Acoustic astrometry with a VLBI-like interferometer

I. Martí-Vidal & J. M. Marcaide *(Universitat de València, SPAIN)*

IAU Symposium # 248. A Giant Step: from Milli- to Micro-arcsecond Astrometry, Shanghai (15-19 Oct 2007)

Abstract

We show how loud speakers, home digital recorders, and common personal computers can be used to emulate VLBI observations at a small scale. These audio-VLBI observations allow for single-field astrometry (sources within the same interferometric field), differenced group-delay astrometry, etc. These experiments can be set up very easily and in many possible configurations. Students may find these experiments very useful to learn about the innermost details of the interferometric technique.

Experimental setup

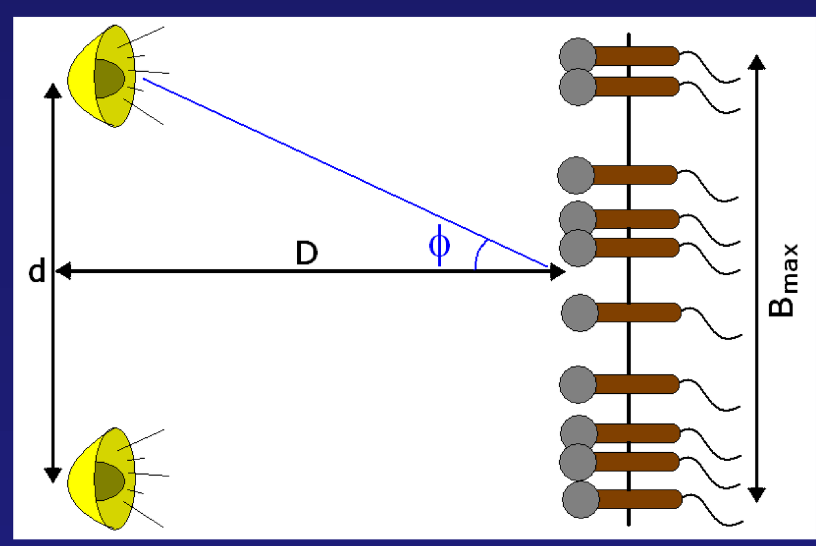

FIG 1. Scheme of our sound inteferometer

We performed VLBI-like observations using, as signal, sound waves generated by two stereo loud speakers separated by a distance **d** (left side of Fig. 1). We used home digital audio recorders, located at a distance **D** from the speakers, as receiving antennas (right side of Fig. 1). Our interferometer consisted of 10 identical antennas, ordered by us in the East-West direction at random distances. The recorded audio signals were treated following all the usual steps of real VLBI data (down-conversion from the observing frequency, Nyquist sampling, amplitude digitization, phase rotation, correlation, Van Vleck correction, amplitude calibration, and fringe fitting).

1. SINGLE-FIELD ASTROMETRY

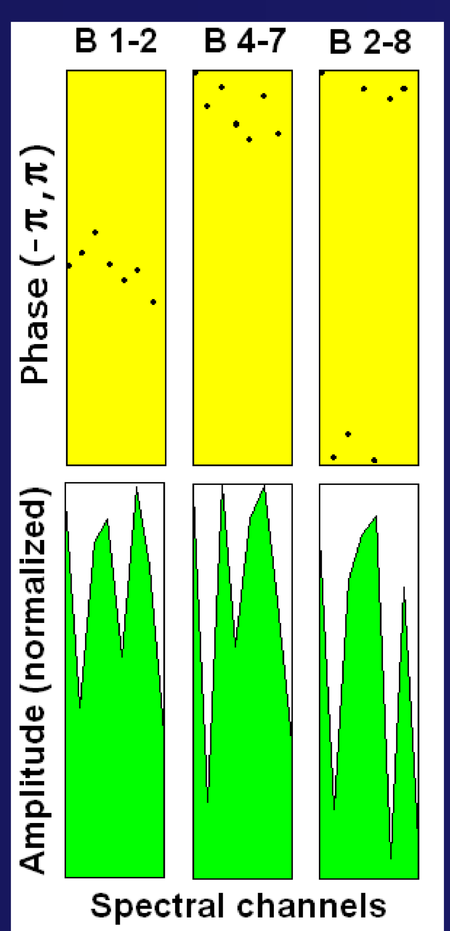

FIG 2. AIPS-like plots of visibility amplitudes and phases for some example baselines (from left to right, 1-2, 4-7, and 2-8)

When the signal bandwidth is narrow enough (10 Hz, with the central frequency at 3 KHz, in our case), for an appropriate geometry (d = 0.5m and D = 2m, see Fig. 1) the signals from both speakers will fall within the same fringe. Thus, the resulting visibilities will correspond to the Fourier transform of a double source. In Fig. 2, we show spectral plots of visibility amplitudes and phases for some example baselines, resulting from an FX correlation. In Fig. 3, we show the fringe, in delay space, resulting from an XF correlation of the data coming from antennas 1 and 2. The plot of correlated amplitudes vs. baseline length (Fig. 4) shows a clear modulation produced by the double source.

Due to the relatively high central frequency (3 KHz) and our low visual precision of the alignment of the signals in delay space, we need to fringe-fit the visibility phases prior to Fourier inverting into the "sky" plane.

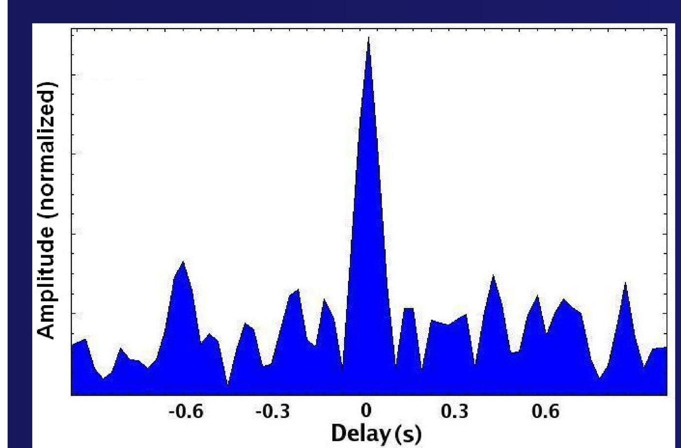

FIG 3. Fringe, in delay space, for baseline 1-2

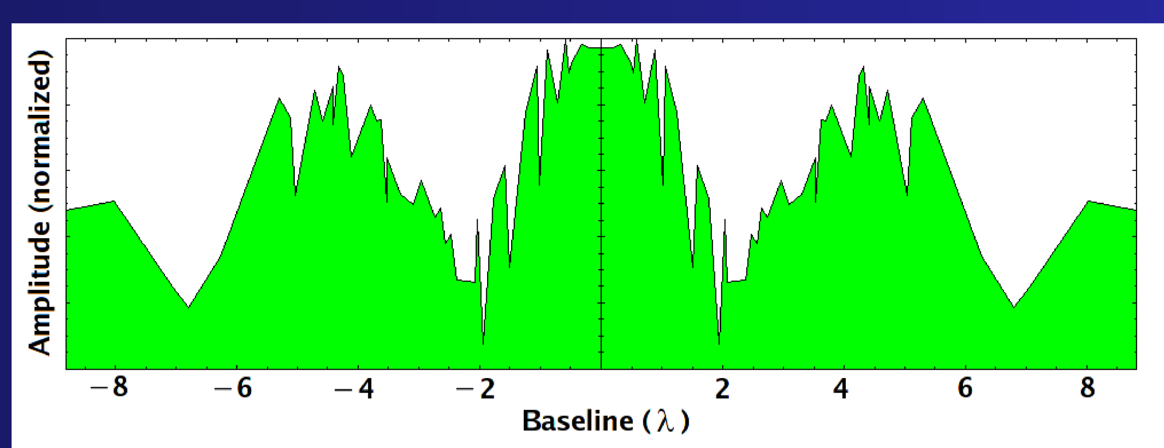

FIG 4. Visibility amplitudes as a function of UV distance

As shown in Fig. 5, after performing Global Fringe Fitting and one Hybrid Mapping iteration to the data, we recover a "sky" map with a clear double source, (note that we have also synthesized resolution in the North-South direction). Given that we know the true angular separation of the speakers, we can use the measured source separation in the map for fitting the free parameters of the geometric model of our interferometer. In our case, the only free parameter is the speed of sound (the fit results in an estimate of ~350 m/s).

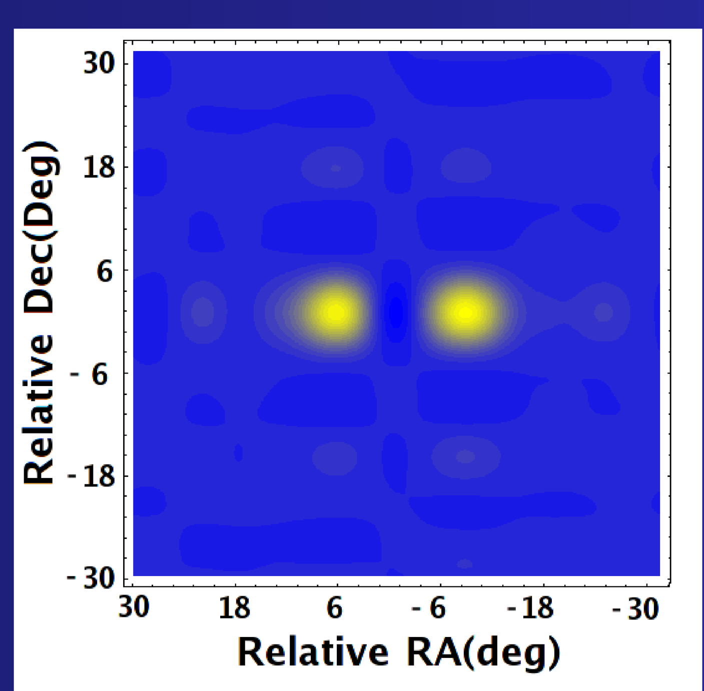

FIG 5. Acoustic map after phase calibration

2. GROUP-DELAY ASTROMETRY

For a wide signal bandwith (22KHz centered on 11KHz, in our case) the signal from each speaker generates its own fringe (i.e. the interferometer sees two single sources, instead of one single double source), provided measures are taken for an appropriate geometry (d =6.5m and D = 12m). In that case, we can separately perform Global Fringe Fitting to the signals coming from each speaker and compute, for each baseline, the differenced (group) delays. The latter are the time separations between the fringe peaks generated by both signals.

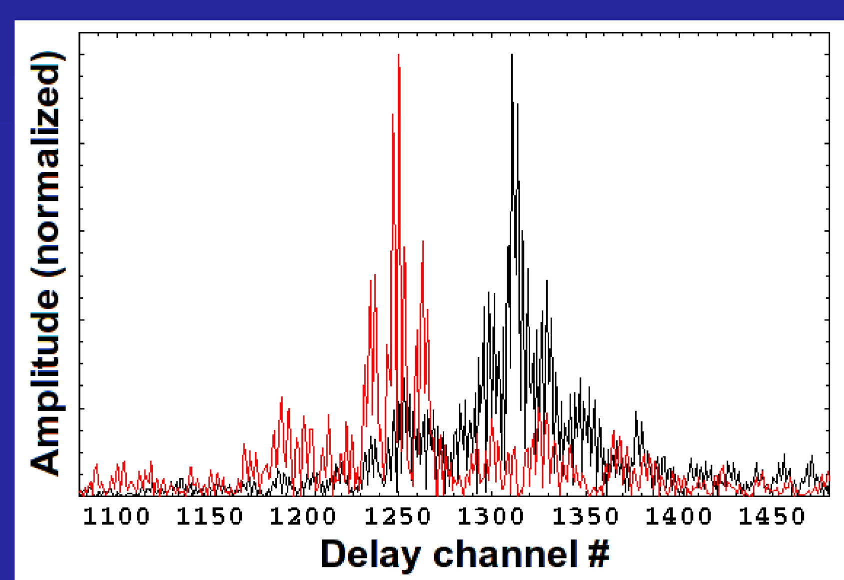

FIG 6. Fringes for the longest baseline (1m). Fringe for the left speaker in red; fringe for the right speaker in black.

Fig. 6 shows example fringes, in delay space, corresponding to our longest baseline and an XF correlation using 3000 delay lags (the figure is a zoom into the delay region of interest).

It can be easily shown that the differenced delay corresponding to a baseline B follows the expression $\tau_{diff} = 2B/c \cdot \mathrm{Sin}(\phi)$ (see Fig. 1), where c is the speed of sound. Fig. 7 shows the measured differenced group-delays as a function of baseline length for all baselines of our interferometer. The linear behavior of the data is clear. The red line corresponds to the model delay, computed with the known values of d and D. Again, the speed of sound appears as a parameter of our astrometry model. From the linear behavior of the differenced delays we can, thus, estimate the speed of sound. The delay model shown in Fig. 7 corresponds to a speed of sound of ~340 m/s.

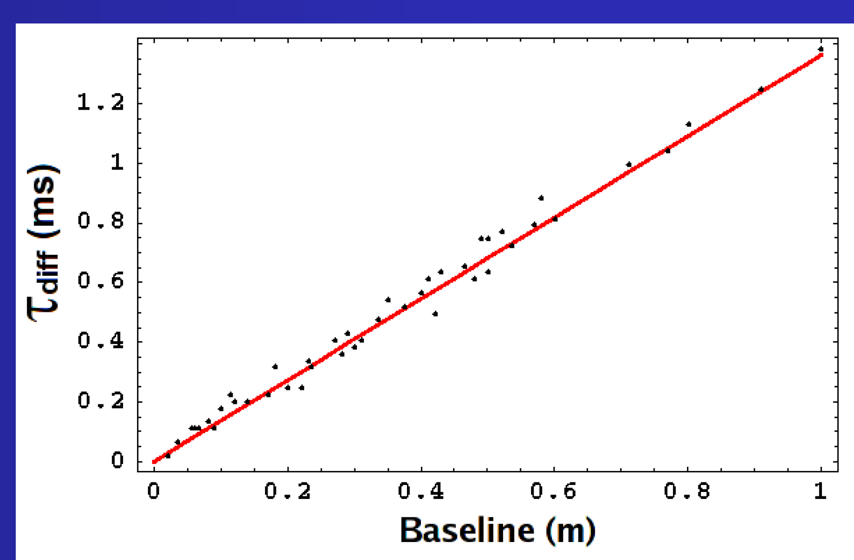

FIG 7. Differenced group-delay as a function of baseline length. The red line represents the delay model computed from the (known) source positions.

Of course, we could perform a similar astrometric analysis using undifferenced group delays. In that case, the model for the delays would be: $\tau_{ij} = B_{ij}/c \cdot \mathrm{Sin}(\phi) + t_i - t_j$, where t_i and t_j would be, respectively, the delays of antenna i and j, which should be fitted together with the speed of sound (or with the source positions, if c is kept fixed). Another possibility would be to perform phase-reference mapping of one source speaker with respect to the other, just Fourier inverting the phase difference between the sources (taking of course into account the geometric effects of the interferometer).

Conclusions:

We have shown that it is possible to perform realistic VLBI emulations using sound waves as signal, home digital recorders as antennas, and a common personal computer as correlator. The observations can be carried out under a large number of different configurations: using the same or different clocks for the recorders, changing the sound pitch, adding spectral lines (i.e. tones) to the continuum, moving the sources during the data acquisition, etc. The educational capabilities of these hands-on experiences appear promising.