Flux Calibration of the MMA

M.A. Holdaway
National Radio Astronomy Observatory
949 N. Cherry Ave.
Tucson, AZ 85721-0655
mholdawa@nrao.edu

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Abstract

I propose that the MMA achieve accurate flux scale calibration by observing extended sources of constant or predictable flux, such as planets or compact HII regions, in total power. The total power flux scale set by this primary flux standard can be used to measure the total power flux of a bright, time variable quasar. Since the quasar is compact to all baselines and frequencies of the MMA, interferometric observations of this bright quasar, whose flux is known through the total power observations, will set the flux scale for interferometric observations.

1 Introduction

Absolute determination of flux is possible for a very well understood instrument. Modern interferometers usually perform relative flux measurements, bootstrapping to the known or assumed fluxes of other bright objects. At centimeter wavelengths, kilometer baseline interferometers such as the VLA can observe sources unresolved to their baselines, but which are still extended over a few hundreds of milliarcseconds, and hence do not vary much on timescales of years. The fluxes of these "primary flux calibrators" such as 3C286, 3C48, and 3C293, are referenced to the Baars absolute scale as derived from Cas A in 1973.

At millimeter wavelengths, any steep spectrum extended emission from quasars such as 3C286 has become too faint to be usable. Quasars which are bright at millimeter wavelengths are dominated by the submilliarcsecond highly variable cores. Millimeter single dishes are able to set their flux scales relative to planets, whose millimeter wavelength fluxes are known to a few percent. Short baseline millimeter wavelength interferometers can also observe planets, but since the measured baselines often correspond to angular size scales smaller than the planet's disk, an Airy pattern is fit to the data to derive the amplitude scaling. Flux calibration of long baseline millimeter interferometers is difficult, since quasars are variable and planets are too big and hence are resolved out, especially in the submillimeter. At long baselines, millimeter interferometers must try to track the fluctuations of the variable quasars. The resulting accuracy of the millimeter interferometer fluxes has been estimated at between 10 and 20%.

2 Proposed Flux Calibration of the MMA

The MMA antennas will have both total power and interferometric capabilities. We assume for now that the flux scales for the total power and interferometric capabilities will not be identical, though they will certainly be closely related. Accurate flux calibration can be achieved by:

- Observing a planet or bright compact HII region (primary flux calibrator) with some or all antennas in total power mode to set the total power flux scale.
- Observing a bright quasar (secondary flux calibrator) with some or all antennas in total power mode to determine the quasars flux.
- Observing the same bright quasar, now of known flux, with all antennas in interferometric mode to set the interferometric flux scale.
- These observations must be corrected for elevation-dependent antenna and atmospheric effects such as the gain curves and time dependent atmospheric attenuation.
- The flux scale is now determined for interferometric and single dish observations of continuum or spectral line observations of the target source.

The lowest signal-to-noise link of the three step flux bootstrap will be the total power measurements of the bright quasar. With its new gain stabilized receivers, the BIMA array will be able to make total power continuum measurements. Fast scanning over the continuum sources will partially remove the atmosphere. Jack Welch comments that BIMA intends to use a flux calibration like this in the near future.

At millimeter wavelengths, this procedure should work very well. Planets will be a few hundred Jy and the brightest quasars such as 3C273 or 3C279 will be a few tens of Jy. The total power system noise per antenna will be a few tens of mJy in one minute, and the interferometric noise for the array will be under a mJy in one minute. Hence, the three step flux bootstrap will not be thermal noise limited. At this time, the uncertainties in the planet fluxes are probably the largest source of error in the flux scale chain. The uncertainty in planet fluxes will likely decrease by the time the MMA is operating, hopefully permitting flux measurements accurate to a few percent.

At submillimeter wavelengths, the planets are increasing with the Plank law, but the flat spectrum quasars are decreasing approximately like $\nu^{-0.5}$, though the brightest quasars are still typically several Jy. The atmospheric attenuation increases drastically, and the system noise will also increase to the order of 100 mJy per total power antenna per minute. Using all antennas to perform the total power observations, the quasar flux could be measured to better than 1% relative accuracy.

In the submillimeter, the primary beam will be comparable to the size of the planets, and the primary beam will probably be less well determined. Pointing errors will affect the measured flux of the planet. The data will likely need to be corrected for a substantial gain curve. And finally, decorrelation due to short time scale random phase errors will also affect the flux scale. These additional factors do not present any insurmountable problems, but will modestly degrade the accuracy of flux measurements at the MMA's highest frequencies.