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From HR 8799 to Y-dwarf binaries: Understanding planet formation across the stellar IMF with JWST Interferometry

Thomas Vandal
Université de Montréal
Supervisor: René Doyon

In collaboration with L. Albert, F. Martinache, D. Mary, P. Calissendorff, M. De Furio, Clémence Fontanive, M. Meyer, JWST GO 2473 Team & JWST NIRISS GTO Team

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Fro ies:
Unders across
the ste ometry

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JWST/NIRISS Aperture Masking Interferometry (AMI)

- High contrast
- Short separations < 100 mas

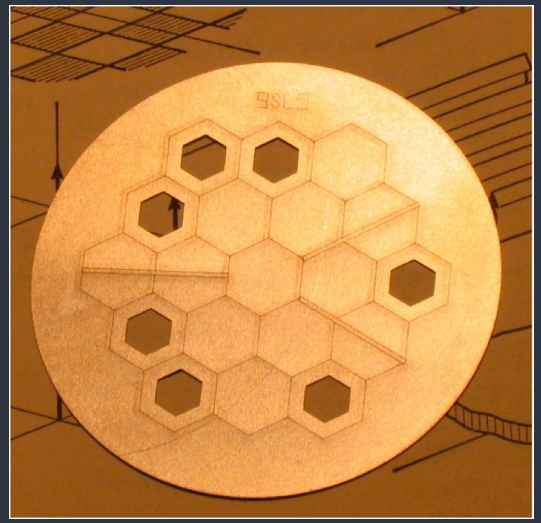


Figure: A. Sivaramakrishnan

NIRISS AMI Guaranteed Time Observations (GTO 1200)

HR 8799

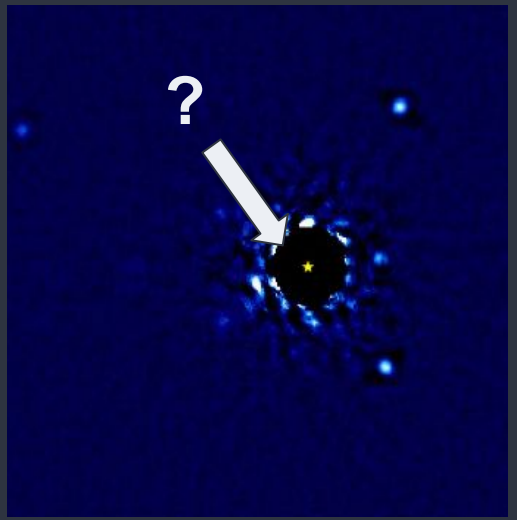


Figure: J. Wang/C. Marois

HD 95086

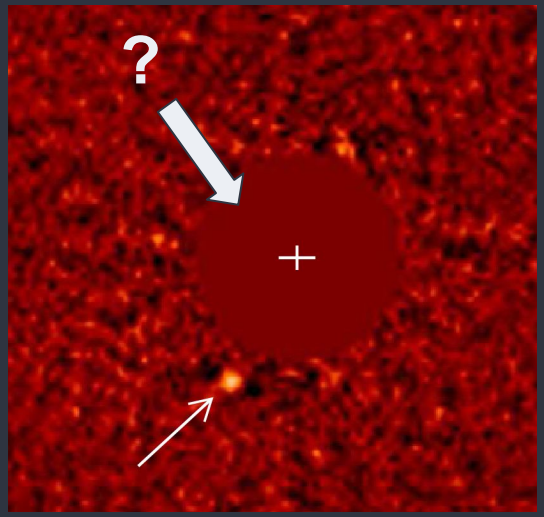
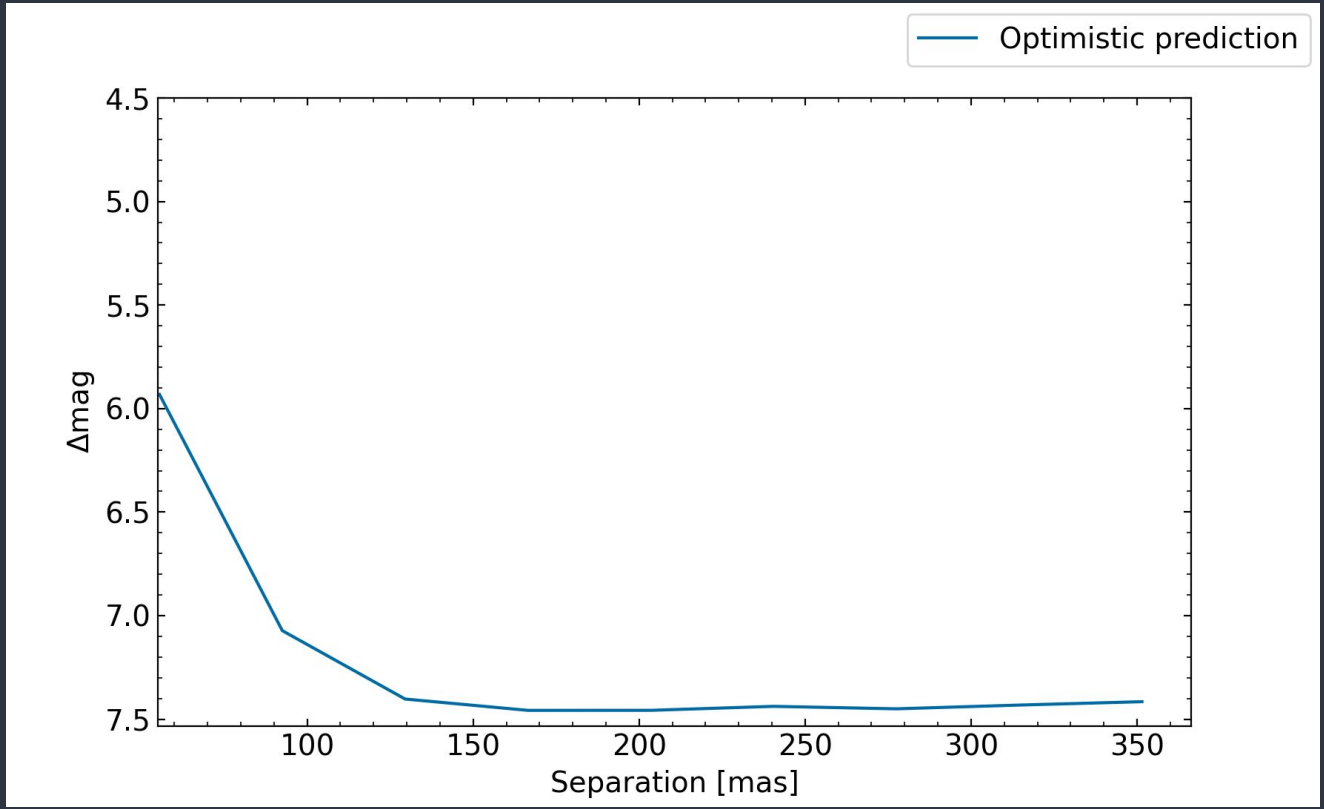
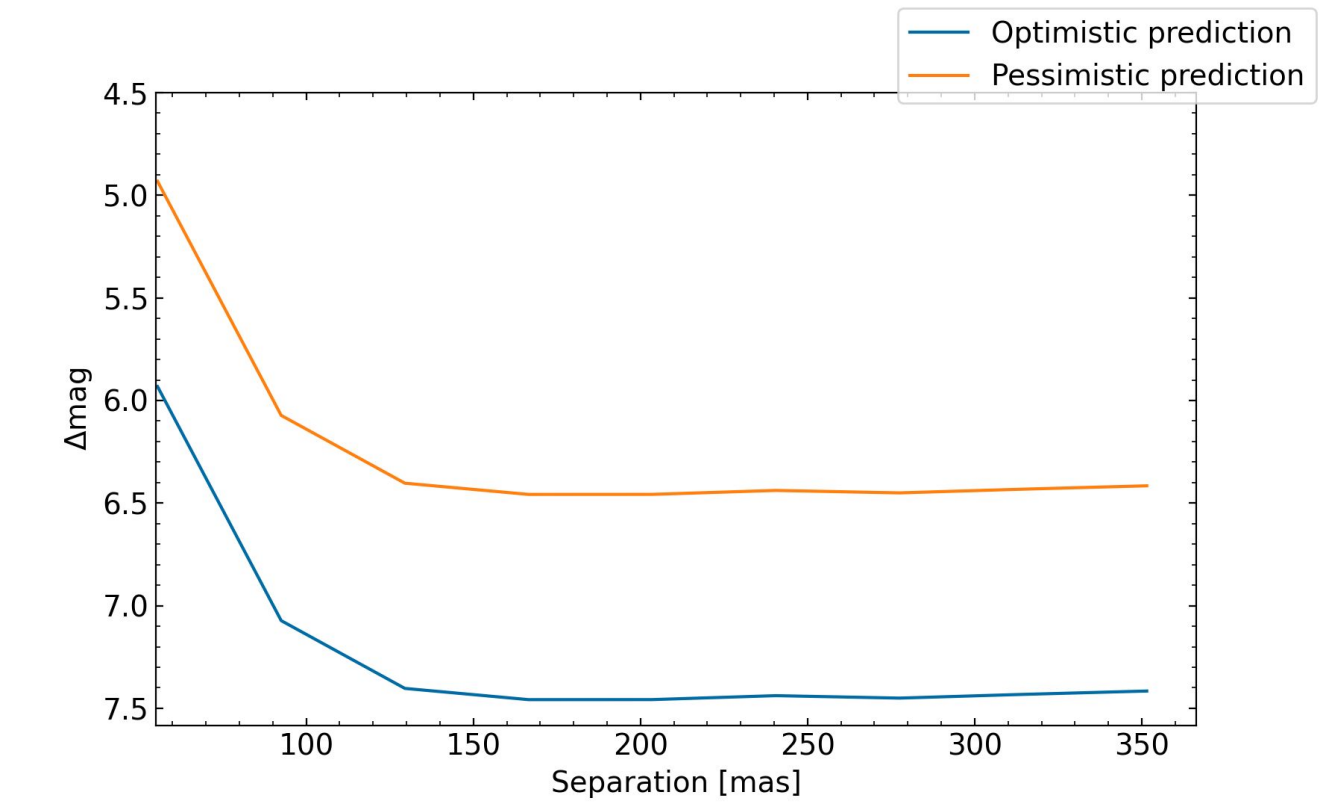


Figure: J. Rameau

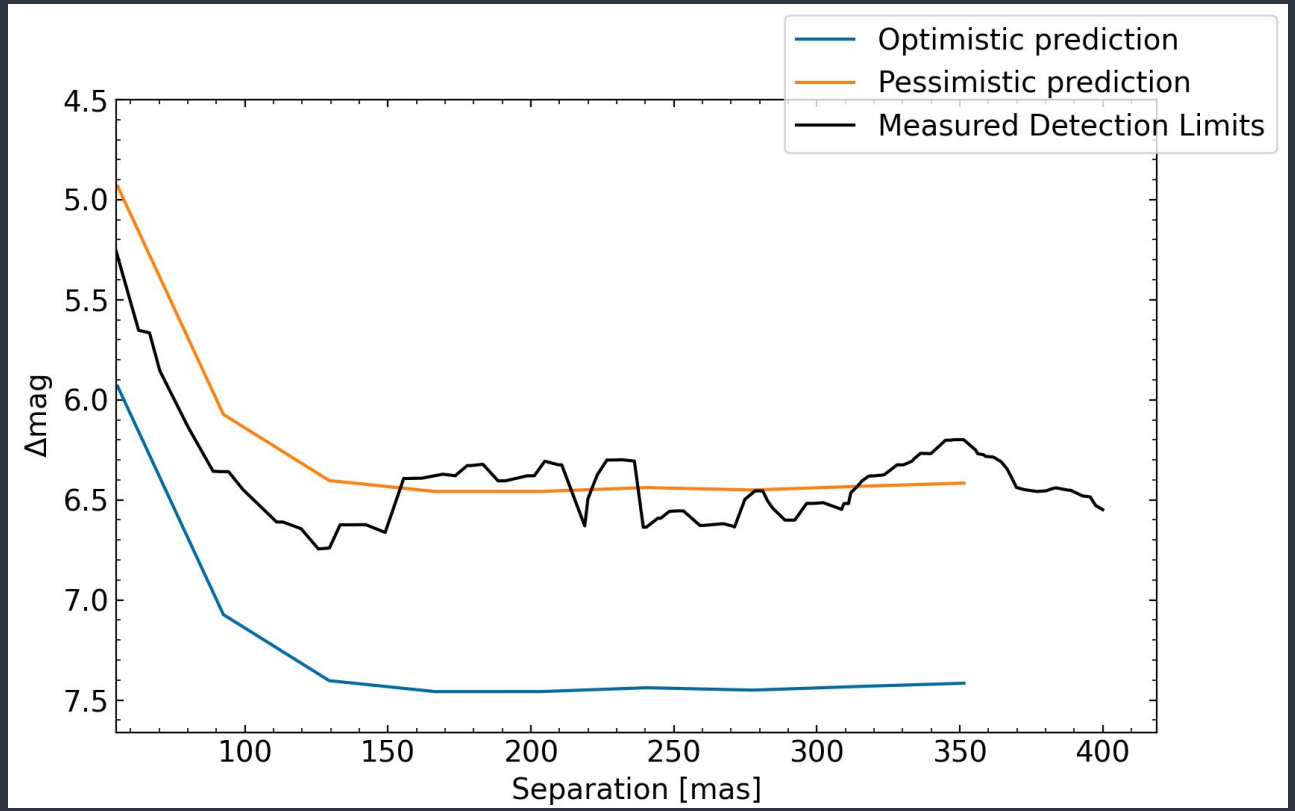
Expected NIRISS AMI Performance

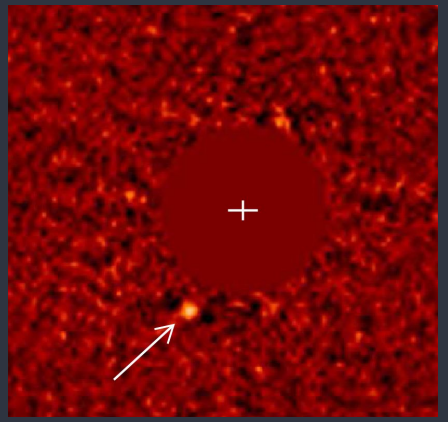


Expected NIRISS AMI Performance

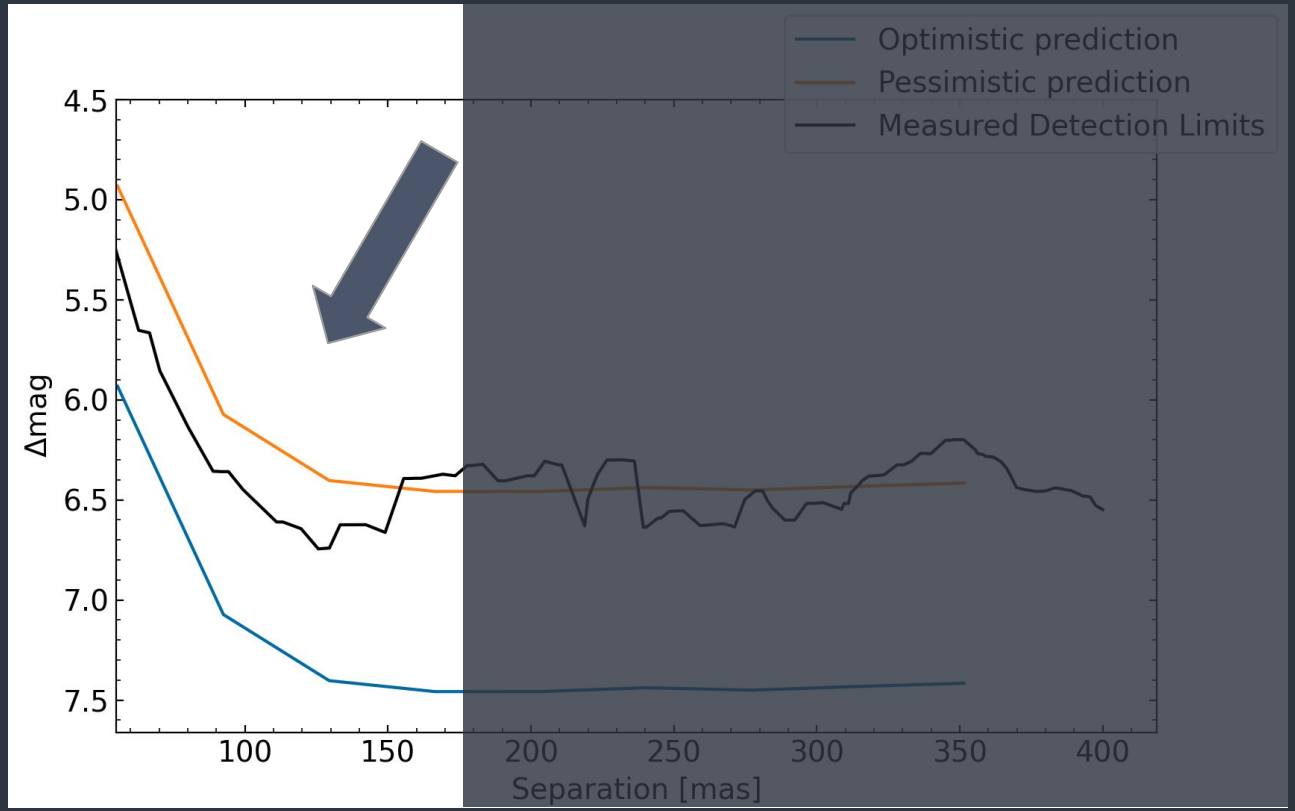


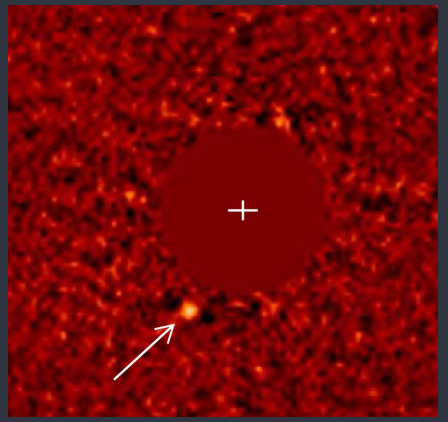
Measured Detection Limits - HD 95086



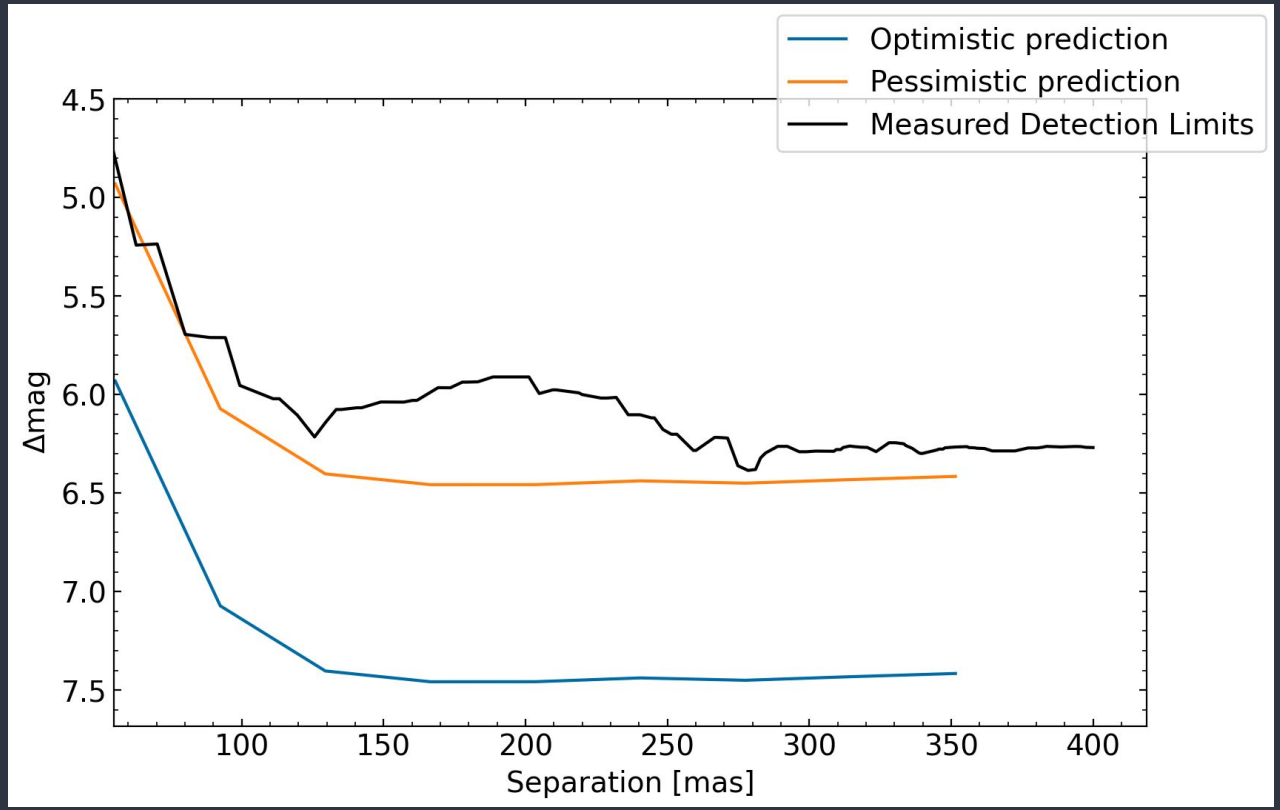


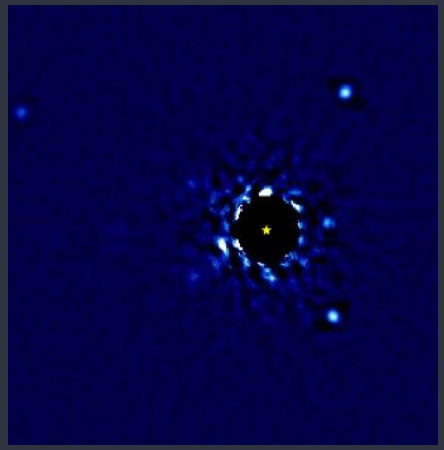
Measured Detection Limits - HD 95086





Measured Detection Limits - HR 8799



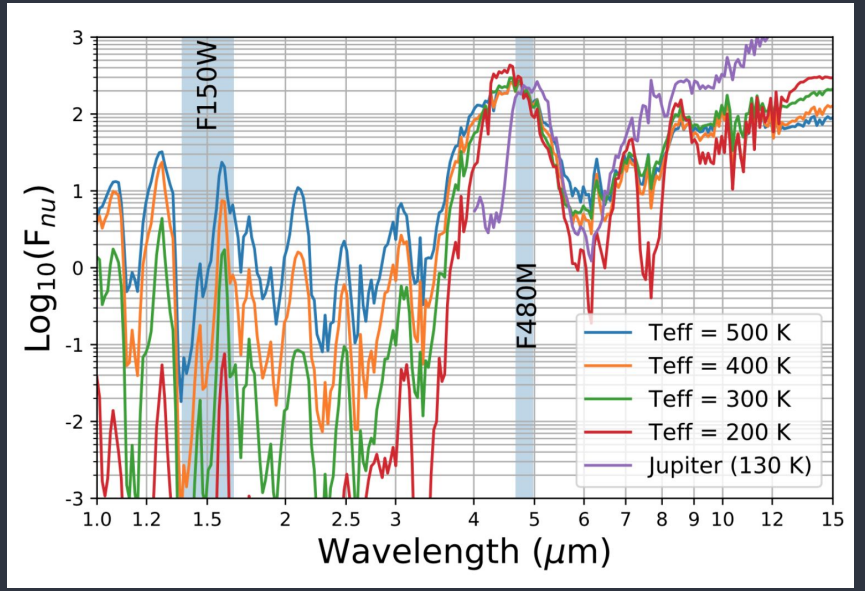


NIRISS AMI Takeaways

- Systematics are the main limiting factor (Charge migration)
- Longer exposures are needed for HR 8799 and HD 95086
- Ongoing efforts:
  - Observing strategies to mitigate charge migration
  - Charge migration correction in reduction pipeline

Probing the multiplicity 20 Y dwarfs with JWST

- Probe **short separations** (< 100 mas)
- Search **cold companions**
- Expected yield: ~1-3 companions
- JWST GO 2473, PI Loïc Albert



AMI will not Work for Faint Primaries

- High contrast
- Short separations < 100 mas
- **Blocks 85% of the light**

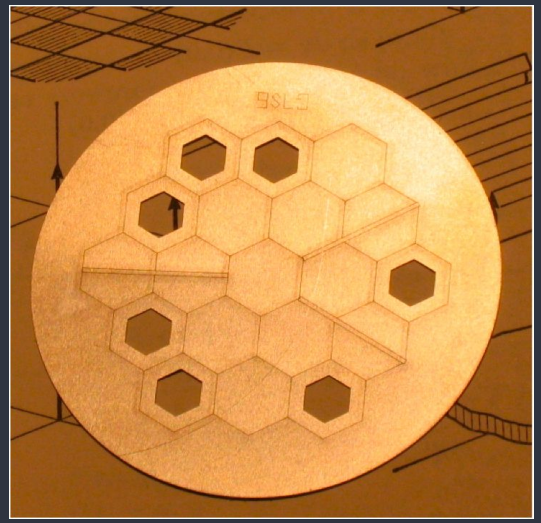


Figure: A. Sivaramakrishnan

Kernel Phase: The Telescope as an “Interferometer”

- High contrast
- Short separations
- CLEAR Pupil

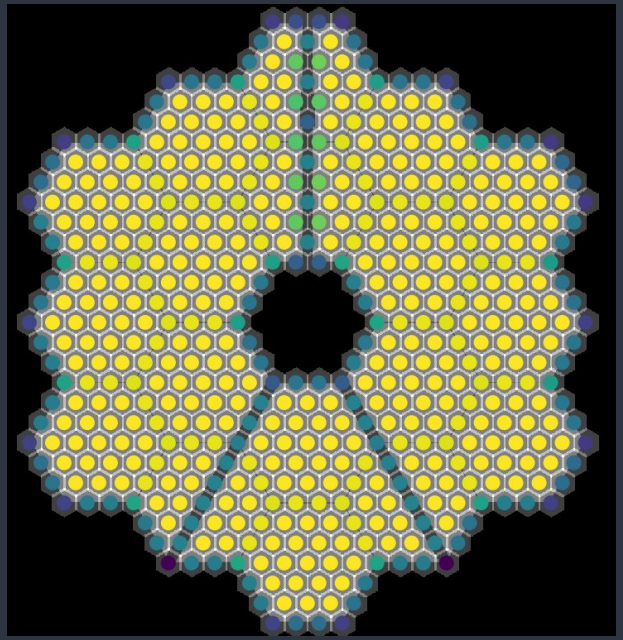
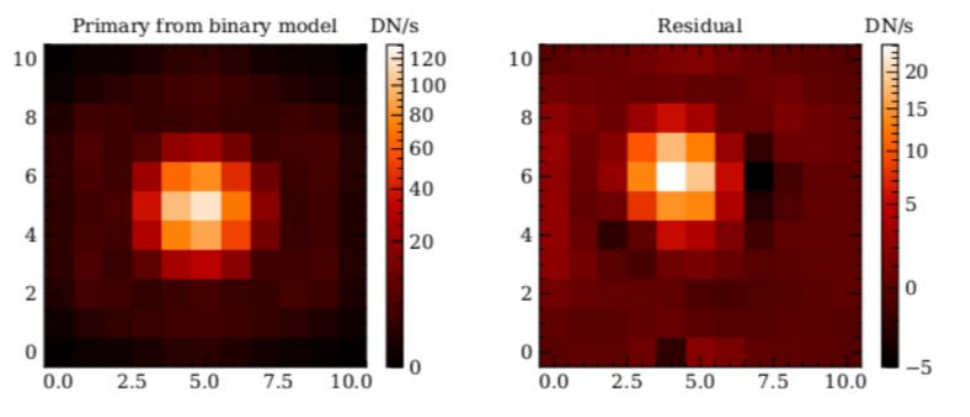


Figure: NASA

WISE-0336: The first Y+Y Binary

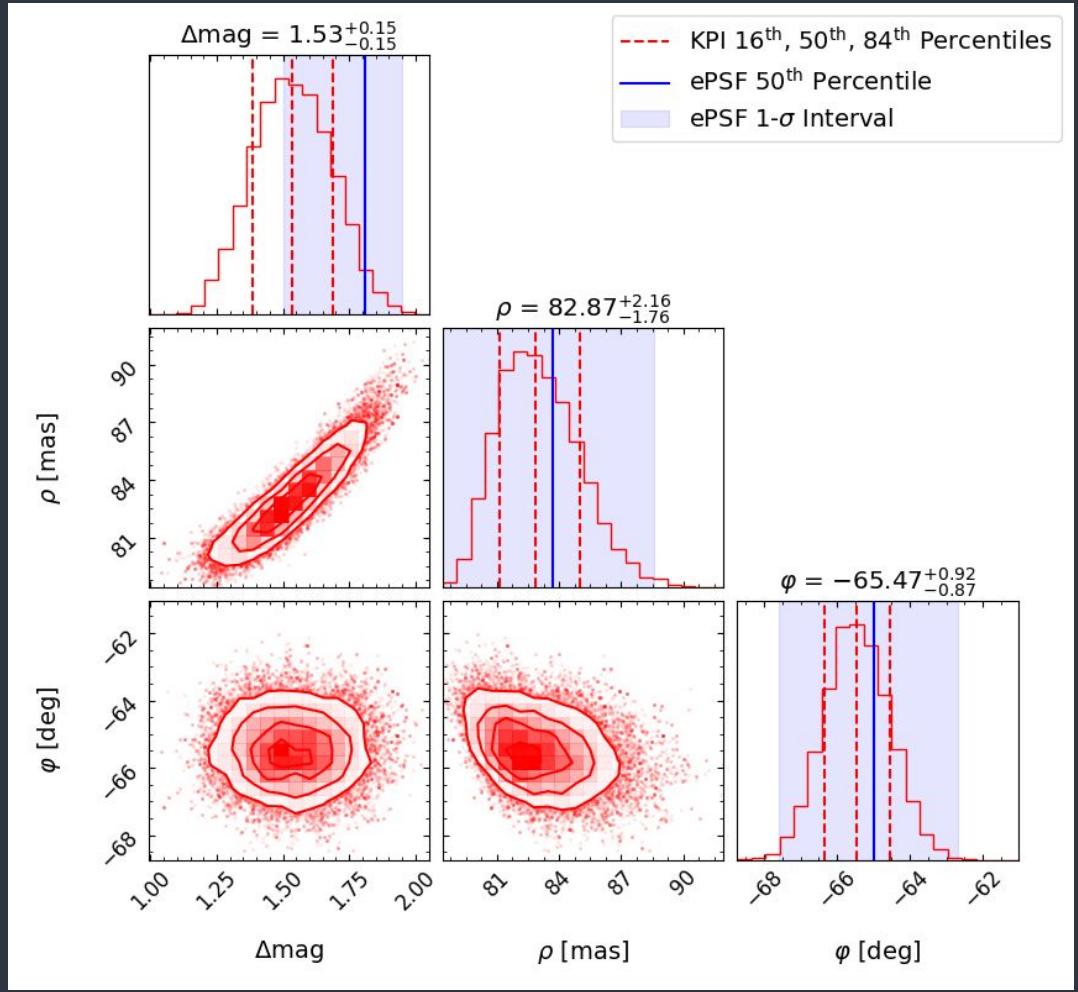
Detected via ePSF modelling (Per Calissendorff et al., 2023)



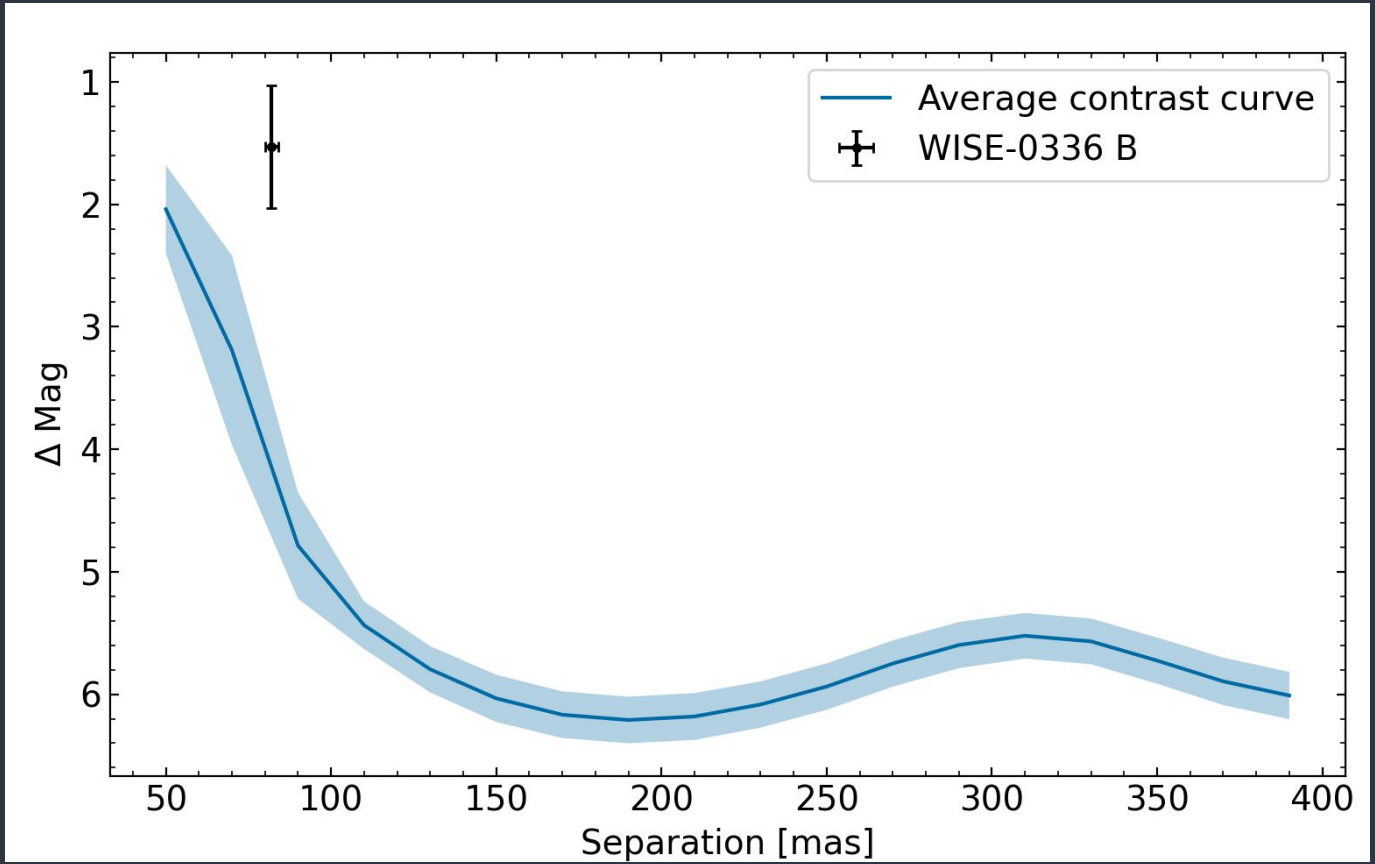
Companion properties

- T_{eff} = 325 K
- Mass between 5 and 12 M_{Jup} depending on age (1-5 Gyr)
- Separation ~ 1 AU (82 mas)

WISE 0336: Kernel Phase Interferometry



Detection limits: NIRCam Y Dwarfs Survey



What’s next?

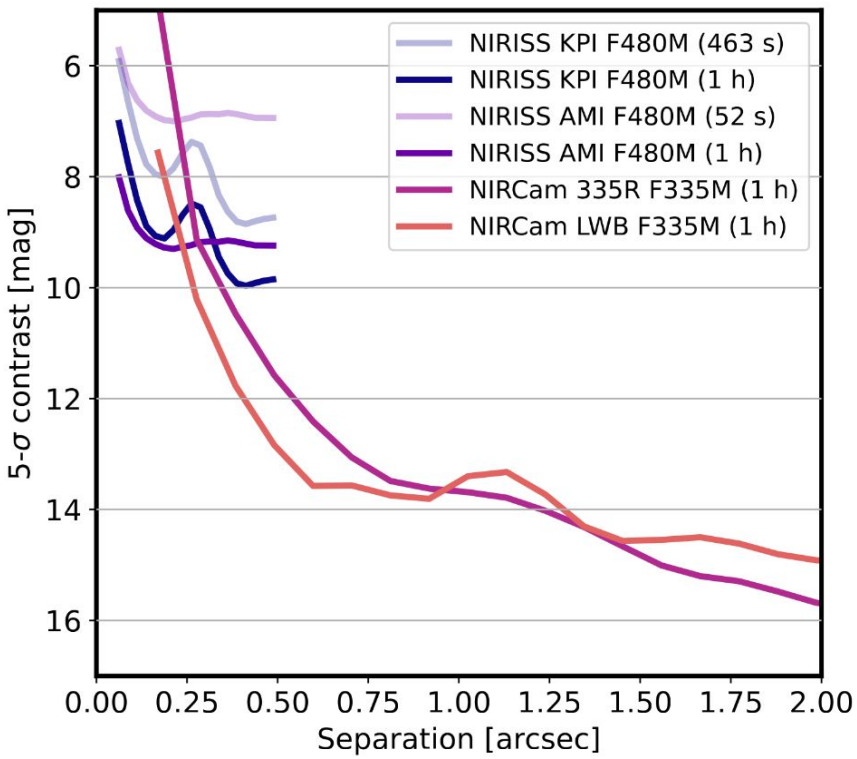
- Multiplicity analysis (Binary frequency)
- Compare performance with ePSF modelling
- Follow-up WISE-0336
- Search around more low-mass brown dwarfs

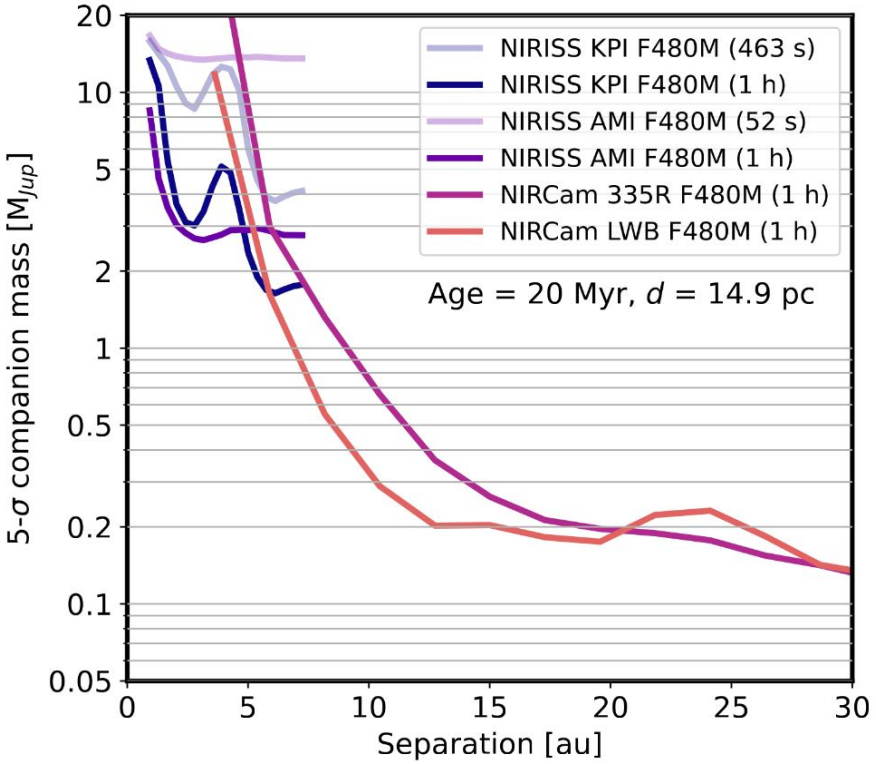
In Summary

- JWST interferometry enables imaging below the diffraction limit, from A-type stars to Y dwarfs
- AMI: still suffers from systematics, but there is hope for cycle 4
- JWST + KPI: unprecedented sensitivity to cold companions around Y dwarfs
- First Y+Y binary WISE 0336 detected with ePSF and confirmed with KPI

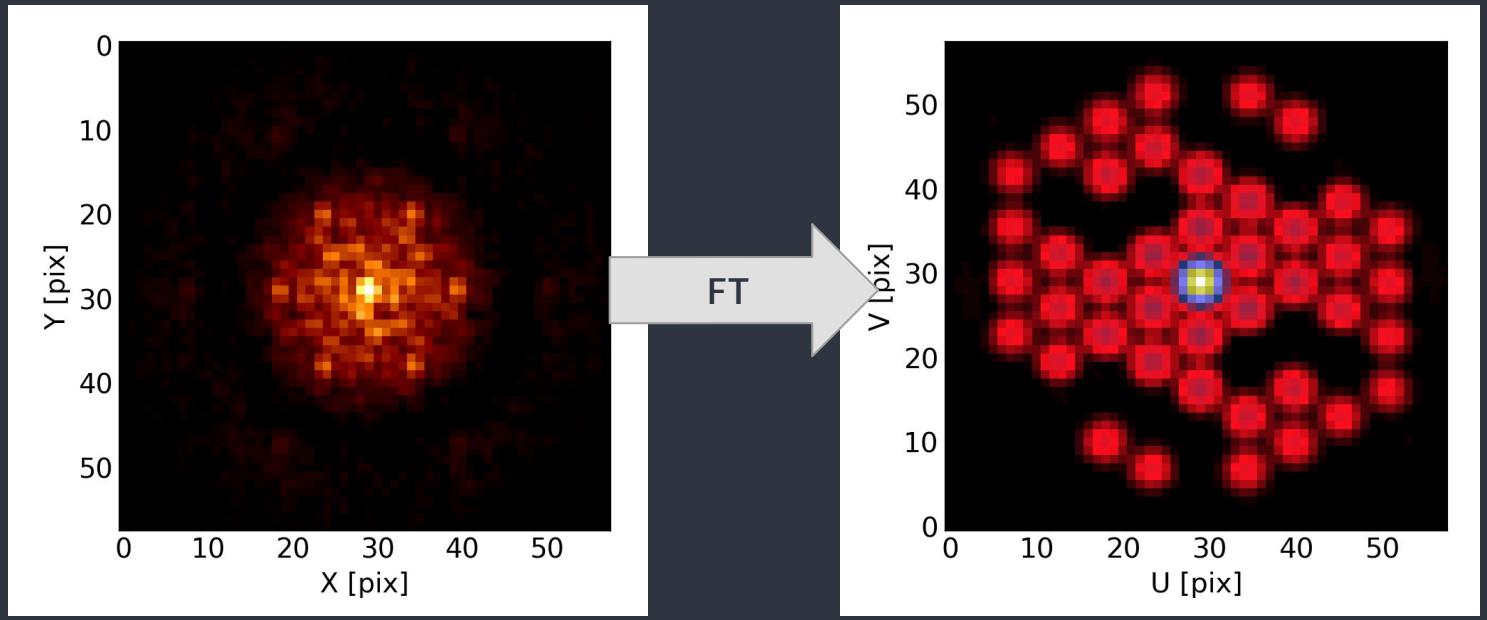
EXTRA MATERIAL

JWST Imaging Modes: Comparison from Commissioning

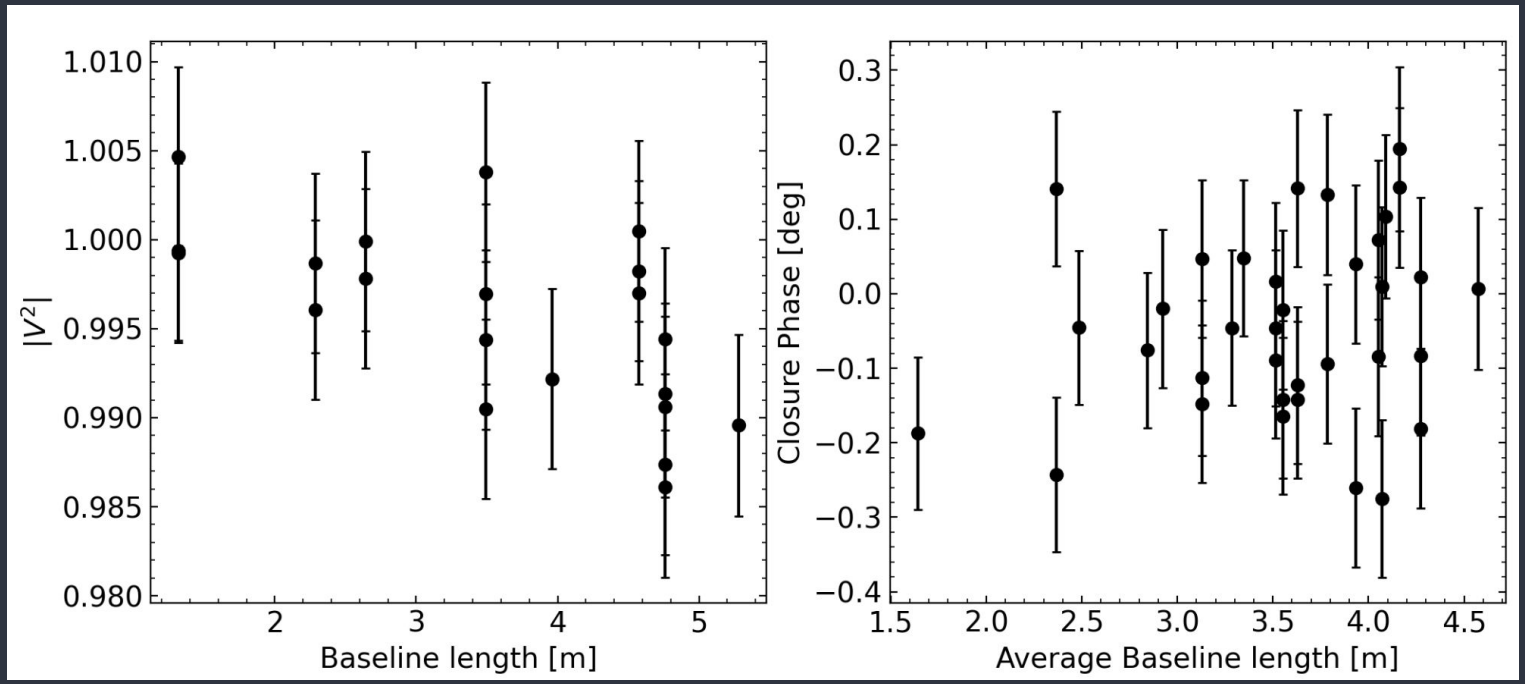




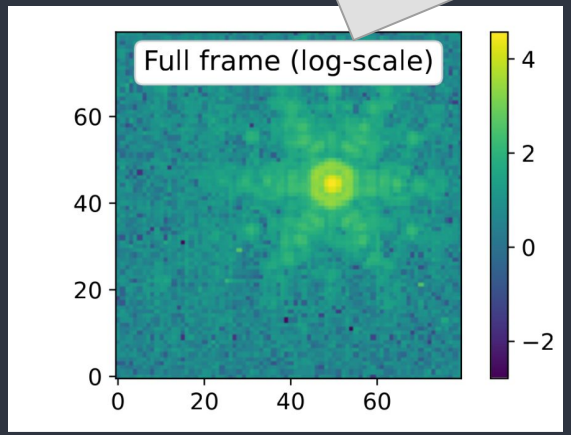
NIRISS AMI Interferogram (PSF) and Power Spectrum



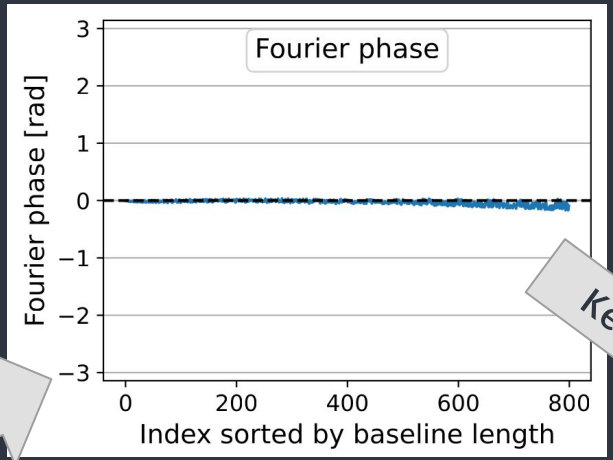
NIRISS AMI Interferometric Observables



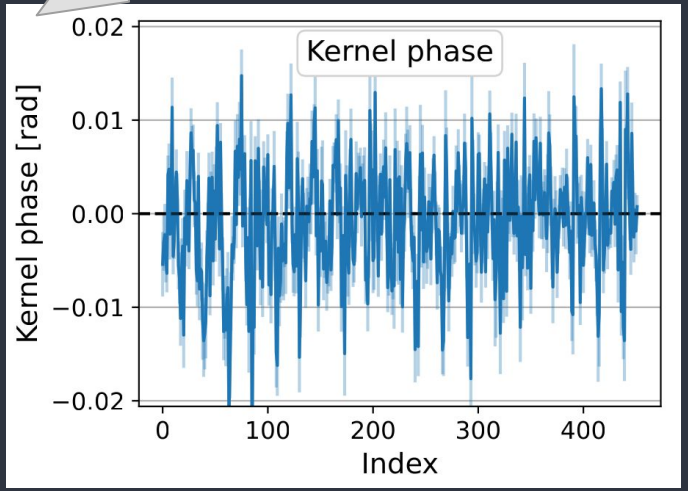
JWST KPI (Kernel Phase Interferometry) in Practice



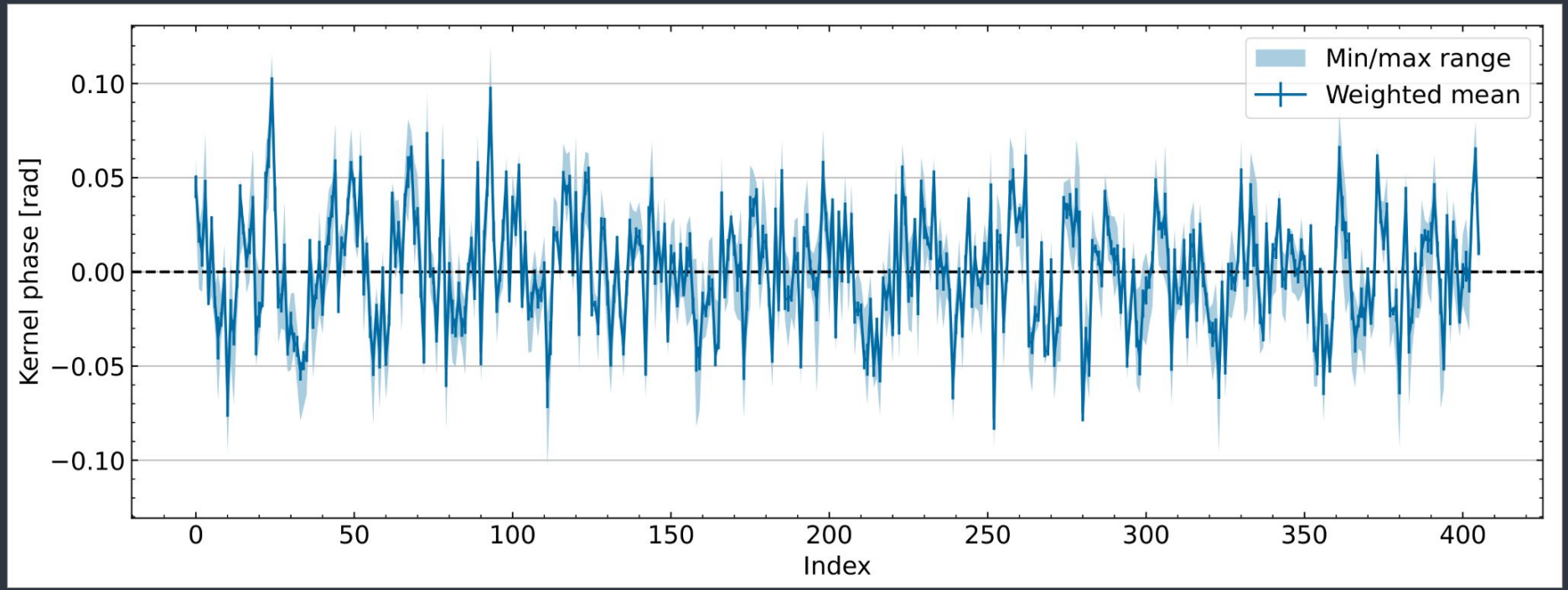
FT



Kernel



WISE-0336 with NIRCam KPI



Closure Phase

Atmospheric turbulence: Impact on phase

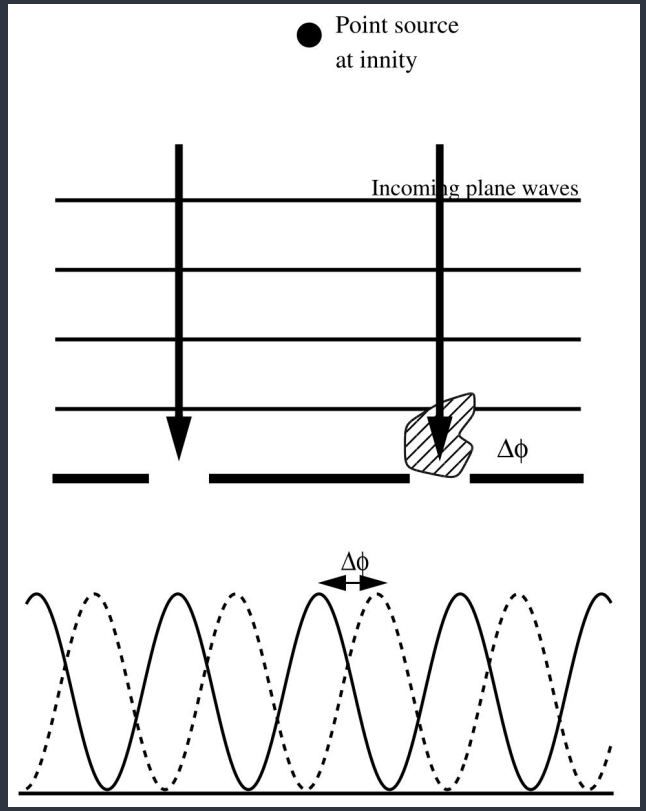
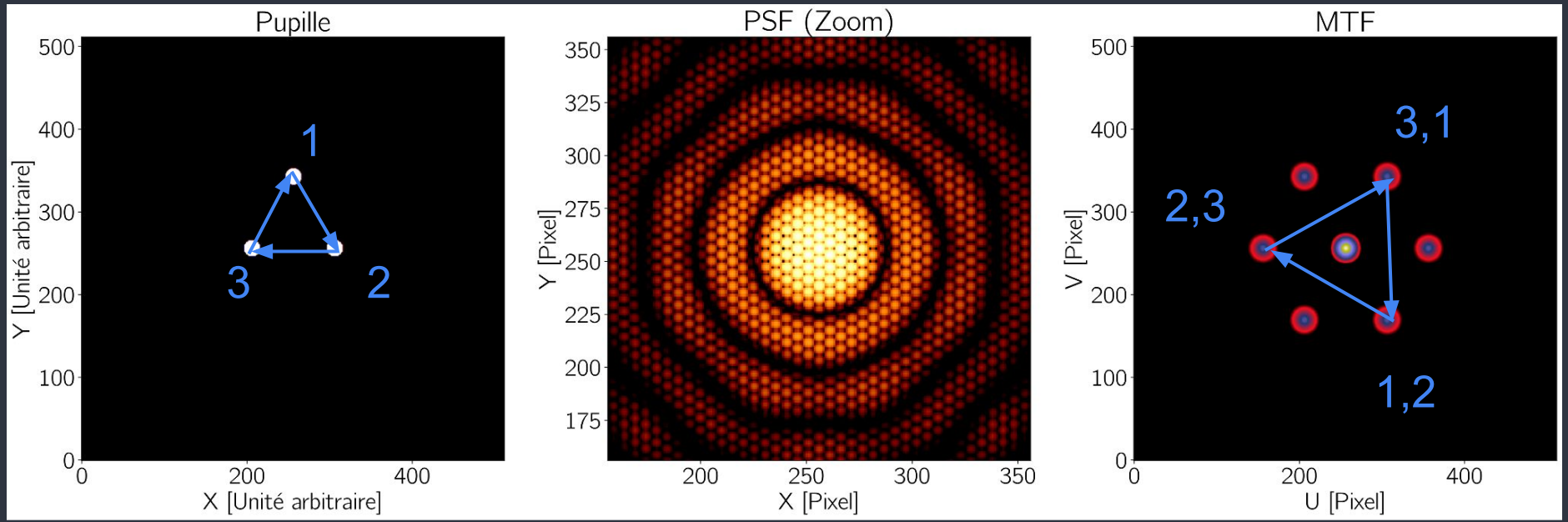


Figure: Monnier 2007

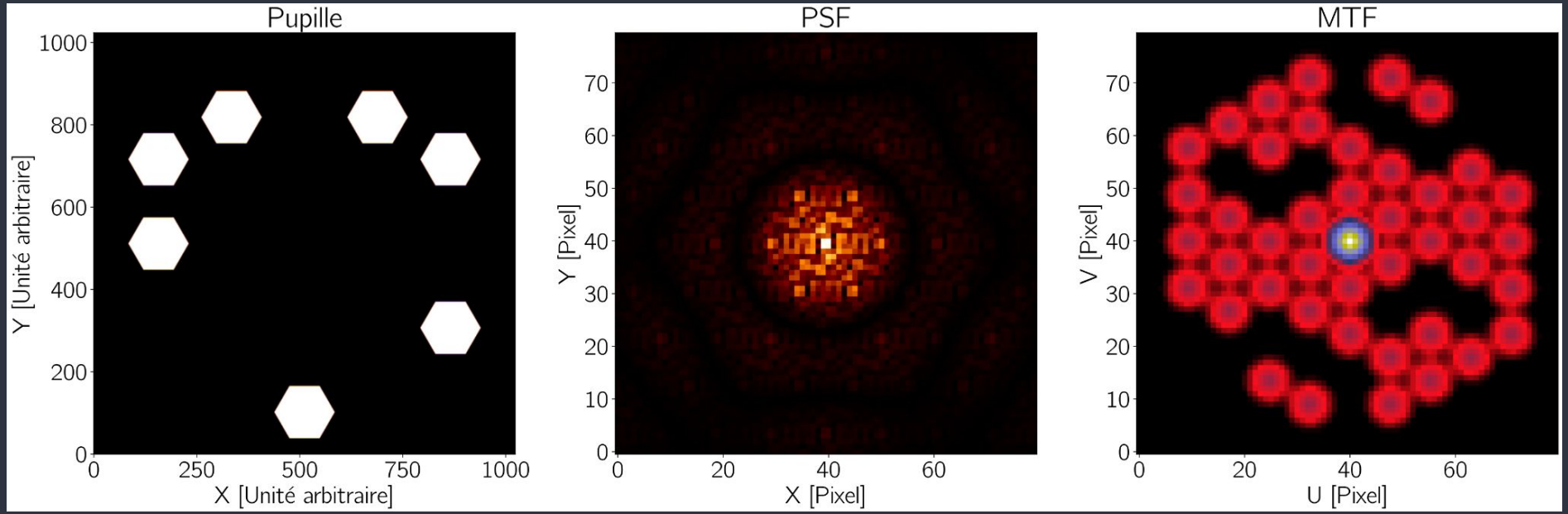
Solution: Closure Phase

$$\phi_{1,2} = \phi^O_{1,2} + \cancel{\varphi_2}^0 - \cancel{\varphi_1}^0$$
$$\phi_{2,3} = \phi^O_{2,3} + \cancel{\varphi_3}^0 - \cancel{\varphi_2}^0$$
$$\phi_{3,1} = \phi^O_{3,1} + \cancel{\varphi_1}^0 - \cancel{\varphi_3}^0$$

$$\Phi_{1,2,3} = \phi_{1,2} + \phi_{2,3} + \phi_{3,1} = \phi^O_{1,2} + \phi^O_{2,3} + \phi^O_{3,1}$$



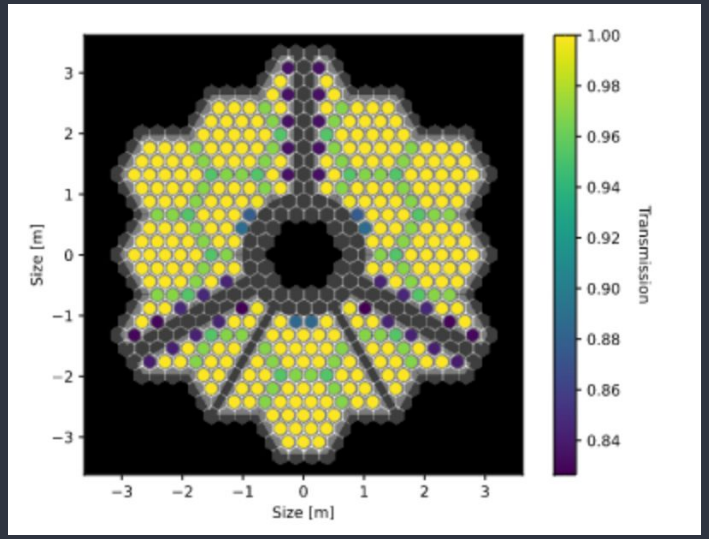
AMI with JWST/NIRISS



KPI: Treat telescope as interferometer

$$e^{i\varphi_k} \approx 1 + i\varphi_k$$

$$\phi = \mathbf{A}\varphi$$



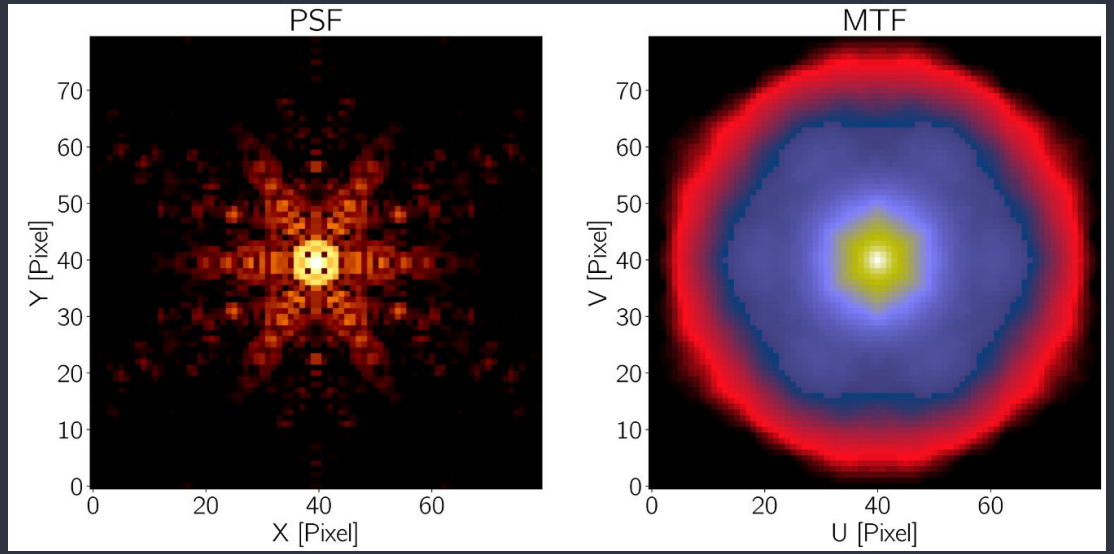


Figure: Kammerer+ 2022

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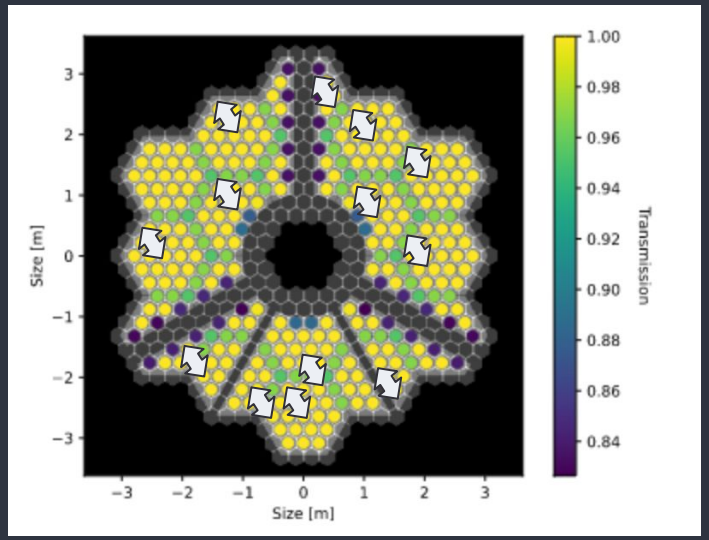

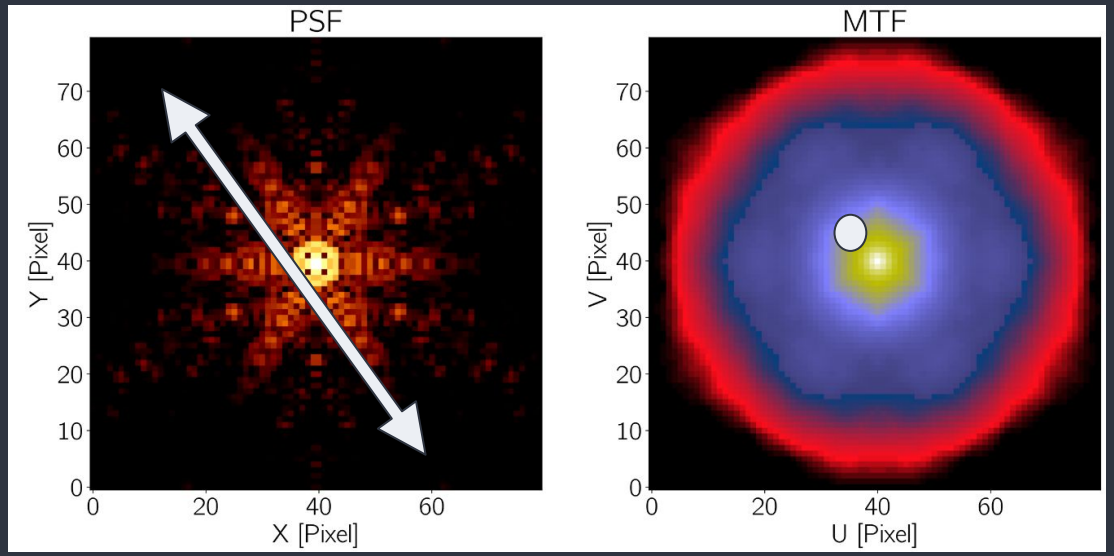

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KPI: Treat telescope as interferometer

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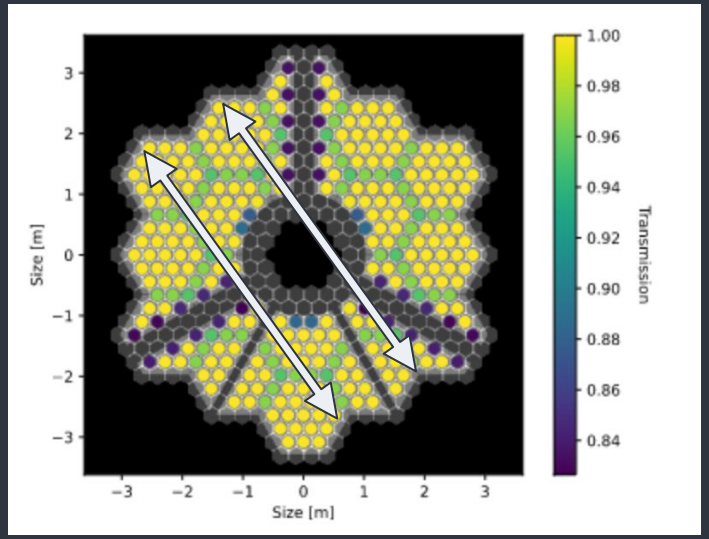
$$\phi = \mathbf{A}\varphi$$



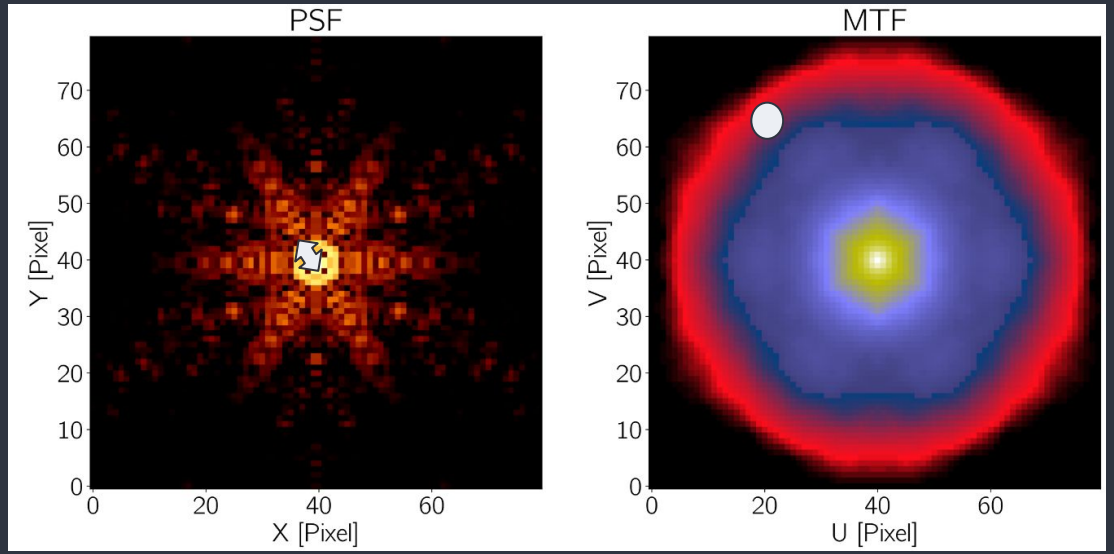


Figure: Kammerer+ 2022

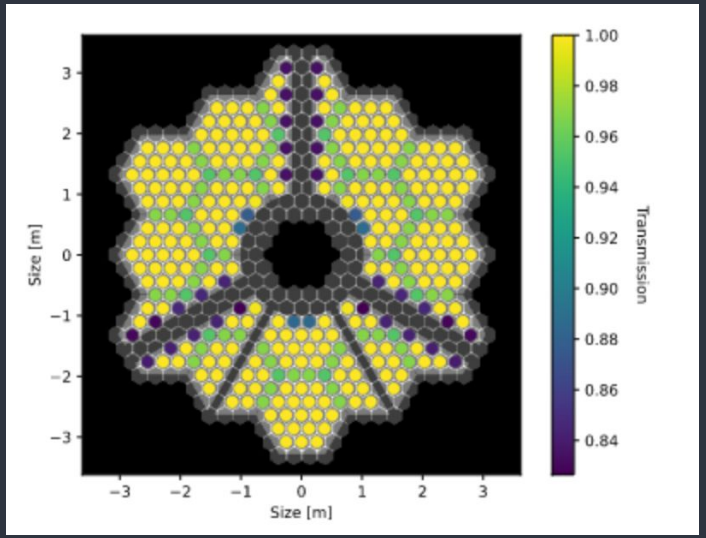
KPI: Treat your telescope as an interferometer

$$e^{i\varphi_k} \approx 1 + i\varphi_k$$

Object

Errors

$$\phi = \phi_O + \mathbf{A}\varphi$$



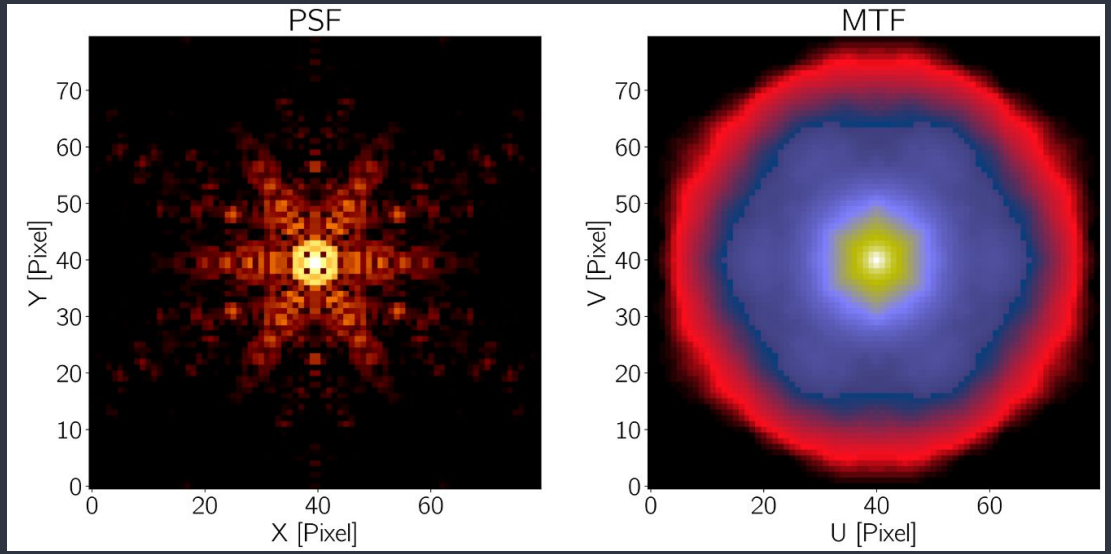


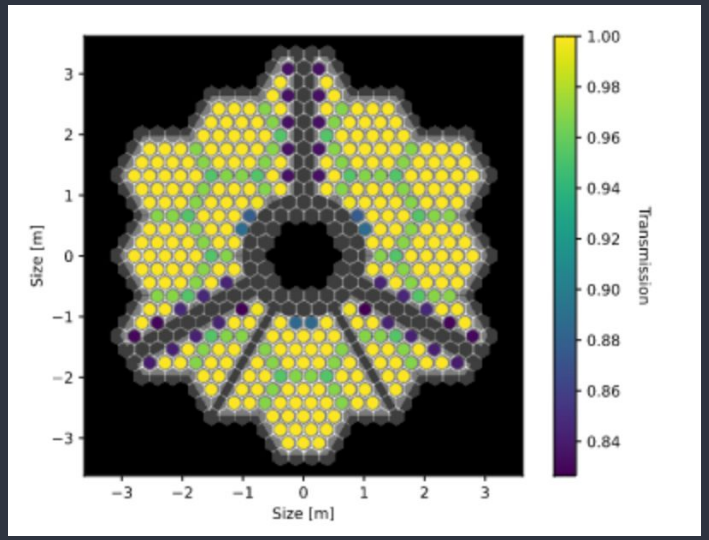
Figure: Kammerer+ 2022

KPI: Treat telescope as interferometer

$$\phi = \phi_O + \mathbf{A}\varphi$$

$$e^{i\varphi_k} \approx 1 + i\varphi_k$$

$$\mathbf{K}\phi = \mathbf{K}\phi_O + \cancelto{0}{\mathbf{K}\mathbf{A}\varphi}$$



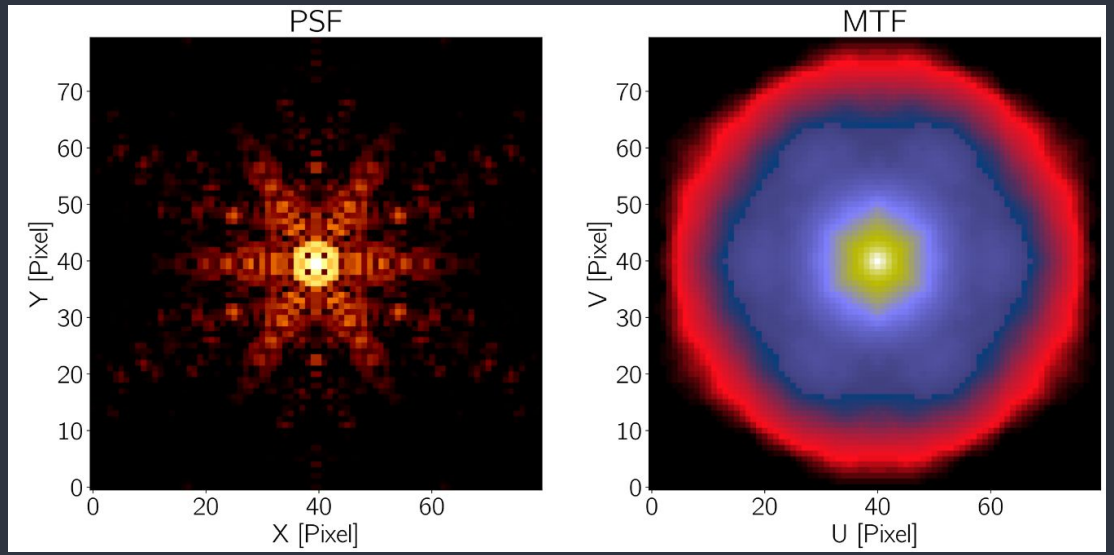


Figure: Kammerer+ 2022