced by PHOENIX, a closed-source radiative transfer code:





Discussion

- Overall, STARDIS can successfully reproduce the solar spectrum in the visible range.
- Minor corrections must be made to the treatment of continuum opacity.
- We are likely using insufficient atomic data as there are many lines present in PHOENIX but not STARDIS.
- The line broadening is nearly perfect, but resonance broadening is needed for the H-α line.
- STARDIS is only tested for class G stars, so more shortcomings could be revealed when modeling other stars.

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