# An Atmospheric Dispersion Corrector Design with Milliarcsecond-Level Precision from 1 to 4 microns for High Dispersion Coronagraphy

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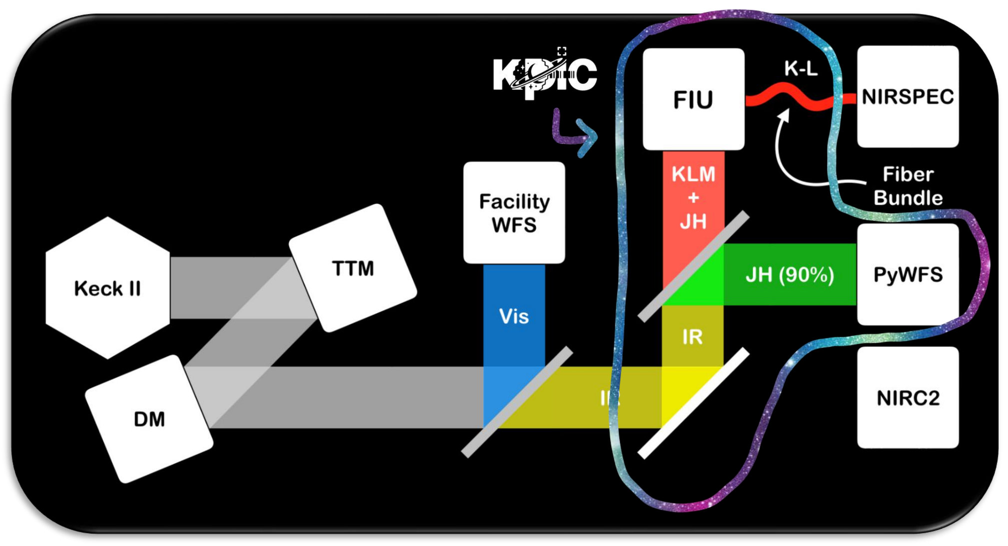
## High Dispersion Coronagraphy with KPIC



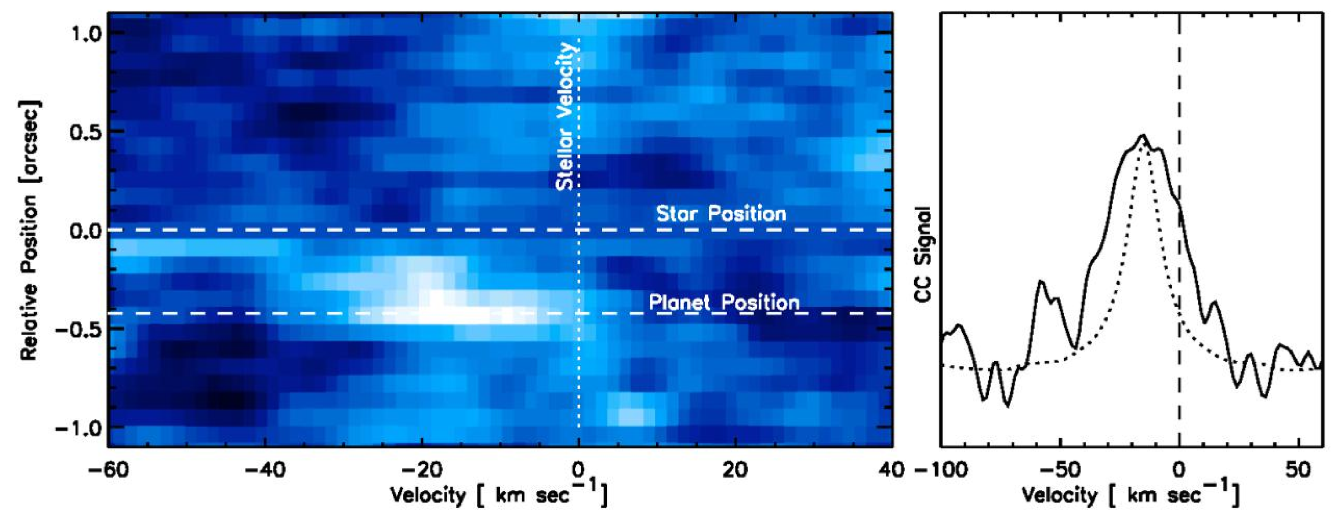

KPIC Schematic

**The Keck Planet Imager and Characterization (KPIC)[1]** combines high-contrast imaging with high-resolution spectroscopy to perform HDC (High Dispersion coronagraphy). KPIC Phase I is the bare minimum necessary to perform this technique. The **Infrared Pyramid WFS (PyWFS)** spatially isolates the light of the faint planet from the bright star. The **Fiber Injection Unit (FIU)** guides the light of the planet into **single mode fibers** that suppress starlight and feed planet light into a high-resolution spectrograph with a stable line spread function.

Studying planets at high spectral resolution constrains several key observables:

- Planetary Radial Velocity
- Planetary Spin
- Atmospheric Composition

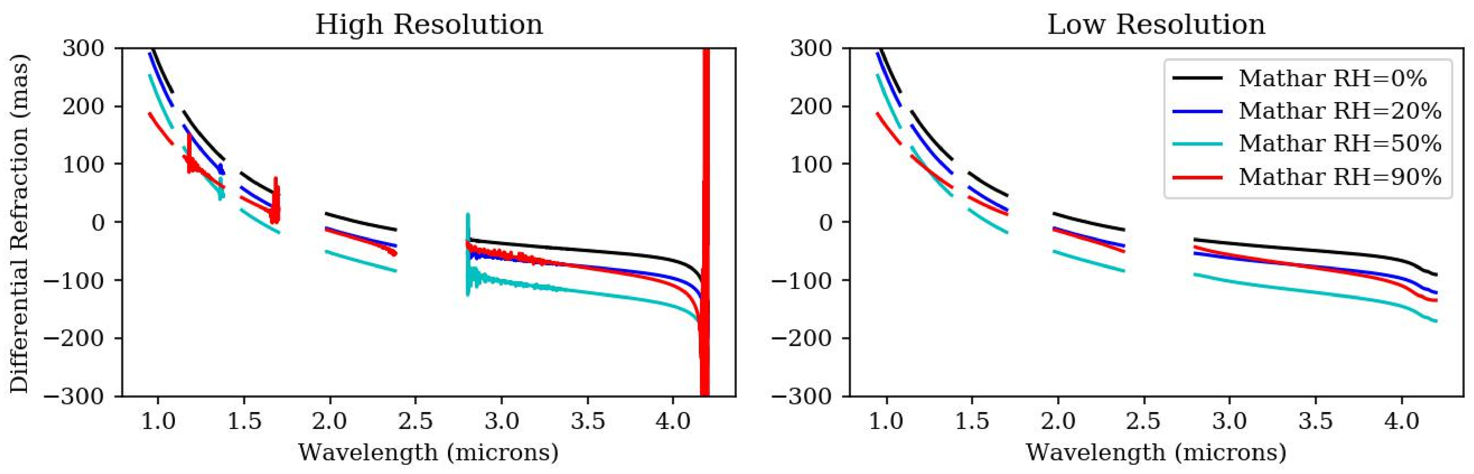
To date, few high-contrast exoplanets have been studied at high spectral resolution (R > 10,000).

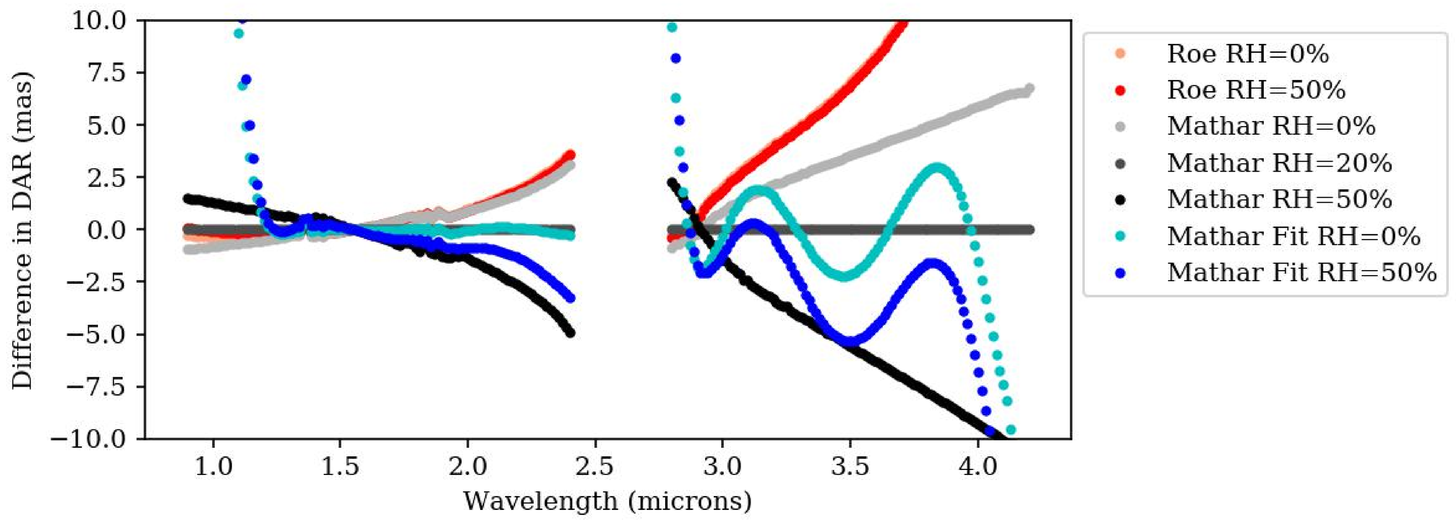



Planet RV and Spin Measurements[2]

## Model of Differential Atmospheric Refraction (DAR)

We used a first-principles model of differential atmospheric refraction for humid air in the infrared[3] . The plot shows the effect of DAR as a function of wavelength and humidity at 60° zenith angle.

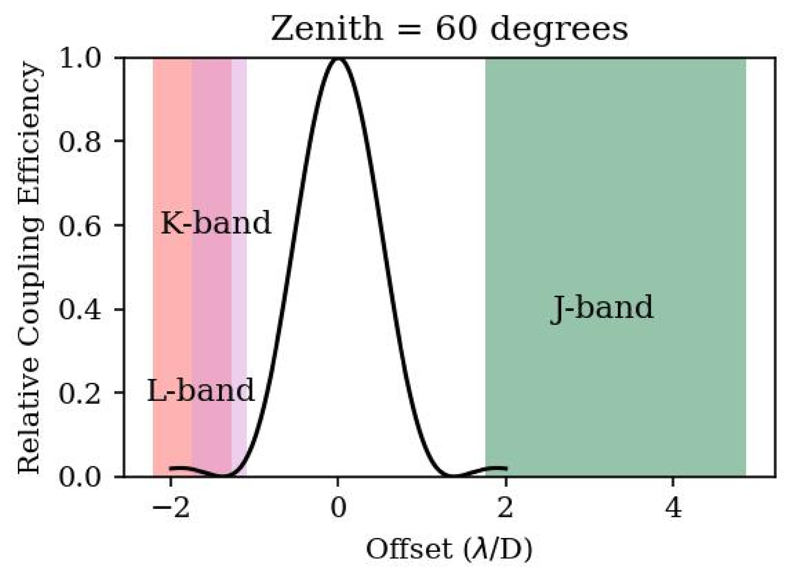



We found approximations to the model (Mathar Fit[3]), including the model used in the popular Zemax software (Roe[4]), to be inaccurate at milliarcsecond level precision at K and L bands.

## The Need for an ADC

**KPIC Phase II** consists of a series of upgrades to the KPIC FIU that will greatly improve fiber injection efficiency, a key performance metric. Included in this is the addition of an atmospheric dispersion corrector (ADC). ADCs are crucial to maximize fiber coupling across a broad bandpass. In KPIC, we do fiber tracking at H-band, but science is done at J, K, and L bands. Both the dispersion between H and the science band and the dispersion in H and the science bands needs to be minimized.

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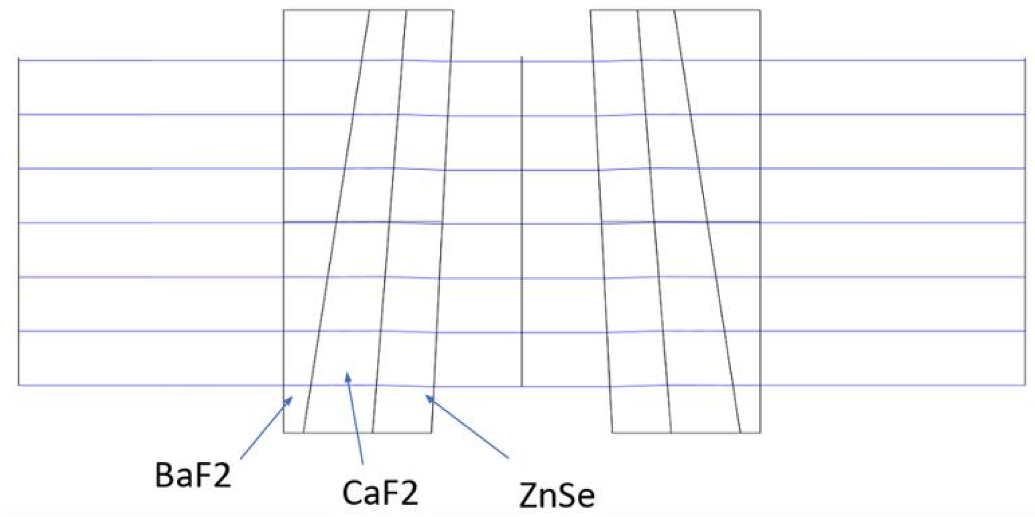
## The Atmospheric Dispersion Correction (ADC) for KPIC

The ADC consists of 2 counterrotating prisms, with each prism consisting of three wedges made of $BaF_2$, $CaF_2$, and ZnSe. The prisms can rotate relative to the optical axis to alter the total dispersion applied.




## ADC Design Optimization

We optimized the three wedge angles of the ADC to meet three requirements:

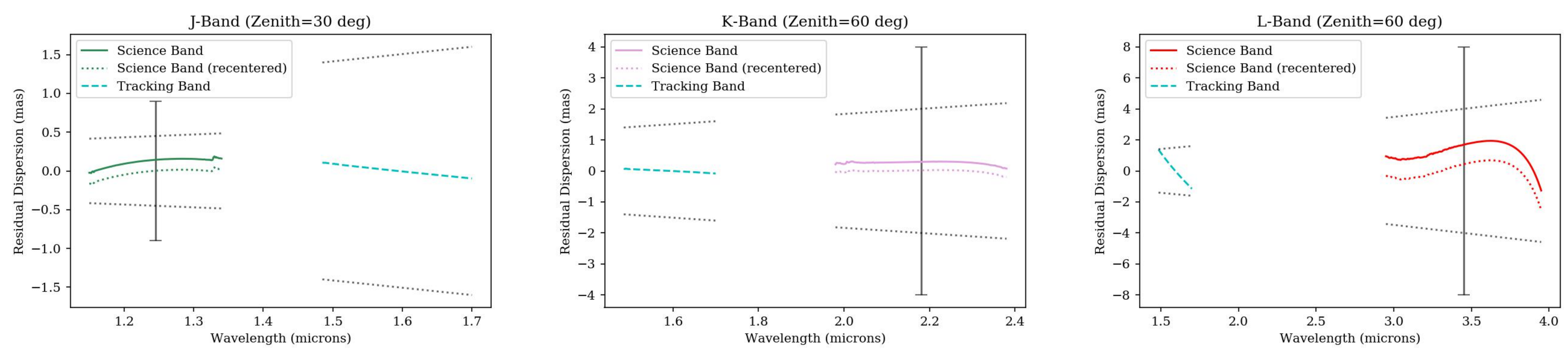
- PTV dispersion in the science band
- Median offset between the science and tracking band
- PTV dispersion in the tracking band

Optimized Wedge Angles

| $BaF_2$ Angle (°) | $ZCF_2$ Angle (°) | ZnSe Angle (°) |
|---|---|---|
| 7.0516 | 3.8050 | 1.1465 |

ADC Performance (Requirements in Parentheses)

| Band | Zenith Angle (°) | Clocking Angle (°) | Science PTV Dispersion (mas) | Science-Tracking Offset (mas) | Tracking PTV Dispersion (mas) |
|---|---|---|---|---|---|
| J | 30 | 74.1892 | 0.22 (0.3) ✔ | 0.14 (0.3) ✔ | 0.21 (3) ✔ |
| K | 60 | 34.1697 | 0.23 (4) ✔ | 0.28 (4) ✔ | 0.16 (3) ✔ |
| L | 60 | 39.1265 | 3.20 (8) ✔ | 1.26 (8) ✔ | 2.52 (3) ✔ |




## Sensitivity Analysis

**Sensitivity to changes in atmosphere**

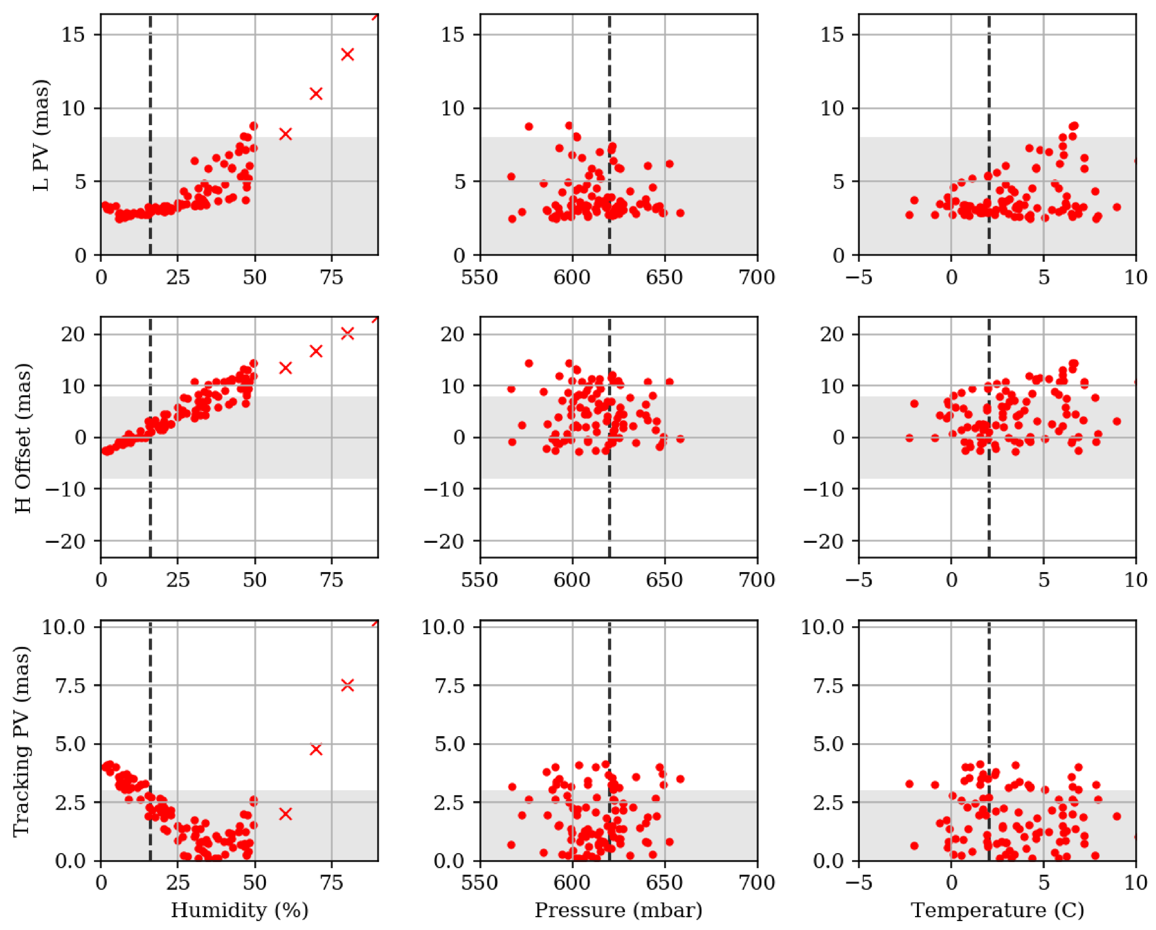
We did the optimization assuming median atmospheric conditions on Maunakea. We simulated the performance of the ADC in 100 different realistic conditions. Only in extreme cases in L-band did the ADC perform slightly below spec (see plot on right).

**Sensitivity to wedge angle errors**

We simulated wedge angle errors up to 0.02° (e.g., due to manufacturing) and found no significant degradation of ADC performance.

**Sensitivity to clocking angle errors.**

We simulated clocking angle errors due to quantization of the rotation stage. We found that we required a rotation stage precision of 0.2° or better to mitigate clocking angle errors.




ADC Performance in L-band at 60° Zenith with Different Atmospheric Conditions

**References:**
[1] Mawet, D., et al. 2016, Proc. SPIE, 9909, 0D.
[2] Snellen, I. A. G., et al. 2014, Nature, 509, 63.
[3] Mathar, R., 2007,
[4] Roe, H., 2002, PASP, 114, 450..