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The Moon as Possible Calibration Reference for Microwave Radiometers

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Instruments on satellites for Earth observation on polar orbits usually employ a two-point calibration technique, in which deep space and an on-board calibration target provide two reference flux levels. As the direction of the deep space view is in general close to the celestial equator, the Moon moves sometimes through the field of view and introduces an unwelcome additional signal. One can take advantage of this intrusion, however, by using the Moon as a third flux standard, and this has actually been done for checking the lifetime stability of sensors operating at visible wavelengths. We discuss the advantages and problems of extending this concept to microwaves, concentrating on the frequency of appearances of the Moon in the deep space view, the factors limiting the accuracy of both measurements and models of the Moon's brightness, as well as benefits from complementing the naturally occurring appearances of the Moon with dedicated spacecraft maneuvers. Such pre-planned rotations of the instrument would allow to observe the Moon at a well-defined phase angle and to put it at the exact center of the field of view. This way they would eliminate the need for a model of the Moon's brightness temperature when checking instrumental stability. Finally we investigate the question, whether foreground emission from objects other than the Moon can contaminate the measurements of the Cosmic Microwave Background, which provides the low reference flux in the deep space view. We show that even the brightest discreet sources do not increase significantly the signal from a single scan.

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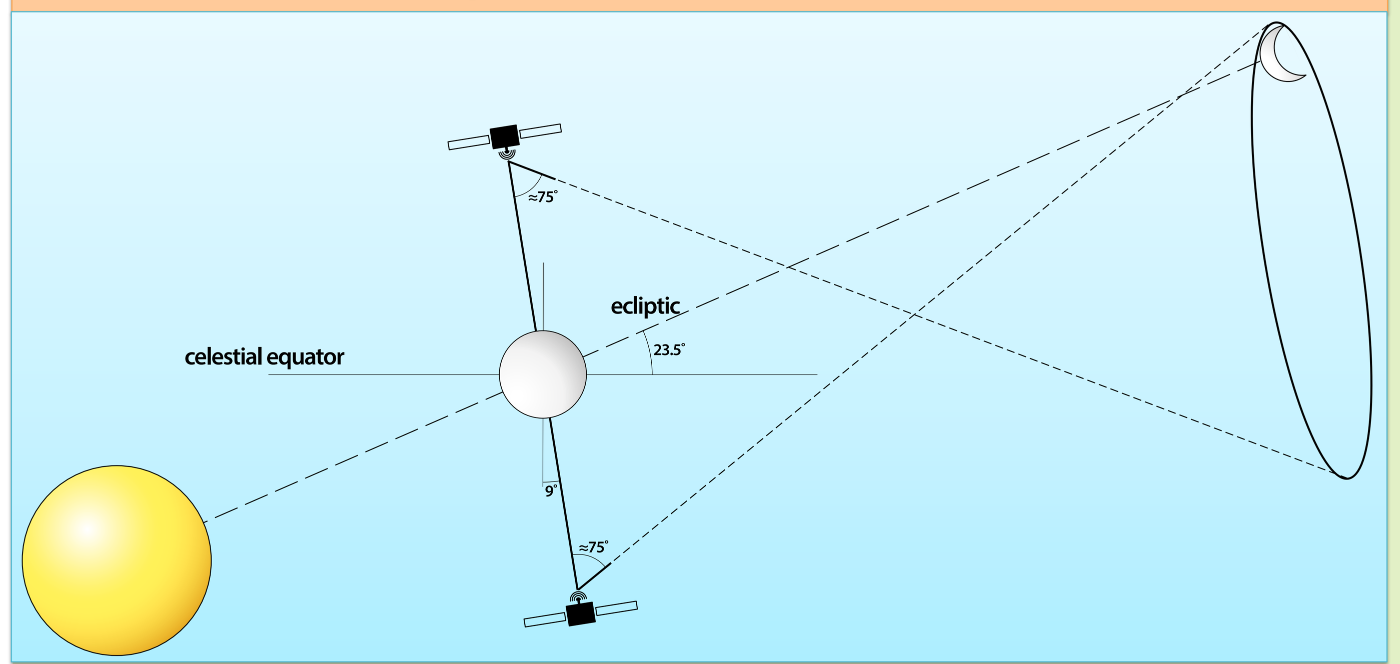
Summary: Instruments on satellites for Earth observation on polar orbits usually employ a two-point calibration technique, in which deep space and an on-board calibration target provide two reference flux levels. As the direction of the deep space view is close to the celestial equator, the Moon moves sometimes through the field of view and introduces an unwelcome additional signal. One can take advantage of this intrusion, however, by using the Moon as a third flux standard for stability analysis of microwave sensors. This method is relevant for FIDUCEO, a project producing fundamental climate data records with traceable estimates of stability and thereby enhanced credibility.

Position of the Moon When Seen by the DSV

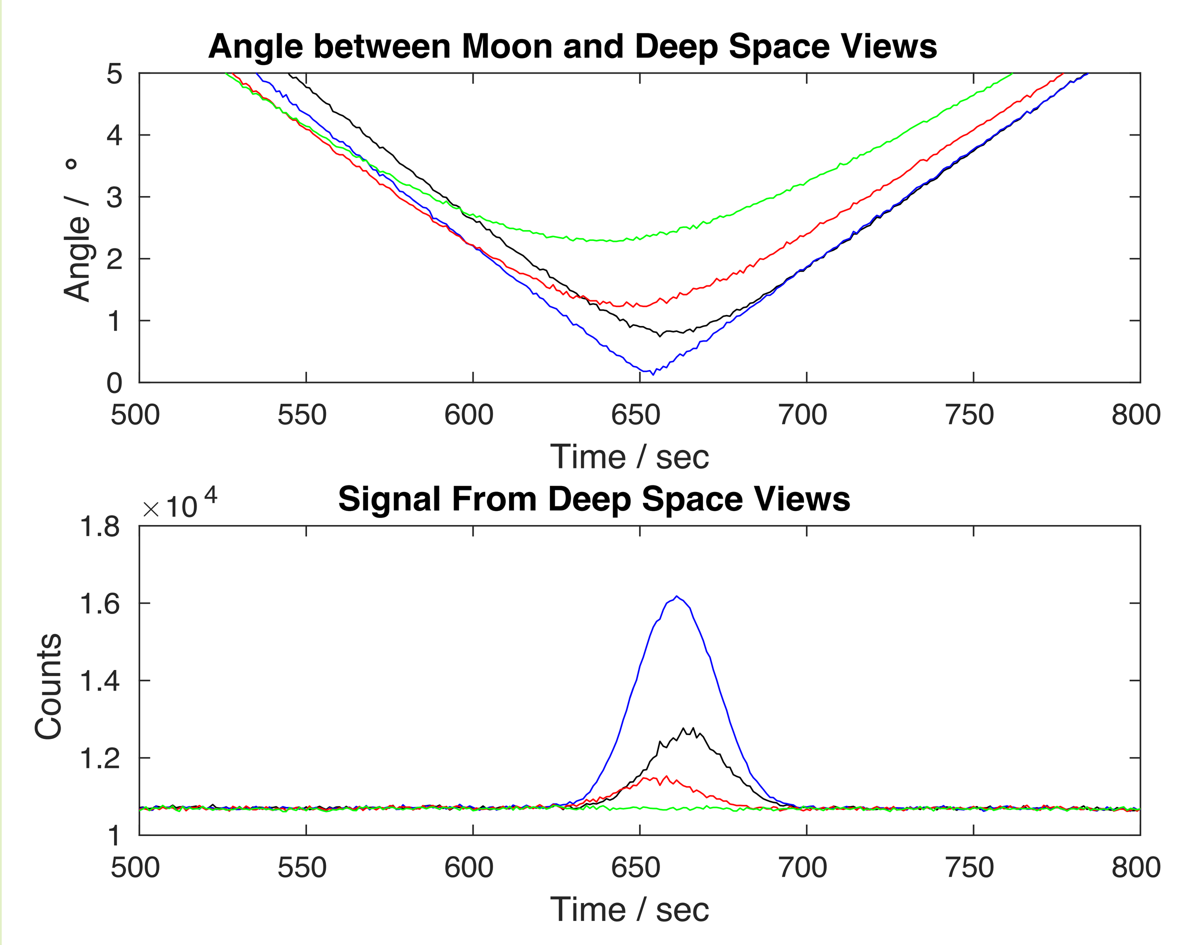
A cross-scanning instrument takes data along a great circle perpendicular to its flight direction. The DSV position is then usually within 20° of the orbital axis of the spacecraft. It describes a circle in the sky, whose center is 9° away from the celestial equator. The Moon crosses this circle several times per year and is seen during several consecutive orbits.

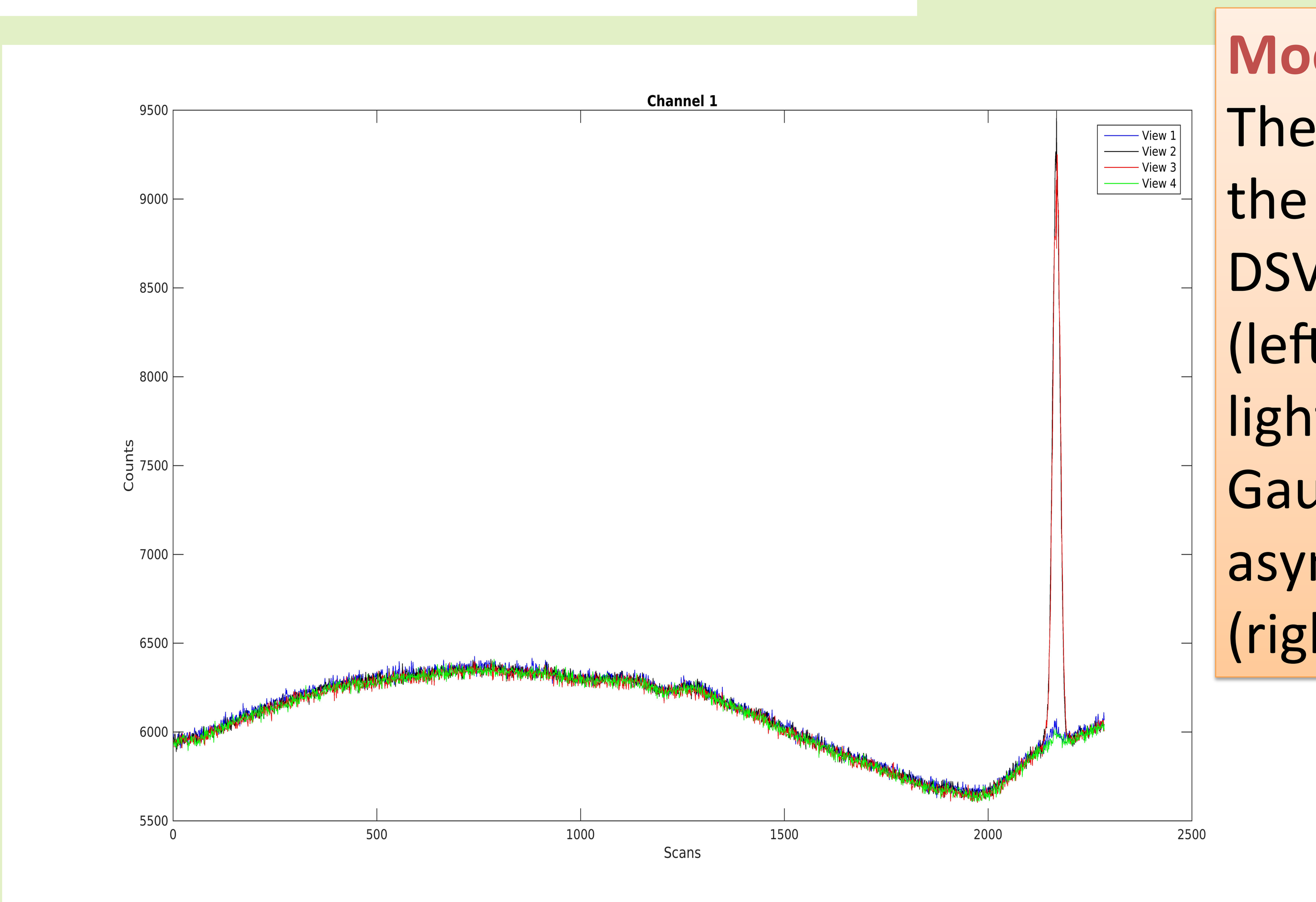


Frequency of Intrusions of the Moon in the DSV

The angle of the deep space view with the orbital axis of the satellite θ/2 determines ultimately the frequency of the Moon glint. But also the equator crossing time of the satellite is relevant, because it fixes the direction of the deep space view in the sky. The Moon can only have a narrow range of phase angle ϕ when seen by the instrument and must not be too far away from the celestial equator at this position in its orbit.

Instr./Sat.	Cone angle ϑ	Intrusions/year	Eq. x-ing	☀-Sat-☾
MHS/MetOp-B	32.4° - 37.2°	7 groups of orbits	21:30	110° - 145°
AMSU-A/N-15	13.4° - 26.6°	5 groups of orbits	17:30	168° - 180°
AMSU-B/N-16	32.4° - 37.2°	4 groups of orbits	16:30	144° - 174°





Strength of the additional signal of the Moon in the DSV

When using the Moon as a flux reference, it is important to have it close to the center of the DSV. This can be achieved with dedicated spacecraft maneuvers. The time difference *Δt* between minimum angle and maximum signal allows to estimate the tangential pointing error:

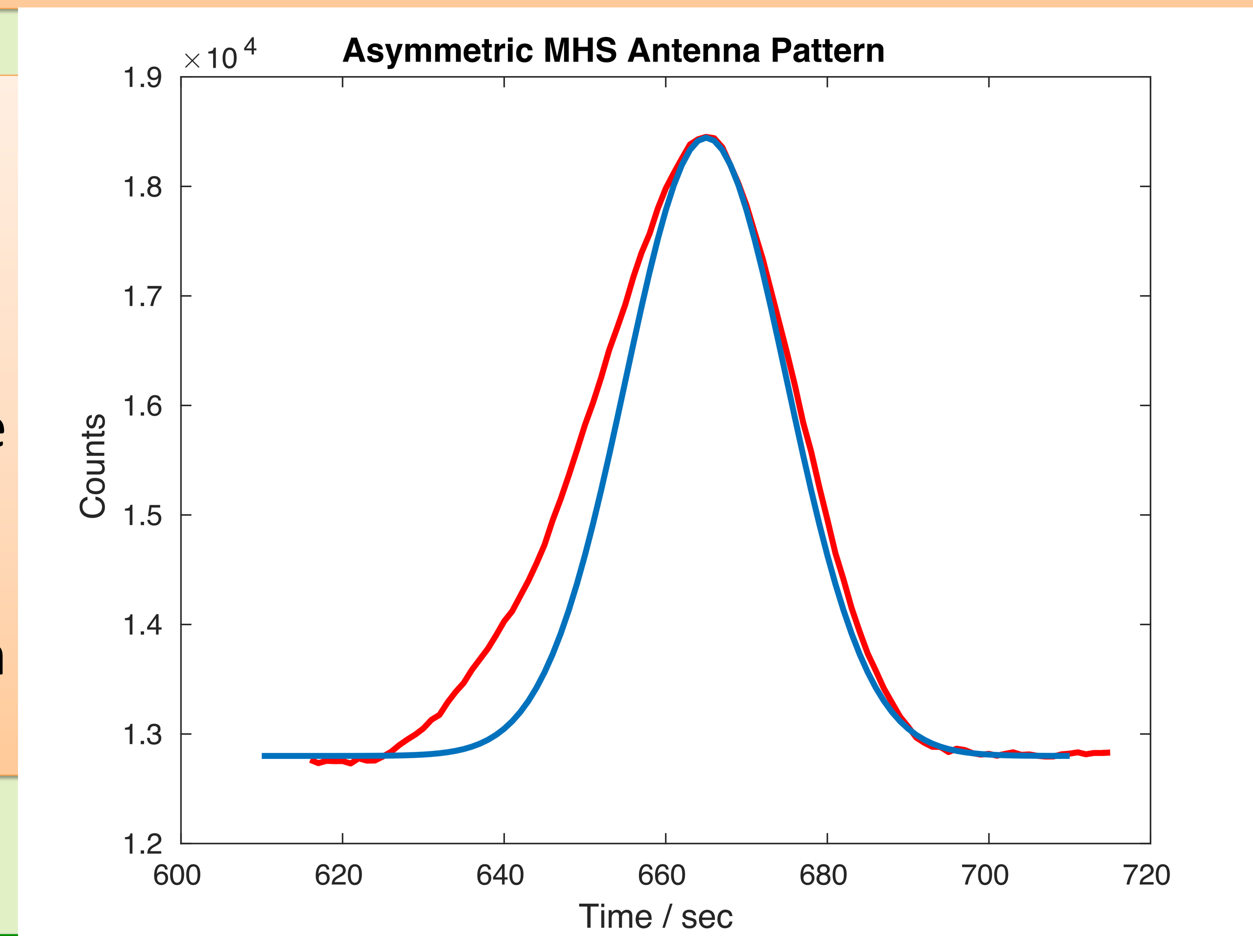
Δt / 100min × 360° × sin(θ/2)

The radial pointing error can be estimated from the maximal signals in consecutive orbits.

Obviously the brightness temperature of the Moon depends on its phase ϕ, and because its absolute radiance is not well known at all frequencies, its best use is for checking the stability of the calibration with observations at fixed ϕ.

Moon and Antenna Pattern

The Moon can be present at the same time in all four DSVs of MHS or AMSU-B (left). The comparison of the light curve (red) with a Gaussian (blue) betrays an asymmetric antenna pattern (right).



Brightness of other foreground objects

An analysis of possible error sources in the cold space radiance requires an estimate of the foreground emission. Jupiter, for example, would add about 20 counts to the cold calibration level of some 10,000 counts – barely detectable.

Object	$T_{B,\ 24\ GHz}$ [K]	$T_{B,\ 183\ GHz}$ [K]	Diameter arcmin	$\Phi_{24\ Hz}$	$\Phi_{183\ GHz}$
OBCT	280	280	-	1	1
CMB	2.725	2.725	-	7.9×10^{-3}	1.3×10^{-3}
Luna	258	258	30	2.1×10^{-2}	1.9×10^{-1}
Jupiter	130	150	0.8	7.6×10^{-6}	$7.8\times^{-5}$
Crab	S = 400 Jy	S = 290 Jy	10	3.2×10^{-5}	2.3×10^{-6}