NEXOTRANS - Next-generation EXOplanet reTRieval and ANalysiS

A detailed analysis of the 0.6 - 12 μm JWST observations of WASP-39b

Scan me

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1. Introduction

JWST is offering observations with higher-resolution and greater precision than ever before. Accurate analysis and appropriate interpretation of these datasets require advanced retrieval frameworks capable of navigating the complex parameter space. Here we introduce "***NEXOTRANS***", an atmospheric retrieval framework that utilizes both Bayesian and machine learning methods for a comparative and independent interpretation of the observations. In this poster, we provide a glimpse of this retrieval framework and few of the results from **Deka et al. 2025**.

2. The NEXOTRANS Retrieval Framework

Some of the salient features of NEXOTRANS are listed as follows:

- Capable of performing retrieval with traditional Bayesian nested sampling algorithms such as ***PyMultiNest, UltraNest***.
- Does machine learning guided retrievals using four different algorithms: ***Random Forest, Gradient Boosting, k-Nearest Neighbor*** and ***Stacking Regressor*** (an ensemble of the first three, shows enhanced performance).
- Incorporates its own equilibrium chemistry grids from a newly developed equilibrium chemistry code - "***NEXOCHEM***".
- Models *approximate disequilibrium chemistry effects* on the spectrum using two new methods: ***Modified Hybrid Equilibrium*** and ***Modified Equilibrium offset chemistry*** .

3. 0.6 - 12.0 μm Retrieval of WASP-39b with NEXOTRANS

We demonstrated NEXOTRANS on the full available JWST observations of the hot Saturn-mass exoplanet WASP-39 b. The 0.6 - 2.8 μm observations (Feinstein et al. 2023) were obtained with the NIRISS instrument as a part of the JWST ERS program. The 0.5 - 5.5 μm observations (Rustamkulov et al. 2023) are from the NIRSpec PRISM, also obtained as a part of the ERS program. Finally, we also included the latest 5 - 12 μm observations from Powell et al. (2024) taken with the MIRI LRS instrument. This enabled retrievals with the combined datasets of the full JWST transmission spectrum of WASP-39b.

We performed a series of retrievals using the different chemistry models available in NEXOTRANS along with the presence of aerosols. We performed the PyMultiNest retrievals at a model resolution of R=20,000 and 2000 live points. We also performed retrievals with NEXOTRANS's machine learning mode which was trained on 60,000 model spectra, that showed consistent results with the Bayesian retrievals. It is worth mentioning that we found NIRISS and MIRI datasets have at least an offset of 57 ppm and 311.13 ppm with respect to the PRISM dataset.

References

1. **Deka et al**. arXiv preprint arXiv:2504.18815 (2025).
2. **Feinstein et al**. Nature 614.7949 (2023): 670-675.
3. **Rustamkulov et al**. Nature 614.7949 (2023): 659-663.
4. **Powell et al**. Nature 626.8001 (2024): 979-983.

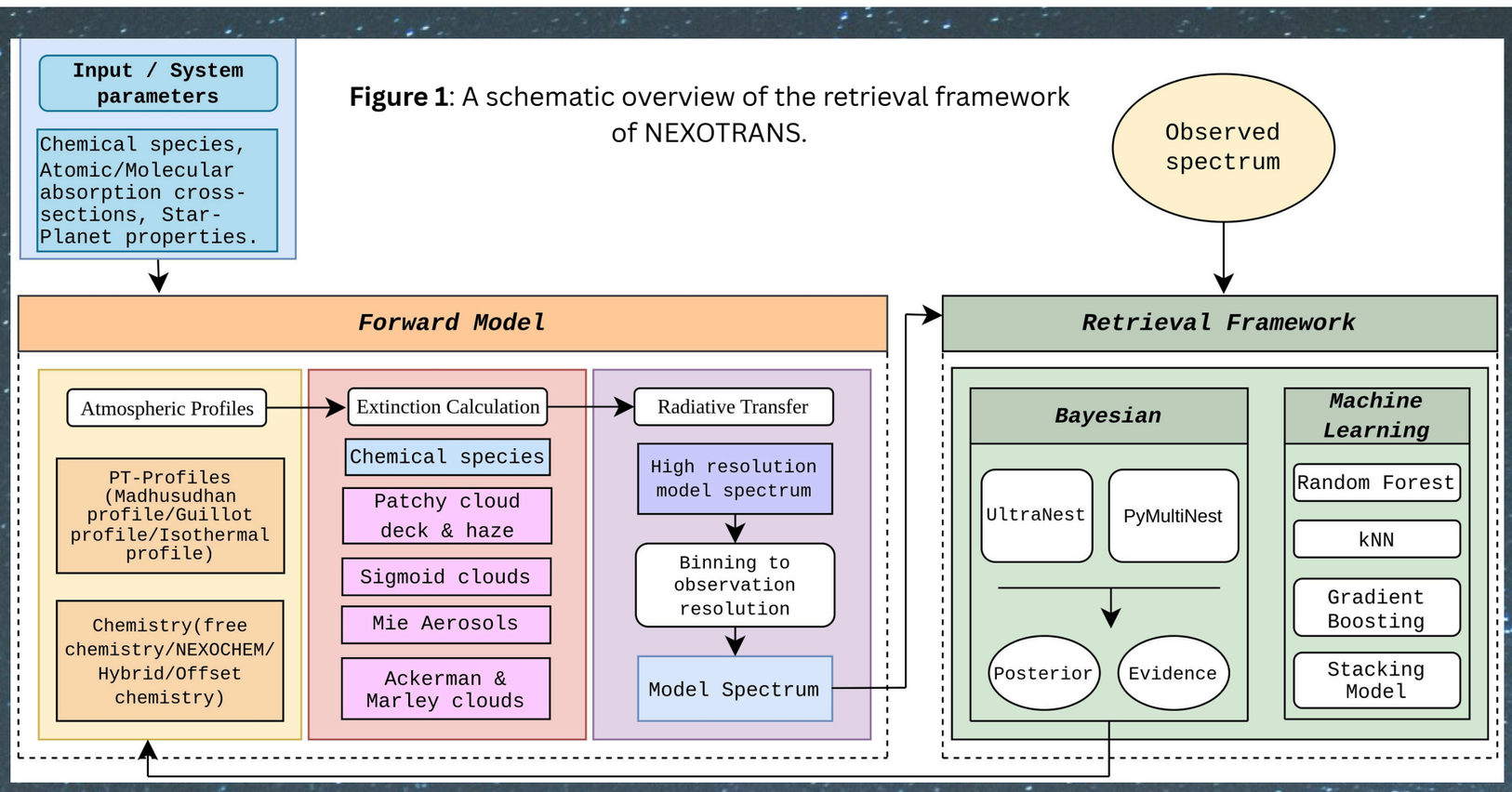

Figure 1: A schematic overview of the retrieval framework of NEXOTRANS.

4. Results

Below, we show one of the results from a set of retrievals performed on the combined data. Of all the retrievals, the modified hybrid equilibrium chemistry model achieved the best-fit with a reduced chi^2 value of 2.97.

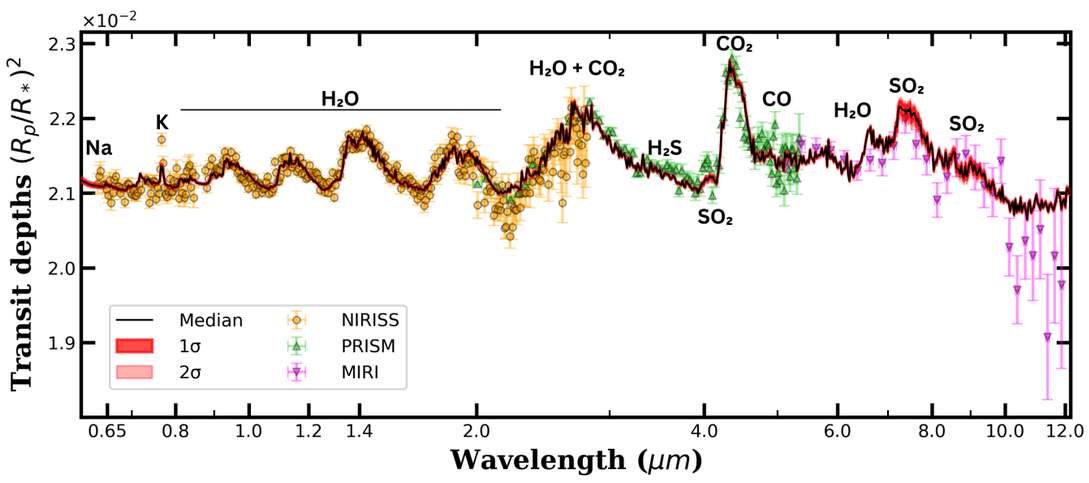

Figure 2: Best-fit retrieved spectrum using Bayesian retrieval for a model assuming hybrid equilibrium chemistry and aerosols.

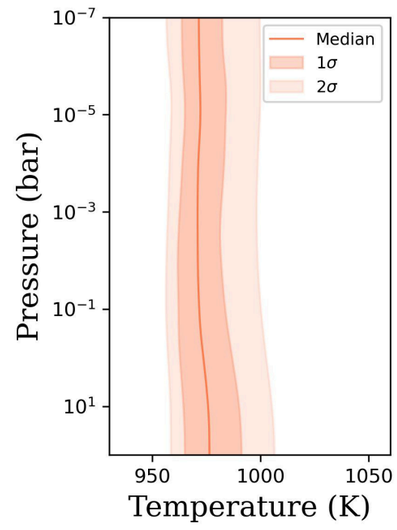

Figure 3: Retrieved PT profile.

5. Retrieved Parameters

Table 1: Retrieved values for selected parameters from the best-fit hybrid chemistry model including aerosols.

	log(H_2O)	log(CO_2)	log(CO)	log(H_2S)	log(SO_2)	log(K)	C/O	[M/H]
Bayesian	-2.89 +0.01/ -0.03	-4.59 +0.05/ -0.05	-1.99 +0.06/ -0.04	-3.93 +0.03/ -0.02	-5.80 +0.11/ -0.13	-8.74 +0.15/ -0.16	0.80 +0.03/ -0.01	1.19 +0.05/ -0.04
ML	-2.60 +0.08/ -0.08	-4.42 +0.17/ -0.55	-2.25 +0.27/ -0.49	-3.81 +0.05/ -0.20	-6.24 +1.14/ -0.32	-8.25 +0.01/ -0.01	0.72 +0.14/ -0.13	1.18 +0.17/ -0.30

6. Conclusions

Some of the conclusions that we make from this work are:

- Chemical models relying purely on equilibrium chemistry cannot produce the observed spectrum, especially the SO_2 feature in the PRISM and MIRI wavelengths (for combined retrievals).
- Approximate non-equilibrium chemistry models such as, Hybrid equilibrium chemistry or Equilibrium offset chemistry models, that combines equilibrium and free chemistry with multiplicative offsets to the equilibrium VMRs are at least needed for proper retrievals of chemical abundances.
- Non-grey cloud or aerosol models are preferred over grey patchy/uniform cloud and haze models. ZnS is preferred in most cases.
- All non-equilibrium chemical models hint at a super-solar C/O (0.72-0.89) ratio along with super-solar Metallicity, [M/H], (1.18-1.66) .

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