European Organization for Astronomical Research in the Southern Hemisphere

VLTI PRIMA Project

VLTI Status

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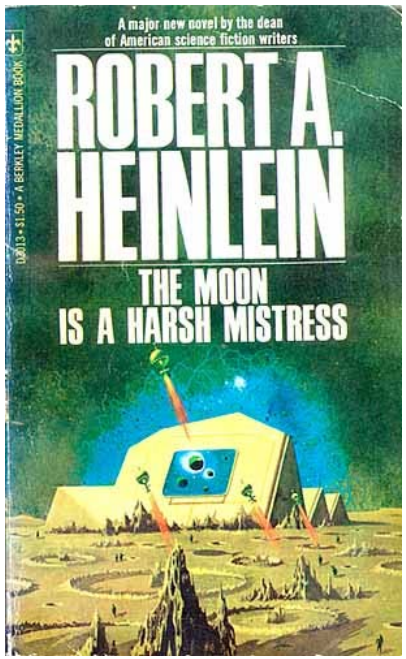
Food for Thought

European Organization for Astronomical Research in the Southern Hemisphere

VLTI PRIMA Project

"There ain't no such thing as a free lunch"[1]
– R. A. Heinlein



[1]Often abbreviated as TANSTAAFL, from *The Moon is a Harsh Mistress*, 1966

Food for Thought

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VLTI PRIMA Project

- What's for lunch?

  → ultra-high-resolution astronomy – easily 2 orders of magnitude beyond conventional techniques

  → Even more resolution? Even more cost

- The price?

  → sensitivity & complexity

  - have to burn precious starlight photons to do real-time alignment of your optics

  → TANSTAAFL turns up pretty much everywhere else in interferometry, too

“The World’s Most Advanced Optical Telescope”

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VLTI PRIMA Project

Current Major Development at Paranal: VLTI PRIMA

PRIMA: The Dual-Feed Facility for VLTI

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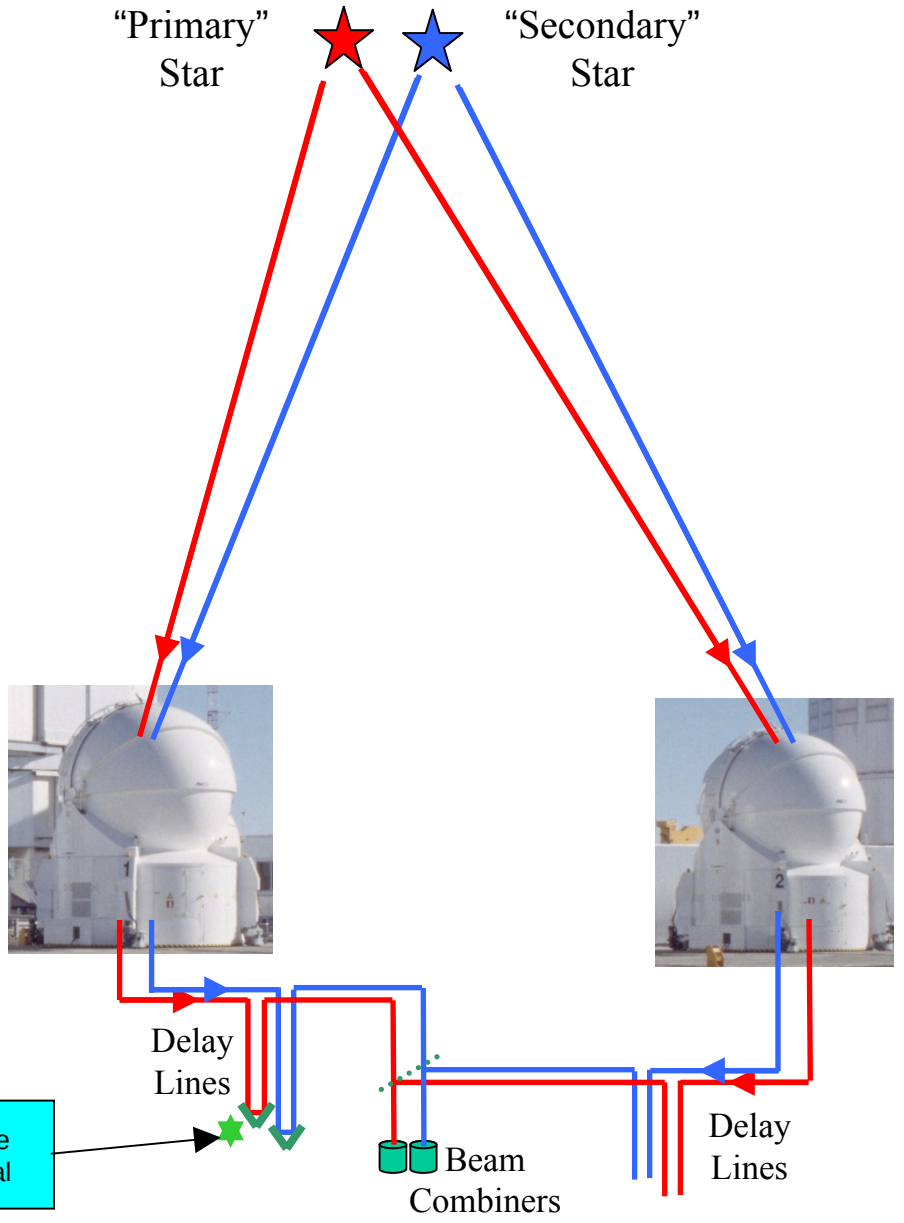
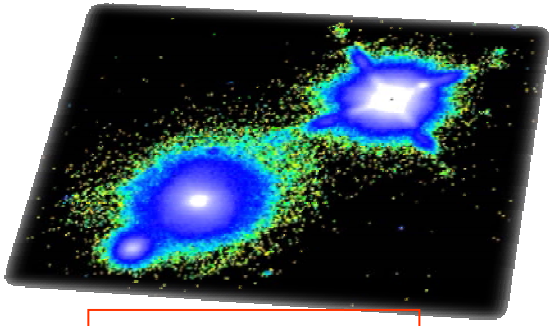
VLTI PRIMA Project

- PRIMA = Phase Referenced Imaging and Microarcsecond Astrometry
- "**Two interferometers in one**" tied together by laser metrology
  - Roughly 3× harder
- 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

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- **Astrometry**
  - Primary star: science target, bright (K<8), possibly has planet, used to phase instrument
  - Secondary star: dim (ΔK<5-7), 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<5-7), 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

Another Way to Think of PRIMA

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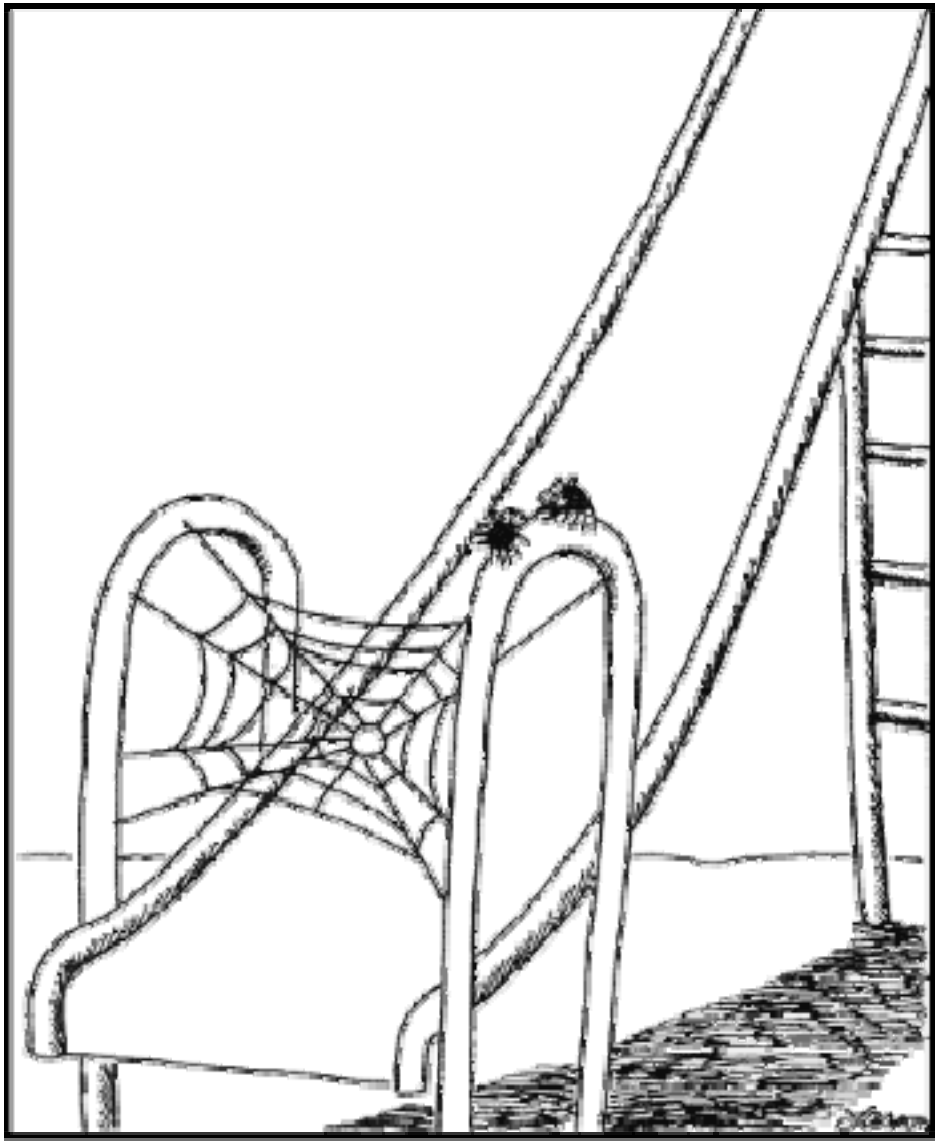

"If we pull this off, we'll eat like kings."

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

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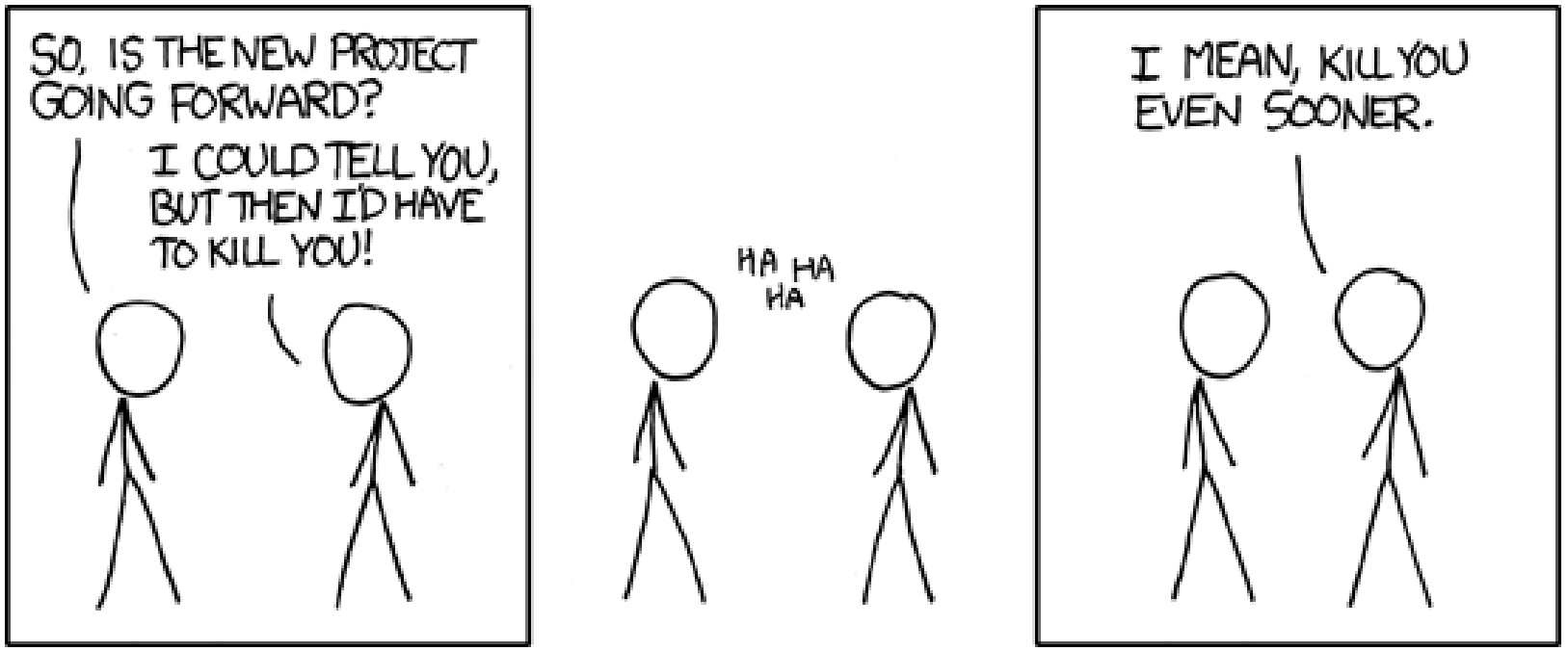

www.xkcd.com

- PRIMA is a little complicated
  - Even making allowance for it being an interferometry project
  - Roughly 3× a 'normal' optical interferometer
- System integration the key challenge here

PRIMA sub- system tests as of April 2010

	FSU	PRIMET	DDL	STS	ADRS	ISS, PRICS	PACMAN	(D)OPDC
FSU	😐 linearity & tip-tilt	☹	X	☺	😐	😐	☺	😐
PRIMET		😐	😐	😐	☹	😐	😐	☹
DDL			☺	X	☹	☺	😐	😐
STS				😐 Pupil	X	☺	X	X
ADRS					☺	X	😐	X
ISS, PRICS						☺	😐	😐
PACMAN							☺	😐
(D)OPDC								☺

☺ tested & working – 😐 partially tested and working – ☹ not yet tested

PRIMA sub- system tests as of Feb. 2011

	FSU	PRIMET	DDL	STS	ADRS	ISS, PRICS	PACMAN	(D)OPDC
FSU	😐 linearity & tip-tilt	☺	X	☺	☺	☺	☺	☺
PRIMET		☺	☺	☺	☺	☺	☺	☺
DDL			☺	X	☺	☺	☺	☺
STS				☺ VCM	X	☺	X	X
ADRS					☺	X	😐	X
ISS, PRICS						☺	☺	☺
PACMAN							☺	☺
(D)OPDC								☺

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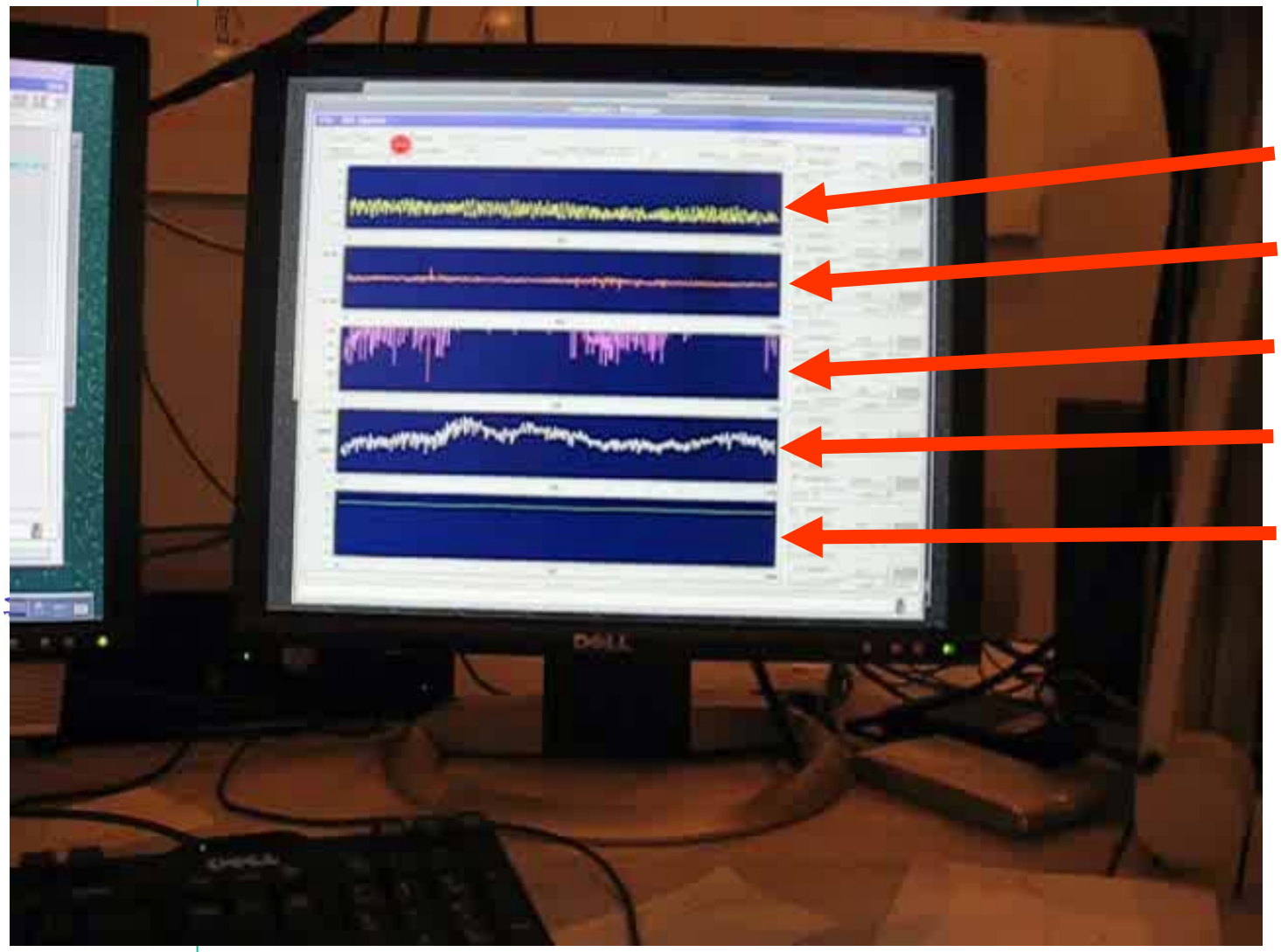
PRIMA Single Fringe Tracking



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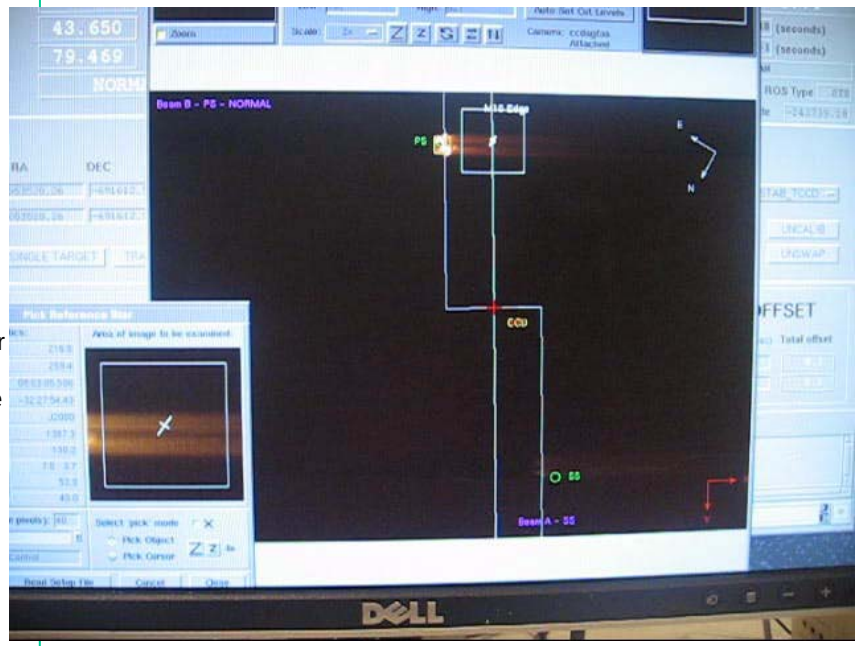

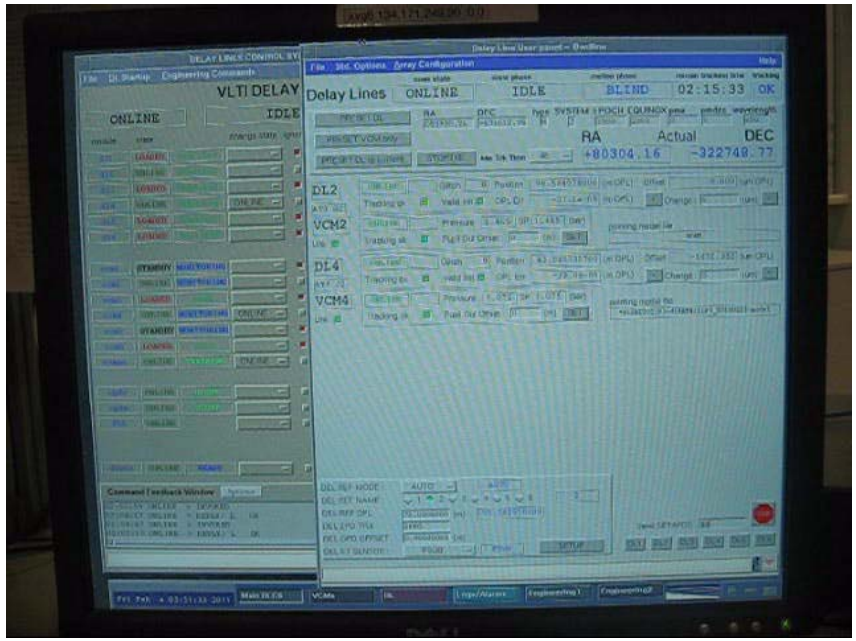

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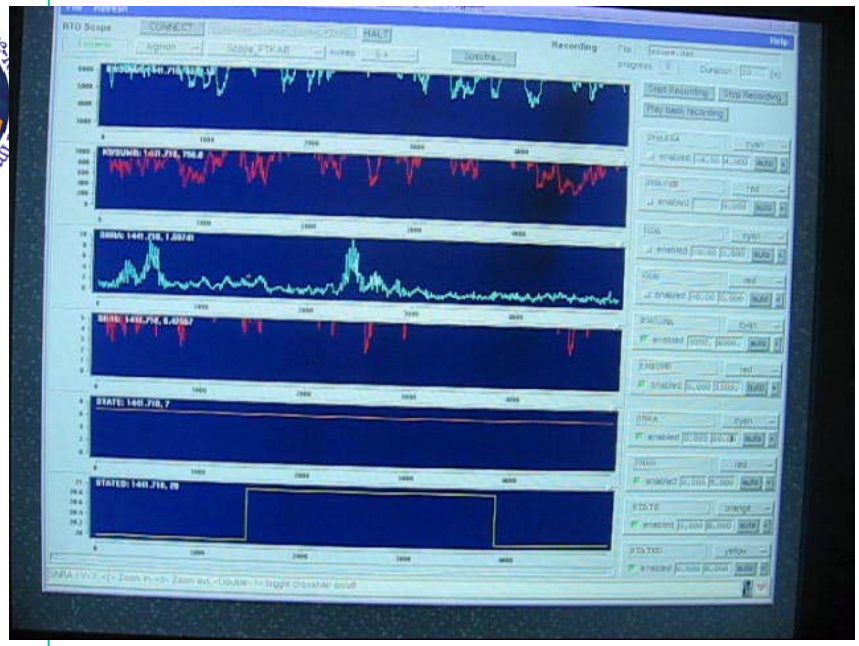
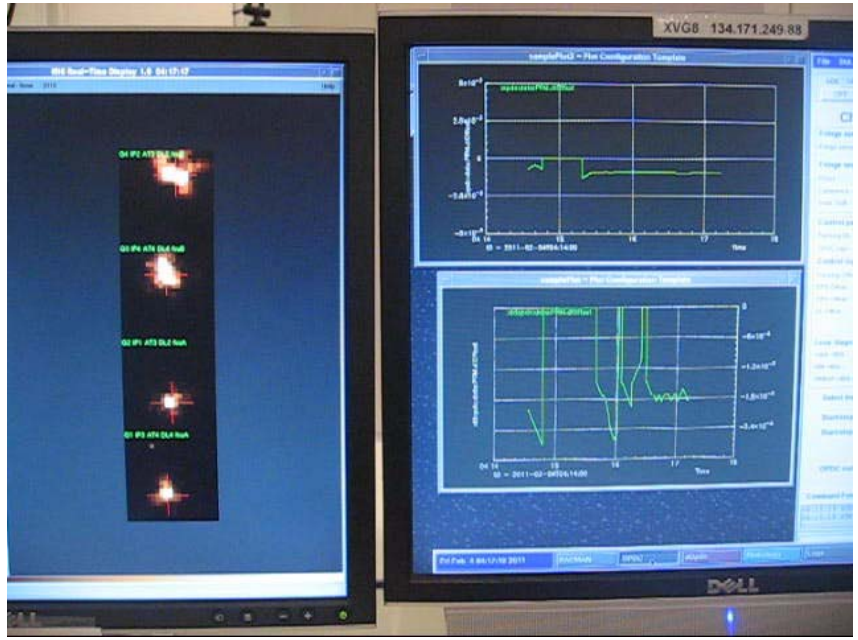
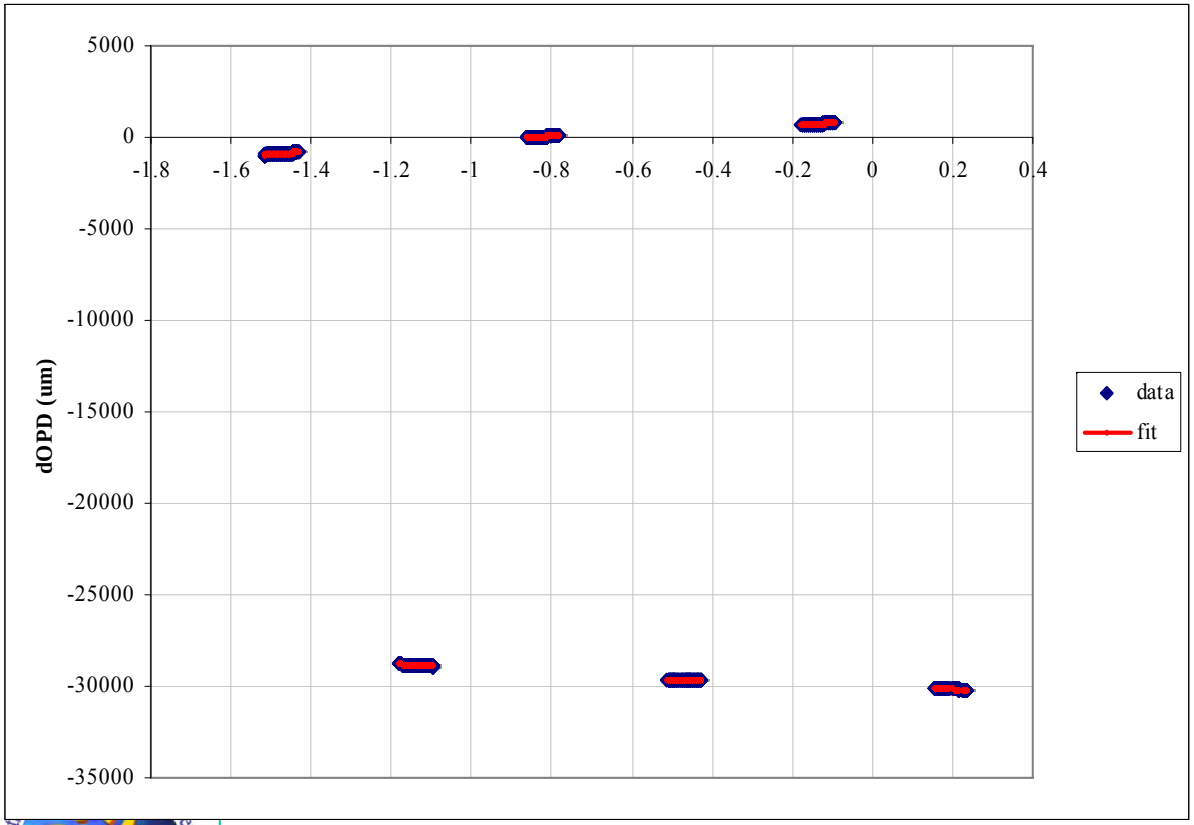
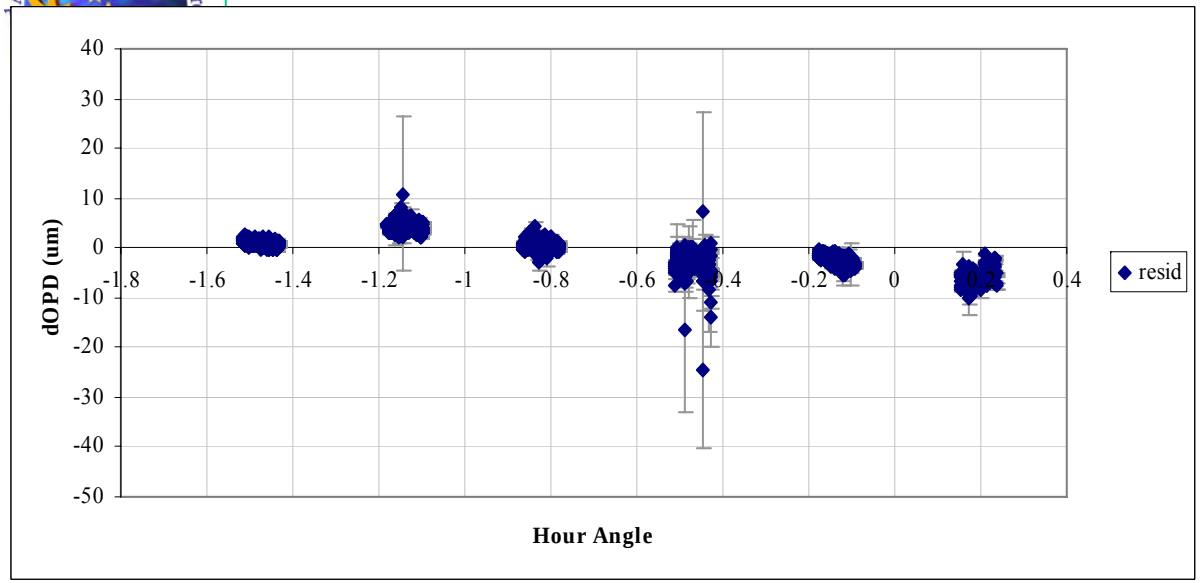


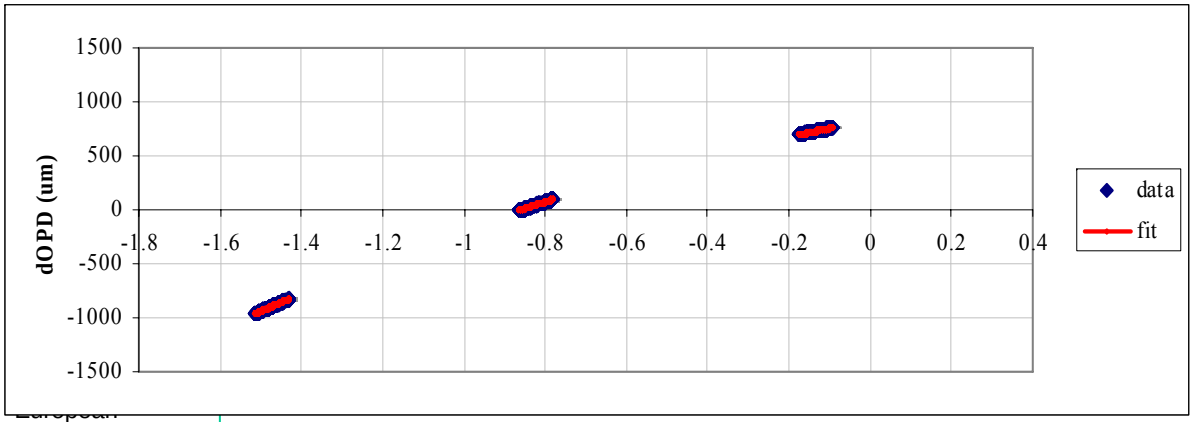


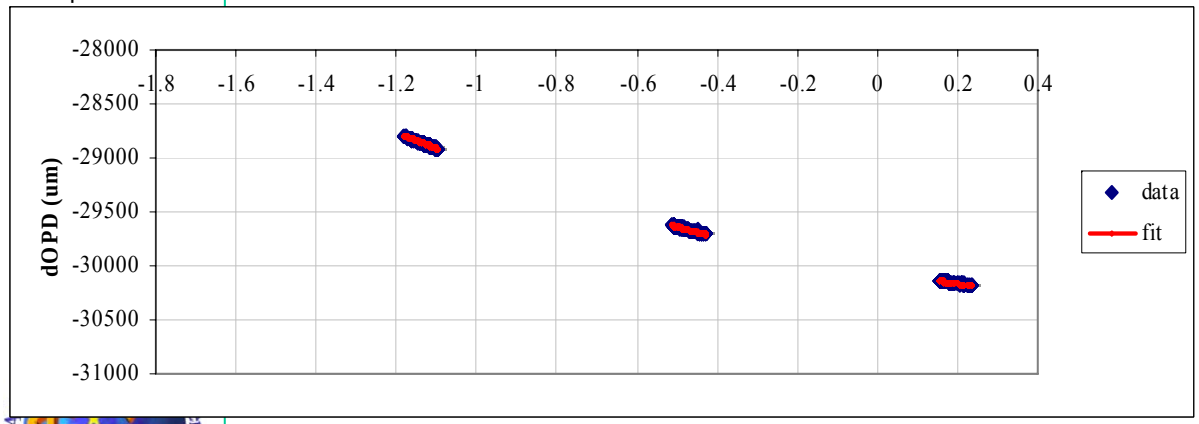


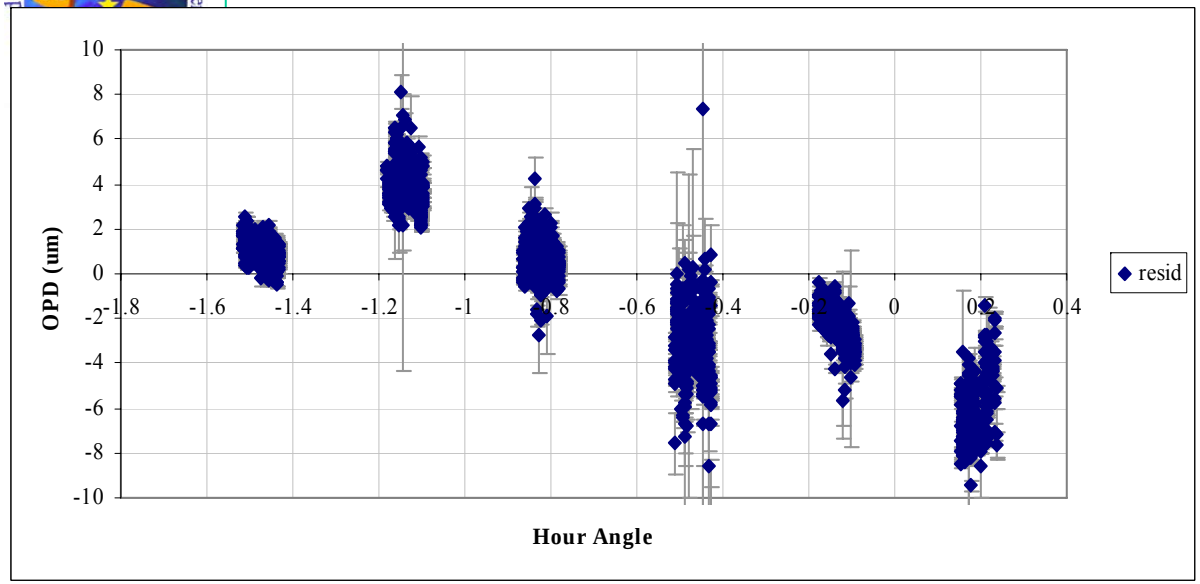


PRIMA Astrometry

- First results
- The first plots shows the measurements of the differential Optical Path Difference (dOPD) between a pair of stars.
- The lower plot shows residuals of a *simple* (zeroth order) astrometric fit
- The dOPD is the projection of the star separation on the interferometer baseline. The time evolution (due to the Earth rotation) is clearly seen (trend).
- The "chopped" nature of the measurements is due to the observational method where both stars are regularly exchanged (swapped) between the 2 Fringe Sensor Units in order to calibrate out some biases. The measurable is the difference between both fits.



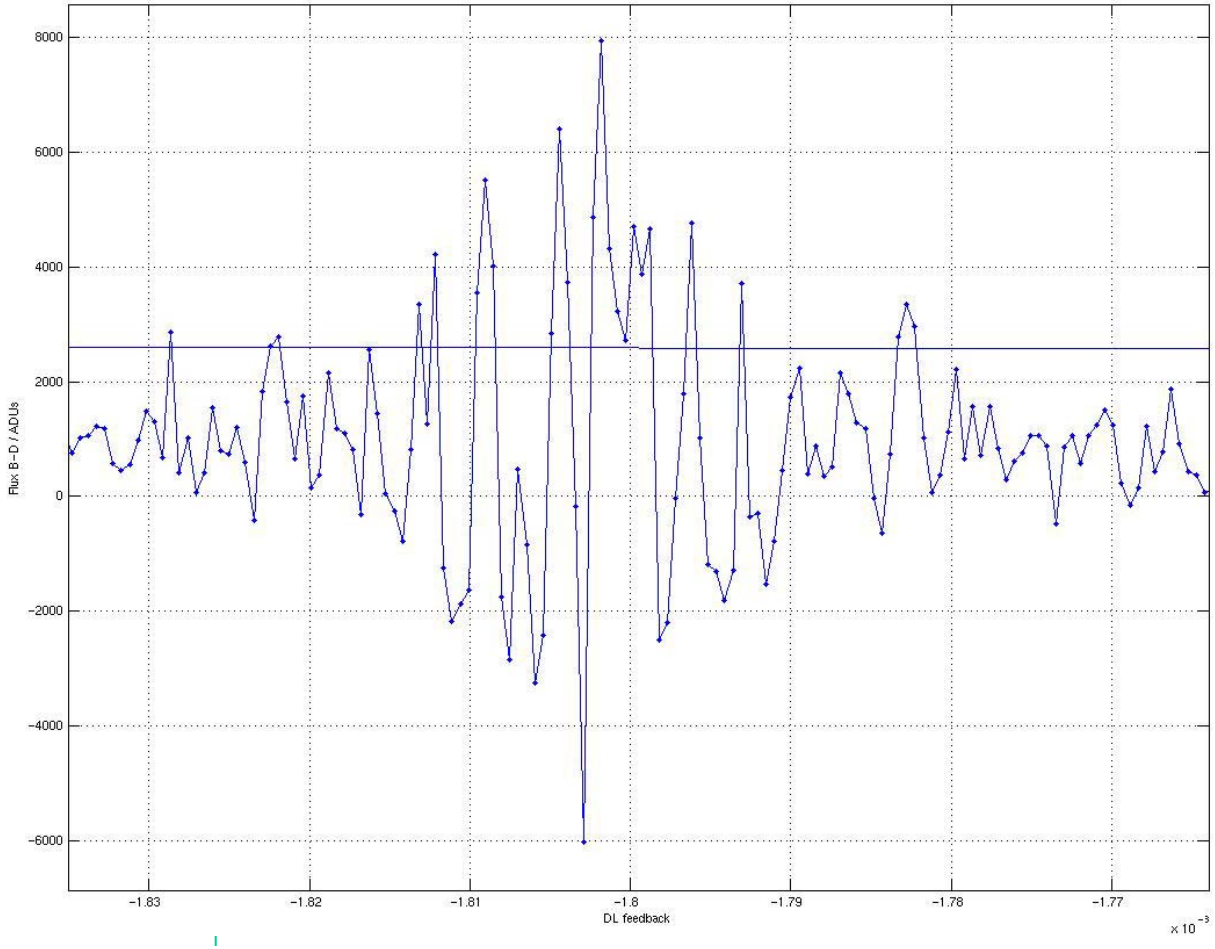




PRIMA Astrometry

- First results (zoomed)
- Twin traces show metrology signal before/after PS-SS and SS-PS swap
- Lower plot shows residuals of *simple* astrometric fit
- Night-to-night repeatability of 75mas
  - Not bad, except goal is >75μas
  - Does not include fringe error signal, other known error terms
  - Clearly some systematics at ±10μm level not accounted for yet
  - Need to be at <1μm for ~ 75μas astrometry

PRIMA Co-Phasing Demonstration



SAO221759 (m_K=7.1) stabilized by HD87640 (m_K=4.8, 6.6" distant)
Seeing monitor: 0.87" with 10ms coherence time
2011.02.05 VLTI PRIMA
"Raw" measurements (no fancy data reduction was applied)

- Use of a bright star to stabilize the system for 'staring' at a fainter one:
  - similar to natural guide star adaptive optics but for interferometry
  - The fringe tracking loop was run at 1kHz on the bright star
  - The fringe tracking on the fainter star was then slowed to 500Hz, 250Hz, …
- Final result: 1Hz scanning
  - Each data point on the left is one full second long
  - We still see the fringes proving that the secondary fringes were effectively stabilized
  - Factor of 1000× in integration time (!)
  - This shows the potential gain in sensitivity that off-axis fringe tracking can bring.

Future Developments

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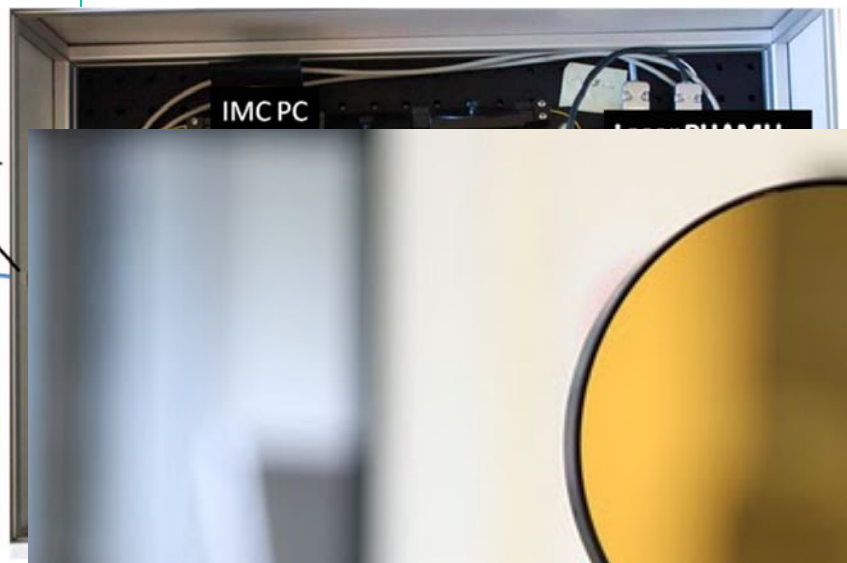
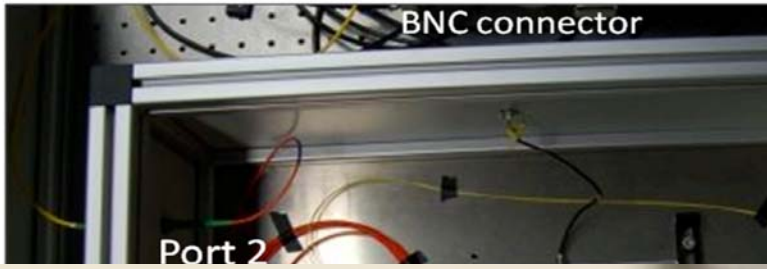
VLTI PRIMA Project

- Currently offered: AMBER, MIDI
  - PIONIER (new; first guest instrument)
- PRIMA dual-beam observations
  - Astrometry (April 2012)
  - MIDI on-axis faint
  - AMBER, MIDI off-axis faint
  - Phased-referenced imaging (TBD)
  - UT STSes
- 2nd Generation Instrumentation
  - GRAVITY (~2014) – 4× high sensitivity (K>16) high resolution (10μas) astrometry
  - MATISSE (~2014) – 4× N-band imaging
- Infrastructure
  - MAMMUT vibration tracking/control
  - NAOMI – AT AO
  - 2nd gen 4× fringe tracker

Details of Selec



Arm B



SU
OUTPUT

PL

VLTI PRIMA
Project

VLT Unit Telescopes

Yes, we've got big glass

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