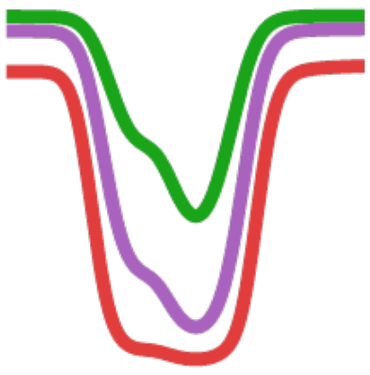


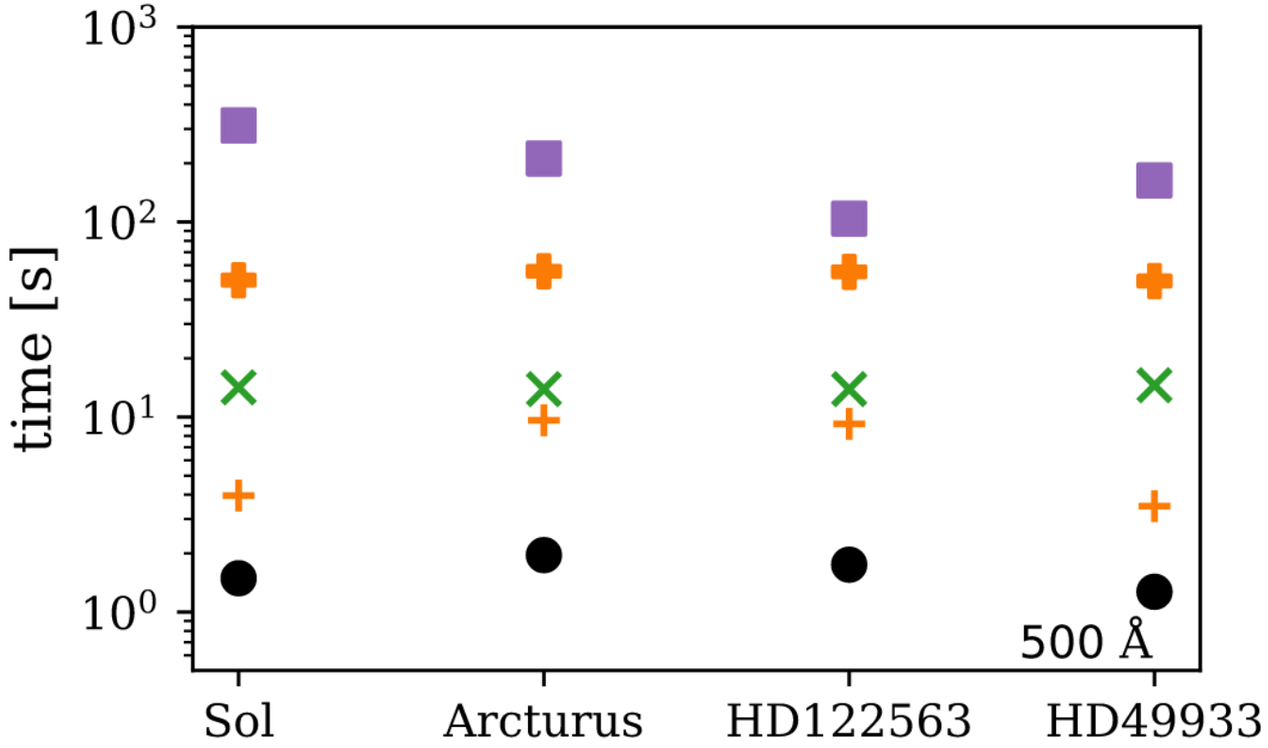
Pitfalls in the modeling of late-type stellar spectra, and the Brackett series

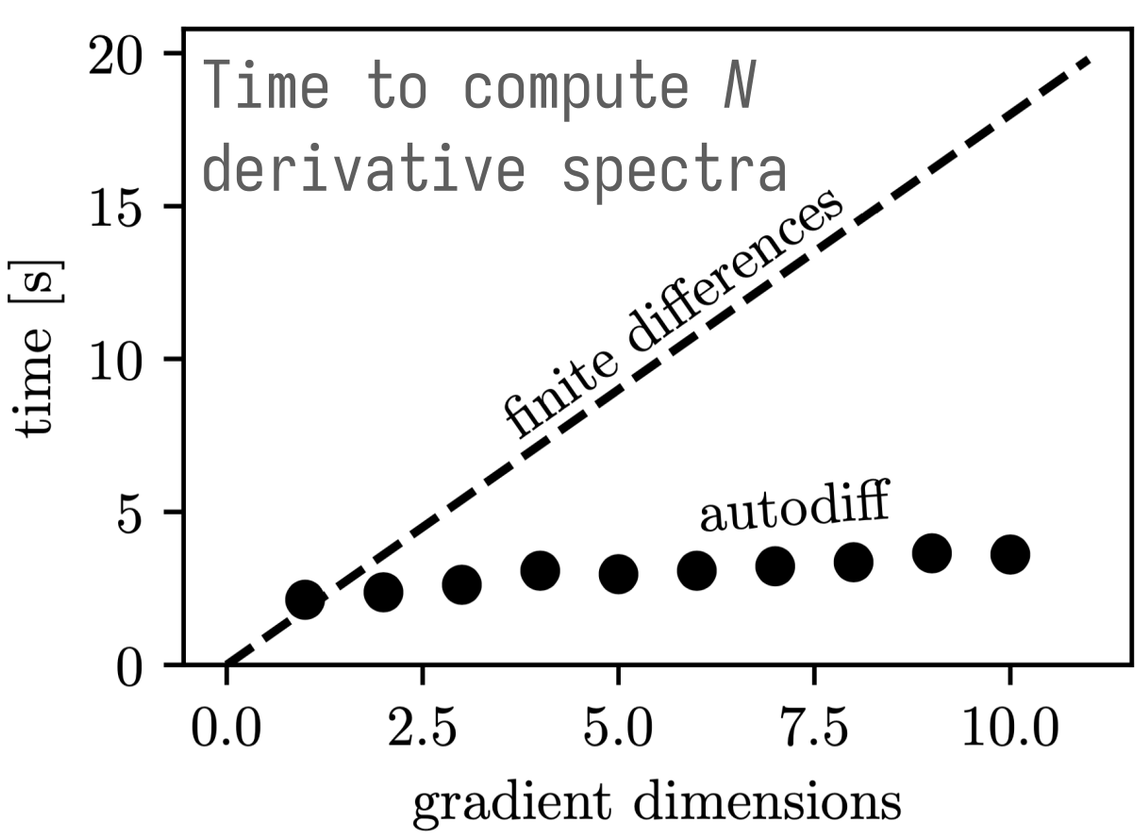
Adam Wheeler — CCAPP Fellows Symposium — 2023/9/28

Korg: A 100% from-scratch* spectral synthesis code

**Brackett line stark profiles adapted from Barklem, Kurucz. More on that later.*

- *Fast, open-source, flexible*
- For my research, SDSS, but also (I hope) for anyone





How to synthesize a spectrum

Inputs: Line data, model atmosphere

↓

Chemical equilibrium

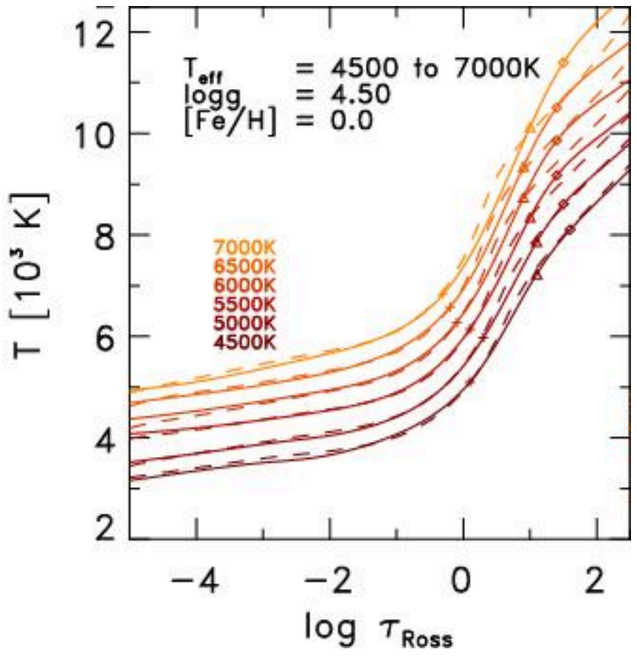
↓

Calculate opacities

↓

Radiative transfer

Model atmosphere, $T(\tau)$



linelist

species	wl	log_gf	E_lower	gamma_rad	gamma_stark	vdW
String	Float64	Float64	Float64	Float64	Float64	Any
Fe I	3000.04	-2.957	3.3014	1.90546e7	0.000123027	4.67735e-8
Fe I	3000.06	-0.964	2.4327	4.67735e7	1.94984e-5	3.16228e-8
V I	3000.1	-0.475	1.1948	2.51189e8	1.34896e-6	2.04174e-8
Cr II	3000.17	-1.487	3.8581	2.45471e8	3.01995e-7	(5.09652e-15, 0.231)
Fe I	3000.2	-3.065	3.2671	1.86209e7	0.000162181	4.67735e-8
Fe I	3000.29	-2.809	2.2786	9.77237e7	6.0256e-6	1.69824e-8
Fe I	3000.39	-0.598	0.859	6.0256e8	1.62181e-6	(1.18732e-14, 0.298)
Ca I	3000.52	-0.983	1.8858	1.51356e8	1.38038e-6	(1.72778e-14, 0.306)

How to synthesize a spectrum

Inputs: Line data, model atmosphere

Chemical equilibrium (Now with polyatomic and charged molecules!)

Calculate opacities

Radiative transfer

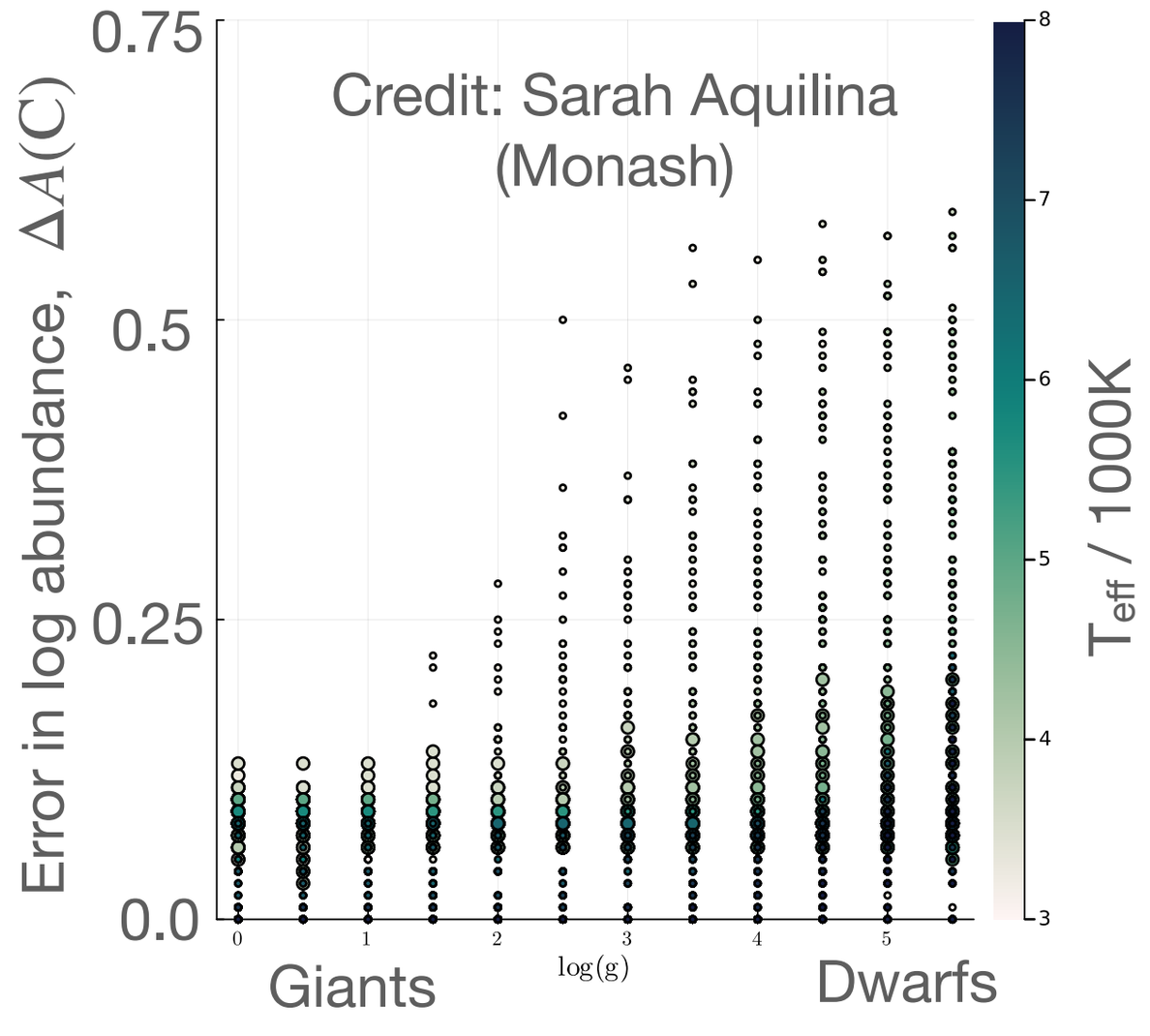
For C_2:

D_0 = 6.37 ± 0.16 eV

(Barklem & Collet 2016)

$$K_{C_2} = \frac{P^2_{C\ I}}{P_{C_2}} = \frac{n(C\ I)^2}{n(C_2)} kT$$

$$K_{C_2} \propto \exp\left(\frac{-D_0}{kT}\right)$$



How to synthesize a spectrum

Inputs: Line data, model atmosphere

↓

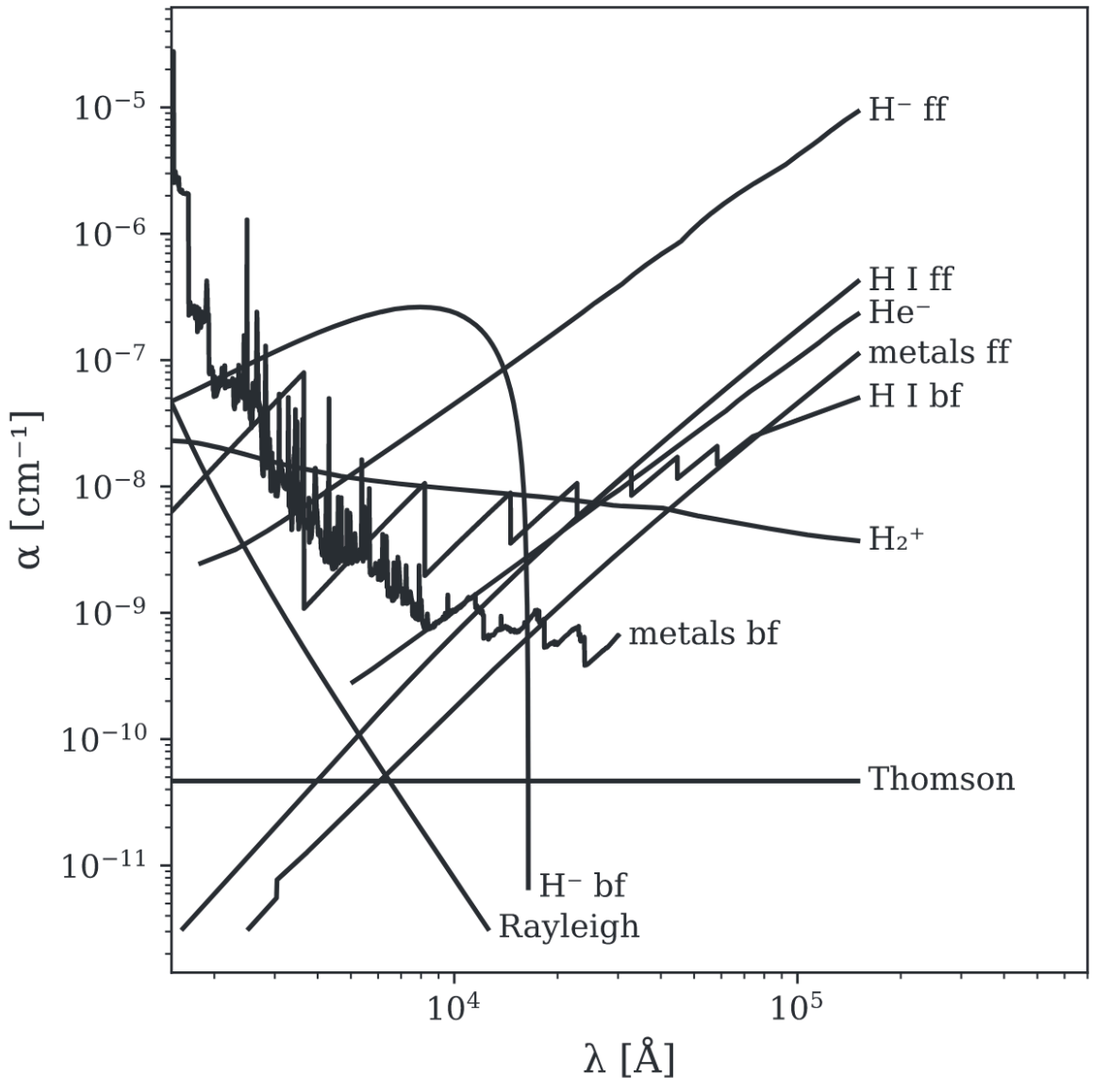
Chemical equilibrium

↓

Calculate opacities

↓

Radiative transfer



I'll discus H lines in a minute

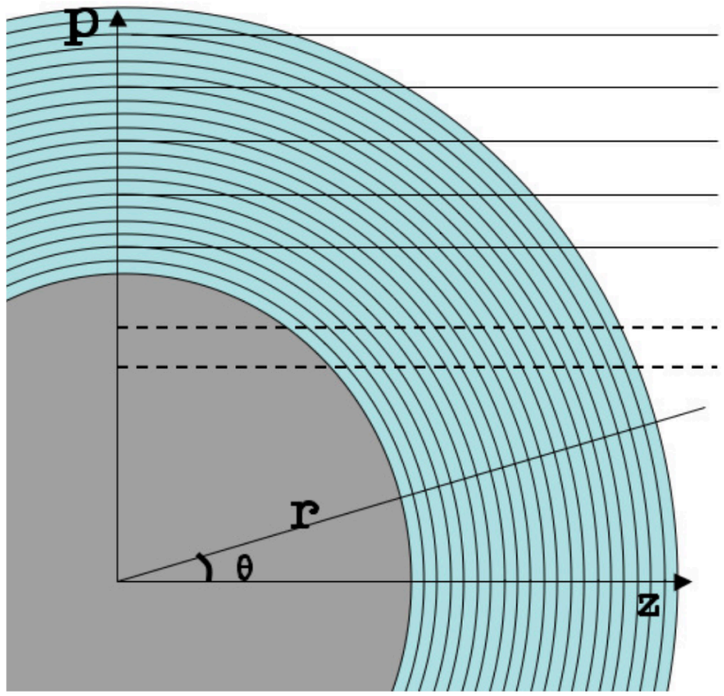
How to synthesize a spectrum

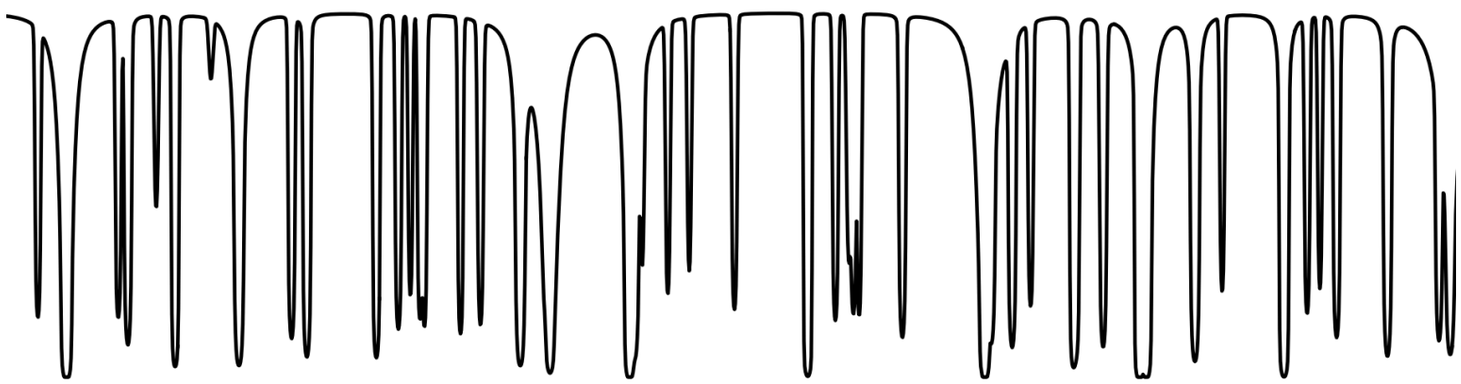
Inputs: Line data, model atmosphere

Chemical equilibrium

Calculate opacities

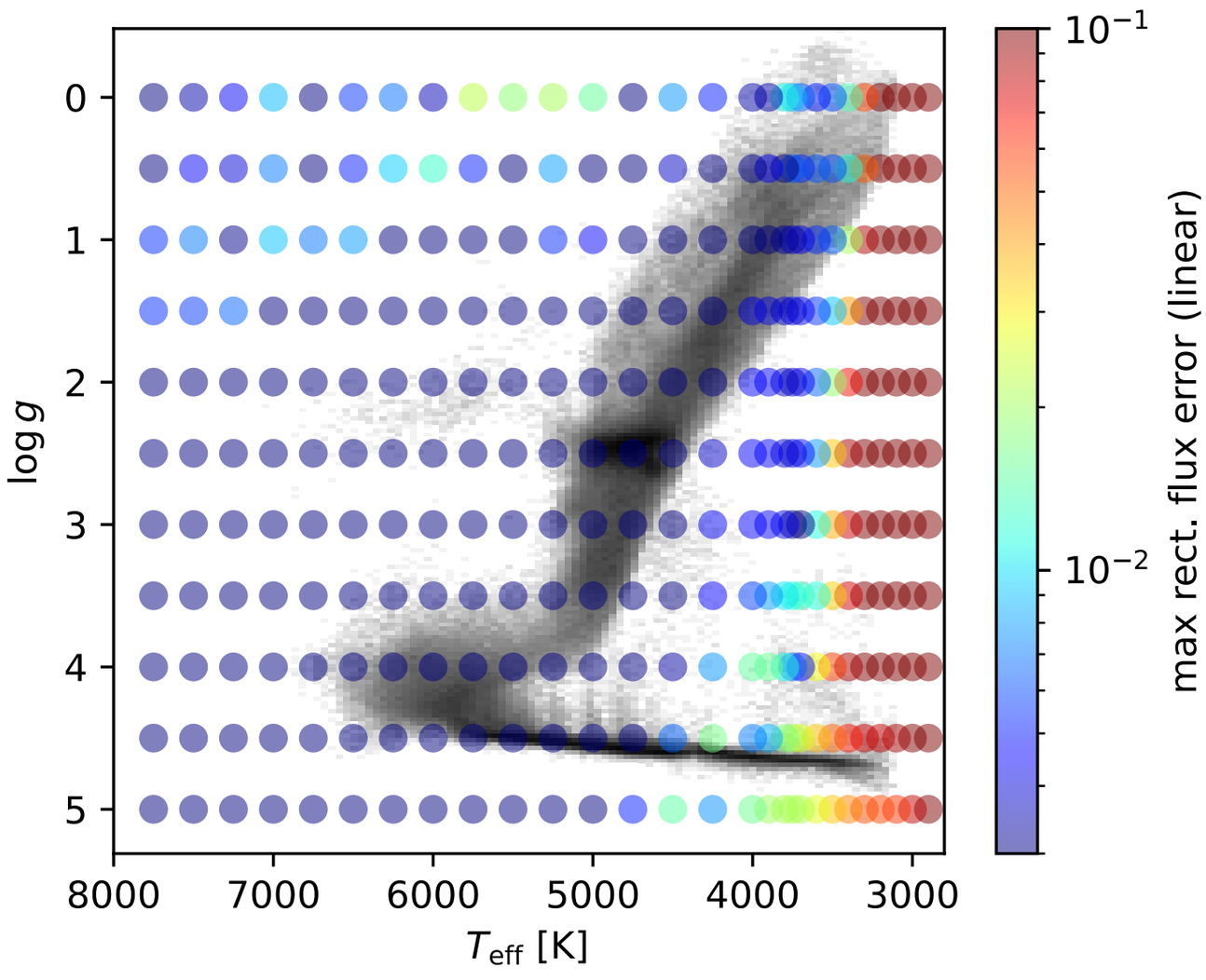
Radiative transfer





Getting cool stars right: Interpolation of model atmospheres

Naive interp



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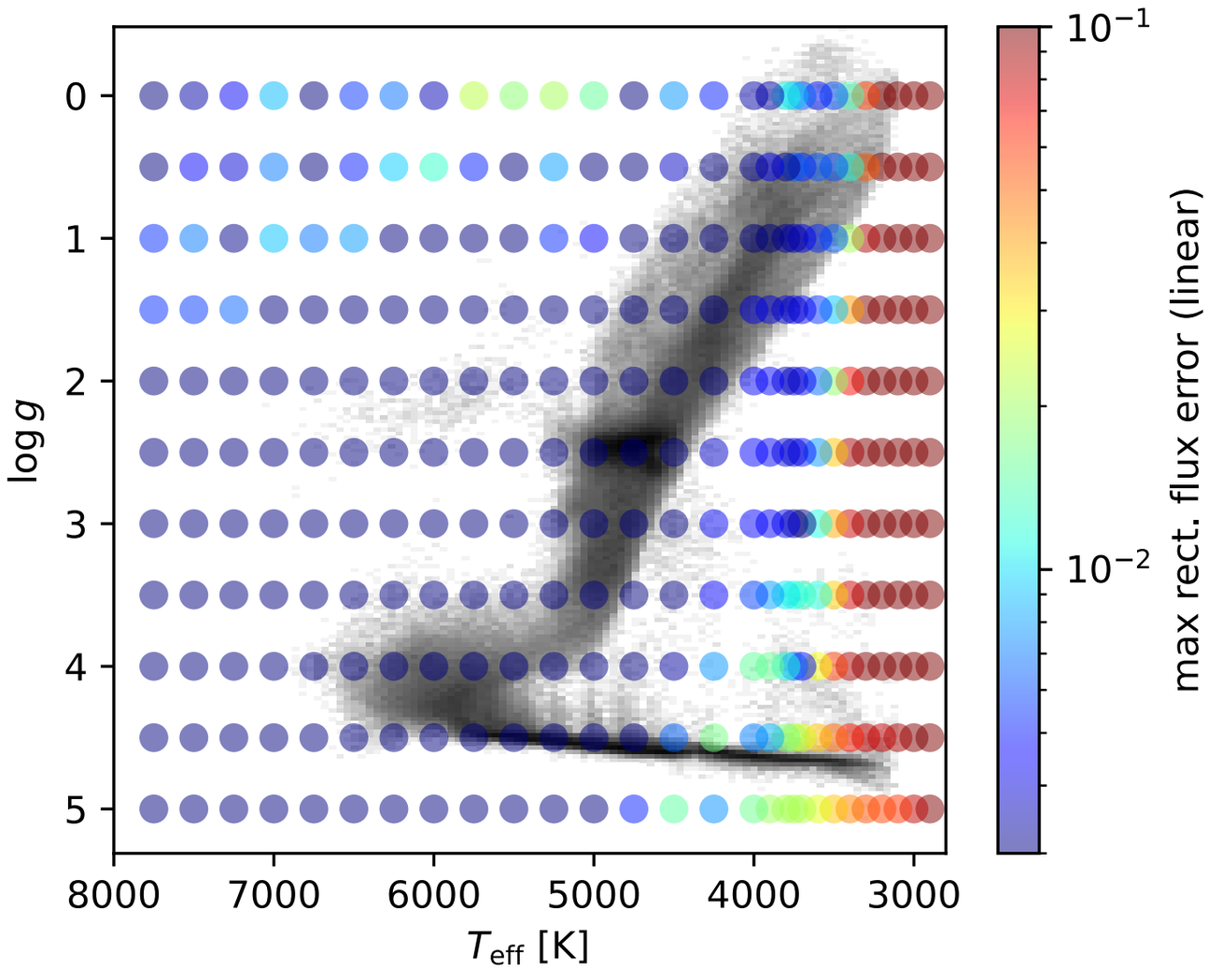

- *Mészáros & Allende Prieto 2013:* interpolate fluxes, not atmospheres

Getting cool stars right: Interpolation of model atmospheres

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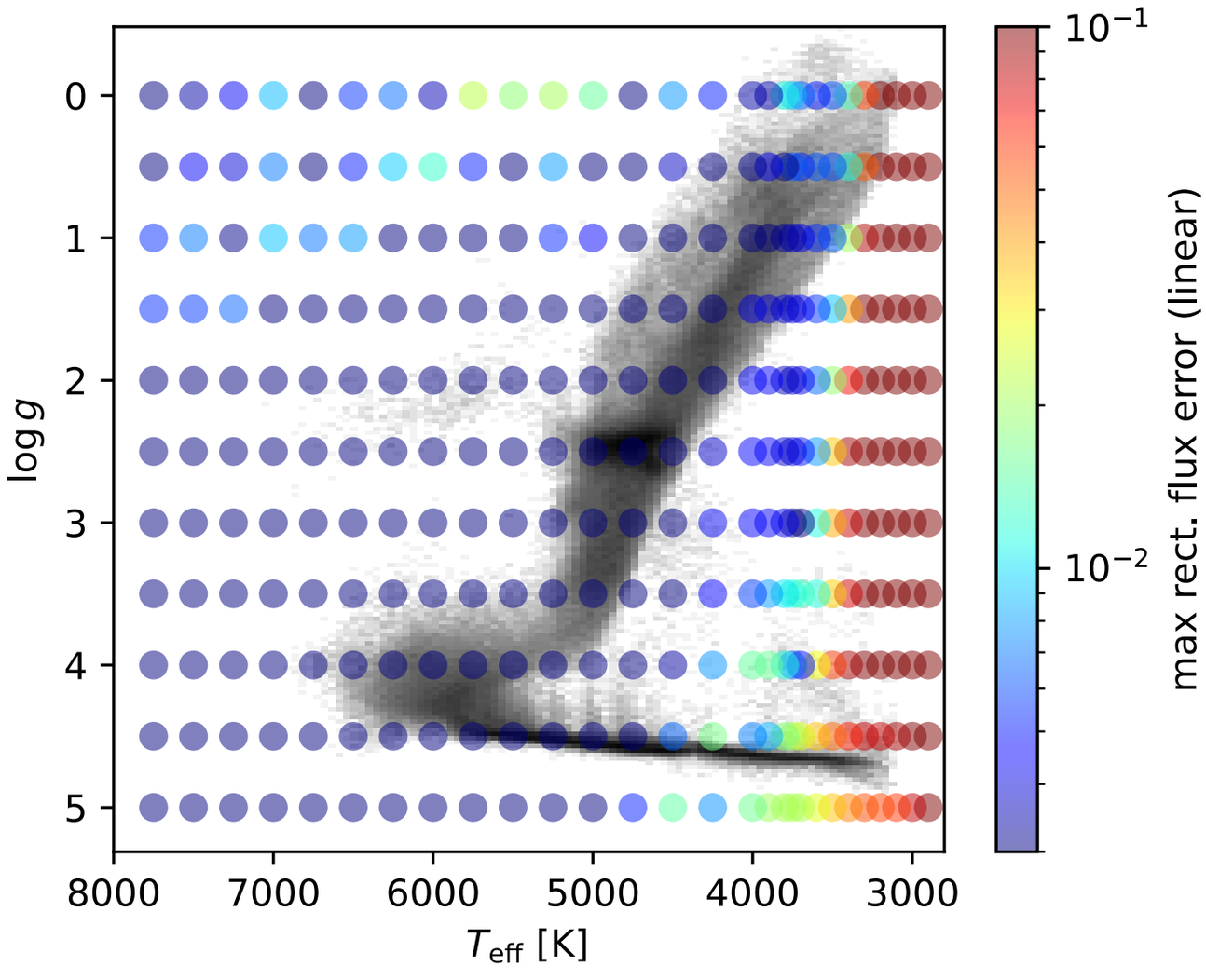

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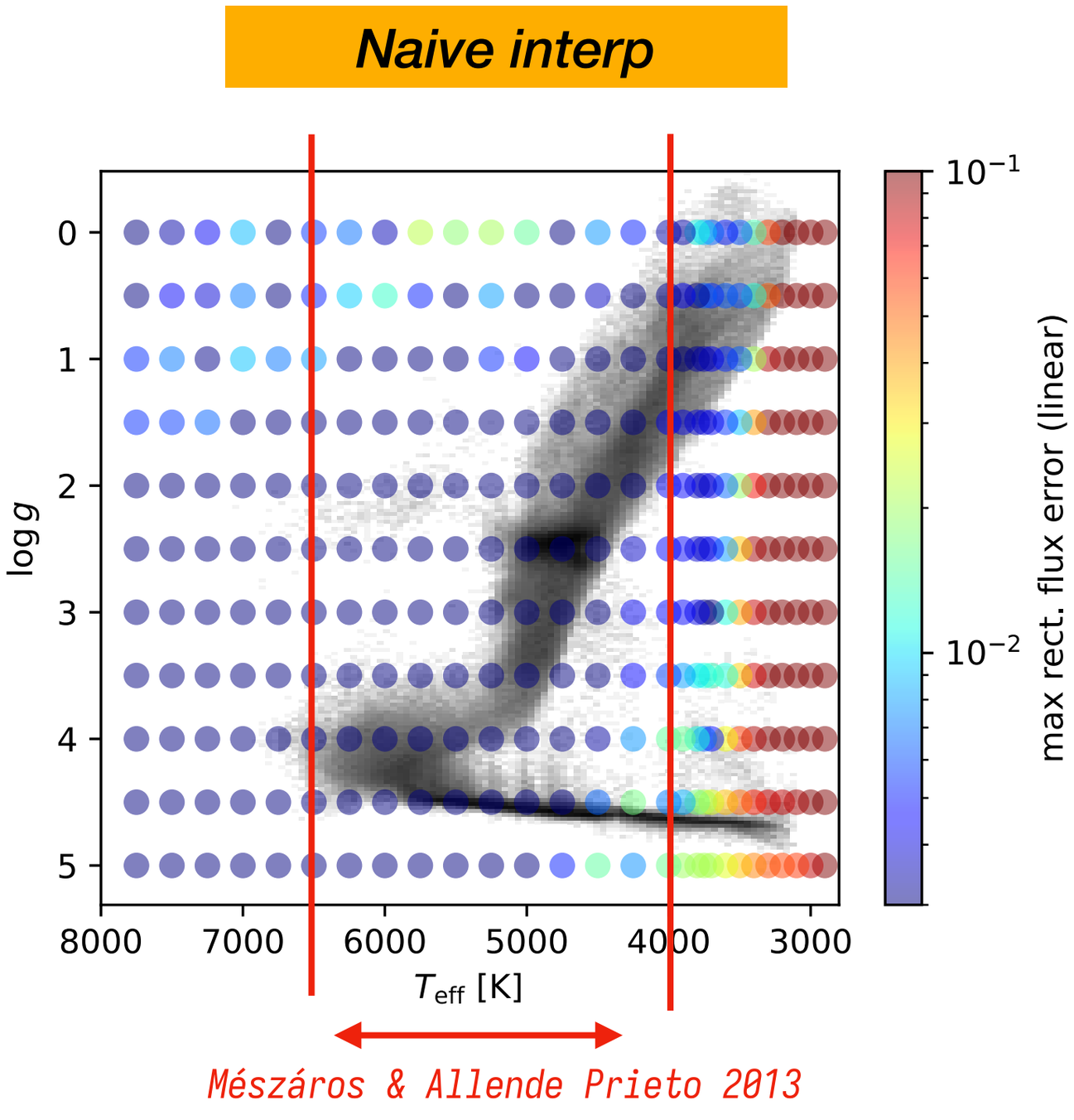
- This is a code-dependent statement

Getting cool stars right: Interpolation of model atmospheres



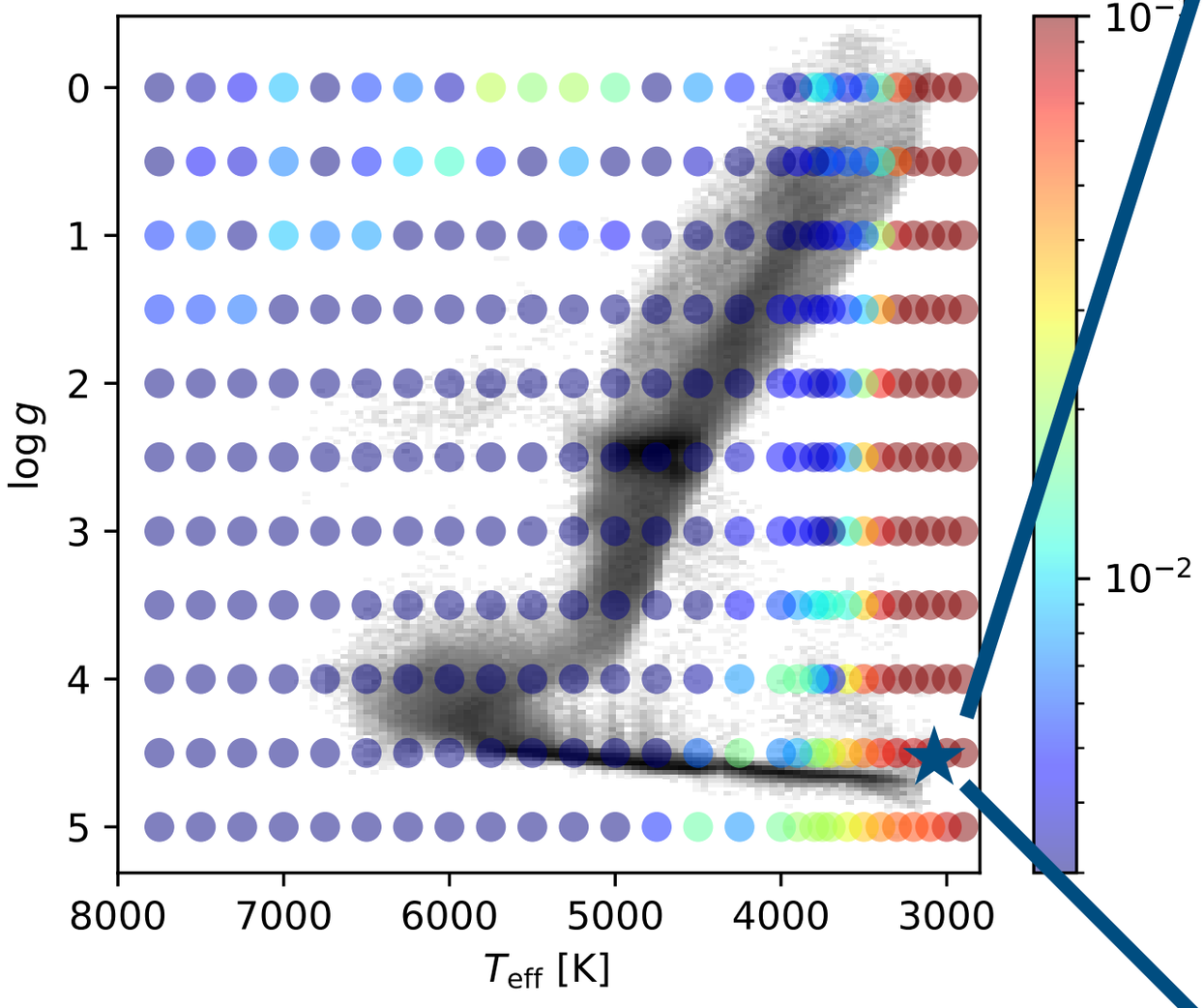
- *Mészáros & Allende Prieto 2013:* interpolate fluxes, not atmospheres

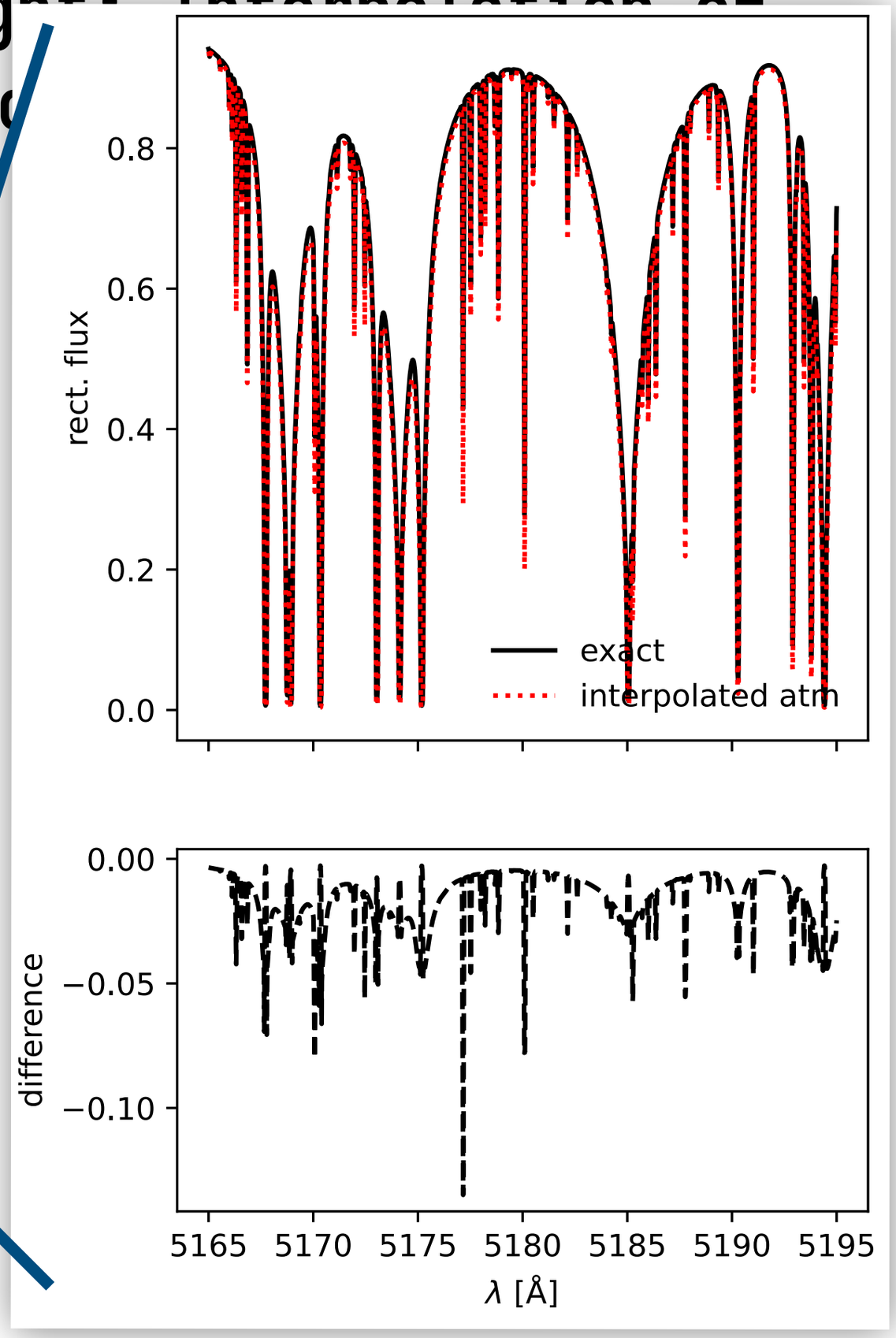
- This is a code-dependent statement

- Cool stars are much harder!

Getting cool stars right: Interpolation of model atmo

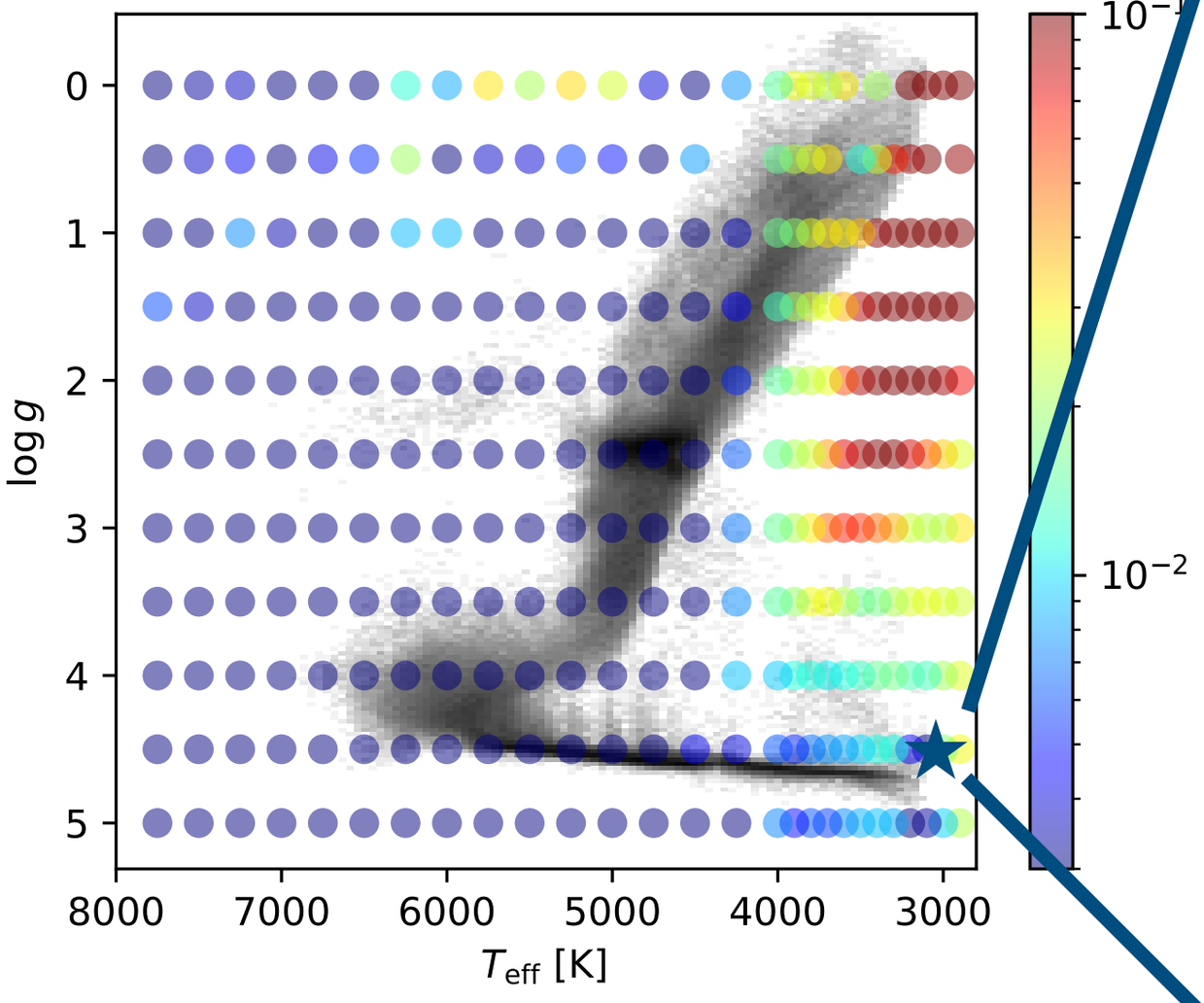
Naive interp

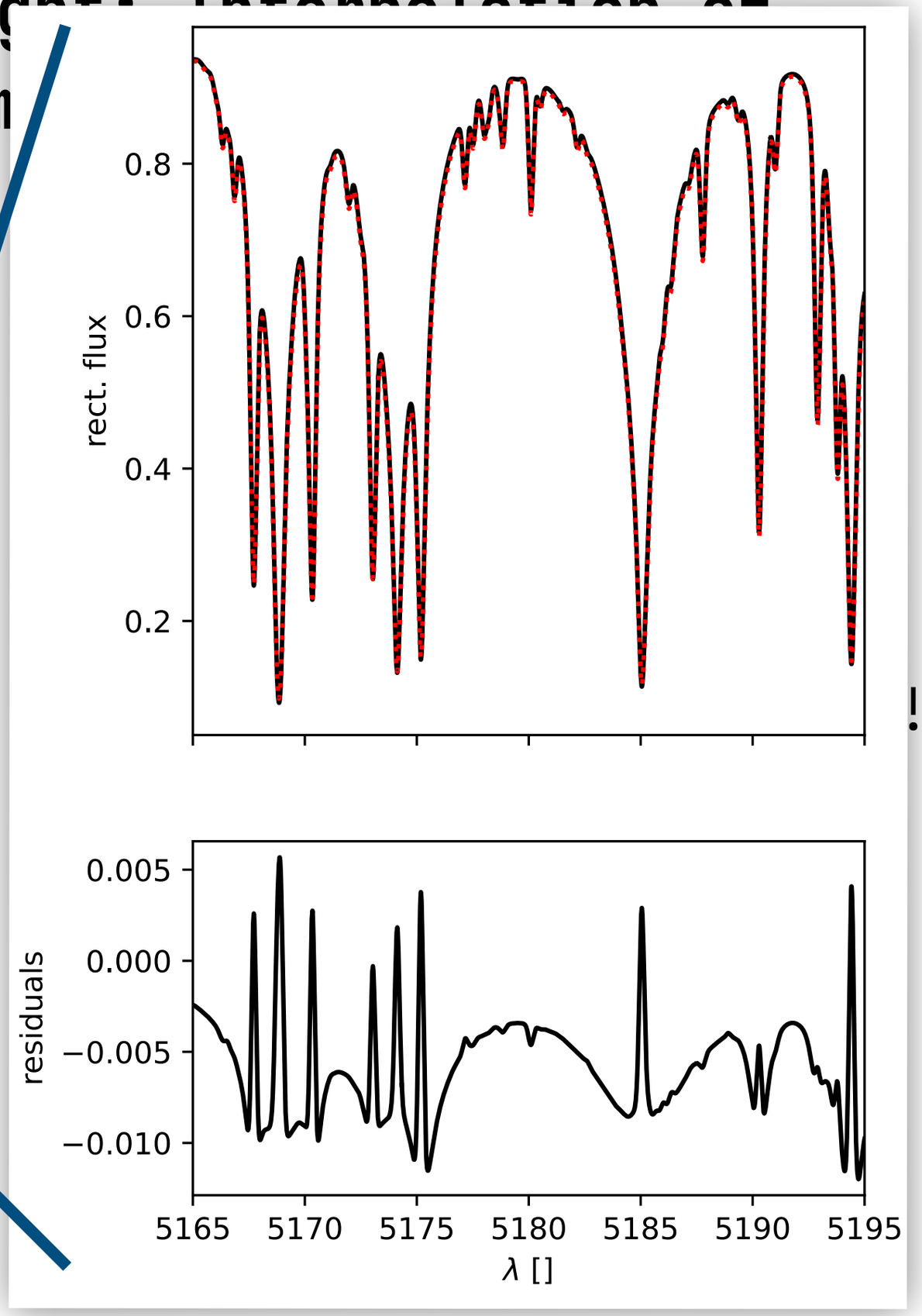




Getting cool stars right: Interpolation of model atm

Tuned for cool dwarfs (cubic, resampled to eliminate changes in τ_{5000})

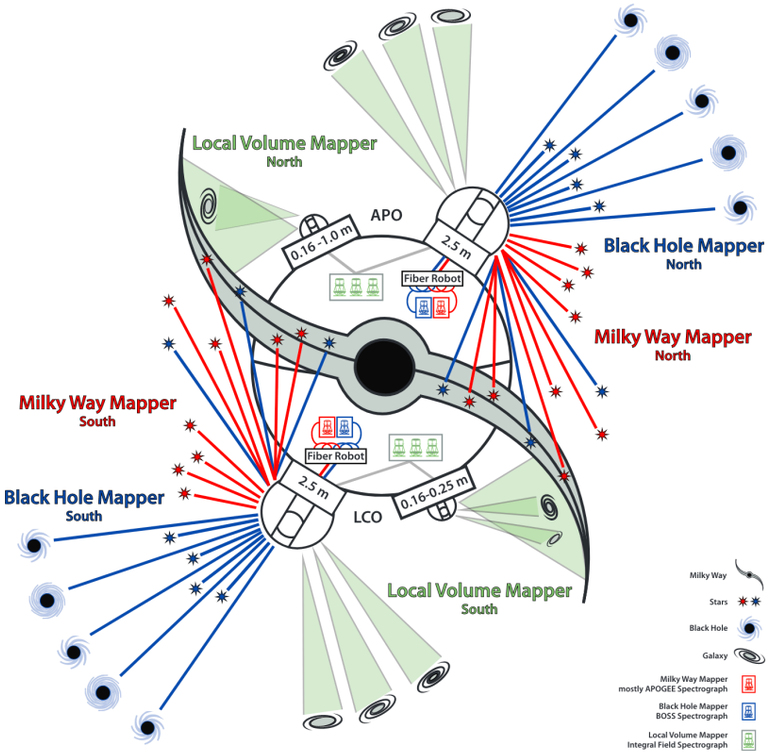


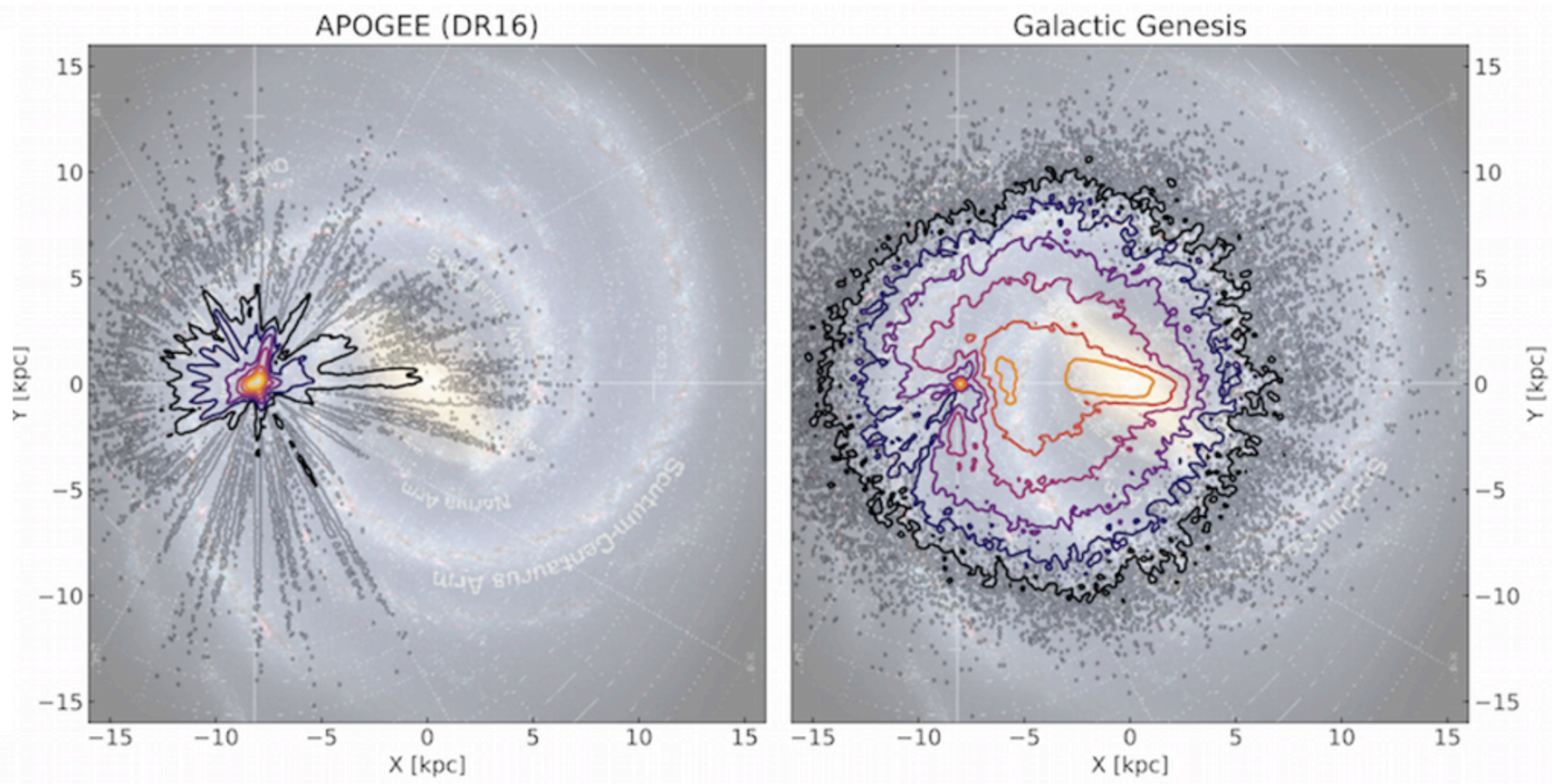


!

Brackett lines: problems with models

Why care about the infrared? SDSS-V!





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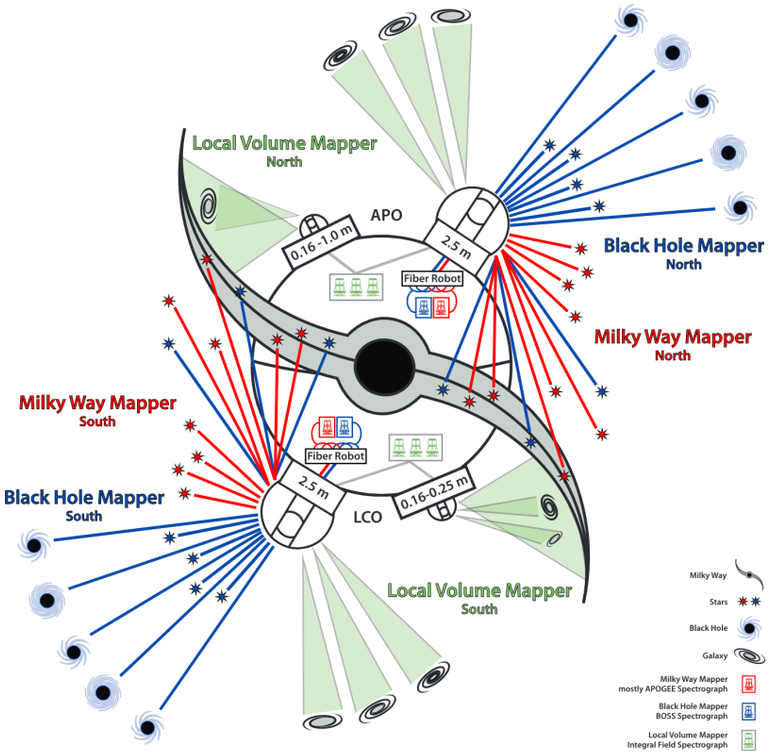
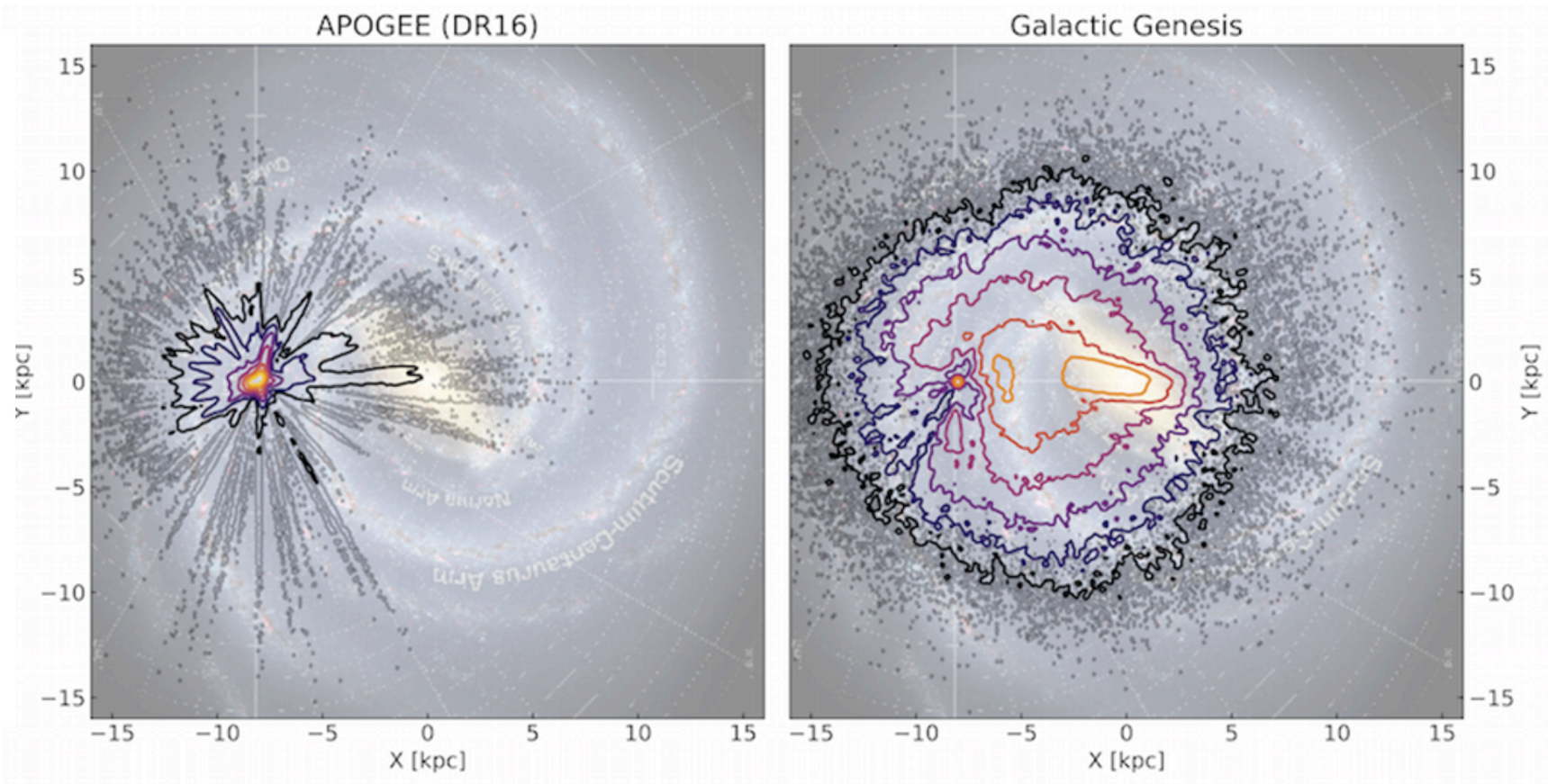
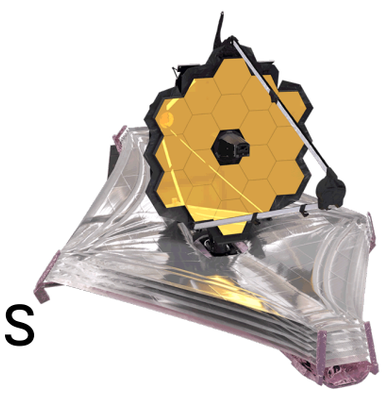
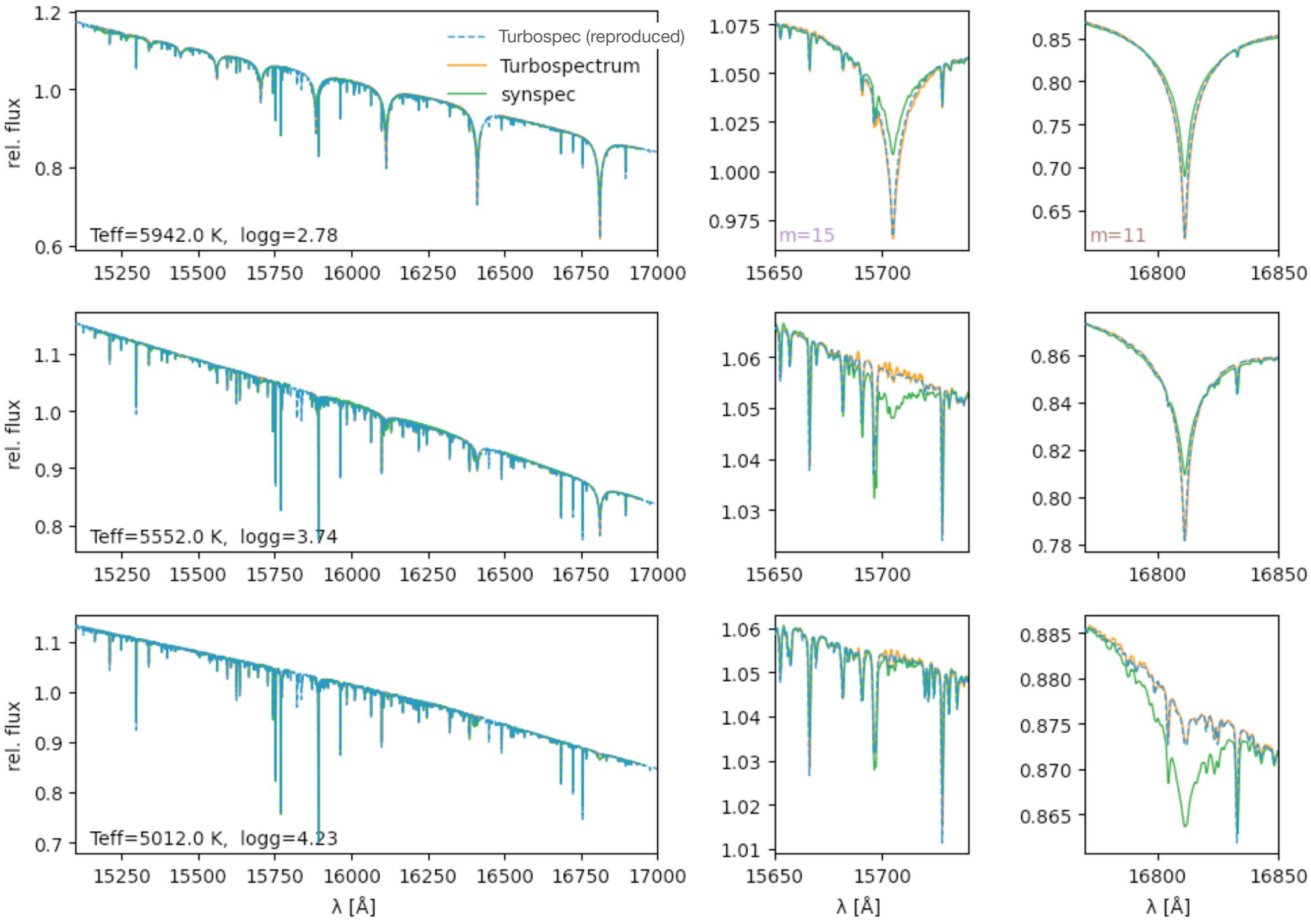




…there are other IR spectrographs



Brackett lines: problems with models



Brackett lines: disagreement between models

$\log g \approx 2.75$

$\log g \approx 3.75$

$\log g \approx 4.25$

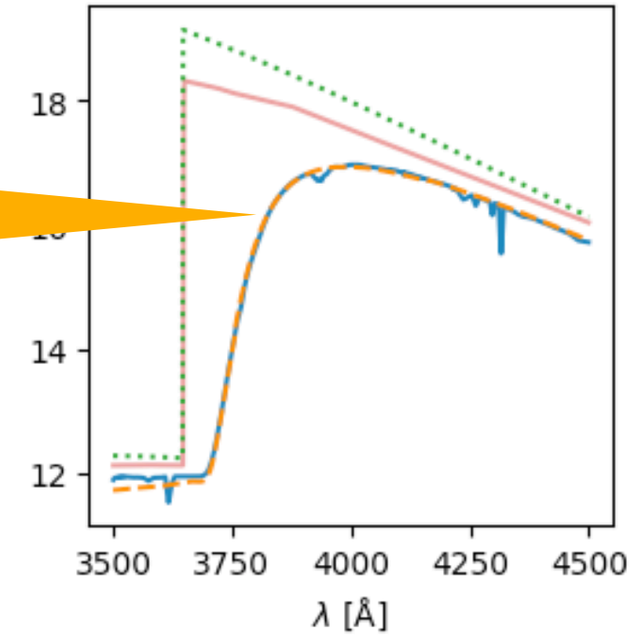
increasing pressure

Brackett lines: disagreement between models

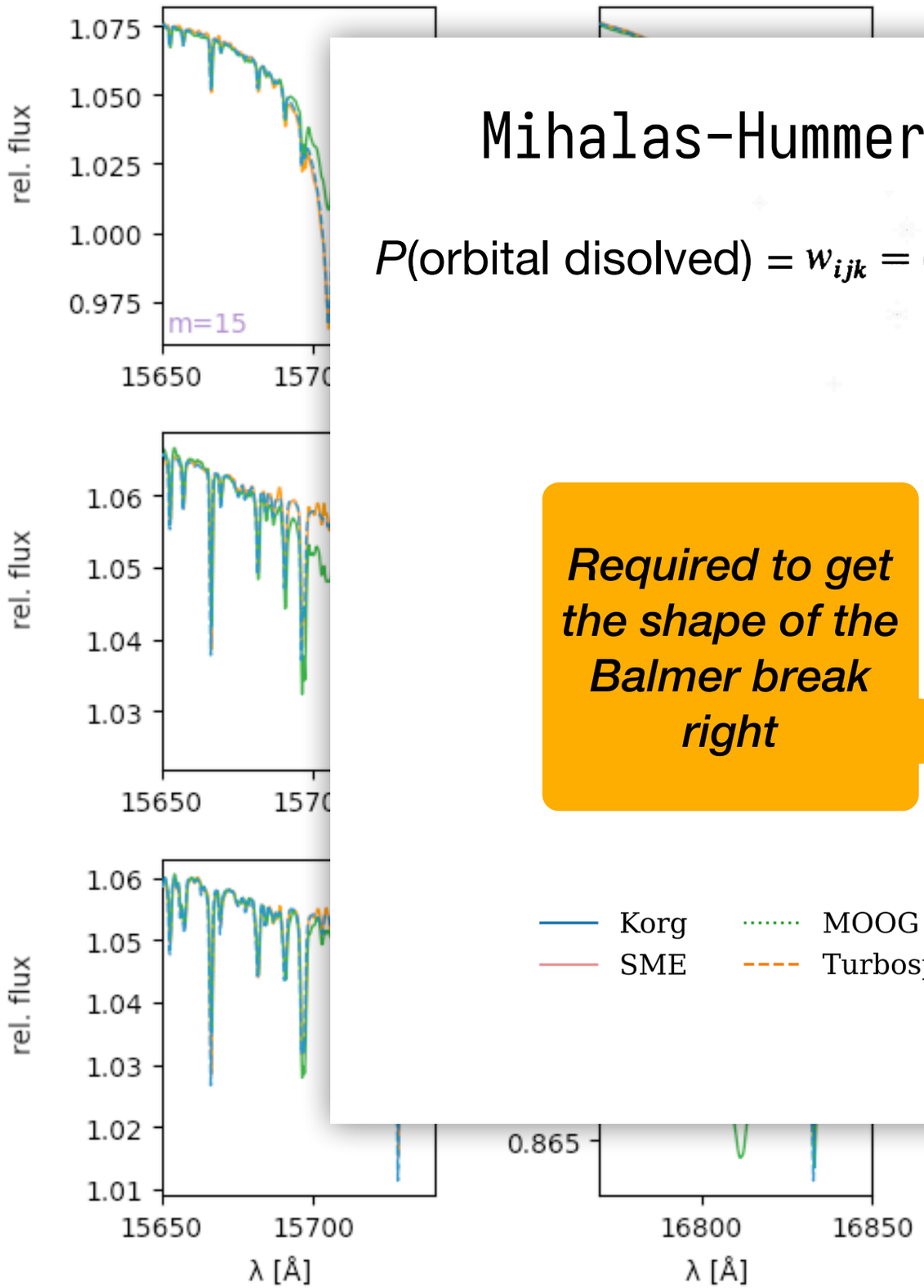
Mihalas-Hummer-Daeppen formalism

$$P(\text{orbital disolved}) = w_{ijk} = \exp\left[\left[-\left(\frac{4\pi}{3V}\right)\left\{\sum_{v'k'} N_{v'k'}(r_{ijk} + r_{1vk'})^3 + 16\left[\frac{(Z_{jk}+1)^{1/2}e^2}{K_{ijk}^{1/2}\chi_{ijk}}\right]^3 \sum_{\alpha \neq e} N_\alpha Z_\alpha^{3/2}\right\}\right]\right]$$

Required to get the shape of the Balmer break right



Korg
SME
MOOG
Turbospectrum



increasing pressure

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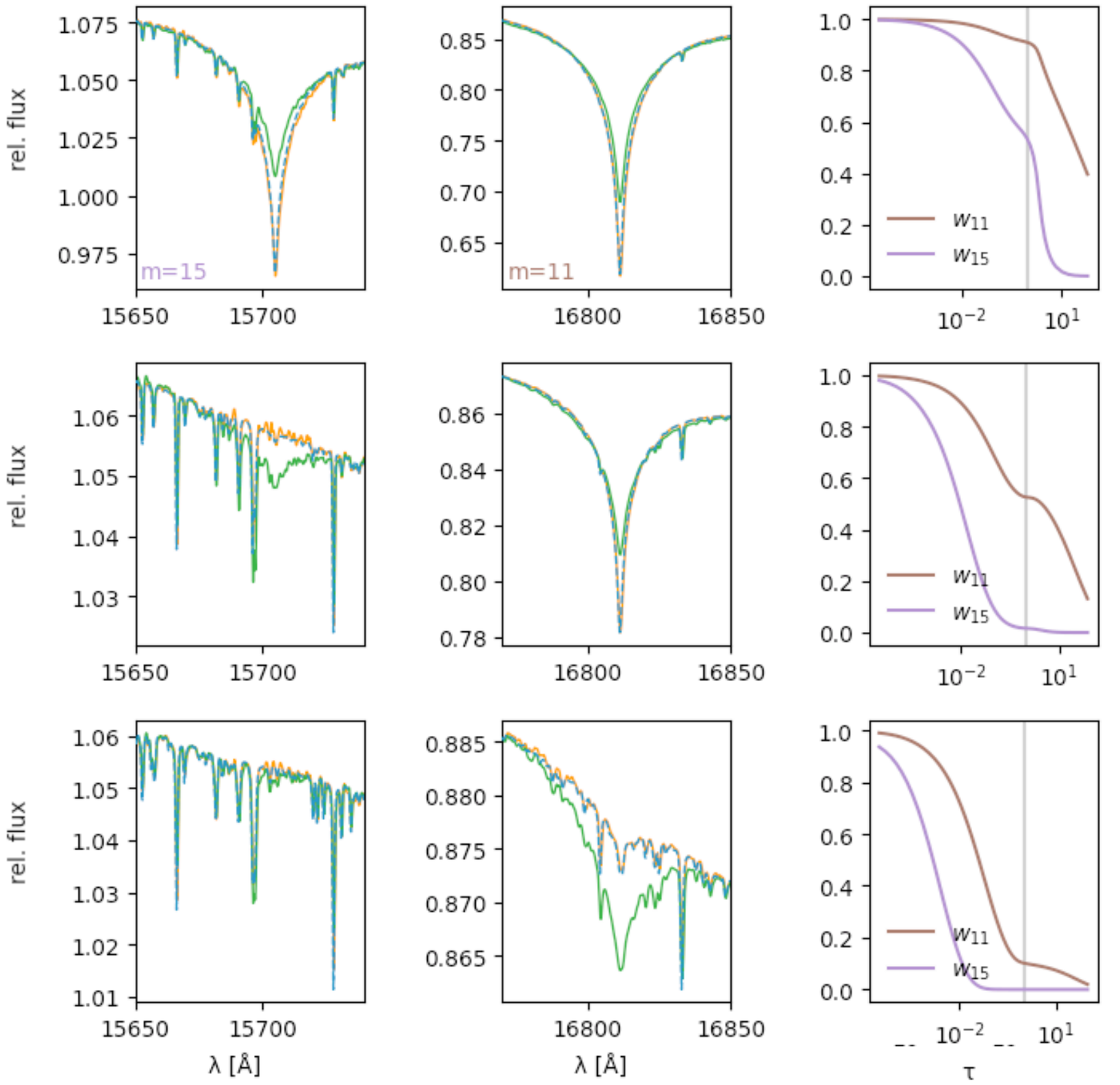

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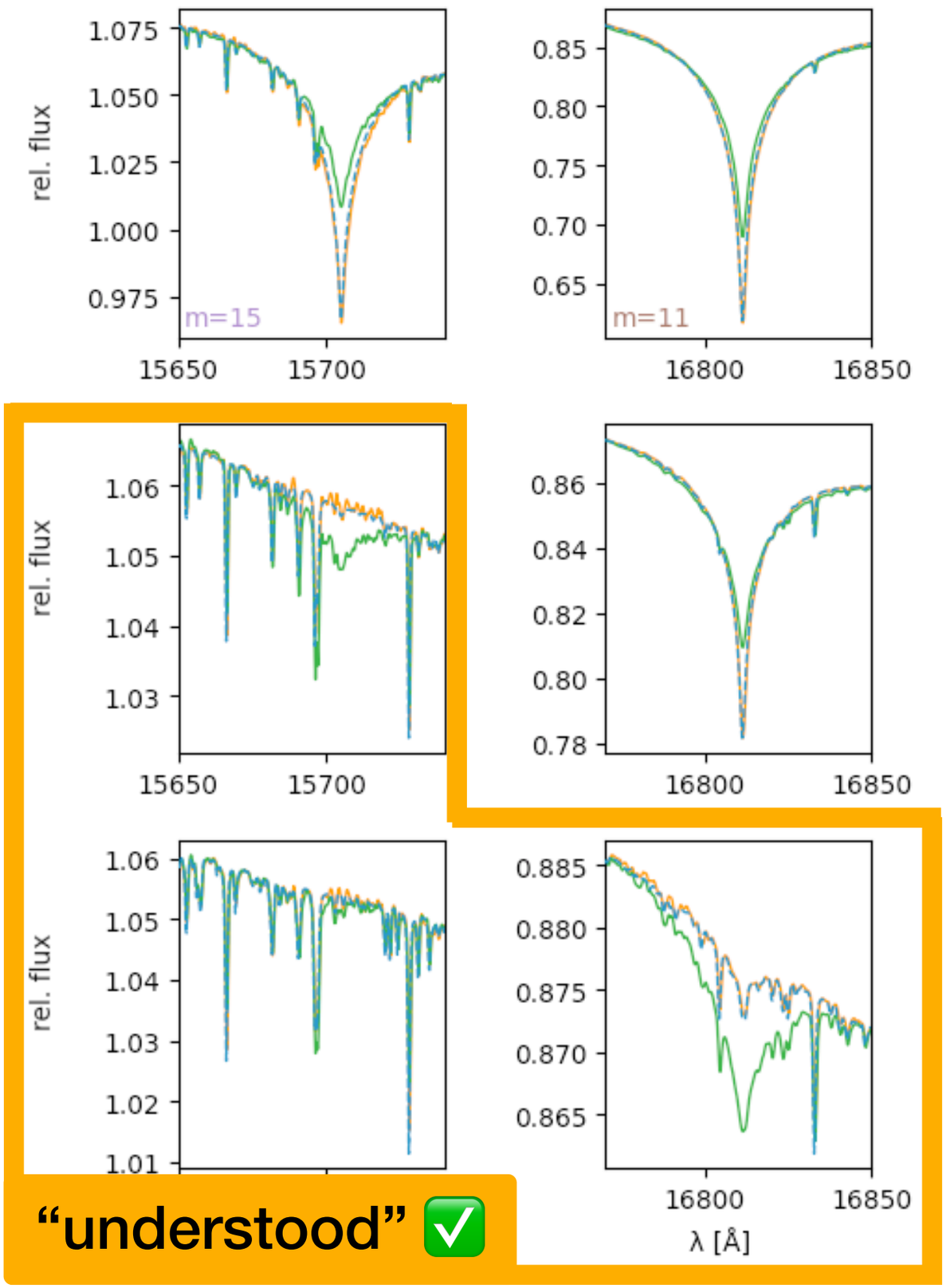

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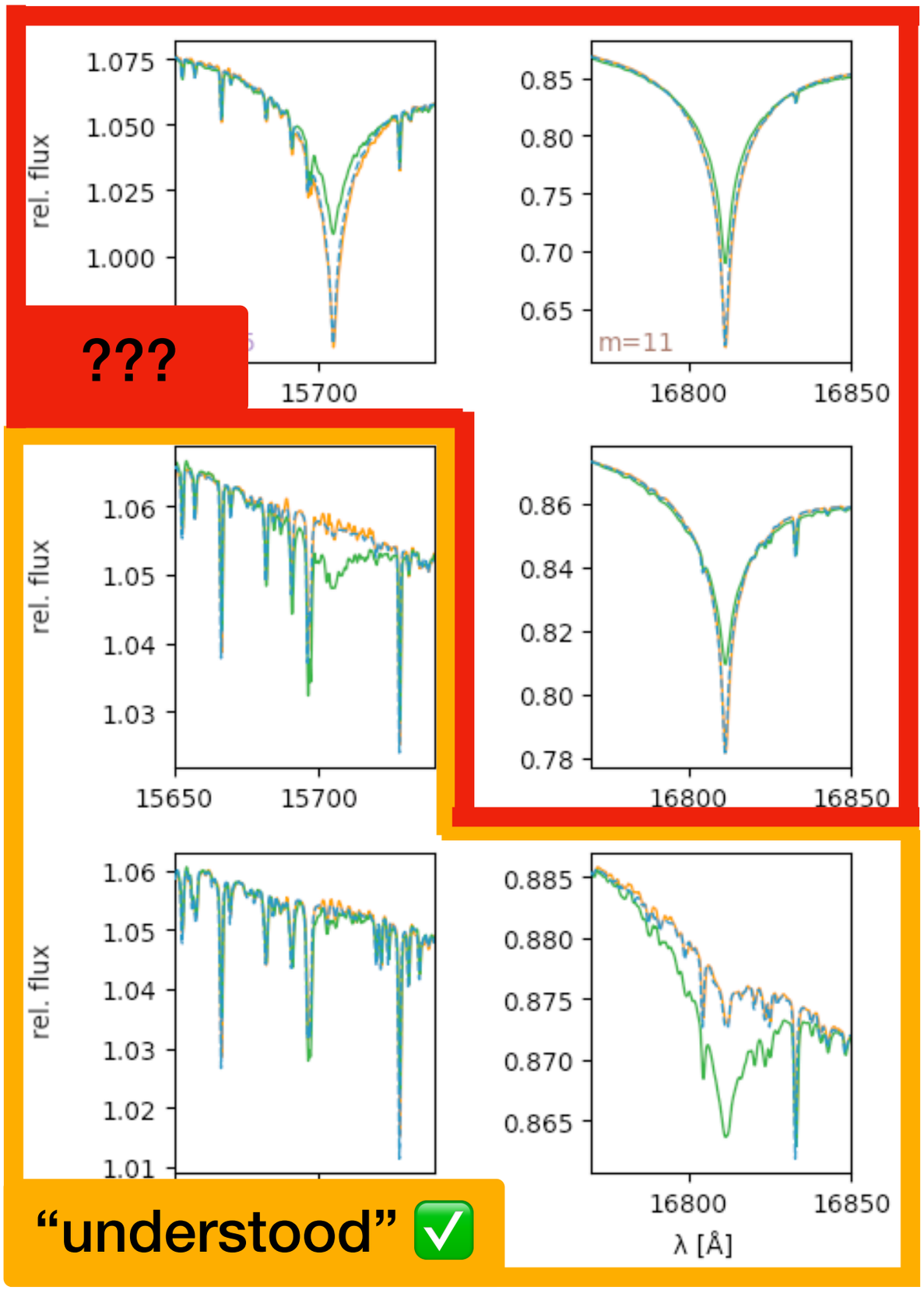
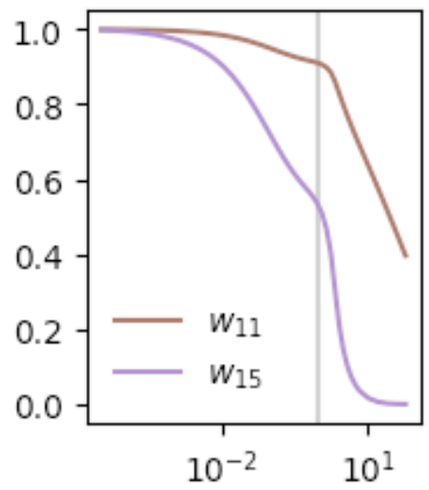
increasing pressure

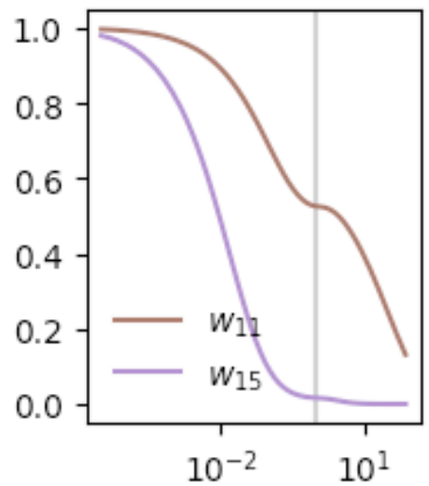
"understood" ✅

Brackett lines: disagreement between models

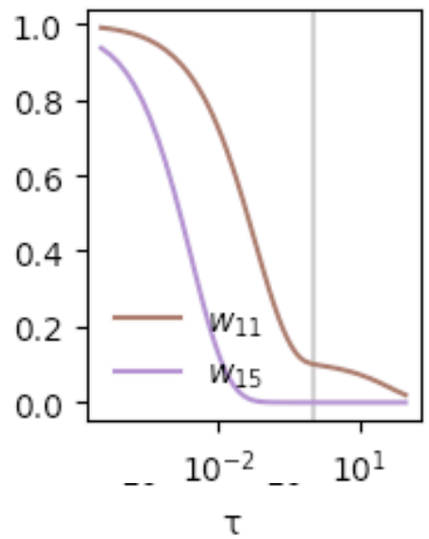




$\log g \approx 2.75$



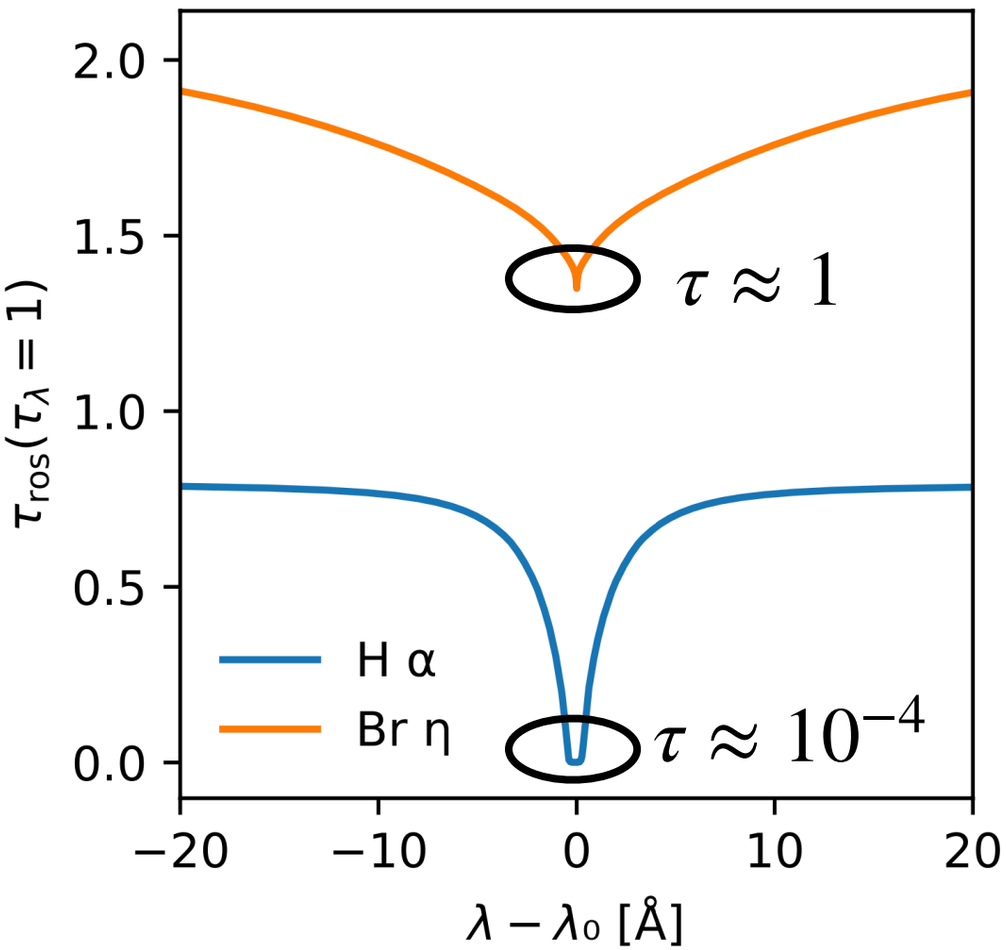
$\log g \approx 3.75$



$\log g \approx 4.25$

increasing pressure

In the IR, lines form much deeper



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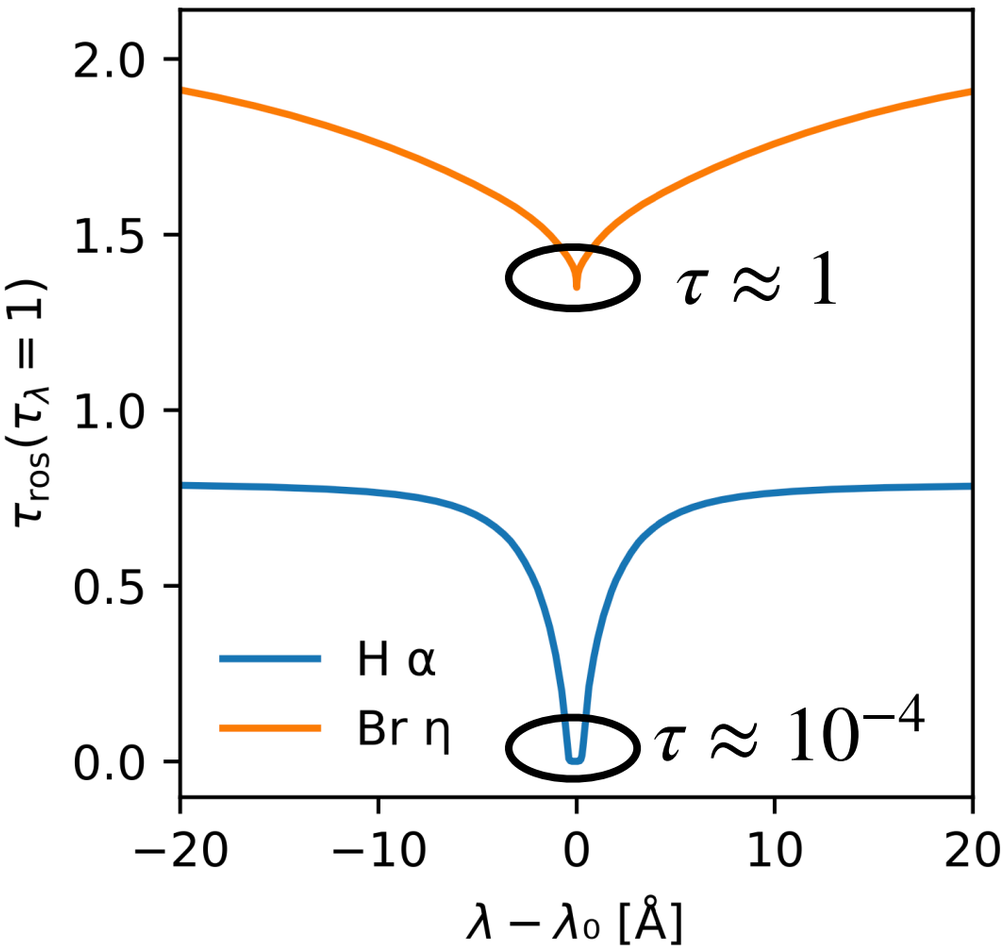
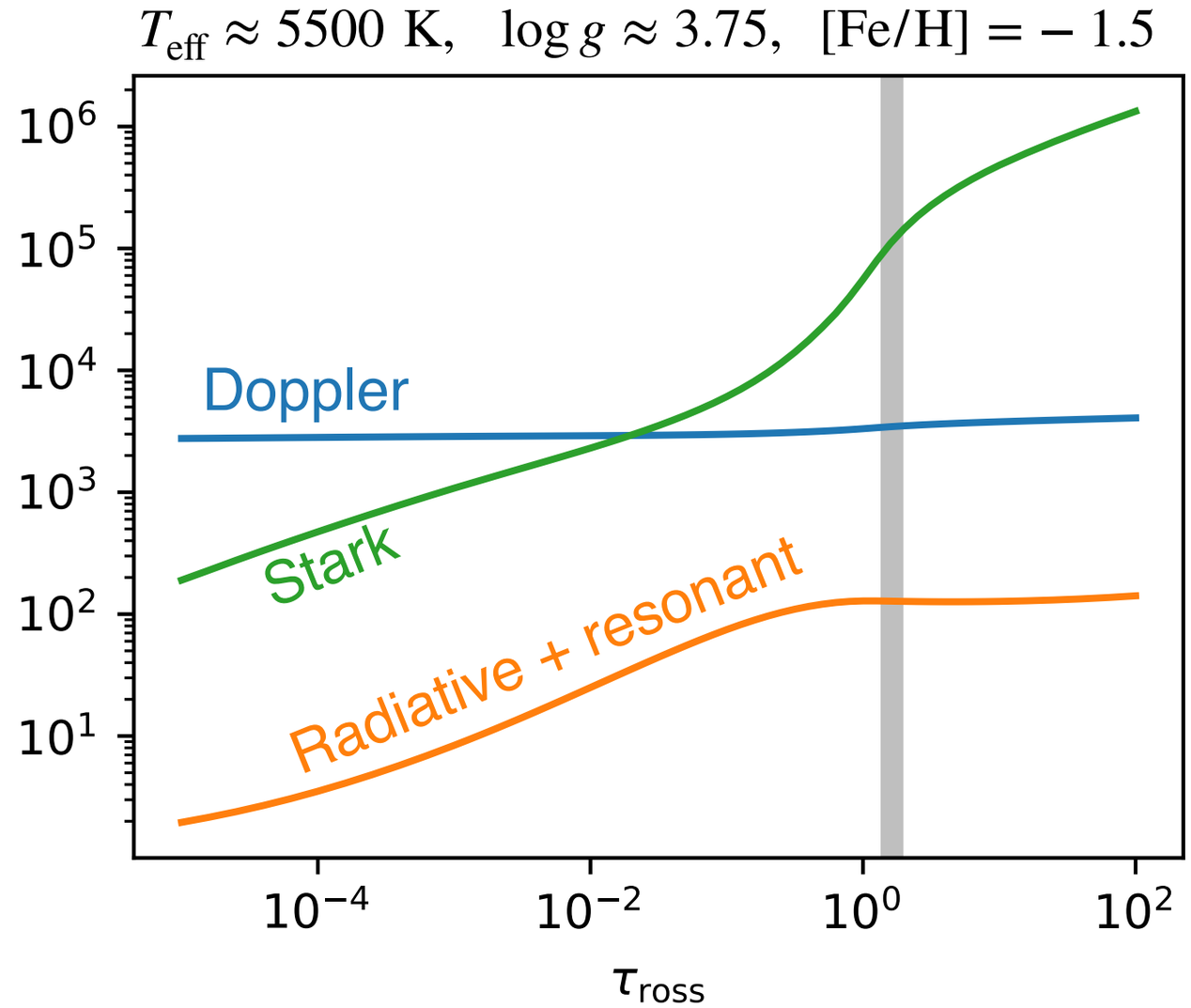
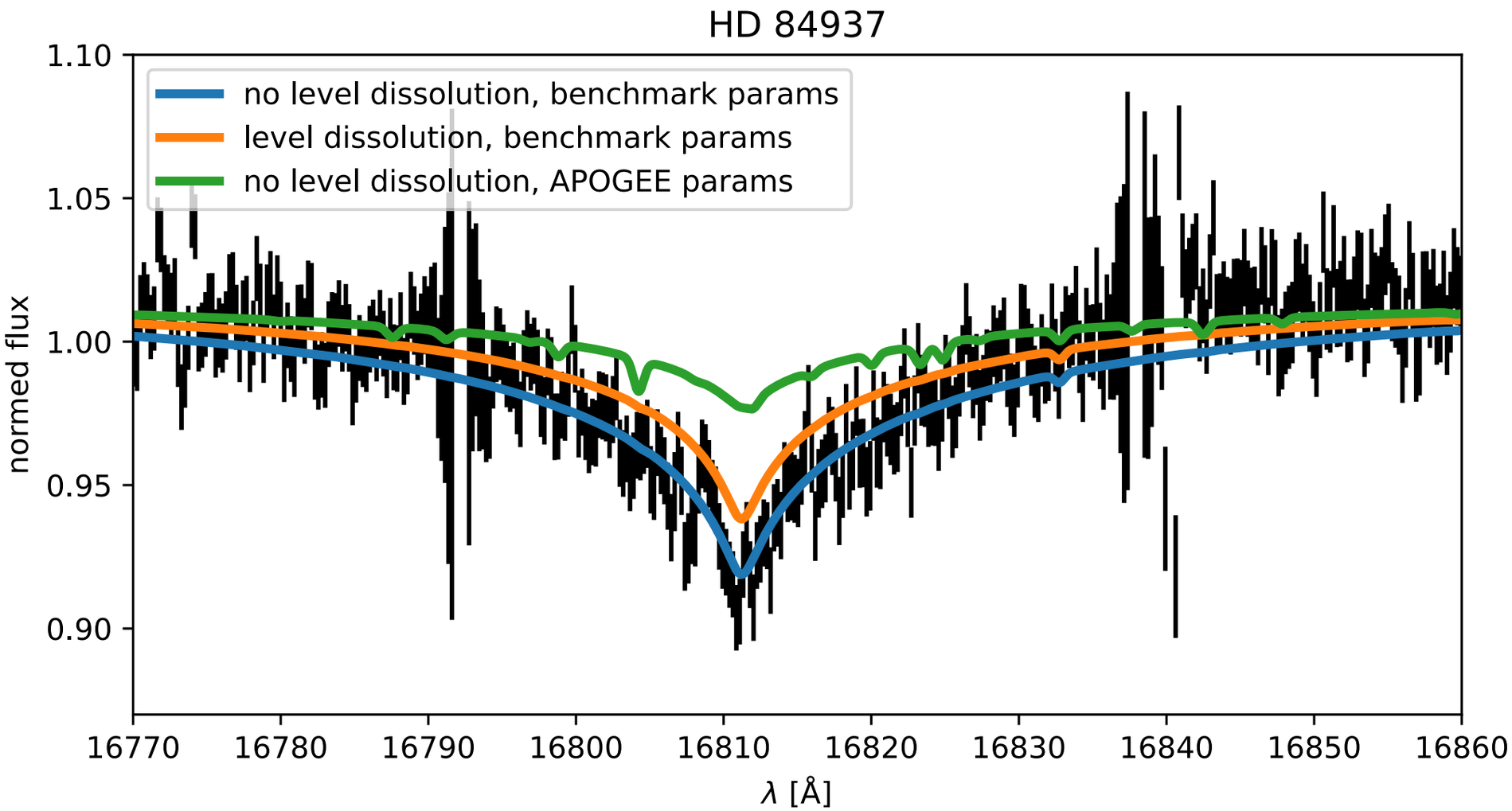


Stark broadening (electron interactions) dominates Brackett line cores!



new Brackett lines give much better fit with benchmark params than APOGEE DR 17 params (ΔT_{eff}=400 K, Δlogg=0.5).

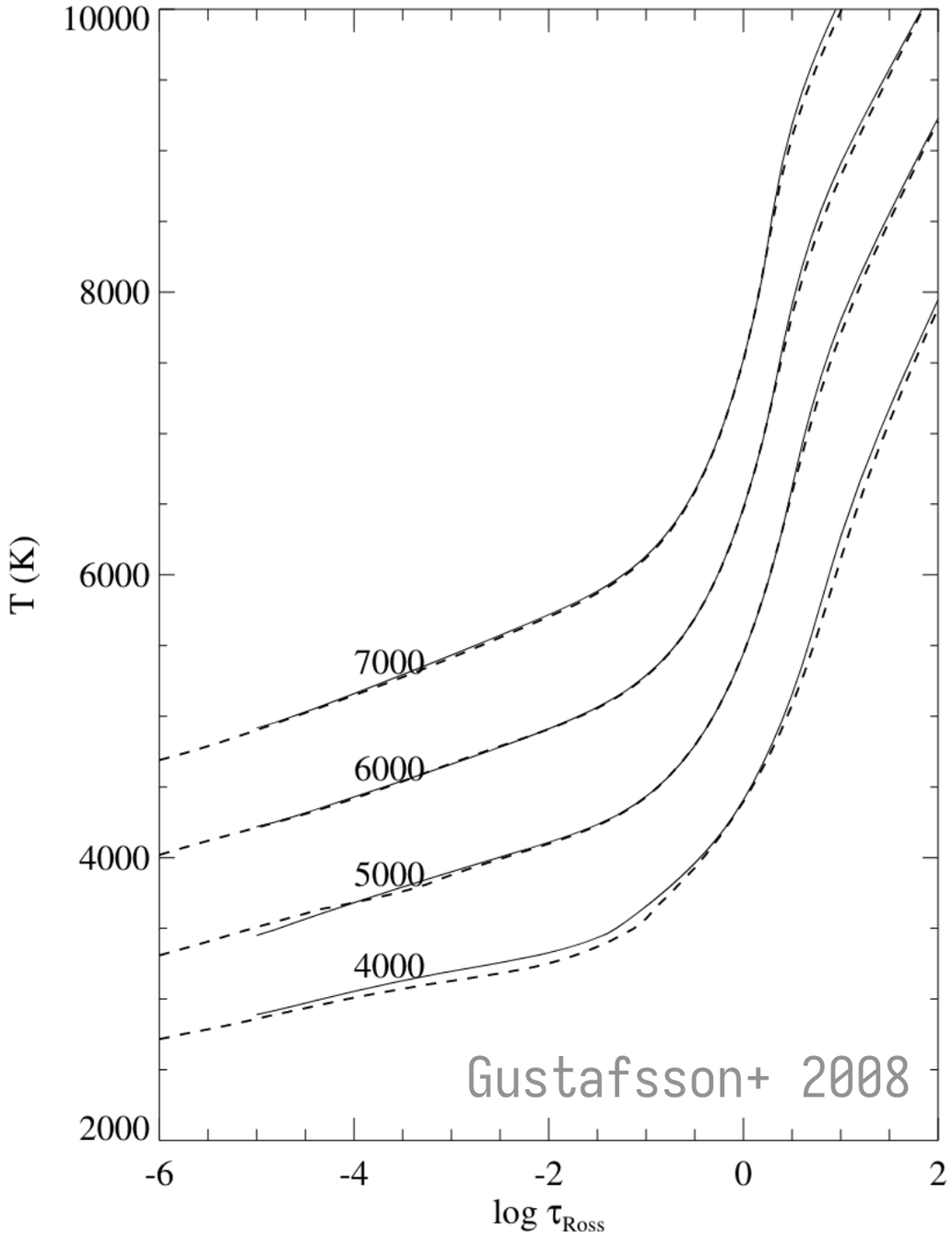
M-H-D formalism seems to not apply.



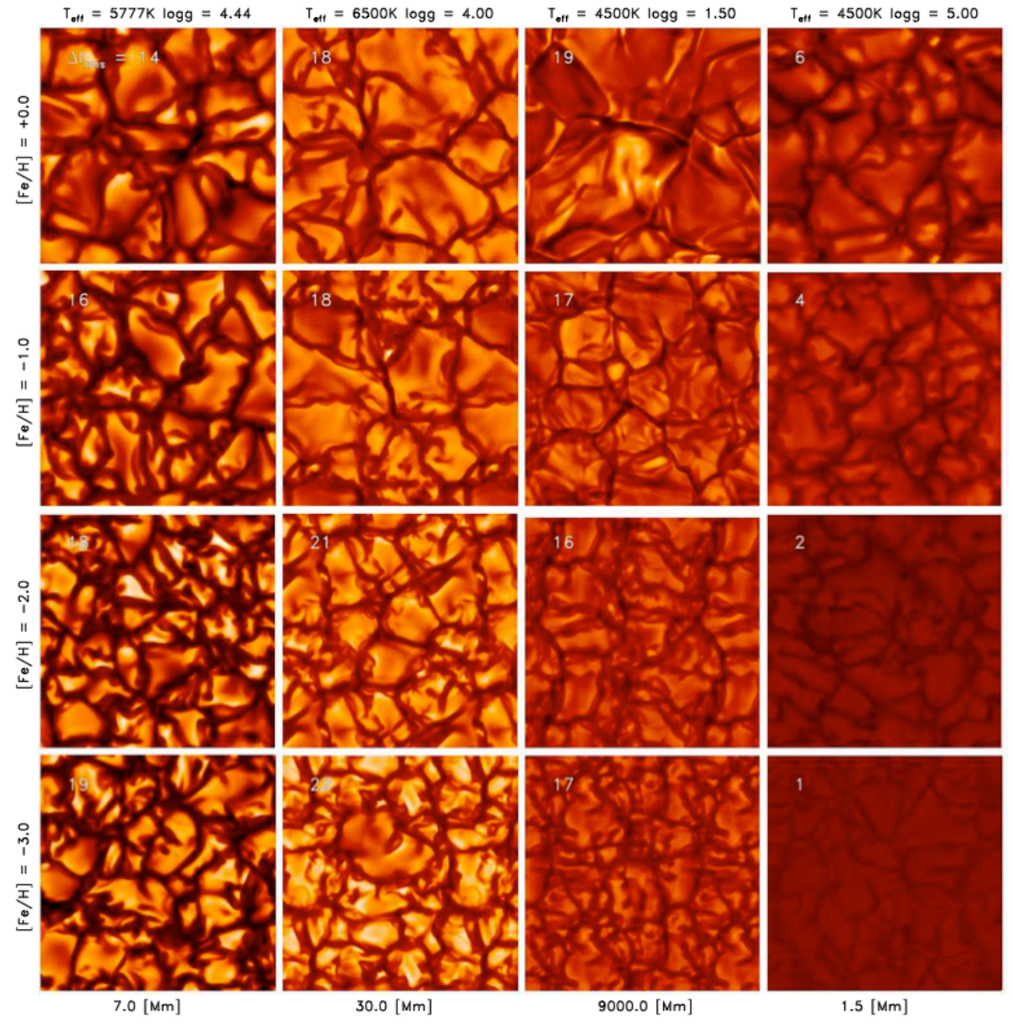
Gaia FGK benchmark data: Heiter+ 2015, Blanco-Cuaresma+ 2014, Jofré+ 2014

A check on model atmospheres: empirical $T(\tau)$ from spectra

We have these by the 10^5



We have these by the dozen



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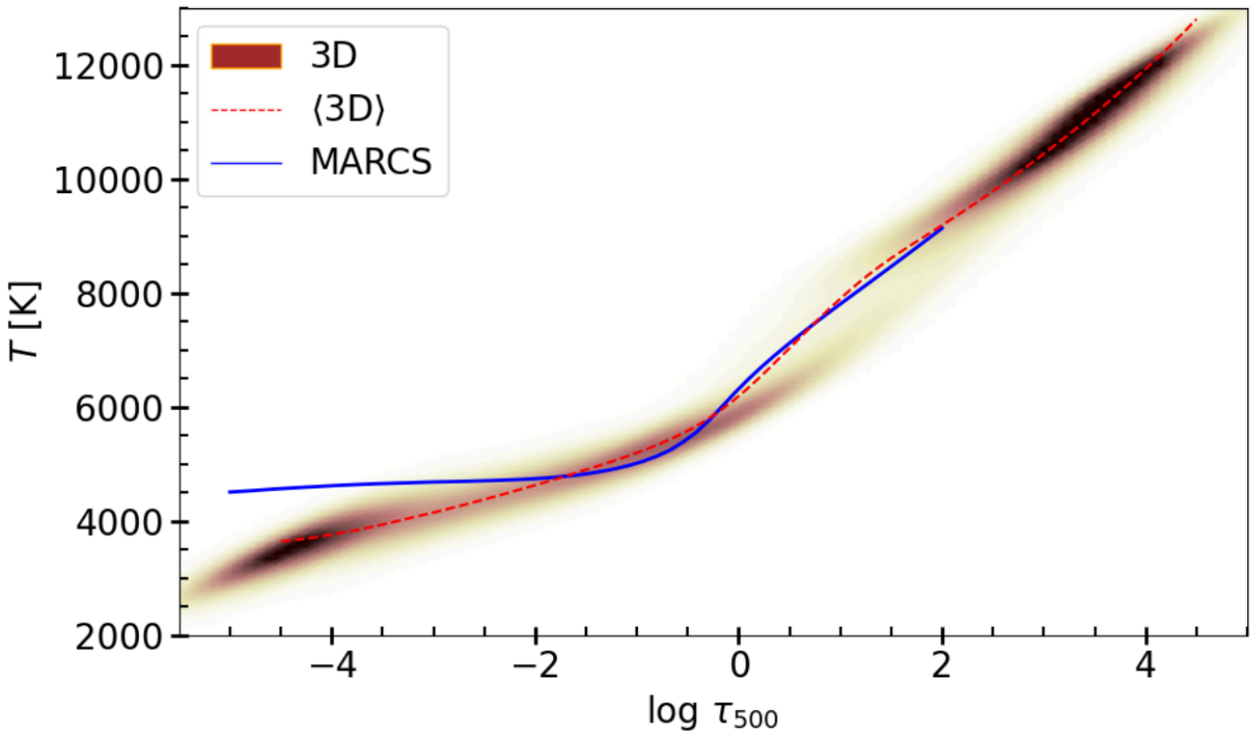
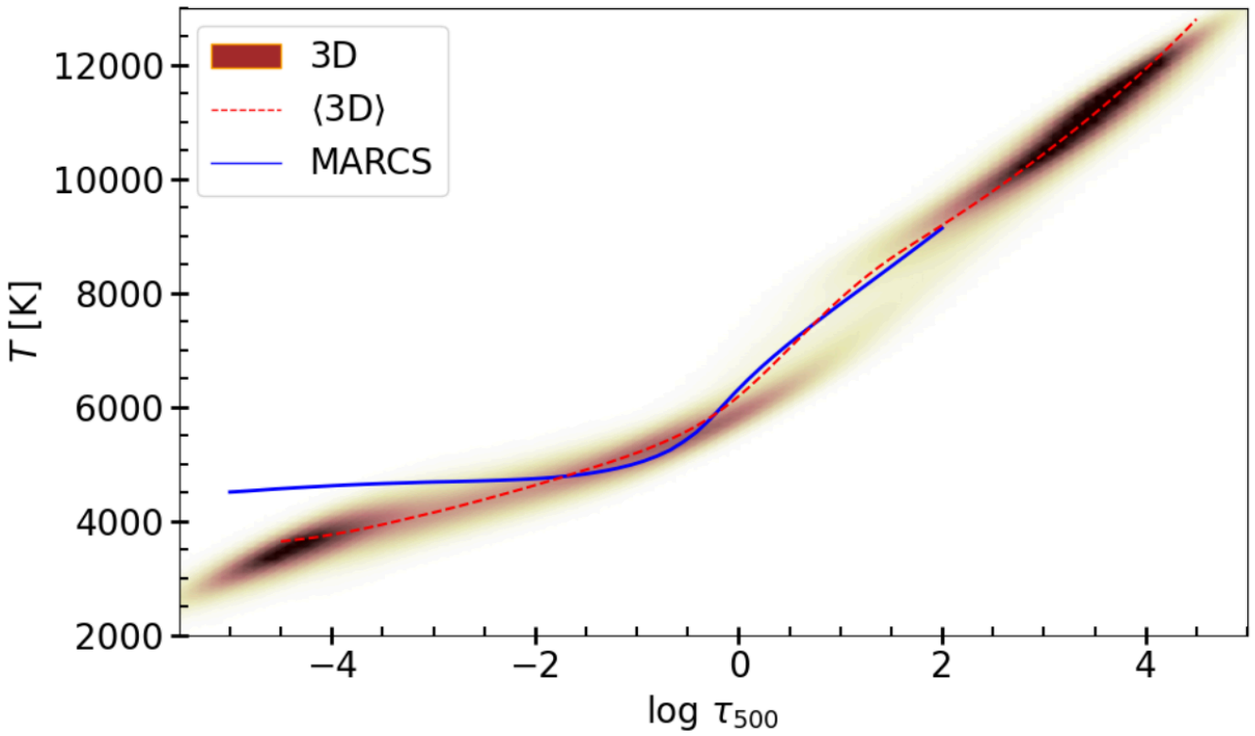


3D effects can be summarized surprisingly well in 1D (Magic+ 2013).

We should be able to infer them from data.

A check on model atmospheres: empirical $T(\tau)$ from spectra



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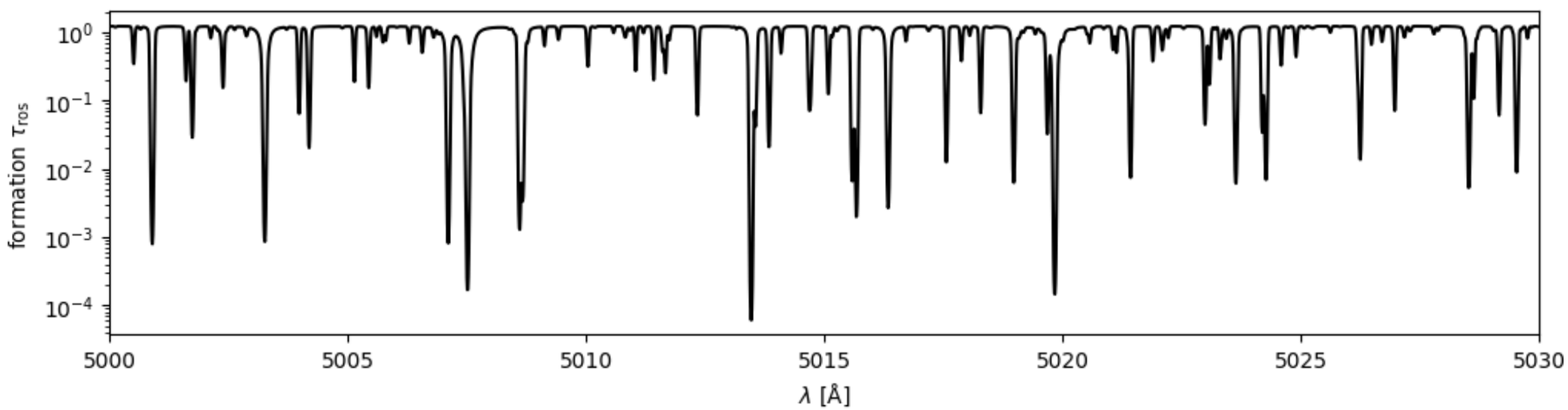
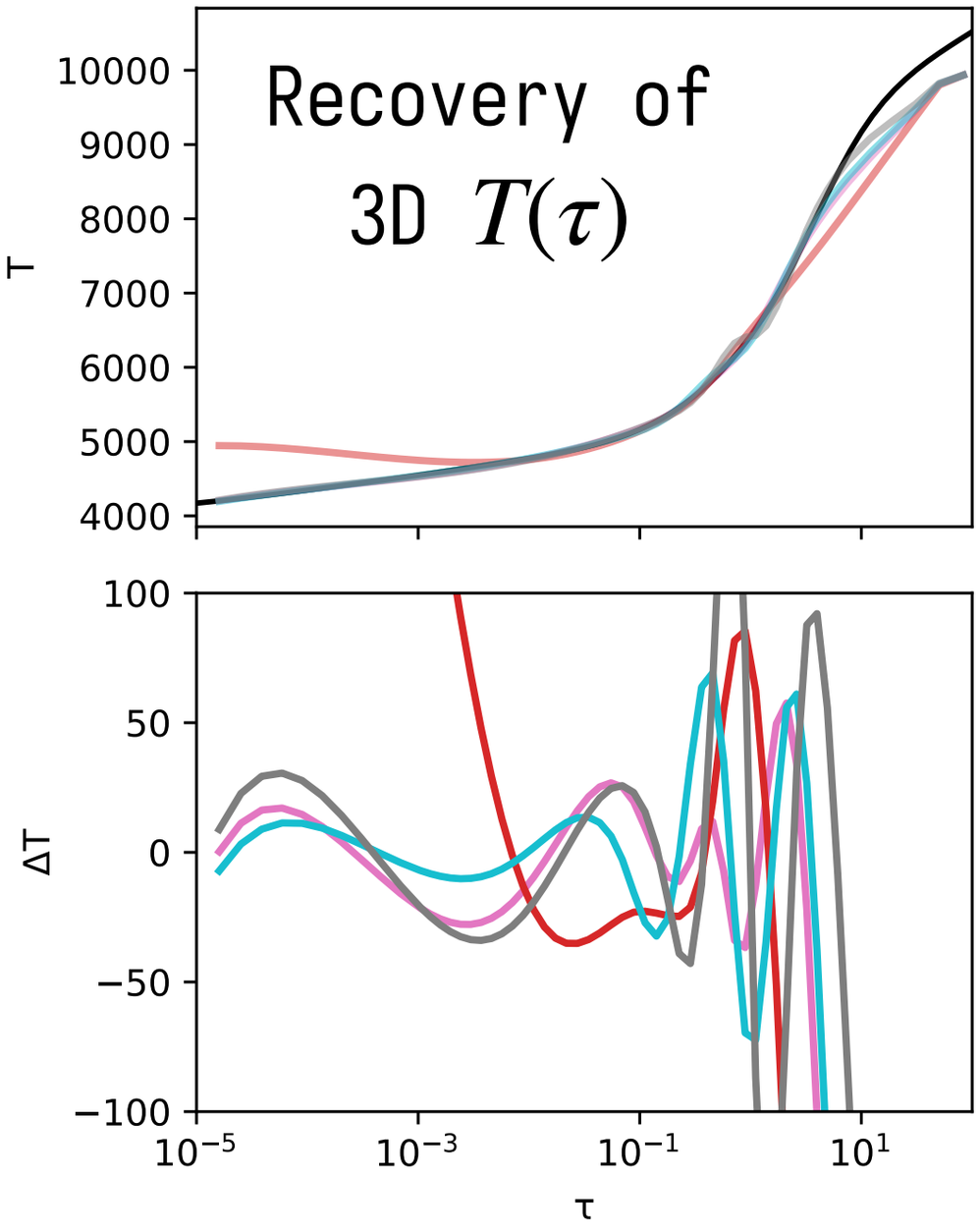
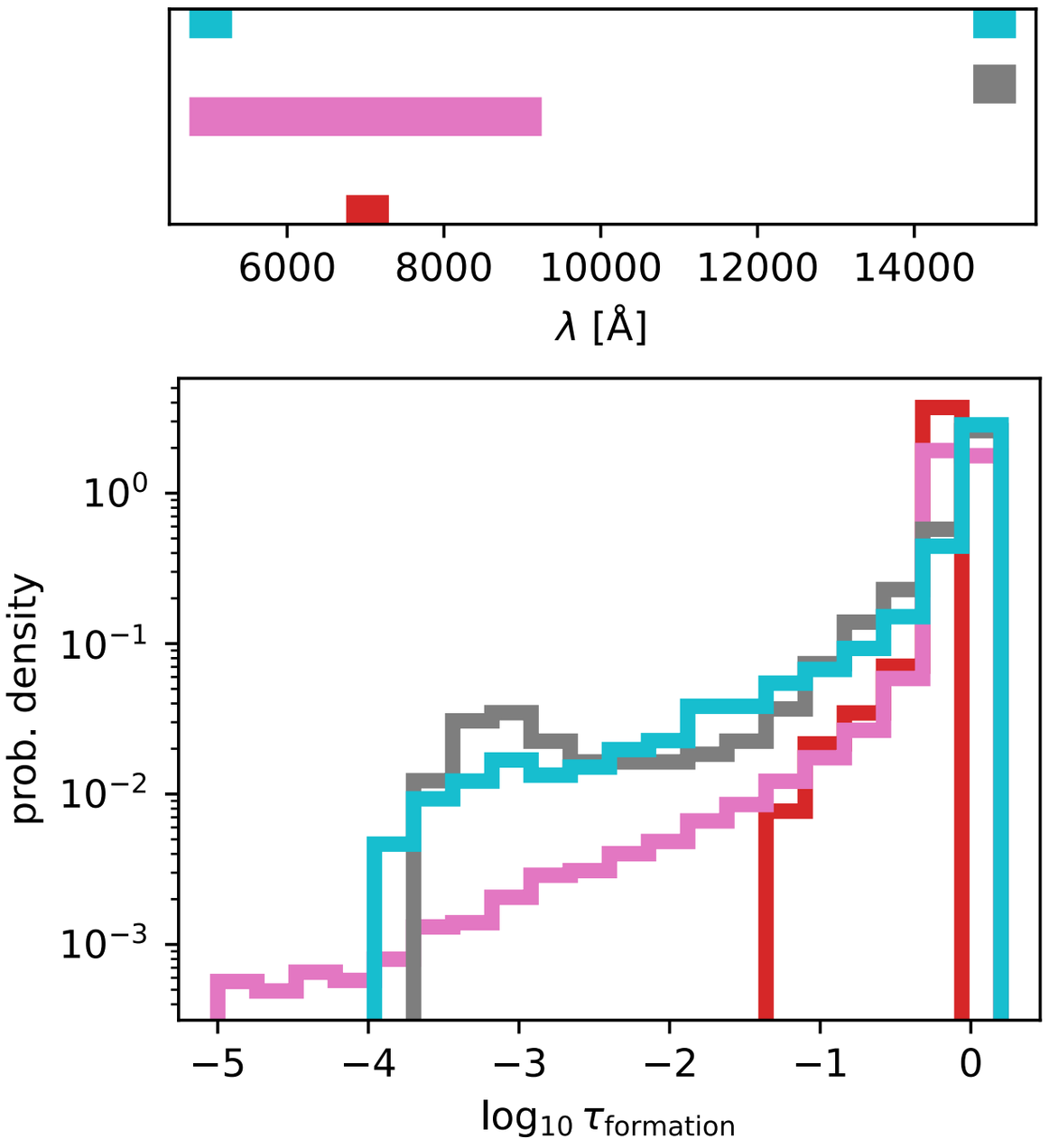
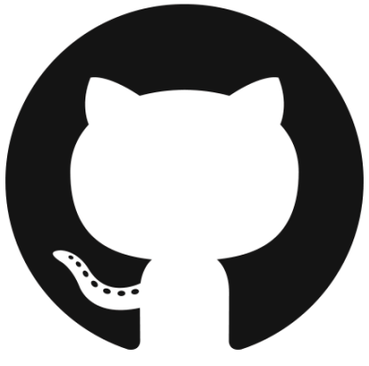


Ability to infer $T(\tau)$ depends on wavelength coverage, but it's possible







Thanks!
github.com/ajwheeler/Korg.jl

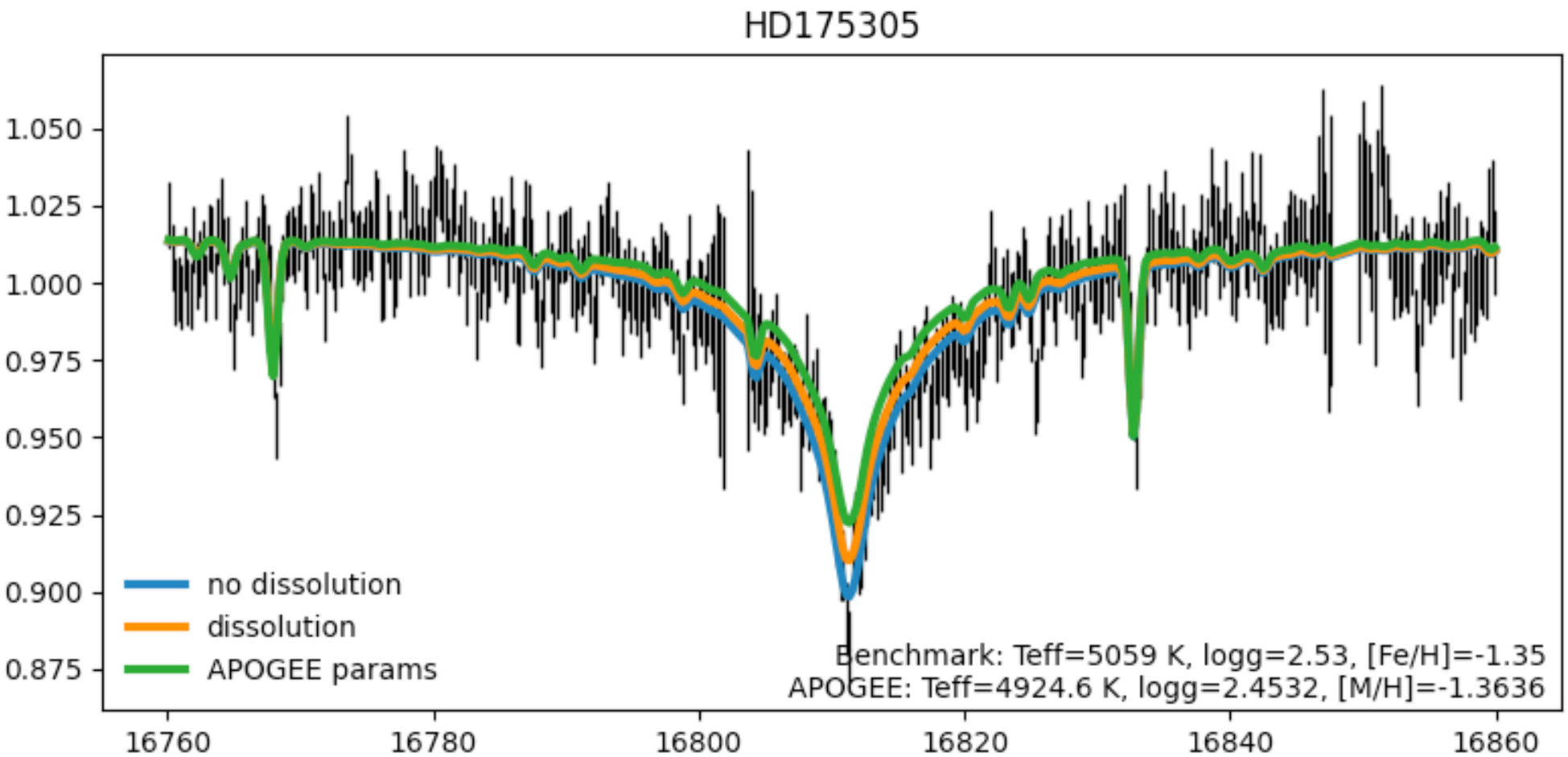
- Consider Korg for you stellar spectral synthesis needs

- Be extremely wary of fits to cool stars, the model atmospheres are treacherous.

- We can now model H lines in the IR better -> stellar params from 5000 K - 8000 K will likewise improve. But there is still a puzzle RE plasma effects.

new Brackett lines give much better fit with benchmark params than APOGEE DR 17 params

M-H-D formalism seems to not apply.



Gaia FGK benchmark data: Heiter+ 2015, Blanco-Cuaresma+ 2014, Jofré+ 2014

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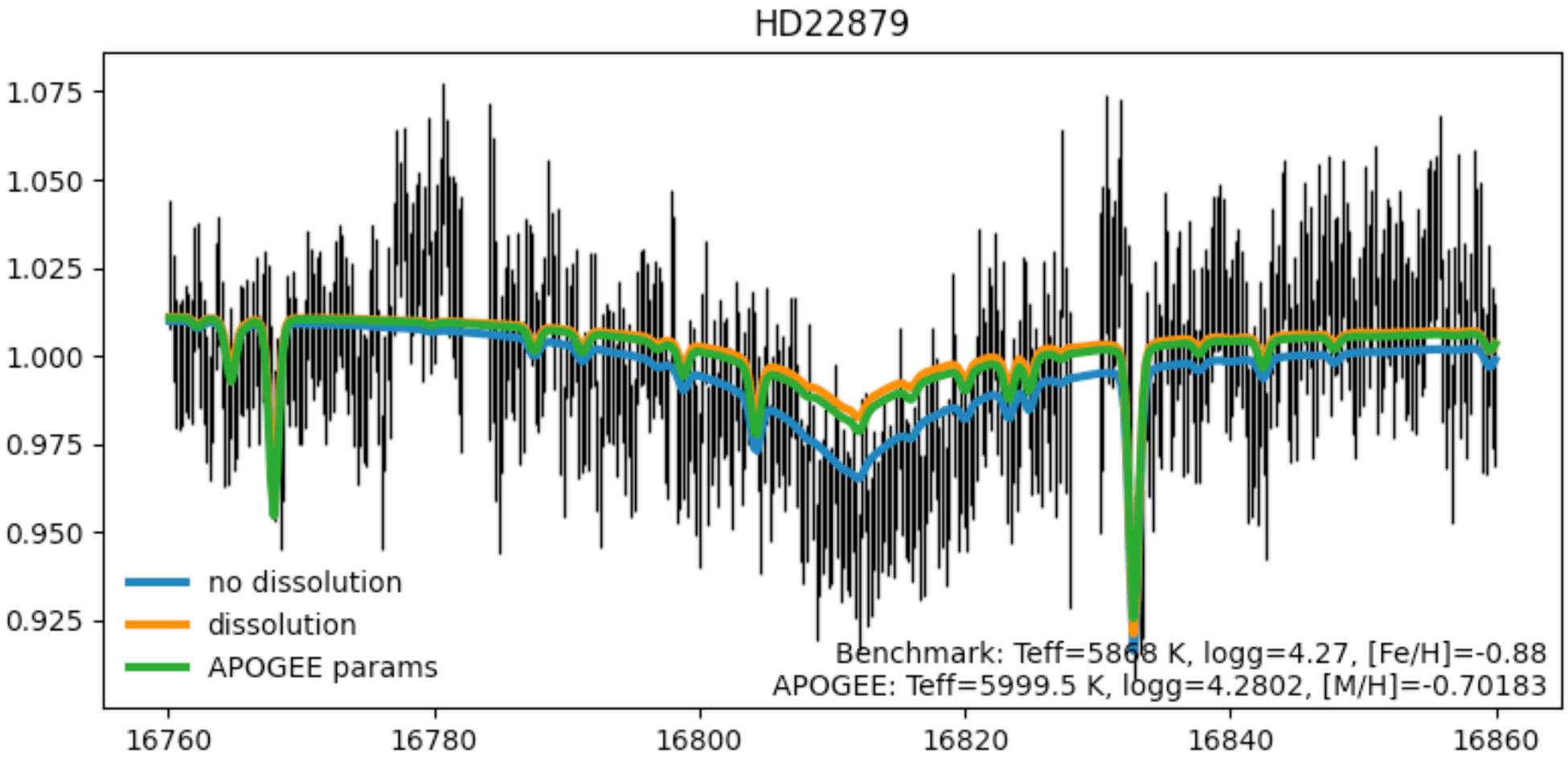

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