AT/39.3/047

The cost of the mm upgrade of the Mopra antenna

January 7, 1995 M. Kesteven

Introduction

Seven antennas were built as part of the AT project in 1986. Six were installed at Narrabri, the seventh at Mopra. All have a diameter of 22m, with a solid reflector surface out to a radius of 7.5m, and a perforated aluminium surface for the remainder.

The Mopra antenna has a large wheel-on-track construction making it a more rigid antenna than its Narrabri siblings. As such it was intended to play a more active role in mm astronomy. The recent mm campaign shewed that it has potential, but a substantial upgrade is recommended.

Current state

Illuminated aperture	15m (diameter)
Efficiency at 86 GHz	$\sim$ 45 Jy/K, ie, $\eta \sim 35\%$
	(suggests surface rms of 0.3mm)
Pointing accuracy	10 arcsec (rms) / axis

The mm campaign of last winter showed that the zenith opacity at 86 GHz was $\leq 10\%$.

We have a reasonable site; on the international scale of mm-quality antennas, Mopra is at present a very modest competitor. It has the potential for major improvements.

Problems

- The perforated panels are transparent to mm radiation. This leads to two serious problems:

  a. The panels don't assist the performance at mm wavelengths. (Hence the illuminated diameter of 15m, not 22m as at lower frequencies). And hence the efficiency of 45 Jy/K rather then 10-20 Jy/K.

  b. Ground radiation percolates up through the perforated panels to scatter off the subreflector and thus raise the system temperature - by 20-40 K.

- The reflector surface is shaped to yield a high on-axis efficiency. Unhappily, this is achieved at the cost of poor off-axis efficiency; beam-switching and (probably) focal-plane arrays are currently out of the question.

The Upgrade Proposal

1. The outer section should be made fully reflective.
2. The off-axis gain should be improved.

    1. The reflector should be refigured to a conic-section.

    OR

    2. A lens system should be devised to improve the off-axis performance.

The outer panels

The outer two rings of panels will need to be replaced since the porous surface ceases to be useful at frequencies above $\sim$ 45 GHz.

The off-axis loss in performance

There is no question that the shaped reflector has very poor off-axis gain; it is bad at present, and would be very much worse with the full aperture. (Granat & James, RPP 3645 (1994). See figs. 1 and 2)

Is off-axis performance important? Beam-switching is clearly dodgy. Focal plane arrays, in their simple implementation are also out. It is possible that an implementation of the Cornwell - Napier scheme would restore the performance - requiring only a substantial correlator and computing effort.

Can we tackle the off-axis performance? Two options are discussed below.

Option 1: Refigure to pure cassegrain

A traditional cassegrain geometry (conic sections) has excellent off-axis performance at the cost of some reduction in the on-axis gain, as the illumination function falls off with radius faster than does the shaped reflector system. G.James estimates the loss (in RPP 3645) at $\sim$ 2dB. (This may be over-stating the cost, as three-reflector designs have been proposed which may recover the gain degradation).

The main question is whether we need to replace all the panels, or whether we need only replace the outer two rings of perforated panels.

Fig. 3 shows the difference between the current main reflector and a parabola; it indicates the magnitude of the problem: all the panels have been carefully (to within $\sim 100\mu$) shaped to a profile which differs significantly from a parabola.

Fig. 4 shows the best compromise so far identified: if we aim for a parabola which matches one of the inner rings (Ring #3), and then shift and tilt all the panels to obtain a best fit (least squares, weighted by the radius) to the parabola, we can achieve a reasonable result: rms $\sim$ 0.07mm for the inner three rings of panels. Ring #4 has an rms of 0.25mm.

Thus we could have an overall rms of $\sim$ 0.1mm if we replaced the two perforated panels (as intended) and replaced Ring #4; the degradation would not be much worse if we retained Ring #4.

There are several caveats which need further consideration:

- The manufacturing accuracy is assumed to be better than 0.1mm; this might be hard to achieve on the outer panels.
- Although the panels have a low rms fit to the parabola, the rms may be a misleading guide to the antenna's performance as the errors are not random, but highly correlated into rings.

Panel reconstruction

A significant fraction of the panel cost lies in the ribbed backup structure, where stretch-bent aluminium 'I' beams were used. There is some prospect that the ribs could be reused. Only the radial ribs would need attention; it may be possible to adjust their curvature with a simple press operation. (A 5mm adjustment is needed on the outer ring ribs).

Subreflector

The reflector and subreflector are a matched set. If we refigure the reflector we would have to refigure the subreflector. Current calculations are not promising: the difference between the present subreflector profile and the corresponding hyperbola exceed the wall thickness of 5mm. Figure 5 shows the best solution found so far. A new subreflector seems likely to be needed.

Option 2: correcting the shaped reflector

The off-axis gain is low because the phase distribution over the aperture has a pronounced cubic term. The gain is restored if this distribution can be remedied. It has been suggested that a lens or mirror could correct the distribution for a given beam-throw. That is, the observer would need to have built a specific lens for a specific frequency and offset. This leads to an operational question (assuming that the lens could actually be built) : how much flexibility is needed?

Additional Problems

Subreflector carriage

There is some evidence that the structural deformation of the antenna with elevation angle leads to a variable offset between the subreflector and the main reflector optical axis. The Connell Wagner estimate (MWP066.MEM) is $\sim$ 5mm, or about 2dB at 100 GHz.

The current assembly allows a focussing adjustment, but no lateral movement. This question will need to be re-examined since the cost of an offset can be high :

$$\Delta G \sim (Offset/\lambda)^2 dB$$

Wind

The outer panels were perforated in order to reduce the influence of the wind :-

- Pointing

  The larger the aperture, the smaller the beamwidth; the larger the aperture, the larger the wind turning moment, and the greater the pointing rms. It was argued that at 100 GHz the pointing errors due to wind gusts would be comparable to the full aperture beamwidth, so the perforated panels were chosen.

  This needs further checks, but the present (slight) evidence is that the servo loop is tight, and the wind gusts do not result in significant problems.

- Safety

  The wind stow limits may need to be reconsidered.

Backup structure rigidity

No gain/elevation angle function has yet been observed, so the present evidence is that the structure is sufficiently rigid.

It should be noted that the weight of the panels will increase, so the gain/elevation performance may change.

Pointing

At present we are able to establish a pointing model which results in blind pointing RMS of order 10 arcsecs/axis. The full-aperture beamwidths will require a more comprehensive pointing model and treatment; a 'reference pointing' strategy to provide local corrections may also be advisable. This does not seem a problem.

Panel installation

It will not be possible to use the tape/theodolite survey technique to reposition the panels since the vertex cone is welded in place. It is likely that we could get the panels back close enough to the required shape that holography will then complete the task. We propose to process the panels in two groups - every second panel in a 'checker-board' pattern. This allows us to retain the original survey settings at all times. We can then offset the panels by the exact amount needed to transfer from the shaped to cassegrain profile.

Cost

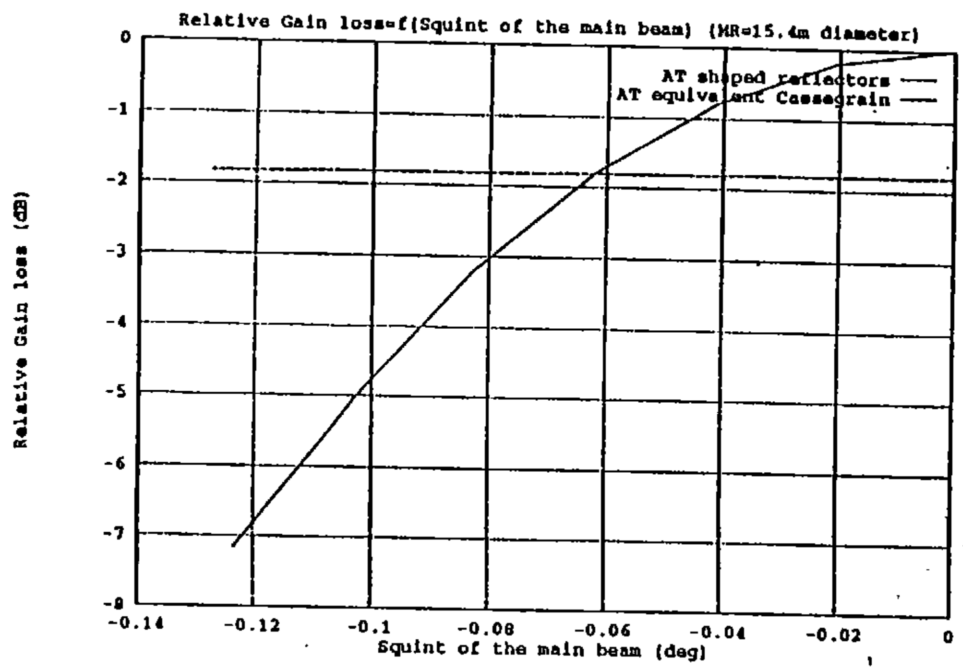
panel reconstruction (Rings 5 and 6)	$200 K
subreflector carriage	$10 K
panel reshaping, Ring 4	$60 K
new subreflector	$40 K
corrector lens	? $5 K

Conclusion

There is not a large difference in cost between the two options since a large fraction lies in replacing the outer two rings of panels. Option 2 (shaped reflector and lens) is interesting, challenging, but inflexible and risky. Option 1 is probably the better choice.

Fig 1

r = 15 m   f = 11.2 GHz

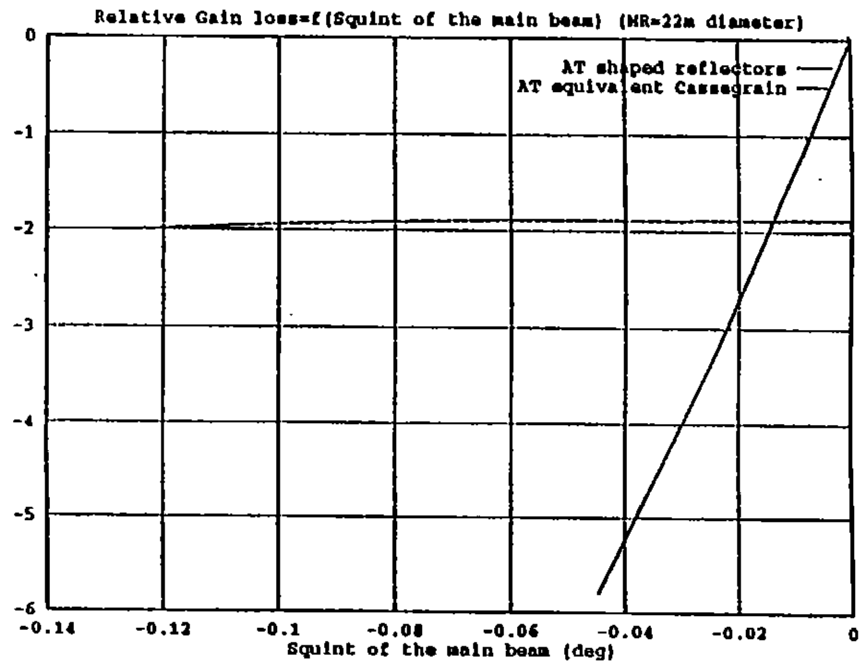


(a)

Fig, 1 Scanning characteristics of the two types of antennas fo
(a) Relative gain loss v squint of the main beam
(b) Feed displacement v squint of the main beam

Fig 2

r = 22 m



(a)

Fig. 2 Scanning characteristics of the two types of antennas f
(a) Relative gain loss v squint of the main beam
(b) Feed displacement v squint of the main beam

fig.3

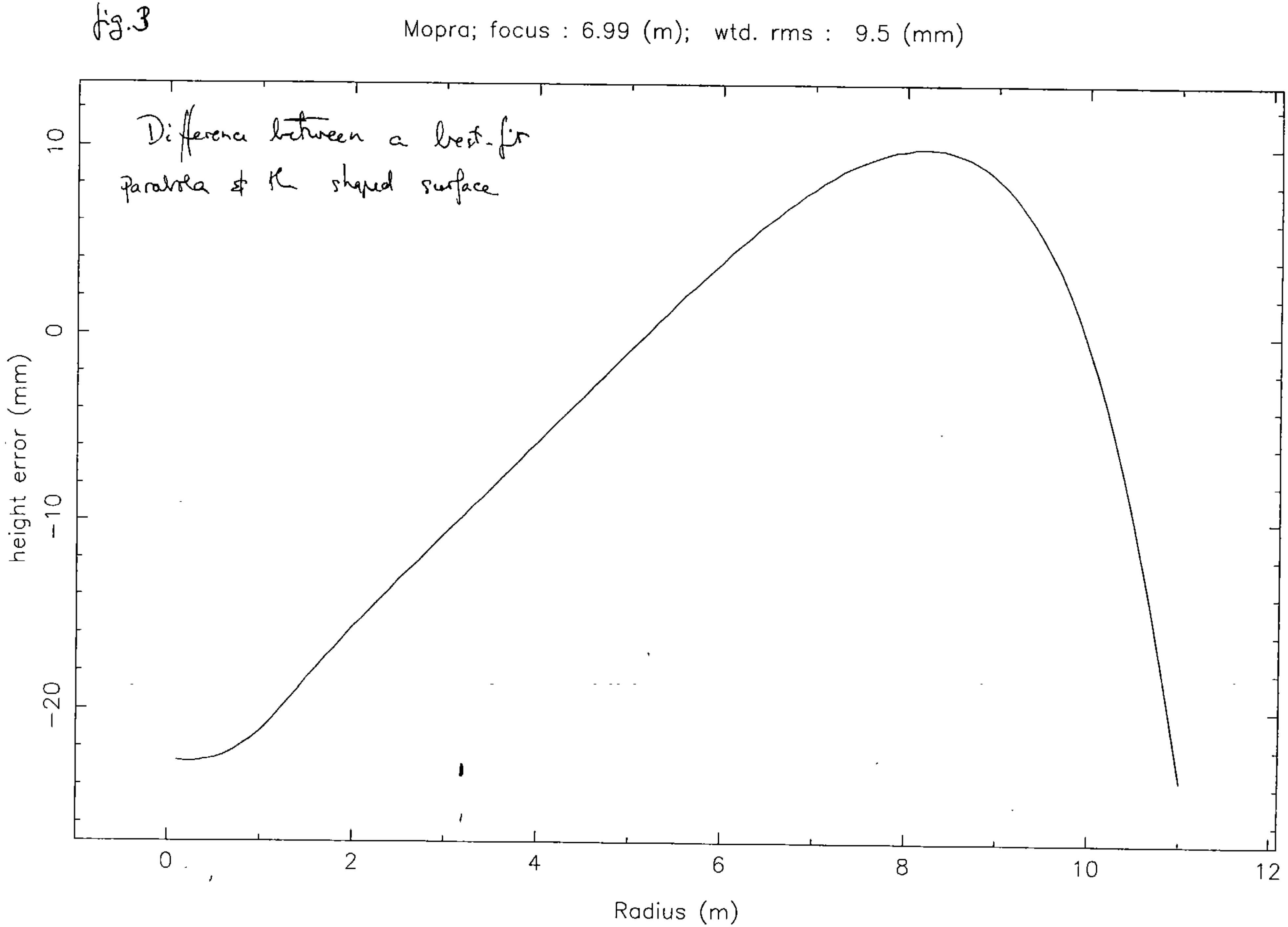

Mopra; focus : 6.99 (m); wtd. rms : 9.5 (mm)
Difference between a best-fit parabola & the shaped surface
height error (mm)
10
0
−10
−20
Radius (m)
0
2
4
6
8
10
12

fig. 4

MOP''A-setting the current panels to ' parabola

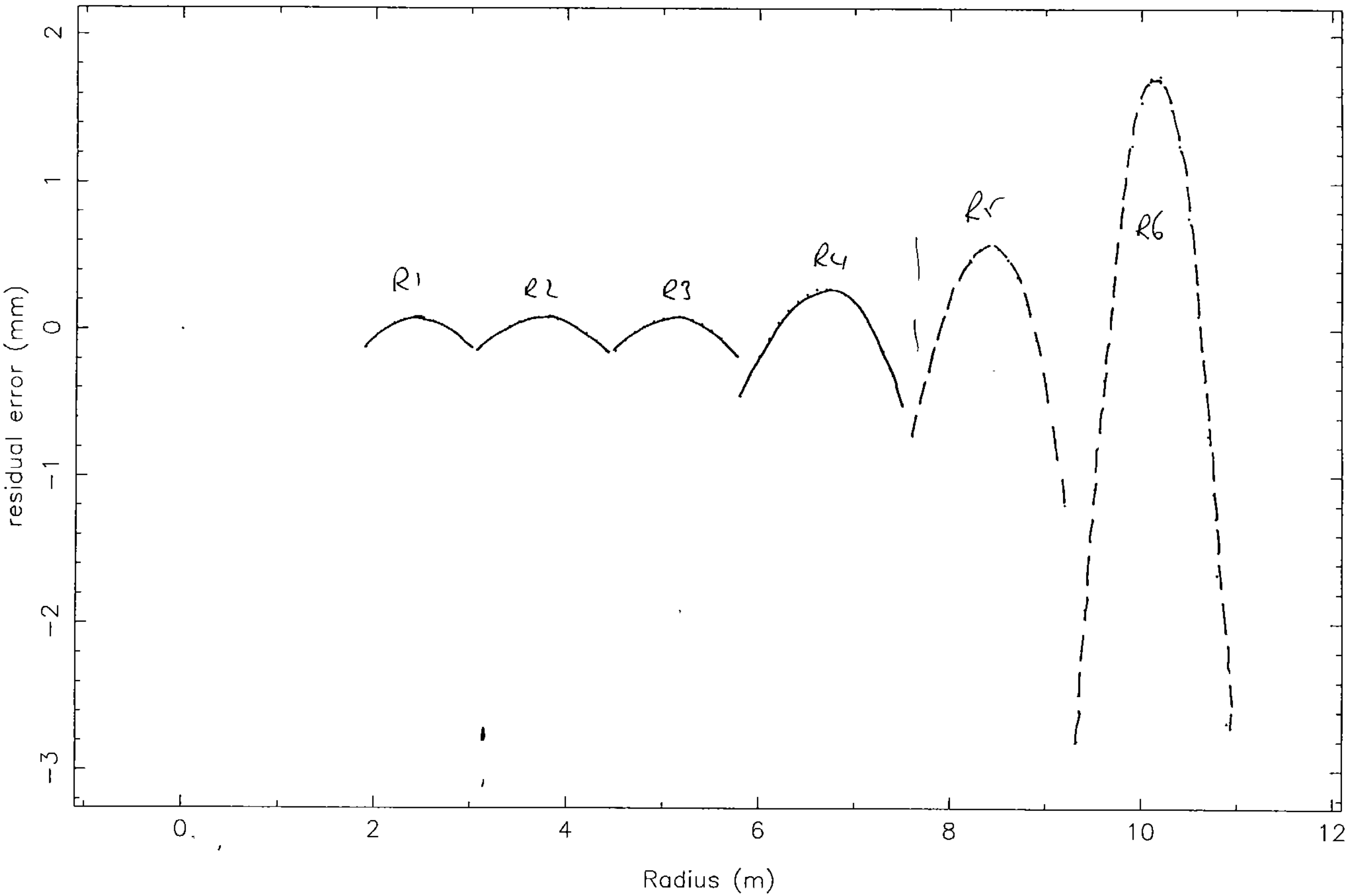
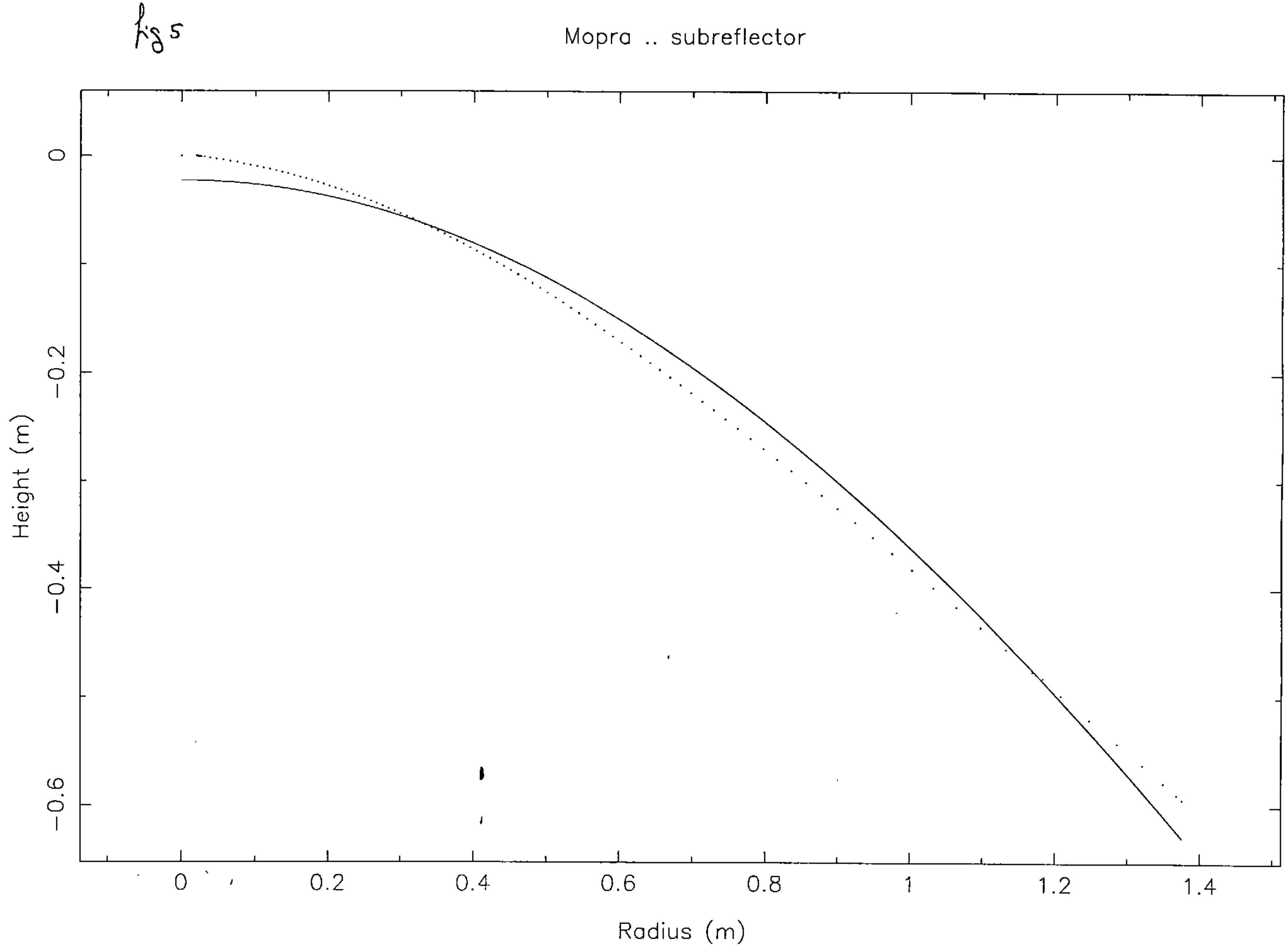


fig 5



Mopra .. subreflector
0
−0.2
−0.4
−0.6
Height (m)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Radius (m)