Skynet – BICEP2 January 2012 Interference Testing Results

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1. Summary:

Interference tests were conducted at South Pole on 13 Jan and 19 Jan 2012 by the Skynet installation team (including Kevin Culin and Joey Walker) and the BICEP2 telescope team (including John Kovac, Justus Brevik, Kiwon Yoon, Jon Kaufman) to determine levels of interference produced by Skynet transmissions in the direction of the telescope. Clear signals were seen in all configurations, ranging from 5×10^{-3} K to 1.5 K in normal observing mode and up to 150 K in beam mapping mode. The normal-mode interference is far larger (up to 5-7 orders of magnitude) than the $\sim 3 \times 10^{-8}$ K CMB B-mode polarization signals which are the science goal of these telescopes. These interference tests help to quantify mitigation factors that can be expected from changing the pointing, location, or power level of the groundstation.

2. Background and Skynet setup:

The Skynet groundstation as configured during the January 2012 interference testing is illustrated in Fig 1. It is a 2.4m offset parabolic dish antenna, situated inside the 9m radome near the RF building (108A on map C-101). An AZ/EL antenna pattern at 8.15 GHz for this dish from the manufacturer (Teletronics) was circulated; the AZ pattern is reproduced as Fig 2. No additional reflective or absorbing microwave shielding is installed on this antenna or its radome enclosure.

For the January interference tests, the groundstation was fed with 40W transmit power (at 0dB atten setting), 8 GHz, with a 1 Hz square wave 100% modulation depth amplitude modulation (i.e. the transmit power was effectively switched on or off every 0.5 second). Attenuation settings from 0 to -16 dB were used. The Skynet antenna was steered over a range AZ=145..157.5, and EL=-0.4..+8.5.

3. BICEP2 setup:

BICEP2 is a telescope which uses 512 superconducting TES bolometers at a 0.25K focal plane to make maps of the CMB polarization that approach sensitivities of 10's of nano-Kelvin. Its focal plane and SQUID readout are enclosed in a continuous Faraday shield, continuous with the conductive ground plane of the focal plane, with RF filters on all electrical feedthroughs. Cryogenic optics are surrounded by microwave/RF absorbing material at 4K. An ambient-temperature co-moving forebaffle shrouds the aperture of the telescope to further limit sidelobe response to in-band and RF radiation. The entire telescope is surrounded by a reflective groundshield that further limits sidelobe response to terrestrial sources. The design of the receiver and shielding scheme is nearly identical to the five SPUD receivers, seen in Fig. 3. SPT and its receiver have similar technology and shielding elements.

For the January interference tests, BICEP2 was operated in two configurations: (1) Normal observing mode, in which all shielding was normally configured, the detectors were biased and operated as for CMB observations, and elevations and AZ scans typical of CMB observations were used, and (2) Beam mapping mode, in which a flat mirror was installed (see Fig 3) to redirect the beam of the telescope over the groundshield toward the horizon, and special biases for high background loading were used.

4. Interference strength vs. BICEP shielding and pointing

For initial tests, Skynet was pointed directly at the direction of BICEP2, transmitting at its usual 40W power level. The 1 Hz modulation of the Skynet signal was clearly visible in most detectors, allowing determination of the peak pickup at Skynet antenna coordinates of AZ=147.5, EL=-0.4. Even in BICEP2's normal CMB observing mode, with Skynet at this pointing the signal is strong enough to be obvious in most detectors in the timestream data without further analysis, see Fig 4. Data were taken with the BICEP2 telescope both stationary and scanning as for normal CMB observations. Peak amplitude of Skynet pickup for all 512 BICEP2 detectors, taken with normal observing mode during CMB scan observations, ranged from 5×10^{-3} K to 1.5 K (see Fig 5). Telescope orientation, including boresight orientation, may strongly affect the amplitude of individual channel pickup within this range.

With BICEP2 in "Beam Mapping Configuration," i.e. with the reflective mirror on BICEP2 directing the beam over the groundshield and further enhancing pickup amplitude, the peak amplitude increased to over 100 K for some detectors, indicating the mirror increases pickup of 8 GHz radiation 100x higher than normal CMB observing mode. The mirror reveals that the spatial response amplitude of each detector vs. BICEP2 pointing (AZ and EL, shown in Fig 6, with variations in DK orientation not shown) is complex. The enhanced coupling also allows us to probe the Skynet antenna beam pattern down to low levels that would otherwise require long integration times.

5. Interference vs Skynet power and pointing

BICEP2 pickup was measured while varying Skynet transmit power level. Plotted in Fig 7 (left) on a log-log scale, this shows a slope closer to ½ than 1; in other words, the BICEP2 pickup amplitude appears to scale with the square-root of the Skynet power level, or directly proportional to transmitted field strength. The Skynet beam profiles taken at two Skynet transmit power levels, illustrated in Fig 7 (right), confirm this scaling.

Plotting the BICEP2 pickup vs. Skynet antenna pointing gives a measurement of the Skynet beam which can be compared directly to the square root of the Teletronics beam power pattern, see Fig 8. BICEP2 interference levels roughly follow the prediction given by the Teletronics data for the field strength vs. Skynet AZ. Extrapolating to larger angles using Fig 2, the field pattern of the Skynet antenna can be expected to be reduced by 10^3 (square root of -60 dB) at a Skynet AZ pointing that is at least 30 degrees away from BICEP2.

The scaling with field strength implies that changing Skynet transmit power from 40W to 10W, or doubling the distance from Skynet to BICEP2 and other Dark Sector telescopes each would only reduce BICEP2 or SPUD pickup by only a factor of 2.

The 10^3 factor reduction to be gained by siting Skynet so it points at least 30 degrees away from the Dark Sector could reduce CMB telescope pickup that is 100's of mK down to 100's of uK. That is still 3-4 orders of magnitude above the ~30 nK target CMB B-mode signals. Additional mitigation is necessary, and some amount can be expected from CMB telescope observing strategies that employ scan differencing and averaging effects which reduce pickup in final maps. Shielding at the source by blocking Skynet antenna sidelobes, e.g. by installing microwave absorber on interior of radomes in the direction of the dark sector, may also be considered.

Figure 1: The 2.4m Skynet antenna (left) inside the 9m radome at the Pole RF facility, January 2012

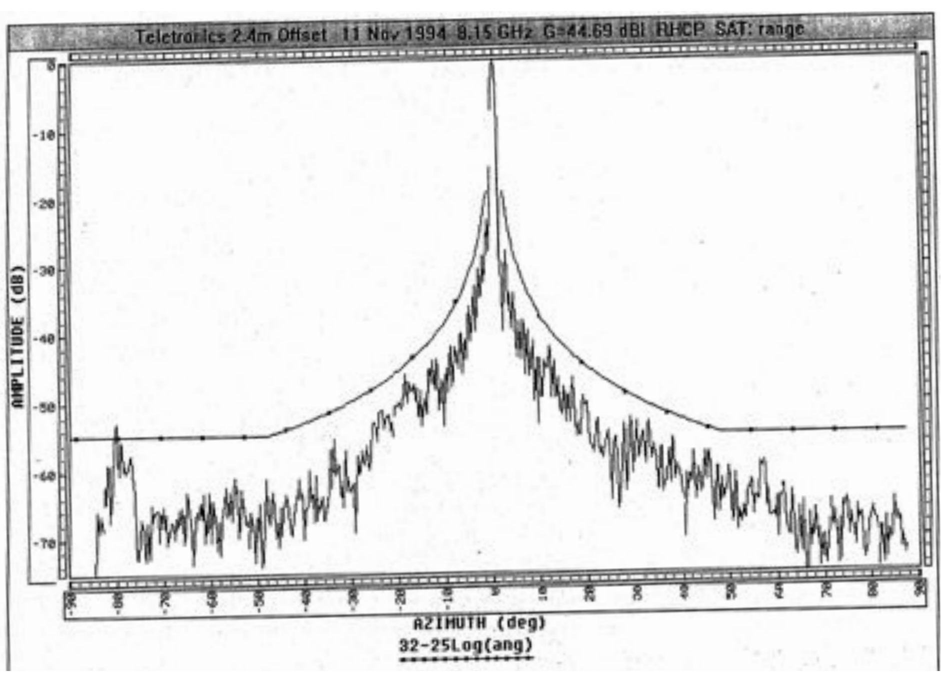

Figure 2: The Teletronics reported beam pattern of the 2.4m Skynet antenna vs. Azimuth.

Figure 3: The BICEP2 focal plane (top left) consists of 512 superconducting TES bolometers at 0.25K and SQUID readout. To minimize RF pickup, a conductive ground plane is continuous with a complete 4K Faraday shield (top center), shown with access ports open. Cryogenic optics (top right) are also surrounded by microwave/RF absorbing material at 4K. An ambient-temperature co-moving forebaffle (bottom left) shrouds the aperture of the telescope to further limit sidelobe response to in-band and RF radiation, while the entire telescope is surrounded by a reflective groundshield that further limits sidelobe response to terrestrial sources. BICEP2 is shown in “beam mapping configuration” with the flat mirror that redirects microwave (and RF) radiation over the groundshield; in “normal observing mode” the mirror and legs are removed. The Keck Array receivers and shielding scheme (bottom right) are nearly identical. The 9m radome and RF building are just visible over the groundshield on the horizon.

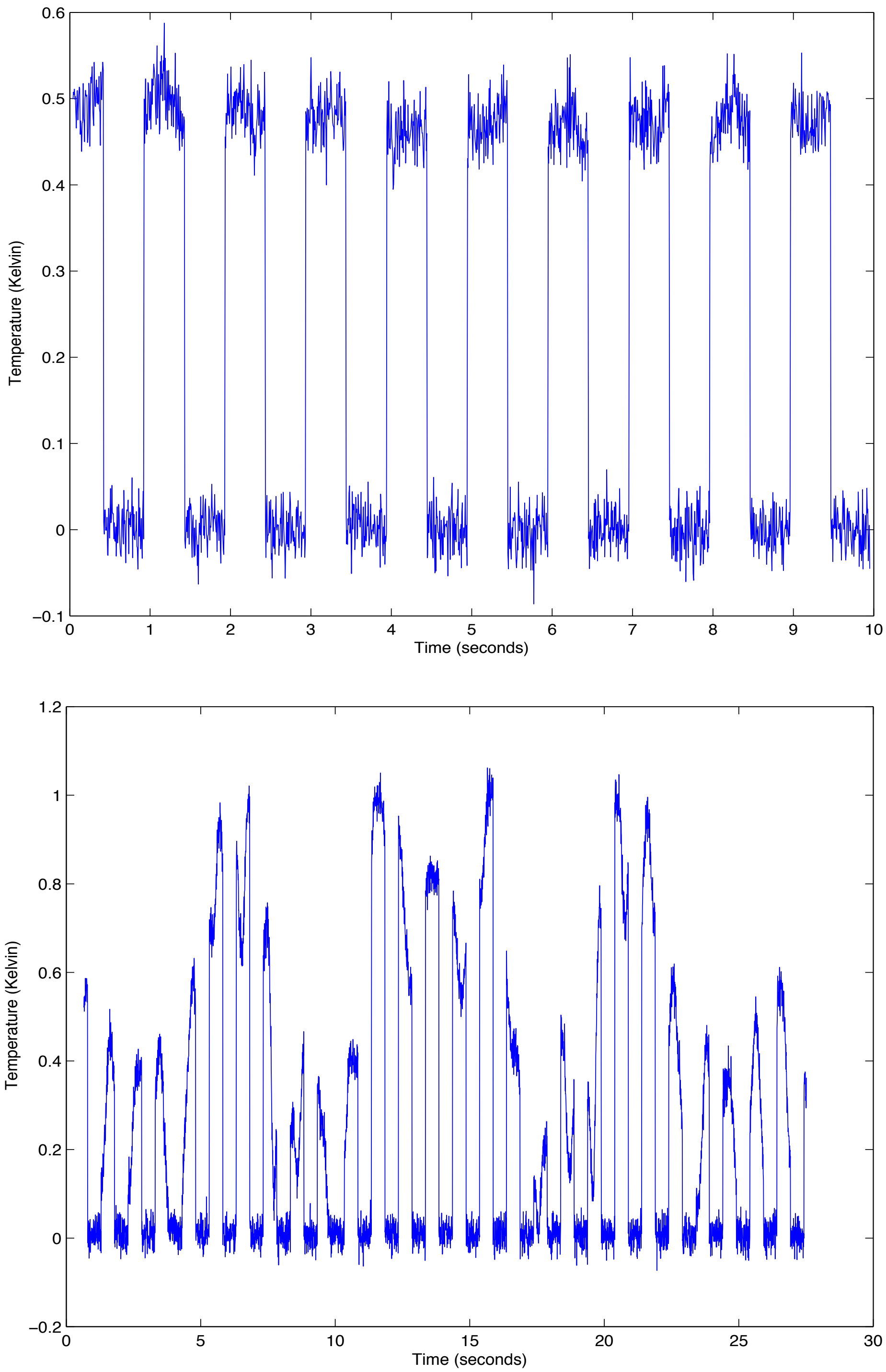

Figure 4: Timestreams of BICEP2 detectors in normal observing mode. Skynet is pointed directly at the AZ of BICEP2, AZ=-147.5, and is transmitting at 40W power level. Even in BICEP2's normal CMB observing mode, with Skynet at this pointing the signal is strong enough to be obvious in most detectors in the timestream data without further analysis, 0.5 K in the top panel (telescope stationary) and ranging from 0.1 to 1 K in the bottom panel (telescope scanning for CMB observations). CMB B-mode polarization signals are as low as 3×10^{-8} K.

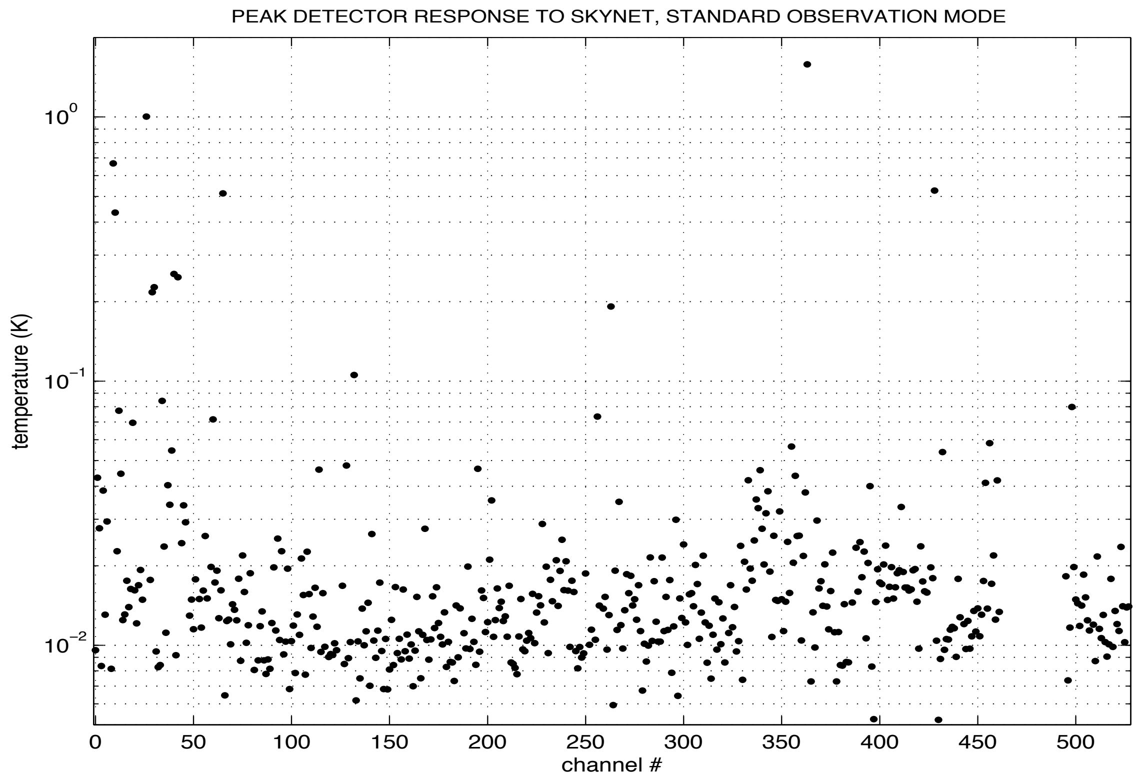

Figure 5: Peak amplitude of Skynet pickup (1 Hz modulation, see Fig 4) for all 512 BICEP2 detectors, taken with normal observing mode during CMB scan observations, ranging from 5×10^{-3} K to 1.5 K. Telescope orientation may strongly affect the amplitude of individual channel pickup within this range.

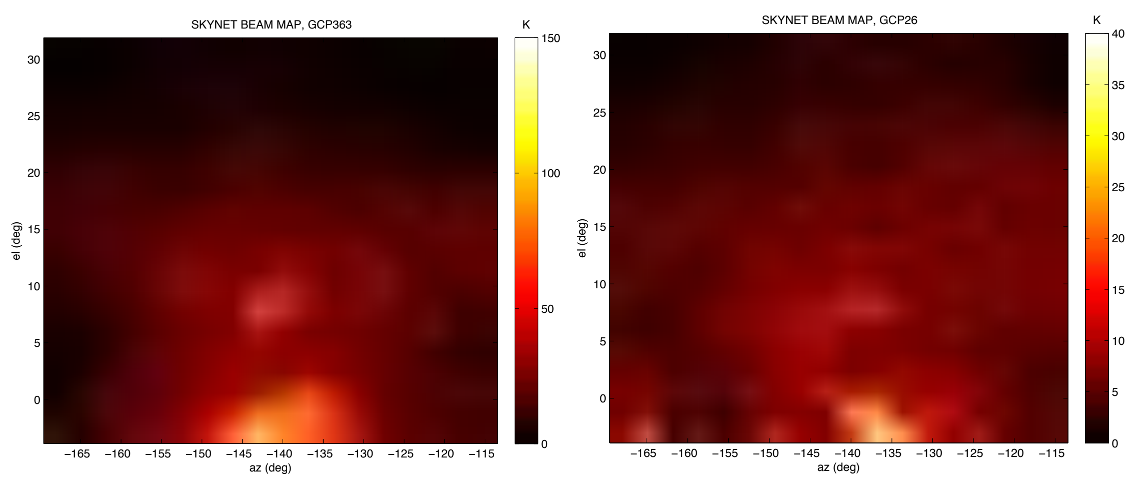

Figure 6: BICEP2 response to Skynet in "Beam Mapping Configuration," i.e. with the reflective mirror on BICEP2 directing the beam over the groundshield and further enhancing pickup amplitude. Peak amplitude for these detectors in this mode are 140 K and 37 K, indicating the mirror increases pickup of 8 GHz radiation 100x higher than normal CMB observing mode. The mirror reveals that the spatial response amplitude of each detector vs. BICEP2 AZ and EL is complex. The enhanced coupling also allows us to probe the Skynet antenna beam pattern (Fig 7) down to low levels that would otherwise require long integration times.

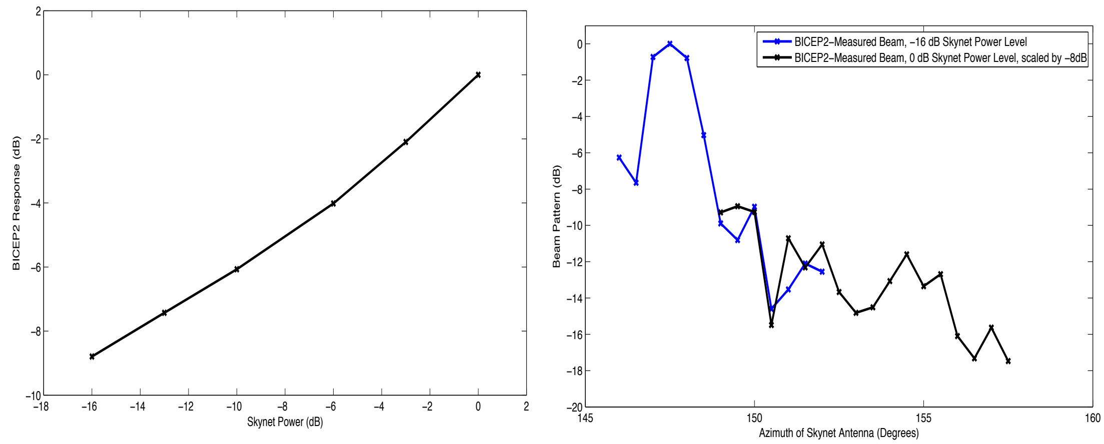

Figure 7: BICEP2 pickup vs. Skynet transmit power level (left), on a log-log scale shows a slope closer to ½ than 1; in other words, the BICEP2 amplitude appears to scale with the square-root of the Skynet power level, or directly proportional to field strength. The Skynet beam profiles (right) taken at two Skynet transmit power levels, 0 and -16 dB, also show this: scaling the higher power curve down by -8 dB (not -16) gives a good match.

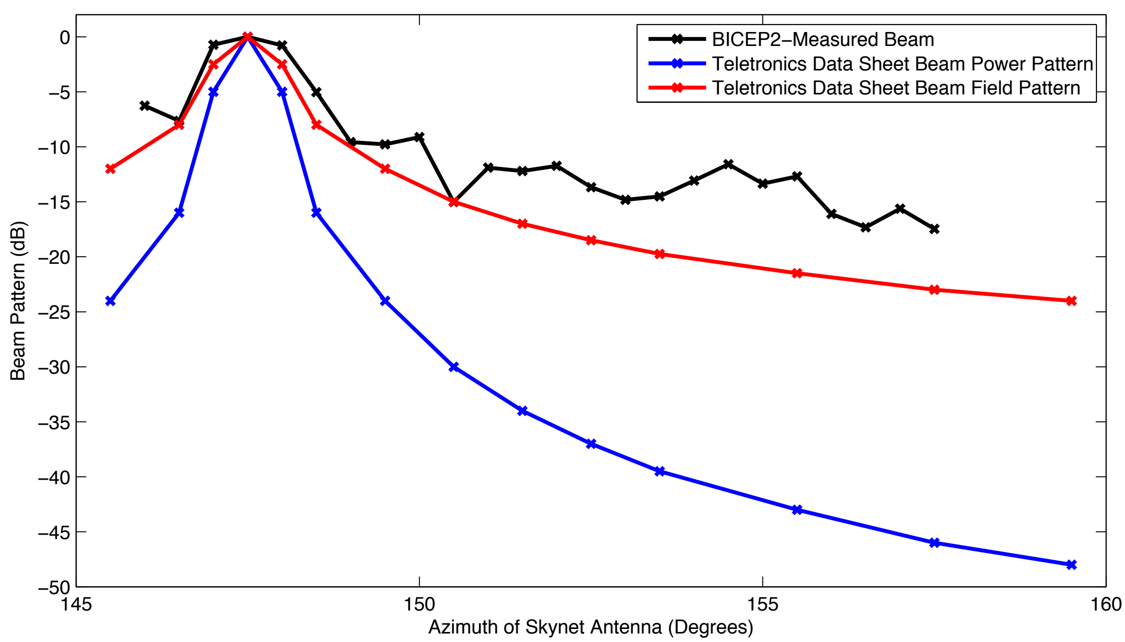

Figure 8: BICEP2 pickup vs. Skynet antenna pointing. The BICEP2 measured beam (black) combines data from Fig 7b. The Teletronics beam pattern (blue) comes from Fig 2. The red curve is the square root of the blue curve, showing that BICEP2 roughly responds as expected for the beam field pattern. Fig 2 indicates that the field pattern of the Skynet antenna is expected to be reduced by 10^3 (square root of -60 dB) going from the peak to a Skynet AZ that is at least 30 degrees away from BICEP2. This would reduce pickup that is 100's of mK to 100's of uK, still 3-4 orders of magnitude above CMB B-mode signals. Additional mitigation factors due to scan differencing and averaging effects may also reduce pickup in final maps. Shielding at the source by blocking sidelobes in the direction of the dark sector using reflectors or microwave absorber may also be considered.