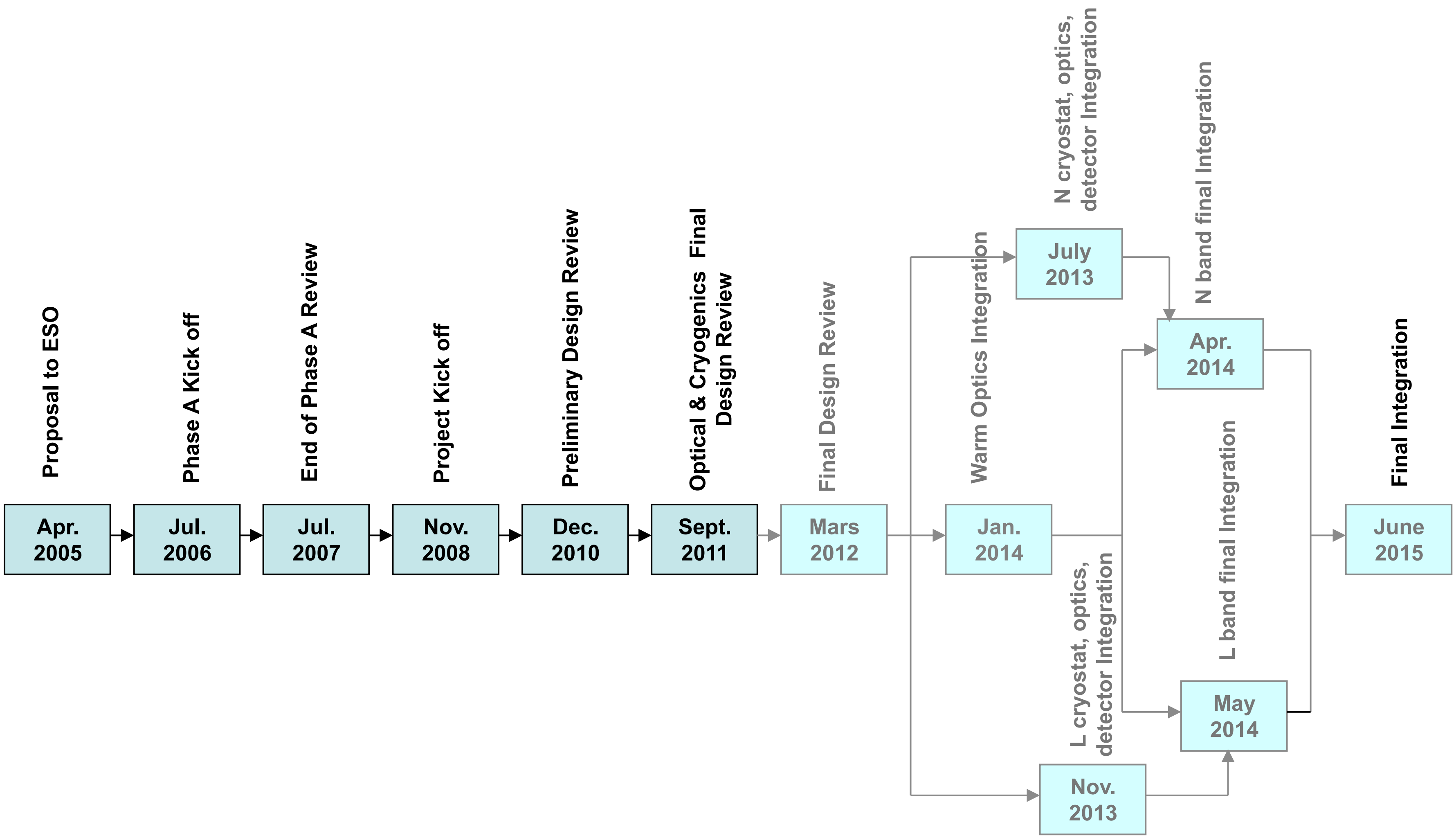
MATISSE

Multi-AperTure Mid-Infrared SpectroScopic Experiment

Bruno Lopez et al.

10 Years of VLTI, ESO Garching 24-27 Oct 2011

Progress



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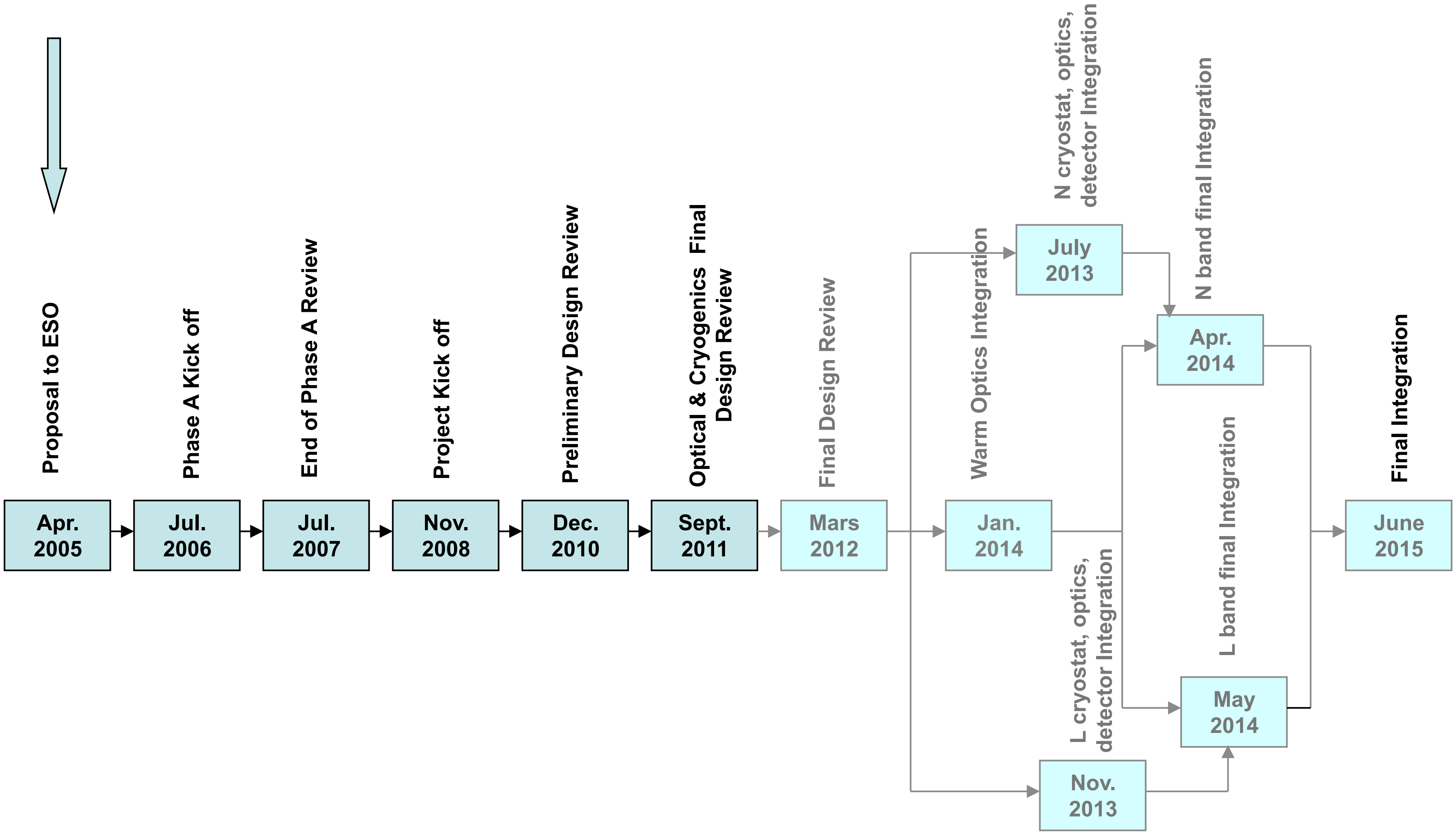

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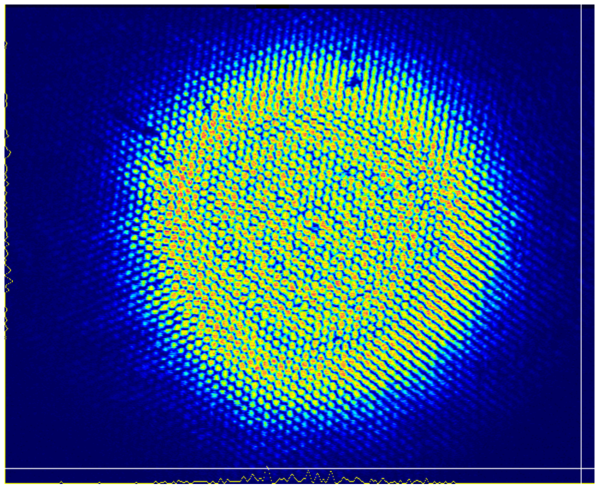
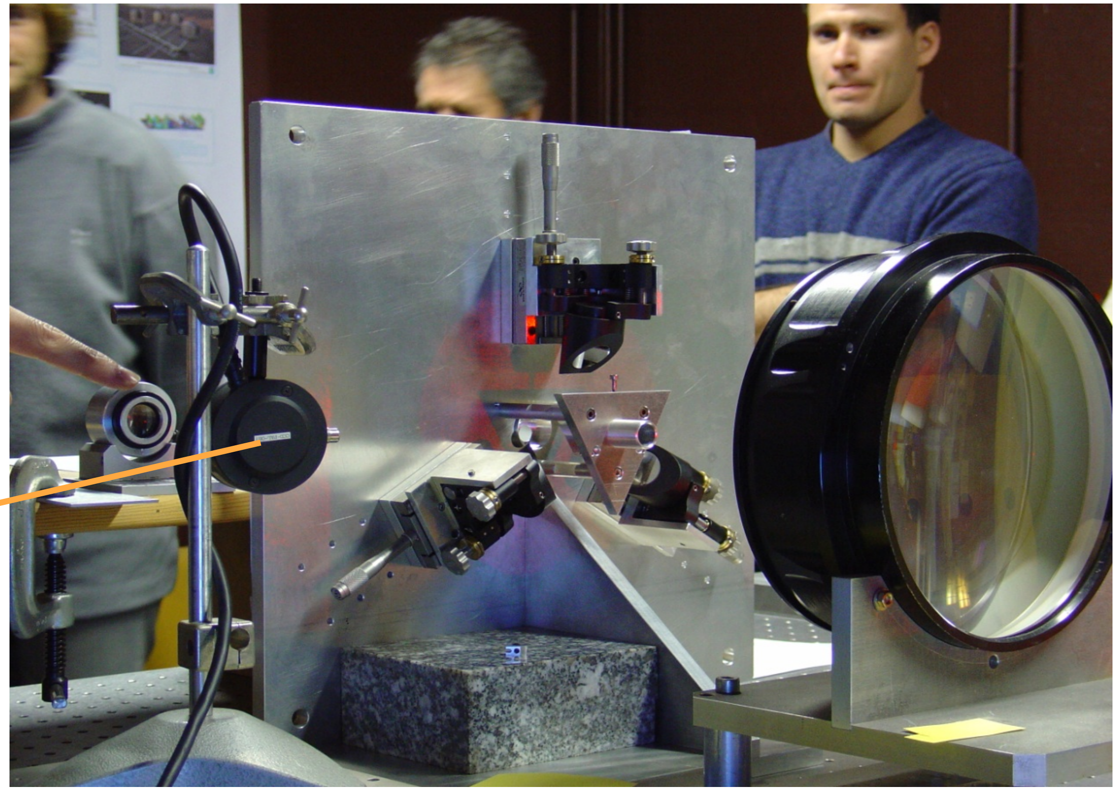
AfterTwelve/APreS-MIDI model experiment, testing a possible optical interface with the current 2 beam MIDI instrument





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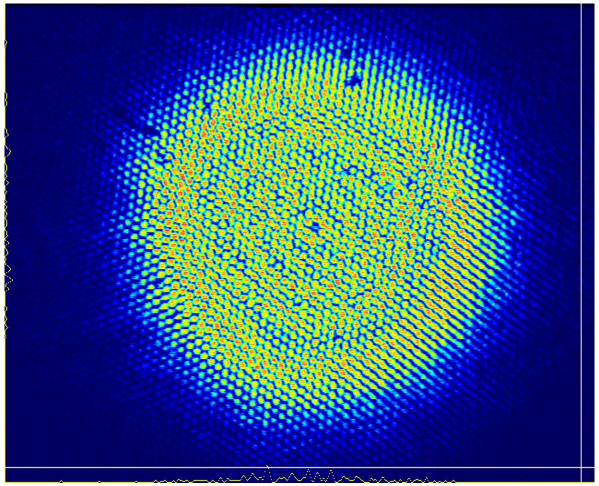
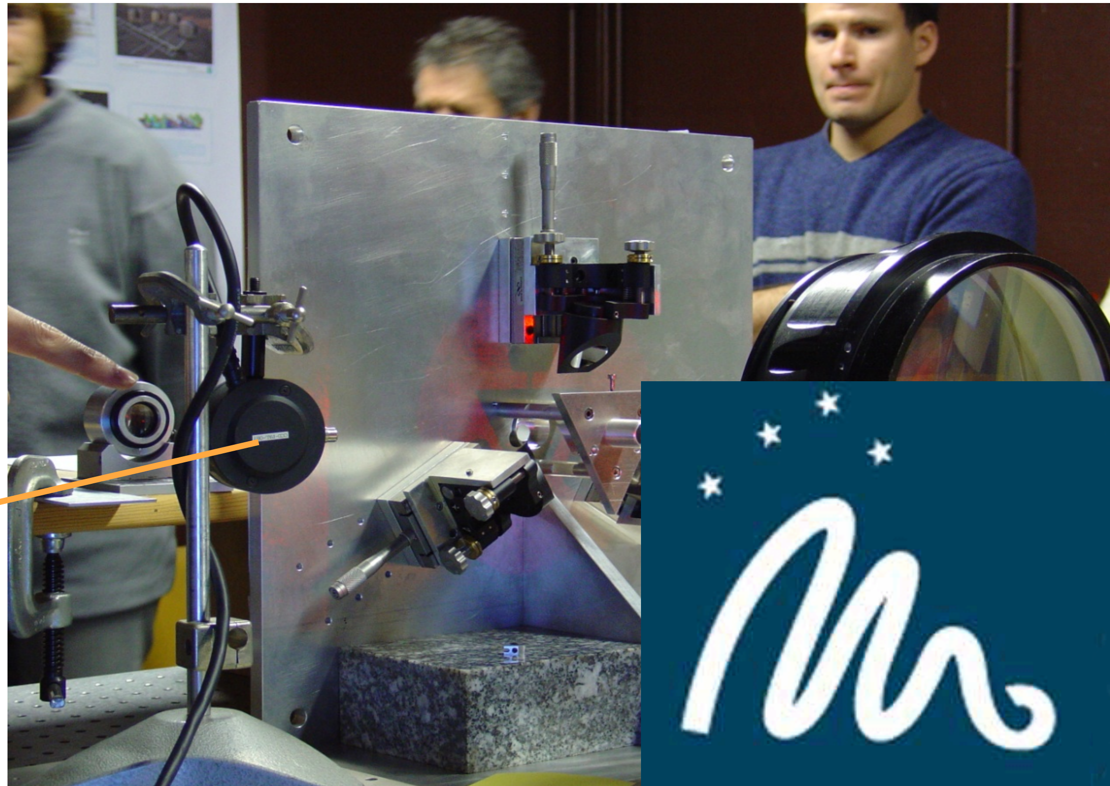
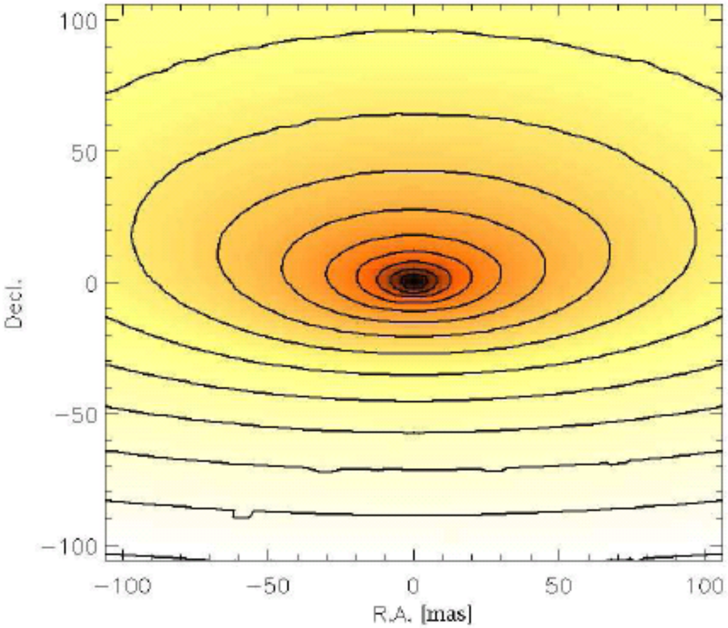


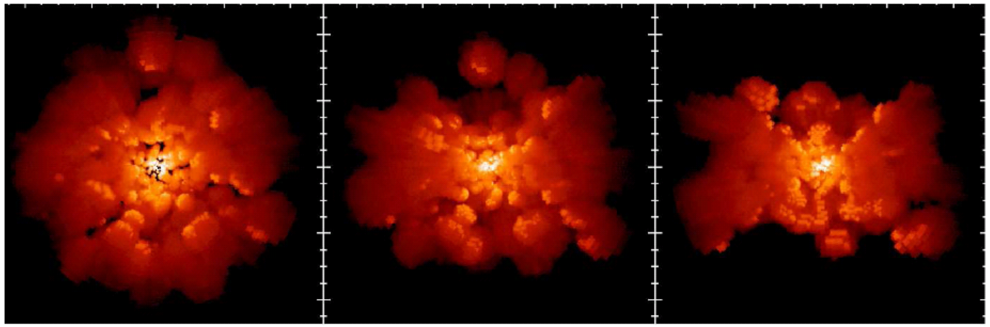


MATISSE

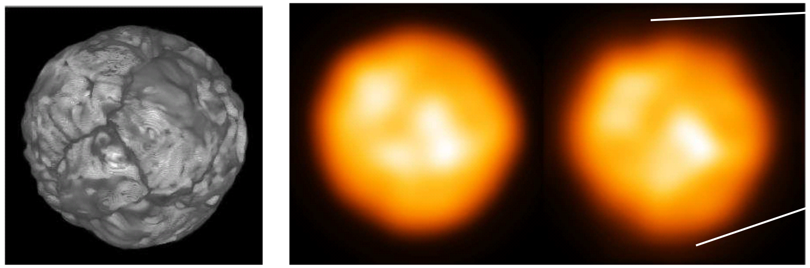
Towards the Imaging in the mid-IR domain



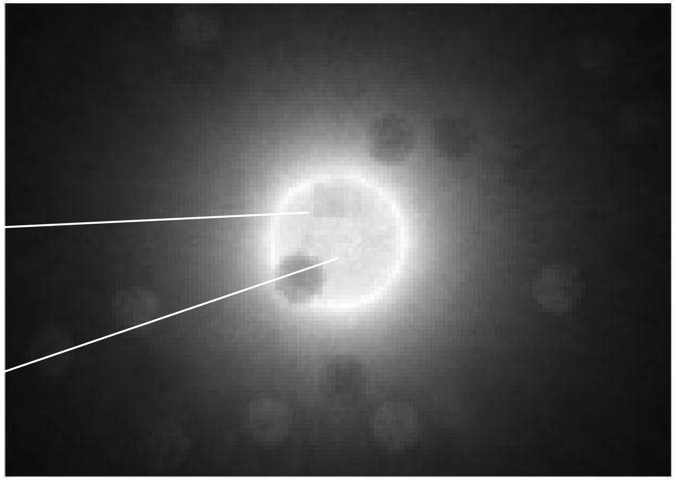
Young star flared disk



Clumpy dust torus of AGN at different inclinations

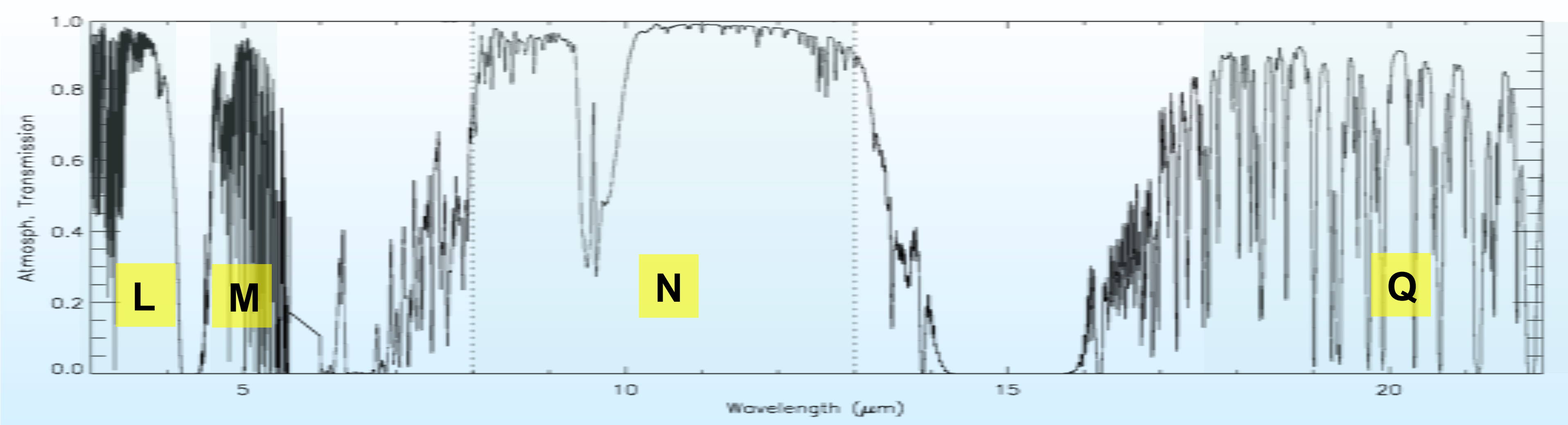


Red giant atmosphere



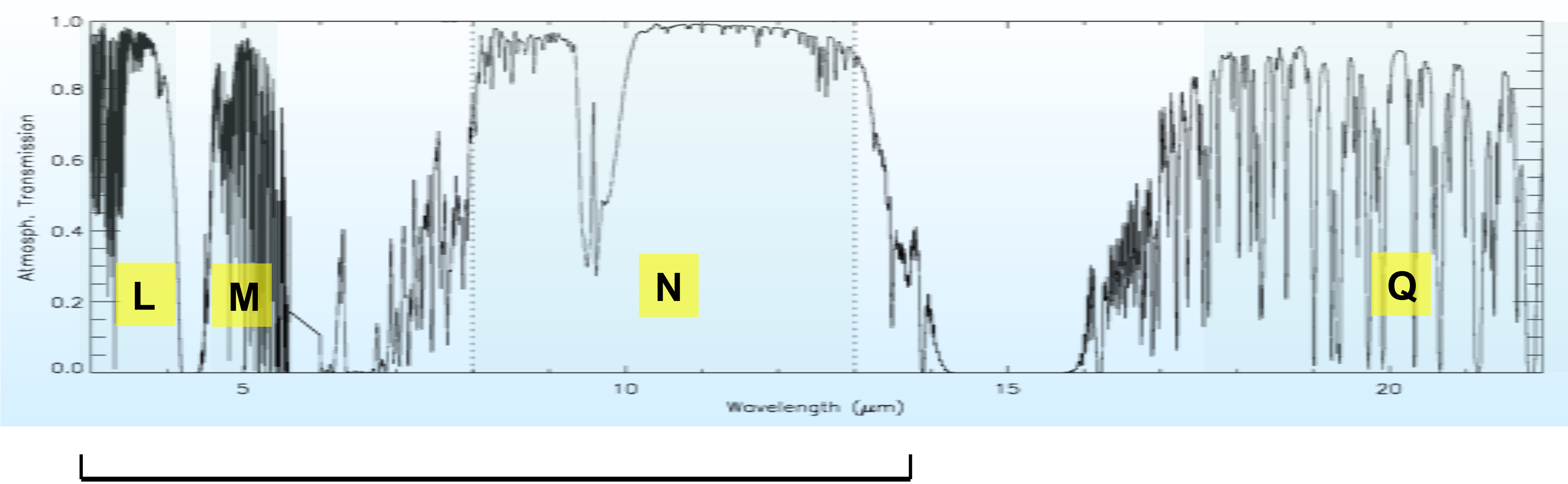
Red giant envelope with bright rim and dust clumps

Towards the Opening of New Spectral Windows



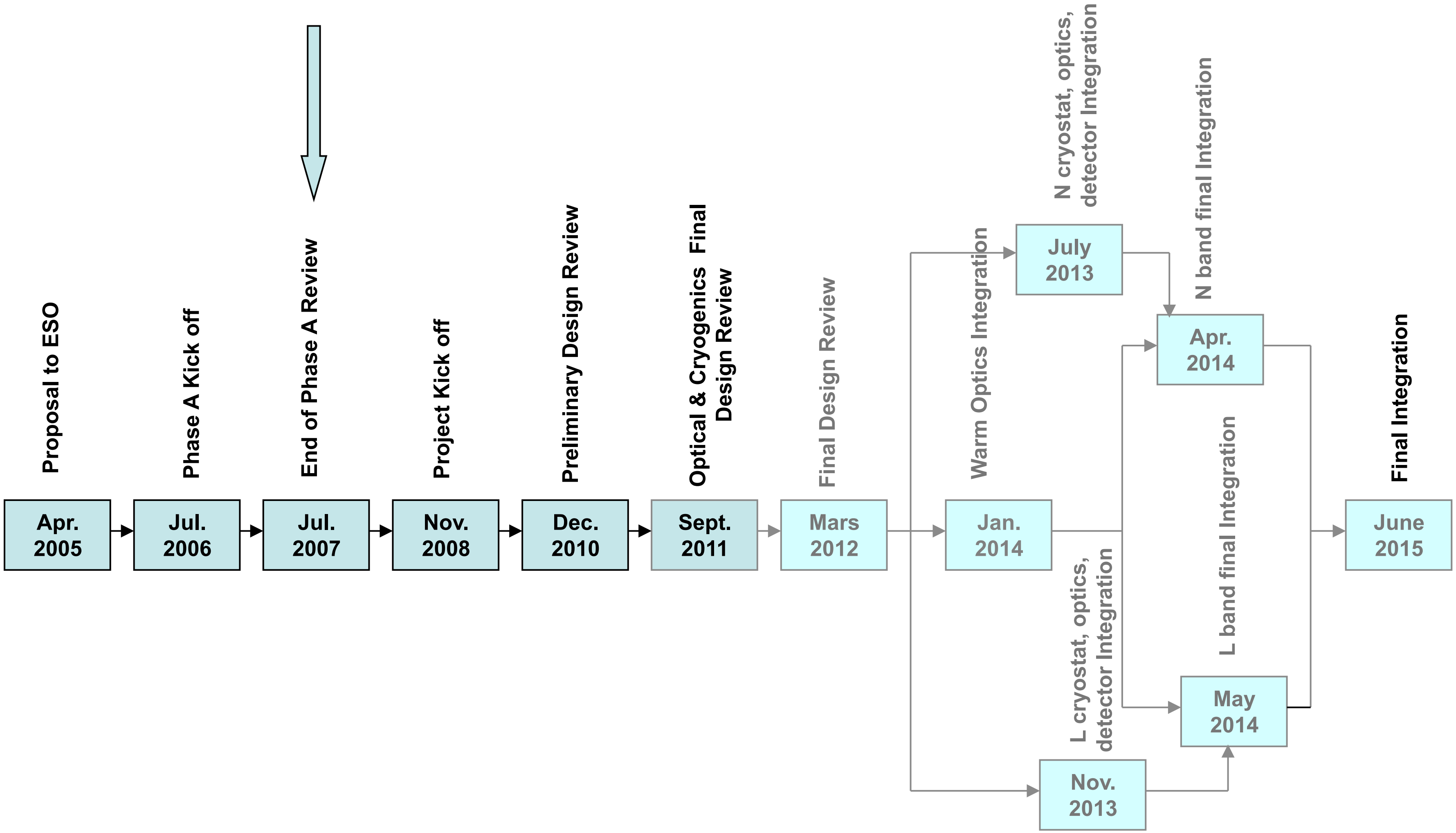
Present MIDI Instrument

Towards the Opening of New Spectral Windows



MATISSE Instrument

Progress



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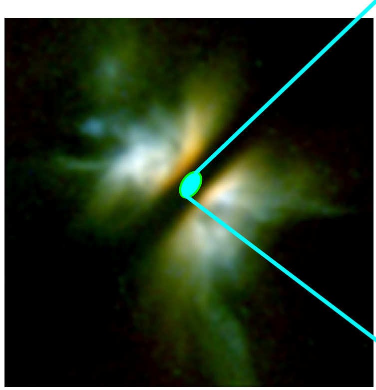
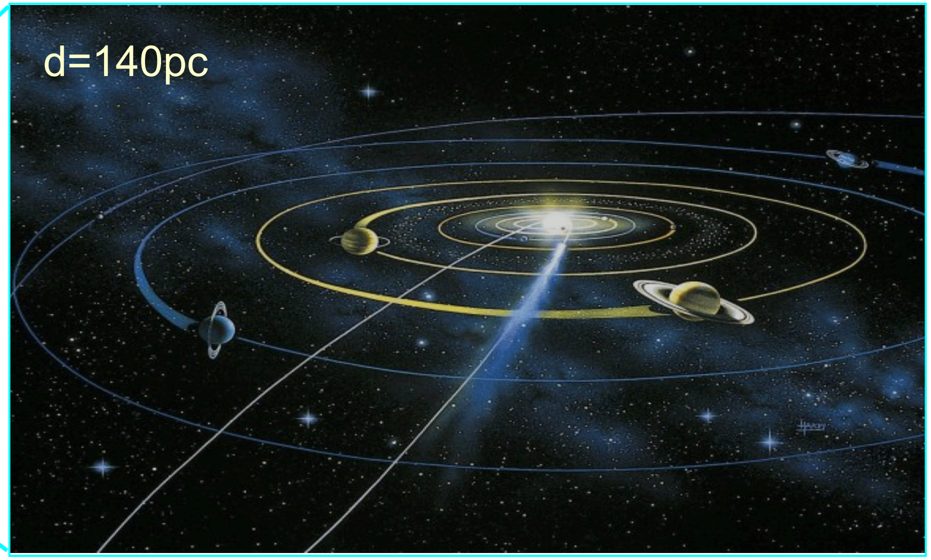
Formation and evolution of the planetary systems

Objectives : to better understand the inner regions of dust disks and the conditions under which the planets form and evolve.

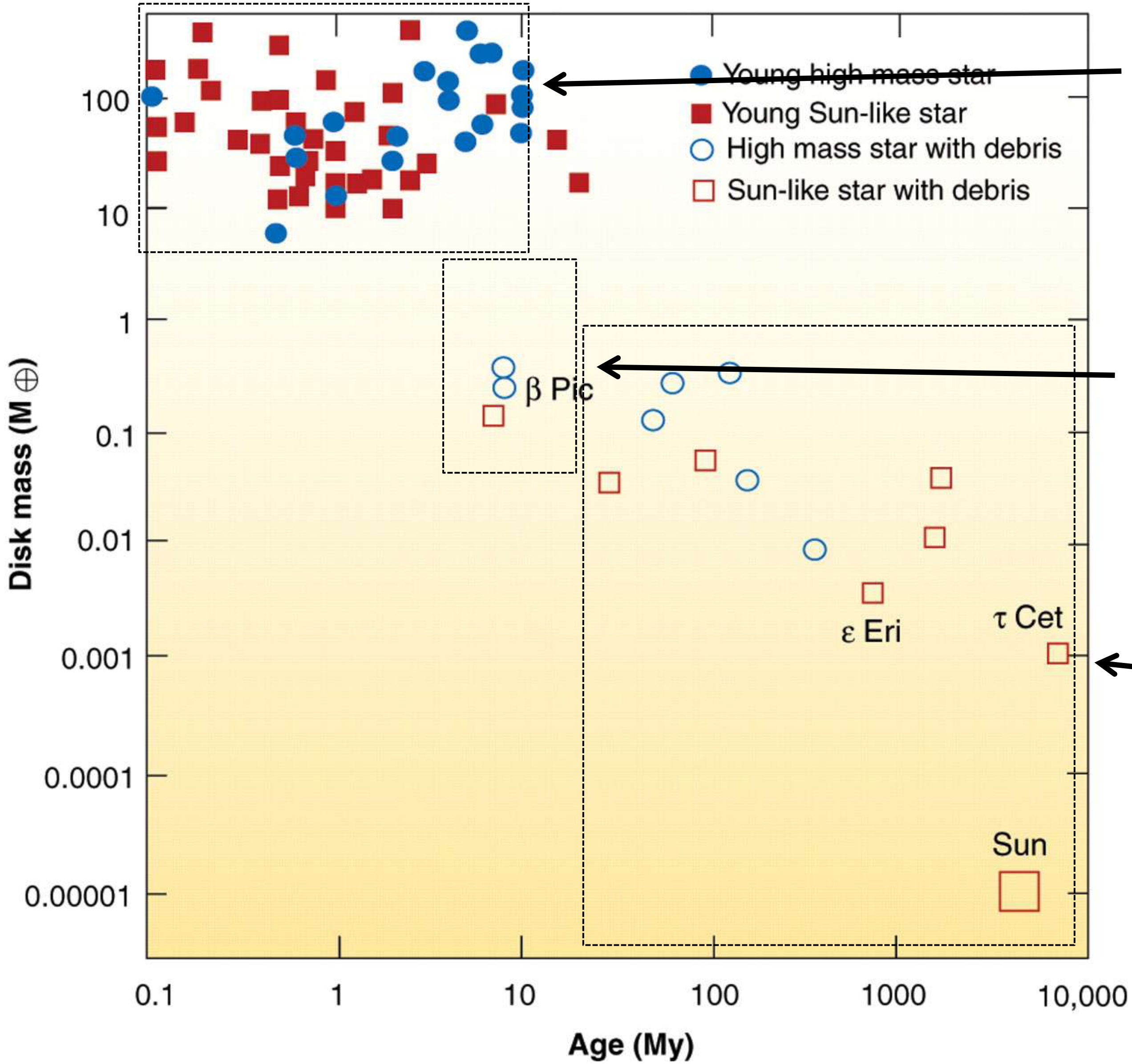


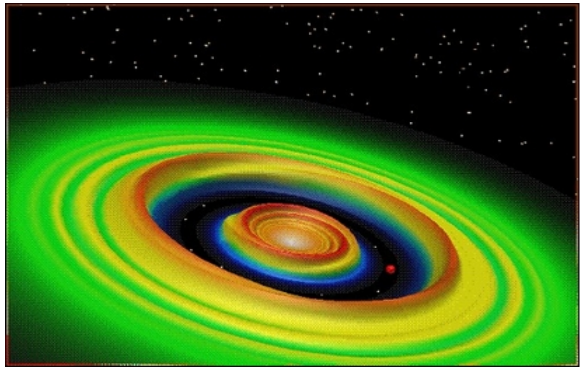
Planet forming region

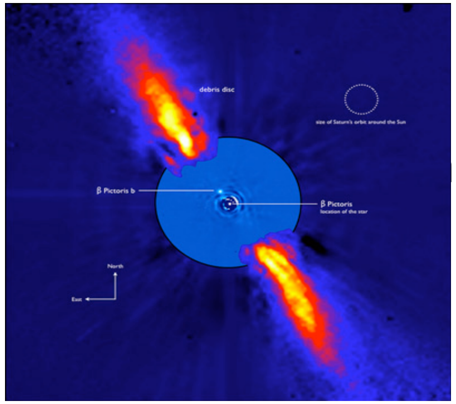


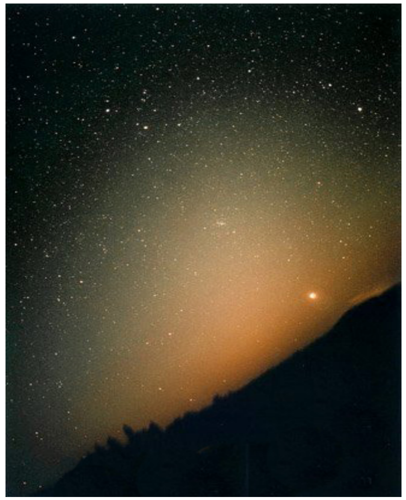
Earth	**-**	**7 mas**
Jupiter	**-**	**36 mas**
Neptune	**-**	**215 mas**

Protoplanetary disk evolution : Mass versus Age









T Tauri sources, Herbig Sources and the required sensitivity

Instrument	T Tauri stars	Herbig stars	Debris disks	Massive YSOs
AMBER	0	13	2	1
MIDI	6	10	1	3
Keck-I	14	6	0	0

Low set of observed T Tauri sources versus Herbig type sources (From MATISSE Science Analysis Report, Issue 1).

T Tauri sources, Herbig Sources and the required sensitivity

Instrument	T Tauri stars	Herbig stars	Debris disks	Massive YSOs
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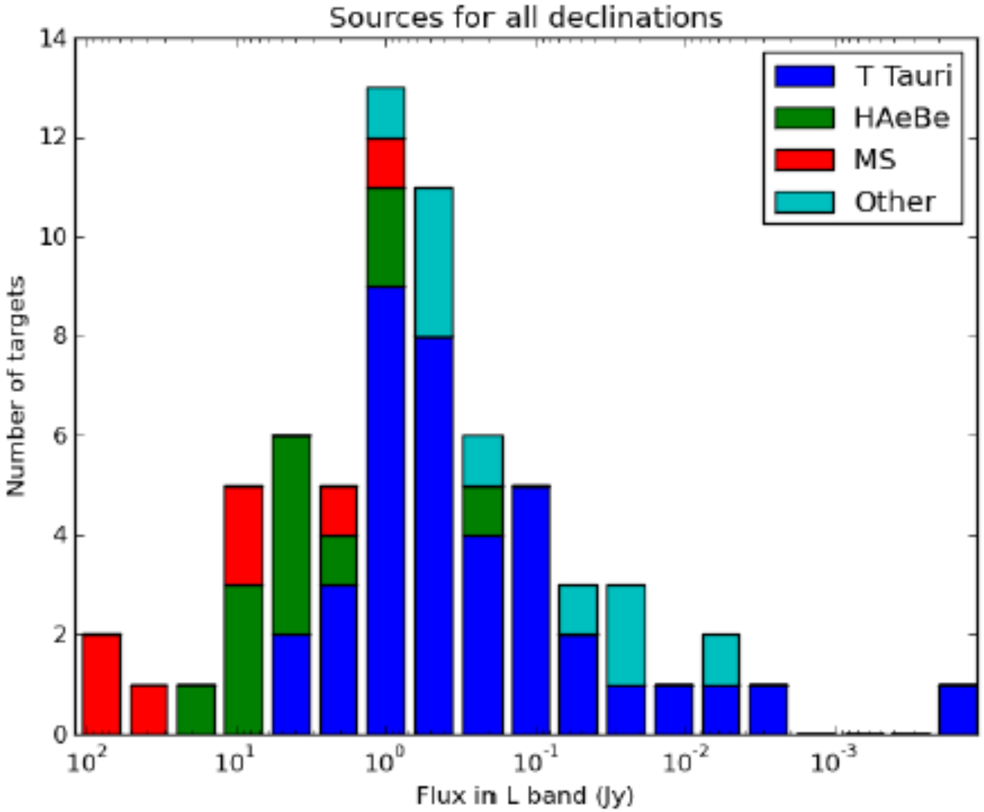
			1	3
			0	0

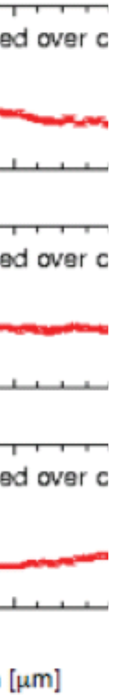


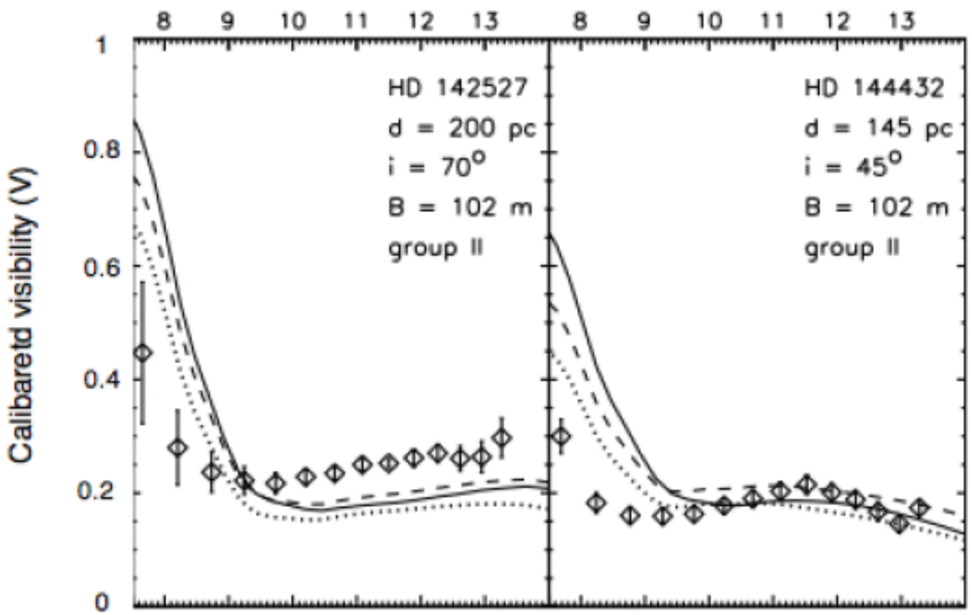
From MATISSE Science Analysis Report, Issue 1.

How to test / analyse the disk evolution ?

How to study protoplanetary disk composition ?

How to search for disk / forming planets (embryos, gaps, waves) ?





From Leinert et al. 2004

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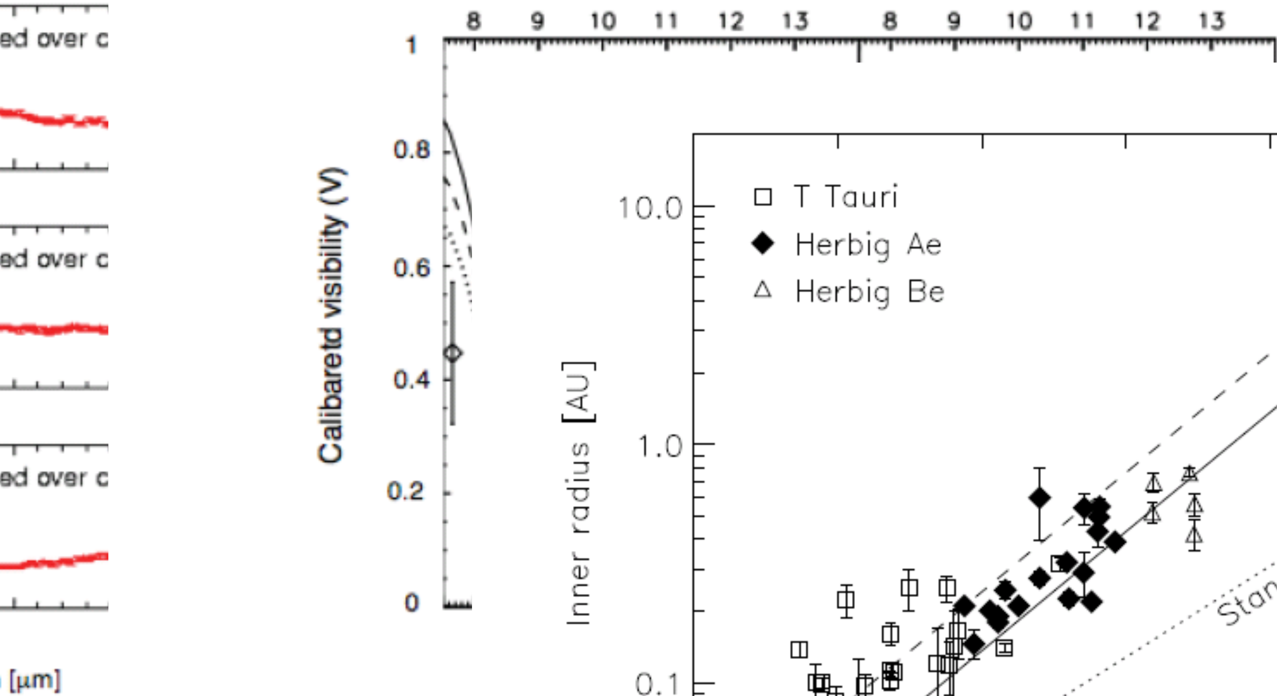

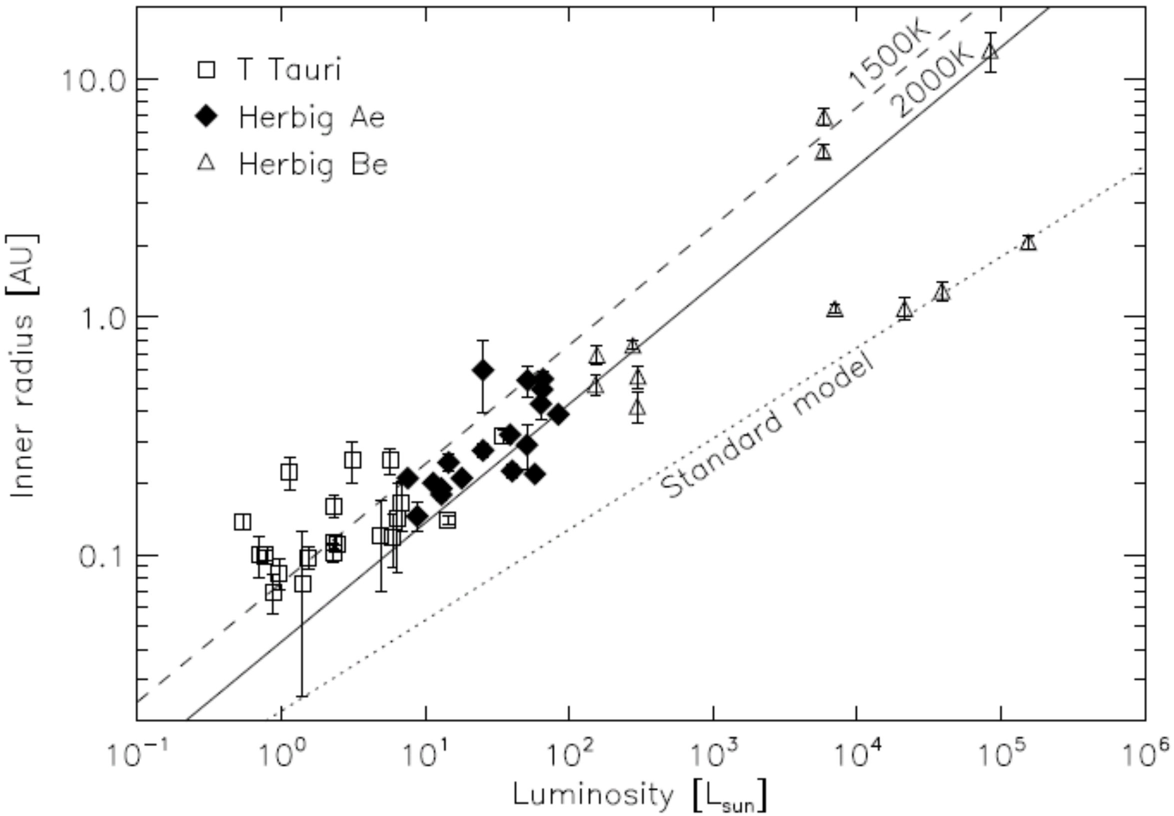

From Dullemond and Monnier 2010

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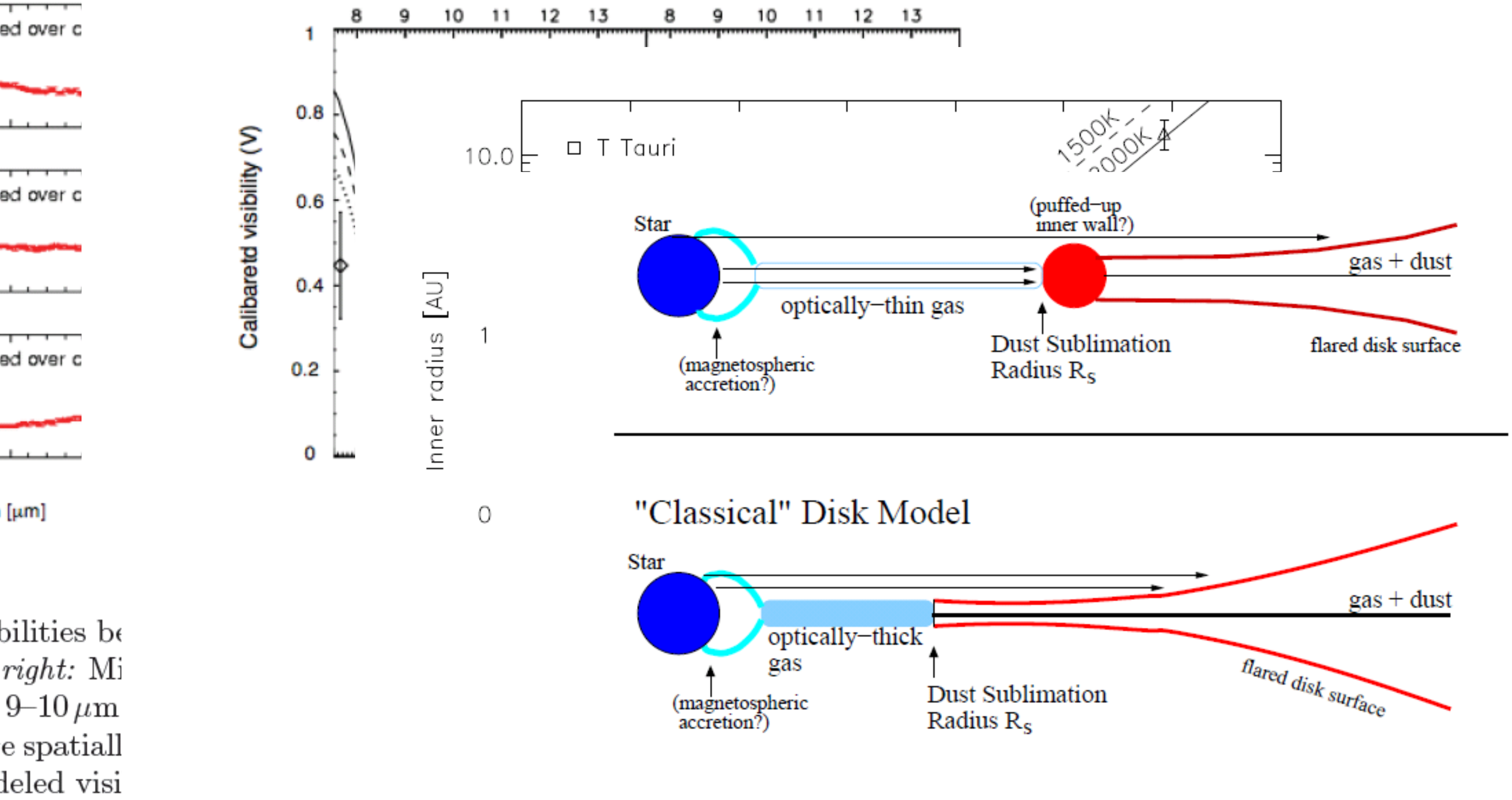

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How to test / analyse the disk evolution ?

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Highlights: L& M band ~ 2.9 – 5.0 mm

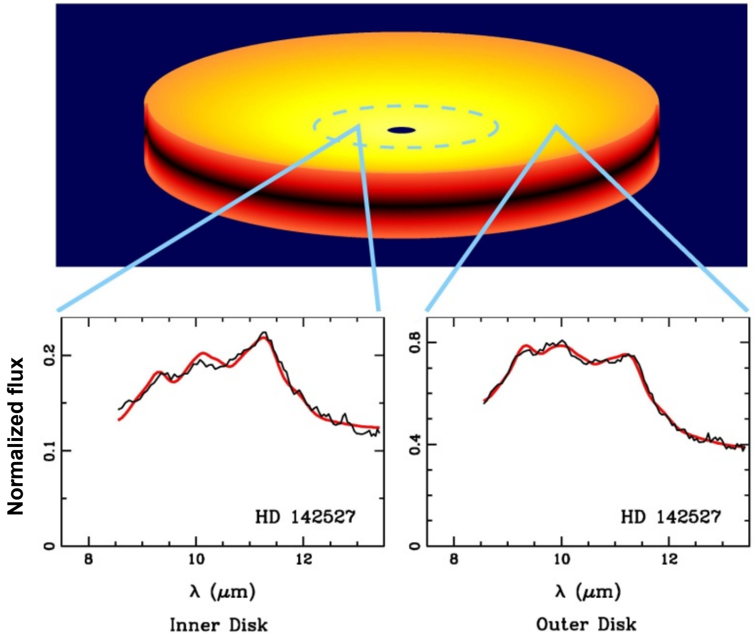
- New dust species: e.g., H_2O ice broad band feature (2.8 – 4.0 μm)
- Polycyclic Aromatic Hydrocarbons (PAHs): 3.3 μm, 3.4 μm;
- Nano-diamonds: 3.52 μm
- Transition from dust scattering to dust thermal reemission as the source of spatially extended emission
- CO fundamental transition series (4.6 –4.78 μm)
- CO ice features 4.6 – 4.7 μm
- Recombination lines, e.g., Pfβ at 4.65 μm

N Band ~ 7.5 – 13.5 μm

- Spectral features to be investigated with MATISSE will be very similar to those studied with MIDI : Silicates, Olivine, Forsterite, SiC.

Example of dust mineralogy effects

van Boekel et al. 2004, Nature, 432, 479



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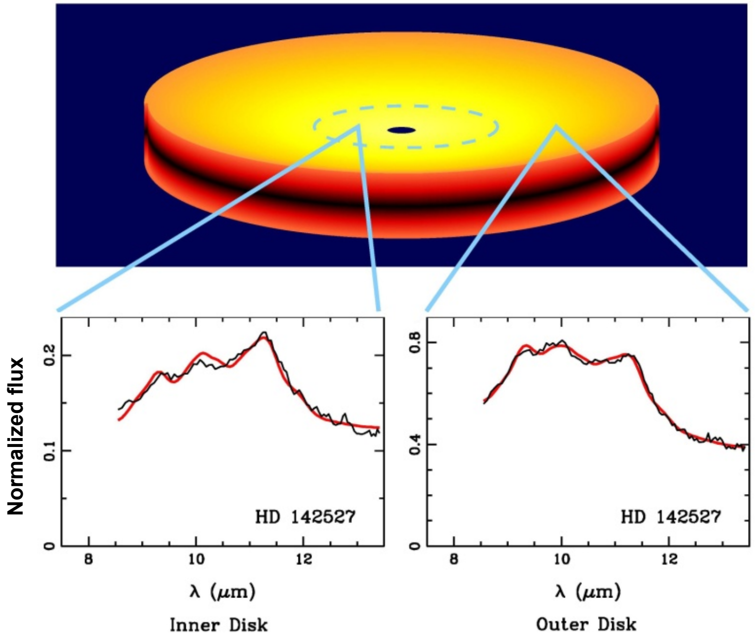
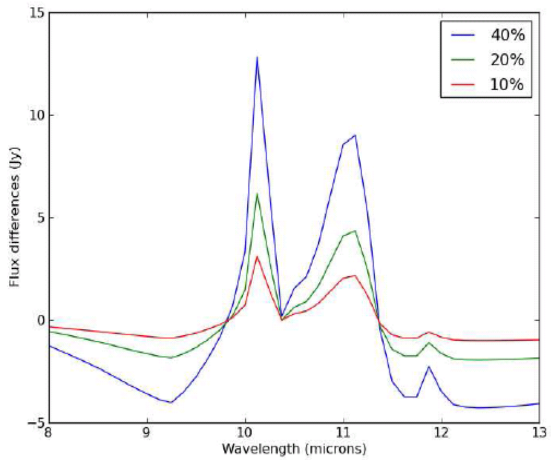


Different scenarii :

- Disk inclination (Δi = 10°)
- Inner rim (Δr_{in} = 1 UA)
- Size of dust grains (Δa_{grain} = 1 μm)
- Dust composition : silicate + **crystalline material**



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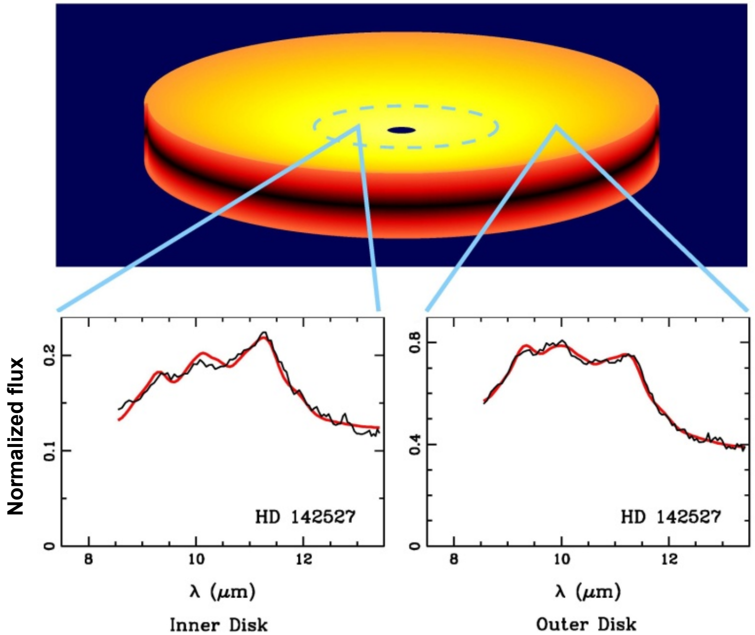

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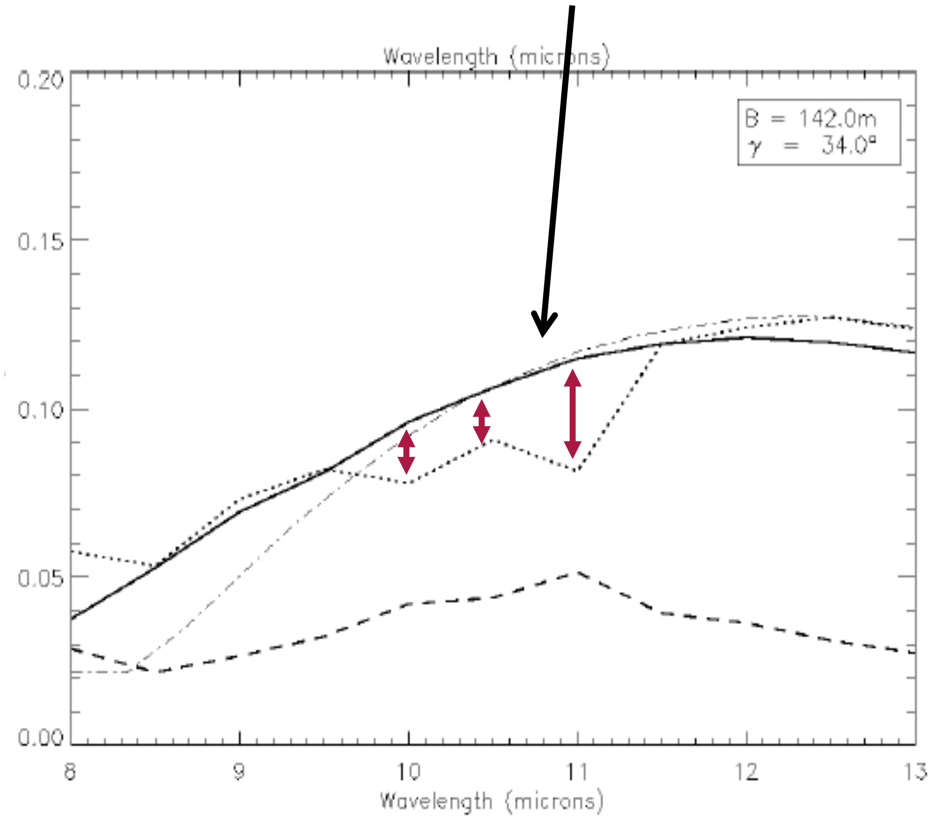

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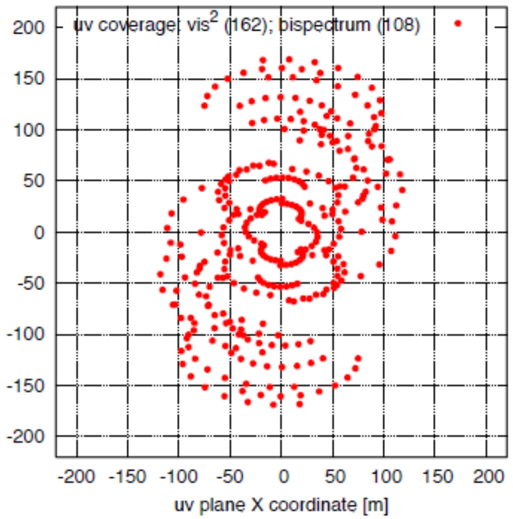
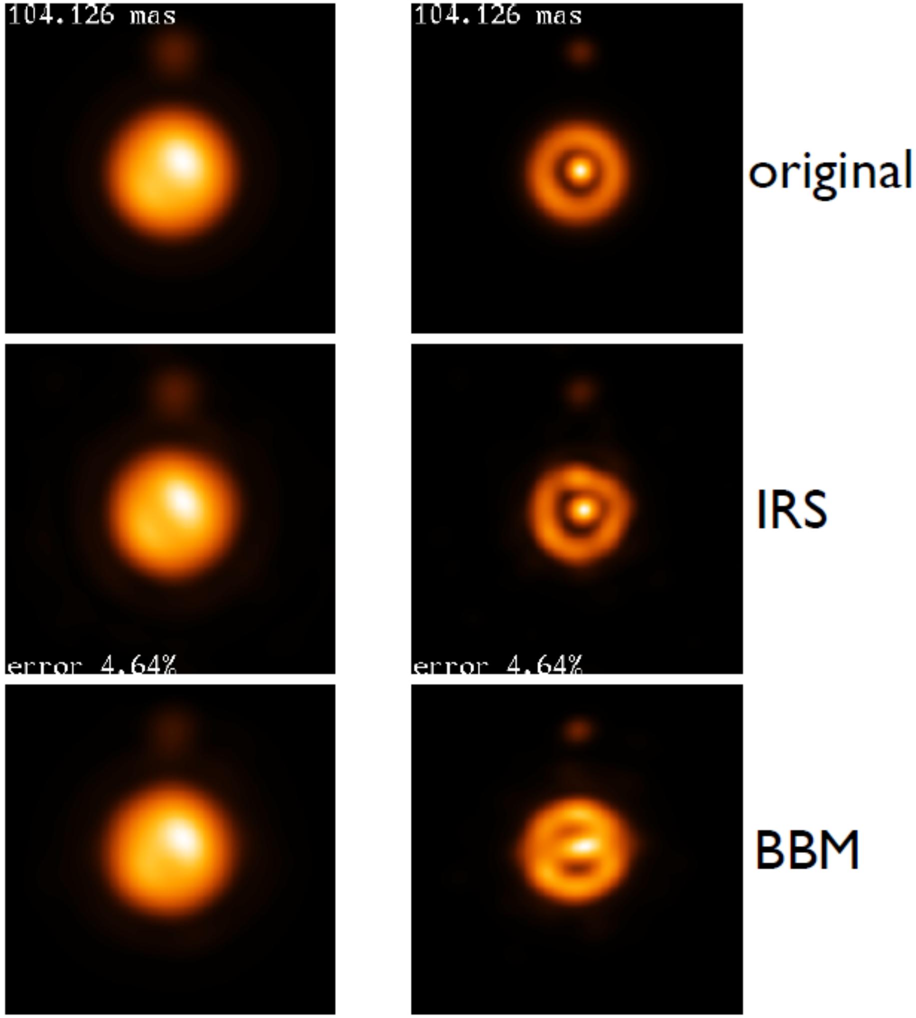
YSO plus planet
(see PDR report)

SNR of squared visibilities = 20

3x4ATs





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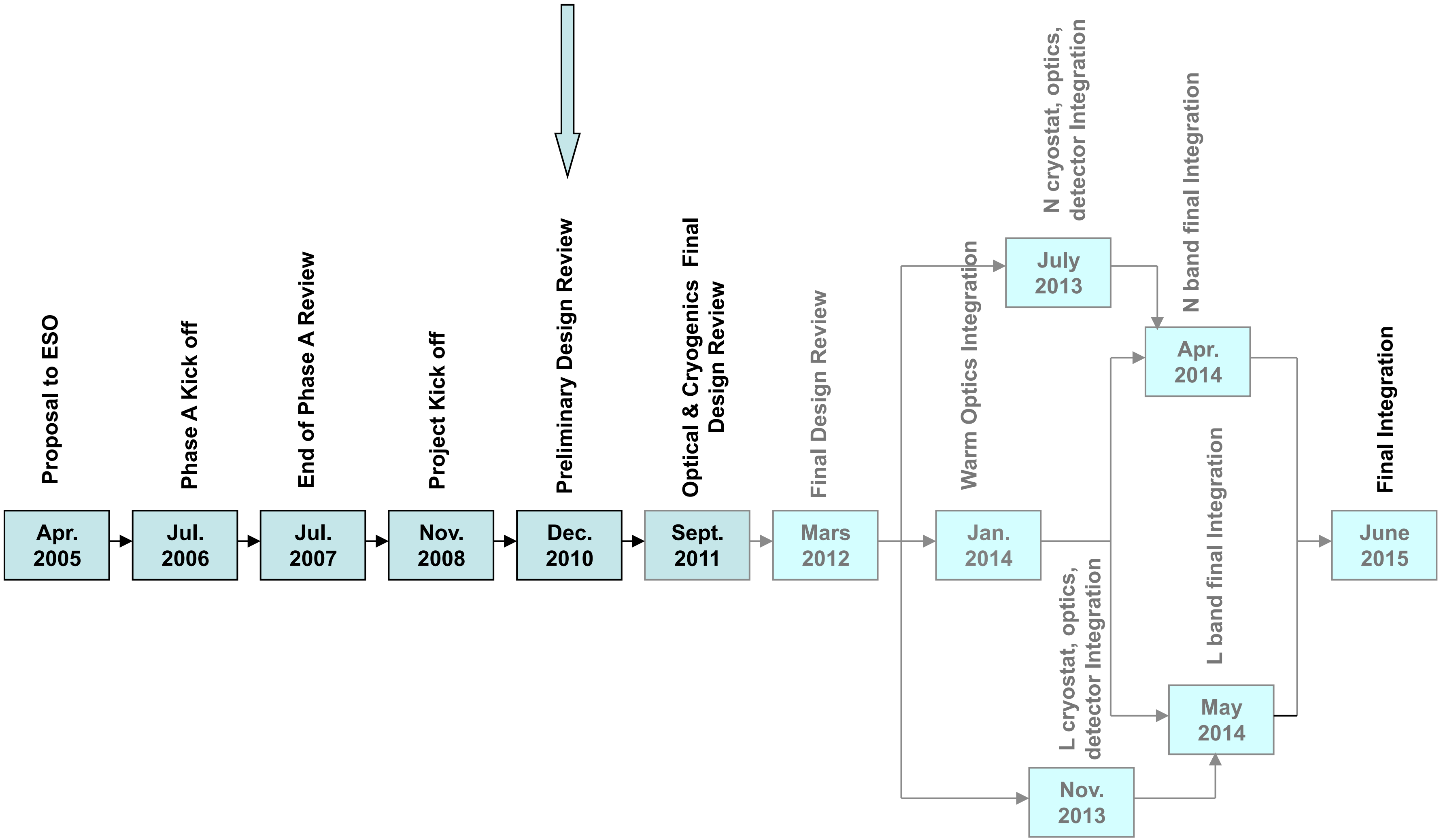

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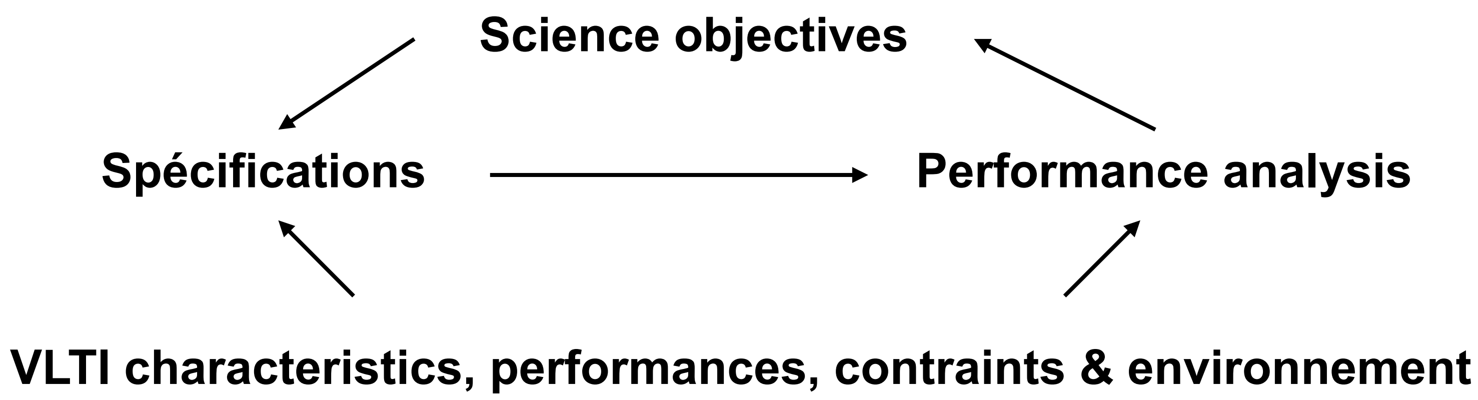
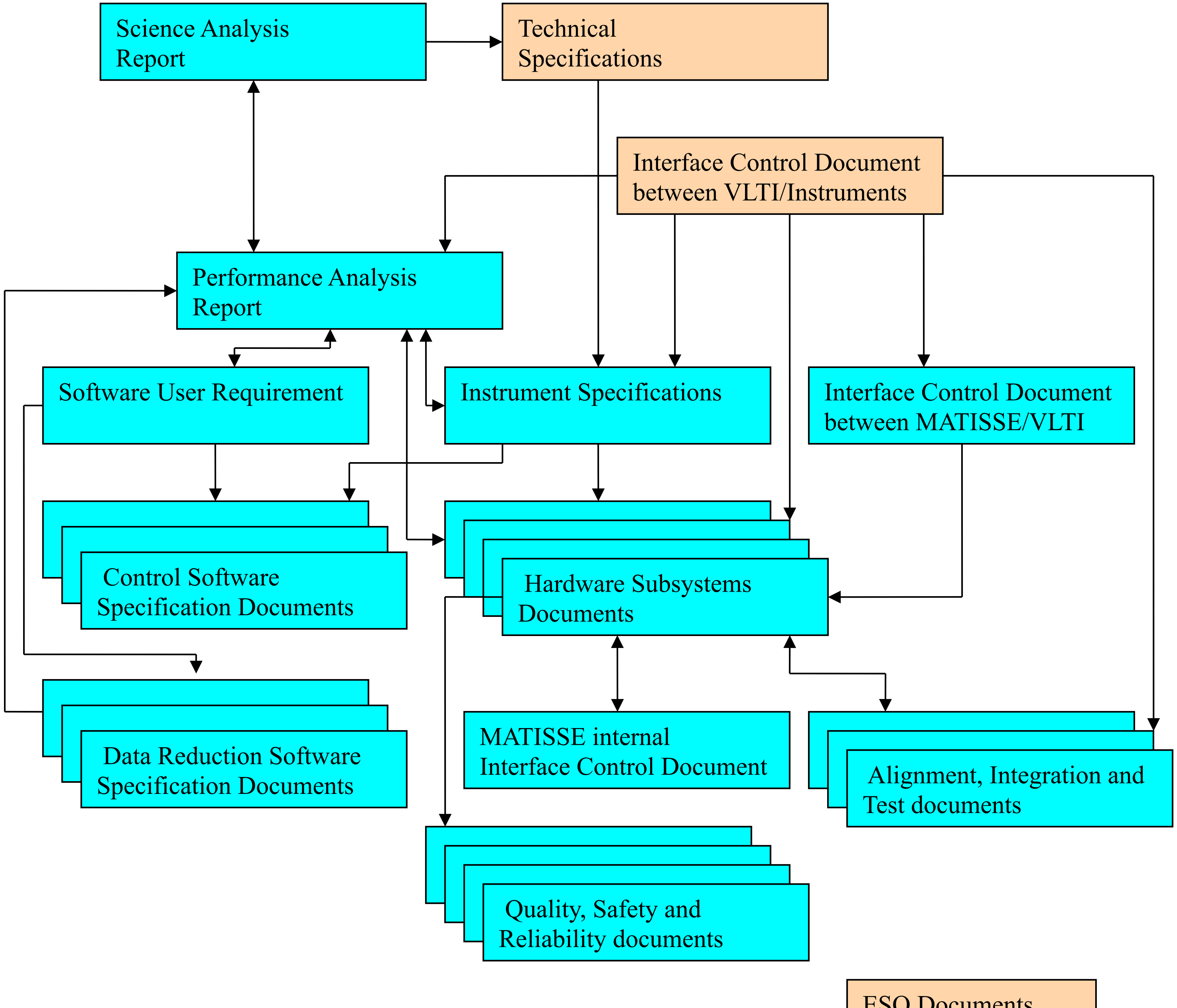
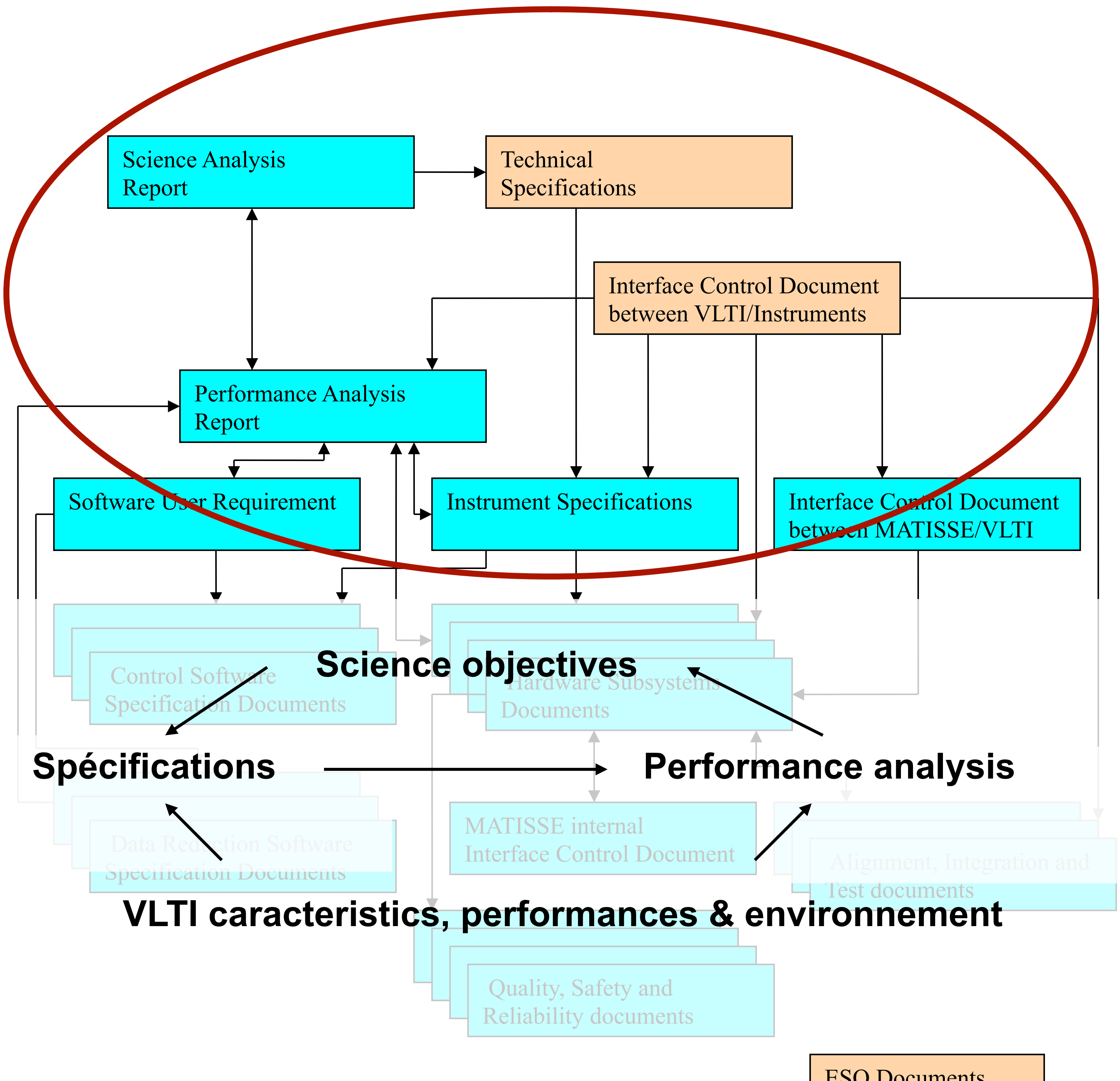
Requirements

Performances answering the science objectives



PDR documents



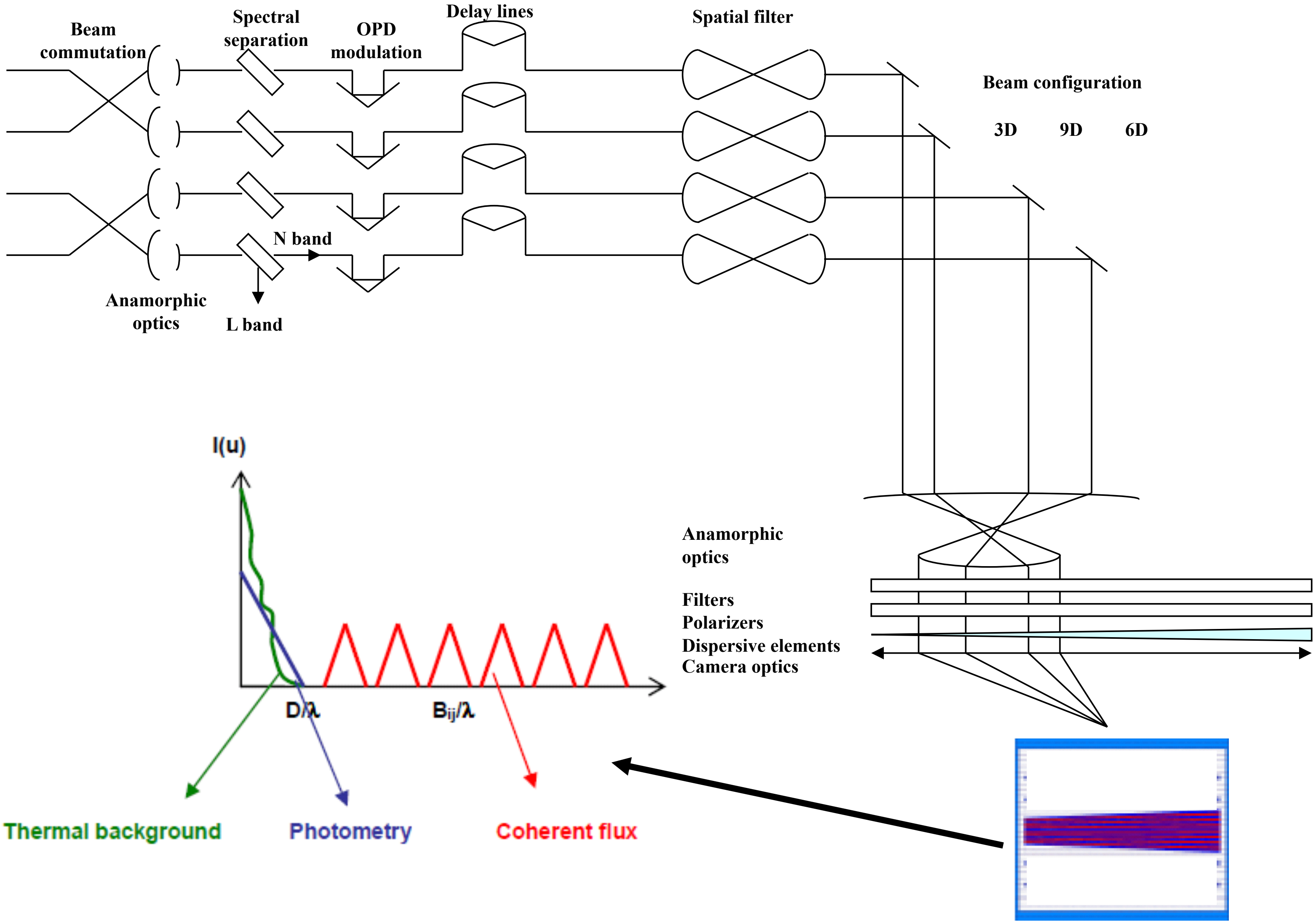


Science Analysis Report
Technical Specifications
Interface Control Document between VLTI/Instruments
Performance Analysis Report
Software User Requirement
Instrument Specifications
Interface Control Document between MATISSE/VLTI
Control Software Specification Documents
Science objectives
Hardware Subsystems Documents
Spécifications
Performance analysis
Data Reduction Software Specification Documents
MATISSE internal Interface Control Document
Alignment, Integration and Test documents
VLTI caracteristics, performances & environnement
Quality, Safety and Reliability documents
ESO Documents

Instrumental concept study

- ✓ Best concept in term of performance (SNR on coherent flux)
  - Co-axial or multi-axial / Pairwise or global combination
  - Taking into account the instrument feasibility
- ✓ Strategy to reduce the effect of the thermal background
  - Use of OPD modulation, spatial filtering, photometric channel, chopping
- ✓ Strategy to optimize the calibrated visibility accuracy
  - Spatial filtering without fiber
  - Contrast stability vs flux loss taking into account VLTI AO performances
- ✓ Strategy to optimize the phase accuracy
  - Beam commutation
- ✓ Study of the parasitic light effects
  - Effect of parasitic fringes (“Fizeau”, “Perot-Fabry”, “Young”) on instrumental performance

MATISSE concept



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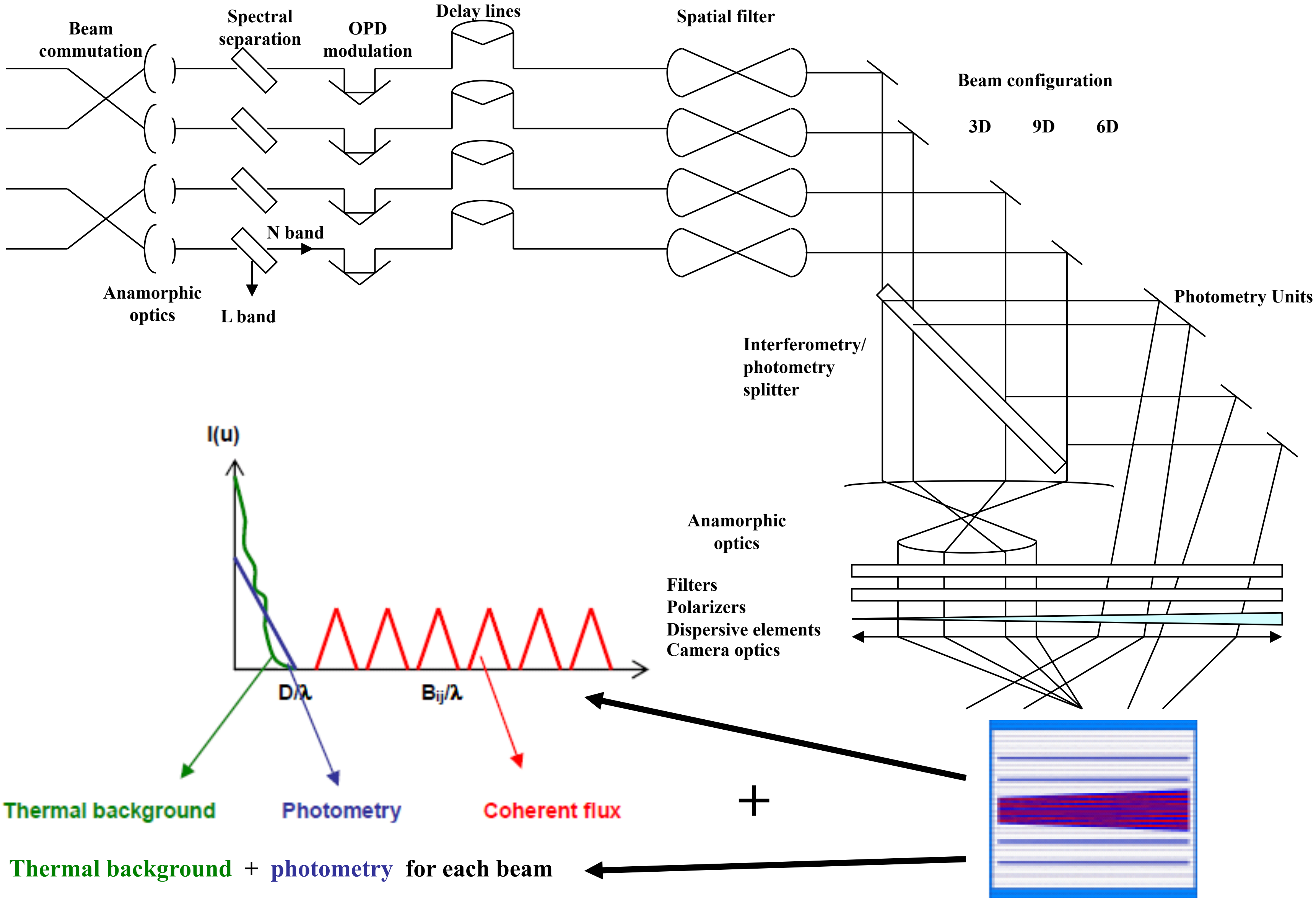

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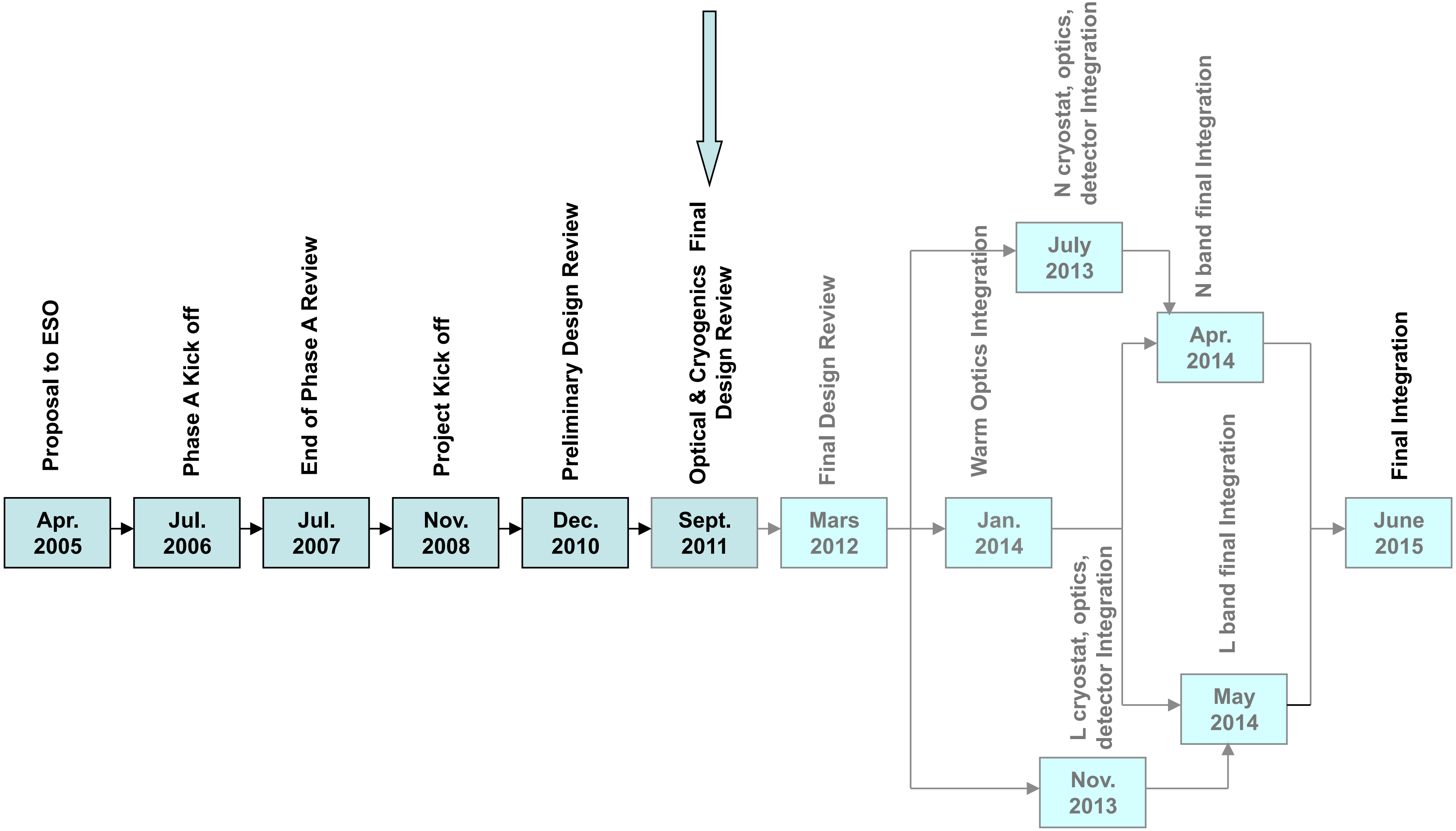
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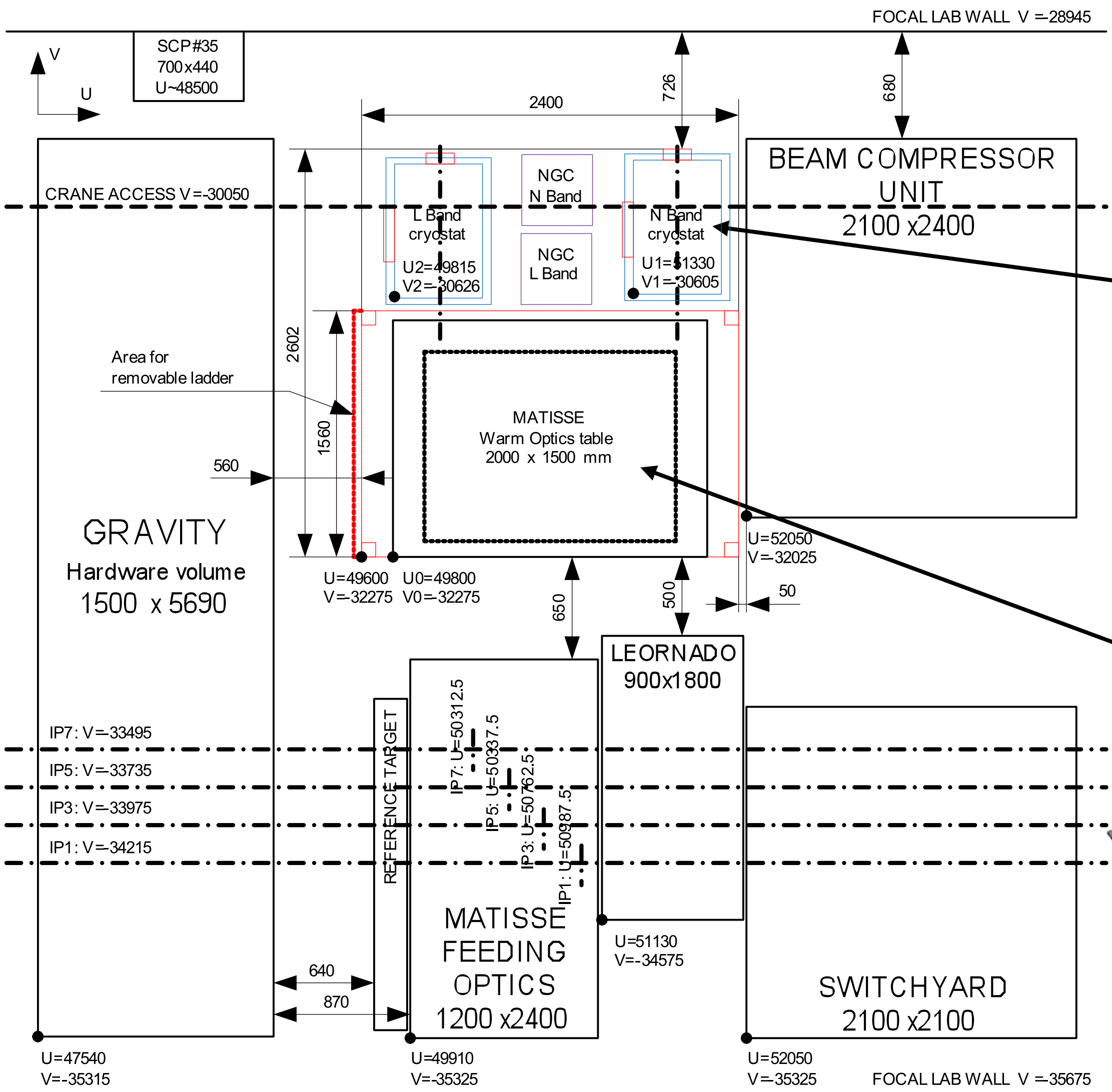
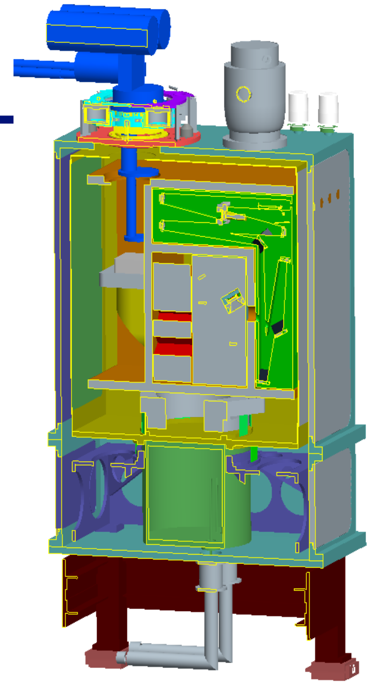
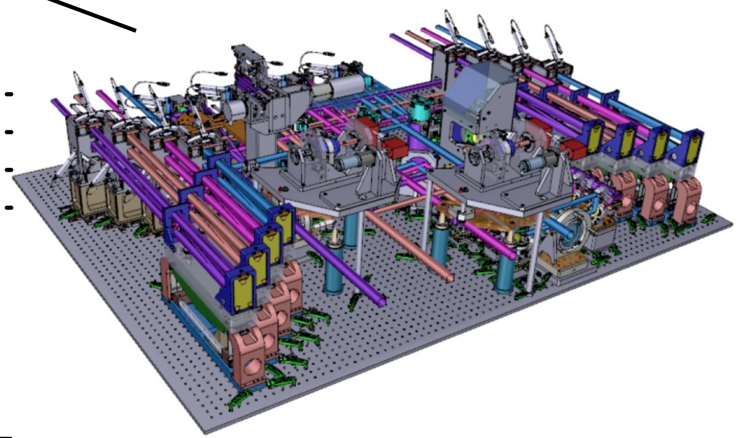
MATISSE in the VLTI focal lab



Cold Optics

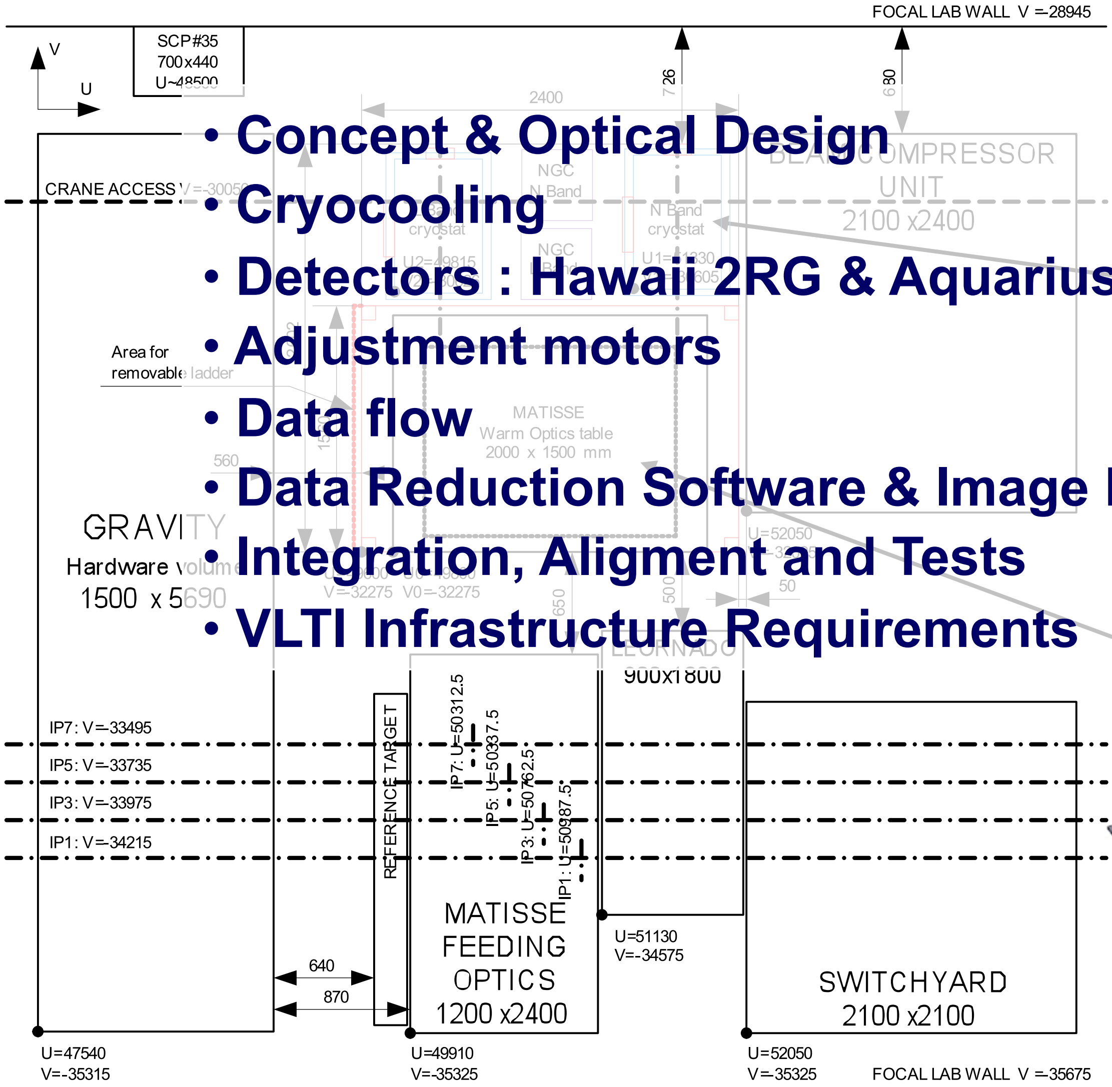


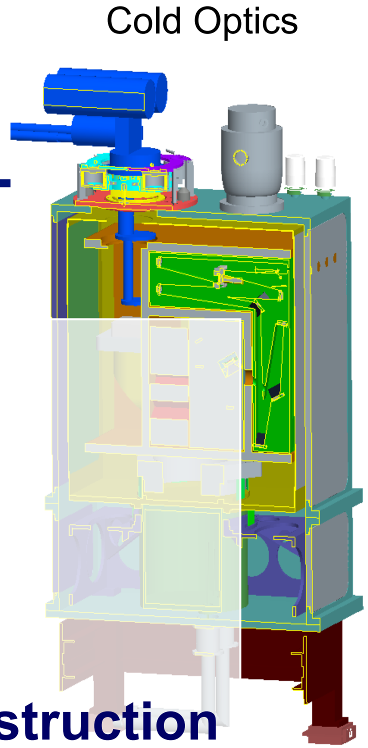
Warm Optics

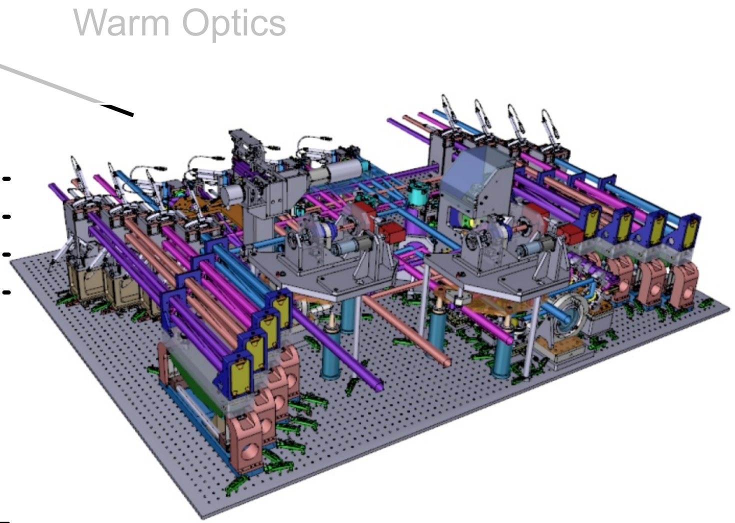


A list of Challenges

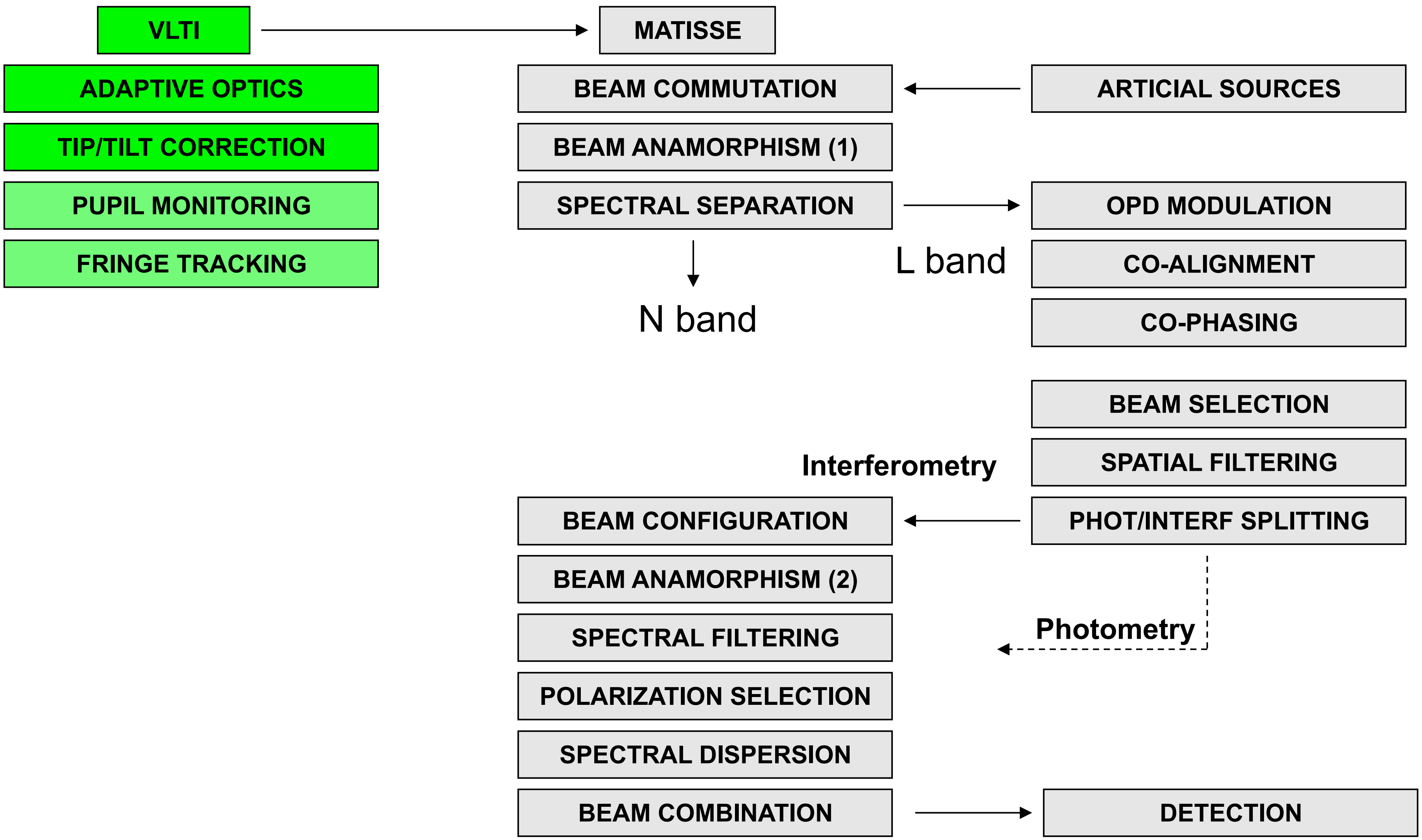
- Concept & Optical Design
- Cryocooling
- Detectors : Hawaii 2RG & Aquarius
- Adjustment motors
- Data flow
- Data Reduction Software & Image Reconstruction
- Integration, Aligment and Tests
- VLTI Infrastructure Requirements







MATISSE FUNCTIONS



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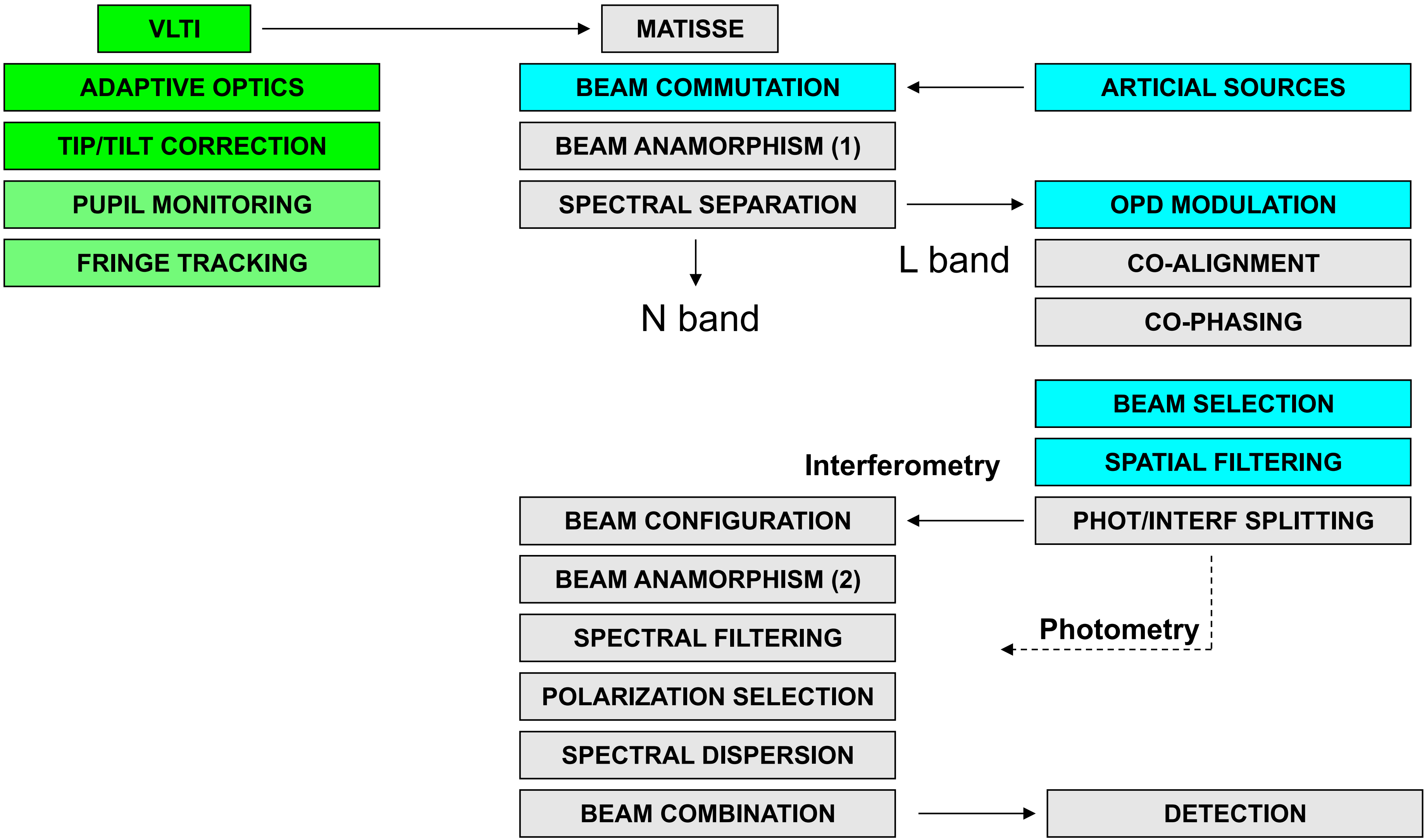

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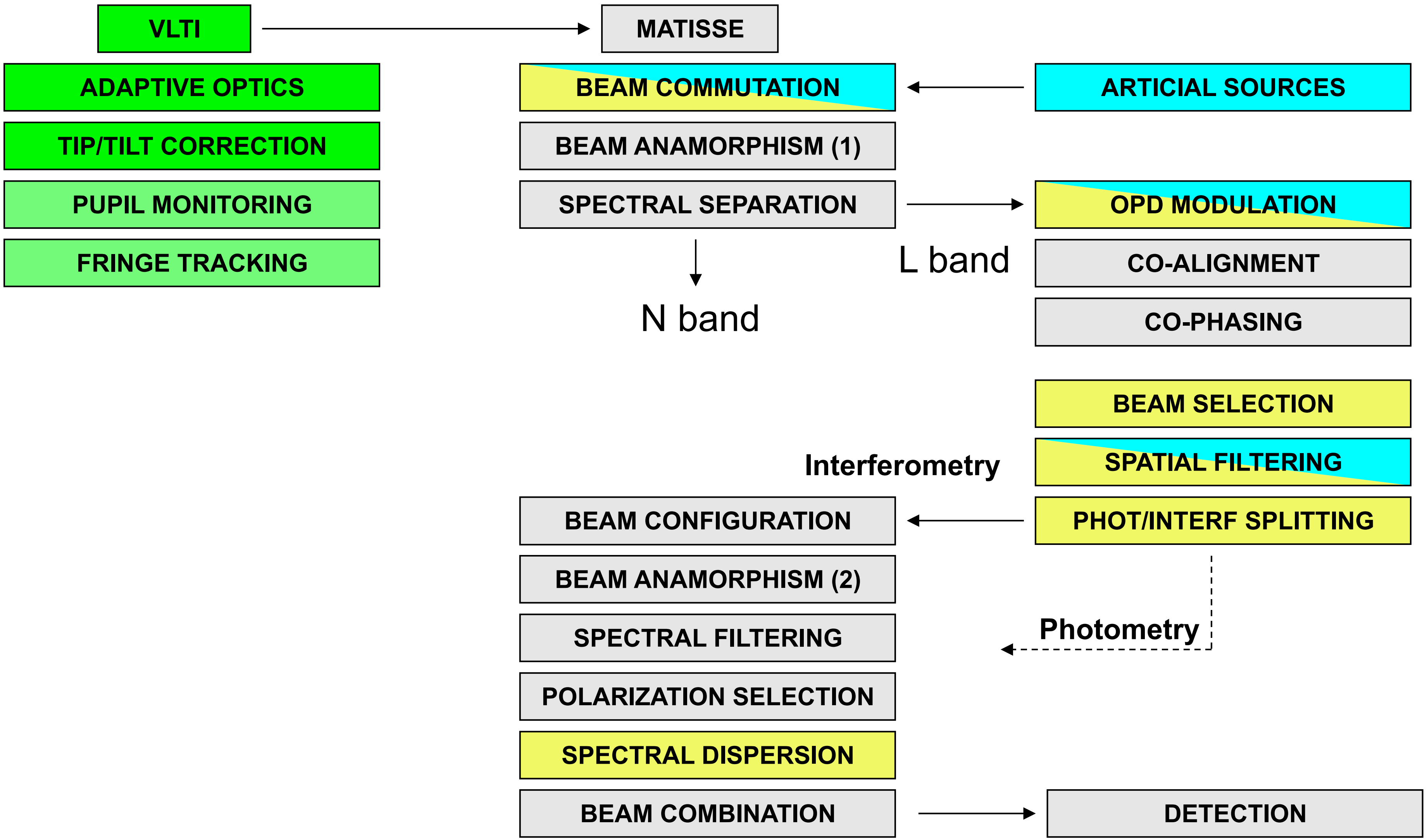

PERFORMANCES

➢ **Sensitivity:**

Limiting Magnitude	L band		N band		
	Tech. Spec.	Performance	Tech. Spec.	Perf.	Perf. (pol)
UT	6.6 (0.65Jy)	8.35 (0.13Jy)	2.7 (3Jy)	4.4 (0.65Jy)	4 (0.9Jy)
AT	4.1 (6.5Jy)	5.85 (1.3Jy)	0.25 (45Jy)	1.45 (9.7Jy)	1.05 (14Jy)

➢ **Calibrated visibility:** Tech. Spec. ≤ 7.5% (goal ≤ 2.5%) with UTs, 20 Jy

Visibility accuracy With UTs (in %)	L band		N band	
	20 Jy	Lim. Mag.	20 Jy	Lim. Mag.
Fringe Tracking	1.5	2	0.8	10.0
Blind mode	1.6	2.4	2.7	10.4

➢ **Closure Phase:** Tech. Spec. ≤ 40mrad (goal ≤ 1mrad) with UTs, 20 Jy

Closure phase With UTs (in mrad)	L band		N band	
	20 Jy	Lim. Mag.	20 Jy	Lim. Mag.
	12	13	4	30


Theresienwiese
St.-Pauls-Platz

Participants and Partner Institutes

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Requirements on the VLTI Infrastructure

- **Fringe Tracker and record of the residuals**
  - Full L&M medium and high spectral resolution reading
  - Sensitivity
  - Accuracy
- **Tip Tilt correction, Pupil monitoring, residuals**
  - Baseline lengths & u coverage
  - Sensitivity
  - Accuracy
- **Adaptive Optics on ATs**
  - Fringe Tracker
  - Sensitivity

- Hybrid mode coupling ATs-UTs
  - Sensitivity & uv coverage
- Simultaneous observations MATISSE-GRAVITY

Some details on the schedule

- Progress Meeting coupled an informal review about the warm optics: June 2011
- O & C FDR: September 2011
- Instrument FDR: March 2012
- Provisional acceptance of the sub-systems
- Instrument laboratory test phase: July 2014 – May 2015
- PAE: June 2015
- PAC: March 2017

Science Programs and their key Issues

Primary Science Cases

Star and Planet Formation

1. Low-mass Star and Planet Formation
   (a) Complex disk structures on large (∼ 100 AU) and small scale (∼ 1 AU); Transitional objects: Status of inner disk clearing
   (b) Mineralogy of proto-planetary disks; Evidence for dust grain growth and sedimentation
   (c) Characteristic structures in disks: Evidence for the presence of giant proto-planets
   (d) The binary mode of star formation: Circumbinary and circumstellar disks; Disk alignment and early evolution of binary systems
   (e) Nature of outbursting YSOs: Structure of young accretion disks
2. Late stage of planet formation – Debris disks:
   (a) The outcome of planetesimal collisions and exo-comets evaporation: Dust grain properties and disk geometry
   (b) Complex spatial disk structure – direct indicators for the presence of planets
   (c) Characterization of Darwin/TPF targets
3. Massive Star Formation
   (a) Spatial distribution of the gas (carbon monoxide and hydrogen) and dust (silicates/graphite and CO ice) in the typically complex and distant high-mass star-forming regions
   (b) Link between low and high-mass star formation? Search and characterization of accretion disks around young massive (proto)stars

Active Galactic Nuclei

Hydro-dynamical models of the central gas and dust distribution in AGN show a dense inner disk (supported by angular momentum) and an outer filamentary structure – the torus.

1. Can we establish the existence of the dense inner disks ? Are the disks present in both Seyfert 1 and 2 galaxies ?
2. Can we find direct evidence that tori are clumpy or filamentary structures?

Outflow phenomena (supersonic winds, jets) are connected with most kinds of AGN activity

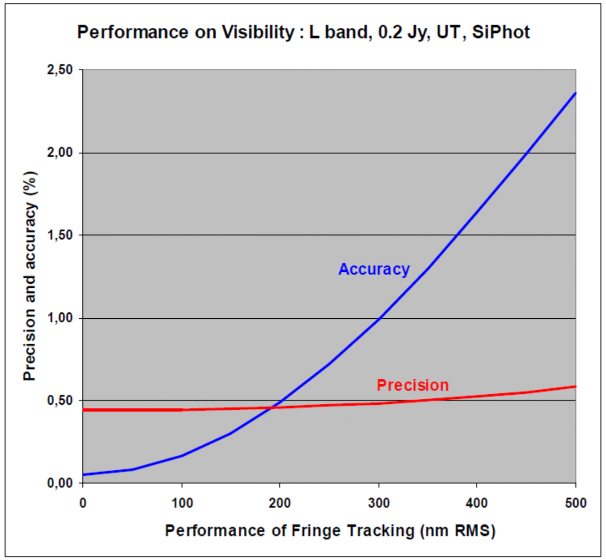
3. To which extend is the torus structure regulated by the outflows ?
4. What fraction of the dust emission from within the inner few parsecs of an AGN is emitted by the torus and what by dust entrained in the outflows?

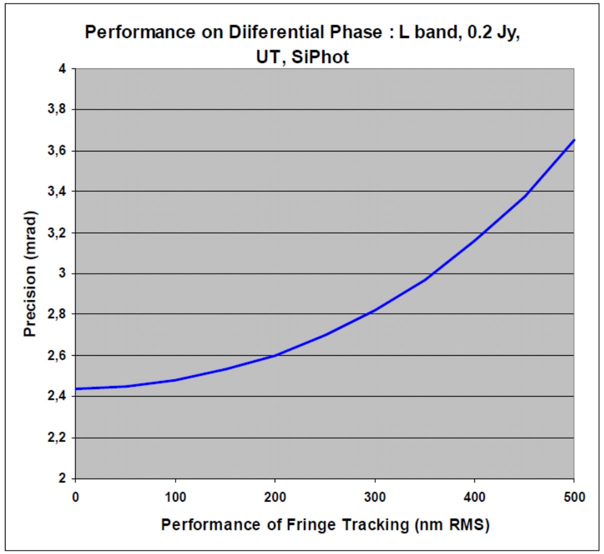
Importance of the Fringe Tracking for MATISSE

- **Full L&M medium and high spectral resolution reading**
- **Sensitivity**
- **Accuracy**

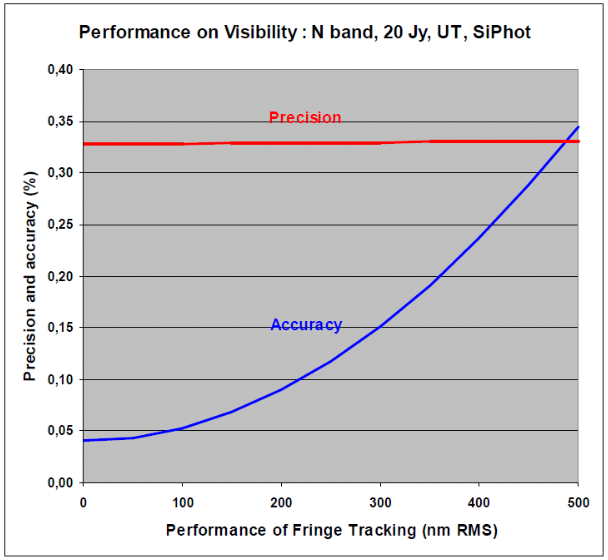
In the 'MATISSE Performance Analysis Report'

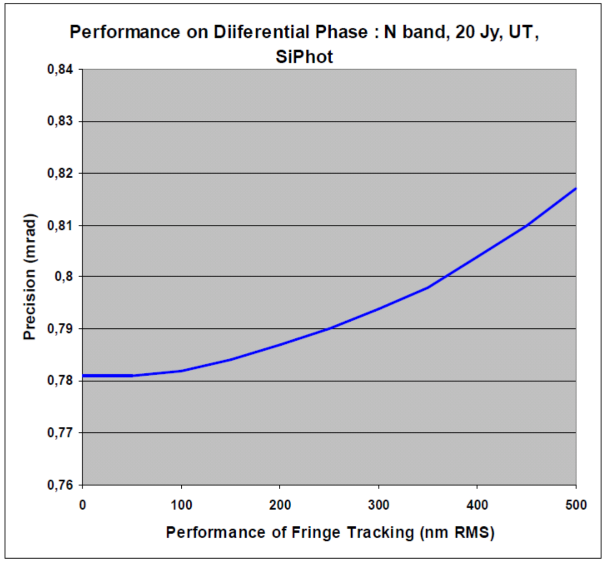
L band





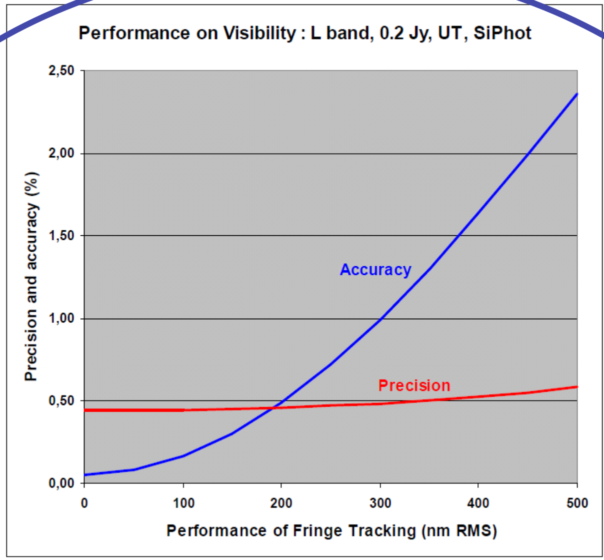
N band

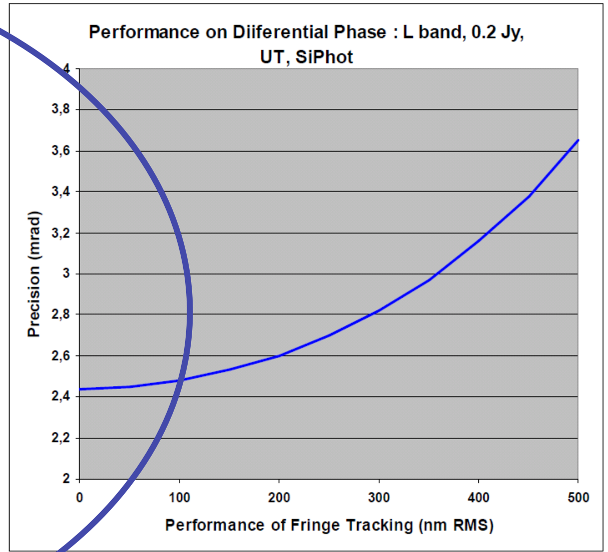




In the ‘MATISSE Performance Analysis Report’

L band





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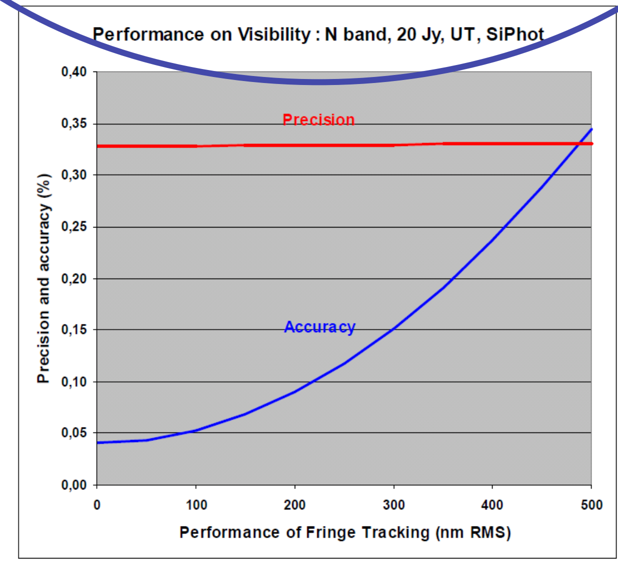

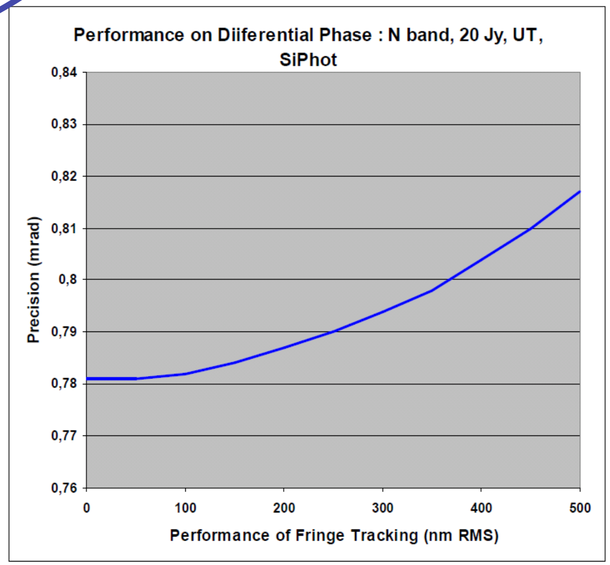

In 'Complement to the Science Case document' of Phase A
A list of AGNs with reference stars

Name	type	RA	DEC	$K_{AGNcore}$	$L_{AGNcore}$	H_{star}	K_{star}	R_{star}	SEP
MCT0146-2813	Sy1	01 48 22.2	-27 58 23	12.3	10.5	10.6	10.5	11.6	19.5
NGC676	Sy2	01 48 57.3	+05 54 21	10.7	8.2	8.6	8.6	10.0	5.1
NGC1204	Sy2	03 04 40.0	-12 20 29	11.4	8.9	9.2	9.1	10.0	12.8
LEDA17016	Sy1	05 16 21.1	-10 33 41	11.2	9.4	10.5	10.3	12.2	12.2
2E2060	Sy1	08 52 15.1	+07 53 37	12.6	10.8	9.3	9.2	10.8	19.6
RBS 999	Sy1	11 34 22.5	+04 11 28	12.9	11.1	9.0	8.8	10.5	22.2
Cen A	Sy2	13 25 27.7	-43 01 09	8.8	6.3	9.4	9.2	11.0	44.0
NGC 5363	Lin	13 56 07.2	+05 15 17	9.7	7.9	10.6	10.3	?	6.2
LEDA 170317	Sy2	13 59 00.3	-20 02 57	12.3	9.8	8.3	8.2	8.0	18.8
MCG+03-40-009	Sy2	15 35 52.6	+14 31 04	12.9	10.4	9.8	9.6	12.5	24.0
ESO 137-34	Sy2	16 35 14.2	-58 04 41	11.4	8.9	7.7	7.3	9.2	13.9
IGR J18027-1455	Sy1	18 02 47.3	-14 54 54	10.9	9.1	9.1	8.6	15.2	15.3
ESO 339-11	Sy2	19 57 37.6	-37 56 05	11.6	9.1	10.5	10.3	10.8	25.0
QSO B2032+107	QSO	20 35 22.0	+10 56 06	12.2	10.4	10.5	10.4	11.8	25.1
LEDA 65714	Sy1	20 55 22.3	+02 21 17	12.5	10.7	9.7	9.6	12.7	26.4
1H 2107-097	Sy1	21 09 09.9	-09 40 15	10.9	9.1	9.0	8.8	12.1	15.4
LEDA 2831185	QSO	22 03 26.9	+17 25 48	12.4	10.6	10.1	10.0	12.2	13.7
MCG+01-57-007	Sy1	22 32 30.8	+08 12 27	11.8	10.0	9.5	9.3	10.7	9.8
ESO 535-1	Sy2	22 59 01.4	-25 31 42	12.4	9.9	10.6	10.4	11.9	24.5

K = 10 off-axis FT

K = 12 on axis FT

Importance of the Fringe Tracking, bonus

- **Full L&M medium and high spectral resolution reading**
- **Sensitivity**
- **Accuracy**

- **Doubling the MATISSE spectral resolution : example, R_{max} in L could go from 100 to 1500**
- **Simultaneous observations MATISSE + GRAVITY**
- **Possible implementation of a Fourier Transform Spectrometer for high spectral resolution > 50 000**

MATISSE Requirements to the VLTI

In relation with the Fringe Tracking :

- Number of telescopes: 4 telescopes

- Sensitivity: K>10 (Goal: K>12, extragalatic program)

- Tracking accuracy: 180nm RMS (over 1mn)

- Chopping compatibility: Current values in ICD OK
  (30ms for fringe reacquisition and 10ms for closing FT loop)

- Sensing processing: FT signal part of MATISSE data for offline processing

Contractual Documents

- Agreement
- Technical Specifications
- Memorandum of Understanding
- Statement of Work
- Management Plan

INSU, Jean-Marie Hameury, NOVA, Wilfried Boland, MPIA, Thomas Henning, MPIfR, Gerd Weigelt, OCA, Farrokh Vakili.

Les requis astrophysiques
en considérant différents sujets et approches

MATISSE

	Coherent Flux Sensitivity	Visibility Accuracy	Closure Phase Accuracy	Differential Phase Accuracy	Differential Visibility Accuracy
Protoplanetary disks (number of available sources)	N ~ 1 Jy UTs ~20 Jy ATs L ~0.2 Jy UTs ~ 4 Jy ATs	–	–	–	–
Protoplanetary disks (signatures in visibility and closure phase)	–	Scenarios 1-2-3-4 : 1 - 10 % in N Scenarios 5-6 : 1 - 5 % in N	Scenarios 1-2-3-4 : 0.05-1 radian in N Scenarios 5-6 : 0.02 – 0.1 radian in N	–	–
Protoplanetary disks (model fitting approach)	–	Foreseen for the second version of this document	Foreseen for the second version of this document	–	–
Protoplanetary disk (image reconstruction approach)	–	10 % best with 2 %	0.2 radian best with 0.01 radian	–	–
AGN	N ~05 Jy UTs L ~0.1Jy UTs	10%	-	-	-
Asteroids	N ~ 1 Jy M < 0.5 Jy L < 0.1 Jy	–	–	–	–
Extrasolar planets	N ~ a few Jy down to 1 Jy L ~ a few Jy up to 10 Jy	–	~ 5 10^{-4} radian in N ~ 10^{-4} radian in L	~ 5 10^{-4} radian in N ~ 10^{-4} radian in L	–

From Table 4 of the Science Analysis Report.

MATISSE atteint ses objectifs scientifiques

	Coherent Flux Sensitivity	Visibility Accuracy	Closure Phase Accuracy	Differential Phase Accuracy	Differential Visibility Accuracy
Are the requirements defined here satisfied by the Performance Analysis Report [RD2] calculations :					
Protoplanetary disks (number of available sources)	Yes	–	–	–	–
Protoplanetary disks (signatures in visibility and closure phase)	–	Yes	Yes	–	–
Protoplanetary disks (model fitting approach)	–	Not studied yet	Not studied yet	–	–
Protoplanetary disk (image reconstruction approach)	–	Yes	Yes	–	–
AGNs	Yes	Yes	-	-	-
Asteroids	Yes in N No in L	–	–	–	–
Extrasolar planets	Yes in L and N	–	Challenging as an exploratory goal	Challenging as an exploratory goal	–

From Table 5 of the Science Analysis Report.

Number of sources per object class

Science Case	L&M band ATs/UTs	N band ATs/UTs
Star and Planet Formation		
- Low-mass Stars and Planet Formation	$\sim$100 / $>$100 [a]	$\sim$100 / $>$100 [b]
- Young low-mass Binary Stars	$>$25 / $>$60	$>$15 / $>$30
- FU Orionis Stars	6 / 9	5 / 13
- Debris Disks	250 / 320	70 / 180
- Massive Star Formation	$\sim$50 [c] / $\sim$50	$\sim$50 [c] / $\sim$60
Active Galactic Nuclei	0 / 47	0 / 17
Evolved Stars		
- Low-mass stars [d] : a) O	$\sim$30 / 30	$\sim$90 / 90
b) C	$\sim$6 / 6	$\sim$15 / 15
c) S	$\sim$2 / 2	$\sim$5 / 5
- R CrB	3 / 10	3 / 10
- PNs	3 / 10	3 / 10
- Cepheids	6 / 6	6 / 6
- High-mass stars: a) B[e] stars	15 / 7	15 / 3
b) WR stars	10 / 25	10 / 15
c) LBV stars	3 / 5	1 / 5
d) Be stars	30 / 30	0 / 0
Solar System Minor Bodies	0 / $\sim$30	$\sim 10^3$ / $\sim 6\times10^3$
Extrasolar Planets	3 / 25	0 / 1
Galactic Center	0 / 1	0 / 1