What AMBER could do for you

Interferometry micro-workshop

ESO, Santiago
January 28, 2004

Martin Vannier
ESO/Chile, VLTI team

credits to:
R. G. Petrov, PI of AMBER
F. Malbet, project scientist of AMBER

Osservatorio Astrofisico di Arcetri

AMBER Consortium

Max-Planck-Institut für Radioastronomie

- Funding, Detector, data acquisition, real time processing.

Osservatorio Astrofisico di Arcetri

- Funding, Cooled spectrograph.

GRENOBLE I UNIVERSITE JOSEPH FOURIER SCIENCES TECHNOLOGIE MEDECINE

- Instrument operation software, data processing, global laboratory integration and tests.

Observatoire de la Côte d'Azur

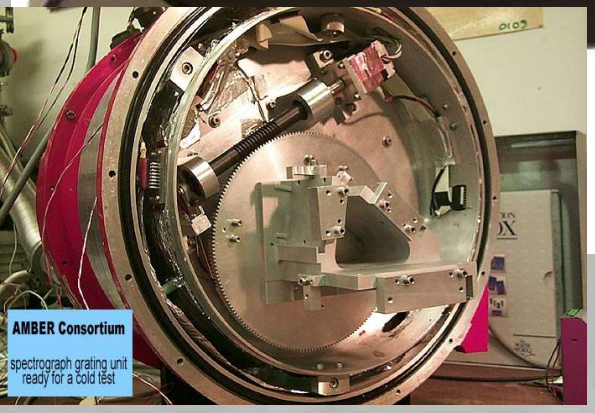
UNIVERSITÉ NICE SOPHIA ANTIPOLIS

- Warm Optics and mechanics, electronics, instrument control software.

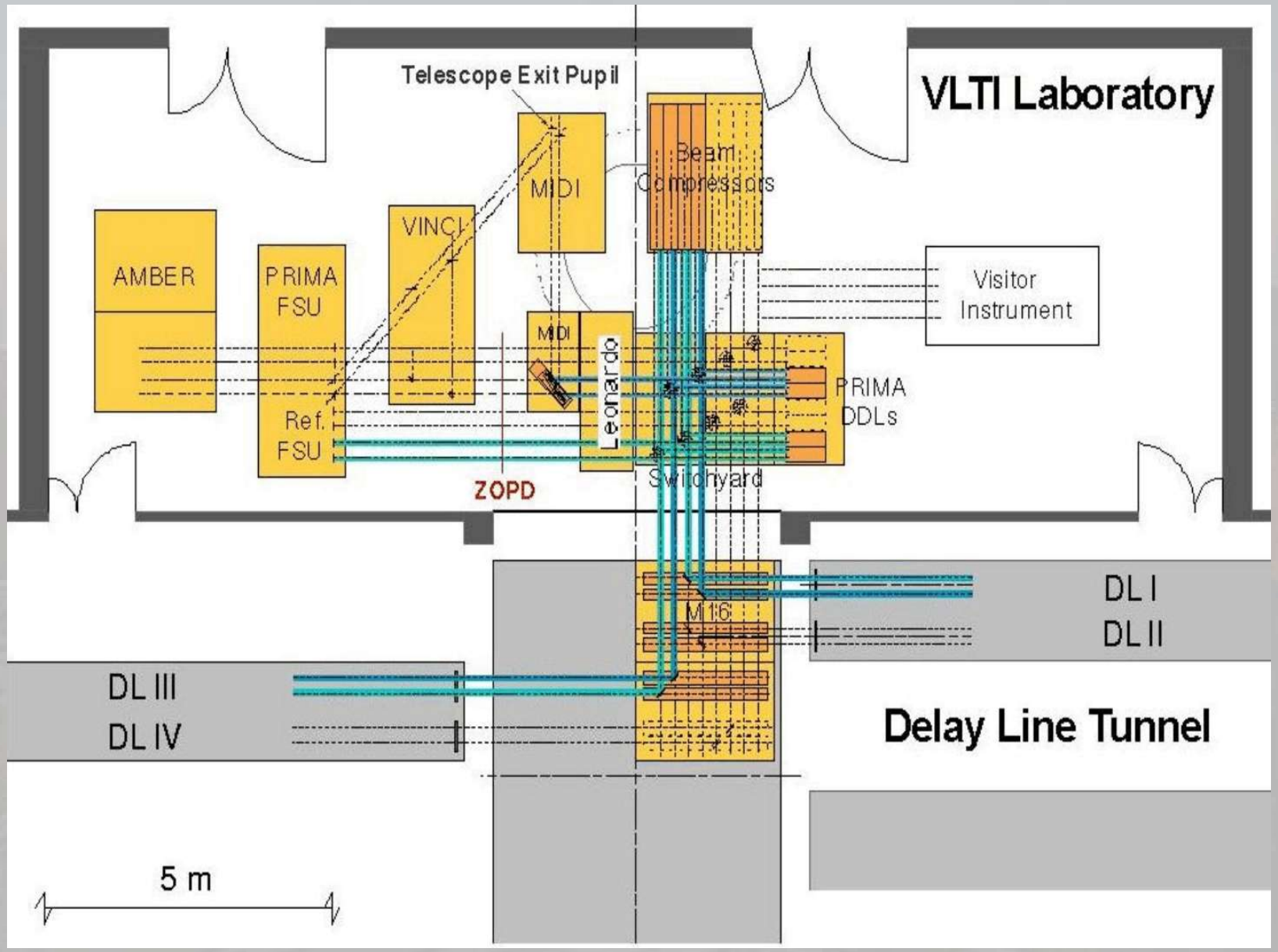
INSTITUT NATIONAL DES SCIENCES DE L'UNIVERS INSU

- Funding, assistance from the technical division

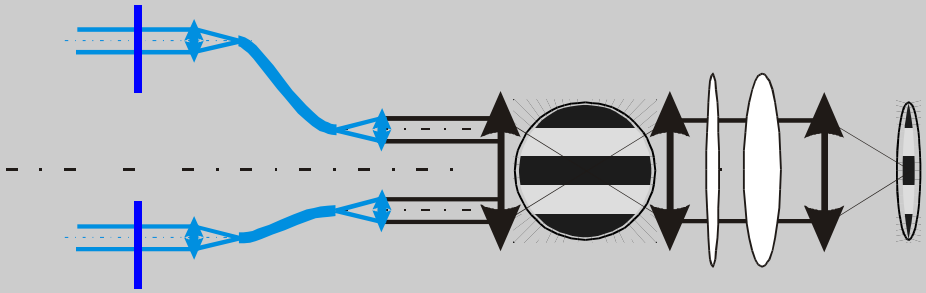
AMBER: Near infrared, three-beams, dispersed fringes, single mode VLTI focal instrument



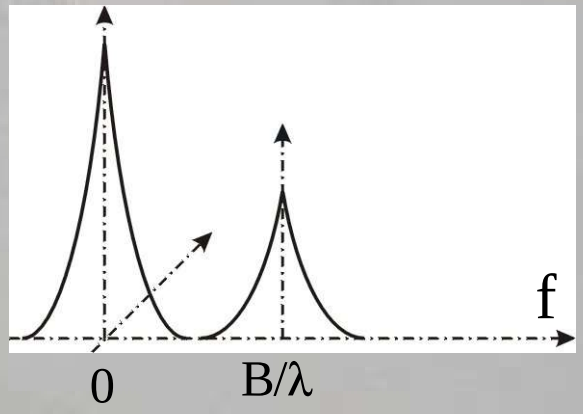
From: " AMBER, the near infrared instrument of the VLTI", F. Malbet, Leiden 12-13/ 01 /04


VLTI Laboratory
Telescope Exit Pupil
MIDI
Beam Compressors
VINCI
AMBER
PRIMA FSU
Visitor Instrument
MIDI
Leonardo
PRIMA DDLs
Ref. FSU
ZOPD
Switchyard
M16
DL I
DL II
DL III
DL IV
Delay Line Tunnel
5 m

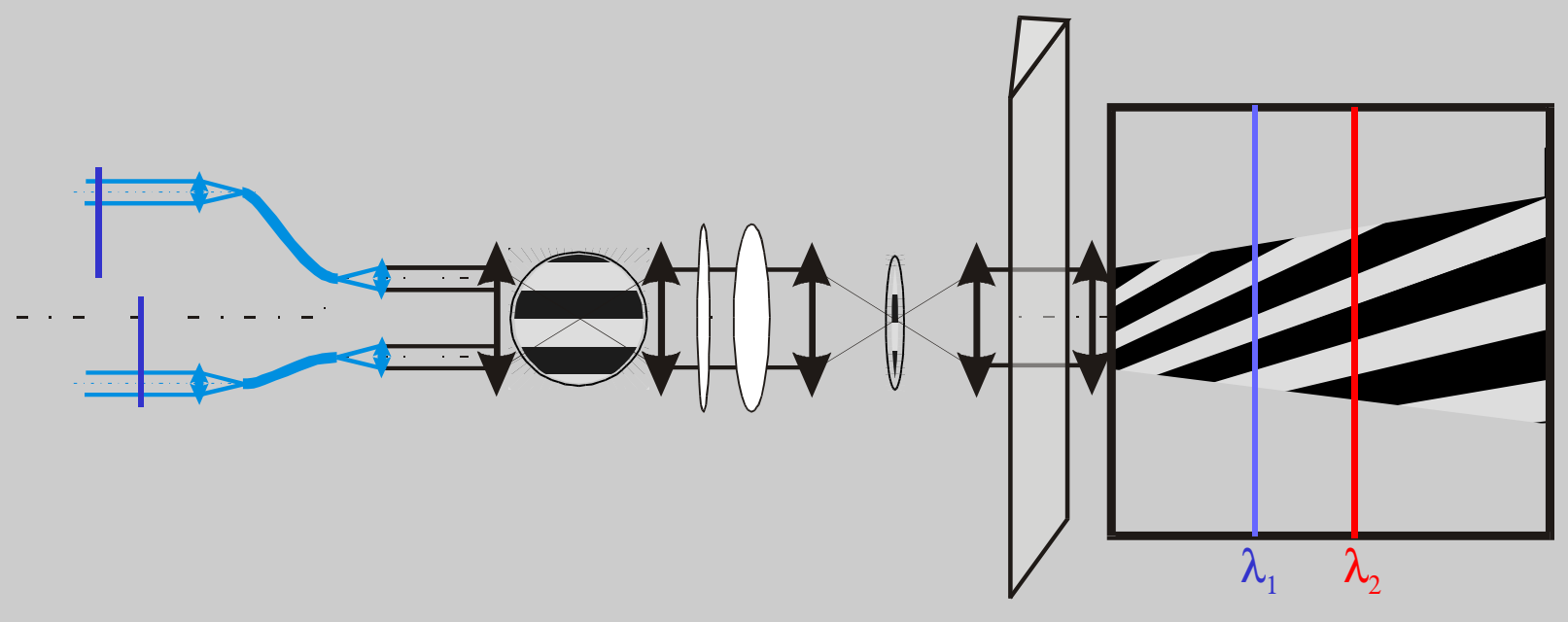
AMBER Principle



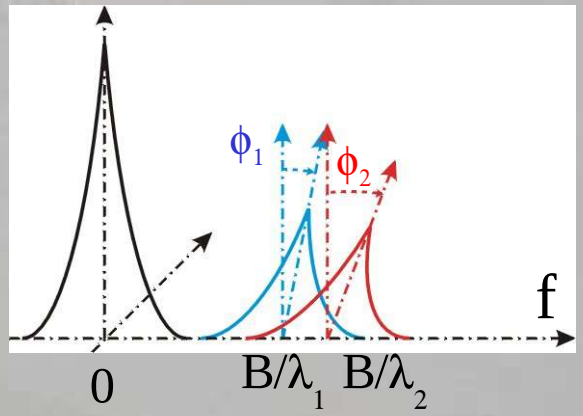
- 2 Telescope multi axial beam combiner with cylindrical optics anamorphosis
- spatial filtering (single-mode optical fibers) corrects WF aberrations of order higher than 1



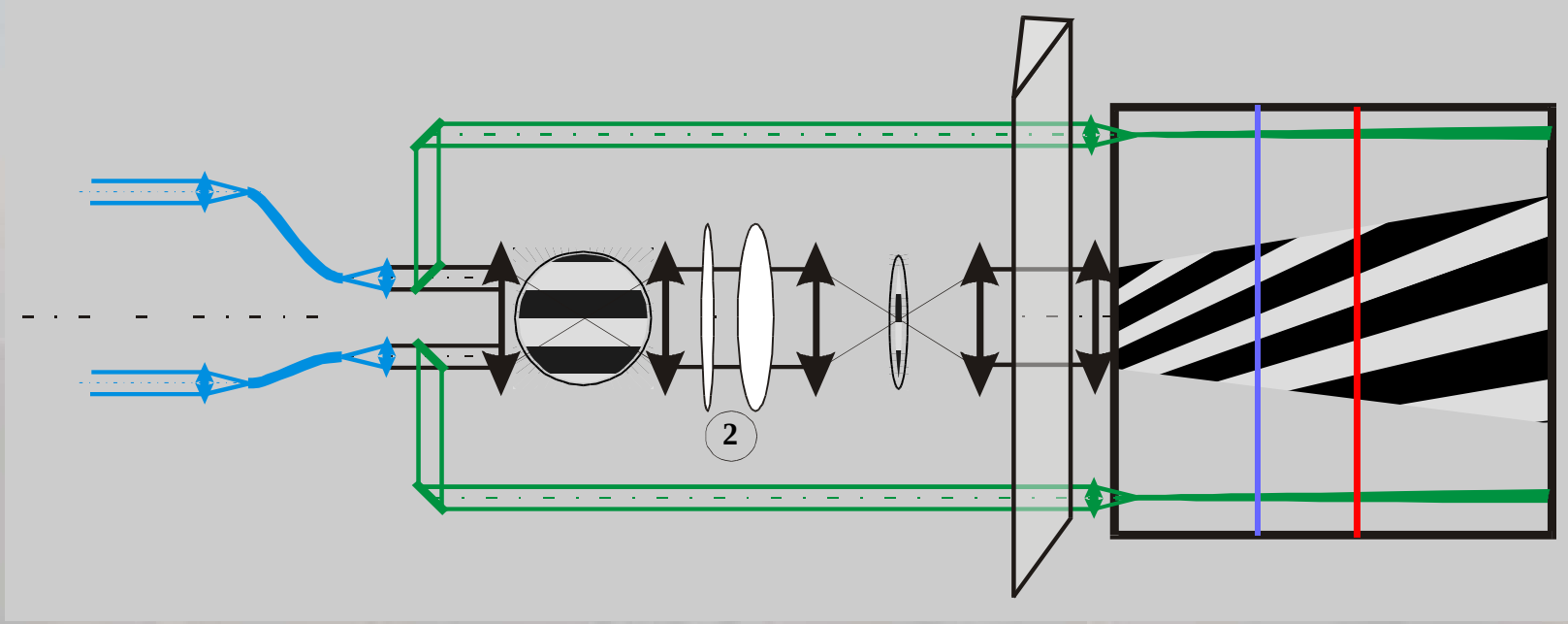
AMBER Principle: 2 T, dispersed fringes



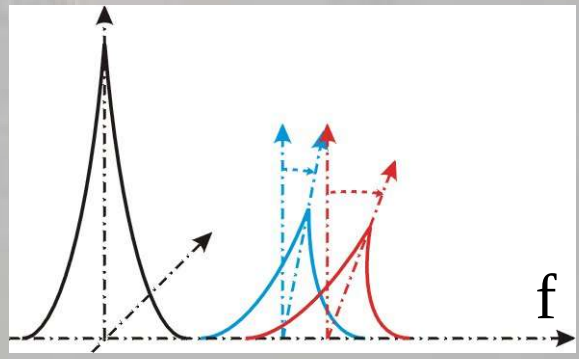
- 2 Telescope multi axial beam combiner with cylindrical optics anamorphosis
- spatial filtering
- fringe peaks with piston and differential phase
- dispersed fringes (prism, grism)



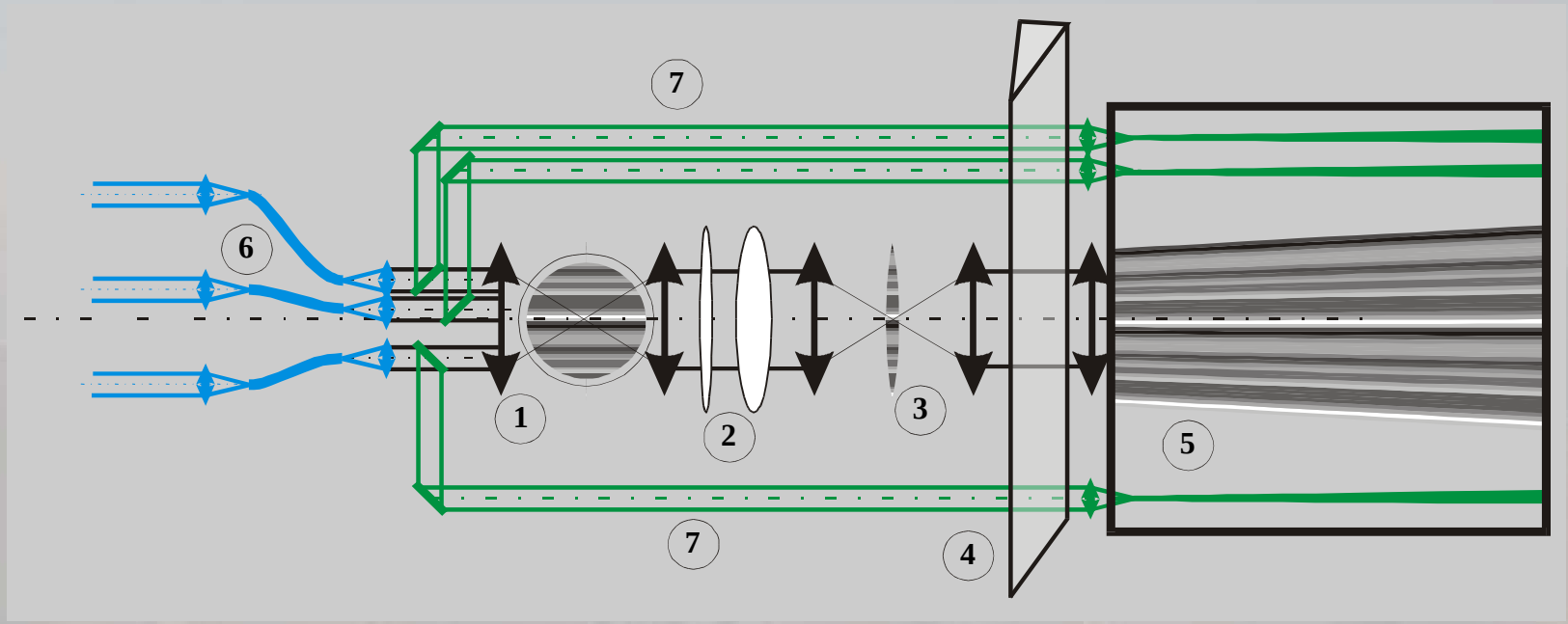
AMBER Principle: 2 T, correction of photometry



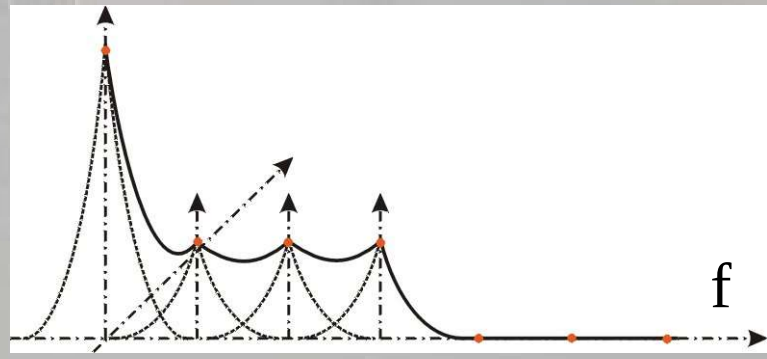
- 2 Telescope multi axial beam combiner with cylindrical optics anamorphosis
- spatial filtering
- fringe peaks with piston and differential phase
- dispersed fringes
- photometric monitoring



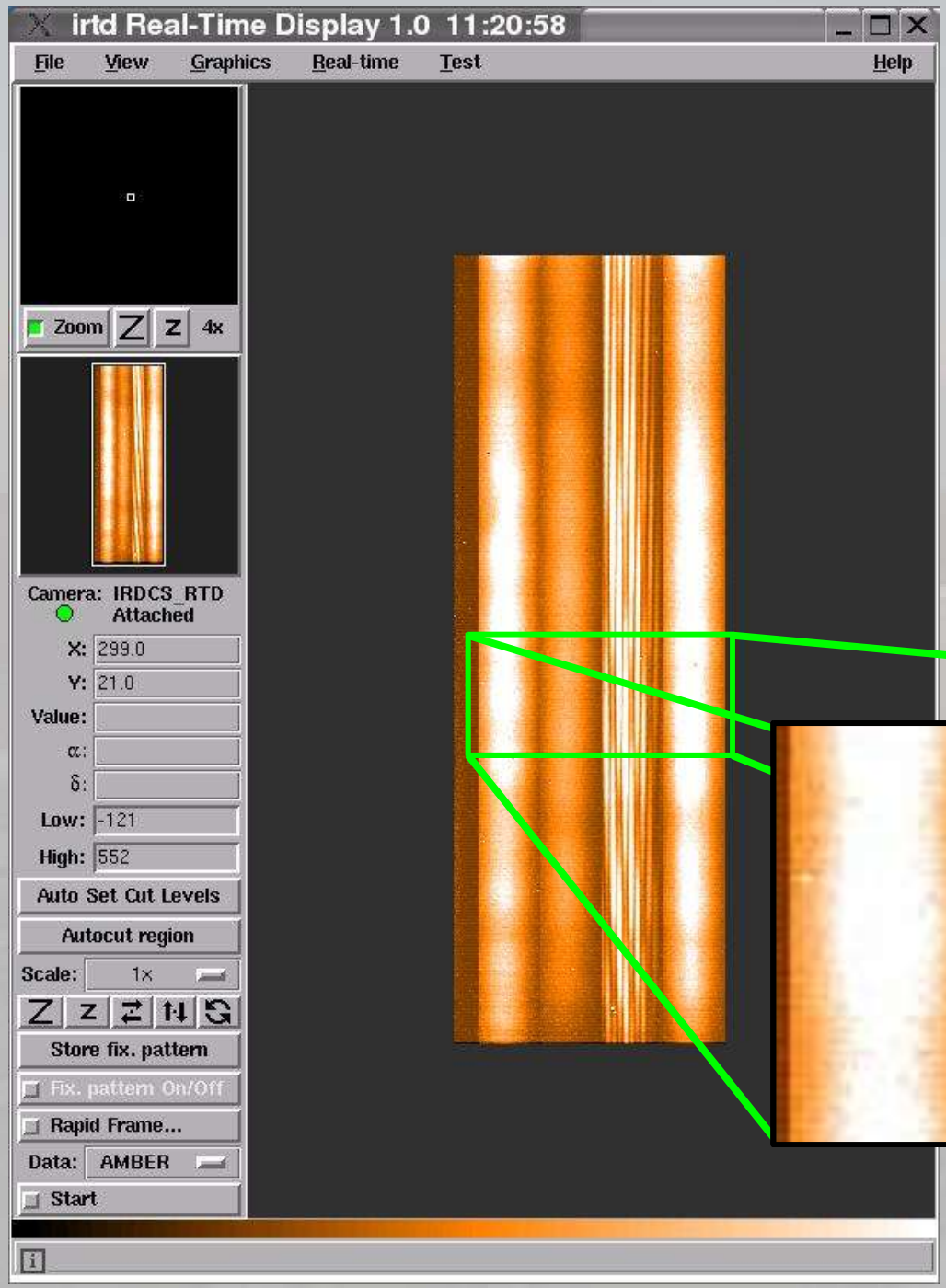
AMBER Principle: 3 T instrument

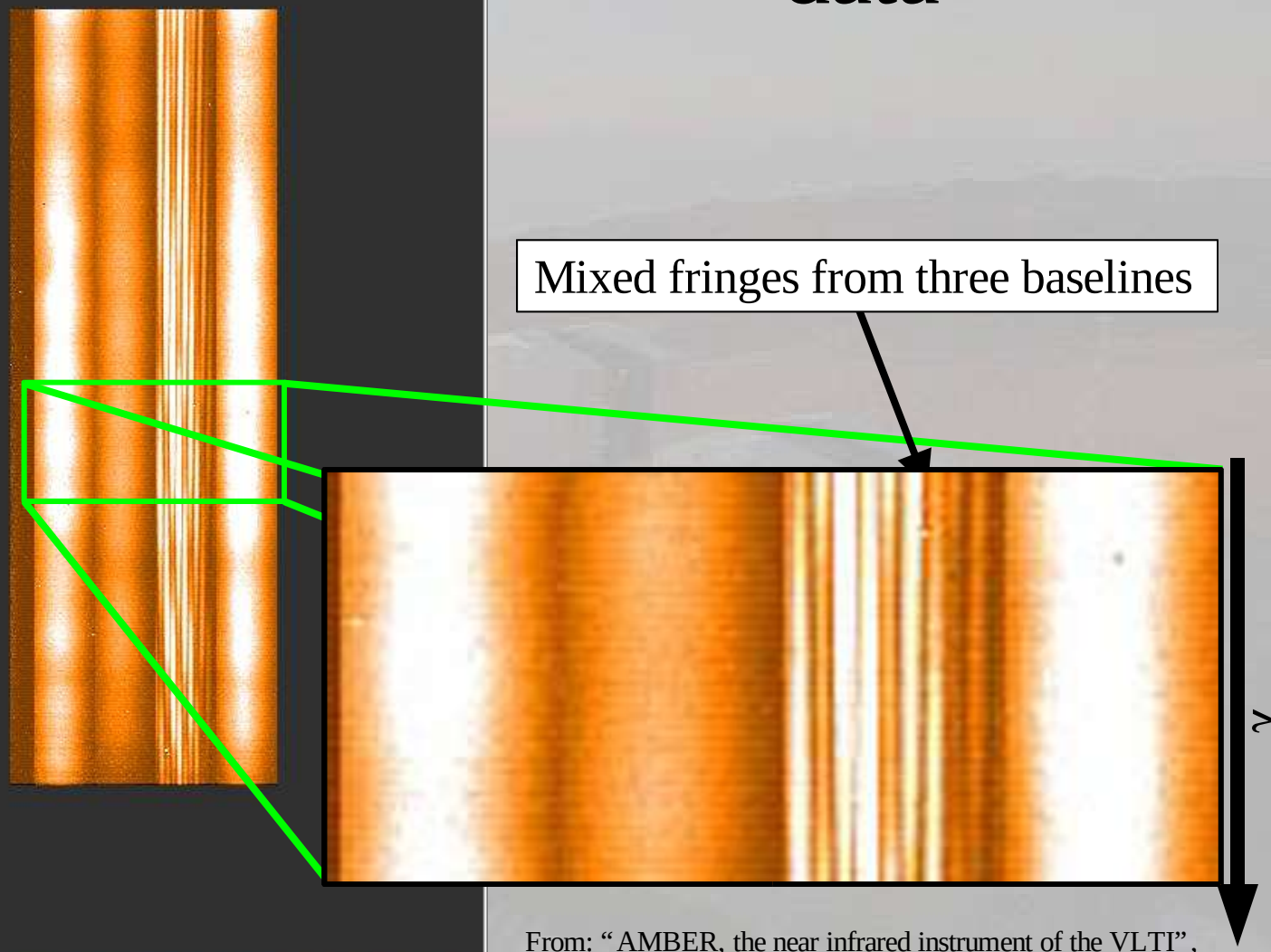


- 3 Telescopes implementation with **compact** non redundant fringe coding



AMBER raw data





From: "AMBER, the near infrared instrument of the VLTI", F. Malbet, Leiden 12-13/ 01 /04

AMBER measurements

Measurements are integrated over a patch around the spatial frequency B_{lm}/λ.
For each baseline B_{lm} (lm=12, 23, 13) :

- Absolute visibility $V_{lm}(\lambda)$
- Differential visibility $V_{lm}(\lambda)/V_{lm}(\lambda_0)$

☞ angular size of brightness distribution

- Differential phase $\Phi_{lm}(\lambda)-\Phi_{lm}(\lambda_0)$

☞ Phase : symetry of brightness distribution.

☞ if source not resolved (size < λ/B), ~ displacement of photocenter with λ , projected on B_{lm}

- Phase closure $\Phi_{123}(\lambda) = \Phi_{12}+ \Phi_{23}+ \quad _{31}$

☞ Autocalibrated from atmospheric and (most of) intrumental biases

- Differential phase closure $\Phi_{123}(\lambda)- \Phi_{123}(\lambda_0)$
- In the future: Astrometrical differential phase (fringe tracking using off-set reference star) ☞ phase referencing imagery.

AMBER general specifications

Characteristic	Specification			Goal		
-Number of beams	3			3		
-Minimum spectral resolution	$30 < \Re < 50$					
-Medium spectral resolution in K	$500 < \Re < 1000$					
-Highest spectral resolution in K				$10\,000 < \Re < 15\,000$		
-Spectral coverage	J,H,K' from 1 to 2.3 μm			J,H,K from 1 to 2.4 μm		
-Spectral resolution in H and J	As it results from the K band equipment. Use order 2 in J.					
Instantaneous spectral coverage	Simultaneous observation of the full spectral domain for $\Re$=35					
-Absolute visibility accuracy	$3\sigma_V$=0.01			$\sigma_V=10^{-4}$		
-Differential phase stability	10^{-3} rad over 1 minute			10^{-4} rad over 1 minute		
-Instrument contrast	0.8			0.9		
-Instrument contrast stability	10^{-2} over 5 minutes			10^{-3} over 5 minutes		
-Optical throughput (optics, fibers, spectro, detector)	2% in K (K=11)	1% in H	1% in J	5% in K	5% in H	5% in J

Sensitivity and accuracy modes

- Fringe detection without fringe tracker:

	UT		AT	
	J	K	J	K
High sensitivity mode (50 to 100 ms)	10.5	12.2	7.7	9.3
High precision mode (10 ms frames)	8.1	9.7	5.4	6.9

- With external fringe tracker (FINITO):

“ long exposures”	≈14	≈11

- Future use of off-set reference star (PRIMA) will improve the limiting magnitude

	UT		AT	
	J	K	J	K
Resolution=35	18.7	19.4	15.7	16.3
Resolution=10000	13.3	15.1	12.3	12.0

AMBER performances in lab

- Contrast V better than 87% in K
- Accuracy on V better than 0.25% for $\Delta\lambda$=50nm
- Stability better than 0.8% in 5 min
- Differential phase stability better than 4.5e-3 rad in 15 min
- Throughput: a few % (within spec.)

? AMBER should reach K ? 11 mag

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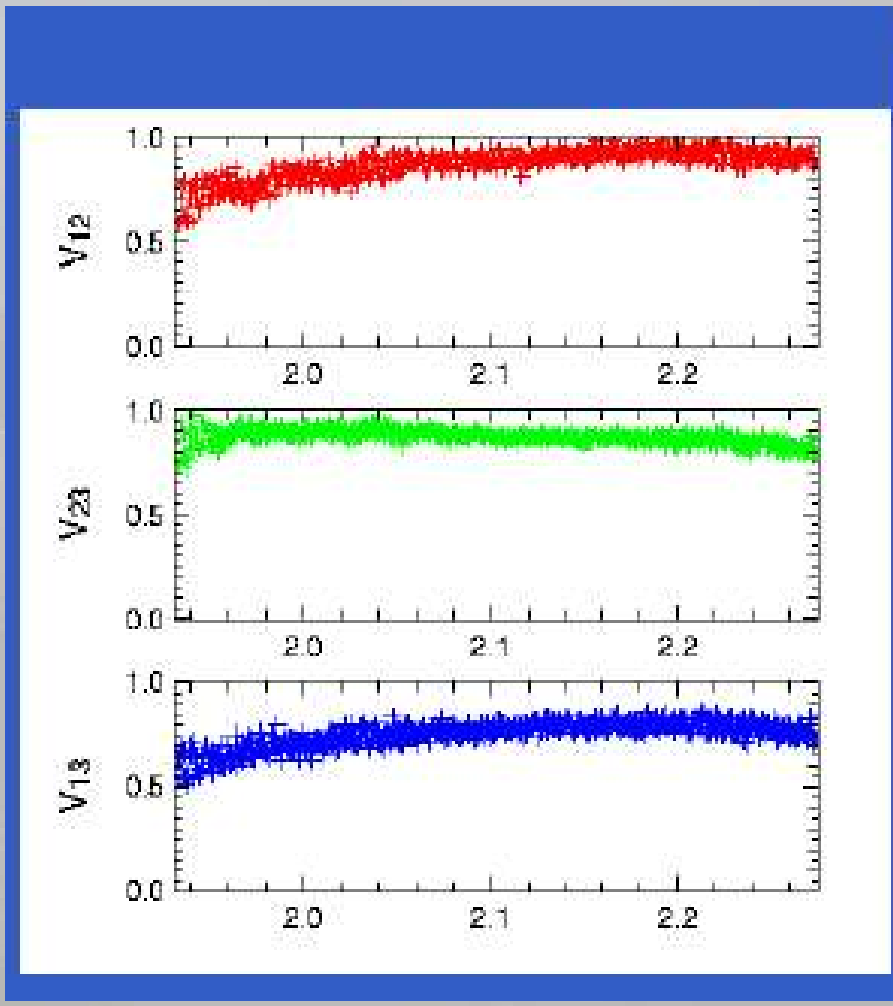
F. Malbet, Leiden 12-13/ 01 /04



Errors on measurements

- "Fundamental" errors: Photon, read-out and thermal noises

$$\sigma^2_{fV}(\lambda) \approx N^2_T\,(n(\lambda)+N_p\sigma^2_{RON}+n_{th}) \,/\, M\,V^2\,(\lambda)\,n^2\,(\lambda)$$

$$\sigma^2_{f\Phi}(\lambda) \approx N^2_T\,(n(\lambda)+N_p\sigma^2_{RON}+n_{th}) \,/\, 2\,M\,V^2\,(\lambda)\,n^2\,(\lambda)$$

- N_T: number of telescopes
- $n(\lambda)$: number of photons per frame in channel λ
- N_p: number of pixels per channel
- $n_{th:}$ number of background photons in channel λ
- $V(\lambda)$: source visibility x instrument visibility
- M: number of frames used for the measurement

Errors on measurements

- "Fundamental" errors: Photon, read-out and thermal noises

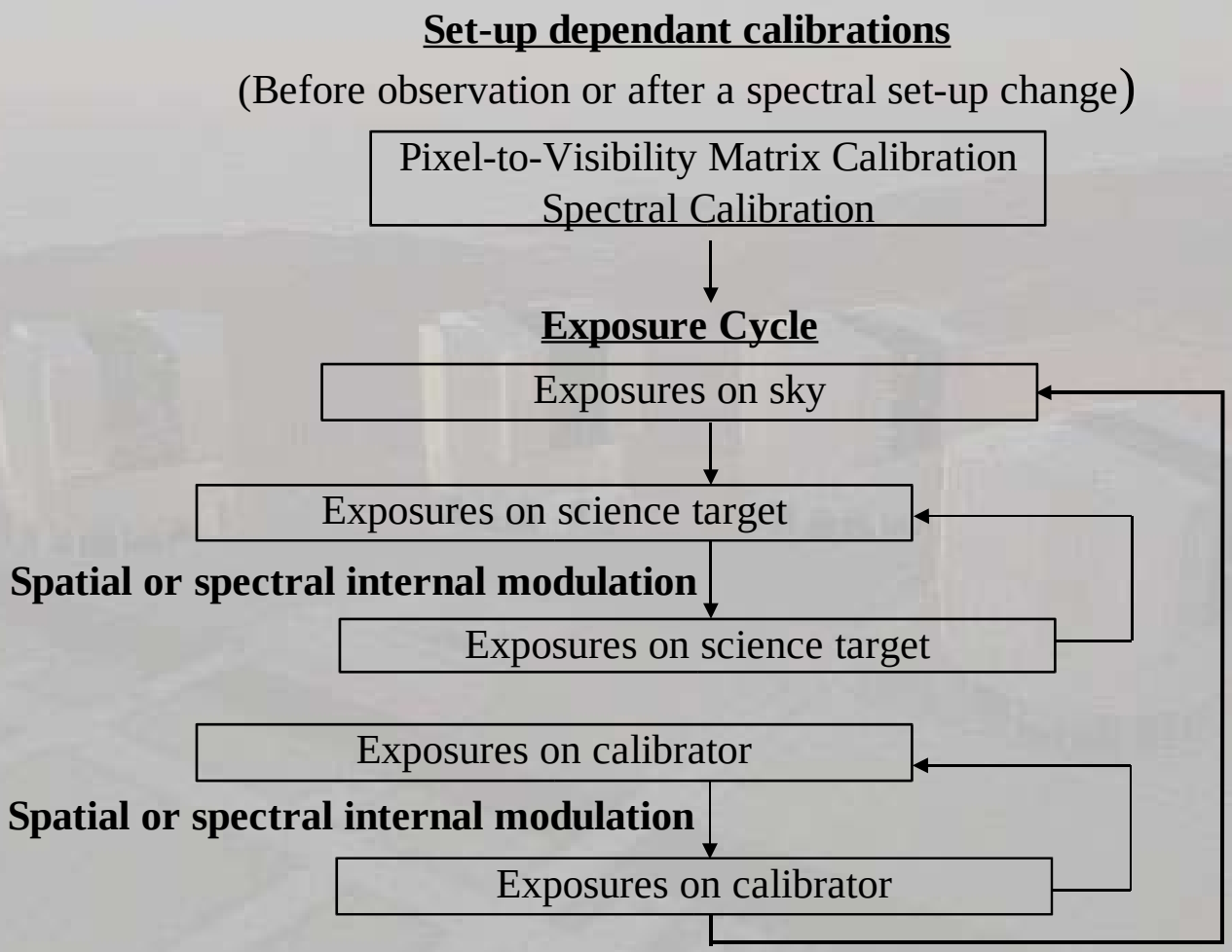
- Instability due to atmospheric and instrumental drifts
  - variable chromatic piston affects color-differential measurements
    - Variation in dispersion index *n( )* in air
    - coupling between beam residual motion and diopters
    - fibers thermal changes
  - spectrograph deformation
  - temporal variation of detector gain
  - ……

The differential phase can be:

☞ Partially calibrated using a reference star (10 mn) and internal spatial modulation (1mn)

☞ Auto-calibrated if observing the phase closure $\Phi_{12} + \Phi_{23} +$ $_{31}$

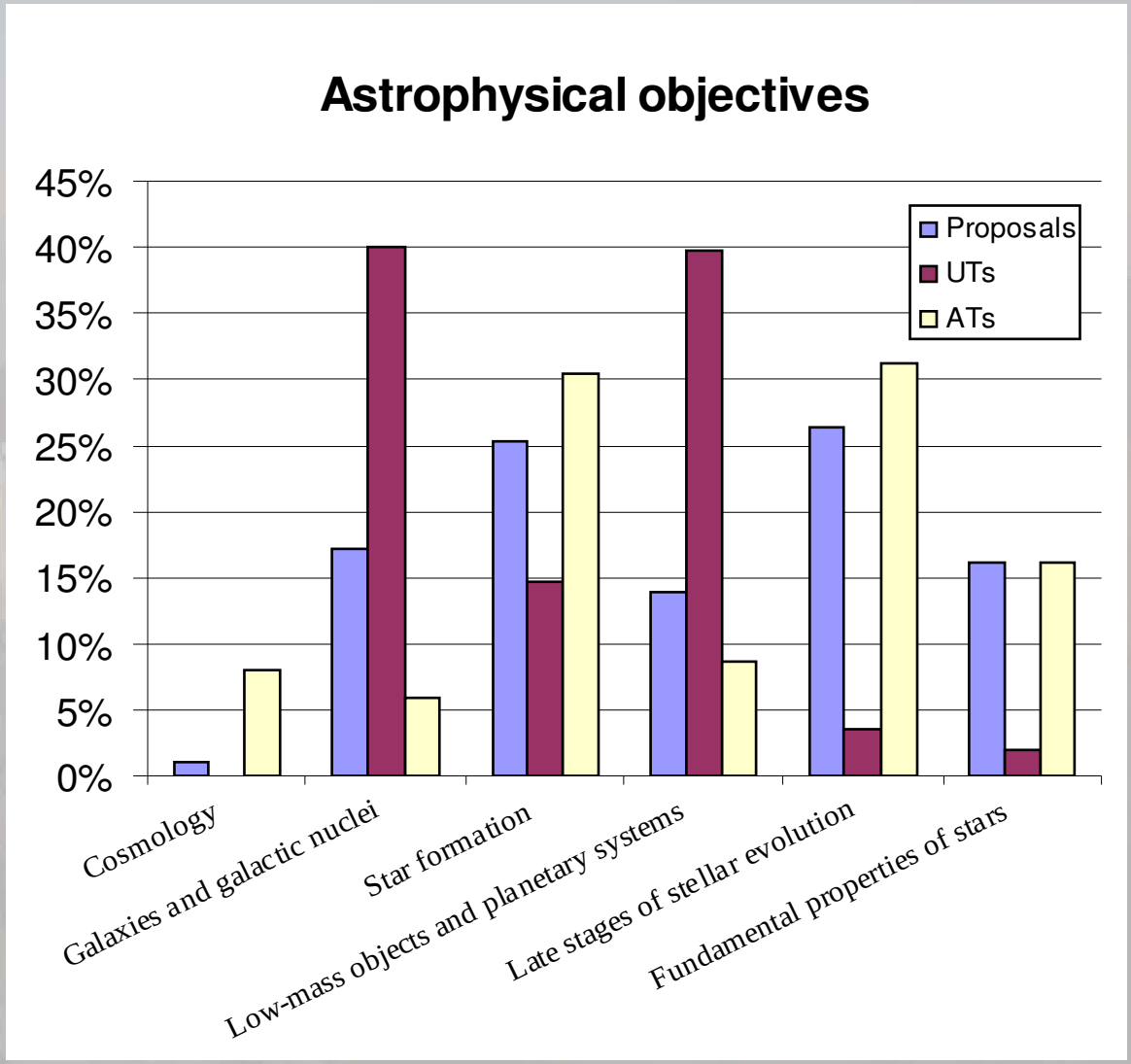
Observation sequences



What shall be observed?

Internal call for ideas in the AMBER consortium has produced... 87 **proposals :**

- Late-type stars
- Star formation
- Extragalactic & AGNs
- Stellar properties
- Low mass objects & exoplanets



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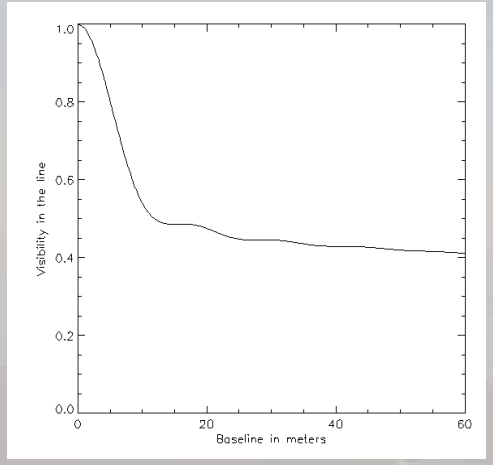
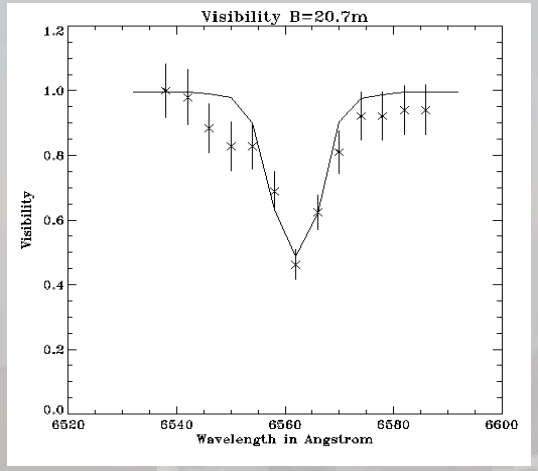
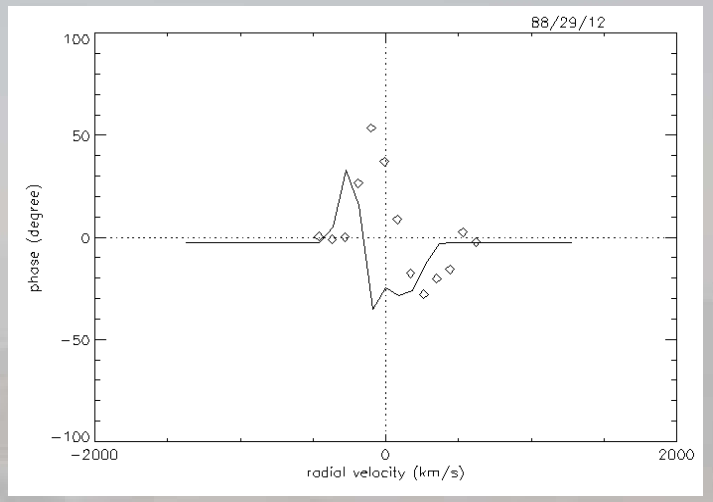
Be star (γ Cas) near emission line (e.g. Br γ)

Young, massive bright, fast rotating star



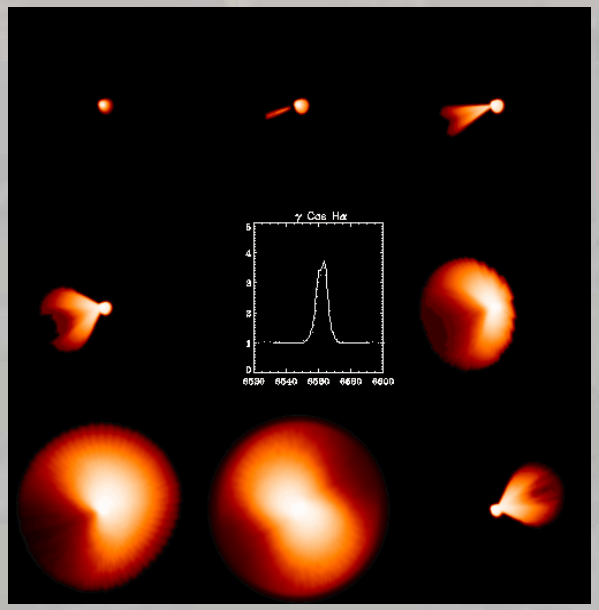


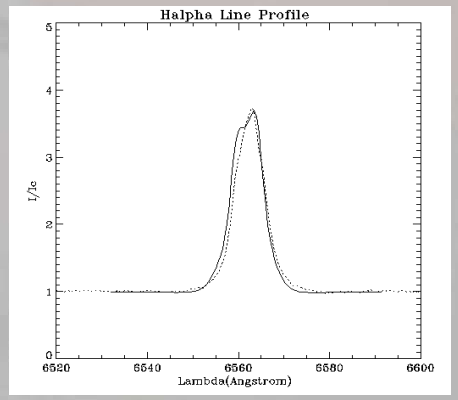


V=f (B) at λ_{el}

V=f (λ)

Phase = f(λ)





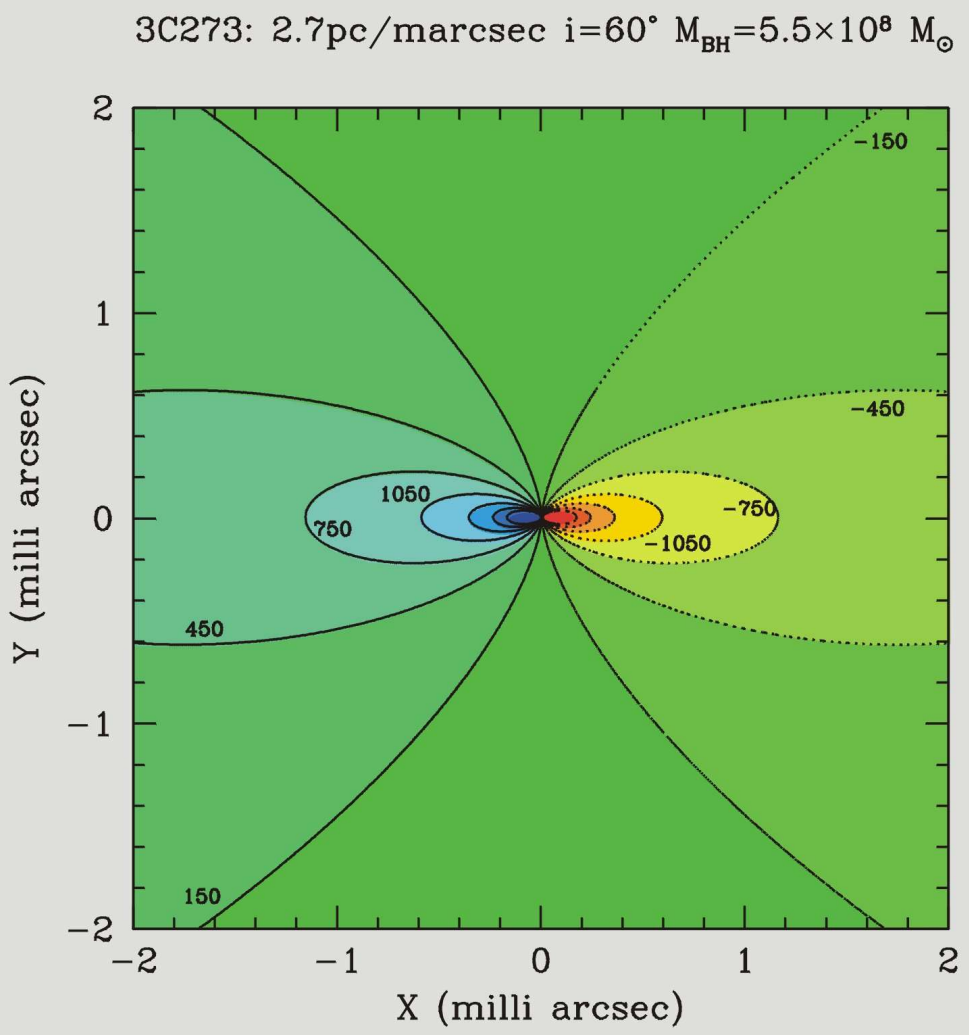
Line profile

Stee & Bittar 2001, A&A, 367, 532 (GI2T)

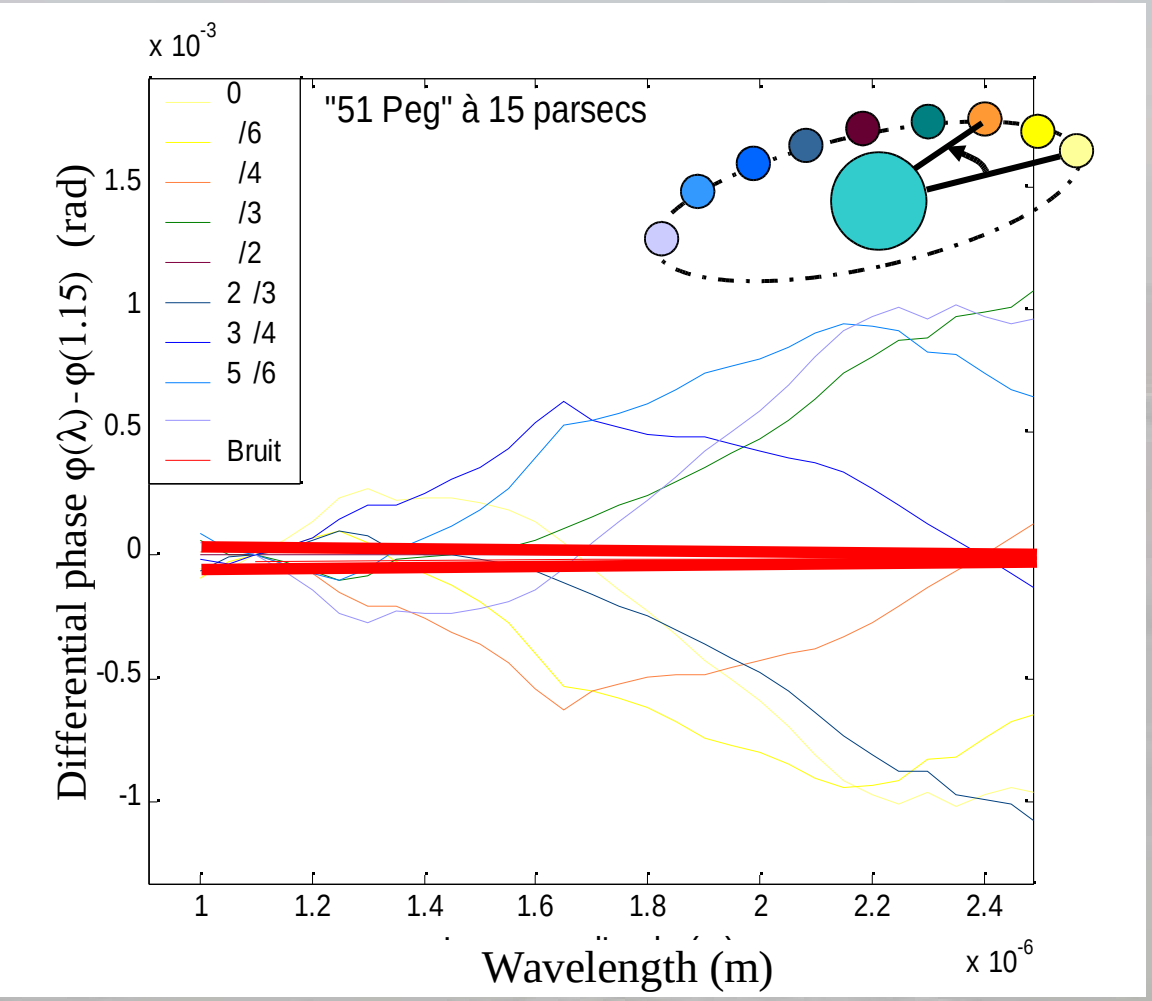
- Brightness distribution (λ)
- Velocity map

BLR in active galaxies

- **Broad band visibility: BLR size if (partially) resolved.**
- **Differential phase with narrow channel resolution (R=1000): constraints on velocity field, possibly for very unresolved structures**
- **For resolved object: differential phase + differential visibility ~ quasi imagery**



Differential phase and Extra-Solar Planets



- Low-resolution spectroscopy and orbital parameters of hot, giant ESPs.
- Uses previous knowledge from RV survey

- Requires an extreme stability of the measurement.

Monitoring and correction of variable dispersion effects : variations of index n(λ) in atmosphere and tunnels.

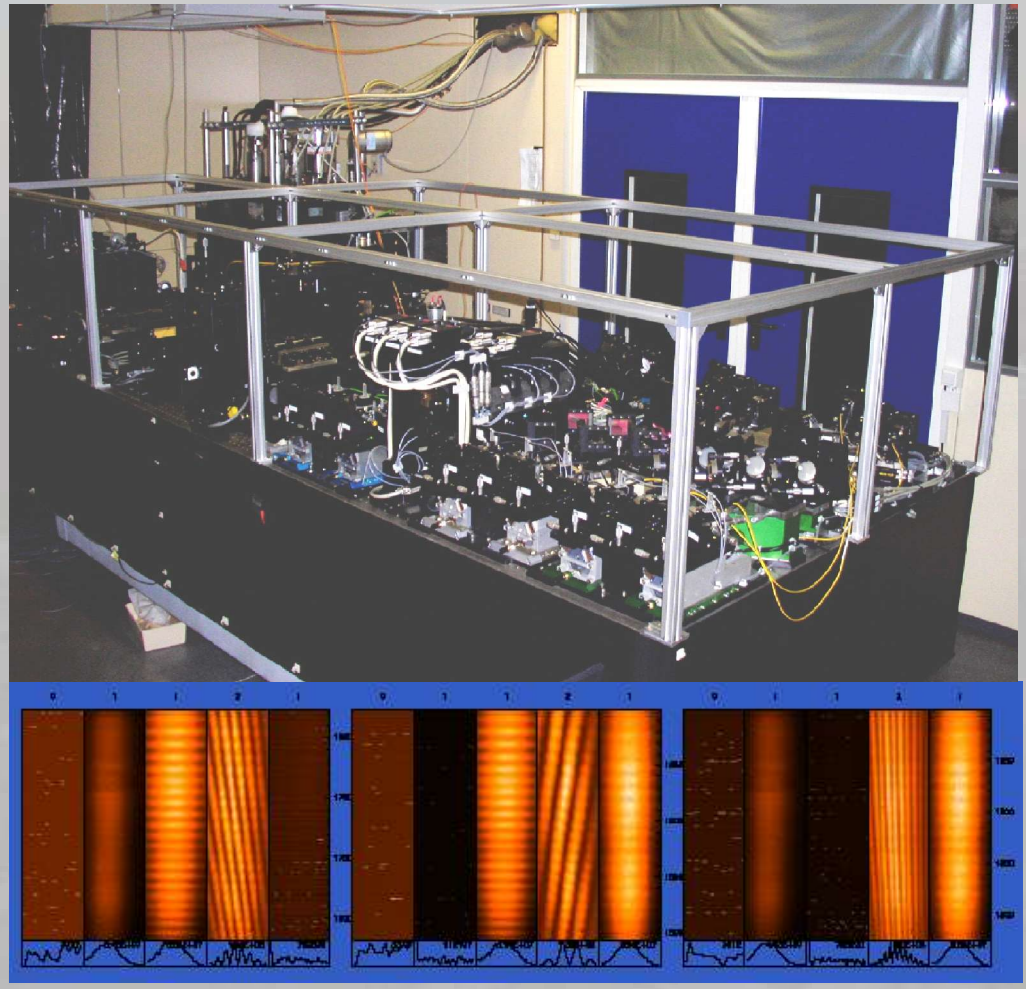
Modeled differential phase signal and noise for a "51 Peg" at 10pc. (2 UTs, B=100m, R=35, T=5h, M=5)

Key scientific programs

Topic	Maximum error on the visibility and/or the differential phase (rad)	Minimum K magnitude	Spectral Coverage	Spectral Resolution
Extra solar planets	10^{-4}	5	J+H+K	35
AGN dust tori	10^{-2}	11	K	35
QSO and AGN BLR	10^{-3}	11	J,H,K	1000
Young Stellar Objects	10^{-2}	7	J,H,K, lines	1000
Circumstellar material	10^{-2}	4	J,H,K, lines	1000
Binaries	10^{-3}	4	K	35
Stellar Structure	10^{-4}	1	lines	10000

Table 1: Scientific programs and requirements used to establish and check the specifications of AMBER

Status and agenda



- Departure on 23 Jan, 2004
- Starting Assembly, Integration and Verification (AIV) on Feb 2004
- First light with siderostats before 25 March 2004 ?
- First light with 3 large telescopes at the end of May?
- Opening to the community on January 2005 ?

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Conclusion

- **AMBER = Near infrared, three-beams, dispersed fringes, single mode VLTI focal instrument**
- **Will be basically used for model fitting using interferometric measurements = f(λ). "Imaging" information in a few case**
- **Broad range of applications: spectral features with spatial dependency, for sources spatially resolved or not.**
- **Phase measurements give access to "super-resolution" (< λ/B)**
- **Limits on accuracy imposed by atmospheric and instrumental instability still to be assessed on-site.**
- **See publications and documents at :**

http://www.obs-nice.fr/amber/

- **AMBER is coming !!**