Practice Work Session P2 (2h)
Observability and (u, v) coverage

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Abstract

This work session is divided into two main parts. The first one intends to give you a clear idea about the (u, v) coverage you will get for baselines of different orientation and targets of different declination. It will also emphasize the delay lines constraints for a 2 and a 3-telescope-array. In the second part, you will have to select different array configurations to efficiently measure the radius of 3 close M dwarfs, the parameters (ρ, Θ, Δmag) of a binary system.

Practical considerations

You will need to use ASPRO and the catalogues named `pws2a.sou` and `pws2b.sou`.

1 Sampling the (u, v) plane with the VLTI

You should first load the catalogue named `pws2a.sou`. It contains 7 stars of R.A. 16:10:00 and of different declinations. These prototype stars pass the meridian the 6th of June 2006 at midnight at Paranal. In this section you will make an intensive use of the *OBSERVABILITY/COVERAGE* menu of **ASPRO**.

1.1 Setting up the observations

- In the *WHEN* menu, *Date & Time Setup* menu check tat the date is `06-JUN-2006` and put the time to `21:00:00`.

- In the *WHERE* menu, select *VLT, 2 Telescopes*

- In the *WHAT* menu, select *Use Object catalog* and select the file `pws2a.sou`.

- Check with the *WHAT* menu *View Object catalog* and the xterm windows

1.2 Observability of the catalog sources

First, we will check the observability of the sources with *OBSERVABILITY/COVERAGE, Observability of Sources*. Set the minimum elevation to 30 degrees, check the *Plot the twilight zones* button and the GO with UT1 and UT2.
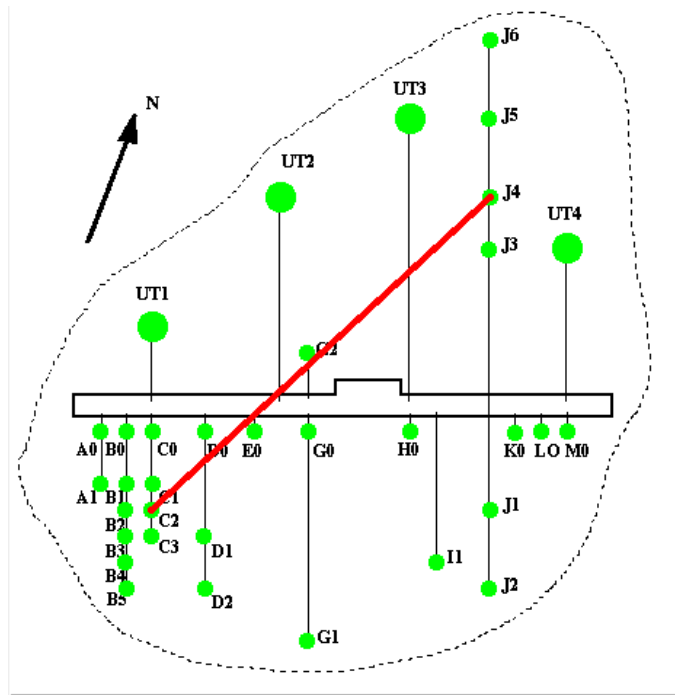
- Which stars are observable?

Figure 1: VLTI stations

- Then play with the parameter called `fixed delay line`. How does it change the observabilty?

- Set back the delay to zero and compare the observability between the UT1-UT2 baseline and the G2-J6 one. Can you find a fixed delay that allow to observe for at least 3 stars?

1.3 (u, v) tracks for a North-South baseline

We will study now the (u, v) coverage of the sources with *OBSERVABILITY/COVERAGE, UV coverage & PSF*.

- Select the star #5 and set the wavelength to 2 microns. In the *Telescopes & Stations* panel, select a 2 telescope baseline oriented N-S (cf. Fig. 1) with a zero fixed delay and see what type of (u, v) coverage you get.

- Change stars, going from positive declination to negative ones and see what happens.

Hint : have a look at the figure of the Earth in Figs. 2 and 3

1.4 (u, v) tracks for a East-West baseline

Select a large 2 telescope baseline oriented E-W. Visualize the observability of the targets with / without delay lines constraints. Plot the (u, v) coverage for several stars and change the fixed delay.

- Why are the (u, v)-tracks elliptical ?

- Have a look at (u, v)-tracks of a star above the equator and below the equator. What do you notice?
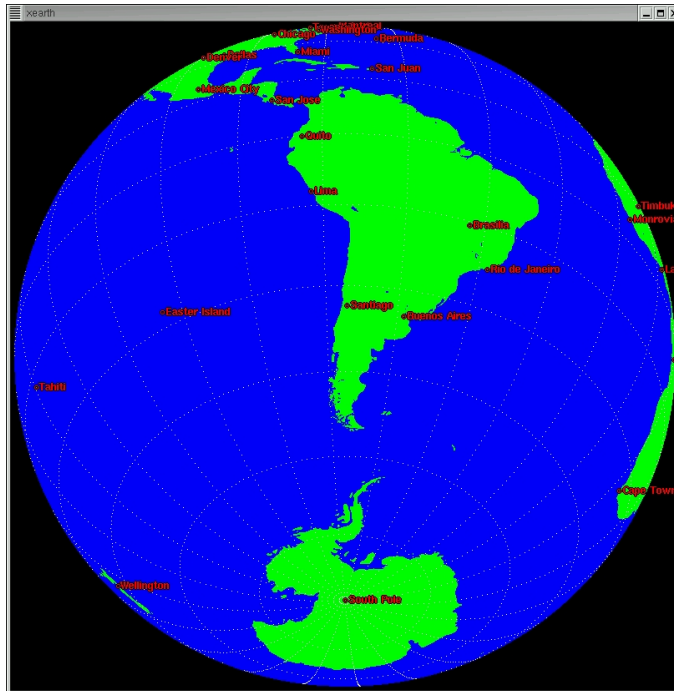
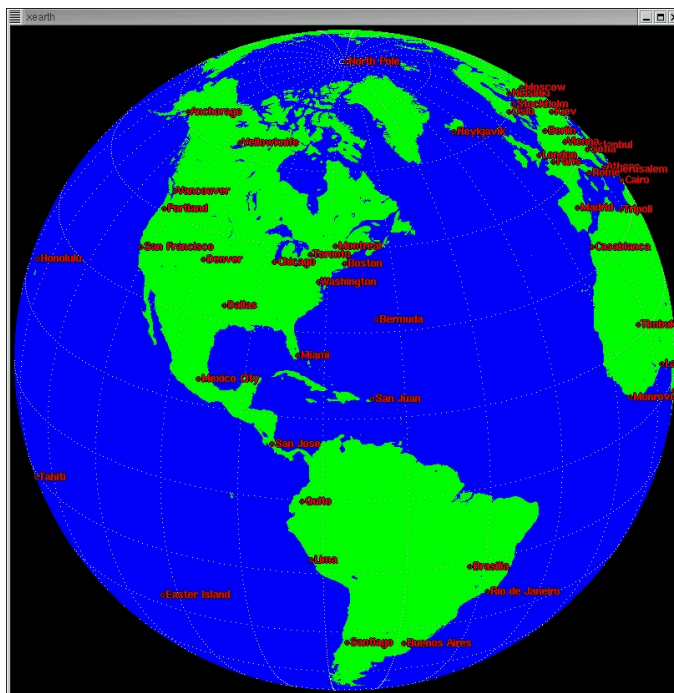Figure 2: The Earth, as seen from a -42 deg. declination

Figure 3: The Earth, as seen from a +25 deg. declination

Table 1: Star main characteristics of catalog `pws2b.sou`

Object	Spectral Type	Distance [pc]	J	Ra	Dec	Diameter [mas]
Gl887	M0V	3.3	4.16	23:05:52	-35:51:11	1.69
Gl551	M5.5V	1.3	5.28	14:29:42	-62:40:46	1.43
Gl752B	M8V	5.9	9.9	19:16:57	+05:08:49	0.16

Hint : have a look at the figure of the Earth in Figs. 2 and 3

Compare the N-S baseline and the E-W baseline in terms of (u, v)-coverage, observability (how much (u, v)-track do you cover with the same fixed delay ?) Play with the star and the end of hour angle range.

1.5 (u, v) tracks for a 3-telescope-array

- Select a large 3 telescope array configuration (in the *WHERE* menu).

- Visualize the observability of the targets with different fixed delay lines values. Look at the *Associated Telescopes & DLs* panel to see why the observability range is smaller with 3 telescopes than wih 2 telescopes.

- In the (u, v) coverage panel, try to add several 3-telescope configuration checking off the *reset frame* button. As an example, you can select 4 configurations i.e. `A0-G1-J6`, `G2-J1-D2` and `A1-B2-C1` with a fixed delay of 100m.

- You can then display the dirty beam by using the *Display PSF* panel.

2 Radius measurements and binary parameter determination

2.1 Direct radius measurement

Until the year 2000, only two M dwarfs radii were measured with great accuracy. This was done in the peculiar case of the eclipsing binary YYgem. Direct radius measurements of a few M dwarfs have been conducted with success at both PTI and the VLTI in 2003 (cf. Table 1). The VLTI will be able to directly measure the radii all M dwarfs located within 5pc thanks to its longest baseline ($> 100m$).

In this part you should load the catalogue named `pws2b.sou`. Select an instrument and the photometric band. You should also select an observing period, an optimal array configuration to determine their radius with the best accuracy. In this section you will make an intensive use of the *WHAT & Object Model* menu (or *UV Model/FIT, Source modelling* menu) and *OBSERVABILITY/COVERAGE* menu of **ASPRO**.

Use the appropriate uniform disk model (see model section in the annex of the document for model syntax and its analytical expression) to either display the amplitude, the phase of the visibility or the derivatives with respect to the diameter to visualize which part of the (u, v) plane really contrain the model.

- Are we able to determine the radius of these stars ?

- Are we able to determine phenomena that occur at higher frequencies like limb darkening?

Table 2: Binary system characteristics

Ra	Dec	ρ [mas]	P.A. [deg.]	Δmag
9:10:00	+10:00:00	3	86	3

Table 3: Gl 886AC characteristics

Object	Spectral Type	Distance [pc]	Ra	Dec	expected ρ [mas]	expected Δmag	expected radii [*mas]
Gl866AC	M7V	3.45	22:38:33	-15:18:06	7.4	0.0	0.27

2.2 Binary parameter determination

2.2.1 A binary star

First load/re-load the catalogue named `pws2a.sou` and then select star number 4. This star passes the meridian the 6th of June 2006 at midnight at Paranal. Let us consider it is a binary system with properties summarized in Table 2.

- Select the Baseline G2 G1

- Visualize the (u, v) coverage and the amplitude. Does this baseline constrain the parameters of the binary ? Plot the visibility as a function of time.

- Select the baselines A0 M0. Visualize the amplitude, the phase, and their derivatives.

- Does this baseline constrain the parameters of the binary ?

- Plot the visibility as a function of time.

- What do you notice about the baseline orientation / the binary system Position Angle ?

2.2.2 The very low mass star Gl866AC

Gl 866ABC is a triple system with very low masses. The component Gl866AC-B is resolved by adaptive optics and accurate radial velocities have been obtained for each component. From radial velocities, we can estimate the separation of the closest pair, Gl866AC. However, the Position Angle is not known. The magnitude difference is expected to be close to zero.

Select an observing period and an optimal array configuration to determine the orbital parameters with the best accuracy. Use the appropriate *binary made of two identical uniform disk model*, (cf. Table 2.2.2) to display the amplitude or the phase of the visibility or the derivatives to visualize which part of the (u, v) plane really contrain the model.

- Are we able to determine the parameters of the binary ?

- Are we able to determine the radius of these stars ?

3   Annex

3.1   Uniform Disk

The intensity distribution of a uniform disk is the following :

$$I(r) = I_s \, \Pi \, (r/D) \tag{1}$$

where D is the apparent diameter of the disk expressed in arcseconds.

The Fourier transform of this radial function is :

$$\widehat{I}(B/\lambda) = I_s 2 \frac{J_1\left(\pi BD/\lambda\right)}{\pi BD/\lambda} \qquad\qquad V(|\mathbf{f}|) = 2 \frac{J_1\left(\pi|\mathbf{f}|D\right)}{\pi|\mathbf{f}|D}$$

where $\mathbf{f} = \mathbf{B}D/\lambda$. You should notice that the visibility of a uniform disk model is real and has 2π phase shifts at $\mathbf{f}D = 1.22, 2.33, 3.33, ...$

3.2   Limb Darkened Disk

Limb darkening is usually represented as follow :

$$\frac{I\left(\mu\right)}{I\left(1\right)} = 1 - \Sigma_{i=1}^{N} \alpha_i \left(1-\mu\right)^{\beta_i} \tag{2}$$

where μ est le cosine of the angle between the photosphere and the xxxxde l'angle entre la ligne de vise et la perpendiculaire la photosphre de l'toile, $I\left(1\right)$ is the intensity at the center of the star, α_i are the limb darkening coefficients and $\beta_i = i$ or $i/2$, depending on models. The value of N also depends on models.

The visibility of a limb darkened disk is :

$$V(|\mathbf{f}|) = \frac{\int_0^1 I\left(\mu\right) J_0\left(|\mathbf{f}|\pi D \left(1-\mu^2\right)^{1/2}\right)\mu d\mu}{\int_0^1 I\left(\mu\right)\mu d\mu} \tag{3}$$

3.3   Binary star

The intensity distribution of a binary star is :

$$I(\mathbf{x}) = I_1\delta(\mathbf{x}) * \Pi\left(r/D_1\right) + I_2\delta(\mathbf{x}-\mathbf{x_2}) * \Pi\left(r/D_2\right) \tag{4}$$

Its Fourier transform is :

$$\widehat{I}(B/\lambda) = I_1 2\frac{J_1\left(\pi BD_1/\lambda\right)}{\pi BD_1/\lambda} + I_1 2\frac{J_1\left(\pi BD_1/\lambda\right)}{\pi BD_1/\lambda}\exp\left(-2i\pi\mathbf{B}\mathbf{\Delta X}/\lambda\right) \tag{5}$$

If one define q as the flux ratio between the secondary and the primary star, $q = \frac{I_2}{I_1}$, and $\bar{V}_i$ as the individual star visibility i then $\bar{V}_i = \frac{J_1(\pi|\mathbf{f}|D_i)}{\pi|\mathbf{f}|D_i}$, and :

$$V(\mathbf{f}) = \frac{1}{1+q}\left(\bar{V}_1 + q\,\bar{V}_2\exp\left(-2i\pi\mathbf{f}\mathbf{\Delta X}\right)\right) \tag{6}$$

La visibilit est alors complexe et son amplitude carre est :

$$|V(\mathbf{f})|^2 = \frac{1}{(1+q)^2}\left(\bar{V}_1^2 + q^2\,\bar{V}_2^2 + 2q\bar{V}_1\bar{V}_2\cos\left(2\pi\mathbf{f}\mathbf{\Delta X}\right)\right) \tag{7}$$

3.4   Simple models with ASPRO

This task allows writing of models directly into a visibility table. The models are either simple or linear combinations of several functions. Currently supported distributions and parameters (aside offset in arc second from the maps center and flux) are:

Table 4: Parameters of the **ASPRO** model software module.

POINT	Point source	None
E_GAUSS	Elliptic Gaussian source	FWHP Axis (Major and Minor), Pos Ang
C_GAUSS	Circular Gaussian source	FWHP Axis
C_DISK	Circular Disk	Diameter
E_DISK	Elliptical (inclined) Disk	Axis (Major and Minor), Pos Ang
RING	Ring	Inner Ring Diameter, Outer ring diam
U_RING	Unresoved Ring	Diameter (1 value: unresolved!)
EXPO	Exponential brightness	FWHP Axis
POWER-2	$B = 1/r^2$	FWHP Axis
POWER-3	$B = 1/r^3$	FWHP Axis
LD_DISK	Limb-Darkened Disk	Diameter, 'cu' and 'cv'
BINARY	Binary	Flux ratio, rho, theta

POINT	Offset R.A.	Offset Dec	Flux	-	-	-
E_GAUSS	Offset R.A.	Offset Dec	Flux	Maj. diam.	Min. diam.	Pos Ang
C_GAUSS	Offset R.A.	Offset Dec	Flux	Diameter	-	-
C_DISK	Offset R.A.	Offset Dec	Flux	Diameter	-	-
E_DISK	Offset R.A.	Offset Dec	Flux	Maj. diam.	Min. diam.	Pos Ang
RING	Offset R.A.	Offset Dec	Flux	Inner Diameter	Outer Diameter	
U_RING	Offset R.A.	Offset Dec	Flux	Diameter	-	-
EXPO	Offset R.A.	Offset Dec	Flux	Diameter	-	-
POWER-2	Offset R.A.	Offset Dec	Flux	Diameter	-	-
POWER-3	Offset R.A.	Offset Dec	Flux	Diameter	-	-
LD_DISK	Offset R.A.	Offset Dec	Flux	Diameter	'cu' and 'cv'	-
BINARY	Offset R.A.	Offset Dec	Flux	FluxRatio	Rho	Theta

Note: for the Binary model, the flux ratio is Flux_secondary / Flux_primary and Rho &
Theta are the angular separation (") and Position angle (degrees) of the binary.
Offset R.A. and **Offset Dec** are usually set to zero while **flux** is set to one.