Various Calibration Methods: What we already know and what we need to derive

Ron Maddalena
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There are four methods of calibration sutable for the ATA: Observations of the Moon, Tippings, observations of a flux calibrator,and Hot Cold tests.

No one method provides all the necessary information. We must use two or more to get accurate values for the system and antenna temperatures.

- Hot-Cold Tests
  - T_{SYS} (Elevation,ν)
  - $T_{Receiver}$ (ν)
  - T_{CMB}
  - T_{Hot}
  - $T_{MilkyWay}(\vartheta,\phi,\nu)$
  - $T_{spillover}$ (Elevation,ν)
  - $T_{ATM}(1 - e^{-\tau \cdot A})$
    - τ(ν,UTC) – Atmospheric Opacity
    - A(Elevation,UTC) - Air Mass
    - T_{ATM} (ν,UTC) – Representative Temperature of Atmosphere

- Tippings
  - T_{SYS} (Elevation,ν)
  - $T_{Receiver}$ (ν)
  - T_{CMB}
  - $T_{MilkyWay}(\vartheta,\phi,\nu)$
  - $T_{spillover}$ (Elevation,ν)
  - $T_{ATM}(1 - e^{-\tau \cdot A})$

Lists all the quantities involved in Hot-Cols tests and Tippings.

Quantities in black are those we want to derive

Green show values that we can obtain from the literature.

Blue are quantities that come from non-sky measurements or derived from models of the telescope.

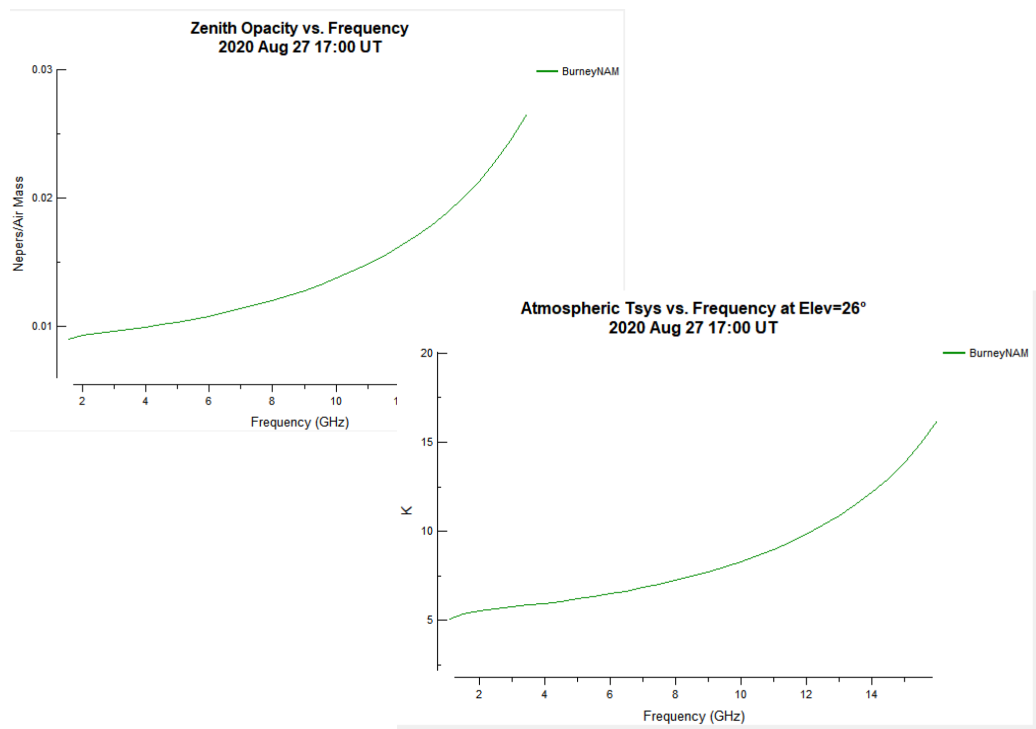
Red are quantities we first need to determine to get to the quantities in black. These quantities are obtained using a different calibration method.

Note that Tippings are the only way to derive T_spillover, which are needed for all other methods.

- Moon
  - T_{SYS} (Elevation,ν)
  - $T_{Receiver}$ (ν)
  - T_{CMB}
  - $T_{MilkyWay}(\vartheta,\phi,\nu)$
  - $T_{spillover}$ (Elevation,ν)
  - $e^{-\tau \cdot A}$
  - $T_{ATM}(1 - e^{-\tau \cdot A})$
  - T_{Moon}(Phase,ν)
  - $L(R_{Moon}, \nu) \cdot \eta_A (\nu)$
    - Beam Shape(ν,ϕ,ϑ)
    - η_A (ν) - Aperture Efficiency
    - Te(ν) – Feed Illumination Taper
- Flux Calibrator
  - T_{SYS} (Elevation,ν)
  - $T_{Receiver}$ (ν)
  - T_{CMB}
  - $T_{MilkyWay}(\vartheta,\phi,\nu)$
  - $T_{spillover}$ (Elevation,ν)
  - $e^{-\tau \cdot A}$
  - $T_{ATM}(1 - e^{-\tau \cdot A})$
  - η_A (ν) - Aperture Efficiency
  - S (ν) – Source Flux Density

Same but for astronomical observations of objects – Moon and flux calibrators

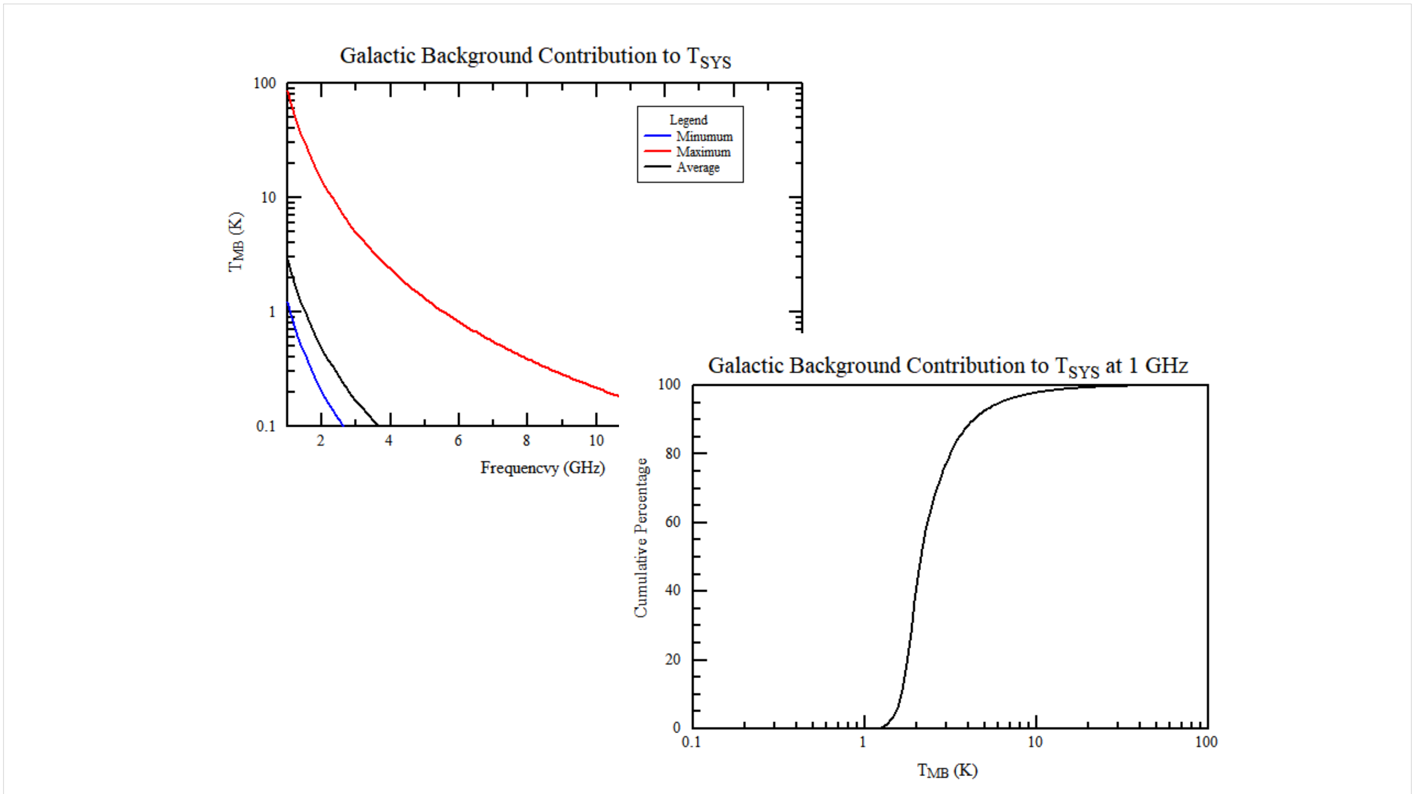
Since the Moon is not a point source at the high frequencies of the ATA, must correct for the beam convolution (L)



To derive receiver temperatures from system temperatures, we need to know what the atmosphere is doing at the time of the on-sky observations.

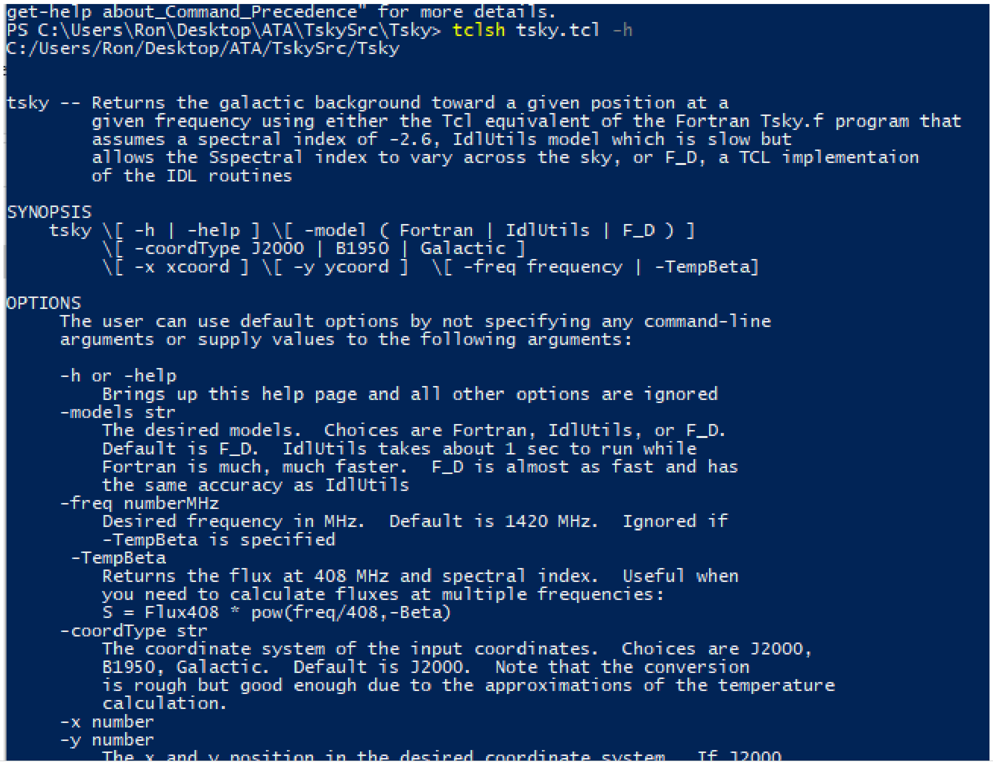
Significant at the higher frequencies and when the weather is bad.

Can be determined under all but the most severe weather conditions with sufficient accuracy of better than a few K from weather products from the National Weather Service.



The Milky Way's contribution varies with on-sky observing location and can be significant (in comparison to the desired accuracy) at the low end of the ATA frequency range. Can be determined from existing maps of the Milky Way intensity.

Examples: Up to 100K at 1 GHz, on the average over the sky of 2 K at 1 GHz. Insignificant above about 4 GHz, regardless of sky position.



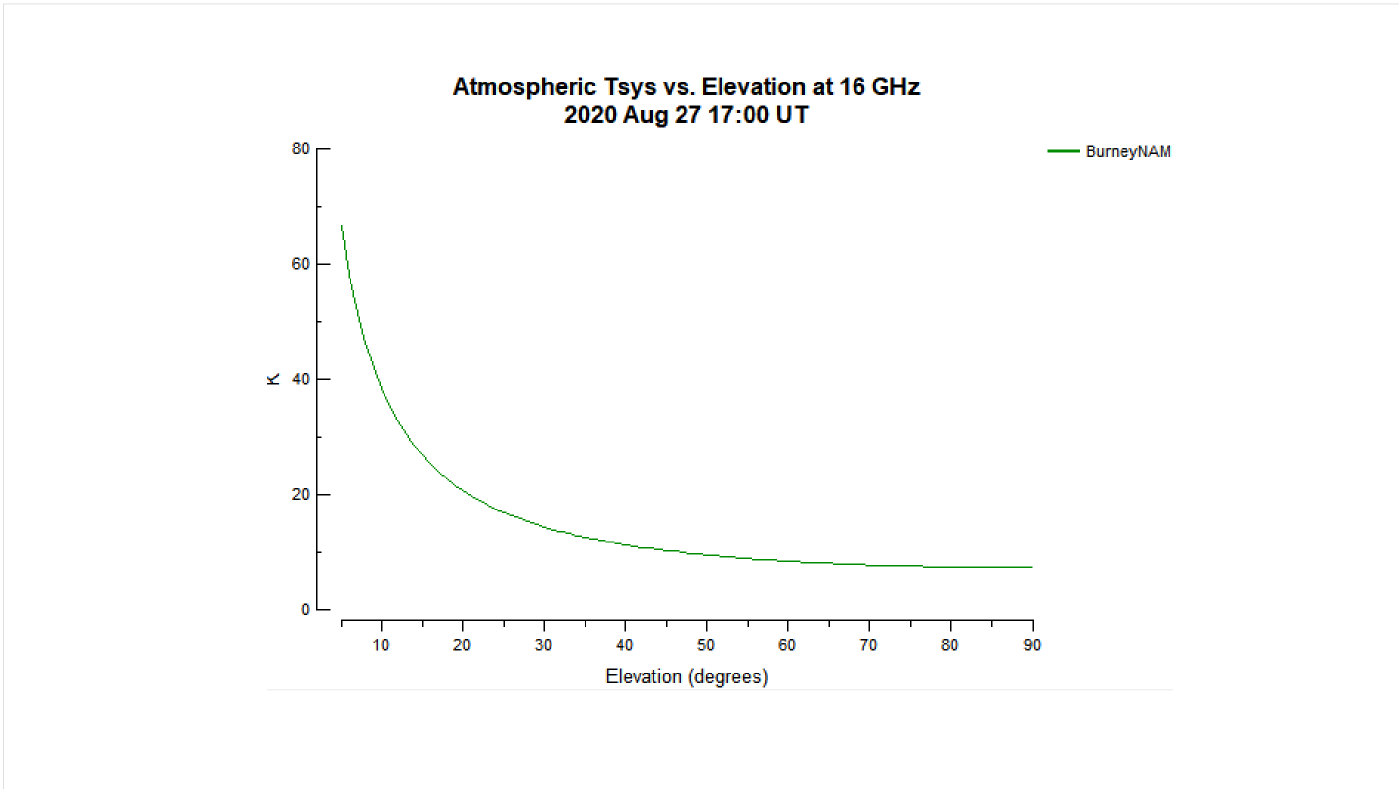
```
get-help about_Command_Precedence" for more details.
PS C:\Users\Ron\Desktop\ATA\TskySrc\Tsky> tclsh tsky.tcl -h
C:/Users/Ron/Desktop/ATA/TskySrc/Tsky

tsky -- Returns the galactic background toward a given position at a
        given frequency using either the Tcl equivalent of the Fortran Tsky.f program that
        assumes a spectral index of -2.6, IdlUtils model which is slow but
        allows the Sspectral index to vary across the sky, or F_D, a TCL implementaion
        of the IDL routines

SYNOPSIS
    tsky \[ -h | -help ] \[ -model ( Fortran | IdlUtils | F_D ) ]
         \[ -coordType J2000 | B1950 | Galactic ]
         \[ -x xcoord ] \[ -y ycoord ]  \[ -freq frequency | -TempBeta]

OPTIONS
     The user can use default options by not specifying any command-line
     arguments or supply values to the following arguments:

     -h or -help
         Brings up this help page and all other options are ignored
     -models str
         The desired models.  Choices are Fortran, IdlUtils, or F_D.
         Default is F_D.  IdlUtils takes about 1 sec to run while
         Fortran is much, much faster.  F_D is almost as fast and has
         the same accuracy as IdlUtils
     -freq numberMHz
         Desired frequency in MHz.  Default is 1420 MHz.  Ignored if
         -TempBeta is specified
      -TempBeta
         Returns the flux at 408 MHz and spectral index.  Useful when
         you need to calculate fluxes at multiple frequencies:
         S = Flux408 * pow(freq/408,-Beta)
     -coordType str
         The coordinate system of the input coordinates.  Choices are J2000,
         B1950, Galactic.  Default is J2000.  Note that the conversion
         is rough but good enough due to the approximations of the temperature
         calculation.
     -x number
     -y number
         The x and y position in the desired coordinate system.  If J2000
```

Here’s a routine available already on an ATA computer for determining the Galaxy’s contribution.

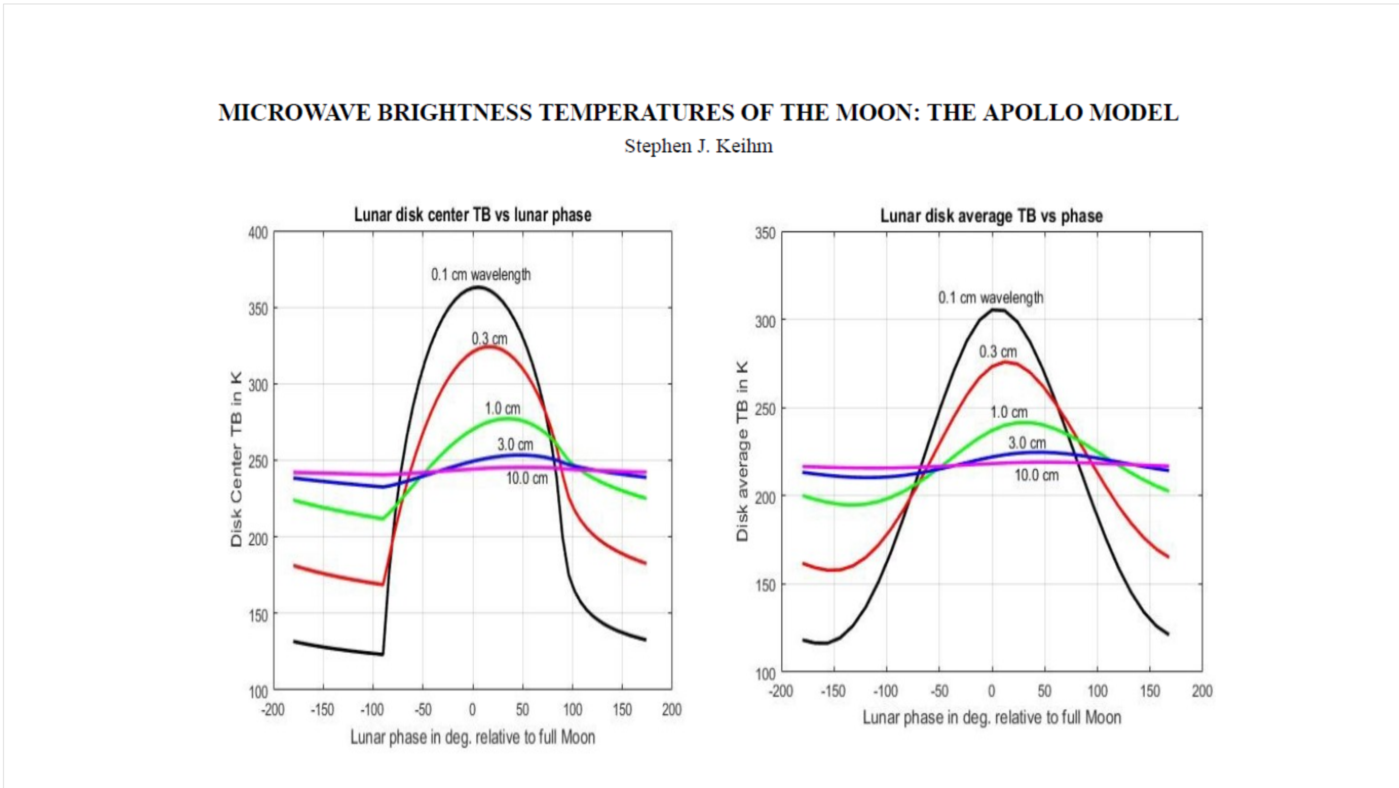
Uses FITS files of the position-dependent flux brightness temperatures and spectral indices from the Haslam et al all-sky survey.

```
op\ATA\TskySrc\Tsky> tclsh tsky.tcl -TempBeta -x 12:34:33 -y 54:12:13
ATA/TskySrc/Tsky
dd): 128.32767 62.74737  F_DTemp(K) at 408 MHz & Beta: 18.46 2.7765
op\ATA\TskySrc\Tsky>
```

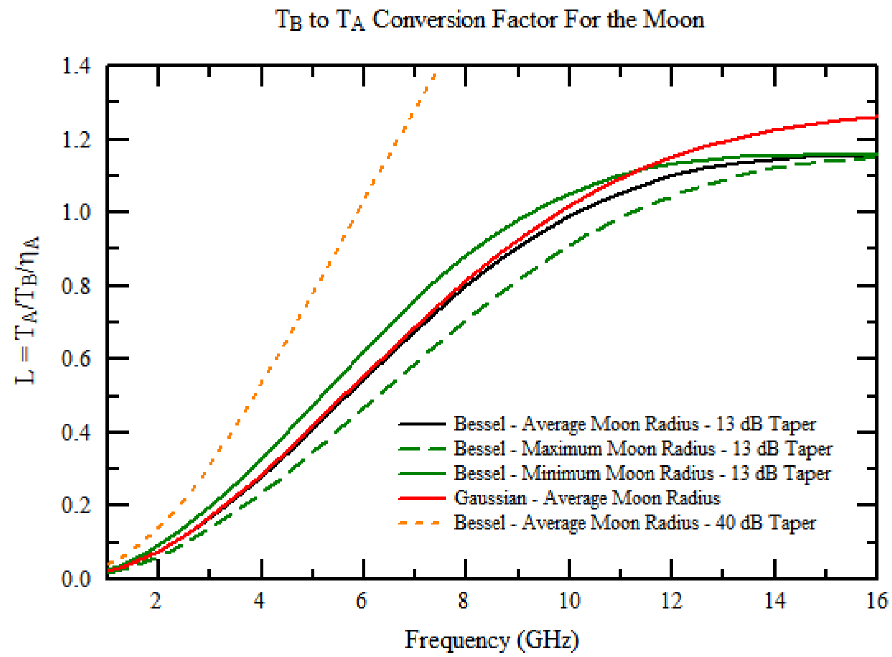
Example output



Atmosphere contribution is also elevation-dependent.



The Moon’s Brightness temperature is dependent upon the observing frequency as well as the Moon’s phase. Taking an average of 210 K over all conditions will give an accuracy of 5%. Do we need better than that?



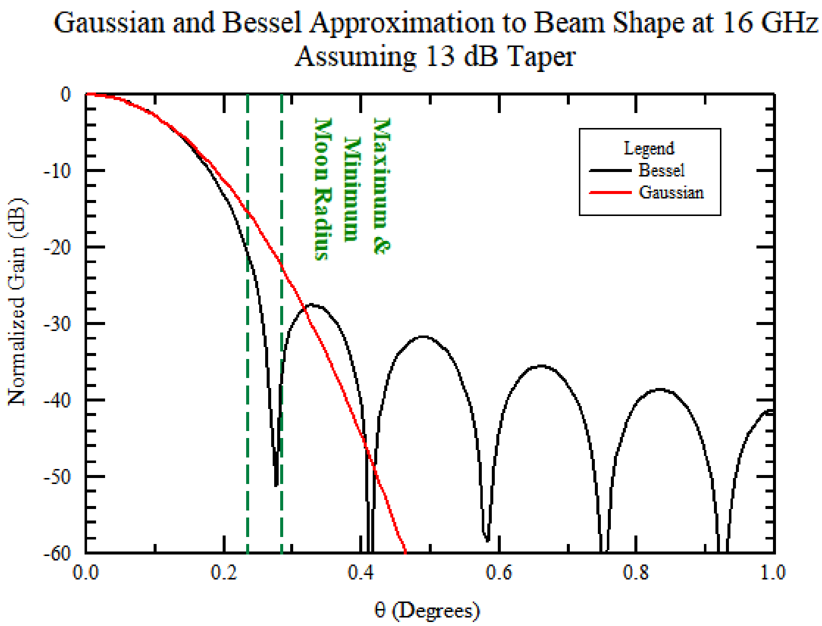
The Antenna temperature of the Moon depends upon the Moon's brightness temperature, convolution of the ATA's beam (frequency dependent) with the solid angle subtended by the Moon (i.e., distance dependent).

L = ratio of T_A to (T_B * aperture efficiency)

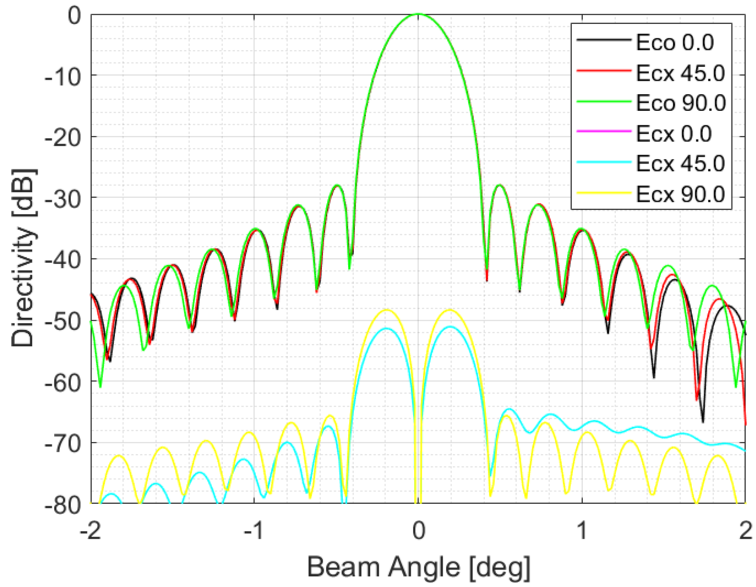
The Moon's orbit is elliptical enough that it's diameter changes by 5% over it's orbit, which gives a 10% change in T_B over the course of a month.

Without this simple-to-derive frequency correction, we'd introduce a 10% error in System Temperature at 6-11 GHz

Note that we need to know aperture efficiency (frequency and elevation dependencies?) with sufficient accuracy.



Shoes how the Moon's diameter changes wrt the ATA's beam at 16 GHz. Need to use the Bessel approximation of the beam shape (not difficult to do), not the simpler Gaussian approximation. Already something that we know how to do



Eco 0.0
Ecx 45.0
Eco 90.0
Ecx 0.0
Ecx 45.0
Ecx 90.0
Directivity [dB]
Beam Angle [deg]
0
-10
-20
-30
-40
-50
-60
-70
-80
-2
-1
0
1
2

- Moon
  - T_{SYS} (Elevation,ν)
  - $T_{Receiver}$ (ν)
  - T_{CMB}
  - $T_{MilkyWay}(\vartheta,\phi,\nu)$
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Recap:

Tippings to get T_spillover

But, still need a way to derive aperture efficiency as it's the only thing we can't measure independently of other parameters. Maybe by comparing Trcvr from Hot-Cold or Spillover tests (independent of efficiency) to that derived from Moon or flux calibrators (dependent on efficiency)?