La Silla
Paranal
Observatory

Interferometric Instrumentation

IOT Overview Talk

The 2007 ESO Instrument Calibration Workshop
Garching, January 23-26, 2007

S. Morel, S. Stefl, F. Rantakyrö,
Ch. Hummel, Th. Rivinius, S. Brillant, M. Schöller,
I. Percheron, M. Wittkowski, A. Richichi, P. Ballester

What interferometric instruments measure (in a nutshell)

- Interferometric instruments coherently combine light from several telescopes. The spatial locations of two telescopes define a baseline vector.
- They measure a **visibility** *V*.

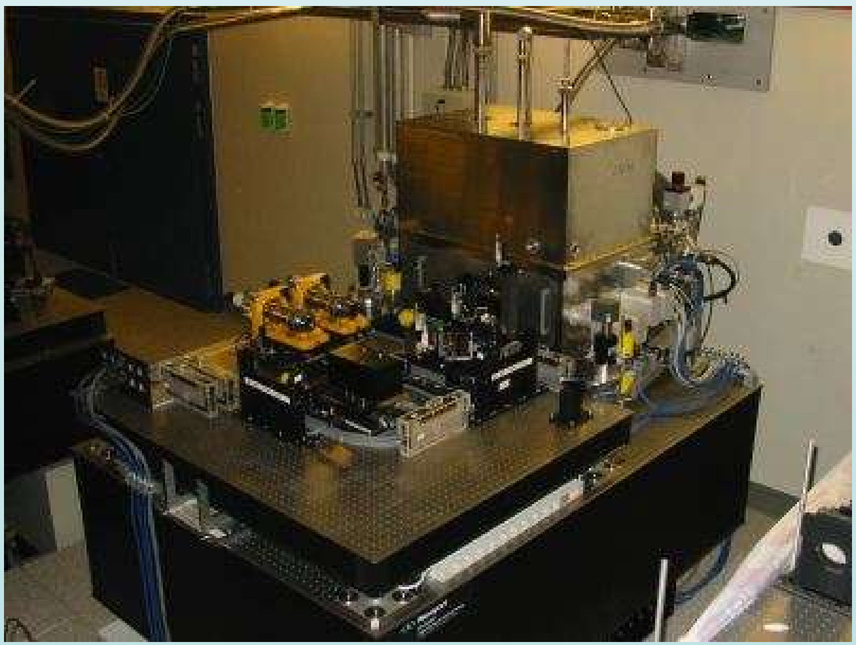
  V = normalized value of modulus, at a given point, of the Fourier transform of the spatial intensity distribution *I* of the target ⇒ high-angular resolution information about the target.
- *V* depends on baseline vector (VLTI: 8 to 200 m), hour angle, latitude, and λ. More baselines ⇒ more info on *I* (+ phase recovery of FT).
- Physically, *V* is the theoretical contrast of the interference fringes formed by the coherent beam combination.
- In addition to fringe interference measures, measure of flux from each telescope ("photometry") before combination is required to get *V*.

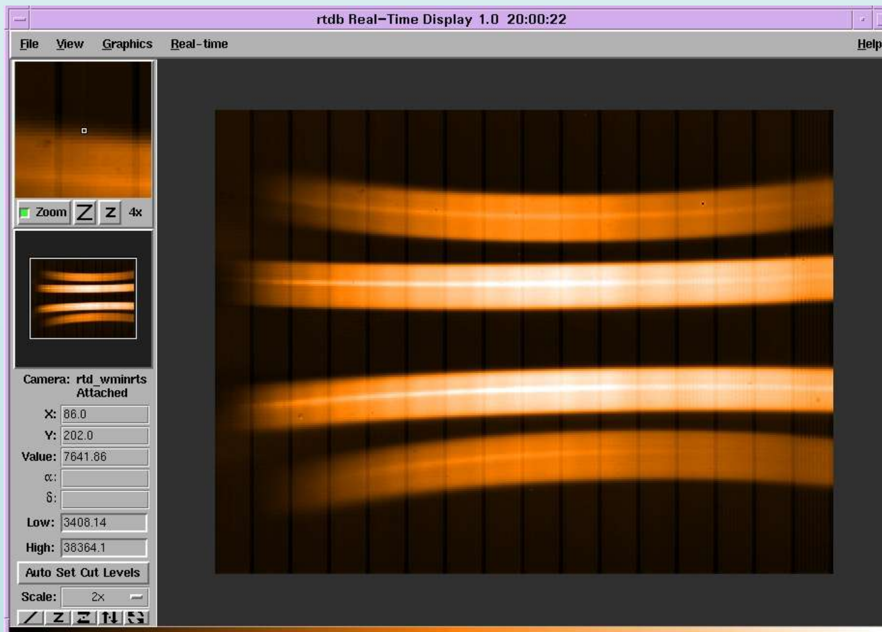
LA SILLA
PARANAL
OBSERVATORY

Interferometric instrumentation at Paranal

MIDI:

- 2 telescopes ⇒ 1 baseline.
- N-band (8 µm < λ < 13 µm), 2 possible spec. res. (R=30 or 230).
- Pupil-plane beam combination (half-transparent ZnSe plate).
- Simultaneous photometry (SCI_PHOT mode) or after fringe exposure by one-beam-only exposures (HIGH_SENS mode).



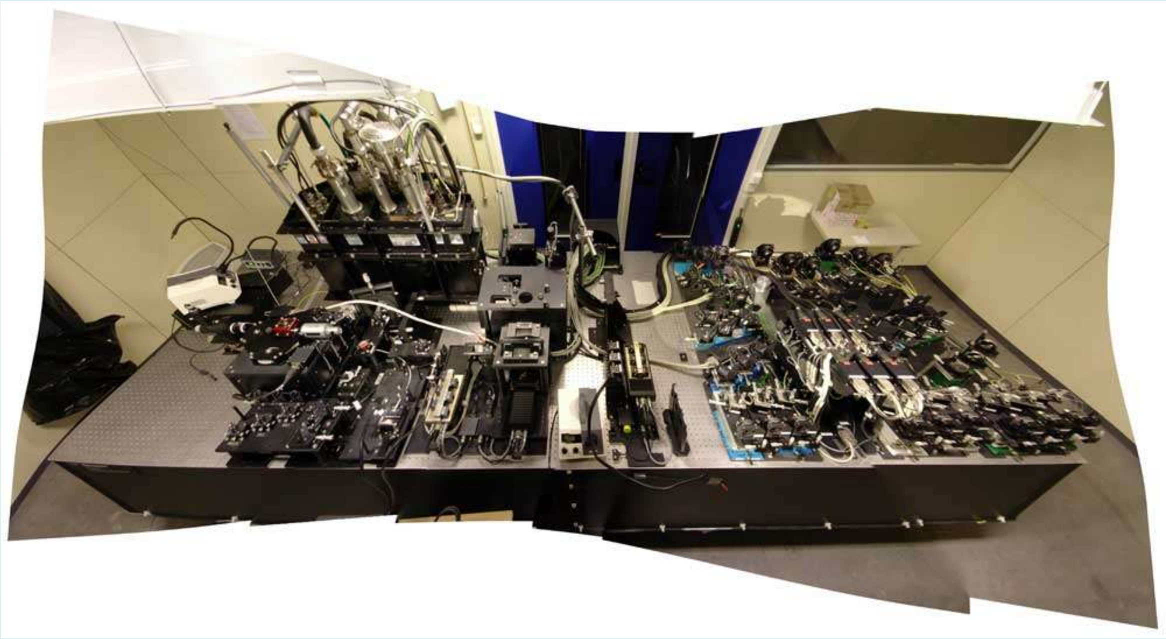


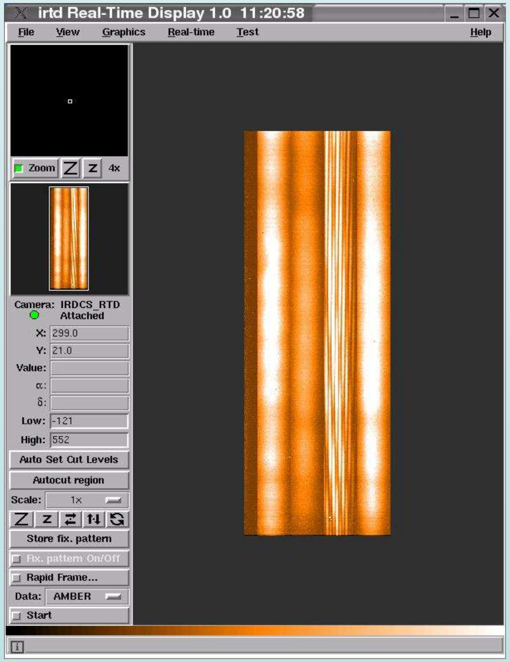
La Silla Paranal Observatory

Interferometric instrumentation at Paranal

AMBER:

- 3 telescopes ⇒3 baselines (can also use 2 telescopes).
- J, H, K bands (1.3 μm < λ < 2.3 μm), 3 possible spectral resolutions.
- Spatial filtering of beams by monomode fibers prior to combination.
- Image-plane beam combination (parallel beams focused on detector).





General calibration plan for VLTI instruments

- Visibility calibrations on-the-sky.
- Flux calibration (i.e., thermal background removal).
- Internal instrument calibrations (optics, detector).
- Instrument health-checks.

Crucial for data quality but not calibrations *stricto-sensu*:

- Optical alignment of VLTI.
- Pupil re-imaging.
- Telescope wavefront correction (MACAO, STRAP).
- Vibration control.
- Fringe-tracking (FINITO).

Visibility calibration

Measured visibility μ is calculated from correlated flux (= interference fringe amplitude) and uncorrelated flux (= photometry from each telescope).

μ is affected by:

- Atmospheric wavefront errors:
  - On each telescope
  - On the optical path difference between the beams.
- Beam overlap fluctuations (MIDI).
- Flux injection fluctuations in monomode fibers (AMBER).
- Instrumental effects (polarizations, vibrations).

$\Rightarrow$ Consequence: $\mu < V$ ($\mu = 0.4V$ to $0.9V$).

Visibility calibration

La Silla Paranal Observatory

⇒ To recover V from μ: measure μ_0 of a target (calibrator) for which the visibility V_0 is known for a given baseline and λ. This will yield $T=\mu_0/V_0$ (interferometric transfer function).

Therefore, $V = \mu/T$

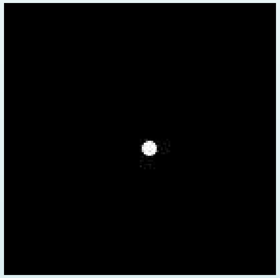
- Observation of calibrator stars:
  - Same instrumental set-up (optical path, detector settings).
  - Same region in the sky (similar turbulence effects).
- Always one calibrator observed for each scientific target

⇒ half of the night time is spent on calibrator observations !

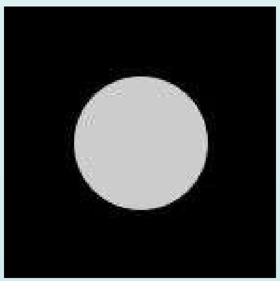
- Actually, $T[\mu_0] \neq T[\mu]$ (temporal fluctuations). T should be measured on several calibrators observed during the night.

⇒ Paramount importance of the choice of the calibrator (stability of V_0).

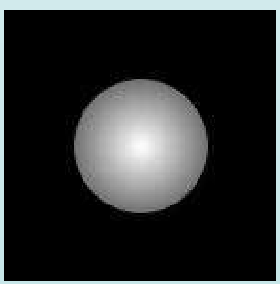
Possible calibrator *I* models



Point source: V=1 at anytime for any baseline. Would actually apply to sources too faint for instruments. OK for very short baselines.



Uniform disk. Angular diameter θ needed.



Limb-darkened disk. More acurate than UD.

Note: for V^2>0.4, relative difference of V^2 between UD and LD models is <0.1%

MIDI calibrators from the consortium

- Calibrator catalog for MIDI (MCC) established by the consortium (B. Stecklum, T. Verhoelst, R. van Boekel).
- Method to select MIDI calibrators:
  - Take candidates from the IRAS and MSX point source catalogs with the criteria:
    - Flux at 12 μm > 5 Jy (MIDI+UT limit: 1 Jy).
    - Declination ≤+35 deg.
    - Color temperature > 4000 K.

    ⇒ 511 candidates.

LA SILLA PARANAL OBSERVATORY

MIDI calibrators from the consortium

- 2nd step: collect photometric information on candidates, from UV to mid-IR: Geneva catalog (UV/visible), SAAO 0.75-m observations (near-IR ; purposely done for MIDI), IRAS and MSX + SPIRIT-II data (mid-IR).
- 3rd step:
  - Correction of photometric data.
  - Fit the SED using Kurucz models with T_{eff}, A_v and θ as free parameters.
- Results were used to:
  - Assess the quality of the calibrators: comparing measured mid-IR flux vs. flux predicted by synthetic SED (reveals IR excess ⇒ bad calibrators) ⇒ Filtered list of 178 "good" calibrators.
  - Get the limb-darkened diameter of the calibrators (± 5% for the filtered list).

⇒ V_0 known at a given baseline.

La Silla Paranal Observatory

The Mérand et al. calibrator catalog (AMBER)

- AMBER calibrators may come from the catalog established by A. Mérand, P. Bordé, V. Coudé du Foresto.
- Method to select calibrators:
  - Start from the Cohen catalog (C99) = set of IRAS objects with constraint on flux (> 1 Jy @ 25 µm), spectral types (A0-G9 (lum. II-IV), K0-M0 (III-V)), IR environment.
  - Relax constraints on C99: flux < 1 Jy, allow extended IR environment (to get more sources in galactic equator).
  - New constraints: Keep only stars listed in SIMBAD, eliminate binary stars, look at radial velocity to eliminate stars that might depart from spherical shape (flattened due to fast rotation).

The Mérand et al. calibrator catalog (AMBER)

- 2nd step: collect photometry data:
  - Near-IR: 2MASS PSC
  - Mid-IR: IRAS PSC + MSX catalog
- 3rd step: fit photometry with stellar templates (Cohen) to get SED

  ⇒ reject stars with χ^2 from fit too large.

∀ ⇒ Limb-darkened diameters.

∀ ⇒ 1320 calibrators for baselines up to 200 m.

LA SILLA PARANAL OBSERVATORY

Catalog of High-Angular Resolution Measurements (CHARM)

Compilation by A. Richichi and I. Percheron of direct measurements of star diameters.

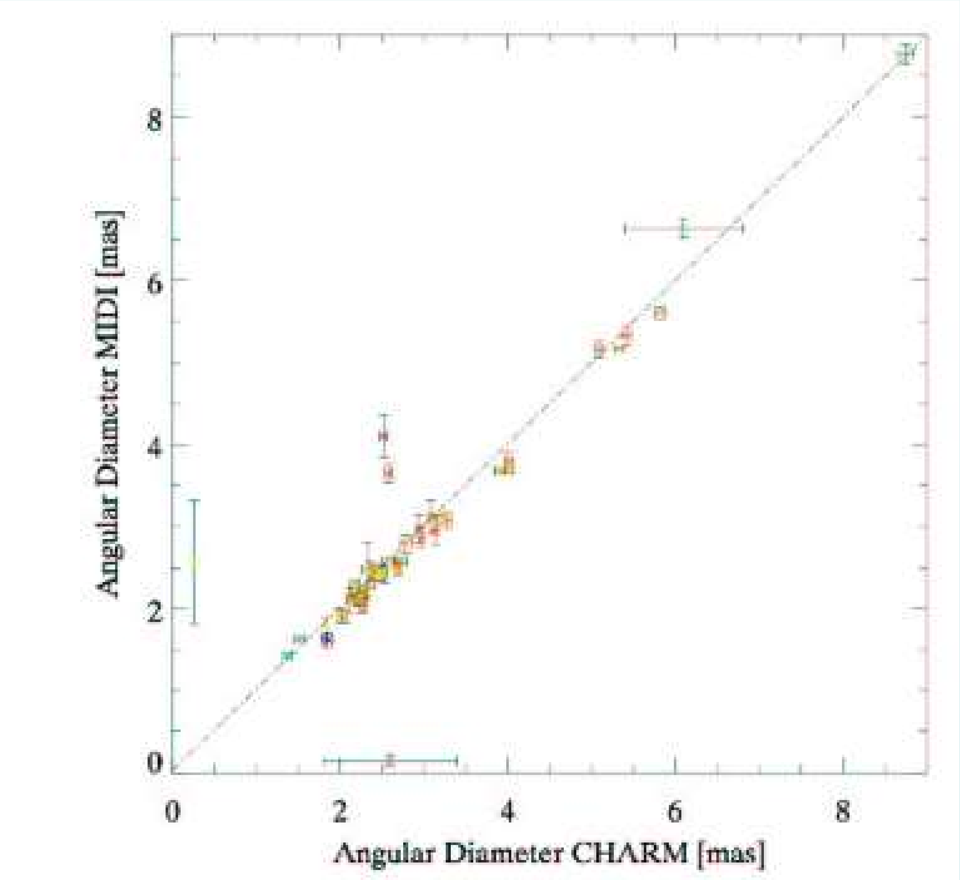
Idea: find suitable calibrators by “bootstrapping” visibilities

- Techniques: lunar occultation and long-baseline interferometry.
- Source: publications and web-doc. until end yr. 2000.
- Collected photometry information to identify variable stars.
- Updated in 2004 with VLTI (VINCI + MIDI-comm.) results $\Rightarrow$ CHARM2 catalog:

  3516 sources, among them: 1596 calibrators.

LA SILLA
PARANAL
OBSERVATORY

Comparison between CHARM and MCC calibrator diameters



⇒ No large discrepancy between the two methods (photometry and direct measurement).

User support for VLTI calibrations

- During phase-2, users select their calibrators for their targets.
- ESO recommends to use the CalVin tool (web-interface controlled) to select the calibrators.
- CalVin database:
  - MCC.
  - Mérand et al. catalog.
  - CHARM2.
- All calibrator data are public $\Rightarrow$ T for a given time can be estimated from all the values measured during a night.

LA SILLA PARANAL OBSERVATORY

CalVin screenshots

Interferometry Exposure Time Calculator

http://www.eso.org:80/observing/etc/bin/vlti/calibSelect/script/calibSelect

Apple Mac Amazon eBay Yahoo! News

List of Calibrators

References

MIDI Workshop on VLTI Calibrators

AMBER [B02] A catalogue of calibrator stars for long baseline stellar interferometry, Bordé, P.; Coudé du Foresto, V.; Chagnon, G.; Perrin, G. 2002A&A...393..183B

AMBER [M04] A catalog of bright calibrator stars for 200-meter baseline near-infrared stellar interferometry, A. Mérand, P. Bordé and V. Coudé du Foresto, A&A accepted

9 calibrators found

ASCII file format - the first column is the universal time

Comparative graphs for *Target* vs. 7 calibrators:- Normalized Visibilities Loss of Correlated Magnitudes Target Altitudes Shadow

No.	Name	R.A. (h.m.s)	Dec. (d.m.s)	Ang. Dist. (deg°)	Ang. Diam. (mas)	Mag_N	Spec. Type	Lum. Class	Qual. Flag	Normalized Visibility ave ± err range	Loss of Correlated Magnitude ave ± err range	RiseTime SetTime Duration	Culmination MaxAltitude	Shadowing
1	*Target*	6 45 8.90	-16 42 58.00	0.0	6.00 ± 0.00					0.91 ± 0.000 0.91-0.91 graph ascii	0.21 ± -0.00 0.21-0.21 graph ascii	35.50UT 35.50UT 0.00hrs	35.50 UT max = 17° graph ascii	max = 0% graph ascii
2	hd48915	6 45 8.92	-16 42 58.00	0.0	6.06 ± 0.13	-1.23	A1	V	1	0.91 ± 0.004 0.91-0.91 graph ascii	0.22 ± 0.01 0.22-0.22 graph ascii	35.50UT 35.50UT 0.00hrs	35.50 UT max = 17° graph ascii	max = 0% graph ascii
3	hd[illegible]	6 54 [illegible]	-12 2 [illegible]	5.2	[illegible]	0.67	[illegible]	III	1	NOT VISIBLE	NOT VISIBLE	NOT VISIBLE	NOT VISIBLE	NOT VISIBLE
4	hd61935	7 41 14.83	- 9 33 4.10	15.4	2.26 ± 0.12	1.64	G9III	III	2	0.99 ± 0.001 0.99-0.99 graph ascii	0.02 ± 0.00 0.03-0.02 graph ascii	22.25UT 22.75UT 0.50hrs	22.25 UT max = 22° graph ascii	max = 0% graph ascii
5	hd36079	5 28 14.72	-20 45 34.00	18.6	2.97 ± 0.16	0.90	G5II	II	2	0.98 ± 0.003 0.98-0.98 graph ascii	0.05 ± 0.01 0.05-0.05 graph ascii	34.00UT 35.50UT 1.50hrs	35.50 UT max = 36° graph ascii	max = 0% graph ascii
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.99 ± 0.001 [illegible]	0.02 ± 0.00 [illegible]	34.25UT [illegible]	35.50 UT [illegible]	[illegible]

(Non-absolute) flux calibrations in science-target or calibrator OBs

- **MIDI:**
  - 0.5-Hz telescope chopping (photometry): remove thermal background (but residuals remain).
  - Interferometric channel subtraction: fringes in phase opposition ⇒ Remove thermal background correlated in both interf. channels + enhance interferometric information.
  - Extra one-beam-only exposures (like HIGH_SENS photometry) in SCI_PHOT+GRISM mode to correct image distortion (new from user feedback, not in original calib. plan).

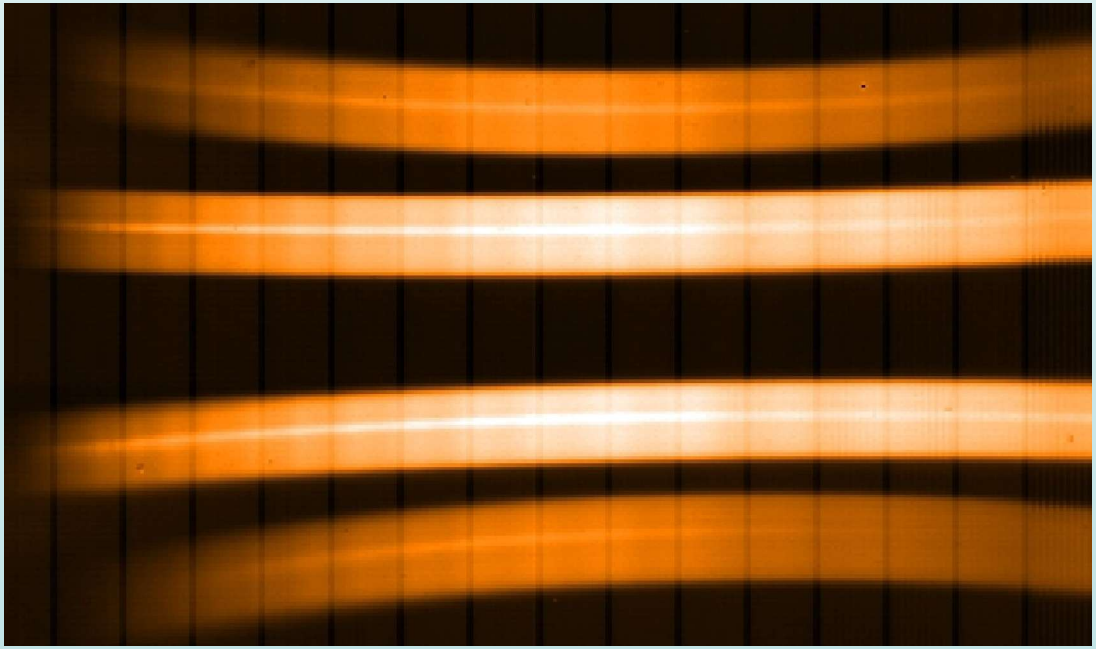
MIDI sensitivity actually limited by photometric, not by interferometric performance !

- **AMBER:**
  - Dark exposure (shutter closed).
  - Sky exposure (telescopes offseted).

LA SILLA
PARANAL
OBSERVATORY

MIDI internal calibrations

- **"Kappa matrix"** = splitting ratios of SCI_PHOT beam combiner (interferometric+photometric channels): performed at the beginning of each night of bright calibrator.
- **Wavelength calibration** using narrow band filters and plastic foils: performed every day.

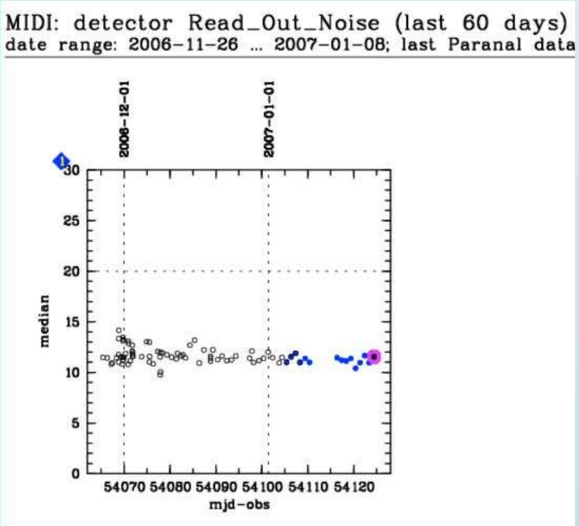


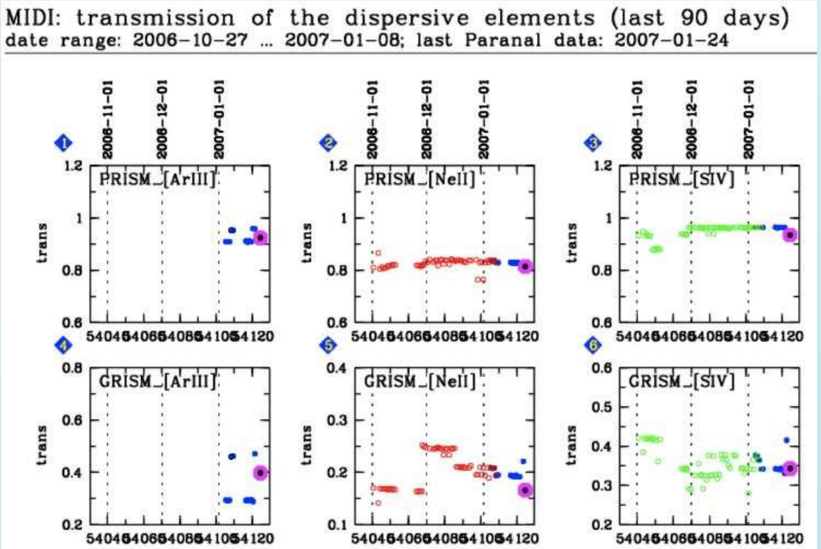
MIDI health-checks

- **Implemented on daily basis in September 2006.**

  (Use a blackbody source on MIDI bench):
  - Detector readout noise and linearity.
  - Dispersive element transmissions (measured at 3 wavelengths).
  - Dispersion stability.
  - Internal alignment.

  As of 2007-01-24: MIDI very stable.



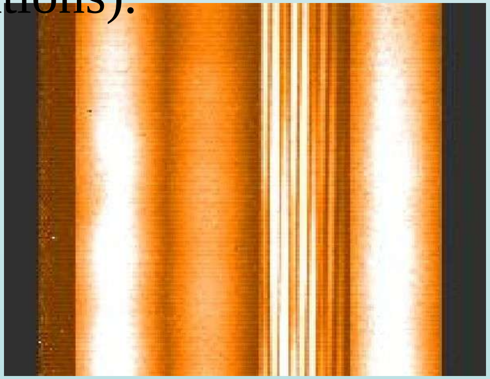


AMBER internal calibrations

La Silla Paranal Observatory

- **Detector bad-pixels map:** measured every 6 to 12 months.
- **Flat-field map**: measured every 6 to 12 months . Used to calibrate detector response (linearity).
- **"P2VM"** = pixel-to-visibility matrix. Internal *T* for each pixel using an internal source (*V*=1). P2VM template includes exposures to measure:
  - Column positions.
  - Flux in interferometric channel from each beam individually.
  - Vertical = spectral offset between interferometric and photometric channels (using etched filter).
  - Fringes and fringes shifted by $\varphi = \pi$.

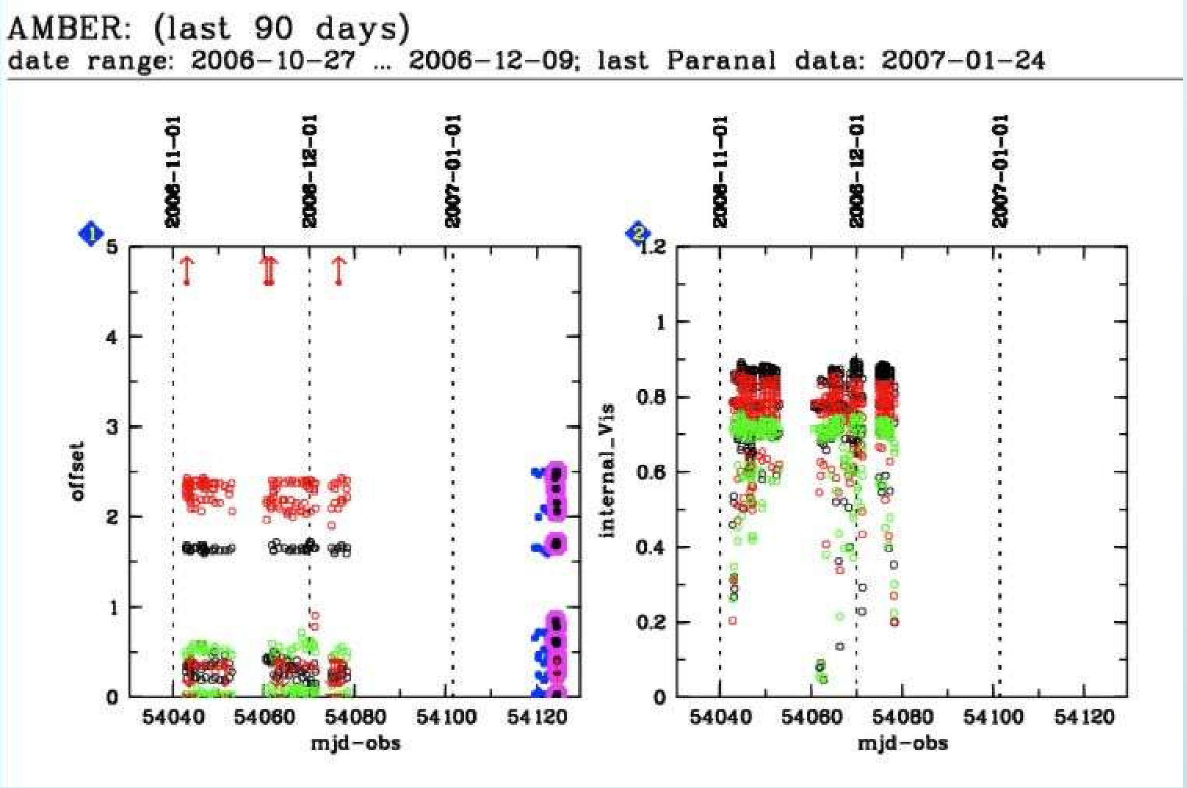
P2VM valid for one mode only (executed when switching to a new mode during observations).



La Silla Paranal Observatory

AMBER health-checks

- **Beam positions on detector:** (quality of alignment of dichroics) performed everyday. Known to be very unstable (dilatation effects).
- **"P2VM":** performed everyday at all resolutions and central wavelength. Used to monitor column offsets and global internal *T*.



Perspectives and projects

- **MIDI:**
  - Measurement of background residuals after chopping on sky (nodding) to improve photometry ? Stationarity issue.
  - Measurement of internal OPD stability for PRIMA phase-referencing mode.
  - Problems of MIDI calibrators for MIDI + FINITO: over-resolved (*V* very small) in H-band for FINITO.
  - Investigate effects of cryo-cooler vibrations.
  - Refine health-checks (grism trans., monitoring of *T*).
- **AMBER:**
  - Better measurement of bad-pixel maps and flat field maps by blackbody source.

  ⇒ More frequent and delivered to the users.

More about VLTI…

LA SILLA PARANAL OBSERVATORY

- **Talks coming up next:**
  - F. Millour, “VLTI with AMBER”
  - W. Jaffe, “MIDI calibration” (presented by C. Hummel).
  - C. Hummel, “QC and analysis of MIDI data using *mymidigui* and OYSTER” (poster presentation).
- **Posters:**
  - I. Percheron, “VLTI instruments: from J to N band instrumental calibrations, from short to long baseline astronomical calibrations”
  - C. Hummel, “QC and analysis of MIDI data using *mymidigui* and OYSTER”
  - P. Cruzalèbes, A. Spang, S. Sacuto, “Calibration of AMBER visibilities”.