COBE and WMAP: Signal Analysis by Fact or Fiction?

by

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Pierre-Marie Robitaille, a Professor of Radiology at Ohio State University, is an expert when it comes to instrumentation and signal analysis. It was Robitaille who conceived and directed the construction of the world's first 8 Tesla Magnetic Resonance Imaging (MRI) scanner [1,2]. In doing so, he nearly doubled the maximum field strength in MRI and gave birth to Ultra High Field Magnetic Resonance Imaging (UHFMRI). Robitaille's scanner immediately revealed anatomical structures within the human brain that were previously never seen on human scans [3]. In recent years, Robitaille has applied his skills to astrophysics, and his findings are very significant.

COBE and WMAP have been hailed by the astrophysical scientists as great triumphs in science, measuring the temperature of the Universe, the ~3K Cosmic Microwave Background (CMB) remnant of the Big Bang; a signal first detected by Penzias and Wilson [4] from the ground, in 1965. Stephen Hawking has dubbed this "*the scientific discovery of the century, if not of all time*" [5, 6]. However, upon closer examination, the claim does not stand up; in fact, it has no valid basis in science, as Robitaille [7, 8] has revealed. According to Robitaille, COBE and WMAP have produced almost nothing of any scientific value. Moreover, Robitaille concludes that the CMB is not cosmic, but a signal produced by the oceans of the Earth: "*Throughout the detection history of the microwave background, it remained puzzling that the Earth itself never provided interference with the measurements. Water, after all, acts as a powerful absorber of microwave radiation. This is well understood, both at sea aboard submarines, and at home within microwave ovens*" [8]; "*... if the Earth's oceans cannot interfere with these measurements, it is precisely because they are the primary source of the signal*" [8].

The COBE and WMAP teams model the Earth as a blackbody source of emission at ~ 280 K. But Robitaille points out that "*since the oceans are not enclosed*" [8] they do not satisfy the requirements for application of Kirchhoff's law of thermal emission, and so the emission profiles of the oceans "*do not necessarily correspond to their true temperatures*" [8]. By means of scattering in steady-state conditions, Robitaille argues: "*Consequently, a mechanism for creating isotropy from an anisotropic ocean signal is indeed present for the oceanic ~3 K Earth Microwave Background*" [9].

Misapplication of Kirchhoff's law of thermal emission is far from the only major problem with both COBE and WMAP. Robitaille has shown that both projects are plagued by very serious problems with the performance of satellite onboard instruments and methods of signal processing. Aboard COBE is the Far Infrared Absolute Spectrophotometer (FIRAS) (figure 1) operating from ~30 to ~3,000 GHz.

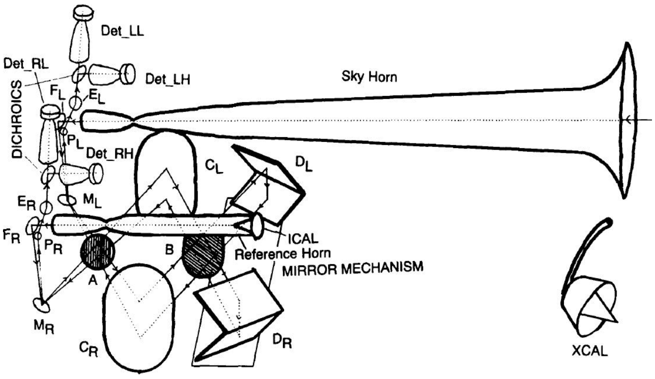

Fig. 1. Salient components of FIRAS:
Sky horn, reference horn, Ical (2 thermometers), and Xcal (3 thermometers)
(Ical = Internal calibrator, Xcal = External calibrator)
From [11] courtesy of NASA and the COBE Science Working Group. Reproduced by permission of the AAS.

"*FIRAS was designed to function as a differential radiometer, wherein the sky signal could be nulled by the reference horn Ical*" [8]. Signal from the sky horn is compared to signal provided by the reference horn. The FIRAS team reported a null point at 2.759 K, which is 34 mK above the reported sky temperature, 2.725 ± 0.001 K. Null should ideally occur at the sky temperature. Owing to 18 mK error in the thermometers, ~ 3 mK temperature drift, 5 mK error in the sky horn Xcal, and 4 mK error in Ical, Robitaille determines an overall error bar of ~ 64 mK in the microwave background. Yet the FIRAS team reports only ~ 1 mK. Errors were evidently dumped into the calibration files. And as Robitaille observes, "*a 1 mK error does not properly reflect the experimental state of the spectrometer*" [8]. The FIRAS team's calibration procedures produced calculated Ical emissivities great than 1.3 at the higher frequencies; but the theoretical maximum for emissivity is 1.

In their initial reports the FIRAS team included data for the frequency range 30 to 60 GHz, but these frequencies disappeared from later reports. According to Robitaille, diffraction of atmospheric photons over the FIRAS shield, which the FIRAS team never adequately tested on the ground, would increase microwave power at lower frequencies, and comparatively reduce microwave power at higher frequencies; bearing in mind that the frequencies of interest for the microwave background are < 600 GHz. Misgivings were expressed by a member of the FIRAS team: "*Dave Wilkinson, the FRIAS team sceptic, argued effectively at numerous meetings that he did not believe that Ned*" (Wright) "*and Al*" (Kogurt) "*had proven that every systematic error in the data was negligible. Dave's worry was that emissions from the earth might be shining over and around the spacecraft's protective shield*" [3,8]. Even so, Wilkinson never contemplated that the entire ~ 3 K signal has its origin in the oceans.

On the balance of the evidence pre-flight testing of COBE's instruments was seriously compromised. Owing to the Challenger disaster, COBE could not be launched by space shuttle, and so the satellite underwent a major late stage redesign. John Mather, a principle investigator on FIRAS, reported: "*Every pound was crucial as the engineers struggled to cut the spacecraft's weight from 10,594 pounds to at most 5,025 pounds and its launch diameter from 15 feet to 8 feet*" [6, p. 195]. "*Getting COBE into orbit was now Goddard's No. 1 priority and one of NASA's top priorities in the absence of shuttle flights. In early 1987 NASA administrator Jim Fletcher visited Goddard and looked over the COBE hardware, then issued a press release stating that COBE was the centerpiece of the agency's recovery*" [6, p.194-195].

The FIRAS team did not examine "*the interaction of the COBE shield with the FIRAS horn*"

[8]; and the effects of earthshine were not "*measured in preflight tests, only estimated from crude (by today's standards) calculations*" [10]. Nor did the team conduct sufficient tests of FIRAS in the flight dewar, and testing of the assembled instrument was curtailed. No RF tests have been reported for side-lobe performance, sensitivity or diffraction on the ground for the fully assembled instrument. Some side-lobe testing was conducted on FIRAS whilst on the ground, at 118μm, 10μm, and 0.5μm, but without its RF shield (figure 2), and some frequencies below 100 GHz were tested. However, only the 118μm in figure 2 "*is within the usable bandwidth of the instrument*" [8]. But without the shield, this data is of little relevance.

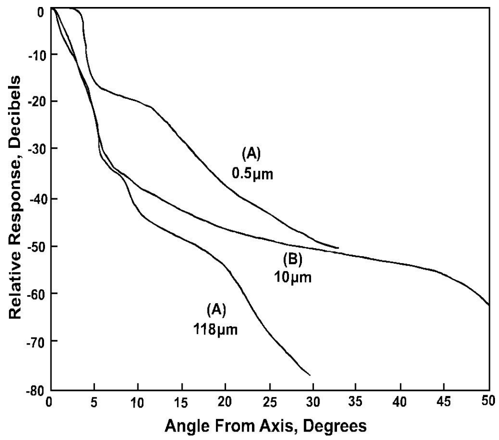

Fig. 2: Side-lobe response of FIRAS horn without the RF shield [18].
Mather J.C., Toral M., Hemmati H., Heat trap with flare as multipole antenna,
Appl. Optics, 1986 v. 25(16), 2826-2830. Reproduced from [18] with permission of *Appl. Optics.*

Since the FIRAS team had little useful side-lobe performance data, they attempted to obtain it in flight, using the Moon assumed as a lambertian emitter at 1,500 GHz (Fig. 3). From this, Fixen et al. [11] concluded a maximum side-lobe response of "*less -38 dB beyond 15^{o} from the center of the beam*" at 1,500 GHz. But the FIRAS team then compared this with data at ~90 GHz obtained on the ground without the RF shield. Furthermore, in-flight data for the lower frequencies where diffraction effects would be strongest are not reported, and no ground data seems to have been obtained at 1,500 GHz, with or without the RF shield in place.

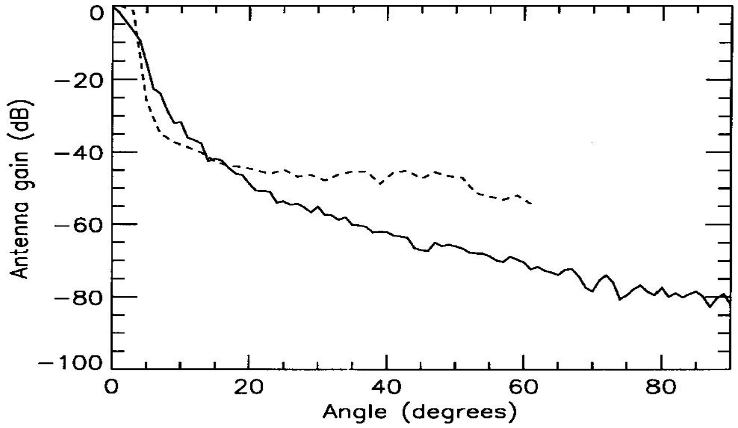

Fig. 3: Side-lobe response for FRIAS shield on ground at 3cm^{-1} (solid line)
and in-flight with lunar source at 50 cm^{-1} (broken line).
From [11] courtesy of NASA and the COBE Science Working Group. Reproduced by permission of the AAS.

Over a period of 13 years the FIRAS team reported a reduction of error in the measured temperature of the microwave background, by almost two orders of magnitude, despite the existence of significant systematic errors (table 1).

Reference	Temperature	Error (mK)[*]	Frequency (cm^{-1})
Mather et al., *ApJ*, 1990, v.354, L37-40	2.735[§]	±60	1-20[#]
Mather et al., *ApJ*, 1994, v.420, 439 -444	2.726[§]	±10	2-20[#]
Fixen et al., *ApJ*, 1996, v.473, 576 -587	2.730[§]	±1	2-21[t]
Fixen et al., *ApJ*, 1996, v.473, 576 -587	2.7255[¶]	±0.09	2-21[t]
Fixen et al., *ApJ*, 1996, v.473, 576-587	2.717[¥]	±7	2-21[t]
Fixen et al., *ApJ*, 1996, v.473, 576 -587	2.728[**]	±4	2-21[t]
Mather et al., *ApJ*, 1999, v.512, 511-520	2.725[§]	±5	2-20[¦]
Mather et al., *ApJ*, 1999, v.512, 511-520	2.7255[¶]	±0.085	2-21[t]
Mather et al., *ApJ*, 1999, v.512, 511-520	2.722[¥]	±12	2-20[¦]
Mather et al., *ApJ*, 1999, v.512, 511-520	2.725[**]	±2	2-20[¦]
Fixen & Mather, ApJ, 2002, v.581, 817-822	2.725	±0.65	2-20[¦]
Fixen & Mather, ApJ, 2002, v.581, 817-822	2.725	±1	2-20[¦]

* 95% confidence intervals

[§] Measurement using FIRAS microwave background lineshape. Calibration sensitive to the thermometers of the external calibrator, Xcal.

[¶] Measurement using FIRAS microwave frequency. Calibration relies on CO and C+ lines at 7.69, 11.53, 15.38, and 16.42 cm^{-1}.

[¥] Measurement using a fit of the dipole spectrum to the 1st derivative of a Planck function describing the microwave background with T_{cmbr} set to 2.728 K.

[**] Composite value obtained from analysis of three previous entries.

[#] Frequency range used is formally stated.

[t] Frequency range used is not formally stated but appears to be 2-21 cm^{-1}.

[¦] Frequency range used is not formally stated but appears to be 2-20 cm^{-1}.

Table 1. Microwave background temperatures obtained by the COBE FIRAS team.
Reproduced from [8] courtesy of Pierre-Marie Robitaille and *Progress in Physics*.

Concerning the blackbody spectrum, Fixen and Mather remark [12]: "*It is sometimes stated that this is the most perfect blackbody spectrum ever measured, but the measurement is actually the difference between the sky and the calibrator.*" Robitaille [8] expresses the relationship thus:

$$(\mathrm{Sky} - \mathrm{Ical}) - (\mathrm{Xcal} - \mathrm{Ical}) = (\mathrm{Sky} - \mathrm{Xcal}).$$

It is clear from this that the effects of Ical and instrumental factors should be negligible: but that is not what the FIRAS team found. It is also clear that if Xcal matches the sky a null will result. Xcal is assumed an ideal blackbody spectrum and so the sky would also be an ideal blackbody spectrum in the event of a null. The FIRAS team assumed from the outset that the sky is as an ideal blackbody. Note that if the calibration obtained with Xcal in place is dominated by leakage of sky signal into the horn then a perfect blackbody spectrum would result because the sky would then be compared with itself. Robitaille has shown that it is most likely that there is significant sky leakage into the horn during calibration with Xcal.

Robitaille relates most significantly that in actual fact FIRAS was unable to obtain proper nulls, despite the FIRAS team's reports that they obtained "*the most perfect blackbody spectrum ever measured*". Unable to obtain a proper null, the FIRAS team blames instrument problems and the calibrations, but never entertains the possibility that the sky, owing to diffraction over the RF shield of emissions originating from the Earth, is not behaving as a blackbody as they assume. The FIRAS team published interferograms for a final temperature of 2.725 ± 0.001 K with Ical set at 2.759 K. The published interferograms consists of three traces (Fig. 4). The top and bottom traces are not drawn to the same vertical scale as the middle trace: "*A correction factor of 3-5 should be applied to place the upper and lower interferograms on scale with the center one*" [8]. Furthermore, noise power analysis with this data reveals that "*the FIRAS team is not maintaining a constant vertical amplification*" [8]. In order to attempt to account for the data, the FIRAS team applies, *ad hoc*, a 4% reflectance to Ical.

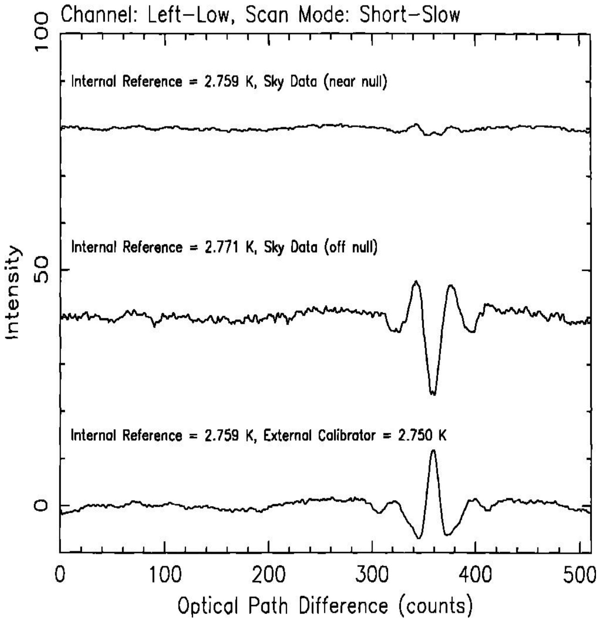

Fig. 4: Interferograms obtained in flight with FIRAS.
From [13] courtesy of NASA and the COBE Science Working Group. Reproduced by permission of the AAS.

The FIRAS team initially published spectra for 1-21 cm^{-1} [13], deviating from a blackbody by less than 1%. But in 1994 [14] a new set of data was published, indicating a deviation from blackbody by 0.03%. Then in 1996 it is reported that the "*rms deviations are less than 50 parts per million of the peak of the cosmic microwave background radiation*" [15]. In 1999 the deviations are reported as less than 0.01% [16]; and in 2002 the deviations become "*50 parts per million (PMM, rms) of the peak brightness of the CMBR spectrum, within the uncertainty of the measurement*" [12]. But Robitaille observes that: "*Using technology established in the 1970's, the FIRAS team reported a spectral precision well beyond that commonly achievable today in the best radiometry laboratories in the world*" [8].

Robitaille also remarks that the blackbody trace published by the FIRAS team [15] "*is unusually drawn, as the frequency axis is offset. This makes it less apparent that data is not being shown below 2 cm^{-1}*" [8]. After 1994, all data below 2cm^{-1} was omitted in FIRAS reports. Fixen et al. make the remark: "*However, the measured emission is higher than predicted, particularly at the lowest frequencies*" [11]; at the very frequencies at which diffraction of photons from Earth would be a maximum over the RF shield. In addition, all data when the Earth illuminated the instrument are rejected outright, thereby removing any effect of earthshine that might well assign the microwave background to the oceans. Furthermore, "*In the end, the FIRAS team transfers the error from the spectrum of interest into the calibration file*" ... "*Using this approach it would be possible, in principle, to attain no deviations whatever from the perfect theoretical blackbody. Given enough degrees of freedom and computing power, errors begin to lose physical meaning. The calibration file became a repository for everything that did not work for FIRAS*" [8].

Both COBE and WMAP must deal with the presence of a microwave dipole, and a galactic foreground that is ~1000 times stronger than the signal sought. This is a dynamic range problem. As Robitaille advises [7], laboratory experience in medicine demonstrates that it is impossible to extract a signal ~1000 times smaller than the background without being able to affect the signal at its sources or without *a priori* knowledge of the source; neither of which are available to WMAP or COBE. George Smoot, the principal investigator for the COBE Differential Microwave Radiometers (DMR), relates that to extract the weak multipoles by data processing, which Smoot calls "*wrinkles in the fabric of time*" [5], required first the removal of the dipole, galactic foreground, and the quadrupole signals. Smoot puzzled over why the multipoles did not appear until the quadrupole was finally removed by data processing methods, since the raw data contained no systematic signal variations. Robitaille's answer is simple: "*when Smoot and his colleagues imposed a systematic removal of signal, they produced a systematic remnant. In essence, the act of removing the quadrupole created the multipoles and the associated systematic anisotropies*" [8]. Smoot's "*wrinkles in the fabric of time*" are nothing more than consistent residual ghost signals produced by his data processing. The appearance of such systematic ghost signals throughout an image when processing large contaminating signals is very well known in medical radiology. Robitaille advises that "*Apparent anisotropy must not be generated by processing*" [7,8].

The foregoing far from exhausts the list of major problems with COBE. Robitaille gives detailed analyses of significant shortcomings in COBE's bolometer performance, grid polarizer performance, emissivities of Xcal and Ical, signal leakage around Xcal, design of the FIRAS horn, antenna gain, determination of error bars on data, and the optical transfer function applied. Concerning the latter, Robitaille [8] makes the following points: (a) there is an unexplained and significant oscillation below ~ 20cm^{-1}; (b) FIRAS detects only 1 photon in 10; (c) FIRAS is non-linear in operation; (d) when applied to data beyond ~ 30cm^{-1} there is a pronounced amplification of spectral noise, indicating that in this frequency range FIRAS is sub-optimal.

WMAP

WMAP does not measure absolute intensity of any microwave signal, but operates by measuring the difference between antennae. All data is therefore difference data. According to Robitaille: "*WMAP images do not meet accepted standards in medical imaging research*" [7]. WMAP samples at five frequencies: K ≡ 23GHz, Ka ≡ 33GHz, Q ≡ 41GHz, V ≡ 61GHz, W ≡ 94GHz. Claiming that the large galactic foreground signal can be removed, despite absence of access to signal source and *a priori* knowledge of it, the WMAP team produces Integrated Linear Combination (ILC) images, effectively assuming, without any scientific basis, that the foreground signal is frequency dependent and the sought after underlying anisotropy frequency independent. WMAP anisotropy maps are composites of 12 sectional images, 11 thereof in the galactic plane. Robitaille notes: "*The WMAP team invokes completely different linear combinations of data to process adjacent regions of the galactic plane*" [7]. Numerical coefficients used by the WMAP team to process each section of their final image, vary by as much as 100%. Robitaille objects that "*The sole driving force for altering the weight of these coefficients lies in the need to zero the foreground. The selection of individual coefficients is without scientific basis, with the only apparent goal being the attainment of a null point*" [7]. Furthermore, the WMAP team arbitrarily weights the V-band [17, Table 5]. There is no scientific reason for preferring the V-band over any other band. To any chosen band there corresponds a particular set of ILC maps, and so different sets of cosmological constants would result depending upon the band emphasised; as products of data processing. Robitaille considers this clear evidence that "*The requirement that the signals of interest are frequency independent cannot be met, and has certainly never been* *proven*” [7], and “*There is no single map of the anisotropy, since all maps are equally valid, provided coefficients sum to 1*” [7] (which is precisely the condition set by the WMAP team). Consequently: “*There is no unique solution and therefore each map is indistinguishable from noise. There are no findings relative to anisotropy, since there are no features in the maps which could guide astrophysics relative to the true solution*” [7].

The most important determinant of image quality is signal to noise. High signal to noise can permit some signal sacrifice to enhance contrast and resolution. Without high signal to noise, contrast and resolution will be poor. WMAP images have a maximum signal to noise that barely exceeds 1, and so “*WMAP is unable to confirm that the ‘anisotropic signal’ observed at any given point is not noise. The act of attributing signal characteristics to noise does not in itself create signal*” [7].

In the absence of high signal to noise, the only indicative feature of images is reproducibility. However, as Robitaille points out, WMAP images cannot evidently be reproduced, since the WMAP team not only selectively weights the V-band, but varies all ILC coefficients from year to year, for the central region of its images, and also averages images for a 3-year data image which differs significantly from the first year image, and did not publish any images for years 2 and 3. Moreover, the WMAP team's difference images are between year 1 and the averaged 3 year, not between images year to year. Figure 5 depicts comparative images, wherein Robitaille draws attention to the fact that “*the difference images are shown with reduced resolution contrary to established practices in imaging science*” [7].

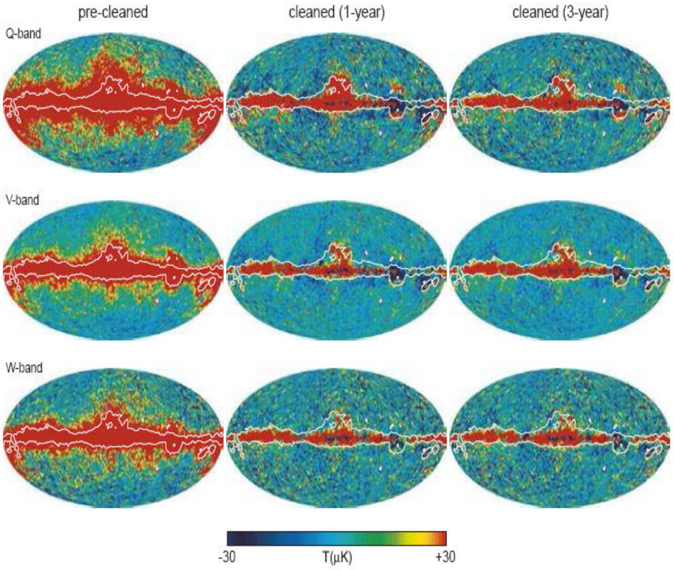

Fig. 5

From [19] courtesy of NASA and the WMAP Science Team. Reproduced by permission of the AAS.

That WMAP and COBE have measured the temperature of the Universe is not substantiated by the facts.

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