YunMa: Clouds and Hazes in the Next Generation of Exoplanet Data

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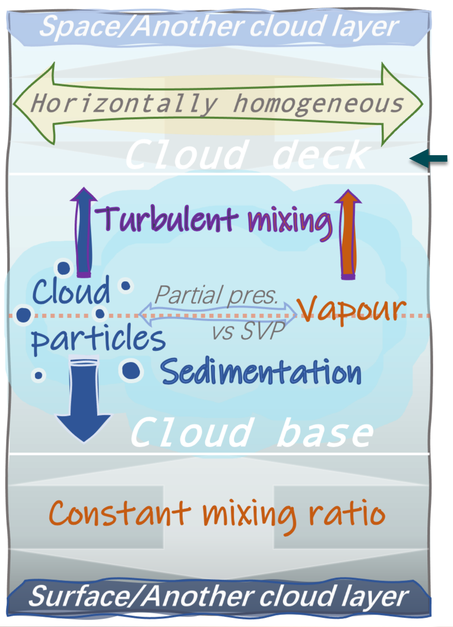
Abstract:

YunMa **is a cloud and haze simulation and retrieval package optimised for transit spectroscopy. It simulates particle size distributions (PSD) from varied physically motivated approaches.** ***YunMa-TauREx***[★] **can constrain cloud/haze formation and characteristic parameters from observations. We applied** ***YunMa*** **in large-scale simulations and data challenges to prepare for the** ***Ariel*** **mission.**

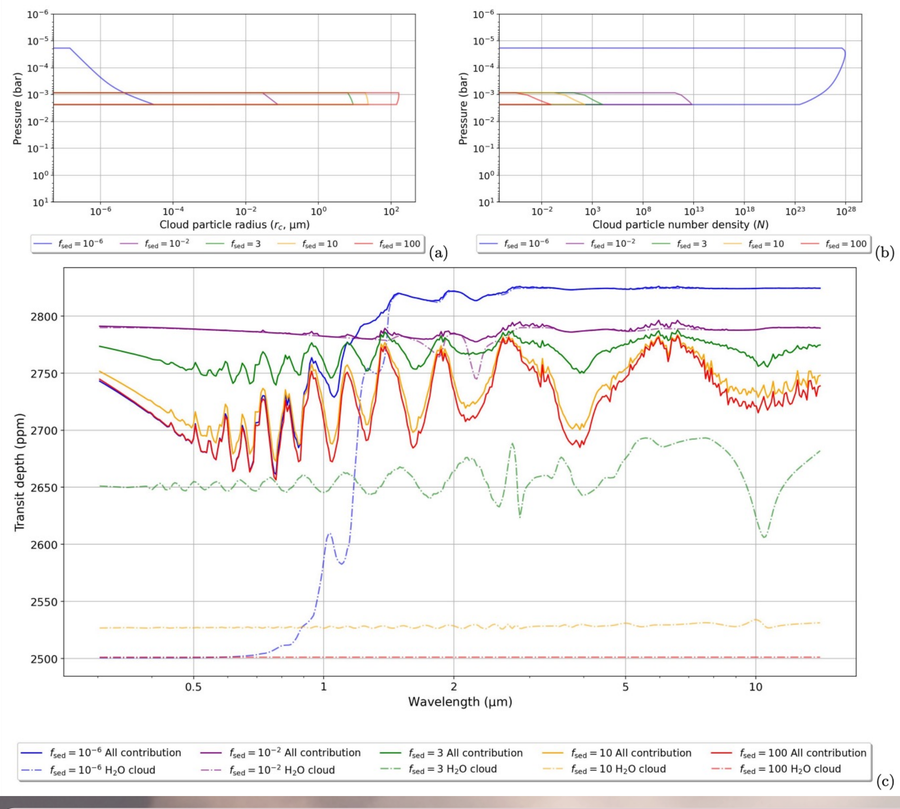
Clouds and Hazes in *YunMa*



YunMa has an inbuilt A-M[▽] cloud microphysics model, an O-K[△] haze model, and a characteristic model. The A-M approach simulates the vertical cloud PSD from draft balance and cloud microphysics. The O-K approach estimates haze PSD analytically, considering haze production and atmospheric diffusion. In the characteristic approach, the user can define the particle size distribution.

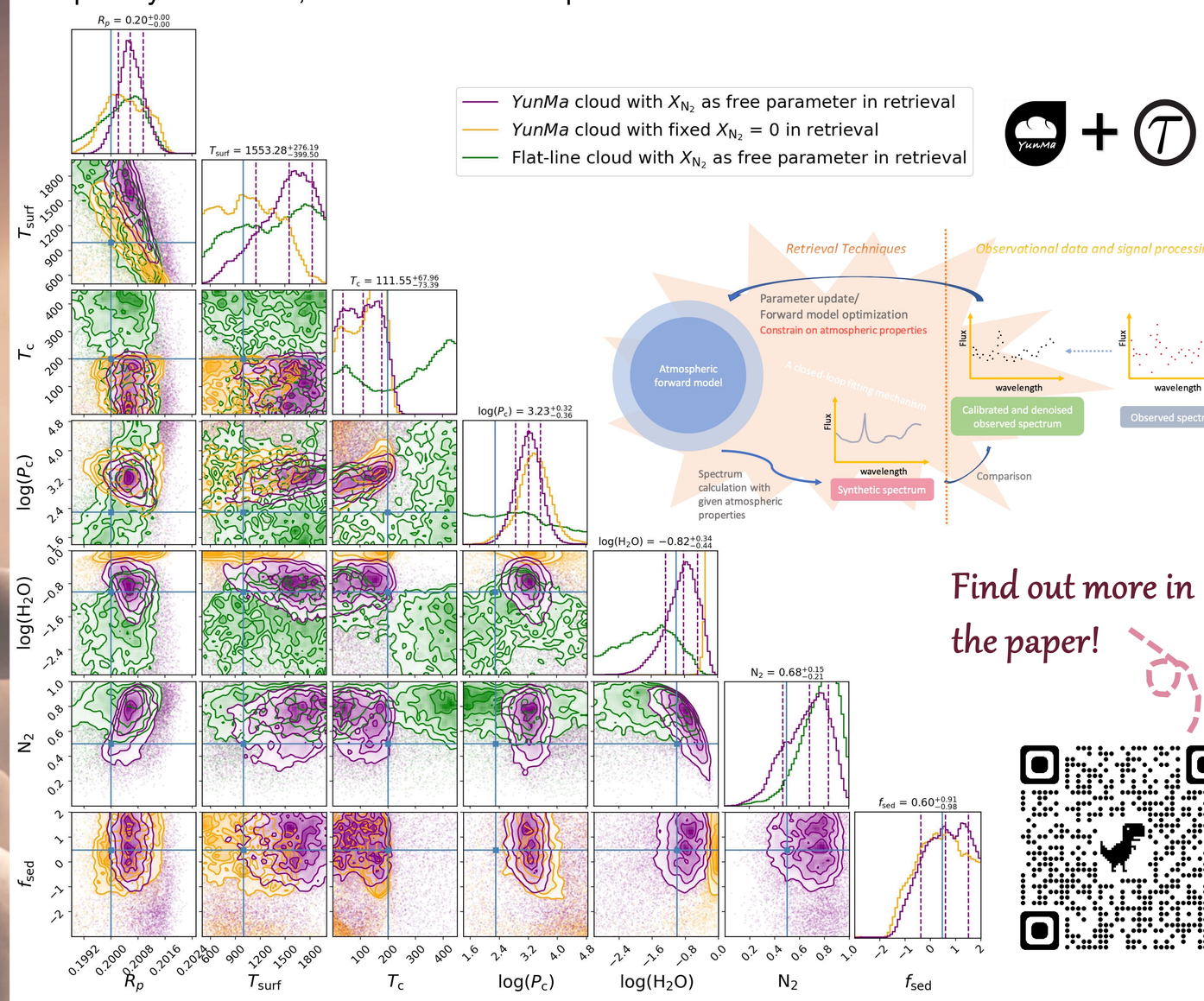
From PSD to Transit Spectra

YunMa estimates the cloud opacity from PSD using BH-Mie[✦]. Here, we show an example of the water cloud PSD and transit spectra of a synthetic cloudy cold sub-Neptune simulated using YunMa, in the typical spectral region we consider for the next-generation instruments. It also shows the spectral impact of water vapor depletion due to cloud formation.



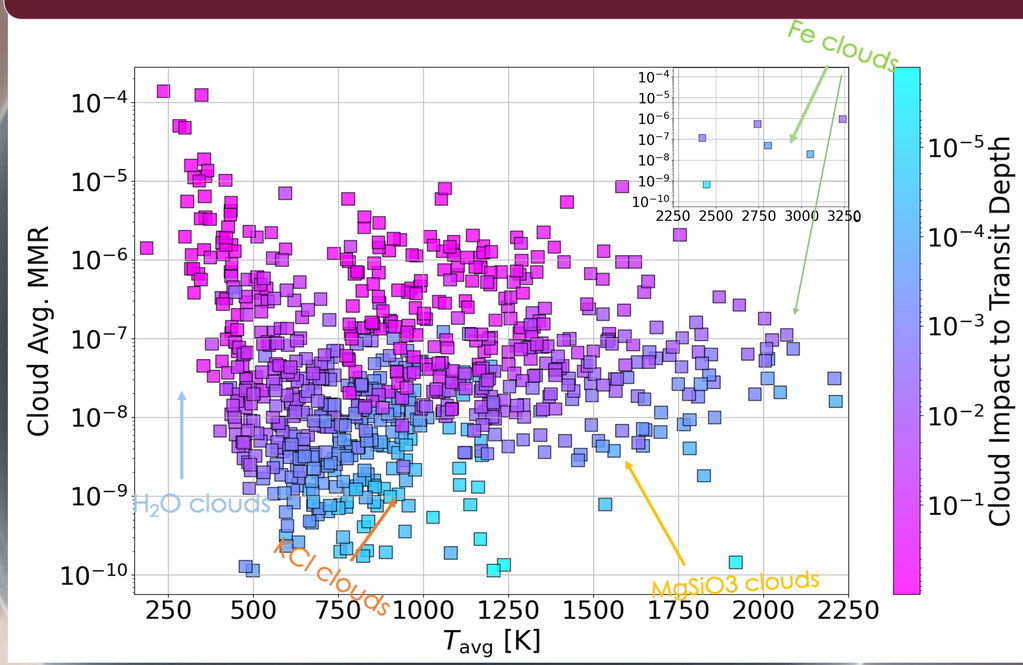
Spectral Retrieval using *YunMa* + *TauREx*

The YunMa-TauREx package adopts Bayesian statistics and nested sampling to constrain atmospheric parameters from the observational data, including cloud/haze formation and characteristic parameters. The corner plot compares the retrieval performance of YunMa, opaque clouds, and YunMa with missing gases. The posteriors in purple suggest YunMa's capability in retrieval, here with semi-transparent clouds.



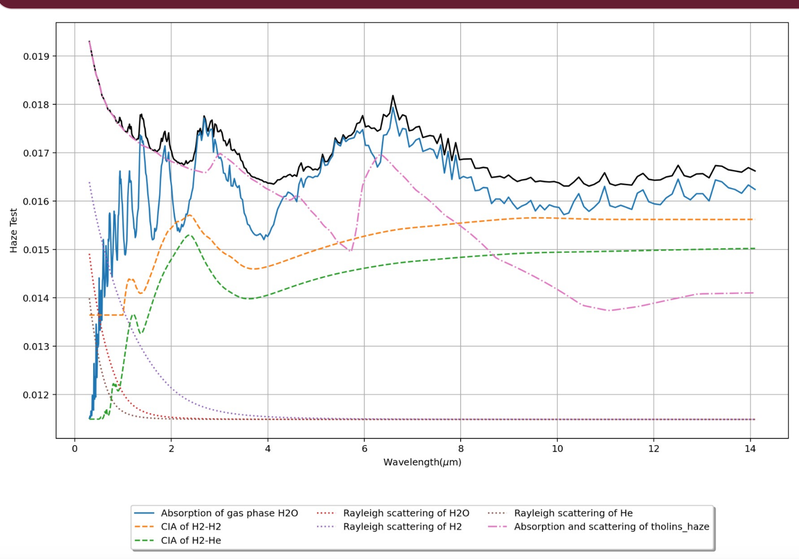
Find out more in the paper!

YunMa in Ariel Large-Scale Simulation



We applied YunMa to the large-scale population study in the Ariel Dry-Run to serve the Observational Tier Strategy. YunMa simulated clouds of different species for ~1000 exoplanet transit candidates. The results show a wide range of particle size distribution and varied spectral impact across planet types and temperature regimes.

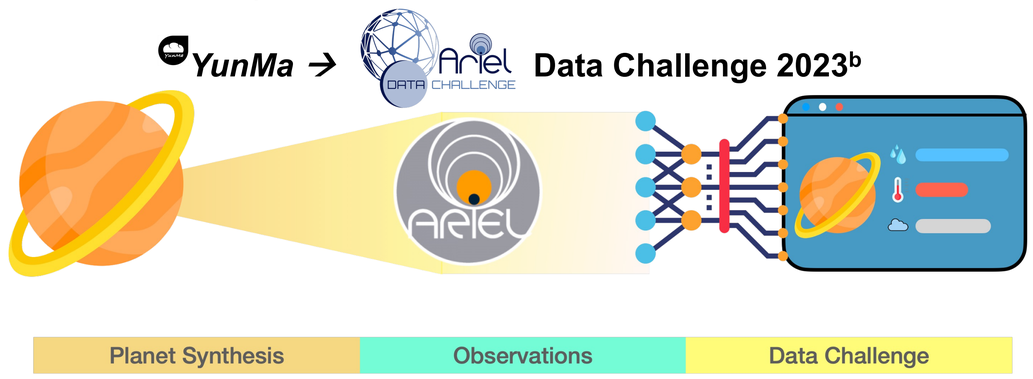
Haze and Rayleigh Slope using *YunMa*



Hazes usually form in smaller particle sizes than clouds. We show a transmission simulation of a warm Jupiter with thick tholin hazes in the atmosphere. Due to the small particle size hazes inhabit, the optical to near-IR wavelengths show a strong Rayleigh slope in this case.

YunMa in Ariel Data Challenge

We used YunMa in producing one of the special testing sets with complex cloud inclusion in the challenge to help evaluate the performance of AI methods in atmospheric retrieval.



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[b] https://arielmission.space/index.php/data-challenges/

[★] Al-Refaie, A. F., Changeat, Q., Waldmann, I. P., & Tinetti, G. 2021, The Astrophysical Journal, 917, 37
[▽] Ackerman, A. S., & Marley, M. S. 2001, The Astrophysical Journal, 556, 872
[✦] Bohren, C. F., & Huffman, D. R. 2008a, Absorption and scattering of light by small particles (John Wiley & Sons)
[△] Kazumasa Ohno & Yui Kawashima 2020, The Astrophysical Journal Letters, 895, 47