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Report #1

HOMOLOGY TELESCOPE DESIGN

SITE SELECTION

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June 30, 1970 I am afraid we will have to be more "qualitative" than I hoped when this was written, but some of the ideas may still be interesting. A <u>defocusing error</u> tolerance should be added to the surface and pointing error tolerances.

HOMOLOGY TELESCOPE DESIGN

CRITERIA FOR SITE SELECTION

Victor Herrero

June 1970

There are many factors to be considered in choosing a site for the radiotelescope.

1) Quiet radio environment

This can be more easily achieved by respecting these subcriteria

a) geographical location away from areas of dense population and heavy cultivation

b) mountain topography providing some shielding from radio interference

2) Proximity to urban areas

There should be a town or small city close to the site to facilitate the provision of suitable accomodation for the staff, with adequate educational, shopping, medical, and entertainment facilities. Daily commuting by automobile should not be burdensome. The site should be readily accessible to a city large enough to have regularly scheduled air services, within a few hours driving time.

3) Utilities and access

Adequate roads and power should pass within reasonable distance to save the considerable expense that their construction would entail.

The preceding general qualitative criteria apply to just about any radio astronomical observatory. Without precluding the later inclusion of other desirable sites, satisfying those requirements, it will be convenient to limit the study at this point to the following selection of radio and optical facilities, already in existence or planned;

Green Bank
Kitt Peak
VLA site
Cerro Tololo
Owens Valley

4) Homological telescope requirements

Some very important specific requirements apply for the site of a Homology Telescope.

a) atmospheric absorption

Since a major effort is being devoted to attaining the shortest possible operating wavelengths, in the millimetric range, atmospheric absorption becomes a very important item, since it reduces the power available at the telescope, and increases the noise.

b) wind and temperature conditions

The fundamental limitation imposed by gravitational deflections is overcome by the homological design; therefore, deformations and pointing errors induced by wind and temperature effects become the limiting factors.

Site quality index

The preceding criterion seems crucial to the successful performance of the Homology Telescope at short wavelengths, and a quantitative comparison of site qualities will be required.

Consider an ideal site, with no wind and no temperature changes. In such a location, a given flux measurement at a wavelength λ, could be performed with a preassigned error in a time T. On the average, in a real site, the same observation will require a time $T' > T$.

Let us define a performance index measuring the quality of the site, from the standpoint of wind and temperature effects, as

$$Q_{wt} = T/T' \tag{1}$$

This quality index will be decomposed into a product of several factors. It may be interpreted as the fraction of observationally usable time, out of the total operational time,

Tolerable errors

To allow useful observations, environmental conditions must satisfy several requirements. If the departures from sphericity of the reflected wavefront are to have a negligible effect in the resolving power of the telescope, the surface of the reflector should not depart from a perfect paraboloid by more than a fraction of the wavelength to be used. In practice, the maximum root mean square value of the error may be taken as $\lambda/16$.

This total error will be accumulated through the contribution of a number of terms such as homology residual errors, assembly tolerances, etc. An individual item, such as the deformation due to wind, can be allowed only a portion of the total error budget, about 1/3 to 1/4. A first requirement then is to have the rms error due to thermal and wind deformations each less than about $\lambda/48$.

Wind and temperature changes also introduce beam pointing errors. We can somewhat arbitrarily set these to be less than 1/5 the half power beam width (HPBW), where

$$\mathrm{HPBW} \sim 1.27\,\lambda/D \qquad (2)$$

$\sim 1.4\,\lambda/D$ for tapered illumination

Statistical expression for the quality index

A worst case study must be conducted to relate the surface deformation and pointing errors to the wind speed, on the one hand, and to the temperature differences between structural members on the other. Let us also assume that statistics are available for wind velocities and temperatures, expressed as cumulative probability distributions $F(x)$, so that $F(x_2)-F(x_1)$ gives the probability of finding the variable x in the range x_1, x_2.

Defining

$F(v_w)$	cumulative distribution for wind speeds
$F(\Delta T)$	" " " temperature differences

$P_w(v_w)$	worst case pointing error due to wind deformations
$S_w(v_w)$	worst case rms surface deformation due to wind deformations
$P_t(\Delta T)$	worst case pointing error due to temperature differences
$S_t(\Delta T)$	worst case rms surface deformation due to temperature differences

and considering, for a given wavelength ,

$$m_{vw} = \underset{v_w}{\text{minimum}} \left[P_w(v_w) < .254\,\lambda/D \; , \; S_w(v_w) < \lambda/48 \right] \qquad (3)$$

$$m_{\Delta T} = \underset{\Delta T}{\text{minimum}} \left[P_t(\Delta T) < .254\,\lambda/D, \; S_w(\Delta T) < \lambda/48 \right] \qquad (4)$$

then,

$$Q_{wt} = F(m_{vw}) \cdot F(m_{\Delta T}) \qquad (5)$$

These quantities have been defined in terms of overall averages, but they might as well be applied to more restricted observing conditions such as night or daytime observing, by using the pertinent probability distributions.

We have assumed that wind speeds and temperature differences are uncorrelated.

Effects of atmospheric absorption and absorption noise on

the site quality

The signal to noise ratio in an observation will be directly proportional to the input power and the square root of the integration time, and inversely proportional to the atmospheric absorption noise temperature, assuming that this becomes the limiting noise factor as receivers are improved.

Consequently, calling

τ attenuation in nepers or optical depth (at the zenith)

T atmospheric absorption noise temperature

the observing time required to perform an observation with a given signal to noise ratio will be

$$t \propto e^{2\tau} T^{2} \qquad (6)$$

and we may define an overall site quality index by

$$Q = Q_{wt}/e^{2\tau}T^{2} \qquad (7)$$

Practical approximations

Assuming

$$P_w = k_{pw} \, v_w^2 \qquad (8)$$

$$S_w = k_{sw} \, v_w^2 \qquad (9)$$

$$P_t = k_{pt} \, T \qquad (10)$$

$$S_t = k_{st} \, T \qquad (11)$$

then

$$m_{vw} = \text{minimum}\left[\left(\frac{0.254}{k_{pw} D}\right)^{1/2}, \left(\frac{1}{48\, k_{sw}}\right)^{1/2}\right] \cdot \lambda^{1/2} \qquad (12)$$

$$m_{\Delta T} = \text{minimum}\left(\frac{0.254}{k_{pt} D}, \frac{1}{48\, k_{st}}\right) \cdot \lambda \qquad (13)$$

From Report 16, p. 9, an exponential power law can adopted for the distribution of wind velocities at Green Bank.

$$F(v_w) \sim e^{-\left(\frac{v_w}{12.2}\right)^{1.46}} \qquad (14)$$

v_w in mph, in the range 0 to 60 mph

We might tentatively assume that approximations of this nature can also be made for other sites and for the temperature difference distribution.

Typical values for the constants in (8)-(11), as computed for the 300' design are (see Report 26, p. 7 and following)

$k_{pw} \sim 2.6''$ $(15\text{ mph})^{-2}$

$k_{sw} \sim 0.24$ mm $(15\text{mph})^{-2}$

$P_t \sim 3.4''$ $(5^\circ\ \text{C})^{-1}$

$S_t \sim 0.788$ mm $(5^\circ\ \text{C})^{-1}$