"Improving the performances of current optical interferometers & future designs"
International colloquium at Haute-Provence Observatory, France
23-27 September 2013

On-axis, off-axis fringe-tracking, and narrow-angle astrometry with KI/ASTRA

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Credits:
- W. M. Keck Observatory
- National Science Foundation
- National Aeronautics and Space Administration Jet Propulsion Laboratory
- NASA Exoplanet Science Institute
- University of Michigan
- University of Arizona

Timeline:
- July 2006: Project started with NSF grant
- April 2008: First light for on-axis fringe tracking
- December 2009: First light for off-axis fringe tracking
- July 2012: First light for LGS AO + IF
- August 2012: Sweet dreams!

1 Self Phase Referencing

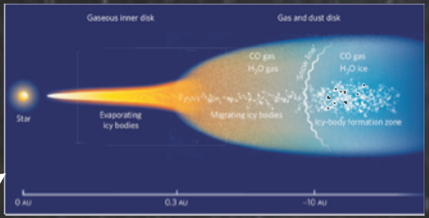
K<8 limit
R~2000

2 Dual Field Phase Referencing

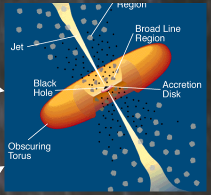
K<8.5 reference
K<15 science

3 Astrometry

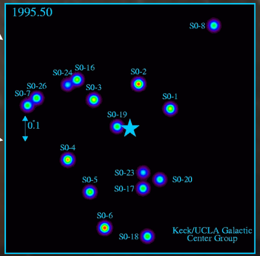
30μ˝ for
30˝ separation



Young Stellar Objects
Chemical Composition at R~2000



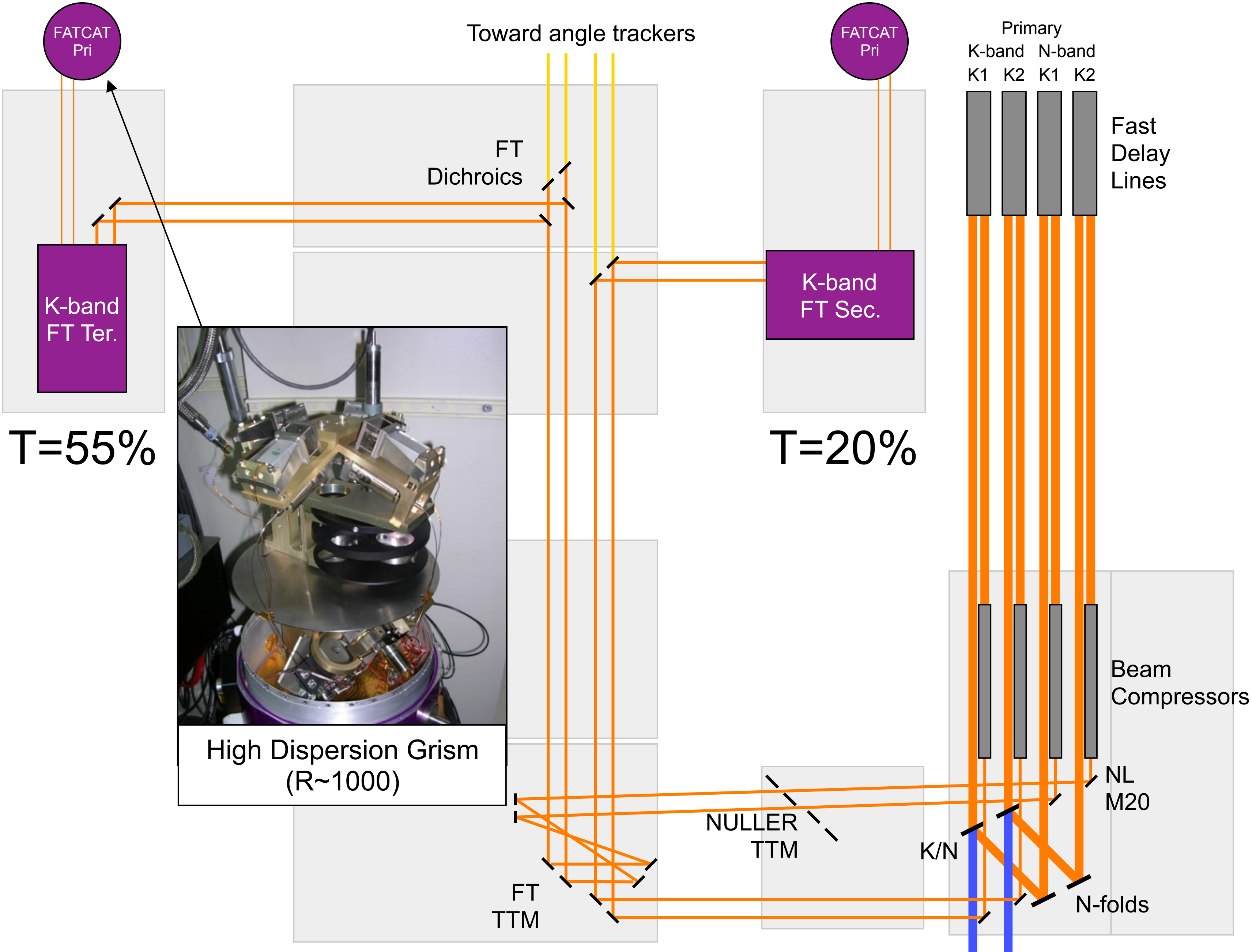
Active Galactic Nuclei
Chemical Composition
Increased Sample



Galactic Center
Stellar Population
BH mass
and GR effects

Exoplanets
Reflex Motion of
Multiple Planet Systems

On-axis fringe tracking (1/3)



On-axis fringe tracking (1/3)

Spectro-astrometric precision

- Shown to follow photon noise model for bright objects
- Achieved 1.7 mrad ~ 1.45 uas

Demonstrated limiting magnitude

- K = 7.8
- Upgrading the Fringe Tracker vs Spectrometer to 90/10: K=9.4

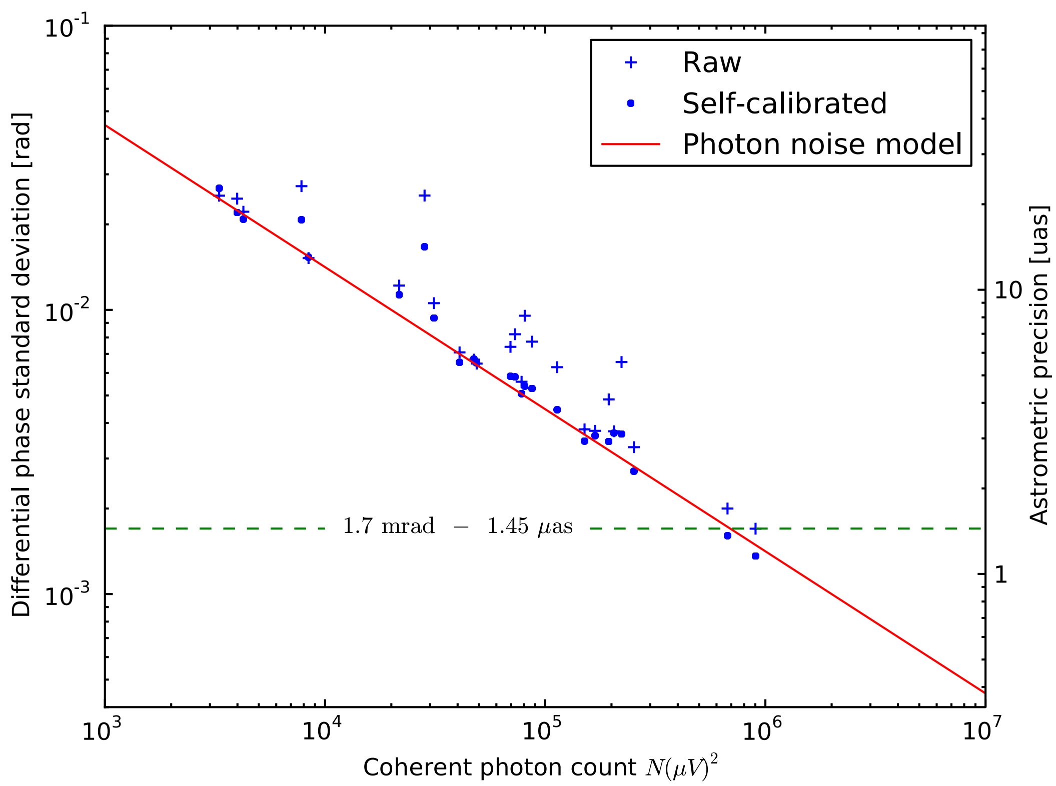


FIG. 8.—Average differential-phase standard deviation vs. total photon count. The self-calibrated average differential phase follows the overlaid photon-noise model, whereas the raw average differential phase shows a slightly higher level of noise, but without any noise floor, implying that longer data collection intervals should yield precisions better than the demonstrated ± 1.7 mrad or ± 1.45 μas differential astrometry. See the electronic edition of the *PASP* for a color version of this figure.

Woillez+ 2012PASP..124...51W

On-axis fringe tracking (1/3)

Observation of Be star 48 Lib

- Brγ detection, with δV^2 and $\delta\Phi$ effects
  => Rotating disk
- Pfund serie
  => One-armed over-density

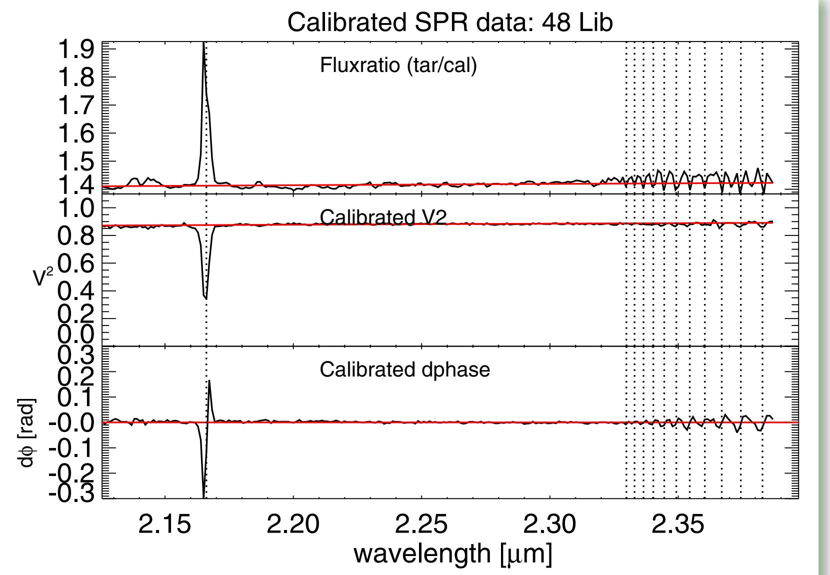
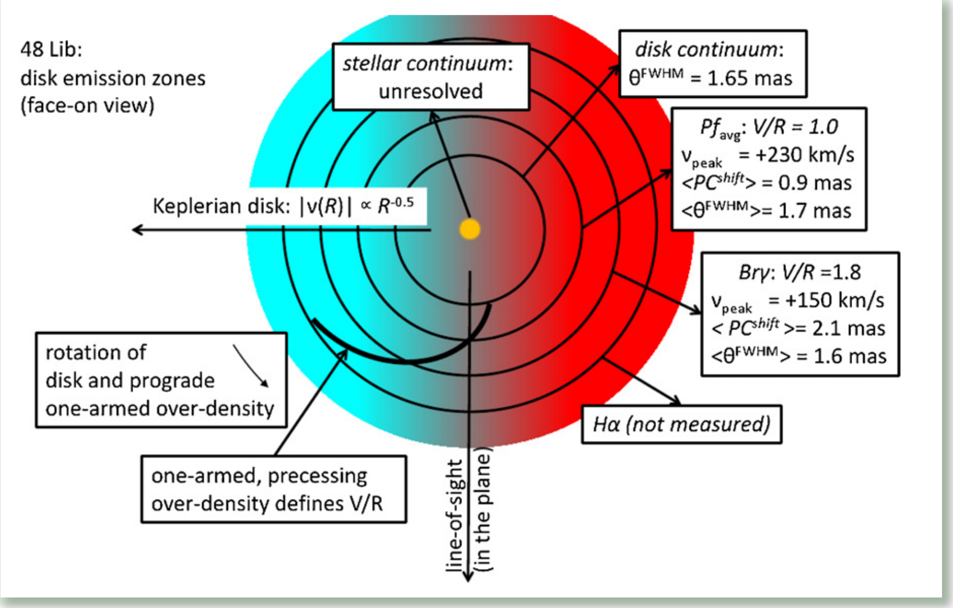
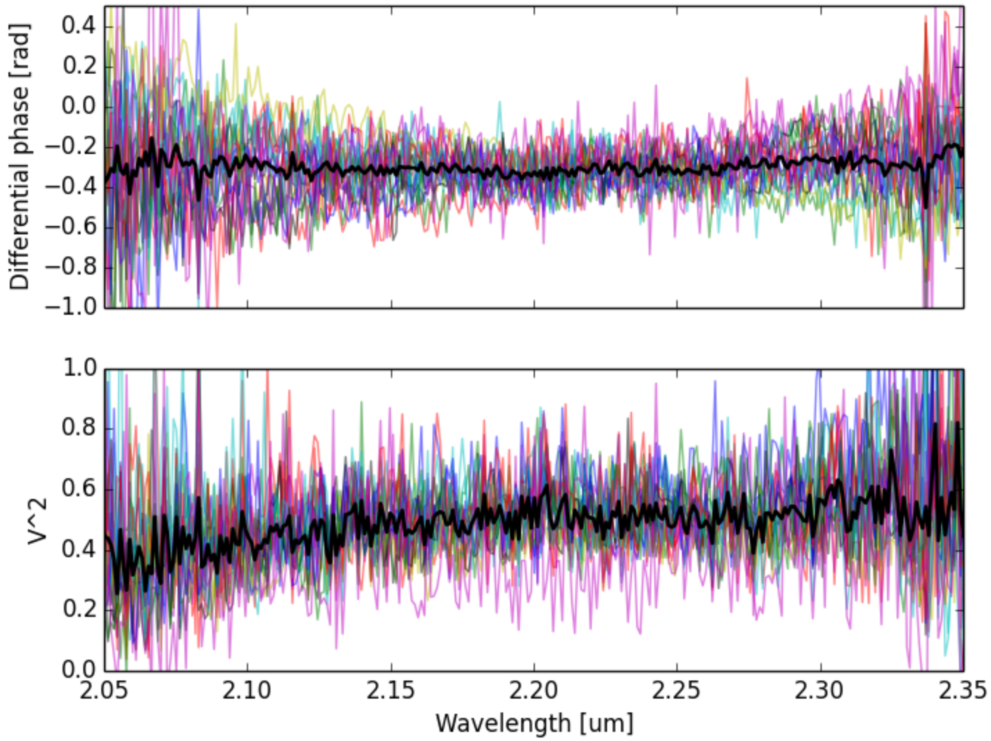


Figure 1. Top: mean calibrated flux ratio between 48 Lib and the continuum divided calibrator. The red solid line marks a linear continuum fit. The different line profiles of Br γ- and Pf-emission lines are clearly visible. Center: mean calibrated V^2 of 48 Lib showing that both the NIR continuum and the recombination line emission are spatially resolved by the interferometer. A linear continuum (red line) was fitted to the line-free regions. Bottom: calibrated differential phase data. The red line marks the zero phase. All plots show the rest wavelength of the target. The vertical dotted lines indicate the rest wavelength of the recombination lines. It is apparent that all lines show the same slope at the line center, as expected for disk emission.

Pott+ 2010ApJ...721..802P



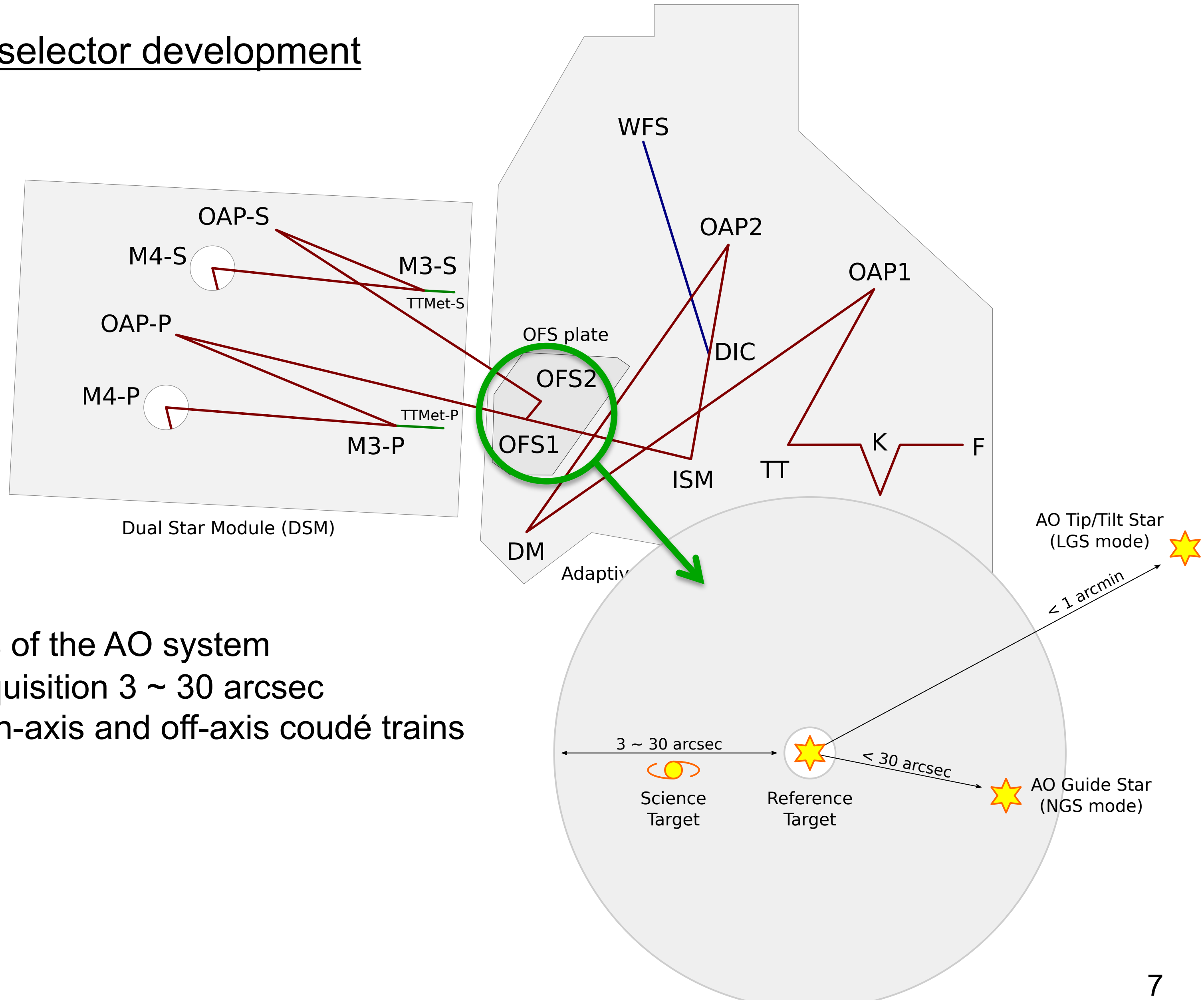
On-axis fringe tracking (1/3)



Non detection at 0.05 rad, 17.5 nm, 42 uas, in 45 minutes on NGC 4151

Off-axis fringe tracking (2/3)

Off-axis field selector development

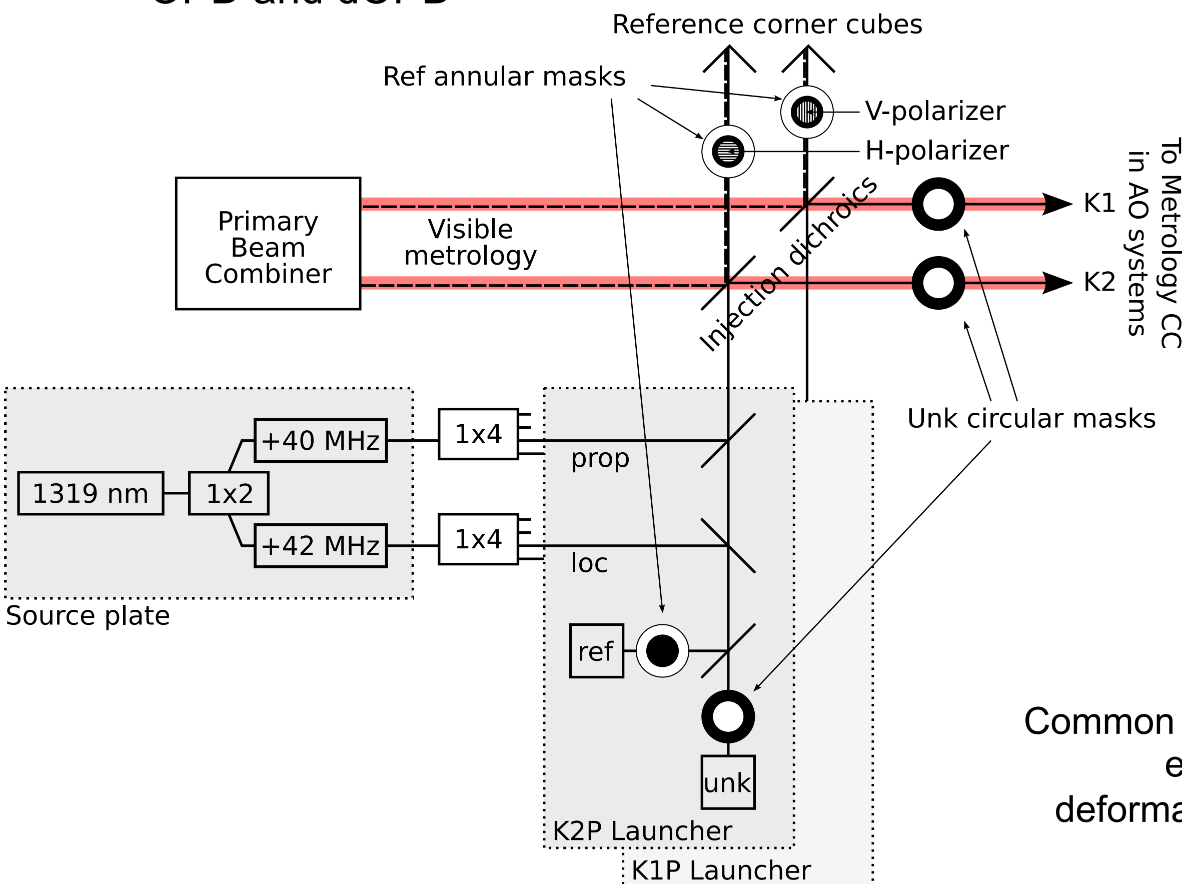


- At the focus of the AO system
- Off-axis acquisition 3 ~ 30 arcsec
- Beams to on-axis and off-axis coudé trains

Off-axis fringe tracking (2/3)

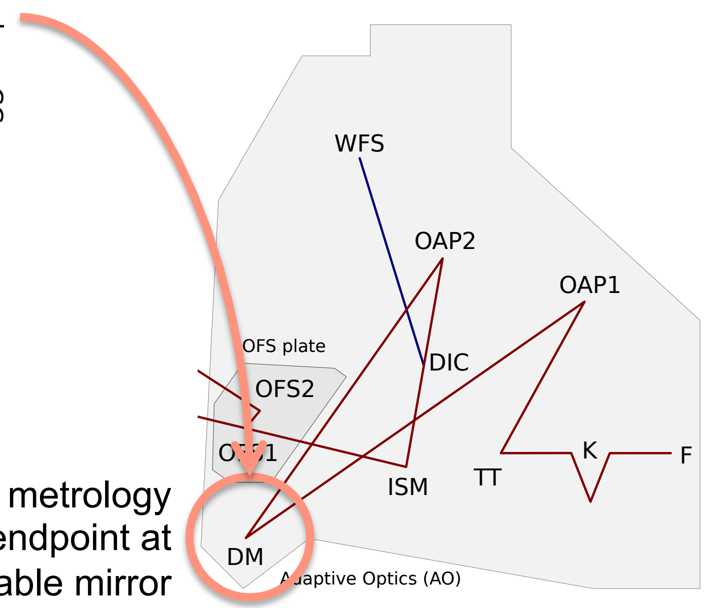
Full non-common path metrology

- Dimensioned for astrometry
  - Zero dOPD with non-stabilized λ = 1319 nm
  - Sidereal dOPD with stabilized HeNe 633 nm
  - Very low cross-talk (with spatial masks)
- OPD and dOPD



Telescope accelerometers

- For full OPD coverage but…
- …missing M2 mirror!

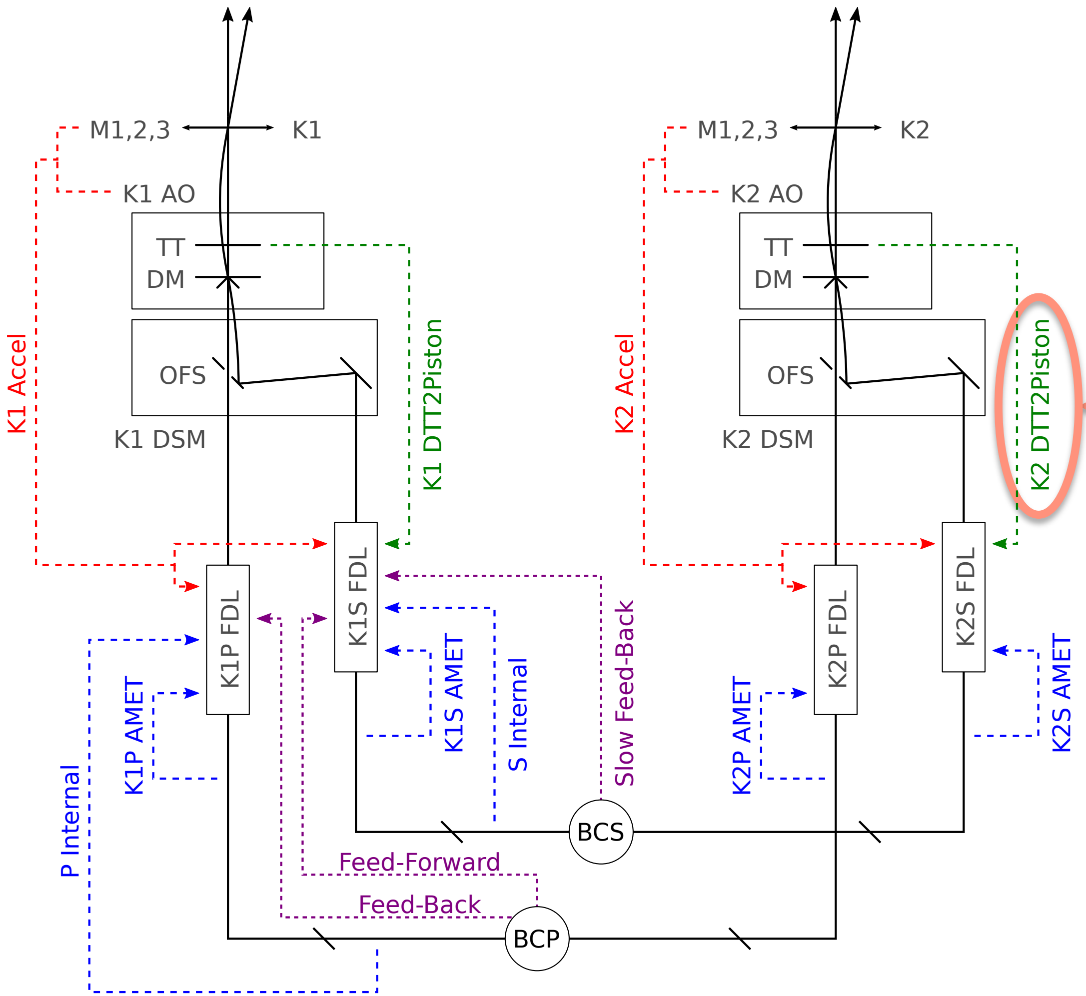


Common metrology endpoint at deformable mirror

Off-axis fringe tracking (2/3)

<u>We needed one more active system!</u>

- It would have been too simple without it…

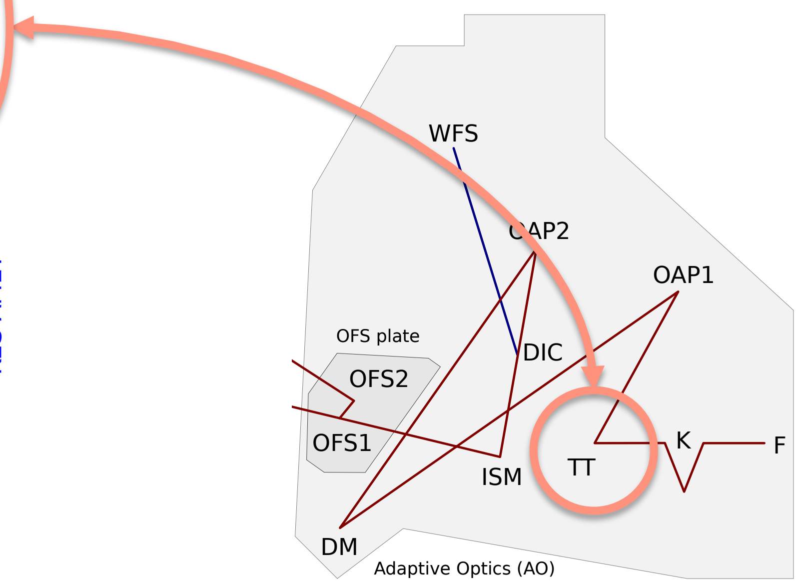


Version ΔOPD_{int}

The TT mirror is not in a pupil, PS and SS have different impact on it, TT motion causes differential internal OPD fluctuations.

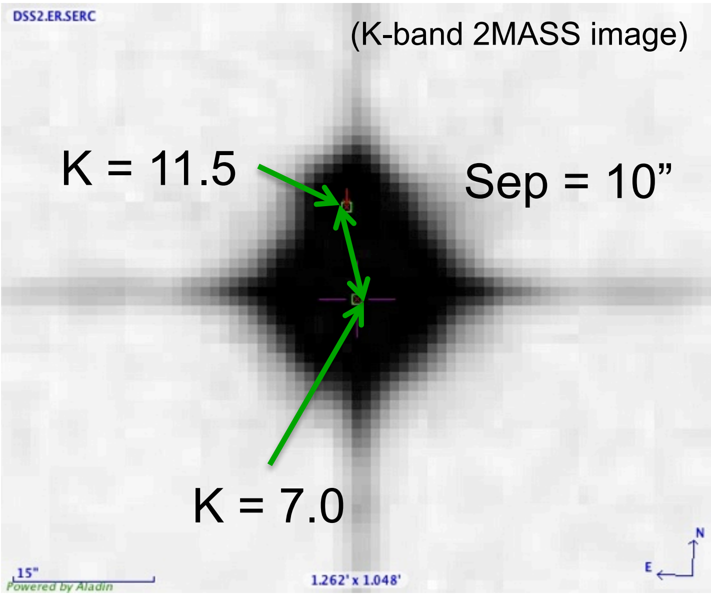
Version ΔB_{NAB}

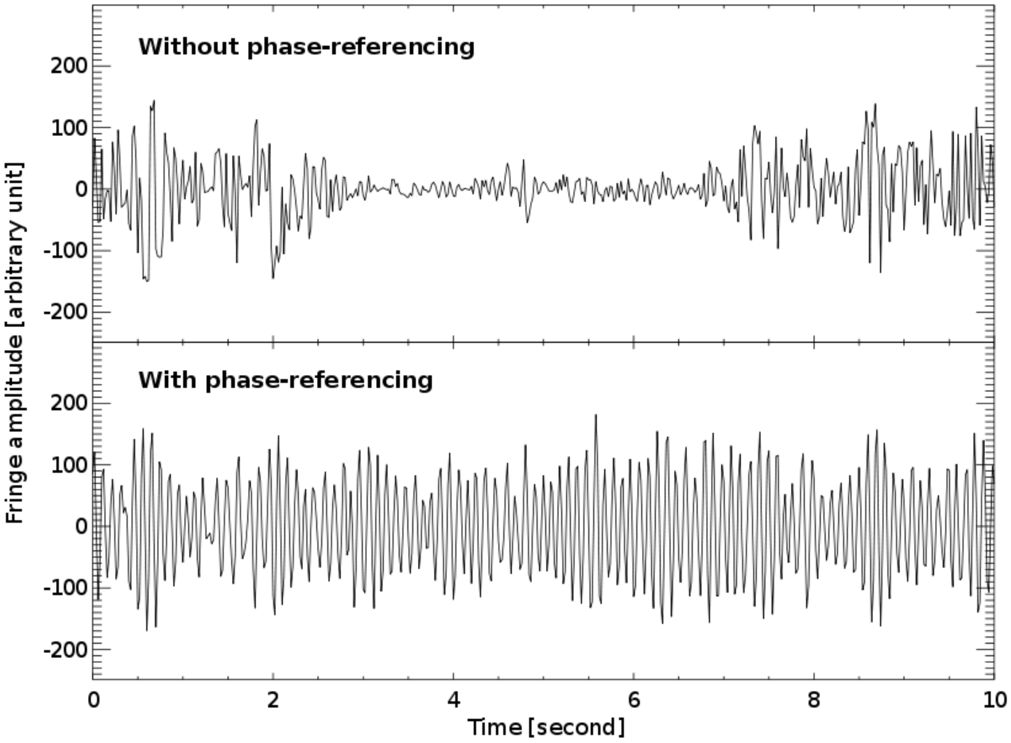
The TT mirror is not in a pupil, the primary space conjugate of the Narrow Angle Baseline changes with the TT motion, which induces a differential internal OPD fluctuation.



Off-axis fringe tracking (2/3)

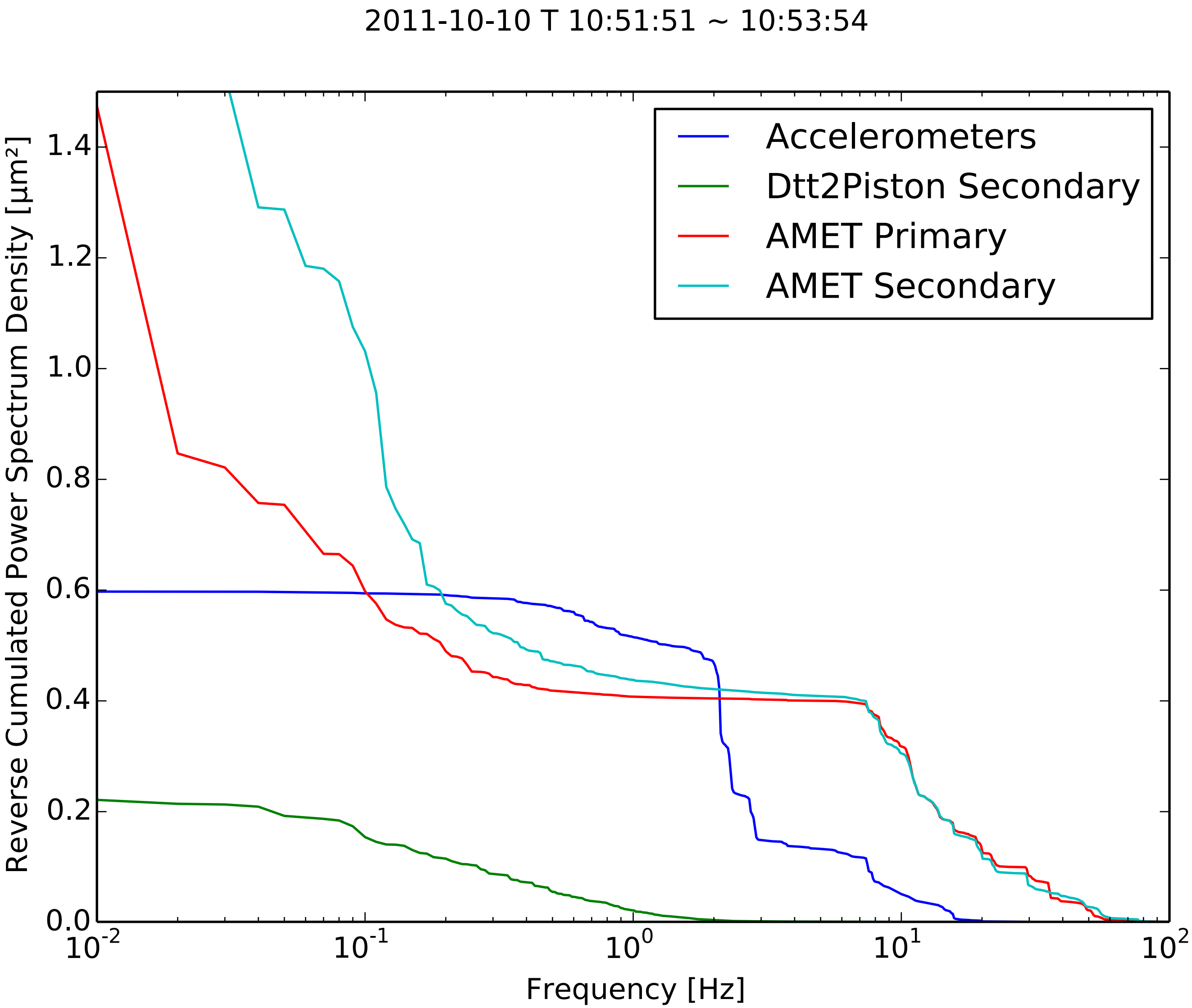
January 22, 2011: K=11.5





Off-axis fringe tracking (2/3)

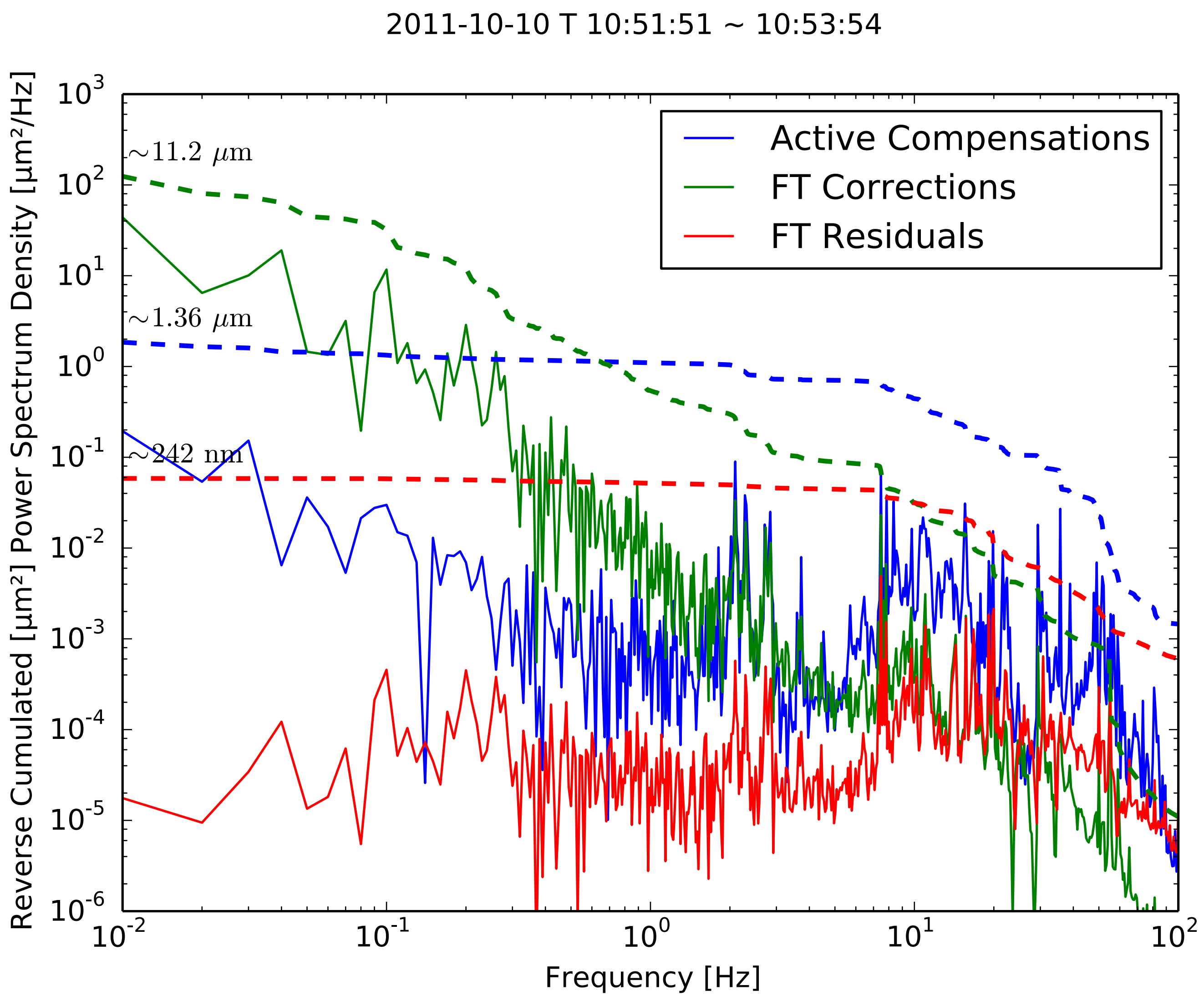
To get rid of as many unwanted instrumental disturbances as possible…



Off-axis fringe tracking (2/3)

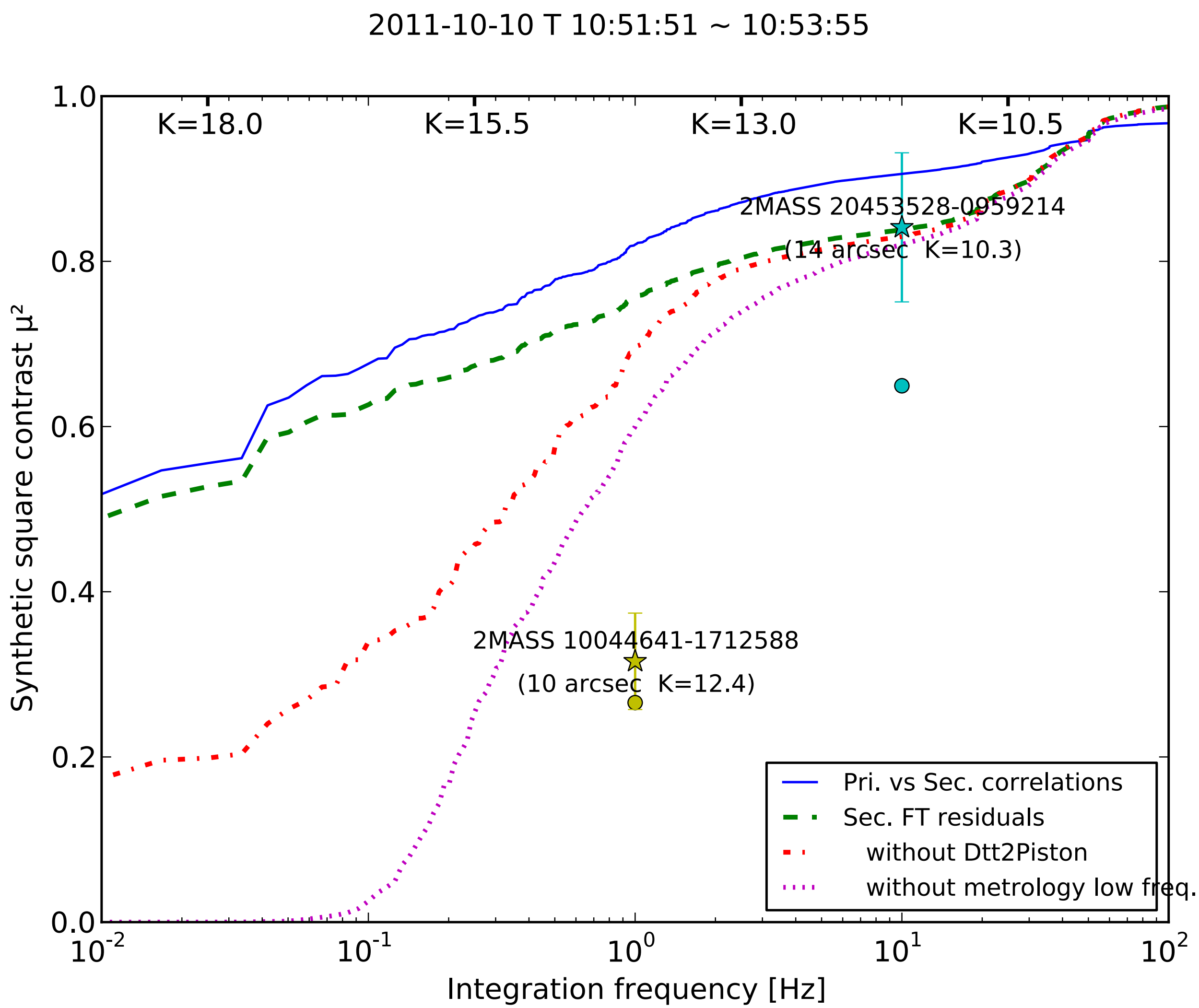
To get rid of as many unwanted instrumental disturbances as possible…

<u>to make the bright fringe tracker close the loop...</u>



Off-axis fringe tracking (2/3)

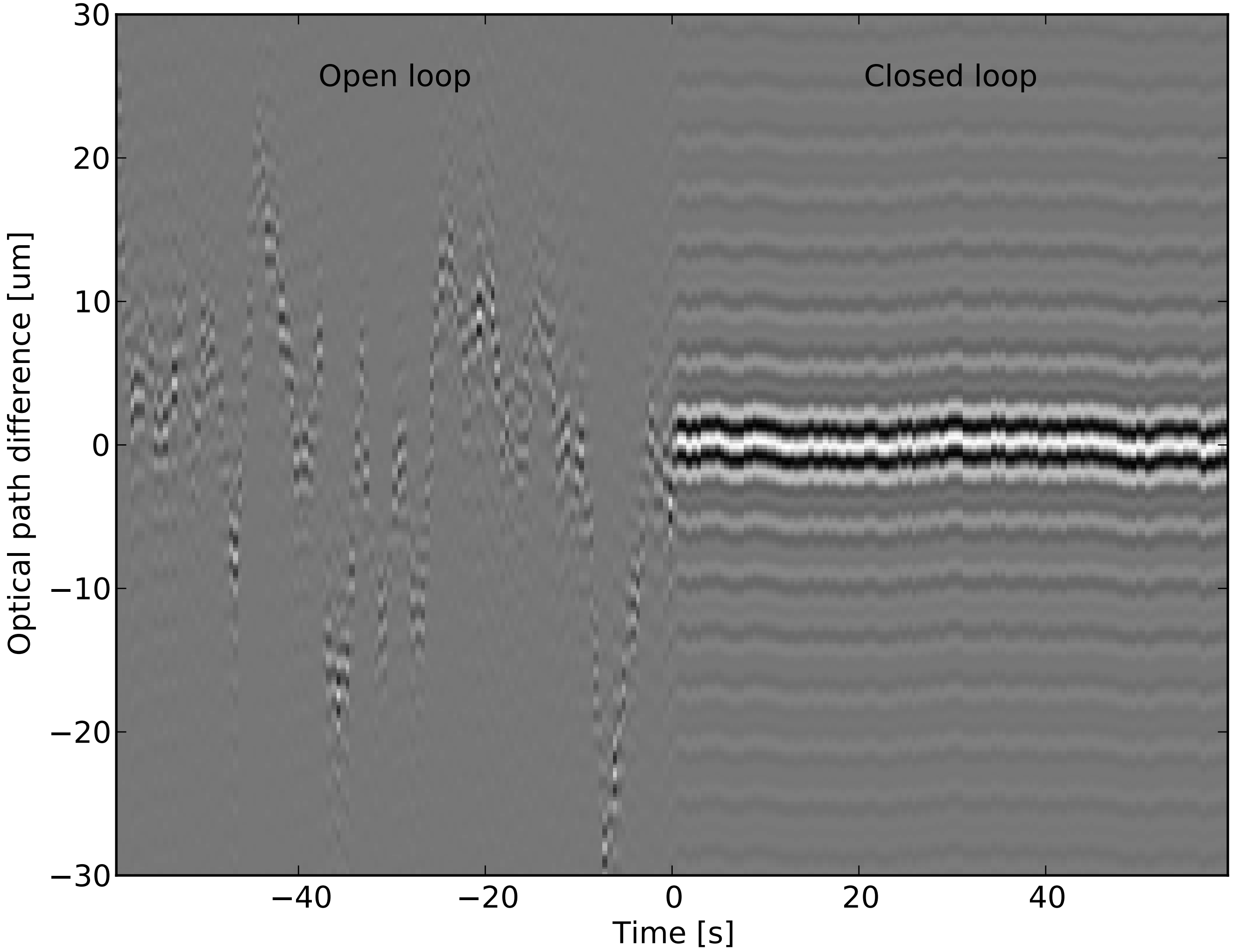
To get rid of as many unwanted instrumental disturbances as possible…
to make the bright fringe tracker close the loop...
<u>and provide a meaningful correction for the secondary target.</u>



Primary vs Secondary correlations on bright pairs, compared to faint observations.

Off-axis fringe tracking (2/3)

A little bit of PR (AO style) at 0.5 s integration period!

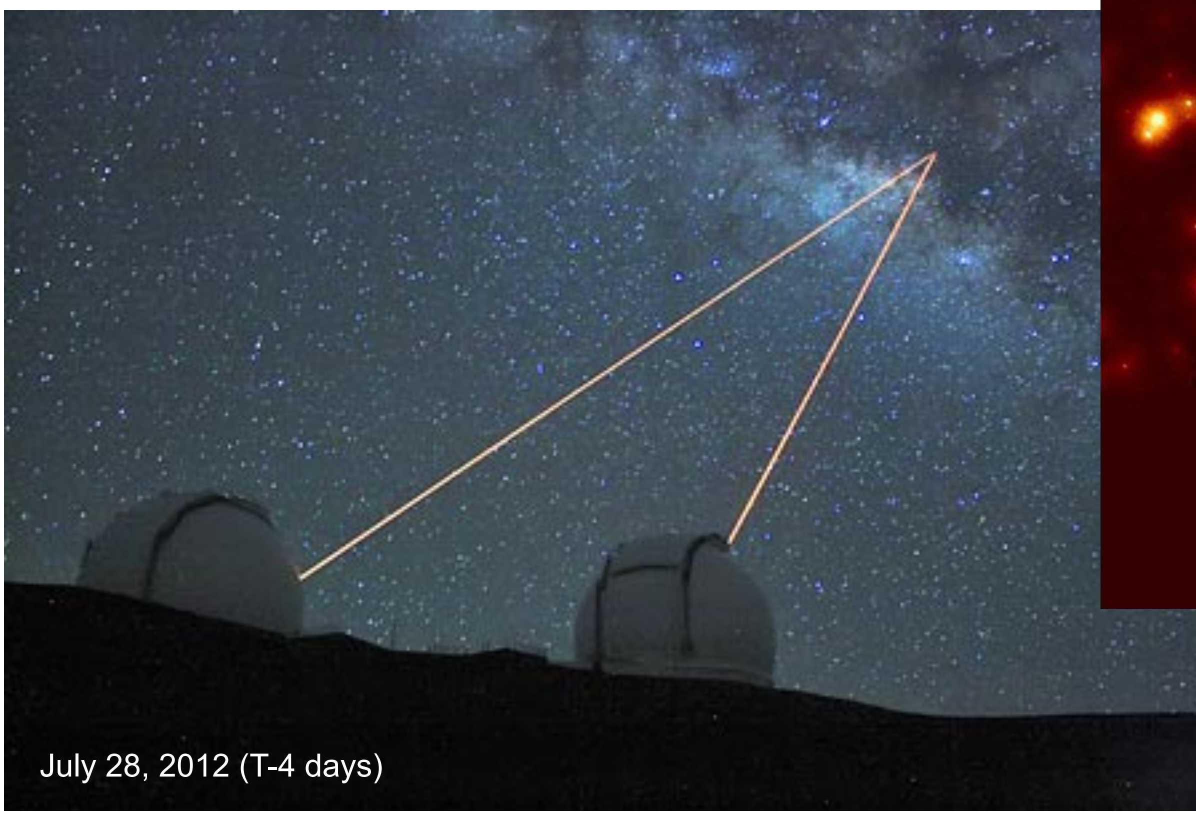


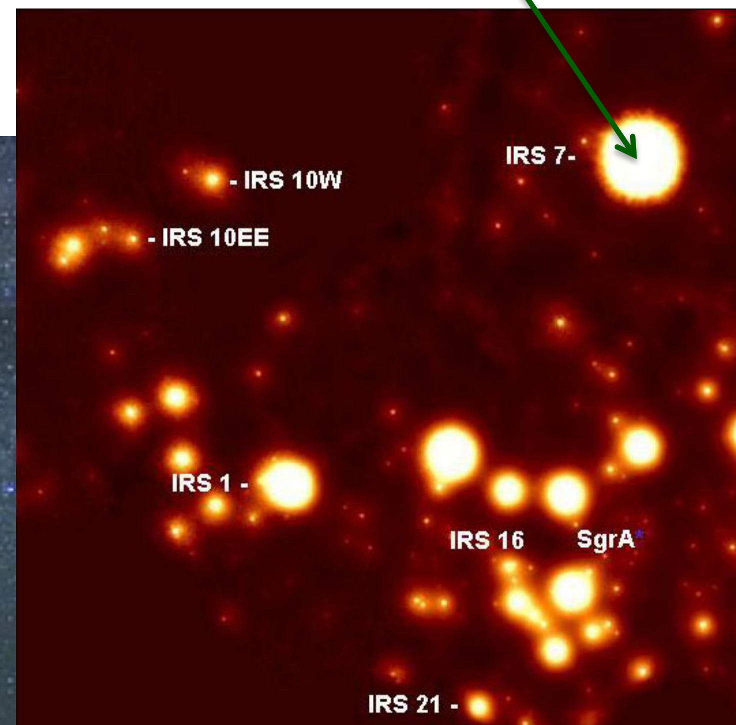
This was around the end of 2011, at T-6 months…

Off-axis fringe tracking (2/3)

R=13.8 tip tilt star 15.7” away
(USNO-A2.0 0600-28577051)

Two laser guide stars on galactic center
Recovered ideal Strehl ratio on GCIRS 7





Astrometry (3/3)

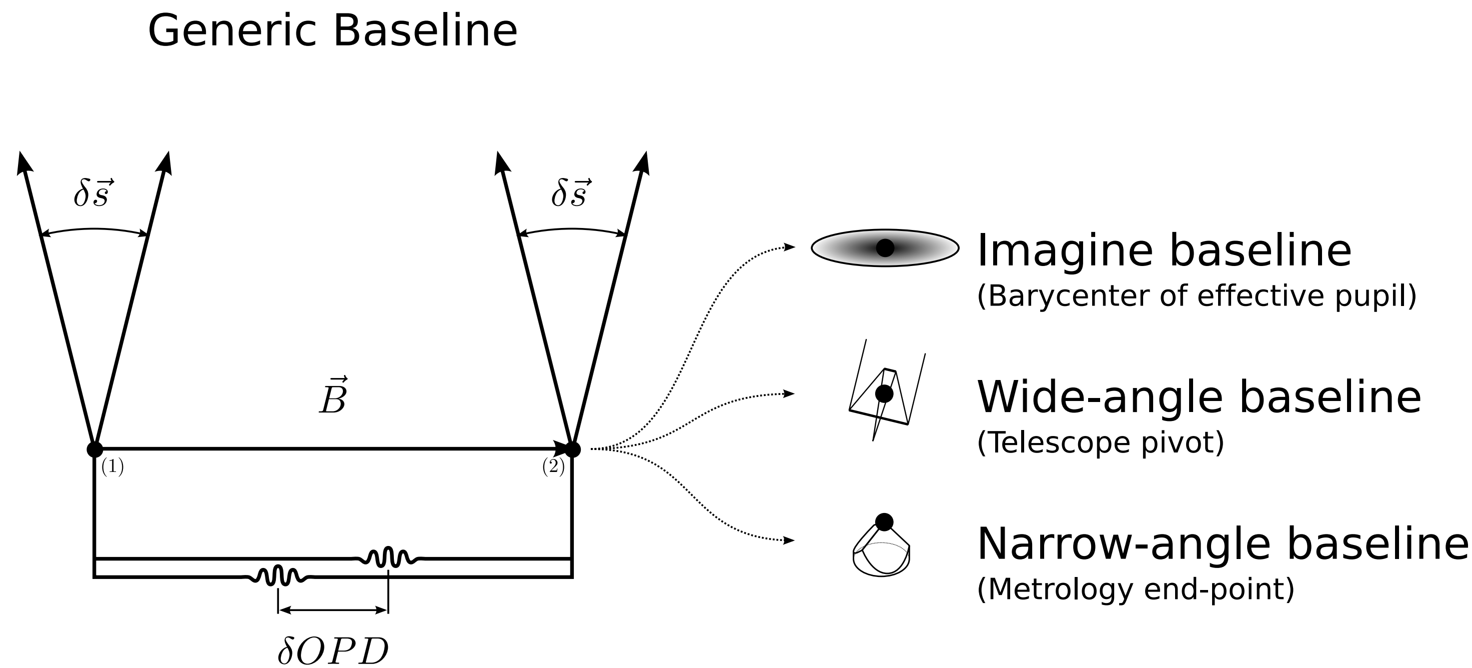


Figure 9. Illustrative unification of WAB, NAB, and IMB.

Woillez & Lacour 2013ApJ...764..109W

The Keck Interferometer

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ABSTRACT. The Keck Interferometer (KI) combined the two 10 m W. M. Keck Observatory telescopes on Mauna Kea, Hawaii, as a long-baseline near- and mid-infrared interferometer. Funded by NASA, it operated from 2001 until 2012. KI used adaptive optics on the two Keck telescopes to correct the individual wavefronts, as well as active fringe tracking in all modes for path-length control, including the implementation of cophasing to provide long coherent integration times. KI implemented high sensitivity fringe-visibility measurements at H (1.6 μm), K (2.2 μm), and L (3.8 μm) bands, and nulling measurements at N band (10 μm), which were used to address a broad range of science topics. Supporting these capabilities was an extensive interferometer infrastructure and unique instrumentation, including some additional functionality added as part of the NSF-funded ASTRA program. This paper provides an overview of the instrument architecture and some of the key design and implementation decisions, as well as a description of all of the key elements and their configuration at the end of the project. The objective is to provide a view of KI as an integrated system, and to provide adequate technical detail to assess the implementation. Included is a discussion of the operational aspects of the system, as well as of the achieved system performance. Finally, details on V^2 calibration in the presence of detector nonlinearities as applied in the data pipeline are provided.

Online material: color figures

Sweet dreams!