PROCEEDINGS OF SCIENCE

The Dawn of SKAI: What really happened

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The SKA process really got going when the Big Boys stepped in, and this paper identifies the approximate moment and the exact place. But before that could happen, hearts and minds had been prepared by hapless others, who usually had little idea how things would develop. This paper discusses some events of 1990, in Dwingeloo and Socorro, which appear to have been not insignificant in retrospect.

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1. Introduction

Historical truth does not exist. Every narrative is necessarily shaped by prejudice, vanity and ignorance. But, for the early SKA story, which may be regarded as a sort of prequel, one at least has the advantage of hindsight, so one may try to identify which of the confusing jumble of events might have caused what appears to be the present situation.

The author (hereafter to be indicated by means of the perpendicular pronoun) happened to be present as a minor player at certain events in 1990, in Dwingeloo and in Socorro, that appear to have been not insignificant in the start of the SKA(I) process. In medieval times, when a castle was taken, the victors (those of the spoils) often scrambled over the wall eventually by means of a pile of nameless bodies. I am excessively proud to be one of undermost of those pioneers.

Somewhat to my consternation I was scheduled to speak directly after Ron Ekers who, within the limits of the above, speaks with much greater authority than I could ever presume. Still, I hope that my contribution complements his to some extent, especially the bit about software going global. In fact, in the conclusions, I conjecture that the AIPS++ project might offer some useful lessons for the realisation of a global radio telescope.

2. The Socorro Conference

In October 1990, a conference was held in Socorro to celebrate the 10th anniversary of the VLA. Since that was the premier radio telescope at the time, everybody who was anybody had come, from all over the world. But, even though the atmosphere was suitably self-congratulatory, it was a strangely passive affair. There seemed to be a hovering concensus that, after a dizzy ride, the heyday of radio astronomy was more or less over, and the next great strides would be made in other wavelength areas. Moreover, it was felt that radio telescopes, including their data-processing, were now mature and would not be greatly improved upon.

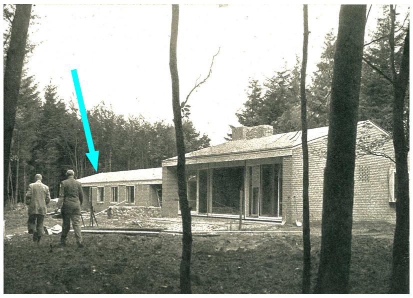
I was tactless[1] enough to point this out to the organisers, adding that we in Dwingeloo had recently been discussing a next generation radio telescope, with a collecting area of *up to a square km*. They scowled a bit, and mumbled something about impudent Dutchmen, but manfully agreed to make room for a small session on the future of radio astronomy. When looking around for a suitable lead speaker, we noticed that Peter Wilkinson looked positively demure, so he was selected for being a fluid native speaker with a good carrying voice. He turned out to be an excellent choice, since he clearly had been thinking about the subject for some time[2]. He gave a rousing talk that was later published under the title of *The Hydrogen Array* [1].

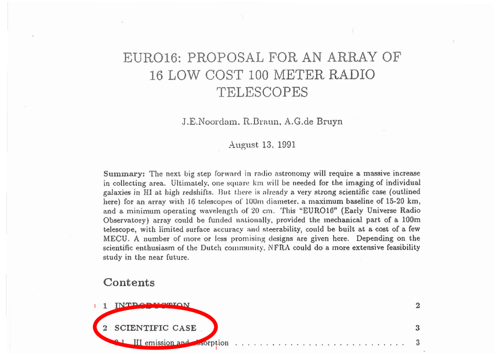
3. What happened in Dwingeloo

In early 1990, over lunch in Dwingeloo, we were happily discussing the merits of a N-S extension of our E-W WSRT. We were very proud of the Blue Riband quality (and fidelity) of WSRT maps, and we felt that a 2D array would be even better to constrain the calibration solution, thus keeping the WSRT at the forefront for another decade or so. But we were rudely awakened

[1] Or, as the Dutch like to think, refreshingly frank.

[2] Others, like Swarup, Pariiskii, Braun had also been thinking about large radio telescopes.





EURO16: PROPOSAL FOR AN ARRAY OF
16 LOW COST 100 METER RADIO
TELESCOPES

J.E.Noordam, R.Braun, A.G.de Bruyn

August 13, 1991

Summary: The next big step forward in radio astronomy will require a massive increase in collecting area. Ultimately, one square km will be needed for the imaging of individual galaxies in HI at high redshifts. But there is already a very strong scientific case (outlined here) for an array with 16 telescopes of 100m diameter, a maximum baseline of 15-20 km, and a minimum operating wavelength of 20 cm. This "EURO16" (Early Universe Radio Observatory) array could be funded nationally, provided the mechanical part of a 100m telescope, with limited surface accuracy and steerability, could be built at a cost of a few MECU. A number of more or less promising designs are given here. Depending on the scientific enthusiasm of the Dutch community, NFRA could do a more extensive feasibility study in the near future.

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Figure 1: On the left is an early picture (1955) of the canteen in Dwingeloo, where we indulged (in 1990) in the design process discussed in the text. The results were later bundled in the EURO16 document [2] shown on the right, one of the inputs for a national discussion in 1991 about the future direction of Dutch astronomy. Eventually, we extended the concept to EURO32, EURO64 and EURO128, i.e. to a total collecting area of about a square km.

from our rosy but parochial dreams by Robert Braun, who told us that we were thinking too small: since T_{sys} was no longer determined by the receiver noise, and bandwidth was needed for spectral work, a massive increase in collecting area was the only way forward[3], deeper into the Universe. We scowled a bit, but had to agree.

Of course we did not believe for a moment that such a huge telescope would be built anytime soon, but since these were leisurely times, we decided to take a little time to figure out how one would go about it. So, for the next few weeks, we spent our lunches (and afternoons) thinking about possible designs for large antennas that could be built cheaply[4]. We are happy to note that we came up with all the ideas that were later investigated (see fig 1), except the Luneburg lens.

- *The Braun Easter Egg* (top left): A 100*m* dish suspended in a 120*m* sphere. We felt that this might be cheaper, and more easy to steer. It could even float.
- *A dish with an adaptable surface* (top right): The frontend was attached to a tiltable pole with a length of half the dish diameter. This gave good sky coverage and illumination for a quite reasonable actuator range.
- *GMRT-like* (bottom right): We paid homage to Govind's ultra-low-cost design.
- *Arecibo-like* (bottom left): The extreme case of largeD-smallN (see below).
- *Aperture Array* (centre): Ultimately the most promising approach, because of multi-beaming and the absence of moving parts. We explored various types of antenna elements. But we

[3] And since most of the WSRT discoveries were made before the invention of selfcal, high dynamic range was obviously not a prime driver. But it will be for SKA, so all our obsession with getting to the noise will not have been in vain after all. On the contary, it puts us in a better position than most to contemplate the new generation of telescopes.

[4] Just notice the picture quality we got away with in those days, when substance ruled over form.

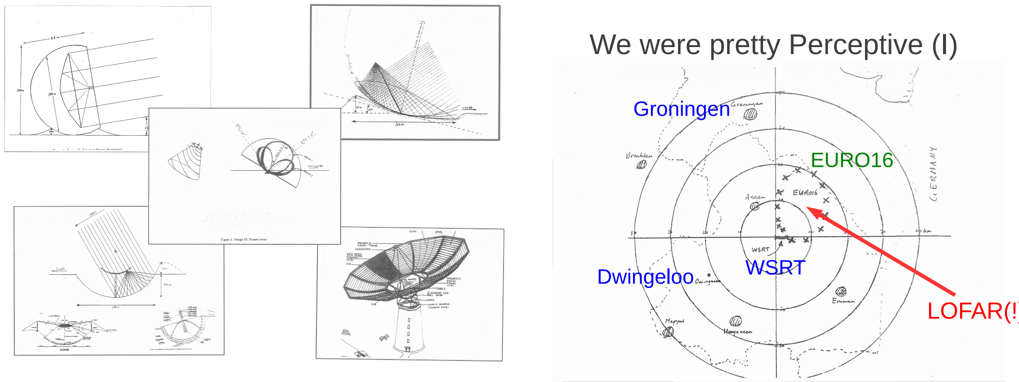

Figure 2: On the left is a mosaic of the various designs for large antennas that were discussed in the EURO16 document [2], which are briefly described in the text. On the right is a map with the tentative location and antenna configuration of the EURO16 telescope. Perhaps not surprisingly, this is almost exactly the same location that we later chose for the LOFAR telescope.

quickly realised that a prohibitively large number of elements would be required for the shorter wavelengths, and also that frequency range was a problem[5].

In those days, the canonical price of a large ground-based telescope was perceived to be about 200M\$, allowing us a paltry \$200$/m^2$ for a square km. So we felt that a frequency range of 150-1500 MHz would be a sensible compromise between cost and science, especially since this might be achieved without moving parts or large 3D structures (the 2 Golden Rules). If all went well, it should be possible to have first light around the year 2000. Such innocence.

Unfortunately, we did not yet realise that a giant telescope would be so sensitive that it would see up to a million 1σ sources. Since these cannot be subtracted from the uv-data, their PSF sidelobes would raise the noise floor unacceptably unless they were smaller than 0.1%[6]. This cannot be achieved with a small number of large $(\approx 100m)$ elements, even with Multi Frequency Synthesis (MFS). We blissfully ignored more sensible proposals (like the DRAO Radio Schmidt) with a large number of smaller $(\approx 10m)$ antennas.

4. The other Seminal Event

Unbeknownst to most, even those directly involved, another seminal event took place on the sidelines of the Socorro conference: The birth of the AIPS++ project, in which seven leading radio astronomy institutes would endeavour to write (and distribute, and maintain, and develop)

[5]It is difficult to think of an AA element with a frequency range greater than a factor of 5. Thus, it may be necessary to build multiple SKAs, for different frequency ranges, which seems a tall order. A possible alternative is the *bath-mat* design proposed for the Tile Telescope [3], where the elements of a tile may be electronically reconfigured to be sensitive to different frequency ranges.

[6]An rms PSF sidelobe level og 0.1% would 'only' double the noise: $\sqrt{10^6} \times 0.001 = 1$

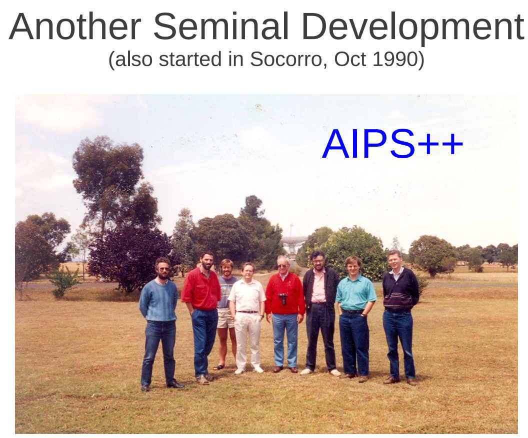

Figure 3: The AIPS++ Steering Committee in 1992, on a team-building (male bonding) visit to the Parkes telescope in Australia. From left to right: Mark Calabretta (ATNF), Jan Noordam (NFRA/ASTRON), Bob Sault (BIMA), Dave Shone (MRAO), Govert Croes (NRAO), Tim Cornwell (NRAO), Ray Norris (ATNF), Tony Willis (DRAO).

a common data reduction package. This marked the point where radio astronomy software went *global*[7].

In Dwingeloo, we had finally come to the conclusion that reducing the data *for* the user, rather than *by* the user, was not a good model[8]. Therefore, we had been looking to use the widely adopted AIPS package to offer WSRT users the specific reduction software that produced the superior WSRT dynamic range. Altough this was not technically difficult, it was not a success. But a new opportunity arose when NRAO talked about modernizing AIPS, and the new computing director (Govert Croes) was interested in collaborating with other institutes. The resulting AIPS++ Consortium comprised ATNF, BIMA, DRAO, MRAO, NFRA(ASTRON), NRAO and TIFR[9].

The project proved much more problematic than we had bargained for. Apart from cultural differences, which made it hard to agree on structure and methods, it turned out to be very difficult to write a large suite of software with a widely distributed team of highly talented (and opiniated) individuals who were used to calling their own shots[10]. But such problems made it an excellent (and necessary!) exercise for SKA, from which critical lessons should be learned[11].

Nevertheless, the AIPS++ project was a huge, albeit qualified success. First of all, the various

[7] Ron Ekers emphasized in his talk that SKA was the first *global* radio telescope (what about VLBI?), but he limited his discussion to hardware and nominal performance parameters. He has promised to be more inclusive in future.

[8] Still, because of the obscene data volumes, we might be forced to adopt that model again for the new telescopes.

[9] All except two were former British colonies, and only one non-native English speaker.

[10] In the decade after the invention of selfcal, about 20 packages were written around this revolutionary technique, of which 4 survive today: AIPS, MIRIAD, DIFMAP, NEWSTAR. It was done by people who made their own decision to provide such a service. For better or for worse, such people have now been bred out of the system.

[11] There are many people who have compiled a list of lessons from AIPS++, but unfortunately they are all rather different. My personal opinion is that we failed to provide superior uv-data handling first, to lure the users away from existing packages.

players now know each other and each other's issues, much more so than before. Secondly, it produced a number of software modules that are widely used around the world: The MS data format[12] (Mark Wieringa) based on the Table System (Brian Glendenning, Ger van Diepen), Fitting (Wim Brouw), Measures (Wim Brouw) and an Imager (Tim Cornwell et al). Thirdly, it excited the formulation in 1995 of the *Measurement Equation* (by Johan Hamaker, Jaap Bregman, Bob Sault), a 2×2 matrix formalism that describes a generic radio telescope. Without the ME, the reduction software for SKA and (its precursors) would be an infinitely more messy affair[13].

5. Conclusions

Fig 4 shows the spot where the SKA process really started, in my humble opinion. The excited babble of visionaries is all very well, but things only start happening when serious players step in, representing serious interests. So, in 1991, the new, young, dynamic and hungry Director of a leading radio astronomical institute, and the most influential radio astronomer in the world, had a long conversation at the hotel De Börken in Lhee, near Dwingeloo.

Since then, a great deal has happened, in the manner that such things go in the world. Some of the developments are a little puzzling (at least to those outside the inner circle), and some may have been somewhat unfortunate, but the SKA idea has certainly ballooned beyond the wildest dreams of those who happened to be involved in 1990[14].

I only worry a bit about the globality of things. We are happy to sit on global committees, but the various institutes do not have a good track record of actually *creating* things together. The first thing that happened was that every institute started building their own SKA precursors, path-finders and prototypes. Some did this in consortia, but these were not conspicuously successful[15]. Under the circumstances, the precursors were a Good Thing, because we would never have been able to solve so many real issues in a distributed fashion. SKA now has several working prototypes to draw on.

But it is not clear (at least to me) how all this magnificent expertise can be bundled into a collective effort of the magnitude of SKA. The recent Salomon's Judgement is not an encouraging sign. At the very least, the organisation that builds SKA should not be building its *first* telescope. And, like the EU, a healthy and well-managed crisis might be needed at some point to encourage the participants to give up some of their precious sovereignity. Perhaps the AIPS++ project still offers a few insights.

References

[1] P.N. Wilkinson, *The Hydrogen Array* IAU Colloquium 131, Socorro (Oct 1990)

[12] It is difficult to overstate the importance of a common data format, like FITS or the Measurement Set.

[13] Apart from being a common language, the ME also provide an obvious framework to structure the software. Unfortunately, because of the sustained success of AIPS, the world is a little slow on the uptake. Only 3 packages have (more or less) adopted the ME by now: AIPS++, LOFAR BBS, and MeqTrees. This should worry the SKA community

[14] It is truly remarkable how the perception of low frequency radio astronomy has changed during the 90's, casting a little doubt on the reliability of such perceptions in general.

[15] The LOFAR Consortium, however cordial and stimulating, definitely complicated matters, until its dutifully lamented demise.

Figure 4: The arrow marks the spot where the new, young, dynamic and hungry Director of ASTRON, and the most influential radio astronomer in the world, had a long conversation in 1991.

[2] J.E. Noordam, R. Braun, A.G. de Bruyn *EURO16: Proposal for an array of 16 low-cost 100m radio telescopes* (Aug 1991) Input for a national discussion. Not published, but can be googled.

[3] J.E. Noordam, J.L.L. Voûte *Design aspects of a Tile Telescope* NFRA Internal Note (Aug 1994) Not published, of course, but it can be googled.