THE PROPOSED AUSTRALIAN SYNTHESIS TELESCOPE

1. Introduction

Australia enters the 1980s with no ground-based radio instrument that can truly complement either the Anglo-Australian Telescope or the projected Space Telescopes. Local innovation has enabled instruments designed in the last two decades, particularly those at Fleurs and Molongolo to enter the Synthesis era with modest performance as continuum instruments at very low cost. Limited observations of hydrogen line emission will be made possible with the completion of the TEST project. As has been seen from the previous papers, the future needs of astronomy require a "quantum jump" in performance and it was from this basis that the concept of a new Australian instrument evolved. Knowledge and experience gained from the Fleurs and Molongolo Telescopes and the TEST project played an important role in this process.

The Australian Synthesis Telescope (AST) proposal has developed during the last five years as a major cooperative effort between Australian institutions involved in astronomy.

In order to appreciate the factors involved in the design of such a telescope, it is necessary first to understand the meaning of synthesis.

2. The "Synthesis" Process

The angular resolution of a large single dish telescope is proportional to its diameter. It is clear that definite limits exist on the possible size of single dish telescopes (the 100m antenna at Effelsberg in Germany is the world's largest).

It is known that there are ways of using numbers of smaller antennas spread out over a large area (for example the Culgoora array) to obtain results similar to a large antenna. The small antennas are synthesizing a large antenna whose diameter equals the largest distance between any two of the small antennas. In the Culgoora radioheliograph, 96 antennas on a 3km circle simulate a 3km diameter antenna. In this case, the simulation is almost instantaneous in order to provide rapid sequences of solar pictures. Other arrangements of antennas, however, require long periods to complete this simulation.

In the case of the AST a small array of antennas is arranged to lie on a straight line in an east-west direction. By processing the signals received by the antennas at a particular time a one-dimensional picture of the source of radiation can be formed which resolves detail in only one direction. This picture is the same as one would form by using a cylindrical lens to focus an image onto a piece of paper*. The resultant picture has high resolution in one direction only, and is smeared out in a direction at right angles.

If we view the earth from space (say from above the South Pole) a line on the Earth's surface running east-west will rotate with the Earth through 180° in 12 hours. Over a 12 hour period then, many smeared pictures can be formed at different angles. If we simply ADD these pictures together we find that a recognizable two-dimensional picture results. The principle is illustrated in Figure 1. In practice, of course, the best picture requires rather more than a simple addition.

Synthesis means "making a whole out of parts". There are two aspects of the synthesis process used for the AST which must be considered. Firstly, we have seen that when a set of one-dimensional images "smeared" in different directions are combined we synthesize a two-dimensional picture. The second aspect of the synthesis process arises in the building up of a one-dimensional picture from parts. For the "ideal" AST a one-dimensional picture would be formed using a set of 300 antennas placed at 20m intervals over a distance of 6km! The imaging process with this ideal array involves multiplying signals from the last antenna with the signals from each of the others. The multiplications do not have to be carried out simultaneously and we could *synthesize* this array using only two antennas initially 20m apart and moving 20m apart each day so that the 300 multiplications are now performed sequentially. This process, however, would now take 300 days.

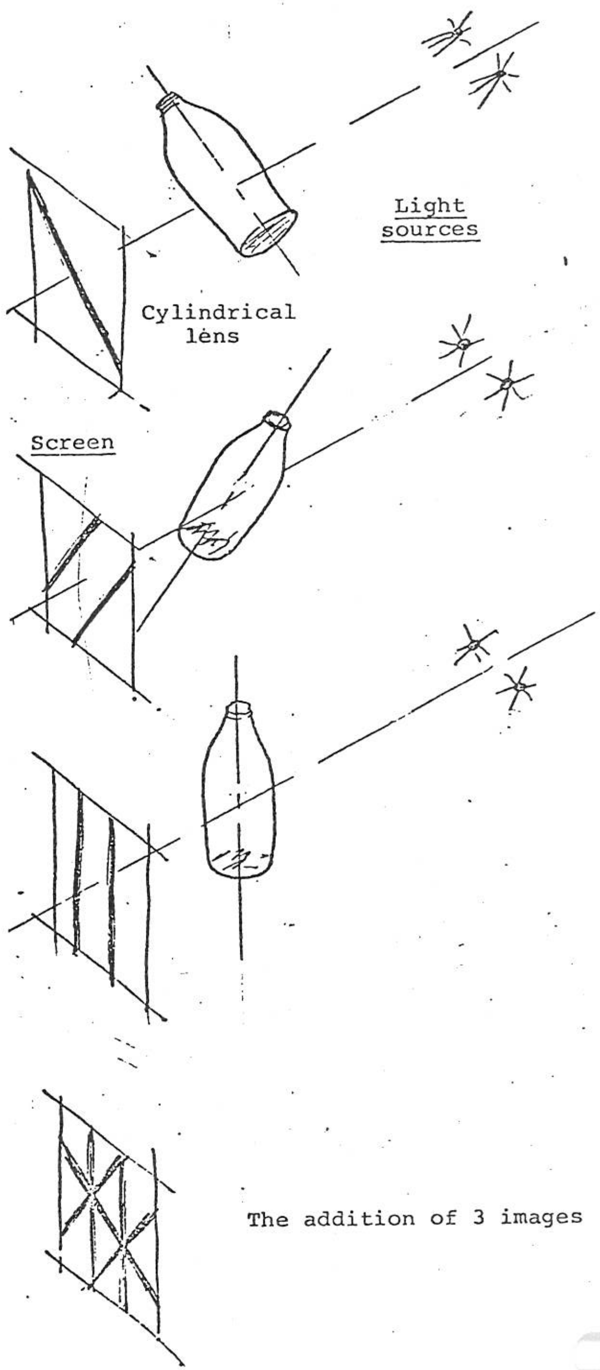
Fortunately, by making a suitable choice of the number of antennas used and their locations on successive days the synthesis process can be completed in a reasonable time with a small number of antennas.

In fact, it is the spacing between the antennas which is important and not their absolute location, so if we have n antennas, the number of possible

* A milk bottle filled with water can be used for simple experiment. If it is used to form an image of two light sources (torches a few metres away) on a wall, two stripes will be formed which merge together for one angle of the bottle. Be careful to cover the top!

Figure 1

The principle of Rotational Synthesis



spacing between pairs is n(n-1)/2. In the present proposal, discussed in the next section, there are 7 antennas, including the Parkes 64m telescope, giving the possibility of 21 spacings per day. By judicious choice of the locations of the antennas, most of the spacings will be independent, giving what is known as a minimum redundancy array. Most of the 300 spacings could then be provided in 15 days.

In recent years, the development of highly sophisticated computing techniques has allowed almost perfect pictures to be formed with much less information than is obtained by synthesizing a full array, and it is thus possible to conceive arrangements with a small number of antennas which will produce maps in one or two days.

The proposed AST design takes full advantage of these techniques.

3. The AST Design

In the present proposal, the AST combines six 22m diameter antennas with the existing 64m Parkes telescope to provide a unique instrument. Five of the new antennas will be mounted on a 3km section of rail, commencing near the 64m telescope and running in an easterly direction. A sixth antenna will be mounted on a short section of rail at 6km from the 64m telescope. A large number of stations will be provided on the 3km rail so that optimum antenna positions can be set for different astronomical programs. An artist's impression of the array and the physical layout are shown in Figure 2. The 22m antenna design is the result of a design study undertaken by Dutch antenna consultant, Ir B.G. Hooghoudt, in conjunction with Macdonald, Wagner and Priddle Pty Ltd, the Civil Engineering Department at Sydney University and the CSIRO Division of Radiophysics.

The present design has achieved an excellent balance where a very high standard of performance has been attained with a minimum number of antennas. The use of only 6 antennas will result in ease of maintenance as well as simplifying equipment changes.

The proposed instrument is unique in a number of respects:

(a) it incorporates a large antenna (the 64m Parkes telescope) with an array of 22m antennas enhancing the resolution and sensitivity of the new system at small additional cost;

(b) the inclusion of the 64m antenna provides important low resolution information in the final picture which is lost to other synthesis telescopes;

Figure 2(a): Artists' impression of A.S.T.

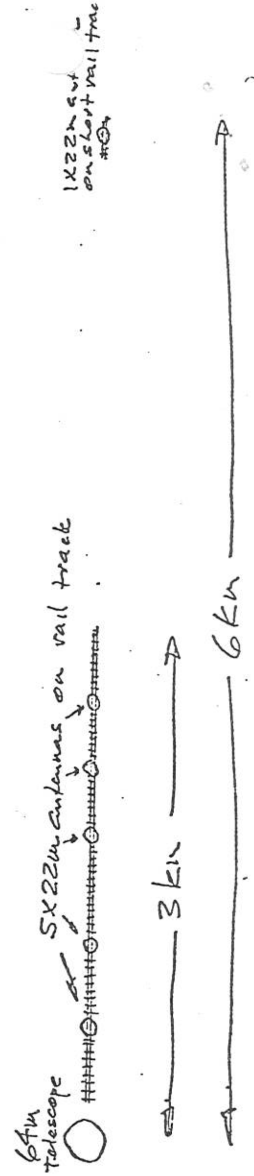


Figure 2(b): Physical layout of A.S.T.

(c) the design provides resolution exceeded only by the $80 million VLA in the USA. This telescope will stand in its own right, in world terms, as a fine instrument;

(d) the design will allow frequency coverage exceeding the existing instruments in the world;

(e) this instrument will provide the only southern hemisphere ground-based support for "all sky" satellite observations in the late 1980s and the 1990s.

(f) innovation in the system design provides an instrument which can map many astronomical objects in only one or two days observing while retaining the ability to perform some specialized observing programs in observations requiring six or more days;

(g) the possibilities of the instrument will be fully exploited by incorporating Australian developments in feed antennas, receivers, correlation methods using both digital and acousto-optical techniques and data reduction techniques.

4. The AST Performance

It is interesting to consider the development of the AST concept since the initial stages. Table I shows the original comparison between the AST and other instruments. The final column shows the present AST proposal on a one day observation; the AST performance exceeds all except the VLA. The VLA maximum resolution is higher, but the AST offers comparable sensitivity in multiple day observations and wider frequency coverage.

On the latest estimates the cost of the AST will be in the range $17-18 million (1980). This is comparable, in real terms, with the investment in the Anglo-Australian Telescope and would bring the total investment in the Parkes Observatory to $30 million (1980). The Australian content is high (greater than 60% overall) as is the direct investment in the Parkes area.

The AST proposal has now matured. It has the capability to achieve beyond the known. It will provide new science. It will be an instrument to be proud of.

18 November 1980 R.H. Frater

TABLE 1

Observational parameters of the Australian synthesis telescope

Observing frequency (GHz)	Resolution (" arc)	Image field size (' arc)	System temperature (K)	Continuum sensitivity (μJy)	Line sensitivity (K)
1 – 2	30	15.0	35	7	1.0
3 – 6	9	4.5	40	8	0.6
7 – 11	4.5	2.5	50	10	0.6
12 – 18	3	2.0	60	15	1.1
18 – 26	2	1.5	80	20	1.4

Notes

(1) Continuum sensitivity is computed for dual polarization, 150 MHz bandwidth and 12-h integration on 24 spacings with mode 1.

(2) Line sensitivity is based on a bandwidth corresponding to a velocity resolution of 1 km s^{-1}. Other parameters as for continuum sensitivity.

(3) Sensitivity quoted is equivalent to r.m.s. noise.

1980's Comparison of major synthesis telescopes*

	Dutch WSRT	UK CSRT	USA VLA	Australian MST	Australian FST	Australian AST (1976)	AST (1980)
Operating frequency (GHz)	0.6 - 5	5, 15	1.4-22	0.8	⩽1.4	1.4-22	1.4-43
Maximum baseline (km)	3.2	4.6	30	1.6	6	1.2	6
Maximum resolution (" arc)	3	0.7	0.07	40	5	2	0.2
Sensitivity (mJy)†	0.1	3	0.01	0.2	1	0.01	0.01
Duration of observation (h)‡	4 x 12	8 x 12	8	12	2 x 8	6 x 12	1 x 12 to 18 x 12
Polarization	Good	Yes	Good	No	May-be	Good	
Spectrometer	Good	No	Yes	No	No	V. Good	

*Parameters are based on expected developments in the next three to seven years. WSRT: Westerbork synthesis radio telescope (Hogbom and Brouw 1974); CSRT: Cambridge 5-km synthesis radio telescope (Ryle 1972); VLA: Very Large Array (Heeschen 1975); MST: Molonglo synthesis telescope (Mills *et al.* 1976); FST: Fleurs synthesis telescope (Christiansen 1976); AST: Australian synthesis telescope.

†Sensitivity is that achieved at full synthesis.

Duration of an observation is the time required to reach full synthesis.