PACS Calibration Status and Plans

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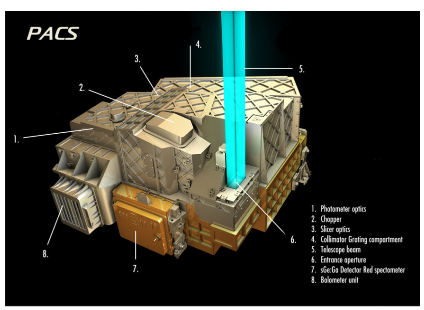
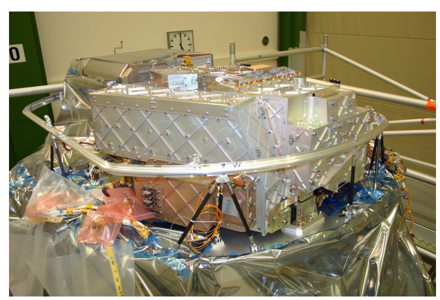
Jürgen Schreiber (MPIA), Bart Vandenbussche (KUL) and Roland Vavrek (ESAC)

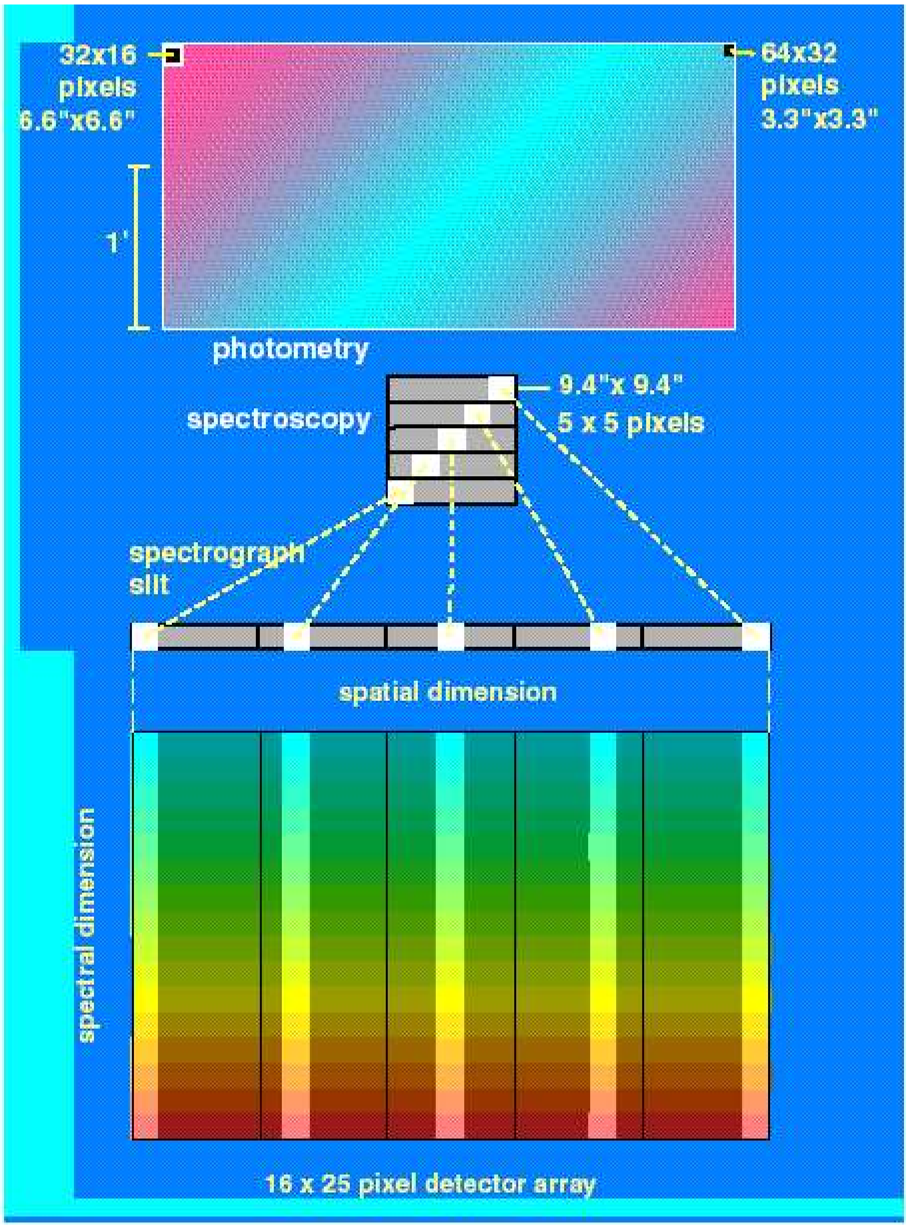
Herschel Space Observatory Calibration Workshop #2

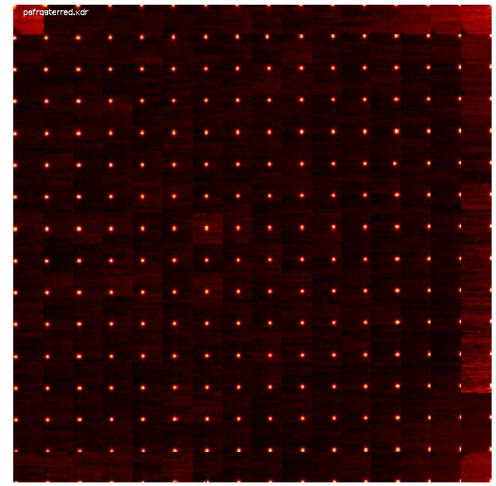
06 – 08 February 2008, CSIC, Madrid, Spain



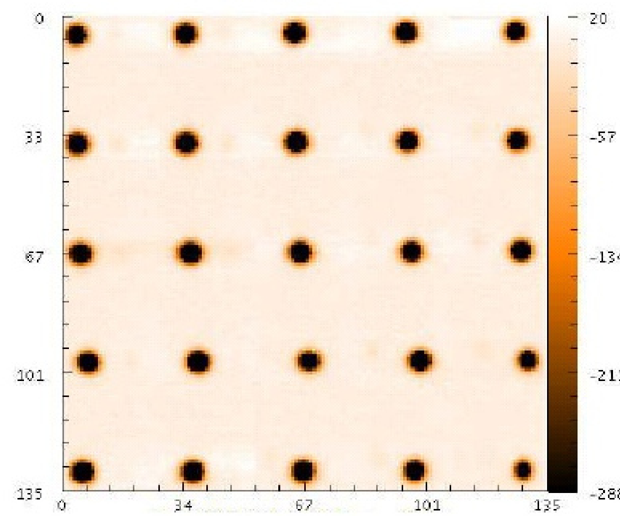


PACS = Photodetector Array Camera & Spectrometer





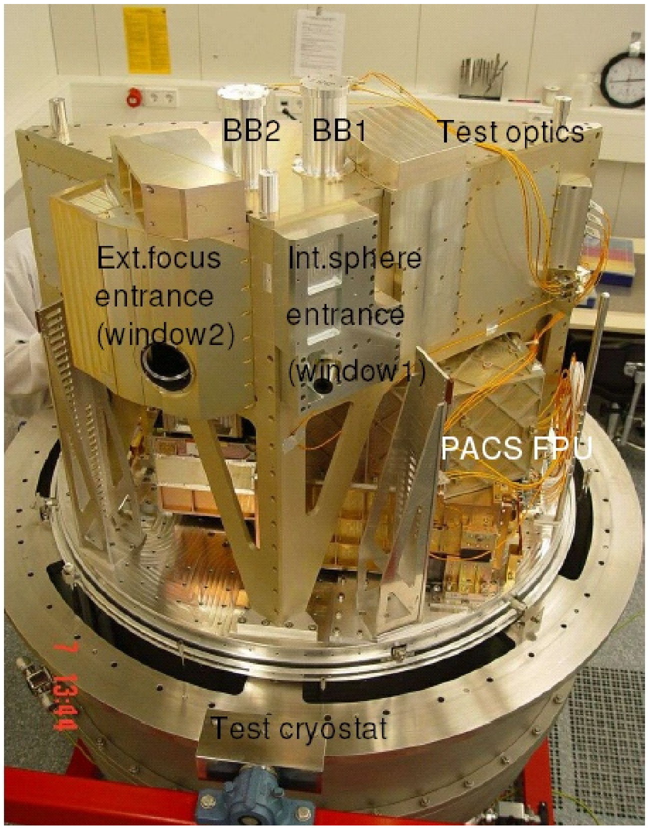
FIR bolometer arrays: 60, 110, 160 μm
32 $\times$ 64 pixels (blue), 16 $\times$ 32 pixels (red)



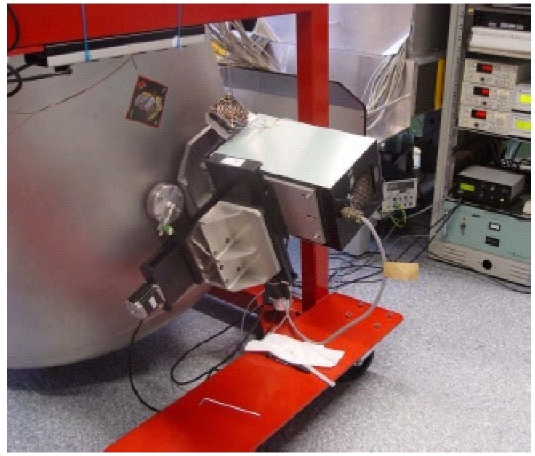
FIR integral field spectrometer : 55 $-$ 210 μm
5 $\times$ 5 spatial pixels $\times$ 16 pixels (λ)

Overview of PACS Calibration Status from Ground Integrated Level Tests

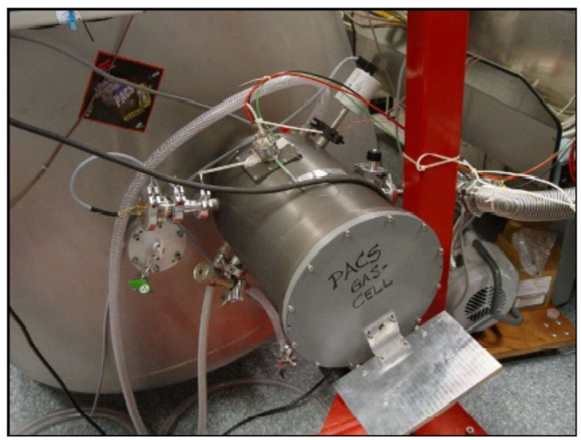
Ground Calibrators



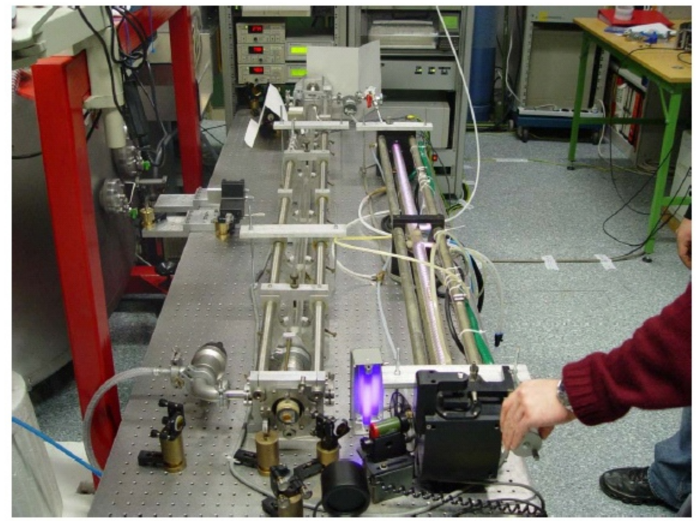
test optics
with internal cold (10 – 50 K) BBs
extended illumination



external hot BB (1000 K)
with hole mask and
x-y-raster stage



gas absorption cells

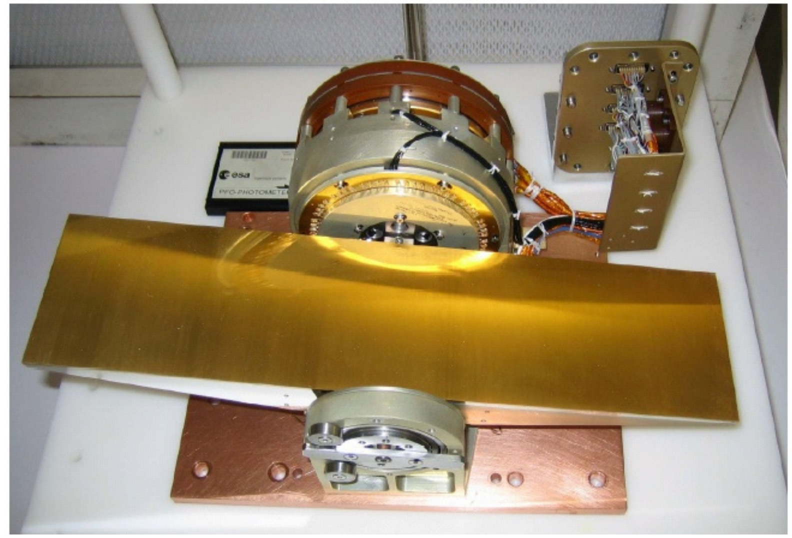


FIR laser

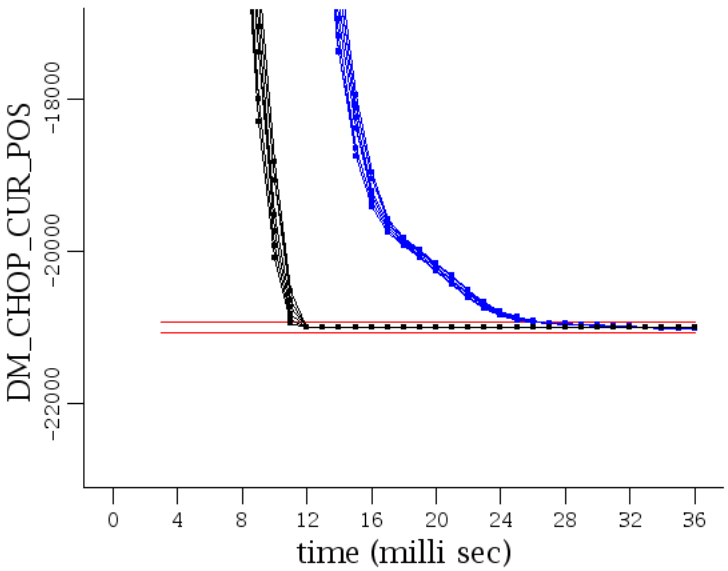
detailed instrument characterisation during 3 cold test runs Nov. 2006 – June 2007

Mechanism Calibration and Performance Optimisation

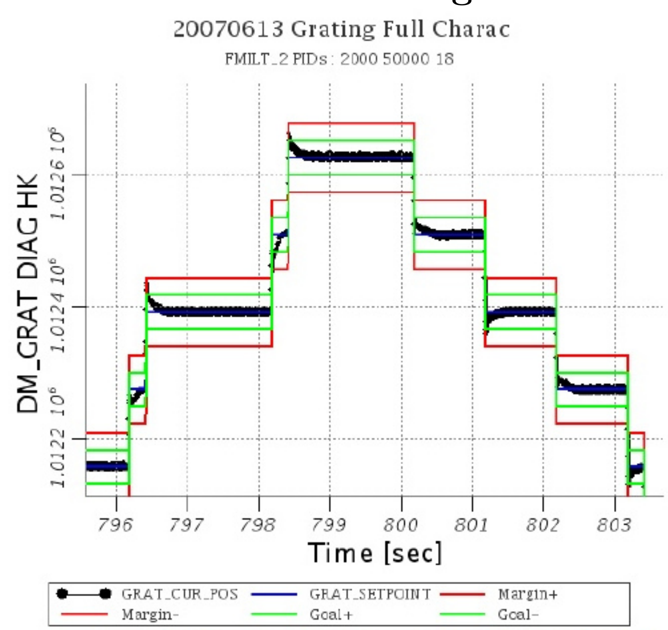
PACS Chopper



PACS Grating

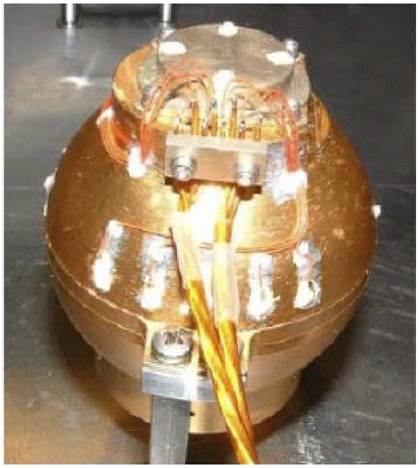


Chopper duty cycle optimisation & angle calibration

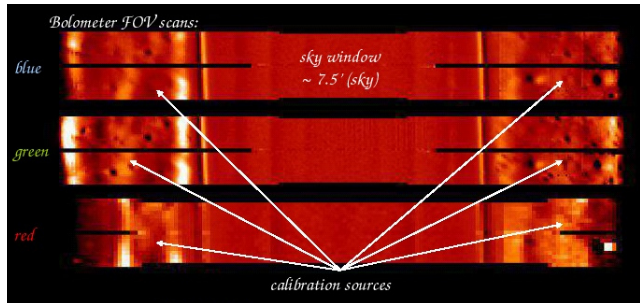


Grating positioning & stabilisation

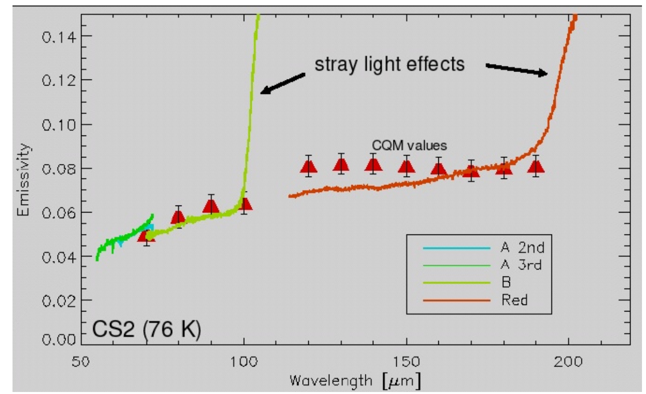
Characterisation of PACS Internal Calibration Sources



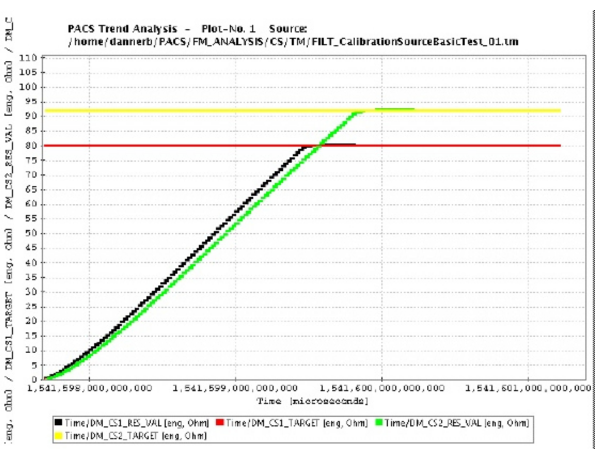
PACS Calibration Sources (2)



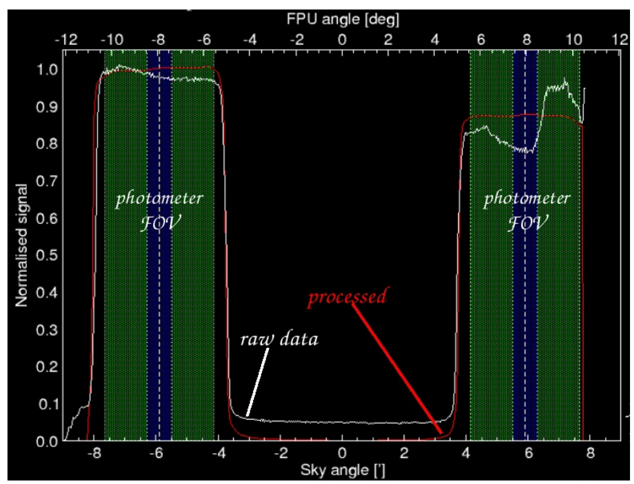
CS homogeneity of emission



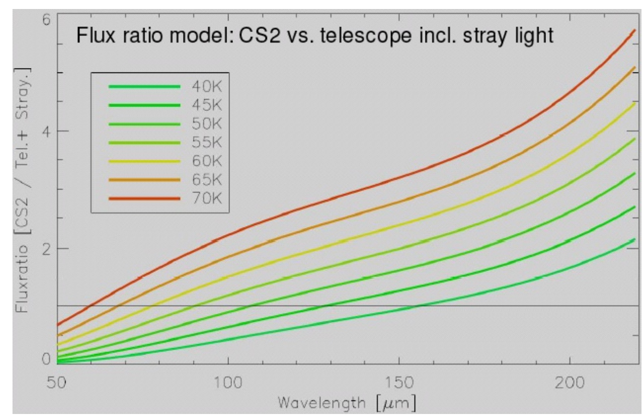
CS emissivity



CS heat-up & temperature stability

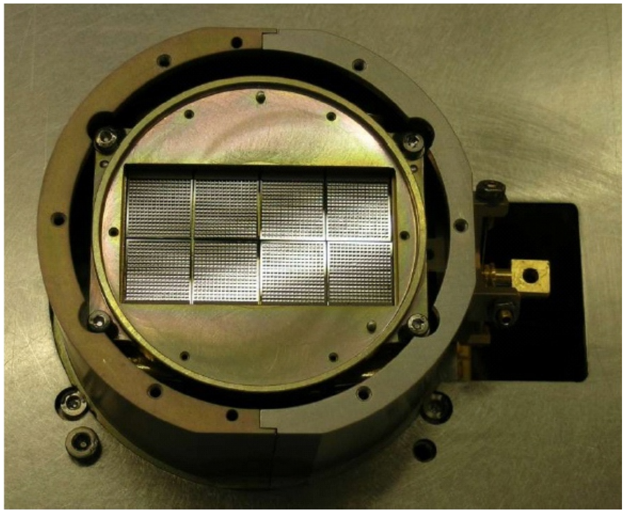


CS optimum position on arrays

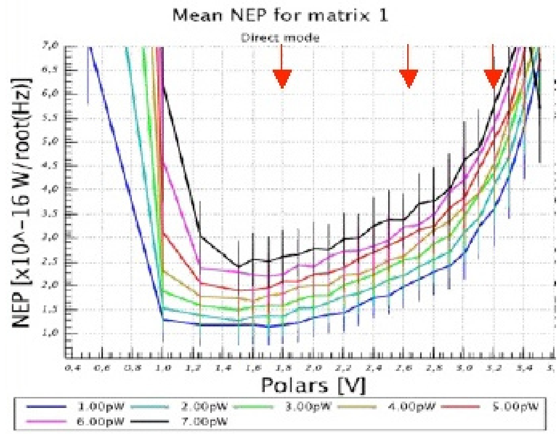


CS tuning to final telescope emission (ε, T)

Characterisation of PACS Photometer Bolometer Arrays

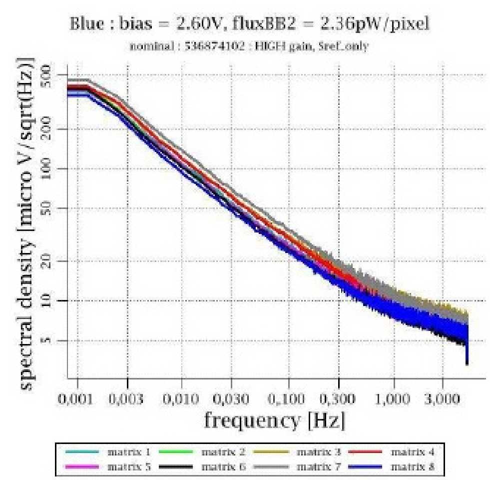


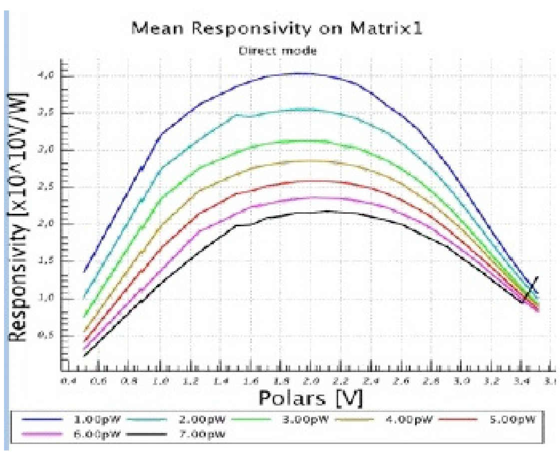
PACS Bolometer Array (blue)



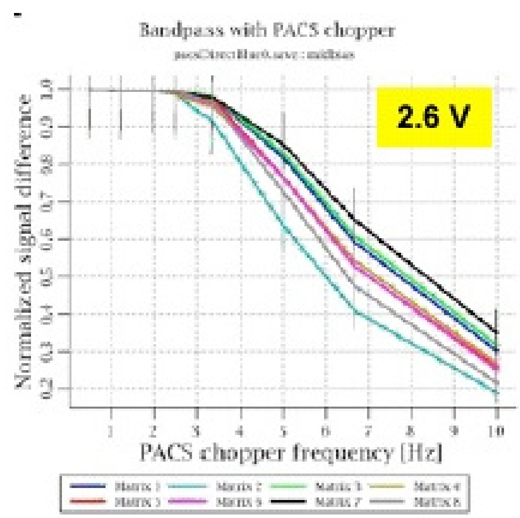
NEP optimisation
low and high gain adjustment

Direct mode



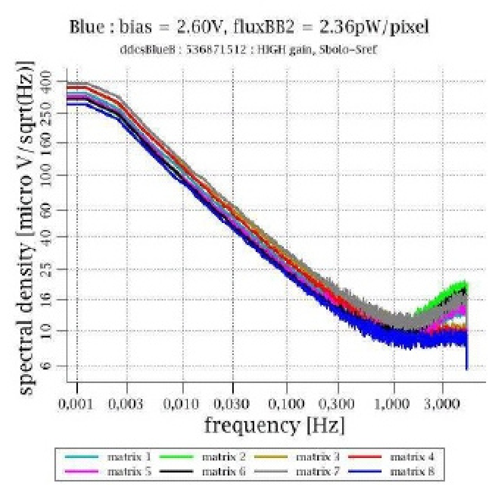


Responsivity dependence on bias & flux
Adjustment to expected background



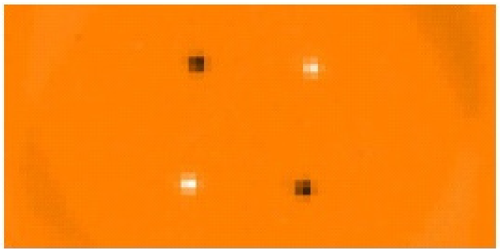
frequency response

DDCS mode

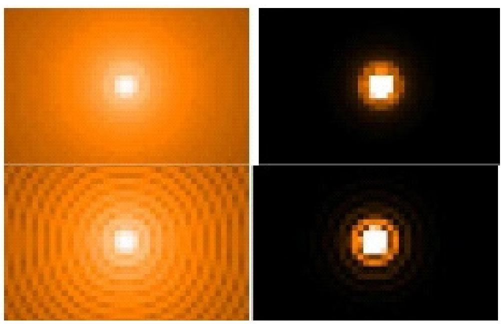


detector read-out mode

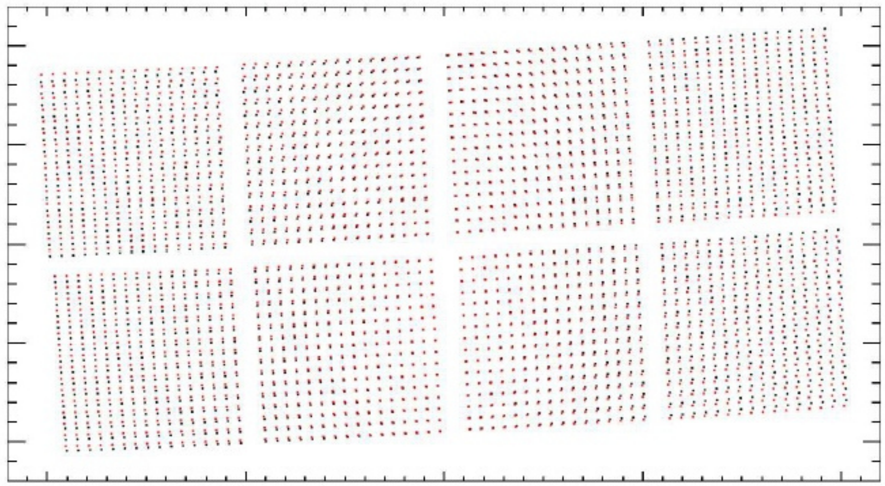
Photometer Spatial & Photometric Calibration



PSF measured
(chop & nod)

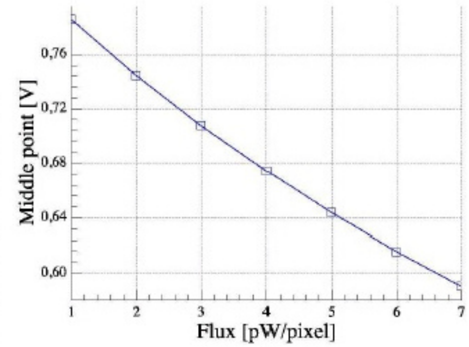


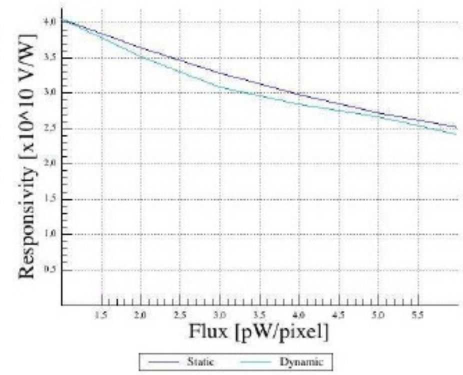
PSF simulated
(monochromatic &
broadband)



detector geometry & distortion

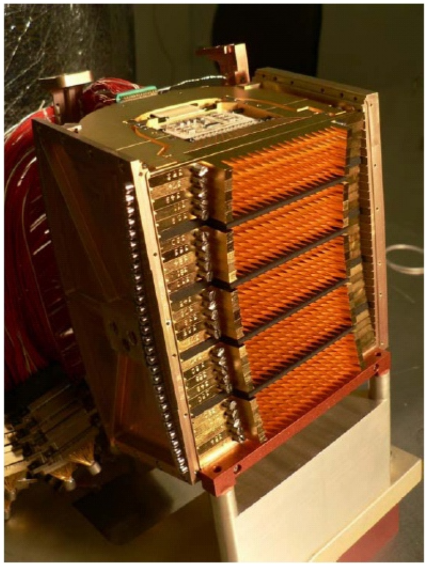
1% of responsivity loss for
0.1 pW/pixel 3 Jy/pixel



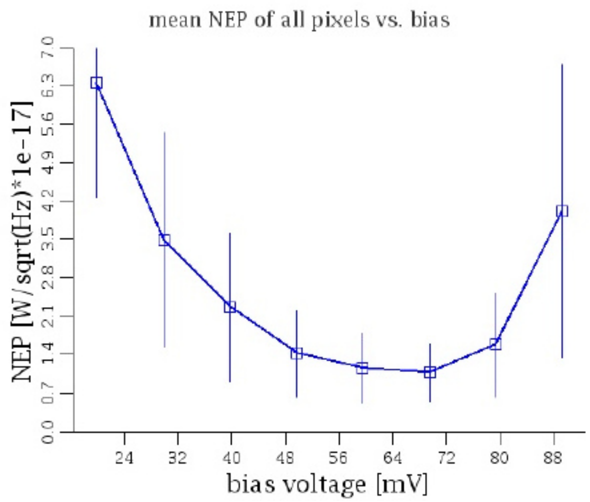


detector linearity with flux /
saturation

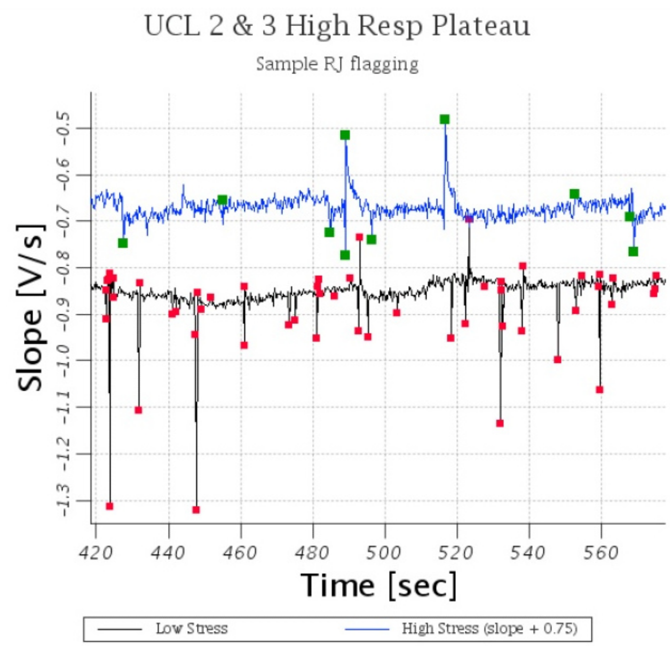
Characterisation of PACS Spectrometer Ge:Ga Photoconductor Arrays



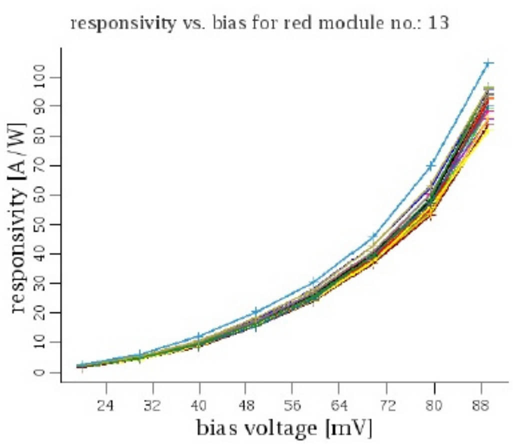
PACS Ge:Ga Array (high stress)



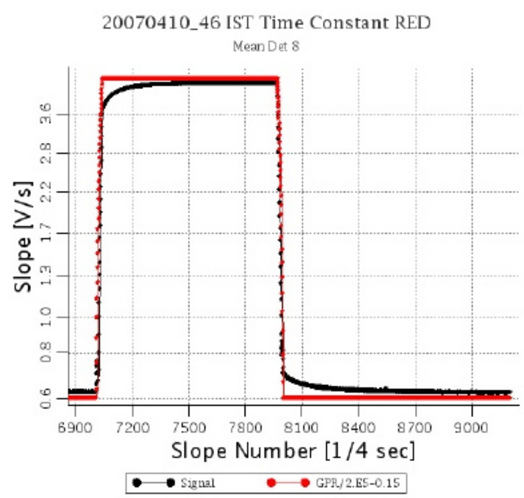
NEP optimisation



detector response to
ionising radiation glitches
(on module level)

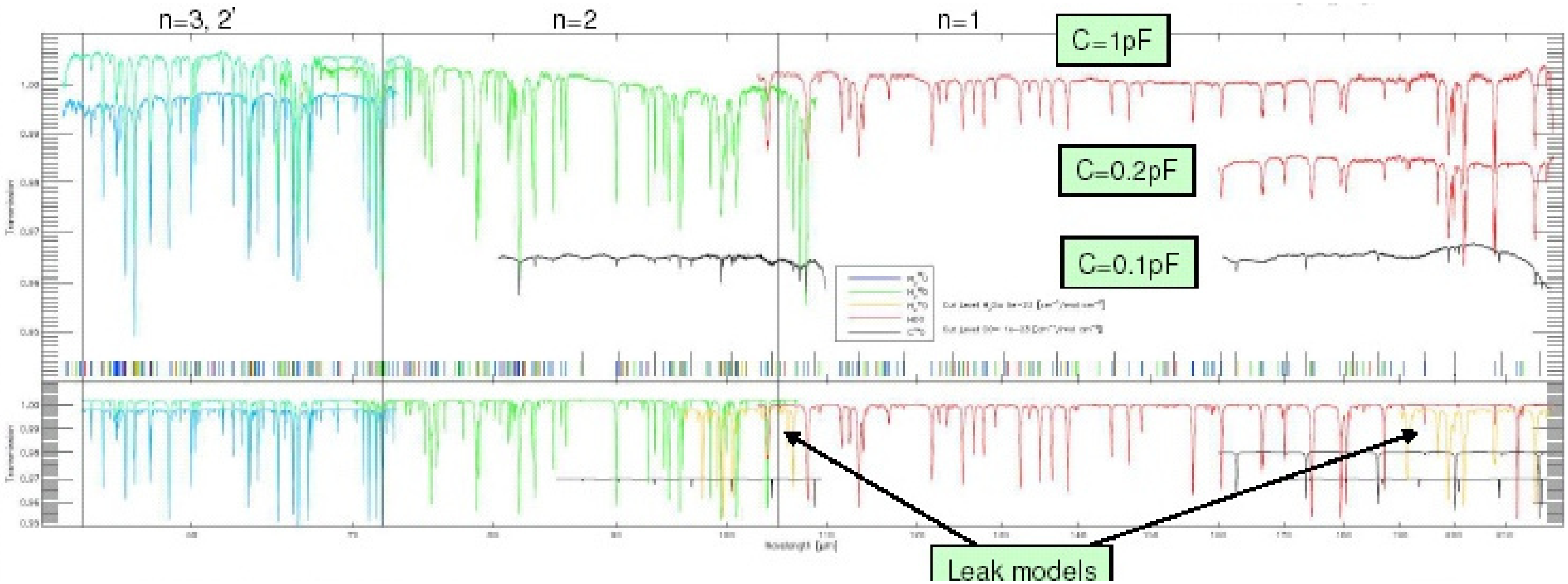


Responsivity dependence on bias

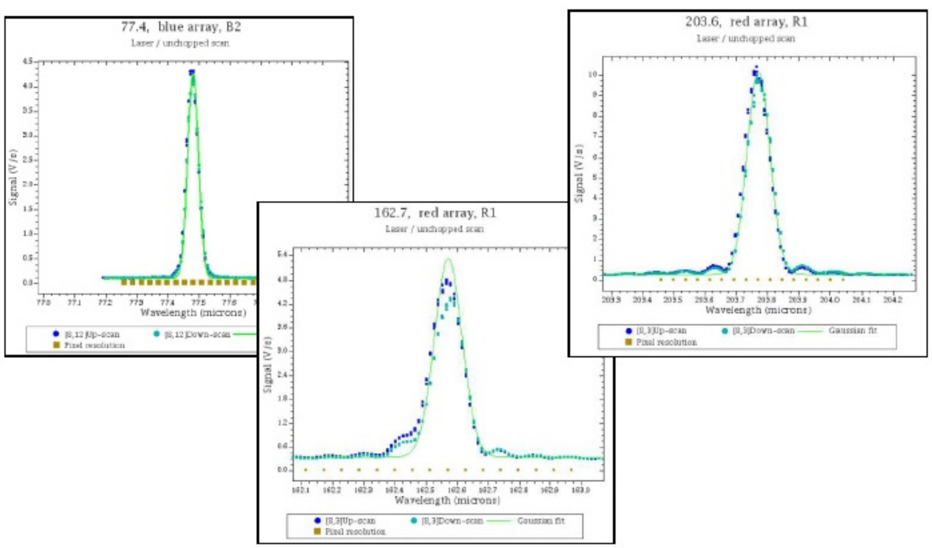


transient characterisation

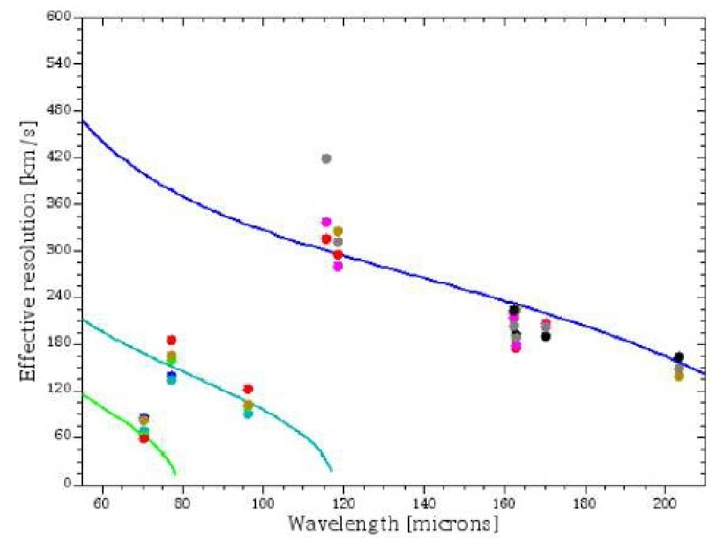
Spectrometer Wavelength Calibration & Spectral Resolution



Spectrometer wavelength calibration, all pixels & dependence on chopper angle

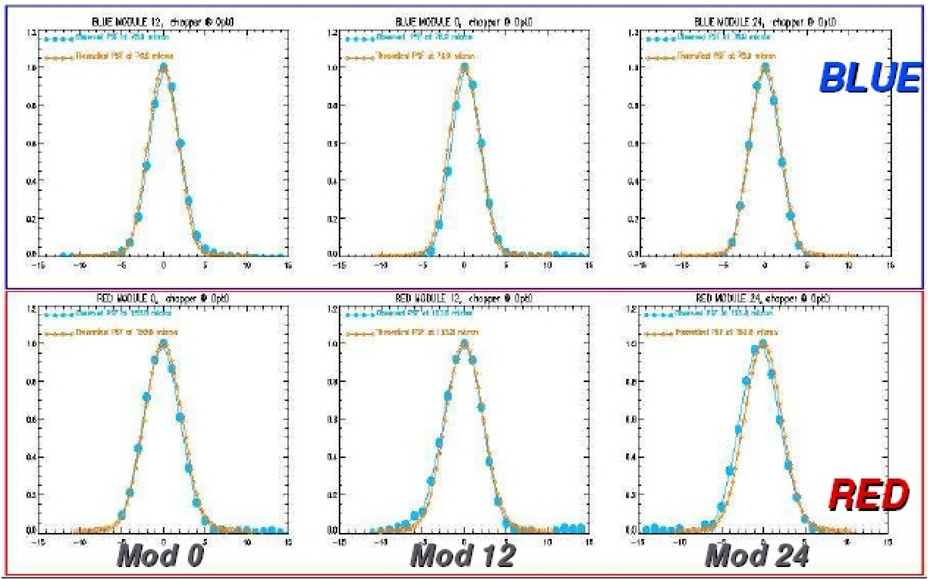


instrumental profile

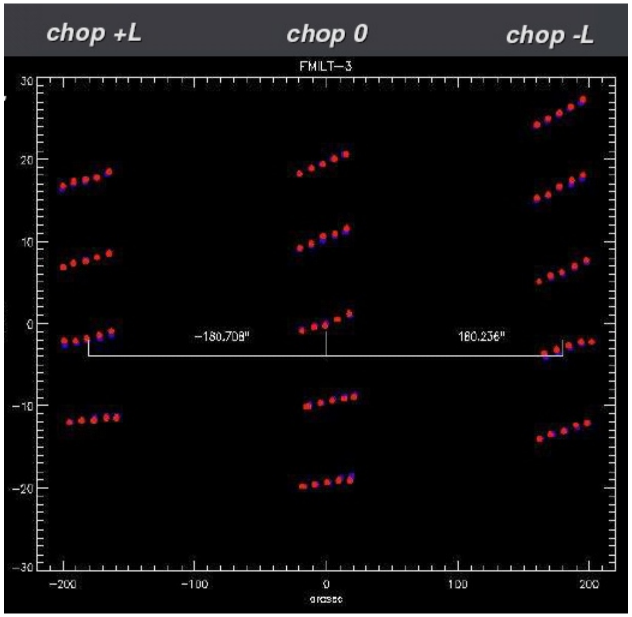


spectral resolution

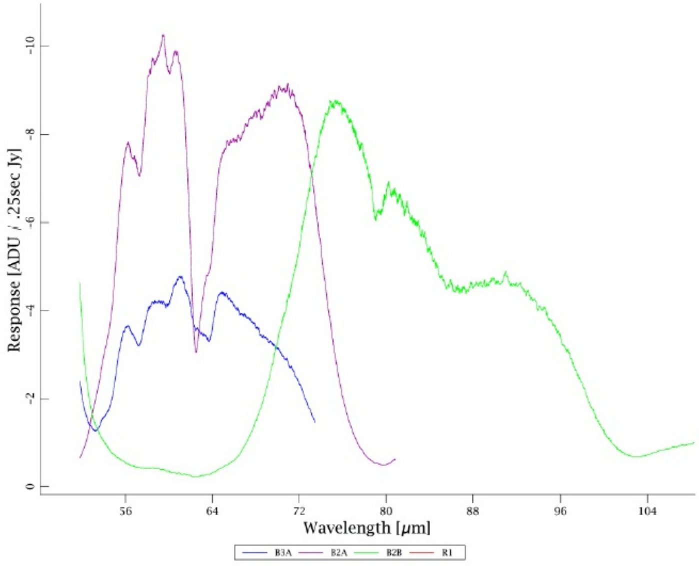
Spectrometer Spatial & Photometric Calibration



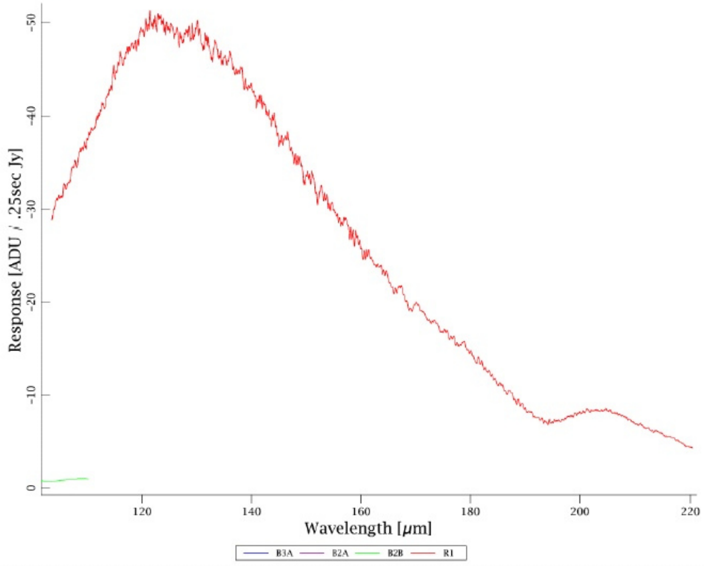
PSF measured versus modelled



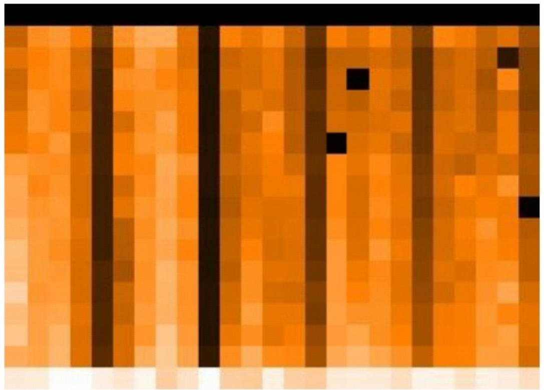
detector geometry & distortion



blue RSRF



red RSRF

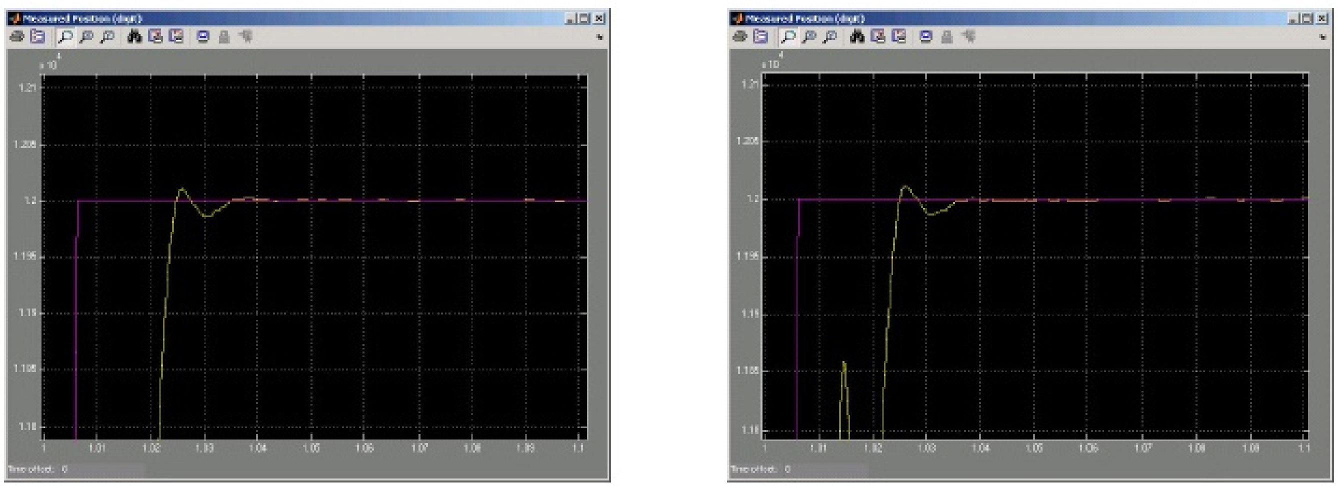


absolute flux calibration

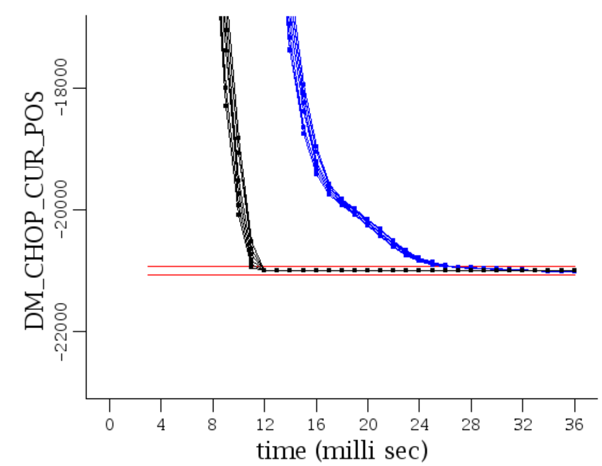
PACS Plans for Establishment of Baseline Calibration during Herschel Space Observatory Commissioning & Performance Verification Phases

Test Block "Control Loop Optimisation"

- contents
  - chopper control loop verification and possible optimisation
  - grating control loop verification and possible optimisation
- duration: 43 h
- phase: Commissioning
- telescope condition: cryo-cover still closed
- celestial standards: n/a
  (HouseKeeping investigation, partly R/T commanding & analysis)



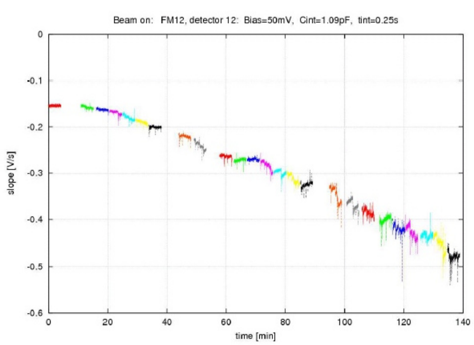
chopper simulation model - variation of PID parameters



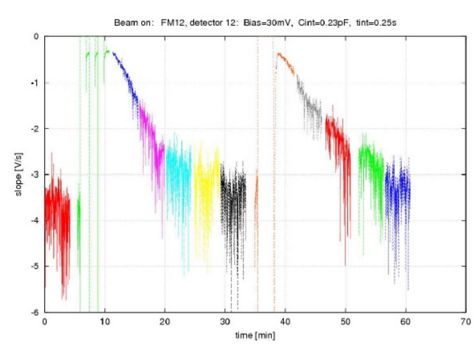
chopper duty cycle

Test Block “Ge:Ga detector set-ups and optimum operation”

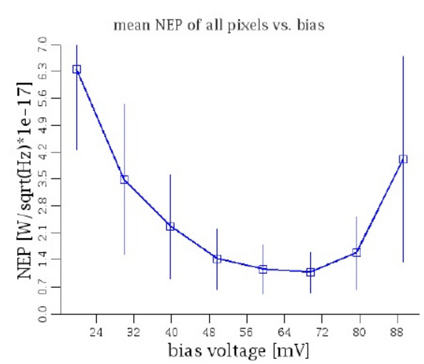
- contents
  - test reduced bias on responsivity plateau (equilibrium between ionising radiation and self-relaxation due to telescope background)
  - test reduced bias scenario with curing (frequency, flash length and strength, responsivity gradients per h)
  - optimum detector set-ups: RI, V_{bias}, $T_{det\,blue}$
  - raw ramp investigations / on-board compression algorithms
- duration: >40 h
- phase: Commissioning
- telescope condition: cryo-cover closed / cryo-cover open
- celestial standards: n/a
  (on internal calibration sources and telescope background blank field)



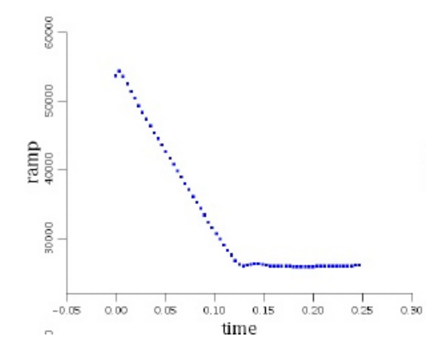
Ge:Ga responsivity increase by ionising irradiation



Ge:Ga responsivity plateau & curing effects



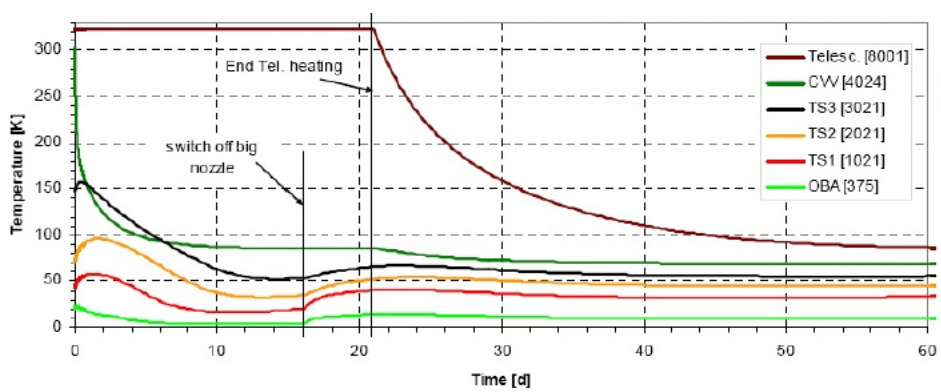
Ge:Ga NEP optimisation



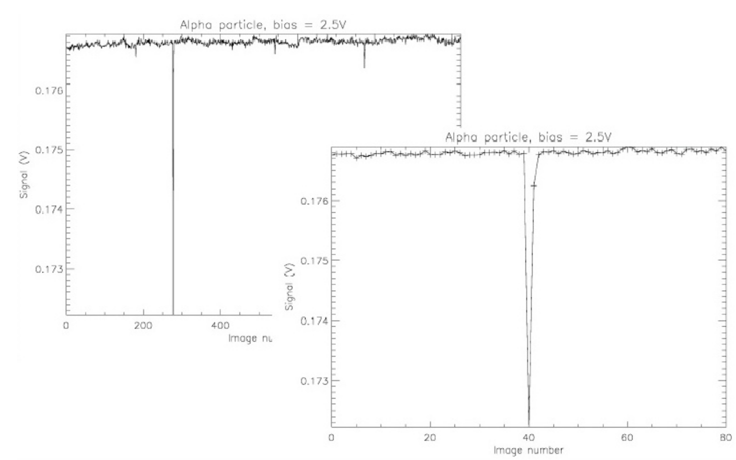
Ge:Ga raw ramp investigation

Test Block “Bolometer detector set-ups and adjustment to telescope background”

- contents
  - verification of operational voltage settings
  - bias adjustment to telescope background (iterative due to telescope cool-down)
  - collect glitch statistics
- duration: ≈17 h
- phase: Commissioning
- telescope condition: cryo-cover closed / cryo-cover open
- celestial standards: crowded field for 1st point source/ scan map AOT test in preparation of Focal Plane Geometry
  (mostly on internal calibration sources and telescope background blank field)



telescope background adjustment



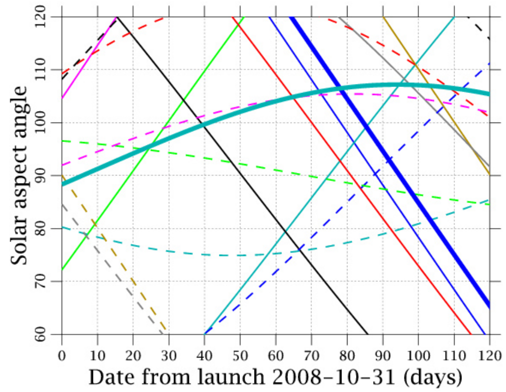
bolometer affected frames by glitches

“Star Tracker versus Line-of-Sight Calibration & Focal Plane Geometry”

- contents
  - star tracker versus PACS field-of-view offset calibration; dependence on solar aspect angle, statistical (≈100 sources per SAA) pointing refinement
  - central pointing position of photometer versus boresight calibration
  - relative pointing offset photometer – spectrometer
- duration: TBD
- phase: Commissioning (& PV, Routine for verification/refinement?)
- telescope condition: cool-down ⇒ slight focus degradation, no focus shift expected
- celestial standards:

  1) Bright isolated IR sources (36) for initial misalignment calibration

  2) Point-like sources with good positional accuracy and $f_{70} > 150\,\mathrm{mJy}$
  ⇒ several 100 stars (Rayleigh Jeans behaviour), blazars, QSOs and merger ULIRGs

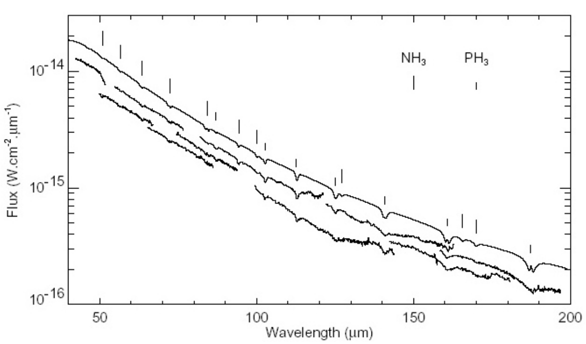


solar aspect angles of pointing stars

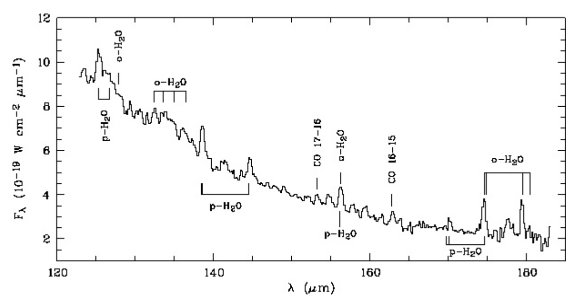
Test Block “Spectrometer Wavelength Calibration”

- contents
  - reverification of ground calibration or refinement
  - verification of instrumental profile on celestial targets
- duration: TBD
- phase: Performance Verification
- condition: final detector settings
- celestial standards:

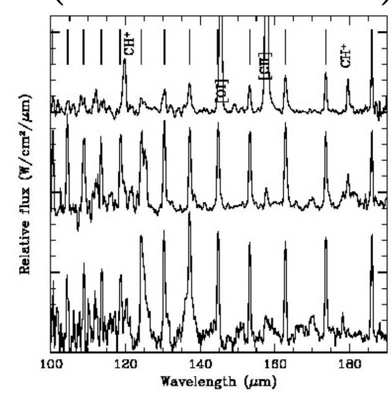
1) Jupiter (H_2O, NH_3, PH_3; fills full 5×5 pixels FOV, bias reduction necessary)
2) Uranus (H_2O), Neptune (H_2O, CO), Saturn (H_2O, NH_3, PH_3)
3) late type stars with water lines (5)
4) PNe (e.g. LWS calibrators) for wavelength checks/ secondary standards
5) AGB stars & PPNe with narrow intrinsic CO line widths ($10 - 20\,\mathrm{km\,s^{-1}}$)



Saturn FIR spectrum



water line star spectrum

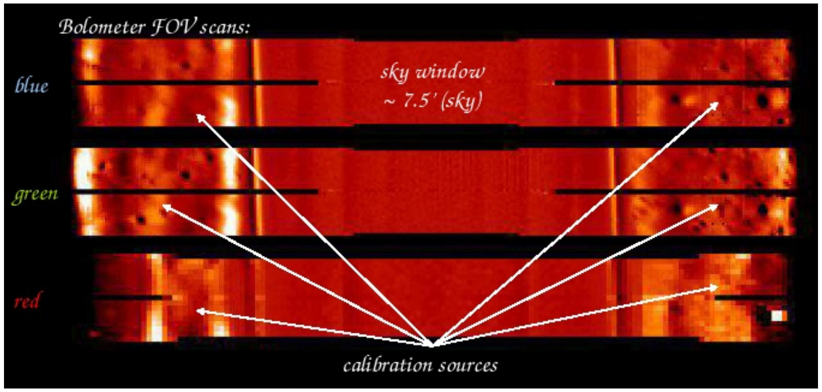


CO line spectra of AGB stars & PN

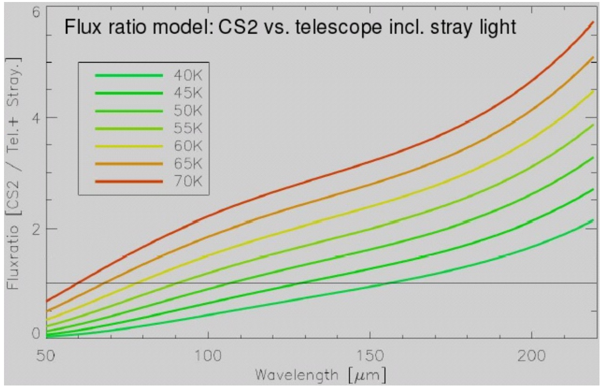
Test Block “FOV Characterisation Spectrometer/Photometer”

- contents
  - adjustment of internal calibration sources to telescope background
  - emissivity homogeneity of calibration sources
  - straylight aspects at boarders of sky FOV / CS FOV
- duration: >20 h
- phase: Performance Verification
- condition: iterative process due to telescope cool-down
- celestial standards:

  1) sky field without any source comparable to telescope background in brightness.



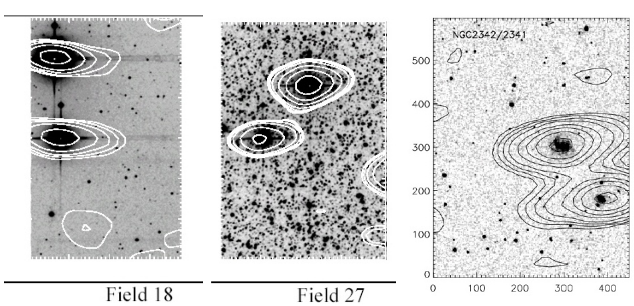
FOV scan



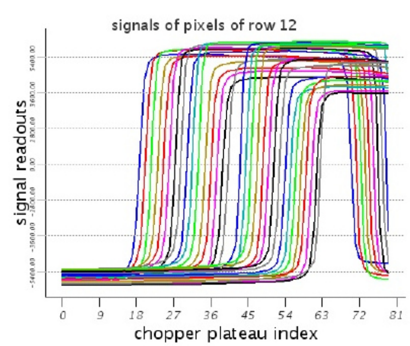
Internal CS to telescope background adjustment

Test Block "Verification of Chopper Angular Calibration"

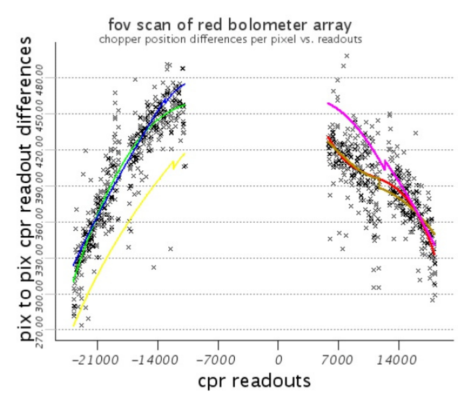
- contents
  - verification of focal plane scale
  - verification of absolute commanded chopper throw
- duration: 10 h
- phase: Performance Verification
- condition: close to final telescope temperature
- celestial standards:
  1) Ks band selected double stars (3 – 14) with 2' – 4' separation and various orientation angles, both partners with sufficient flux
  2) double galaxies (13) with 35" – 150" separation, compact well located and distinguishable emission component
  3) asteroid – asteroid, asteroid – planet encounters, moons



double star & galaxy spatial calibrators



pixel by pixel scan of target with chopper



chopper step size dependence on throw

Test Block "Photometer Spatial Calibration"

- contents
  - telescope focus verification
  - photometer array PSF & distortion
  - ghosts & near-field straylight by bright sources
- duration: >56 h
- phase: Performance Verification
- condition: close to final telescope temperature
- celestial standards:

  1) PSF standards, truly point-like, brighter 10 Jy
     - blue sources: 3 fiducial flux standards, AGB stars (thin dust shells?), asteroids
     - red sources: blazars, distant IR galaxies, KBOs(?)

  2) targets for distortion measurements:
     - double stars, double galaxies, asteroid – asteroid & asteroid – planet encounters, moons
     - structured regions, e.g. nearby galaxies with HII regions

  3) targets for straylight measurements:
     - planets (Mars, Jupiter, Saturn)
     - late-type stars >500 Jy, environment with little structure

Test Block “Spectrometer Spatial Calibration”

- **contents**
  - **- spectrometer array PSF & distortion**
  - **- ghosts & near-field straylight by bright sources**
- **duration: TBD**
- **phase: Performance Verification**
- **condition: close to final telescope temperature**
- **celestial standards:**

  1) PSF standards, truly point-like, brighter 100 Jy

  - AGB stars (thin dust shells?), asteroids, ULIRGs

  2) targets for distortion measurements: brighter 60 Jy, close to point-like

  - PSF standards

  - double galaxies, asteroid – asteroid & asteroid – planet encounters

  3) targets for straylight measurements:

  - planets (Mars, Jupiter, Saturn)

  - late-type stars >500 Jy, environment with little structure

Test Block "Photometer Photometric Calibration"

- **contents**
  - **- absolute calibration accuracy**
  - **- system linearity**
  - **- relative filter-to-filter calibration, color correction**
  - **- reproducibility**
- **duration: TBD**
- **phase: Performance Verification**
- **condition: very close to final telescope temperature**
- **celestial standards:**

  **1) fiducial stars (20) in flux range 100 mJy – 10 Jy
  with well modelled photospheric emission (5–10% absolute accuracy)
  no chromospheric emission or dust debris, not variable**

  **2) asteroids (50) in flux range 1 Jy – 500 Jy
  with well determined shapes (thermophysical model), variability assessment, knowledge of surface properties**

  3) planets within linear regime of photometer (Neptune, Uranus?)

  4) faint stars with fluxes down to 10 – 20 mJy for accuracy assessment in the faint flux regime (10–15% absolute flux accuracy)

Test Block "Spectrometer Photometric Calibration"

- **contents**
  - **- absolute calibration accuracy at key wavelengths**
  - **- system linearity**
  - **- relative spectral response function**
  - **- spectral flat-field**
  - **- reproducibility**
- **duration: >50 h**
- **phase: Performance Verification**
- **condition: very close to final telescope temperature**

Test Block "Spectrometer Photometric Calibration (continued)"

- celestial standards:

  1) absolute flux calibration at key wavelengths
     - bright fiducial stars (6) in flux range 1 Jy – 10 Jy with well modelled photospheric emission (5–10% absolute accuracy)

  2) RSRF assessment
     - asteroids (50) in flux range 1 Jy – 500 Jy & planets (Neptune, Uranus)

  3) linearity assessment
     - asteroids (50) in flux range 1 Jy – 500 Jy & planets (Neptune, Uranus)

  4) flat-field assessment
     - bright compact secondary calibrators and spectral PSF standards

  5) reproducibility
     - primary & secondary calibrators

  6) system stability
     - telescope background

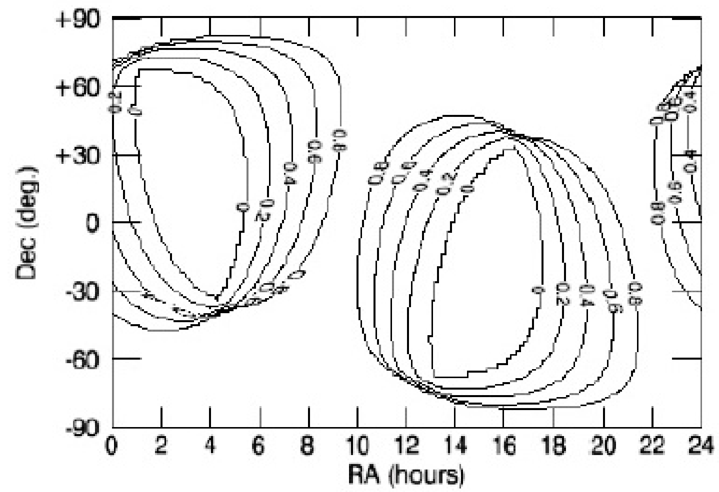
“Astronomical Observation Template Validation & Optimisation”

- contents
  - calibration accuracy of individual AOT modes with regard to point and extended sources
  - dynamic range, image quality
  - consistency check with other AOT modes
  - check of internal calibration scheme (robustness against drifts)
  - check of pointing, raster map and scan map mode parameter selection
  - decide on final option for some parameter settings
  - improve AOT design in case of insufficient performance
- duration: >60 h
- phase: Performance Verification & Science Demonstration
  - whenever possible for calibration observations using standard set-ups.
  - dedicated validation observations on targets with reference observations from earlier observations (morphology, SED, total flux, ...)
- condition: representative for Routine Phase
- celestial standards:
  primary standards (stars & SSOs), slightly extended sources (PNe), structured areas (SNRs, cirrus fields), cosmological fields

Outlook on PACS Calibration Issues and Activities for the Herschel Space Observatory Routine Phase

Main Objectives for the Routine Calibration Plan (1)

- Main goal of the Performance Verification Phase is to establish the initial core calibration of PACS.
- Routine calibration has to address:
  1) Repetition of failed PV observations.
  2) Completion of PV calibration programs for celestial standards not visible during PV proper.
  3) Extension of PV calibration program, e.g. with regard to flux range of standards.
  4) Completion of PV calibration with regard to parameter space of AOT settings.
  5) Refinement of PV calibrations along the progress in data processing (e.g. more sensitive set-up, design of measurement to avoid disturbing effects).



Cumulative visibility of sky during PV Phase

Main Objectives for the Routine Calibration Plan (2)

- Routine calibration has to address (continued):
  6) Robustness of calibration, i.e. verification with a relatively large set of standards in order to cancel out systematic calibration offsets possibly introduced by individual standards.
  7) Long-term reproducibility and stability. $\Rightarrow$ frequent visit of secondary & primary flux and wavelength calibrators.
  8) Check for environmental changes (space weather) and
     possible adaptation of instrument set-up due to increased solar activity.
  9) Check for aging effects by trend anaylsis, e.g. zero points & scales of mechanical elements or offsets in voltages or occasional erratic behaviour of electronics (mission duration).