NATIONAL RADIO ASTRONOMY OBSERVATORY

Charlottesville, Virginia

February 7, 1977

25 Meter Millimeter Wave Telescope
Memo #73

MEMORANDUM

TO: Addressee

FROM: H. S. Liszt

SUBJECT: Kitt Peak, Mauna Kea, and Millimeter Wavelength Astronomy

I. The Scientific Advantages of Mauna Kea

A. Extinction, Noise, and Sky and Frequency Coverage

In an earlier memorandum, Butler Burton and I stressed the advantages of placing the 25-meter telescope at low latitude, but without regard to atmospheric conditions, i.e., the discussion was merely one of spherical trigonometry. Here, I will discuss the efficacy of observing at Kitt Peak and Mauna Kea in terms of latitude and atmospheric extinction. The purpose is to apply the numbers in Cam Wade's final site report in a practical manner. All references can be found in the bibliography there; the purpose is to show that:

1) Mauna Kea is significantly better than Kitt Peak for observing Orion above ≈115 GHz.

2) Mauna Kea is significantly better than Kitt Peak for observing the galactic center above ≈90 GHz.

3) At 230 GHz, one hour's observing time at Mauna Kea is worth 3-5 hours time at Kitt Peak depending on declination. At 150 GHz, the ratio is ≈2.

4) If one assumes a practical elevation limit of 15° at Kitt Peak at a given frequency, the corresponding limit at Mauna Kea is 6°-7°. All of the galactic plane rises above 7° at Mauna Kea. Alternatively, if 15° is the limit at Mauna Kea, equivalent conditions at Kitt Peak would require an elevation of 40°.

These points are important if some 20% more observing time is available at Kitt Peak due to the afternoon cloudiness in Hawaii. In this context "significantly better" means so much better that the additional time at Kitt Peak is outweighed by poorer, clear-sky transparency.

The effect of the atmosphere upon millimeter wavelength observations is two-fold. First, with opacity τ, the transmission $f \equiv e^{-\tau}$. Second, noise is added in the amount T_{atm} (1-f) where $T_{atm} \simeq 273$ K. This second effect, although noticeable, is not significant at present because receiver temperatures are high, 800-1500 K (SSB) and because we do not observe at frequencies where $\tau > 0.2$ at the zenith, with the possible exception of CO. But the next generations of receivers, Sandy's varactor down-converter or a Josephson junction, are theoretically capable of system temperatures $\simeq$ 100K (SSB). Then the atmospheric noise contribution is substantial. Below, we consider a receiver with 200 K (SSB). It may be worth noting that Tom Phillips of Bell Labs is currently observing at 345 GHz with 300K (SSB).

Below, we show the median transmission at Kitt Peak and Mauna Kea and other relevant quantities for Orion and Sgr B_2 at transit. These two sources lie in the galactic center and anti-center and give a crude sample of conditions typical of the galactic plane.

	Sgr B_2				Ori A			
	Transmission		Atm Noise (K)		Transmission		Atm Noise (K)	
ν	KP	MK	KP	MK	KP	MK	KP	MK
90	0.84	0.94	44	16	0.89	0.96	30	10
115.3	0.54	0.74	126	71	0.70	0.80	82	55
150	0.71	0.91	77	25	0.81	0.93	52	19
230	0.51	0.82	134	49	0.65	0.87	96	35
345	0.13	0.57	238	117	0.28	0.66	196	93

To apply these numbers to actual integration times at the two sites we must form the ratio (total noise)/transmission, square it and take the ratio for Kitt Peak and Mauna Kea. The following table results (higher numbers favor Mauna Kea).

Ratio of Equivalent Observing Times (KP/MK)

ν	Sgr B_2	Orion
90	1.6	1.4
115.3	2.7	1.6
150	2.5	1.7
230	4.7	2.8
345	37	10

This table demonstrates points 1-3 above. At 230 GHz, Kitt Peak is a poor site indeed. In fact it is not efficacious to observe much above 115 GHz at Kitt Peak, given this comparison.

At Kitt Peak it is difficult, although possible, to observe at elevation $h = 15°$ for $\nu \simeq 100$ GHz. I can only wonder what it will be like observing at $h = 15°$ and $\nu >> 100$ GHz, but strongly suspect that it will be very difficult. At the zenith, $\tau(KP)/\tau(MK) = 2.2\text{-}2.6$ for $\nu > 90$ GHz. If one can observe at 15° from Kitt Peak, through 4 air masses, one has equivalent conditions on Mauna Kea through 9-10 air masses, i.e., $h \gtrsim 6°$, and <u>all</u> of the galactic plane rises above this. Alternatively, if $h = 15°$ is the practical limit at Mauna Kea, equivalent conditions are only reached at Kitt Peak for $h = 35°\text{-}40°$. Sky coverage is not determined solely by site latitude. Whereas Kitt Peak will not cover as much sky as its latitude indicates, Mauna Kea will.

Let me iterate point (3) above. For Sgr B_2 and $\nu = 230$ GHz, one can do in one hour at Mauna Kea work equivalent to 5 hours at Kitt Peak (one day's useful work). Because Sgr B_2 is accessible for $\gtrsim 7$ hours at Mauna Kea, one day there is roughly equivalent to <u>one week</u> at Kitt Peak.

B. The Numbers Game or Am I Lying with Statistics?

Those familiar with memorandum #64 of the 25-meter telescope project will recognize that the radiosonde data and the water vapor levels quoted in the original telescope proposal lead to very different views on the value of Mauna Kea as a scientific site at $\nu \lesssim 345$ GHz. Below we review the water vapor measurements of Kuiper (radiosonde) and Westphal (ir); the 12-month ir value is an estimate derived from assuming equal ratios of 9- and 12-month medians in Kuiper's and Westphal's data.

Median Water Vapor (mm): 9^{mo} averages
(figures in parenthesis represent 12^{mo} averages)

	Measured			Used	
	Kuiper	Westphal	(K+W)/2	Wade (Liszt)	25-meter proposal
KP	5.1(6.7)	3.0(4.0)	4.0(5.3)	5.1	3.3
MK	1.8(1.9)	2.6(2.7)	2.2(2.3)	1.9	2.5

The figures used here, although they mix a 9^{mo} average for Kitt Peak and 12^{mo} for Mauna Kea, are similar to the 12^{mo} average of the ir and radiosonde data. They probably are much more reasonable than use of the ir data alone (which do not include the summer quarter or bad weather) or the numbers in the 25-meter proposal.

The important point here is that atmospheric conditions at Mauna Kea <u>definitely</u> are compatible with heavy use of the 25-meter dish at $\nu > 150$ GHz. Kitt Peak, on the other hand, is a much more dubious proposition, and it is a gamble to place a 230 GHz telescope there.

C. Galactic Dead Time

If one assumes a practical elevation limit of h = 15° at either site, Mauna Kea gives an added 35° of galactic longitude coverage or about 12% more than Kitt Peak. But, as shown earlier in the memorandum with Burton, this added coverage at $\ell < 0°$ contains a grossly disproportionate fraction of interesting galactic objects. Now at Kitt Peak, one is forced, after Orion sets at $\simeq 9^h$ LST to observe only those parts of the plane which transit at LST $\gtrsim 16^h$. For this reason, the time between LST 9^h-14^h is called dead time; for spectral line work, the only available galactic objects are IRC + 10216 and a few dark clouds at $\alpha \simeq 16^h$. On Mauna Kea, one can observe objects in the galactic plane which transit at 12^h or earlier, thereby eliminating galactic dead time. One gains $\gtrsim 4^h$ of time for useful work at Mauna Kea, which will remain "dead" at Kitt Peak.

II. Alternative Sites, Alternative Results

The kinds of scientific results which one can produce at the two sites will differ both quantitatively and qualitatively. If, at the design frequency, Kitt Peak observers will struggle for days to produce results obtained at better sites in hours, then these observations are better left to more marginal efforts at these sites. The correct instrument for Kitt Peak is a 40-meter telescope designed to work below 180 GHz, but capable of observing at higher frequencies during those infrequent intervals when conditions permit.

There are various advantages to either the 25-meter or 40-meter designs when these operate at compatible sites. The 40-meter dish has a (relatively) vast collecting area for continuum studies and much better spatial resolution for line work in regions of the spectrum which are currently available. The 25-meter telescope will, however, yield even better spatial resolution if one can observe at 230 rather than 115 GHz. Of course, Mauna Kea will open new spectral regions as well as more sky. But if a 25-meter telescope is placed on Kitt Peak, frequency and sky coverage as well as spatial resolution, will all be sacrificed relative to better match-ups of site and telescope. There is a real possibility that we will erect an instrument on Kitt Peak which is suited to neither the site nor the demands of mm-wave astronomy 5-10 years hence. After two years of deliberation on possible sites, we will be deciding to put the new telescope in our own backyard, on Kitt Peak, because it took that long to determine that our resources were insufficient to support a telescope at any other acceptable site. Construction of a 25-meter telescope on Kitt Peak is not a compromise between two scientifically better alternatives because it reinforces the natural limitations of that site and the 25-meter telescope.