



# **SMEC and Spectrometer Performance Review**

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**SPIRE Science Verification Review 3**

**Stockholm, October 29, 2007**

# Spectrometer Requirements

## Outline

### Section 1: Spectrometer

**Review and assess the following requirements:**

- IRD-SPEC-R01, IRD-SPEC-R02, IRD-SPEC-R03, IRD-OPTS-R07, IRD-OPTS-R09, IRD-SPEC-R10, IRD-SPEC-R11, IRD-SPEC-R14

### Section 2: Spectrometer Mechanism

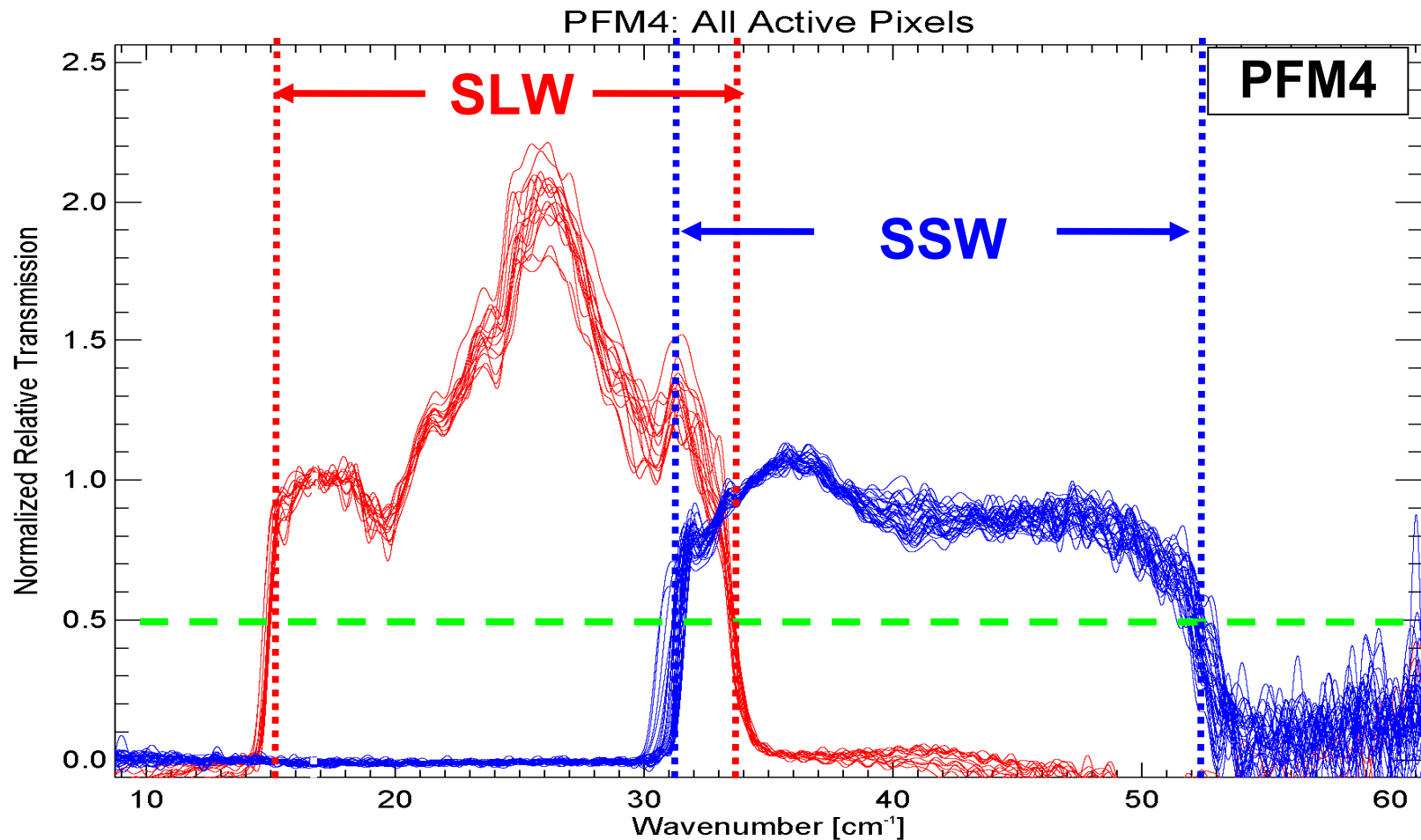
**Review and assess the following requirements:**

- IRD-SMEC-R01, IRD-SMEC-R02, IRD-SMEC-R03, IRD-SMEC-R04, IRD-SMEC-R05, IRD-SMEC-R06, IRD-SMEC-R07, IRD-SMEC-R08, IRD-SMEC-R09

# Spectrometer Requirements

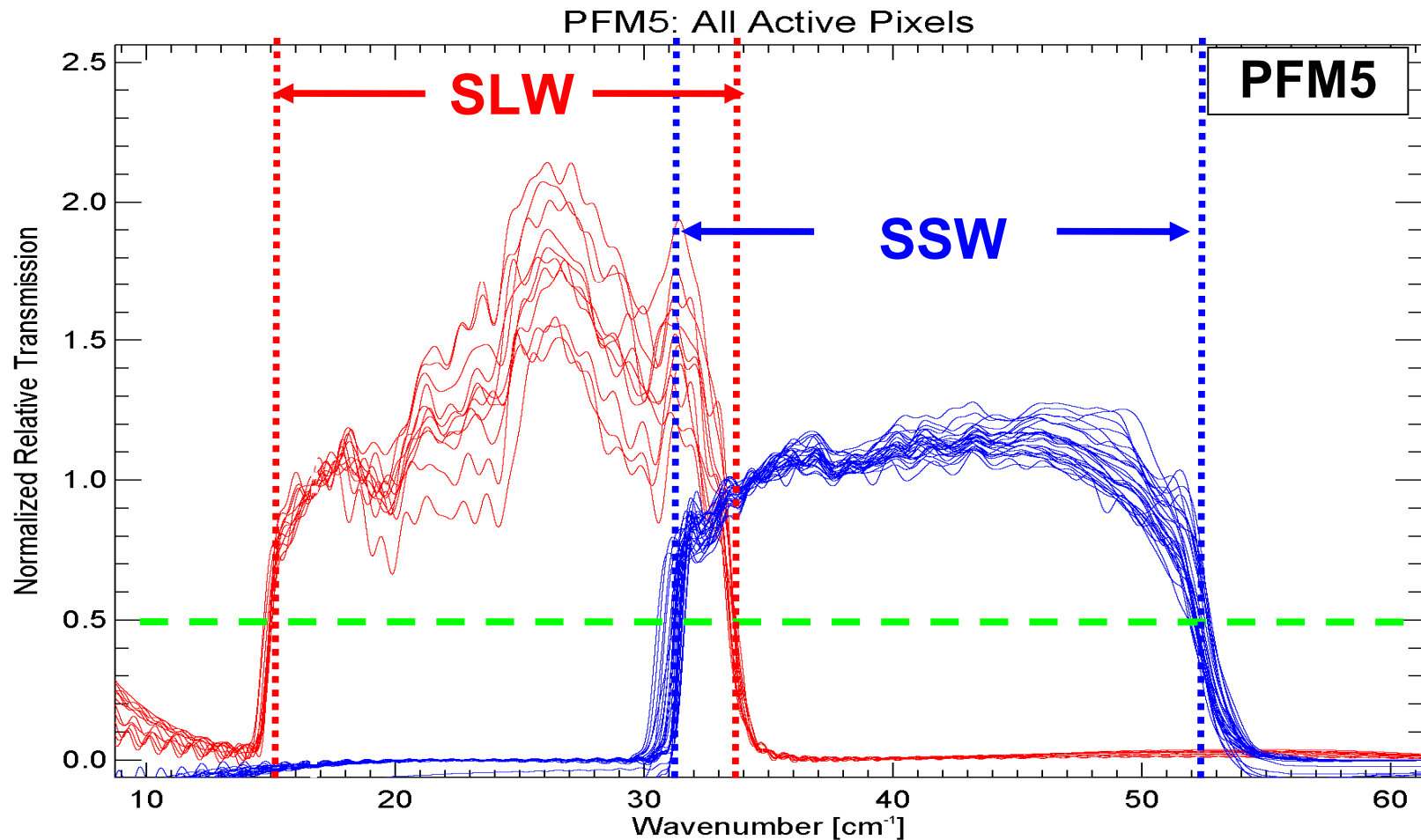
IRD-SPEC-R01	Wavelength Range	SSW: 200—300 $\mu\text{m}$ , 33.3—50 $\text{cm}^{-1}$ SLW: 300 — 670 $\mu\text{m}$ , 14.9—33.3 $\text{cm}^{-1}$	
IRD-SPEC-R02	Max. Resolution	Req: 0.4 $\text{cm}^{-1}$ Goal: 0.0483 $\text{cm}^{-1}$	
IRD-SPEC-R10	Off-Axis Resolution	FWHM < 110% of nominal resolution	
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IRD-OPTS-R07	Balancing of Output Ports	Beamsplitters shall have $2RT=R^2+T^2$ to within 90% over the band	
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# IRD-SPEC-R01 Wavelength Range



Band	Specification ( $\text{cm}^{-1}$ )	Measured ( $\text{cm}^{-1}$ )	Specification ( $\text{cm}^{-1}$ )	Measured ( $\text{cm}^{-1}$ )
<b>SSW</b>	30.40 — 31.15	<b>31.30 ± 0.35</b>	52.08 — 53.19	52.12 ± 0.37
<b>SLW</b>	14.64 — 15.02	14.91 ± 0.10	33.00 — 33.67	33.535 ± 0.084

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<b>SLW</b>	14.64 — 15.02	14.98 ± 0.13	33.00 — 33.67	33.57 ± 0.11

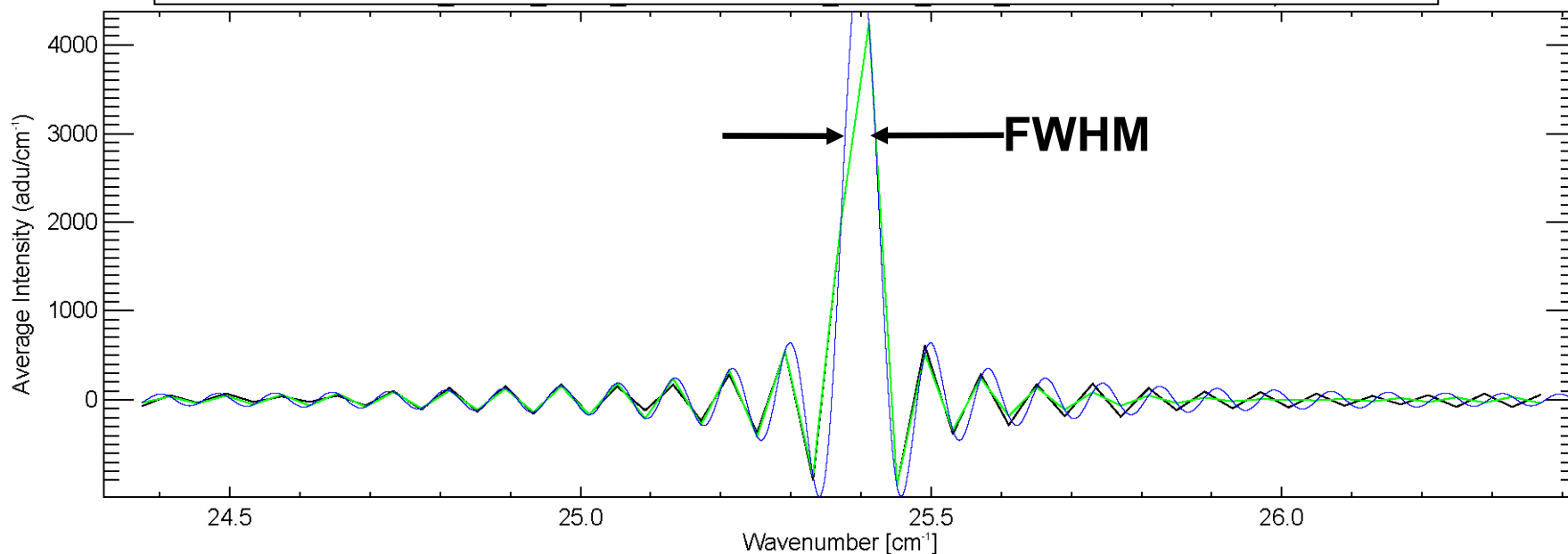
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# IRD-SPEC-R02 Maximum Resolution IRD-OPTS-R10 Off-Axis Resolution



**Resolution determined by the FWHM of the Sinc function fit to the spectrum of the measured laser line ( $\sigma = 25.40\text{cm}^{-1}$ ,  $\lambda = 393.7 \mu\text{m}$ ).**

**For a Sinc ILS:**

$$FWHM = \frac{1.21}{2OPD_{max}}$$



# IRD-SPEC-R02 Maximum Resolution IRD-OPTS-R10 Off-Axis Resolution

## Selected PFM4 Test Results

Pixel	Line Centre (μm)	Line Centre (cm <sup>-1</sup> )	Measured Resolution (cm <sup>-1</sup> )	R (= $\lambda/\Delta\lambda$ )
<b>SLWC3</b>	<b>393.7</b>	<b>25.40</b>	<b>0.0484 ± 0.0035</b>	<b>524 ± 25</b>
SLWE2	394.5	25.35	0.0529 ± 0.0033	479 ± 10
<b>SSWD4</b>	<b>202.4</b>	<b>49.41</b>	<b>0.0484 ± 0.0012</b>	<b>1024 ± 28</b>
SSWA2	202.6	49.35	0.0516 ± 0.0010	960 ± 60

- For each laser line that was studied, the measured FWHM resolution met the goal.
- Knowledge of the instrument line shape indicates that a resolution of 0.040cm<sup>-1</sup>, corresponding to  $1/2OPD_{max}$  will be possible.
- Measured resolution for off-axis channels did not exceed 110% of nominal resolution (0.0483cm<sup>-1</sup>), meeting the IRD-OPTS-R10 requirement.

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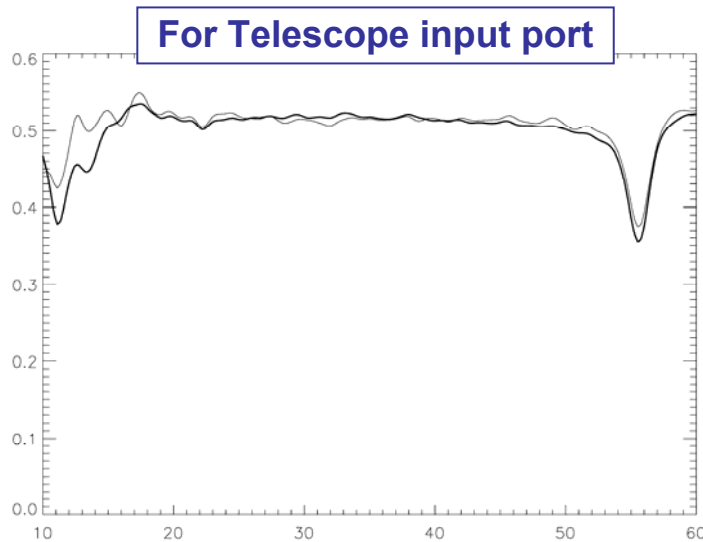
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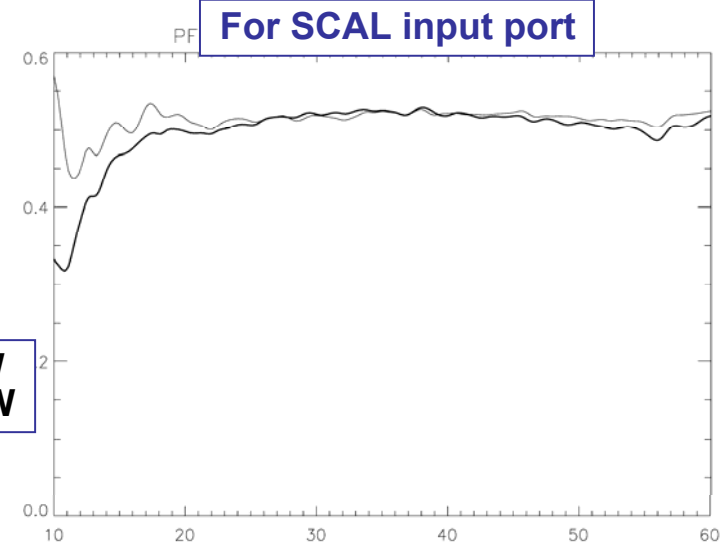
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# IRD-OPTS-R07 Balancing of Output Ports



Thin line: SLW  
Thick line: SSW



- For each input port, the beamsplitters divide the output to the two detector arrays equally to within 5% over the range 20—50cm<sup>-1</sup> and to within 10% at the long wavelength SLW edge (15—20cm<sup>-1</sup>).
- In both cases, the results agree within the 10% requirement.

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# IRD-OPTS-R09 Straylight

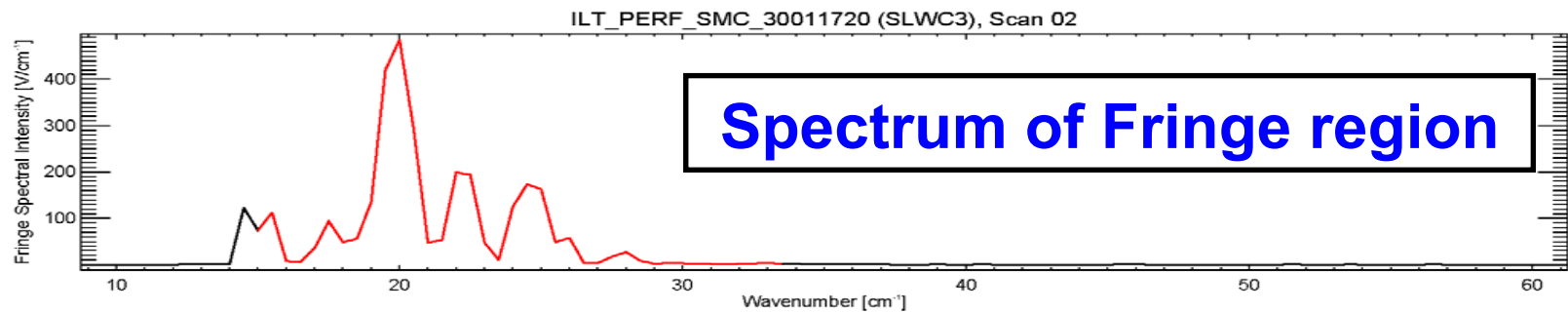
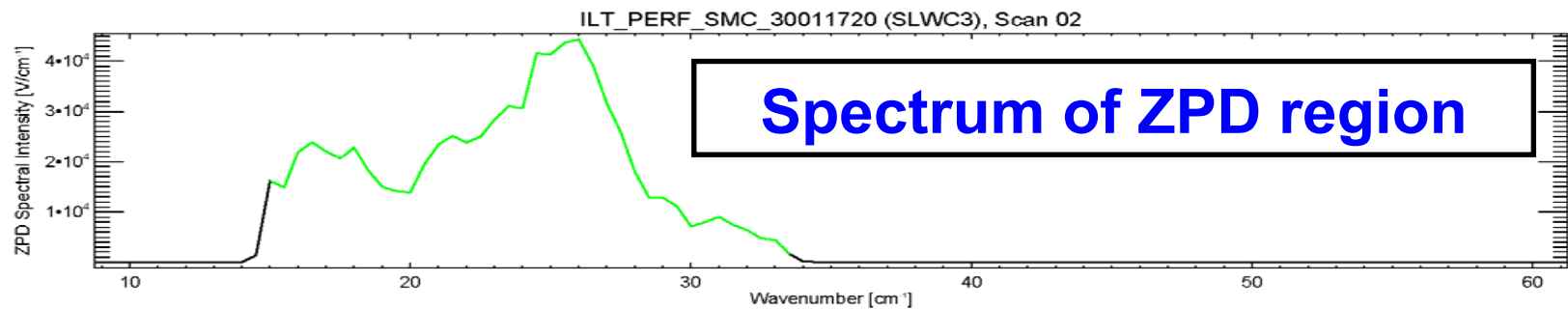
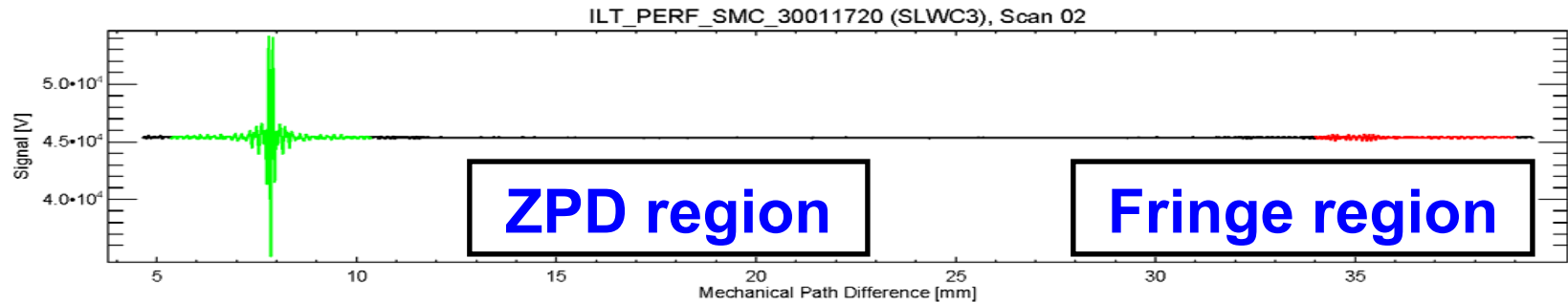
## Notes

- **Channel fringes, an indicator of straylight in the spectrometer system, have been observed in all high resolution interferograms during the PFM test campaigns.**
- **The integrated in-band spectral power was determined for spectra derived from both the ZPD and fringe regions.**

### **Fringe region:**

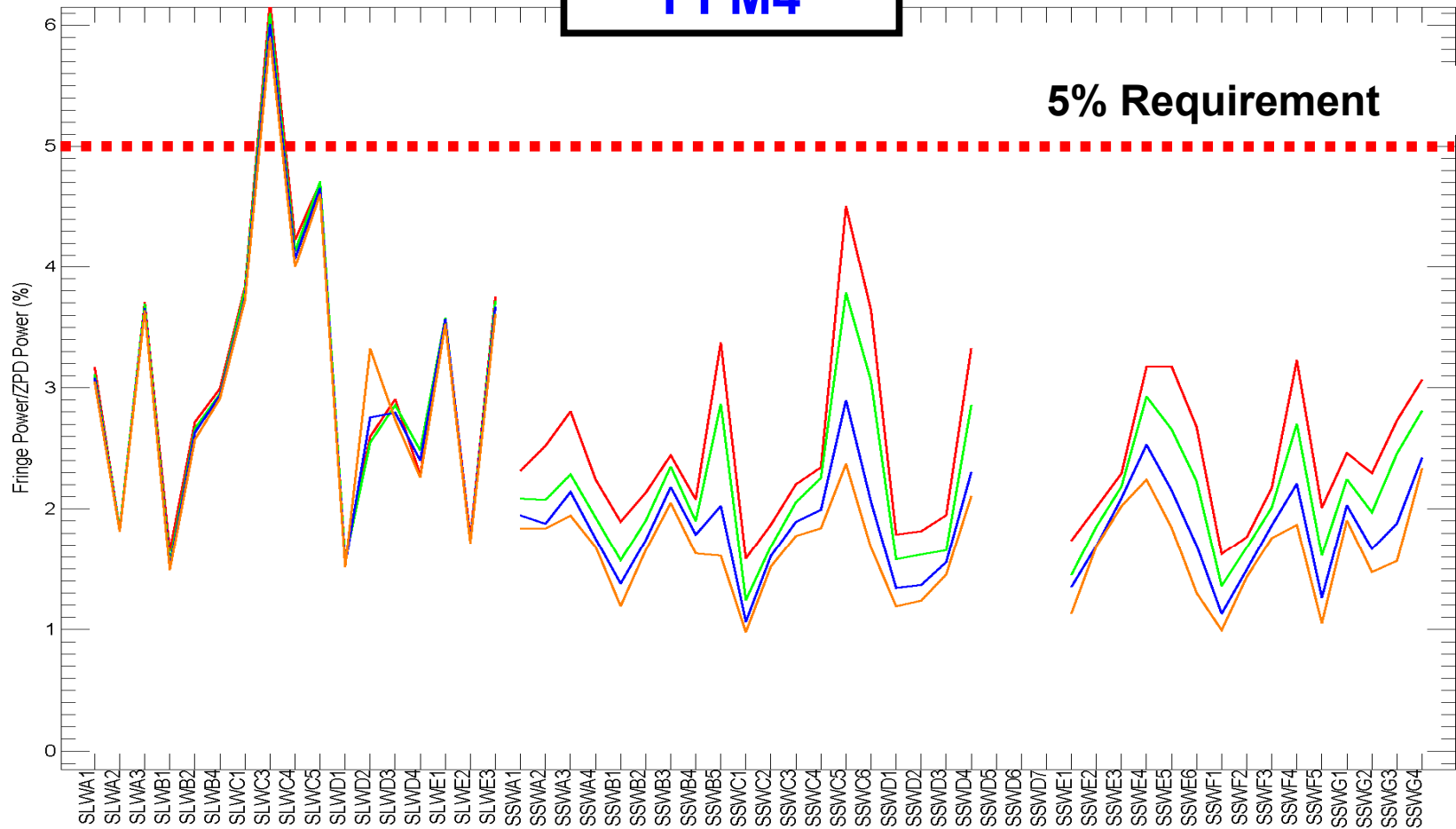
- **SLW: 10.2 cm OPD**
- **SSW: 7.8 cm OPD**
- **To evaluate the performance of the spectrometer with respect to this requirement, the ratio of the integrated fringe power to the integrated ZPD power was derived.**

# IRD-OPTS-R09 Straylight



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## PFM4



**CBB Temps: 7.2K, 7.7K, 8.2K, 8.7K**

## IRD-OPTS-R09 Straylight

### Notes

- The overlapping curves in the preceding plots show that fringe amplitude is related to input signal for SLW.
- Straylight due to fringes is within the 5% requirement (except for SLWC3).
- While fringes have the potential to interfere with the measurement weak line sources, their stability means that their effects can be minimized in post-processing. Fringes should therefore have no effect on the spectral resolution.
- NB: Fringe behaviour has only been studied for extended sources.

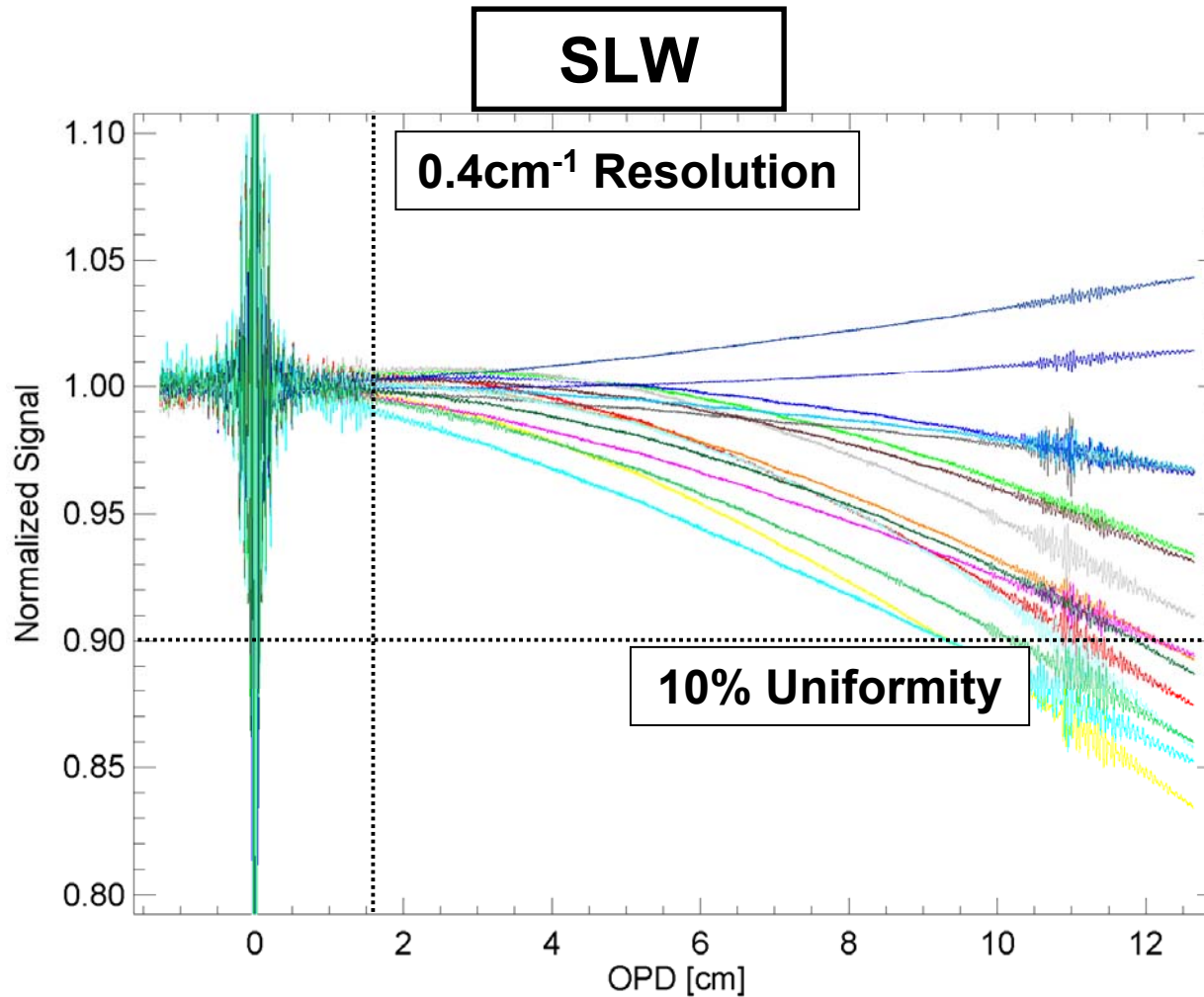
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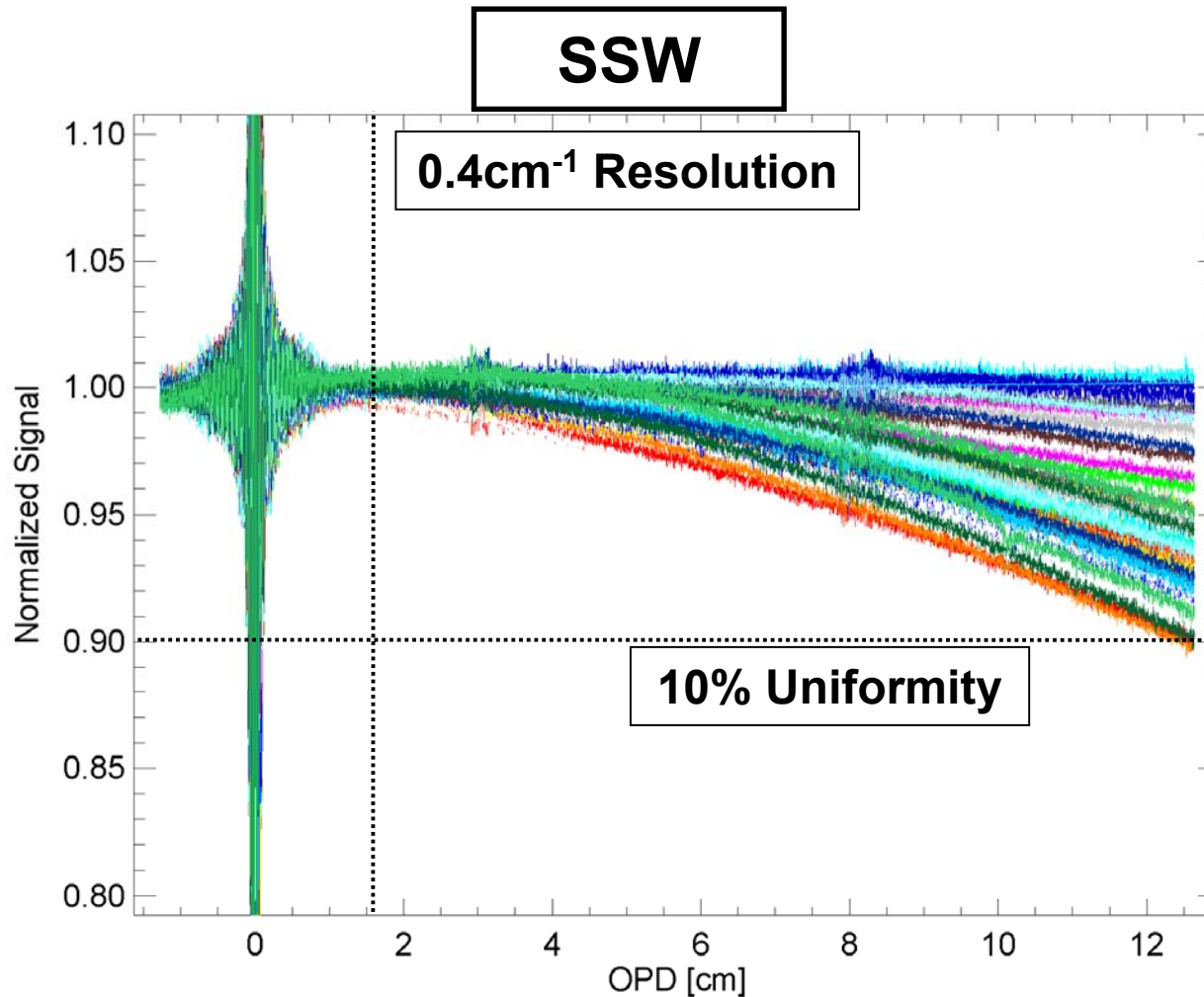
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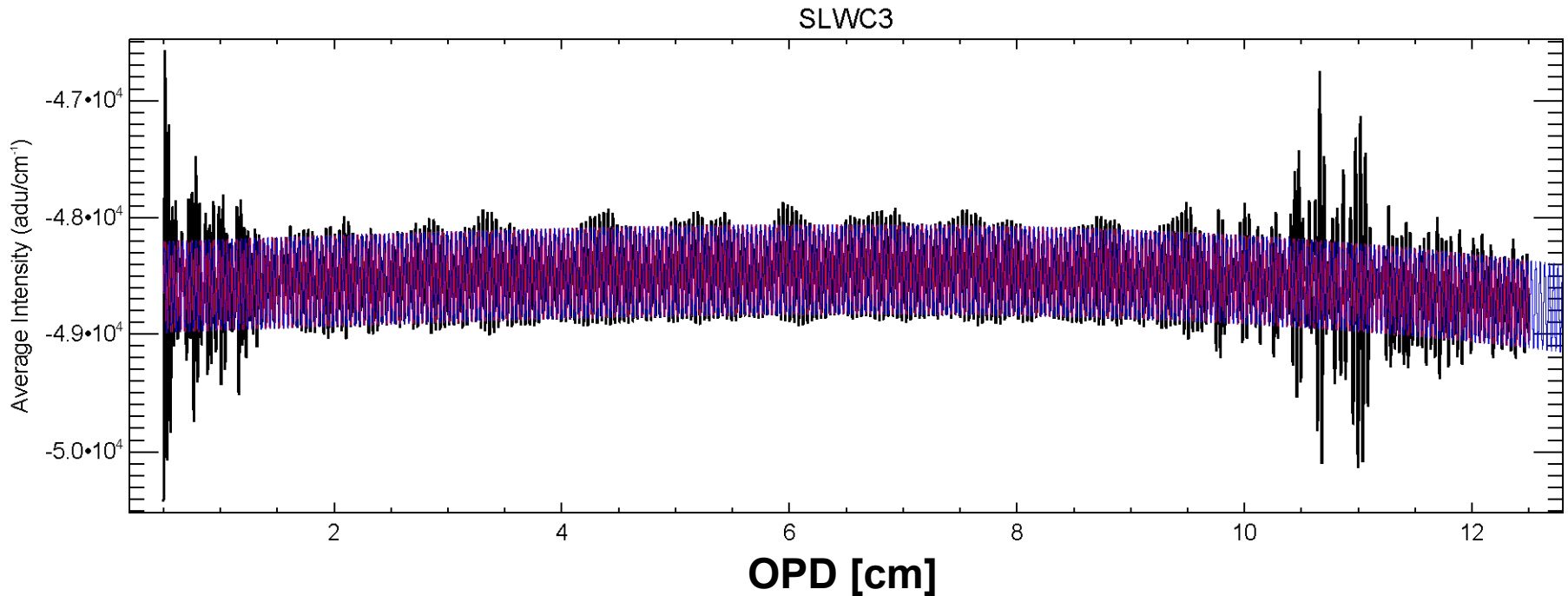
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# IRD-SPEC-R14 Fringe Contrast

## PFM4 Results



- For PFM4, modulation efficiency was calculated from a fit of a model to the measured interferograms.

$$InterferogramModel = A \cos bx \cos 2_c x$$

# IRD-SPEC-R14 Fringe Contrast

## PFM4 Test Results

Target Pixel	Line Centre [ $\text{cm}^{-1}$ ]	Line Centre [ $\mu\text{m}$ ]	Fringe Contrast at Max OPD (%)
SLWC3	25.399	393.7	95
SLWC5	25.357	394.4	84
SLWD2	25.379	394.0	96
SLWE2	25.350	394.5	83
SSWD4	49.412	202.4	94
SSWA2	49.350	202.6	97
SSWB3	49.380	202.5	96
SSWB4	49.350	202.6	99
SSWD3	49.398	202.4	95
SSWE3	49.404	202.4	90
SSWF3	49.381	202.5	85

- **PFM4 results show that the fringe contrast requirement was achieved for the selected pixels each of which lie within the unvignetted field of view.**

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# Spectrometer Requirements

## Summary

- **Spectrometer performance within specifications with respect to the wavelength range, resolution, balancing of ports, and vignetting. For vignetting, the requirement was met not just for the target resolution ( $0.4\text{cm}^{-1}$ ) but for the maximum resolution as well ( $0.0483\text{cm}^{-1}$ ).**
- **Fringe contrast requirement was met for the subset of the pixels that were studied.**
- **Actual straylight environment will only be known in flight. Straylight due to channel fringes fall within the budget for all but one of the pixels studied. The stability of the channel fringes indicates they can be corrected in post-processing.**

# SMEC Requirements

IRD-SMEC-R01	Linear Travel	14cm OPD	
IRD-SMEC-R02	Min. Sampling Interval (µm)	SSW: 5 SLW: 7.5	No Change from SVR-2
IRD-SMEC-R03	Sampling Step Control (µm)	Variable between 5 and 25	
IRD-SMEC-R04	Scan Length	Able to begin scan from either side of ZPD	
IRD-SMEC-R05	Dead-time	<10% for 0.4cm <sup>-1</sup> resolution	
IRD-SMEC-R06	Mirror Velocity	Req: 0.1cm/s MPD Goal: 0.2 cm/s MPD	
IRD-SMEC-R07	Velocity Control	Selectable from 0 to 0.1 cm/s MPD	
IRD-SMEC-R08	Velocity Stability	<10µm/s over the full range	
IRD-SMEC-R09	Position Measurement	0.1µm within ±0.32cm OPD, 0.3µm elsewhere	



## IRD-SMEC-R01 Linear Travel

- The scan range of mechanical motion for the FM SMEC as measured from the PFM4 and PFM5 test campaigns was 39.5mm.
- Taking into account the factor of four conversion between mechanical to optical path travel due to the Mach-Zehnder design of the SPIRE FTS gives a total optical path difference of 15.8cm, exceeding the requirement of 14cm OPD.
- The maximum single-sided optical path travel, factoring in the mean position of zero path difference as measured during the PFM4 test campaign (7.86mm MPD) was found to be 12.656cm.

# SMEC Requirements

IRD-SMEC-R01	Linear Travel	14cm OPD	Achieved
IRD-SMEC-R02	Min. Sampling Interval (µm)	SSW: 5 SLW: 7.5	No Change from SVR-2
IRD-SMEC-R03	Sampling Step Control (µm)	Variable between 5 and 25	
IRD-SMEC-R04	Scan Length	Able to begin scan from either side of ZPD	
IRD-SMEC-R05	Dead-time	<10% for 0.4cm <sup>-1</sup> resolution	
IRD-SMEC-R06	Mirror Velocity	Req: 0.1cm/s MPD Goal: 0.2 cm/s MPD	
IRD-SMEC-R07	Velocity Control	Selectable from 0 to 0.1 cm/s MPD	
IRD-SMEC-R08	Velocity Stability	<10µm/s over the full range	
IRD-SMEC-R09	Position Measurement	0.1µm within ±0.32cm OPD, 0.3µm elsewhere	

# SMEC Requirements

IRD-SMEC-R01	Linear Travel	14cm OPD	Achieved
IRD-SMEC-R02	Min. Sampling Interval (µm)	SSW: 5 SLW: 7.5	No Change from SVR-2
IRD-SMEC-R03	Sampling Step Control (µm)	Variable between 5 and 25	
IRD-SMEC-R04	Scan Length	Able to begin scan from either side of ZPD	
IRD-SMEC-R05	Dead-time	<10% for 0.4cm <sup>-1</sup> resolution	
IRD-SMEC-R06	Mirror Velocity	Req: 0.1cm/s MPD Goal: 0.2 cm/s MPD	
IRD-SMEC-R07	Velocity Control	Selectable from 0 to 0.1 cm/s MPD	
IRD-SMEC-R08	Velocity Stability	<10µm/s over the full range	
IRD-SMEC-R09	Position Measurement	0.1µm within ±0.32cm OPD, 0.3µm elsewhere	

# SMEC Requirements

IRD-SMEC-R01	Linear Travel	14cm OPD	Achieved
IRD-SMEC-R02	Min. Sampling Interval (µm)	SSW: 5 SLW: 7.5	Achieved Achieved
IRD-SMEC-R03	Sampling Step Control (µm)	Variable between 5 and 25	
IRD-SMEC-R04	Scan Length	Able to begin scan from either side of ZPD	
IRD-SMEC-R05	Dead-time	<10% for 0.4cm <sup>-1</sup> resolution	
IRD-SMEC-R06	Mirror Velocity	Req: 0.1cm/s MPD Goal: 0.2 cm/s MPD	
IRD-SMEC-R07	Velocity Control	Selectable from 0 to 0.1 cm/s MPD	
IRD-SMEC-R08	Velocity Stability	<10µm/s over the full range	
IRD-SMEC-R09	Position Measurement	0.1µm within ±0.32cm OPD, 0.3µm elsewhere	

# SMEC Requirements

IRD-SMEC-R01	Linear Travel	14cm OPD	Achieved
IRD-SMEC-R02	Min. Sampling Interval (µm)	SSW: 5 SLW: 7.5	Achieved Achieved
IRD-SMEC-R03	Sampling Step Control (µm)	Variable between 5 and 25	
IRD-SMEC-R04	Scan Length	Able to begin scan from either side of ZPD	
IRD-SMEC-R05	Dead-time	<10% for 0.4cm <sup>-1</sup> resolution	
IRD-SMEC-R06	Mirror Velocity	Req: 0.1cm/s MPD Goal: 0.2 cm/s MPD	
IRD-SMEC-R07	Velocity Control	Selectable from 0 to 0.1 cm/s MPD	
IRD-SMEC-R08	Velocity Stability	<10µm/s over the full range	
IRD-SMEC-R09	Position Measurement	0.1µm within ±0.32cm OPD, 0.3µm elsewhere	

## IRD-SMEC-R03 Sampling Step Control

- **During the PFM4 and PFM5 test campaigns the step-and-integrate mode was tested and the  $1\text{-}\sigma$  position errors were found to be  $0.533\mu\text{m}$  for each step.**
- **While this value exceeds the specification, it was found that this position error did not have a negative impact on the detector noise (IRD-SMEC-09).**
- **In addition, the observing mode to which this requirement applies is a non-standard mode (step and integrate).**

# SMEC Requirements

IRD-SMEC-R01	Linear Travel	14cm OPD	Achieved
IRD-SMEC-R02	Min. Sampling Interval (µm)	SSW: 5 SLW: 7.5	Achieved Achieved
IRD-SMEC-R03	Sampling Step Control (µm)	Variable between 5 and 25	Non-standard AOT
IRD-SMEC-R04	Scan Length	Able to begin scan from either side of ZPD	
IRD-SMEC-R05	Dead-time	<10% for 0.4cm <sup>-1</sup> resolution	
IRD-SMEC-R06	Mirror Velocity	Req: 0.1cm/s MPD Goal: 0.2 cm/s MPD	
IRD-SMEC-R07	Velocity Control	Selectable from 0 to 0.1 cm/s MPD	
IRD-SMEC-R08	Velocity Stability	<10µm/s over the full range	
IRD-SMEC-R09	Position Measurement	0.1µm within ±0.32cm OPD, 0.3µm elsewhere	

# SMEC Requirements

IRD-SMEC-R01	Linear Travel	14cm OPD	Achieved
IRD-SMEC-R02	Min. Sampling Interval (µm)	SSW: 5 SLW: 7.5	Achieved Achieved
IRD-SMEC-R03	Sampling Step Control (µm)	Variable between 5 and 25	Non-standard AOT
IRD-SMEC-R04	Scan Length	Able to begin scan from either side of ZPD	
IRD-SMEC-R05	Dead-time	<10% for 0.4cm <sup>-1</sup> resolution	
IRD-SMEC-R06	Mirror Velocity	Req: 0.1cm/s MPD Goal: 0.2 cm/s MPD	
IRD-SMEC-R07	Velocity Control	Selectable from 0 to 0.1 cm/s MPD	
IRD-SMEC-R08	Velocity Stability	<10µm/s over the full range	
IRD-SMEC-R09	Position Measurement	0.1µm within ±0.32cm OPD, 0.3µm elsewhere	



## IRD-SMEC-R04 Scan Length

- **This functionality was not formally tested during any of the PFM test campaigns.**
- **There were occasions during the PFM4 test campaign where the mechanism began a scan from the position of maximum optical path difference.**
- **These instances demonstrate the SMEC's ability to start a scan on either side of zero path difference.**

# SMEC Requirements

IRD-SMEC-R01	Linear Travel	14cm OPD	Achieved
IRD-SMEC-R02	Min. Sampling Interval (μm)	SSW: 5 SLW: 7.5	Achieved Achieved
IRD-SMEC-R03	Sampling Step Control (μm)	Variable between 5 and 25	Non-standard AOT
IRD-SMEC-R04	Scan Length	Able to begin scan from either side of ZPD	Achieved though not specifically tested
IRD-SMEC-R05	Dead-time	<10% for 0.4cm <sup>-1</sup> resolution	
IRD-SMEC-R06	Mirror Velocity	Req: 0.1cm/s MPD Goal: 0.2 cm/s MPD	
IRD-SMEC-R07	Velocity Control	Selectable from 0 to 0.1 cm/s MPD	
IRD-SMEC-R08	Velocity Stability	<10μm/s over the full range	
IRD-SMEC-R09	Position Measurement	0.1μm within ±0.32cm OPD, 0.3μm elsewhere	

# SMEC Requirements

IRD-SMEC-R01	Linear Travel	14cm OPD	Achieved
IRD-SMEC-R02	Min. Sampling Interval (μm)	SSW: 5 SLW: 7.5	Achieved Achieved
IRD-SMEC-R03	Sampling Step Control (μm)	Variable between 5 and 25	Non-standard AOT
IRD-SMEC-R04	Scan Length	Able to begin scan from either side of ZPD	Achieved though not specifically tested
IRD-SMEC-R05	Dead-time	<10% for 0.4cm <sup>-1</sup> resolution	
IRD-SMEC-R06	Mirror Velocity	Req: 0.1cm/s MPD Goal: 0.2 cm/s MPD	
IRD-SMEC-R07	Velocity Control	Selectable from 0 to 0.1 cm/s MPD	
IRD-SMEC-R08	Velocity Stability	<10μm/s over the full range	
IRD-SMEC-R09	Position Measurement	0.1μm within ±0.32cm OPD, 0.3μm elsewhere	

# IRD-SMEC-R05 Dead Time

- The dead-time, the time from the end of the preceding scan to that time when the SMEC reaches its nominal speed was measured for these SMEC PID settings and speeds.

PID Settings			Speed, MPD (cm/s)	Dead-time (s)	Dead-time [% of scan time for R=0.4cm <sup>-1</sup> ]
Kp	Ki	Kd			
<b>1000</b>	<b>2000</b>	<b>10000</b>	<b>0.05</b>	<b>0.427</b>	<b>2.8</b>
1000	2000	10000	0.10	0.462	6.2
<b>1000</b>	<b>2000</b>	<b>2500</b>	<b>0.05</b>	<b>0.478</b>	<b>3.2</b>
2000	1000	700	0.01	0.290	0.04
2000	1000	700	0.03	0.463	1.9
<b>2000</b>	<b>1000</b>	<b>700</b>	<b>0.05</b>	<b>0.290</b>	<b>1.9</b>
2000	1000	700	0.10	0.265	3.5

These tests demonstrate that the SMEC has met the requirements for mirror velocity and velocity control, IRD-SMEC-R06 and IRD-SMEC-R07 respectively.

# SMEC Requirements

IRD-SMEC-R01	Linear Travel	14cm OPD	Achieved
IRD-SMEC-R02	Min. Sampling Interval (µm)	SSW: 5 SLW: 7.5	Achieved Achieved
IRD-SMEC-R03	Sampling Step Control (µm)	Variable between 5 and 25	Non-standard AOT
IRD-SMEC-R04	Scan Length	Able to begin scan from either side of ZPD	Achieved though not specifically tested
IRD-SMEC-R05	Dead-time	<10% for 0.4cm <sup>-1</sup> resolution	Achieved
IRD-SMEC-R06	Mirror Velocity	Req: 0.1cm/s MPD Goal: 0.2 cm/s MPD	Achieved TBD
IRD-SMEC-R07	Velocity Control	Selectable from 0 to 0.1 cm/s MPD	Achieved
IRD-SMEC-R08	Velocity Stability	<10µm/s over the full range	
IRD-SMEC-R09	Position Measurement	0.1µm within ±0.32cm OPD, 0.3µm elsewhere	

# SMEC Requirements

IRD-SMEC-R01	Linear Travel	14cm OPD	12.656cm from ZPD
IRD-SMEC-R02	Min. Sampling Interval (µm)	SSW: 5 SLW: 7.5	Achieved Achieved
IRD-SMEC-R03	Sampling Step Control (µm)	Variable between 5 and 25	Non-standard AOT
IRD-SMEC-R04	Scan Length	Able to begin scan from either side of ZPD	Achieved though not specifically tested
IRD-SMEC-R05	Dead-time	<10% for 0.4cm <sup>-1</sup> resolution	Achieved
IRD-SMEC-R06	Mirror Velocity	Req: 0.1cm/s MPD Goal: 0.2 cm/s MPD	Achieved TBD
IRD-SMEC-R07	Velocity Control	Selectable from 0 to 0.1 cm/s MPD	Achieved
IRD-SMEC-R08	Velocity Stability	<10µm/s over the full range	
IRD-SMEC-R09	Position Measurement	0.1µm within ±0.32cm OPD, 0.3µm elsewhere	

**IRD-SMEC-R08 Velocity Stability  
IRD-SMEC-R09 Position Measurement**

- The SMEC meets the speed and position stability requirements for two of the three SMEC PID control settings studied during the PFM4 test campaign.**

PID Settings			Unfiltered		Filtered	
			Speed Jitter, RMS (µm/s)	Position Jitter, RMS (µm)	Speed Jitter, RMS (µm/s)	Position Jitter, RMS (µm)
Kp	Ki	Kd				
1000	2000	10000	360	1.00	5.5	0.15
1000	2000	2500	30	0.58	6.4	0.15
2000	1000	700	50	0.85	40	0.62

**IRD-SMEC-R08 Velocity Stability**  
**IRD-SMEC-R09 Position Measurement**

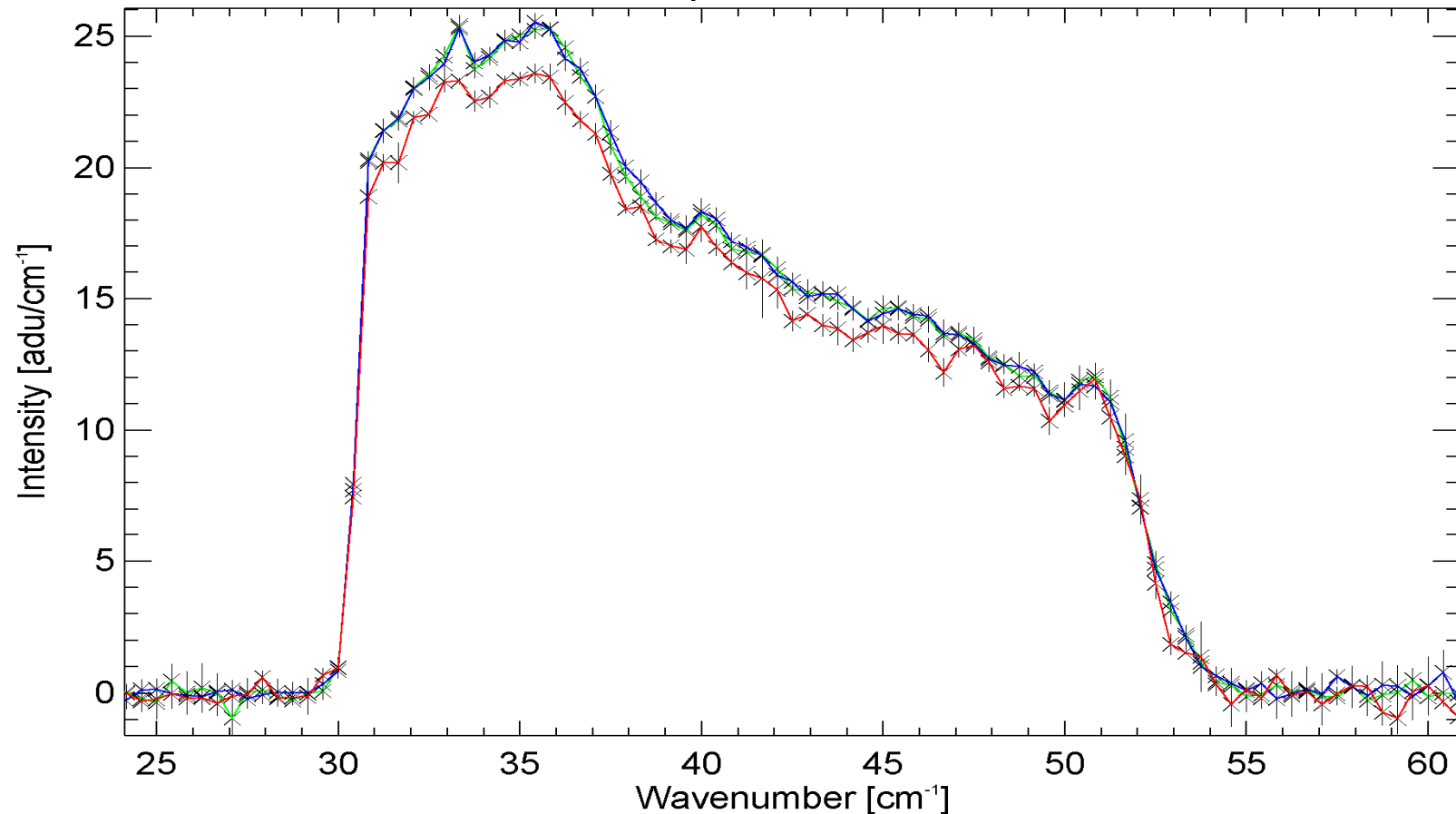
- **Further study of the effect of SMEC speed and position jitter was undertaken.**
- **Three observations of similar sources differing only in their PID settings were investigated.**

PID Settings			Temperature (K)			
Kp	Ki	Kd	CBB	SCAL	SCALA	SCALB
1000	2000	10000	6.71	4.52	4.7	4.58
1000	2000	2500	6.69	4.50	4.6	4.56
2000	1000	700	6.71	4.52	5	4.59



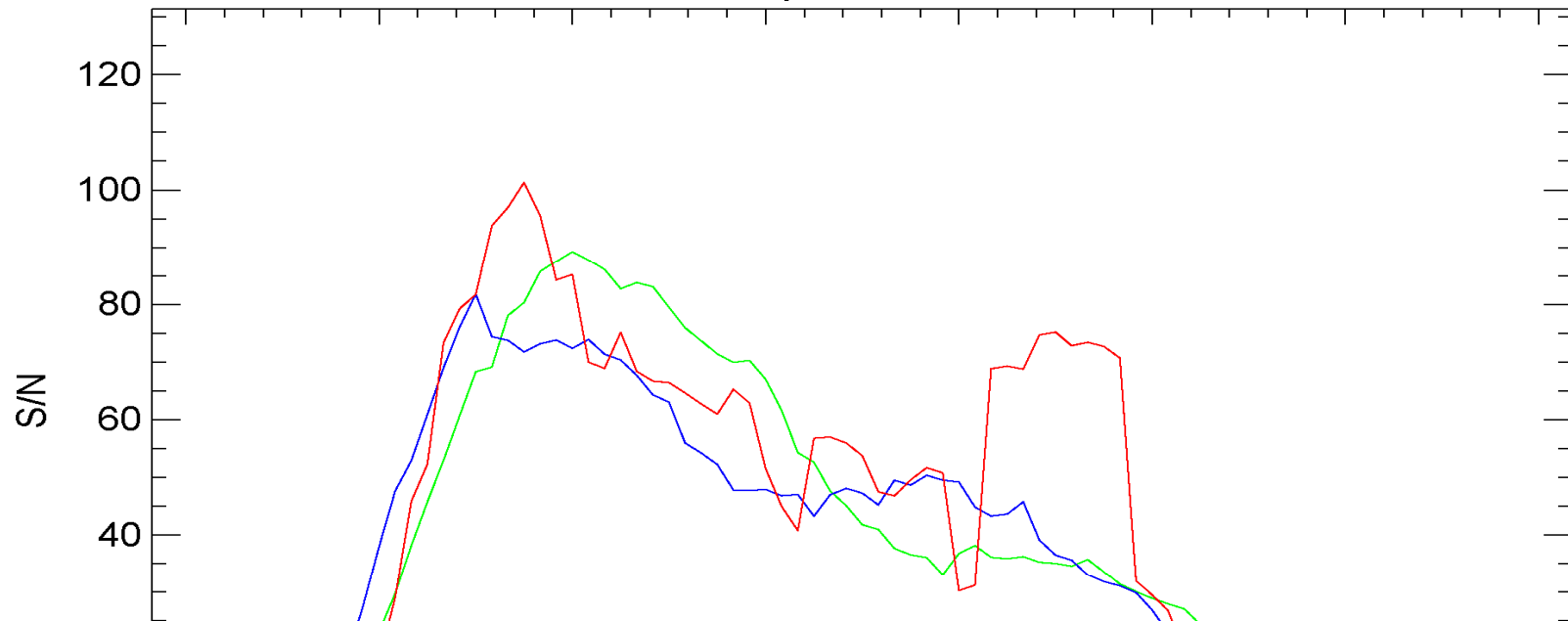
# IRD-SMEC-R08 Velocity Stability IRD-SMEC-R09 Position Measurement

PC Spectra, SSWE4



# IRD-SMEC-R08 Velocity Stability IRD-SMEC-R09 Position Measurement

### S/N Comparison, SSWE4



- **Similarity of the spectral SNR for each PID setting indicates that the increased SMEC jitter can be compensated by metrology.**

# SMEC Requirements

IRD-SMEC-R01	Linear Travel	14cm OPD	Achieved
IRD-SMEC-R02	Min. Sampling Interval (µm)	SSW: 5 SLW: 7.5	Achieved Achieved
IRD-SMEC-R03	Sampling Step Control (µm)	Variable between 5 and 25	Non-standard AOT
IRD-SMEC-R04	Scan Length	Able to begin scan from either side of ZPD	Achieved though not specifically tested
IRD-SMEC-R05	Dead-time	<10% for 0.4cm <sup>-1</sup> resolution	Achieved
IRD-SMEC-R06	Mirror Velocity	Req: 0.1cm/s MPD Goal: 0.2 cm/s MPD	Achieved TBD
IRD-SMEC-R07	Velocity Control	Selectable from 0 to 0.1 cm/s MPD	Achieved
IRD-SMEC-R08	Velocity Stability	<10µm/s over the full range	Achieved
IRD-SMEC-R09	Position Measurement	0.1µm within ±0.32cm OPD, 0.3µm elsewhere	Achieved

# SMEC Requirements

IRD-SMEC-R01	Linear Travel	14cm OPD	Achieved
IRD-SMEC-R02	Min. Sampling Interval (µm)	SSW: 5 SLW: 7.5	Achieved Achieved
IRD-SMEC-R03	Sampling Step Control (µm)	Variable between 5 and 25	Non-standard AOT
IRD-SMEC-R04	Scan Length	Able to begin scan from either side of ZPD	Achieved though not specifically tested
IRD-SMEC-R05	Dead-time	<10% for 0.4cm <sup>-1</sup> resolution	Achieved
IRD-SMEC-R06	Mirror Velocity	Req: 0.1cm/s MPD Goal: 0.2 cm/s MPD	Achieved TBD
IRD-SMEC-R07	Velocity Control	Selectable from 0 to 0.1 cm/s MPD	Achieved
IRD-SMEC-R08	Velocity Stability	<10µm/s over the full range	Achieved
IRD-SMEC-R09	Position Measurement	0.1µm within ±0.32cm OPD, 0.3µm elsewhere	Achieved

# SMEC Requirements

## Summary

- **SMEC performance within specifications with respect to the linear travel, minimum sampling interval, scan length, dead-time, mirror velocity, velocity control and stability, and position measurement.**
- **Measurements with respect to sampling step control exceeded requirements, but this is a non-standard AOT.**
- **Further investigation of the effects of SMEC speed and position stability on the measured spectra show that even when requirements are not met, the impact on spectral SNR is minimal.**