Direct Imaging in Taurus and Ophiuchus with Keck/NIRC2 and the Pyramid Wavefront Sensor

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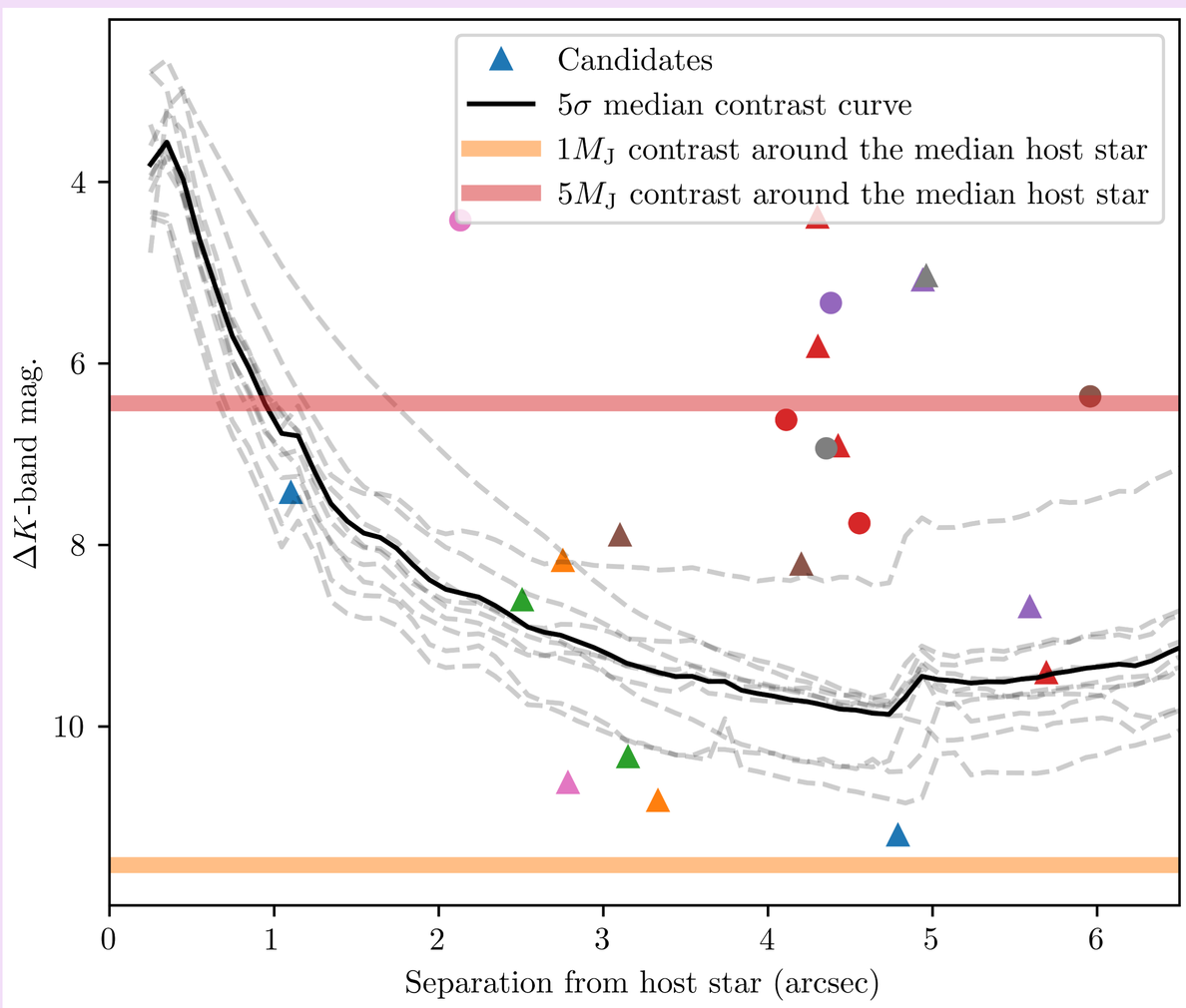
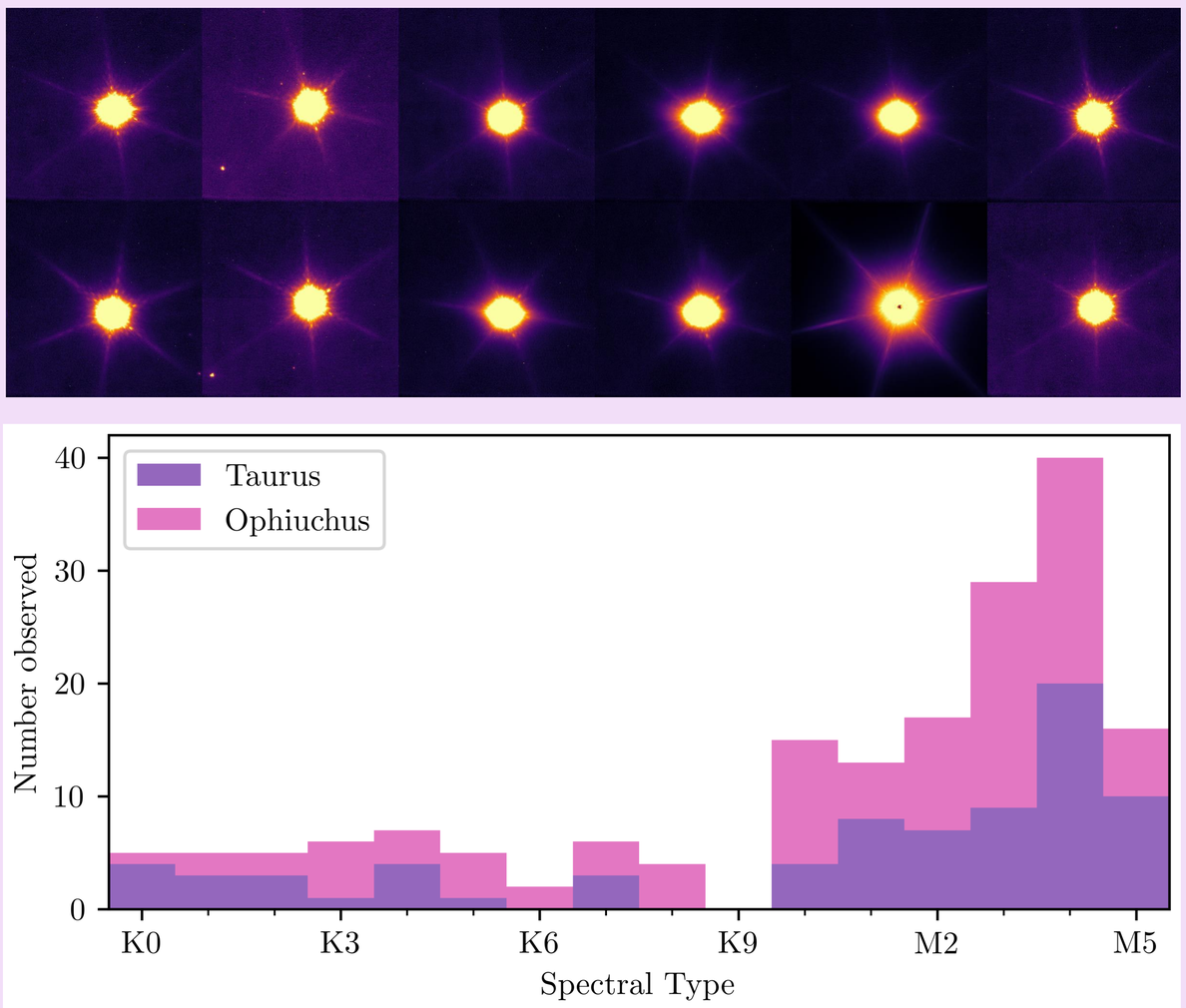
Direct imaging of planets in star-forming regions like Taurus and Ophiuchus can provide a unique window on the earliest epochs of planet formation at **ages of 1-5 Myrs**. We have imaged **over 200 stars in Taurus and Ophiuchus** with Keck/NIRC2 in *K*-band. A majority of these observations were made with the Pyramid wavefront sensor (PyWFS), which used the *J* and *H* bands for natural guide star adaptive optics correction. With these data we have reached **Jupiter-mass sensitivities at wide orbits** (assuming hot-start evolutionary models).

Keck/NIRC2 *K*-band Observations



Above: a subset of candidate companions from our sample, along with the median 5σ contrast curve from the corresponding observations and illustrative contrasts for 1- and 5-Jupiter-mass hot-start companions.



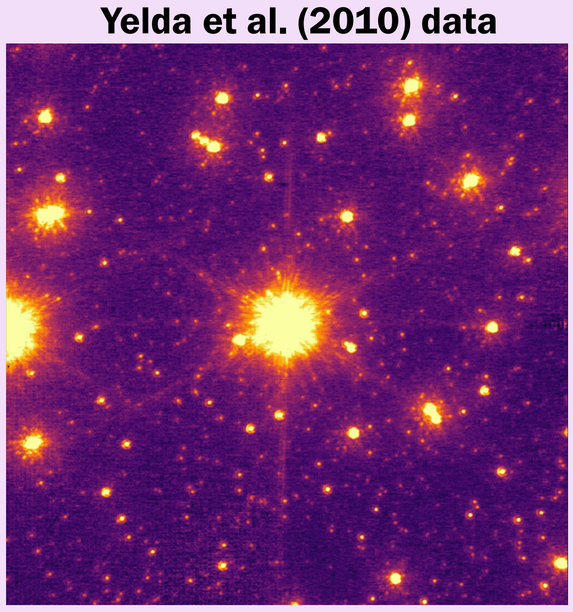
Above: 10" images from our survey, and a histogram showing the spectral types of target stars in Taurus and Ophiuchus that we have observed thus far.

NIRC2 image distortion with the PyWFS

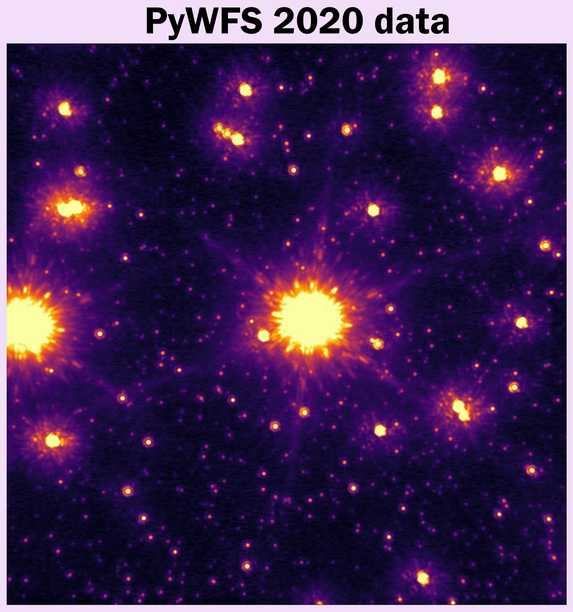
We imaged M92 between 2019 and 2023 and compared these observations to M92 data from Yelda et al. (2010) to discover if optical distortion on NIRC2 differs when using the PyWFS.

We find that a **rotation of 0.118 ± 0.006° anticlockwise** is necessary to transform the Yelda et al. data to our M92 data. This rotation is **not accounted for in the current NIRC2 distortion solution** (Service et al., 2016). The pixelscale we recover agrees with Service et al. within 3σ.

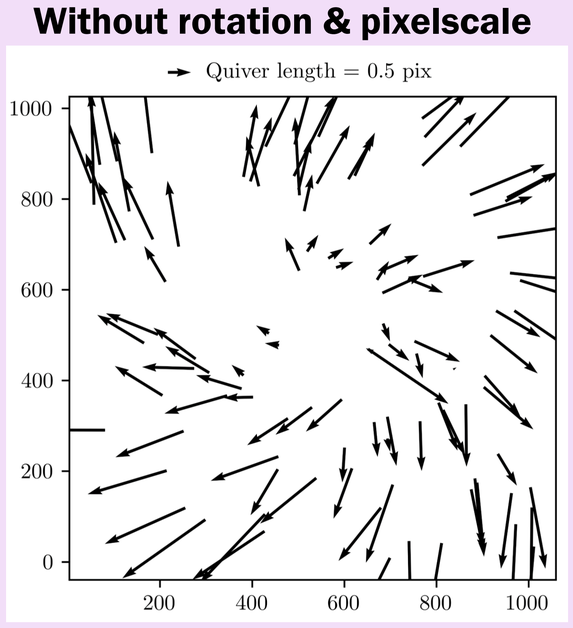
Yelda et al. (2010) data



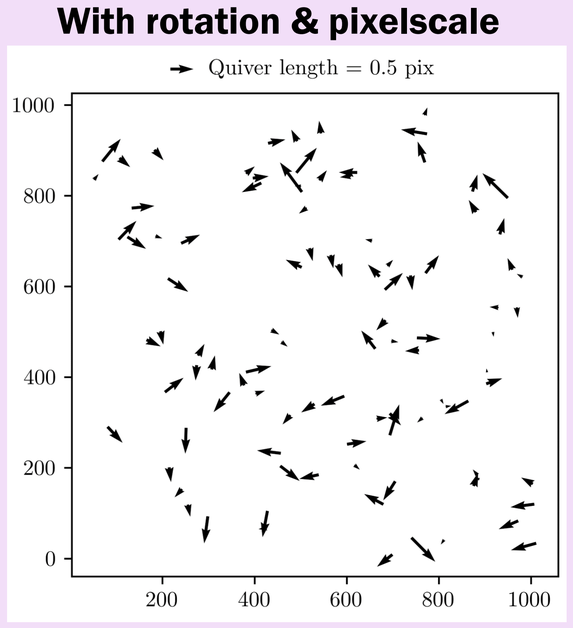
PyWFS 2020 data



Without rotation & pixelscale

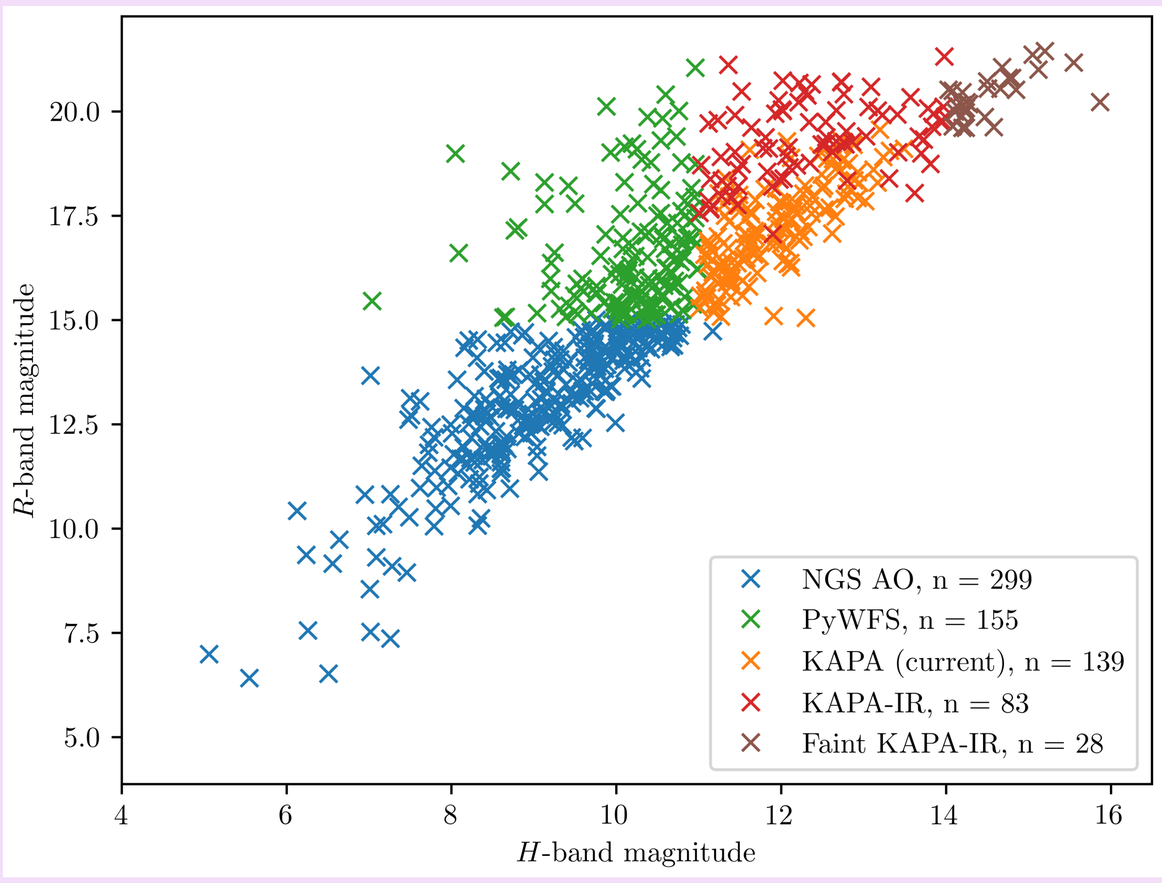


With rotation & pixelscale



Looking ahead to KAPA on Keck I

A considerable number of stars in Taurus and Ophiuchus are too faint or too red to be observed using the PyWFS. To image these stars, we plan to use the **Keck All-Sky Precision Adaptive Optics (KAPA) upgrade to Keck I**, due to be available on-sky in 2025A. KAPA will allow **on-axis, high-Strehl observations** with the OSIRIS imager of **stars in star-forming regions inaccessible via other methods**.



Above: Numbers of target host stars in Taurus and Ophiuchus accessible using different AO modes at Keck. KAPA-IR refers to efforts to deepen KAPA's sensitivity in both the optical and IR. Target stars taken from Esplin & Luhman (2019, 2020).

Yelda et al. (2010), ApJ, 725, 1, 331-352
Service et al. (2016), PASP, 128, 967, 095004
Esplin & Luhman (2019), AJ, 158, 2, 54
Esplin & Luhman (2020), AJ, 159, 6, 282