VLTI Update

and

A Proposal for Optical ‘Self-Cal’

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A Humble Competitor to Mt. Wilson
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**

- **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
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
PRIMA Modes Details

- **Astrometry**
  - Primary star: science target, bright \((K<8)\), possibly has planet, used to phase instrument
  - Secondary star: dim \((\Delta K<5)\), background, astrometrically stable (as verified by RV if necessary)
  - \(\Delta\text{OPD}\) between two interferometers \(\rightarrow\) astrometric separation vector \(\rightarrow\) science at the \(\sim30\mu\text{as}\) level

- **Faint object science**
  - Primary star: bright \((K<8)\), boring, used to phase instrument
  - Secondary star (or ? see image above): science target, dim \((\Delta K<5)\), fed into AMBER/MIDI
  - \(V^2\) measurements of AMBER/MIDI \(\rightarrow\) science

- **Phase referenced imaging**
  - Like faint star science operationally, with addition of PRIMET metrology
  - \(V^2, \Delta \phi\) measurements of AMBER/MIDI \(\rightarrow\) science

NTT SOFI Image of galaxy ESO 548-81
Faint-Object Mode Example

- 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

Lane & Colavita 2003

HD 177724
4 Aug 1999

No Phase Referencing

Phase Referencing

Lane & Colavita 2003
PRIMA Commissioning

- 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

www.xkcd.com
PRIMA Architecture

- 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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**RED:**
New for PRIMA

Also: ISS/PSS, PACMAN, ADRS, dOPDC
PRIMA Commissioning:
Sub-System Testing during 2009

- 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

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Gerard van Belle
PRIMA Commissioning: FSUA+MIDI Fringe Tracking Tests

- **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 ($F_{12} \approx 1\text{Jy}$)
    - 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

- 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

Dec 2009, Feb 2010: Light in lab from 2 stars, 2 telescopes
PRIMA Commissioning Plans: P85, P86

- 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 $4 \times 10^d$
  - 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
Additional Future Plans

- **PIONIER**: next 12 months
- **Infrastructure**
  - AT Upgrade: next 12 months
  - NAOMI, etc.: next 2-3 years
- **MATISSE, GRAVITY**: ~2013-2014
Optical Interferometry ‘Self-Cal’
Simple Starting Point

- 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

- Measured signal is less than unit visibility for point sources
  - Drives the need for \textit{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 \textit{cal-sci-cal} renormalization, particularly for low cadence rates
Consider $V^2_{\lambda_1}/V^2_{\lambda_2}$ Ratios

- 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

- 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

![Graph showing Absolute Visibility for 2.5mas UD Model](image)
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![Visibility Ratios for 2.5mas UD Model](chart.png)
Fit to HIP113715 Data

- Fit is done for 2.1, 2.3/2.2μm ratios
  - Avoids HCN, H₂O, 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’ ($V^2 \sim 0.3$ to 0.6)
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-\(\lambda\) 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?
Any questions?

“Optical Self-Cal”? Are you kidding?