Observability (and (u,v) coverage)

Erasmus Summer School

The 2010 VLTI summer school

April 17 – April 22

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

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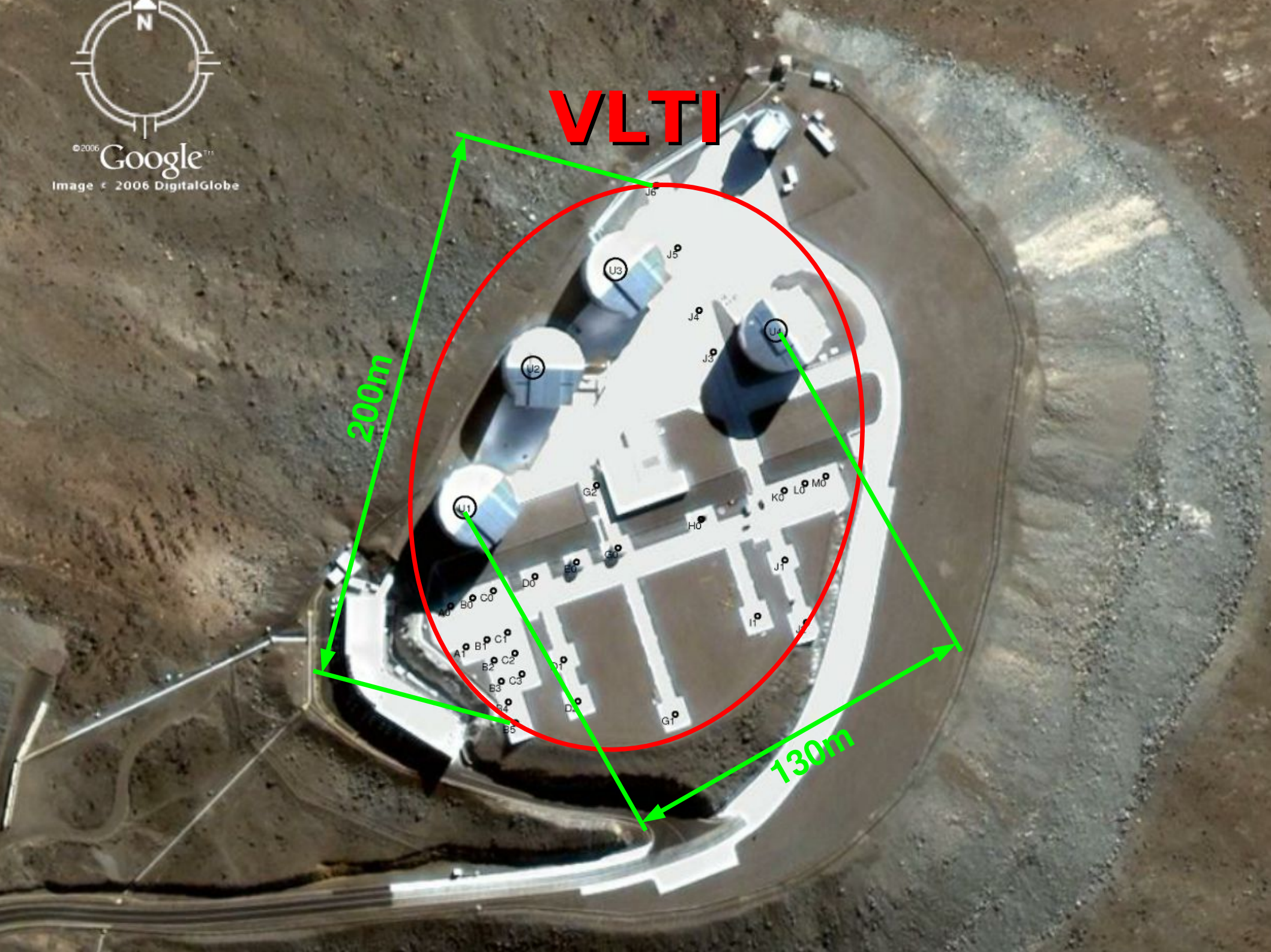
VLTI
N
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200m
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Observability

- ***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

What is (u,v) plane ?

Fourier transform

$$V(u,v)=\frac{\hat{I}(u,v)}{\hat{I}(0,0)} \qquad \hat{I}(u,v)\Leftrightarrow I(x,y)$$

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

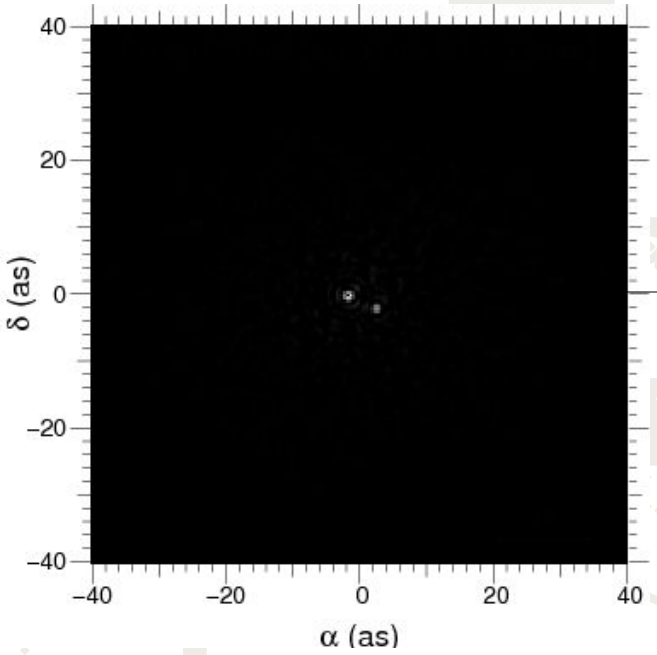
$(u,v)=\frac{1}{\lambda}(\Delta X,\Delta Y)$ are the spatial frequencies

Spatial frequencies:

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

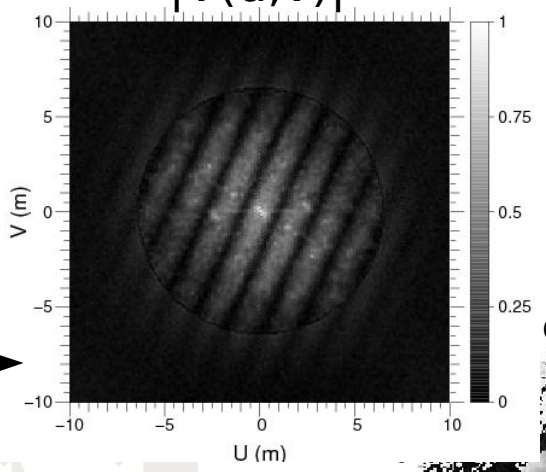
(u,v) plane and single dish telescope

Object observed at the
Special Astronomical Observatory (Zelentchouk)



TF

|V(u,v)|



ϕ (u,v)

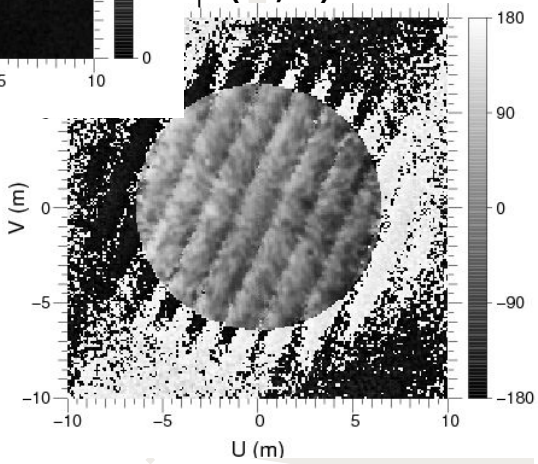


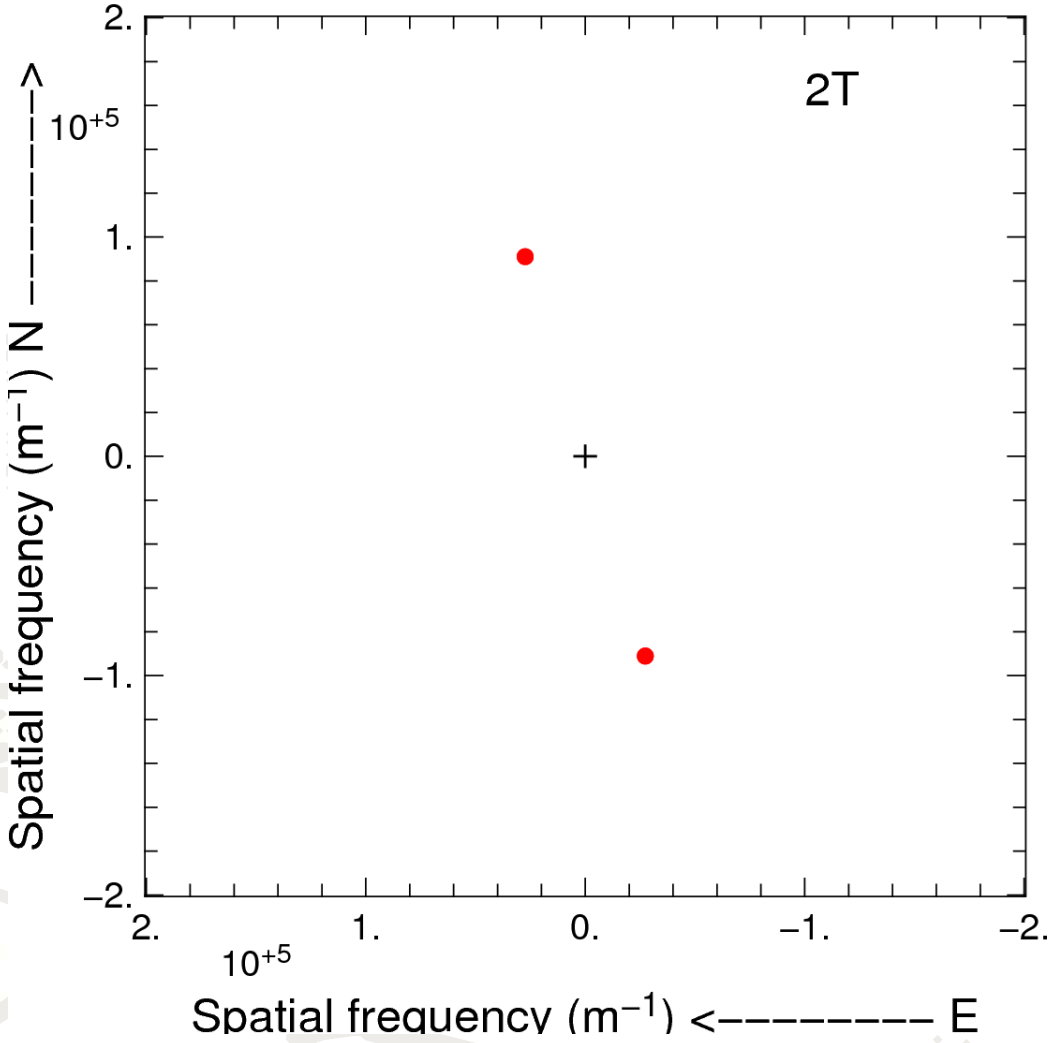
Image : I(x,y)=O*PSF

|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 (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**

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(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) points per measurement.

• A N telescopes interferometer gives access to **N(N-1)/2** (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

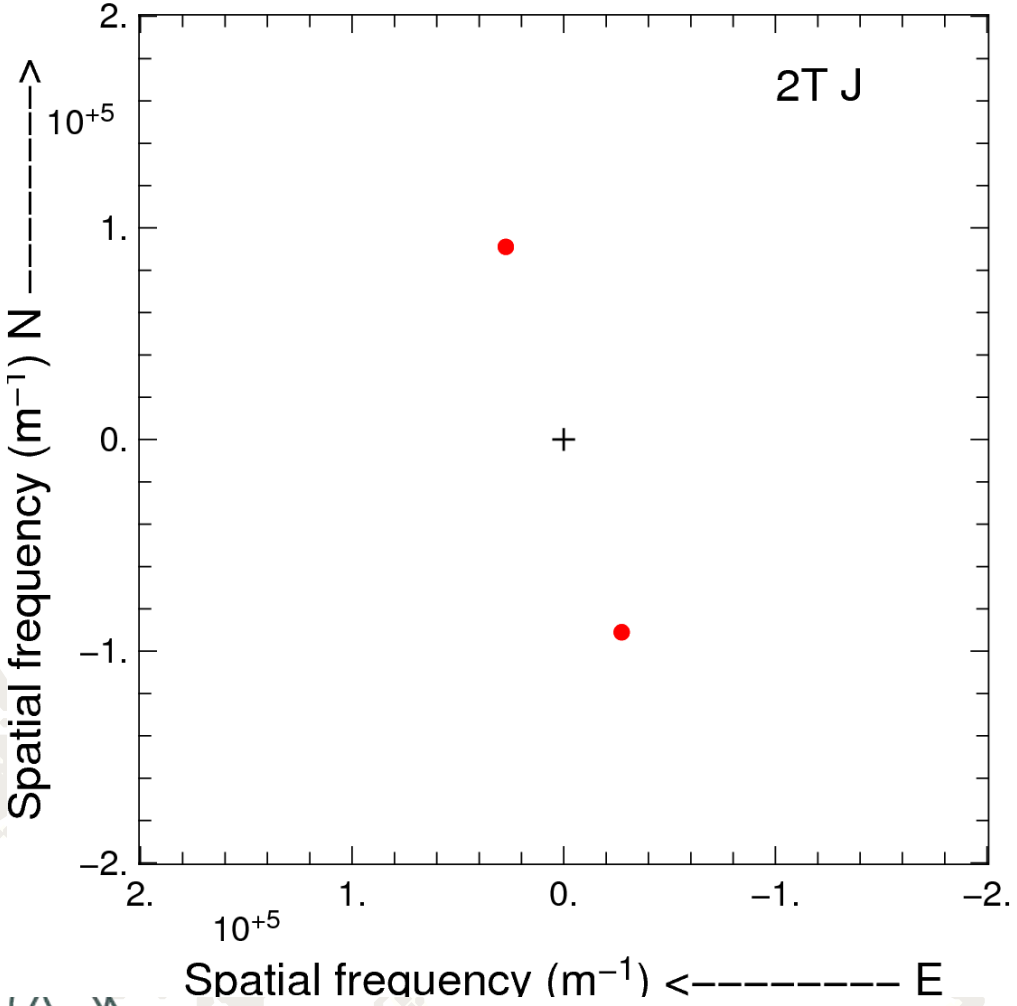
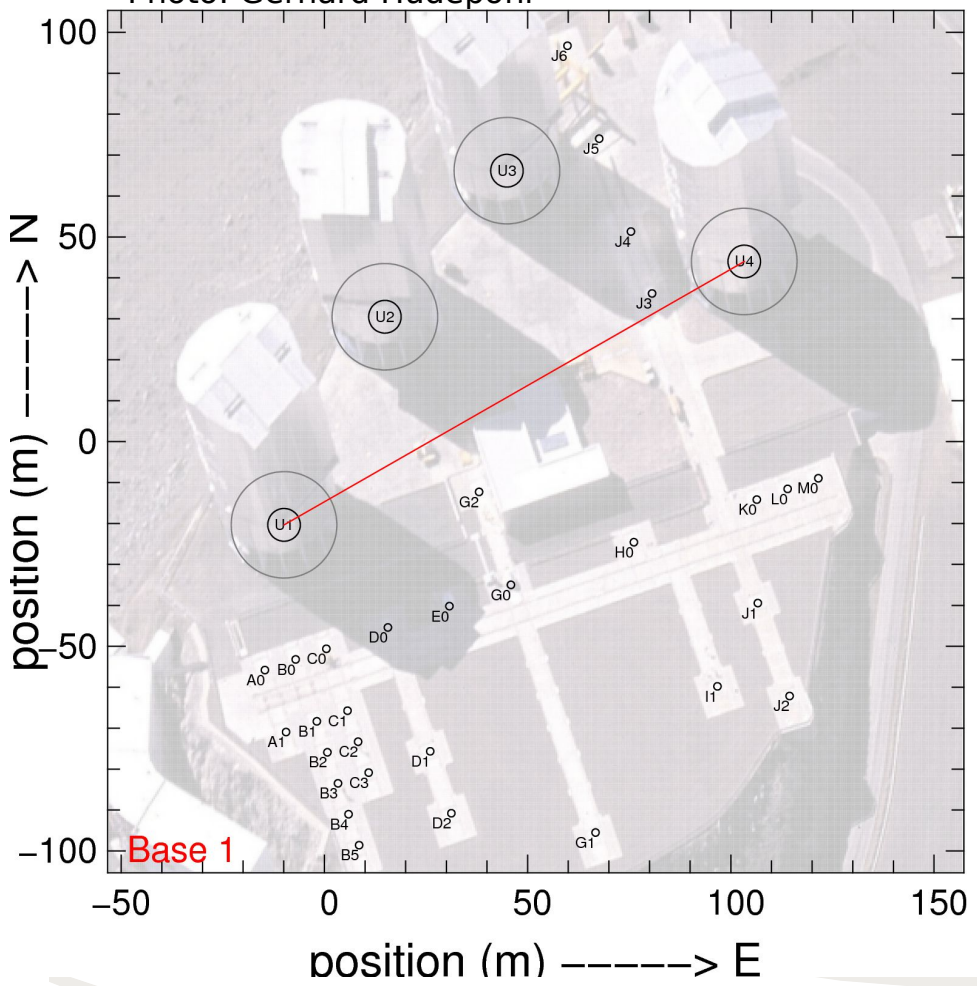
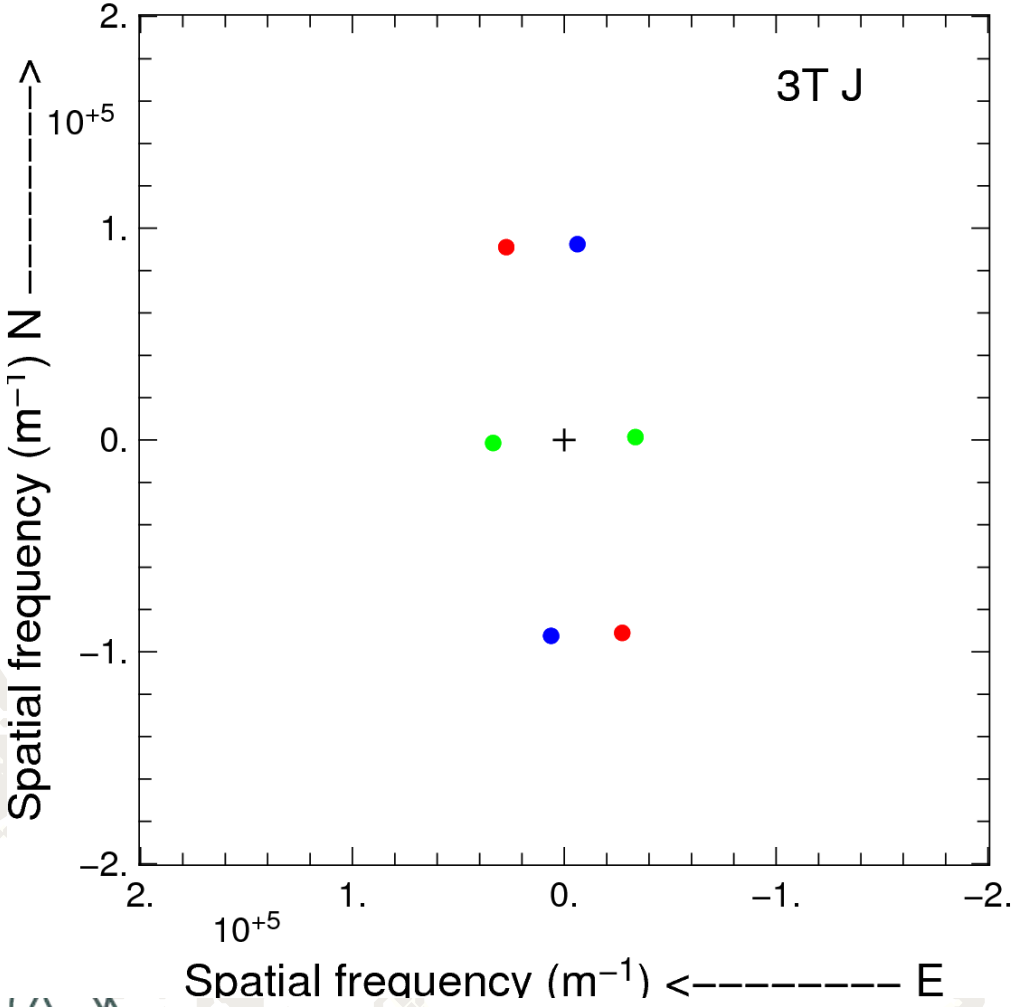


Photo: Gerhard Hüdepohl



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



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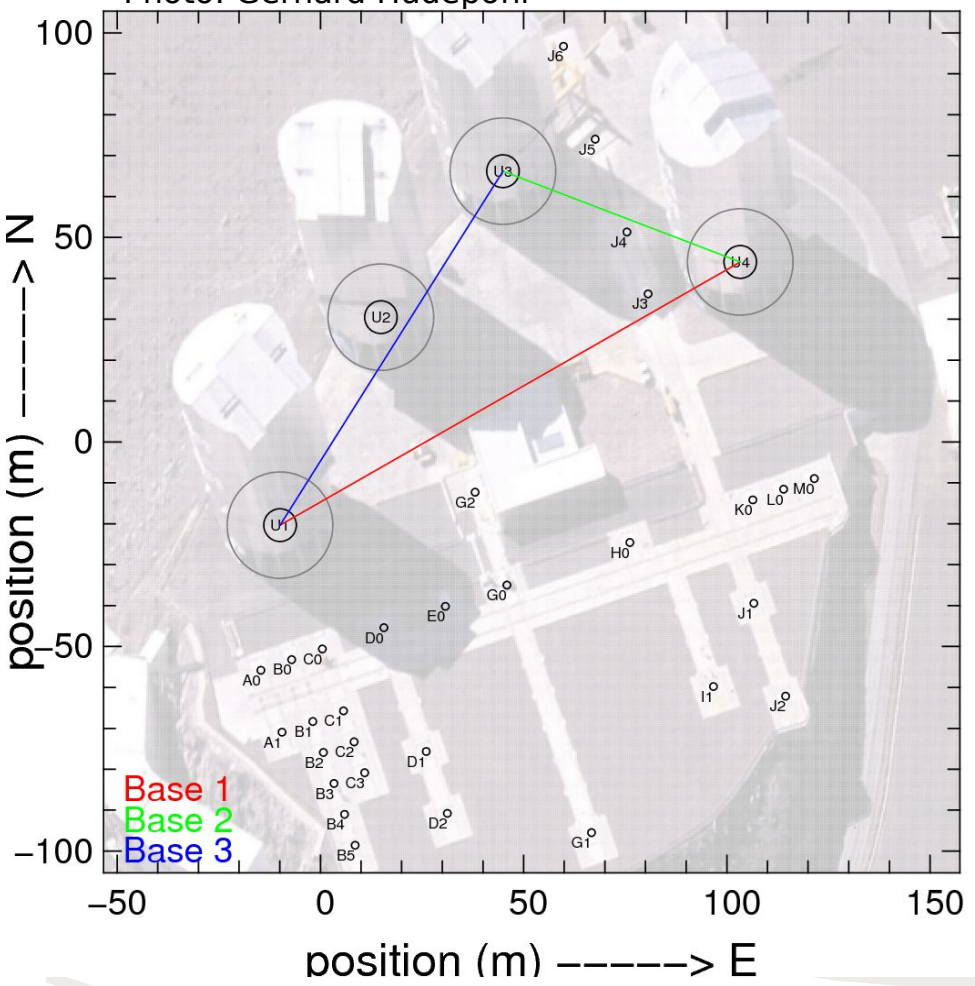

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(u,v) plane filling with more telescopes: 4T

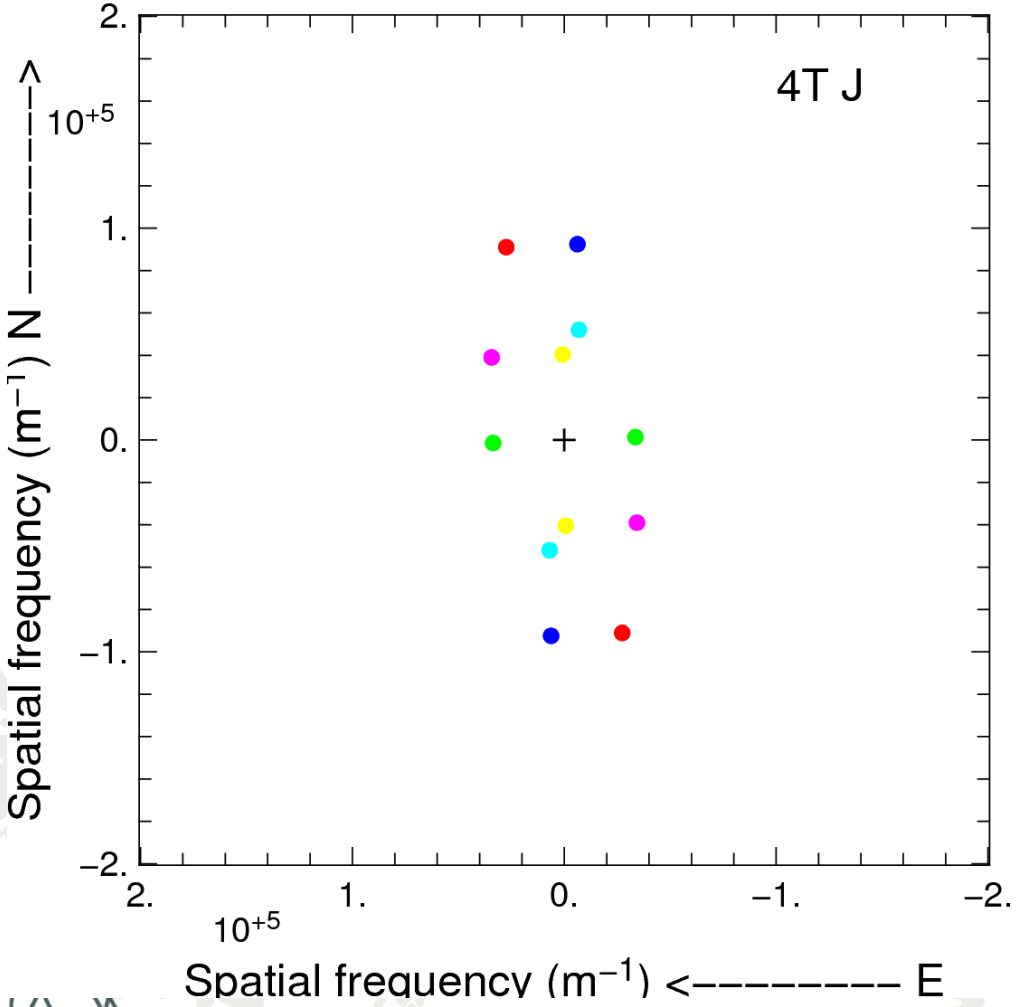
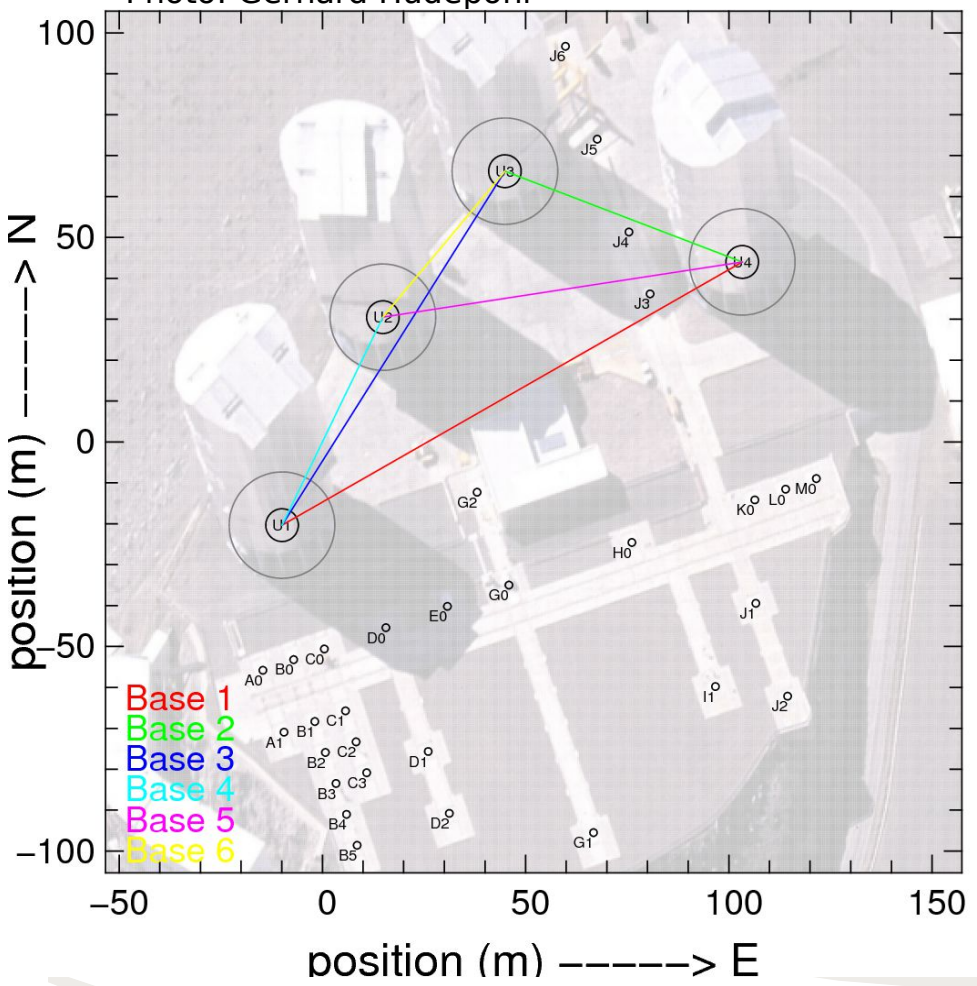


Photo: Gerhard Hüdepohl



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

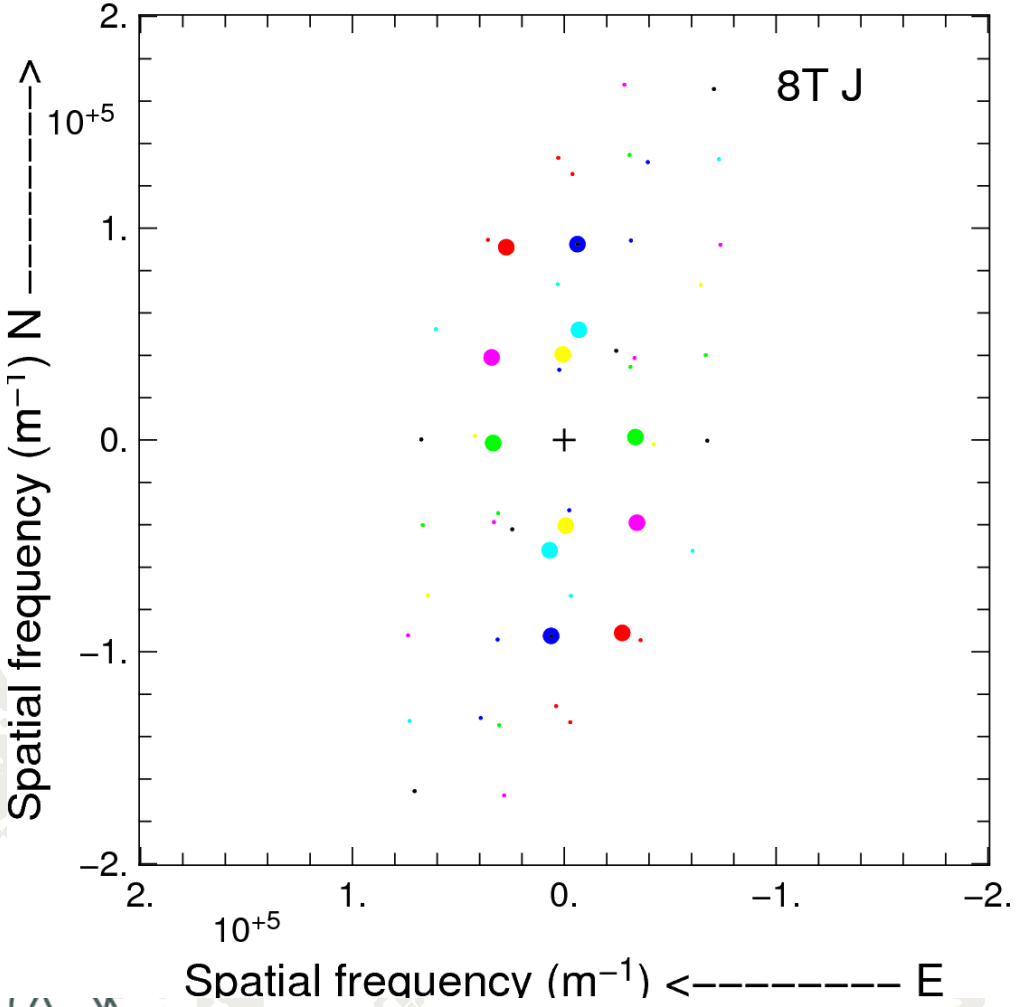
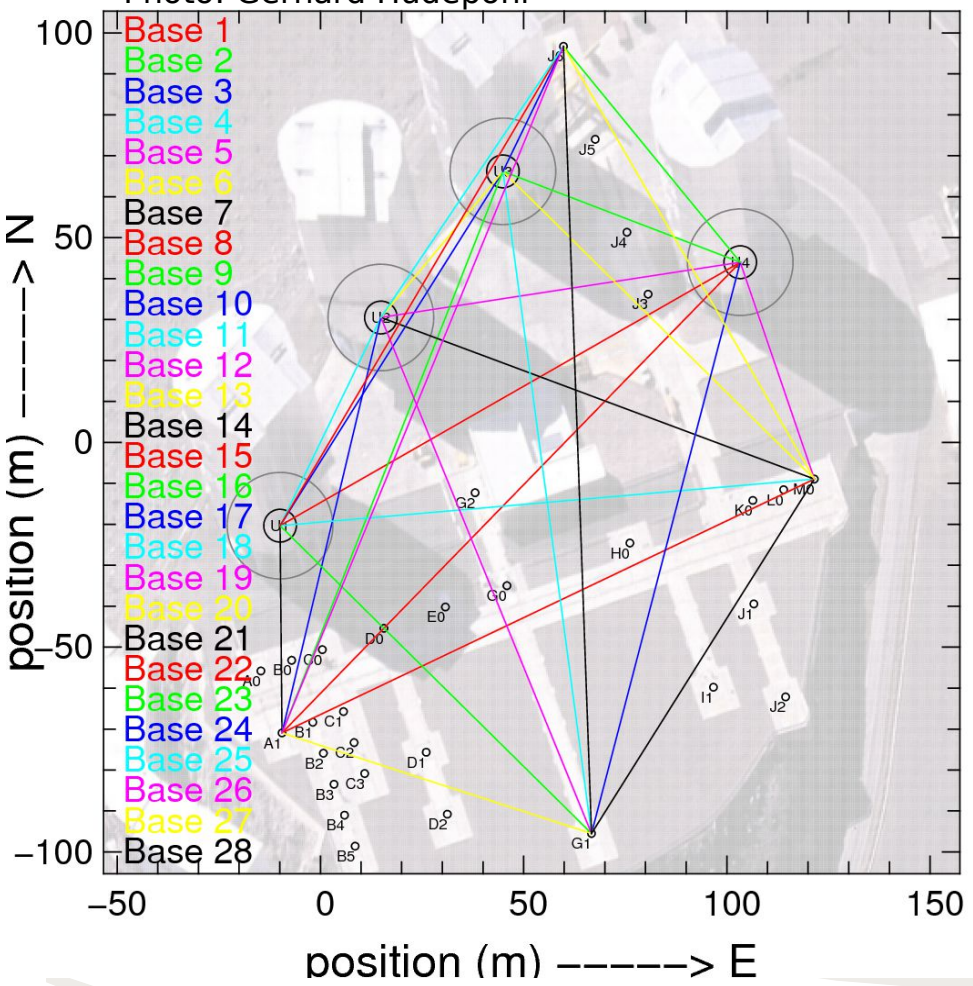


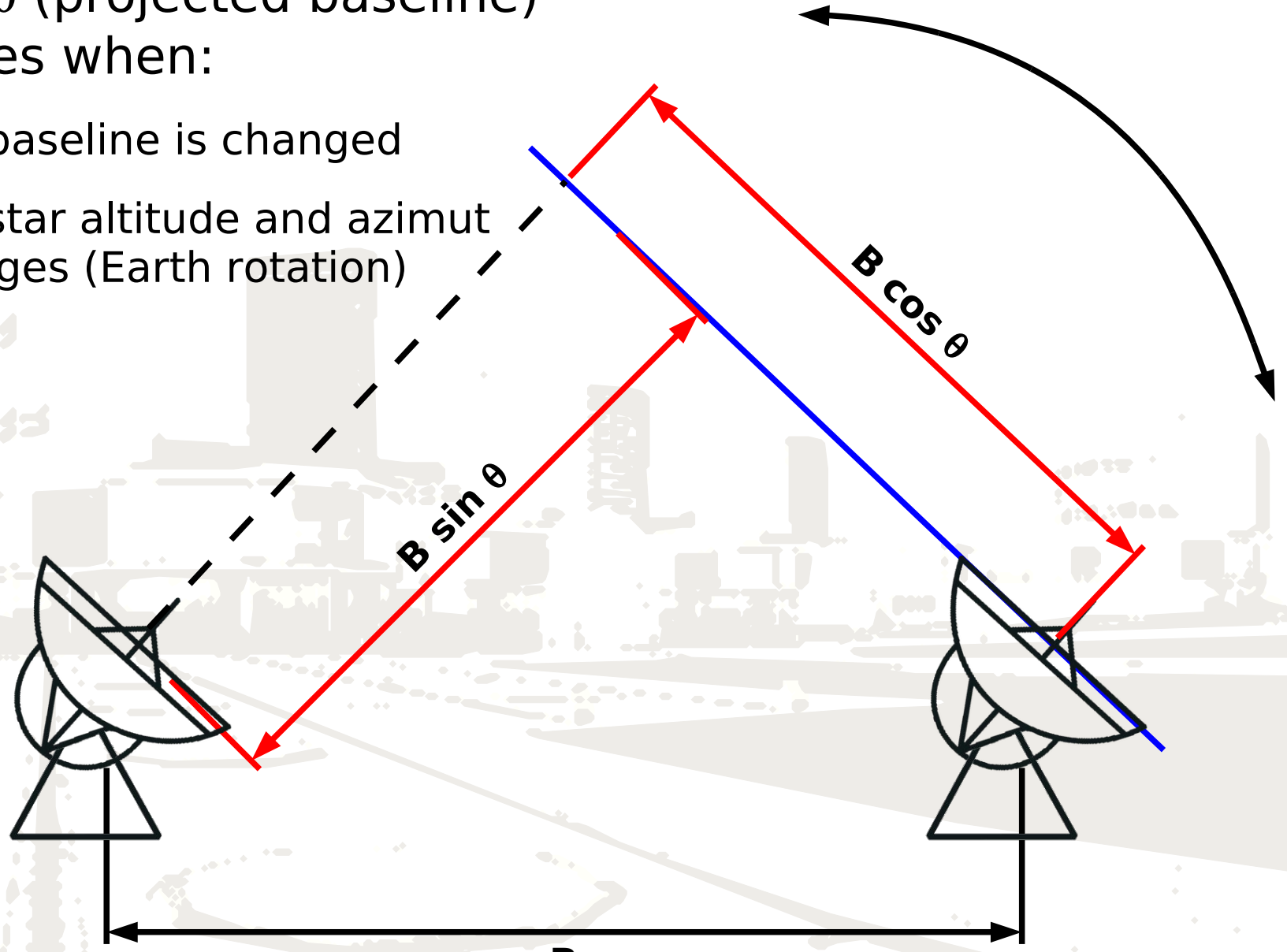
Photo: Gerhard Hüdepohl



Supersynthesis

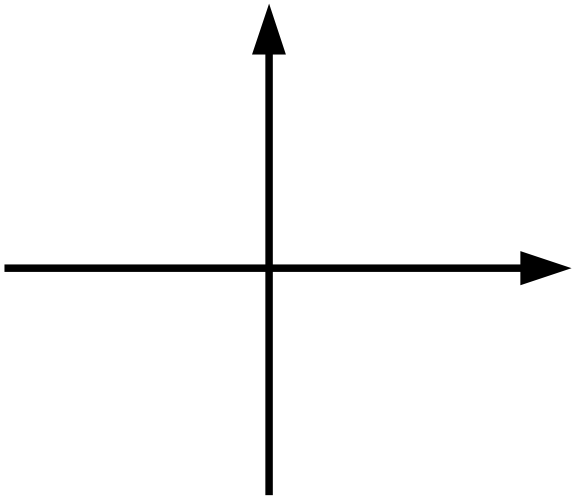
B cos θ (projected baseline) varies when:

- The baseline is changed
- The star altitude and azimut changes (Earth rotation)



This is
A blue marble

This is the
on-sky projection



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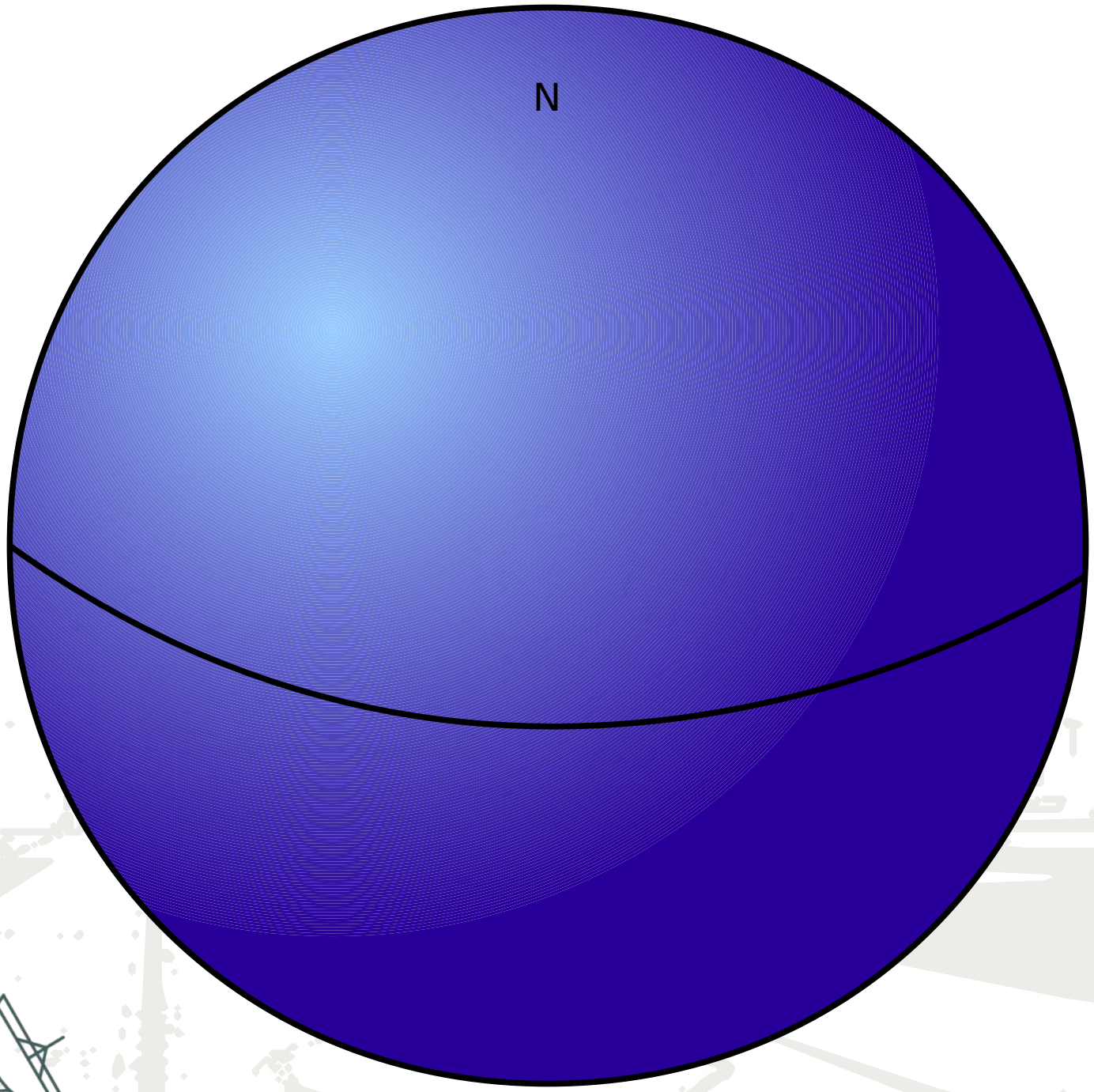

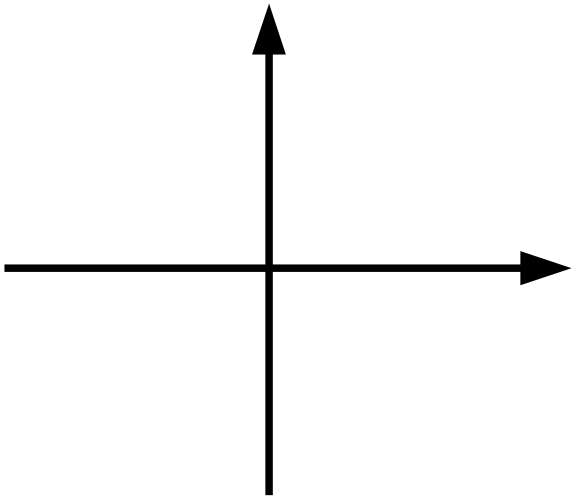

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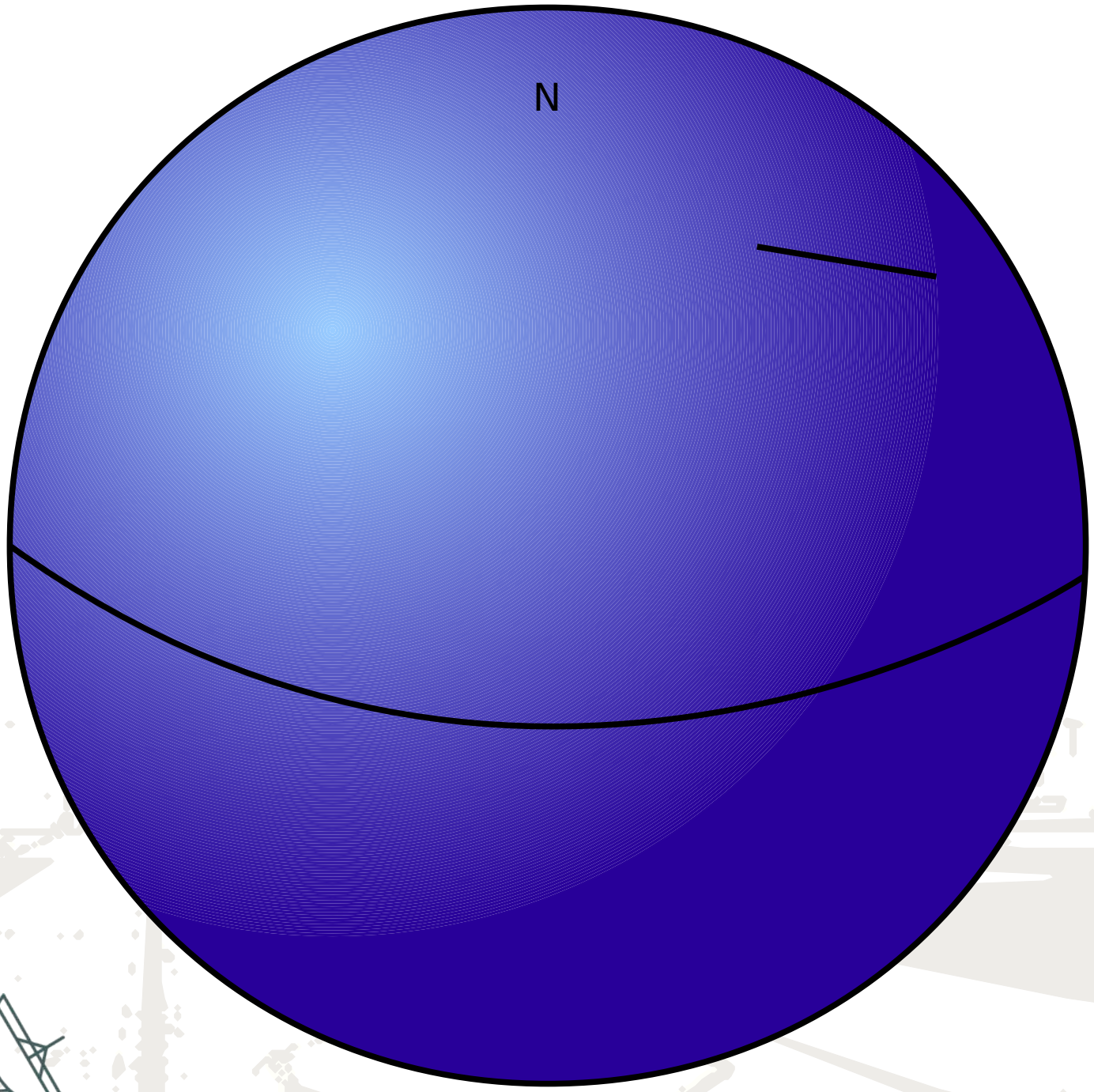
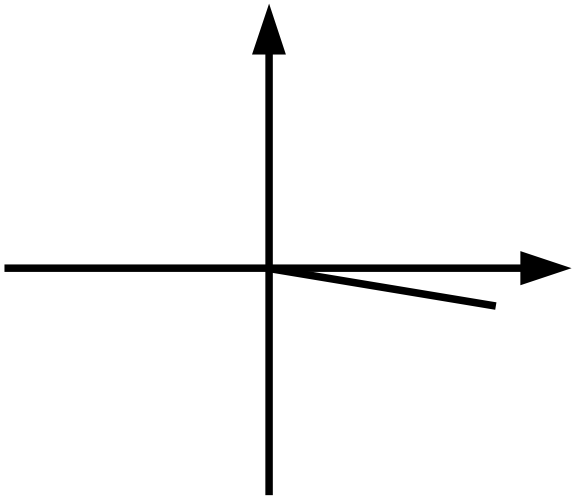


When the Earth rotates...



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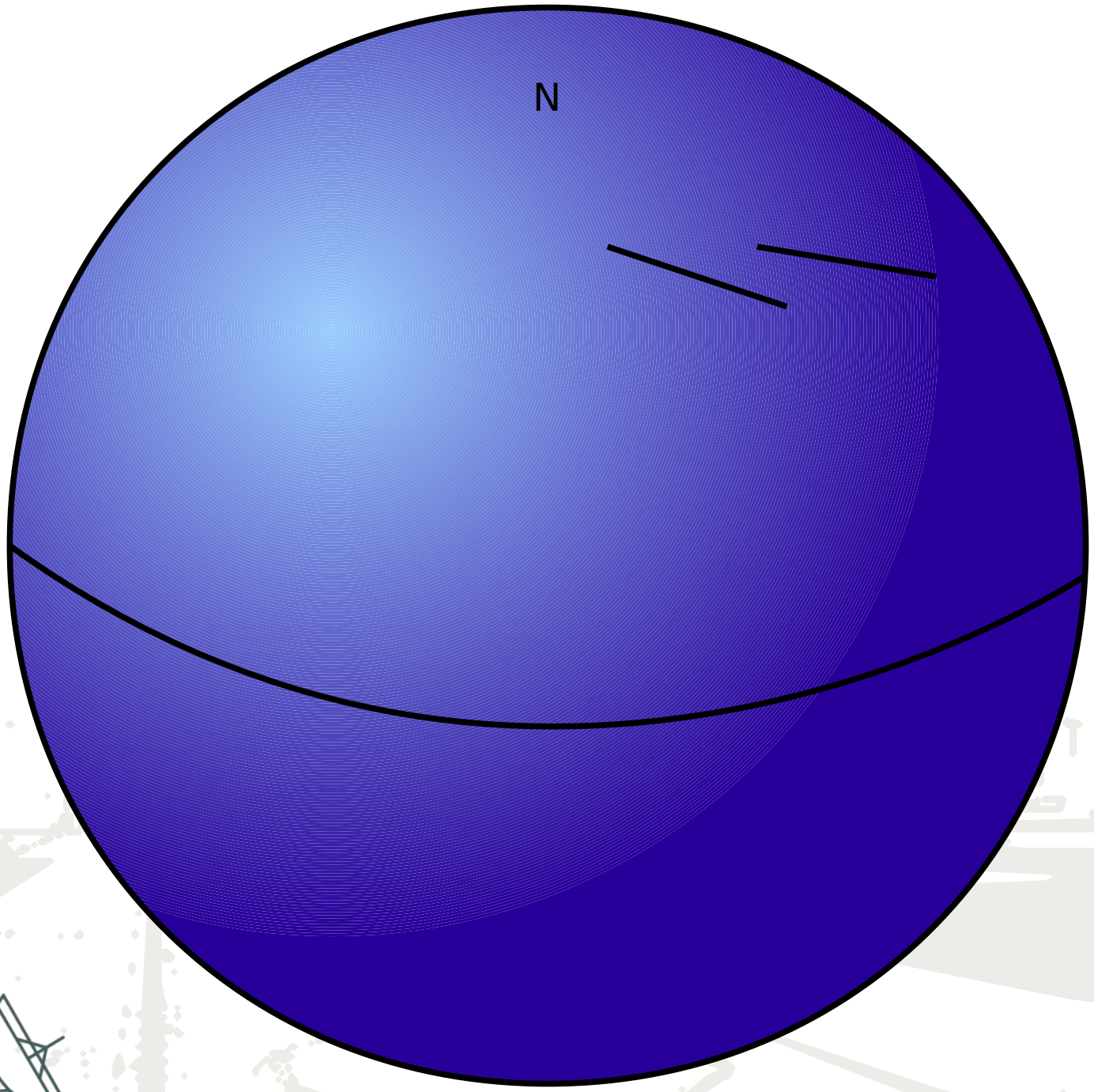

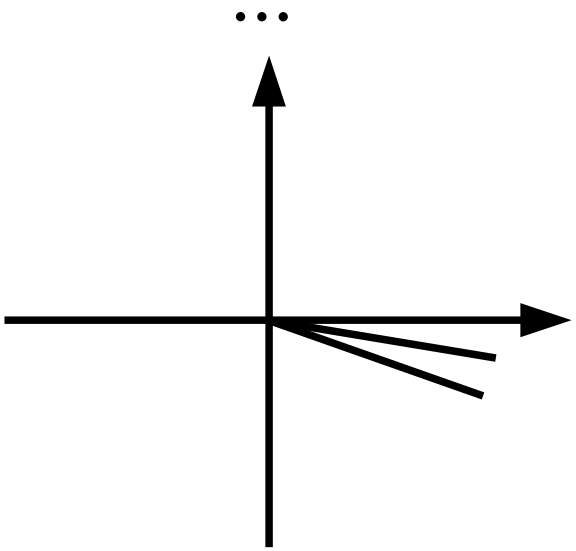

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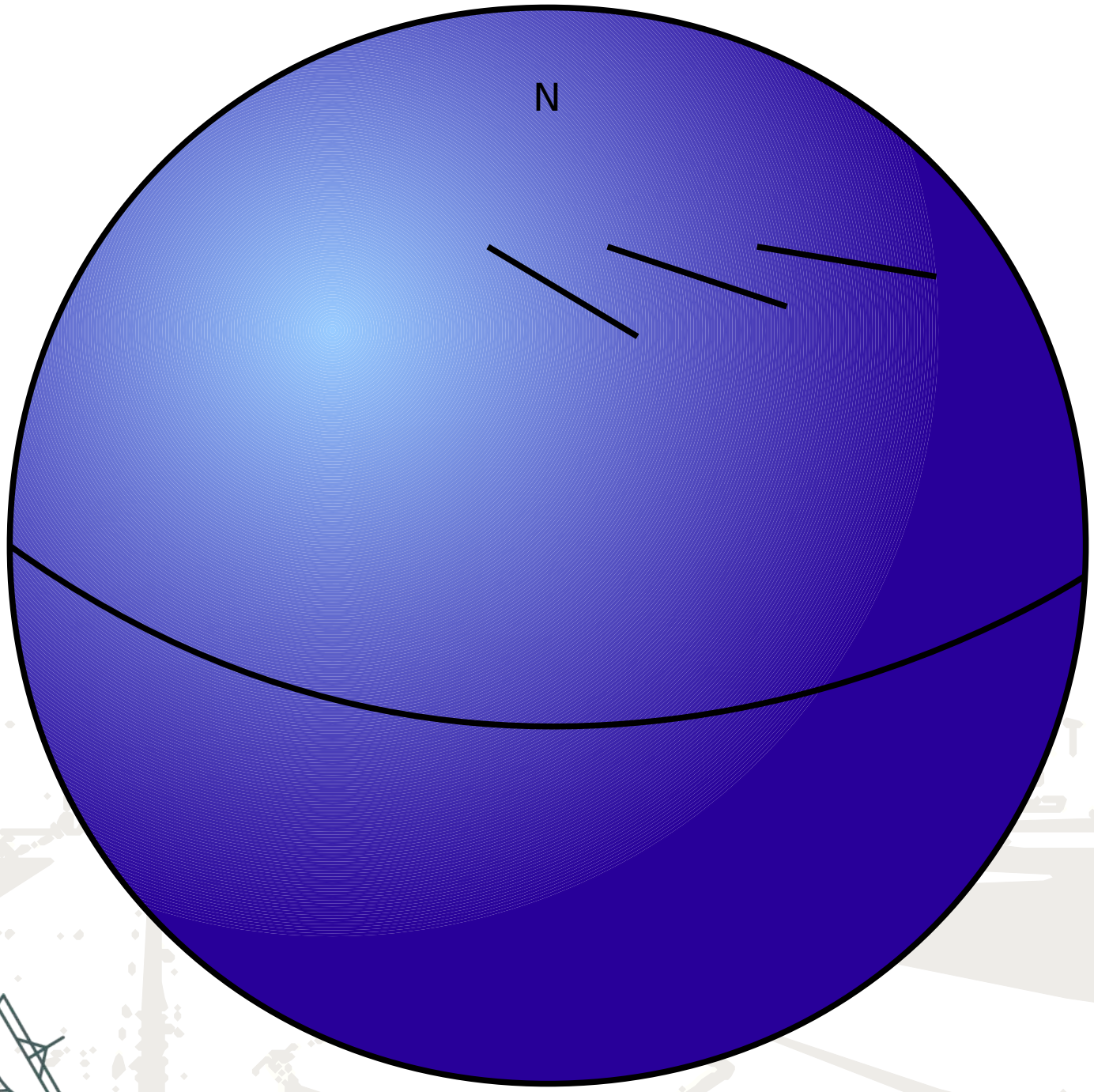

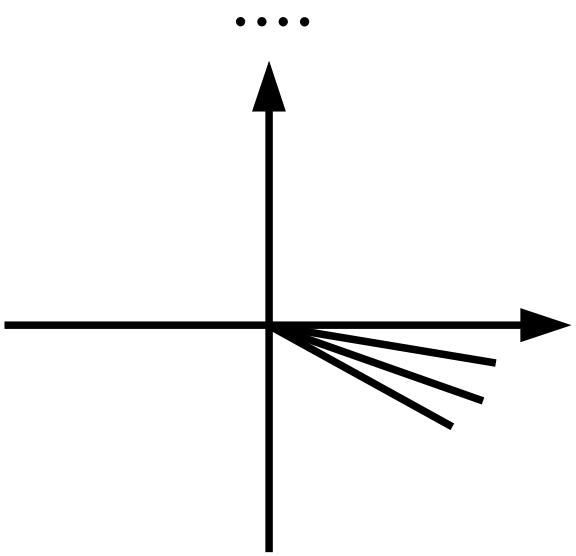

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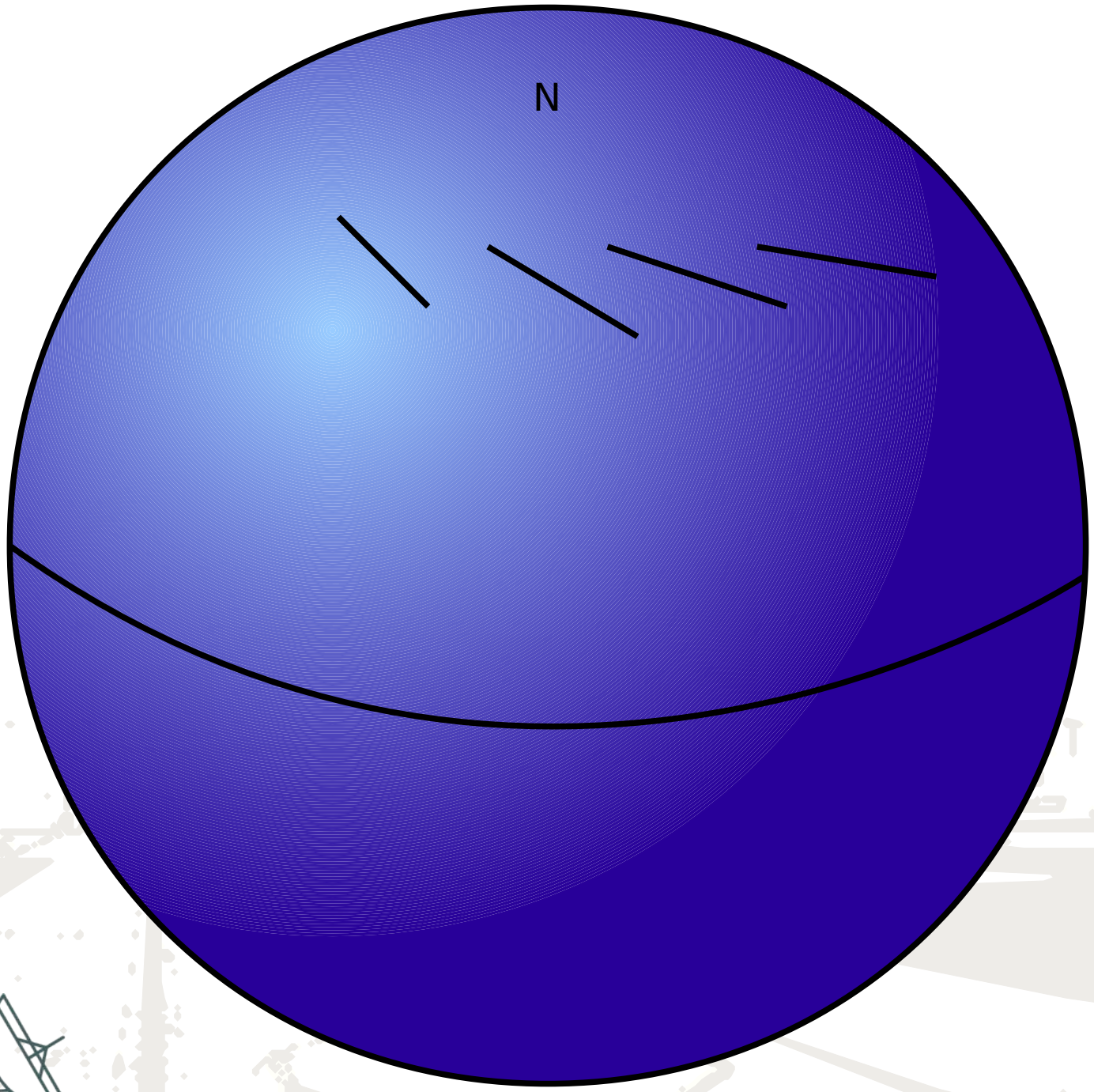

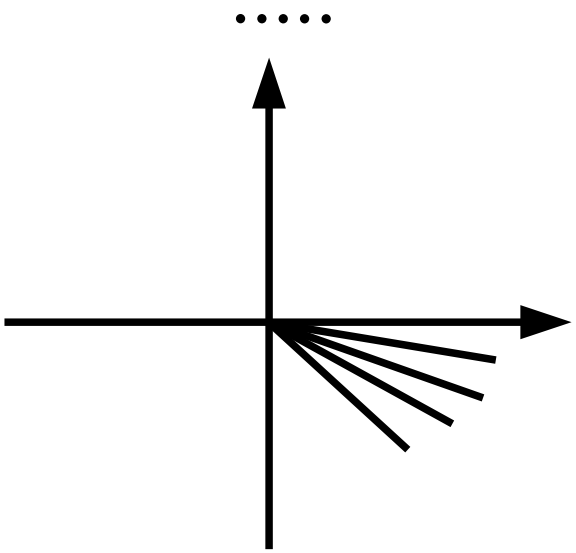

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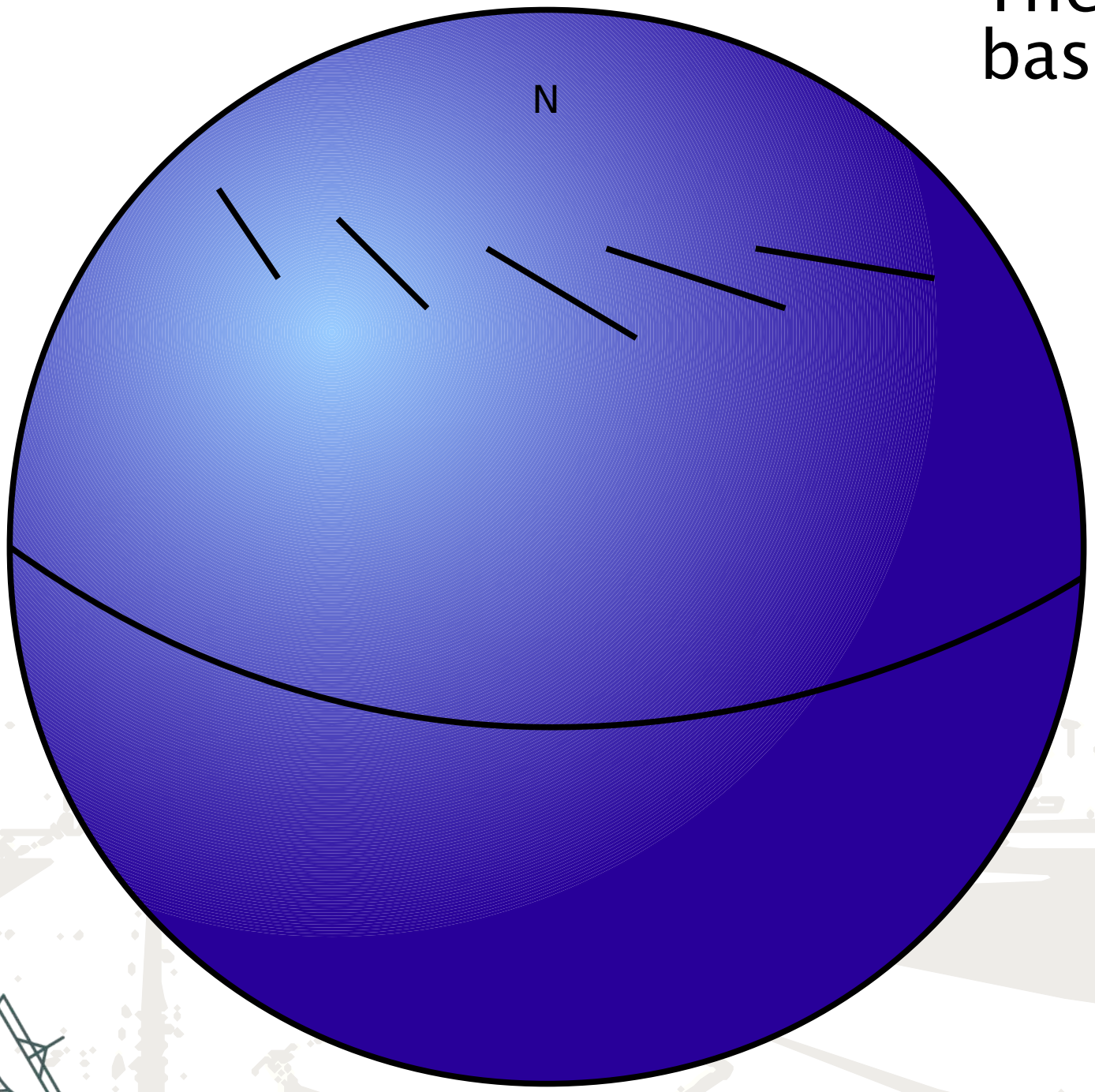
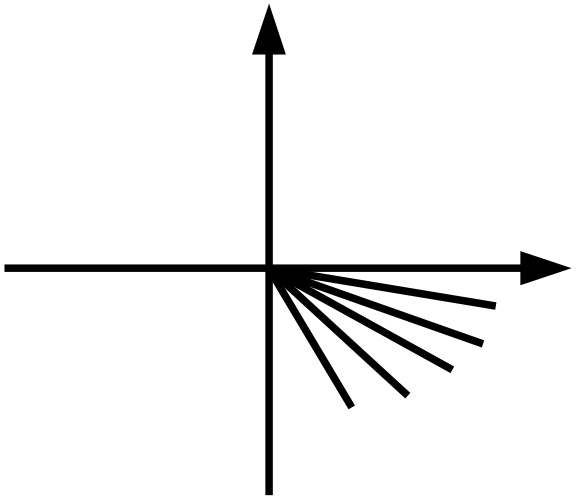
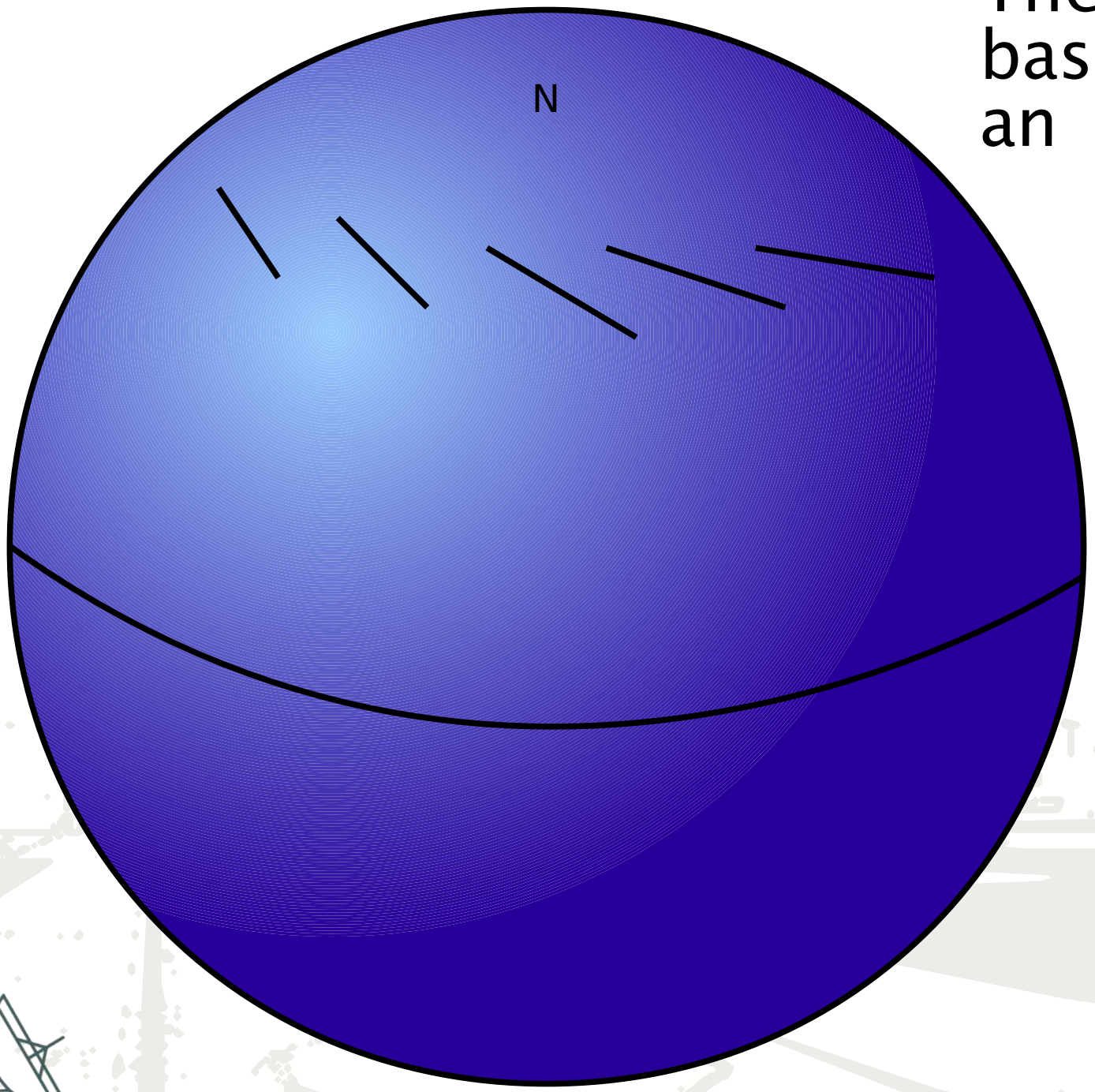
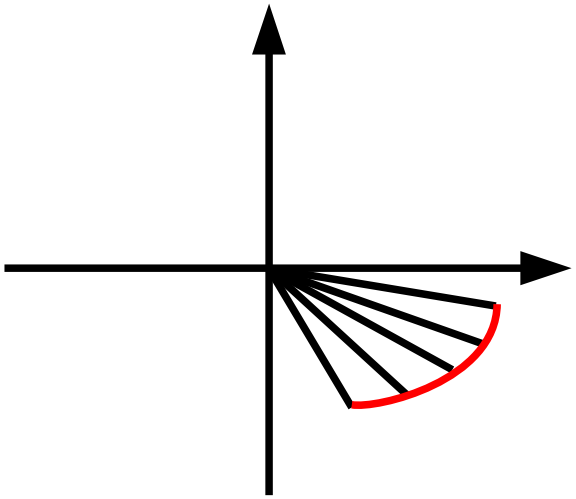
The projected baseline traces...



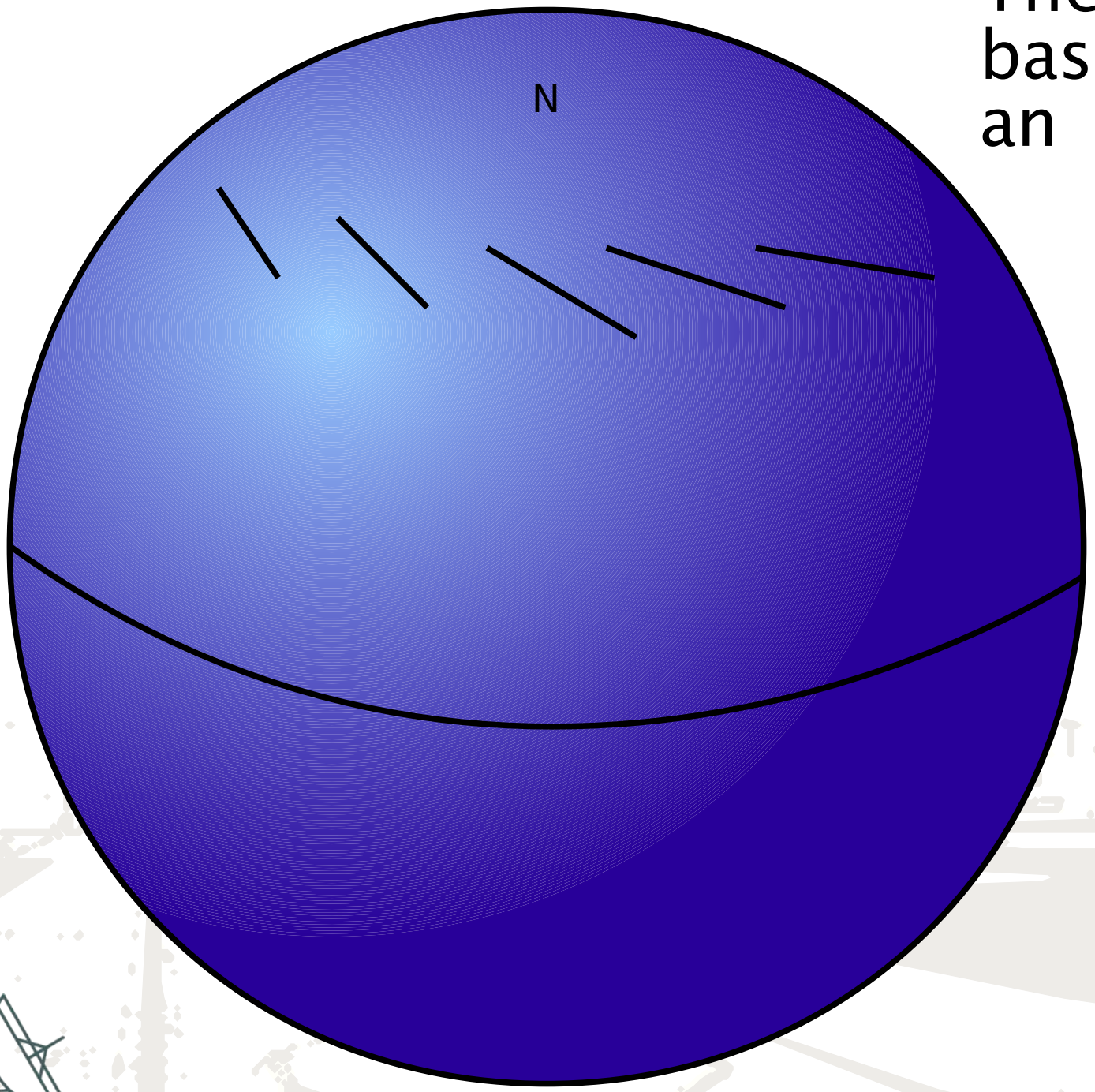


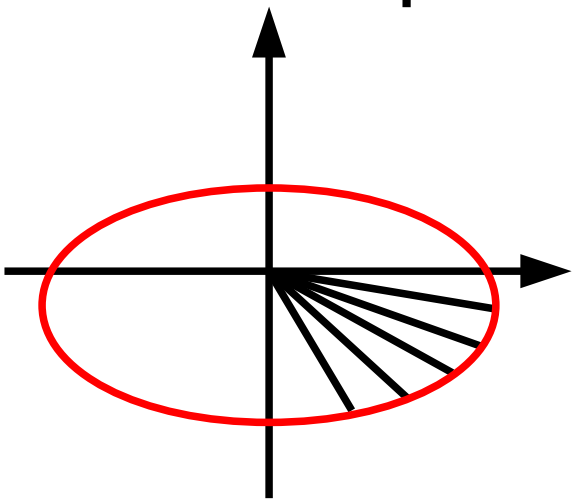
The projected baseline traces an arc...



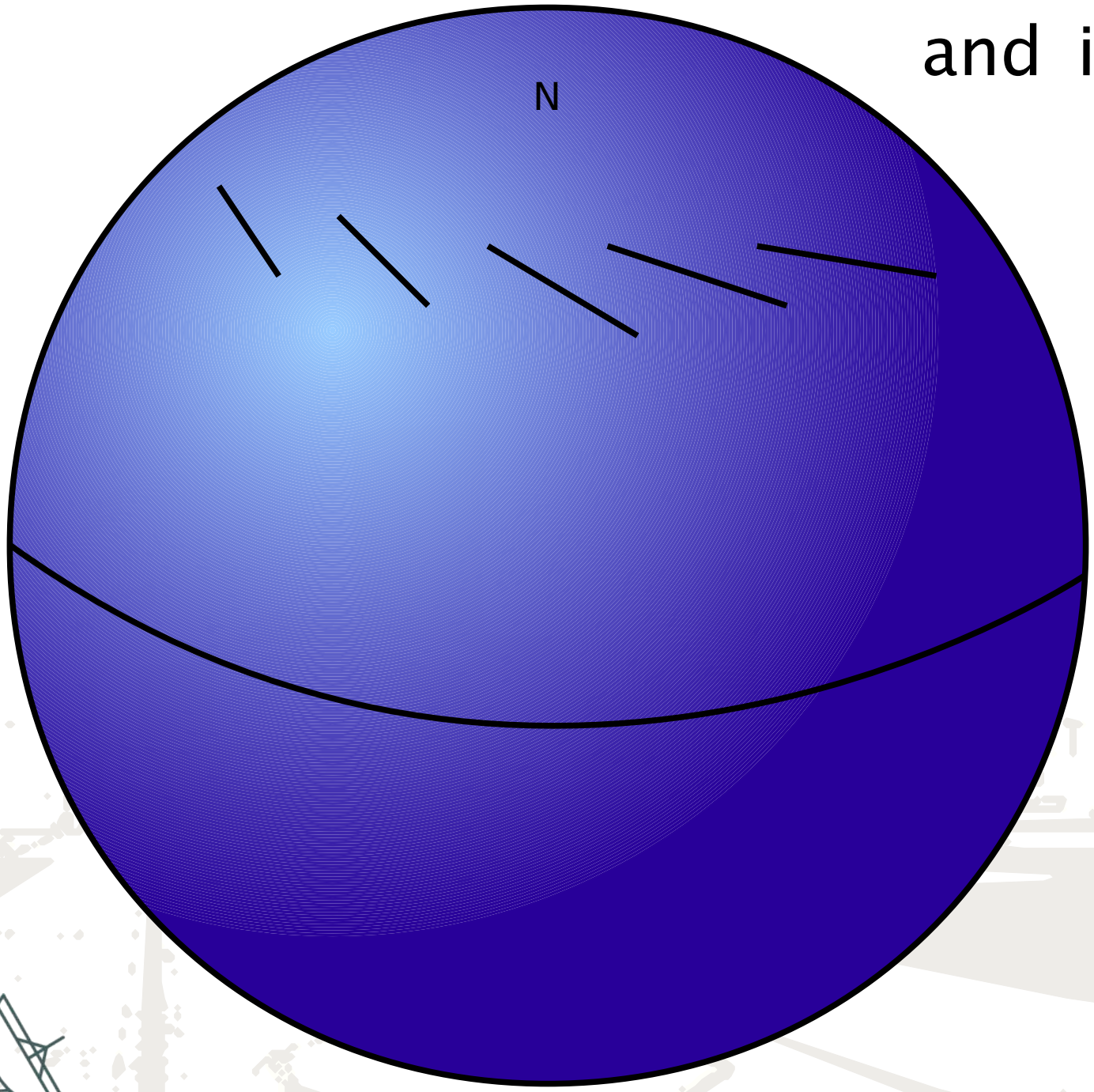


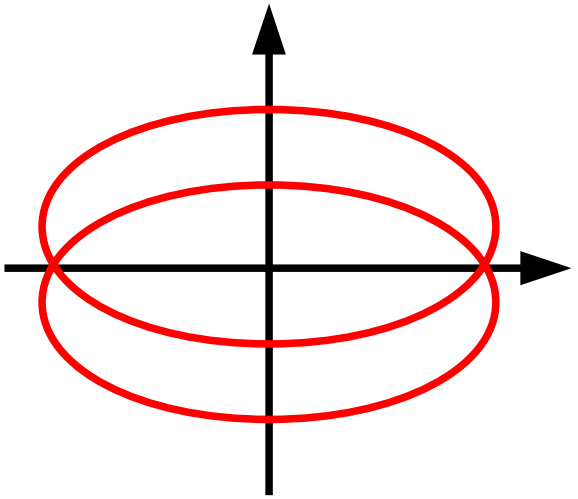
The projected baseline traces an arc of ellipse





and its counterpart





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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:

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

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Supersynthesis (2T)

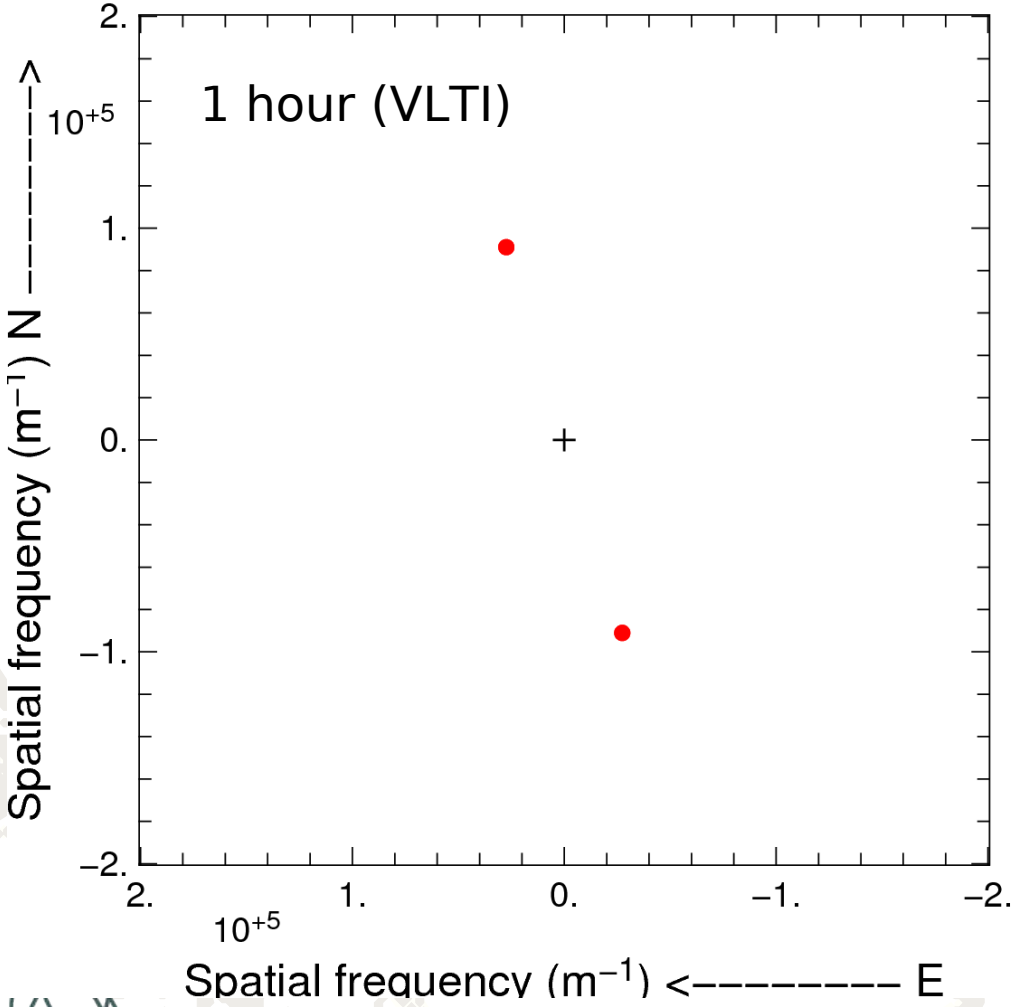
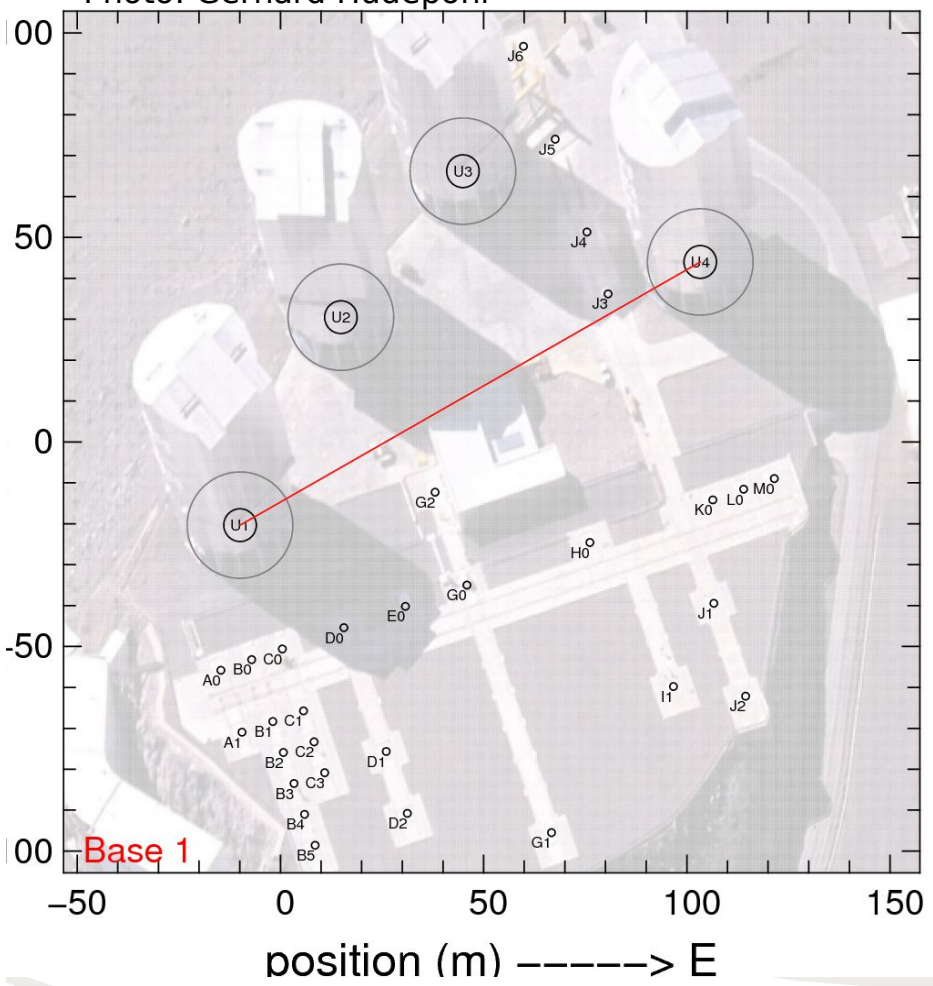
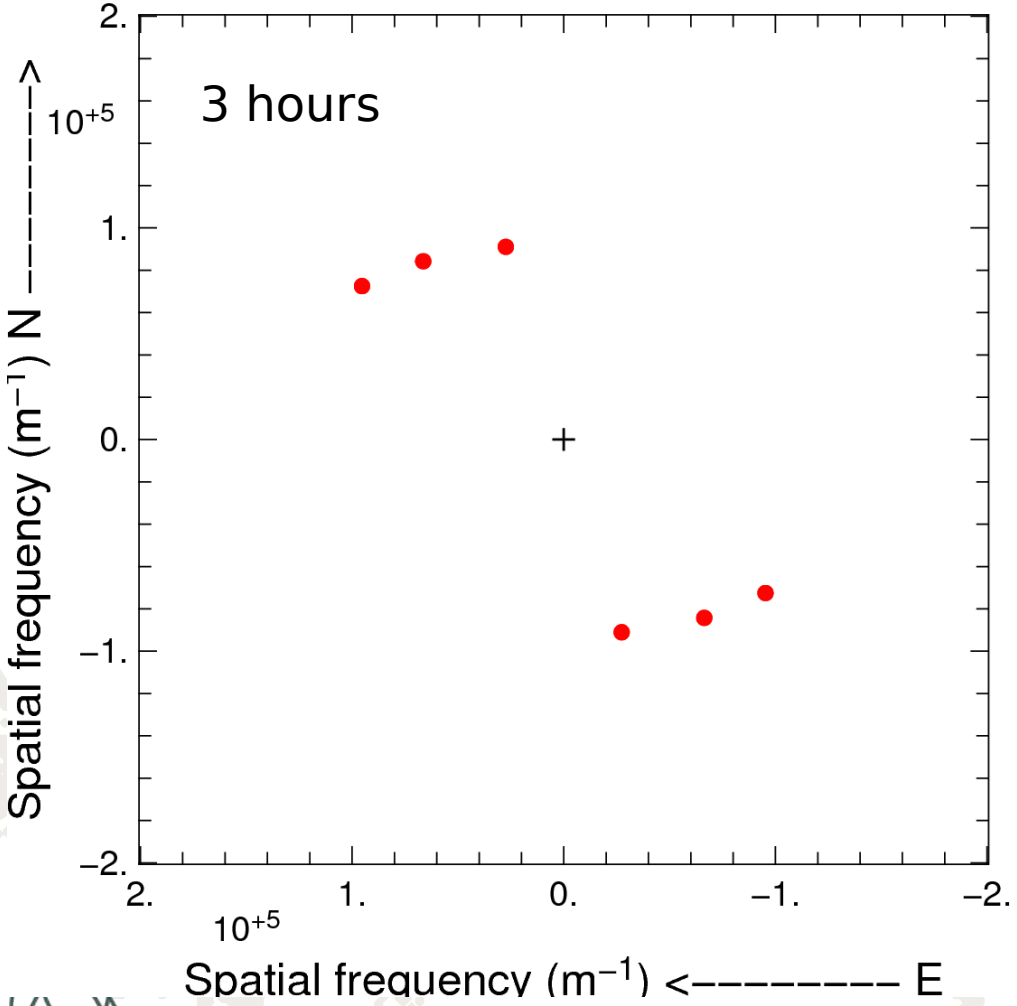


Photo: Gerhard Hüdepohl



Supersynthesis (2T)



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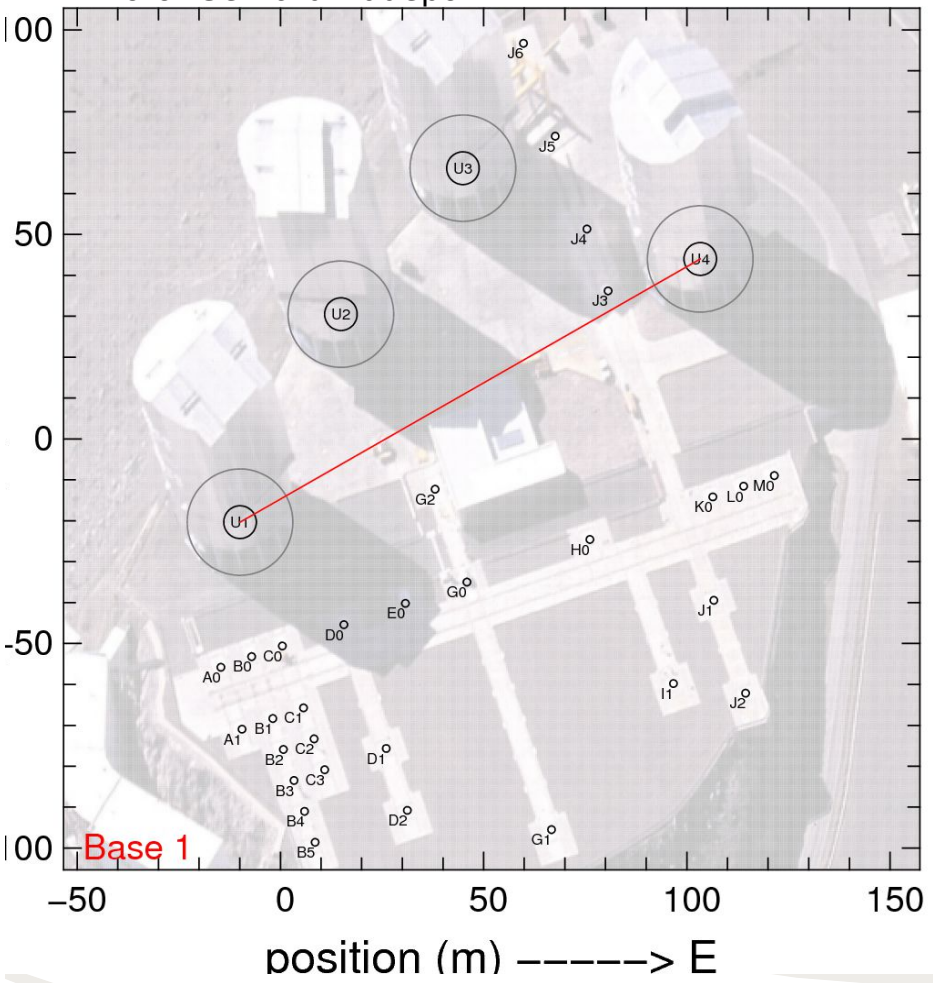


Supersynthesis (2T)

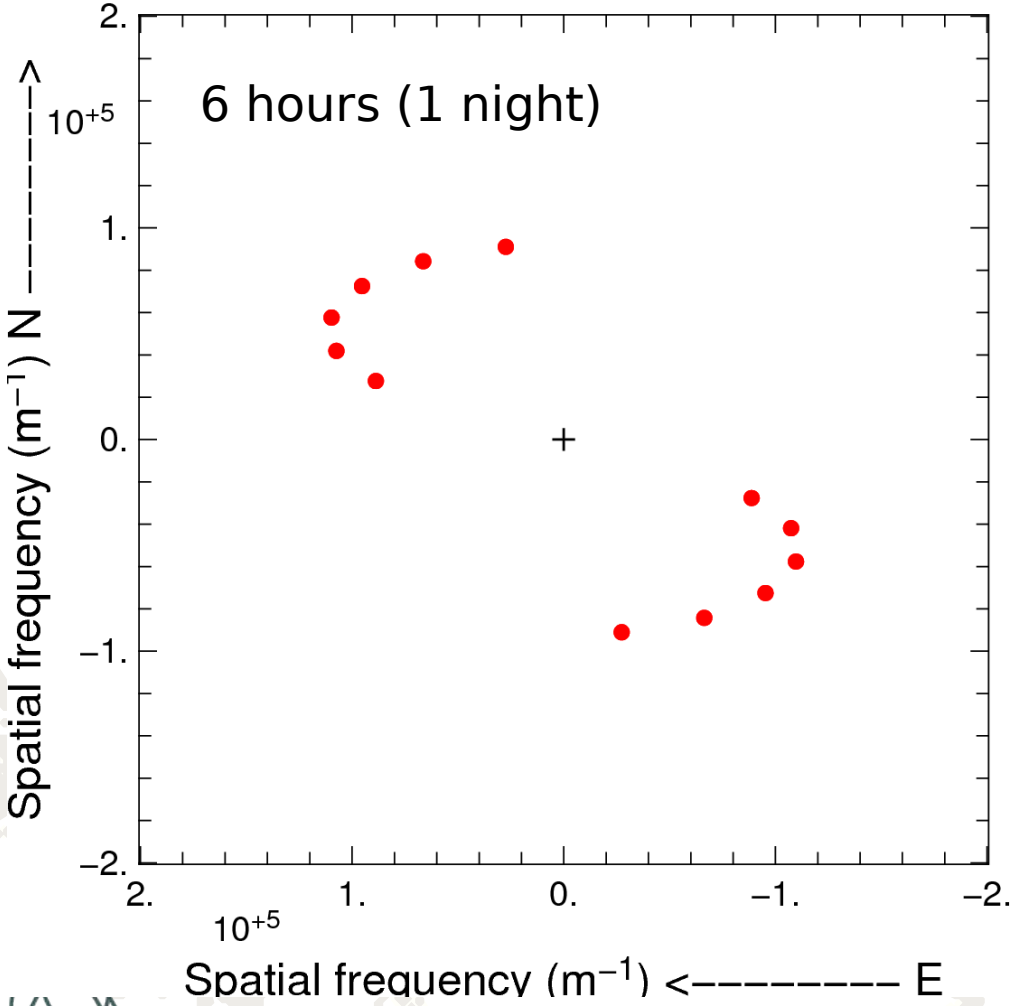
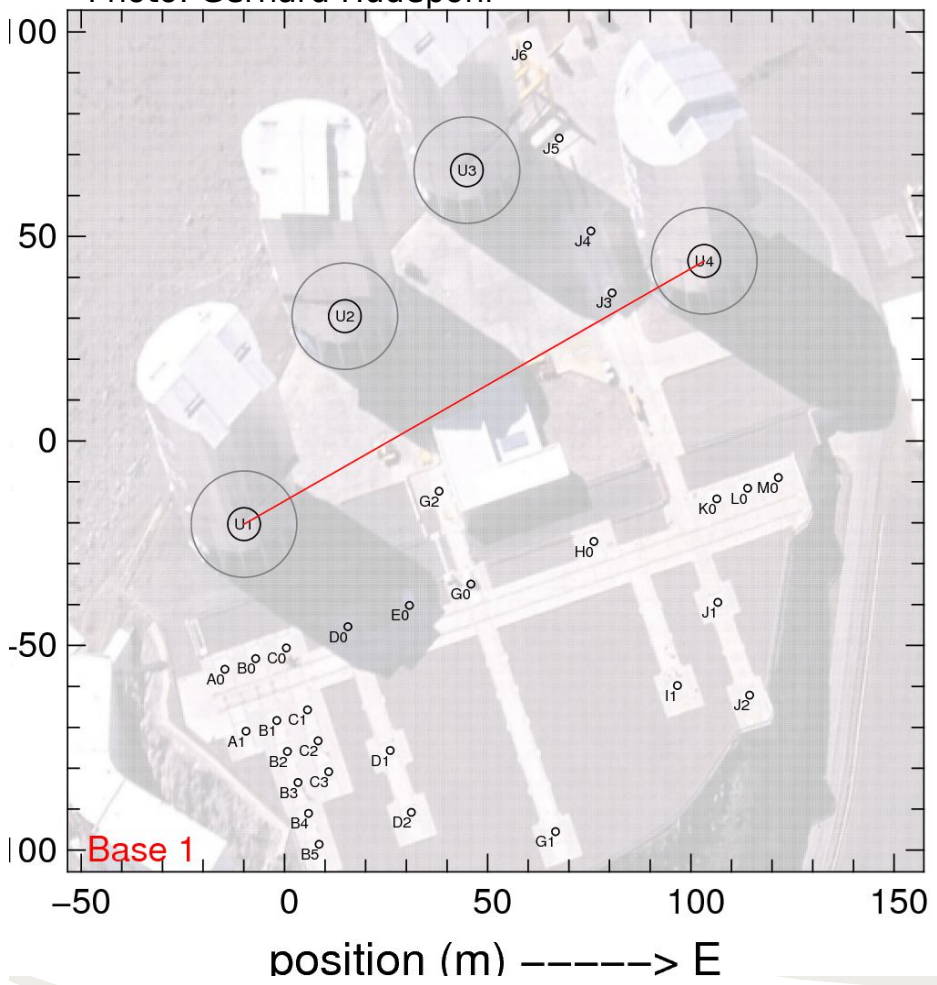
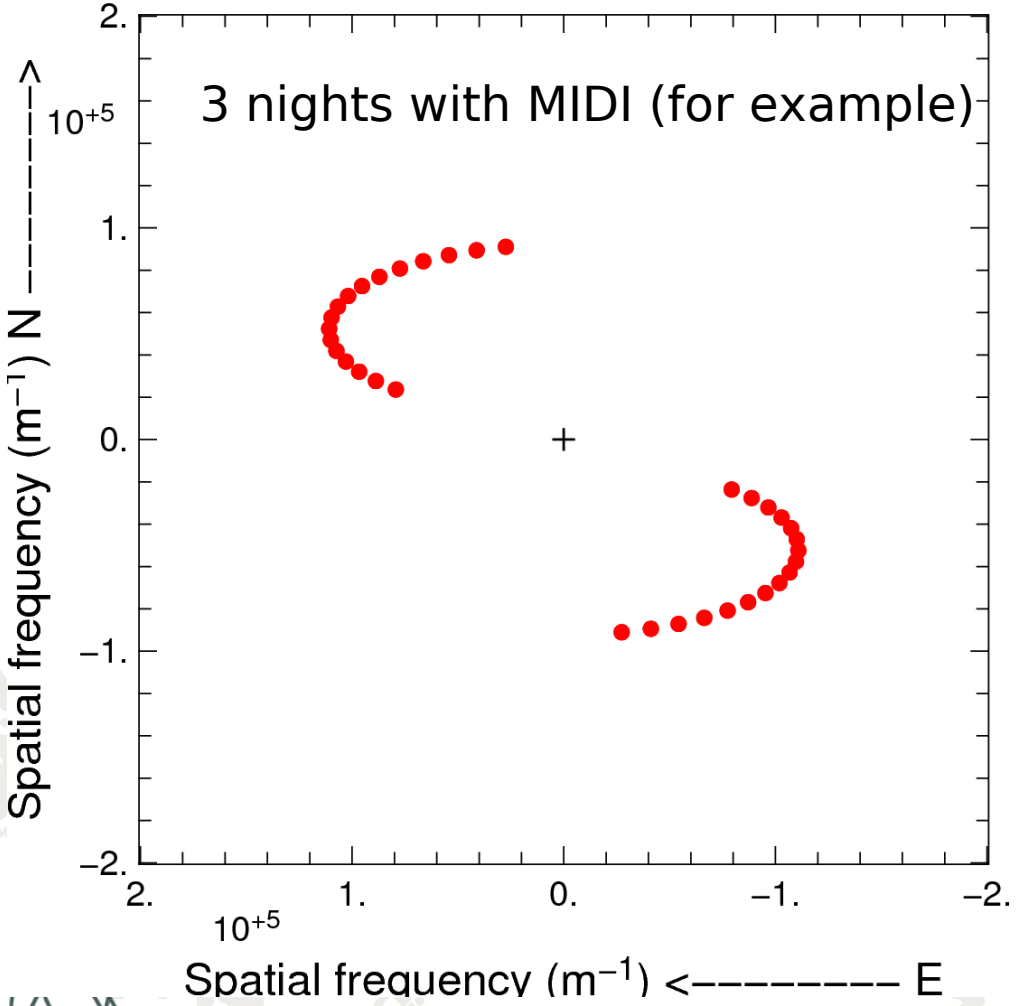


Photo: Gerhard Hüdepohl



Supersynthesis (2T)



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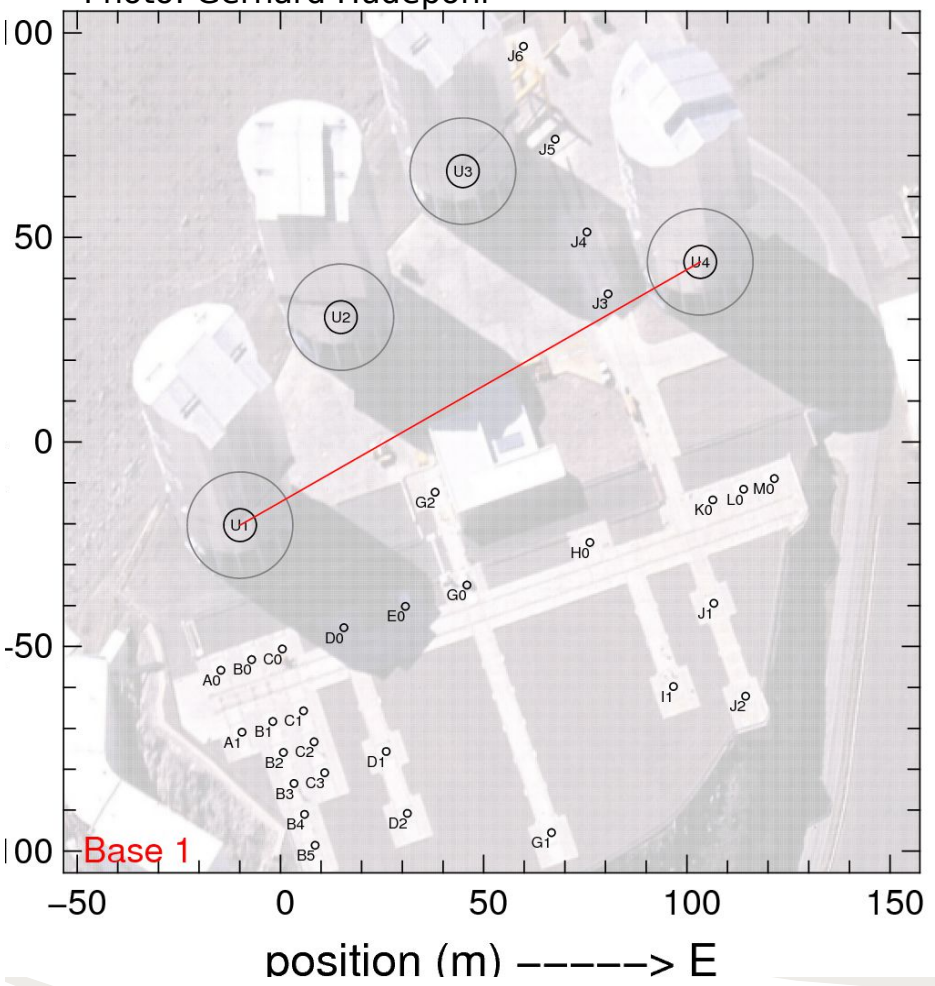


Supersynthesis (2T)

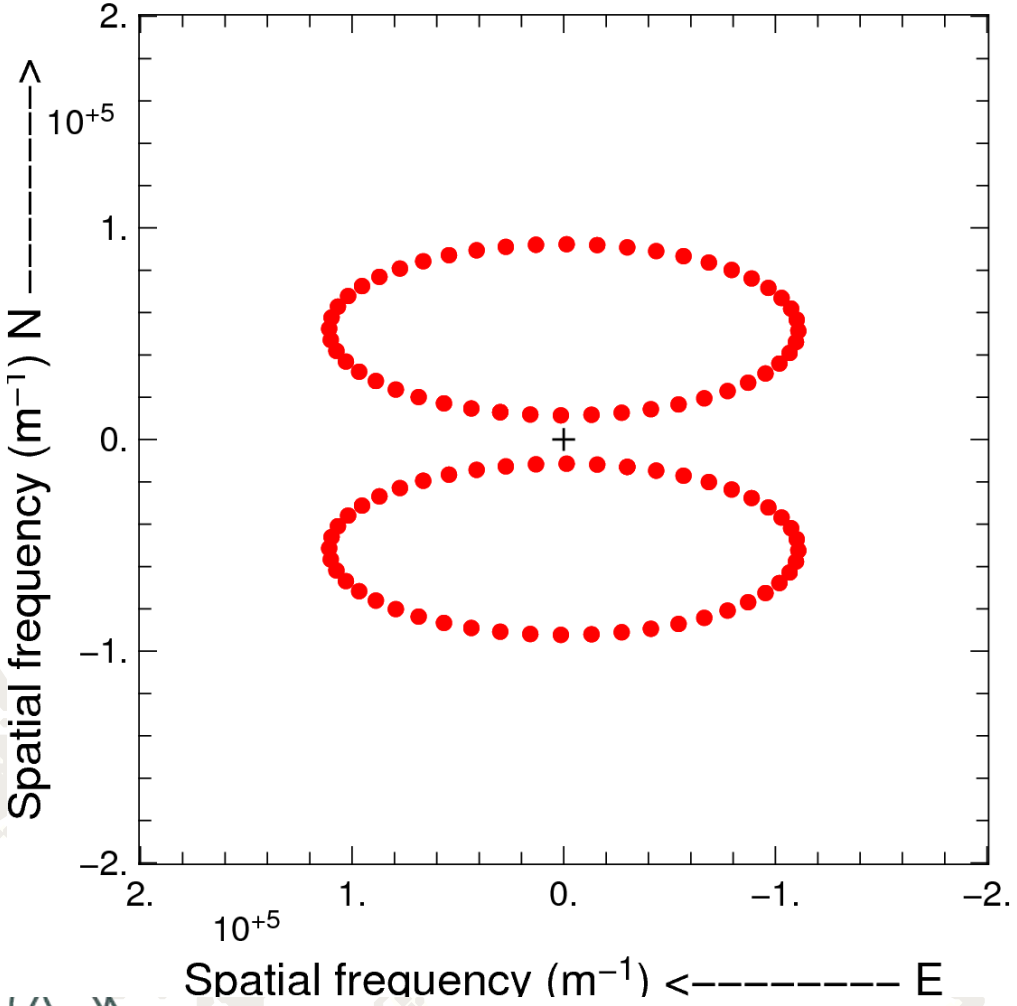
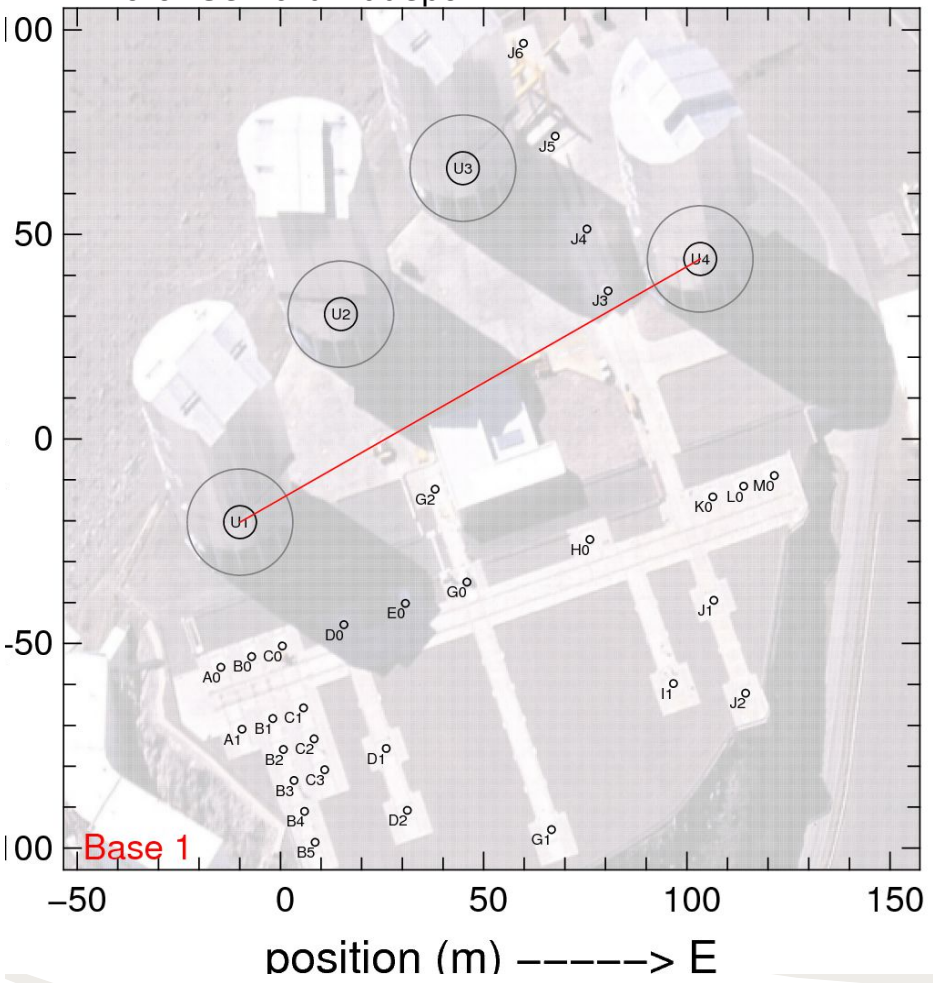


Photo: Gerhard Hüdepohl



Supersynthesis (3T)

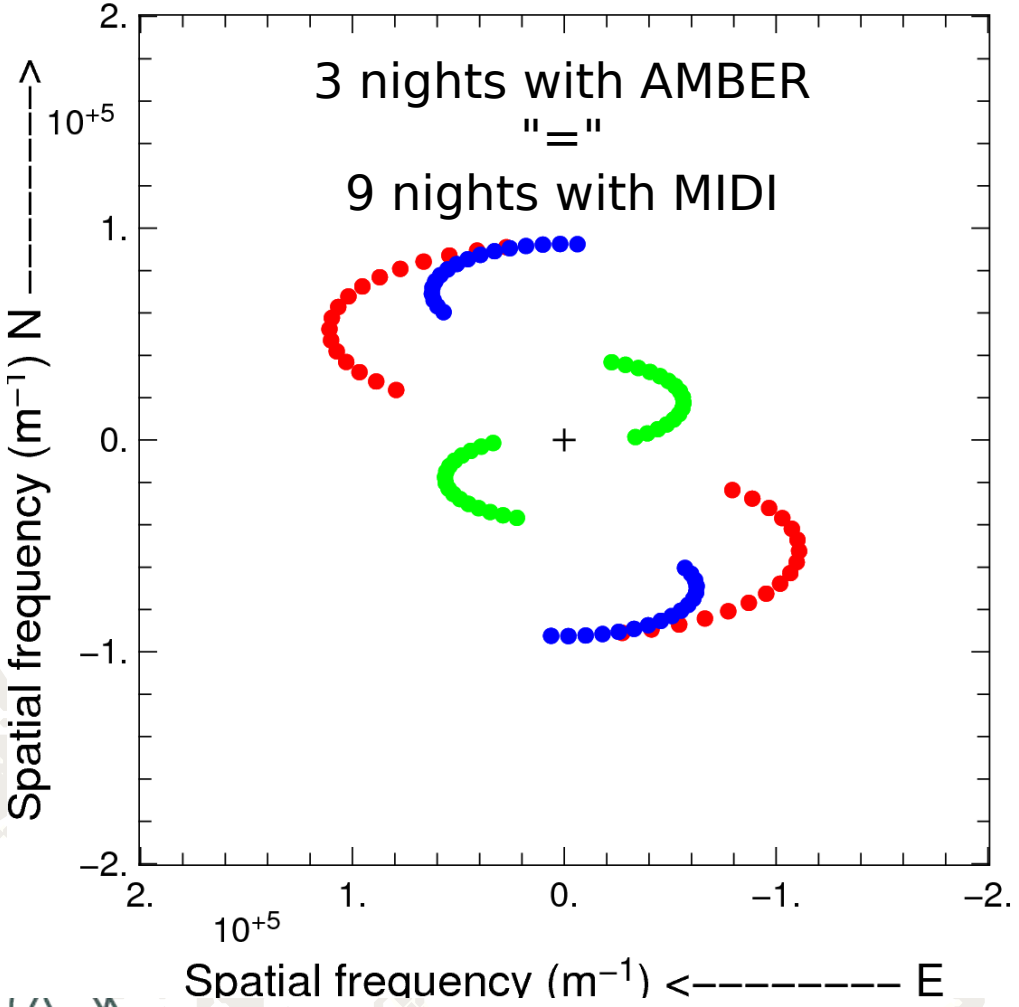
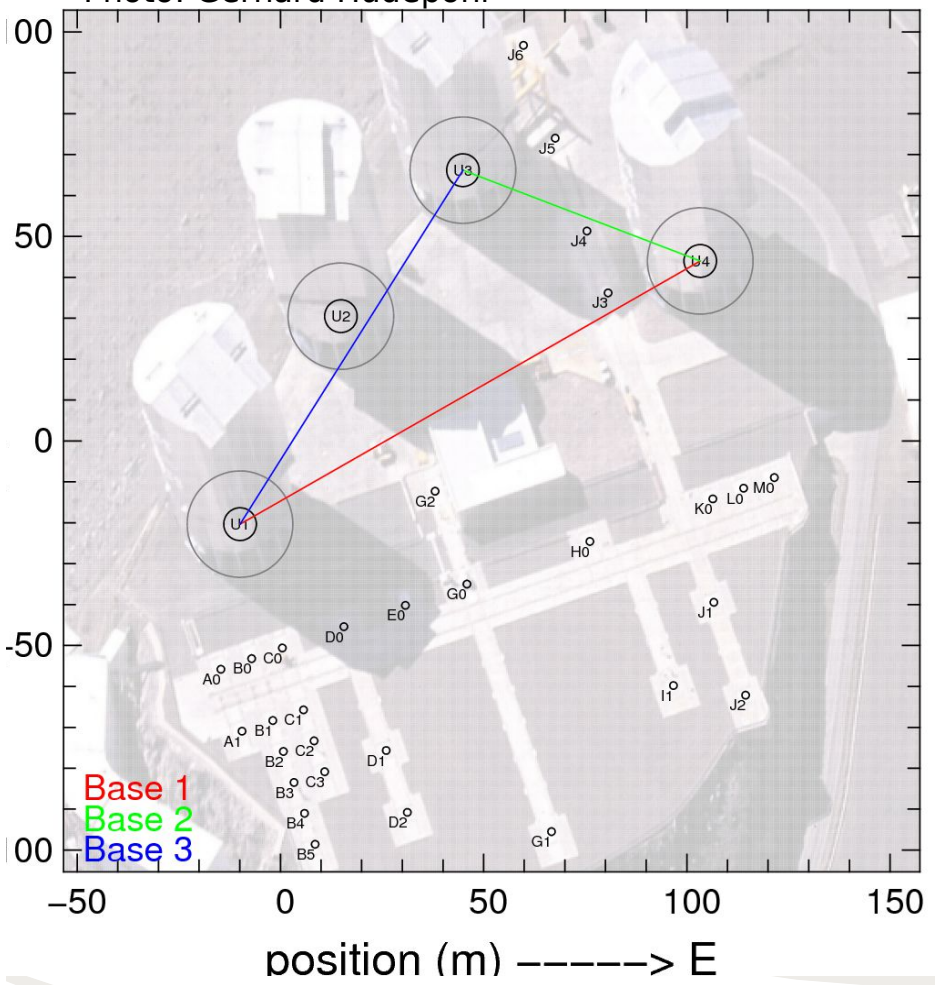


Photo: Gerhard Hüdepohl



Supersynthesis (4T)

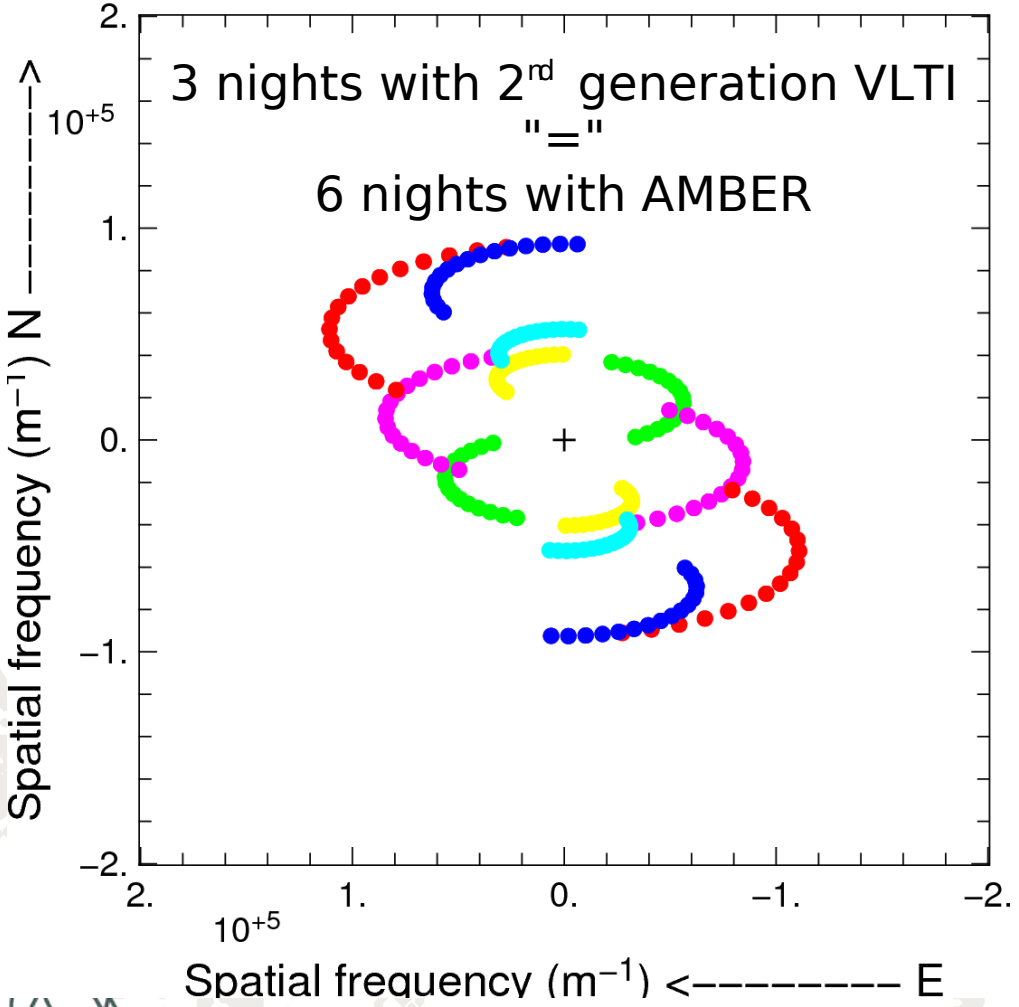
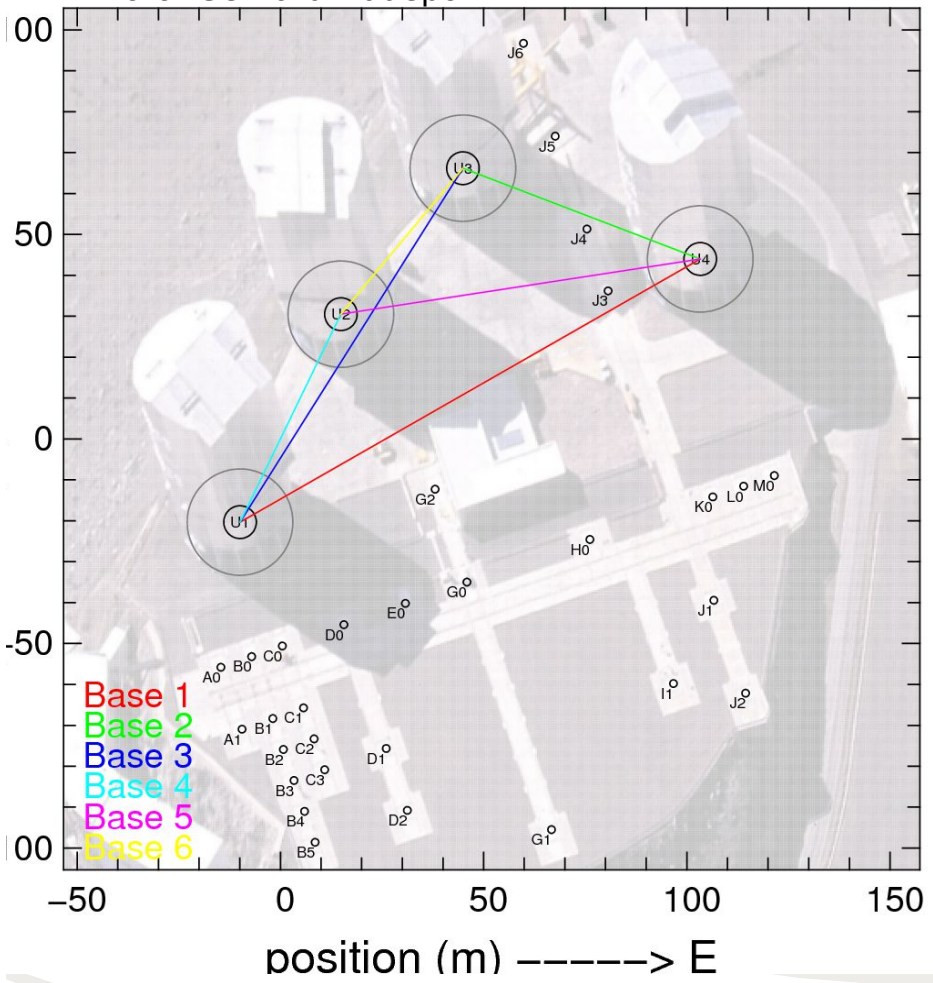


Photo: Gerhard Hüdepohl



Supersynthesis (8T)

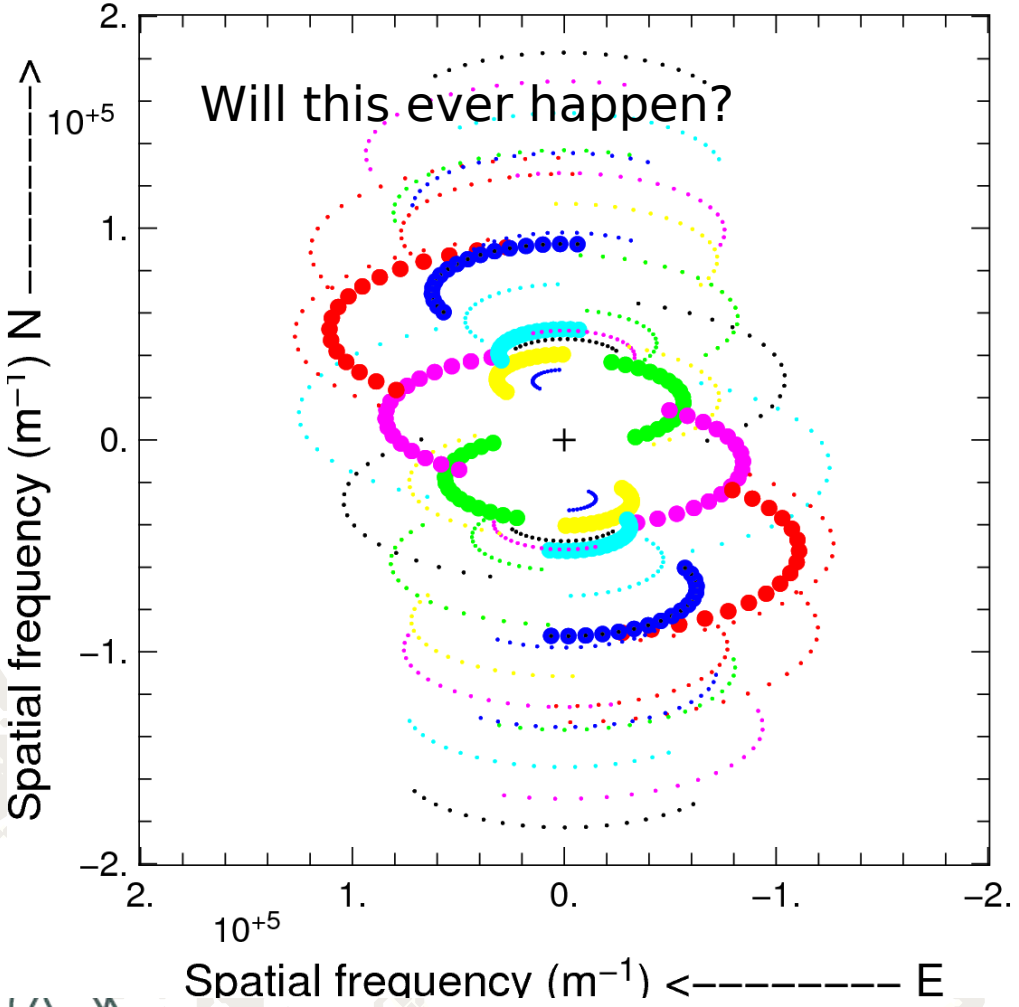
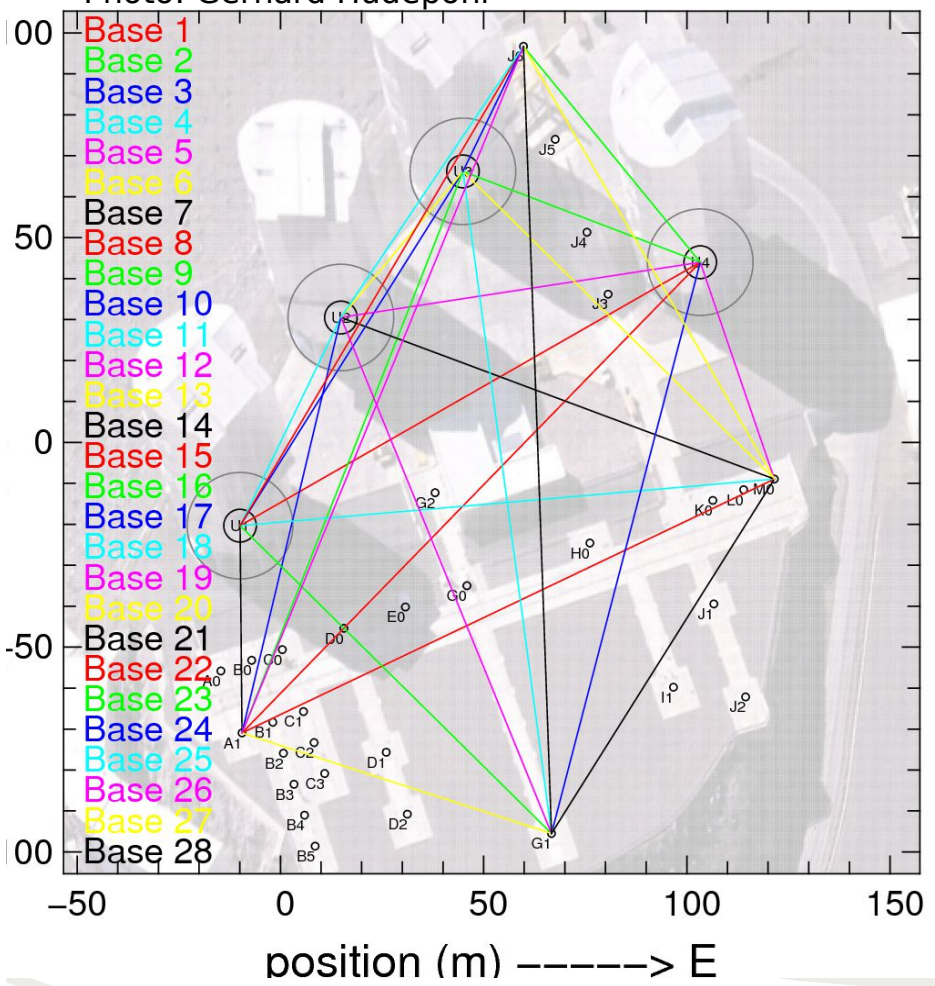


Photo: Gerhard Hüdepohl



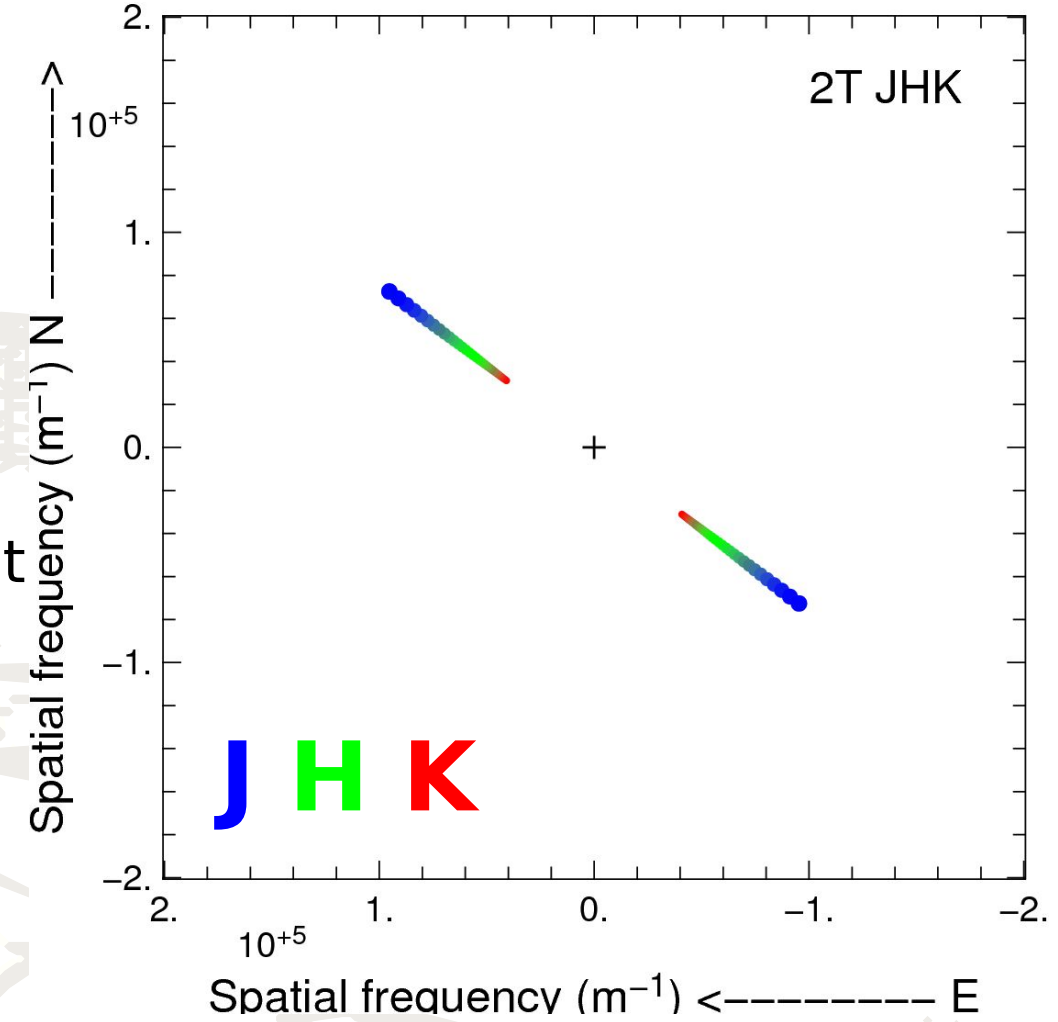
(u,v) plane filling with spectral coverage

- 2T

- **Spatial frequencies:**

$$f = B/\lambda$$

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



Supersynthesis + spectral coverage (2T)

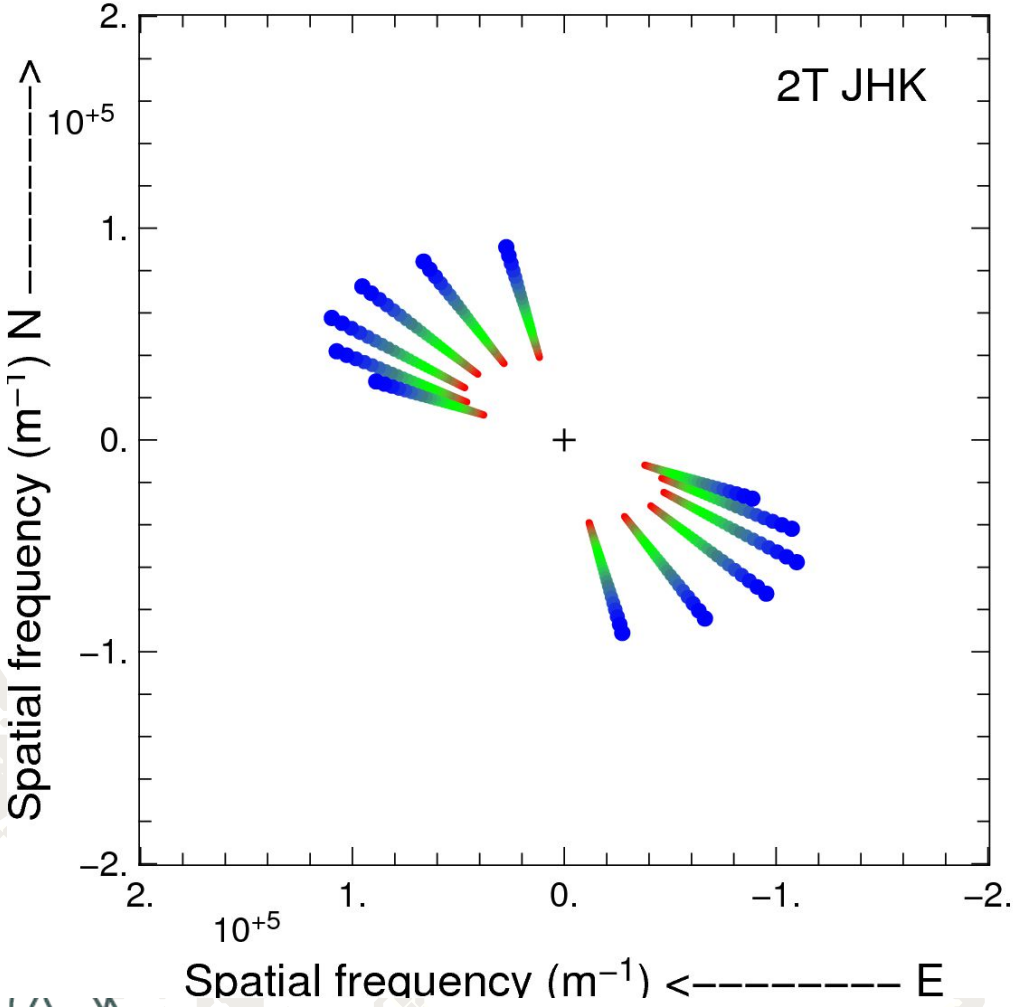
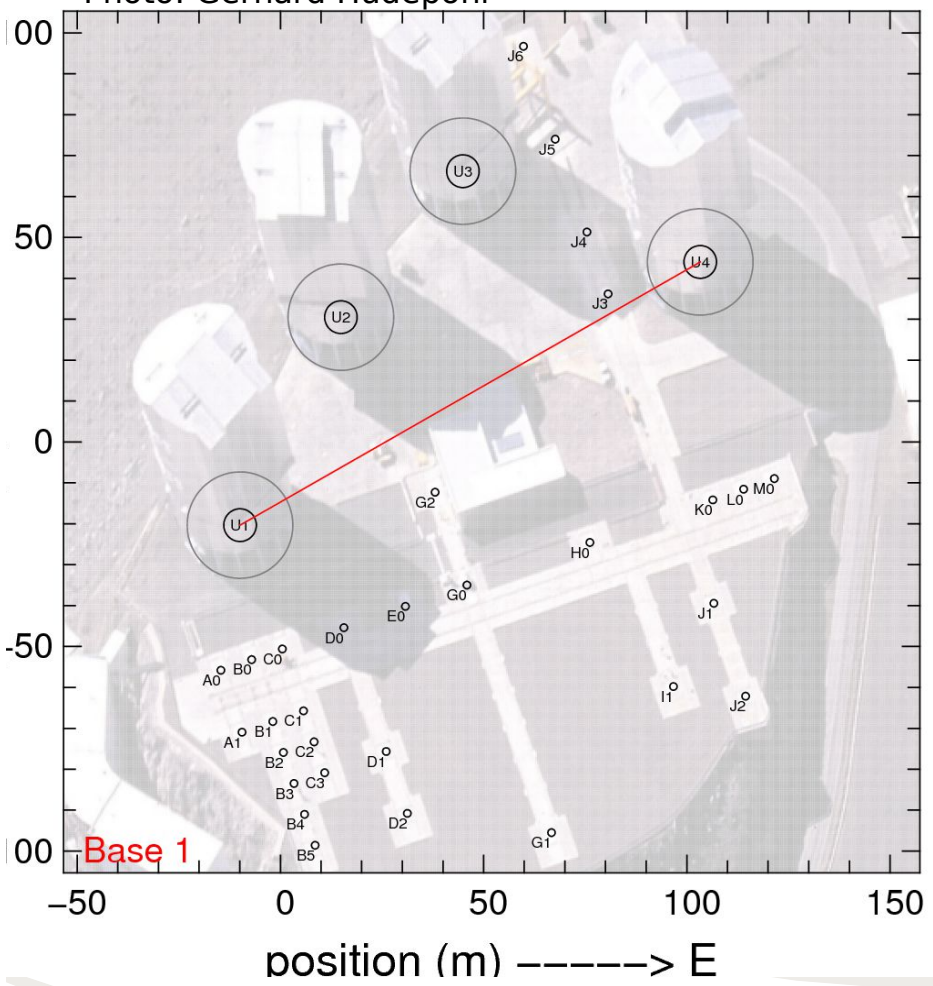


Photo: Gerhard Hüdepohl



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Supersynthesis + spectral coverage (3T)

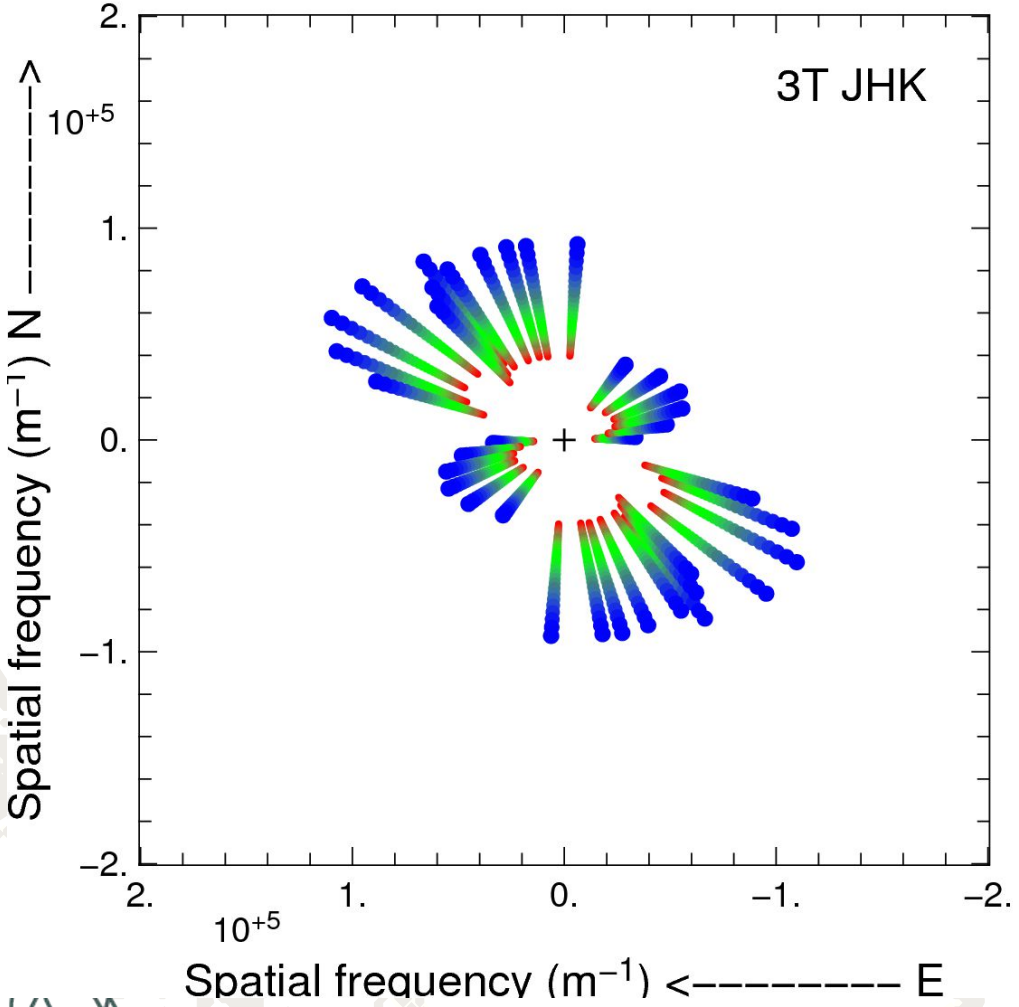
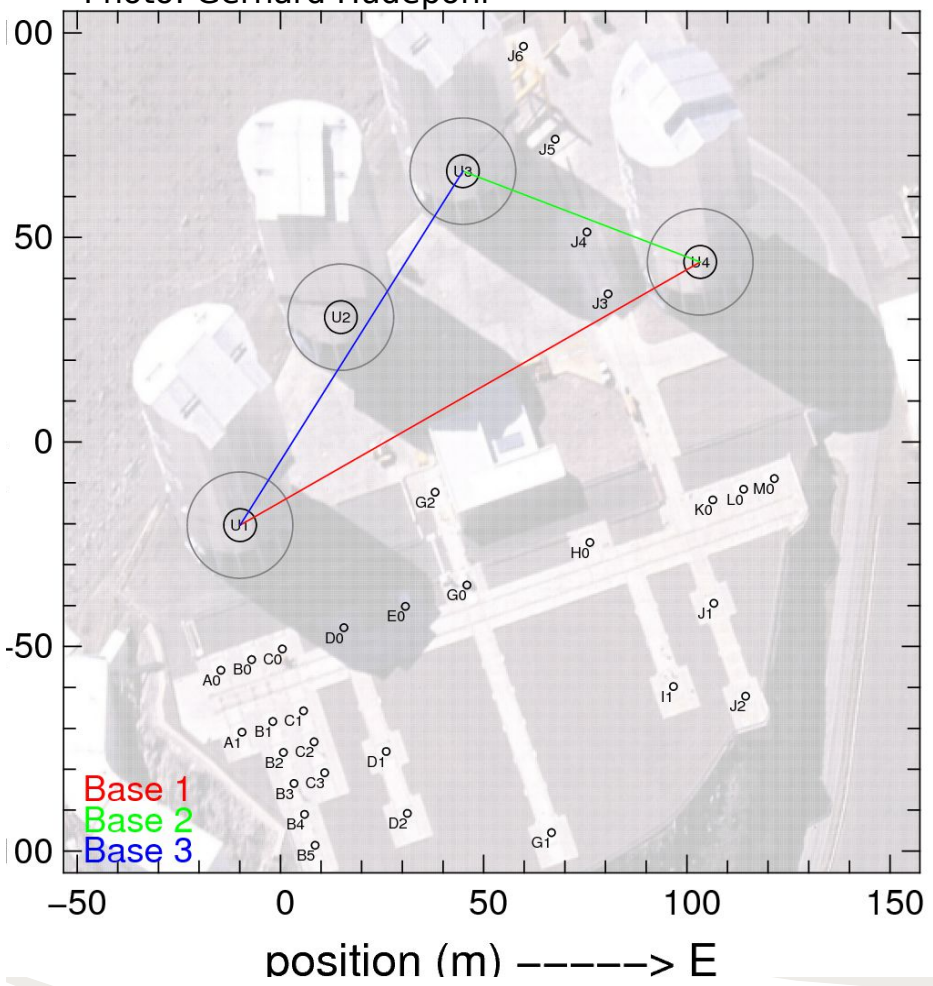


Photo: Gerhard Hüdepohl



Supersynthesis + spectral coverage (4T)

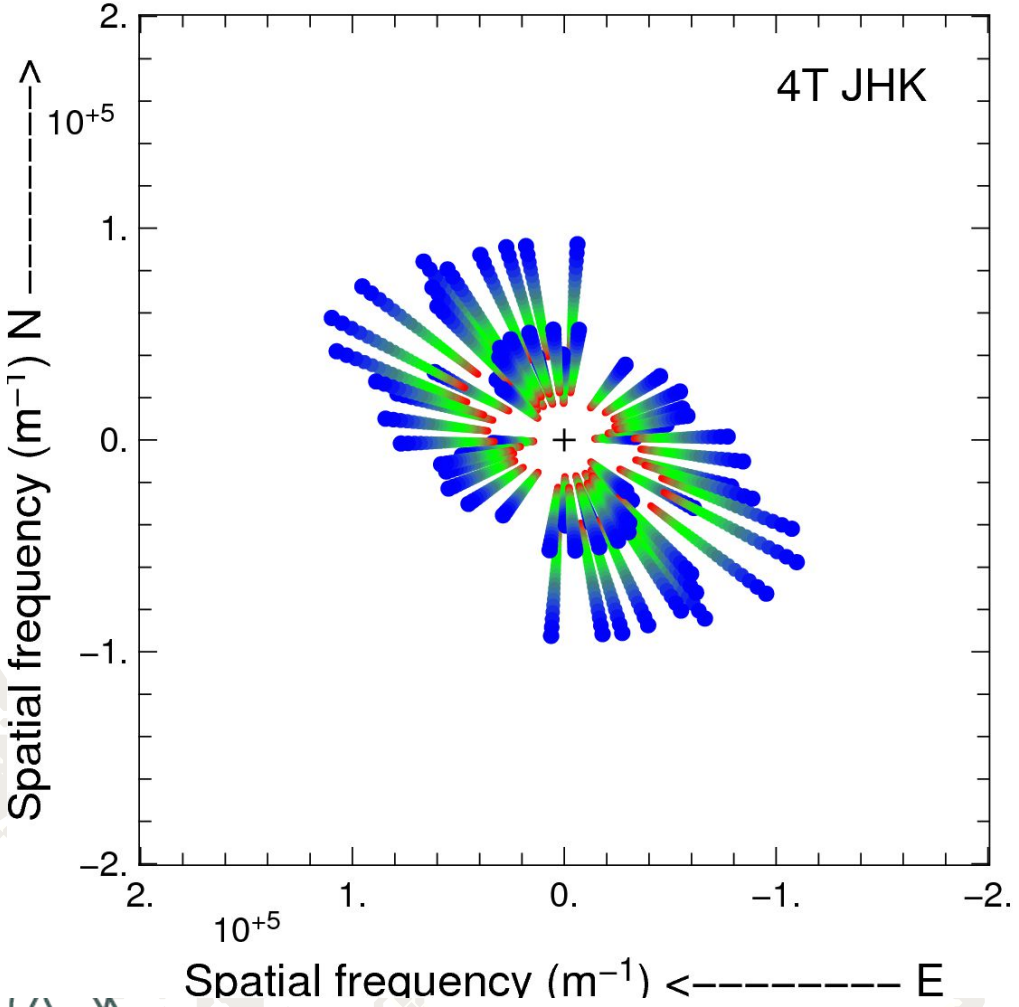
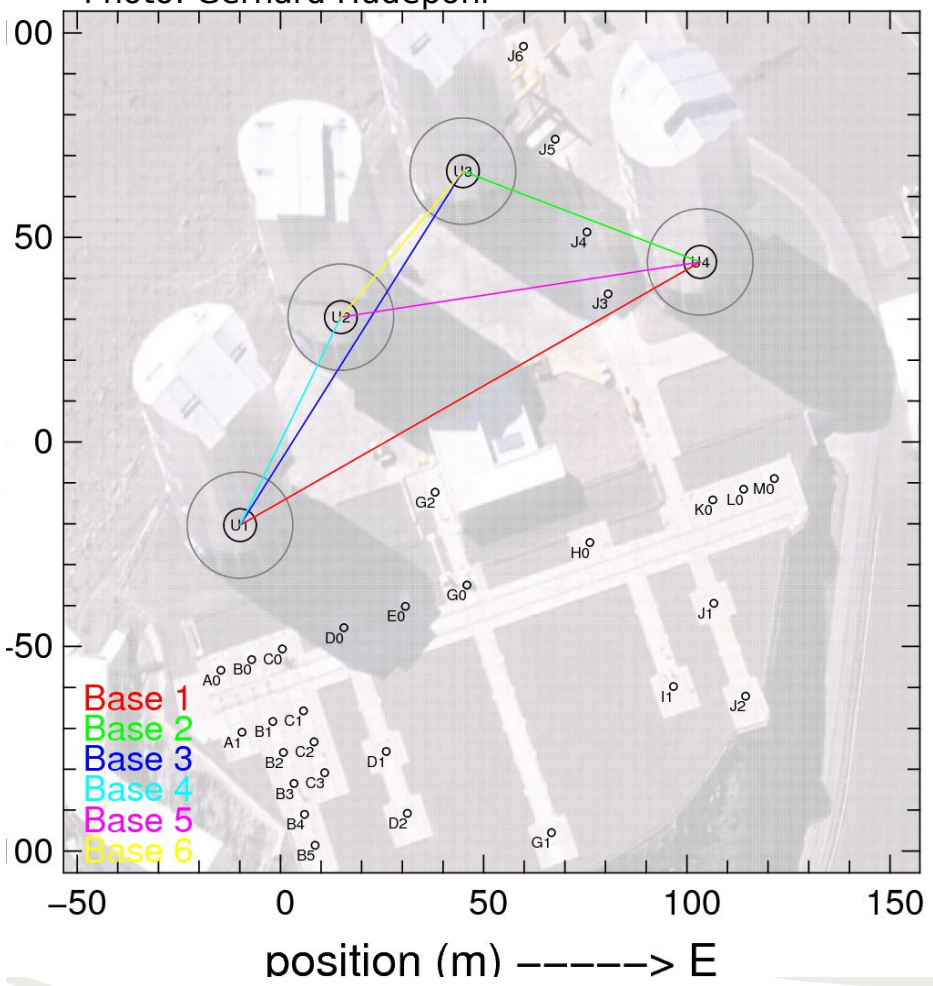


Photo: Gerhard Hüdepohl



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Supersynthesis + spectral coverage (8T)

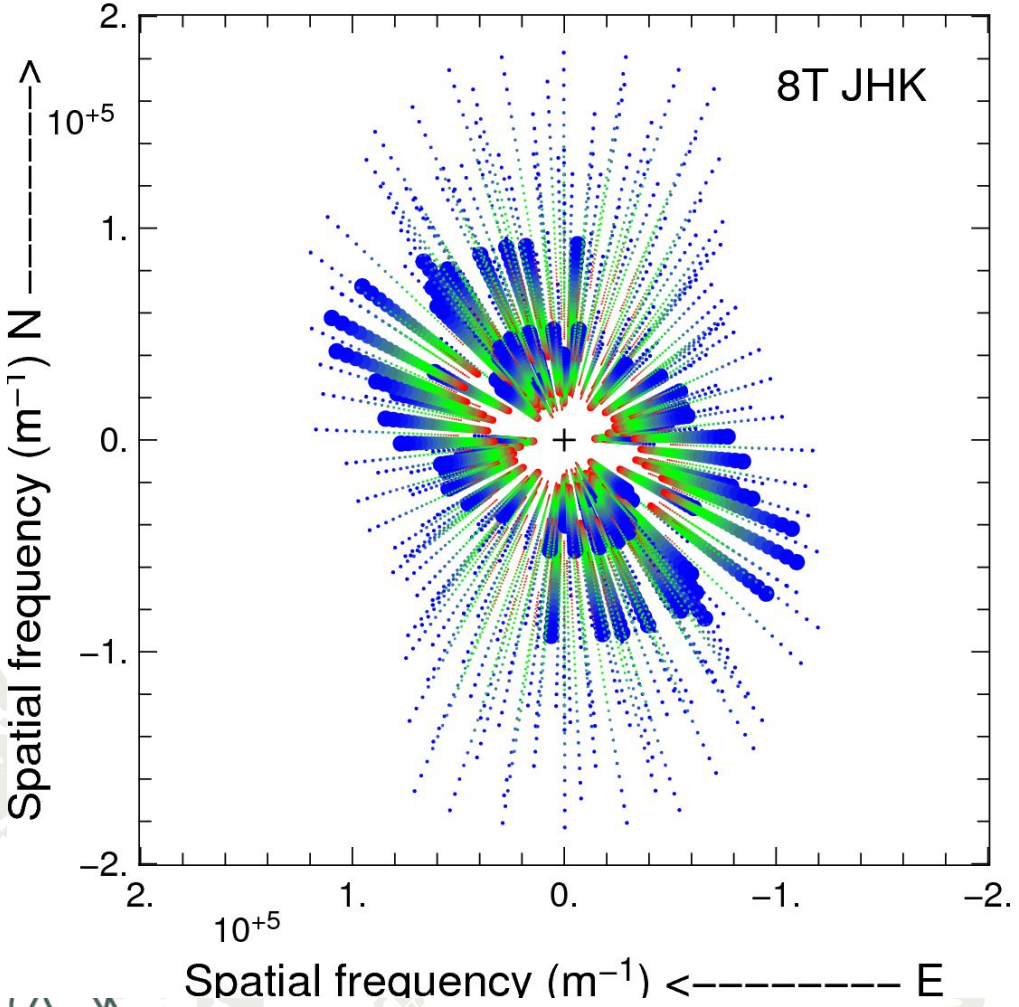
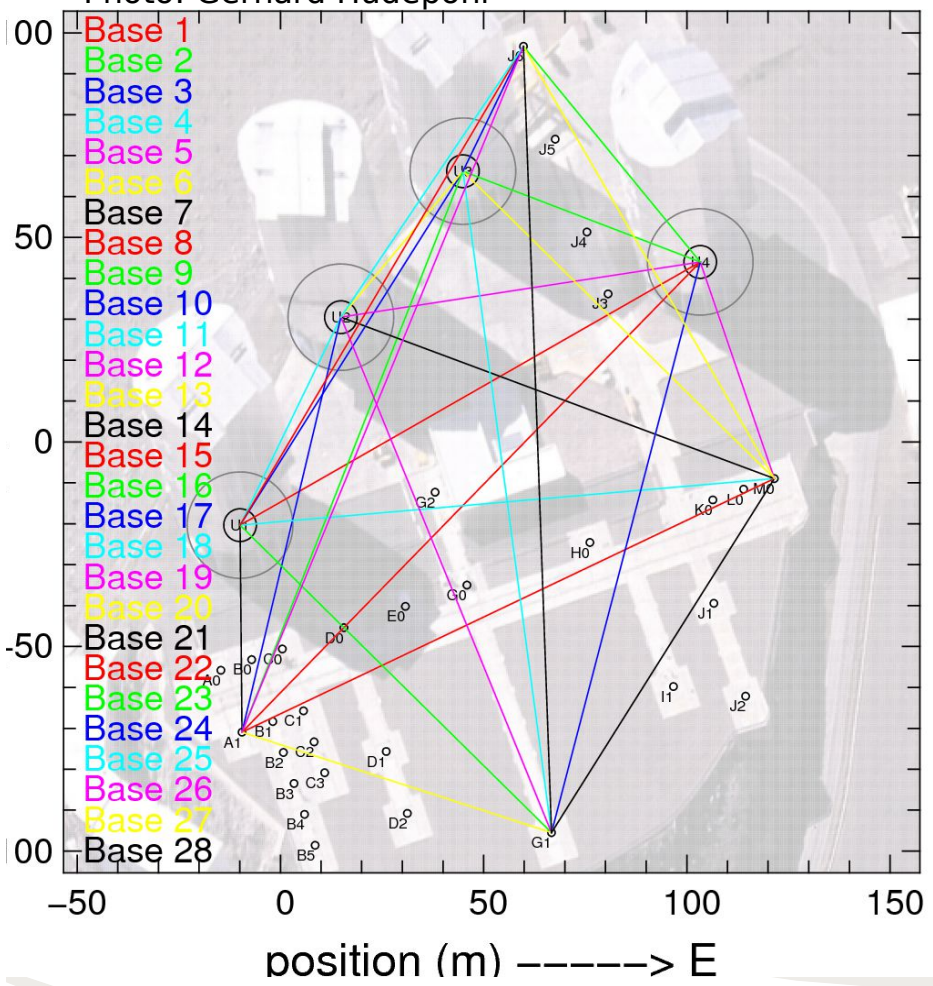


Photo: Gerhard Hüdepohl



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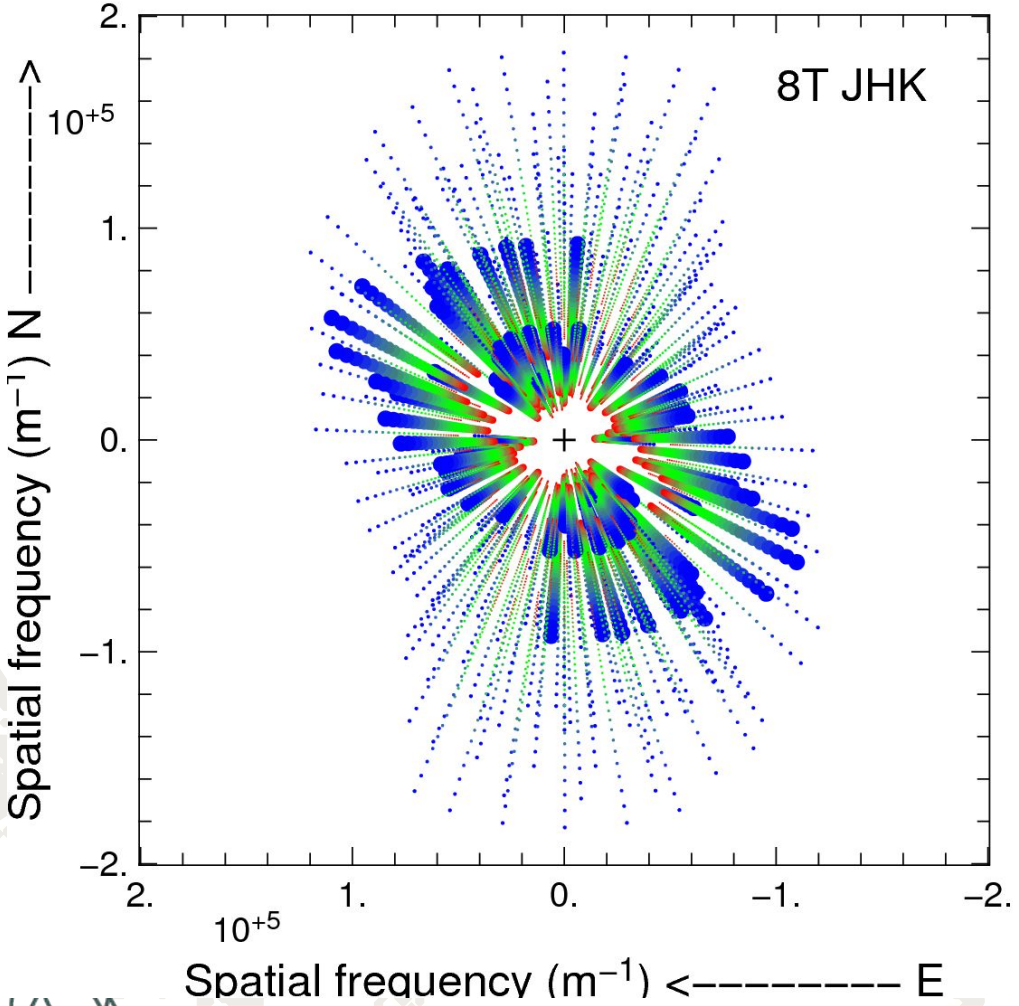
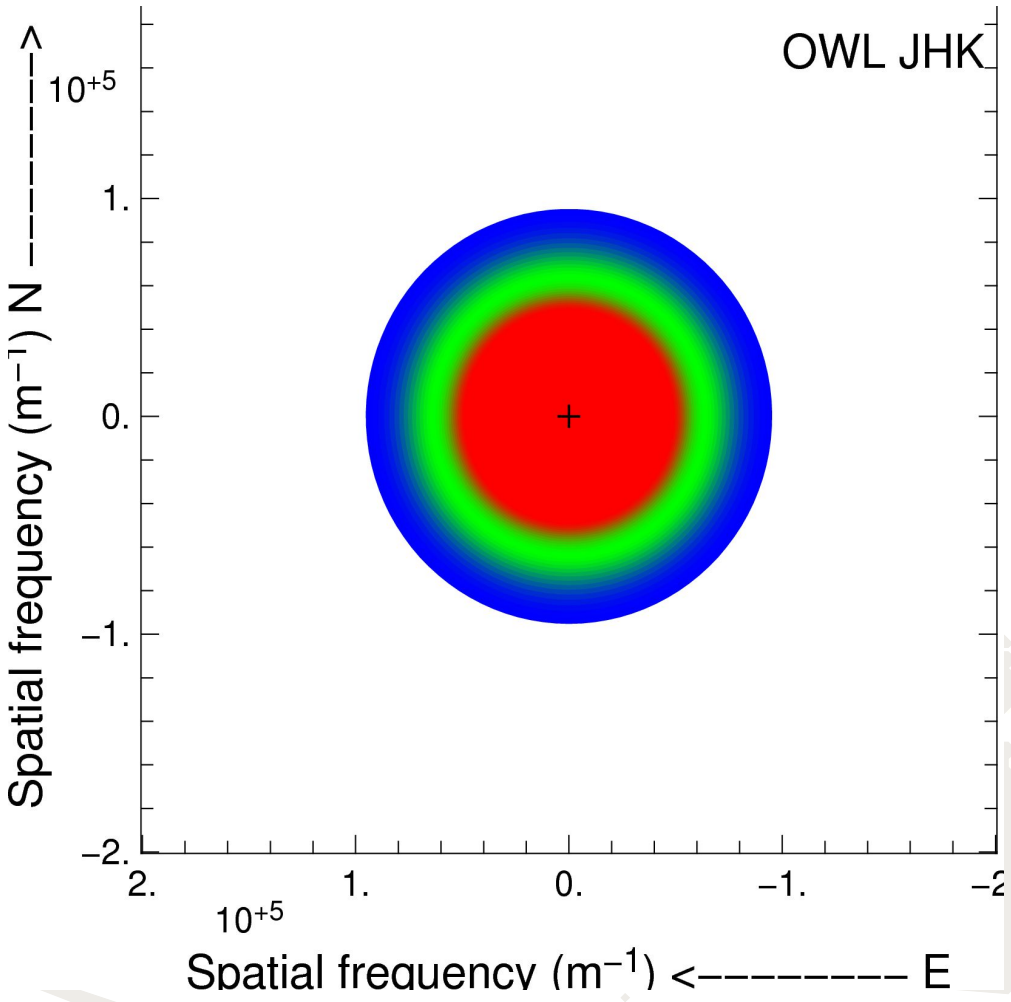
Supersynthesis + spectral coverage (8T)





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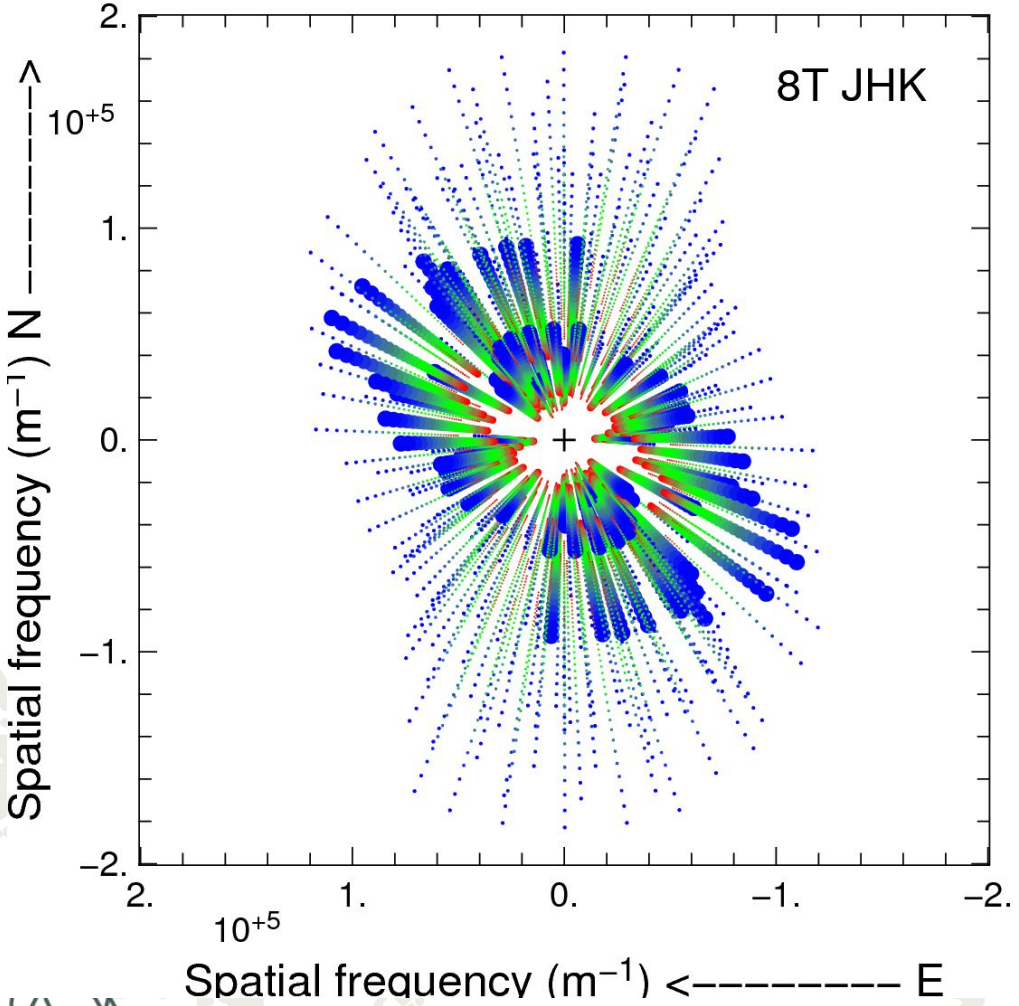
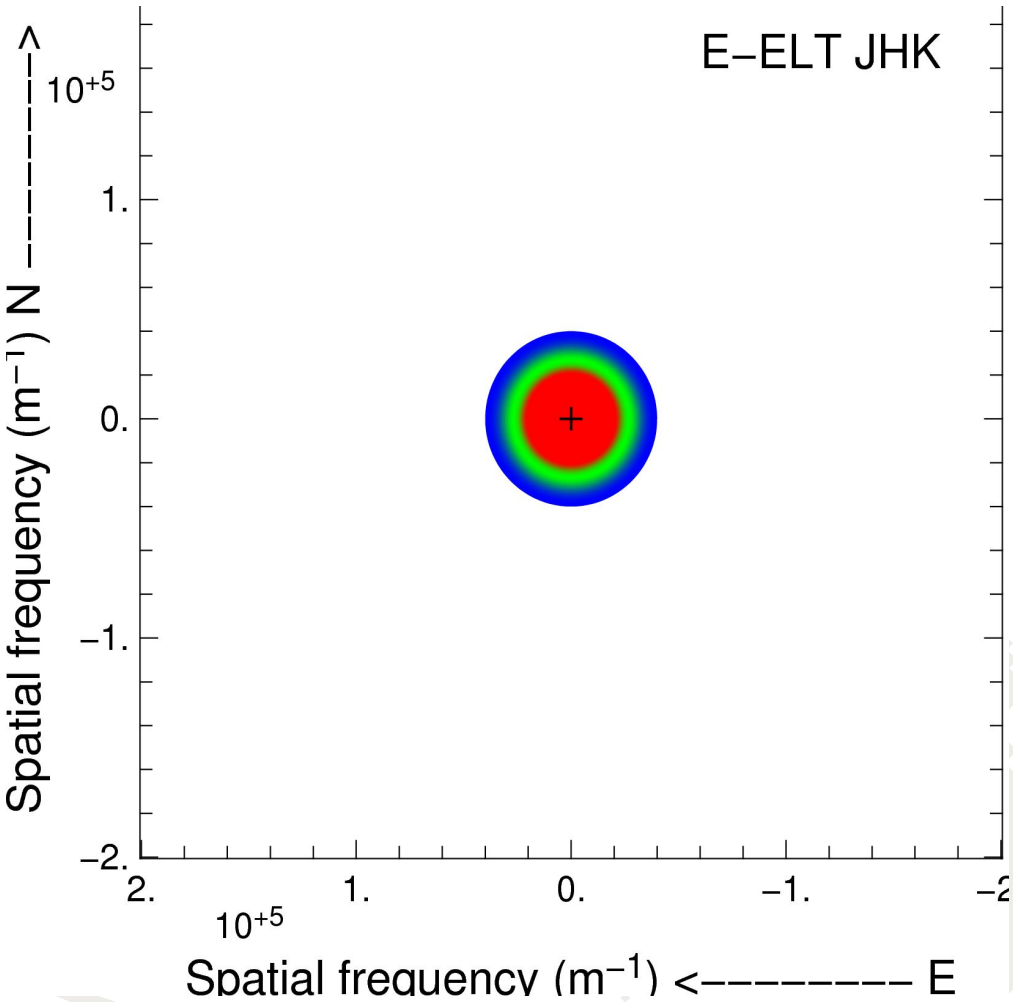
Supersynthesis + spectral coverage (8T)





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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
  vs
  “advanced” model fitting
  vs
  imaging

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

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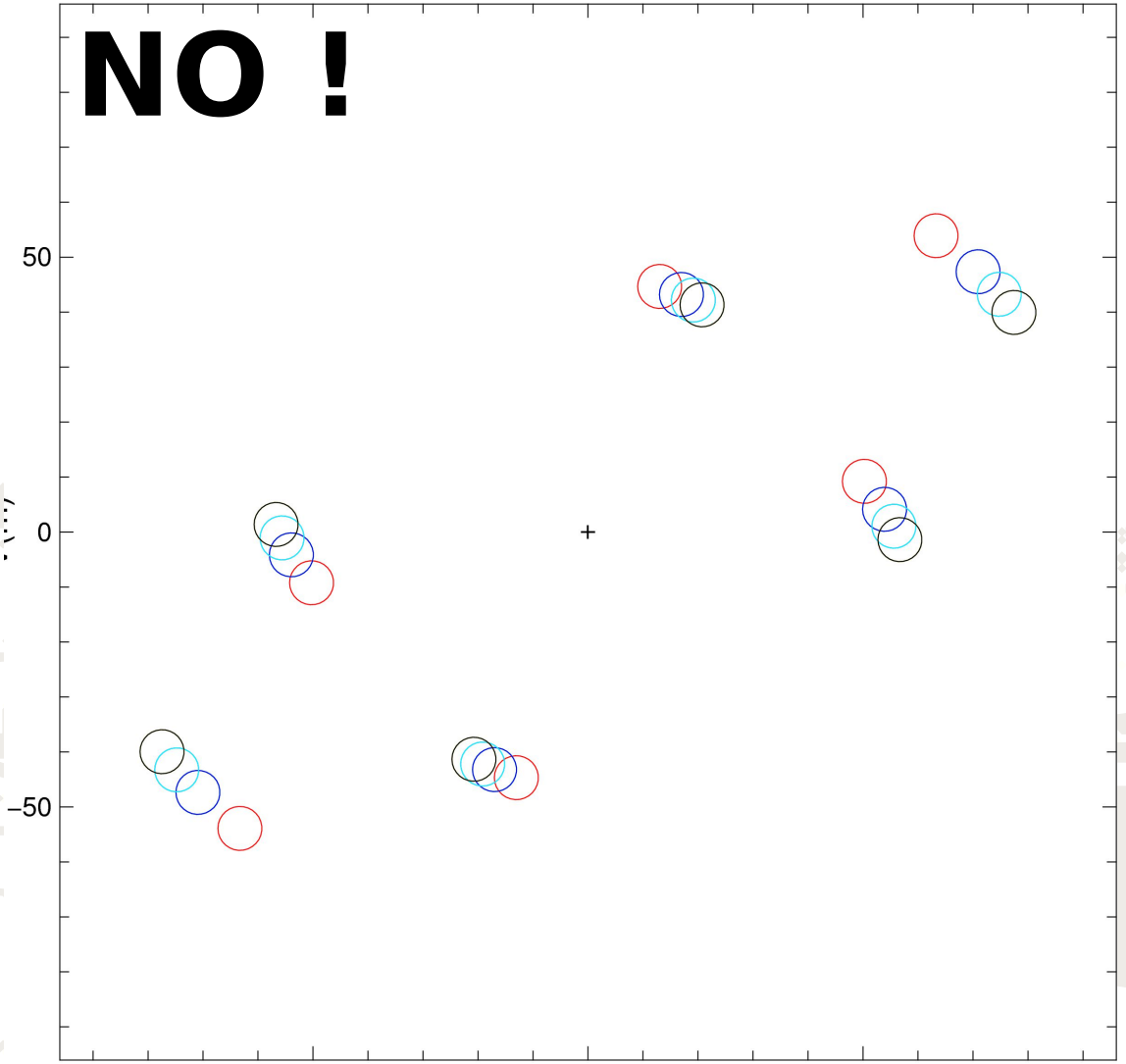
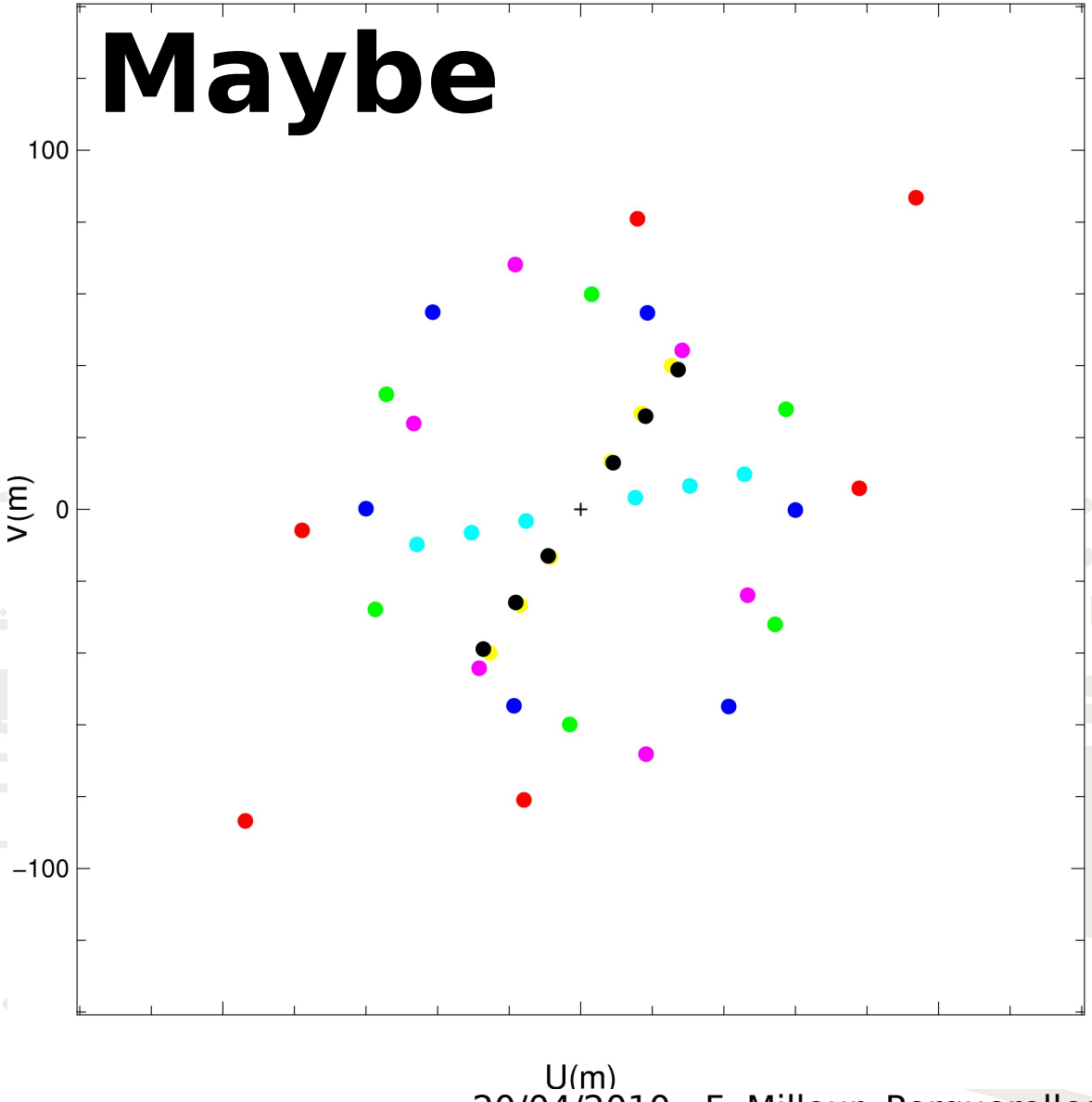
Is your UV plane suitable for imaging ?



Is your UV plane suitable for imaging ?



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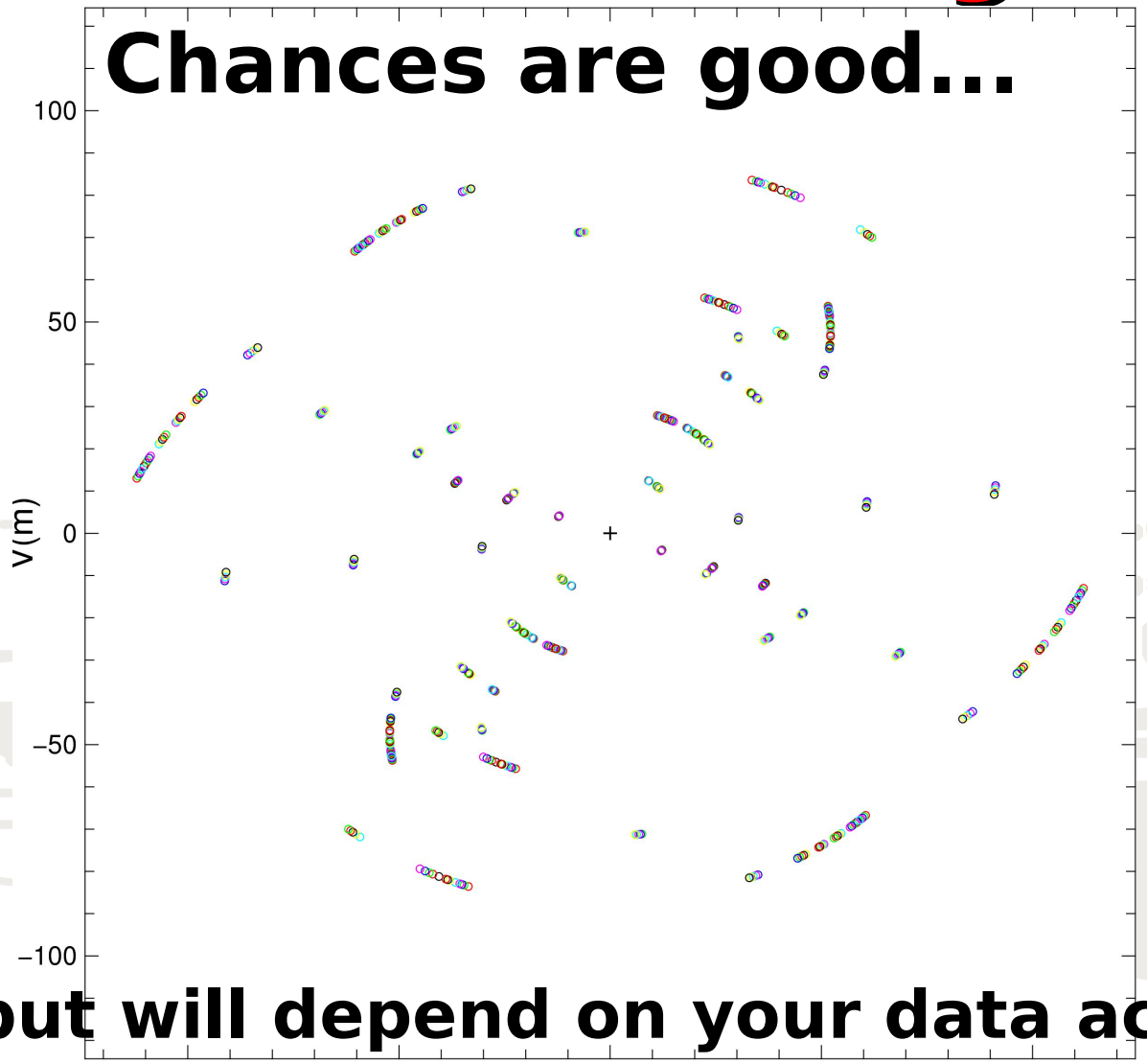
Is your UV plane suitable for imaging ?



...but will depend on your data accuracy

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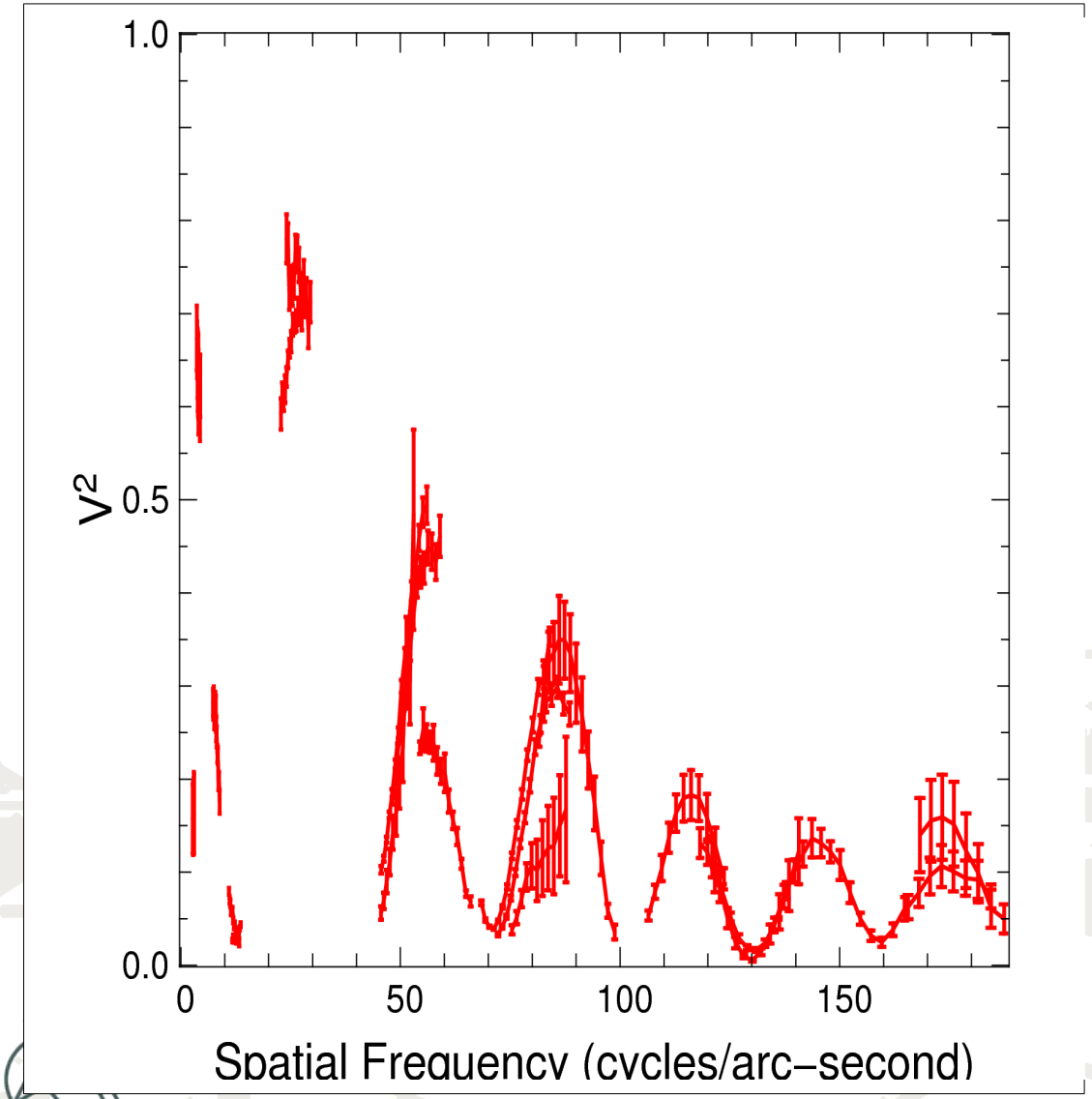
Example (1)

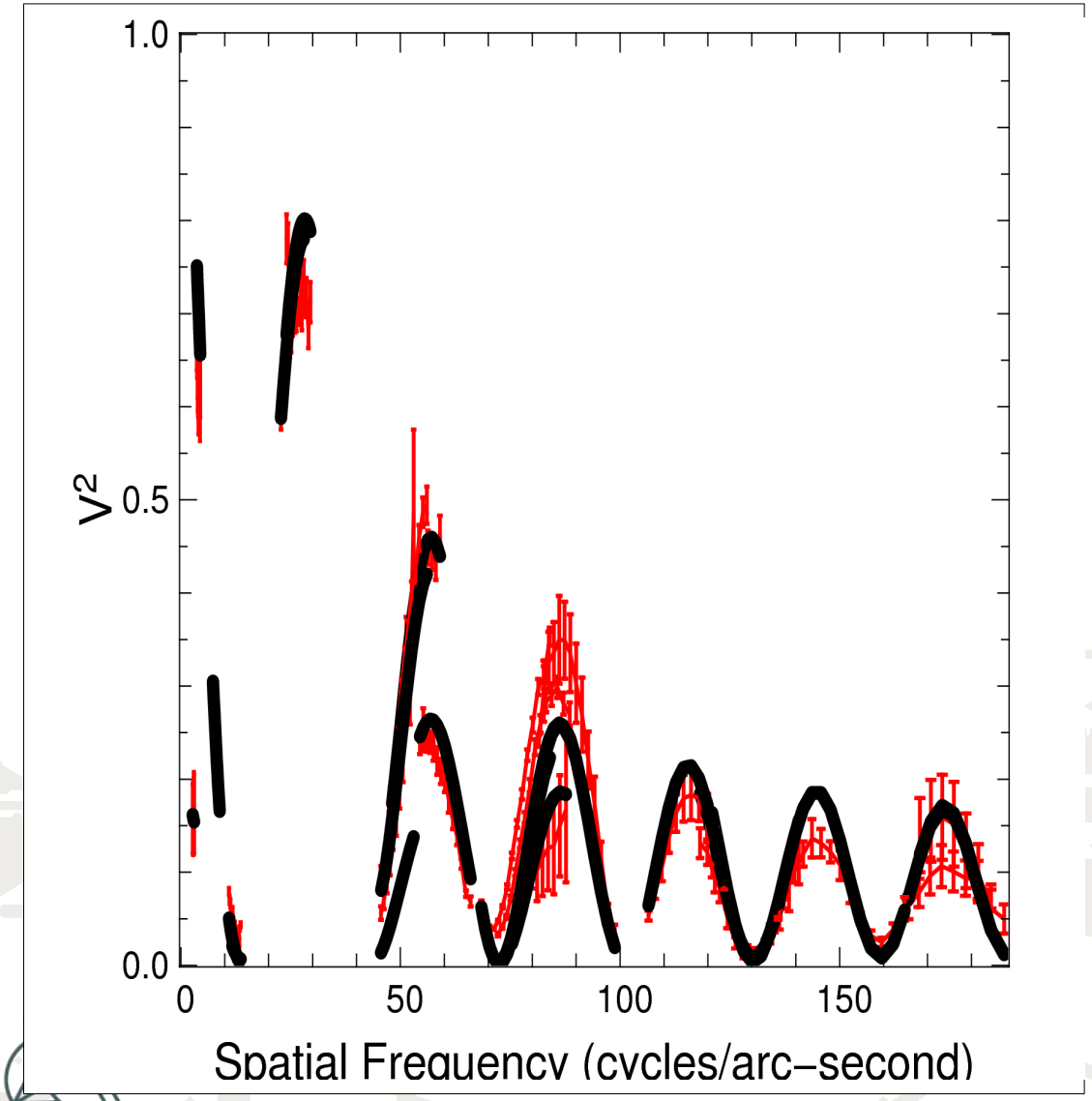


HD87643, Millour et al. in prep, 2008(9?)

Binary star + enveloppe

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

Example (1)

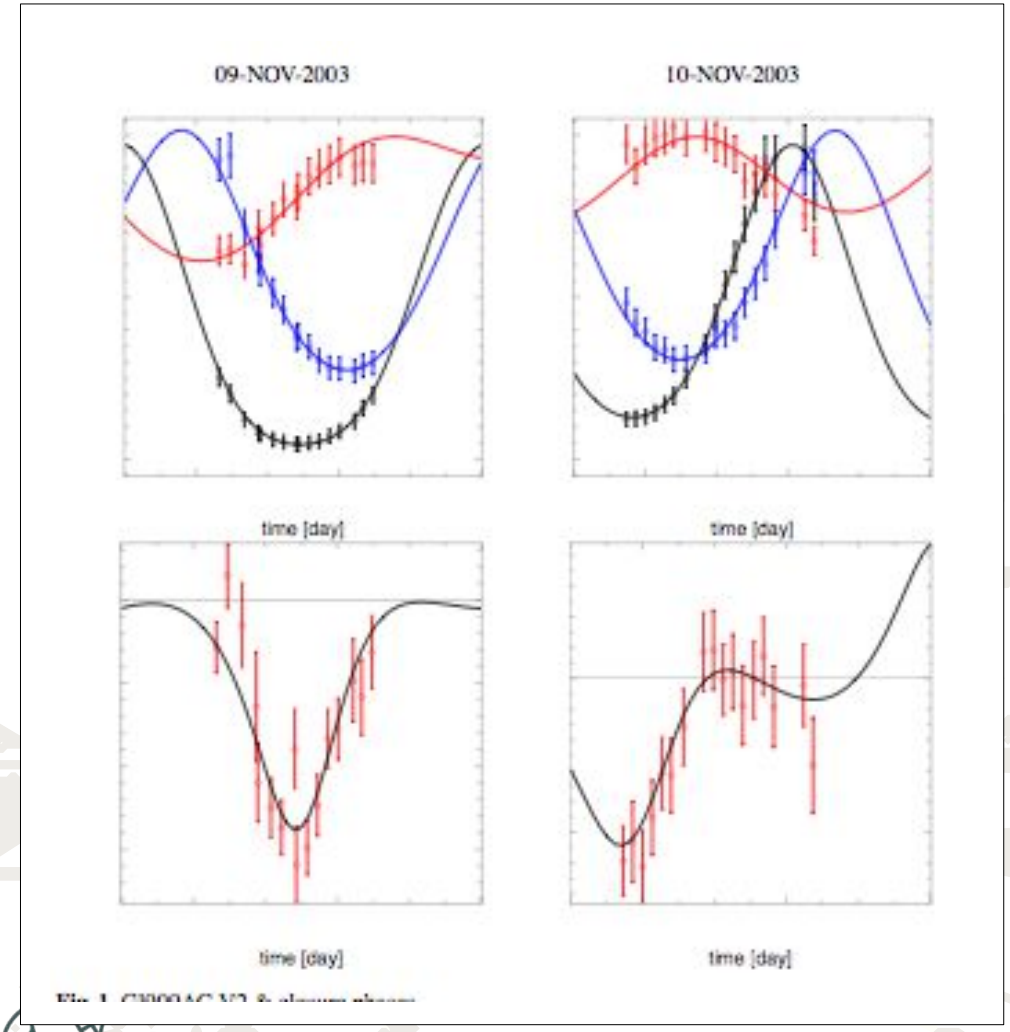


HD87643, Millour et al. in prep, 2008(9?)

Binary star + enveloppe

- N telescopes = 3
- accuracy on V^2 > 5%
- moderate UV coverage
- use of spectral coverage to improve UV coverage

Example (2)

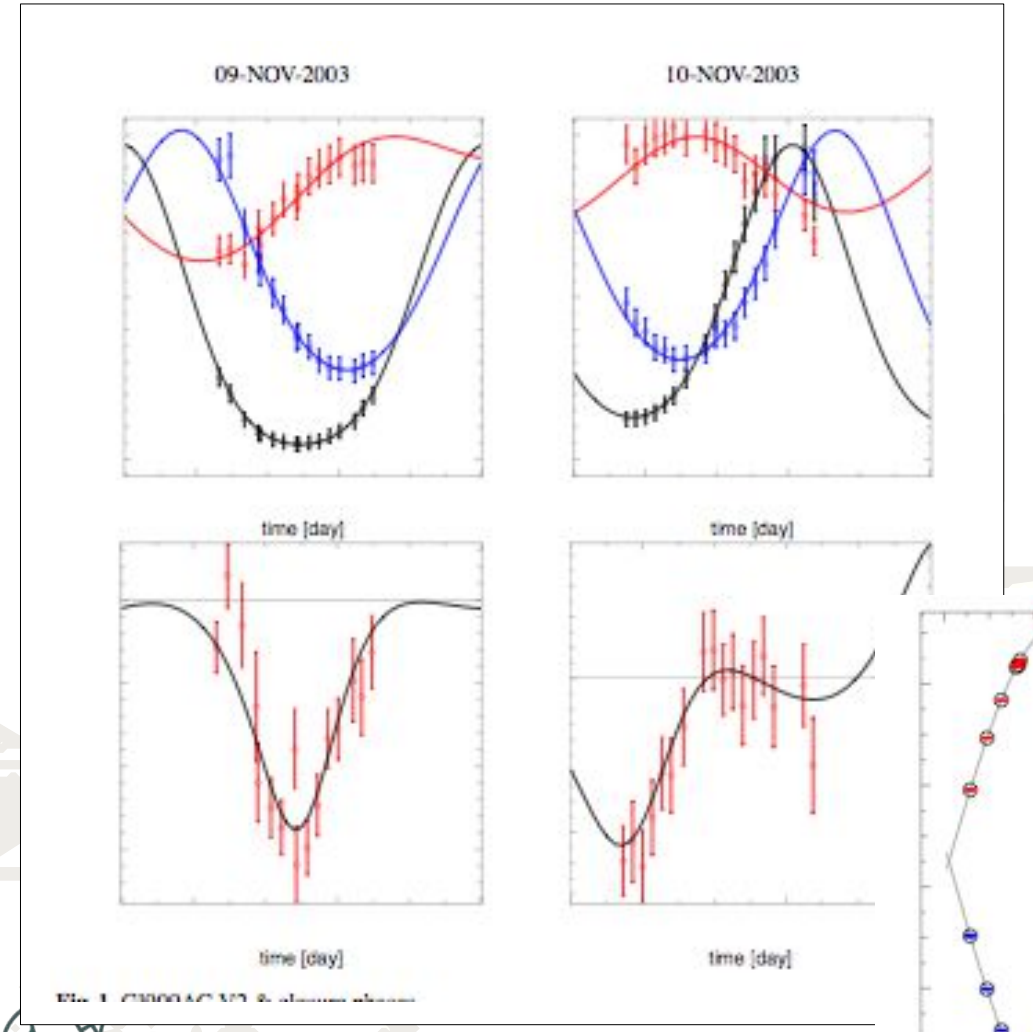


Segransan 2006 (Goutelas)

Binary star observation with IOTA

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

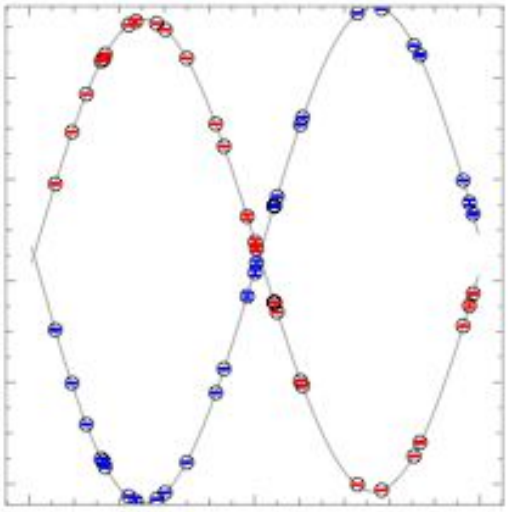
Example (2)

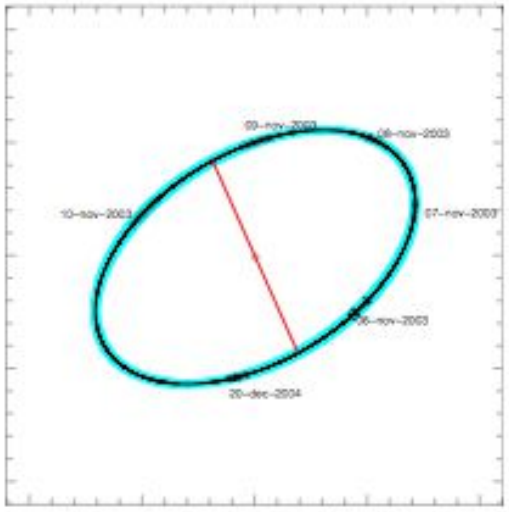


Segransan 2006 (Goutelas)

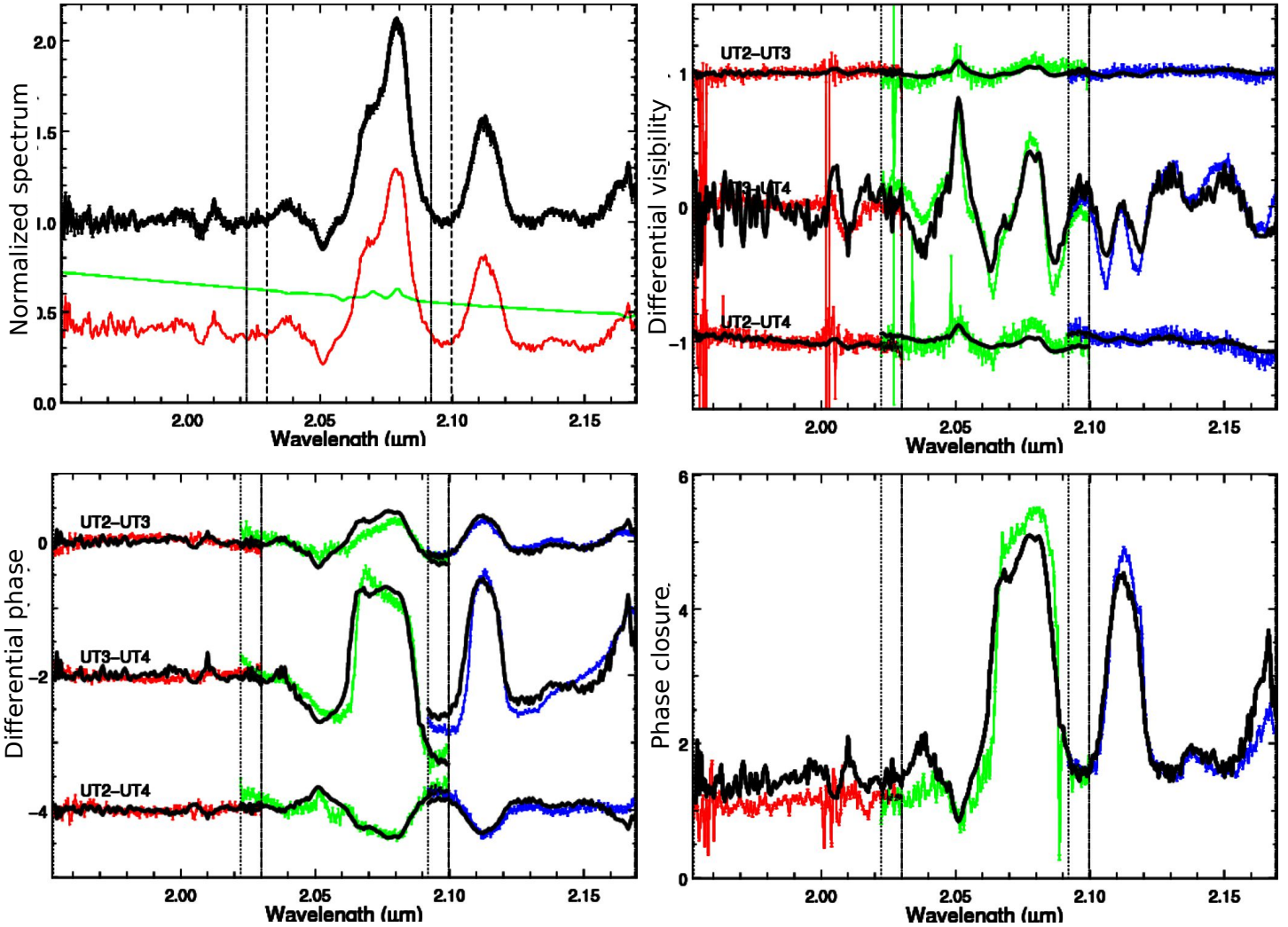
Binary star observation with IOTA

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





Example (3)

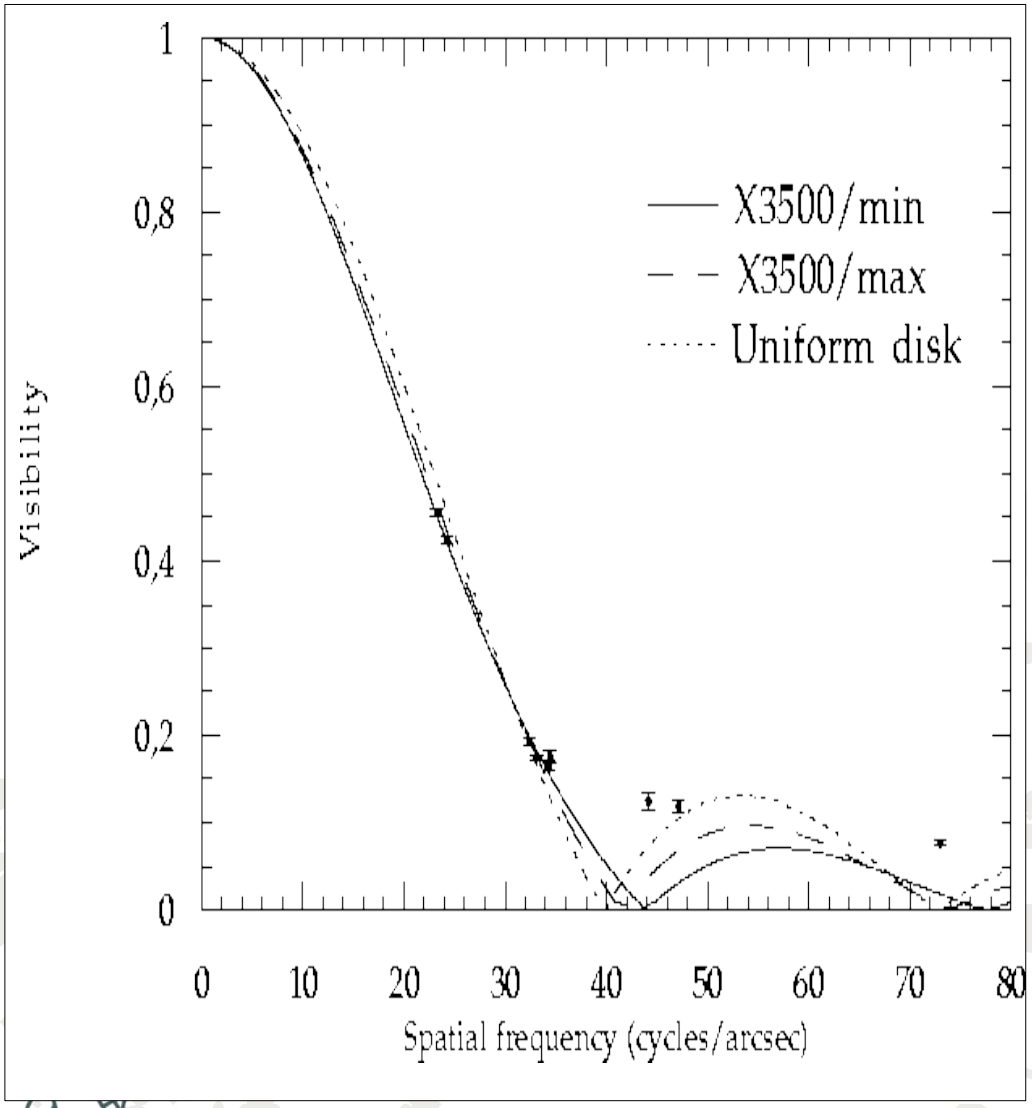


Very poor (u,v) coverage (1 snapshot), but …

Spectral coverage and varying flux ratio makes it working !

γ^2 Vel, Millour et al. 2007

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

<u>but …</u>

a few points at the right place do the job

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

There is no simple answer!

This is why ASPRO was created

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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