Observability (and (u,v) coverage)

Euro Summer School
Circumstellar disks and planets at very high angular resolution
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Florentin MILLOUR

(Max-Planck Institut fur Radioastronomie)

based on the presentation of D. Segransan at the Goutelas Summer school (2006)

Observability

• ***Single dish telescopes:***

Constraints are HA and Fz

=> one needs LST, RA and DEC

Observing **efficiency is high** (uv coverage, low overheads)

• ***Interferometers:***

Constraints are HA, Fz, (u,v)

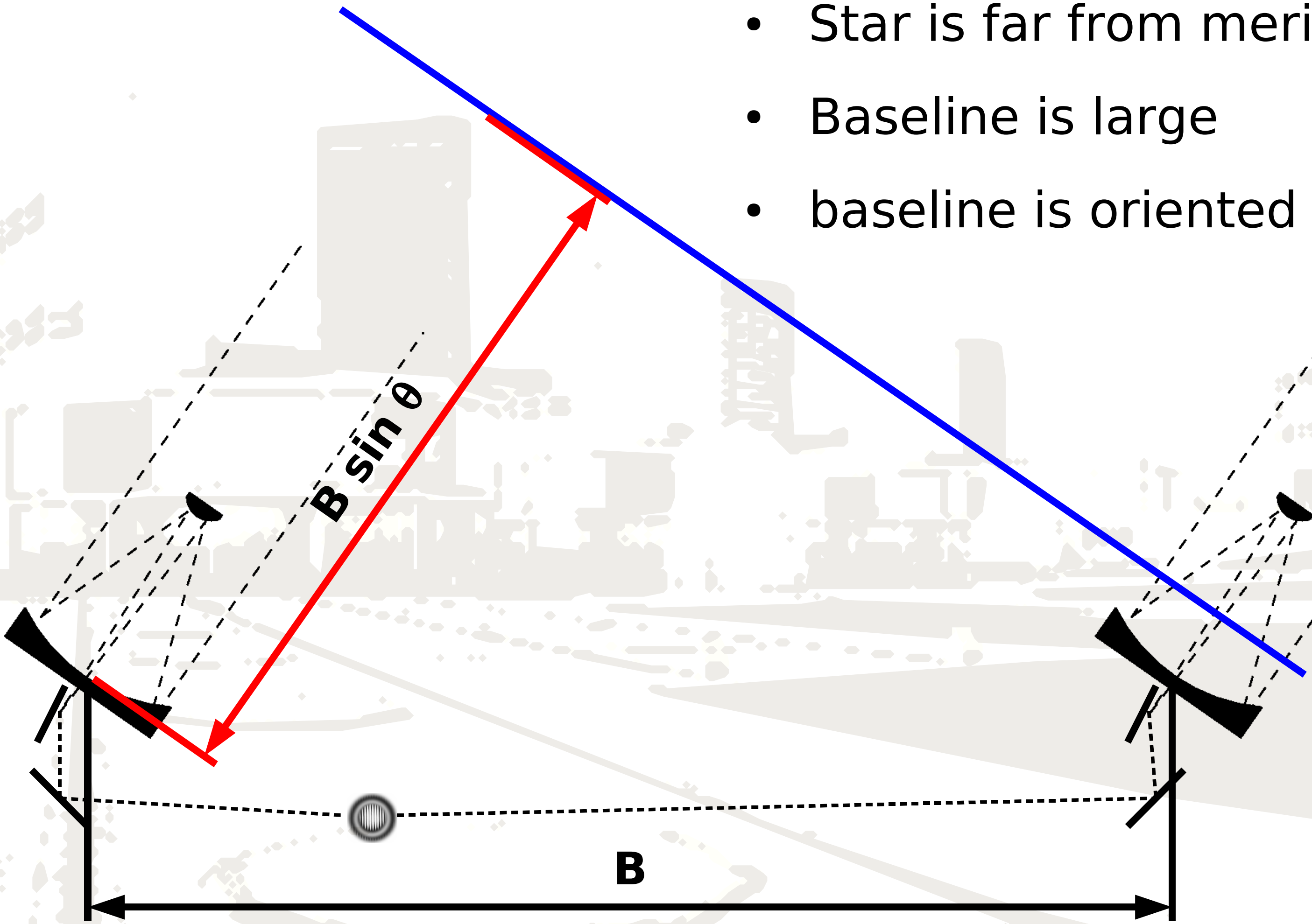
=> one needs LST, RA, DEC and Bvect

+ Hardware constraints : DL stroke, Dome vignetting

Observing **efficiency is low** (poor uv coverage, high overheads)

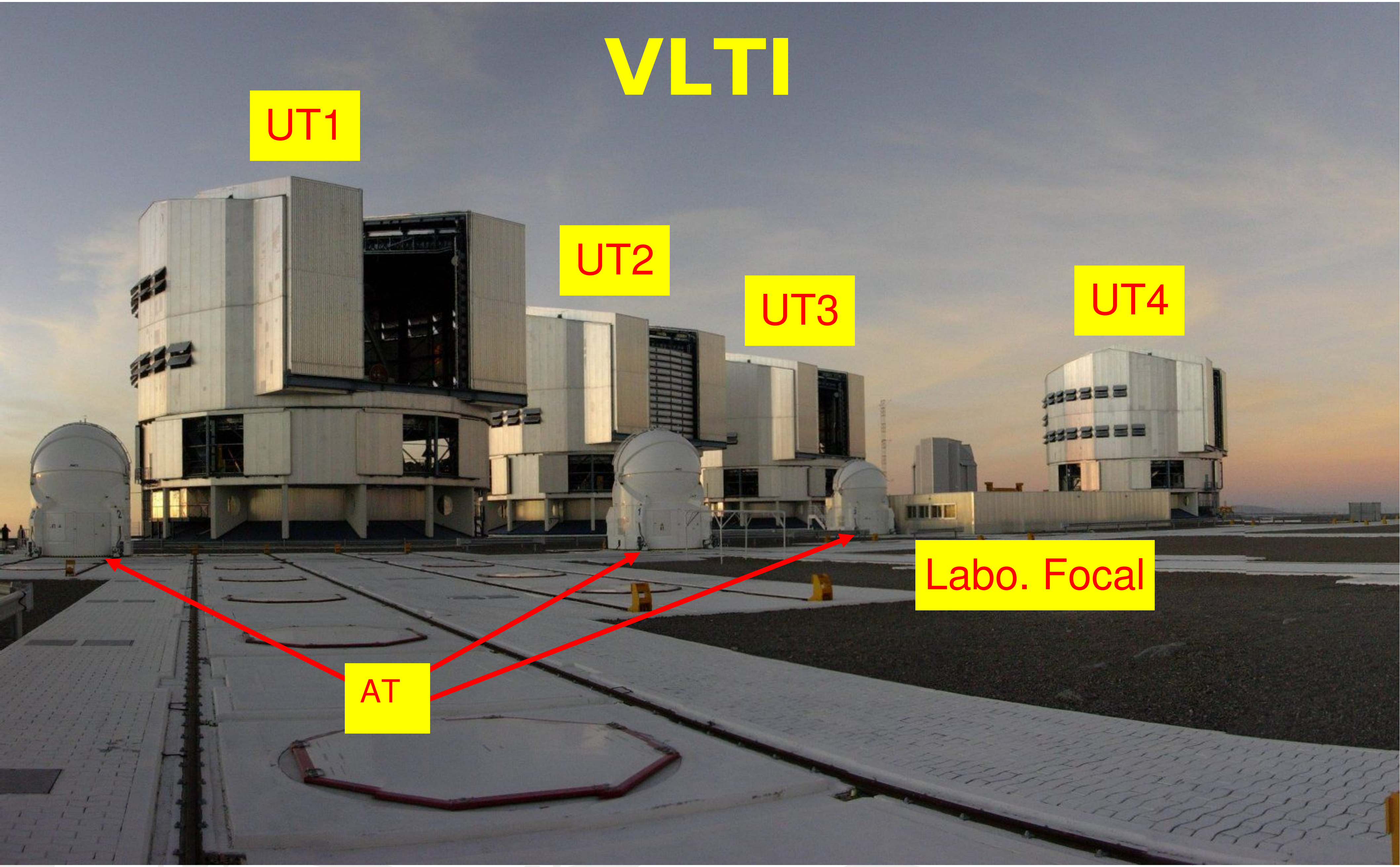
=> A good Observation Preparation Software is required

OPD



B sin θ can be very large if:

- Star is far from meridian
- Baseline is large
- baseline is oriented East-West


VLTI
UT1
UT2
UT3
UT4
Labo. Focal
AT

VLTI
200m
130m
Google
Image © 2006 DigitalGlobe
U1
U2
U3
U4
J6
J5
J4
J3
J1
J2
A0
B0
C0
D0
E0
G0
G2
H0
K0
L0
M0
I1
A1
B1
C1
B2
C2
B3
C3
B4
B5
D1
D2
G1

VLTI (?)

What is (u,v) plane ?

$$V(u,v) = \frac{\hat{I}(u,v)}{\hat{I}(0,0)}$$

Fourier transform

$$\hat{I}(u,v) \Leftrightarrow I(x,y)$$

$$\vec{B} = (\Delta X, \Delta Y, \Delta Z)$$ is the projected baseline vector

$$(u,v) = \frac{1}{\lambda}(\Delta X, \Delta Y)$$ are the spatial frequencies

Spatial frequencies:

- unitless (radians^{-1})
- represent distances in the wavefront in wavelength units
- (u,v) are conjugated to (x,y)

(u,v) plane and single dish telescope

Object observed at the
Special Astronomical Observatory (Zelentchouk)

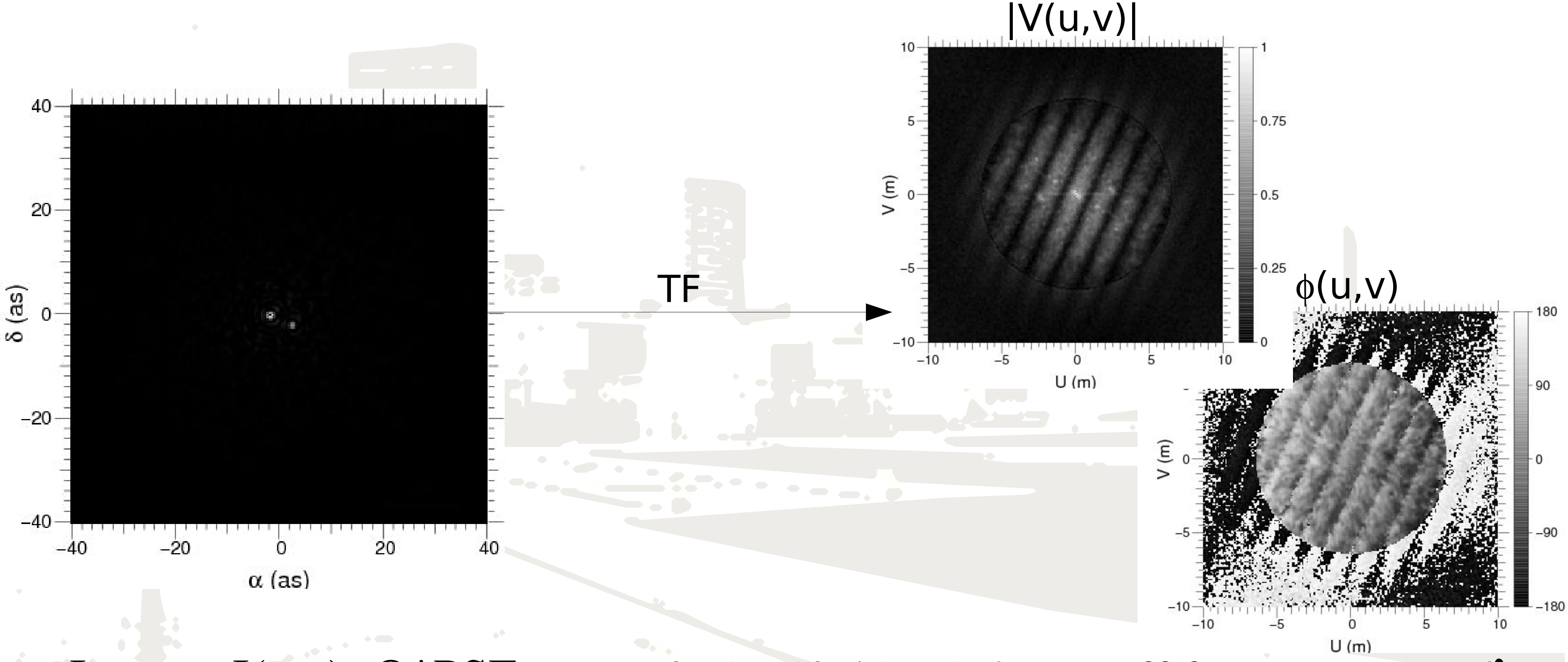
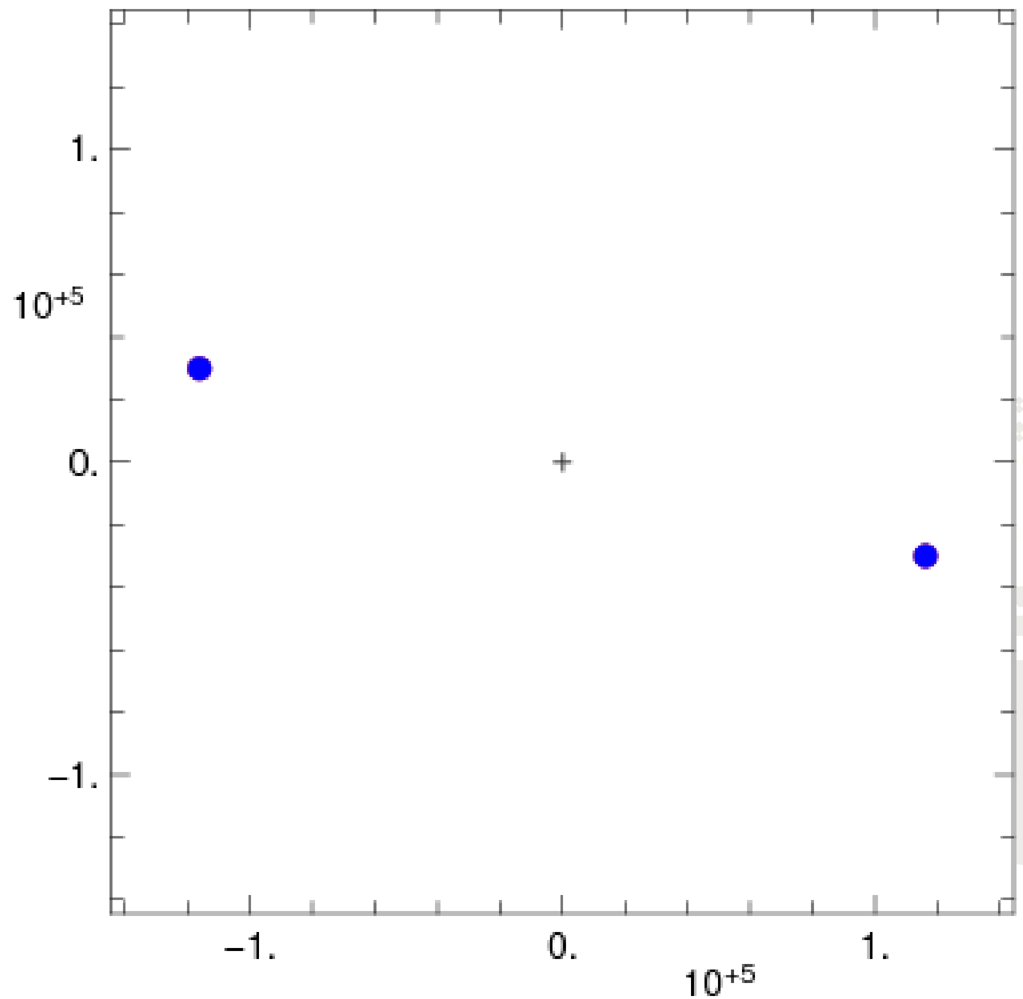


Image : I(x,y)=O*PSF |V(u,v)|, ϕ(u,v) & cut-off frequency at D/λ

(u,v) plane with an interferometer: 2T snapshot



How to fill the gaps ?

- "cheap" way:
  - Earth rotation (supersynthesis) → – **Time consuming**
  - Wavelength range → – **Lower sensitivity**

- "expensive" way:
  - Increase Nr of telescopes → – **Expensive**
  - Baseline reconfiguration → – **Time consuming & expensive**

(u,v) plane filling with more telescopes

- A 2 telescopes interferometer gives access to **1** (u,v) point per measurement.

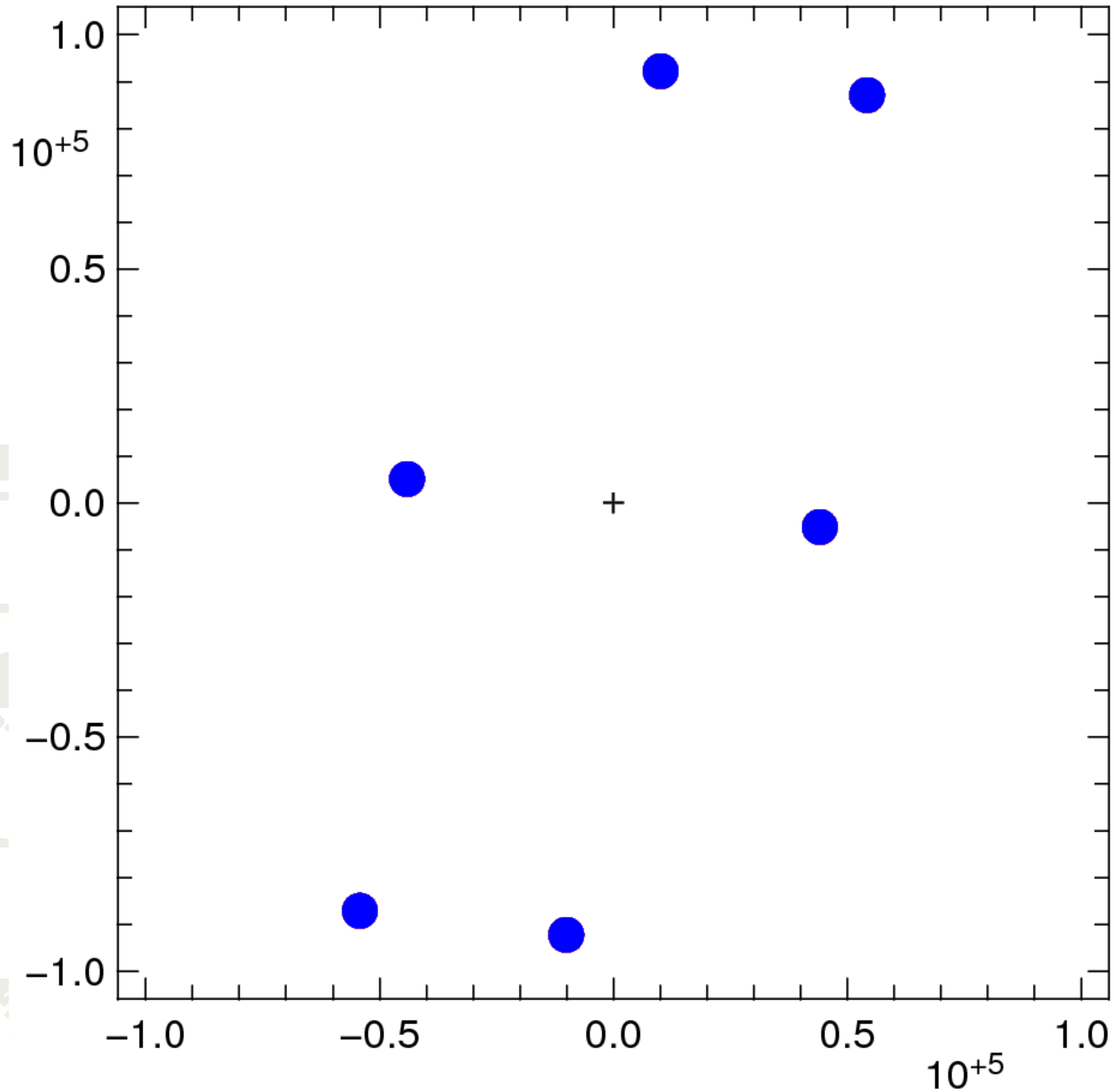
- A 3 telescopes interferometer gives access to **3** (u,v) point per measurement.

- A N telescopes interferometer gives access to N(N-1)/2 points per measurements

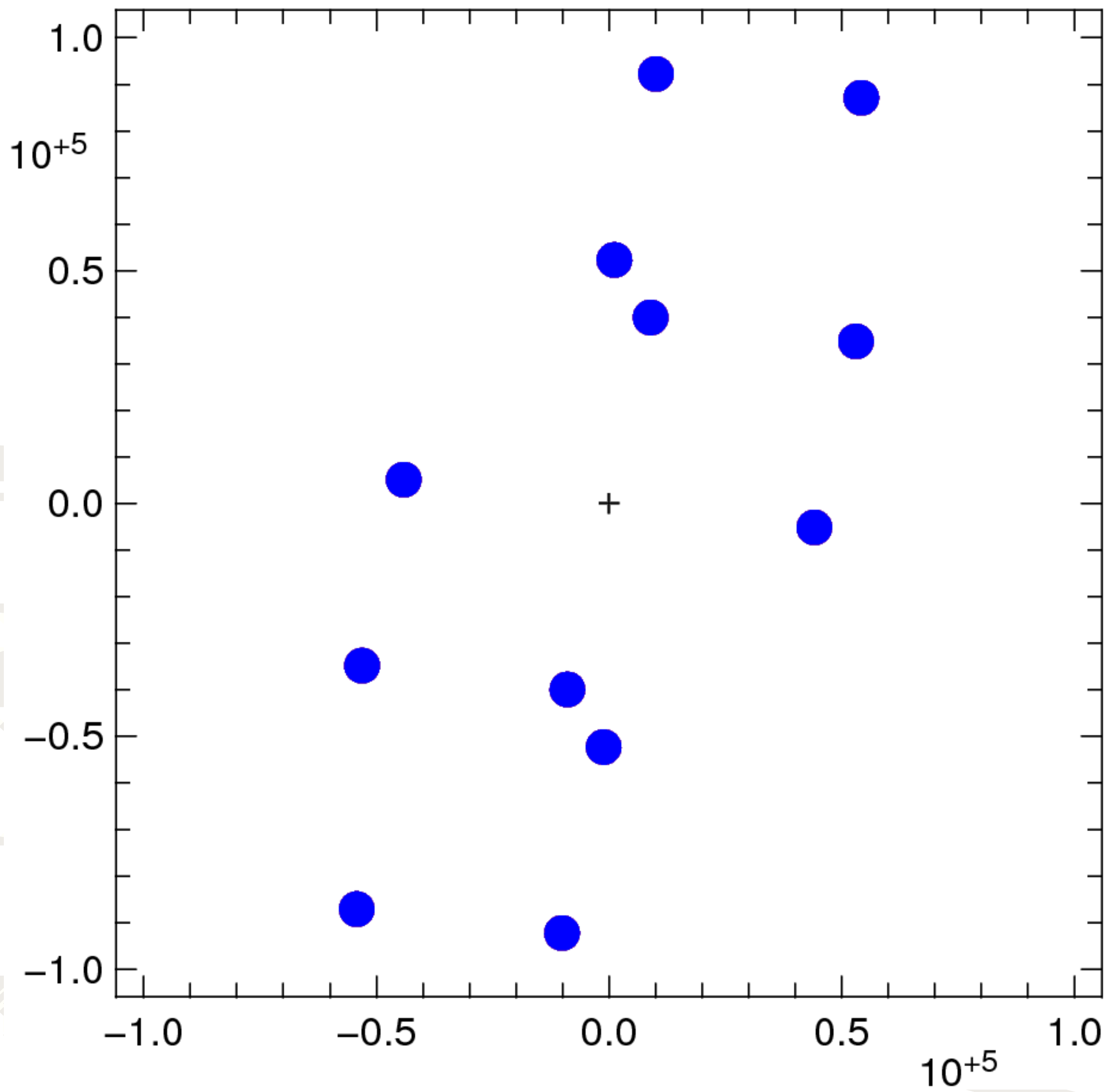
=> We have access to high spatial frequencies but …

A lot of gaps remain in the (u,v) plane

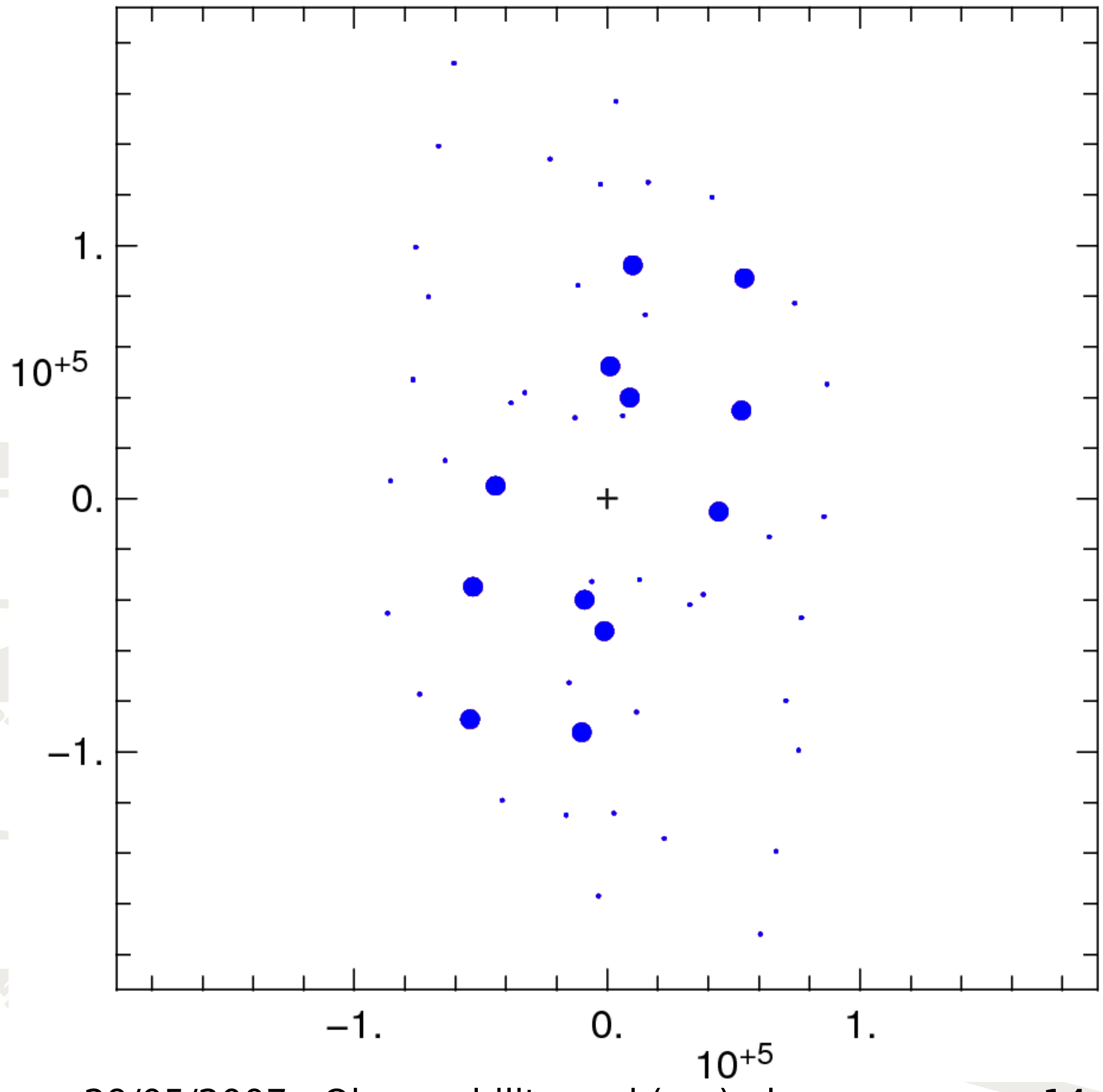
(u,v) plane filling with more telescopes: 3T



(u,v) plane filling with more telescopes: 4T



(u,v) plane filling with more telescopes: 8T



(u,v) plane filling with the earth rotation (supersynthesis)

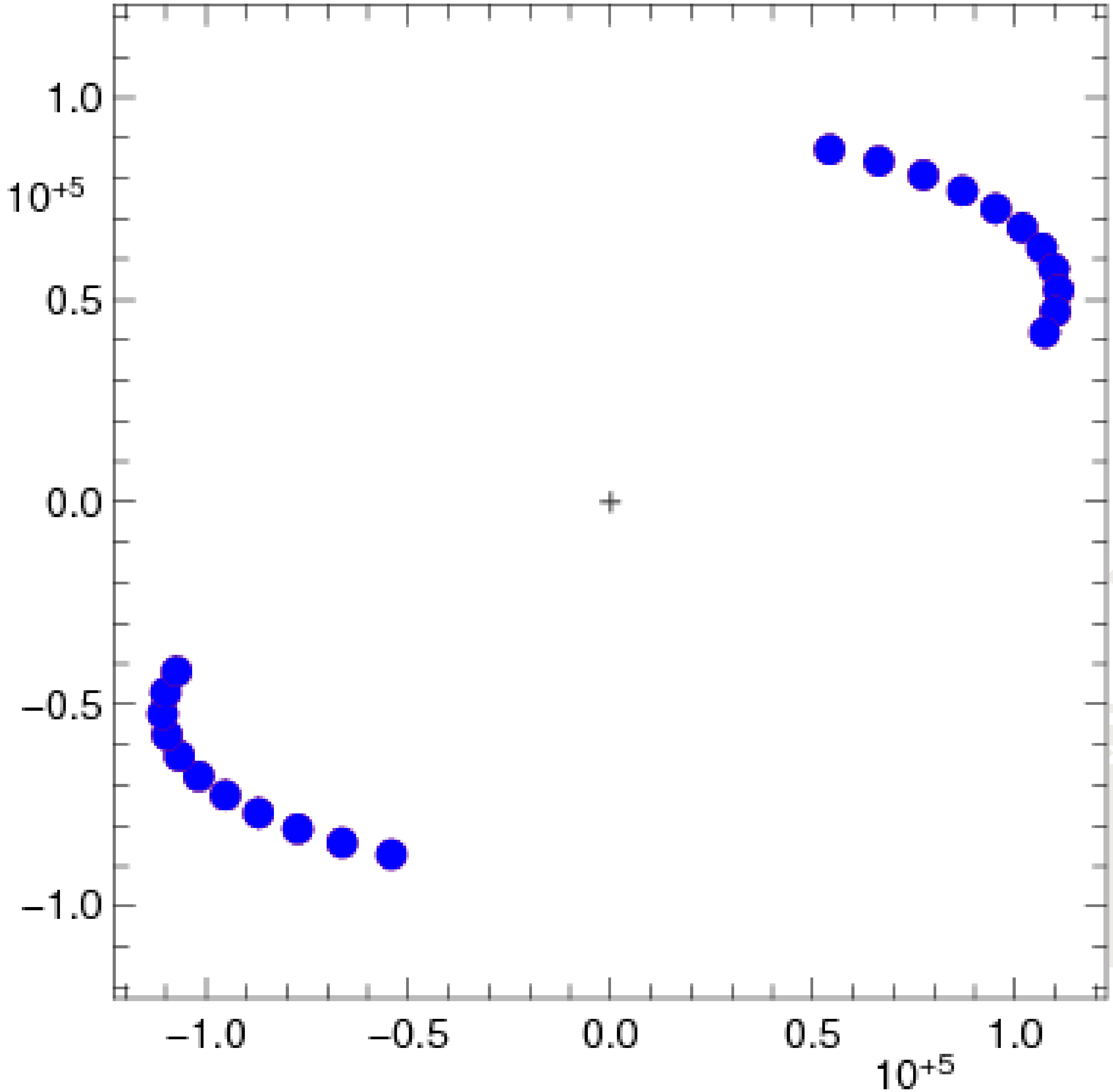
- (u,v) plane sampling depends on:
  - hour angle
  - source declination d
  - baseline vector (X,Y,Z)

$$\begin{pmatrix} u \\ v \\ w \end{pmatrix} = \frac{1}{\lambda} \begin{pmatrix} \sin(h) & \cos(h) & 0 \\ -\sin(\delta)\cos(h) & \sin(\delta)\cos(h) & \cos(\delta) \\ \cos(\delta)\cos(h) & -\cos(\delta)\sin(h) & \sin(\delta) \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

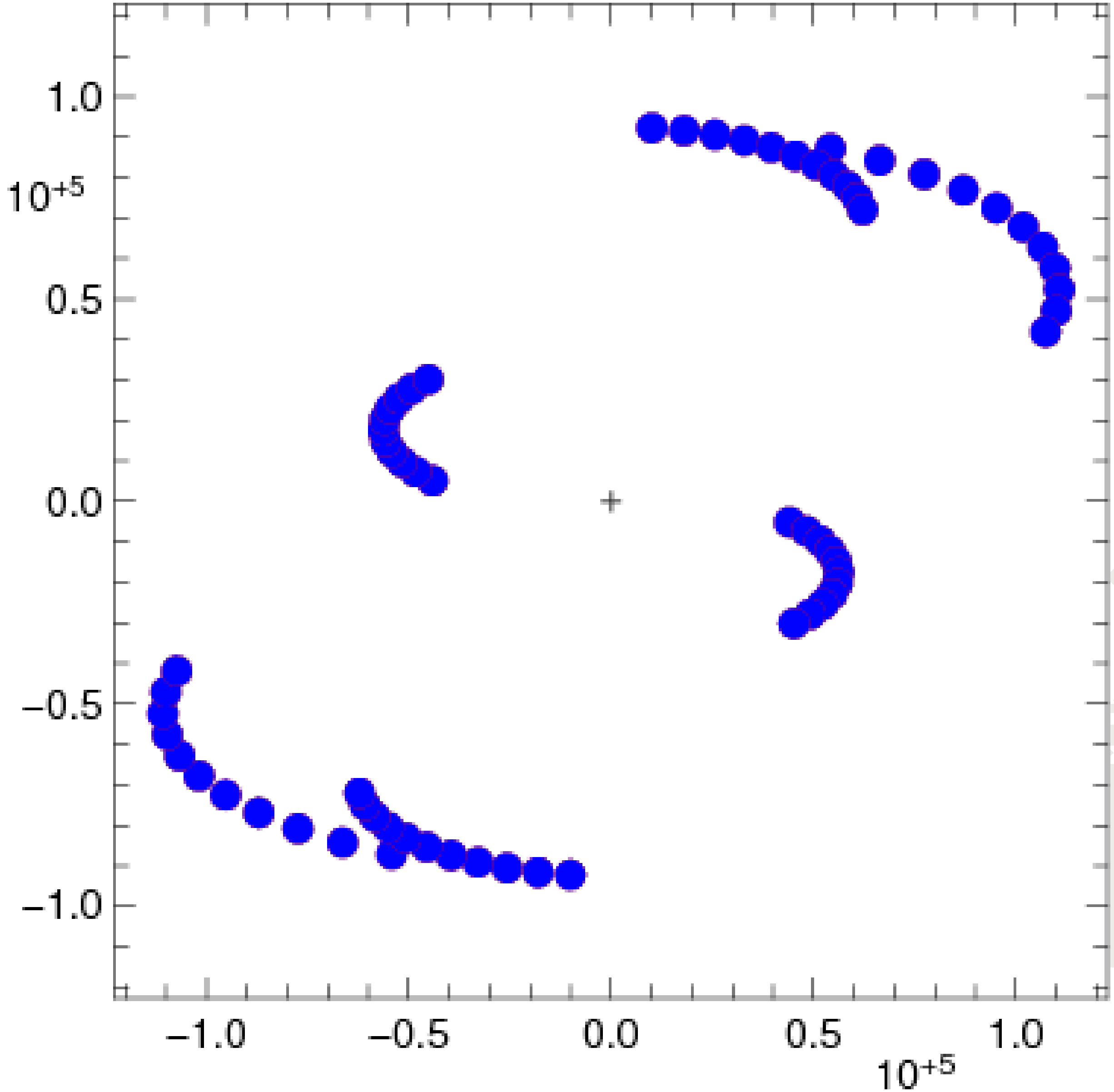
- Eliminating h from the equation above gives an ellipse equation:

$$u^2 + \left(\frac{v - \frac{Z}{\lambda}\cos(\delta)}{\sin(\delta)} \right)^2 = \frac{X^2 + Y^2}{\lambda^2}$$

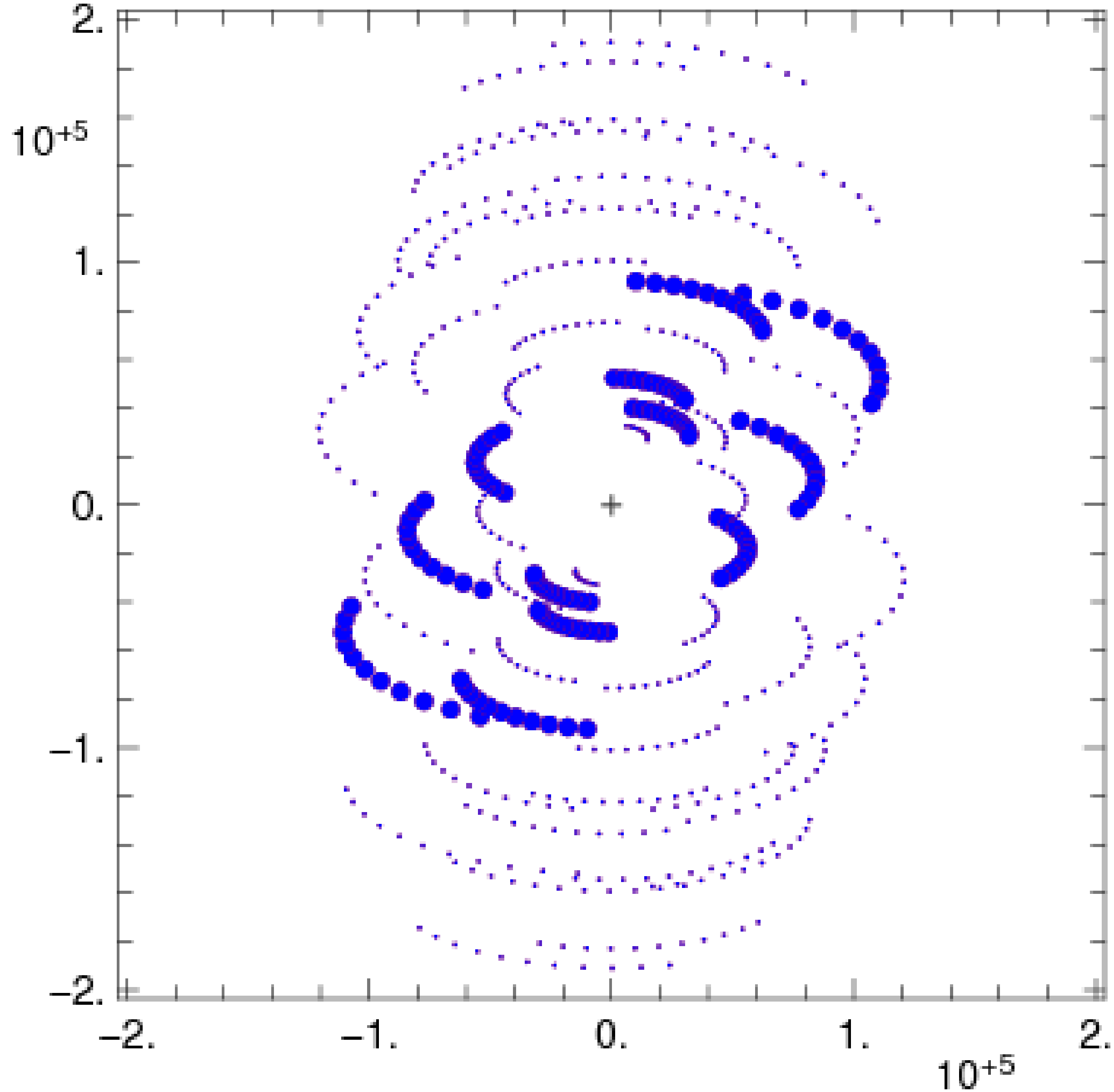
Supersynthesis (2T)



Supersynthesis (3T)



Supersynthesis (8T)



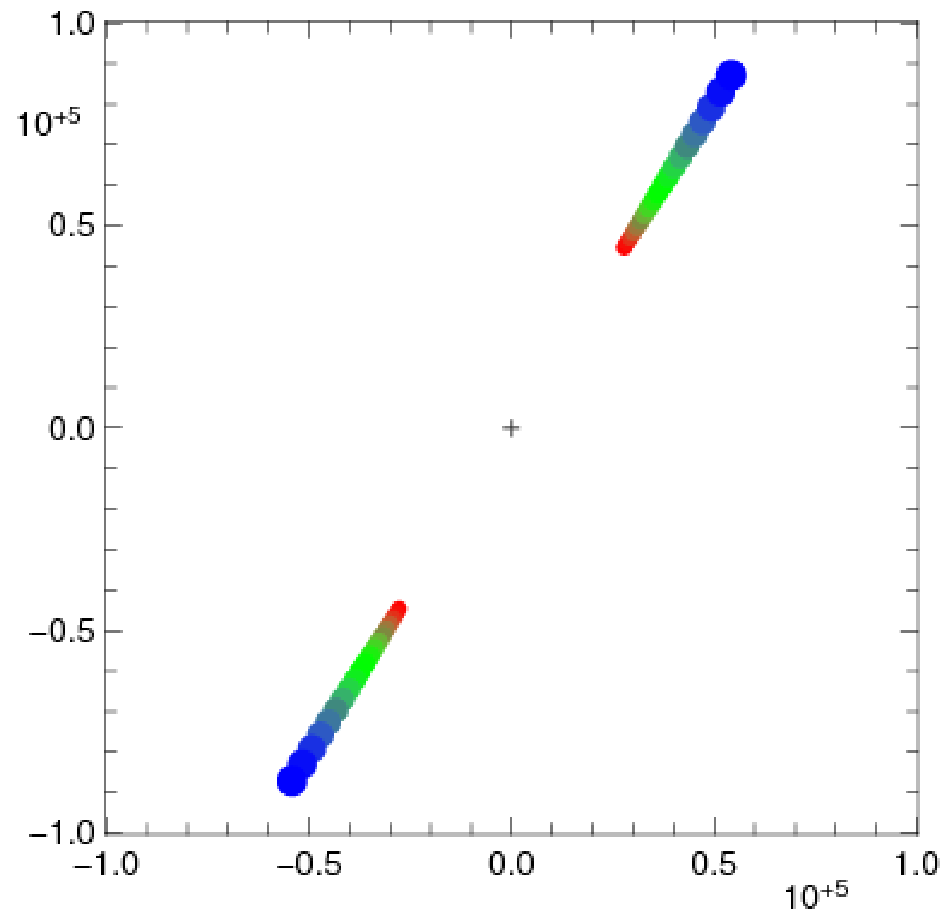
(u,v) plane filling with spectral coverage

- **Spatial frequencies:**

$$\mathbf{f = B/\lambda}$$

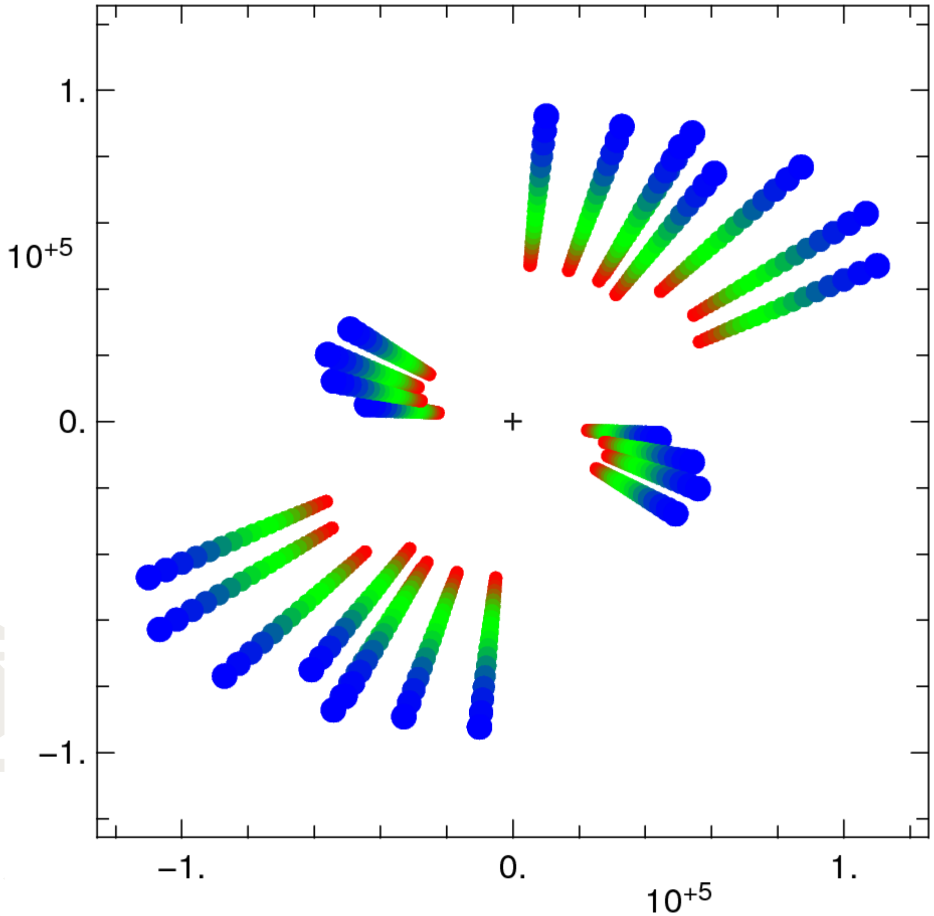
=> You scan different spatial frequencies at different wavelengths for a given baseline (achromatic object) !

- 2T

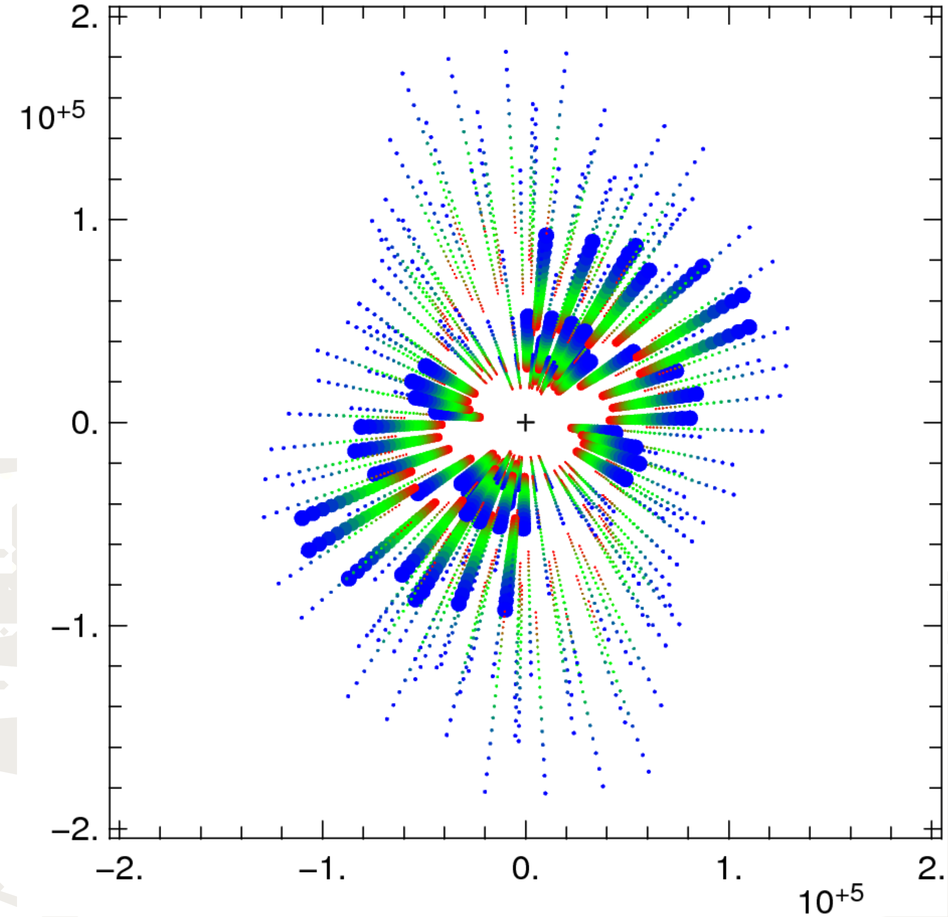


Supersynthesis + spectral coverage

- 3T



- 8T



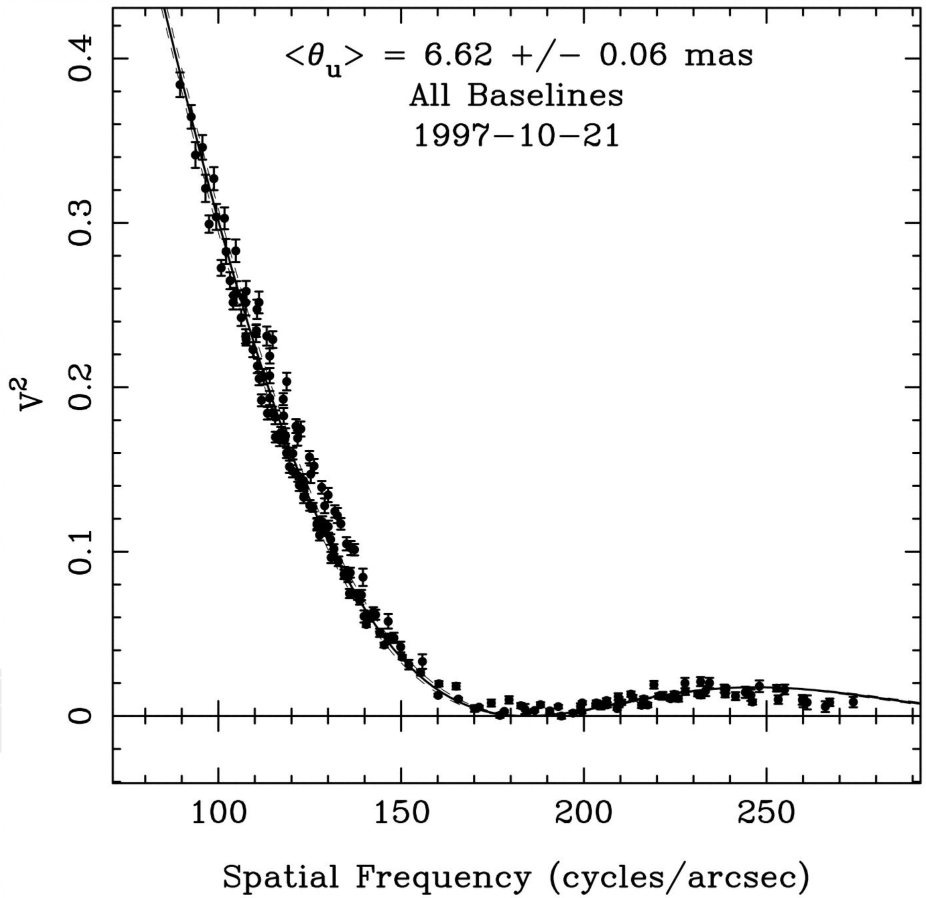
What is an <u>appropriate</u> UV-plane sampling?

- Well, it depends ...

- on the object you are observing
  - angular size of the source
  - simple vs. complex source
  - model fitting vs. image reconstruction

- on the instrument you are using
  - accuracy on visibilities
  - spectral resolution

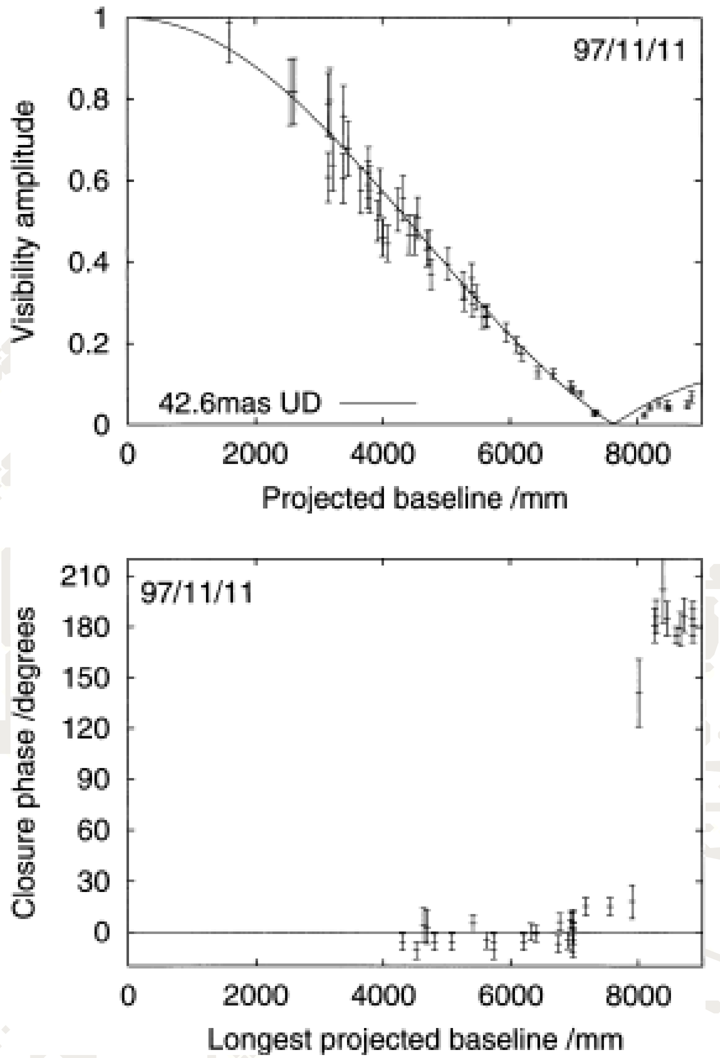
What is an **appropriate** UV-plane sampling?



Radius measurement with NPOI

- N telescopes >2
- accuracy on V^2 > 1%
- big UV coverage
- use of spectral resolution to improve UV coverage

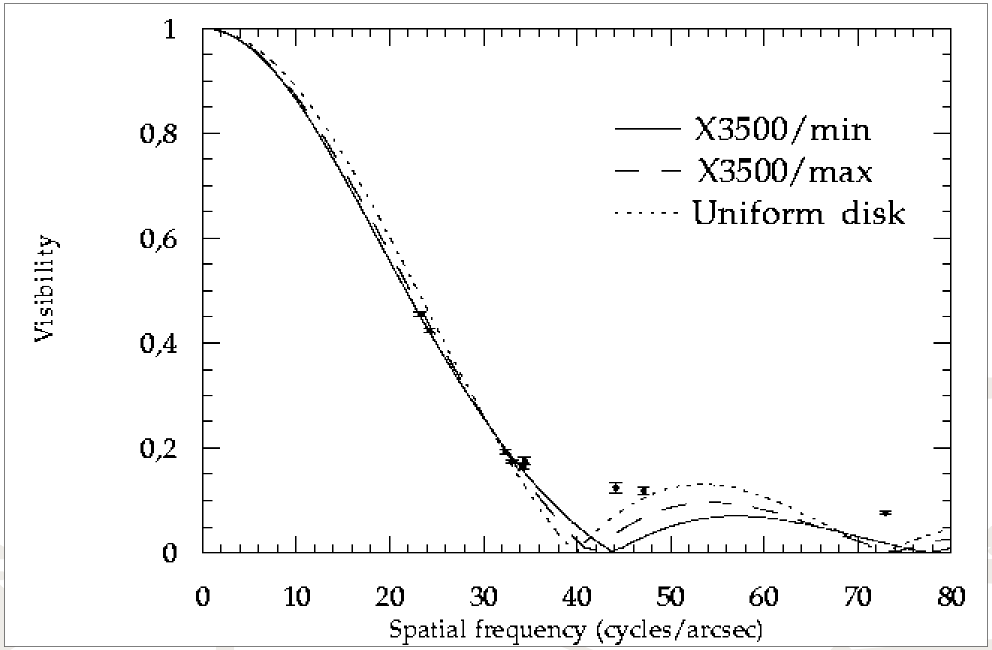
What is an appropriate UV-plane sampling?



Radius measurement with COAST

- N telescopes = 3
- accuracy on $V^2 > 5\%$
- good UV coverage (lots of measurements)
- transition in the closure phase is observed

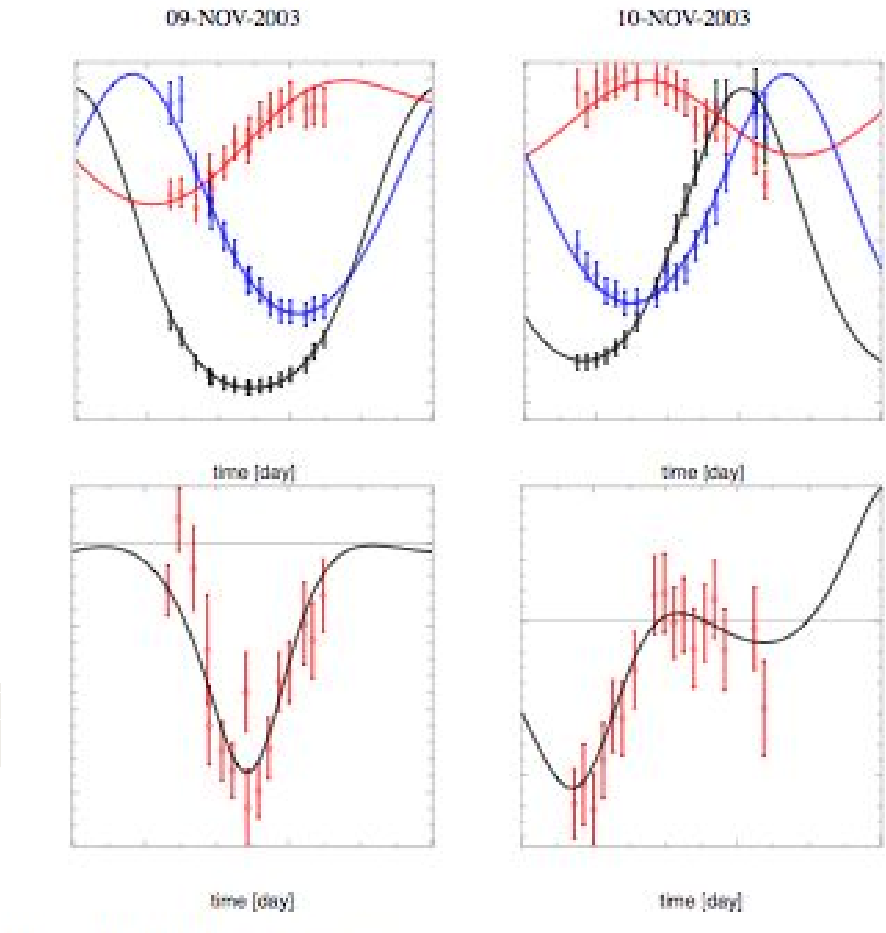
What is an appropriate UV-plane sampling?



Radius measurement with IOTA/FLUOR

- N telescope = 2 (at that time)
- accuracy on V^2 << 1%
- poor UV coverage but ... a few points at the right place do the job

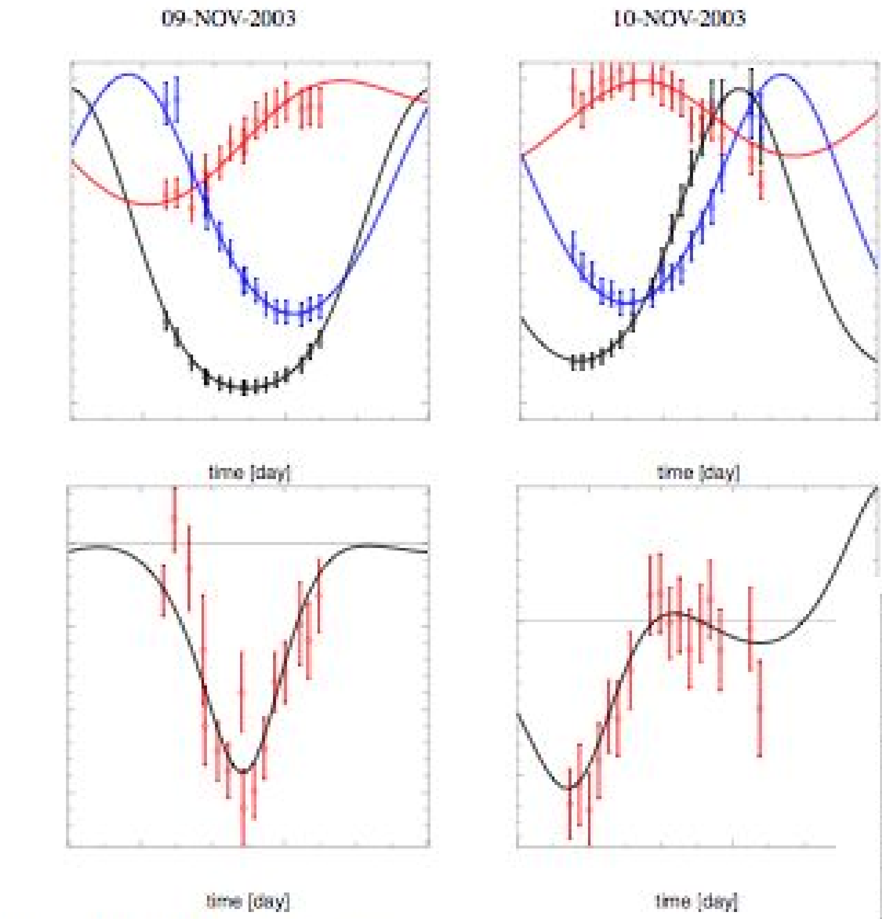
What is an <u>appropriate</u> UV-plane sampling?



Binary star observation with IOTA

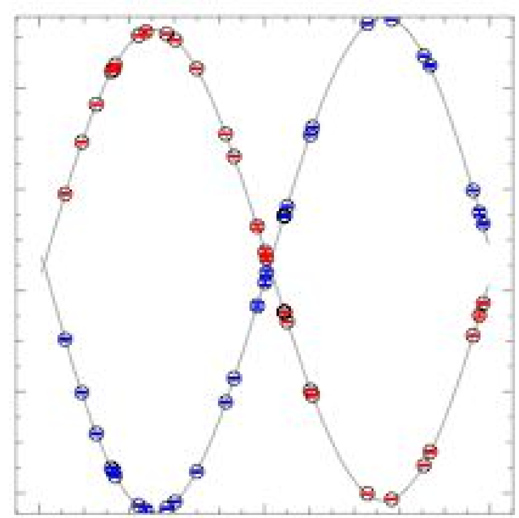
- accuracy on $V^2 > 1\%$
- limited UV coverage
- but … binary observed at different orbital phases

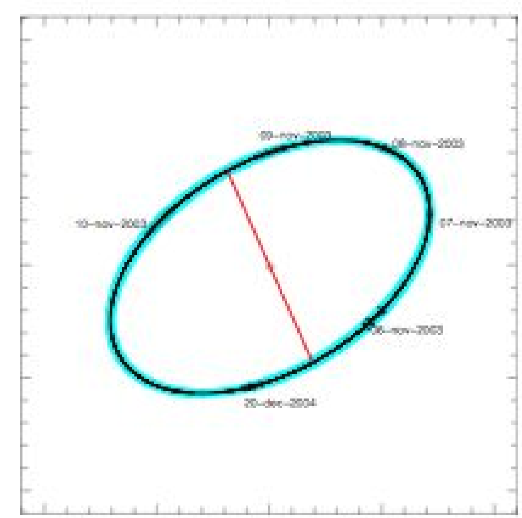
What is an appropriate UV-plane sampling?



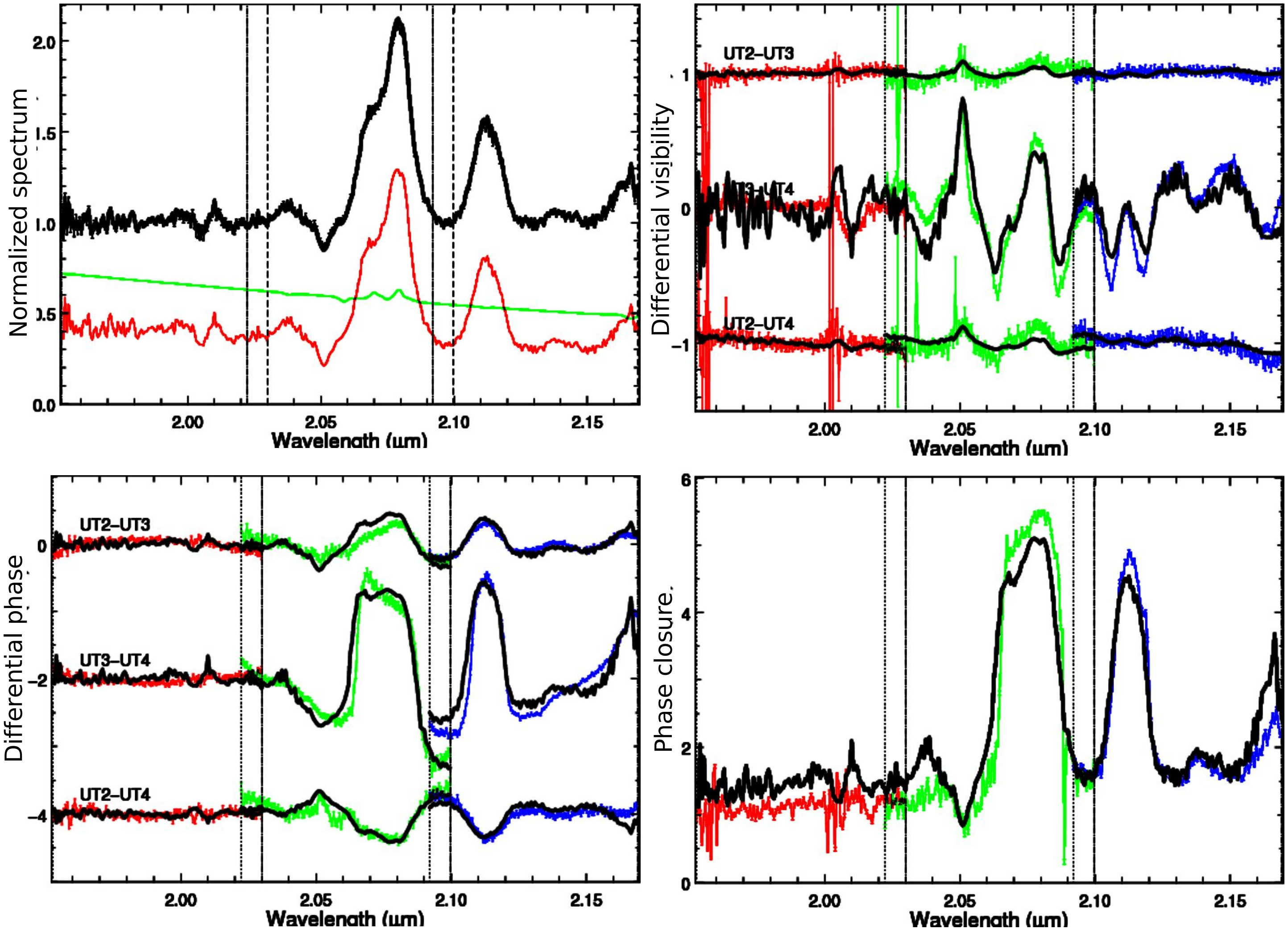
Binary star observation with IOTA

- accuracy on $V^2 > 1\%$
- limited UV coverage
- but … binary observed at different orbital phases
- and … radial velocities





What is an appropriate UV-plane sampling?



Very poor (u,v) coverage (1 snapshot), but ...

Spectrally varying flux ratio makes it working !

γ^2 Vel, Millour et al. 2007

What is an appropriate UV-plane sampling?

There is no simple answer.

This is why ASPRO was created

http://www.mariotti.fr