Spectroscopy Made Easy

(18th Russbach School on Nuclear Astrophysics, 14 March, 2023)

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Outline

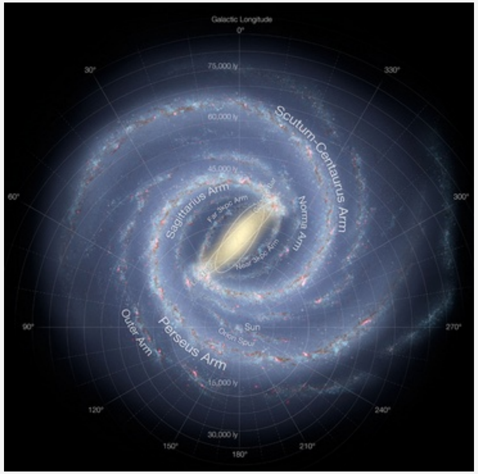
1) Motivation and aim

2) Overview of stellar parameters

3) Pipeline: Deriving physical quantities from stellar spectra

1) Motivation and aim

- In the context of **Galactic archaeology** we want to understand the formation of stellar populations in the Milky Way, e.g.: How did the prominent bar in the Milky Way form?



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- The stars are our fossils that provide insight into the formation history and evolution of the Milky Way.

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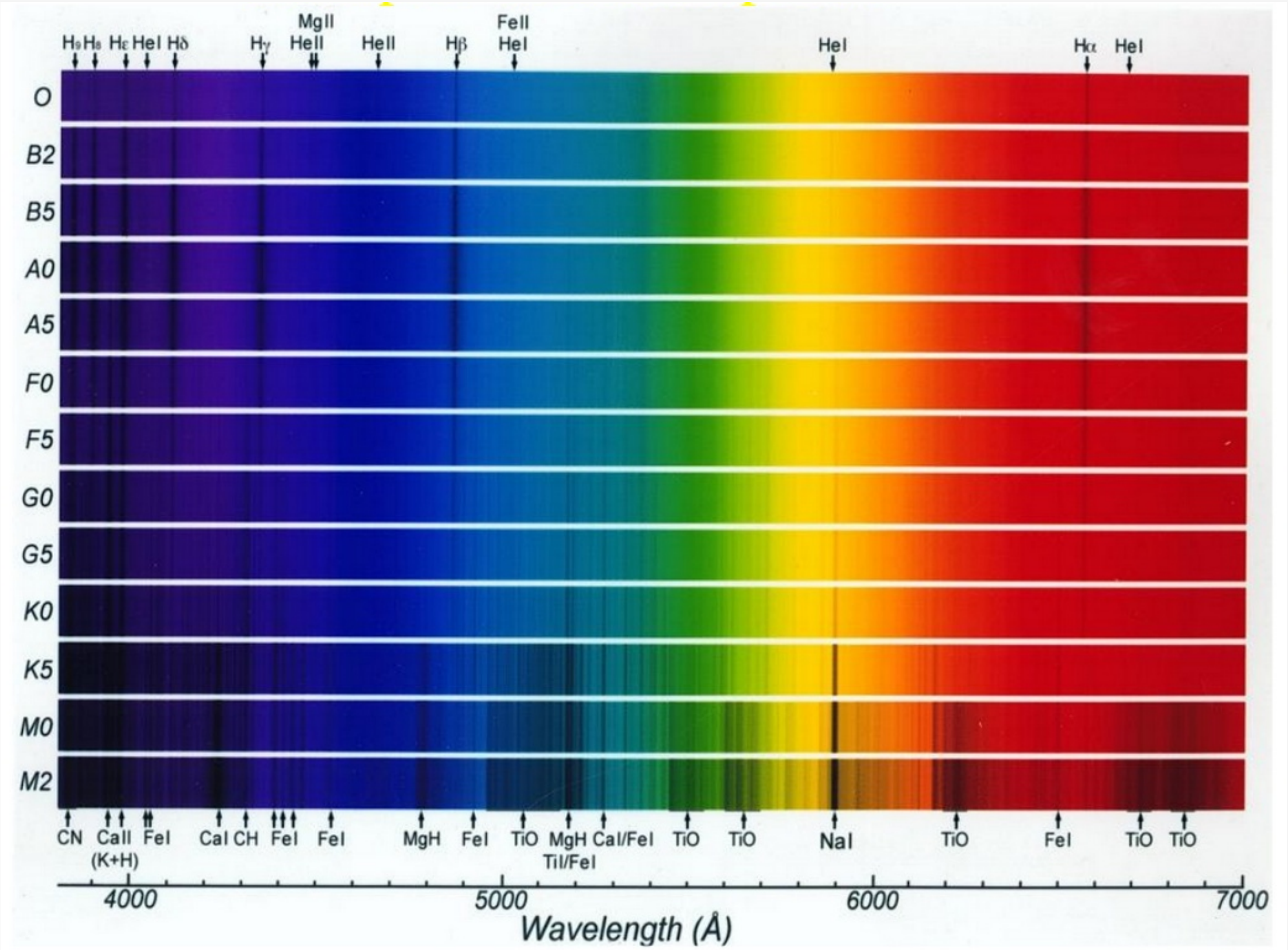
→ We need to measure accurately the **chemical composition** (and dynamics) of the stars.

1) Motivation and aim



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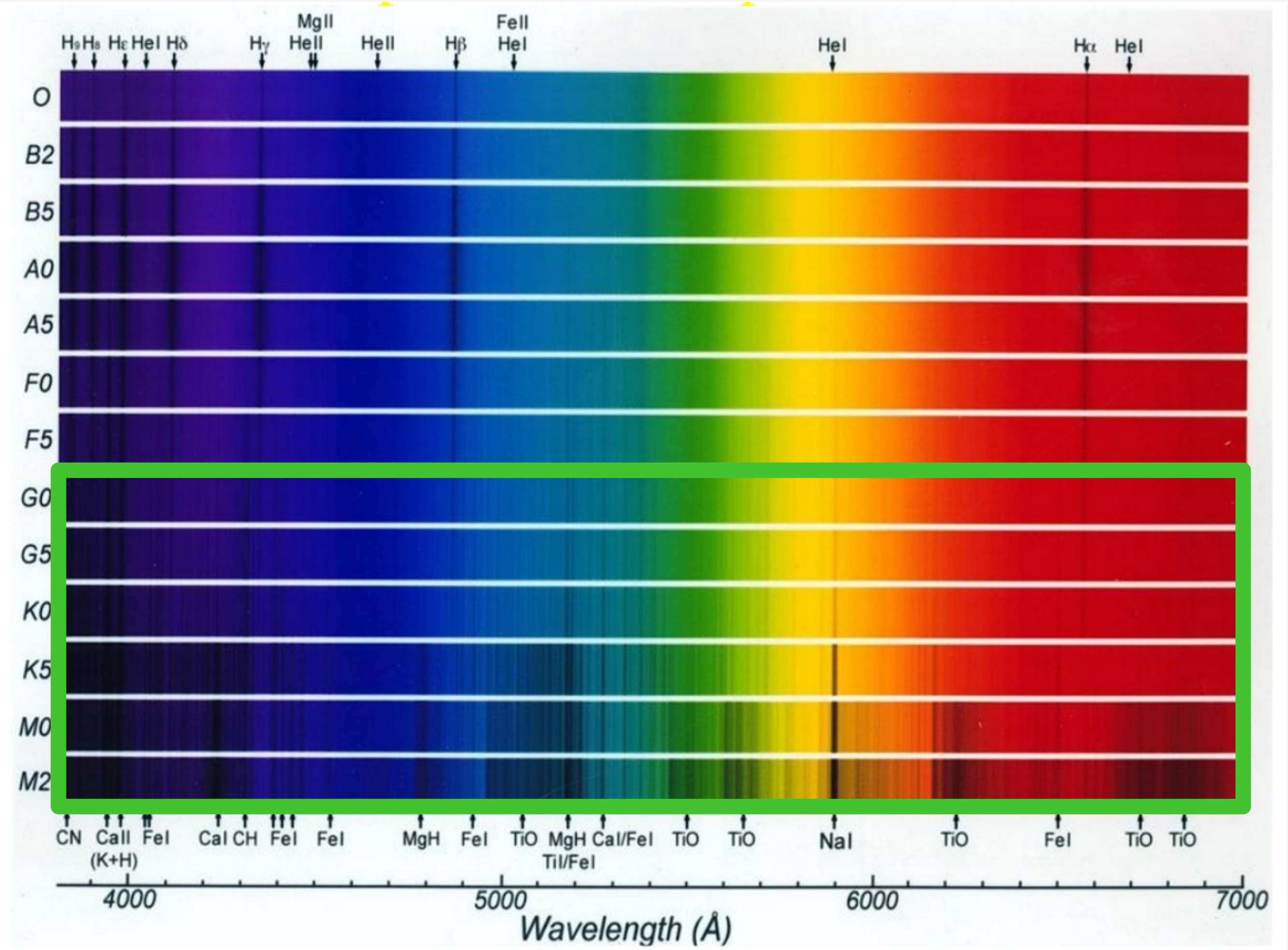
1) Motivation and aim



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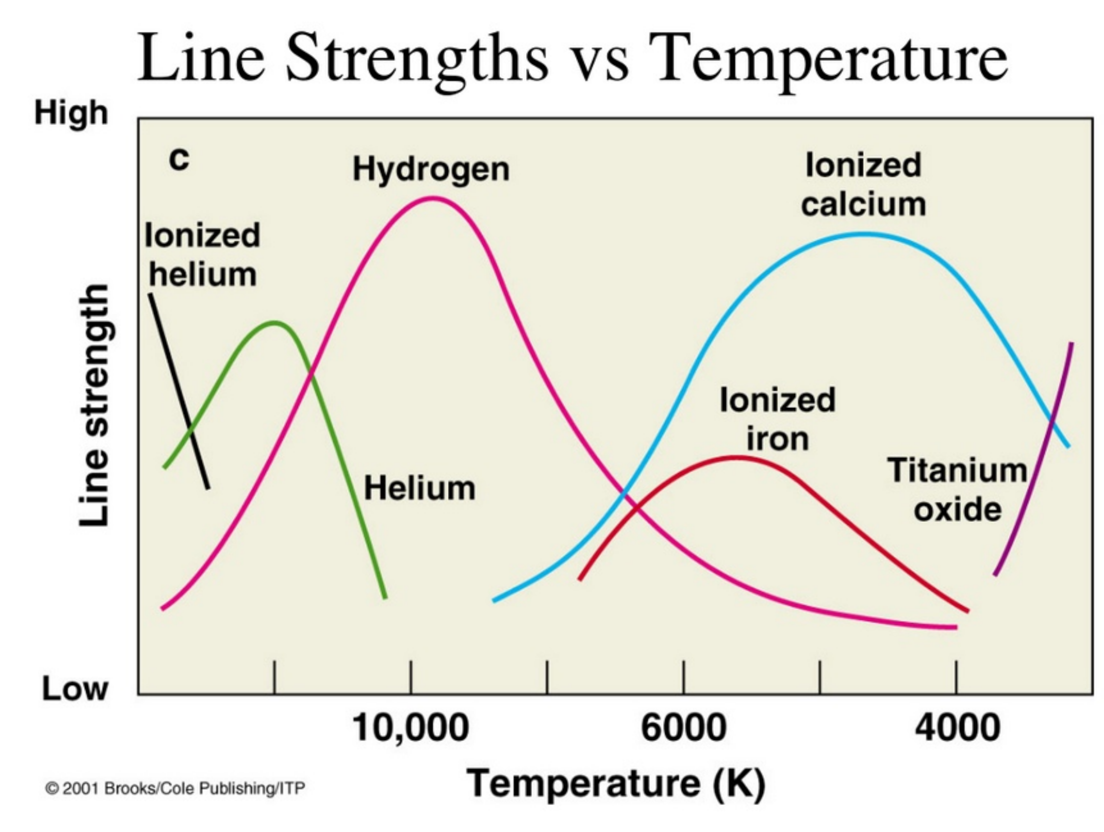
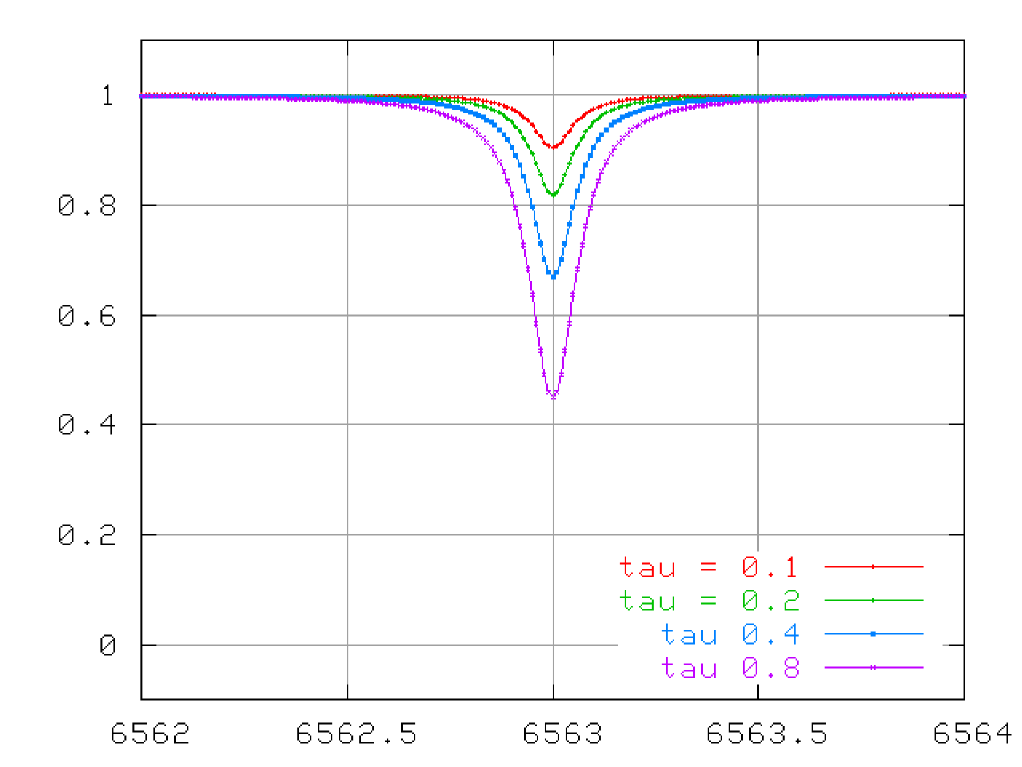
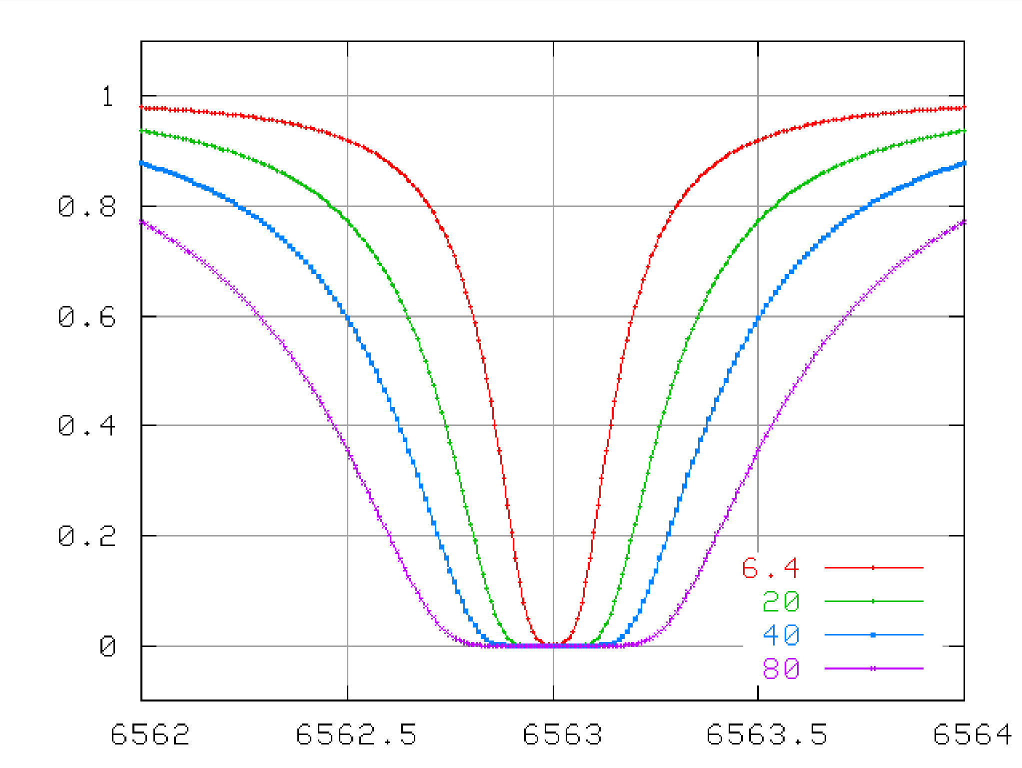
1) Motivation and aim



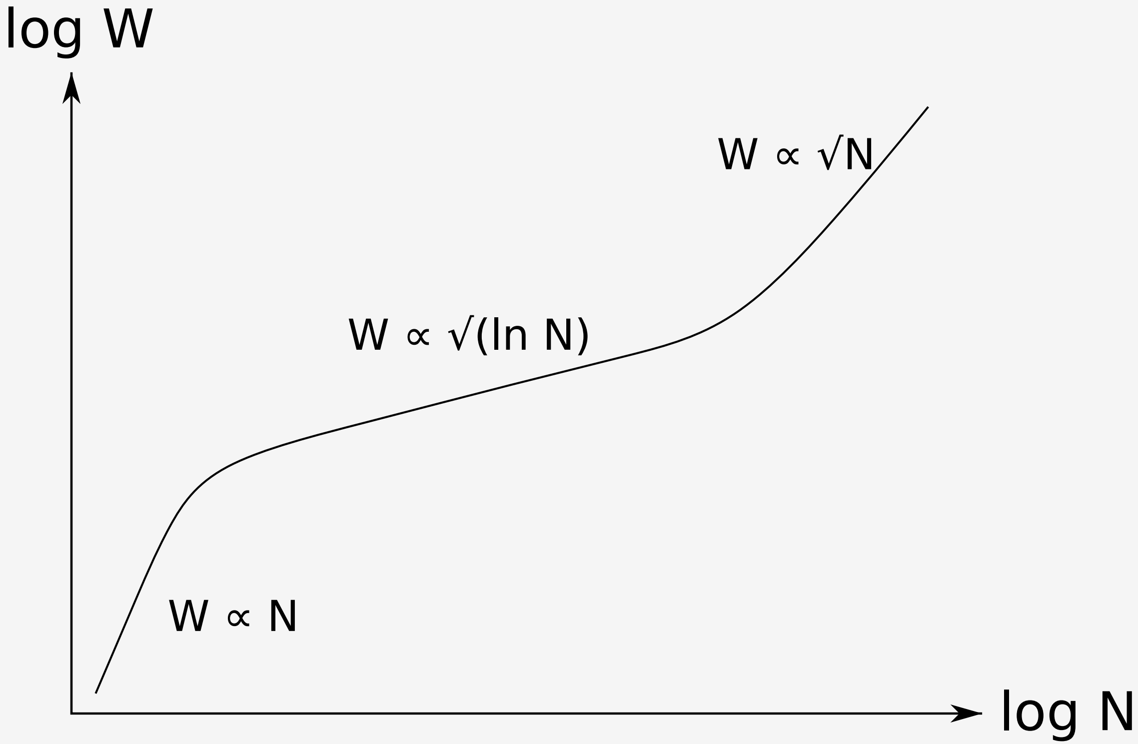
Collapsed 2D spectrum → 1D



Collapsed 2D spectrum → 1D



Curve of Growth



2) Stellar parameters

Stellar photospheres can be characterized by a handful of parameters:

→ **Effective temperature (Teff)**

temperature of a black body with the same integrated flux as star

$$\boxed{\int F \, d\lambda = \sigma_B \, T_{eff}}$$

→ **Surface gravity log g**

logarithm of the gravitational acceleration at the surface of the star

$$\boxed{g \propto M/R^2}$$

In the outer layers of the star, where the spectrum is created and M is essentially independent of the radius, it determines gas density!

2) Stellar parameters

Stellar photospheres can be characterized by a handful of parameters:

→ Metallicity [M/H]

the star mostly consists of hydrogen and helium, but other elements are important too. We define metallcity relative to solar values:

$$\boxed{[M/H] = \log_{10}\left(\frac{M}{H}\right) - \log_{10}\left(\frac{M_\odot}{H_\odot}\right)}$$

M... number of particles of all metals
H... number of hydrogen particles

(sun has [M/H]=0 by definition)

2) Stellar parameters

Stellar photospheres can be characterized by a handful of parameters:

→ Projected rotational velocity v sin(i)
stellar rotation as seen from Earth, with i being the inclination of the rotation axis relative to line of sight

→ microturbulence v_{mic} and macroturbulence v_{mac}
high-order pulsations, turbulence, convection and stellar activity cannot be spatially resolved → v_{mic} and v_{mac} are used to describe effects on line

motions on scales < mean free path length
→ increased line opacity

motions on scales > mean free path length
→ change line shape, not strength

2) Stellar parameters

Note: A star has more characteristics, e.g. age, evolutionary status, or binarity, but those are not relevant for the measured stellar flux. The pipeline only includes parameters, that we need to measure with high precision, in order to accurately model the stellar spectrum.

3) Pipeline

- Pipeline based on SME (Spectroscopy Made Easy) which was written in `IDL` and complemented by a `C++` and `FORTRAN` library (Valenti & Piskunov 1996)

- Library has undergone significant development (Piskunov & Valenti 2017)

- Recently, Wehrhahn et al. (2022) translated code to `python`

3) Pipeline

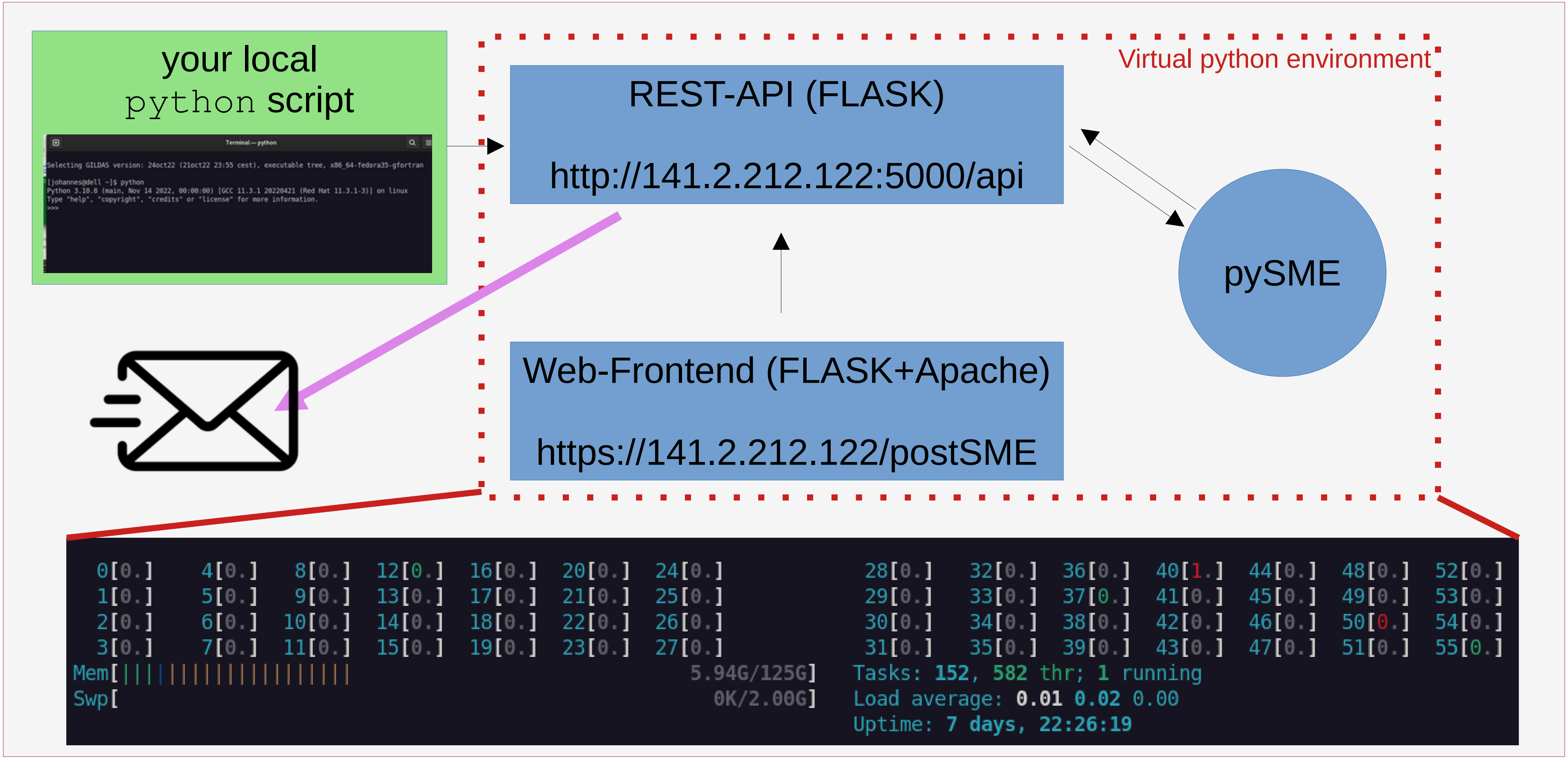
- We extended pySME with two new features:
  i) a web interface that allows users to upload and visualize observed 1-dimenstional spectra

  ii) implementation of MCMC routines to infer uncertainties of the derived parameters

- Moreover, we updated some of the intrisic features to produce results based on the latest developments in the field:
  i) we make use of the Gaia-ESO line list of Heiter et al. (2021)

  ii) inclusion of the most recent solar reference abundances of Asplund, Amarsi and Grevesse (2021) to allow for accurate metallicity derivations.

3) Pipeline Development



Minimum example script to call REST-API

```
import requests

api_url='http://141.2.212.122:5000/api'

json={'spectrum':'sun.fits', 'email': ['johannes@jpuschnig.com'],\
     'fitparams': ['teff', 'logg', 'monh'],'abund': ['asplund2021'],\
     'linelist': ['Gaia-ESO']}

headers = {'Content-type': 'application/json; charset=UTF-8'}
response = requests.post(api_url, json=json, headers=headers)

result_html=response.text

file = open('result.html', 'w')
file.write(result_html)
file.close()
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```
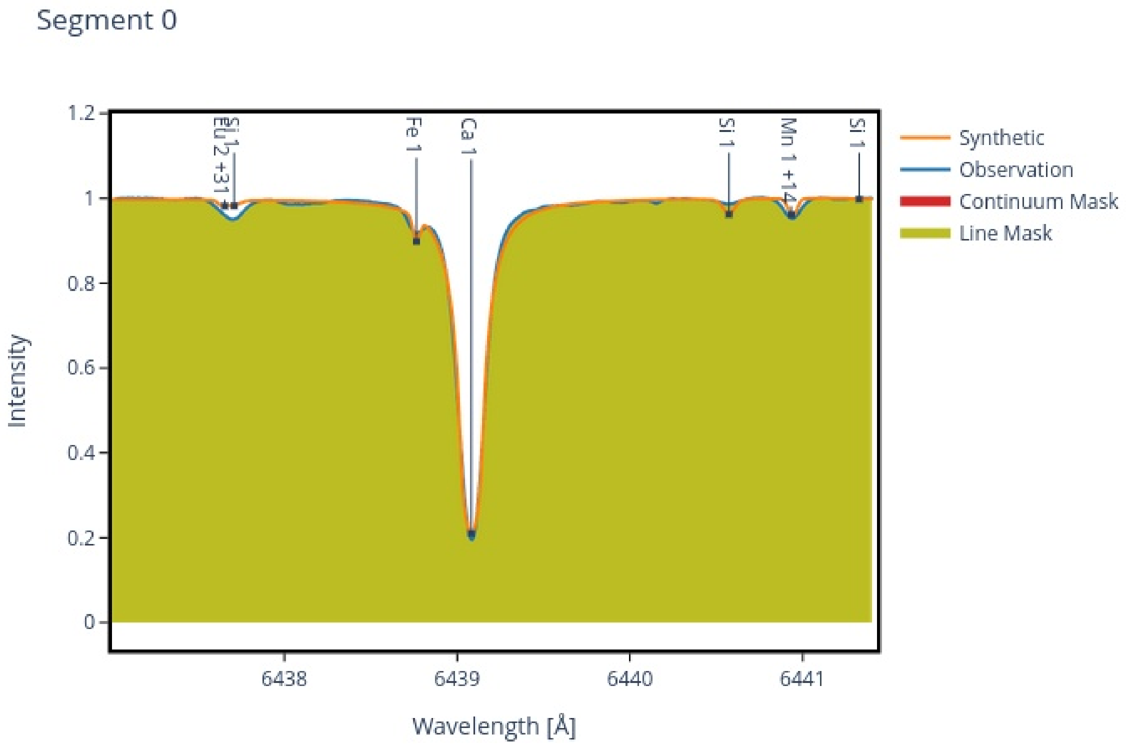
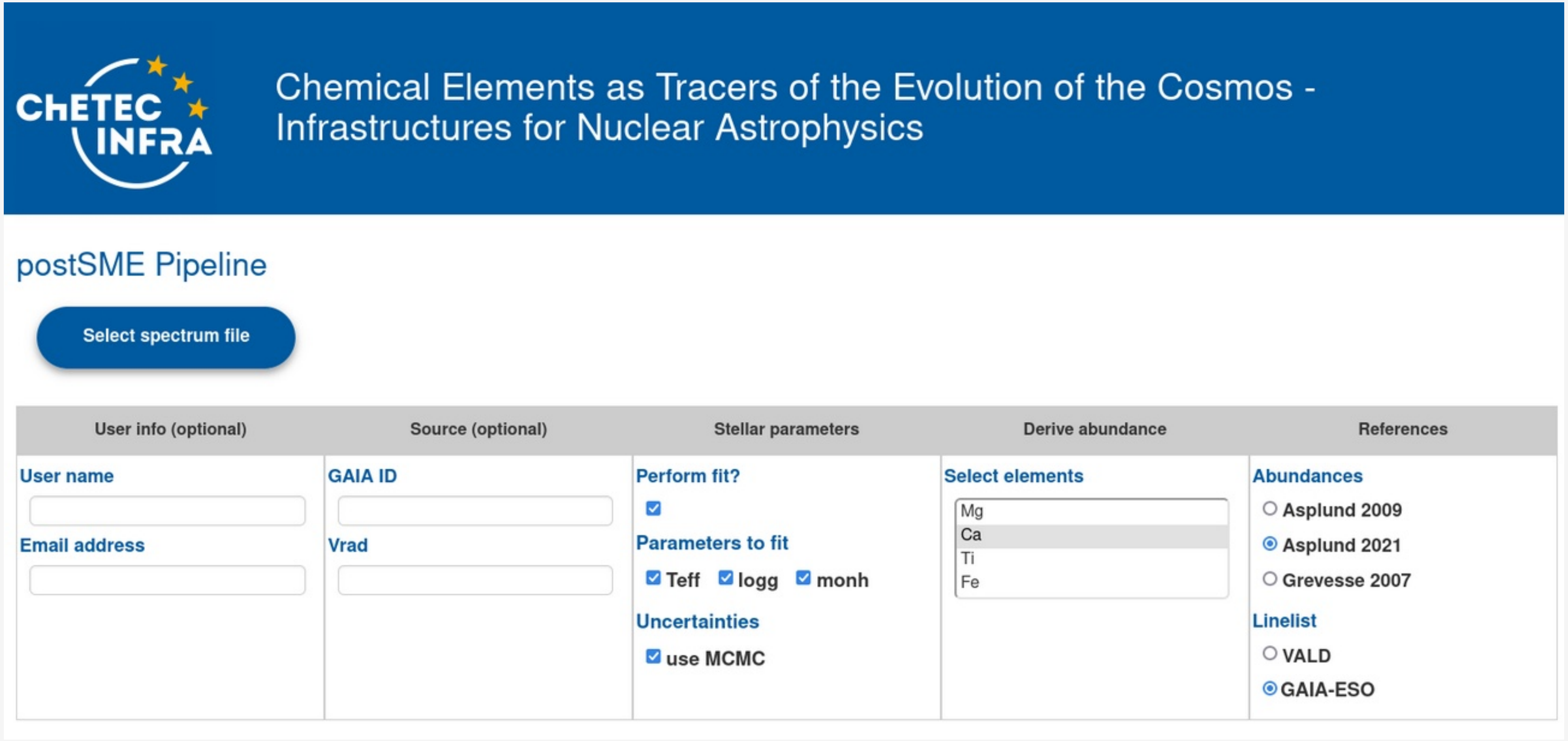

3) Pipeline Result

postSME Results

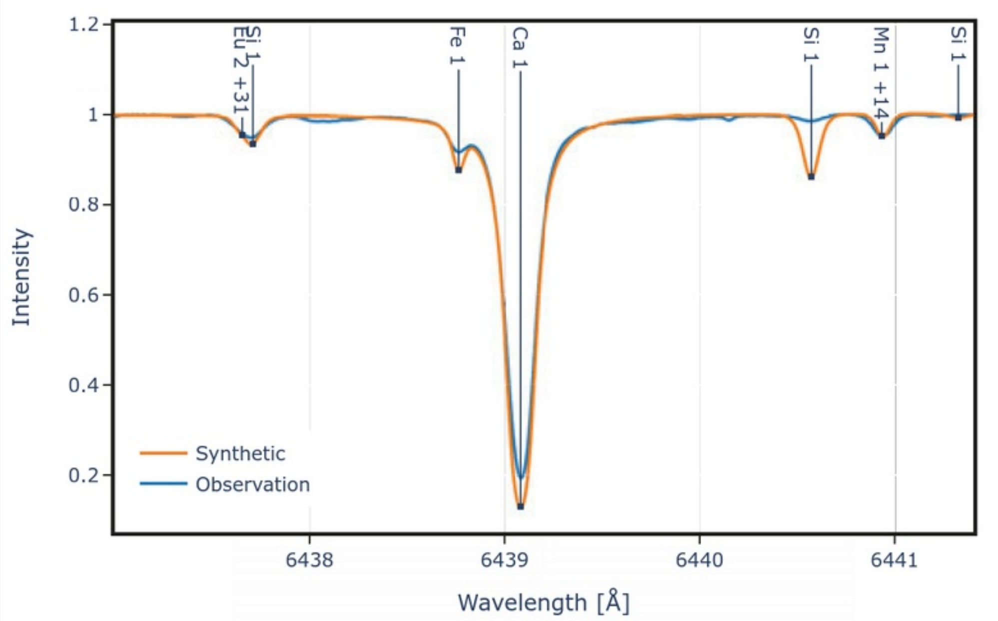
teff: 4906.846
logg: 4.213
monh: -0.815

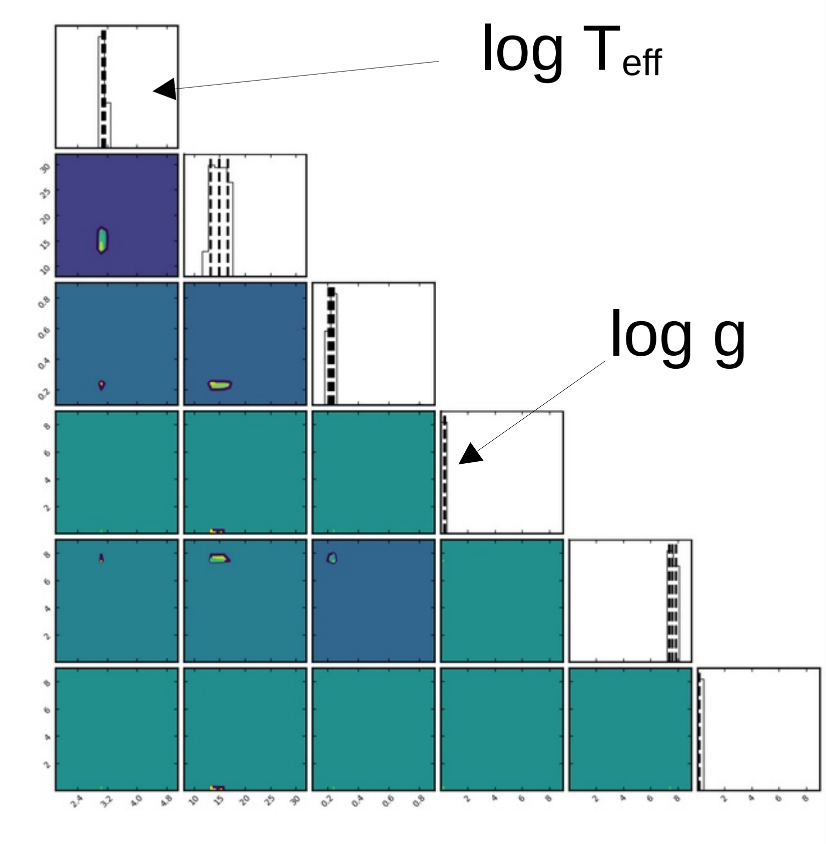


3) Pipeline – Web Frontend



3) Pipeline – Result





Thanks for Listening

Questions?

The pipeline will be made publicly available soon.