AST6245: Radiative Processes and Stellar atmospheres
Fall 2023
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Final Project Assignment - Part III
(due December 13, 2023)

The aim of this final project is to explore the physical properties of an optically thin gas in a plane-parallel stellar atmosphere with a gradient in T, ρ, and P as a function of atmospheric height, and then code up various fundamental formulae that are at the base of any radiative transfer problem and level populations exercise you will encounter in your classwork or research.

For stars, the photons are generated in the optically thick interior (the nuclear burning core for most stars, excepting pre-main sequence objects, white dwarfs, and neutron stars). These photons propogate through the $\tau >> 1$ stellar interior, and after the order of millions of years, have their first chance to escape at the bottom of the stellar atmosphere, defined by $\tau = 1$. However, the gas remaining at the $\tau < 1$ region is the place where all of our diagnostics about the star are imprinted on the Planck function that forms the input spectrum for the radiative transfer, specified by $T = T(\tau = 1)$. Note that this is not the same T as T_{eff}, which is defined as $T = T(\tau = 2/3)$.

The project is divided into three parts, exploring a realistic model atmosphere of the Sun and using it to diagnose the Solar spectrum. In this assignment, you will now tackle the final Part III.

Please turn in a report that outlines the logic of your foray into understanding the stellar atmosphere problem, along with the requested figures including appropriately numbered (according to the corresponding part), labeled, clear and detailed figures and figure captions. ***This is a continuation of the same project. Therefore, do not start another report. Simply, resubmit your full project up until this point including your previous answers to Part I and Part II, as well as your new answers to Part III, clearly distinguishing between the two (Remember this is ONE full project) .*** *Making good descriptive figures with captions and writing solid abstracts is one of the most important skills you can develop while in graduate school. Please hand in your project report typed along with tables, figures, and any other relevant materials. Utilizing a peer-review paper style journal template for your report such as ApJ or MNRAS will count for extra credit. Neatness and organization count so please pay attention to details. DO NOT turn in your Jupyter Notebooks.*

Part III- Finally, we come to the climax of our spectral lines exercise! With the various functions you have written, you are now able to compute and plot stellar spectral line profiles by combining the code you have for the solution of the radiative transfer equation, with the code for α_λ and τ_λ, including broadening.

s. Write a sequence of your functions that computes line profiles in the Schuster-Schwarzschild two-layer approximation that we have adopted. Hint: start by coding the emergent intensity in Equation 1, using τ computed from the extinction coefficient α_λ in Equation 2, and take $T_l = 5700$ K, $T_u = 4200$ K, $a = 0.1$, $\lambda = 5000$Å. These values are good approximations for the solar photosphere, as seen in the optical part of the spectrum.

t. Plot a profile of I against u for $\tau(0) = 1$. Use the dimensionless $u = \lambda - \lambda_0/\Delta\lambda$ units for the wavelength scale so that you don't have to evaluate the Doppler width $\Delta\lambda_D$.

u. Finally, compare your line profile emergent intensity for the Na I D1 line in the Solar spectrum. How do they compare? Was there another source of opacity that should have been taken into account in our model? Explain.

v. OPTIONAL (EXTRA POINTS): If you plot your profiles in terms of I_λ/I_{cont}, you are scaling to the local continuum and can thus measure the line equivalent width, defined as $W_\lambda = \int (1 - I_\lambda/I_{cont}) d\lambda$. This is an empirical measure of the strength of a spectral line. You should calculate the equivalent width of your line by performing a direct integration, though in practice (i.e. with real data) this is done by fitting a function such as a Gaussian or Voigt profile to the generally somewhat noisy data. Make this profile integration a function, e.g. `cog`. You want a large range in u, so as to capture the entire line all the way out to where it meets the continuum, but also a fairly fine spacing so as to capture the behavior near line center. Measure the equivalent width of the Na I D1 and D2 lines.