Calibration of the Reflection Grating Spectrometers

- Physical model
- Scientific performance
- Current SAS implementation
- Conclusions

- **SRON**: J.W. den Herder, A. Brinkman, A.J. den Boggende, J. Kaastra, T. Tamura, C. de Vries
- **Columbia**: S. Kahn, J. Cottam, F. Paerels, J. Peterson, A. Rasmussen, D. Reynolds
- **MSSL**: G. Branduardi-Raymont
- **PSI**: M.Audard, M.Güdel
- **ESA/SSD**: C. Erd
- **+ others**

Physical model

- Optical design
- Mirror response
- Grating response
- Camera/CCD response

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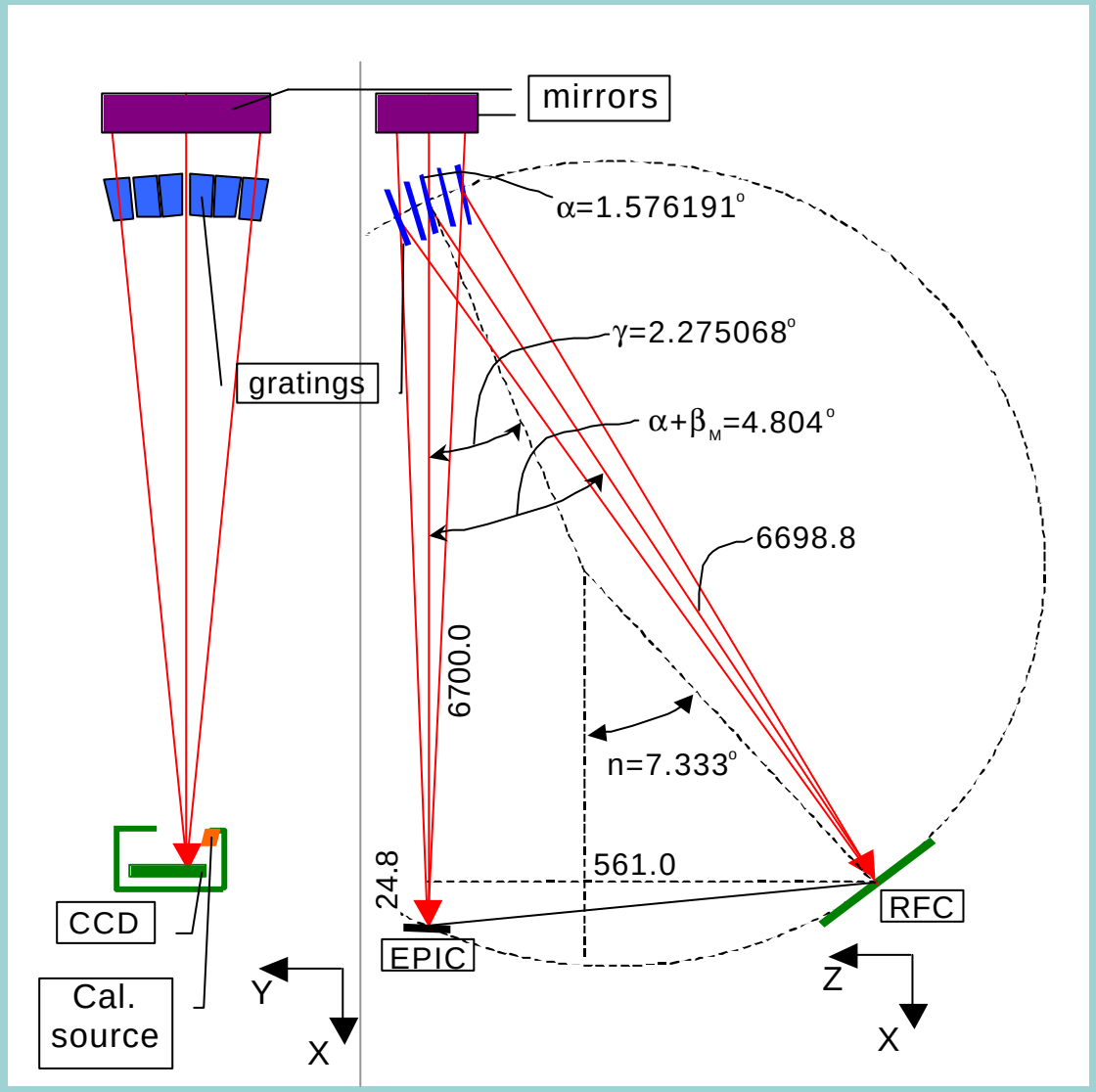
Optical design (1)



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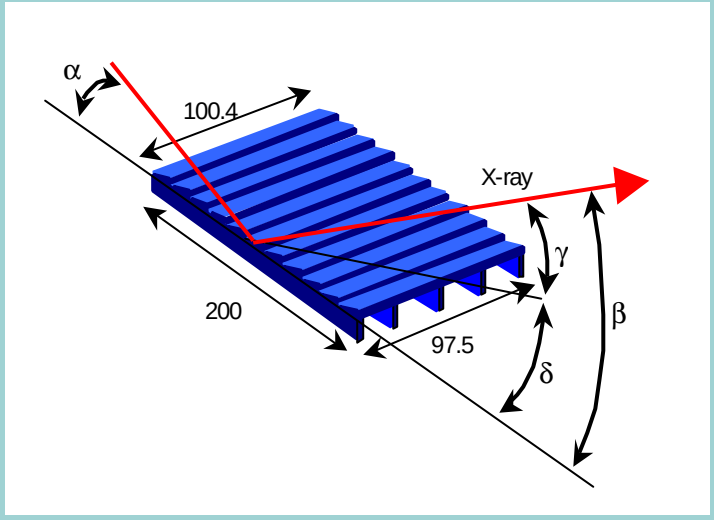

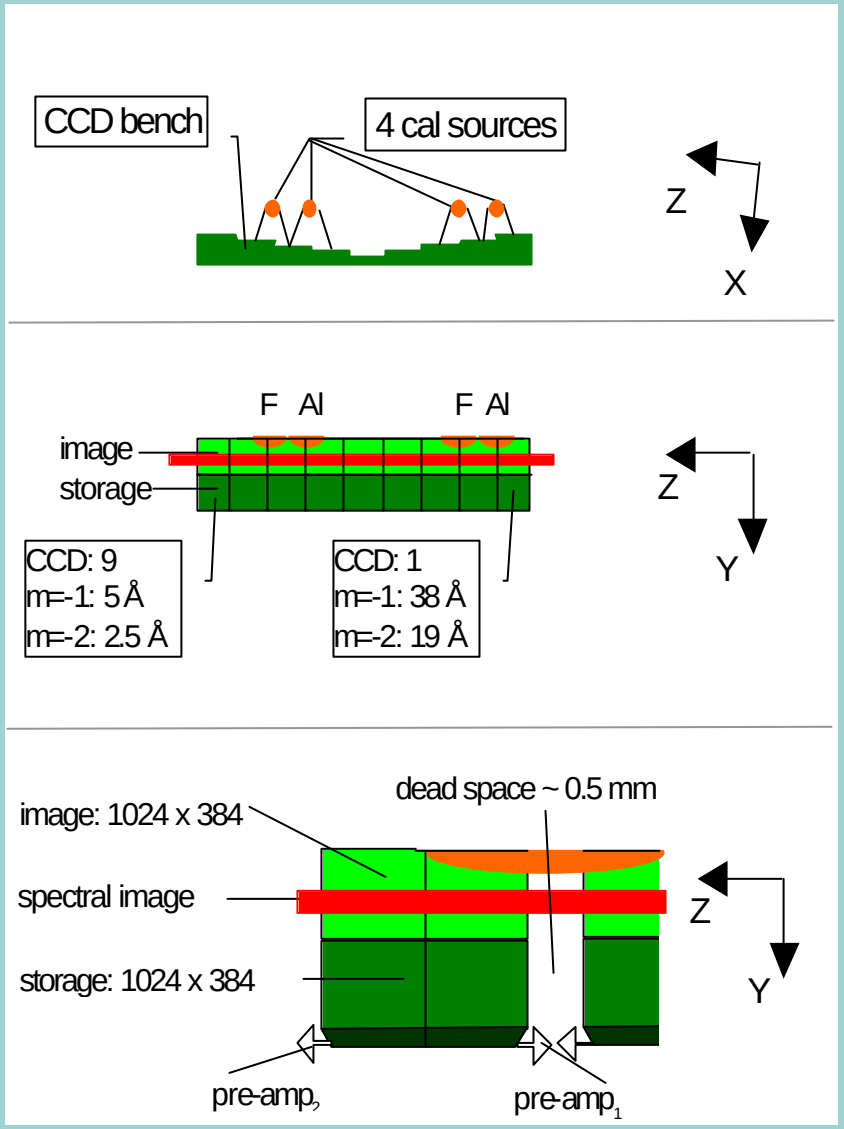

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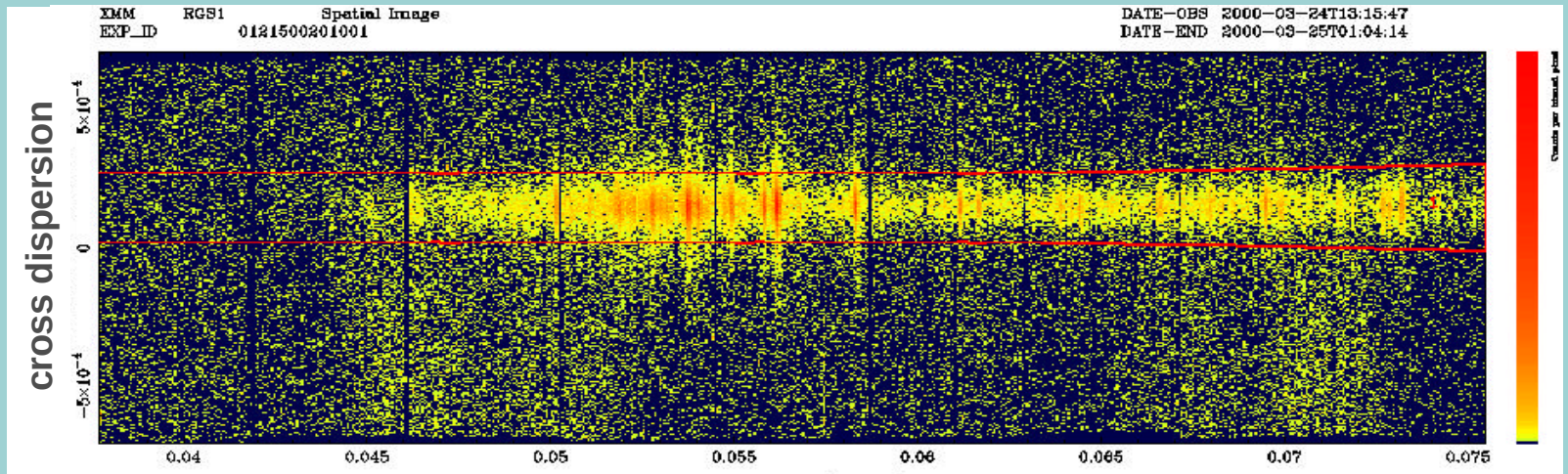
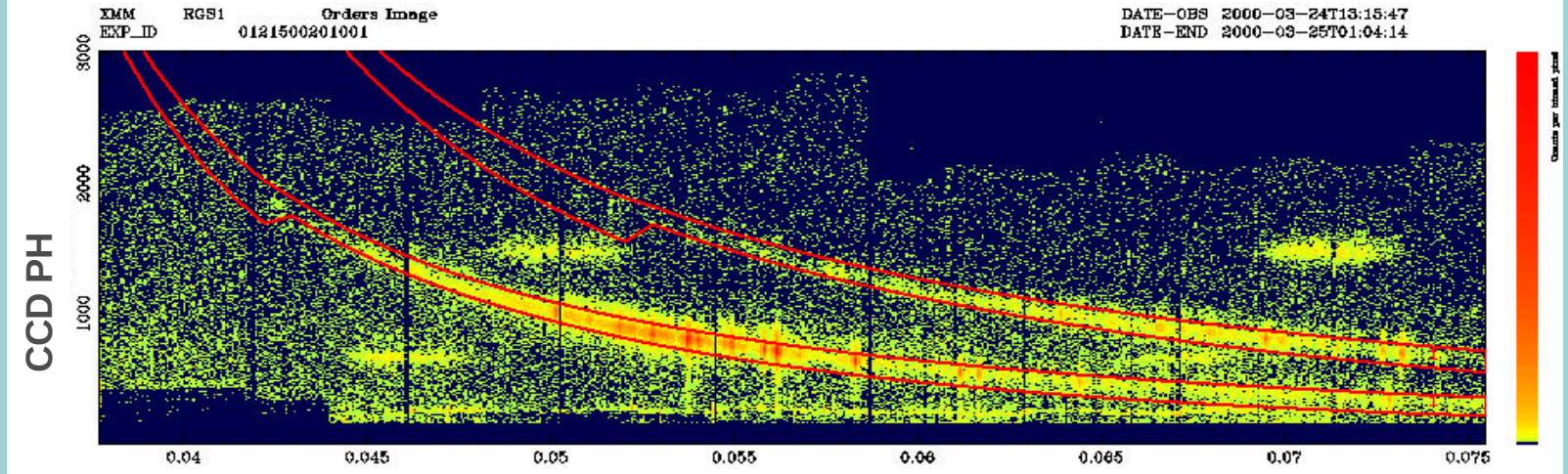
Optical design (3)



b, outgoing angle from gratings



b, outgoing angle from gratings

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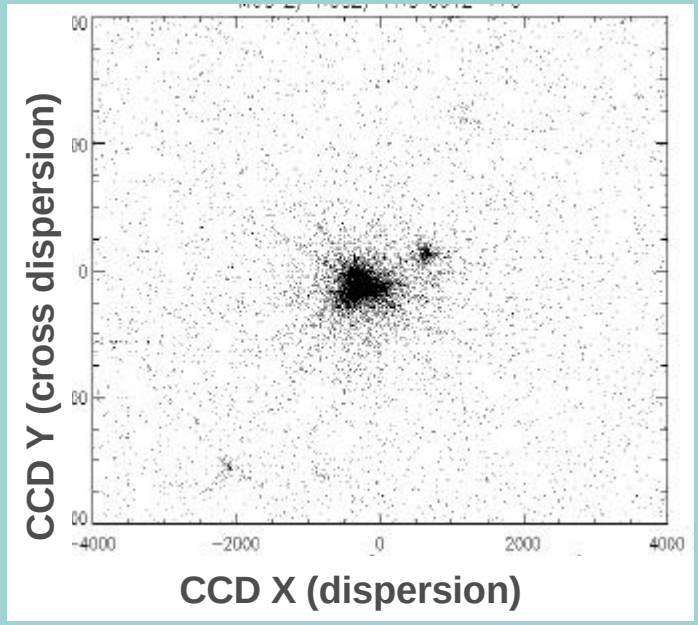
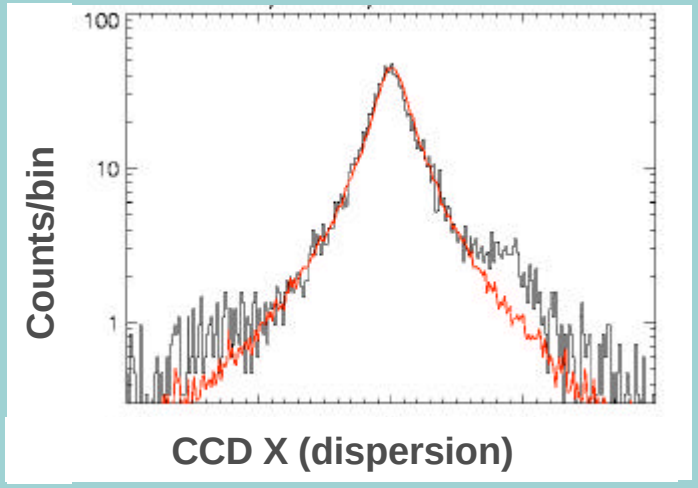
Mirror response

- Empirical fit to raytrace results (consistent with to flight data PKS 0312-770), projected on dispersion axis
- mirror effective area
- empirical fit to cross dispersion data (Mkr 421) on RGS detector (Row-land circle is not optical mirror focus)





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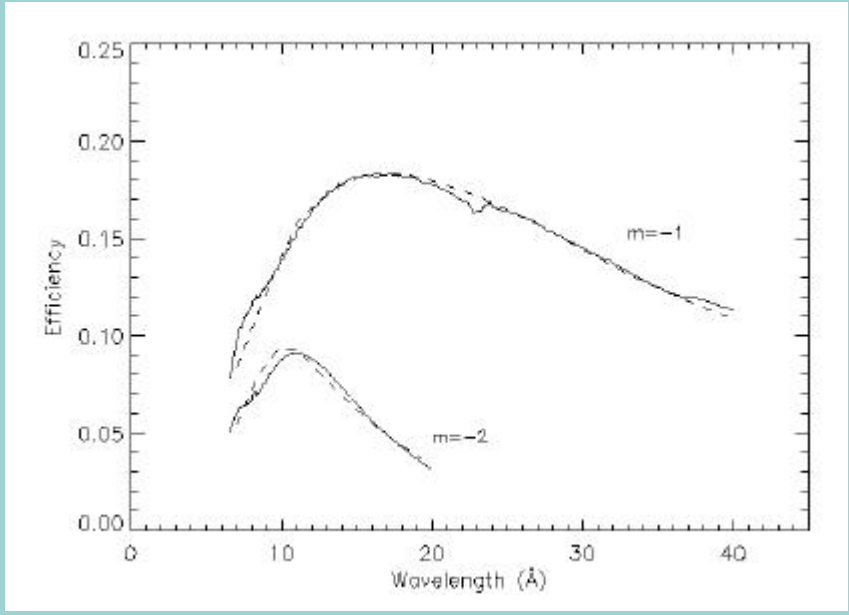
Grating response

- Calculation of efficiency using Maxwell equations
- Fit blaze angle to various datasets (Bessy, α dependence, orders)
- incoherent scattering (scalar theory) with two distributions (small and large angle) in the dispersion direction
- large angle scattering in cross dispersion direction
- Add alignment information

Bessy data and model



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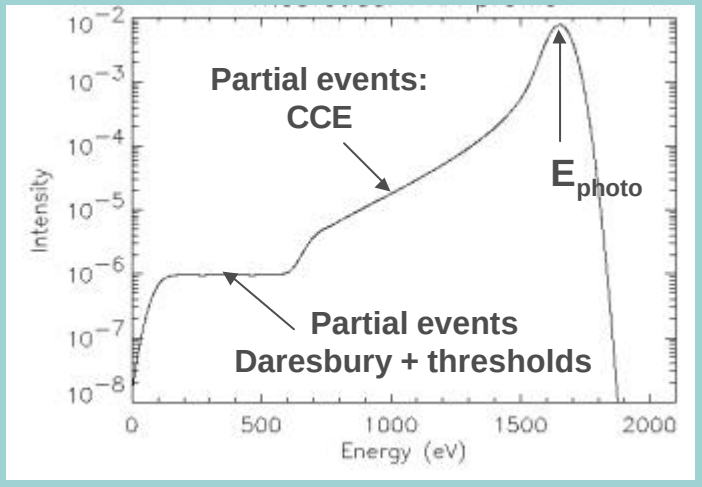
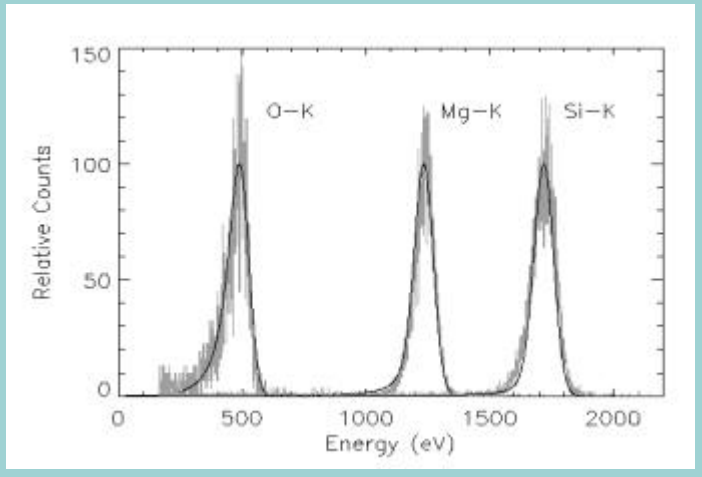
CCD response: redistribution

- CCD energy response used to separate orders (less critical)
- CCD redistribution function includes partial event tail and CCE at the backside
- CCD redistribution function verified in orbit as for a given position on the detector the energy is ‘monochro-matic





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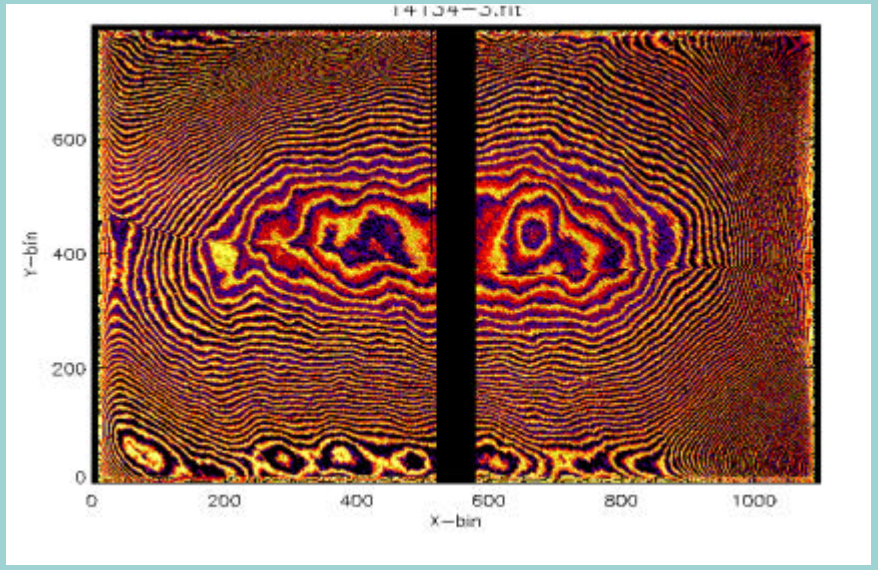
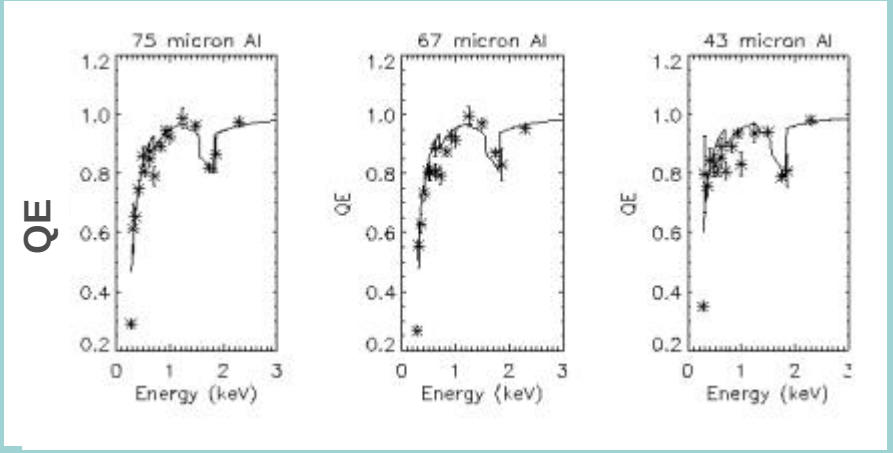
CCD response: QE

- QE based on CCD thickness (verified by IR) and thickness of various layers (optical Al filter of 45, 68 and 75 nm and MgF_2 insulation layer)
- QE verified during ground calibrations
- CTI/gain corrections determined in orbit using onboard calibrations sources (Al and F) as well as astrophysical objects





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Scientific performance

- Line spread function(LSF)
- Wavelength scale
- Effective area
- Background
- In-orbit monitoring

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Line spread function

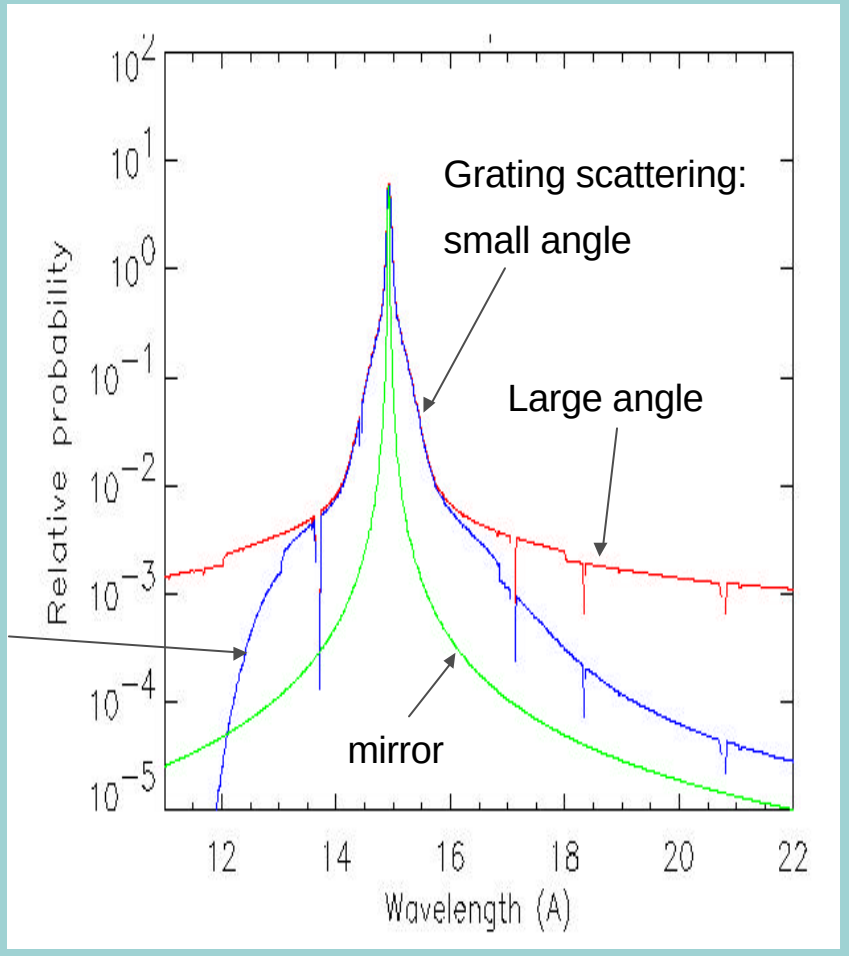
- Expected LSF is convolution of

  - mirror response

  - grating response

  - and CCD response

  - (+ electronics)



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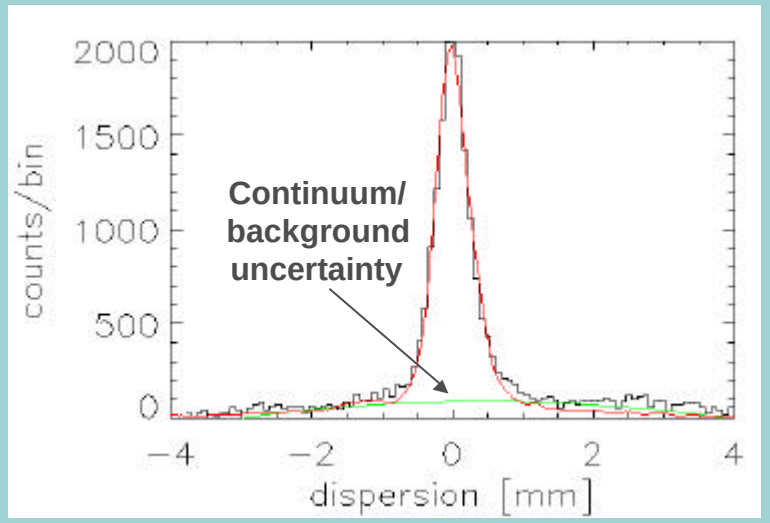
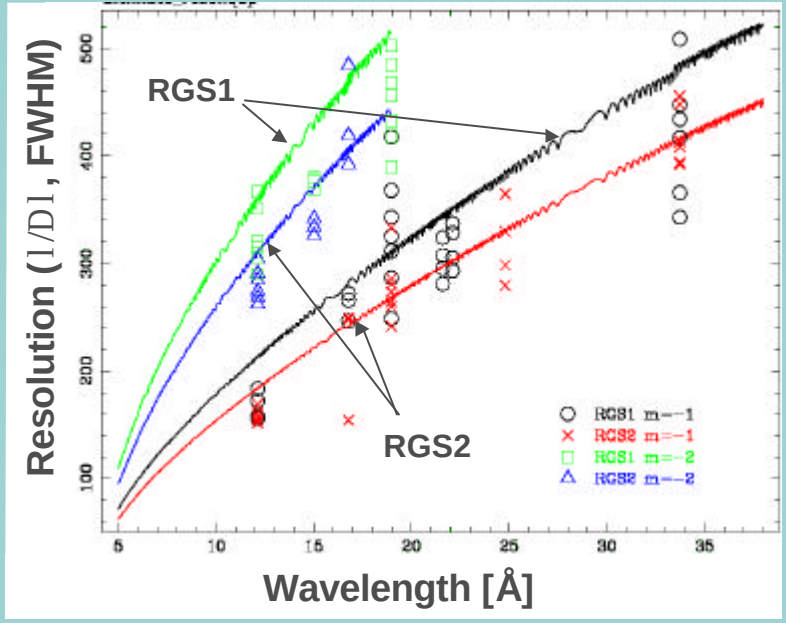
In-orbit verification of the LSF

- Verified on number of strong unblended lines
- Model (raytrace) in good agreement with data (some uncertainty in background/continuum)
- Calculated response (FWHM) in good agreement with larger set of data





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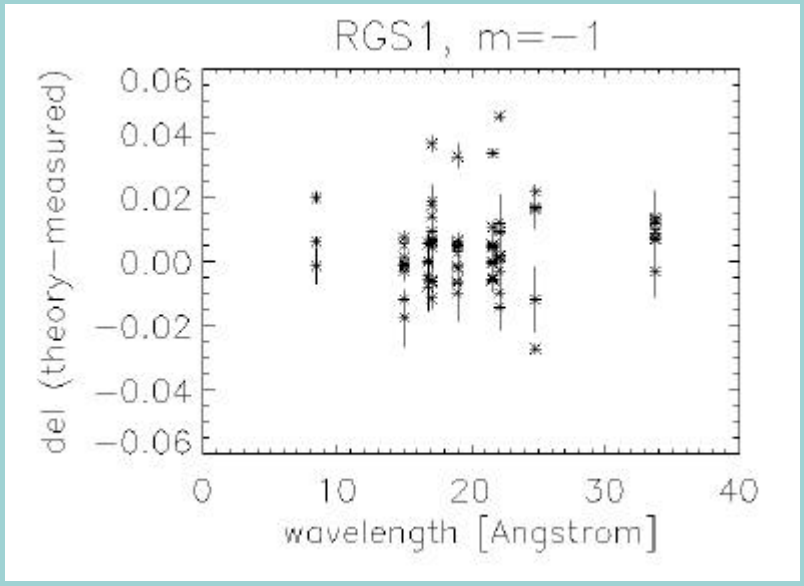
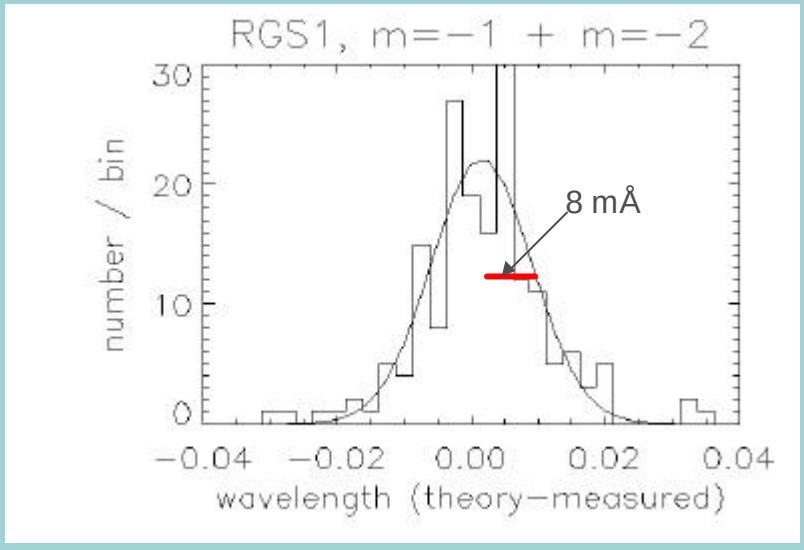
λ scale verification

- Ground alignment does not give ultimate accuracy
- Comparison of strong lines (Lyα) with laboratory wavelengths for a number of pointings
- Result: ± 8mÅ (1 σ)
- RGS1 + 1.5 mÅ
- RGS2 – 1.6 mÅ





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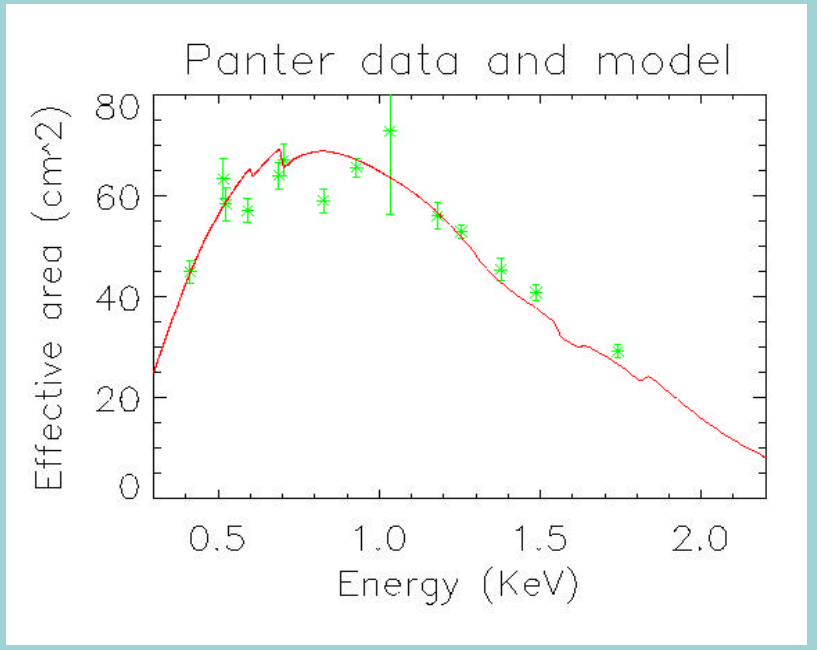
Effective area

- Based on physical model
- Validated during long beam tests (which is not fully representative)
- Verified in-orbit on BL Lac (PKS2155) resulting in number of changes



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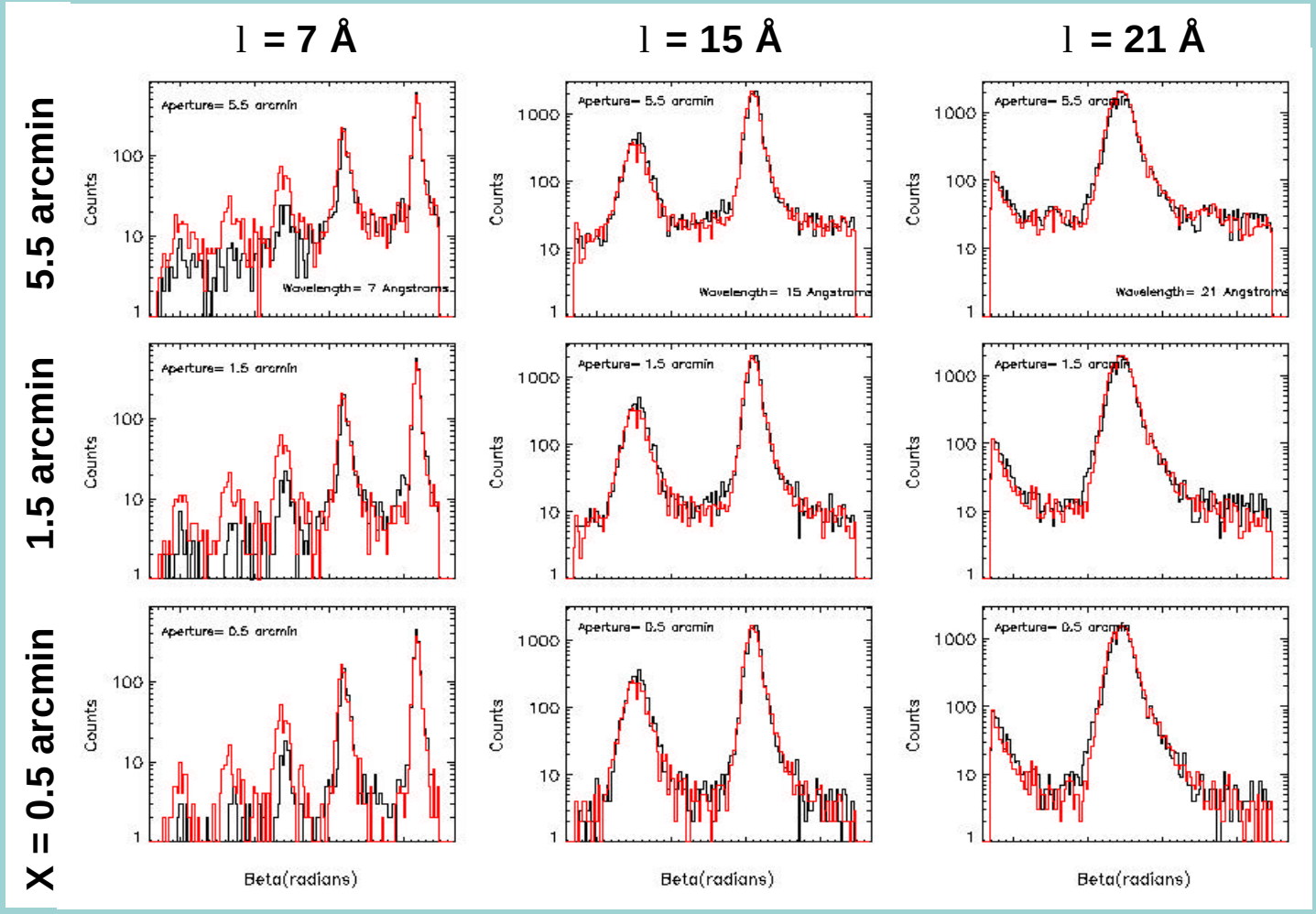
Effective area 2

Optimization of scatter parameters to describe the flight data
(red = model, black = data)



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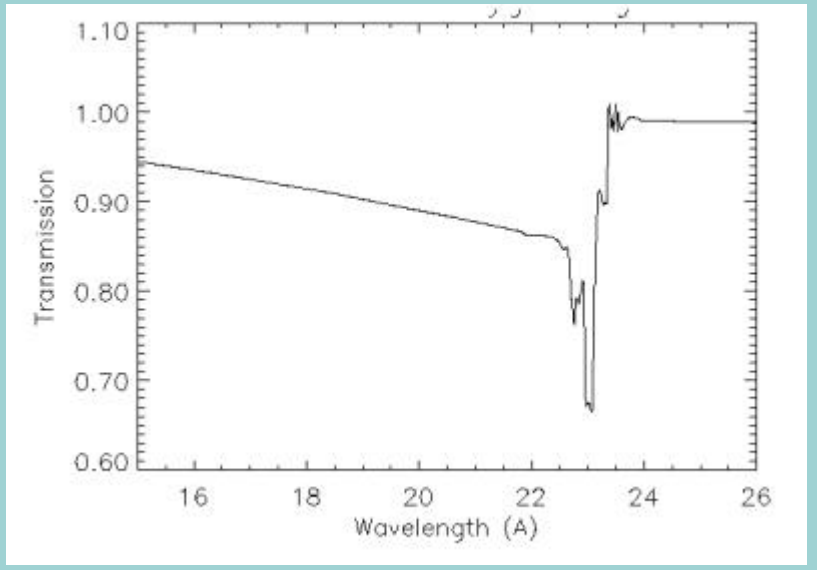
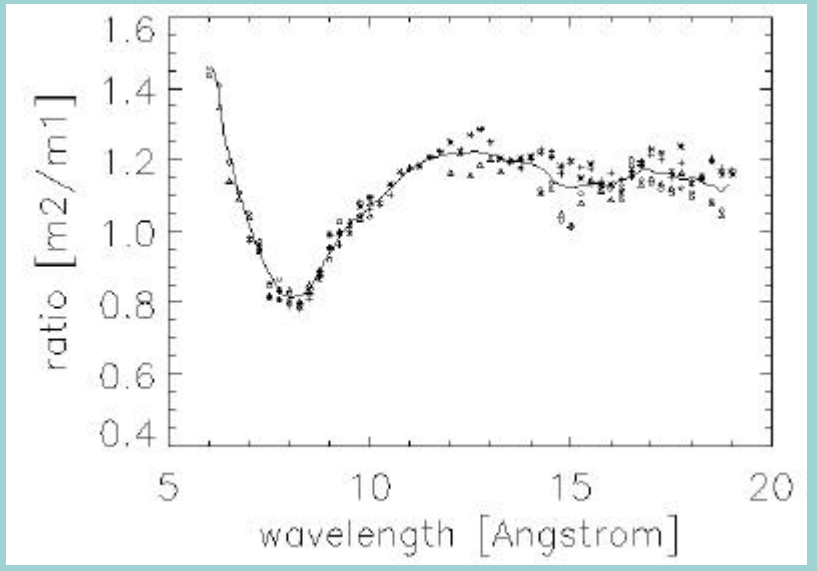
Effective area (3)

- Apply correction factors for:
  - Difference RGS1 and RGS2 (b dependent)
  - O-edge
  - Second order spectra





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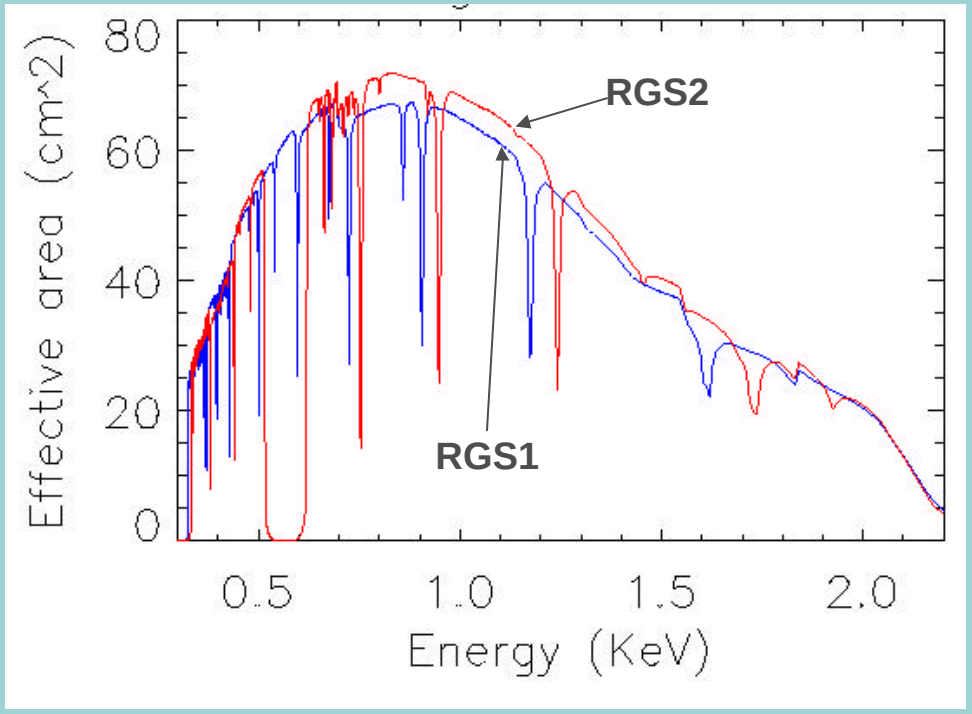
Effective area: result

- Predicted effective area for RGS1 and RGS2
- includes hot columns and failing CCD chain (only shown for RGS2)
- No sharp features due to scattering wings
- Edges due to O, F, Mg and Al + finite thickness of Si (~ 30 μm)



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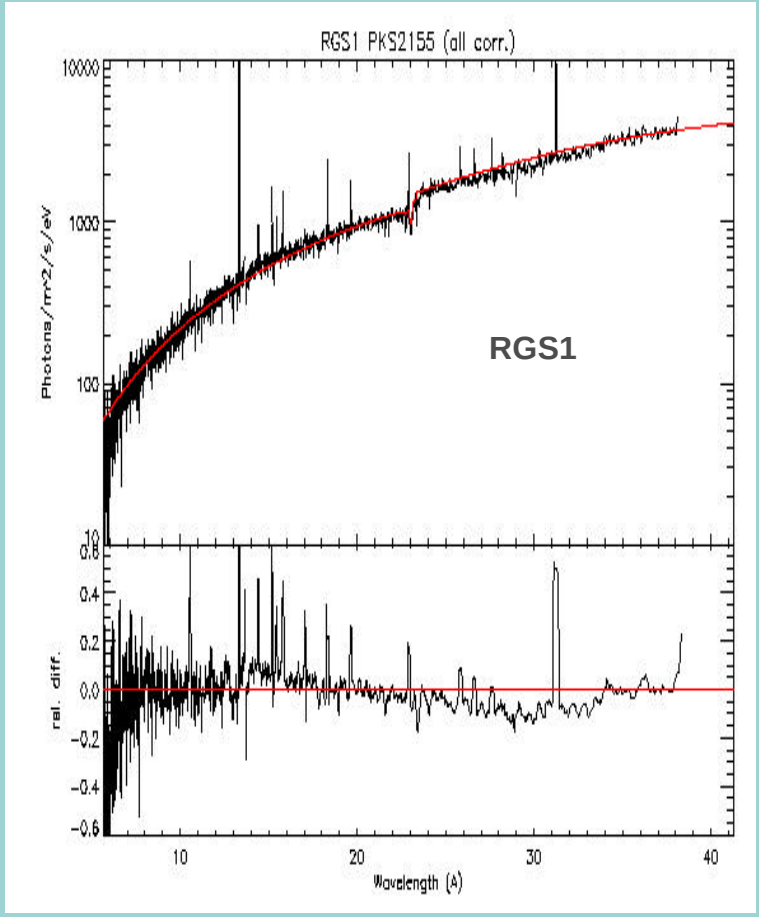
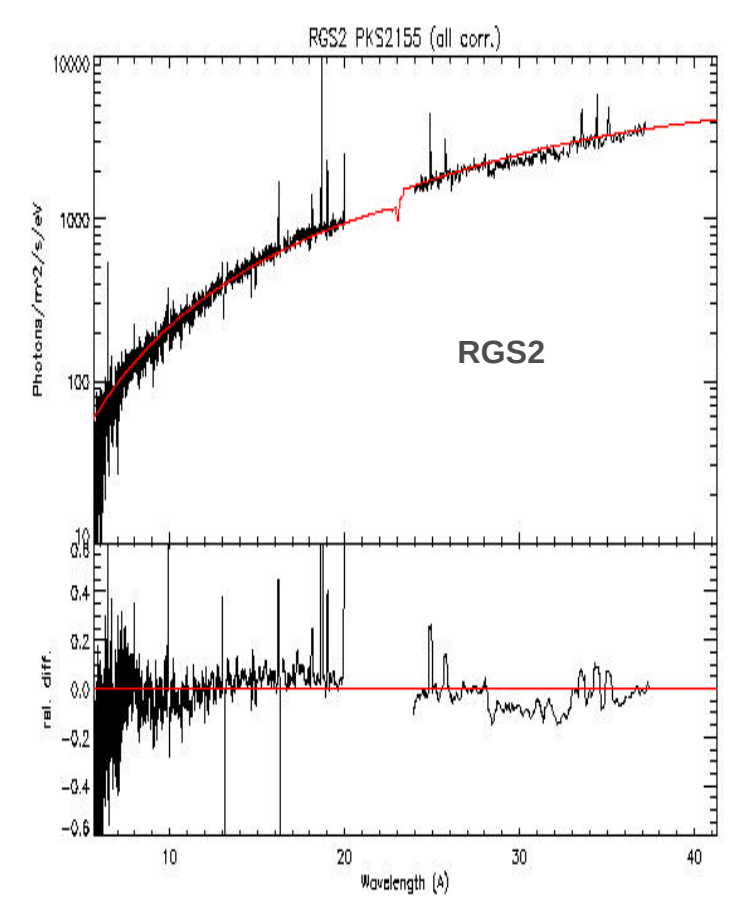
Effective area: verification

- Result for PKS2155 consistent with single power law for both instruments (within 5% except for < 7 Å)





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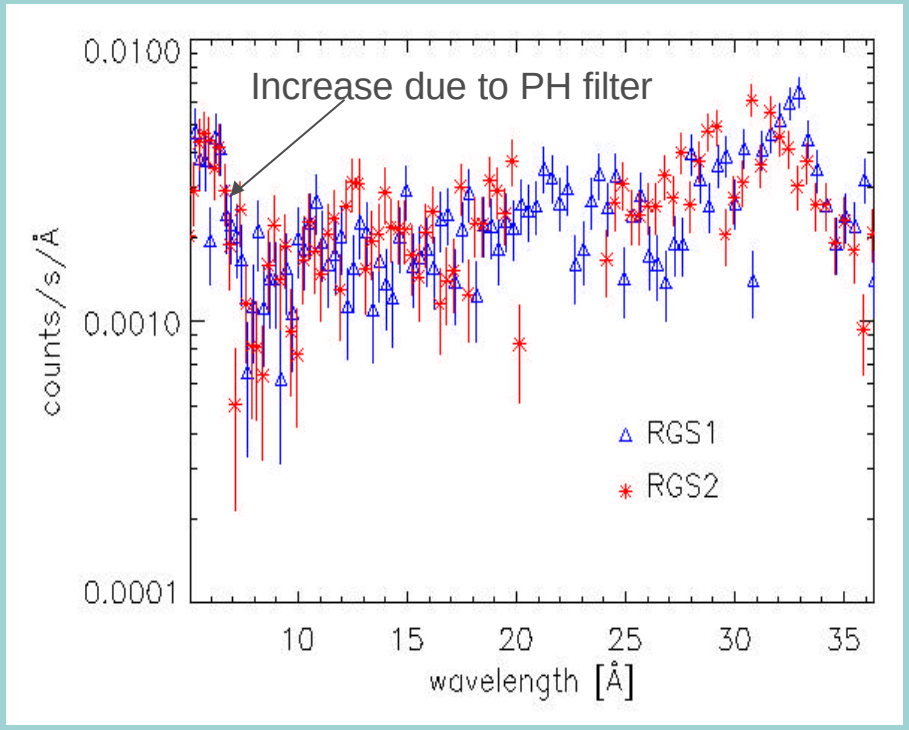
Background

- Different background components:
  - Minimum ionizing particles
  - Electrons
  - Onboard calibration source
  - Fluorescence lines
  - Read-out noise
  - Soft protons entering the telescope (highly variable)



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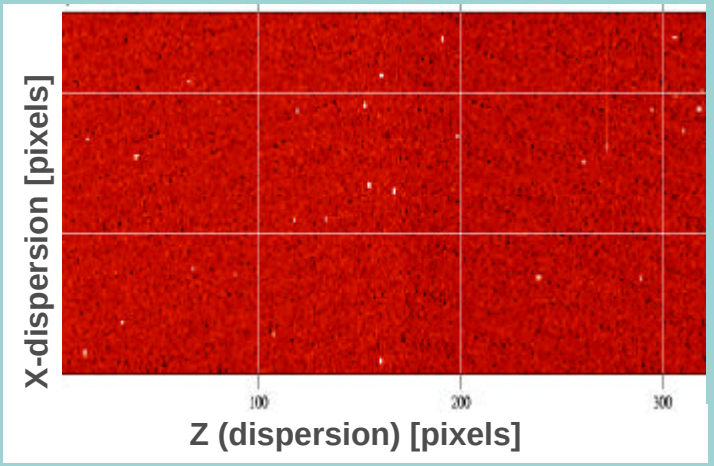
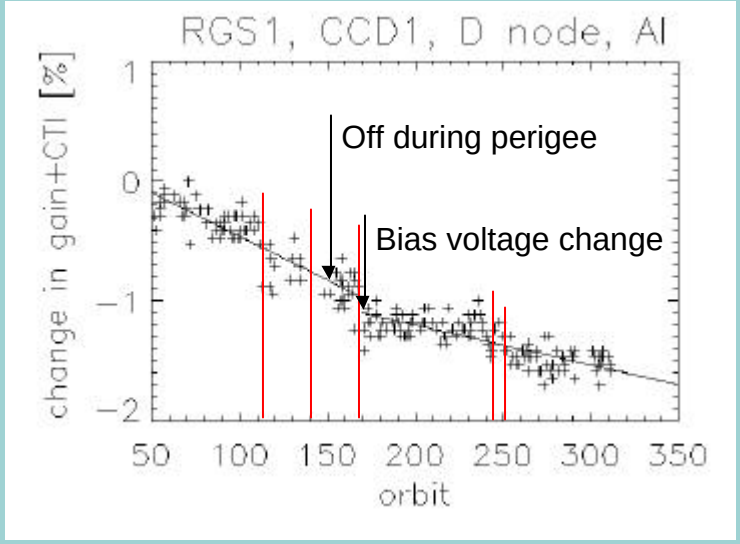
In orbit monitoring (1)

- Dark current and optical load (
  - uniform, less than 1 e^- contribution to read-out noise of 5 e^-,
  - few defects
  - Particle background
- CTI + gain (on chip amplifier and electronics)
  - Effect less than 1% (normalized on orbit 165)
  - Slope change, presumably since electronics is off during perigee





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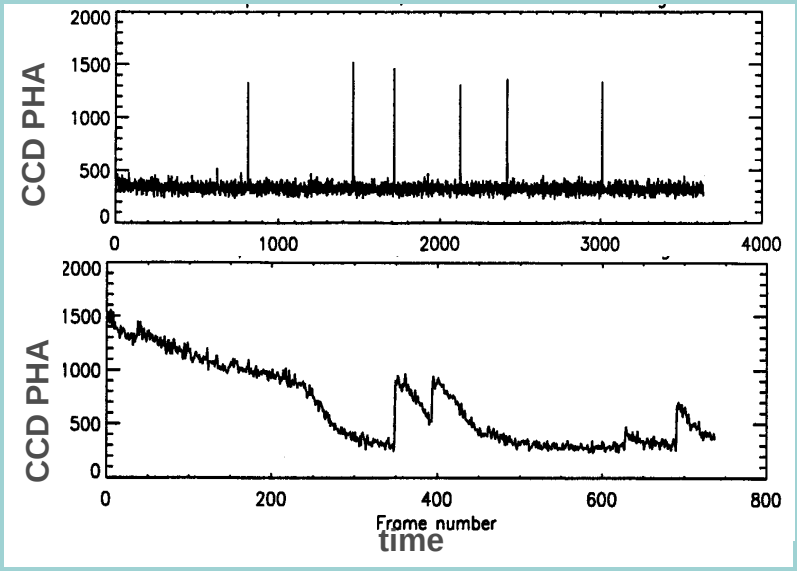
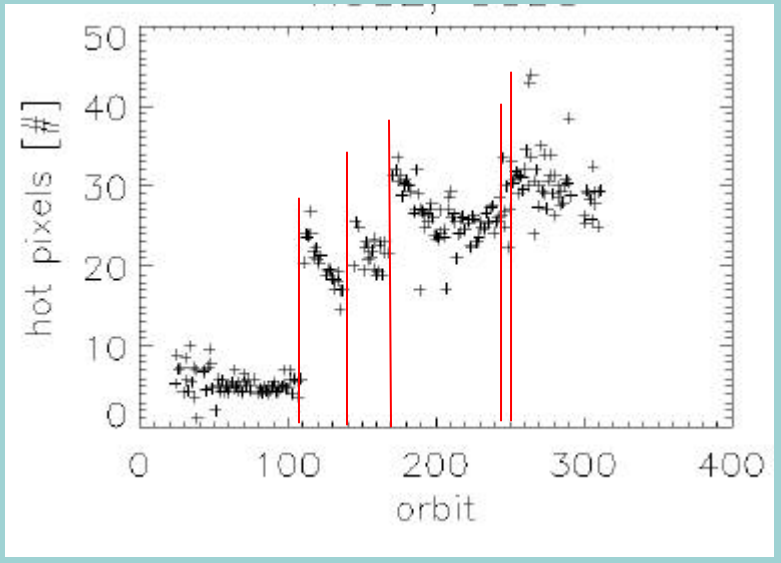
In-orbit monitoring (2)

- Hot and flickering pixels (small fraction << 1% with intensity which depends on time)



- Increase following solar events and gradual repair of defects (at –80°C)



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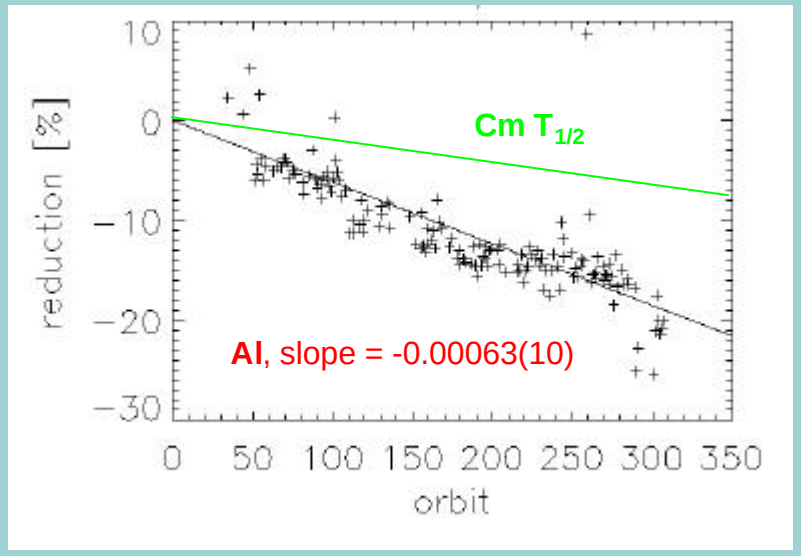
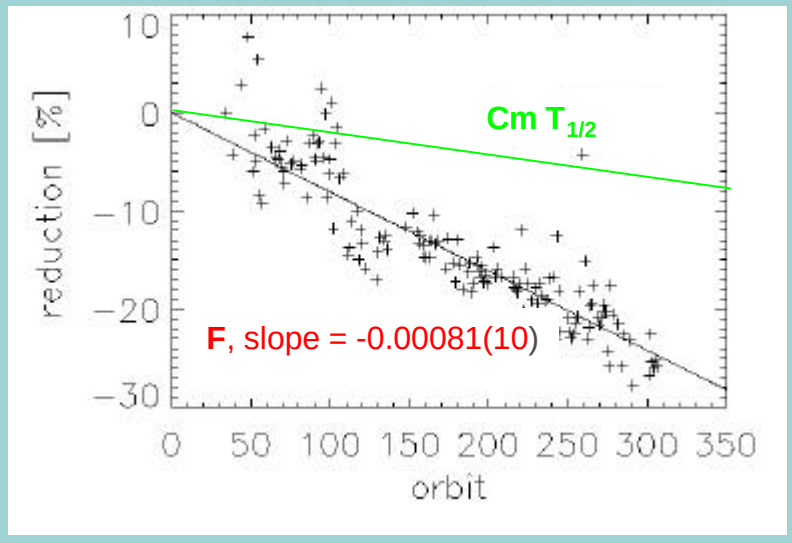
In-orbit monitoring (3)

- Contamination verified using intensity of the onboard calibration sources
  - Al and F continuously illuminate parts of CCD
  - No significant difference in slope (but also not consistent with $T_{1/2}$ of Cm source)
  - No contamination on detector
  - Marginal contamination on source stopping a particles





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SAS products

- SAS version 5.2 (and related CCFs) give reasonable results

- Not included are:
  - correction to force RGS1 to RGS2 (β dependent)
  - Correction for second orders
  - Proper vignetting function of the gratings
  - Proper description of O-edge including fine structure

- Without these corrections LSF, λ scale are correct, A_{eff} less accurate

- After these corrections response can be normalized to reference source

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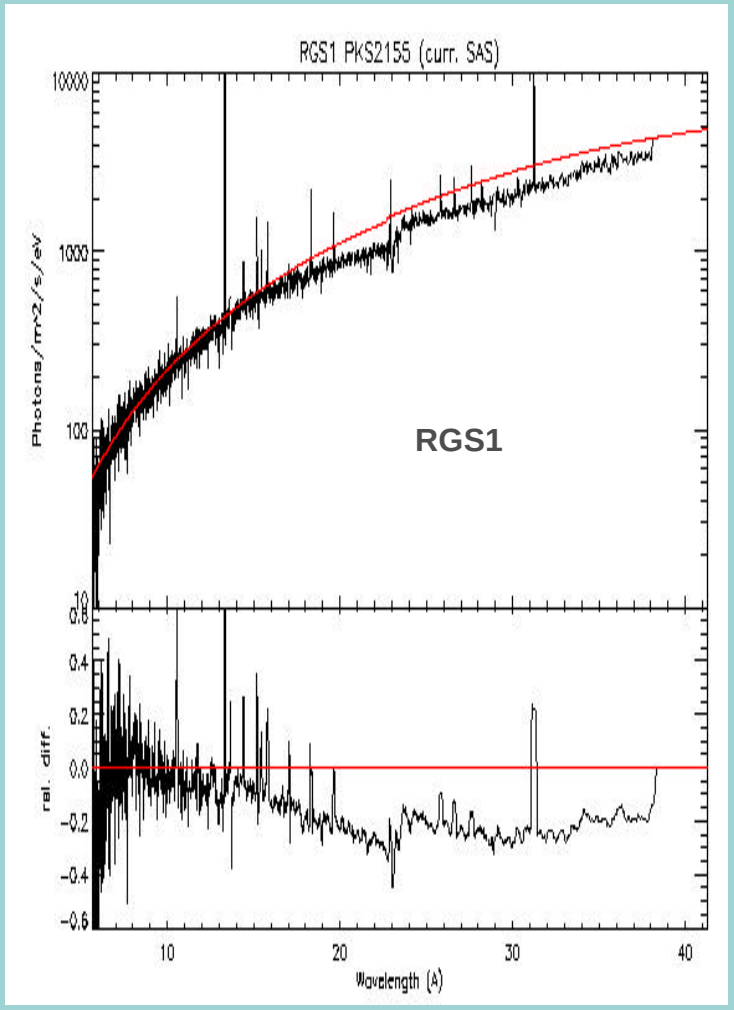
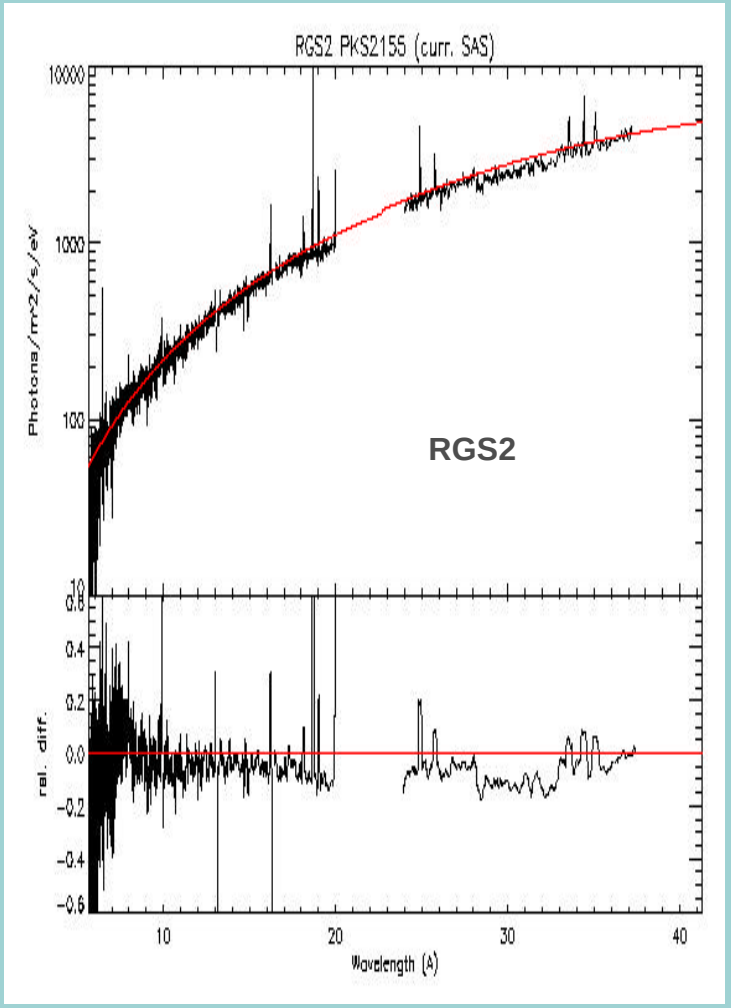
SAS products (2)

- Not all parts of calibration in public version of SAS (yet)





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Conclusions

- Quality of calibrations in good agreement with pre-flight predictions based on a physical model of the instrument
- Improvements are feasible in l scale and response model (but require significant further work)
- Normalization of response to PKS2155 reduces uncertainties
- In-orbit performance as expected
- Current public SAS reasonable but various improvements identified to improve A_{eff}

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