SPIRE-AST-REP-002637

Title: **Explanations for excess EQM Straylight**

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Issue	Date	Sheet	Description of Change	Release
Draft			new document	
1	24.04.06		new calculation results and other findings implemented	

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1 Introduction

This document discusses the straylight results obtained during the EQM tests.

In HP-2-ASED-TN-0076, 2.69% respectively 5.76% of the telescope straylight are predicted for PACS respectively SPIRE (for scattered straylight only, not including diffracted straylight, and independent of wavelength). During the EQM tests, excess straylight was found by PACS (see PACS-ME-TR-059), when compared to these predictions. The excess factors reported by PACS are 46 at 88 µm (i.e. measured 124%) and 26 at 177 µm (i.e. measured 70%). SPIRE also reported excess straylight (SPIRE-RAL-NOT-000, dated 31/01/06).

Specified is ≤ 10% of the telescope straylight.

Following these findings, some specific straylight tests have been performed by PACS on EQM in December last year (see PACS-ME-TR-060). 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 thermal emissions have been changed, mainly by changing the temperature of the emitting source, and looking whether the straylight on PACS changes. During this testing the thermal emission 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. A cable on the optical bench has been excessively heated by leading a current through it. 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 too 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 Entrance Baffle cylinder 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 scattering on cryocover mirrors (PACS) and by structural parts of the instruments (SPIRE).
   It should be noted, that in TN-0076 also about half of the straylight is expected from the Entrance Baffle cylinder. The other part mainly comes from the warm CVV.

3 Observed differences compared to calculated straylight in TN-0076

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-0076 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-0076 (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-0076, page 29).

The values measured by PACS correspond to 124% of the telescope straylight at 88 µm and to 70% of the telescope straylight at 177 µm, whereas the specified value is ≤ 10%.

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.

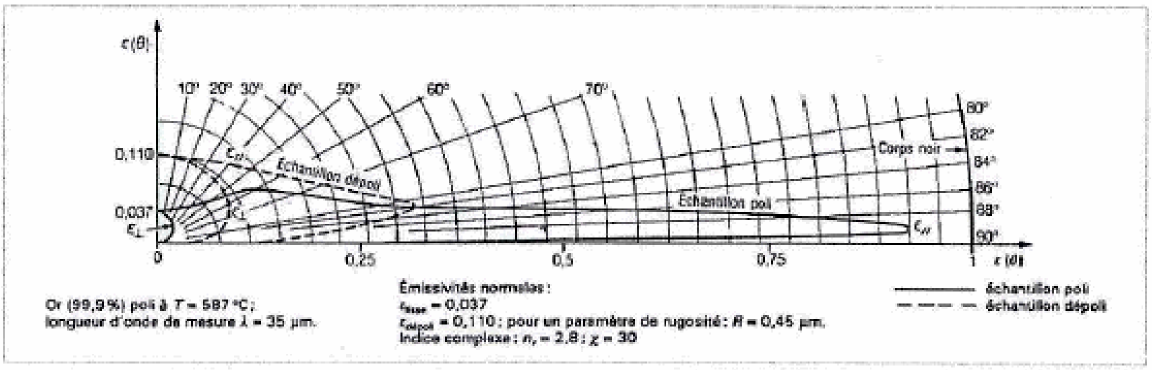
4 Observed differences EQM-configuration versus (old) straylight model

- Entrance Baffle flat aperture is missing in EQM.
- On +X side of Entrance Baffle cylinder there was an elongation made with Al-foil (glued to the baffle cylinder). The elongation in +X direction was about 16 – 18 mm. The gap between CVV bottom and Entrance Baffle cylinder top is 14.5 mm in the model. Therefore this elongation goes somewhat into the CVV hole, but anyway does not touch the CVV, because the opening in the CVV has a somewhat larger diameter. The temperature of this elongation could not be determined. From the attachment point of view it should have about the temperature of the Entrance Baffle. However, it turned out that the attachment was not very good. The (worst case) temperature of this elongation therefore is assumed to be in the middle between Entrance Baffle temperature and CVV temperature, which is 180 K. This elongation also covers about the upper 14 mm of the Entrance Baffle cylinder.
- 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 cm² area. The actual average reflectivity of the entrance section therefore is assumed to be 0.95.
- HiFi is 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, leads some less straylight from the LOU windows into HiFi via other holes. It also could bend more light from the LOU windows towards the path between instruments and Instrument Shield, but this is minor and is covered by the model assumptions.
- 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 slightly, because more straylight is absorbed by them.
- The boundary between PACS and SPIRE cryocover mirrors is slightly curved in the Y-Z-plane. In the model this is approximated by a straight boundary.
- Temperature of Entrance Baffle cylinder during straylight measurements was higher than expected (67 K instead of 57 K in calculations)

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. And SPIRE reported verbally, that it would need very thick contamination to make an effect. So in total this explanation is unlikely.
- The 3rd straylight inspection showed, that some light goes also through the inactivated HiFi channels, but significantly less than through the nominal channel No. 3. In the analysis, the Flight Model HiFi is contained with 7 active channels. This represents a worst case for HiFi.
- The filling port of the Tank is at 300 K. There are small slits in the MLI surrounding this filling port at each feed through of the thermal shields. This could lead some 300 K emission towards the instruments, via paths between Thermal Shield 1 / Instrument Shield and between Instrument Shield / Instruments. However, these slits are small compared to the openings in the LOU baffle, where 300 K emission goes through directly towards the space between Thermal Shield 1 / Instrument Shield and between Instrument Shield / Instruments. This filling port therefore has been neglected. The same apply to the fixation struts between CVV and He-tank.
- Structural surfaces are contained not completely in the models for SPIRE, PACS and HiFi. This makes calculations with reflecting internal structural surfaces questionable to a certain extend, at least for the high reflective surfaces of SPIRE.
- The contribution from the blank horizontal surface next to the cryocover mirrors has been neglected so far. The reason is that this surface transports much more straylight from other objects than it emits itself. Only the contribution from the tilted black section of the cryocover has been considered therefore.
- 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).



Or (99,9%) poli à $T = 587$ °C ;
longueur d'onde de mesure $\lambda = 35$ µm.

Émissivités normales :
$\varepsilon_{\text{lisse}} = 0{,}037$
$\varepsilon_{\text{dépoli}} = 0{,}110$; pour un paramètre de rugosité : $R = 0{,}45$ µm.
Indice complexe : $n_r = 2{,}8$; $\chi = 30$

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 Changes in the model

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, in order to better reflect the EQM:

- Better search strategy (revealed some additional straylight paths).
- Entrance Baffle flat aperture was deleted, because not in the EQM
- Entrance Baffle cylinder 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.
- Introduction of an additional surface with 95% reflectivity on the +X side of the Entrance Baffle cylinder, covering also the upper 14 mm of the Entrance Baffle cylinder itself.
- Change of reflectivity of SPIRE input section from 0.05 to 0.95.
- Introduction of 95% reflectivity for the other SPIRE structural surfaces, apart from the input section itself. This was not in the model before.
- Calculation of additional paths and sources not considered before:
  - Path from LOU windows through HiFi
  - Path from LOU windows towards the gap between Entrance Baffle cylinder and Instrument Shield (previous calculation considered only the path from LOU windows towards the gap between Instrument Shield and Instruments)
  - Thermal emission from the gap between Entrance Baffle cylinder and the Instrument Shield cylinder

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

- Thermal emission of white surfaces different from Lambertian law.

- In the model, the boundary between PACS and SPIRE is a straight line in the Y-Z-plane.

The following differences between new model / model geometry and EQM / EQM geometry are negligible (e.g. against 300 K emission from LOU), and therefore are not in the model:

- Filling port of the Tank
- Fixation struts between CVV and He-tank

Both sources could lead some 300 K emission towards the space between Instrument Shield / Instruments via holes in the Optical Bench, and towards the space between Instrument Shield / Thermal Shield 1, in a similar way as the 300 K emission from LOU windows, but with much less cross sections.

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	2.59	0.35	4.76	3.70
Crown surfaces	293 K / 0.05	1.80	0.24	2.15	1.68
Entrance Baffle (ENB) cylinder	67 K / 0.50	25.12	6.74	85.41	86.77
elongation of ENB cylinder	180 K* / 0.05	1.04	0.15	1.38	1.12
short outer cone of Cryocover	75 K / 0.50	4.81	1.25	17.94	17.53
gap between ENB cylinder and Instrument Shield cylinder	67 K / 0.90	3.14	0.86	3.19	3.24
gap between Instrument Shield and instruments	14 K / 0.90	0.00	0.06	1.34	7.92
Tank via holes in OB	50 K / 0.90	0.56	0.29	2.92	3.38
LOU- and alignment-windows via HiFi	295 K / 0.90	0.04	0.01	0.92	0.71
LOU- and alignment-windows via gap between ENB cylinder and Instrument Shield cylinder	295 K / 0.90	1.62	0.21	0.66	0.52
LOU- and alignment-windows via gap between Instrument Shield and instruments	295 K / 0.90	1.70	0.27	2.22	1.72
sum scattered light without diffraction / misalignment		**42.4**	**10.4**	**122.9**	**128.3**
additional diffracted light (5 % of scattered light assumed)		2.12	0.52	6.14	6.41
misalignment (30 % of scattered light assumed)		12.73	3.13	36.86	38.48
calculated total		**57.3**	**14.1**	**165.9**	**173.2**
measured during EQM test		**124**	**70**		

Data for PACS and SPIRE are in % with 100% = telescope irradiation (70 K, total $\varepsilon = 0.03$)
* = best estimate only, no destination of temperature possible.
exact measured values during EQM test for SPIRE cannot be given, but also exceed the specification of 10% by more than a factor of 10

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.

The main differences to the much lower calculation results presented in HP-2-ASED-TN-0076 are due to

PACS: much higher cryocover BRDF

SPIRE: high reflectivity of SPIRE structural surfaces

6.3 Potential explanation of the sharp spot seen in the PACS FOV

In PACS-ME-TR-060 it is reported that there exist an up to now not explained relative sharp straylight spot in the PACS FOV. In the following, it is shown that a larger particle located on the entrance mirror (called TROG1 in the ASAP code) could generate such a spot. It has been investigated with ASAP, how large this potential particle must be, in order to explain the observed feature:

- A small emitting source of 1 mm² area close to TROG1 generates a sharp spot on the detector, via reflection on the cryocover mirror (see Figures 6.3-1 to 6.3-3). The irradiation onto the detector is about 2.5E-3, if the source emits 1 into hemisphere.
- In a second step it was investigated how much irradiation this 1 mm² area gets from the ENB, either directly or via scattering at the cryocover mirror. Result: This 1 mm² receive about 8% of the light which the telescope emits onto the whole detector area, for 88 µm wavelength.

The total result in terms of the usual %age of the telescope emission therefore is 0.02% for 88 µm, which however is concentrated in a small spot on the detector. The spot size in PACS-ME-TR-060 is very roughly estimated by ASED to be about 1/2000 of the detector area (quite uncertain, should be confirmed by PACS, respectively PACS should determine the relative amount of irradiation in this spot compared to the overall straylight in the PACS FOV). If we assume that a 1 mm² particle generates this, then the reflection of light with origin from ENB emission alone would be about 40% of the telescope emission on a 1/2000 fraction of the detector area, exceeding the average level of the straylight from the ENB (25% in Table 6.2-1) locally by about a factor of 1.6.

ASED cannot destine the relative height of the peak in Figure 2 of PACS-ME-TR-060, respectively cannot destine the amount of straylight in this peak relative to the total straylight, because it does not know the zero level.

A photograph taken before the 3rd EQM straylight inspection shows a particle on the PACS entrance mirror (see Fig. 6.3-4).

PACS noted that this peak nevertheless cannot be explained by this mechanism, because it moves twice as fast with chopper angle as the other straylight background, and therefore needs twofold reflection at the chopper.

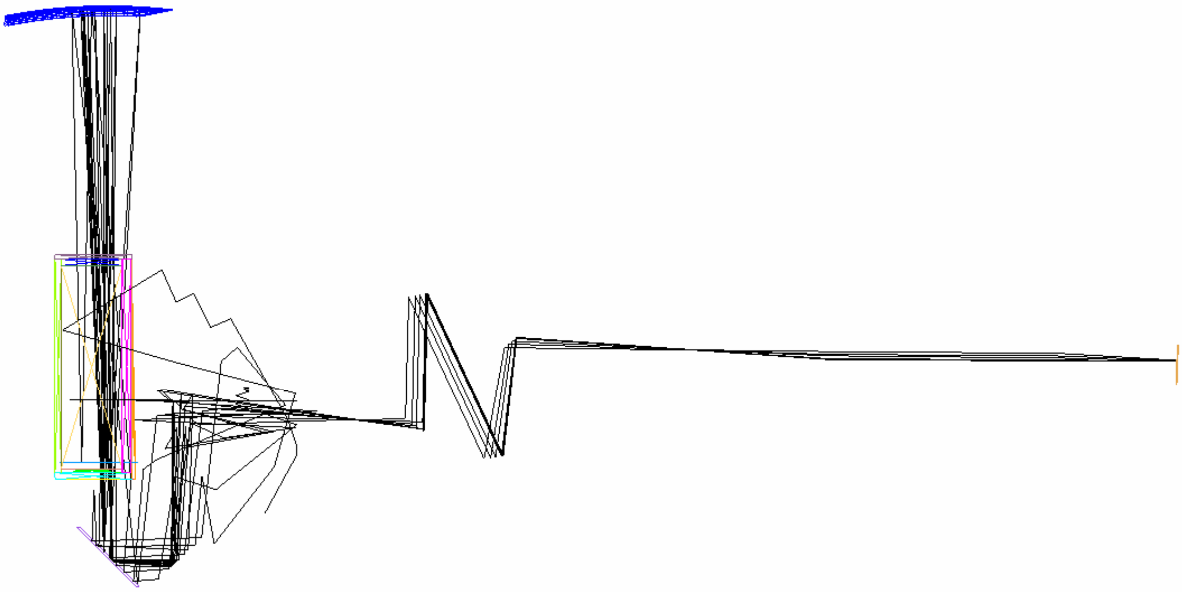


Fig. 6.3-1: General straylight path from particle on TROG1 via cryocover mirror onto PACS detector. For reasons of better visibility of the straylight path only few of the PACS surfaces are shown, and the emitting rays are limited to +/- 5° from normal (not in the real calculation).

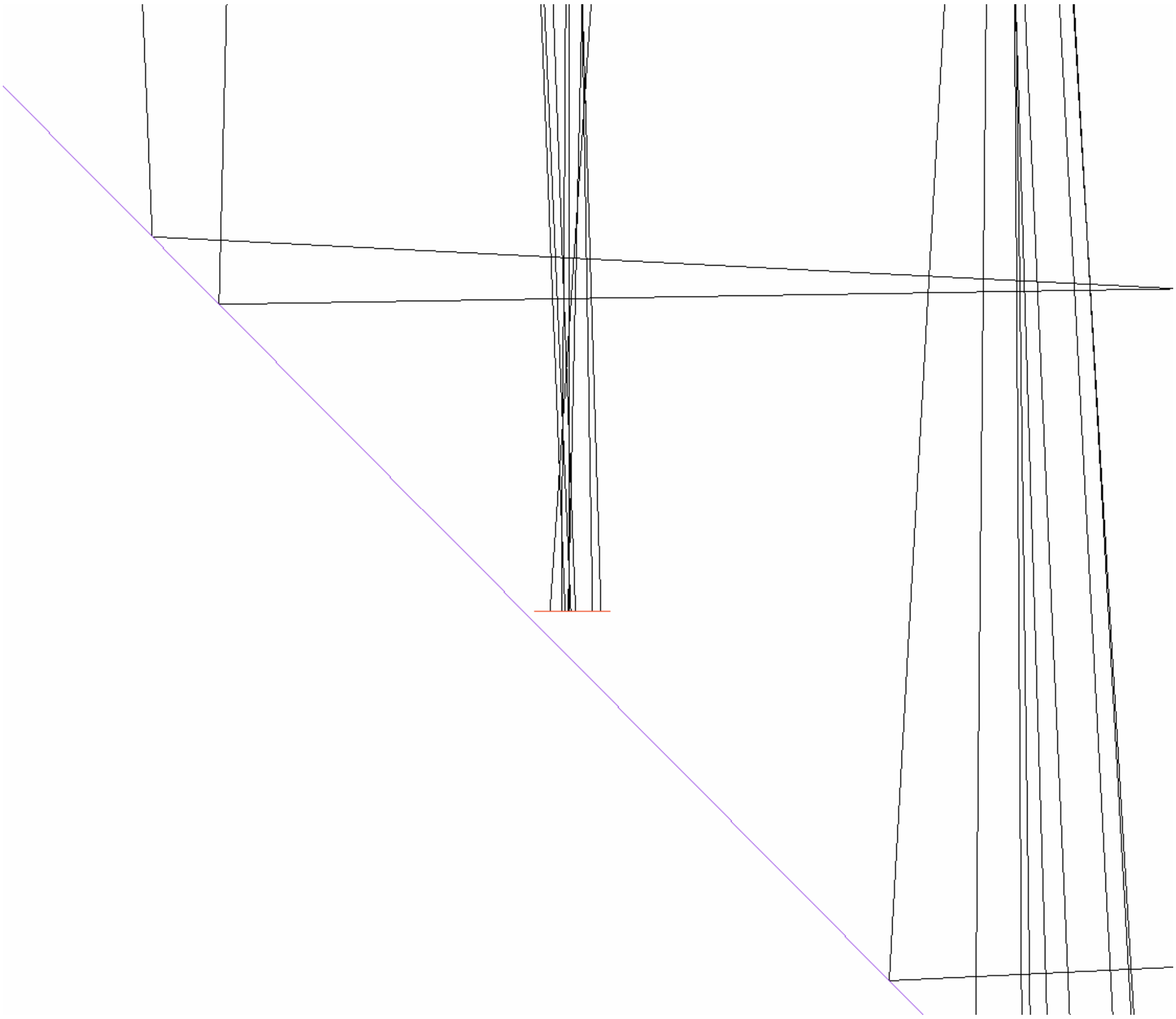


Fig. 6.3-2: Much enlarged cutout of Fig. 6.3-1. Shown are the emitting source (small pink horizontal line) and a section of TROG1 (lilac-coloured tilted line)

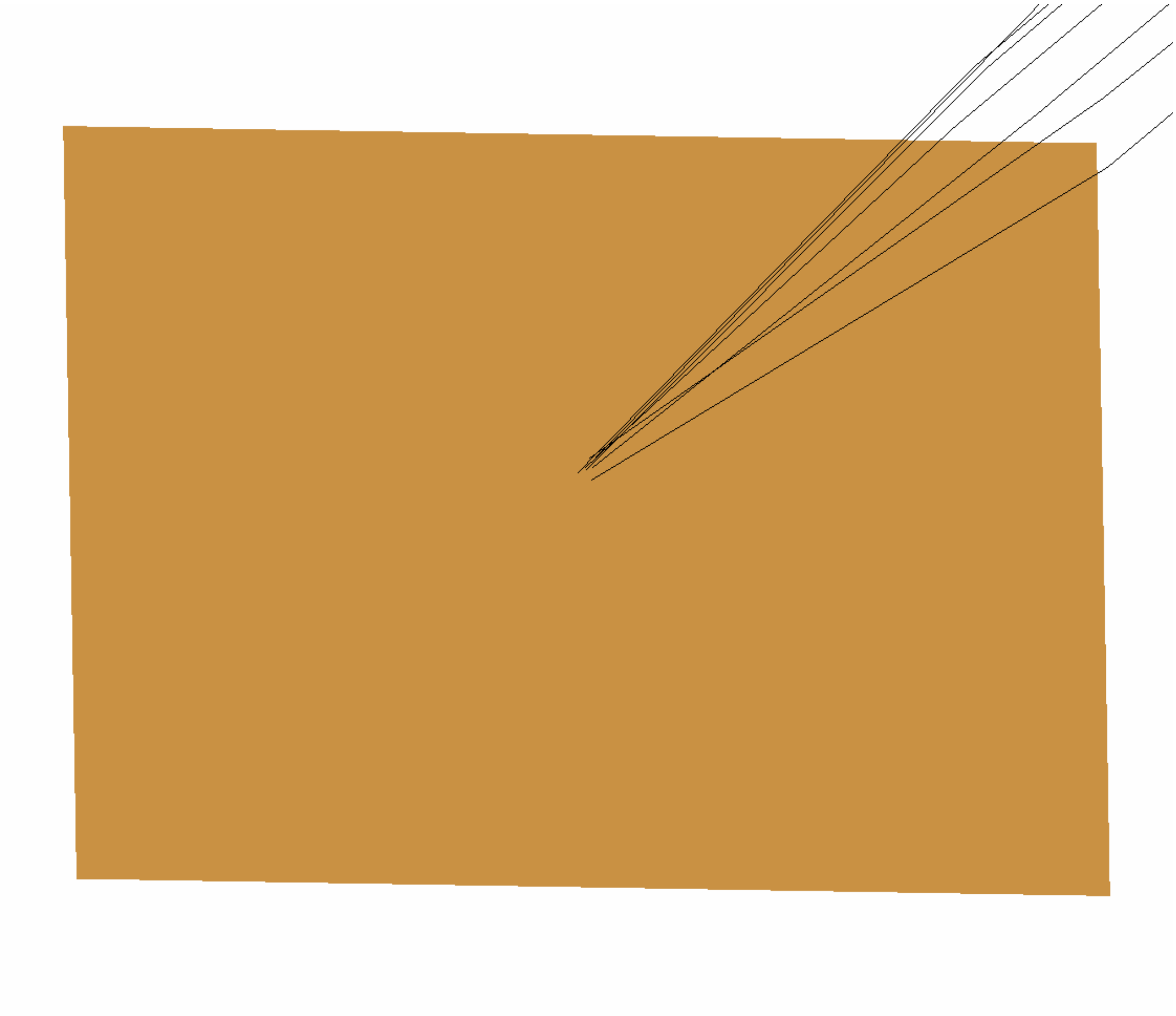


Fig. 6.3-3: Tilted view of the PACS detector, with impinging rays

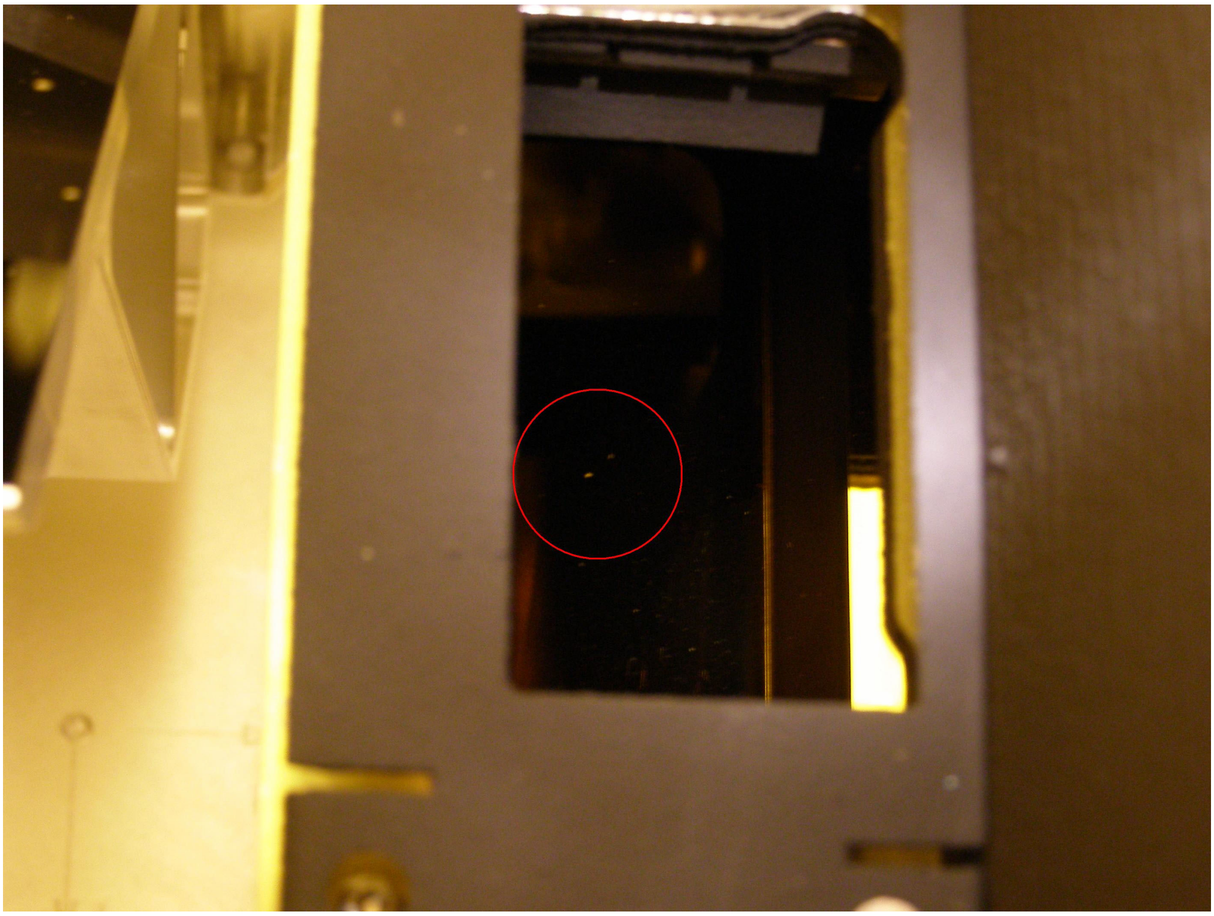


Fig. 6.3-4 Particle on PACS entrance mirror.

7 Summary and expected straylight for flight configuration

7.1 PACS

Based on the EQM test results, only part of the excess straylight (57 out of 124 at 88 µm and 14 out of 70 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 e.g. reflections from internal structural surfaces (not very likely), or the PACS entrance mirrors are contaminated much (also not very likely), or there are other reasons up to now not detected, then the in flight straylight situation in orbit will be 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.

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 important.

The spot like feature seen on EQM will not be present in flight, because it needs the cryocover mirror reflecting back into PACS.

7.2 SPIRE

The most likely reasons for the excess straylight on EQM are reflections at the SPIRE internal structural surfaces. Because the BRDF of the cryocover mirror is much smaller at SPIRE wavelengths, reflection and scattering from this mirror contribute only a small part to the total SPIRE straylight. A drastic reduction for FM will come from the blackening of the input section. Whether this alone already will reduce the straylight to the levels predicted in TN-0023 or whether further SPIRE internal surfaces should be blackened to achieve this is unclear at present.

8 Further Actions to reduce straylight and to clarify discrepancies

Investigations and H/W changes presently are ongoing in order to

- possibly reduce straylight on STM and FM
- clarify discrepancies between measured and predicted straylight

Reduction of straylight for STM and for FM is foreseen by

- Polishing the cryo-cover mirrors for STM and FM (eliminating the artificial cryo-cover micro-roughness). This will reduce the cryo-cover BRDF by orders of magnitude and will reduce the PACS straylight quite similar. The SPIRE straylight will be not much reduced by this.
- new design of the already existing LOU entrance baffle
- additional baffles between the LOU entrance baffle and HIFI FPU
- SPIRE will blacken the SPIRE FPU input section

Further clarifications of discrepancies between measured and predicted are foreseen:

- Measurements on sample of existing cryo-cover. BRDF measurement seems to be not possible in this region of wavelengths. However, a TIS (Total Integrated Scatter) value can be derived from reflectivity measurements. This will lead to potential corrections of the calculated values.
- Further investigations of straylight paths through HIFI FPU.

END OF DOCUMENT

	Name	Dep./Comp.		Name	Dep./Comp.
X	Alberti von Mathias Dr.	ASG22		Schweickert Gunn	ASG22
	Barlage Bernhard	AED13		Steininger Eric	AED32
	Bayer Thomas	ASA42	X	Stritter Rene	AED11
	Brune Holger	ASA45		Suess Rudi	OTN/ASA44
	Edelhoff Dirk	AED2		Thörmer Klaus-Horst Dr.	OTN/AED65
	Fehringer Alexander	ASG13		Wagner Klaus	ASG22
X	Fricke Wolfgang Dr.	AED 65	X	Wietbrock Walter	AET12
	Geiger Hermann	ASA42		Wöhler Hans	ASG22
	Grasl Andreas	OTN/ASA44			
	Grasshoff Brigitte	AET12			
X	Hartmann Hans	AED32	X	Alcatel Alenia Space Cannes	ASP
	Hauser Armin	ASG22	X	ESA/ESTEC	ESA
	Hendry David	Terma			
	Hengstler Reinhold	ASA42		**Instruments:**	
	Hinger Jürgen	ASG22	X	MPE (PACS)	MPE
X	Hohn Rüdiger	AED65	X	RAL (SPIRE)	RAL
	Hölzle Edgar Dr.	AED32		SRON (HIFI)	SRON
	Huber Johann	ASA42		**Subcontractors:**	
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X	Idler Siegmund	AED312		Air Liquide, Space Department	AIRS
	Ilsen Stijn	Terma		Air Liquide, Orbital System	AIRT
	Ivády von András	FAE12		Alcatel Alenia Space Antwerp	ABSP
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	Kalde Clemens	ASM2		Austrian Aerospace	AAEM
	Kameter Rudolf	OTN/ASA42		APCO Technologies S. A.	APCO
X	Kettner Bernhard	AET42		Bieri Engineering B. V.	BIER
	Knoblauch August	AET32		BOC Edwards	BOCE
	Koelle Markus	ASA43		Dutch Space Solar Arrays	DSSA
	Koppe Axel	AED312		EADS Astrium Sub-Subsyst. & Equipment	ASSE
X	Kroeker Jürgen	AED65		EADS CASA Espacio	CASA
	La Gioia Valentina	Terma		EADS CASA Espacio	ECAS
	Lamprecht Ernst	OTN/ASQ22		EADS Space Transportation	ASIP
	Lang Jürgen	ASE252		Eurocopter	ECD
	Langenstein Rolf	AED15		European Test Services	ETS
	Langfermann Michael	ASA41		HTS AG Zürich	HTSZ
	Much Christoph	ASA43		Linde	LIND
	Müller Jörg	ASA42		Patria New Technologies Oy	PANT
	Müller Martin	ASA43		Phoenix, Volkmarsen	PHOE
	Peltz Heinz-Willi	ASG13		Prototech AS	PROT
	Pietroboni Karin	AED65		QMC Instruments Ltd.	QMC
	Platzer Wilhelm	AED2		Rembe, Brilon	REMB
	Reichle Konrad	ASA42		Rosemount Aerospace GmbH	ROSE
	Runge Axel	OTN/ASA44		RYMSA, Radiación y Microondas S.A.	RYM
X	Schink Dietmar	AED32		SENER Ingenieria SA	SEN
X	Schlosser Christian	OTN/ASA44		Stöhr, Königsbrunn	STOE
	Schmidt Rudolf	FAE12		Terma A/S, Herlev	TER