High spatial resolution observation of stellar activity
and
Recent improvement at the VLTI

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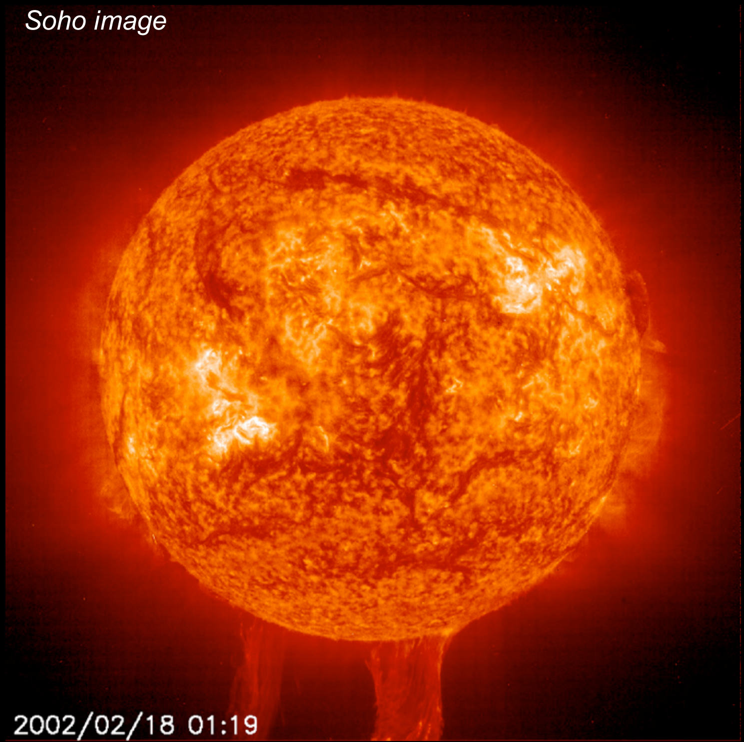
Spatially resolved observation of stars

Studies of local features = key to understand the physics of stars
(rotation, convection, magnetism, mass loss…)



The only really resolved star:
our Sun !

- Main objectives of the project
  - Stellar activities
  - Long term effort toward direct imaging of stellar surfaces

- Instrumental issues
  - Need for spectral resolution
    $\Rightarrow$ long DIT, large telescopes
  - Resolving stellar diameter

1mas @ 1µm = 200m telescope

$\Rightarrow$ Long Baseline Interferometry

Road map… and realistic steps

Previous results :

- evolution/atmospheric models
- diameters – limb darkening
- rotation – oblatnes

Current ongoing studies :

- Diameters…
- material around supergiants, Be stars
- evolved, Mira stars
- photosphere of K and M giants

⇒ Extension to other / smaller types of stars

- photosphere of smaller giant stars
- photosphere of Main Sequence stars

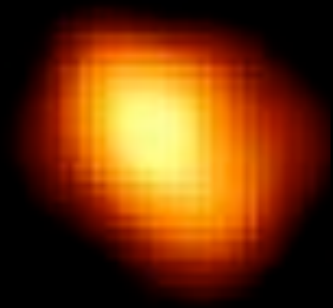
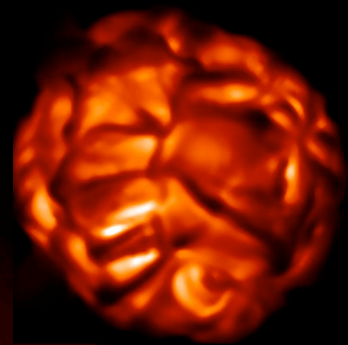
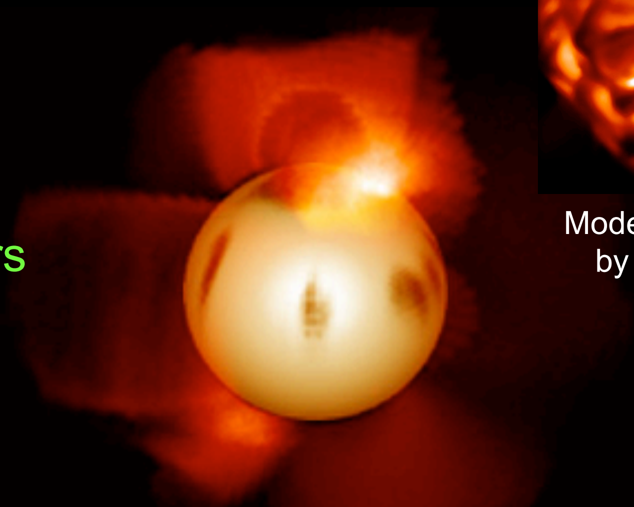


Image of Mira in UV
by HST



Model of Betelgeuse
by Freytag et al.

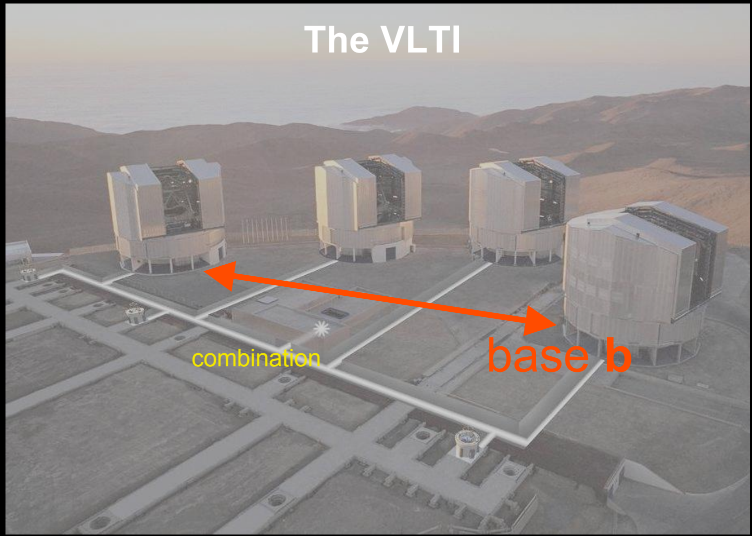


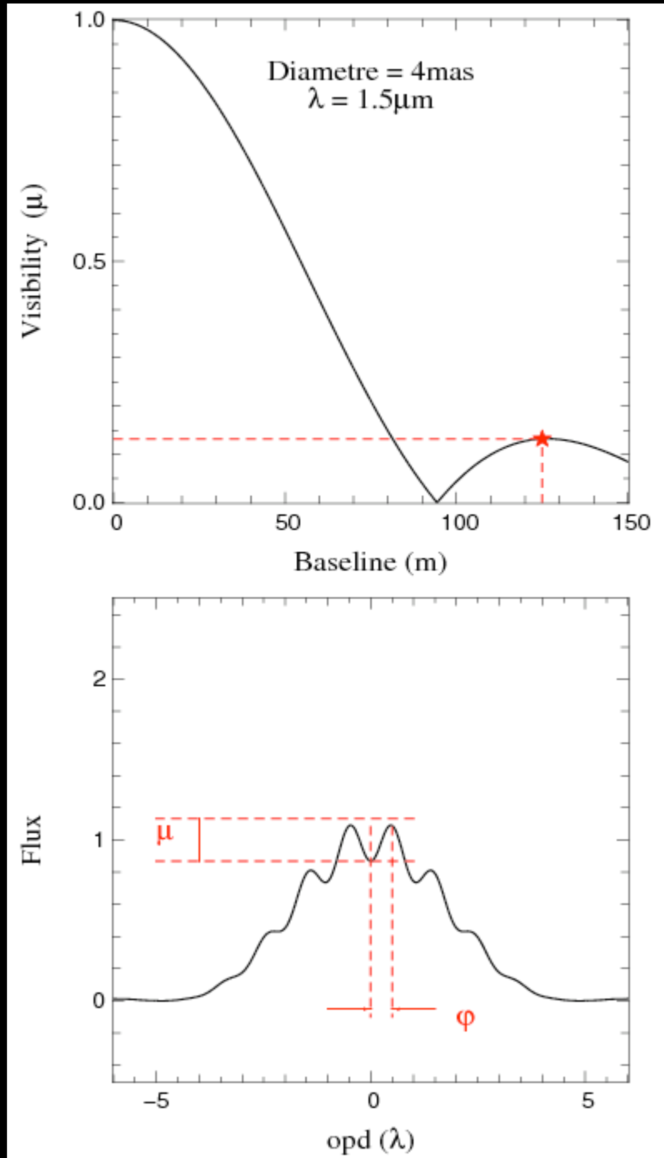
Reconstruction of AB Dor
by Cameron et al.

Outline

- High Spatial Resolution Observation of stellar activity
  - principle of interferometric observations
  - 1 - material around evolved stars
  - 2 - looking for photospheric stars spots in K and M giants
- Recent improvement at the VLTI: fringe-tracking
  - the issue of turbulence
  - the FINITO fringe-tracker : recent advances on the ATs
  - toward fringe-tracking with the UTs

Principle of interferometric observations



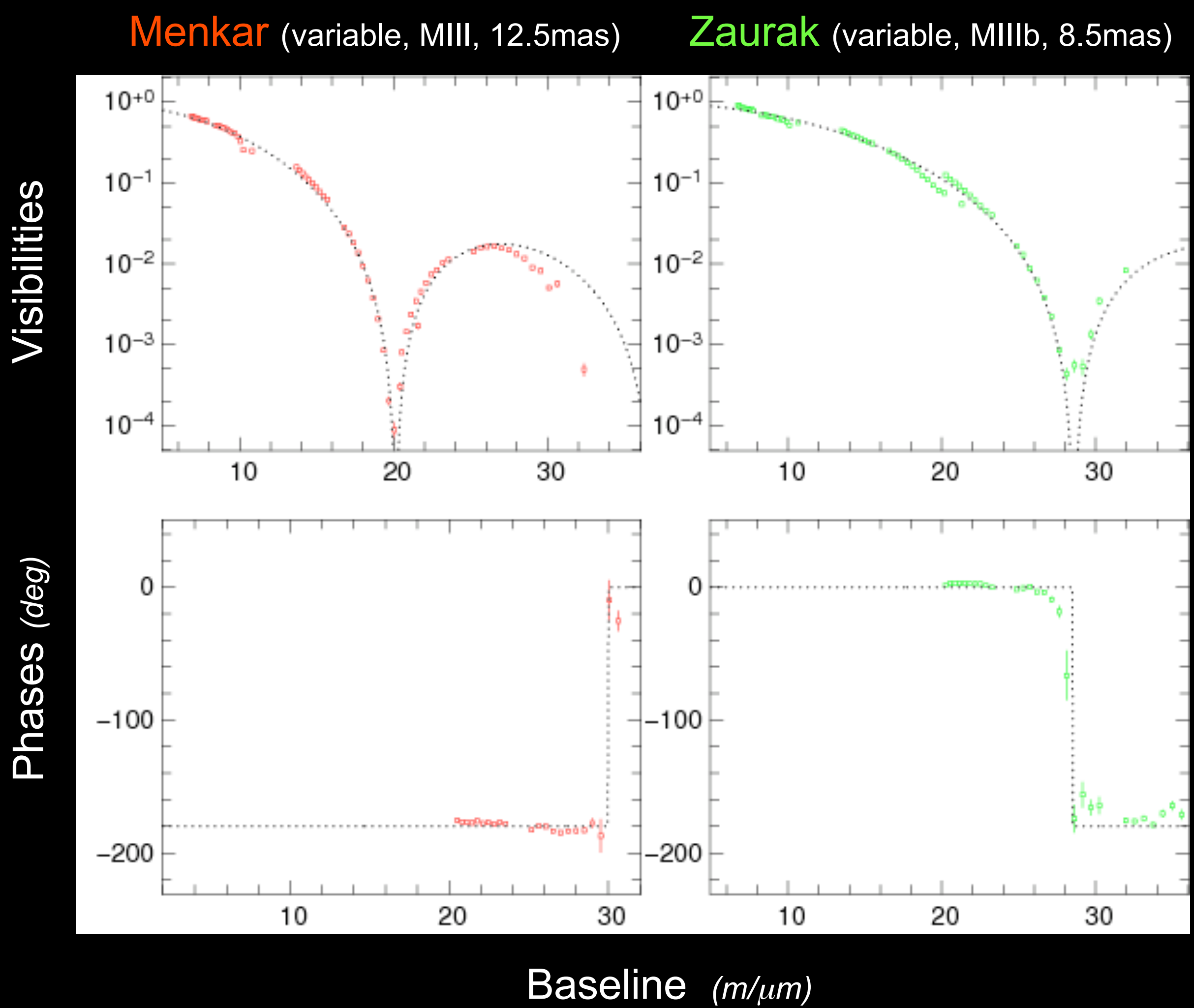


- Interferometric observables
  - visibility μ et phases φ
  - fonction of the target shape :

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

Principle of interferometric observations

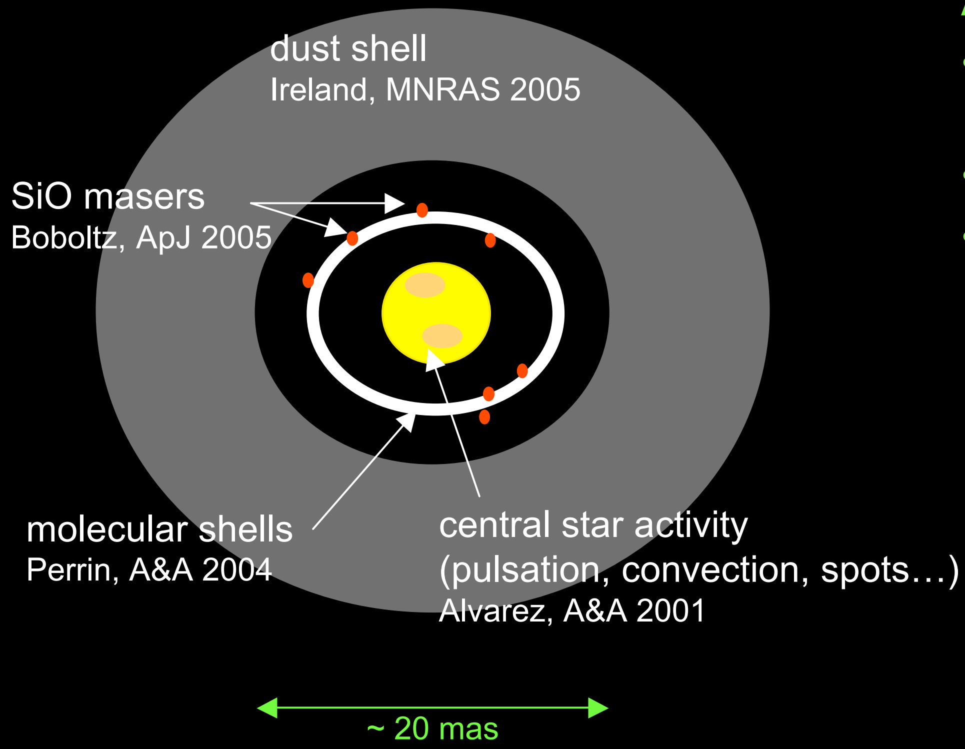
Example of resolved single stars with AMBER



- Menkar:
  - high precision diameter
  - clear limb-darkening
  - no obvious structures
- Zaurak:
  - smooth phase jump
  - features on or above the photosphere

1- Studying evolved stars with interferometry

Example: Close environment of pulsating Miras



Astrophysical issues:

- Connection between large scales and photosphere ?
- Role of pulsation ?
- Dust formation processes ?

Instrumental requirements:

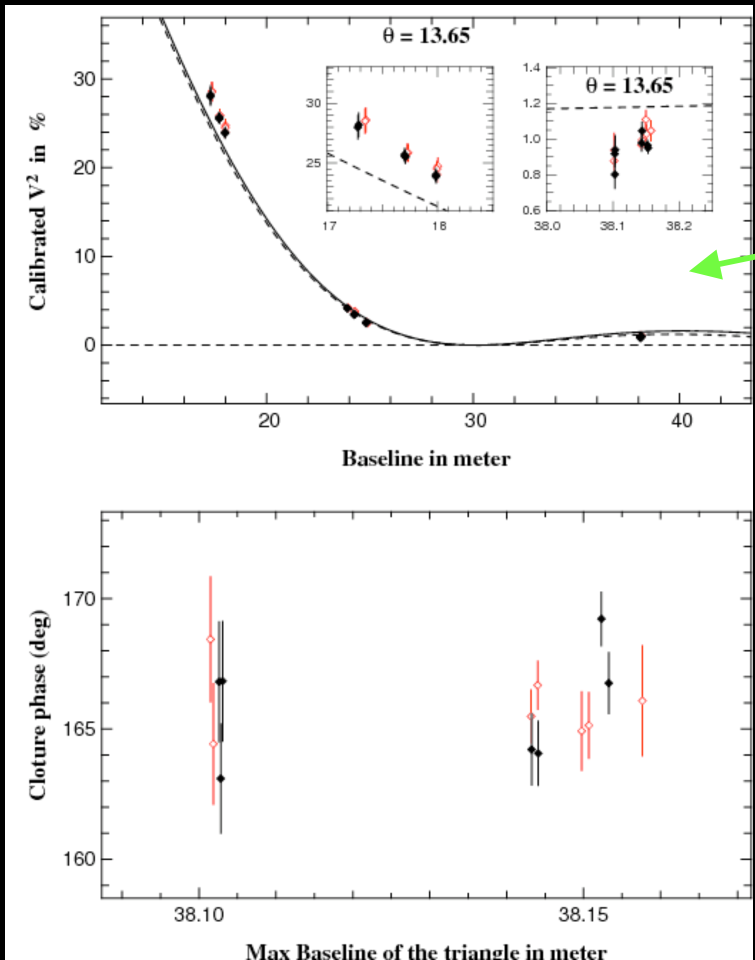
- high angular resolution
- spectral analysis
- precision (= dynamic)

1- Studying evolved stars with direct probe

Example of recent observations

Polar - interferometry

(IOTA array, 2006)

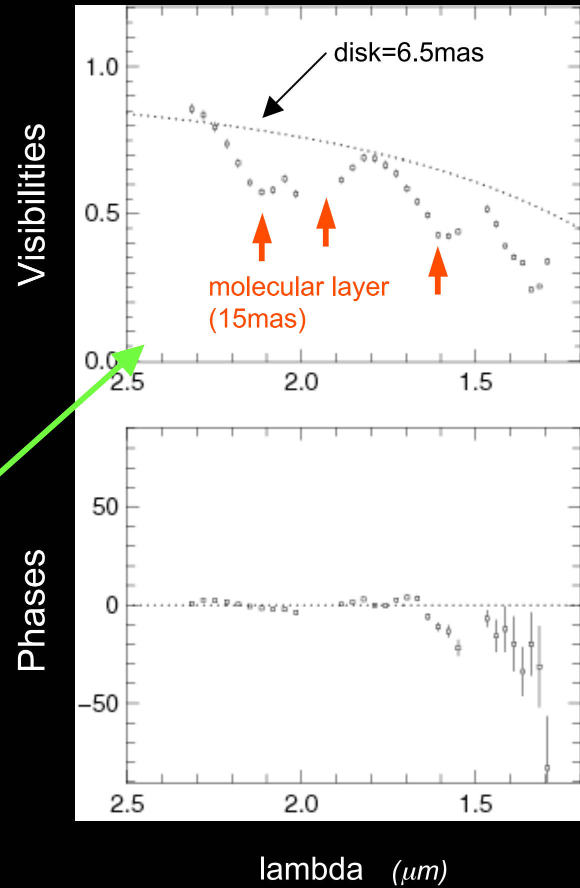


No difference of morphology between the linear polarizations (black/red)

Strong difference of size across the J,H and K bands

Spectro - interferometry

(VLTI-Amber, 2007)



2- Resolving the photosphere of K and early M giants:

Astrophysical interests

- Cool spots in late-type stars are related to the dynamo process
  - rapidly rotating stars are well studied by doppler imaging *(Strassmeier et al, ...)*
  - slowly rotating giants offer different conditions…
    but cannot be studied by indirect doppler imaging.

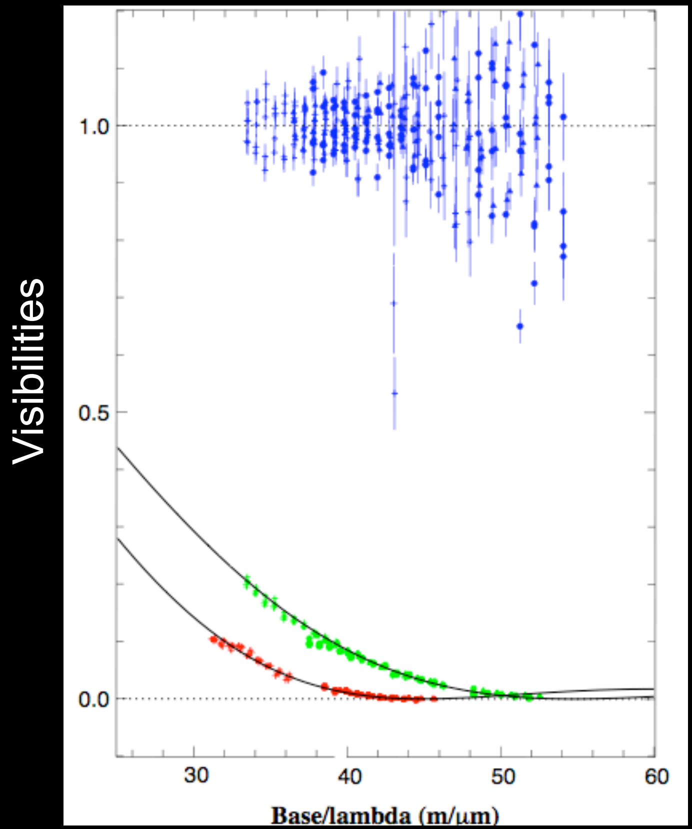
- Radial and non-radial pulsations:
  - interferometric and asteroseismic constraints provides crucial test of the internal structure *(Setiawan et al, …)*
  - for unbiased measurements, spotless photosphere is mandatory

- K giants have been used as calibrator for interferometry
  - accurate calibration for incoming long baseline requires proved
  - spotless photosphere

2- Resolving the photosphere of K and early M giants

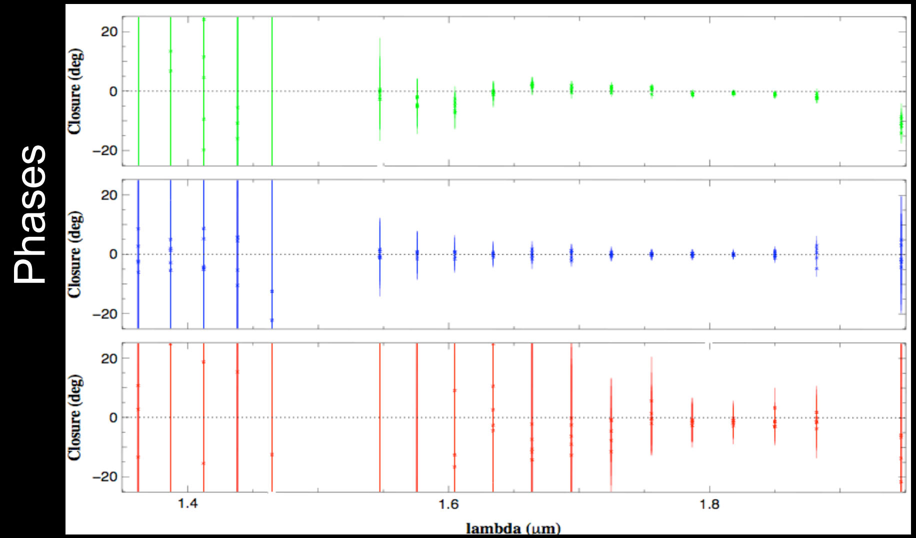
Example of preliminary results

- Example of observations:
  - psiVir, variable M3III, K=0.4
  - nu Hya, variable K5III, K=0.3
  - 3 ATs, DIT=25ms, R=40



- Goals:
  - accurate diameters (visibilities)
  - asymmetric structures (phases)

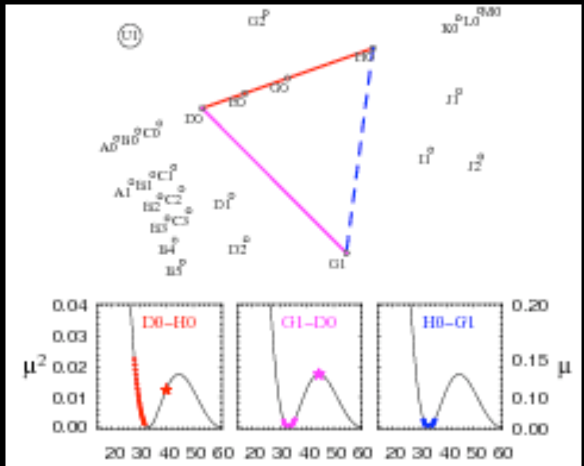
- Method:
  - sample of K and M variables stars (accepted proposal for p80, 4 additional stars)
  - interferometric measure close to the visibility minimum



2- Resolving the photosphere of K and early M giants

High dynamic observation of V3879 Sgr

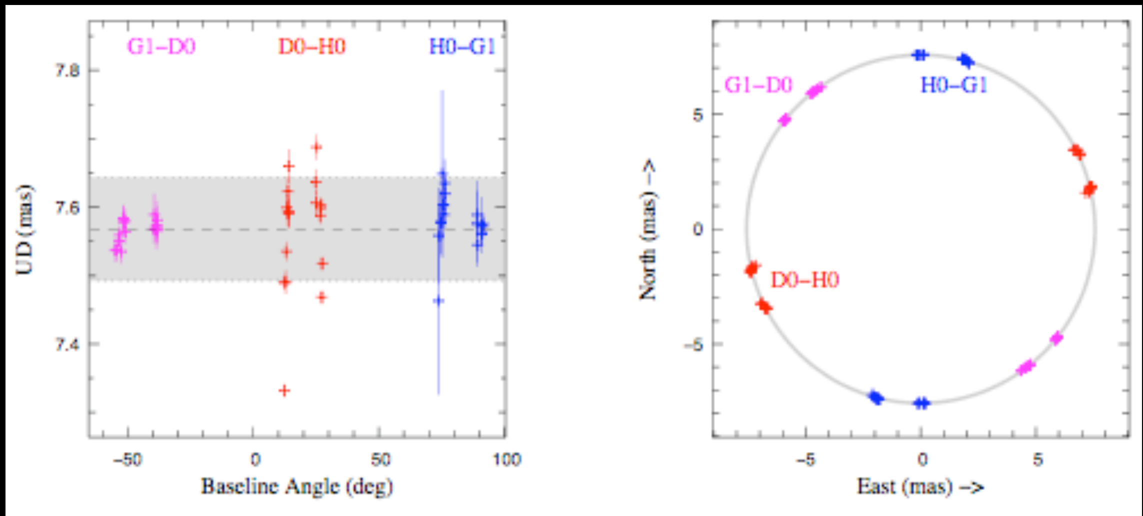
Observational Setup



- High Precision Diameter:
  - diam=7.56 mas +/- 0.2%
  - this variable star is round down to 0.2%

- Measuring the visibility minimum value:
  - all the light of the 'centro-spherical' component vanishes. So a minimum value different from zero proves the presence of structures
  - measured value: *Vmin=0.5%+/1%*
  - no structures down to this level of contrast

Results converted into diameter



- Observation requirements
  - 1h long
  - 3 ATs, R=1000
  - high accuracy = deep dynamic
  - Need for "long" DIT (>1s)

Outline

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  - principle of interferometric observations
  - current projects:
    - material around evolved stars
    - looking for photospheric stars spots in K and M giants

- Recent improvement at the VLTI: fringe-tracking
  - the issue of turbulence
  - the FINITO fringe-tracker : recent advances on the ATs
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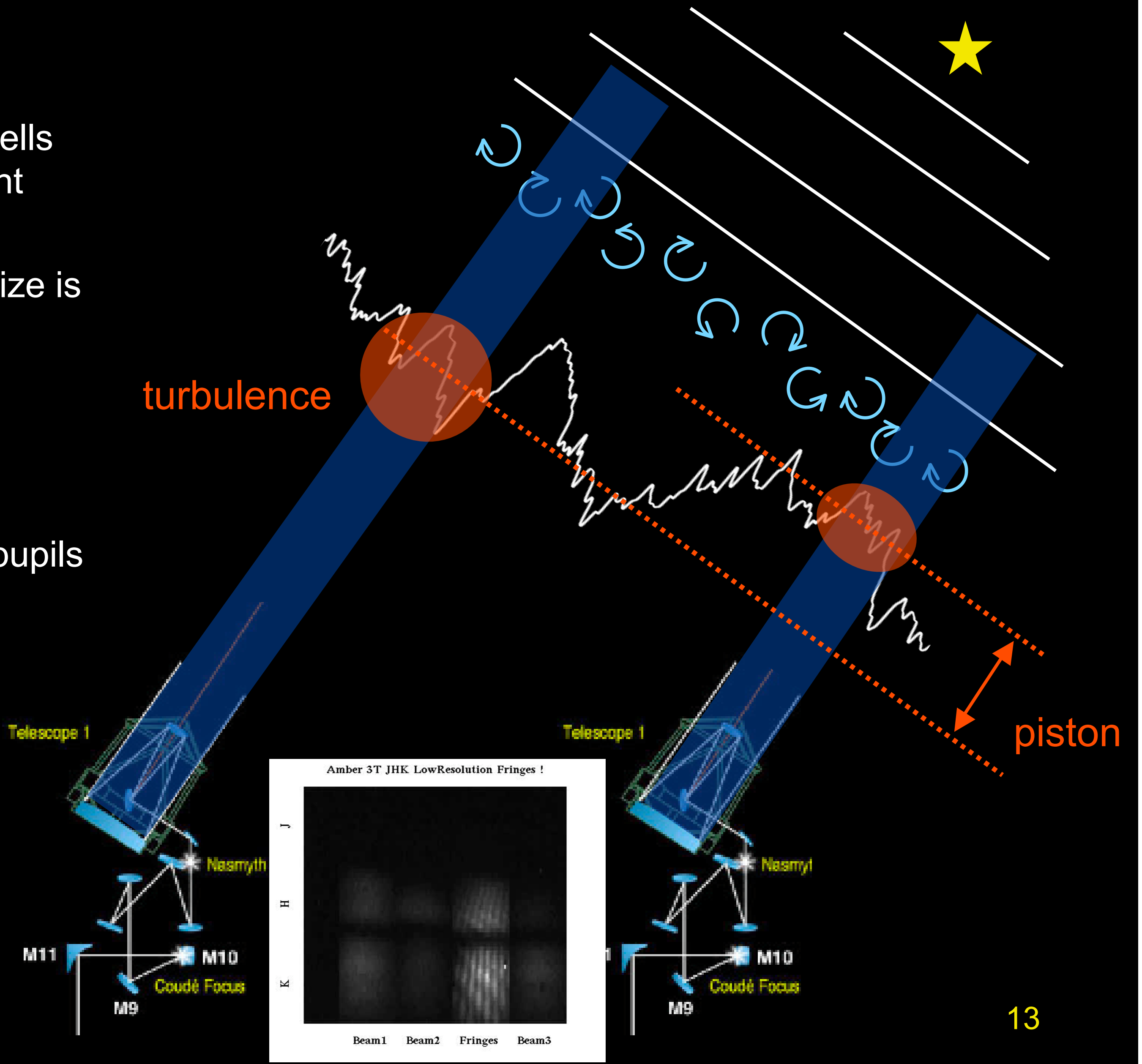
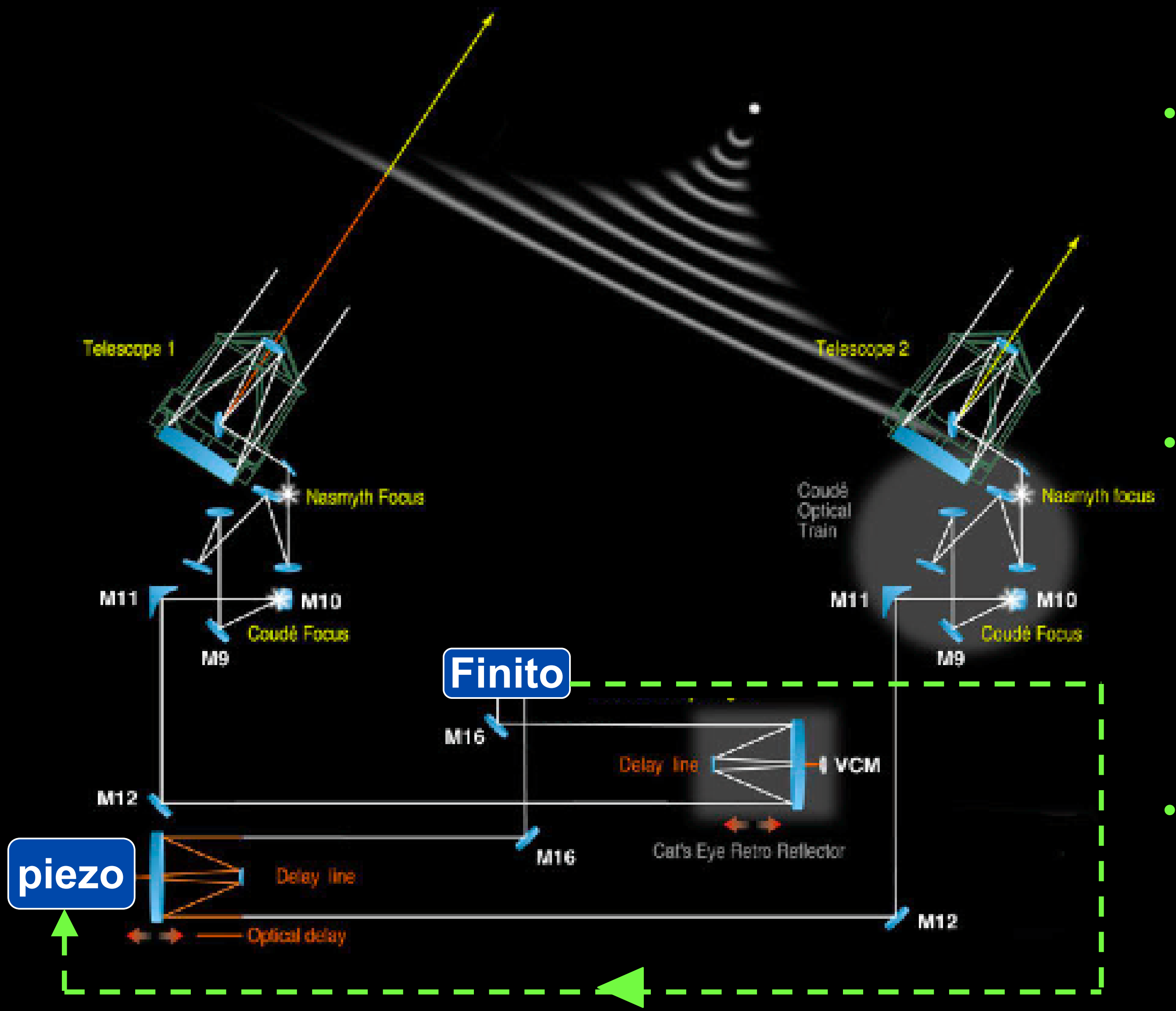
Atmospheric turbulence and piston issue

- Atmospheric turbulence cells distort the stellar wavefront
- Distortion over the pupil size is called turbulence
  - bad flux injection
  - tip/tilt or AO mandatory
- Global shift between the pupils is called piston
  - real-time fringe motion
  - small DIT mandatory



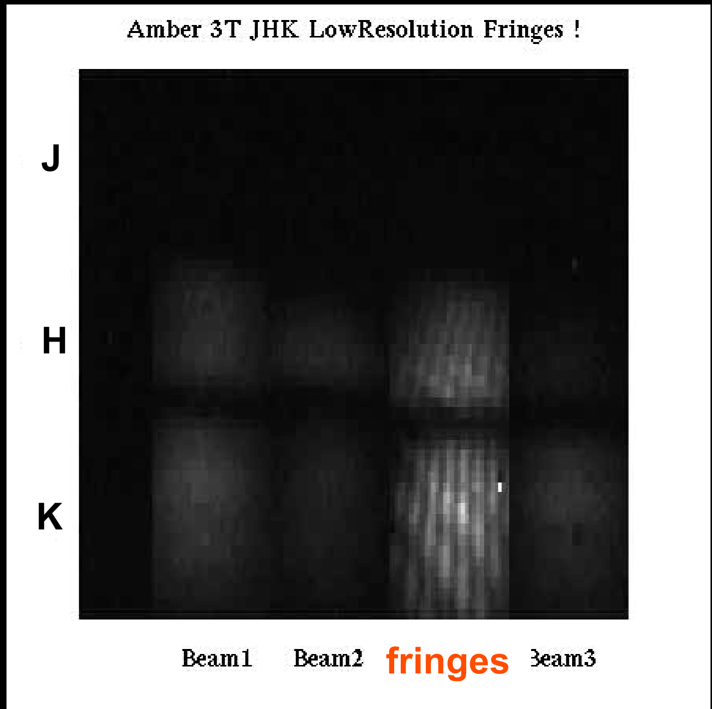
Fringe Tracking at VLTI: FINITO concept



- FINITO:
  - H band
  - measure the phase
  - send real-time correction to the DLs
- Fringe are locked:
  - longer DIT
  - larger spectral resolution available
  - better fringe quality = better dynamic
- Offered with the ATs only (yet).

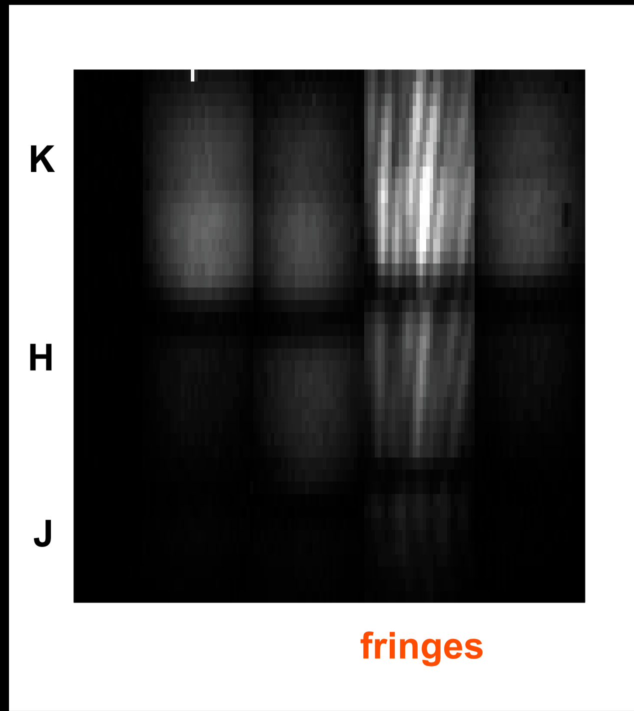
FINITO ATs : Example of raw AMBER data

Without FINITO



DIT=50ms

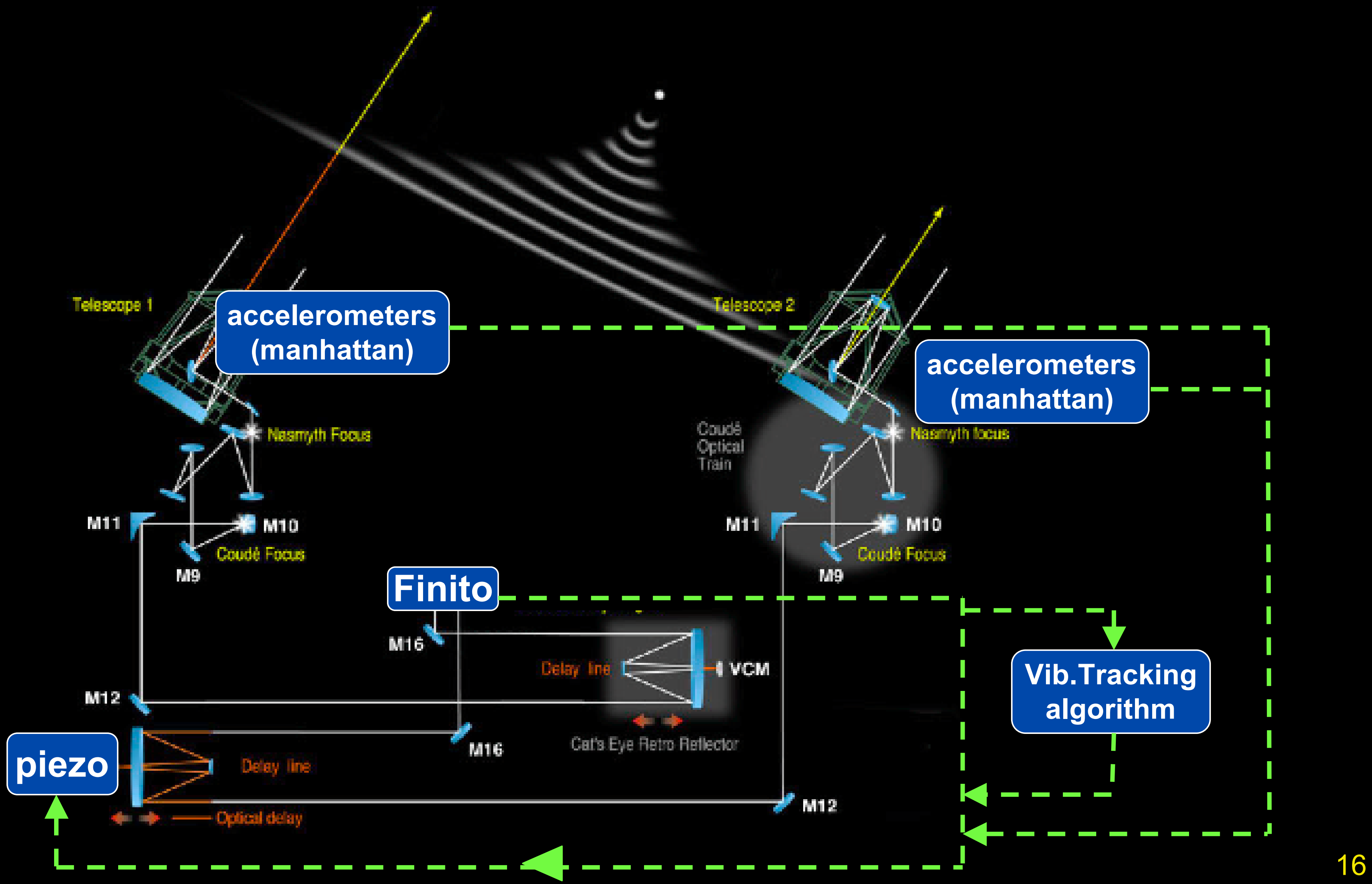
With FINITO



DIT=1s

- Fringe are locked = longuer DIT
  - DIT can be improved by a factor of ~100
  - larger spectral resolution available
  - better fringe quality = better dynamic

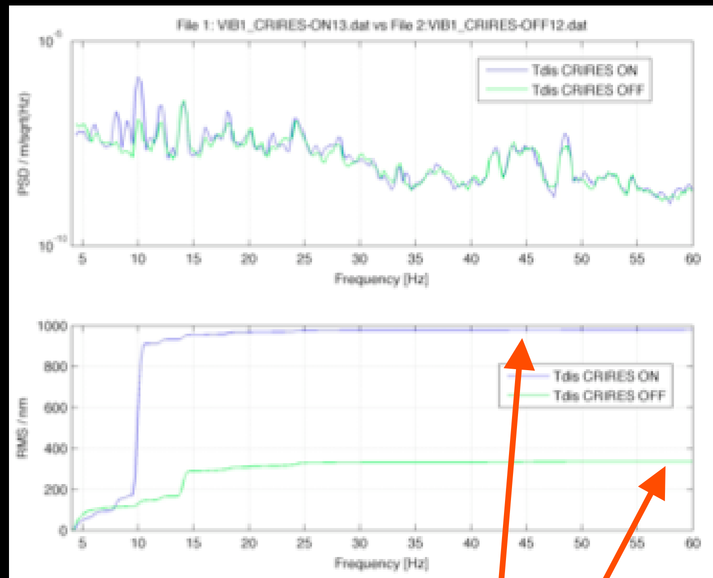
FINITO UTs : the control version 2.0 !



FINITO UTs : effect of other systems and instruments

- What has been tested:
  - MACAO fans = critical
  - NACO rotation angle = small
  - UTs ATU = nothing
  - enclosure tracking far from zenith = nothing
  - enclosure tracking at zenith = critical
  - enclosure pumps = nothing
  - UTs air-exchanger = small

- Still under investigation
  - other UTs should be investigated (other instruments)
  - performances not easily repeatable, looks dependent on the environment (wind?)



CRIRES ON = 1000nm
CRIRES OFF = 320nm

Conclusions

- Resolving stellar surface is a key tool to better understand the stellar activity but is a challenging project:
  - high angular resolution (few mas)
  - need for fringe-tracking:
    - better data quality = better dynamic
    - higher spectral resolution (R~1000)

- Recent progress make AMBER+FINITO already a useful machine:
  - well demanded on service/visitor mode
  - at least on bright stars (H<5) since offered with the ATs only

- Going fainter requires FINITO on the UTs
  - extend the high and medium spectral resolution up to H=
  - main issues is vibration

FINITO UTs : conclusions

- Not offered on P81 since last test-nights were lost due to bad weather.

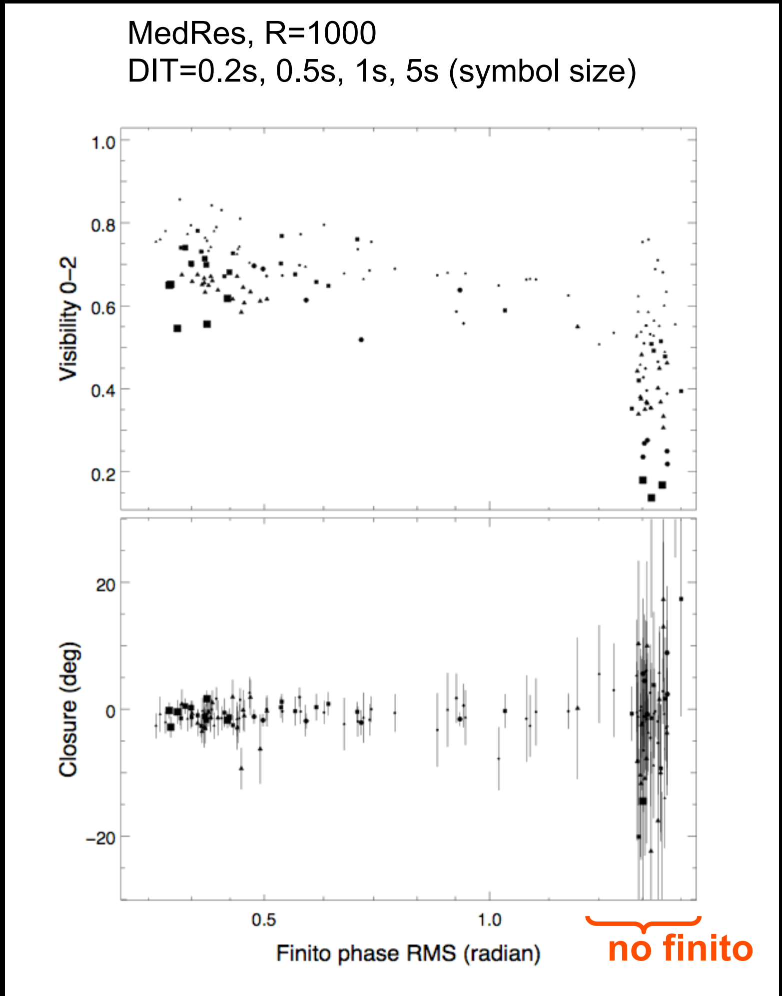
- Probably in P82
  - with Manhattan since its is a critical upgrade
  - without Vibration Tracking

- Issues for users:
  - never really commissioned in “a science way”
  - absolute calibration of interferometric data still unknown
  - Data Reduction Software still not optimized for

    ⇒ lack of manpower (astronomers and software)

- Best performances (200nm rms) only achievable with big efforts:
  - 4 engineers during the night + astronomer(s) + TiO
  - 48 hours for preparation and health check
  - intensive care and tuning during operations

FINITO ATs : Improvements for AMBER



- Few commissioning for FINITO+AMBER
  - ‘long’ DIT available
  - better accuracy on the phase
- Not really investigated yet:
  - stability of the fringe contrast (15%, 5%, 1% ?)
  - capability of ‘correcting’ the AMBER data by post-processing the FINITO data

Current Call For Proposal for ATs:

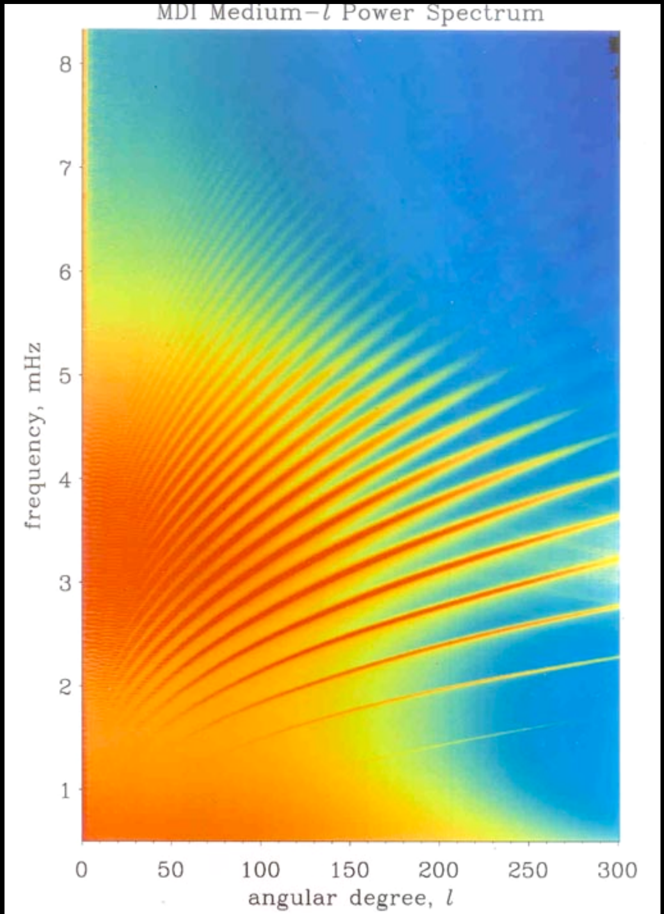
Seeing	Magnitude
<1.2”	H=3.0
<0.8”	H=4.0
<0.6”	H=5.0

in all modes: R~45, R~1000 and R~10000

Spatially resolved observation of stars

Example : helioseismology .vs. asteroseismology

Observation of the Sun *(Soho data)*

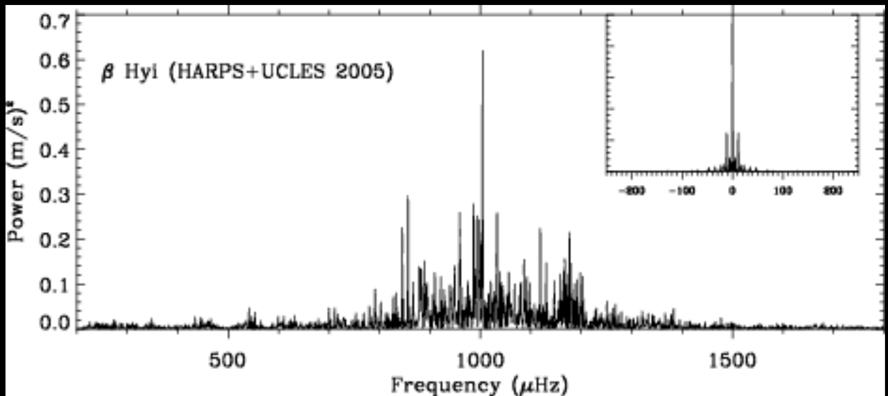


Time dimension *(frequency)*

Spatial dimension *(angular degree)*

- Spatial resolution:
  - 2D versus 1D observational parameter-space
  - High order modes are observables

Observation of a G2IV star *(Bedding et al, ApJ 2007)*



Time dimension *(frequency)*