Observability (and (u,v) coverage)

Euro Summer School

Astrometry and Imaging with the Very Large Telescope Interferometer

June 1 – June 14

Florentin MILLOUR
(Max-Planck Institut fur Radioastronomie)
fmillour@mpifr-bonn.mpg.de

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

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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)
Example: NACO imaging ~1-2 hrs

- ***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)
Example: AMBER *moderate* UV coverage ~ 1-2 nights

=> A good Observation Preparation Software is required

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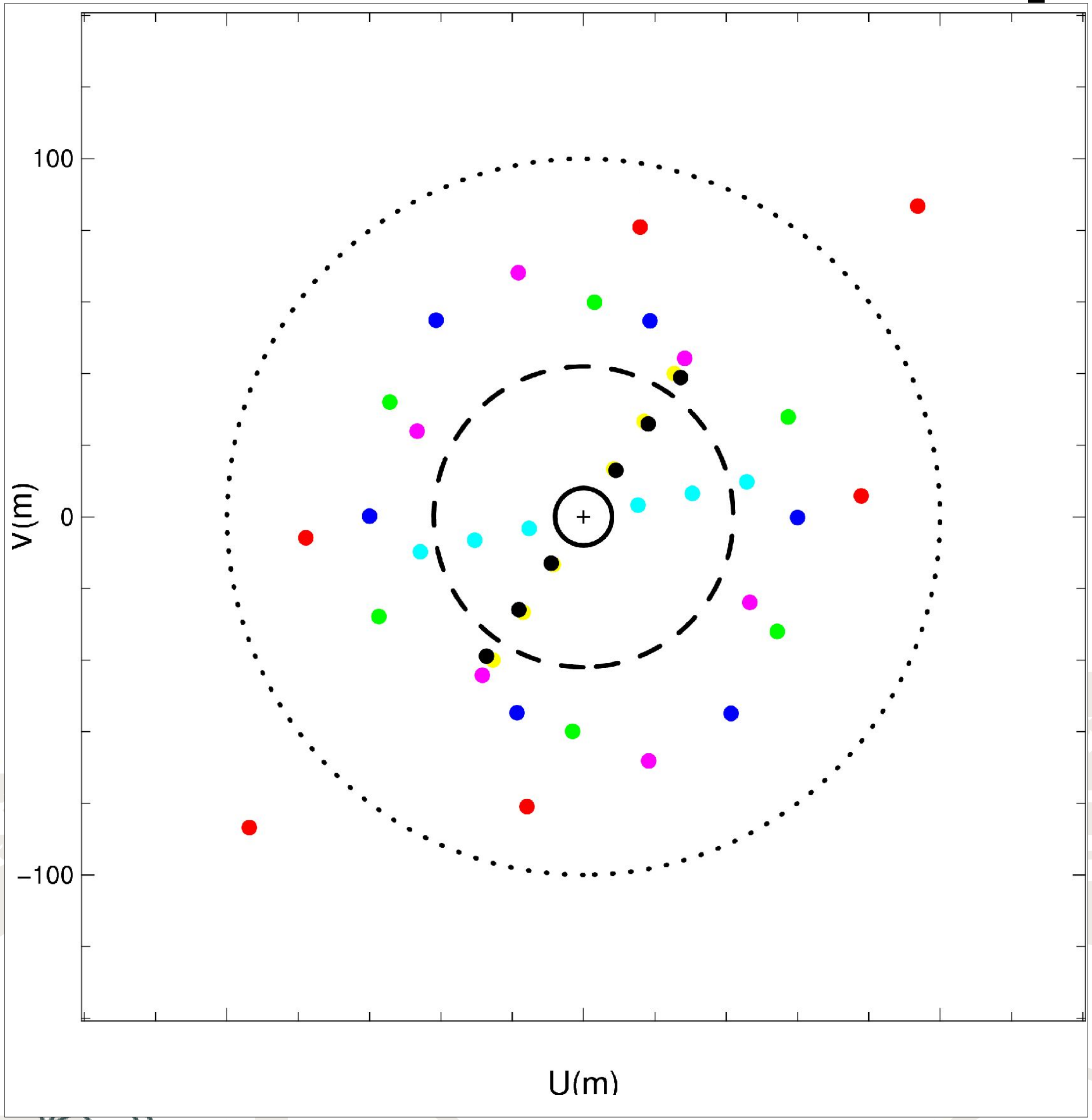
So, why is interferometry so unique?



- Full circle = **VLT <u>today</u>.** (NACO ~ 1-2 **<u>hours</u>**)
- Dashed circle = **E-ELT** (42m). (??? hrs, available in ??? yrs)
- Dotted circle = **OWL** (100m). (will never exist)
- Colour points = **AMBER <u>today</u>**. (1.5 **<u>night</u>**, with <u>short</u> baselines)

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

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)

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(u,v) plane and single dish telescope

Object observed at the
Special Astronomical Observatory (Zelentchouk)

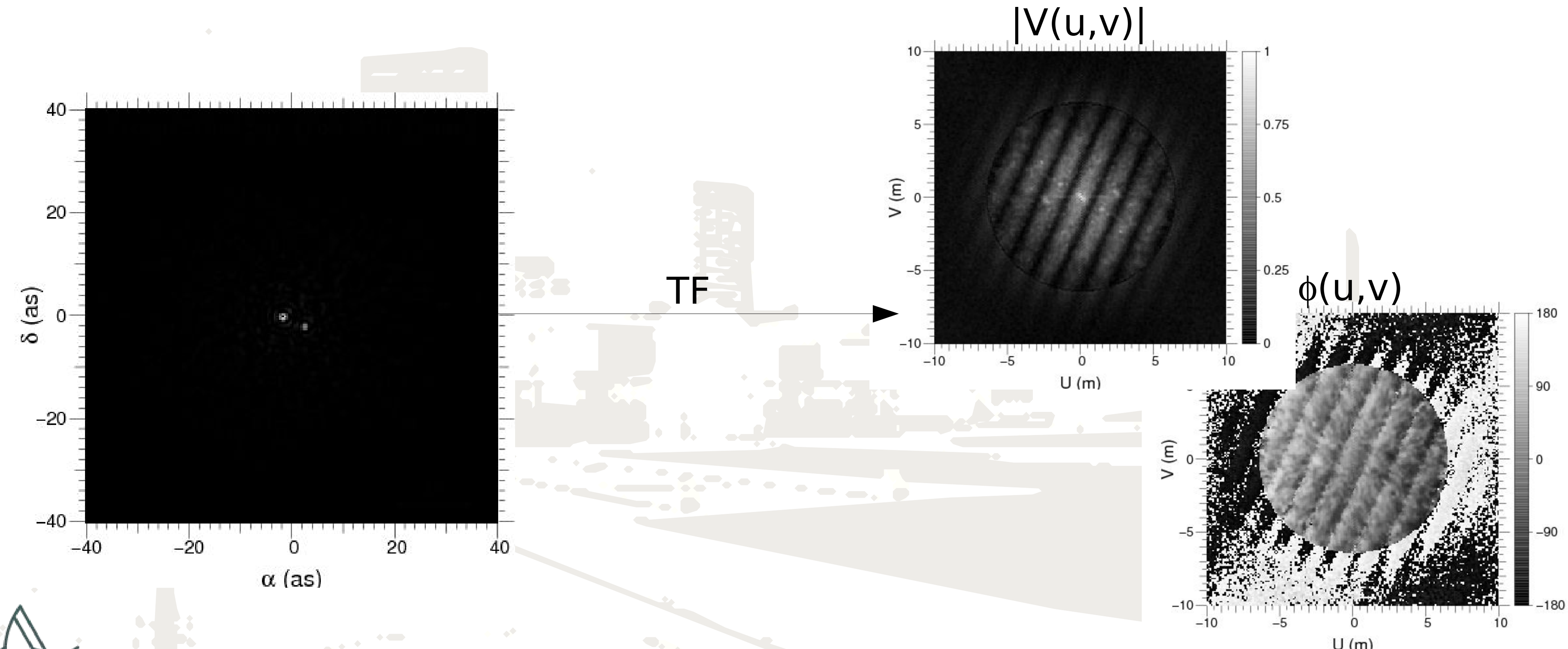

Image : I(x,y)=O*PSF

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

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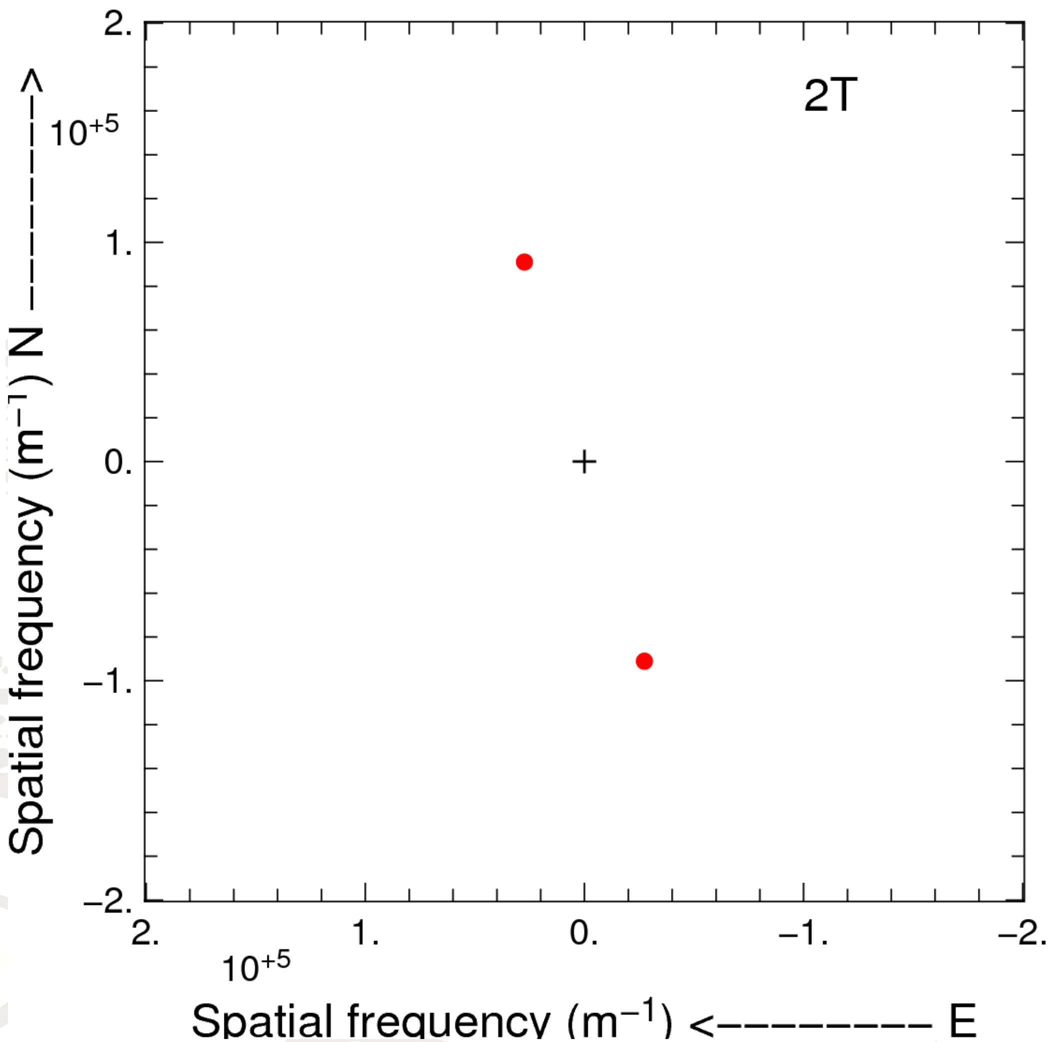
(u,v) plane with an interferometer: 2T snapshot

(u,v) plane is poorly sampled.

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



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How to fill the (u,v) 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 <u>2 telescopes</u> interferometer gives access to <u>**1**</u> (u,v) point per measurement.

• A <u>3 telescopes</u> interferometer gives access to <u>**3**</u> (u,v) points per measurement.

• A <u>N telescopes</u> interferometer gives access to <u>**N(N-1)/2**</u> (u,v) points per measurements

=> We have access to high spatial frequencies but ...

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

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(u,v) plane filling with more telescopes: 2T

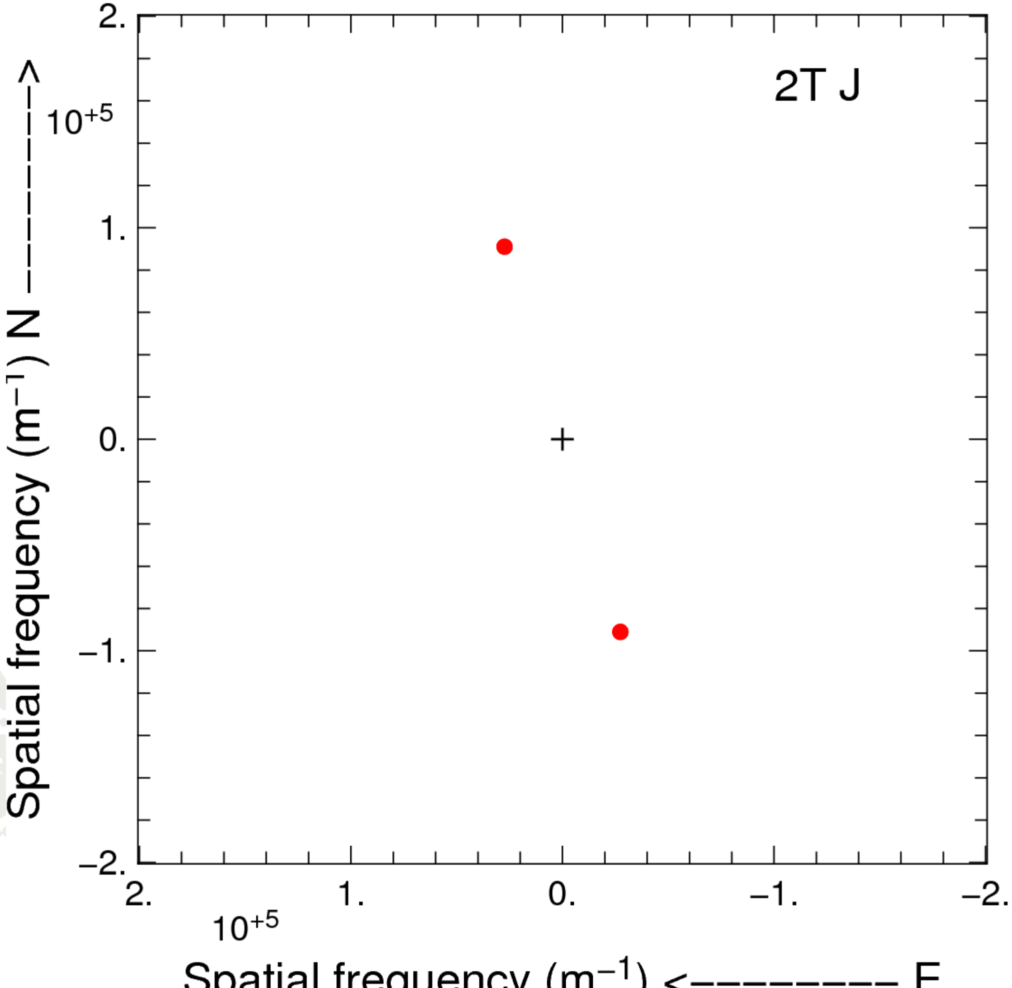
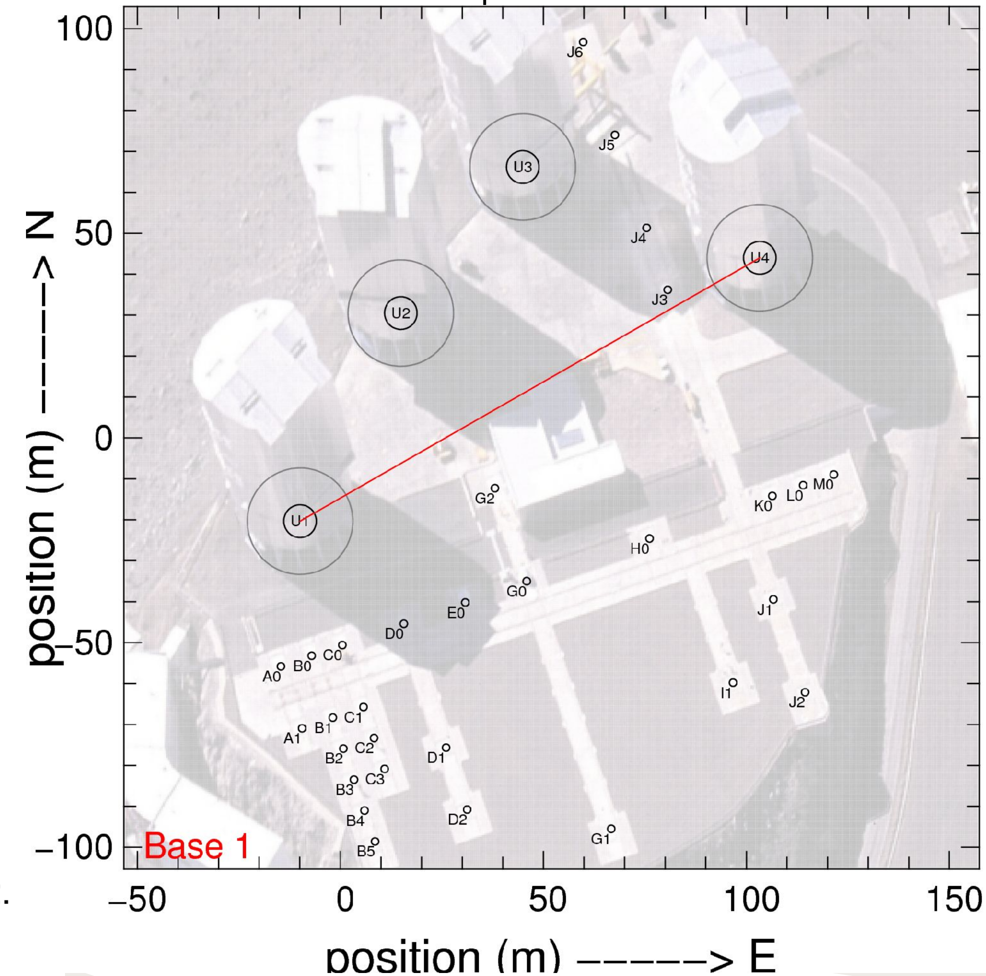


Photo: Gerhard Hüdepohl



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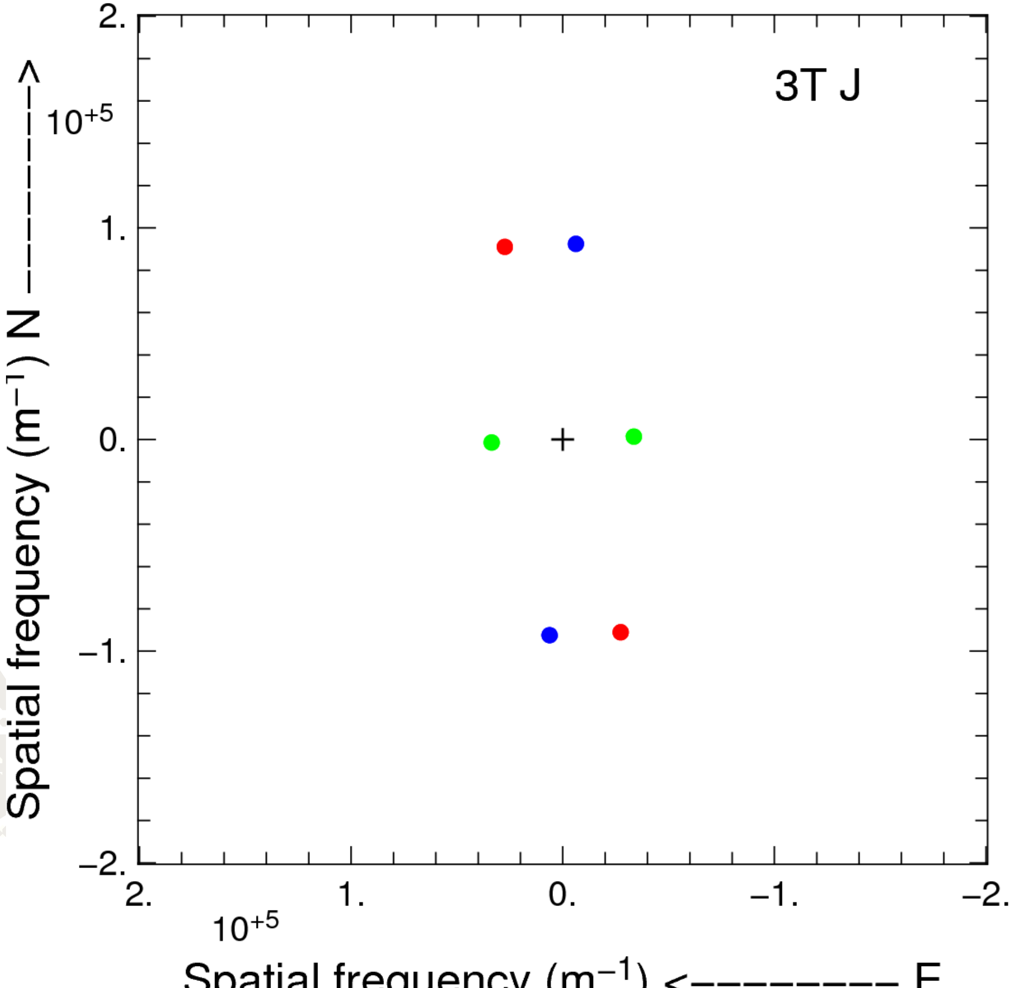
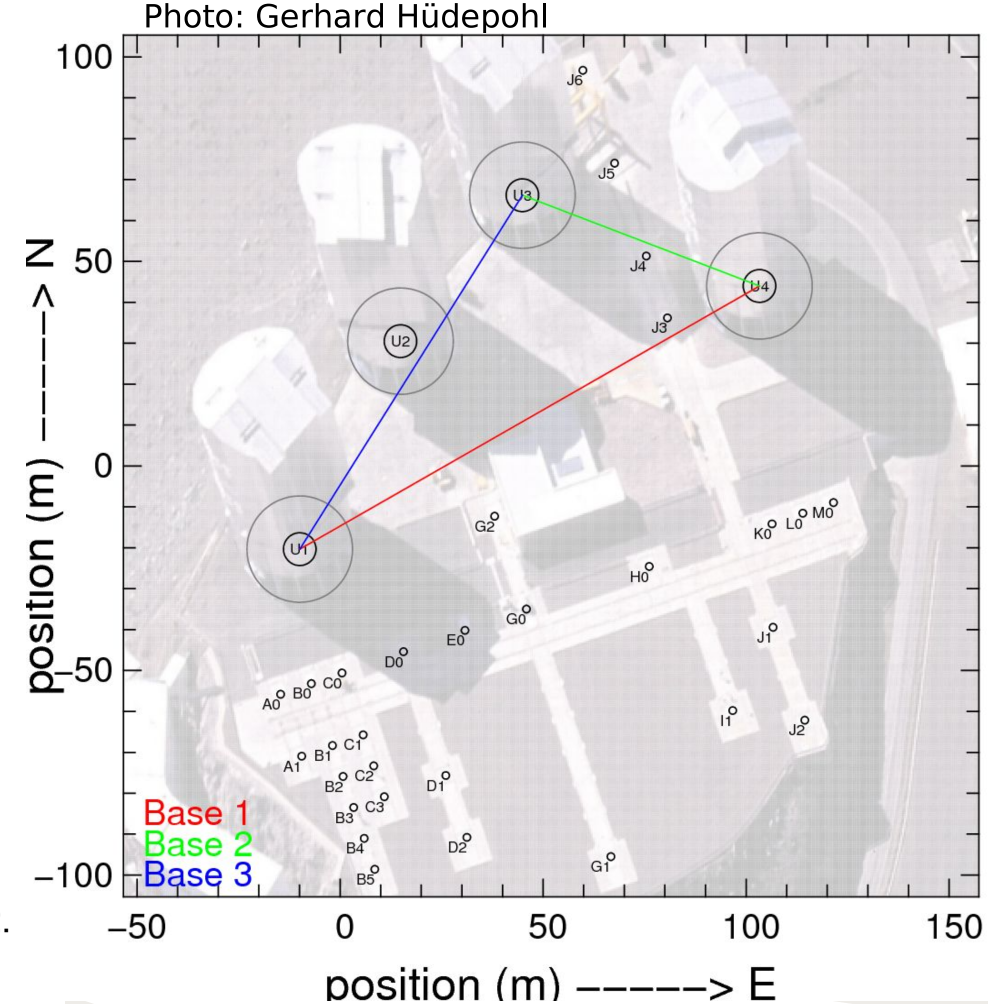
(u,v) plane filling with more telescopes: 3T





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

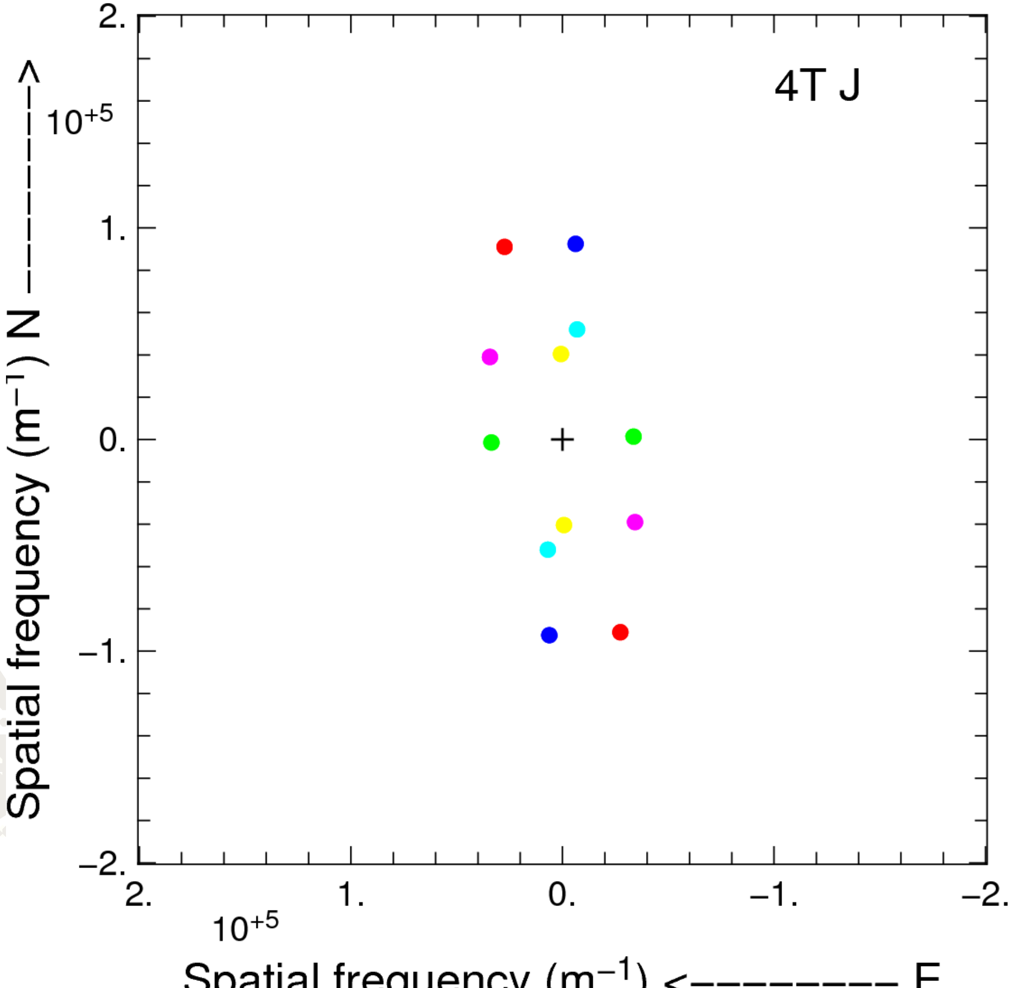
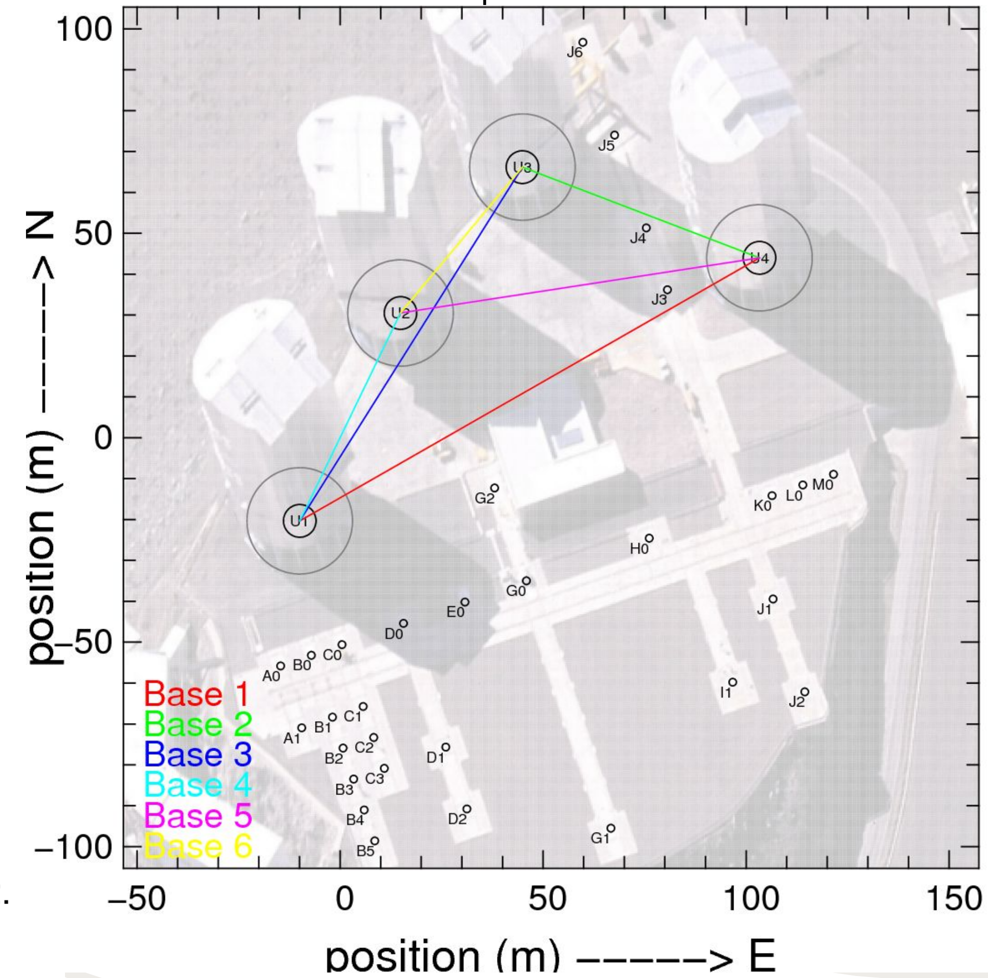


Photo: Gerhard Hüdepohl



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

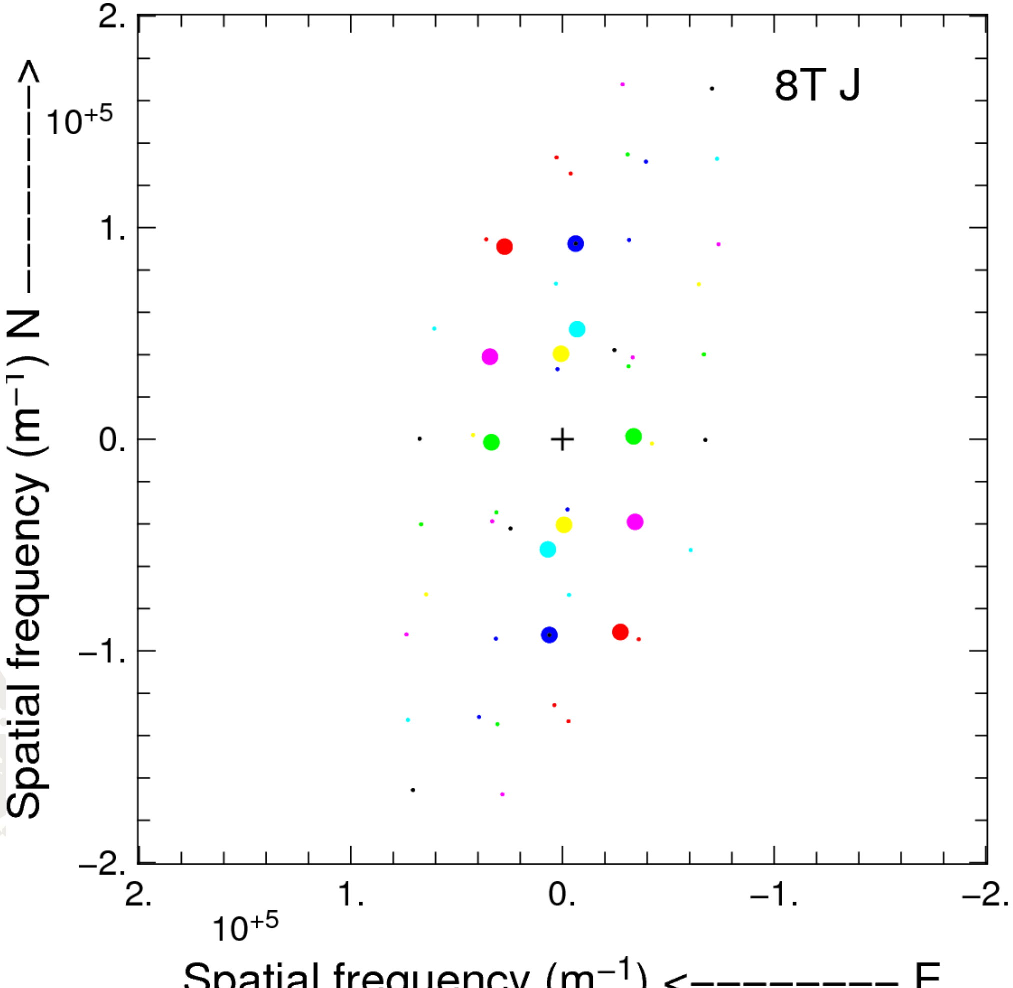
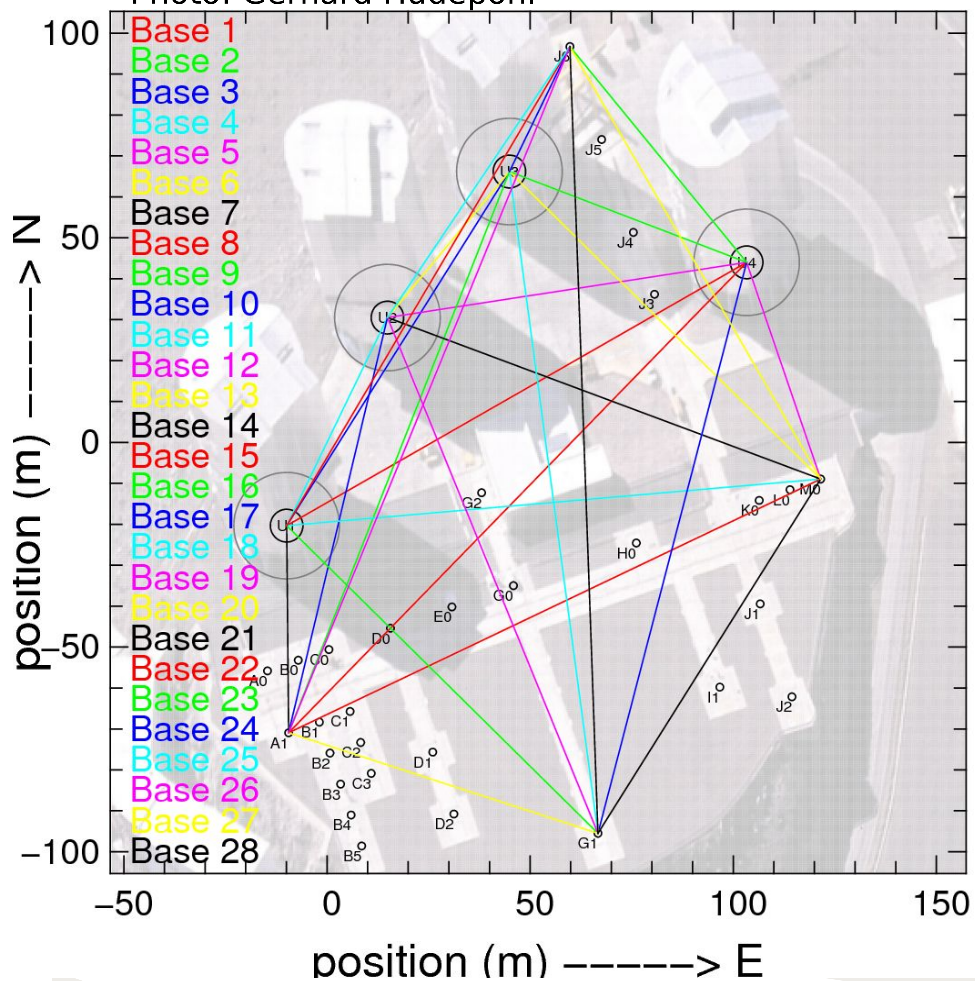


Photo: Gerhard Hüdepohl



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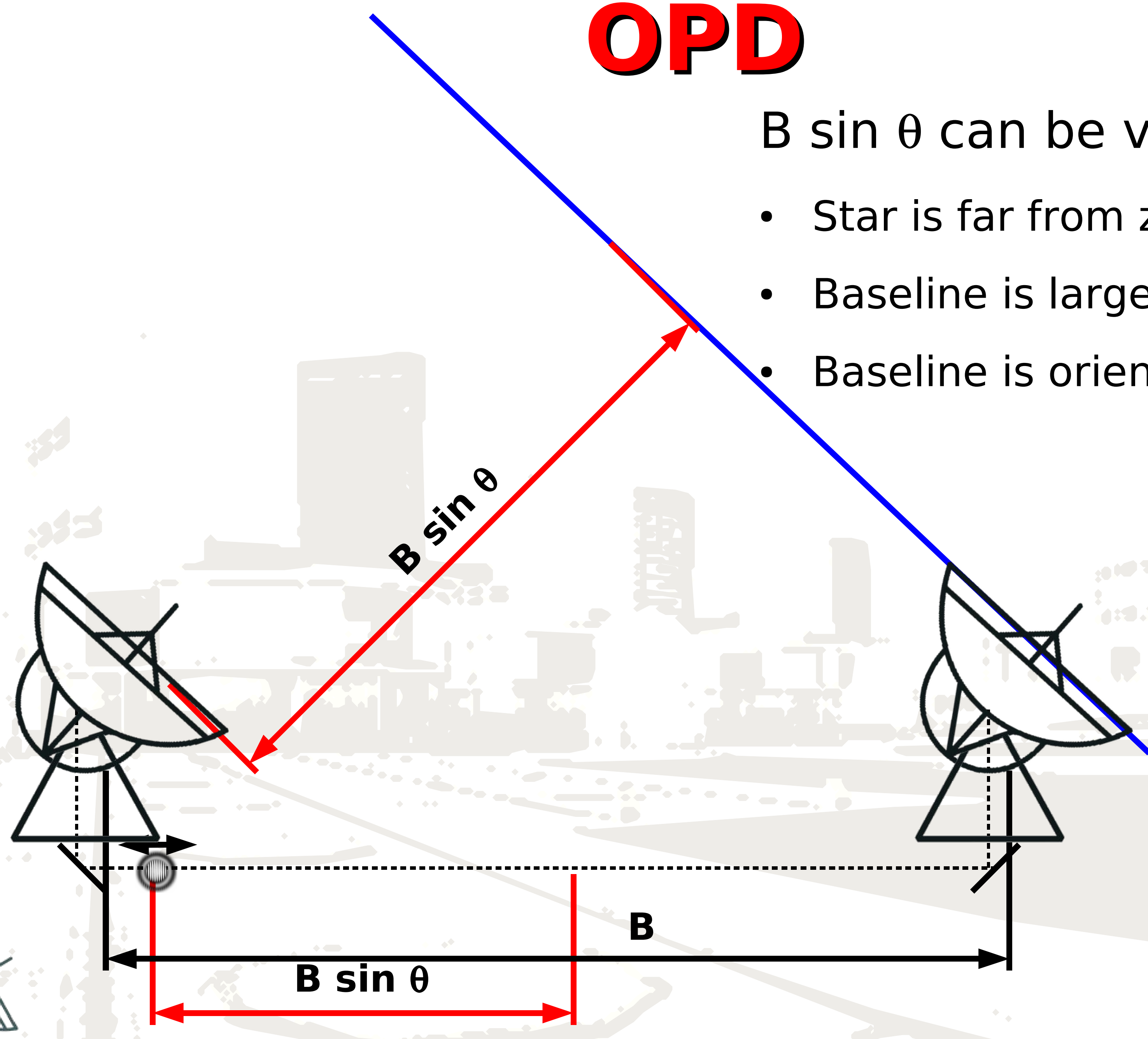
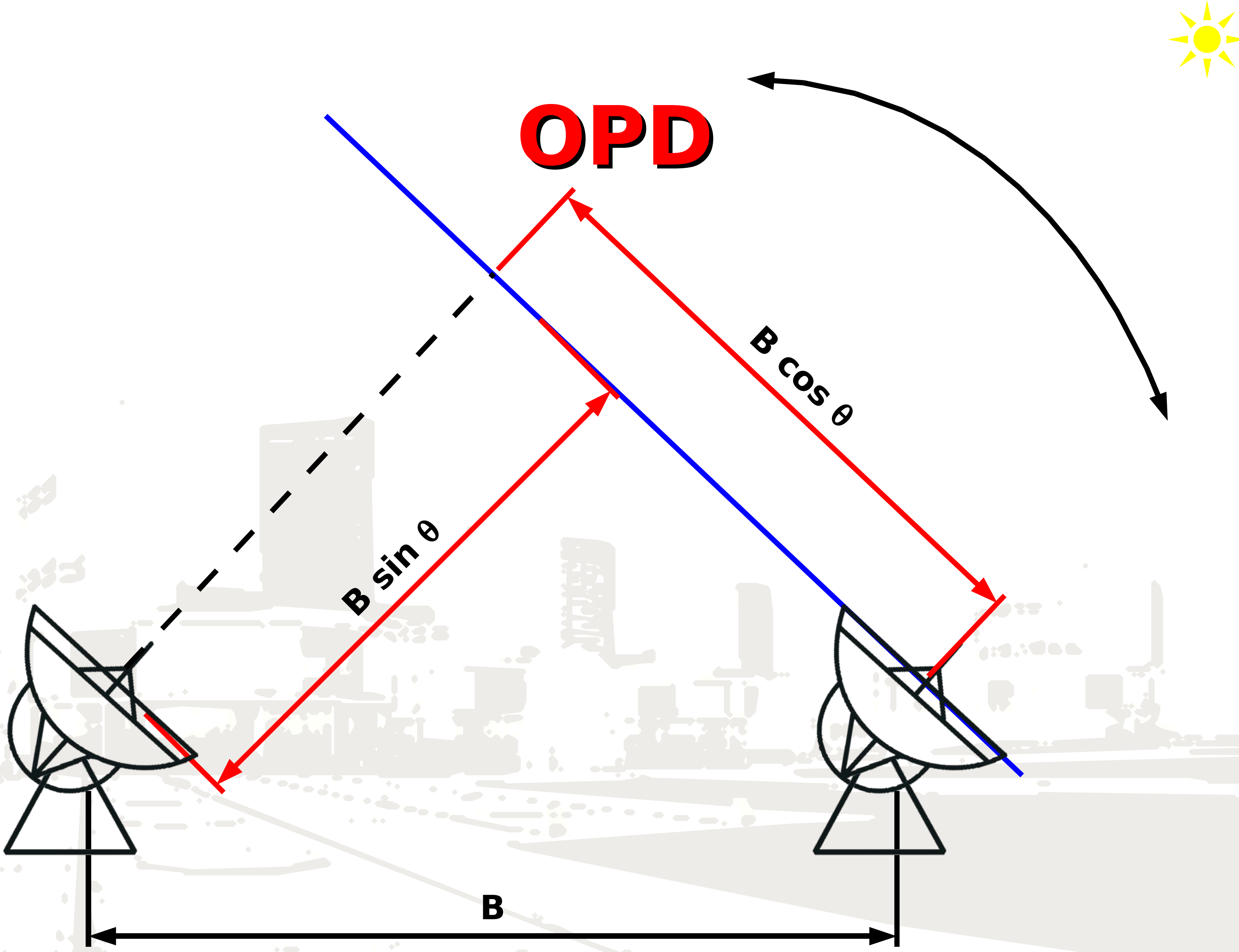
OPD

B sin θ can be very large if:

- Star is far from zenith
- Baseline is large
- Baseline is oriented East-West





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(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)

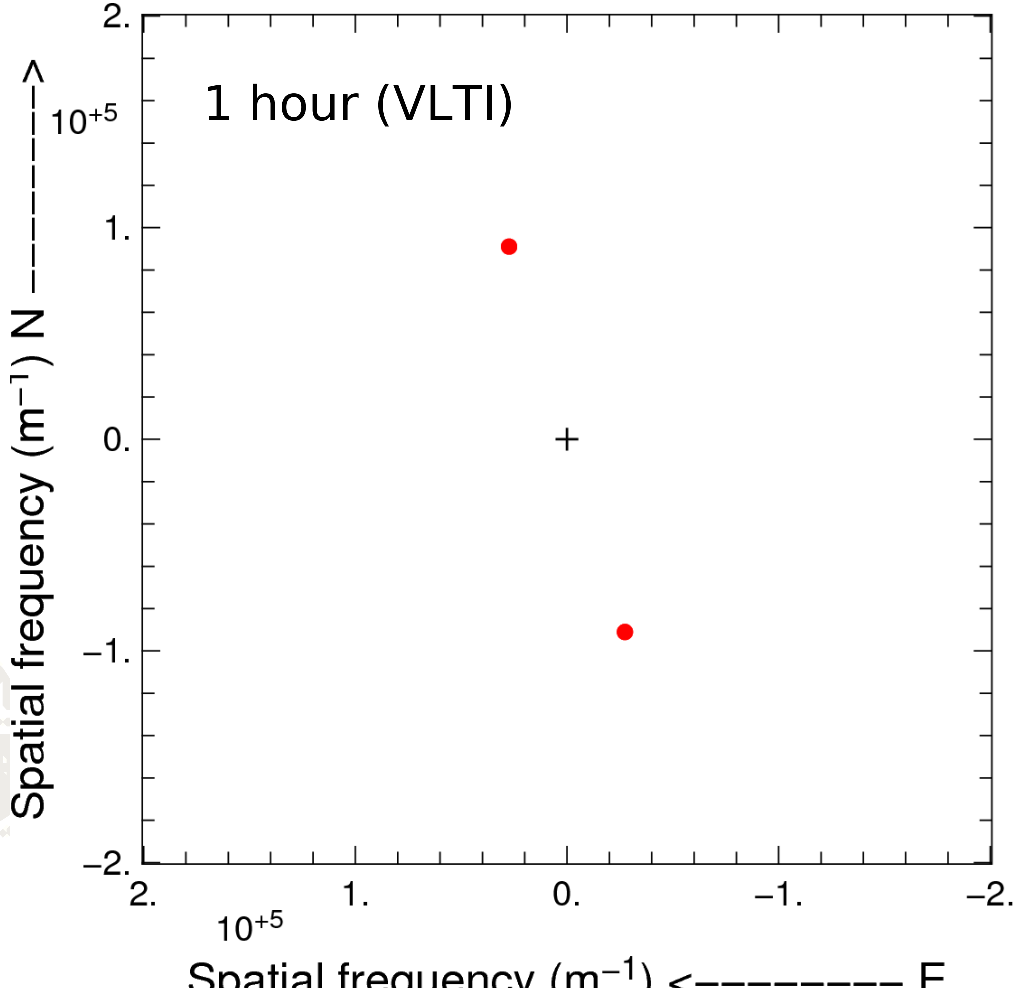
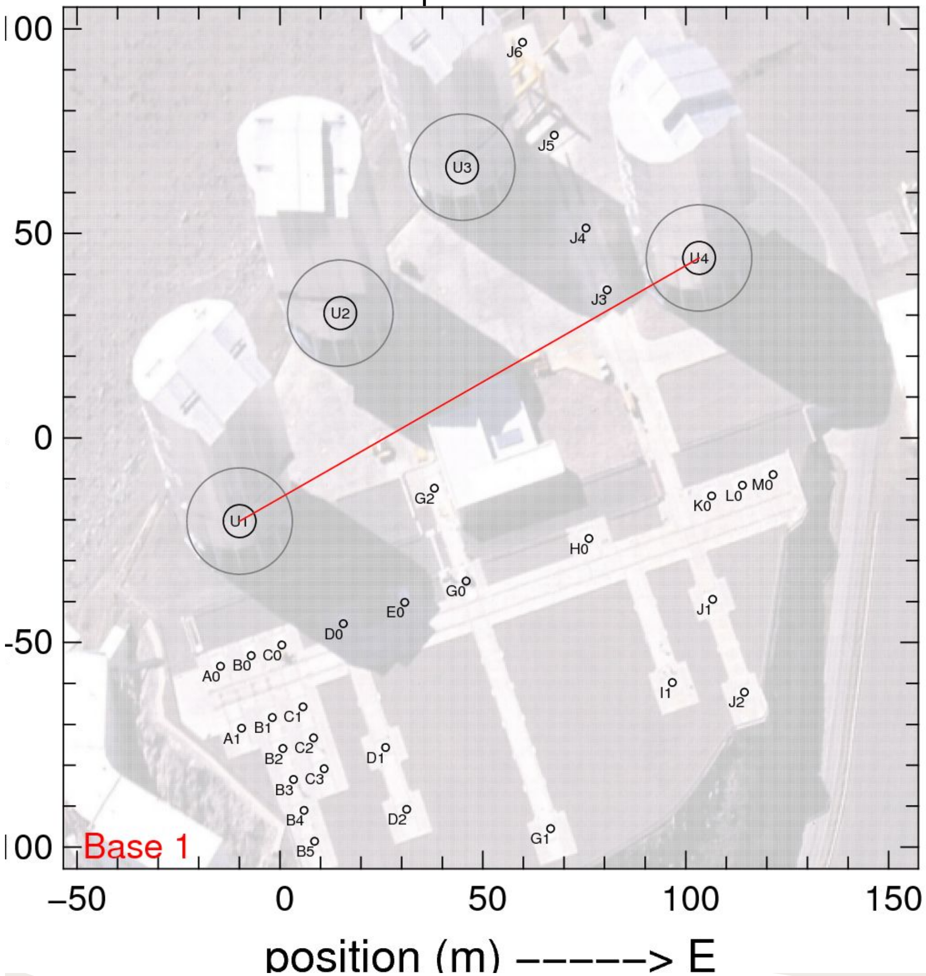


Photo: Gerhard Hüdepohl



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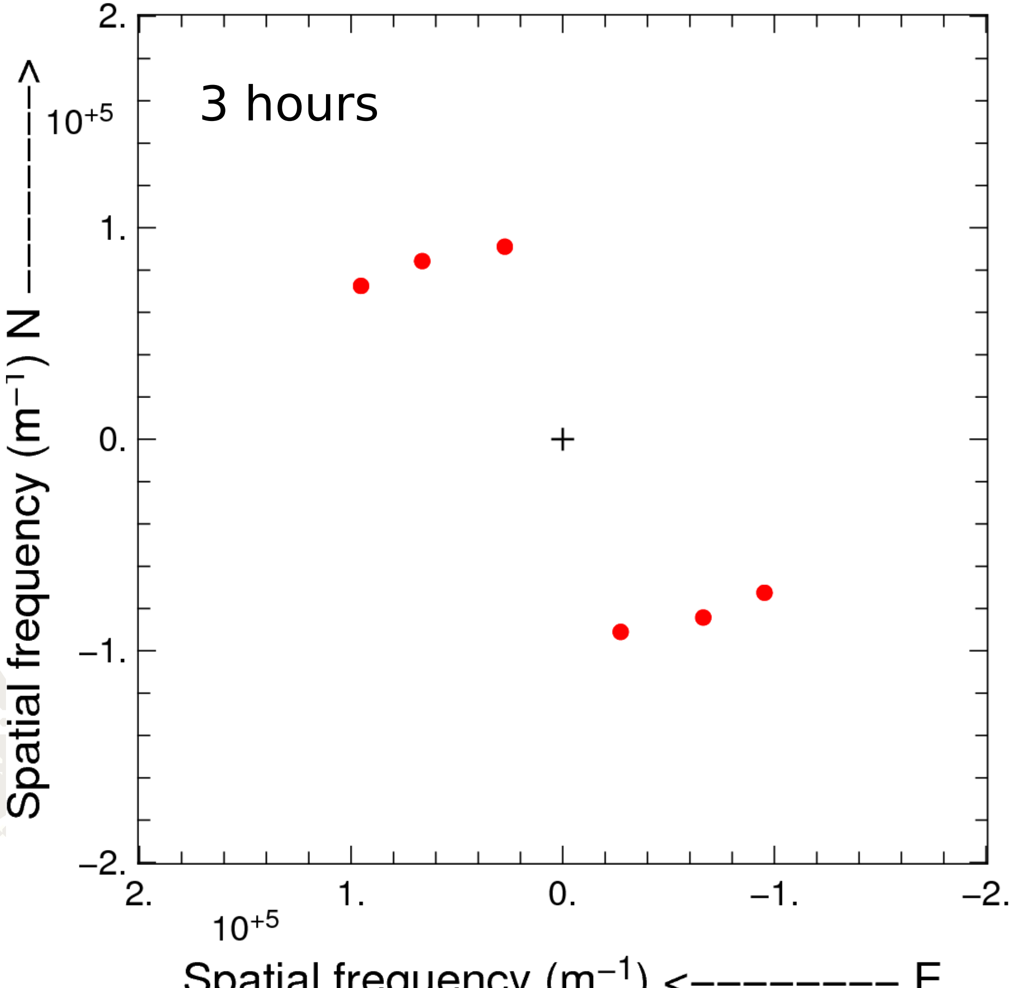
Supersynthesis (2T)



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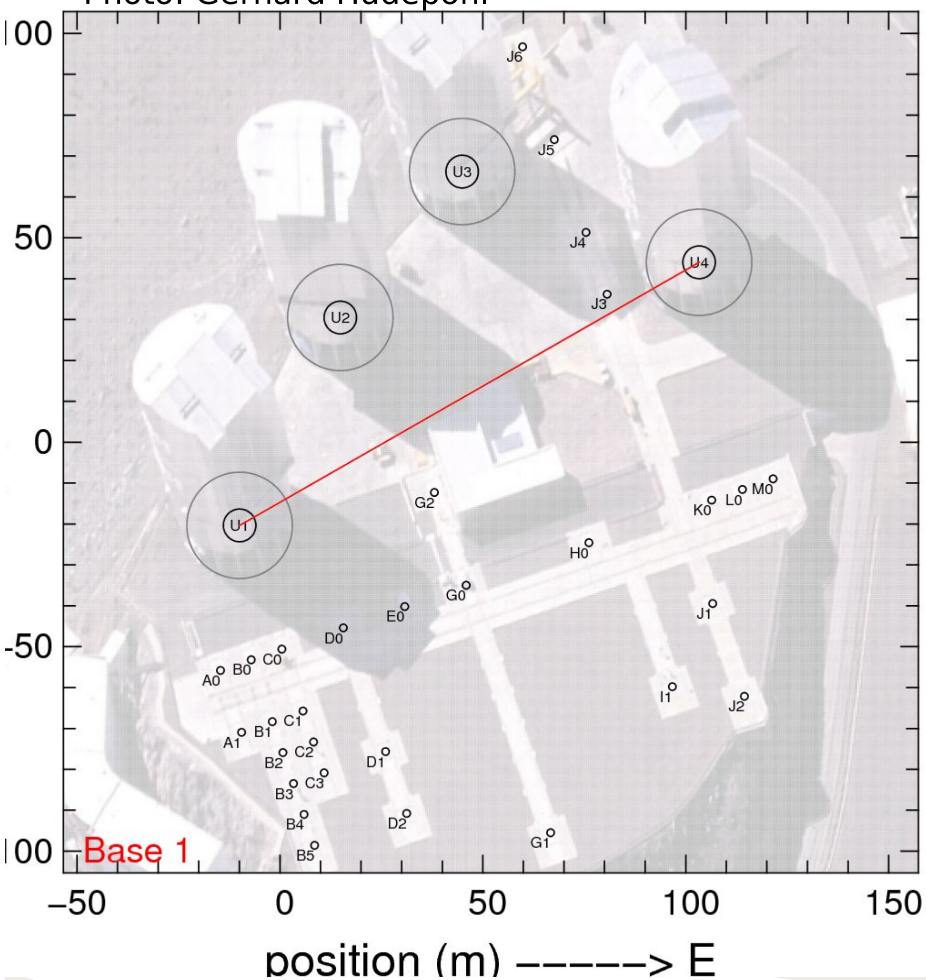
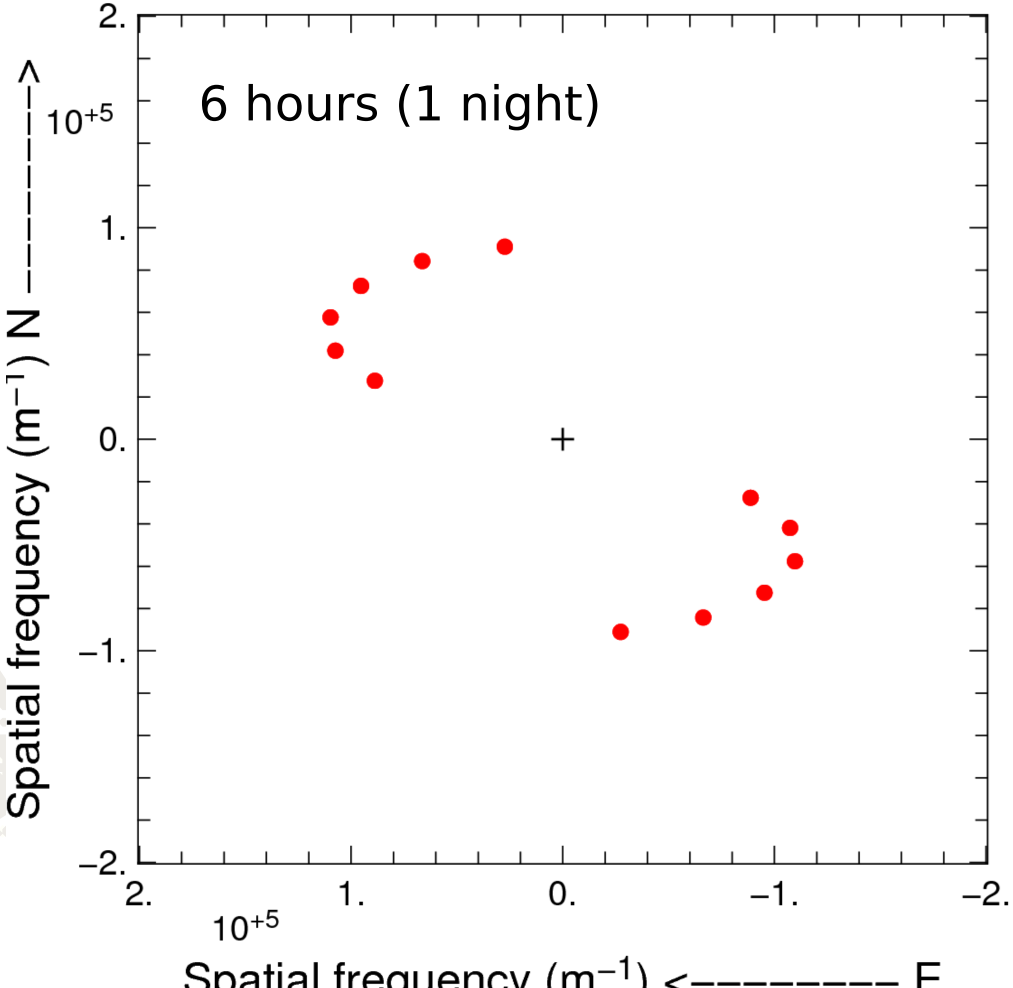
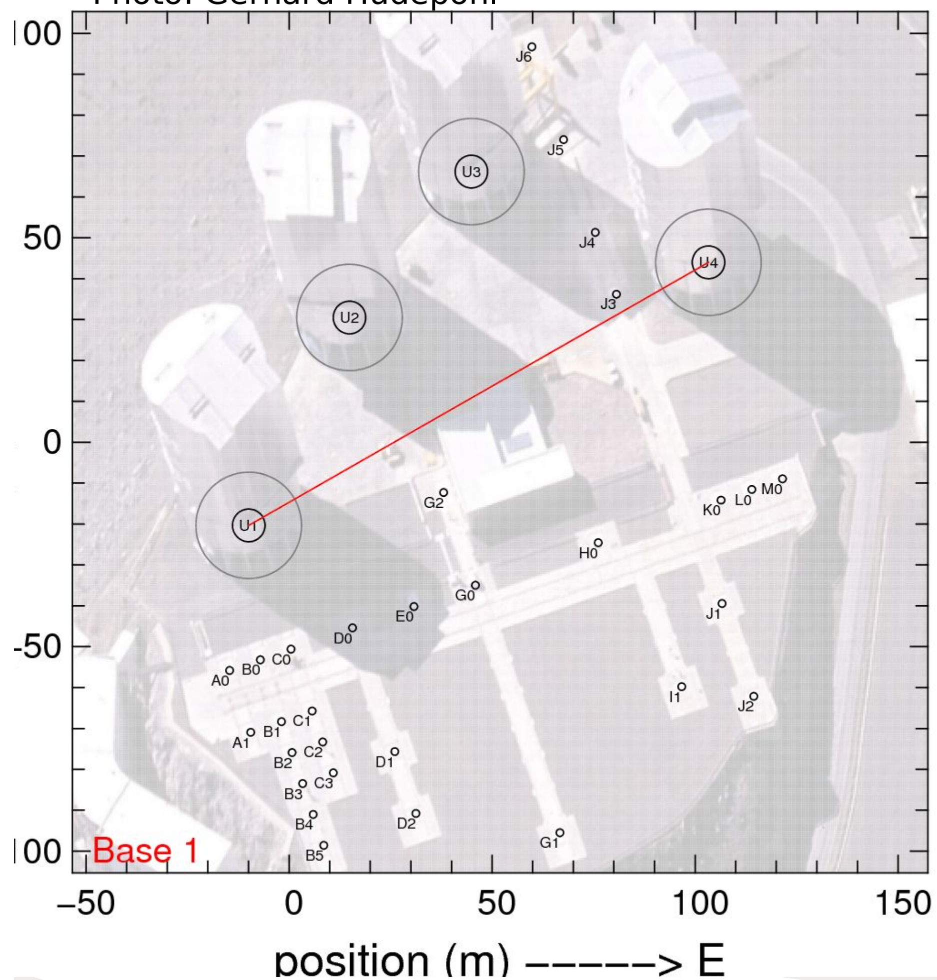


Supersynthesis (2T)





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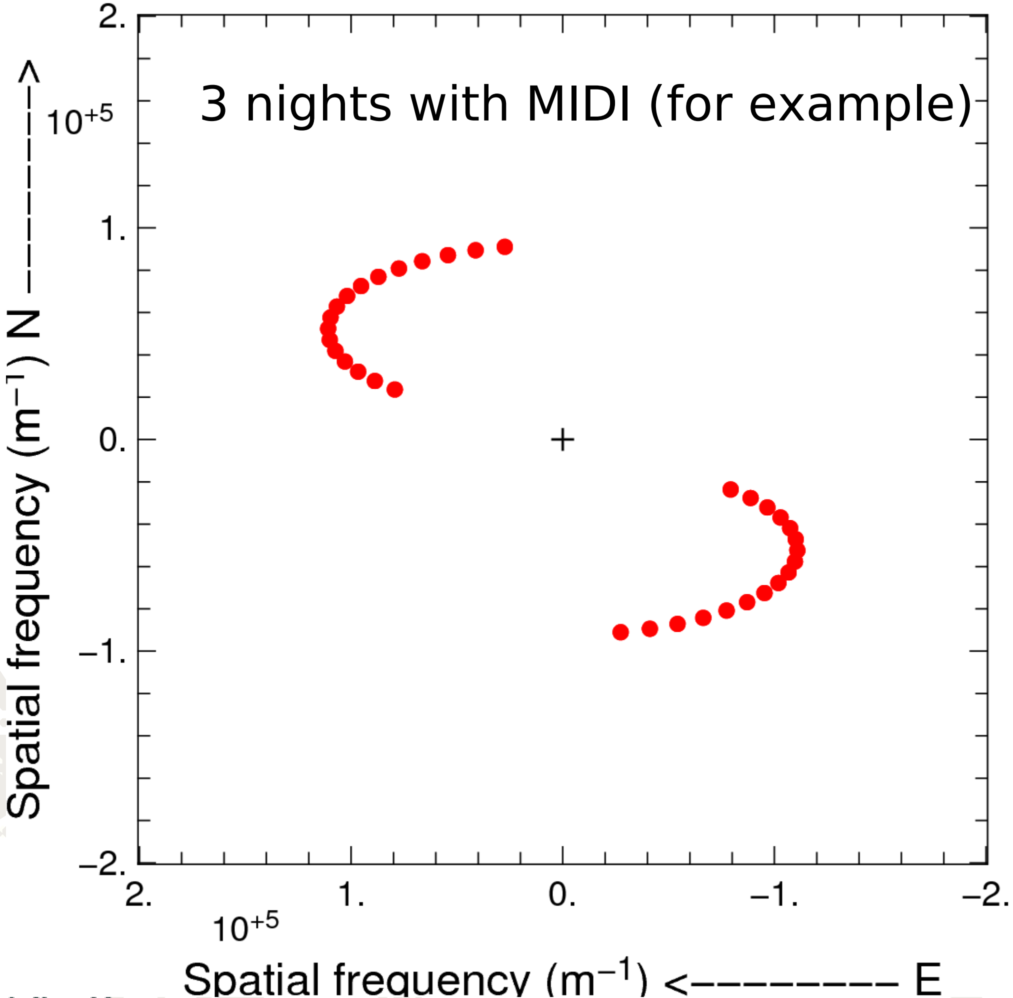
Supersynthesis (2T)



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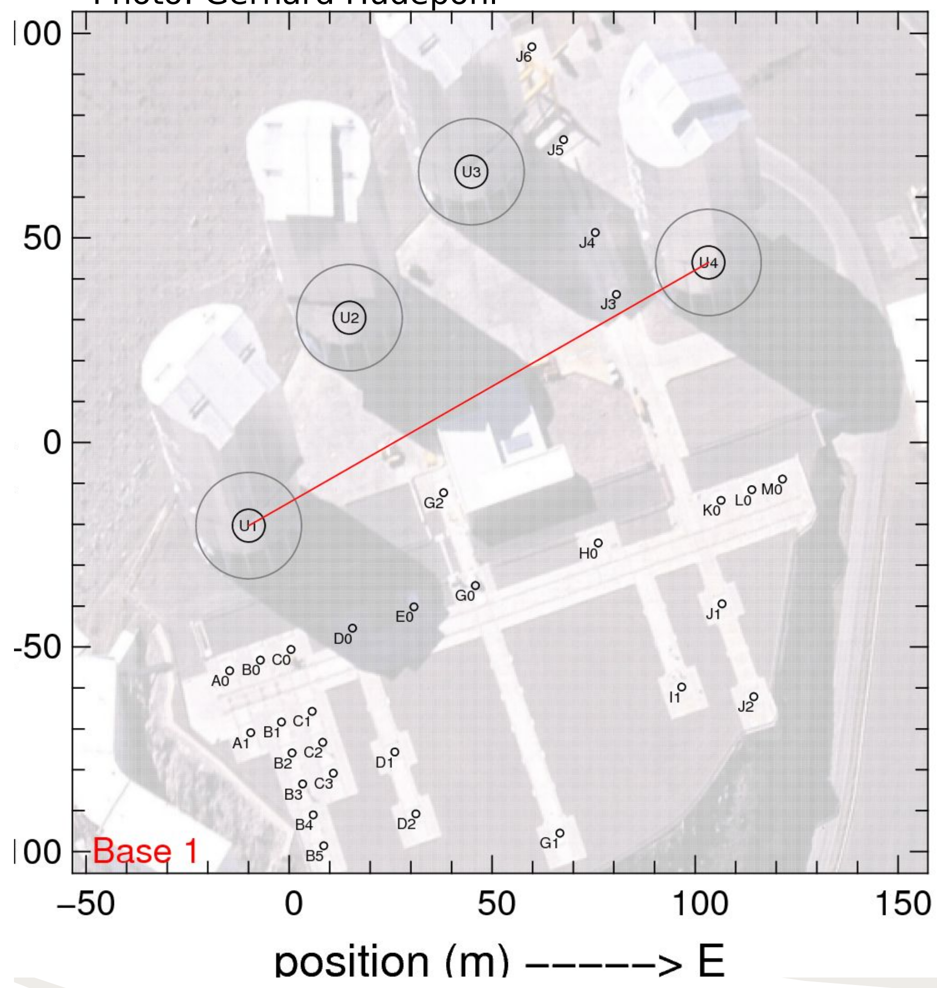

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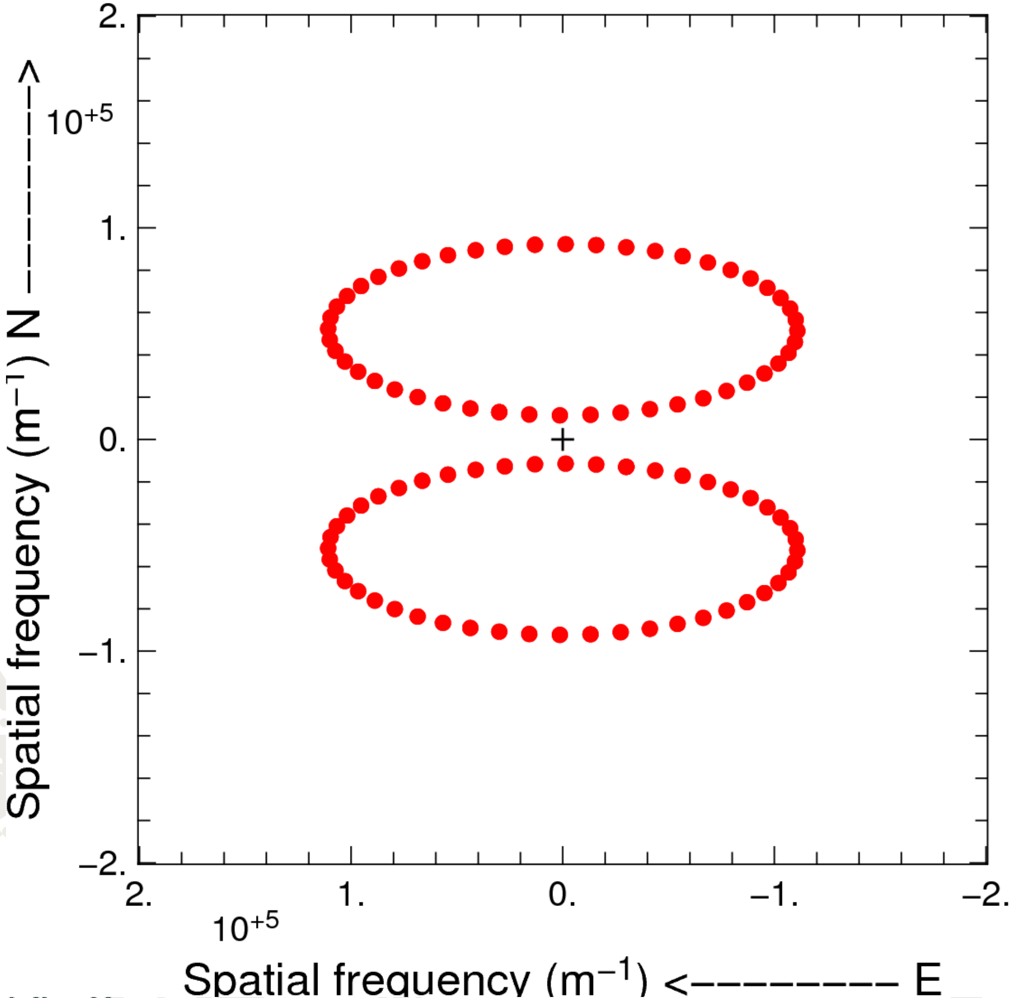
Supersynthesis (2T)



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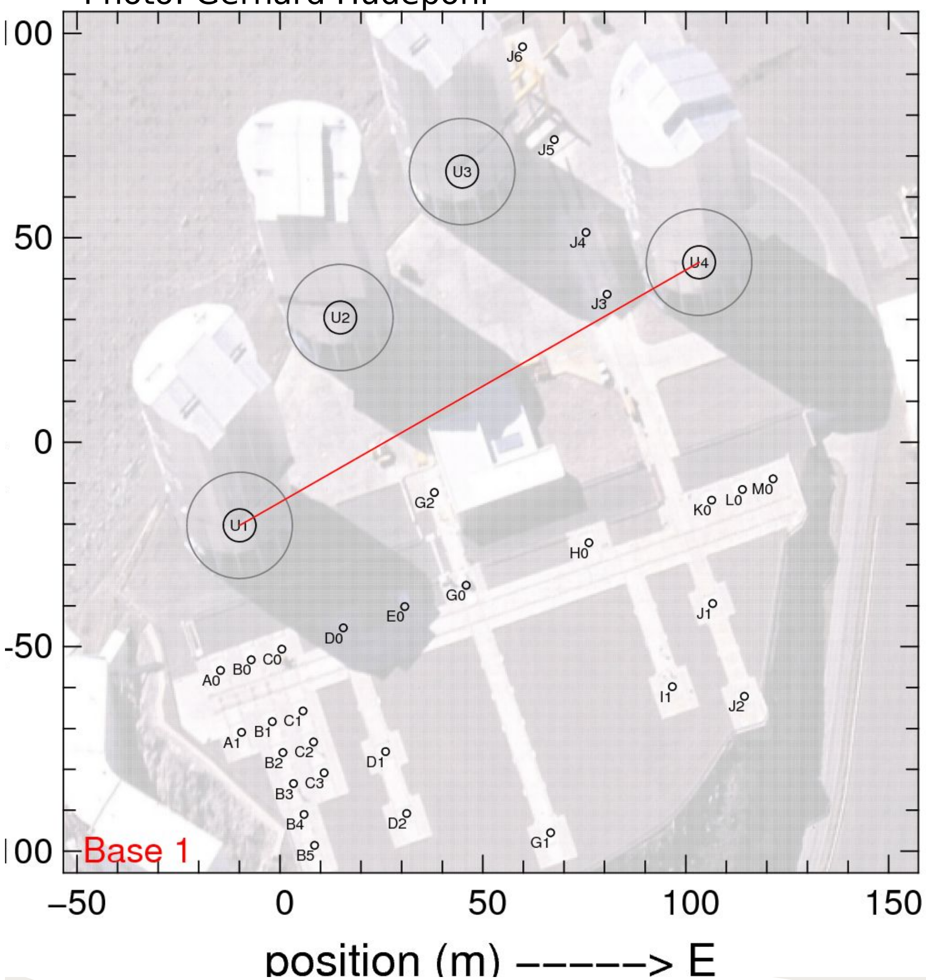

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Supersynthesis (3T)

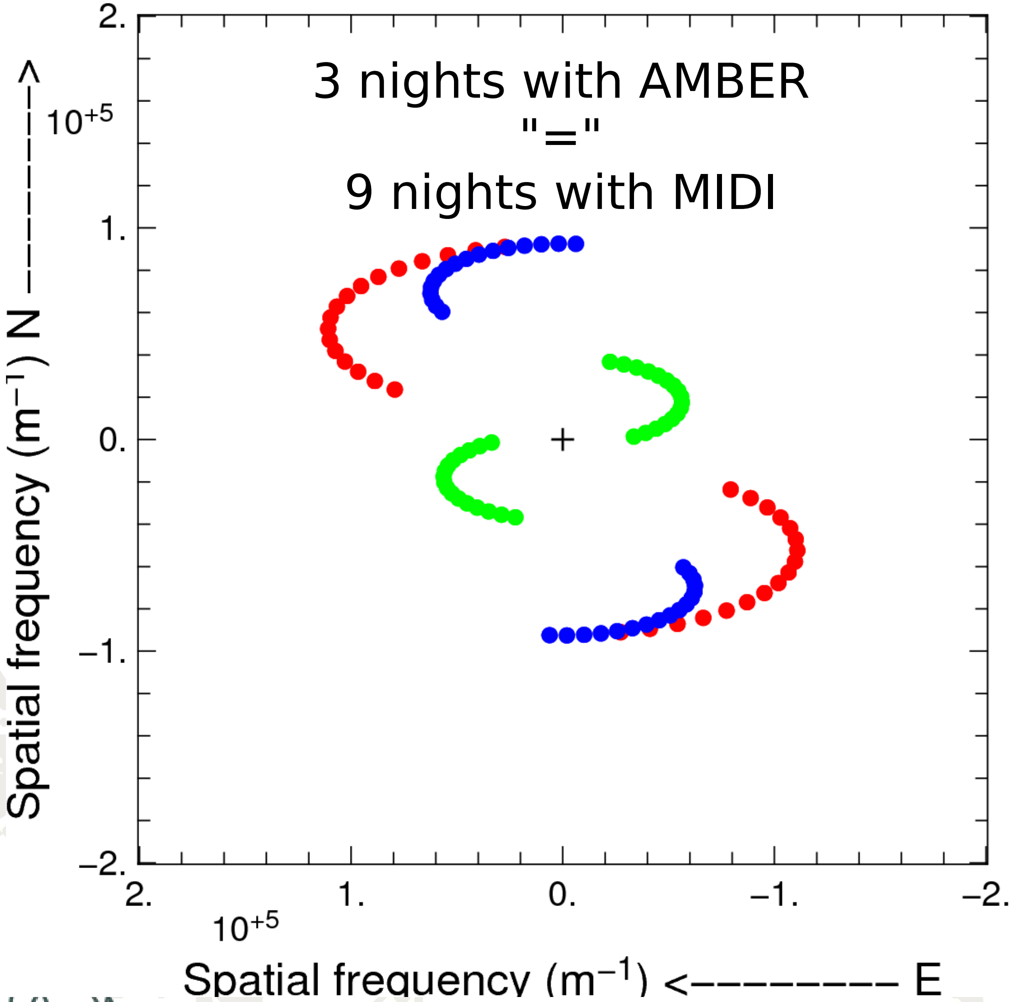
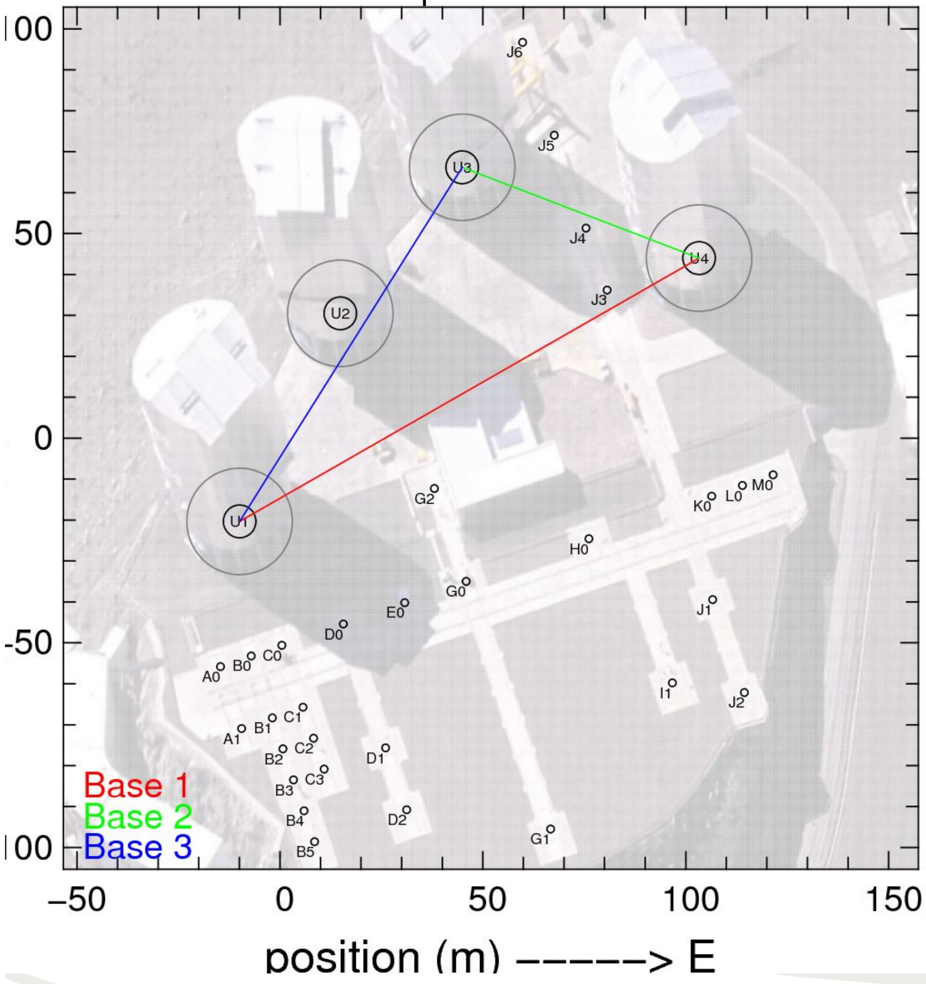


Photo: Gerhard Hüdepohl



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Supersynthesis (4T)

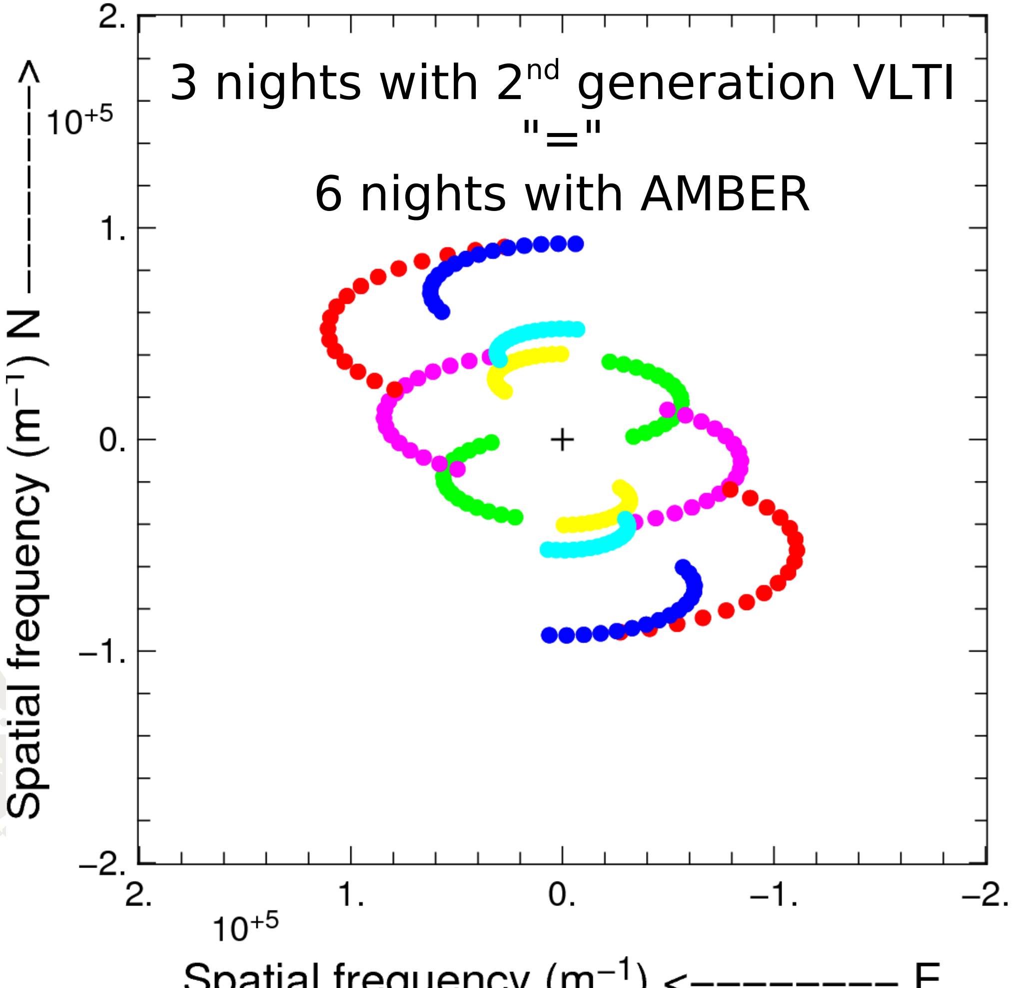
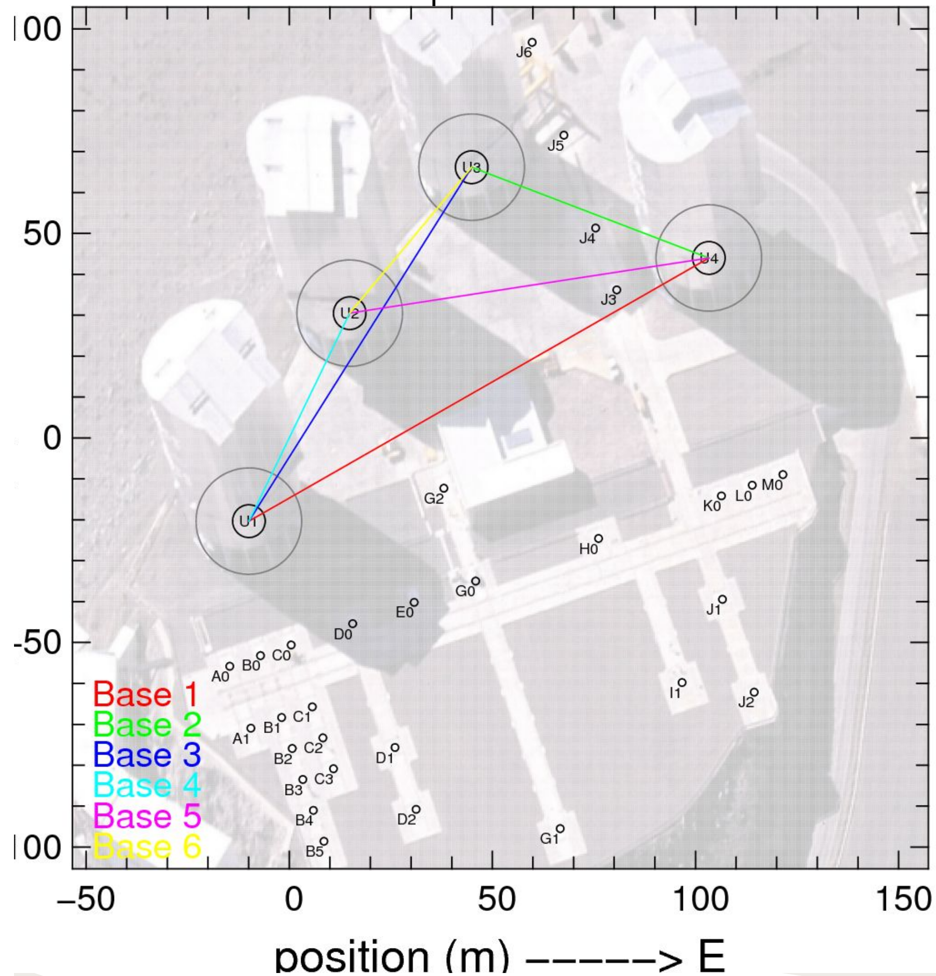
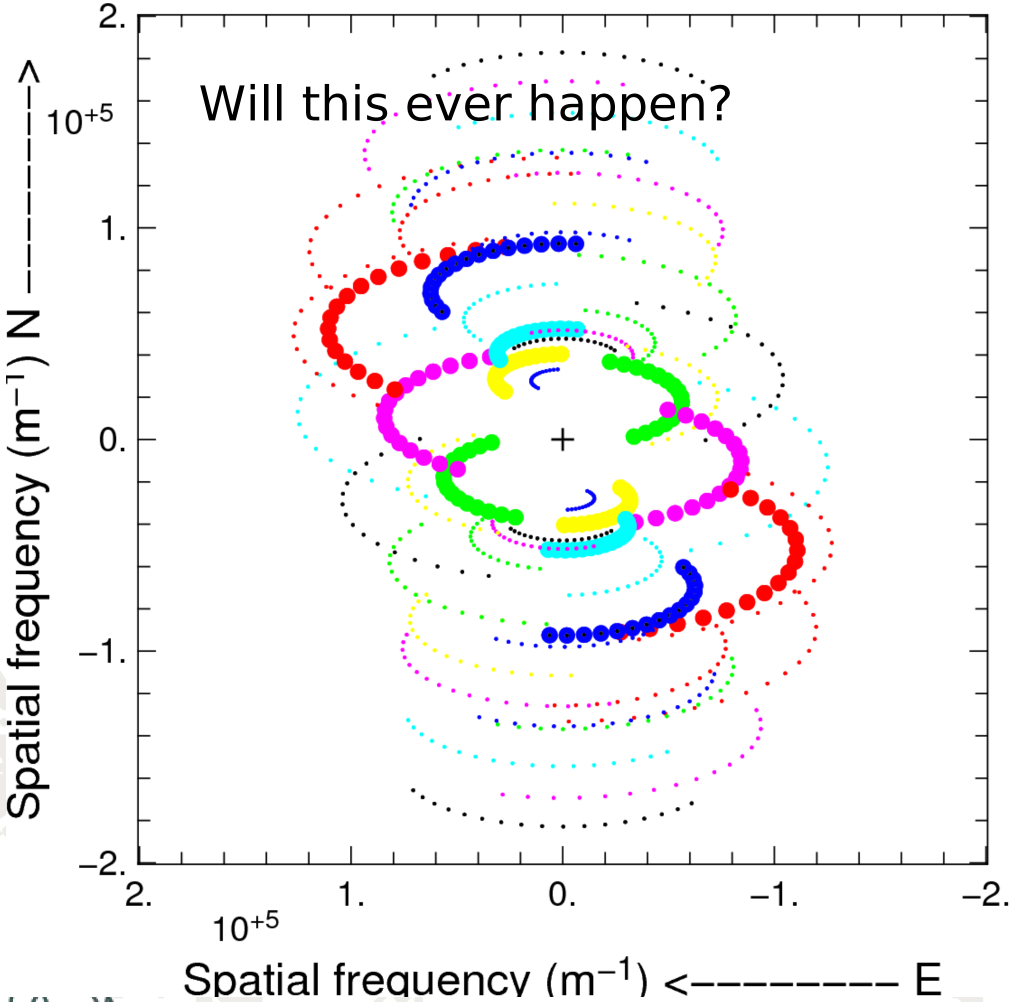
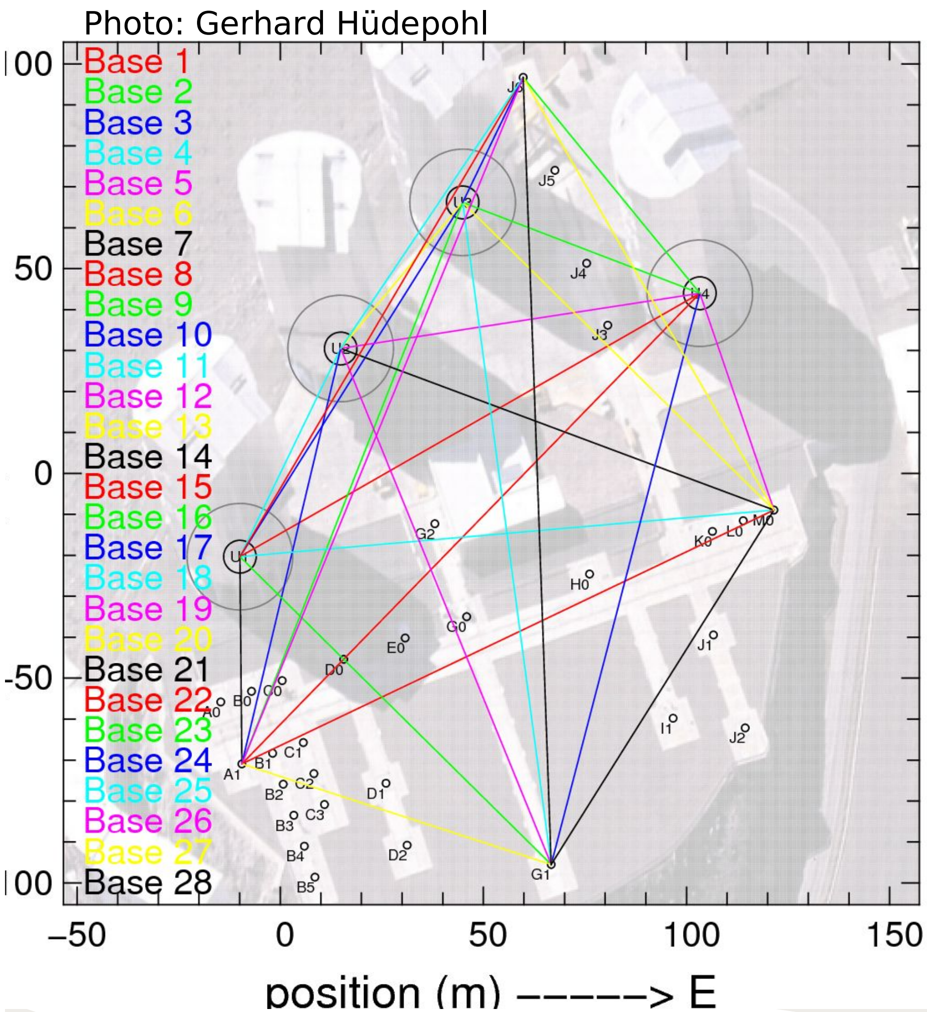


Photo: Gerhard Hüdepohl



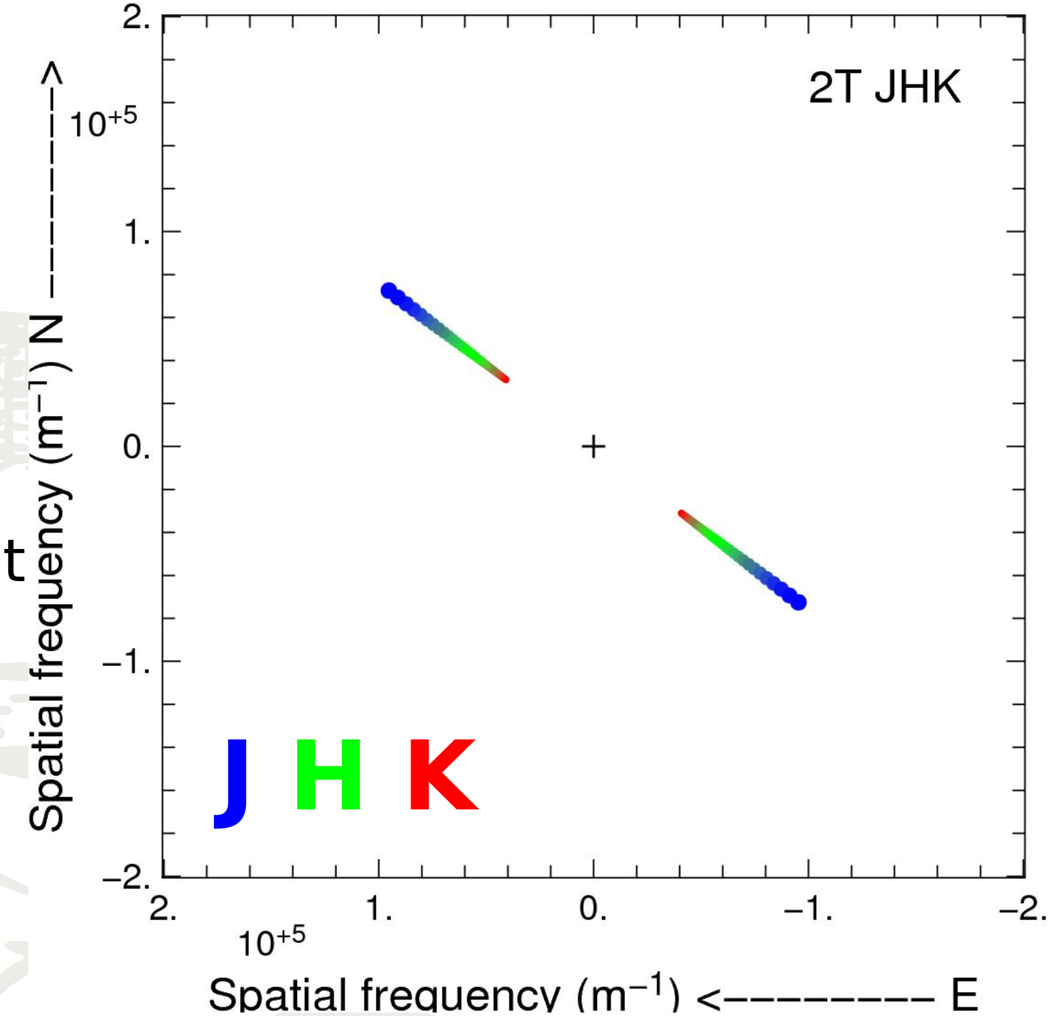
Supersynthesis (8T)





(u,v) plane filling with spectral coverage

- 2T



- **Spatial frequencies:**

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

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

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Supersynthesis + spectral coverage (2T)

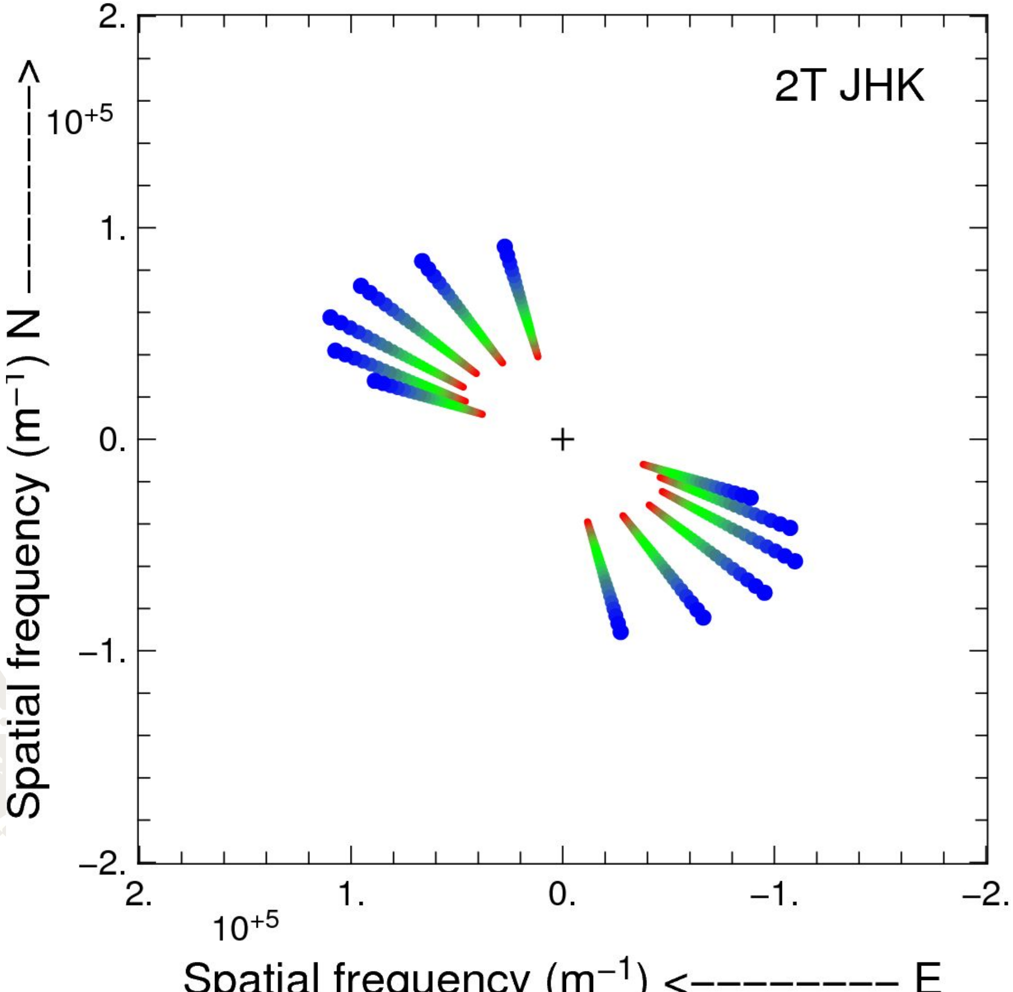
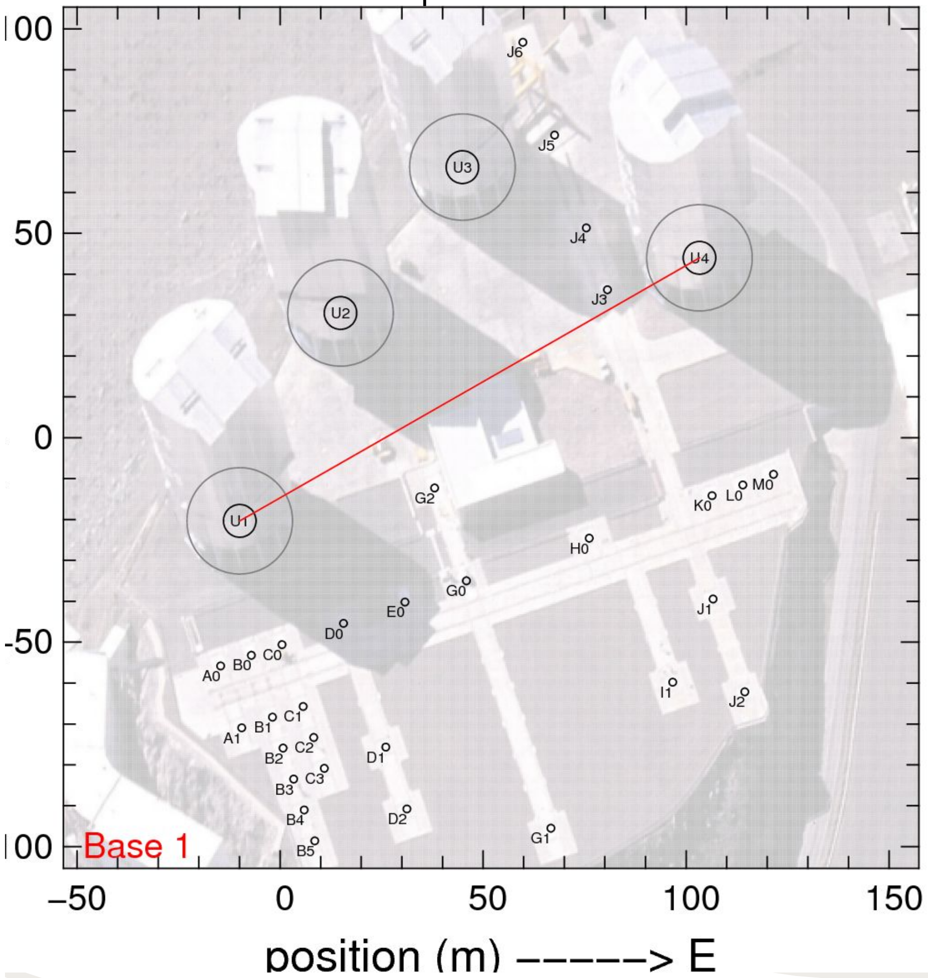
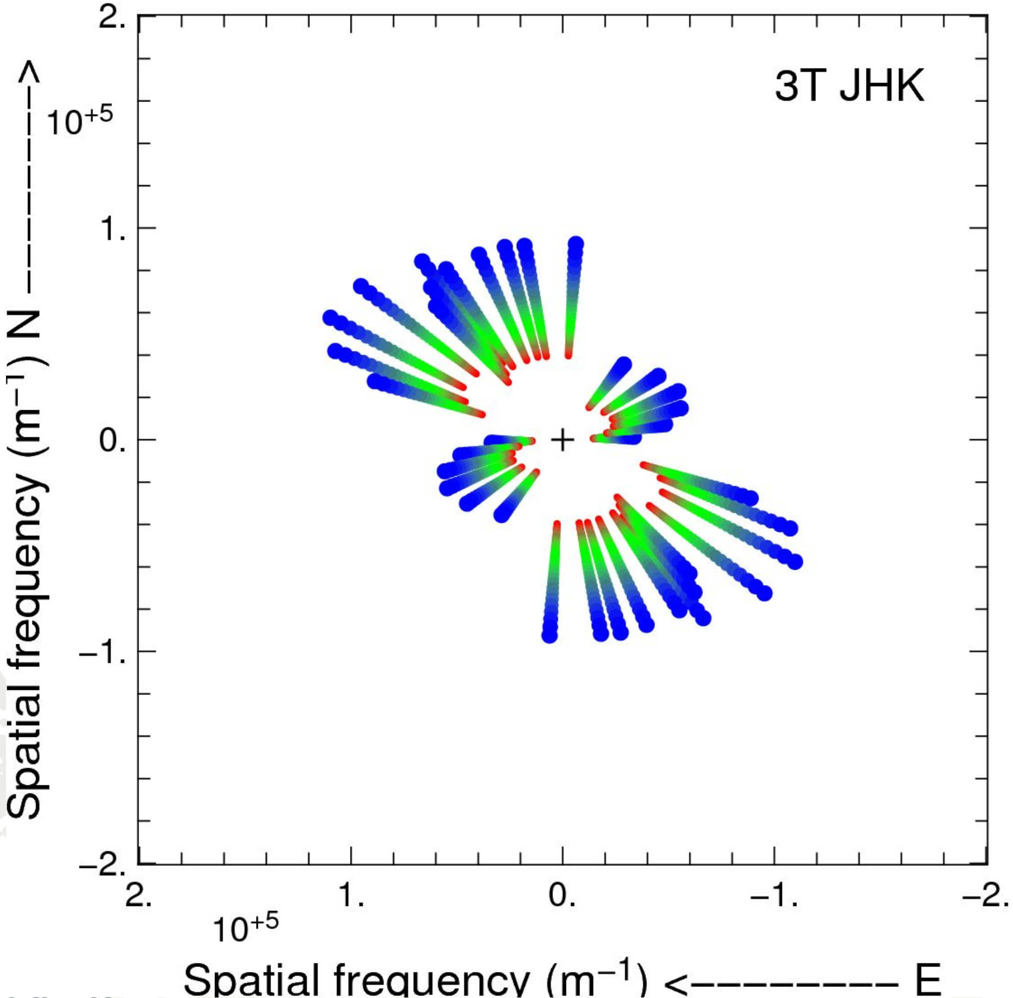


Photo: Gerhard Hüdepohl



Supersynthesis
+ spectral coverage (3T)



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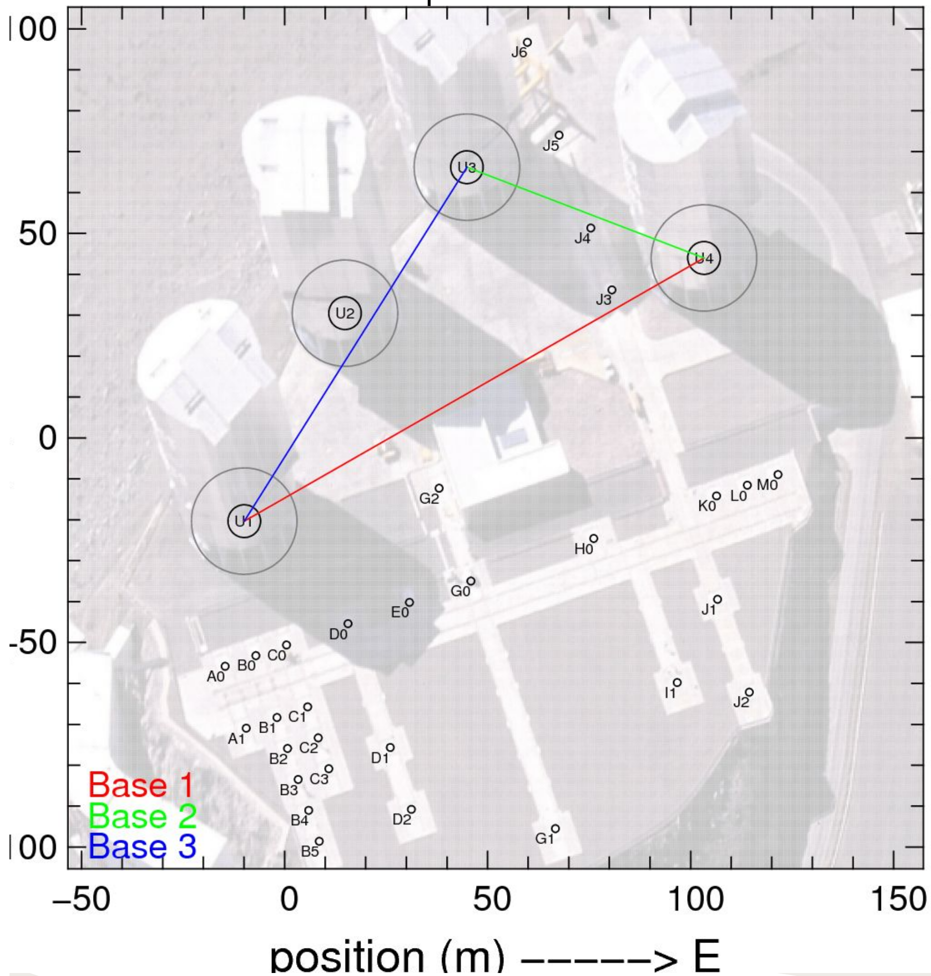

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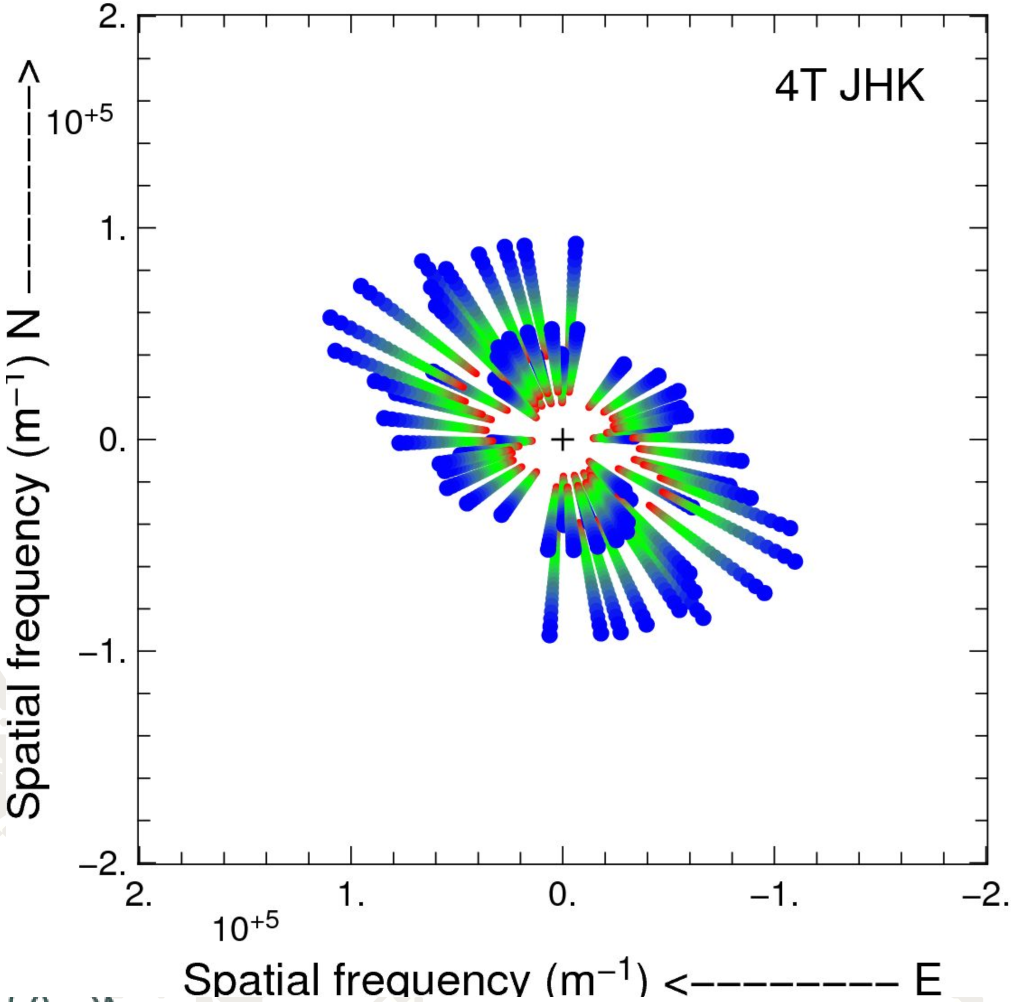
Supersynthesis + spectral coverage (4T)



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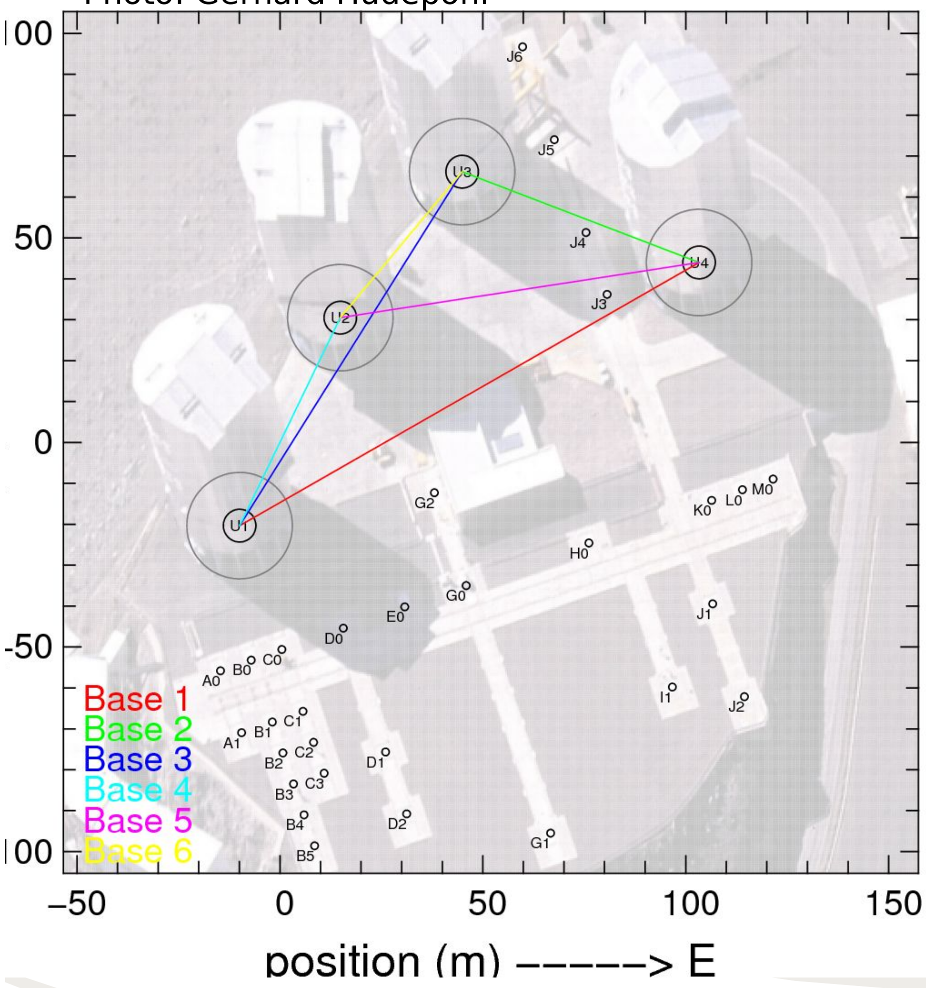
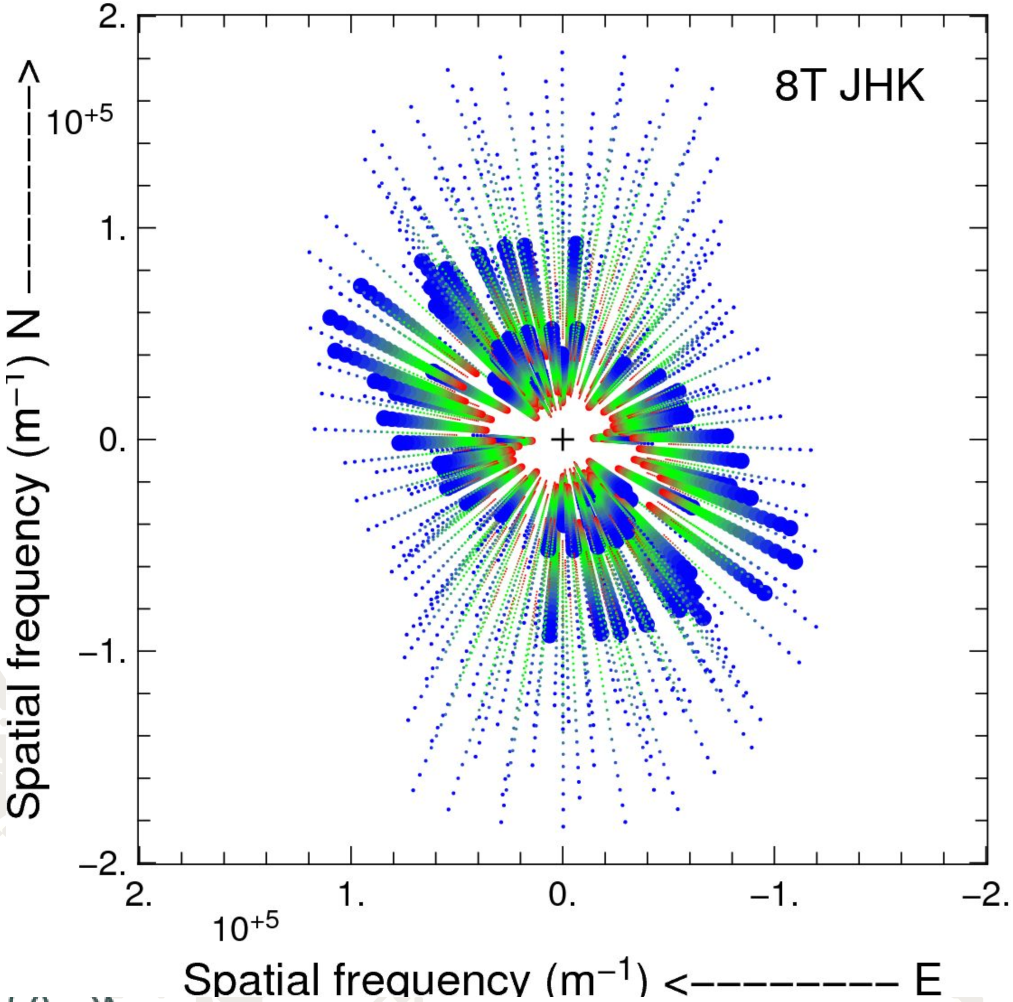


Supersynthesis + spectral coverage (8T)



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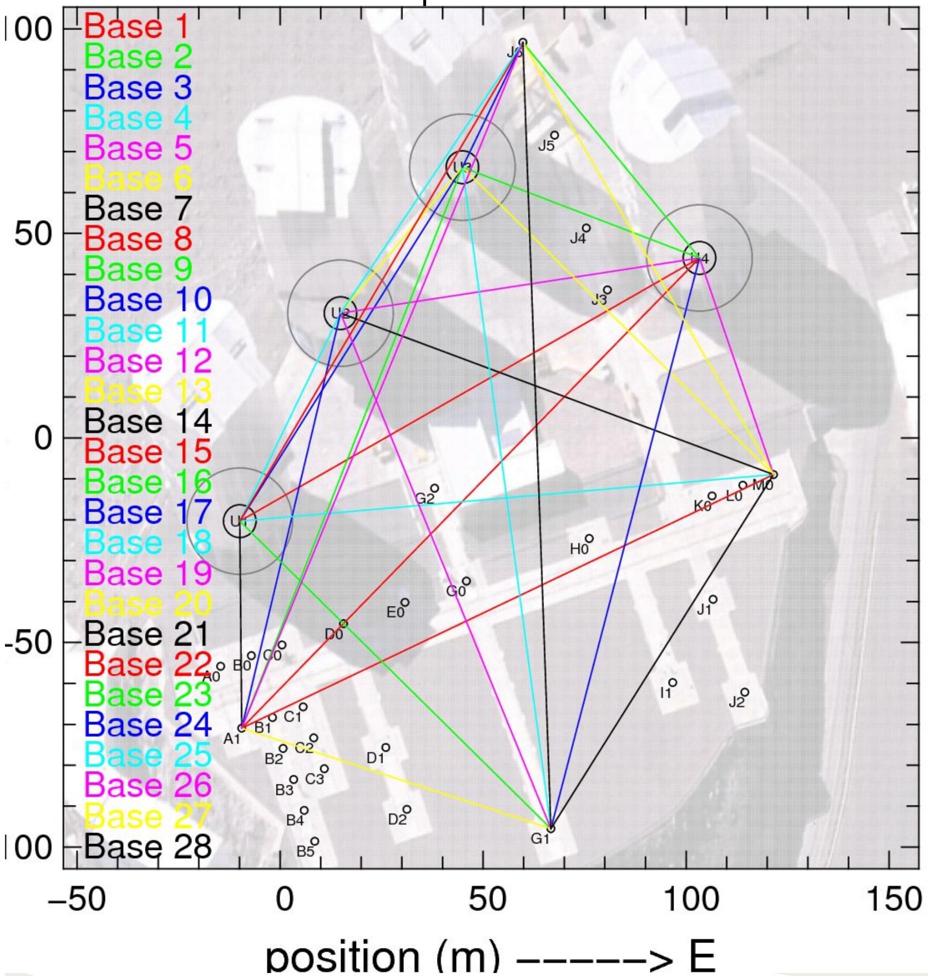

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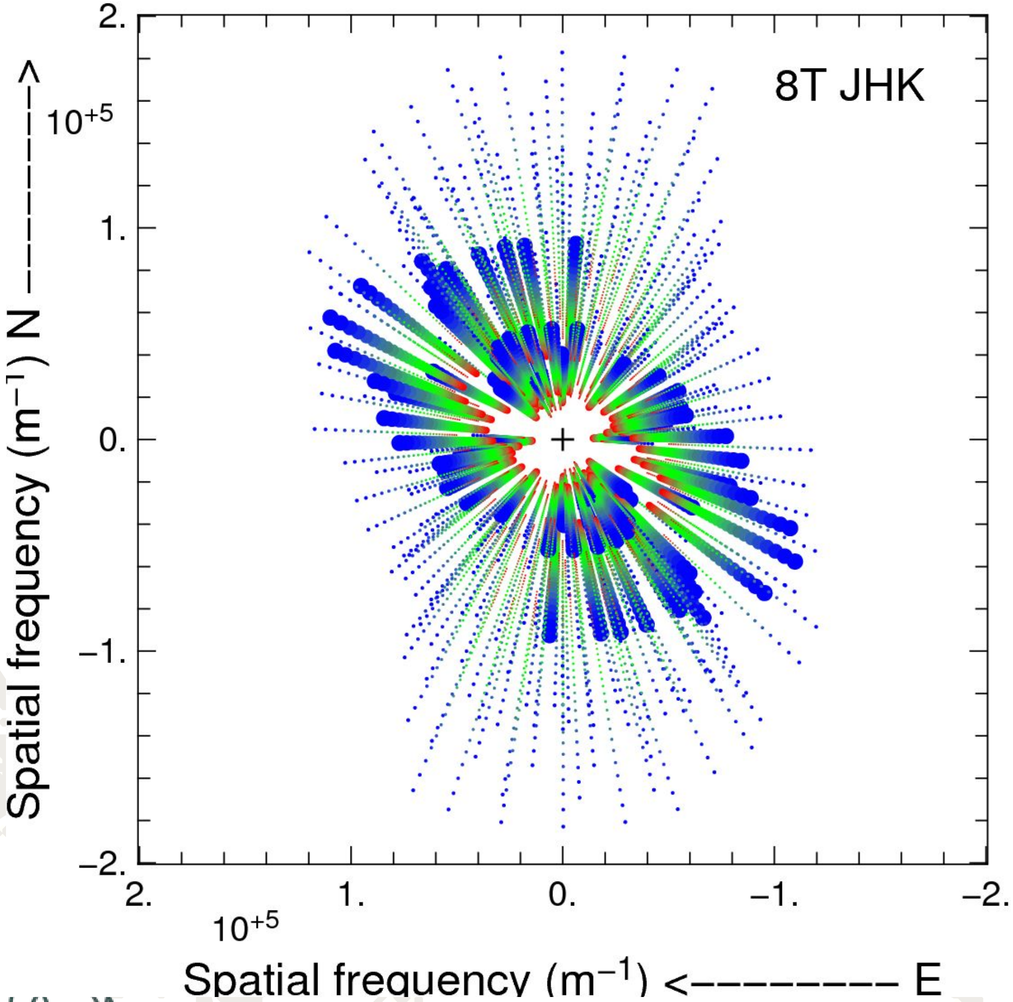
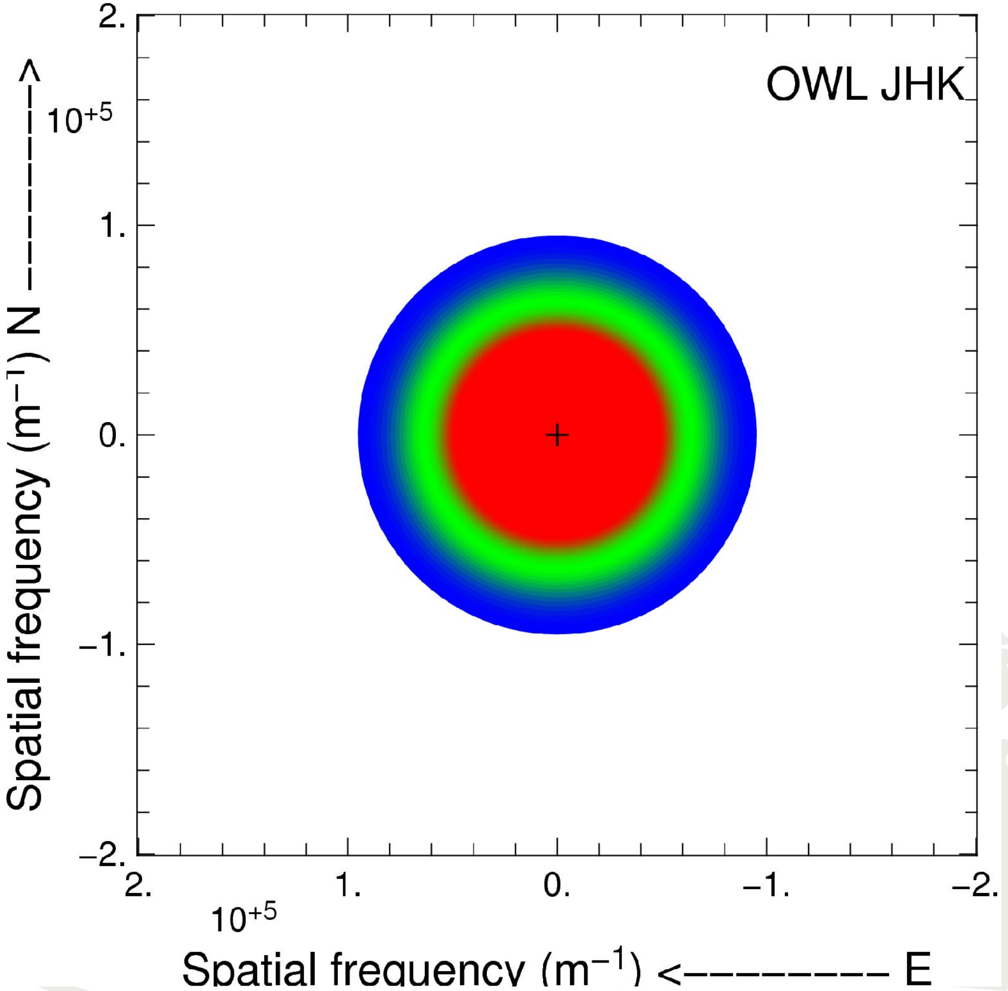
Supersynthesis + spectral coverage (8T)





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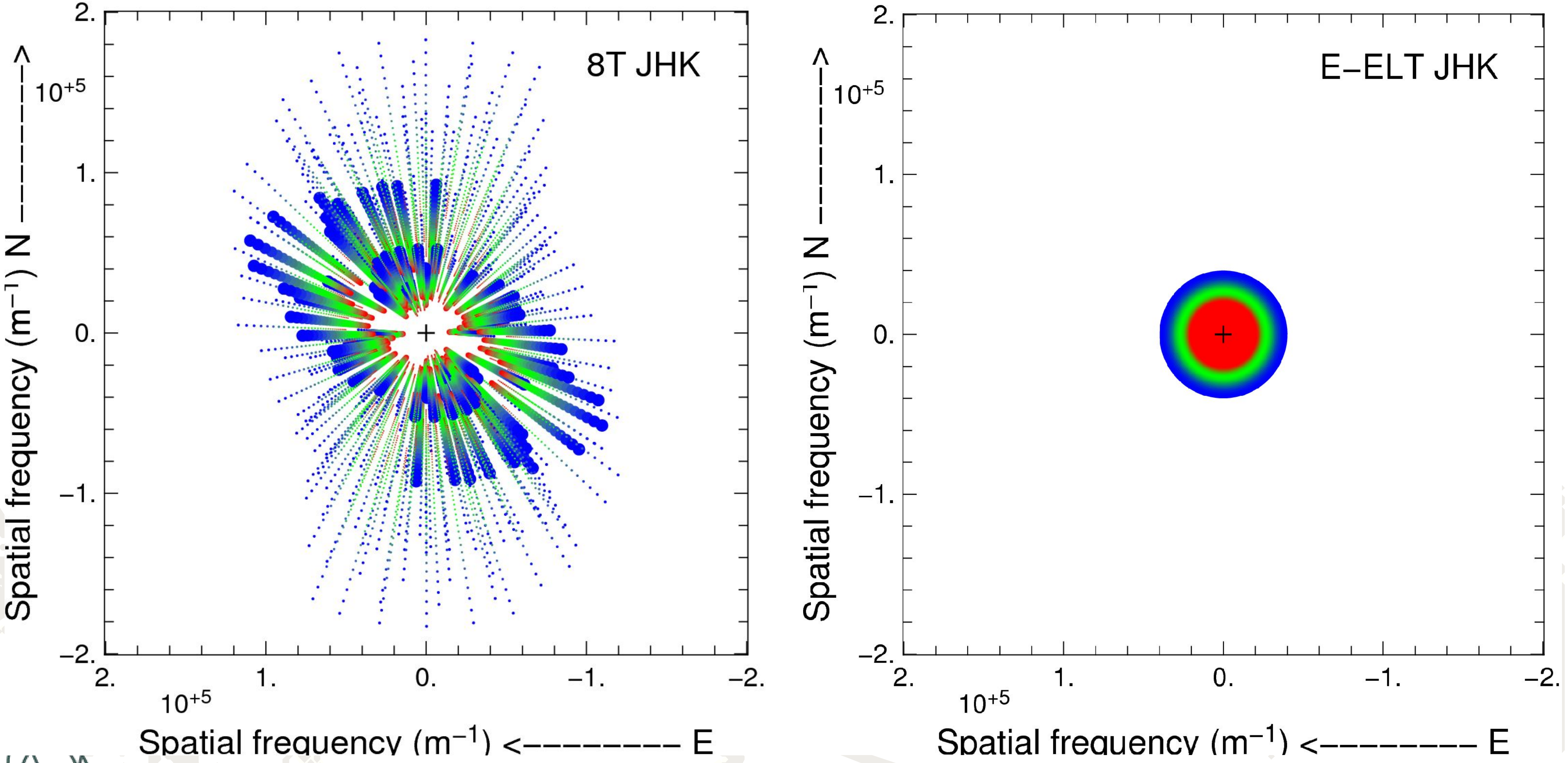
Supersynthesis + spectral coverage (8T)



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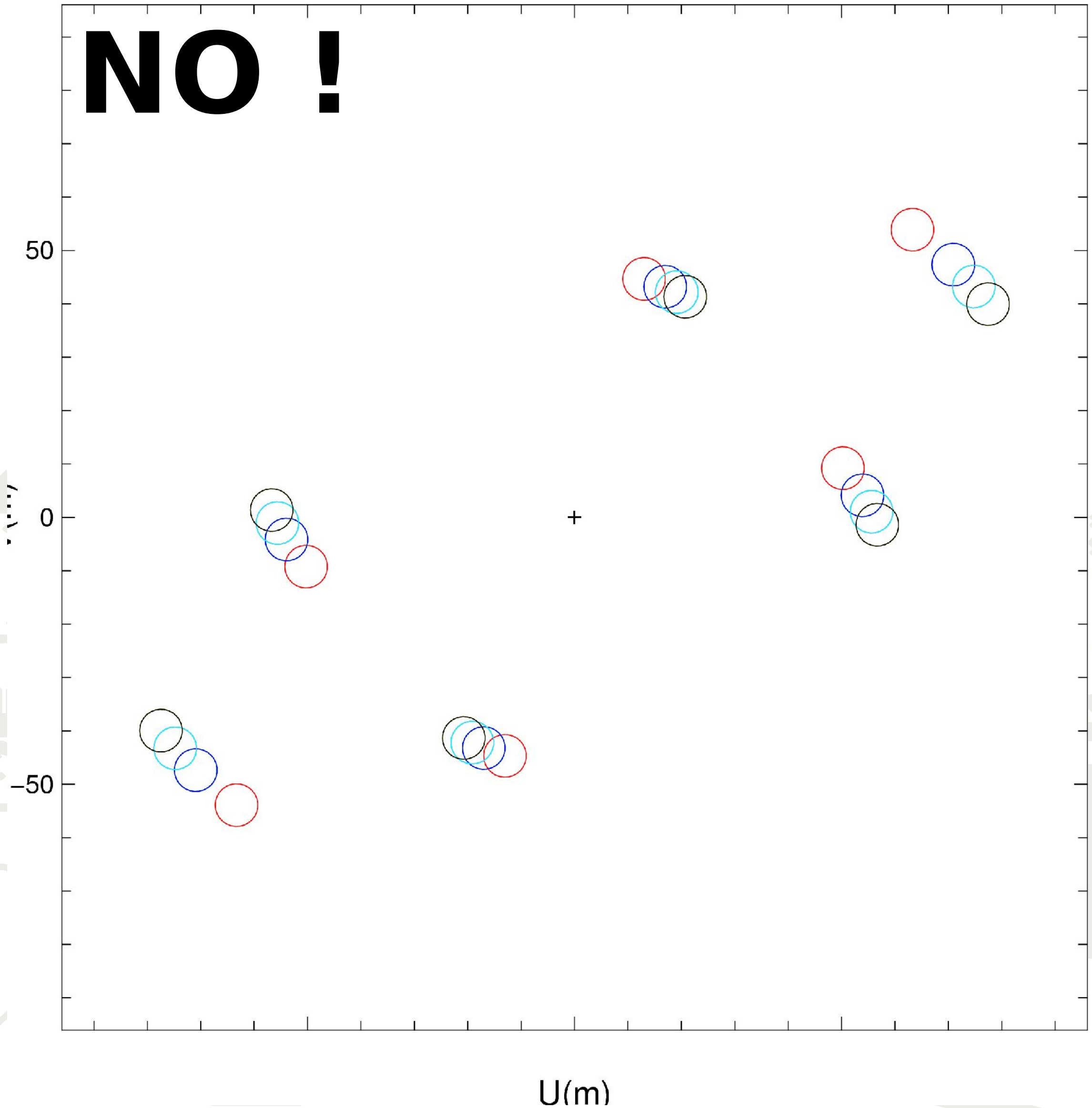
What is an appropriate UV-plane sampling?

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,
  number of telescopes,
- on **your own scientific goal.**
  simple model fitting,
  “advanced” model fitting,
  imaging,

i.e. **it depends on everything which is important for an observation**

Is your UV plane suitable for imaging ?



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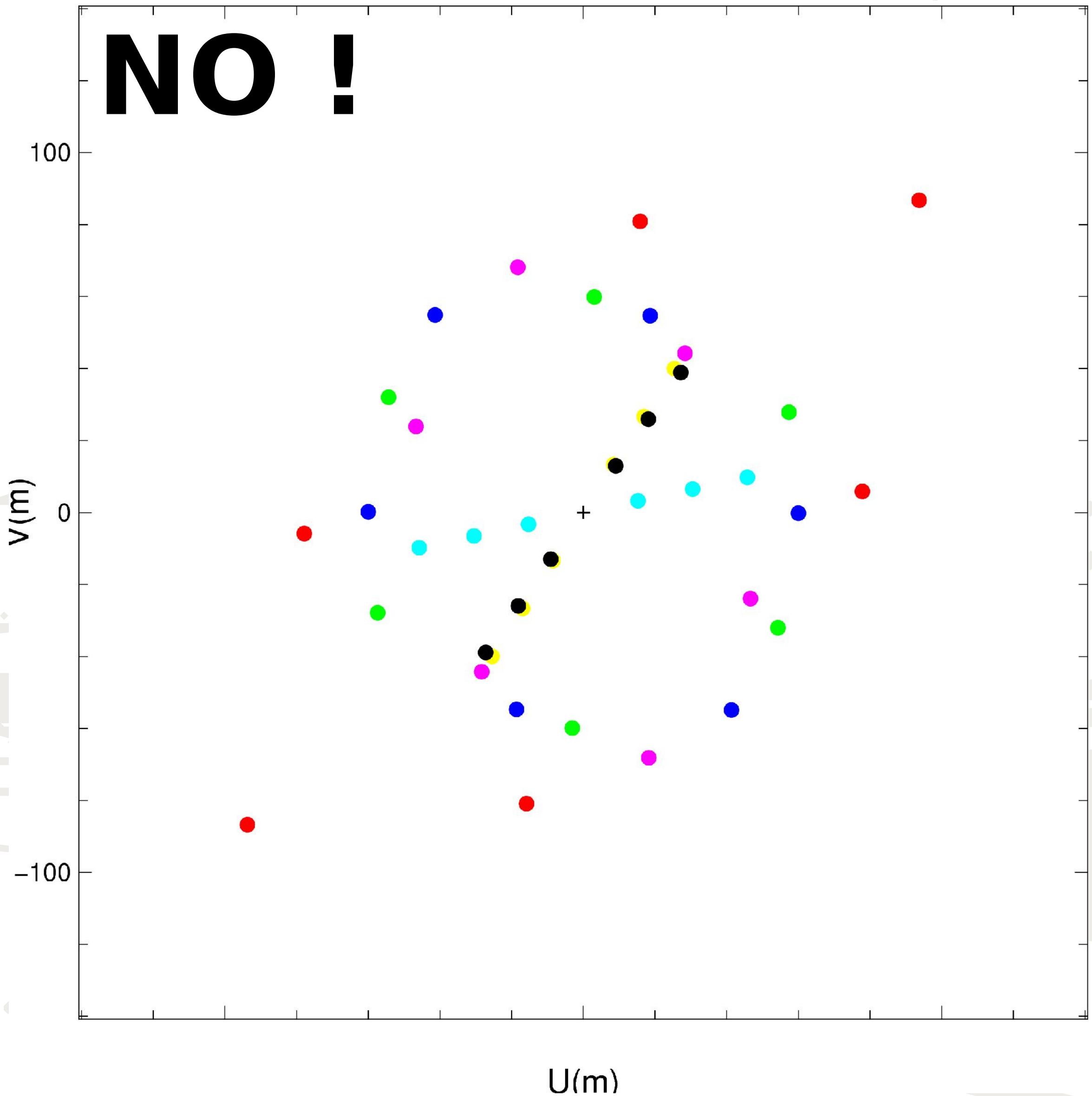

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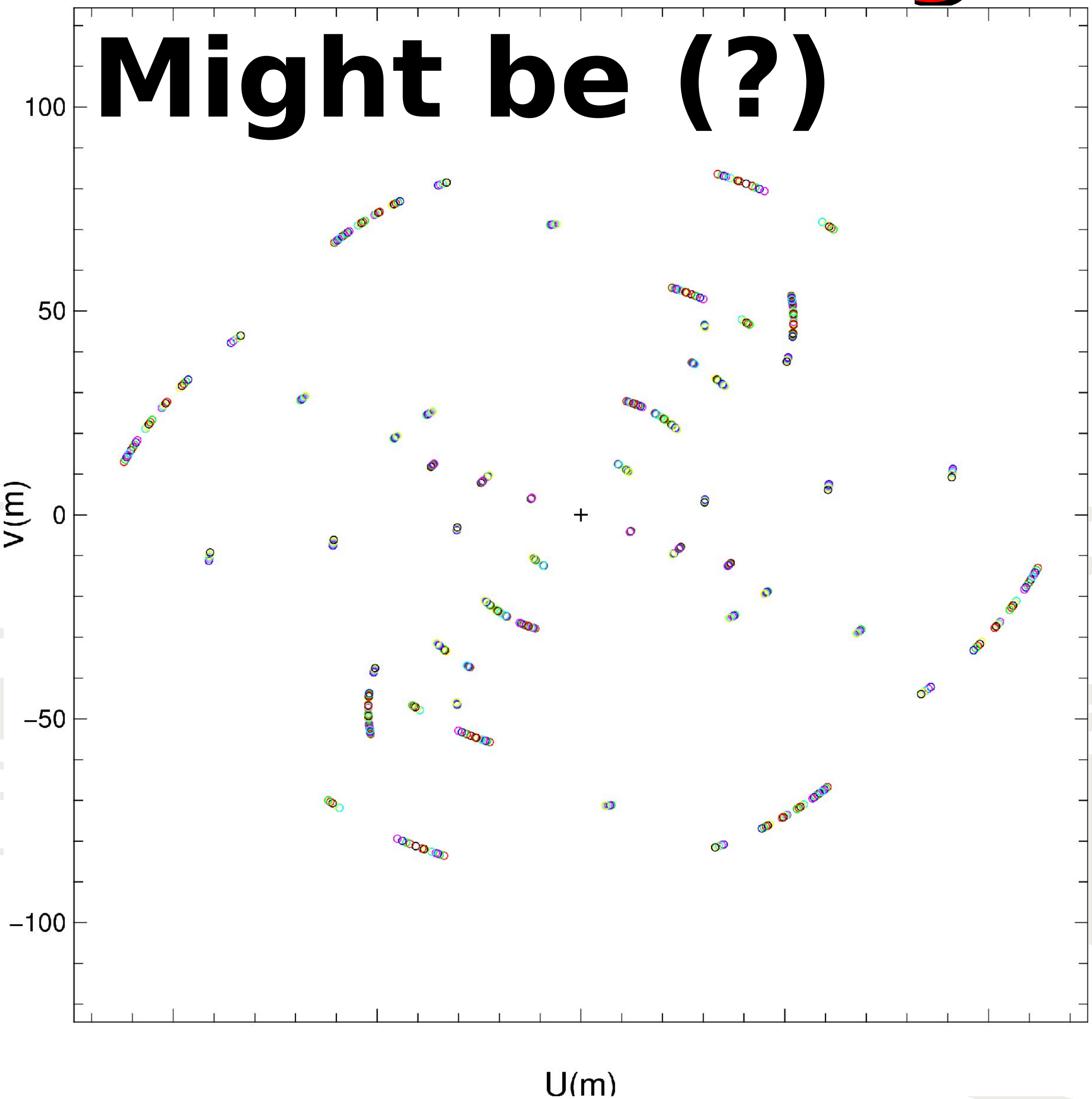
Is your UV plane suitable for imaging ?

Might be (?)



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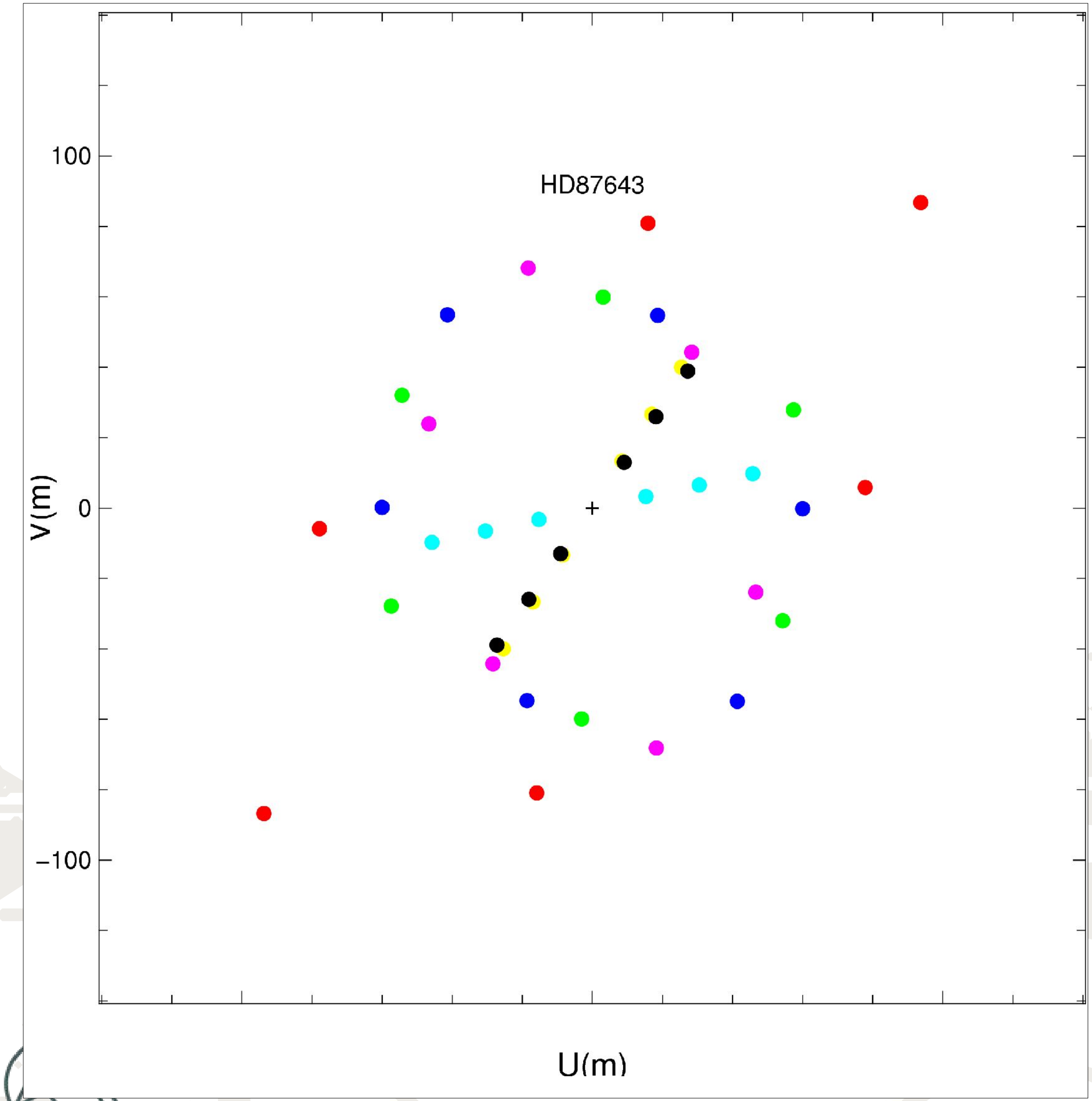
Example (1)

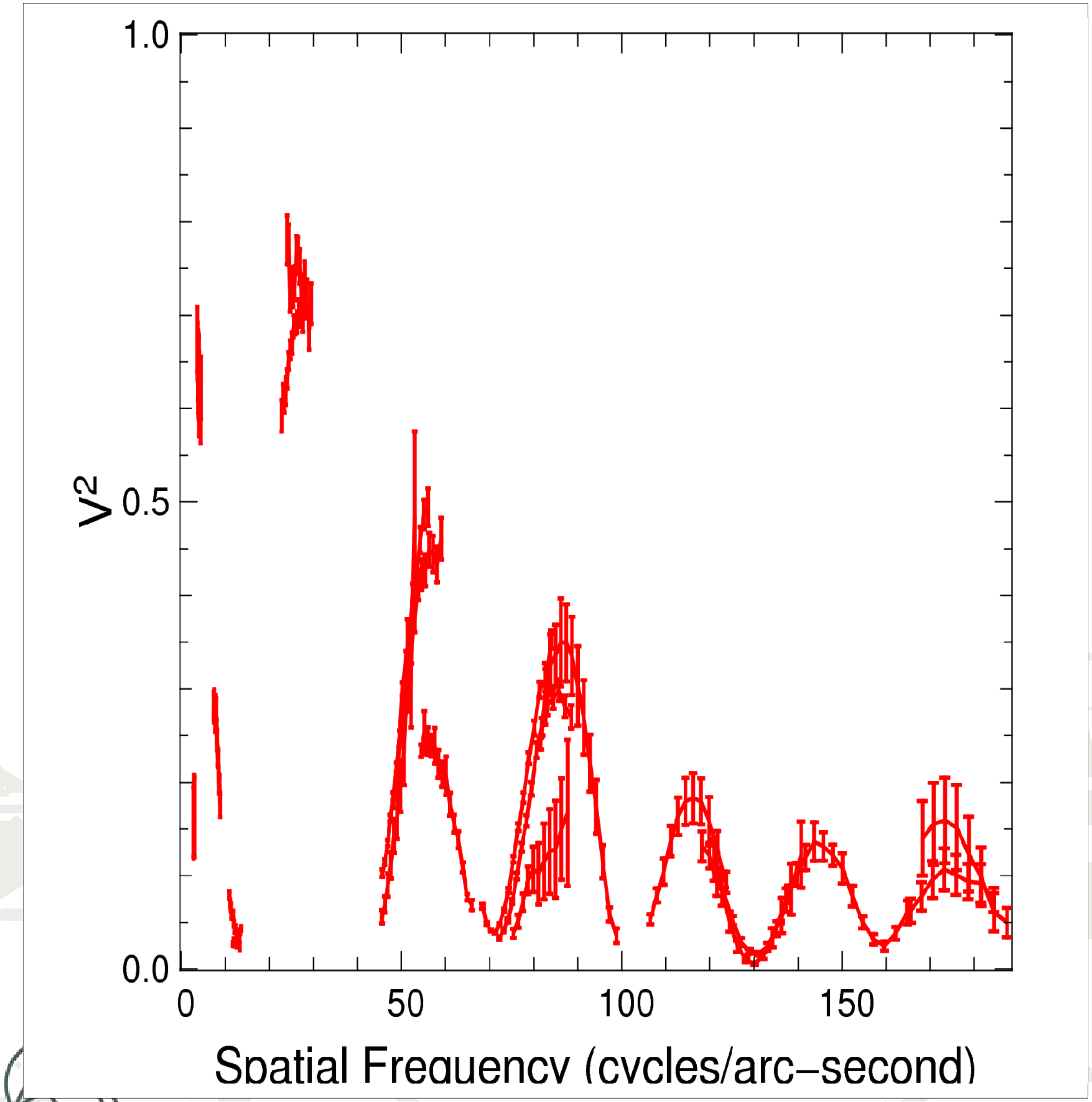


Binary star ? + Enveloppe ?

- N telescopes = 3
- accuracy on $V^2 > 1\%$
- **moderate** UV coverage (1.5 **night** !)
- use of spectral resolution to improve UV coverage

HD87643, Millour et al. in prep, 2008(9?)

Example (1)



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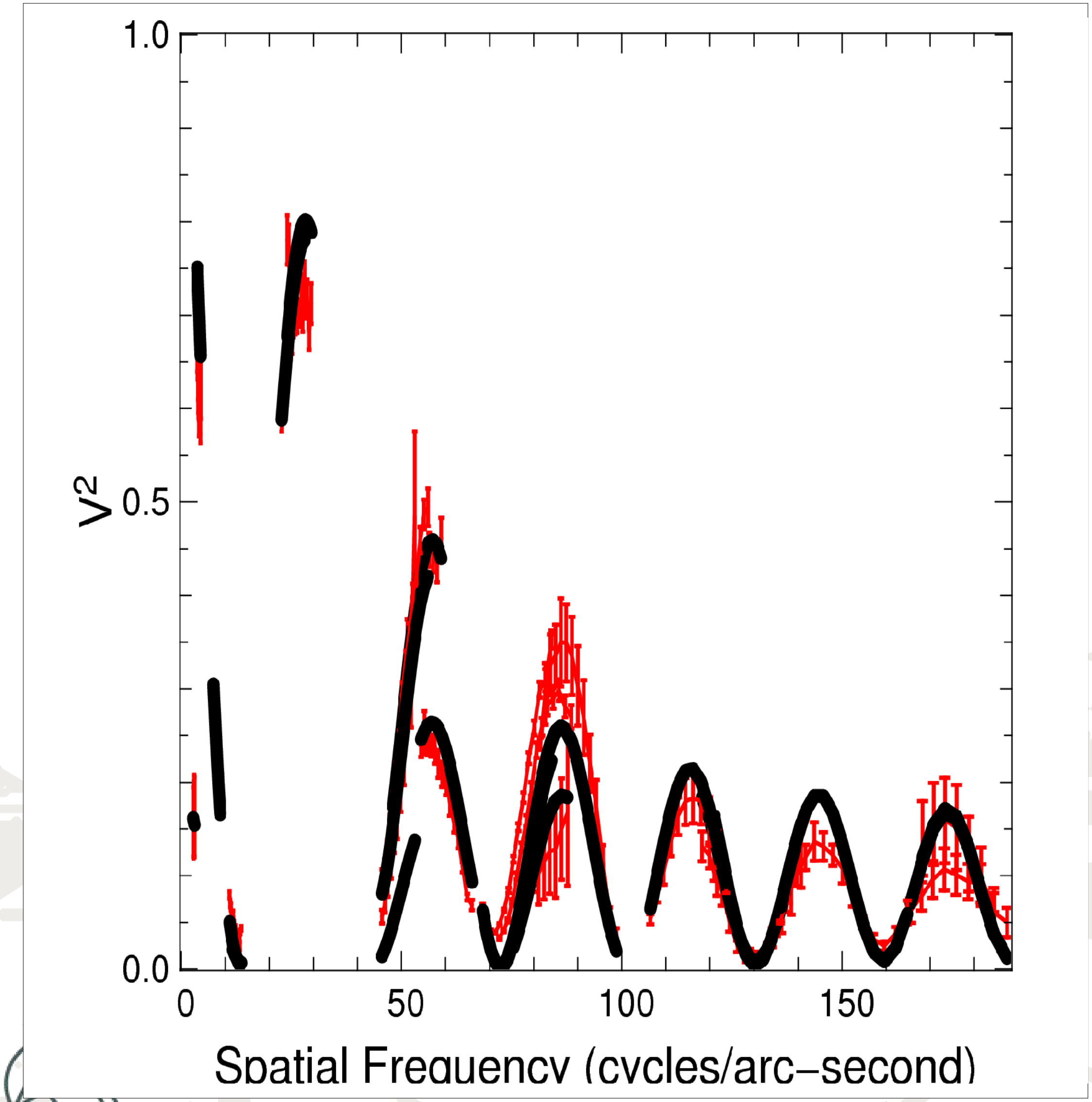

Binary star + enveloppe

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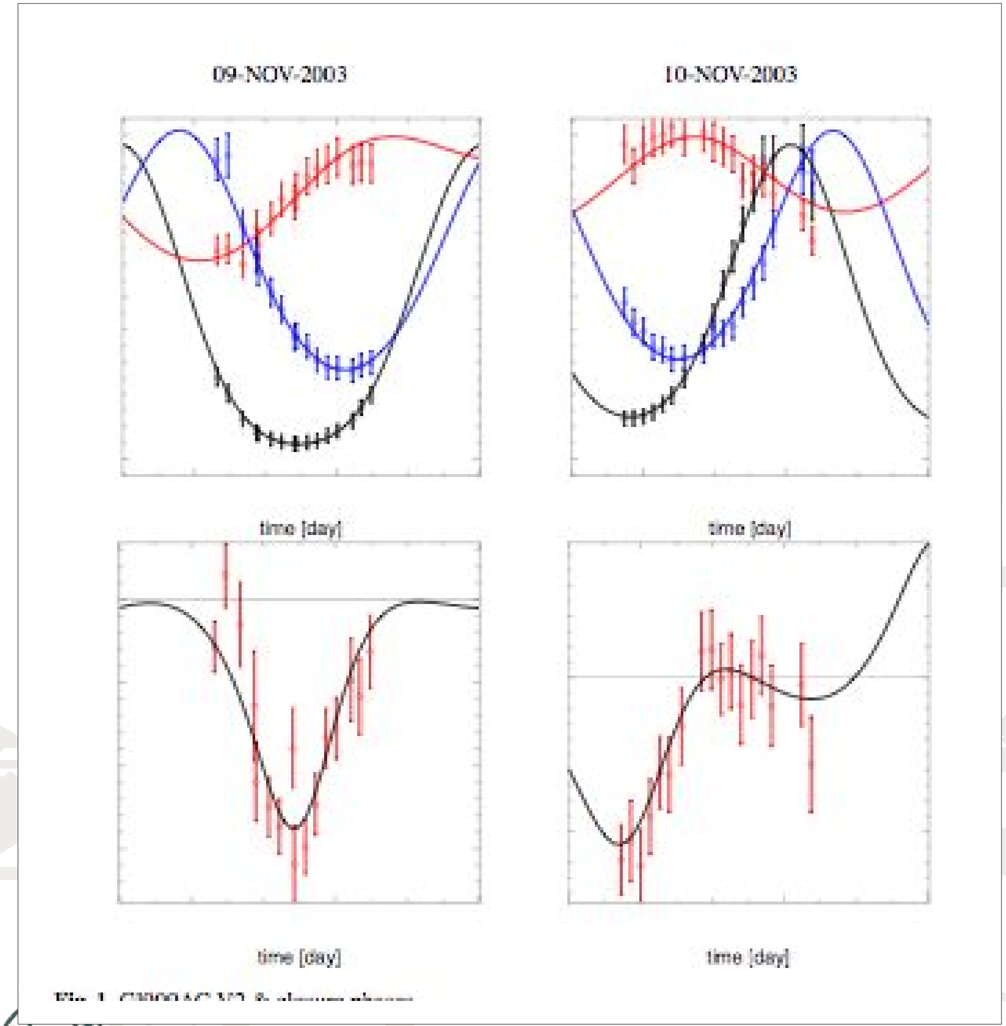
Example (2)



Binary star observation with IOTA

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

Segransan 2006 (Goutelas)

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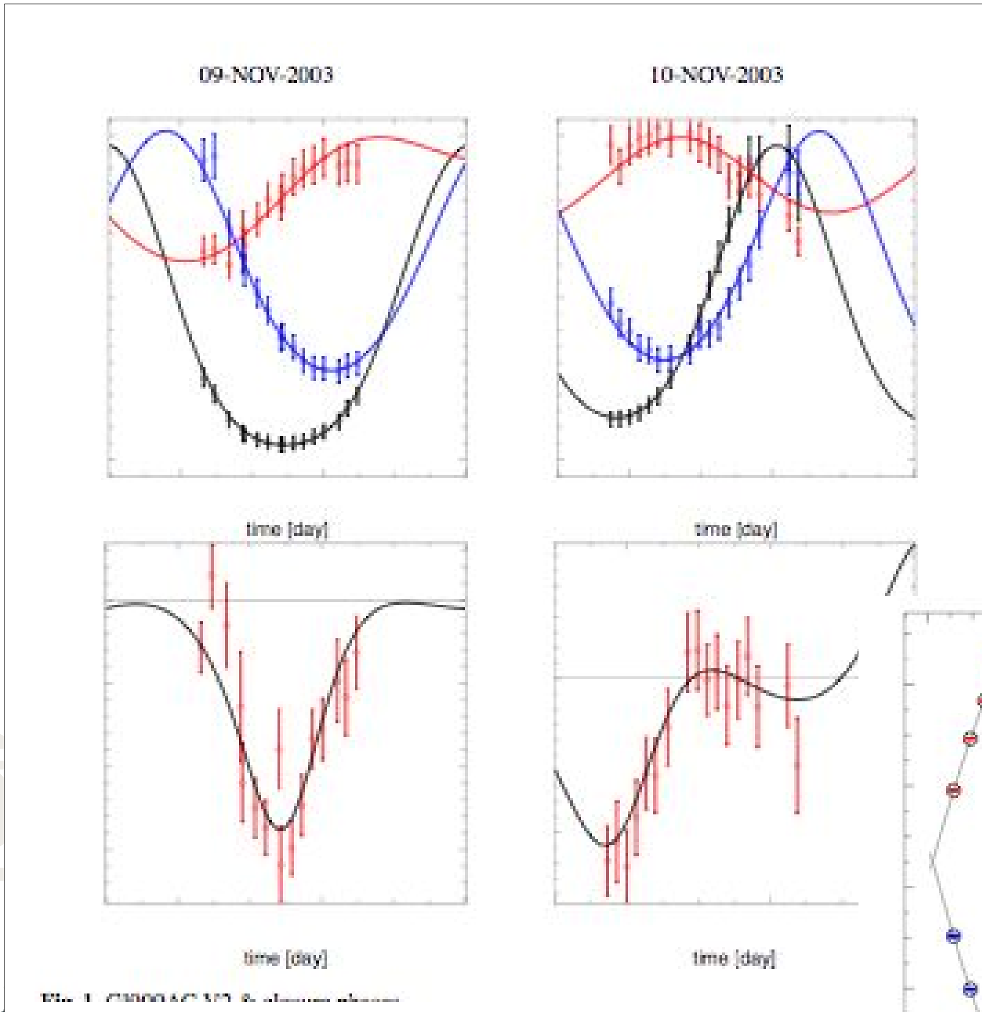
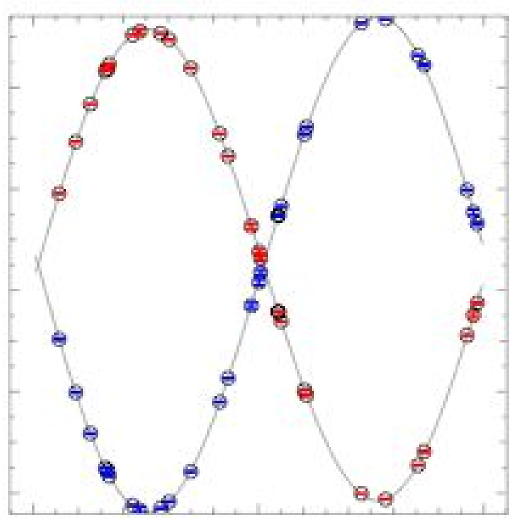
Example (2)

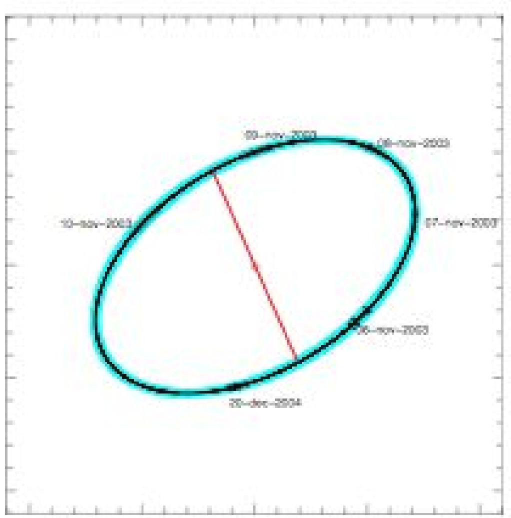


Segransan 2006 (Goutelas)

Binary star observation with IOTA

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





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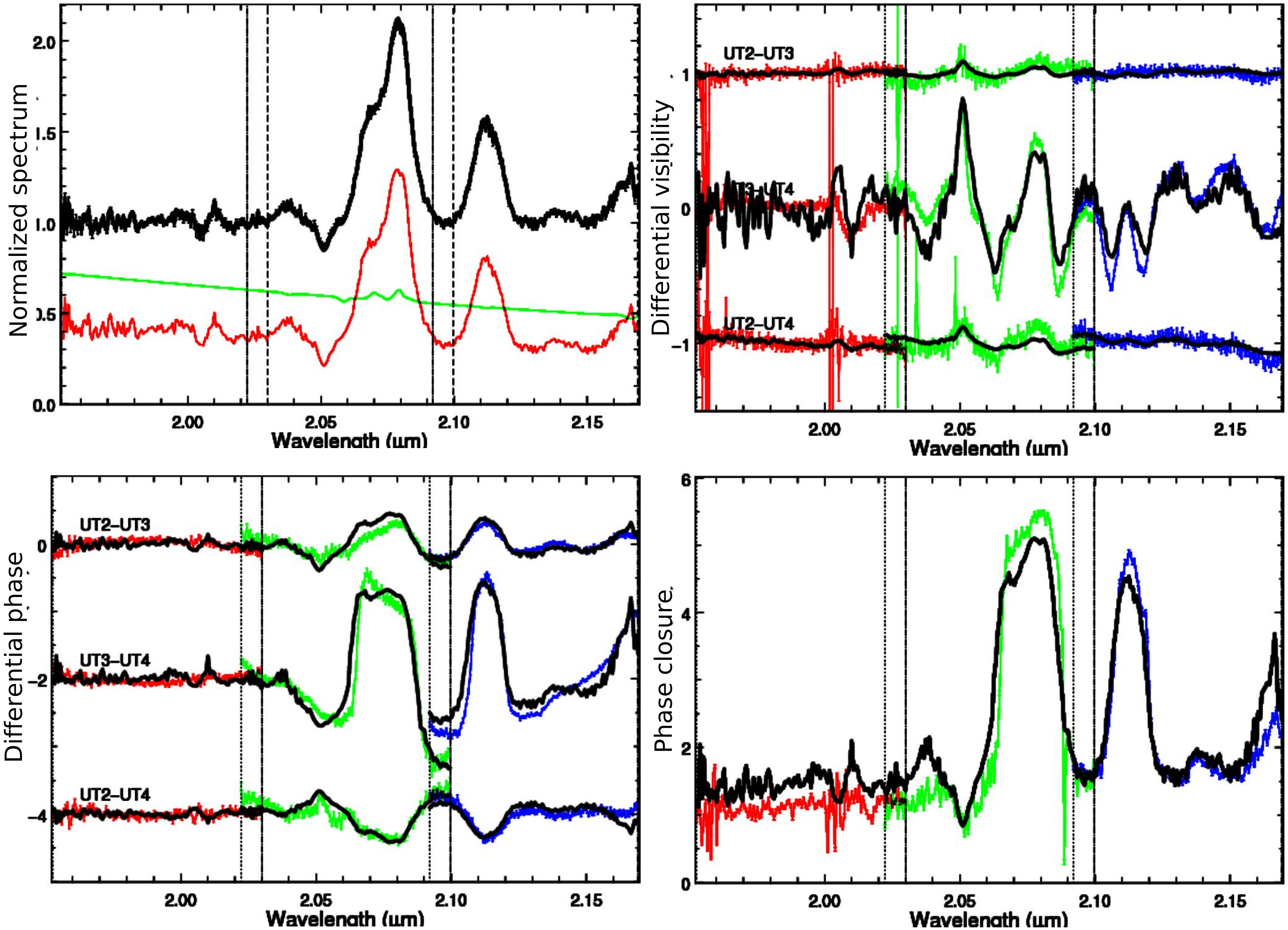
Example (3)



γ² Vel, Millour et al. 2007

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

Spectral coverage and varying flux ratio makes it working !

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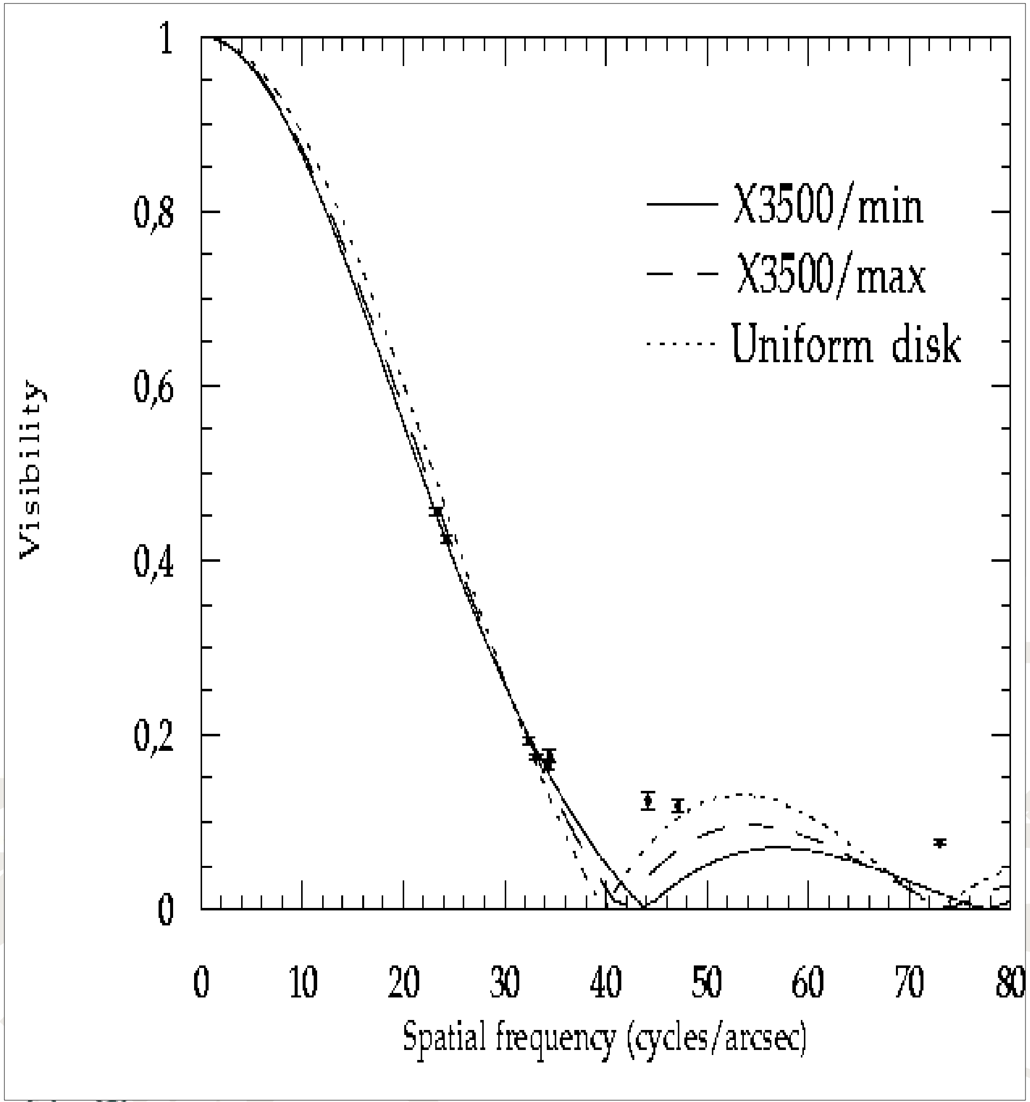
Example (4)



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

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

There is no simple answer!

This is why ASPRO was created

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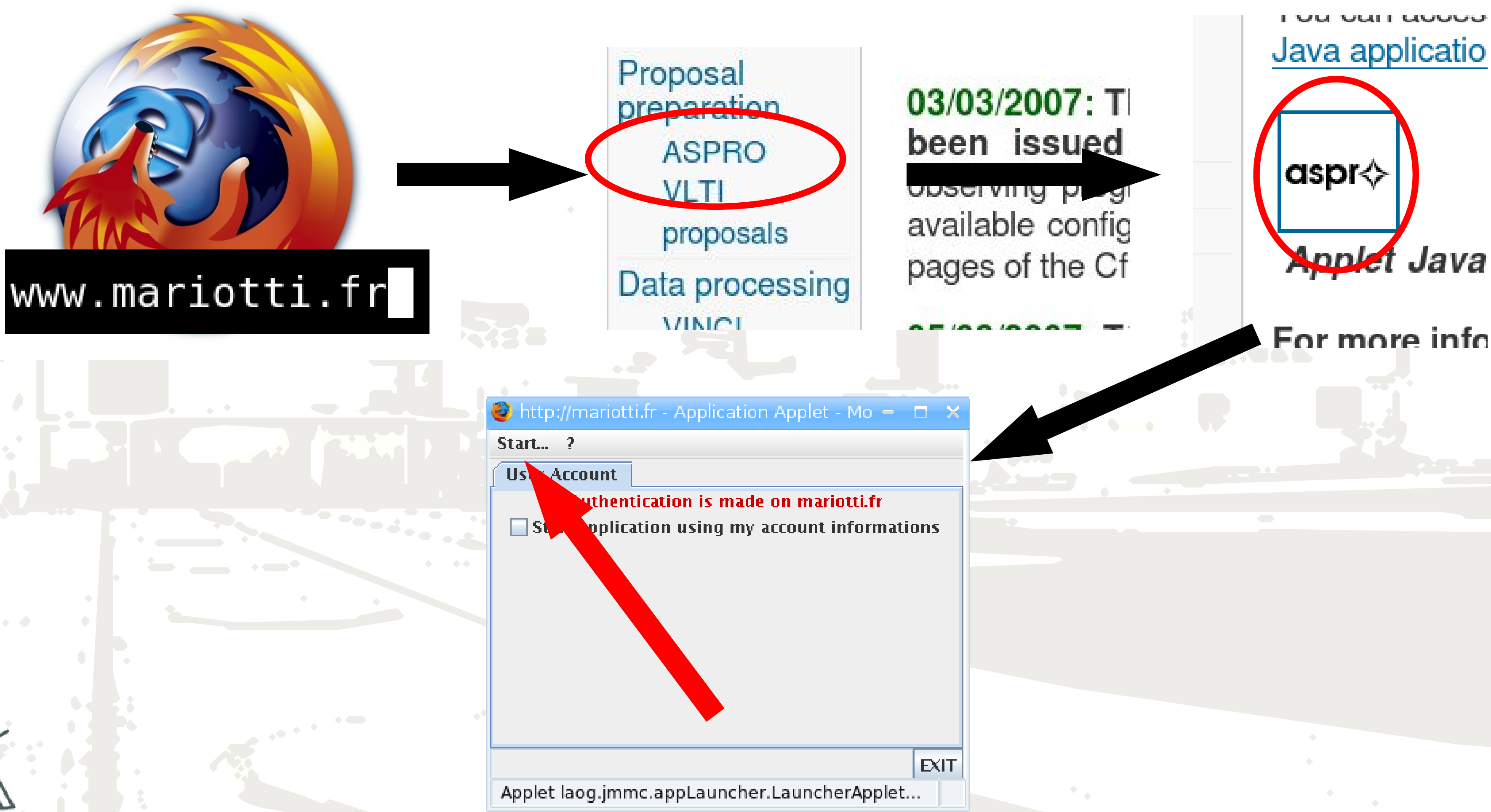
How to launch ASPRO (on the web)

- Start your favourite browser



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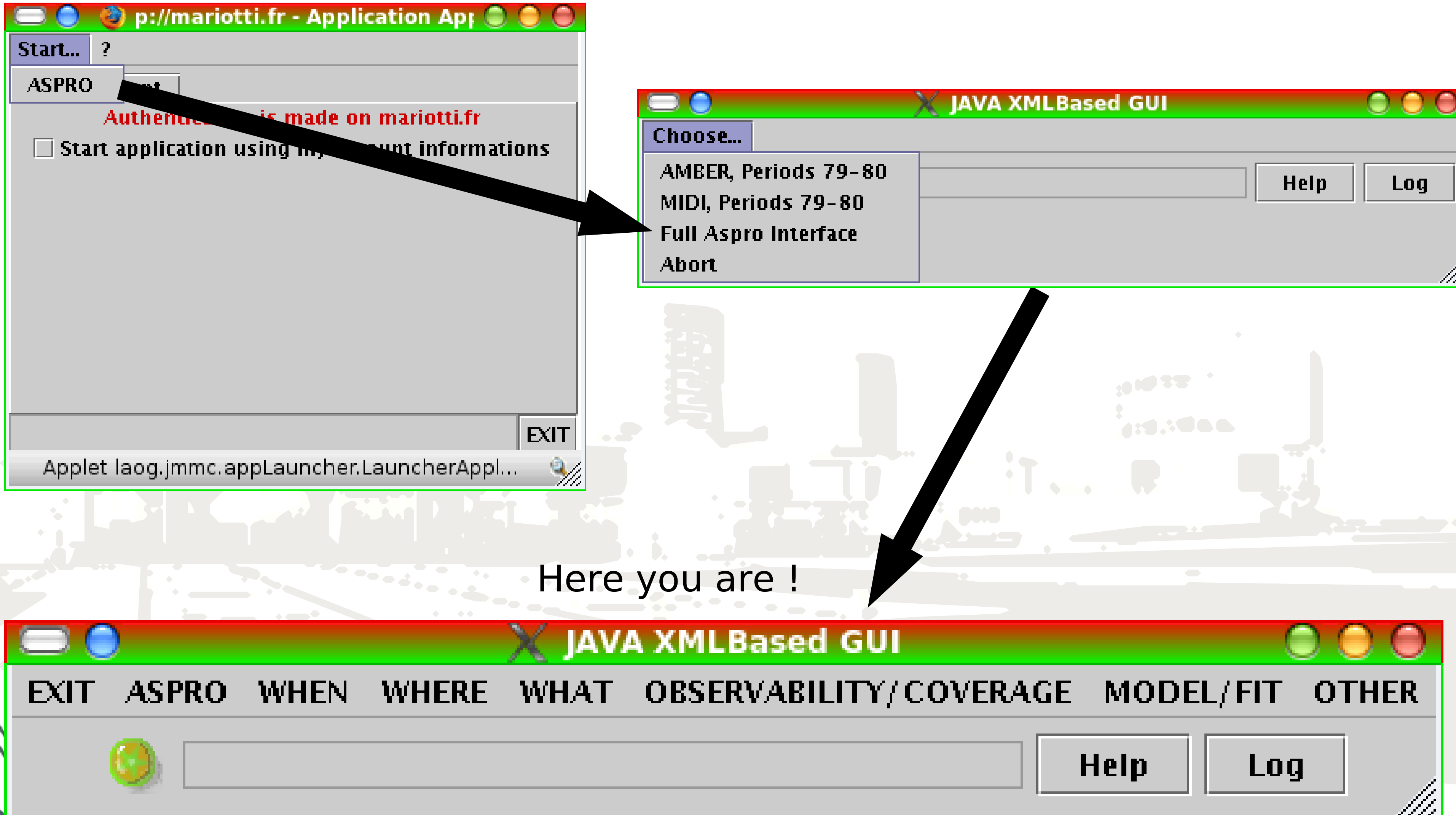
How to launch ASPRO (on the web, continued...)



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ASPRO tips and tricks

- Check out the command line !
- Do not hesitate to restart ASPRO in case of doubt
- ASPRO modules communicate with files, so check the file names in case of problem
- ASPRO does **NOT** normalize visibilities, so the sum of fluxes you enter **MUST** be 1

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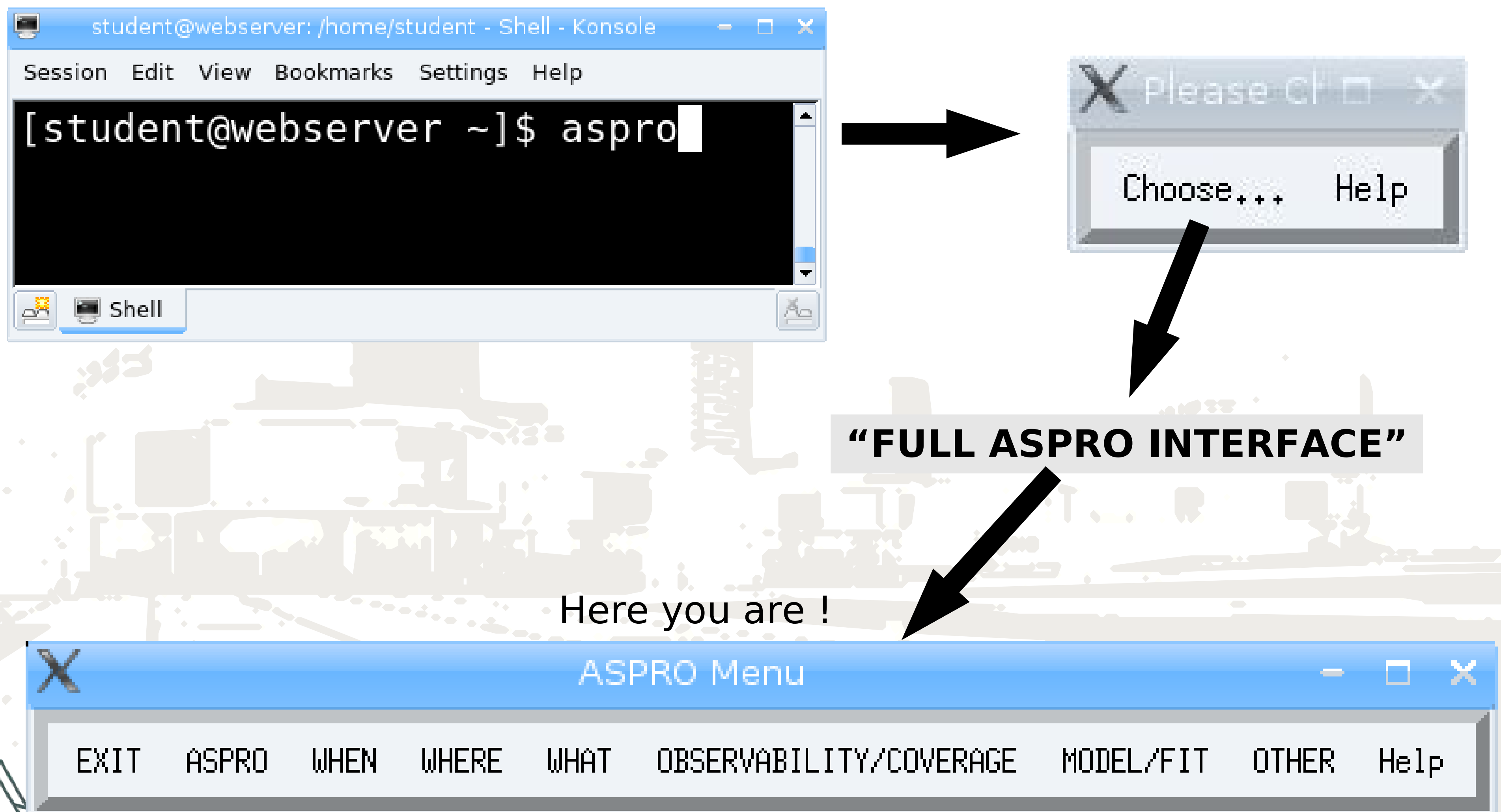
How to launch ASPRO (local installation)



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