PIONIER

Precision Integrated Optics Near-infrared
Imaging ExpeRiment
a visitor instrument for the VLTI

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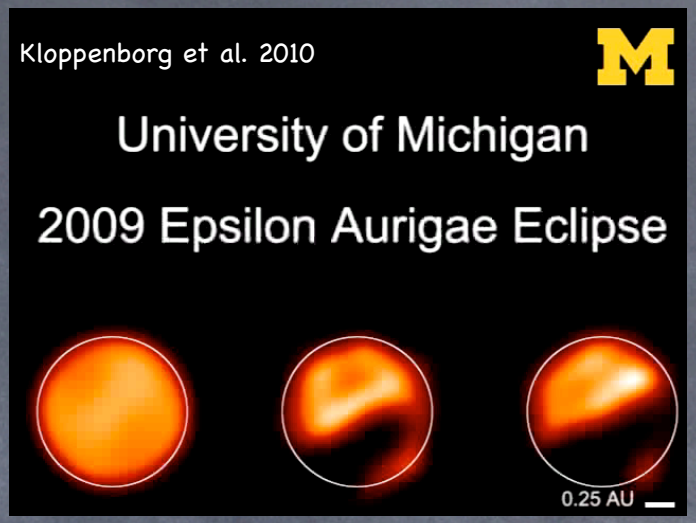
ESO-Vitacura
August 24 th 2010

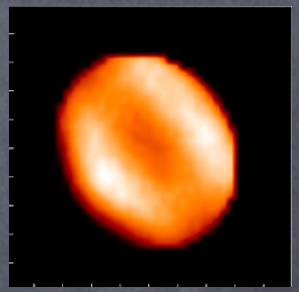
Context and motivation

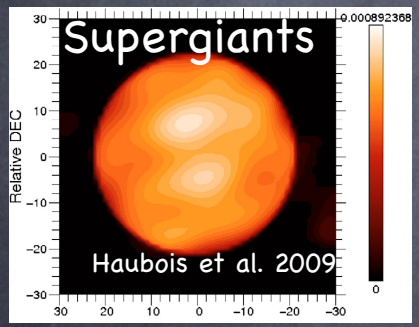
Motivation: imaging with interferometers is finally there



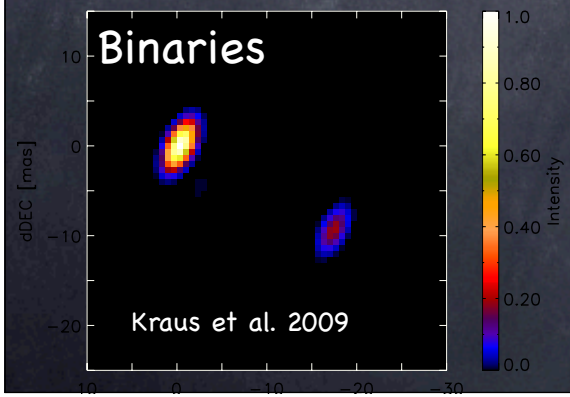
Rapid rotators

ζ Andromeda

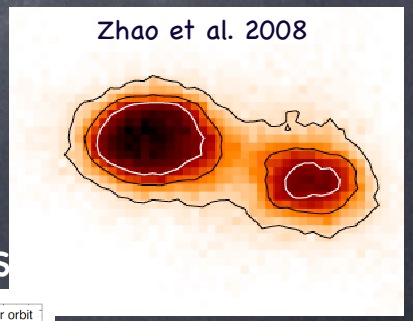


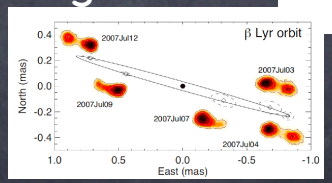


- MIRC/CHARA and VLTI/AMBER have recently produced scientifically meaningful images;
- MIRC/CHARA work has shown that 4T operation adds real scientific value to the image;

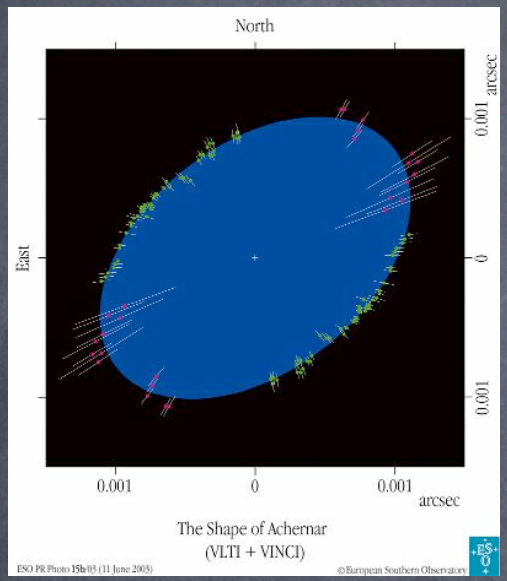


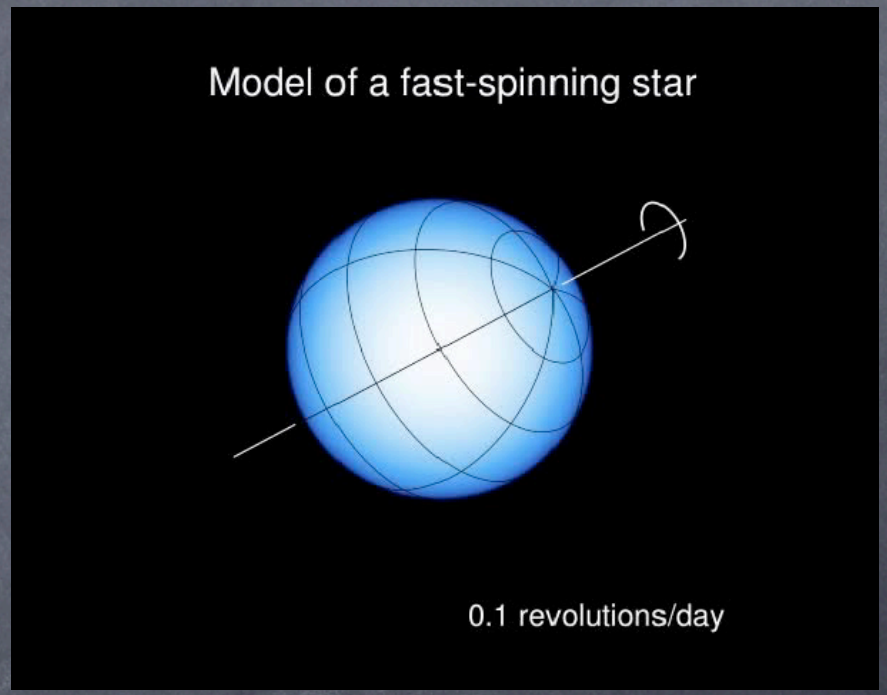
Interacting binaries



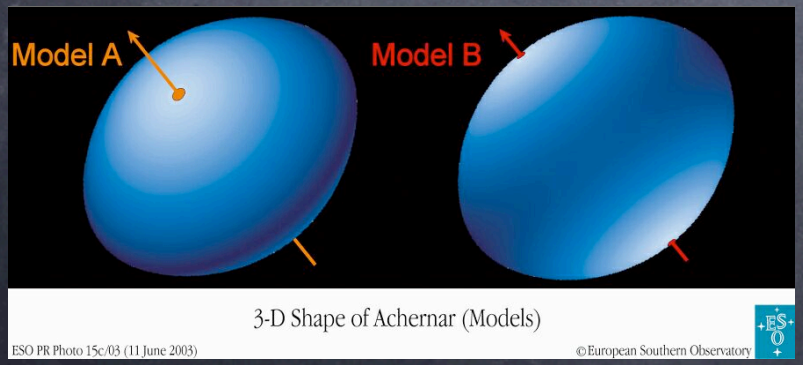


How to get to an image ?



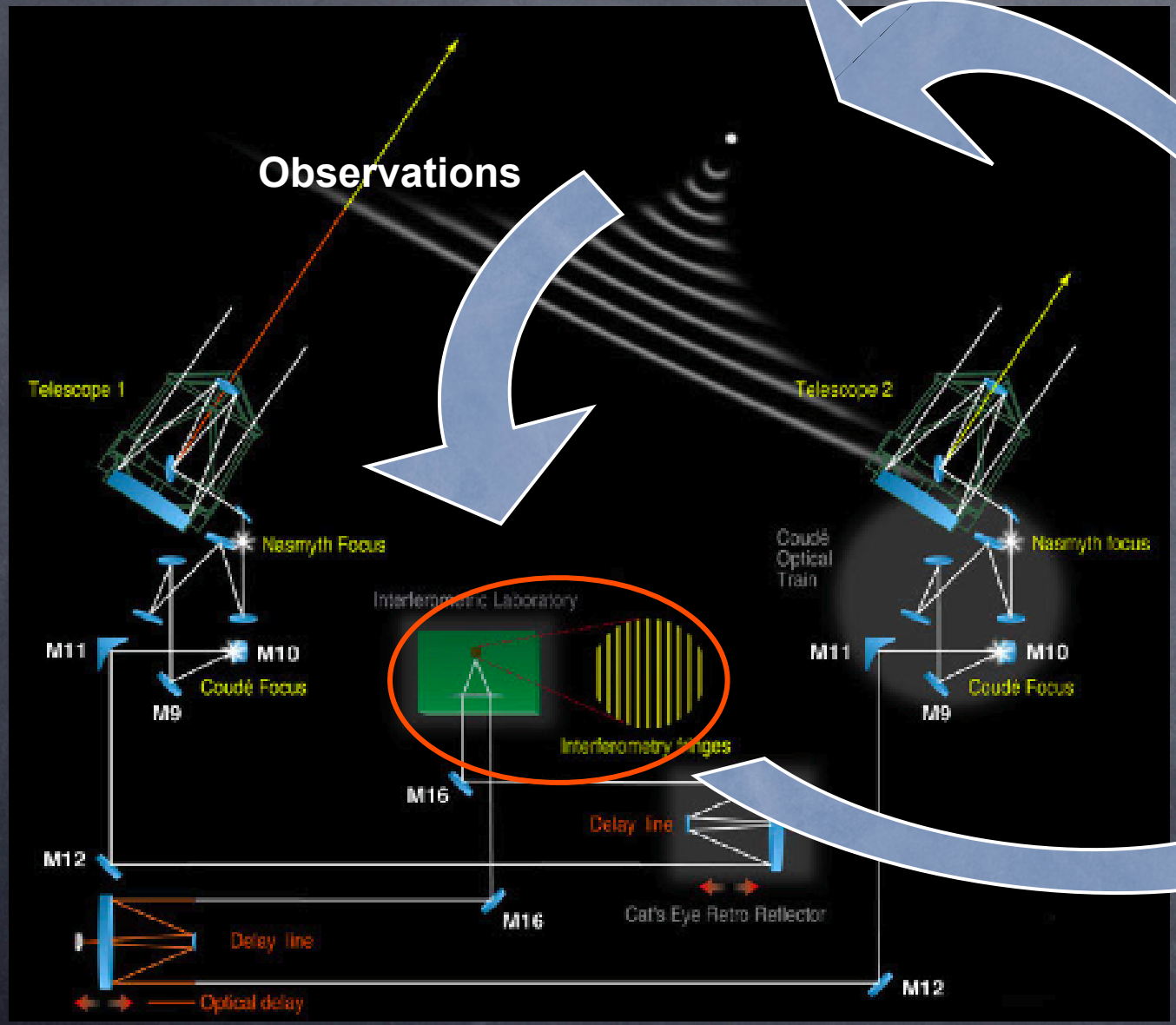


Monnier et al. Science 2007



Armando Dominiciano et al (2003)

La réduction des données

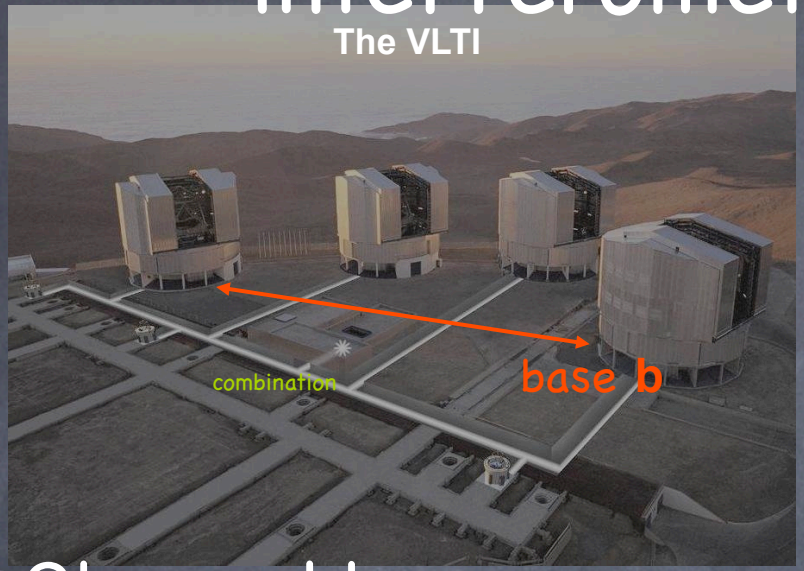


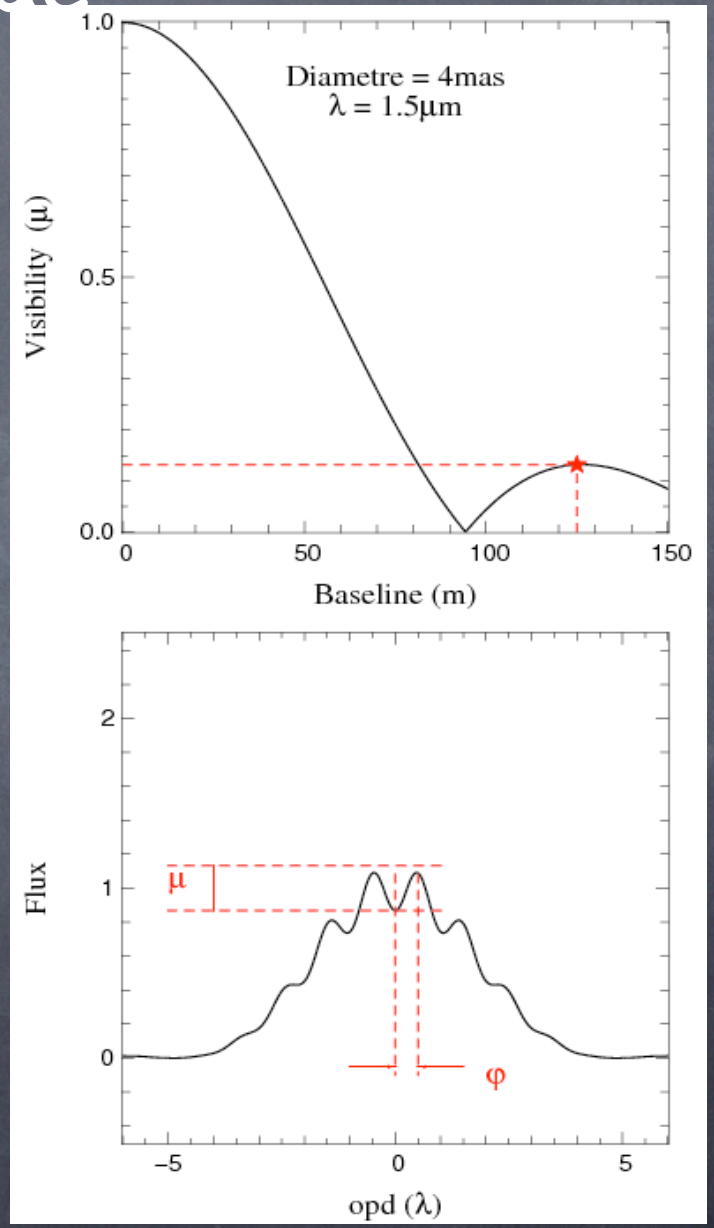
Analyse des données

visibilities μ
phases φ

Réduction et données et étalonnage

Le principe d'une observation interférométrique

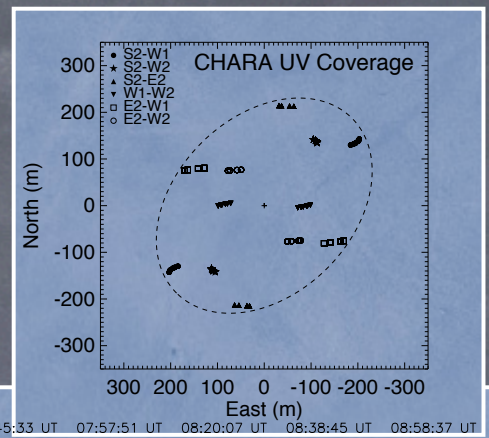


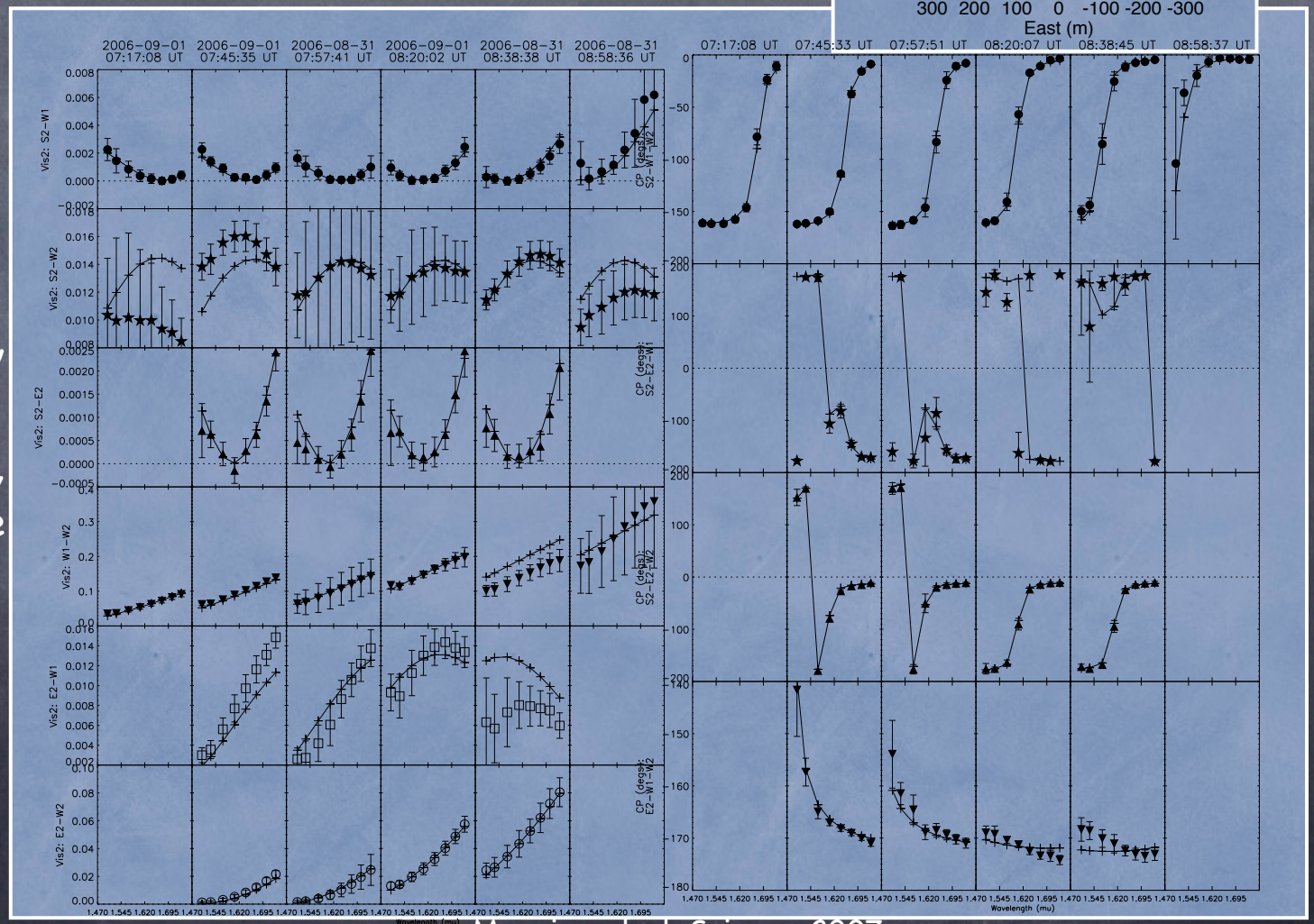


- Observables interférométriques
  - visibilité μ et phase φ
  - dépendent de la répartition d'intensité de l'objet:

$$\mu\, e^{i\varphi} = TF\{\text{ objet }\}\,(b/\lambda)$$

The case of ALTAIR





Monnier et al. Science 2007

- "Good" uv coverage
- Object clearly spatially resolved;
- Sufficient visibility, closure phase, triple amplitude precision

Image reconstruction

- Image reconstruction algorithm proceed with a minimization of a function involving the data and weighted a priori information.

$$\boldsymbol{x}_{\text{best}} = \arg\min_{\boldsymbol{x}\in\boldsymbol{\Omega}} \left[f_{\text{data}}(\boldsymbol{x};\boldsymbol{y}) + \mu\, f_{\text{prior}}(\boldsymbol{x}) \right]$$

Table 1 Comparison of the image synthesis algorithms used in optical interferometry.

Code name	Data	Regularization	Optimization Strategy
MiRA	any	positivity, TV, ℓ_2, ℓ_2–ℓ_1, Gull-Skilling entropy with floating or given prior image	limited memory quasi-Newton with bound (positivity) and normalization constraints
BSMEM	bispectra, power spectra, complex visibilities	Gull-Skilling entropy with given prior image, multi-scale entropy	non-linear conjugate gradients with unsupervised hyper parameter control
WISARD	pseudo-complex visibilities formed from phase closures and power spectra	positivity, ℓ_2, ℓ_2–ℓ_1	alternative minimization and self calibration
BBM	bispectra	positivity, sparseness	matching pursuit
MACIM	any	any	global optimization by simulated annealing

What is PIONIER ?
Why proposing it now ?

- PIONIER is a proposition for a simple instrument 4 beam combining imaging capability (MIRC/CHARA) and Precision (VINCI) at VLTI.
- There is a window of opportunity for highly rewarding science at VLTI that is complementary to current instrumentation capabilities;
- Competition is strong and active NOW.

History

- First idea: Marseille 2008
- Decision to go: December 2008 once agreement with W. Traub (JPL) and Rafael Millan-Gabet secured
- December 2008 first contacts with ESO Paranal/Garching
- Feb 2010: transfert of PIship: JP Berger -> JB Lebouquin
- November 2009: ESO STC go-ahead

Pionier Science Objectives

The proposing team

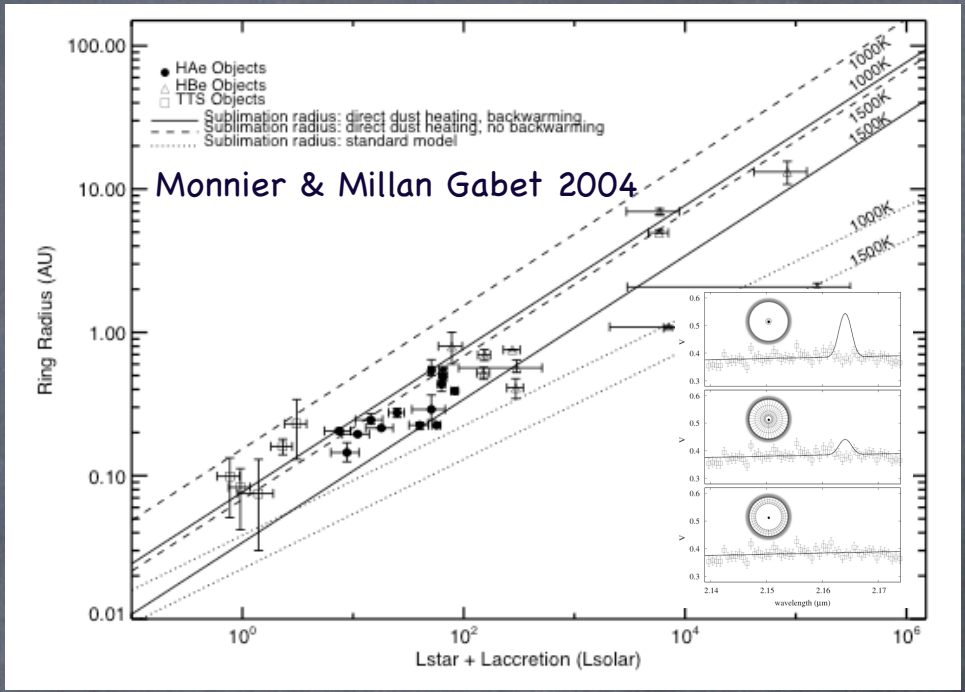
- Star and planet formation team at LAOG (FOST) with support from the Instrument development team (CRISTAL) at Grenoble
- Rafael Millan-Gabet (Caltech), W. Traub (JPL)
- O. Absil (U. Liège)
- external collaborators

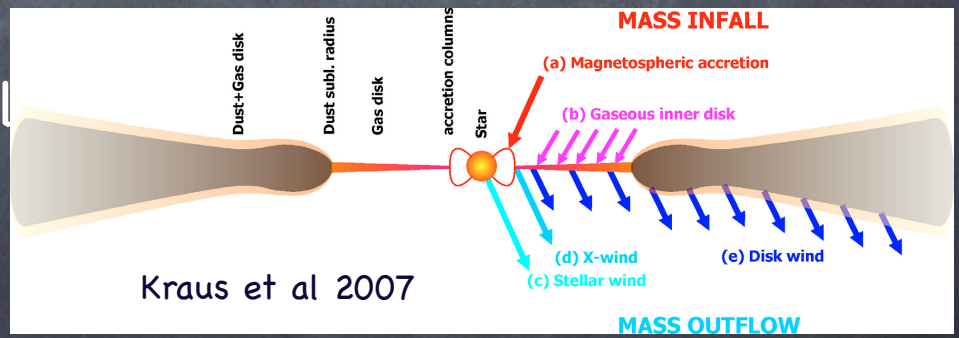
Main astrophysical interest:
The study of young stars environments at the AU scale

1. Direct imaging of the inner boundaries of disks around Herbig AeBe stars;
2. Solving the T Tauri size/luminosity enigma;
3. Studying the interaction of young multiple systems with their environment
4. Revealing the structure of debris-disk hot dust component
5. Detecting directly one hot Jupiter
6. But also: interacting binaries, stellar surfaces ...

The Herbig AeBe inner disk paradigm

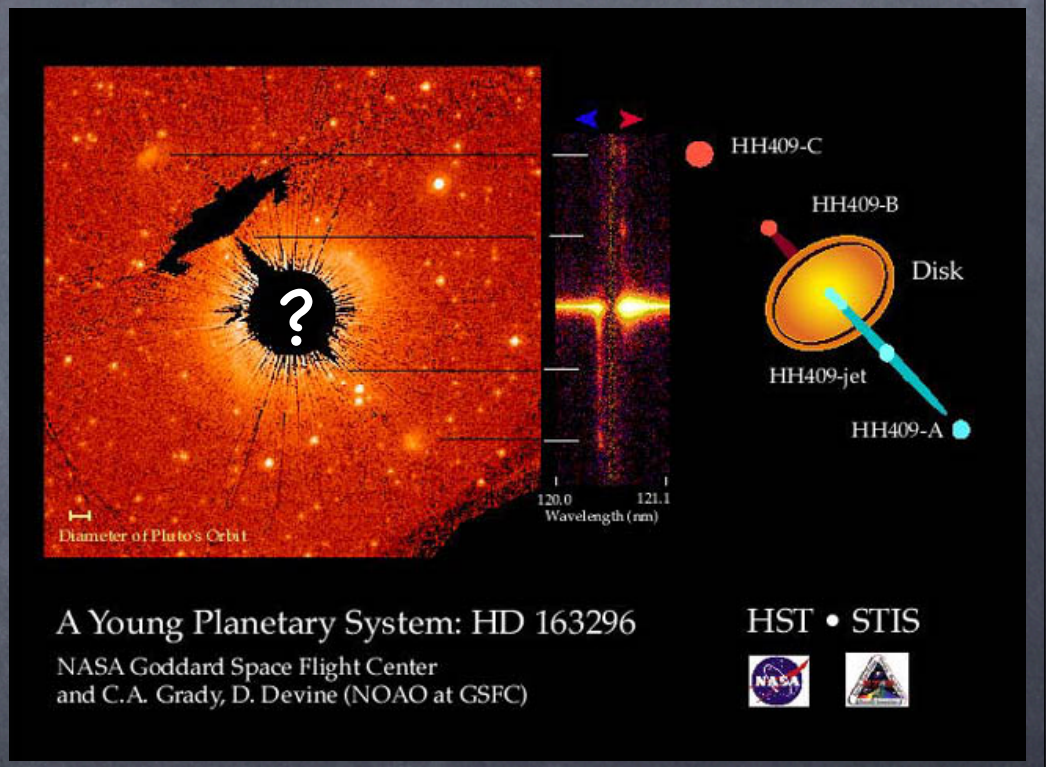
- Interferometry pinpoints the AU scale emission (planet formation): important reforms of the disk paradigm
- however mostly size determinations: degenerate solutions
- AMBER is now a major actor in that field (spectral resolution)
- next major step: imaging





The Herbig AeBe inner disk paradigm first AMBER image reconstruction attemps

- GOAL: probing the inner astronomical unit of protoplanetary disks:
  - constraining the disk structure ?
  - revealing the nature of the putative dust "inner rim"
  - Probing the link between accretion&ejection, disk&wind&&jet



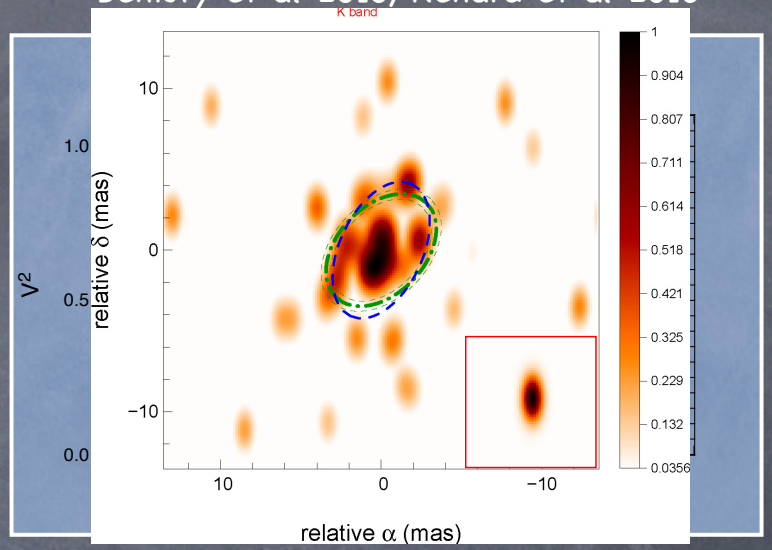
MWC 275

Inner cavity material revealed: what is its nature, link with accretion ?

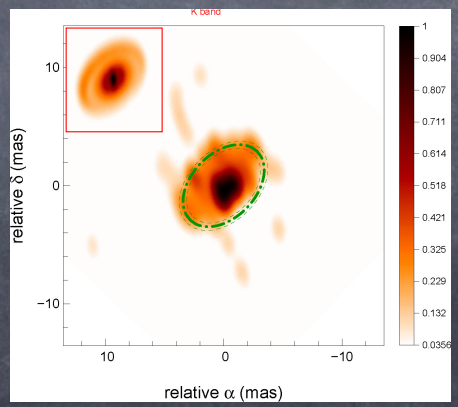
Limitations

- UV coverage
- Simultaneity
- Precision

Benisty et al 2010, Renard et al 2010

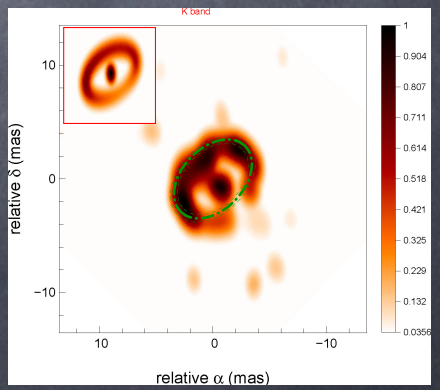


Refractory material and/or gas



Model

Material free cavity



Model

Image reconstruction: a subtle tweak...

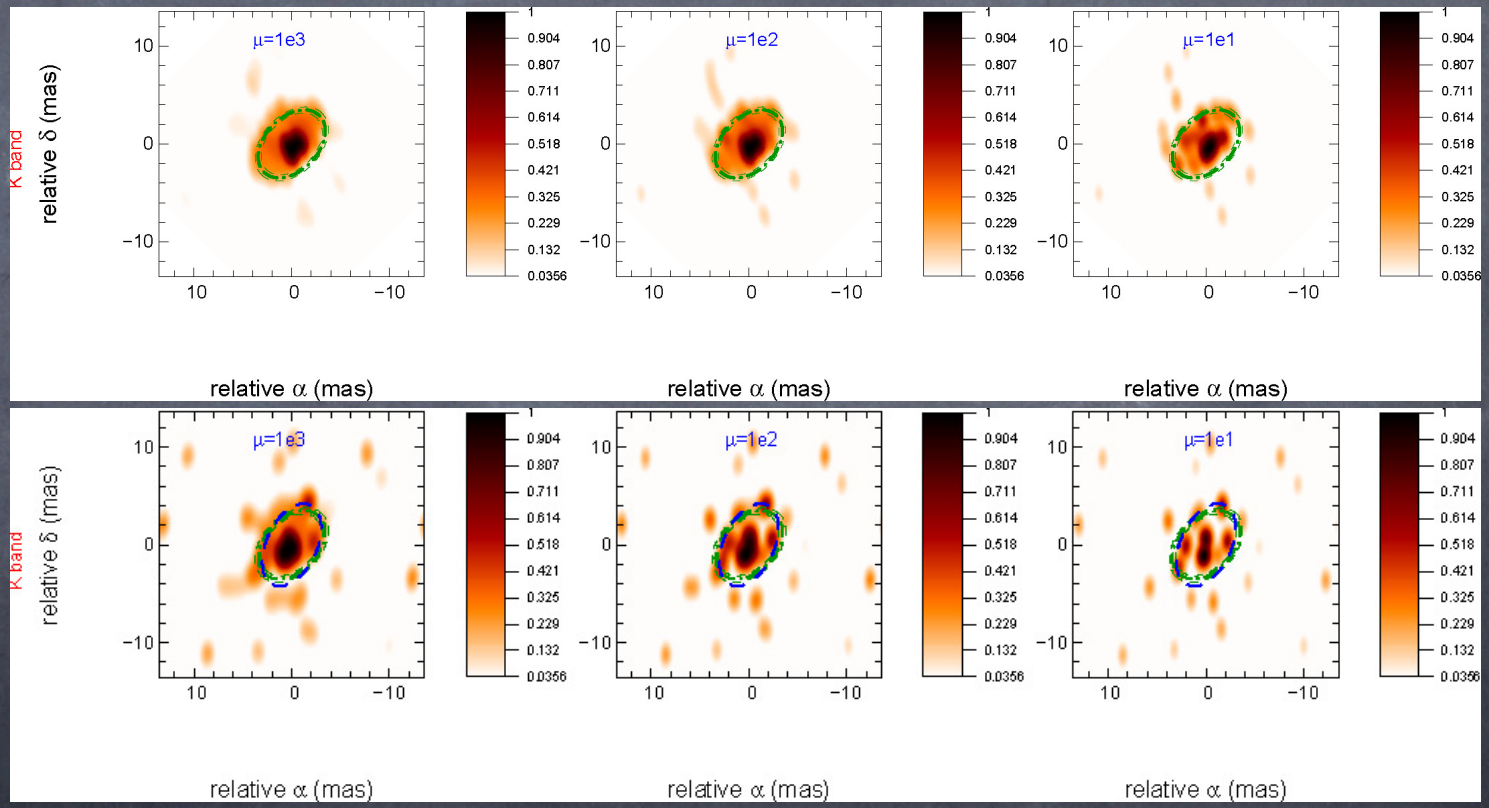
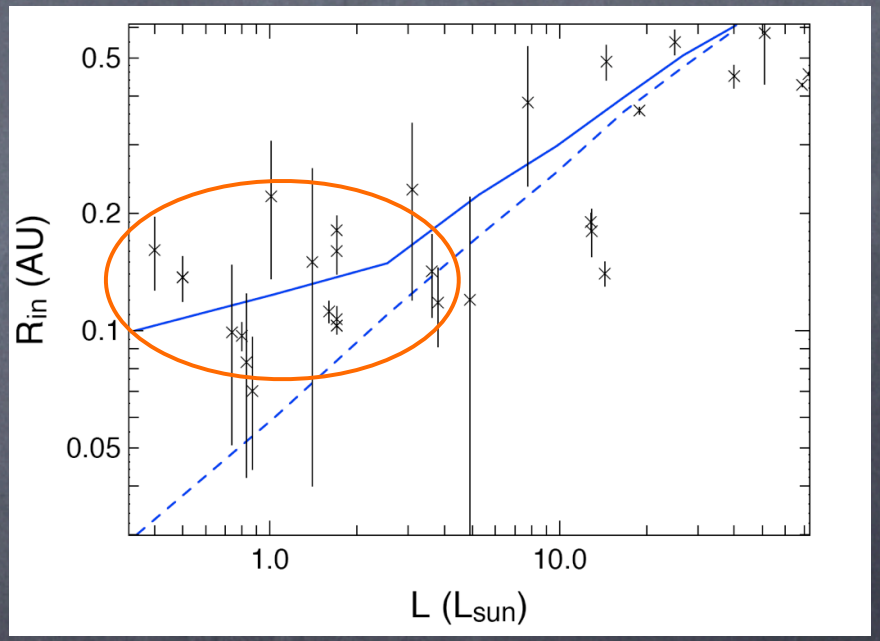


Fig. B.1. Reconstructed images of HD 163296 in the K band from simulated data of the B10 model (up) and from the real data (bottom), for 3 different values of the weight factor μ. conventions as in Fig. 1.

Solving the T Tauri size luminosity relation enigma

- Near-infrared emission in HAeBe is dominated by stellar reprocessing
- In T Tauri there are competing physical mechanisms at play;
- Extraordinary laboratory for inner AU disk studies in solar-analogs PMS
- Need for 10x increase in visibility precision

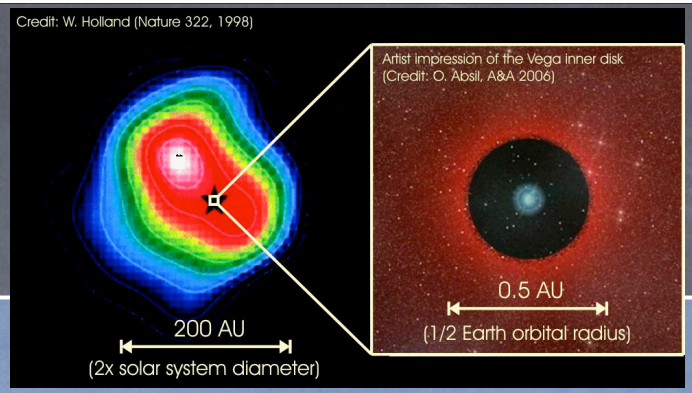
Accretion luminosity, thermal scattered emission, hot inner gas?

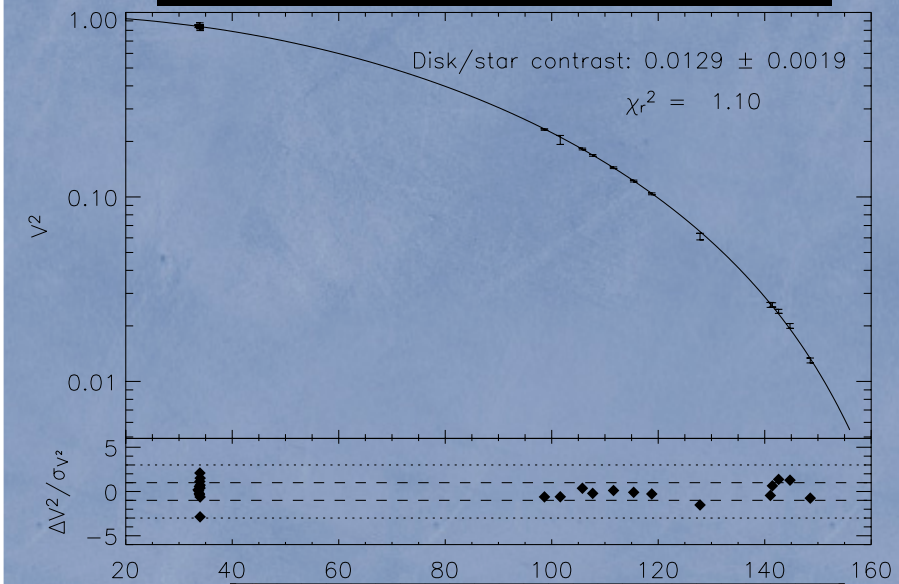


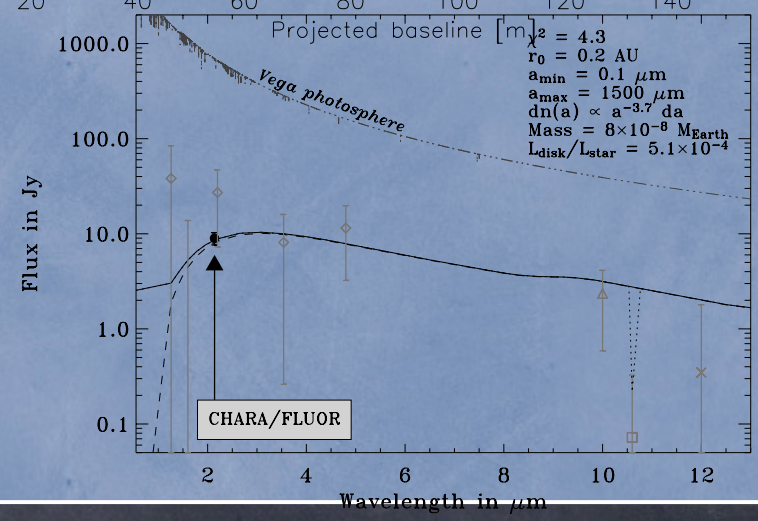
Pinte et al 2008

Debris disk

- Hot inner dust revealed by Fluor/ CHARA (Absil etal. 2006)
- Precision is key (small visibility deficit)
- Only a Vinci like instrument could reach those precisions

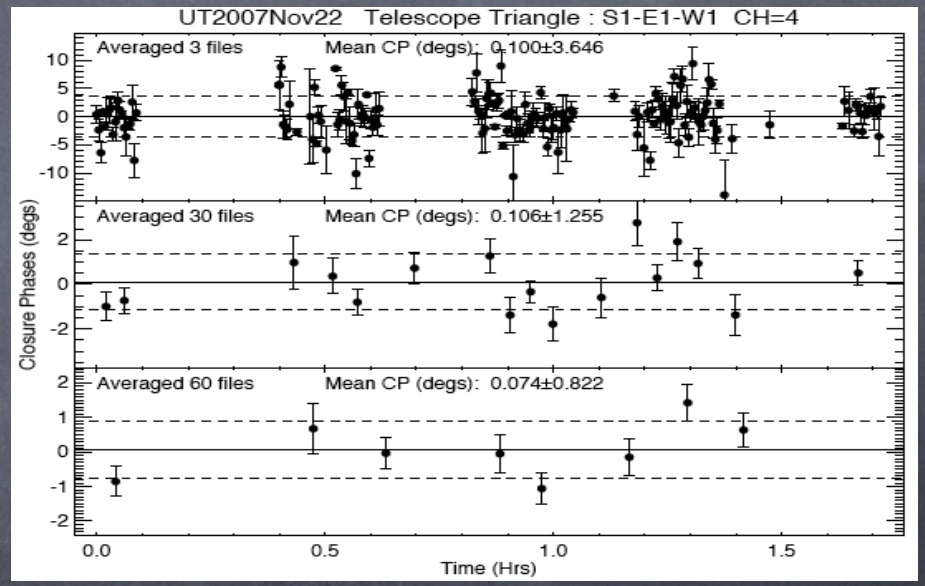






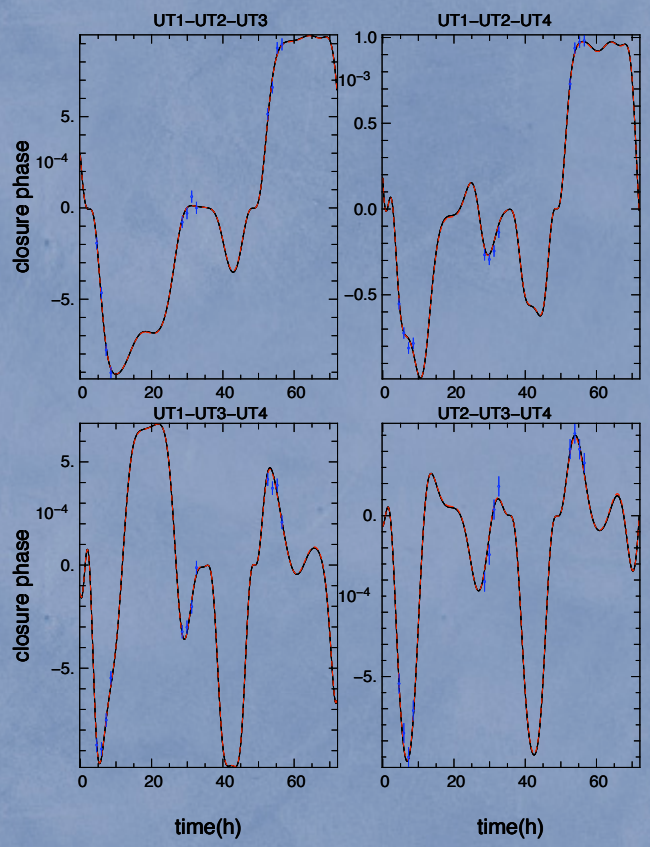
Hot jupiter direct detection ?

- 0.01 deg closure phase needed
- MIRC attempt (Zhao et al. 2008): sig = 0.06 need 6 x SNR improvement for 3 sig detection;



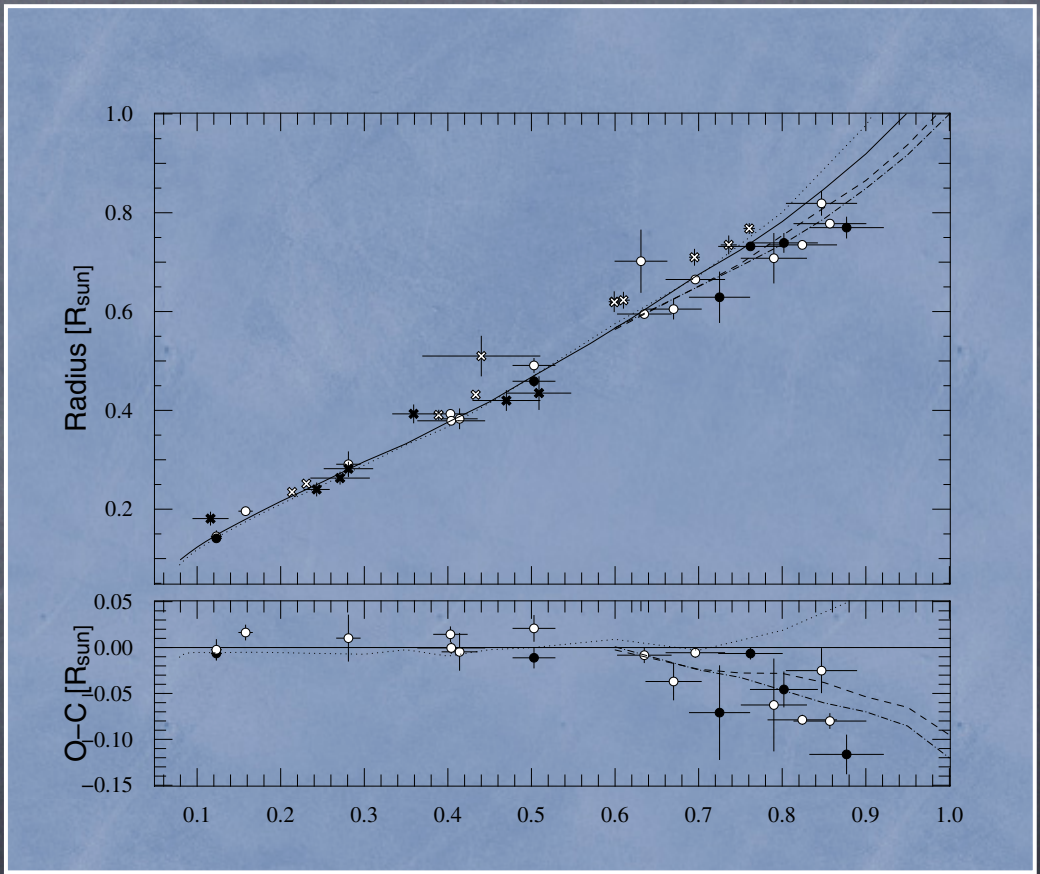
First image and nir spectrum of a Hot Jupiter orbiting its star ?

- 0.01 deg closure phase needed
- MIRC attempt (Zhao et al. 2008): sig = 0.06 need 6 x SNR improvement for 3 sig detection;
- PIONIER with UT can do it (in theory !)



Other potential science cases for which PIONIER brings new potential to VLTI

Science
Hot Jupiters
Protoplanetary disks
Debris disks
Interacting binaries
Cepheids
Rapid rotators
Supergiant hydrodynamics
Low-mass stars radius
Precise diameters



Demory et al 2009

Conclusion

- There is room for an instrument that combines imaging capability (4 telescope) and precision.
- Competition is good, strong and working NOW.
- Pionier/VLTI has a unique combination of good (u,v) coverage, sensitivity and precision

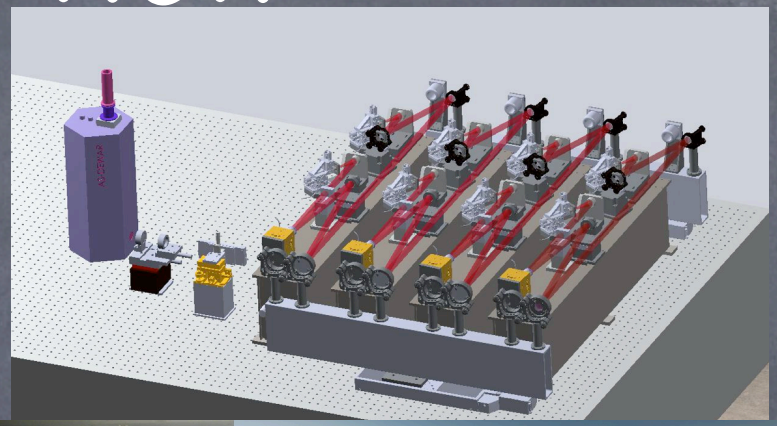
The project

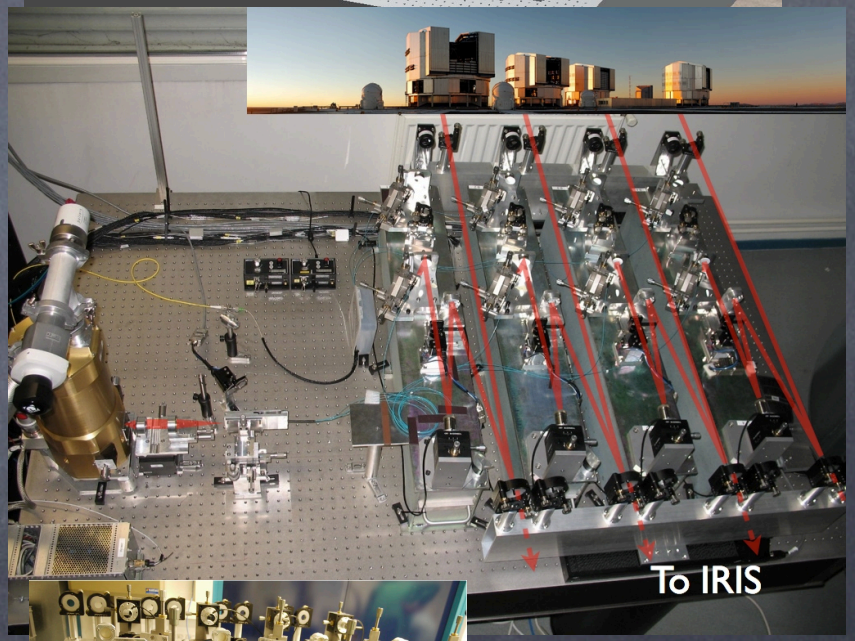
- "Off-the shelf" lightweight instrument
  - 4 way IO ABCD combiner (H and K)
  - infrared camera (scanning like Vinci, no FT)
- Spectral resolution: H or K broadband or R ~40
- VISITOR instrument to avoid to weight on ESO ressources and to guarantee two years perennial status;
- French side: no weight on financial or technical ressources devoted to Gravity/Matisse/VSI
- Installed Fall 2010 on VINCI table operated until 2012 (Gravity's arrival) hopefully more ...
- JB Lebouquin (PI), JP Berger (PS), G. Zins (PM), B. Lazareff (SI)

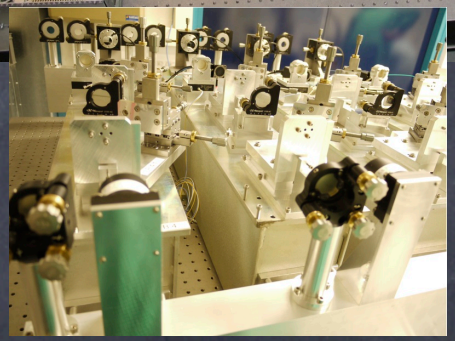
Pionier technical description

General description

- Located on the VINCI table
- Separated units:
  - Injection and OPD modulation unit;
  - Alignment and calibration
  - IO combiner
  - Imaging and detector unit (PICNIC (IOTA))
  - Control unit
- Removable
- A technical description document is available

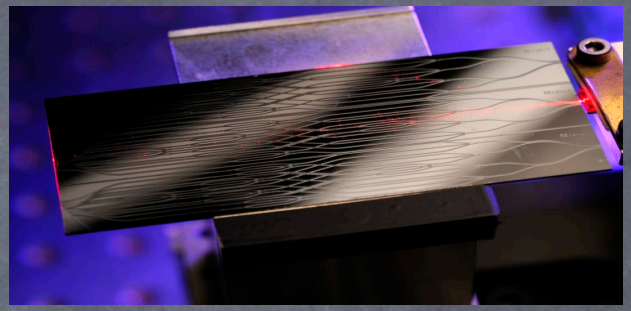


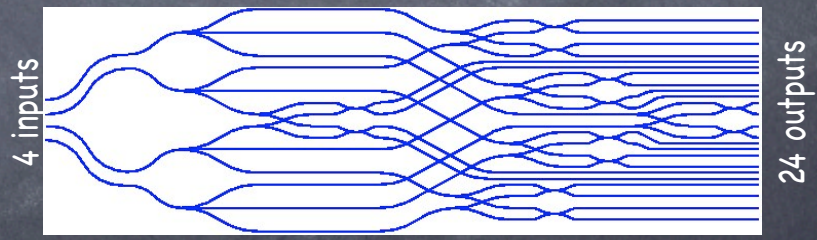




IO combiner

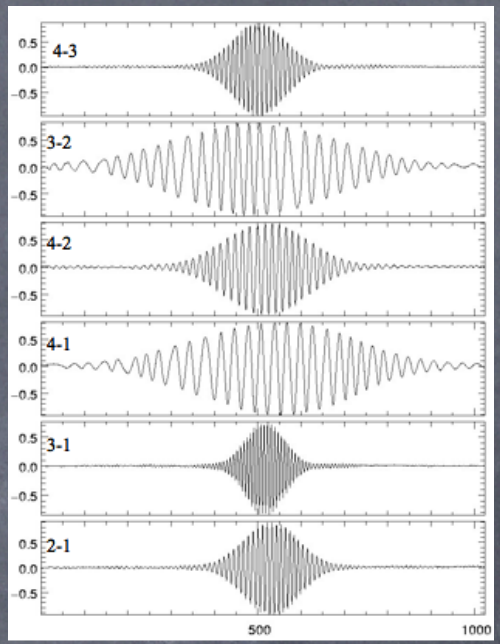
- Pairwise with ABCD encoding (Benisty et al 2009 A&A)
- 4 inputs maximum 24 outputs (4 per baseline)
- 24 (x2 polarization ?) pixels to read (fast) on the detector
- Ambient temperature

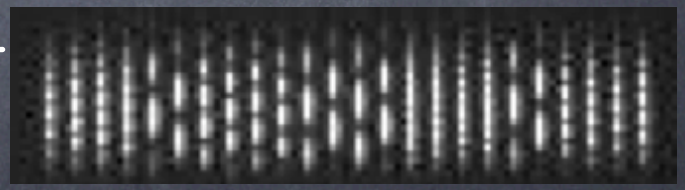




Fringe acquisition

- With PIONIER one fringe encoding is envisioned
  - VINCI like: all the fringe envelop is scanned (kHz rate);
  - Added value ABCD recording with dispersion;
- PIONIER will have its internal group delay tracking that will not rely on fast delay line operation (long range piezos);





Performances

- High precision mode
  (Photon noise regime)
  exposure times up to 20x faster than AMBER
- High sensitivity mode
- Precision goals (photon noise regime) simulation
  - V < 1% (Vinci)
  - CP = <1 deg

SNR 10	H	K
AT	6-8	7-9

Limiting magnitude should be taken with caution since they are the result of necessary approximative simulations.

Project status

Timeline

- Shipped to Paranal: mid-october
- October 2010: first commissioning run (VLTI 4 telescopes)
- November 2010: PIONIER commissioning run + first science
- Accepted proposals ~10 nights

Collaborations welcome

- Focus on bright "enigmatic" targets (eps Aurigae like) requesting imaging;
- Science requiring precision measurements e.g: cepheids pulsations, low-mass stars diameters, many others ...