MATISSE

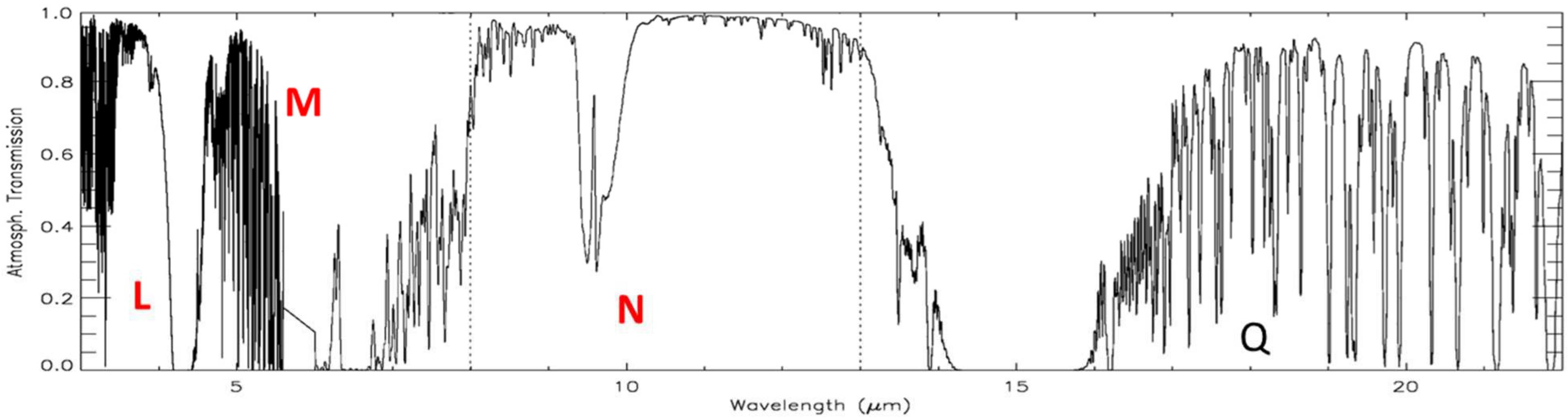
Multi-AperTure Mid-Infrared SpectroScopic Experiment

4 Telescopes

3 – 13 µm

R= 20 - 5000

for the Very Large Telescope Interferometer (VLTI)



MIDI

L (3.2 – 3.9 µm), **M** (4,5 – 5 µm),
N (8 – 13 µm)

The MATISSE Consortium

Observatoire de la Cote d' Azur, Nice:

PI: Bruno Lopez
Project Manager (Pierre Antonelli)
- General Optical Design
- Warm Optics
- Instrument Software: OS
- Data Reduction Software (DRS)
- Final Integration, PAE, Commissioning

MPI für Astronomie:

- **Co-PI: Thomas Henning**
  - Cryogenics (2 cryostats)
  - Control electronics
  - Instrument Control Software: ICS
  - Contribution to integration/test of cold optics and detector in cryostat
  - Contribution to detector subsystem

Leiden Observatory / ASTRON / NOVA:

- **Co-PI: Walter Jaffe**
  - Cold optics
  - Instrument Software: NRTS, Simulator
  - Contribution to Data Reduction Software

MPI für Radioastronomie:

- **Co-PI: Gerd Weigelt**
  - Detector adaption to MATISSE
  - Detector Control Software: DCS
  - Contribution to DRS (image de-convolution)

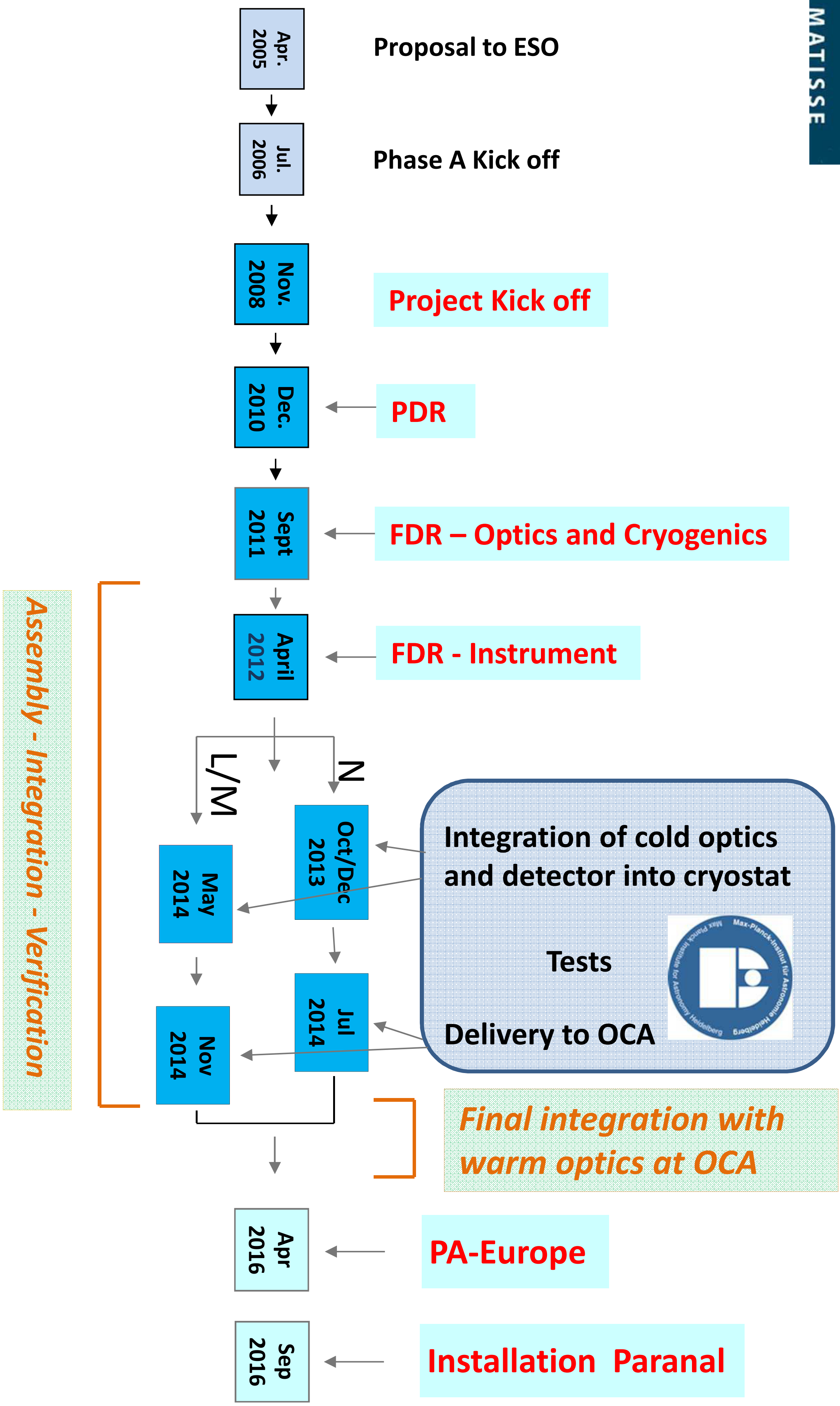
With further contributions from **ESO** (detectors + read-out electronics), **Uni Kiel** (Sebastian Wolf, head of Science group) and **Vienna** (Joseph Hron, Calibrator list)

Total costs: 3,125 Mill €, 134 FTE; MPIA contribution: ≈ 24 %

Die MatissianerInnen am MPIA:

Projektwissenschaftler:	*Thomas Henning (Co-PI)*
Projektmanager:	***Uwe Graser***
Kryostate:	***Markus Mellein, Werner Laun***
Elektronik:	***Michael Lehmitz****, Lars Mohr + Abteilung*
Feinwerktechnik:	***Klaus Meixner****, Armin Böhm + Abteilung*
Software:	***Udo Neumann****, Florian Briegel*
Konstruktion:	*Monika Ebert, Ralf-Rainer Rohloff*
Detektor:	*Vianak Naranjo /* ***Johana Panduro****, Peter Bizenberger*
Data simulation:	*Rainer Köhler*
Science Group:	*Klaus Meisenheimer, Roy van Boekel, Jörg-Uwe Pott*

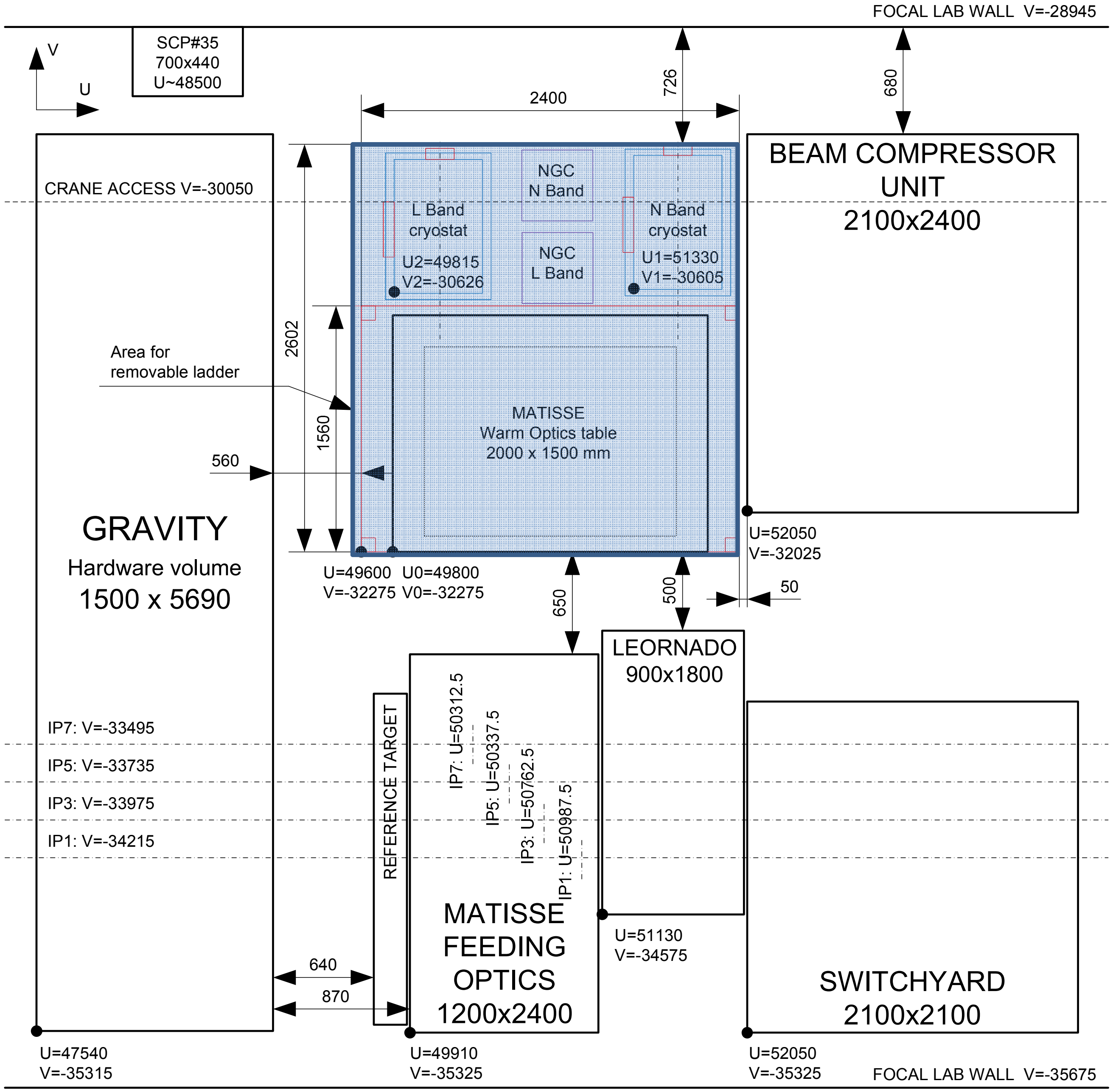
The Timeline of MATISSE .....

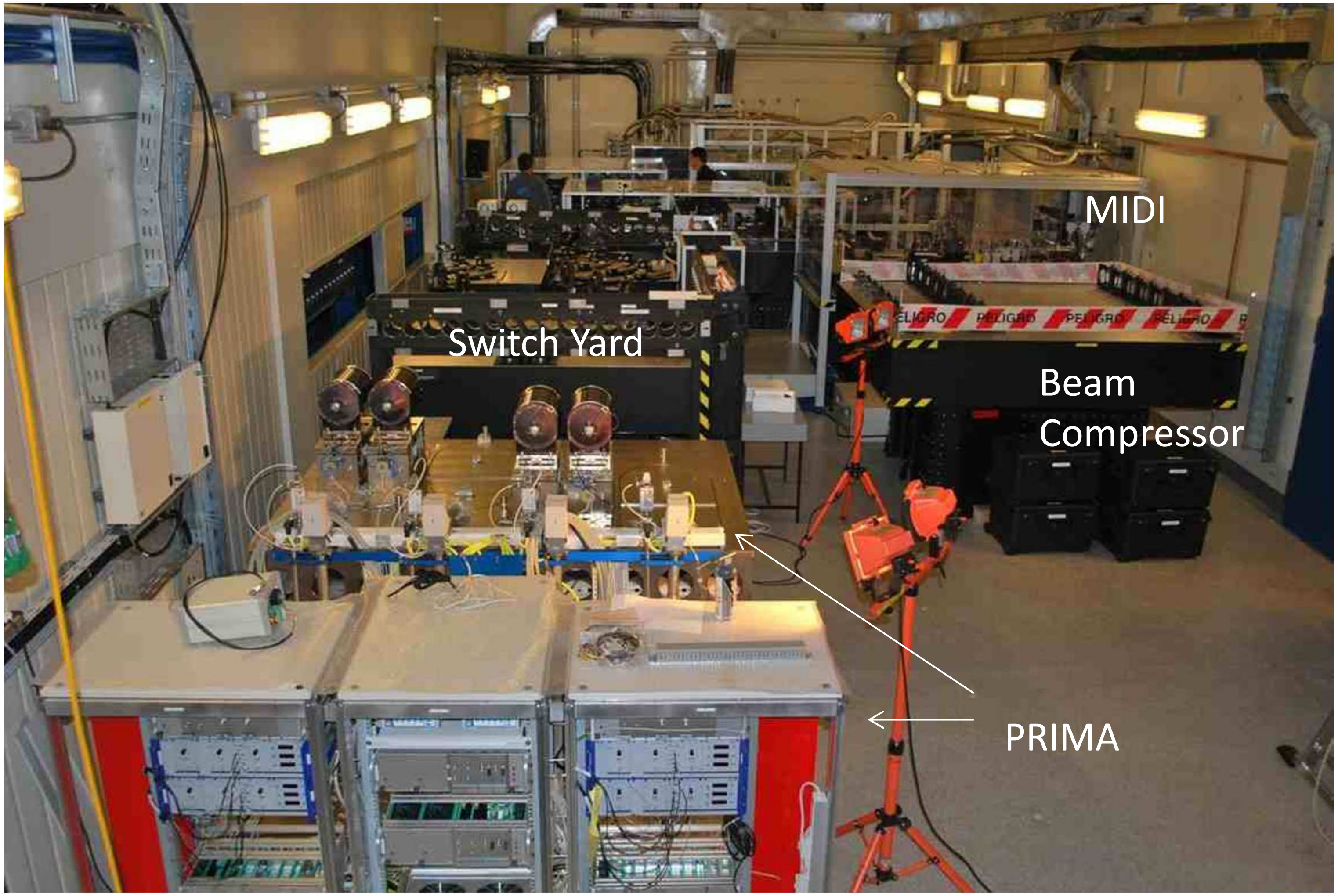


Science characteristics of MATISSE …..

MATISSE measures:	visibility, imaging (closure phases, differential phases)	
Number of beams/telescopes	4 (2 or 3 possible)	
Wavelength bands	L (3.2 – 3.9), M (4.5 – 5) and N (8 – 13 µm)	
Field of view	2 arcsec (UT)	
Spectral resolution	L /M	N
Low	20 <R<40	20<R<40
Medium	200<R<400	200<R<400
High	750<R<1250	
Very high	5050 at 4.05 µm (Br-α) in 6th order 3800 at 4.7 µm (CO) in 5th order	
Spatial resolution (λ/D for 100m)	0.007 arcsec	0.02 arcsec
Sensitivity (UT) with fringe tracking	0.02 Jy (L=10.4)	0.02 Jy (N=8)
Sensitivity (AT) with fringe tracking	0.4 Jy (L=7)	0.4 Jy (N=5)

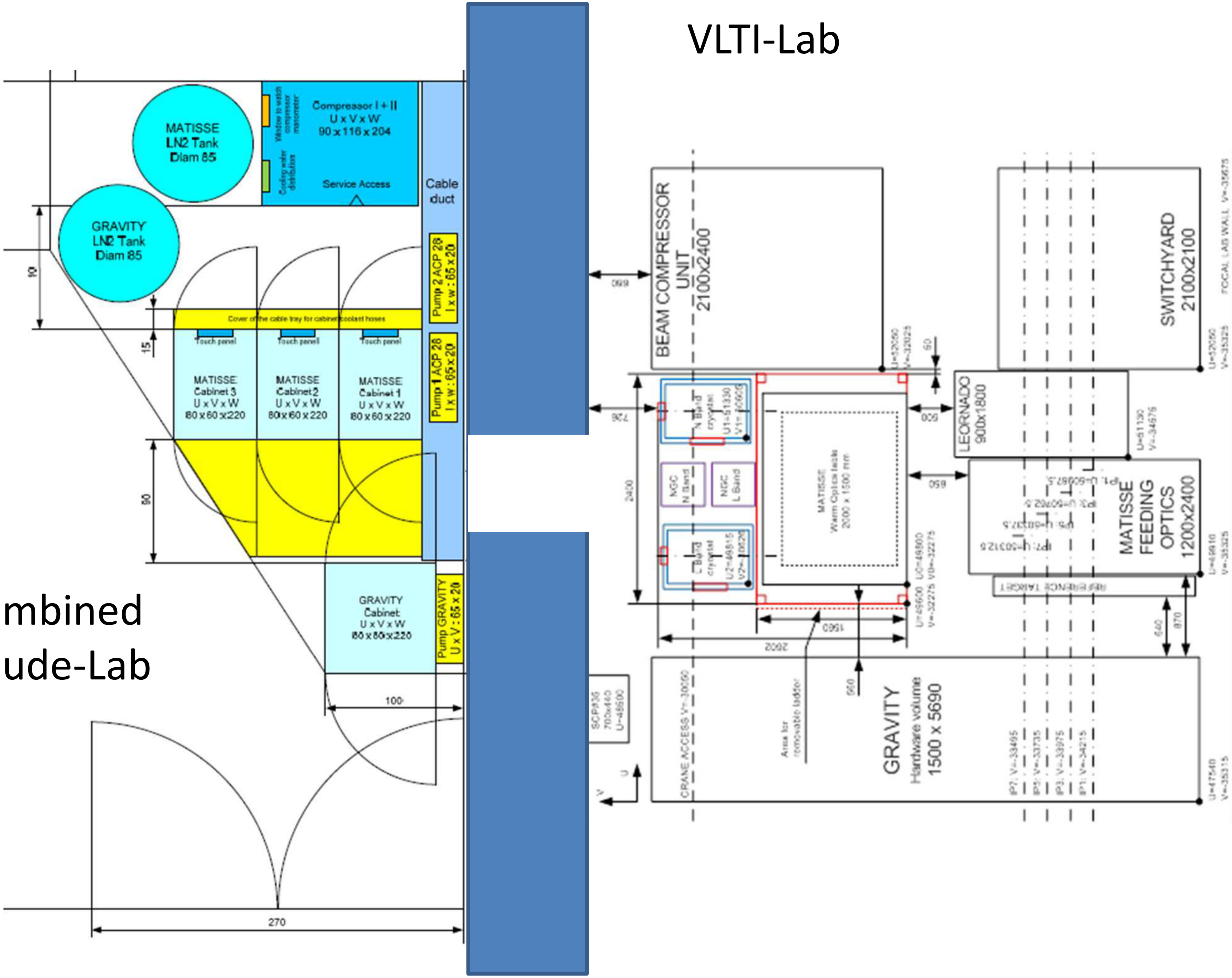
MATISSE im VLTI-Lab .....





Current view of VLTI Lab ……

VLTI-Lab

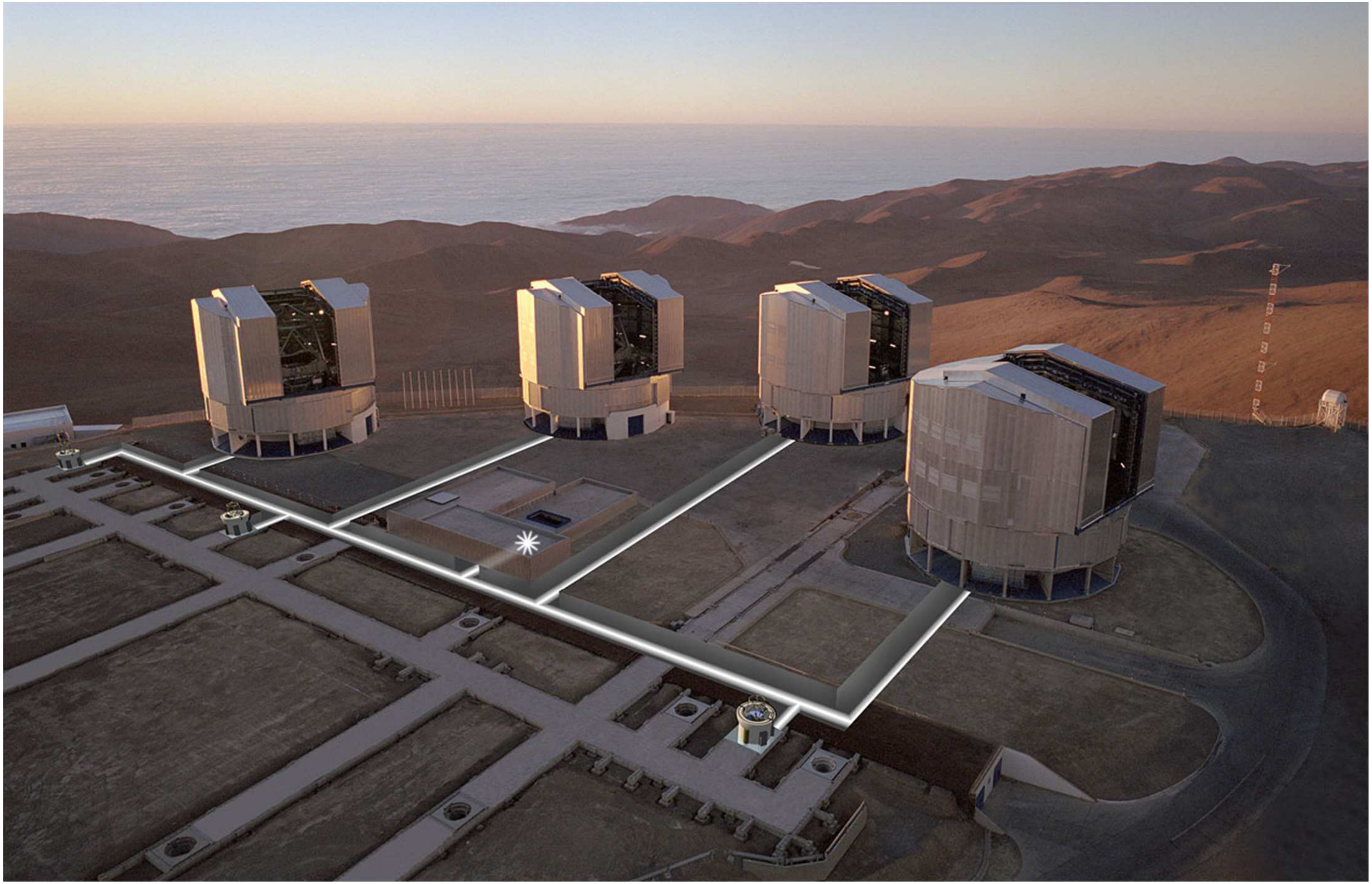


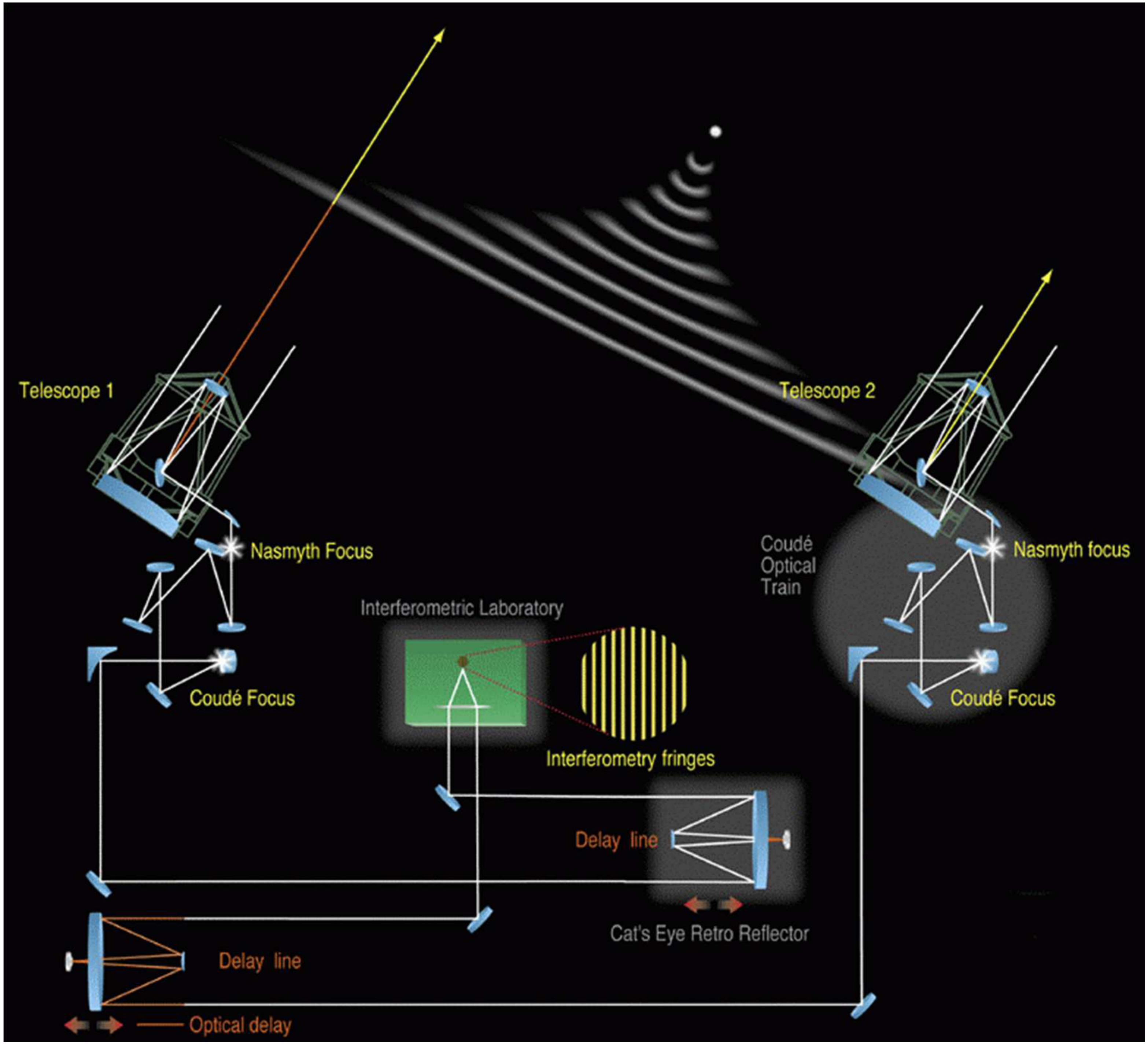
Combined Coude-Lab

MIDI in Combined Coude Lab

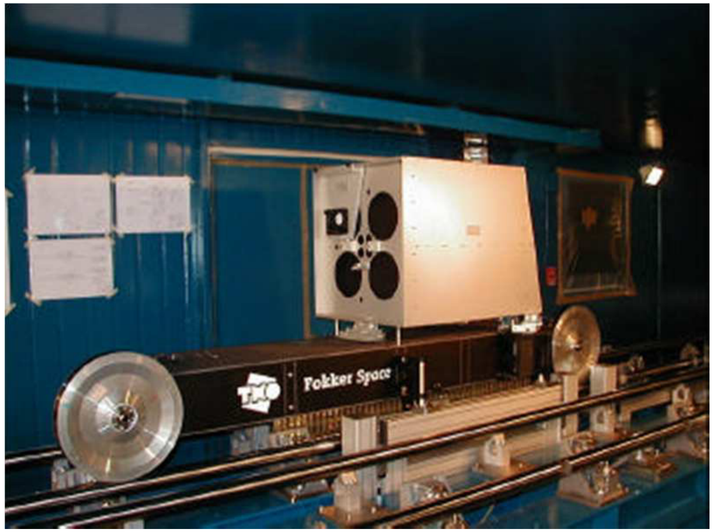
Interferometry !?

.... what's that ???

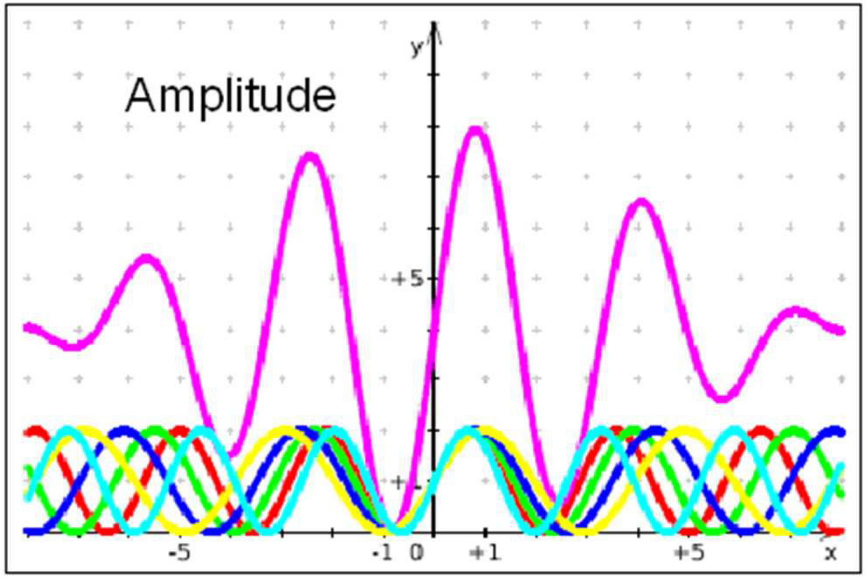



Telescope 1
Telescope 2
Nasmyth Focus
Nasmyth focus
Coudé Optical Train
Interferometric Laboratory
Coudé Focus
Coudé Focus
Interferometry fringes
Delay line
Cat's Eye Retro Reflector
Delay line
Optical delay

Delay-Lines on Paranal



Fringes and coherence ......



Relative Delay

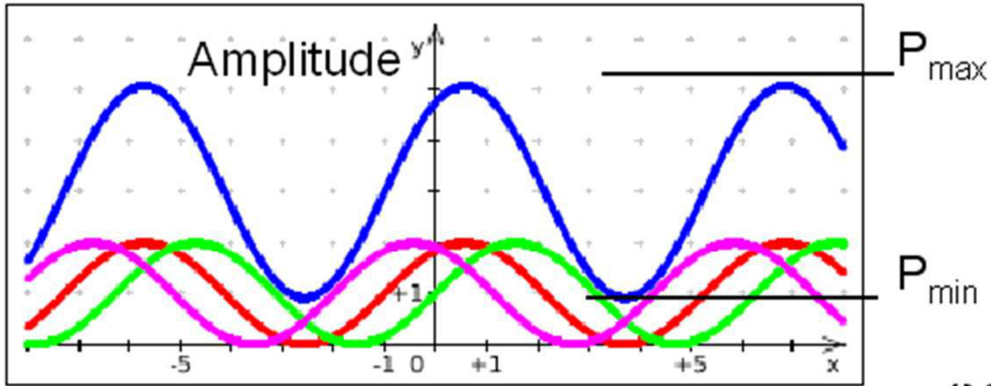
Poly-chromatic fringes of a point source

→ „white-light fringe“

Coherence length:

Range of OPD, in which fringes appear: $\lambda^2/\Delta\lambda$

(≈ 14 µm für λ=10 / $\Delta\lambda$=7 µm)



Relative Delay

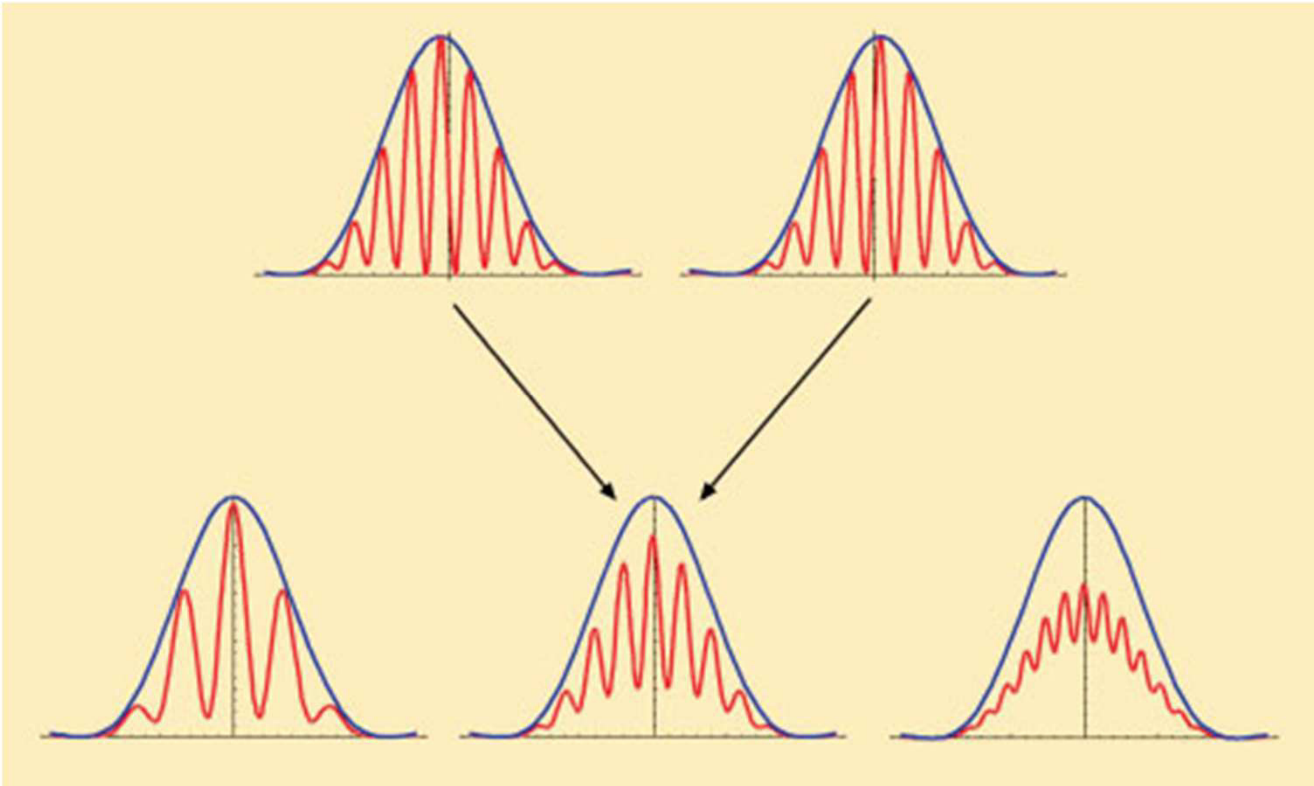
Mono-chromatic fringes of an extended source

Visibility = degree of spatial coherence

$$V = \frac{P_{max} - P_{min}}{P_{max} + P_{min}}$$

(Calibrator: V=1)

(Michelson‘s Fringe Visibility)



Upper row: fringe pattern of a single point source at *+* $\alpha_0/2$ *und at* – $\alpha_0/2$

Lower row: three fringe patterns with both point sources in the field and the baseline increasing from left to right

- *Astronomical target emits light with intensity I_ν (Θ,Φ) from a small region at sky (x,y around Θ_0 and Φ_0)*

- *From the interferometric signal on the detector (i.e. the amplitude and phase of fringes)*
  → derive the ***Visibility V(u,v)*** *(Visibility function V (D, λ, object))*

- *(u,v) =* $\vec{D}/\lambda$ *= baseline vector* $\vec{D}$ *projected onto plane of the sky in units of λ → u,v plane*

Van Cittert-Zernike Theorem:
The visibility is equal to the Fourier transform of the object brightness distribution $I_\nu(\vec{r})$

$$\left| V_\nu\left(\frac{\vec{D}}{\lambda}\right)\right| e^{-i\phi_{V_\nu}} = \frac{\int_{\delta\Omega} dx_\Omega\, dy_\Omega\, I_\nu(\vec{r}_\Omega) e^{-2\pi i((\vec{D}/\lambda)\cdot\vec{r}_\Omega)}}{\underbrace{\int_{\delta\Omega} dx_\Omega\, dy_\Omega\, I_\nu(\vec{r}_\Omega)}_{\text{Total specific flux}}}$$

$$\vec{r}_\Omega = (x_\Omega, y_\Omega),$$

Measure: Visibility V(u,v) and phase of fringes → deconvolution → $I_\nu(\vec{r})$

→ *Spatial resolution of interferometer ~ Wavelength / Baseline*

$\Delta\,\Theta_{\text{interferometer}} = \lambda/2b$ [rad] (b= max baseline)

Calibration *by an unresolved point source* ***(„calibrator", V=1) →***
neccessary because of atmospherical and instrumental effects

Creation of images:

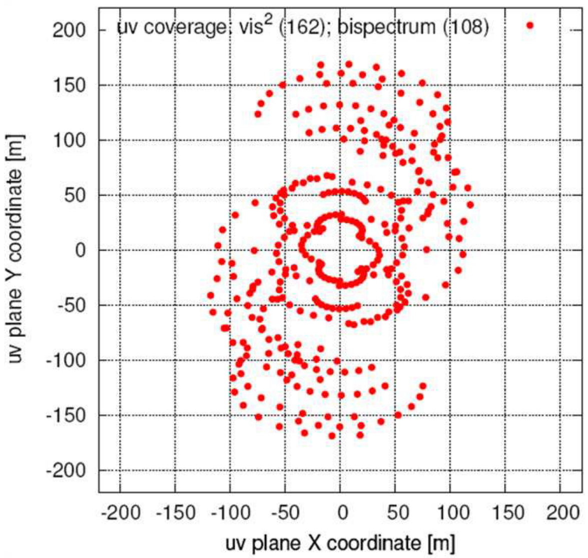
- *fill the u,v plane as much as possible (many different baselines)*
- *Image needs measurement of amplitude and phase of visibility*
- *Add regularisation (constraints, boundary conditions, additional information)*
- *Fit an image to the data (deconvolution, iteration ……)*

Measuring phases:

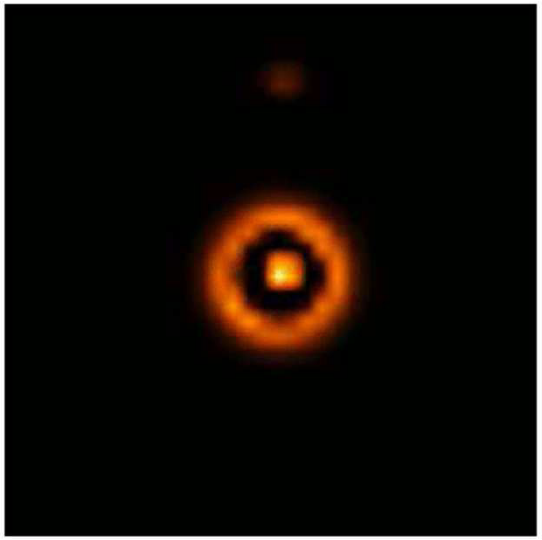
1) *Usage of fringe tracker („phase referencing") + determination of* φ_{offset}
   (e.g. by metrology FT -> MATISSE)
2) *Usage of closure phases („a closed triangle of baselines")*
   (Closure phase (1-2-3) = ϕ_0(1-2) + ϕ_0(2-3) + ϕ_0(3-1))

Accreting planet in disk

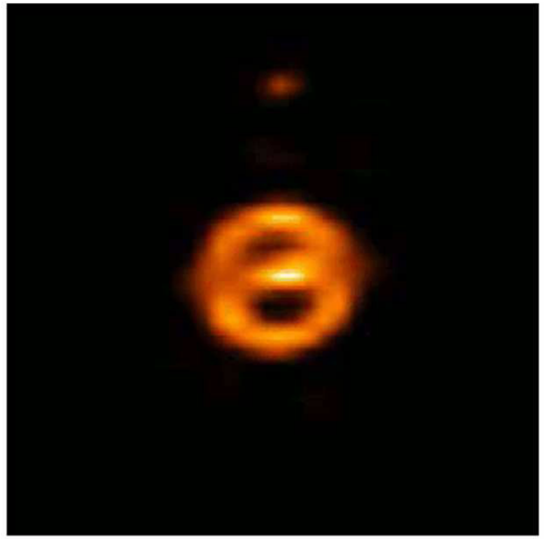
UV coverage



input image (RT model)



re-constructed image



- ATs, 3 configurations, N-band
- star:planet contrast ratio 200:1 (pretty optimistic)
- average visibility SNR = 20

Beam recombination concepts …..

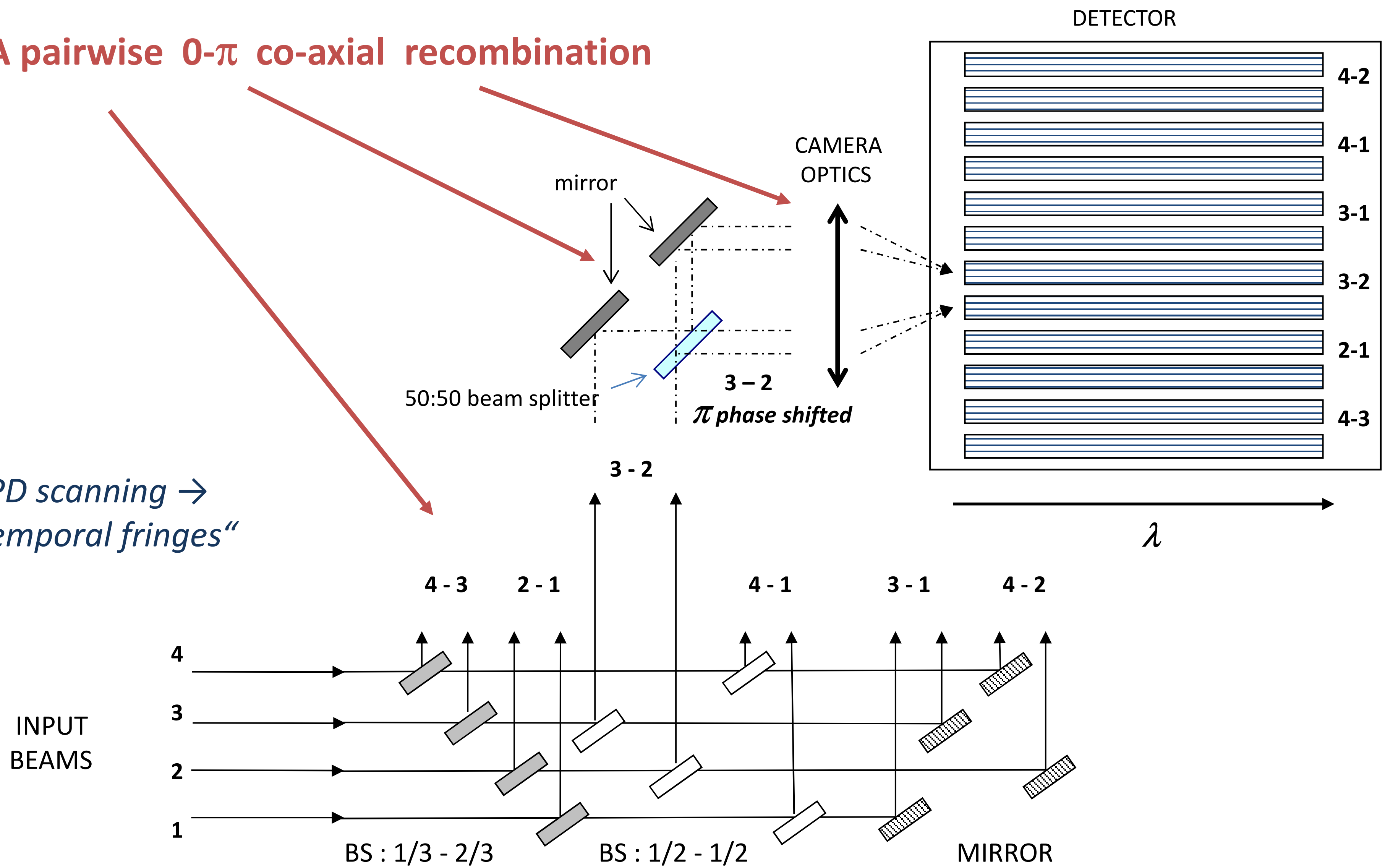
- *co-axial, **combination in image plane***   *(AMBER, MATISSE)*

- *multi-axial, **combination in pupil plane*** *(MIDI)*

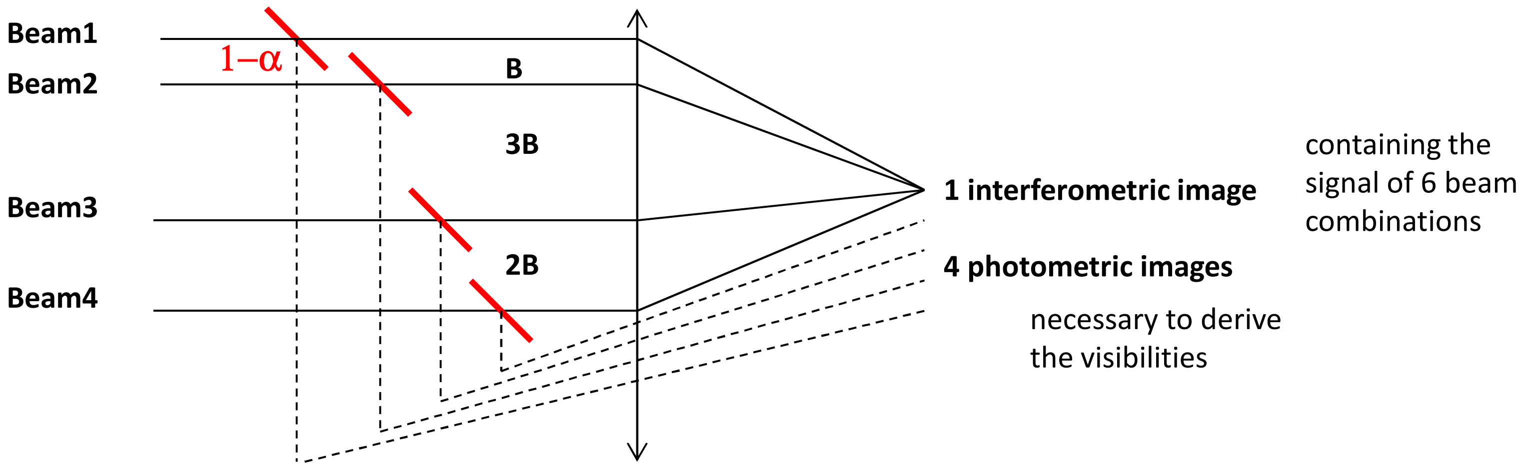
Recombination Concept with 4 telescopes (MIDI-type)

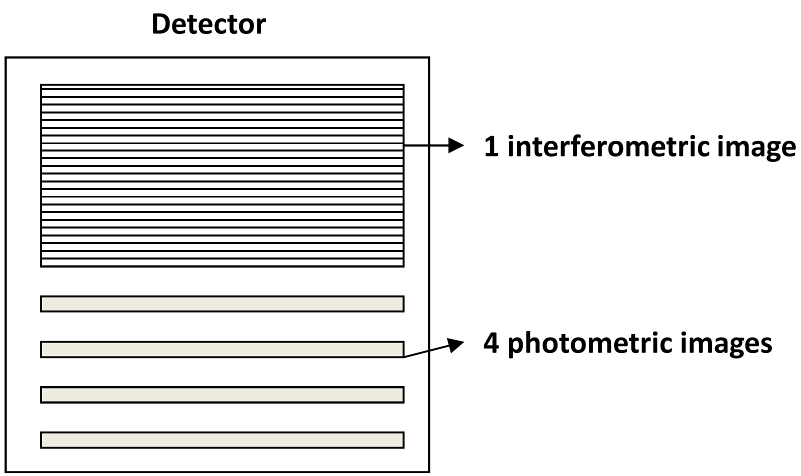
A pairwise 0-π co-axial recombination

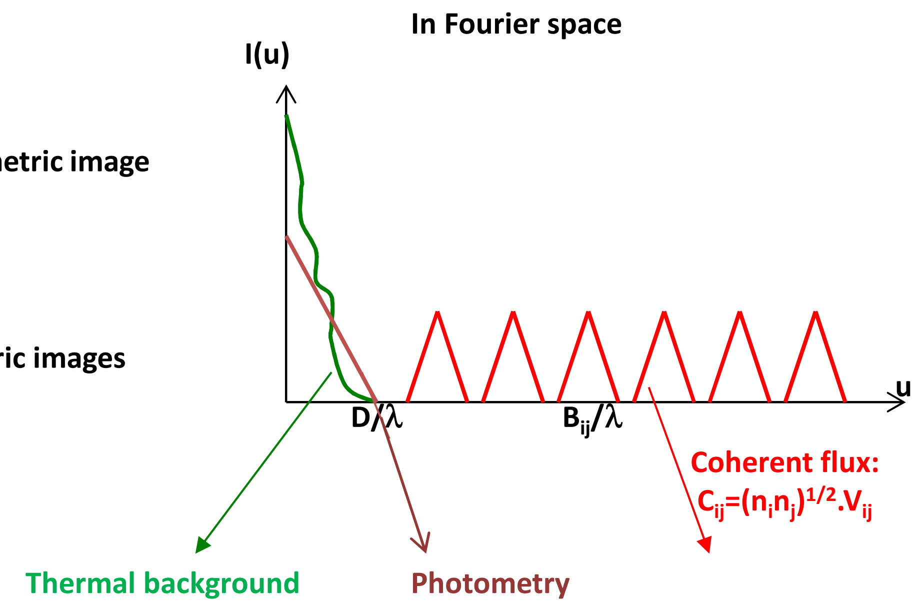
OPD scanning → „temporal fringes"



The multi-axial Beam combination:







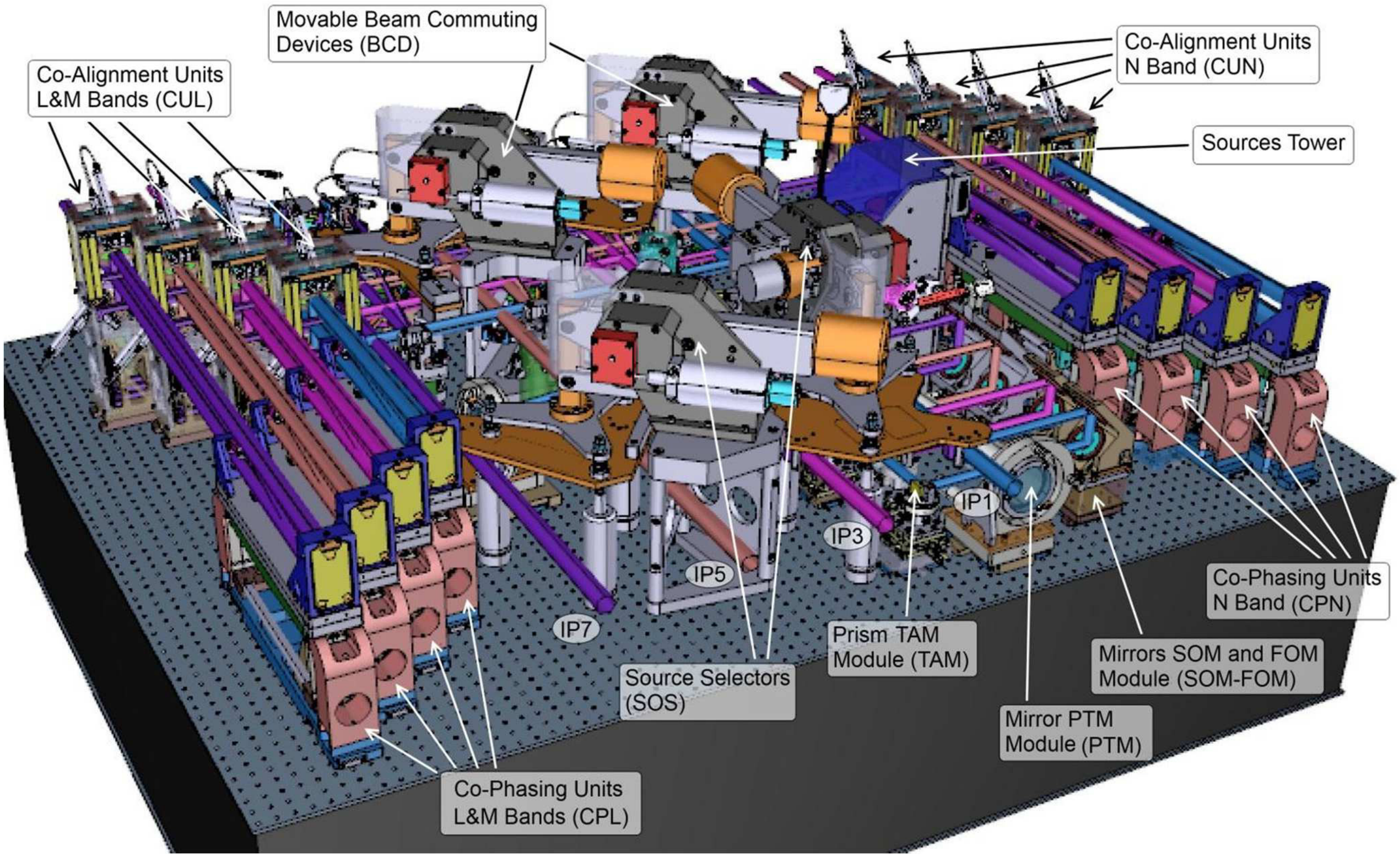
MATISSE Instrument Parameters

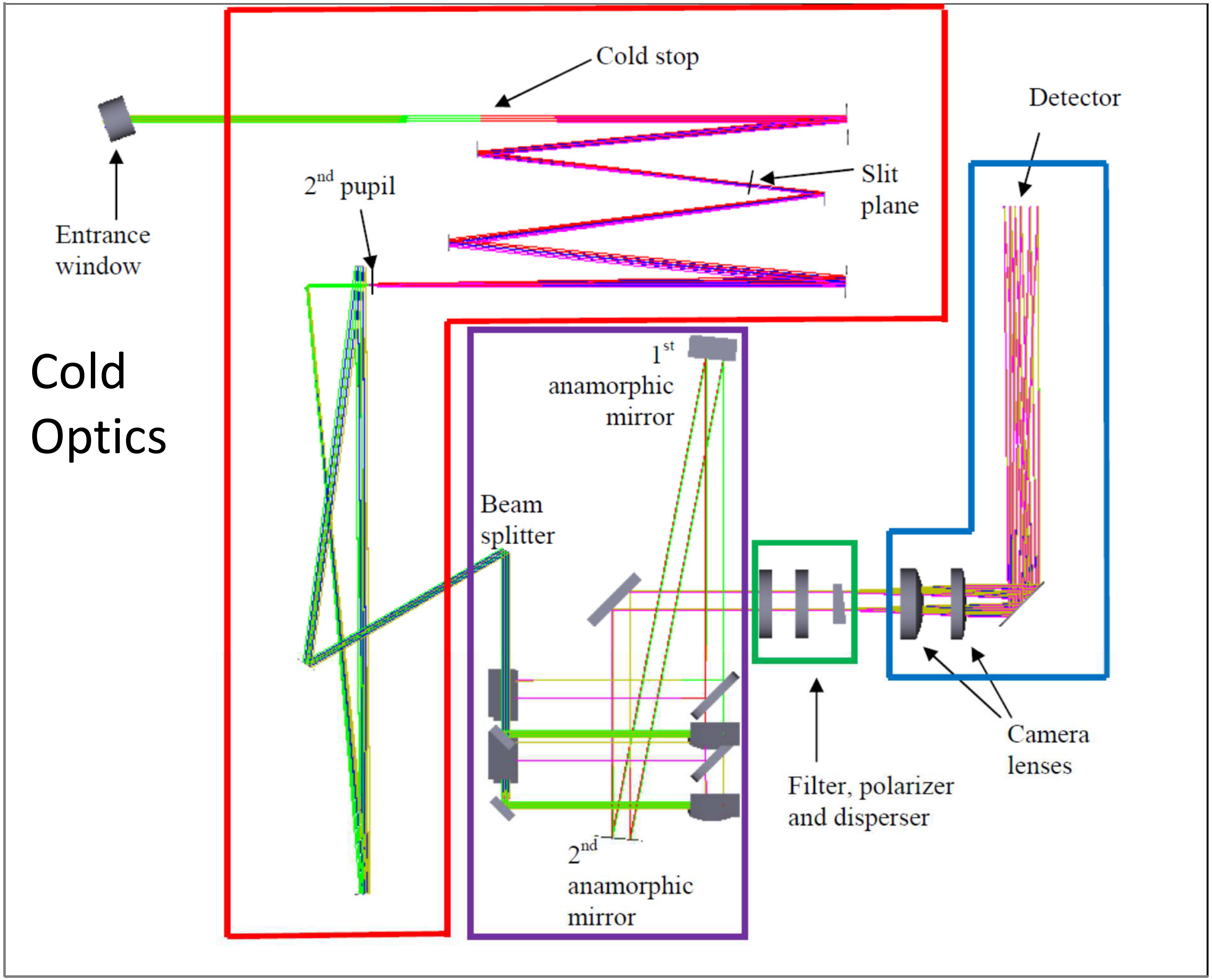
	L/M-Band (3-5 µm)	N-Band (8-13 µm)
Hardware:	one warm optical bench + two independent cryostats	
Optics: Entrance pupil size / Anamorphosis	18 mm / 24 : 1	
Cryostats: Size / weight	2044 x 972 x 672 mm / ~ 1500 kg	
Cooling	Pulse Tube Cooler (Cryomech PT 410)	
Temperature of Optics /Detector	40 K / 40 K	40 K / 8 K
Position adjustable / accuracy:	+/- 5 mm / < 0.2 mm	
Temperature stability: Detector, Optics	< 0.1 K	
Cool-down time:	3.5 days	
Detector	Hawai II RG 5 µm	Raytheon Aquarius
Pixel / Pixel-size	2k x 2k / 18 µm	1k x 1k / 30 µm
Frame time / RON / Pixel clock	30 msec / 3 e / 1.28 MHz	30 msec / 300 e / 1.52 MHz
Data rates NGC -> LLCU / LLCU -> IWS	192 / 34 MByte/sec	307 / 110 MByte/sec

MATISSE Warm Optical Bench …..

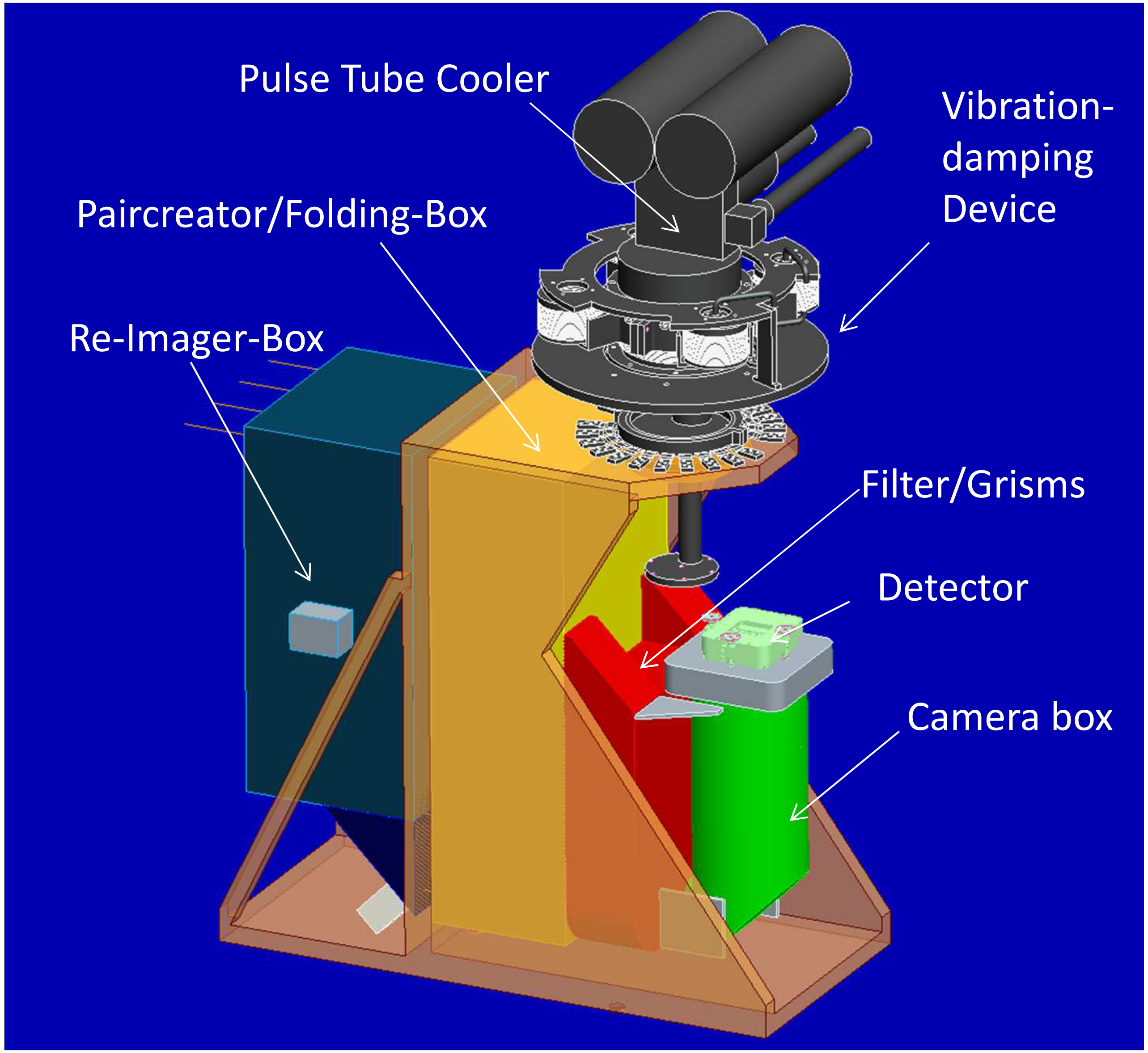
- *Beam commuting device for calibration purposes (IP 1 <-> IP 3; IP 5 <-> IP7)*
- *Anamorphism by cylindrical optics (1:4)*
- *Dichroics for wavelength separation (N-band and L/M-band)*
- *Periscopes to feed the 4 beams into each of the two cryostats,*
  co-alignment between warm optics and cold optical bench
- *Delay lines (8 piezos) to equalize the OPDs*
- *Calibration devices (internal optical sources + source selector module)*

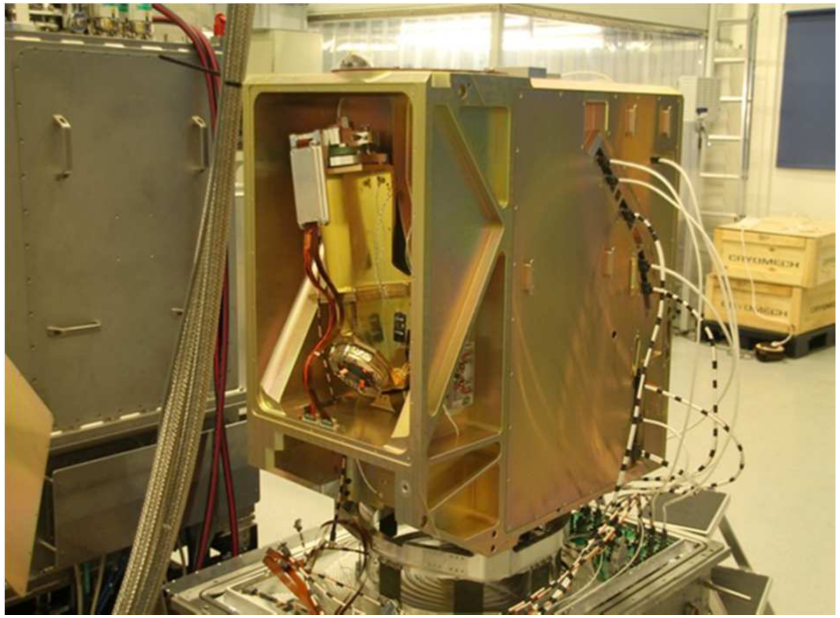
MATISSE Warm Optical Bench .....




Cold stop
Detector
Slit
plane
2nd pupil
Entrance
window
Cold
Optics
1st
anamorphic
mirror
Beam
splitter
Camera
lenses
Filter, polarizer
and disperser
2nd
anamorphic
mirror

MATISSE cold optics + PTC




CRYOMECH

The MATISSE cryostats ……

Some requirements / specifications

Temperatures: COB: < 40 K
detector: Aquarius: 7 – 9 K, Hawaii II RG: 40 K (T-Control)
camera housing: < 28 K,
pre-amp: 60 (T-Control)

Temperature: temporal stability
COB: < 0.1 K
Detector: < 0.1 K

Temperature gradients during cool-down and warm-up for detector and optics
Aquarius: dT < 2,5 K/min (T> 50 K), dT < 10 K /min (T < 50 K)
Hawaii: < 2K / min
Optics: < 2K / min

Vibrations inside: detector displacement in vertical direction
Hawaii II RG: < 1.8 µm ptv
Aquarius: < 3.5 µm ptv
Vibrations outside: "low" vibrations at cryostat surface, He-tubes, floor, …..

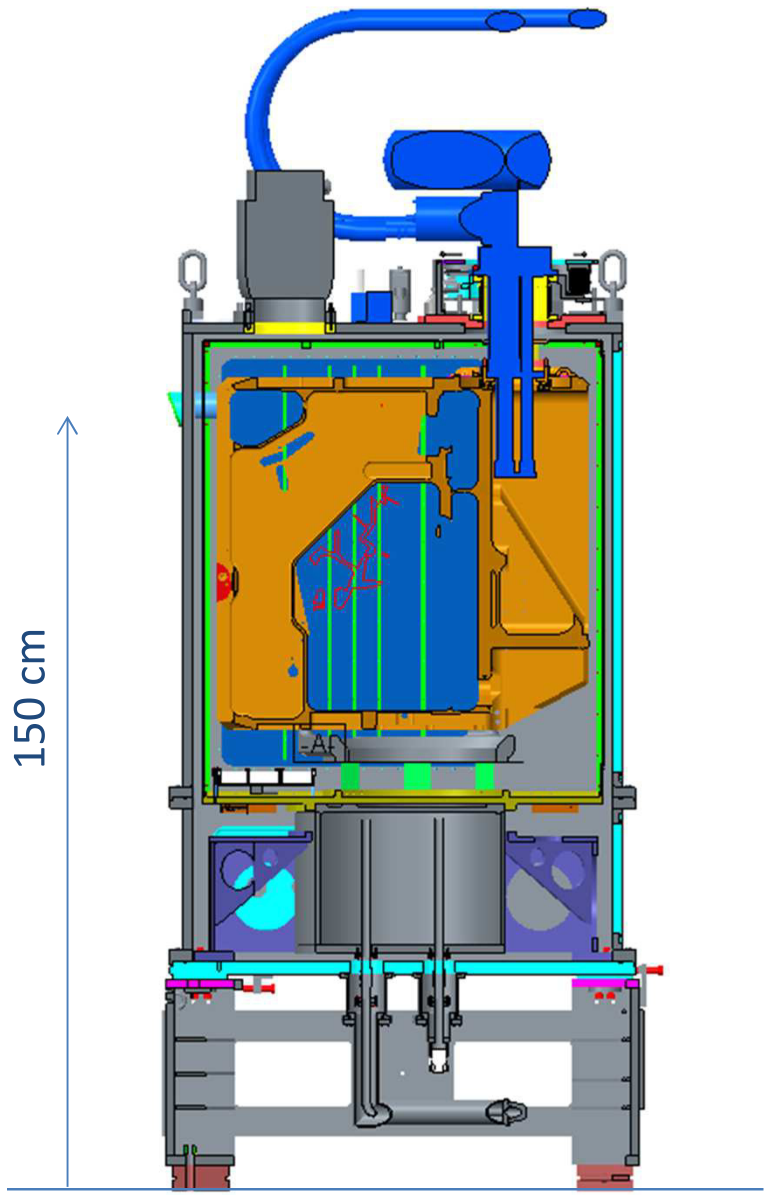
Power dissipation in VLTI-lab: VLTI-ICD -> heat load < 10 W, cooling load < -20 W
Surface temperatures of cryostats and He-lines:
VLTI-ICD -> ΔT < +0.5 / -1 ^{o} Celsius compared to ambient air temperature

Position adjustment ranges for cryostats (medium alignment step):
height: range: +- 3 mm, accuracy = 0.2 mm
x,y: range: +- 5 mm, accuracy = 0.25 mm

Accessibility of optics and detector ➞ opening the cryostat from two sides

The MATISSE cryostat

- *Pulse Tube cooler Cryomech PT410*
- *N2 cooled radiation shield*
- *Super insulation*



The MATISSE control-electronics

- … in 3 electronic racks
- Usage of PLCs for cryogenic control and housekeeping
- 70 motors: 58 in the warm (4 DC / 54 Stepper), 12 in the cold (Stepper)
- 8 Piezos, 8 cold shutter, 2 calibration lamps, 37 T-sensors, 17 heaters
- Electrical power:

	Cool-down	Normal Operation	Warm-up
UPS:	2.6 kW	3.3 kW	2.6 kW
Non-UPS:	22.2 kW	16.5 kW	7.6 kW

The 3 MATISSE electronics cabinets

MoU with ESO:

Article 10. MATISSE Guaranteed Observing Time

The amount of GTO UT and AT time rewarding the work of the MATISSE Consortium is :

37.5 4-UT nights and 173 nights of observing time at VISA (VLTI array of Auxiliary Telescopes) over a period of 8 years (refer to The Agreement N° 39662/ESO/11/31373).

Article 11. Use of the Guaranteed time

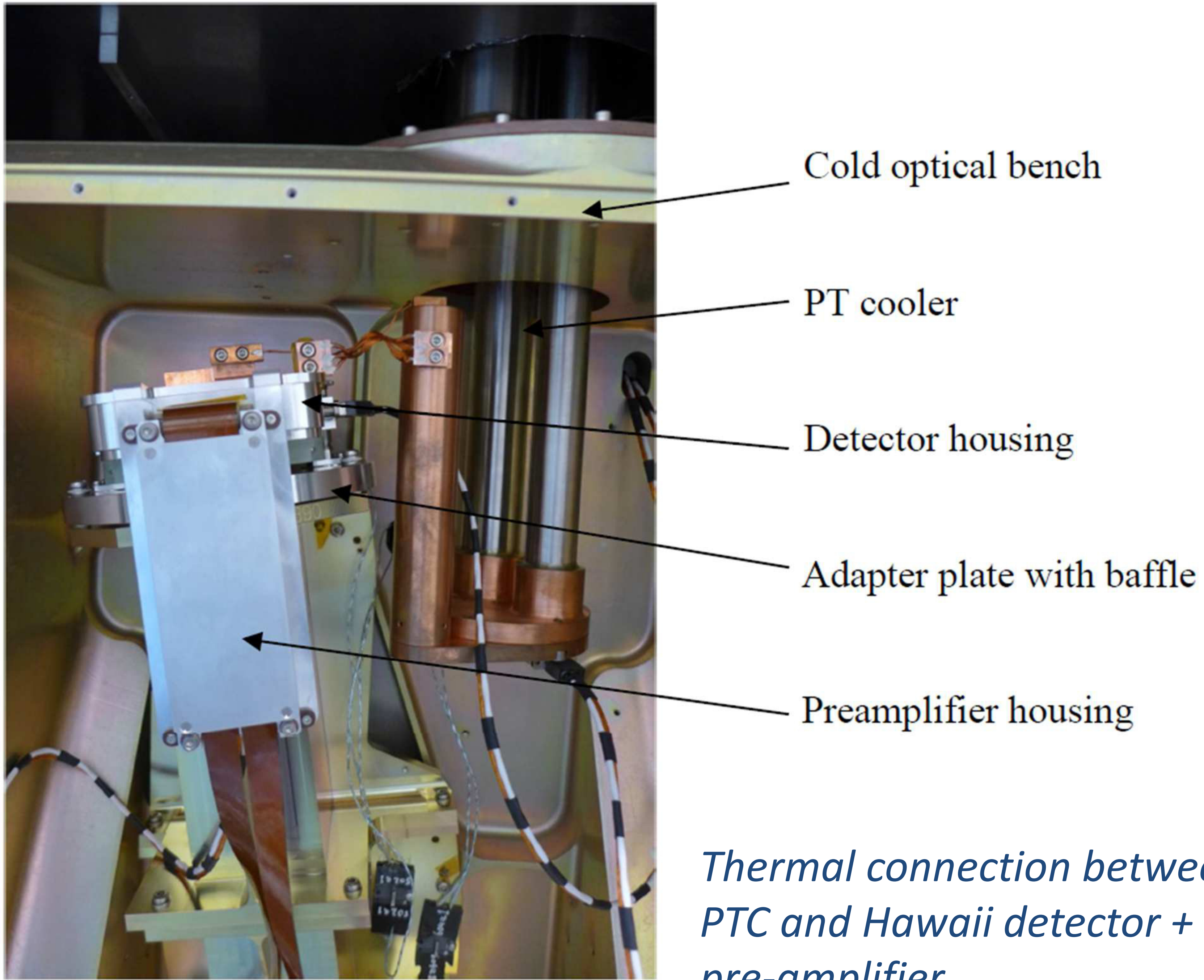
- The PI, co-PIs, and Science Group will define a joint science program to be executed in the Guaranteed Observing Time.
- The Guaranteed Observing Time will be distributed to the contributing institutes proportionally to their share defined in Article 9.

…. and now some pictures of MATISSE at the Experimantierhalle and at OCA/Nice

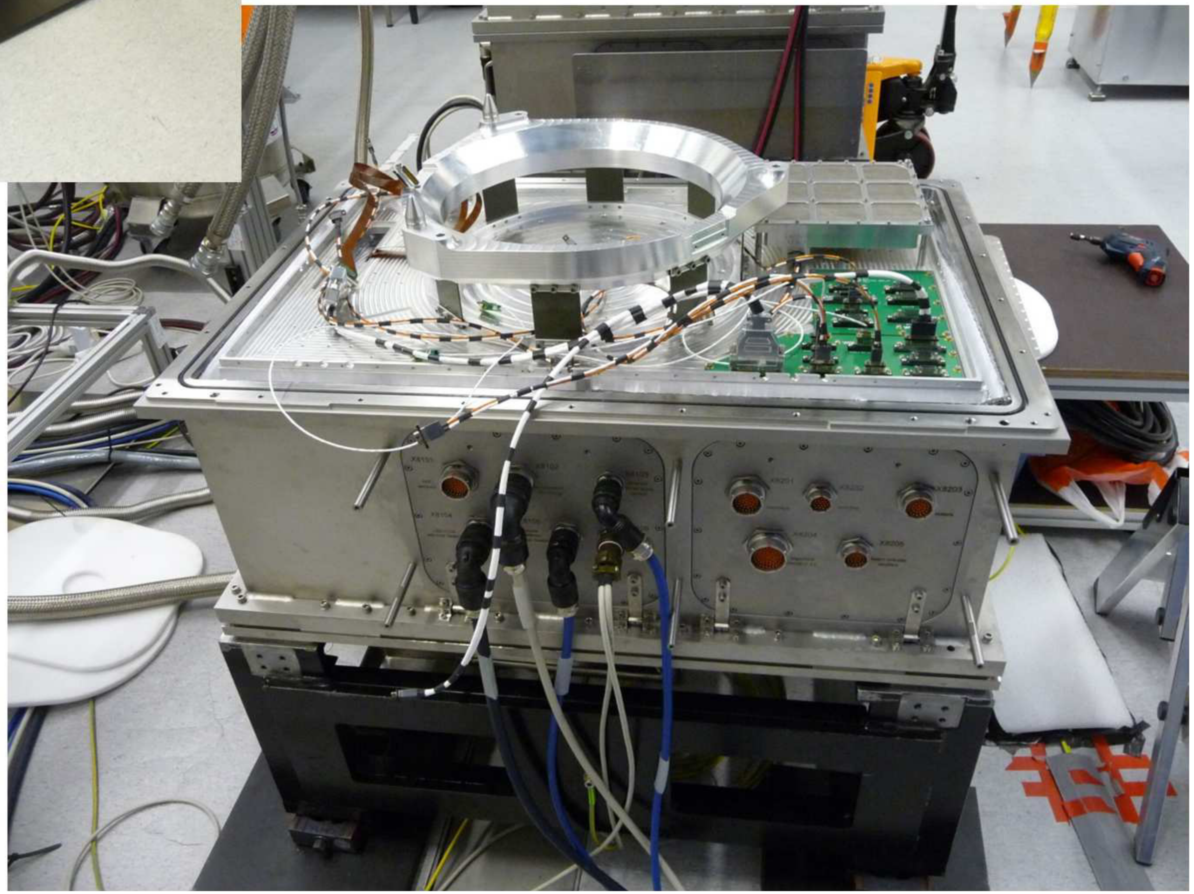

ATORN


MATISSE

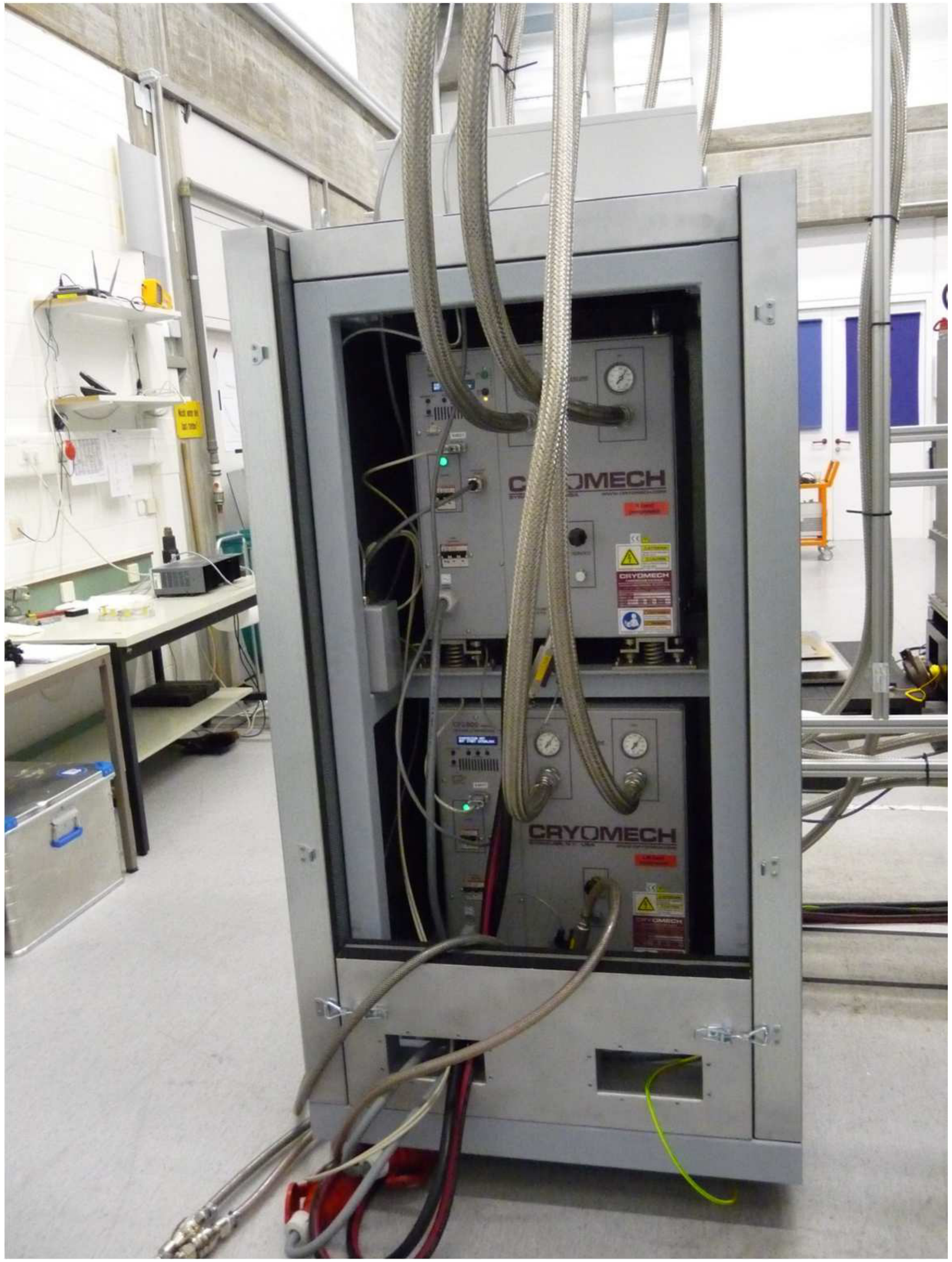

Gefahr durch Kran!



Thermal connection between PTC and Hawaii detector + pre-amplifier

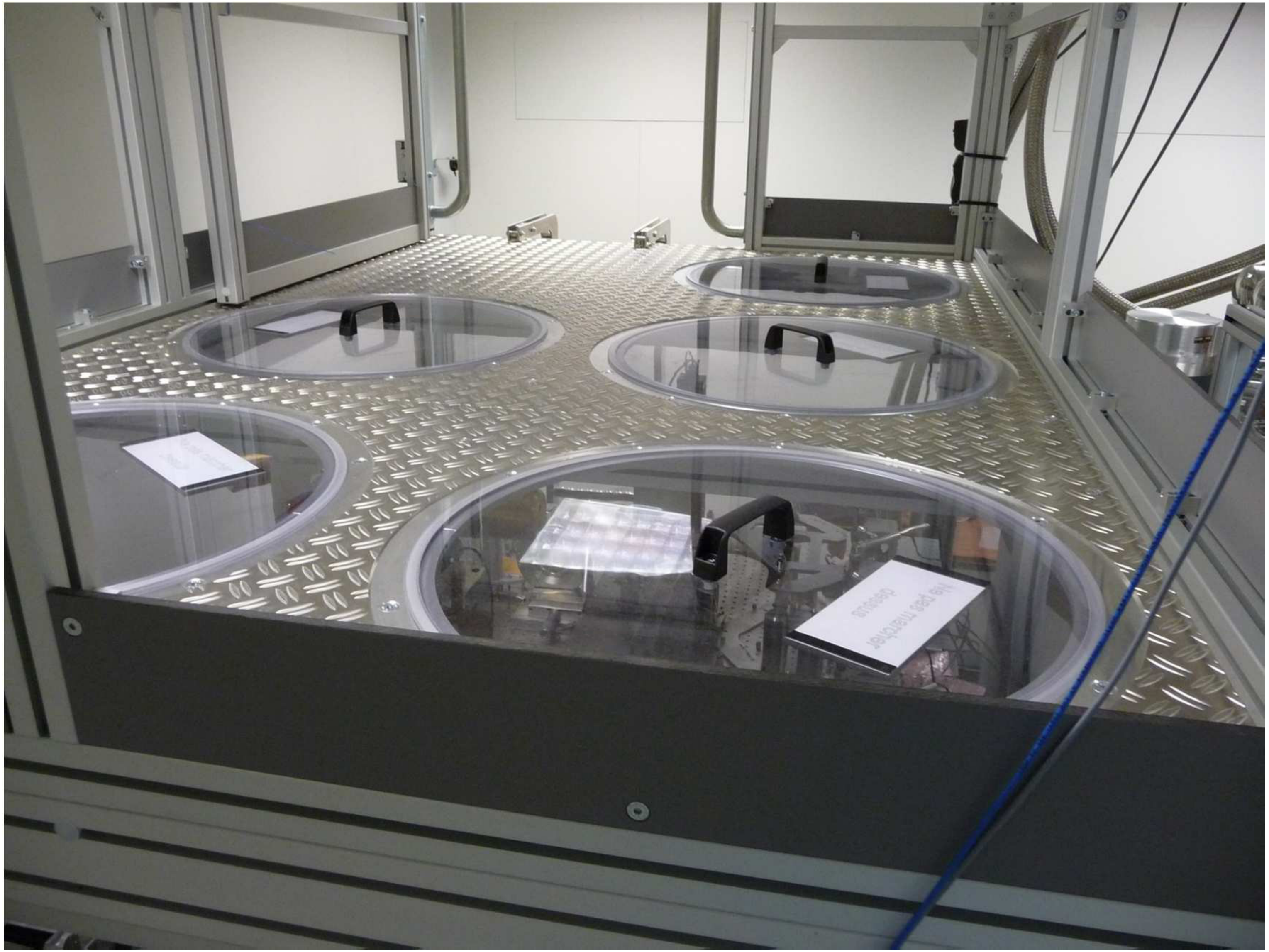



X8010
LM-band

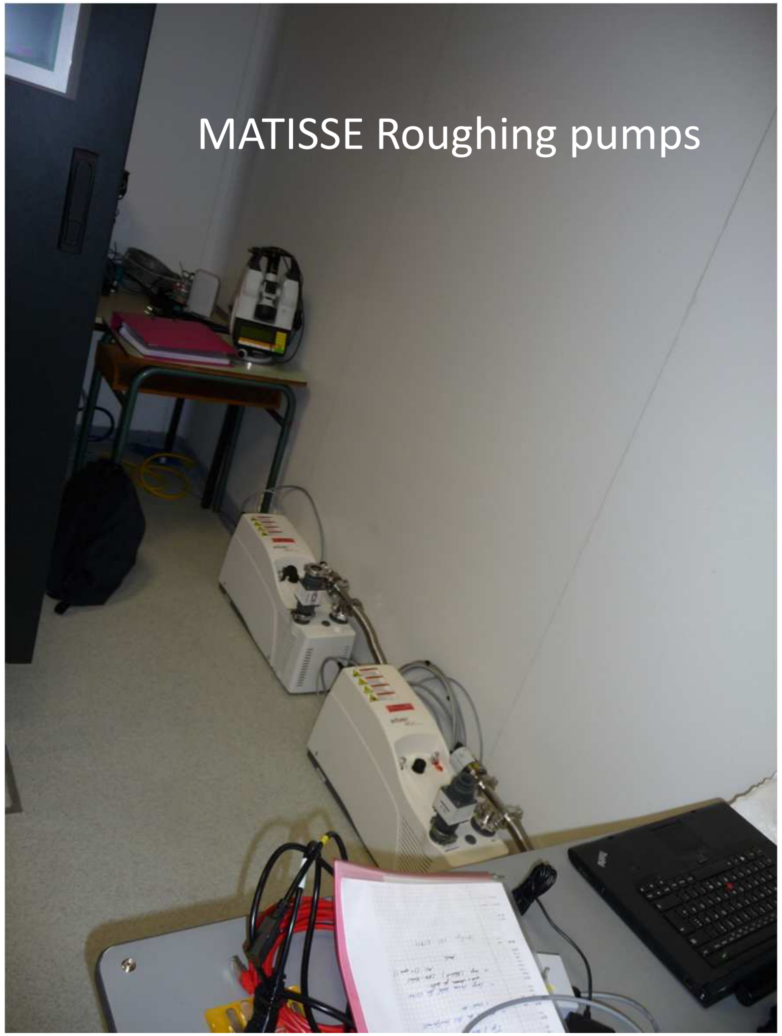

CRYOMECH
CRYOMECH

The current status at Nice …..


XRP
FRAGILE




Compressor rack
with coolant panel


MATISSE Roughing pumps

This is (not) the end ....