A novel tool for the spectroscopic inference of fundamental stellar parameters

Chambliss Entry!

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Abstract: We present a novel approach for making accurate and unbiased inferences of fundamental stellar parameters (e.g., effective temperature, surface gravity, metallicity) from spectroscopic observations, with reference to a library of synthetic spectra. The forward-modeling formalism we have developed is generic (easily adaptable to data from any instrument or covering any wavelength range) and modular, in that it can incorporate external prior knowledge or additional data (e.g., broadband photometry) and account for instrumental and non-stellar effects on the spectrum (e.g., parametric treatments of extinction, spots, etc.). We use covariance kernels to account for systematic discrepancies between the observations and the synthetic spectral library, ensuring that issues like uncertainties in atomic or molecular constants do not strongly bias the parameter inferences. In addition to extracting a set of unbiased inferences of the stellar parameters, our modeling approach also "maps" out problematic spectral regions in the synthetic libraries that could be used as a basis for improving the models. As a demonstration, we present some preliminary results from modeling optical spectra of well-characterized exoplanet host stars and nearby pre-main sequence stars. A basic set of adaptable software that performs this modeling approach will be released publicly.

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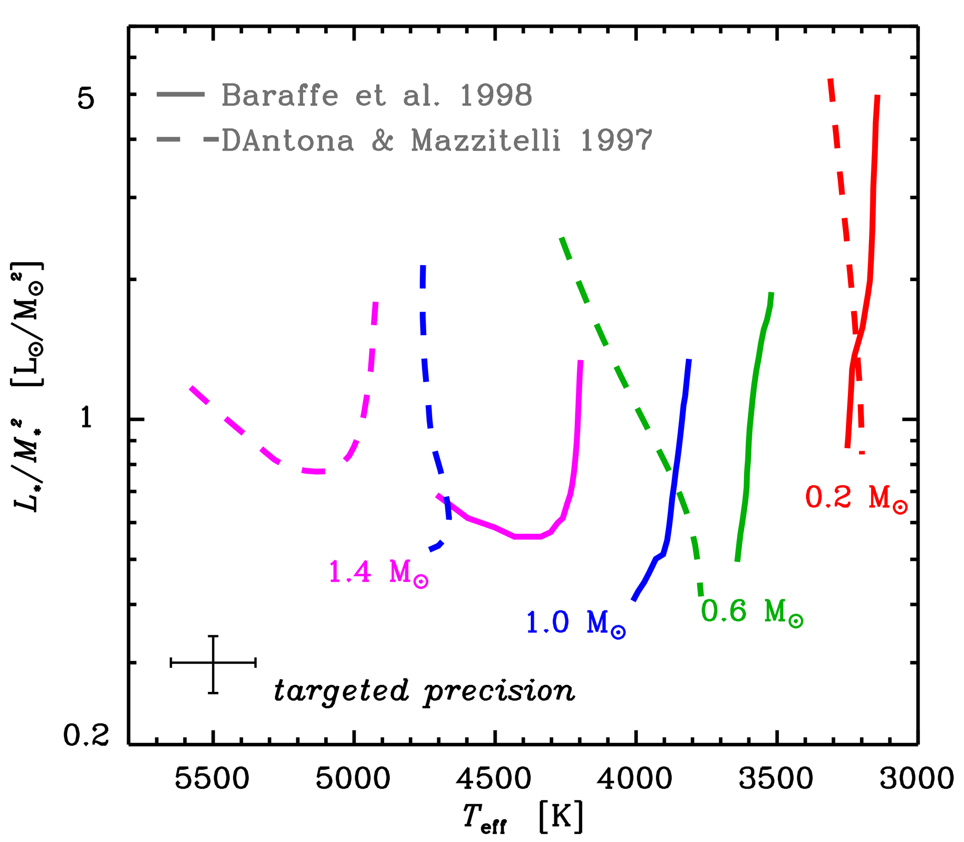
We seek to determine the properties of young, pre-main sequence stars in order to calibrate the earliest stages of stellar evolution.

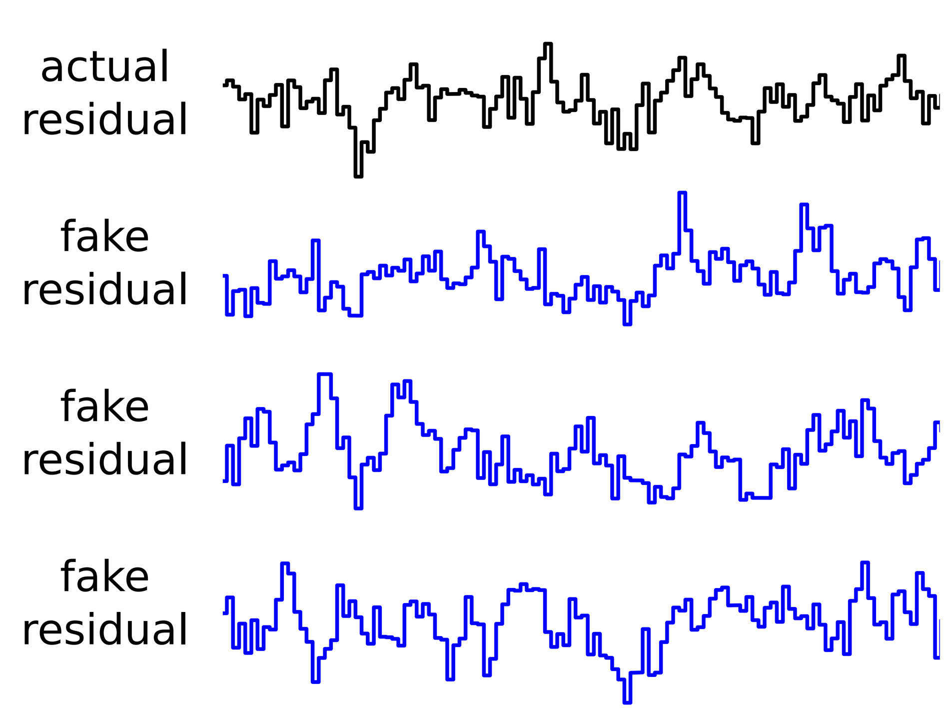
Below: A theoretical HR diagram, showing the how the temperature and luminosity evolution depends on the mass of the star.

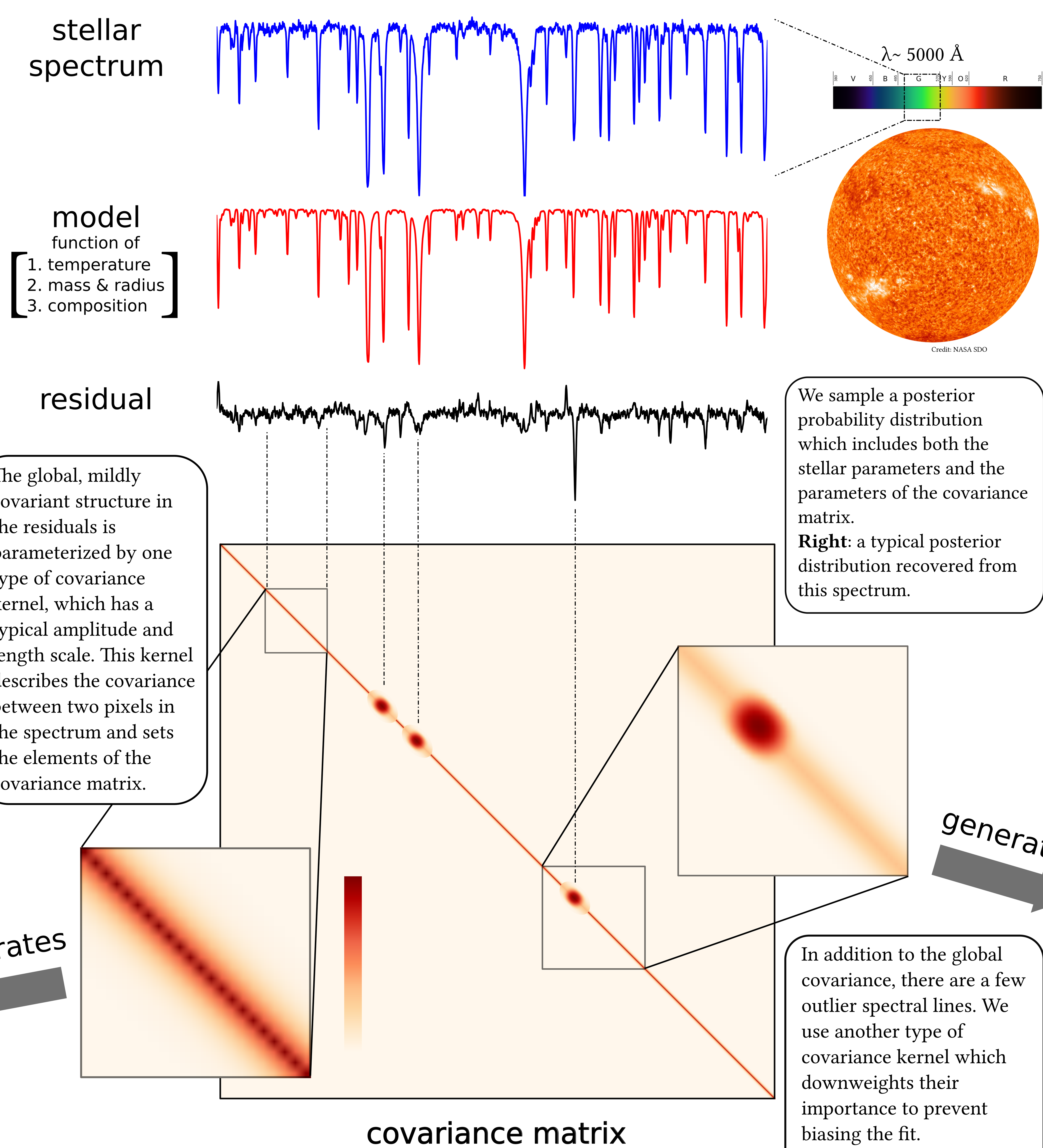
We determine stellar properties by matching a stellar spectrum to synthetic spectra (**Right**).



However, a pixel-by-pixel comparison between a stellar spectrum and a model--even a high quality one--can result in large, correlated residuals. We account for this covariance when fitting for parameters by using a non-trivial covariance matrix (**Right**).

Below: To show that we can properly parameterized the noise, we draw random samples from the covariance matrix and compare to the structure of the residuals.





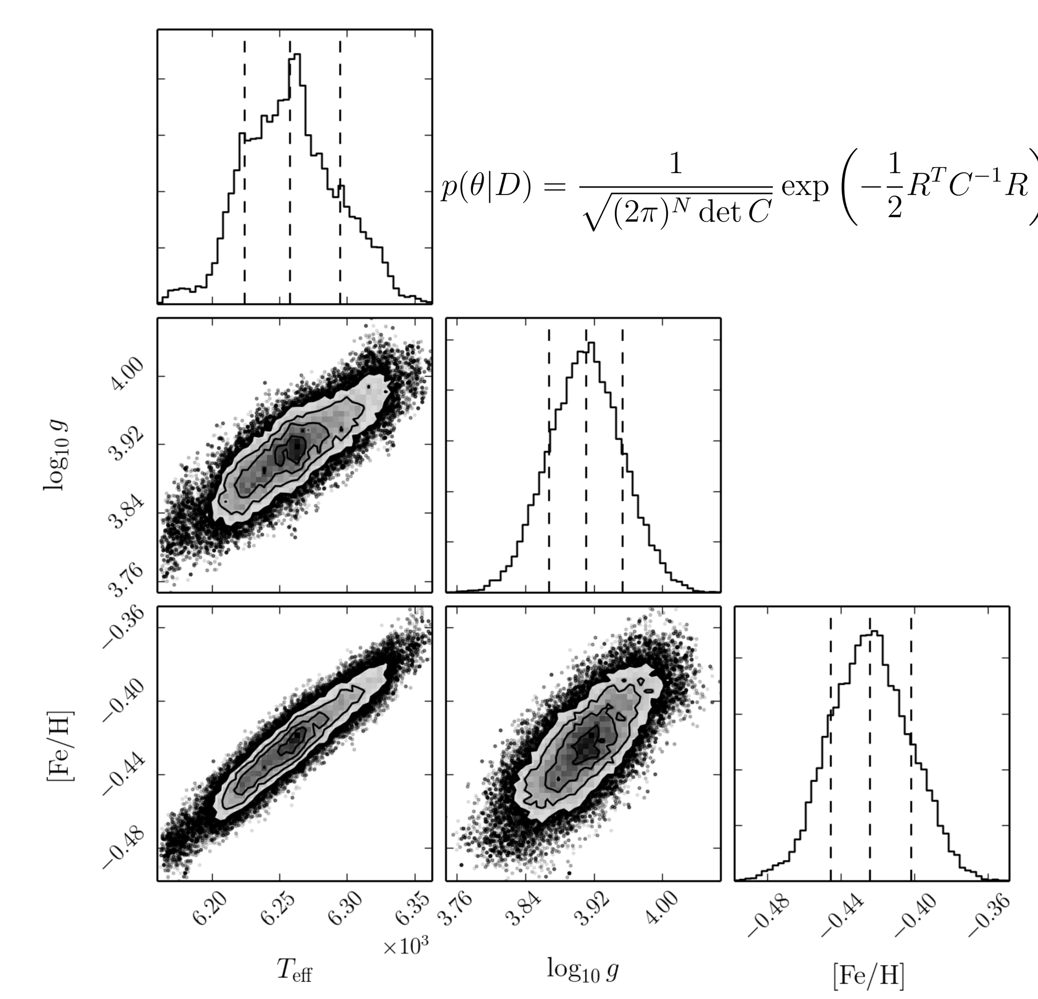
The global, mildly covariant structure in the residuals is parameterized by one type of covariance kernel, which has a typical amplitude and length scale. This kernel describes the covariance between two pixels in the spectrum and sets the elements of the covariance matrix.

We sample a posterior probability distribution which includes both the stellar parameters and the parameters of the covariance matrix.
Right: a typical posterior distribution recovered from this spectrum.

In addition to the global covariance, there are a few outlier spectral lines. We use another type of covariance kernel which downweights their importance to prevent biasing the fit.
Right: random samples.

Properly accounting for the covariance of the residuals yields unbiased stellar parameters with realistic uncertainties. Additionally, posteriors which are true to the quality of the data-model fit reveal the true degeneracies between stellar parameters, such as temperature and metallicity.

$$p(\theta|D) = \frac{1}{\sqrt{(2\pi)^N \det C}} \exp\left(-\frac{1}{2} R^T C^{-1} R\right)$$



Sampling for the parameters of the covariance kernels enables us to self-consistently determine the stellar parameters and the outlier regions of the spectrum. This "map" of outlier regions could even be used to improve the synthetic spectral models themselves!

References: Torres et al. 2012; Husser et al. 2013; Rasmussen & Williams 2005; Foreman-Mackey et al. 2012; Hogg et al 2010.