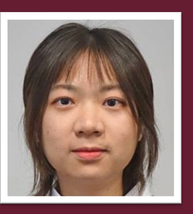
YunMa: An Exoplanet Cloud Simulation and Retrieval Package



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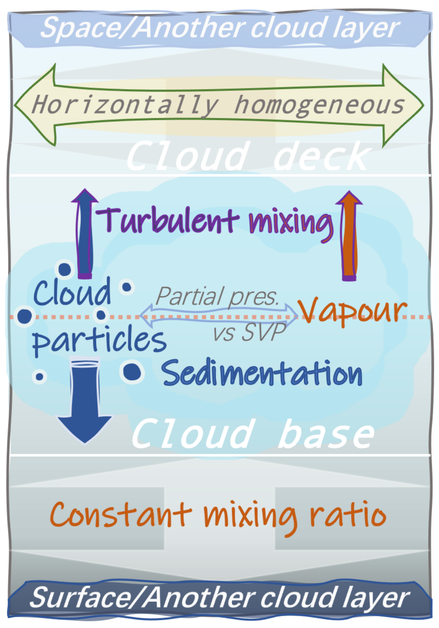
Abstract:

YunMa **is a cloud simulation and retrieval package for retrieval study of cloudy atmospheres of exoplanets in transit spectroscopy. It is integrated into *TauREx*[★] retrieval platform and has a flexible API for taking cloud models coded in Python.**

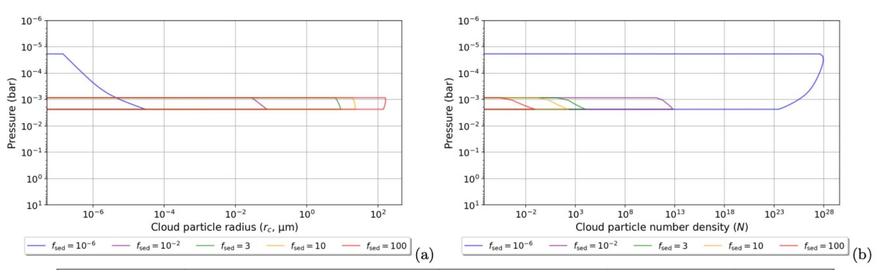
Cloud Simulation using *YunMa*

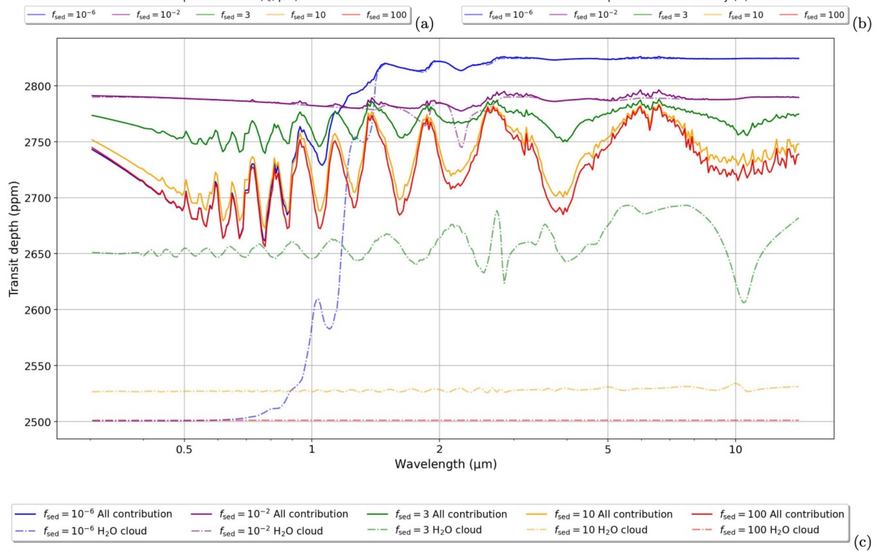


The current YunMa has an inbuilt A-M[▽] cloud microphysics model. According to the A-M theory, we simulate the vertical cloud particle size distribution from cloud microphysics. The cloud forms with different size distributions to maintain the balance between the upward turbulent mixing and the downward sedimentation molecular drafts of condensable species.

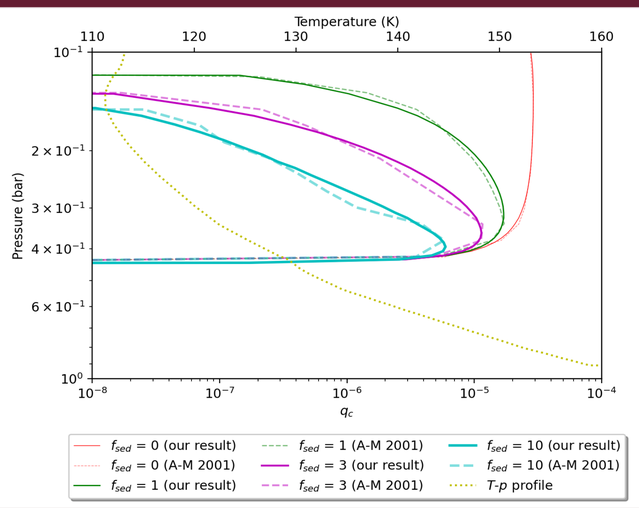
Transit Simulation using *YunMa*

Here we show an example of water cloud particle size distribution and transit spectra of a synthetic cloudy cold sub-Neptune simulated using *YunMa*. The water vapour absorption features are perturbated due to the water cloud formation, wavelength-dependently in the typical spectral region of the next-generation instruments.





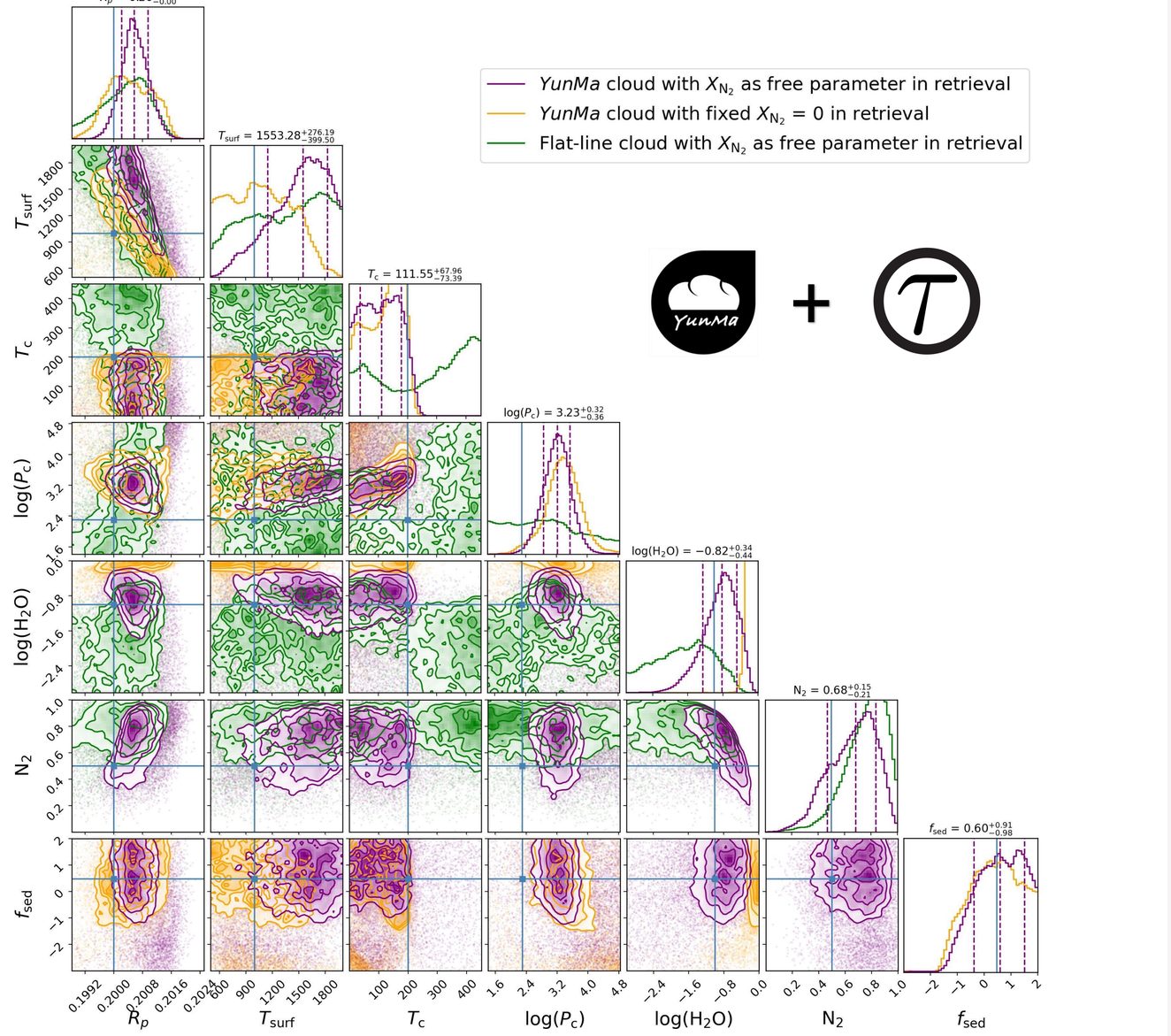
Validation of *YunMa* Forward Simulations



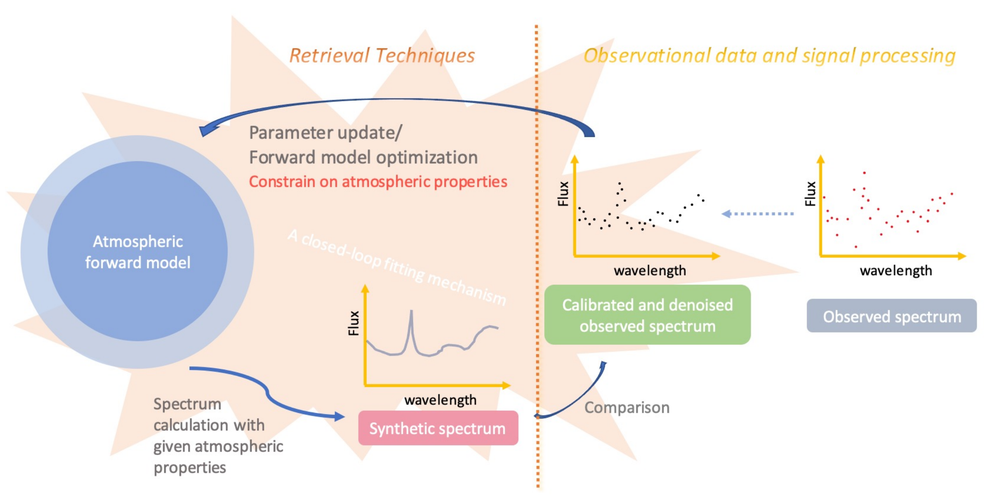
We validated the *YunMa* cloud simulation with previous work of Jovian ammonia cloud, KCl cloud on large exoplanets and water cloud on sub-Neptunes. We also validated the cloud particle radiative transfer simulation based on BH-Mie[✦] with published work.

Spectral Retrieval using *YunMa* + *TauREx*

Integrating *YunMa* into *TauREx* platform enables the retrieval study taking into account the cloud formation from microphysics. *YunMa* is able to constrain the atmospheric chemistry in cases where the flat-line cloud model shows poor performance.

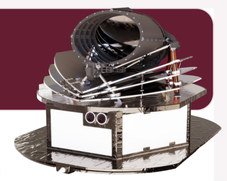


Bayesian Retrieval Technique



The current retrieval study of transit spectroscopy adopts Bayesian statistical techniques to constrain the atmospheric parameters from the observational data. *YunMa* integrated in *TauREx* platform covers both the forward and inverse modelling in the schematic and constrains the parameters in cloud formation.

Application of *YunMa* to *Ariel*



YunMa → Ariel Data Challenge 2023[b]

Planet Synthesis	Observations	Data Challenge

YunMa **→ Ariel Dry-Run**

YunMa is applied in the population study of different tiers in the Ariel Dry-Run to follow up the observation tier selection of *Ariel* targets. YunMa provides a better consideration of cloud impact on the selection strategy.

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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)