ALMA Memo 493
Finding Fast Switching Calibrators for ALMA

M.A. Holdaway
C. Carilli
R. Laing

April 29, 2004

Abstract

In order to perform fast switching phase calibration effectively, we need to have a database of bright point-like sources at millimeter wavelengths. Optimally, this would include flux measurements at 86 GHz and spectral information at higher frequencies.

We present a sample of 31145 compact flat spectrum radio sources with $-40 < \delta < +60$, presumed extragalactic, which will be likely candidates for calibrator sources. A sample of variable steep spectrum source (ie, sources that could harbor a flat spectrum core even though they appear to be steep spectrum) adds another 1767 sources. And a sample of weak but highly inverted sources adds another 5296 potential sources to observe. Hence, we have as many as 38208 sources which are likely to be detected at millimeter wavelengths, though some of the steep spectrum variable sources and highly inverted source candidates may be abandoned based on detection rate.

The Prototype Interferometer (PI) at the ALMA Test Facility (ATF) may be available to verify if these sources are indeed bright at 86 GHz. The sensitivity of the prototype receivers should permit a noise level of about 3.5 mJy at 86 GHz and about 10 mJy at 250 GHz. We expect about a third of the sources will be brighter than 20 mJy at 86 GHz, and these detections will be reobserved at 86, 106, 215, and 263 GHz to determine the spectrum at higher frequencies and to have some data on variability. These observations should take about 80-90 days of time on the Prototype Interferometer, and it is suggested that these observations could be done at night in the spring and fall of 2005, subject to availability of equipment and manpower.

1 Introduction

Phase calibration of the ALMA will be of principle importance for high frequency and long baseline observations. As median atmospheric phase stability conditions result in 50% loss in sensitivity from phase decorrelation for 230 GHz observations on a 300 m baseline, long baselines are not really all that long, and high frequency is really not all that high. The two competing phase calibration schemes are water vapor radiometry and fast switching. There are many reasons to believe that a combination of the two techniques may be useful and even required (ie, not-so-fast switching plus water vapor radiometry; the details of combining fast switching with water vapor radiometry have not been worked out.)

In straight fast switching, we will typically spend about 20 s on the target source at the target frequency, then zip over to a nearby bright calibrator (say 50-100 mJy and 1.5 deg away) while changing frequency to 90 GHz, detect that calibrator with high SNR over an observation that could last less than 1 s, and zip back over to the target source. On time scales less than the instrumental stability time scale, we must also solve for the instrumental phase difference at the calibrator and target frequencies, which must be performed on a calibrator which is bright at both the target and calibrator frequencies.

These calibrators need to be compact (< 100 mas), bright at 90 GHz, and ubiquitous, with one within 1-2 deg of your favorite source. Flat spectrum quasar cores satisfy these requirements. For fast switching (or even not-so-fast switching) to work, we will need to have a database of the quasars, which will be very nearly point sources at millimeter and sub-millimeter wavelengths. Butler (2003) has suggested that thermal sources, with their rising spectrum, may make good calibration sources, but Holdaway, Carilli, and Bertoldi (2004; hereafter HCB) demonstrate that thermal sources will be resolved out for long baselines or high frequencies. Due to the falling spectra of quasars, some researchers have doubted the existence of enough quasars to fulfill the promise of fast switching. Holdaway, Owen, and Rupen (1994) have performed observations which measure the spectral index distribution of these quasars in order to estimate, without actually finding them, the quasar source counts at 90 GHz. Holdaway and D'Addario (2003) have extrapolated these source counts into the sub-millimeter, assuming a spectral steepening of +0.5 (for $S_\nu \propto \nu^{-\alpha}$) above 90 GHz, to permit computations for fast switching at high frequencies. While this is a reasonable start, we do still need to find our 90 GHz calibrator sources, and we need to understand what these sources are doing at higher frequencies.

Recently, HCB, based on observations by Voss *et al.* (2004) have presented evidence that there may be more quasars at 250 GHz than our estimates predict. So, it would be very useful to go out and look for these calibrator sources at, say, 90 GHz and 250 GHz.

The individual single dish prototype antennas at the ALMA Test Facility (ATF) would not be well suited to searching for these sources, as 1/f noise in the receivers would spoil the sensitivity. However, it is planned that two of the antennas will be linked to form the Prototype Interferometer (PI). The 1/f gain fluctuations will not affect the sensitivity of a one baseline interferometer. In fact, the sensitivity of a one baseline interferometer will be pretty good, permitting a few mJy rms in a minute of observations. The antennas will be equipped with band 3 (90 GHz) and band 6 (230 GHz) receivers, so some relevant spectral information will be available.

The big question is: which sources should we observe? This memo identifies these sources.

2 Our Sample

2.1 What Will These Sources Look Like?

In a dream world, we would perform an all sky survey at 90 GHz to find all potential calibrator sources. However, such a survey is not as practical as it is at lower frequencies. At this time, the best we can do is to identify sources from low frequency (ie, 1.4 and 4.85 GHz) surveys whose properties make them likely to be bright and compact at 90 GHz: ie, select on bright, compact, flat spectrum non-thermal radio sources, or the quasar cores.

Before we go into those low frequency catalogs, consider the non-thermal sources found quite unexpectedly in a 2200 square arcminute field at 250 GHz in Voss *et al.* (2004). The radio spectra for these three sources are shown in Figure 1. The first of these sources appears

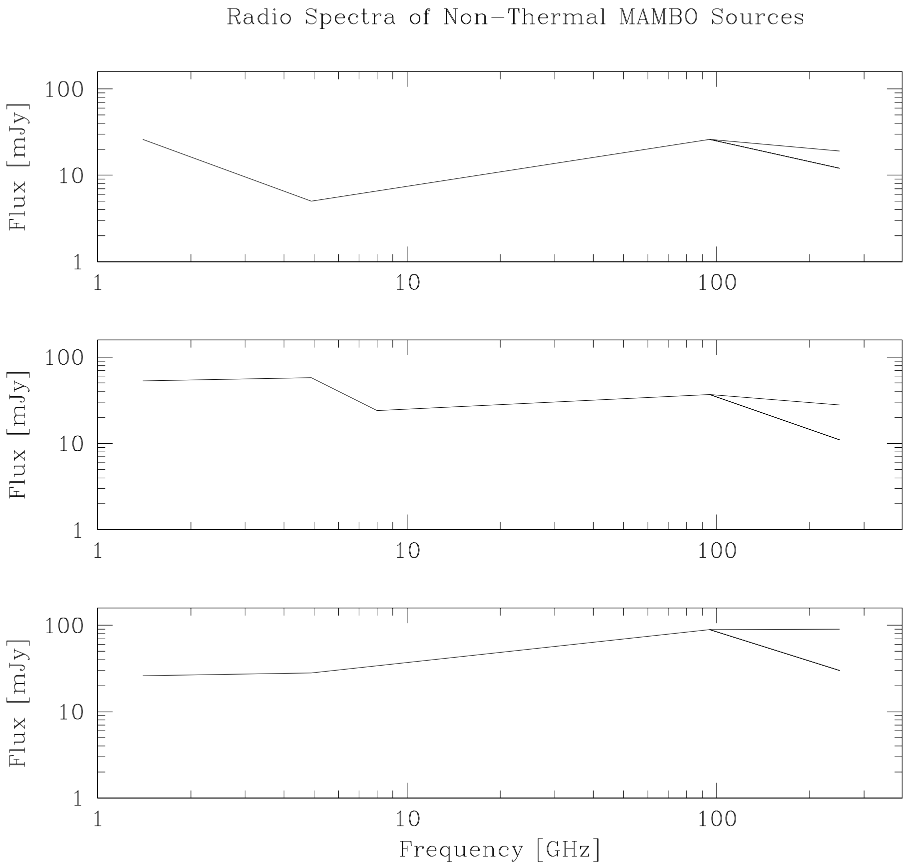

Figure 1: Radio spectra of the three non-thermal sources "discovered" by MAMBO at 250 GHz (Voss *et al.*, 2004). The two lines between 90 and 250 GHz represent the range of 250 GHz fluxes that have been observed in monitoring.

to be steep spectrum between 1.4 and 5 GHz, and would not be expected to be shining bright at millimeter wavelengths. However, it does rise to the occasion. The second source is a pretty straight ahead flat spectrum source and would show up in a reasonable list of sources selected at centimeter wavelengths. The third source, however, is fairly inverted, rising by a factor of 3 in flux from 5 GHz to 90 GHz. So, two out of the three non-thermal sources that were found in a blind sample at 250 GHz are oddball, one appearing to be steep spectrum and the other being somewhat inverted. Two out of three sources might not make it into a sample reasonably selected on centimeter flux and spectral index. How many other such oddball sources are out there? How will we find them? We'll present some ideas later on.

2.2 Defining Our Sample: Flat Spectrum Compact Objects

Barring a blind survey of the sky, the next best thing to do is to select sources from big low frequency surveys which we think will be likely to show up at high frequencies.

We take for our starting point the 1.8 million sources in the NRAO VLA Sky Survey (NVSS) catalog (Condon et al, 1998). The NVSS catalog is made from VLA D array observations at 1.4 GHz from the celestial north pole down to -40 deg declination. The thermal noise is about 0.6 mJy, the catalog goes down to 2.2 mJy, the typical upper limit of the source size determination (for point sources) is about 20 arcsec, and the positional accuracy is about an arcsecond, much less than the beam of the prototype ALMA antennas at 250 GHz (ie, quite accurate for our purposes in finding these sources). We restrict ourselves to sources south of 60 deg declination, close to the northern extent of ALMA observations. Also, we select sources which are 9 mJy or brighter at 1.4 GHz.

We need to get some spectral information on these sources so we can determine which sources are flat spectrum and therefore likely to be detected at 90 GHz or above. So, we have correlated these NVSS sources with the GB6 catalog (Gregory et al, 1996), which was generated from 4.85 GHz observations with the Green Bank 300 ft telescope between 0 deg $< \delta < +75$. The minimum flux presented in GB6 is 18 mJy, and the positional errors are significantly larger than the NVSS catalog, typically about 20 arcsec rms in each axis. So, we searched for GB6 sources which were within 4-sigma of the positions of all qualifying NVSS sources. For southern sources, we correlated the NVSS sources with the Parkes-MIT-NRAO (PMN) catalogs (Griffith and Wright, 1993; Griffith et al 1994) between declination -40 and +10. The PMN catalogs were generated from the Parkes 64 m dish observing at 4.85 GHz. While the positional accuracy and sensitivity of the PMN catalog is not quite as sharp as the GB6 catalog, it is a very good match to the GB6 for southern sources. A 1-sigma positional error of 28 arcsec in each axis was assumed for the PMN source positions.

In correlating the NVSS sources with the GB6 sources, we found that most bright 1.4 GHz sources found a matching source at 4.85 GHz. However, several sources which were bright (ie, above 200 mJy in the north or 300 mJy in the source) at 1.4 GHz had no corresponding source at that location at 4.85 GHz. We called these the "bright orphans". There were about 2600 bright 1.4 GHz orphans which were not in the GB6 or PMN surveys. By eliminating sources more extended than 30 arcsec, this was reduced to about 1000 bright orphans, with 100 brighter than 1 Jy. We need to spend a bit more time understanding exactly what these sources are about.

In all, we have about 104000 sources which are brighter than 9 mJy at 1.4 GHz and which have positional matches with catalog sources at 4.85 GHz. If we select for sources with NVSS size smaller than 30 arcsec (3C273, with a bit of extended structure, had a fit size of 21.5 arcsec, and the upper limits for unresolved sources in the NVSS are typically 15-20 arcsec) and a spectral index ($S(\nu) \propto \nu^{-\alpha}$) less than 0.5, our catalog is reduced to 31145 sources, after removing duplicates due to the overlap in PMN and GB6 catalogs between 0 and 10 deg declination. This sample is approximately the right size for our calibrator list. We need approximately one calibrator per square degree or two. As our sample runs from -40 deg to +60 deg, or about 75% of the sky, we need about 15000 calibrators in order to get a source within 1-2 degrees of your favorite target source. The fact that many of the sources in our sample will end up going undetected at millimeter wavelengths indicates that we may need to look for some other sources through other means. Later sections will explore how we might

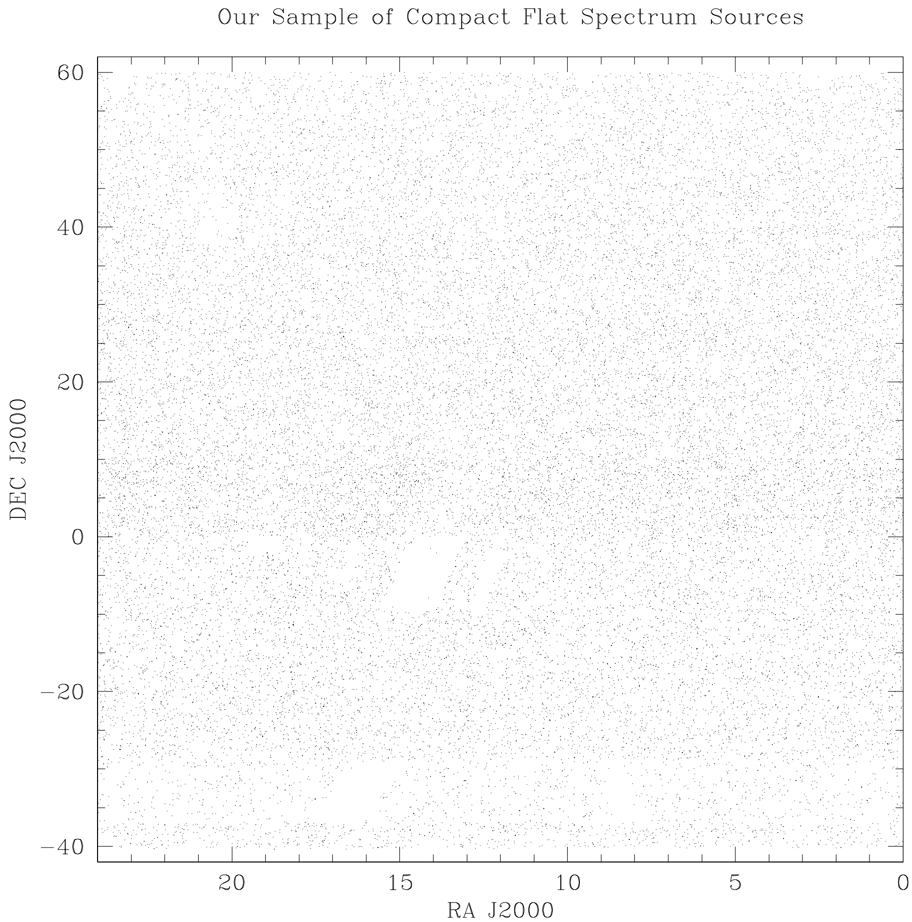

Figure 2: The distribution on the sky of the 31145 sources resulting from selecting on $\alpha < 0.5$ and a source size less than 30 arcsec. The southern gaps are in the PMN catalog.

find some other sources among the variables and inverts.

2.3 Properties of Our Sample

Figure 2 shows where our main sample of 31145 sources sit in the sky. The southern gaps are due to omissions in the PMN survey. While the NVSS and GB6 surveys have excellent coverage over the sky, there are also some places where our sample is very sparse (such as around 21 hours, +40 degrees) because of confusion in the GB6 catalog around the galactic plane. In regions which suffer from confusion due to the galactic plane or missing PMN data, we will supplement our sample with sources selected only from NVSS data. In that case, we should pick sources based on NVSS compactness and NVSS flux.

Figure 3 shows a histogram of spectral index between 1.4 and 4.85 GHz for sources in our sample with 1.4 GHz fluxes above 30 mJy, only counting sources above 10 deg where there will be no contamination with PMN-matched sources (there seem to be more problems with the

PMN data and matches than with GB6). Aside from the sharp cutoff at a spectral index of 0.5 (which we imposed by our selection criteria), it looks nice and reasonable, giving us hope that our process of aligning sources between 1.4 and 4.85 Ghz was in fact finding the attributes of legitimate sources, rather than just matching up unrelated sources, some of which would happen to have highly inverted spectra. But note that there is a healthy population of inverted sources, which accounts for about 22% of our sample. (Compare: between 8 GHz and 90 GHz, Holdaway, Rupen, and Owen found 15% had inverted spectra).

2.4 What About $\delta <$ -40 ?

The NVSS, with its small beam, very low noise level, and excellent positions, is the gold standard in this game, and unfortunately it doesn't extend all the way down to the the South Celestial Pole (can this be Jim Condon's biggest shortcoming?). We are in a bit of a bind. It seems a reasonable way to proceed south of $\delta = -40$ is to make targeted observations of PMN sources with ALMA at 86 GHz. The 1 σ position errors of the PMN sources are about the same as the half power half width of the beam, so some PMN sources will fall outside the ALMA beam. Unfortunately, the 30 GHz band won't be available on the early ALMA – the wider beam at low frequency would solve this problem. Instead, we'll just have to make a little mosaic around each selected PMN position to search for the source.

This process will be labor and observing time intensive, and is beyond the scope of the current project. It is likely that the southern ALMA calibrator catalog will lag behind the northern catalog in completeness for years into ALMA operations. Eventually (perhaps a decade into operations?) some researcher will do a systematic 30 GHz continuum survey in total power, and with follow-up interferometric observations, the southern sky will finally catch up to the northern sky in calibrator completeness.

2.5 More Sources: Variable "Steep Spectrum" Sources

In a sample selected on compact flat spectrum objects which are bright at centimeter wavelengths, we will be missing sources like the one in the 250 GHz field of Voss *et al.* (2004) which had a steep spectrum between 1.4 and 4.85 GHz. In fact, that source was way below the minimum flux threshold for GB6 at 4.85 GHz. How will we find such sources? Are we to observe steep spectrum sources? All sources that show up in the NVSS? Most of those sources will not show up at 90 or 250 GHz. How do we efficiently find these sources?

First of all, why did that source have a steep spectrum between 1.4 GHz and 4.85 GHz? One possibility is that the source was dominated by extended emission at 1.4 GHz and had a weak inverted core. Such sources would be very hard to find, and would probably be pretty interesting as well if not exceedingly rare. Another possibility is that the source is core dominated even at 1.4 GHz, but is highly variable, and just appears to appear to be steep spectrum due to the variability. There is good hope for finding sources like this.

All three non-thermal sources we found at 250 GHz were seen in the NVSS survey at 1.4 GHz. One of them is definitely variable at 1.4 GHz, and a second one may be variable. One source which was 53 mJy at 1.4 GHz last year was 38.6 mJy around 1995 when the NVSS observations were made. Another source which was 26 mJy at 1.4 GHz last year shows up as 50.6 mJy in the NVSS, but rather than variability, that might be due to extended emission that did not show up in the recent higher resolution observations.

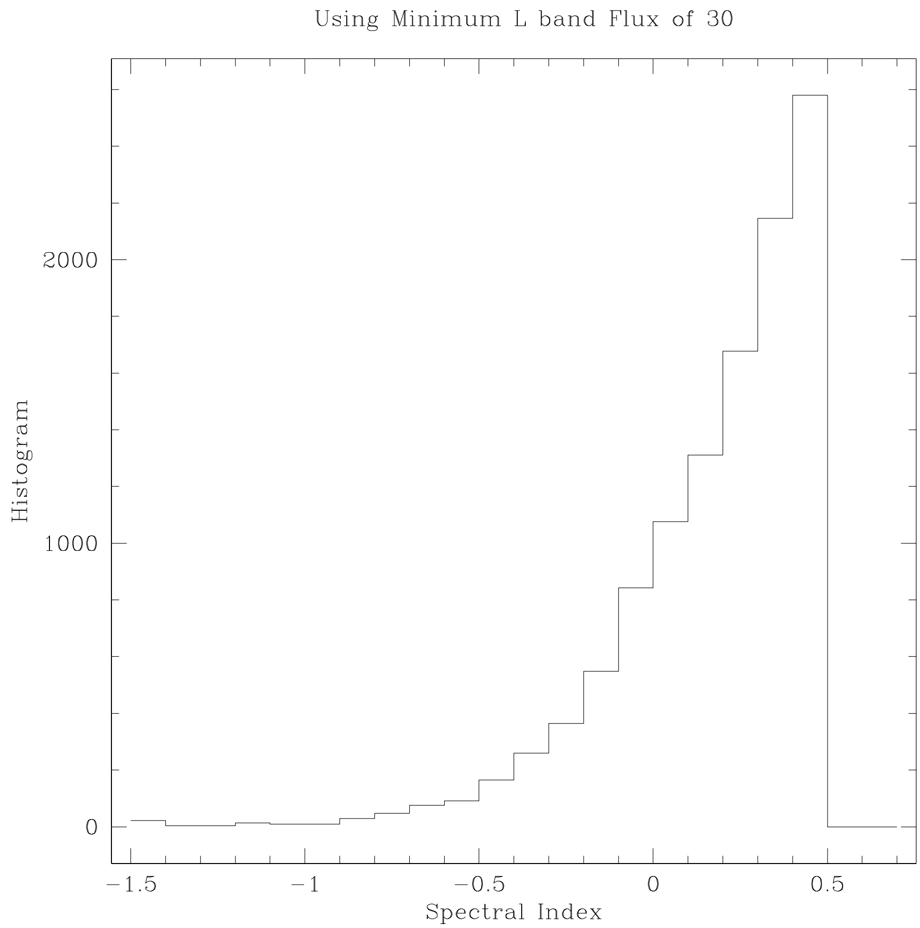

Figure 3: The distribution of spectral index α ($S(\nu) \propto \nu^{-\alpha}$) between 1.4 and 4.85 GHz for the members of our sample north of 10 degrees declination and brighter than 30 mJy. The reasonable shape of the distribution between -1.0 and 0.0, and the scarcity of sources with even more inverted spectral index, indicate that very few sources have been mismatched from the 1.4 GHz and 4.85 GHz.

Observations for GB6 took place in November 1986 and October 1987. Comparing catalogs made from the two epochs should permit us to select variable sources with 4.85 GHz flux greater than 25 mJy on at least one of those epochs, and some of these sources will appear to have steep spectrum between the NVSS and GB6 catalogs, and hence will not be in our sample unless we find them from their variability.

Gregory *et al.* (1996) have made catalogs from the maps of the GB6 1986 and 1987 observations, and a nice web tool exists at `http://pulsar.physics.ubc.ca/gregory` for comparing the two catalogs to find variable sources. We basically selected all sources in the GB6 sky area ($0^\circ < \delta < 75^\circ$) which were vaguely variable, which resulted in 18940 sources. We define the *variability significance ratio* as

$$\beta = |S_{86} - S_{87}|/\sqrt{\sigma_{86}^2 + \sigma_{87}^2}, \tag{1}$$

and selected out only those sources with a variability significance ratio of 2 or greater, reducing our list to 3918 variable sources. Many of these sources, perhaps half, will end up not being variable, but just having large noise excursions. On the other hand, if we took a proper 3 σ limit, there would be some variable steep spectrum sources that we would miss. We correlate this list of likely variable sources with the 1.4 GHz NVSS data to find the spectral index of these sources, and found 3931 sources were matched. How could we get more matches than we started with? It turns out that about 200 sources look to be classical doubles which were resolved in the VLA's NVSS catalog, but which showed up as a single source in the GB6 catalog. The doubles got matched twice. These are good candidate sources for high frequency work: sources dominated by extended emission, but with a variable core. Anyway, after removing the doubles from the list, we then remembered to eliminate sources north of 60 deg. We show a scatter plot of the spectral index verses the variability significance ratio of these sources in Figure 4, delineating between non-variable, variable flat spectrum, and variable steep spectrum. We looked to see how many of these variable sources were already in our compact flat spectrum sample, and removed those, leaving 1767 sources which were likely to be variable but had a steep spectrum. We propose observing this additional sample of 1767 likely variable steep spectrum sources in addition to the flat spectrum sample.

2.6 More Sources: Highly Inverted Sources

When selecting NVSS and GB6 sources for our sample, we selected only NVSS sources with a flux of 9 mJy or higher. As the GB6 catalog goes down only to 18 mJy, and the PMN catalog goes down only to 40 mJy, any matches with these weak NVSS sources will be steep spectrum. We got about 1600 matches between the true positions of the NVSS sources with $S_{1.4} > 9$ mJy and simulated GB6 and PMN catalogs with *random* positions on the sky – ie, we expect about 5% of the matches between the 1.4 GHz and 4.85 GHz catalogs will be chance superpositions. This is a very small contamination, but if we go lower in NVSS flux, we will have increasingly more false matches. We suspect that there will be some, but not many, highly inverted sources which have very weak 1.4 GHz fluxes, but are bright at millimeter wavelengths. The observations of Voss *el at.* (2004) points to their existence. Such sources could be very important for ALMA fast switching calibration, and would be interesting from a scientific point of view as well.

We can make another sample which is specifically designed to ferret out these highly inverted sources by selecting the NVSS sources with 2.2 mJy $\leq S_{1.4} < 9$ mJy (we've already processed

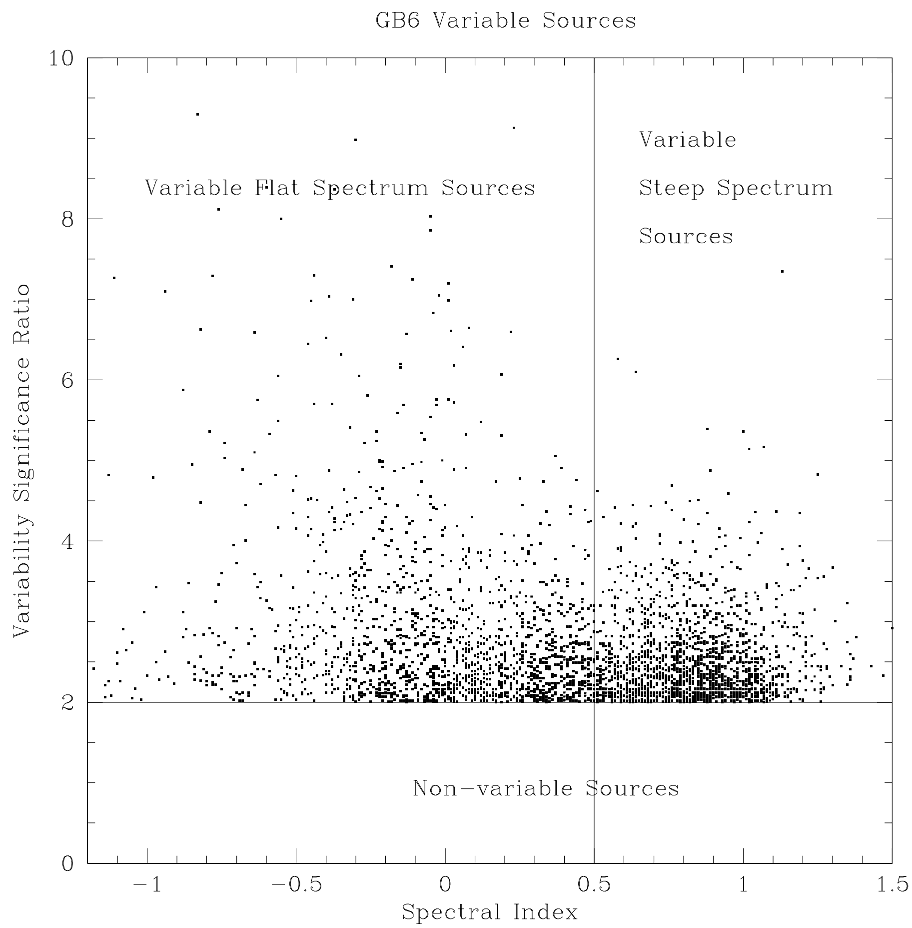

Figure 4: Scatter plot of the variability significance ratio as a function of spectral index. Variable sources should have prominent cores and are likely to show up at millimeter wavelengths. Most variable sources have spectral index $< +0.5$, but some variable sources have steeper spectral index, either because they are variable and look steep due to observations being made at different times, or because at low frequency they are dominated by extended steep spectrum emission. The variability significance ratio is another way of finding sources that might be millimeter wavelength calibrators.

the brighter sources) and finding those sources which had a 3 σ positional match (we backed off of 4 σ with the two 4.85 GHz catalogs. As the GB6 and PMN catalogs had flux limits of 18 and 40 mJy respectively, any source which is a match will have a highly inverted spectral index. We got about 5000 matches with apparent spectral index ranging from -0.5 all the way down to -3.0, but simulations with random positions for the 4.85 GHz catalogs indicate that about 2500 of these matches should be chance superpositions. Hence, we expect half of this sample of highly inverted sources to be complete garbage, and many of the valid matches will probably be non-detections at 86 GHz, but the sources from this sample which we *do* detect at 86 GHz will be among the most interesting of our observations.

3 The Observations

We would very much like to observe these sources with the ALMA Prototype Interferometer at the ATF. In addition to the technical and scientific benefits of this survey, these observations would also awaken the science operations, requiring a level of competence in the telescope operations that otherwise would not come for many more years. This is exactly the sort of cultural shift, away from WBS schedules and engineering requirements, which could serve to engender some excitement and momentum in the ALMA project, and pave the way for more interesting ad hoc science projects being done on the PI, and later, the early ALMA array.

3.1 Observing Frequencies

We'd like to understand as much as we can about these sources, and we can observe at two different frequencies in each band. In addition to having spectral information that would help us extrapolate these sources' fluxes to frequencies above 90 GHz, it will be useful to understand something about why some of these sources have inverted spectra and also to understand flaring. Since the flares become optically thin at the higher frequencies first, and then slowly spread to the lower frequencies, we can gain some useful information on flares and inverted spectrum sources by observing simultaneously at several different frequencies. We propose 86 GHz and 106 GHz in band 3 and 215 GHz and 263 GHz in band 6, as shown in Figure 5. Sources which do not give a significant detection (say < 20 mJy) at 86 GHz should not be observed at higher frequencies where the source flux will generally be lower and the noise will be higher.

3.2 Observe at a Single Parallactic Angle?

We will be observing our sources with a 1-baseline interferometer, so we will only get information on the position of the source in the coordinate parallel to the baseline projected on the sky. Normally, if we wanted to find out about this source, we would want a range of baseline orientations. However, the baseline of the Prototype Interferometer will be short enough that we really won't be getting information about the source positions any more accurately than the NVSS positions anyway, so we don't really gain positional information by doing multiple observations of a source at different parallactic angles.

Also, we don't expect these sources to have any extended structure visible to our baselines (except for a few HII regions which could contaminate our sample near the galactic plane), so we can just perform an observation at a single parallactic angle. (Multiple scans at different parallactic angle could help determine if a source such as a HII region were shaped

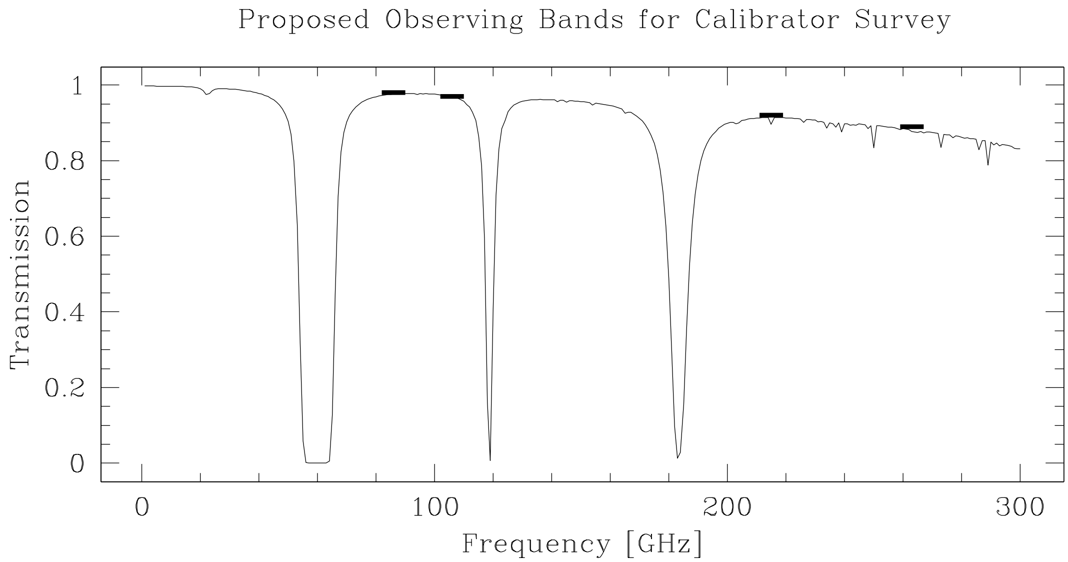

Figure 5: The four 8 GHz wide frequency bands which we propose using to investigate our sources.

asymmetrically.)

3.3 Sensitivity

Observing for 30 s at 90 GHz will give is an rms noise level of 3.5 mJy, which is very good and good enough, as the minimum flux level we are interested in is 25-50 mJy. At 250 GHz, we will have an rms noise level of about 10 mJy.

3.4 Calibration

Calibration will be a bit iffy. At the very least, we can use Neptune and Uranus as primary flux calibrators, but this will not be any more accurate than 5-10%. For our purposes, this level of accuracy is fine. We will also identify and monitor a set of bright non-volatile quasars to use as a secondary reference. With a 30 m baseline, we won't have to worry too much about phase calibration. If we detect a source, we may see the phase change a bit over 30 s due to the atmosphere, and we would remove most of the decorrelation by fitting a simple functional form to the phase and subtracting that, and then vector averaging the complex visibility to get an estimate of the source flux. The sensitivity of non-detections will be somewhat degraded by uncorrectable decorrelation when the phase stability is poor, so we will need to monitor the phase stability with the nearby radio seeing monitor so we can estimate the decorrelation. We will also need to perform pointing calibrations, focus calibrations, and baseline and delay calibrations. The transparency is pretty good at the frequencies of interest, so we won't need to worry too much about short time scale opacity fluctuations, but we will need to correct for the opacity. We will check the opacity with the antennas working as single dishes every hour or so.

3.5 Automated Scheduling and Observing

With over 35000 sources, we will rely upon a high degree of automazation. As the ATF control system uses a PYTHON shell, we anticipate it will be fairly simple to build a high-level tool which uses the standard software observing components to make some calibration observations and then efficiently go through our list, finding a set of yet-to-be observed nearby sources which are most likely to be detected, observe them, and mark them as having been observed so they don't get re-observed.

Data reduction will likely be performed in glish/AIPS++.

3.6 What We Expect to See

The source count estimates of Holdaway, Owen, and Rupen (1994), and the high frequency extrapolation of Holdaway and D'Addario (2003), indicate that at 90 GHz there are about 20,000 sources above 20 mJy (6 σ) over the sky, or about 15,000 sources in the $-40 < \delta < +60$ range of this experiment. However, we won't see them all, as we'll miss the sources that are 5 mJy at 1.4 GHz but have a spectral index of -0.5. Also, at 250 GHz, there should be about 10,000 sources above 30 mJy (3 σ) over the whole sky, or 7,500 for the sky area of our sample. There seems to be a better chance that we will find most of these, as the sources which are weak at 1.4 GHz with inverted spectral index which come in under our radar, will be falling down again, many falling below our detection limit, so we hope that most sources above our detection limit will be sources which were above our selection threshold at 1.4 and 4.85 GHz.

Another way of estimating how many sources from our sample we expect to see is to perform a calculation based on the counts an spectral indices of the sources in our sample. It is expected that the spectral index will steepen somewhat between 4.85 GHz and 90 GHz. How much steepening is reasonable? Well, there are about 200 sources in the sky brighter than 1 Jy at 90 GHz (or 150 in our band of the sky with $-40° < \delta < +60°$), and NONE of these should sneak under the radar. That is, they are buried in our sample, either as 10 Jy sources at 1.4 GHz with a falling spectral index of 0.5, or a few as 0.5 Jy sources at 1.4 GHz with inverted spectral index of -0.2, but we should see them all. Now, if we take all of our sample, throw out any sources with apparent spectral index between 1.4 and 4.85 GHz more inverted than -1.0 (these are mostly among the weakest sources and among southern sources relying upon the PMN for 4.85 GHz matches), we can achieve the magic 150 1 Jy sources at 90 GHz by using the matched 1.4 GHz to 4.85 GHz spectral indices steepened by 0.356. Assuming the same median spectral steepening applies for weaker sources, and looking at the the weaker sources extrapolated to high frequency, we expect we should detect about 10,000 sources above 20 mJy at 90 GHz (this is not including our highly inverted sources or our steep spectrum variable sources). Therefore, we expect to detect about one third of the sources at 90 GHz at a level bright enough to proceed with the higher frequency observations. And it seems that our sample will result in finding about 2/3 of the expected sources at 90 GHz.

3.7 Total Time of Observations

Phase I: Preparation First, lets assume we will spend 10-20 days of telescope time debugging and verifying software and the observing techniques. In reality, this time is totally unknown. This is largely work that will need to be done on the Prototype Interferometer anyway, even if this observing program is not accepted.

Phase II: Detection Now, lets assume that 50% of the time is used on calibration, slewing, and setup overhead. Our initial pass over the sky will observe each source at 86 GHz only, 30 s integration on each source, or 60 s including overhead. This will take a total of about 24 days. Adding 25% additional time for weather and equipment problems brings us to 30 days.
Phase III: Spectral Study We assume that we detect 1/3 of these sources at the 20 mJy level, or higher, at 86 GHz. We then proceed by observing at all four frequencies, for a total of four minutes per source, including overhead. Repeating 86 GHz will also give us an idea of short term source variability. This will take an additional 32 days, or 40 days including 25% additional time for weather and equipment.
Phase IV: Followup There may well be additional work in this project, but we are not yet in a position to speculate on it.

In total, we expect to need the Prototype Interferometer for about 80-90 days during good weather conditions to complete the observations of this sample.

The Prototype Interferometer is slated for first fringes in November 2004, but nobody believes this. The systems group will be testing the integration of various components, and the antenna vendors are interested in some time on the antennas as well. It is hoped that even though there is modest demand on the Prototype Interferometer that it could still be used for astronomical observations at night, which is the best time for high frequency observations anyway. If we observe mainly at night, then we'd want to observe in two opposite seasons. At this point, it seems reasonable to ask for 85 half days in the spring and 85 half days in the fall of 2005. We believe we have ample man-power, between MH, CC, RL, and a few post docs.

References

Butler, Bryan J., "Distance to Possible Calibration Sources as a Function of Frequency for ALMA", ALMA Memo 478, 2003.

Condon, J.J., et al, (NVSS reference), AJ, 115, p 1693, 1998.

Gregory, P.C., W.K. Scott, K. Douglas, and J.J. Condon, (GB6 reference), ApJS, 103, 427, 1996.

Griffith M.R., Wright A.E., "The Parkes-MIT-NRAO (PMN) surveys. Part I: The 4850MHz Surveys and data reduction", AJ, 105, 1666, 1993.

Griffith M.R., Wright A.E., Burke B.F., Ekers R.D., "The Parkes-MIT-NRAO (PMN) surveys. Part III. Source catalog for the Tropical Survey", ApJS, 90, 179, 1994.

Holdaway, M.A., Owen, and Rupen, "Source Counts at 90 GHz", ALMA Memo 123, 1994.

Holdaway, M.A., C. Carilli, and F. Bertoldi, "ALMA Calibration Source Counts at 250 GHz", LAMA Memo 805, 2004.

Holdaway, M.A., and D'Addario, L., "Simulations of Atmospheric Phase Correction Combined With Instrumental Phase Calibration Using Fast Switching", LAMA Memo 803, 2004.

Voss, Hauke, Frank Bertoldi. Chris Carilli, Frazer N. Owen, Dieter Lutz, and Mark Holdaway, "Non-thermal sources in the MAMBO surveys", *to be submitted to* **A&A** *, 2004.*