SCIENTIFIC EMPHASIS OF THE MILLIMETER ARRAY

R. L. Brown, D. E. Hogg, G. R. Knapp,
H. S. Liszt, B. E. Turner, H. A. Wootten

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I. INTRODUCTION

The overall design of the Millimeter Array (MMA) was done in recognition of the spatial complexity of the sky at millimeter wavelengths and in recognition of the fact that the MMA observations often will be used for astronomical research in conjunction with observations at other wavelengths. The thermal emission processes which predominate at millimeter wavelengths characterize a wide range of objects from highly compact protostars and stellar photospheres to enormous molecular cloud complexes and nearby galactic disks. For this reason the MMA is reconfigurable; not only is it a high resolution array but it also may simulate a 70 m filled aperture or it may be used as forty 8 m single dishes. When the MMA is observing in one of its larger configurations, the resulting images will have the resolution of the best ground-based optical and infrared telescopes. In its largest configuration the angular resolution of the MMA equals or exceeds that set as the design goal of the HST. With the MMA scientists can tune the capabilities of the array by choosing an array configuration and frequency that is appropriately suited to the goals of their research. Flexibility is a primary design goal of the MMA.

Although the MMA will make fundamental contributions to a wide range of scientific investigations, there are certain areas where its capabilities are unparalleled by instruments operating on earth or in space at any wavelength. The triple combination of MMA sensitivity, angular resolution, and velocity resolution available at frequencies at which dusty astrophysical environments are optically thin is the key to understanding protostars, protoplanetary systems, AGB stellar outflows, and galactic nuclei. For observations of large regions the rapid mosaicing capability is most important. And so forth for the other defining characteristics of the MMA, all of which were specified by the MMA scientific working groups over the last decade of MMA design studies. However, in setting priorities and to aid the decision-making process for the MMA, we need to understand the relative scientific emphasis to be given to each of the important capabilities of the array. In particular, the MMA site characteristics must be such as to support the demands for long baseline observations and high frequency observations.

Here we attempt to estimate these demands quantitatively. We don't expect our analysis to be the last word on this subject; rather, it is the first such attempt in a process that will continue with further analysis and iteration.

II. PROCEDURE

Our specific goal is to estimate the scientific demand for the MMA as a function of frequency and as a function of array configuration. That is, we would like to know what fraction of the MMA users will want to observe at 3 mm wavelength, what fraction at 1 mm, and so forth. In a similar way we asked about the demand for the various array configurations.

Fortunately there exists a reasonable amount of material on which such an estimate can be based. Not only do we have the reports of the MMA Green Bank scientific workshops but we also have the MMA proposal and knowledge of the distribution of scientific programs that currently run on the 12 Meter Telescope, the CSO, and the two California millimeter arrays. Projections of our own scientific experience and perspective undeniably will figure into our estimate as well.

We began with a list of the MMA working group topics from the proceedings of the first MMA Design Study Workshop. These are:

Sun

Solar System

Stars

Circumstellar Shells and Evolved Stars

Molecular Clouds and Star Formation

Astrochemistry of Galactic Molecular Clouds

The Local Universe

The Distant Universe

There is, of course, considerable overlap between the topics that needs to be resolved. We have defined studies of the chemical composition near regions of star formation as being in the category "Molecular Clouds and Star Formation," not "Astrochemistry." Similarly, astrochemical studies of circumstellar shells and galactic disks were incorporated in "Circumstellar Shells and Evolved Stars" and "The Local Universe," respectively, not in the topic "Astrochemistry." Observations of maser emission are divided between "Circumstellar Shells and Evolved Stars" and "Molecular Clouds and Star Formation" as appropriate.

Given the list of scientific topics, and the definitions of what was included in each, we independently estimated the fraction of observing time that the MMA would spend in a year on observations in each of these scientific areas.

Next we chose to assume that the MMA would be capable of observing in precisely the way it is specified in the MMA proposal. That is, at frequencies from 30-336 GHz and in four configurations of 70, 300, 1000, and 3000 m plus the mode of forty 8 m single dishes. The performance specifications are summarized in Table 1. In addition, we assumed that the site imposed no limitations to the required observations other than a mean zenith opacity of 0.10 at 225 GHz. This assumption was made because we were interested in estimating the MMA scientific demand, the need for array capabilities, not the scheduling of the array on a specific site.[1]

Given our assumptions, we then estimated, for each scientific category, the fraction of the time that the MMA would be observing at each of its frequency bands and in each of its array configurations. Each of us made our estimates independent of the others. For each scientific area, the final step was to multiply the fraction of time that we imagined the array would be in each of its frequencies/configurations by the fraction of the year that we estimated the MMA would be engaged in that scientific area and then multiply by 365 and average the results to get the total time in observing days per year. The results are given in matrix form in Tables 1 and 2.

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[1] One could, of course, take the opposite approach and ask what is the distribution of science that can be scheduled on a particular site given that site's atmospheric transparency and stability characteristics. Once a site is selected it would be useful to frame the question in this way and repeat the analysis.

Table 1. MMA Angular Resolution
(arcseconds)

Array	Frequency				
	35	90	150	250	350
SD	221	86	52	31	22
0.07	25	9.8	5.9	3.5	2.5
0.30	5.9	2.3	1.4	0.82	0.59
1.0	1.8	0.69	0.41	0.25	0.18
3.0	0.60	0.23	0.14	0.08	0.06

III. DISCUSSION

Both Table 2, the observing time (days/year) spent at each of the MMA frequencies, and Table 3, the observing time spent in each of the array configurations, show in bold font the eight scientific categories and the subdisciplines included within these categories. The right-most column is the sum of days per year observing in each scientific category, while the bottom row presents the sum of days/year spent observing at each array configuration and frequency.

Although our task is highly subjective, we were generally impressed with the overall agreement among our independently determined estimates. To some extent this may be attributable to our starting with the same reference material, the Green Bank MMA Workshop proceedings and the MMA Proposal. But each of us supplemented the reference material with our own knowledge of recent experience at telescopes with which we are familiar, conversations with colleagues, and so forth.

Figure 1 illustrates the distribution of demand expected for the MMA as a function of frequency. On an annual basis more than 200 days will be required at frequencies in the 1 mm and 0.8 mm atmospheric windows (frequencies > 200 GHz), approximately 140 days will be spent observing in the 2 mm and 3 mm windows combined, and less than a month will be needed at frequencies < 50 GHz. The preferential demand for the higher frequencies arises for two reasons. First, the desire to study dust continuum emission in a wide range of astrophysical environments necessarily implies the need for high-frequency observations since the flux density increases as ν^{3-5}. Second, the highest angular resolution is obtained on the longest array baselines and at the highest frequencies. In those cases where angular resolution is of paramount importance—observations of protostars or galactic nuclei, for example—the astronomer will want to use the 3 km array at 200 GHz or higher. These will be challenging observations.

Figure 2 shows the days needed per year for the MMA in each of its four imaging configurations and the days needed for observations as forty 8 m single dishes. We estimate that the four array configurations will each be needed for 80-90 days a year. In terms of technical challenges facing the MMA design, or its site, the need to observe nearly half the year on baselines of 1 km or longer is surely the most demanding.

TABLE 2. MMA FREQUENCIES

OBSERVATION	OBSERVING TIME (DAYS/YEAR) FREQUENCY BAND (GHz)					SUM.
	30-50	68-115	130-183	195-300	300-366	
SUN	2	3	3	4	3	15
SOLAR SYSTEM	1	2	4	8	7	22
Planetary Atmospheres						
Solid Surfaces						
Comets						
STARS						
Active/Flare/Nonthermal	2	6	7	12	9	36
Stellar Winds						
Main Sequence Photospheres						
Planetary Nebulae						
Novae						
CIRCUMSTELLAR SHELLS AND EVOLVED STARS	3	10	7	12	11	43
Dust Formation/Outflow						
Chemical/Isotopic Abundances						
Masers						
Supernova Remnants						
Extragalactic Supernovae						
MOLECULAR CLOUDS AND STAR FORMATION	3	18	17	30	20	88
Young Stellar Objects						
Masers						
Cloud Physics/Structure (Em/Abs)						

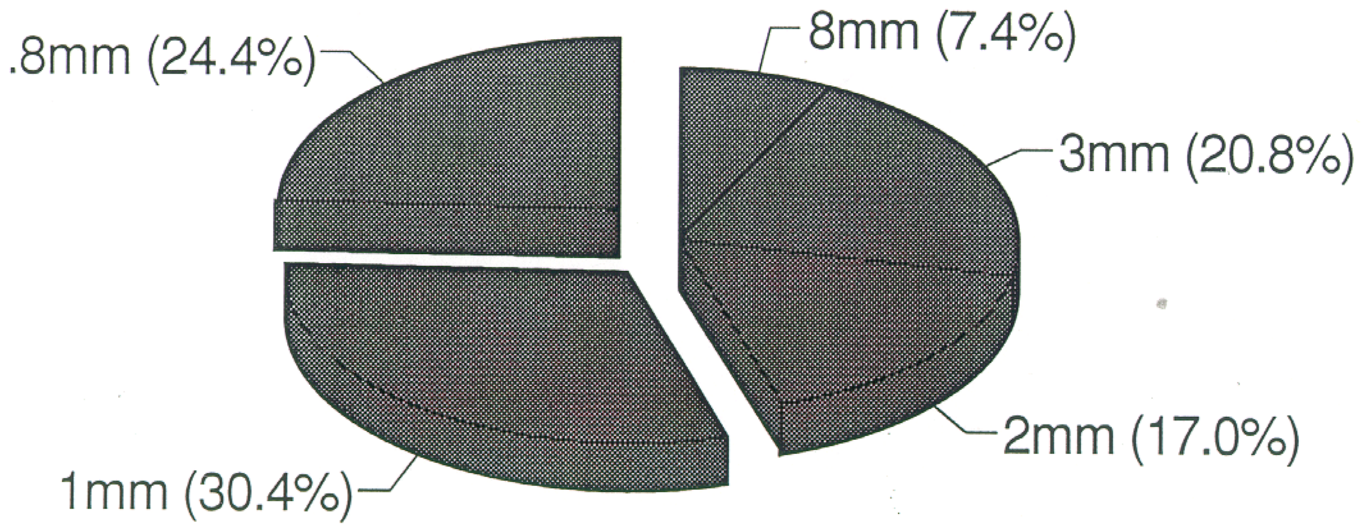
OBSERVATION	OBSERVING TIME (DAYS/YEAR) FREQUENCY BAND (GHz)					SUM.
	30-50	68-115	130-183	195-300	300-366	
Search for Cold Cores						
Characterization of Protostars						
Protostellar Disks						
Bipolar Outflows						
ASTROCHEMISTRY OF GMCs	2	5	3	6	5	21
THE LOCAL UNIVERSE	2	17	10	25	19	73
Chemistry of Galactic Disks						
Dust in Galaxies						
THE DISTANT UNIVERSE	12	15	11	14	15	67
AGNs/Radio Galaxies						
Chemistry of Early Galaxies						
Search/Study Dusty Protogalaxies						
CMB Fluctuations						
S-Z Effect						
SUM (Days/Year)	27	76	62	111	89	365

TABLE 3. MMA CONFIGURATION

OBSERVATION	OBSERVING TIME (DAY/YEAR) ARRAY CONFIGURATION (KM)					SUM.
	nSD	0.07	0.30	1.0	3.0	
SUN	2	6	4	1	2	15
SOLAR SYSTEM	3	3	6	7	3	22
Planetary Atmospheres						
Solid Surfaces						
Comets						
STARS	1	3	5	9	18	36
Active/Flare/Nonthermal						
Stellar Winds						
Main Sequence Photospheres						
Planetary Nebulae						
Novae						
CIRCUMSTELLAR SHELLS AND EVOLVED STARS	1	10	6	9	17	43
Dust Formation/Outflow						
Chemical/Isotopic Abundances						
Maser						
Supernova Remnants						
Extragalactic Supernovae						
MOLECULAR CLOUDS AND STAR FORMATION	8	16	15	23	26	88
Young Stellar Objects						
Masers						
Cloud Physics/Structure (Em/Abs)						

OBSERVATION	OBSERVING TIME (DAY/YEAR) ARRAY CONFIGURATION (KM)					SUM.
	nSD	0.07	0.30	1.0	3.0	
Search for Cold Cores						
Characterization of Protostars						
Protostellar Disks						
Bipolar Outflow						
ASTROCHEMISTRY OF GMCs	4	6	5	3	3	21
THE LOCAL UNIVERSE	5	19	28	13	8	73
Chemistry of Galactic Disks						
Dust in Galaxies						
THE DISTANT UNIVERSE	4	17	23	13	10	67
AGNs/Radio Galaxies						
Chemistry of Early Galaxies						
Search/Study Dusty Protogalaxies						
CMB Fluctuations						
S-Z Effect						
SUM (DAYS/YEAR)	28	80	92	78	87	365

MMA Band Demand
(Projected)



MMA Configuration Demand
(Projected)