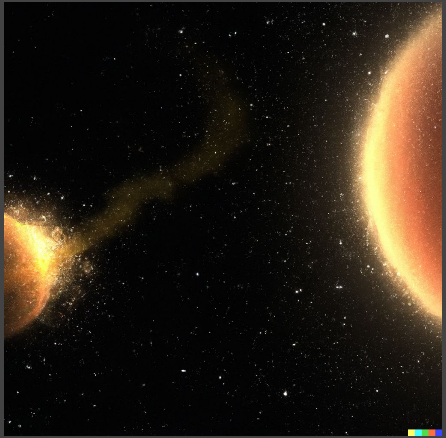
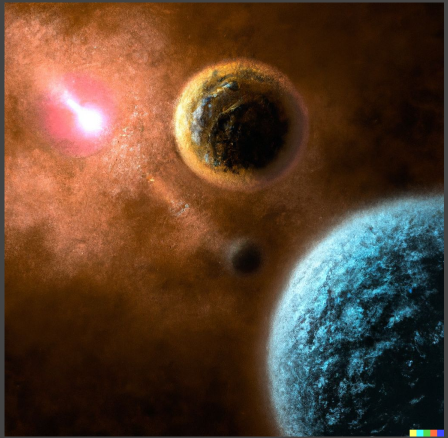
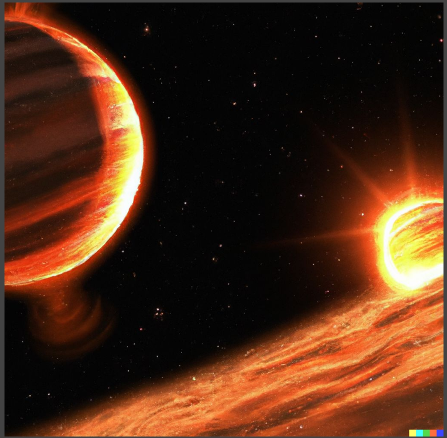
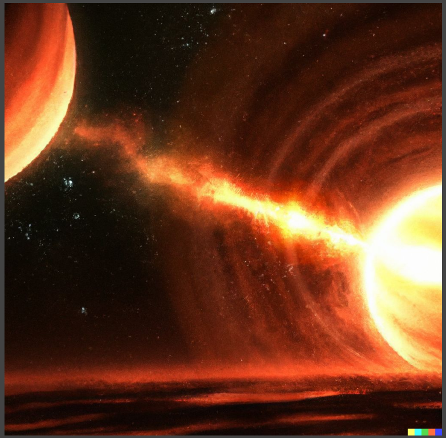
Searching for Accreting Protoplanets with Kernel Phase Interferometry

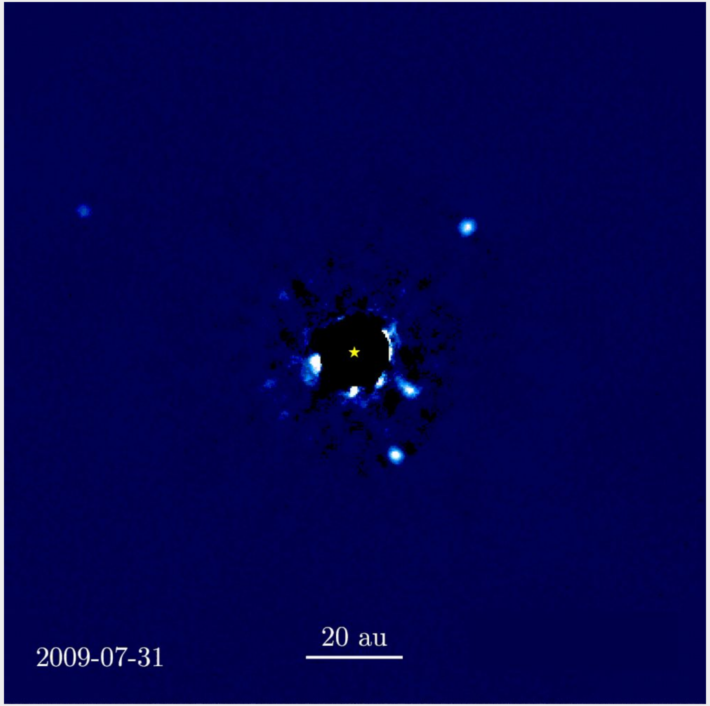





Images generated by DALL-E 2 from the talk abstract

Alex Chaushev, Steph Sallum & CHARIS Team (UC Irvine)

ExSoCal 2023

Direct imaging targets a unique population of planets



HR 8799 - Jason Wang (Caltech)/Christian Marois (NRC Herzberg)

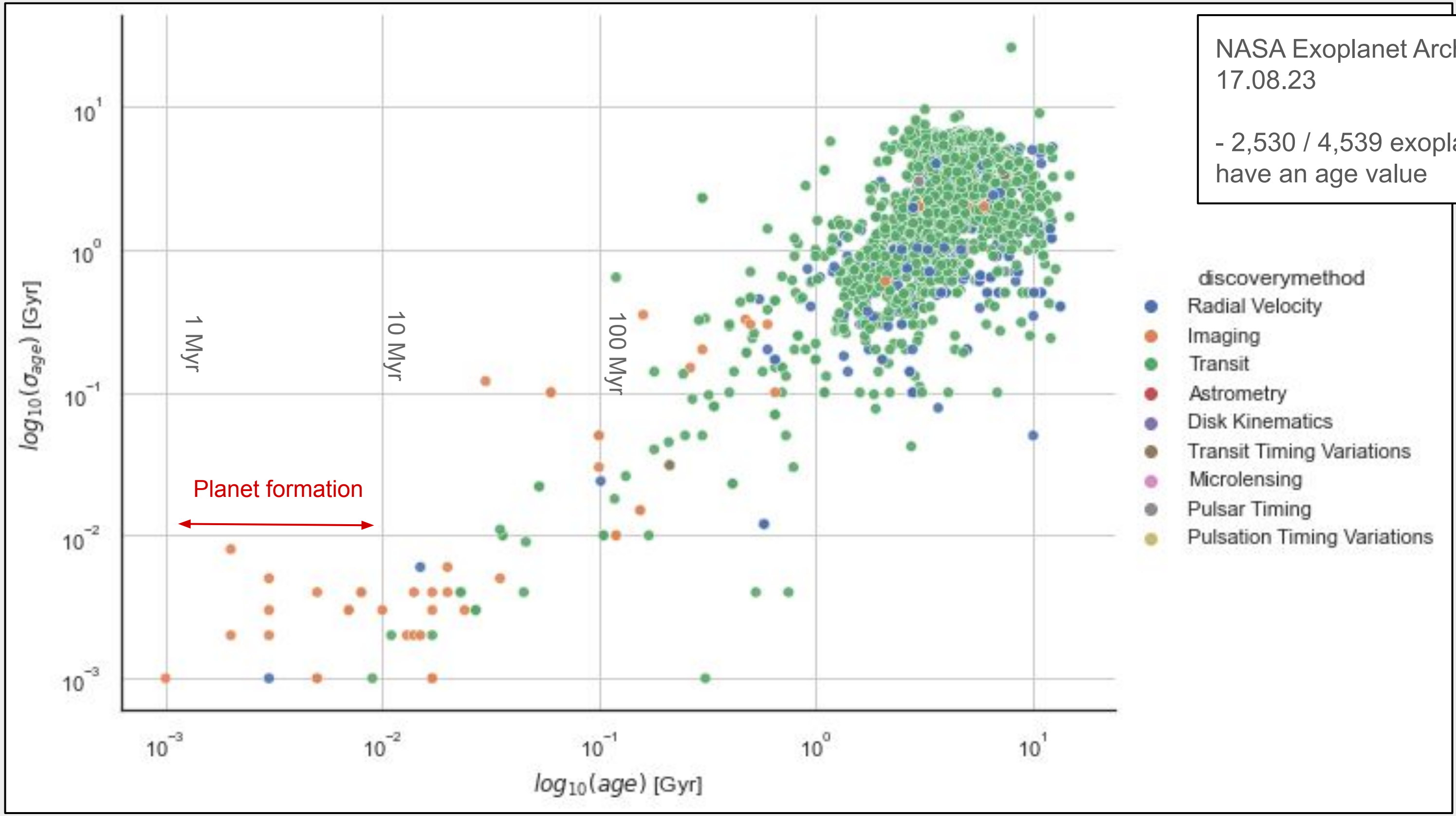
Direct imaging is a powerful technique for the detection and characterisation of exoplanets:

- It provides access to planets at larger orbital separations (vs. transits and RV)

- Medium/high-resolution spectroscopy of directly imaged planets provides direct evidence of composition and formation history

- Imaging is the most likely way we will determine habitability of other worlds

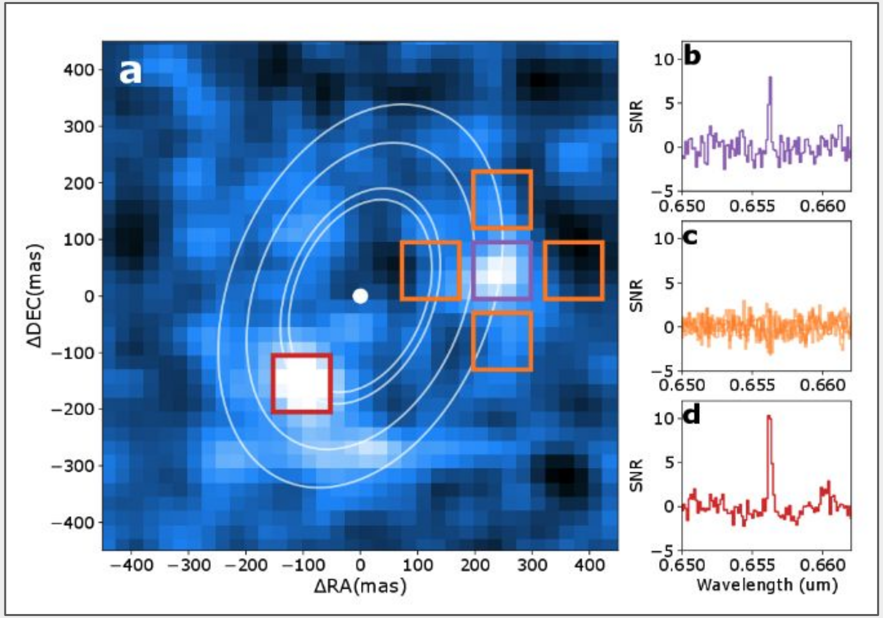
Most exoplanets do not *directly* inform us of the planet formation process



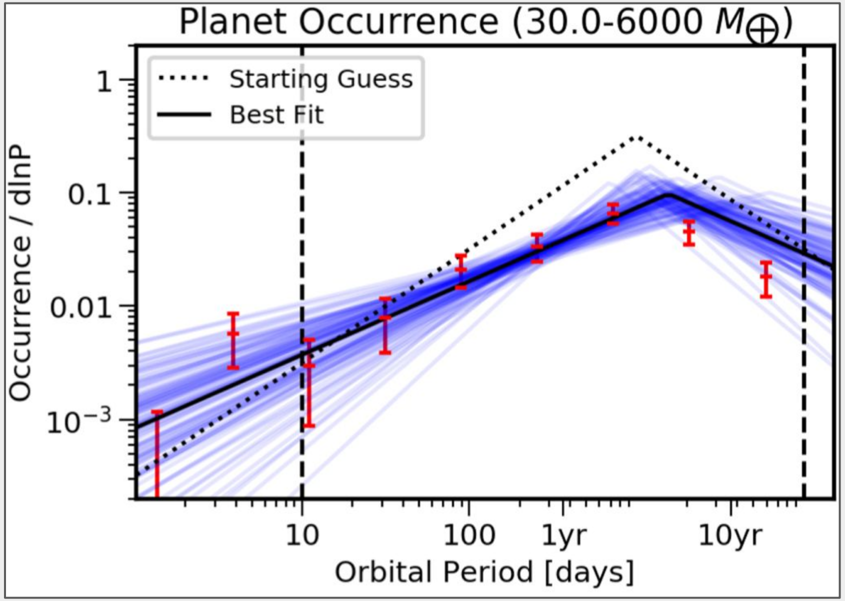
NASA Exoplanet Archive
17.08.23

- 2,530 / 4,539 exoplanets have an age value

Accreting protoplanets allow us to observe planet formation in situ

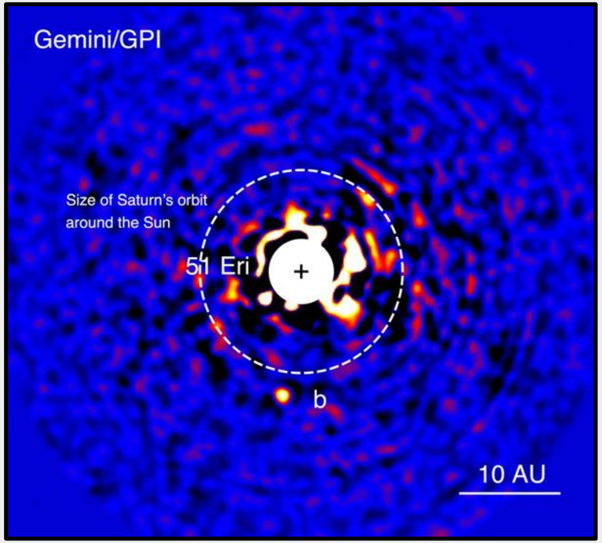


The H-alpha detection map for PDS 70 b and PDS 70 c. (Haffert et. al. 2019 Nat Astro)



Fernandes et al. (2019)

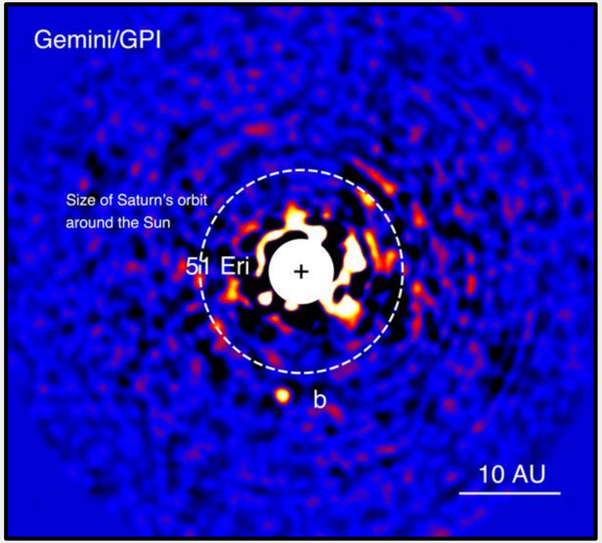
Direct imaging searches are often limited by quasi-static speckles at inner working angles of ~1-3 λ/D…



GPI discovery image of 51 Eridani b (~30 pc)

Image credits: Gemini Observatory and J. Rameau (UdeM) and C. Marois NRC Herzberg

Direct imaging searches are often limited by quasi-static speckles at inner working angles of ~1-3 λ/D…



GPI discovery image of 51 Eridani b (~30 pc)

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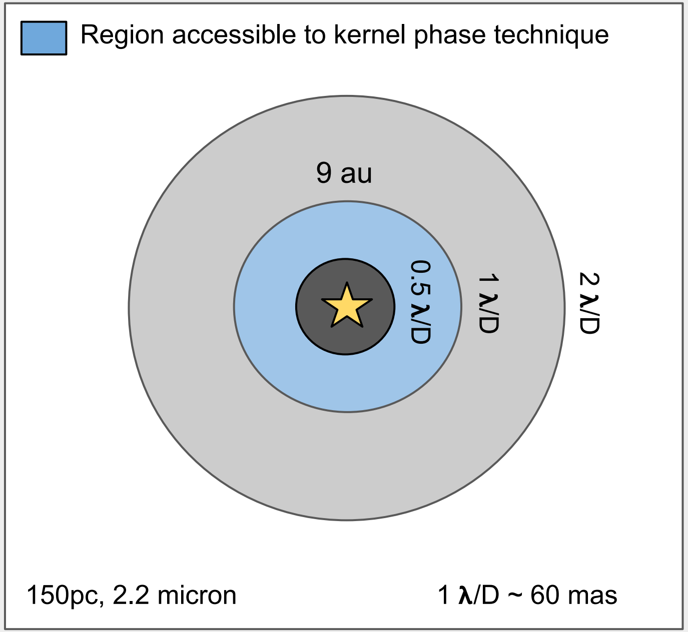
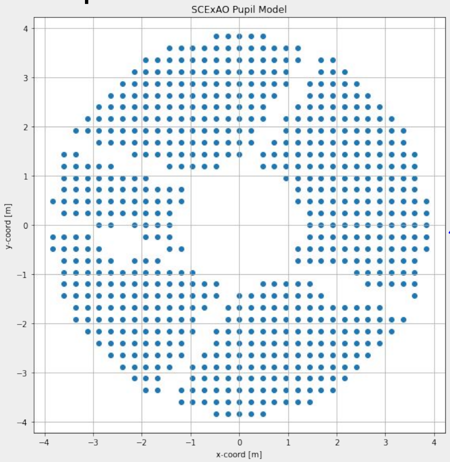


Improvement in resolution offered by KPI vs 'traditional imaging' at 150 parsec

Martinache 2010, 2020

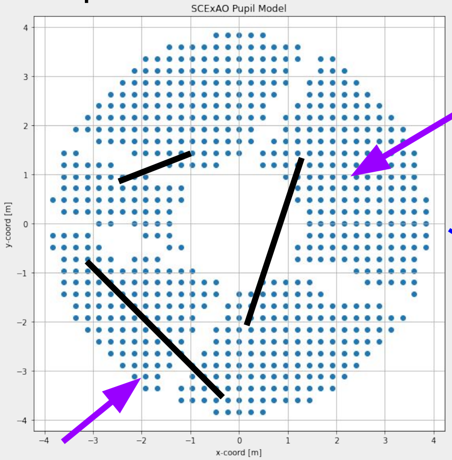
Pupil transmission model



Kernel Phase Interferometry

Martinache 2010, 2020

Pupil transmission model



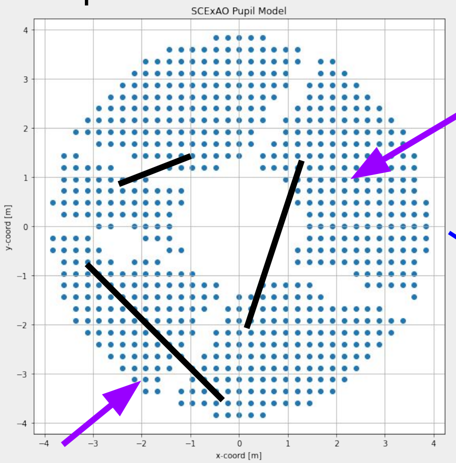
Virtual sub-aperture (our “interferometric array”)

Virtual baseline

Kernel Phase Interferometry

Martinache 2010, 2020

Pupil transmission model

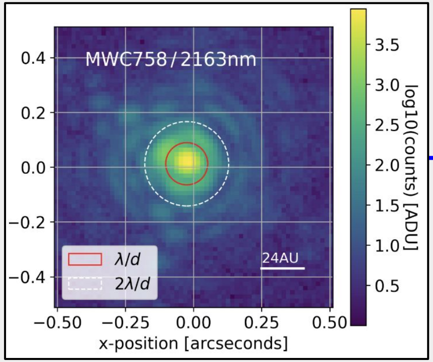


Virtual sub-aperture (our “interferometric array”)

Virtual baseline

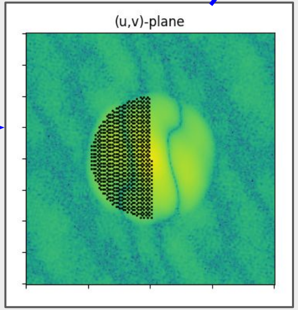
Kernel Phase Interferometry

CHARIS image



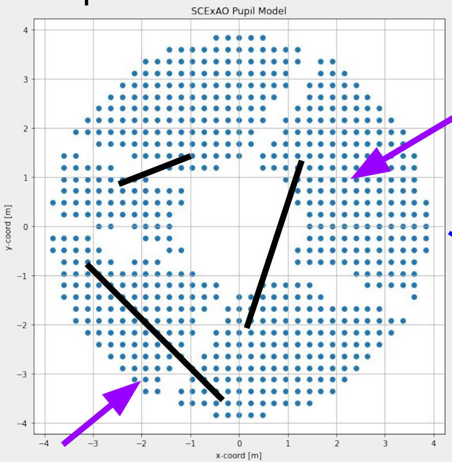
Fourier transform

Image Phases ($\boldsymbol{\Phi}$)



Martinache 2010, 2020

Pupil transmission model

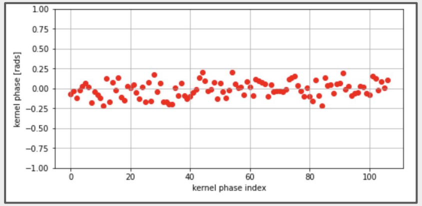


Virtual sub-aperture (our “interferometric array”)

Virtual baseline

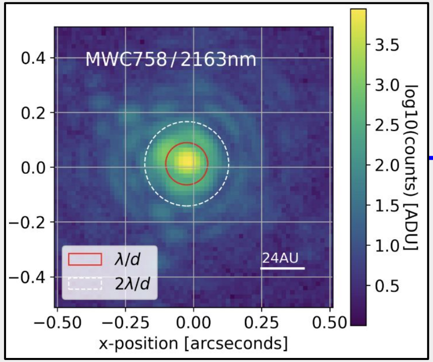
Kernel Phase Interferometry

Linear combinations of baselines



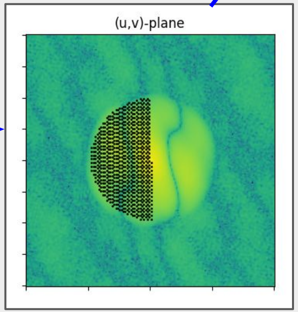
Kernel phases (self-calibrated interferometric observable)

CHARIS image

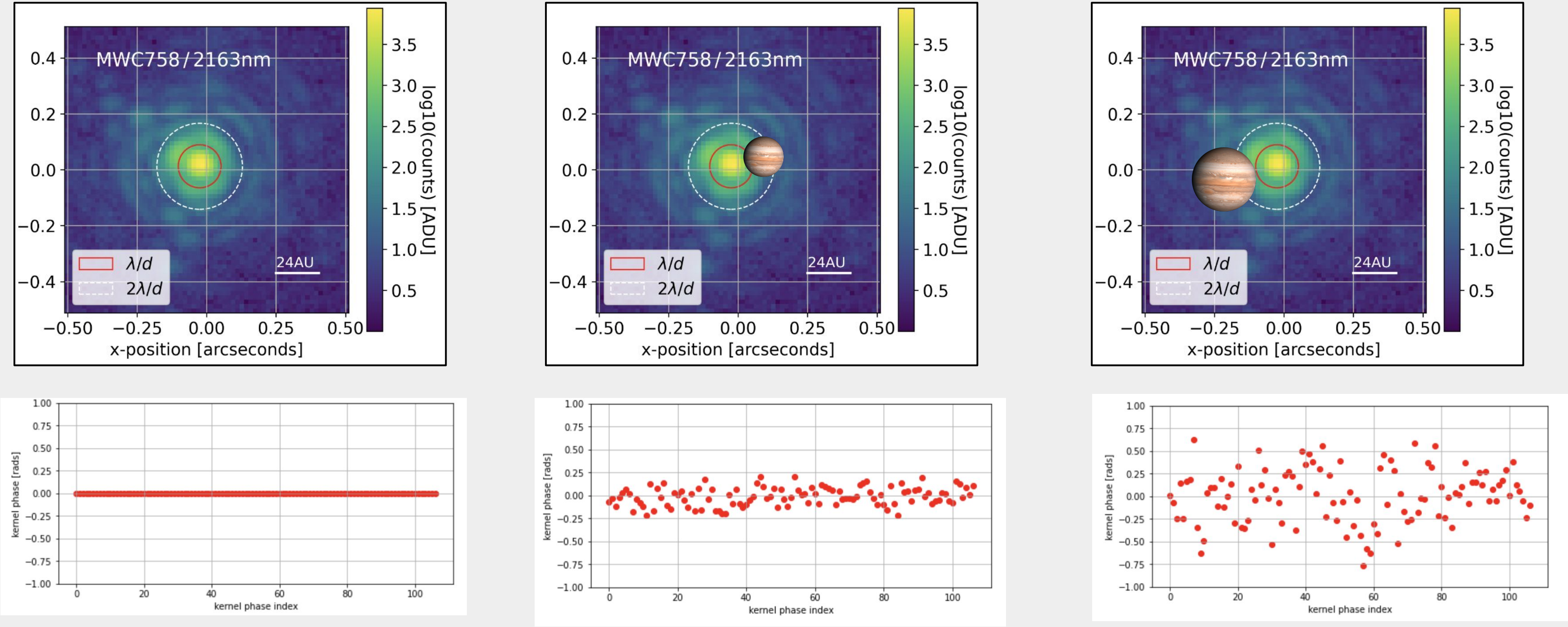


Fourier transform

Image Phases ($\boldsymbol{\Phi}$)



A simpler view of kernel phases



Kernel phase works for sub-λ/D!

A&A 646, A36 (2021)

Mid-infrared photometry of the T Tauri triple system with kernel phase interferometry★

J. Kammerer[1,2], M. Kasper[1], M. J. Ireland[2], R. Köhler[3], R. Laugier[4], F. Martinache[4], R. Siebenmorgen[1], M. E. van den Ancker[1], R. van Boekel[5], T. M. Herbst[5], E. Pantin[6], H.-U. Käufl[1], D. J. M. Petit dit de la Roche[1] and V. D. Ivanov[1]
+

Received: 8 September 2020 | **Accepted:** 25 November 2020

OPEN ACCESS

NICMOS Kernel-phase Interferometry. II. Demographics of Nearby Brown Dwarfs

Samuel M. Factor[1] and Adam L. Kraus[1]

Published 2023 February 24 •

The Astronomical Journal, Volume 165, Number 3

Citation Samuel M. Factor and Adam L. Kraus 2023 *AJ* **165** 130

DOI 10.3847/1538-3881/aca475

The Palomar kernel-phase experiment: testing kernel phase interferometry for ground-based astronomical observations FREE

Benjamin Pope, Peter Tuthill, Sasha Hinkley, Michael J. Ireland, Alexandra Greenbaum, Alexey Latyshev, John D. Monnier, Frantz Martinache

Monthly Notices of the Royal Astronomical Soci

Pages 1647–1653, https://doi.org/10.1093/mn

Published: 17 November 2015 **Article his**

ARTICLES

DANCING IN THE DARK: NEW BROWN DWARF BINARIES FROM KERNEL PHASE INTERFEROMETRY*

Benjamin Pope[1], Frantz Martinache[2], and Peter Tuthill[1]

Published 2013 April 2 •

ber 2

10

PAPER • OPEN ACCESS

The Near Infrared Imager and Slitless Spectrograph for JWST. V. Kernel Phase Imaging and Data Analysis

Jens Kammerer[1], Rachel A. Cooper[1], Thomas Vandal[2], Deepashri Thatte[1], Frantz Martinache[3], Anand Sivaramakrishnan[1,4,5], Alexander Chaushev[6], Tomas Stolker[7], James P. Lloyd[8], Loïc Albert[2] + Show full author list

Published 2023 February 6 •

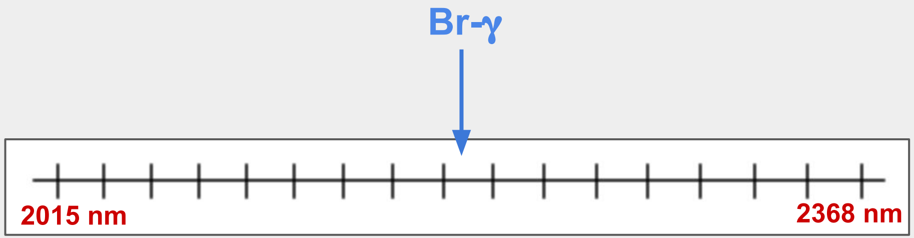
Publications of the Astronomical Society of the Pacific, Volume 135, Number 1043

Citation Jens Kammerer *et al* 2023 *PASP* **135** 014502

DOI 10.1088/1538-3873/ac9a74

IFS' allow spectral calibration strategies and line-emission searches

Observing with SCExAO/CHARIS in high-res K-band mode



R = 77.1 with 17 output channels

KP - Spectral Differential Imaging (SDI)

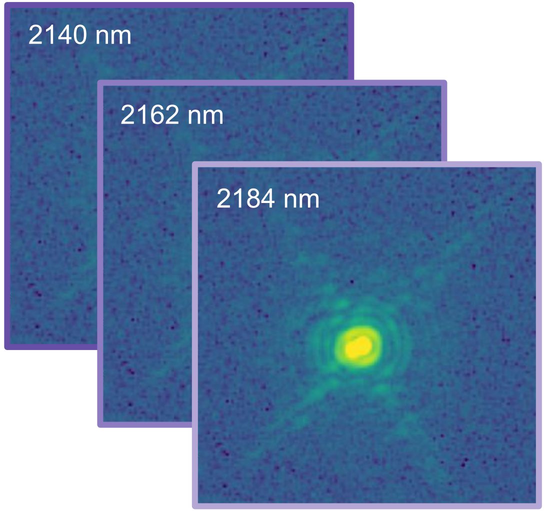
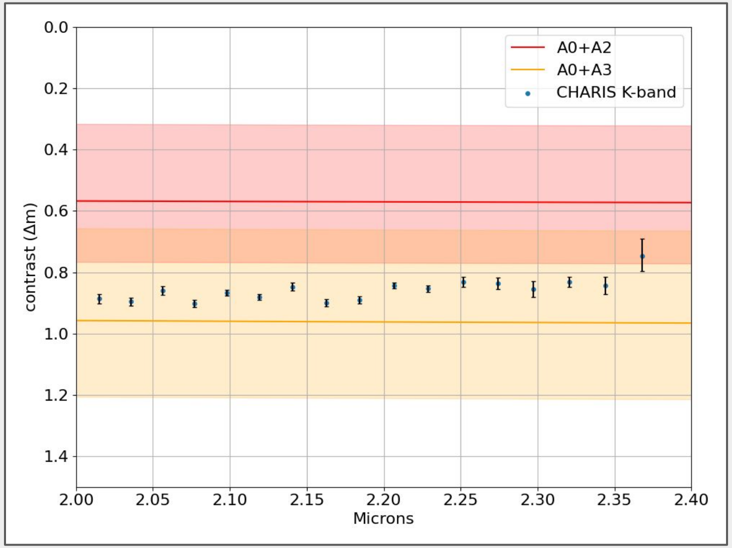
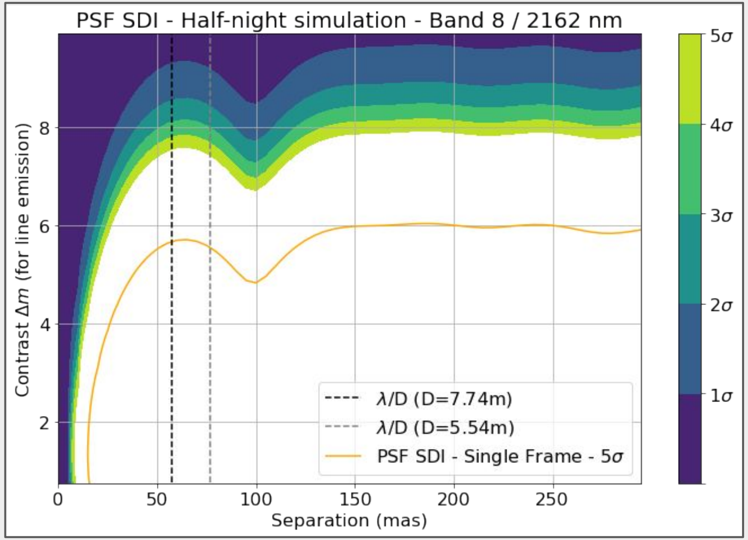


Fig. using adjacent spectral bins for self-calibration

Results: Demonstrating Kernel Phase with SCExAO/CHARIS



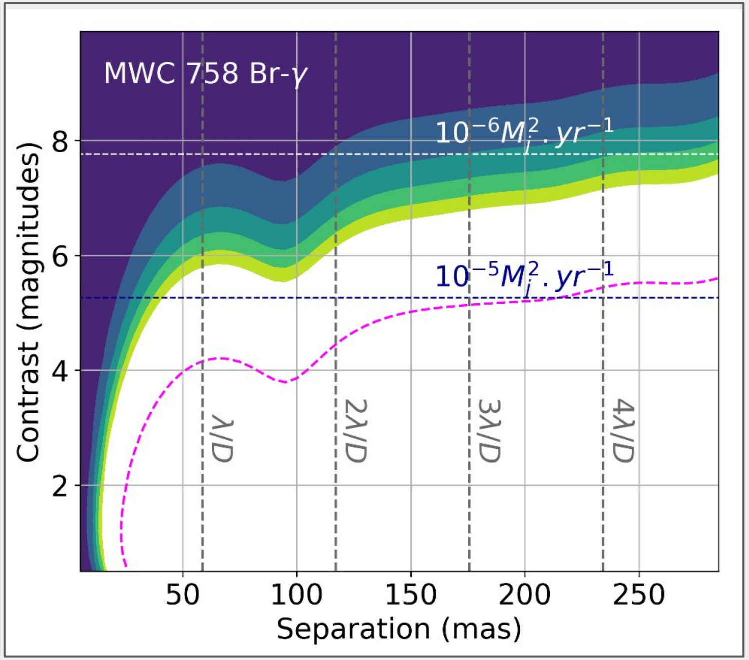
The spectrum of HD 44927 B with respect to HD 44927 A recovered with kernel phase.

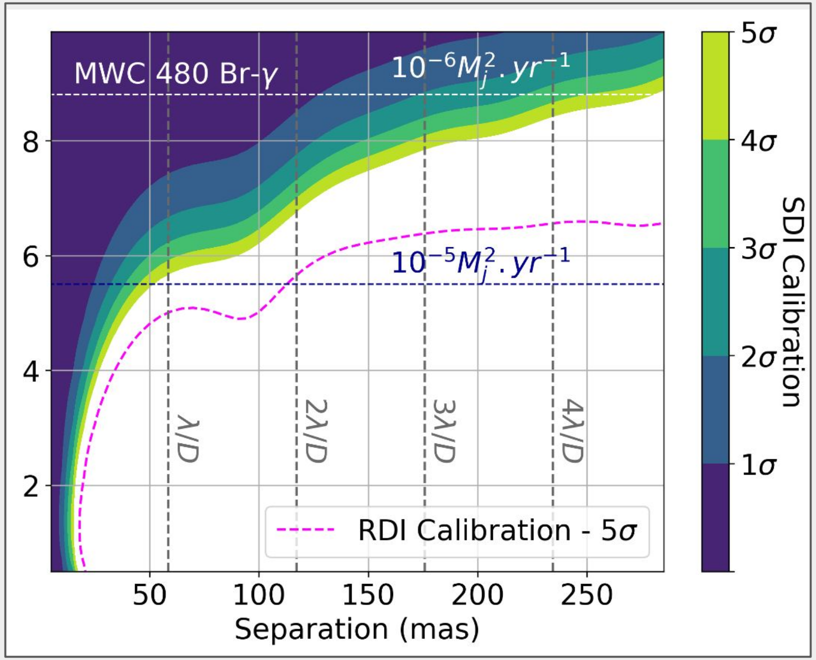


Characterisation of a spectral differential imaging (SDI) calibration for a simulated Br-γ search

Chaushev et al. (2023), JATIS
Chaushev et al. (2022), Proceedings of the SPIE

Results: New limits for MWC 758 and MWC 480

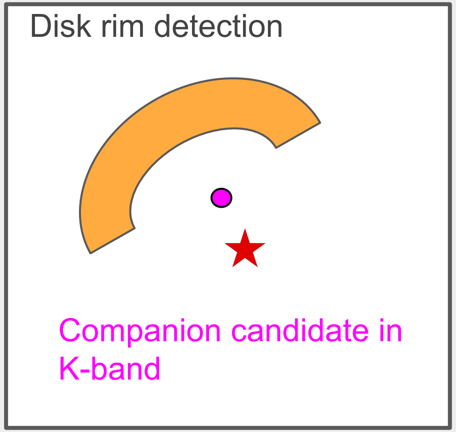




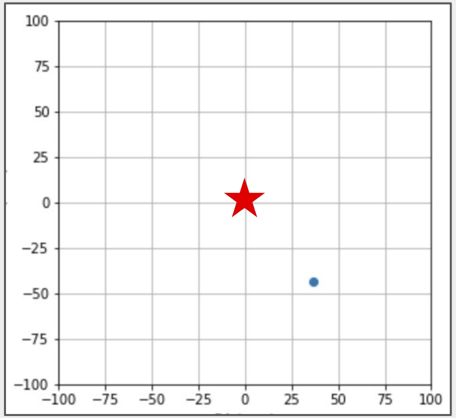
Setting upper limits on planet formation around MWC 758 and MWC 480 using a Br-γ accretion search and spectral differential KPI

Chaushev et al. (2023/24), AJ [under review]

Results: Application to a known planet candidate…
** extremely tentative detection at ~45mas **

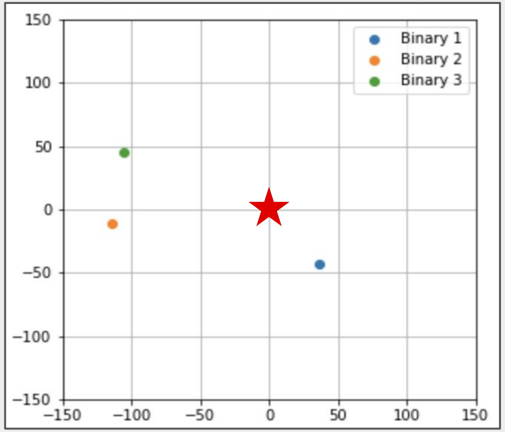


Prior observations



Single companion fit
(star + 1 point source)

Three companions iterative fit
(star + 3 point sources)



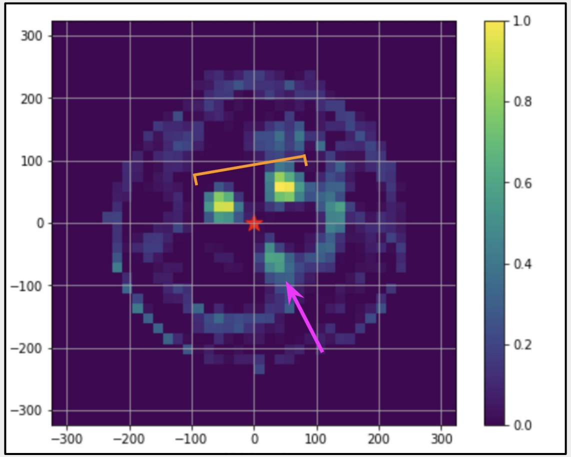
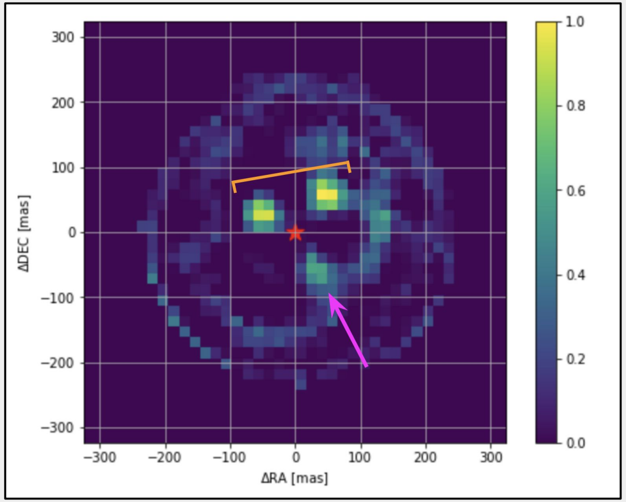


Image reconstruction using gradient descent

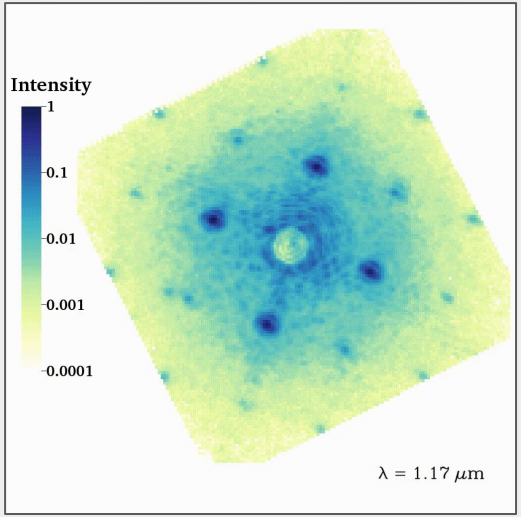
Chaushev et al. (2024?), in prep pending Subaru…

Results: Pipeline Development for CHARIS and JWST kernel phase



Kernel phase image reconstruction using automatic differentiation and gradient descent for SCExAO/CHARIS, JWST/NIRISS and JWST/NIRCAM

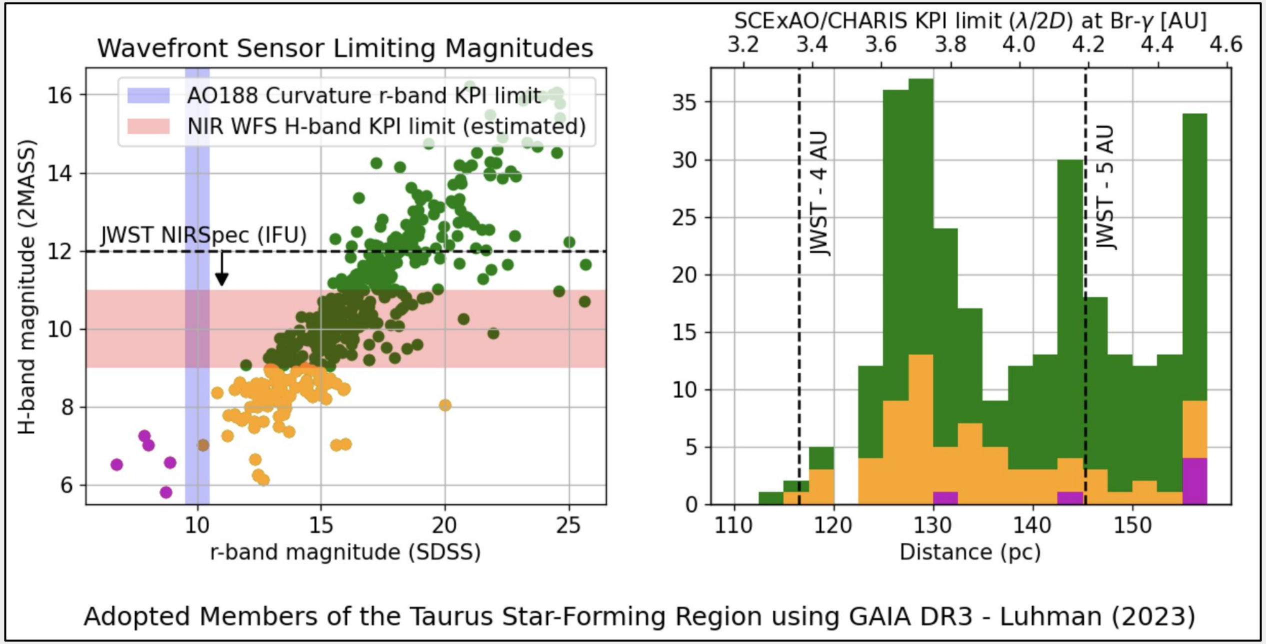
Chaushev et al. (2023), SPIE, 12680, 219-225
Chaushev et al. in prep



CHARIS-KP: A public kernel phase pipeline for SCExAO/CHARIS

Chaushev et al. in prep for SPIE 2024

Future Work: A KPI Survey of Taurus?



Limiting angular resolution and wavefront sensor magnitudes for KPI when observing young stars in Taurus

AO188 NIR WFS

A new near infrared wavefront sensor (PI: J. Lozi) is available on Subaru as of 2024A!

Future Work: JWST/NIRSPEC

JWST/NIRSPEC Kernel Phase

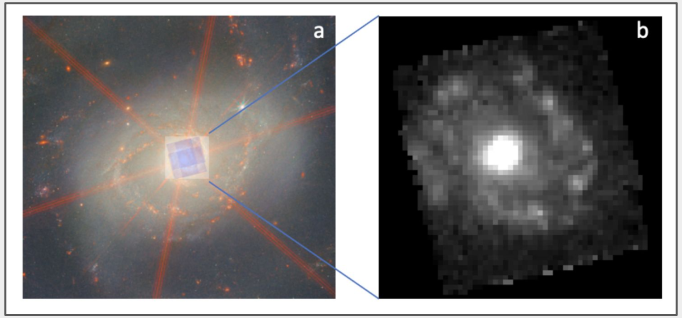
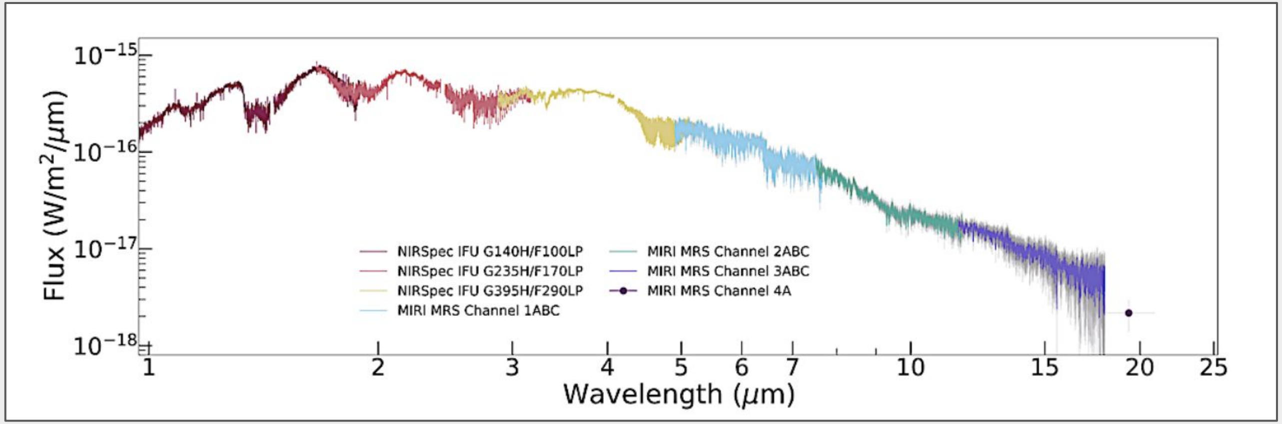
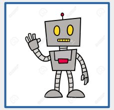


Image from ERS Program 1328; Spectrum of brown dwarf VHS 1256b, Miles et. al.



Can we do extremely high-angular resolution spectroscopy with KPI and JWST/NIRSPEC?

- Future direct imaging surveys such as GPI 2.0 and SPHERE+ will be detecting planets in the 5-10 AU range



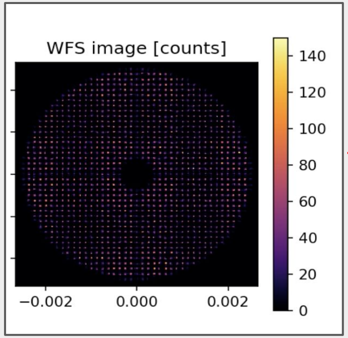
What is the sensitivity limit of KPI?
Can we boost this with machine learning?

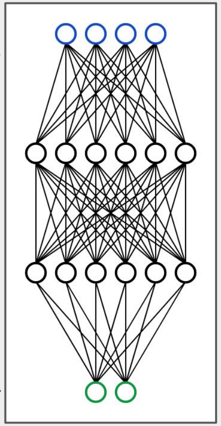
Automatic differentiation for better kernel phases

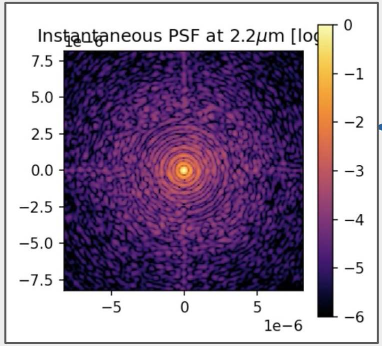
d() / dx = ?

Deriving kernel phases from a numerical model of the telescope.
Pope et al. (2019)

Deep neural networks for kernel phase systematic reconstruction







https://docs.hcipy.org/0.5.1/tutorials/ShackHartmannWFS/ShackHartmannWFS.html

Summary: **We can use interferometric data processing to search for ‘close-in’ protoplanets at 5-10 AU, where they are more abundant!**

Thank you for listening!