Observability and UV coverage of sources

Euro Summer School

Observations and data reduction with the Very Large Telescope Interferometer

Goutelas, France
4-16, 2006

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Observability

Single dish telescope :

Constraints are HA and Fz => one needs LST, RA and DEC

Global efficiency is high (uv coverage, low overheads)

Interferometers :

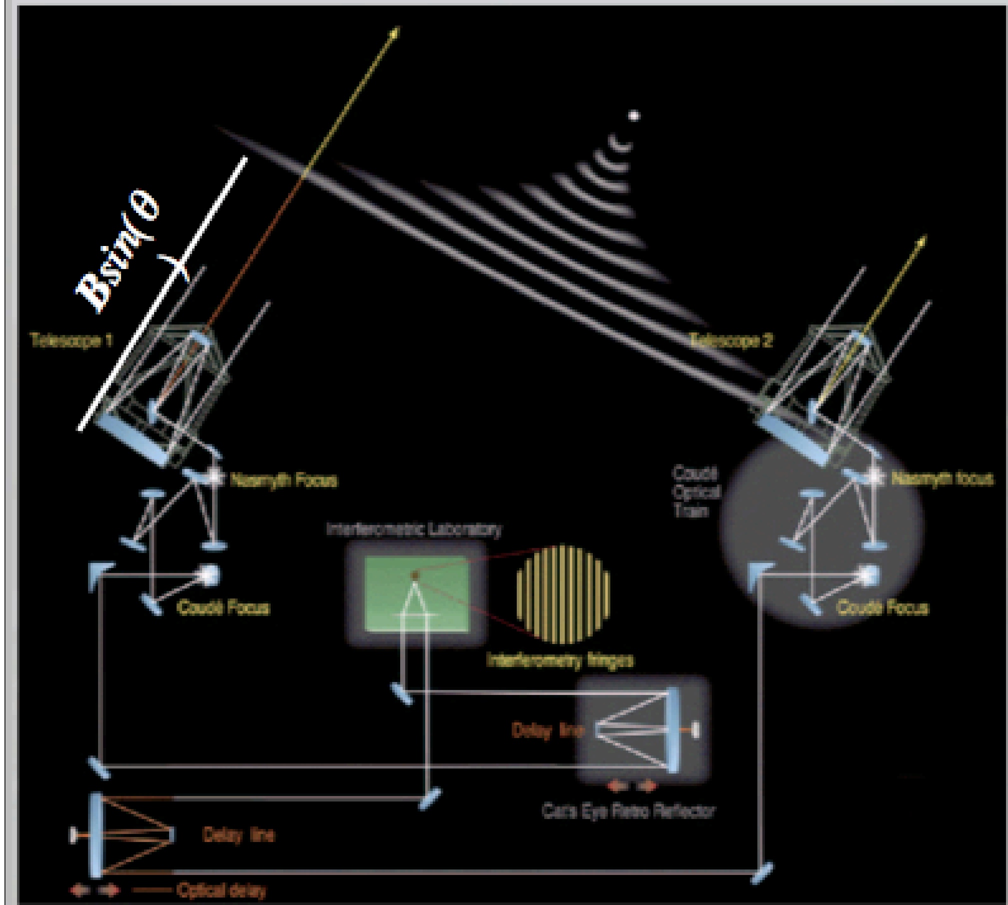
Constraints : HA, Fz, (U,V) => one needs LST, RA, DEC, Bvect

Hardware constraints : Delay lines stroke, Dome vignetting

Global efficiency is low (poor uv coverage, high overheads)

A good Observation Preparation Software is required

What about OPD and Delay lines

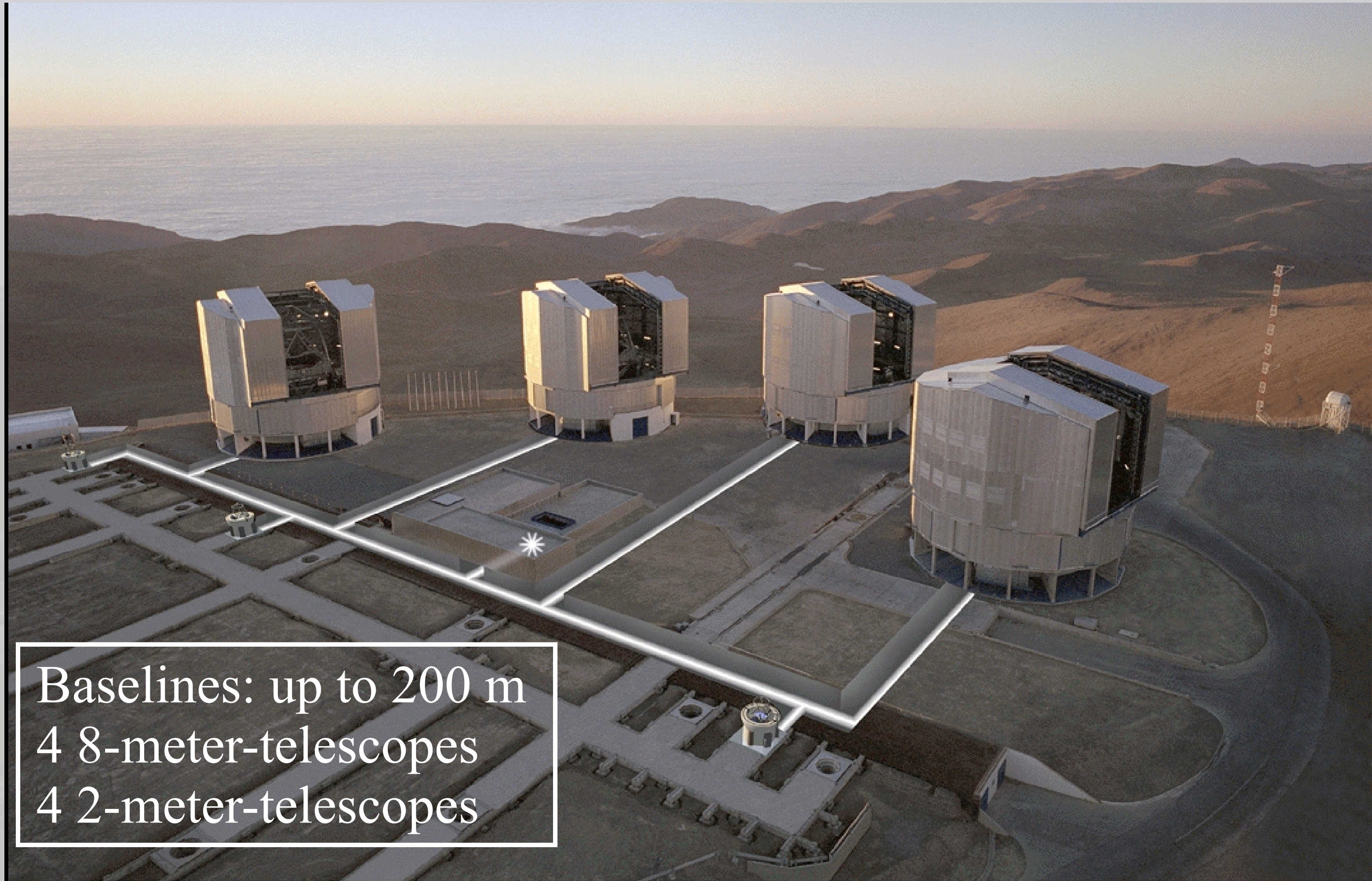


B sin(θ)

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 δ = 0 deg.
Opd=141m

VLTI at ESO Paranal, Chile



Reminder: what's the UV plane

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

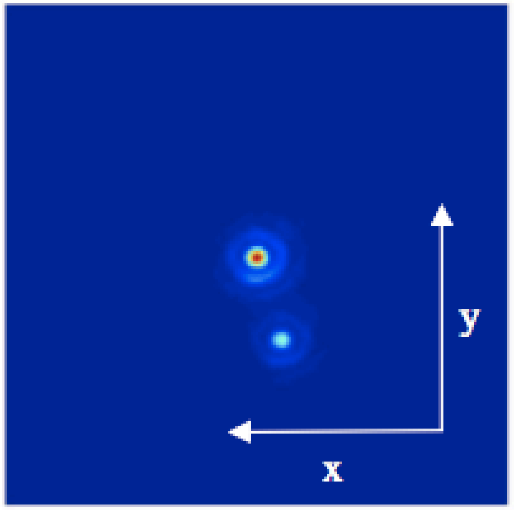
$\vec{B} = (\Delta X, \Delta Y, \Delta Z) = (X_{T2} - X_{T1}, Y_{T2} - Y_{T1}, Z_{T2} - Z_{T1})$ is the projected baseline vector

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

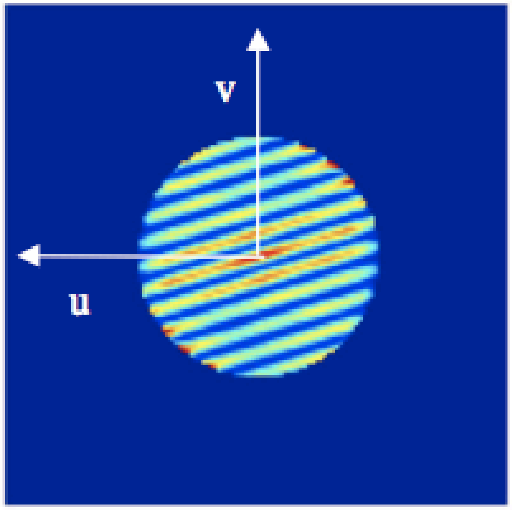
Spatial frequencies :

- 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



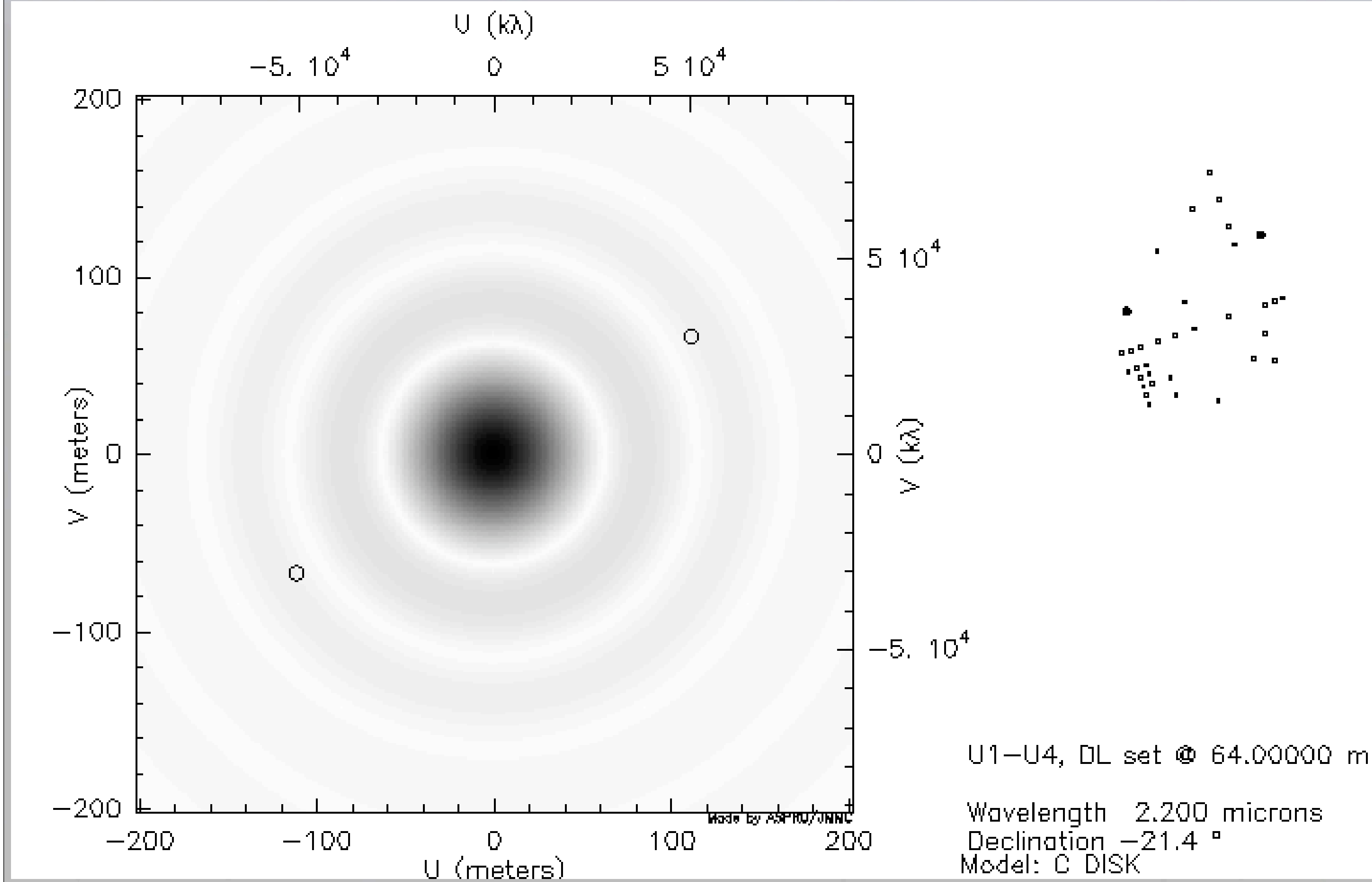
$I(x,y)$



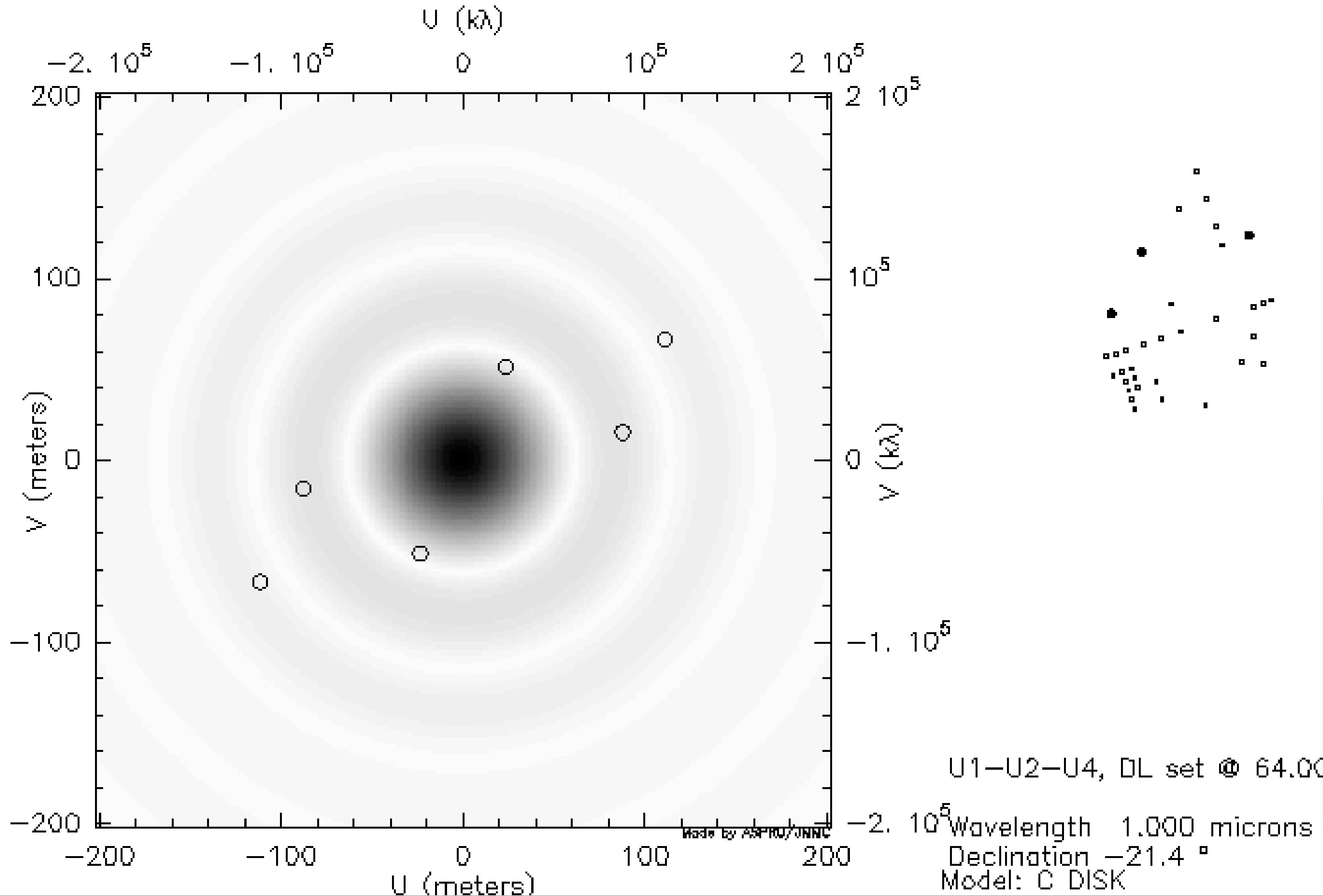
$|V(u,v)|^2$

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

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



U (kλ)
−5. 10^4
0
5 10^4
200
100
0
−100
−200
V (meters)
5 10^4
0
−5. 10^4
V (kλ)
−200
−100
0
100
200
U (meters)
U1−U4, DL set @ 64.00000 m
Wavelength 2.200 microns
Declination −21.4 °
Model: C DISK


U (kλ)
−2. 10^5
−1. 10^5
0
10^5
2 10^5
200
100
0
−100
−200
V (meters)
V (kλ)
−1. 10^5
−2. 10^5
−200
−100
0
100
200
U (meters)
U1−U2−U4, DL set @ 64.0
Wavelength 1.000 microns
Declination −21.4 °
Model: C DISK

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)*

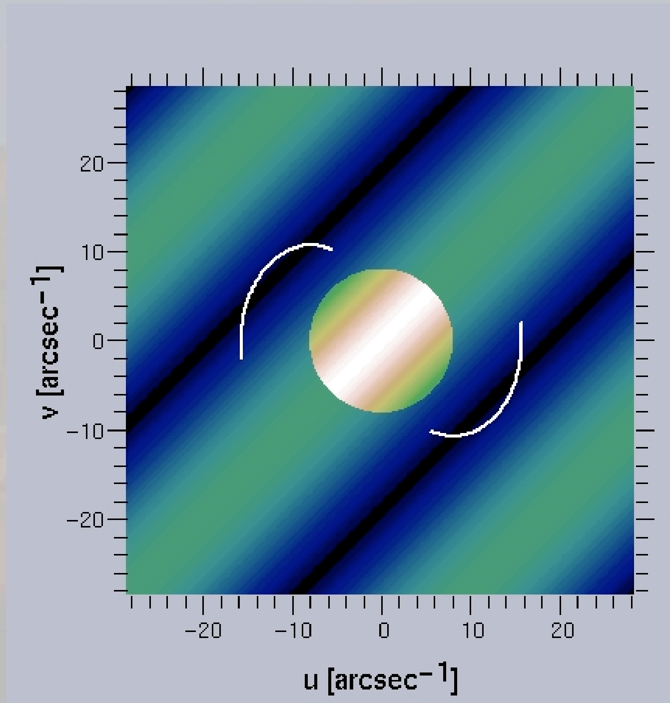
$$\begin{pmatrix} u \\ v \\ w \end{pmatrix} = \frac{1}{\lambda}\begin{pmatrix} \sin(h) & \cos(h) & 0 \\ -\sin(\delta)\cos(h) & \sin(\delta)\cos(h) & \cos(\delta) \\ \cos(\delta)\cos(h) & -\cos(\delta)\sin(h) & \sin(\delta) \end{pmatrix}\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

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

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

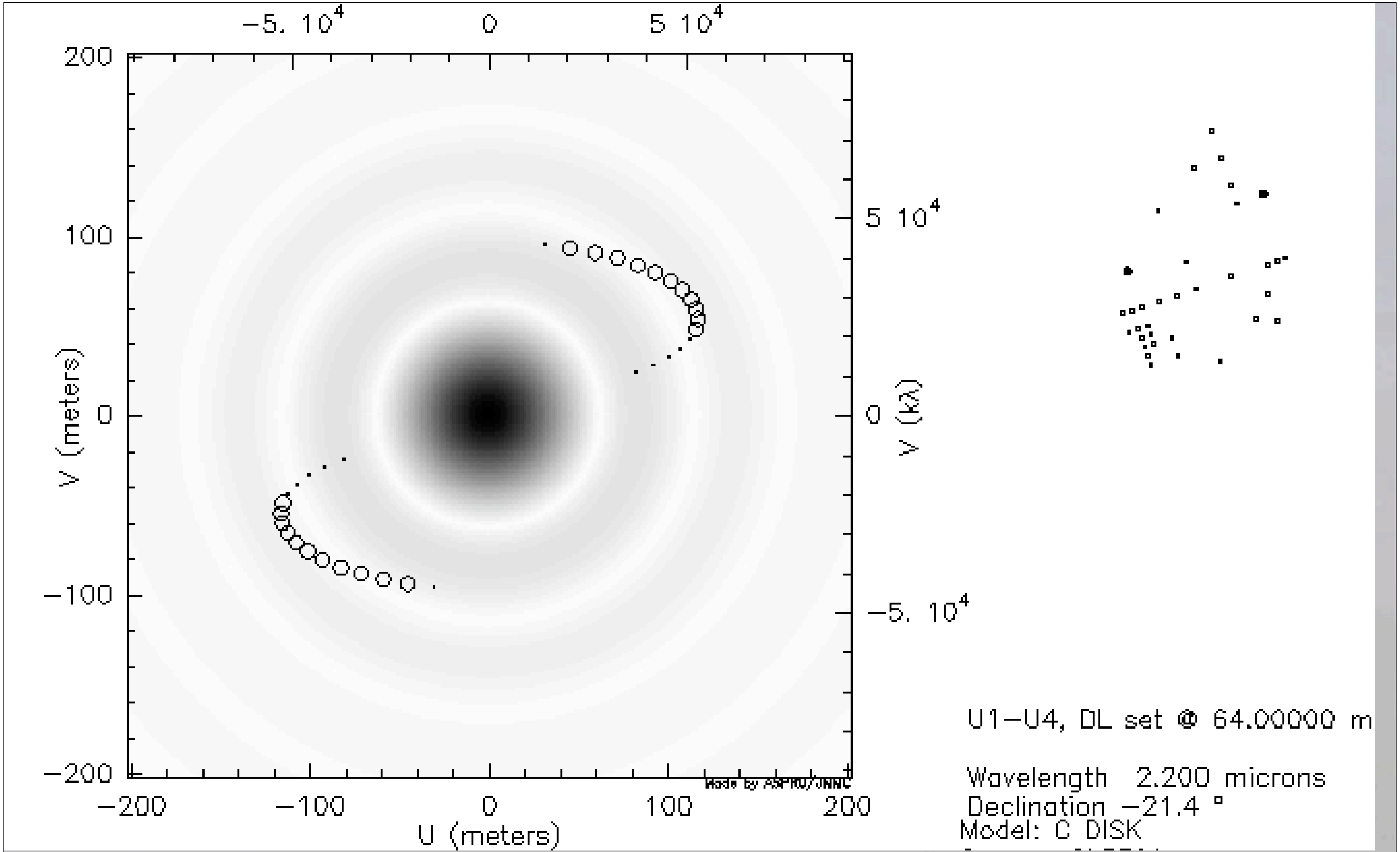
Reminder : what 's the UV plane (4)

- A 2 telescope interferometer gives access to **1** (u,v) point per measurement.
- A 3 telescope interferometer gives access to **3** (u,v) point per measurement.
- We have access to high spatial freq but …

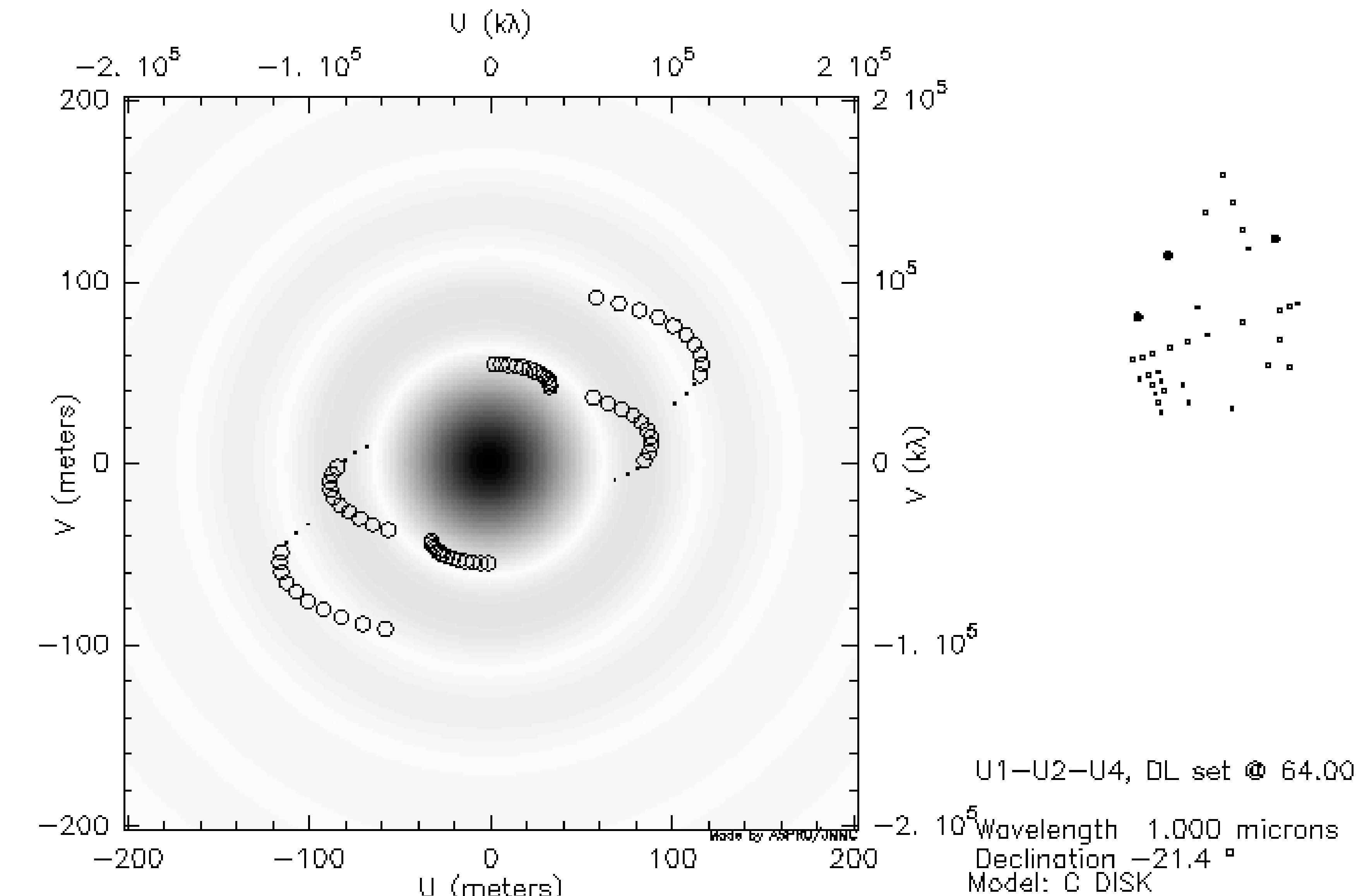


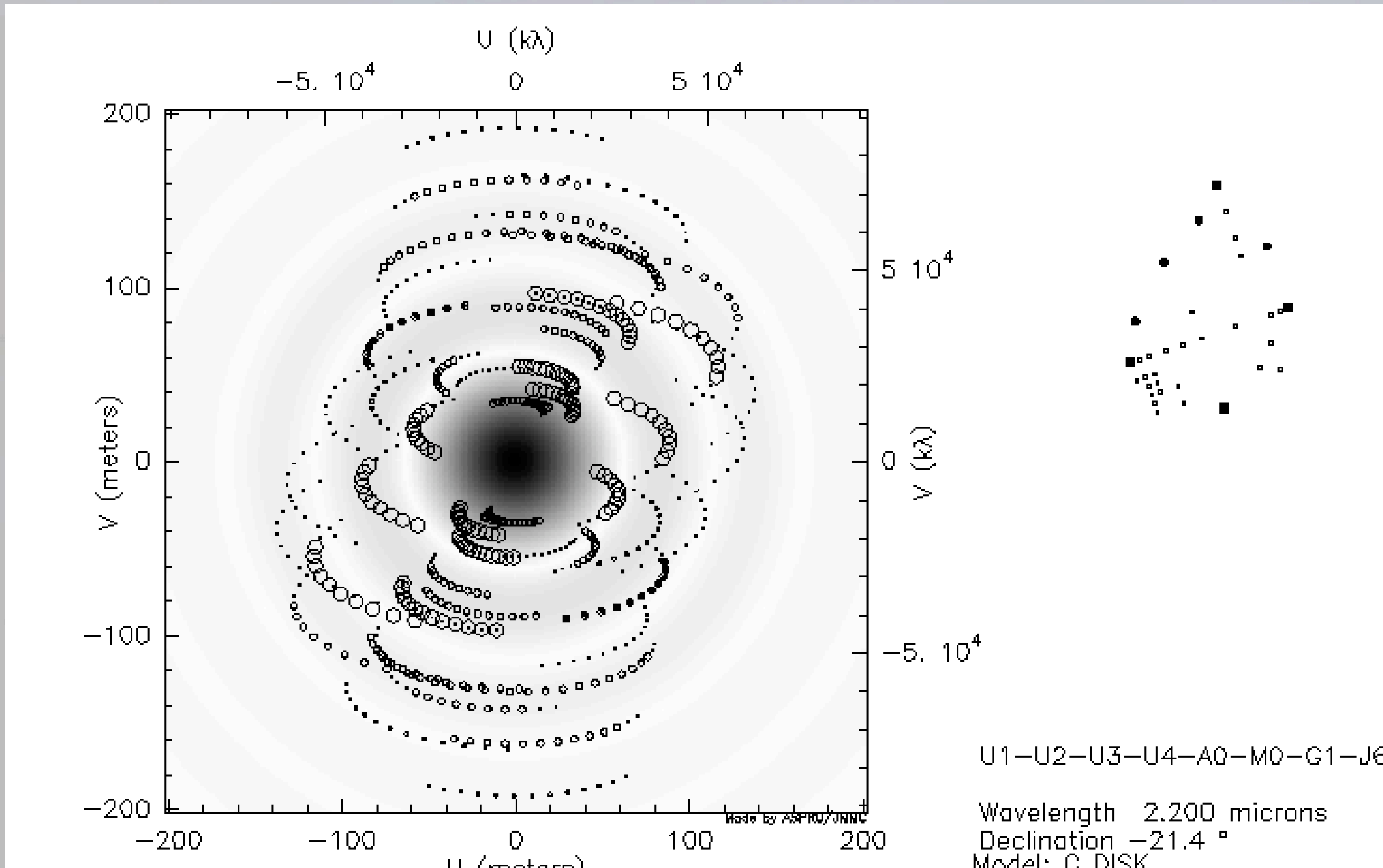
|Visibility|^2, cut-off frequency & uv-tracks (6 hours observation)

A lot of GAPS remain in the UVplane



−5. 10⁴
0
5 10⁴
200
100
0
−100
−200
V (meters)
5 10⁴
0
−5. 10⁴
V (kλ)
−200
−100
0
100
200
U (meters)
Made by ASPRO/JMMC
U1−U4, DL set @ 64.00000 m
Wavelength 2.200 microns
Declination −21.4 °
Model: C DISK


U (kλ)
−2. 10^5
−1. 10^5
0
10^5
2 10^5
200
100
0
−100
−200
V (meters)
V (kλ)
−200
−100
0
100
200
U (meters)
U1−U2−U4, DL set @ 64.00
Wavelength 1.000 microns
Declination −21.4 °
Model: C DISK


U (kλ)
−5. 10^4
0
5 10^4
200
100
0
−100
−200
V (meters)
5 10^4
0
−5. 10^4
V (kλ)
−200
−100
0
100
200
U1−U2−U3−U4−A0−M0−G1−J6
Wavelength 2.200 microns
Declination −21.4 °

Filling the gaps in the UV plane

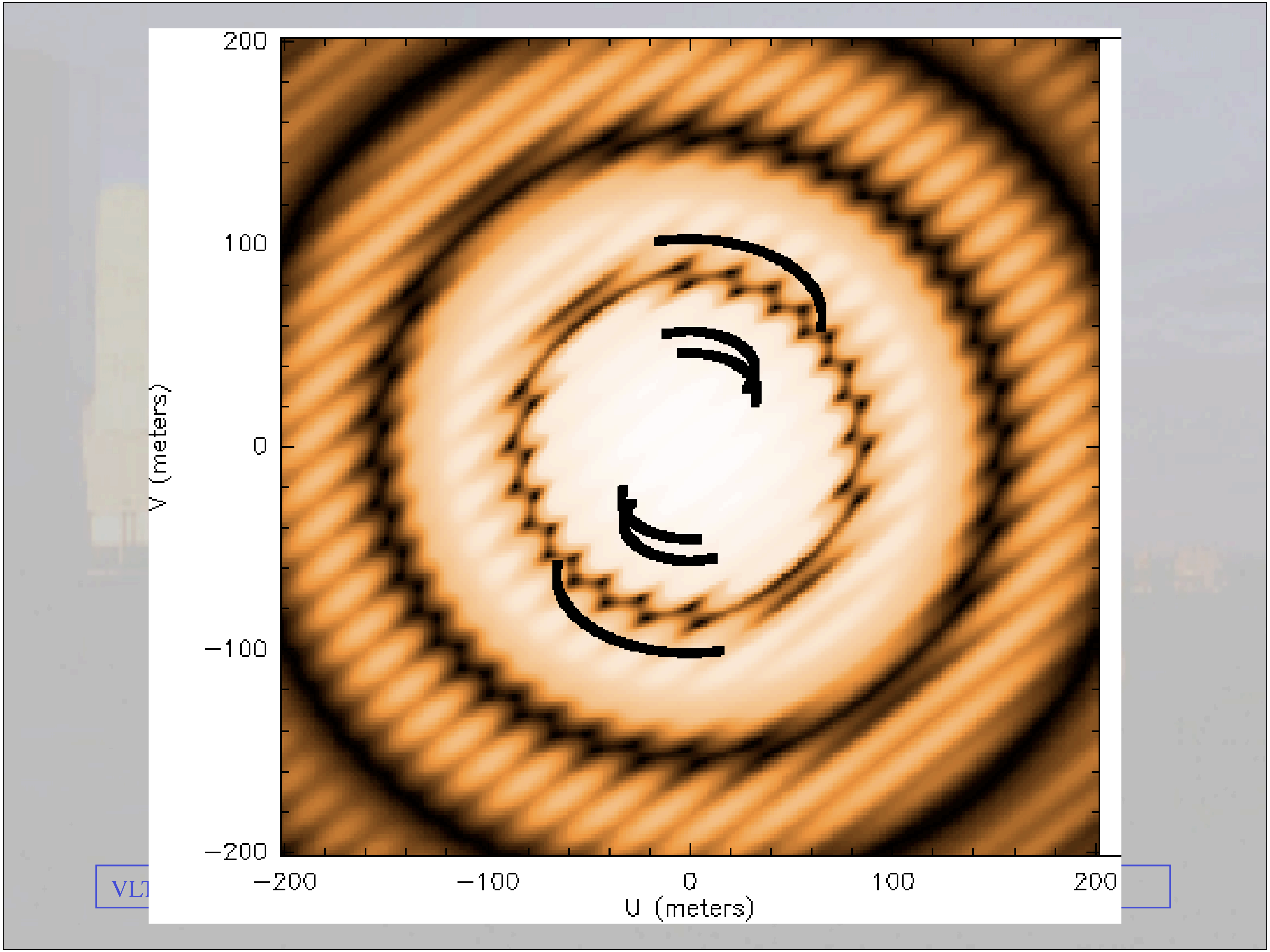
The easy way

- 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



200
100
0
−100
−200
V (meters)
−200
−100
0
100
200
U (meters)
VLT

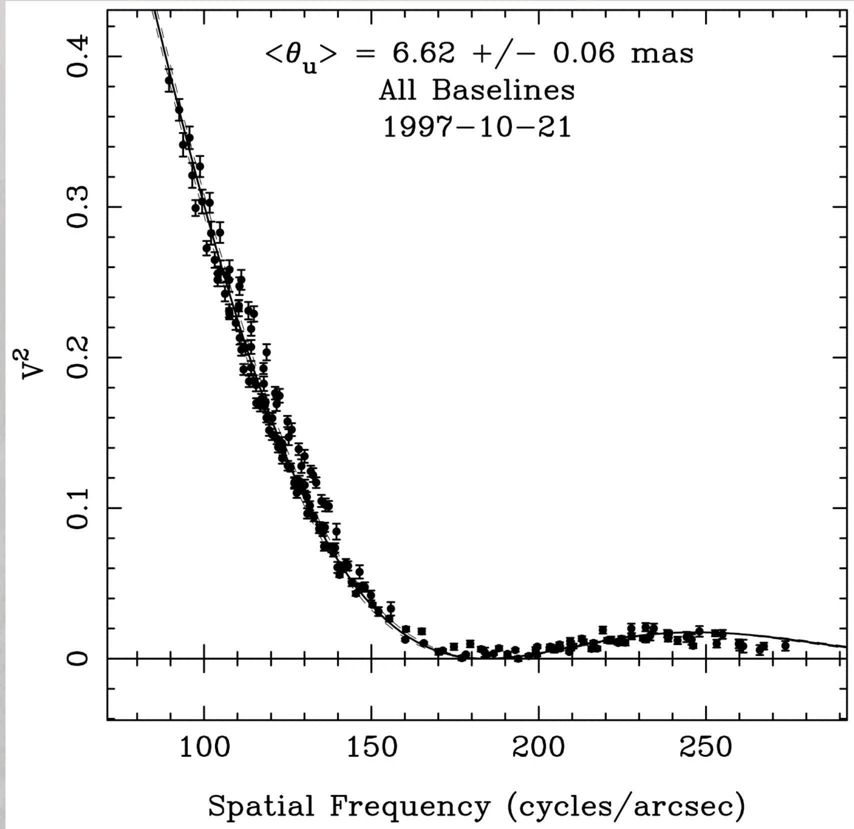
What is an <u>appropriate</u> UV-plane sampling?

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

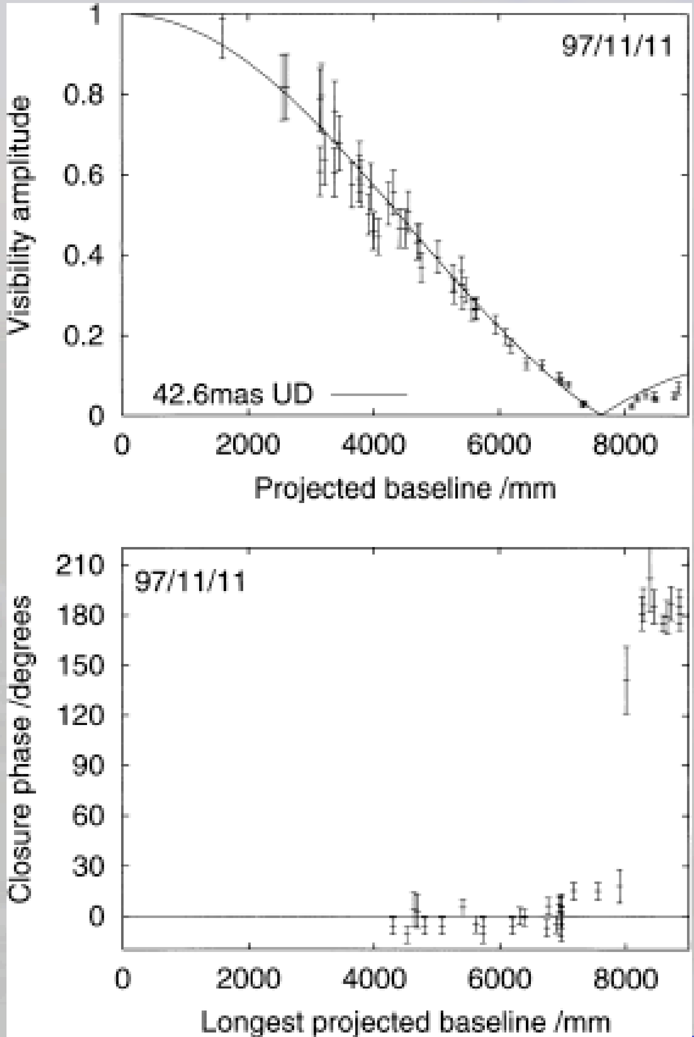
What is an appropriate UV-plane sampling?



Radius measurement with NPOI

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

What is an appropriate UV-plane sampling?



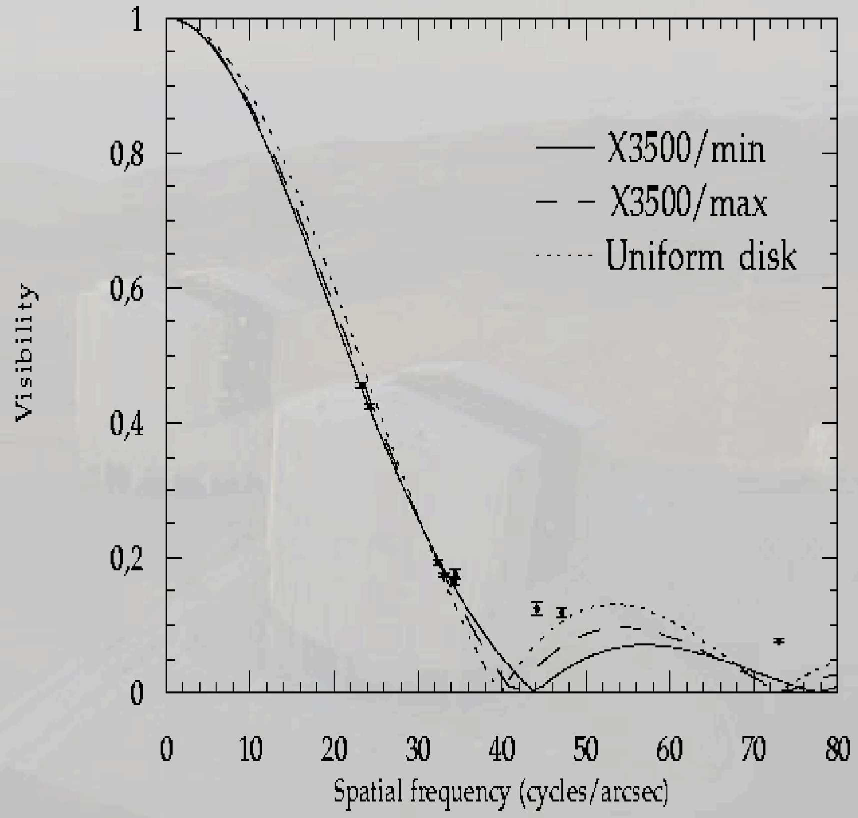
Radius measurement with COAST

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

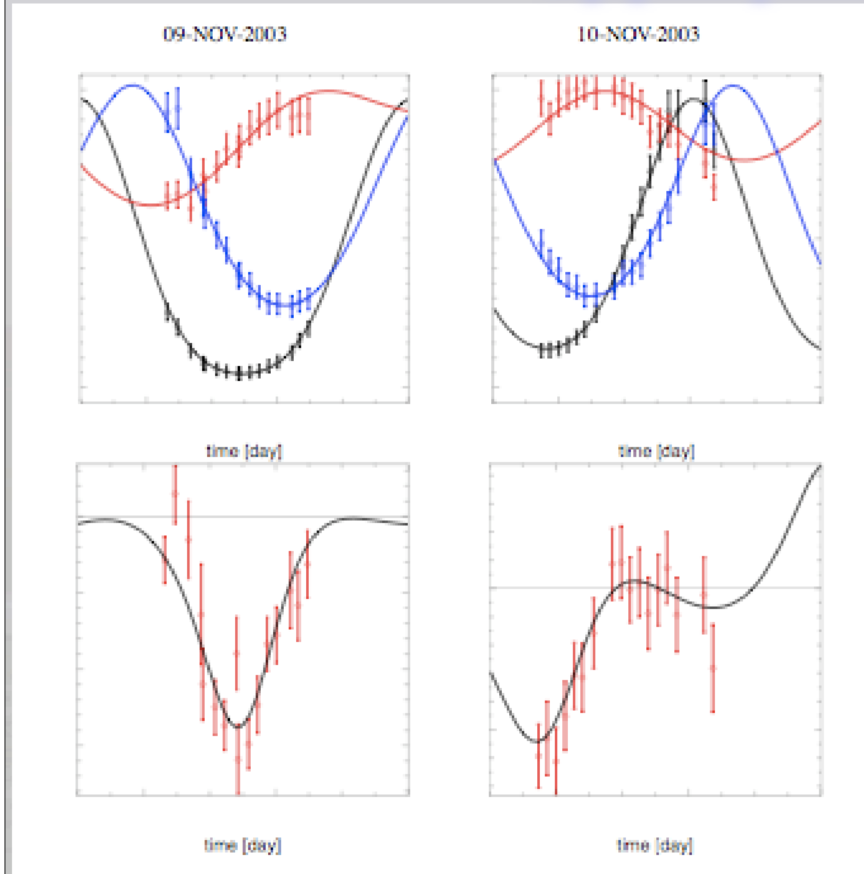
What is an appropriate UV-plane sampling?

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 do the job



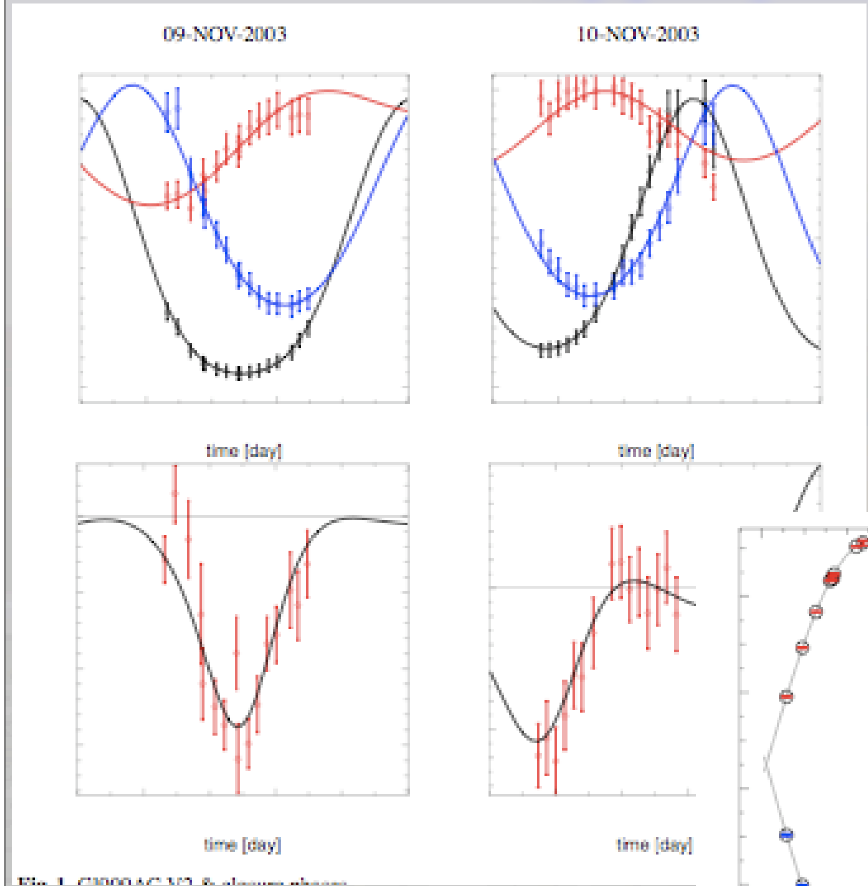
What is an appropriate UV-plane sampling?



Binary star observation IOTA

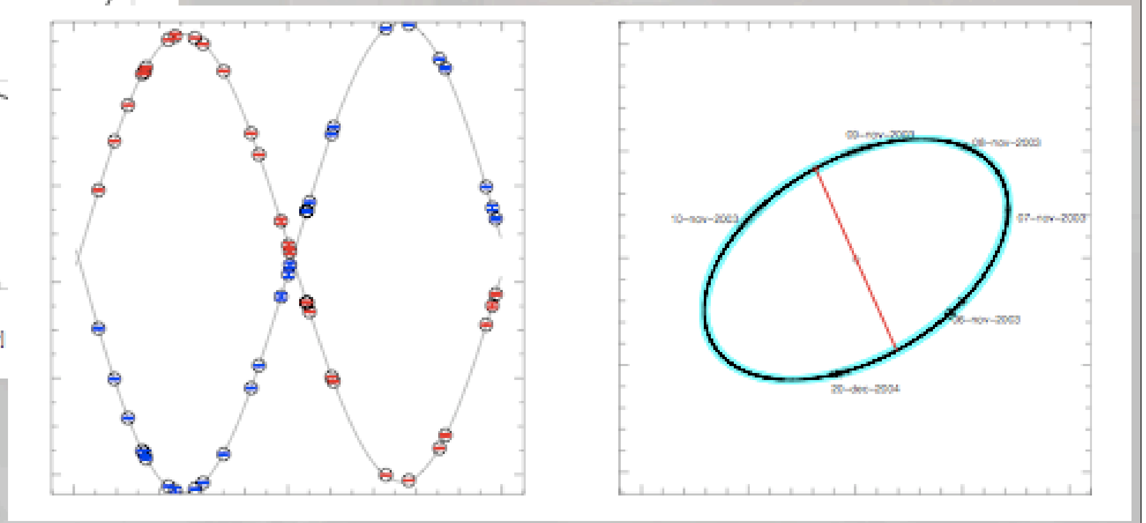
- accuracy on $V^2 > 1\%$
- limited UV coverage
- but … binary observed at different orbital phases

What is an appropriate UV-plane sampling?



Binary star observation with PTI

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



What is an appropriate UV-plane sampling ?

There is no simple answer.

This is why ASPRO was created

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?

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

⇒ Some spectral resolution makes life easier

Observability & uv coverage practice work session

Date : 05-FEB-2002

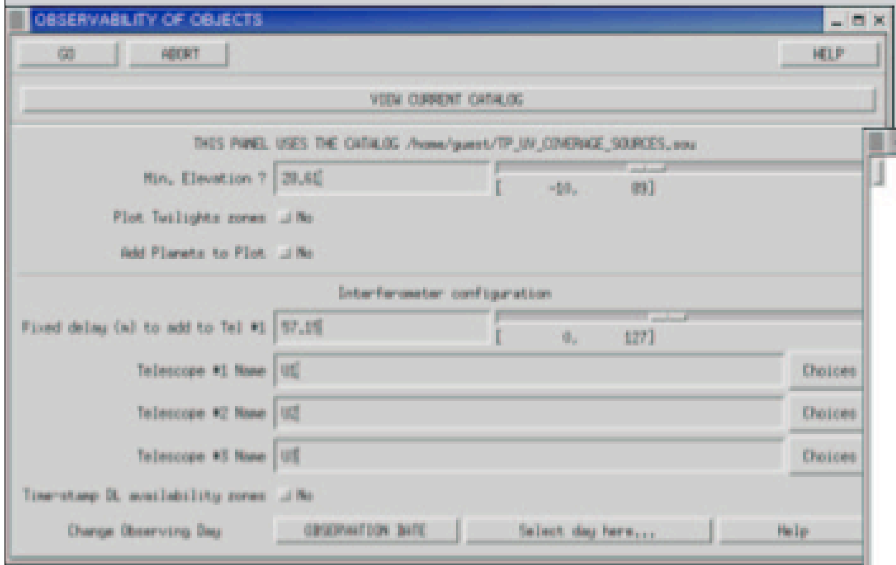
Local Time : 00:00:00

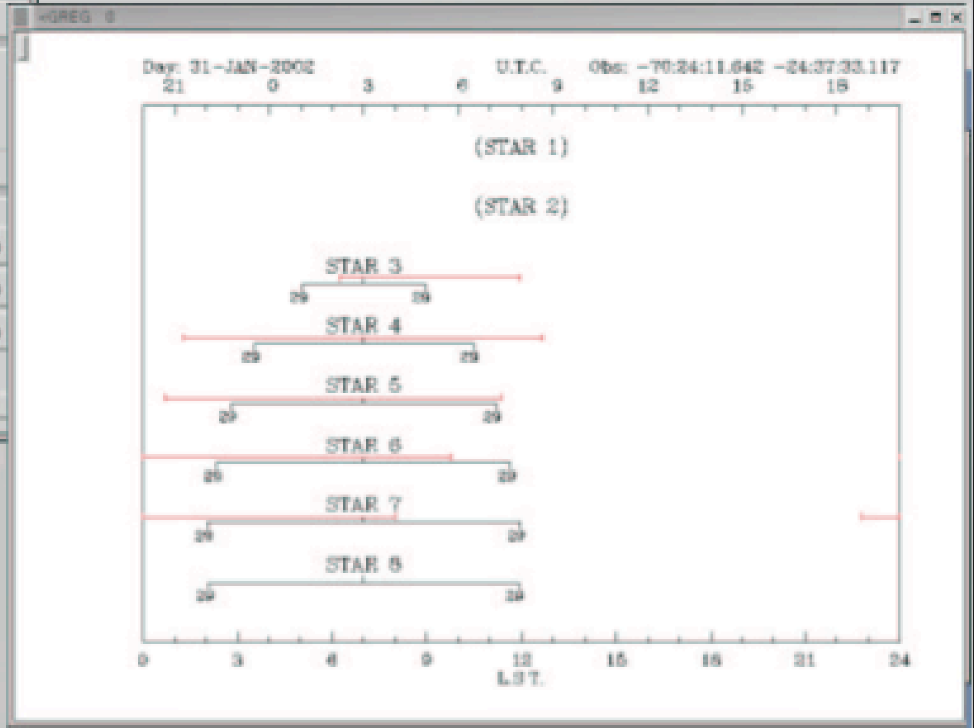
VLTI 2T

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

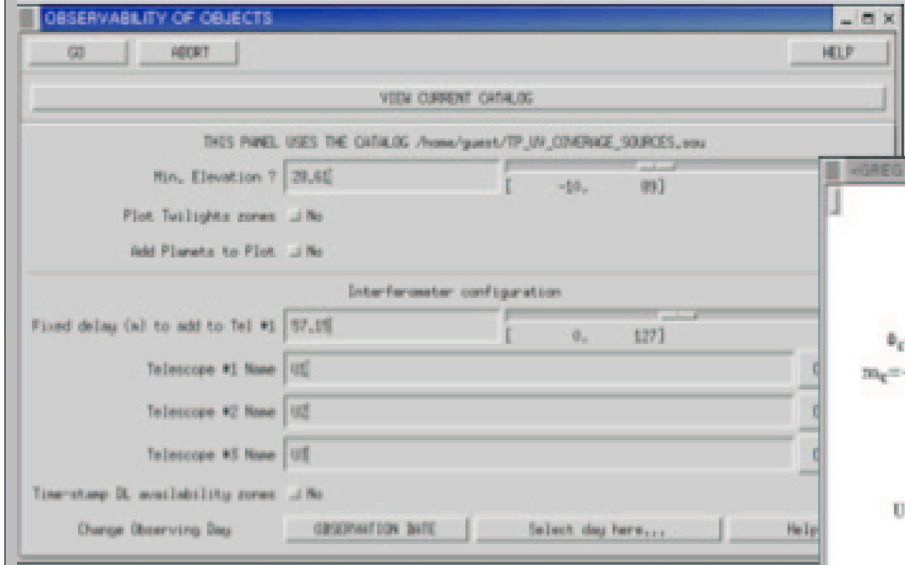
Observability: delay lines 2T

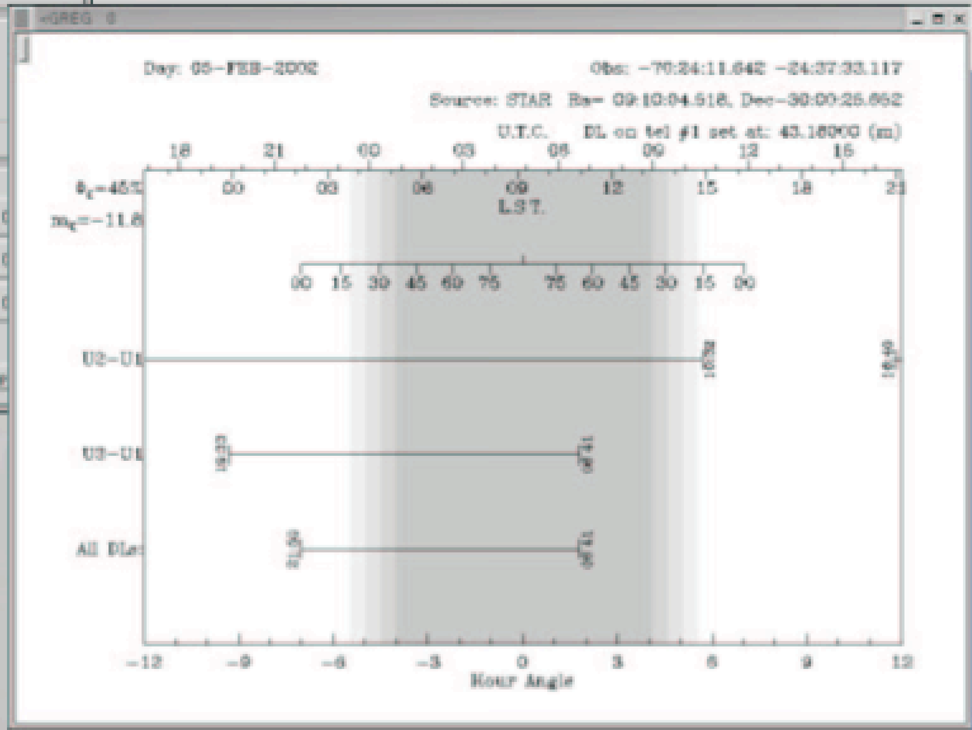




STAR_1	9:10:00.000	70:00:00.00
STAR_2	9:10:00.000	50:00:00.00
STAR_3	9:10:00.000	30:00:00.00
STAR_4	9:10:00.000	10:00:00.00
STAR_5	9:10:00.000	-10:00:00.00
STAR_6	9:10:00.000	-20:00:00.00
STAR_7	9:10:00.000	-30:00:00.00
STAR_8	9:10:00.000	-50:00:00.00
STAR_9	9:10:00.000	-70:00:00.00

Observability: delay lines 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

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 ?