MILLIMETER ARRAY
SCIENCE MEMO NO. 4

REPORT OF THE WORKING GROUP ON THE SUN AND STARS

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THE SUN

1) Gamma ray–mm wave flares

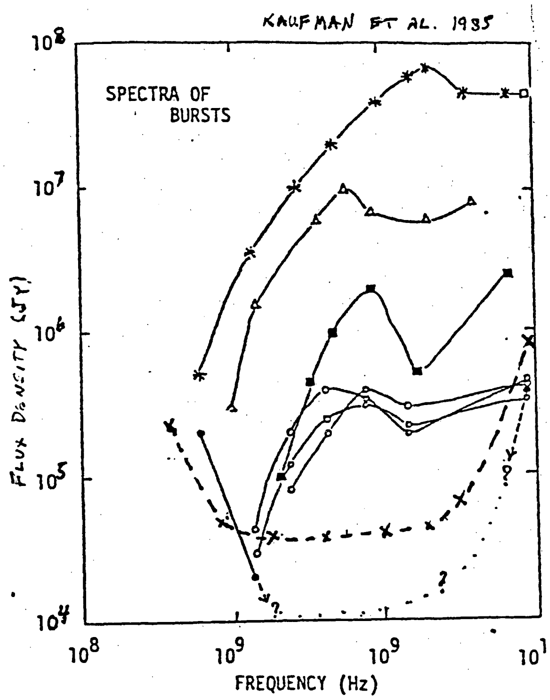
The most important solar problem that can be addressed with a mm wave array (given the present state of knowledge) is probably that of gamma ray–mm wave flares. As the instrumental requirements for this problem equal or exceed those for any other solar problem, it acts as a driving force on the mm array design.

In gamma ray–mm wave flares, recent evidence (mostly from the Solar Maximum Mission spacecraft and mm wave radiometers) has demonstrated that electrons and protons are accelerated almost simultaneously to very high energies. In particular, electrons attain energies of 10 to 100 MeV within one or two seconds of flare onset, and emit both mm waves and continuum gamma rays of high intensity. This continuum radiation is accompanied by nuclear gamma ray lines at energies less than about 10 MeV due to protons, and neutrons are sometimes detected at Earth (e.g. Chupp 1984, *Ann. Rev. Astr. Ap.* **22**, 359).

At the present time there is no widely accepted explanation for this very rapid acceleration. Some argue that a "first phase" process must be the cause because of the very short time scale, possibly involving electric fields in double layers. Others argue that stochastic acceleration can act on short enough time scales (e.g. Melrose 1983, *Solar Phys.* **89**, 149; Bai et al. 1983, *Ap. J.* **267**, 433).

With the firm evidence that some physical process produces relativistic electrons on the Sun so rapidly, we must accept that the same process operates at other locations where magnetic energy is available, i.e. on a wide range of stars including flare stars, interacting binaries and X-ray binaries. Possibly, but less surely because of the uncertain role of magnetic fields, the same processes may be important in the centers of active galactic nuclei.

In the radio range, the special characteristic of gamma ray–mm wave flares is that the flux density increases with frequency into and perhaps beyond the mm regime. Figure 1 shows spectra of several flares, most of them recorded before the gamma ray connection was realized.



Observations at mm waves are obviously of great interest: there have been no spatially resolved studies in either mm waves or gamma rays. Instruments being designed may achieve arcsec resolution in hard X rays of a few hundred keV energy, but not in the energy range > 10 MeV of greatest interest here. Hence the mm wave array is of utmost importance in the elucidation of these most energetic of solar flares.

We now list some of the most important characteristics of gamma ray–mm wave flares together with the implied instrumental requirements.

Characteristic: $\lesssim 1$ s time scales:

> This time scale is characteristic of the ion-acoustic travel time in a magnetic flux tube of length $\sim 10^9$ cm, which is somewhat longer than the fast electron travel time in that flux tube.
>
> Requirement: $\lesssim 0.1$ s time resolution:
>
> This is needed to distinguish between the ion acoustic travel time and the electron travel time. For the former we need to resolve the temporal expansion of a source, and for the latter to observe the near simultaneous brightening of footpoints of a flaring flux tube. The high data rate sug-

gests that data compression is desirable, going automatically to high time resolution when a flux or brightness threshold is exceeded.

Characteristic: $\lesssim 1''$ size scales:

Source sizes in mm waves are probably smaller than $1''$ as judged by scaling from $30''$ at 20 cm to $10''$ at 6 cm to $3''$ at 1.3 and 2 cm and then to mm waves.

Requirement: array sizes of 300 m to 1 km

Characteristic: complex background sources

Solar active regions in which gamma ray–mm wave flares occur are bright and have multiple structures, time-varying. Mm bursts may sometimes be less bright than these background sources.

Requirement: good uv coverage in the snapshot mode

It would be desirable to have more than 21 antennas, 30 or more, to give good snapshots in the 1 km array and to provide redundancy for selfcal.

Characteristic: burst location uncertain beforehand

Exact flare locations within active regions of size 3 arcmin or more cannot be predicted.

Requirement: large field of view of 3 arcmin or more

Three possible solutions are:

1) Mosaicing, with 3 by 3 mosaics completed every 0.1 s.
2) Make an image with the 4 m antennas of the central element, determine the burst source position to $\sim 10''$, and use this information to position the 10 m antennas, all within 0.1 s of burst onset.
3) Underilluminate the 10 m antennas, making the equivalent of 3 to 4 m antennas, perhaps with a flip-out lens. This is the preferred solution because it would allow imaging from the first 0.1 s when the most illuminating phenomena begin to occur.

Characteristic: changing brightness spectrum

Measurement of the rapidly varying brightness spectrum in mm waves is very important in order to define the energetic electron spectrum as a function of position and time. In particular there is a need for simultaneous measurements at two frequencies in the mm band.

Requirement: simultaneous imaging at 1 and 3, or 3 and 9 mm

Characteristic: circularly polarized radiation

We expect a degree of circular polarization $\lesssim 10\%$ for $\gtrsim 10$ MeV electrons radiating in a 100 gauss field at the 300th harmonic of the gyrofrequency. Circular polarization is an excellent diagnostic of magnetic field strength and direction when the electron energy spectrum is known from gamma ray or mm wave spectra. (Neither spectral lines nor linear polarization have ever been incontrovertibly detected in solar radio radiation.)

Requirement: accurate circular polarization

An accuracy of about 1% is required. Thus either linear feeds or "clean" circular feeds (on axis?) are desirable.

2) Penetration of electron beams into the lower atmosphere

In many flares, brightenings occur in Hα, EUV, and even white light simultaneously with hard X-ray bursts. There is a controversy over the cause of these brightenings, whether due to electrons, to protons, or to an ion acoustic conduction front. For the first it is uncertain whether they are able to penetrate deeply enough into the dense atmosphere, for the second it is unknown how an adequate number can be accelerated in the required 1 s, and for the third it is uncertain whether heat conduction can be fast enough.

Observations in mm waves can help answer these questions because they originate in the relevant region of the atmosphere, the low chromosphere, in contrast to cm waves that, during flares, originate in the corona. The mm wave emission mechanism in most flares is probably thermal bremsstrahlung from the heated plasma, so it is relatively straightforward to relate radio wave brightness to the density-temperature structure in the heated regions. The relative timing of mm wave vs. cm wave bursts should help distinguish among the possible causes.

The instrumental requirements for the mm array for this problem are nearly identical to those for the gamma ray–mm wave flare problem. Flares amenable to study here are much more frequent than gamma ray–mm wave flares, with several per day (vs. one per few weeks) occurring during sunspot maximum.

3) Thermal phase of flares

In some flares, energy continues to be released over durations of tens of minutes, and energetic particles are continually accelerated. The source of this energy is controversial. Magnetic energy stored in the corona seems to be insufficient to account for the total in some large flares, arguing for storage below the photosphere. If so there should be a signature in the low chromosphere where mm waves arise.

The instrumental requirements are similar to those of gamma ray–mm wave flares, but with relaxed time scales.

4) Mapping of solar active regions

Mm wave emission from active regions is due to free-free bremsstrahlung, and is partially polarized due to the difference between x mode and o mode emissivities. It therefore gives information about the magnetic field strengths and topology in the low chromosphere, whereas most magnetogram data apply to the photosphere, below the supposed region of magnetic dissipation in coronal heating and flares. Changes in magnetic field topology, pre- to post-flare, should be much larger in the chromosphere than the photosphere, and hence much more evident at mm wavelengths.

Instrumental requirements are similar to those above, but with relaxed time constraints, tightened polarization accuracy, and, because of active region complexity, best possible uv coverage.

5) Mapping of solar filaments and prominences

The variation of brightness temperature with frequency in the cm–mm wave domain provides easily interpretable information on the temperature and density structure of the transition sheath surrounding filaments, those dense clouds of cool gas suspended high in the corona. From the temperature gradient observable at mm waves the thermal energy conducted into the filament from the corona can be calculated. Mini-flares whose cause is unknown occur in filaments: magnetic reconnections and thermal instabilities are possibilities. Comparison of high spatial resolution observations at mm and cm wavelengths can relate the geometry of the filament and its surrounding coronal cavity, leading to a determination of the density–temperature structure of the sheath and coronal cavity, and to reasons for their existence.

For this problem it is necessary to image a field of about 1 arcmin with a resolution of about 1 arcsec at 1 mm. This is feasible with a 3 × 3 mosaic, or by under-illuminating the 10 m dishes. Quasi-simultaneous observations at 1, 3 and 9 mm are required, with intermediate bands near 2 and 6 mm being desirable. Scaled arrays, e.g. the central element at 1 mm and the array at 3 mm, would provide the great advantage of having identical resolution at two frequencies.

6) Mapping of the quiet Sun: quiet regions and coronal holes

At 36 GHz, recent Japanese 45 m results (Kosugi et al. 1985, *Publ. Astron. Soc. Japan*, in press) demonstrate that coronal holes are brighter than quiet regions, contrary to what is observed at almost all other frequencies (e.g., 10 and 98 GHz). Earlier reports of this highly unexpected effect came from U.S. and Russian observers, but seem not to have been taken seriously, perhaps because of the relatively poor spatial resolution. The cause of the anomalous brightening is unknown: it is possibly related to a lower gradient of density and temperature in the transition region of coronal holes compared with average quiet regions, or to a wider temperature plateau in the upper chromosphere. Maps with arcsec resolution are desirable to determine whether the brightness difference is related to fine structures or widespread emission, and to compare brightness distributions at the solar limb where the emission scale height is only about $1''$.

Instrumental requirements include simultaneous mapping at 9, 3 and 1 mm, with intermediate wavelengths near 6 and 2 mm being desirable. Mosaics of fields 3 arcmin or more are required.

7) Miscellaneous, speculative

Coronal heating:

Mechanisms that cause heating of the outer atmospheres of the Sun and stars is not understood. For the Sun we know that mechanical energy deposition due to sound waves is inadequate. The magnetic field comes through the photosphere in small bundles with strength greater than 1000 gauss, and these field lines spread out by the time they get to the corona. Parker (1983, *Ap. J.* **264**, 235) and others have demonstrated that there is no equilibrium topology for helical bundles in the general case, and hence there must be dissipation of energy. Proof that this heats the corona is lacking.

Mm maps of brightness and polarization with better than $1''$ resolution might reveal the emergent magnetic flux topology and its spreading in the chromosphere. Sites of heating in the low corona may be evident in a series of maps spaced about 1 s apart. If so, temperatures and densities of heated pockets could be derived.

The instrumental requirements for this study include excellent uv coverage in the 300 m and 1 km configurations; the latter might require $\gtrsim 30$ antennas. The small field of the 10 m antennas, $\approx 20''$, is adequate.

Oscillations and pulsations:

Some modes of oscillation and pulsation may be observable at mm wavelengths by metrology. For example, if radial and torsional oscillations of low order could be observed, they would reflect the structure of the deep solar interior.

The instrumental requirements include accurate measurements ($\lesssim 0.1''$) of the relative positions of opposite solar limbs as a function of time (tens of minutes to many hours). Two subarrays would be needed, pointed at opposite limbs.

THE STARS

Radio astronomy of the stars has recently become of major importance, largely because of the availability of a new instrument, the VLA, with its factor of 10 to 100 increase in sensitivity and resolution. The proposed mm array would be another giant step upward in sensitivity and resolution in its wavelength band, and results of major importance are to be anticipated. Some problems that would be attacked are given below. Summaries of the present state of knowledge are given in the book edited by Hjellming and Gibson (*Radio Stars*, D. Reidel, 1985) and the review article by Dulk (*Ann. Rev. Astron. Ap.*, 1985, **23**, 169).

1) Outbursts from active stars and close binary systems

Here we are mainly concerned with flare stars (dwarf stars with emission lines of spectral class dMe) and close binaries such as those of type RS Canes Venatici (RS CVn). Millimeter observations offer the important advantage of allowing detection of fast electrons much closer to the acceleration site, in the same way as for the Sun and many other objects. Thus it is to be expected that the correspondence between optical/UV flare emission and mm emission will be close. It is likely that cm–dm flare emission arises in fairly large, optically thick sources located high in a stellar corona, perhaps at a distance of $\sim 1\ R_*$ above the photosphere, whereas mm sources should be only a small fraction of a stellar radius in size and located much lower. Hence flares can be associated better with centers of activity (starspots or active longitudes) than has been possible at cm waves.

Flare spectra of stars sometimes have a positive slope at least to short cm wavelengths. The frequency of peak flux (where the optical thickness of the radiating source changes from thick to thin) may then be in the mm band. The location of the peak is mainly sensitive to the magnetic field strength (typically $\gtrsim 10^3$ gauss) and the energy of the radiating electrons (typically $\lesssim 1$ MeV), hence measurements of the peak frequency greatly constrain these parameters.

Flare emission may occur in mm waves at low harmonics of the gyrofrequency if the field strengths attain values of $\sim 10^4$ gauss. Certainly strong fields exist on many active stars as evidenced by flare activity and quiescent emission in cm waves. Fields of 10^4 gauss have not been observed directly, but several kilogauss fields have been observed on G to M dwarf stars. When these same techniques are applied to dMe stars they usually give only limits consistent with the existence of 10^4 gauss fields, and the dMe star AD Leo has measured fields of ~ 4 kG over about 70% of its surface (Saar and Linsky 1985, *Ap. J.*, in press). If in fact peak fields of $\sim 10^4$ G do exist, it is possible that cyclotron maser emission, occurring at low harmonics of the gyrofrequency, occurs at mm waves. Such emission is characterized by high degrees of circular polarization

($\gtrsim 90\%$), high brightness temperatures ($\gtrsim 10^{14}$ K), and rapid time variations (< 10 ms). Bursts with these characteristics have been observed at frequencies up to 5 GHz from the Sun, the Earth, Jupiter Saturn, the RS CVn system HR 1099, the dMe flare stars L726-8A and AD Leo, and the cataclysmic variable binary AM Herculis. (not all of these characteristics have been observed in all objects, e.g., high time resolution has only rarely been achieved for stars, and planetary masers occur only at low frequencies.) If observed in the mm band such bursts would offer strong evidence of magnetic fields near 10 kilogauss.

In addition to "normal" flares that accelerate electrons to the range 100 keV to 1 MeV, some solar flares exhibit evidence for electron energies of 10 to 100 MeV, and these radiate intensely in the mm band even with low field strengths. Mm observations of flare stars and RS CVn's will reveal whether stellar counterparts of such flares exist. Normal flares on a star 5 pc distant would give fluxes of order 10 mJy at 3 mm, whereas gamma ray-mm wave flares should give fluxes more than 10 times larger. While these unusual flares might not be identifiable at cm wavelengths, they would stand out in mm waves and allow determination of the electron energy spectrum.

The requirements on a mm array that will ensure appropriate observations include the following:

i) High sensitivity in the continuum mode: better than 1 mJy at 1 mm. This is the overriding consideration, one which requires the largest possible collecting area, the lowest system temperatures, and the largest bandwidths.

ii) High time resolution, better than 1 s.

iii) Accurate circular polarization, better than 10%.

iv) Operation at two frequencies simultaneously is highly desirable.

2) Quiescent emission from chromospheres/coronae of active, late-type stars

Quiescent emission is observed in the cm/dm band from a number of nearby dMe stars, late type stars, and close binaries. There is no accepted model for this emission—it may be due to gyrosynchrotron radiation from predominantly thermal electrons or from nonthermal electrons in a power law tail. Observations in the mm band can distinguish between these possibilities since there are many more fast ($\gtrsim 1$ MeV) electrons in a nonthermal tail (able to emit mm waves) than there are in a thermal electron distribution with its exponential cutoff at high energies. Extrapolations from observed microwave fluxes indicate that dMe quiescent emission is undetectable (~ 0.05 mJy) for thermal gyrosynchrotron radiation, while the nonthermal tail model predicts detectable emission (~ 0.5 mJy).

For active late type stars and RS CVn systems, the flux levels at all frequencies are higher than for dMe stars due to the larger source areas. Mm wave fluxes greater than 10 mJy are predicted from a nonthermal tail of energetic electrons.

Instrumental requirements for this study are similar to those of 1) above. The longer integration times possible here are mostly offset by the lower flux densities expected for quiescent emission compared with outbursts.

3) Winds of hot stars

Observations at 1.3 and 3 mm are of fundamental importance to studies of winds from hot stars. Current problems with wind fluxes at cm waves (variability, spectrum oddities, failure to fit expected visibility curves with model temperatures) argue that mm data will be critical in sorting thermal from nonthermal radiation.

The simple theory of radio emission from winds predicts:

$$S_\nu \propto \nu^{0.6}, \qquad R_* \propto \nu^{-0.6},$$

and typical values at 2 cm are: $S_\nu \sim 100$ mJy and $R_* \sim 0.1''$. As shown below, this rising spectrum allows many wind sources to be detected at mm waves. Effects of nonthermal electron populations are much smaller at mm waves than cm waves, so that "pure" wind radiation should be more common, and uncertainties in derived mass loss rates should be smaller.

Because of the $\nu^{0.6}$ spectrum, the flux density S_ν of wind sources is roughly 10 times larger at 1.3 mm than at 6 cm. The mass loss rate $\dot{M}$ goes as $\dot{M} \propto S_\nu^{3/4}$. If the sensitivity at 1.3 mm were the same as currently available at 6 cm, this implies that 6 times smaller mass loss rates would be observable. Alternately, sources with the $\dot{M}$ now detectable at 6 cm with the VLA would be observable out to a distance about 3 times farther than is now possible.

How many stellar wind sources would then be detectable with the mm array?

i) Wolf-Rayet (W–R) stars: 24 W–R stars have been detected with the VLA at 6 cm, roughly all such stars within 2.5 kpc. With the mm array, all known galactic W–R stars at observable declinations will be detectable, roughly doubling the sample size, depending somewhat on atmospheric attenuation vs. declination.

ii) O–B stars: About 16 O–B stars thought to be wind sources have been detected with the VLA at 6 cm. This number will be increased with the mm array because of two factors: First, stars of lower $\dot{M}$ will be detectable within the present limiting distance. Given the relation $\dot{M} \propto L_*^{1.6}$, the luminosity threshold for detection will be lowered by about a factor of 3. With the estimated initial mass function for O–B stars, roughly 70 new sources will be detectable. Second, stars like those presently observable can be detected at larger distances. This factor is not as important as might be thought because all O–B stars are near the galactic plane (i.e. in a cylindrical volume a few hundred parsecs thick rather than a spherical volume), but some 20 new, distant sources should be detectable.

An increased sensitivity beyond the paradigm array, due to a larger A_{eff}, larger bandwidth, or smaller T_{sys}, would lead to a correspondingly larger number of detections, going roughly as $S_{lim}^{-0.8}$.

We list two main reasons why detecting more stellar winds represents an important scientific goal: First, with the relatively small number now observable there are uncertainties related to small number statistics. More importantly, the presently known objects may be the outliers of a population, unusual objects not representative of the whole. Second, lowering the $\dot{M}$ threshold will enable both UV and radio analysis techniques to be applied to the same stars. Currently, almost all stars with $\dot{M}$ large enough for radio detections have UV resonance lines that cannot be analyzed because they are completely saturated.

We turn now to the importance of having long enough baselines in the mm array to resolve wind sources. The character of wind sources leads to two components: an optically thick central core, and an optically thin outer region. To date no core has been resolved; the largest, P Cygni, has a diameter of about 0.1 to $0.2''$ at 6 cm. If the mm array has baselines comparable with the VLA, P Cygni and one or two other wind sources may have resolvable cores.

Optically thin outer parts of two stellar winds have been resolved with the VLA for two stars, the O–B star P Cygni and the W–R star γ^2 Vel; the "resolution" was accomplished by comparing visibility versus baseline. From such data, four vital pieces of information can be derived:

i) The temperature of the wind.

ii) A verification that the radio emission is indeed bremsstrahlung from wind material.

iii) Isotropy on the plane of the sky can be established.

iv) If accomplished at multiple frequencies, the temperature can be derived as a function of radius.

Resolution of the optically thin outer parts of winds requires a S/N ratio of about 50 to 1, a value that would be achieved for essentially all stars currently detected at 6 cm. In addition, nearly all of these would be resolvable at 1.3 mm, giving a strong justification for long baselines in the mm array.

In summary, the instrumental requirements for the study of wind sources are similar to 1) above, but here baselines of 35 to 70 km are required in order to resolve a significant number of stars.

4) Main sequence stars

About 600 stars, a few main sequence but mostly giants, will be detectable with a mm array simply because of the thermal radiation from their photospheres or low chromospheres. Figure 2 is an HR diagram showing the detectable stars and the limiting distances at which stars of various spectral and luminosity classes can be detected with the paradigm mm array. It also shows the approximate number of stars expected to have flux densities of various levels. The star numbers are probably lower limits because any effect that increases the effective temperatures or stellar radii (e.g. dense transition regions, coronae or winds) would allow more stars to be detected. Figure 2 was derived from the 9110 stars of the Yale Bright Star Catalog; catalogued values of spectral class, luminosity class, apparent magnitude, and color index were used to derive bolometric magnitudes, effective temperatures, distances and stellar radii. From these, the 1.3 mm flux density was derived.

Because $S \propto T_{eff} R_*^2$, mm observations can check on the canonical values (mostly inferred indirectly, few measured) of R_*, or with less sensitivity, T_{eff}. One should expect surprises, with radio sizes or effective temperatures being different from canonical.

In addition to simple detections, several other studies become possible if the array sensitivity is high enough, for example:

i) Sixty or more nearby stars should be resolvable with VLA-like baselines, providing a direct check on the stellar radii. Figure 3 is an HR diagram showing 63 stars that can be resolved with 35 km baselines. About ten stars have diameters of two or more beamwidths. Stellar winds, common on red giant stars but not included in theses estimates, would increase the number and resolvability of such stars. Criteria for resolving stars have been presented by Mutel (1985, in *Radio Stars*, op. cit., p. 359.)

ii) Starspots and/or active regions would modulate the flux at the stellar rotation period. Long term monitoring allows a direct measurement of how stellar activity cycles relate to spot numbers and sizes.

iii) Stellar pulsations such as are expected in some parts of the HR diagram may modulate the flux enough to be detected.

iv) Metrology of star positions over periods $\gtrsim 1$ year, with a few milliarcseconds resolution, may reveal the binary nature of some stars, and perhaps demonstrate the existence of low mass (planetary) companions.

The requirements for these studies are again high sensitivity and long baselines. The need for high sensitivity is emphasized by the realization that the number detectable

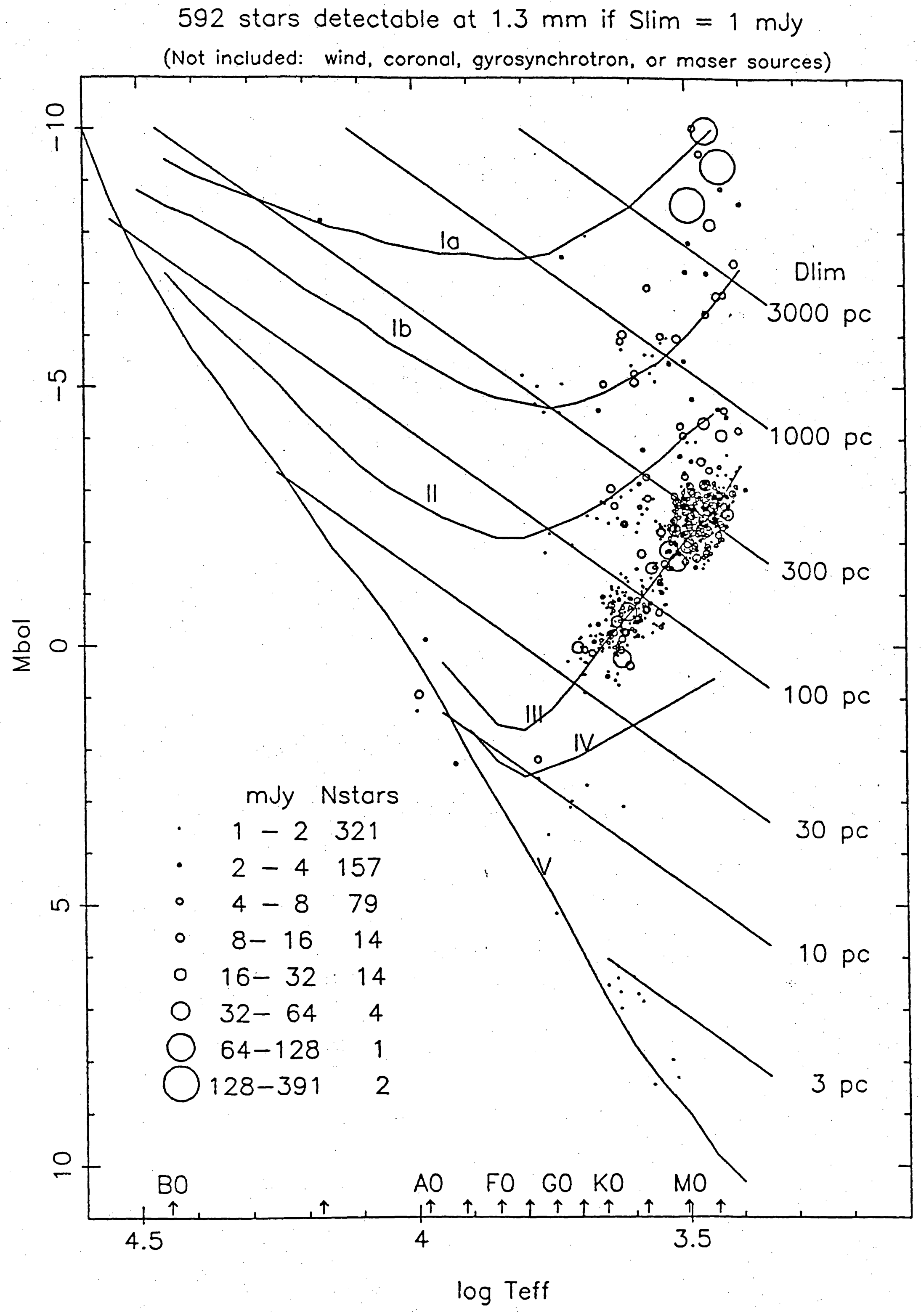


Figure 2. HR diagram showing stars that will be detectable with the paradigm mm array at $\lambda = 1.3$ mm if the minimum detectable flux density is 1 mJy.

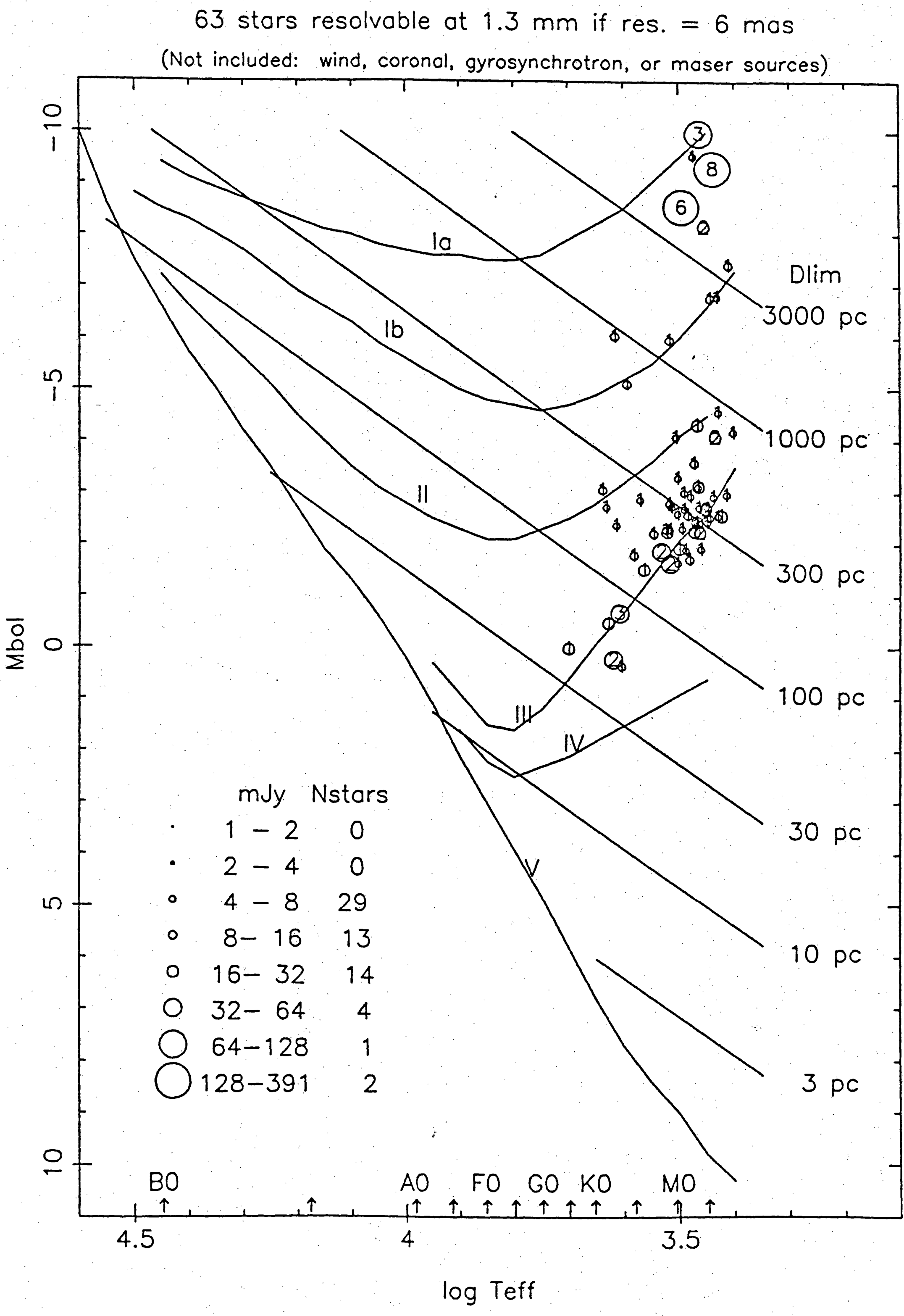


Figure 3. HR diagram showing stars that will be resolvable with the mm array at $\lambda = 1.3$ mm if baselines to 35 km are available. The sizes of the circles are proportional to flux density, and the numbers inside the circles indicate the number of resolution elements across the star.

is proportional to $S_{lim}^{-1.5}$, where S_{lim} is the limiting sensitivity (e.g. 4σ); for example, in Figure 2, more than half of the stars have flux densities in the 1–2 mJy range. The precision of positions, sizes, etc. is proportional to the signal to noise ratio. Hence there is an overriding need for high A_{eff}, wide bandwidth (> 10 GHz), low system temperature, and self-calibration of weak sources (which may require the redundancy provided by a number of antennas larger than 21).

5) Cool supergiant chromospheres

In the mm band radiation of these stars comes from locations where energy deposit (mechanical?) causes partial ionization of the winds, whereas cm wave radiation arises outside of that region where the limiting ionization of 1 to 2% has been attained. Betelgeuse and Antares are strong sources with flux densities of 200–300 mJy, spectral indices of about 1.2 to 1.4, and angular sizes of about 50 mas in the mm range. Imaging of these two stars with $\gtrsim 6 \times 6$ pixels is possible at 1.3 mm with a 35 km array (they are represented by the two large circles at the upper right of Figures 2 and 3). One then expects asymmetries, starspots and possibly pulsations to appear in the data. With a sensitive mm wave array, it is possible to measure the spectrum of several other cool supergiants.

Regarding requirements on the mm array, this is an excellent example of a project for which baselines of 30 km and more are essential.

6) Miscellaneous

A number of stars exhibiting very interesting phenomena are observable at mm wavelengths; many of these are in the area of overlap between this working group and that on Evolved Stars. Here we will briefly mention some of these objects; a few of them are reviewed in more detail by the Evolved Star group.

Time variations of X-ray binaries

Cyg X-3, SS 433 and LSI+61°303 are binary stars with strong X-ray and gamma-ray emission. Their radio sources, particularly Cyg X-3, exhibit shorter and shorter time scales as frequency increases, e.g. tens of minutes at 70 GHz. Observations in mm waves, especially if nearly simultaneous at 1 and 3 mm, will directly reflect the energetic electron spectrum as a function of time at a location very close to the region of particle acceleration.

Novae and recurrent novae

At mm wavelengths, one can observe nova shells in the early stages of expansion, in the months coinciding with optical studies. The combined data will be much more powerful than either by itself in constraining models of shell density and velocity. Outbursts such as that on RS Ophiuchus in January 1985 would be especially revealing if observed with a mm array. In that case there were two components, an extended shell and a compact component that had a spectrum still rising at 22 GHz and an observed brightness temperature $T_B \gtrsim 10^6$ K. Possible causes for the radiation include synchrotron emission from shock-generated fast electrons, and fast electrons trapped in some sort of stellar magnetosphere. Mm wave observations, spectra, and resolution of source sizes and positions, are essential in distinguishing among models.

Ejected shell/wind objects and small planetary nebulae

Some kinds of circumstellar shells and compact planetary nebulae produce bremsstrahlung radiation which is optically thin only at mm wavelengths, hence only there amenable to certain kinds of diagnostics. A significant number are large enough to be imaged with a mm array, allowing the determination of the density profiles. As some of these sources are associated with shocks moving into fossil red giant winds, parameters of the shocks will be derivable. Source sizes are typically a few arcseconds, so the optimum resolution (consistent with source brightnesses) is about $0.1''$.

VV Cephei and symbiotic star binaries

Here we deal with ionized, optically thick sub-regions of supergiant stars (VV Cep binaries) and giant stars (symbiotic binaries). The ionized regions are associated with relatively small, hot, ionizing stars orbiting deep inside dense, mostly un-ionized winds from cool primary stars. The HII regions thus produced are exceptionally dense ($n \gtrsim 10^7$ cm^{-3}) and almost certainly hot ($T_e \gtrsim 10^5$ K); somewhere in the mm band they change from being optically thick to optically thin. Models of these ionized regions are very dependent on the orbital parameters of the binaries and on asymmetries or temporal variations in the winds. Mm wave observations are ideal for the probing of the ionized subregions, and of fluctuations and asymmetries that exist deep within the cool winds.

Acknowledgements. This working group has greatly benefited from discussions with and comments from G. Hurford, D. Abbott, and R. Mutel.

SUMMARY OF DESIRED INSTRUMENTAL PROPERTIES

SUN:

Good snapshot imaging in arrays of ≤ 1 km ($\lesssim 1''$ resolution)

Integration time: $\lesssim 0.1$ second

Fast frequency switching among 1, 3 and 9 mm ($\lesssim 1$ s). Bands near 2 and 6 mm are desirable.

Simultaneous observations at two frequencies are highly desirable.

Accurate circular polarization: better than 1 percent

Field of view of 3 arcmin or more at 3 mm by:

i) mosaicing at ~0.01 sec, or
ii) feedback of pointing from MT to 10 m dishes in ~0.03 sec, or
iii) underillumination of 10 m dishes (preferred solution)

STARS:

High sensitivity: large A_{eff}, large bandwidth, low T_{sys}

Long integration times: selfcal on weak sources

Moderate time resolution: $\lesssim 1$ second

Two frequencies simultaneously highly desirable

Accurate circular polarization: better than 10 percent

Long baselines (35 to 70 km) required for some studies