5   Observability and *UV* coverage (Correction)

The same procedure as before was used to produce these corrections: `ASPRO` was used for getting the figures and `GIMP` to over-plot the graphs together for illustration. **As in the previous section, please try the exercises first before reading these corrections**.

Exercise 1: Setting up an observation

After having set the date, time, place, and target (Fig. 14), you can start using `ASPRO` and its many features to check and prepare observations. Fig. 15 is what you should get in your shell when setting *View Object Catalog* correctly.
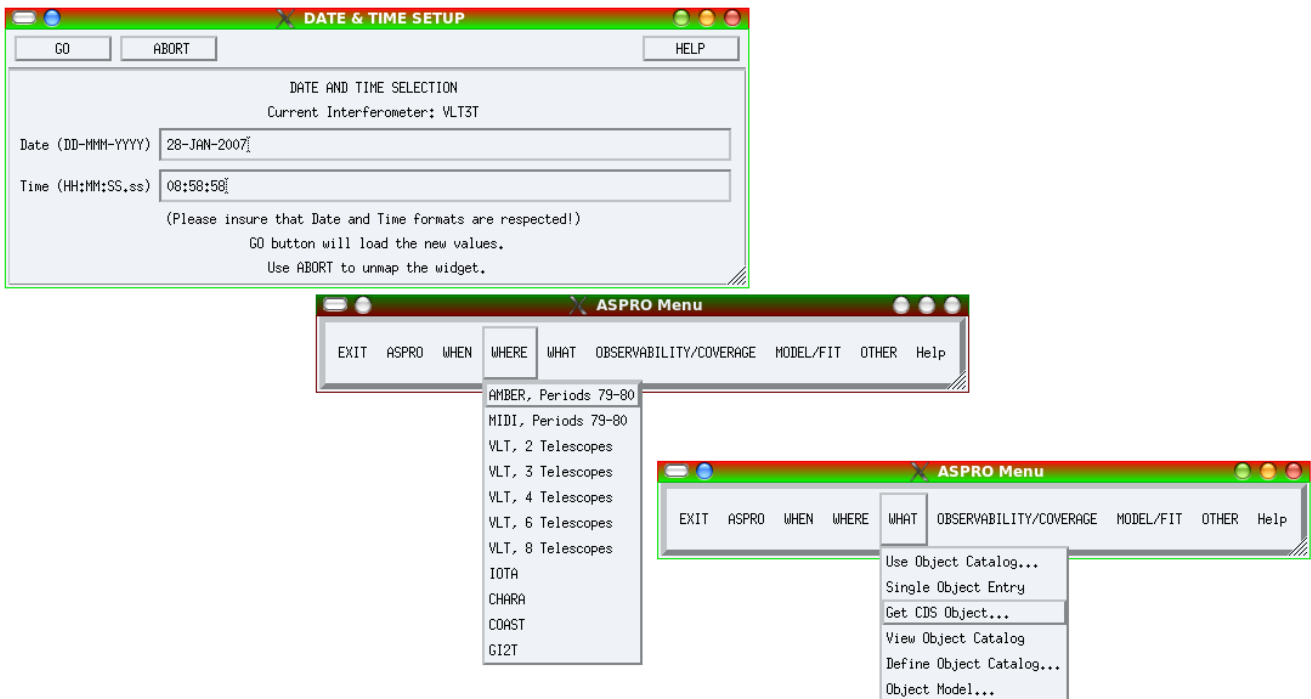

Fig. 14.   How to set the date, place, and object. Top: the date setup window appearing when pressing the *WHEN* menu. After changing the date and time, just press *GO*. Middle: the *WHERE* menu, where one can choose between all the supported interferometers. Bottom: the *WHAT* menu. The *Get CDS Object...* is very convenient for quickly finding a target.

```
Aspro>
!-----------------------------------------------------
! sampleSources1.sou
!-----------------------------------------------------
ACHERNAR     EQ 2000.000     01:37:42.8466 -57:14:12.327
NGC_1068     EQ 2000.000     02:42:40.8300 -00:00:48.400
BETELGEUSE   EQ 2000.000     05:55:10.3053 +07:24:25.426
HD_68273     EQ 2000.000     08:09:31.9503 -47:20:11.716
HD_81720     EQ 2000.000     09:25:19.2802 -54:27:49.559
```

Fig. 15.   Display of the catalog in the terminal window.

Exercise 2: Observability of sources at different declinations and delay line constraints

Which stars are observable?   Fig. 16 shows the observability for the second catalog of sources (`sampleSources2.sou`). The gray area corresponds to the night, and the black lines correspond to

the observability of sources by their height above the horizon (here 30°). First, you can see that a source at declination +40 is not observable at all, due to the latitude of Paranal: about 30°.

Delay lines limitation: The additional constraints coming from the interferometer are displayed in red just above the usual observability plot: the left graph is for stations UT1-UT4 and the right one is for G1-J6. You can see the difference for 2 extreme cases: a (roughly) East-West baseline (UT1-UT4) and a North-South baseline (G1-J6). The North-South baseline restricts the access to northern sources, whereas the East-West baseline restricts the observability during the night.
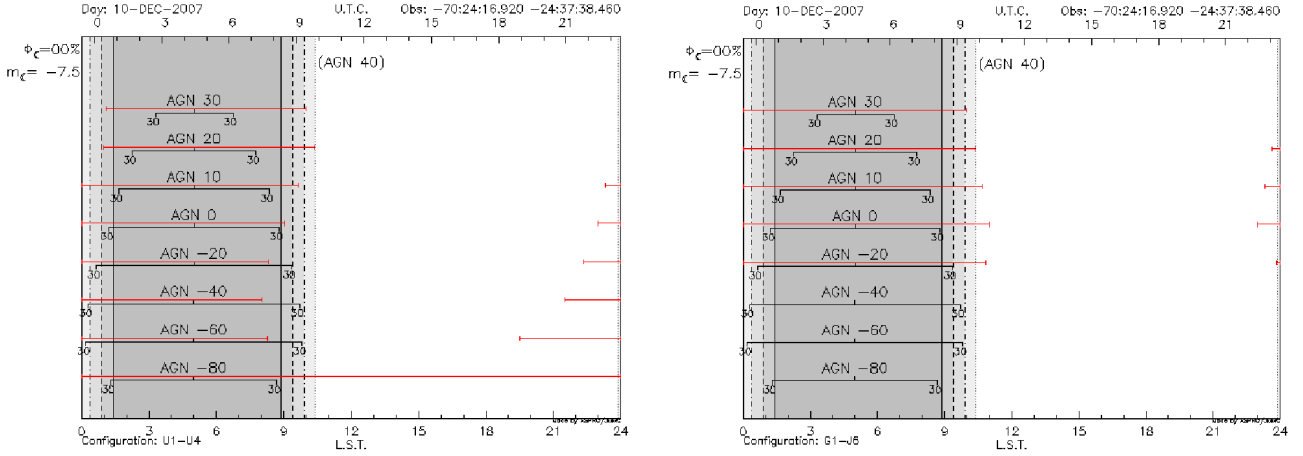

Fig. 16. **Left:** Observability of sources at different declinations for the UT1-UT4 baseline (roughly East-West baseline). **Right:** Observability of sources for the G1-J6 baseline (North-South).

Exercise 3: UV tracks for a North-South baseline

The *UV* tracks for the targets of the 2nd catalog (`sampleSources2.sou`) are shown in Fig. 17. The North-South baseline gives roughly North-South *UV* tracks, but the limitations due to the delay line limits are quite severe here since a very long baseline (G1-J6) was used. This can be seen in the very short accessible *UV* tracks for the 20 and 30° declination targets. One can see here that the 0° declination target gives a line in the *UV* plane.

Exercise 4: UV tracks for an East-West baseline

UV **tracks shape:** For the answer to this question, please refer to Millour (2008). The *UV* tracks correspond to the projection of a circle (due to the Earth rotation) on an inclined plane (the plane of sky) and are therefore arcs of ellipses.

UV **tracks and target declination:** Fig. 18 now shows the East-West baseline. As one can see, East-West baselines will never give a North-South *UV* projection on the sky. Also, the total range of *UV* plane projected angles is maximum for high declination targets (either positive or negative). As for the previous case, a 0° target gives a straight line in the *UV* plane and, therefore, provides less coverage than a high declination target.
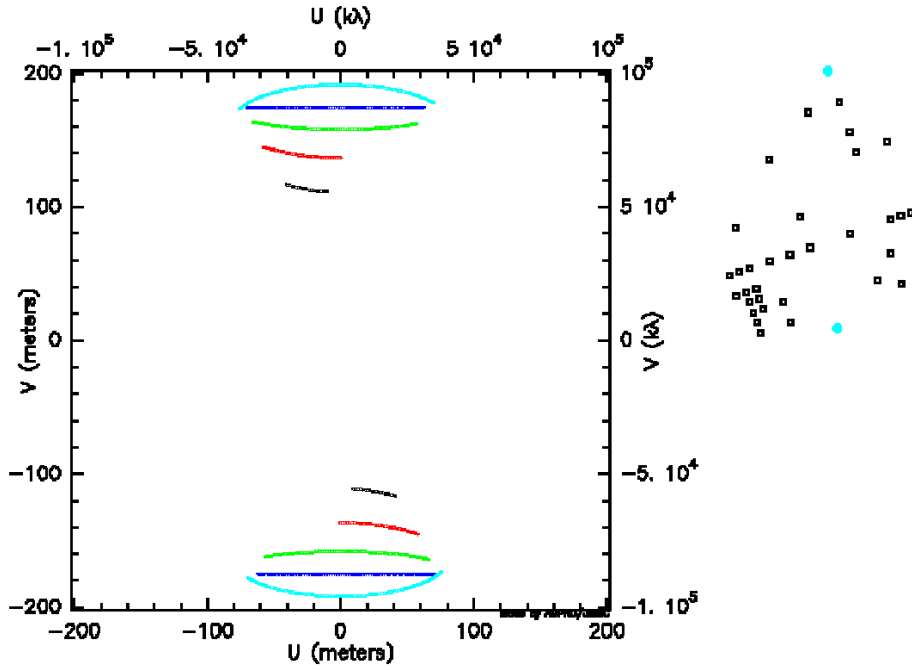
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Fig. 17. *UV* plane tracks due to the Earth rotation for a N-S baseline (G1-J6) and for different declinations: cyan for -20°, blue for 0°, green for 10°, red for 20° and black for 30°.
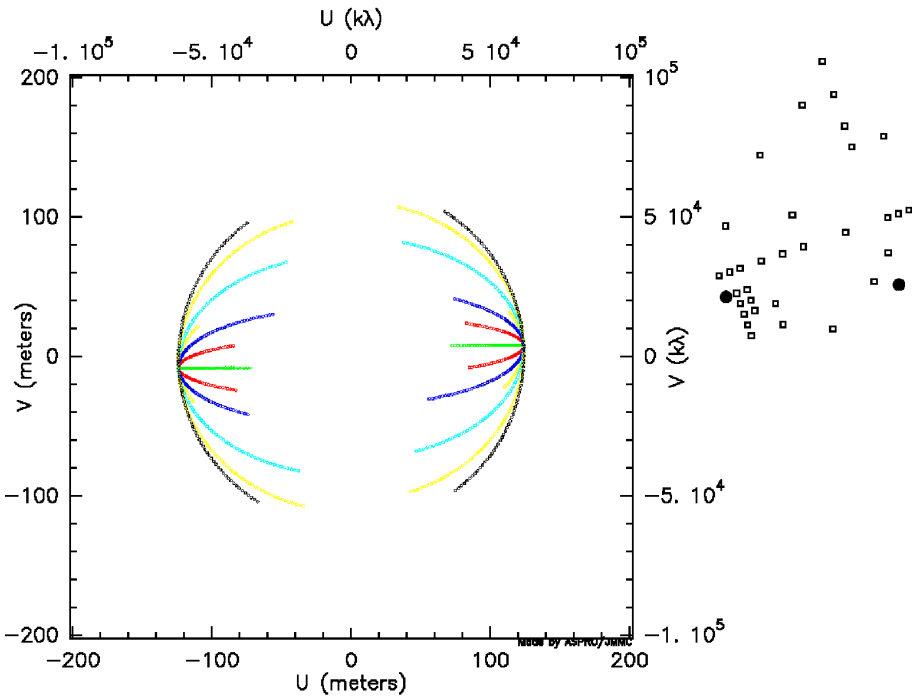

Fig. 18. *UV* plane tracks due to the Earth rotation for an E-W baseline (A1-J2). The color-coding for the different declinations is the following: black for -80°, cyan for -40°, blue for -20°, green for 0°, red for 20° and yellow for 40°.

Exercise 5: *UV tracks for a 3-telescope-array*

Observability: First, one needs to check the observability when taking a big triangle (B5-J6-M0, Fig. 19, left panel). As one can see, the observability constraints are much more stringent than before, using a lower number of telescopes. The *Observability limits due to delay lines* panel (right side) now gives meaningful information; i.e., splitting the constraint by delay line. Here, one can see that the most constraining baselines are the B5-J6 and M0-B5, and the M0-J6 baseline does not too much constrain the observability.
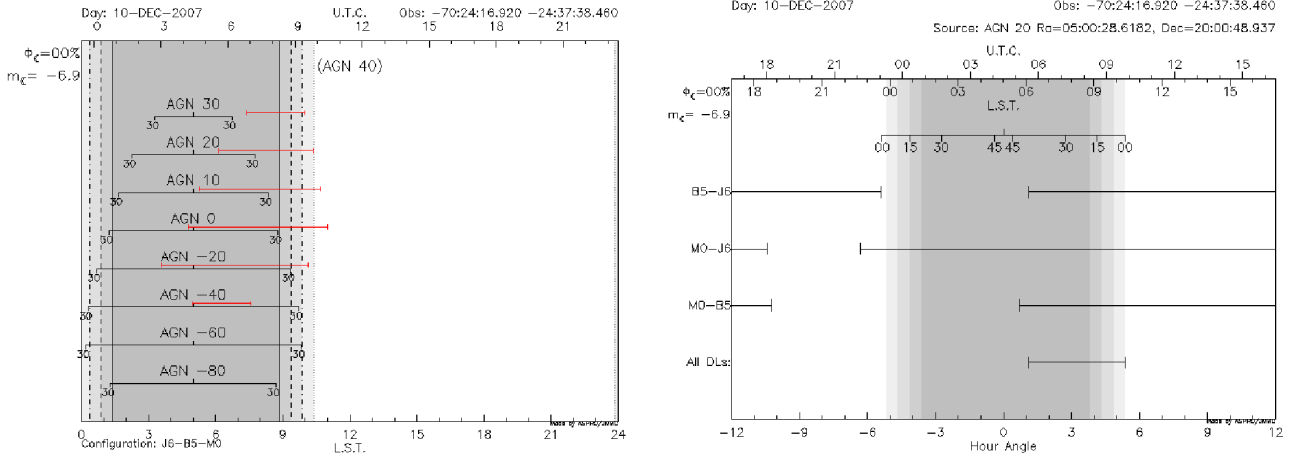
Fig. 19. **Left:** Observability of sources for a big triangle of baselines (B5-J6-M0). The constraints due to the delay lines (red lines) are now larger than for 2 telescopes. **Right:** Detail of the delay line constraints: the B5-J6 and M0-B5 are the most constraining baselines.

UV tracks for different configurations: In Fig. 20, the UV tracks for the different triangles and different object declinations (0°, -20° and -40° from top to bottom) are shown. One can see that many aspects will affect the UV coverage:

- declination - which affects the quantity of different position angles.
- delay lines constraints - which prevent one from observing with large baselines (bottom graph).
- available baselines - which limits the available stations due to the interferometer possibilities.

Beam shape: One can see that the many aspects raised before will affect the UV coverage and, therefore, the quality of the PSF (plotted using the *show dirty beam* option):

- declination affects the quality of different position angles and gives irregular secondary lobes to the PSF.
- The delay line constraints prevent one from observing with large baselines (bottom graph) and widen the PSF (loss of angular resolution).
- The available baselines give an elongated PSF in the E-W direction for the VLTI, since the longest baseline is in the N-S direction.

Exercise 6: *Radius measurement of a star (uniform disk)*

Optimizing the observability of a series of sources: The first step is to set up an observation date in order to be able to observe all targets together in one night. The optimal date of observation would be the 15th of December, but the moon is full on the 20th. However, one can choose this date (Fig. 21) since interferometry is insensitive to the moon phase. I also chose the UT1-UT3-UT4 triplet since there is a faint target in my sample (NGC 1068) and checked that it does not put too many additional constraints on the observability of the source due to delay lines.

Radius measurement: First of all, you need to look at the standard accuracy of the instrument you will use to be able to know what you can expect from your observations. The ESO *Call for Proposal* [6] gives you information about AMBER and MIDI (the two offered instruments) accuracy you can expect. For AMBER in P81, the accuracy is 3% for an uncalibrated visibility point; i.e., about 5% for a calibrated one. If you look at the different targets here (I have taken a diameter of
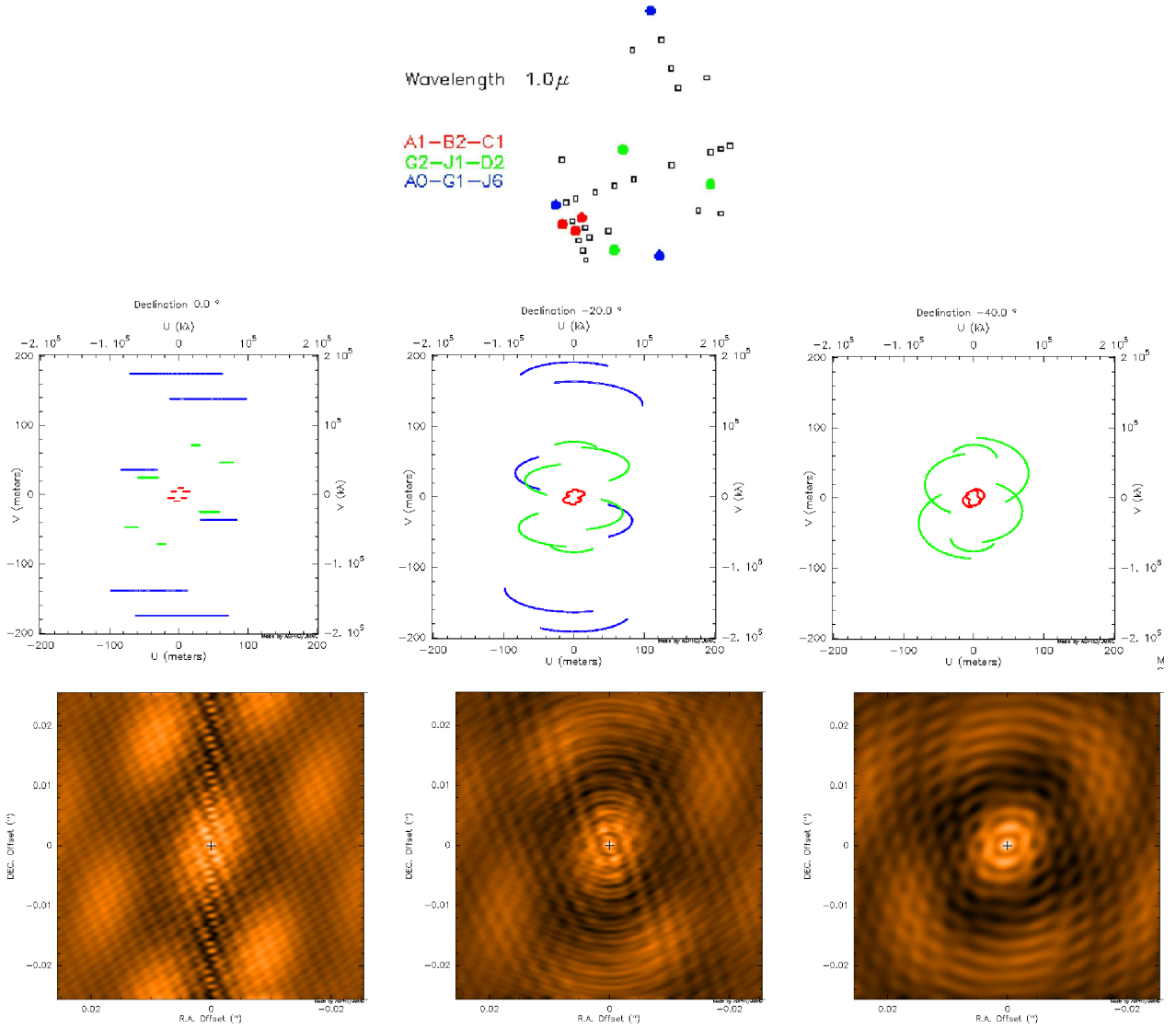
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[6] `http://www.eso.org/sci/observing/proposals/`

Fig. 20. **Top:** Sketch of the stations used in this example. **Middle-Left:** *UV* tracks for a 3-telescope observation on a 0° declination object and several telescopes configurations: A1-B2-C1, A0-G1-J6 and G2-J1-D2, corresponding roughly to 3 observing nights using AMBER and with complete freedom in the stations selection. **Bottom-Left:** The corresponding "dirty beam", or what would look like the PSF if one would observe a point-source with a telescope having an aperture similar to the previous *UV* track. **Middle:** Same as 1st plot, but for a -20° declination target. **Bottom-Middle:** The corresponding dirty beam. **Middle-Right:** Same as before but for a -40° declination target. Note that the biggest triangle does not appear in this plot, as the constraints due to the delay lines prevents from observing with these telescopes. **Bottom-Right:** The corresponding dirty beam.

3 mas for NGC 1068, see Fig. 22), you can see that with this accuracy, both the star Betelgeuse and HD 68273 (γ^2 Vel) are unreachable for diameter measurement. The star HD 81720 will be measurable but with a poor accuracy on the diameter. Therefore the targets you will really be able to observe using these baselines are Achernar, NGC 1068, and partially HD 81720. For the two other stars (HD 68273 and Betelgeuse), you will need other configurations (a short baseline triplet for Betelgeuse and the longest available baselines for HD 68273) to reach your goal of measuring a diameter.

More details about the object: You should also notice that limb-darkening measurements, which need at least one point in the second lobe of visibility, are not achievable, except for Betelgeuse. Finally, one baseline setup is not sufficient to measure all the star diameters: you will need at least a 3-baseline setup to reach your proposal goal (one short baseline setup for Betelgeuse and one very long baselines needed for HD 68273 and HD 81720 to reach a better accuracy).
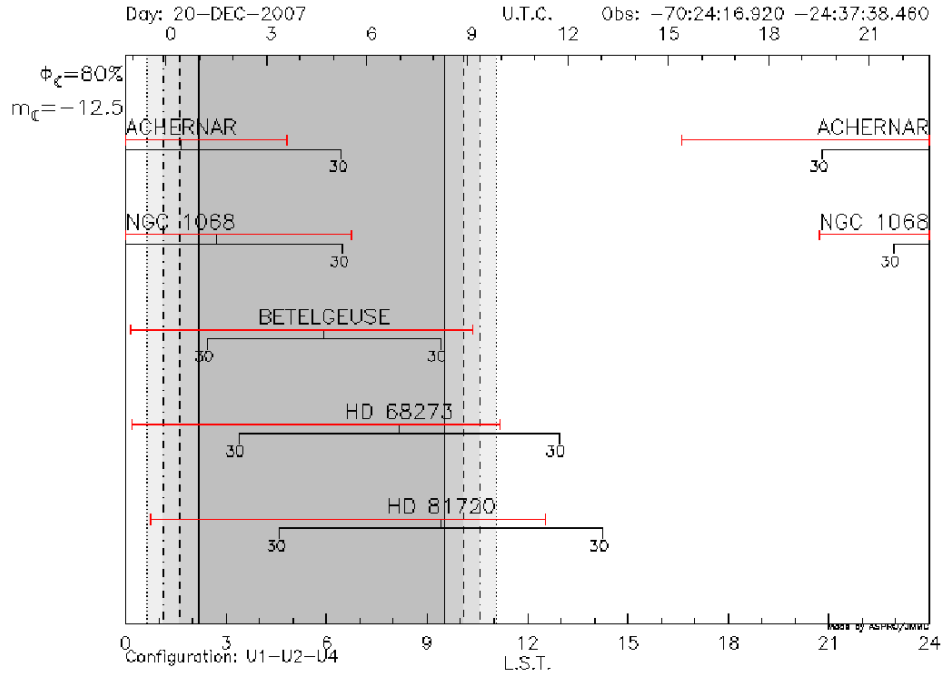
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Fig. 21. Observability of the 1st catalog.

Knowing the limitations: By browsing the ESO call for proposals [7], you can find that the current AMBER accuracy is 0.03 on the raw visibilities. This means 0.05 on calibrated measurements. Therefore, as seen in Fig. 22, only Achernar and NGC1068 will allow one to "easily" measure a non-zero or non-1 visibility. HD68273 and Betelgeuse will make the measurement very difficult, as the expected visibility is very close to 0 or 1. Then, HD81720, whose visibility at maximum baseline is 0.85, will be marginally resolved and only an upper limit to the diameter will be measurable.

Exercise 7: Binary parameter determination

If the reader has reached this point carried out all of the exercises without any problems, he is now an expert in long-baseline stellar interferometry and can do this exercise without any difficulty ;-)

APPENDIX

References

Berger, J. P. & Segransan, D. An introduction to visibility modeling, New Astronomy Review, 2007, 51, 576-582

Millour, F., All you ever wanted to know about optical long baseline stellar interferometry, but were too shy to ask your adviser, New Astronomy Review, this issue.
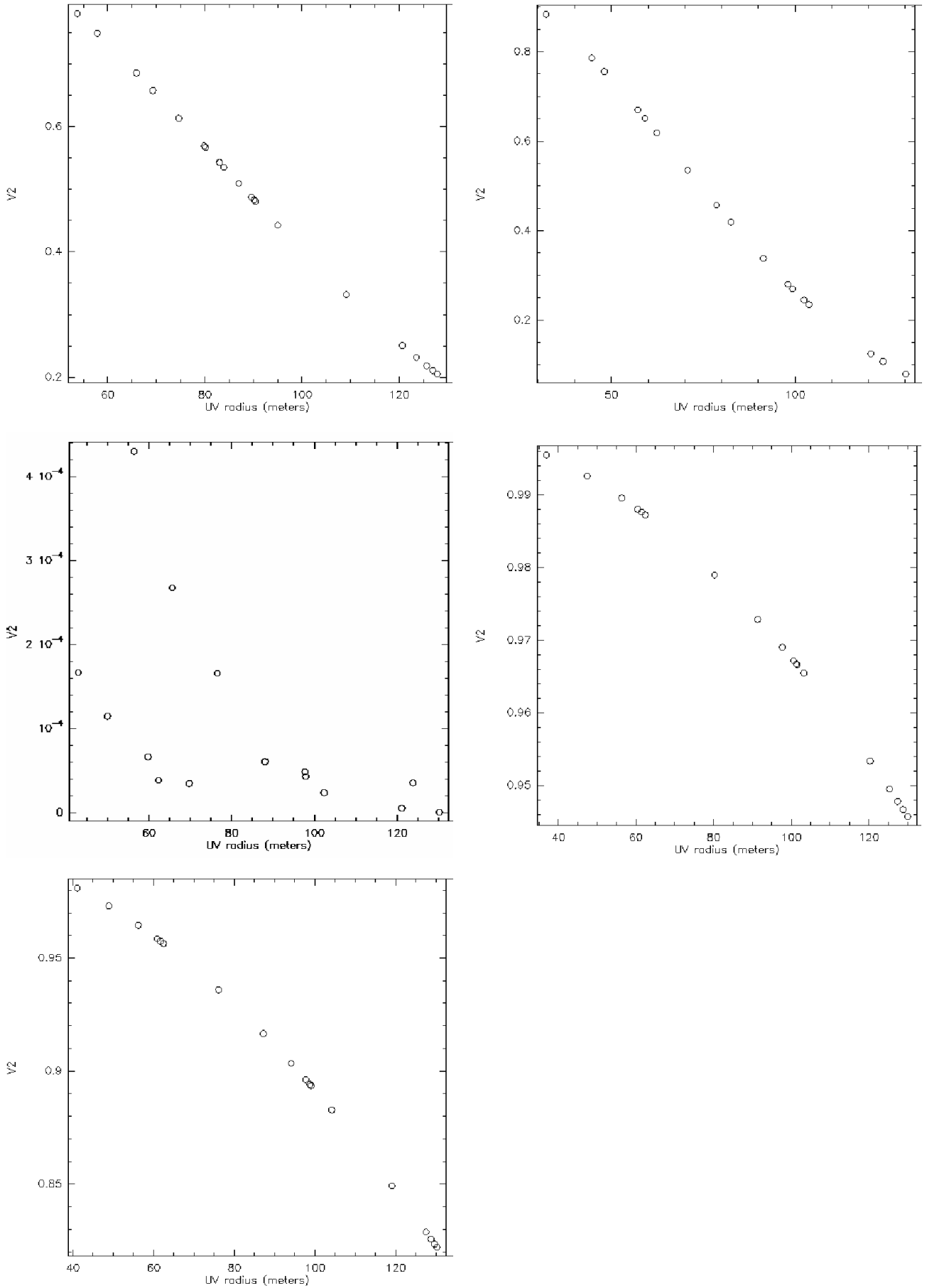
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[7] http://www.eso.org/sci/observing/proposals/

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Fig. 22. **Top-Left:** Achernar visibilities for the largest baselines, given a radius of 2.53 mas. **Top-Right:** Same for NGC 1068 and a diameter 3 mas. **Middle-Left:** Same for Betelgeuse, diameter of 44 mas. **Middle-Right:** Same for HD68273, diameter of 0.5 mas. **Bottom-Left:** same for HD81720, diameter of 0.93 mas.