Title: **Explanations for excess EQM Straylight**

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Table of Contents

Table of Figures

Fehler! Es konnten keine Einträge für ein Abbildungsverzeichnis gefunden werden.

List of Tables

1 Introduction

During EQM tests, excess straylight was found by PACS, when compared to the findings in HP-2-ASED-TN-0076. The excess factors reported by PACS are 46 at 88 µm and 26 at 177 µm. SPIRE also reported excess straylight (SPIRE-RAL-NOT-000, dated 31/01/06).

Following these findings, some specific straylight tests have been performed by PACS. Various temperatures and irradiations have been changed in order to find the straylight source.

Also new straylight calculations have been made, with some important changes compared to previous calculations.

2 EQM straylight tests performed

In order to find the reason for the excess straylight, various irradiations have been changed, mainly by changing the temperature of the emitting source, and looking whether the straylight on PACS changes. During this testing the radiation from the cryocover as an intended source was suppressed, by cooling the cryocover to below 20 K.

The EQM straylight tests concentrated on items which could be varied easily. In total four potential sources have been tested.

1. The one open LOU window has been illuminated with a lamp. The other windows are replaced by Al-flanges on EQM and therefore could not be removed for this test. No change in straylight was observed.
2. The cables on the optical bench have been excessively heated by leading a large current through them. No change in straylight was observed.
3. In order to exclude, that contamination on the cryocover mirrors lead to excess straylight, the cryocover mirrors have been heated to around 220 K for about 10 minutes. This should remove any water contamination from these mirrors. No change in straylight was observed, after the cryocover mirrors were down to below 20 K again.
   However, it turned out that these cryocover mirrors have been at 220 K for a longer period up to only 3 days before. This is to less time to build a significant contamination layer. An influence of potentially contaminated instrument mirrors, mainly at the instrument entrance, cannot be excluded from this. These mirrors were at low temperatures already several months, and the straylight impact can go with the square of the contamination thickness.
4. The temperature of the thermal shield 2 was varied. This showed a large effect on straylight. At least half of the straylight can be explained by this. The reason nevertheless is not a higher emission from this source, but a better transport of this straylight by mirrors (cryocover mirrors and instrument mirrors) and also structural parts of the instruments.
   It should be noted, that in TN-0076 also about half of the straylight is expected from the thermal shield 2. The other part mainly comes from the warm CVV and crown.

3 Observed differences compared to calculated straylight.

As already mentioned in the introduction, PACS measured a factor of 46 higher straylight at 88 µm and a factor of 26 higher straylight at 177 µm, compared to the calculations for straylight in TN-76 of 2.69% of the telescope straylight. It must be mentioned, that these 2.69% are scattered straylight only, there is an additional contribution from diffraction, which is treated separately in TN-76 (chapt. 4.2). It also must be noted that these calculations are for ideal configuration. Misalignments as to be expected might contribute another factor of 1.2 to 1.3 (calculated for the case of a cryocover mirror tilt of 40 arcminutes as an example in TN-76, page 29).

In relation to the nominal telescope contribution (=100%), the measured total straylight except the cryocover mirrors itself therefore is about 124% at 88 µm and about 70% at 177µm.

SPIRE also reported excess straylight and give some hints where it could come from (SPIRE-RAL-NOT-000, dated 31/01/06). The calculated straylight in TN-0076 here was 5.76% of the telescope straylight.

Temperature of Thermal Shield 2 was higher (67 K instead of 57 K in calculations)

4 Observed differences EQM-configuration versus straylight model

- Thermal Shield 2 Baffle Flat Aperture is missing in EQM.
- On +X side of Thermal Shield 2 Baffle Tube there was an elongation made with Al-foil (glued to the baffle tube). The elongation in +X direction was about 16 – 18 mm. The gap between CVV bottom and Thermal Shield 2 Baffle Tube top is 14.5 mm in the model, actual gap in EQM is tbd. Because this foil therefore most likely touches the warm CVV, it is crushed in unpredictable manner, and its temperature also will be higher in an unpredictable manner, somewhere in the middle between CVV temperature and Thermal Shield 2 Baffle temperature. It means that the crown surfaces most likely are covered completely by this foil, and therefore do not contribute to the straylight, except small irregular slits. Instead of that, the straylight from CVV rim and from the black cryocover cone have better access.
  This additional blank foil also covers about the upper 15 mm of the Thermal Shield 2 Baffle Tube.
- SPIRE surfaces from the entrance plane up to the filter 1 were modelled black, with reflectivity 0.05. It turned out that this entrance section is metallic, with much higher reflectivity, except for a small section of estimated 30 – 50 cm area. The actual average reflectivity of the entrance section therefore may be somewhere between 0.8 and 0.9.
- HIFI was modelled with flight configuration. In the EQM, only channel 3 is in flight configuration, the other channels are covered by a tilted Al-plate, which, however, could lead straylight from the LOU windows into HIFI via other holes. HIFI to clarify whether this is real or not. It also could bend more light from the LOU windows towards the path between instruments and Instrument Shield.
- Only Thermal Shield 1 was polished internally to have a high reflectivity, whereas the other thermal shields and the Instrument Shield surfaces were untreated surfaces, leading to higher absorption. In terms of straylight this improves the situation, because more straylight is absorbed by them.

5 Further potential impacts not considered in the straylight model

- Contamination of the entrance mirrors in both PACS and SPIRE could cause additional scattering not considered in the model. Contrary to the CVV mirrors, which have been heated up to remove contamination, but were at cold temperatures only for a period of 3 days before, the instrument entrance mirrors were at cold temperatures for about 3 months, and therefore could have collected much more water contamination (factor of about 30) than the CVV mirrors. Note also that the straylight effect (TIS) goes with about the square of roughness. If the roughness goes with thickness, then the effect onto straylight could be about a factor of 900 higher for the instrument mirrors. However, PACS also explained that severe contamination would probably cause other effects, which would be noticed by PACS. So in total this explanation is unlikely, at least for PACS.
- The high observed straylight of SPIRE could come from internal reflections within SPIRE. **This is the most likely reason for the excess straylight seen by SPIRE, especially because the input section is not black.** Up to now these internal reflections are not considered in the model. The ASAP model received from SPIRE has some simplifications in geometry, which would make such calculations questionable.
- For PACS an explanation from high internal reflections seems unlikely, because it has black internal surfaces.
- Presently it is not clear, whether there may be additional straylight being caused by the HiFi channels which are closed for the usual way through HiFi, but instead of that opens a different straylight path through HiFi. This has to be clarified by HiFi.
- The filling port of the Tank is at 300 K and seems to be close to the optical path, eventually not suppressed enough. Details to be clarified.
- The emissivity of surfaces is assumed to be according to Lambertian law. This is not the case for low reflective surfaces. Example of high polished gold surface shows expected low emissivity only for angles up to about 70 – 80° from normal, whereas for grazing angles the emissivity goes to quite high values (see fig. 5.1-1 below).

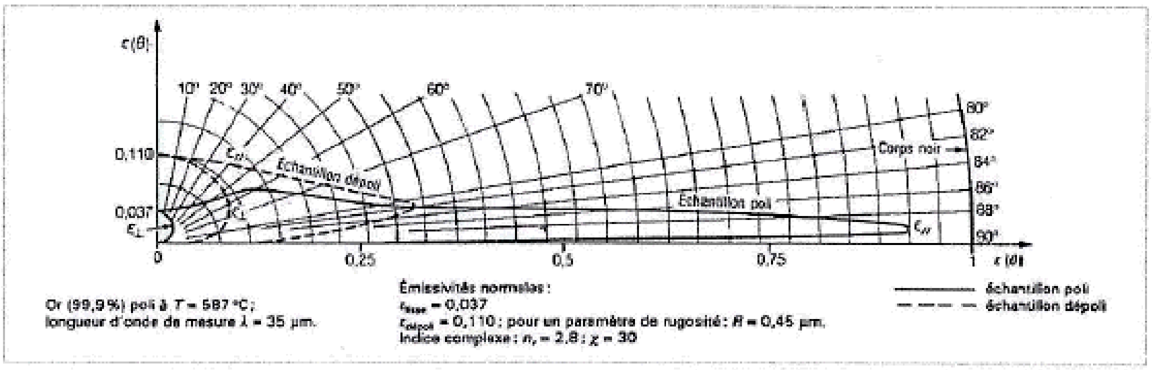

Figure 19 – Indicatrices d'émission de l'or poli et de l'or dépoli

Fig. 5.1-1: Emissivity of gold surfaces as a function of angle against surface normal.

6 New ASAP calculations

6.1 General

Due to the large discrepancies, new ASAP calculations have been performed, in order to calculate with more actual design and in order to detect potential calculation errors. The new calculations up to now have been made with the following changes:

- Better search strategy (revealed some additional straylight paths).
- Thermal shield 2 baffle flat aperture was deleted, because not in the EQM
- Thermal shield 2 tube temperature changed from 57 to 67 K.
- The BRDF for the cryocover mirror was detected to be too low for PACS by a factor of most likely 10 to 15 at 88 µm, and a factor of most likely 2.5 to 3.75 at 177 µm. Therefore the cryocover mirror BRDF was increased by a factor of 15 for 88 µm and a factor of 3.75 for 177 µm. For SPIRE, the previous BRDF was about o.k. at 230 µm respectively even overestimated at longer wavelengths, here no change was made.
  It should be noted, that the new BRDF values are theoretical values only, and should be substituted later by measured values, if possible.
- Radiation from the gap between Thermal Shield 2 baffle tube and the Instrument Shield Tube was added as a new straylight path.

The following further differences between new model geometry and actual EQM geometry, found during the EQM straylight inspections still have to be implemented (see chapt. 4), and calculations to be performed:

- Deletion of crown and introduction of the additional Al-foil on top of Thermal Shield 2 Baffle Tube instead.
- Change of reflectivity of SPIRE input section from 0.05 to 0.9.

The following important differences between new model / model geometry and EQM / EQM geometry presently cannot be modelled, at least not in an easy way:

- Emission of white surfaces different from Lambertian law.
- Instrument internal reflections from structural surfaces (especially important for high reflective surfaces of SPIRE, but requires more detailed design of SPIRE model).

The following potential differences between new model / model geometry and EQM / EQM geometry have to be clarified and eventually included in the new model, depending on result of findings:

- Potential paths through HiFi
- Filling port of the Tank at 300 K.

6.2 Results of new calculations

Emitting object	temperature/ emissivity	PACS detector		SPIRE detector	
		88 µm	177 µm	230 µm	670 µm
CVV ring	295 K / 0.05	*4.1*	*0.6*		
crown surfaces (to be substituted by elongation of thermal shield 2 baffle tube)	293 K / 0.05 (180 K* / 0.05)	*14.2*	*1.9*		
thermal shield 2 baffle tube	67 K / 0.50	28.9	*8.0*	*3.6*	*3.7*
short outer cone of cryocover	75 K / 0.50	*3.7*	*1.0*		
gap between thermal shield 2 tube and instrument shield tube	67 K / 0.90	*2.4*	*0.7*		
gap between instrument shield and instruments	12 K / 0.90	*0.0*	*0.1*		
Tank via holes in OB	50 K / 0.90	*0.9*	*0.4*		
LOU- and alignment-windows via gap between instrument shield and instruments	295 K / 0.90	*2.8*	*0.4*		
sum scattered light without misalignment		**57.0**	**13.1**		
additional diffracted light (5 % of scattered light)		*2.9*	*0.7*		
misalignment (30 % of scattered light)		*17.1*	3.9		
sum total		**77.0**	**17.7**		

Data for PACS and SPIRE are in % with 100% = telescope irradiation (70 K, total ε=0.03)
* = best estimate only, no destination of temperature possible.
Figures in italic are preliminary estimates, because calculations are preliminary and have not been evaluated in detail up to now.
Figures do not contain straylight from reflections on instrument internal structural surfaces (except entrance section).

Table 6.2-1: Calculated EQM straylight.

Calculations have been performed for scattered light only, with ideal alignment. Additional straylight caused by diffraction and by misalignment then have been added coarsely by certain multiplication factors.

7 Expected straylight for flight configuration

7.1 PACS

At present, only part of the excess straylight (about half at 88 µm and about a quarter at 177 µm) can be definitively explained by a higher BRDF for the cryocover mirrors. This well may change after a potential measurement of the BRDF at PACS wavelengths. Provided that the reason for the excess straylight really is caused by the high BRDF of the cryocover mirror alone, the in flight straylight is expected to be as in TN-0023, because the cryocover mirror then is not in the main straylight path anymore.

If there is significant additional straylight caused by reflections from internal surfaces (not very likely), or the PACS entrance mirrors are contaminated much (also not very likely), then the in flight straylight situation in orbit is worse, when compared to results in TN-0023. But it still should be lower than on ground, because much of the on ground straylight is caused by these cryocover mirrors.

Potential contributions from HiFi due to paths different from FM would not contribute to FM straylight.

The directional dependence of thermal emission could change the straylight situation somewhat, but cannot be implemented in the model.

There also could be a further explanation. If revealed true, this could cause a much higher BRDF especially at angles around 12° from normal: The artificial roughness of the cryocover mirror is made such that a larger portion of the microscopic surface seems to be tilted by about 6° against the macroscopic surface (see HP-2-ASED-TR-0038). This also seems to be about the maximum tilt angle. The question is, whether the long wavelengths still can "see" this preference in tilting or not. A BRDF measurement therefore is essential.

7.2 SPIRE

The most likely reasons for the excess straylight are reflections at the SPIRE internal structural surfaces. Because the BRDF of the cryocover mirror is much better at SPIRE wavelengths, reflection and scattering from this mirror contribute only a small part to the total SPIRE straylight. It therefore most likely will be not much better in flight configuration. The temperatures of CVV and Thermal Shield 2 Baffle are lower, this may help to reduce the in flight straylight from these sources by about a factor of 2. However, then additional straylight is expected from the structure above the CVV (e.g. sunshade, M1-baffle cone and cylinder), which suffer also from instrument internal reflections and therefore is much higher than predicted in TN-0023.

8 Summary and Conclusion

The excess straylight most likely is caused by

- PACS: much higher scattering of cryocover mirror (BRDF) compared to the previous model. With present best guess BRDF this explains about half of the straylight at 88 µm and about a quarter at 177 µm. But the real BRDF could be even higher, such to explain the total straylight. It therefore should be measured, if possible. Other potential sources such as PACS internal reflections and contamination are unlikely to contribute significantly.
- SPIRE: Internal reflections on structural surfaces, because SPIRE structural surfaces are blank metallic and therefore high reflective.

Expected straylight for in flight conditions:

- PACS: provided that all excess straylight finally can be attributed to the excess scattering of the cryocover mirrors, the in flight straylight will be as predicted in TN-0023, because this cryocover mirror BRDF do not contribute to in-flight straylight. If the other potential sources contribute significantly, the straylight will be higher, but most likely still below the EQM results, due to lower temperatures.
- SPIRE: The in flight straylight is expected to be about the same as on ground. The additional straylight from e.g. Sunshade and M1 baffle most likely will outweigh the less straylight from lower temperatures of Thermal Shield 2 and CVV. The only possibility to reduce this straylight is to make structural surfaces of SPIRE black.

E N D O F D O C U M E N T

	Name	Dep./Comp.		Name	Dep./Comp.
	Alberti von Mathias Dr.	AOE22		Runge Axel	OTN/AOA54
	Barlage Bernhard	AED11		Schink Dietmar	AED44
	Bayer Thomas	AOA52	X	Schlosser Christian	OTN/AOA54
	Brune Holger	AOA55		Schmidt Rudolf	FAE22
	Edelhoff Dirk	APS3		Schweickert Gunn	AOE22
	Fehringer Alexander	AOE13		Steininger Eric	AED32
X	Fricke Wolfgang Dr.	AED 65	X	Stritter Rene	AED11
	Geiger Hermann	AOA52		Suess Rudi	AOA54
	Gerner Willi	AED11		Thörmer Klaus-Horst Dr.	OTN/AED65
	Grasl Andreas	OTN/AOA54		Wagner Klaus	AOE22
	Grasshoff Brigitte	AET12	X	Wietbrock Walter	AET12
	Hauser Armin	AOE22		Wöhler Hans	AOE22
	Hendry David	Terma Resid.		Wössner Ulrich	ASE442
	Hengstler Reinhold	AOA 5	X	Alcatel	ASP
	Hinger Jürgen	AOE22	X	ESA/ESTEC	ESA
	Hofmann Rolf	ASE442		**Instruments:**	
	Hohn Rüdiger	AED65	X	MPE (PACS)	MPE
	Hölzle Edgar Dr.	AED44	X	RAL (SPIRE)	RAL
	Huber Johann	AOA52		SRON (HIFI)	SRON
	Hund Walter	ASE442		**Subcontractors:**	
X	Idler Siegmund	AED312		Air Liquide, Space Department	AIR
	Ilsen Stijn	Terma Resid.		Air Liquide, Space Department	AIRS
	Ivády von András	FAE22		Air Liquide, Orbital System	AIRT
	Jahn Gerd Dr.	AOE22		Alcatel Bell Space	ABSP
	Kalde Clemens	APE3		Astrium Sub-Subsyst. & Equipment	ASSE
	Kameter Rudolf	OTN/AOA54		Austrian Aerospace	AAE
	Kettner Bernhard	AET42		Austrian Aerospace	AAEM
	Knoblauch August	AET32		APCO Technologies S. A.	APCO
	Koelle Markus	AOA53		Bieri Engineering B. V.	BIER
	Koppe Axel	AED312		BOC Edwards	BOCE
X	Kroeker Jürgen	AED65		Dutch Space Solar Arrays	DSSA
	Kunz Oliver Dr.	AOE22		EADS CASA Espacio	CASA
	Lamprecht Ernst	OTN/ASI21		EADS CASA Espacio	ECAS
	Lang Jürgen	ASE442		EADS Space Transportation	ASIP
	Langenstein Rolf	AED15		Eurocopter	ECD
	Langfermann Michael	AOA51		European Test Services	ETS
	Mack Paul	OTN/AOA54		HTS AG Zürich	HTSZ
	Maute Thomas	AOA52		Linde	LIND
	Much Christoph	AOA53		Patria New Technologies Oy	PANT
	Müller Jörg	AOA52		Phoenix, Volkmarsen	PHOE
	Müller Martin	AOA53		Prototech AS	PROT
	Müller Ralf	FAE22		QMC Instruments Ltd.	QMC
	Peltz Heinz-Willi	AOE13		Rembe, Brilon	REMB
	Pietroboni Karin	AED65		Rosemount Aerospace GmbH	ROSE
	Platzer Wilhelm	AED22		RYMSA, Radiación y Microondas S.A.	RYM
	Reichle Konrad	AOA52		SENER Ingenieria SA	SEN
	Reuß Friedhelm	AED62		Stöhr, Königsbrunn	STOE
X	Rühe Wolfgang	AED6		Terma A/S, Herlev	TER