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VLTI PRIMA Project

The VLTI PRIMA[1] Facility

Dr. Gerard van Belle
PRIMA Instrument Scientist

March 1, 2010

Solarmass Stars: the VLTI Primer

[1]Phase-Referenced Imaging and Micro-Arcsecond Facility

Credit where Credit is Due

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VLTI PRIMA Project

- A ‘cast of thousands’ inside and outside of ESO

Roberto Abuter, Matteo Accardo, Luigi Andolfato, Pascal Ballester, Hendrik Bartko, Bertrand Bauvir, Henri Bonnet, Stephane Brillant, Fabio Caruso, Jeroen de Jong, Benard Delabre, Frederic Derie, Nicola di Lieto, Thanh Phan Duc, Nick Elias, Michel Fleury, Robert Frahm, Simond Gilles, Bruno Gilli, Philippe Gitton, Pierre Haguenauer, Thomas Henning, Christian Hummel, Laurent Jacou, Andreas Jost, Bertrand Koehler, Rainer Köhler, Ralf Launhardt, Samuel Leveque, Jean-Louis Lizon, Jorge Melnick, Serge Menardi, Sebastien Morel, Jean-Michel Moresmau, Judith Ngoumou, Ralf Palsa, Francesco Pepe, Isabelle Percheron, Monika Petr-Gotzens, Oliver Pfuhl, Michel Pichard, Dan Popovic, Ester Pozna , Florence Puech, Didier Queloz, Andreas Quirrenbach, Andres Ramirez, Fredrik Rantakyro, Sabine Reffert, Andrea Richichi, Thomas Rivinius, Johannes Sahlmann, Markus Schoeller, Nicolas Schuhler, Fabio Somboli, Stan Stefl, Ingo Stiltz, Bob Tubbs, Gerard van Belle, Anders Wallander, Stefan Wehner, Markus Wittkowski

PRIMA: The Dual-Feed Facility for VLTI

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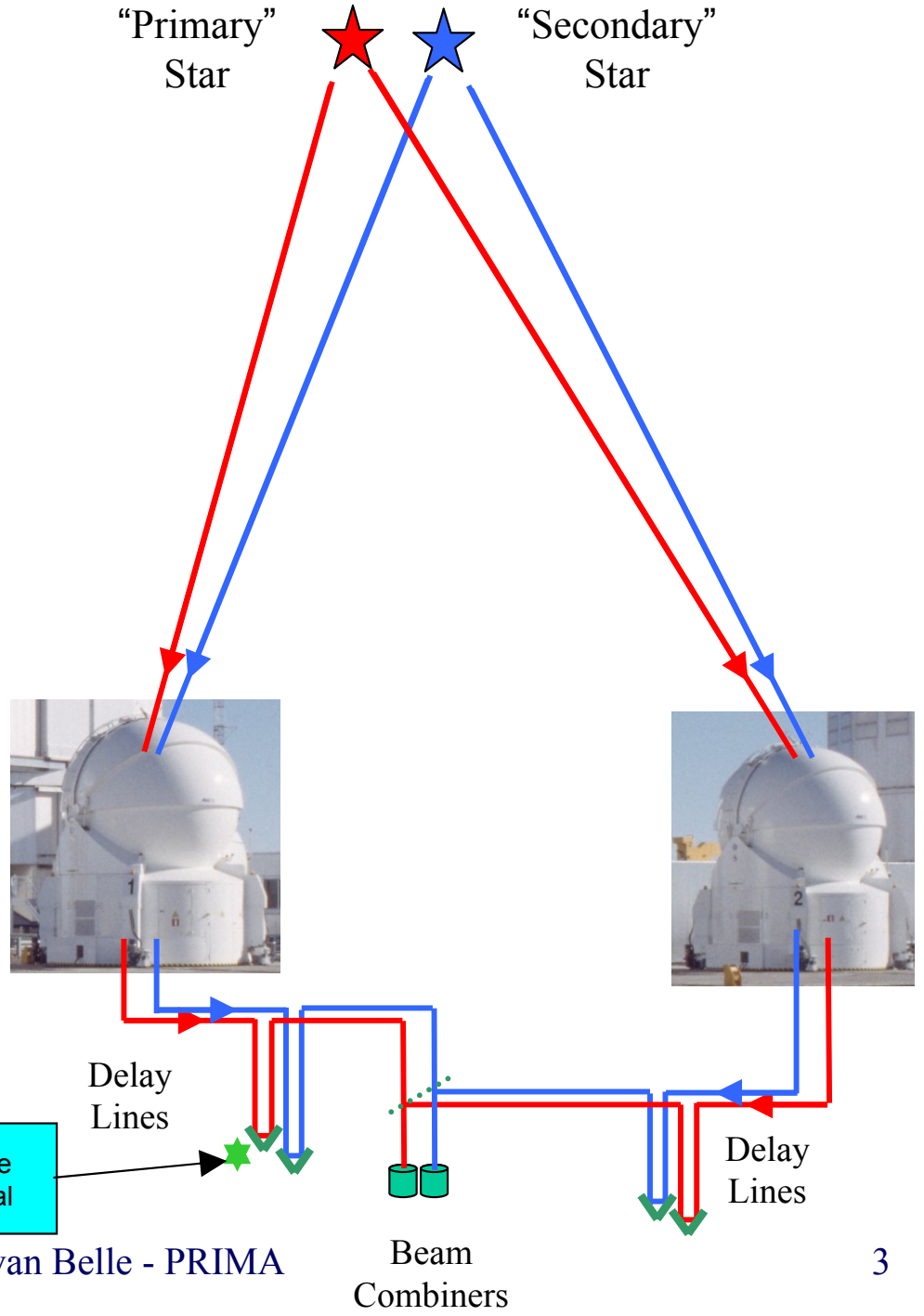
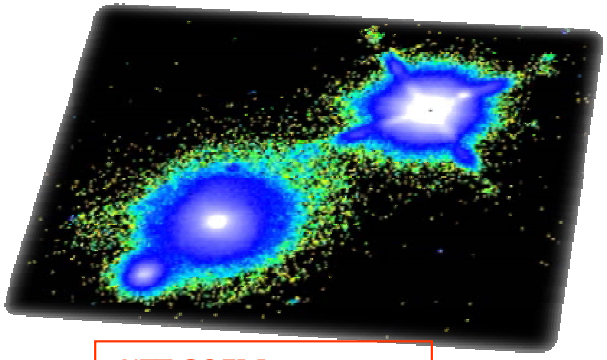
VLTI PRIMA Project

- PRIMA = Phase Referenced Imaging and Microarcsecond Astrometry
- "**Two interferometers in one**" tied together by laser metrology
- An instrument or a facility?
  - A bit of both
- Enables 3 new modes:
  - Stand-alone instrument: **Astrometry**
  - Facility feeding AMBER/MIDI:
    - **Faint star science** (like single-aperture NGS)
    - **Phase-referenced imaging**



PRIMA Modes Details



NTT SOFI Image of galaxy ESO 548-81

- **Astrometry**
  - Primary star: science target, bright (K<8), possibly has planet, used to phase instrument
  - Secondary star: dim (ΔK<5), background, astrometrically stable (as verified by RV if necessary)
  - ΔOPD between two interferometers → astrometric separation vector → science at the ~30μas level
- **Faint object science**
  - Primary star: bright (K<8), boring, used to phase instrument
  - Secondary star (or ? see image above): science target, dim (ΔK<5), fed into AMBER/MIDI
  - V^2 measurements of AMBER/MIDI → science
- **Phase referenced imaging**
  - Like faint star science operationally, with addition of PRIMET metrology
  - V^2, Δφ measurements of AMBER/MIDI → science

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Astrometry Mode Example: PTI Dual-Star Observations of 61 Cygni

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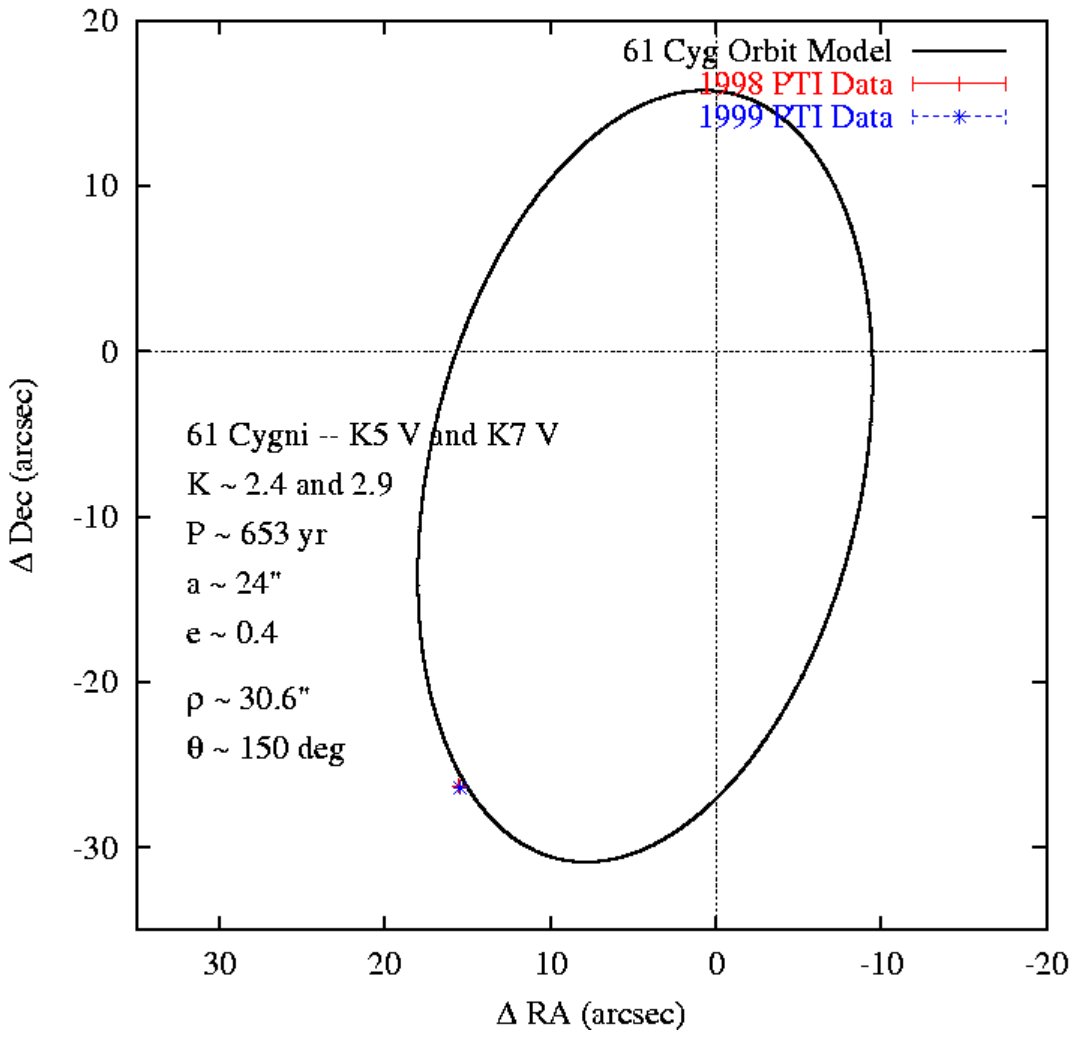
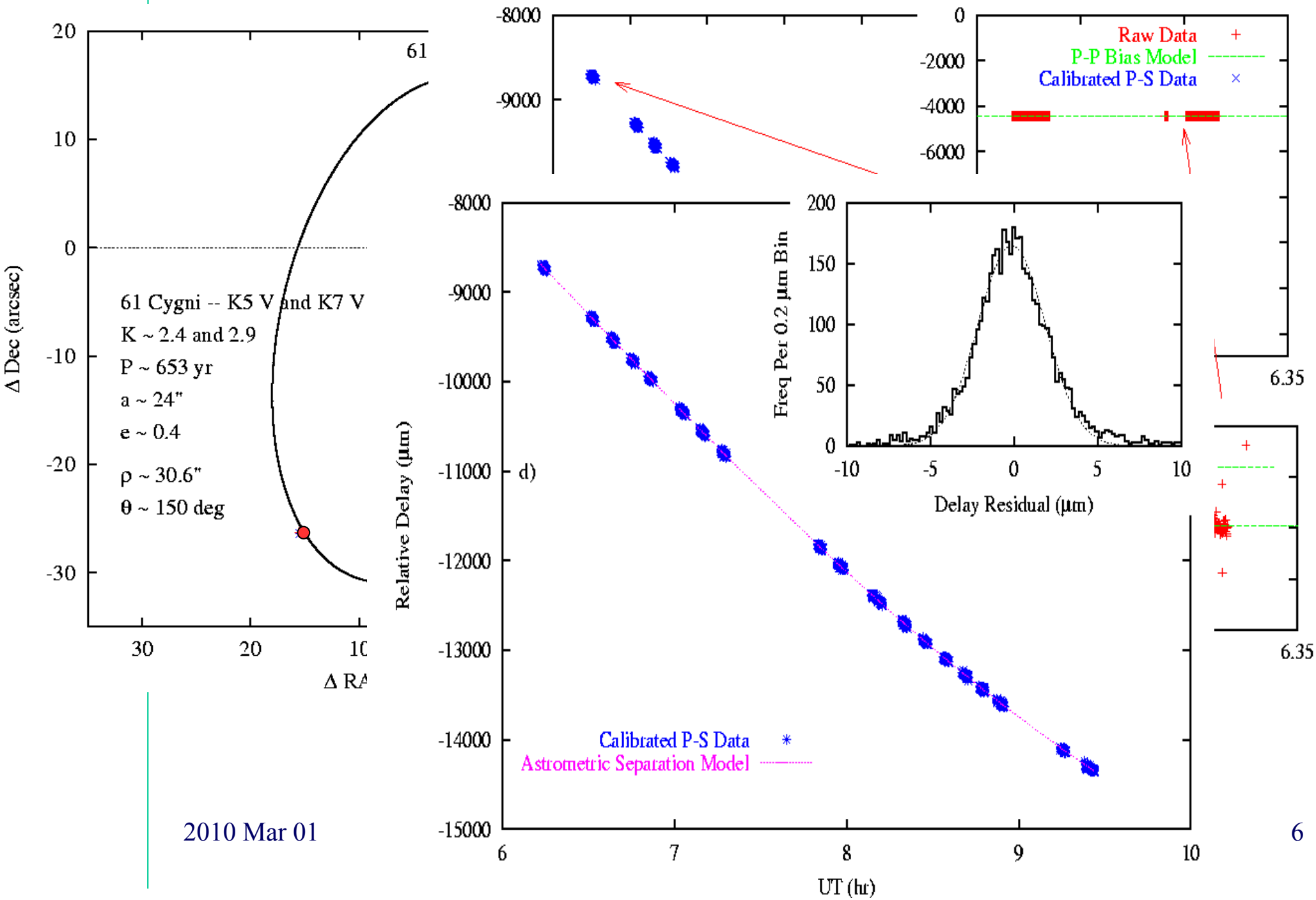
- Palomar Testbed Interferometer (PTI)
  - NASA-JPL dual-beam testbed
  - K-band, 109m baseline
  - Operated 1997-2009
  - *Very* limited sensitivity
- 61 Cygni
  - Nearby K-dwarf Visual Binary (*K*~2.5)
  - ~30” separation
  - ~ 650 yr period eccentric orbit
  - ‘God’s gift to dual-star testing’ (if you live in the N hemisphere, δ=+38°)
- We have it on Good Authority (Marcy) that There is *Nothing* Going on in This System WRT Planets



PTI Astrometry 61 Cygni I.



PTI Astrometry on 61 Cygni II.

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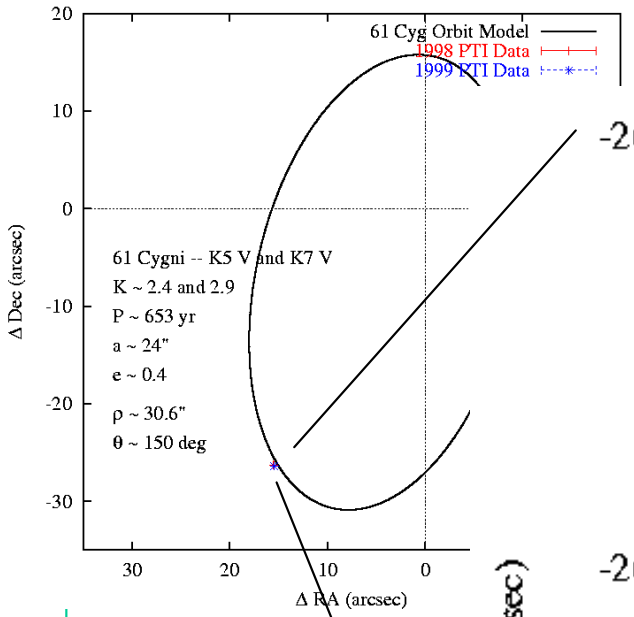
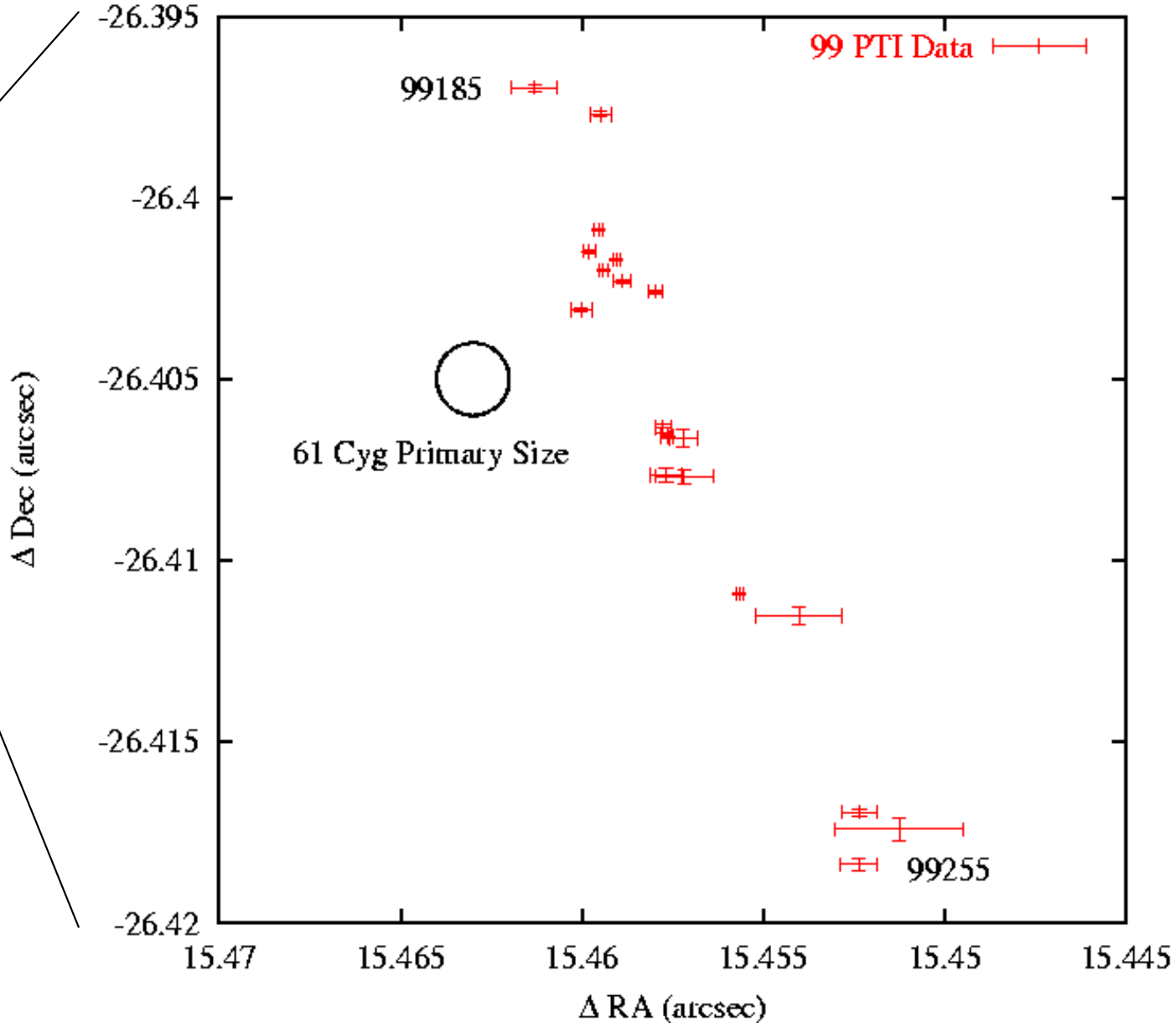


2000x



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2010 Mar 01

61 Cyg 1999 Declination-Only Data

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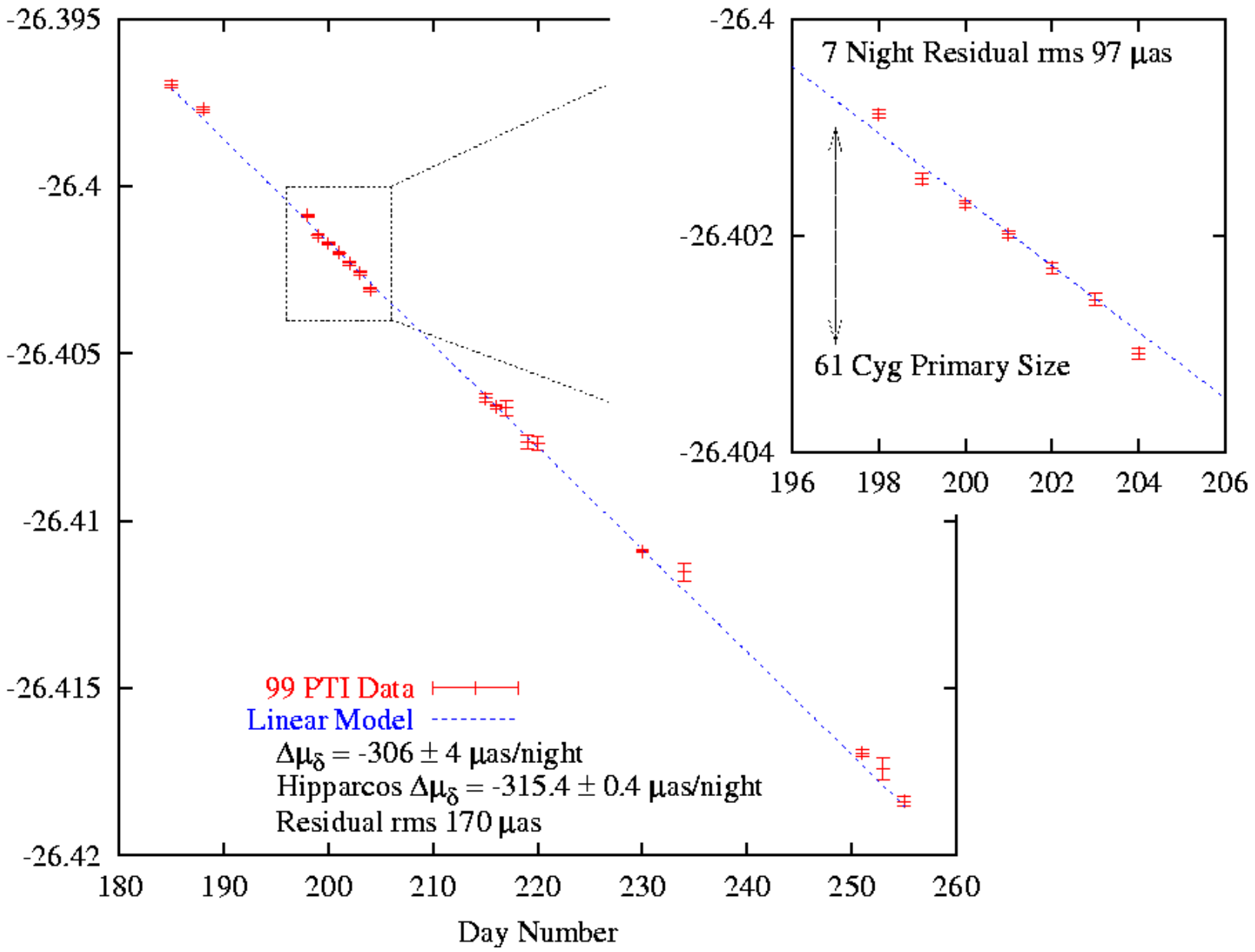

Experimental Verification

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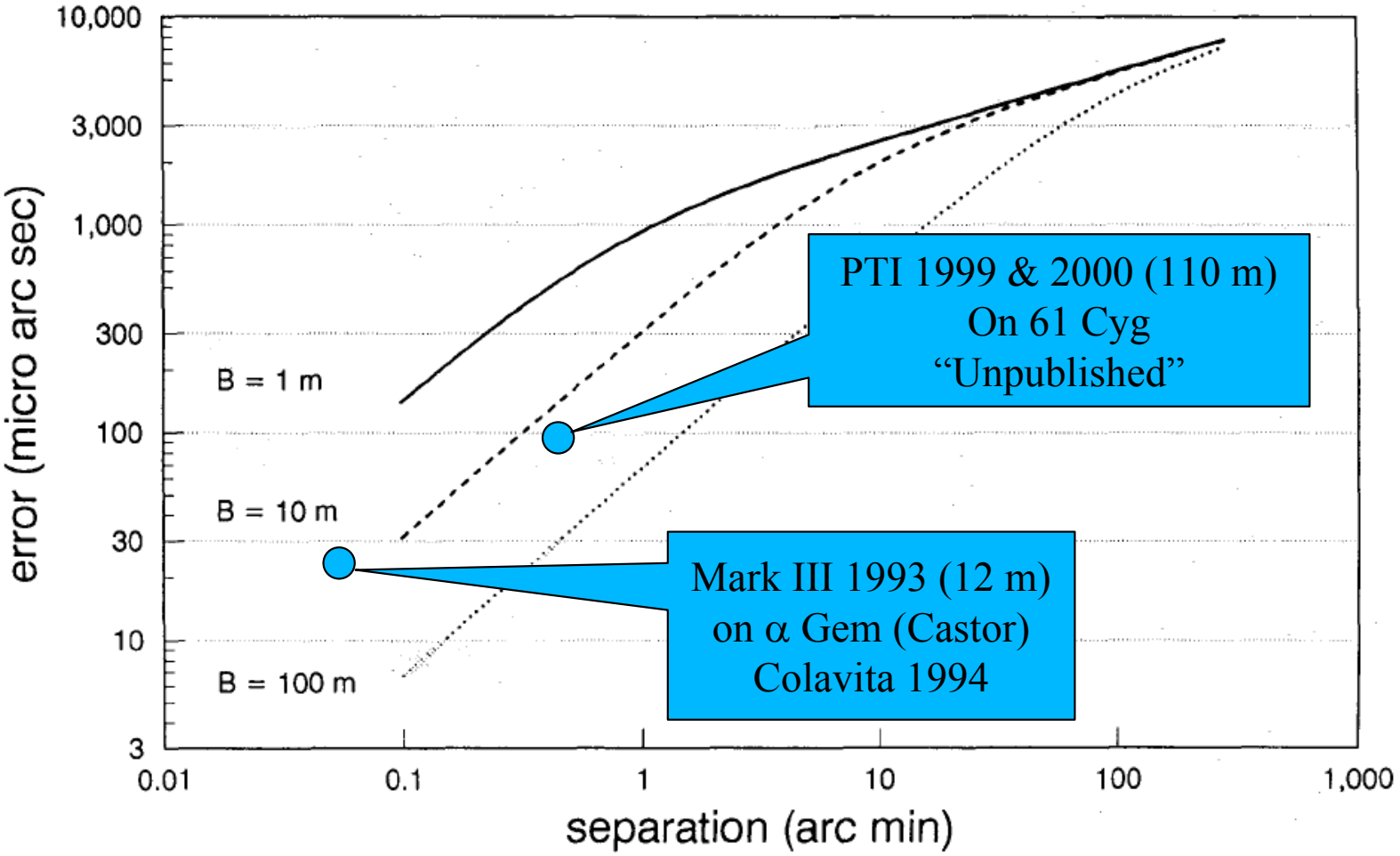

Fig. 2. Narrow- and very-narrow-angle astrometric error for several baseline lengths using measured Mauna Kea turbulence profiles and an integration time of 1 h

From Shao & Colavita 1992

Faint-Object Mode Example

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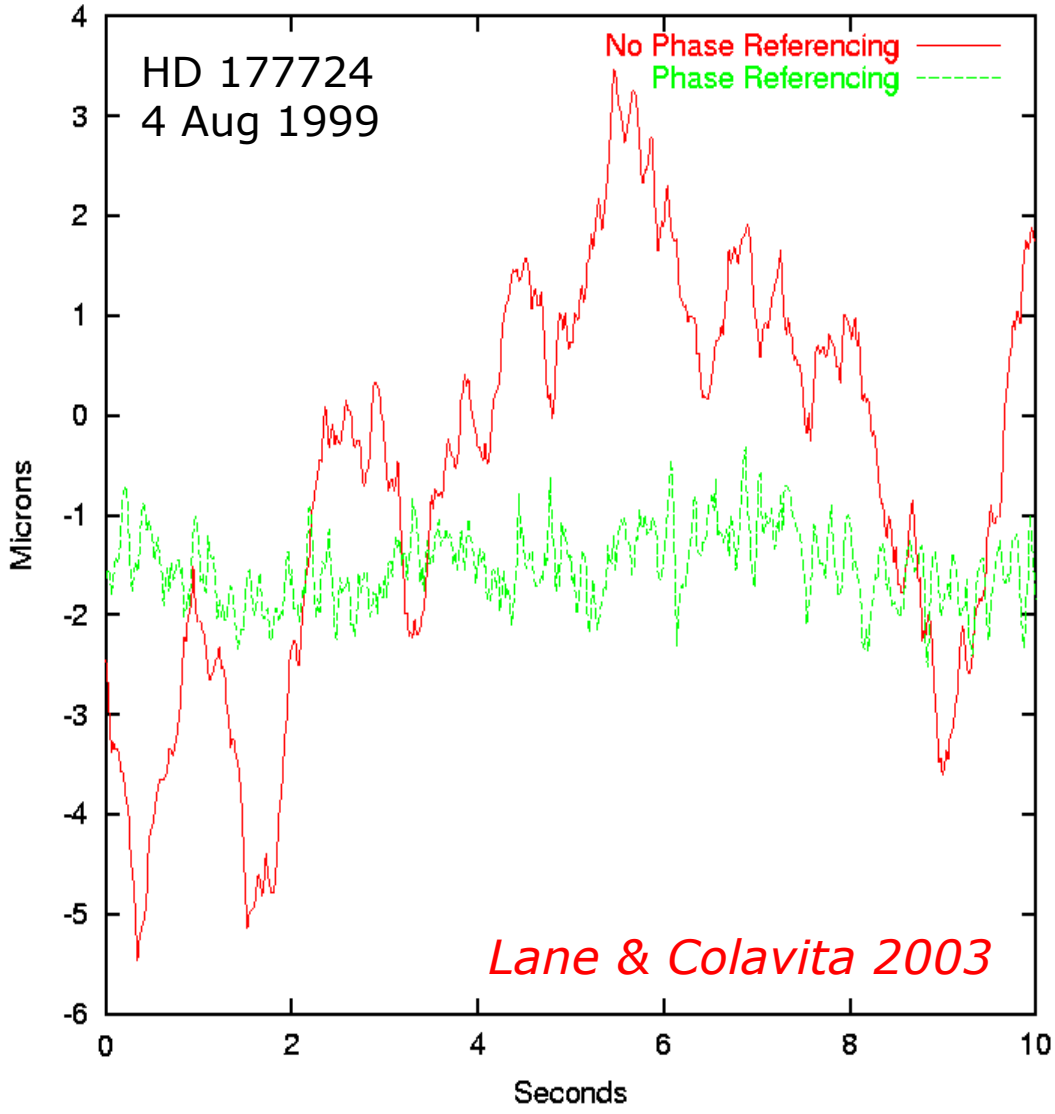
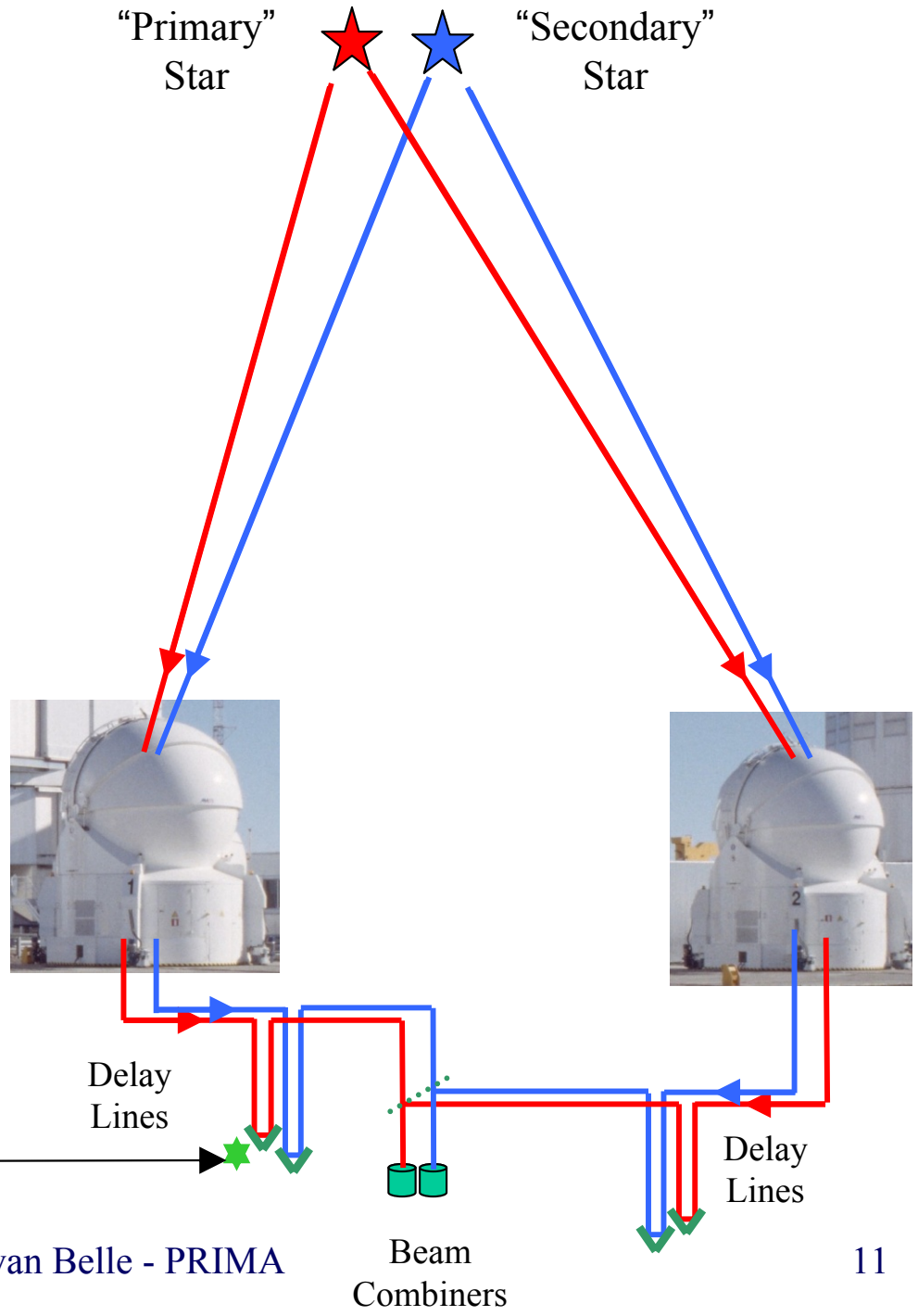
- Objective: long synthetic coherence time for faint-object detection – fundamentally enabled by dual-beam optical design
- The analog of single-aperture AO
  - Fringe tracking piston correction signal on one object is used to correct the piston on a second, nearby (isoplanatic separation) object
  - Required for VLTI (and KI) faint-object interferometry
  - Phase error with and without loop closed between the two PTI fringe trackers
  - Two data segments taken within 200 s of each other



Phase-Referenced Interferometry Mode

- PRIMA's 3rd mode
- Start with the 1st mode: 'Simple' PRIMA faint-star operations
  - Each telescope provides two fields on-sky
  - Two beam combiners
  - Different sky positions → Slight difference in pathlength through interferometry lab
- Phase is being corrupted by the atmosphere
  - And lost; only observable in this mode is visibility amplitude



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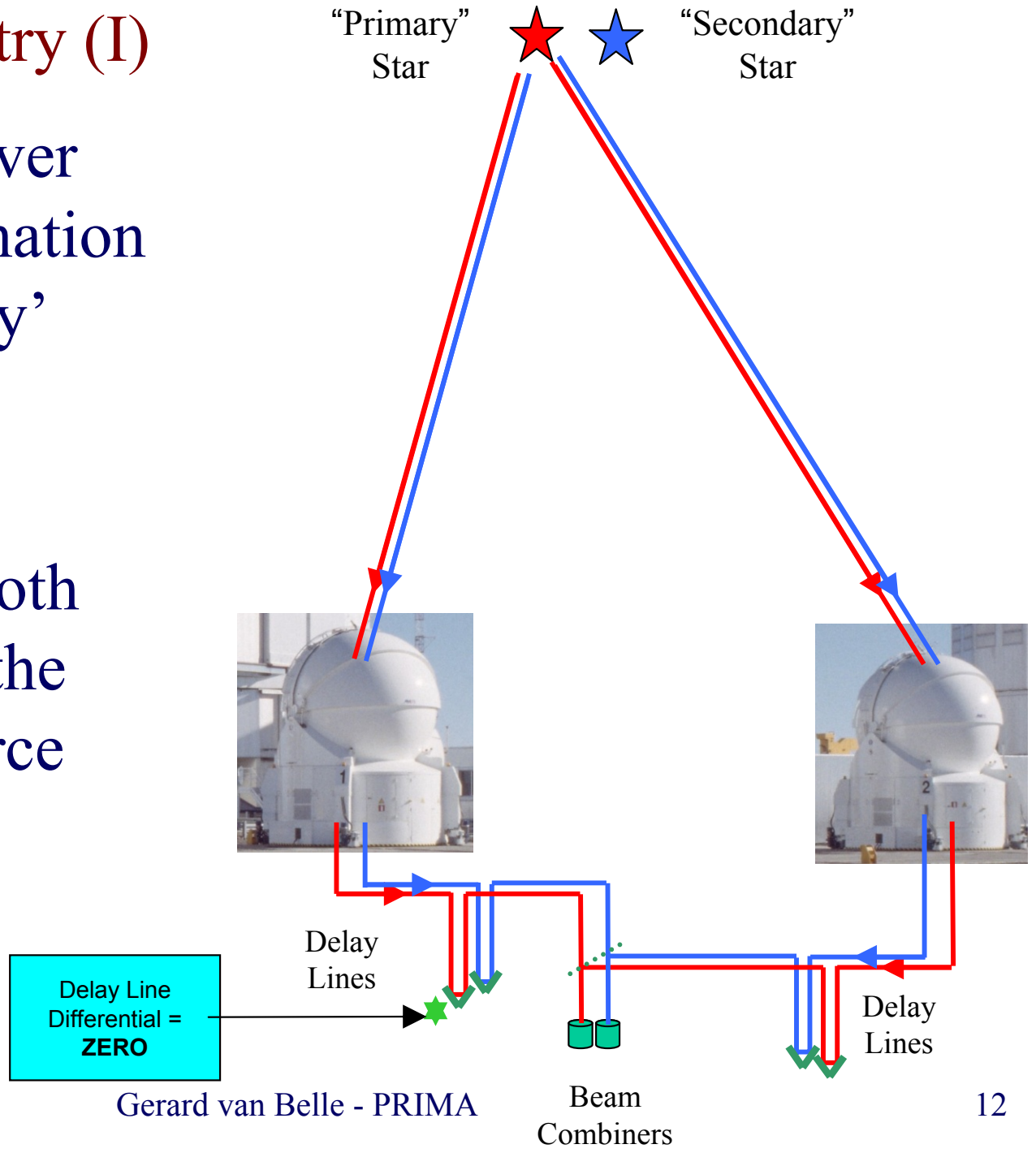
Phase-Referenced Interferometry (I)

- How to recover phase information of 'secondary' source?
- 3 easy steps
- First, steer both beams onto the primary source



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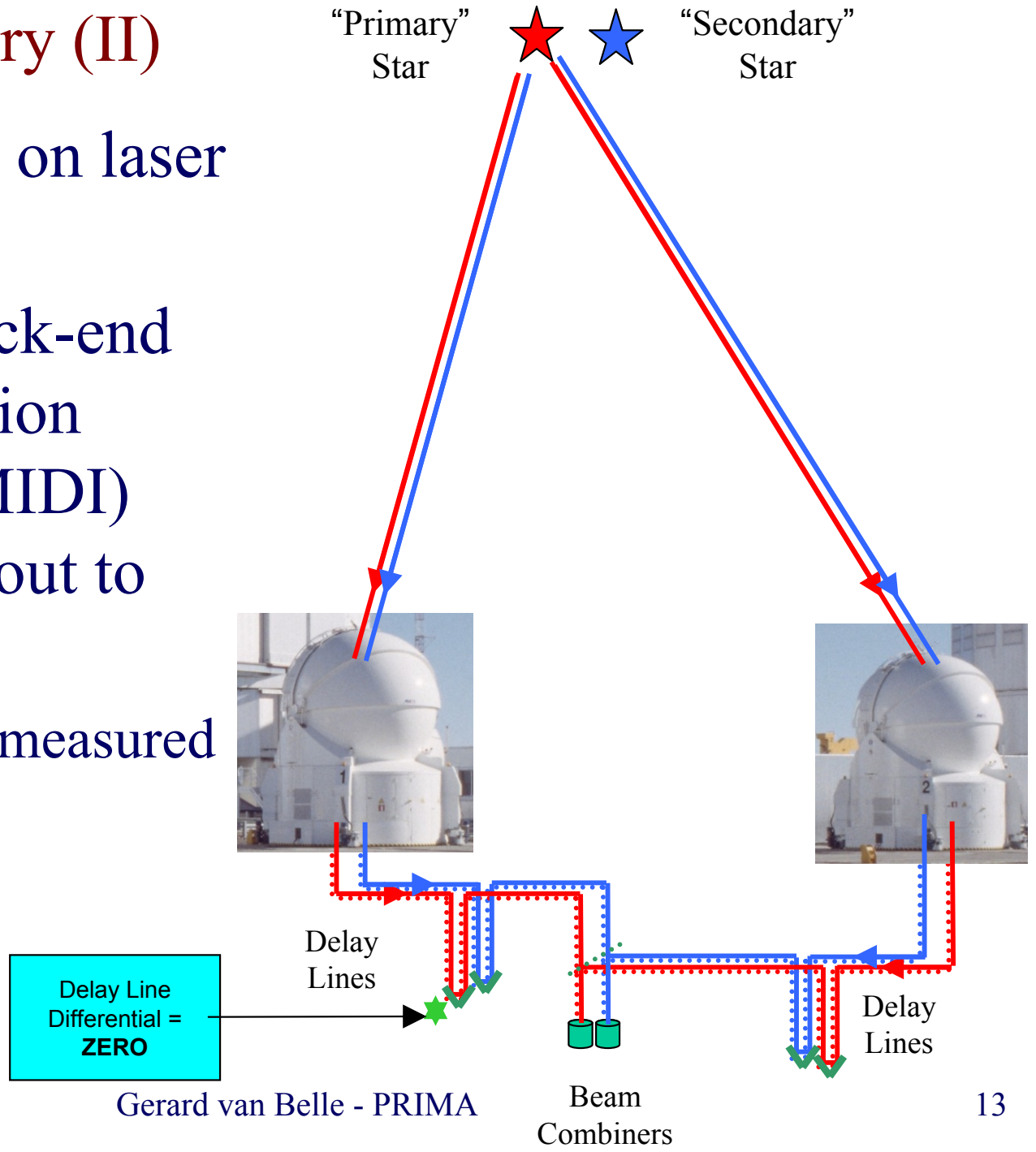
Phase-Referenced Interferometry (II)

- Second, turn on laser metrology
- Connects back-end instrumentation (AMBER, MIDI) optical path out to telescopes
  - Pathlength measured to ~10nm



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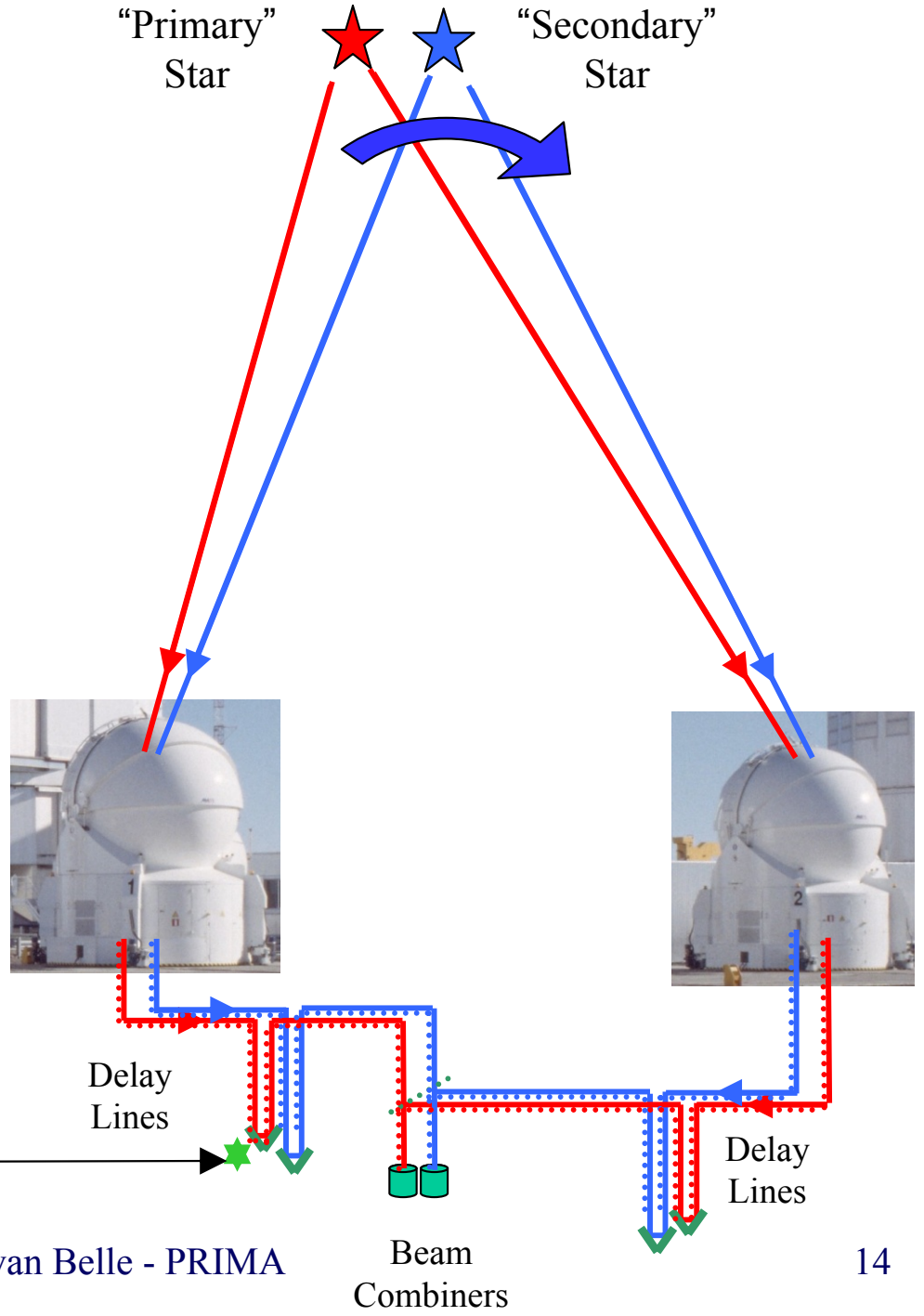
Phase-Referenced Interferometry (III)

- Third, sweep secondary FOV beam over target of interest
- Maintain metrology tracking
  - Pathlength OPD is directly related to (relative) phase
  - Recovers phase in a 1-D sense
  - Earth rotation of baseline can build image



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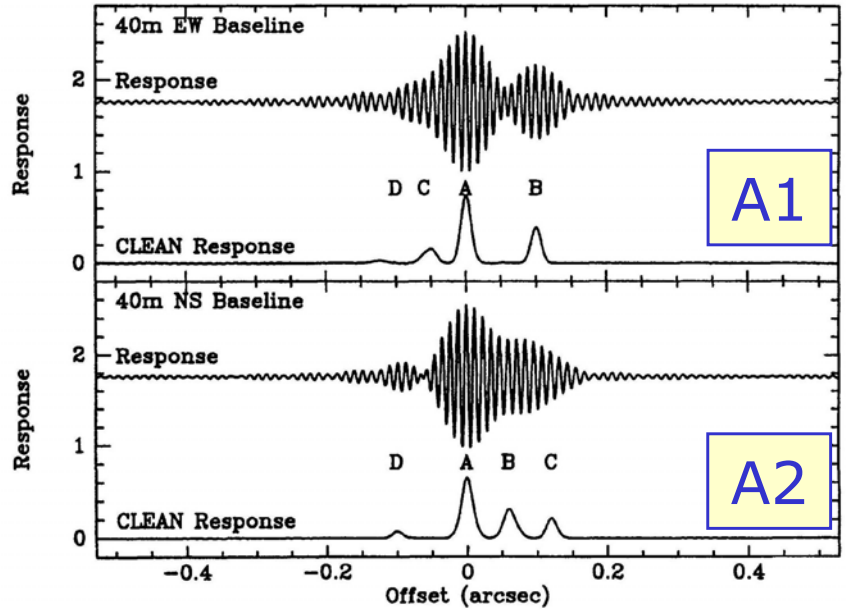
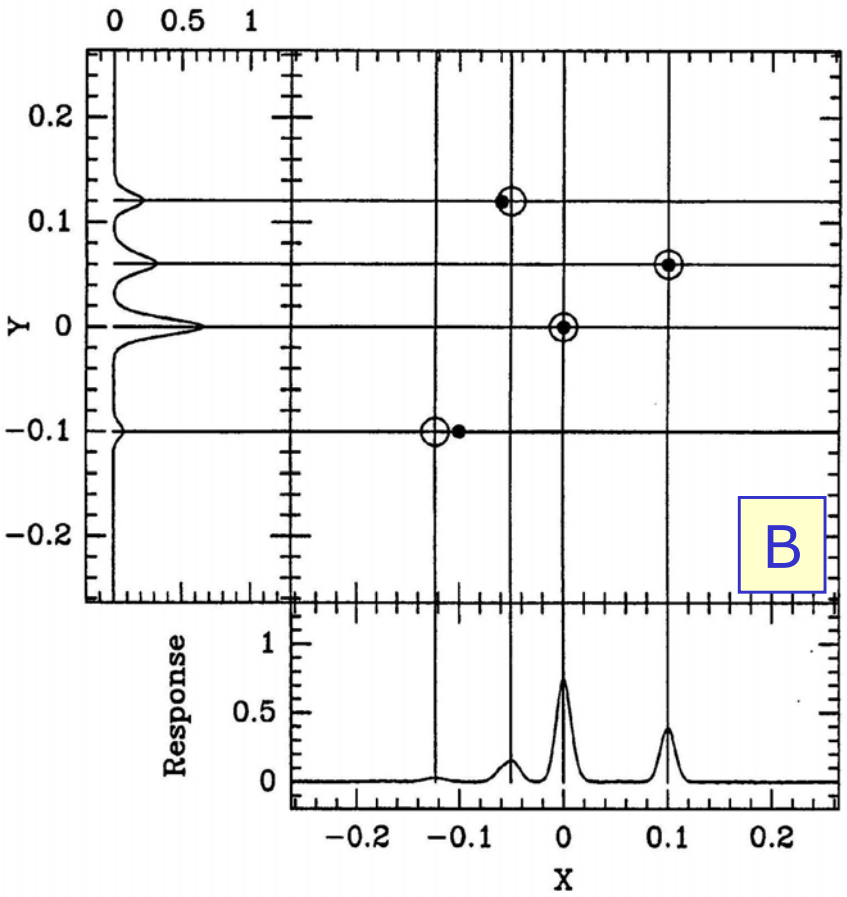
Phase-Referenced Interferometry (IV)

- Simple example of image reconstruction from Dyck, Benson, Schloerb (1995)
- Synthetic interferograms & CLEAN components from a 40m E-W baseline (A1)
- 40m N-S baseline (A2)
- Backprojection (B)
- A:B:C:D flux ratio is 10:5:3:1





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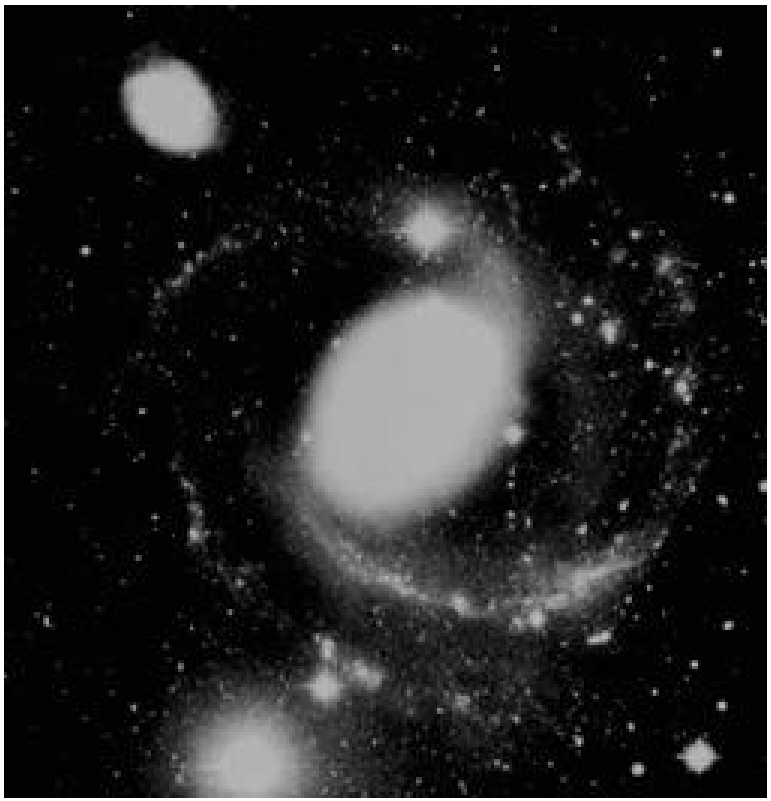
Novel Ideas for PRIMA Observing:
Parallaxes

- Distance determination
- Relative sense
  - Use dim (eg. distant) reference stars, correct for relative parallax
  - This is effectively how ~1 mas HST FGS parallaxes are done (eg. Benedict et al 2007)
- Absolute sense
  - Start with a sample of known 'fixed' fiducials
    - eg. AGNs
  - Find any science targets that may lurk nearby them
    - Then proudly declare those targets are of course interesting



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Novel Ideas for PRIMA Observing:
Very Narrow-Angle Astrometry of Hierarchical Systems

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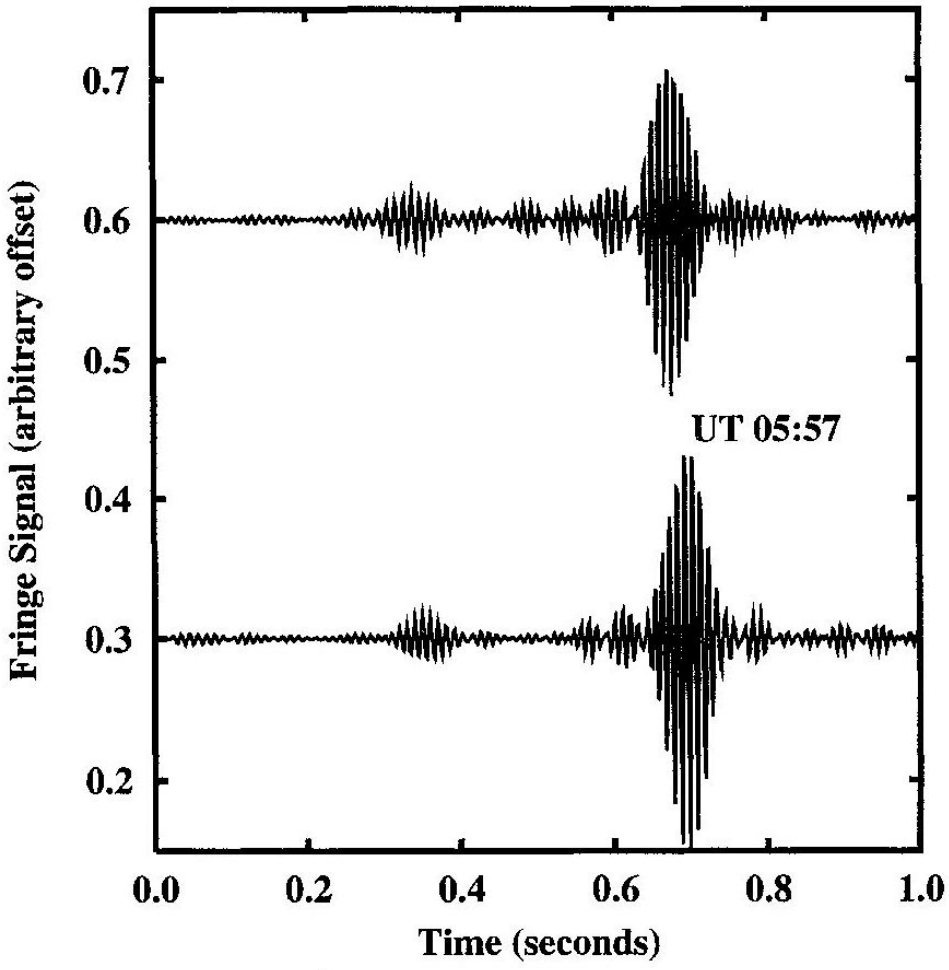
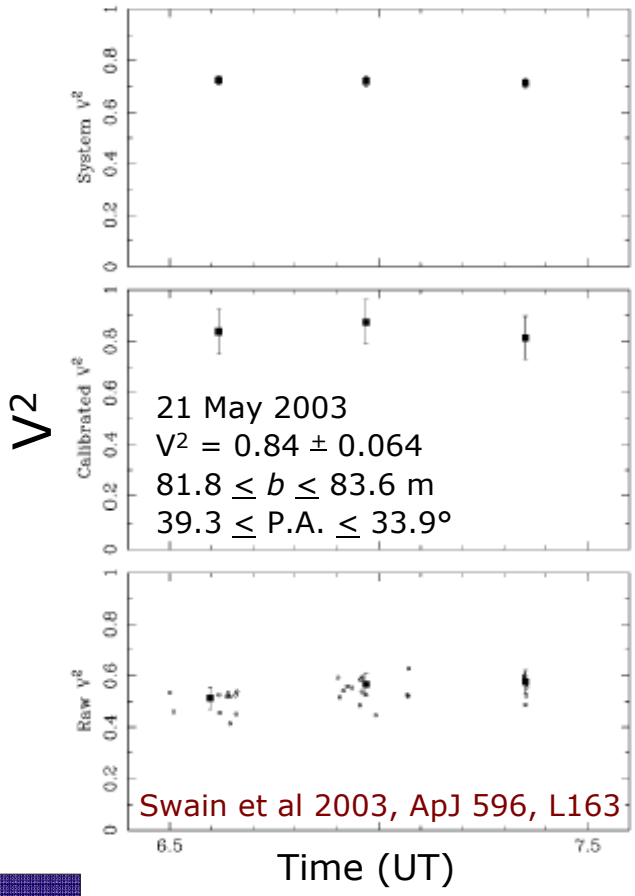
- Can use a system with one wide (ρ=1-30”) and one narrow (ρ<1”) component
  - Inherently well setup for PRIMA observing: use bright single star to fringe track
- Fringe ‘slow-scan’ of binary first demonstrated at IOTA
  - ζ Her separation of ρ=1466±5 mas
  - Limited to milliarcsecond precisions due to scan time of ~300mas
- Many examples of attractive targets in Tokovinin catalog

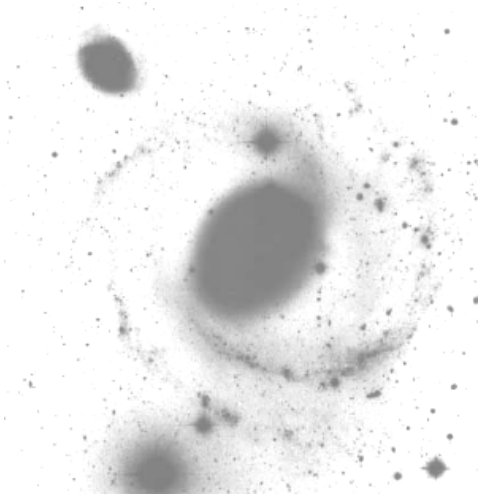


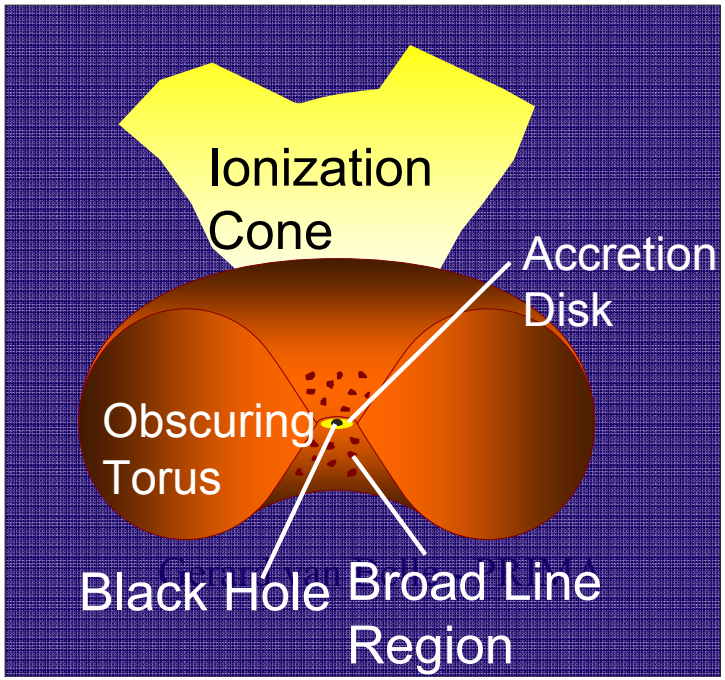
Observations of ζ Her:
Dyck Benson & Schloerb 1995

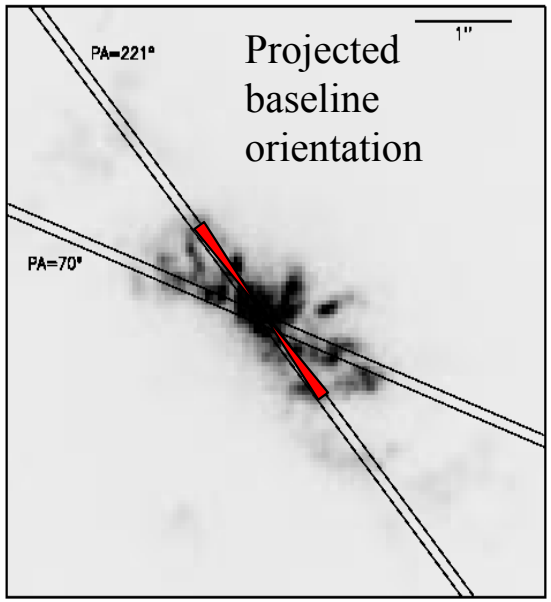
Novel Ideas for PRIMA Observing: AGNs

- Keck Interferometer observations of NGC4151
  - First extra-galactic source detected with optical/IR interferometry
  - Measured 2 micron emission to be very compact ≤ 0.1 pc.
  - *The measurements rule out models in which the majority of the K-band nuclear emission is produced on scales larger than 0.1 pc for this P.A.*
  - Results interpreted as 2 μm light originating from thermal gas (dust possible)
- Establish which sources have nearby bright star for fringe tracking
- PRIMA: Need bright guide star nearby AGN









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Novel Ideas for PRIMA Observing:
Planet Transits, GR Effects

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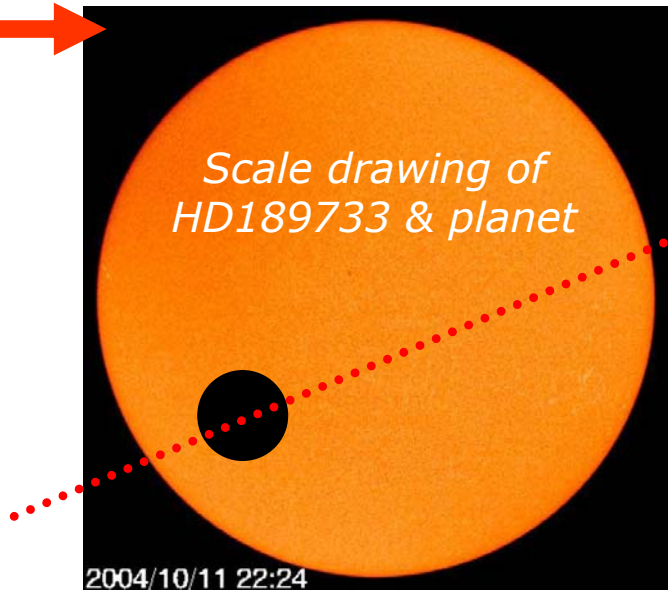
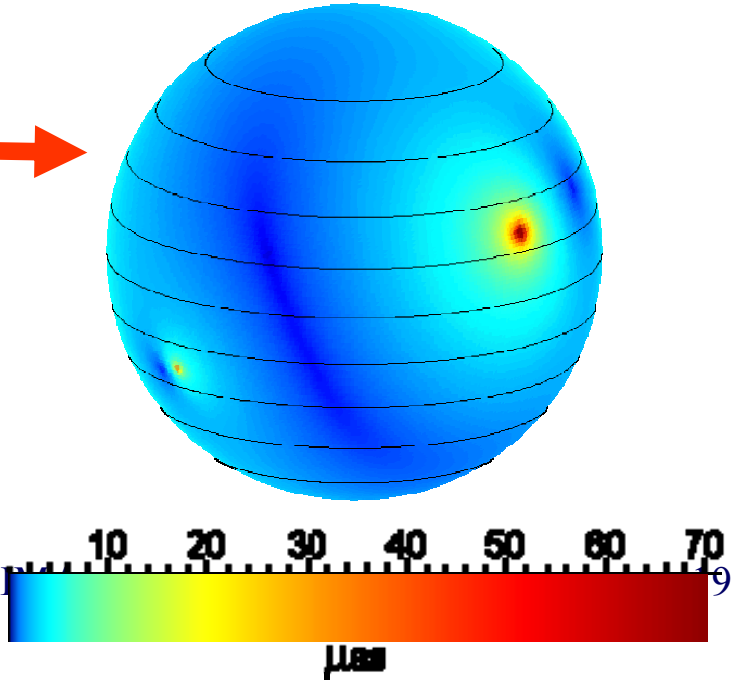
- Planet transit host stars
  - Transit event induces a photocenter shift on the star
  - Effectively a perfectly black 'starspot'
- Example case: HD189733
  - 0.376±0.031 mas (CHARA, Baines & van Belle et al. 2007)
  - Transiting planet diameter of ~60μas
  - Ratio of the areas indicates a shift of ~5uas on star centroid
    - This may be difficult
- Direct detection of GR effects
  - Measure astrometric shifts due to nearby passage of Jupiter, other large solar system bodies
- Weighing solar system objects
  - Precision astrometry of orbits





PRIMA Commissioning

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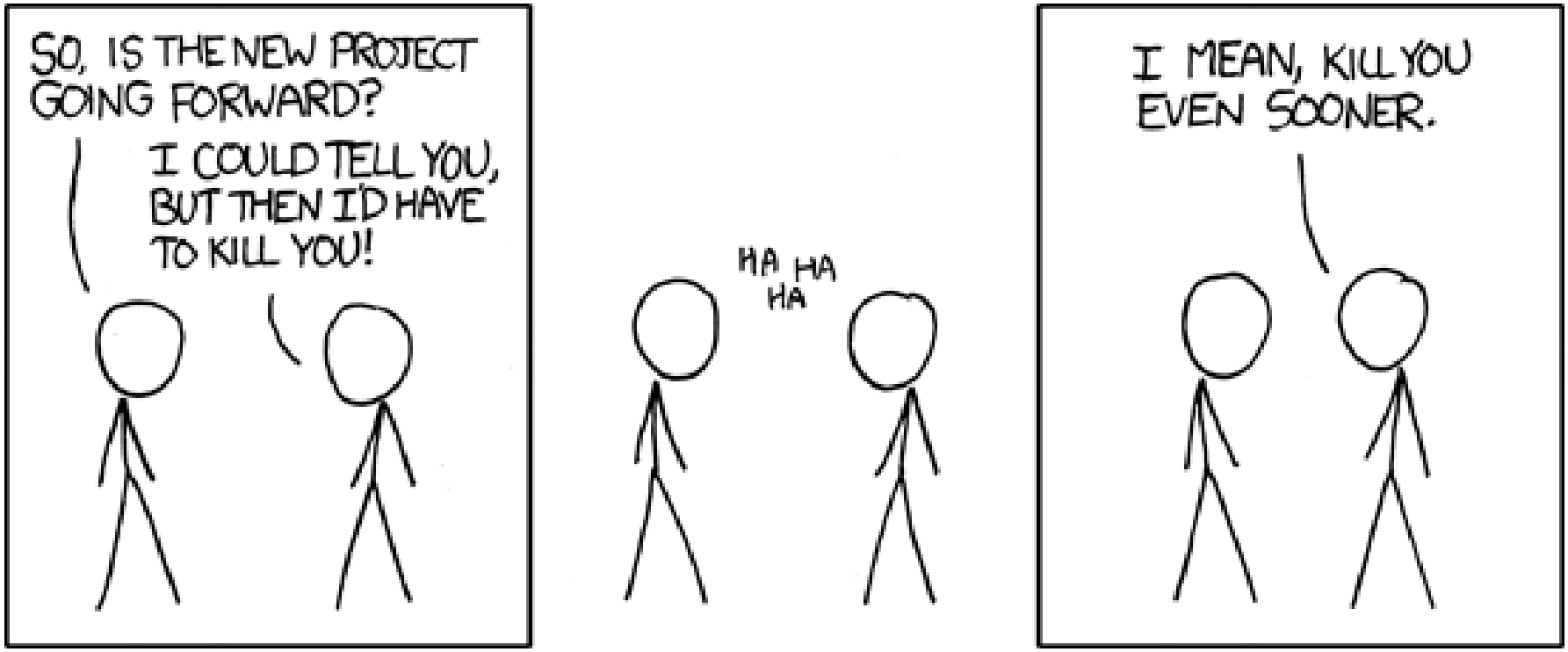

www.xkcd.com

- All this possible science sounds *great*
- When's it going to be ready?
  - See cartoon above
- Let's take a step back and see *how* it's being done

PRIMA Architecture

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VLTI PRIMA Project

- Auxiliary Telescopes (ATs)
  - Collects starlight
- Star Separators (STSs)
  - Picks out two sources in a 120” FOV
  - Tip-tilt field stabilization (STRAP)
  - Metrology endpoint
- Main Delay Lines
  - Provide optical path delay to both starlight beams
- Differential Delay Lines (DDLs)
  - Provide optical path delay to individual starlight beams
- Fringe Sensor Units (FSUs)
  - Twin fringe trackers for starlight
- PRIMA Metrology (PRIMET)
  - Ties two starlight beam paths together
- Infrared Image Stabilizer (IRIS)
  - Tracks residual tip-tilt errors in lab
- MARCEL
  - Calibration source

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PRIMA Commissioning: Sub-System Testing during 2009

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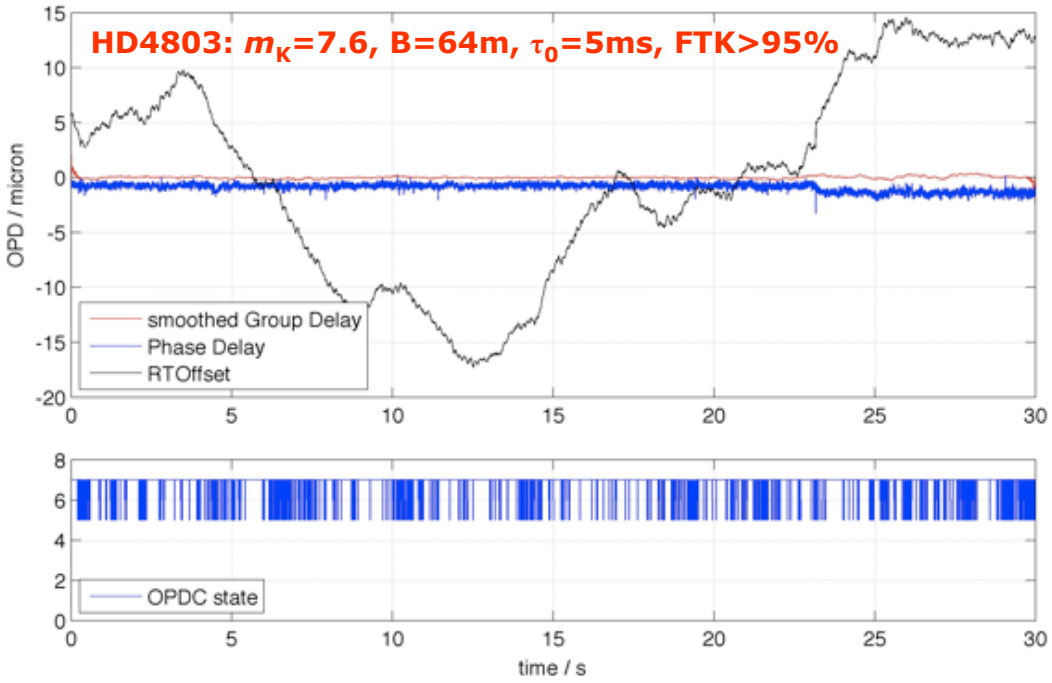
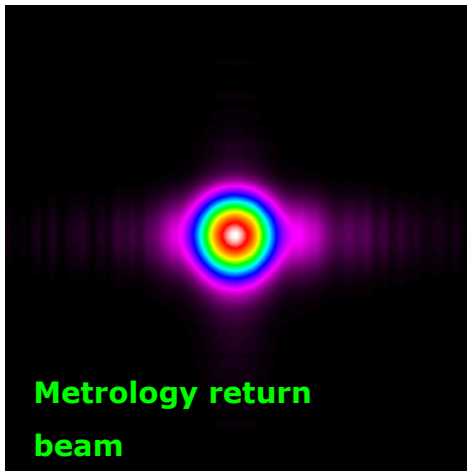
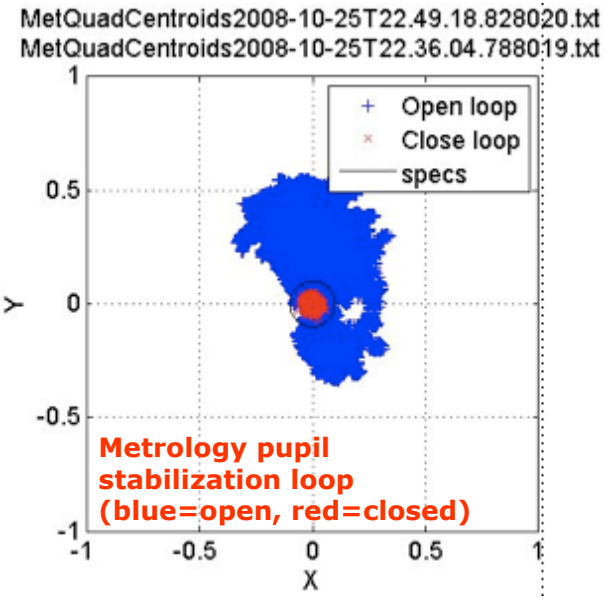
VLTI PRIMA Project

- FSU demonstrated good performance
  - $m_K \approx 8$ expected for reasonable conditions
- PRIMA metrology operating out from VLTI lab to ATs & back
- Additional subsystems functional and/or maturing rapidly
  - Differential delay lines, ISS software, star separators, astrometric software







PRIMA Commissioning: FSUA+MIDI Fringe Tracking Tests

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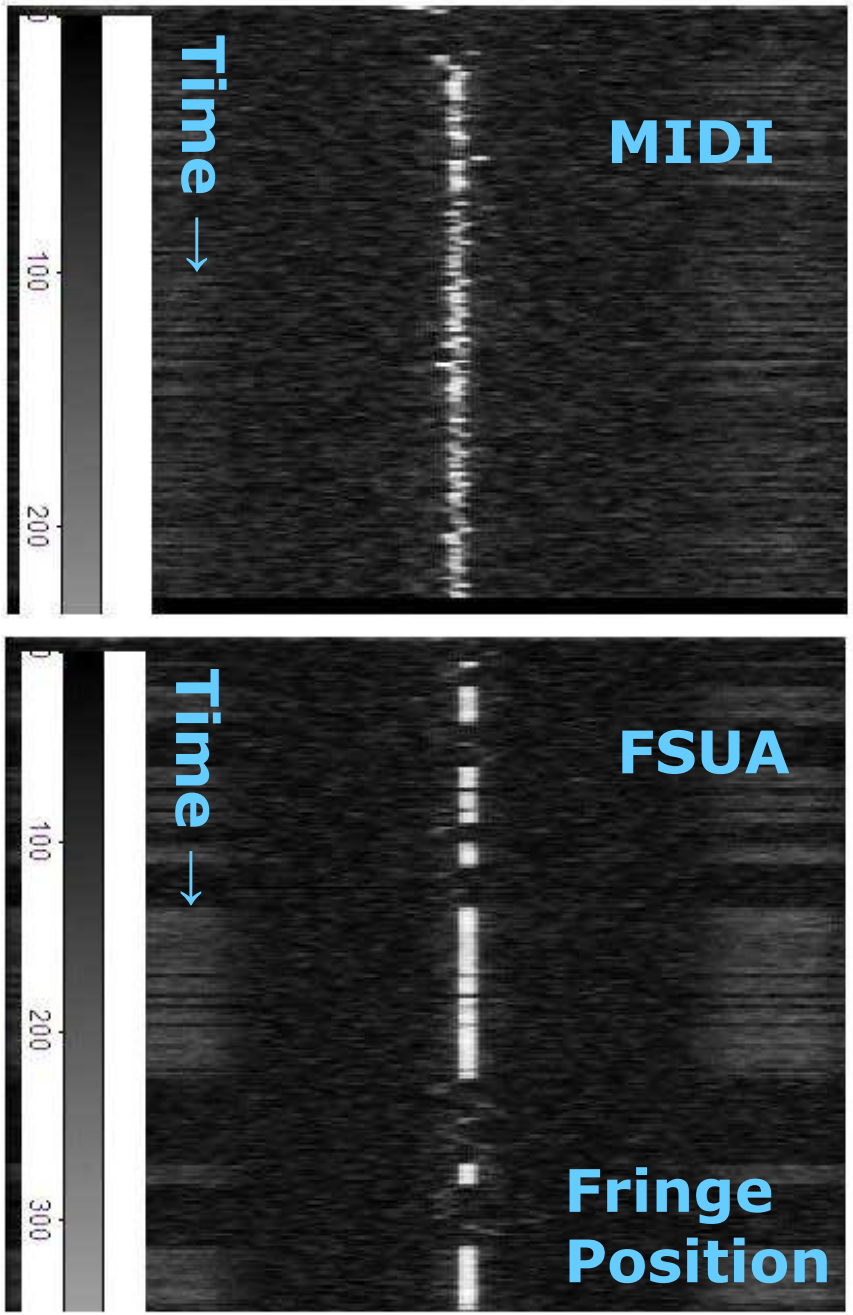

- **Engineering test** of PRIMA+MIDI
  - MIDI can provide fringe tracking (FTK) for itself
  - Same function can also be provided by PRIMA
  - Tests carried out in July, Sept 2009 commissioning runs
  - **Caveat emptor: Non-standard mode**
- Promising results
  - FTK errors (group delay residuals) are an order of magnitude less with PRIMA FTK
  - Also, fringes detected for targets too faint for MIDI FTK ($F_{12} \approx 1$Jy)
    - Well below the AT limit of 20Jy
  - Calibration **unclear**, though, due to open photometry questions – work in progress on that front
- Future work
  - Follow-up tests with PRIMA+MIDI, PRIMA+AMBER in dual-feed

PRIMA Commissioning: Dual Beam tests in Dec 2009, Feb 2010

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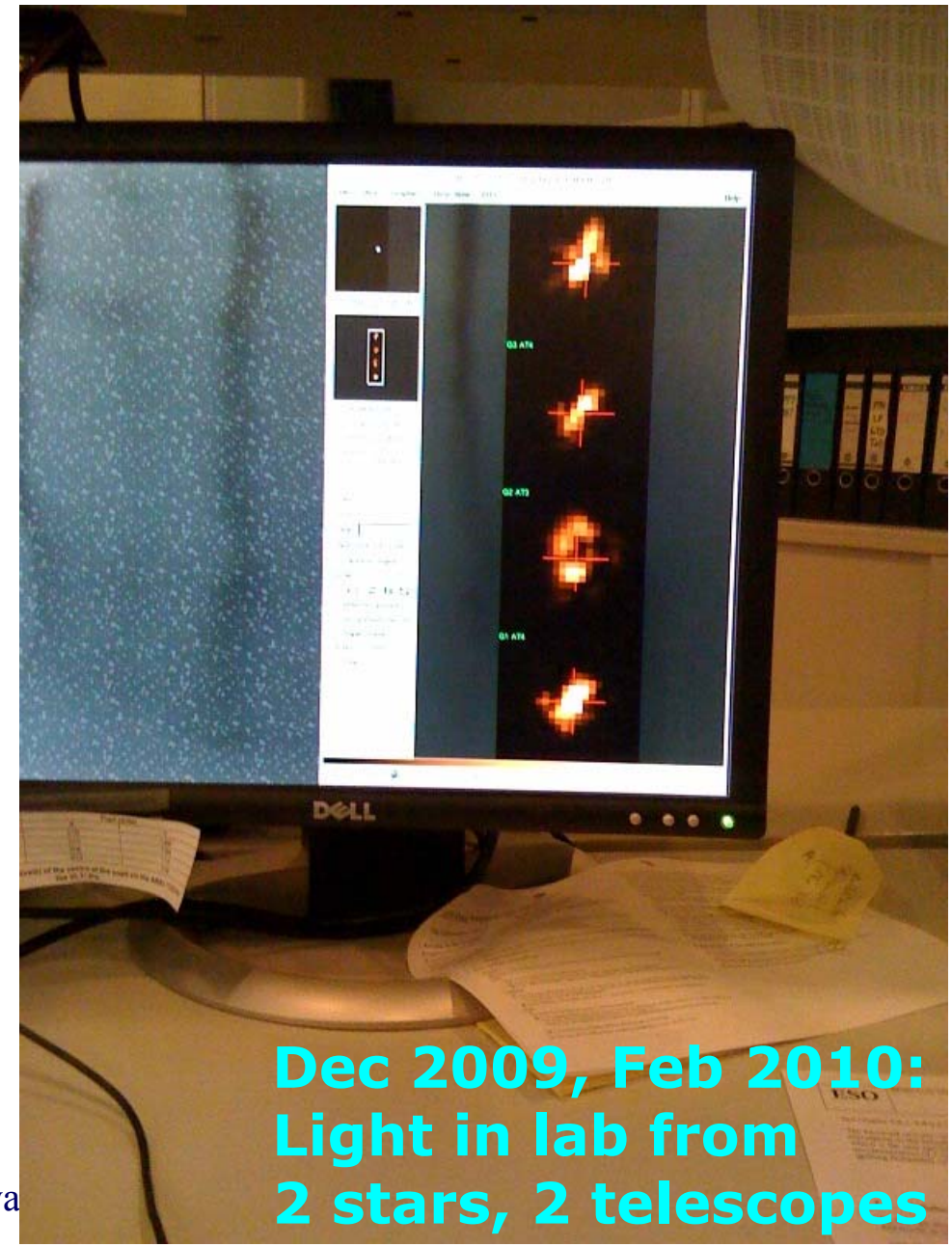
- PRIMA's unique strength will be through simultaneous interferometry of 2 stars at once
- Four starlight beams (2×2 stars) stabilized in tip-tilt for the 1st time in VLTI lab in Paranal in Dec 2009
  - Further testing in Feb 2010
  - Dual-star astrometry then follows with 2×FTK+metrology
- Development of this functionality into a fully operational capability the major goal of P85 commissioning work
  - Many sub-system punchlist items remain, along with system integration challenges
  - First PRIMA astrometry to be demonstrated in P85



PRIMA Commissioning Plans: P85, P86

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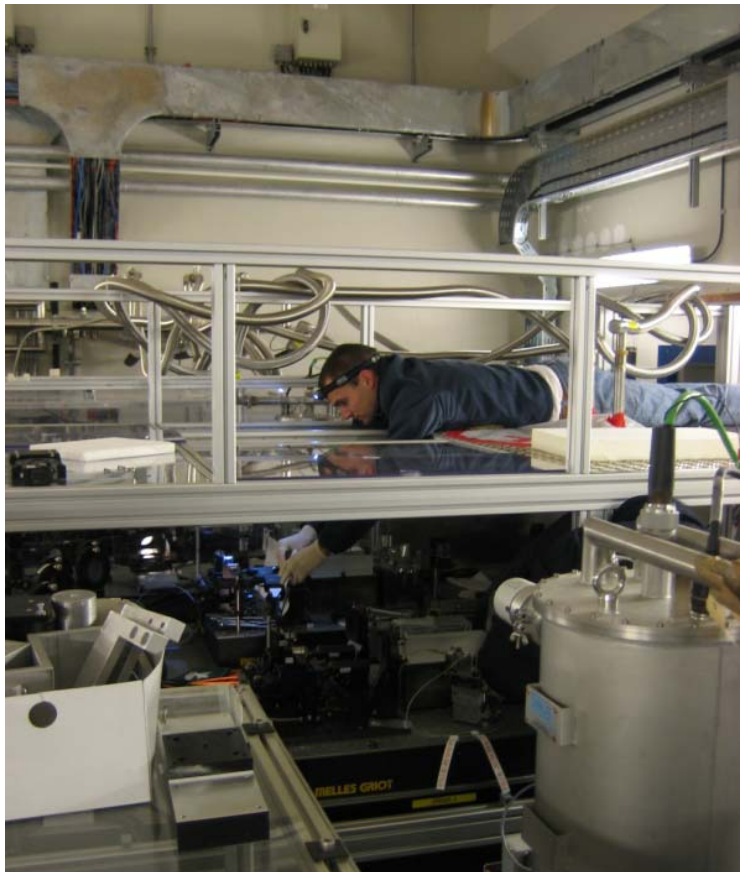
- Next commissioning runs: July, September 2010
  - Heavy science subscription prior to July
  - Dual-star FTK demonstration → astrometric separation vectors
- Period 86 (Oct 2010-Mar 2011)
  - Astrometric commissioning runs
    - Minimum of 4×10^d
  - PRIMA + MIDI, AMBER-2T commissioning, SV?
    - Two short runs should suffice for faint object mode commissioning



Johannes Sahlmann (Geneva Obs.) does the PRIMA AIV circus act: trapeze not included

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