

Commissioning the first visible photonic lantern spectrograph for sub-diffraction-limit astronomy on Subaru/SCEAO

Vievard, Huby, Lacour, Guyon, Lallement, Nowak, Kim, Walk, Sarrazin, Fitzgerald, Leon-Saval, Betterts, Lozi, Lucas, Deo, Jovanovic, Norris, Currie, Martinache, Perrin

¹SEI - CoE - IFA - University of Hawaii, ²Subaru telescope, ³Astrobiology Center, ⁴LIRA - Observatoire de Paris, ⁵University of Arizona, ⁶KASI, ⁷SAIL, ⁸Univ. of Texas, ¹⁰IPAG, ¹²IFA - University of Hawaii, ¹³University of Sydney, ¹⁵UCLA

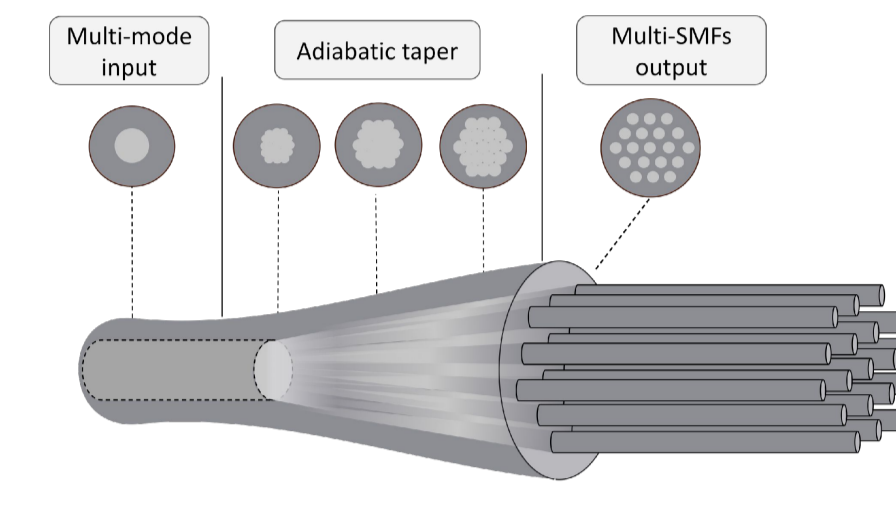
The authors wish to recognize and acknowledge the very significant cultural role and reverence that the summit of Mauna Kea has always had within the Hawaiian community. We are most fortunate to have the opportunity to conduct observations from this mountain.

FIRST-PL : A Visible Photonic Lantern on the Subaru Telescope

“The photonic lantern is a low-loss optical waveguide device that connects one multimode core to several cores that each support fewer modes” (Birks et al., The photonic lantern, Adv. Opt. Photon. 2015)

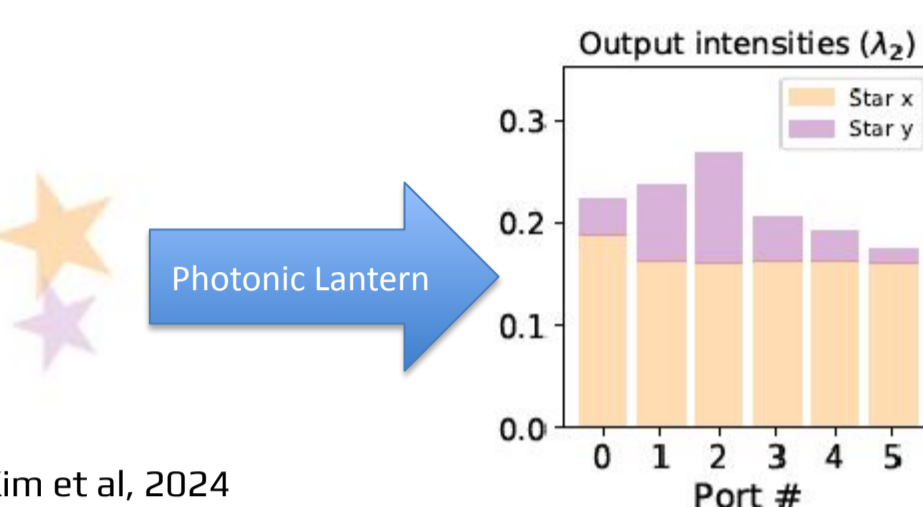
High throughput

Enabling SMF-fed spectroscopy with high efficiency



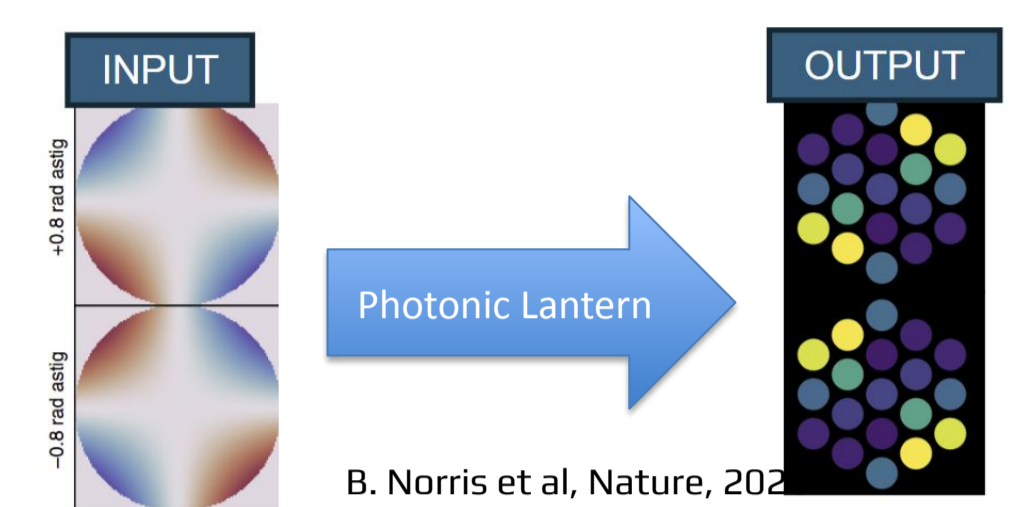
Sensitive to input scene

Output flux distribution depends on the observed object



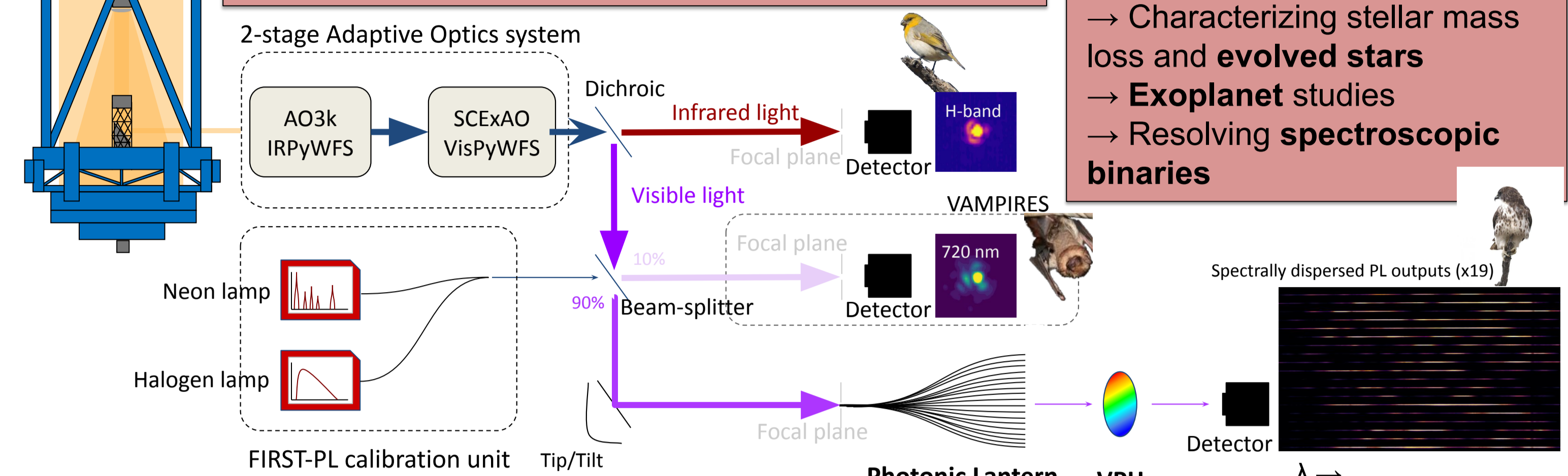
Sensitive to input wavefront

Output flux distribution depends on the input wavefront



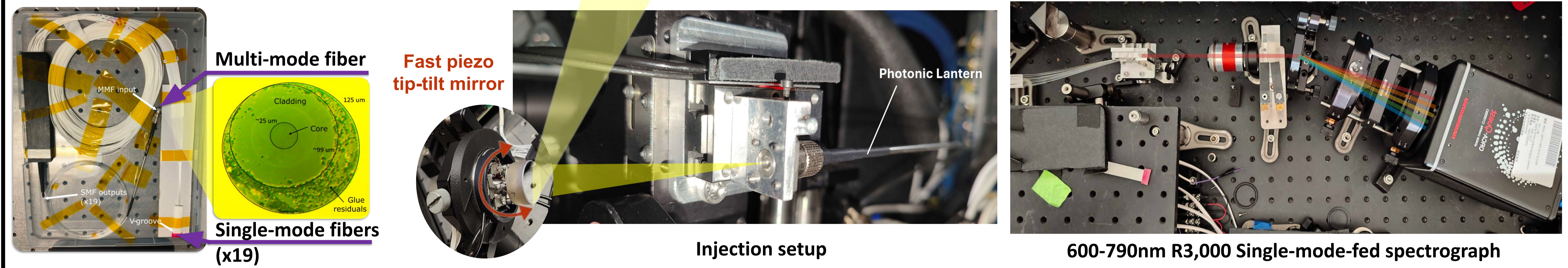
FIRST-PL: Imaging Spectrometer on Subaru/SCEAO

- Visible light : 600-790 nm, R=3000
- Ultra-high angular resolution (sub-diffraction limit)



- Science objectives :
- Mapping gas accretion onto protoplanets (H α)
 - Characterizing stellar mass loss and evolved stars
 - Exoplanet studies
 - Resolving spectroscopic binaries

Hardware



Observing modes

SPECTROASTROMETRY

IMAGING

On-axis image reconstruction

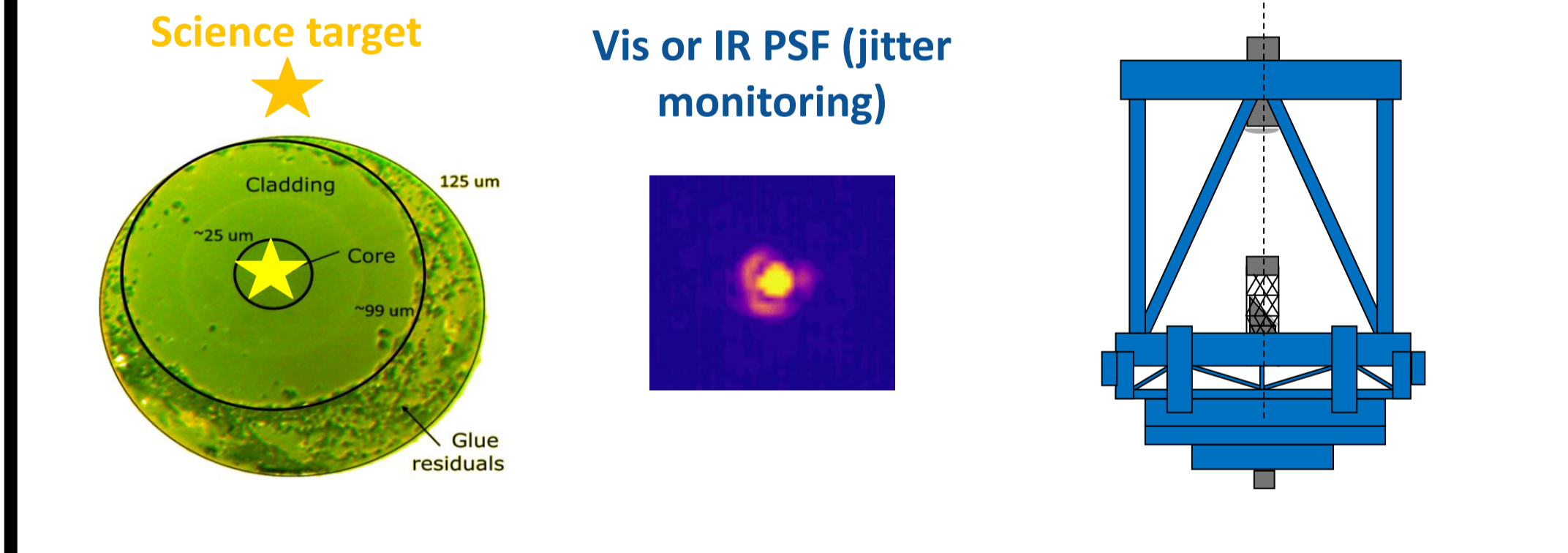
Off-axis image reconstruction

Required data:

- PL data without modulation
- Vis or IR PSF images for PL response calibration

Principle: PSF jitter provides position diversity to reconstruct the photonic lantern spatial response as a function of wavelength

Science sub λ/D : Star formation & evolution (YSOs accretion, Herbig Ae/Be stars)

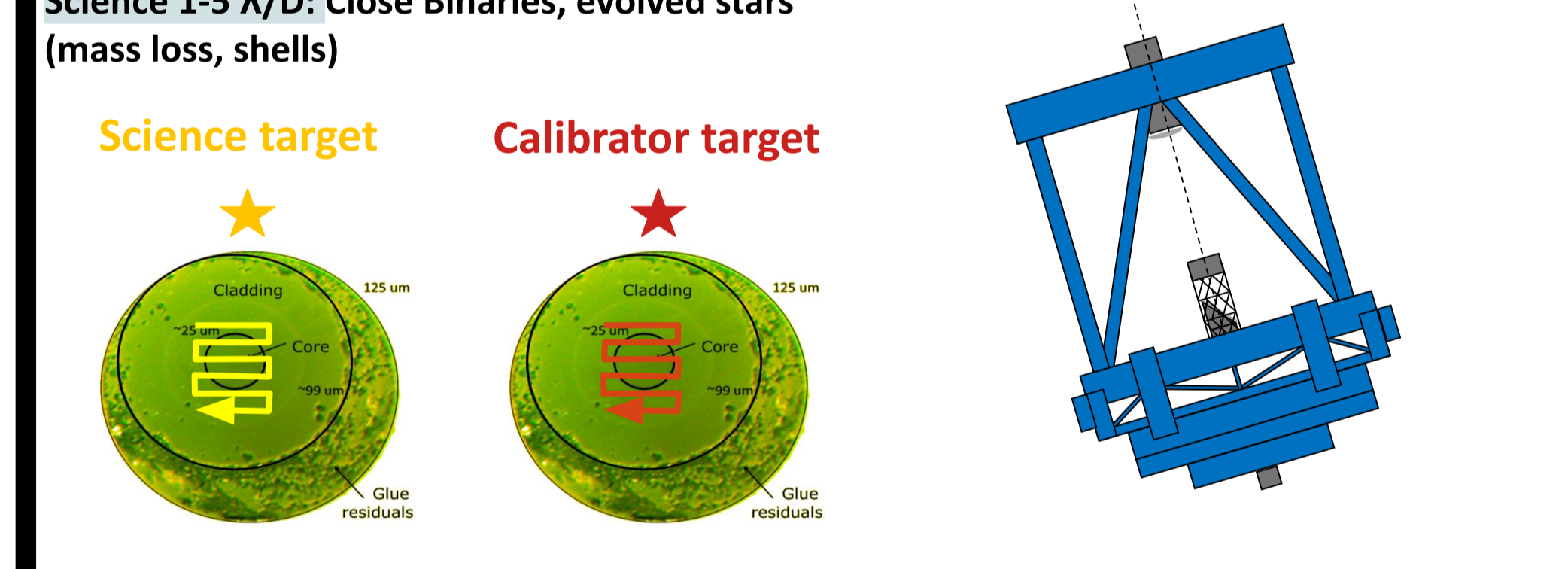


Required data:

- PL data with modulation on Science target
- PL data with modulation on a Calibrator target

Principle: the spatial modulation provides the diversity required to reconstruct the PL spatial response, estimated on the calibrator target, and applied on the science target to reconstruct the image.

Science 1-5 λ/D : Close Binaries, evolved stars (mass loss, shells)

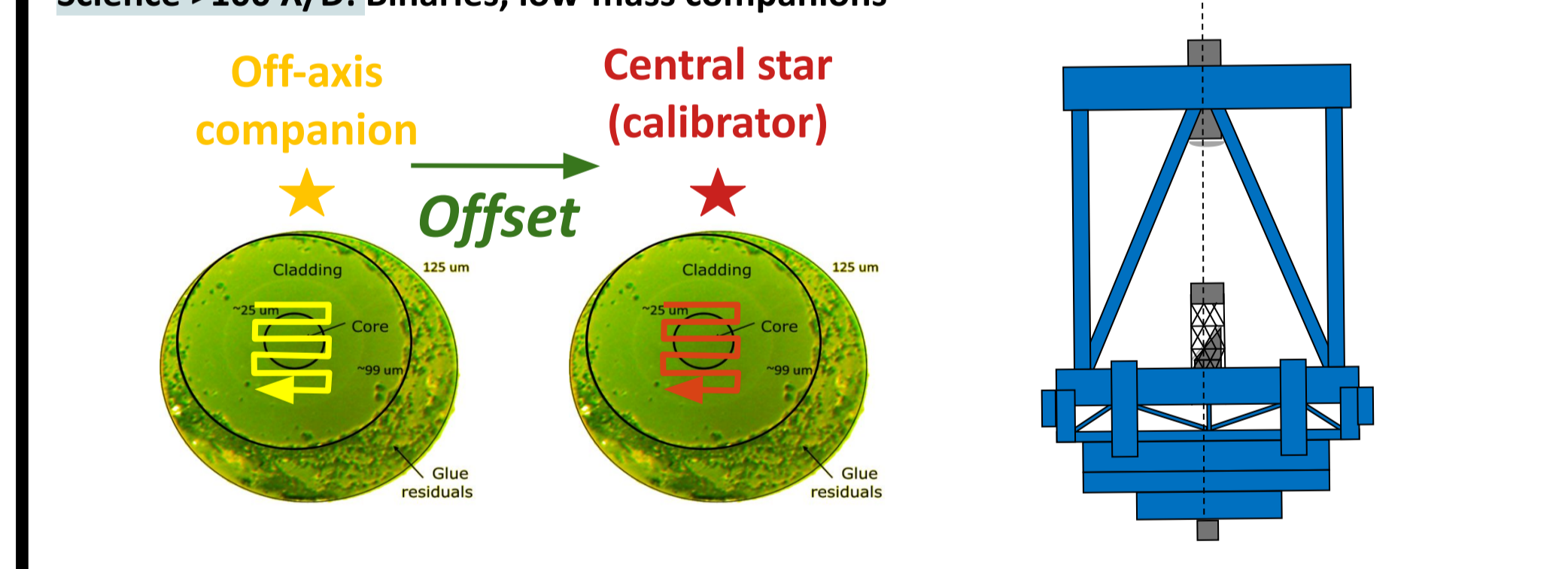


Required data:

- PL data with modulation on off-axis companion
- PL data with modulation on central star

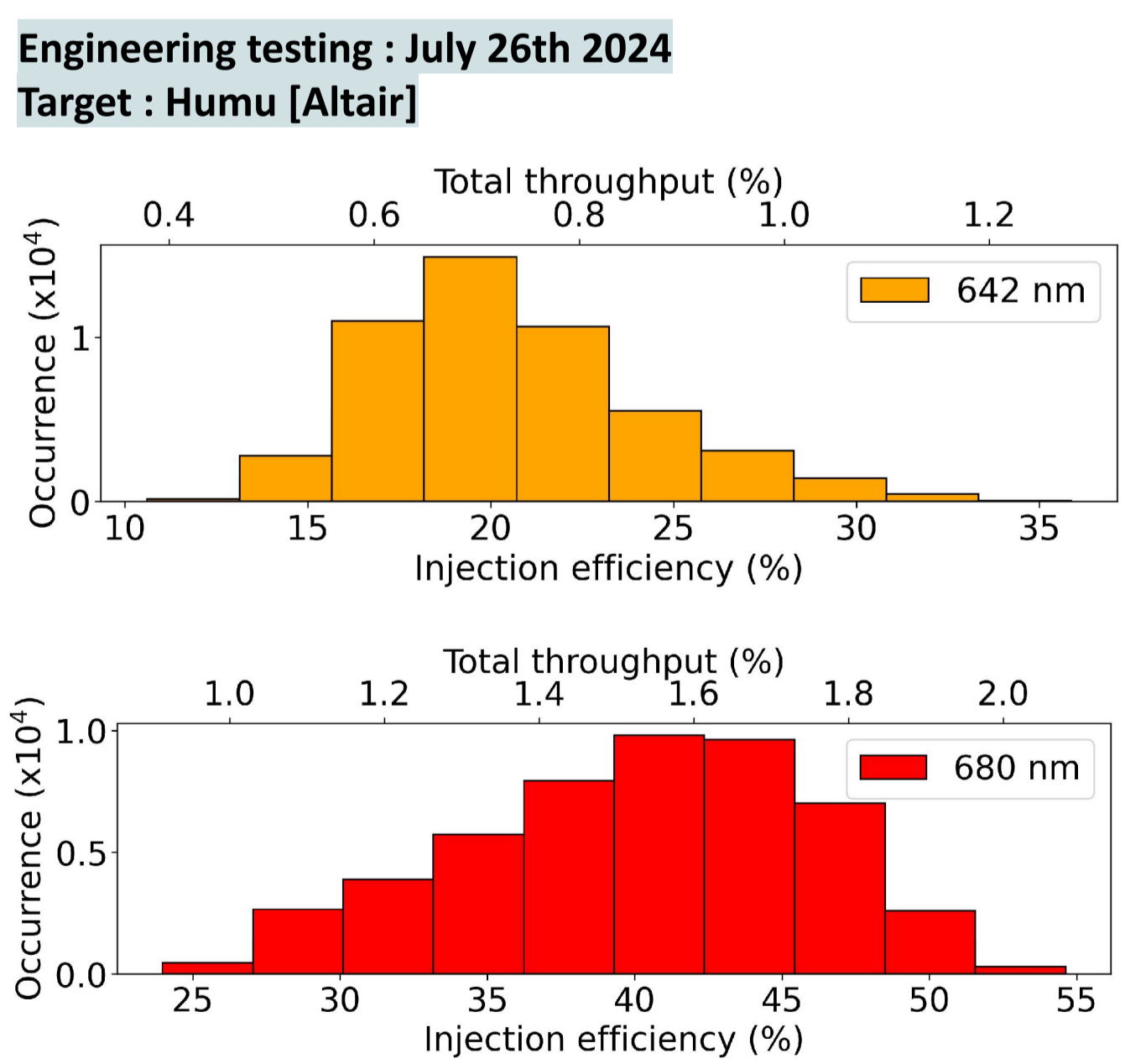
Principle: the spatial modulation provides the diversity required to reconstruct the PL spatial response, estimated on the central star, and applied on the off-axis companion to reconstruct the image.

Science $>100 \lambda/D$: Binaries, low-mass companions



FIRST-PL on-sky

Instrument efficiency



Spectro-astrometry

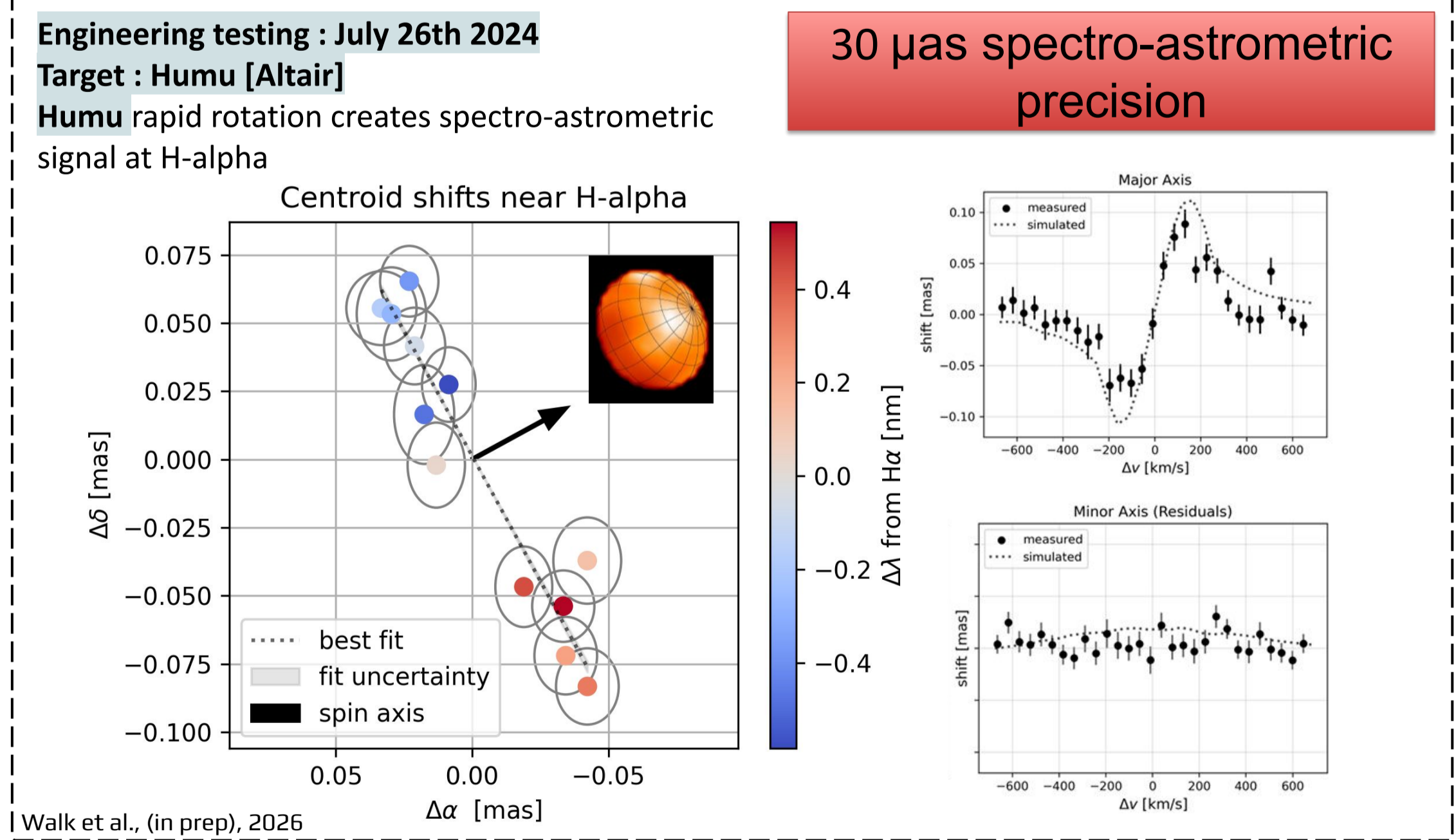
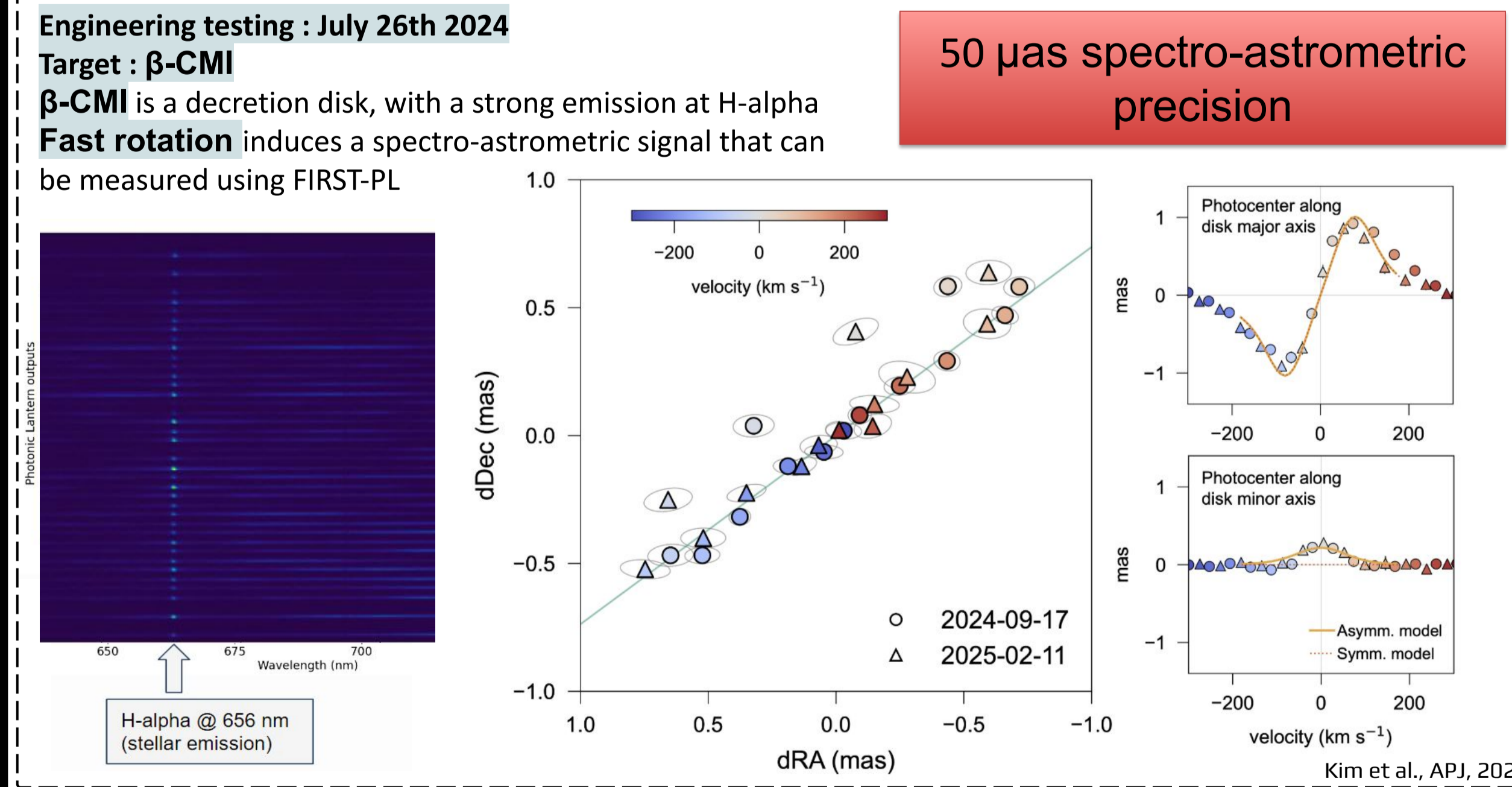
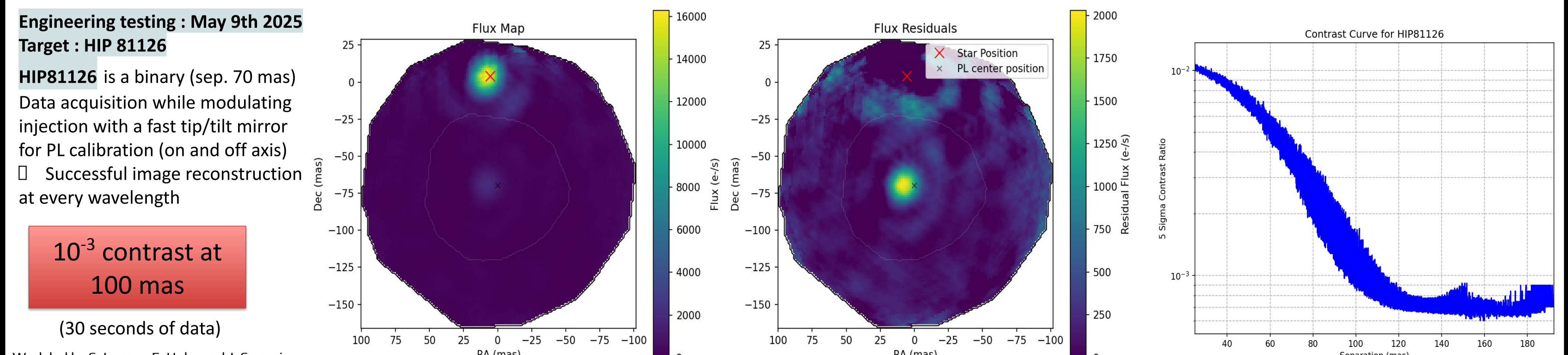


Image reconstruction



Conclusion / Perspectives

- FIRST-PL: Open for science starting S26B**
- First Photonic Lantern commissioned for sub-diffraction limit science
 - Two programs accepted
- On-sky performance validated**
- Three operational modes demonstrated
 - Spectroastrometry : 30-50 μ as precision
 - Image reconstruction : 20 mas resolution
 - High contrast imaging : >1000 contrast at 100 mas (HIP 81126)
- Future developments**
- Data reduction on fainter objects
 - New R~60,000 mode in development
 - Integrated wavefront sensing (AO loop, PSF reconstruction, Low Wind Effect)
- Leon-Saval et al., Optics Letters, 2005 | Norris et al. Nature, 2020
Kim et al., ApJ, 2024 | Huby et al., SPIE, 2024 | Vievard et al., A&A, 2024
Kim et al., ApJ, 2025