VIRGO Radiometry: An Update of the Characterization of PMO6V and DIARAD.

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1 Introduction

The performance of the VIRGO radiometers PMO6V and DIARAD has been described in Fröhlich et al. (1997a,b), but in the mean time the understanding of the details about degradation and other changes in space have substantially improved. With the information from the development of the PMO6 radiometers for SOVIM and their characterization the situation is such that the characterization of the VIRGO radiometers needs to be revised.

2 Revised characterization of the PMO6V radiometers

In the FORTRAN level0 programs the following radiation constants R are used 50.59976 and 50.68111 for PMO6V-A and B, respectively. These were determined from WRR comparisons and then corrected for space by removing the non-equivalence and adding the diffraction correction. The results of the characterization for VIRGO-2 and 4, which are on ground and available for tests, and PMO6V-A and B, which are still operating in space on VIRGO/SoHO, are summarized in Table 1 (see also Brusa and Fröhlich, 1986), with the non-equivalence, C_{NE}, the reflectivity of the cavity, C_{RF}, the lead heating, C_{LH} and diffraction, C_{DR}. The second value of the non-equivalence uncertainty is used for operation in vacuum with C_{NE} is assumed to be negligible. After the first results from space the characterization was revised, mainly the original non-equivalence values from the air-to-vacuum measurements for the flight instruments were replaced by those from a re-evaluation by Urs Schütz with 3162 and 1605 ppm for A and B. Using all existing air-vacuum measurements made 1993/94 I get for A and B a weighted mean of 1635 ± 190 and 2675 ± 344 ppm, respectively. These values are quite different from the original and the re-evaluated ones, but are probably more representative as they are determined with a new fitting procedure. This algorithm fits a third order polynomial to the measured points which are offset during the vacuum periods by the value we are searching for - the difference between the air and vacuum response. How important the explicit accounting of the temporal variation is, is illustrated by an example for VIRGO-2 (Fig. 1). /subsectionNew analysis of the air-to-vacuum ratios and the influence of scattering

Most of the available air-to-vacuum ratios for SOVIM-1 and 2, Virgo-2 and SOVA-R111 and R 113 have been re-analyzed with this method and examples of the results are presented in Fig. 2 as a function of the illuminated area on the precision aperture. The most interesting result is the linear dependence on the illuminated area which was detected the first time during the extensive tests of the PMO6 radiometers for SOVIM, the experiment on the International Space Station. The main reason for this discovery was mainly due to the fact that ISS provided solar pointing within only 1° , which requires a larger view-limiting aperture of 10.3 mm diameter instead of the normal with 8.5 mm. With the larger aperture the air-to-vacuum ratio became very low or even negative. This could not be the non-equivalence as thought before and many air-to-vacuum-ratio measurements with different view-limiting apertures were performed in the period of July 2003 to

Table 1: *Characterization of the PMO6V radiometers of VIRGO. The radiation constants R are given in* $10^3\ m^{-2}$. *The two values of the uncertainty of* C_{NE} *is for air and vacuum, respectively. The uncertainties of the radiation constants corresponds to the rms sum and include 100 ppm for the electrical measurements. The uncertainty stated in Fröhlich et al. (1997b) for the PMO6V amounts to 1700 ppm as determined by Brusa and Fröhlich (1986) at the* 3σ*-level or 1040 ppm in air and 880 ppm in vacuum with the uncertainties presented here.*

	VIRG0-2	PMO6V-A	PMO6V-B	U (ppm)
D_{org} (mm)	5.0023	5.0099	5.0153	
A_{org} (mm^2)	19.6530	19.7128	19.7554	120
C_{RF} (ppm)	405	260	250	70
C_{DR} (ppm)	-1180	-1180	-1180	180
C_{NE} (ppm)	2600	2100	2000	170, 50
C_{LH} (ppm)	410	550	540	140
C_{SL} (ppm)	-250	-250	-250	100
R_{air}	50.9837	50.8034	50.6878	345
R_{vacuum}	50.8515	50.6970	50.5866	294
Ratio to WRR		0.9994488	0.9975283	

December 2004 to understand its reason (Rüedi et al., 2003–2005). The slope of VIRGO-2 is very similar to the SOVIM-1 and 2 and a weighted average of the three radiometers of 2324±415 ppm/mm^2 is used for the PMO6V-A and B radiometers as typical value. The SOVA R, which were more than an year in space during the EURECA mission and then retrieved, are substantially lower with 887 and 1768 ppm/mm^2 which is due to the changed reflectivity of the primary aperture during the exposure in space. In order to complete this picture also under-filled air-to-vacuum ratios were determined for all these instruments. The SOVIMs were measured with a laser beam in the optics laboratory of PMOD/WRC during Nov/Dec 2003, and at NPL during June/July 2003; the VIRGO-2 and the SOVAs were measured at PMOD/WRC during Nov/Dec 2003. The values shown on Fig. 2 are all weighted averages of the individual determinations of each radiometer, re-calculated with the new algorithm. The weighting is $1/\sigma^2$ of the individual determinations and the uncertainty is the rms value of the individual σ^2 and the square of the weighted standard deviation from the mean.

The fact that the extrapolations of the linear fits coincide within the uncertainties with their under-filled values, may be interpreted as a linear relationship between the air-to-vacuum ratio and the illuminated area and thus of the amount of the reflected light from the precision aperture. The effective non-equivalence in air corresponds to the under-filled air-to-vacuum ratio and is much larger than assumed from the direct values and ranges now from about 2000 to over 4000 ppm for the PMO6 radiometers. Moebus (2005) found similar values for the PMO6-9 and 11 (2900 and 4000 ppm) in 2005. The rather large range may be explained by slightly different relative placement of the cavity within the shield during manufacturing and possibly also by differences of the roughness of the surfaces which influences the conduction in air. From the difference of the thermal conduction of air ($\approx 20\,\mathrm{Wm^{-2}K^{-1}}$) and the exchange by radiation between gold-plated surfaces ($\approx 0.25\,\mathrm{Wm^{-2}K^{-1}}$) the non-equivalence in vacuum is below 1% of the value in air and can be safely neglected as always assumed (e.g. Brusa and Fröhlich, 1986). When this area dependence was discovered we thought that this effect is related to the heating of the precision aperture and some experiments together with model calculations started to investigate the related effects. Fröhlich (2010) could show that the effect in vacuum is rather small with about 110 ppm (Fig. 3) for the shuttered operation and the effect is limited to the heating of the thin edge of the aperture. This means that this effect should be independent of the illuminated area in the shuttered mode as only changes between open and closed are important and not the overall temperature of the aperture. In air the effect seems somewhat larger with 170 ppm, but the assumptions for the heat exchange in air are rather crude and it seems reasonable to assume an effect of about 150 ± 80 ppm for both air and vacuum operations. Investigation of the straylight of these radiometers were performed by Rüedi et al. (2003–2005) and yielded interesting results which had no ready explanation at the time. The measurements were performed with a laser illuminating the precision aperture of the radiometer and measuring the response directly. Other experiments with the cavity replaced by a silicon diode were also performed in order to distinguish from scattered and infrared radiation from heated parts of radiometer by reflected or absorbed radiation falling on the precision aperture. In a first experiment the reflectivity of the stain-less steel aperture was determined as about 0.4 and the amount of the reflected radiation leaving the radiometer through the view-limiting aperture was only about 20% of the reflected radiation, so 80% are illuminating the baffle or about 18 mW with 1400 Wm^{-2} from the sun. This is a very large amount, which will heat the baffle substantially.

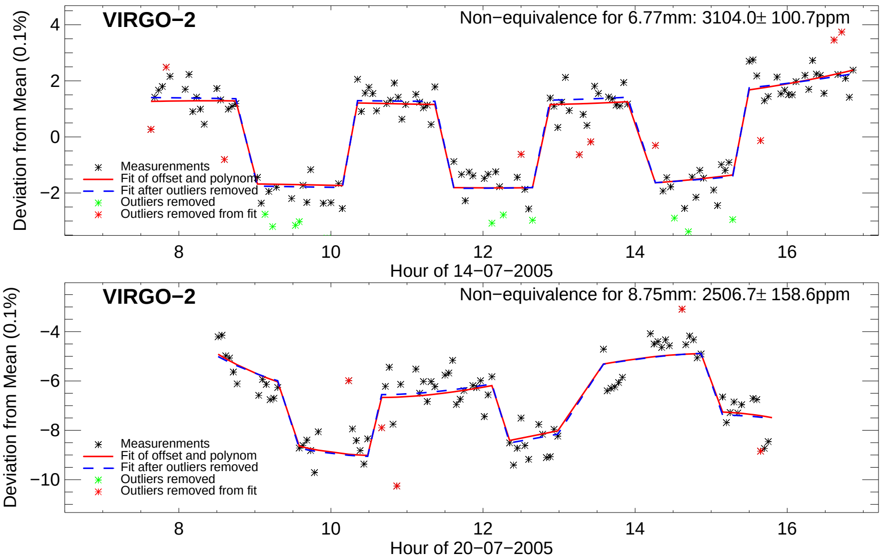

Figure 1: *Air-to-vacuum measurements for the VIRGO2 radiometer for two different view-limiting apertures with the sun as source. From both plots it is clear that the temporal variation has to be taken into account.*

For these measurements the precision aperture was illuminated with a slightly divergent, clean laser beam of about 0.5 mm diameter at the aperture; the power in beam was of the order of 30-40 mW power. The axis of the radiometer is parallel to the beam and can be moved in the horizontal and vertical direction and the beam is pointed at a point on the aperture about 0.8 from the edge of the 5 mm diameter opening. Within about ± 0.3 mm the beam could be moved without changing the result. The radiometer is operated in the 90-90s open/closed mode and the amount of the scattered and the infra-red radiation was determined as 1354 ± 150 ppm, a weighted mean of the measurements of 15. and 16. January 2004 and with an estimate of the incoming laser power of 30 mW (as the day before). Similar values were determined for SOVIM 1 and 2 namely 1527 and 1287 ppm with incoming laser power directly measured, indicating that the estimate of the power is probable not too far off. The assumed uncertainty corresponds to the standard deviation of the three values. These do not include the aperture heating because the edge is not illuminated, but represent the infrared radiation from the baffle,which is heated by the reflected light. It is important to note that such measurements are made with the shutter operation as during normal operation because the shutters of PMO6 radiometers are located inside the baffle and behind the view-limiting aperture. So part of the illuminated area by the reflected light is shut-off during the reference phase which means that the difference between open and closed is higher by the amount of the missing part between the shutter and the view-limiting aperture.

The results of the measurements of the scattered light with the diode showed values of 50-150 ppm for SOVIM-3, which has a better polished precision aperture than those from the batch used for VIRGO-2 and SOVIM-1 and 2. As no shutter was used these values underestimate the effect and thus a scatter correction 200 ± 100 ppm is assumed for all PMO6V radiometers. This is well within the values 320 ± 210 ppm of the seven radiometers determined by Brusa and Fröhlich (1986).

With the results of these measurement we know the effect in air and can now determine from the air-to-vacuum ratios the effect of the infrared radiation from the baffle in vacuum. From the slope of VIRGO-2 and SOVIM-1, 2 the difference in infrared radiation in air and vacuum amounts to 2325 ± 415 ppm and by adding the effect in air minus the directly scattered part of 1154 ± 180 ppm we get 3479 ± 452 ppm for the infrared part received from the baffle in vacuum. This correction is determined with the 90-90s mode whereas in space and during the TRF comparison 60-60s mode used and for the latter with an external shutter. The time constant of this effect is about 250 s from the analysis of PMO6V radiometer in the covered mode which reduces the 90-90s measurements by a factor of 1.13 and yields a final correction due to the infrared radiation from the baffle of $C_{AV} = 3086 \pm 422$ ppm for the VIRGO-2 and SOVIM-1 and 2 radiometers.

VIRGO-2 was also investigated at TRF and the results are described in Fehlmann (2011). The difference between VIRGO-

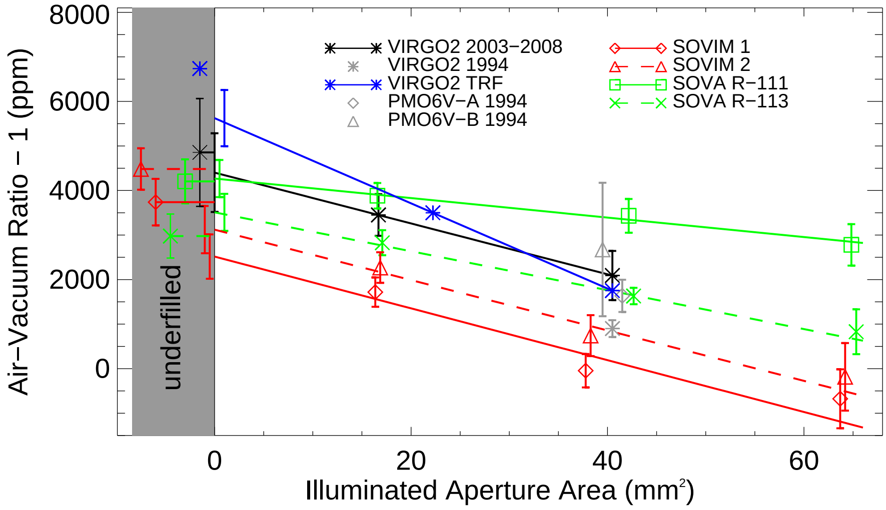

Figure 2: *Air-to-vaccum ratios as a function of the illuminated area of the precision aperture for different radiometers. SOVIM 1 and 2 are PMO6-type radiometers which were developed for the SOVIM experiment on the International Space Station. SOVA R radiometers are PMO6-type with a reflectiometer and were in space during the EURECA mission and afterwards retrieved. Note that the slope of R-111 is much lower than for the other radiometers, indicating that its 'stray-light' is smaller.*

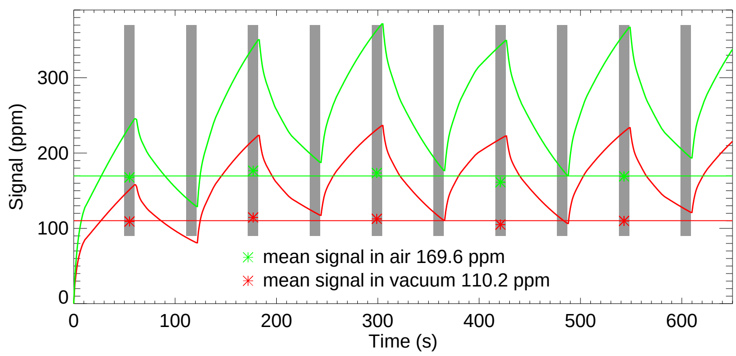

Figure 3: *Aperture heating for $\alpha = 0.4$ and $\varepsilon = 0.5$ and a thermal conductance to the heat-sink at the outer part of the aperture. The result is calculated as the difference between open and the two adjacent closed values averaged over the last 10 s of each cycle.*

2 and the cryogenic radiometer for beam diameters of 2.0, 7.3 and 11.0 mm amount to 7314 ± 195, 7952.6 ± 244 and 10302.0 ± 242 ppm (these values are corrected to the same radiation constants for all three measurements and thus slightly different from those in Fehlmann (2011)). The reason for the rather high overall value is due to a wrong assignment of the leads for the two voltmeters used to measure current and voltage of the heater as observed also for PREMOS-3; this error is not important for this analysis and can be assumed to be constant during the different measurements. As these measurements were done with an external instead of the internal shutter the results underestimate the effect of the scattered light, as explained earlier. Adding up the difference between the 7.3-2mm and the 11-7.3mm values one gets 2988.0 ppm and by subtracting the diffraction at 532 nm of 672.0 ± 50.0 ppm 2316.0 ± 343.7 ppm. This includes 200 ppm of scattered light and 150 ppm of aperture heating and the reduced value amounts to $C_{\mathrm{TR}Fdir}$ 1966.0 ± 366.7 ppm, which is much lower than the value from the air-to-vacuum ratio. Another way to calculate the effect is to scale the result from the 7.3-11mm difference minus diffraction to the total illuminated area (from 22.2 to 40.5 mm^2) yielding 3716.5 ppm which includes only stray-light and without reduces to $C_{\mathrm{TR}Fext}$$3516.5 \pm 361.4$ ppm. This value is higher than $C_{\mathrm{A}V}$ by more than 500 ppm, but within the overlap of the uncertainties. Also the slope of the air-to-vacuum ratio determined at TRF is higher with 3872.9 ppm which could mean, that the effect in air is almost zero, possibly due to a more efficient cooling by air with an always open shutter. After all, $C_{\mathrm{A}V}$ - determined as an average of VIRG=-2 and SOVIM-1 and 2 results - seems to be a reasonable value to be used in the new characterization of the PMO6V radiometer.

Table 2: *Revised characterization of the PMO6V radiometers. The radiation constants R are given in* $10^3\,m^{-2}$. C_{NE} *is determined from the extrapolated (1) or underfilled (2) value for VIRGO-2 and corrected for A and B by their air-to-vacuum ratio difference at the normal view-limiting aperture. The two values of the uncertainty of* C_{NE} *is for air and vacuum, respectively. The uncertainties of the radiation constants corresponds to the rms sum and include 100 ppm for the electrical measurements. The uncertainty at the* 3σ*-level is 2060 ppm in air and 1670 ppm in vacuum.*

	VIRG0-2	PMO6V-A	PMO6V-B	U (ppm)
D_{org} (mm)	5.0023	5.0099	5.0153	
A_{corr} (mm^2)	19.6658	19.7256	19.7681	220
C_{RF} (ppm)	405.0	260.0	250.0	70
C_{DR} (ppm)	-1175.0	-1175.0	-1175.0	200
C_{NE} (1) (ppm)	4401.2	3945.3	4985.7	550, 50
C_{NE} (2) (ppm)	4854.6	4398.7	5439.1	550, 50
C_{LH} (ppm)	410.0	550.0	540.0	140
C_{SLair} (ppm)	-1354.0	-1354.0	-1354.0	197
C_{SLvac} (ppm)	-3478.9	-3285.5	-3285.5	422
C_{AH} (ppm)	-150.0	-150.0	-150.0	80
R_{vacuum}	50.6494	50.5051	50.3961	557
R_{used}		50.5998	50.6811	
Ratio $R_{\mathrm{vacuum}}/R_{\mathrm{used}}$		0.9981301	0.9943762	
R_{air} (1)	50.9783	50.8004	50.7427	686
R_{air} (2)	51.0013	50.8234	50.7656	686
Ratio to WRR (1)		0.9993786	0.9985936	
Ratio to WRR (2)		0.9998302	0.9990443	

2.1 New characterization of PMO6V radiometers

From all these new results we get a revised characterization summarized in Table 2. The corrected aperture areas (A_{corr}) are the METAS areas multiplied by the average deviation of the 7 PMOD apertures measured by NIST which amounts to 1.00065 ± 0.00019; to account for this correction the uncertainty is increased from the original value of 160 to 220 ppm.

During the first switch-on of VIRGO PMO6V-A and B were compared yielding a ratio of B/A= 0.9967660, referred to the new R_{vacuum}. On ground a ratio of B/A= 0.9980784 was determined with the original air-to-vacuum ratio, and with the one of Table 2 it becomes 0.9992140. Now we can refer the PMO6V values to both radiometers for the change of the absolute scale. Thus the present values of PMO6V-A have to be reduced by 0.9981301 or if we include B by $(0.9981301 + 0.9943762 * 1.0032445)/2 = 0.9978663$. The absolute uncertainty is now at the 3σ level 1670 ppm.

An interesting result related to the WRR comparison done before launch in the package are the changes from the original radiation constants to the new ones and more specifically to the ones using the under-filled determinations of the non-equivalence yielding 0.9998302 and 0.9990443 for PMO6V-A and B. On average they yield 0.9994372 and a ratio of A/B of 1.0007866 which is now well within the stated uncertainty 1670 ppm; this was not the case for the earlier and also the extrapolated results. So, the use of the directly determined non-equivalence from the under-filled measurements and the determination of the scattered and infrared radiation with the shutter operated seems to be the correct way to determine the response of these radiometer in air. With all these results it is clear that the inversion of the precision and view-limiting aperture avoids most of these problems and allows a much easier analysis of the results. Furthermore, there is a problem with the location of the shutter in the present PMO6 radiometers because the thermal environment is not the same for open and closed measurements. So the analysis of the measurements has to be done for the corresponding mode of operation, which is not always feasible and/or done and can lead to problems in the interpretation of the results. In new versions of the PMO radiometers – with the precision aperture in front – the shutter must be in front of the aperture in order to keep the thermal environment constant during open and closed operation.

3 Revised characterization of the DIARAD radiometer

In May-June 2013 IRMB participated in TRF comparisons with a refurbished SOVA-1 radiometer which has an aperture of 10 mm diameter, replacing the original 8 mm one. It has also a new determination of the sensitivity and thus a better definition of the correction for the non-equivalence. The power comparison agreed very well with a beam of 3 mm diameter, if the non-equivalence due to different areas covered by the electrical and radiative heating is taken into account for a 3 mm diameter beam and the 12.7 mm diameter electrical heater. A separate measurement of the diffraction and scattering at the view-limiting aperture was performed and the results indicate that there is only diffraction and no additional contribution by scattered radiation. This is well understood, because of the curved primary aperture with its focus at the view-limiting aperture and all light falling on the precision aperture is reflected out of the radiometer. Moreover, scattered light from the precision aperture is received by the front baffle the most part of which is seen by the reference channel and is so automatically canceled. The fact that DIARAD does not show any early increase confirms that there is essentially no influence of scattered light.

3.1 Non-equivalence due to the different area of electrical and radiative heating

In order to avoid a first order non-equivalence most radiometer have by design equal and co-located areas for the electrical heater and the incoming radiation. In all DIARAD they are with nominal diameters of 12.7 mm and 8 mm substantially different. This difference leads to a large non-equivalence between electrical and radiative heating besides the more subtle effects from the different temperature distribution within the cavity for radiative and electrical heating, as described in Meftah et al. (2013) and re-determined for the DIARAD in space in 3.2. The effect of this area difference can be determined from the measurements of the local sensitivity at the bottom of the cavity from Chevalier et al. (1995, page 10-11) and shown in Fig. 4. The measurements are fitted by a 4th degree polynomial with the constraint that the linear and 3rd order coefficients are zero. This makes the curve symmetrical relative to its peak which is normalized to 1.00 and slightly offset relative to the center of the cavity (by 0.82 and 0.53 mm, for Right and Left). The signal in the heat-flux

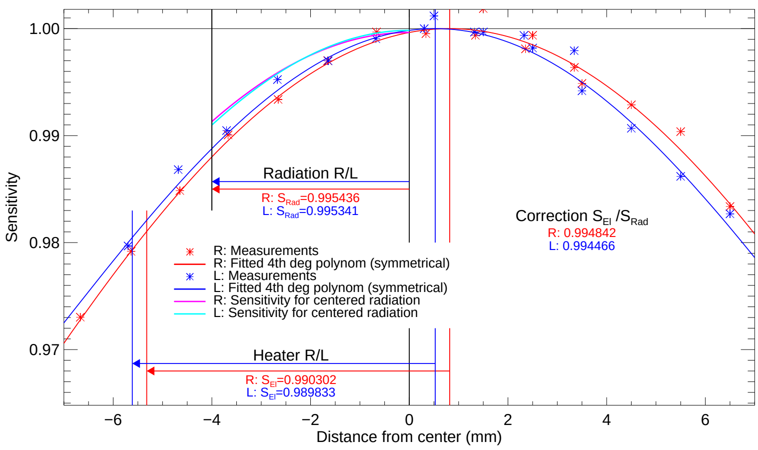

Figure 4: *Sensitivity of the DIARAD left and right at the bottom of the cavity.*

meter is $S \times P$ with P the power in the electrical heater or incoming radiation. As during measurements $P_{el} = P_{rad}$ we only need to compare sensitivities S which are

$$S_x = \frac{2\pi}{\pi {R_x}^2} \int_0^{R_x} s_x(r) dr. \tag{1}$$

The electrical heater of all IRMB radiometers is a circular strain gauge from Vishay (EA-05-500JD-120) with a nominal diameter of 12.7 mm for the heater element. As it is wound in spirals the effective diameter is somewhat smaller with 12.28 mm or $R_{el} = 6.14$ mm. The sensitivity for the electrical heater with $R_{el} = 6.14$ mm amounts to $S_{el} = 0.990302$

and 0.989833 and for the centered radiation with $R_{\rm rad} = 4.00$ mm $S_{\rm rad} = 0.995436$ and 0.995341, for Right and Left, respectively. If the center of the radiation is moved to the corresponding electrical center the result is slightly different with $S_{\rm rad} = 0.995777$ and 0.995488. This difference can be used as an estimate of the 1σ uncertainty of between 150 and 350 ppm as we do not know where the irradiated disk is really located. From the fit the standard deviation of any value is about 0.00022 which adds in rms to about 450 ppm. Thus, the non-equivalence or the correction to the DIARAD absolute value which is the ratio of the electrical to the radiative sensitivity or 0.9946441 ± 0.0001770 and 0.9943809 ± 0.0000760 for Right and Left. So, the original values of DIARAD-L in the VIRGO analysis need to be reduced for the new absolute value by 0.99438. This correction has a formal uncertainty of 76 ppm to which an uncertainty of the effective area of the electrical heater of about 180 ppm has to be added. So, we need to add to the total uncertainty of DIARAD about 300 ppm (360 and 260 ppm for Right and Left) due to this correction and about 250 for a possible off-center illumination. Fröhlich et al. (1997b) stated 0.15% for the total uncertainty as estimated by IRMB from the original characterization, which is at 2σ, so the final uncertainty becomes 0.16% and 0.23% depending on rms or direct adding.

3.2 Calculation of the radiative efficiency of the cavity

The efficiency of the cavity ϵ is calculated as described by Crommelinck et al. (1995) and used as a parameter in the evaluation of the radiative power of DIARAD. The present evaluation uses values of 0.9959183 and 0.9973377 for Right and Left. The finer integration by using the fitted curves instead of the direct observations may change these values, so they are recalculated. Moreover, it seems that the sensitivity of the cylinder can be represented by a linear function as shown in Fig. 5 which makes sense and demonstrates that the measured points are indeed quite noisy (probably due to the low angle of incidence on the cylinder). The paint used is assumed to be Lambertian in reflection and absorption. So, the part not absorbed from the incoming radiation is reflected into a hemisphere. This is an important assumption to use the standard radiation transfer configuration factors or 'view factors' $F_{1\to 2}$ from surface 1 to 2, instead of a detailed ray-tracing.

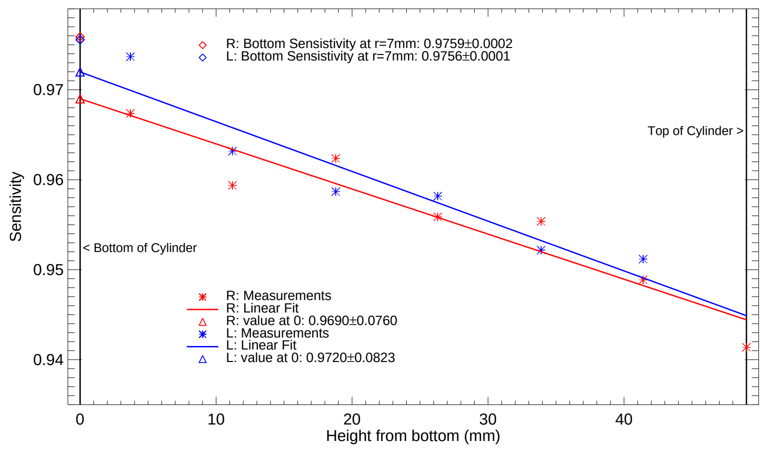

Figure 5: *Sensitivity of the DIARAD left and right along the cylinder of the cavity.*

For the following calculations the sensitivity curves on the bottom have been centered as well as the incoming radiation. This is justified by the small changes observed by moving the relative position of the radiation and the sensitivy curves and simplifies the calculations. The incoming radiation falls on an centered area of 8 mm diameter and the portion α, the absorptivity of the paint (0.98184 ± 0.00064 from Chevalier et al. (1995, page 6)), is sensed by the heat-flux meter providing a signal $S \times P$. With the normalized radiative power $P \equiv 1$, $s(r)$ the sensitivity on the bottom of the cavity (Fig. 4) and $R_0 = 4.0$ mm the signal from the bottom becomes

$$S_{00} = \alpha \frac{1}{R_0} \int_0^{R_0} s(r) dr. \tag{2}$$

Moreover, $(1-\alpha)$ is reflected from the disk of diameter 8 mm and received by the cylinder which provides a further signal at the heat-flux meter. With the view factor from the illuminated disk to dh on the cylinder $F_{{\rm d}isc\to dh}$, $s(h)$, the sensitivity on the cylinder (Fig. 5) and $H = 49$ mm the signal from the first reflection becomes

$$S_{10} = \alpha(1-\alpha)\int_0^H s(h) F_{\mathrm{d}isc\to dh} dh. \tag{3}$$

Then, we have also a second reflection from the cylinder dh_1 to dh_2 on the cylinder and to a ring dr on the bottom. This second reflection illuminates the cylinder with $F_{\mathrm{d}h_1\to dh_2}$ and the bottom with $F_{\mathrm{d}h_1\to dr}$ which increases S_{00} and S_{10}. With $R_1 = 7$ mm $S_{0,1}$ becomes now

$$S_0 = S_{00} + \alpha(1-\alpha)^2 \int_0^{R_1} s(r) \int_0^H F_{\mathrm{d}isc\to dh} F_{\mathrm{d}h\to dr} dh\, dr \tag{4}$$

$$S_1 = S_{10} + \alpha(1-\alpha)^2 \int_0^H s(h) \int_0^H F_{\mathrm{d}isc\to dh_1} F_{\mathrm{d}h_1\to dh} dh_1 dh \tag{5}$$

Finally, we have a last term from the mirror at the cavity side of the precision aperture. The spherical mirror has a radius of 10 mm and produces a small image of the illuminated disc on the bottom of 0.76 mm diameter at 51.3 mm from the bottom. The radiative power in the image is proportional to $F_{\mathrm{d}isk\to mirror}$ and contained in the rays from the mirror to the image which finally reach the cylinder between $h = 39.5$ and 47.2 mm. By assuming that this radiation is equally distributed we can take the average of the sensitivity and with the solar-spectrum-weighted reflectivity of the gold coating $\rho = 0.94$ and $H_1 = 39.5$, $H_2 = 47.2$ mm the signal from the mirror is

$$S_2 = \alpha(1-\alpha)\rho \frac{F_{\mathrm{d}isk\to mirror}}{(H_2 - H_1)} \int_{H_1}^{H_2} s(h) dh. \tag{6}$$

This last result is quite different from what is reported in Crommelinck et al. (1995). As I do not understand their derivation, I take my approach. For Right and Left the three components are 0.9790757, 0.0168486, 0.0019006 and 0.9788820, 0.0168932, 0.0019022 and the sum equals the efficiency ϵ times the measured cavity absorptance α_c (0.999362$\pm$0.000147 and 0.9993913 $\pm$ 0.000067 for Right and Left from Chevalier et al. (1995, page 6)) which amounts to 0.9978249 and 0.9976773 for Right and Left. By dividing these values by α_c we get ϵ which is equivalent to the real non-equivalence between electrical and radiative heating of the cavity, namely 0.9984620 and 0.9982850 or 1538 and 1715 ppm for Right and Left – an interesting result by itself. In the evaluation program $\epsilon\alpha_c$ is set to $0.995918 \times 0.999809 = 0.995728$ and $0.997338 \times 0.999809 = 0.997147$ for Right and Left. Thus, the re-calculated efficiency requires a correction by $0.995728/0.9978250 = 0.9978983$ and $0.997147/0.9976773 = 0.9994684$ or -2102 and -532 ppm for Right and Left. With this correction the original difference between Right and Left of 4080 ppm at the beginning of the mission reduces to 2510 ppm and with the area related non-equivalence of 0.9946441 and 0.9943809 for Right and Left it is increased by 260 ppm. This difference of 2770 ppm is now just within the bounds of the corrected 2σ uncertainty for DIARAD of $\pm$1600 ppm and could well be real and not due to an accident as assumed by IRMB (in e.g. Fröhlich et al., 1997b) to explain the very large difference of nearly 0.5%.

This analysis should be repeated for the corrections in air in order to also trace back the results of the WRR comparison in 1995. The ratios to WRR were determined as 1.00667 and 1.01216 for left and right with DIARAD in VIRGO together with the PMO6V-A and B (see Section 3.2).

4 New absolute value of VIRGO TSI

The objective of the ISSI Team 'An Assessment of the Accuracies and Uncertainties in the Total Solar Irradiance Climate Data Record' is to characterize and compare all existing TSI data. To facilitate this task, TSI averages during the minimum period 2008/09/20 – 2009/05/05 are requested from all participating teams.

From a radiometric point of view it is clear that an equal consideration of PMO6V-A and B and DIARAD-L and R seems adequate. The early results of PMO6V-A and B on 24-12-1995, during first light with both operated in the 60 s open/closed mode can be used in the final analysis. As the difference between DIARAD-L and R is now within the stated uncertainty there is no reason to believe that there were some uncontrolled changes of DIARAD during its manufacturing and/or

Table 3: *TSI values for the different radiometers within VIRGO for the period 2008-09-20 – 2009-05-05. The values of PMO6V-B, DIARAD-R are deduced from PMO6V-A, DIARAD-L with the difference recorded at the beginning of the mission. (A+B) or (L+R) means average of A and B or L and R.*

	PMO6V-A	PMO6V-B	PMO6V-(A+B)	DIARAD-L	DIARAD-R	DIARAD-(L+R)
V 6.4	1365.0394	1360.6248	1362.8321	1365.7992	1371.3696	1368.5844
V 6.4,L,R corr	1365.0394	1360.6248	1362.8321	1365.0731	1368.4873	1366.7802
V 7.0	1362.4869	1358.0806	1360.2837	1357.1511	1360.9082	1359.0296

integration into VIRGO. This is also indicated by the fact that the large difference in space of 4079 ppm was already seen during the test on ground with 5665 ppm and is now – at least – partly explained by some erroneous constants in the evaluation program. It is interesting to note that the change of DIARAD R/L ratio from ground to space of 1586 ppm is similar in magnitude to the change of PMO6V A/B by 1332 ppm. The values of the VIRGO TSI for the agreed period are summarized in Table 3 for PMO6V-A and B and DIARAD-L and R and from these results the new VIRGO TSI values can be derived (A+B or L+R means average of A and B or L and R).

The final value of VIRGO TSI version 7.0 during the period 2008/09/20 – 2009/05/05 is $1359.66 \pm 2.47\,\mathrm{Wm}^{-2}$ with the uncertainty given as standard deviation of the four PMO6V-A & B and DIARAD-L & R values. Compared to the TIM/SORCE value for the same period of $1360.52\,\mathrm{Wm}^{-2}$ the VIRGO value is 633 ppm or $0.86\,\mathrm{Wm}^{-2}$ lower, which is still within the absolute uncertainty of these radiometers of the order of 1700 ppm. The corresponding values of PMO6V (scale of average PMO6V-A and B) and DIARAD (scale of average R and L) are 1360.28 and $1359.03\,\mathrm{Wm}^{-2}$ and the factors to convert version 6.4 values to version 7.0 are 0.9957789, 0.9965161, 0.9950435, for VIRGO, PMO6V and DIARAD respectively.

5 Discussion

The differences between A and B of 3240 ppm is large and just within two times the uncertainty of 1700 ppm. This large difference may be partly due to the fact that we have used for both radiometer $C_{SLvac} = 3285 \pm 600$ ppm, the value for VIRGO-2 with the uncertainty from the scatter including the results of SOVIM-1 and 2. An other difference may exist from the aperture area comparison at NIST (Johnson et al., 2013) which determined the maximum differences between the determination by the Swiss Metrology Institute and NIST as 550 ppm for 6 apertures, including those of VIRGO2 and 4. So, we may explain about 1000 ppm of the PMO6V difference. The ground comparison scaled to the new radiometric constants yield a much smaller difference $A-B$ of 790 ppm which may indicate that their are still some explained effects in the PMO6 type radiometers. The difference between L and R with 2760 ppm is also important and of similar magnitude as for the PMO6Vs. From the aperture area comparison at NIST the spread of the difference between the determination by Belgium Metrology Institute and NIST for 4 apertures amounts to 1060 ppm. The result of the ground comparison cannot be directly used because the analysis the measurements in air is still not done, but it is probably in the same order of magnitude. So, for both type of radiometers only about one third to half of the difference between the operational and backup radiometer can be readily explained which could still mean that the absolute uncertainty is underestimated.

Anyway, these results are on each radiometer's generic absolute scale and not referred to the Word Radiometric reference nor to the Space Absolute Radiometric Scale (SARS). It is also interesting to note that the difference between PMO6V and DIARAD is smaller than the standard deviation of all 4 radiometers, which may indicate that the applied corrections for both the PMO6V and DIARAD are well established. This is also confirmed by the difference of Version 7.0 to TIM of 600 ppm during the last solar minimum.

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