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Memo to: J. Findlay, H. Hvatum, D. Heeschen.
from: S.v.Hoerner

Guide Lines for the 65-m Telescope Design

I. Intention

It is intended to provide, for the most urgent fields of observation, a break-through in telescope design; to be regarded as a prototype for various future telescopes.

The most exciting future discoveries are certainly those which nobody can guess at present, and any instrumental break-through would be desirable. At present, some of the most urgent fields of observation are (1) molecular lines, (2) the short-wavelength variability of quasars, and of related N-type and Seyfert galaxies, down to normal ellipticals; (3) a sky survey at short wavelengths, for young quasars and exploding galaxies at larger redshifts; (4) structure and dynamics of our own and nearby galaxies.

This leads to a demand for short wavelengths, say $\lambda \lesssim 1$ cm, but also to a desire for a large diameter in order to find and study a satisfactorily large number of objects within a managably short time. Furthermore, the telescope should still be in competition with other existing telescopes in the range $\lambda = 1 \ldots 3$ cm.

In summary, we want a telescope as large as financially feasible, and for a wavelength (below 1 cm) as short as technically possible. It must be designed for short-wavelength surveys.

II. Basic Design Principles

Any large radio telescope is basically designed for stability in survival conditions, which defines the major part of the cost. High accuracy, up to some natural limits, can be achieved by careful design and engineering, with only low extra cost. Inaccurate telescopes cannot be made much cheaper than accurate ones. This can be proven on general grounds, and it is verified by several existing and planned telescopes.

For the present design, high accuracy (at low cost is achieved by the following new basic principles:

1. <u>Homologous Deformations</u>

   Permits crossing the gravitational limit in Fig. 1, up to the thermal limit, at almost no extra cost.

2. <u>Optical Pointing Reference</u>

   No structural accuracy is needed between the center of the back-up structure and the ground. This system omits (1) soil settlement; (2) rail deviations; (3) all thermal deformations and (4) slow wind deformations of trucks, towers and telescope suspension. Total cost about 300,000 $ independent of D.

3. <u>Surface Plates with Internal Adjustments</u>

   Each plate of 15 ft^2 has 36 internal adjustment screws, to be adjusted by manufacturer before delivery (about 1 hour per plate). High accuracy ($2 - 3 \times 10^{-3}$ inch) can be achieved at medium cost (about 40 $ / ft^2)

4. <u>New Telescope Measuring Techniques</u>

   Fast and very accurate distance measurments are possible with the Hewlett-Packard laser-beam interferometer (better than one part per million). A method used by Zeiss gives ± .15 mm, with pentaprism and tape. The Mekometer announced by Kern (Swiss) claims ± .20 mm, but looks improvable.

III. Choice of D and λ

The selection of size and wavelength was guided by the following demands:

Demand	Reference	Result
1. $\lambda \lesssim 1$ cm, in atmospheric window	Fig. 2, Table 1.	$\lambda \approx .8, 1.3, 2.2, 3.2, 8.8$ mm
2. Medium cost surface, $\lesssim 50$ \$ / ft^2	Green Bank work shop.	$\lambda \gtrsim 2 \ldots 3$ mm
3. Thermal limit at night	Fig. 1.	$\lambda \gtrsim 5$ mm (D / 100 m)
4. Cost feasible, $\lesssim 6 - 8$ M\$	Cost estim. of 300-ft design.	$D \lesssim 60 \ldots 70$ m
5. Size competing at $\lambda = 1 .. 3$ cm	Fig. 1.	$D \gtrsim 210$ ft $= 64$ m

Demands 4 and 5 yield a diameter of about 65 m. The thermal limit then gives a shortest wavelength of about 3.5 mm, which then is also alright with demands 1 and 2. Thus:

$$\left\| \begin{array}{l} D = 65 \text{ m}, \\ \lambda = 3.5 \text{ mm}. \end{array} \right\|$$

IV. Choice of the Cassegrain System

(Detailed calculations given in Report 31; Feb. 24, 1970)

1. Reasons for Planning a Cassegrain System

Table 1 lists the six reasons mostly given in favour of a secondary mirror, plus one more connected with our special pointing system. They are listed in the order of increasing importance regarding the 65-m telescope (zero means no difference, positive is in favour of a secondary, negative is against it).

Table ~~1~~ 2. Reasons for a secondary mirror.

Reason	Remarks for 65-m design	Estimated importance (-5 to +5)
1. Easy access	Service tower for prime focus is planned anyway. Access, then, is even easier there.	-2
2. Heavy equipment	Feed legs rest on most basic points of back-up structure. Additional weight at prime focus gives less surface deviation than at vertex (factor 3.4).	-2
3. Scanning ability	Telescope is fully steerable.	0
4. Reduced spillover	A spillover shield at prime focus (Report 3, 1965) is just as good but cheaper; usable for λ ≤ 20 cm for 65-m. Needs to be tested at 140-ft.	0
5. Multiple feed for alternative observations	Important for short wavelength and weather changes. But can also be done with rotating bottom of prime focus cabin, see Parkes telescope.	2
6. Improvement of pointing accuracy	Bypassing the lowest dynamical frequency of the whole telescope (1.5 cps) with a fast-correcting secondary mirror. Estimated 20-30% improvement of pointing accuracy; to be known better after O. Heine's platform experiment.	3
7. Cluster of many feeds for simultaneous observations.	Survey of whole sky at short wavelength. Completely impossible at prime focus because of long duration; 25 - 900 years for whole sky.	5

2. Selection of diameter $d = 12$ ft

Table ~~4~~ 3. Limits for diameter d of secondary mirror.

No.	Problem	Adopt	Demand	Report 31 Equation	Limit
1	multiple feed, n, cluster size c	$c = 9$ ft $\lambda = 3.5$ mm	$n \geq 1000$	(29a)	$d \geq 7.3$ ft
2	limited cabin length ℓ	$\ell = 12$ ft	$\lambda_m \geq 3$ cm	(25a)	$d \geq 10.8$ ft
3	full use of cabin width	$c = 9$ ft $\lambda = 3.5$ mm	$\gamma_c \geq 15$ dB coma	(37)	$d \leq 12.3$ ft
4	improved pointing accuracy	$W \sim d^{2.5}$ weight	$\nu \geq 4.4$ cps dyn. freq.	(48)	$d \leq 13.4$ ft
5	blocking by secondary mirror	$B = 4/m^2$	$B \leq 2\%$ gain loss	(18)	$d \leq 15.1$ ft
6	homologous dF, fixed feed	$dF = 1$ inch $\lambda = 3.5$ mm	$L \leq 2\%$ gain loss	(6)	$d \leq 22.4$ ft

λ_m = max. wavelength at Cassegrain focus

Table ~~5~~ 4. Secondary mirrors of various size.

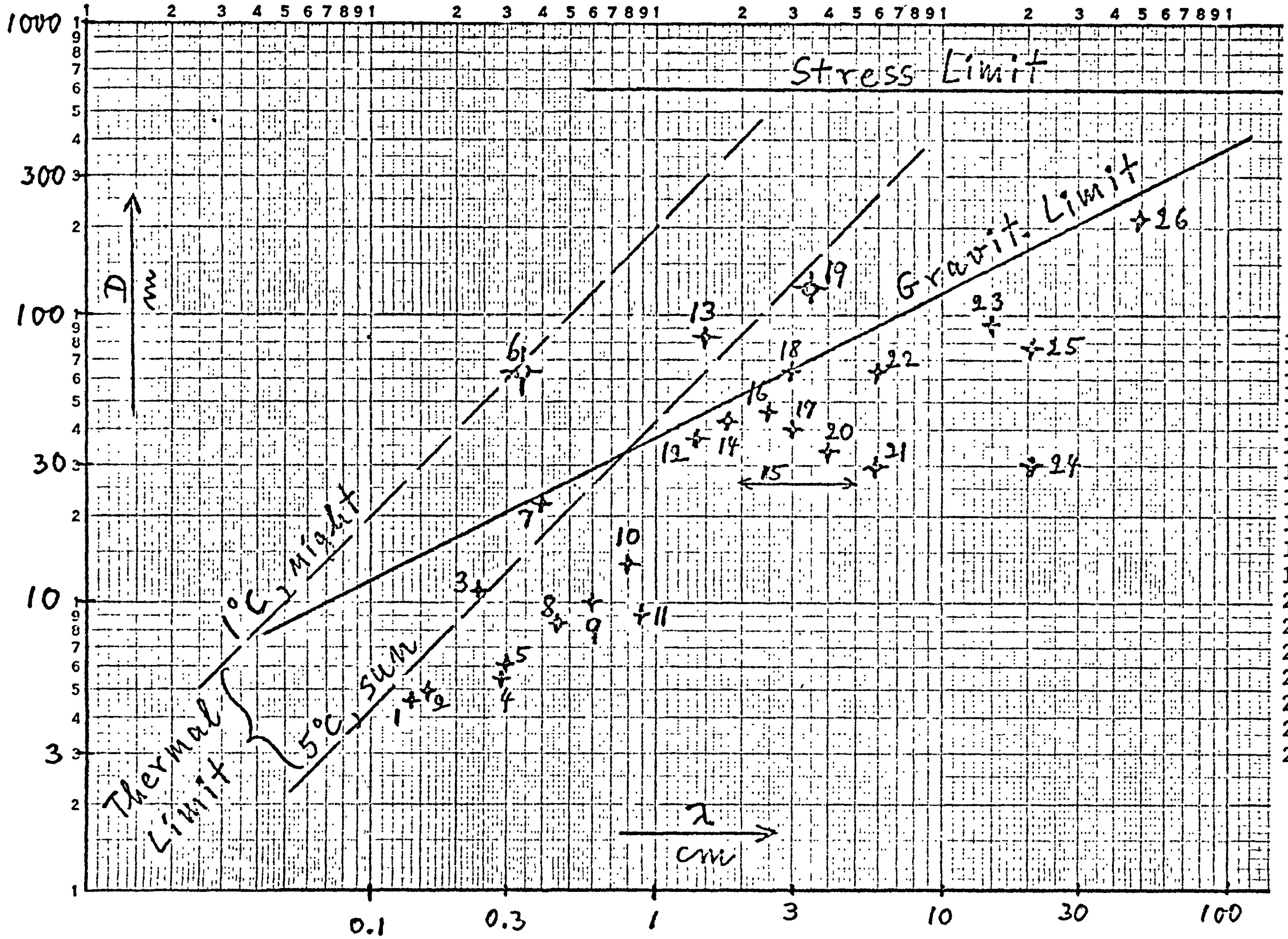
d	m $= \frac{d}{D}$	M multipl factor	λ_m	Side + Coma Lobe γ_0 γ_c axis γ_0	6.37 ft off-axis, γ_c $\lambda =$ 6 mm	6.37 ft off-axis, γ_c $\lambda =$ 3.5 mm	Number n_m of feeds, in 9 x 9 ft cluster $\lambda =$ 6 mm	Number n_m of feeds, in 9 x 9 ft cluster $\lambda =$ 3.5 mm	W weight	ν_t dynamic frequency
ft			cm	dB	dB	dB			lb	cps
8	26.6	24.1	1.6	23.4	23.1	21.4	424	1192	327	4.89
10	21.3	19.1	2.6	23.1	21.9	18.6	661	1875	571	4.74
⇒ 12	17.7	15.7	3.8	22.8	19.8	15.3	965	2753	901	4.55 ⇐
14	15.2	13.4	5.2	22.5	17.3	12.6	1312	3758	1324	4.33
16	13.3	11.6	7.0	22.2	14.8	10.1	1738	4992	1849	4.11
18	11.8	10.1	9.2	21.9	12.4	7.7	2278	6561	2482	3.87

3. Results and Summary

A discussion of several arguments leaves only one crucial reason for a secondary mirror: a large cluster of many feeds needed for a survey of the whole sky at shortest wavelength (which would take 25 - 900 years at the prime focus). A removable Cassegrain is suggested, to be used for 3.5 mm $\leq \lambda \leq$ 3.8 cm, while longer wavelengths must be observed at the prime focus (excessive horn length at secondary focus), using a spillover shield. The Cassegrain mirror should be mounted at three feed legs, on computer-controlled jacks, allowing ± 1 inch movement in all directions with an accuracy of ± .002 inch up and ± .010 inch sideways.

For structural reasons, the secondary focus is located only 5 ft above the vertex. The cabin is 10 x 10 ft wide, and 12 ft long. The maximum feed cluster is 9 x 9 ft. There should be two exchangeable cabins.

Two lower limits and four upper ones are derived for the diameter d of the secondary mirror, resulting in d = 12 ft. The magnification, then, is 15.7; the longest wavelength at the Cassegrain focus is 3.8 cm; the first side lobe is 22.8 dB, and the coma lobe is lower than 15 dB at the corner of the feed cluster for all wavelengths; the maximum number of feeds is 965 for λ = 6 mm, and larger for smaller λ; the weight of the secondary mirror is about 900 lb, and its lowest dynamical frequency is 4.5 cps (sufficient for fast corrections of the pointing, bypassing the dynamical lag of telescope and towers).



1. Aerospace
2. Univ. Texas
3. Kitt Peak, NRAO
4. JPL
5. Hat Creek
6. Homol. Tel. Design
7. RT-22, Crimea, Russia
8. MIT, Lincoln Lab.
9. Bonn, Germany
10. Itapetinga, Brazil
11. CRC, Canada
12. Haystack, MIT
13. Bonn, Germany
14. 140-ft, NRAO
15. Various 85-ft Tel.
16. Algonquin, Canada
17. Owens VAlley
18. Goldstone
19. NEROC Design
20. Werthoven, Germany
21. Mark II, England
22. Parkes, Australia
23. 300-ft, NRAO
24. Mark III, England
25. Mark I, England
26. Arecibo

Fig. 1. Three Natural Limits for Tiltable Conventional Telescopes

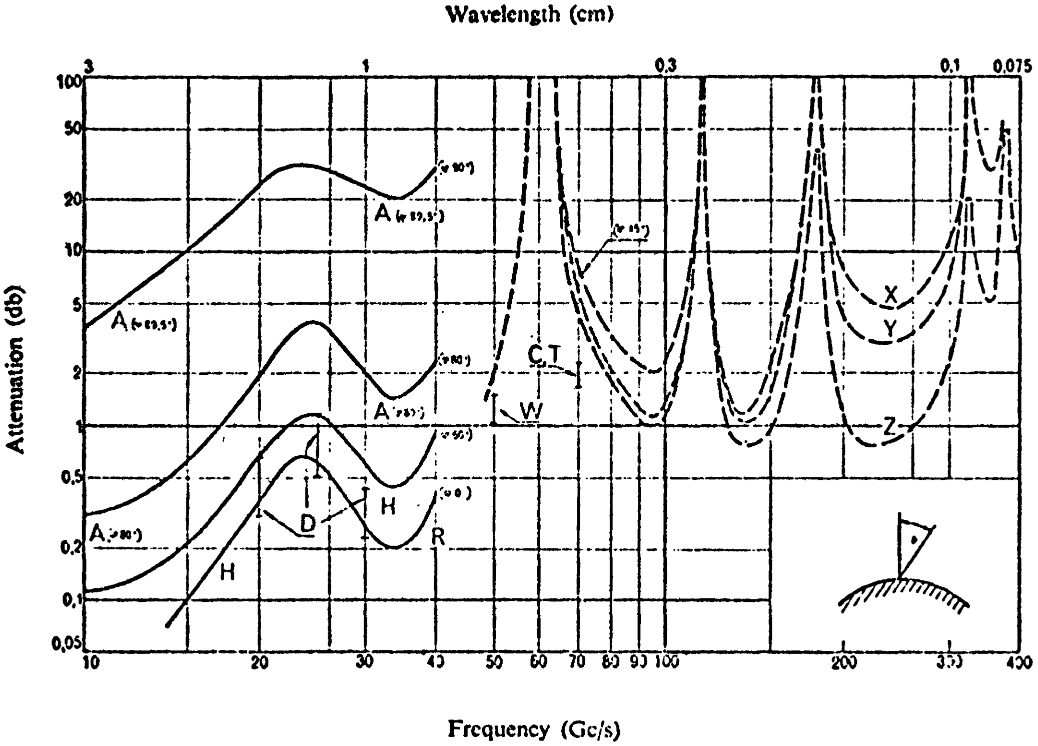


FIGURE 2

Total attenuation for a one-way transmission through the atmosphere

A: AARONS 1958
D: DICKE et al 1946
W: WHITEHURST 1957
T: TEXAS 1960
C: COATES 1958

H: Handbook Geoph. 1960
R: RING (HOGG 1960)
——— HOGG 1959, 1960
— — — THEISSING and KAPLAN 1958

X: humid
Y: mean
Z: dry

Table 1. Atmospheric Windows

λ (mm)	Atten. (db)	Limits D(m), Fig. 1	
		gravit.	Therm, night
0.83	5	11	17
1.3	0.8	14	26
2.2	0.8	18	42
3.2	1.0	22	65
8.8	0.2	35	170