SPIRE-UCF-MHO-002481

Overview of Instrument Test Programme

Bruce Swinyard

Overview of Instrument Test Programme

- Instrument test programme so far has been in three phases:
  - CQM1 – January-March 2004
  - CQM2 – September-October 2004
  - PFM1 – March-April 2005
- The build standard for each test was slightly different
- Here I give a rapid review of the major points of each test phase and describe what is yet to come
- I give a summary of the performance requirements in the IRD and say how these have been addressed in the test programme.

CQM 1

- Build standard
  - Only one operating BDA in PLW position
  - No mechanisms
  - Full optics chain both side of instrument
  - AVM DPU
  - QM1 analogue electronics – no MCU – “power bench” instead of PSU
- Aim of test programme
  - First operation of SPIRE – first light on SPIRE
  - Basic thermal performance
  - Basic optical performance
  - Basic sensitivity measurements
  - Operation of test facility

CQM 2

- Build standard
  - As CQM1 – improved thermal links between detector boxes
  - EM Power supply with correct flight configuration

- Aim of test programme
  - Repeat performance test following vibration
  - Test of thermal performance with improved connections
  - Repeat of ambiguous or in complete CQM1 tests
  - First EMC tests

PFM 1

- Build standard
  - First build of flight model – spectrometer side only
  - Both spectrometer flight arrays
  - CQM SMEC
  - Flight model beam steering mirror
  - Flight cooler
  - Engineering model 300 mK strap
  - Flight photometer thermal control (PTC)
  - QM1 analogue electronics with “power bench”
- Aim of test programme
  - First operation of mechanisms
  - First test of spectrometer operation and performance

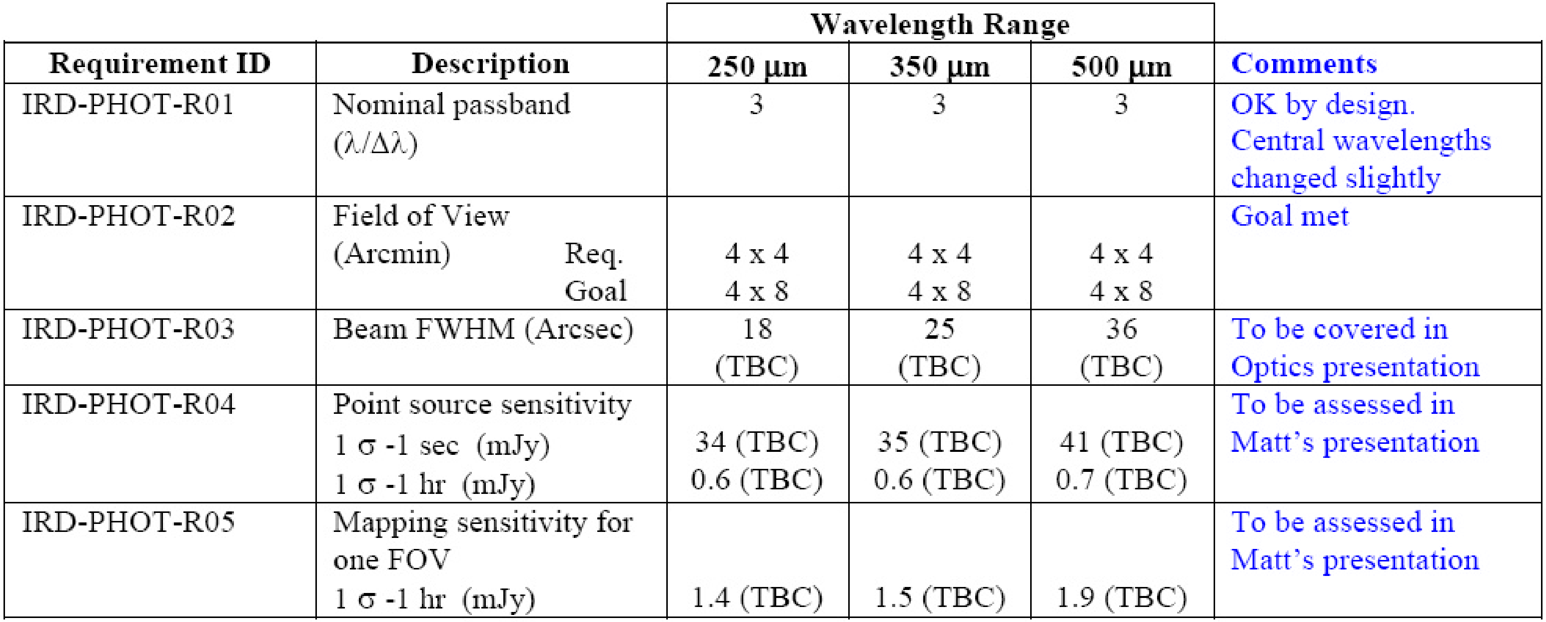
PFM 2

- Starting now – will be cold mid-August
- Build standard
  - First build of complete FPU – all five flight arrays
  - Full thermal requirements (CFRP feet; 5N 300 mK bus bar)
  - CQM SMEC
  - Dichroics flight performance but non-flight
  - QM2 electronics
    - near flight performance
    - Non-redundant
    - EM PSU
    - Four LIA cards missing
- Aim of test programme
  - First operation of both sides of instrument
  - First test of full photometer performance
  - Pre vibration test

…and then

- Optimistically….
  - Fit DM SMEC and flight dichroics
  - Cold vibration (October)
  - Fit flight SMEC Nov 05
  - Flight electronics delivered Jan 06
  - Calibration starts Dec 05
  - “Ready” for delivery March 06
- Realistically will be nearer May or June 06 to complete calibration

Instrument Performance Requirements - Photometer

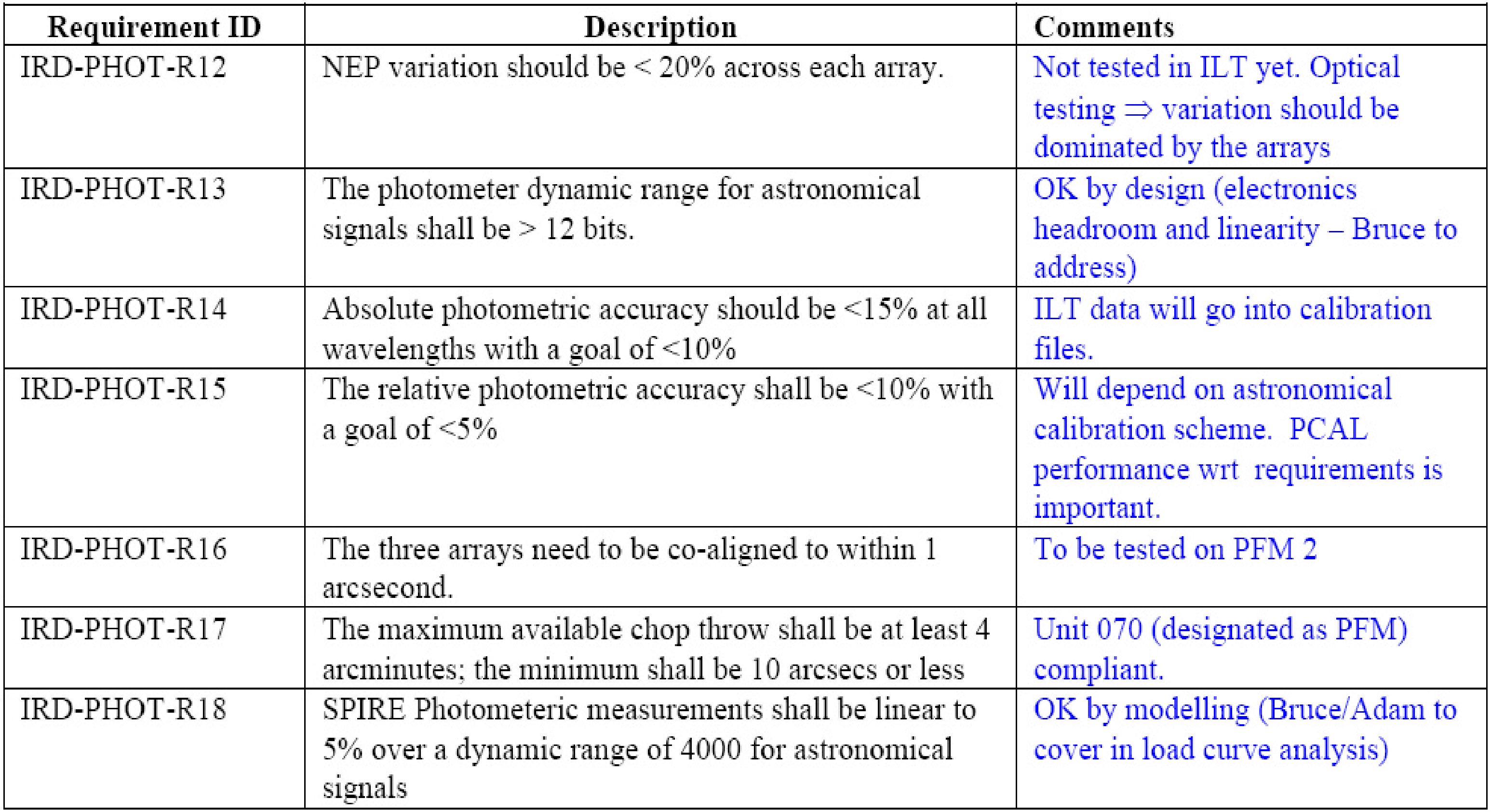


		Wavelength Range			
Requirement ID	**Description**	**250 μm**	**350 μm**	**500 μm**	**Comments**
IRD-PHOT-R01	Nominal passband ($\lambda/\Delta\lambda$)	3	3	3	OK by design. Central wavelengths changed slightly
IRD-PHOT-R02	Field of View (Arcmin) Req. Goal	4 x 4 4 x 8	4 x 4 4 x 8	4 x 4 4 x 8	Goal met
IRD-PHOT-R03	Beam FWHM (Arcsec)	18 (TBC)	25 (TBC)	36 (TBC)	To be covered in Optics presentation
IRD-PHOT-R04	Point source sensitivity 1 σ -1 sec (mJy) 1 σ -1 hr (mJy)	34 (TBC) 0.6 (TBC)	35 (TBC) 0.6 (TBC)	41 (TBC) 0.7 (TBC)	To be assessed in Matt's presentation
IRD-PHOT-R05	Mapping sensitivity for one FOV 1 σ -1 hr (mJy)	1.4 (TBC)	1.5 (TBC)	1.9 (TBC)	To be assessed in Matt's presentation

IRD Reqs ctd….Photometer

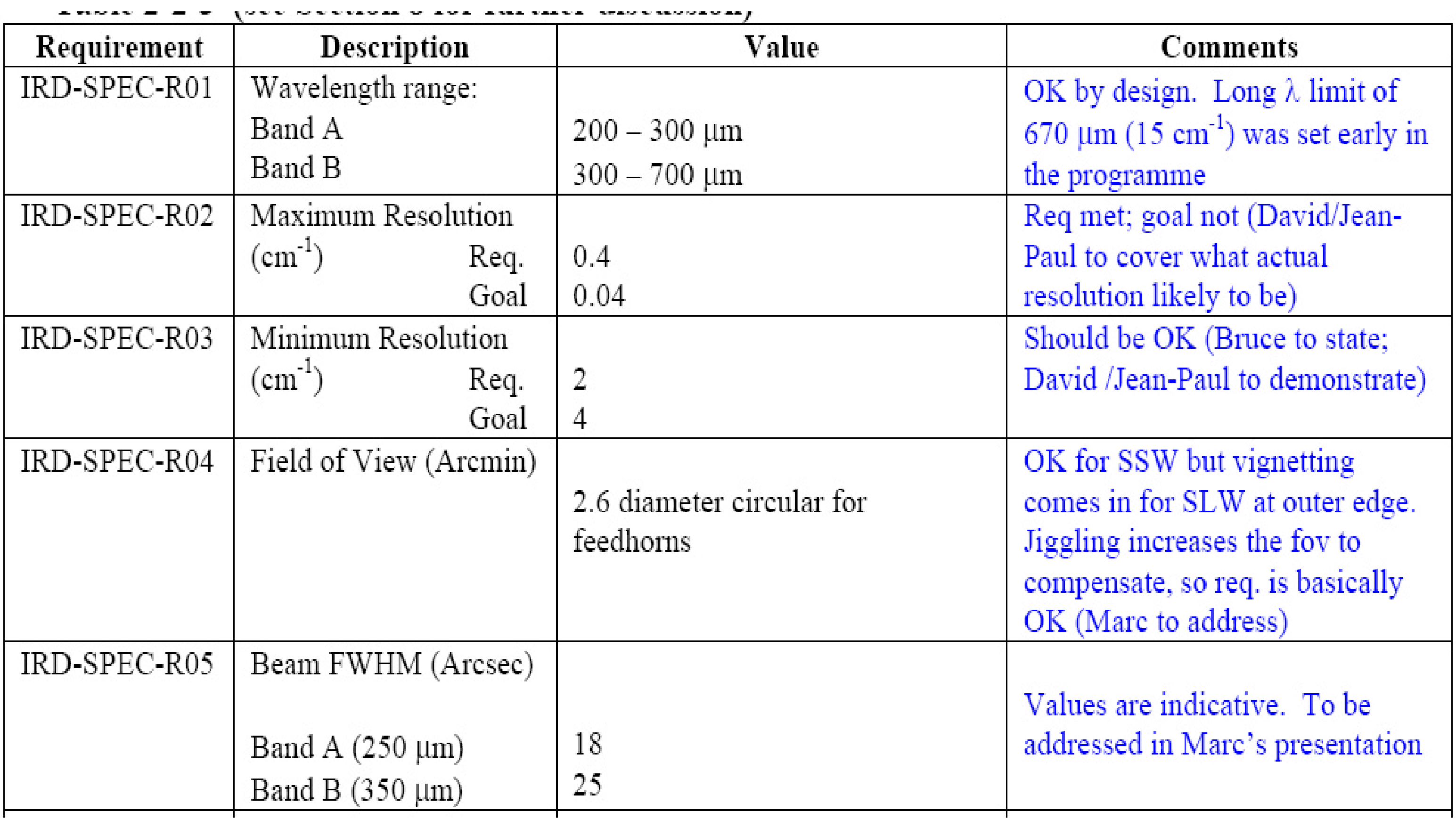
Requirement ID	Description	Comments
IRD-PHOT-R06	Maximising 'mapping speed' at which confusion limit is reached over a large area of sky is the primary science driver. This means maximising sensitivity and field-of-view (FOV) but NOT at the expense of spatial resolution.	OK by design
IRD-PHOT-R07	*Removed version 1.0*	
IRD-PHOT-R08	*Removed version 1.0*	
IRD-PHOT-R09	*Removed version 1.0*	
IRD-PHOT-R10	Field distortion must be <10% across the FOV	To be covered in Optics presentation
IRD-PHOT-R11	Electrical crosstalk should be <1% (goal 0.5%) between nearest-neighbour pixels and <0.1 % (gaol 0.05%) between all other pixels in the same array.	Not explicitly tested yet. To be mentioned in this presentation

IRD Reqs ctd….Photometer



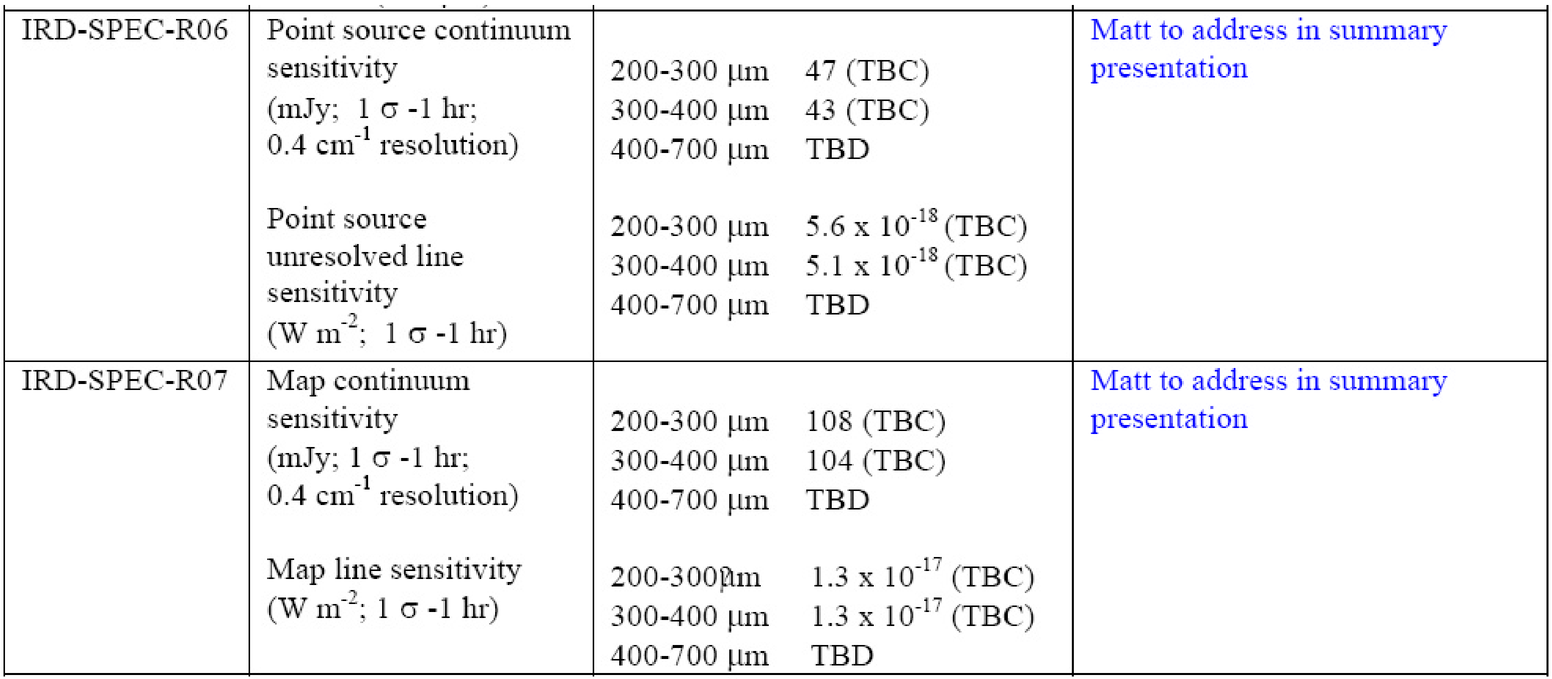
Requirement ID	Description	Comments
IRD-PHOT-R12	NEP variation should be < 20% across each array.	Not tested in ILT yet. Optical testing ⇒ variation should be dominated by the arrays
IRD-PHOT-R13	The photometer dynamic range for astronomical signals shall be > 12 bits.	OK by design (electronics headroom and linearity – Bruce to address)
IRD-PHOT-R14	Absolute photometric accuracy should be <15% at all wavelengths with a goal of <10%	ILT data will go into calibration files.
IRD-PHOT-R15	The relative photometric accuracy shall be <10% with a goal of <5%	Will depend on astronomical calibration scheme. PCAL performance wrt requirements is important.
IRD-PHOT-R16	The three arrays need to be co-aligned to within 1 arcsecond.	To be tested on PFM 2
IRD-PHOT-R17	The maximum available chop throw shall be at least 4 arcminutes; the minimum shall be 10 arcsecs or less	Unit 070 (designated as PFM) compliant.
IRD-PHOT-R18	SPIRE Photometeric measurements shall be linear to 5% over a dynamic range of 4000 for astronomical signals	OK by modelling (Bruce/Adam to cover in load curve analysis)

IRD Reqs ctd….Spectrometer



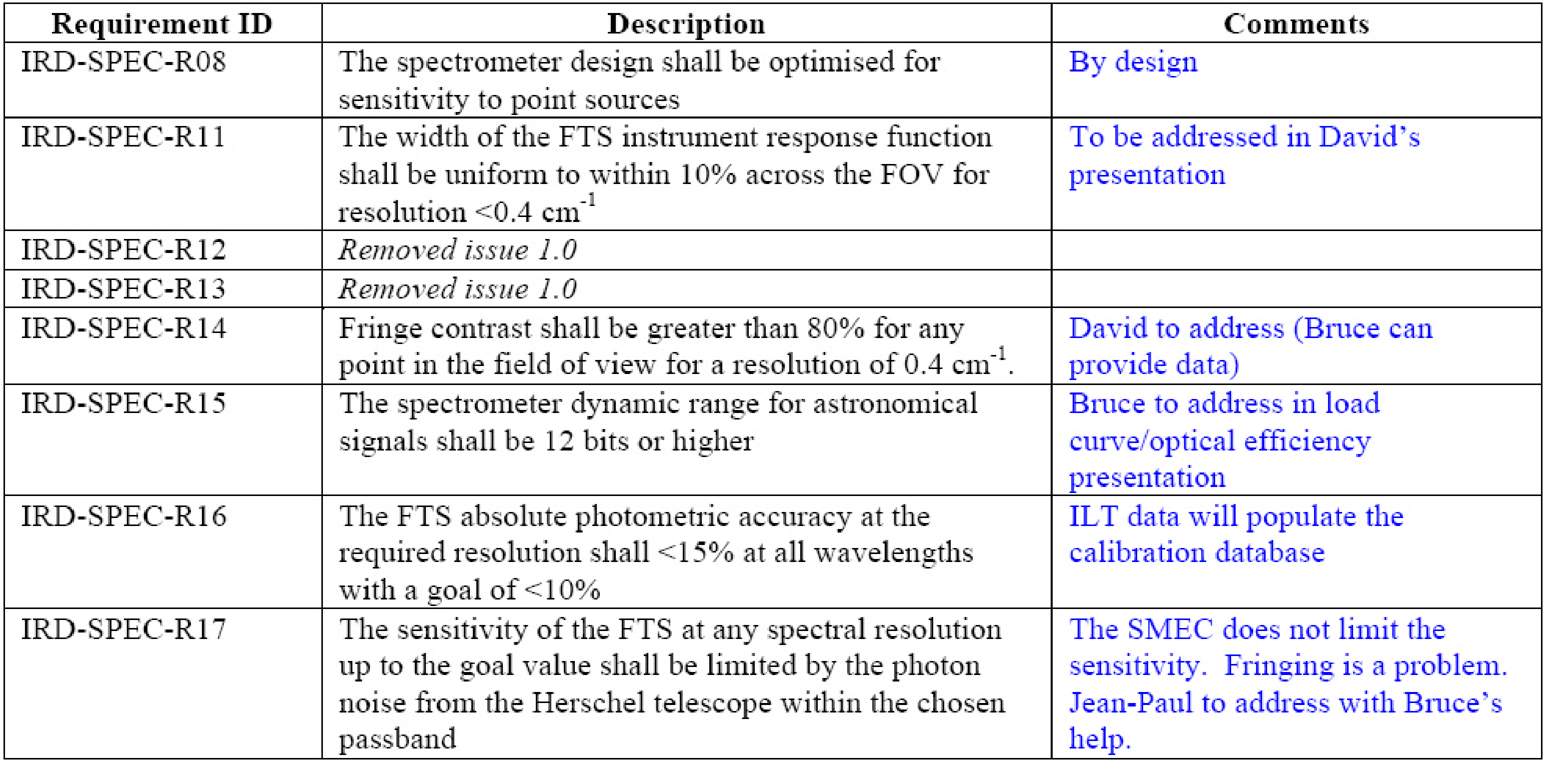
Requirement	Description	Value	Comments
IRD-SPEC-R01	Wavelength range: Band A Band B	 200 – 300 µm 300 – 700 µm	OK by design. Long λ limit of 670 µm (15 cm^{-1}) was set early in the programme
IRD-SPEC-R02	Maximum Resolution (cm^{-1}) Req. Goal	0.4 0.04	Req met; goal not (David/Jean-Paul to cover what actual resolution likely to be)
IRD-SPEC-R03	Minimum Resolution (cm^{-1}) Req. Goal	2 4	Should be OK (Bruce to state; David /Jean-Paul to demonstrate)
IRD-SPEC-R04	Field of View (Arcmin)	2.6 diameter circular for feedhorns	OK for SSW but vignetting comes in for SLW at outer edge. Jiggling increases the fov to compensate, so req. is basically OK (Marc to address)
IRD-SPEC-R05	Beam FWHM (Arcsec) Band A (250 µm) Band B (350 µm)	 18 25	Values are indicative. To be addressed in Marc's presentation

IRD Reqs ctd….Spectrometer



IRD-SPEC-R06	Point source continuum sensitivity (mJy; 1 σ -1 hr; 0.4 cm^{-1} resolution)	200-300 μm 47 (TBC) 300-400 μm 43 (TBC) 400-700 μm TBD	Matt to address in summary presentation
	Point source unresolved line sensitivity (W m^{-2}; 1 σ -1 hr)	200-300 μm 5.6 x 10^{-18} (TBC) 300-400 μm 5.1 x 10^{-18} (TBC) 400-700 μm TBD	
IRD-SPEC-R07	Map continuum sensitivity (mJy; 1 σ -1 hr; 0.4 cm^{-1} resolution)	200-300 μm 108 (TBC) 300-400 μm 104 (TBC) 400-700 μm TBD	Matt to address in summary presentation
	Map line sensitivity (W m^{-2}; 1 σ -1 hr)	200-300μm 1.3 x 10^{-17} (TBC) 300-400 μm 1.3 x 10^{-17} (TBC) 400-700 μm TBD	

IRD Reqs ctd….Spectrometer

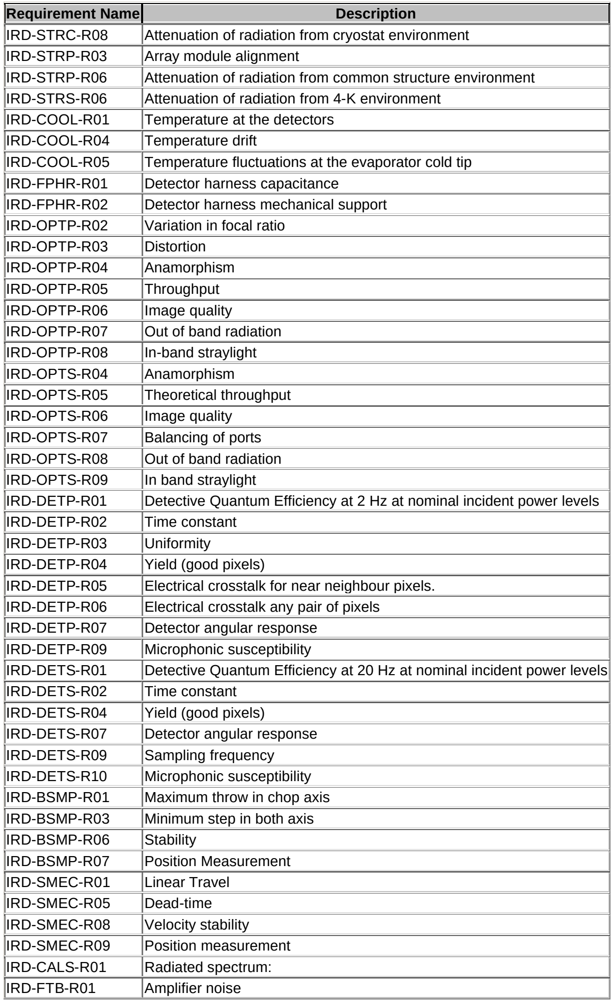


Requirement ID	Description	Comments
IRD-SPEC-R08	The spectrometer design shall be optimised for sensitivity to point sources	By design
IRD-SPEC-R11	The width of the FTS instrument response function shall be uniform to within 10% across the FOV for resolution <0.4 cm^{-1}	To be addressed in David's presentation
IRD-SPEC-R12	*Removed issue 1.0*	
IRD-SPEC-R13	*Removed issue 1.0*	
IRD-SPEC-R14	Fringe contrast shall be greater than 80% for any point in the field of view for a resolution of 0.4 cm^{-1}.	David to address (Bruce can provide data)
IRD-SPEC-R15	The spectrometer dynamic range for astronomical signals shall be 12 bits or higher	Bruce to address in load curve/optical efficiency presentation
IRD-SPEC-R16	The FTS absolute photometric accuracy at the required resolution shall <15% at all wavelengths with a goal of <10%	ILT data will populate the calibration database
IRD-SPEC-R17	The sensitivity of the FTS at any spectral resolution up to the goal value shall be limited by the photon noise from the Herschel telescope within the chosen passband	The SMEC does not limit the sensitivity. Fringing is a problem. Jean-Paul to address with Bruce's help.

Derived Requirements

- There are ~370 requirements placed on the instrument – not all of these are directly relevant to the performance (interfaces, environment, safety etc etc…)
- The IRD database links the derived requirements on the sub-systems to the top level performance requirements
- There are the 46 directly relevant to the instrument performance…..(next slide)
- Through the database and the VCD we are checking these as well – many are verified at sub-system level

Derived Requirements



Requirement Name	Description
IRD-STRC-R08	Attenuation of radiation from cryostat environment
IRD-STRP-R03	Array module alignment
IRD-STRP-R06	Attenuation of radiation from common structure environment
IRD-STRS-R06	Attenuation of radiation from 4-K environment
IRD-COOL-R01	Temperature at the detectors
IRD-COOL-R04	Temperature drift
IRD-COOL-R05	Temperature fluctuations at the evaporator cold tip
IRD-FPHR-R01	Detector harness capacitance
IRD-FPHR-R02	Detector harness mechanical support
IRD-OPTP-R02	Variation in focal ratio
IRD-OPTP-R03	Distortion
IRD-OPTP-R04	Anamorphism
IRD-OPTP-R05	Throughput
IRD-OPTP-R06	Image quality
IRD-OPTP-R07	Out of band radiation
IRD-OPTP-R08	In-band straylight
IRD-OPTS-R04	Anamorphism
IRD-OPTS-R05	Theoretical throughput
IRD-OPTS-R06	Image quality
IRD-OPTS-R07	Balancing of ports
IRD-OPTS-R08	Out of band radiation
IRD-OPTS-R09	In band straylight
IRD-DETP-R01	Detective Quantum Efficiency at 2 Hz at nominal incident power levels
IRD-DETP-R02	Time constant
IRD-DETP-R03	Uniformity
IRD-DETP-R04	Yield (good pixels)
IRD-DETP-R05	Electrical crosstalk for near neighbour pixels.
IRD-DETP-R06	Electrical crosstalk any pair of pixels
IRD-DETP-R07	Detector angular response
IRD-DETP-R09	Microphonic susceptibility
IRD-DETS-R01	Detective Quantum Efficiency at 20 Hz at nominal incident power levels
IRD-DETS-R02	Time constant
IRD-DETS-R04	Yield (good pixels)
IRD-DETS-R07	Detector angular response
IRD-DETS-R09	Sampling frequency
IRD-DETS-R10	Microphonic susceptibility
IRD-BSMP-R01	Maximum throw in chop axis
IRD-BSMP-R03	Minimum step in both axis
IRD-BSMP-R06	Stability
IRD-BSMP-R07	Position Measurement
IRD-SMEC-R01	Linear Travel
IRD-SMEC-R05	Dead-time
IRD-SMEC-R08	Velocity stability
IRD-SMEC-R09	Position measurement
IRD-CALS-R01	Radiated spectrum:
IRD-FTB-R01	Amplifier noise

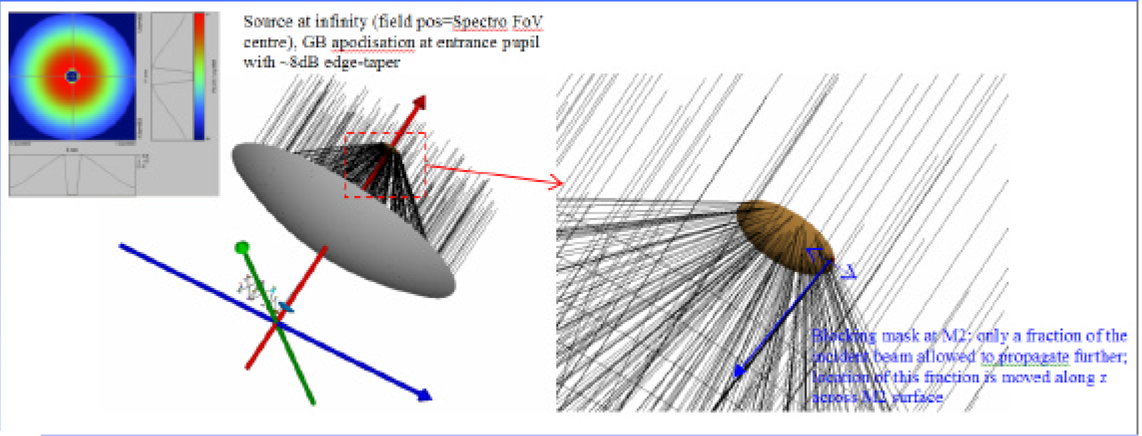
SPIRE CQM2 & PFM1

Optical performances

Bruce Swinyard
(on behalf of Marc Ferlet)

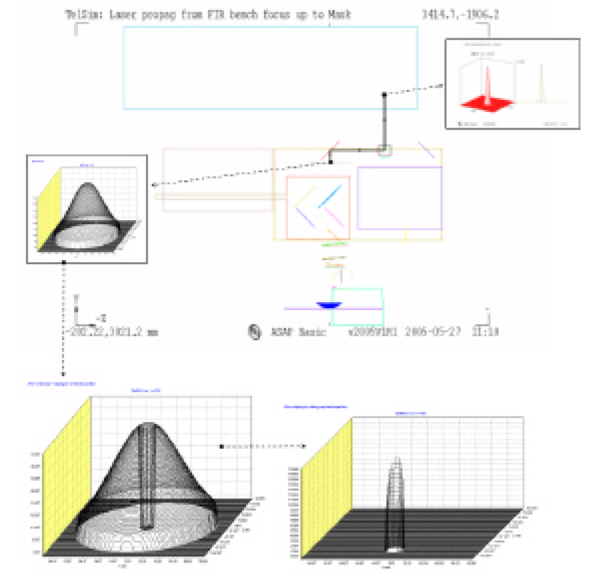
Pupil imaging (I): modelling

- 1st order simulation with SPIRE+HSO telescope model: moving mask sliding across M2 along Z, with geometric aperture (no diffraction) as per scaled value of the experimental mask



Source at infinity (field pos=Spectro FoV centre), GB apodisation at entrance pupil with ~8dB edge-taper

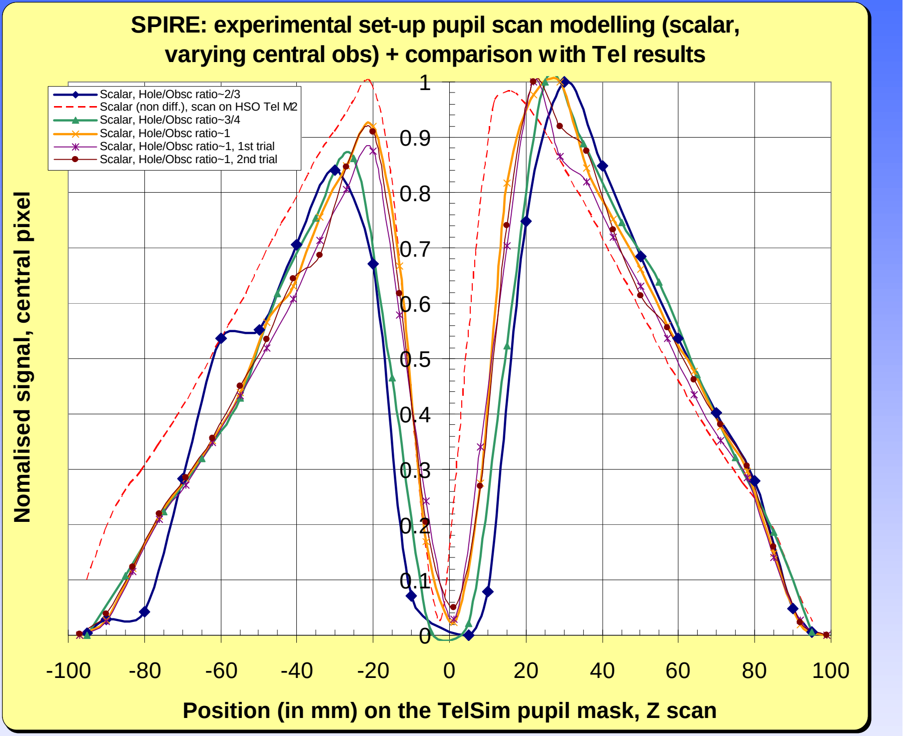
Blocking mask at M2: only a fraction of the incident beam allowed to propagate further; location of this fraction is moved along z across M2 surface



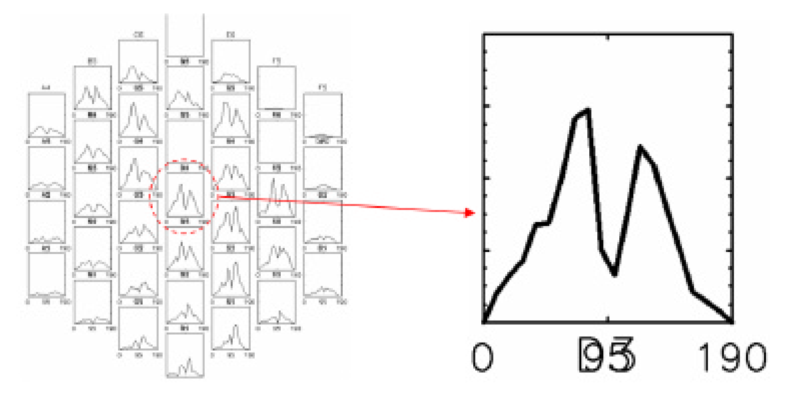
- More advanced simulation with SPIRE test facility optical model, replicating the actual test & associated effects: moving mask sliding across TelSim pupil mask aperture, with geometric, diffractive, radiometric and sampling effect

Pupil imaging (II): comparison of results

Modelled Z profile scans (baseline, valid for Phot and Spectro tests)


SPIRE: experimental set-up pupil scan modelling (scalar, varying central obs) + comparison with Tel results

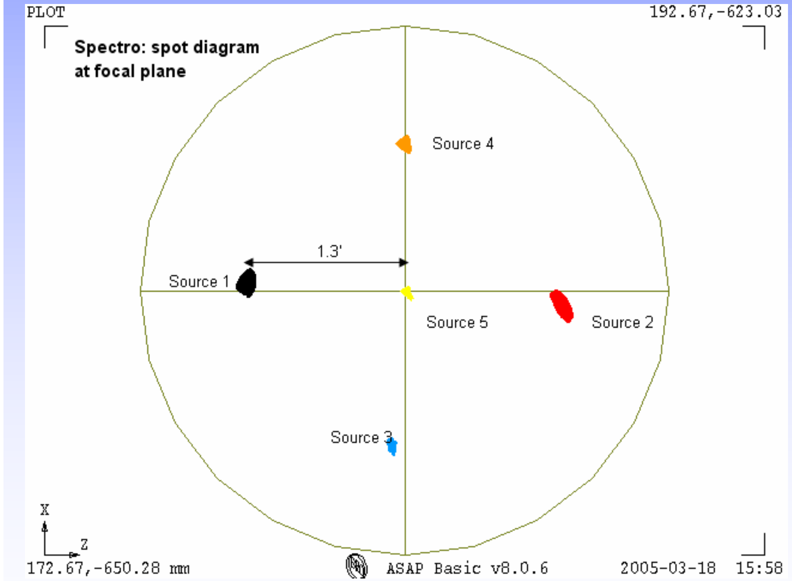
Manual Z profile scan (laser source): SSW data

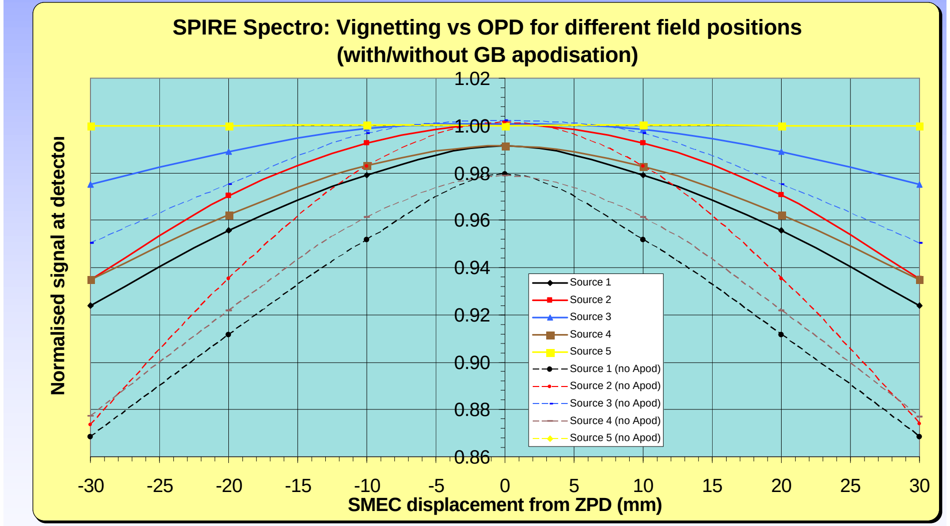


- Good agreement with test set-up model, some differences at the edges of M2;
- Give an indication of the pupil alignment quality during the test (very good for PFM1)
- Test could be complemented by an external OOF test (=scan beyond the field stop)

Pupil & vignetting (I)

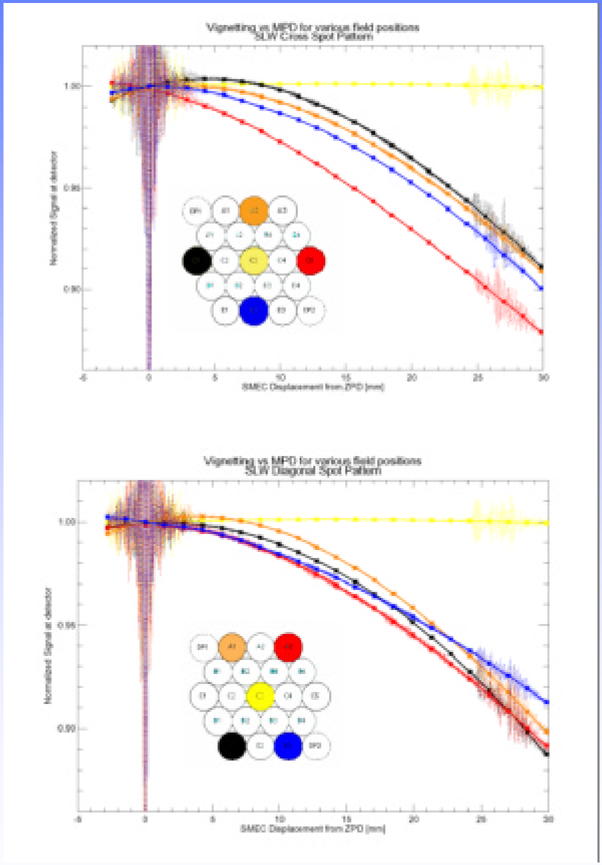
- Field lenses added to SSW and SLW to improved telecentricity of incoming beam onto extended multi-elements planar detectors,
- Improvement but not perfect: design including the lens expects a signal reduction as function of OPD (image of pupil “wanders” with the SMEC position), limited by the approx GB apodisation of the pixel (feedhorn),

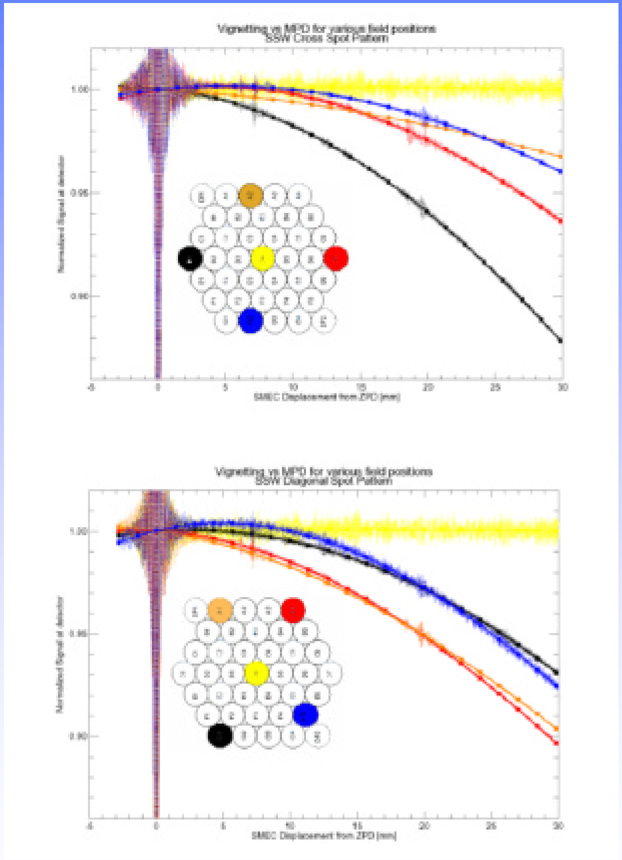




Pupil & vignetting (II)

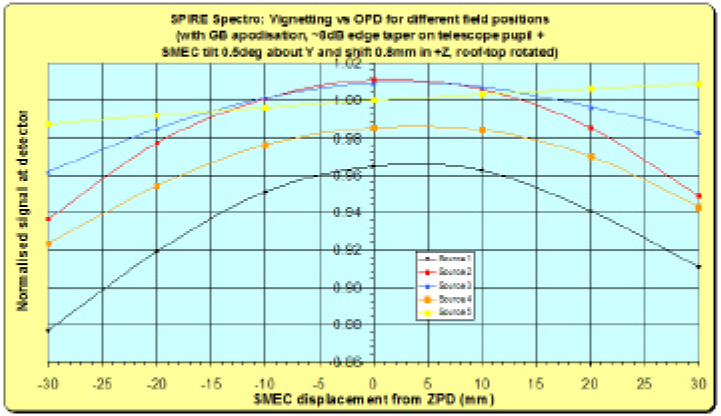
- Good agreement with the variations of the interferogram baseline for both SSW and SLW => effect close to design expectations

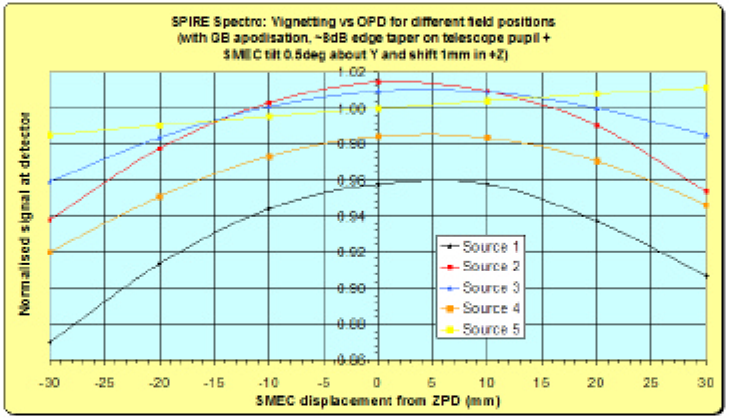


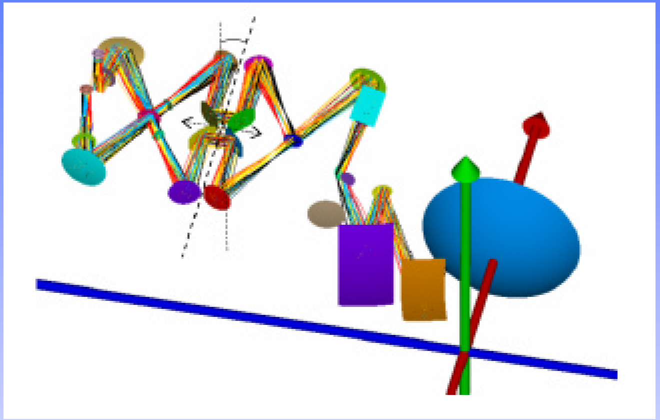


Pupil & vignetting (III)

- Modified model in an attempt to simulate the offset of the interferogram baseline variations: equivalent simple offset & tilt perturbation at SMEC



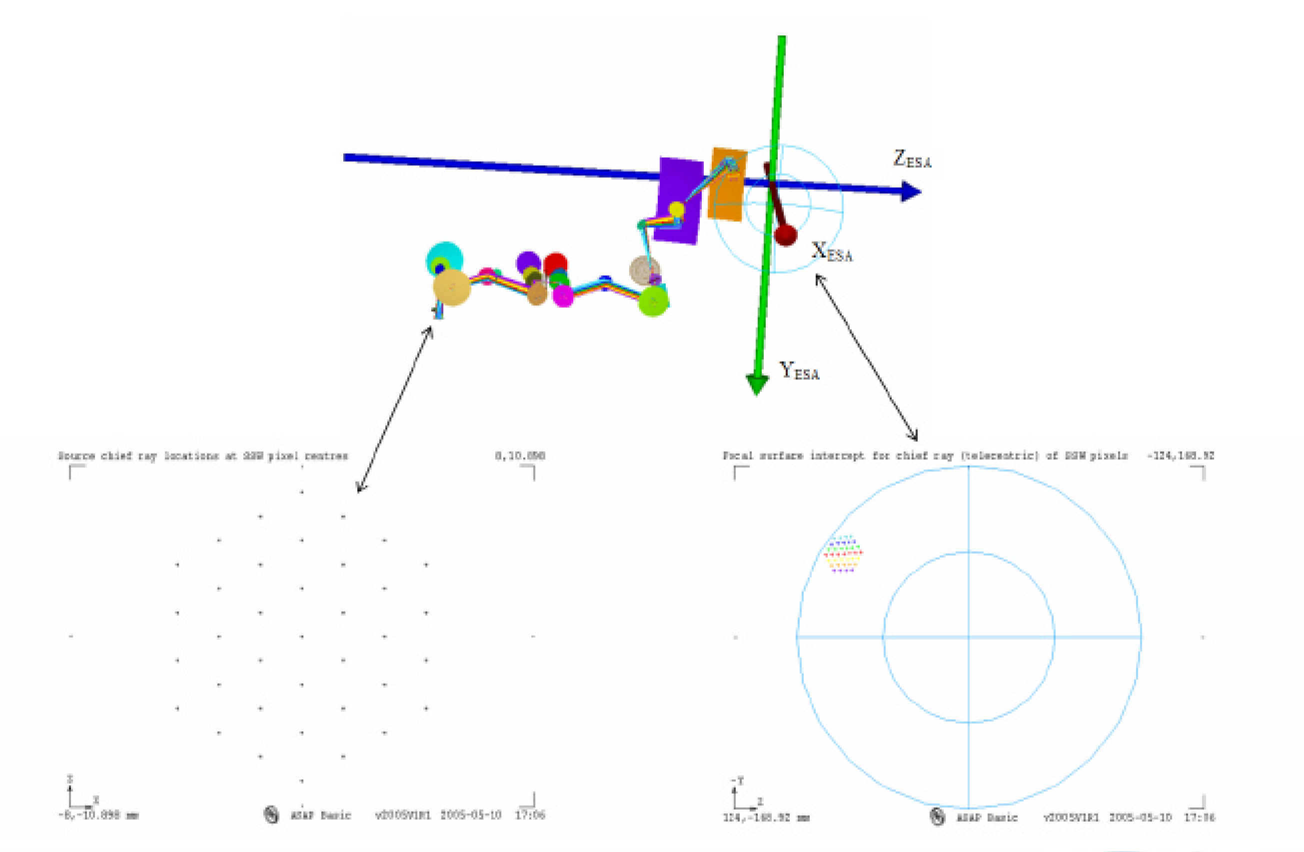




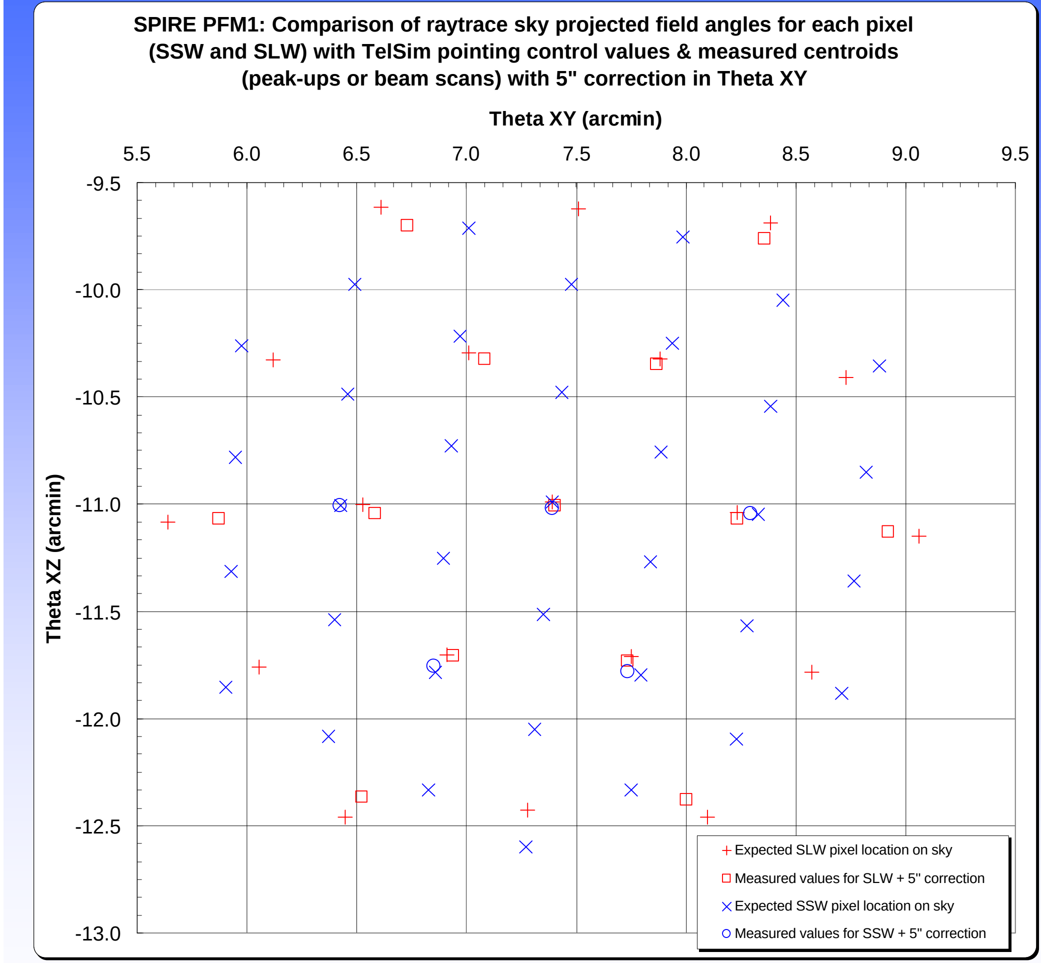
- Can match the interferogram decentring,
- No unique solution + does not pinpoint which component is the source,
- Data reduction on CCB source seems to indicates ZPD shifted at ~8.2mm with planar (not radial) +/-0.24% variations over FoV => not yet fully linked to the above

Field imaging (I): FoV geometric modeling

- Backward model includes design FoV distortion,
- Interface surface is Telescope entrance surface + projected on-sky



Field imaging (II): pixel map



- Comparison with on-sky map of measured data (SSW and SLW results merged),
- Good agreement when extra 5 arcsec offset added => not explained, could be internal or external to FPU (BSM unlikely),
- Residual difference is a few % radially (more clearly seen on SLW) => possible lensing effect,
- Constraints on as-built final F#:

$4.5<F_{SLW}<5$ (design is 4.85+/-0.1)

$4<F_{SSW}<4.5$ (design is 4.35+/-0.1)

NB: No perfect SLW/SSW overlap for lateral pixels but expected

Field imaging: beam pattern (I)

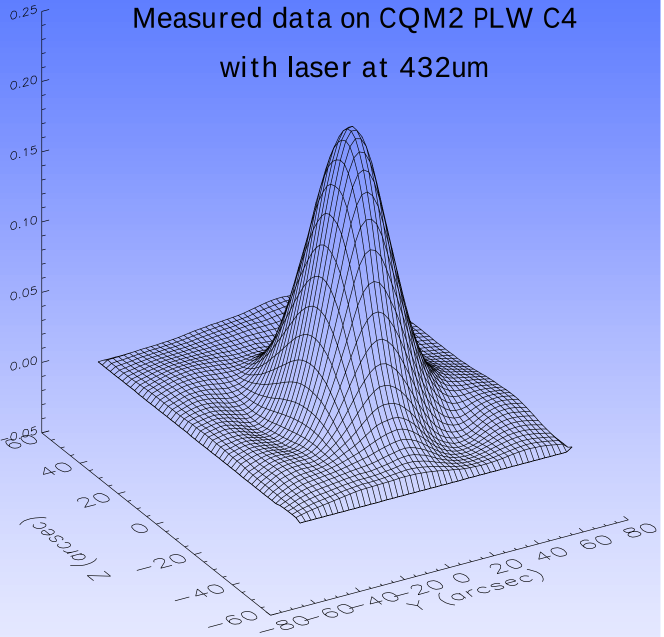
- On-going analysis of beam scans (and some peak-ups) initially via adaptative GB fitting of profiles (of limited used for mutli-mode behaviour eg most Spectro data), recently augmented by higher-order moments characterisation (M2 beam quality factor incl. diffraction and coherence)

- **Results for *PLW (from CQM2 tests):***

  FWHM on-sky for SPIRE only (removal of external instrumental effect) on C4 at 432mm= *<u>30+/-4.8arcsec</u>* (equivalent to ~34.7+/-5.5arcsec at 500mm so approximately compliant with IRD-PHOT-R03)

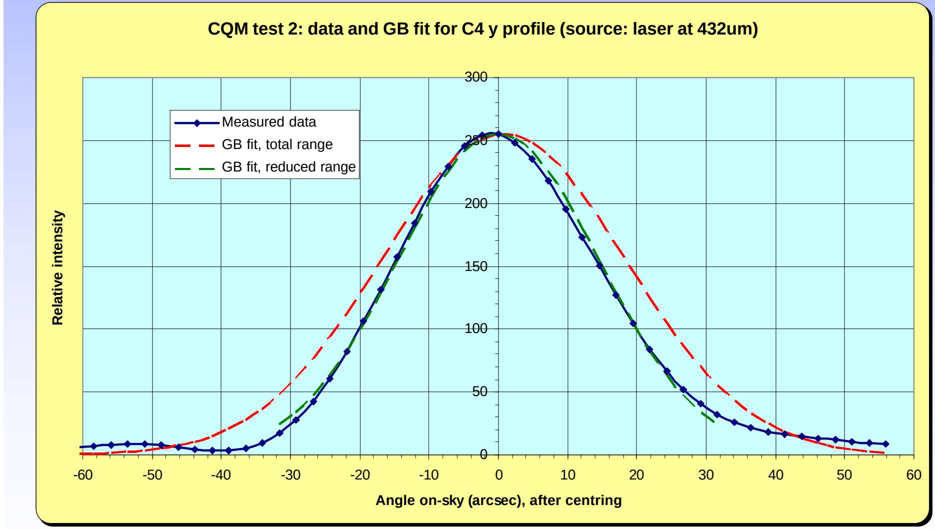
? Large uncertainty at the moment due to only one relevant measurement (PLW/C4 with laser at 432 µ*m*); except C4, beam scan data only available for C5 (broadband point source) and E7 (432µ*m* point source, externally vignetted & misaligned): more data needed to constrain results,

? Broadband point source response modelled via a single effective wavelength but issue with the source (HBB via TFTS) spectral variation.



Measured data on CQM2 PLW C4

with laser at 432um

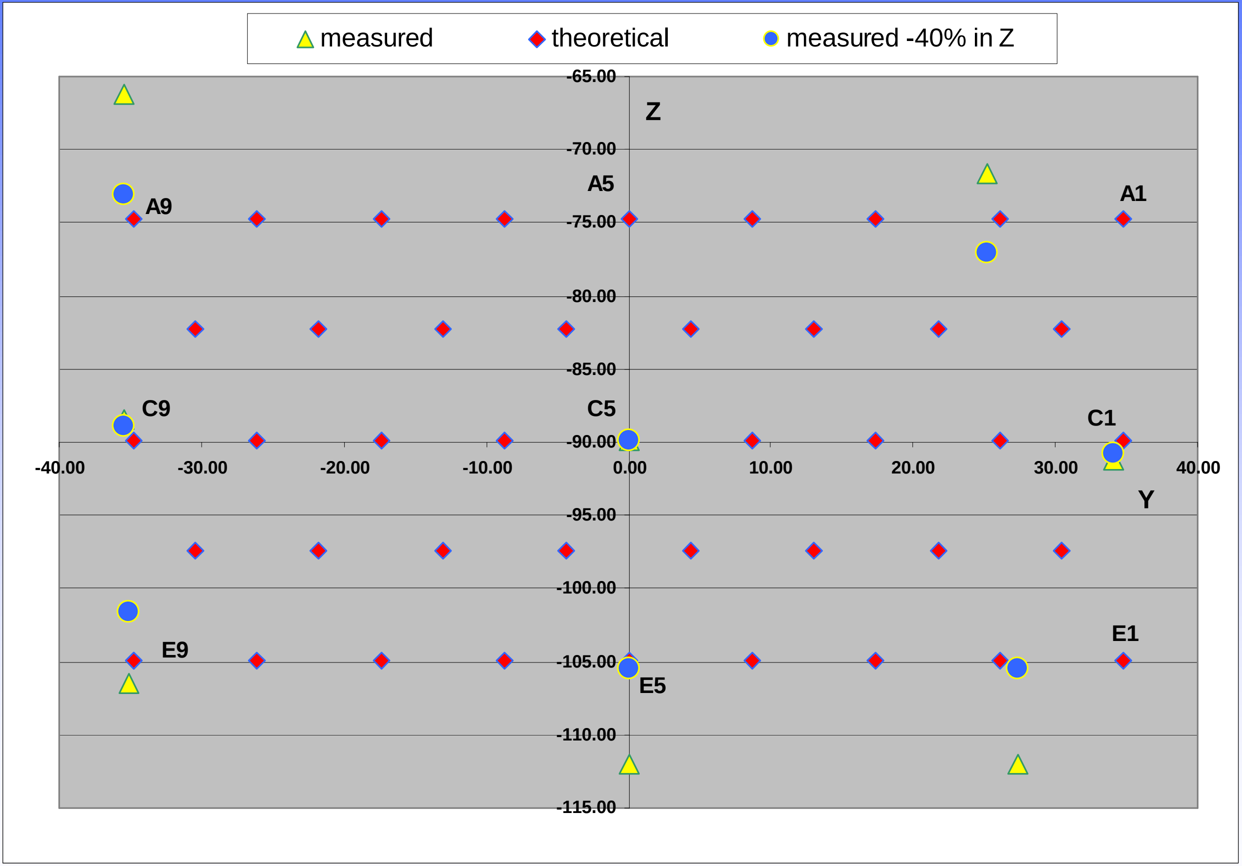


CQM test 2: data and GB fit for C4 y profile (source: laser at 432um)

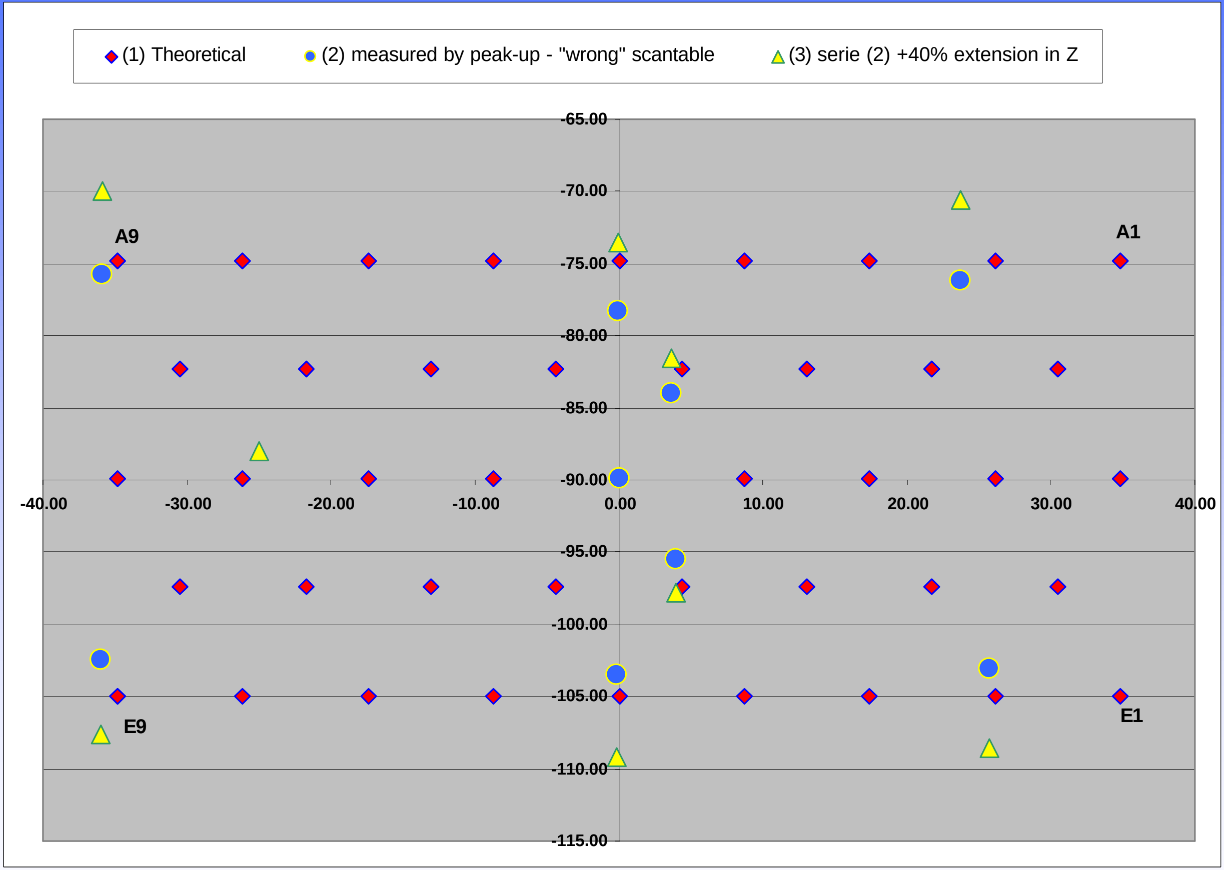
Adaptative range GB fit

on CQM2 PLW C4

PLW Centring CQM1



Centring CQM2



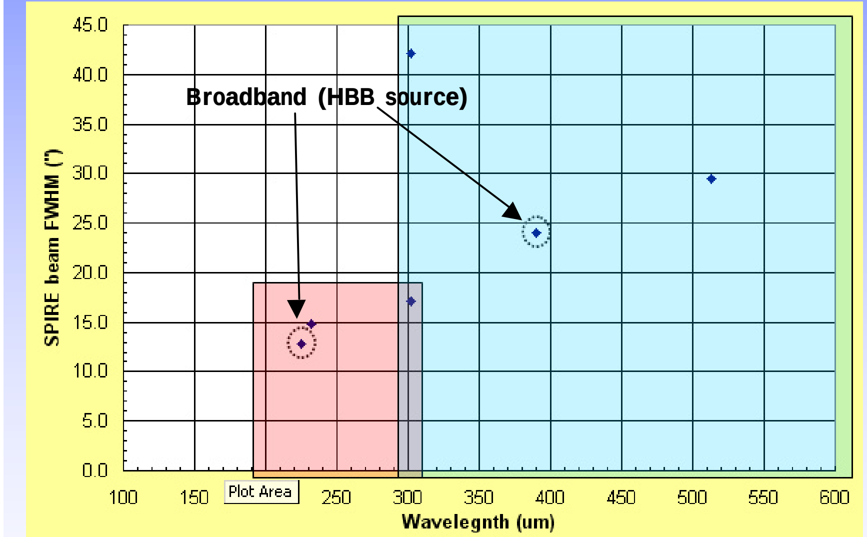
Field imaging: beam pattern (II)

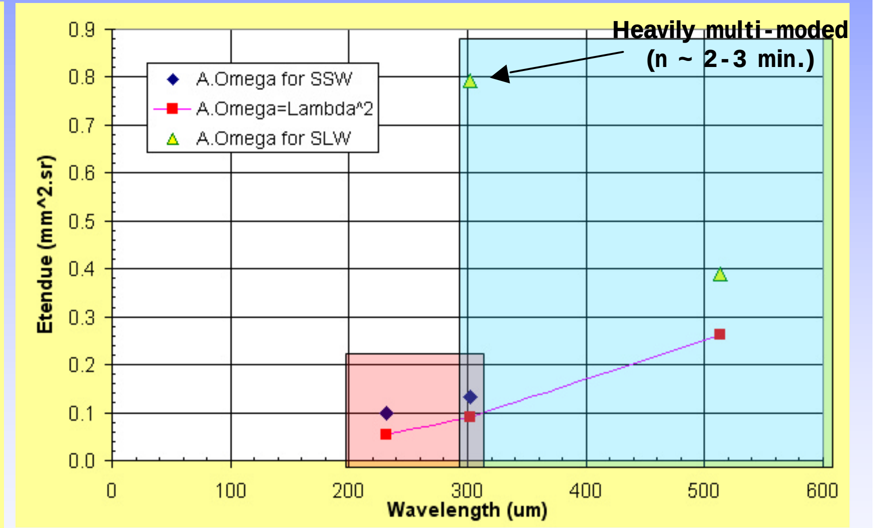
- **Results for *SSW and SLW (from PFM1 tests):***

  Derived FWHM on sky and etendue AΩ for central pixels (SSW/D4 and SLW/C3) for different laser lines; similar results off-axis => indication of good spatial response uniformity over the FoV,

  Broadband case (HBB source) not relevant (specially for SLW) because inaccuracy in the test source spectrum knowledge (internal effect of the TFTS),

- ***Comparison with IRD-SPEC-R05:*** **compliance at 250um as FHWM is extrapolated from SSW 232um data to ~16+/-2arcsec; but at 350um (short wave zone of SLW), IRD spec of 25arsec is not taking into account the multi-modal behaviour (leading to more realistically expected ~35+/-5arcsec, TBC by next tests).**



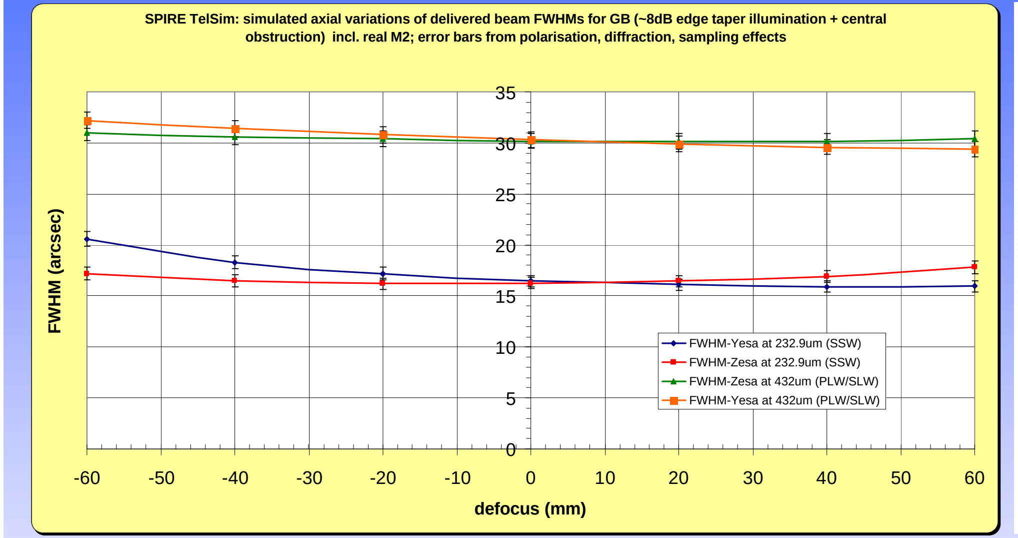


- ***Implication for future tests:***
  - Same tests repeated at different other intermediate wavelengths (shorter than 225um, 300-500um, >550um);
  - *Optional:* Extension of the point source beam scan beyond the 1st Airy ring and/or depth-of-focus in defocus;

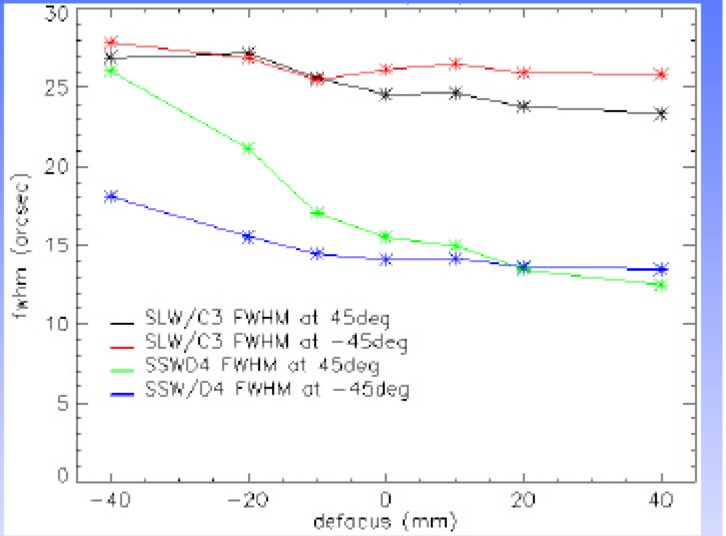
Field imaging: beam pattern & defocus

- **Defocus:**

Simulation of test beam profile size for SSW and SLW/PLW



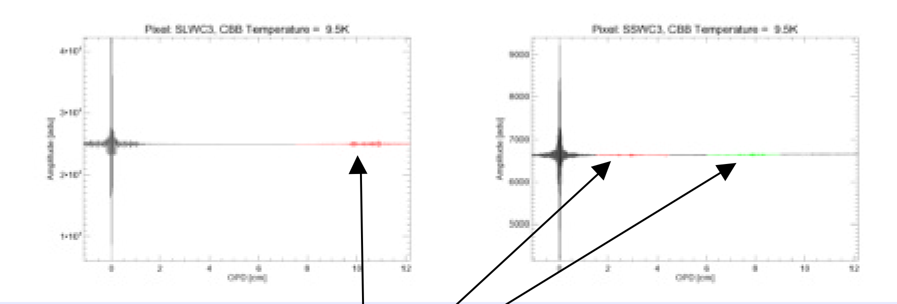
PFM1 data measured response vs SPIRE/Tel. external defocus

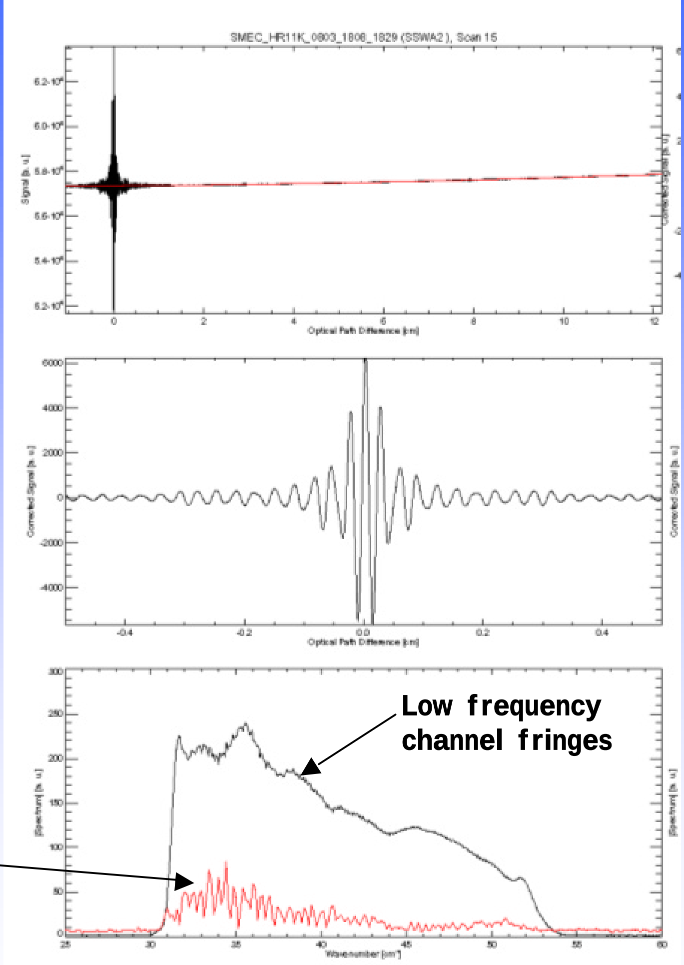


- Long depth-of-focus (cm size at SPIRE/HSO Tel interface for SLW) as expected,
- Some beam asymmetry/ellipticity (additional from intrinsic low ellipticity feedhorn beam pattern) of the pattern,
- Simulation is for SPIRE entrance plane only i.e. (long-)wavelength dependent defocus from SPIRE relay imaging not taken into account => higher resolution beam scan defocus data to be used instead for relative SSW/SLW defocus assessment and in-band Strehl ratio estimation,
- Data is broadband but comparison still qualitatively OK as summarised by single effective wavelength in simulations (still issue for final interpretation for SPIRE due to long-wavelength-clipped source spectrum).

Field imaging: ghost (spectral)

- Consequence of the presence of the lenses: in-band fringing => OK expected and seen,
- New features is the “high frequency channel fringe” at localised zones in interfeorgrams,
- Ghost “lens+detector” potential candidate, other source (stray) still possible => open point





Low frequency channel fringes

High frequency channel fringes

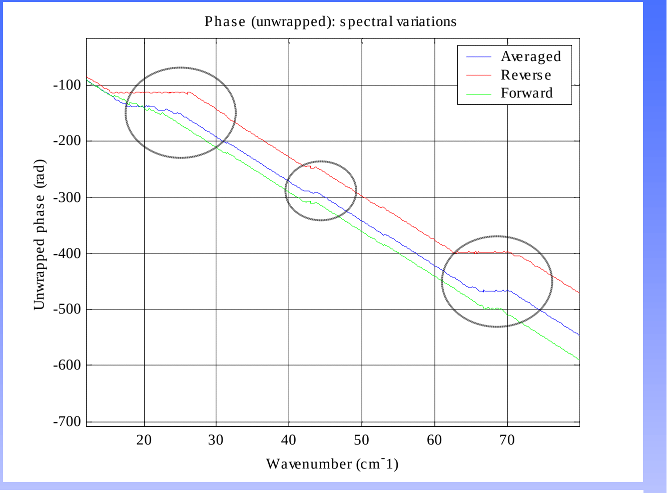
Characterisation in spatial & spectral domain

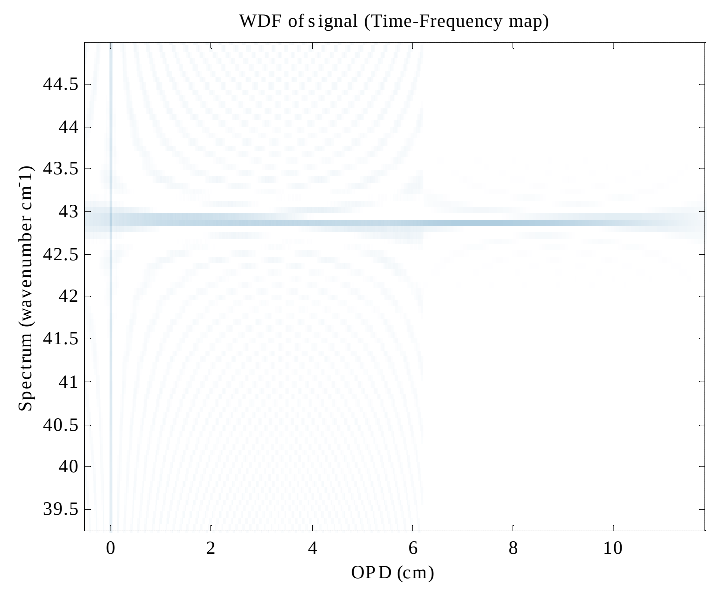
- Example for SSW with point source, laser line (232,94um), D4 pixel: Some anomalies in the spectral variations of the phase at the line position + beyond passband edges
  => finite non-null optical thickness of BS + differential tilt ?

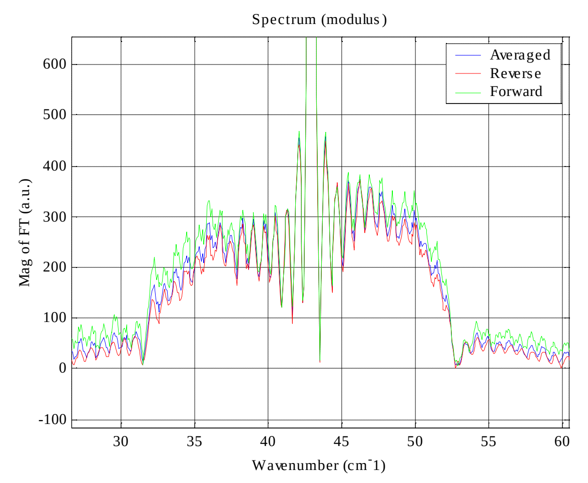
- Interferogram signal characterisation via WDF:

$$WDF(OPD,s) = \int_{-\infty}^{+\infty} s(OPD+\frac{x}{2}).s^{*}(OPD-\frac{x}{2}).e^{-i2psx}.dx$$

- WDF gives < ~0.1%/cm of OPD variations of the central wavelength + No appearance of “high frequency channel fringe” => to be repeated for SLW and/or edge pixels



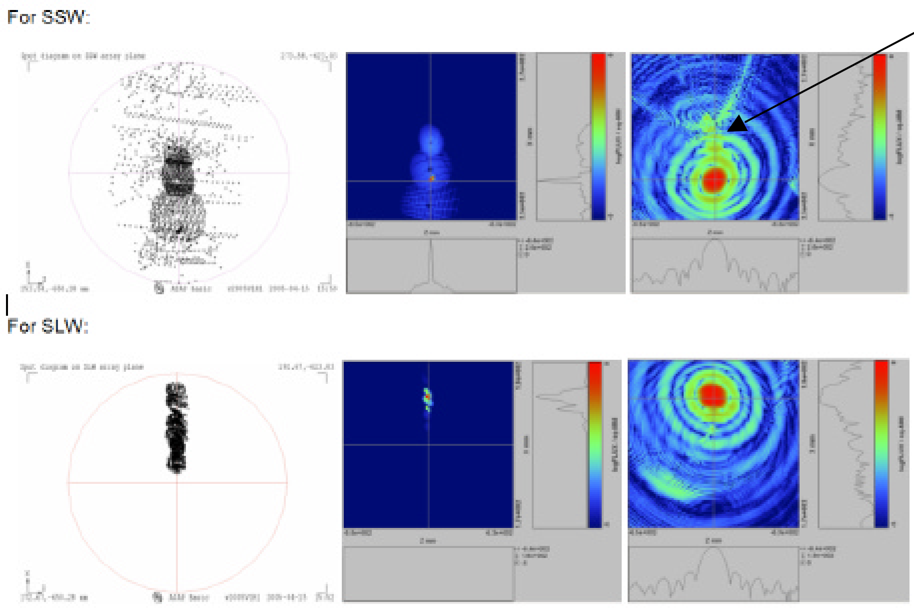


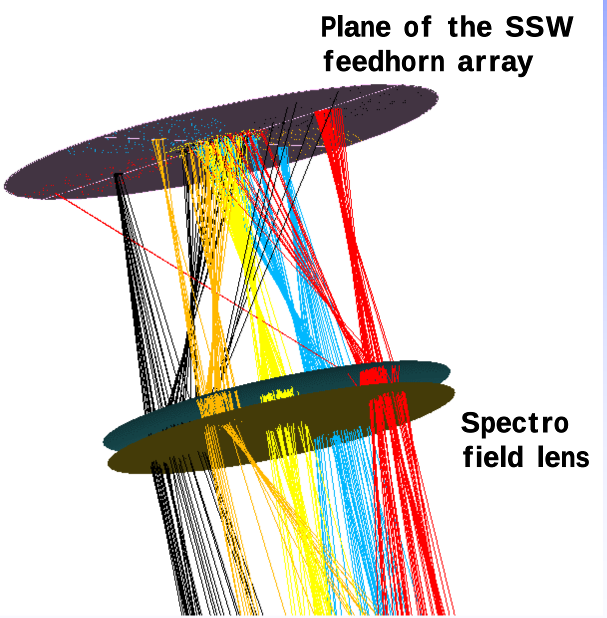


Field imaging: ghost (spatial)

- Lenses in image space are known to give rise to ghost (spread or cross-talk),
- Model from design baseline shows ghosts sent radially inwards for SSW (can dominate diffraction past the 1st / 2nd Airy ring), overlapping the same pixel for SLW (=more fringing, less cross-talk),
- No expected variations with SMEC position.

Ghost from off-axis source image dominant over diffraction close to the SSW FOV centre





Load Curve Analysis

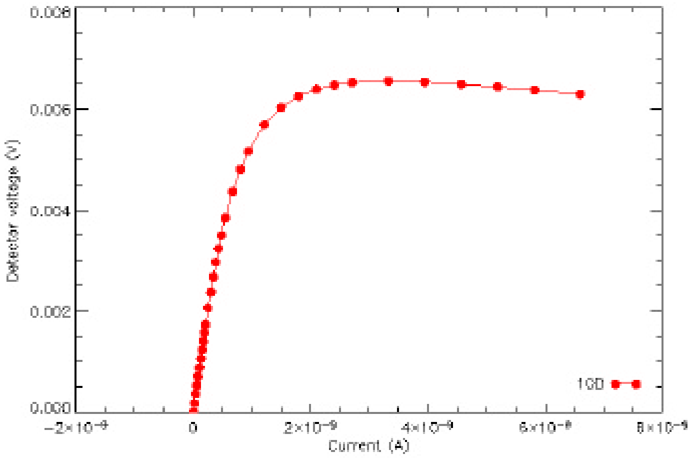
Adam Woodcraft

Cardiff University

Introduction

Introduction

- **Load curves are measurements of bolometer voltage vs current**
  - **For characterisation only; not done as part of normal operations**
  - **Important bolometer properties can be determined from load curves:**
    - **Directly from one or more load curves**
    - **By using load curves to find parameters for a model describing the bolometer behaviour**



Summary of measurements

- **Load curves measured:**
  - **At JPL:**
    - **sub-system (array) level (BODAC)**
    - **DC bias (easy to understand)**
  - **At RAL:**
    - **system level (instrument) (AIV)**
    - **AC bias (flight electronics) + (CQM only) DC bias**

Temp.	Loading	JPL	RAL	Uses
Approx. 300 mK	Blanked	Few	Many	Derive G(T)
Various	Blanked	Yes		Derive R(T)
Approx. 300 mK	Various	Yes	Yes	Derive optical efficiency

- **Analysis enables model parameters to be determined**

Ideal bolometer model

- **Ideal bolometer model:**
  - **Properties depend only on:**
    - **Thermal conductance G(T) between absorber and heat sink**
    - **Thermistor resistance R(T) as a function of temperature**
  - **Assume simple equations:**

$$G(T) = G_{so} T^{b}$$

$$R(T) = R^{*} \exp\left(\sqrt{\frac{T_g}{T}}\right)$$

  - **With these four parameters, plus optical efficiency, we can predict the bolometer behaviour for any:**
    - **Heat sink temperature**
    - **Bias current**
    - **Optical load**

JPL (BODAC) measurements

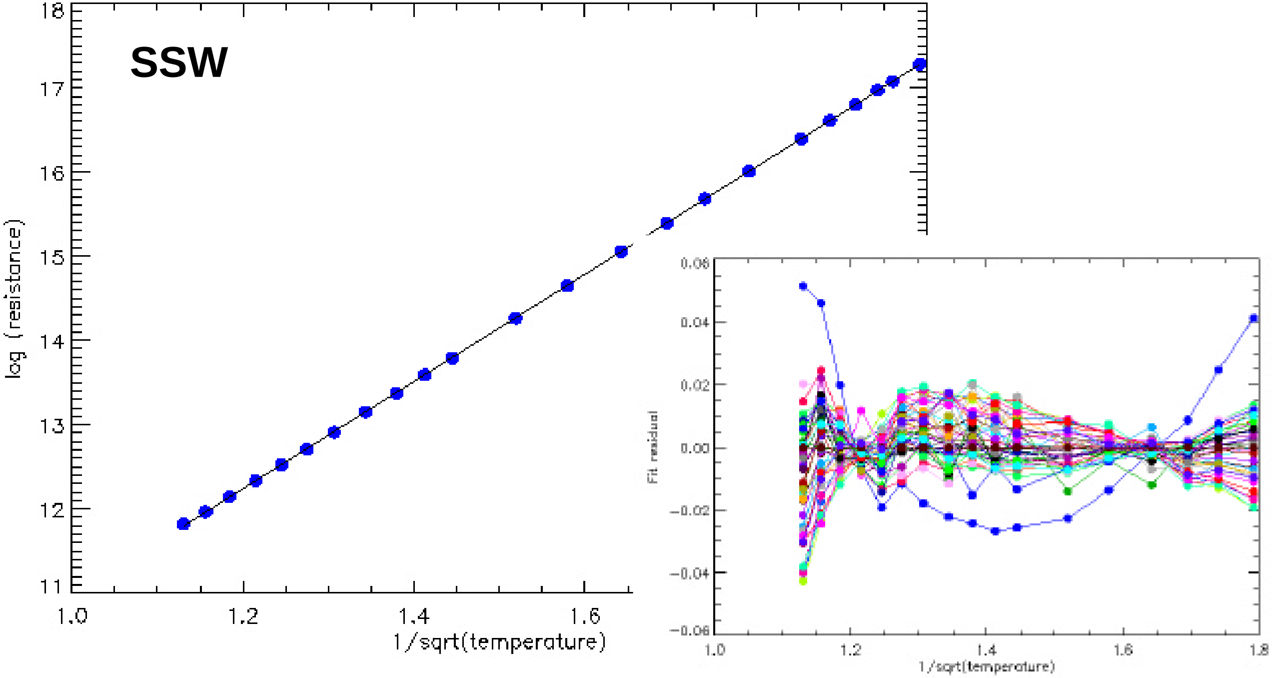
subsystem (array) level

JPL (BODAC) measurements

- Measurements:
  - Dark load curves (small bias range)
    - determine R(T)
    - one set of load curves
  - Dark load curves (large bias range)
    - determine G(T)
    - Three curves (SSW), one curve (SLW)
  - Optically loaded load curves
    - determine optical efficiency
    - not discussed here

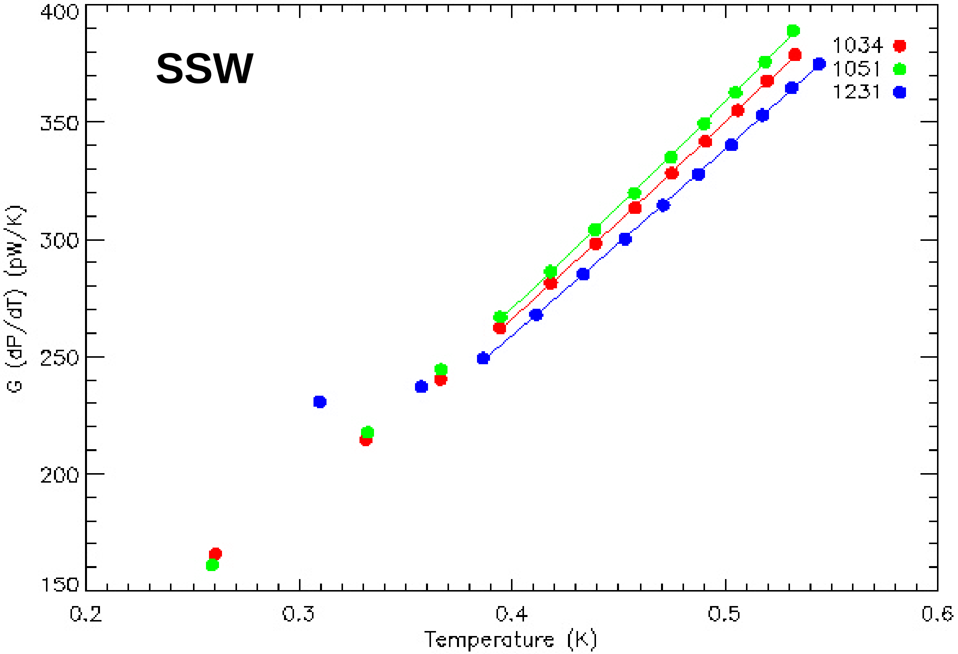
JPL (BODAC) R(T)

- Expressions for R(T) fit very well (above 300 mK)



JPL (BODAC) G(T)

- JPL (BODAC) measurements show:
  - G(T) can be approximated well by simple power-law
    - Obtained by differentiation of P=V*I
    - Some difference between different measurements
    - (Shouldn’t depend on temperature, load etc.)



JPL measurements - bolometer model

- Therefore requirements are met for ideal bolometer model
- Indeed, the model works well

- Model can be used to predict behaviour for any set of operating conditions

JPL EIDPs

- **Some discrepancies between values quoted in EIDPs for SLW and SSW and my analysis of the JPL data**
- **These do not affect the conclusions here, but need to be addressed, and other EIDPs examined.**

RAL (AIV) measurements

system (instrument) level

RAL (AIV) measurements

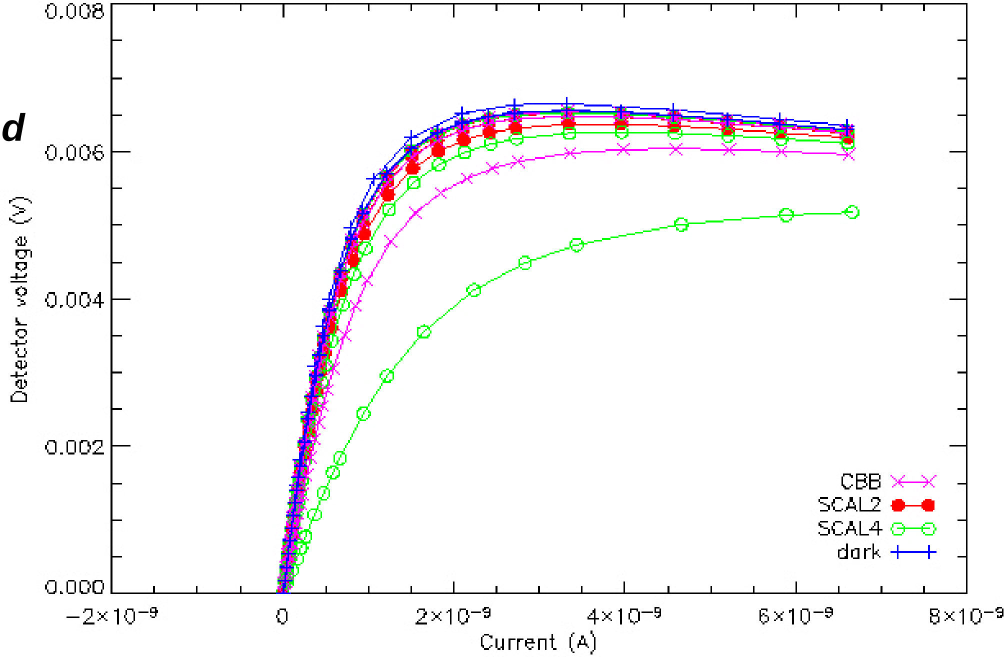
- Measurements on PFM:
  - Dark load curves
    - Four taken during the measurement period
  - Load curves with black-body (CBB) heated
    - One set with different CBB temperatures
  - Load curves with SCAL2 and SCAL4 illuminated
    - One set for each of SCAL2 and SCAL4
  - Load curve looking into room
- Note that SPIRE is not designed for taking load curves
  - Time consuming task

RAL (AIV) measurements

- **Different measured load curves for one pixel**

- **Results vary depending on optical load *and* 300 mK fridge temperature**

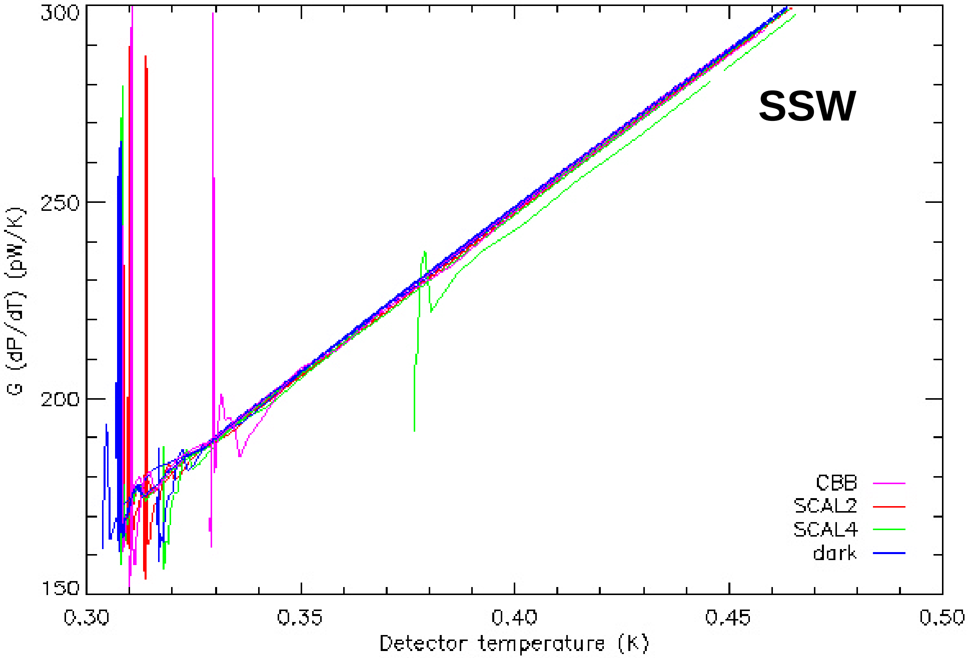
- **Can compare load curves more easily by plotting G(T)=dP/dT - same for all load curves**



AIV G(T)

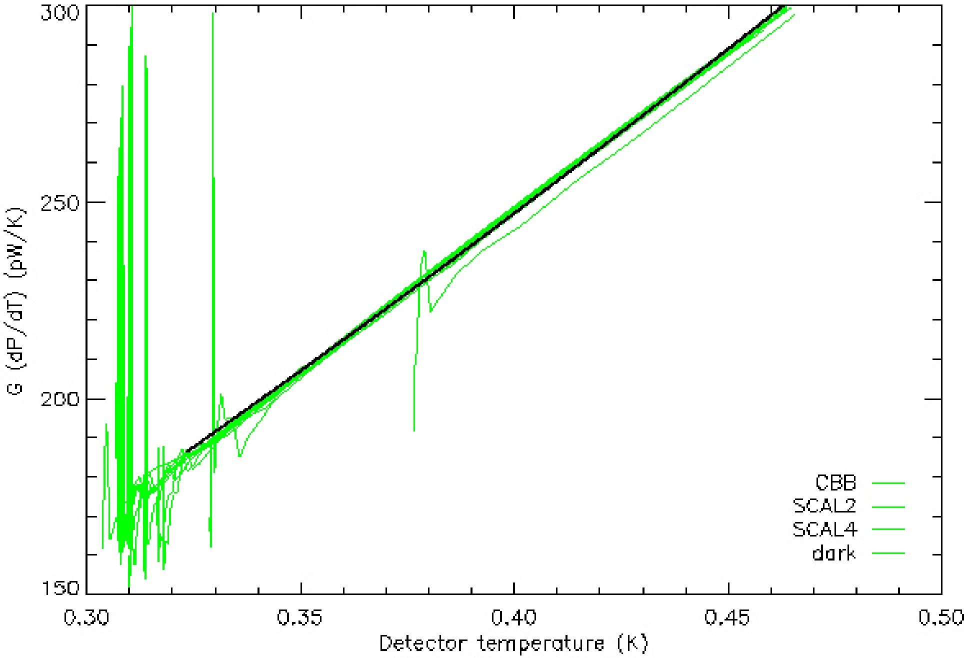
- G(T) from different load curves is in excellent agreement
  - Take R(T) from BODAC measurements (can't measure)

- Results for most pixels look as good as this
- Having many load curves aids analysis significantly
- Load curves for several fridge cycles



AIV G(T)

- **Powerlaw fits G(T) well**



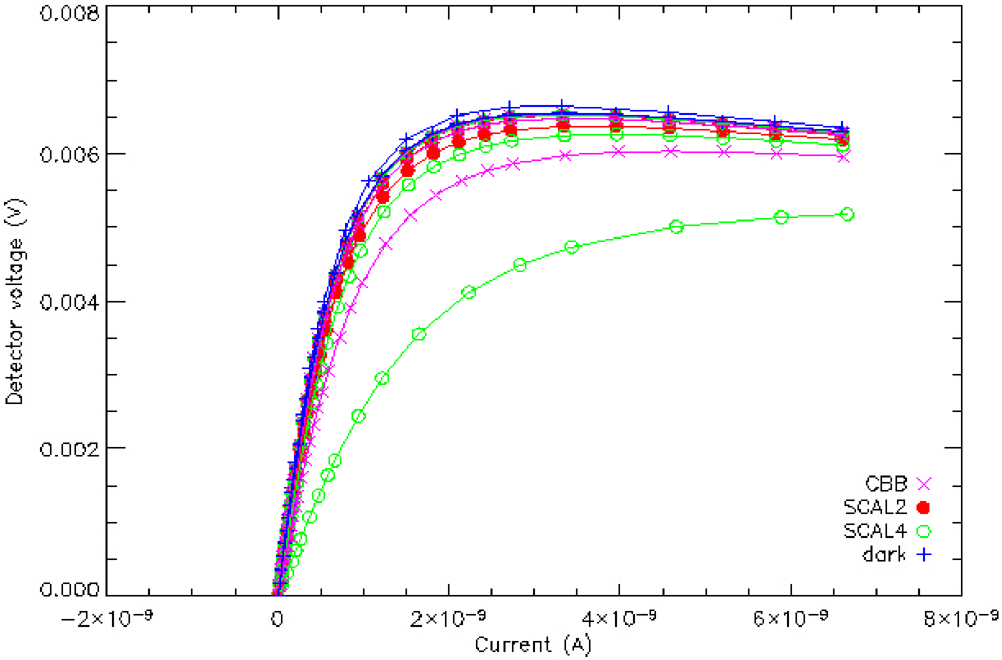
AIV G(T)

- G(T) from different load curves is in excellent agreement, and follows a power-law
- This tells us that:
  - The read-out systems are reasonably well behaved
    - Many (but not all) problems would show up as a disagreement between load curves at different fridge temperatures and different optical loads
  - The system is stable
    - Repeated measurements give the same result
  - The ideal bolometer model should work well
    - Since the assumption that G(T) is a powerlaw is met

- The detectors should therefore be well behaved in flight, should retain a calibration, and should be easy to model

AIV measurements - bolometer model

- As expected, bolometer model fits results extremely well
  - Lines are model fits, not measured data!



AIV measurements - summary

- Therefore we can predict the bolometer behaviour for a given bias, fridge temperature and optical load
  - Simplifies calibration hugely compared to doing everything empirically

Comparison between AIV and JPL

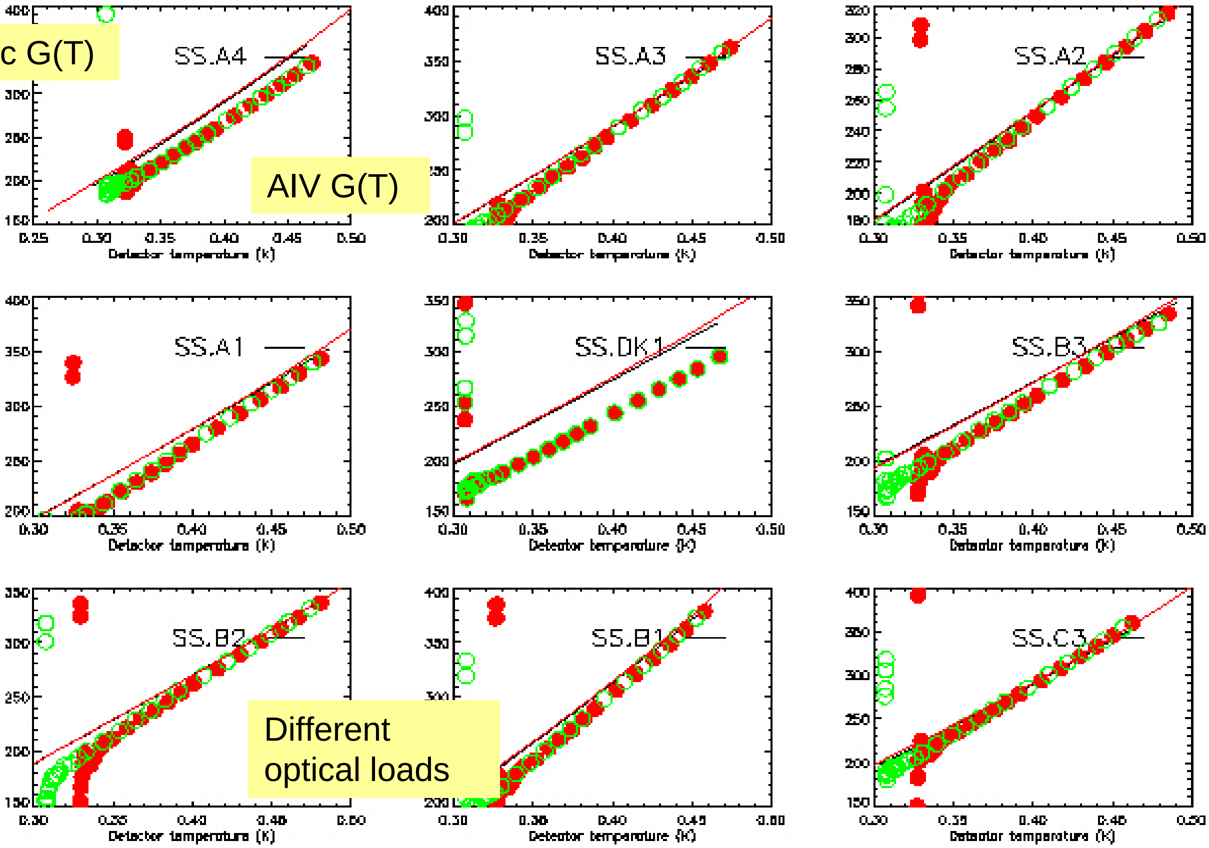
Comparison between AIV and JPL

- **Load curves measured at JPL and AIV do not entirely agree**
  - **Using JPL R(T) values, bolometer zero bias temperature (temperature in the absence of self-heating) varies from channel to channel**
  - **G(T) values differ significantly from JPL measured values**

  - **We can let the gain vary between channels, and choose a value for each channel to give the same zero bias temperature**
    - **This then also brings G(T) into much better agreement with JPL**
    - **However, there is no gain value which gives complete agreement**

  - **Seen for both PFM and CQM**

Comparison between AIV and JPL



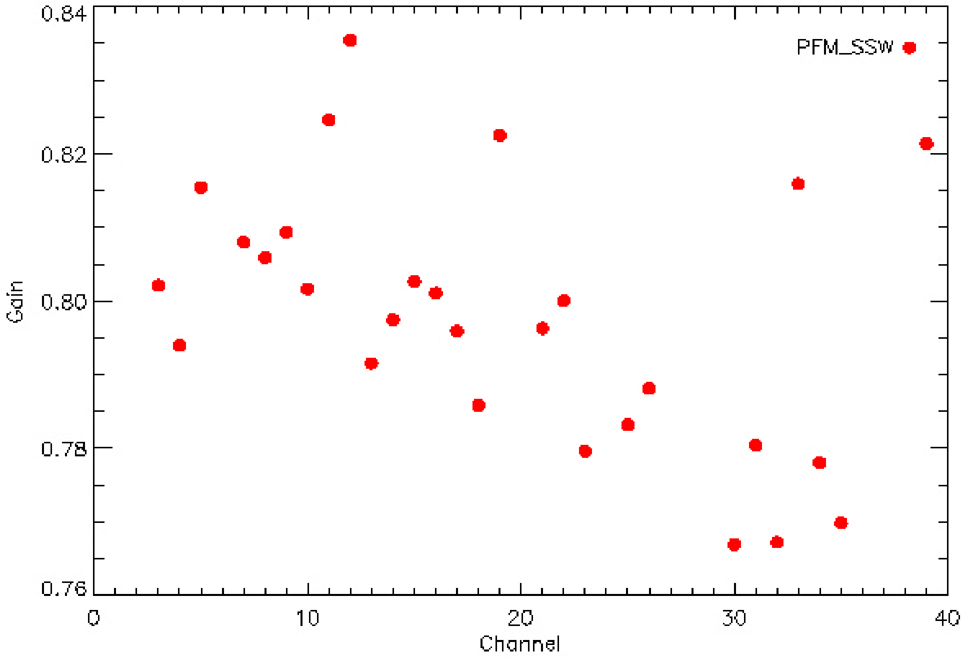
Bodac G(T)

AIV G(T)

Different optical loads

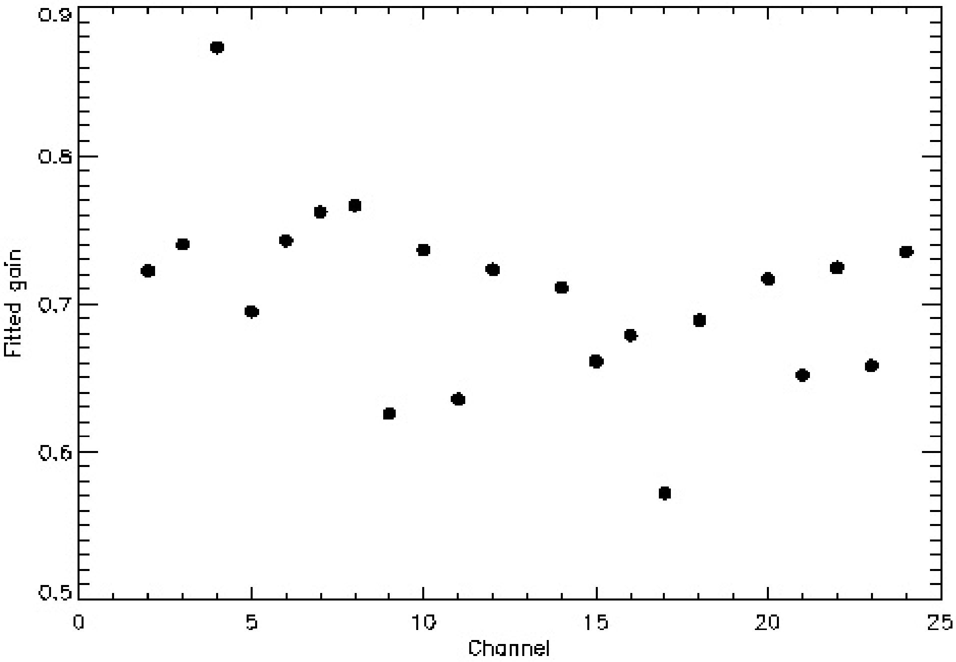
Comparison between AIV and JPL

- Systematic variation in apparent gain vs channel for SSW
  - Any ideas why this should happen?



Comparison between AIV and JPL

- Maybe a systematic variation for SLW
  - Note: mean values lower than for SSW



Comparison between AIV and JPL

- **Understanding the discrepancies is not essential**
  - **Ultimate calibration will come from astronomical observations**

  - **BUT:**
    - **An assurance that the read-out system is accurate as well as precise would simplify calibration further**
    - **It would be good to be sure that we really understand the flight electronics read-out system**
    - **Work on this issue is therefore on-going**

DC load curves in AIV

- DC load curve measurements on CQM disagree with AC measurements
  - Need to change gain to get agreement
  - Same gain used for every channel
- This suggests that the gain changes we require to get AIV results to agree with BODAC has two parts:
  - A change that is the same for each pixel that is to do with using ac bias
  - A change that varies between pixels that is not directly to do with using ac bias

Conclusions

Future work

- Should take dark load curve following each cooler cycle for future tests
  - Get more information on stability
  - Don’t necessarily need to be over full range
- Would be very useful to have a load curve at elevated temperature and low optical background
  - Not easy; maybe do as fridge is cooling or warming back up?
- Discrepancies between JPL and AIV measurements need to be discussed with electronics team
  - We are reaching the limits of what we can deduce just from looking at the measurements

Conclusions

- Ideal bolometer model can be used to fit both JPL (subsystem level) and AIV (system level) measurements
- AIV measurements show excellent stability and repeatibility
- Therefore the detectors should operate well in flight with a straightforward calibration

- However, there is some disagreement between JPL and AIV measurements
  - This will not prevent an accurate calibration
  - However, resolving discrepancies should simplify calibration even further and assure us that we understand the read-out system

Conclusions

- **Ideal bolometer model can be used to fit both JPL (subsystem level) and AIV (system level) measurements**
- **AIV measurements show excellent stability and repeatibility**
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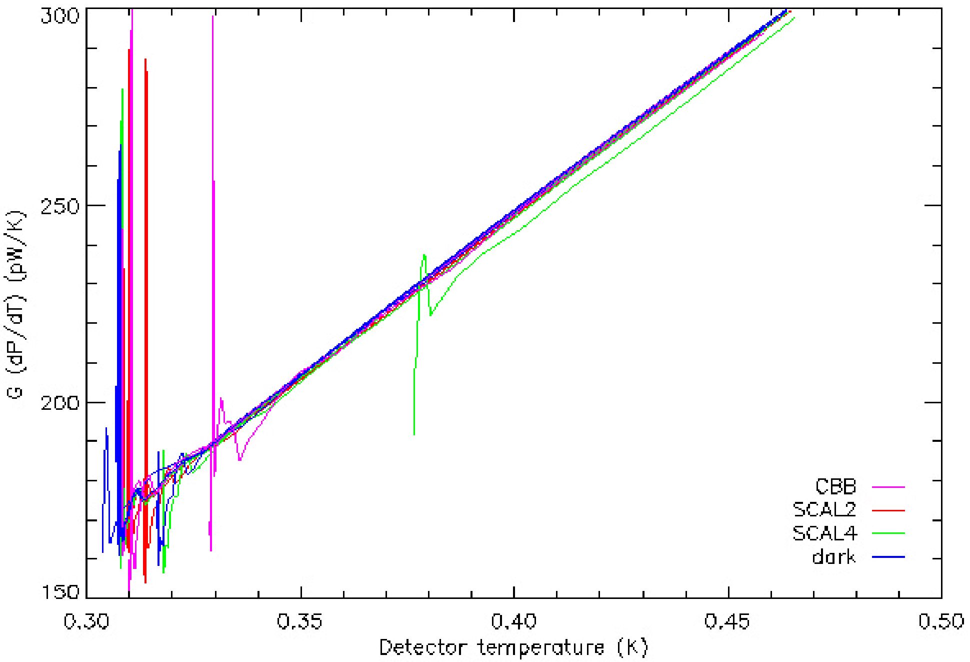
- **However, there is some disagreement between JPL and AIV measurements**
  - **This will not prevent an accurate calibration**
  - **However, resolving discrepancies should simplify calibration even further and assure us that we understand the read-out system**

Final conclusion

- **The detectors behave very well**



Final conclusion

- The detectors behave very well

Spectrometer Noise PFM1

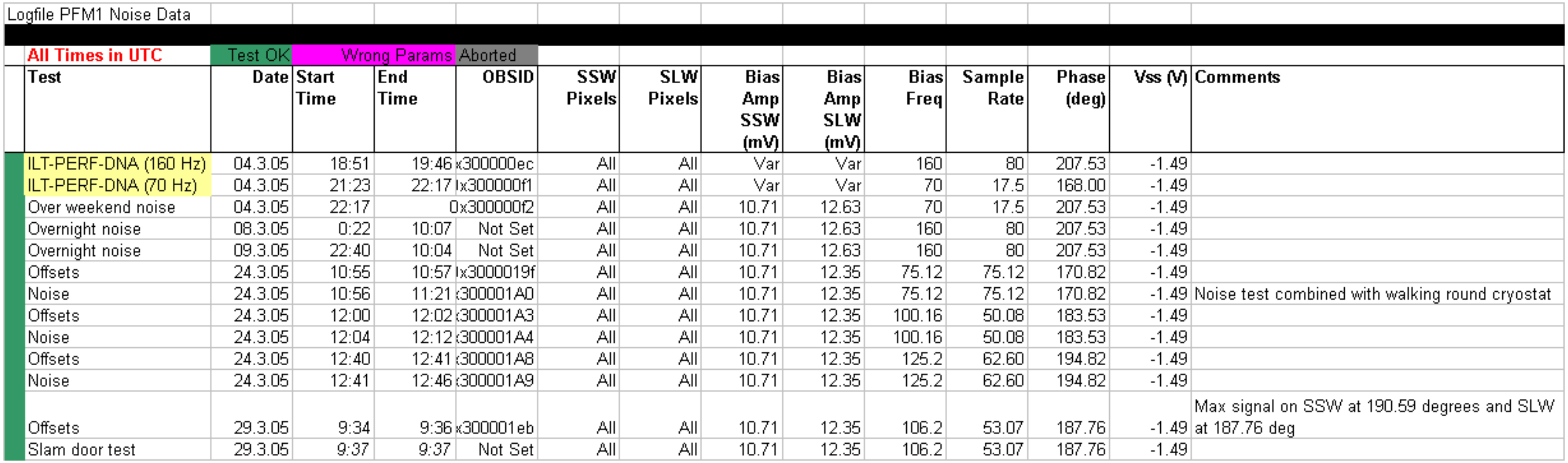
Bernhard Schulz

with contributions by

Lijun Zhang

Caltech/IPAC

Data Considered from PFM1 Tests



Logfile PFM1 Noise Data

All Times in UTC | 🟩 Test OK | 🟪 Wrong Params | ▨ Aborted

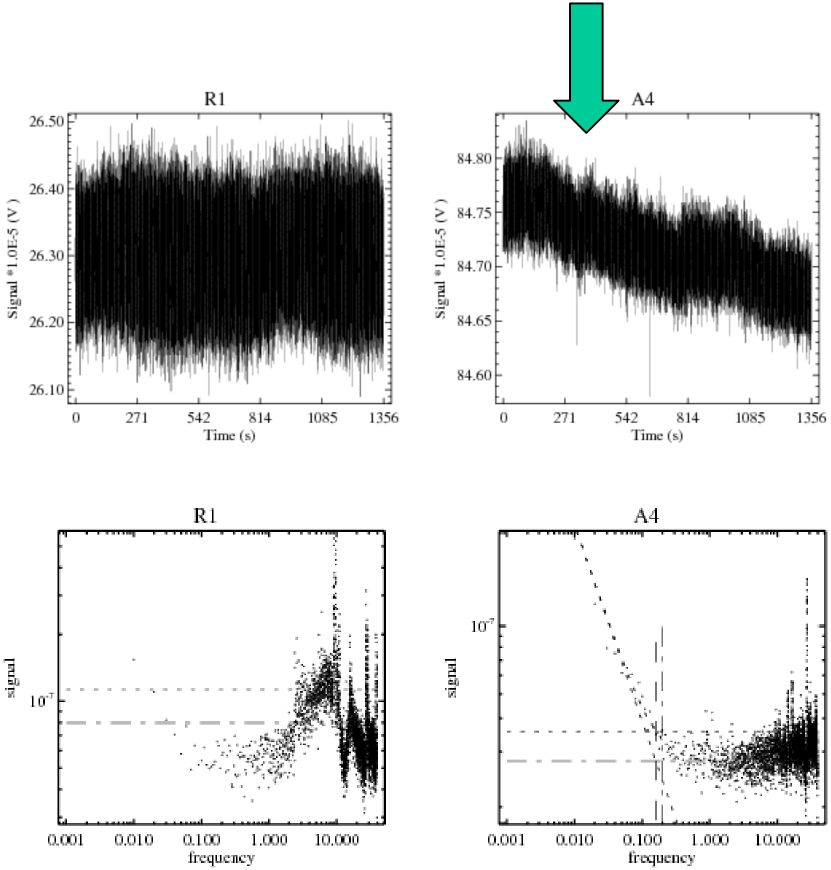
	Test	**Date**	**Start Time**	**End Time**	**OBSID**	**SSW Pixels**	**SLW Pixels**	**Bias Amp SSW (mV)**	**Bias Amp SLW (mV)**	**Bias Freq**	**Sample Rate**	**Phase (deg)**	**Vss (V)**	**Comments**
🟩	ILT-PERF-DNA (160 Hz)	04.3.05	18:51	19:46	x300000ec	All	All	Var	Var	160	80	207.53	-1.49	
🟩	ILT-PERF-DNA (70 Hz)	04.3.05	21:23	22:17	x300000f1	All	All	Var	Var	70	17.5	168.00	-1.49	
🟩	Over weekend noise	04.3.05	22:17		0x300000f2	All	All	10.71	12.63	70	17.5	207.53	-1.49	
🟩	Overnight noise	08.3.05	0:22	10:07	Not Set	All	All	10.71	12.63	160	80	207.53	-1.49	
🟩	Overnight noise	09.3.05	22:40	10:04	Not Set	All	All	10.71	12.63	160	80	207.53	-1.49	
🟩	Offsets	24.3.05	10:55	10:57	x3000019f	All	All	10.71	12.35	75.12	75.12	170.82	-1.49	
🟩	Noise	24.3.05	10:56	11:21	x300001A0	All	All	10.71	12.35	75.12	75.12	170.82	-1.49	Noise test combined with walking round cryostat
🟩	Offsets	24.3.05	12:00	12:02	x300001A3	All	All	10.71	12.35	100.16	50.08	183.53	-1.49	
🟩	Noise	24.3.05	12:04	12:12	x300001A4	All	All	10.71	12.35	100.16	50.08	183.53	-1.49	
🟩	Offsets	24.3.05	12:40	12:41	x300001A8	All	All	10.71	12.35	125.2	62.60	194.82	-1.49	
🟩	Noise	24.3.05	12:41	12:46	x300001A9	All	All	10.71	12.35	125.2	62.60	194.82	-1.49	
🟩	Offsets	29.3.05	9:34	9:36	x300001eb	All	All	10.71	12.35	106.2	53.07	187.76	-1.49	Max signal on SSW at 190.59 degrees and SLW at 187.76 deg
🟩	Slam door test	29.3.05	9:37	9:37	Not Set	All	All	10.71	12.35	106.2	53.07	187.76	-1.49	

- Noise dependence on bias levels measured at two bias frequencies.
- Three series of signals measured over night at 160 and 70 Hz bias frequency.
- Data taken at four more bias frequencies

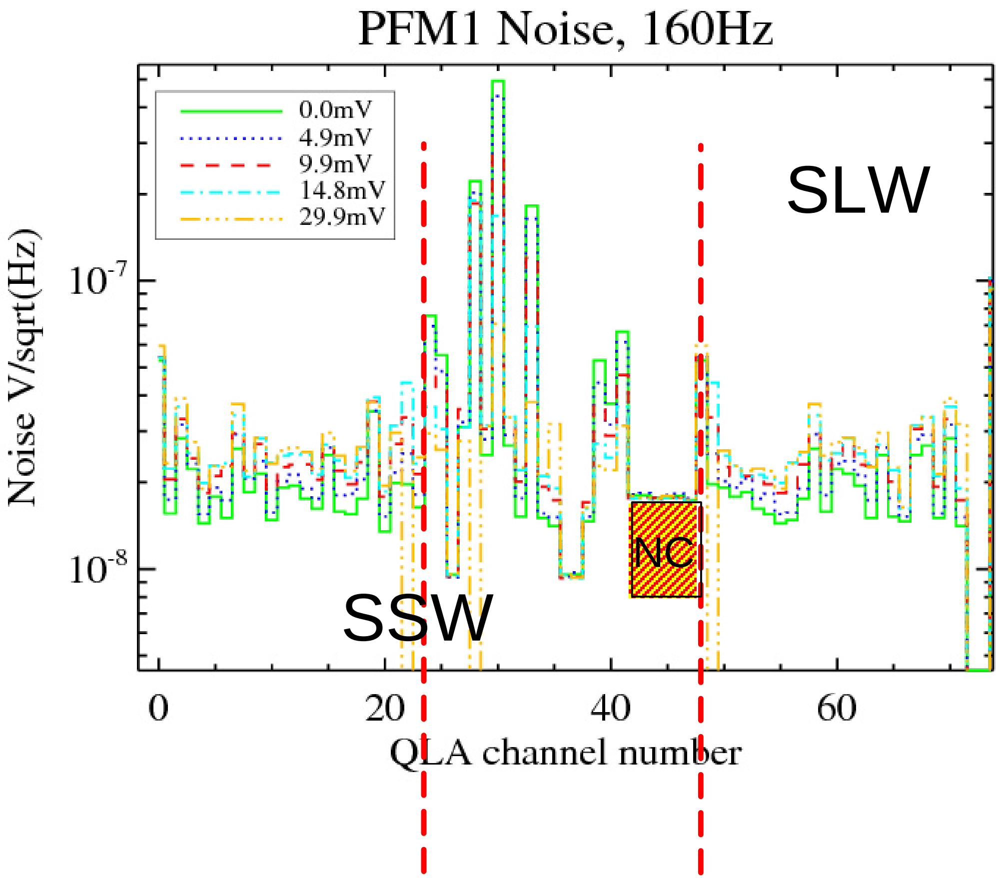
Procedures

- Using detector output voltage versus time.
- Sample rates were not constant and vary between 17.5 and 80 Hz.
- Calculate power spectrum: cut data stream into 100 s intervals, FFT, and add quadratically.
- Determine noise plateau and 1/f knee frequency.
- Results are plotted and printed to ASCII tables.
- Same procedures used as for BDA tests at JPL.

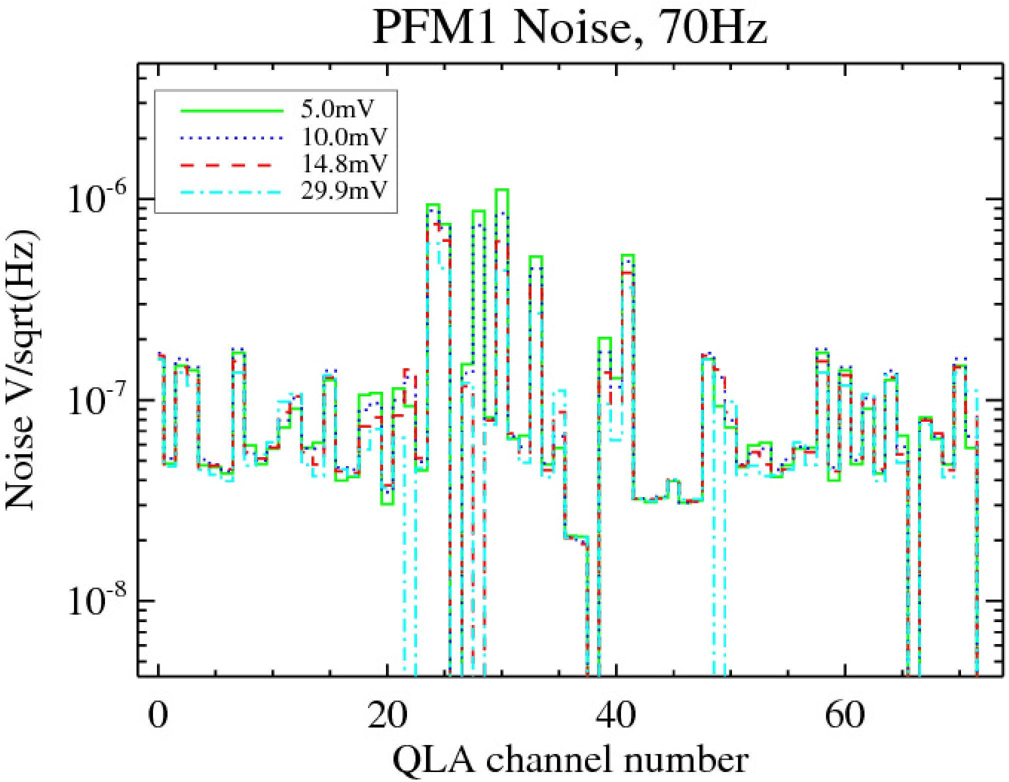
likely due to temperature drift



Noise at Different Bias Levels



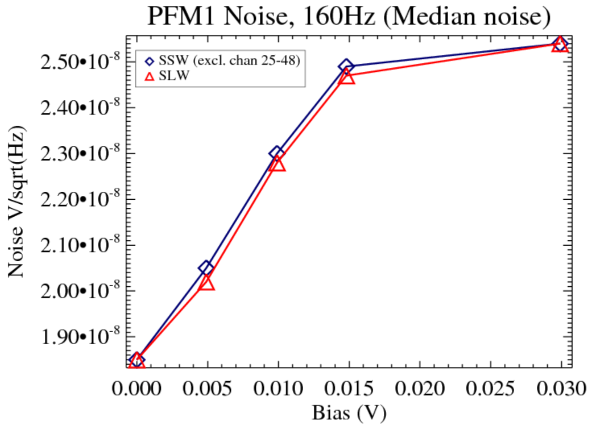
Noise at Different Bias Levels

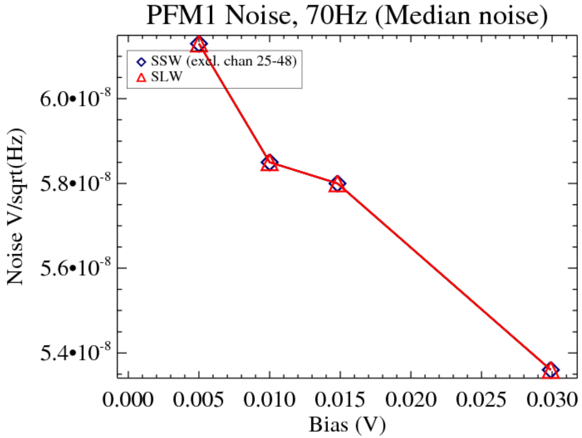


Noise at Different Bias Levels

- Noise is very high for 70 Hz bias.
- Noise is increased in 2nd module, (channels 24-41 correspond to J6 connector)
- Shielding was probably compromised by quick fix of J6.

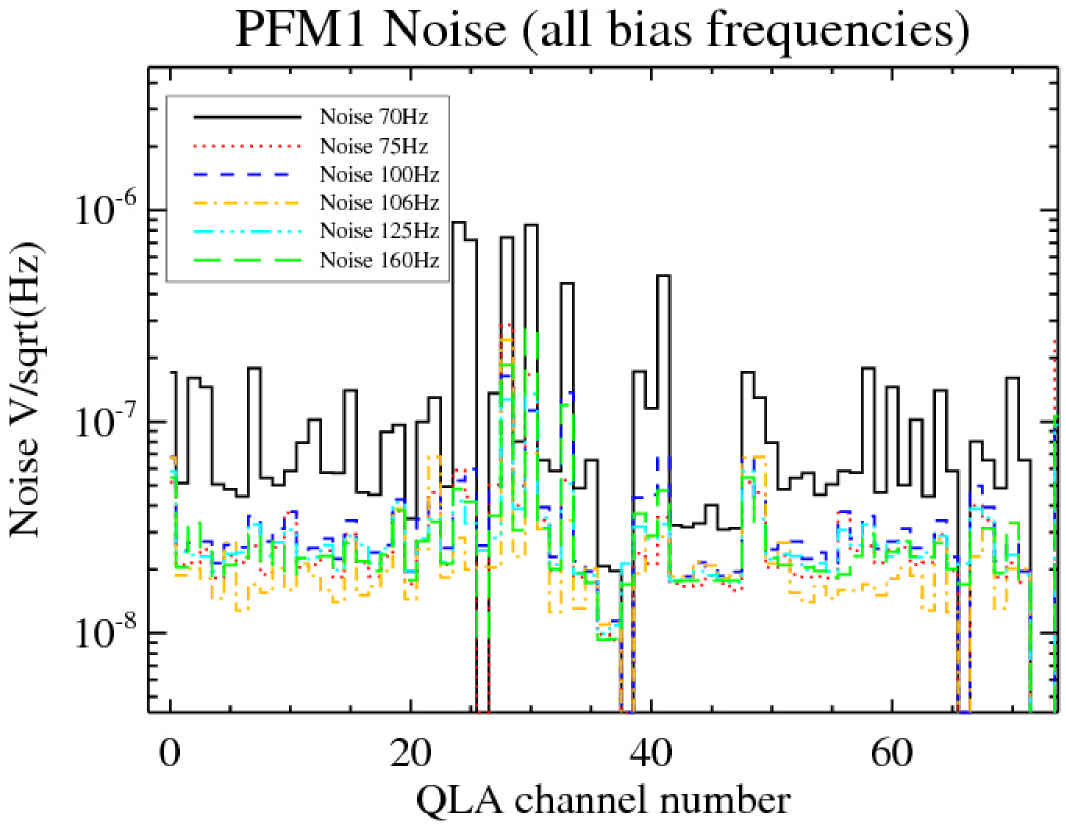
Noise at Different Bias Levels



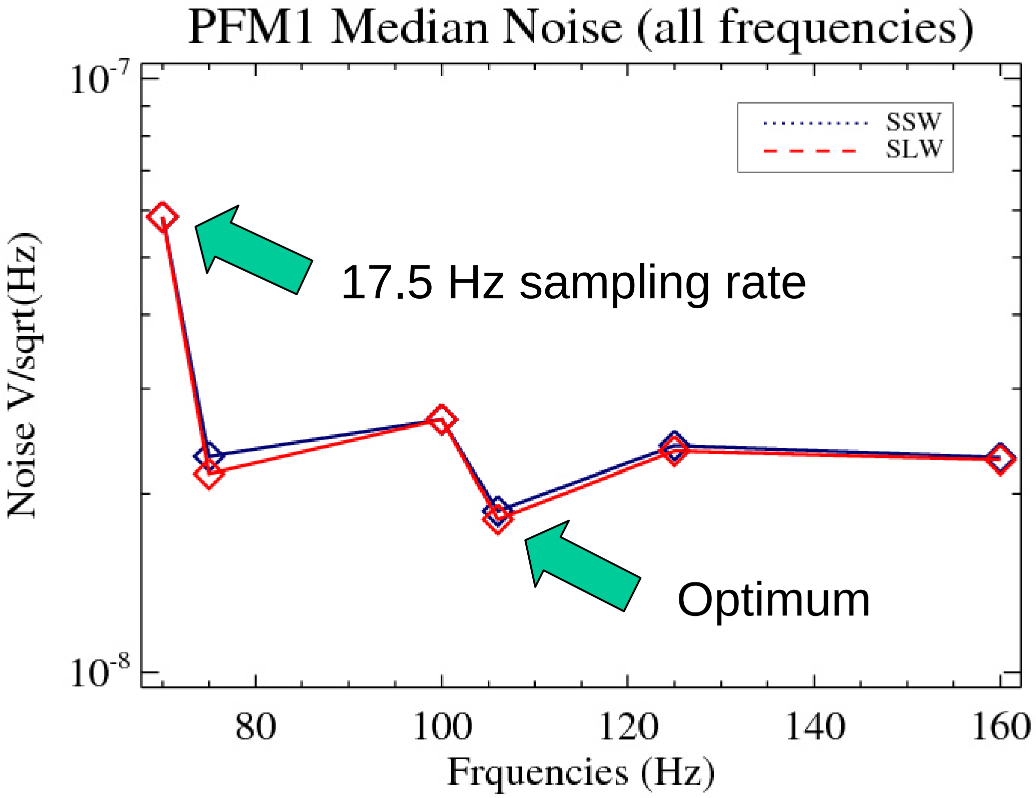


- Median noise increases with bias rms voltage as expected for 160Hz data.
- Pixels of J6 module were excluded.
- Anomal behavior of noise measured at 70 Hz bias.
- SSW and SLW show no significant difference.

Noise at Different Bias Frequencies



Noise at Different Bias Frequencies

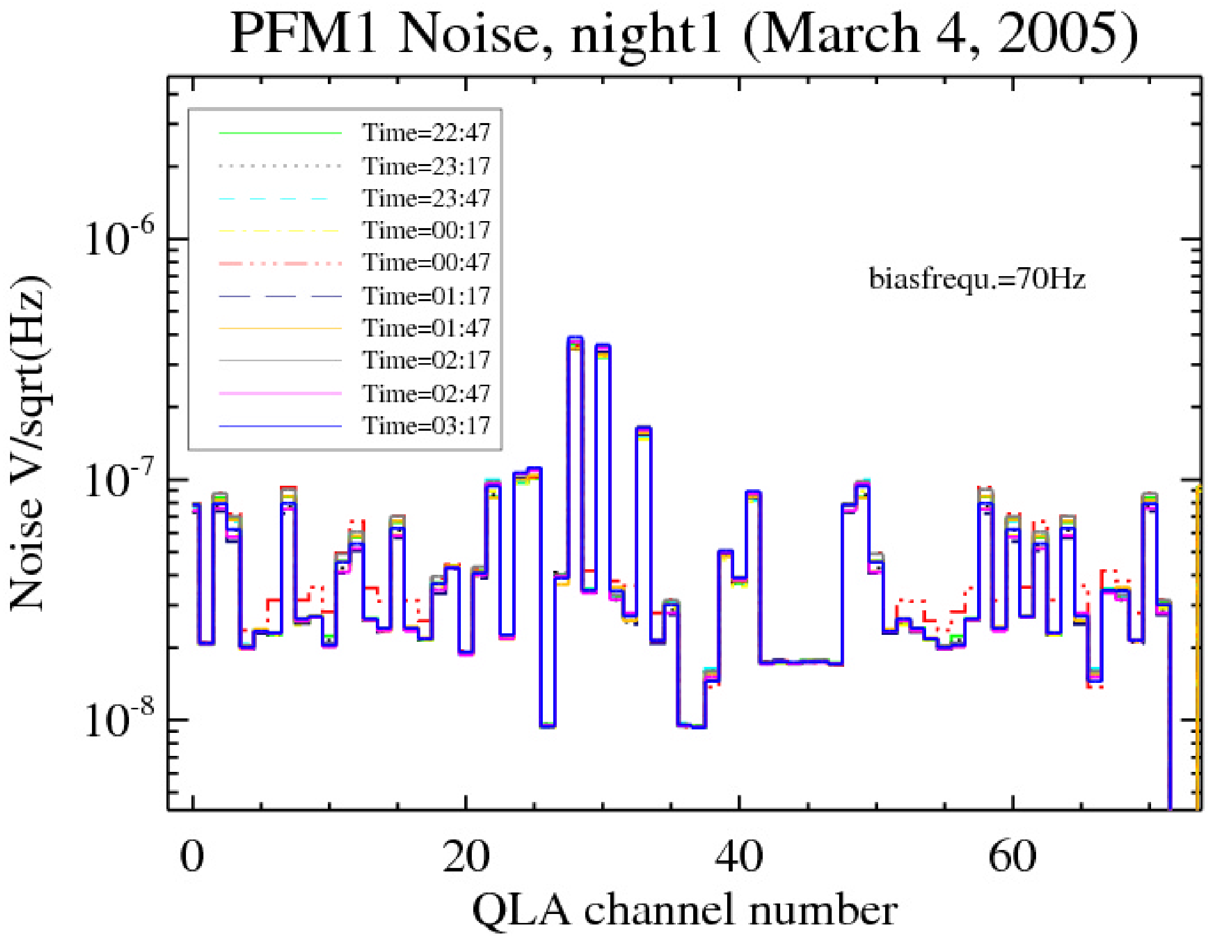


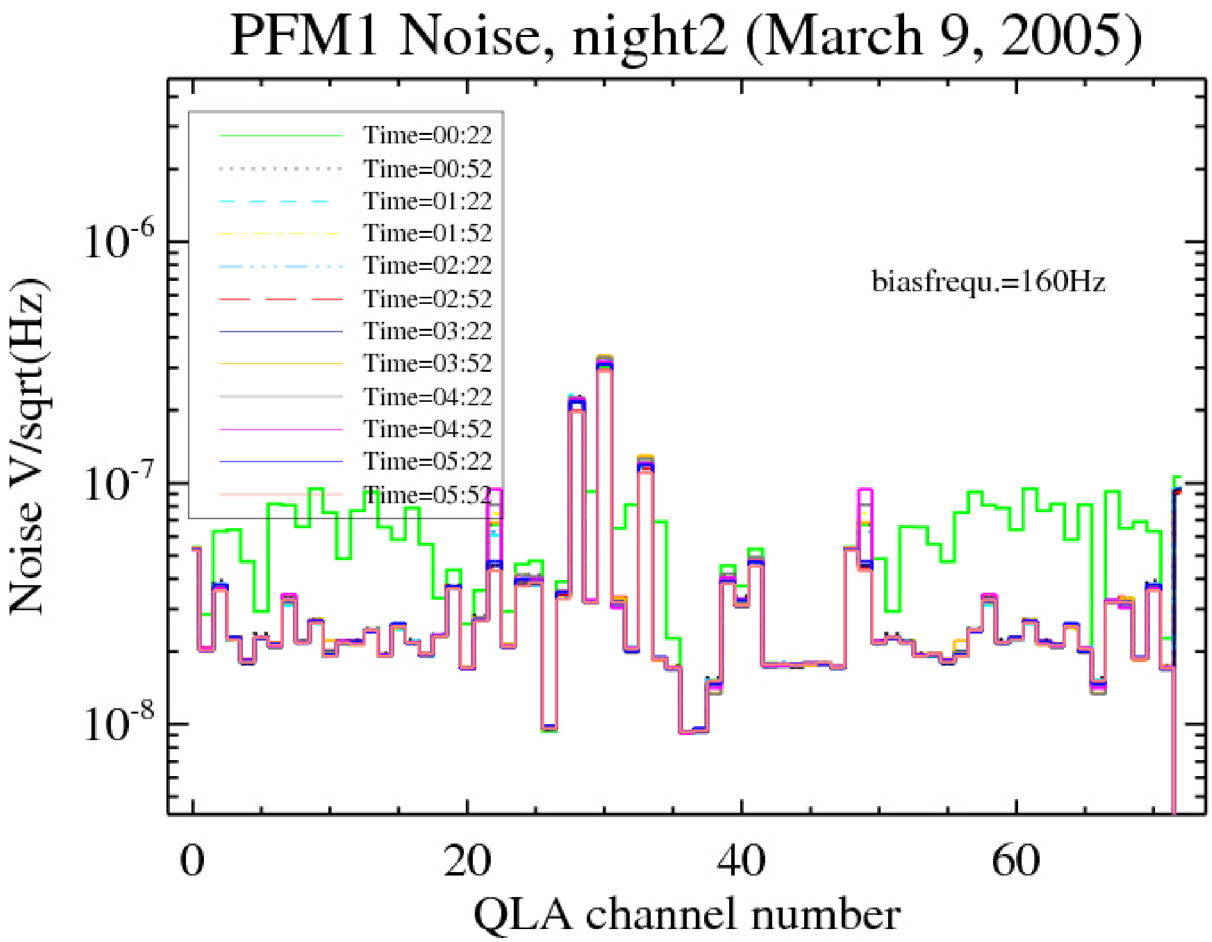
17.5 Hz sampling rate

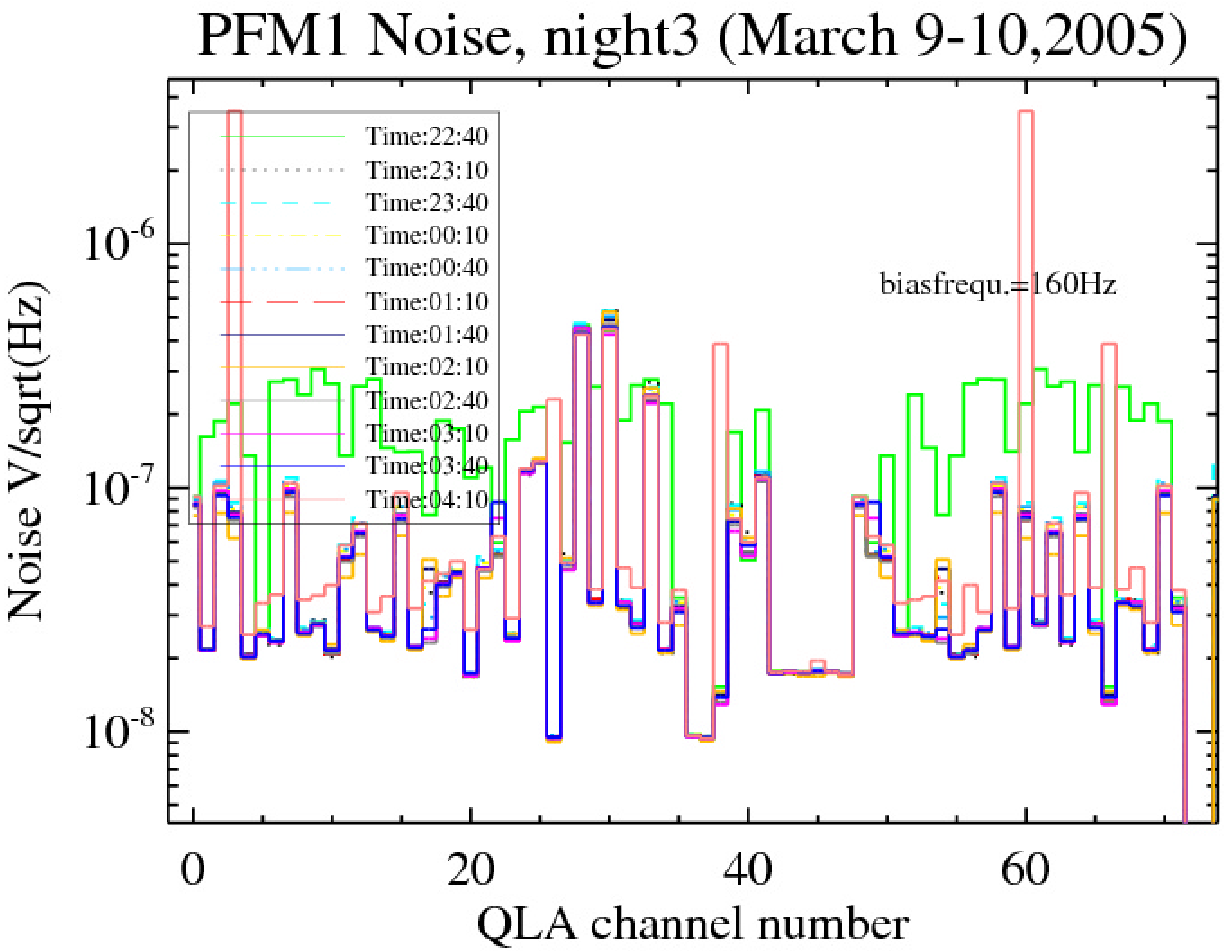
Optimum

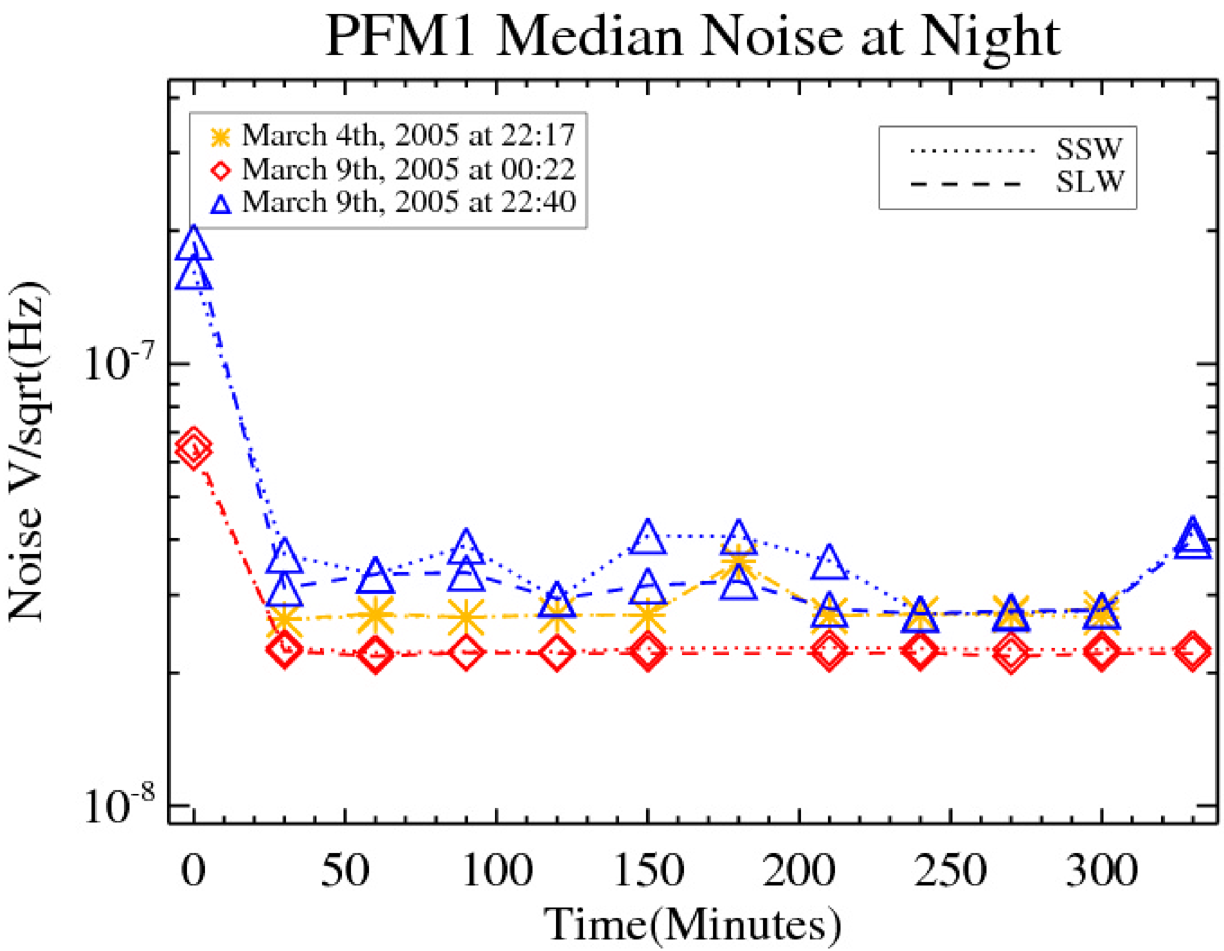
Noise at Different Bias Frequencies

- Noise is high for 70 Hz bias frequency only.
- Only 70 Hz bias measurements were done at a sampling rate of 17.5 Hz.
- 75 Hz bias measurement (at sampling rate 75 Hz) shows low noise comparable to other measurements.
- Other sampling rates were between 50 and 80 Hz.
- Lowest noise levels were found at 106 Hz bias frequency (sampling rate 53 Hz).
- We may need a more detailed program to determine optimum combinations of bias frequency and sampling rate.

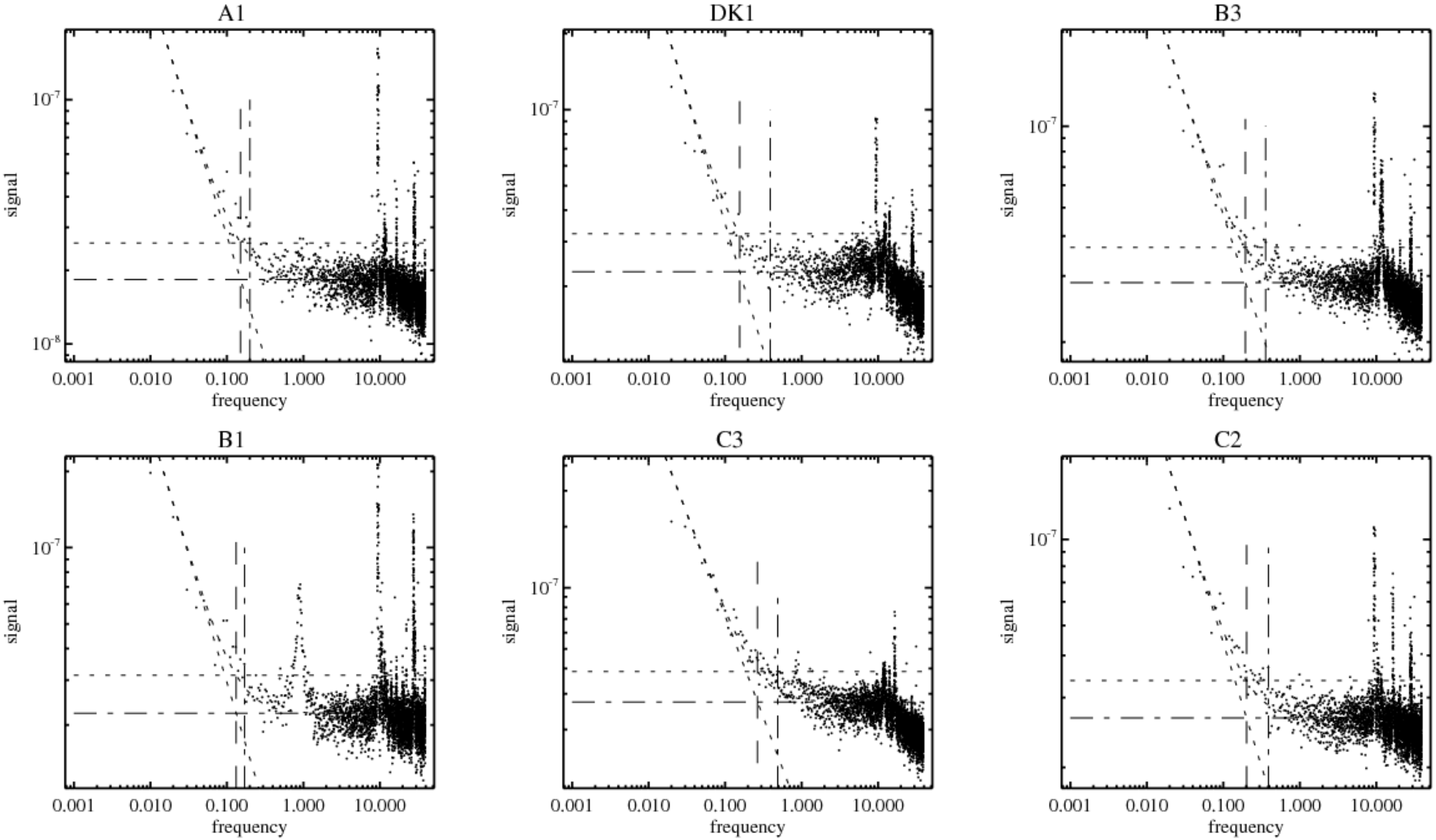

PFM1 Noise, night1 (March 4, 2005)
Time=22:47
Time=23:17
Time=23:47
Time=00:17
Time=00:47
Time=01:17
Time=01:47
Time=02:17
Time=02:47
Time=03:17
biasfrequ.=70Hz
Noise V/sqrt(Hz)
10-6
10-7
10-8
0
20
40
60
QLA channel number


PFM1 Noise, night2 (March 9, 2005)
Time=00:22
Time=00:52
Time=01:22
Time=01:52
Time=02:22
Time=02:52
Time=03:22
Time=03:52
Time=04:22
Time=04:52
Time=05:22
Time=05:52
biasfrequ.=160Hz
10^{-6}
10^{-7}
10^{-8}
Noise V/sqrt(Hz)
0
20
40
60
QLA channel number


PFM1 Noise, night3 (March 9-10,2005)
Noise V/sqrt(Hz)
QLA channel number
10^{-6}
10^{-7}
10^{-8}
0
20
40
60
biasfrequ.=160Hz
Time:22:40
Time:23:10
Time:23:40
Time:00:10
Time:00:40
Time:01:10
Time:01:40
Time:02:10
Time:02:40
Time:03:10
Time:03:40
Time:04:10


PFM1 Median Noise at Night
March 4th, 2005 at 22:17
March 9th, 2005 at 00:22
March 9th, 2005 at 22:40
SSW
SLW
Noise V/sqrt(Hz)
10-7
10-8
0
50
100
150
200
250
300
Time(Minutes)

Night 2 Power Spectra



PFM1 1/f knee frequencies generally higher than BoDAC values

Night Noise

- The J6 channels were excluded from the median.
- The settling time is < 30min.
- Night 2 showed the lowest median noise and was most stable.
- Night 3 was the most noisy.
- 1/f Frequencies generally higher than BoDAC values
- Stronger microphonic environment at RAL.

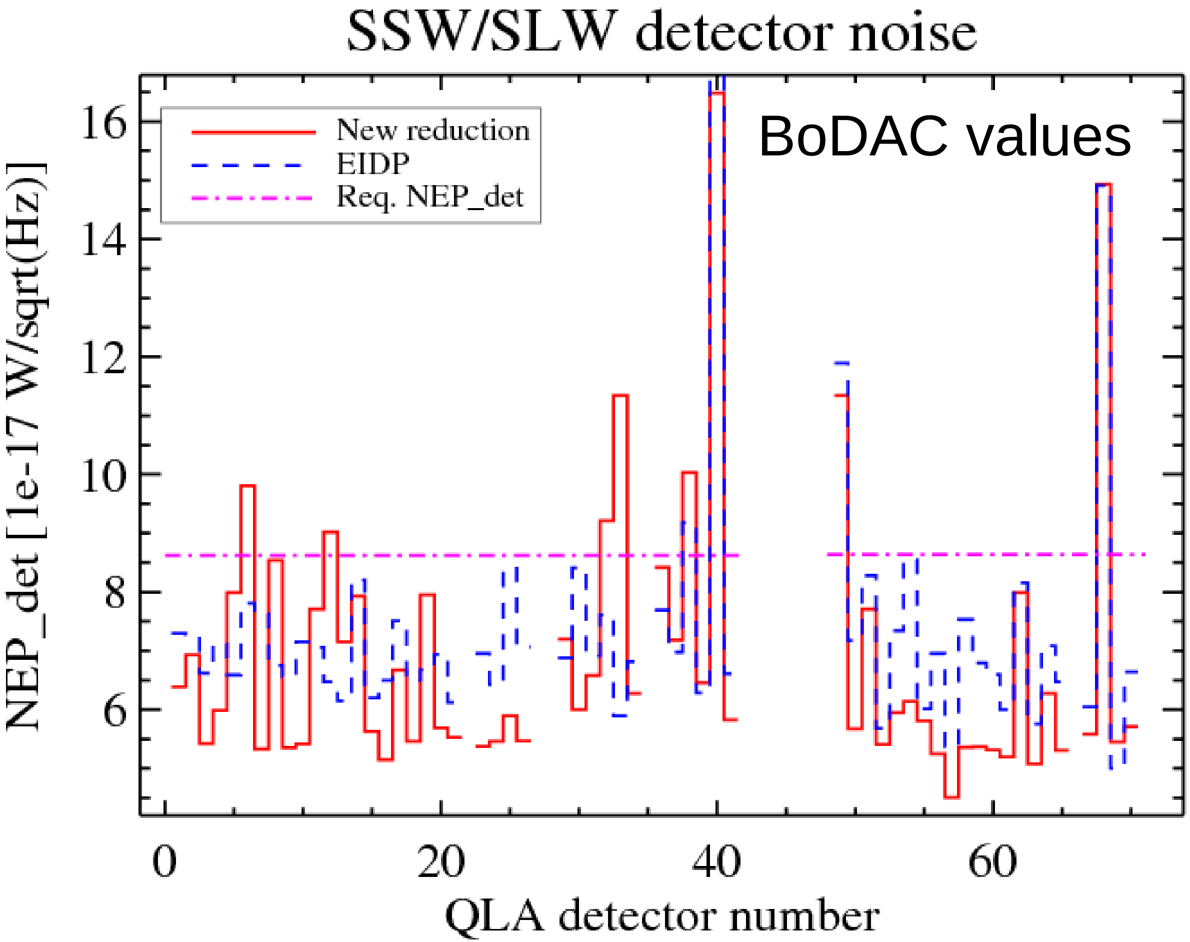
NEP

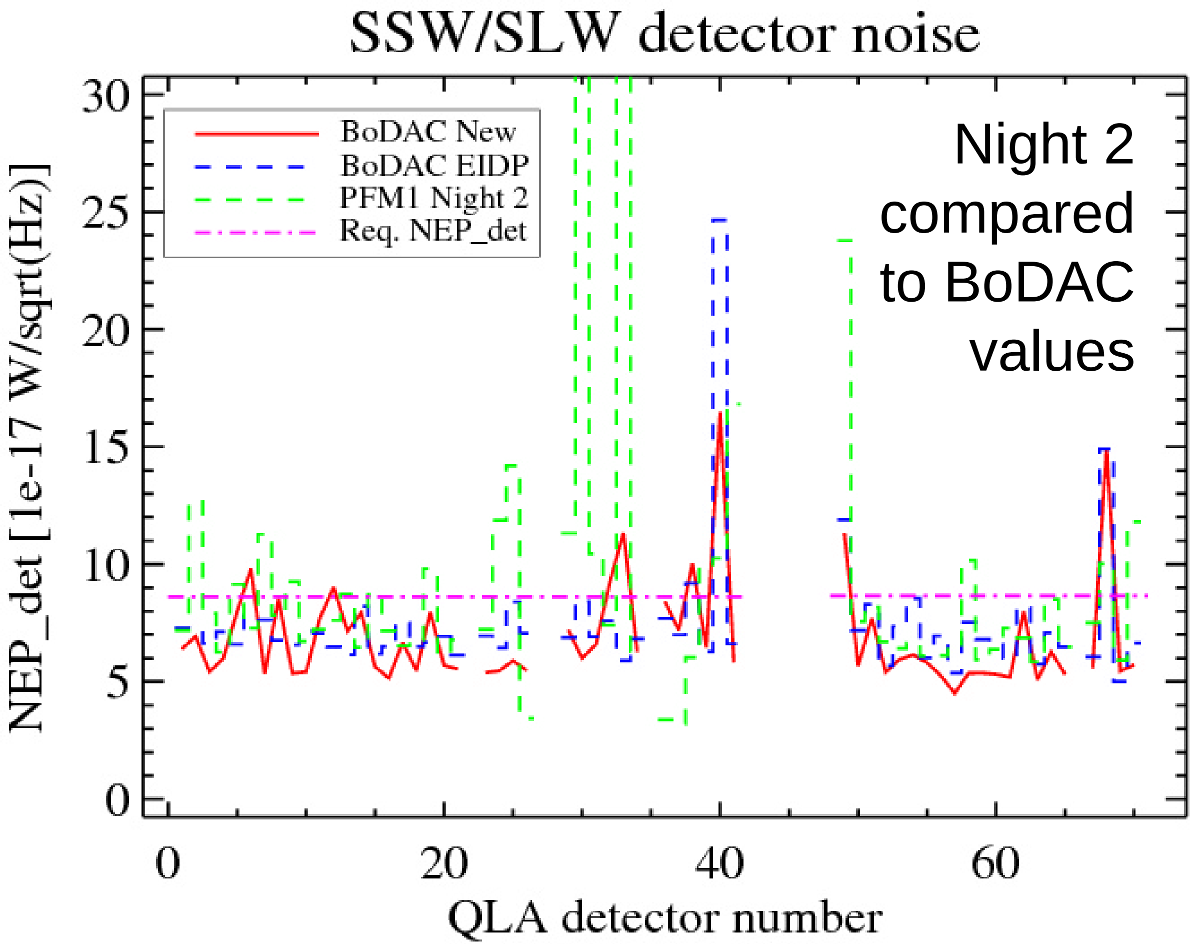
- Requirements:

10^-17 W/sqrt(Hz)	NEP_{BLIP}	NEP_{tot}	NEP_{det}	Min. perf. yield
SLW	10.5	13.6	8.6	5 pixels
SSW	13.6	16.1	8.6	9 pixels

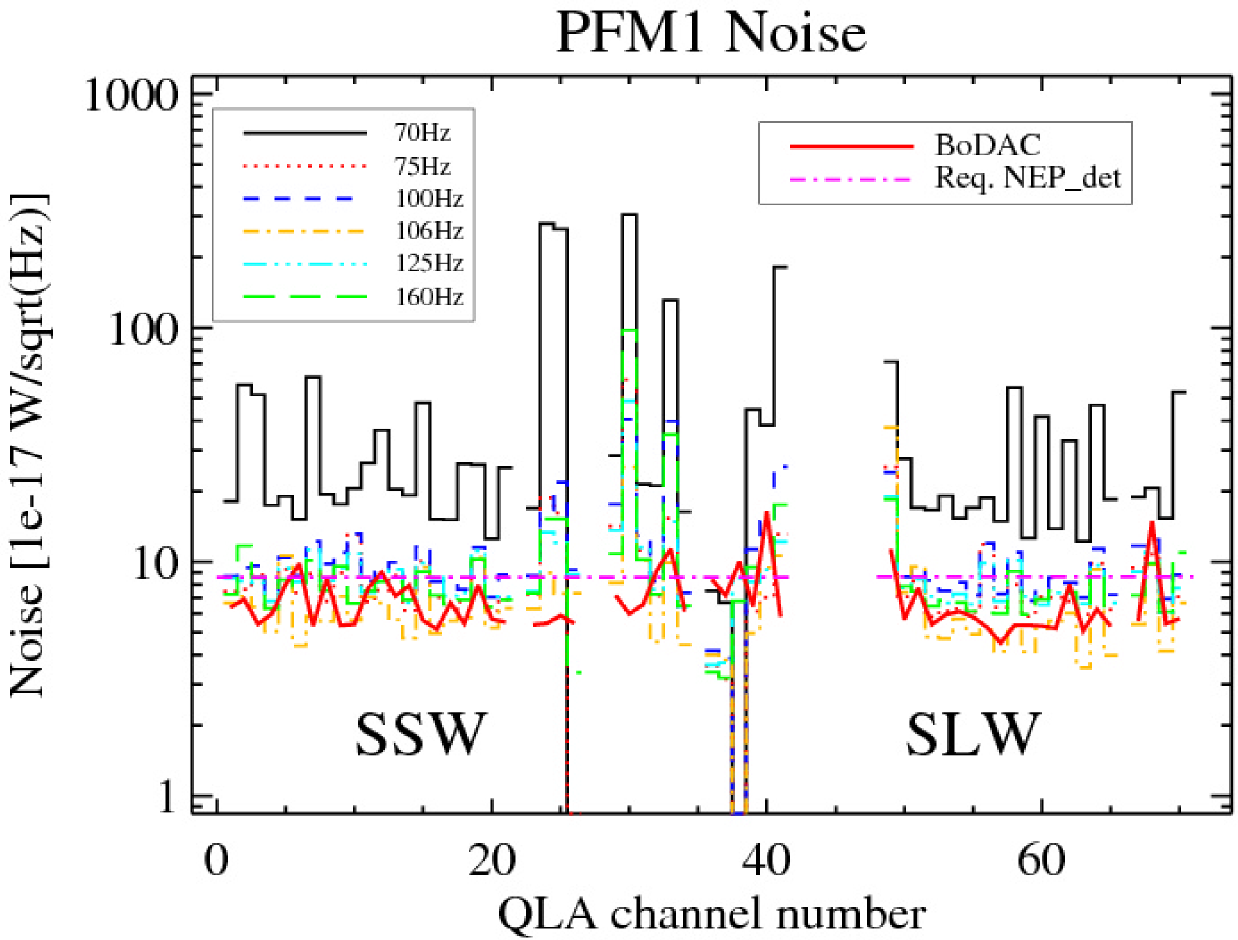
From: Detector Subsystem Specification Doc.
SPIRE-JPLPRJ-000456, Issue 3.2

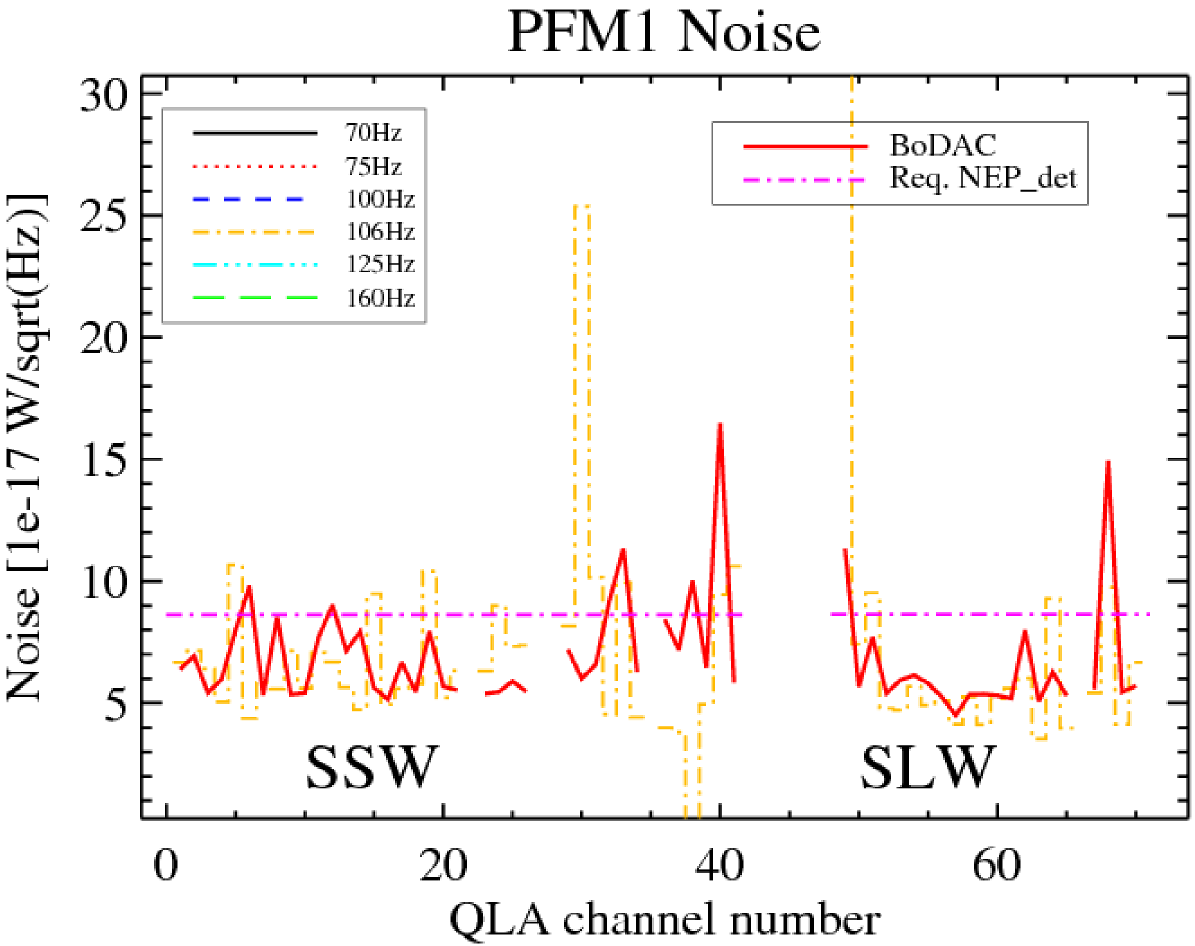
- NEP = normalized noise / responsivity


SSW/SLW detector noise
New reduction
EIDP
Req. NEP_det
BoDAC values
NEP_det [1e-17 W/sqrt(Hz)]
6
8
10
12
14
16
QLA detector number
0
20
40
60



Night 2 compared to BoDAC values


PFM1 Noise
Noise [1e-17 W/sqrt(Hz)]
1000
100
10
1
0
20
40
60
QLA channel number
70Hz
75Hz
100Hz
106Hz
125Hz
160Hz
BoDAC
Req. NEP_det
SSW
SLW


PFM1 Noise
70Hz
75Hz
100Hz
106Hz
125Hz
160Hz
BoDAC
Req. NEP_det
SSW
SLW
Noise [1e-17 W/sqrt(Hz)]
30
25
20
15
10
5
0
20
40
60
QLA channel number

Conclusion

- Noise is within requirements for NEP and minimum performance yield.
- Noise depends on electronics configuration.
- With optimum settings noise is consistent with BoDAC data.
- SLW NEP is often as low as 60% of required NEP.
- Low sampling frequencies seem to cause increased noise.
- High noise of J6 channels probably due to shielding problem introduced by quick fix.
- Higher 1/f knee frequencies and noise drop at beginning of night phases indicate stronger microphonic environment at RAL.
- We may need a more detailed program to determine optimum combinations of bias frequency and sampling rate.

Photometer Calibration Source (PCal)

Performance test results – CQM2 & PFM1

Peter Hargrave & Tim Waskett
Cardiff University

Requirements

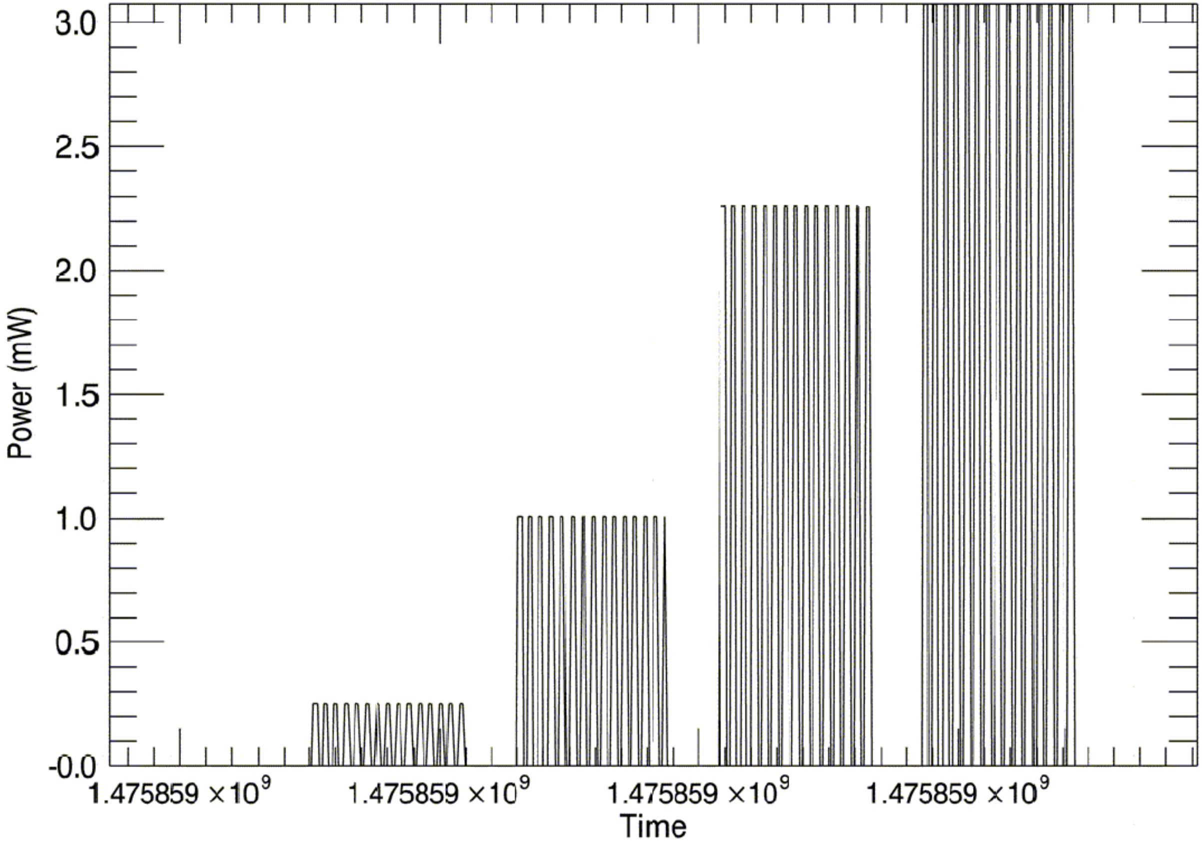
- IRD-CALP-R01: Nominal operating output
  - S/N of 500 in 1s integration on photometer arrays with nominal detector parameters
  - Equivalent to 0.05pW at detectors
  - Use CQM data for PLW and project to other arrays and flight detectors
- No requirement for Spectrometer arrays
  - Use PFM1 data to see what response is achieved and measure uniformity

Requirements

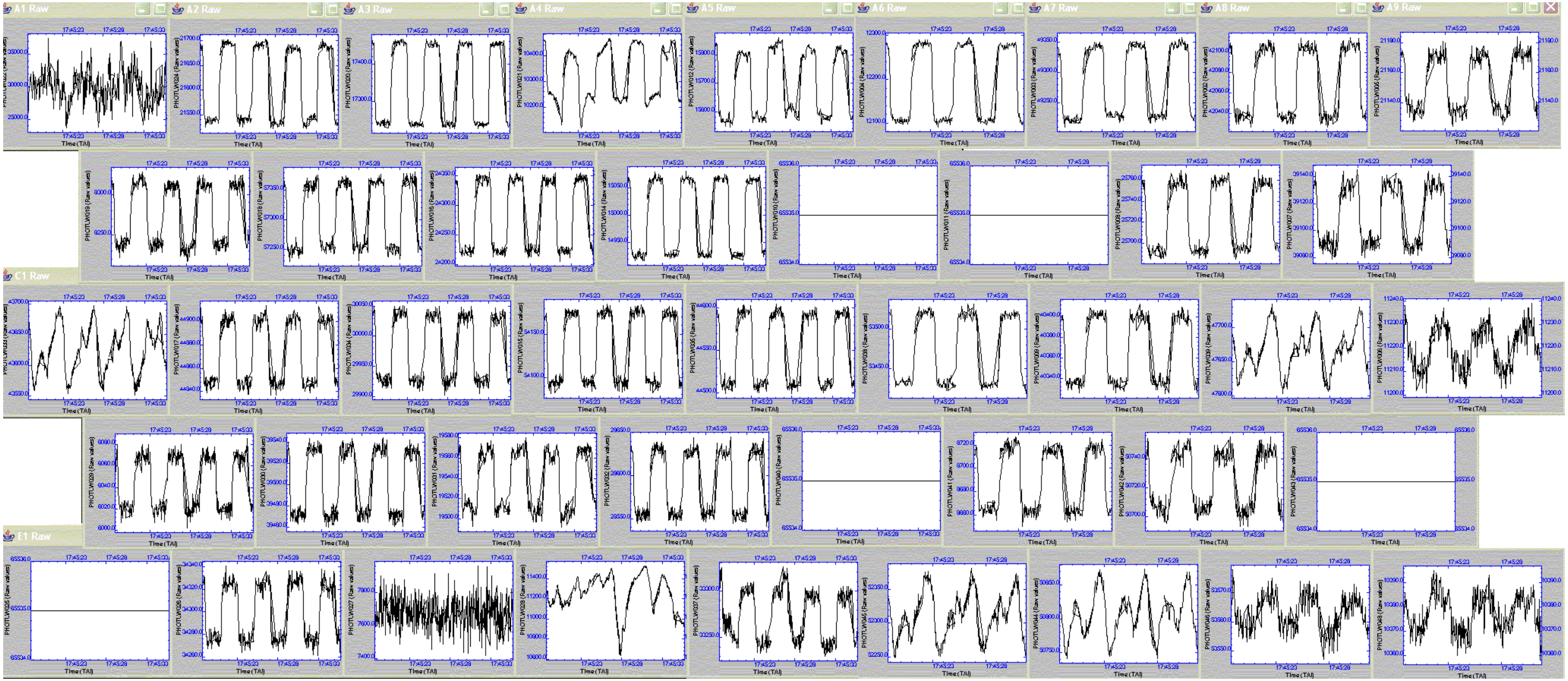
- Uniform illumination of arrays - not a requirement but desirable
- IRD-CALP-R04: Speed of response
  - 90% settling time less than 350ms (req); 70ms (goal) - verified at unit level, compare to instrument level
- IRD-CALP-R05: Repeatability
  - RMS output of signal better than 1% over 20 cycles - verified at unit level
  - 1% for 12 calibration ops. over 12hrs - verified at unit level
  - Drift <10% over mission life – verified from life tests

CQM2 data – “standard flash”

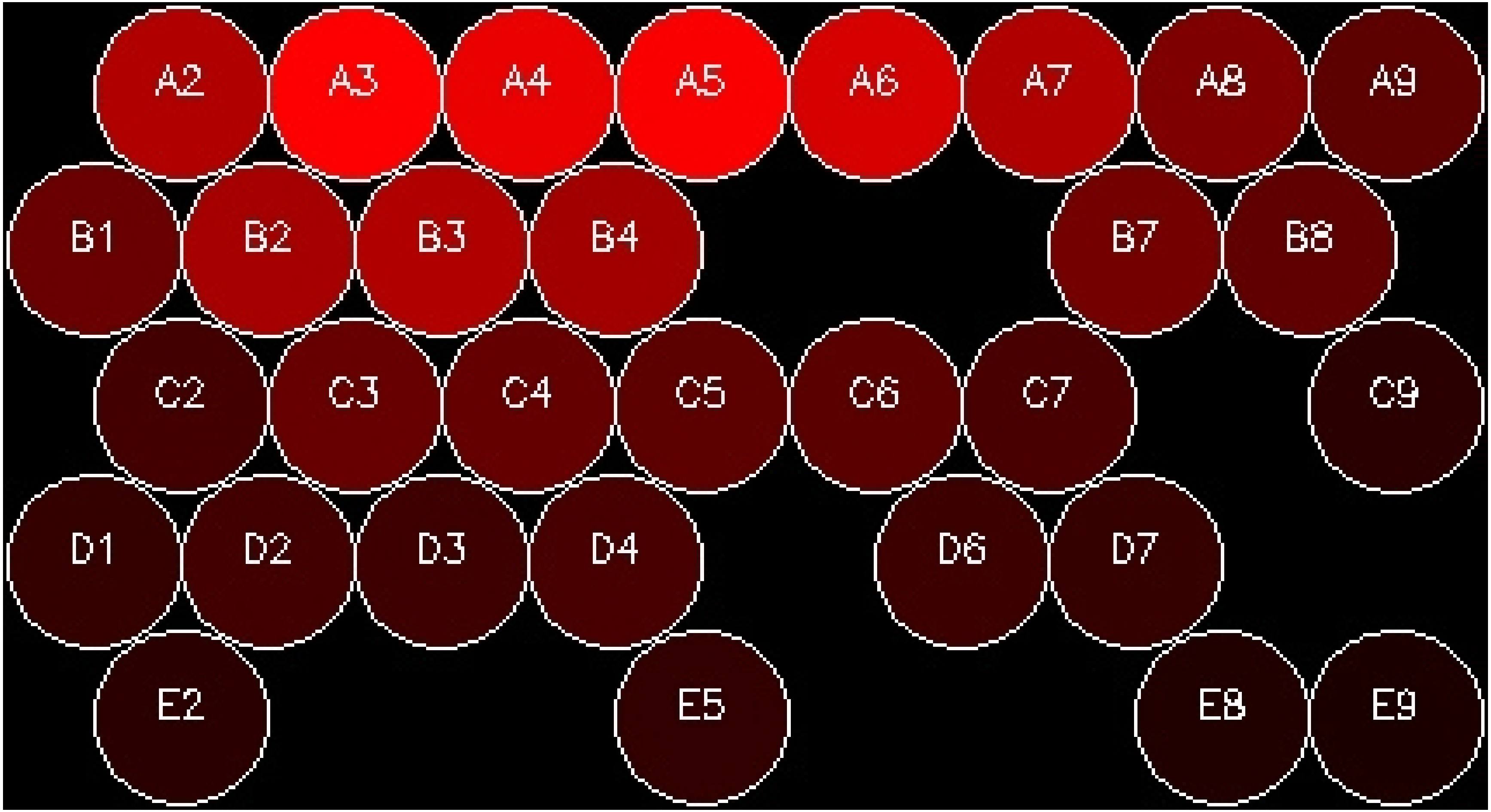
- 0.25, 1.01, 2.26, 3.07 mW
- 15 flashes each
- 0.25 Hz



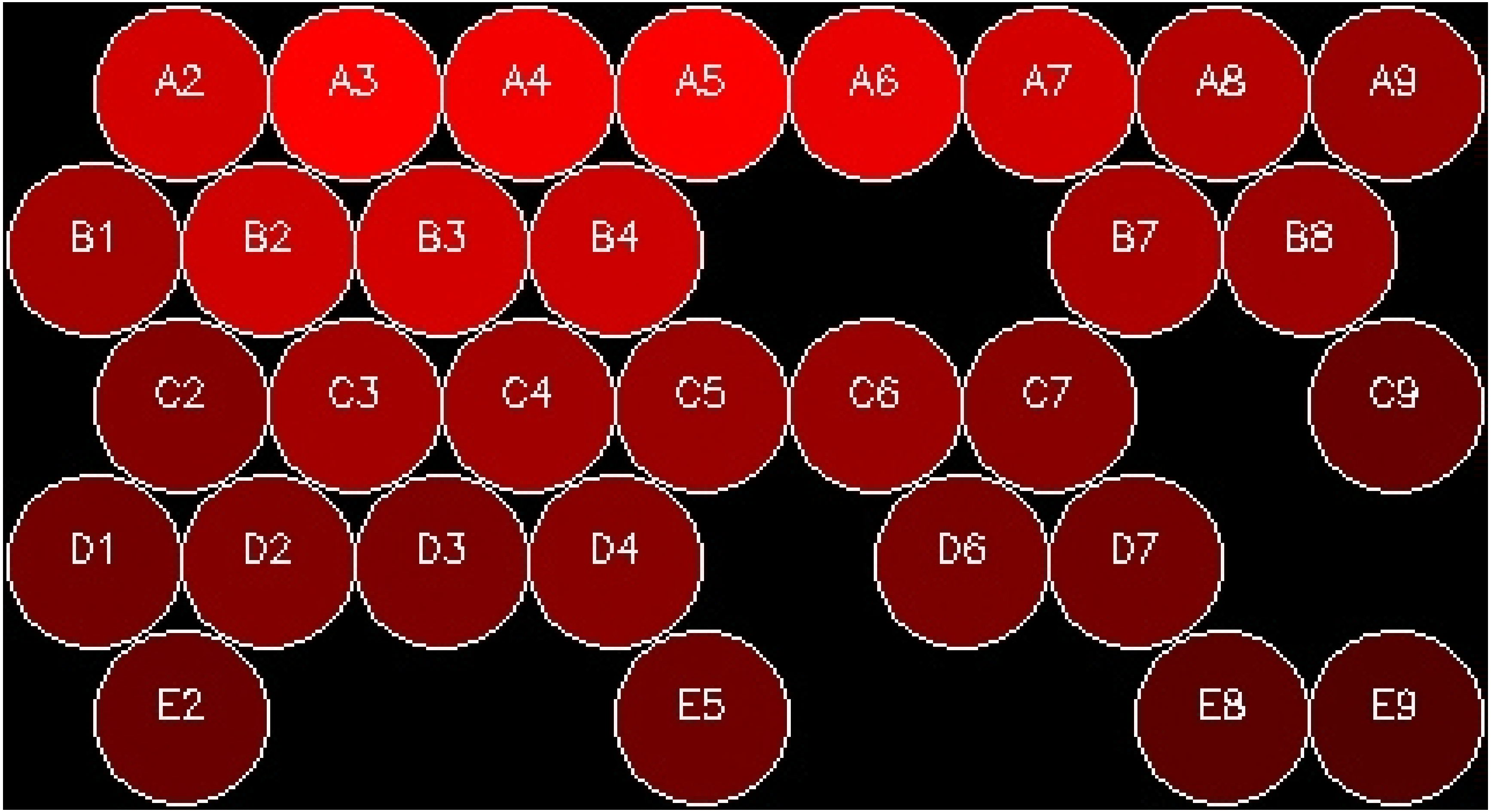
Whole array – first few flashes



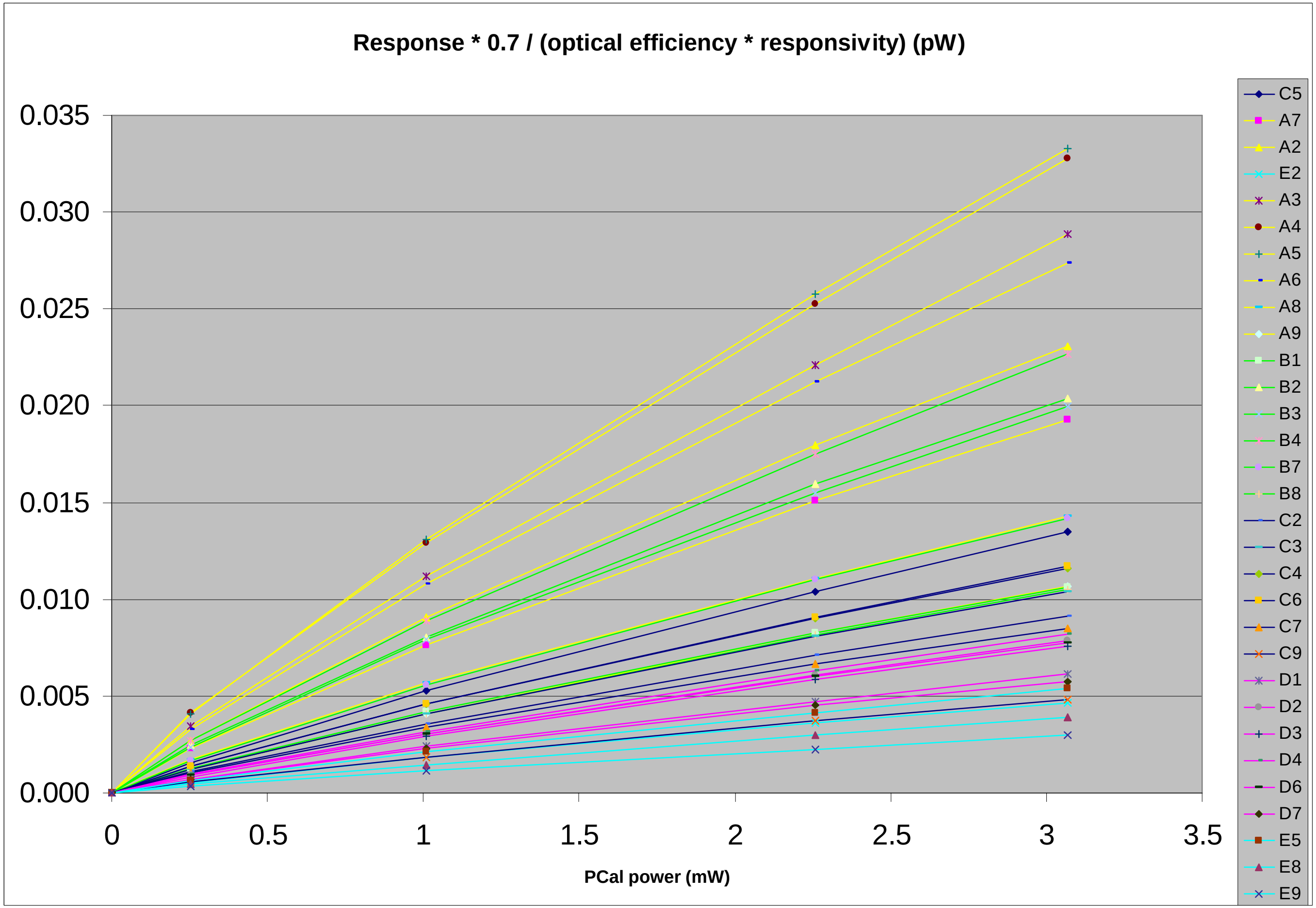
PLW Illumination Pattern - Linear Scale



PLW Illumination Pattern – Square-Root Scale



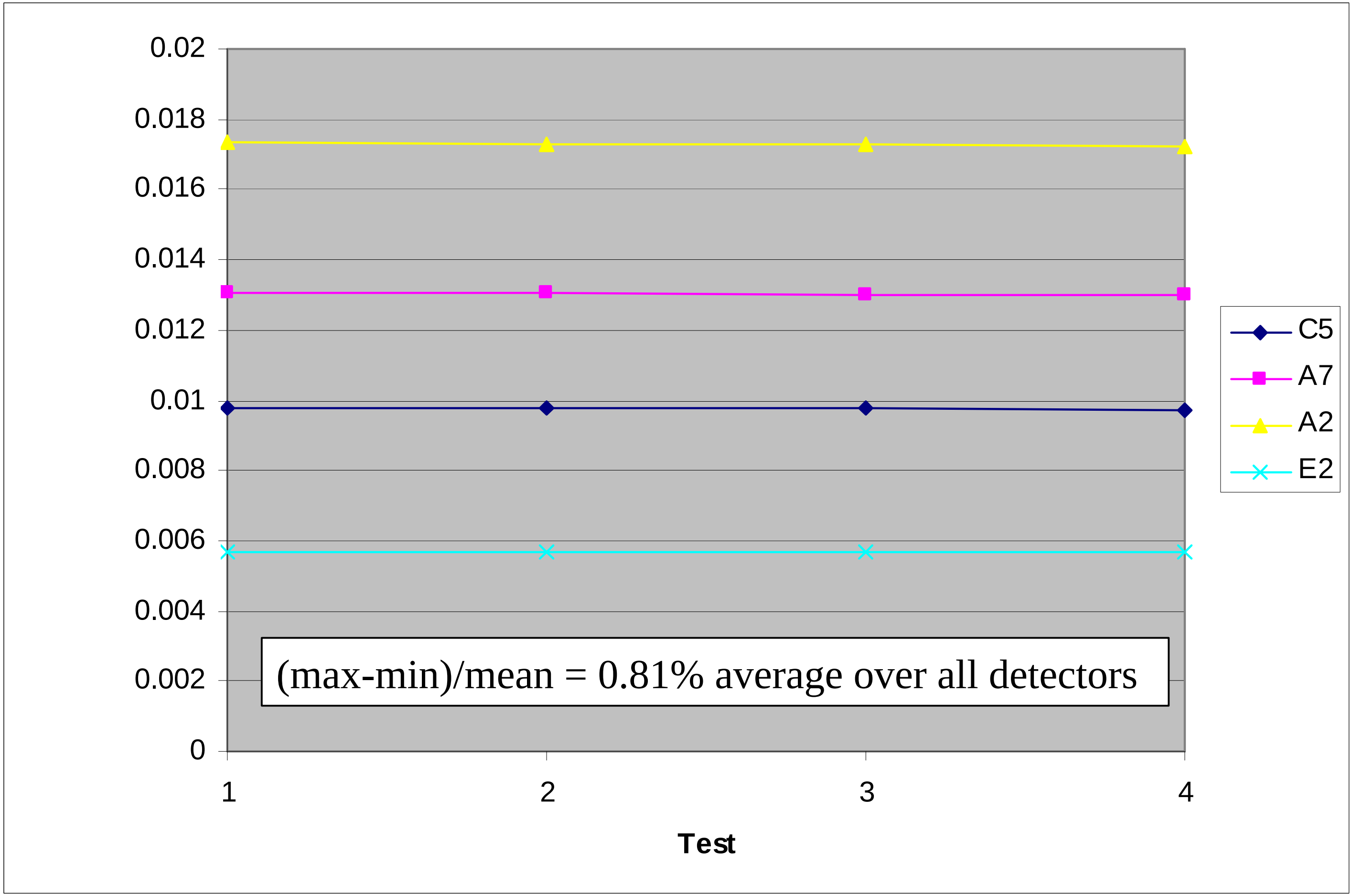
PCal array illumination



IRD-CALP-R01: 0.05pW at detectors

- Nearly reached for brightest pixel
- Requires PCal power of ~5mW to reach 0.05pW at detectors (test at PFM2)
- Large gradient across array

IRD-CALP-R05: Repeatability



(max-min)/mean = 0.81% average over all detectors

Viewing CBB

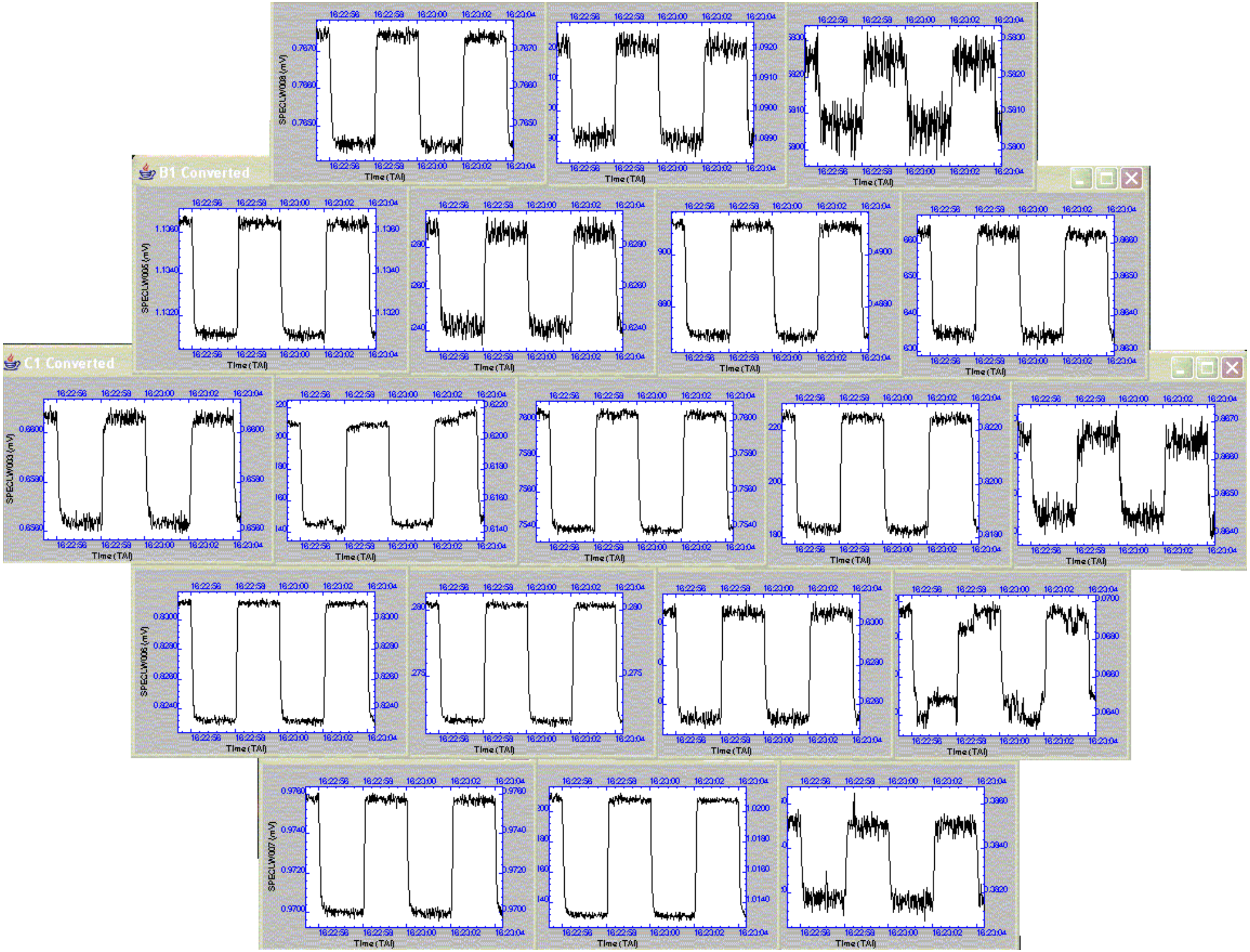
Viewing room

PFM1 PCal standard flash

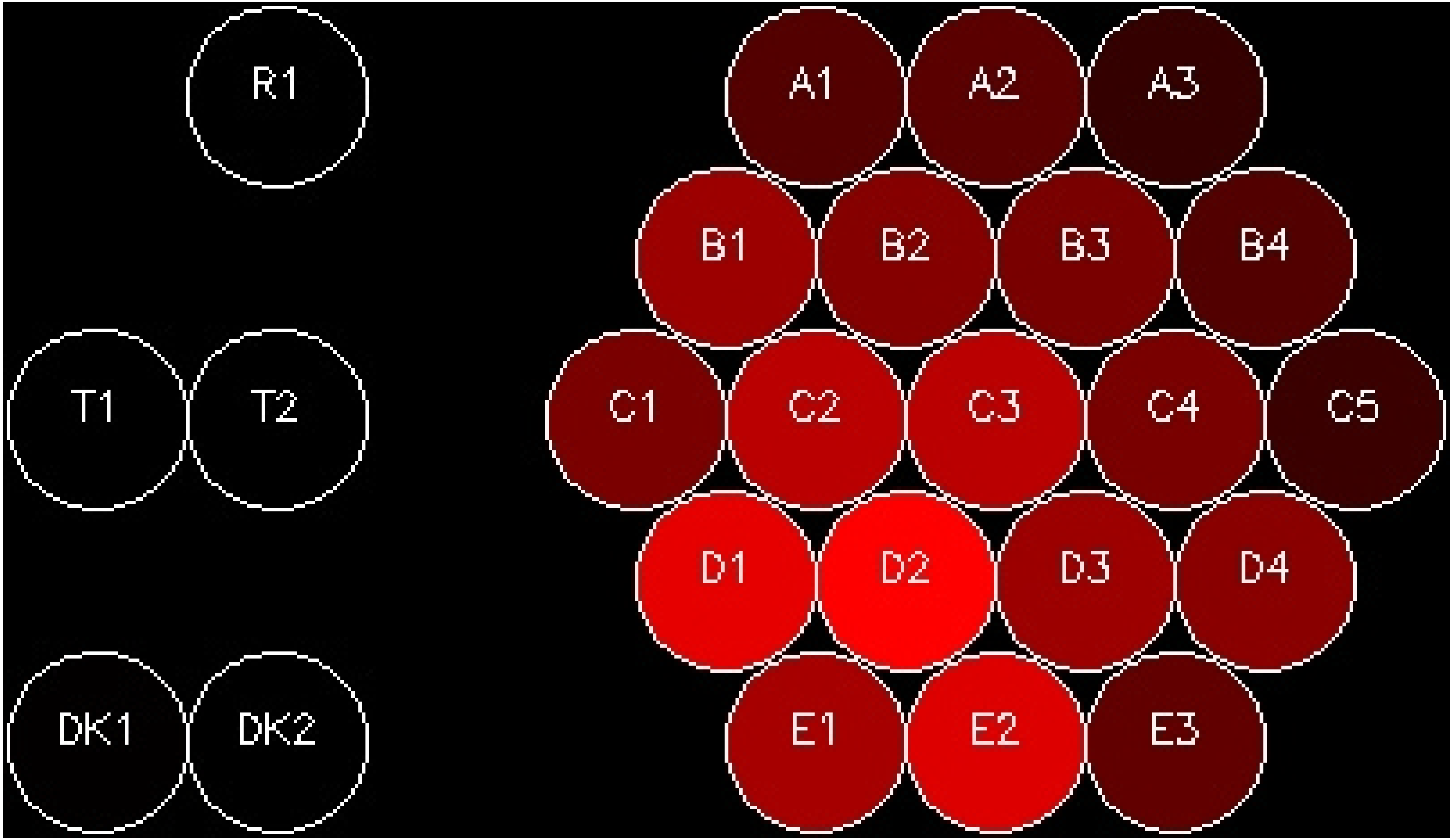
- 2.75 mW
- 10 flashes
- 0.25 Hz

- Also done at various SMEC positions
  - 0.1, 4, 12, 20, 24, 32, 36, 38 mm
- Note also, not yet flight PCal

SLW – SMEC at 0.1mm from stop



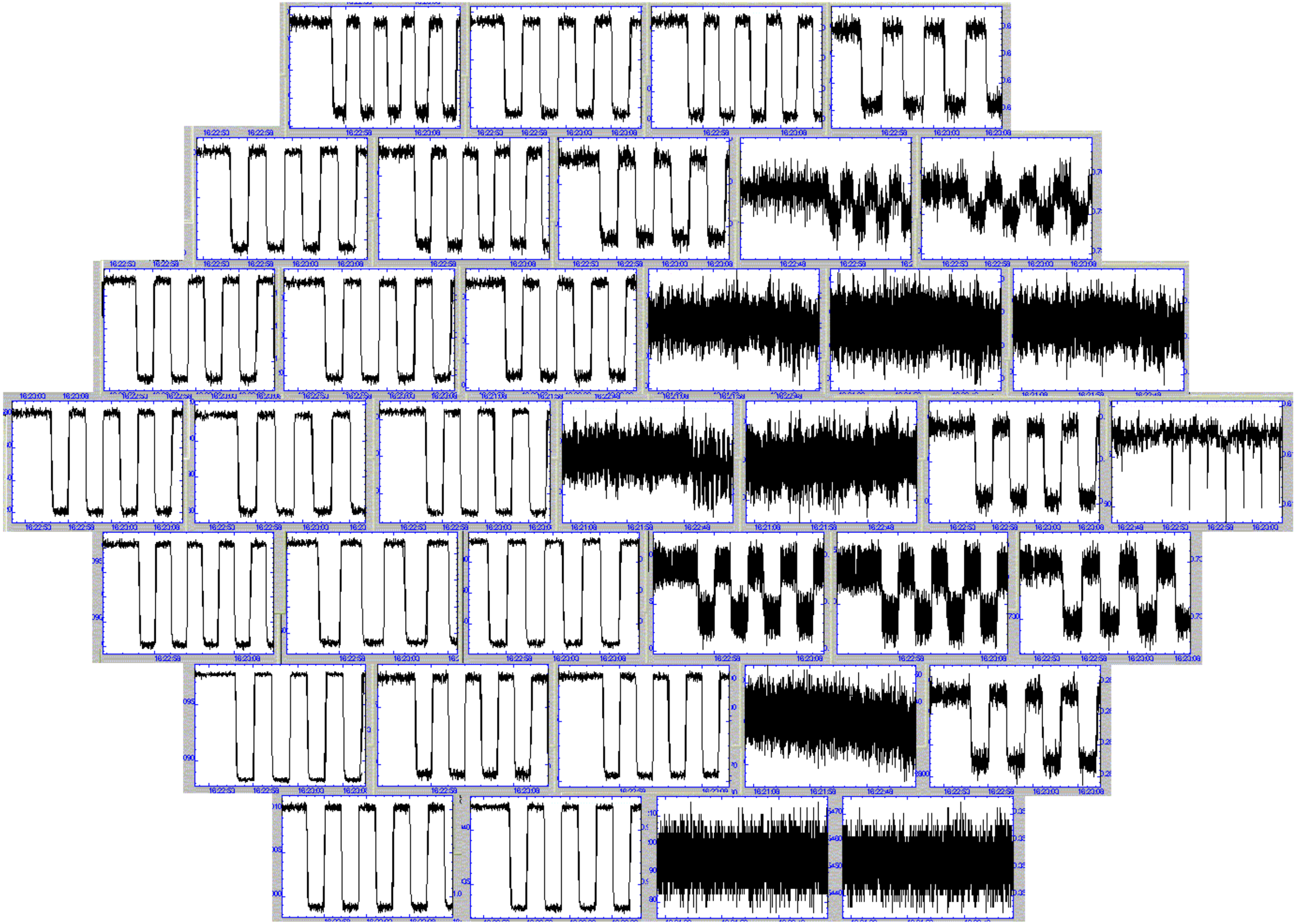
SLW Illumination Pattern



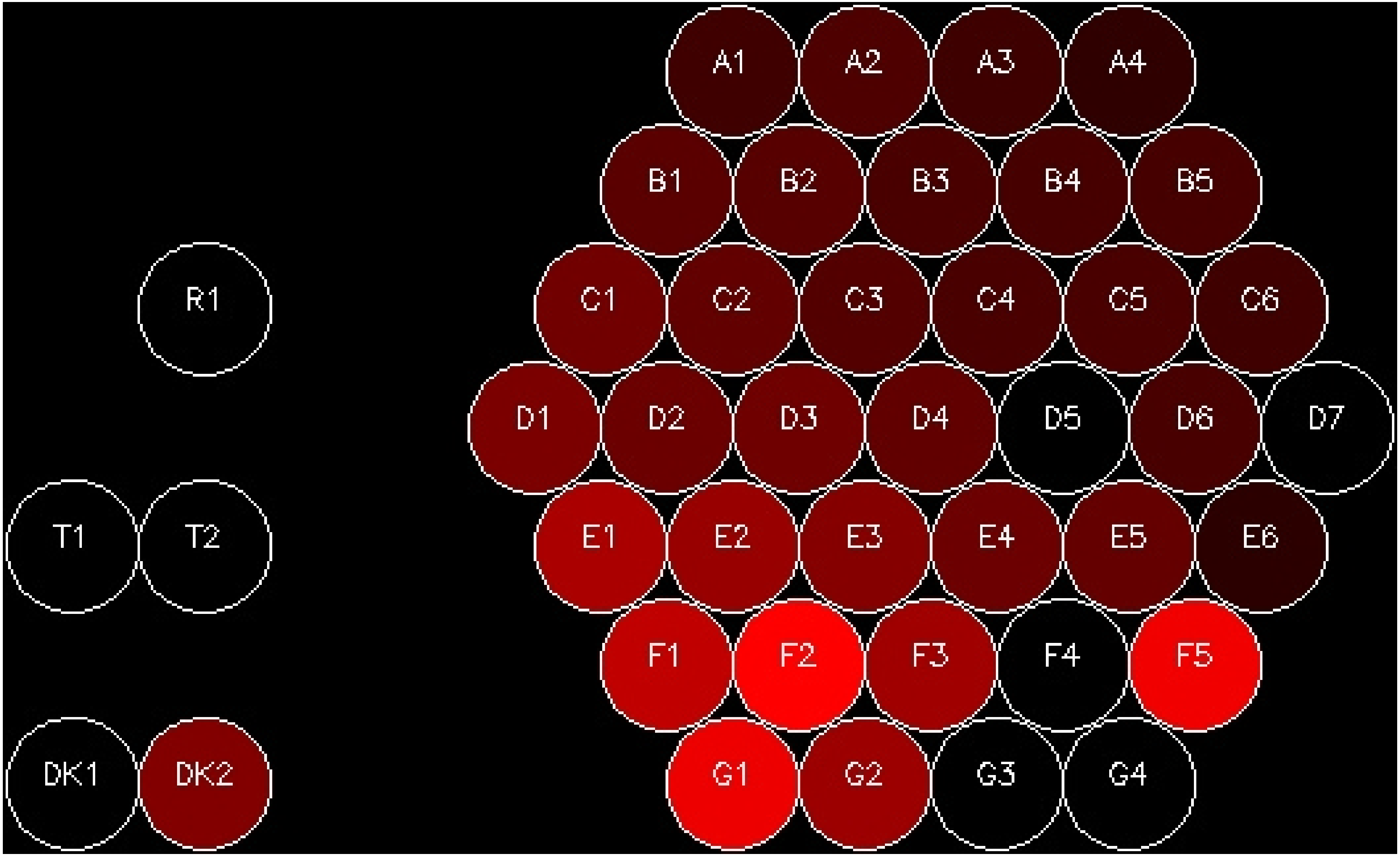
SLW Central Pixel

- Over 10 flashes RMS output = 0.46%
- Absorbed power = 0.025pW
- Equivalent to S/N in 1s of ~250
- Brightest pixel absorbed power = 0.035pW
- S/N ~350

SSW



SSW illumination pattern

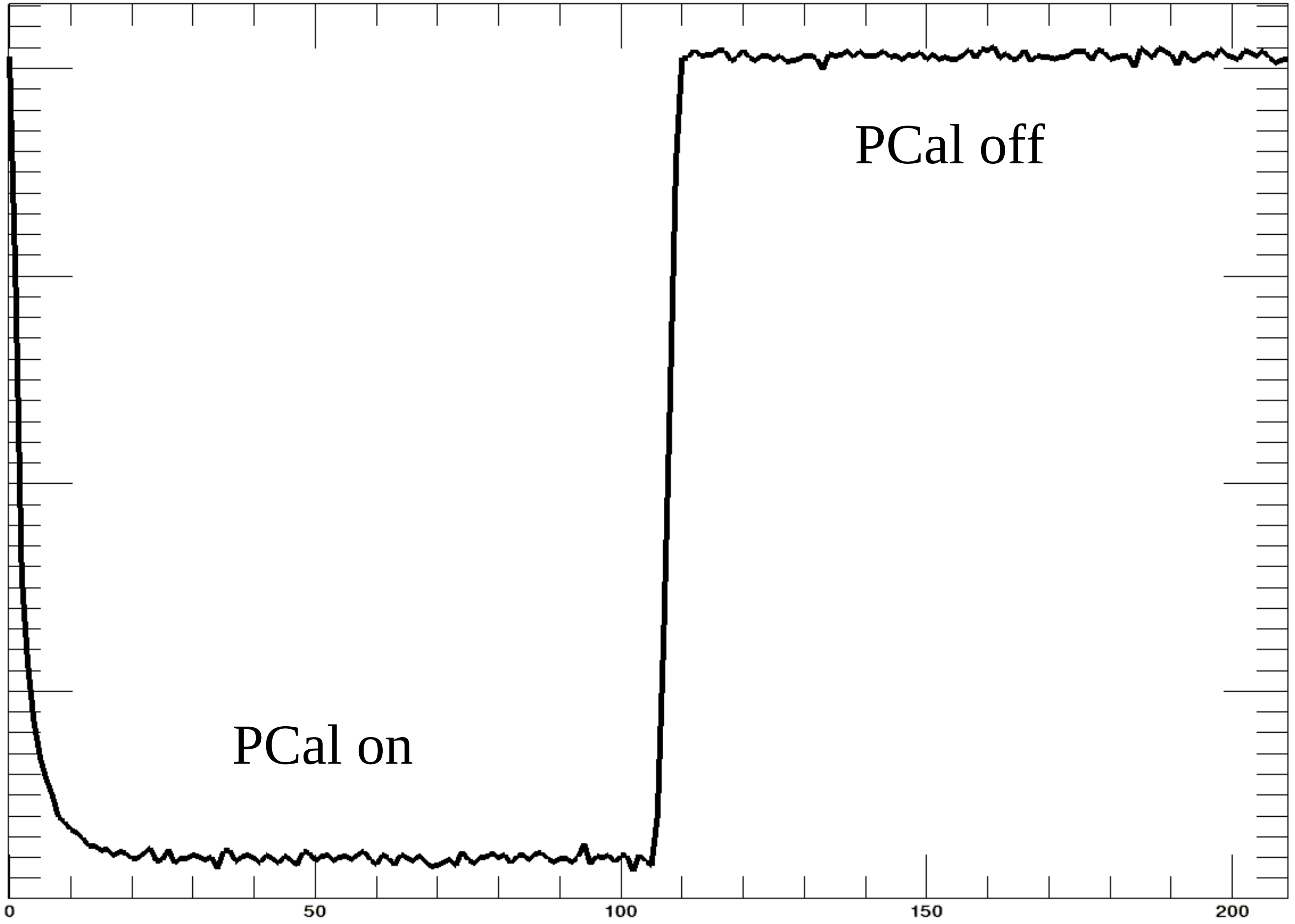


SSW pixel D3

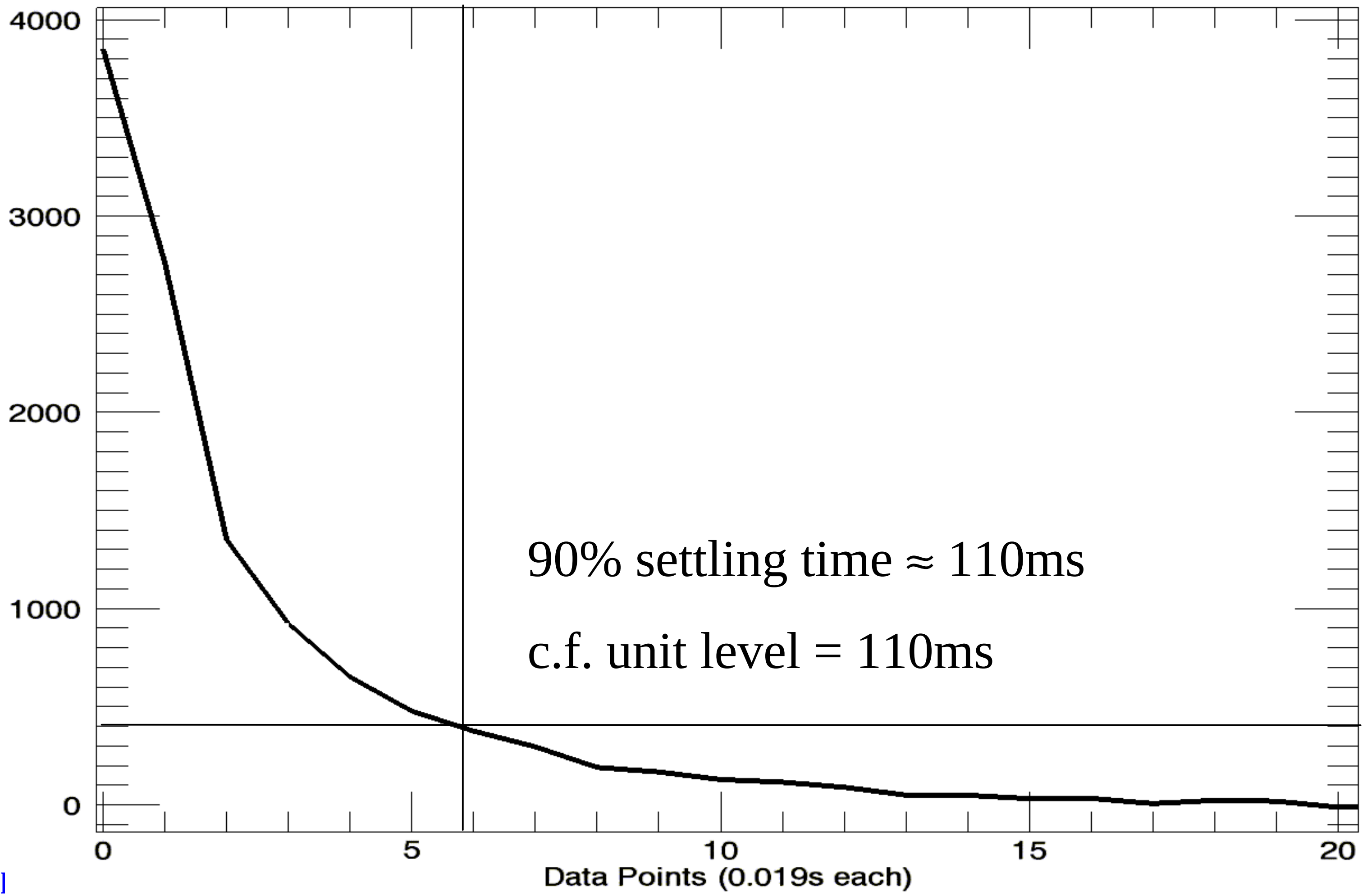
- Problem with central pixel (harness) so use neighbouring D3
- Over 10 flashes RMS output = 0.34%
- Absorbed power = 0.026pW
- Equivalent to S/N in 1s of ~260 for flight detectors
- Brightest pixel absorbed power = 0.045pW
- S/N ~450

SSW G2 – pixel with best S/N

- 8 PCal flashes added to further reduce noise



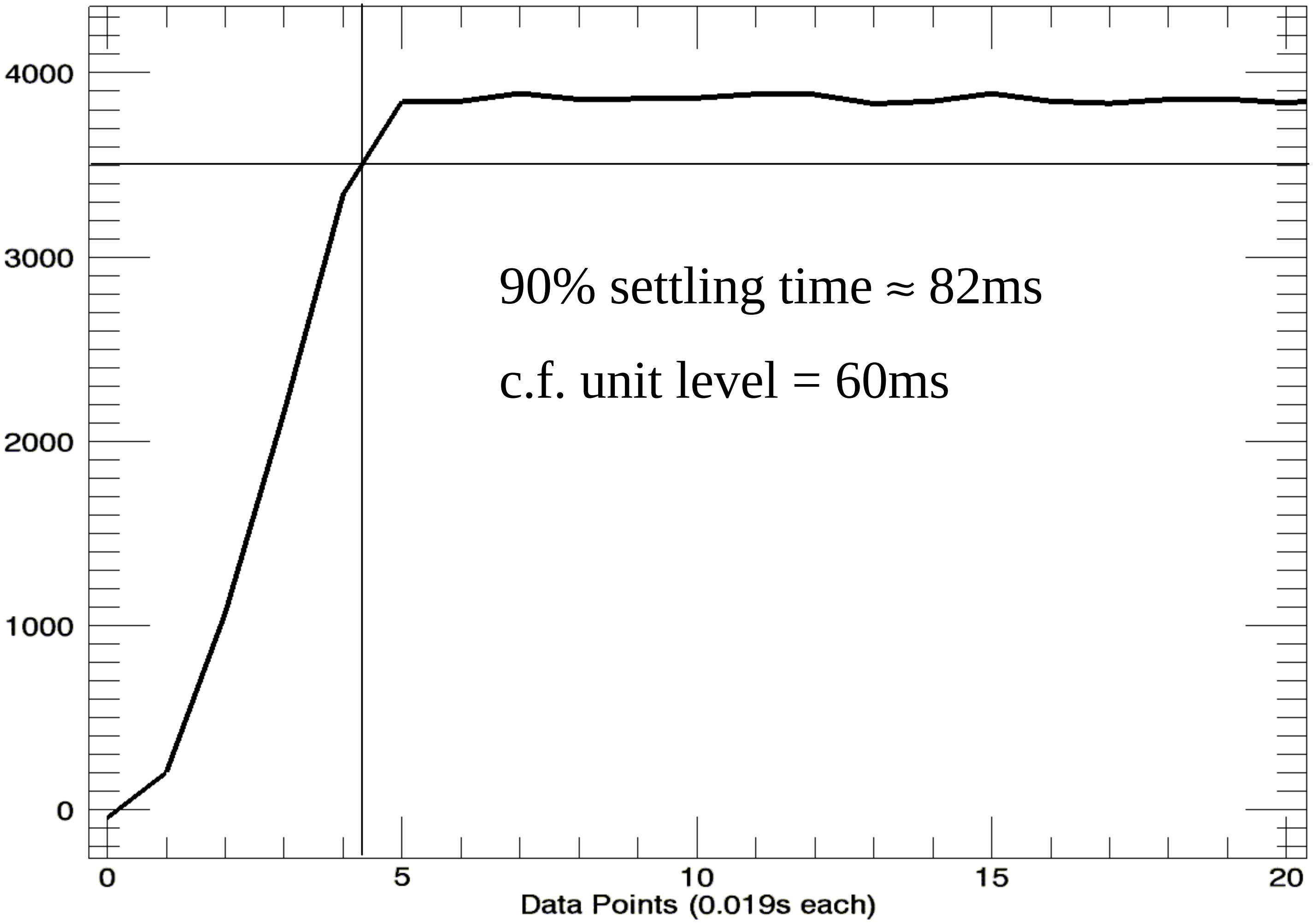
PCal on



90% settling time ≈ 110ms

c.f. unit level = 110ms

PCal off



90% settling time ≈ 82ms

c.f. unit level = 60ms

IRD-CALP-R04: Speed of response

- Unit level performance verified
- Requirement already met for this PCal
- Flight PCal is slightly better (unit level tests)

Conclusions

- Large gradient in the illumination by PCal
- PCal consistent under different conditions and reproducible to better than 1%
- t consistent with unit level performance

Spectrometer Calibration Source (SCal)

Peter Hargrave

Cardiff University

FM and FS models delivered

Introduction

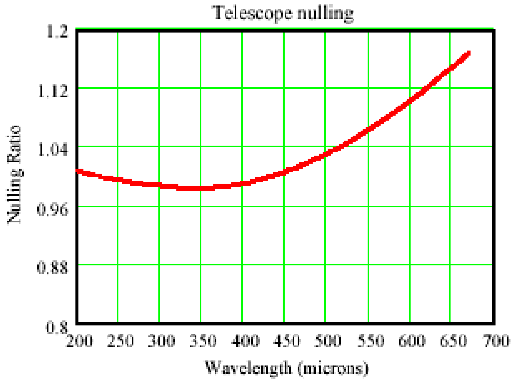
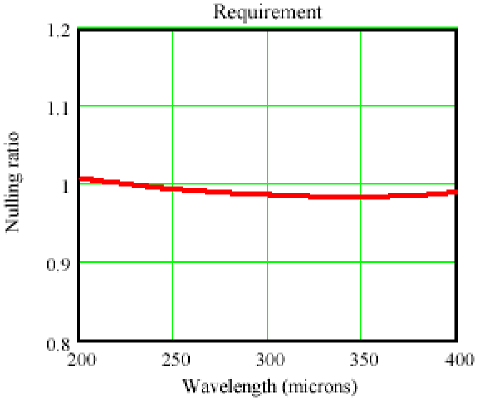
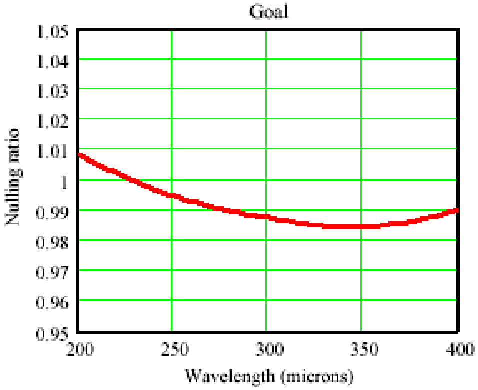
- Requirements
- Performance in PFM1 tests
- Compliance matrix / summary
- Issues

Requirements

- **IRD-CALS-R01 - Radiated spectrum**
  - **Null the central maximum to accuracy of 5% (goal 2%)**
  - **Replicate the dilute spectrum of the telescope to an accuracy of better than 20% (goal 5%) over 200-400 μm.**

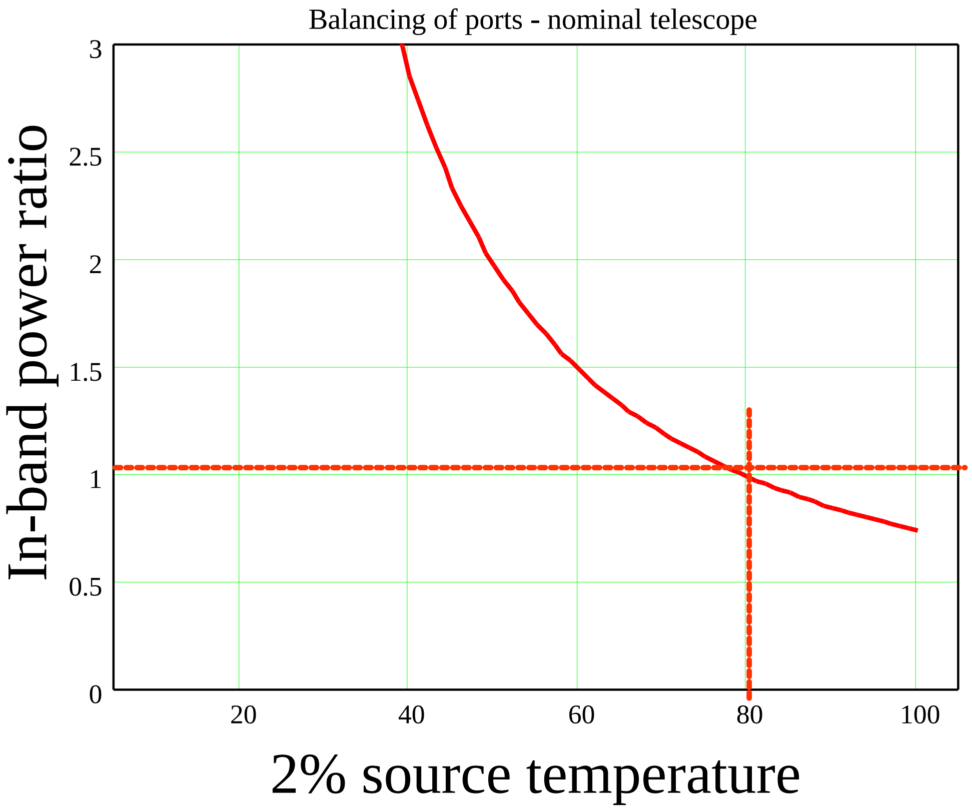
Requirements

- **IRD-CALS-R01 - Radiated spectrum – spectral match**
  - From modelling, with baseline telescope parameters
  - Best spectral match achieved with 2% @ 88K

<table>
<tr><th>Telescope Temperature (K)</th><th>Telescope Emissivity (%)</th><th>4% Source Temperature (K)</th><th>2% Source Temperature</th></tr>
<tr><td>80</td><td>4</td><td>5</td><td>88</td></tr>
<tr><td colspan="2">Power applied to each source (mW)</td><td>0</td><td>2.4</td></tr>
<tr><td colspan="4">Predicted nulling achievable</td></tr>
<tr><td>
</td><td colspan="2">
</td><td>
</td></tr>
</table>

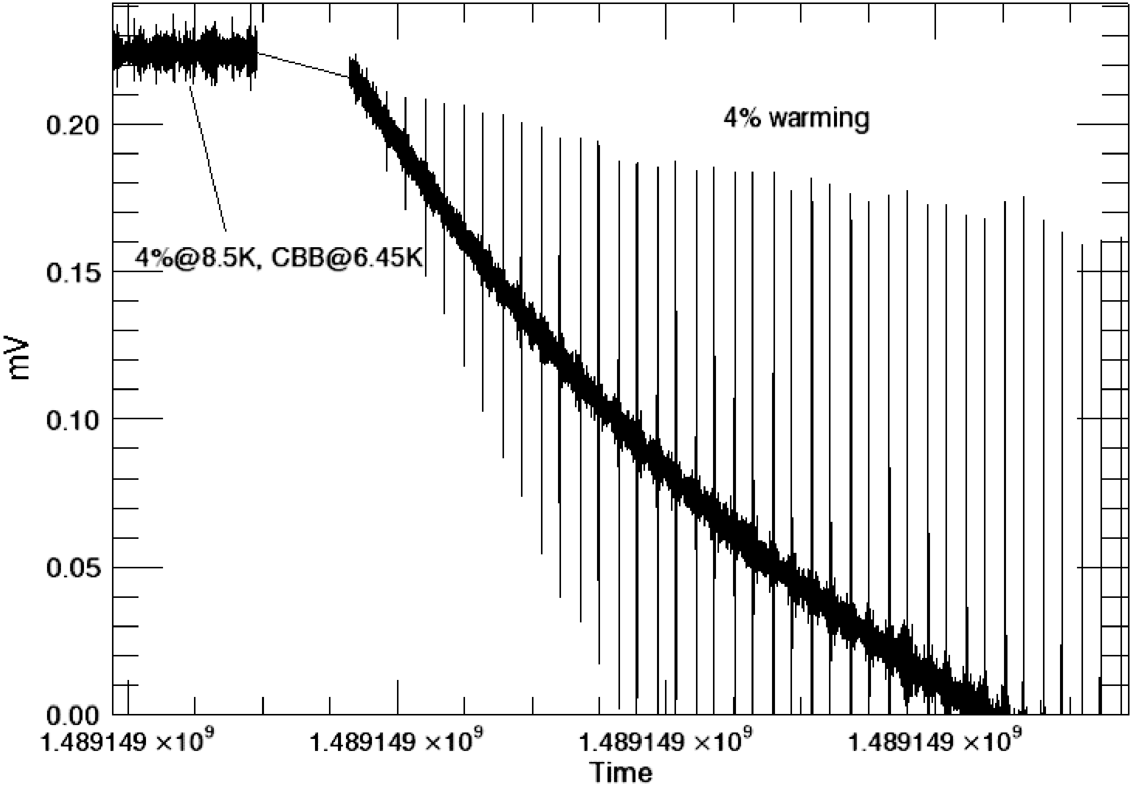
Requirements

- IRD-CALS-R01 - Radiated spectrum – power nulling
  - From modelling, with baseline telescope parameters
  - In-band power ratio from Scal source & telescope
  - Best match – 2% @ 80K



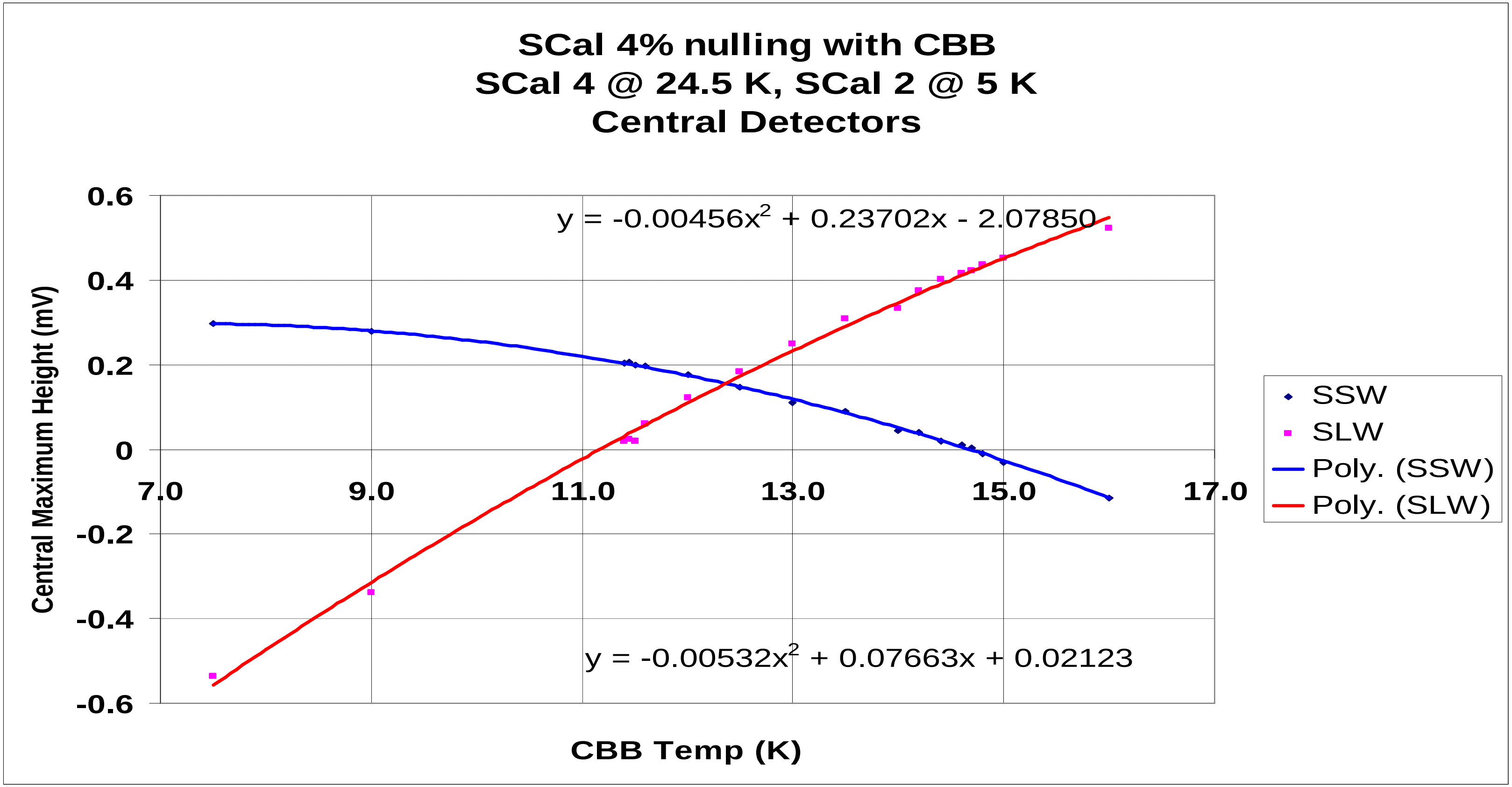
Requirements

- IRD-CALS-R01 - Radiated spectrum
  - Model fidelity proven by PFM1 test results
  - Several data sets – different CBB / Scal source temperatures



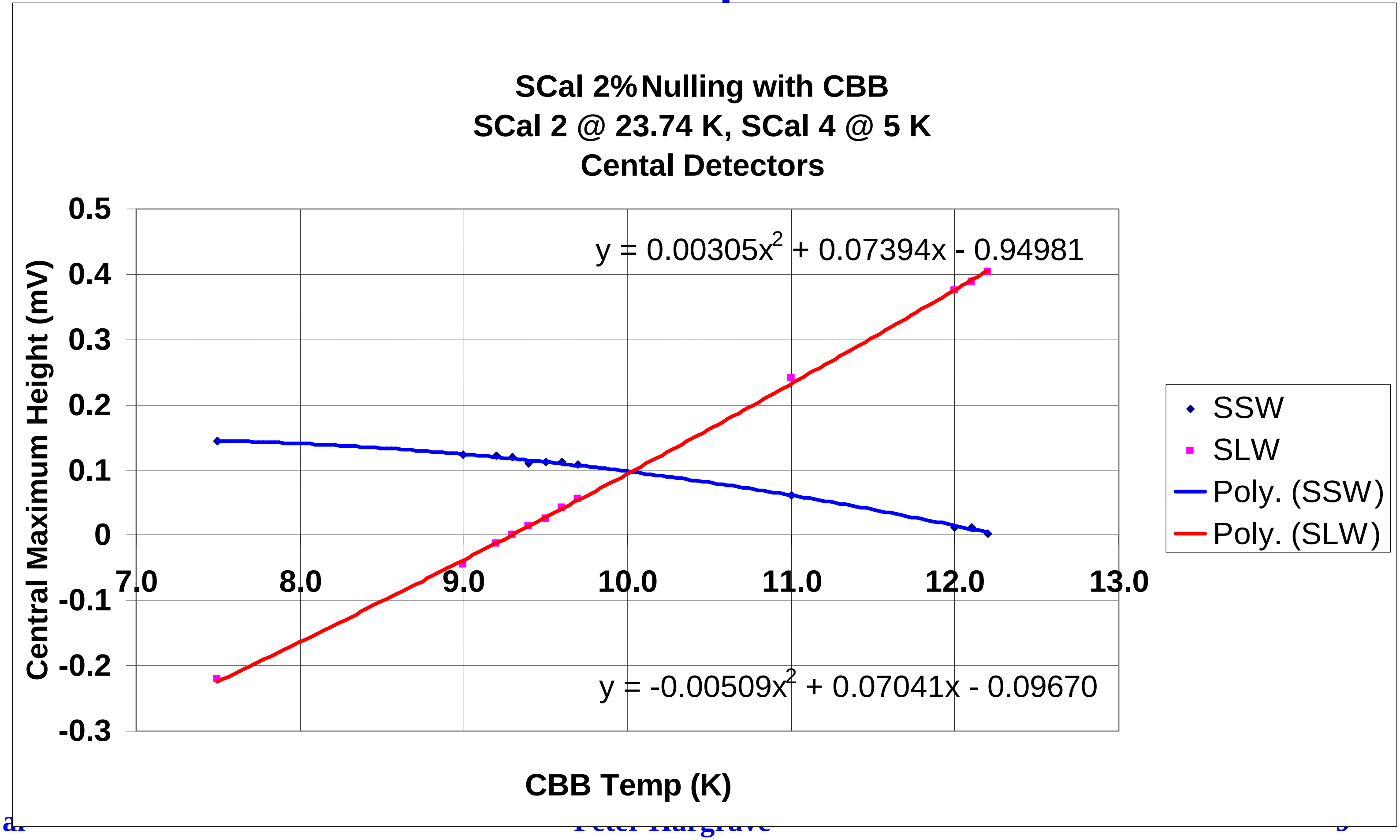
Requirements

- **IRD-CALS-R01 - Radiated spectrum**



Requirements

- **IRD-CALS-R01 - Radiated spectrum**



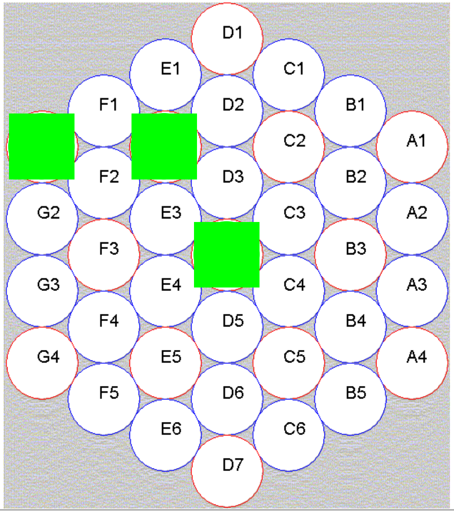
Requirements

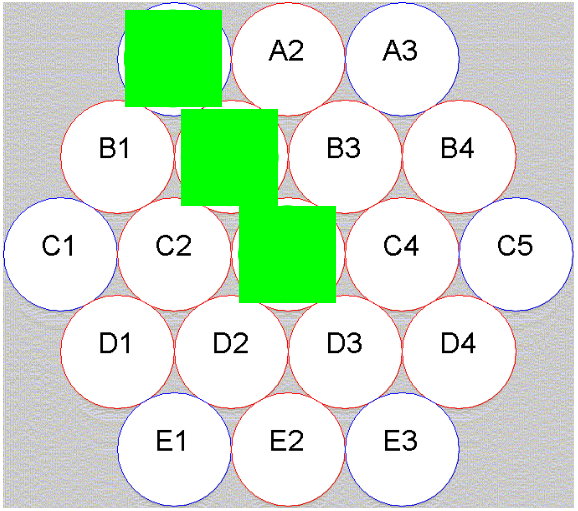
- IRD-CALS-R01 - Radiated spectrum
  - Model vs experimental results

	Band	CBB temperature for power match (K)	
		Experiment	Model
4% source @ 24.5K	SSW	14	13.31
	SLW	11.5	10.72
2% source @ 23.77K	SSW	~11.3	10.61
	SLW	9.48	8.24

Requirements

- **But:-**





	SSW			SLW		
	Central D4	Mid-way E2	Edge G1	Central C3	Mid-way B2	Edge A1
SCal 4% @24.5 K	**14.7**	**15.5**	**13.8**	**11.2**	**11.0**	**8.9**
SCal 2% @27.4 K	**12.3**	**12.2**	**11.0**	**9.3**	**9.3**	**9.6**

SCal

CBB temp. (K) for nulling of central max.

Requirements

- IRD-CALS-R04 – Uniformity
  - The uniformity of the intensity from the cal. source across the field image at the detector shall be better than 5%
    - This cannot be determined at unit level, and is really a requirement on SPIRE optics.
    - PFM1 tests indicate ~10% non-uniformity (worst case) across detector, c.w. CBB

Requirements

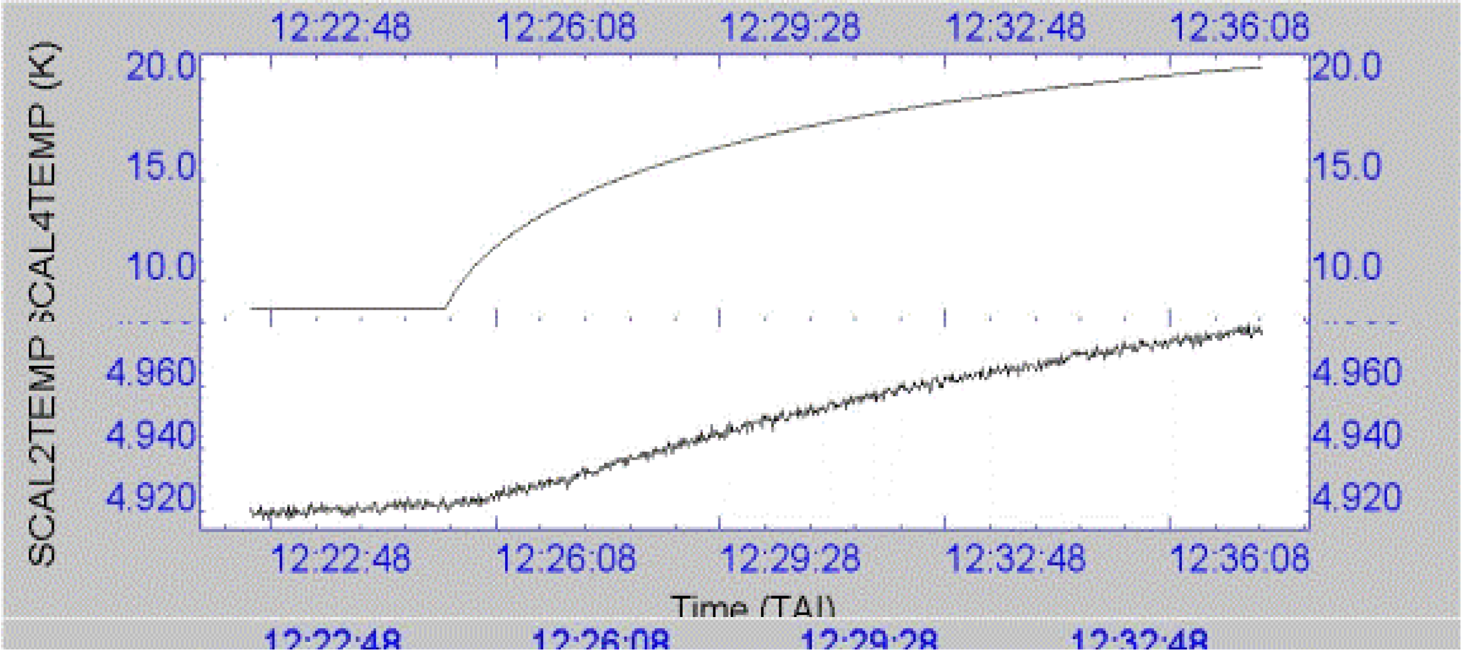
- IRD-CALS-R05– Repeatability & drift
  - The output intensity of the calibration source shall drift by no more than 1% over one hour of continuous operation. The absolute change in the output intensity of the source shall be no more than 15% over the mission lifetime
    - This depends partially on the stability of the warm electronics drive. No drift noticeable on a day-to-day basis – unit level and system level tests.
    - At the conclusion of life tests, the source temperature increased by 3% for the same nominal applied power.
- IRD-CALS-R06 – Operation
  - The calibration source shall be capable of continuous operation for periods of up to 2 hours with no loss of operational performance.
    - In PFM1 tests, Scal was operated typically with the sources at fixed temperatures for ~18 hr periods with no drift.

Requirements

- IRD-CALS-R09 – Power dissipation on focal plane
  - “Shall be within the specification given in the (now obsolete) systems budget document”
    - No formal requirement, but numbers were 5mW (req), 2mW (goal).
    - Nominal case power dissipation is 2.4mW
  - IRD now updated – compliant with numbers in the SPIRE thermal design document

Requirements

- **IRD-CALS-R12 – Thermal isolation**
  - The temperature of the SCAL housing and surrounding structure shall rise by no more than 1 K over the temperature of the FPU structure after one hour of continuous operation.



Requirements

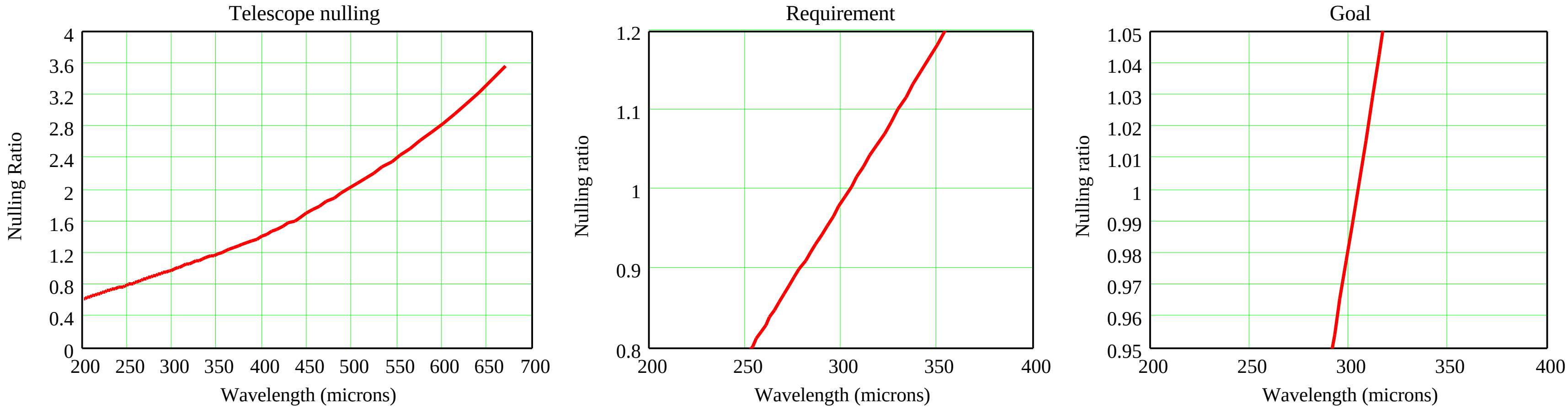
- IRD-CALS-R16 – Time response
  - Warm-up time: Stable nominal operating temperature to be reached in less than 30 min (req.); 15 min (goal).Cool-down time from nominal operating temperature to < 10 K: 3 hrs (requirement); 30 min (goal)
    - Compliant if enhanced warm-up procedure is used i.e. PID control in software. Time response was compromised due to need for reduced power dissipation (=lower G).
      - Constant 2.4mW – 2% source warms to 90% of equilibrium level in 30.3 minutes.
    - Cooling – worst case – 4% source cools from 160K to <10K in 144 minutes
      - Nominal case, 2% source cools from 88K in 54 minutes

Issues

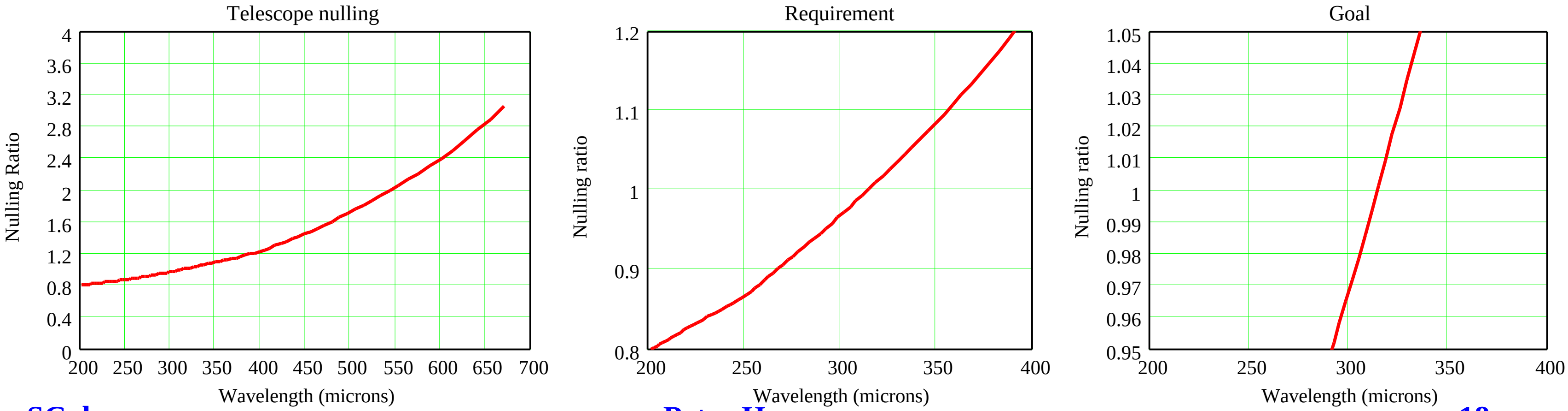
- **Telescope emissivity**
  - With default telescope parameters, 4% source will only be used if emissivity is >4%
  - Lab measurements (J. Fischer et. al.) indicate telescope emissivity will be ~1%
  - Very difficult to match this, even with 2% source
  - Propose to swap 4%(5mm dia) source for 1.5mm dia. source.
  - Replacement Scal has been built, and is currently being calibrated
  - May be installed post-PFM2 testing – TBD.

“New” telescope issues

Current SCal



“New” SCal



Thermal Verification

Bruce Swinyard
(on behalf of Anne-Sophie Goizel)

Thermal Design Overview

Overview of the thermal performances having an impact on the instrument scientific performances:

- Cooler Hold Time
- Detector Temperatures
- Temperature Stability

Cooler Hold Time [1/7]

- The thermal model (CDR Issue) predicted a 48 hrs cooler hold time for the “goals” interface temperatures.

- The CQM thermal balance test campaign was run successfully, allowing to confirm that the approach used to test the instrument thermal performances was adapted.

- The instrument thermal performances couldn’t be fully verified at this stage however, as the following flight hardware was missing:

  - Five flight detectors arrays,

  - L1/L0 isolation supports.

Cooler Hold Time [2/7]

- The instrument cooler performances was measured during the CQM2 test campaign for two Level-0 interface temperatures:

Test Cases L0 Interface Temperature	Level-0 Enclosure Actual Temperature	Cold Tip Temperature Range	Measured Hold Time	"Measured" Cooler Load [*]
1.7K	~ 1.74 K	276.5-279mK	~ 47 hrs	26.1-32.7uW ~ 29.4uW
2K	~1.94 K	283-285mK	~ 36 hrs	28-35 uW ~31.5uW

[*] Using the pump characterisation approach.

- The cooler was recycled in similar conditions in both test case with the evaporator temperature at end of condensation about ~2K

- The SOB temperature was ranging between 4.2 and 4.5K

- The change in L0 enclosures temperatures is directly responsible for the change in hold time.

Cooler Hold Time [3/7]

Test Cases L0 Interface Temperature	"Measured" Average Cooler Load [*]	Measured Hold Time	Thermal Model Predictions	Thermal Model Predictions
1.7K	~ 29.4uW	~ 47 hrs	30.6 uW	46.3 hrs
2K	~31.5uW	~ 36 hrs	38.6 uW	36.7 hrs

- The thermal model correlates rather well with the measured performances, with the exception of the “measured” cooler load for the 2K test case.
- The “measured” cooler load is based on the pump temperatures and it is suspected that some error was present in the temperature readings for this case.
- As the cooler was recycled in similar conditions, the change in measured hold time should be proportional to the change in the measured cooler load:
  - 29.4 uW x (47hr / 36 hr) = 38.4 uW, in good accord with the thermal model.

Cooler Hold Time [4/7]

- Summary of changes since CDR affecting the cooler hold time performances:

Positive Impact	
FM Cooler slightly overcharged	Increased amount of helium available for the cold phase.
L1 Kapton interface changed to larger glued area	Reduced temperature drop across the L1 interface.
Improved L0 interbox strap design	Reduced temperature drop between the L0 enclosures.

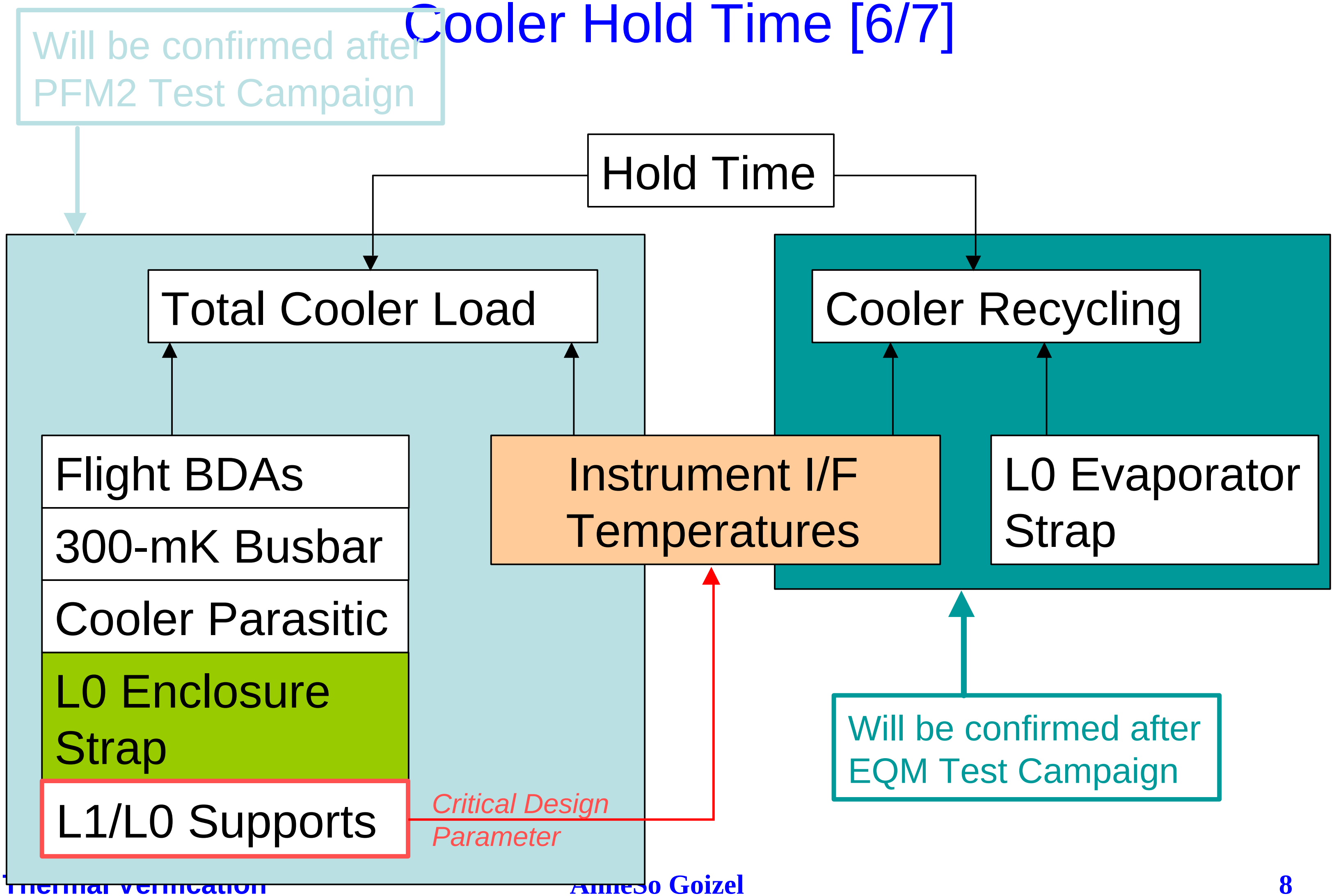
Cooler Hold Time [5/7]

Possible Negative Impact	
L0 straps conductance doesn't currently meet the 0.15 W/K requirement.	0.08W/K measured in last test at Cardiff.
Increased mechanisms and electronics power dissipation	SCAL increased from 1.5 to 2.3 mW.
	SMECm actuator possibly higher (still to be confirmed)
	JFET power dissipation increased from 42 mW versus 60 mW.

- The new L1/L0 isolation supports play an important role in the overall instrument thermal performances as they have a direct impact on the Herschel cryostat interface temperatures.

- They will be tested for the first time during the PFM2 test campaign and their performance should confirm whether the above points will be an issue or not for the instrument performances.

Cooler Hold Time [6/7]



Will be confirmed after PFM2 Test Campaign

Hold Time

Total Cooler Load

Cooler Recycling

Flight BDAs

300-mK Busbar

Cooler Parasitic

L0 Enclosure Strap

L1/L0 Supports

Critical Design Parameter

Instrument I/F Temperatures

L0 Evaporator Strap

Will be confirmed after EQM Test Campaign

Cooler Hold Time [7/7]

- Future analyses:
  - The PFM2 test campaign will provide a set of thermal data that will be used for correlation with the thermal model.
  - Once all recent changes in design have been confirmed by the subsystems and/or verified by testing, they will be integrated in the thermal model.
  - A new set of flight predictions will then be run and issued for the Autumn 2005.

Detectors Temperature [1/4]

- **Large temperature drops were measured between the cooler cold tip and the PLW BDA during the CQM test campaigns.**

- **Recent developments have been carried out to improve the temperature drop between the cooler cold tip and the BDA thermal interfaces.**

- **A new 5Ns copper with high thermal conductivity has been sourced and has been used for the PFM2 thermal hardware.**

- **The various Busbar joint conductances have been characterised at 300-mK.**

Detectors Temperature [2/4]

- CQM Test Campaigns Results Overview:

Test Campaign	Level-0 Temperature	Setup	Cold Tip Temperature	PLW Temperature	Temperature Drop [*]
CQM1	~ 2.1 K	Only PLW connected to the cooler	261 mK	336 mK	75 mK
CQM2	~ 1.7 K	PLW and 4 STM BDAs connected to cooler	277mK	310 mK	33 mK
CQM2	~1.9 K	PLW and 4 STM BDAs connected to cooler	286mK	350 mK	64 mK

[*] At detector array, so also includes the temperature drop internal to the BDA.

Please note that a 4Ns copper was used for the CQM1 Busbar, while a 5Ns copper was used for the CQM2 Busbar.

A 53mK temperature drop had been predicted at the PLW BDA thermal interface for the CQM2 test case with the Level-0 enclosure at ~2K.

A 5Ns copper with a higher thermal conductivity (than the CQM2 5Ns) has been sourced for the PFM2 Busbar.

Detectors Temperature [3/4]

With the new 300-mK Busbar copper material, the following temperatures have been predicted at each of the detector thermal interfaces:

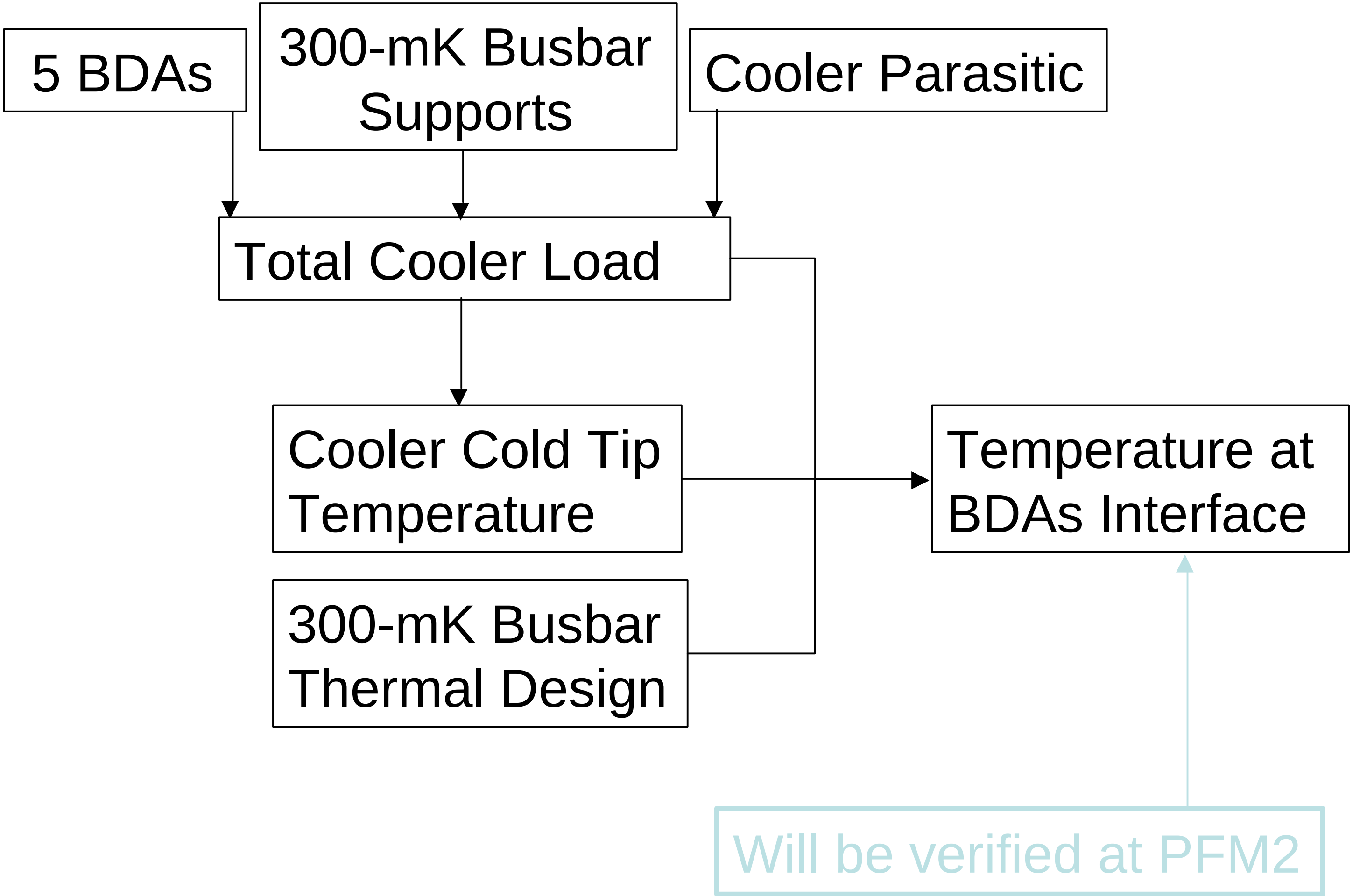
<table>
<tr><th colspan="3">Cooler Cold Tip [mK]</th></tr>
<tr><td colspan="3">285</td></tr>
<tr><td>BDA</td><td>Delta T [mK]</td><td>Temperature [mK]</td></tr>
<tr><td>PSW</td><td>8</td><td>293</td></tr>
<tr><td>PMW</td><td>9</td><td>294</td></tr>
<tr><td>PLW</td><td>10</td><td>295</td></tr>
<tr><td>SSW</td><td>6</td><td>291</td></tr>
<tr><td>SLW</td><td>7</td><td>292</td></tr>
</table>

- The temperature drop inside the BDA (~ 10mK) needs to be added to these values to obtain the detector absolute temperature.

- A nominal load of 30 uW has been assumed at the cooler cold tip.

- These predictions will be verified during the PFM2 test campaign.

Detectors Temperature [4/4]



5 BDAs

300-mK Busbar Supports

Cooler Parasitic

Total Cooler Load

Cooler Cold Tip Temperature

300-mK Busbar Thermal Design

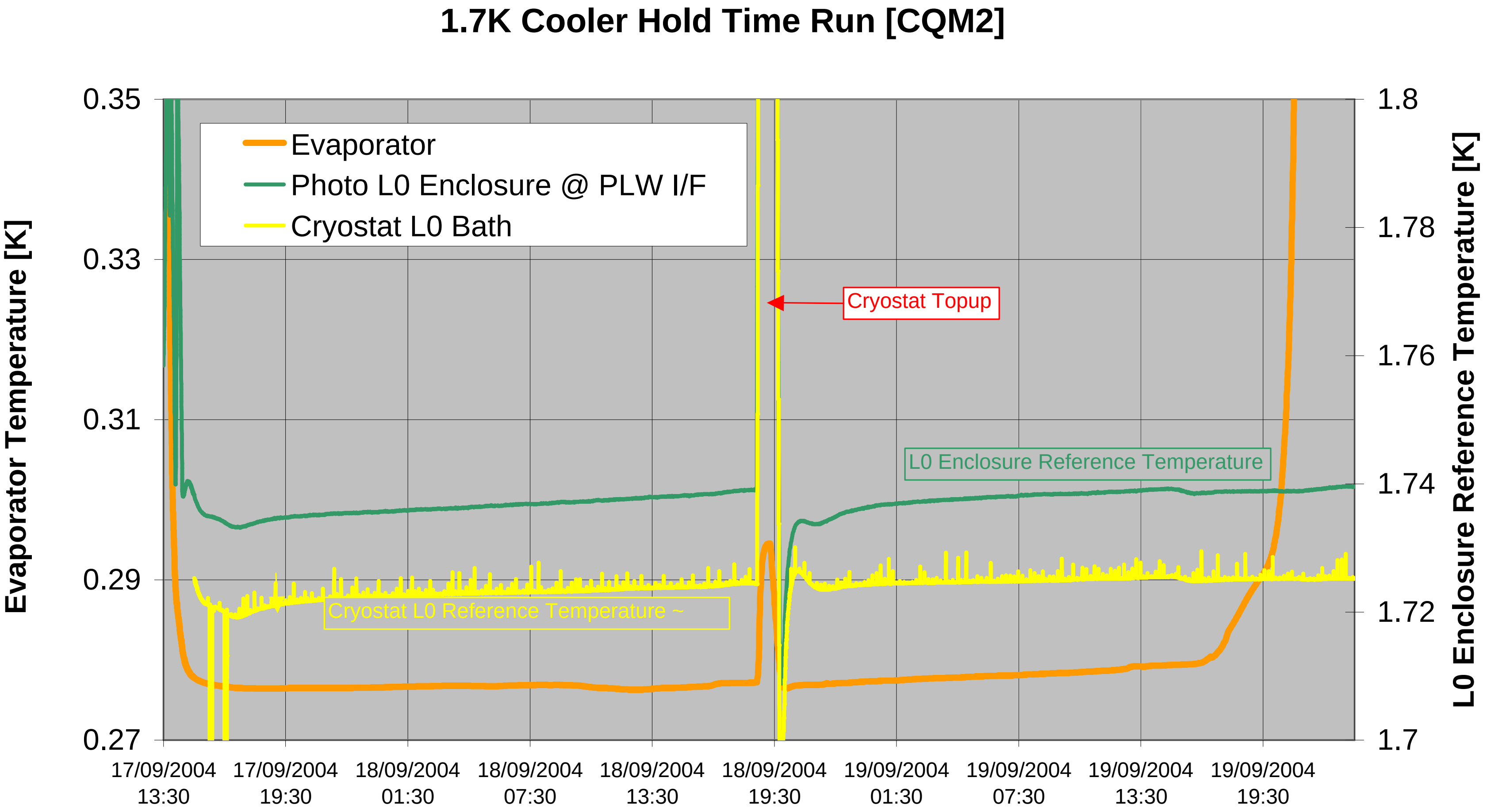
Temperature at BDAs Interface

Will be verified at PFM2

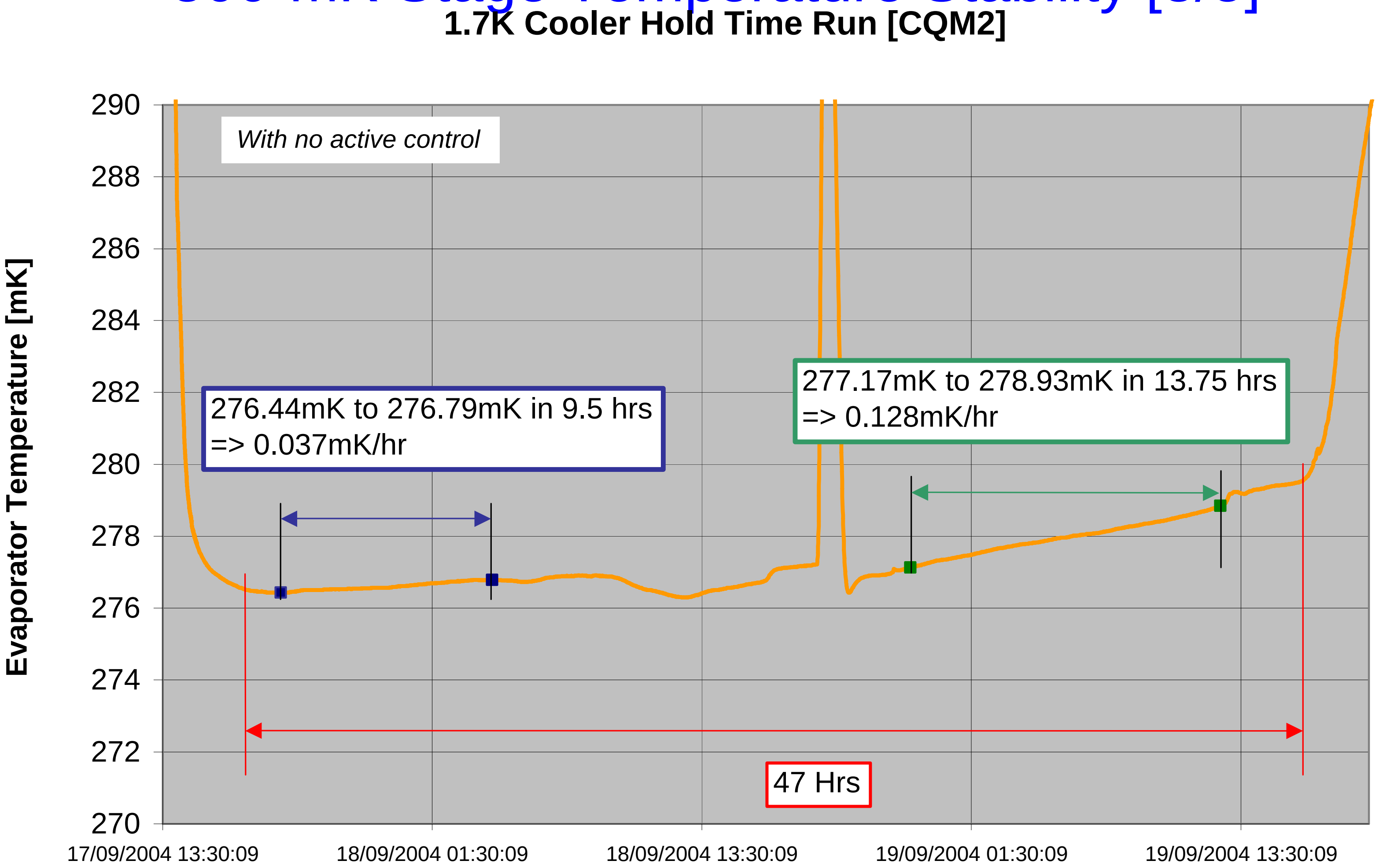
300-mK Stage Temperature Stability [1/5]

- The CQM test data provided an insight of the cooler cold tip stability after recycling,
- Test performed at EQM level will be more representative as the full spacecraft dynamics will be simulated,
- The PTC control will be tested during PFM2 should it be required for the photometer mode.

300-mK Stage Temperature Stability [2/5]

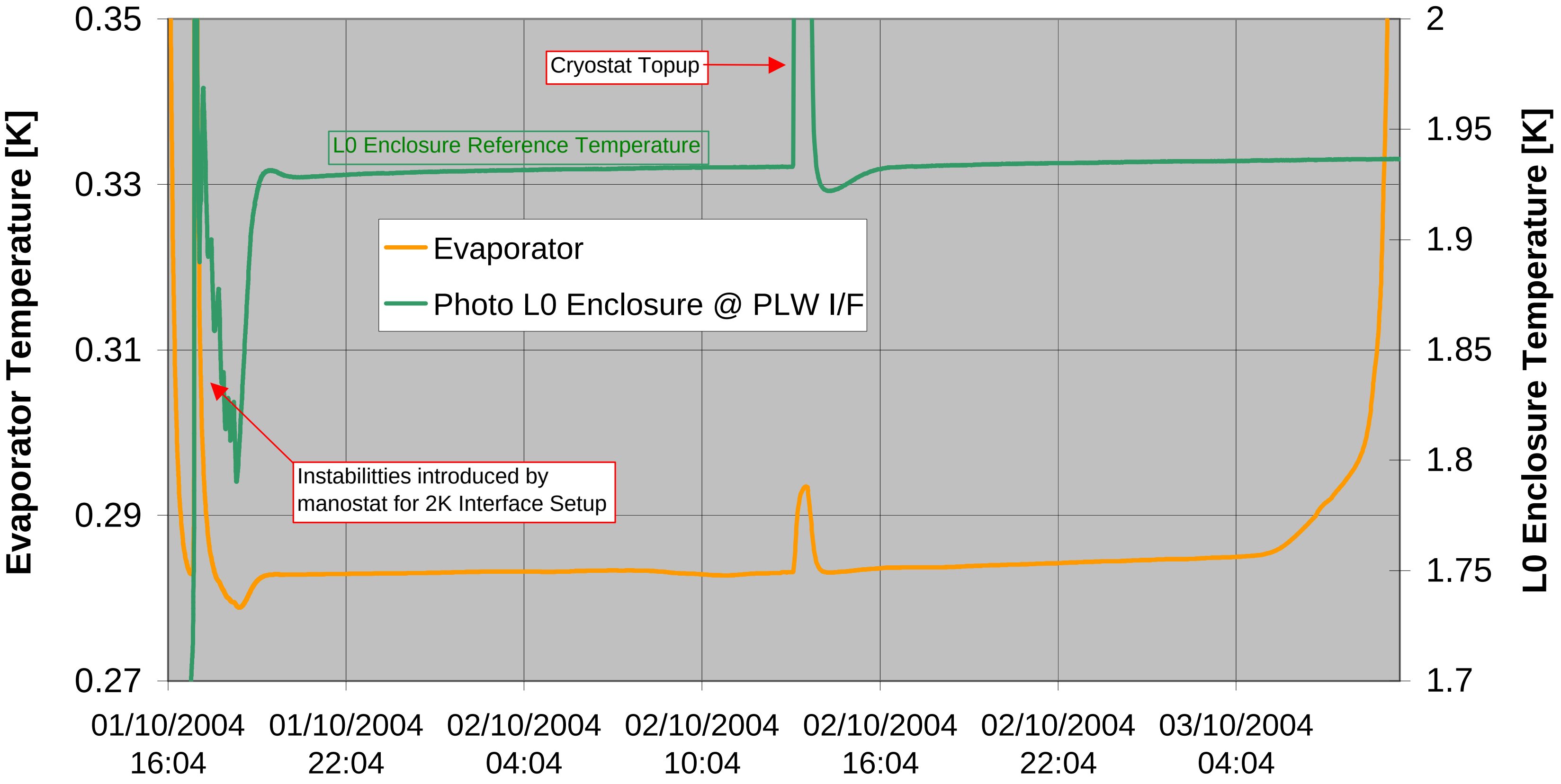


300-mK Stage Temperature Stability [3/5]



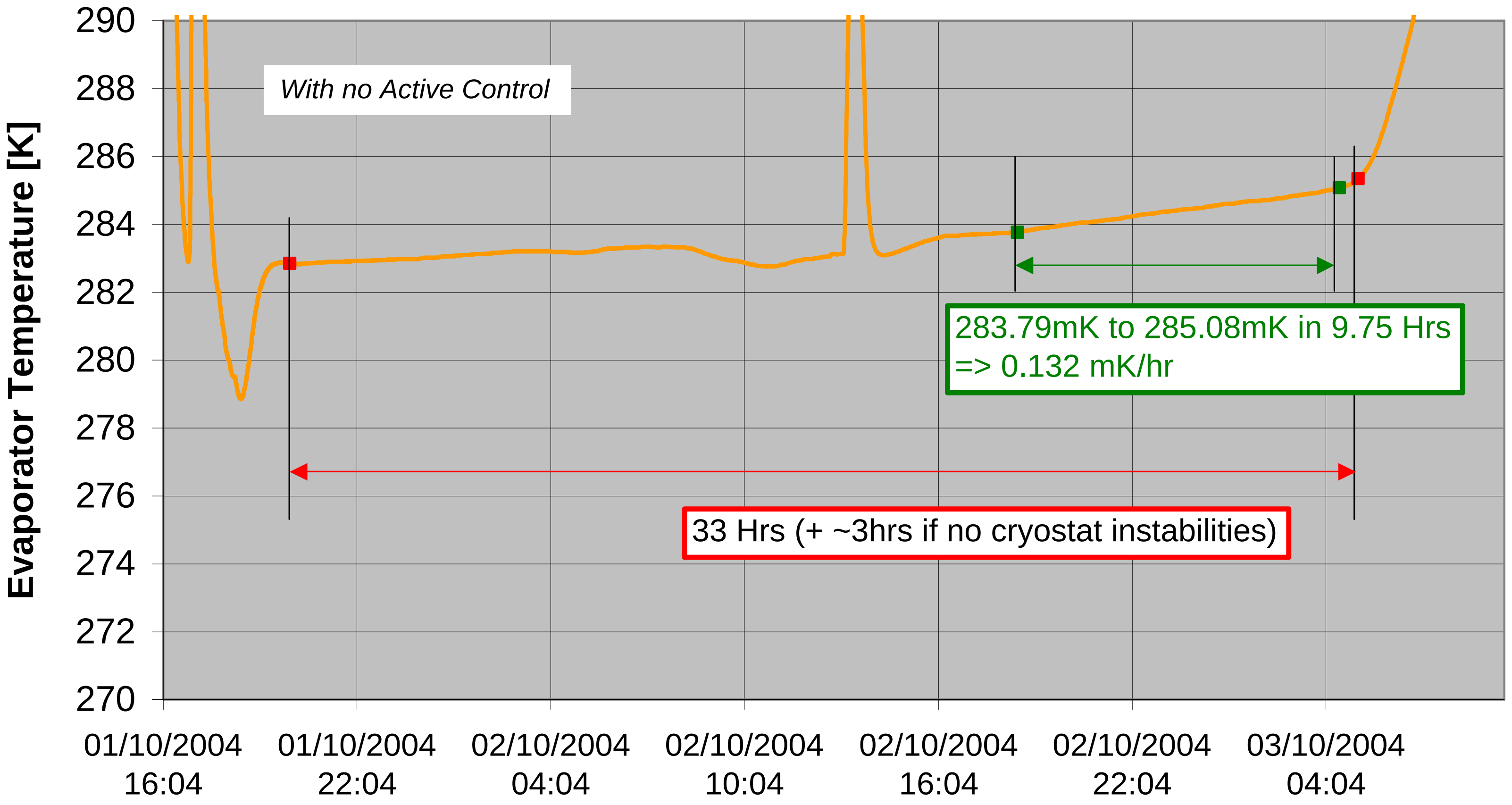
300-mK Stage Temperature Stability [4/5]

2K Cooler Hold Time Run [CQM2]



300-mK Stage Temperature Stability [5/5]

2K Cooler Hold Time Run [CQM2]



With no Active Control

283.79mK to 285.08mK in 9.75 Hrs
=> 0.132 mK/hr

33 Hrs (+ ~3hrs if no cryostat instabilities)

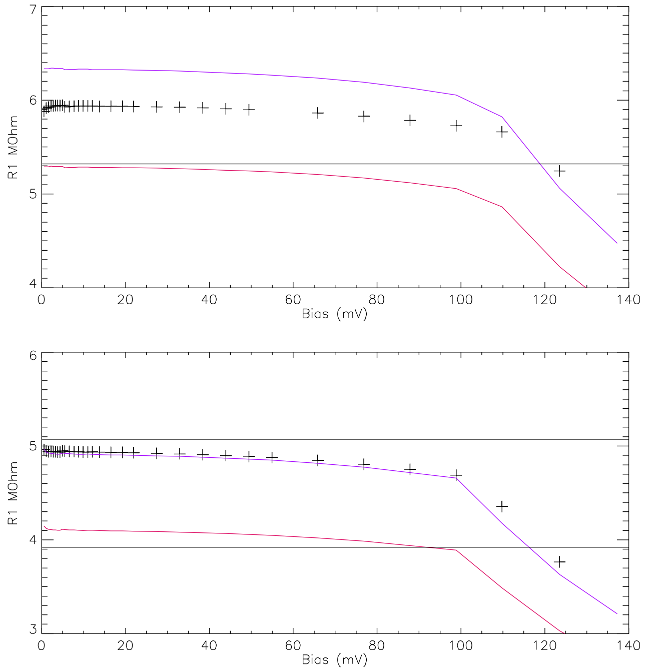
Instrument Throughput

Bruce Swinyard

SPIRE PFM1 Optical Efficiency from Loadcurves

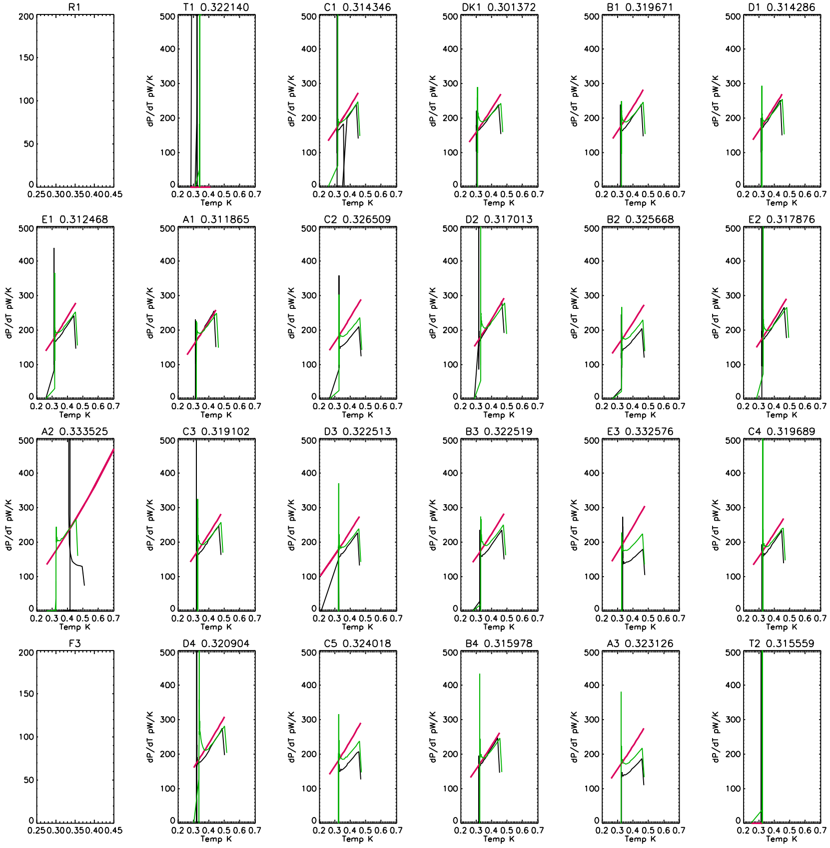
- Data taken with the CBB off (6.5 K) and set at 10 and 15.5 K
- Bias frequency at 70 Hz 6.5; 10 and 15.5K also set to 160 Hz for one 6.5 K
- Gain correction applied to SSW using Adam's method of assuming all bolometers are at the same temperature
- "Standard" processing applied using JPL parameters provided in SLW EIDP 14 and SSW EIDP 9

Gain check using Resistor channels



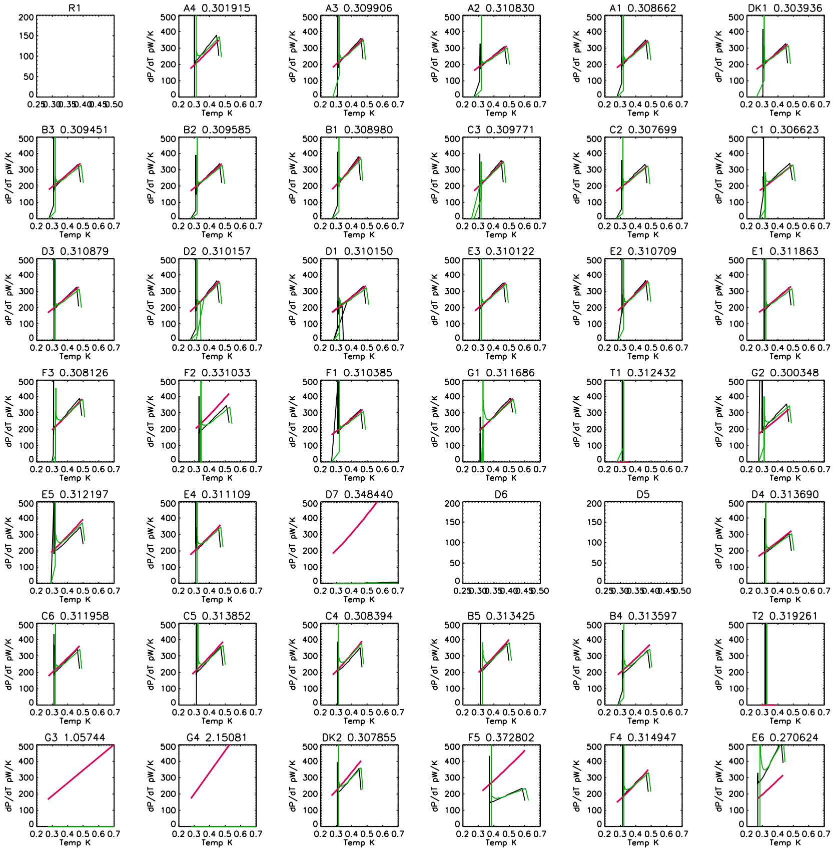
70 Hz (crosses) and 160 Hz R1 measured resistance versus applied bias – red curve is 160 Hz with gain = 1 and purple is with gain = 0.835. The upper panel is for SLW and the lower for SSW.

SLW Gain – 160 and 70 Hz compared at CBB 6.5



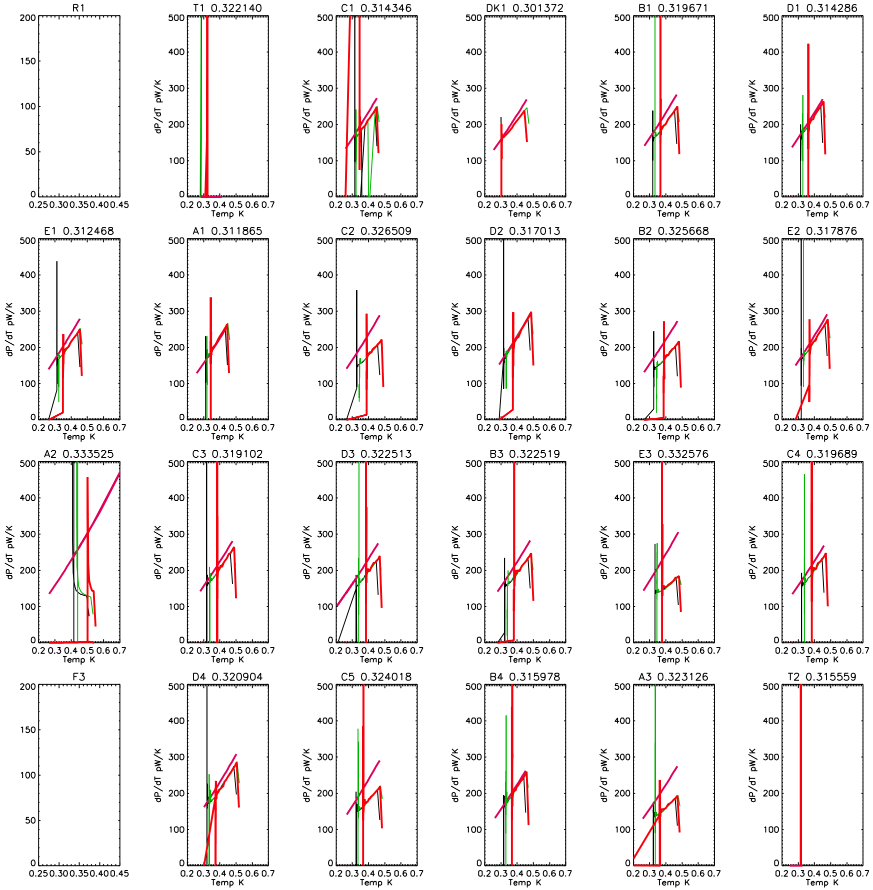
dP/dT vs T - gain at 70 set to 0.835 – gain at 160 set to 1.0

SSW Gain – 160 and 70 Hz compared at CBB 6.5

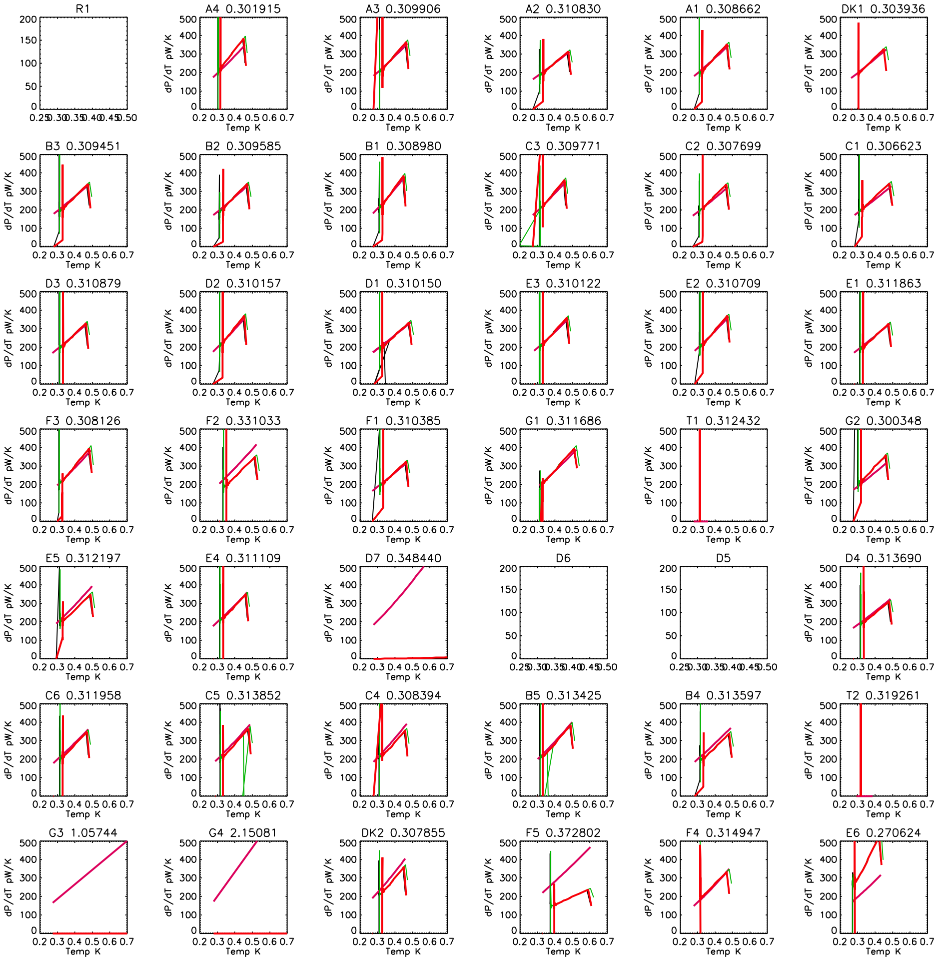


dP/dT vs T gain at 70 set to 0.835 – gain at 160 set to 1.0

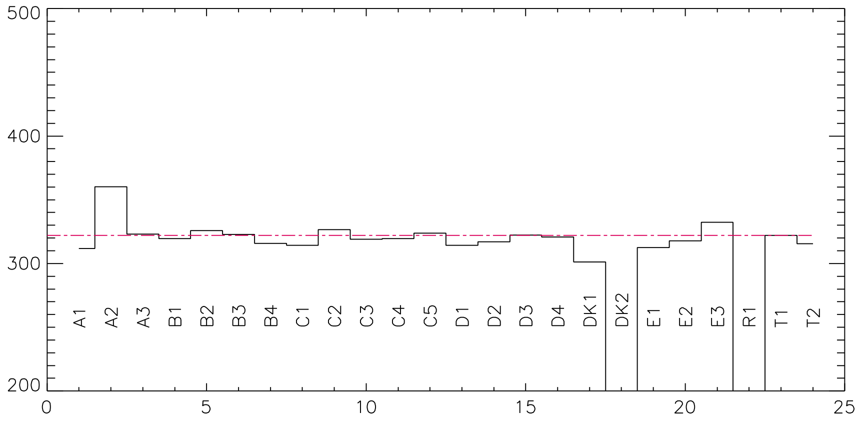
SLW dP/dT vs T cf JPL

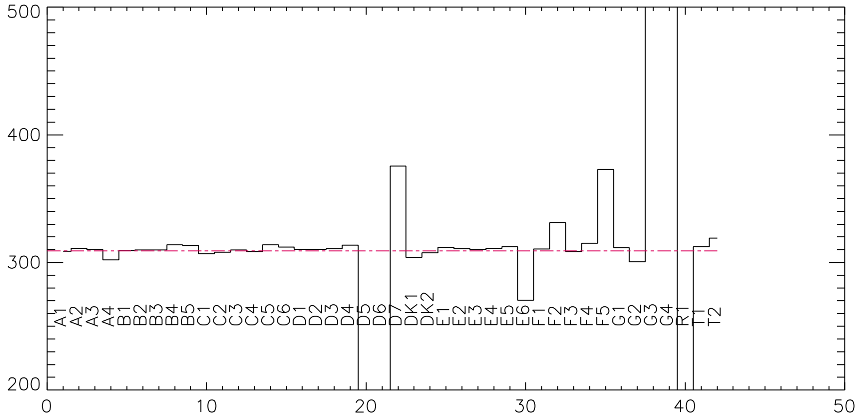


SSW dP/dT vs T cf JPL

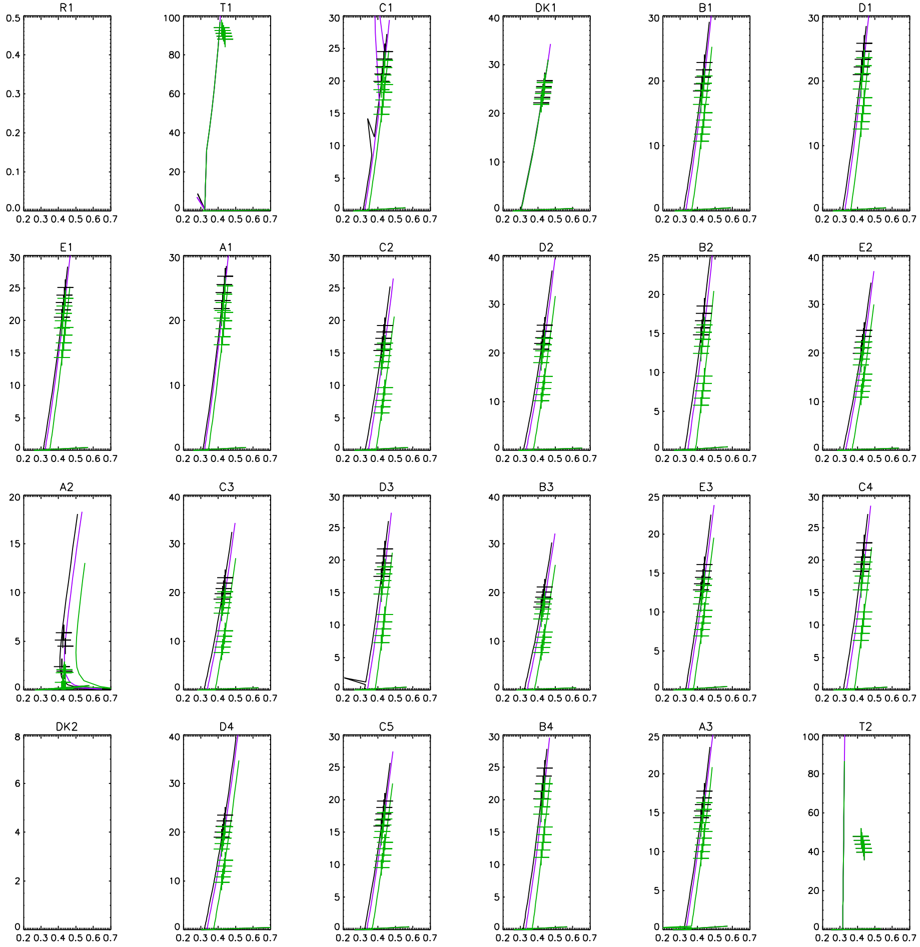


Detector Temps with CBB at 6.5 K

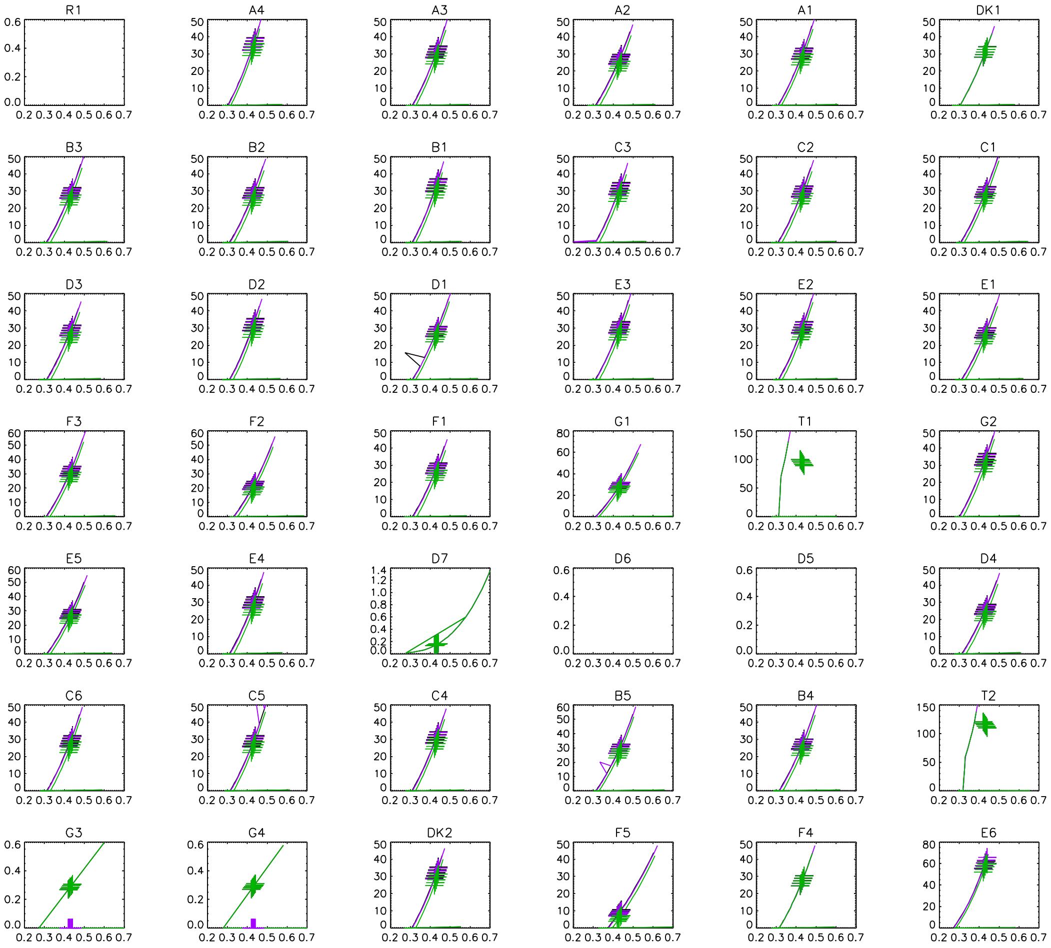




SLW P_e vs T three load conditions



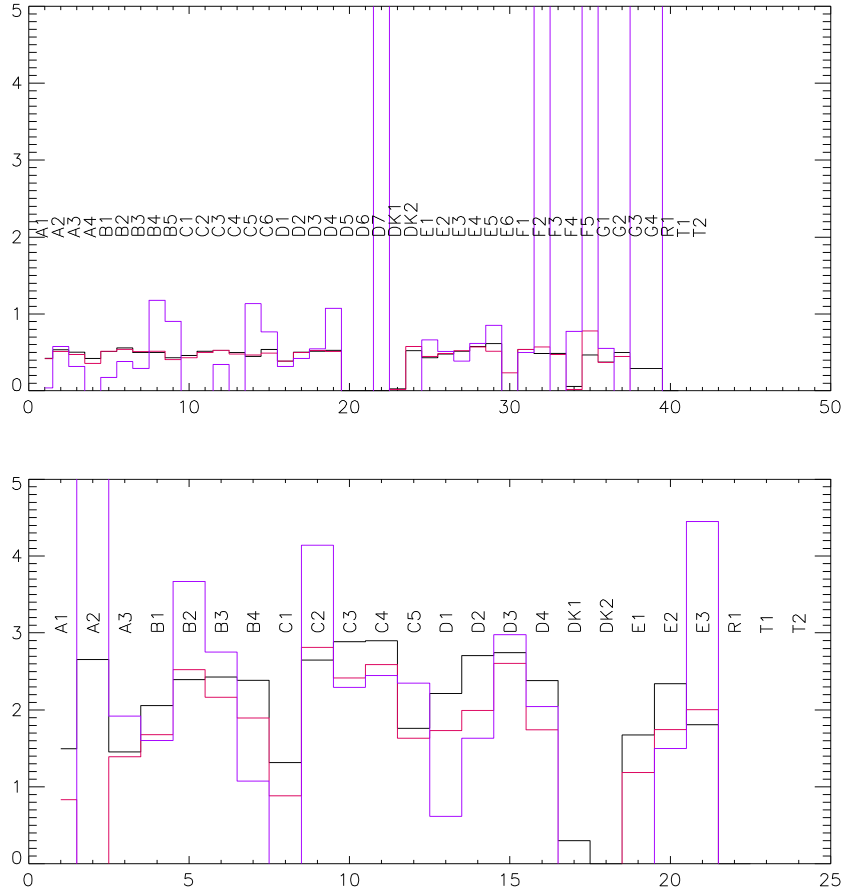
SSW P_e vs T three load conditions



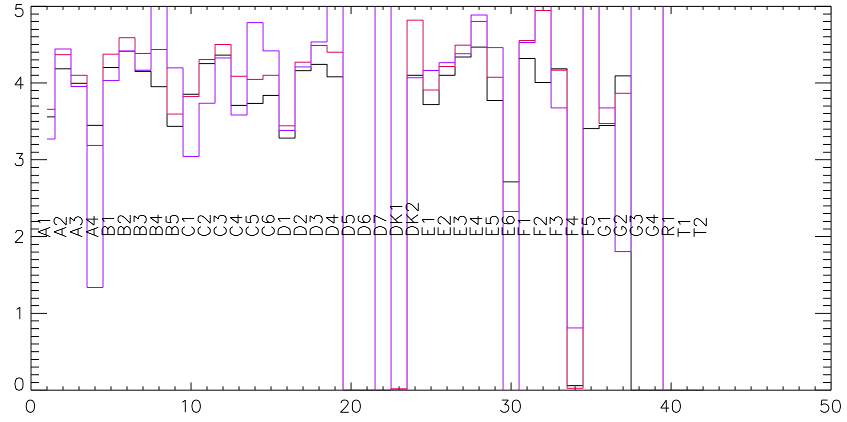
Three ways to calculate optical power

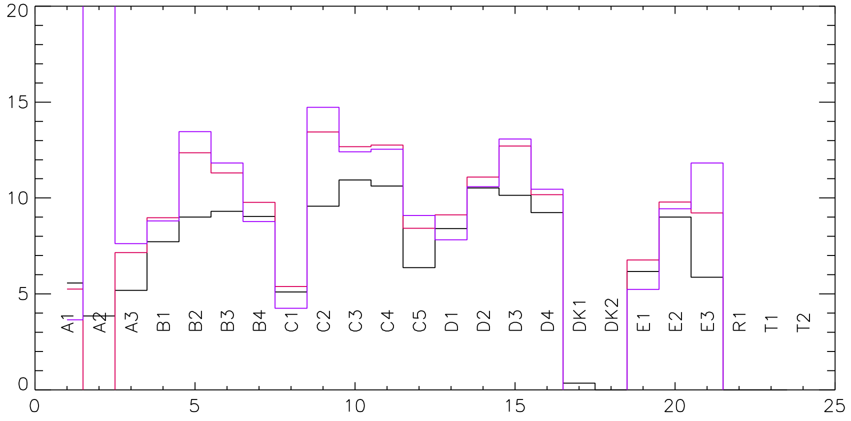
- Difference in electrical power between 10, 15.5 and 6.5 K loadcurves
- Use DT between bolometer with 6.5 K and 10 and 15.5 K
- Use DT between thermistor on array and each bolometer – i.e. direct calculation not using 6.5 K case at all

Optical Power difference for CBB 6.5 and 10 K



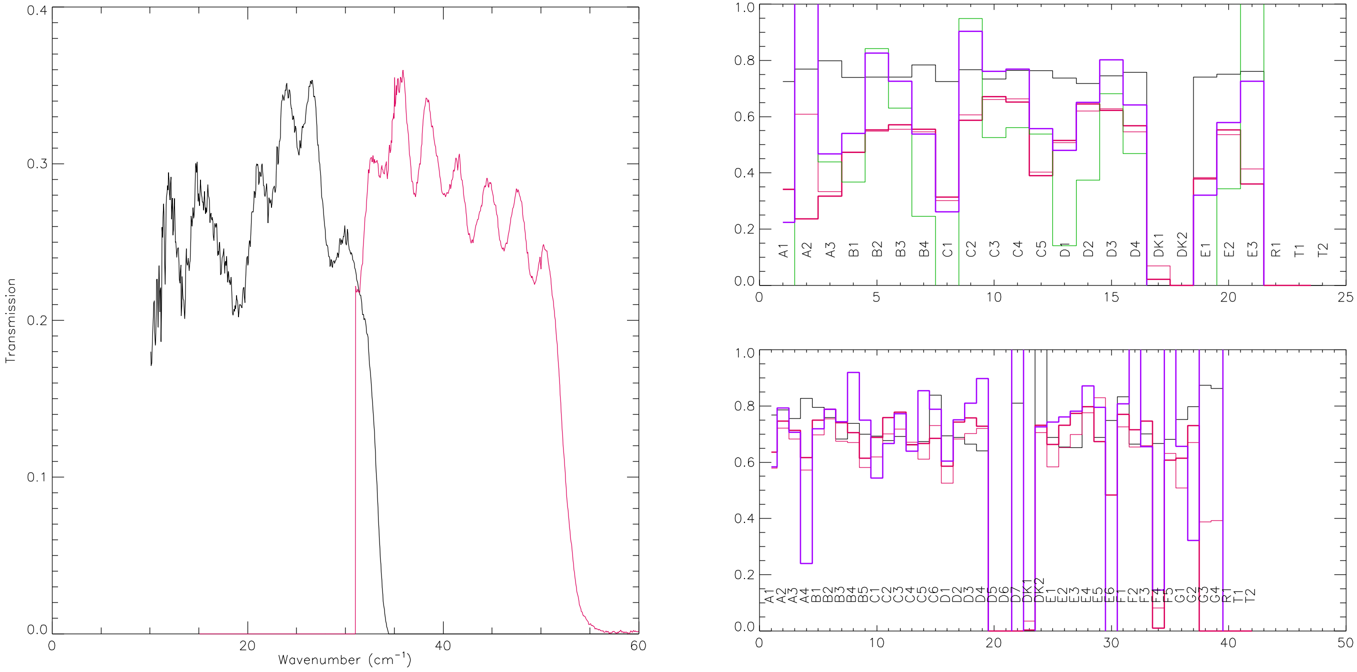
Optical Power difference for CBB 6.5 and 15 K





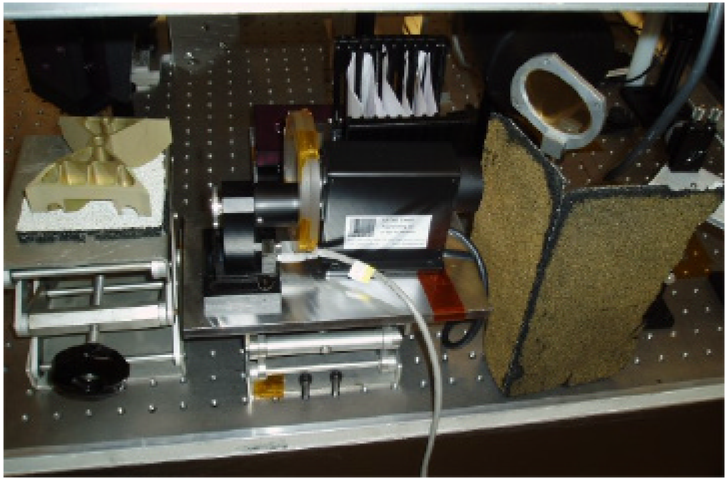
Detector Optical Efficiency assuming l^2 throughput

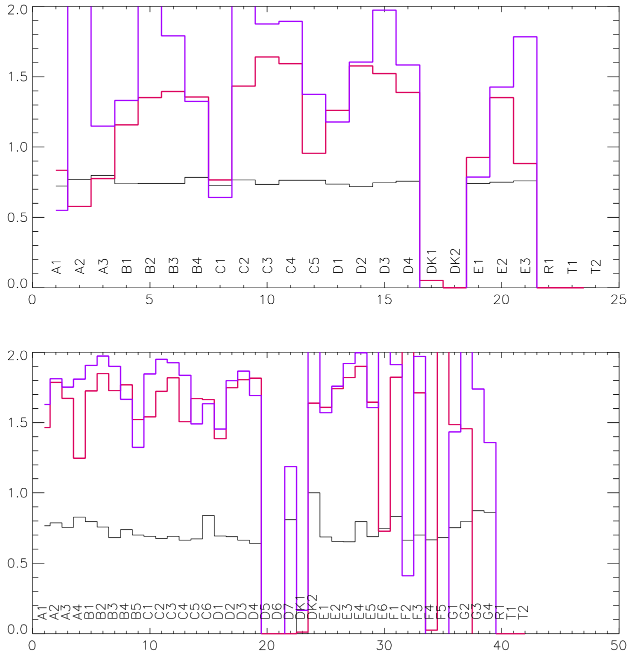
(..but forgetting the 0.5 for FTS not at ZPD)



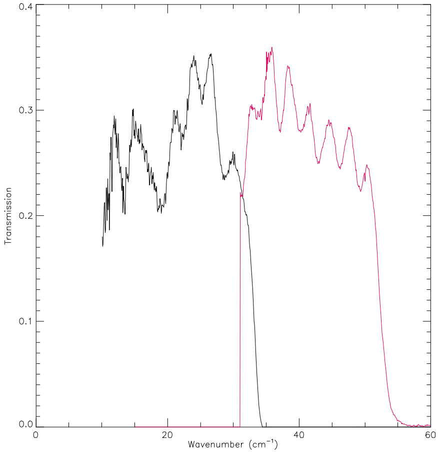
Detector Optical Efficiency assuming l^{2} throughput

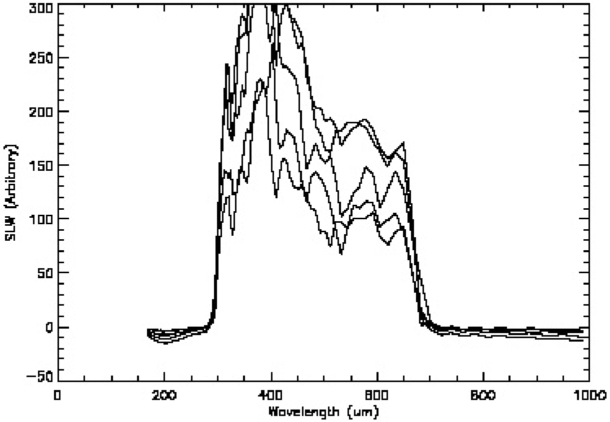
(…with 0.5 for FTS and 0.81 for RT transmission)

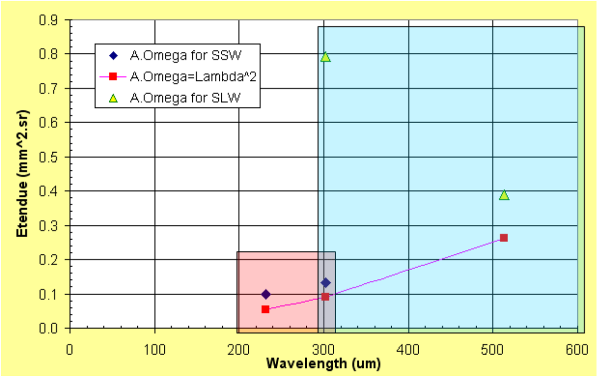


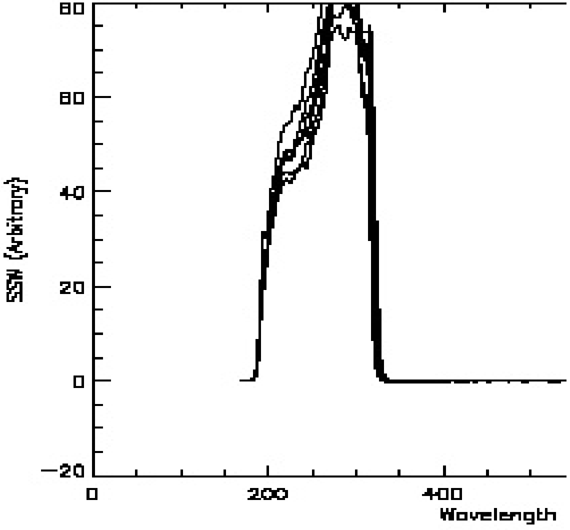


Spectrometer Relative Spectral Response

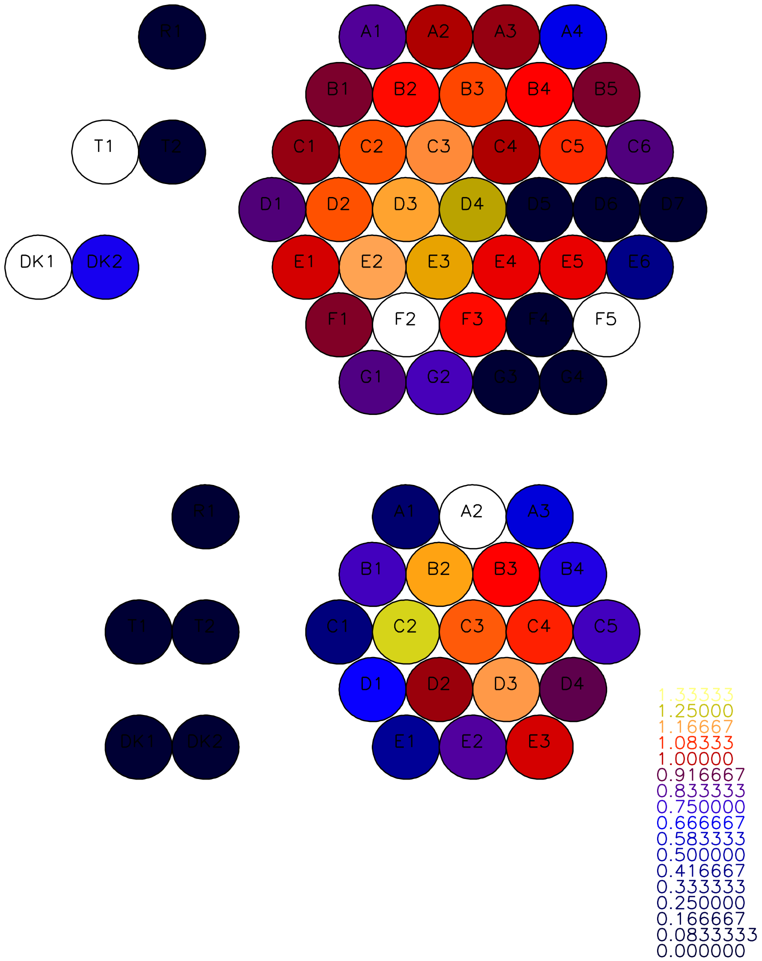




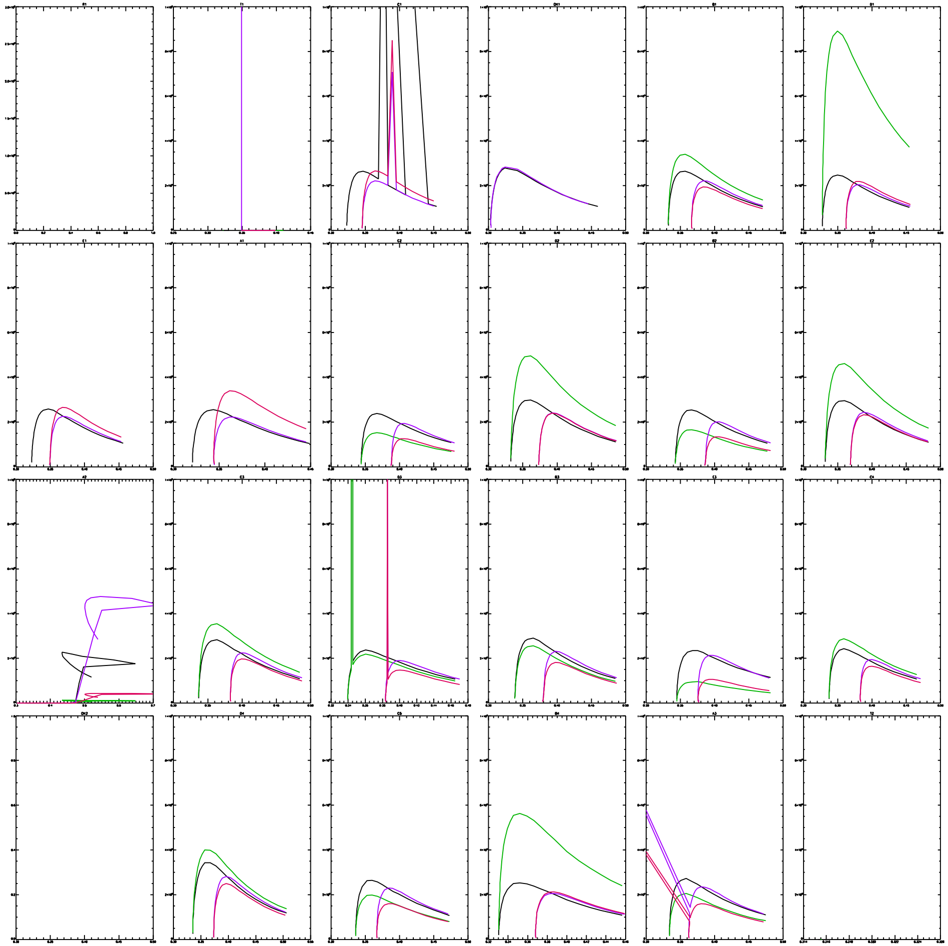




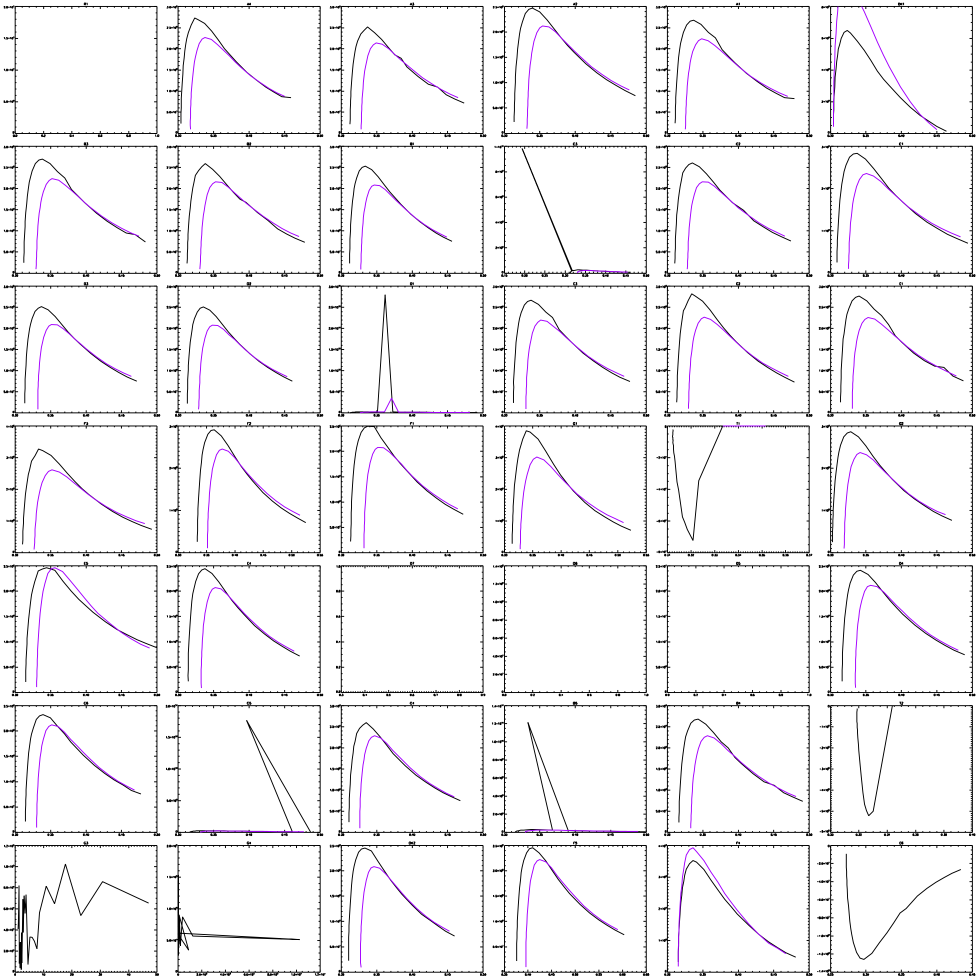
Spectrometer Relative Efficiency



SLW response versus temperature

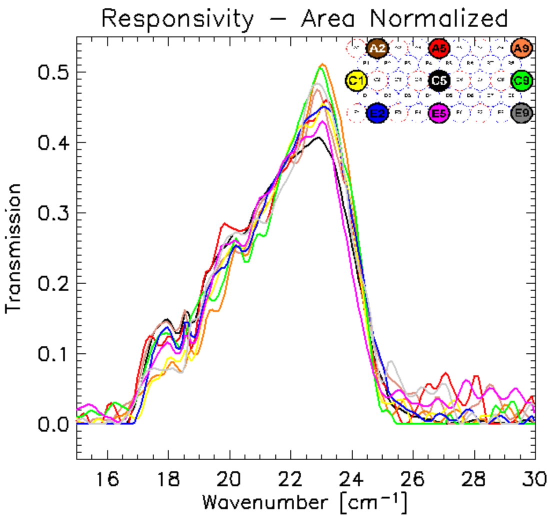


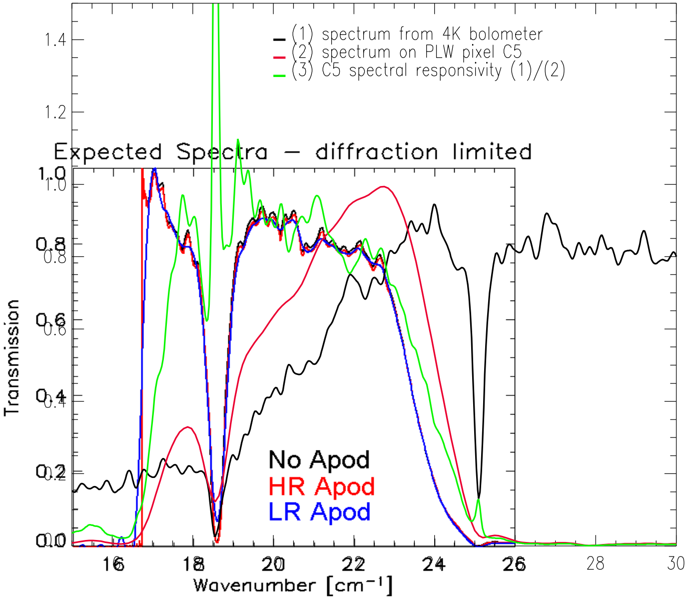
SSW response versus temperature



CQM PLW Spectral response

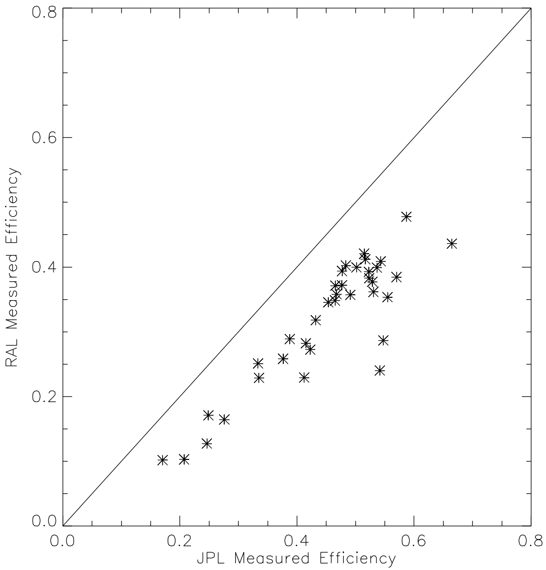
- **Test FTS worked very well – air path not dry enough or stable enough during CQM1 – much better during CQM2**
- **Stand alone tests using test detector show strange shape is not associated with SPIRE**

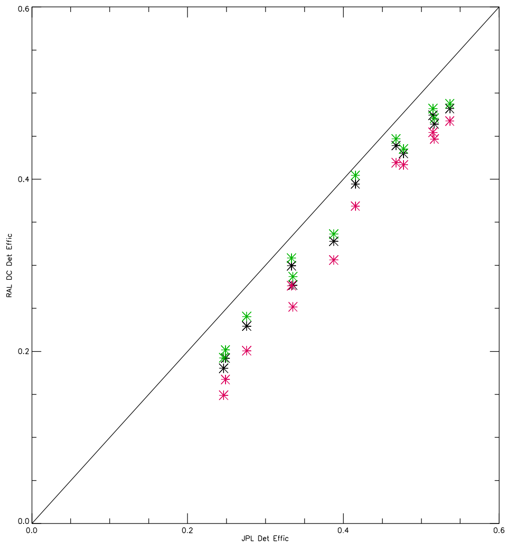




CQM PLW Optical Efficiency

- Comparing difference between optical load with 11.5 and 8 K CBB during CQM1 to deduce optical efficiency of BDA
- Comparison with JPL shows similar pattern across array but offset amounting to ~20%
- During CQM2 we used higher temperatures and DC rather than AC curves – differential less than 10% cf JPL measurement





Summary and Implications for Scientific Performance

Matt Griffin

- Compliance with top-level Science Requirements
- Instrument Sensitivity estimates
- ESA plans for Science Verification Reviews
- Conclusions and next steps

R1, R2: Photometer Sensitivity

- **R1**: The photometer should be capable of diffraction-limited extragalactic blind surveys of at least 60 sq. deg. of the sky, to 1-s detection limit of 3 mJy in all bands with an observing time of six months or less
  - Today’s estimates are marginally compliant:
    - Current sensitivity model (SPIRE-QMW-NOT-000642; Dec. 13 2004) predicts (1.8, 2.5, 3.2 days)/sq. deg. for (PSW, PMW, PLW) Þ 192 days for 60 sq. deg.
    - Caveat: the uncertainty on this figure is large

- **R2**: The photometer should be capable of a galactic survey covering 1 deg. sq. to a 1-s depth of 3 mJy at 250 mm within an observing time of one month or less
  - Much less stringent than R1
  - Complaint according to current estimates

R3, 4, 5, 7: Photometer Design

- **R3: Maximising the ‘mapping speed’ at which confusion limit is reached over a large area of sky is the primary science driver. This means maximising sensitivity and field-of-view (FOV) but NOT at the expense of spatial resolution.**
  - **Complaint by design**

- **R4: The photometer observing modes should provide a mechanism for telemetering undifferenced samples to the ground.**
  - **Compliant by design**

- **R5: The photometer should have an observing mode that permits accurate measurement of the point spread function**
  - **Compliant by design (Jiggle or scan mapping)**

- **R7: The photometer field of view shall be at least 4 x 4 arcmin., with a goal of 4 x 8 arcminutes**
  - **Requirement met for Jiggle-map**
  - **Goal met for scan map**

R9, 11, 12, 13: Photometer Design

- **R9**: The maximum available chop throw shall be at least 4 arcminutes; the minimum shall 10 arcseconds or less
  - Compliant by design and test (BSM meets spec.)
- **R11**: The photometer dynamic range for astronomical signals shall be 12 bits or higher
  - Compliant by design
- **R12**: SPIRE absolute photometric accuracy shall be 15% or better at all wavelengths, with a goal of 10%
  - To be verified in orbit. Design of instrument, observing modes, and proposed calibration scheme based on planets and stars, are compatible with this requirement
- **R13**: The relative photometric accuracy should be 10% or better with a goal or 5%.
  - Compliance at satellite level to be verified in orbit.
  - Instrument is compliant by design and test (PCAL and detector stability)

R23, 24, 25: Photometer Design

R23: The SPIRE photometer shall have an observing mode capable of implementing a 64-point jiggle map to produce a fully sampled image of a 4 x 4 arcminute region

- Compliant by design
- Flight BSM meets spec.

R24: The photometer observing modes shall include provision for 5-point or 7-point jiggle maps for accurate point source photometry.

- Compliant by design

R25: The photometer shall have a "peak-up" observing mode capable of being implemented using the beam steering mirror.

- Compliant by design
- Implementation is TBD

SRD-R6, 8, 10: Photometer Performance

- **R6**: Optical field distortion should be less than 10% across the photometer field of view.
  - Compliant by optical alignment and submm measurements on CQM.

- **R8**: For 2Fλ feedhorns, crosstalk shall be less than 1% (goal 0.5%) for adjacent detectors and 0.1% or less (goal 0.05%) for all non-adjacent detectors in the same array; for 0.5Fλ pixels, the requirement is 5% (goal 2%) to adjacent detectors and 0.1% (goal 0.05%) to all others. (Note: This requirement is under review).
  - To be verified: Dedicated tests needed on PFM

- **R10**: The rms detector NEP variation across any photometer array should be less than 20%.
  - To be verified (final BDA EIDPs + PFM 2 tests)

R14, 15: Photometer Performance

R14: SPIRE photometric measurements shall be linear to 5% over a dynamic range of 4000 for astronomical signals

- Compliant
- Basic point source NEFDs = (42, 48, 55) mJy $Hz^{-1/2}$.
- 4000*NEFD = (170, 190, 220) Jy
- Sensitivity model predicts linearity to within 2% (without correction) for S_n = 200 Jy
- ILT results and detector modelling indicate non-linearity may be calibrated out for source fluxes in excess of 1000 Jy (TBC)

R15: For feedhorn detectors, the overlapping sets of three detectors at the three wavelengths should be co-aligned to within 2" on the sky (goal = 1 ").

- To be verified by PFM 2 measurements

R16, 17, 18: Spectrometer Performance

R16: The spectrometer design shall be optimised for optimum sensitivity to point sources but shall have an imaging capability with the largest possible field of view that can be accommodated.

- Compliant by design

R17: The sensitivity of the FTS at any spectral resolution up to the goal value shall be limited by the photon noise from the FIRST telescope within the chosen passband.

- Compliant (but not a well-posed requirement

R18: The spectrometer dynamic range for astronomical signals shall be 12 bits or higher

- Compliant by design

R19, 20: Spectrometer Performance

R19: The FTS absolute photometric accuracy at the required spectral resolution shall be 15% or better at all wavelengths, with a goal of 10%.

- To be verified in orbit. Design and instrument performance are compatible with this requirement.

R20: The FTS shall be capable of making spectrophotometric measurements with a resolution of 2 cm^{-1}, with a goal of 4 cm^{-1}

- Compliant by design and test on PFM 1.
- Goal of 4 cm^{-1} not met (requires unrealistic spec. for SMEC)
  - Consequences not serious scientifically. Resolution of 2 cm^{-1} provides good characterisation of SED (l/Dl = 7 – 25)

R21, 22: Spectrometer Performance

R21: The width of the FTS instrument response function at the required spectral resolution shall be uniform to within 10% across the field of view.

- **Compliant for required resolution**
- **Further tests needed for goal resolution**

R22: The maximum spectral resolution of the FTS shall be at least 0.4 cm^{-1} with a goal of 0.04 cm^{-1}

- **Compliant by design**
- **Extrapolation of PFM 1 tests (not quite at full travel)**
- **Current plan is to use BES pivots which allow full range within power dissipation req.**
- **But channel fringing may compromise the maximum resolution**

Bolometer Performance

(Summary by Jamie)

PFM Bolometer Array Summary

Model		**PFM**	**PFM**	**PFM**	**PFM**	**PFM**
Array		**S/LW**	**S/SW**	**P/LW**	**P/MW**	**P/SW**
DQE	**median**	**0.63**	**0.72**	**0.53**	**0.63**	**0.69**
	goal	0.60	0.71	0.55	0.63	0.70
	guideline	0.50	0.59	0.46	0.53	0.59
h **(opt)**	**median**	**0.75**	**0.70**	**0.76**	**0.71**	**0.71**
	goal	0.70	0.70	0.85	0.85	0.85
	guideline	-	-	0.65	0.65	0.65
Yield (end-to-end)	# opt pixels	19	37	43	88	139
	# bad	0	1+1	0	0	2+1
	meas	**1.00**	**0.95**	**1.00**	**1.00**	**0.98**
	BDA goal	0.90	0.90	0.90	0.90	0.90
	BDA guideline	0.75	0.75	0.75	0.75	0.75
	JFET goal	0.90	0.90	0.90	0.90	0.90
t [ms]	**median**	**5**	**4**	**6**	**6**	**5**
	goal	4	4	18	13	11
	guideline	14	8	32	32	32
NEP(dark) [1e-17 W/rtHz]	**median 1 Hz**	**5.8**	**5.0**	**3.5**	**3.9**	**3.4**
	median 0.1 Hz	**6.9**	**5.4**	**4.0**	**4.2**	**4.7**
	model	5.2	5.6	3.7	3.6	3.6
	target	5.6	5.6	3.3	3.5	3.5
Overall MS median at 100 % JFET yield	**median**	**0.47**	**0.48**	**0.40**	**0.45**	**0.48**
	perfect bolo	0.42	0.50	0.47	0.54	0.60
	goal	0.34	0.40	0.38	0.43	0.48
	guideline	< 0.26	< 0.31	0.22	0.26	0.29

PFM JFET Summary

Module		**PFM / Spectrometer**		**PFM / Photometer**					
#		**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Type		S/OE	S/OE	S/OE	S/OE	S/OE	S/OE/Perf	Perf	Perf
Noise [nV/rtHz]	**median**	**6.9**	**6.8**	**9.0**	**7.2**	**7.9**	**6.8**	**9.2**	**7.3**
	goal	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
	guideline	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
# Bad	**meas**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	goal	4	4	4	4	4	4	4	4
	guideline	11	11	11	11	11	11	11	11
Power	**meas**	**10.8**	**10.5**	**10.3**	**9.6**	**9.0**	**9.0**	**9.1**	**9.1**
	reqt	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0

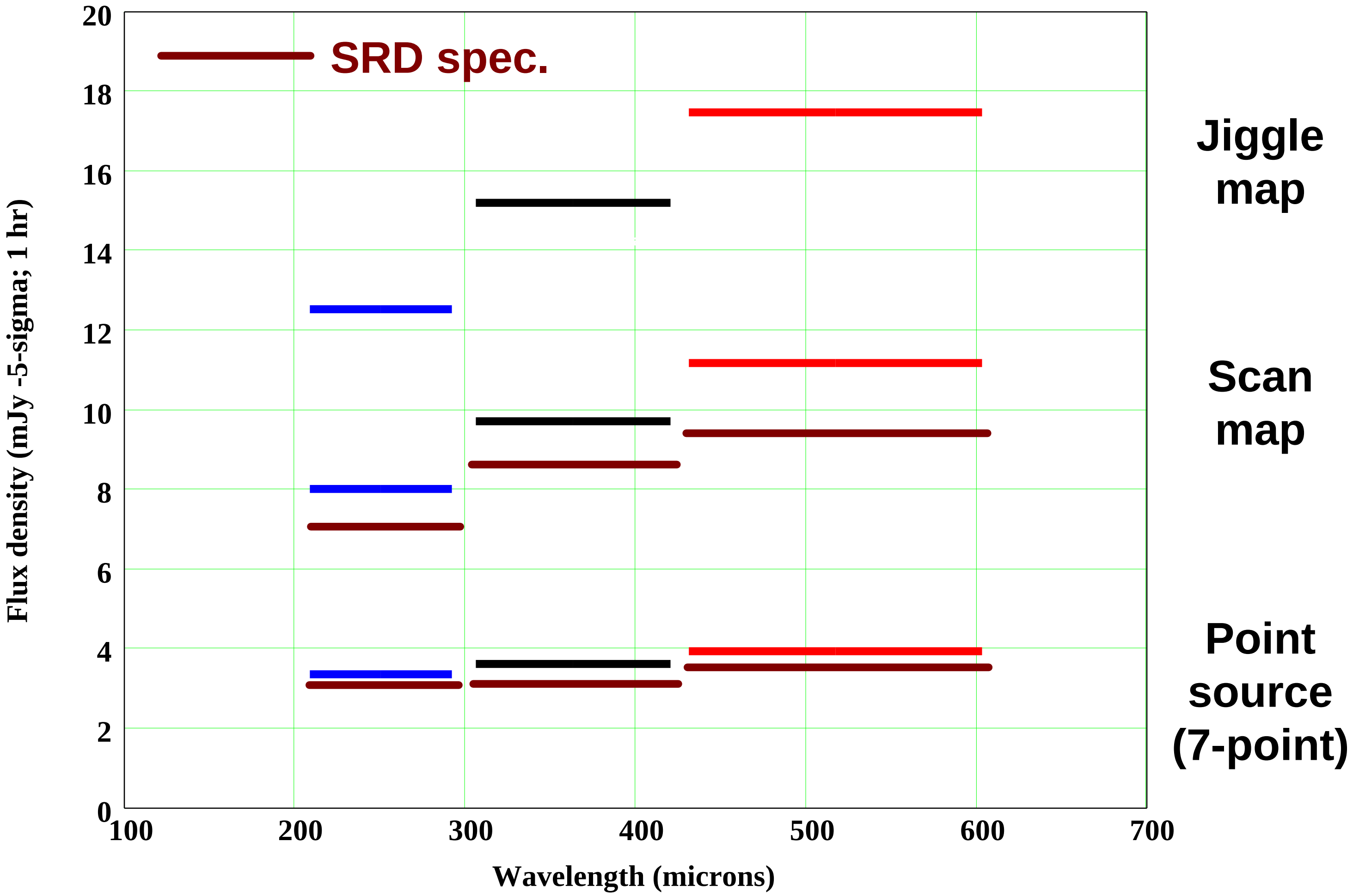
FS Bolometer Array Summary

Model Array		PFM S/LW	PFM S/SW	PFM P/LW	PFM P/MW	PFM P/SW
DQE	**median**	**0.64**	**0.74**			**0.73**
	goal	0.60	0.71	0.55	0.63	0.70
	guideline	0.50	0.59	0.46	0.53	0.59
h **(opt)**	**median**	**0.82**	**0.88**			**0.78**
	goal	0.70	0.70	0.85	0.85	0.85
	guideline	-	-	0.65	0.65	0.65
Yield (end-to-end)	# opt pixels	19	37	43	88	139
	# bad	1	0+4			2+4
	meas	**0.95**	**0.89**			**0.96**
	BDA goal	0.90	0.90	0.90	0.90	0.90
	BDA guideline	0.75	0.75	0.75	0.75	0.75
	JFET goal	0.90	0.90	0.90	0.90	0.90
t [ms]	**median**	**4**	**2**			**10**
	goal	4	4	18	13	11
	guideline	14	8	32	32	32
NEP(dark) [1e-17 W/rtHz]	**median 1 Hz**	**5.6**	**5.4**			**3.4**
	median 0.1 Hz	**6.8**	**8.1**			**4.7**
	model	5.5	5.7			3.7
	target	5.6	5.6	3.3	3.5	3.5
Overall MS median at 100 % JFET yield	**median**	**0.50**	**0.58**			**0.54**
	perfect bolo	0.42	0.50	0.47	0.54	0.60
	goal	0.34	0.40	0.38	0.43	0.48
	guideline	< 0.26	< 0.31	0.22	0.26	0.29

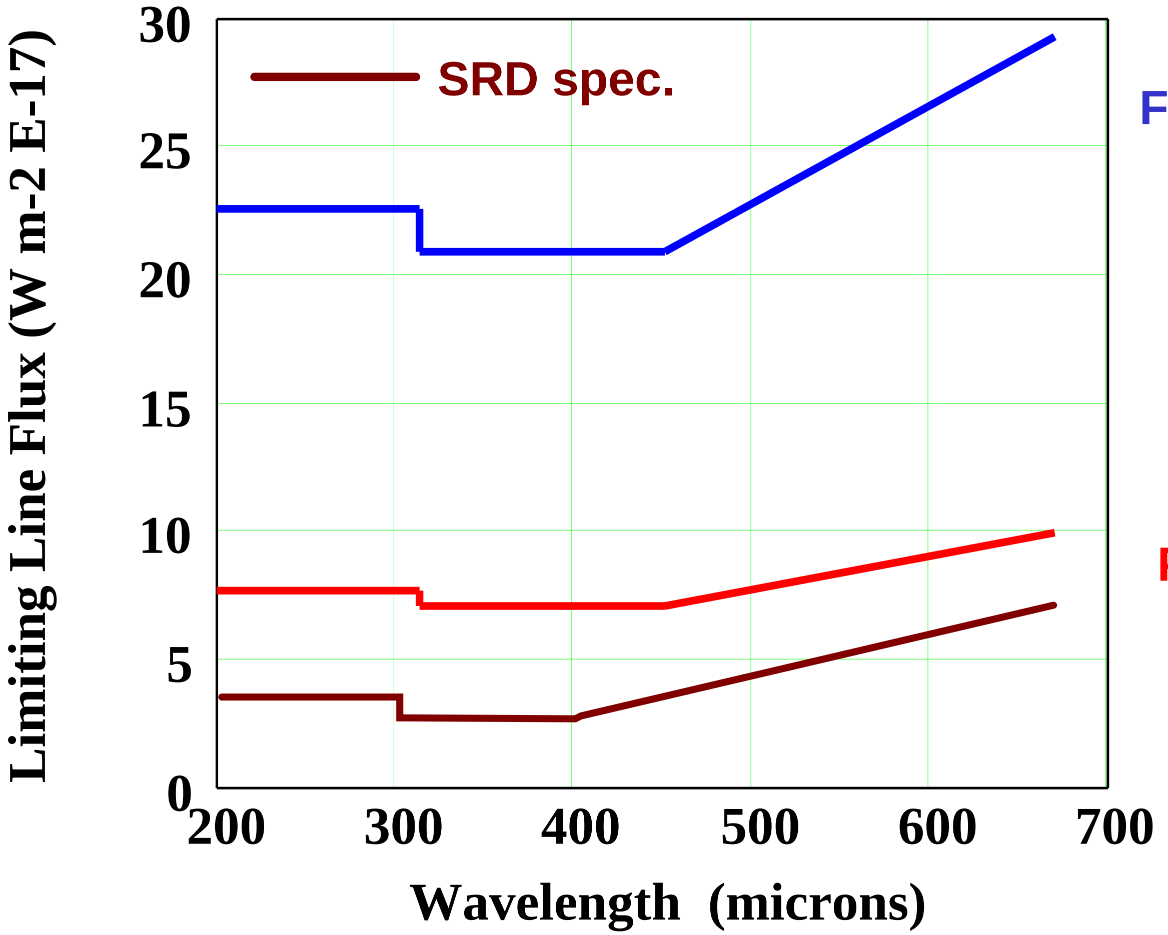
Instrument Sensitivity Summary

(Based on December 2004 Sensitivity Models Note)

Photometer (5σ-1hr; point source extraction)



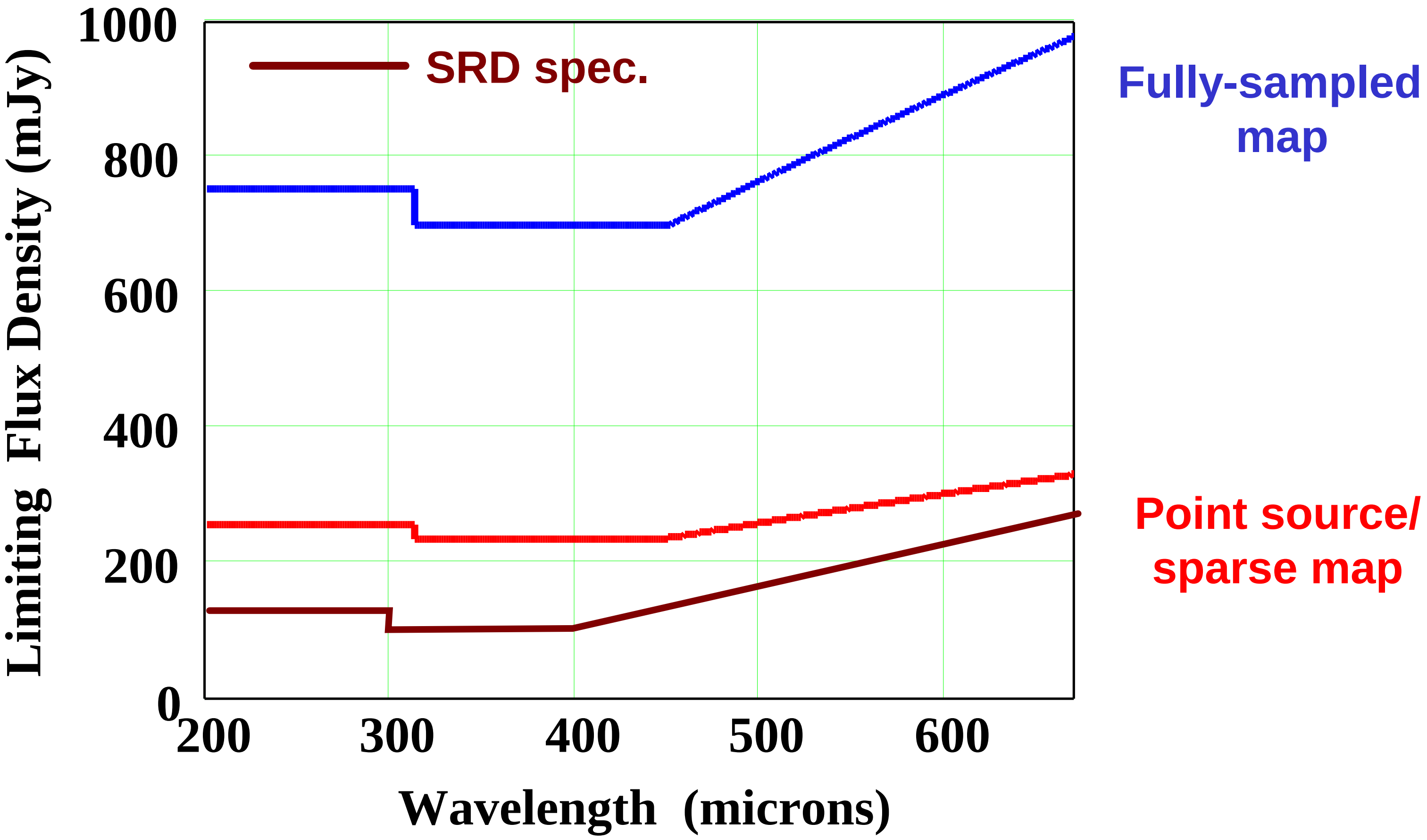
Line Spectroscopy (5s-1hr)



Fully-sampled map

Point source/ sparse map

Spectrophotometry (5s-1hr)



ESA Science Verification Reviews

- ESA Project Scientist (Göran Pilbratt) has proposed a series of Science Verification Reviews for the Herschel payload
- Proposal has been strongly endorsed by the Herschel Science Team
- Objectives:
  - Ensure adequate scientific performance: "meeting expectations"
  - Provide the best possible assessment of actual performance (before issue of AO for Key Programmes)
- Reviews will cover:
  - Science instrument performance
  - Telescope performance
  - Spacecraft performance directly relating to scientific performance

1. CQM ILT/EQM & FM ILT Preparation Review

- **Timeframe: October 2005**
- **Objectives:**
  - **Take stock of results from**
    - **CQM ILT (actions from IQRs)**
    - **Herschel system-level (EQM) tests (planned for Sept. 2005)**
  - **Identify and confirm FM ILT requirements**
    - **Agree on the FM ILT plan**
      - ***SPIRE FM ILT already underway, but we need the review to plan the last phases***
    - **Ensure nothing missed**
    - **Provide a set of agreed essential measurements**
    - **Assess predicted in-flight performance**
    - **Feed into draft AO preparations**

2. FM ILT Pre-Completion Review

- Timeframe:
  - Towards end of FM ILT (Q2 2006?)
  - Before issuing the Key Project AO

- Objectives:
  - Take stock of preliminary results from FM ILT
    - Has everything been achieved?
  - Go/no-go decision on completion of FM ILT (last chance to make lab measurements)
  - Assess predicted in-flight performance
  - Update AO documentation and tools with latest information

3. Instrument Performance Review

- **Timeframe:**
  - **After proper digestion of FM ILT results (Q3/Q4 2006)**
- **Objectives**
  - **Take stock of results from FM ILT**
  - **Assess in-flight performance estimates**
  - **Feed results into**
    - **Flight Acceptance Review**
    - **Herschel Performance Review**
    - **Flight Readiness Review**
    - **Operations preparation**

Conclusions

- The current scientific performance predictions are basically compatible with what was proposed
  - No descopes in science capabilities
  - Key goal performance levels have been achieved
    - FTS resolution (nearly)
    - Photometer field of view
  - Subsystem performance generally to spec.
  - FTS performance not as good as originally proposed
    - Raw sensitivity (modelling needs further review)
    - Channel fringing may degrade maximum resolution and will complicate data analysis
      - Project decision not to fix the problem (too risky)
    - But overall mechanism performance is regarded as very good

Conclusions

- **But:**
  - **Many aspects remain to be verified by ILT**

  - **The SRD requirements are not the full story: we need to**
    - **Itemise performance with respect to the full list of IRD requirements**
    - **Take into account other factors (e.g., telescope emissivity, pointing performance, overheads)**

- **In the cycle of Science Verification Reviews, we will cover all aspects formally and in more detail.**

Next Steps

- **Incorporate explicit detector and instrument performance and properties into sensitivity model**
- **Assess impact of FTS channel fringing on FTS high-resolution spectroscopy**
- **Optimise observing modes in the context of actual instrument performance**
- ***SPIRE Sensitivity Models*: issued Dec. 2004 for review**
  - **Few comments received, although thoroughly reviewed by Tim Waskett and Bruce Sibthorpe**
  - **Question over FTS theoretical sensitivity – currently under review by David Naylor**
- **Sensitivity estimates will be updated for the October Science Verification Review (following review of all data after the PFM 2 campaign)**

Next Steps

- Instrument simulators will be enhanced with details of actual instrument performance
- For science programme preparation:
  - No change for now to the “official” sensitivity figures
  - Programmes should not be scientifically vulnerable to changes in instrument sensitivity
- Compile comprehensive summary of performance wrt IRD reqs. and plan for Phase 1 of SVR

Some Points Raised in Discussion

- Optics
  - Important to verify SPIRE illumination pattern on the secondary
  - Many more tests needed to evaluate beam profiles across the arrays
  - Important to understand the FTS multimoding
    - Beam profiles
    - Signal and background coupling to detectors

- Load curves and noise analysis
  - Dedicated measurement programme needed to optimise bias frequency and sampling rate

- FTS
  - Channel fringing is a problem
  - 1 cm^{-1} is about optimum for low-resolution spectrophotometry
  - Potential to increase FTS throughput by improving rooftop surface

PACS Bolometer Focal Plane current status

SAp team

SPIRE Co-I meeting
Pasadena
July 19 - 21, 2005

Blue Flight BFP

All (8) 16*16 px sub arrays sorted out to populate the Blue BFP are extracted from one wafer only.

These detectors, received between July 2004 and May 2005, were not all tested in the same conditions:

different electronics: off the shelf and flight like
a lot was learnt from the detectors in between

performance quoted for each detectors are indicative only.

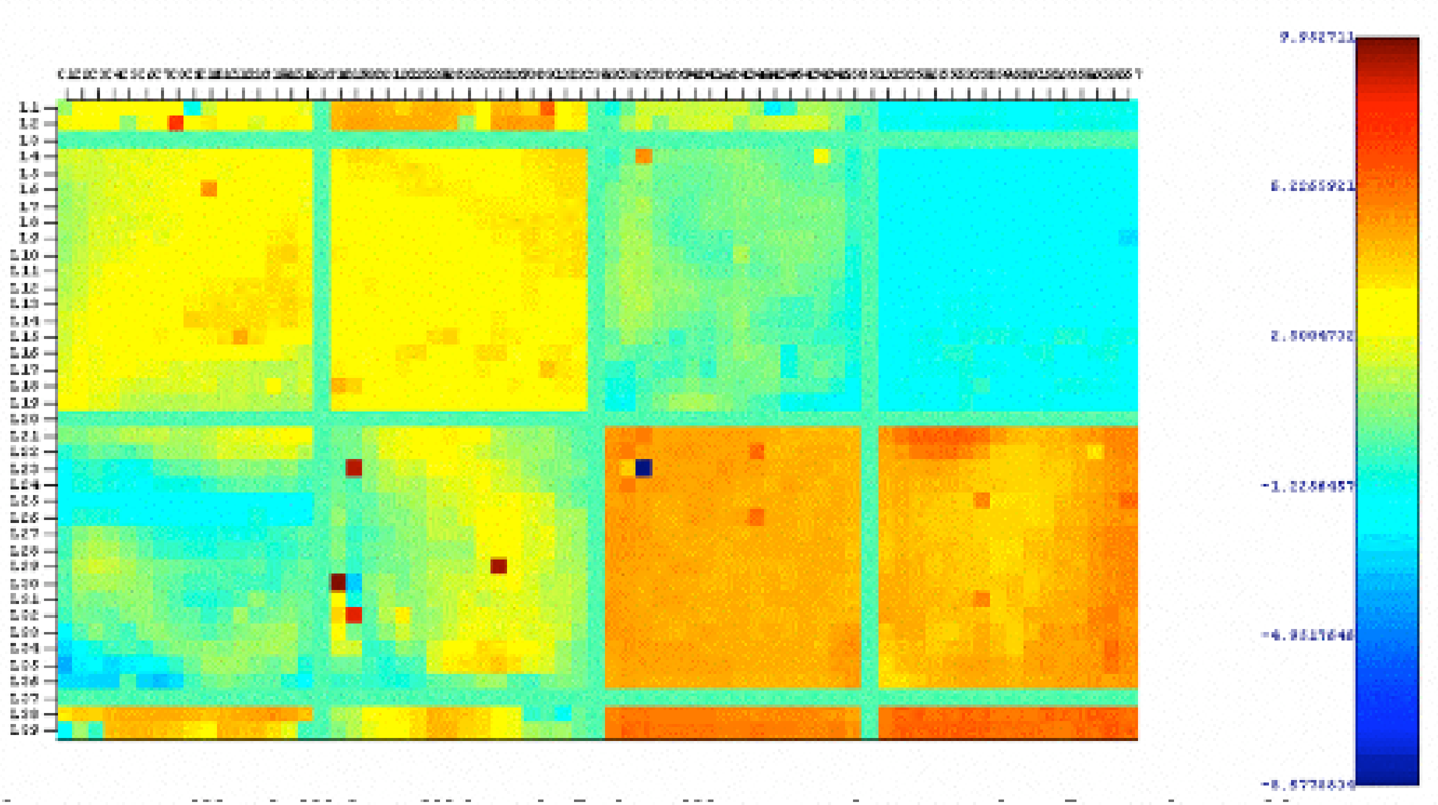
The blue BFP is now mounted in the test cryostat at Saclay and cooled 15-17 July.

We are starting measurements 3rd week of July in the final configuration (8 arrays working at the same time).

FM Status

Composite image of the tested arrays "as mounted”

Array cosmetic is very good (1 to 6 dead.px/ sub-array, 24 in total)

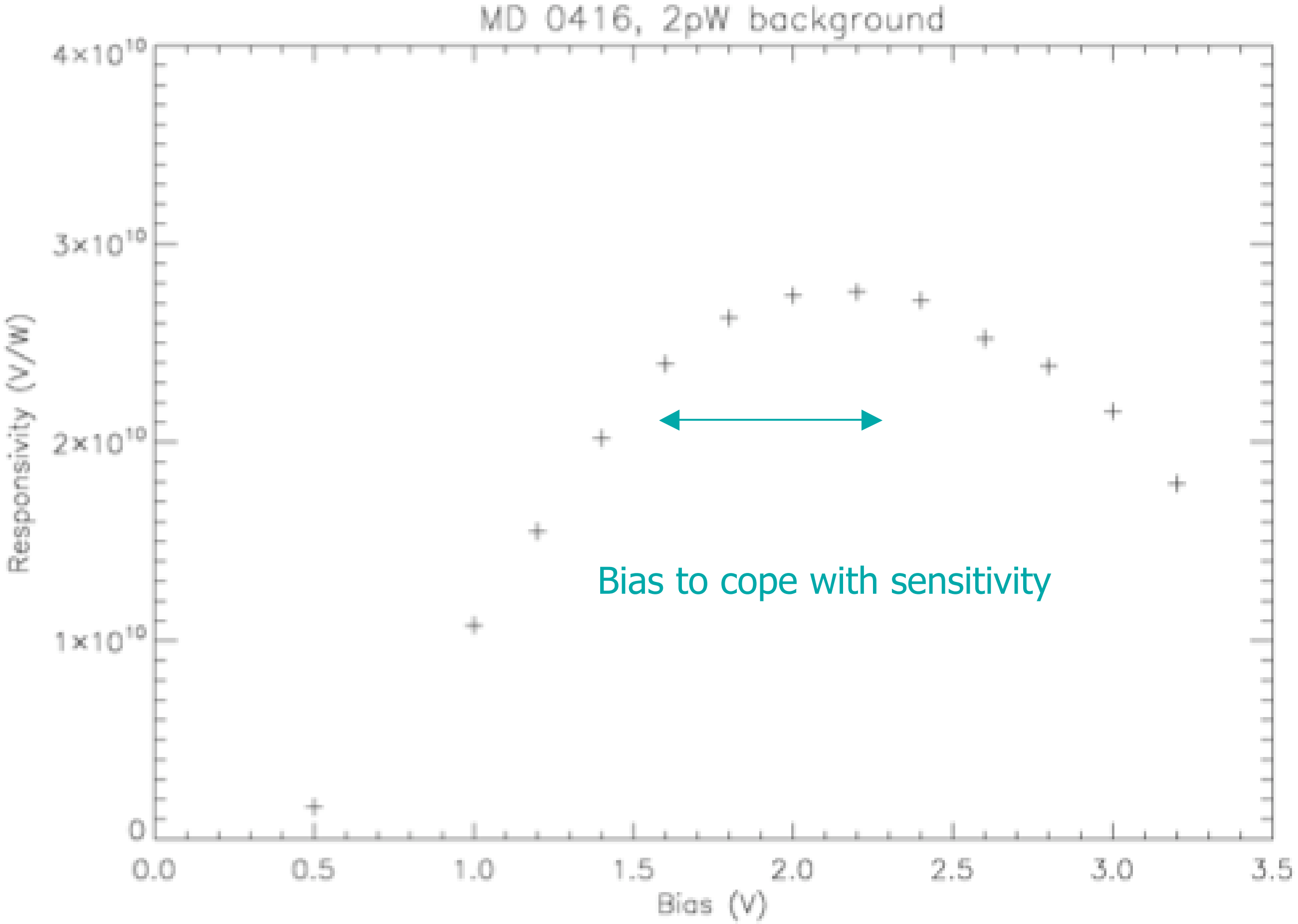


Detector signal amplitude

including continuum

Red BFP sub arrays (2 only) have been sorted at CEA saclay

FM Summary of results: Response



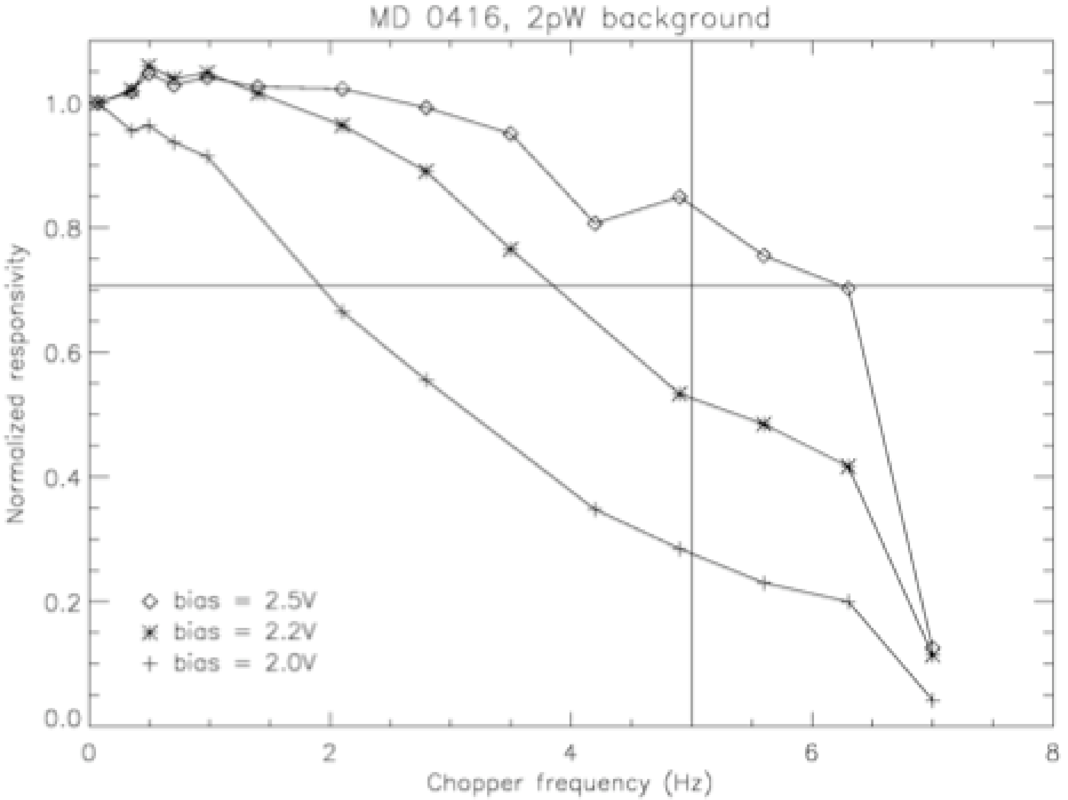
Bias to cope with sensitivity

Response ≈ 3 10^{10} V/W

FM Summary of results: Bandwidth

Bolometers in these arrays are still rather impedants.

→ Response hampered by a cut in bandwidth (2 Hz)

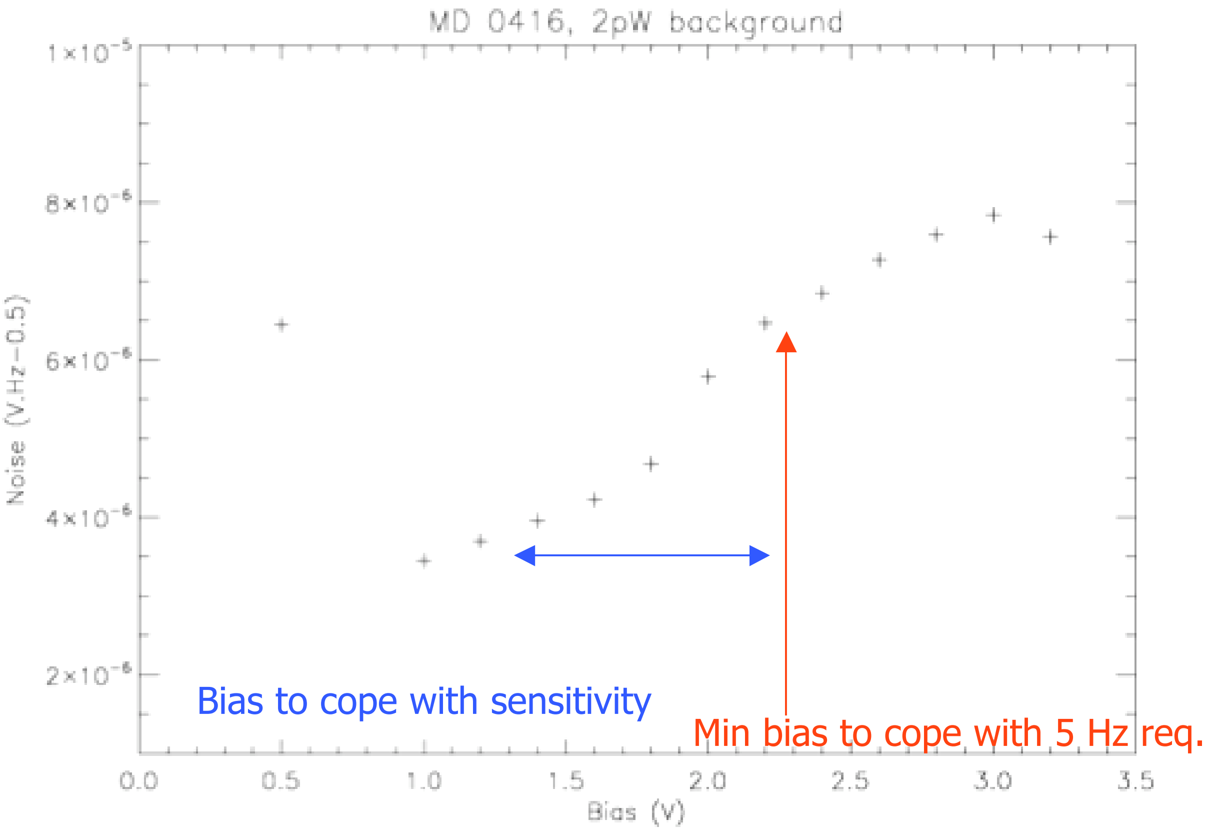


At 2pW/pix BKGD

FM Summary of results: Noise

This can be overcome by 50% overbias… at the cost of x 2 in noise.

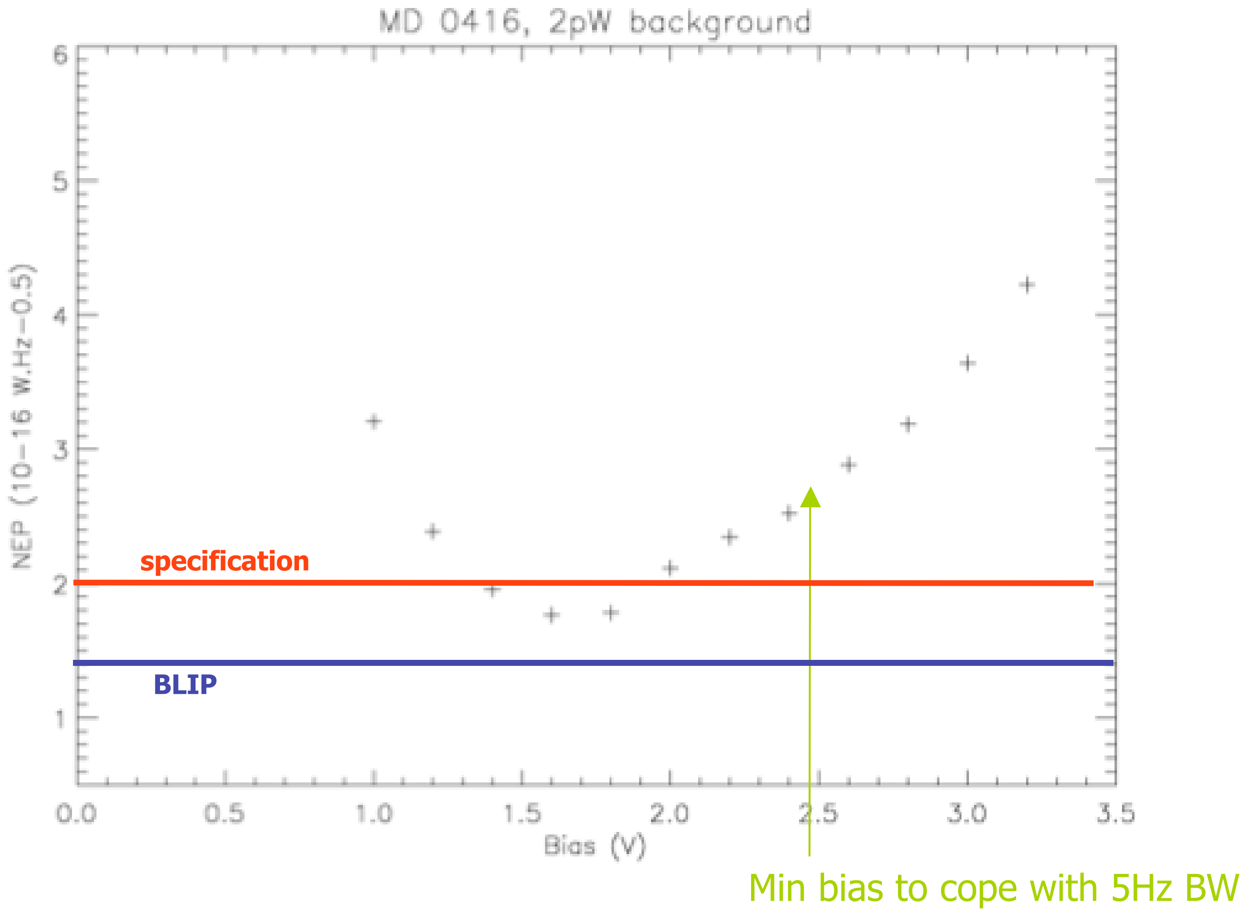
Noise density



Bias to cope with sensitivity

Min bias to cope with 5 Hz req.

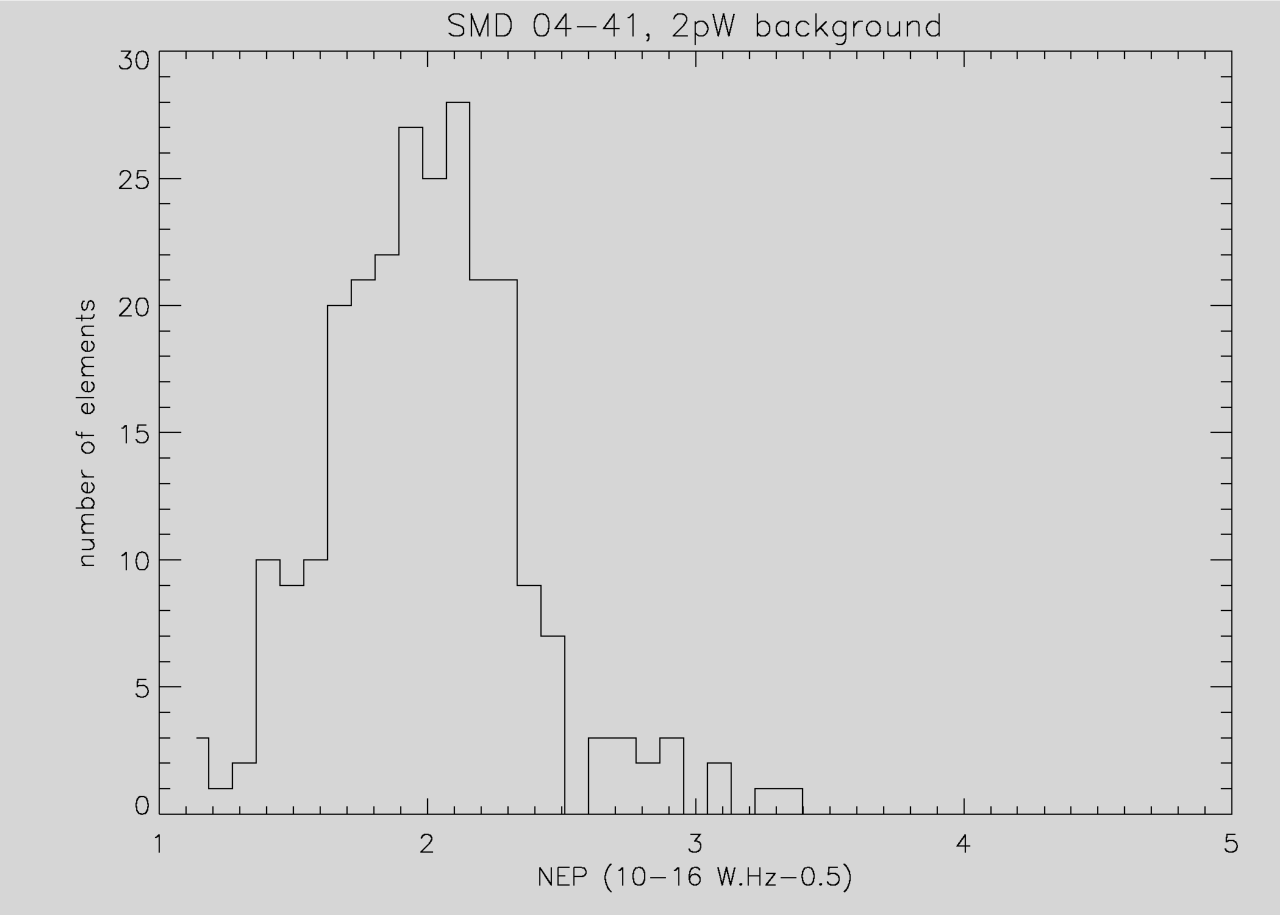
FM Summary of results: Sensitivity



Two operating modes can be envisaged:

→ High sensitivity (but slow) for faint sources,
→ Low sensitivity (> 5Hz) for large bright structures.

noise distribution (overbias) in a sub array

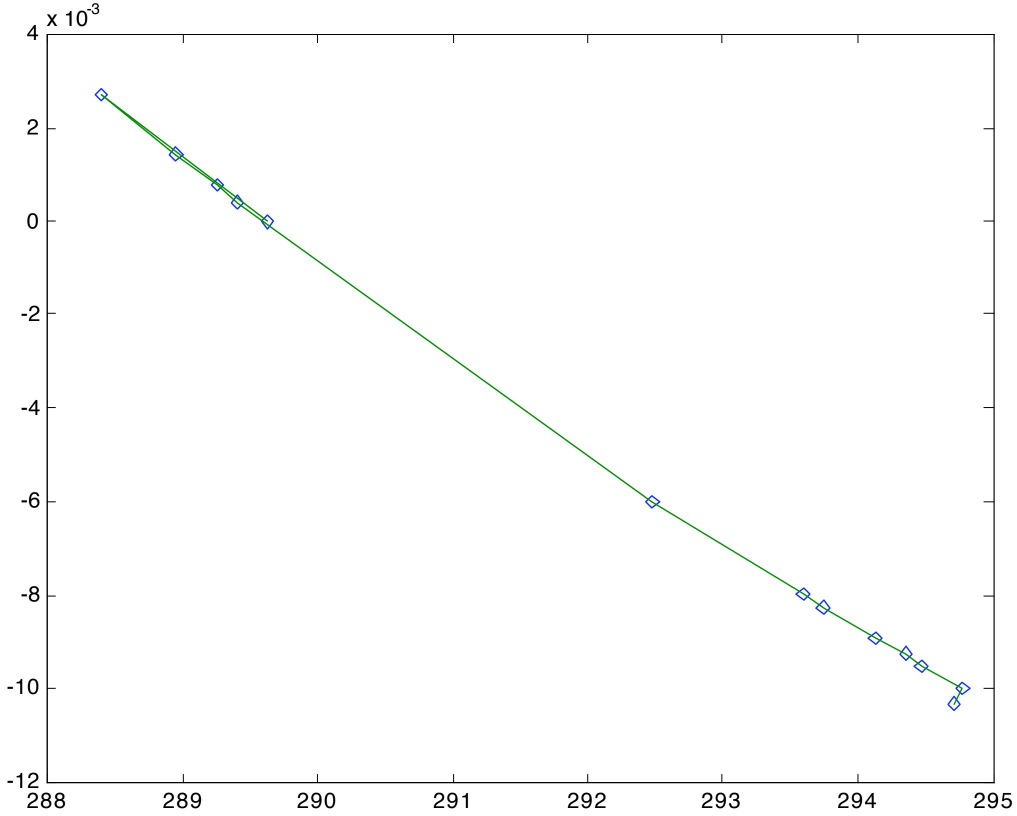


Low frequency drifts

Measurements overnight (12 hours)

==> Show that drifts are strongly correlated with cryocooler cold tip variations

Offset (V)

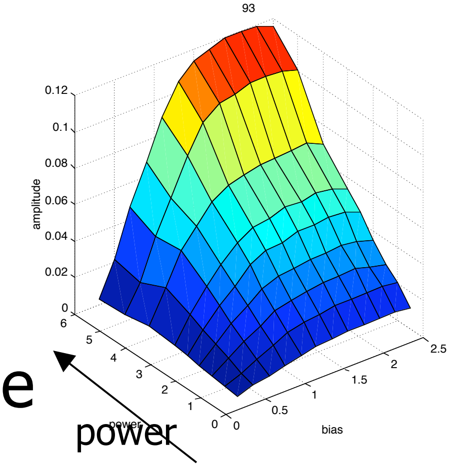


Température (mK)

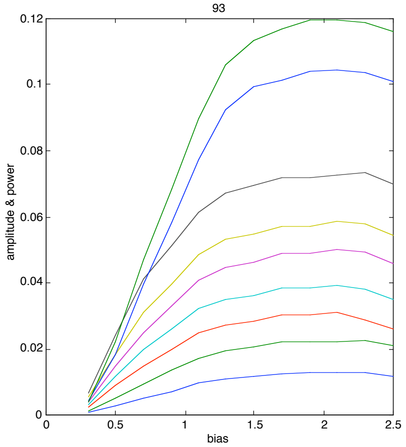
Variations with flux

How behaves the detectors with increasing flux?   Here 0.5--> 6 pW

For the response



power



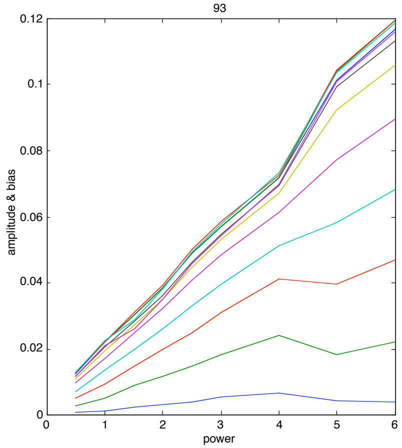
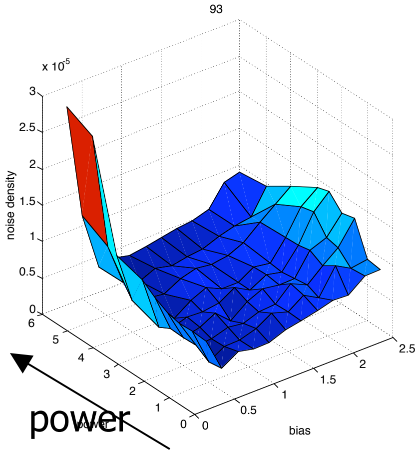
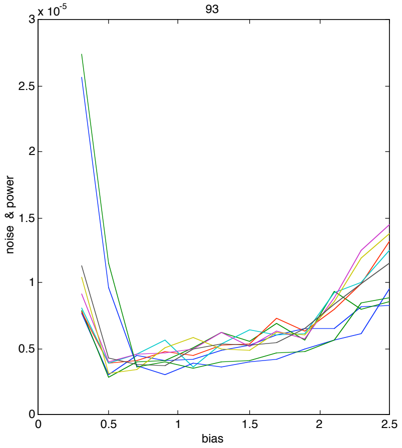


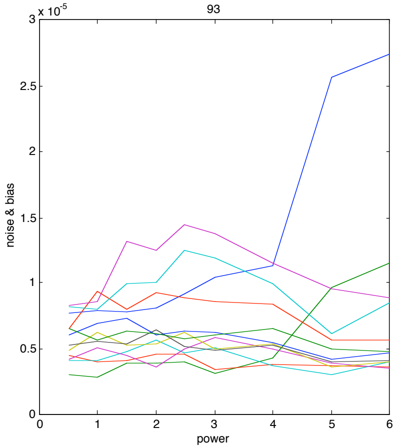
Figure shows that detectors are not saturated up to 6 pW

For the noise



power

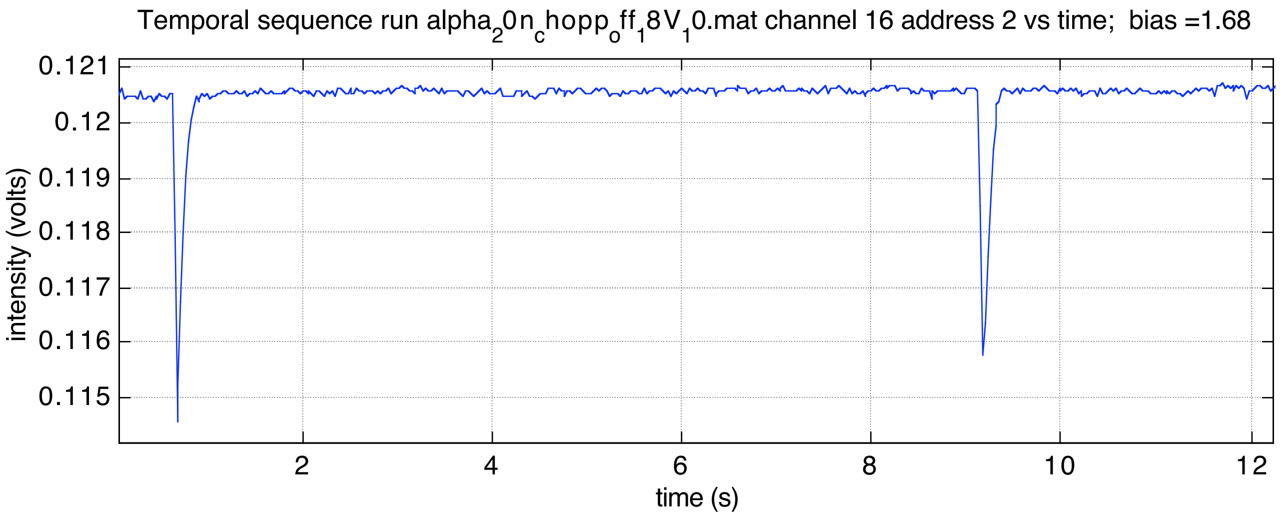




Other measurements

Behaviour of the detectors with ionizing particles
Protons irradiations made in June 2004.

New campaign in May 2005:
Protons and alpha particles at the Orsay Tandem



Detectors recover within 10 frames (40 Hz), the largest alpha impacts