

Modeling M-Earth Atmospheres in Transit

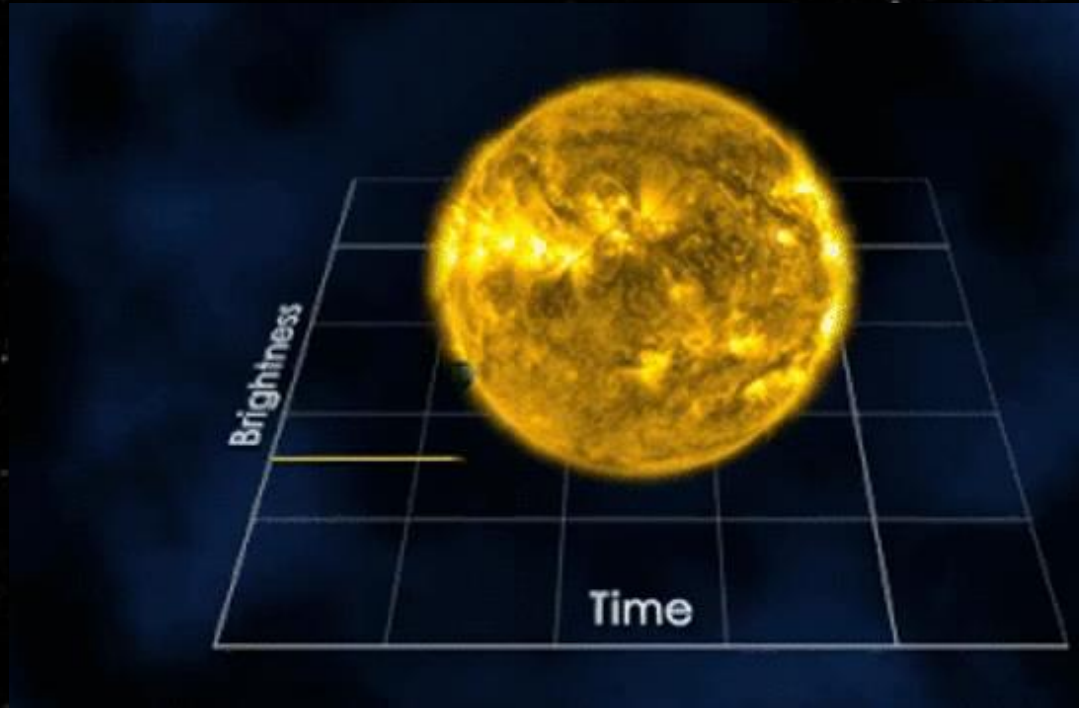
James Mang, University of California – Berkeley

Mentor: Avi Mandell

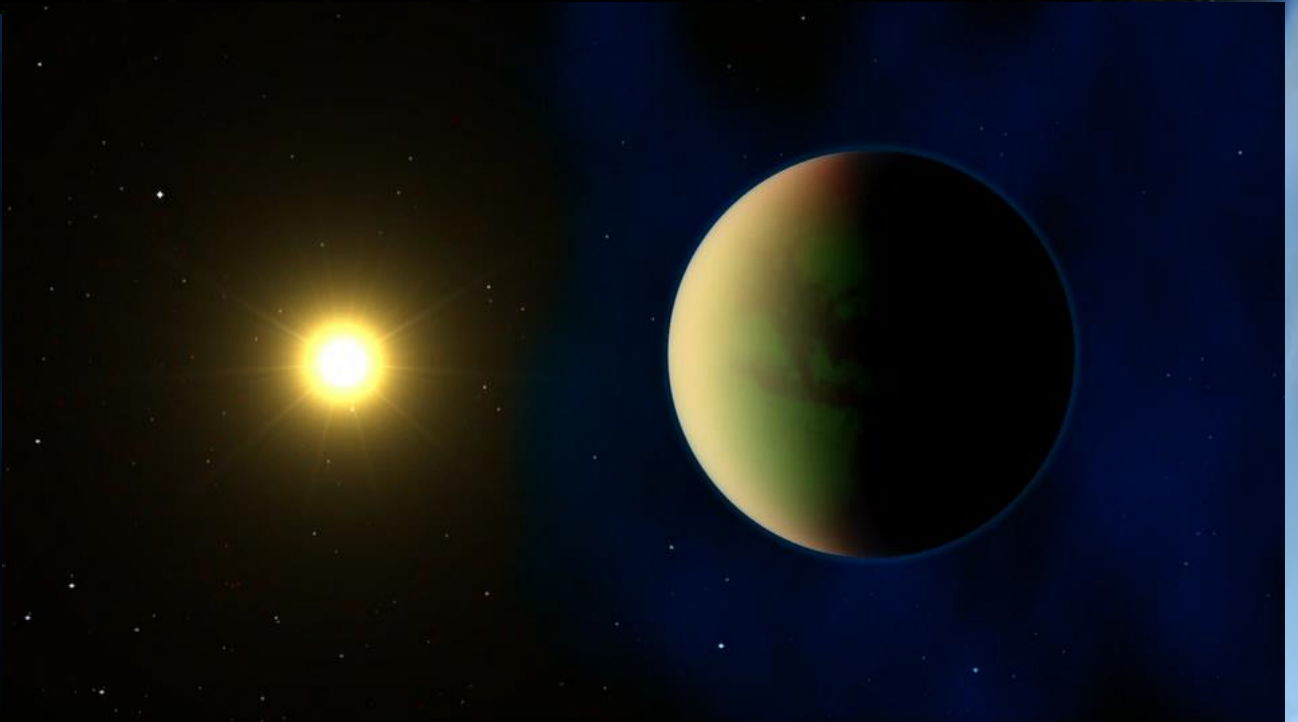
Collaborators: Geronimo Villaneuva, Michael
Himes, Mike Moore, Adam J.R.W. Smith



What is a transit? How do we study these planets?



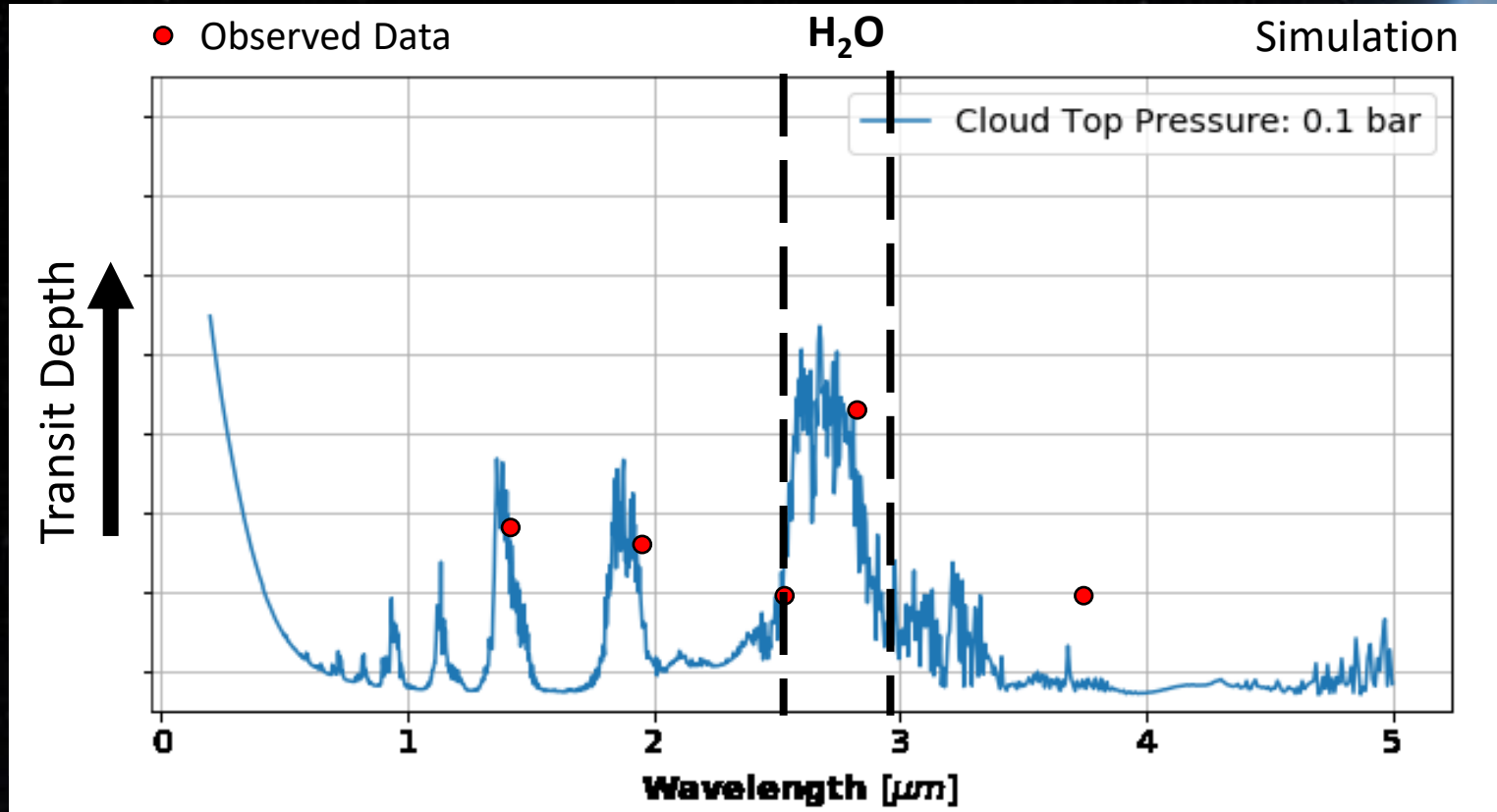
A transit event occurs when the light from the host star is blocked by planet crossing in front



We can characterize their atmospheres based on the molecules absorption of light

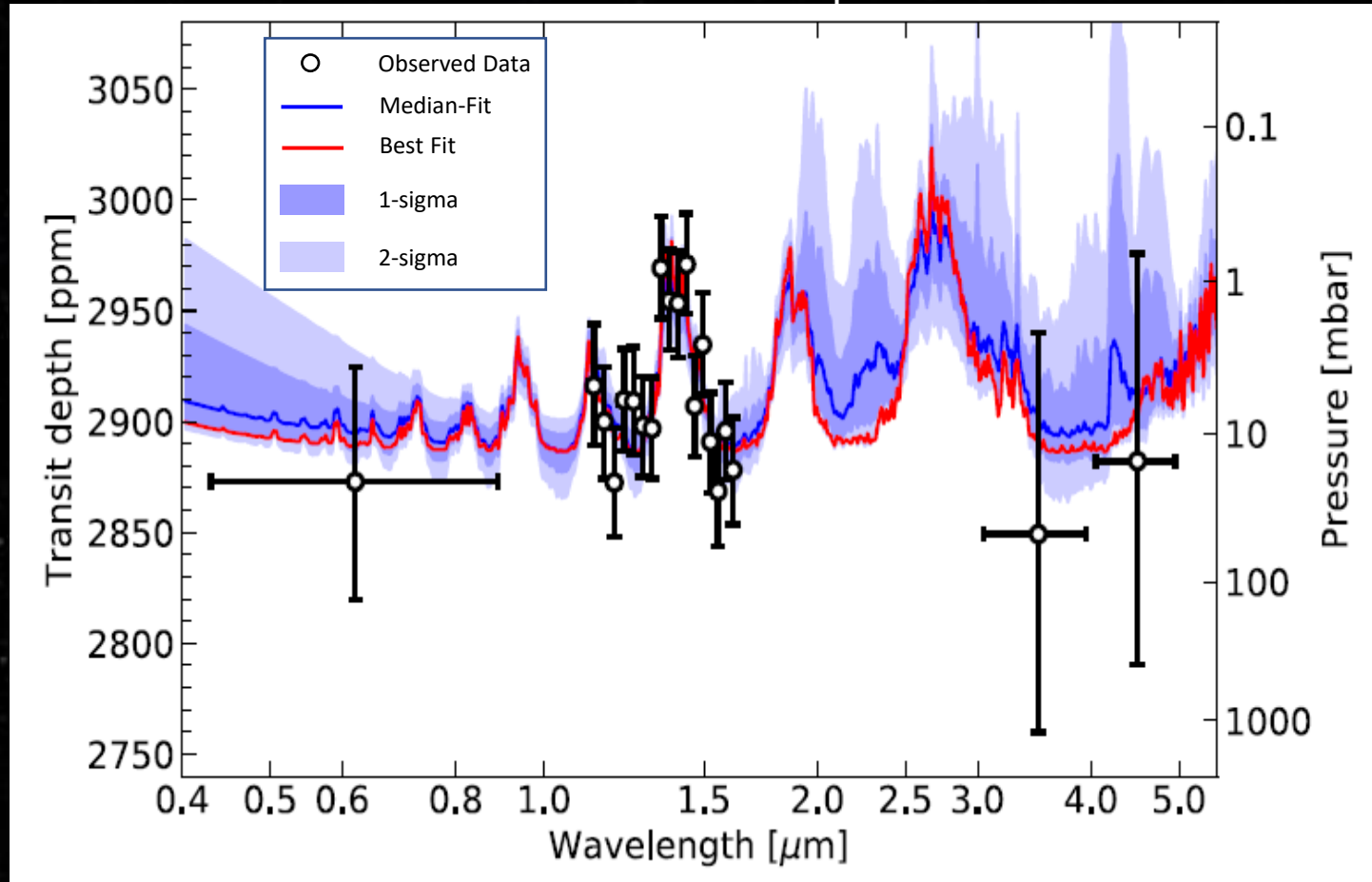
Project Scope

- I designed a pipeline able to take the observational data to retrieve the parameters of the planet by fitting the data to a set of atmospheric profiles we create
- The purpose of training on old datasets is to prepare for JWST which will provide a whole new round of observations of M-Earths



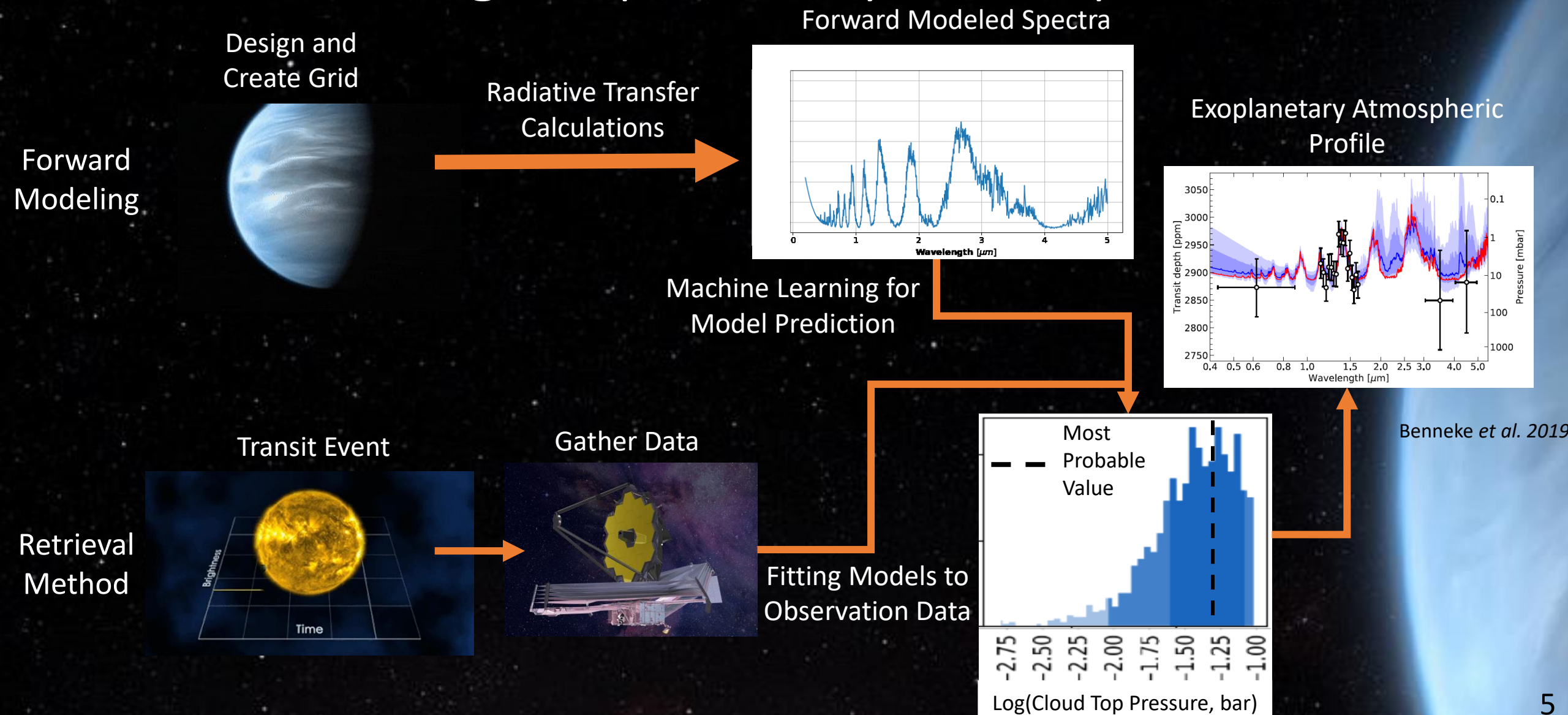
Test Case: K2-18b

Adapted from Benneke *et al.* 2019



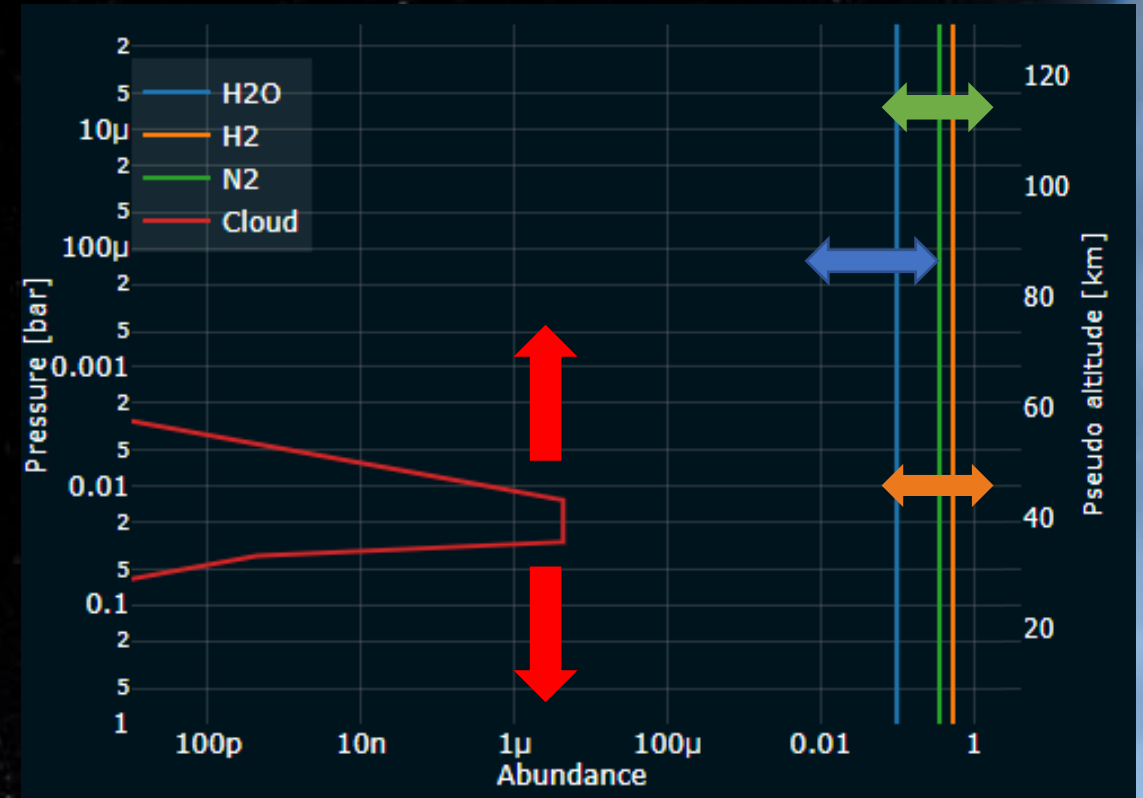
- We use K2-18b as the test planet for this entire pipeline, since it has well established published results for HST and Spitzer data
- Analysis suggests K2-18b has water vapour and clouds

Characterizing Exoplanetary Atmospheres



Generating Our Grid

Parameters	Range (# of Samples)
Planet Radius [R_{Earth}]	2.2 – 3.0 (5)
Planet Mass [M_{Earth}]	8.2 – 9.0 (5)
Radius of Cloud Particulate [microns]	0.1 – 10.0 (5)
Cloud Top Pressure [log(bars)]	-3.0 – -1.0 (5)
Water Abundance [log(abun)]	-7 – -0.01 (7)
Background Gas Ratio	0.0 – 1.0 (6)
Total Grid Size	26,250

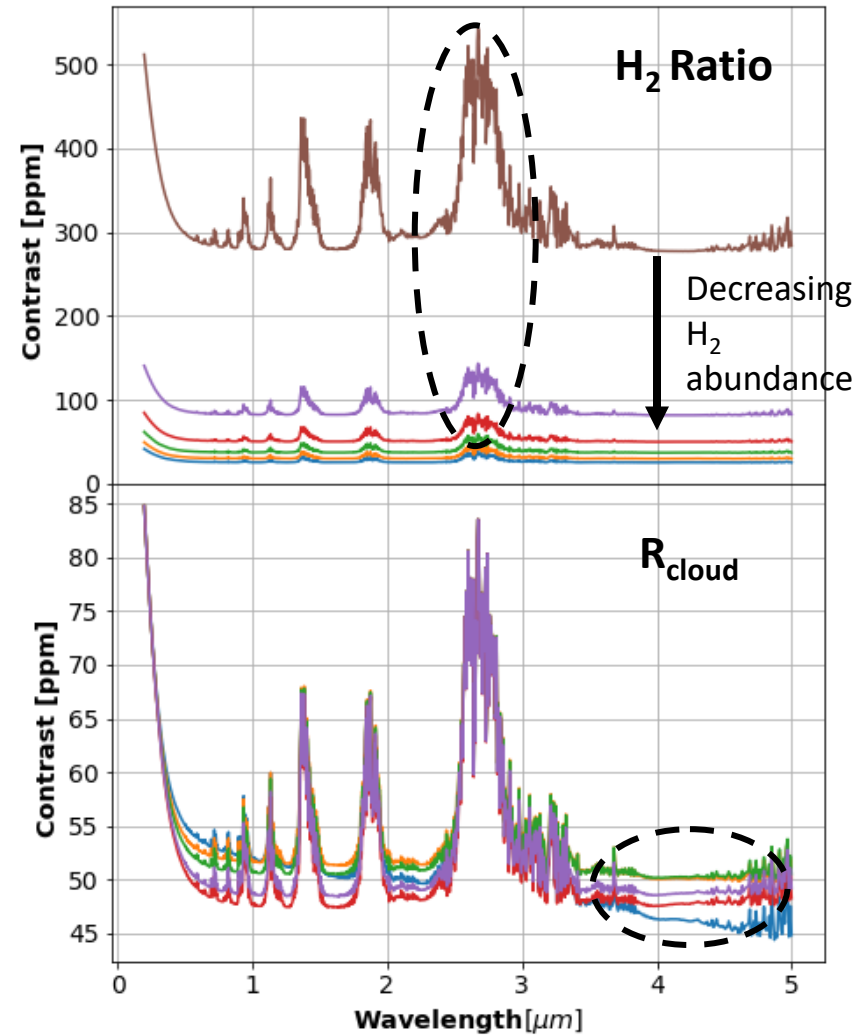
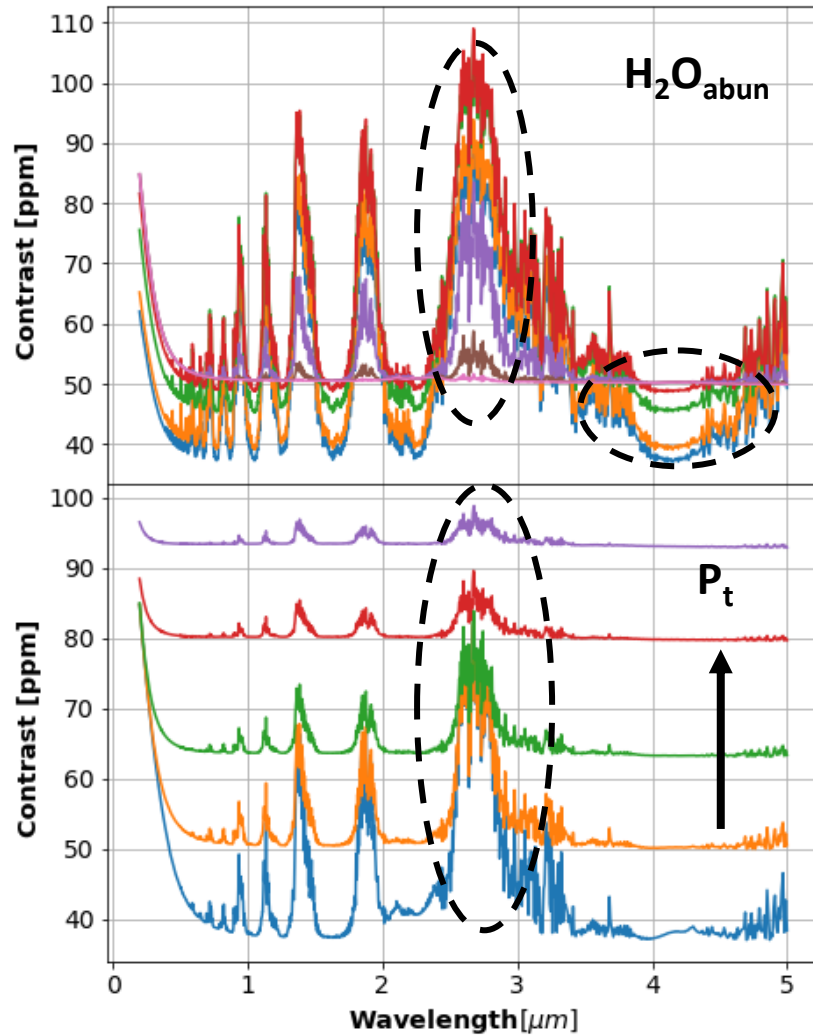


General Assumptions:

- Isothermal Atmosphere – 250 K
- Surface Pressure is 1 bar

- Single Absorbing Species
- H_2/He and H_2 / N_2 Background Gases
- No Physical Cloud Formation Model

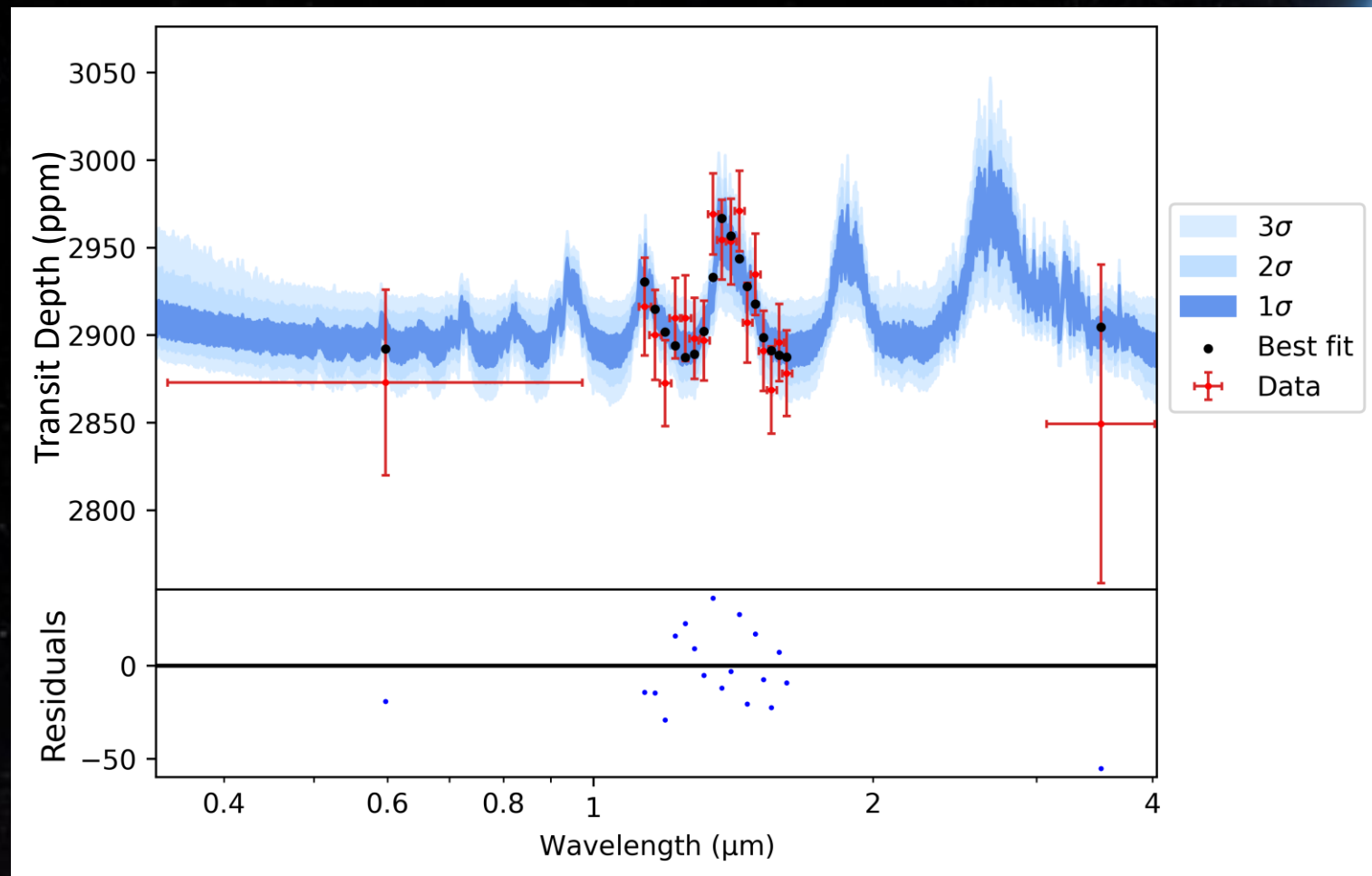
Grid Spectra Result



Example of the expected spectra from our grid as processed through PSG

Our Atmospheric Retrieval Algorithm: MARGE & HOMER

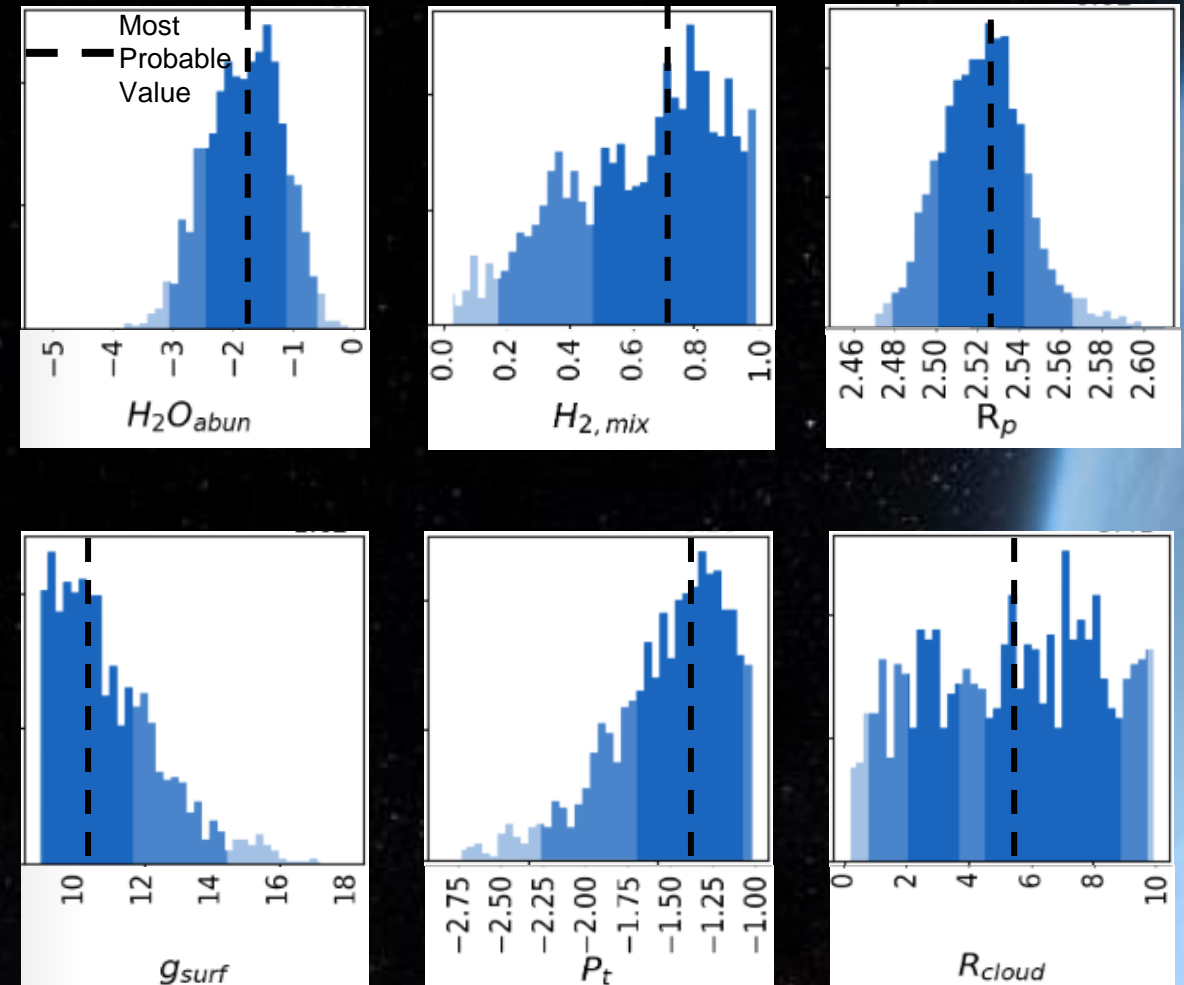
- MARGE+HOMER is a Bayesian retrieval algorithm developed by Michael Himes (Himes et al. 2020)
- Uses Bayesian sampling statistics to constrain uncertainties in planetary parameters
- Uses Machine Learning (ML) to produce spectral forward models



Best fit spectrum from my model to the
observed data from Benneke et al. 2019

Atmospheric Retrieval Results – H₂/He

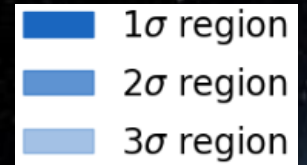
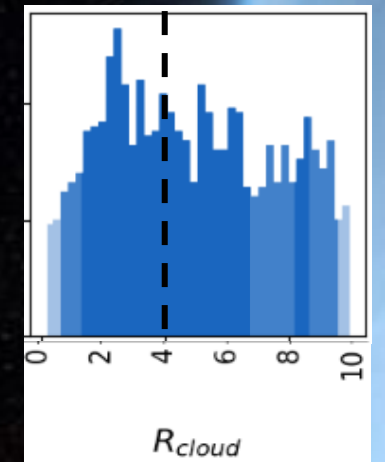
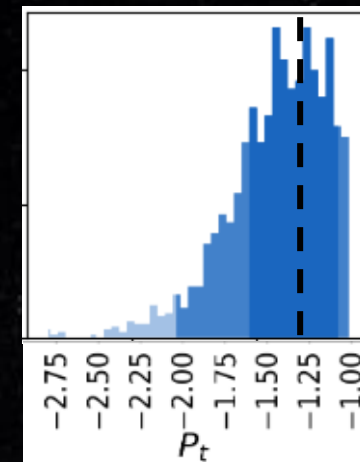
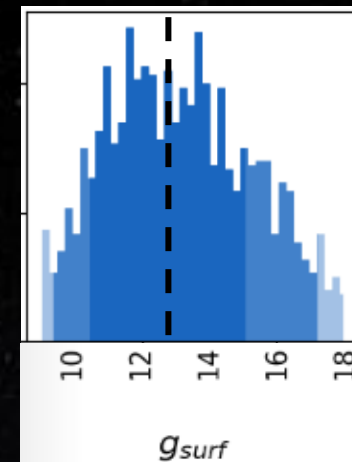
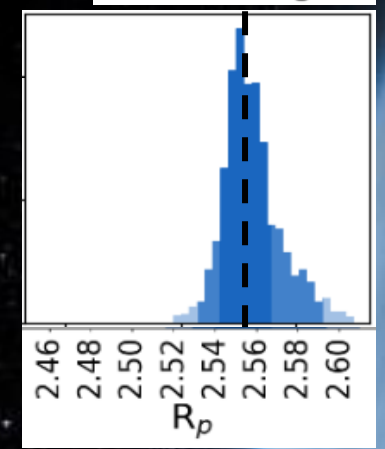
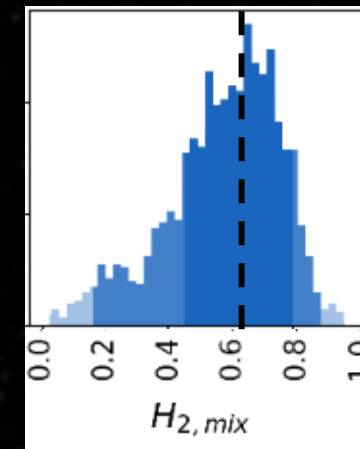
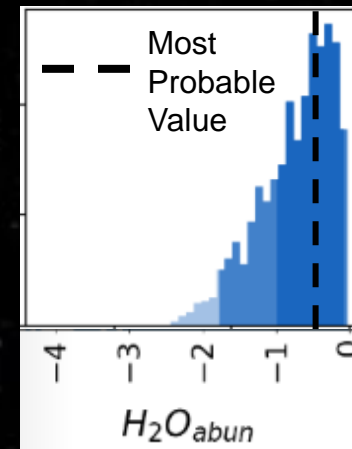
Parameters	Retrieved Value	Benneke et al. Value
Planet Radius [R_{Earth}]	$2.54^{+0.02}_{-0.02}$	$2.610^{+0.087}_{-0.087}$
Surface Gravity [m/s^2]	$10.63^{+1.06}_{-1.62}$	$12.43^{+2.17}_{-2.07}$
Radius of Cloud Particulate [microns]	$5.44^{+3.47}_{-3.41}$	N/A
Cloud Top Pressure [log(bars)]	$-1.46^{+0.4}_{-0.26}$	$-2.11^{+0.56}_{-0.94}$
Water Abundance [log(abun)]	$-1.88^{+0.65}_{-0.66}$	$-2.08^{+1.03}_{-1.39}$
Mean Molecular Weight of Atmosphere [g/mol]	$2.88^{+0.4}_{-0.57}$	$2.42^{+1.27}_{-0.12}$



- HOMER takes in the trained model from MARGE to retrieve the parameters of the atmospheric profile

Atmospheric Retrieval Results – H₂/ N₂

Parameters	Retrieved Value	Benneke et al. Value
Planet Radius [R_{Earth}]	$2.57^{+0.01}_{-0.1}$	$2.610^{+0.087}_{-0.087}$
Surface Gravity [m/s^2]	$13.04^{+2.04}_{-2.61}$	$12.43^{+2.17}_{-2.07}$
Radius of Cloud Particulate [microns]	$4.71^{+3.93}_{-3.43}$	N/A
Cloud Top Pressure [log(bars)]	$-1.43^{+0.36}_{-0.22}$	$-2.11^{+0.56}_{-0.94}$
Water Abundance [log(abun)]	$-0.76^{+0.68}_{-0.46}$	$-2.08^{+1.03}_{-1.39}$
Mean Molecular Weight of Atmosphere [g/mol]	$8.76^{+1.49}_{-1.97}$	$2.42^{+1.27}_{-0.12}$



Key Takeaways

- PSG is a powerful tool that can be used to help in simulations for future observations as well as retrievals
- I developed a full pipeline and have two grids of 26,250 cases for K2-18b with H₂O as the absorbing species and will continue to expand this grid to include other absorbing species on K2-18b as well as other M-Earths
- We are able to properly train a model on our grid and use observational data to retrieve expected planetary parameters comparable to literature values using machine learning assisted retrievals
- The pipeline is ready for future observations and characterization of rocky planets with the upcoming JWST mission

Thank you to Avi, Geronimo, Michael, Mike, Adam and the URAA committee for the support and collaboration!