Accurately Measuring the Spillover of a Radio Telescope

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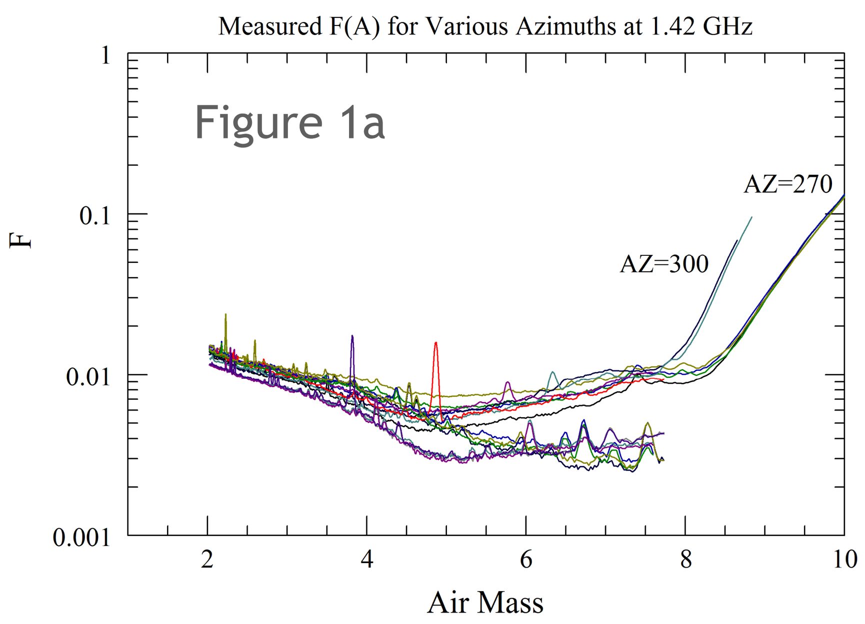
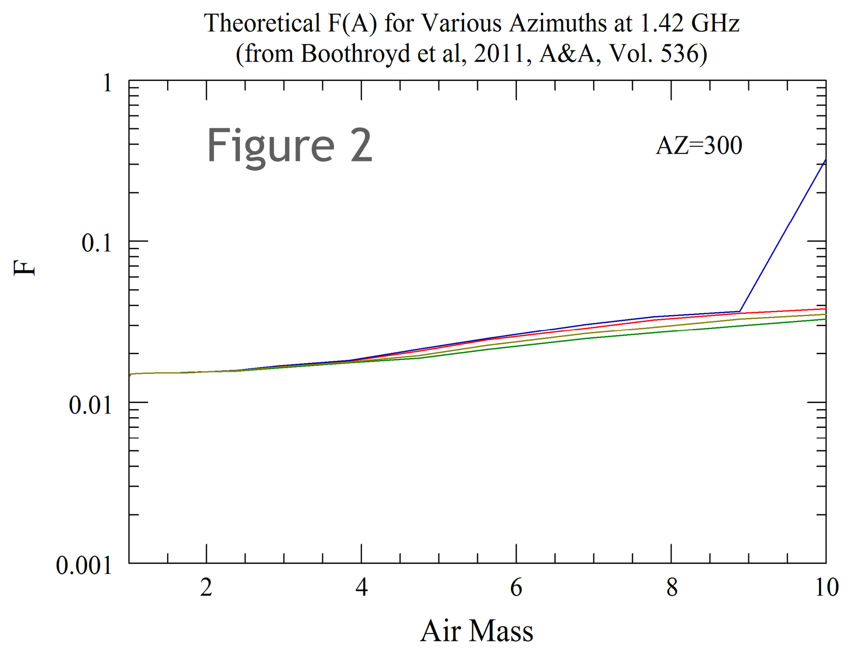
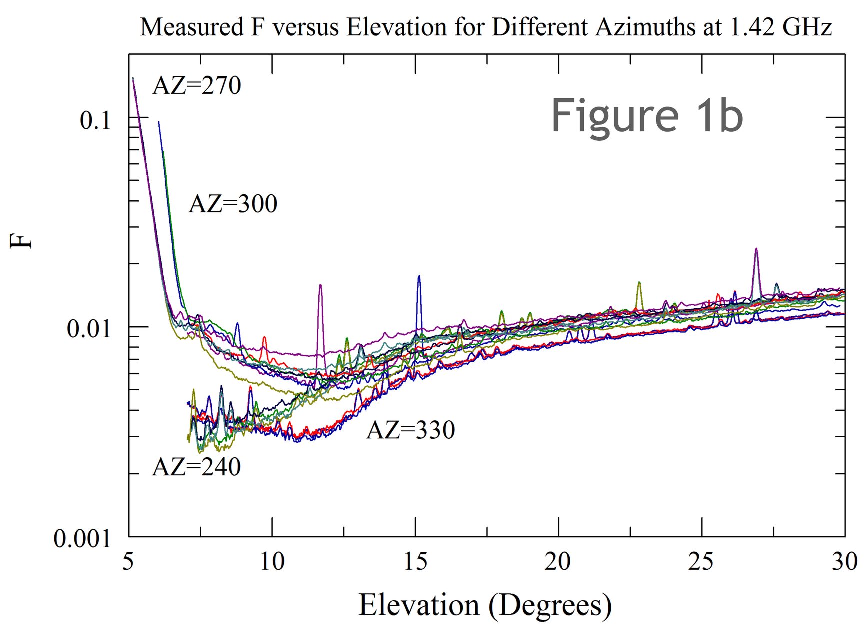
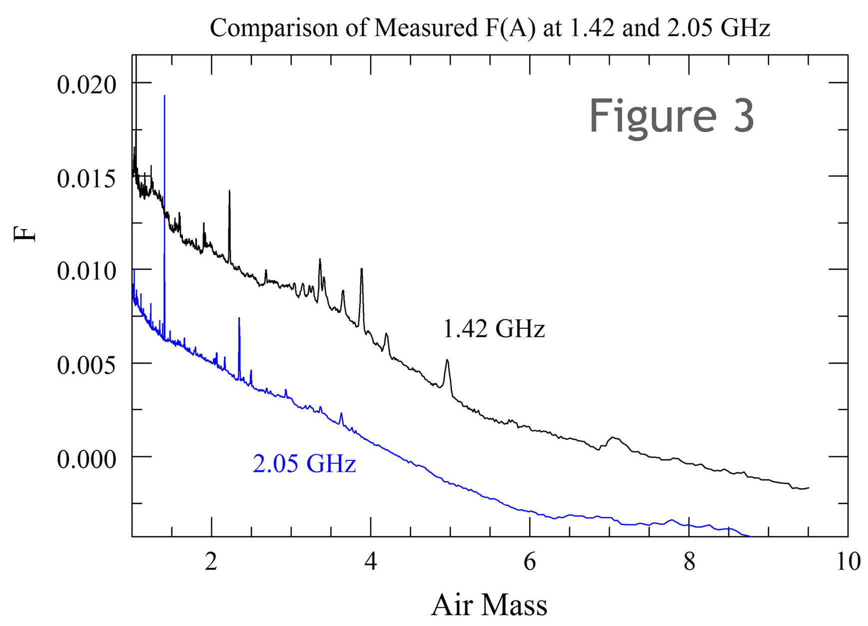
Spillover, the fraction of power received by a radio telescope that originates from the ground, contributes to the system temperature (T_{Sys}) and, thus, degrades slightly the performance of the telescope. Some methods of calibrating data from radio telescopes require accurate knowledge of the spillover contribution. Since the amount of power received from the ground changes with elevation, so does the contribution to T_{Sys}. In most cases, there is no way to distinguish empirically between the elevation-dependent contribution to T_{Sys} from spillover and from the Earth's atmosphere. Thus, determining spillover is usually done from theoretical models of the telescope's optics. By using recently-constructed, accurate models of the contribution to T_{Sys} from the Earth's atmosphere, we have derived a method whereby one can determine to an accuracy of less than a percent the elevation dependence of the contribution of spillover to T_{Sys}. The measured spillover can then be compared to the theoretical models. We have applied this technique to the Green Bank Telescope, a challenging telescope since it has an extremely low spillover contribution, and have found that the measured and theoretical spillovers are in disagreement.









Observing Technique:

- On-the-fly, observations at 1.42 and 2.05 GHz, which are frequencies:
  - with well-established and small atmospheric affects that do not change significantly with the weather,
  - with known, small contributions from Galactic continuum emission,
  - that are higher than most of the ionospheric affects,
  - Have well-established calibration,
  - Already have theoretical models of spillover for comparison.
- Moved through the full range of elevations at various and repeated azimuths, including those where the topography is above the 5˚ elevation limit of the telescope. Avoided azimuths close to the plane of the Galaxy.

Modeling of Spillover:

- From the measured voltages, derive gain and system temperature:

$$g = T_{Diode} / \left(V_{DiodeOn} - V_{DiodeOff}\right)$$

$$T_{Sys}(A) = g \cdot V(A)$$

- From the standard model of how T_{Sys} changes with air mass, derive how fractional spillover, F, changes with air mass.

$$T_{Sys}(A) = T_{Rcvr} + \left(1 - F(A)\right) \cdot \left[\left(T_{CMB} + T_{MW}\right) \cdot e^{-\tau \cdot A} + T_{Atm} \cdot \left(1 - e^{-\tau \cdot A}\right)\right] + F(A) \cdot T_{Ground}$$

$$\boxed{F(A) = \frac{\left(T_{CMB} + T_{MW} - T_{Atm}\right) \cdot e^{-\tau \cdot A} + T_{Atm} + T_{Rcvr} - T_{Sys}(A)}{\left(T_{CMB} + T_{MW} - T_{Atm}\right) \cdot e^{-\tau \cdot A} + T_{Atm} - T_{Ground}}}$$

Definitions:

A = Air mass ≈ 1/sin(elevation)
F(A) = Fractional spillover as a function of air mass
g = gain (K/Volt)
T_{Atm} = Representative temperature of the atmospheric emission
T_{CMB} = Cosmic Microwave Background = 2.7 K
T_{Diode} = Intensity of calibration diode (K)
T_{Ground} = Approximate black-body temperature of the local ground.
T_{MW}(A)= Contribution of the Milky Way continuum to T_{Sys}
T_{Rcvr} = Receiver temperature (K)
T_{Sys}(A) = Measured System Temperature as a function of air mass
τ = zenith atmospheric opacity
V(A) = Measured voltage as a function of air mass

Discussion:

- Figure. 1: Multiple measurements of F(A). At low A (high elevation) there is a high degree of repeatability and agreement. Deviations at high A (low elevations) are due to azimuthal changes in the local topography. Small-scale structure are from astronomical sources. Except for the x-axis, Figs. 1a and 1b are identical.

- Figure. 2: The best theoretical model of F(A) for the same azimuths as Fig. 1. ***In comparison to Fig 1, at low A the slope is reversed while at high A the contribution from the local topography differs significantly.***

- Figure 3: Due to differences in feed design, the expected F(A) at 2.05 and 1.42 GHz were expected to be noticeably different. Yet, the measured F(A) are negligibly different. (The offset between curves should be ignored as it is from small, expected uncertainties in T_{Rcvr}.)

Possible Sources of Errors:

$$\Delta F \approx \frac{T_{Sys}}{T_{Ground} T_{Diode}} \Delta T_{Diode}$$

$$\Delta F \approx \frac{-1}{T_{Ground}} \Delta T_{Rcvr}$$

$$\Delta F \approx \frac{-A}{T_{Ground}} \Delta\left(T_{Atm} \cdot \tau\right)$$

$$\Delta F \approx \frac{T_{Sys} - T_{Rcvr} - T_{CMB} - T_{MW} - T_{Atm} \cdot \tau \cdot A}{T_{Ground}^2} \Delta T_{Ground}$$

ΔT_{Diode} : Discrepancy requires a 30% error in T_{Diode} while the actual value is known to 2%, as confirmed by measurements against a flux calibrator.

ΔT_{Rcvr} : An error in T_{Rcvr} produces an elevation-independent offset in values, not a change in shape or slope.

ΔT_{Ground} : Discrepancy requires ~300 K error in assumed value for T_{Ground}, which is not possible.

ΔT_{Atm} : Discrepancy requires T_{Atm}~200K, which is not physically possible in the atmospheric layers that produce opacities at 1420 MHz.

Δτ : Discrepancy requires τ ~ 0.006, which disagrees with the well-established value of ~0.01±0.001 measured by multiple authors using various techniques and telescopes (e.g., Williams, 1973, A&AS, 8, 505; van Zee, Maddalena, Haynes, Hogg, & Roberts, 1997, AJ 113, 1638).

None of the expected sources of error in the terms that determine F can account for the difference in slope between the theoretical and measured spillover.

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