Practice Work Session #2 (3h)

Observability and UV coverage

EuroWinter School

Observing with the Very Large Telescope Interferometer

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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 UV 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, and the characteristics of the disk around FU Orionis.

1 Sampling the UV plane with the VLTI

You should first load the catalogue named pws2a.sou. It contains 7 stars of R.A. 09:10:00 and of different declination. These prototype stars pass the meridian the 5th of February 2002 at midnight at Paranal. In this section you will make an intensive use of the **OBSERVABILITY/COVERAGE** menu of **ASPRO**. In the different widget, select a **minimum elevation of 40 degres and a hour angle range of -3h to +3h**.

1.1 UV tracks for a North-South baseline

Select a 2 telescope baseline oriented N-S (**WHERE** and **OBSERVABILITY/COVERAGE**).
Visualize the observability of the sources with/without delay lines constraints **OBSERVABILITY/COVERAGE**.
Plot the uv coverage for several stars and change the fixed delay. Why are the uv-tracks straight ?
(Hint : have a look at the figure of the earth at the end of the document)

1.2 UV 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 uv coverage for several stars and change the fixed delay. Why are the uv-tracks elliptical ? Have a look at uv-tracks of a star above the equator and below the equator. What do you notice?
(Hint : have a look at the figure of the earth at the end of the document)

Compare the N-S baseline and the E-W baseline in terms of UV-coverage, observability (how much UV-track do you cover with the same fixed delay ?)

1.3 UV tracks for a 3-telescope-array

Select a large 3 telescope array configuration. Visualize the observability of the targets with/without delay lines constraints. Plot the uv coverage for several stars and change the fixed delay. What do you notice?
In which case is it important to observe with three telescope ?

2 Radius measurements and binary parameter determination

2.1 Direct radius measurement

Until very recently, only two M dwarfs radii had been directly 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 very recently with success at PTI. The VLTI will be able to directly measure the radii of the closest M dwarfs thanks to its longest baseline ($> 100m$).

Table 1: Star main characteristics

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

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, **OBSERVABILITY/COVERAGE** menu of **ASPRO**. In the different widget, select a **minimum elevation of 40 degres and a hour angle range of -3h to +3h**. Use the appropriate uniform disk model (see model section at the end 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 UV 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?
Some of the late M dwarfs are fast rotators, propose an observing strategy to efficiently detect a possible assymetry in the simple disk model.

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 5th of February 2002 at midnight at Paranal. Let's consider it is a binary system with properties summarized in the following table.

Select the Baseline G2 G1

Visualize the uv coverage and the amplitude. Does this baseline constrain the parameters of the binary ?

Table 2:

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

Select the baselines A0 M0
Visualize the amplitude, the phase, and their derivatives.
Does this baseline constrain the parameters of the binary ?

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 + uniform disk model** to display the amplitude or the phase of the visibility or the derivatives to visualize which part of the UV 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 ?

Table 3:

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

3 Material

You will need to use ASPRO and the catalogues named pws2a.sou and pws2b.sou. It is assumed that you know how to load a catalogues and select an observing date and time.

4 Reminder on Visibilities

4.1 Uniform Disk

The intensity distribution of a uniform disk is the following :

$$I(r) = I_s \; \Pi \left(r/D \right) \tag{1}$$

where D is the apparent diameter of the disk expressed in arcseconds.
The Fourier transform of this radial function is :

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

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 $\mathbf{f}D = 1.22,\ 2.33,\ 3.33,\ ....$

4.2 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 :

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

4.3 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 :

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

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 :

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

La visibilit est alors complexe et son amplitude carre est :

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

4.4 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:

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

Table 4: 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.

4.5 Baselines

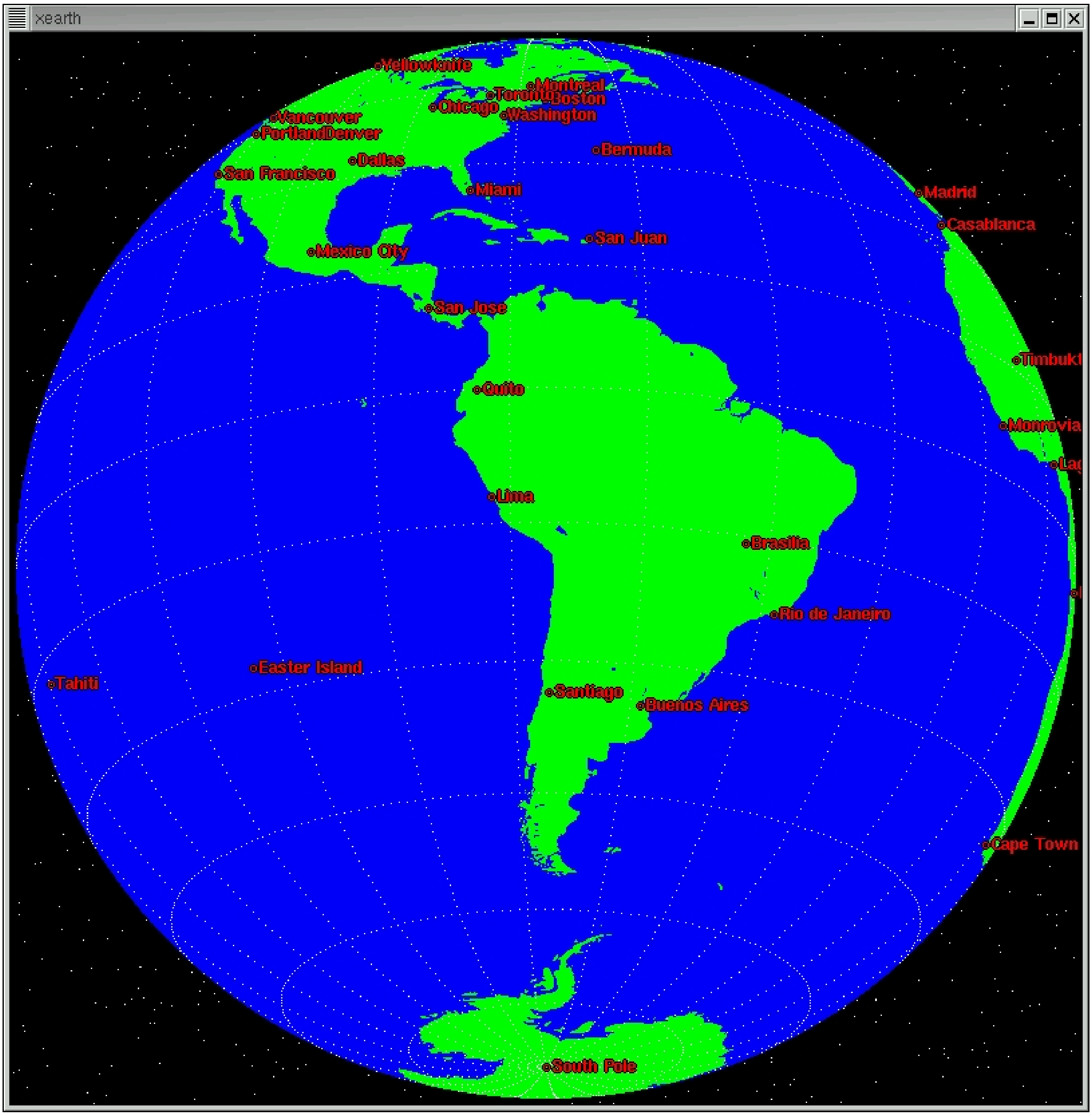

Figure 1: Look at the earth, you will understand projected baseline

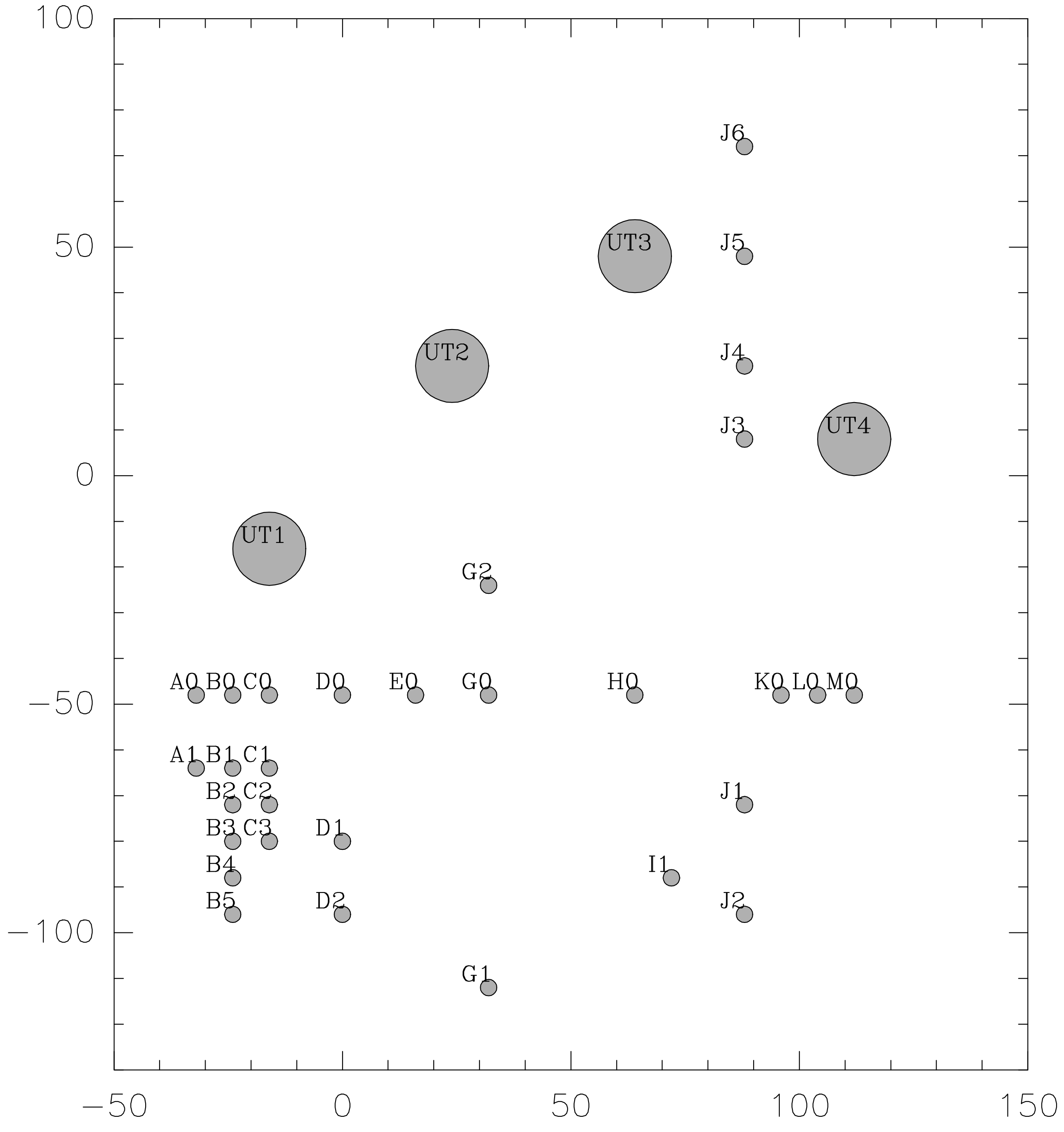

Figure 2: VLTI stations

Length (m)	Name(s)
8	B0-A0,B0-C0,B1-A1,B1-C1,B2-C2,B3-C3,K0-L0,M0-L0,B2-C1,B3-C2,B4-C3,B1-C2, B2-A1,B2-C3
16	A0-C0,A1-C1,D0-C0,D0-E0,D1-C3,E0-G0,K0-M0,B0-A1,B1-C0,B3-C1,B4-C2,B5-C3, B0-C1,B1-A0,B1-C3,B3-A1,A1-C2,D1-C2,I1-J2
24	A1-C0,D0-C1,I1-J1,A0-C1,A1-C3,D1-C1,D2-C3,B0-D0,D1-B3,D2-B5,J3-UT4,UT3-J5, G2-G0,B2-D1,D2-B4,D1-B4,B2-C0,B4-C1,B5-C2,K0-J1,B0-C2,B2-A0,B4-A1
32	B1-D0,D1-B5,D0-C2,G2-E0,J1-L0,A0-C2,D2-C2,B1-D1,B3-D2,UT4-J4,C0-E0,D0-A0, D0-G0,G0-H0,K0-H0,UT1-C0,B0-UT1,B3-C0,B5-C1,B0-C3,B3-A0,B5-A1,D0-B2,J6-UT3, M0-J1,B2-D2,H0-J1,UT3-J4
40	C1-E0,D0-A1,A0-UT1,D0-C3,D1-E0,A0-C3,D0-UT1,D1-C0,D2-C1,D1-A1,G1-D2,B0-E0, H0-L0,E0-C2,G2-D0,D0-B3,B0-D1,B1-D2,G2-H0,B4-C0,B4-A0,I1-H0,B1-E0
48	D1-G0,E0-C3,D1-A0,D2-A1,G1-D1,UT1-E0,B2-E0,G1-I1,UT2-UT3,D0-B4,I1-K0, UT3-J3,UT4-J5,A0-E0,C0-G0,E0-H0,M0-H0,UT1-C1,G2-UT1,B1-UT1,B5-C0,K0-J2, B5-A0,G2-UT2,A1-E0,C1-G0,D2-E0,L0-J2,UT1-A1,D2-C0,B3-E0,I1-L0
56	C2-G0,G2-C0,D0-B5,M0-J2,B0-D2,H0-J2,B0-G0,M0-UT4,UT1-C2,B4-E0,I1-M0, UT1-UT2,B2-UT1,L0-UT4,K0-J3,G0-I1,C3-G0,D2-G0,D2-A0,G1-C3,UT1-G0,G1-B5, B1-G0,G1-J2,K0-UT4,L0-J3
64	B2-G0,G2-B0,H0-J3,M0-J3,G0-J1,G1-B4,G2-C1,B5-E0,G1-C2,UT3-UT4,A0-G0, D0-H0,G0-K0,UT2-J4,UT1-C3,B3-G0,G2-J3,G2-D1,B3-UT1,G1-B3,UT2-J3,A1-G0, D1-UT1,G1-E0
72	G2-C2,G1-C1,G2-A0,UT2-J5,J6-UT4,G2-K0,B4-G0,G1-J1,G2-B1,E0-I1,G1-B2, D1-H0,G1-H0,G1-D0,G0-L0,D1-I1,D2-I1,B4-UT1,UT2-E0,K0-J4,UT2-G0,B5-G0,G2-B2, G2-J4,G2-C3,H0-UT4,L0-J4,G0-J2,G1-B1,G2-J1,G2-A1,G2-I1
80	E0-J1,G2-L0,D0-UT2,H0-J4,M0-J4,G2-D2,G2-UT3,G0-J3,G2-B3,C0-H0,E0-K0,G0-M0, D2-H0,UT2-J6,J1-J3,G1-C0,G1-A1,B5-UT1,C1-H0,D2-UT1,C0-UT2,UT2-H0,D0-I1
88	G2-M0,C2-H0,J1-UT4,G2-B4,G1-B0,C3-H0,G2-UT4,UT1-H0,B0-UT2,E0-J2,B0-H0, D2-J2,E0-L0,G1-G2,C3-I1,D1-J1,C2-I1,D1-J2,UT2-UT4,B1-H0,G1-K0,G1-A0,C1-I1, D0-J1,B2-H0,D2-J1,E0-J3,A0-UT2,G0-J4,G2-J5,G2-B5,G2-J2
96	B3-H0,A0-H0,B4-I1,D0-K0,E0-M0,H0-UT3,J1-J4,B3-I1,B5-I1,G1-L0,K0-J5,B4-H0, UT2-C1,C0-I1,B2-I1,A1-H0,I1-J3,L0-J5,G0-UT4,B1-I1,H0-J5,M0-J5
104	B5-H0,B1-UT2,D0-J2,D1-K0,G0-UT3,K0-UT3,E0-J4,UT2-K0,G1-M0,UT1-UT3,C2-J1, D0-L0,I1-UT4,UT2-C2,J2-J3,L0-UT3,B0-I1,C1-J1,C3-J1,D0-J3,A1-UT2,C3-J2,A1-I1, C0-J1,C2-J2,UT1-J3,D1-UT2,J2-UT4,D2-K0,B2-UT2,E0-UT3,G1-UT1,M0-UT3
112	UT2-L0,C1-J2,D1-L0,E0-UT4,G0-J5,G2-J6,UT1-J4,UT2-C3,A0-I1,B2-J1,B5-J2, C0-K0,D0-M0,B1-J1,B4-J2,B3-J1,B3-J2,B4-J1,C1-K0,I1-J4,D0-J4,UT1-I1,UT2-M0, B0-J1,B2-J2,B5-J1,C2-K0,D2-L0,B3-UT2,C0-J2,D0-UT3,UT2-J1
120	B1-J2,UT1-K0,C3-K0,D1-M0,C0-J3,UT1-J1,B0-K0,C0-L0,E0-J5,J1-J5,J2-J4, A1-J1,J6-K0,B1-K0,C1-L0,J6-L0,D2-M0,B4-UT2,UT2-I1,B0-J2,UT1-J5,A0-J1,B2-K0, C2-L0,D2-UT2,J6-H0,J1-UT3,J6-M0
128	A1-J2,UT1-L0,B3-K0,C3-L0,D1-J3,C0-UT3,B0-J3,D0-UT4,B4-K0,C0-J4,C1-J3, A0-K0,B0-L0,C0-M0,A1-K0,B1-L0,C1-M0,B5-K0,B5-UT2,A0-J2,B2-L0,C2-M0,UT1-UT4, B0-UT3,D0-J5,C2-J3,UT1-J2
136	UT1-M0,B3-L0,C3-M0,A0-J3,G0-J6,G1-J3,B0-J4,B1-J3,B4-L0,A0-UT3,A0-L0, B0-M0,UT2-J2,C1-J4,C3-J3,UT1-J6,D1-J4,D2-J3,G1-UT2,I1-UT3,B5-L0,A1-L0, B1-M0,I1-J5,B2-J3,C1-UT3,B2-M0
144	B3-M0,C0-UT4,A0-J4,A1-J3,E0-J6,C0-J5,C2-J4,B4-M0,B1-J4,B3-J3,D1-UT4, B1-UT3,D1-UT3,A0-M0,J2-J5,J6-J1,B5-M0,C2-UT3,G1-UT4,A1-M0,J2-UT3,C1-UT4, B0-UT4,C3-J4,G1-J4
152	B0-J5,B2-J4,B4-J3,A1-UT3,A1-J4,B2-UT3,D0-J6,D2-J4,C2-UT4,C3-UT3,B3-J4, B5-J3,D2-UT4,C1-J5,A0-J5,B1-UT4,A0-UT4,C3-UT4,B3-UT3,D1-J5
160	D2-UT3,B2-UT4,B1-J5,B4-J4,C0-J6,C2-J5,J6-I1,A1-UT4,B3-UT4,B4-UT3,G1-UT3
168	A1-J5,B0-J6,B2-J5,B5-J4,C3-J5,B4-UT4,J6-J2,B5-UT3,D2-J5,G1-J5,A0-J6, B3-J5,B5-UT4,C1-J6
176	D1-J6,B1-J6,B4-J5,C2-J6
184	A1-J6,B2-J6,B5-J5,C3-J6
192	B3-J6,D2-J6,G1-J6,B4-J6
200	B5-J6

Table 5: VLTI baselines sorted by length