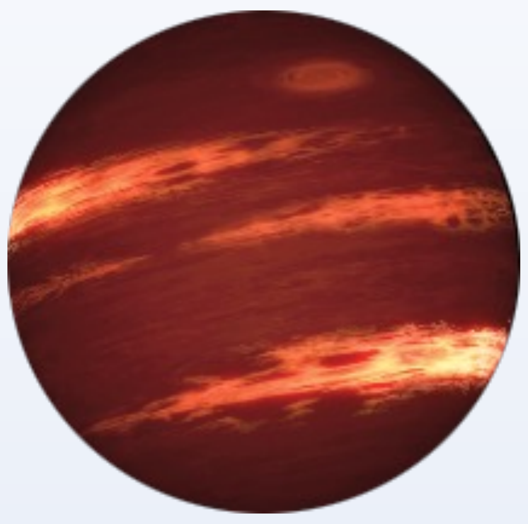

VHS 1256 b, HIP 99770 b, AF Lep b: Expected Thermal Light Polarization

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Background

- Polarimetry can be a powerful tool that complements flux observations in the characterization of exoplanets
  - Polarized light broken into Stokes vector S = (I, Q, U, V), V≈0 for giant exoplanet/brown dwarf atmospheres
- Signal is typically low for thermal emission, but already measurable (e.g. Zapatero Osorio et al. 2011, Miles-Páez et al. 2013, Manjavacas et al. 2017, Millar-Blanchaer et al. 2020)
- Here we look at the potential polarized light curves for 3 imaged exoplanets (Table 1).
  - VHS 1256 b
    - JWST observations of VHS 1256 b found the first confirmed detection of silicate clouds in an exoplanet atmosphere (Miles et al. 2023)
  - HIP 99770 b
    - Recent discovery and observation (Currie et al. 2023, Bovie et al. 2025), suggested equilibrium chemistry
  - AF Lep b
    - closest directly imaged exoplanet to date (De Rosa et al. 2023, Mesa et al. 2023, Franson et al. 2023)

Target Parameters			
Parameter	VHS 1256 b	HIP 99770 b	AF Lep b
Distance (a, AU)	102 [1]	$16.9^{+3.4}_{-1.9}$ [2]	8.8-9.1 [3]
Gravity (logg[cgs])	3.2-4.5 [4]	4-5 [2]	3.5-4.25 [5,3]
Teff (K)	1100-1240 [11,6]	1250-1600 [2]	800-1000 [3]
Inclination	24^{+10}_{-15} [7]	148^{+13}_{-11}–$152.1^{+9.2}_{-11.6}$ [2,9]	50^{+9}_{-12}–$55.8^{+6.2}_{-7.2}$ [8,10]

Table 1: Parameters for each target used in this work. 1: Gauza et al. (2015), 2: Currie et al. (2023), 3: De Rosa et al. (2023), 4: Hoch et al. (2022), Miles et al. (2018), Gauza et al. (2015), 5: Mesa et al. (2023), 6: Miles et al. (2018), 7: Dupuy et al. (2023), 8: Franson et al. (2023), 9: Zhang et al. (2024), 10: Bonse et al. (2025), 11: Miles et al. (2023)

Methods

- Followed method of Mukherjee et al. (2021) utilizing **picaso** (Mukherjee et al. 2023) and **virga** (Batalha et al. 2020) to build the cloudy atmospheres off of the **Sonora Bobcat** models (Marley et al. 2021), and **ARTES** (Stolker et al. 2017) to find the polarization.
- Models used log k_{zz} = 5 with $1 \leq f_{sed} \leq 4$ and we assumed:
  - 0-3 cloud bands 0-2 clouds (Fig. 1)
- Created light curves for all maps, and tested effect of f_{sed}, dT_{eff}, log g, inclination on them
  - Produced possible light curves for our three exoplanets
- Created inclination function that transformed cloud coordinates using 3D rotation matrices. "Generic" models were produced without the inclination function.

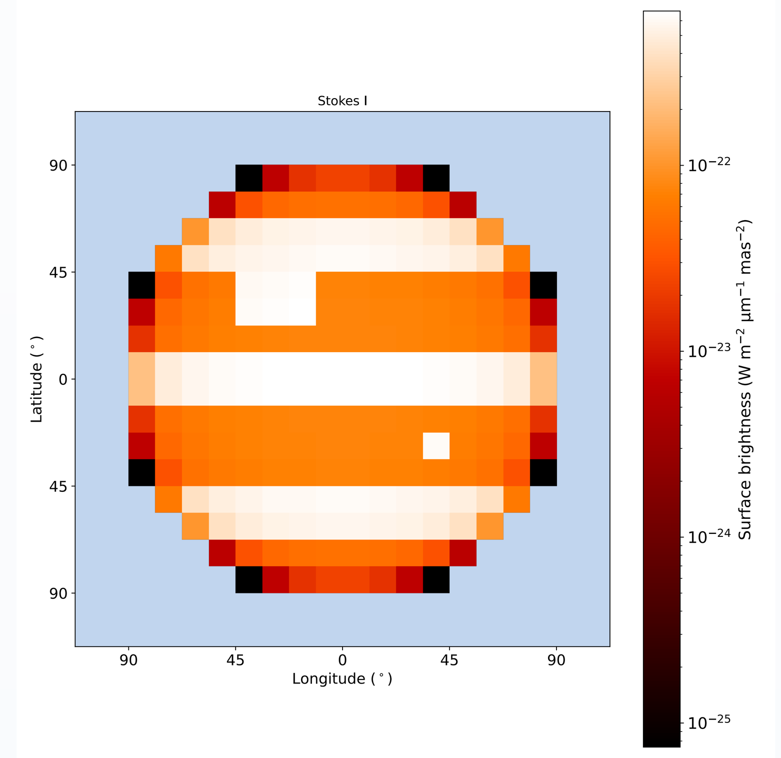

Fig. 1: An example map showing the range of cloud cases used. This map uses our primary "generic" case with a base layer T=1400 K, f_{sed} = 2, a cloud layer T=1600 K, f_{sed} = 4, and log g = 4.0.

Results

- As expected, increased symmetry decreases the degree of polarization, shown by the 0 and 3 band cases in Fig. 4 being within 1σ using Millar-Blanchaer et al. (2020)'s observational error bars. They remain indistinguishable with small clouds, but can be differentiated with larger clouds creating non-zero polarization in U/I.
- The impact of log g on the light curve is highly model dependent, with lower log g resulting in higher variation from the baseline for models with warmer clouds and the inverse occurring for models with colder clouds → larger scattering difference between cold vs hot spot models where $\tau_{\text{sum,cld}} \leq 1$
- Inclination has the most obvious impact, with the amplitude of variation decreasing as the inclination increases from an equator on view to a pole on view. It also, notably, effects where features in the light curves present and the angle of polarization (χ) as a function of phase angle.
- f_{sed} largely has the strongest effect on both Q/I and U/I polarization while the impact of log g is more minor. Q/I is also more sensitive to the number of cloud bands while U/I is more sensitive to cloud size. Spacing between the clouds has stronger effect than cloud size alone.

J-band cloud comparison

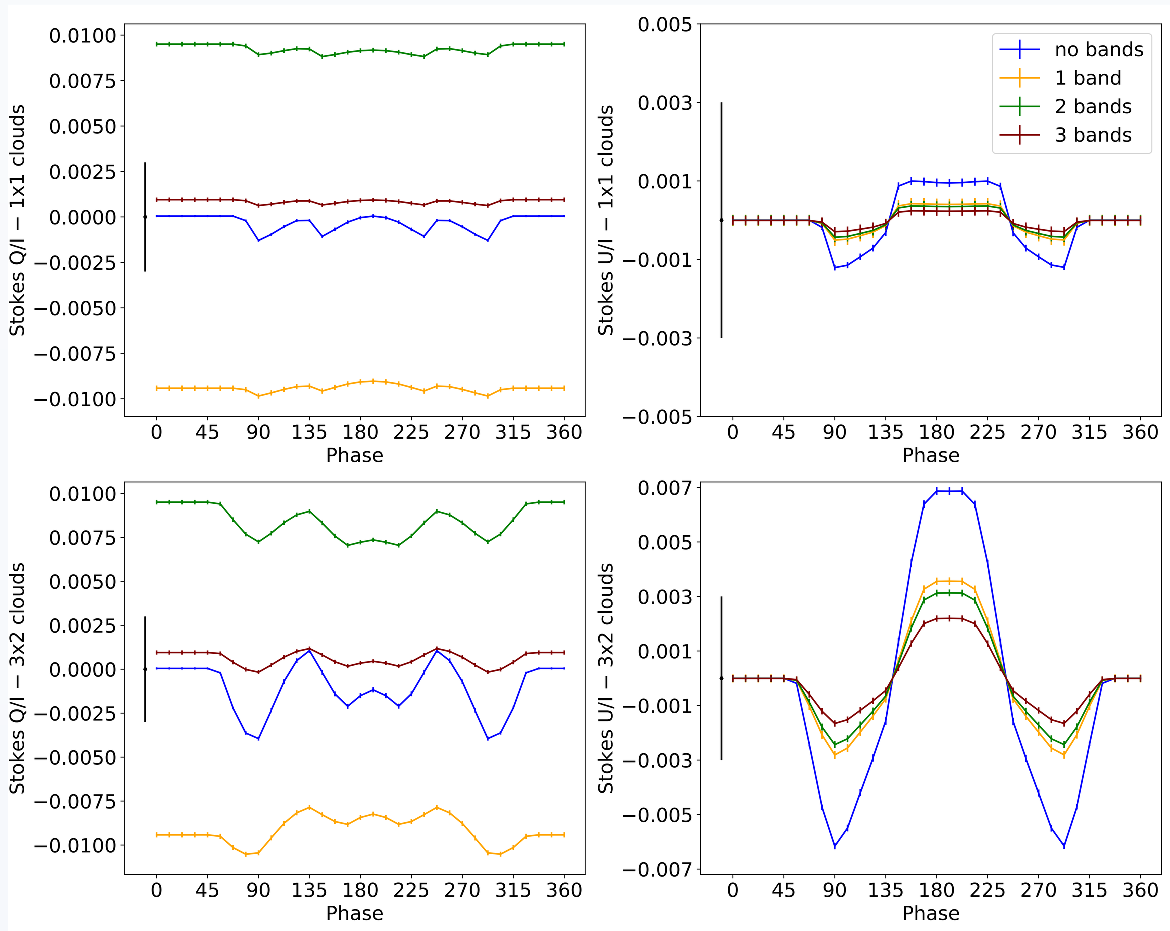

Fig. 4: Q/I (left) and U/I (right) light curves for our "generic" case with no bands (blue lines), 1 equatorial band (orange lines), 2 bands (green lines), or 3 bands (red lines) alongside the observational error bars from Millar-Blanchaer et al. (2020). Inclination was not considered in this case.

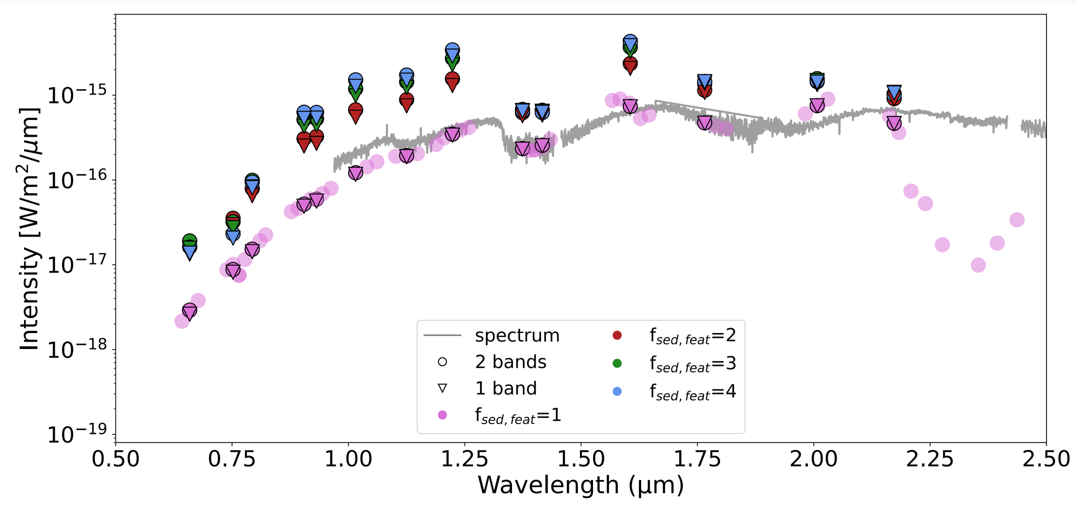

Fig. 2: JWST spectra of VHS 1256 b (gray line) compared to photometry using our models at log g = 4.5 with either a single equatorial band (triangles) or 2 bands (circles) and varying in the value of f_{sed} for the cloud features. Inclination was not considered in this case.

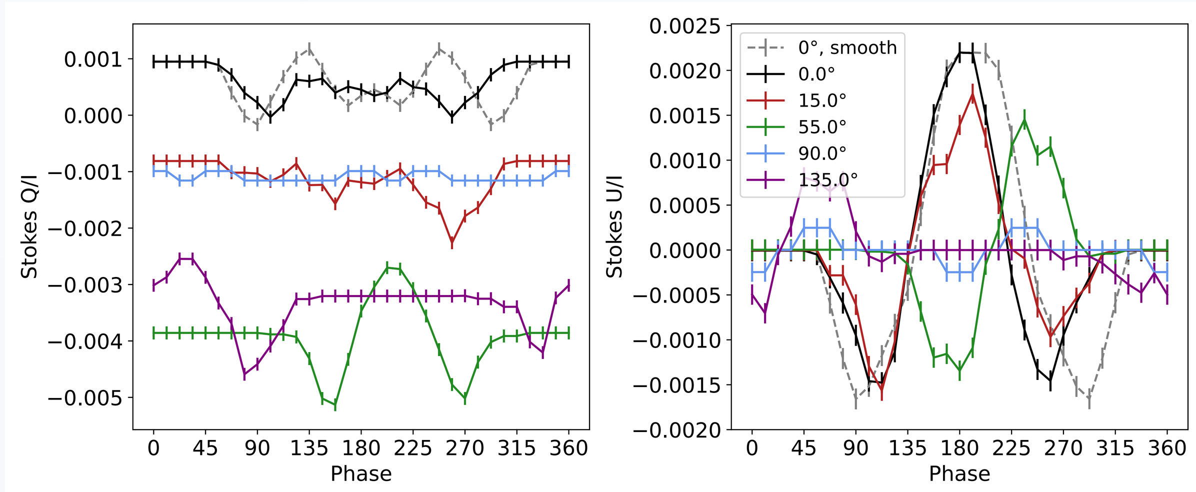

Fig. 3: Q/I (left) and U/I (right) light curves for our "generic" case with 3 bands at different inclinations and compared to our model that ignores inclination (dashed gray line). The southern cloud is minimally visible at the edge at i=55° between phases 90° and 213°.

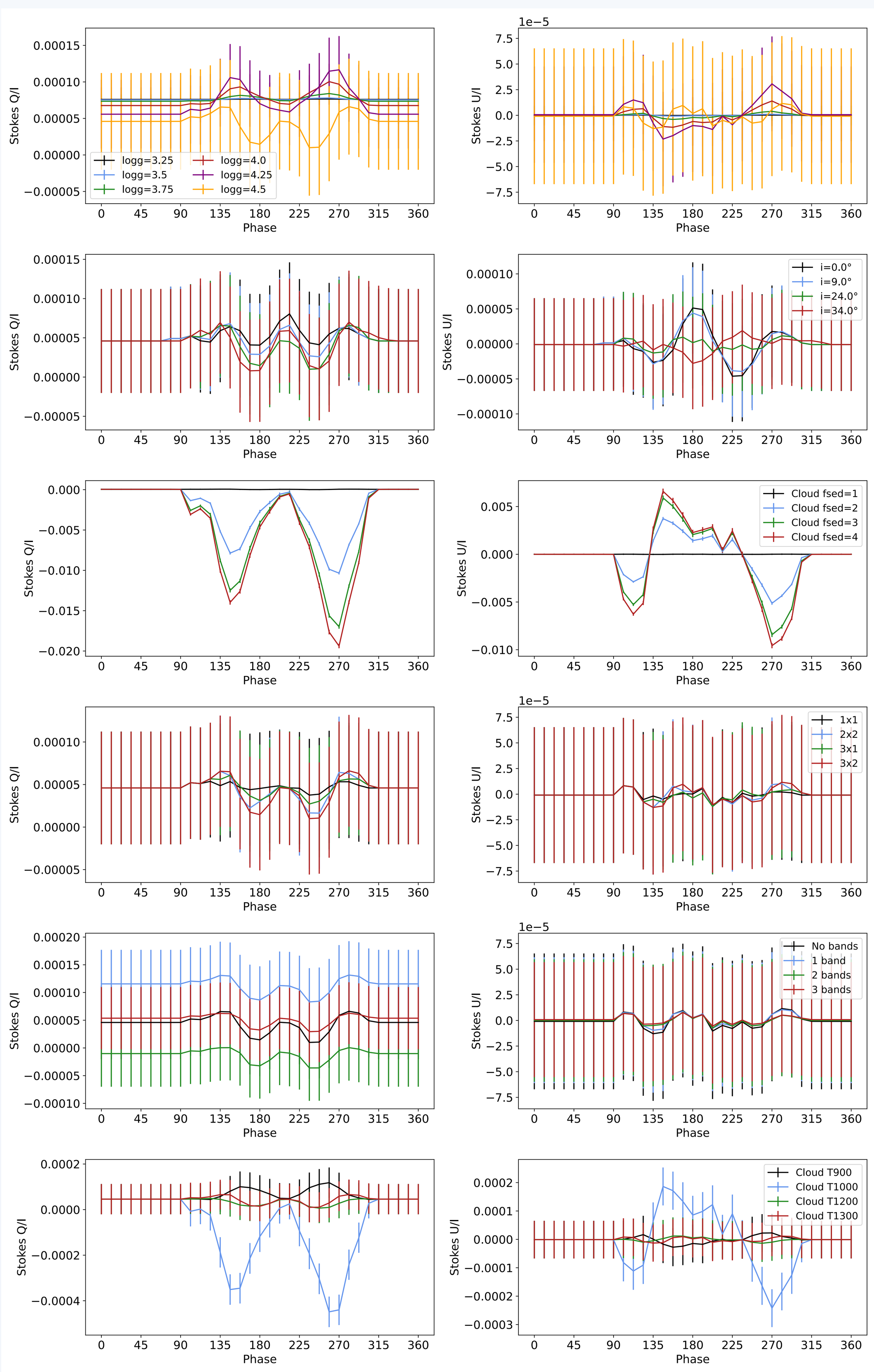

Fig. 5: Various parameters for VHS 1256 b and how their Q/I and U/I light curves are affected. Each case is varied off of a "base" case with a base layer T=1100 K, f_{sed} = 1, a cloud layer T=1300 K, f_{sed} = 1, log g = 4.5, two large (3x2) clouds, no cloud bands, and i=24°.

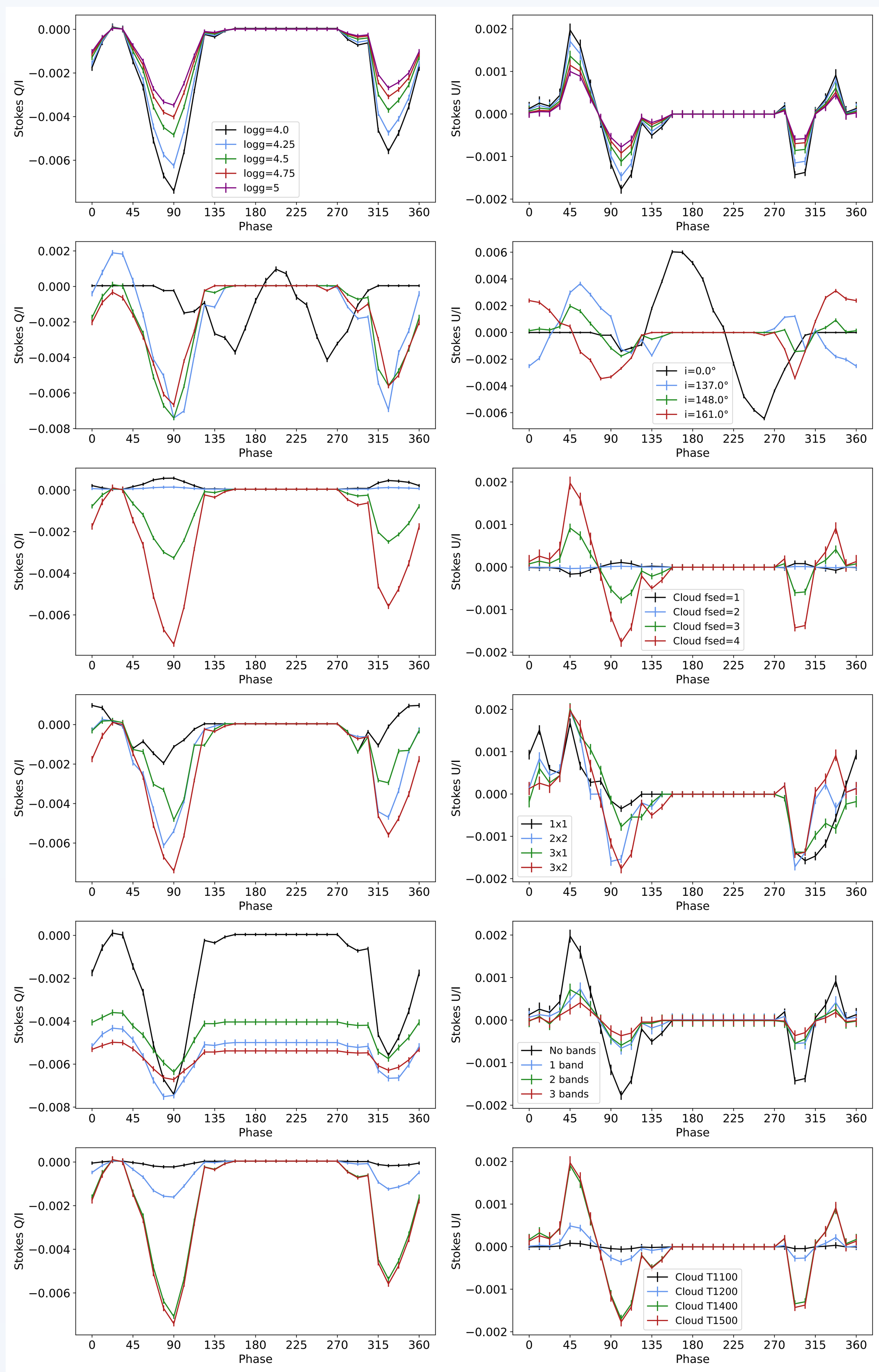

Fig. 6: Same as Fig. 3 for HIP 99770 b. Each case is varied off of a "base" case with a base layer T=1300 K, f_{sed} = 2, a cloud layer T=1500 K, f_{sed} = 4, log g = 4, two large (3x2) clouds, no cloud bands, and i=148°.

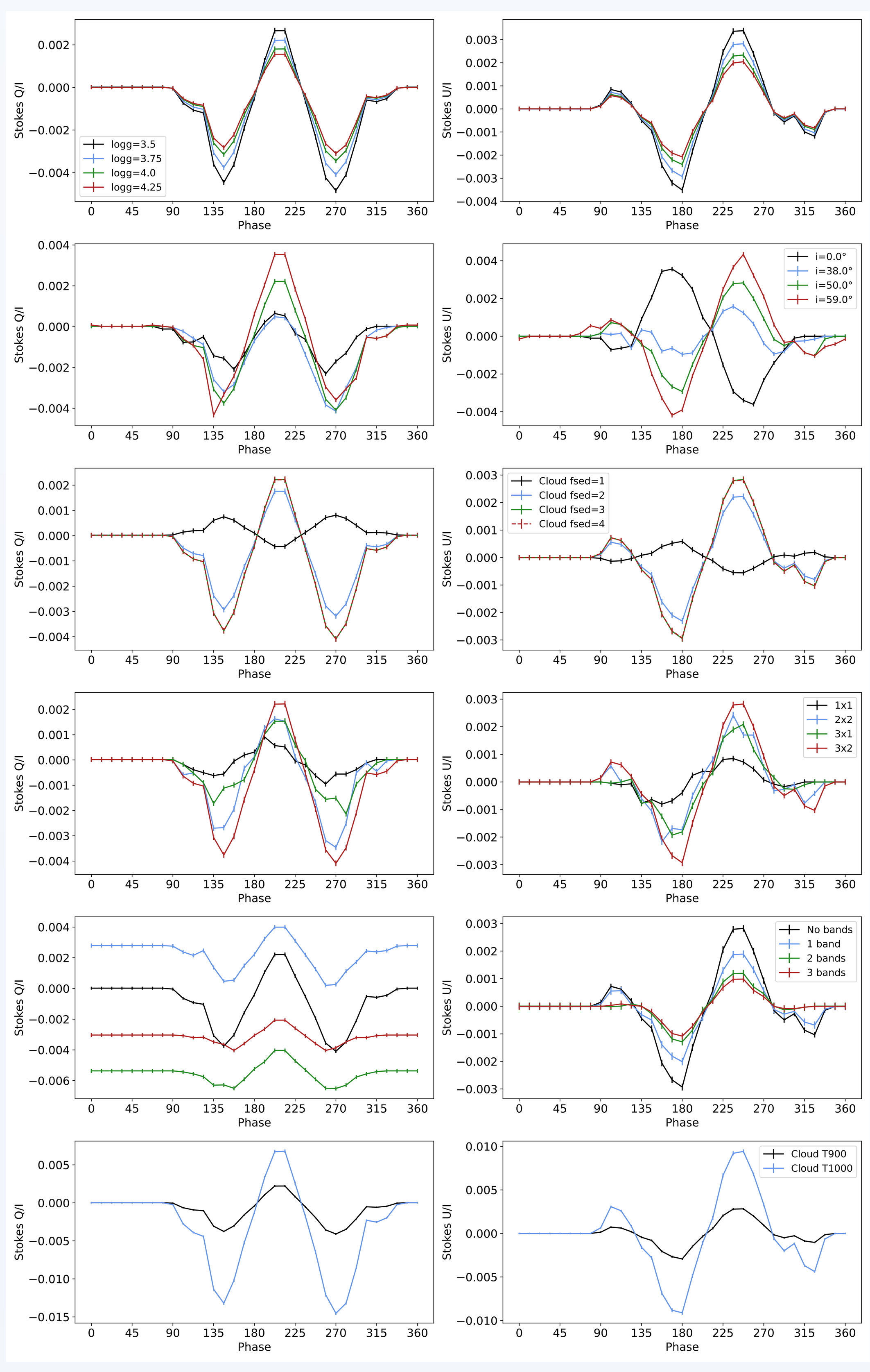

Fig. 7: Same as Fig. 3 for AF Lep b. Each case is varied off of a "base" case with a base layer T=800 K, f_{sed} = 2, a cloud layer T=900 K, f_{sed} = 4, log g = 3.75, two large (3x2) clouds, no cloud bands, and i=50°.

Conclusions and Future Work

Our results emphasize the need to rely on both Q/I and U/I for full characterization of an atmosphere, as two models being undifferentiable in one does not necessarily lead to them being undifferentiable in the other. Larger differences tend to be due to inclination, cloud (spots and bands) size, f_{sed}, and spacing, and temperature contrast, while the impact of parameters like gravity are more dependent on the other parameters. In this work, we used a constant log k_{zz}, which can underestimate the impact of clouds in the spectrum in the K-band (Fig. 2). This will be further explored in our future work expanding this grid of models, which we will show part of in the paper this poster is based on.

Acknowledgements

Maxwell Galloway, Theodora Karalidi and Max Millar-Blanchaer acknowledge the support of NASA Exoplanets Research Program grant 80NSSC21K0396. Maxwell Galloway and Theodora Karalidi acknowledge the University of Central Florida Advanced Research Computing Center high-performance computing resources made available for conducting the research reported in this poster (https://arcc.ist.ucf.edu).