MagAO-X visible imaging of β-pic b

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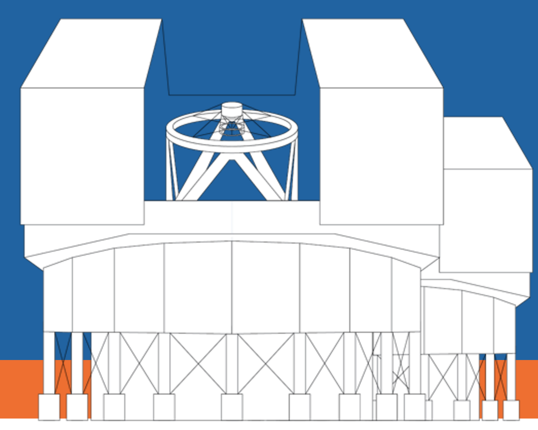

Direct Imaging

Directly imaging young, self-luminous planets provides key insights into atmospheric composition, chemistry, and ultimately formation histories. The β Pic system consists of two exoplanets assumed to have formed simultaneously embedded in a debris disk and thus remains especially interesting for photometric characterization. β Pic b is a wide separation (9AU, 0.5") super-Jupiter (10-15 M_J) characterized as an early L dwarf [1]. MagAO-X is now capable of observing shorter wavelengths than previous bluest photometry point of Y_s (0.985 μm) measured on MagAO [2], wavelengths that are especially effective at constraining effective temperature. These high contrast images are achieved with the architecture in Fig 1.

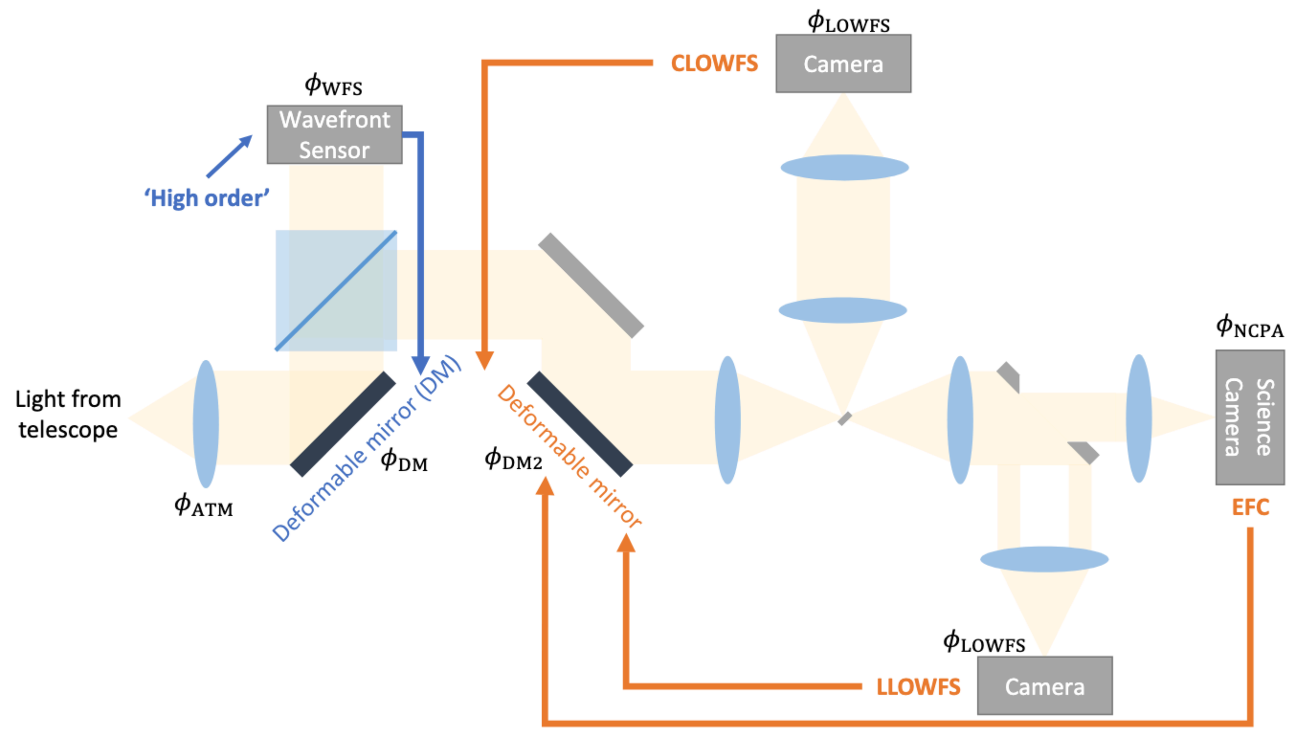

Fig 1. A schematic overview of a High Contrast Imaging (HCI) instrument including coronagraphs and advanced control schemes used by MagAO-X. [3]

MagAO-X Instrument

The Magellan Adaptive Optics Extreme (MagAO-X) system [4], is a coronagraphic instrument on the Magellan Clay 6.5m telescope in Chile. The high contrasts it can achieve at narrow speration in visible wavelengths (0.5 – 1.0 μm) enabled these novel β Pic observations.

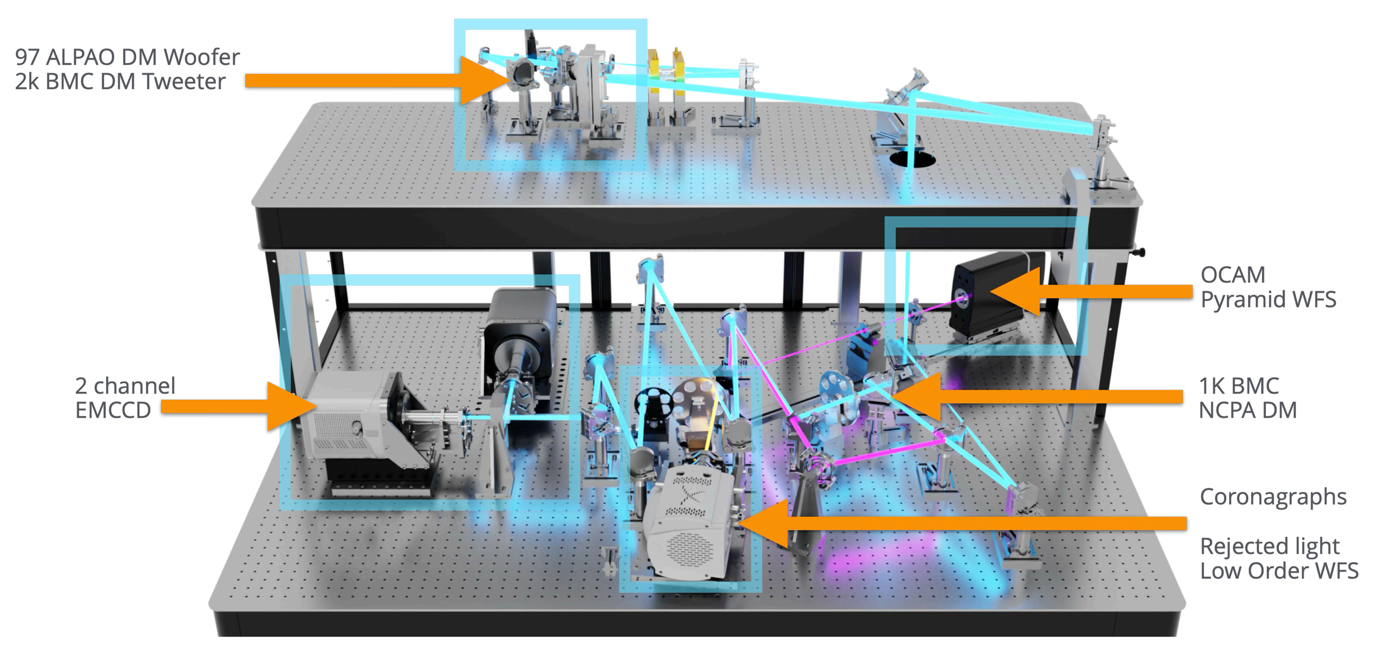

Fig 2. Render of the MagAO-X optical table, highlighting key components of the extreme adaptive optics instrument. Recent upgrades have included the 1,000 actuator NCPA DM, improved coronagraphs, and additional dual channel beam splitters.

Observations

MagAO-X *β* Pic b ADI observations shown as KLIP-reduced SNR images in *z' (Left)* and *i' (Right)*. Stellar coronagraph residuals are covered by a central mask. These preliminary reductions illustrate the high contrast imaging capabilities of MagAO-X at 500 mas.

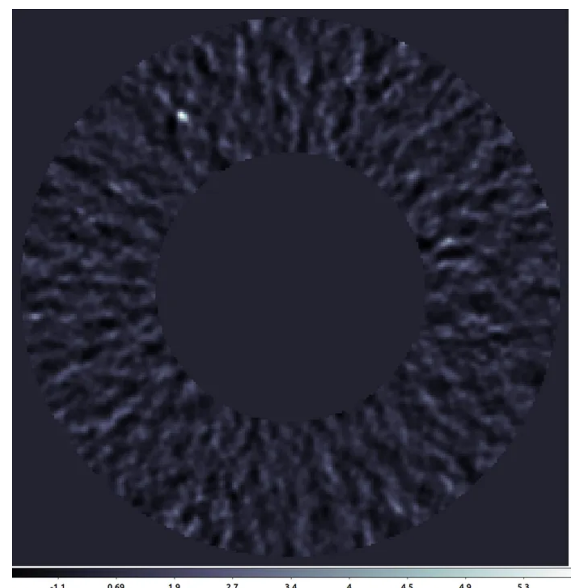

Fig 4. z' SNR Map – The z' measurement (λ_0 = 0.908 μm , w_{eff} = 0.13 μm) trivially yielded a contrast of 3e-6 SNR of 5.6 in 20 minutes, and SNR of 9 in 50 minutes.

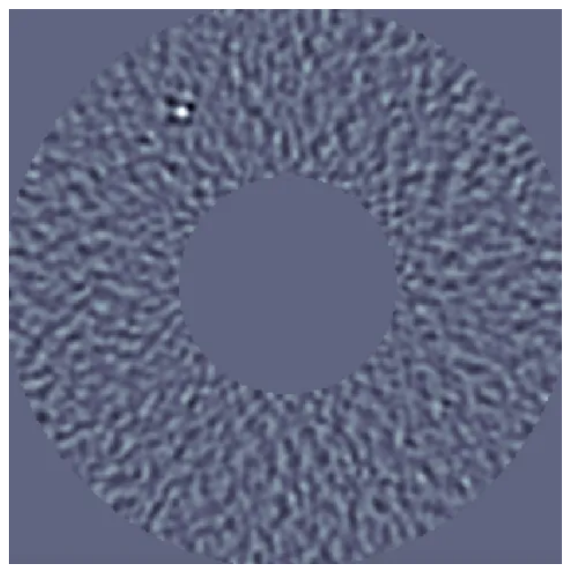

Fig 5. i' SNR Map - The i' observation (λ_0 = 0.762 μm, w_{eff} = 0.126 μm) returned a 9e-7 contrast measurement at SNR 10 in 120 minutes.

Atmosphere Model Fits

The new MagAO-X flux values are preliminarily consistent with the lower (<1700K) DRIFT PHX [5] temperatures at a smaller radius (1.4 R_J), and the higher (> 1500K) temperature in the BT-Settl [6] models with a larger radius (1.6 R_J). However, considering $L \propto R^2 T^4$ these results are contradictory.

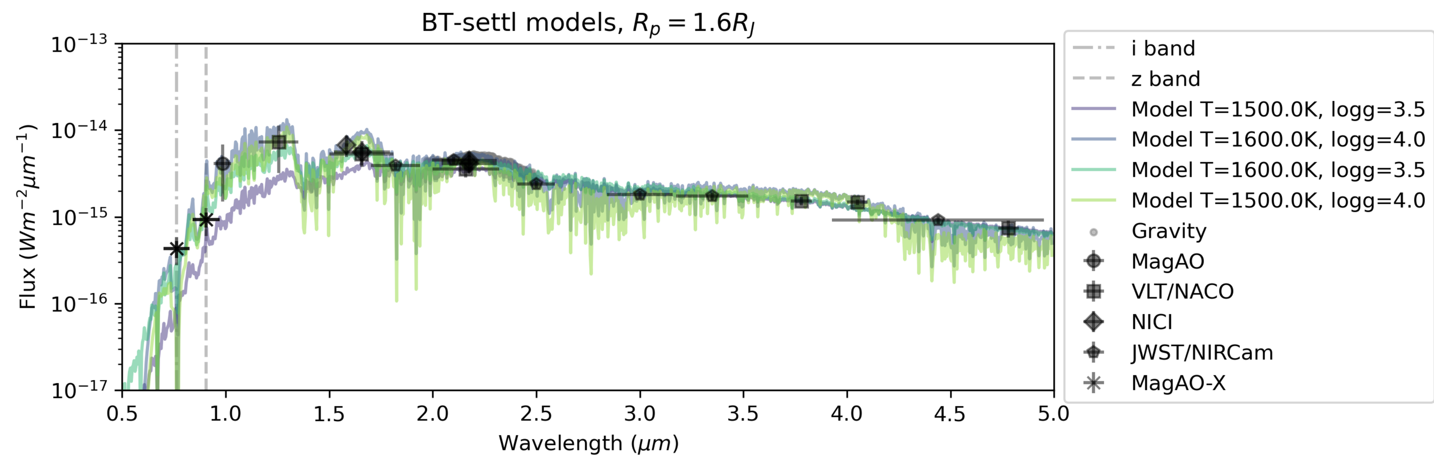

Fig 6. Best fit for BT-Settl models of *β* Pic b spectra fits derived for new NIRCam photometry [7]. MagAO-X observations shown on grey filter lines. Bluer wavelengths such as *r'* serves to further constrain model temperature in steep spectral drop off in the visible.

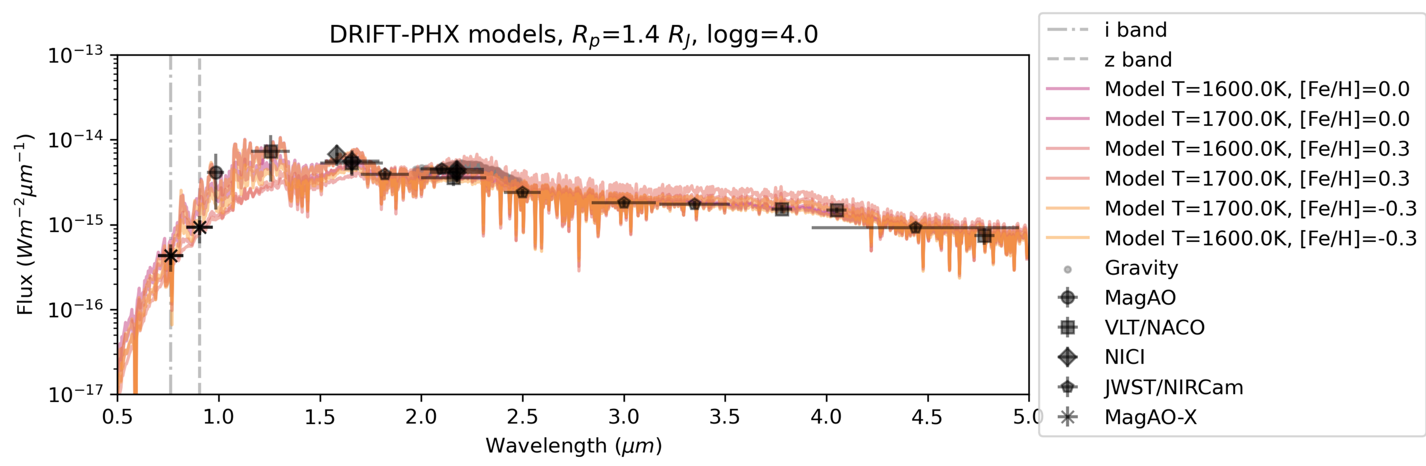

Fig 7. Best fit for DRIFT-Phoenix models of *β* Pic b spectra fits derived for new NIRCam photometry [7]. MagAO-X observations shown on grey filter lines. The modeled clouds and metallicity fit from previous studies are consistent with the new visible band photometry points.

Color Analysis

In Figure 8 we compare *z-i* color for low mass brown dwarfs to *β* Pic b. The color transform between MagAO-X (*i'* and *z'*) to the Pan-STARRS1 [8] (i_{p1} and z_{p1}) varies minimally across best fit models, and places *β* Pic b bluer than other early L dwarfs. This implies a better fit to cloudy models, and greater likelihood of detection in bluer observation bands.

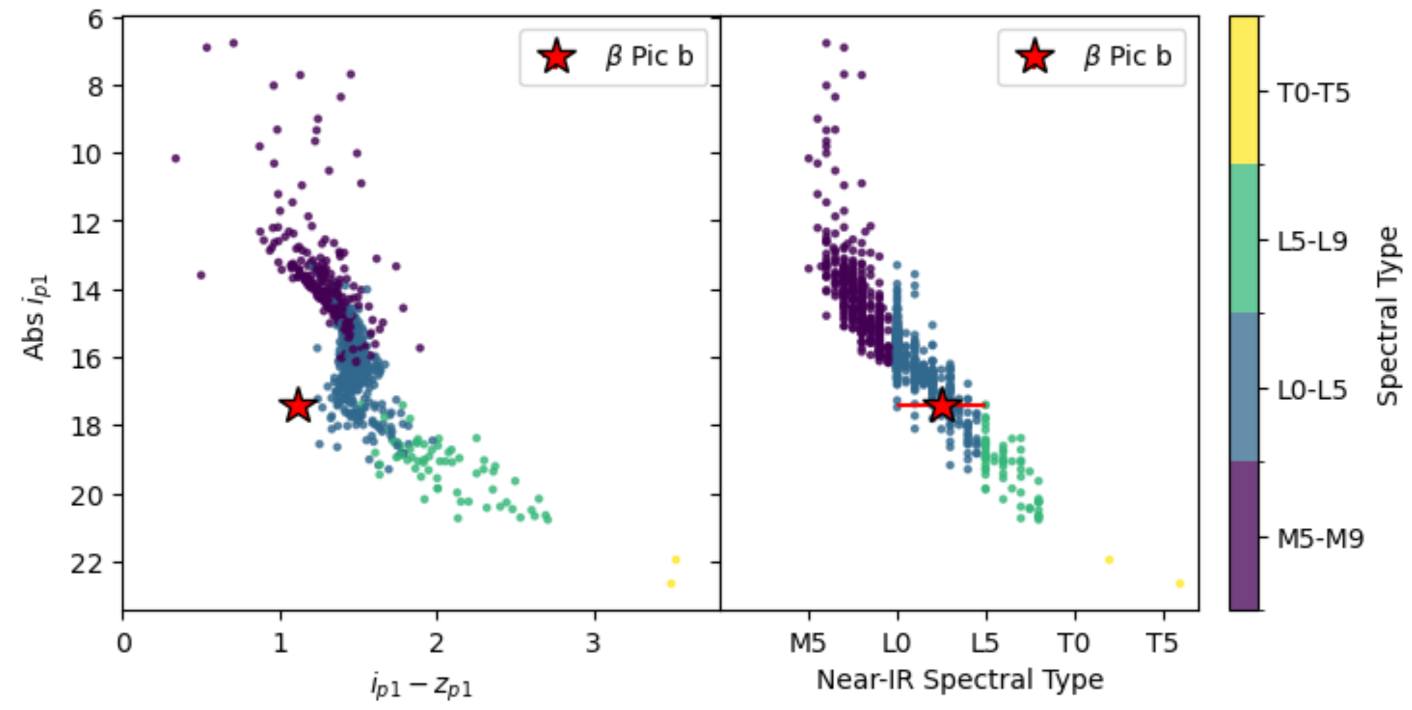

Fig 8. Color Magnitude diagrams of Ultracool Dwarfs [9] in the Pan-STARRS1 filters. The left figure shows the absolute magnitude vs color of the two blue filters transformed to PS1. The right figure shows the same objects organized by spectral type, with β Pic b falling in the L0-L5 SpT.

Future Work

Further detailed analysis on this data set is forthcoming, including rigorous model fitting to literature values and contrast curve calculations. A 2025B proposal for 2.5 nights on MagAO-X was approved to reobserve *β* Pic b in *r'* (λ_0 = 0.615μm, w_{eff} = 0.11μm), enabling even further model discrimination due to the rapid SED drop off. Short observations in narrowband 0.875μm and 0.925μm filters will be taken to investigate the depth of absorption features visible in cloudy models.

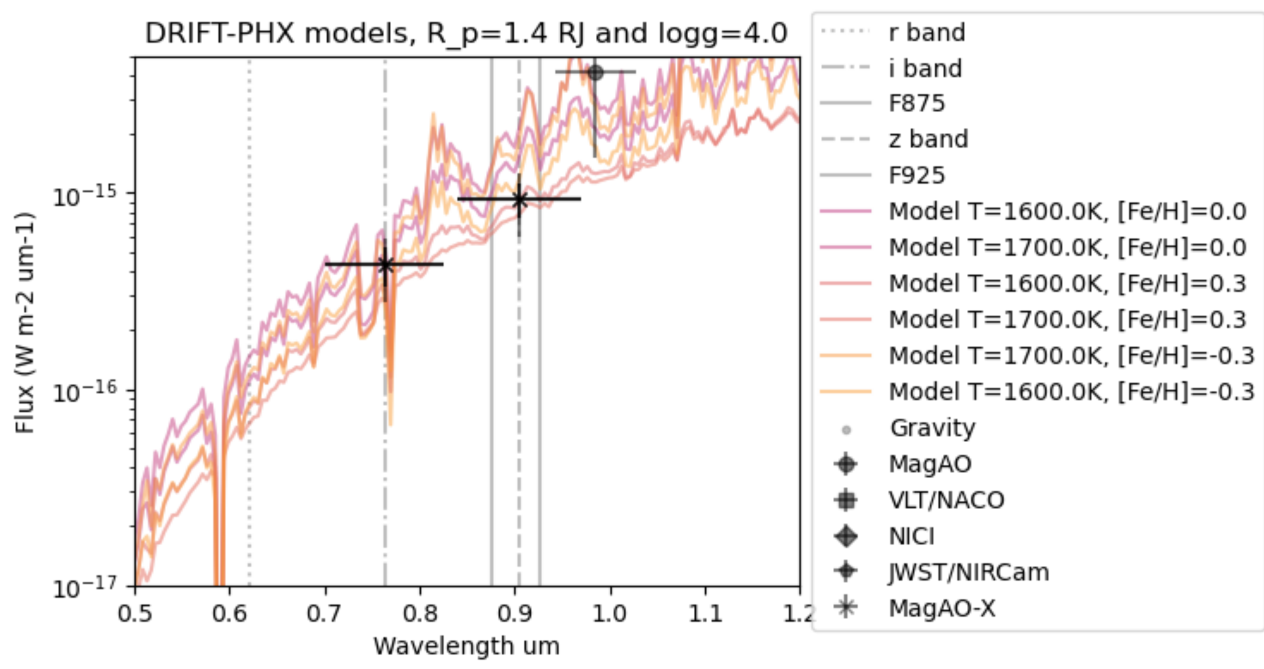

Fig 9. Close up of DRIFT-Phoenix model in wavelengths accessible to MagAO-X. Instrument filters denoted in gray lines, filter width denoted with horizontal errorbars. Future observations selected in r', F875 and F925 band.

Acknowledgements

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References

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[2] Males et al. 2014
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[7] Kammerer et al. 2024
[8] Tonry et al. 2012
[9] Best & Dupuy 2025