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VLTI Update
and
A Proposal for Optical 'Self-Cal'

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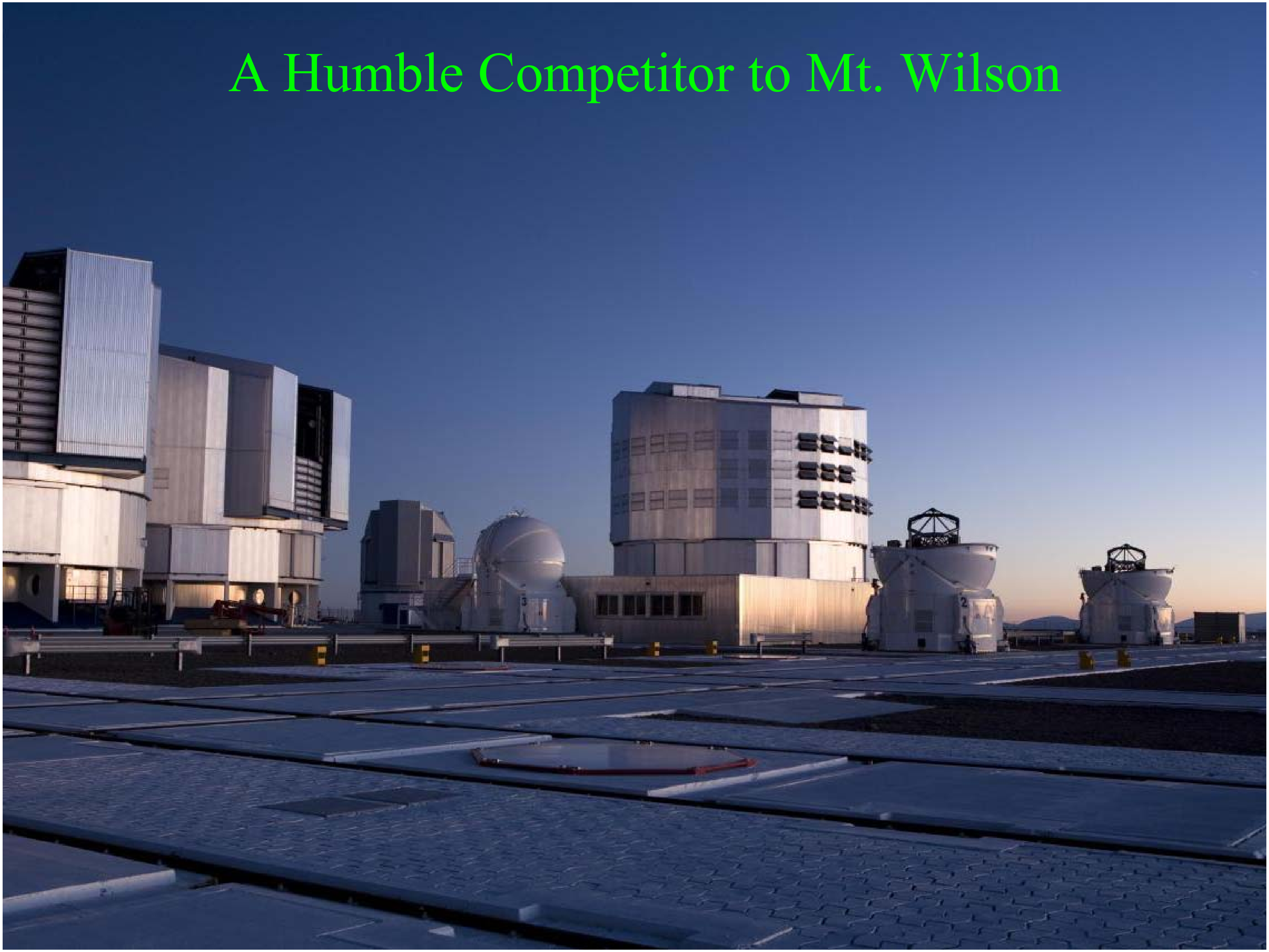
European Southern Observatory

March 9th, 2010

VLTI PRIMA Project

A Humble Competitor to Mt. Wilson



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VLTI PRIMA Project

VLTI status

- Mature instruments
  - AMBER/MIDI
  - FINITO
- VLTI Developments
  - AT Upgrades
  - Instrumentation
    - PRIMA
    - GRAVITY
    - MATISSE
    - PIONIER
  - Infrastructure studies
    - 2GFT (4×fringe tracking)
    - NAOMI (adaptive optics)
    - MAMMUT (pathlength control)

VLTI status: New Instruments

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VLTI PRIMA Project

- PRIMA
  - Dual-beam 2×AT, UT observing
- GRAVITY
  - Dual-beam 4×UT 10μas faint (m_K<19) astrometry
  - Probe strong gravity regime by observing galactic center
- MATISSE
  - 4×AT, UT L,M,N-band imaging
- PIONIER
  - Visitor instrument
  - 4×AT, UT K-band imaging

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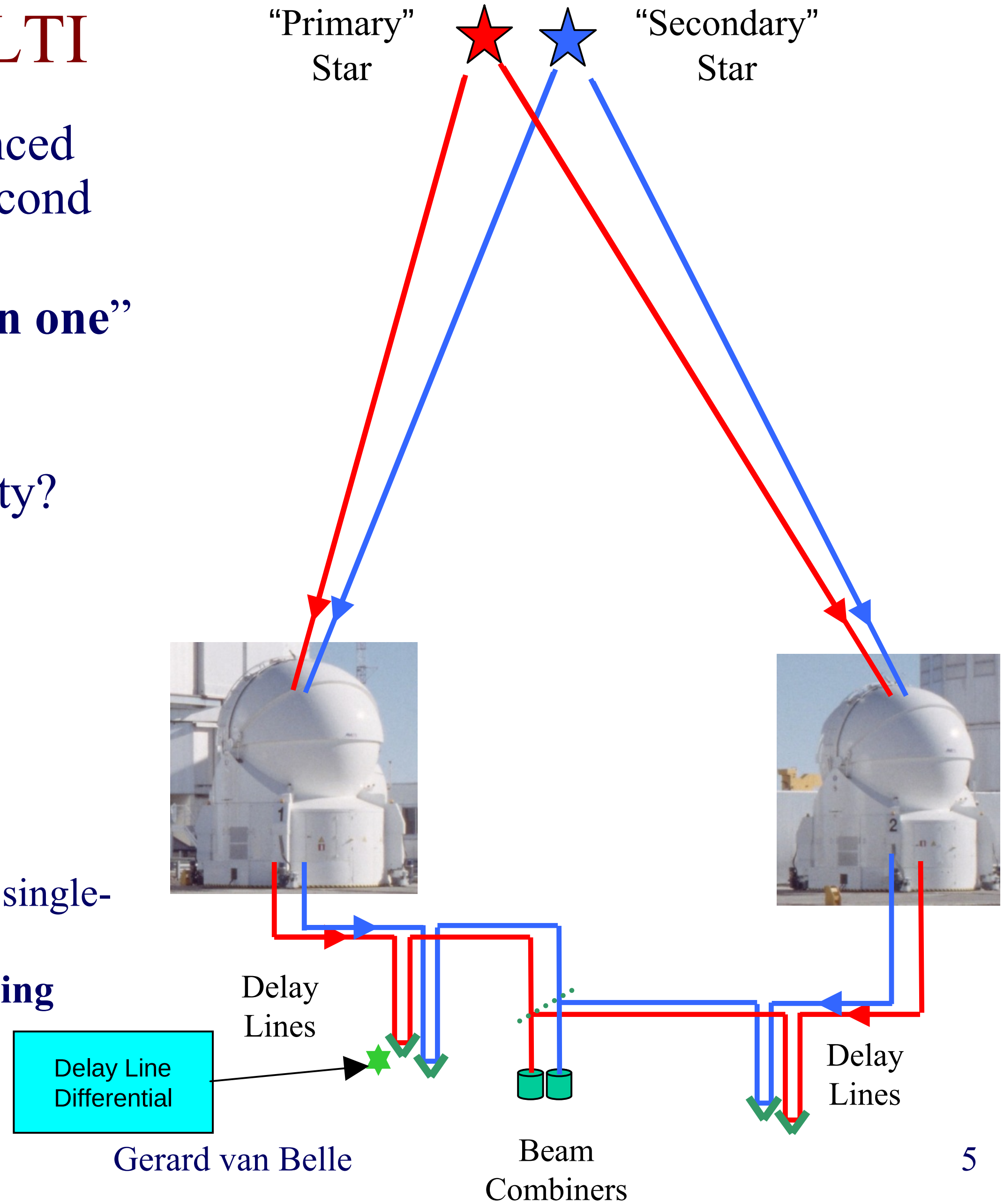
VLTI PRIMA Project

PRIMA: The Dual-Feed Facility for VLTI

- 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**



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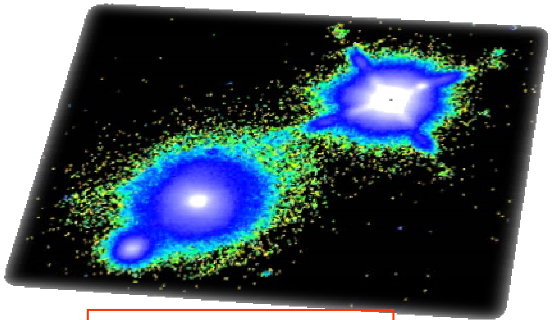
VLTI PRIMA Project

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

Faint-Object Mode Example

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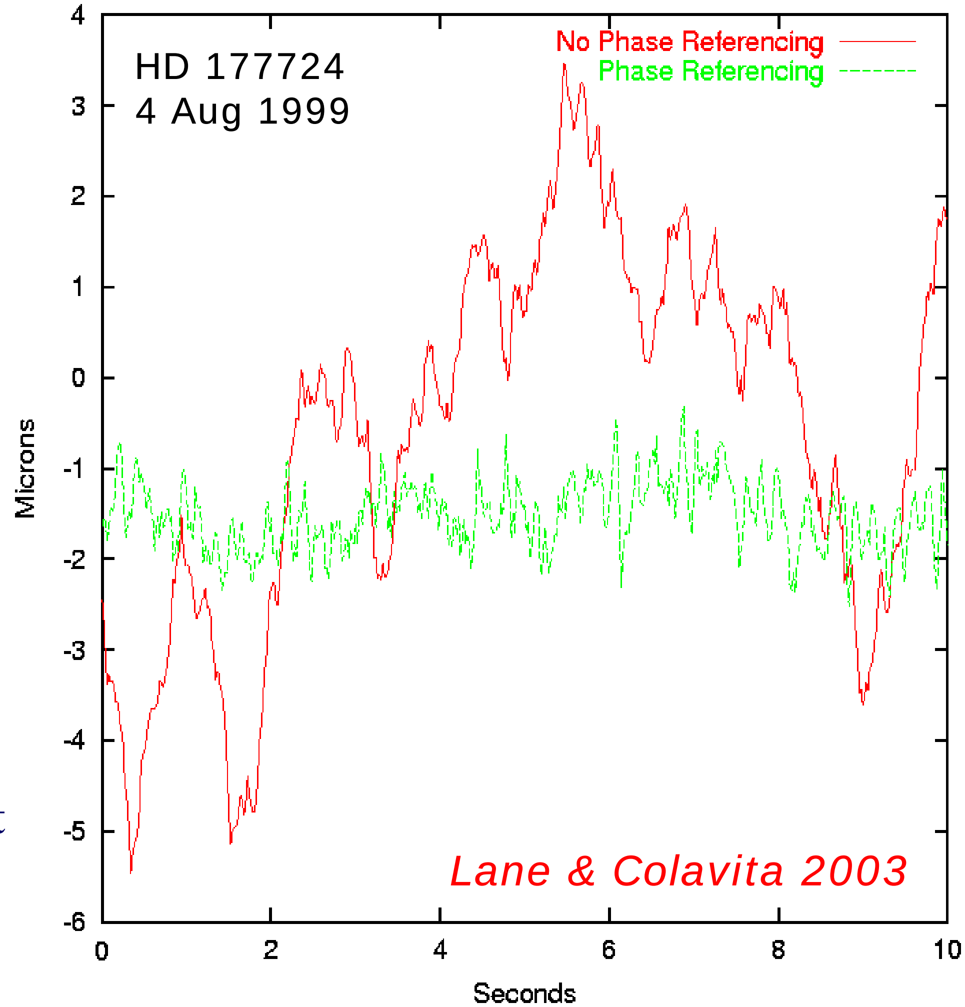
- Objective: long synthetic coherence time for faint-object detection – fundamentally enabled by dual-beam optical design
- The analog of single-aperture AO
  - Fringe tracking piston correction signal on one object is used to correct the piston on a second, nearby (isoplanatic separation) object
  - 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



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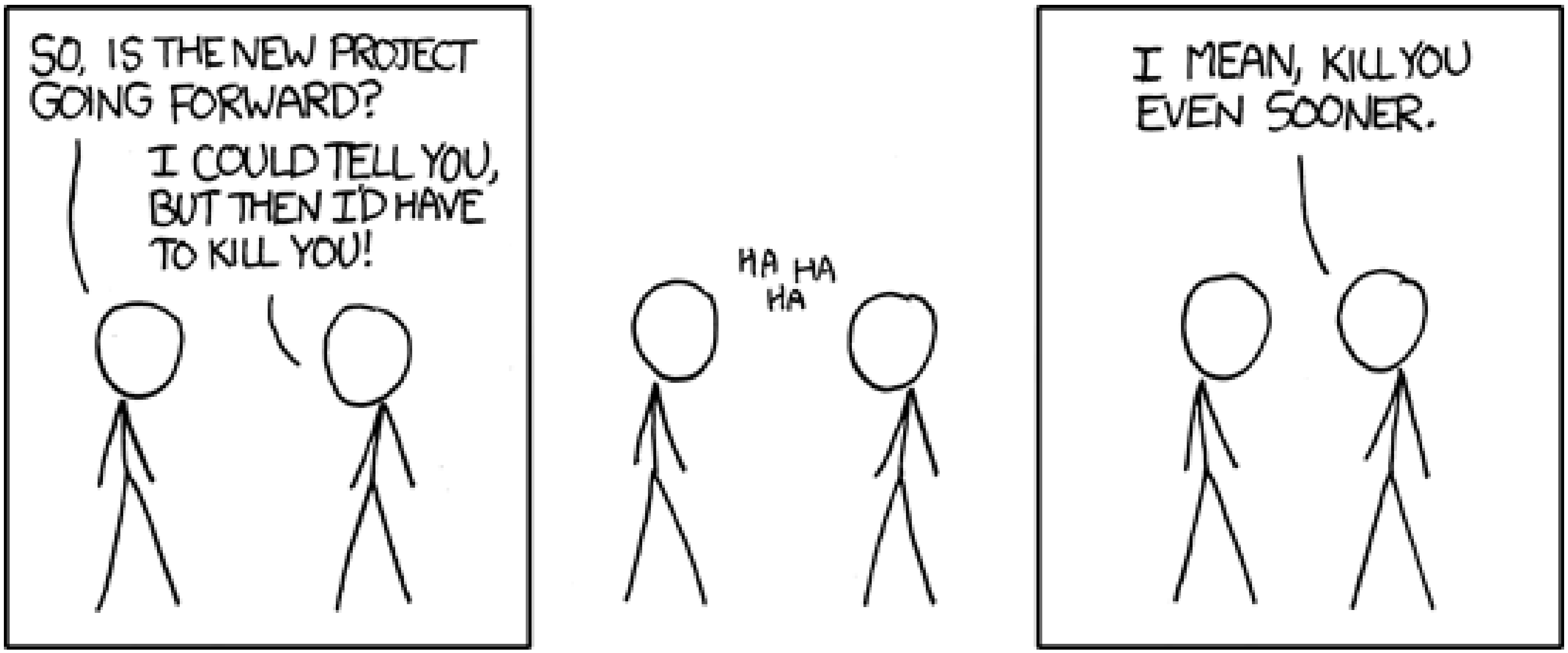
VLTI PRIMA Project

PRIMA Commissioning



www.xkcd.com

- All the 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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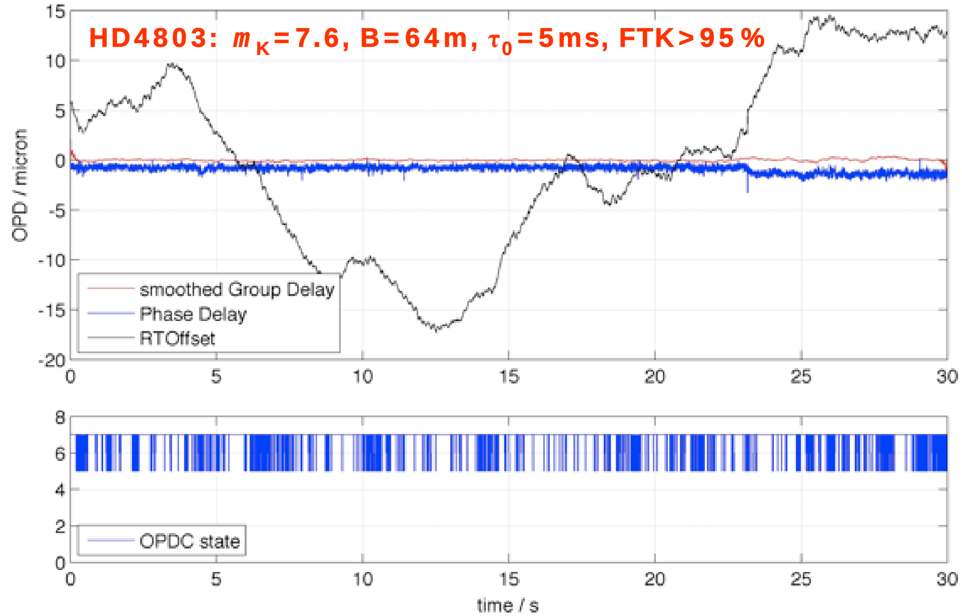
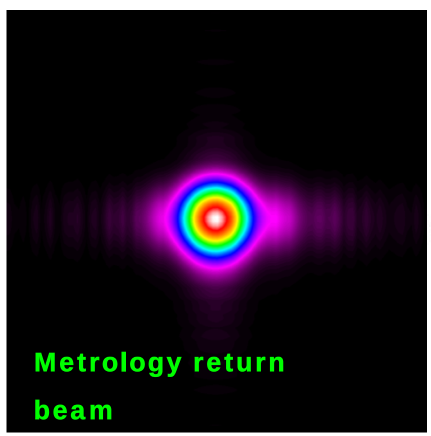
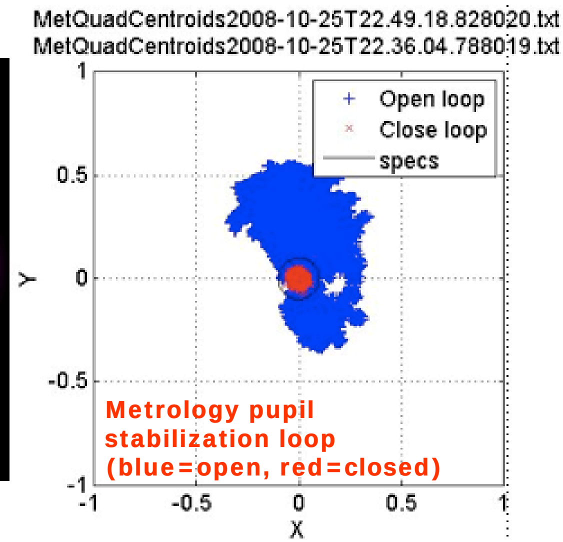
VLTI PRIMA Project

- 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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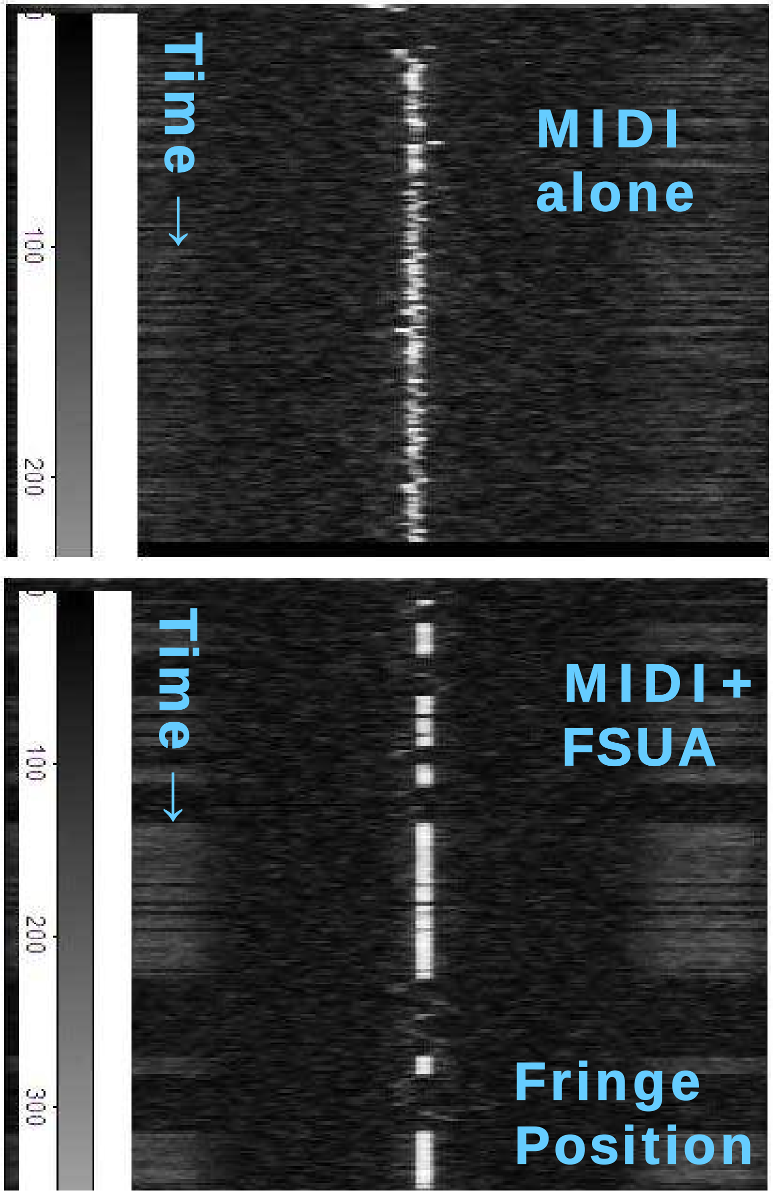

- **Engineering test** of PRIMA+MIDI
  - MIDI can provide fringe tracking (FTK) for itself
  - Same function can also be provided by PRIMA
  - Tests carried out in July, Sept 2009 commissioning runs
  - **Caveat emptor: Non-standard mode**
- Promising results
  - FTK errors (group delay residuals) are 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

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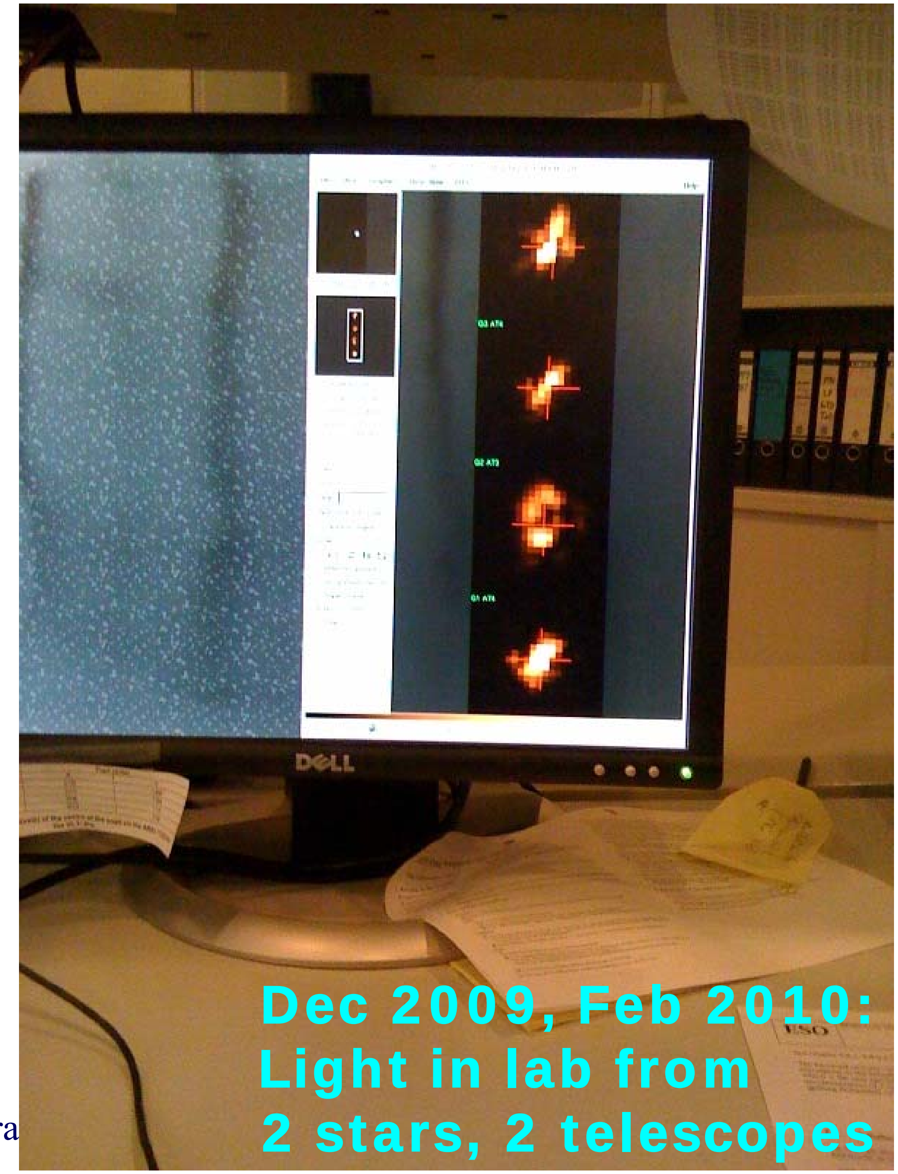
PRIMA Commissioning:
Dual Beam tests in Dec 2009, Feb 2010

- 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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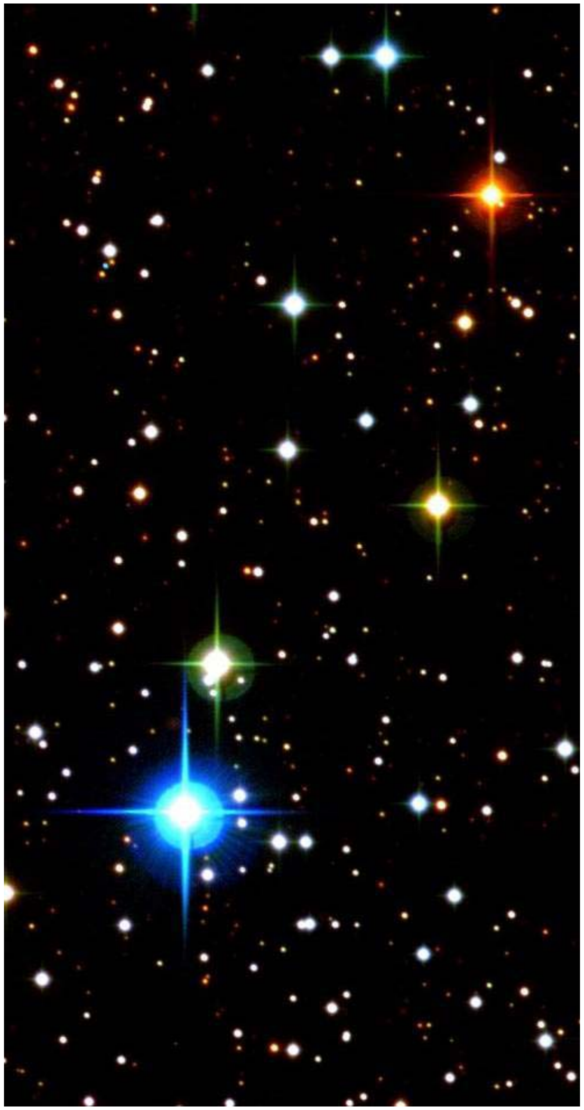
Additional Future Plans

- PIONIER: next 12 months
- Infrastructure
  - AT Upgrade: next 12 months
  - NAOMI, etc.: next 2-3 years
- MATISSE, GRAVITY: ~2013-2014



CFHT MegaPrime image - 2003

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Optical Interferometry ‘Self-Cal’

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Simple Starting Point

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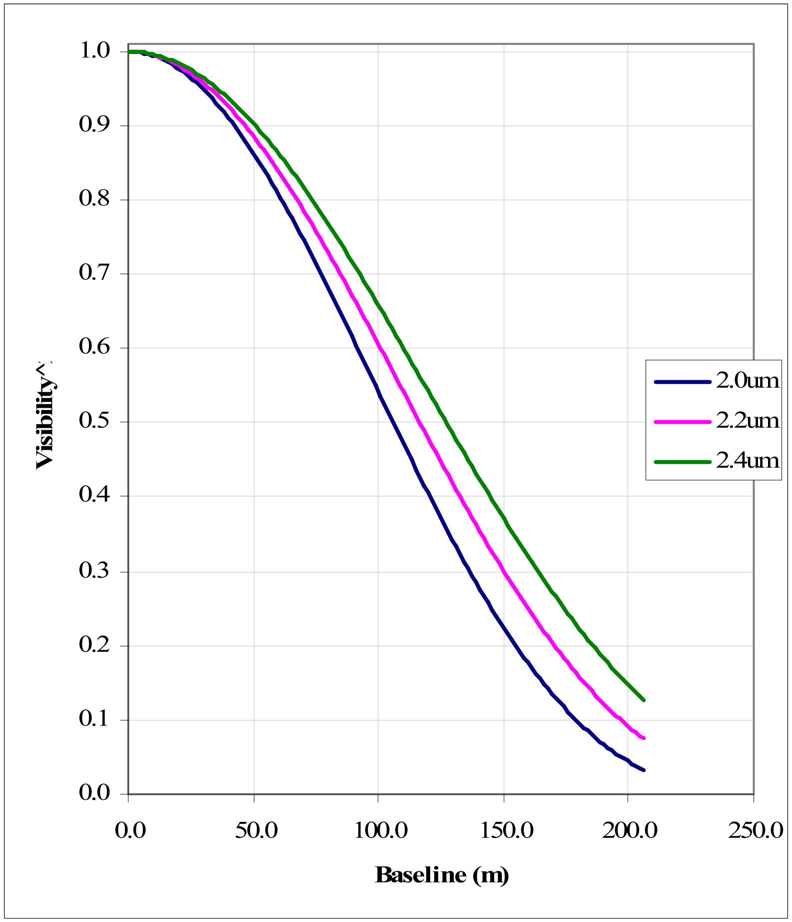
- Example: Uniform Disk Star
  - Angular size = 2mas
- 'True' signal of V^2
  - Decreases with increasing baseline
  - Rate of decrease is connected to wavelength of operation



Imperfect Observation: Atmosphere, Instrument

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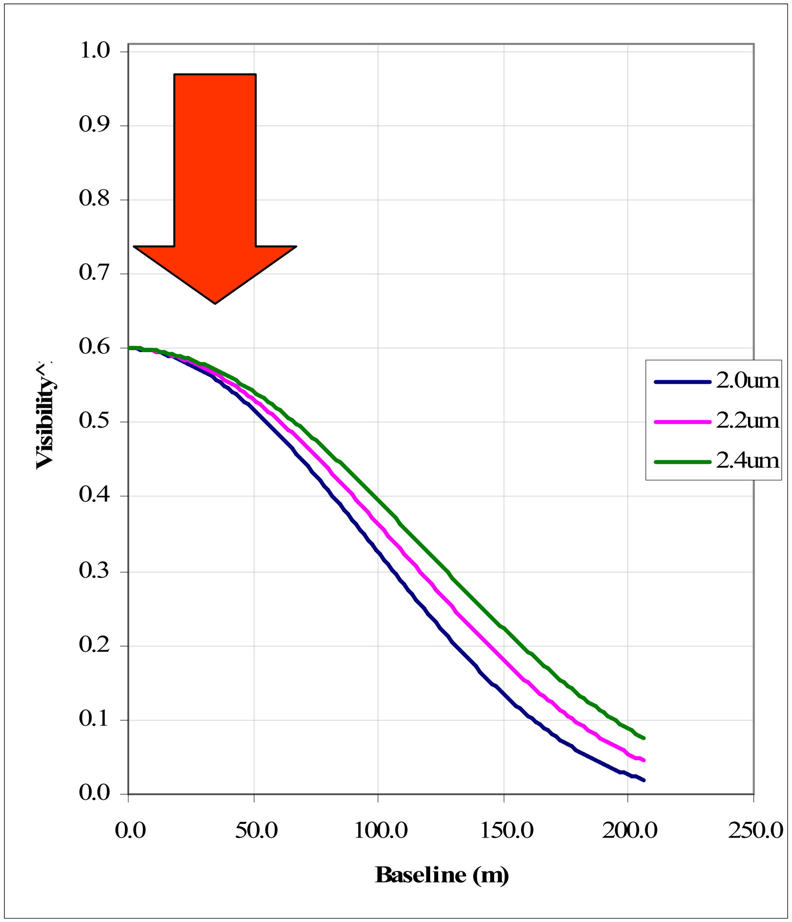
- Measured signal is less than unit visibility for point sources
  - Drives the need for **`cal-sci-cal`** observation cycle to re-normalize data
    - Additional requirement for point sources, too
  - See the discussion in van Belle & van Belle (2005)
- Furthermore, can be time-variable
  - Changes in seeing, instrument parameters
  - Weakens the validity of **`cal-sci-cal`** renormalization, particularly for low cadence rates



Consider $V^2_{\lambda 1}/V^2_{\lambda 2}$ Ratios

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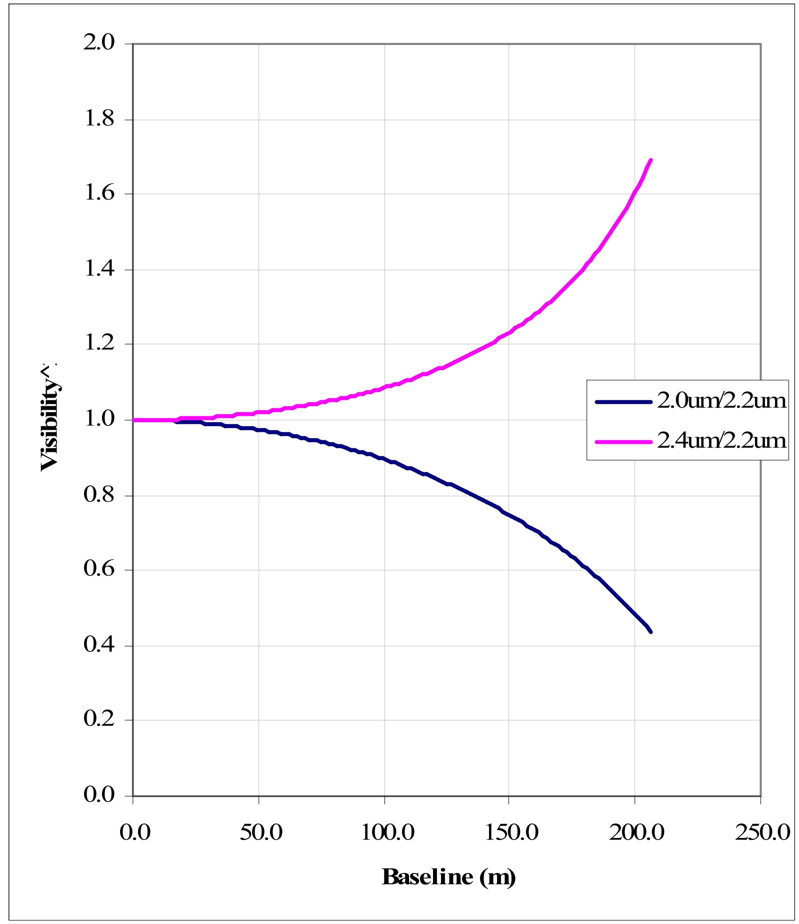
- At a given baseline, $V^2_{\lambda 1}/V^2_{\lambda 2}$ ratio is uniquely linked to angular size
- *Important:* **Ratio is independent of normalization**
- Single **`sci`** measurement, spectrally dispersed, can provide ratios, without corresponding **`cal`** observation



Example Case: HIP113715

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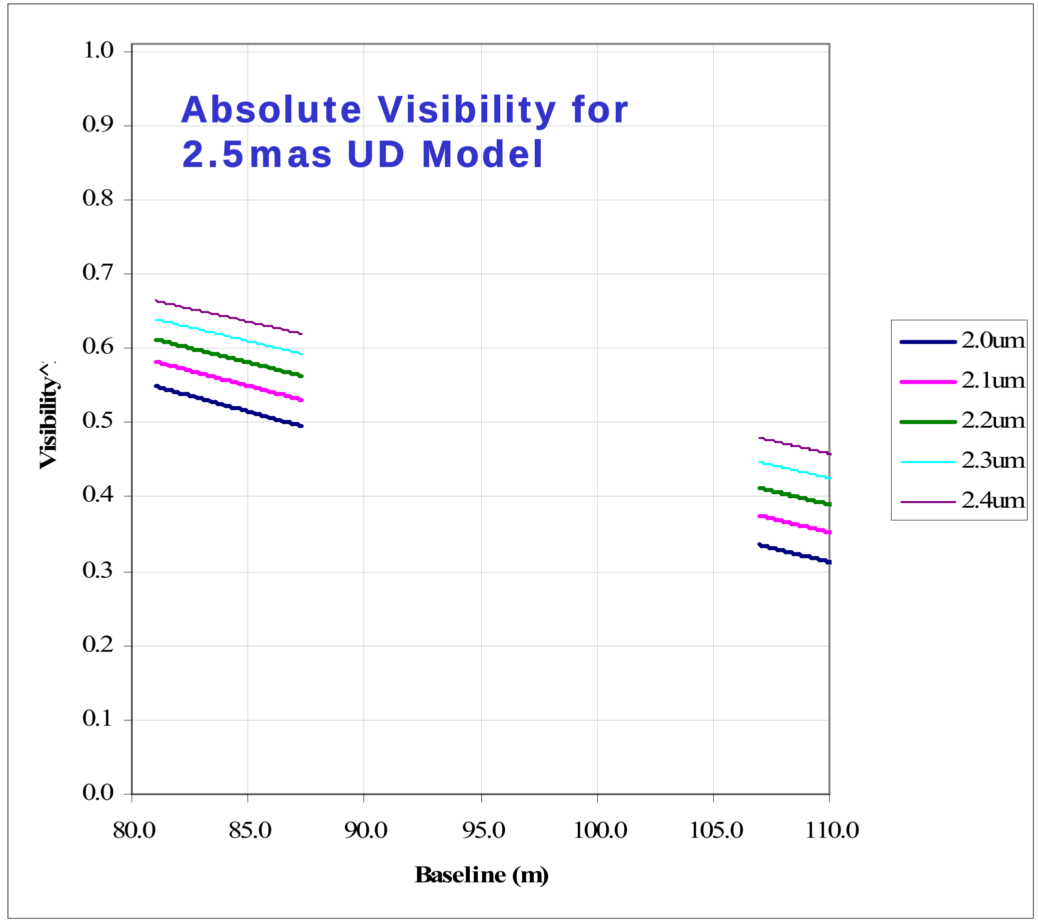
VLTI PRIMA Project

- PTI observations
  - 85m, 109m baselines both used
  - Multiple nights
- 5 'narrow-band' channels across K-band
- Carbon Star
  - Deviates from UD assumption strongly, particularly at band edges



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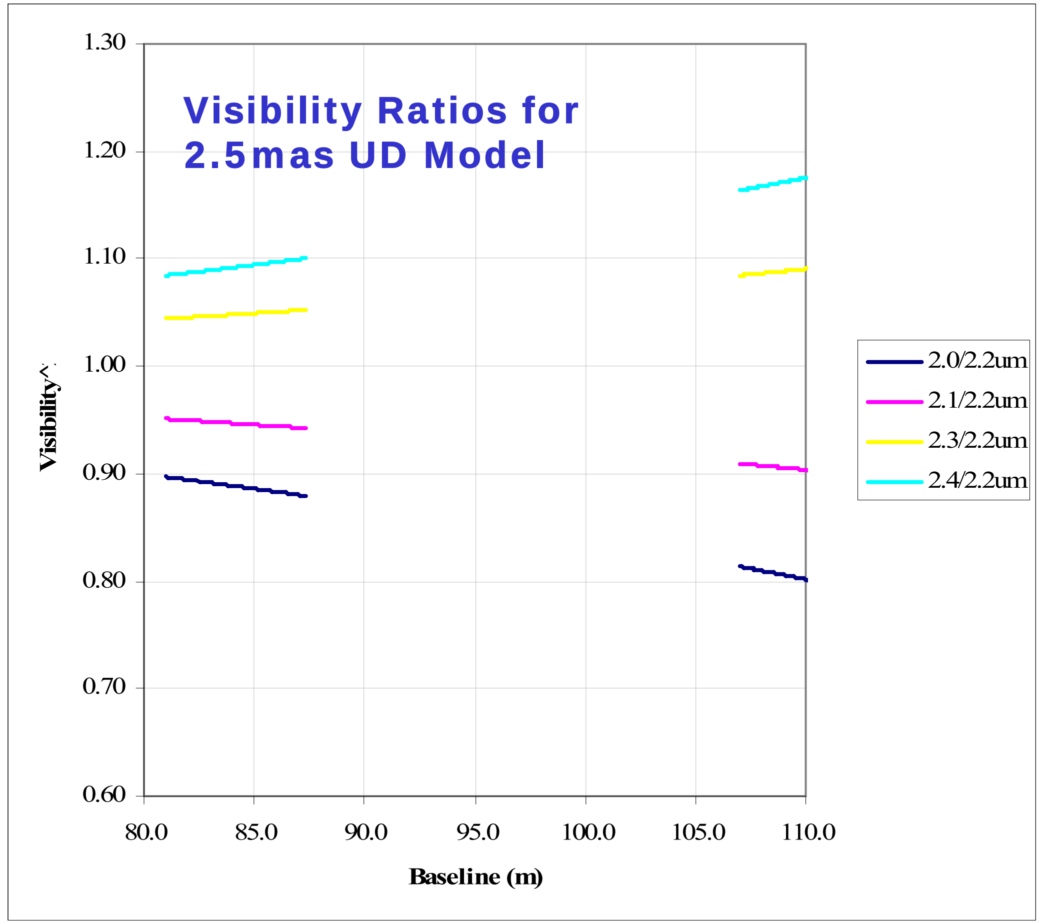

Fit to HIP113715 Data

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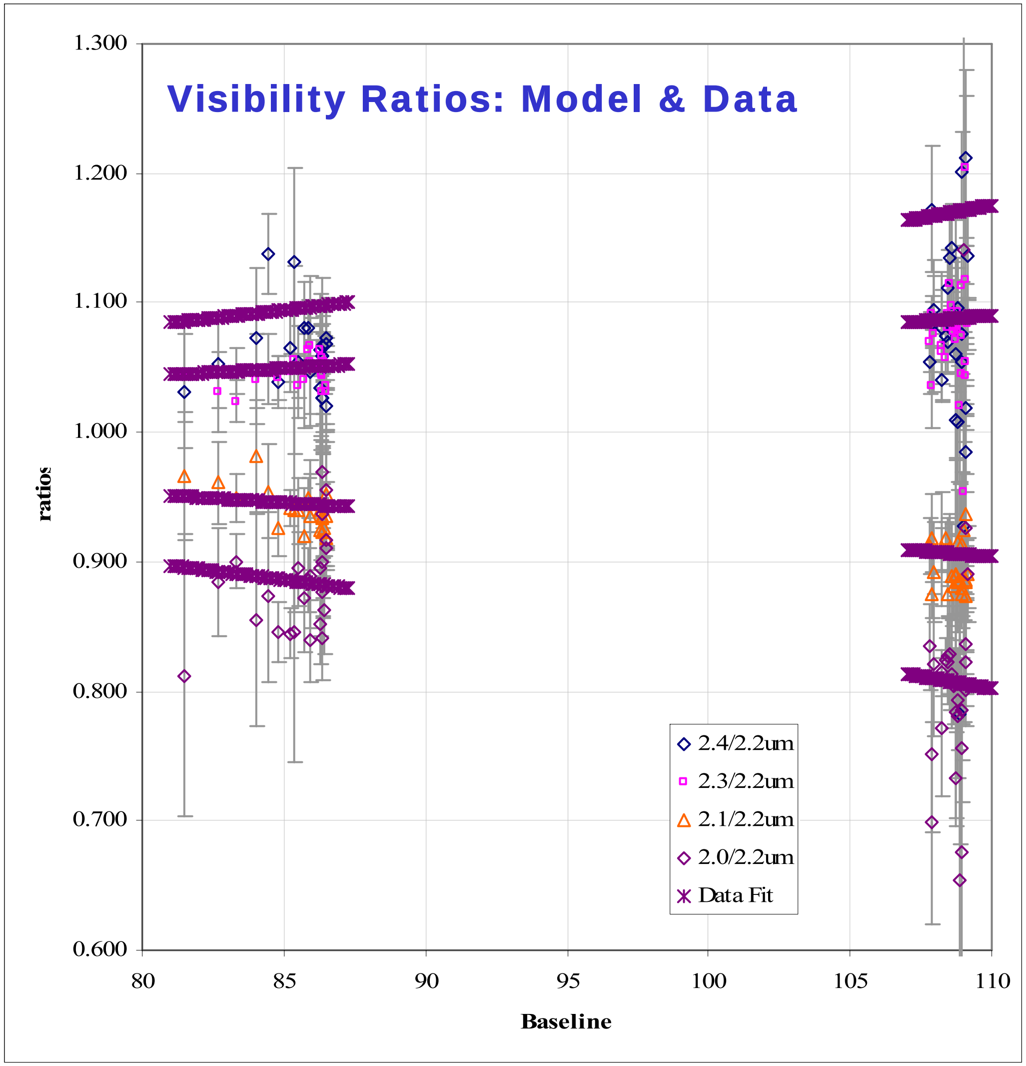
- Fit is done for 2.1, 2.3/2.2μm ratios
  - Avoids HCN, H_2O, CO bandheads at edges of K-band
  - 2.1-2.3μm channels are 'continuum'
  - Size: 2.446±0.032 mas
- Existing 'normal' **`cal-sci-cal`** data
  - Size: 2.470±0.003 mas
  - Errors probably underestimated here
  - Ratios not in 'sweet spot' (V^2 ~ 0.3 to 0.6)



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Something useful here?

- Pro
  - No cal-sci-cal cycle needed
    - Greater throughput, no sensitivity to seeing changes
  - In fact, no point-like calibrator needed?
    - Could be quite useful for short-λ instruments
- Con
  - Is visibility normalization wavelength-dependent?
    - If so, can this be calibrated? Just once for a night or run?
  - Different 'sweet spot' is further down visibility curve → lower resolution at a given wavelength
  - Uniform disk assumption here is stronger than before
    - But approach seems to work for a carbon star, so should be OK for 'better behaved' photospheres?

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