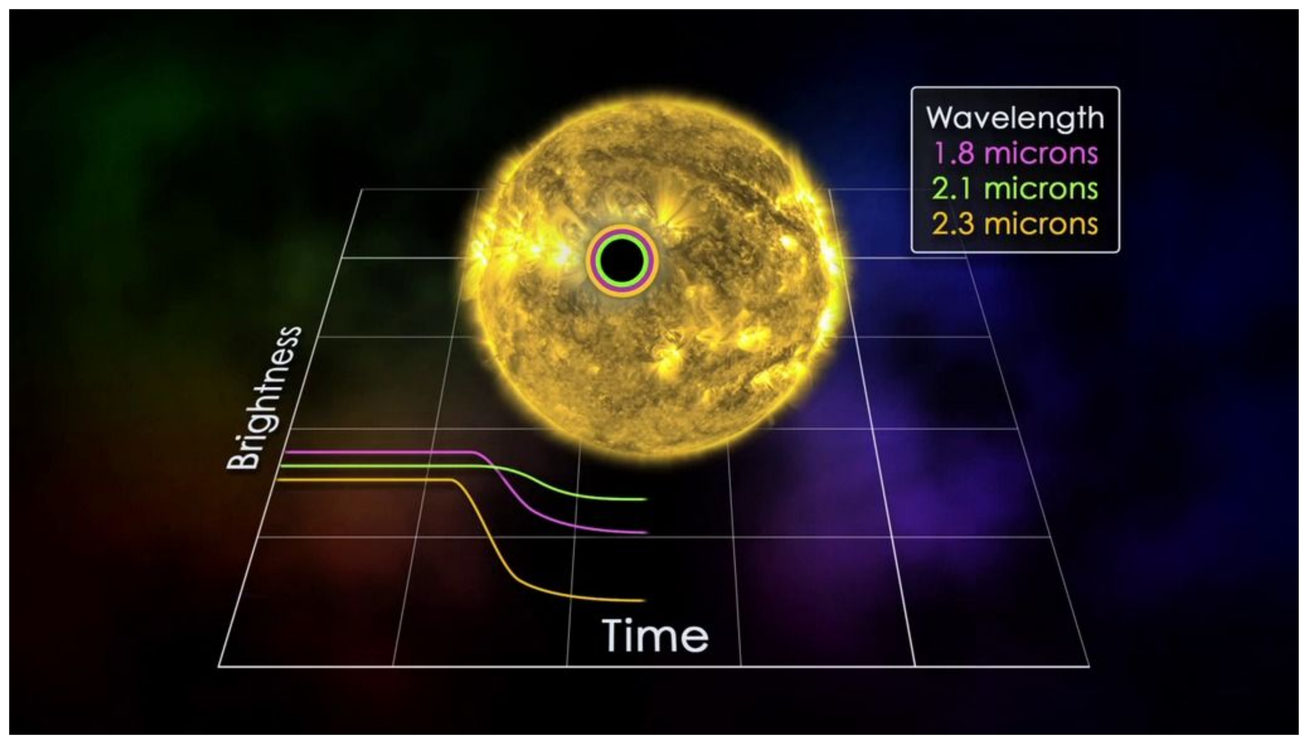
Unravelling the Atmospheres of Faraway Worlds with Adaptable Planetary Atmosphere Model

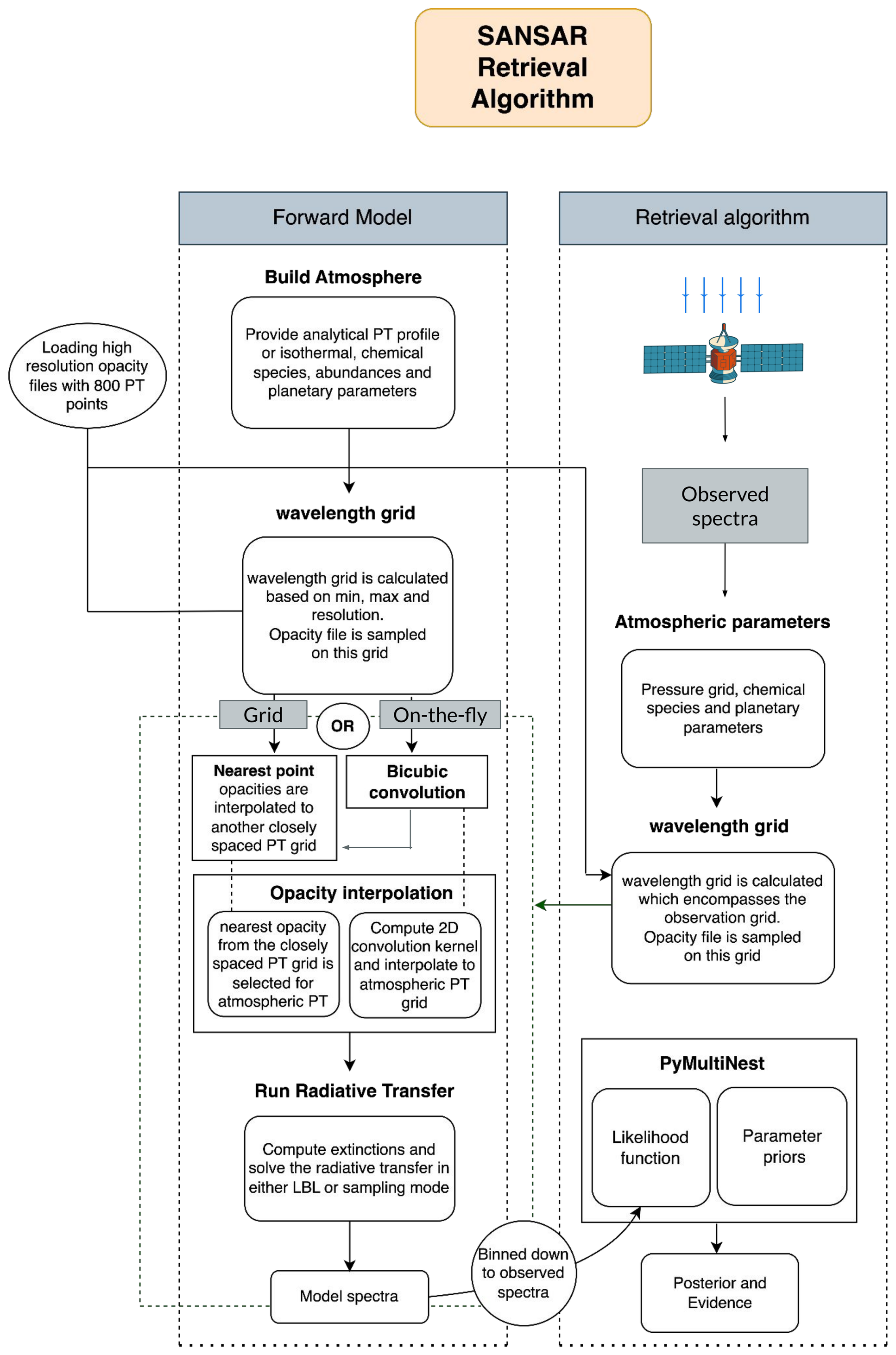
[1]Avinash Verma (avinash.verma@niser.ac.in), [1]Jayesh M. Goyal (jgoyal@niser.ac.in)
[1]National Institute of Science Education and Research (NISER), Odisha, India

Motivation



- More than 5500 confirmed Exoplanets. However, atmospheres of less than 100 have been characterized.
- Atmosphere important for planetary habitability.
- Atmosphere of an exoplanet imparts a unique fingerprint on the starlight passing through it, which can be measured at Earth using Transmission Spectroscopy.
- Interpreting transmission spectra observations require fast and accurate Radiative Transfer model.
- We can constrain atmospheric composition, their abundances, radius as well as clouds and hazes using this models.
- We present a subset of our **Suite of Adaptable plaNetary atmoSphere model And Retrieval** (SANSAR) that can be used to interpret transmission spectra observations of a large range of exoplanet atmospheres.

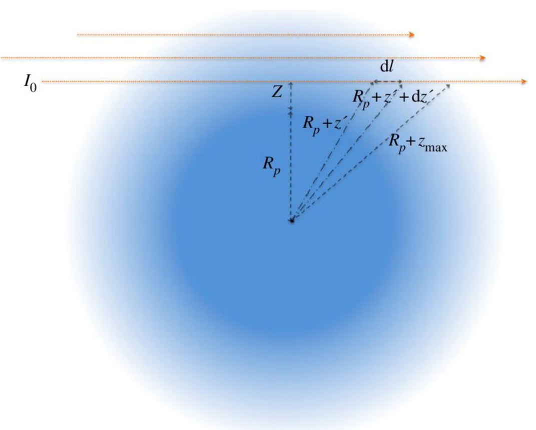
Methodology



Transit depth [1]:

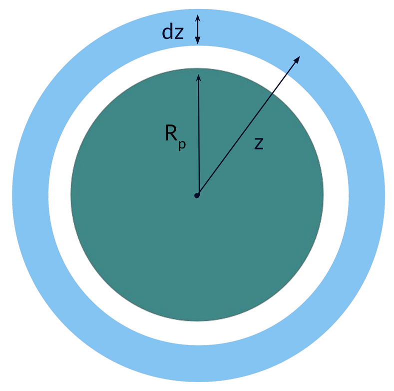
$$depth(\lambda) = \frac{R_p^2 + 2\int_0^{z_{max}} (R_p + z)(1 - e^{-\tau(\lambda, z)})dz}{R_\star^2}$$

R_p = Radius of the planet below which no light can pass
Z = impact parameter of the ray
τ = optical depth at z



Source: M.D.J. Hollis, M. Tessenyi, G. Tinetti, 2013

depth(λ) = (Circular area of the planetary disk + Σ fractional area of circular ring at impact parameter z with thickness dz that blocks the light) / Circular area of star disk



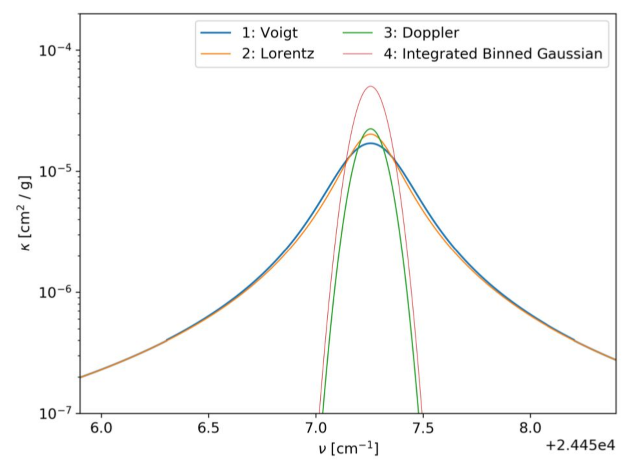
High resolution cross section:

Lorentz profile:

$$f_L(\nu) = \frac{1}{\pi} \frac{\gamma_L}{(\nu - \nu_0)^2 + \gamma_L^2}$$

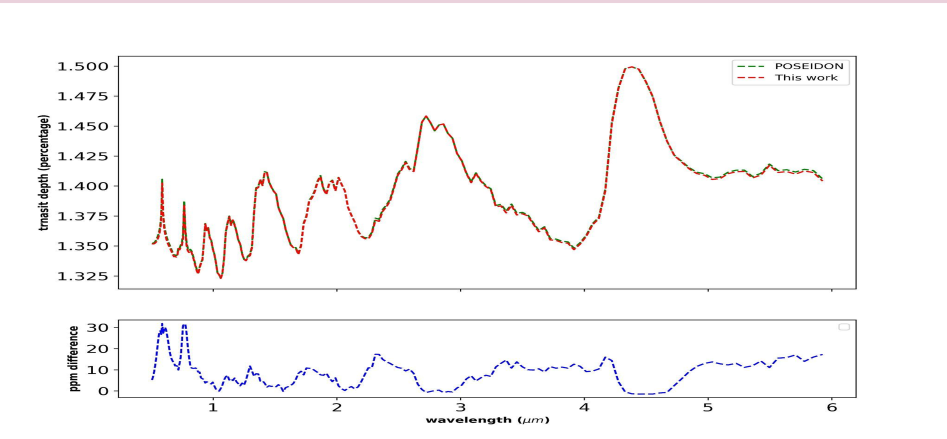
Doppler profile:

$$f_G(\nu) = \sqrt{\frac{ln(2)}{\pi}} \frac{1}{\alpha_D} \exp\left(-\frac{(\nu - \nu_0)^2 ln(2)}{\alpha_D^2}\right)$$

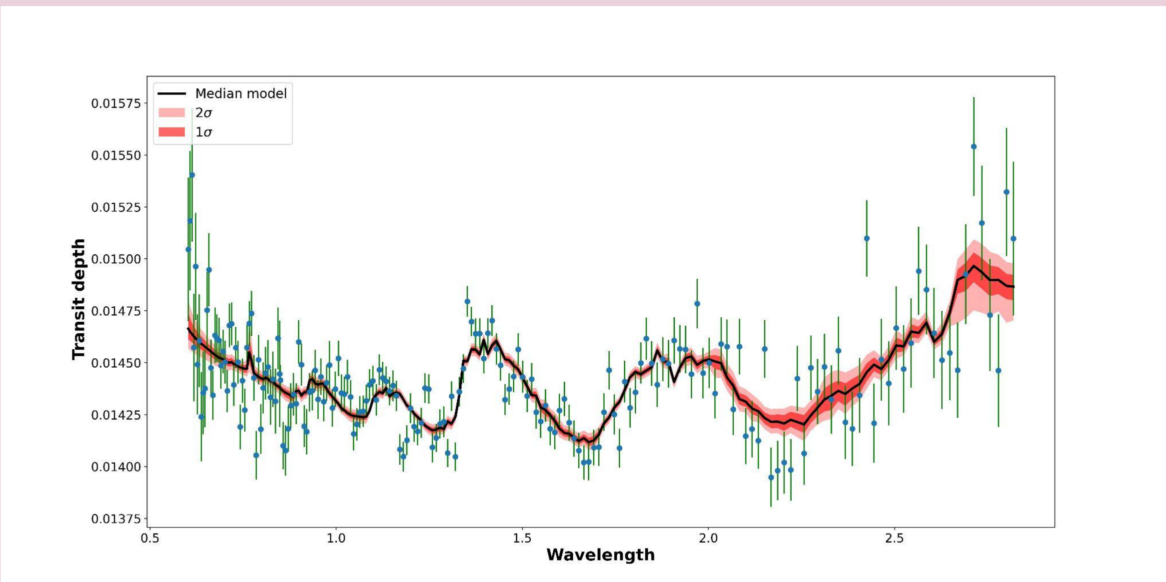


Source: Helios-K

Results



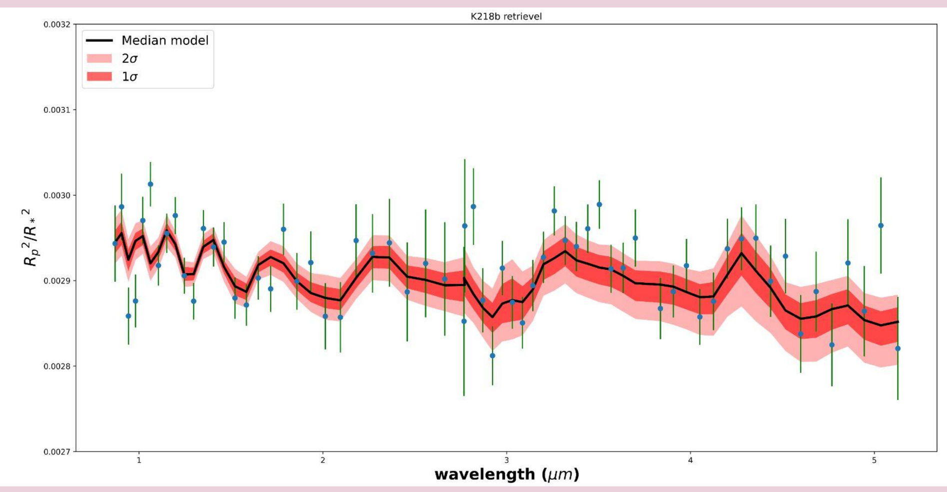
Forward model comparison from POSEIDON [2] for WASP-96b



Result from retrieval for WASP-96b
Reduced χ^2 = 1.95 (best fit model)

Cloud & Haze parameters retrieval

	log(haze_a)	haze_gamma	log(CTP)	phi(patchy)
POSEIDON	$1.7^{+0.59}_{-0.40}$	$-3.75^{+0.68}_{-0.90}$	$0.37^{+1.05}_{-1.08}$	$0.91^{+0.07}_{-0.16}$
SANSAR	$2.01^{+0.82}_{-0.60}$	$-4.34^{+0.98}_{-1.18}$	$0.44^{+1.00}_{-1.05}$	$0.82^{+0.13}_{-0.19}$
AURORA	$1.85^{+0.72}_{-0.47}$	$-4.00^{+0.76}_{-1.01}$	$0.39^{+1.05}_{-1.06}$	$0.88^{+0.09}_{0.17}$



Preliminary results from retrieval for K218b
Reduced χ^2 = 1.081 (best fit model)

	log(H2O)	log(CO)	log(CO2)	log(Na)	log(K)
Aurora [3]	$-3.59^{+0.35}_{-0.35}$	$-3.25^{+0.91}_{-5.06}$	$-4.38^{+0.47}_{-0.57}$	$-6.85^{+2.48}_{-3.10}$	$-8.04^{+1.22}_{-1.71}$
CHIMERA [4]	$-3.73^{+0.21}_{-0.20}$	$-3.39^{+0.74}_{-3.71}$	$-4.80^{+0.37}_{-0.52}$	$-4.10^{+0.60}_{-2.31}$	$-7.14^{+0.60}_{-1.02}$
POSEIDON [2]	$-3.70^{+0.36}_{-0.32}$	$-3.22^{+0.81}_{-2.83}$	$-4.87^{+0.54}_{-0.86}$	$-5.13^{+1.07}_{-3.13}$	$7.90^{+0.85}_{-1.59}$
SANSAR	$-3.73^{+0.37}_{-0.35}$	$-3.22^{+0.76}_{-2.79}$	$-4.75^{+0.52}_{-0.66}$	$-6.51^{+2.30}_{-3.11}$	$-8.45^{+1.60}_{-1.49}$

Comparison of VMR from other retrieval codes for WASP-96b

Conclusion

- We have developed our own forward model from scratch which is fast (~30ms for one run) and accurate.
- Developed in-house high resolution opacity file database (Δnu = 0.001 cm^{-1}) to be used for large range of exoplanet atmospheres.
- We benchmark our model with results of WASP-96b from different retrieval codes and found it to be in agreement.
- We also run the retrieval for K218-b and found good fit between the model and observed spectra. More investigation will follow for abundances retrieval.
- We have been able to put good constrains on reference radius, cloud parameters, haze, temperature as well as as abundances with our code
- We have also used correlated-k as a method for opacity treatment along with opacity sampling. Here the k-tables are generated using exo_k[5]

Future Work

- We are adding chemistry, emission and radiative convective framework
- We will be making the framework more general (i.e. 3D atmosphere, mie scattering,)
- Study of earth as an exoplanet
- More retrievals will follow

Acknowledgement

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References

[1] M.D.J. Hollis, M. Tessenyi, G. Tinetti (2013)
[2] MacDonald, R. J., (2023). POSEIDON: A Multidimensional Atmospheric Retrieval Code for Exoplanet Spectra
[3] Aurora (Welbanks & Madhusudhan 2021)
[4] CHIMERA https://github.com/mrline/CHIMERA
[5] Leconte (2020)