The bricks of the VLTI

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The beginnings of optical interferometry

- Interferometric Astronomy is founded on the principles of interference of light waves.

Christaan Huygens
(1629-1695)

- Describe the nature of light in terms of **waves**

Thomas Young
(1773-1829)

- Describe the **interference** of light

Armand Fizeau
(1819-1896)

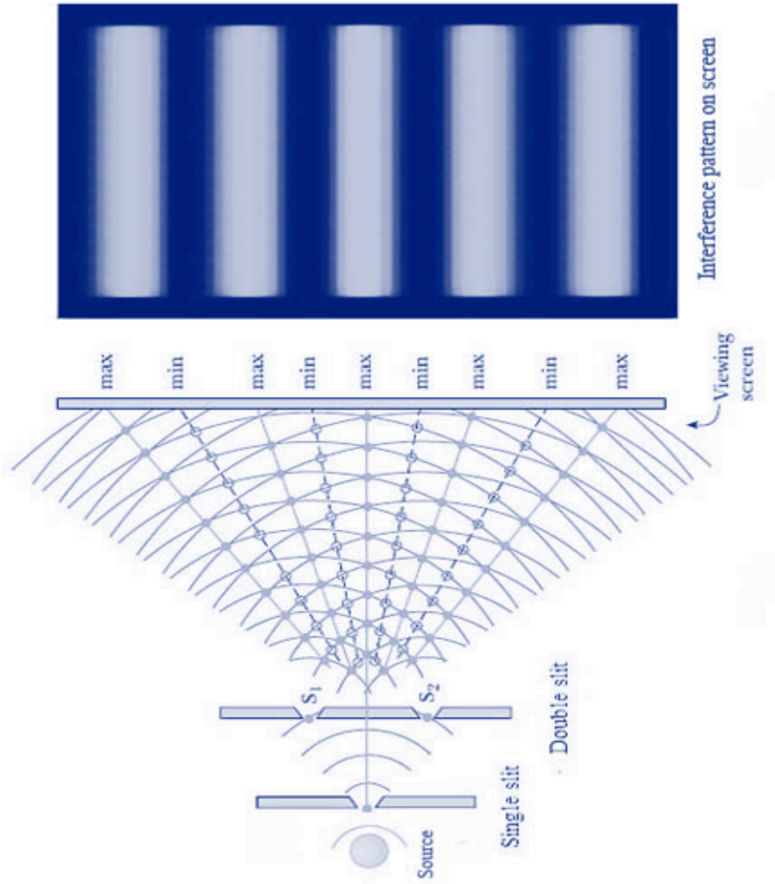
- Suggested by first time the use of **interferometry in Astronomy**

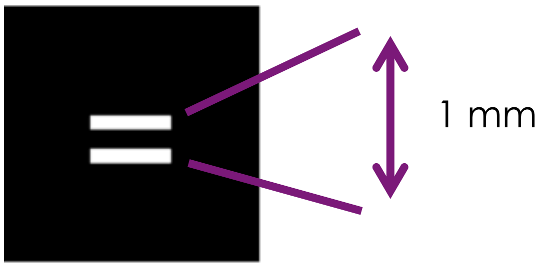
Albert Abraham Michelson
(1852-1931)

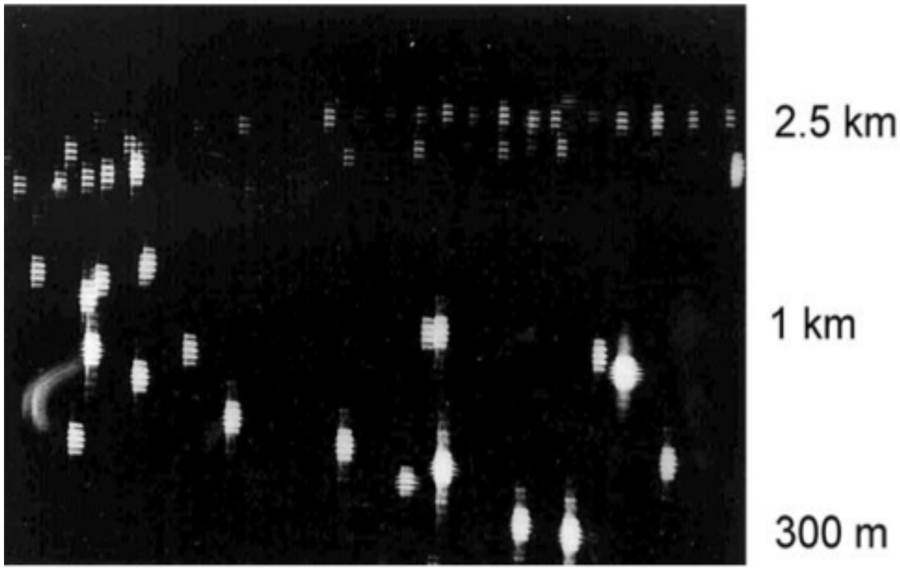
- Invented the concept of **visibility**

Young’s experiment

- All the physical optics to understand astronomical interferometry are based on the quantitative examination of Young’s fringes.

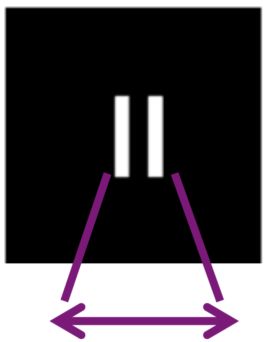




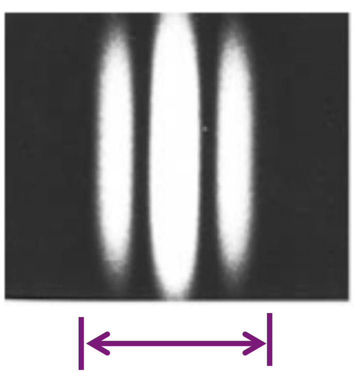


The fringes' properties

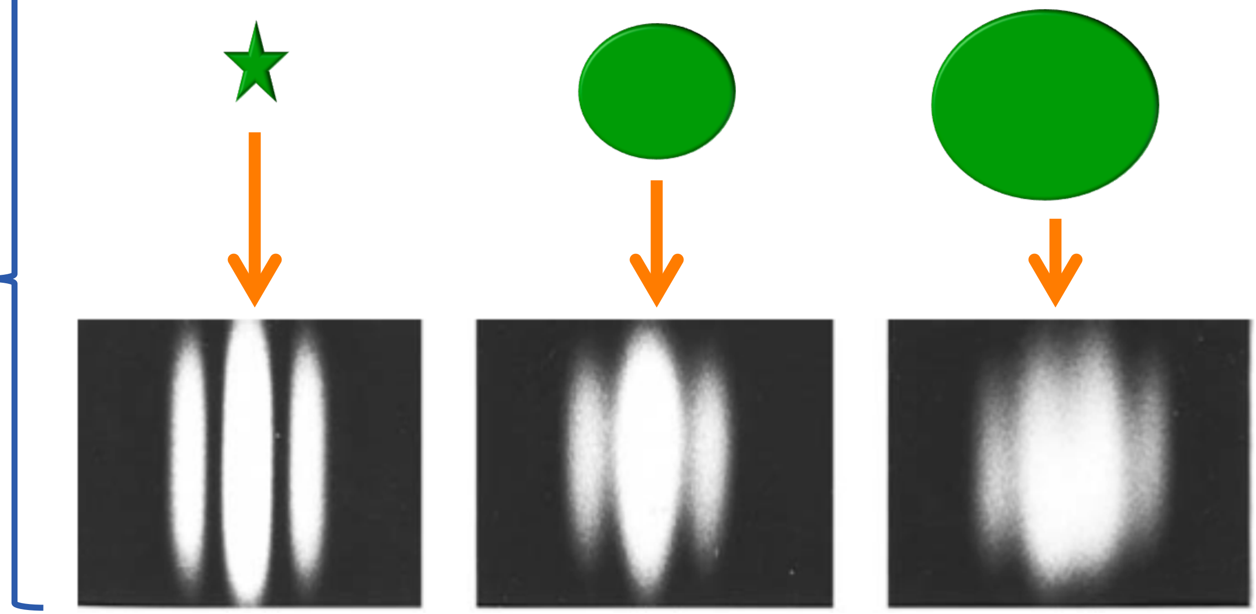
The **visibility** is the normalized fringe contrast
Angular resolution: $\theta = \lambda / B$



B=1 mm, λ =500nm, θ = 103''



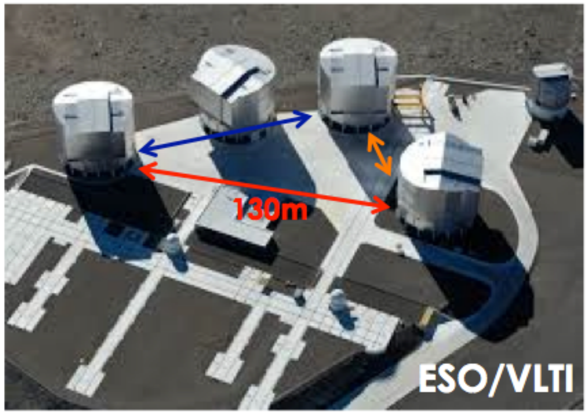
R≈ 1/(The size of the slit or telescope)

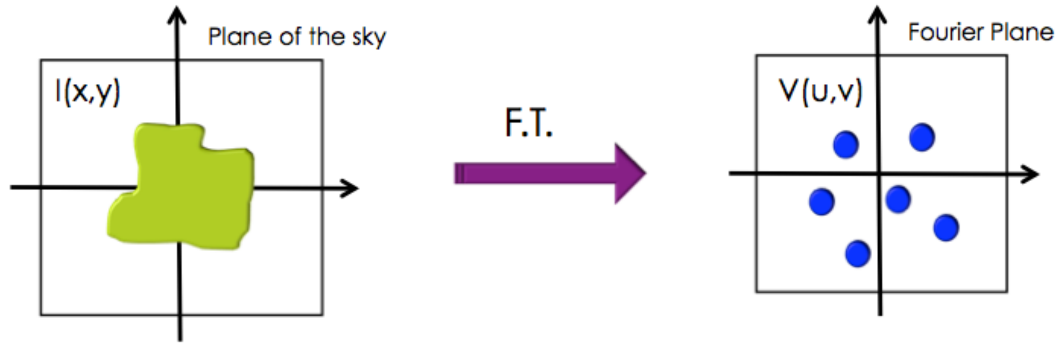


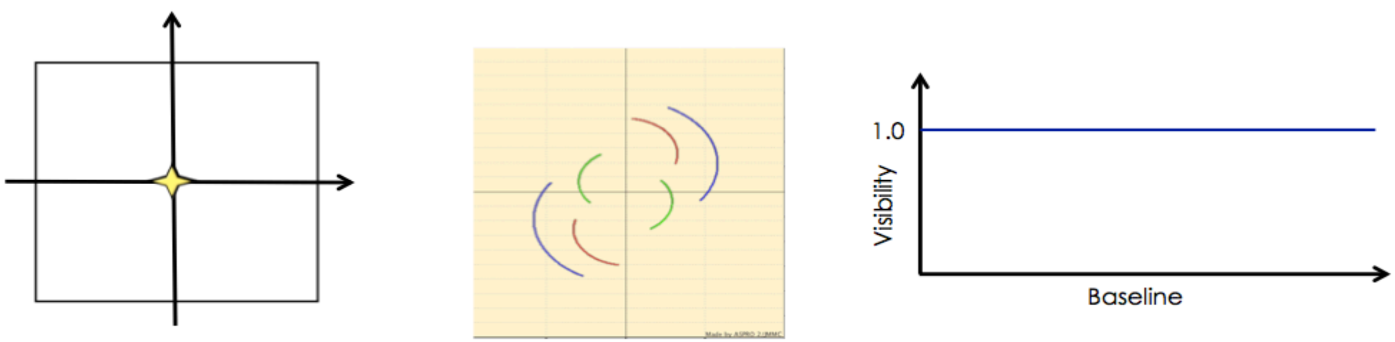
Van Cittert-Zernike Theorem:

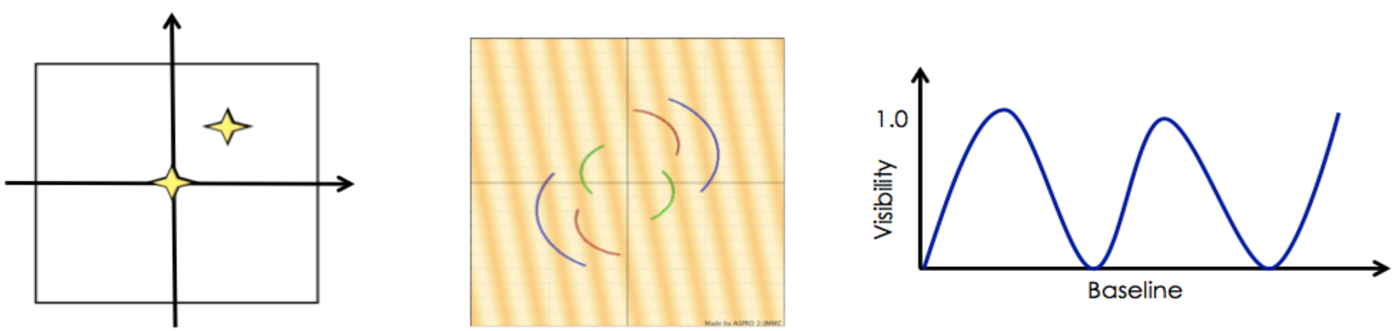
Spatial coherence function → Fourier Transform → Angular intensity distribution * System transfer Function

The fringes' properties

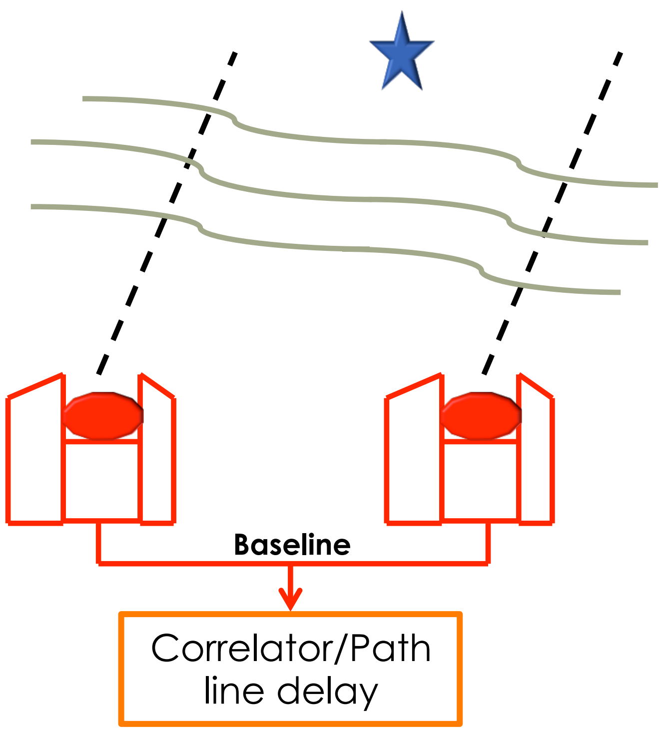








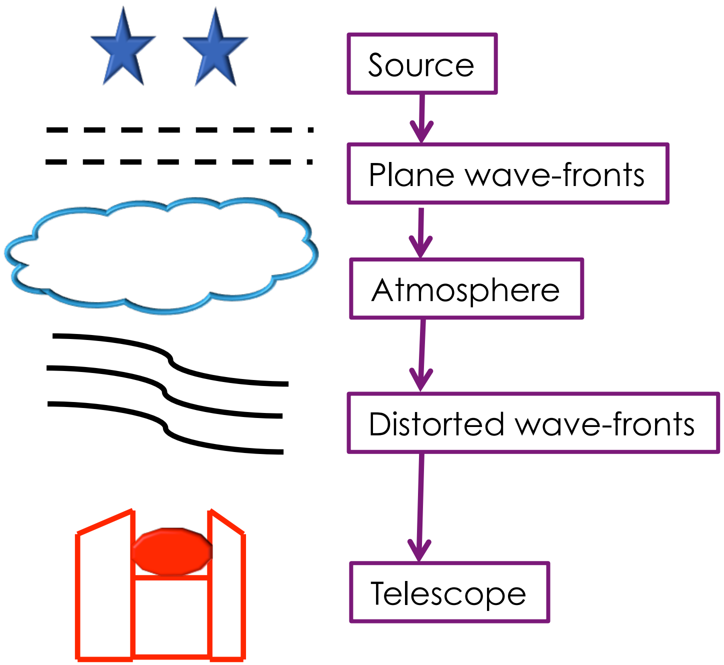
Optical/IR vs Radio Interferometry



- Visibilities are complex quantities
- They have **AMPLITUDE** and **PHASE**

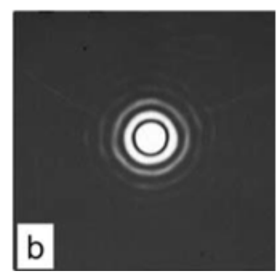
- Optical wavelengths are significantly shorter than radio wavelengths (10^4-10^7)
- More important atmospheric effects at optical wavelengths.
- The properties of the received radiation are very different between RADIO and OPTICAL/IR wavelengths.

The atmospheric effect



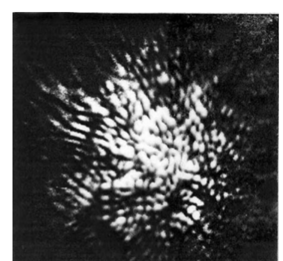
- The atmosphere introduces temporal and spatial anomalies in the wave-front
- **Fried's parameter:** The circular aperture size over which the mean wave-front error is 1 rad^2. $r_0 \approx \lambda^{6/5}$. Large telescopes requires **Adaptive Optics** to achieve diffraction-limited resolution.
- **Coherence time:** Time over which the mean wave-front error changes by 1 rad^2. $t_0 \approx \lambda^{6/5}$

	Radio	**Optical/IR**
Wavelength	1.3 cm	2.2 μm
Coherence time	15 minutes	20 milliseconds
Fried's parameter	15 km	1 m



$D<r_0$

$$\Theta = \lambda / D$$



$D>r_0$

$$\Theta = \lambda / r_0$$

The quantum effect

- **Ocupation number :** The average mean energy by the energy of a photon

$$\bar{n} = \frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

- **Radio:** (1cm), T=2.7 K, <n>≈1.4

  (2cm), T=5000 K, <n>≈7000

- **Optical:** (0.5 μ m), T=5000 K, <n>≈0.003

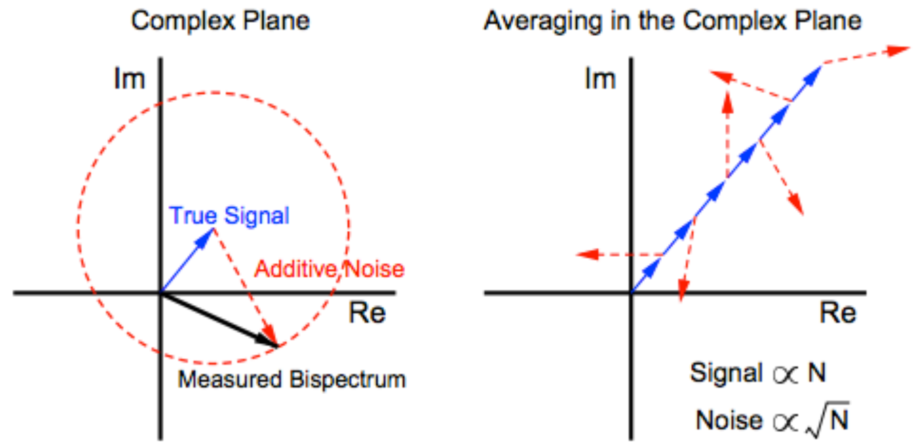
  (2cm), T=1500 K, <n>≈0.008

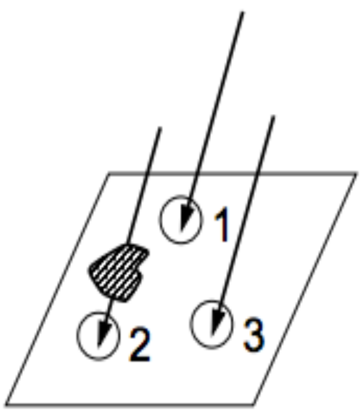
- **n>>1, rms ≈n**
- **n<<1, rms ≈sqrt(n)**
- **S/N≈V^2*N**
- **S/N<<1**

Interferometric Observables

- In radio interferometry the observables are the **amplitude of the visibility (V)** and the **phase.**

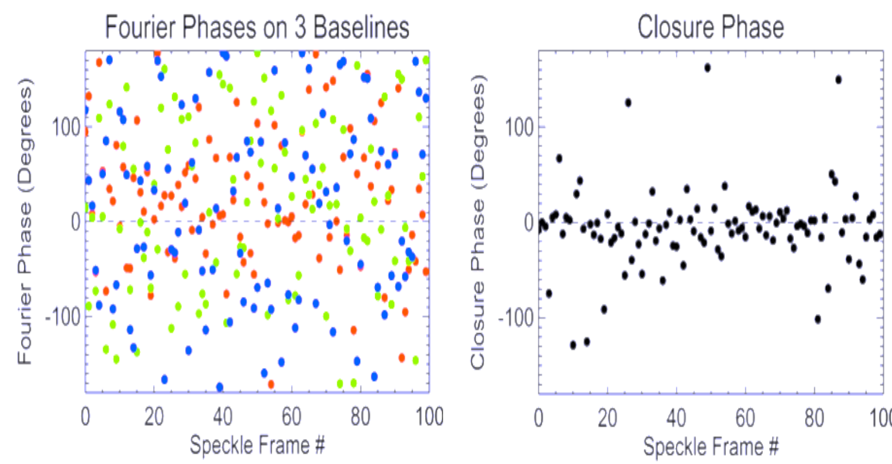
- In optical/IR interferometry we use the **modulus of the visibility (V^2)** and the **closure phases.**





Observed = Intrinsic + Atmosphere

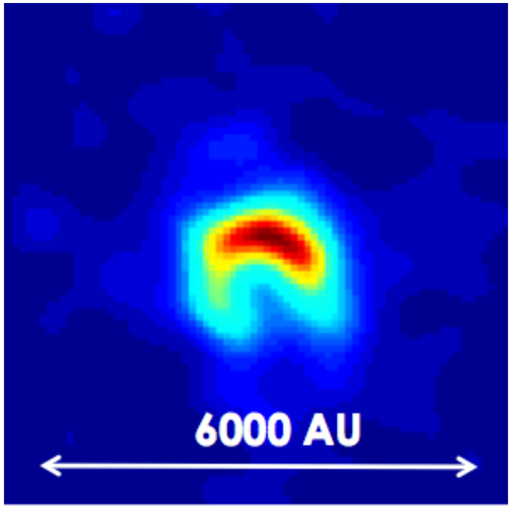
$$\Phi(1\text{-}2) = \Phi_0(1\text{-}2) + [\phi(2)-\phi(1)]$$
$$\Phi(2\text{-}3) = \Phi_0(2\text{-}3) + [\phi(3)-\phi(2)]$$
$$\Phi(3\text{-}1) = \Phi_0(3\text{-}1) + [\phi(1)-\phi(3)]$$

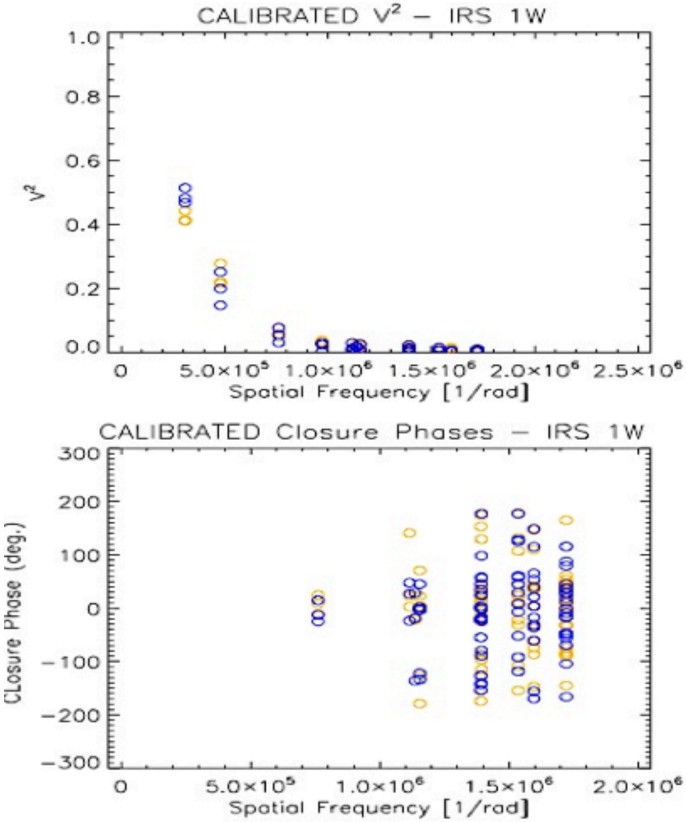


- **Closure phases:** Product of three visibilities produced by a closed triangle of baselines.

Calibration and Imaging

- Interwoven observations of Calibrator and target are required.
- Calibrators should be point-like sources with similar magnitudes and spectral types as the targets
- Calibrators at few deg. from targets
- At least three software packages available bases on bispectra maximum entropy methods

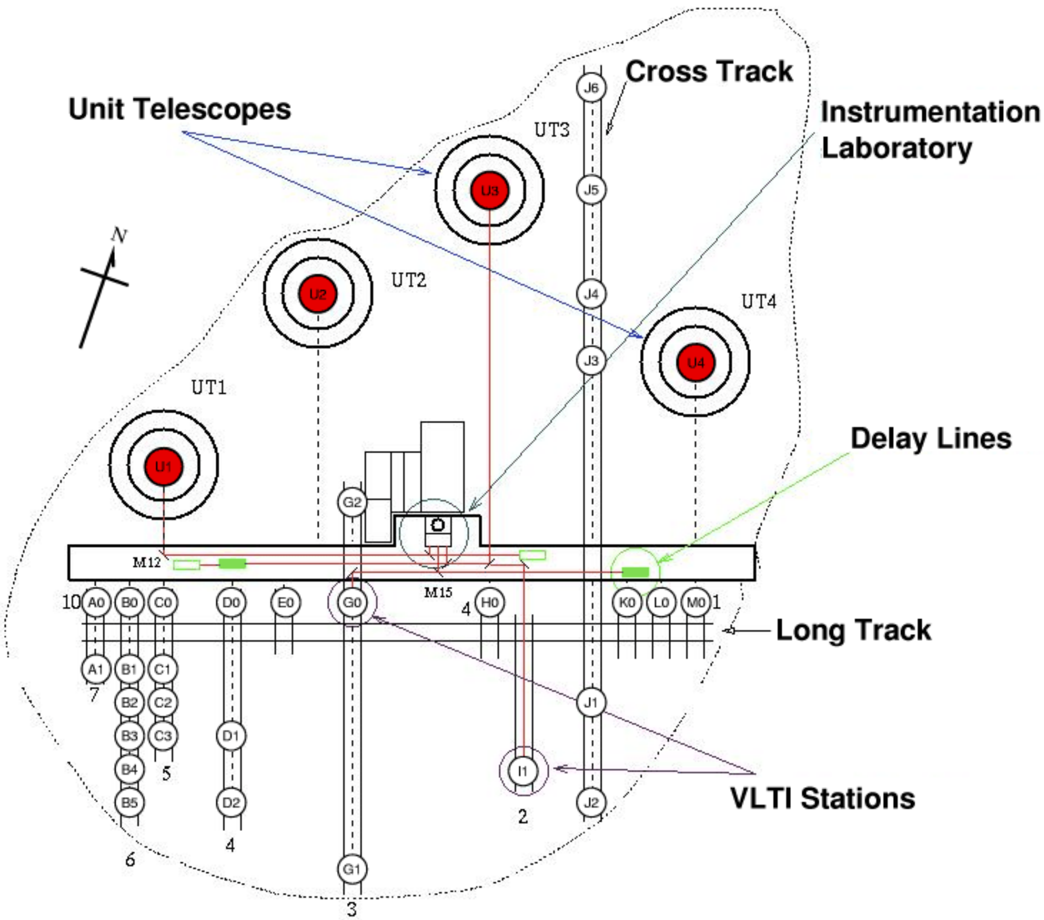




To keep in mind

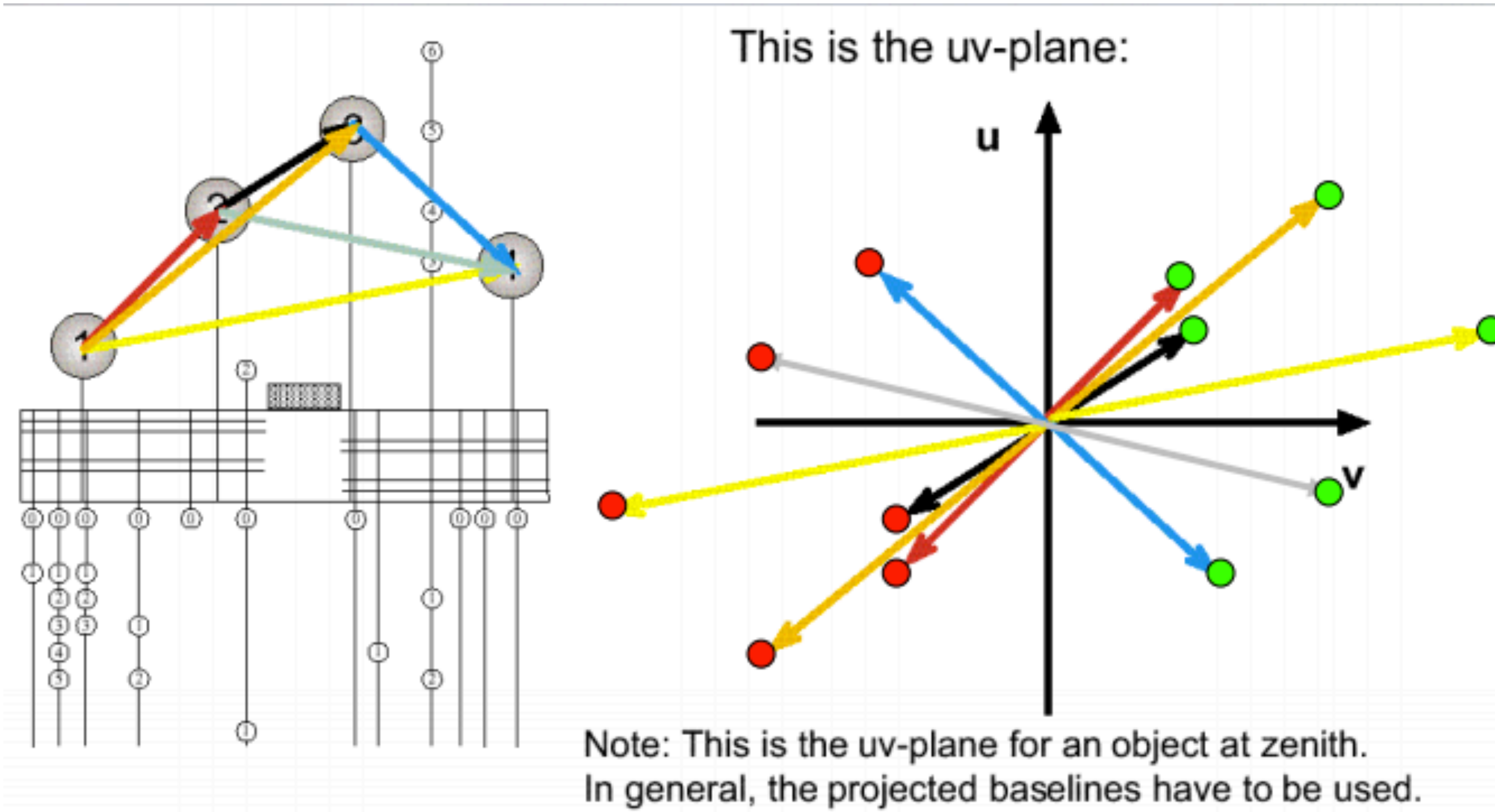
- Optical/IR interferometry is different from radio interferometry.
- In Optical/IR interferometry the atmosphere plays an important role in the detection of the Interferometric fringes.
- In Optical/IR interferometry we do not measure the amplitude and the phase of the coherence function directly.
- The interferometric observables in Optical/IR interferometry are the $\mathbf{V^2}$ and the **closure phases.**
- **Closure phases** allow us to test whether a source has point-like symmetry.

The Very Large Telescope Interferometer

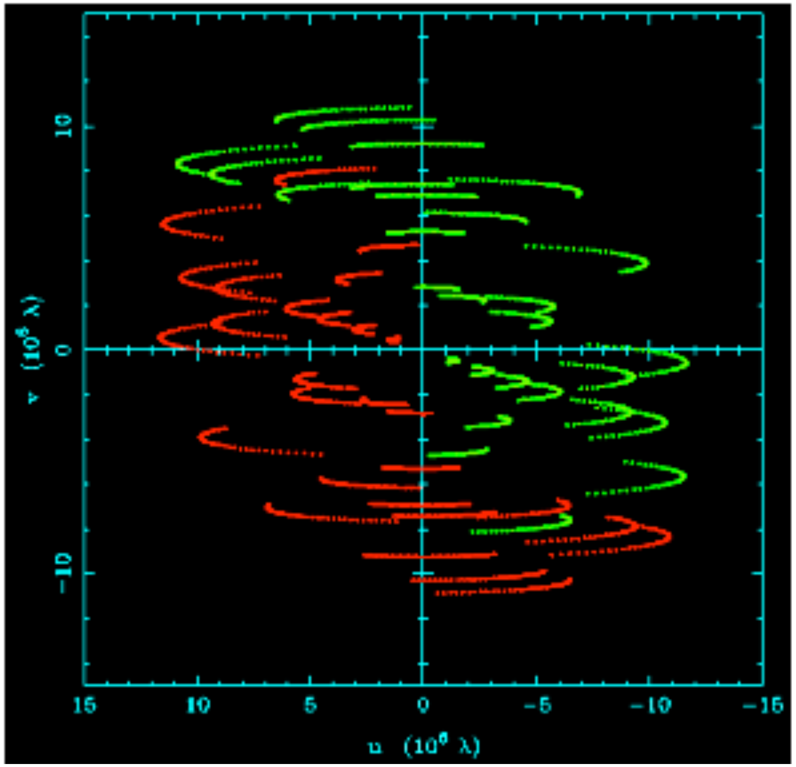


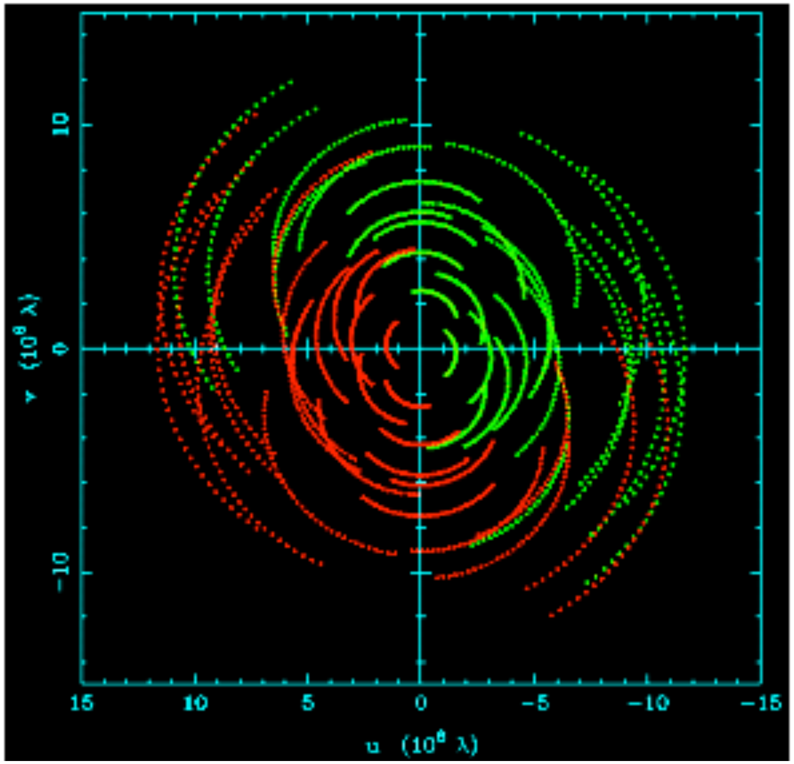
- 4 Unit telescopes of 8 m
- 4 Auxiliary telescopes of 1.8 m
- Maximum baseline: 140 m
- Minimum baseline: 11 m
- Instruments at NIR: **AMBER, PIONIER**
- Instruments at MIR: **MIDI**

VLTI UTs u-v coverage



VLTI UTs u-v coverage

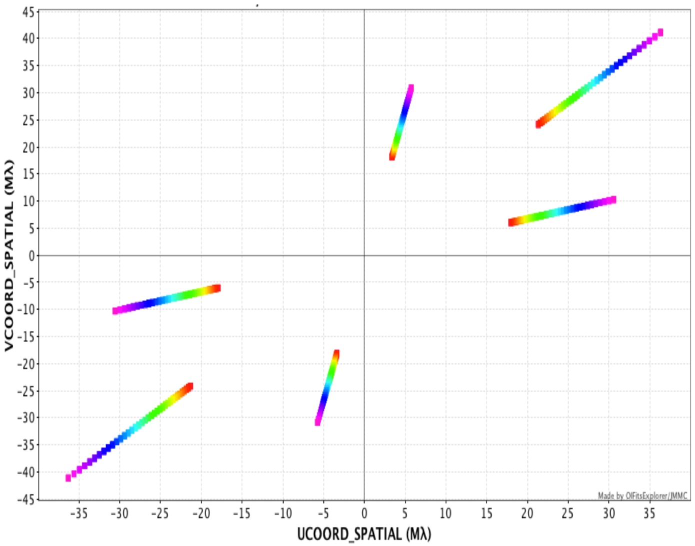


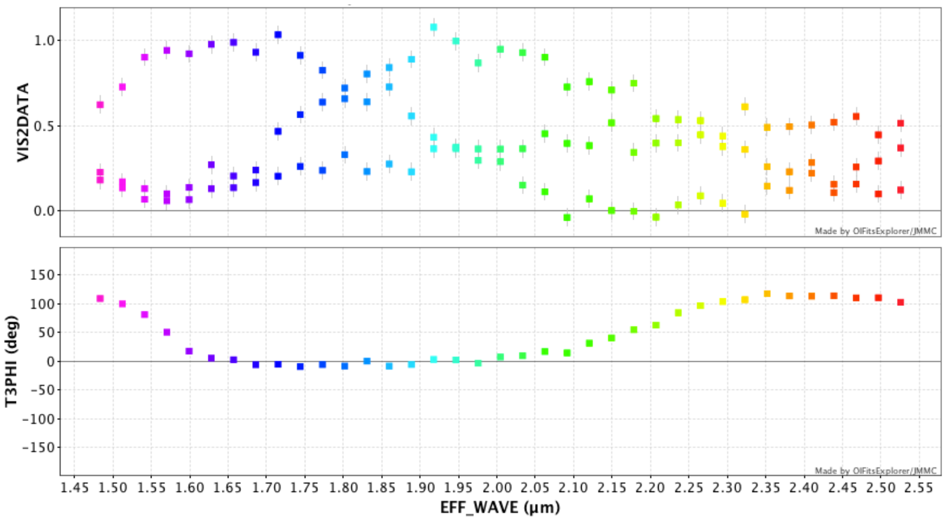


AMBER – Astronomical Multi-Beam combineR

- Combine 3 UT's or AT's.
- Works in J, H, Ks filters.
- Resolution ≈2 -50 mas with UT's (≈2 -140 mas with AT's)
- Sensitivity to observe sources with magnitudes H=7 and H=5 with the UT's and AT's.
- Works in combination with MACAO
- Three resolution modes:

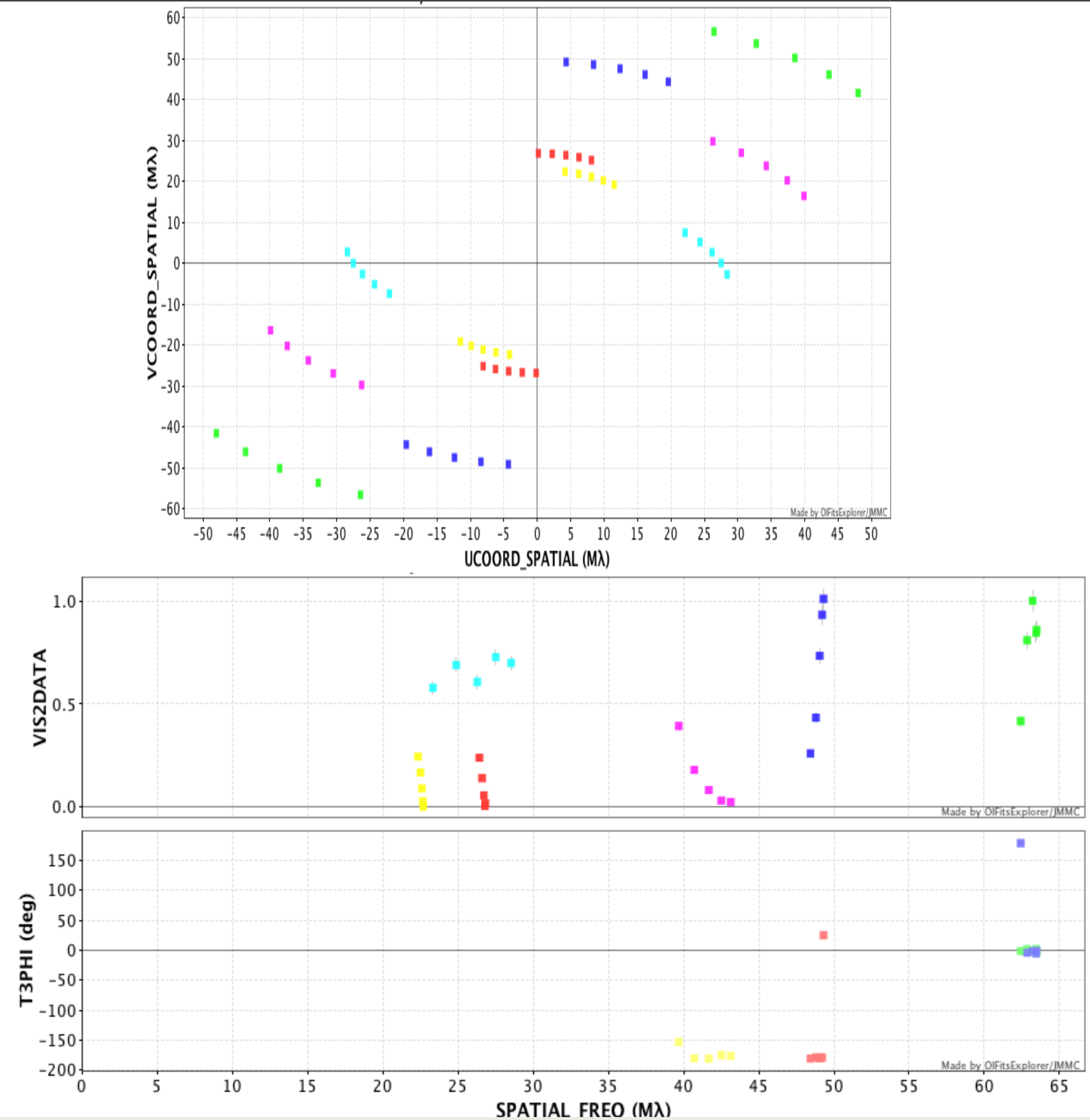
Mode	Spectral Resolution
LR-HK	35
MR-K	1500
HR-K	12000





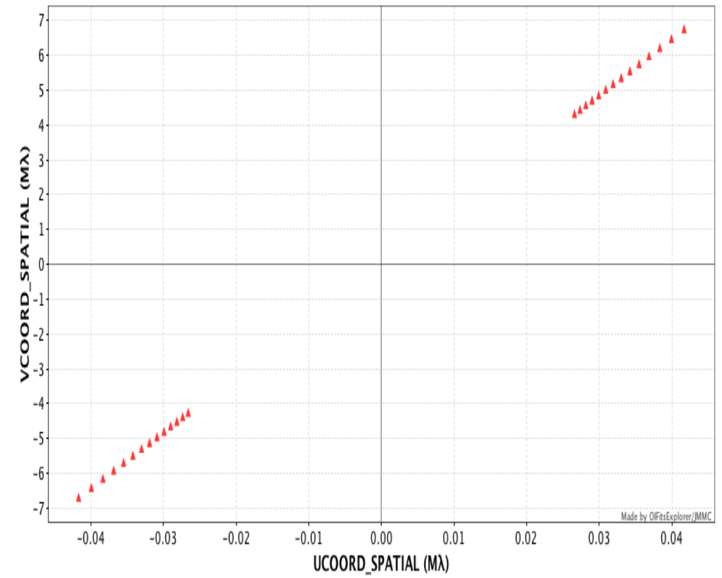
PIONIER

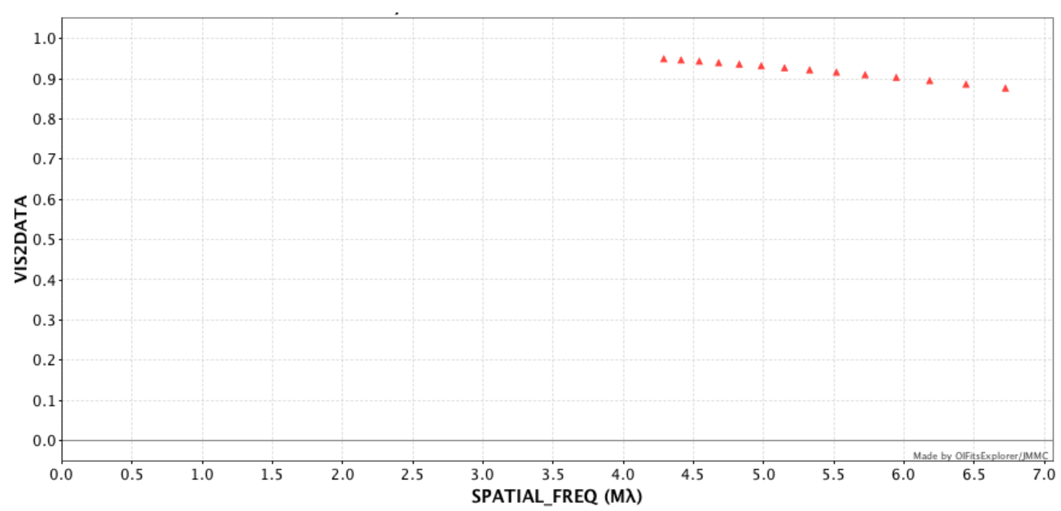
- Visitor instrument (October 2010)
- Developed by the Institut d'Astrophysique de Grenoble
- Developed to study different evolutionary stages of planet-forming environments.
- Similar baselines to **AMBER**
- Two filters H and K. **NO SPECTRAL INFORMATION!**
- Limit sensitivity: H=7.5
- Proposals through collaboration with the instrument PI.



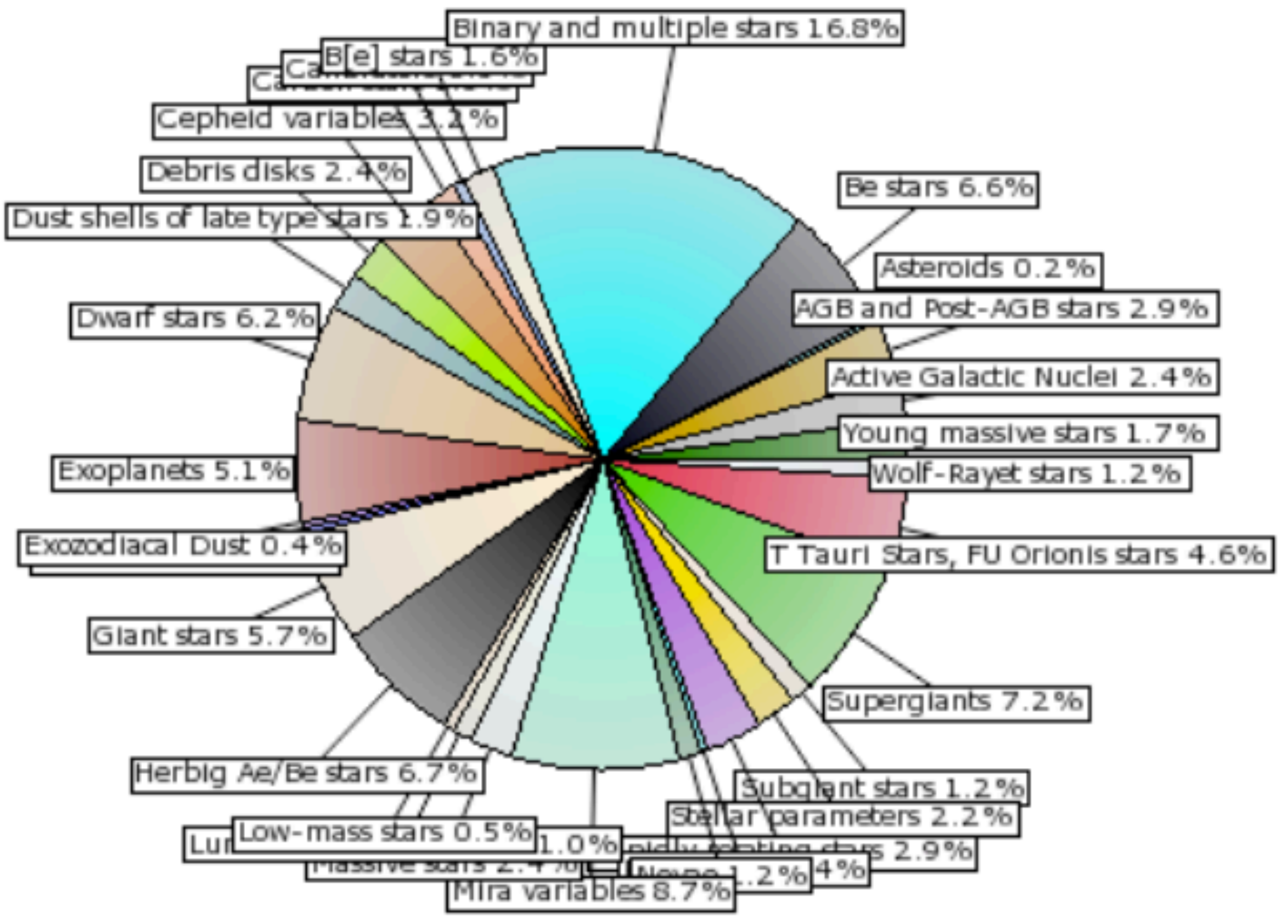
MIDI-MID-infrared Interferometric Instrument

- Combine 2 telescopes
- No **closure phase** information
- No imaging can be performed.
- Two spectral resolutions (R=30, R=230)
- Works in the N-band (8-13 μm)
- Limit sensitivity: V=17 (UTs), V=13.5 (ATs)





Scientific Cases



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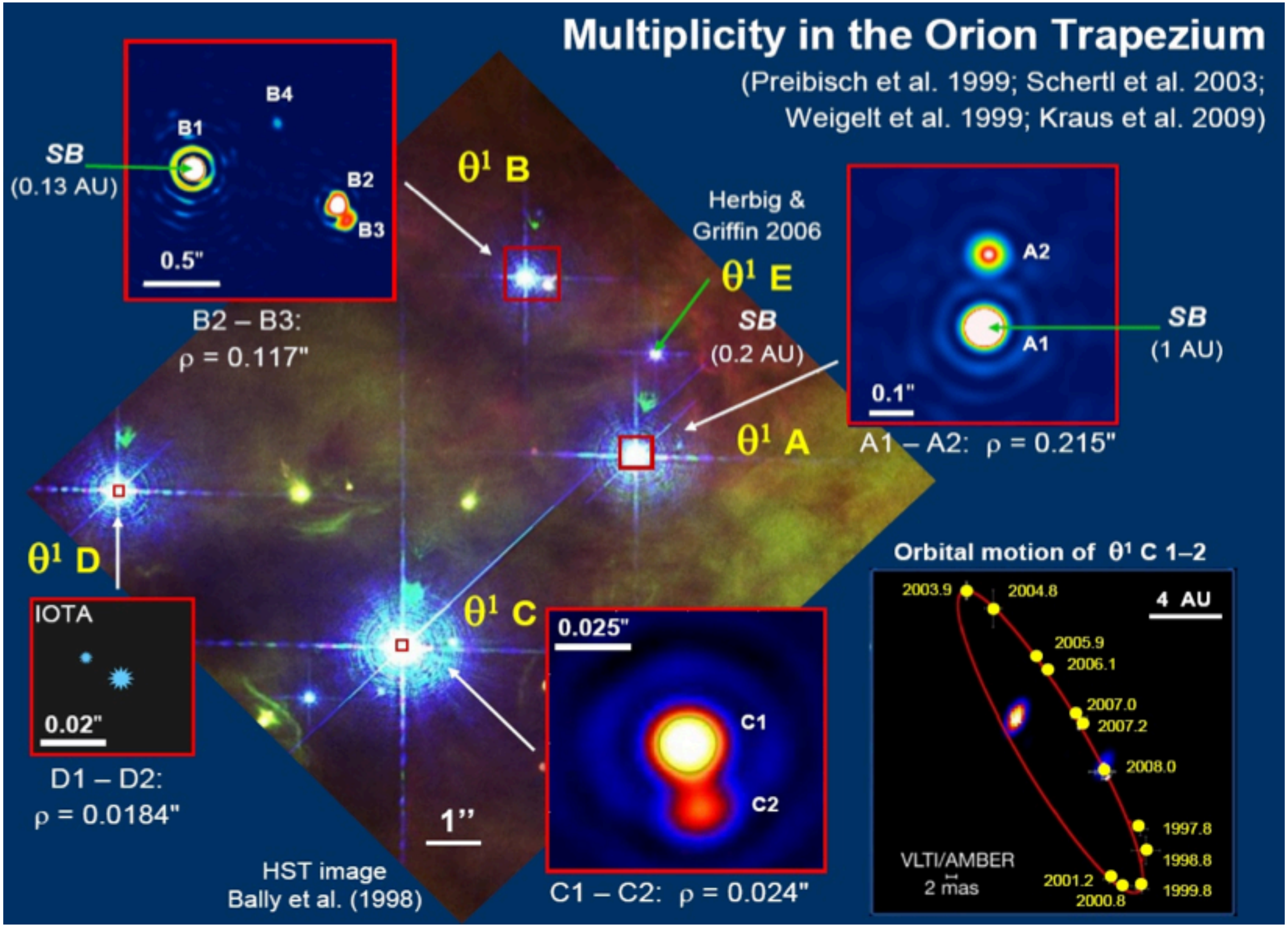
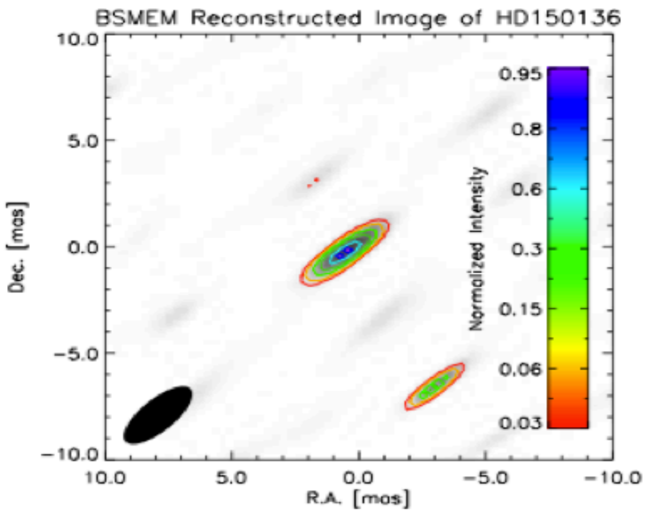
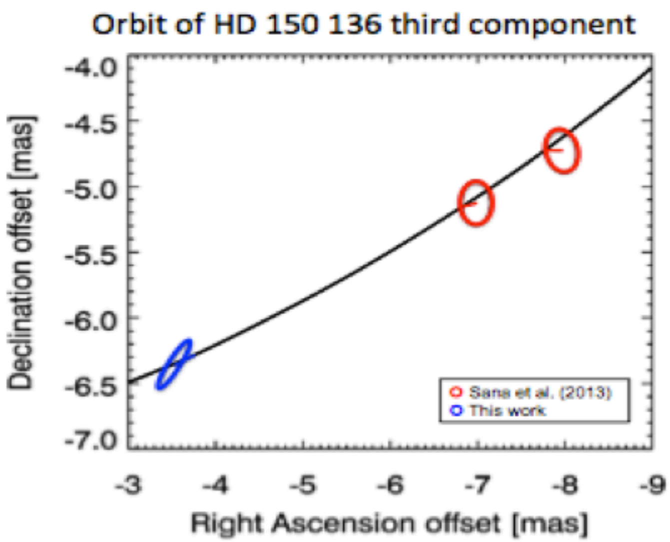
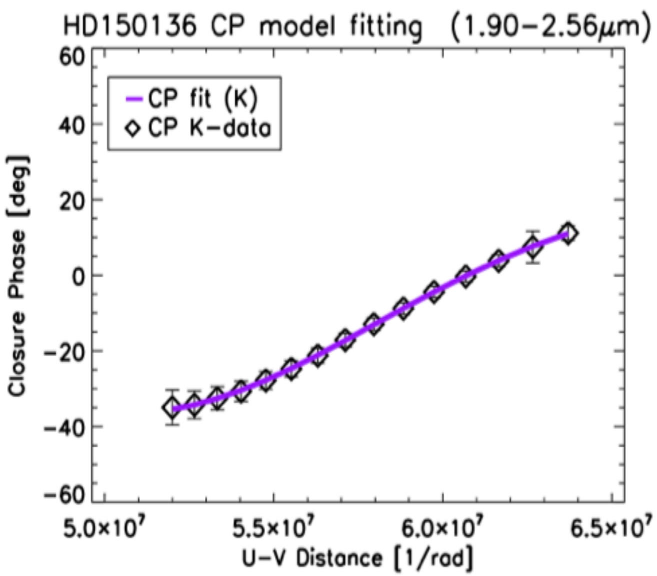
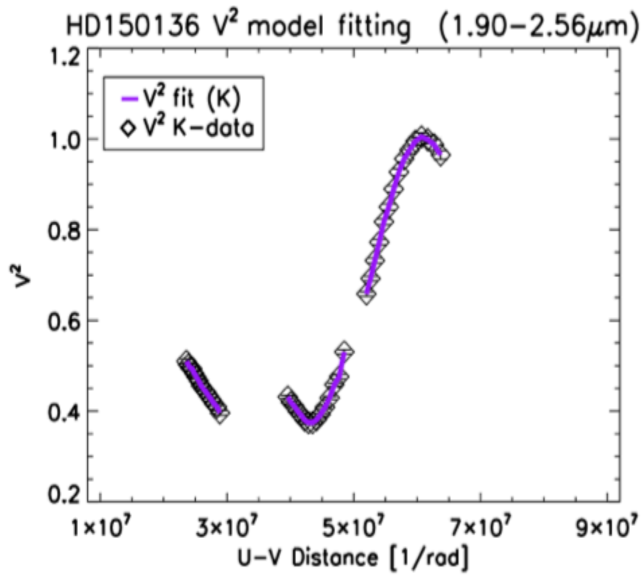


Scientific Cases









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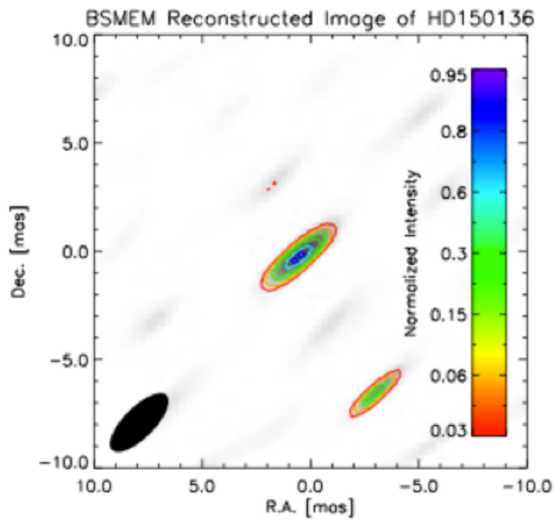

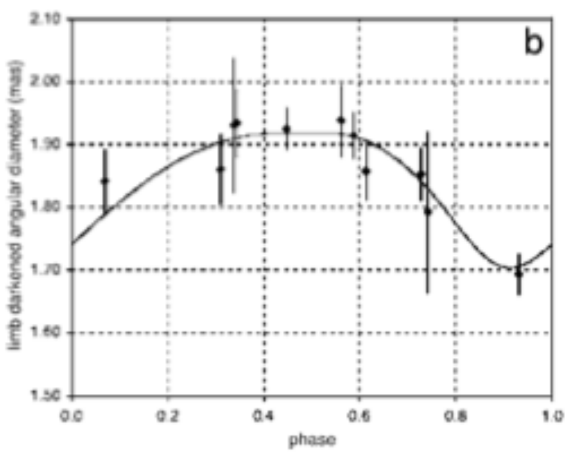

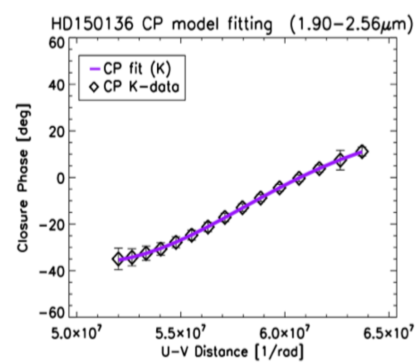

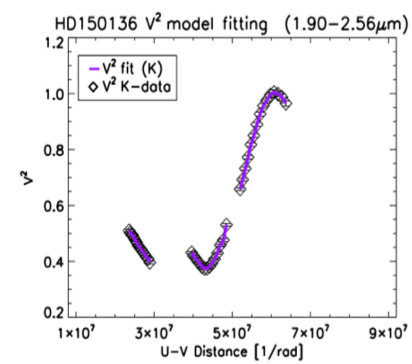

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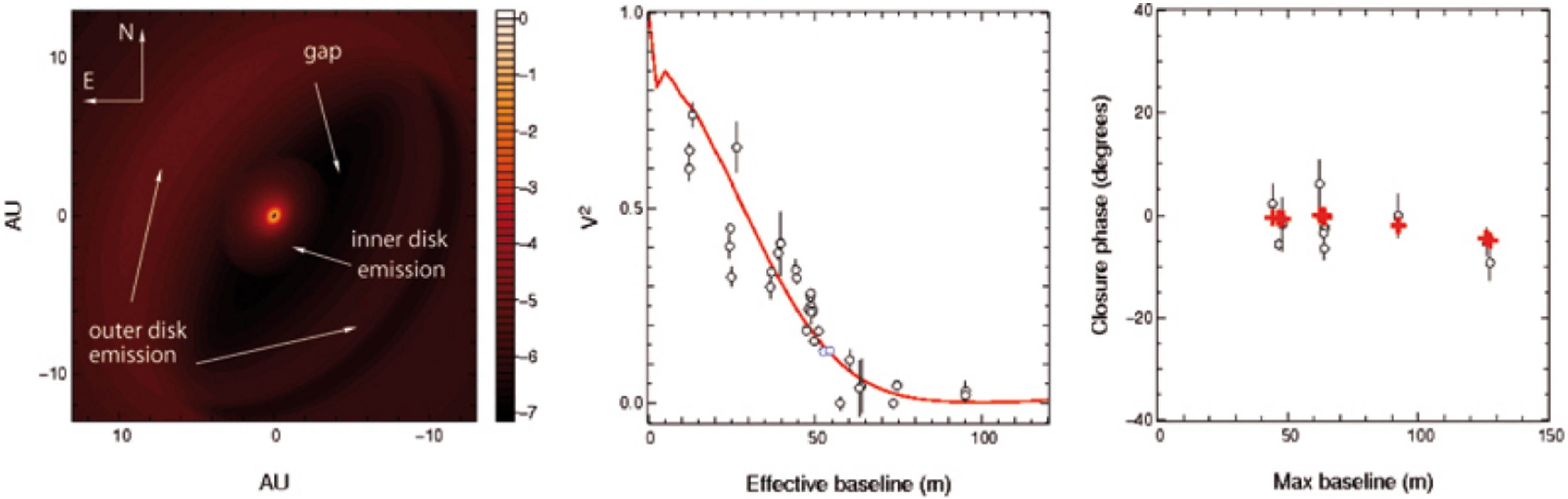

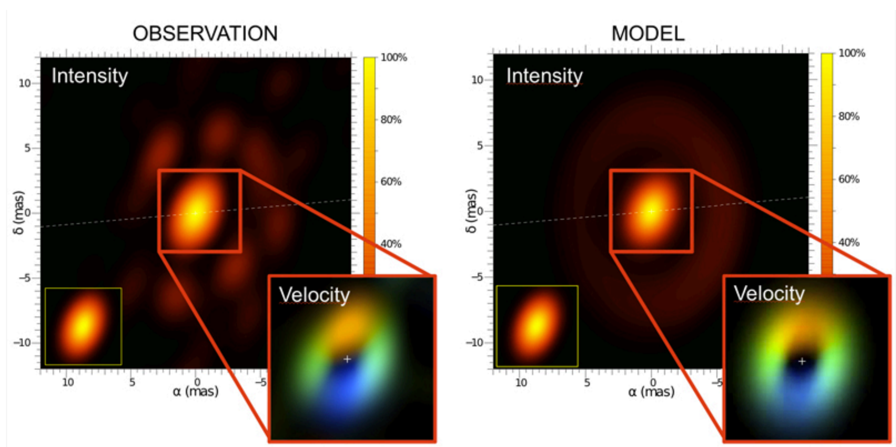

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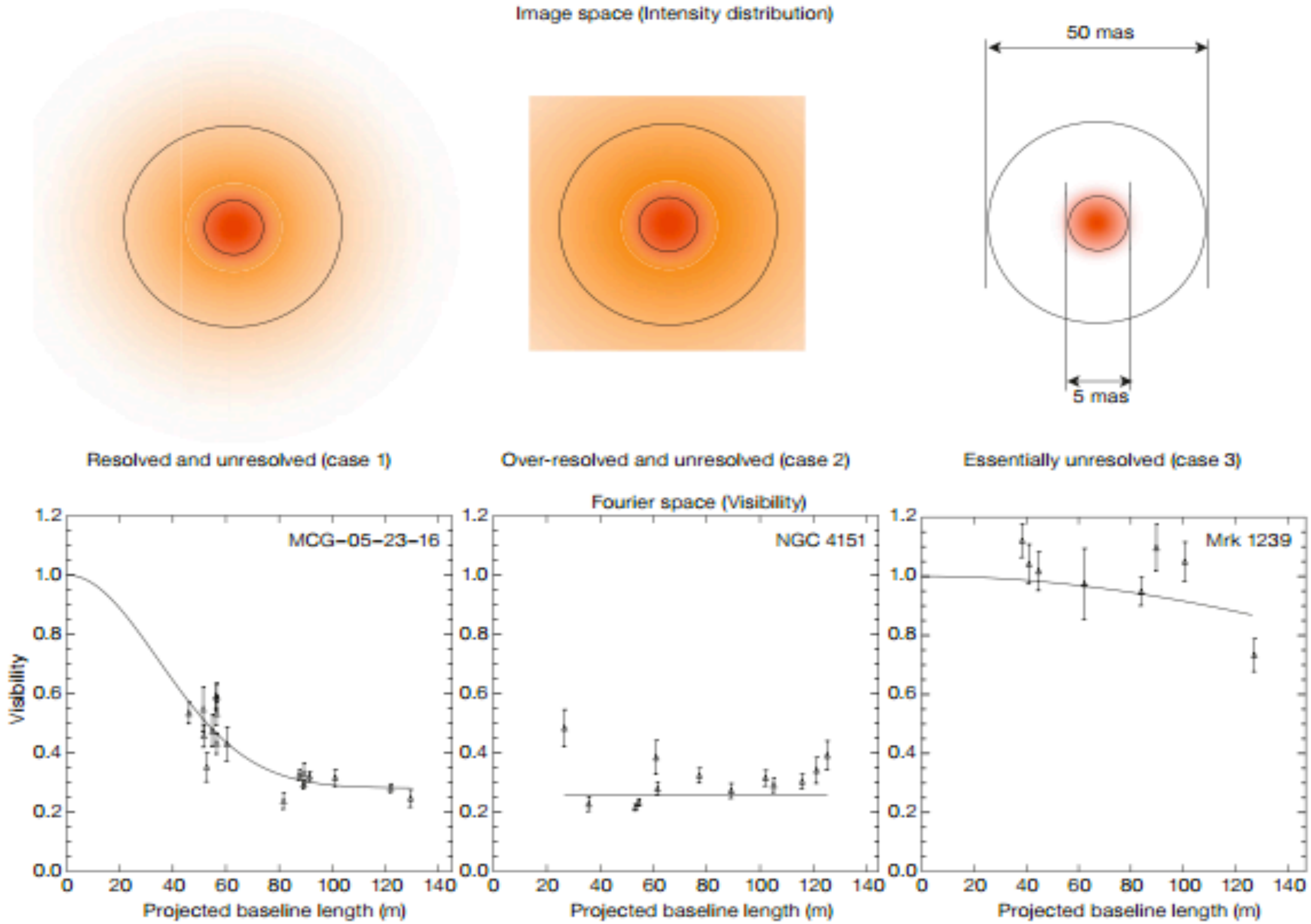

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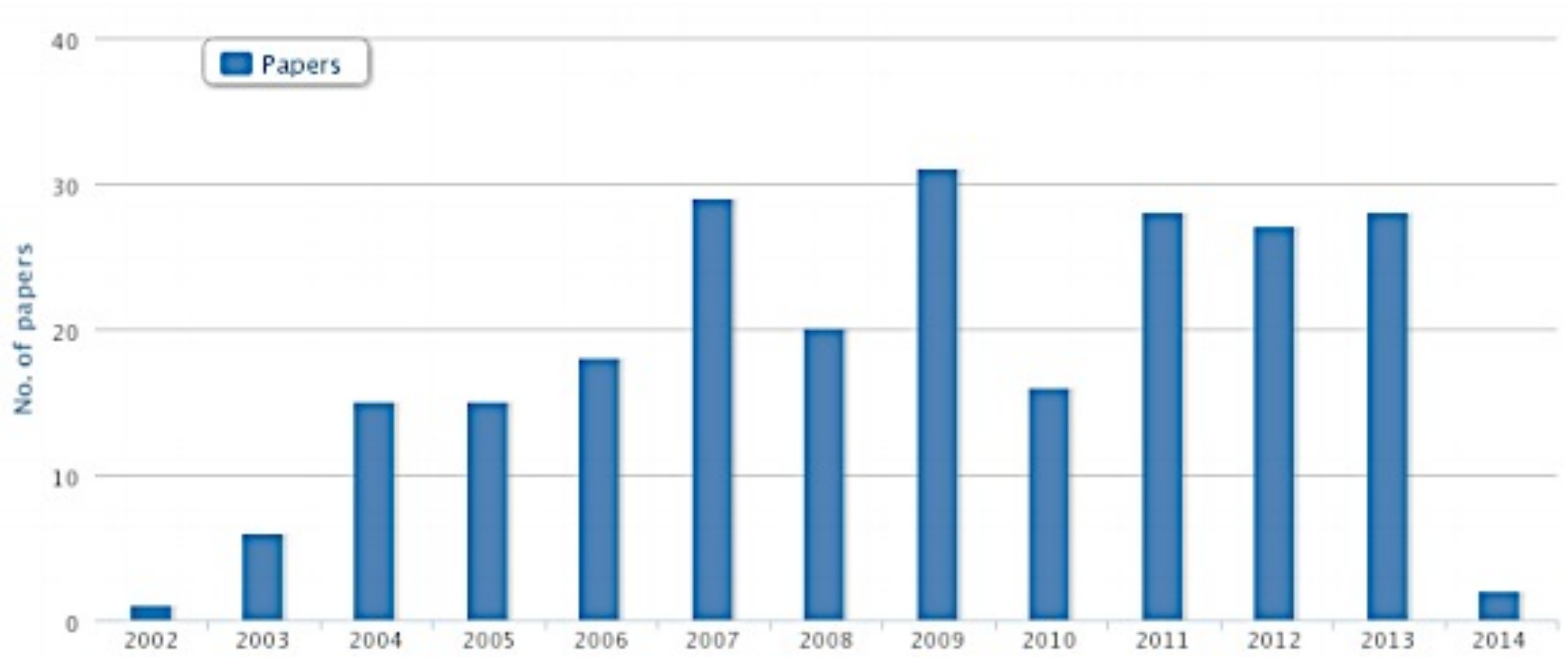
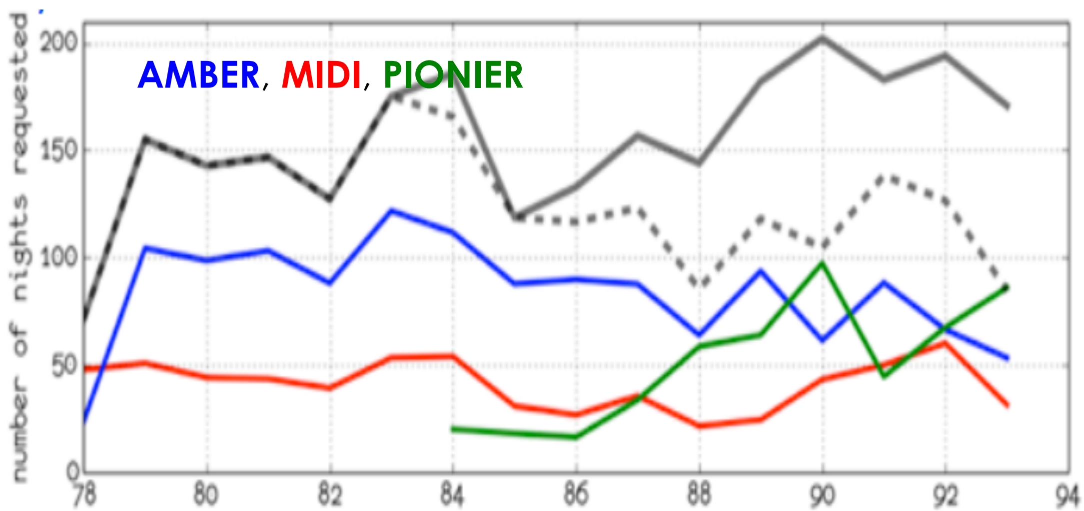


Call for proposals

- Strong scientific cases needed
- Two call for proposals per year (March, September)
- Keep in mind technical strengths and limitations (uv-coverage, sensitivity, etc)
- Similar pressure factor for UT's and AT's
- Model of the visibilities always useful

	AMBER	MIDI	PIONIER
AT / UT	66% / 33%	40% / 60%	90% / 10%
small quadruplet medium quadruplet large quadruplet	26% 37% 37%	20% 40% 40%	15% 25% 60%
service / visitor	12% / 88%	35% / 65%	0% / 100%



The future

- VLTI has been continuously improved in the decade
- Second generation of instruments (**GRAVITY and MATISSE**) coming soon
- Adaptive optics on Ats (NAOMI)
- Better sensitivity and spectral resolution
- Pipelines

GRAVITY:

- Will replace AMBER
- 4 telescopes combined
- Planet formation, circumstellar disks, Intermediate mass black holes, Sgr A* flares

MATISSE:

- Will replace MIDI
- 4 telescopes combined
- Imaging allowed!
- L and M bands also offered
- Evolution of planetary systems, birth of massive stars, environment around evolved stars

Instrument	Action
AMBER	Stays until 2016
PIONIER	Pending…
MIDI	Removed in P94
GRAVITY	Ready in 2015
MATISSE	Ready in 2014

To keep in mind

- VLTI has the best angular resolution in Europe
- Three different instruments: 2 in the NIR and 1 in the MIR
- New instruments coming soon
- Improvements of sensitivity and u-v coverage
- Pipelines and software still need improvements
- Useful facility to study stellar astrophysics and AGNs

THANK YOU!