MATISSE

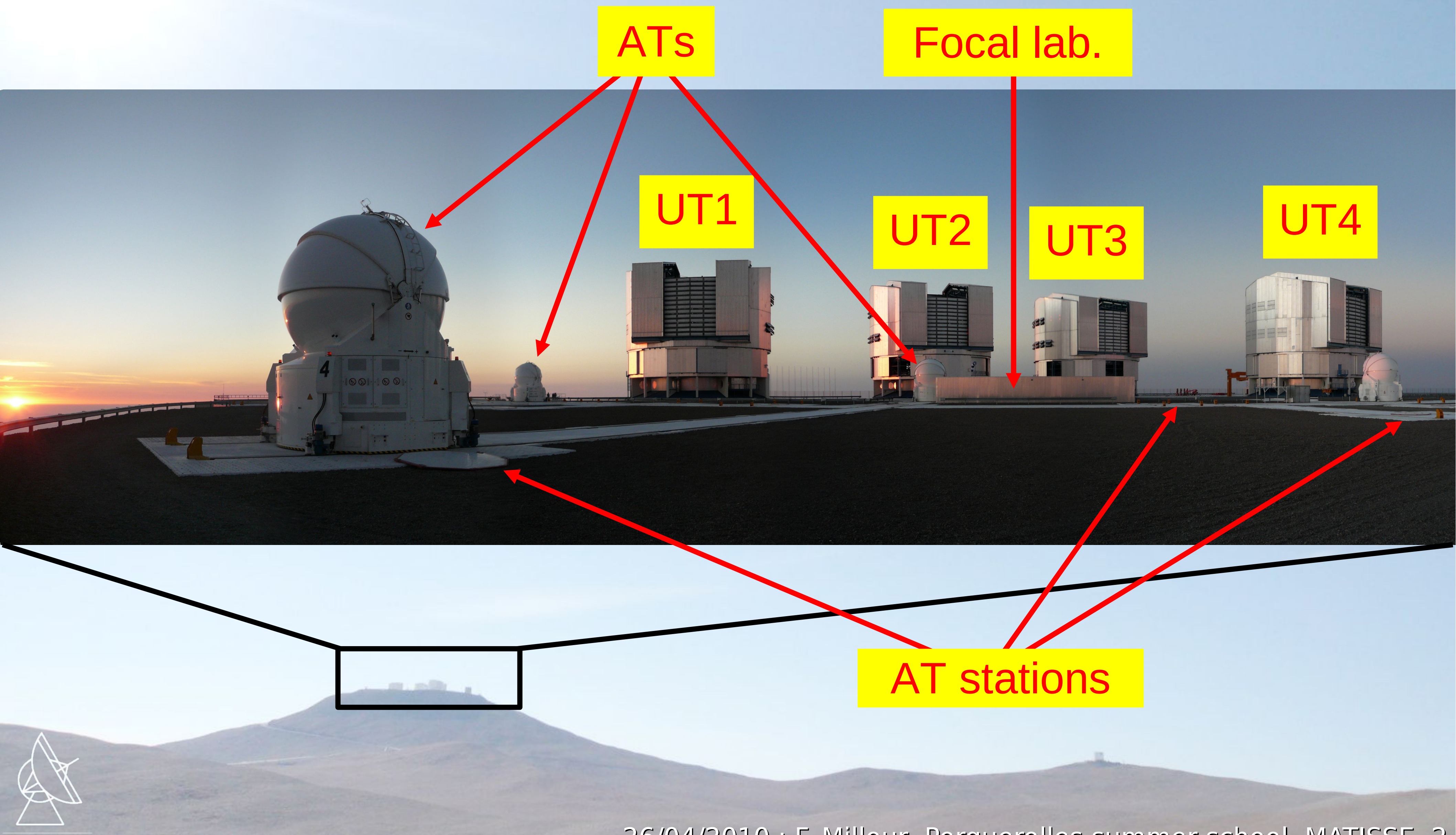
Multi AperTure mid-Infrared SpectroScopic Experiment

PI : Bruno Lopez
PS : Sebastian Wolf
PM : Pierre Antonelli

Florentin Millour, Porquerolles 2010 VLTI summer school

Presentation based on a MATISSE presentation from O. Chesneau

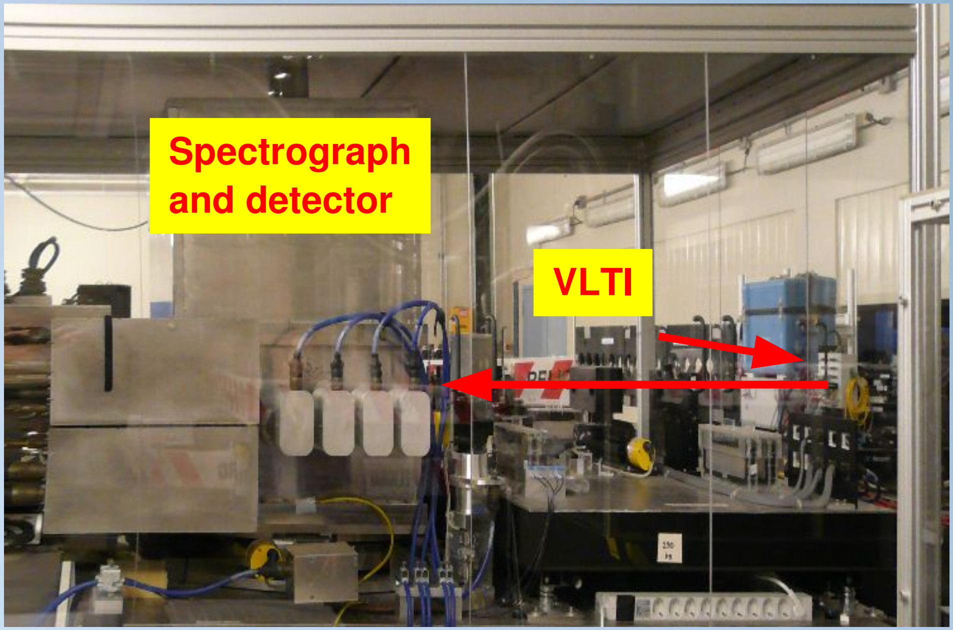
VLTI

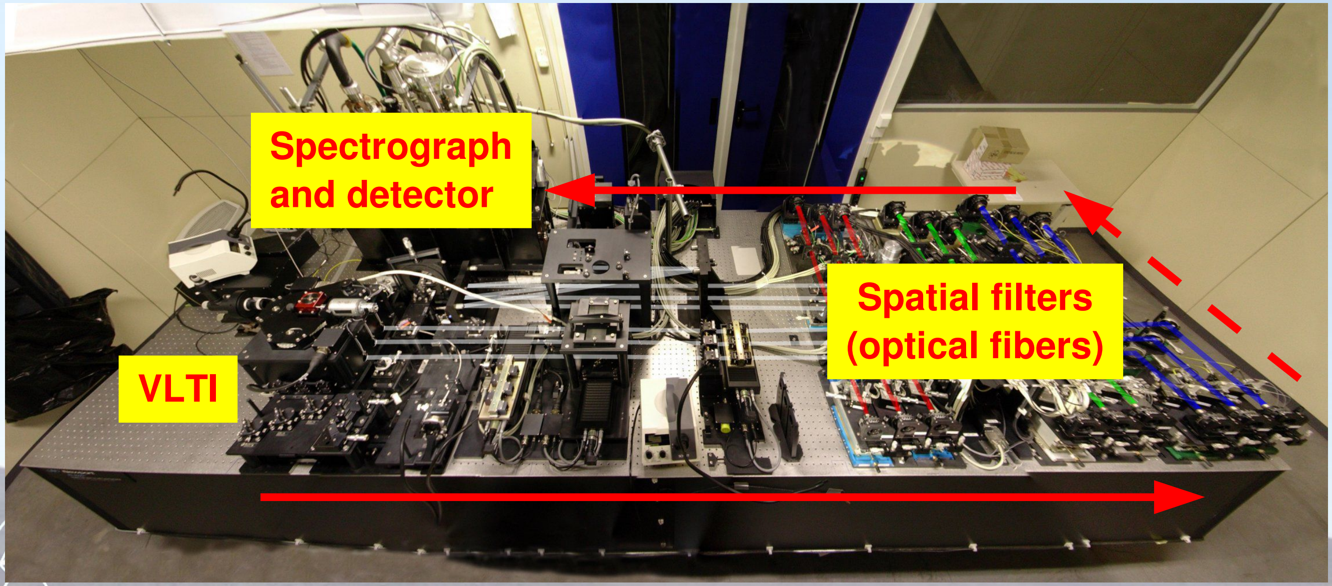


Current VLTI instruments

MIDI:

- 2 telescopes
- N band (8-13μm)
- Spectral resolutions R=30 & 300





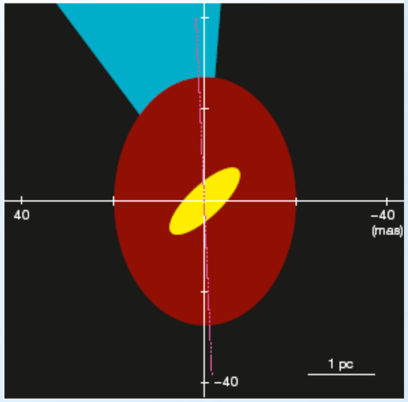
AMBER:

- 3 telescopes
- Optical fibers
- J, H & K simultaneously
- Spectral resolutions R=35, 1500 & 12000

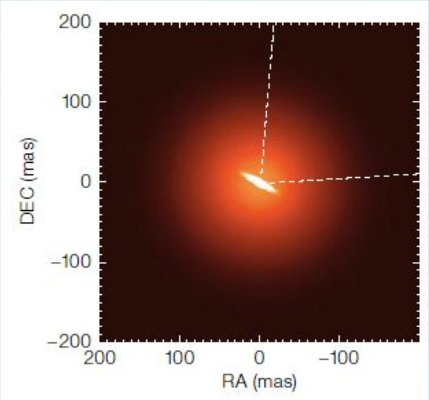
MIDI: a very successful instrument

47 refereed papers, about 20 in the publishing pipeline

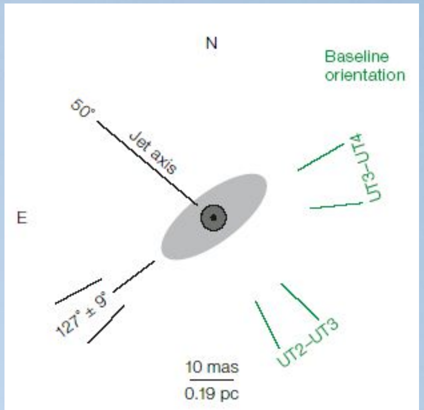
- AGNs: Since Jaffe et al., 2005, 8 referred papers



NGC 1068: Jaffe et al. 2005

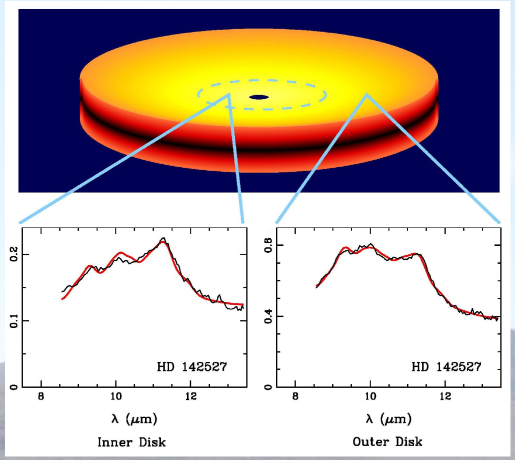


Circinus: Tristram et al. 2007



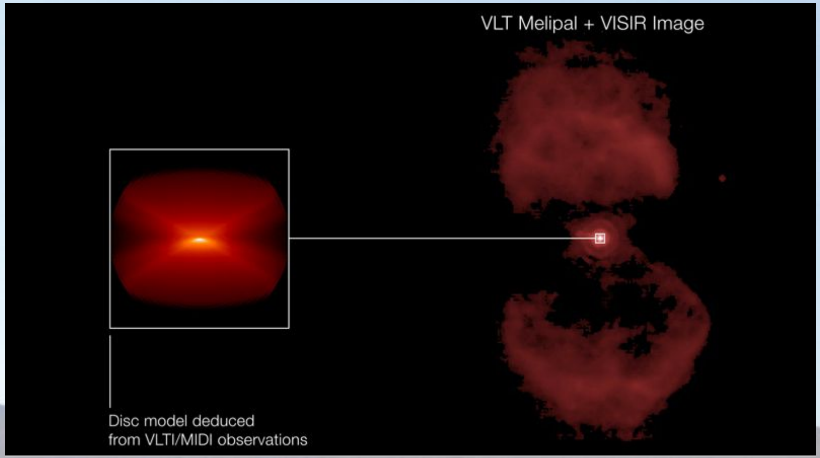
Centaurus A: Meisenheimer et al. 2008

- YSOs:



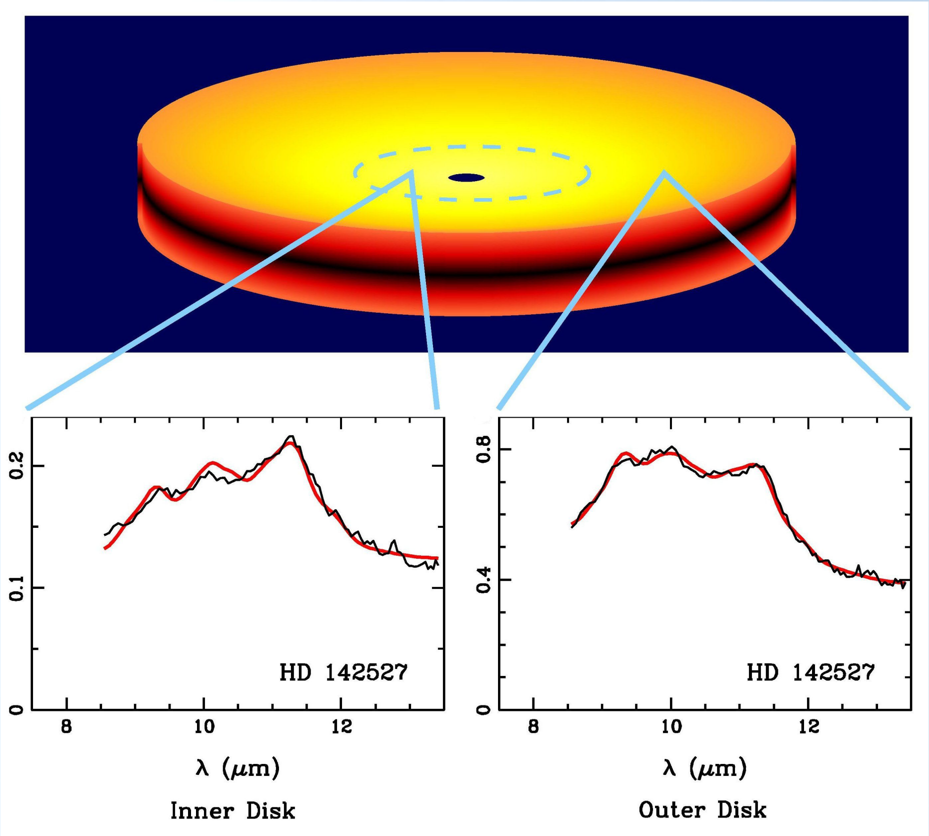
HD 145527: van Boekel et al. 2004

- Evolved stars:



Ant nebula: Chesneau et al. 2004

Young Stellar Objects



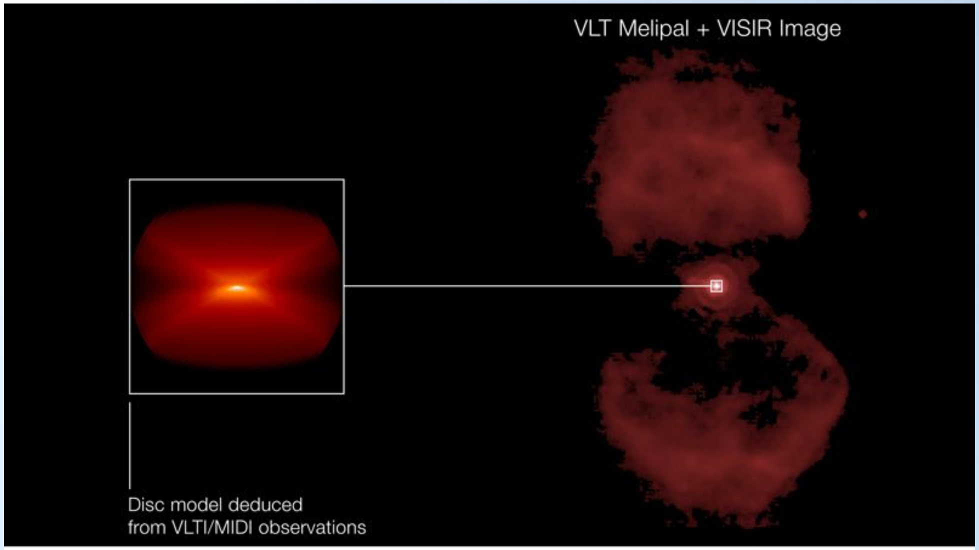
Van Boekel et al. 2004

The location of crystalline versus amorphous silicate dust was constrained

BUT

No real information on the GEOMETRY of both components due to the very limited number of baselines recorded.
Still few papers detailing the geometry of a YSO
-Acke et al. 2008, MWC297
-Di Folco et al. 2008, AB Aur

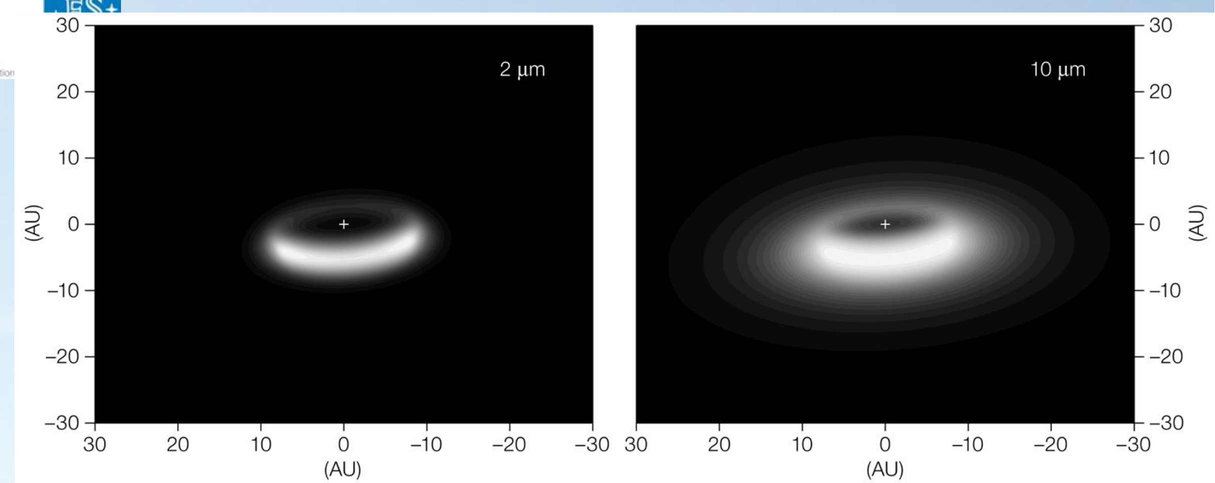
Evolved stars



A Disc in the Ant Nebula

ESO Press Photo 42/07 (27 September 2007)

Chesneau et al. 2007
Lucky case:
Stratified disk seen edge-on, 6 visibilities can constrain the model. A very good fit was matched.



A Disc Around An Aged Star

ESO Press Photo 43/07 (27 September 2007)

Deroo et al. 2007
Disk at lower inclination
The fit of the visibilities gets more difficult. In this case, the information from AMBER was crucial.

The problem of complex sources

Crystalline dust vs. Amorphous dust?

- Spectroscopic features vs. interferometric signal
- Geometry of each component

Dust vs. gas?

- Dust is often the ONLY component fitted to the data
- Stratified disk were successful models in many cases

In reality?

- many intermediate cases for which a dust signature can be confused with interferometric signal or gas (for both MIDI and AMBER used alone)
- many sources with different emitting components in the mid-IR: star+extended source+disk, or binary, or free-free component…

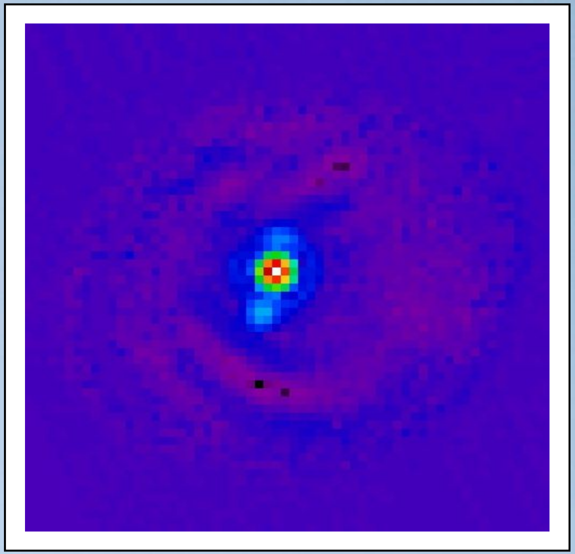
MIDI measurements

Acquisition image (very useful for extended sources, but only on UTs)

Spectrum (flux-calibrated) : $S(\lambda)$

Visibility : $V^{2ij}(\lambda)$

Diff. phase : $\Phi^{ij}_{dff}(\lambda)$



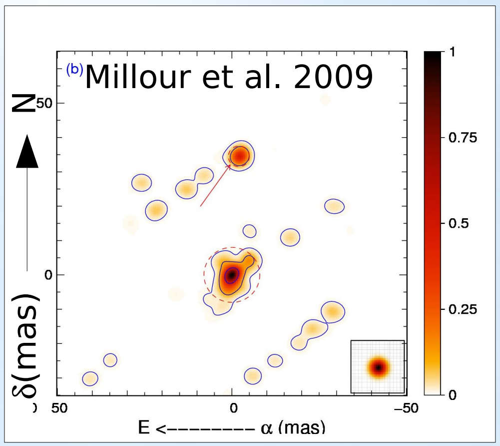
The binary YSO
FU Ori

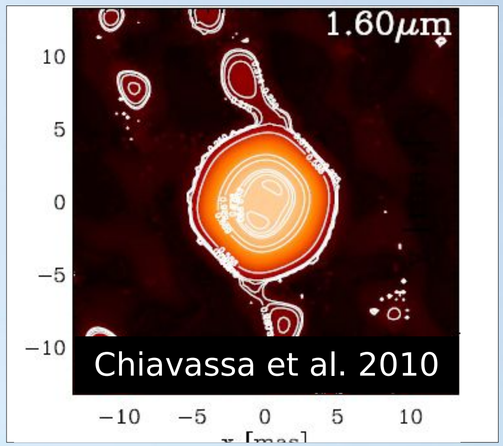
BUT:

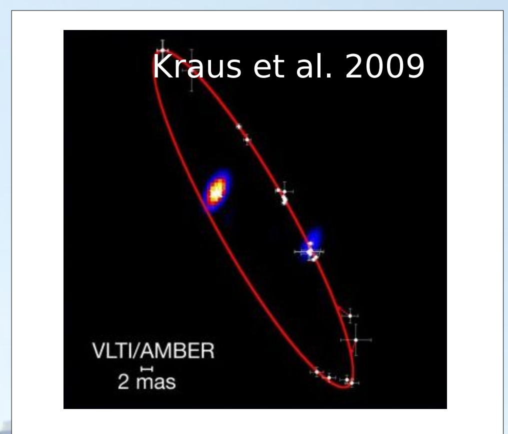
Visibilities measurements limited to 4-10
Accuracy limited to 4-5%

AMBER: First images with the VLTI

50 refereed papers, and many more to come





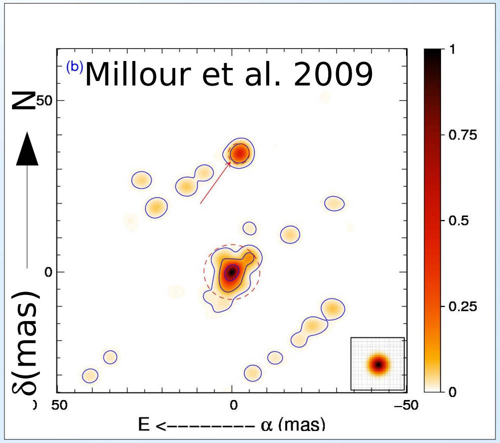


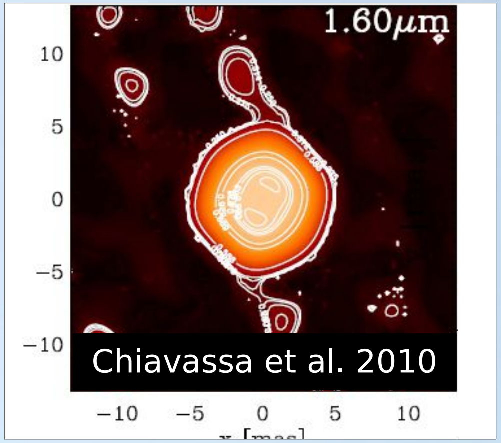
- **Squared visibility (V²)**
- If N_{tel} >3
  Closure phase
- If dispersed light
  Spectrum,
  Differential phase,
  Differential visibility
- If large amount of data
  Image synthesis

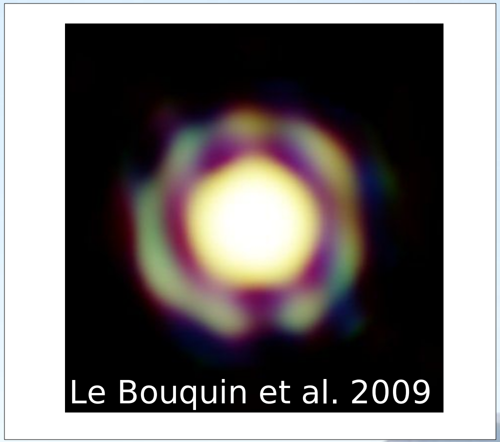
Max-Planck-Institut für Radioastronomie

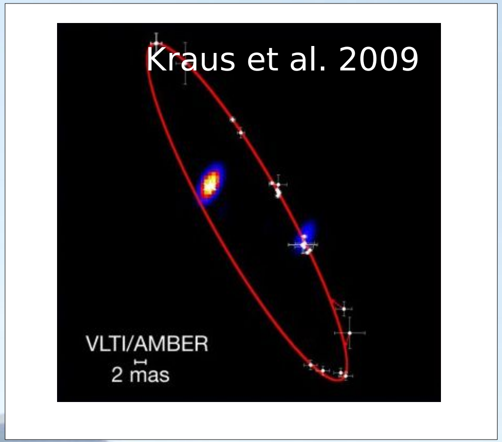
AMBER: First images with the VLTI

50 refereed papers, and many more to come









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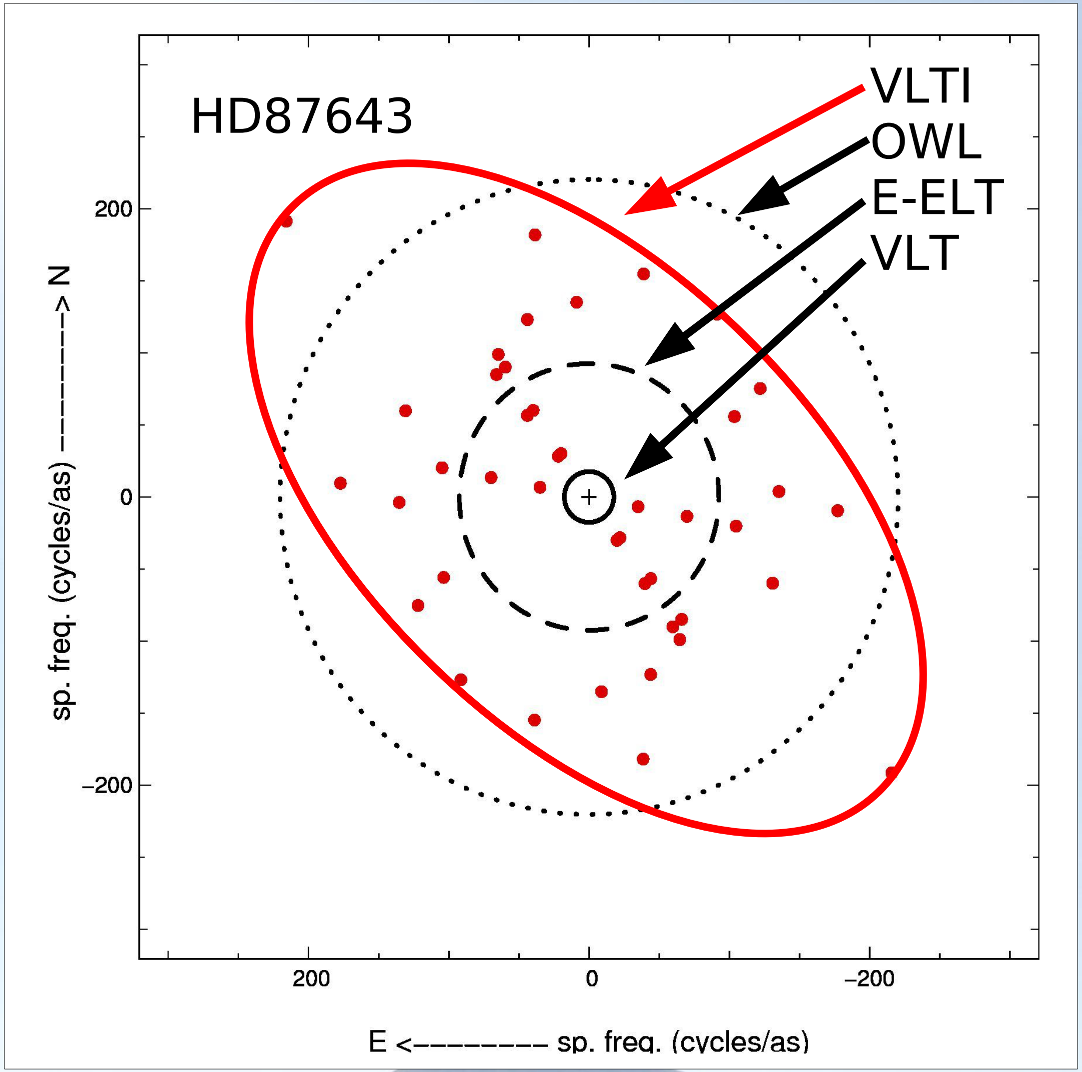
Aperture synthesis

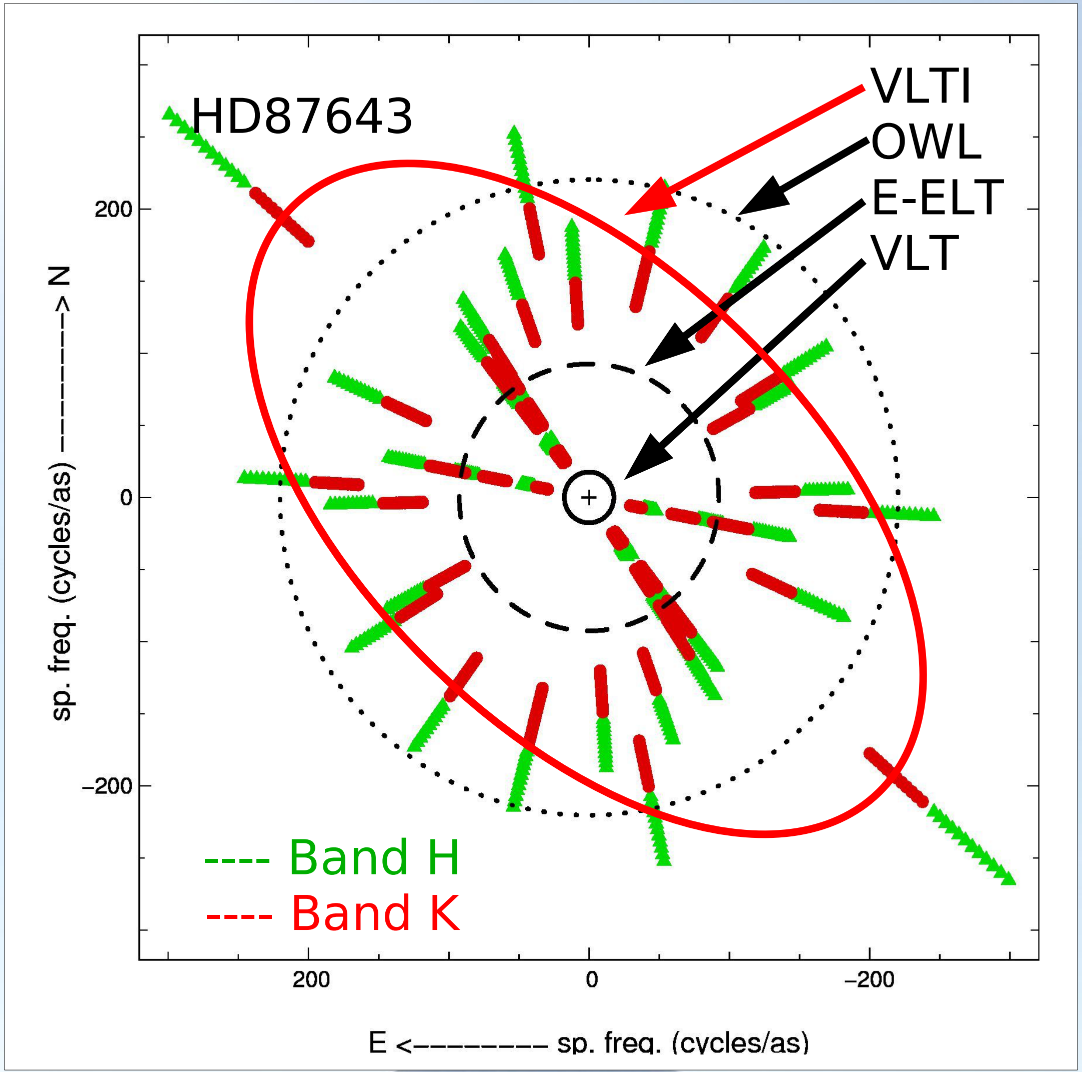


VLTI brings unprecedented angular resolutions

Image-reconstruction software:

- **MIRA**
- **BSMEM**
- **BBM**

Aperture synthesis



VLTI brings unprecedented angular resolutions

BUT:

- **(U,V) plane "filled with holes"**
- **Weak-phase interferometry**

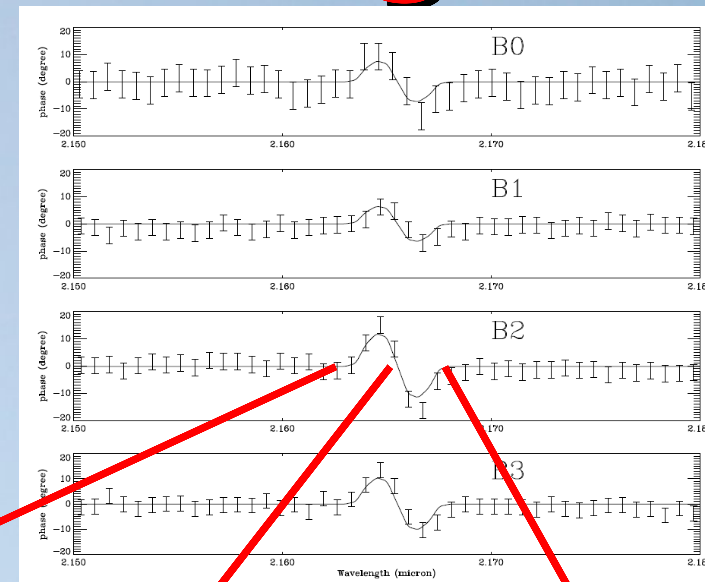
➔ ***Gain with spectral coverage***

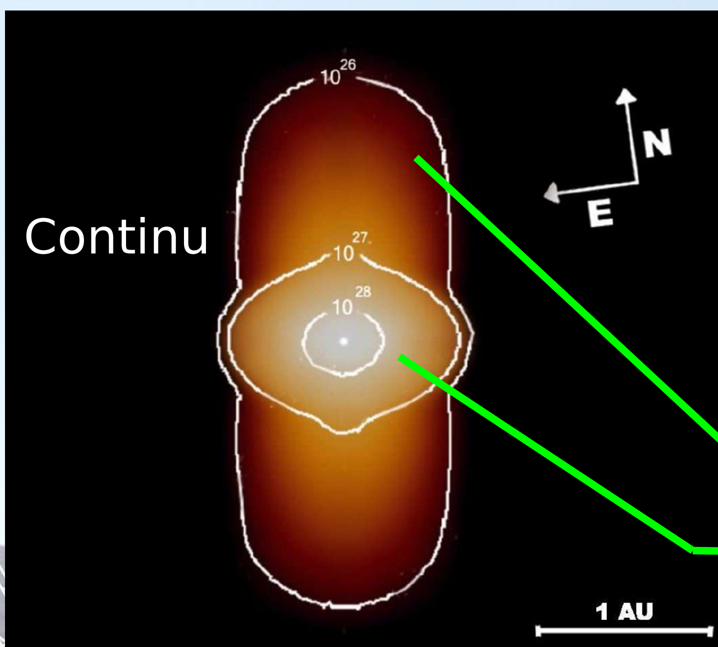
➔ ***Gain with hypotheses on the object (special morphologies)***

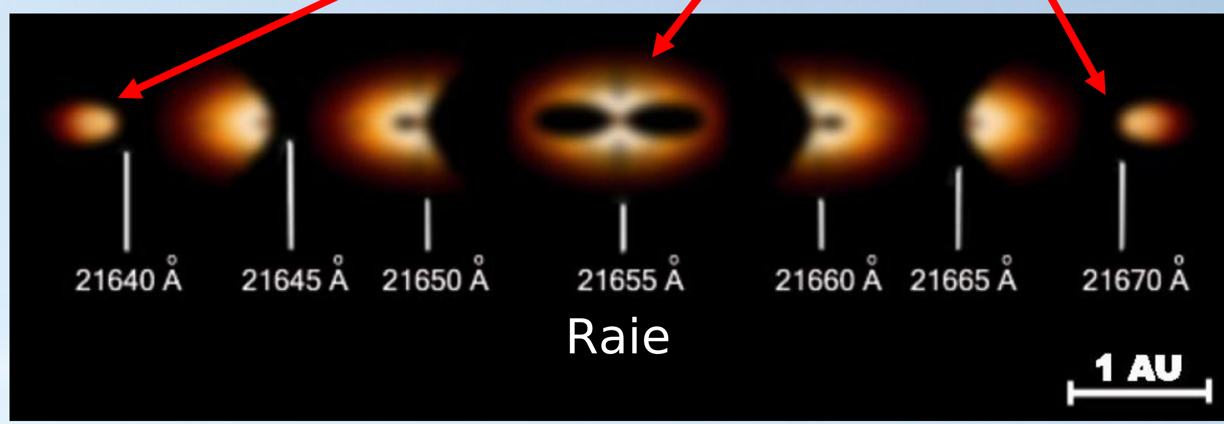
➔ ***Gain with phase reference (PRIMA)***

AMBER: model-fitting

- Dispersed observations are critical to understand the objects
- Multi-λ model-fitting is critical to interpret dispersed observations





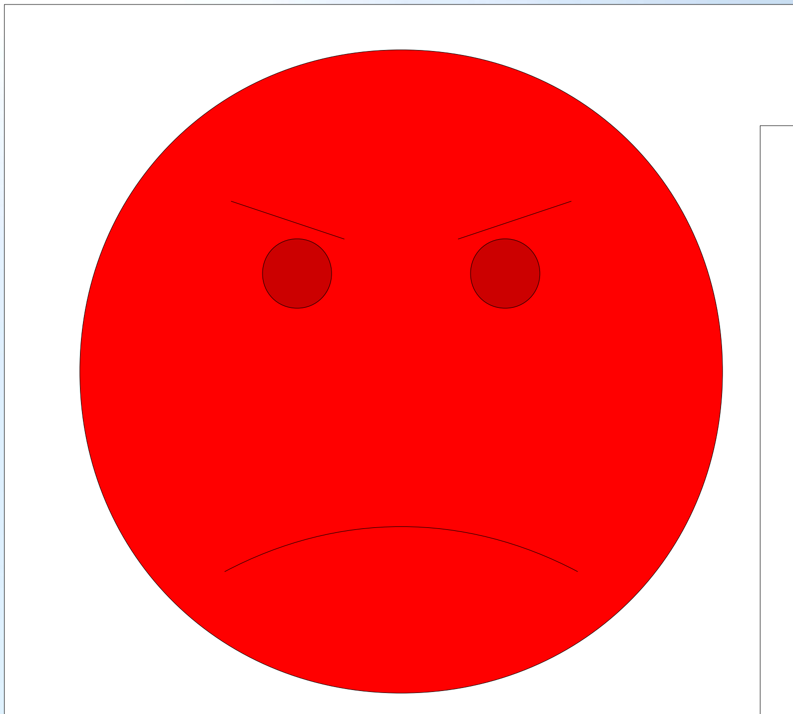


Polar wind

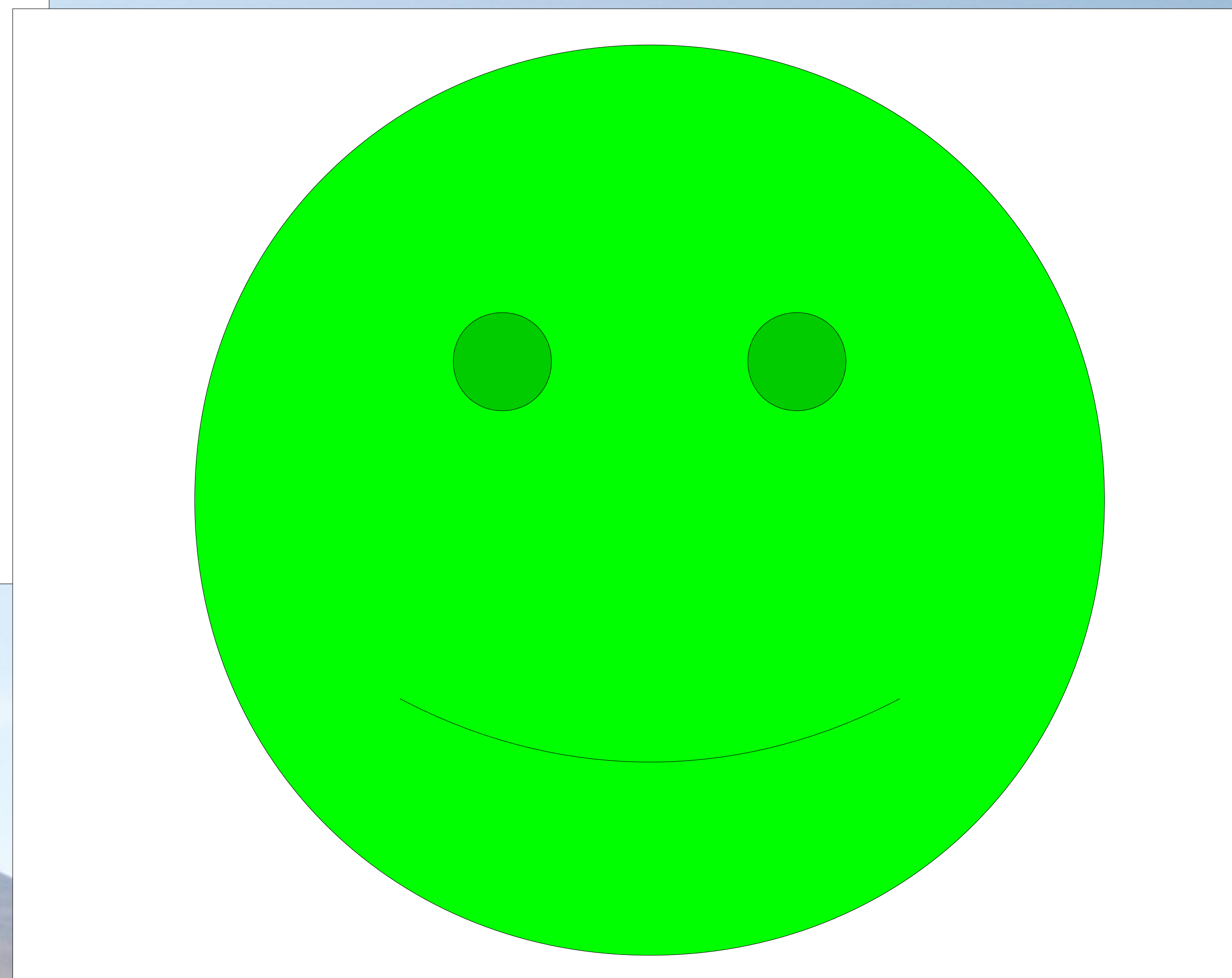
Equatorial disk

Meilland, et al., A&A 2007

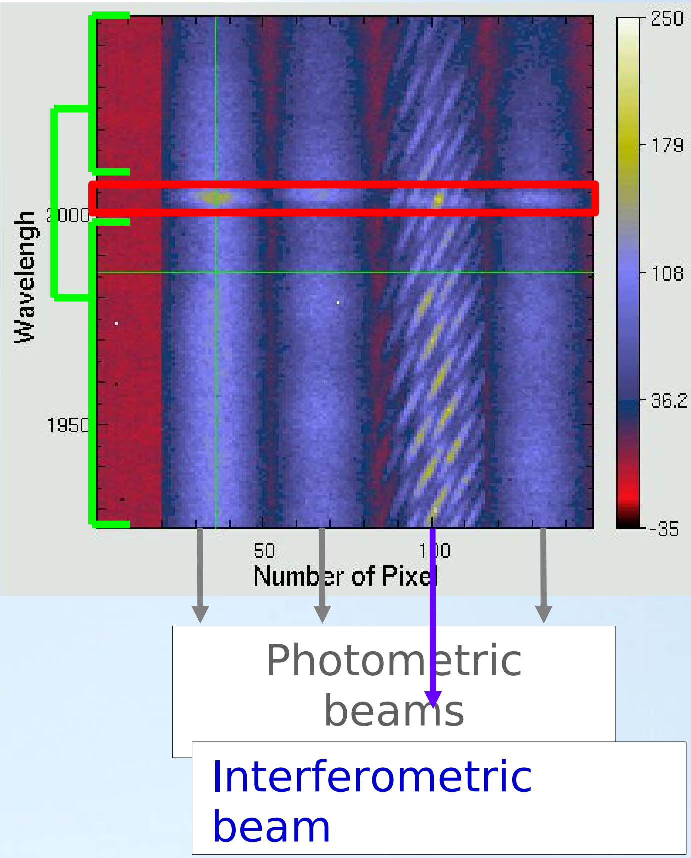
AMBER: a way to disentagle gas from dust



Millour et al. (submitted)



AMBER observables



Spectrum :	$S(\lambda) = N(\lambda)$
Visibility :	$V^{2i,j}(\lambda)$
Phase closure :	$\Psi^{123}(\lambda)$
Diff. phase :	$\Phi^{i,j}_{diff}(\lambda)$
Diff. visibility :	$V^{ij}_{diff}(\lambda)$

BUT:

Accuracy limited to 5-10%
AMBER is far from doing images on a regular basis

SO WHAT?

MIDI

- Just size estimates, no real information on the GEOMETRY
- No imaging capability
- No (or few) gas study possibilities

AMBER

- Limited accuracy
- Limited imaging capabilities
- Dust analysis limited to (very) hot dust

IN ADDITION

- K and N bands have been used a lot. Need to open new wavelength windows

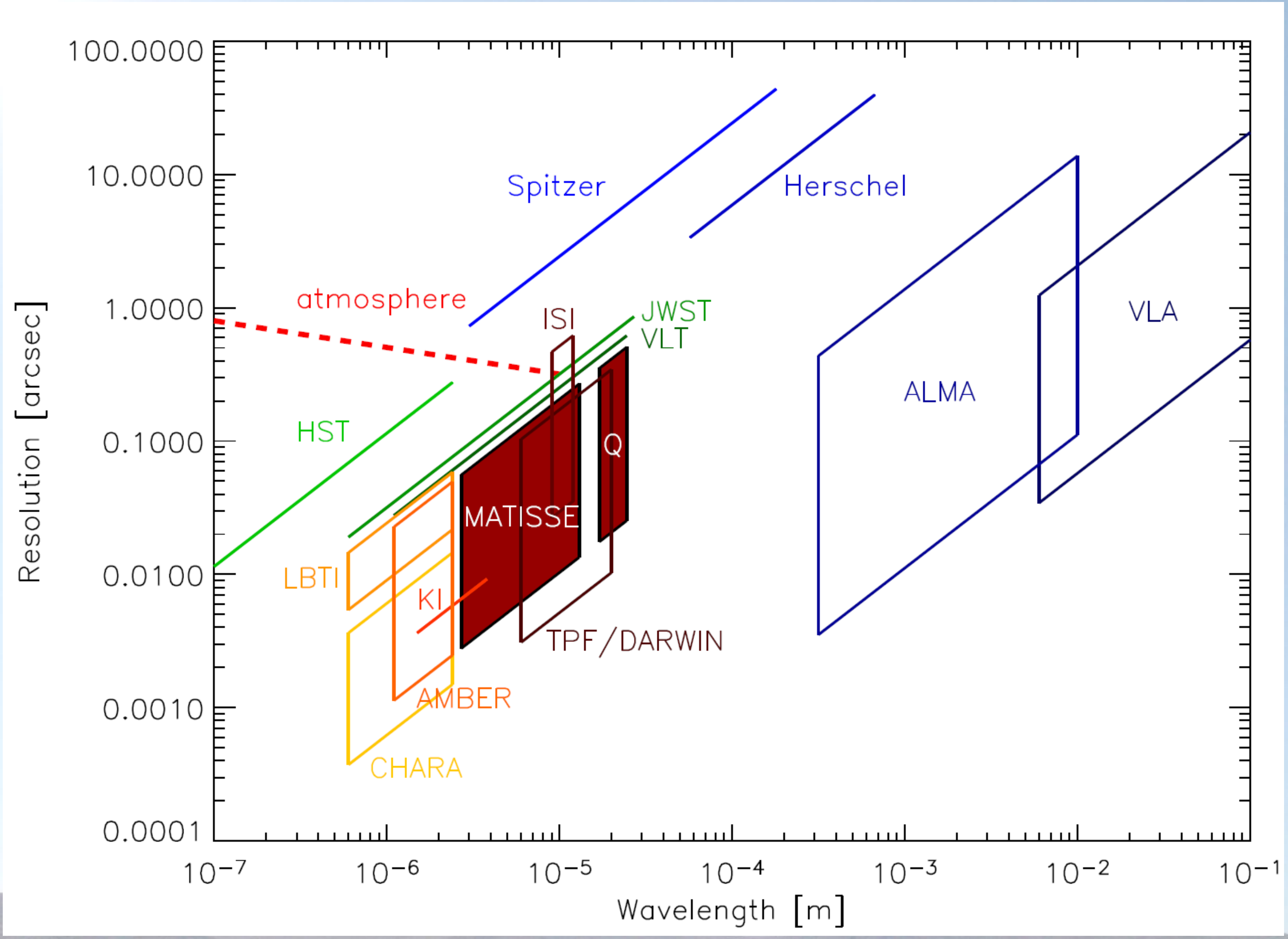
Jumping to 4 Telescopes: the next big step

- 2 Telescopes: 1 V^2, 1 DP = 2 M
- 3 Telescopes: 3 V^2, 3 DP, 1 CP = 7 M
- 4 Telescopes: 6 V^2, 6 DP, 3 CP, 1 CA = 16 M
- 6 Telescopes: 15 V^2, 15 DP, 10 CP, 5 CA = 45 M

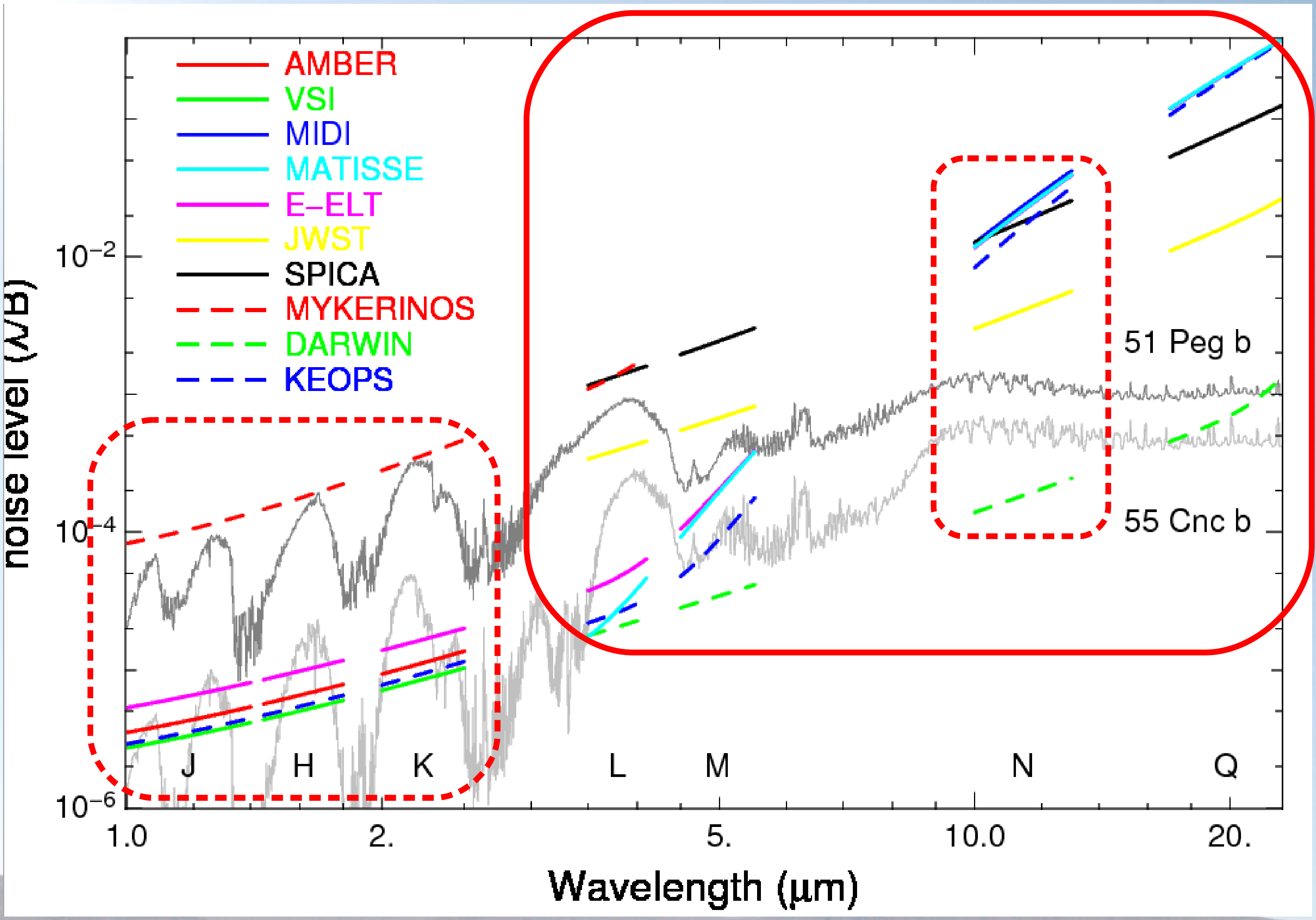
Nr of measurements scales with the square of Nr of telescopes

Going from 3 to 4 telescopes more than doubles the number of available measurements

What wavelength range?



What wavelength range?



MATISSE

Multi AperTure mid-Infrared SpectroScopic Experiment

PI : Bruno Lopez
PS : Sebastian Wolf
PM : Pierre Antonelli

- **Imaging capabilities in the N band (4T)**
- **Opening the spectral windows L&M**

MATISSE

Multi AperTure mid-Infrared SpectroScopic Experiment

- Observatoire de la Cote d'Azur, Nice, France
- MPI for Astronomy, Heidelberg, Germany
- MPI for Radioastronomy, Bonn, Germany
- Leiden Observatory, The Netherlands
- ASTRON Dwingeloo, The Netherlands
- Astronomical Institute Amsterdam, The Netherlands
- Torun Centre of Astronomy, Poland
- Konkoly Observatory, Budapest, Hungary

+ individual contributions

Information about MATISSE

Webpage:
http://www.oca.eu/matisse/index.html

Articles
- Lopez et al. 2008, SPIE
http://hal.archives-ouvertes.fr/hal-00335606/fr/
- Lagarde et al. 2008, SPIE
- Hoffman et al. 2008, SPIE

What science with MATISSE?

- Planet formation
- Star formation
- Circumstellar disk evolution
- Active Galactic Nuclei (AGNs)
- Extrasolar planets
- Solar system minor bodies
- Dust and wind from evolved stars

Expected science on YSOs

[1] What is the surface brightness profile in circumstellar disks around T Tauri HAeBe stars ?

(whatever the inclination of the source, and particularly for the optically thin case)

[2] Does the brightness profile show evidence for dust grain growth and sedimentation ?

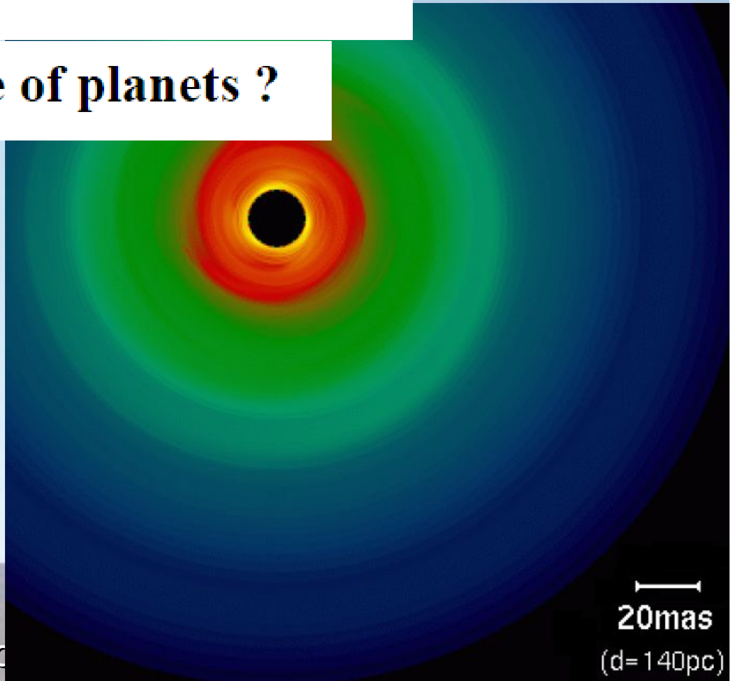
(based on the accurate differential comparison between reconstructed images or visibilities in continuum and amorphous/crystalline bands)

[3] Is the inner disk structure modified by early stages of planet formation ?

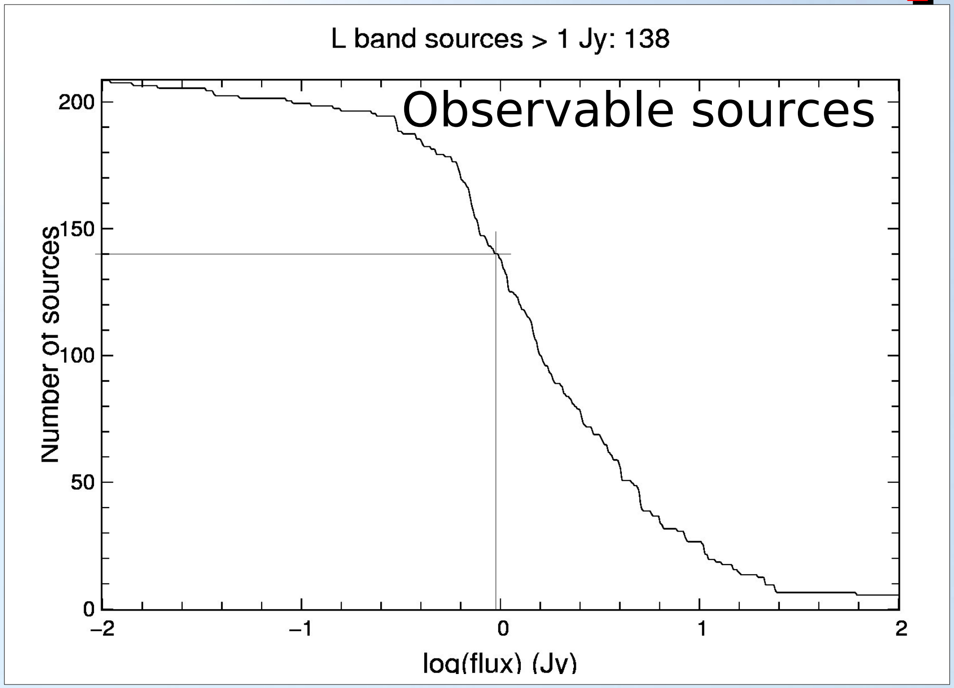
[4] Is there indirect or even direct evidence for the presence of planets ?

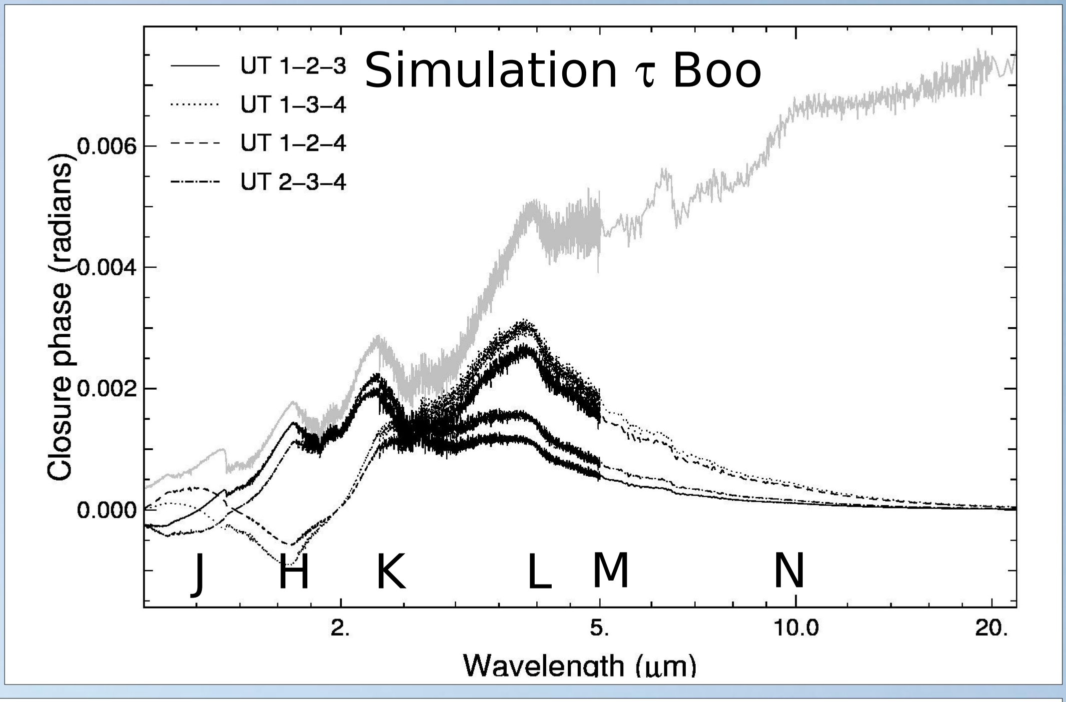
From Lopez et al. 2008, and science group document.

Simulation from Wolf & Klahr →



Exoplanets

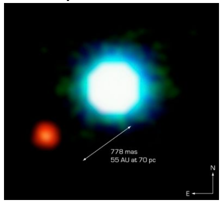




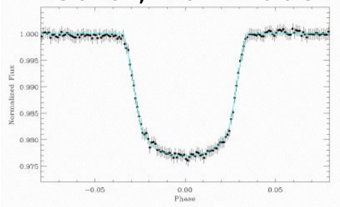
High angular resolution + high dynamic range

– ***Optique adaptative / Coronographie :***
ρ > 100 mas, i quelconque, spectre & masse planètes "éloignés"

NACO, A&A 2006

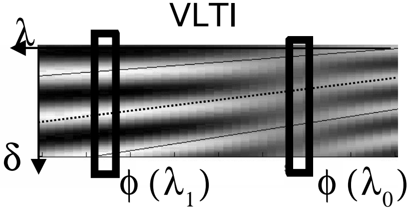


Corot, A&A 2008



– ***Transits :***
i >80°, spectre, masse et diamètre planètes "proches"

VLTI



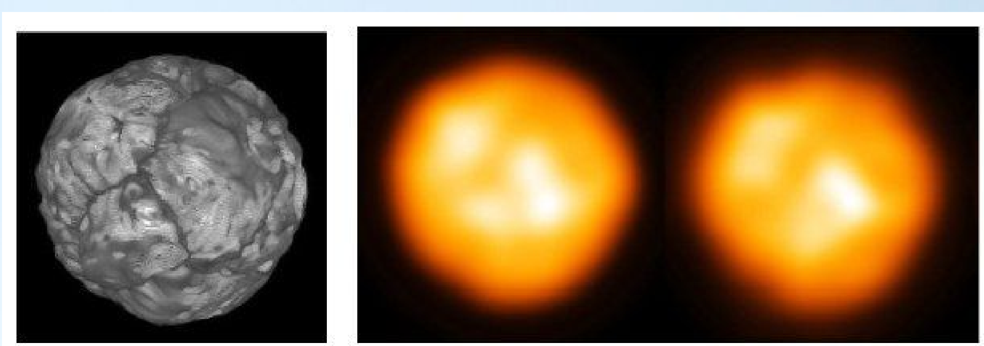
– ***Interférométrie différentielle :***
2 mas < ρ < 20 mas, i quelconque, spectre & masse planètes "proches"

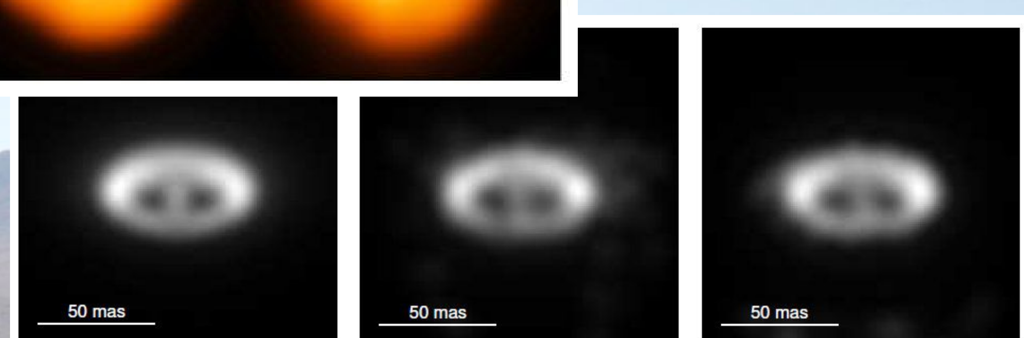
➔ **techniques complémentaires**

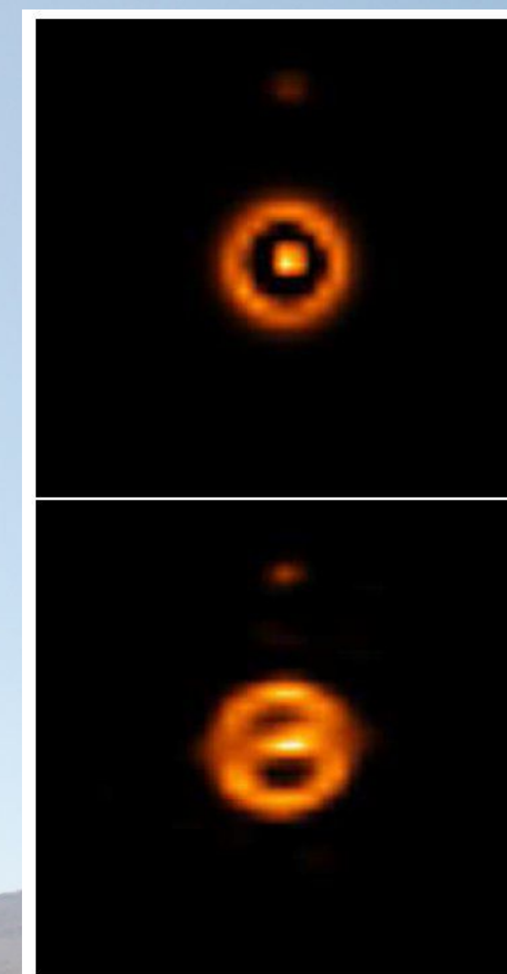
Image reconstruction tests

From the MATISSE science case, summarised in Hoffman et al. 2008, SPIE

- Given 3 nights with 3 different AT configurations
- Need of a fringe tracker
- Size of target: min 14 mas, max 120 mas
- V^2 errors of 5-10% → Images errors of 10-15%







The core of MATISSE

The instrument concept / system design of MATISSE is optimized with respect to the following goals:

Priority 1 : Multispectral imaging

Priority 2 : Simultaneous observations in L&M and N band

Challenges:

- 4 telescopes in the mid-infrared
- Synchronised LM/N Bands
- One band “master“, one “slave“

Maximum Spatial Resolution

Band	Usage of ATs	Usage of UTs
L	3 – 4 mas	6 mas
M	5 mas	8 mas
N	10 mas	16 mas

[A.2] Spectroscopic Resolution

Three different spectroscopic resolutions were identified in order to allow the investigation and characterization of selected prominent gas and dust emission features:

Bands	Spectral Resolution ($\lambda/\Delta\lambda$)	Application
L&M / N	30 / 30	Amorphous dust emission features
L&M / N	500 / 250	Crystalline dust emission features
L&M	750 – 1500	Molecular bands; Selected atomic lines

What sensitivity?

Close to current MIDI sensitivity limits

L band

	N coherent flux limit		L coherent flux limit	
	UT	AT	UT	AT
Without fringe sensing or tracking	0.4 Jy N=5	8 Jy N=1.7	0.03 Jy L=9.9	0.6 Jy L=6.7
With internal L band fringe sensing	0.04 Jy N=7.2	1 Jy N=4	0.03 Jy L=9.9	0.6 Jy L=6.7
With external on-axis K band fringe tracking	0.02 Jy N=8.2	0.4 Jy N=5	0.02 Jy L=10.4	0.4 Jy L=7.1
With external off-axis K band fringe tracking	0.02 Jy N=8.2	0.4 Jy N=5	0.001 Jy L=13.6	0.02 Jy L=10.4

Fringe tracking is crucial for sensitivity:
-Internal in L band,
-External K band specialized fringe tracker recommended

'PRIMA' mode

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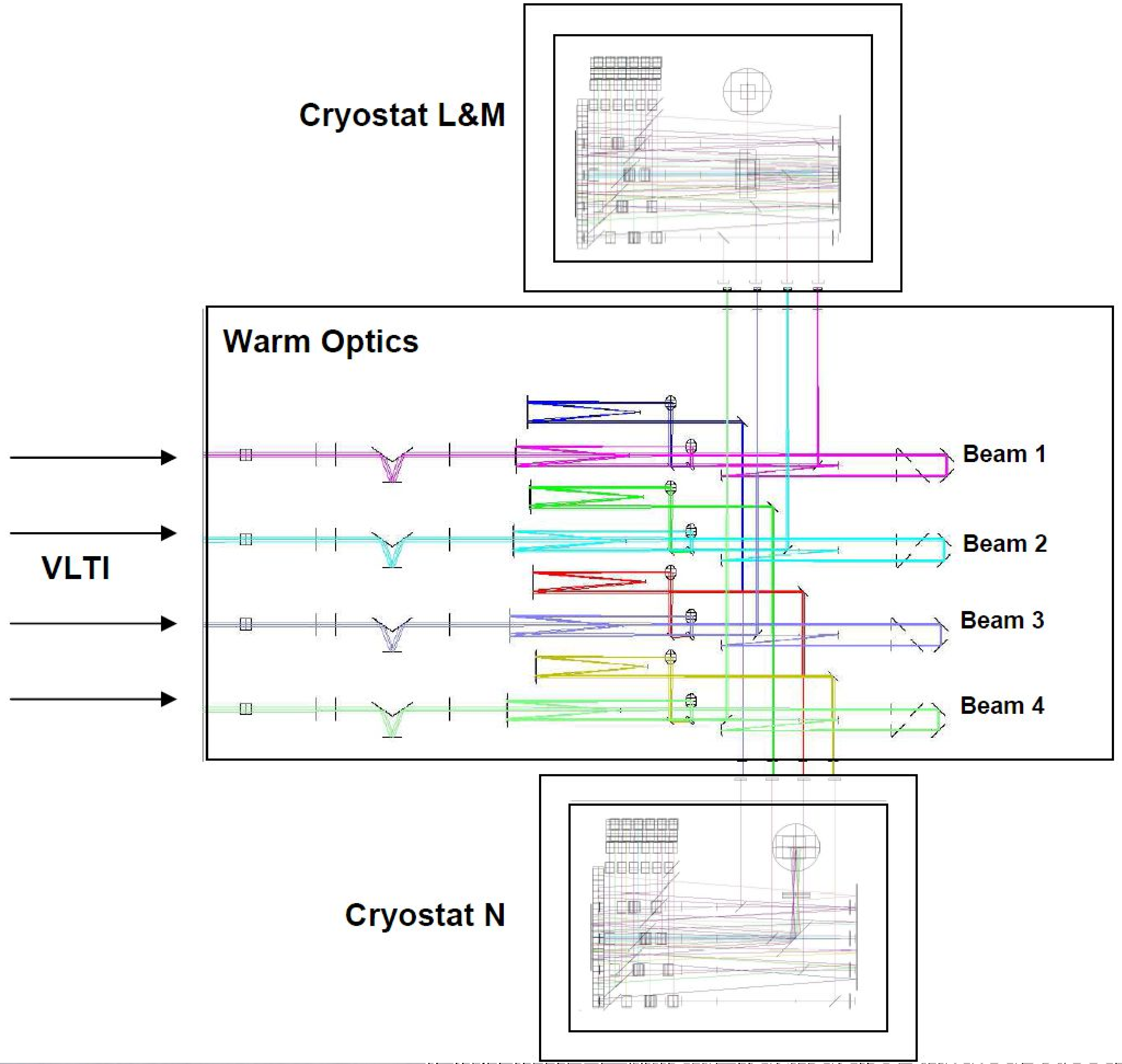
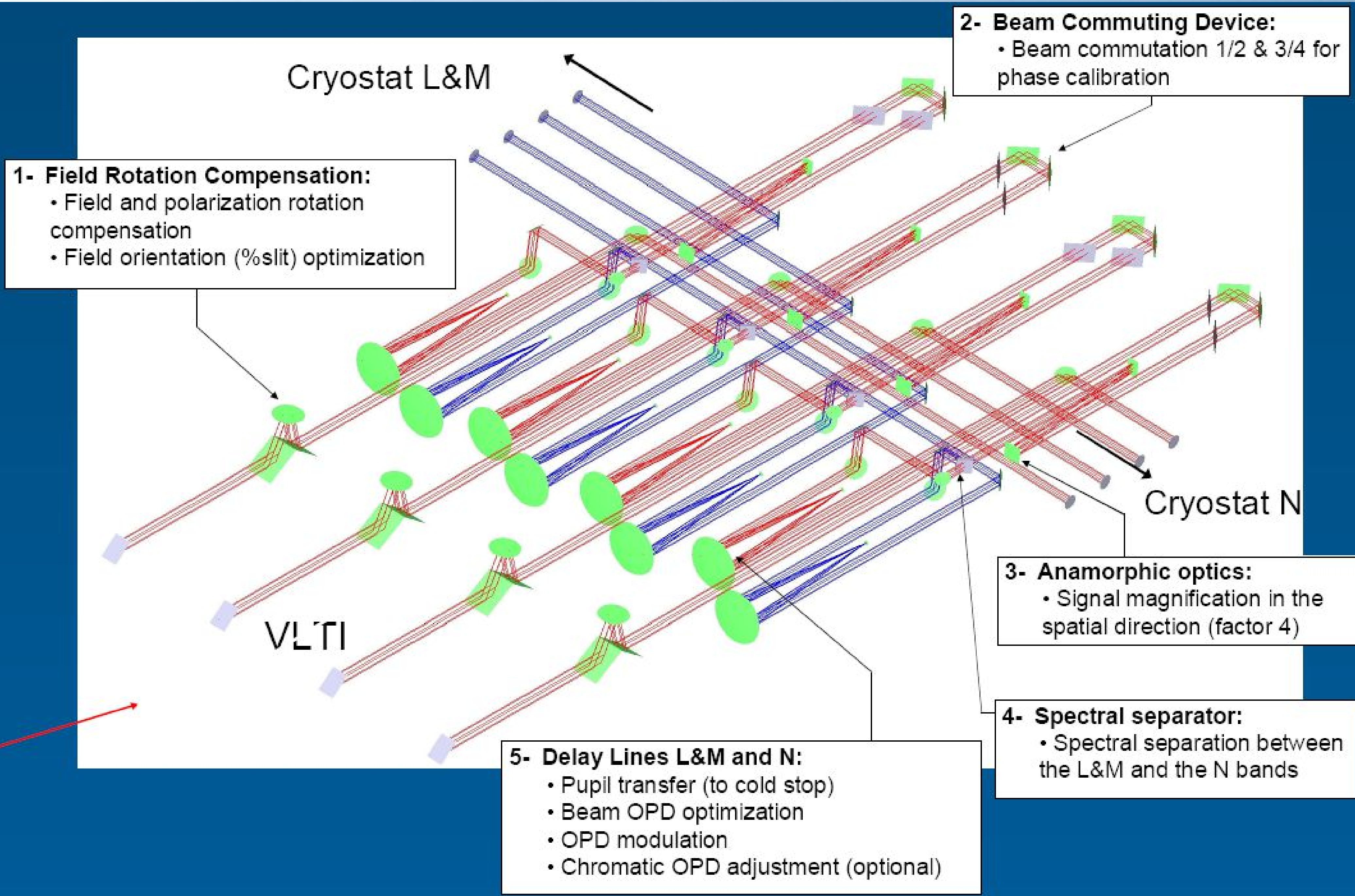
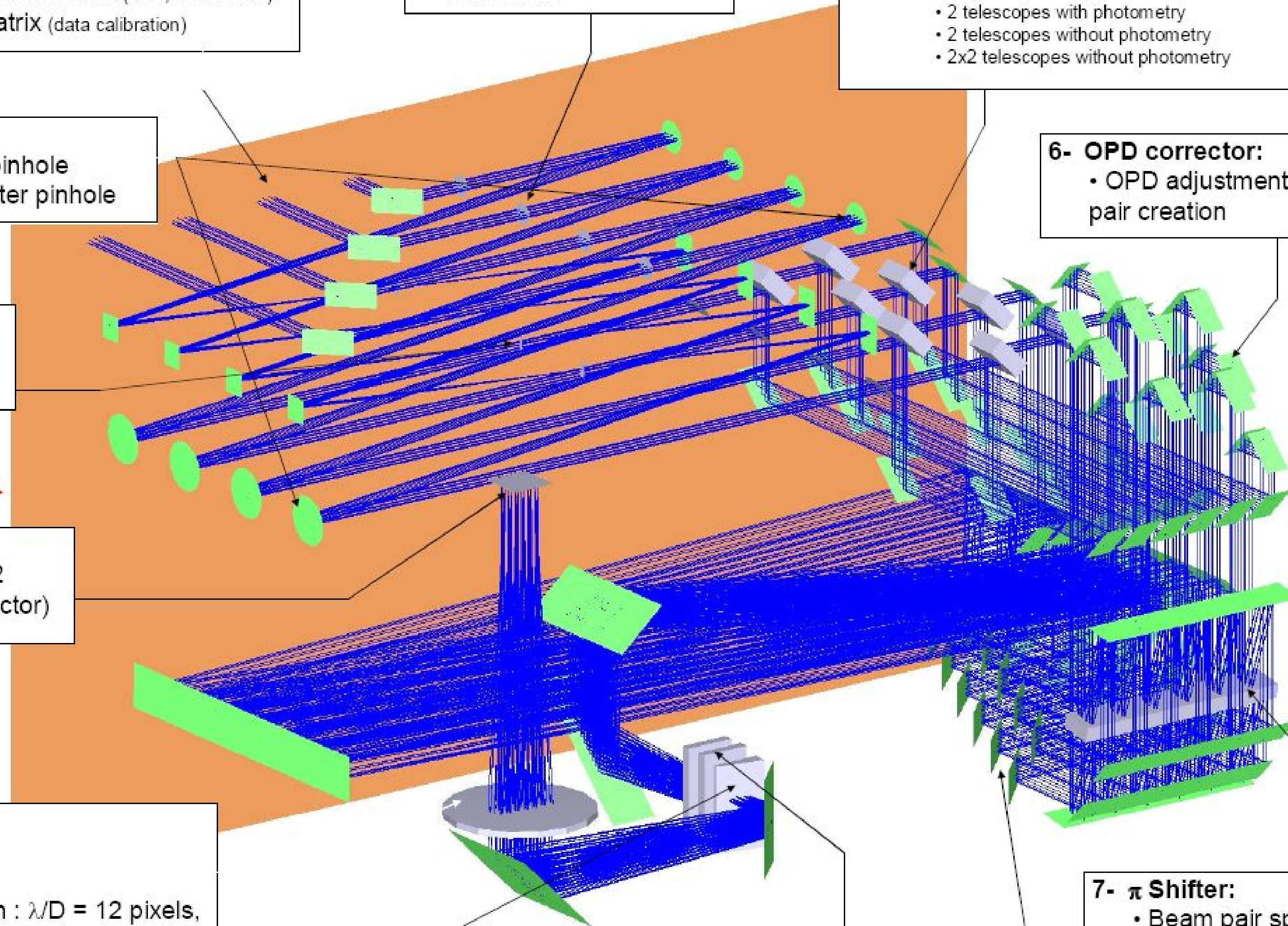

Cryostat L&M
Warm Optics
VLTI
Beam 1
Beam 2
Beam 3
Beam 4
Cryostat N



Cryostat L&M
2- Beam Commuting Device:
• Beam commutation 1/2 & 3/4 for phase calibration
1- Field Rotation Compensation:
• Field and polarization rotation compensation
• Field orientation (%slit) optimization
Cryostat N
VLTI
3- Anamorphic optics:
• Signal magnification in the spatial direction (factor 4)
4- Spectral separator:
• Spectral separation between the L&M and the N bands
5- Delay Lines L&M and N:
• Pupil transfer (to cold stop)
• Beam OPD optimization
• OPD modulation
• Chromatic OPD adjustment (optional)

MATISSE COLD OPTICS



1- Shutter:
- Beam selection
- Detector Calibration (dark, remanence)
- Kappa Matrix (data calibration)

2- Pupil Mask:
- Thermal background reduction

3- Re-Imager:
- Beam focusing on pinhole
- Beam collimating after pinhole

4- Pinhole/slit slider:
- Spatial filtering
- Spectrograph slit

5- Pair Creator:
- Creation of beam pairs (split the 4 beams in 6 pairs) – 5 observation possibilities:
  - 4 telescopes without photometry
  - 3 telescopes with photometry
  - 2 telescopes with photometry
  - 2 telescopes without photometry
  - 2x2 telescopes without photometry

6- OPD corrector:
- OPD adjustment after the pair creation

7- π Shifter:
- Beam pair splitting in 2 parts with a π phase between them

8- Image positioning device:
- Positioning of the 12 images at different detector locations

9- Filters and polarizers:
- Spectral filtering (acquisition, thermal background reduction, spectral superimposition elimination)
- Polarization selection

10- Dispersive Optics:
- Spectral Dispersion
  - R (L band) =30 / 300 / 1000
  - R (N band) = 30 / 300

11- Camera Optics:
- Beam combination
- Signal sampling:
  - spatial direction : λ/D = 12 pixels, λ/B = 4 pixels
  - spectral direction : λ/D = 3 pixels

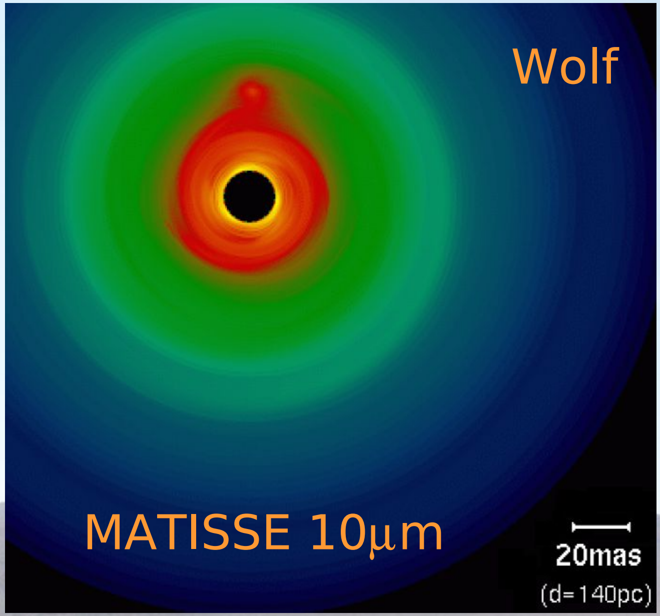
12- Detector:
- Signal detection (12 images on each detector)

MATISSE and ALMA

MATISSE

- Robust Imaging 4UTs/4ATs
- typical 5-40mas resolution
(Baselines from 8m to 150m)
- Wideband Coverage: LM and N simultaneously (3.7-5μm, and 8-13μm)

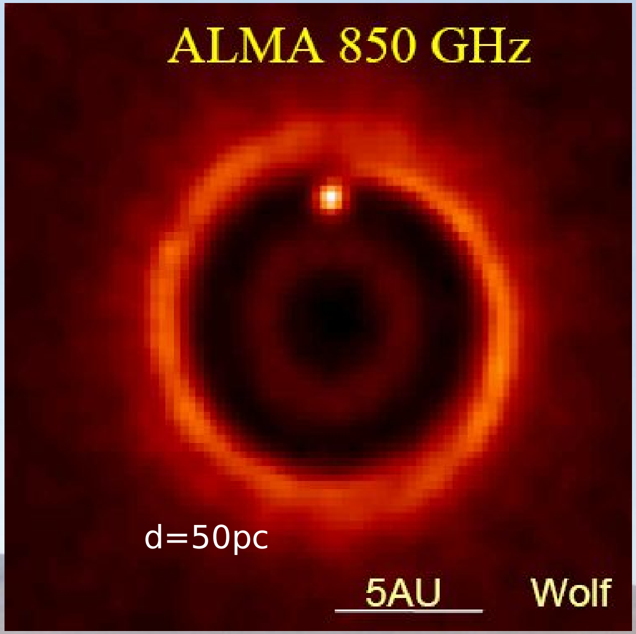
- Full operations: 2014-2015



ALMA

- High Fidelity Imaging (54 antennas).
- 20-40mas resolution
(Baselines from 150m to 15km)
- Wideband Frequency Coverage
(for radio…)
- Submillimeter Receiver System.
- Full Polarization Capability.
- System Flexibility.

- Full operations: 2013-2014



MATISSE timeline

Design préliminaire 2009	Design final	Intégration	Acceptance Europe	Première lumière 2015

Construction and integration

Cold Optics: built at Astron/Dwingeloo, Netherland
Warm Optics: built at OCA, France

Cryostats: Built and integrated with cold optics at MPIA, Heidelberg,

N band Detector: controller developed at ESO and detected tested at MPfIr, Bonn and ESO

Final integration; testing and acceptance Europe: OCA, France

MATISSE Kick-Off meeting 20-21 November, Nice

MATISSE Preliminary Design Review in mid-2009, Nice

The first fringes may be recorded in 2014

Thanks! Questions?