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Astrophysical Implications from the Lab: Advances in Atomic Theory and the Effects on White Dwarf Model Atmospheres

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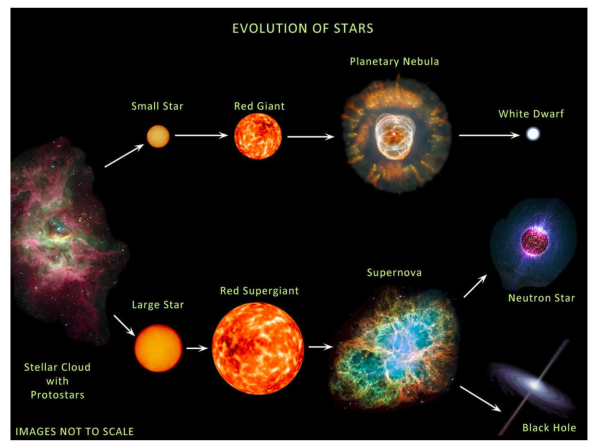
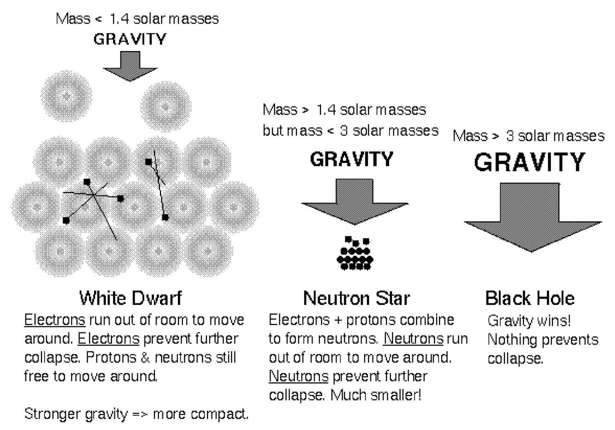
Motivation

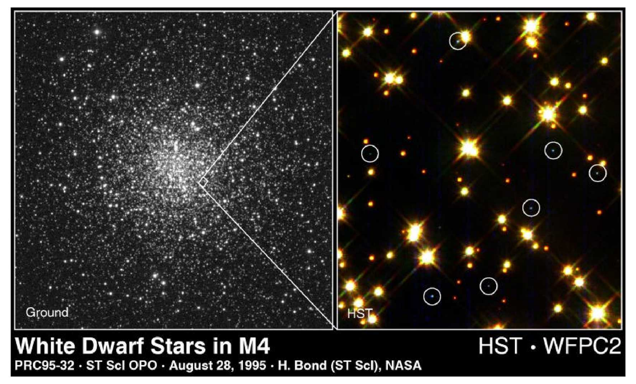
- White dwarfs are the evolutionary end points of 98% of all stars.
- They provide essential clues on a wide spectrum of interesting astrophysical problems.



Physics of Degenerate Matter



Age and History of the Universe

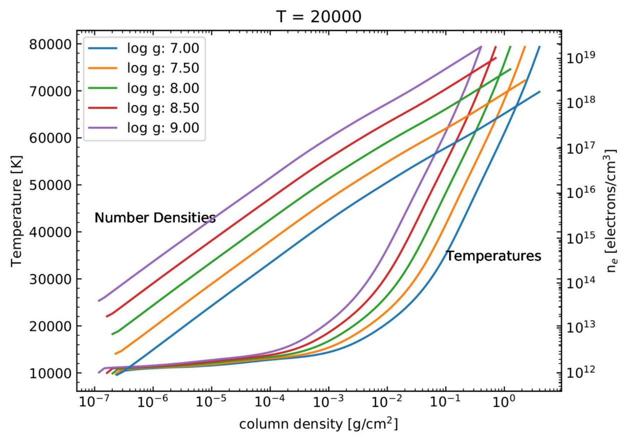


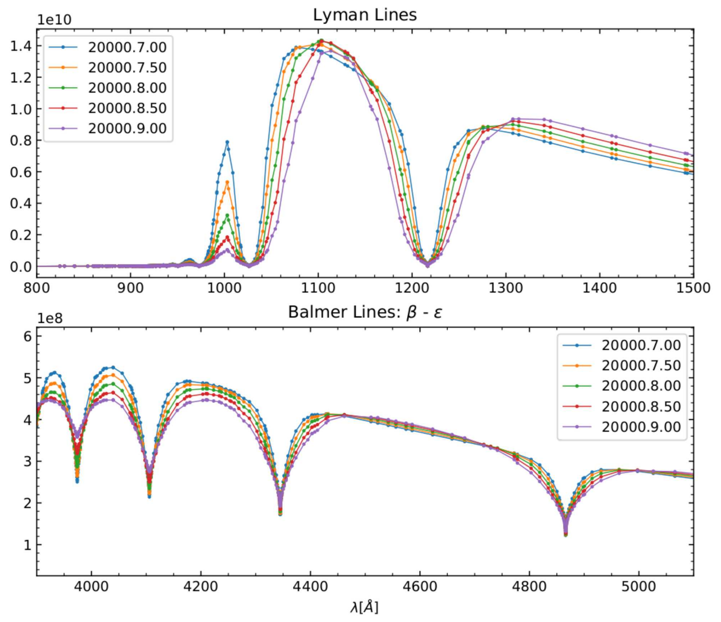
Problem

Properties of White Dwarfs are most commonly determined by relying on the sensitivity of features in the emergent stellar spectrum to changes in the effective temperature and gravity of the star. However, there are multiple pieces of evidence suggesting this method is inaccurate.

White Dwarf Model Construction

1. Plane parallel horizontally homogeneous stratified layers
2. Hydrostatic/radiative equilibrium
3. Radiative transfer equations
   i) solved for each distinct layer of atmosphere
   ii) requires line profiles for each atomic transition at T and N_e spanned by atmosphere

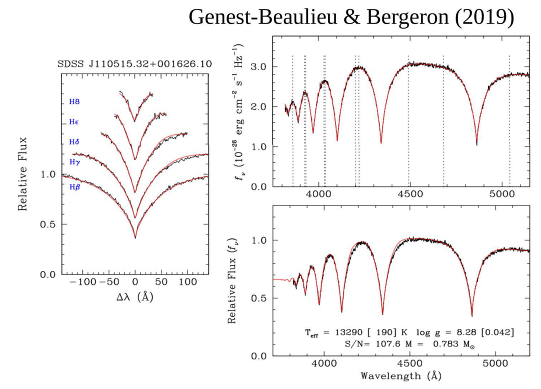




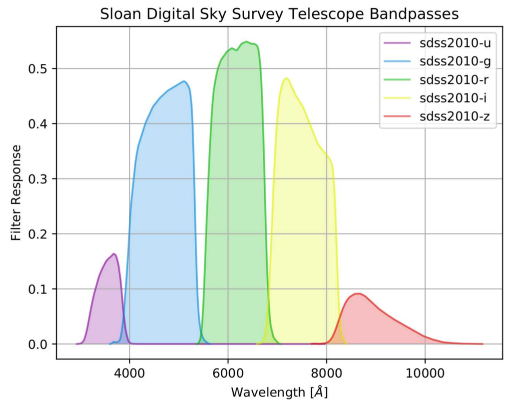
Model Dependent Mass Determinations

The spectroscopic and photometric methods are the two most commonly used mass determination techniques for White Dwarfs; both rely on model atmospheres. In spectral fitting, the widths of the lines in the observed spectra are fit to a grid of modeled spectra. In the photometric method, the observed brightness of the star in a particular frequency range (bandpass) is compared to that of the modeled spectrum.

Spectral Fitting Method

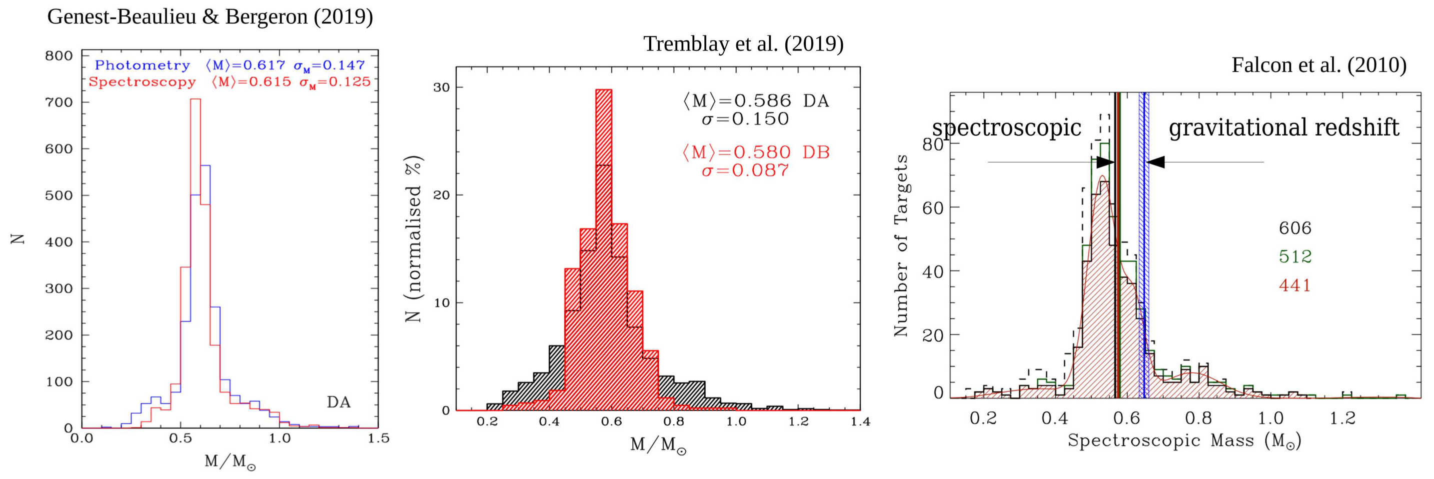


Photometric Method



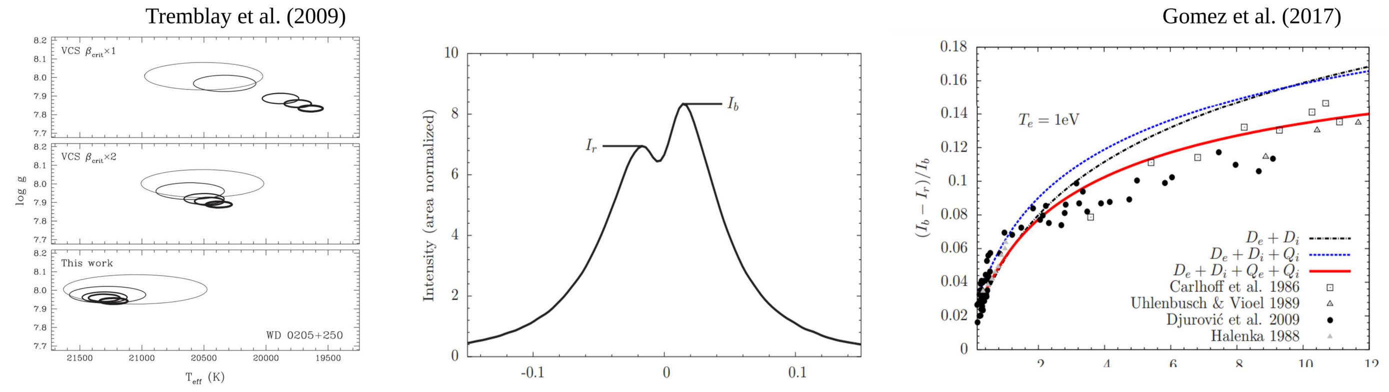
Significant Differences in Mean Mass

There is an unresolved set of discrepancies in mean mass determinations made using different techniques.
1. Spectroscopic and GR mean mass measurements differ by almost 11%.
2. Photometric mean mass measurements using two different sets of photometric observations differ by over 5%.



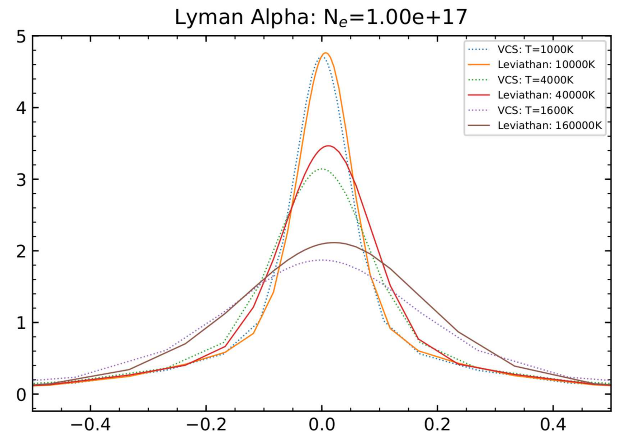
Hypothesis: Line Shape Theory is Inaccurate

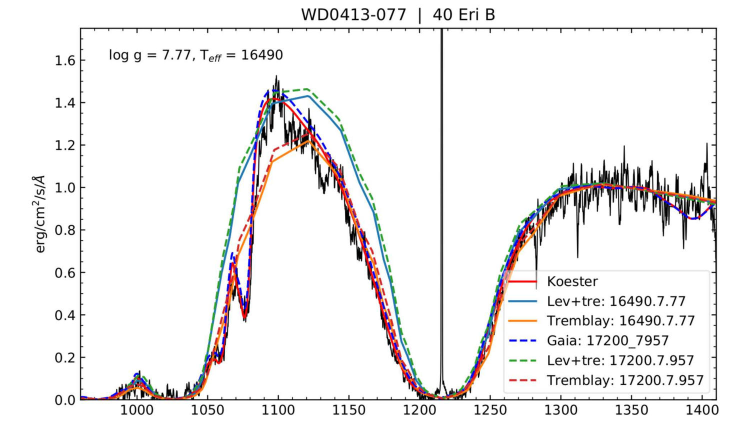
- The accuracy of spectroscopic fits performed using individual lines decreases with increasing principle quantum number. Stark effect energy level perturbations increase with higher n suggesting Stark broadening may be inaccurately treated.
- Recently, Stark broadening in line shape calculations has been refined by including higher order multipole moments in the Coulomb interaction and electron exchange which have previously been neglected. The changes in the line profiles become larger with increasing density in a regime relevant to WDs.



Incorporating New Line Shape Calculations In White Dwarf Model Atmospheres

We use the Leviathan and Xenomorph line shape codes to generate a grid of line profiles. We input these profiles into TLUSTY, a stellar model atmosphere code and generate a grid of model atmospheres and associated stellar spectra.





We notice differences in the wings of the profiles which affect the final emergent stellar spectrum more than we anticipated. Additionally, whereas previous theories performed their calculations in wavelength space, we perform ours in frequency which properly introduces an asymmetry in the profiles. The differences in the line profiles manifest in the emergent stellar spectrum, which will modify fundamental parameter determinations.

Next Steps

- Close examination of the entire grid of line profiles revealed portions of the code which turned out to be insufficiently precise. Necessary modifications are currently being made.
- Poor fits to data using the new models suggest additional pieces of missing physics in the line shape calculations. We are currently investigating the effect of density matrix correlations and additional opacities from the quasi-molecular (H_2 and H_2^+) and H^- transient states.

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