MIDI
the Mid-Infrared Instrument of the VLTI

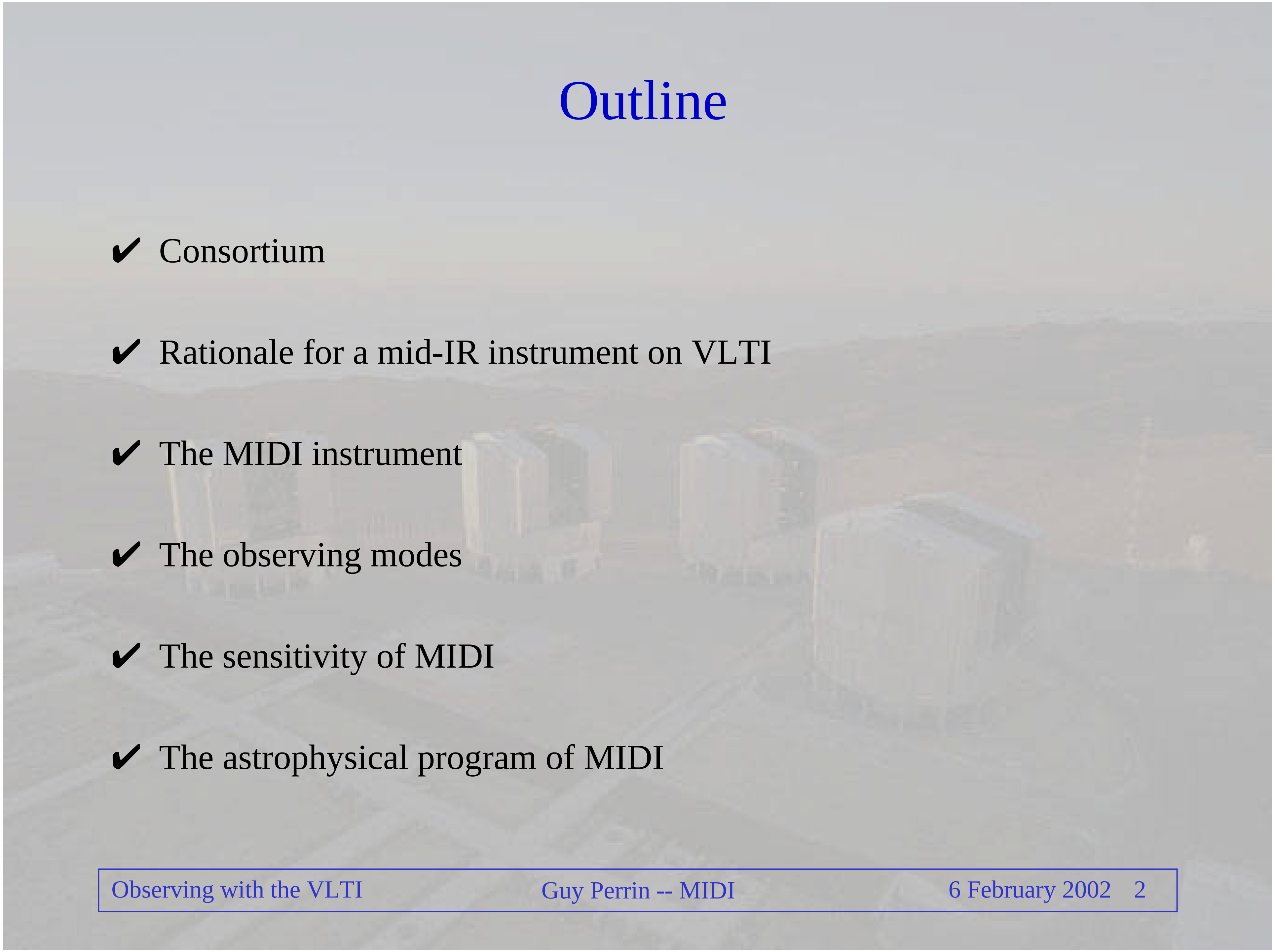
EuroWinter School

Observing with the Very Large Telescope Interferometer

Les Houches, France
February 3-8, 2002

Guy Perrin
Observatoire de Paris
on behalf of the MIDI consortium
6 February 2002

Outline



- ✔ Consortium
- ✔ Rationale for a mid-IR instrument on VLTI
- ✔ The MIDI instrument
- ✔ The observing modes
- ✔ The sensitivity of MIDI
- ✔ The astrophysical program of MIDI

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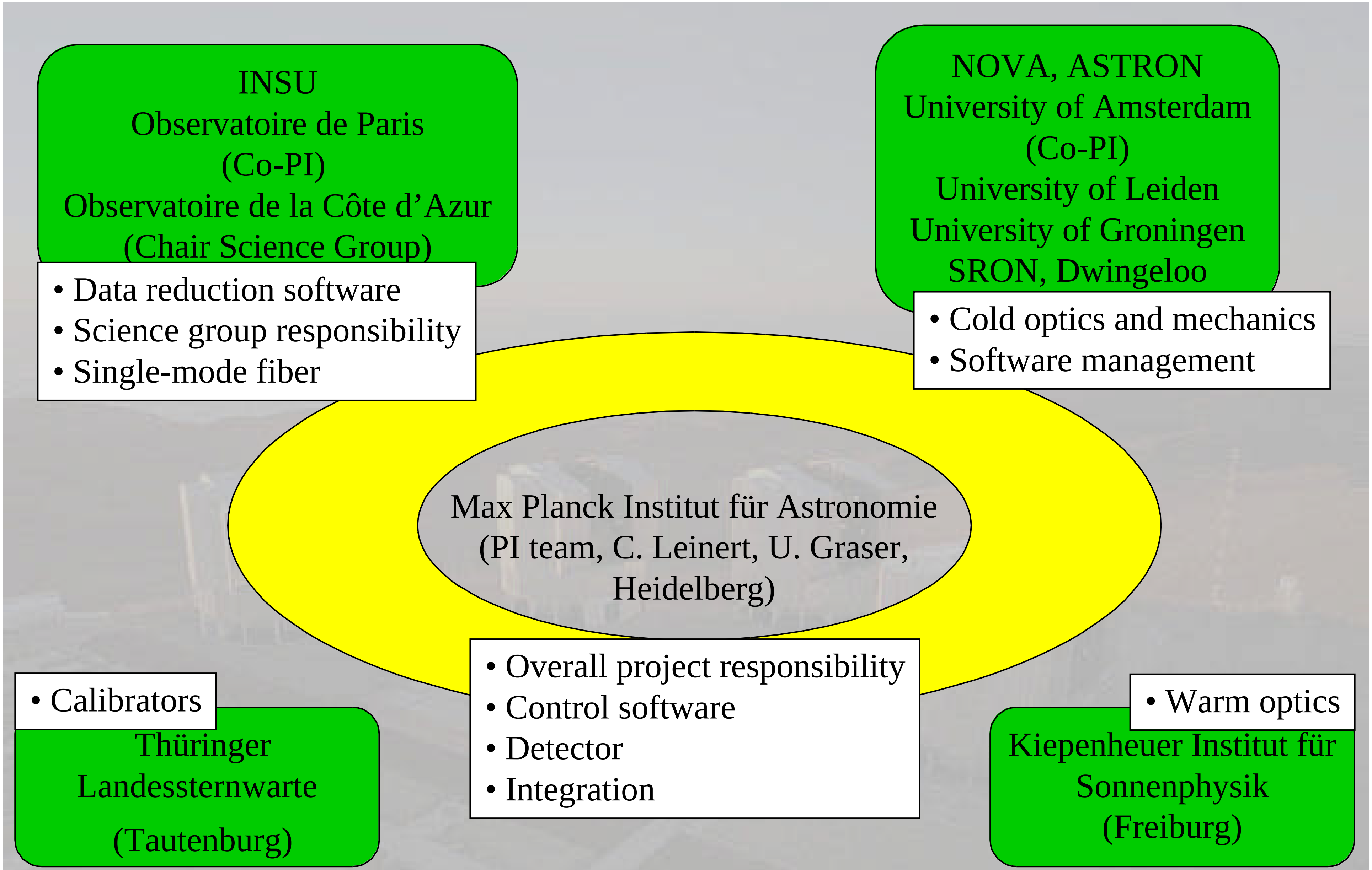

INSU
Observatoire de Paris
(Co-PI)
Observatoire de la Côte d’Azur
(Chair Science Group)

- Data reduction software
- Science group responsibility
- Single-mode fiber

NOVA, ASTRON
University of Amsterdam
(Co-PI)
University of Leiden
University of Groningen
SRON, Dwingeloo

- Cold optics and mechanics
- Software management

Max Planck Institut für Astronomie
(PI team, C. Leinert, U. Graser,
Heidelberg)

- Overall project responsibility
- Control software
- Detector
- Integration

- Calibrators

Thüringer
Landessternwarte
(Tautenburg)

- Warm optics

Kiepenheuer Institut für
Sonnenphysik
(Freiburg)

http://www.mpia-hd.mpg.de/MIDI/

A little bit of history

First consortium meeting	**July 1998, Heidelberg**
Concept Design Review	**December 1998**
Final Design Review (part I) ➾ green light for the optics	**July 1999**
Final Design Review (part II) ➾ green light for the mechanics	**February 2000**
Beginning of integration in Heidelberg	**Spring 2001**

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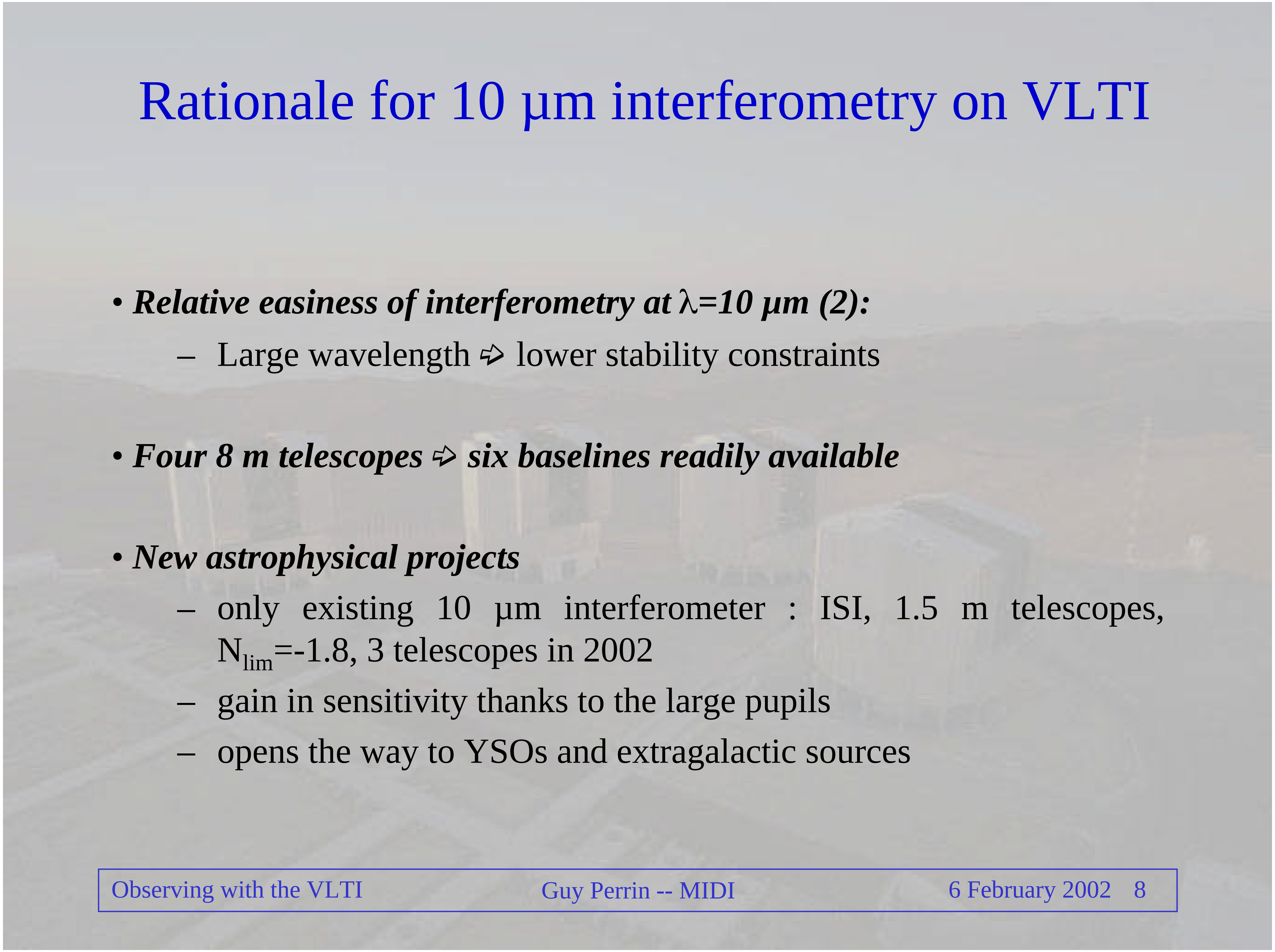
Rationale for 10 µm interferometry on VLTI

- ***Gain in angular resolution :***
  - Diffraction limit is large at λ=10 µm: λ/D = 260 mas with D=8 m
  - To be compared to the resolution limit with an 8 m telesecope at 1µm: 26 mas
  - With a B=130 m baseline (UT1-UT4): λ/B = 16 mas

- ***Relative easiness of interferometry at λ=10 µm (1):***
  - Fried parameter $r_0 \sim \lambda^{6/5}$ ➪ UTs almost diffraction limited at 10µm ($r_0 \sim 6.15$ m)
  - Turbulence correlation time $\tau_0 \sim \lambda^{6/5}$ ➪ longer integration times, easier fringe tracking ($\tau_0 \sim 100$ ms)
  - *a priori* large coherence volume available : $\pi r_0^2/4.\tau_0$

    ➪ good sensitivity

Rationale for 10 µm interferometry on VLTI



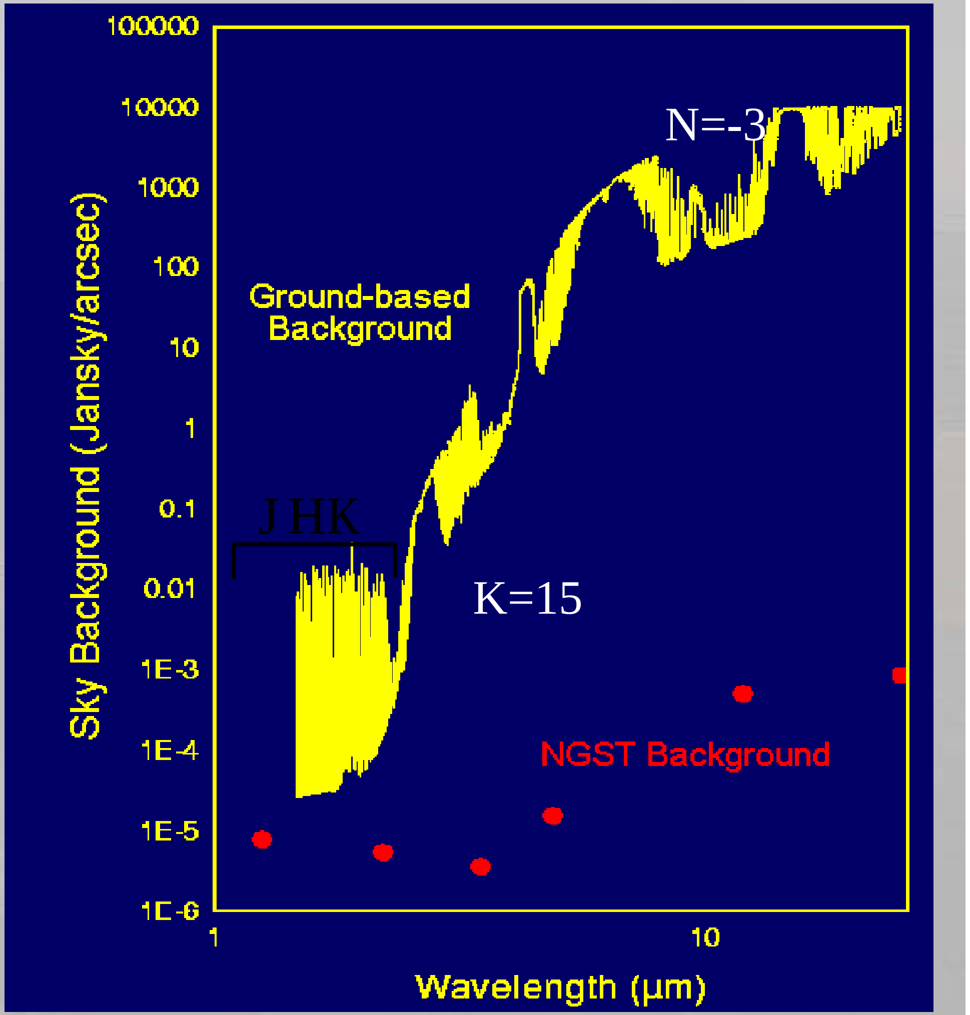
- ***Relative easiness of interferometry at λ=10 µm (2):***
  - Large wavelength ➪ lower stability constraints
- ***Four 8 m telescopes ➪ six baselines readily available***
- ***New astrophysical projects***
  - only existing 10 µm interferometer : ISI, 1.5 m telescopes, N_{lim}=-1.8, 3 telescopes in 2002
  - gain in sensitivity thanks to the large pupils
  - opens the way to YSOs and extragalactic sources

YET !

- Observations are limited by the emission of the thermal background

- The emission from the sky and the optics is important ➪ ***experiment has to be cooled down to gain in sensitivity***

- Detectors are poorer than at shorter wavelengths:
  - QE = 40%
  - RON = 1000 e^-



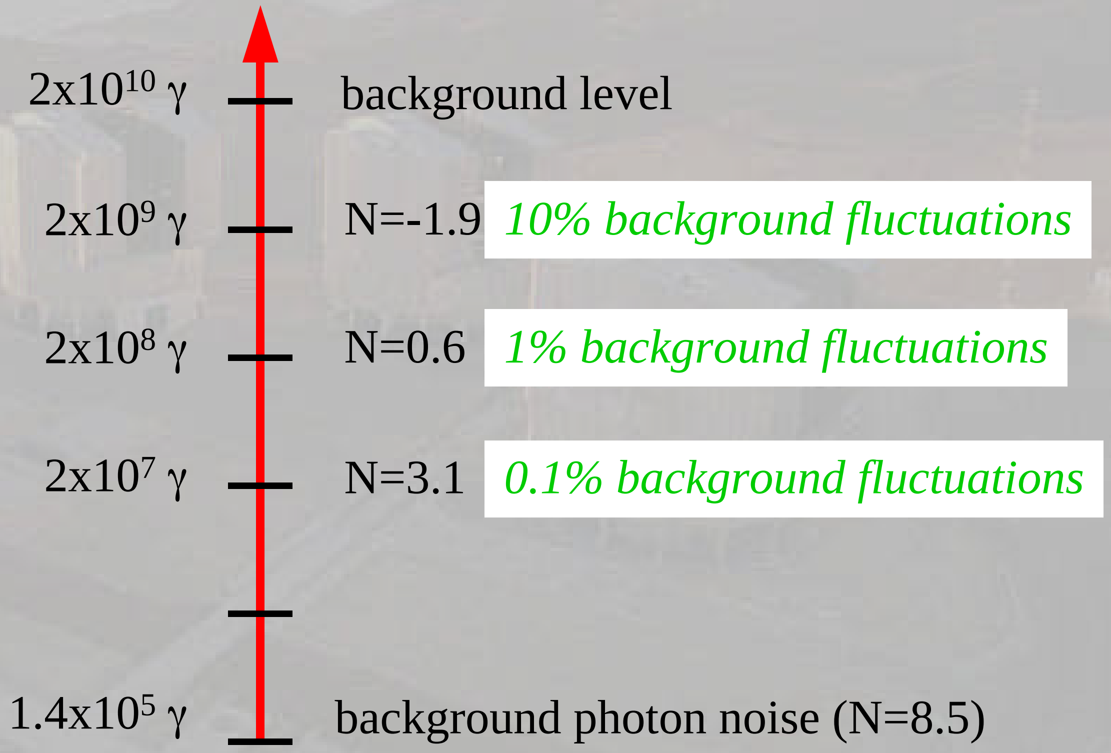
Background fluctuations

- The limiting noise = background noise : - photon noise

  - *and* background fluctuations

Background: 2.10^{11} photons/s/Airy disk at the detector

With 100 ms per fringe:



2x10^{10} γ background level

2x10^{9} γ N=-1.9 *10% background fluctuations*

2x10^{8} γ N=0.6 *1% background fluctuations*

2x10^{7} γ N=3.1 *0.1% background fluctuations*

1.4x10^{5} γ background photon noise (N=8.5)

Rationale for 10 µm interferometry on VLTI

- Number of photons collected from the background :

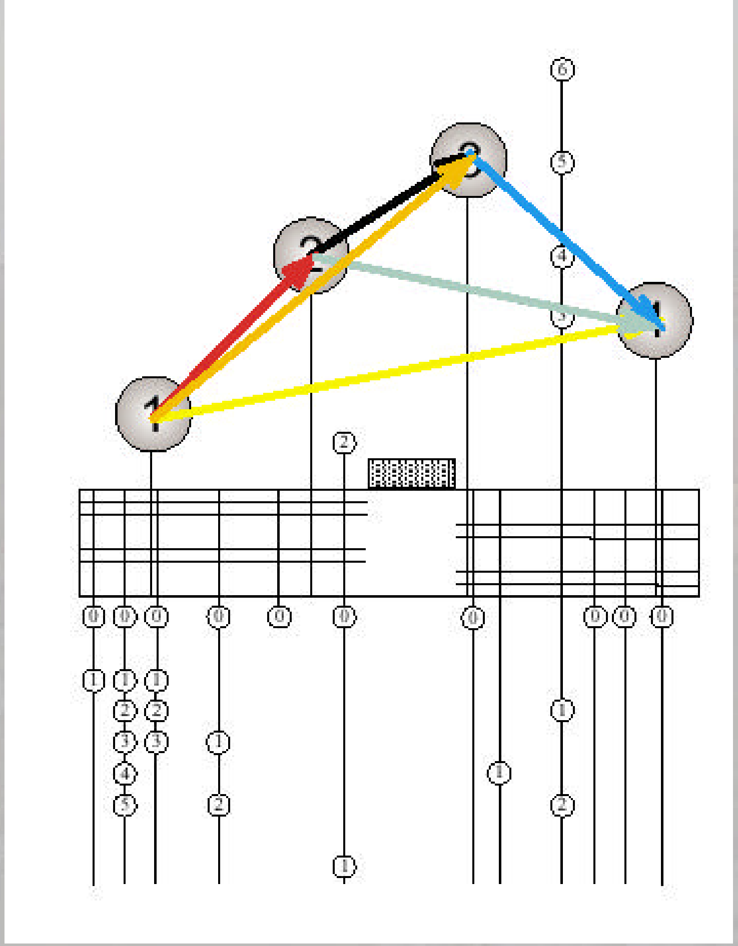
$$f[B_{\lambda}(T_{back})]*\textit{beam étendue}$$

- For diffraction limited observations : *beam étendue* = λ^2

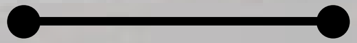
- Hence background noise is independent of telescope diameter and SNR~D^2

The four 8 m pupils and maximum 130 m baseline of VLTI are unique to open a new science era in the 8-12 µm range

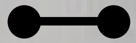
VLTI competitors at 10 µm



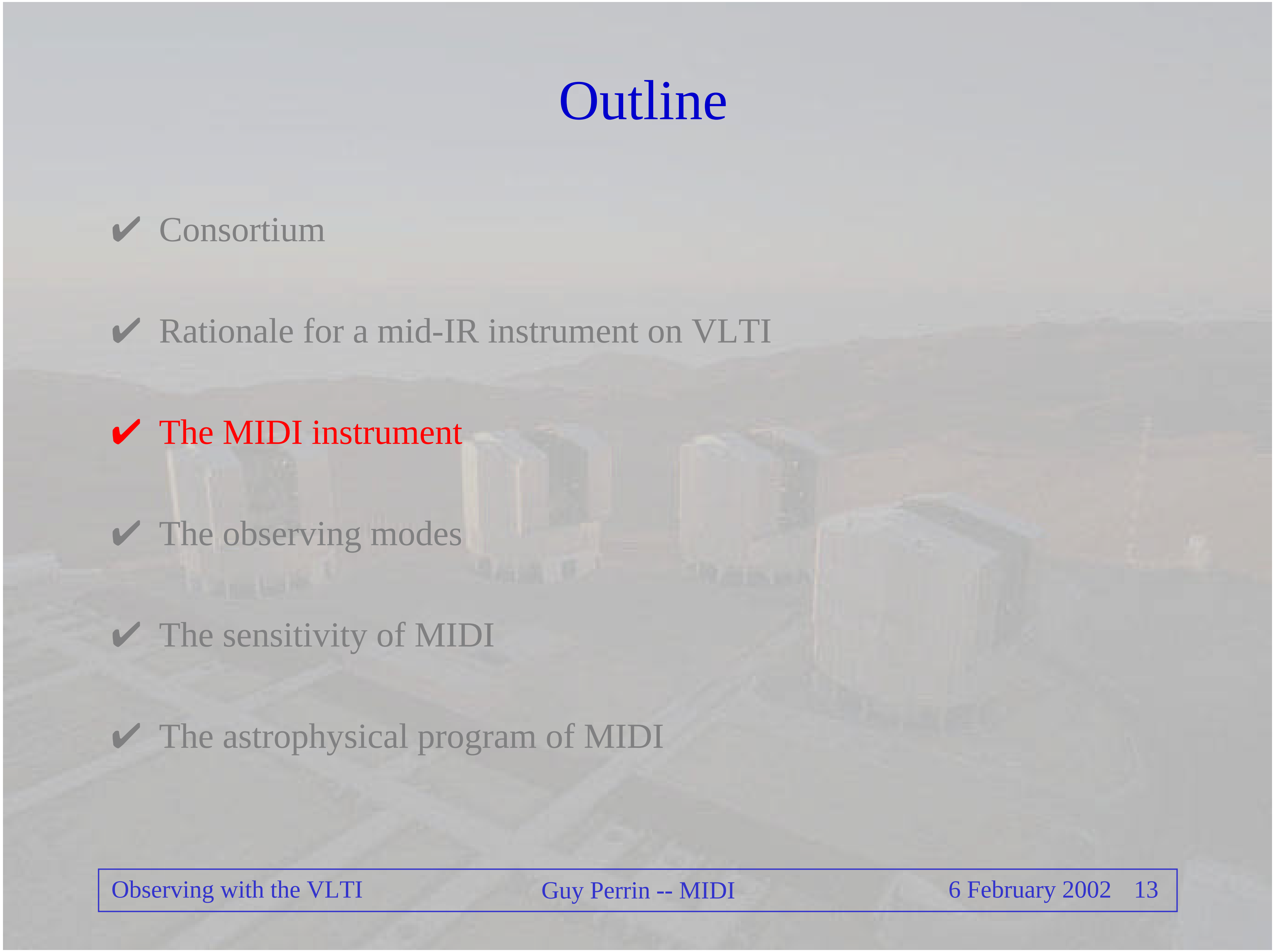
Keck (2x10 m)
80 m
(2002)



Large Binocular Telesccope (2x8 m)
15 m
(2005)



ISI (3x1.5 m)
64 m
(2002)



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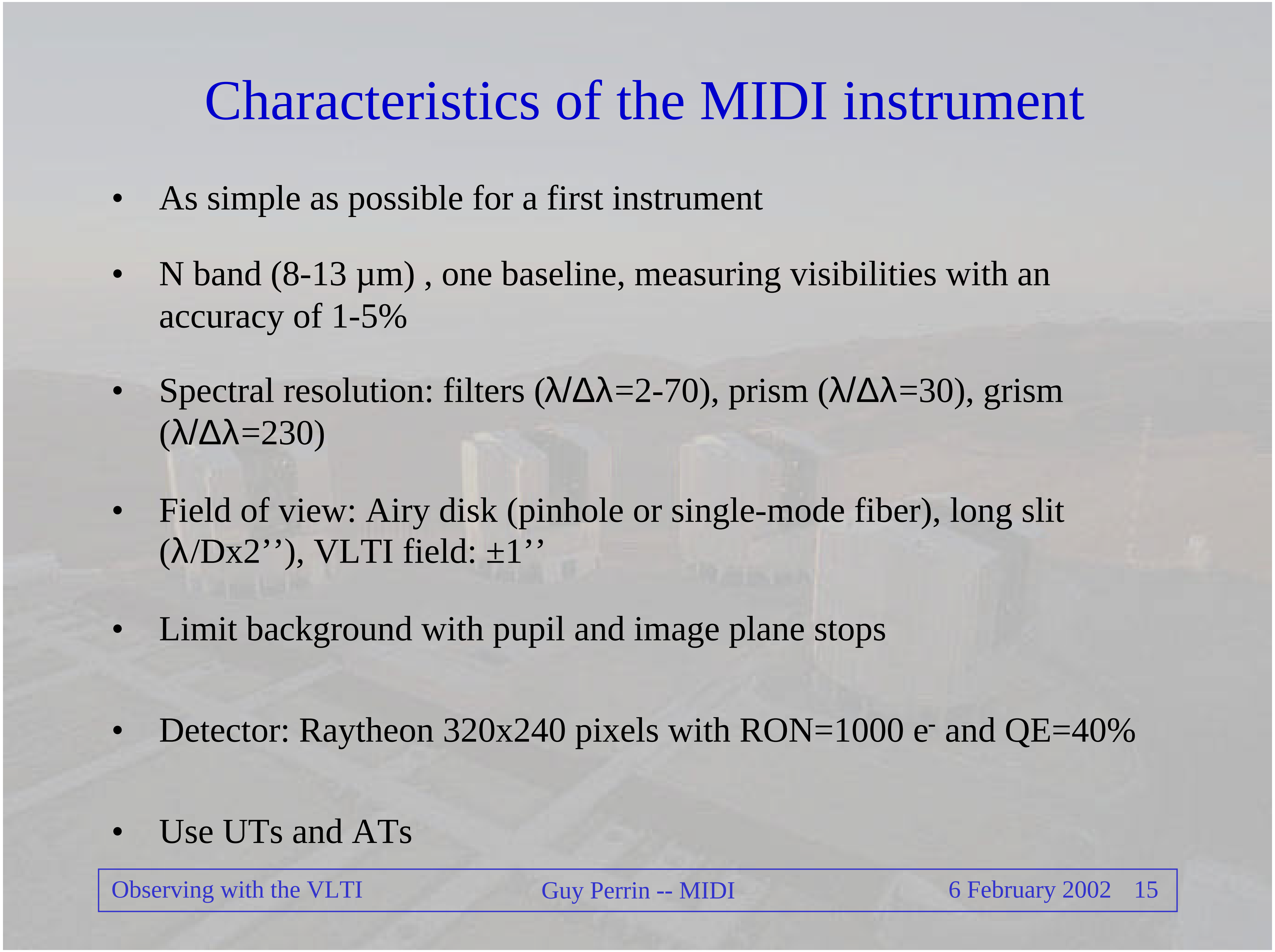
Constraints to instrument design

- ***From the atmosphere:***

  - Optical path difference fluctuation has rms ≈ 30 µm
    acceptable phase shift (λ/10 = 1 µm) in 100 ms
    ➪ integration time per fringe ≈ 100 ms
  - sky fluctuations occur on time scales of 200 ms
    ➪ chopping frequency of 5 Hz required

- ***From the VLTI optical train:***

  - Transmission = 40 % i.e. emissivity = 60 % in the N band
    ➪ emission larger than the sky: 2.10^{11}γ/s/Airy disk
    does not fit into one pixel (well depth = 10^7 electrons)
    ➪image needs to be spread over at least 200 pixels in the full N band: spatial and spectral dispersion required



Characteristics of the MIDI instrument

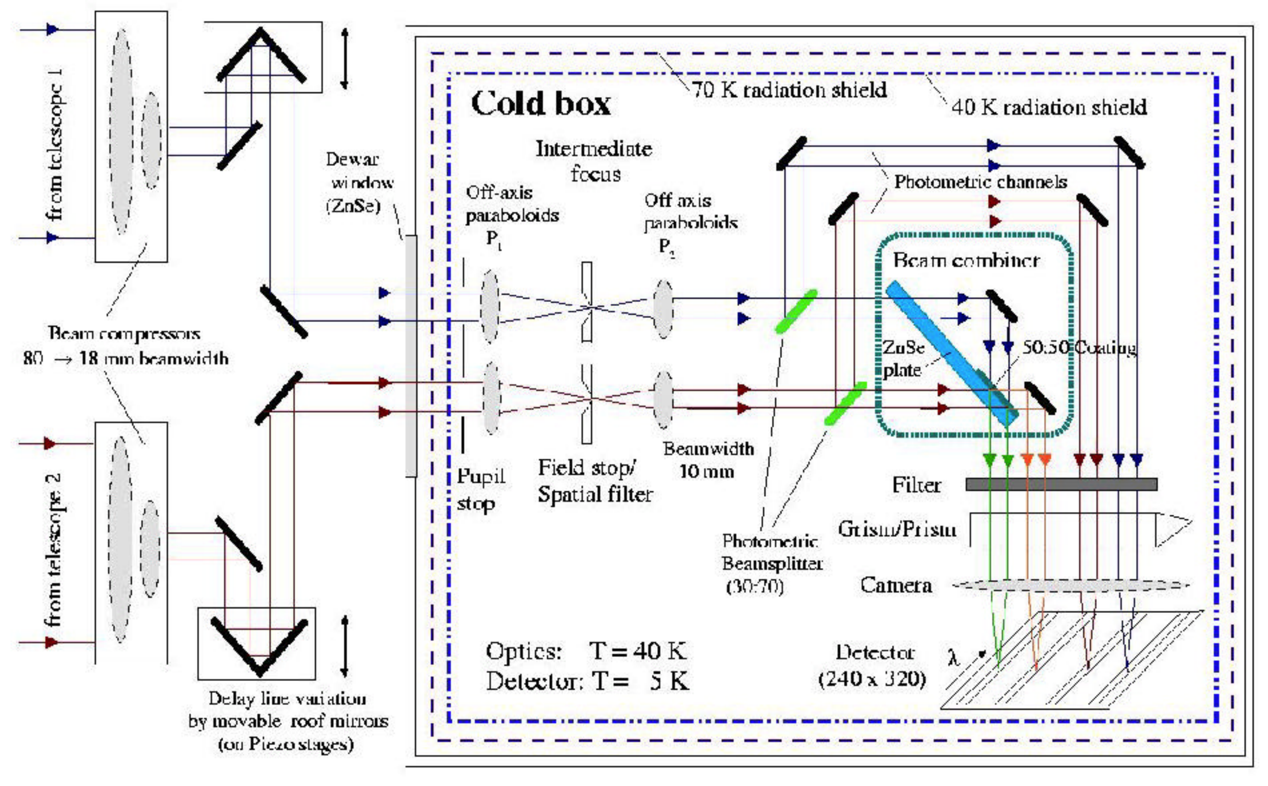
- As simple as possible for a first instrument
- N band (8-13 μm) , one baseline, measuring visibilities with an accuracy of 1-5%
- Spectral resolution: filters ($\lambda/\Delta\lambda=2$-70), prism ($\lambda/\Delta\lambda=30$), grism ($\lambda/\Delta\lambda=230$)
- Field of view: Airy disk (pinhole or single-mode fiber), long slit (λ/Dx2’’), VLTI field: ±1’’
- Limit background with pupil and image plane stops
- Detector: Raytheon 320x240 pixels with RON=1000 e^- and QE=40%
- Use UTs and ATs

Constraints on the design

- The instrument has to be compact to work at cryogenic temperatures
  - 2 beams (no closure phases)
  - simple features

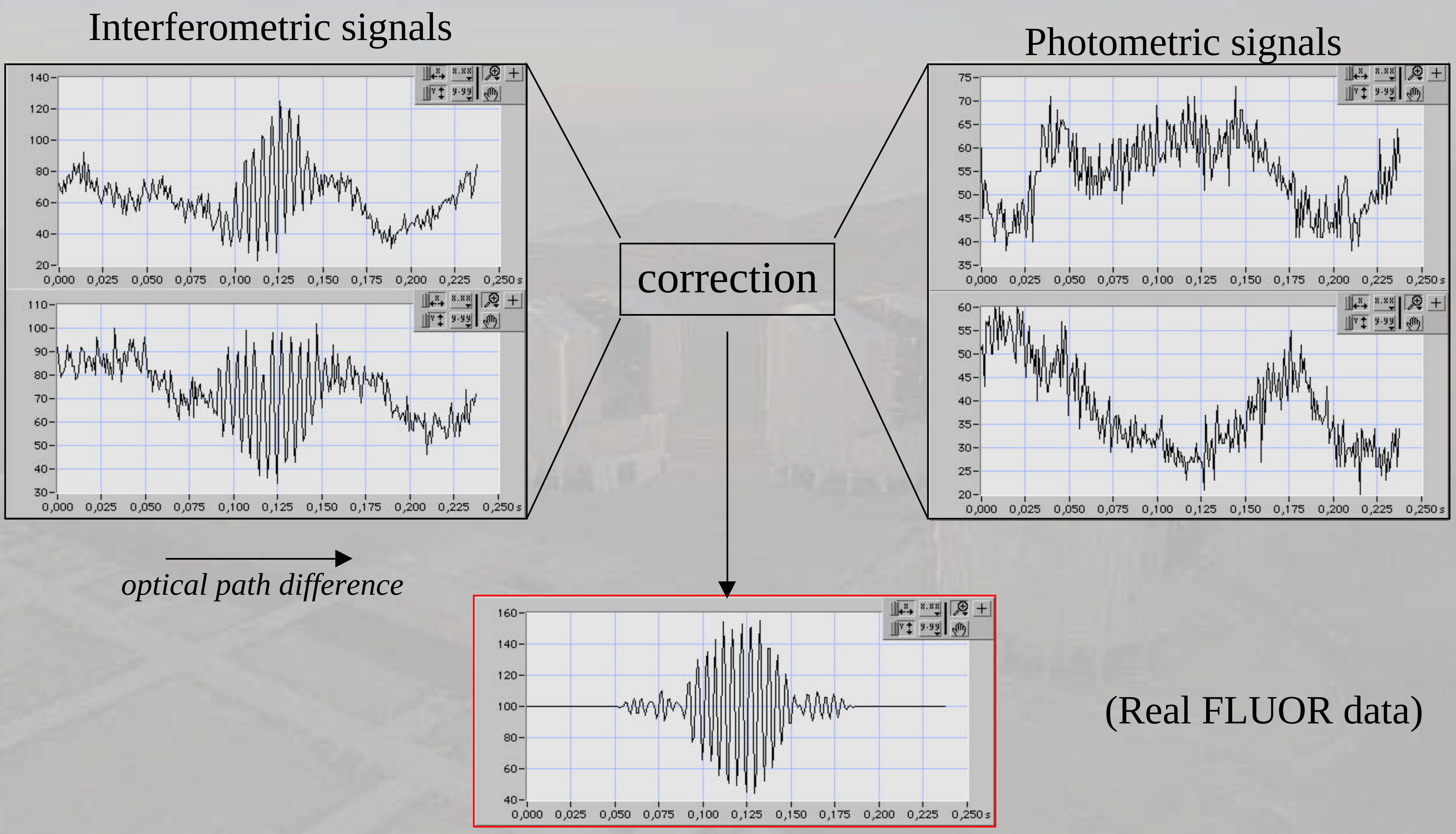
- Low coherence losses:
  - losses in the beam combiner < 10-15%
  - total losses in the instrument < 25%
  - ➪ Beam overlap: ±0.1 mm (≤1%)
  - ➪ Beam tilt: ±0.1λ/D (≤1%)

The MIDI concept



Co-axial interferometer, temporal coding of the fringes

What MIDI fringes will look like
(Fourier Mode)


Interferometric signals

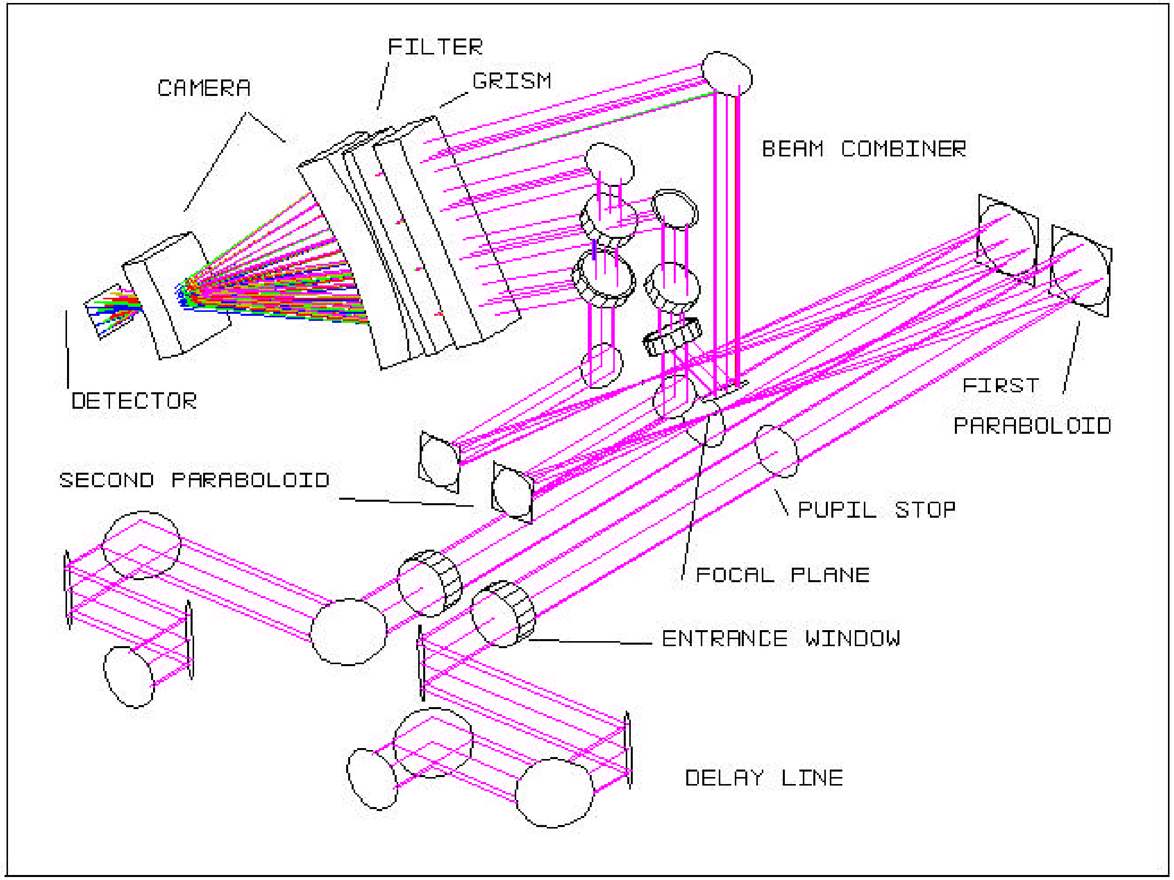
Photometric signals

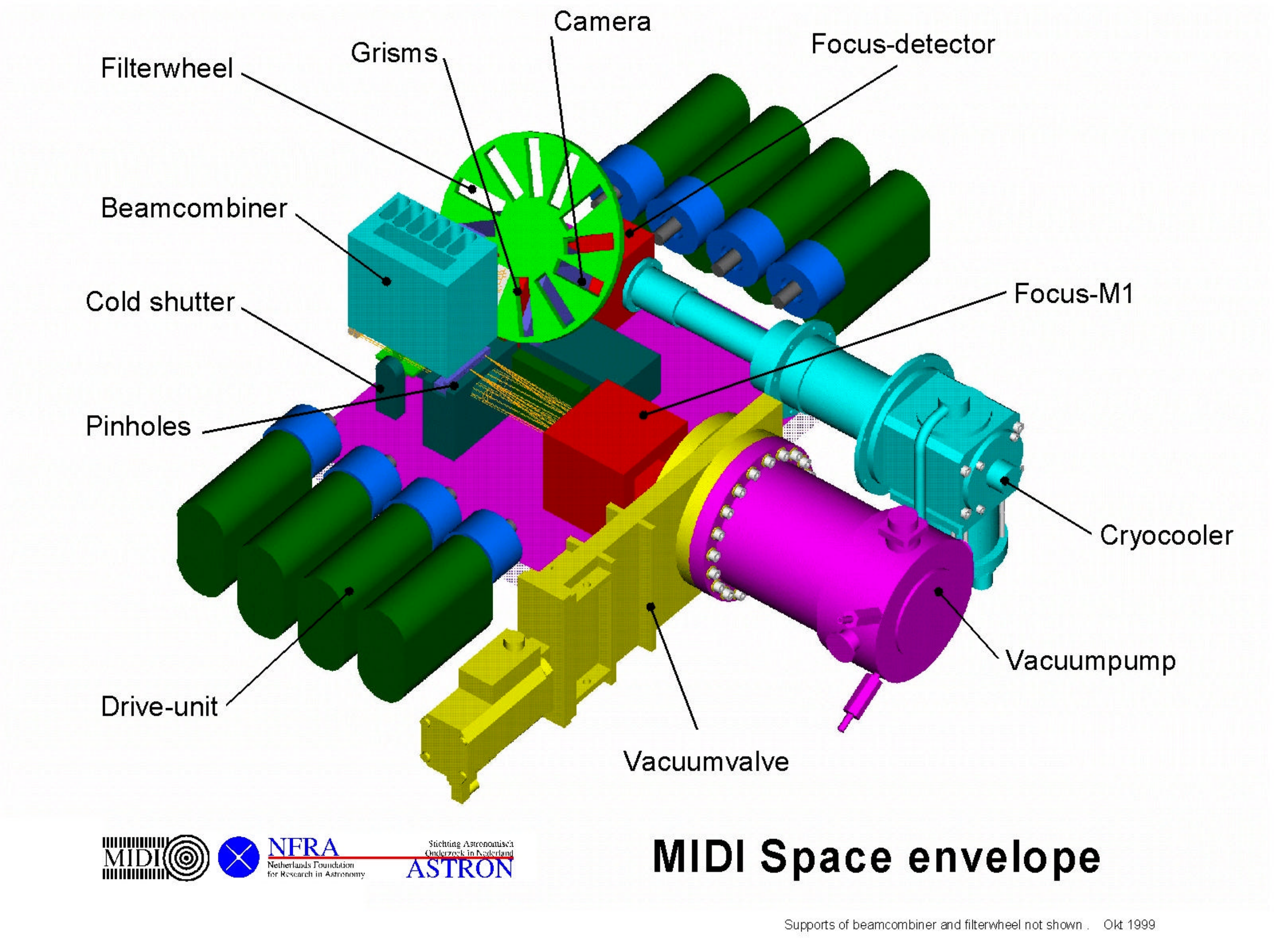
correction

optical path difference

(Real FLUOR data)

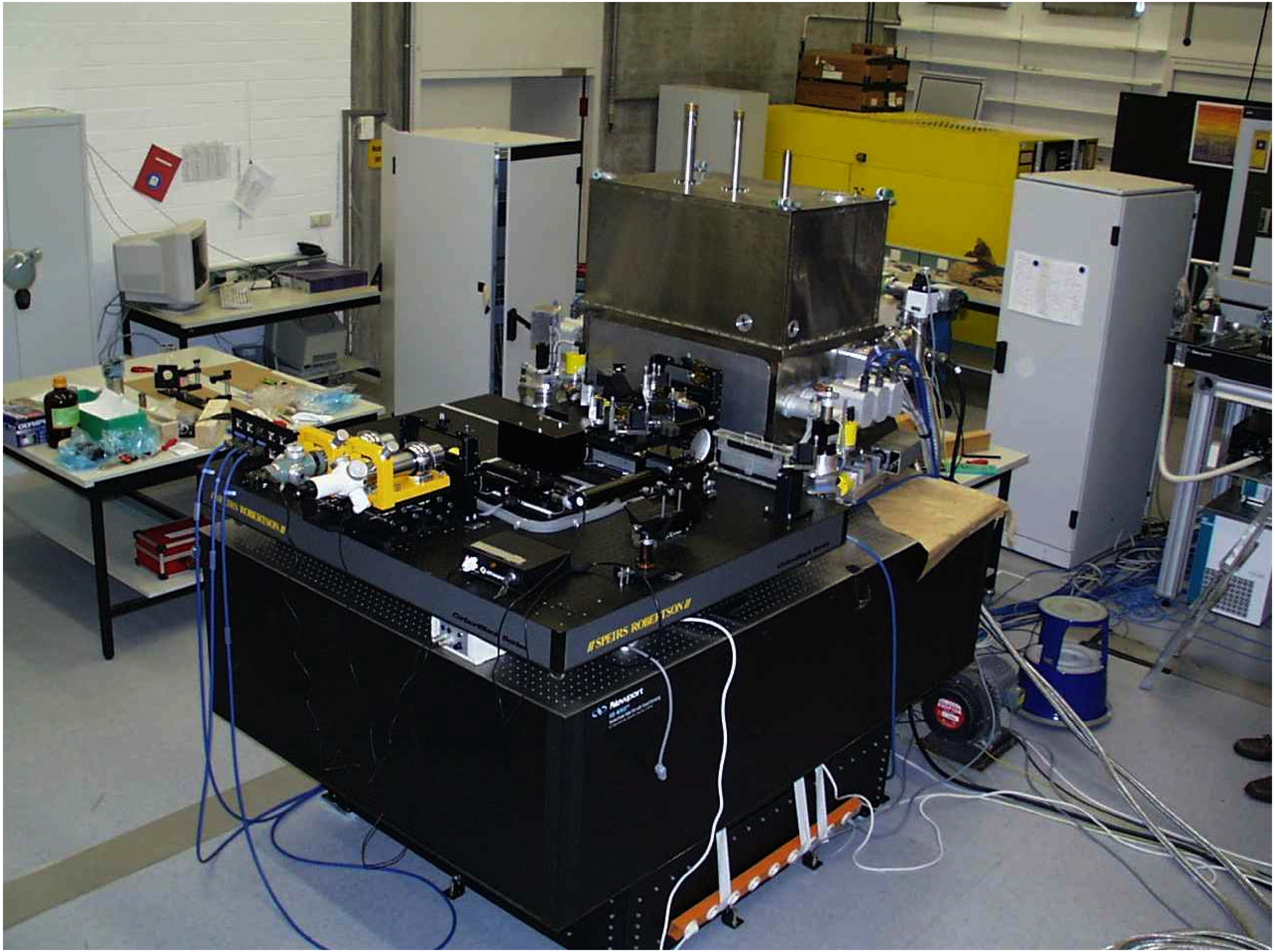
MIDI optics design

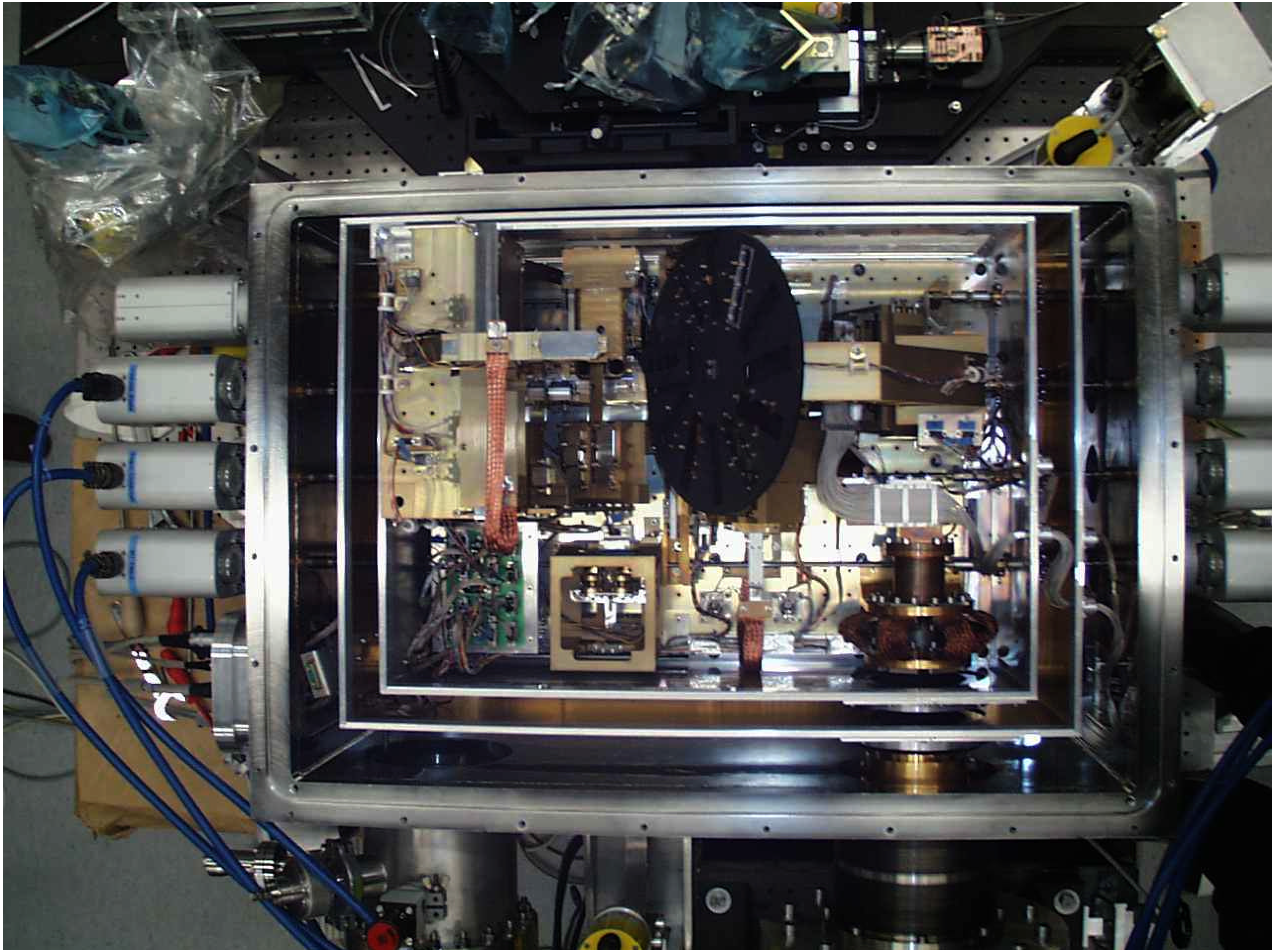


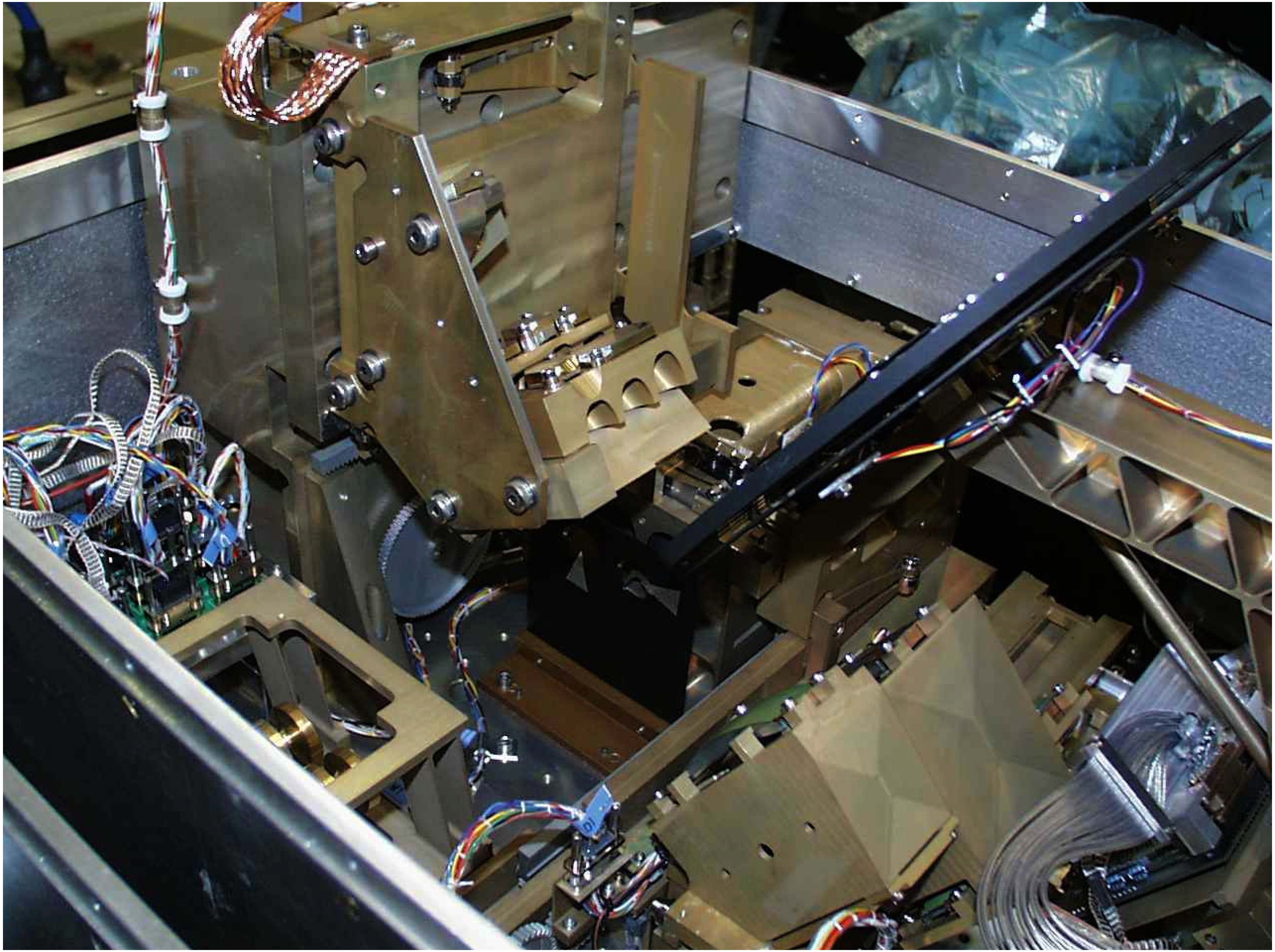


MIDI Space envelope

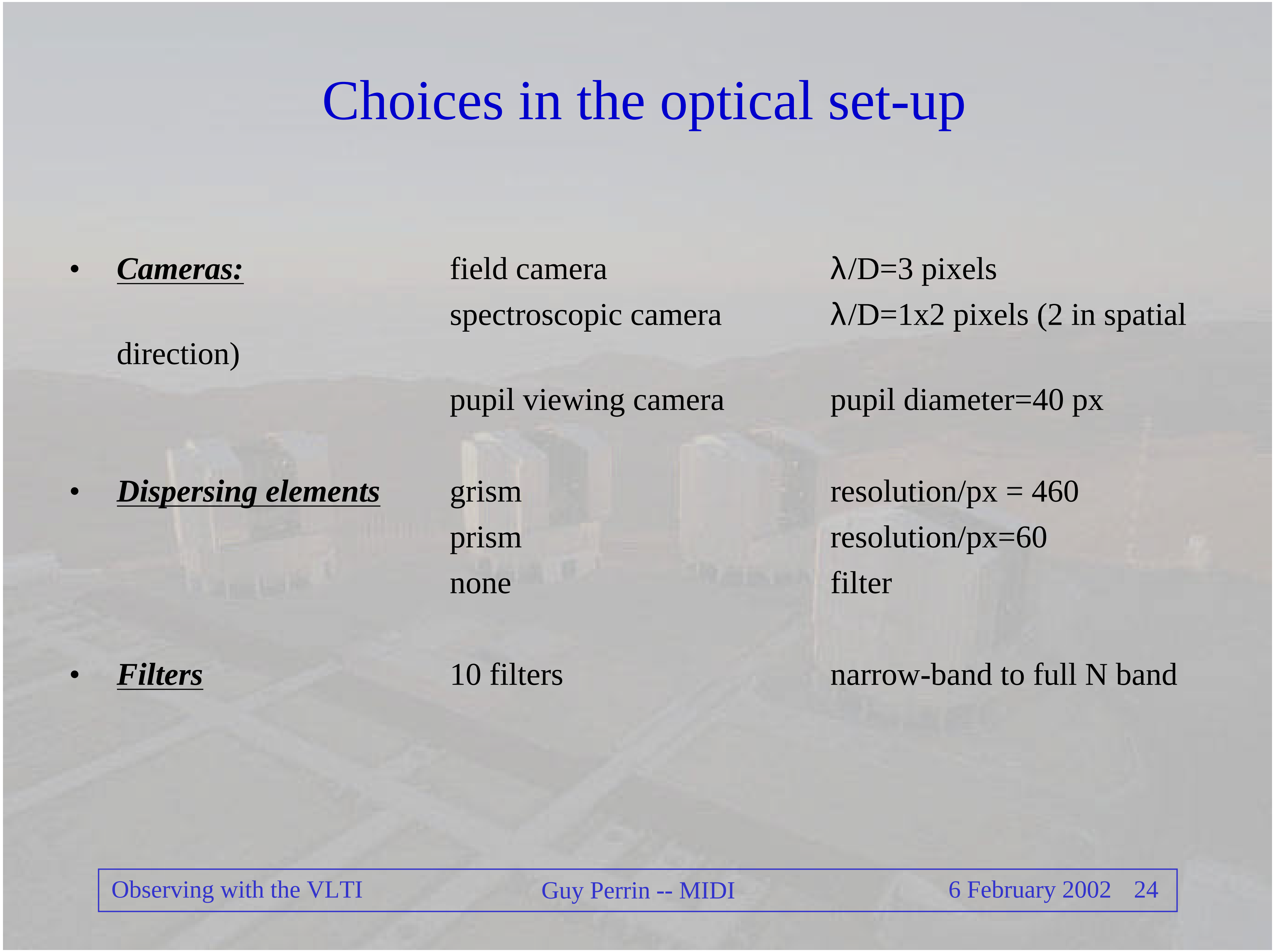
Supports of beamcombiner and filterwheel not shown. Okt 1999


SPEIRS ROBERTSON
SPEIRS ROBERTSON
Newport



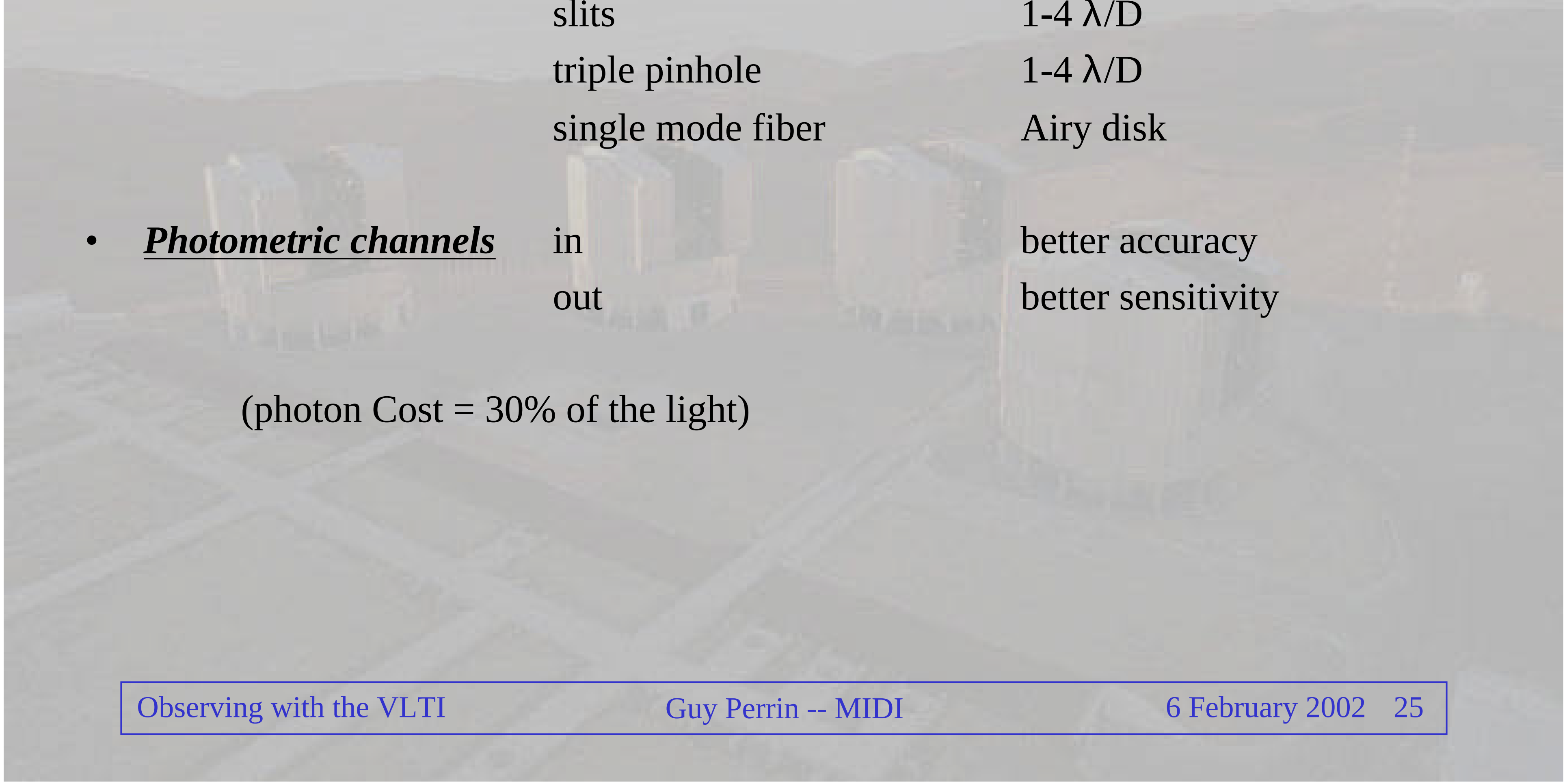


Choices in the optical set-up



Cameras:	field camera	λ/D=3 pixels
	spectroscopic camera	λ/D=1x2 pixels (2 in spatial direction)
	pupil viewing camera	pupil diameter=40 px
Dispersing elements	grism	resolution/px = 460
	prism	resolution/px=60
	none	filter
Filters	10 filters	narrow-band to full N band

Choices in the optical set-up

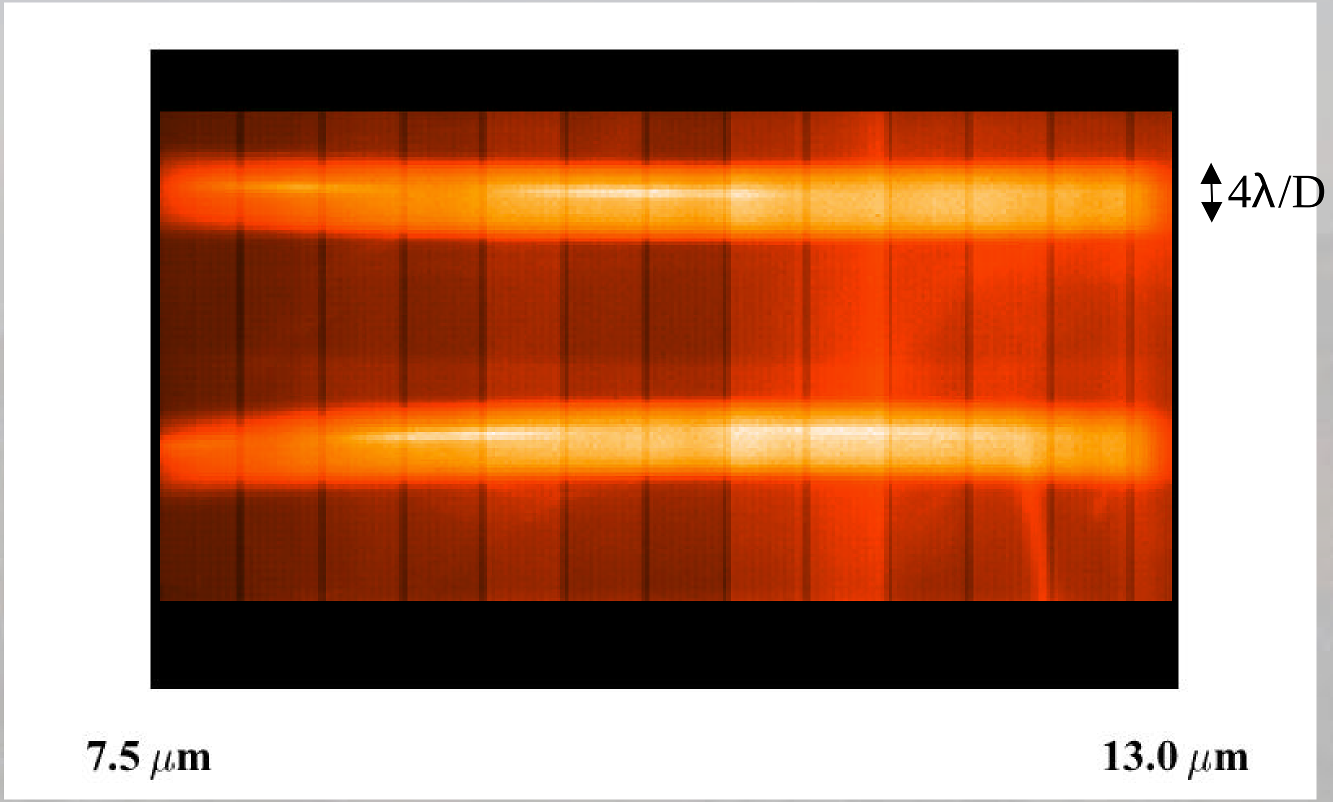


• ***Focal plane***	open	full field of ±1’’
	slits	1-4 λ/D
	triple pinhole	1-4 λ/D
	single mode fiber	Airy disk
• ***Photometric channels***	in	better accuracy
	out	better sensitivity

(photon Cost = 30% of the light)

First lab fringes

Channeled spectrum

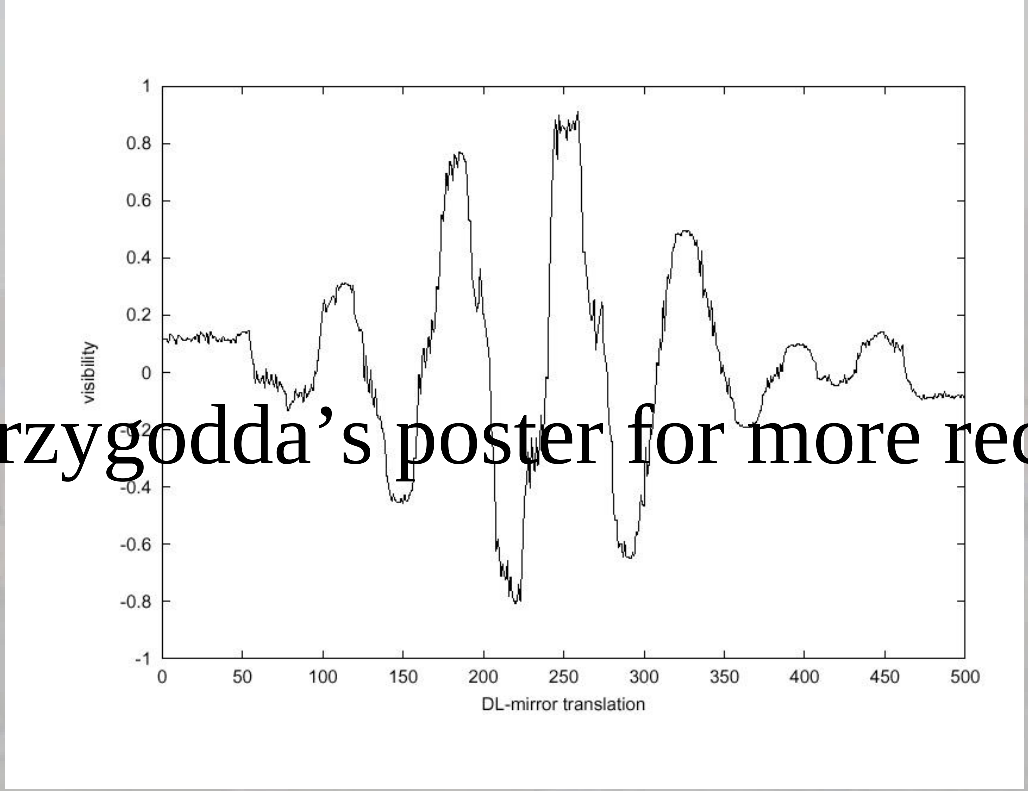


$$I(\sigma) = B(\sigma)[1 + V(\sigma)]\cos\left(2\pi\sigma x + \varphi(\sigma)\right)$$

$$x = optical\ \ path\ difference\ (fixed)$$

First lab fringes

white light interferogram



See F. Przygodda’s poster for more recent news!

$$I(x) = \int B(\sigma)[1 + V(\sigma)]\cos(2\pi\sigma x + \varphi(\sigma))d\sigma$$

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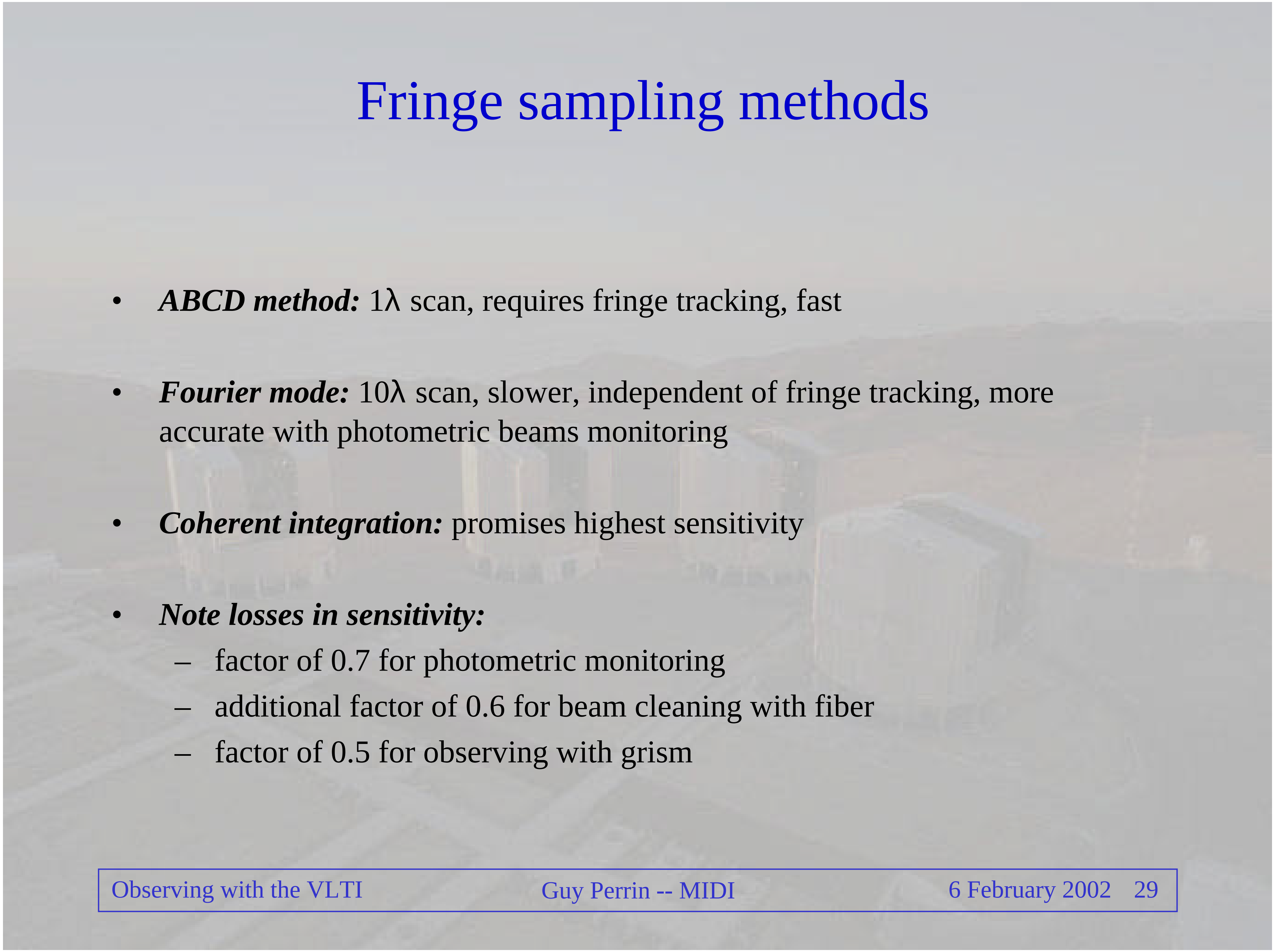
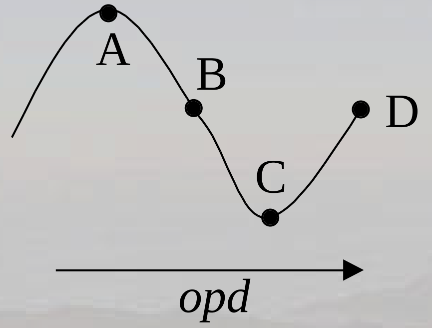


Fringe sampling methods

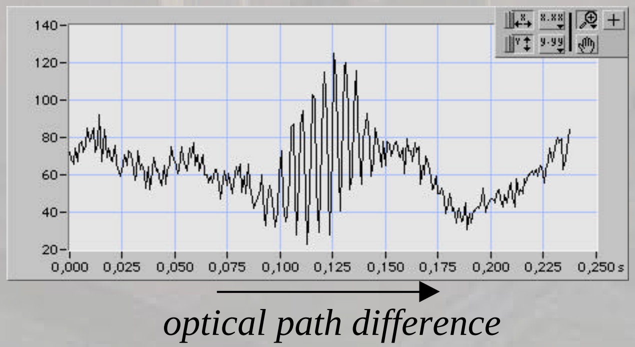
- ***ABCD method:*** 1λ scan, requires fringe tracking, fast
- ***Fourier mode:*** 10λ scan, slower, independent of fringe tracking, more accurate with photometric beams monitoring
- ***Coherent integration:*** promises highest sensitivity
- ***Note losses in sensitivity:***
  - factor of 0.7 for photometric monitoring
  - additional factor of 0.6 for beam cleaning with fiber
  - factor of 0.5 for observing with grism

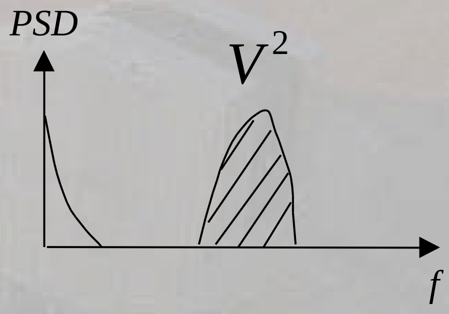
ABCD:



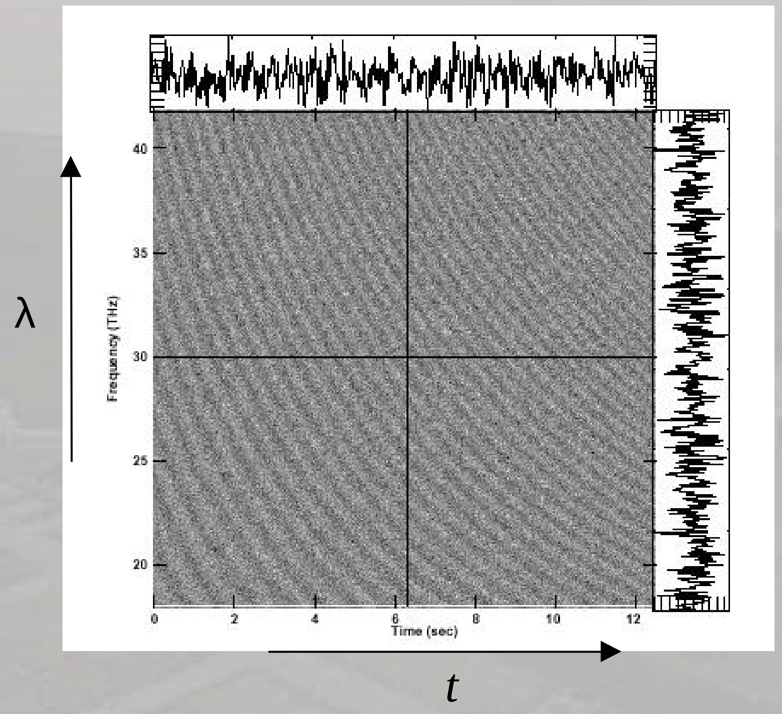
$$V^2 = 4\,\frac{(A-C)^2 + (B-D)^2}{(A+B+C+D)^2}$$

Fourier:

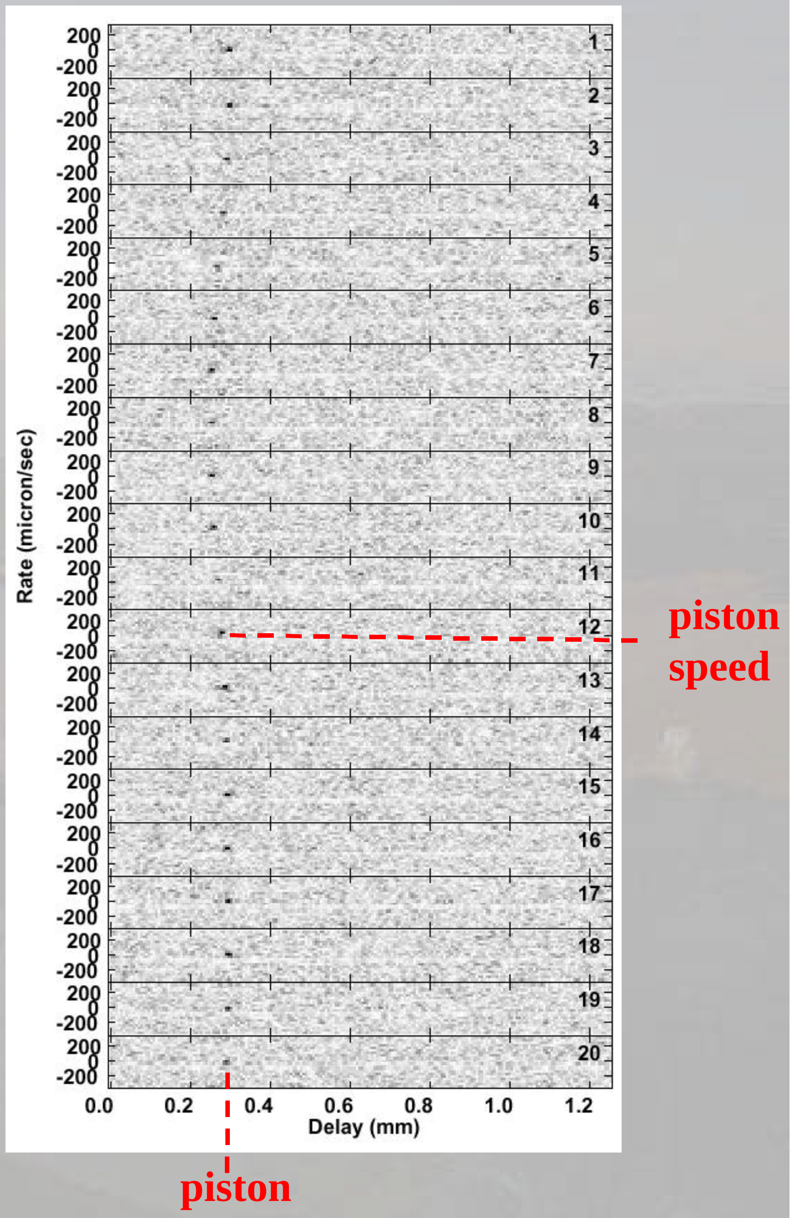


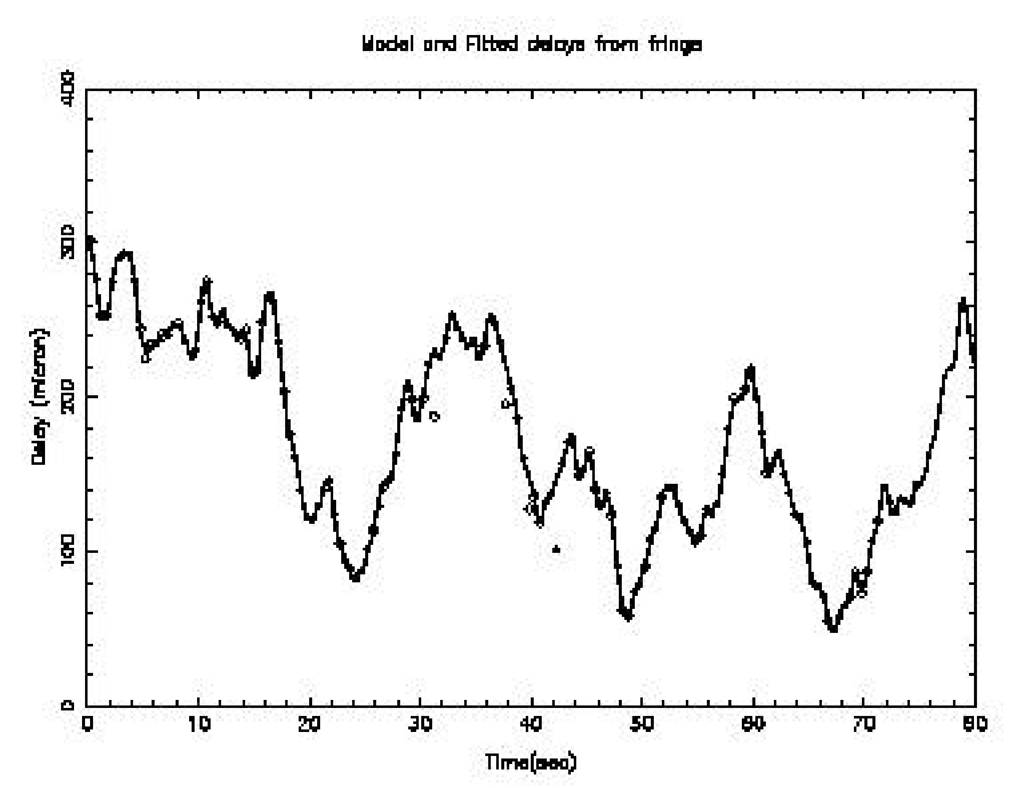


Coherent integration:



Fourier Tranform short sequences



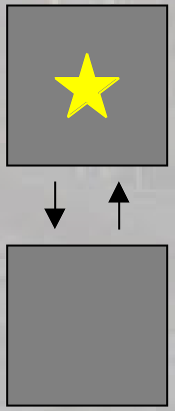


The differential piston can be measured and fringes can be co-added *a posteriori* as if there was no turbulence.

Background subtraction

Background subtraction is necessary to calibrate the unmodulated part of the signal (measure the photometric 0)

<u>Solution:</u> CHOPPING = quick alternation between object and nearby sky background with secondary mirror



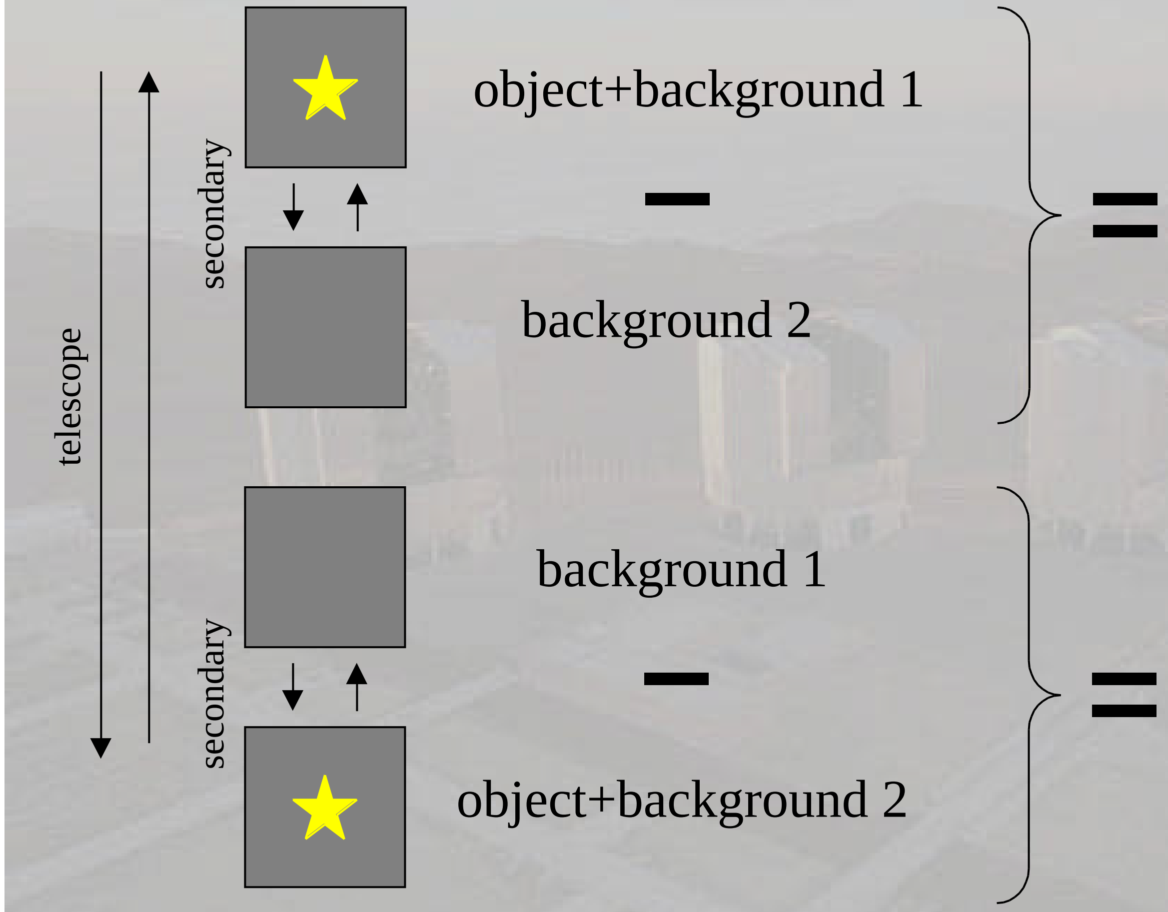
object+background 1

−

background 2

= OBJECT+residual pattern of background emission

The residual background is corrected by **NODDING**: switch beams with the telescope



object+background 1

−

background 2

= OBJECT+residual pattern of background emission

background 1

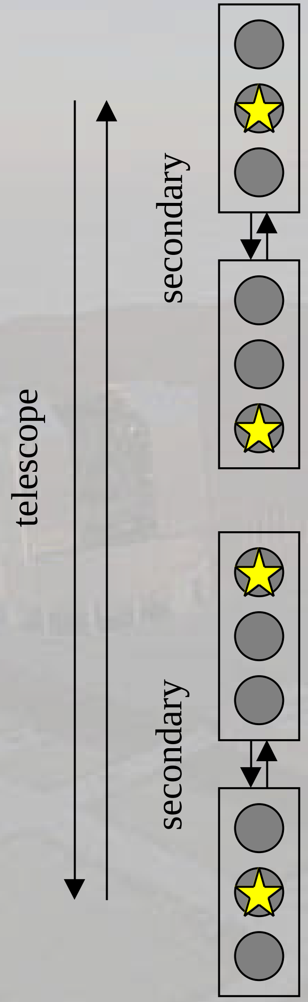
−

object+background 2

= - OBJECT+residual pattern of background emission

total = 2 x OBJECT

Chopping and nodding with a triple pinhole on MIDI:



object is available 100% of the time

Overheads:

- on-source	100 ms
- M2	20 ms
- off-source	100 ms
- adaptive optics	≥320 ms
- fringe tracker (self or external)	≥320 ms

total time for 100 ms on-source:	≥760 ms

Solution :

- first interferometry	Nx100 ms
- then chopping	Nx(100ms +100 ms)

Minimum time for a visibility measurement: 15 min

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Limiting magnitude for self-fringe tracking

Assumptions:

- Transmission of VLTI = 40%
- Transmission of the cold optics of MIDI = 60%
- Detector QE=40%
- 1.9×10^{11} γ/s/Airy disk at the detector

Observing mode: ABCD with 25 ms samples, broad band (8-13 µm)

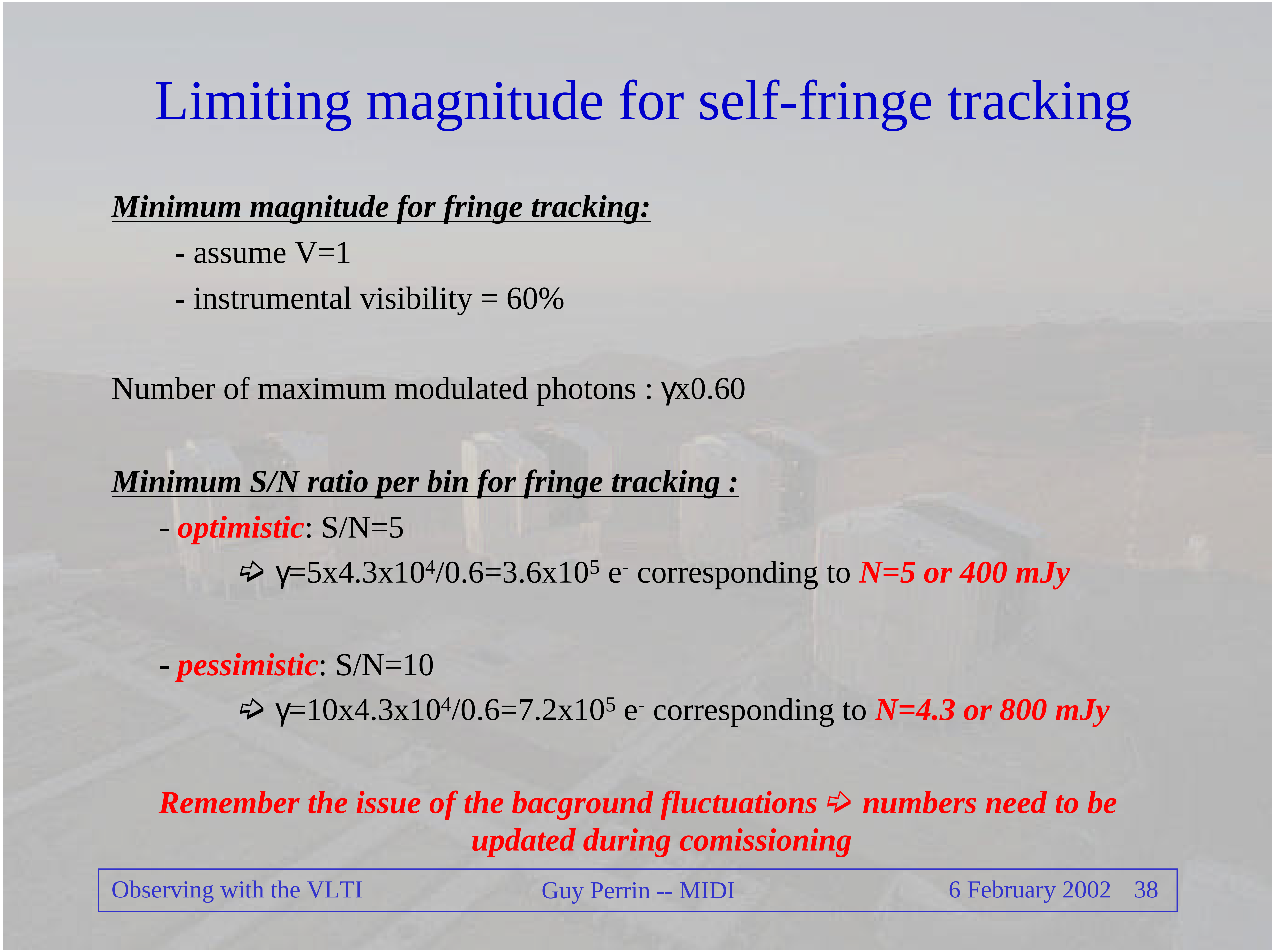
Determine noise from background in one basic measurement:

1.9×10^{11} γ/s/Airy disk ⇨ 1.9×10^{9} e^- per 25 ms sample ⇨ shot noise = 4.3×10^{4} e^-

Signal has to be spread over ~ 200 pixels to avoid saturation

⇨ total noise variance = $\#\gamma + 200\times(\mathrm{RON})^2 \approx 1.9\times10^{9} + 200\times1000 \approx \#\gamma$

Observations are always limited by background photon noise (at least)



Limiting magnitude for self-fringe tracking

Minimum magnitude for fringe tracking:

- assume V=1
- instrumental visibility = 60%

Number of maximum modulated photons : $\gamma \times 0.60$

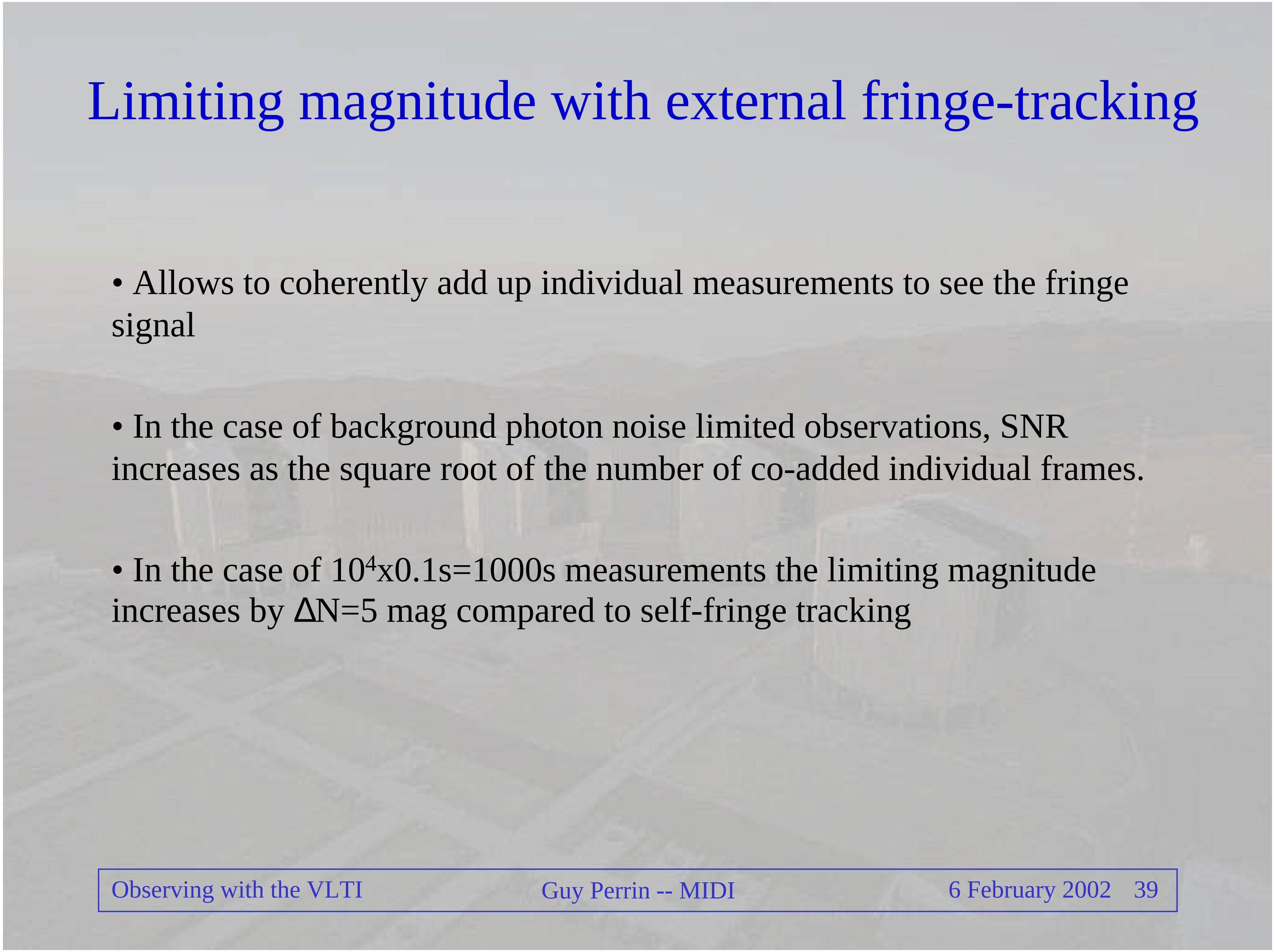
Minimum S/N ratio per bin for fringe tracking :

- ***optimistic***: S/N=5
  ➪ $\gamma=5 \times 4.3 \times 10^{4}/0.6=3.6 \times 10^{5}$ e^{-} corresponding to ***N=5 or 400 mJy***

- ***pessimistic***: S/N=10
  ➪ $\gamma=10 \times 4.3 \times 10^{4}/0.6=7.2 \times 10^{5}$ e^{-} corresponding to ***N=4.3 or 800 mJy***

Remember the issue of the bacground fluctuations ➪ numbers need to be updated during comissioning

Limiting magnitude with external fringe-tracking



- Allows to coherently add up individual measurements to see the fringe signal

- In the case of background photon noise limited observations, SNR increases as the square root of the number of co-added individual frames.

- In the case of 10^4x0.1s=1000s measurements the limiting magnitude increases by $\Delta N=5$ mag compared to self-fringe tracking

Summary of limiting magnitudes for MIDI

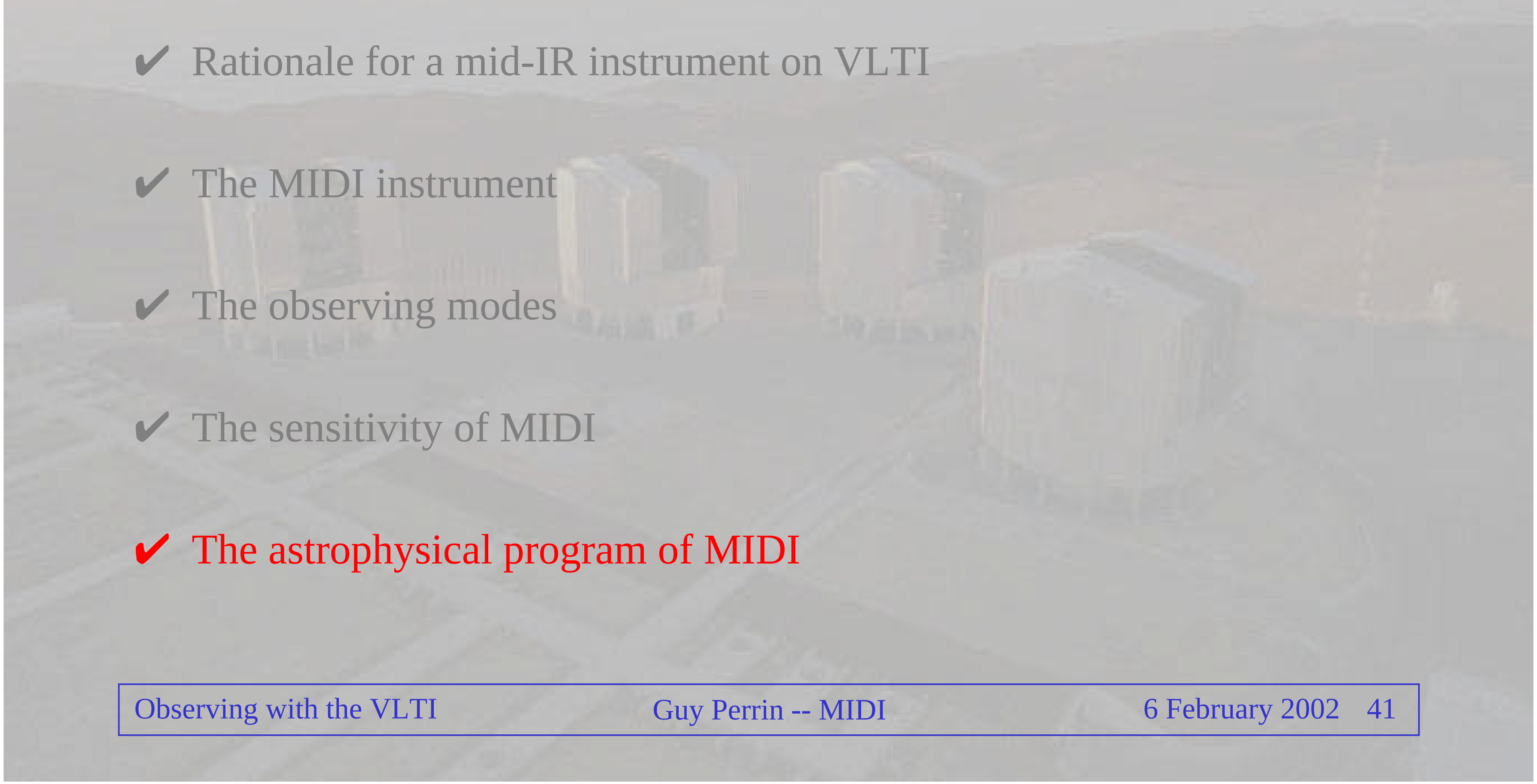
Filter				
Broad band	Prism (R=30)		Grism (R=230)	
N=4.3	Full band	N=4.3	Full band	N=3.4*

* detector read-out noise cannot be neglected

- Add ΔN=5 mag with external fringe tracking

- Remove ΔN =3.3 magnitudes for the ATs

Outline



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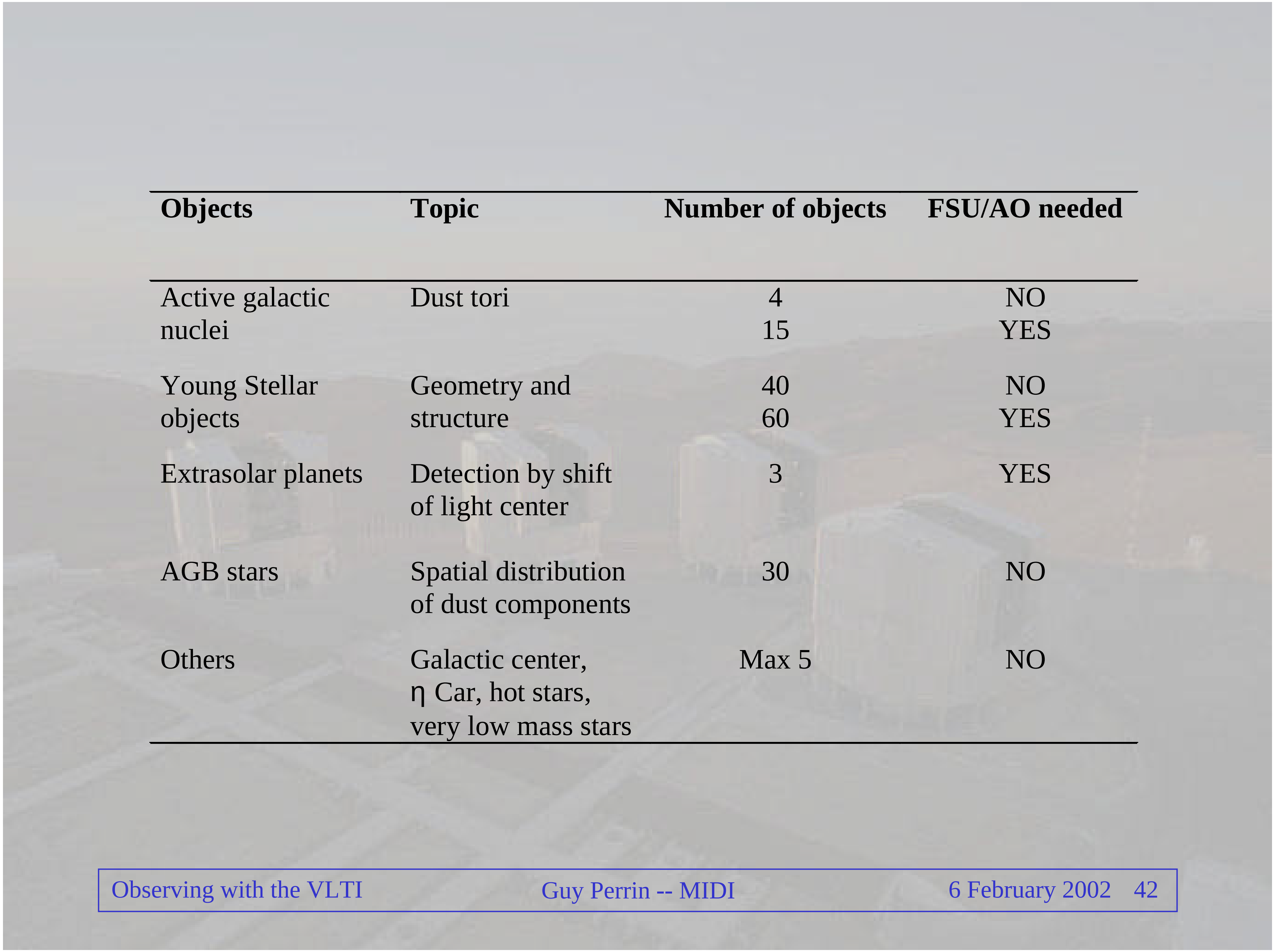
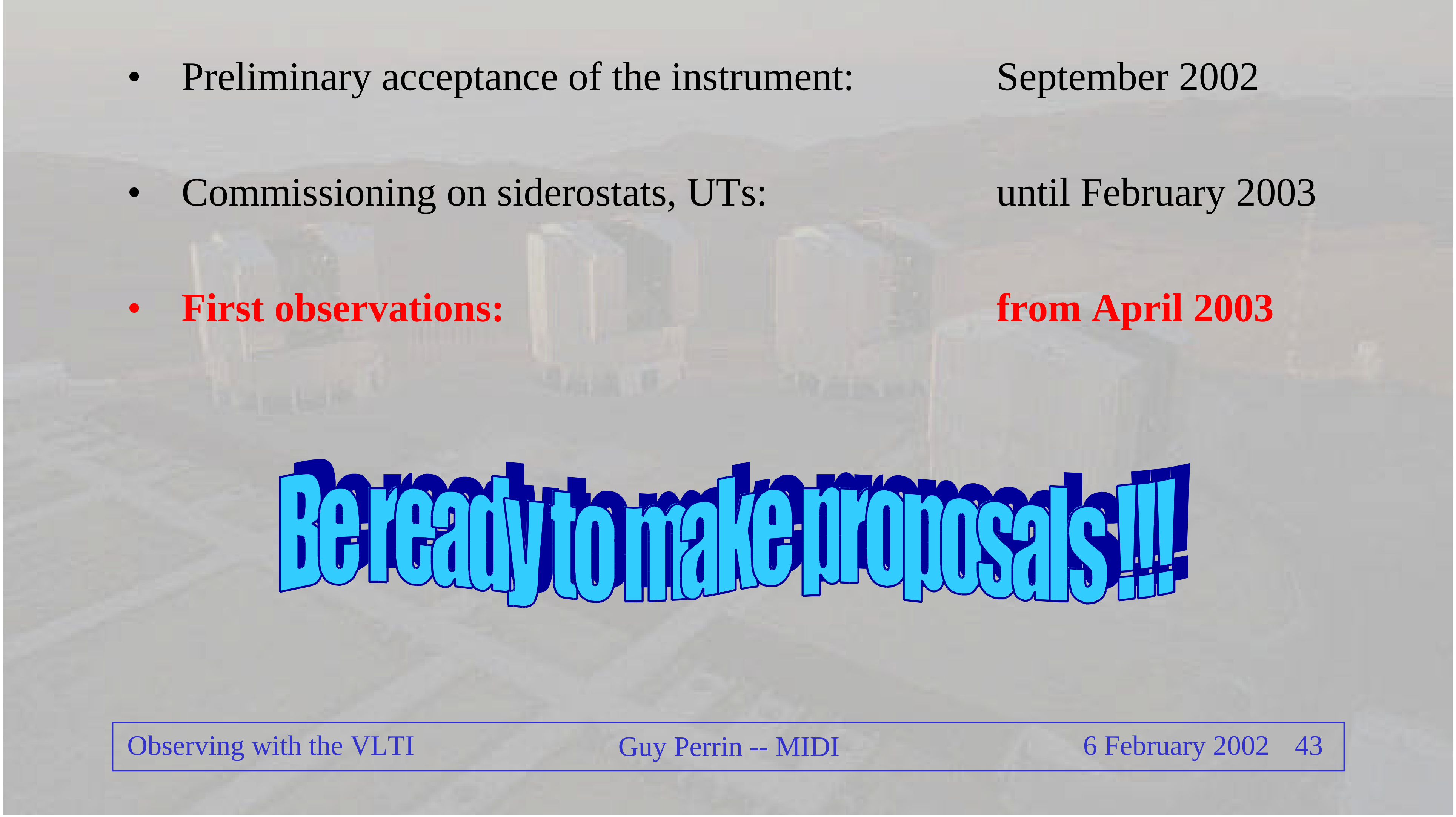


Objects	**Topic**	**Number of objects**	**FSU/AO needed**
Active galactic nuclei	Dust tori	4 15	NO YES
Young Stellar objects	Geometry and structure	40 60	NO YES
Extrasolar planets	Detection by shift of light center	3	YES
AGB stars	Spatial distribution of dust components	30	NO
Others	Galactic center, η Car, hot stars, very low mass stars	Max 5	NO

When ?



- Preliminary acceptance of the instrument: September 2002
- Commissioning on siderostats, UTs: until February 2003
- **First observations: from April 2003**

Be ready to make proposals !!!