Multi-waveband phase-referencing at VLTI: (first science) and technical progress

“10 yr VLTI”

ESO, Garching

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Content

- Scientific motivation
- Background: the evil water vapor
- VLTI: *MIDI+FSU* on-axis as pathfinder
- Firsts results from real data
- near-future outlook

Scientific motivation 1:

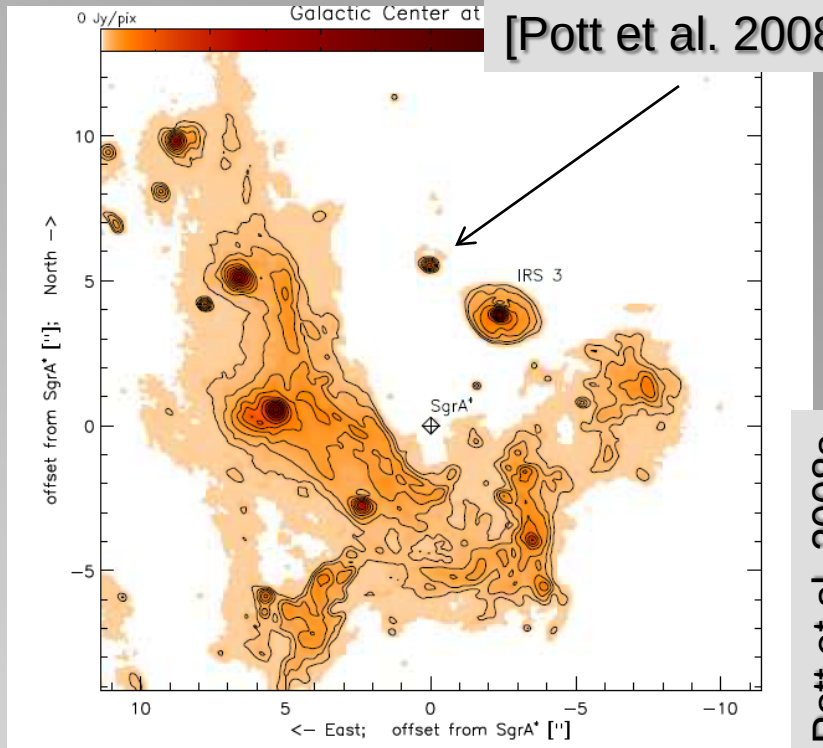
Faint object science: On-axis single-band interferometry is limited to bright targets

Example: Galactic center

- Currently only the few brightes sources can be observed

Reasons to go deeper

- Star and dust formation close to a quiescent black hole
- Binary fraction
- Stellar astrometry
- MIR detection of SgrA* limited by source confusion
- ...



IRS7 a good 2um reference [Pott et al. 2008b]

Pott et al. 2008a

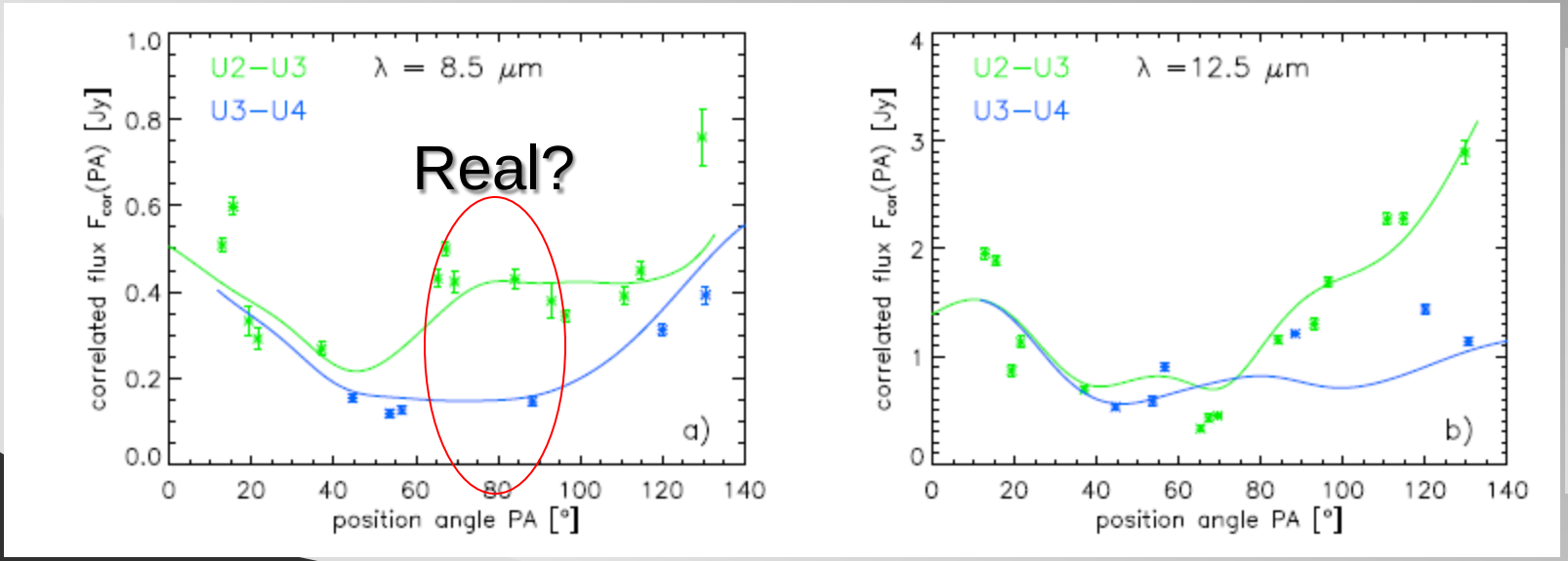
Numerous 10um MIDI sources, doable in off-axis phase-referencing

Scientific motivation 2:

High precision science: Phase referencing gives an independent measurment of the current array performance

Example: AGN torus-fine-structure

- Dusty RT models require self-shielding clouds
- Dust formation in the BLR / disc wind would be a natural explanation
- Resolvable clouds give large uv-plane visibility gradients
- We heared about NGC1068 in other talks



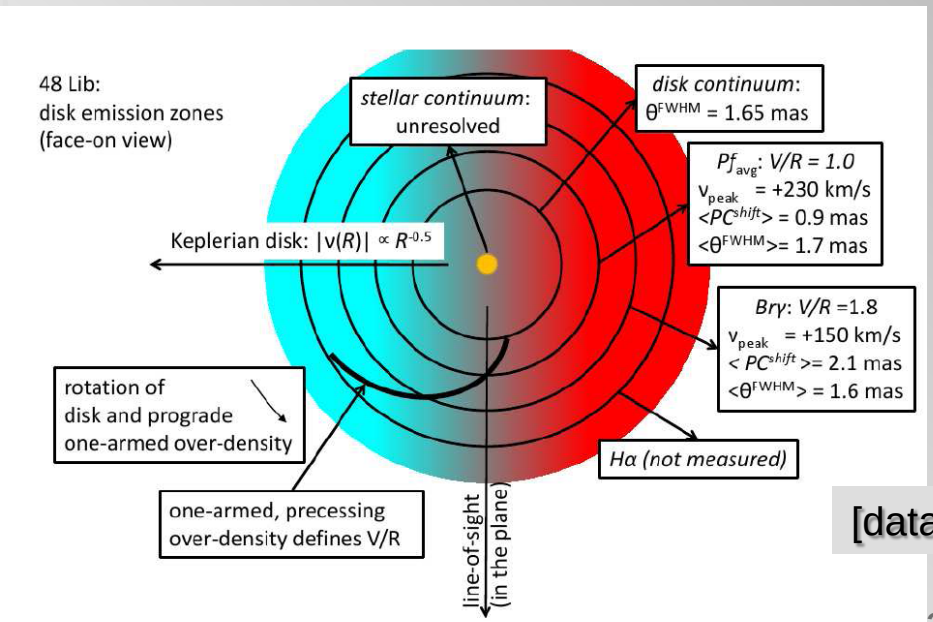
Circinus, [Tristram'07]

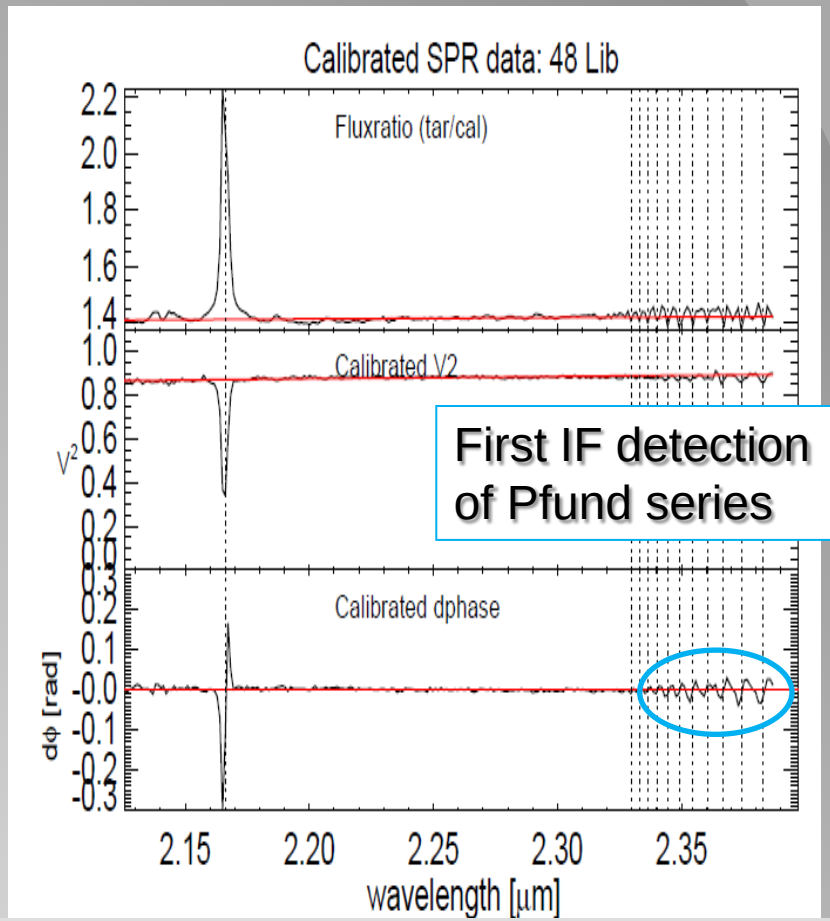
Scientific motivation 3:

High resolution spectroscoy: Phase referencing gives an independent measurment of the current array performance

Example: Spectro-interferometric astrometry at 5uas precision

- on-sky centroid shift of up to 3 μas -> a relative precision of 10^{-3}
- 2 orders of mag. better than state-of-the-art single-telescope spectro-astrometry
- resolve gas disk kinematics in detail





First IF detection of Pfund series

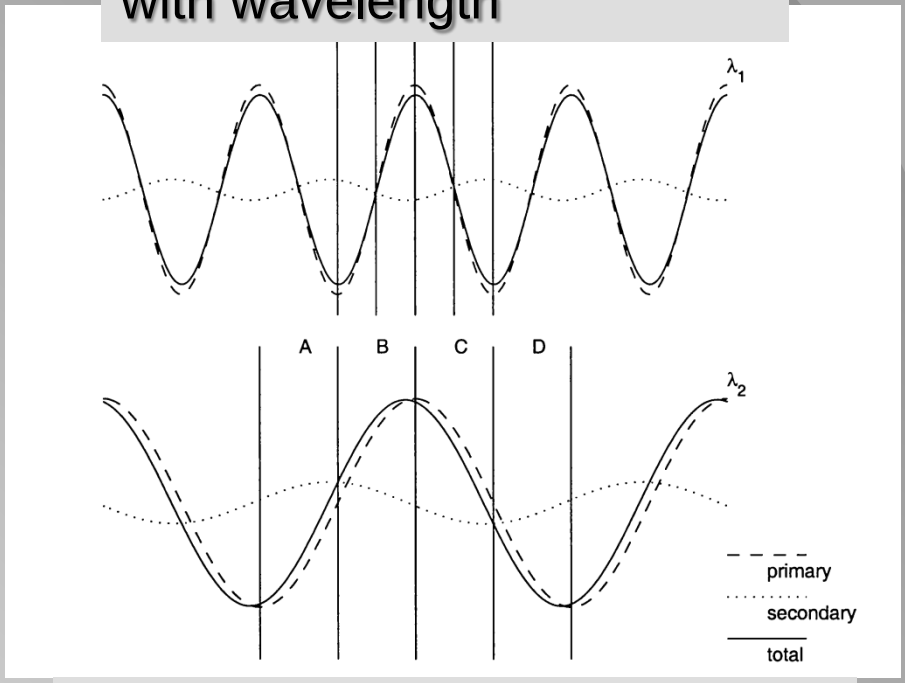
[data and plots from Pott et al. 2010], see also other talks

Scientific motivation 4:
Faint companion detection: understanding low-order changes in the differential phase

Example: ExoPlanet detection

- direct spectral and 2d astrometric constraints on non-transiting planets
- nearby companions produce modest phase slope -> hard to distinguish from atmosphere and instrument
- need an independent method to calibrate differential phase

Total fringe position shifts with wavelength



from Akeson+00, see also Matter+2010

Phase-referencing has three central advantages which increase IF science

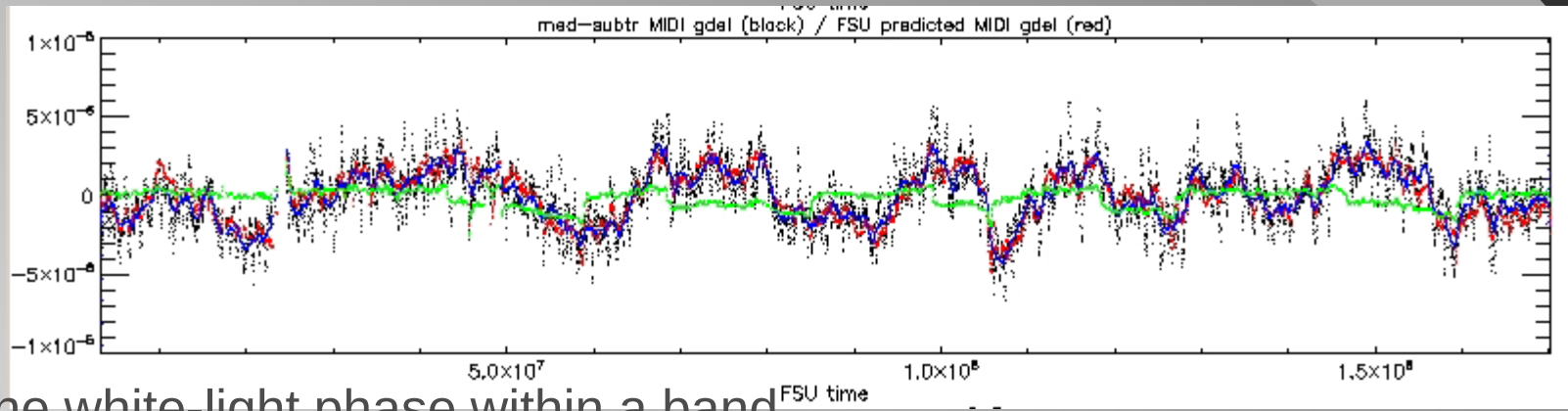
- You can pick the band with the highest SNR to stabilize / calibrate, and not with the best science
- Integrations beyond the coherence time to do faint objects and spectroscopy
- Immediate measurement of the current instrumental group and phase delays
  - understand the instrument performance
  - improved the calibration precision

Phase-referencing pioneers

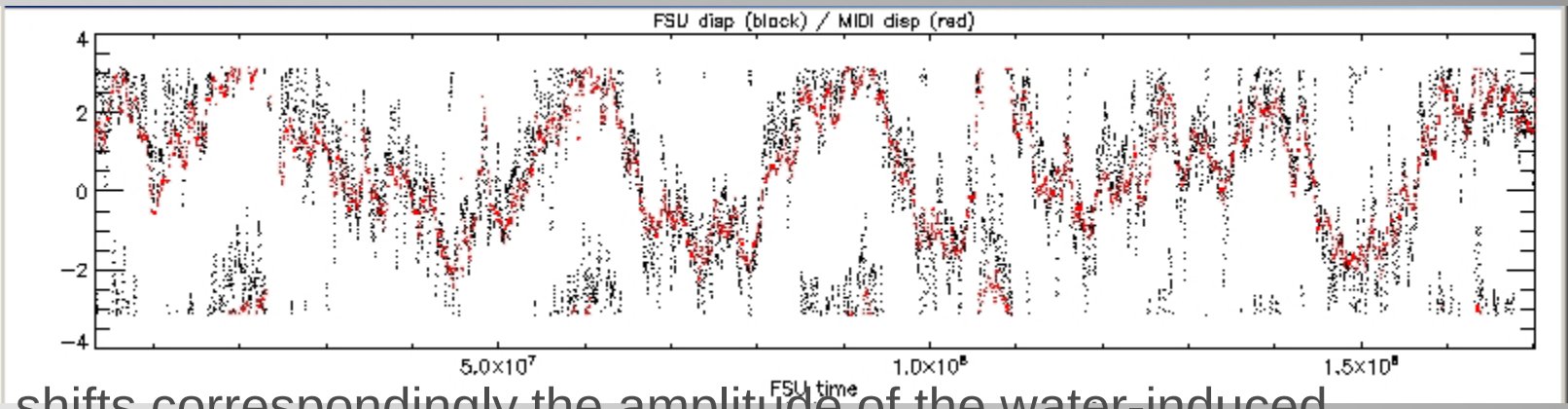
- VLTI – FINITO: single band H-band phase delays
  - H=6..7mag, R=12000 with AMBER
- Keck-IF ASTRA: single K-band phase and group delay, high sensitivity
  - R=2000 at 8mag@2um [Woillez+11]
- Keck-Nuller: multi-band (K -> N) phase and group delay
  - multi-band approach was necessary to reach the impressive Nuller performance (3*10^-3 at 2 Jy@10um) [Colavita+10]
  - online-water vapor prediction

Multi-lambda PR: Evil water vapor seeing

- Shifts the fringe positions (group delay) between the bands



- Varies the white-light phase within a band



- … and shifts correspondingly the amplitude of the water-induced differential phase curvature within a band

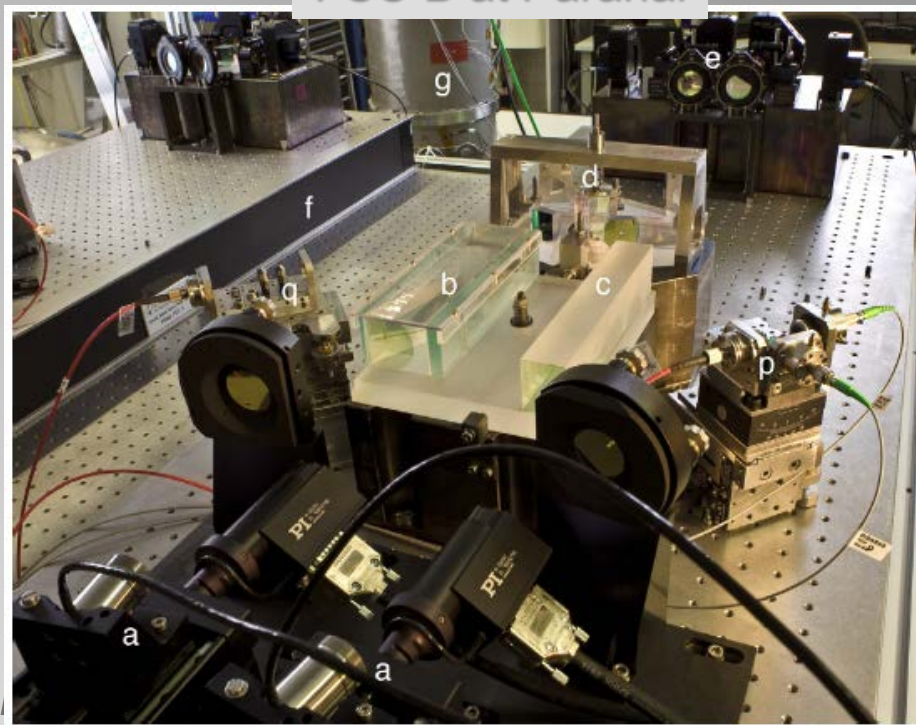
All these things limit the usefulness of multi-band phase-referencing unless properly taken into account

Multi-band phase-referencing at VLTI

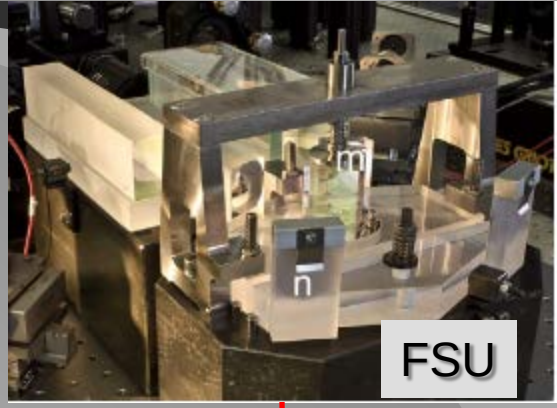
PRIMA fringe sensing unit (FSU)

- FSU-phase referencing modes with 1st gen VLTI (MIDI, AMBER) are part of PRIMA, and a Pathfinder for 2nd gen VLTI (MATISSE, GRAVITY) external fringe tracking
  - off-axis fringe tracking for faint sources
  - spectro-astrometric interferometry
  - fringe- and water vapor tracking

FSU B at Paranal



What *MIDI+FSU* currently stands for



- MIDI+PRIMA FSU-A with **Auxiliary telescopes** only
- **On-axis** fringe tracking support for N-band observations
- **One baseline** fringe tracking
- **Not** another FINITO
  - different band (FSU uses K vs. FINITO uses H)
  - more sensitivity (K=8.5@AT vs. H=7.5@UT)
  - instantaneous multi-λ ABCD (vs. broad-band temporal ABCD)
    - less vibration sensitive
  - water-vapor sensitive
  - better for MIR science bands
    - lower spatial resolution, higher flux for red sources

What MIDI+FSU currently does *not yet* stand for

- accepted (“paranalized”) MIDI fringe tracking option
- UT interferometry
- Off-axis fringe tracking
- Multi-baseline imaging
- we try to do one step at a time but these options are close ...

What can be done with MIDI+FSU

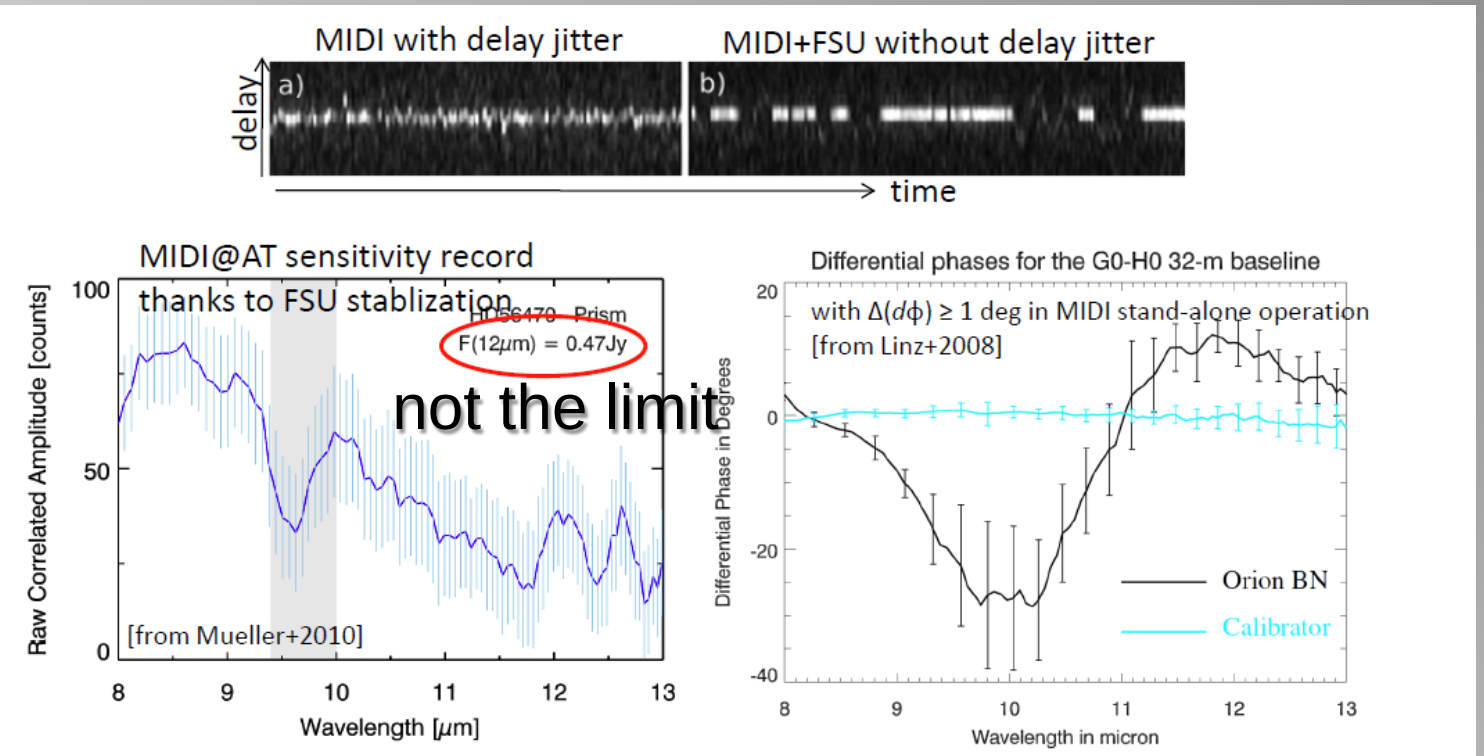


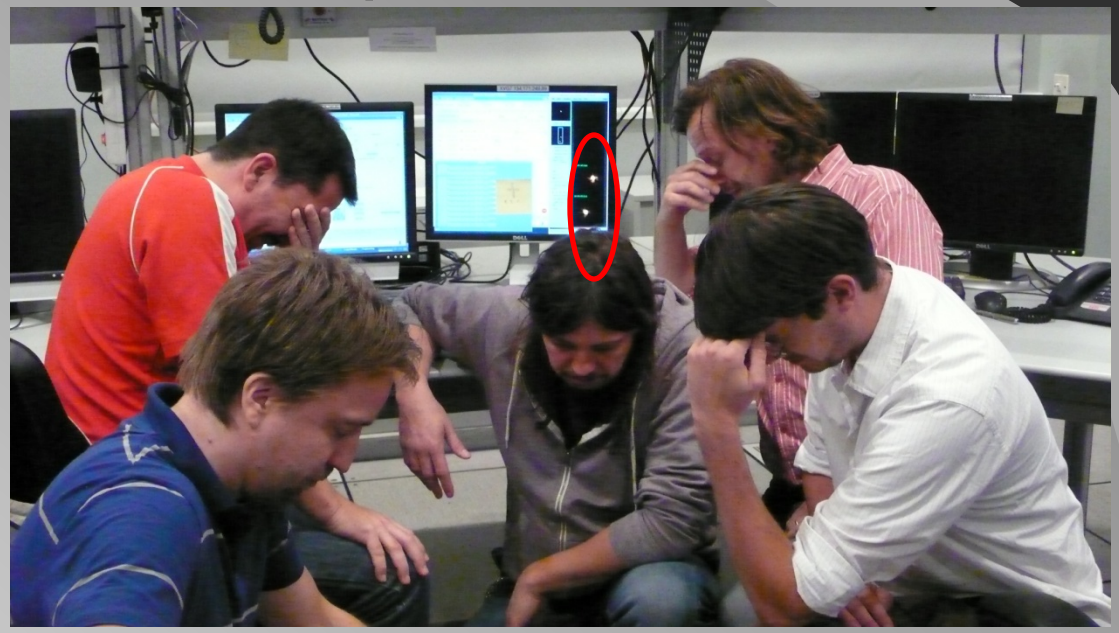
Fig. 1: **Up:** Increased OPD stability due to FSU fringe tracking during MIDI+FSU first light. **Left:** Sensitivity record of MIDI@AT thanks to FSU operation. **Right:** We plan to reobserve MIDI source with known $d\phi$ like above to demonstrate the improved $d\phi$ calibration thanks to MIDI+FSU operation.

3 nights of MIDI+FSU science demonstration in Sep‘11

- incl. few technical time before to set up the system
- main science goals are the observation of:

1. several unresolved calibrators of various brightness
2. Interferometrically confirmed 100 mas binaries
3. young stellar objects, which showed interesting spectra
4. ExoPlanet experiment (like Akeson’00, Matter+10).

3 nights of MIDI+FSU in Sep‘11

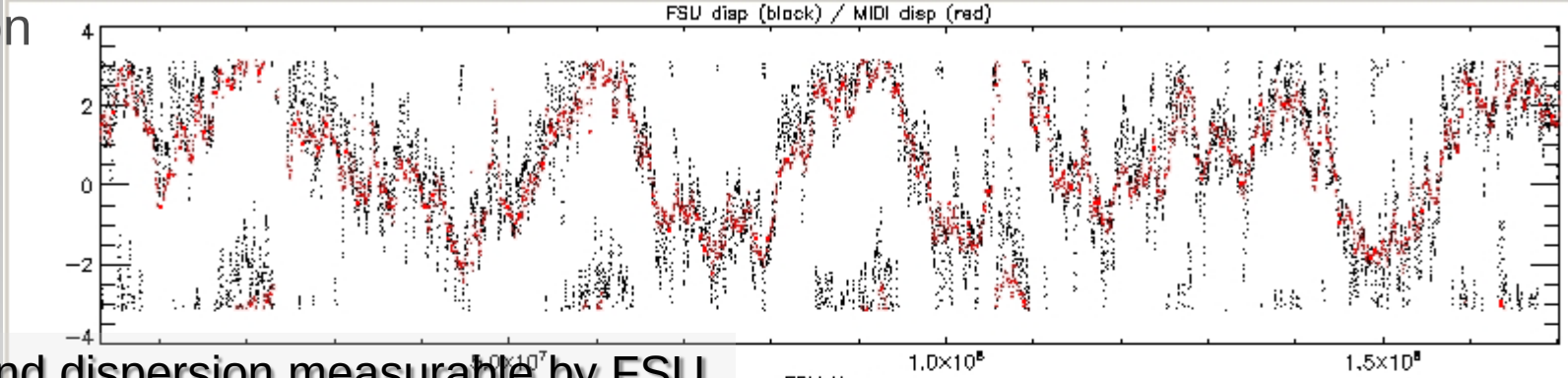


- Last light of IRIS
- first hardware failure
- then software problems
- IRIS never failed so far...

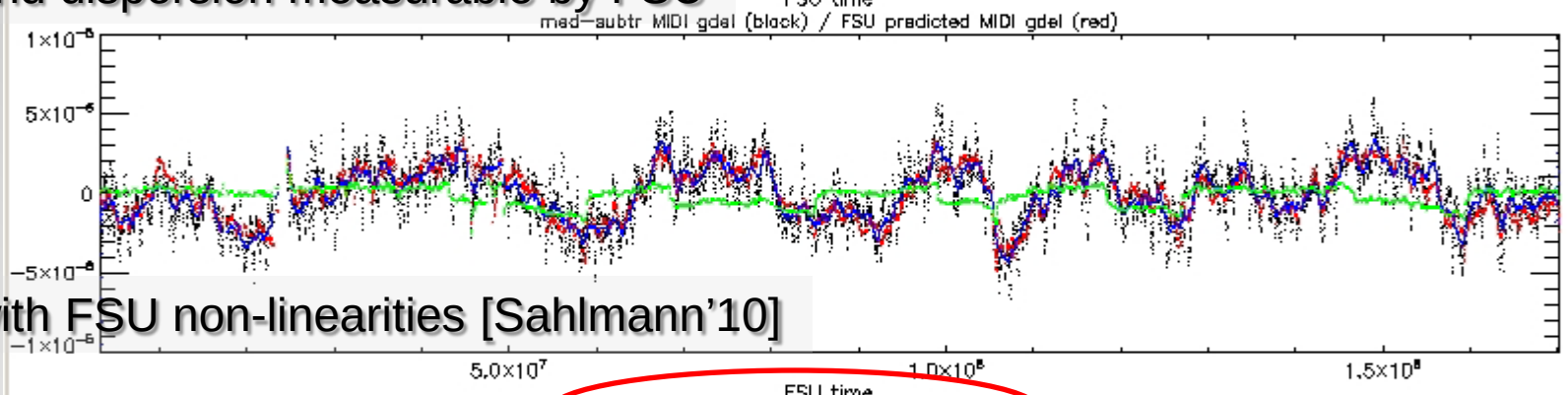
- No lab TT-control
- 0.8“ seeing not enough
- We used the time to try to fix it instead of doing regular AT-MIDI science
- In the end there is ONE star of data ...
- But we will have the chance to repeat part of the program in November‘11

MIDI+FSU is technically ready for science

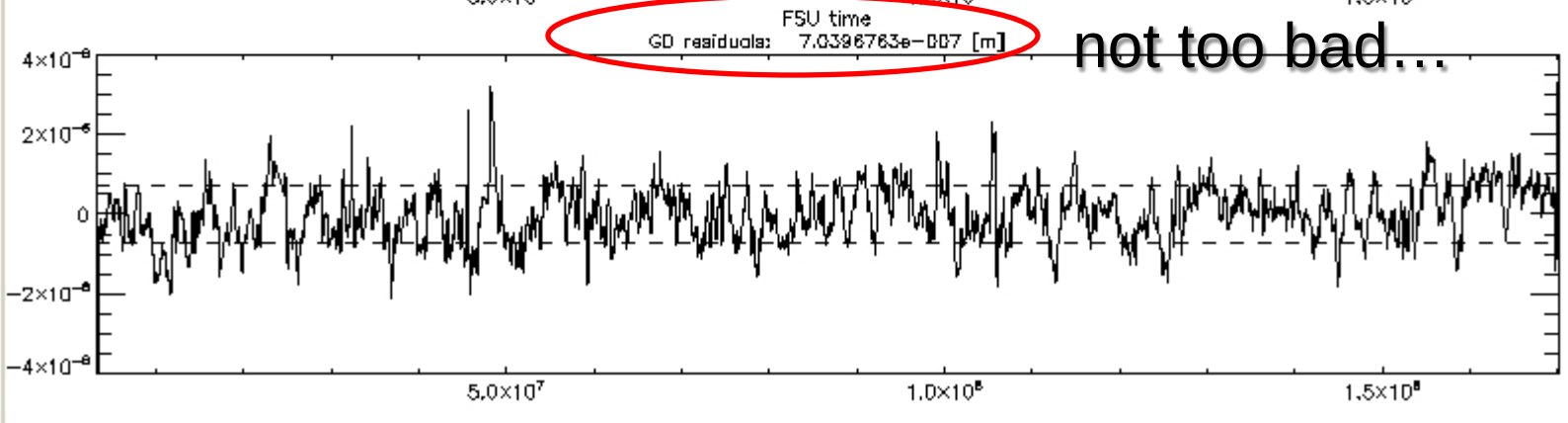
- Commissiong data give first indication for high absolute and λ-differential precision



random N-band dispersion measurable by FSU



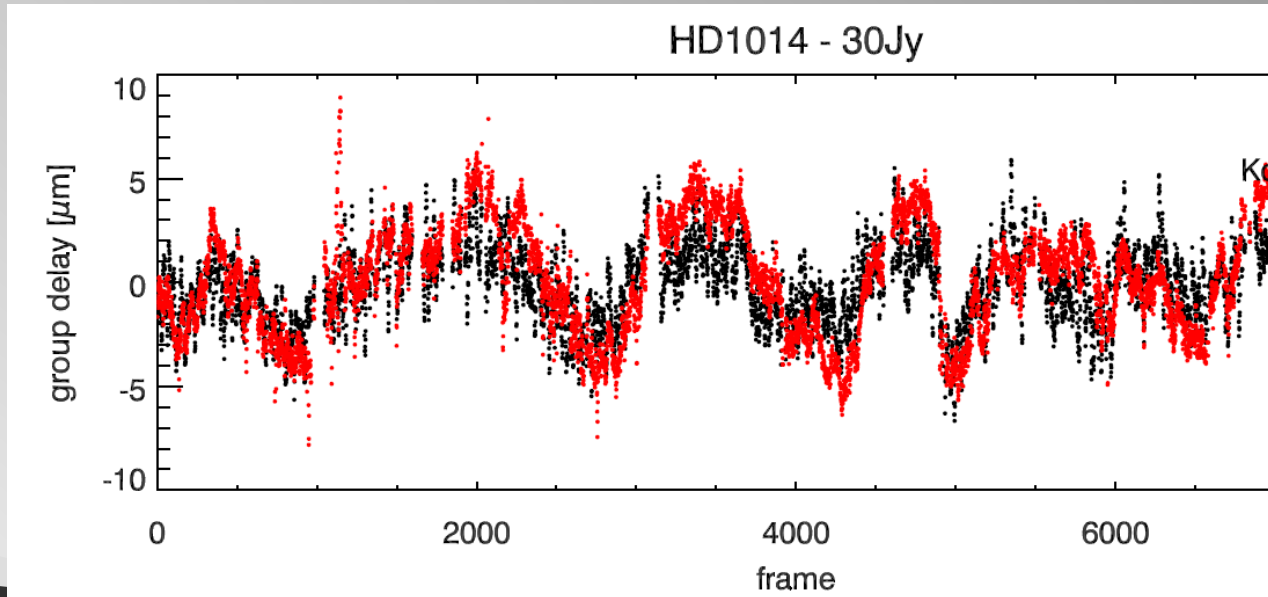
no problem with FSU non-linearities [Sahlmann'10]



not too bad…

MIDI+PRIMA FSU - water vapor seeing

- Room for improvements:
  - implement a woofer-tweeter approach in the data analysis
    - 10-100Hz GD and DISP FSU measurements are used to stabilize the MIDI fringes and allow:
    - 0.1-1 Hz MIDI GD- and DISP offset estimation
  - current AT limit of 0.5Jy can probably be improved
  - FSU blind-tracking needs to be explored [see talk by R. Petrov]
  - hints for higher precision of MIDI+FSU data vs. MIDI stand-alone for fainter sources (work in progress)



MIDI+PRIMA FSU-A outlook / wishlist

- MIDI-FSU on-axis SDT program for November
  - main goal is to get confirmed sensitivity / accuracy / precision
- Testing MIDI-FSU off-axis as soon as technically (software-wise) ready
  - data reduction is the same as for MIDI+FSU
  - great science waiting there
- Get UT experience
  - the gain in MIDI sensitivity translated to UT's gives 50mJy fringes, might be better, might be worse
  - FSU@AT sensitivity is already K~8..9 in phase tracking
- UT vibration stabilization / FSU fringe tracking should profit from faster delay line controllers (ongoing Paranal engineering effort), which currently limits servo bandwidths to << 100 Hz
  - implement the prototype controller and increase the loop gains