Quality Control of Synthetic Spectra for Sirius A

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Context and Need

Sirius A is a well constrained, A-type star used as a standard for astronomical measurements (Rieke et al. 2023). The parameters of Sirius have been measured with high precision (1%), due to its slow rotation and binary star system partner, Sirius B. The characteristics and parameters of Sirius provide insight into stellar atmospheres and evolution, thanks to the high precision of its parameters. Despite being well constrained, the chemical abundances of Sirius have significant uncertainty. Abundances of the elements found in the atmosphere, assuming local thermodynamic equilibrium (LTE), are known at best to 25%, many uncertain by 200% or more (Landstreet 2011). For lesser constrained stars, this uncertainty can be even greater.

In 1979, Kurucz and Furenlid determined that LTE models would be a good approximation for the atmosphere of Sirius, with the high collision rates between particles that correspond to its high surface gravity. Using this theory, Kurucz and Furenlid constructed a spectral atlas for Sirius A, which compares a high-resolution spectrum to a synthetic spectrum, spanning 3540 Å to 4400 Å.

Task

Comparing a normalized non-LTE Phoenix model (Hauschildt & Baron 1999) to archival data from LBT/PEPSI (Large Binocular Telescope Potsdam Echelle Polarimetric and Spectroscopic Instrument) and VLT/UVES (Very Large Telescope Ultraviolet and Visual Echelle Spectrograph), we have constructed an atlas in the range 3050 Å to 8500 Å, eliminating the LTE assumption for over 500,000 spectral lines. Over 2,000,000 "background" spectral lines remain in LTE.

With the atlas, the accuracy of our model spectrum can be analyzed, comparing it with data taken from LBT/PEPSI and VLT/UVES. Where the model differs from data, we note differences in atomic data values in the model to values from the National Institute of Standards and Technology (NIST).

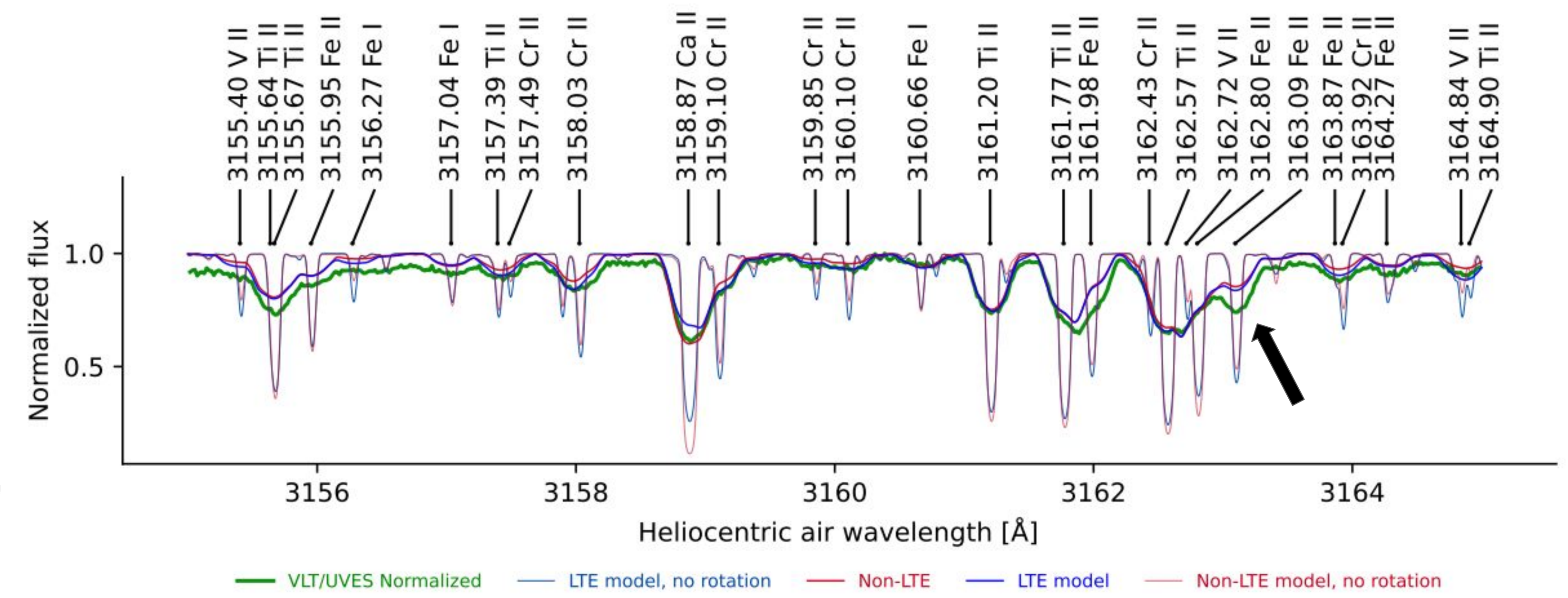

Figure 1: Small section of the atlas showing a problematic non-LTE Fe II line at 3163.09 Å.

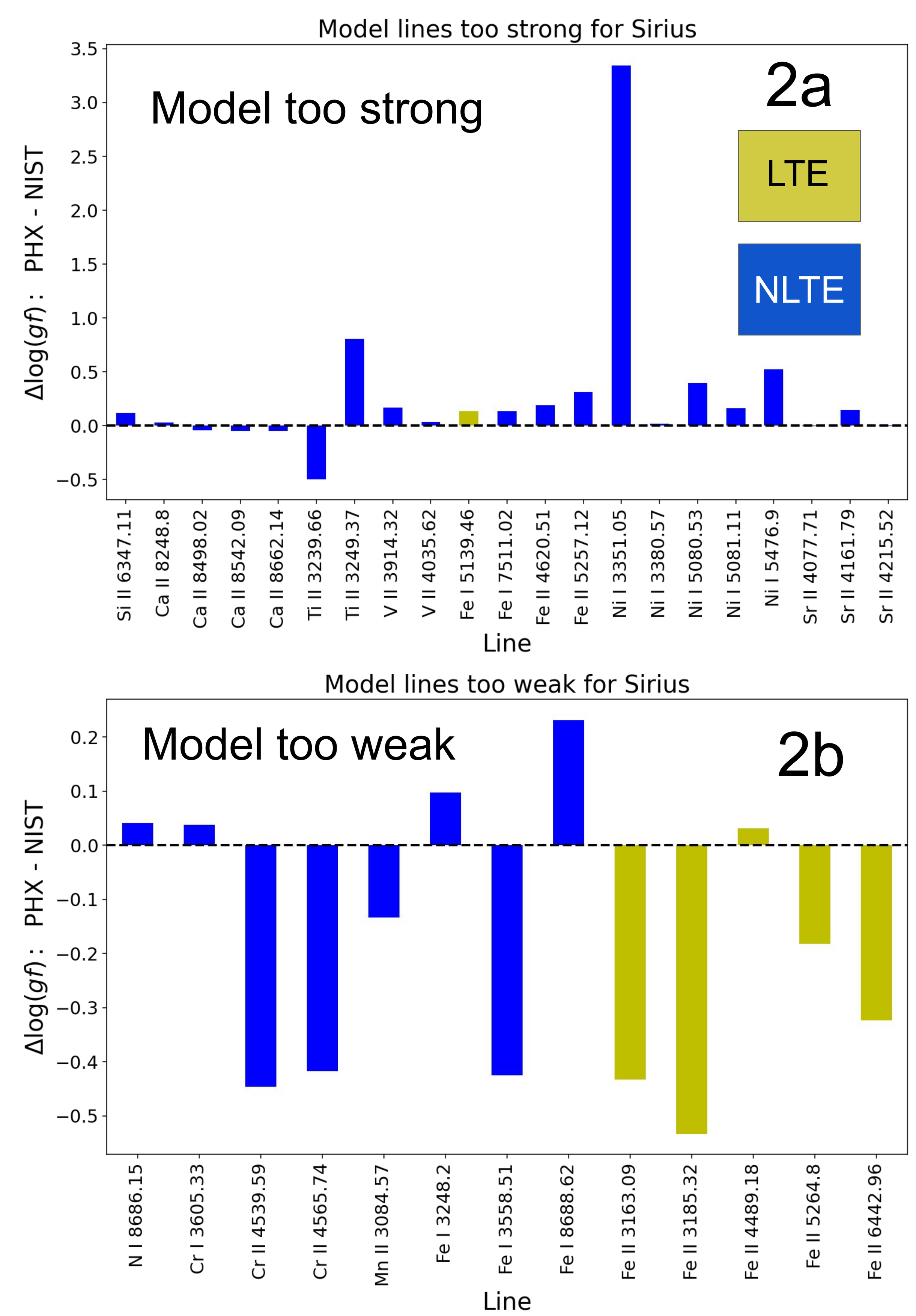

Figure 2a , 2b: Model lines that don't fit the UVES and PEPSI data well, too strong(a), too weak (b). Magnitude of the differences displayed with the loggf values.

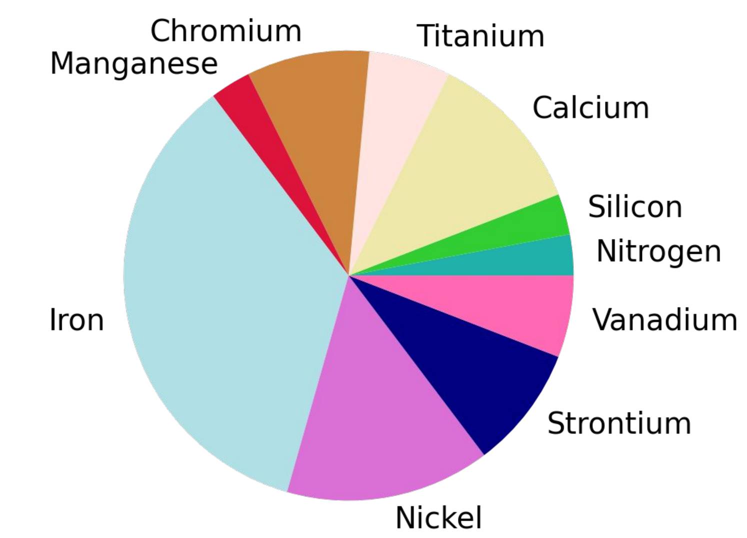

Figure 3: Distribution of elements that show a mismatch to the spectral data from UVES and PEPSI.

Conclusions

Through careful analysis of our model spectrum, we found that less than 1.5% of the total modeled spectral lines don't match to the observed spectra, which includes 87 LTE lines that are improved by using NLTE assumptions. Forty NLTE lines are poorly matched with the observed spectra, which is likely due to inconsistent atomic data in at least 60% of these specific cases.

Perspectives

Our next steps will be to adjust the atomic data values in our model to be more consistent with NIST values, which will allow us to further refine the elemental-abundance values for Sirius A.

References

Sirius A as a photometric standard: see Rieke et al. (2023) in the *Astronomical Journal*, 165, 99.

VLT/UVES spectrum of Sirius: Paranal Observatory Project program, see Bagnulo, S., Jehin, E., Ledoux, C., et al. 2003 in The European Southern Observatory (ESO) *Messenger,* 114, 10.
PEPSI spectrum of Sirius: see K. G. Strassmeier, I. Ilyin, and M. Weber (2018) in *Astronomy & Astrophysics* 612, A45

The original atlas from R. Kurucz and I. Furenlid (1979) in Sample Spectral Atlas for Sirius Special, Report 387. *Smithsonian Astrophysical Observatory*.

General information on the project taken from Aufdenberg, J., Sonnen, K. (2023) in *Expanded Spectral Atlas of Sirius,* Discovery Day 2023.

Chemical abundance uncertainties from Landstreet, J. D. (2011) in *Astronomy & Astrophysics,* 528, A132

Model atmospheres were computed using the Phoenix code, see Hauschildt and Baron (1999) in *Journal of Computational and Applied Mathematics,* 109, 41. Model spectra were normalized using the Python code Rassine from Cretignier et al. (2020) in *Astronomy & Astrophysics*, 640, A42.

Python code development was aided using Jupyter notebooks at **cocalc.com**.
Translation from IDL into Python assisted by ChatGPT (OpenAI. (2023). Mar 14 version, [Large language model].)

National Institute of Standards and Technology atomic data is from Kramida, K., Ralchenko, Y. & Reader, J. and NIST ADS Team, NIST Atomic Spectra Database (ver. 5.10), October 2022.