Observability (and (u,v) coverage)

Euro Summer School
Active Galactic Nuclei at the highest angular resolution: theory and observations
August 27 - September 7

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(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** (large (u,v) coverage, low overheads)

- ***Interferometers:***

Constraints are HA, Fz **and** (u,v)

=> one needs LST, RA, DEC **and Bvect**

+ Hardware constraints : DL range, Dome vignetting

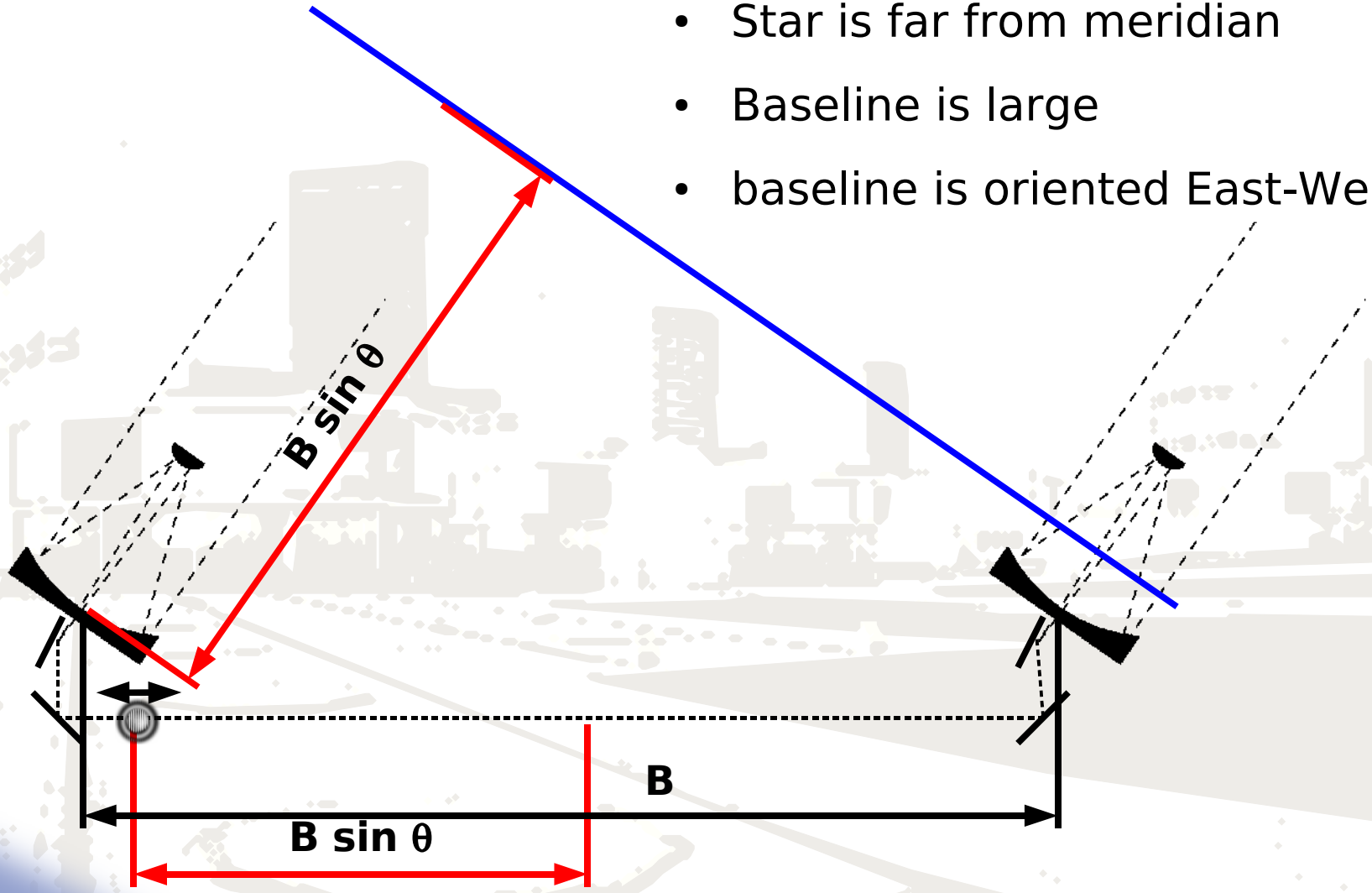
Observing **efficiency is low** (poor (u,v) coverage, high overheads)

=> 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



OPD

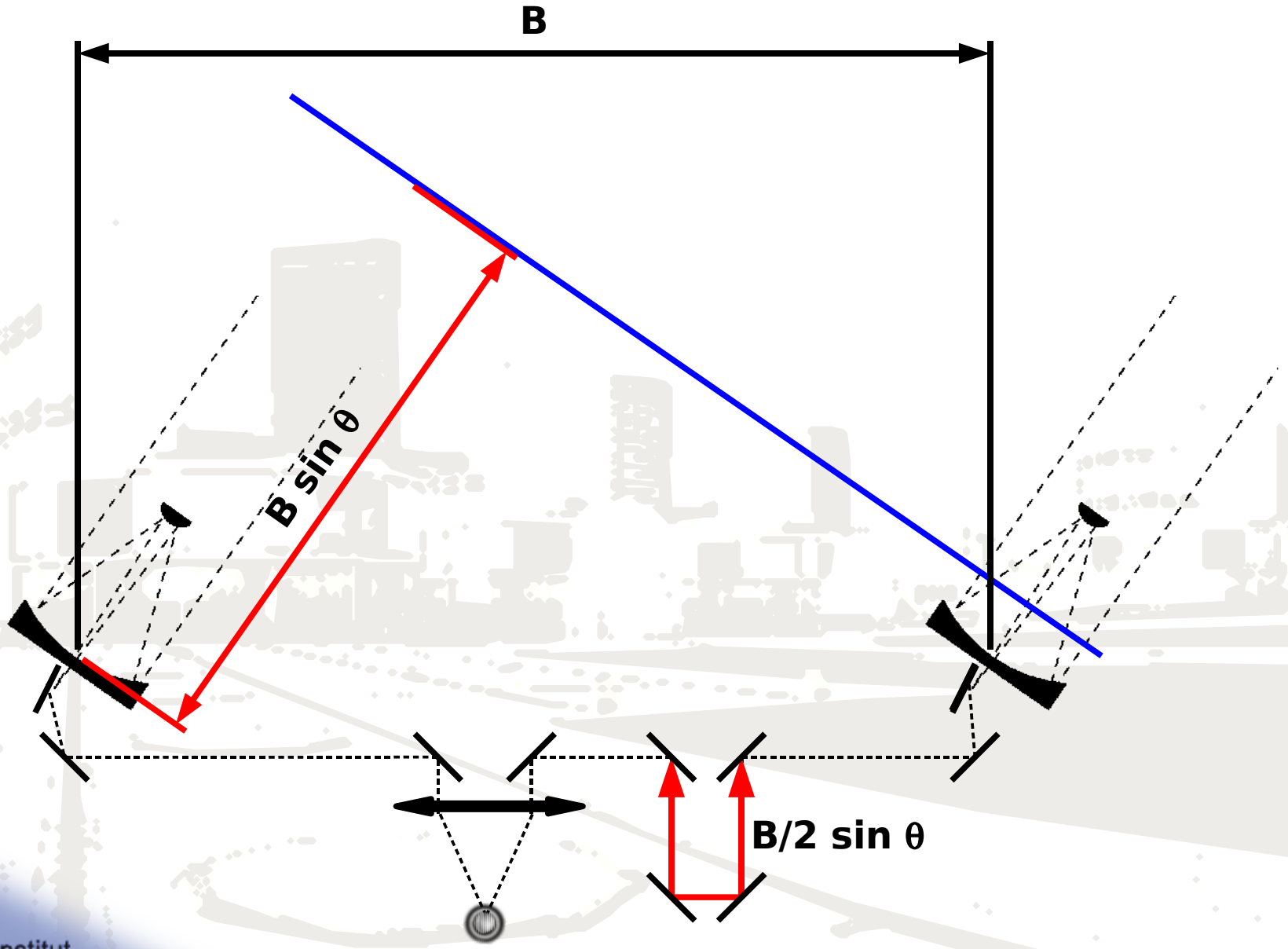


Photo: Florentin Millour

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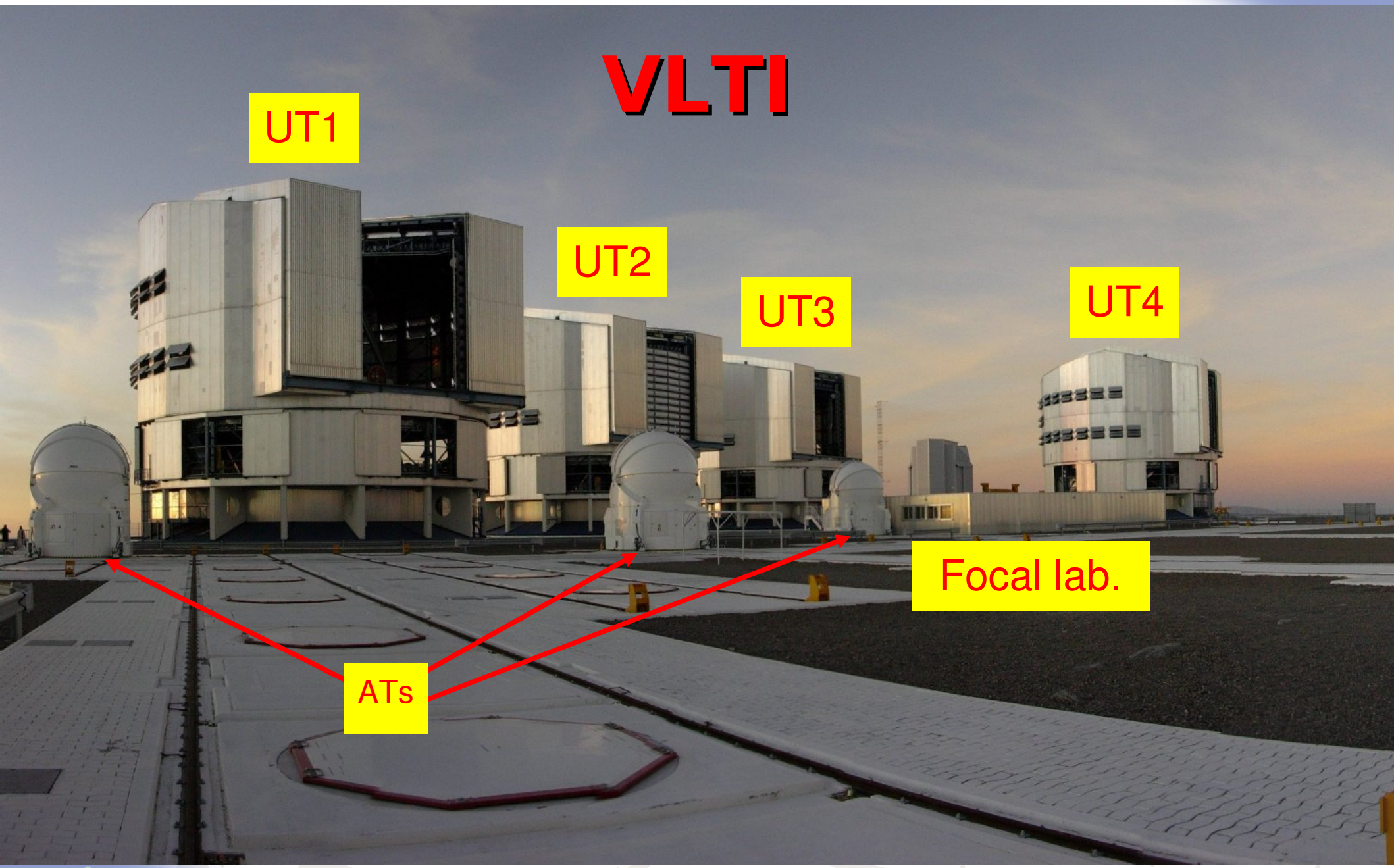



VLTI
N
©2006 Google™
Image © 2006 DigitalGlobe
200m
130m
U1
U2
U3
U4
J6
J5
J4
J3
G2
H0
K0
L0
M0
J1
I1
D0
E0
G0
B0
C0
A1
B1
C1
B2
C2
B3
C3
G1

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)

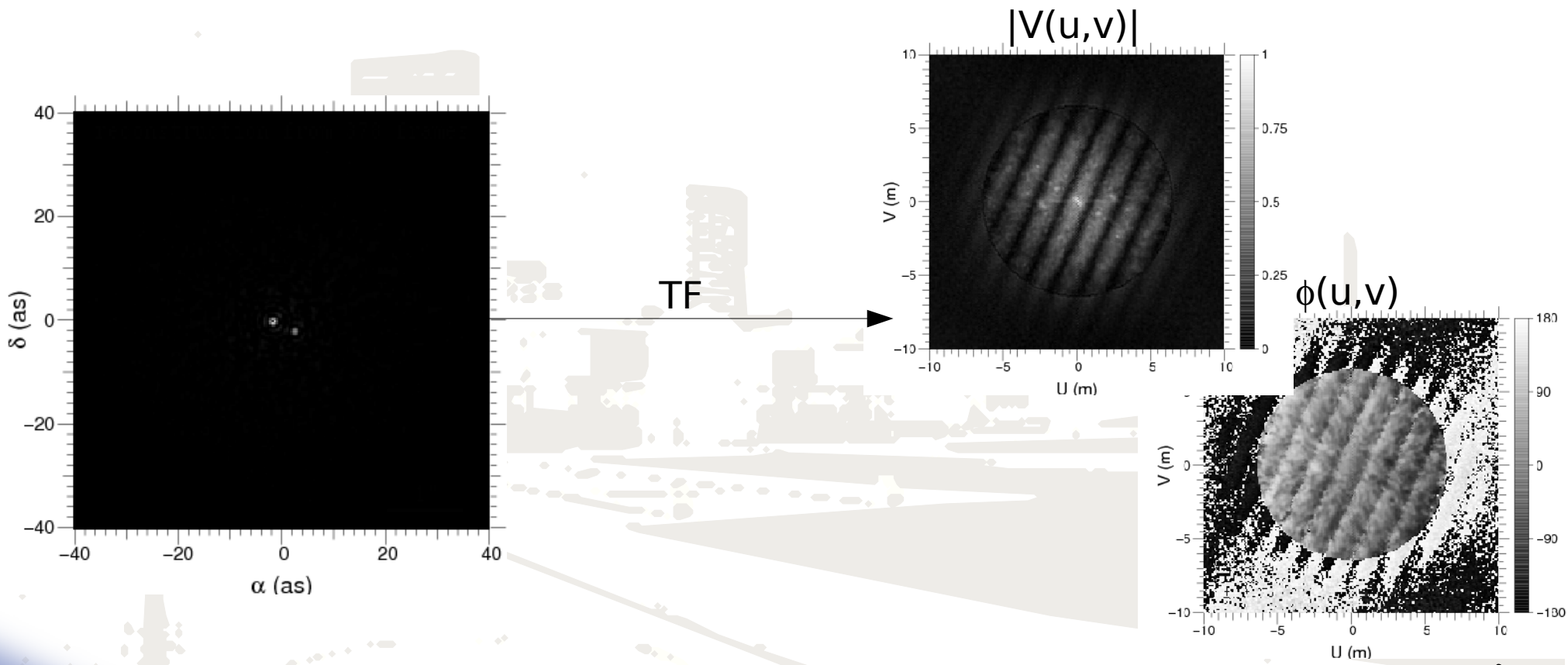


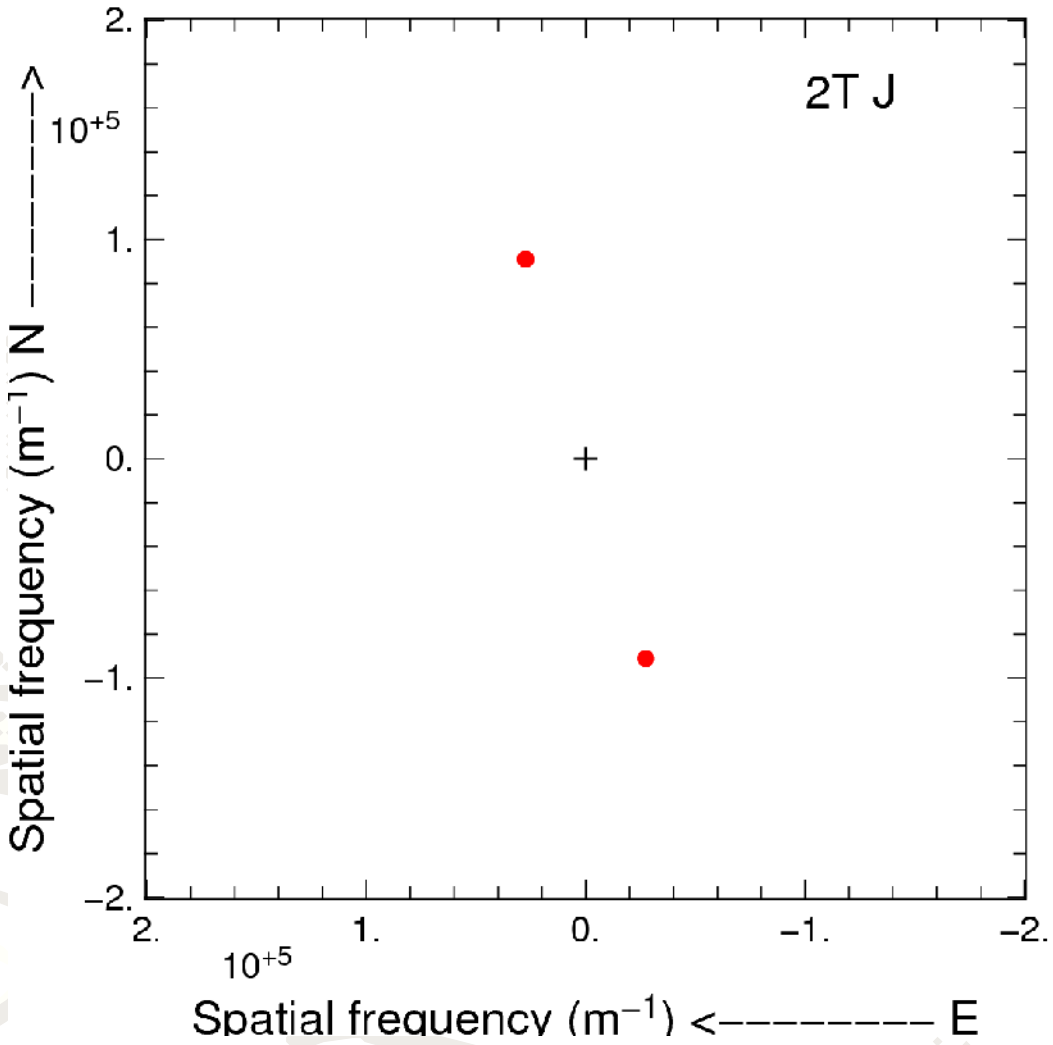
Image : I(x,y)=O*PSF

|V(u,v)|, ϕ(u,v) & cut-off frequency at D/λ

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

(u,v) plane is poorly sampled.

A lot of the object's information is missing due to the (u,v) gaps.



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: 2T

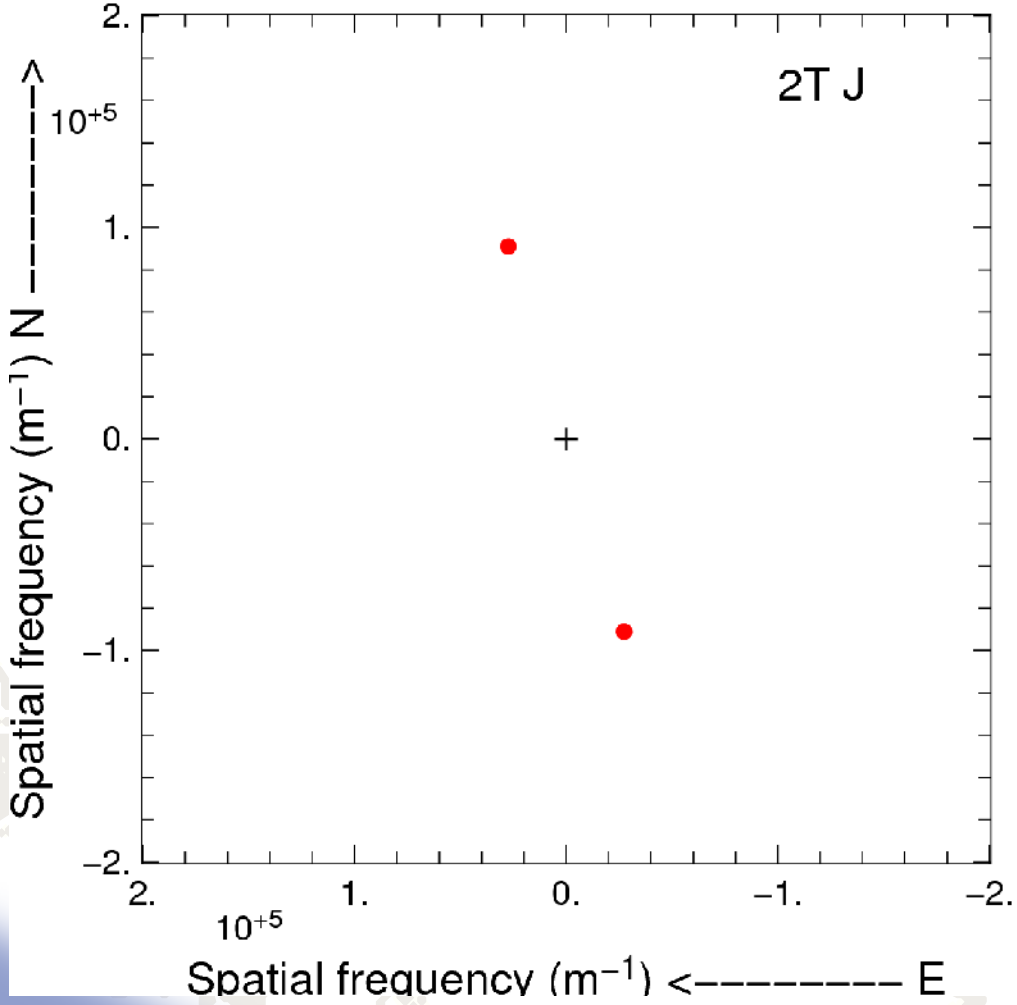
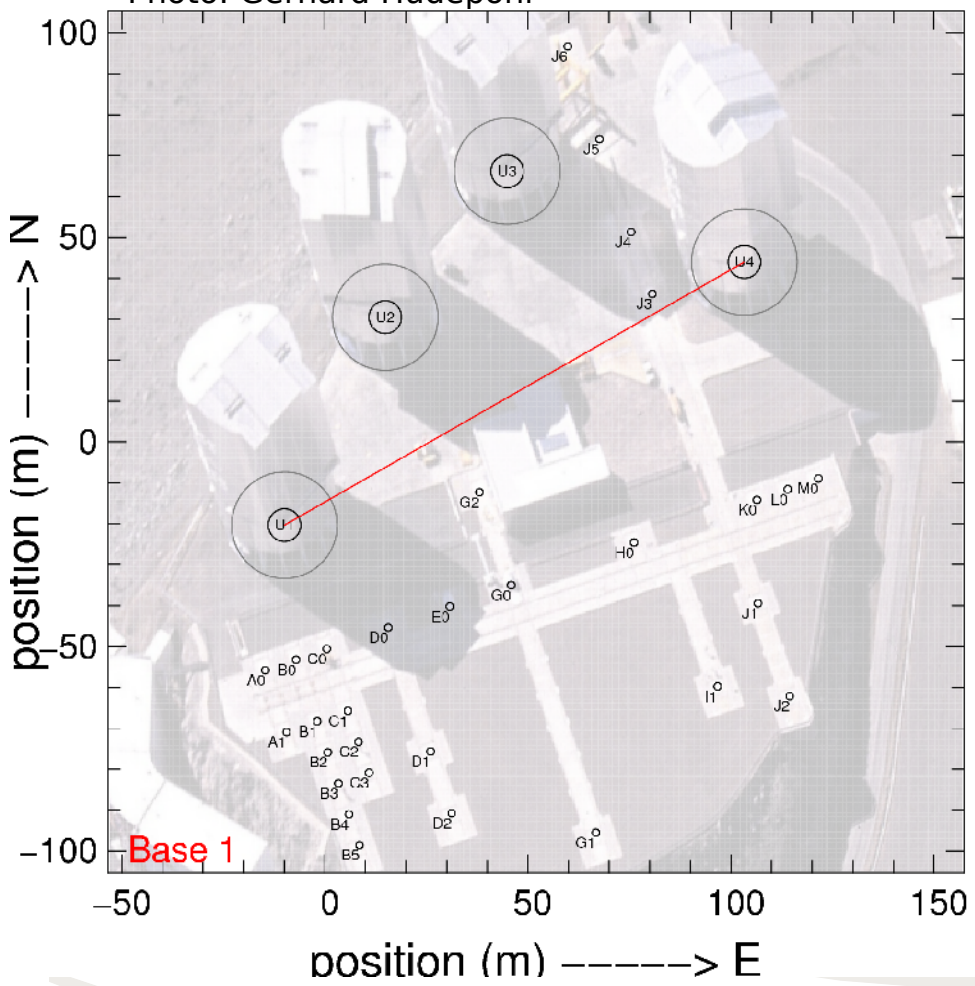


Photo: Gerhard Hüdepohl



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

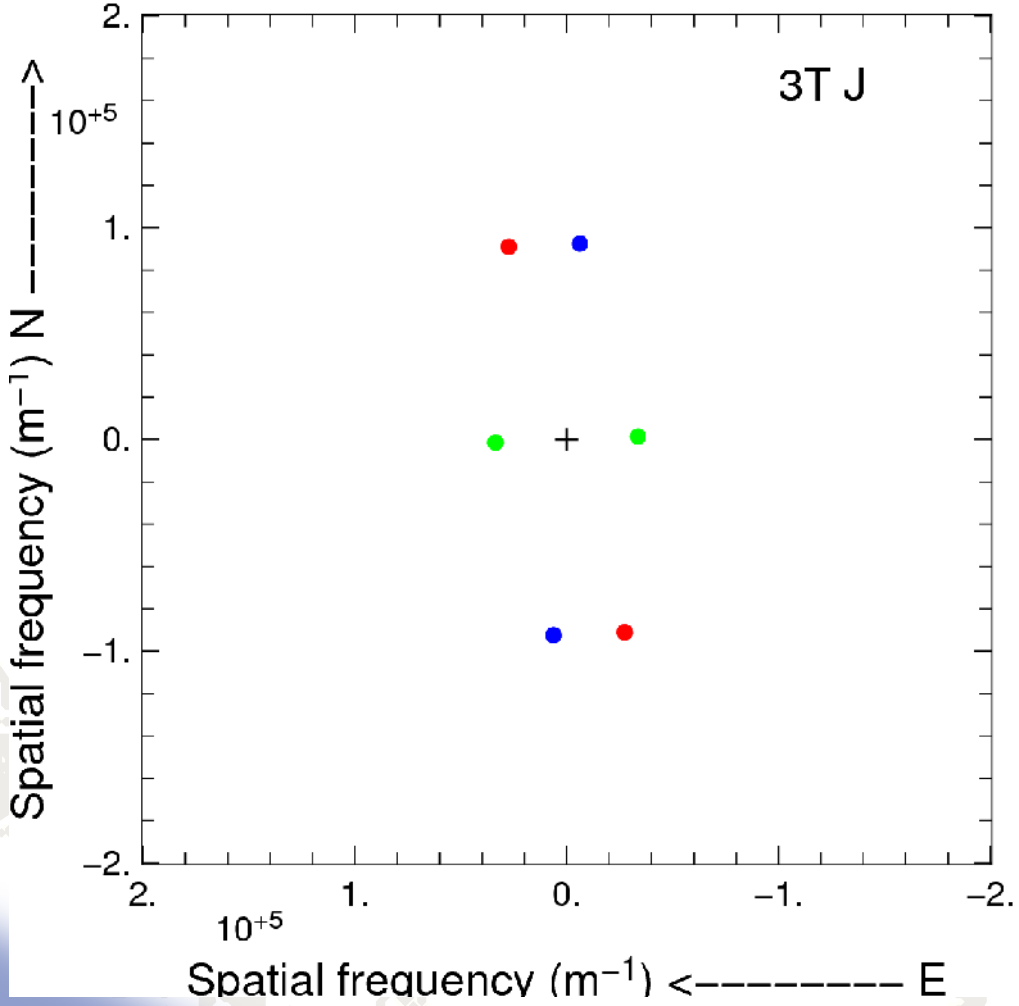
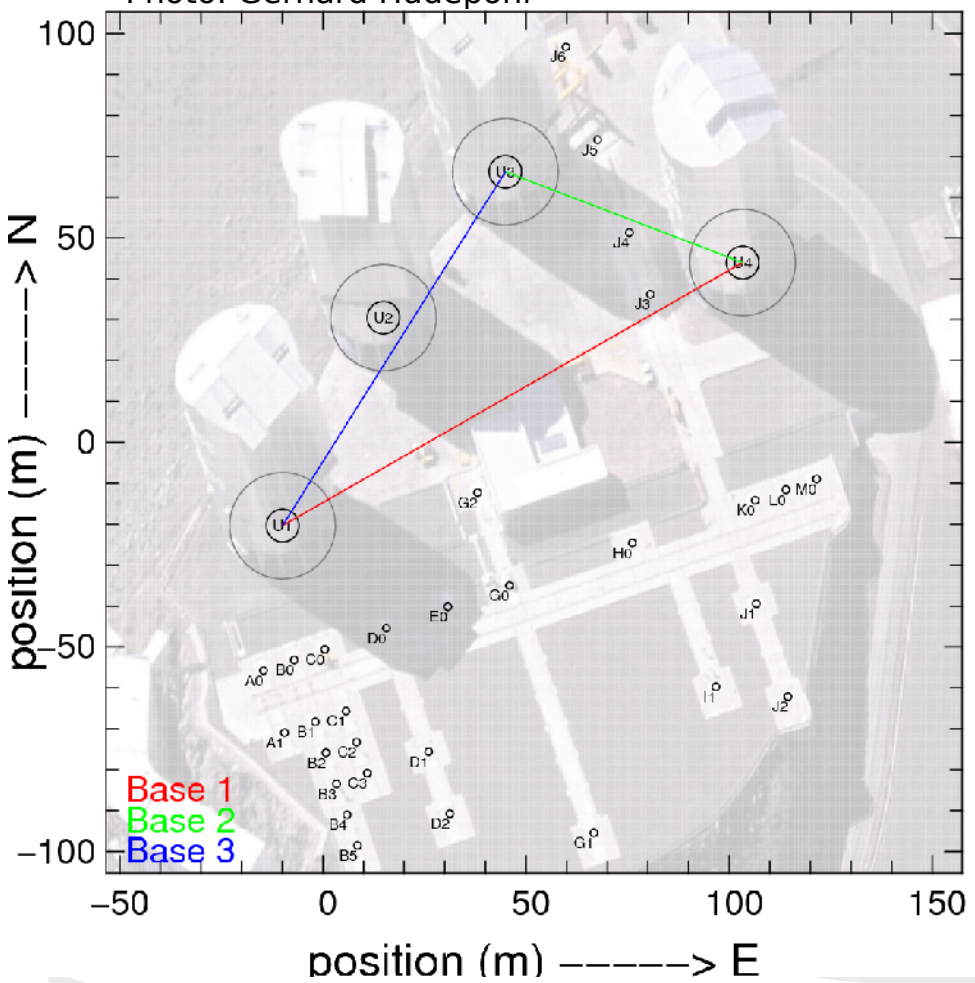


Photo: Gerhard Hüdepohl



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

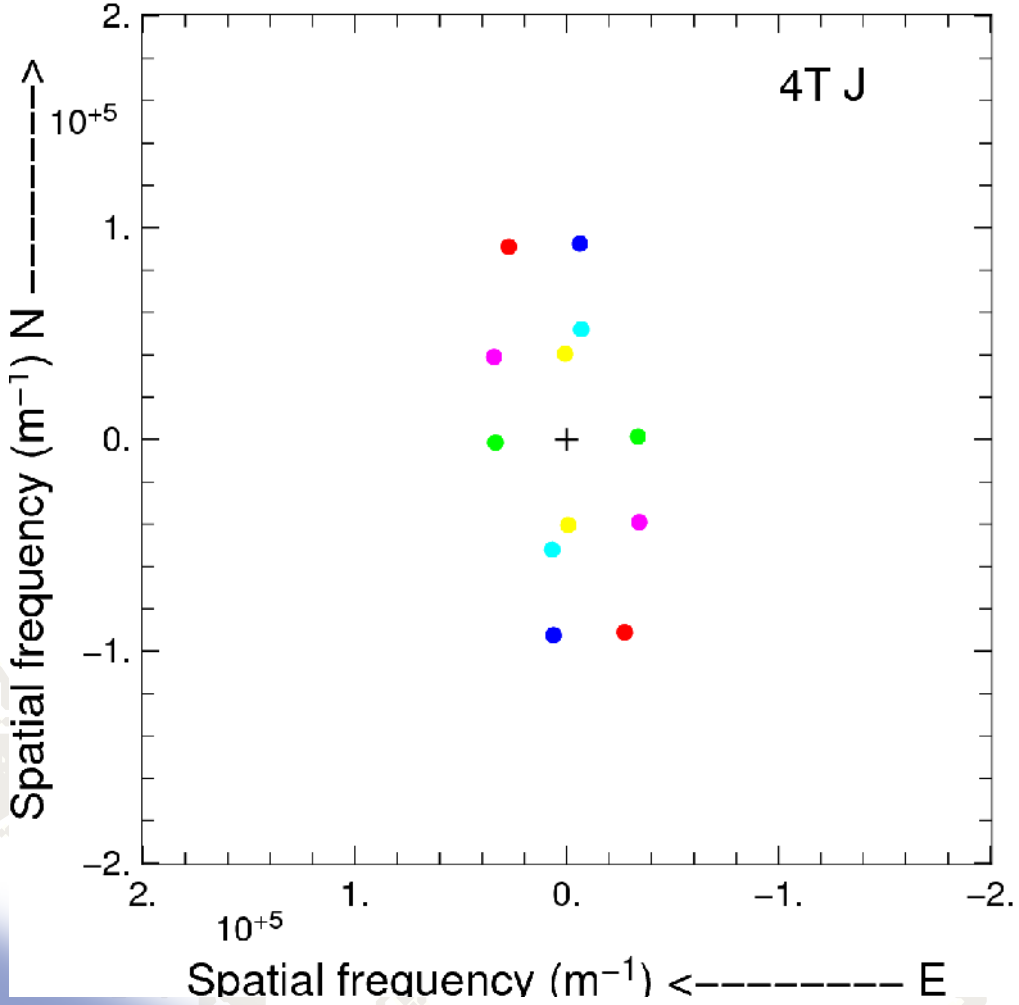
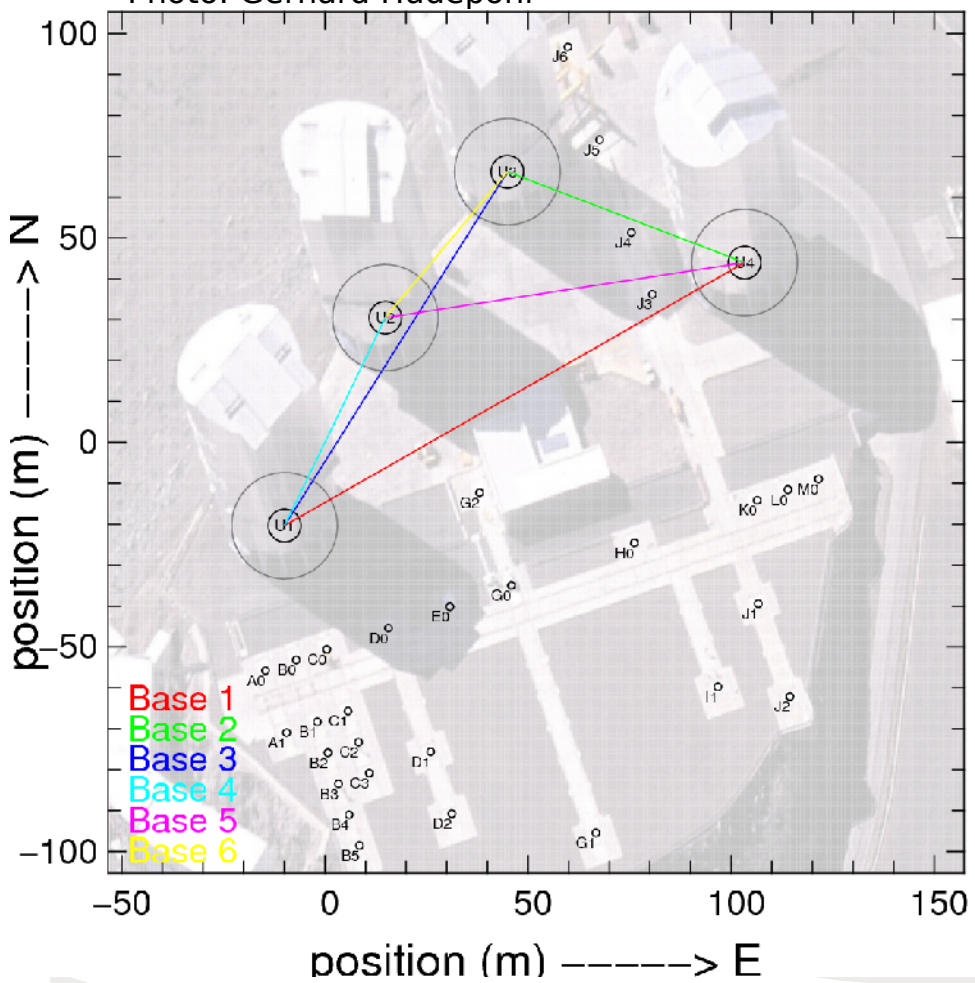


Photo: Gerhard Hüdepohl



(u,v) plane filling with more telescopes: 8T (4AT & 4UT)

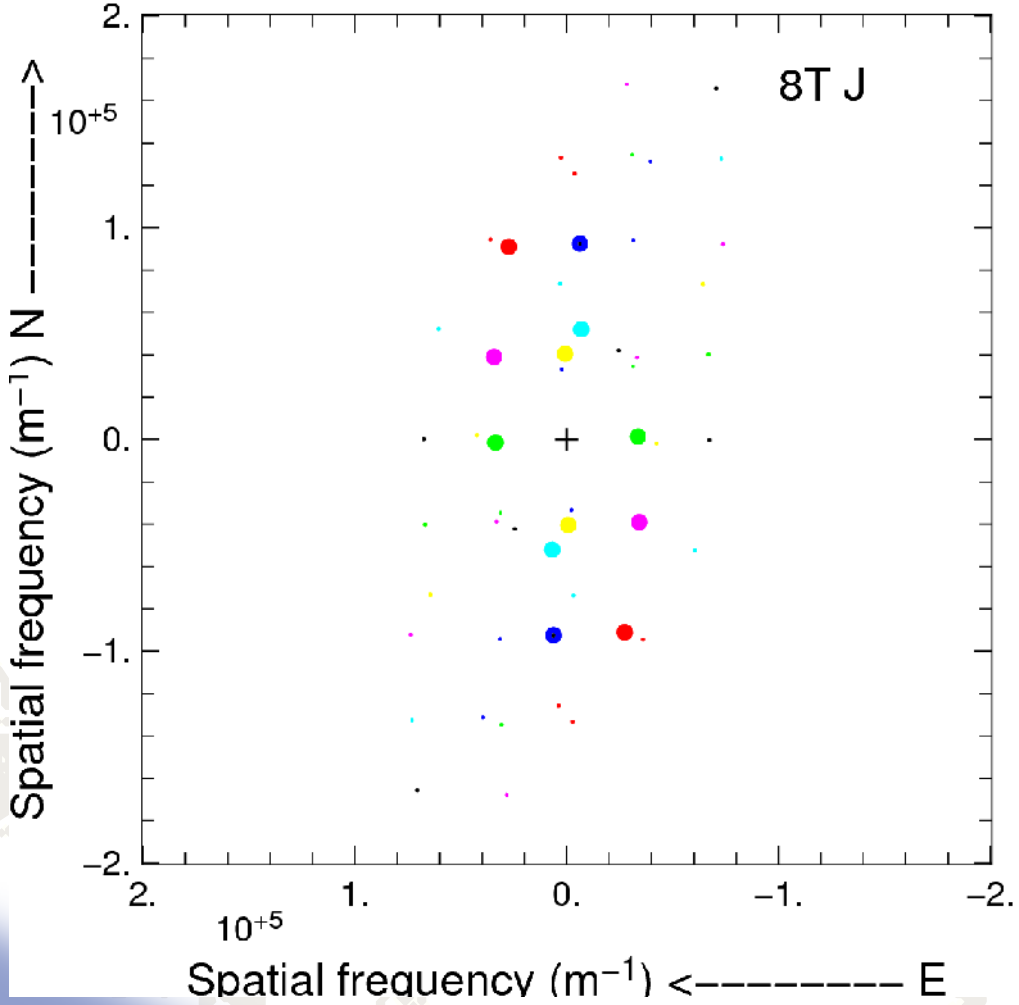
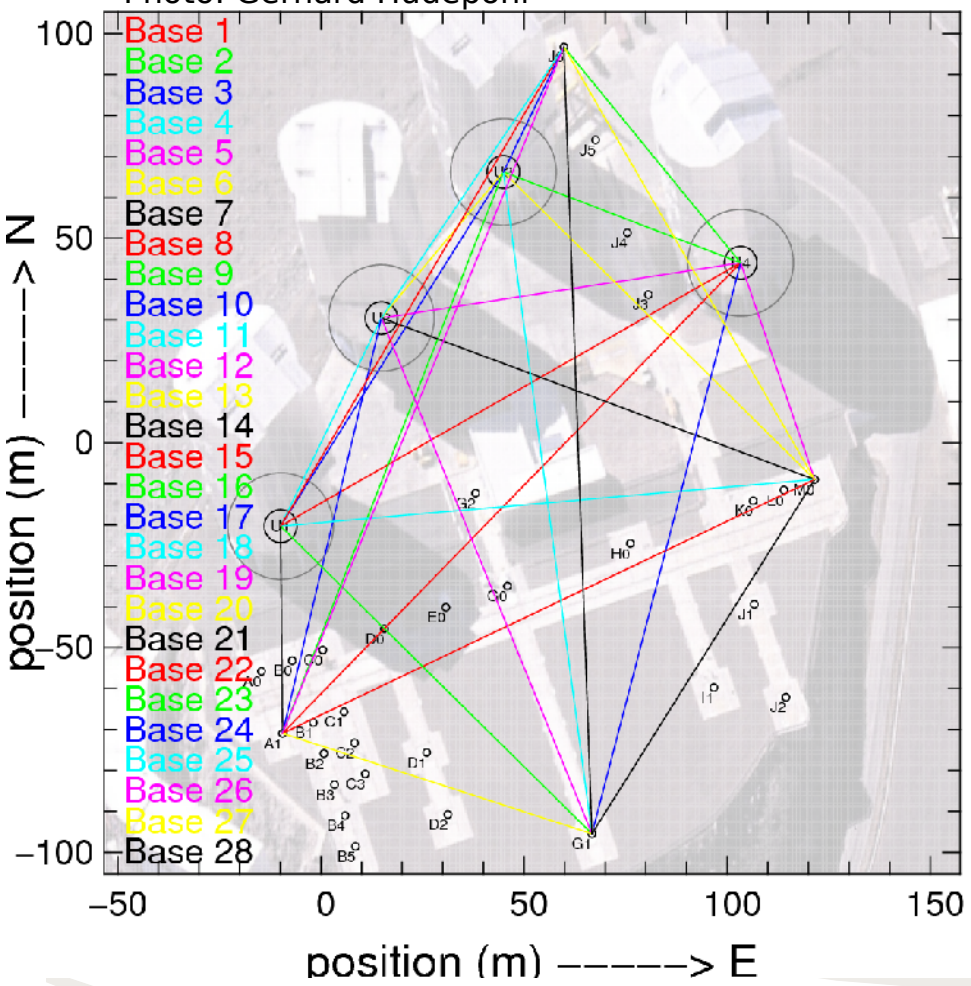


Photo: Gerhard Hüdepohl



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

- (u,v) plane sampling depends on:
  - hour angle h
  - source declination δ
  - 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)

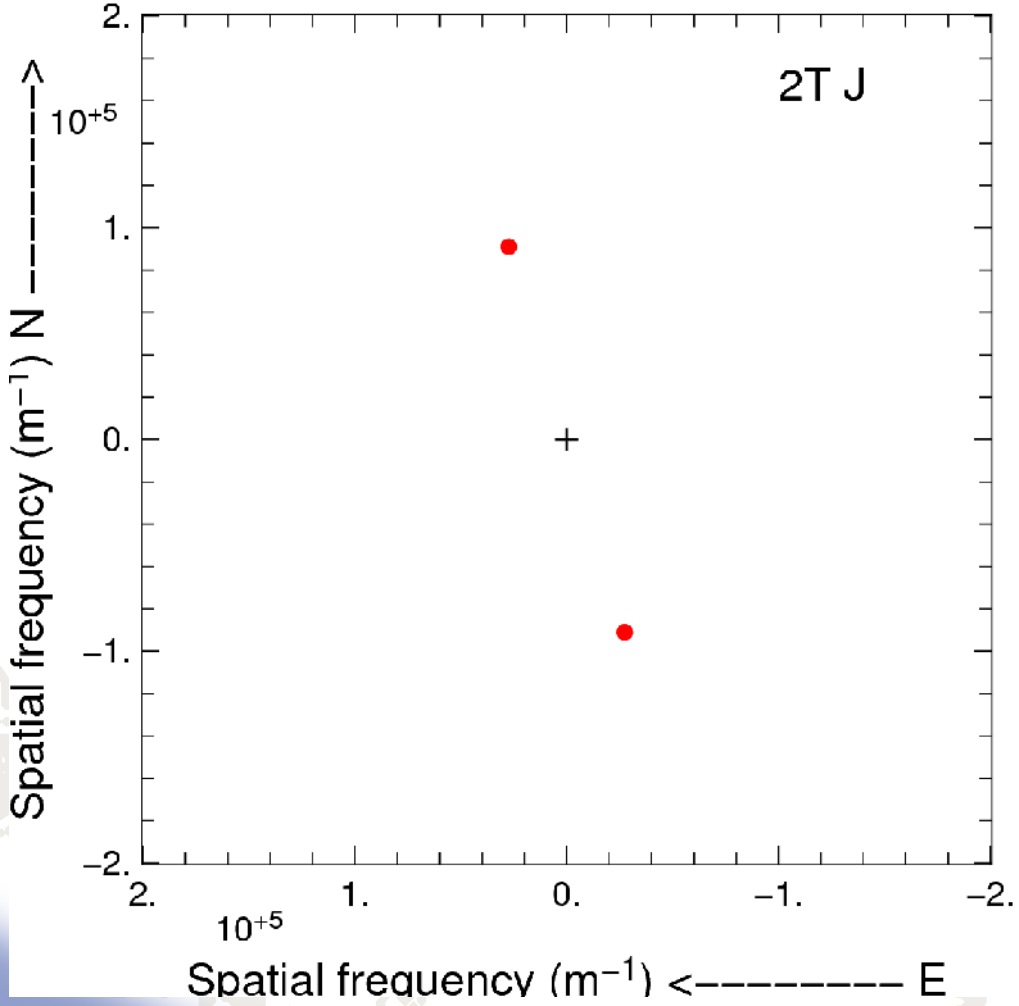
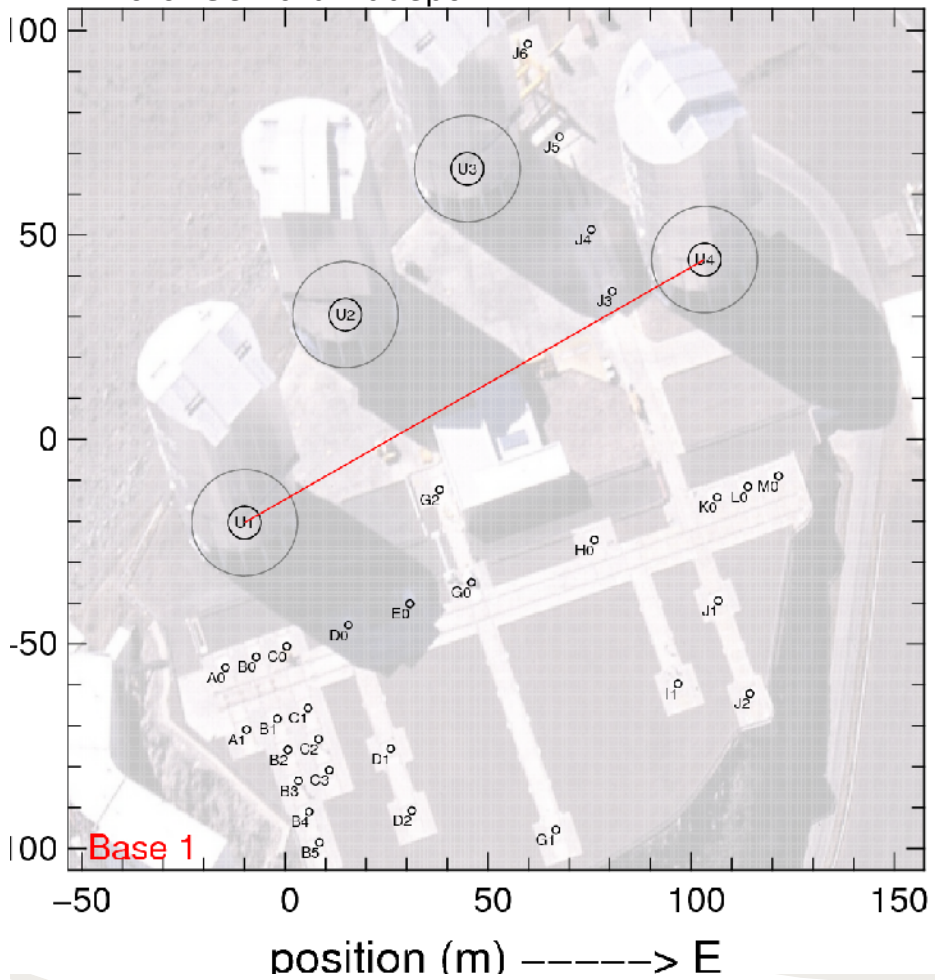


Photo: Gerhard Hüdepohl



Supersynthesis (2T)

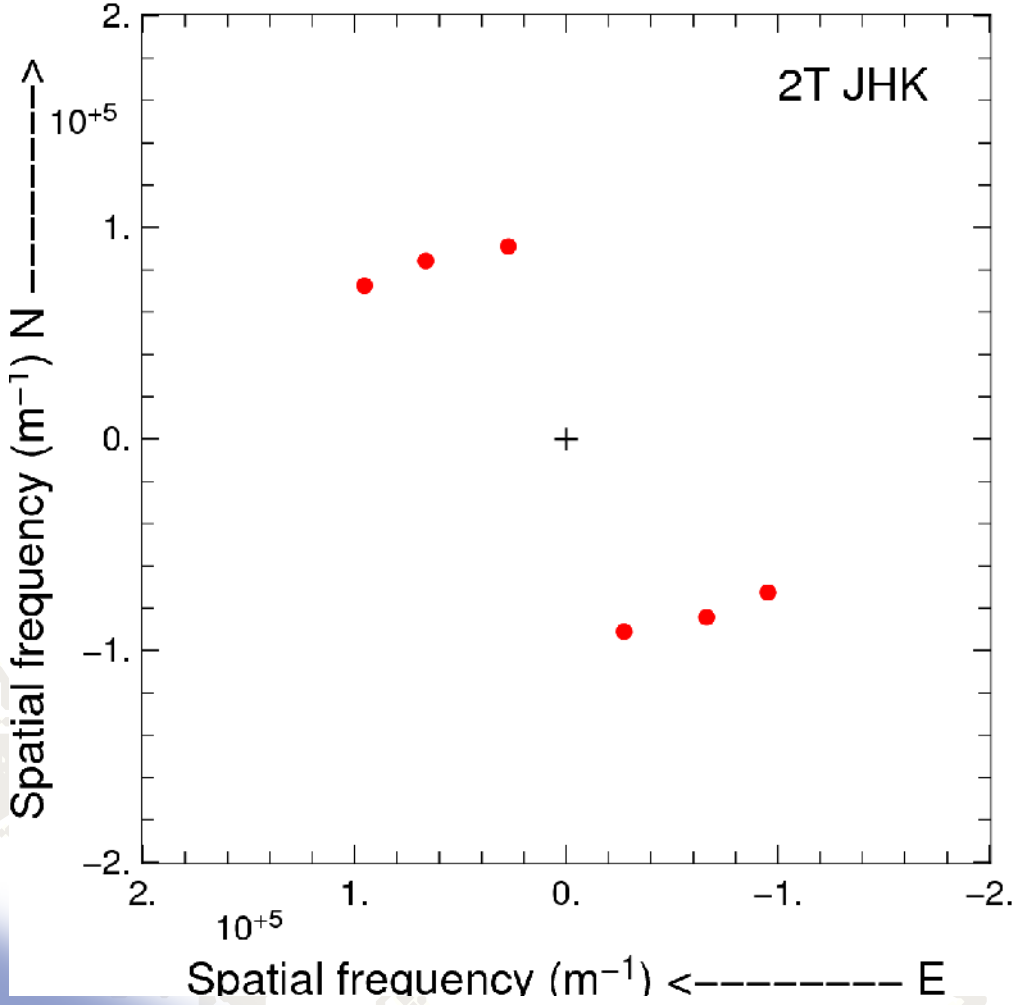
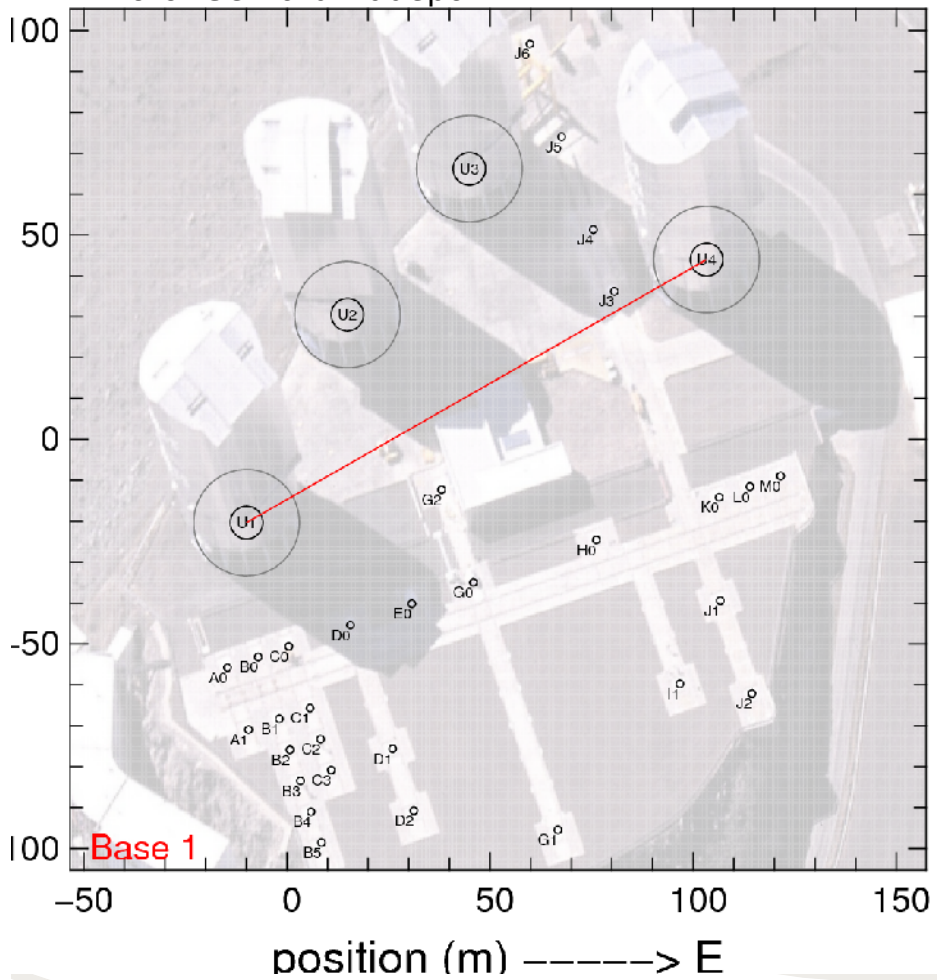


Photo: Gerhard Hüdepohl



Supersynthesis (2T)

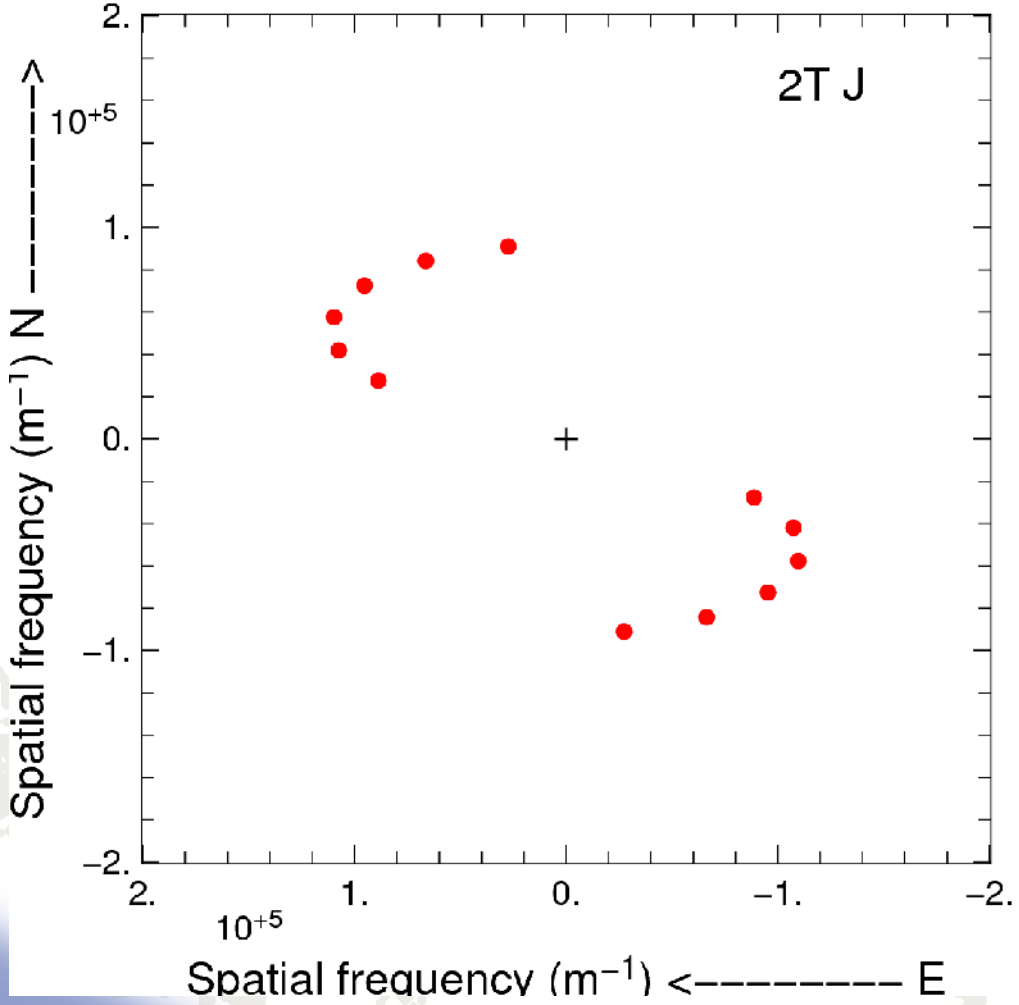
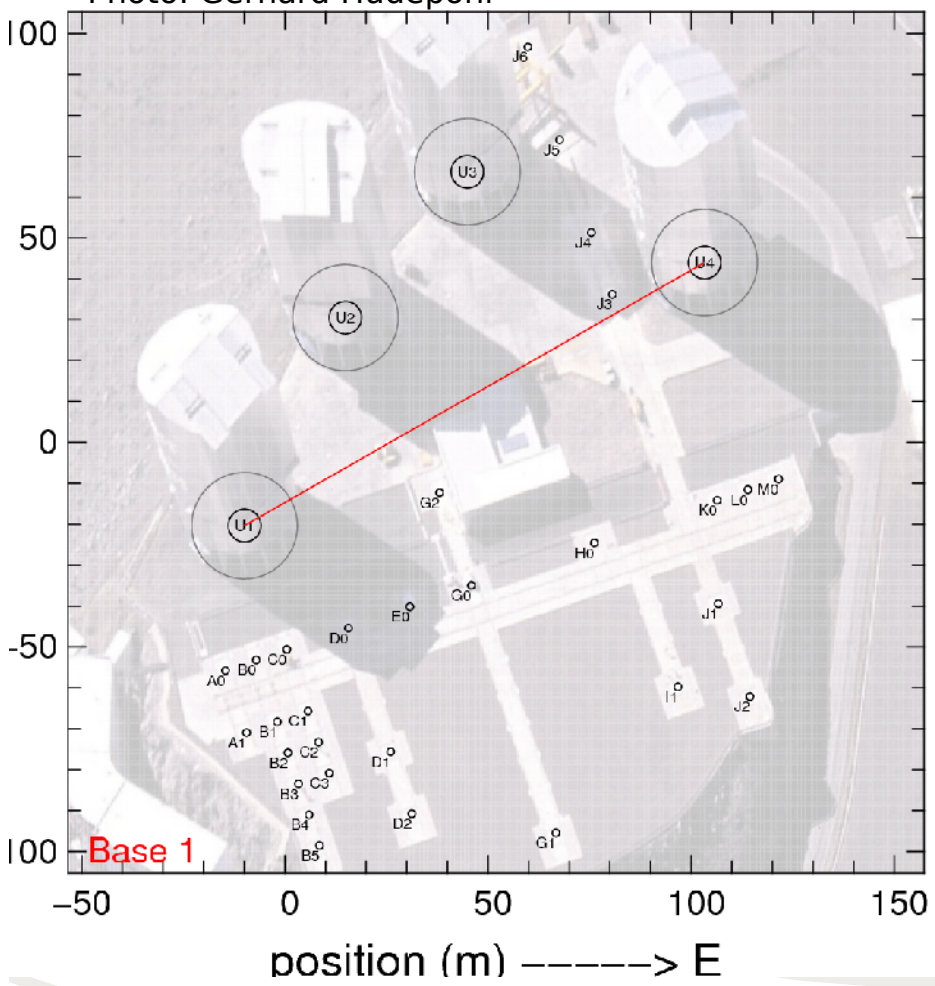


Photo: Gerhard Hüdepohl



Supersynthesis (2T)

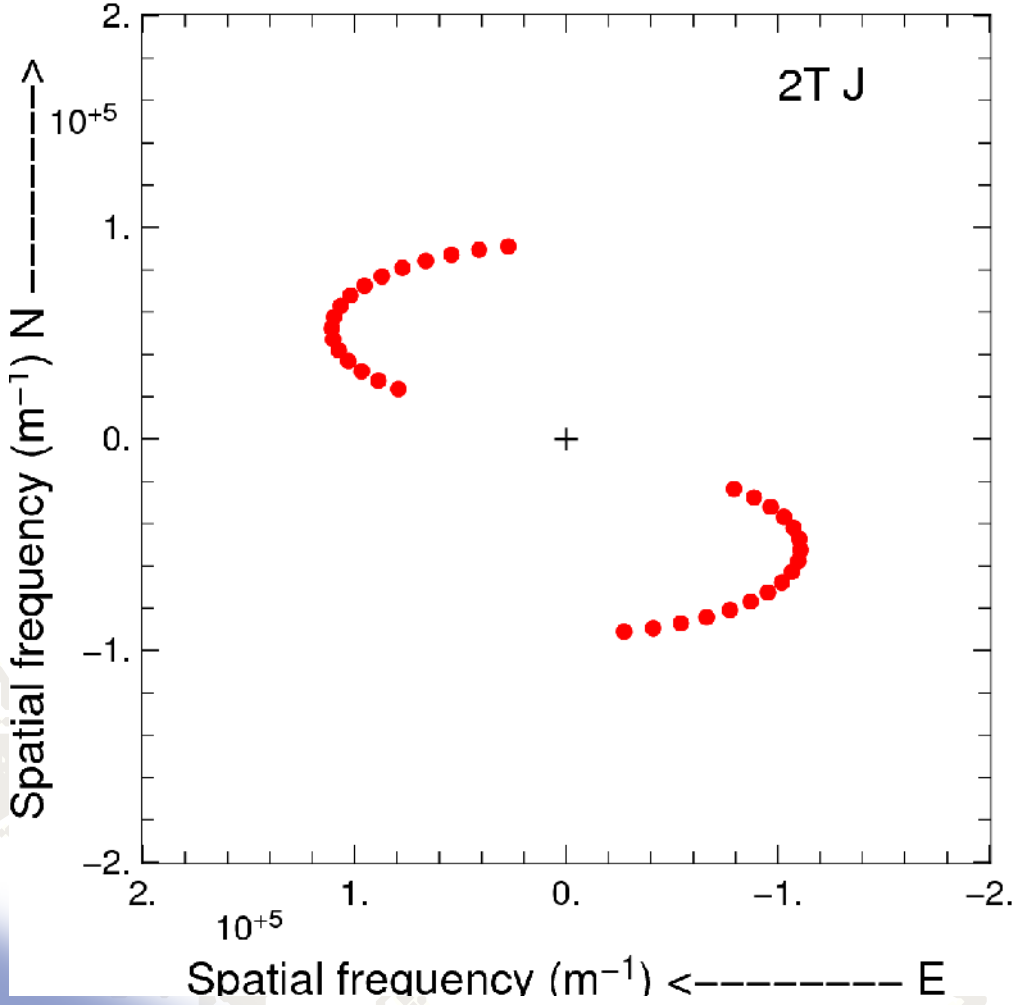
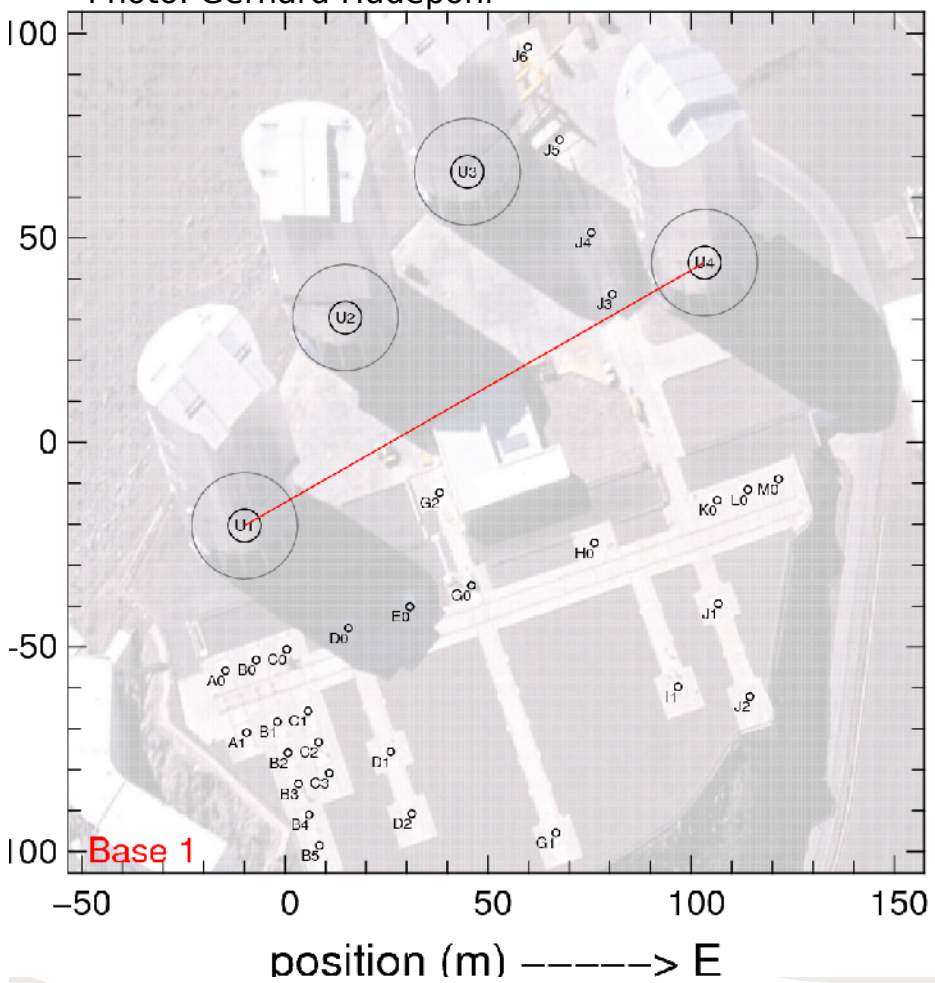


Photo: Gerhard Hüdepohl



Supersynthesis (2T)

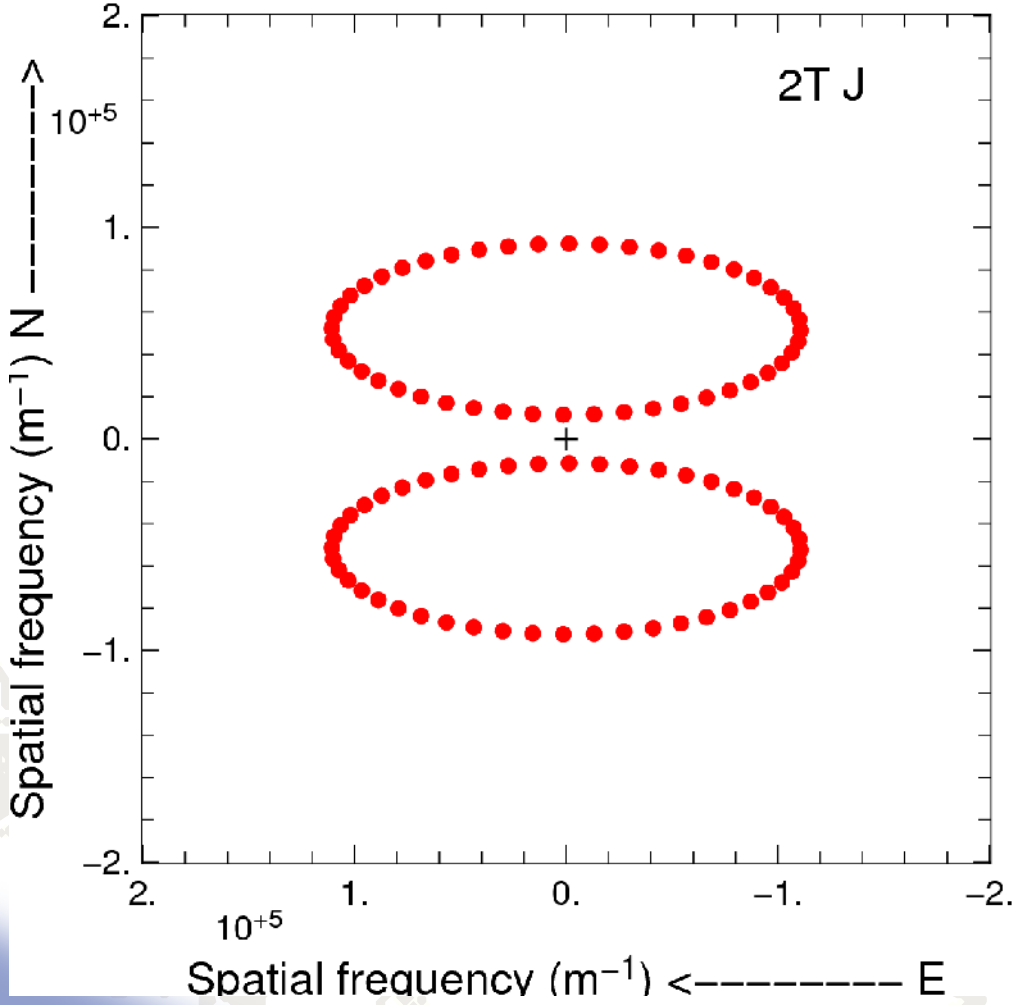
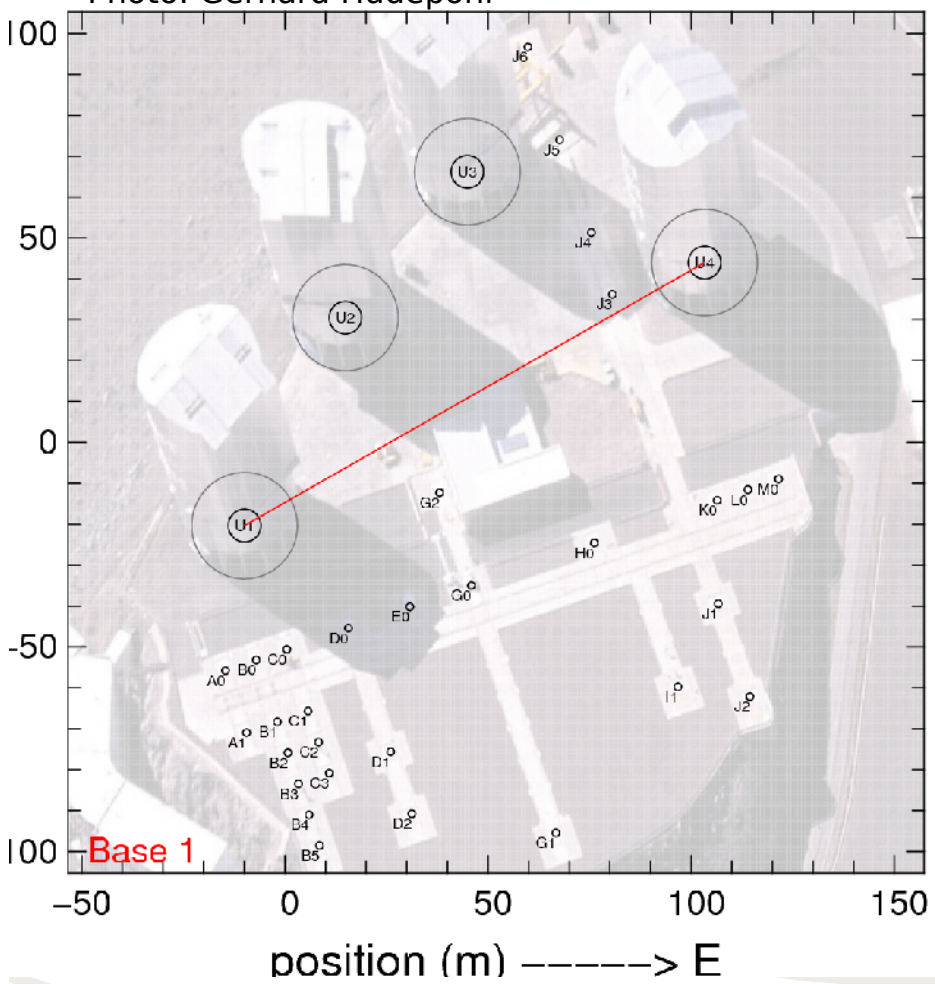


Photo: Gerhard Hüdepohl



Supersynthesis (3T)

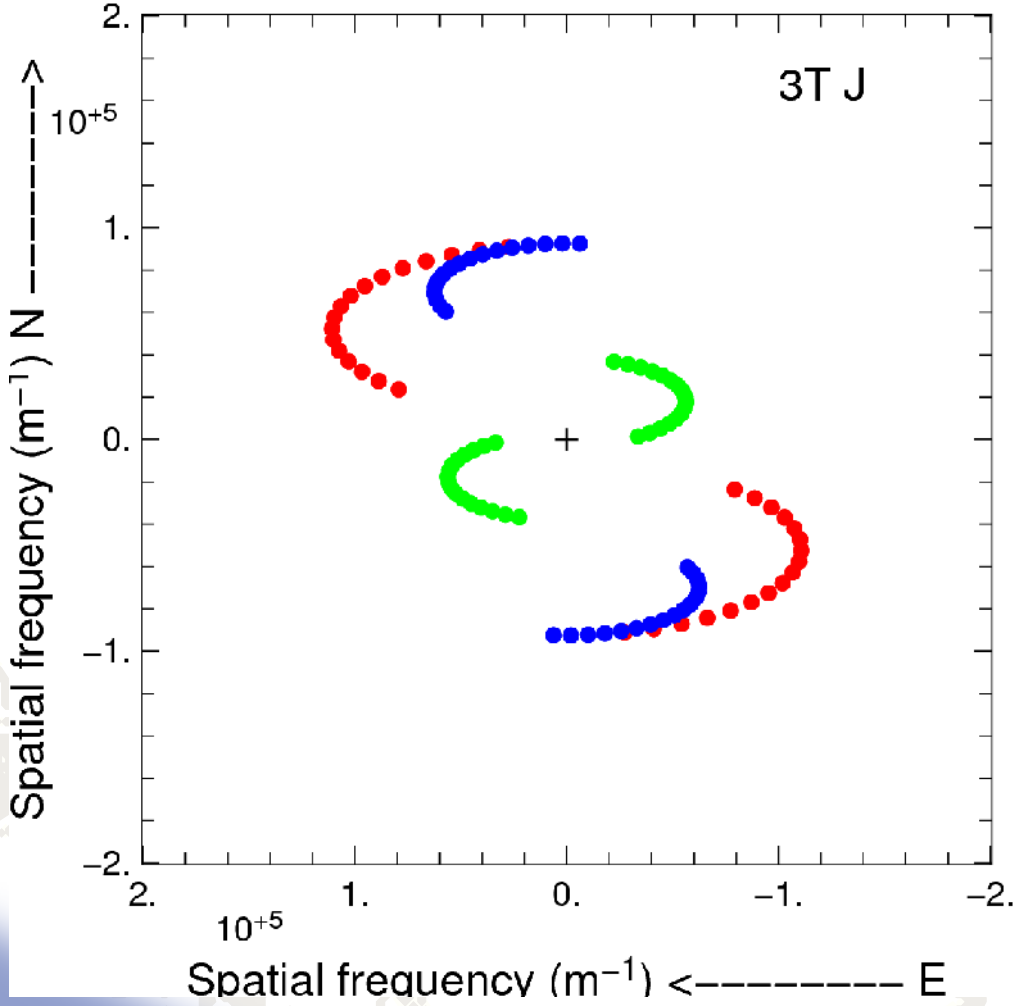
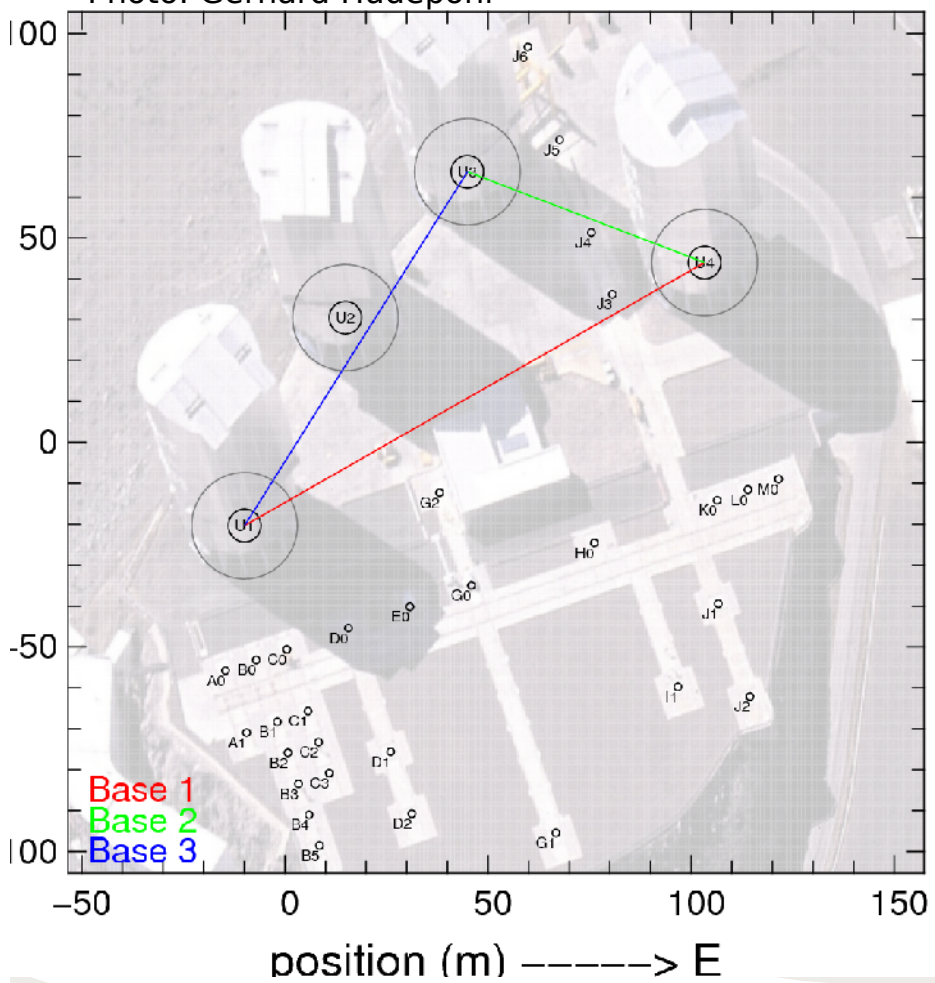


Photo: Gerhard Hüdepohl



Supersynthesis (4T)

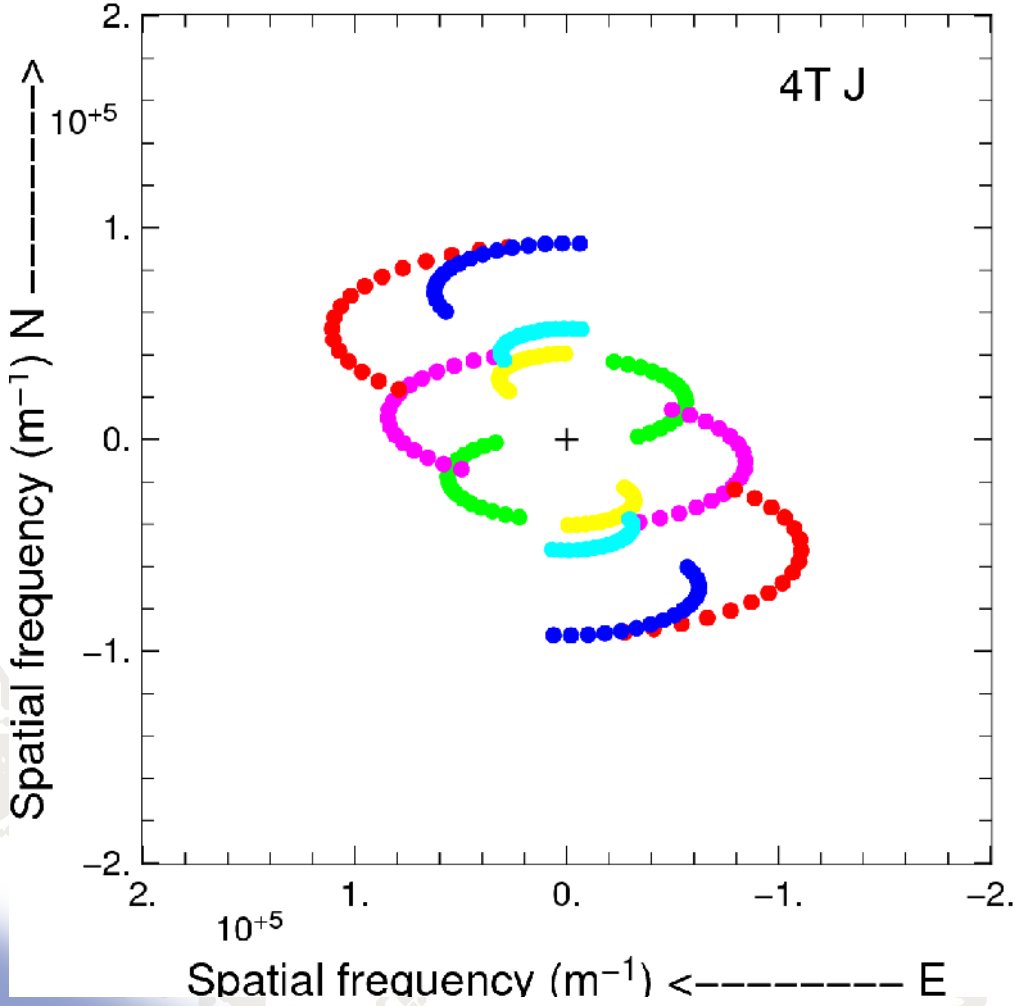
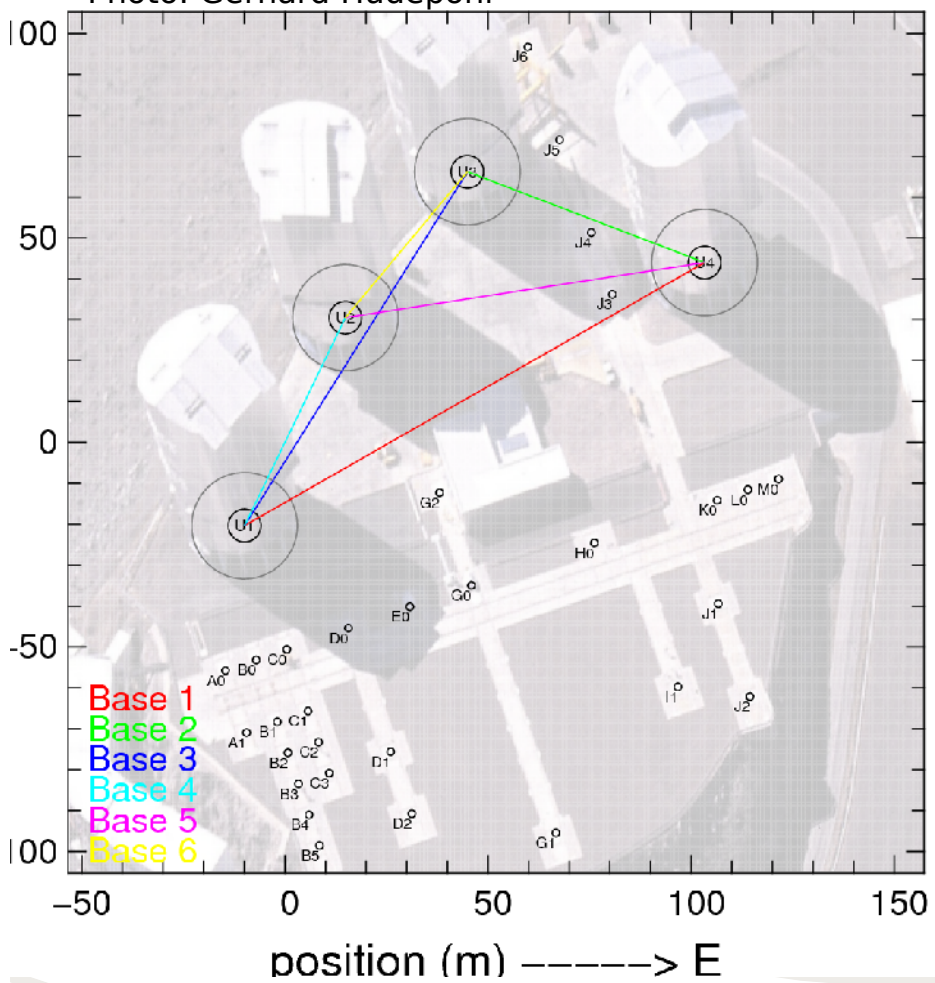


Photo: Gerhard Hüdepohl



Supersynthesis (8T)

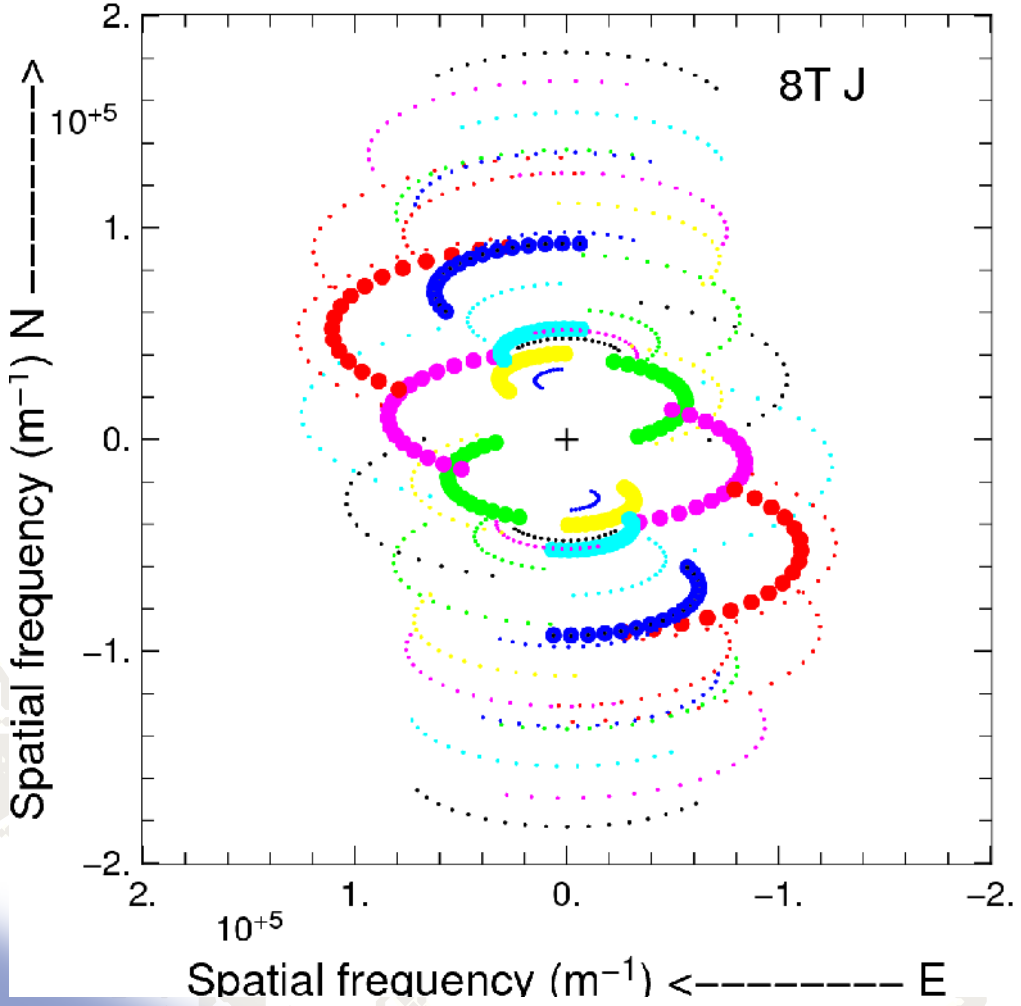
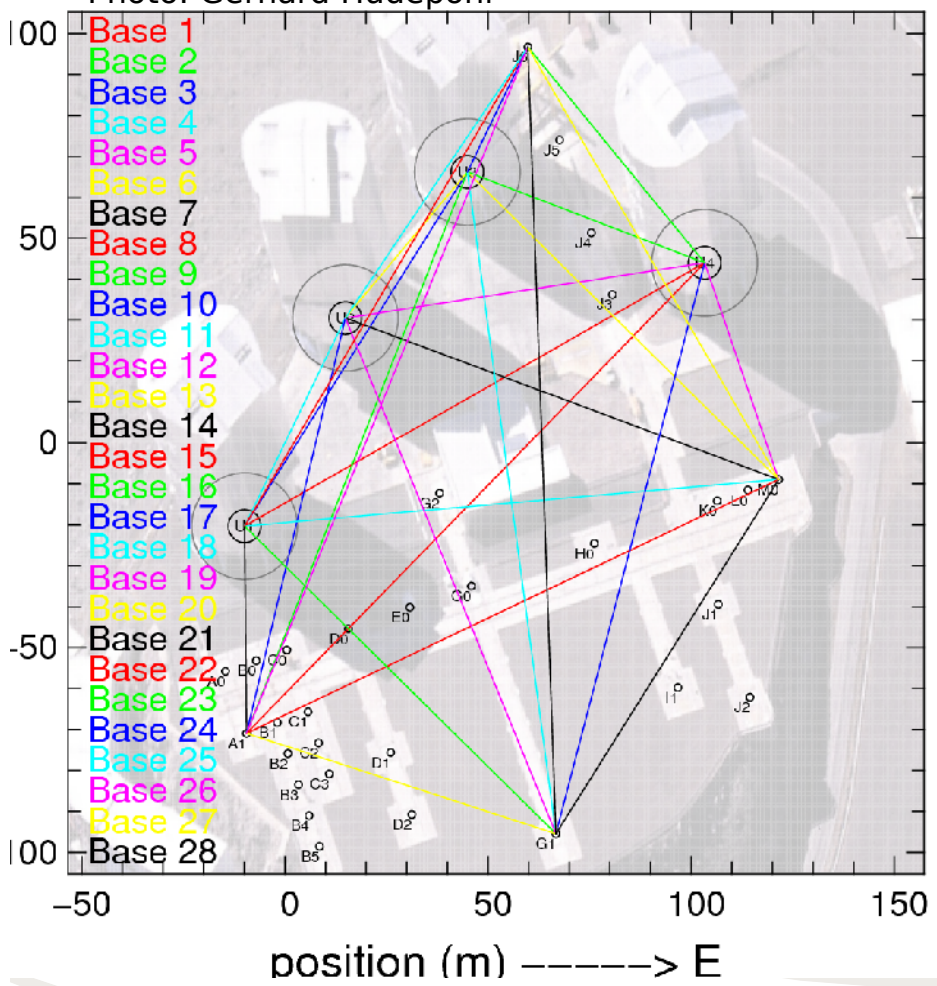


Photo: Gerhard Hüdepohl



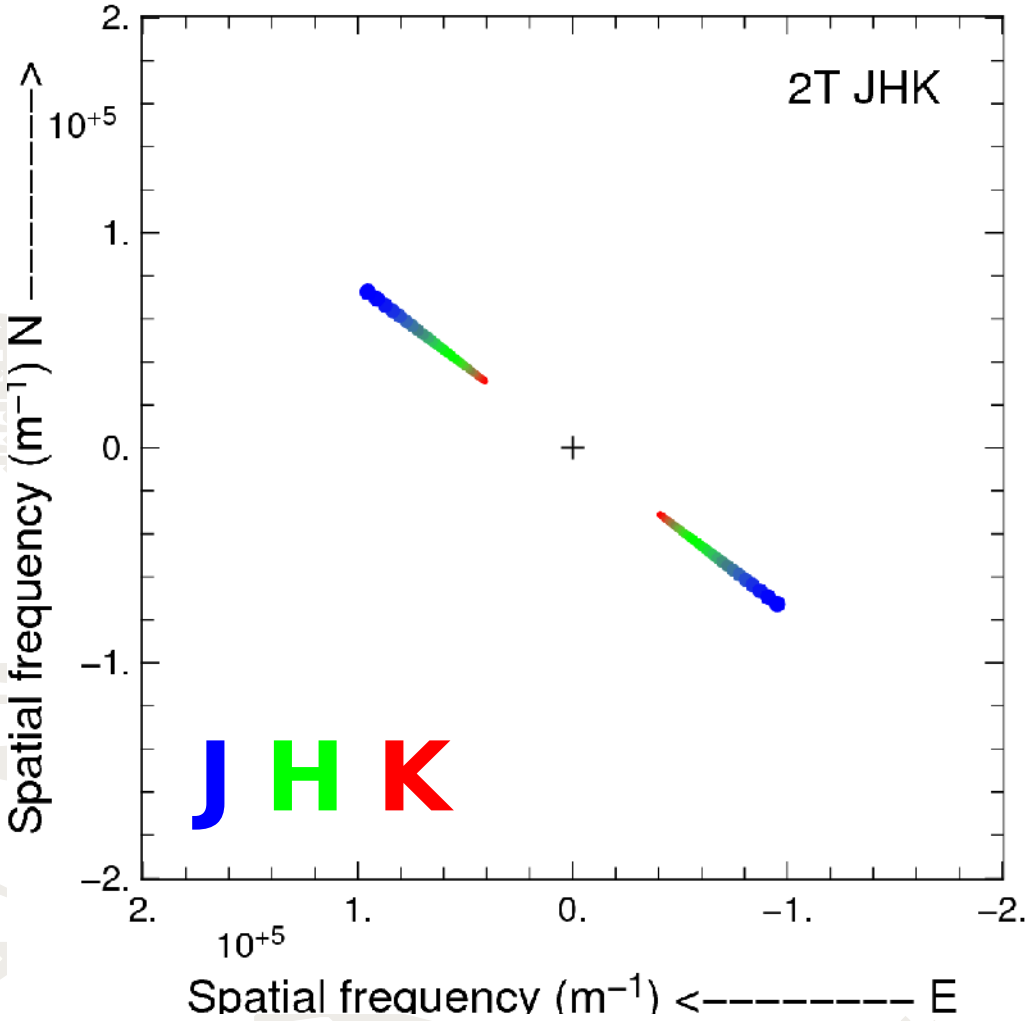
(u,v) plane filling with spectral coverage

- **Spatial frequencies:**

$$f = B/\lambda$$

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

- 2T



Supersynthesis + spectral coverage (2T)

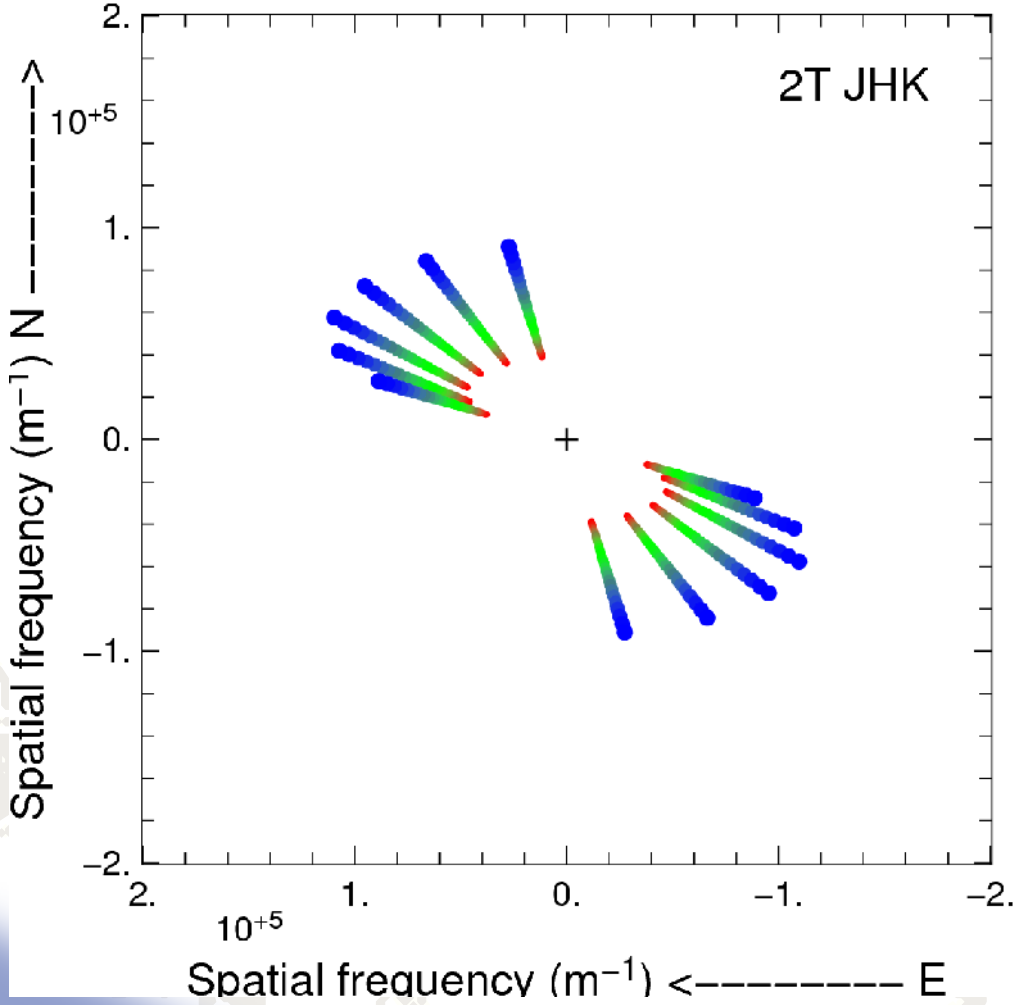
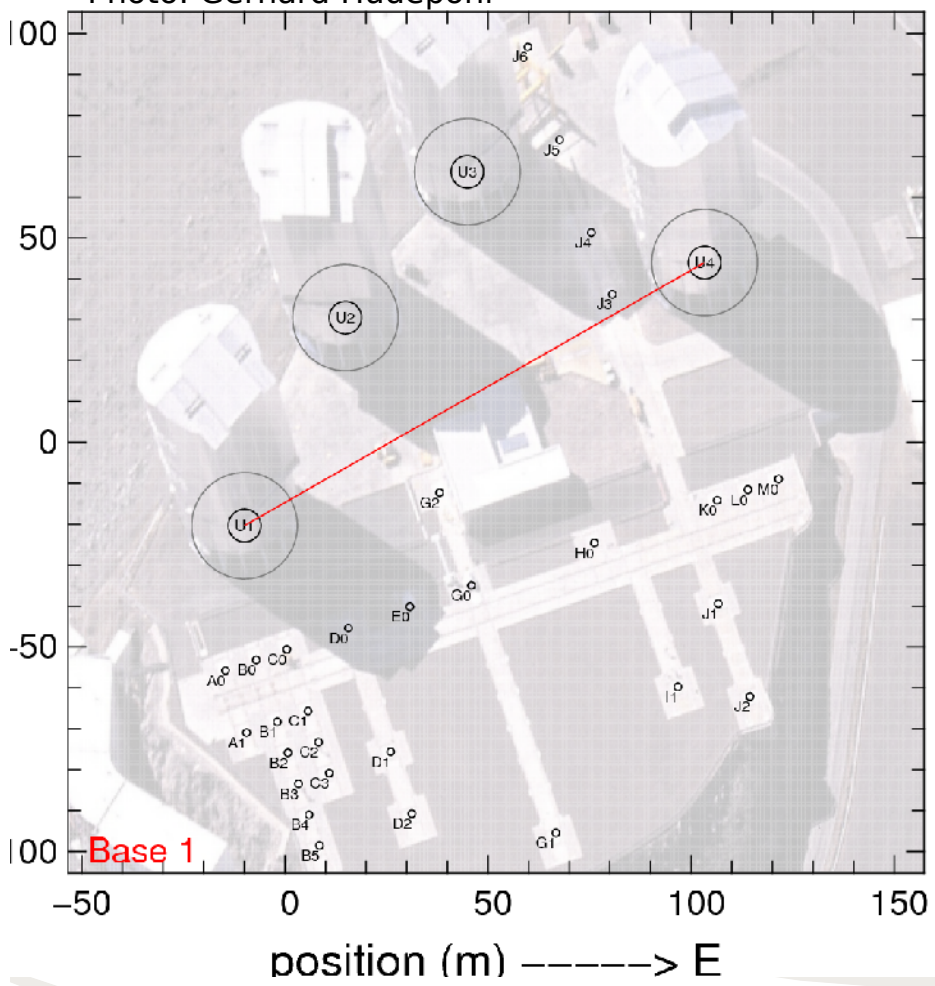


Photo: Gerhard Hüdepohl



Supersynthesis + spectral coverage (3T)

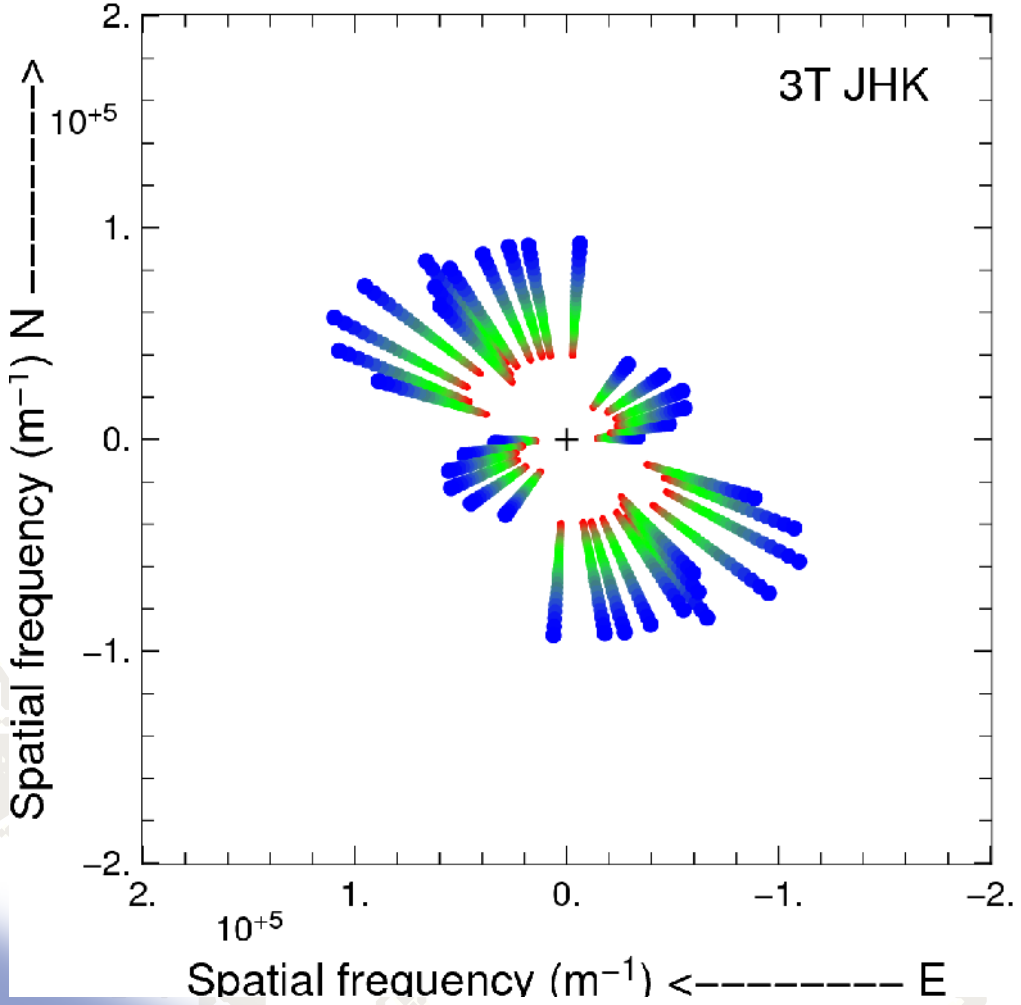
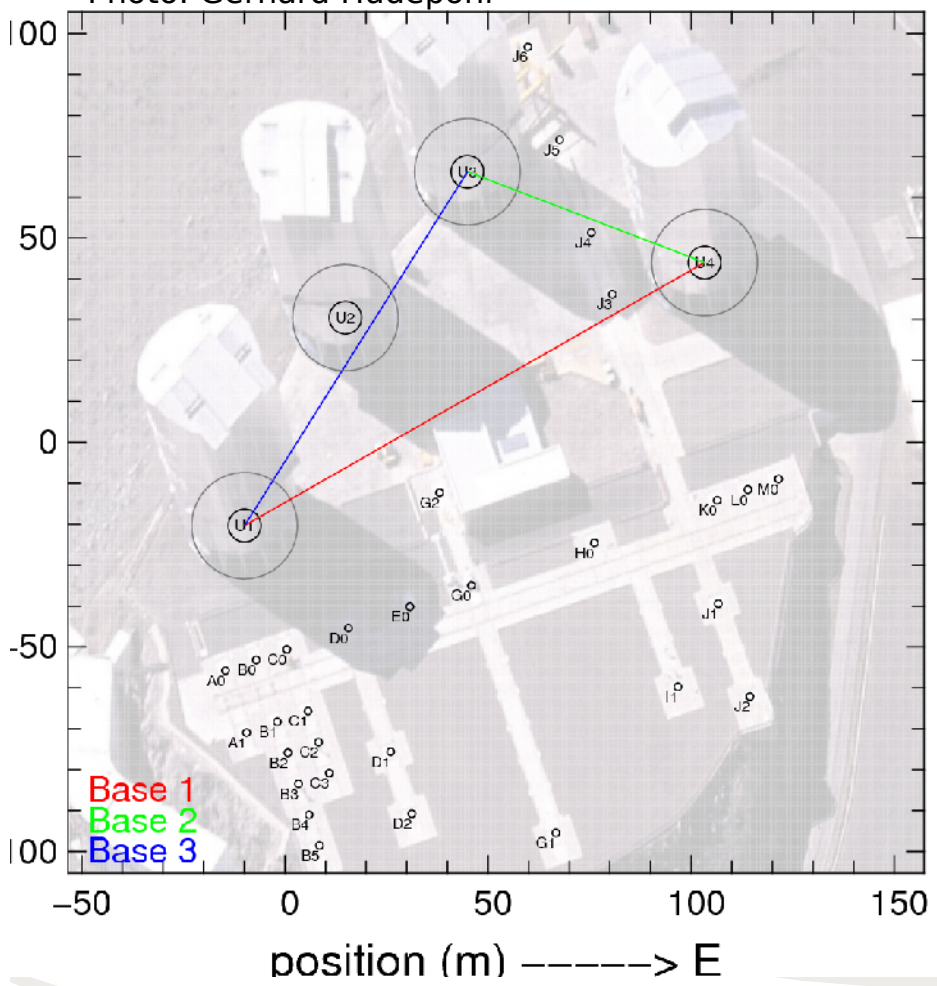


Photo: Gerhard Hüdepohl



Supersynthesis + spectral coverage (4T)

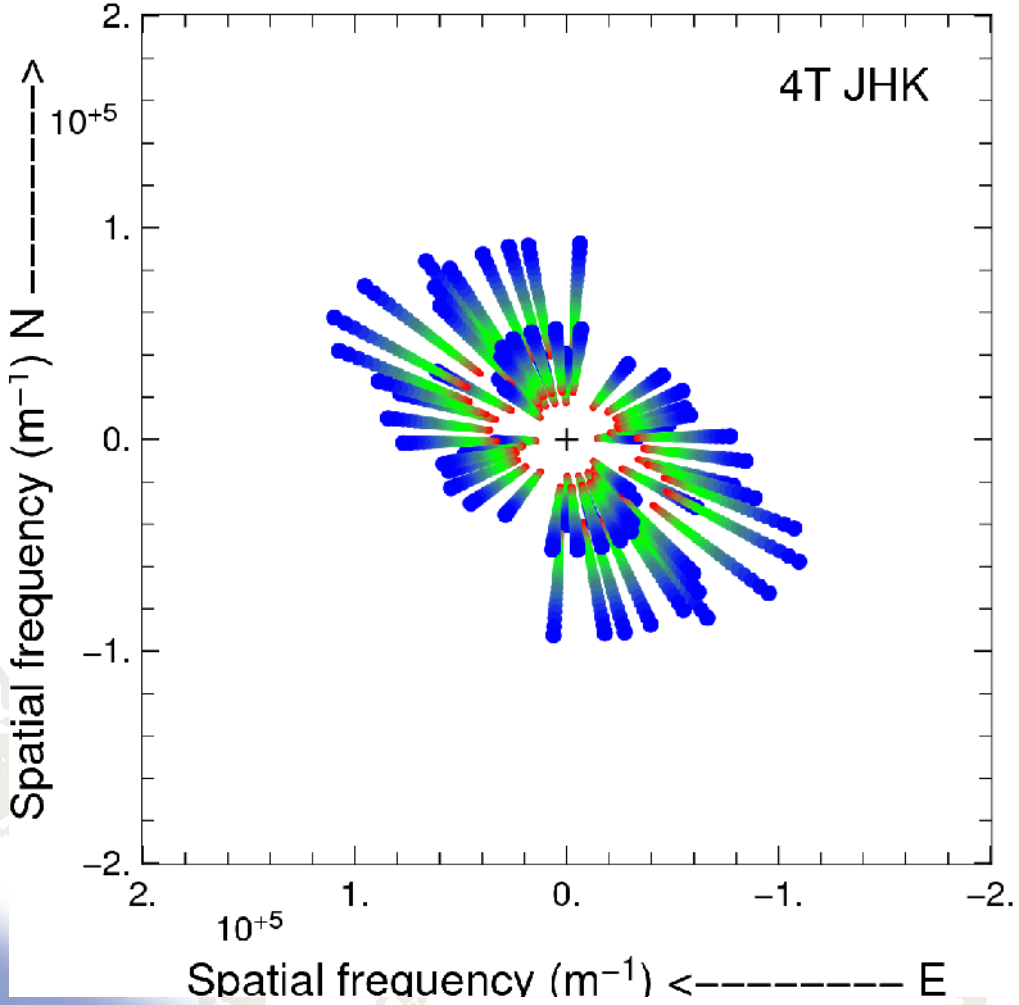
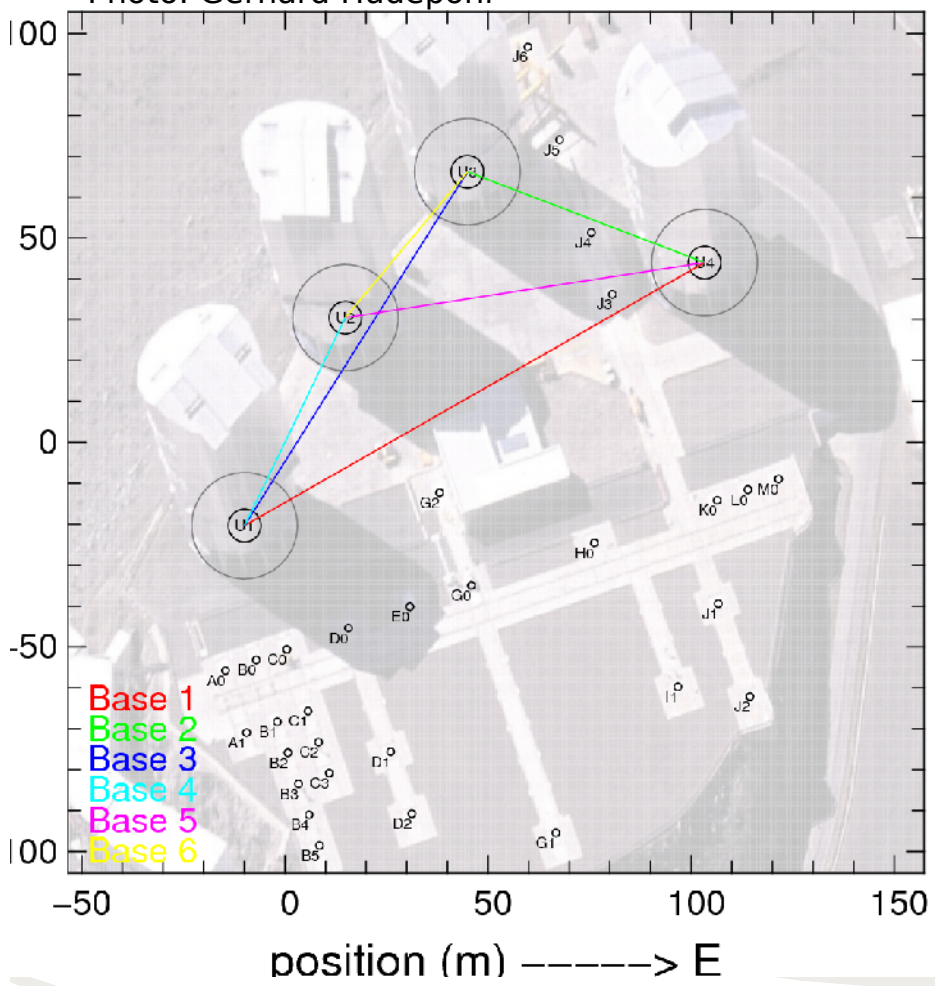


Photo: Gerhard Hüdepohl



Supersynthesis + spectral coverage (8T)

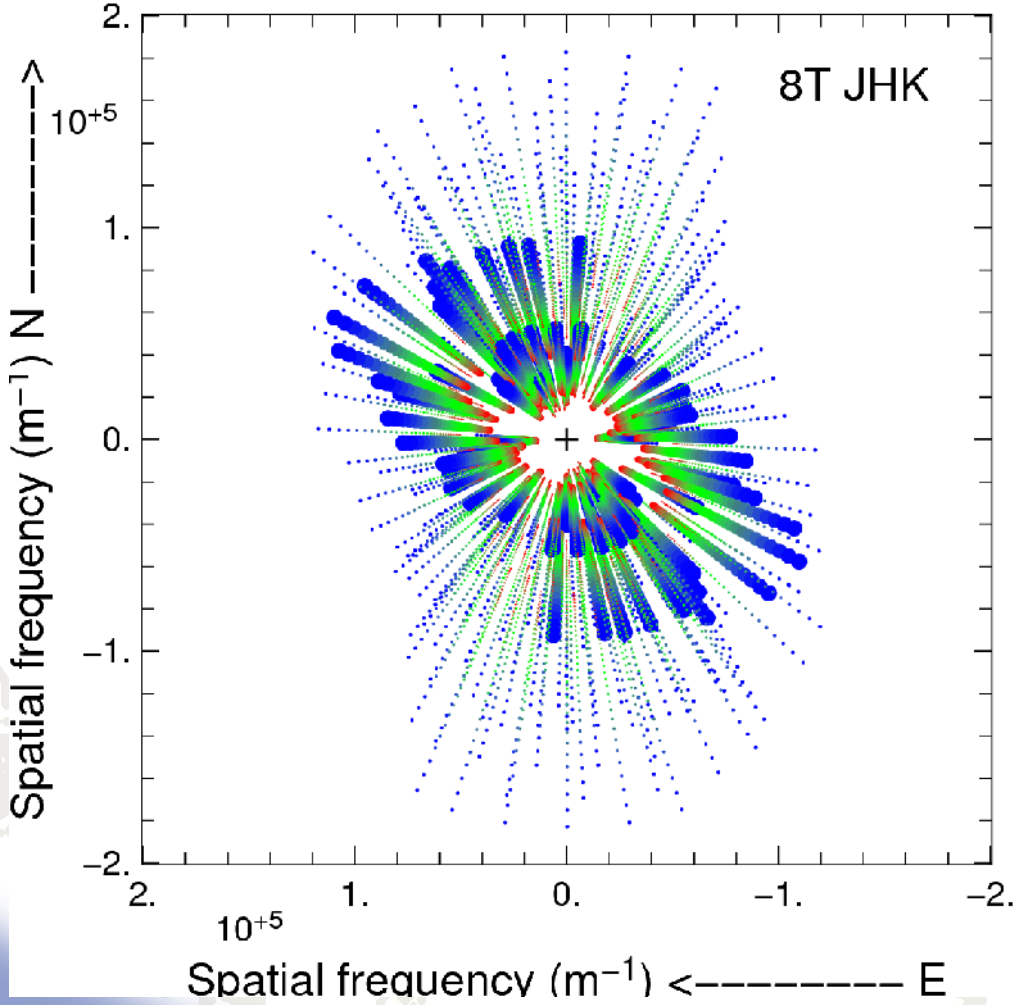
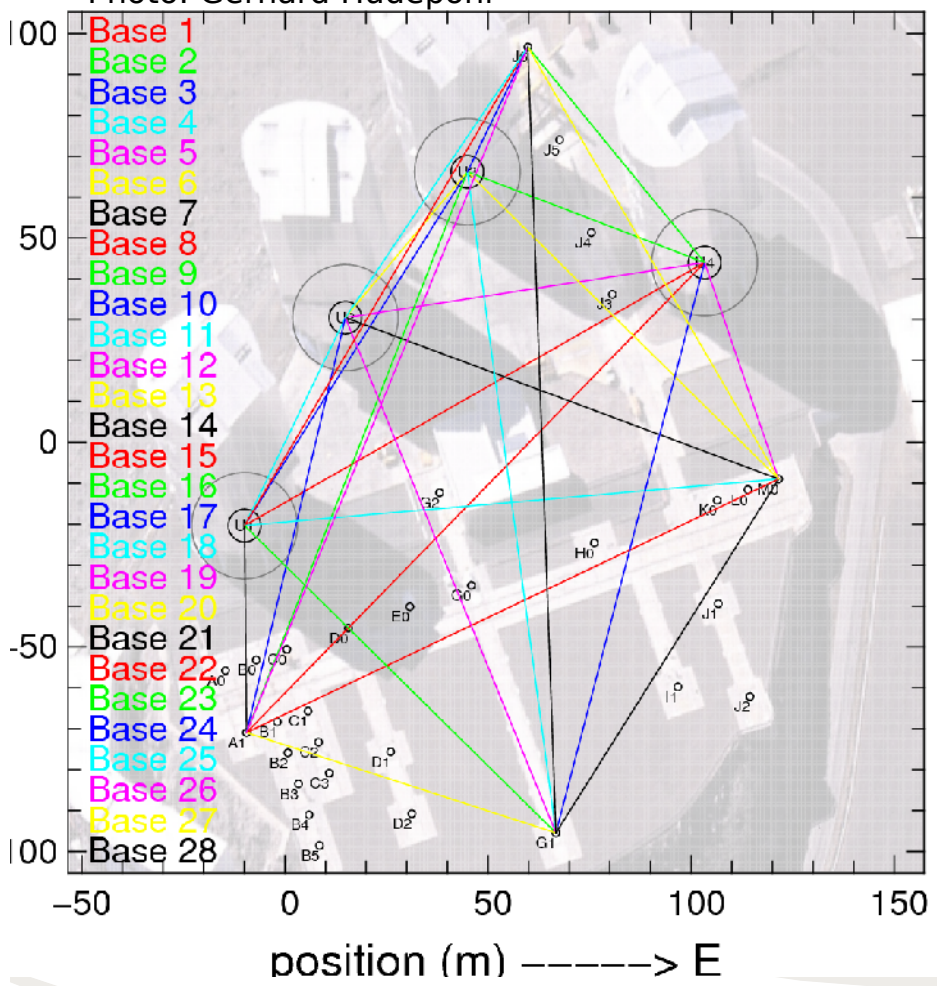


Photo: Gerhard Hüdepohl



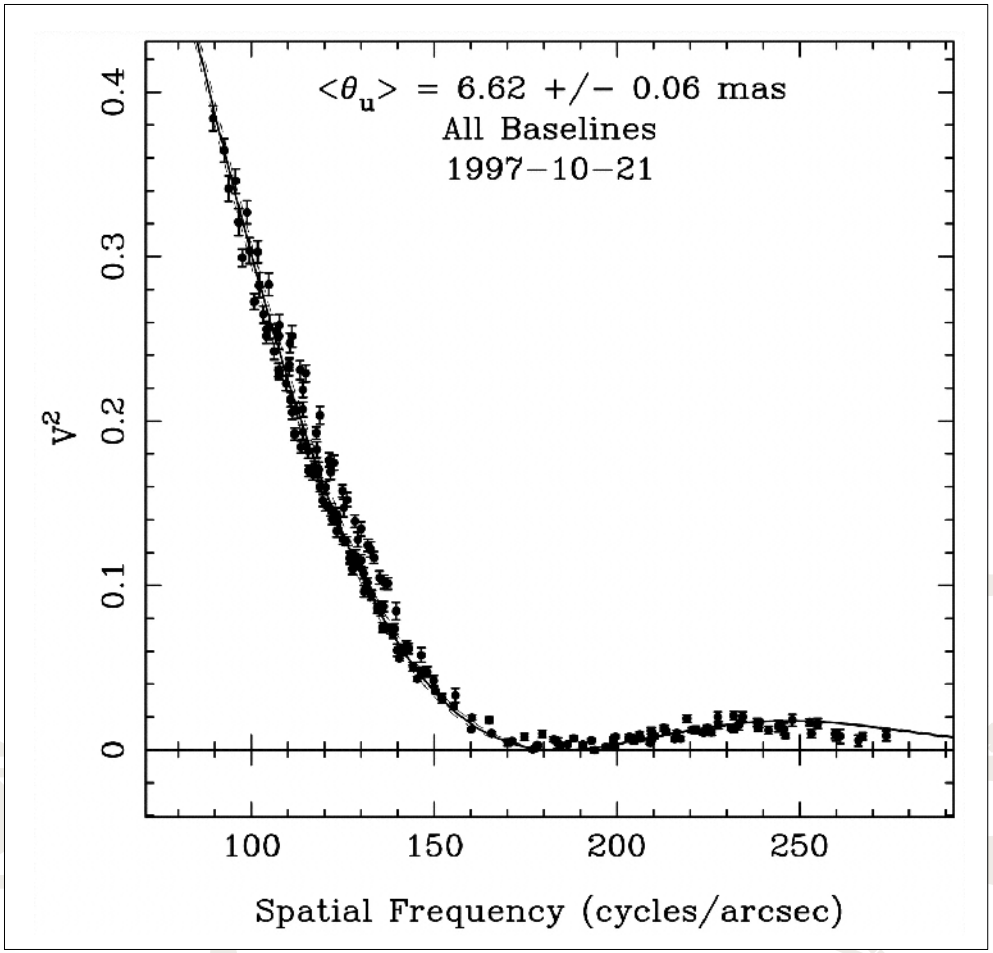
What is an appropriate UV-plane sampling?

- 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

Example (1)

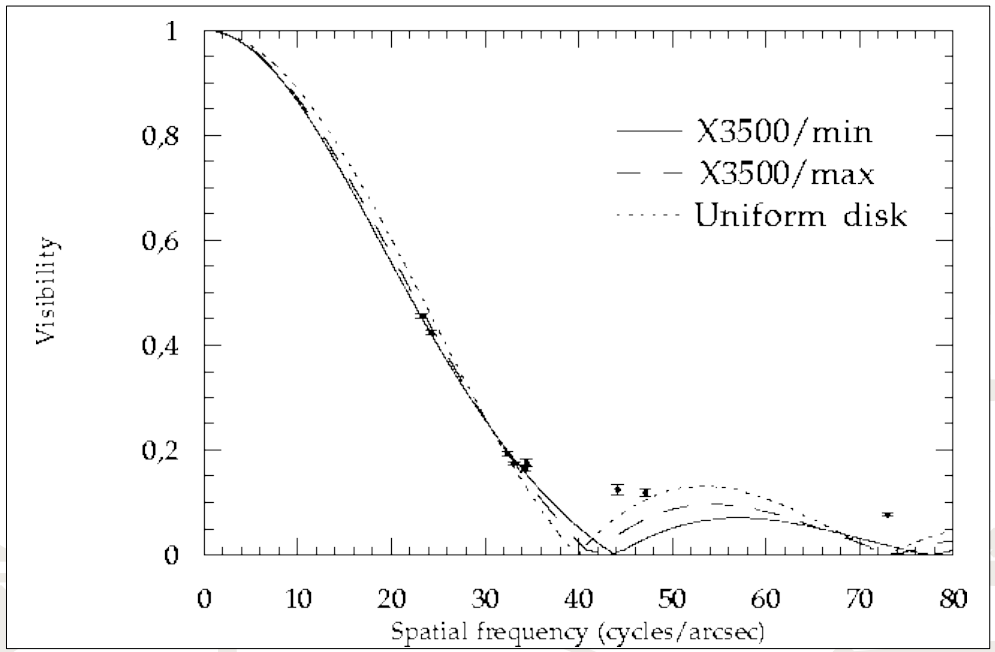


γ Aql, Germain et al. 1999

Radius measurement with NPOI

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

Example (2)

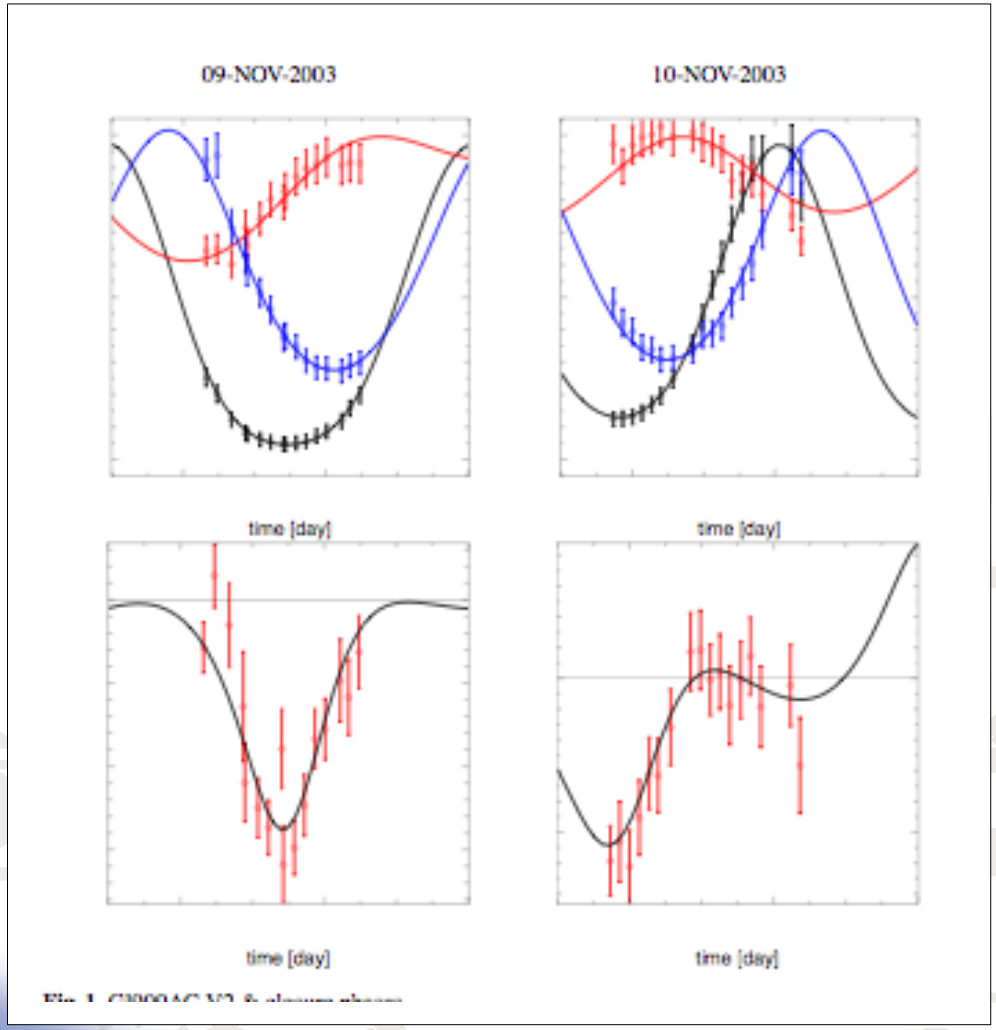


R Leo, Perrin et al. 1999

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

Example (3)

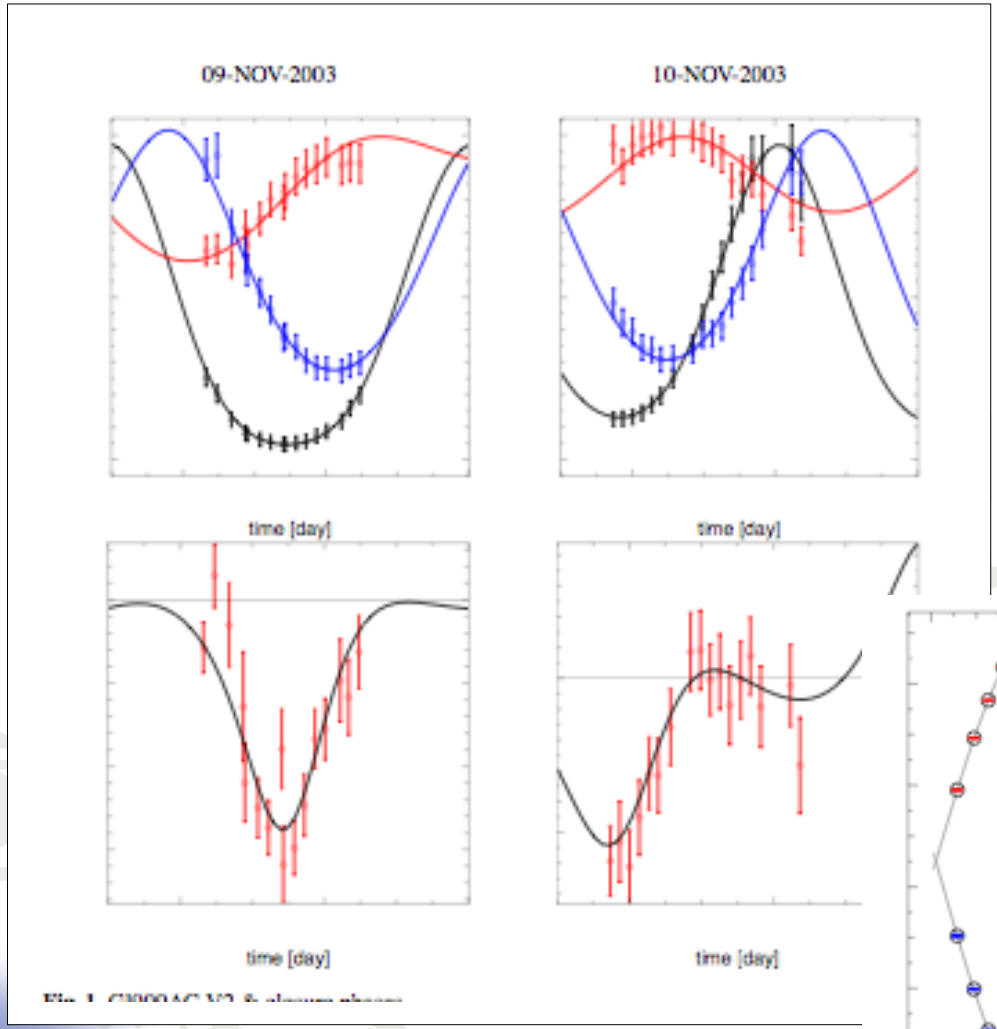


Segransan 2006 (Goutelas)

Binary star observation with IOTA

- accuracy on $V^2 > 1\%$
- limited UV coverage

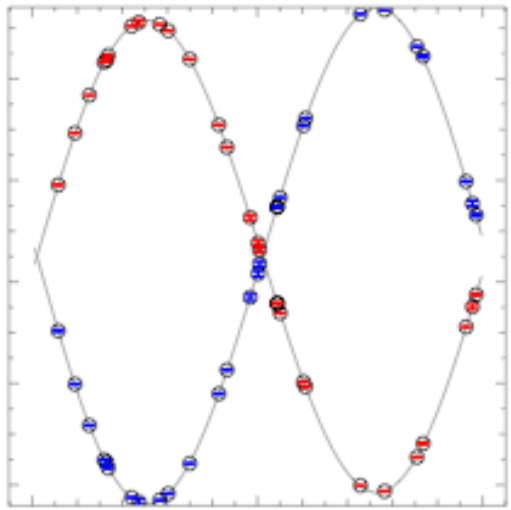
Example (3)

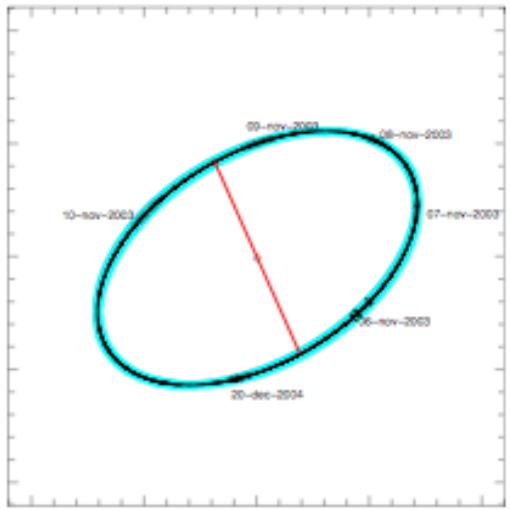


Segransan 2006 (Goutelas)

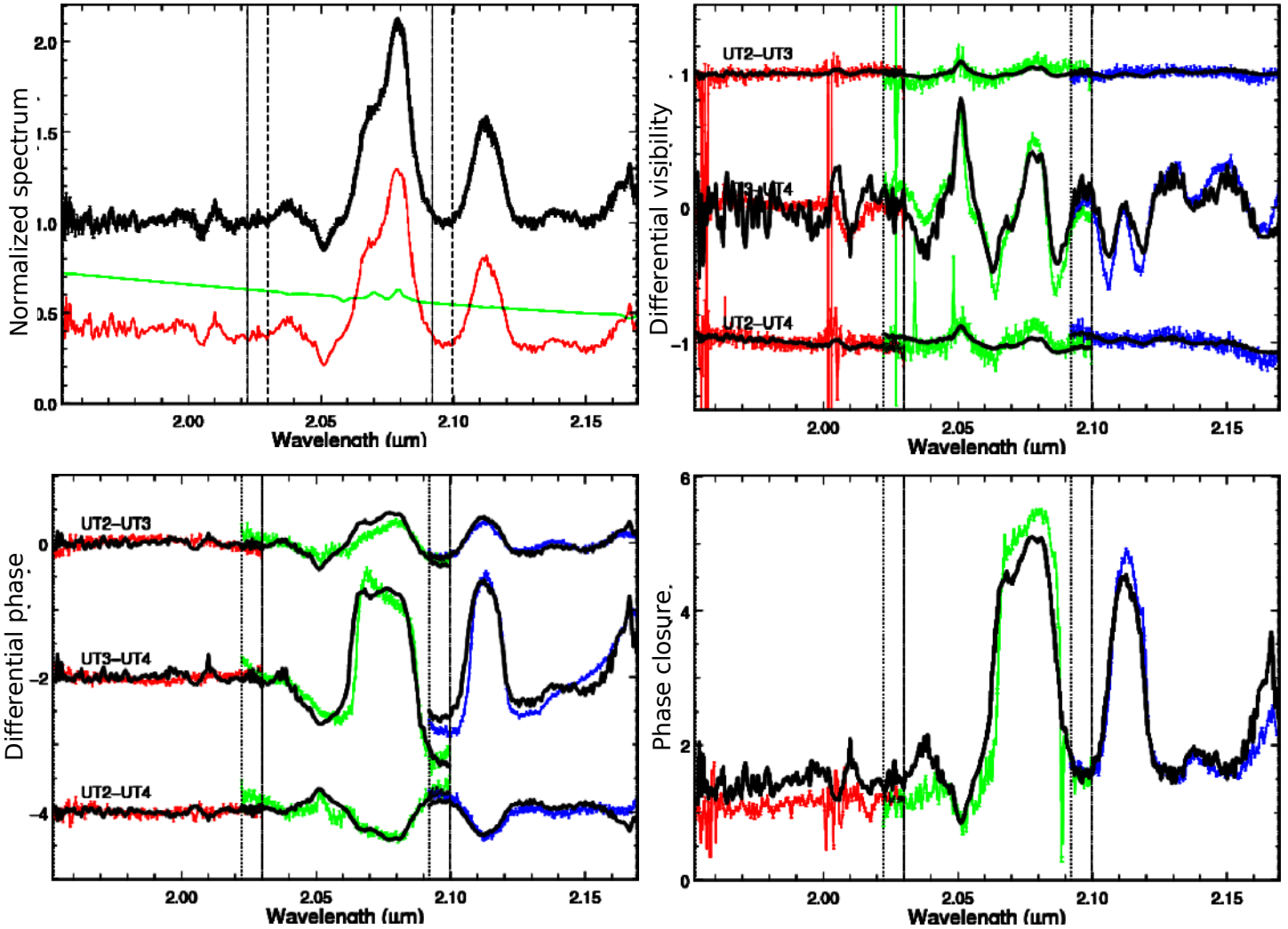
Binary star observation with IOTA

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





Example (4)



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

Spectrally varying flux ratio makes it working !

γ^2 Vel, Millour et al. 2007

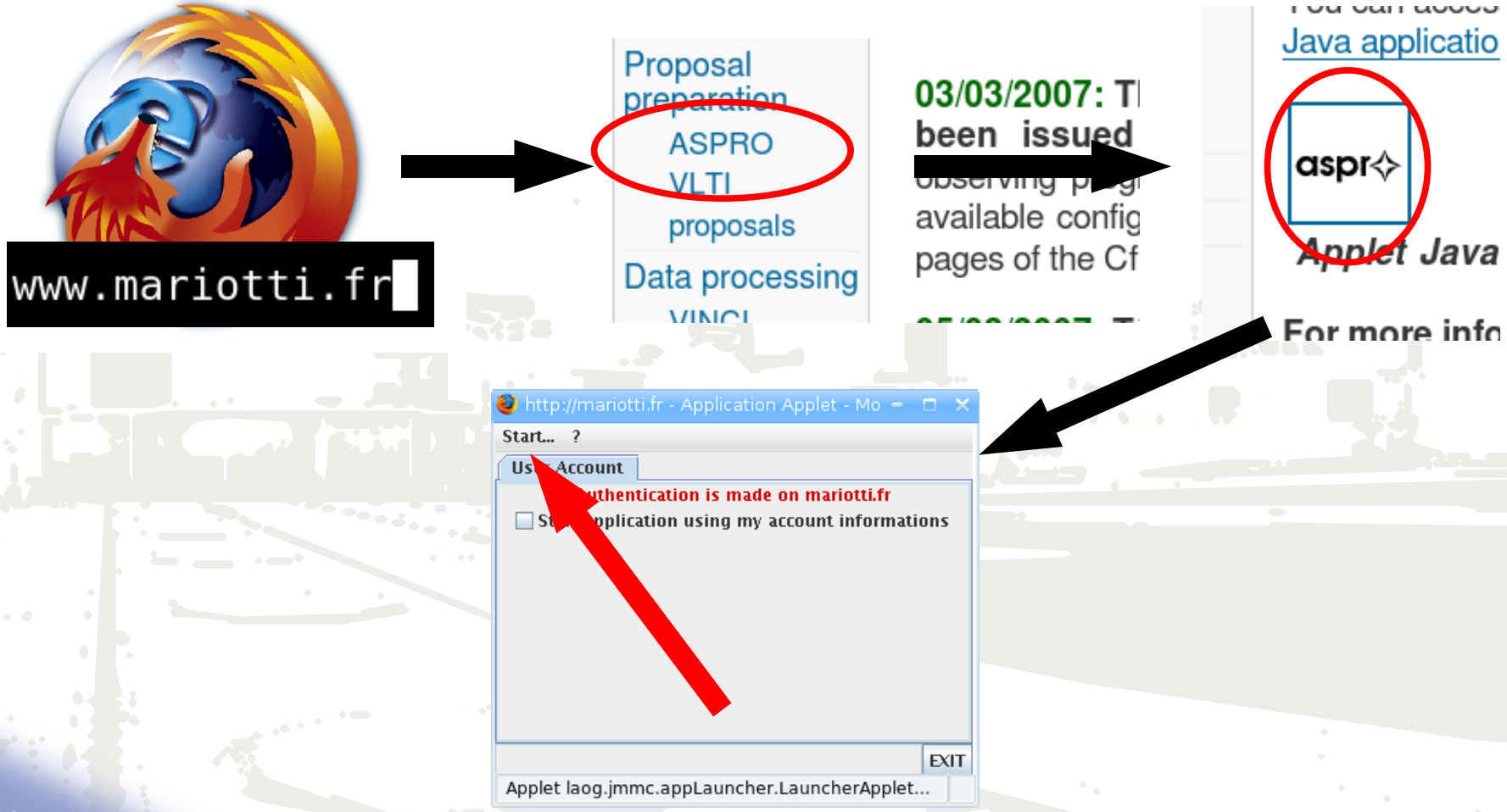
What is an appropriate (U,V)-plane sampling?

There is no simple answer.

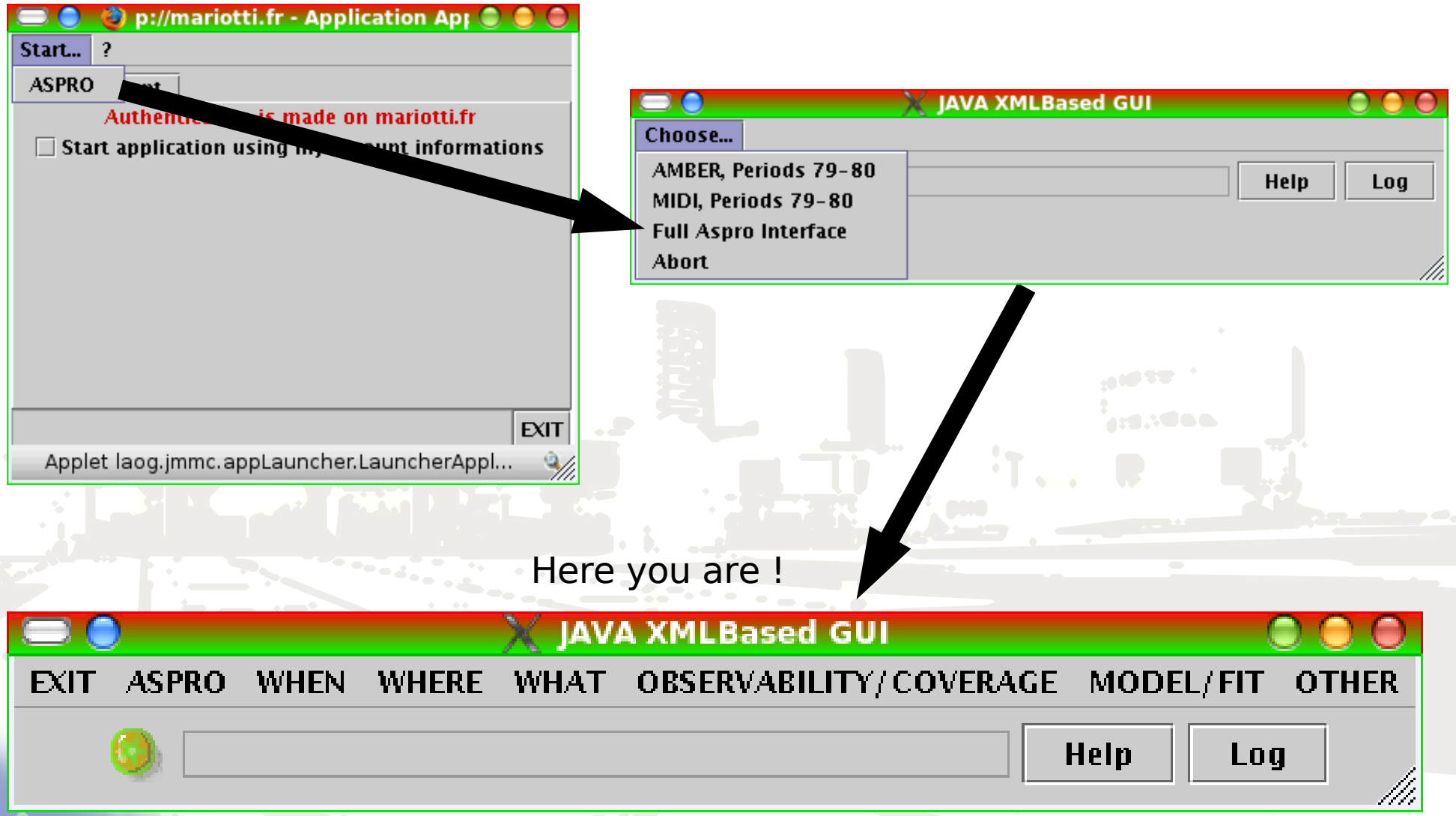
This is why ASPRO was created

How to launch ASPRO (on the web)

- Start your favourite browser



How to launch ASPRO (on the web, continued...)



How to launch ASPRO (local installation)