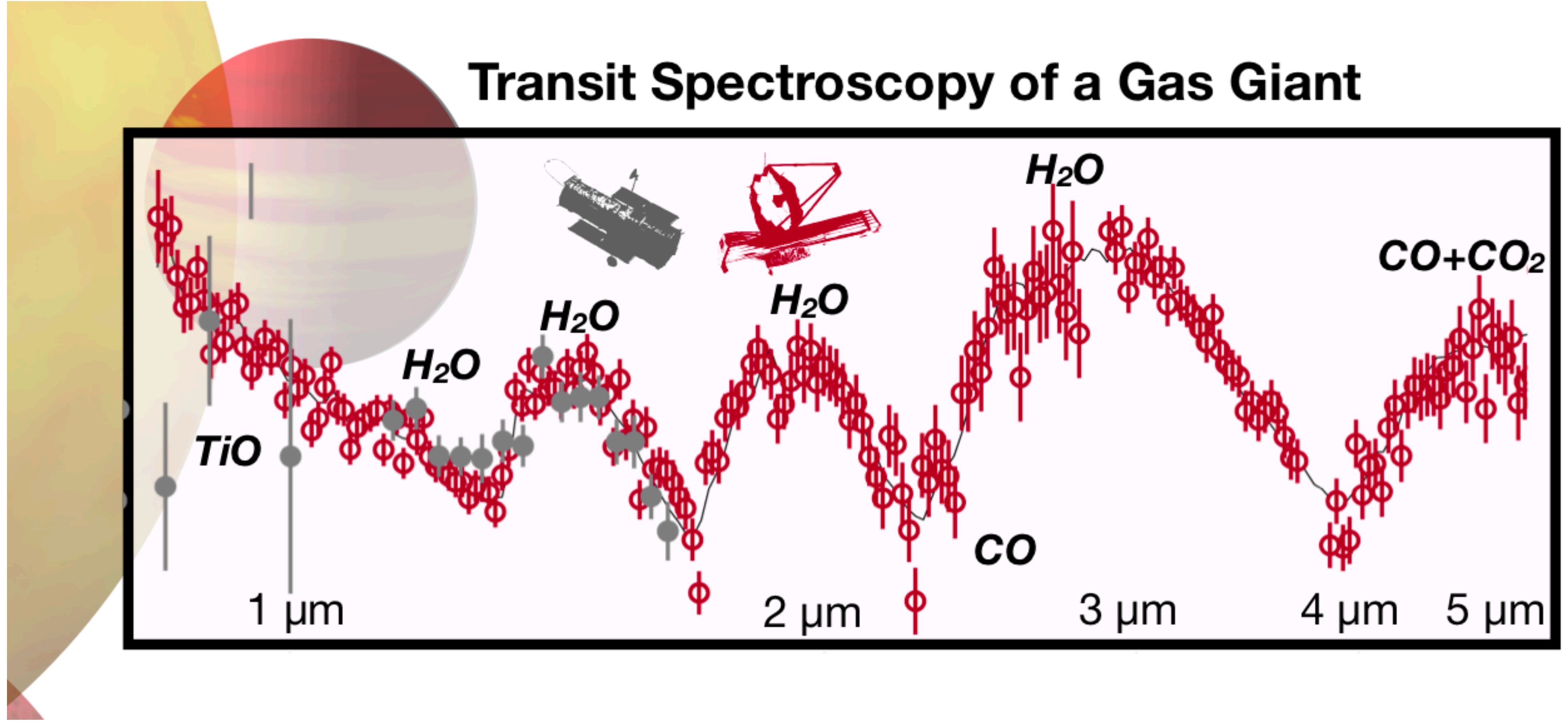
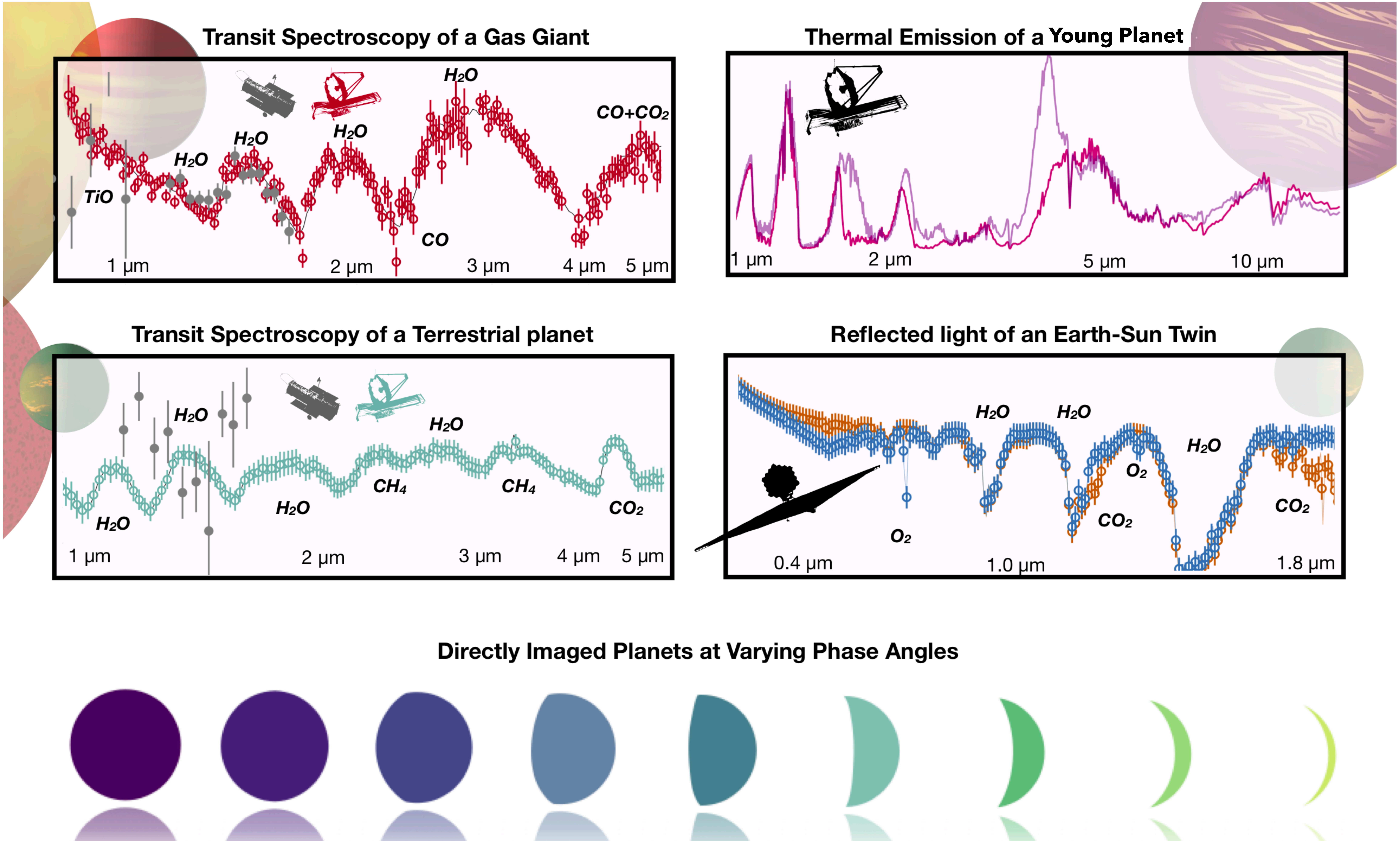


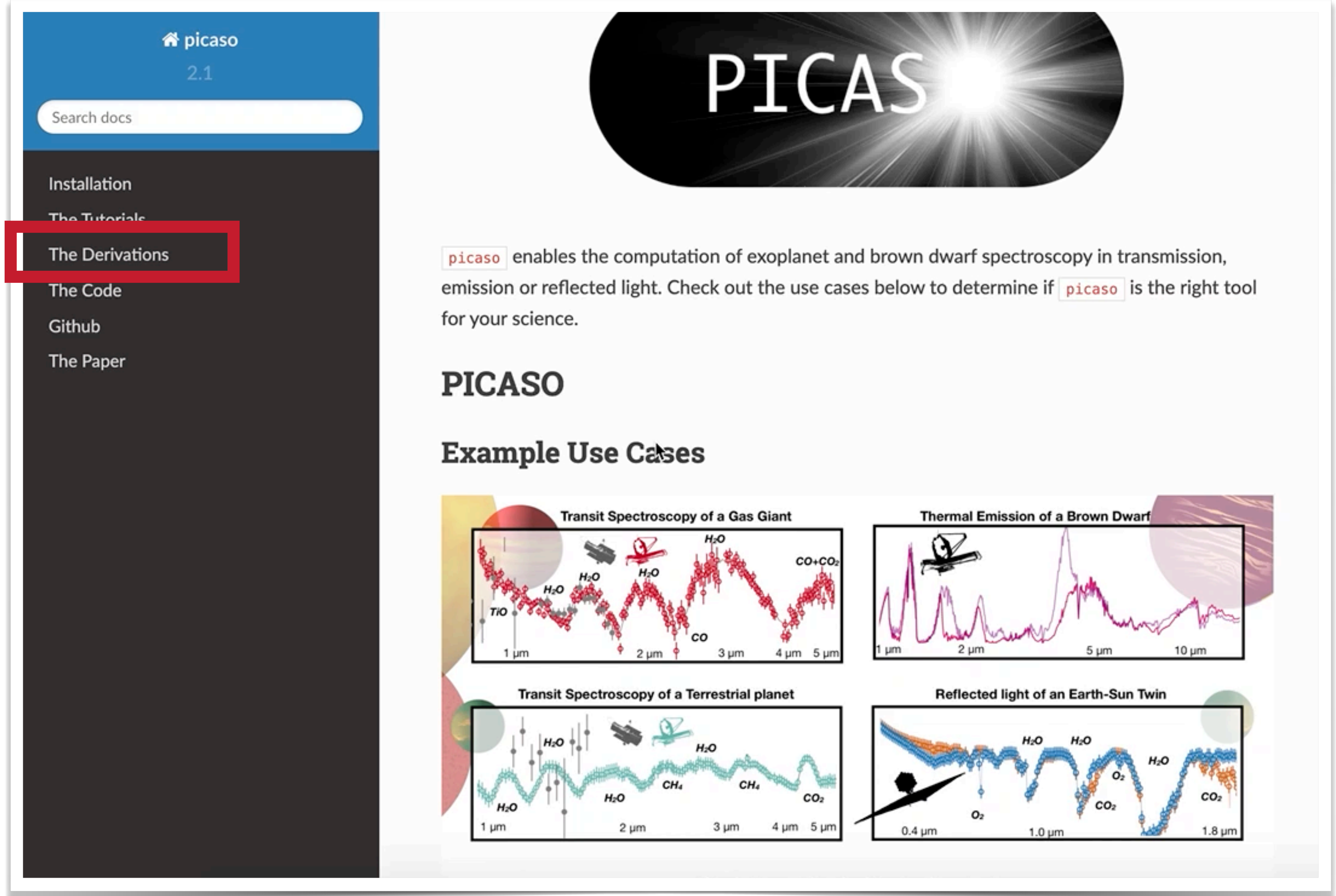
7/26/2023

Forward Modeling with PICASO

Natasha Batalha (NASA Ames)


Transit Spectroscopy of a Gas Giant
TiO
H2O
H2O
H2O
H2O
CO
CO+CO2
1 µm
2 µm
3 µm
4 µm
5 µm
Thermal Emission of a Young Planet
1 µm
2 µm
5 µm
10 µm
Transit Spectroscopy of a Terrestrial planet
H2O
H2O
H2O
H2O
CH4
CH4
CO2
1 µm
2 µm
3 µm
4 µm
5 µm
Reflected light of an Earth-Sun Twin
H2O
H2O
H2O
O2
O2
CO2
CO2
0.4 µm
1.0 µm
1.8 µm
Directly Imaged Planets at Varying Phase Angles

- Code Docs: https://natashabatalha.GitHub.io/picaso



The Tutorials

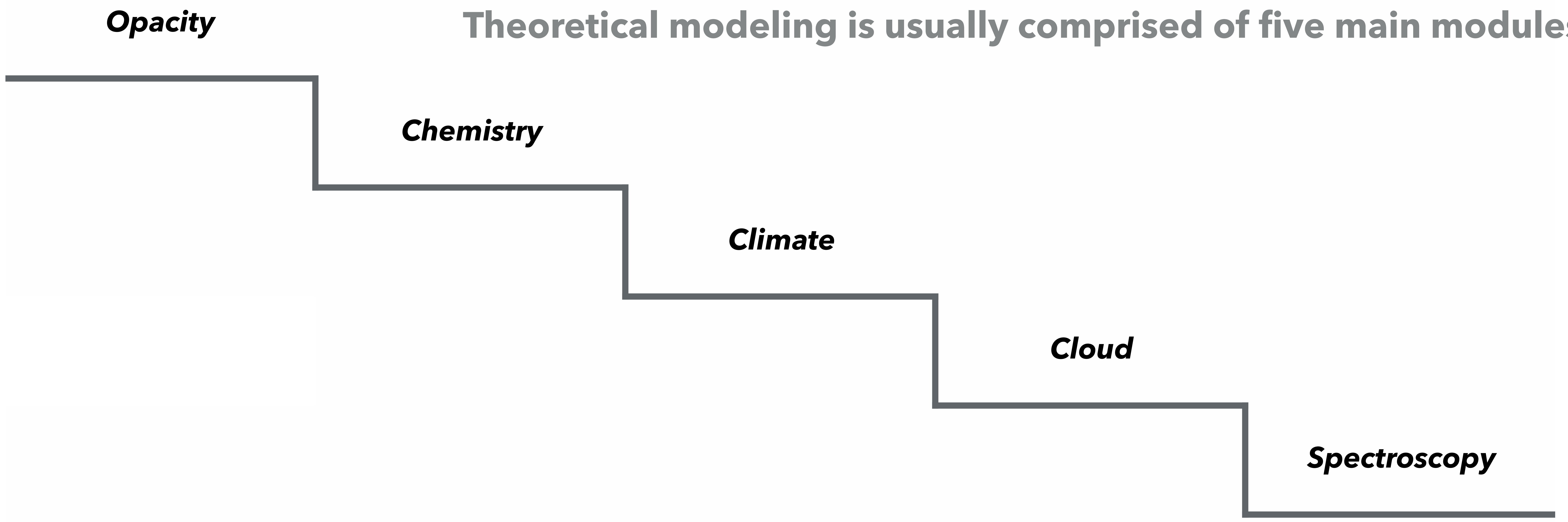
- Basics of Reflected Light
- Basics of Transmisison
- Basics of Thermal Emission
- Cloud Modeling with *Virga*
- Moving to 3 Dimensions
- 1D Climate Modeling
- Fitting models to data
- Model Storage & Reuse
- Opacities
- Radiative Transfer Techniques
- FAQs
- Code Help
- References

The Radiative Transfer in PICASO

An explanation of the code.

Scroll Down

Theoretical modeling is usually comprised of five main modules



Theoretical modeling is usually comprised of five main modules

Opacity

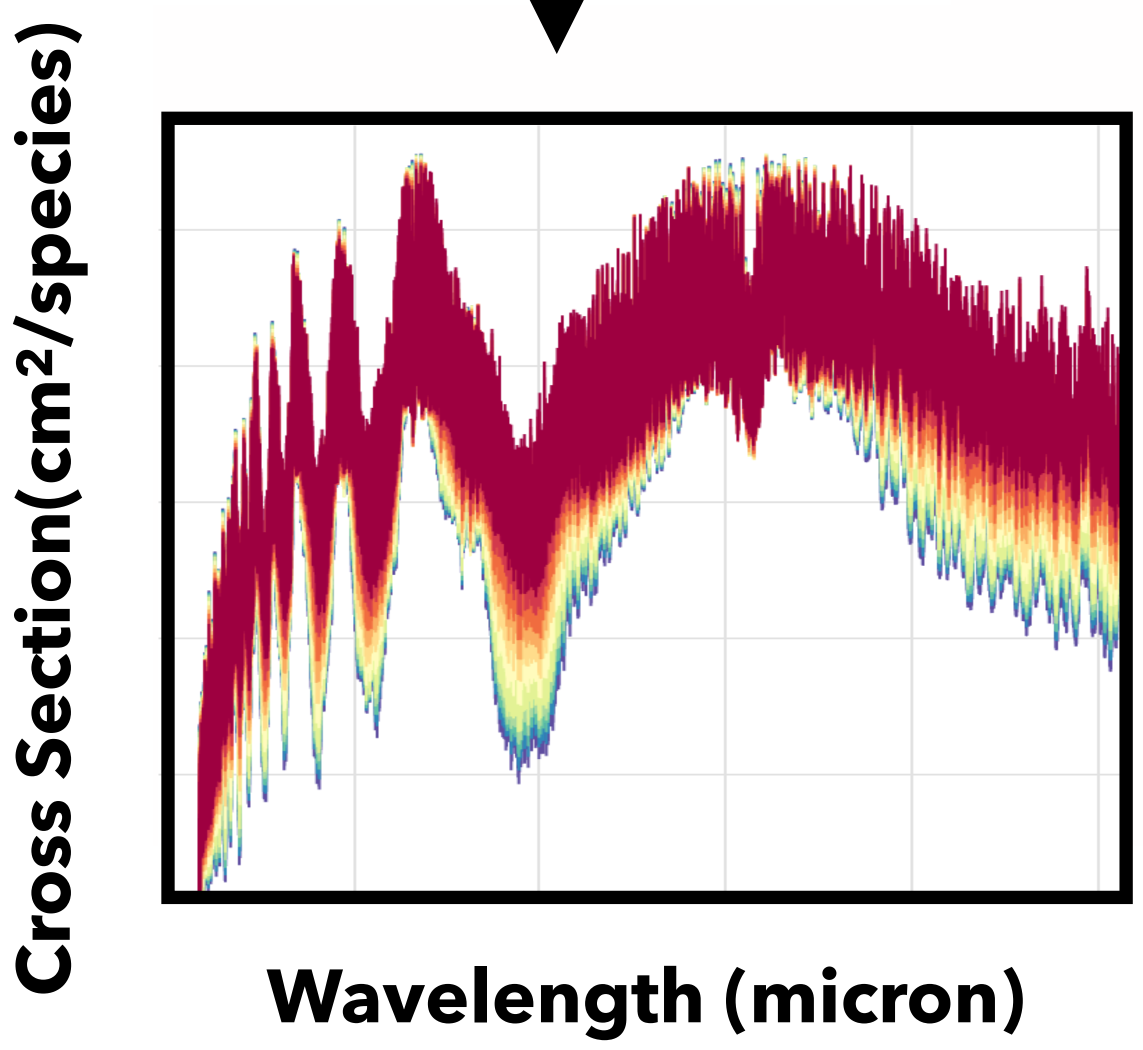
Chemistry

Climate

Cloud

Spectroscopy

```
[ ] opa = jdi.opannection(wave_range=[2.7,6])
```

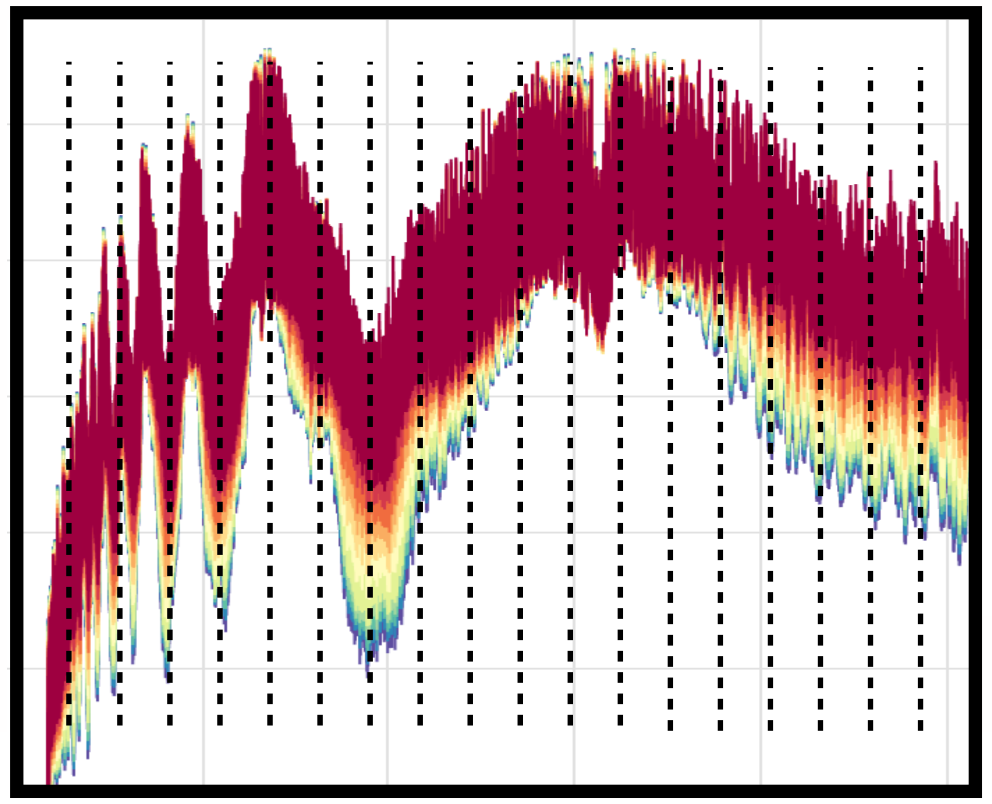


Cross sections are computed "line-by-line"

R=1,000,000

~16 Gig/molecule

What is this processing?



RESAMPLED to R=10,000

But I gave you a much smaller file with cross sections of just a few molecules

What does this mean for my models?

If you are using resampled cross sections, you must rebin your final spectral to 100x lower resolution!!

```
x,y = jdi.mean_regrid(i['wavenumber'],i['thermal'], R=100)
```

Theoretical modeling is usually comprised of five main modules

Opacity

opannection

Chemistry

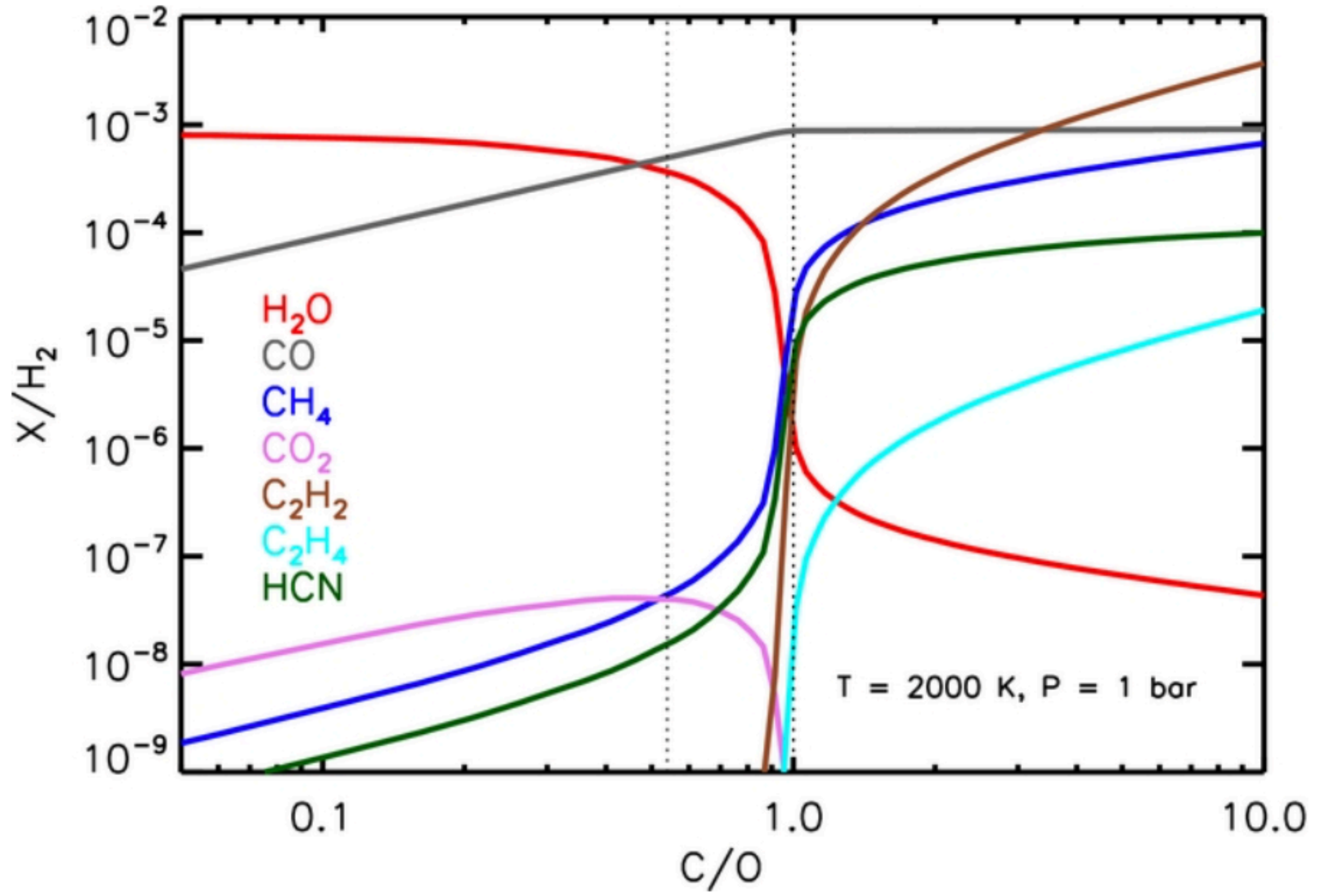
Chemical Equilibrium

Climate

Cloud

Spectroscopy

```
[ ]  w39.chemeq_visscher(c_o, log_mh)
```




```
[ ]  w39.inputs.keys()
```

```
[ ]  w39.inputs['atmosphere']['profile'].head()
```

```
[ ]  #grab CO2 array, for instance
     w39.inputs['atmosphere']['profile']['CO2'].values
```

Make sure to explore the output!

Theoretical modeling is usually comprised of five main modules

Opacity

opannection

Chemistry

Chemical Equilibrium

Climate

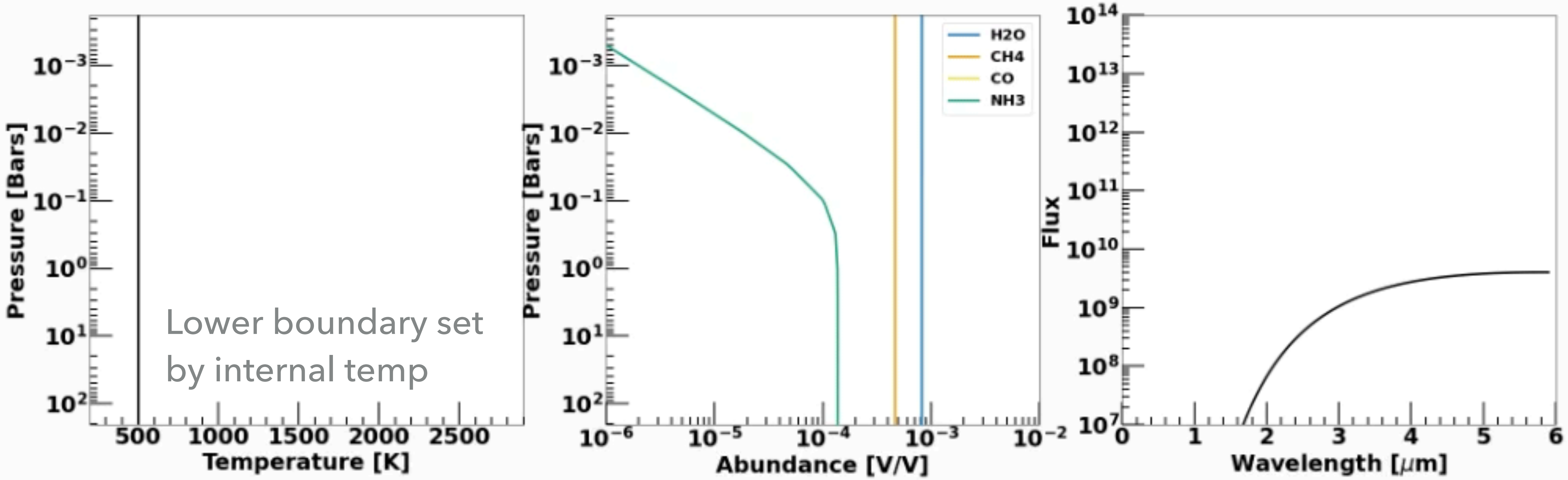
Radiative-convective equilibrium

Cloud

Spectroscopy

```
[ ]  cl_run.inputs_climate(temp_guess= temp_guess, pressure= pressure,
                           nstr = nstr, nofczns = nofczns , rfacv = rfacv)
```

Upper boundary set by stellar irradiation



Theoretical modeling is usually comprised of five main modules

Opacity

opannection

Chemistry

Chemical Equilibrium

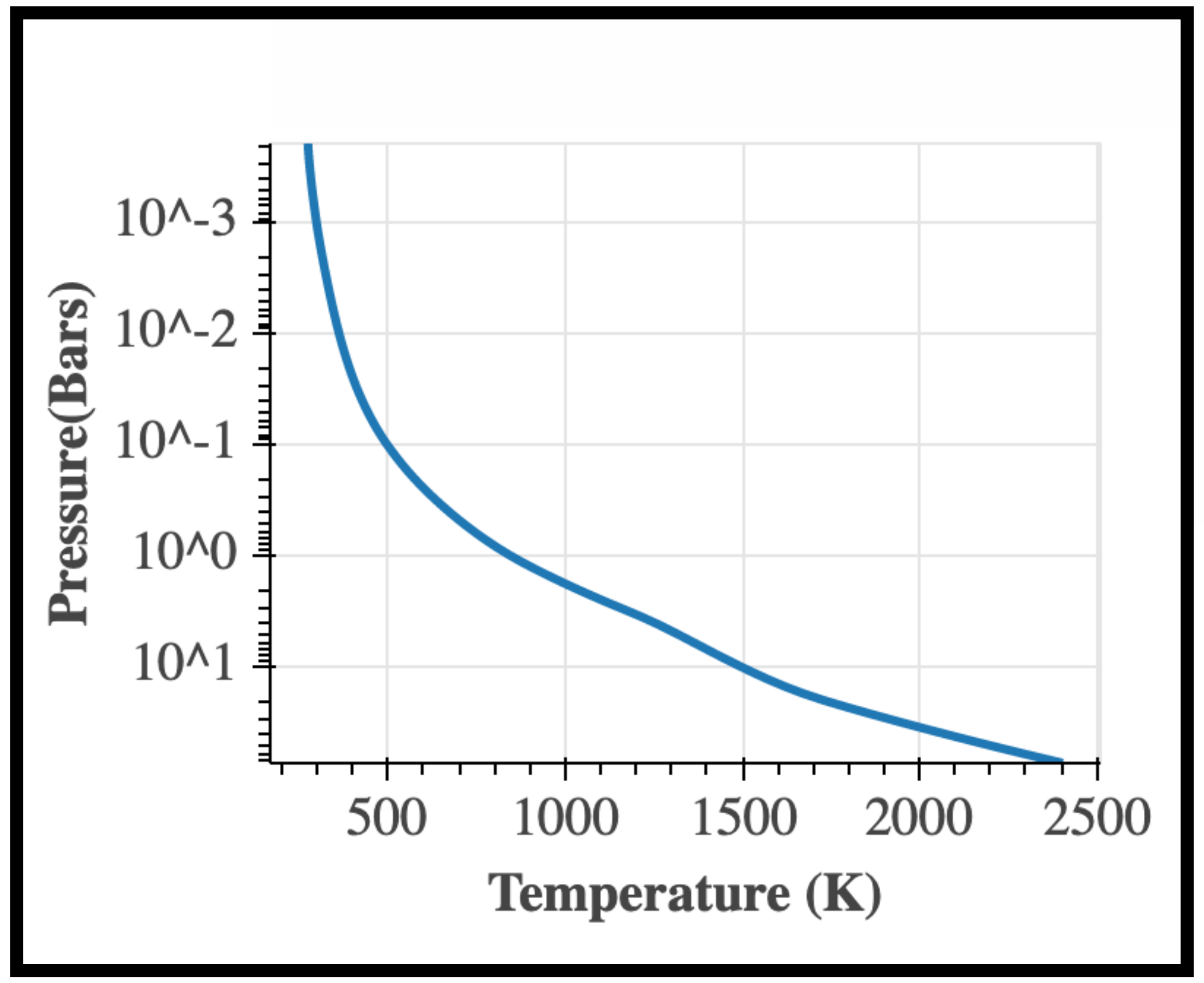
Climate

Radiative-convective equilibrium

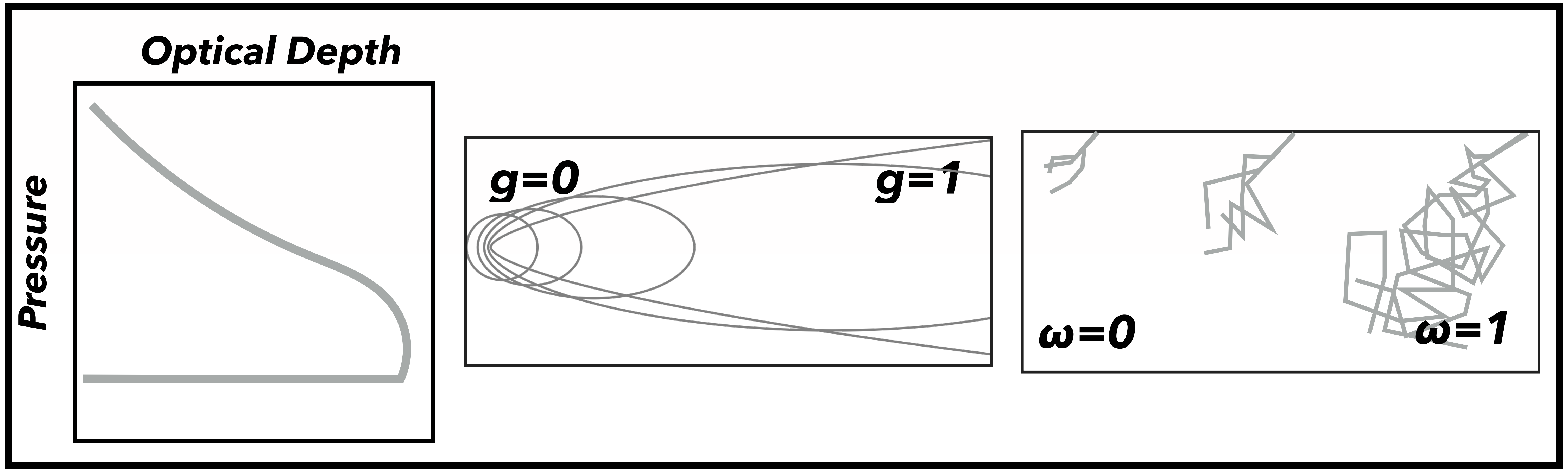
Cloud

virga

Spectroscopy



Input PT profile



Compute cloud profile based on what condenses

Theoretical modeling is usually comprised of five main modules

Opacity

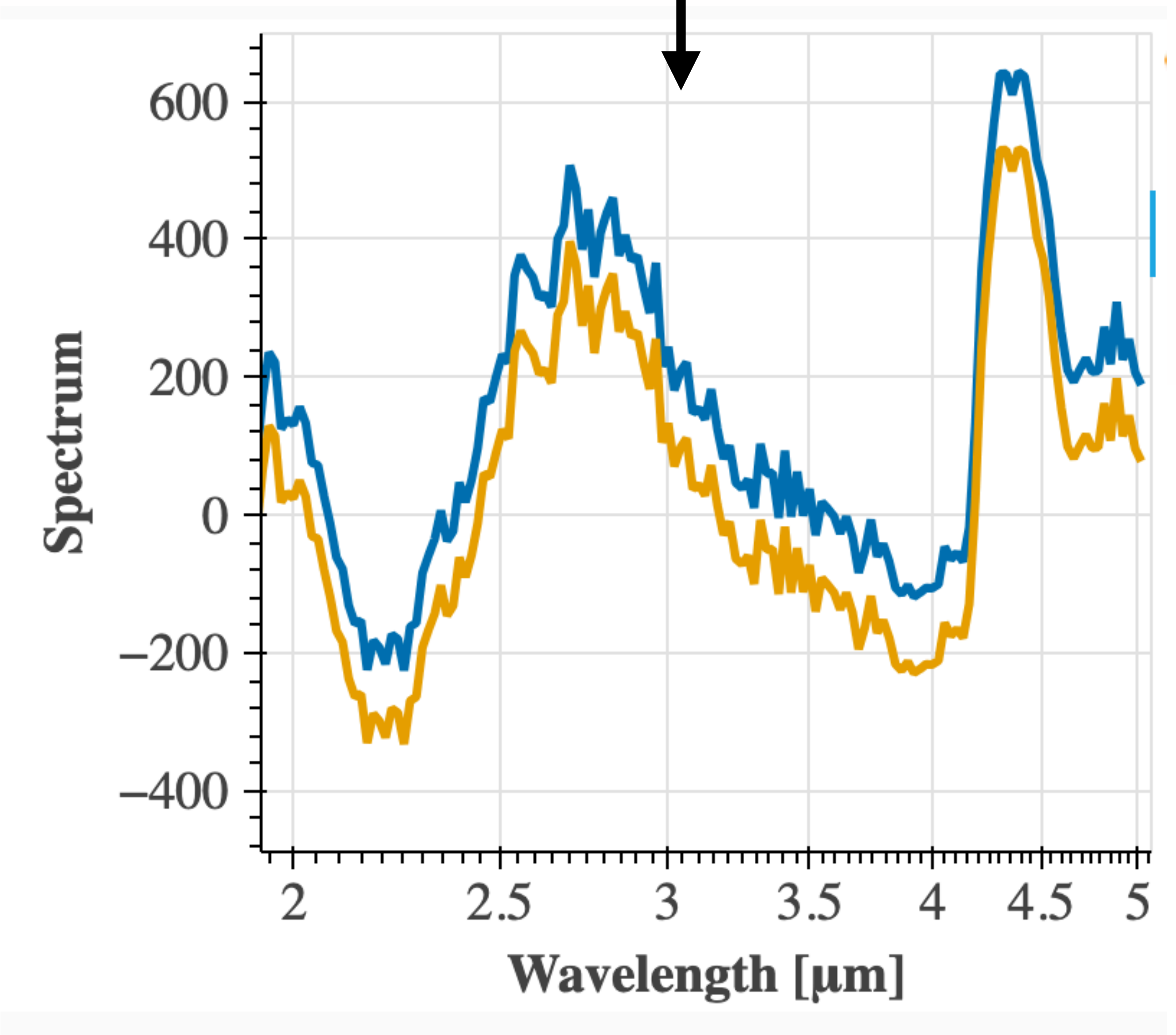
Chemistry

Climate

Cloud

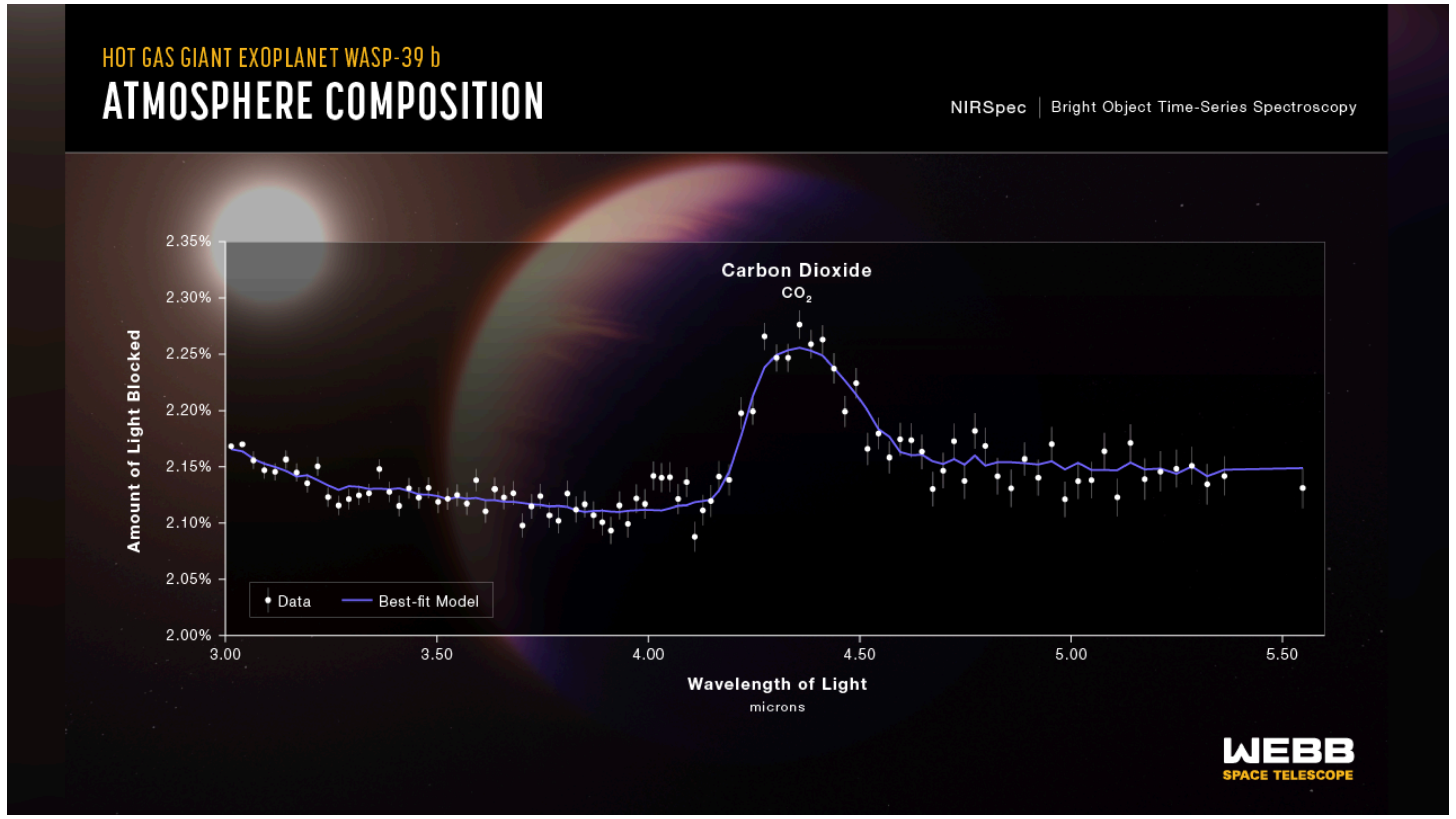
Spectroscopy

```
model_iso = w39.spectrum(opa,
                         #other options are 'thermal' or "reflected"
                         #or a combination of two e.g. "transmmission+thermal"
                         #note that for the hands on session you may want to use s
                         #transimisison
                         calculation='transmission',
                         full_output=True)
```

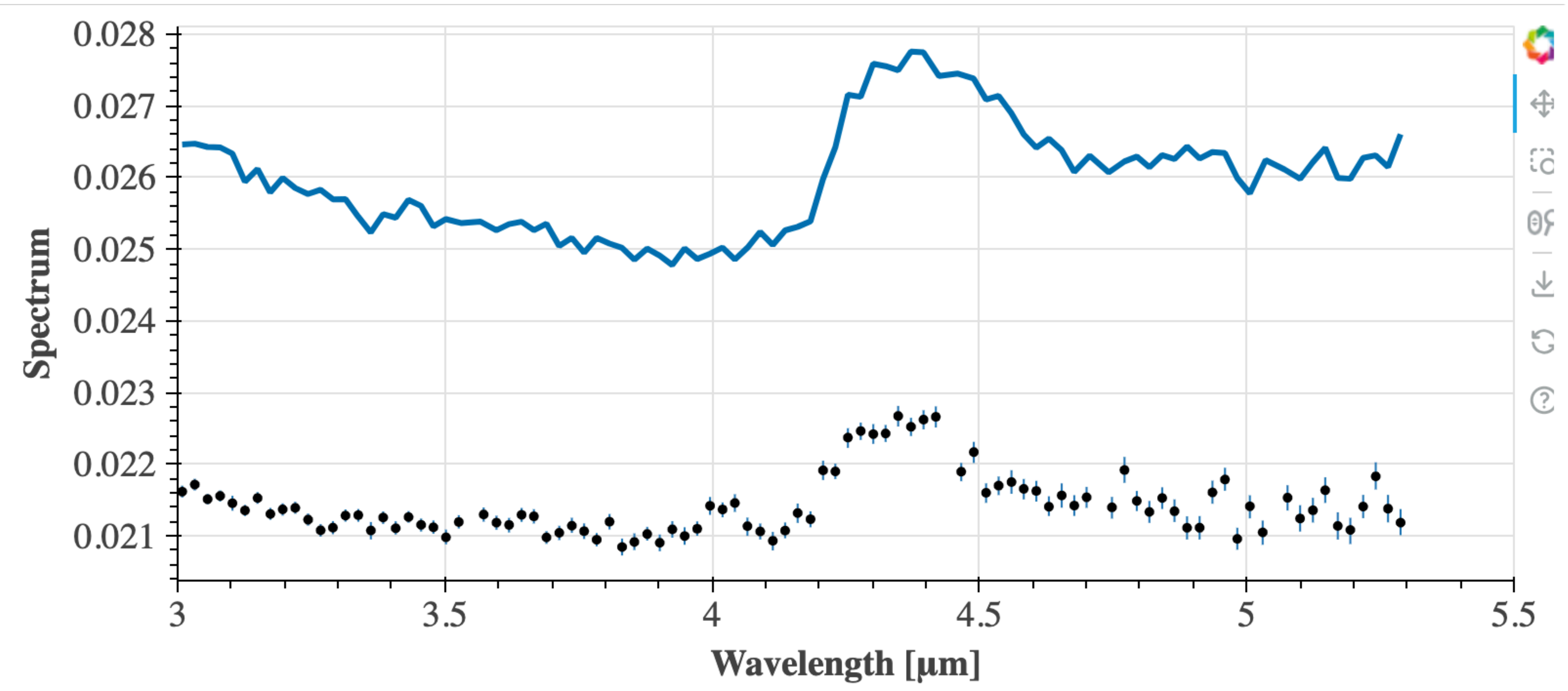


After all that hard work we are often left wondering why our models don't match the data

Compare to data!!



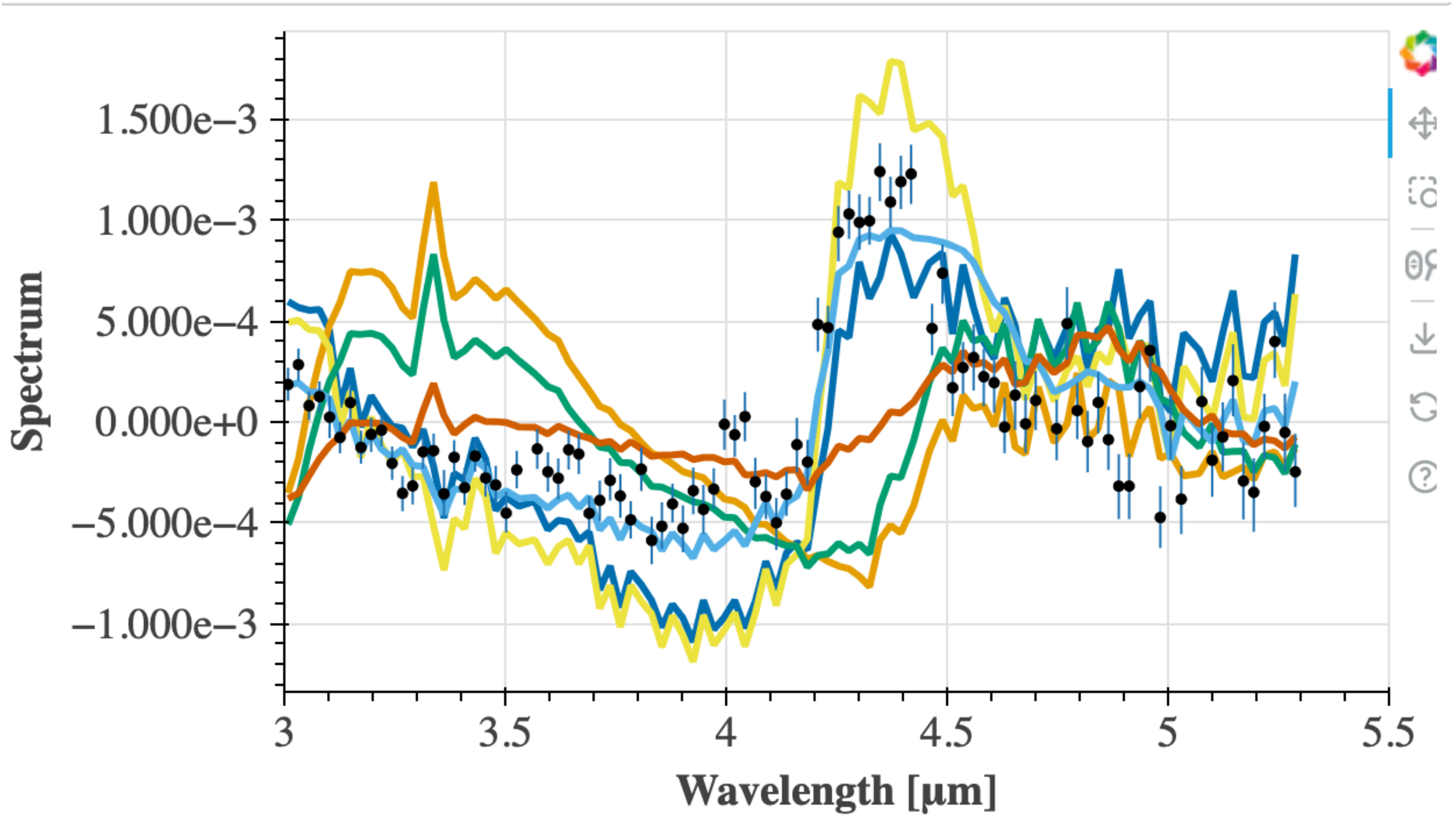
How to troubleshoot models so that they can better match our data?



What did we get right??

What did we get wrong??

What assumptions did we make that could be affecting our fit?



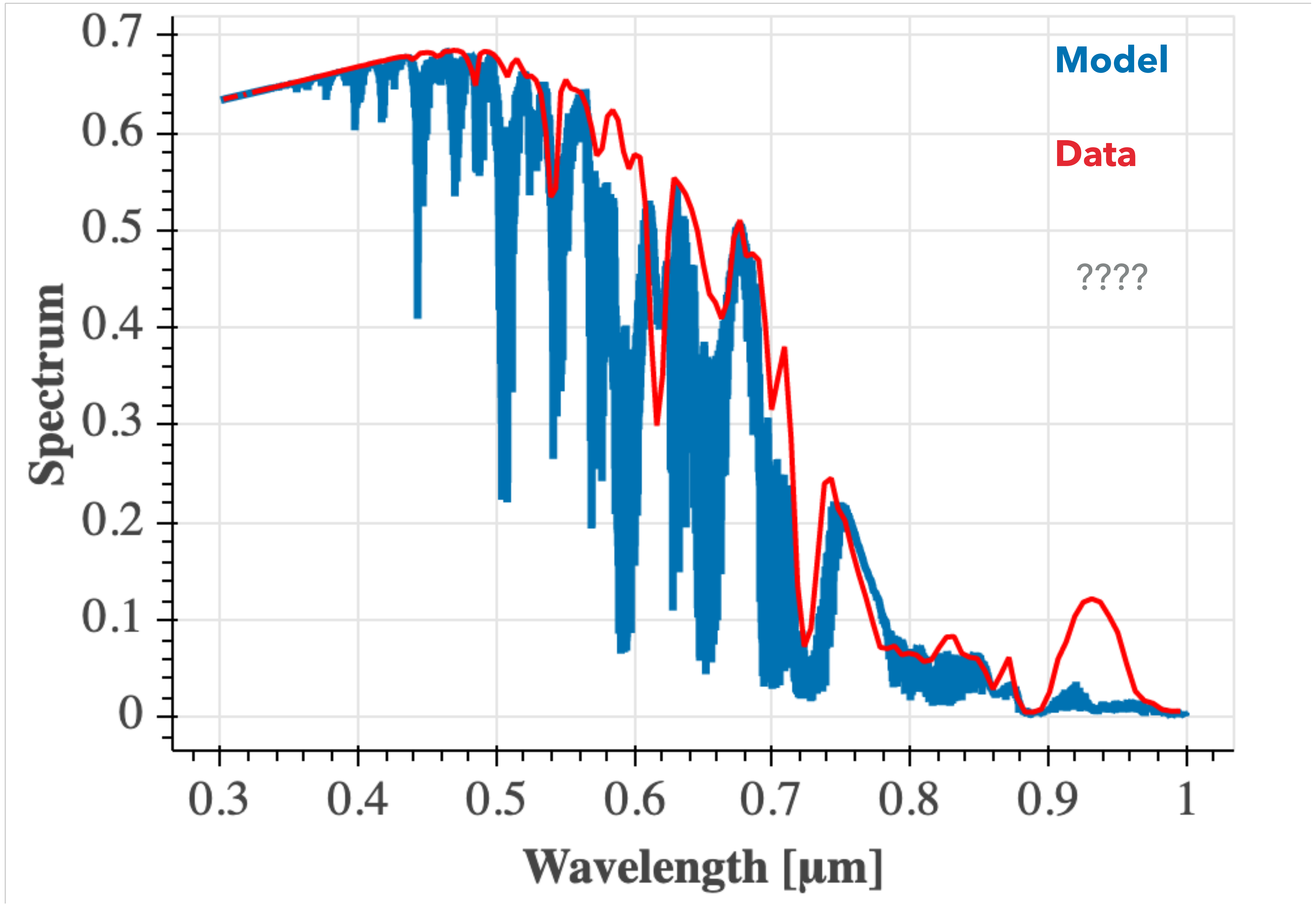
What model values can we reliable estimate based on the data?

What additional complexity could we add to improve the fit?

OVERVIEW OF HANDS ON SESSION KEY SCIENCE GOALS

Building Intuition for Spectroscopy

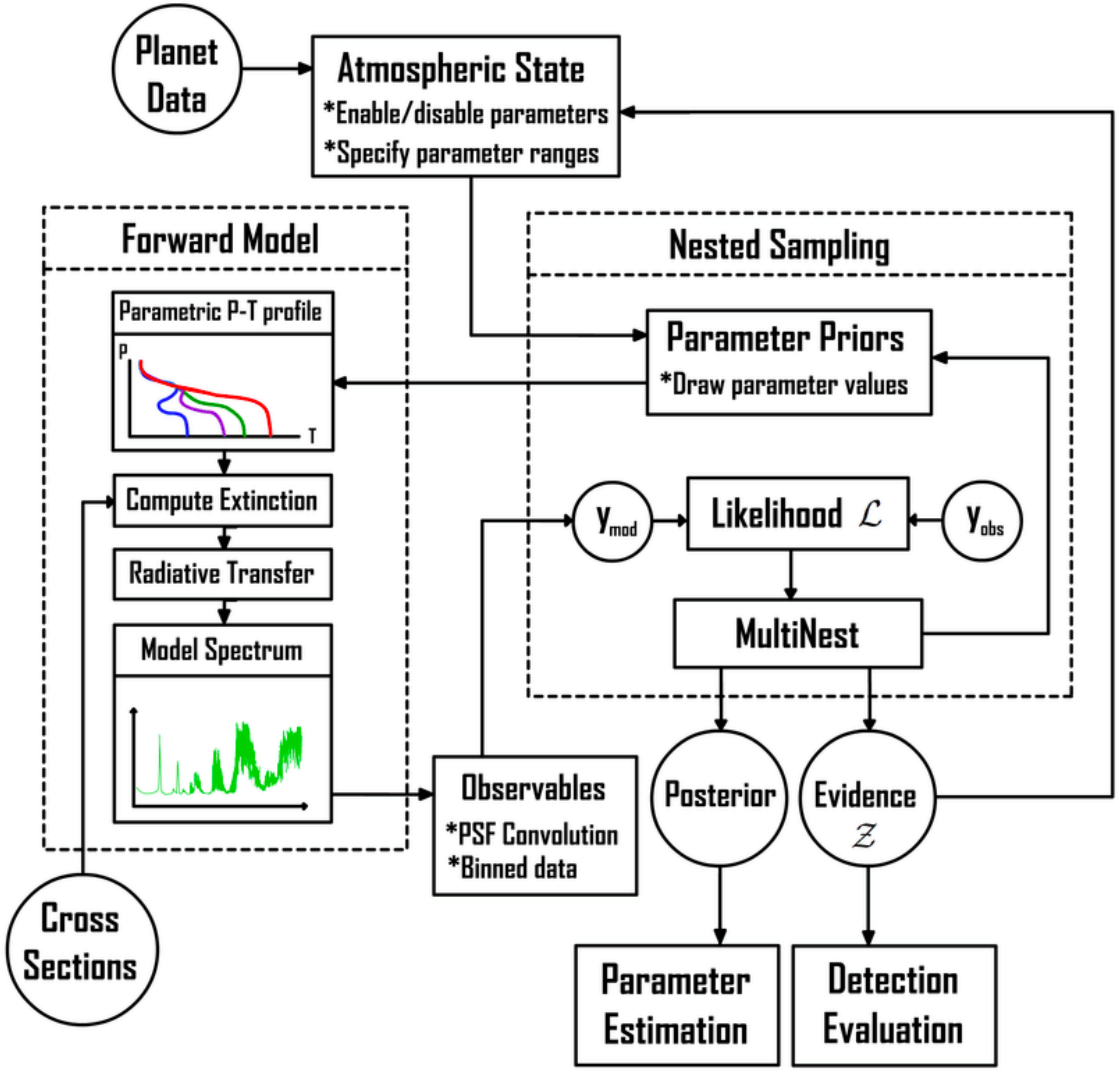
1) Understand what modules/inputs are needed to create a model of planet atmosphere
2) Determine how to dissect a planetary spectrum
3) Understanding how to dissect a planet spectrum will enable you to trouble shoot your data-model comparisons
4) Understand how to increase the complexity of your model



CONNECTION TO THE FOLLOWING SESSION ON RETRIEVALS

Forward models are part of every retrieval scheme!

In most cases, radiative convective climate models are too slow to run in a retrieval



In this hands on session you will be doing "parameter-estimation-by-eye"

For the group project you will be using grid models to do a more robust chi-square analysis of forward models

Fig Credit: Poseidon; Ryan MacDonald

Final tips for the hands on exercise!

1. Do not just click “run” on all cells! Explore the code, making sure you understand why each step is necessary.
2. Ask questions!
3. Use the #python-help channel for coding questions
4. Make sure to debrief group discussions with your neighbors!