Observability and UV coverage of sources

EuroWinter School

Observing with the Very Large Telescope Interferometer

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Reminder: what's the UV plane

$$V\left(\frac{\vec{B}}{\lambda}\right)=V(u,v)=\frac{\hat{I}(u,v)}{\hat{I}(\vec{0})} \quad \text{where} \quad \hat{I}(u,v) \underset{\text{Fourier} \quad \text{Transform}}{\longleftrightarrow} I(x,y)$$

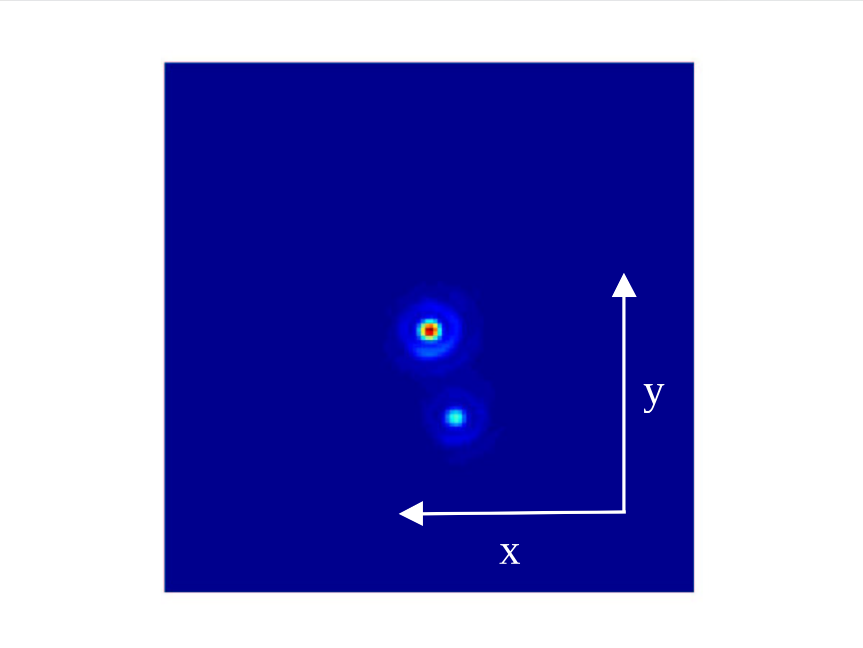
$$\vec{B}=(\Delta X,\Delta Y,\Delta Z)=(X_{T2}-X_{T1},Y_{T2}-Y_{T1},Z_{T2}-Z_{T1})$$ is the projected baseline vector

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

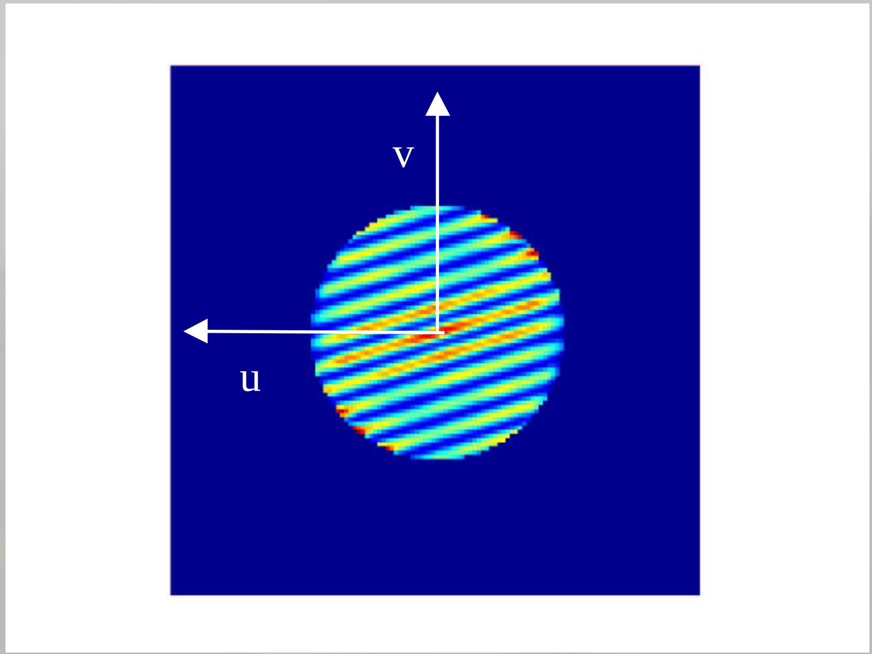
Spatial frequencies :

- Unitless: [**arcsec^{-1}**]
- They represent distances in the incident wavefront measured in wavelength units
- *(u,v)* are the conjugated coordinates of *(x,y)*

UV plane sampling with single dish telescope and adaptive optics



I(x,y)

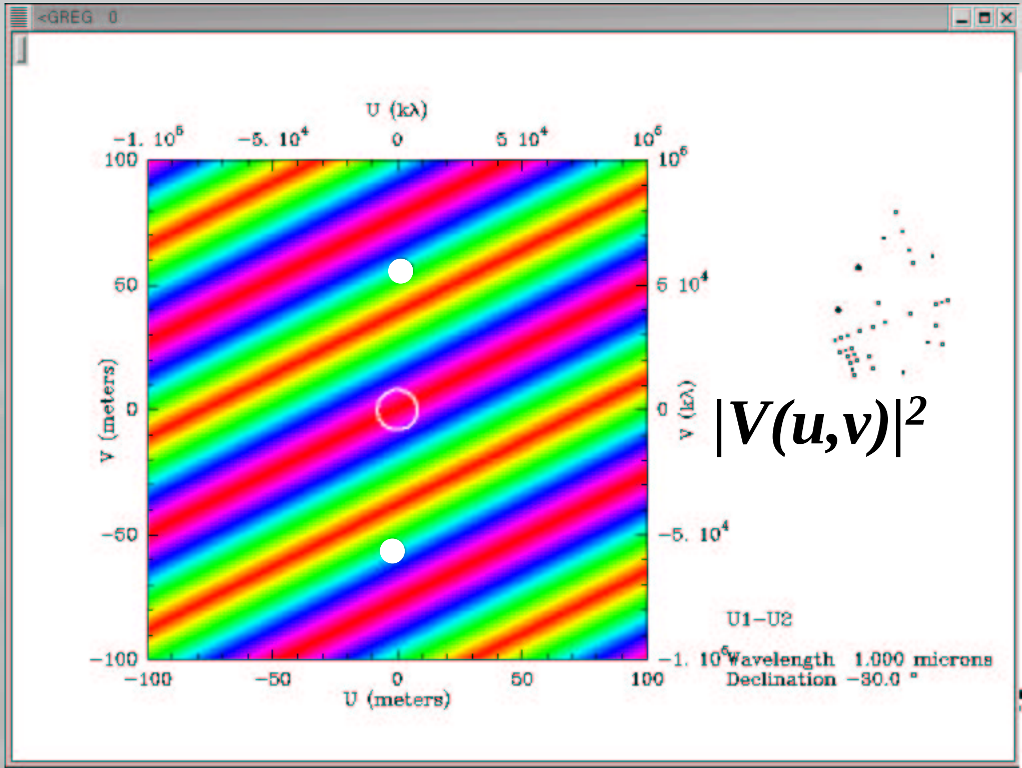


$|\boldsymbol{V(u,v)}|^2$

(cut-off frequency at $f_c=D/\lambda$)

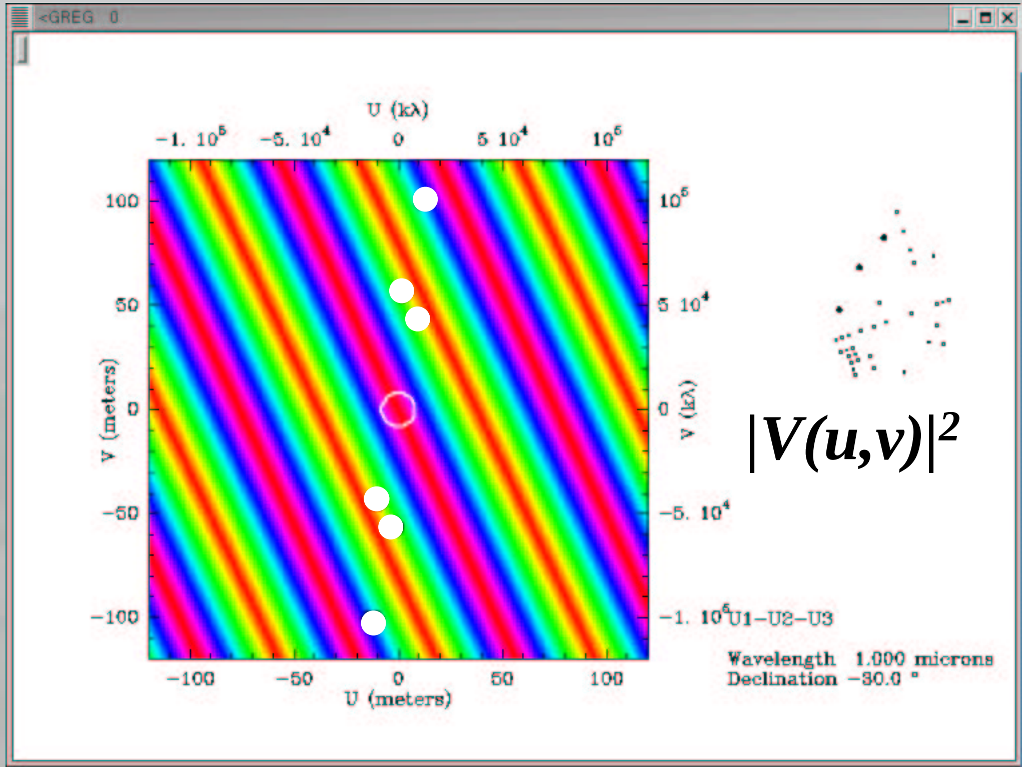
Resolved binary star at Canada-France-Hawaii Telescope with adaptive optics

UV plane sampling with an interferometer



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

UV plane sampling with an interferometer



A 3-telescope-interferometer gives access to **three** *(u,v)* points per measurement.

Filling the gaps in the UV plane

The easy way

- Take advantage of the earth rotation
- Observe at several wavelengths at once

$$(u,v)=\frac{1}{\lambda}(X,Y)$$

The hard way

- By using many telescopes
- By reconfiguring the array a lot

UV plane sampling using the earth rotation

UV plane sampling depends on:

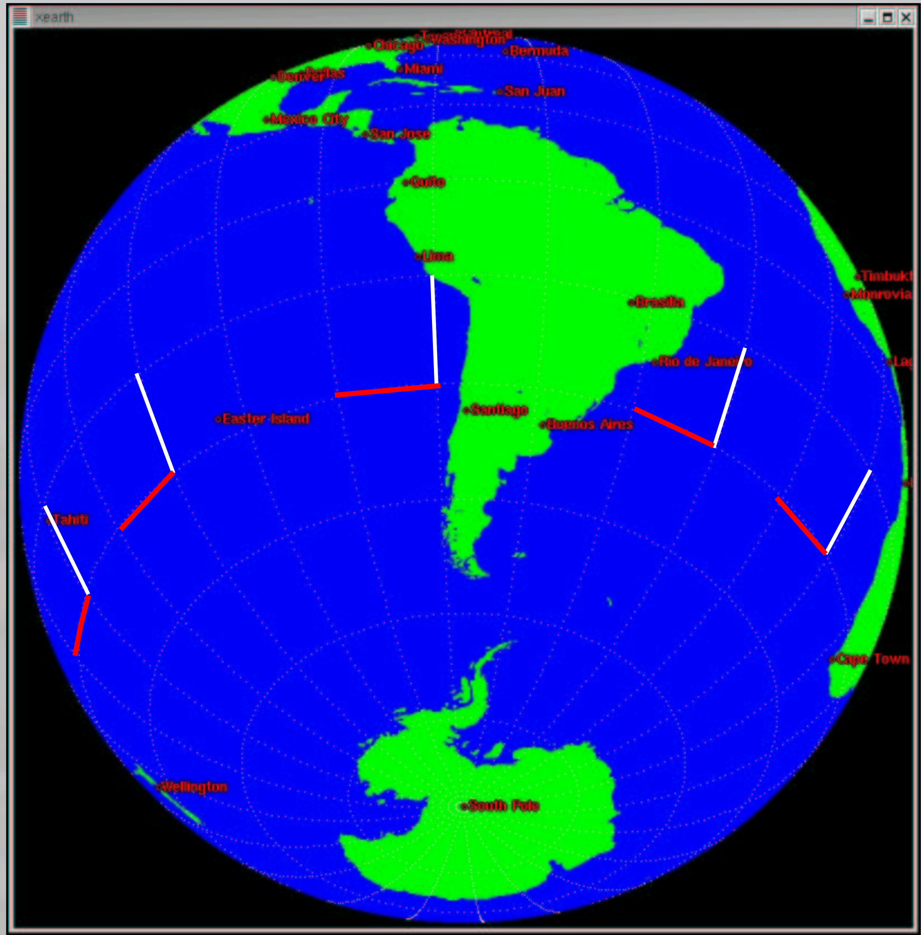
- the hour angle, h
- the source declination, δ
- the baseline vector *(X,Y,Z)*

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

Eliminating h from the above equations, one get an **ellipse equation**:

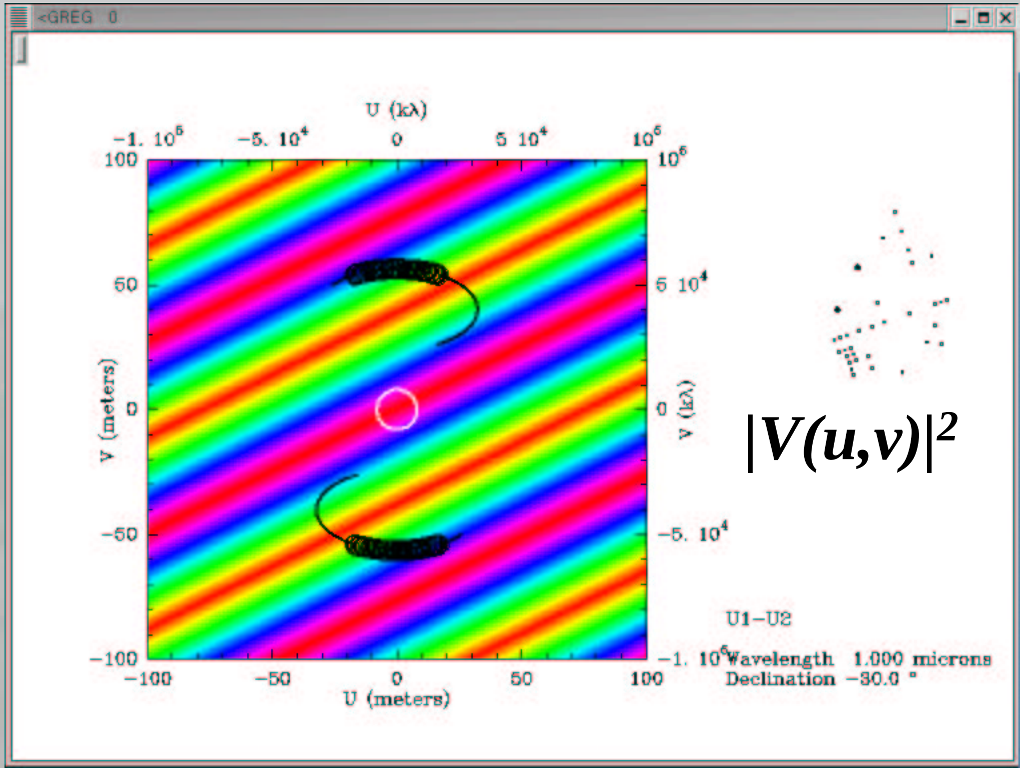
$$u^2 + \left(\frac{v - (Z/\lambda)\cos(\delta)}{\sin(\delta)} \right)^2 = \frac{X^2 + Y^2}{\lambda^2}$$

UV plane sampling using the earth rotation



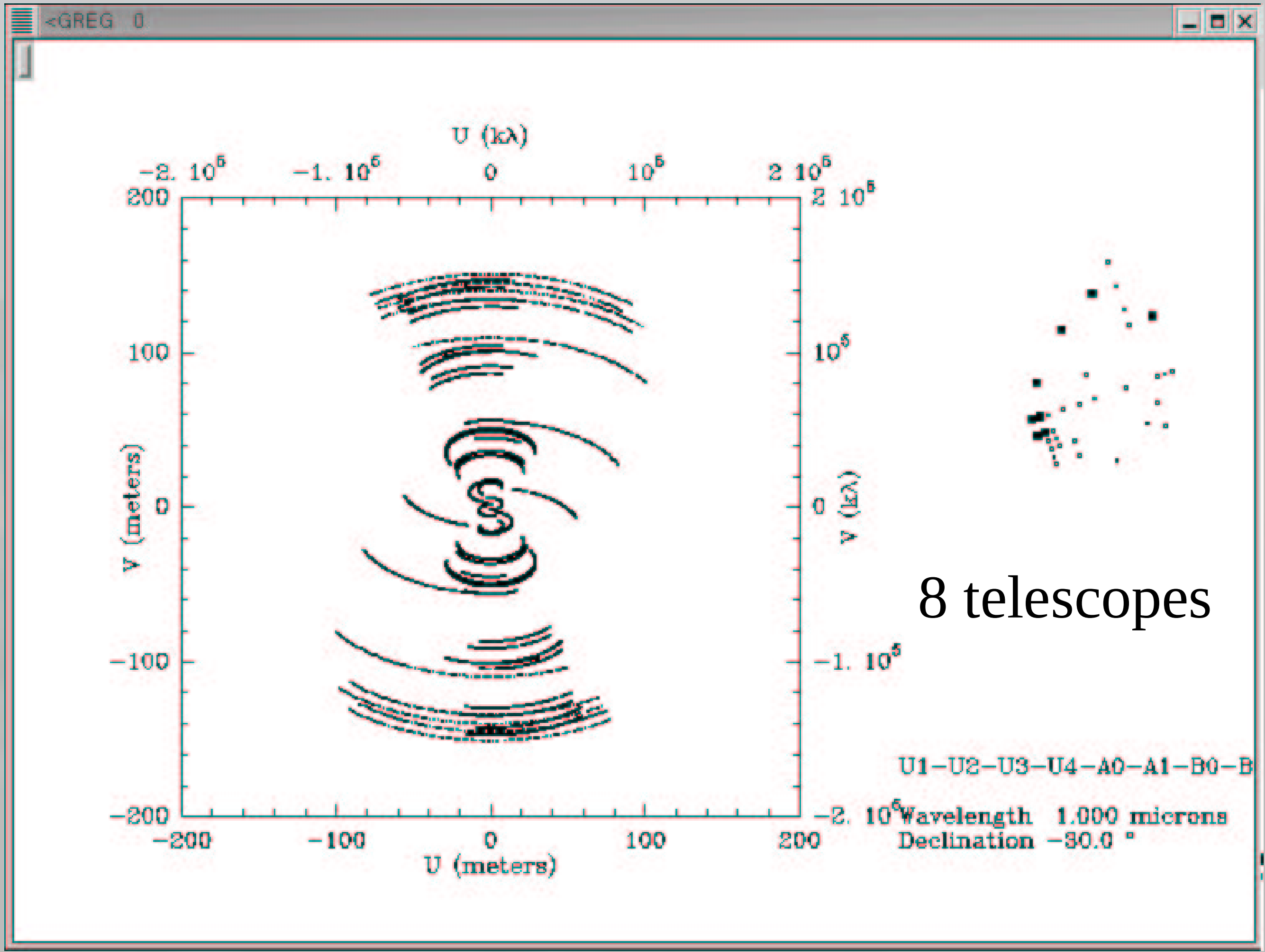
North-South & East-West baseline as seen from a star at δ=-42deg.

UV plane sampling using the earth rotation



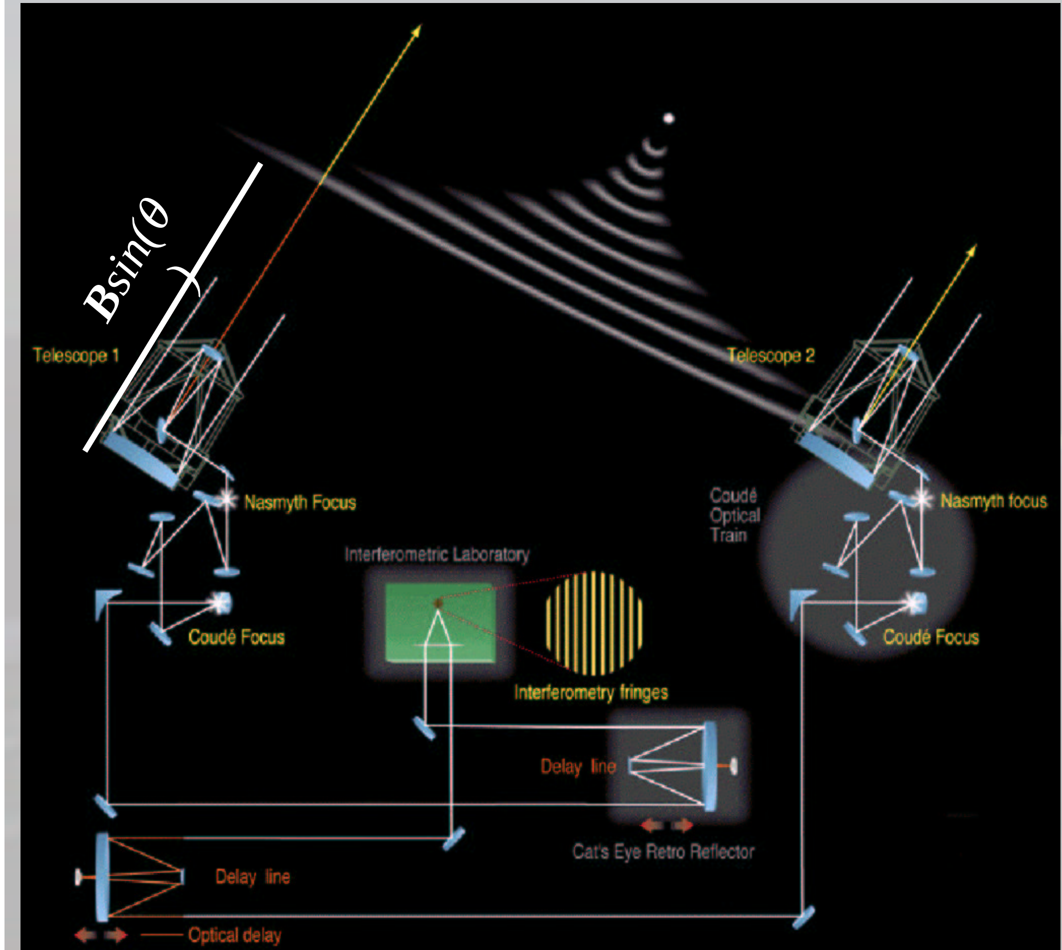
This UV plane sampling corresponds to 6 hours observation

UV plane sampling with many telescopes & earth rotation



8 telescopes

What about OPD and Delay lines



***B** sin(θ)*

***B** sin(θ)* can become very large when :

- the baseline is oriented east-west
- the baseline is large
- the star is far from the meridian

Ex :

a 200-meter-baseline (east-west)

a star at h=3 hours and $\delta = 0$ deg.

Opd=141m

Observability & uv coverage practice work session

Date : 05-FEB-2002

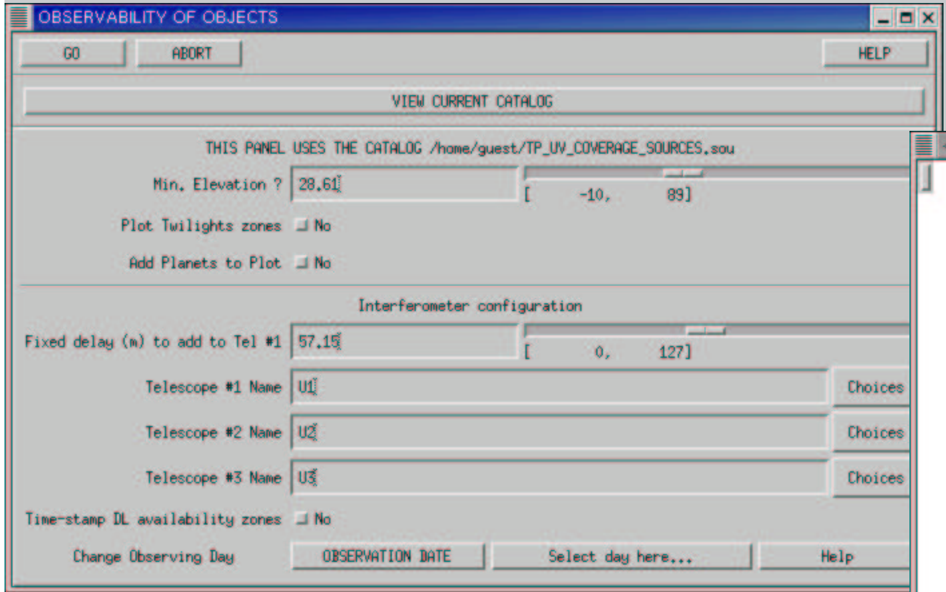
Local Time : 00:00:00

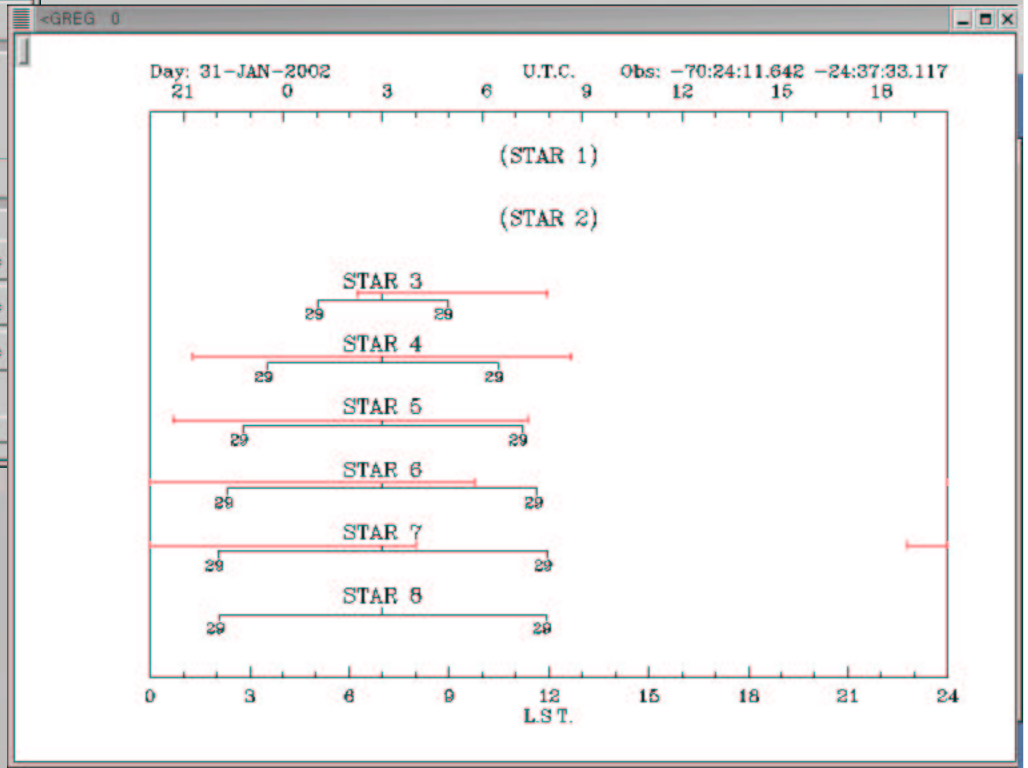
VLTI 2T

NEXT SLIDE

STAR_1	9:10:00.000	**70**:00:00.000
STAR_2	9:10:00.000	**50**:00:00.000
STAR_3	9:10:00.000	**30**:00:00.000
STAR_4	9:10:00.000	**10**:00:00.000
STAR_5	9:10:00.000	**-10**:00:00.000
STAR_6	9:10:00.000	**-20**:00:00.000
STAR_7	9:10:00.000	**-30**:00:00.000
STAR_8	9:10:00.000	**-50**:00:00.000
STAR_9	9:10:00.000	**-70**:00:00.000

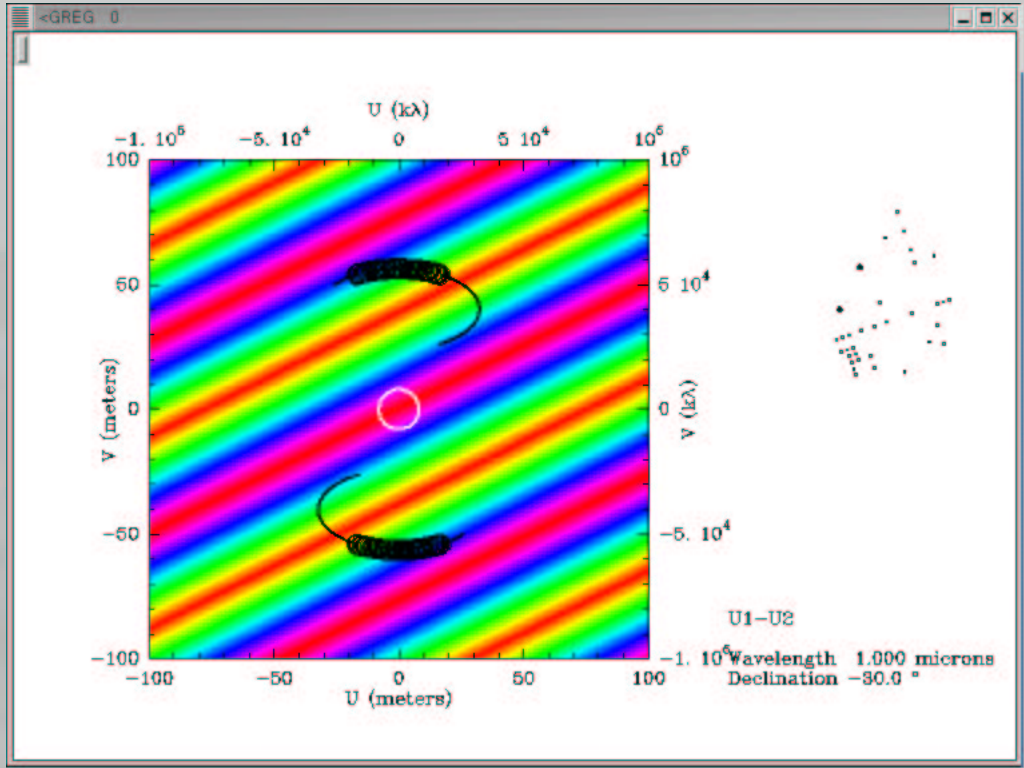
Observability: delay lines 2T



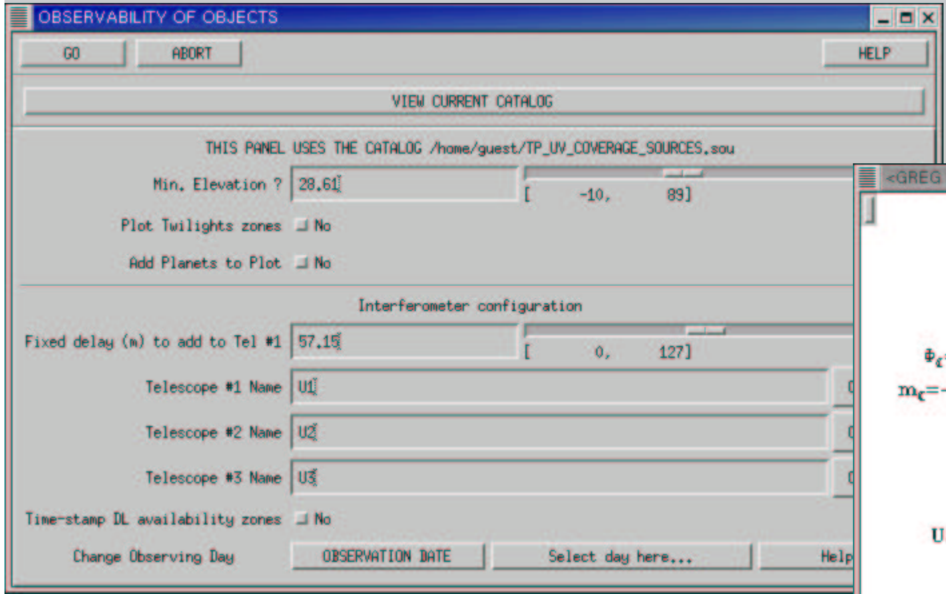


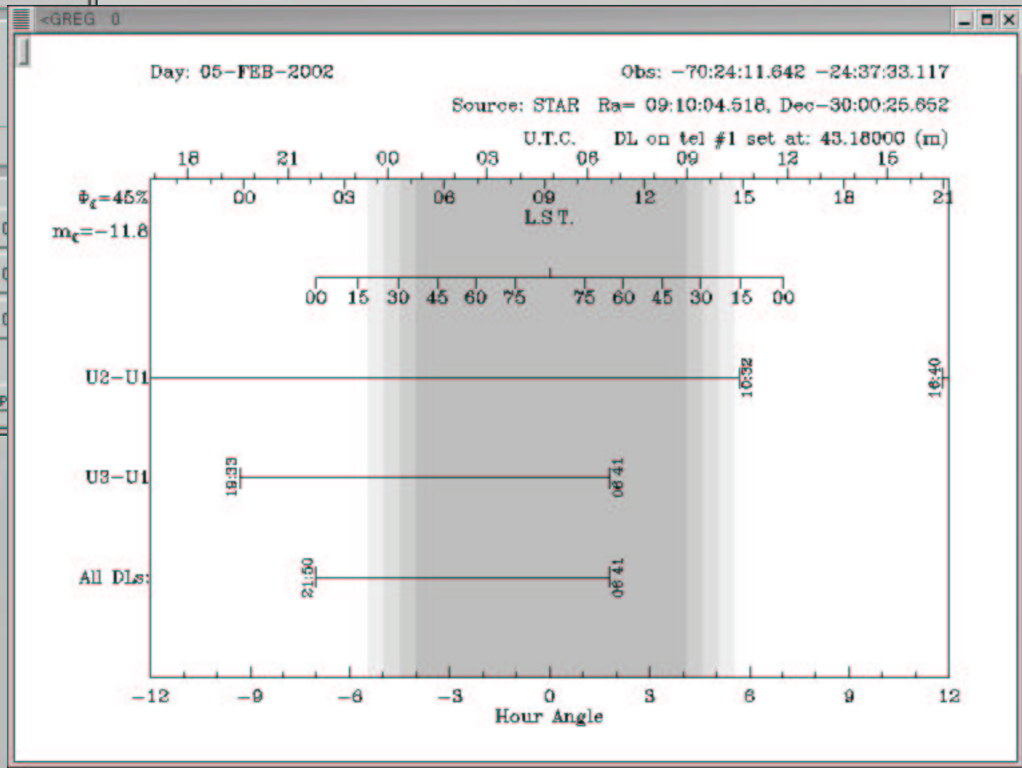
STAR_1	9:10:00.000	**70**:00:00.00
STAR_2	9:10:00.000	**50**:00:00.00
STAR_3	9:10:00.000	**30**:00:00.00
STAR_4	9:10:00.000	**10**:00:00.00
STAR_5	9:10:00.000	**-10**:00:00.00
STAR_6	9:10:00.000	**-20**:00:00.00
STAR_7	9:10:00.000	**-30**:00:00.00
STAR_8	9:10:00.000	**-50**:00:00.00
STAR_9	9:10:00.000	**-70**:00:00.00

Observability: delay lines 2T



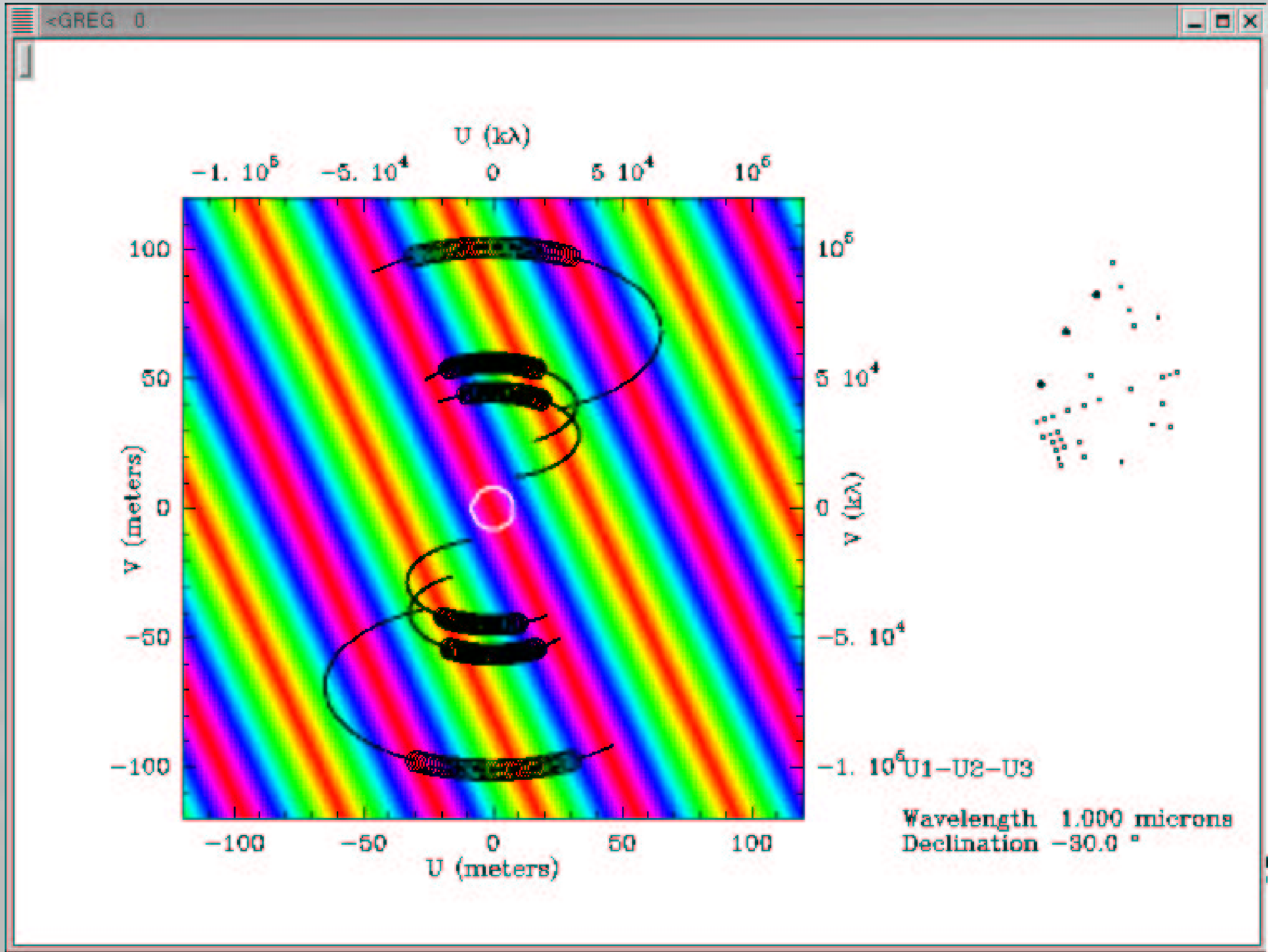
Observability: delay lines 3T





STAR_1	7:00:00.000	70:00:00.000
STAR_2	7:00:00.000	50:00:00.000
STAR_3	7:00:00.000	30:00:00.000
STAR_4	7:00:00.000	10:00:00.000
STAR_5	7:00:00.000	-10:00:00.000
STAR_6	7:00:00.000	-30:00:00.000
STAR_7	7:00:00.000	-50:00:00.000
STAR_8	7:00:00.000	-70:00:00.000

Observability: delay lines 3T



Observing with the VLTI

Several limitations

- Limited number of recombined telescopes
  (2-3 for the first generation of instruments on the VLTI)
- Shadowing (telescopes may see each other)
- Delay line stroke may not be long enough
- Changing the telescope configuration IS NOT straightforward

⇒ Covering the UV-plane is «very expensive» in observing time with 2-3 telescopes

The goal IS NOT to cover the whole UV-plane

Which UV-coverage do I need to conduct my observing program?

ASPRO demo 1

Direct diameter measurement of the red dwarf Gl887 (M0V)

- Easy target for AMBER : J=4.16
- RA : 23:05:52 Dec : -35:51:11
- Expected diameter 1.69 mas

- Baseline B5-J6 does constrain the diameter of this M dwarf

ASPRO demo 2

Parameters of a binary star

- RA : 22:38:33 Dec : -15:18:06
- Expected separation 7.4 mas
- Expected star diameter 0.27 mas
- No information about the PA.

What baseline configuration should we use ?

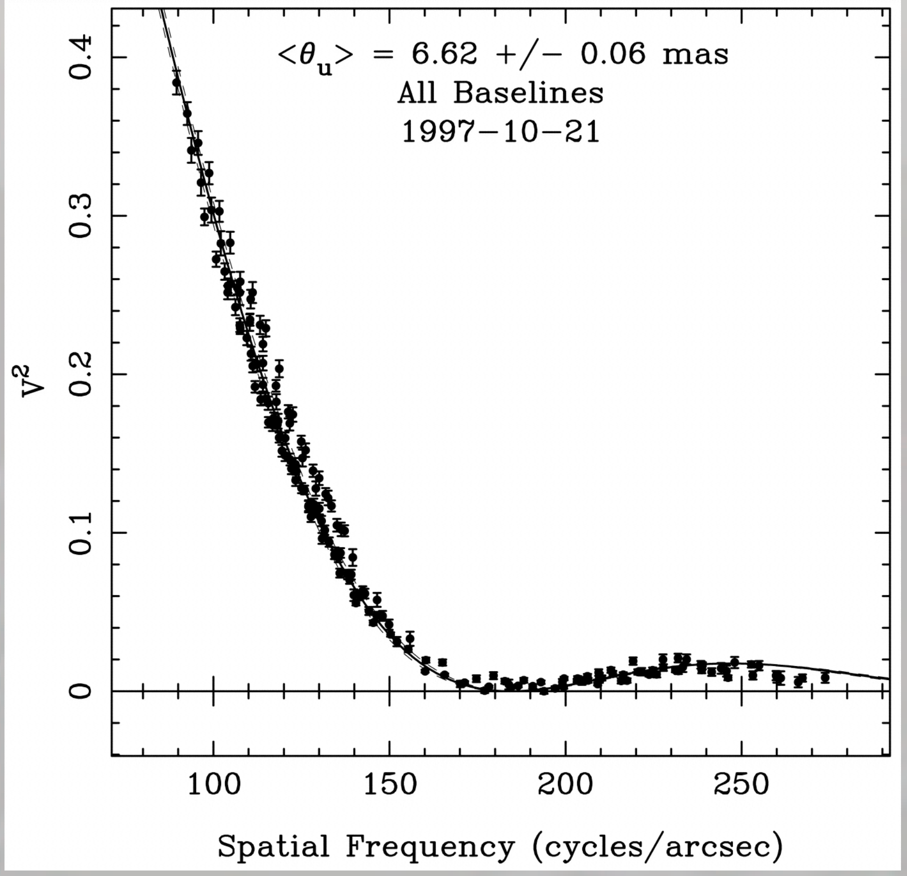
What is an appropriate UV-plane sampling?

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

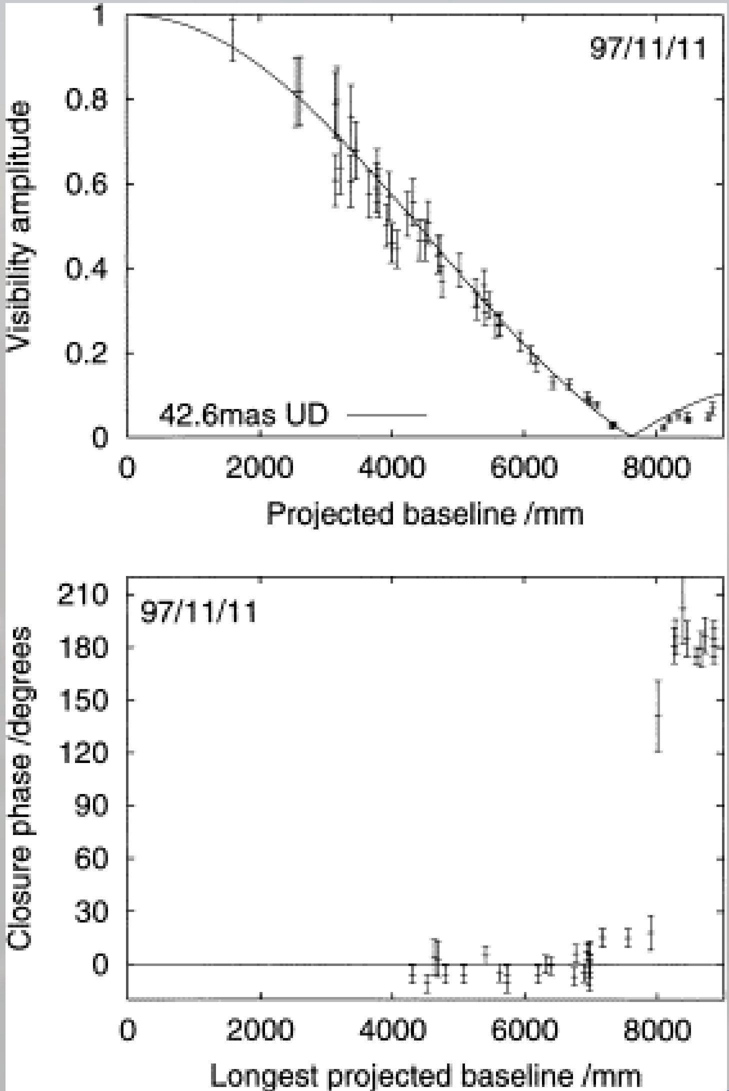
What is an <u>appropriate</u> UV-plane sampling?



Radius measurement with NPOI

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

What is an appropriate UV-plane sampling?



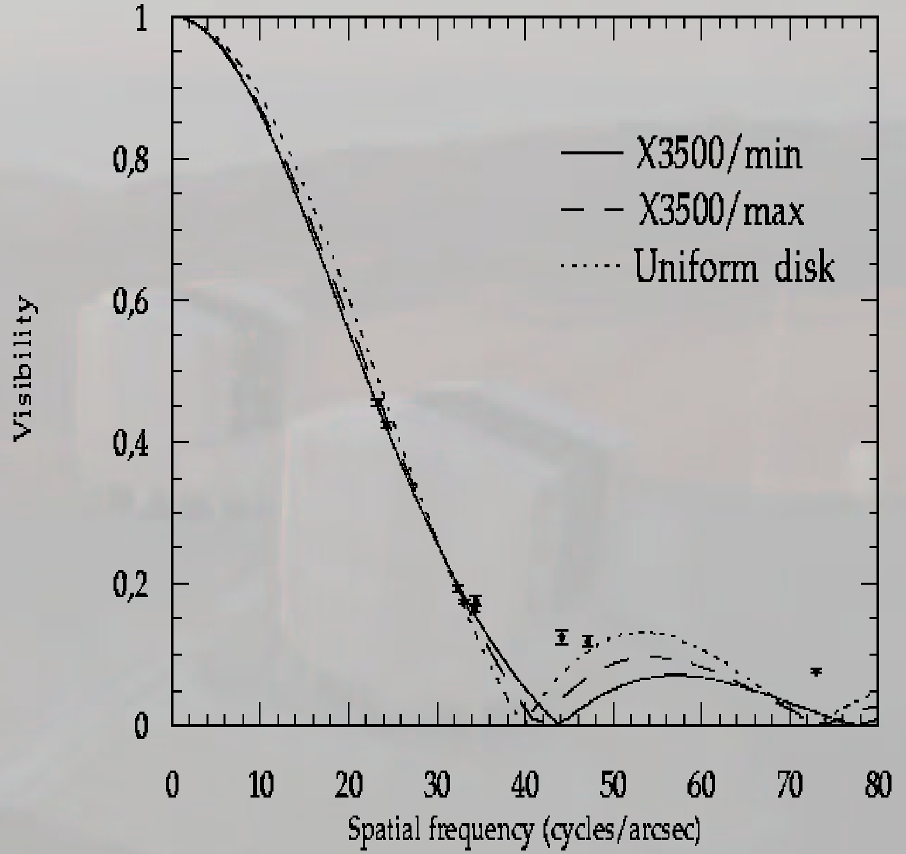
Radius measurement with COAST

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

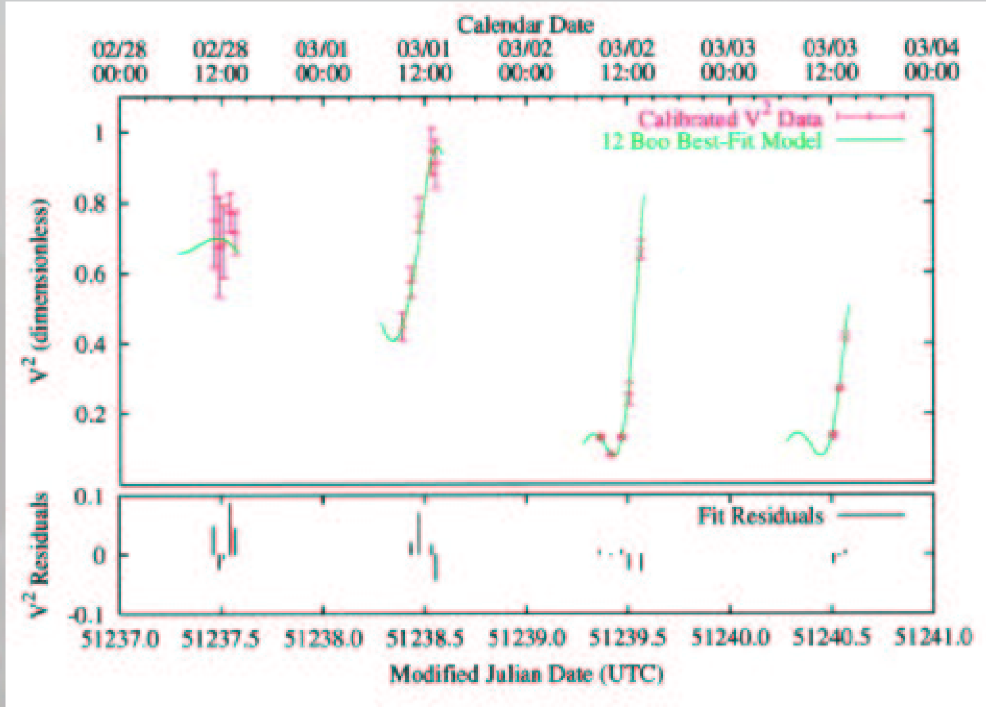
What is an appropriate UV-plane sampling?

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 can do the job



What is an appropriate UV-plane sampling?



Binary star observation with PTI

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

One last difficulty

Observing in Broad

$$(u,v) = \frac{1}{\lambda}(X,Y)$$

- The visibility you measure is averaged over the band
- There is some incertitude about the effective *(u, v)* coordinate
- Your target may behave differently at different wavelengths

$\Rightarrow$ Some spectral resolution makes life easier