JPL

Palomar Testbed Interferometer (PTI)
&
Keck Interferometer (KI)

Mark Colavita

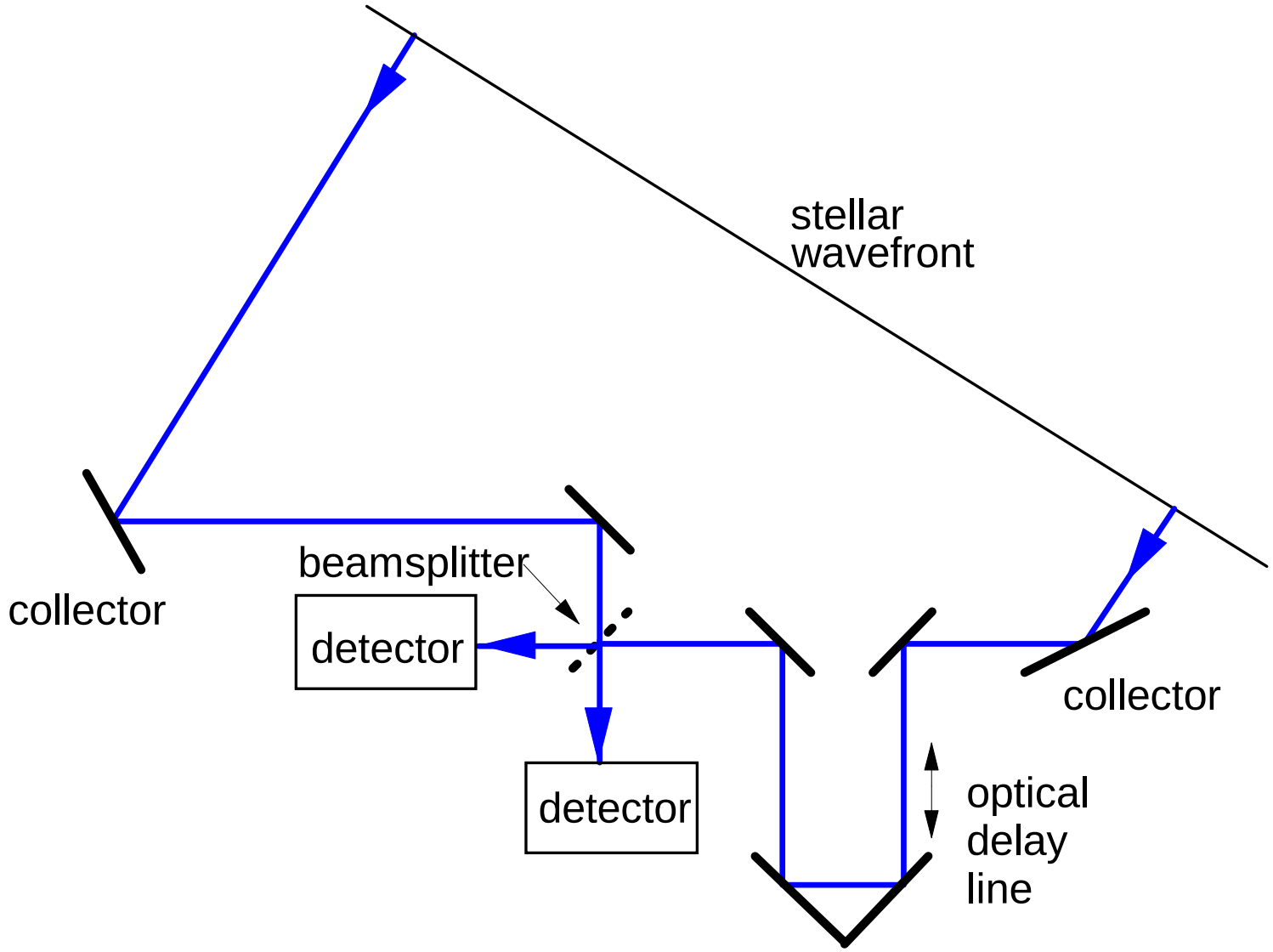
7/29/2005

Michelson Summer School

Pasadena, CA


PTI as seen from the catwalk of the 200” telescope

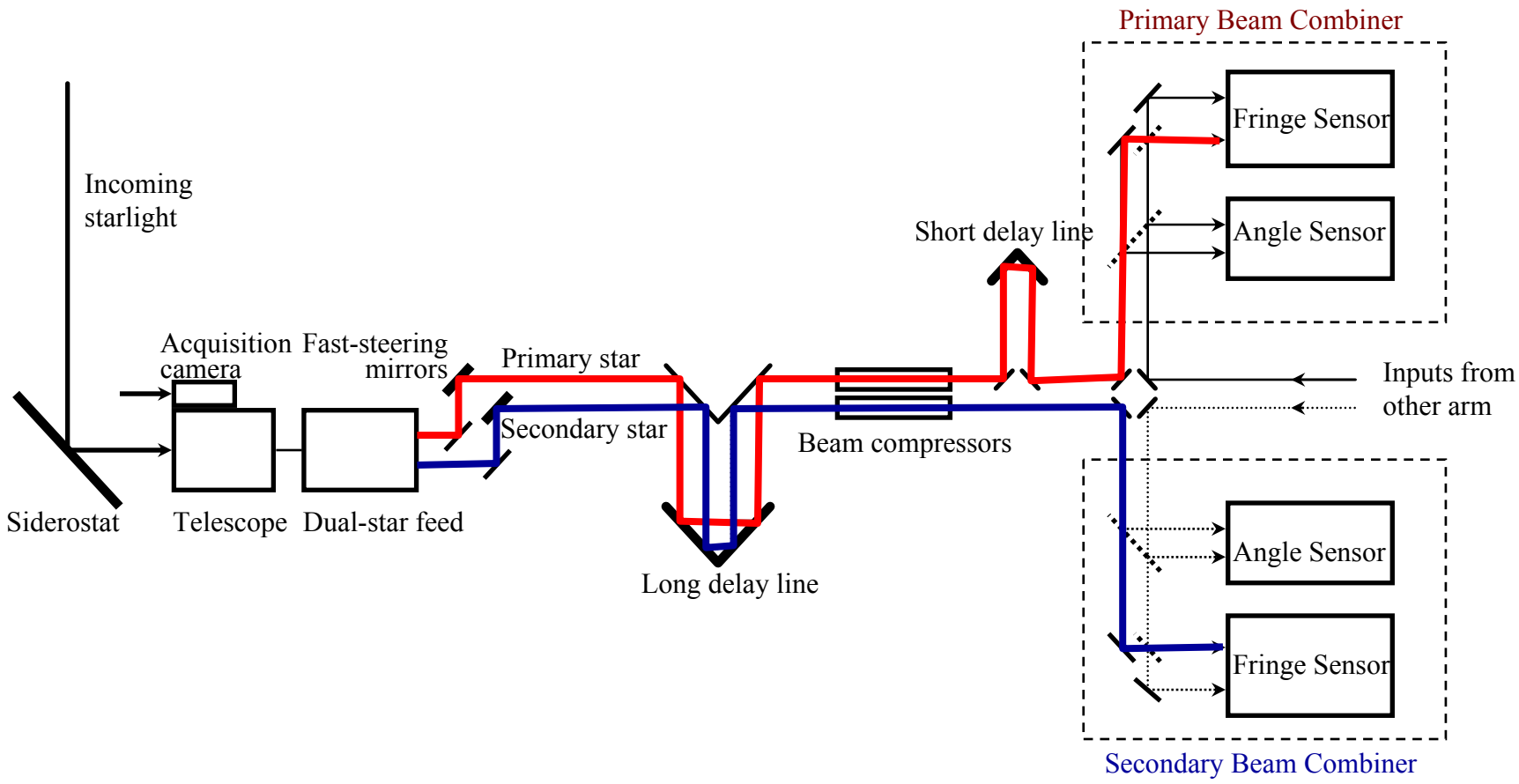
Michelson Interferometer



PTI Description

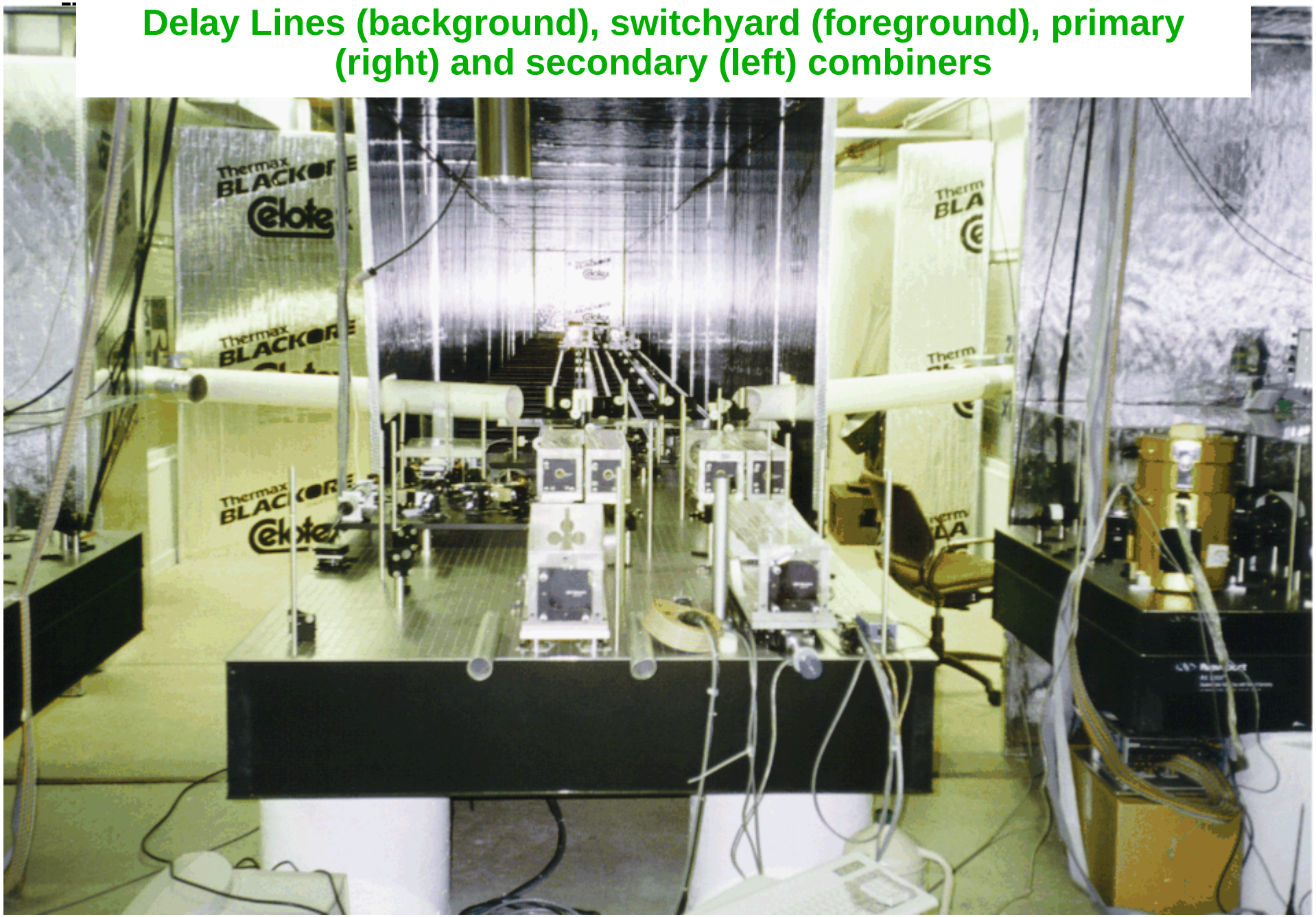
- NASA funded, tech dev. for Keck and other interferometers; first fringes 1995
- 2-way system, 110 m max baseline
- 40 cm collecting apertures
- Active broadband fringe tracking at K (2-2.4 mm) or H (1.5-1.8 mm)
- Angle tracking at R + I (0.7 – 1.0 mm)
- Single-beam capability for visibility and very-narrow-angle astrometry (<1”)
- Dual-beam capability for very-narrow-angle astrometry (1” - 1’)
- Refs: http://pti.jpl.nasa.gov; ApJ 510, 505 (1999)

PTI block diagram

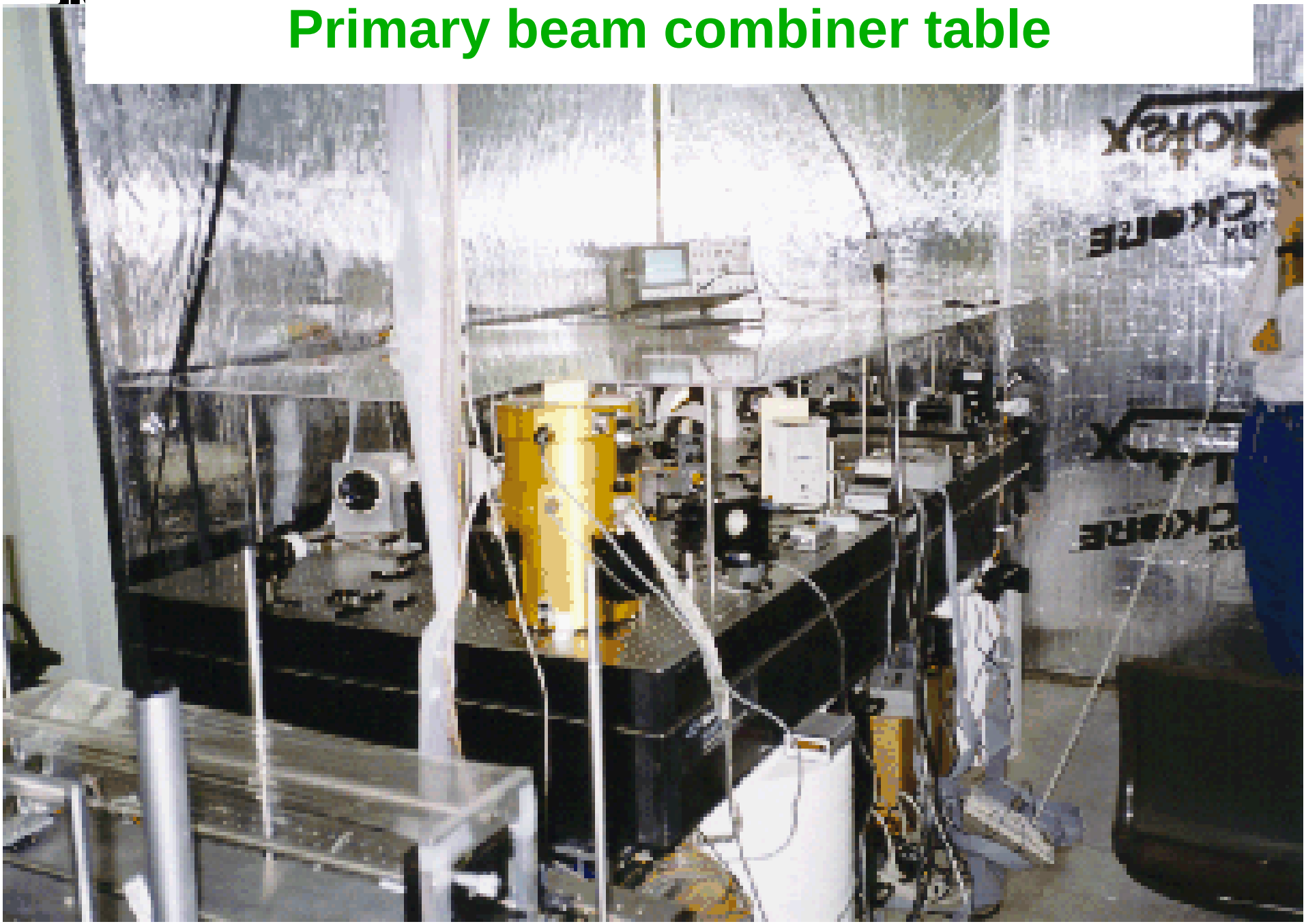


Siderostat & compressor

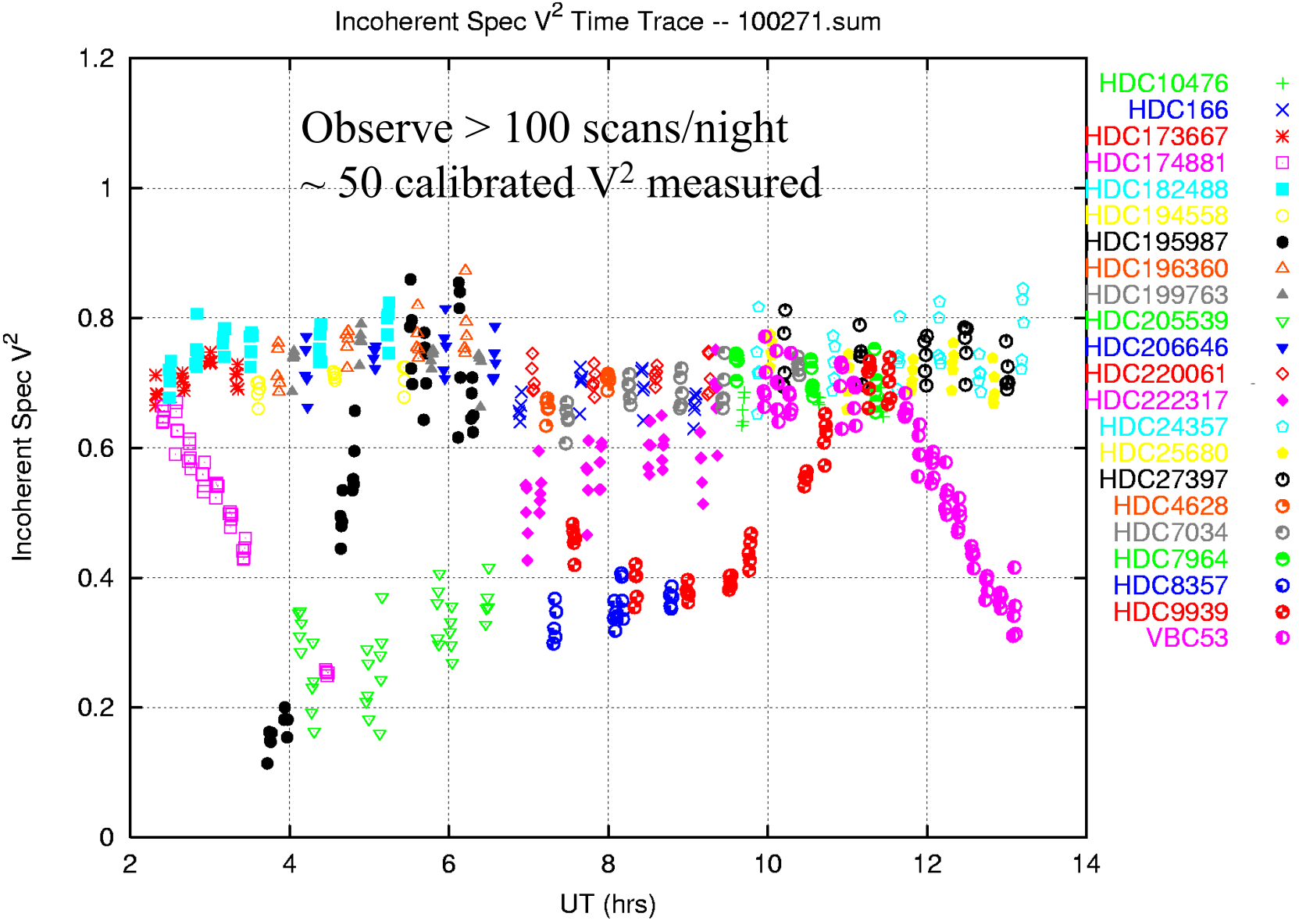
Delay Lines (background), switchyard (foreground), primary (right) and secondary (left) combiners



Primary beam combiner table

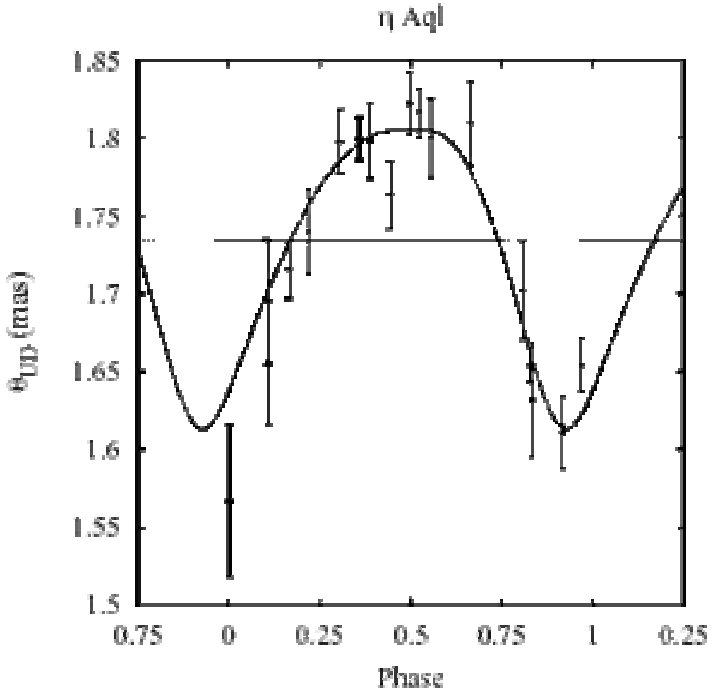


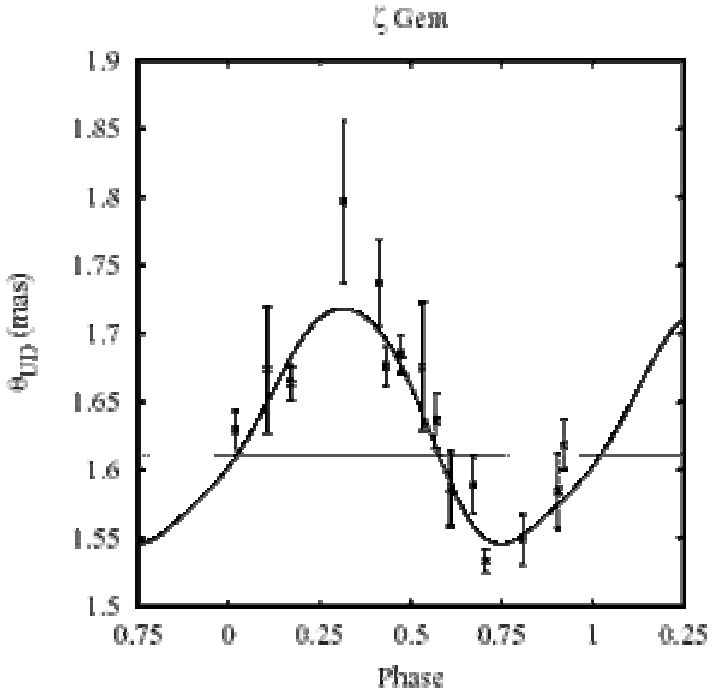
A "Typical" Night of PTI V^2 Data...



Cepheid Studies

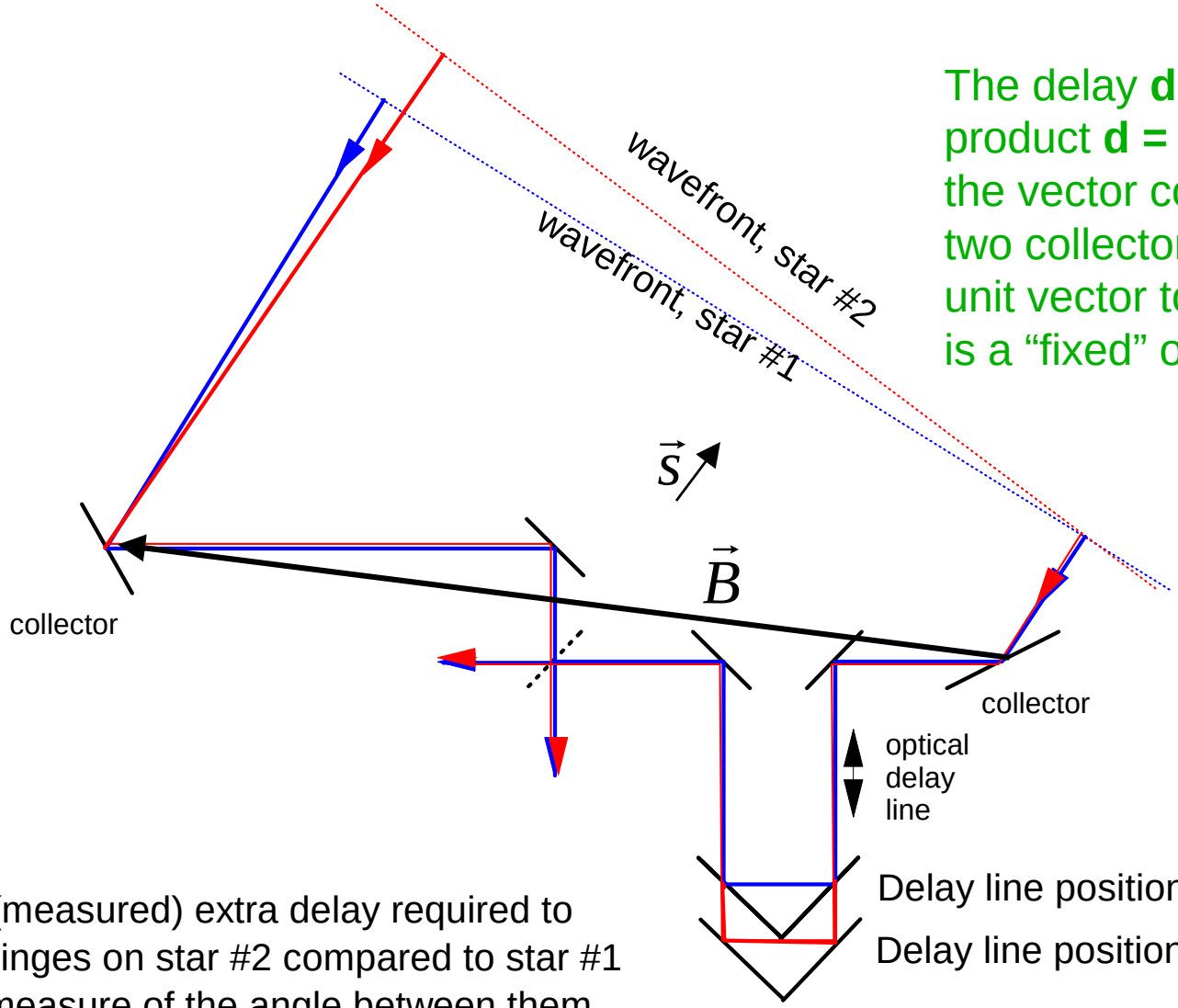
- PTI made the first direct detection of Cepheid pulsations
- Lane et al. 2002 Cepheid modeling combined PTI and NPOI data





Lane et al. 2000, Nature 407, 485
Lane et al. 2002, ApJ 573, 330

Astrometry with an Interferometer

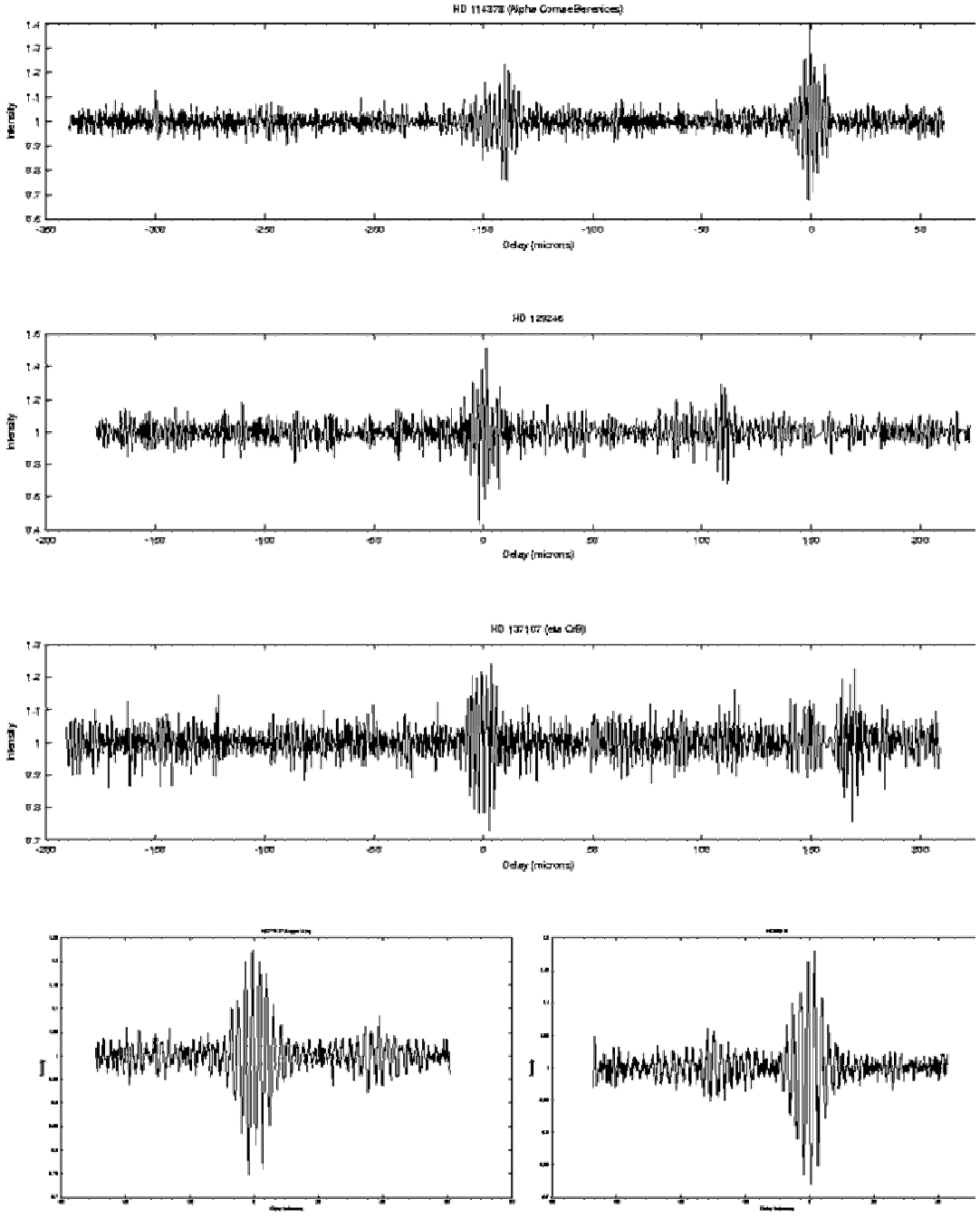


The delay **d** is the dot product **d = B·s + C** of the vector connecting the two collectors and the unit vector to the star; **C** is a “fixed” offset

The (measured) extra delay required to get fringes on star #2 compared to star #1 is a measure of the angle between them

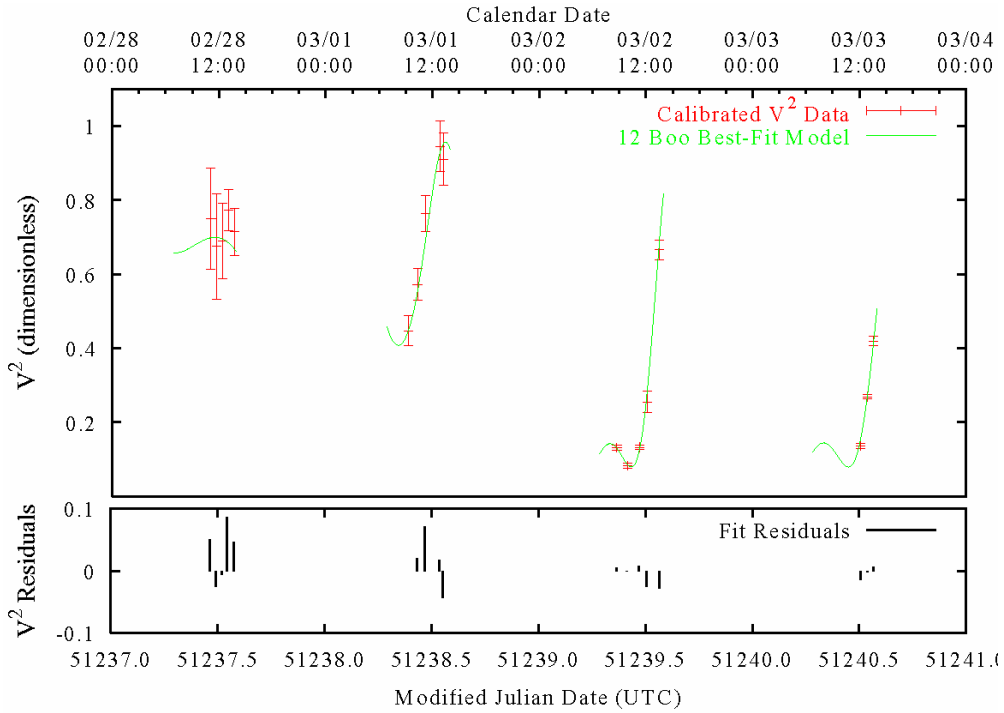
Single-Beam Astrometry

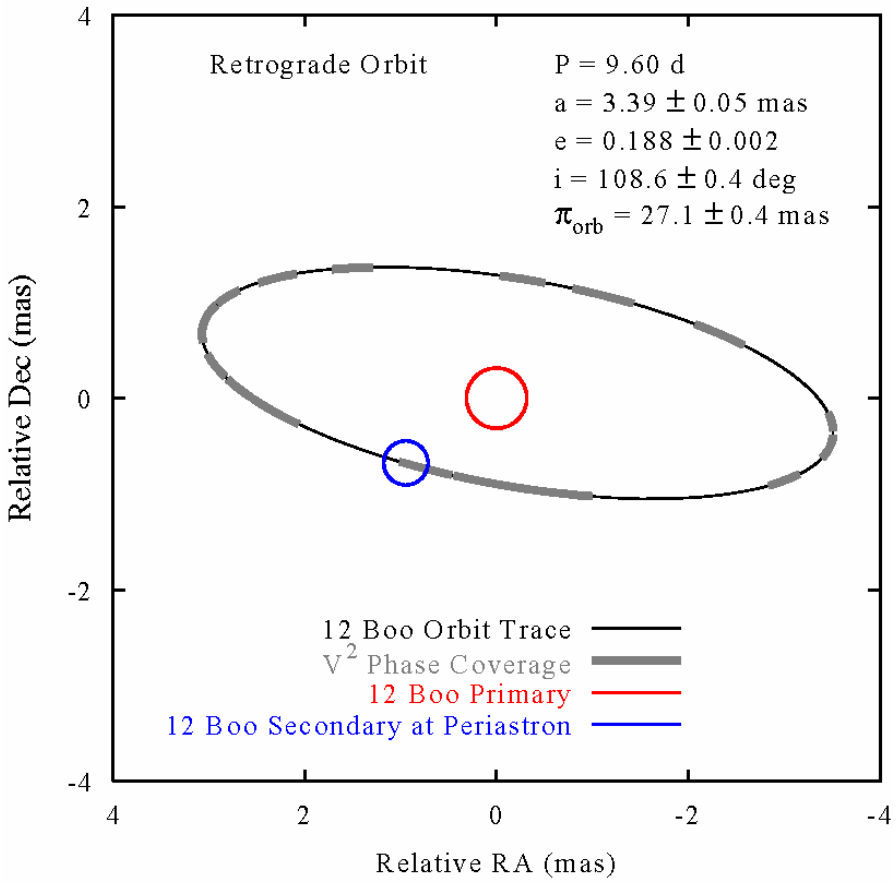
Fringe Scanning Examples

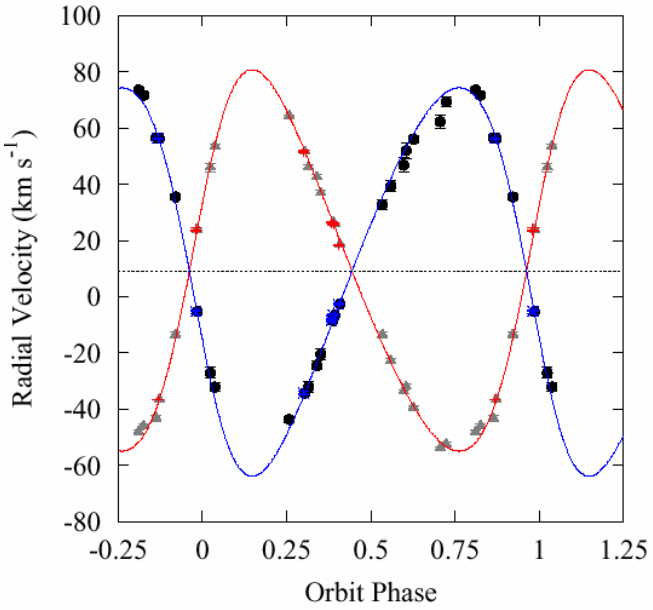


Images Courtesy
Of M. Muterspaugh

12 Boo Analysis

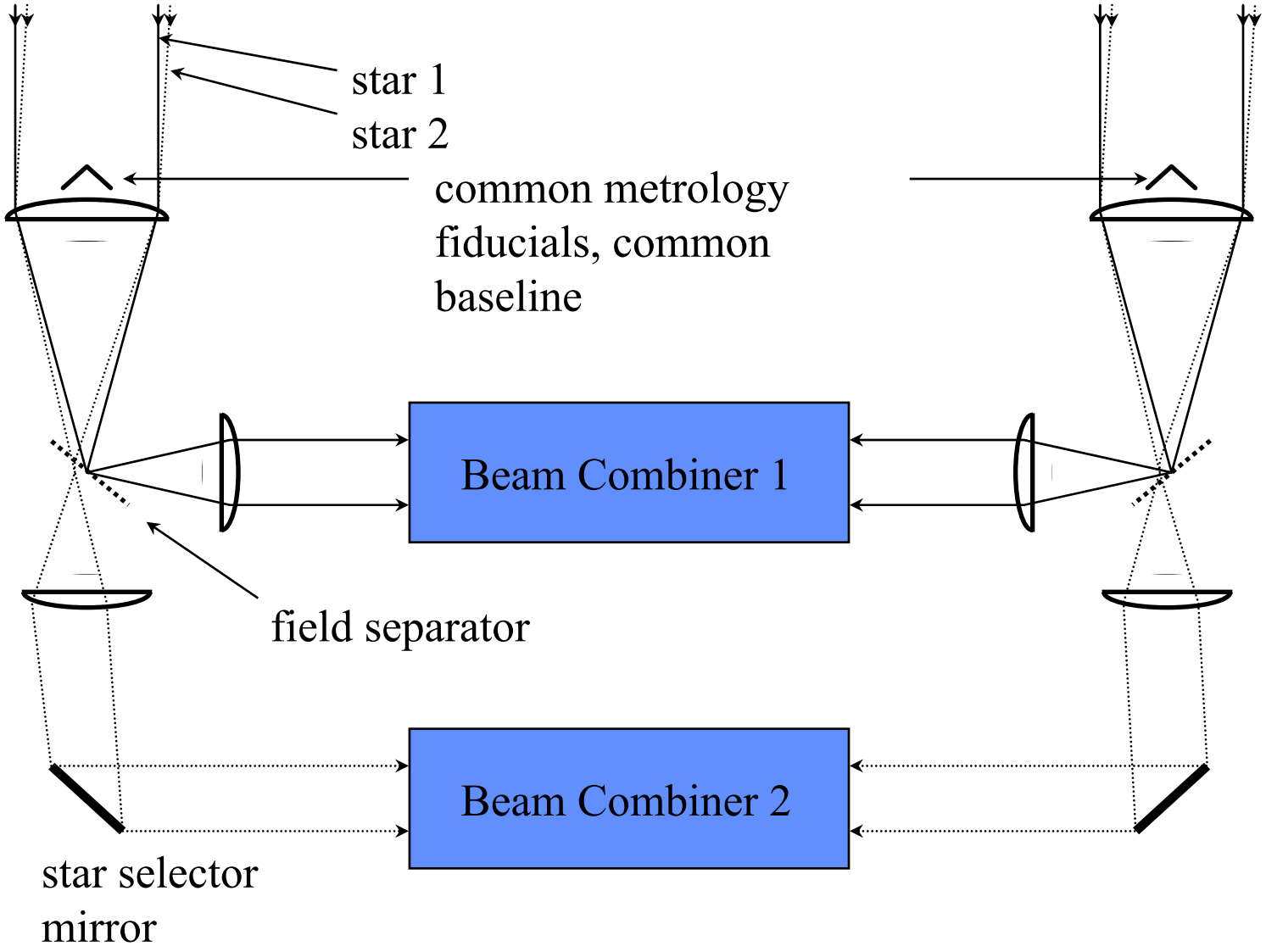






A.F. Boden, M.J. Creech-Eakman, and D. Queloz, 2000, *ApJ*, **536,** 880.

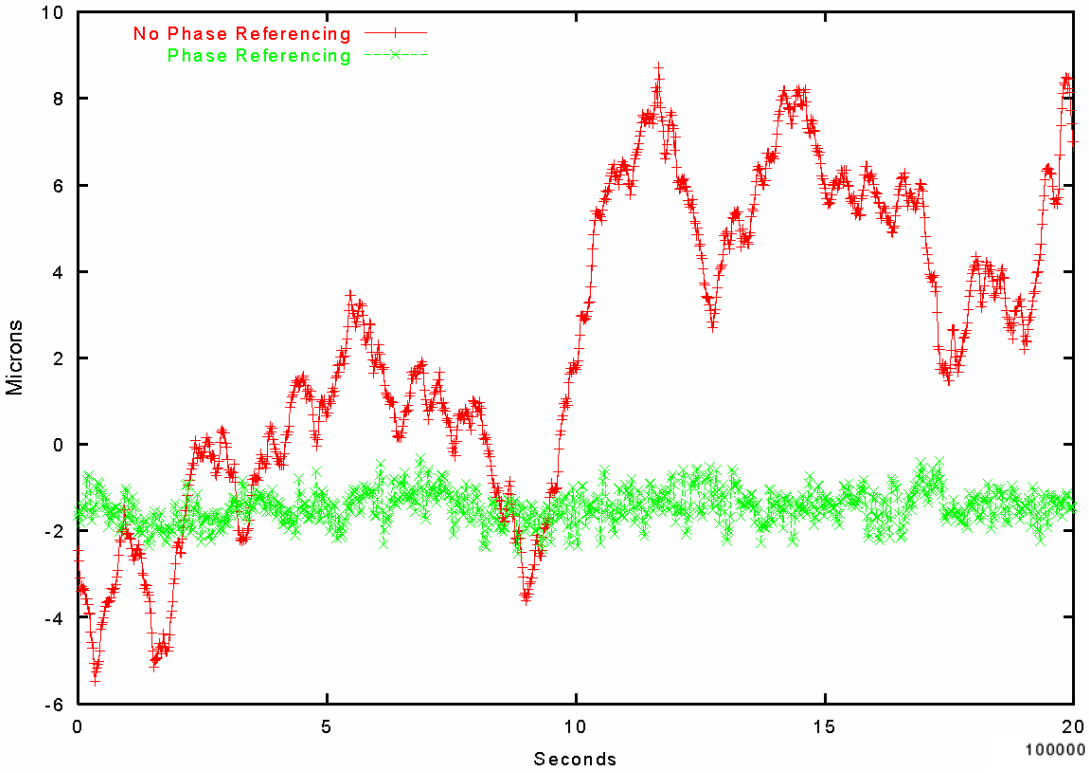
Dual-Star Concept

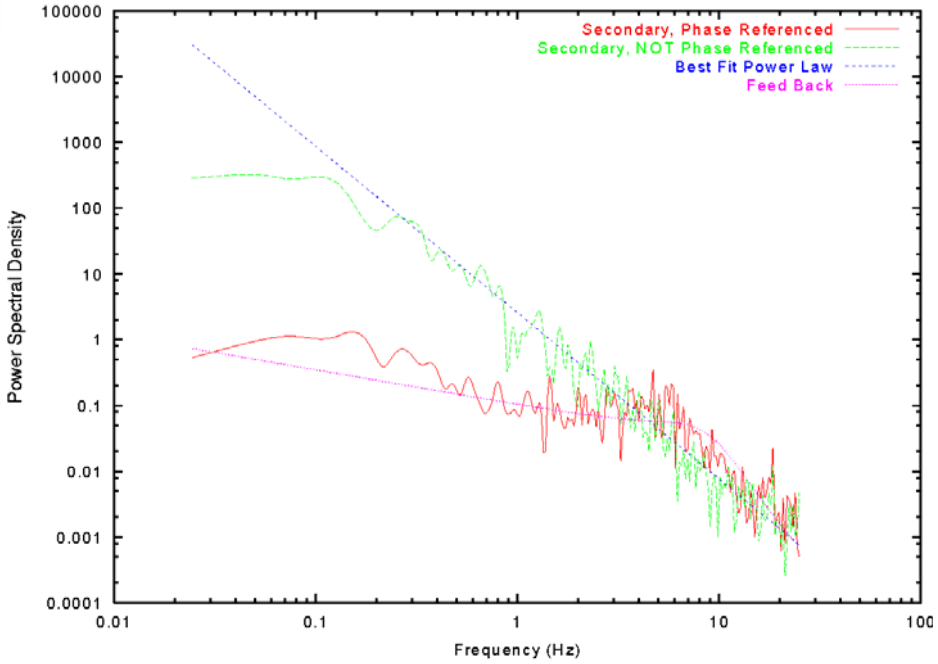


Phase referencing with PTI

- Analogous to adaptive optics on a large telescope
- Approach
  - Fringe track on a bright star within the isoplanatic patch of the target star
  - Use as a probe of the atmospheric effects on the target star
  - Correct using optical delay lines by
    - » Feedback same signal to both stars' delay lines
    - » or... Feedforward signal to secondary star's delay line
- Advantage
  - Allows longer integration times that would ordinarily be possible

Phase referencing with PTI

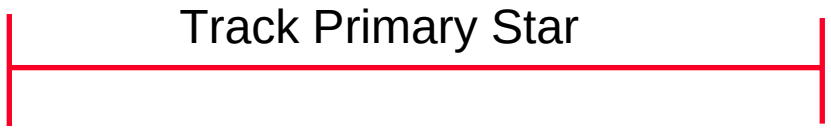




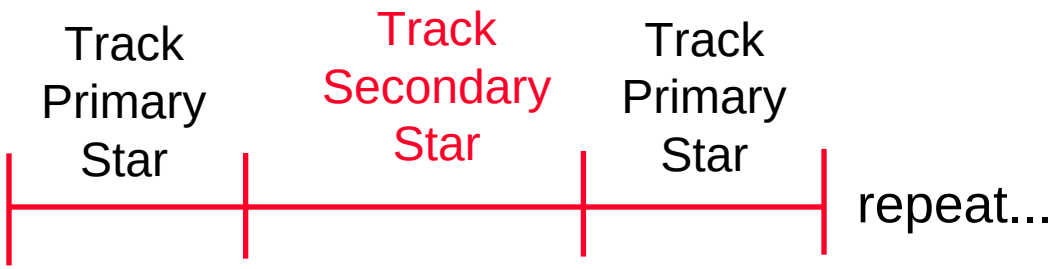
Lane & Colavita, AJ, 125, 1623.

Astrometry Observation

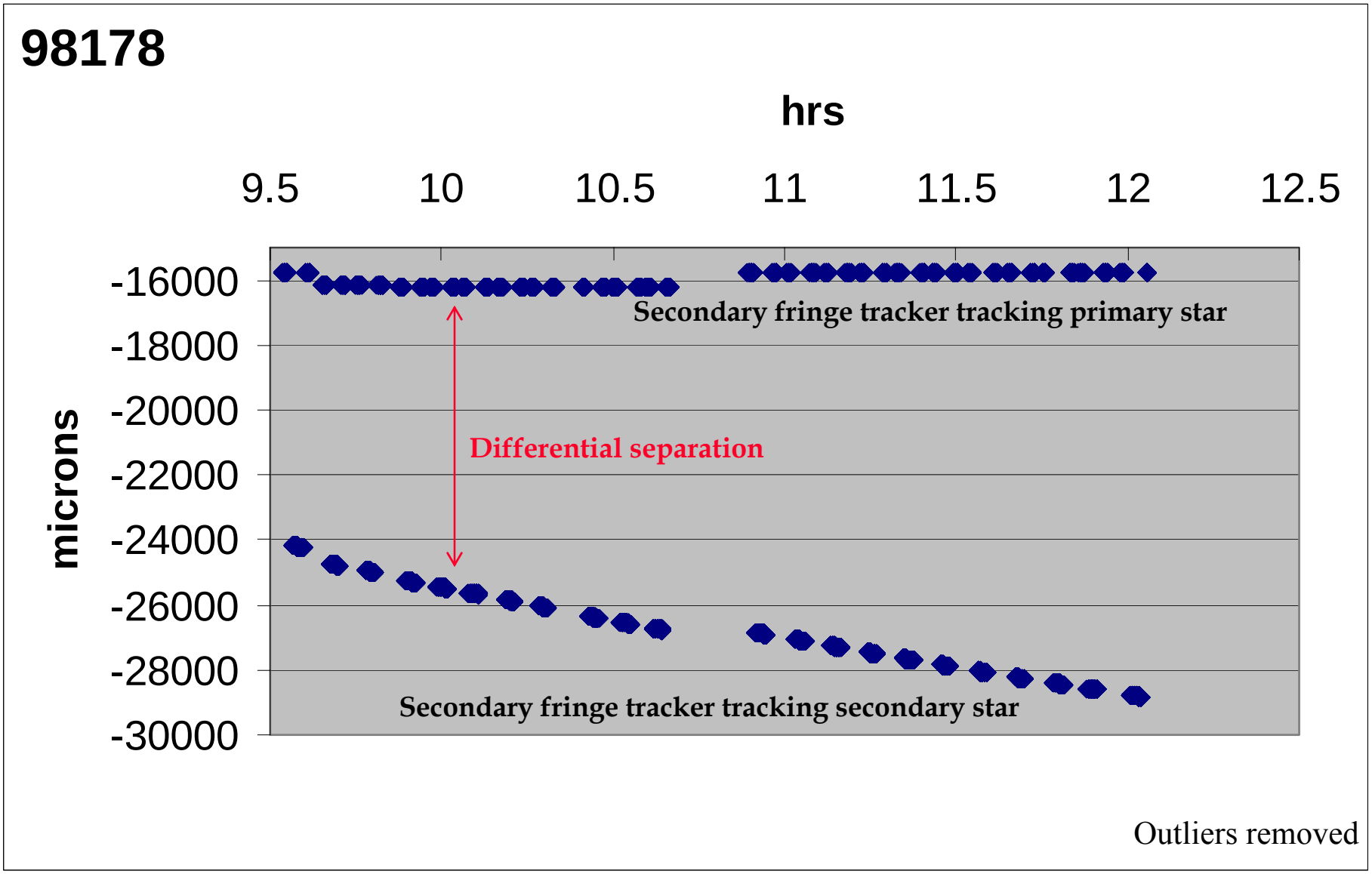
Primary Combiner



Secondary Combiner
(chops between primary and secondary)



Raw data


98178
hrs
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11
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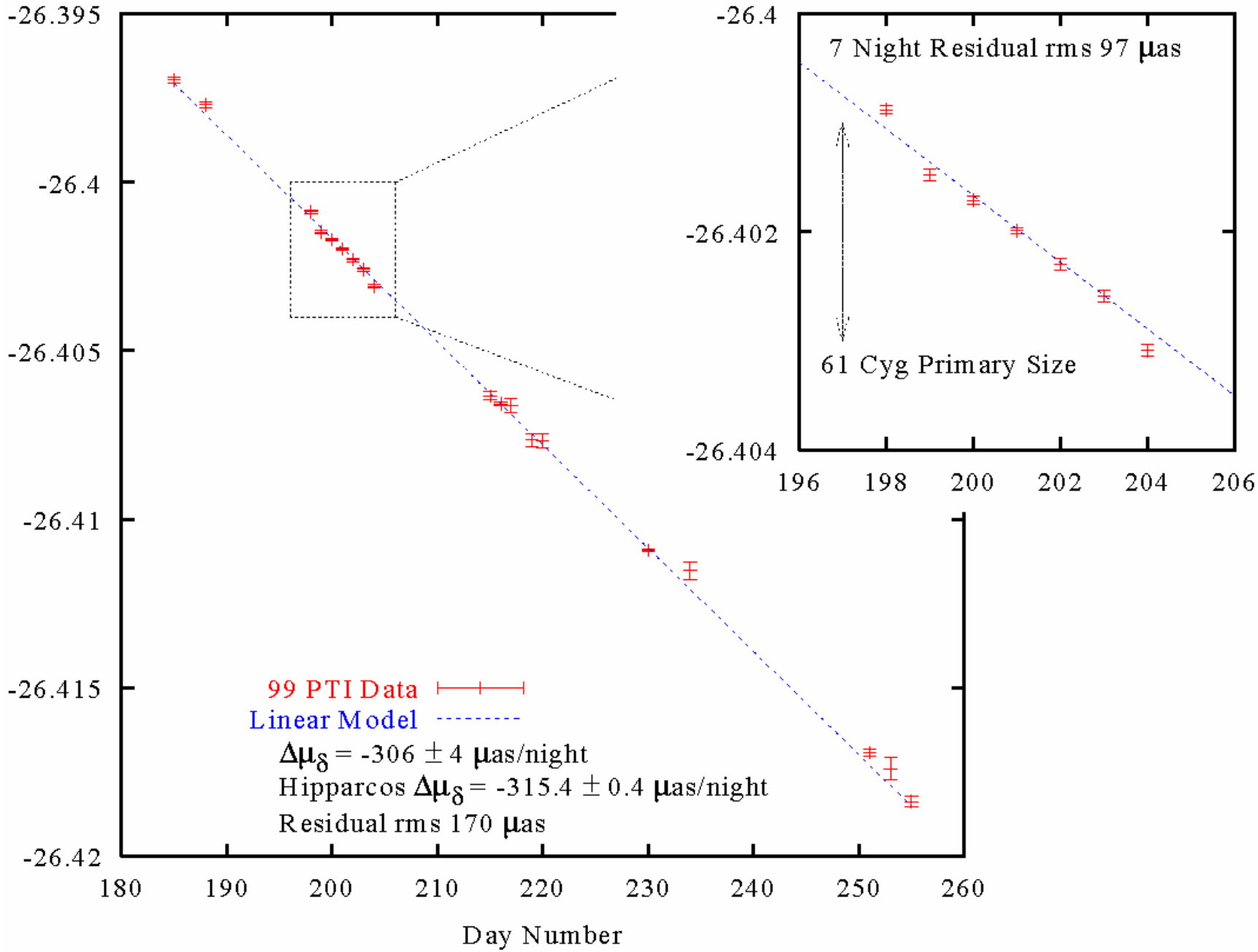
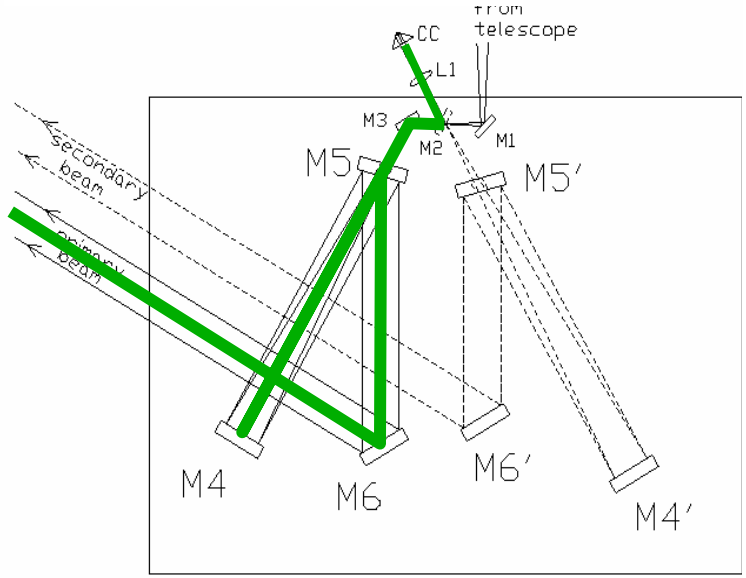
microns
-16000
-18000
-20000
-22000
-24000
-26000
-28000
-30000
Secondary fringe tracker tracking primary star
Differential separation
Secondary fringe tracker tracking secondary star
Outliers removed

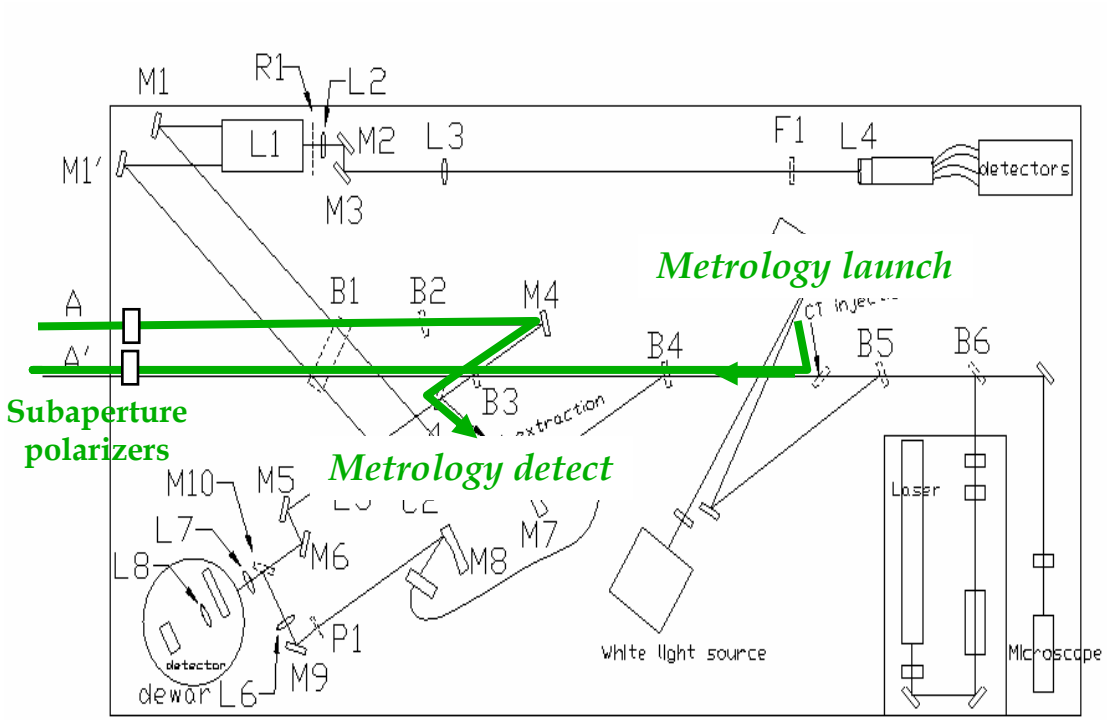
61 Cyg Astrometry



Constant-term metrology

Corner cube in dual-star feed





Keck Interferometer

- **Keck Interferometer links the two 10 m Keck telescopes**
- **NASA-funded joint development: JPL, Keck, Caltech (MSC)**

Refs: SPIE 5491, 454 (2004); SPIE 4838, 79 (2003)

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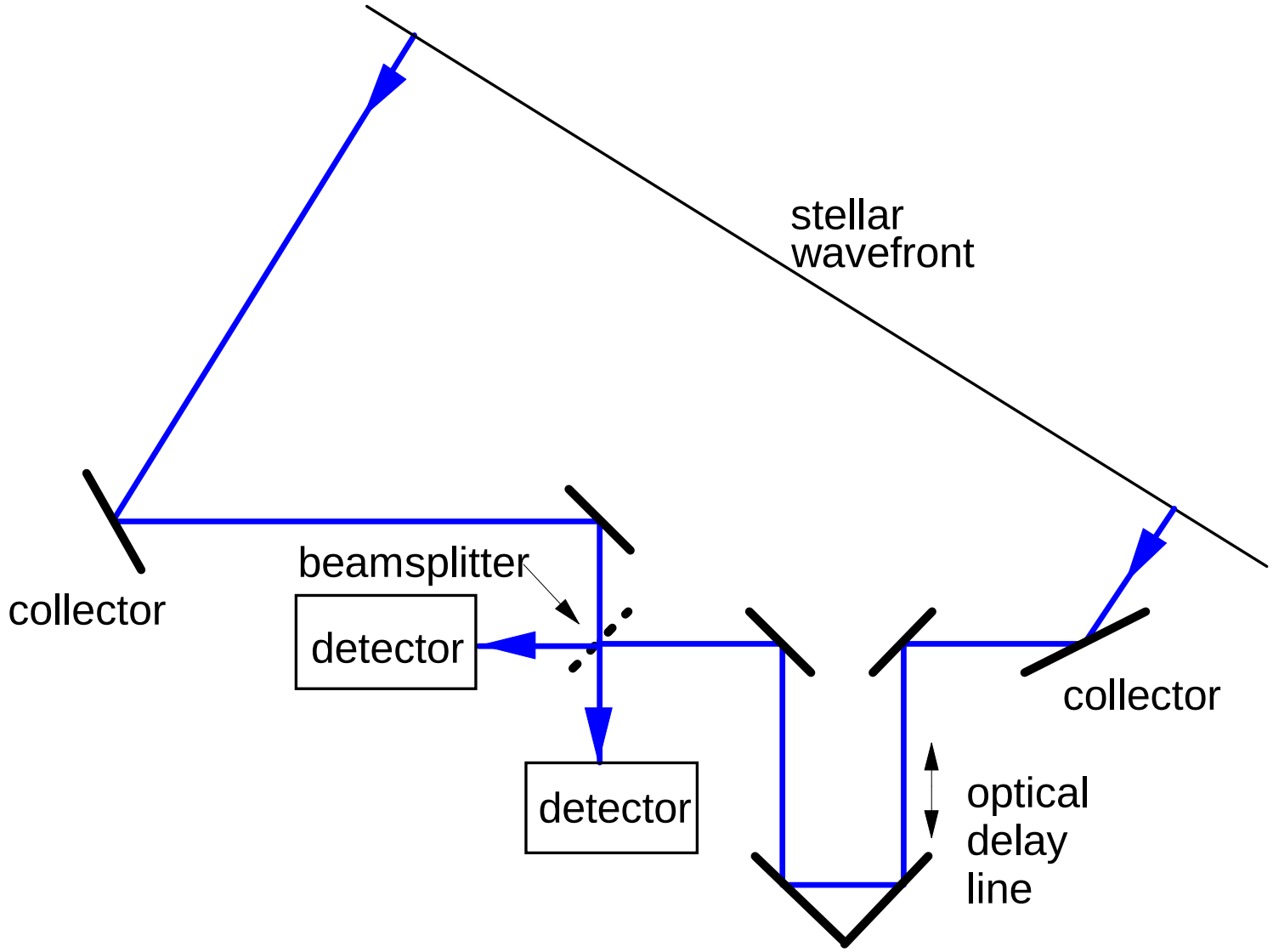
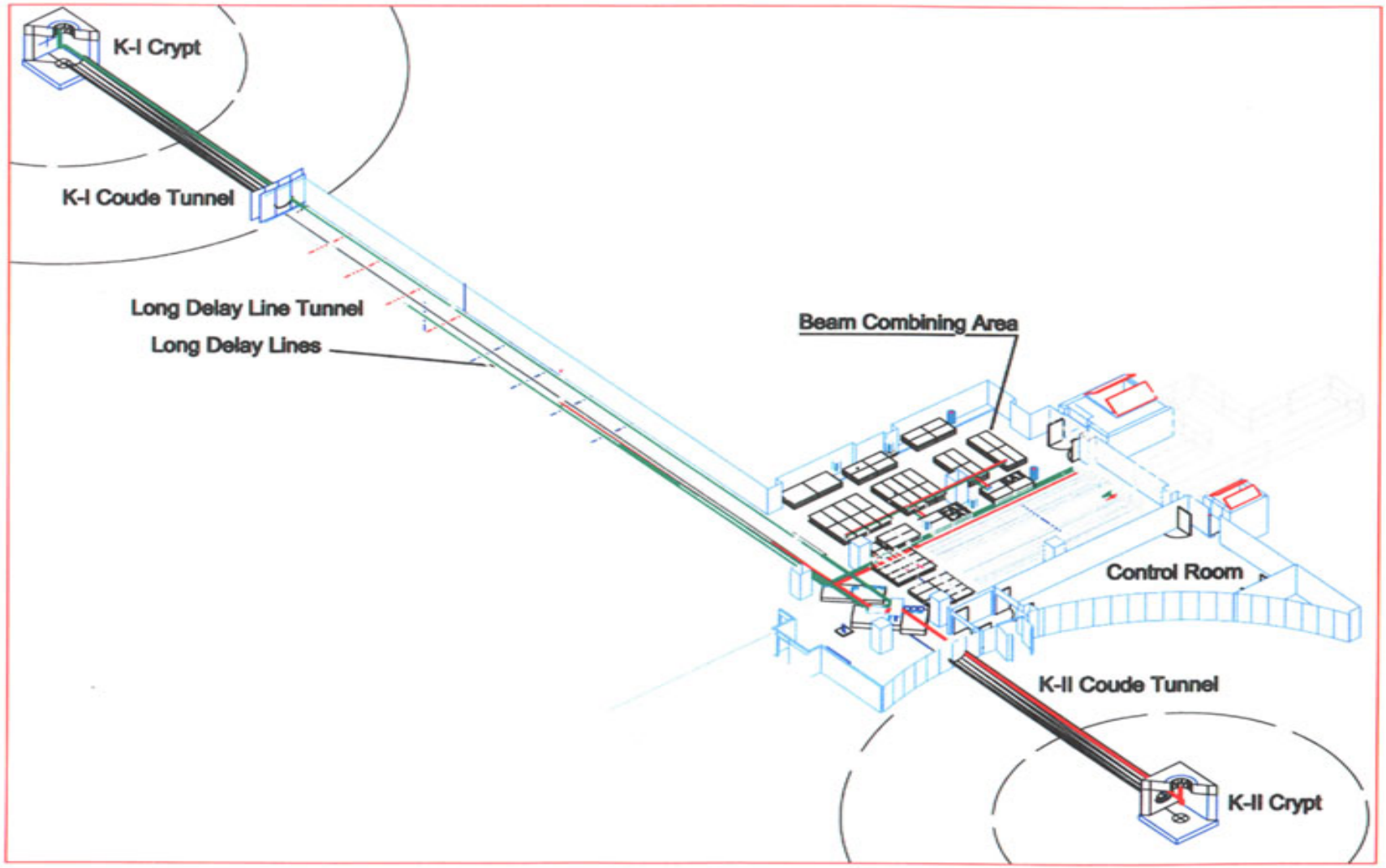
Keck Interferometer modes

- High sensitivity fringe visibility (V^2) measurements
  - Combines the AO-corrected beams
  - V^2 measurements in the near-IR
- Infrared nulling at 10 um
  - Nulling beam combiner to suppress central star
  - Measure zodiacal dust around nearby stars
- Differential-phase interferometry
  - Multi-color fringe measurements
  - Detect the fringe shift caused by hot companions to nearby stars

Michelson Interferometer



Configuration at the Summit



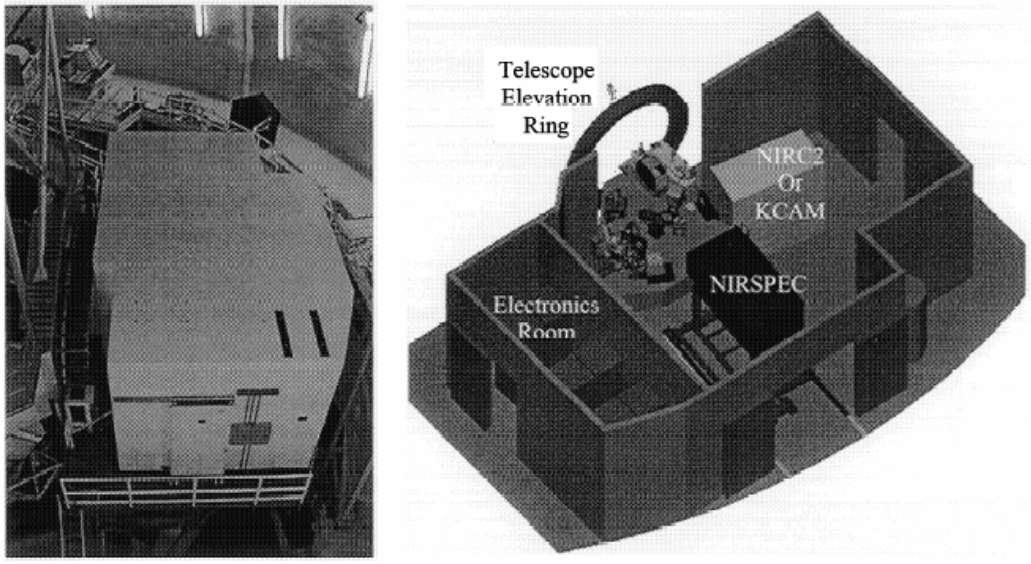
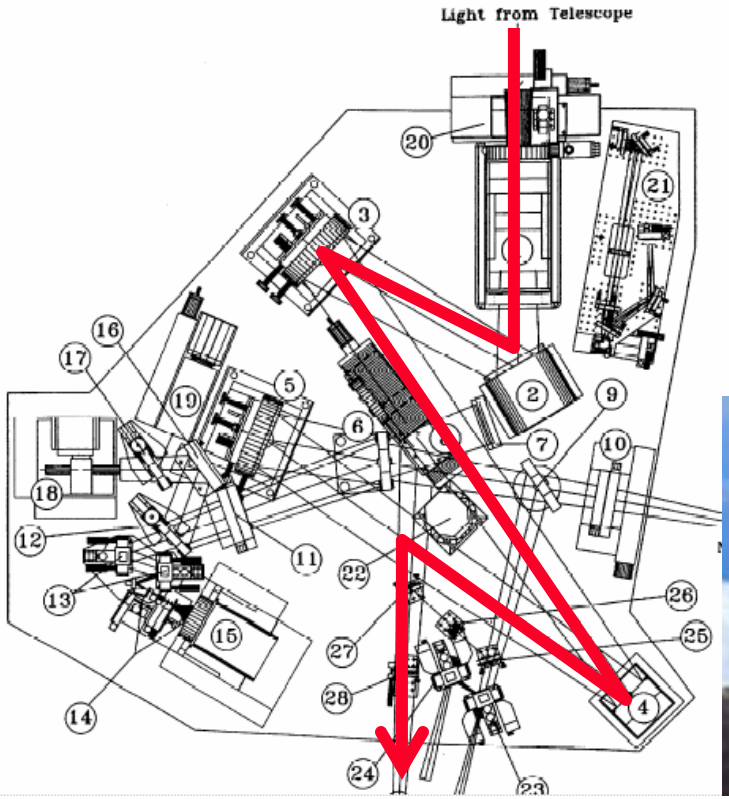


Figure 1. Left: The AO enclosure on the left Nasmyth platform of the Keck II telescope. Right: A schematic view of the AO enclosure with its roof removed.

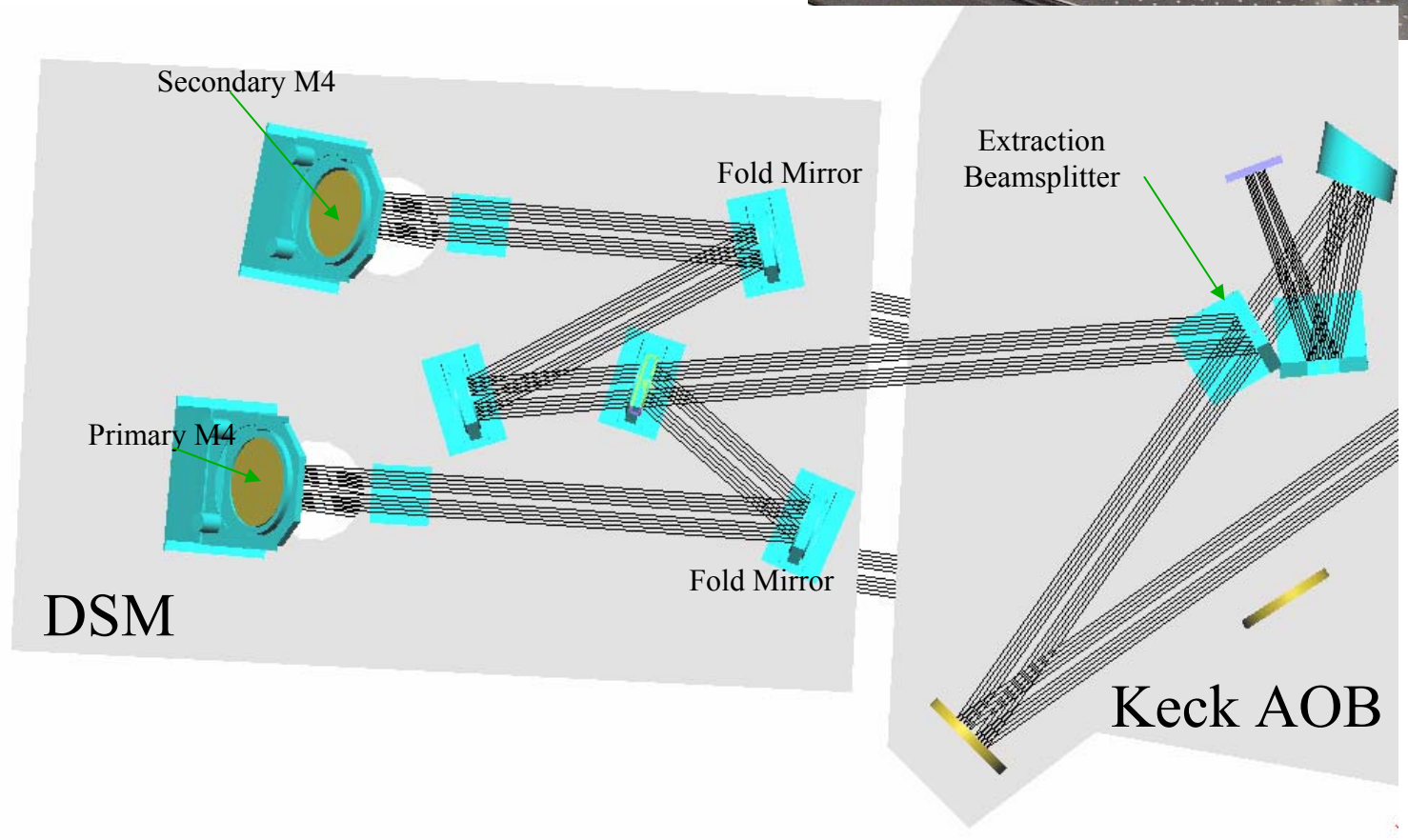
Telescope & AO

- Extract beam in collimated space on AO bench after deformable mirror
- 9 m inscribed circle on Keck primary mirror maps to 112 mm collimated beam
  - 80.4 : 1 demagnification

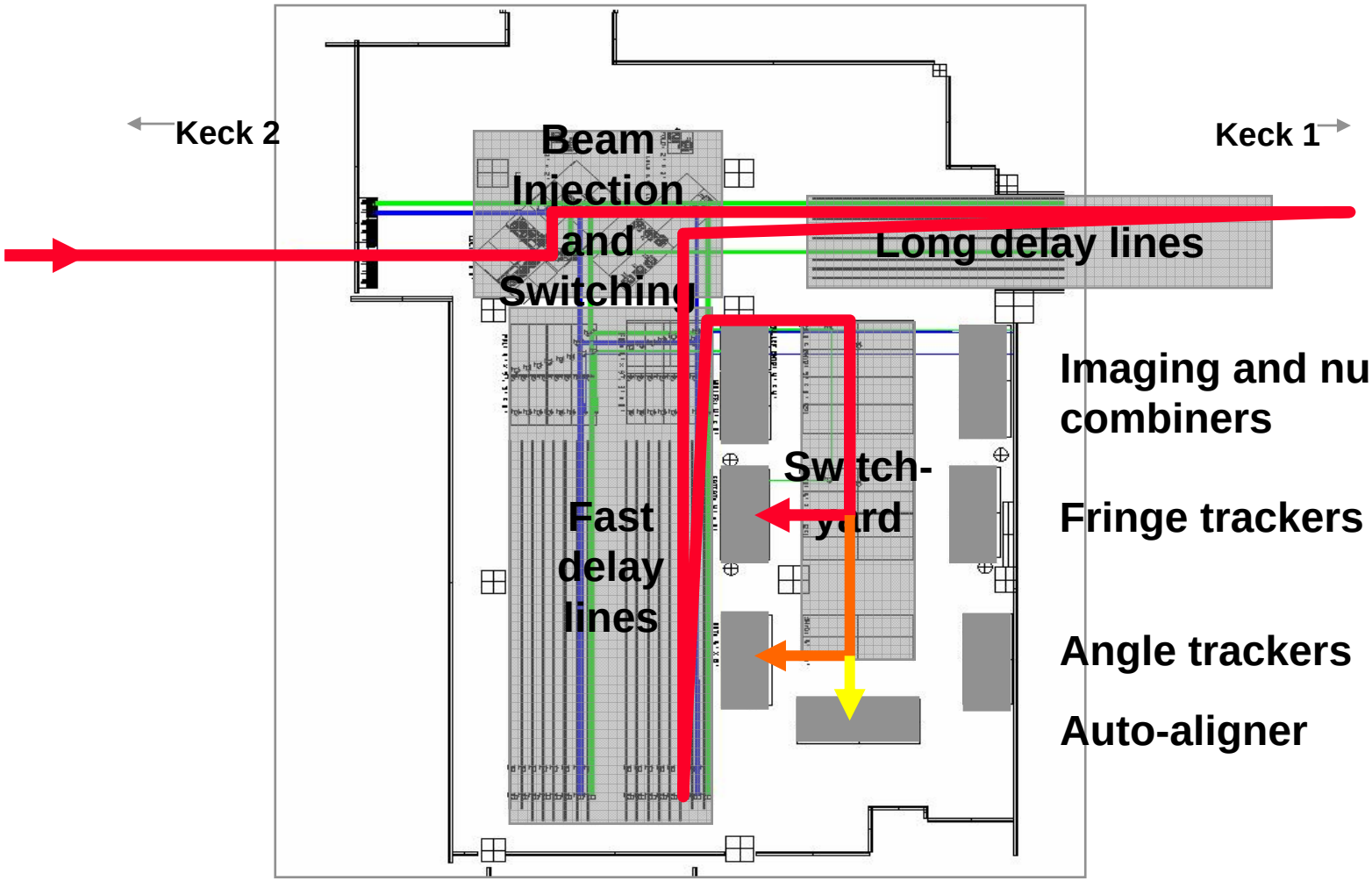


Dual star module

- Slides in adjacent to AO system like other Nasmyth instruments
- Sends collimated beam into coude beam train

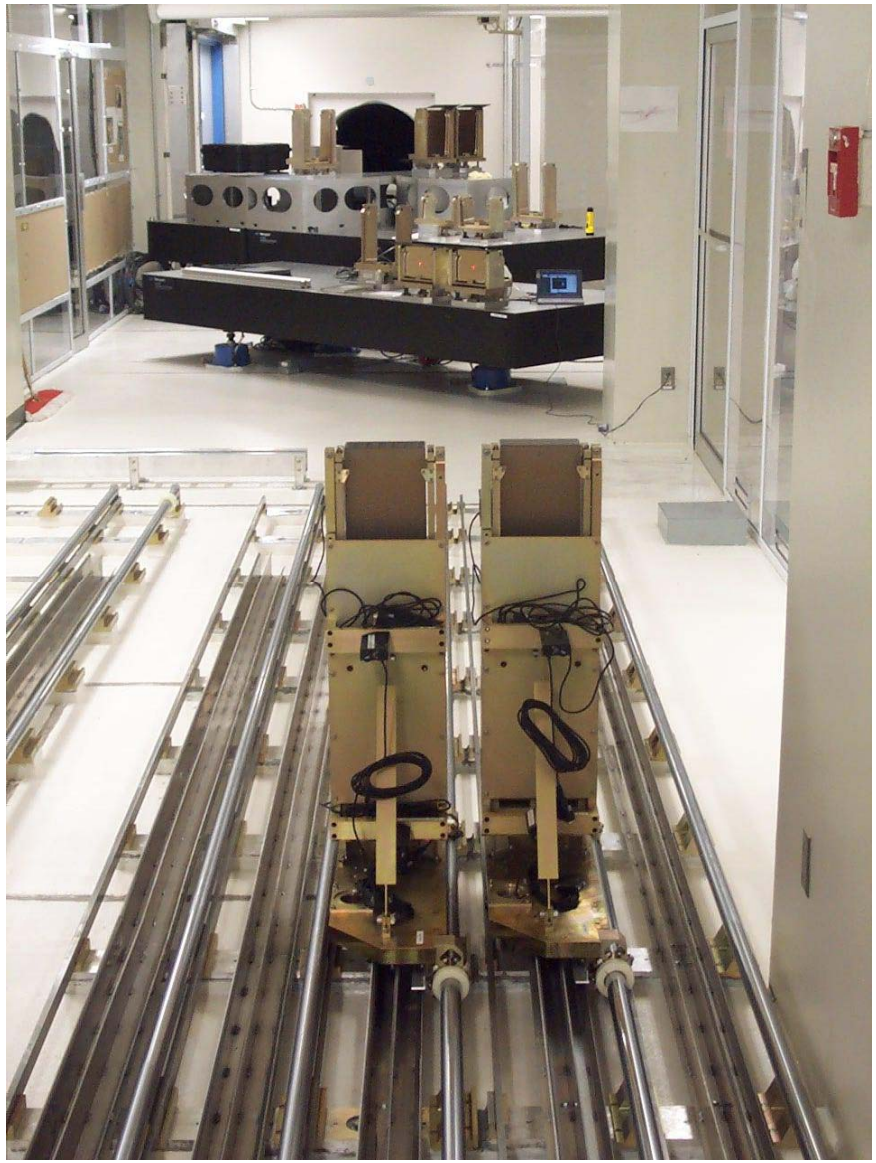


Beam Combining Lab Optical path



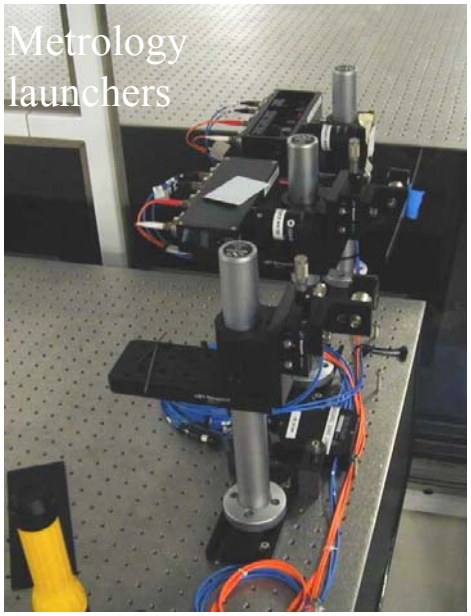
Long delay lines

- Installed in coude tunnel
- Provides coarse delay positioning (static during observation)
- Double-height mirror accommodates two beams for phase referencing



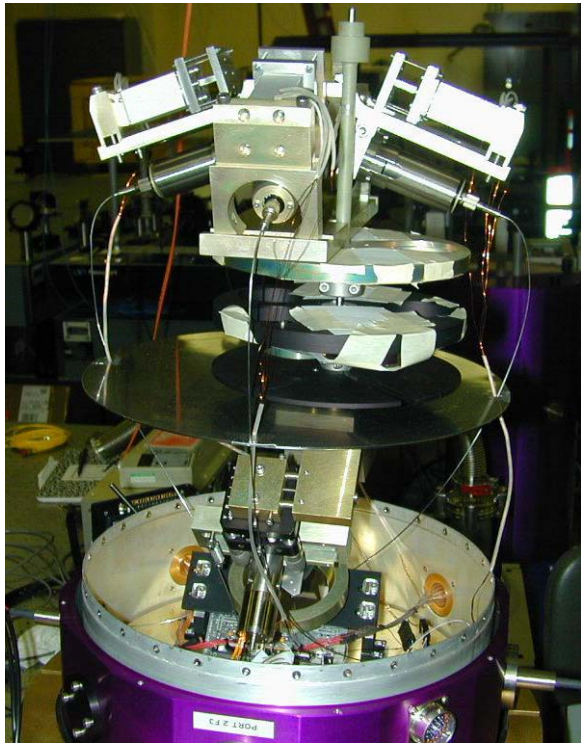
Fast delay lines

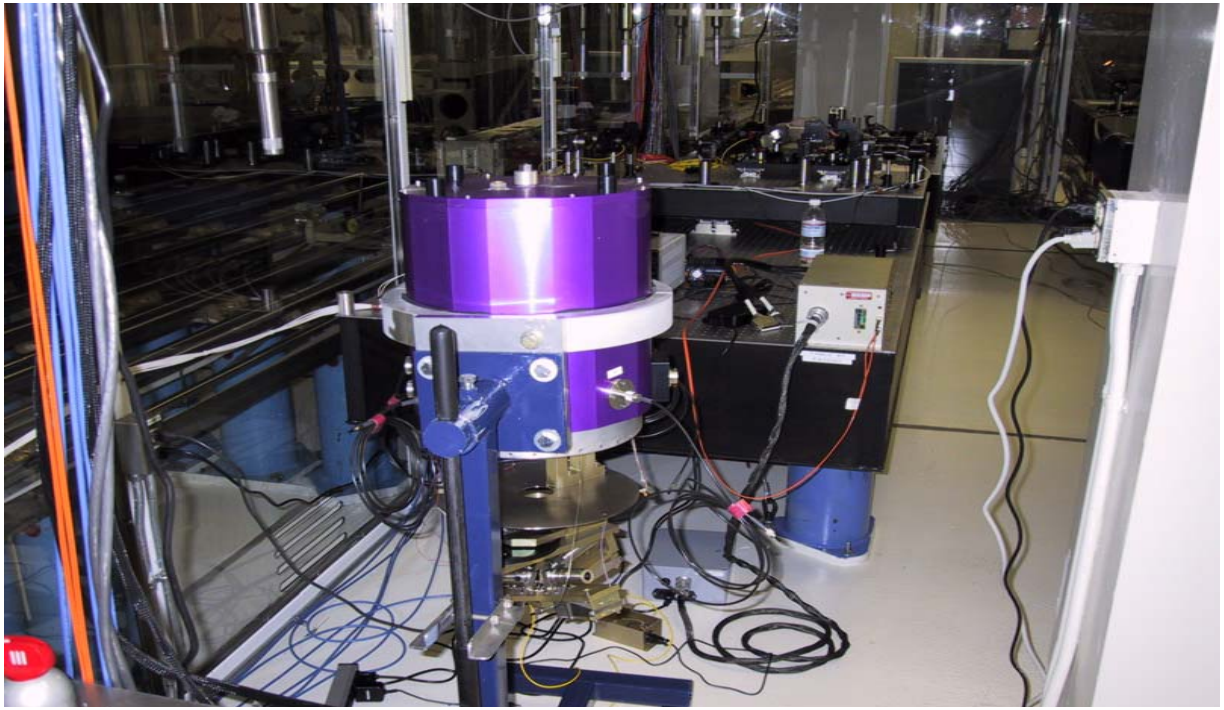
- 4-stage cat's-eye design
- Fiber-fed laser metrology
- Delay range +/- 15m
- High speed position and rate commanding



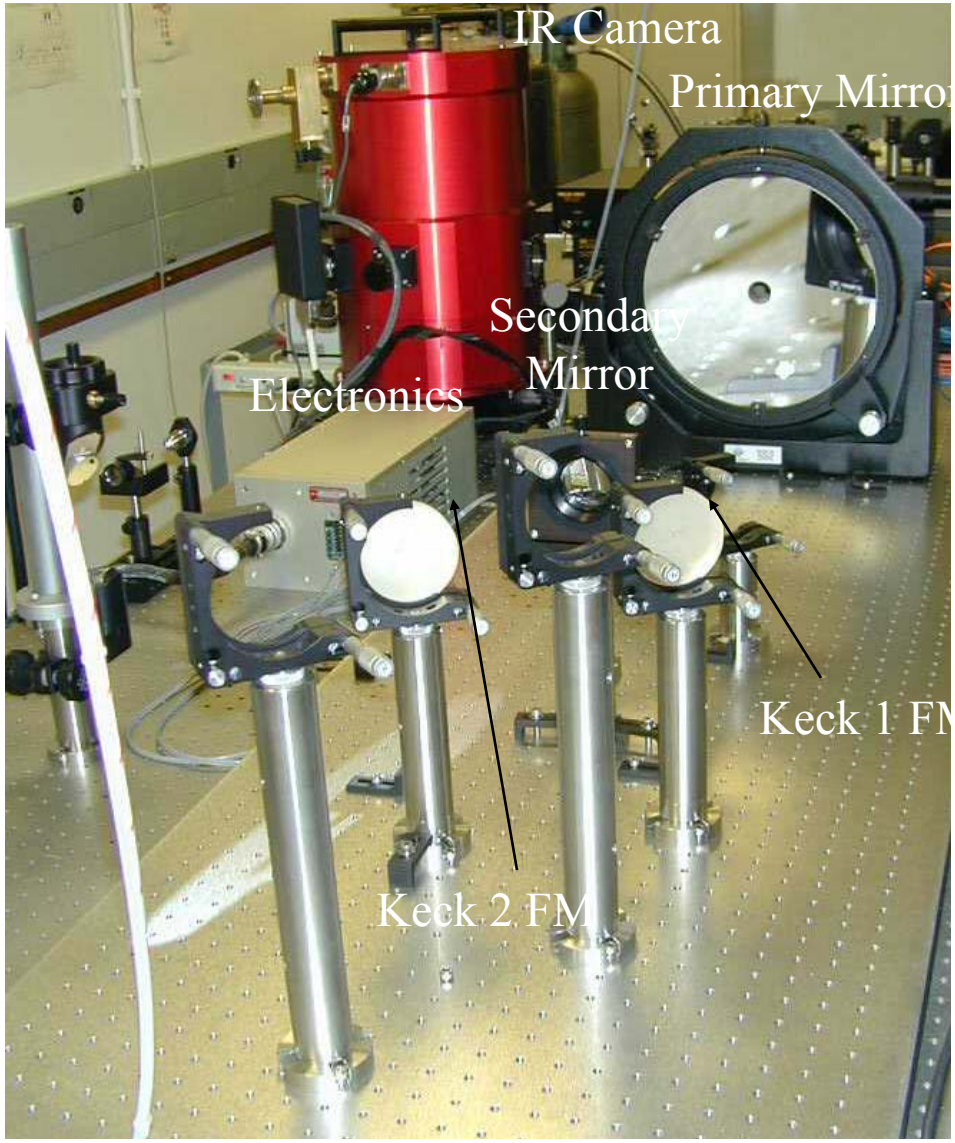
FATCAT (Fringe tracker)

- Free-space Michelson beam combination at H and K bands
- HAWAII array camera fed by single-mode fluoride fibers
- White-light and spectrometer channels; frame rates of 100-1000 Hz
- Fringe tracking with coherent fringe demodulation, closed-loop to delay line



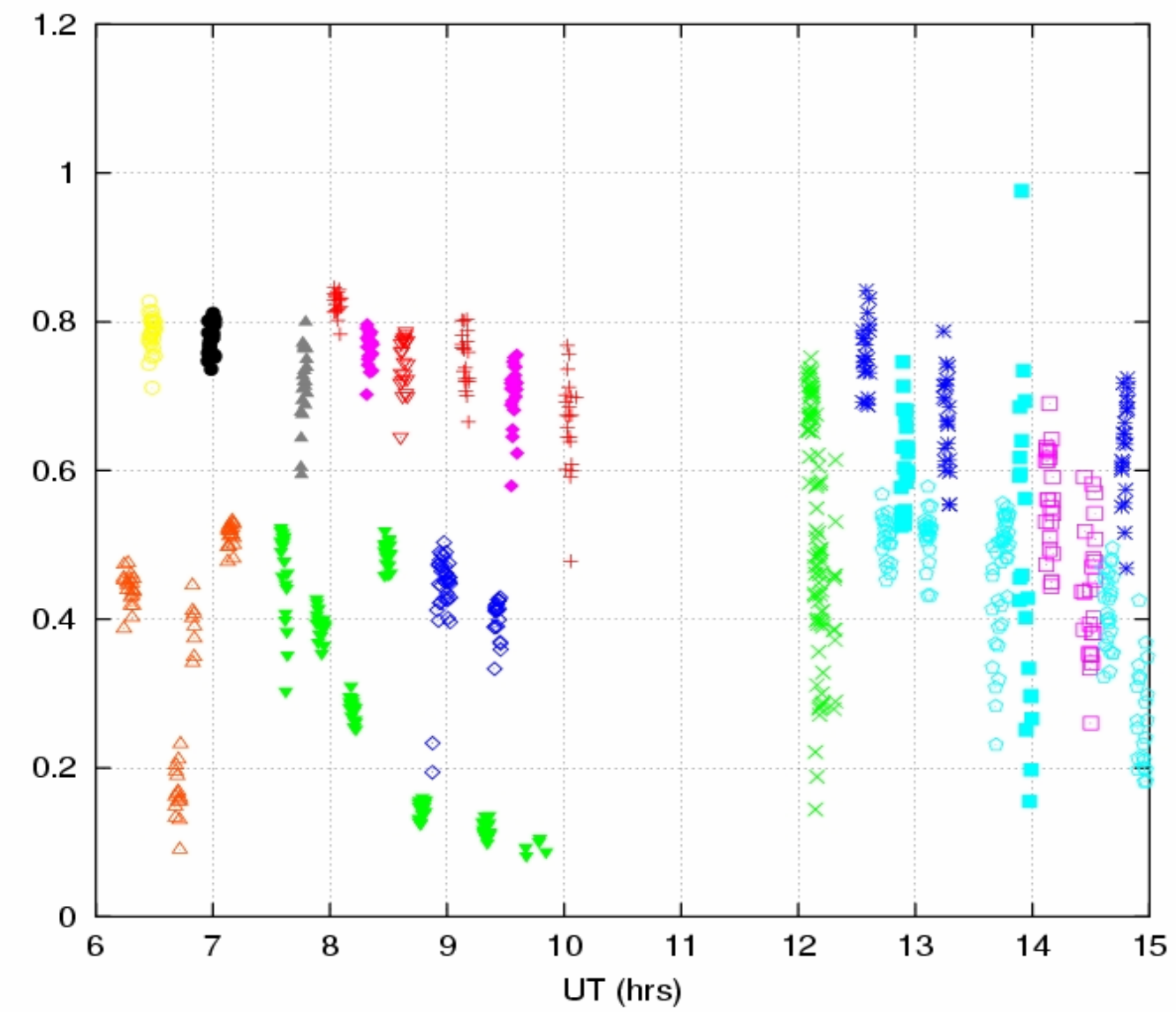


Angle tracker



- H and J band angle tracking
- DCR corrector for good sky coverage
- Images from two Kecks multiplexed onto one quadrant of HAWAII array
- 100 Hz readout
- High-speed updates to local tip/tilt mirror
- Low-speed off-loads to AO system

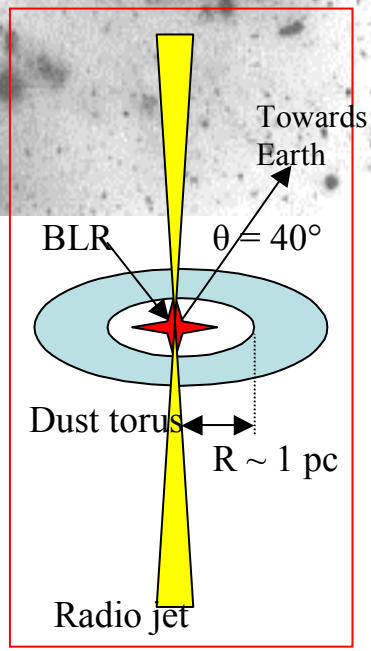
Visibility-Mode observations at KI



National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

KI first results: NGC4151

- Swain et al., 2003, ApJL, 596, L163
- First detection of any source outside our galaxy with infrared interferometry
  - NGC 4151 is a Seyfert galaxy at a distance of ~13 Mpc
  - The interferometer clearly resolved the emission
    - Examined several possible sources of emission
      - Star cluster: too big
      - Dust torus: too big
      - Jet: did not fit SED
      - Accretion disk: consistent with observations
    - Data implies the emission comes from a region < 0.1 parsec across



Interferometer

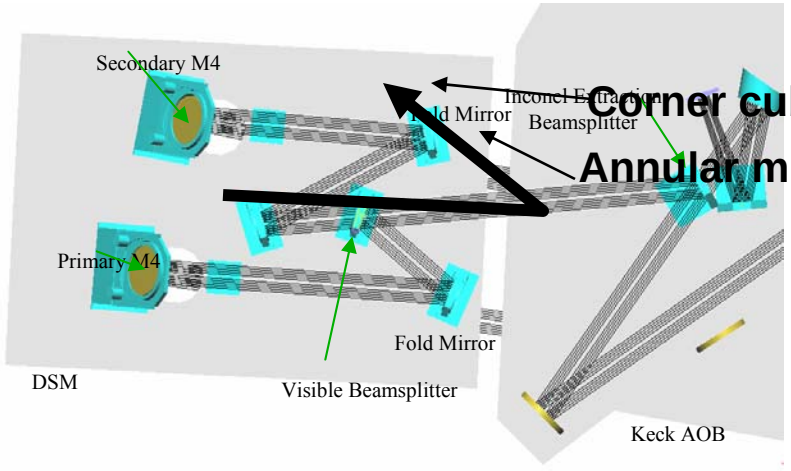
KECK

JPL

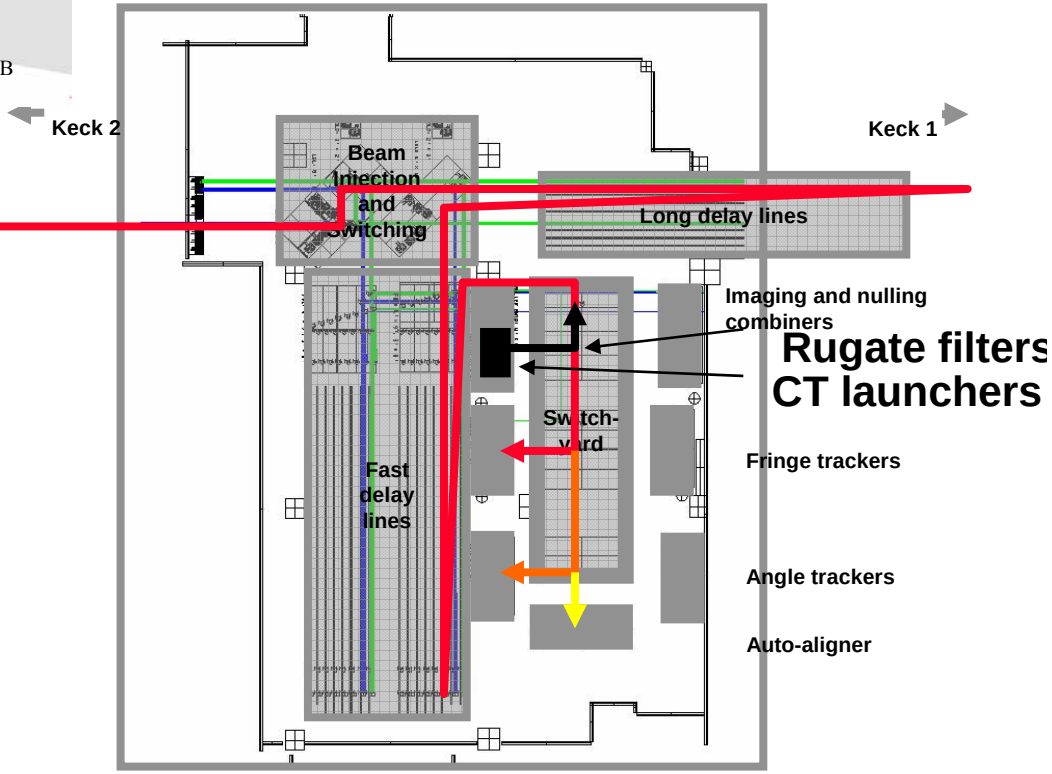
Technologies

- Enabling technologies for very narrow angle interferometric astrometry
  - Laser metrology
    - » Nuller uses 16 systems to measure and control
  - Fringe tracking
    - » Nuller uses 2 K-band trackers along with 3 trackers at N band (not simultaneous)
  - Phase referencing
    - » Used to stabilize N band fringes; similar function to stabilizing primary star while scanning secondary one

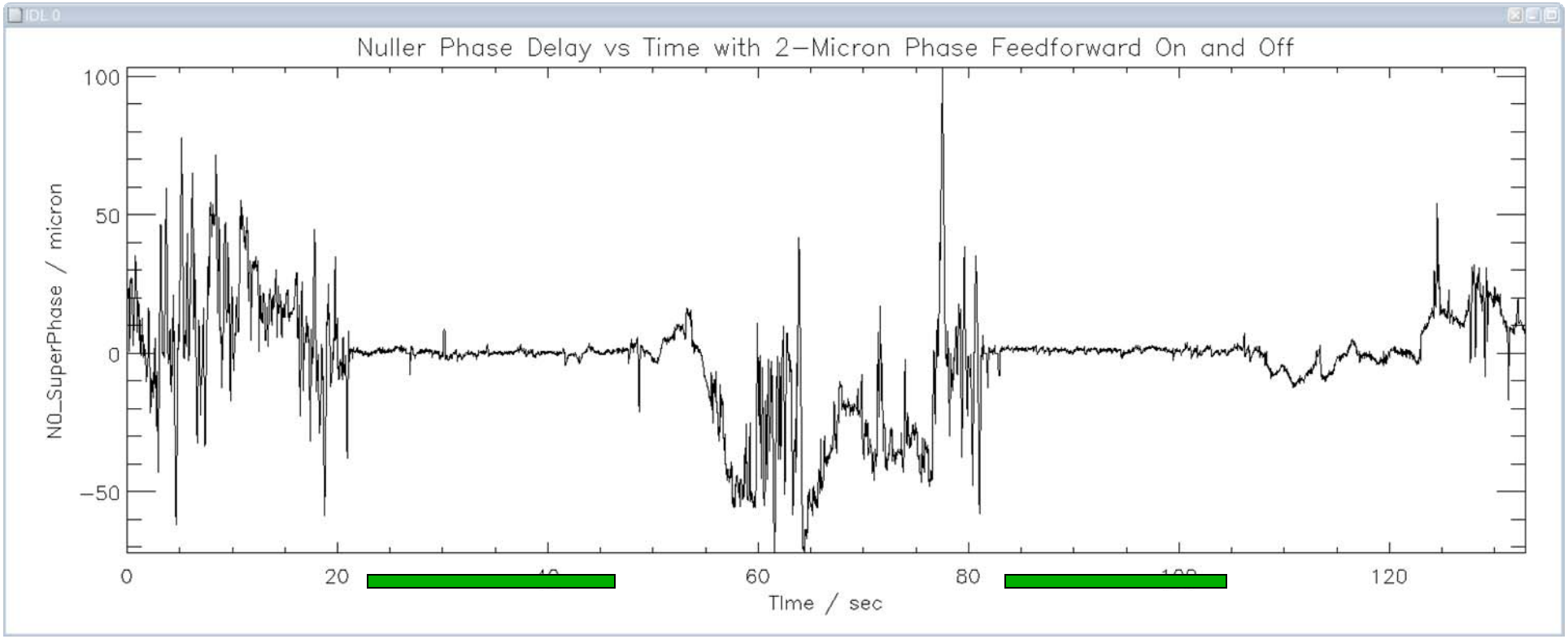
Internal pathlength (CT) metrology



- Adds laser metrology of (almost) entire optical path, not just FDL
- Measured position error combined with local FDL metrology to control FDL position



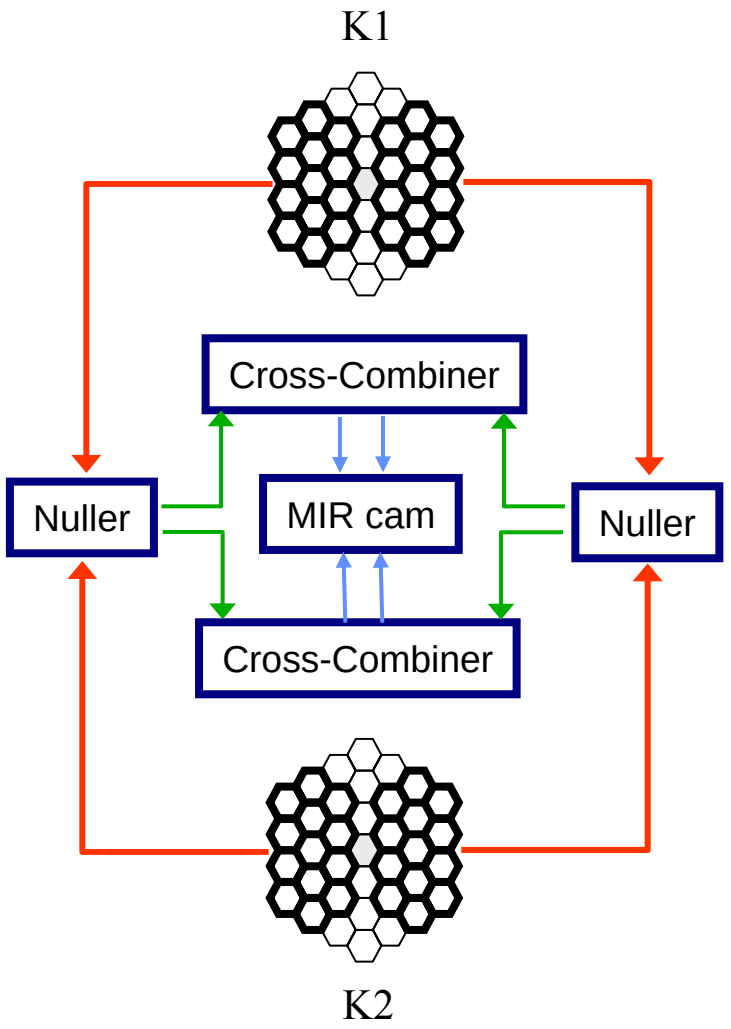
Phase reference test



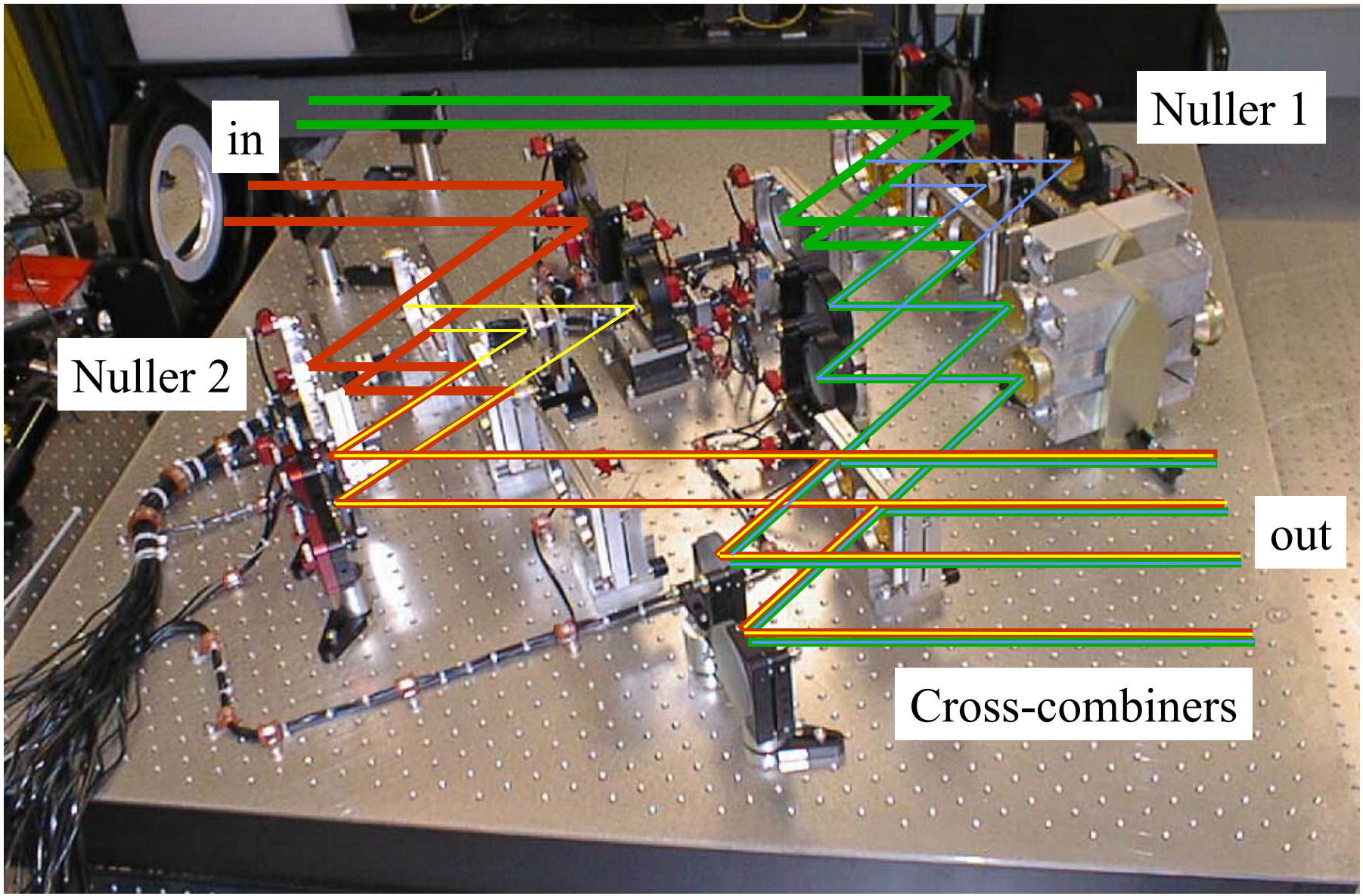
-Plotted is fringe phase vs. time on the primary nuller
-Green bars indicate times when K-band to nuller phase referencing was enabled
-Nuller was operated with zero gain, so all stabilization is attributable to phase referencing

Approach: Dual-baseline Nulling

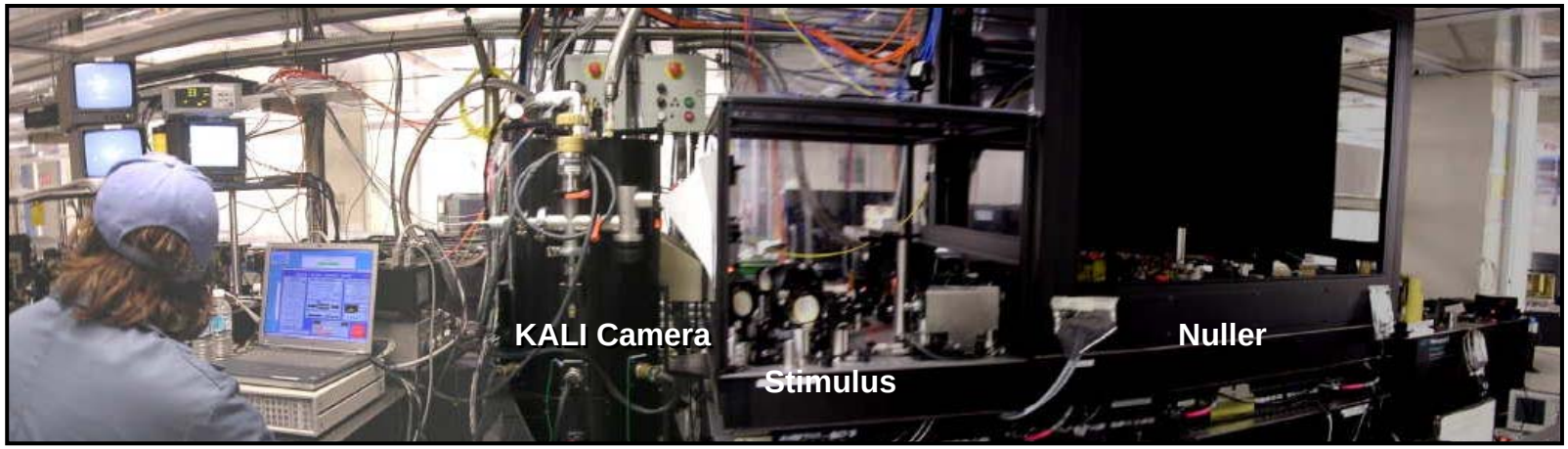
- Implement dual-baseline nulling to remove both star and thermal background
  - Use subapertures on Keck telescopes
- Two step beam combination
  - Null star on pair of K1-K2 baselines
  - Measure exozodi fringe with rapid scan between two nulled outputs
- Operates at 10-12 μm (+)
- Resembles some TPF approaches

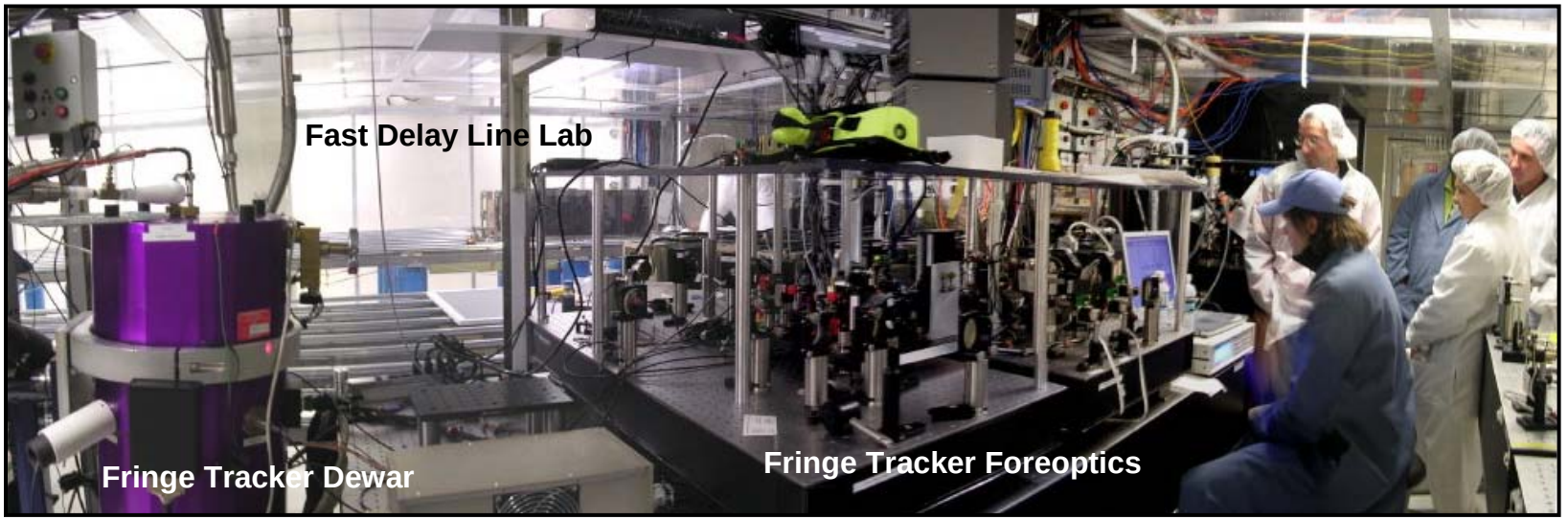


Keck nulling beam-combiner: 2 nullers & 2 X-combiners

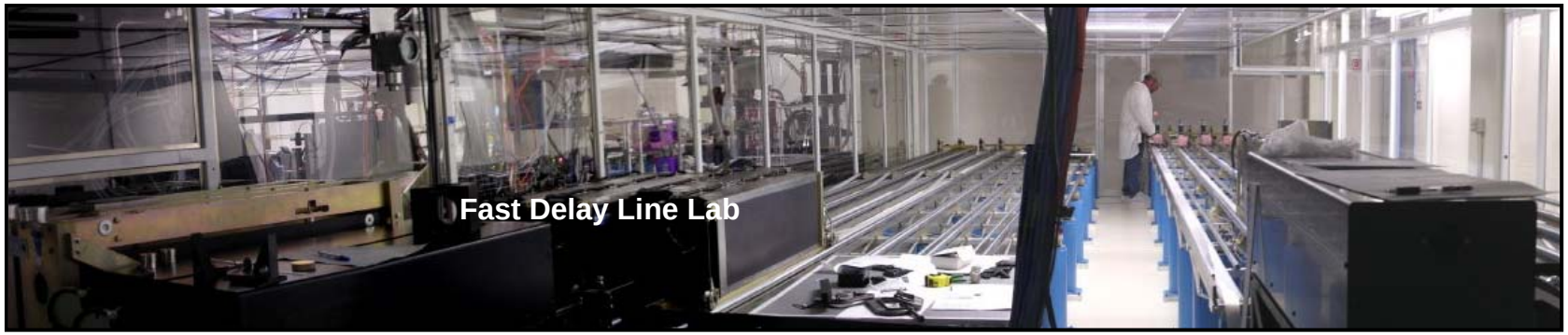


Nuller Summit Installation

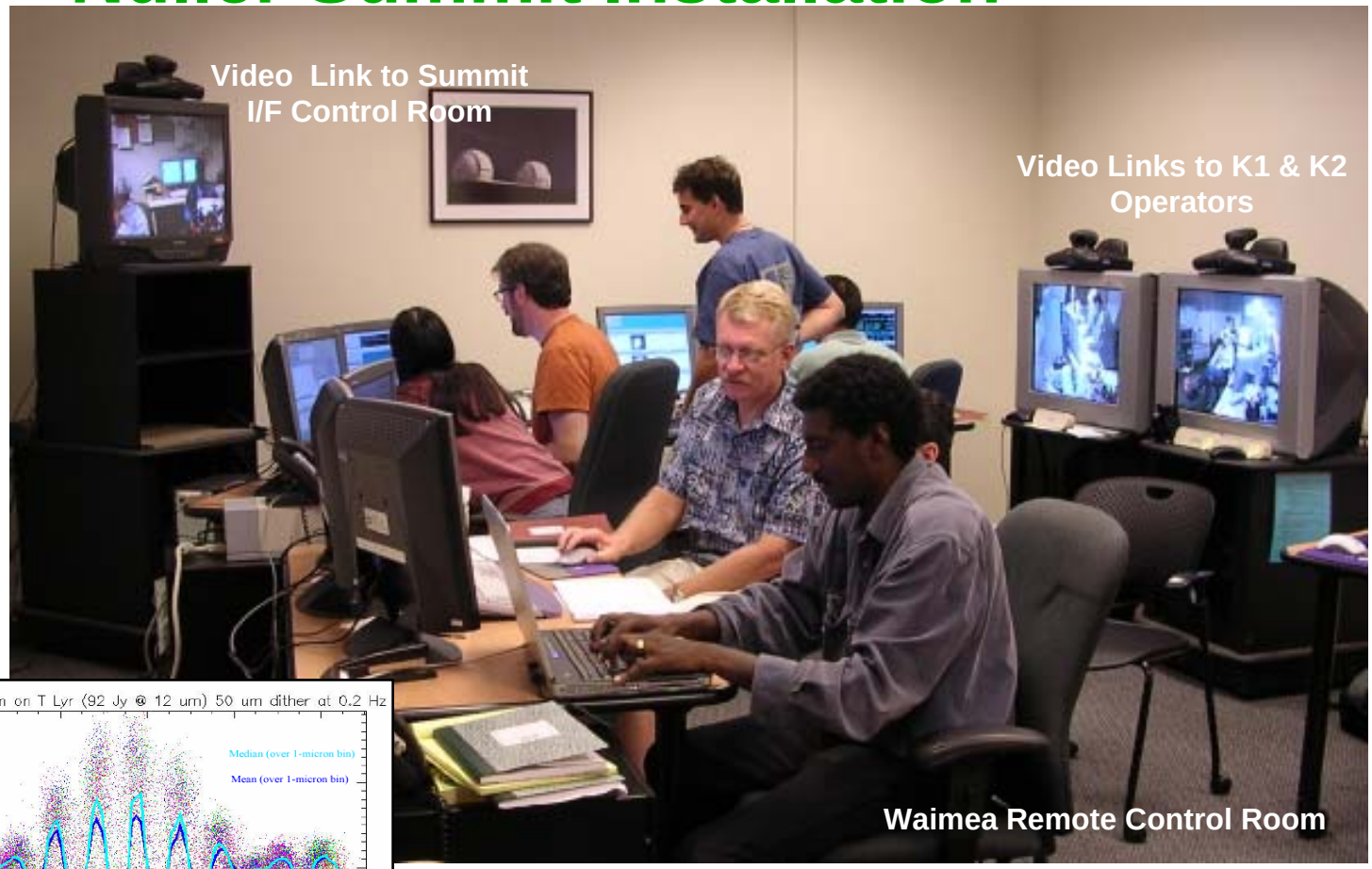


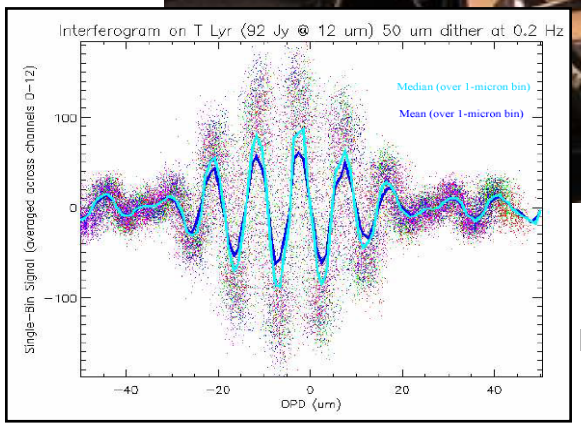


Nuller Summit Installation



Nuller Summit Installation





Post-Processed White Light (10-um) Interferogram