DISEQUILIBRIUM CHEMISTRY INDICATES A CARBON-RICH ATMOSPHERE ON WASP-69b

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MOTIVATION

WASP-69b is a short-period, warm gas-giant exoplanet (P$\sim$ 4 days, $T_{eq} \sim 950$ K) with a rich atmospheric molecular composition including **CH_4, NH_3, CO, H_2O and C_2H_2** (Guilluy et al. 2022). Its high-resolution ground-based transmission spectroscopy signal is dominated by CH_4, suggesting the atmosphere is carbon-rich. We investigated whether the observed spectra is influenced by the non-equilibrium processes photochemistry and vertical mixing (Bangera et al., submitted).

We conducted a parameter study of the atmosphere accounting for disequilibrium for the following parameters

- 4 × Gas temperature profiles (TP)
- 4 × Carbon-to-Oxygen ratios (C/O)
- 3 × Eddy diffusion coefficients (Kzz)

METHODS

VERTICAL DIFFUSION of gases and **PHOTOCHEMISTRY** are two key processes that can drive a planet's atmosphere out of chemical equilibrium. We use the 1D code ARGO (Rimmer & Helling 2016) to model the gas-phase composition of WASP-69b's atmosphere. ARGO solves the 1D continuity equation for each chemical species i,

$$\frac{\partial n_i}{\partial t} = P_i - L_i - \frac{\partial \phi_i}{\partial z} \qquad (1)$$

where the vertical flux is given by,

$$\phi_i = -K_{zz}\left[\frac{\partial n_i}{\partial z} + n_i\left(\frac{1}{H_0} + \frac{1}{T}\frac{dT}{dz}\right)\right] - D_{zz}\left[\frac{\partial n_i}{\partial z} + n_i\left(\frac{1}{H_i} + \frac{1+\alpha_T}{T}\frac{dT}{dz}\right)\right] \qquad (2)$$

with Kzz being the eddy diffusion coefficient and Dzz the molecular diffusion coefficient.

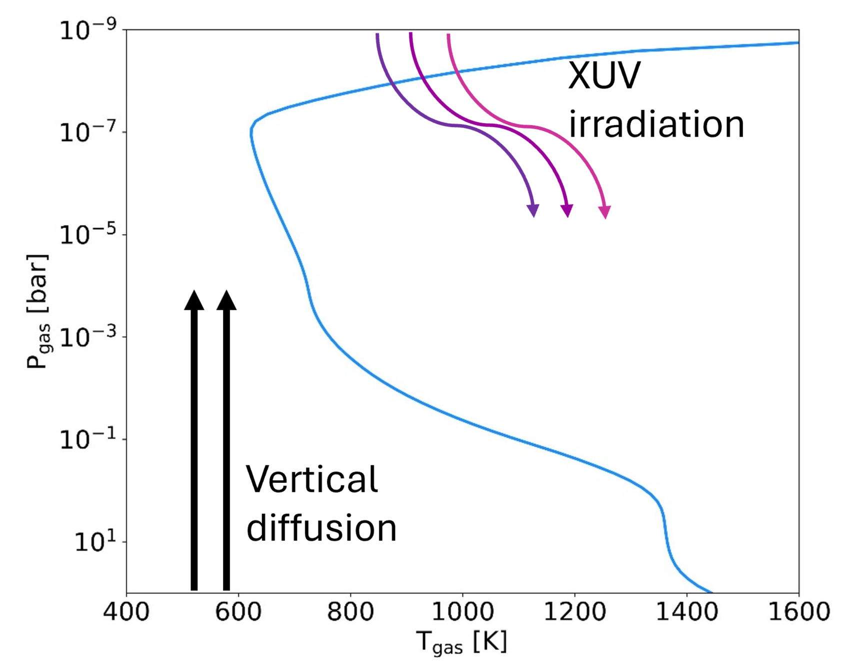
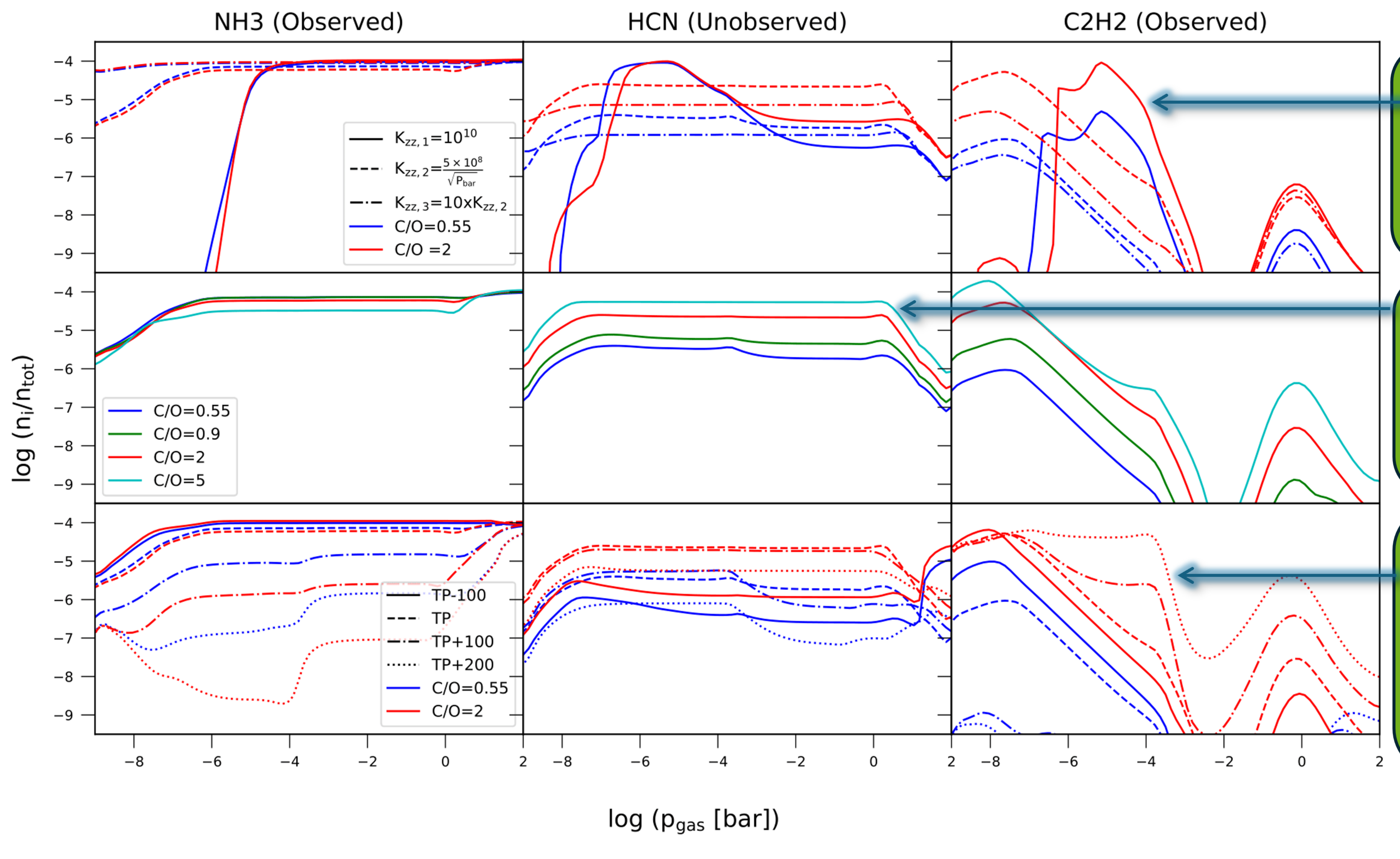


Figure 1: Disequilibrium processes that may impact the atmospheric composition and thus the transmission spectra of WASP-69b.

RESULTS

Non-requilibrium gas-phase C_2H_2 concentrations are high for C/O ≥ 2 at the pressure range (1 bar - 1 μbar) probed by the GIANO-B near-infrared spectrograph at the Telescopio Nazionale Galileo. We find that three models that best compare to observations all have C/O =2 but differ in vertical mixing efficiency (Kzz) and gas temperature profile (T_{gas}).



Kzz :
For a less efficient diffusion, more C2H2 is produced photochemically while the photodissociated NH3 and HCN remain unreplenished.

C/O:
NH3 remains unaffected by the rise in C/O until HCN becomes the dominant nitrogen bearing molecule. Both HCN and C2H2 concentrations increase steadily with a increase in C/O.

T_{gas}:
C2H2 shows opposite relation to temperature in carbon rich vs oxygen rich environments. HCN formation increases with rise in temperature but drops when concentrations of parent molecule NH3 deplete.

Figure 2: Local non-equilibrium gas-phase concentrations $\frac{n_i}{n_{tot}}$ for NH_3, HCN and C_2H_2 for the terminator region of WASP-69b. **Top:** varying eddy diffusion, for TP, C/O=0.55 and 2. **Middle:** varying C/O ratios, for TP and $K_{zz,2}$. **Bottom:** varying (T_{gas}, p_{gas}), for $K_{zz,2}$ and C/O=0.55 and 2.

HCN CONUNDRUM

HCN remains unobserved on WASP-69b despite three most-favoured models predicting high HCN concentrations. Less efficient eddy diffusion, higher metallicity or lower N/H ratio may reduce HCN concentrations but also diminish NH_3 and C_2H_2 concentrations and thus are unfavorable solutions.

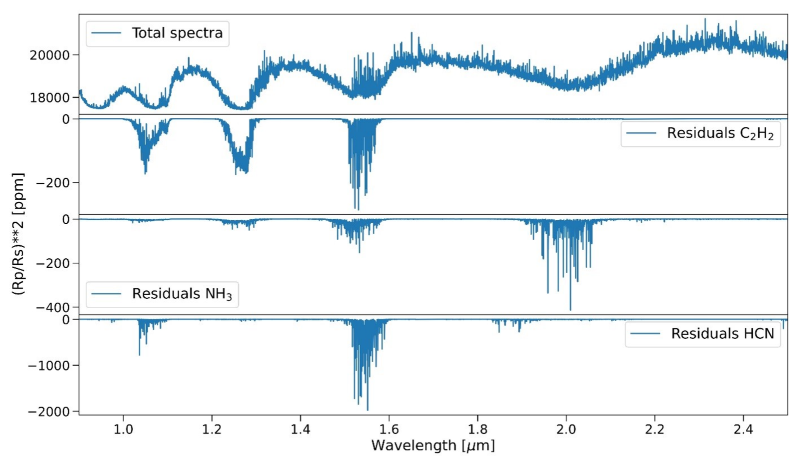


Figure 3: Predicted HCN signal from top-fit models $\sim 10\times$ stronger than NH_3 and C_2H_2 signals.

SUMMARY

- 1D photochemical-kinetic modeling of WASP-69b suggests the planet is carbon-rich with C/O$\sim$2.
- Most-favoured models predict high concentrations of HCN, which hasn't been observed.
- Further observations and 3D atmospheric modelling is required to solve the HCN conundrum and to disentangle different Kzz-T_{gas} scenarios.

References;
Guilluy, G., et al. 2022, *A&A*, 665; **Bangera, N.** et al. submitted ;**Rimmer, P. B. and Helling, C.**, 2016, *ApJ* 224, no. 1.

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