Center for Astrophysics

Harvard College Observatory
Smithsonian Astrophysical Observatory

MEMORANDUM

January 23, 1991

To: SMA Project

From: Jim Moran

Subject: Technical Document #44: Sensitivity to Sources in the Galactic Center vs. Site

One of the STAG members said that we should give strong preference to Mauna Kea (20° latitude) over Mt. Graham (32° latitude) as the site of the SMA because of the much better sensitivity to the Galactic Center from Mauna Kea due to its lower latitude. I have written a simple computer program to quantify such a comparison. The result is that, over a reasonable range of opacities and receiver temperatures, the ratio of sensitivities of Mauna Kea and Mt. Graham for a one-day observation (horizon-to-horizon) of the Galactic Center is about 2. (Hence, the ratio of observing time to achieve the same sensitivity is about 4.) Also, the ratio of sensitivities for a site in Chile (at $\delta = -29°$, where the Galactic Center goes exactly overhead – tough on al-az mounts!) and Mauna Kea is also about 2.

The calculation is based on the following four formulas.

Zenith angle track

$$\cos z_i = \sin\phi \sin\delta + \cos\phi \cos\delta \cos H_i \quad , \tag{1}$$

where z_i is the zenith angle of the ith measurement, ϕ is the station latitude, δ is the source declination, and H_i is the source hour angle.

Effective system temperature

$$T_{s_i} = T_R e^{\tau_0/\cos z_i} + T_0(e^{\tau_0/\cos z_i} - 1) \quad , \tag{2}$$

where T_s is the system temperature referred outside the atmosphere, T_R is the receiver temperature, T_0 is the ambient temperature, and τ_0 is the zenith opacity.

Sensitivity

$$\sigma_i = \frac{2k}{A} \frac{T_{s_i}}{\sqrt{Bt}} \quad , \tag{3}$$

where σ_i is the rms noise level in flux density (ignoring loss factors), k is Boltzmann's constant, A is the collecting area, B is the bandwidth, and t is the integration time.

Overall sensitivity (optimum weighting for computation of average)

$$\sigma = \left[\sum \frac{1}{\sigma_i^2}\right]^{-1/2} \quad . \tag{4}$$

The results are summarized in Tables 1 and 2. The entries are the ratio of rms noise levels for the sites indicated for horizon-to-horizon tracks of data computed according to equation (4).

The elevation tracks for a source at $\delta = -29°$ for three sites (Mt. Graham, Mauna Kea, and Chile) are shown in Figure 1. The corresponding system temperatures for ($\tau_0 = 1$, and $T_R = 1000$ K) are shown in Figure 2. The actual sensitivities for Mauna Kea for various values of T_R and τ_0 are shown in Figure 3. Most of the latitude effect on sensitivity is directly related to the zenith angle at transit, but the lower latitude sites also allow more integration time at lower zenith angles. Hence,

$$\frac{\sigma_1}{\sigma_2} \sim \frac{T_R(e^{\tau_0/\cos z_1}) + T_0(e^{\tau_0/\cos z_1} - 1)}{T_R(e^{\tau_0/\cos z_2}) + T_0(e^{\tau_0/\cos z_2} - 1)} \quad , \tag{5}$$

which is

$$\frac{\sigma_1}{\sigma_2} \simeq \frac{e^{\tau_0/\cos z_1}}{e^{\tau_0/\cos z_2}} \quad , \tag{6}$$

when $T_R \gg T_0$ or $e^{\tau_0/\cos z} \gg 1$. Mauna Kea is about 20% better than equation (6) would suggest because of increased integration time.

For synthesis observations, Mauna Kea provides longer tracks on the Galactic Center at lower zenith angle compared to Mt. Graham. Because of the enormous effects of atmospheric opacity, variance-weighting of the visibility data is probably desirable when constructing images of weak sources.

Table 1
σ(Mt. Graham)/σ(Mauna Kea) for $\delta = -29°$

T_R	τ_0 0.2	0.5	1.0	1.5	2.0
100	1.4	1.6	2.0	2.6	3.4
500	1.3	1.5	2.0	2.6	3.4
5000	1.2	1.5	1.9	2.5	3.3

Table 2
σ(Mauna Kea)/σ(Chile, $\phi = -29°$) for $\delta = -29°$

T_R	τ_0 0.2	0.5	1.0	1.5	2.0
100	1.5	1.9	2.4	3.0	3.8
500	1.4	1.7	2.2	2.8	3.6
5000	1.4	1.6	2.1	2.7	3.6

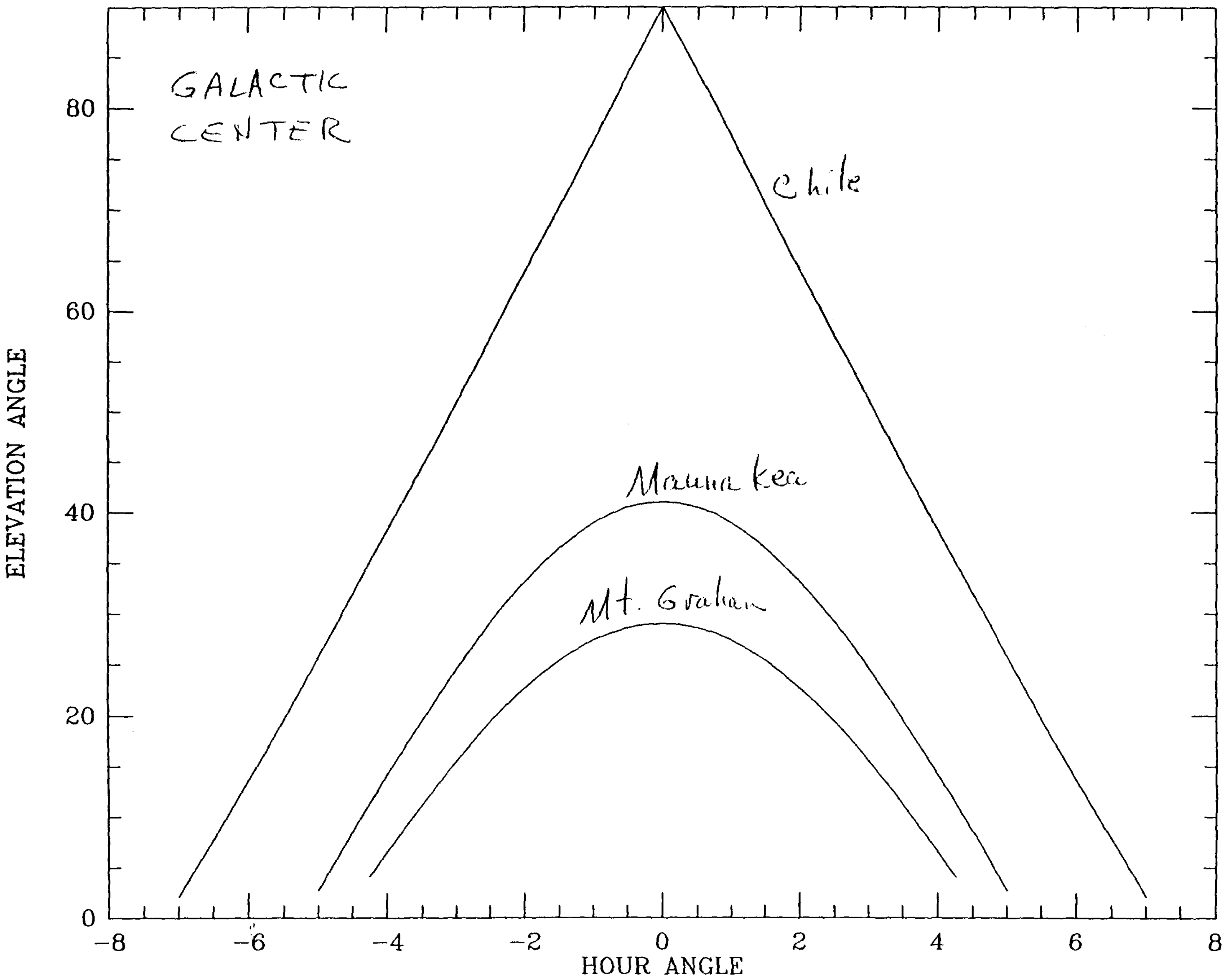
GALACTIC CENTER
Chile
Mauna Kea
Mt. Graham
ELEVATION ANGLE
HOUR ANGLE
0
20
40
60
80
−8
−6
−4
−2
0
2
4
6
8

FIGURE 1

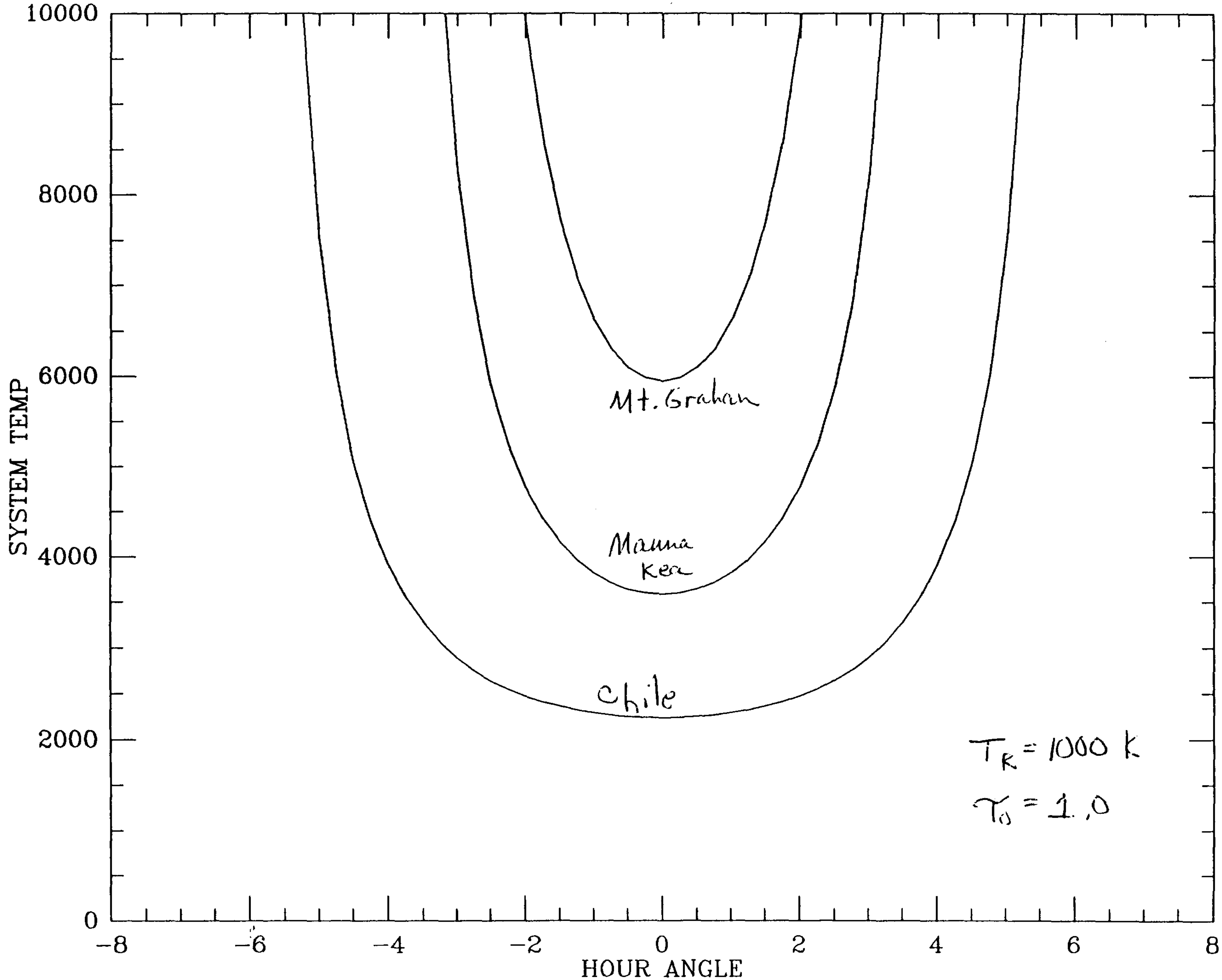
10000
8000
6000
4000
2000
0
SYSTEM TEMP
−8
−6
−4
−2
0
2
4
6
8
HOUR ANGLE
Mt. Graham
Mauna Kea
Chile
T_K = 1000 K
τ_0 = 1.0

FIGURE 2

MAUNA KEA

OUTPUT OF PROGRAM

SNR

LATITUDE = 20.0 DECLINATION = -29.0 MAX ZENITH = 75.0

ELEVATION TRACK

IND	HOUR ANG	ZENITH	LOSS(TAU=1)	IND	HOUR ANG	ZENITH	LOSS(TAU=1)
1	-3.75	73.09	31.15	2	-3.50	70.46	19.87
3	-3.25	67.91	14.28	4	-3.00	65.46	11.11
5	-2.75	63.12	9.13	6	-2.50	60.91	7.82
7	-2.25	58.83	6.90	8	-2.00	56.91	6.24
9	-1.75	55.16	5.76	10	-1.50	53.59	5.39
11	-1.25	52.23	5.12	12	-1.00	51.09	4.91
13	-0.75	50.19	4.77	14	-0.50	49.53	4.67
15	-0.25	49.13	4.61	16	0.00	49.00	4.59
17	0.25	49.13	4.61	18	0.50	49.53	4.67
19	0.75	50.19	4.77	20	1.00	51.09	4.91
21	1.25	52.23	5.12	22	1.50	53.59	5.39
23	1.75	55.16	5.76	24	2.00	56.91	6.24
25	2.25	58.83	6.90	26	2.50	60.91	7.82
27	2.75	63.12	9.13	28	3.00	65.46	11.11
29	3.25	67.91	14.28	30	3.50	70.46	19.87
31	3.75	73.09	31.15				

RMS NOISE LEVEL IN MJY FOR 1 TRACK, EFFECTIVE COLLECTING AREA OF 100 M2 AND BW OF 1 GHZ

TR	OPACITY					
	0.2	0.5	1.0	1.5	2.0	4.0
100.	1.25	3.07	9.20	23.17	54.62	1380.25
200.	1.92	4.25	12.01	29.68	69.43	1743.97
500.	3.92	7.76	20.43	49.22	113.86	2835.15
1000.	7.26	13.60	34.48	81.78	187.90	4653.77
2000.	13.93	25.27	62.56	146.89	335.99	8291.00
5000.	33.95	60.30	146.80	342.23	780.25	19202.72

FIGURE 3