Telescope Consultation

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SOME REMARKS FOR FUTURE TELESCOPES

On May 26 and 27 we had meetings in Charlottesville about new designs: for the mm-Array and a large single dish. Also at Green Bank we had several discussions.- The following is in addition to my last Report "What Next?" at the 300-ft Workshop (Sept. 1987).

I. GENERAL REMARKS

1. Telescope Optics

We summarize the systems described in the last Report, and add a new one with reduced scatter.

Parabolic Primary: recommended only for very long wavelengths, mostly at prime focus. Disadvantage: either large spillover or low illumination efficiency.

Sphere with Gregorian: cheapest high-accuracy surface (one mold for all panels, easy tested). Better efficiency than paraboloid.

Two Shaped Symmetric Surfaces: maximum gain, negligible spill-over. Same cost as conventional parabola-hyperbola Cassegrain.

Symmetric systems have blockage (support legs, subreflector), normally about 5% geometrical shadow, giving 10% gain loss. More important for low-noise receivers is the pickup of ground noise. If half the 5% scatter hits the ground, this gives about 7.5°K.

Shaped asymmetric surfaces: clear view, no scatter: the ideal system. But the tilted longer primary and the complicated legs may add about 30% cost. And all panels are different from each other (computer-controlled milling) which is expensive.

Symmetry, Reduced Scatter: if the legs are just unbraced single pipes (slenderness ratio l/r=120 for buckling stability) they will cast at least 4% shadow. If they are laterally braced, they can have flat cross sections with less shadow. But too many steel guy cables would themselves cast too much shadow for long wavelengths. Rick Fisher suggested <u>dielectric guy cables</u>; if a good material can be found, this would be a fine solution of the scatter problem without the expensive asymmetry.

For example: four bracing points, one high up (rotation-stable secondary) and three along the leg, would cut its unbraced length by four, allowing a reduction of its lateral width also to 1/4. If the mirrors have a diameter ratio D/d=14 (as at our 140-ft), the total shadow can be 2% or less, which is 4% gain loss and about 3°K ground noise. More brace points can yield further reductions.

Beam-Switching (and receiver change): flat 45° mirror at the vertex, rotatable 360° about z-axis and 1° perpendicular; with receivers distributed radially around it. If close to the largest feed, the mirror is only somewhat larger than the width of that feed, thus much smaller than the secondary and faster to rock. Beam-switching can go in any wanted direction, for any receiver.

Field of View: Peter Napier said the parabola-hyperbola has the largest field of view, which is less for spherical or shaped surfaces; but focal arrays or mosaicing need a large field. I hope that large fields will always be obtained by small secondaries for reduced scatter. But this needs a numerical investigation.

2. Natural Limits

For conventional unsophisticated telescopes from steel and with good white paint, I suggest to use (see Fig.1 of last Report):

Thermal,	$\delta T=1°C$:	$= 5$ mm $(D/100\ m)$	night, sky/ground,	(1)
	$\delta T=5°C$:	$= 25$ mm $(D/100\ m)$	day, sun/shadow,	(2)
Gravity:		$= 70$ mm $(D/100\ m)^2$	convent.backup.	(3)

To pass the **thermal** limit, the Pico Veleta Telescope has its whole backup structure enclosed in a "rucksack", with internal ventilation and cooling. Observers feel no difference between day and night. The extra cost is said to be only 10%. The 10-m SMT (design and parts finished, but Mt. Graham site uncertain) is exposed to the sun, but has members and surface from carbon fiber.

To pass the **gravitational** limit, we can approach homologous deformations to various degrees:

1. Astigmatism only: deformable subreflector (140-ft), or supporting the backup at four equal-soft points. [Improvement about a factor 2 in wavelength]

2. Good trial and error (Effelsberg, 10-m SMT). [Factor ≈ 4]

3. Iterative algorithm (P.Veleta, Nobeyama, 65-m). [Factor ≈ 8]

The algorithm works for any analytically described surface: for the parabola and the sphere. But since a shaped primary is still close to its best-fit parabola, a few alternations between shaping and homology should give good results. For axisymmetric systems, shaping does not add any cost; homology may add about 15%.

3. Wind Deformations

They give mostly more pointing errors than surface deformation. And if a structure is stable at survival winds, V_s, it is then stiff enough for observations up to winds V_o as follows. Let the bar areas A be defined by the maximum allowed stress, S=force/area $= D^2V_s^2/A$. The angular deformation (bending, pointing error) then is given by the modulus of elasticity, E, as $\delta\Phi=D^2V_o^2/AE$, thus

$$\text{pointing error:} \quad \delta\Phi = (S/E)(V_o/V_s)^2 = 100 \text{ arcsec } (V_o/V_s)^2. \quad (4)$$

If designed for 120 mph survival, and observing at 17 mph, the pointing error is about 2 arcsec, without additional stiffening. This is 1/6 of the beamwidth for all telescopes at limit (1). Proper scheduling helps if the site has regular winds. At the VLA most winds above 20 mph occur between 1 and 4 pm, coming from SSW.

4. Panel Size

The size of the surface panels is limited by their internal deformations, and this size defines the number of support points at the backup structure. For larger numbers it gets more difficult to obtain homology. Panels thus should be as large as possible, and precise telescopes may need **intermediate** structures between the homologous backup points, supporting several panels.

If L is the length of a panel and H its thickness, the thermal deformation goes as (L^2/H) and the gravitational one as $(L^2/H)^2$. Using measured values of test panels for the 65-m design, with a width up to L/2, the rms deformations are, in general,

Thermal (night):	$\sigma_T = 1.19\ (L^2/H)$	with σ in µm,	(5)
Gravity:	$\sigma_G = .031\ (L^2/H)^2$	L and H in m.	(6)

If both are equal, then

$$\sigma_T = \sigma_G = 46\ \mu m \quad \text{and} \quad L^2/H = 38\ m. \tag{7}$$

If the deformations are specified smaller than 46 µm, then the size is defined by thermal deformations of (5); and by gravity of (6) if larger deformations are permitted.

The thickness ratio was L/H = 18 for the 65-m design. But it should be smaller (thicker panels) to permit a reduced number of larger panels, with less complicated intermediate structures.

Assuming a panel width of 0.4 L, its area is $0.4\ L^2$, and the number of panels on a telescope of diameter D is about

$$N = 1.96\ (D/L)^2. \tag{8}$$

II. THE MM-ARRAY

1. Optics

The specifications call for a wavelength range from 0.85 mm to 10 mm, and a diameter of D=7.5 m. If a blockage between 1% and 2% can be tolerated, we suggest:

Shaped axisymmetric, with reduced scatter:
Subreflector about d = D/15 = 50 cm. (9)

The size of the subreflector will be a compromize between blockage (low-noise receiver) and diffraction (longest wavelength).

2. Deformations

We see from (1) to (3), or Fig.1 of last Report, that gravity and thermal deformations at night are no problem; but sunshine is, for wavelengths below 2 mm. For observation at 0.85 mm in sunshine an exposed telescope should not be larger than D = 3.4 m. We thus may need thermal shielding, as at Pico Veleta (but less powerful ventilation and cooling).

Either: observe ≤ 2 mm at night only,
Or: thermal shielding (rucksack). (10)

III. THE LARGE STEERABLE DISH

1. The Precise Telescope

For the optics we suggest the same as (9): shaped axisymmetric, reduced scatter, subreflector about d=D/15. With the 45° mirror.

Since gravity can be dealt with by homology, the maximum size is defined by thermal deformations and shortest wavelength. Both depend on its purpose. If used by NASA as ground station for a space interferometer, we must demand λ = 13 mm, all time (sun, 5°C). If only used as single dish, short-wave observation can be confined to nights (1°C). Here are a few examples:

λ night	λ sun	D	
5 mm	25 mm	100 m	single dish
4	20	80	single dish
3.5	18	65	single dish
3	13	52	NASA

(14)

For a cost estimate, John Findlay suggested to use our 65-m design, but without its (avoidable) complications: the optical pointing system and intermediate panel structures.

This 65-m design, carried out in detail with a lot of effort, and being well documented, could serve as a good start for any new large precise telescope. And its position in Fig.1 of last Report would make it a unique and superior instrument, world-wide.

It would again take a long effort to develop, for a different design, a geometry of the backup structure, converging well to homologous deformations. Thus we better use what we already have. If scaled down for NASA to 52 m, the cost reduction would be a factor about $(65/52)^{2.6}$ = 1.8. With larger (thicker) panels, the intermediate structures could be very simple. They and their panels could be constructed and adjusted on the ground, then lifted onto the telescope. Pointing could be done the usual way, but with correction from two inclinometers each on the two towers.

2. The Cheap Telescope

Rick Fisher suggested to investigate a less accurate large telescope for minimum cost. It seemed that about D = 100 m and λ = 6 cm may be a good choice: a slightly improved but fully steerable version of our 300-ft. Rick works also on very interesting new ideas for extreme scatter reduction at the prime focus. The optics then would call for a prime focus paraboloid.

I suggest to make it larger than Effelsberg, to give it some uniqueness; say, D $\geq$ 120 m. And a good location was already found close to the Greenbriar at Green Bank.

John Findlay suggested, for the cost estimate, to use our 300-ft design data, adding wheels and tracks. And for comparison, I would like to see how much it would cost to lift our 300-ft dish a bit, where it is, and put towers, wheels and tracks under it.

Thermal deformations would not matter, see (1) and (2). And all we need for gravity is avoiding astigmatism, with just a 4-point support of a backup structure which could be that of the 300-ft.