Empirical effective area calibration of RGS using blazar spectra

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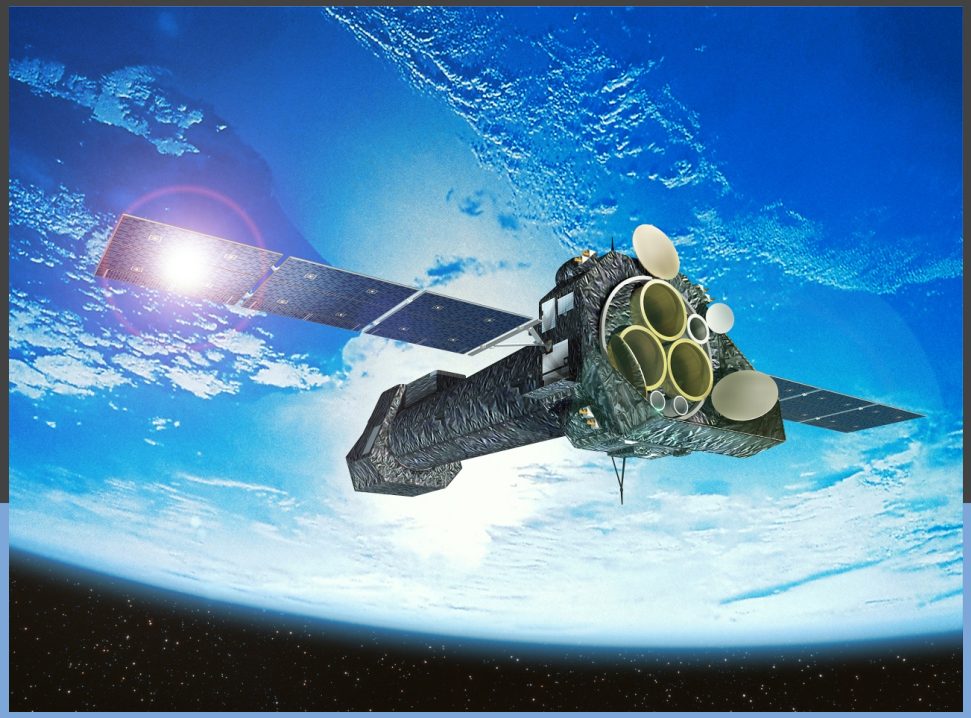

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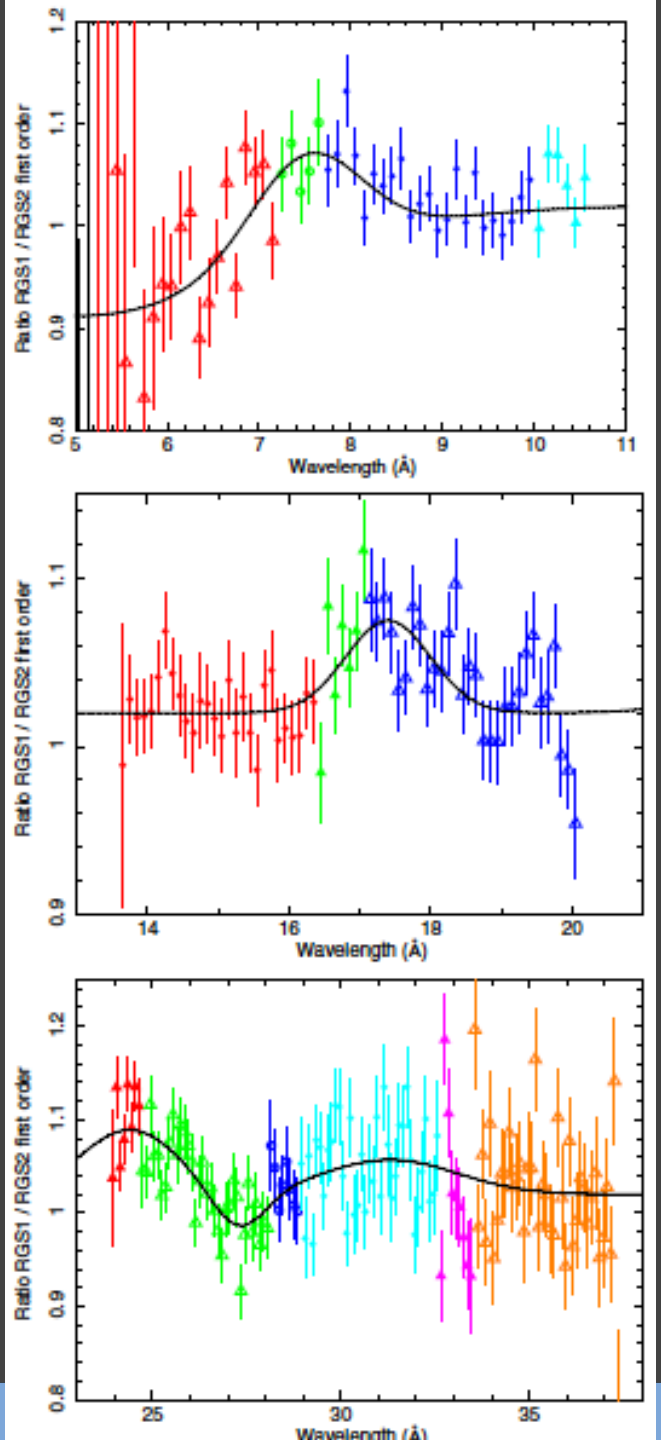
Introduction & motivation

- Deep Mrk 509 study in 2011 revealed wiggles in RGS1/RGS2 effective area
- SAS 13.5.0 contains many improvements in a.o. wavelength binning.
- In 2015, follow-up study of RGS effective area.



Mrk 509, Kaastra et al. (2011)

Two data sets

- Data set for RGS-pn comparison (840 ks)
  PKS 2155-304
  3C 273
  H 1426+428

- Data set for RGS analysis (4.1Ms)
  Mrk 421
  PKS 2155-304
  3C 273
  H 1426+428

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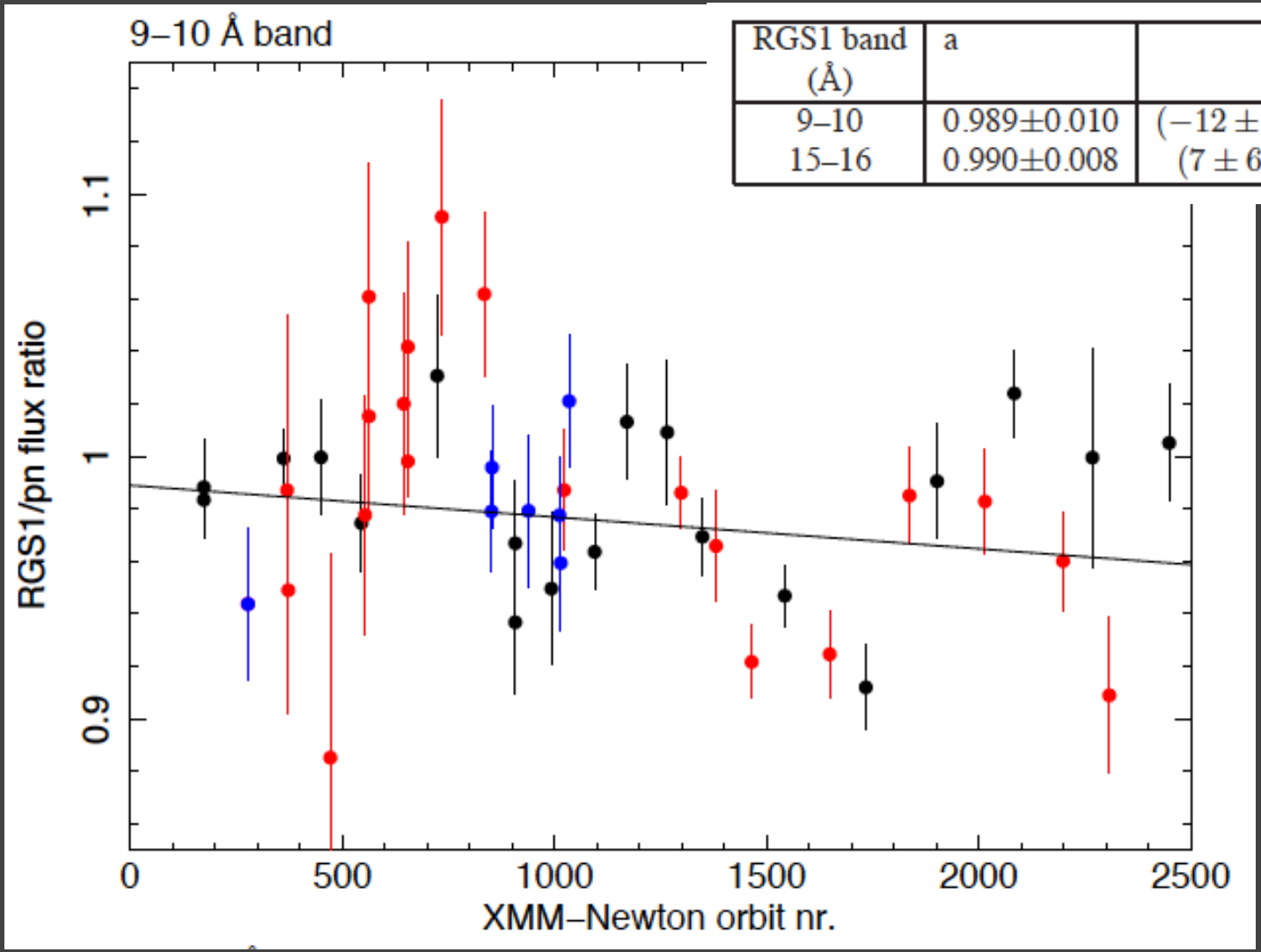
RGS data analysis

- SAS version 13.5.0
- Make spectral fits (SPEX) using power law and 'hot' absorption model
- Convert count spectra into fluxed spectrum using best fit model
- Bin fluxed spectra into 1 A bins

PN Analysis

- 1: Power-law fit + hot in 0.3-2.5 keV range
- 2: Spline fit in 0.3-10 keV range
- Converted to fluxed spectra

RGS1/pn trend over time



RGS1 band (Å)	a	b	n	χ^2
9–10	0.989±0.010	$(-12 \pm 7) \times 10^{-6}$	47	112.0
15–16	0.990±0.008	$(7 \pm 6) \times 10^{-6}$	47	113.5

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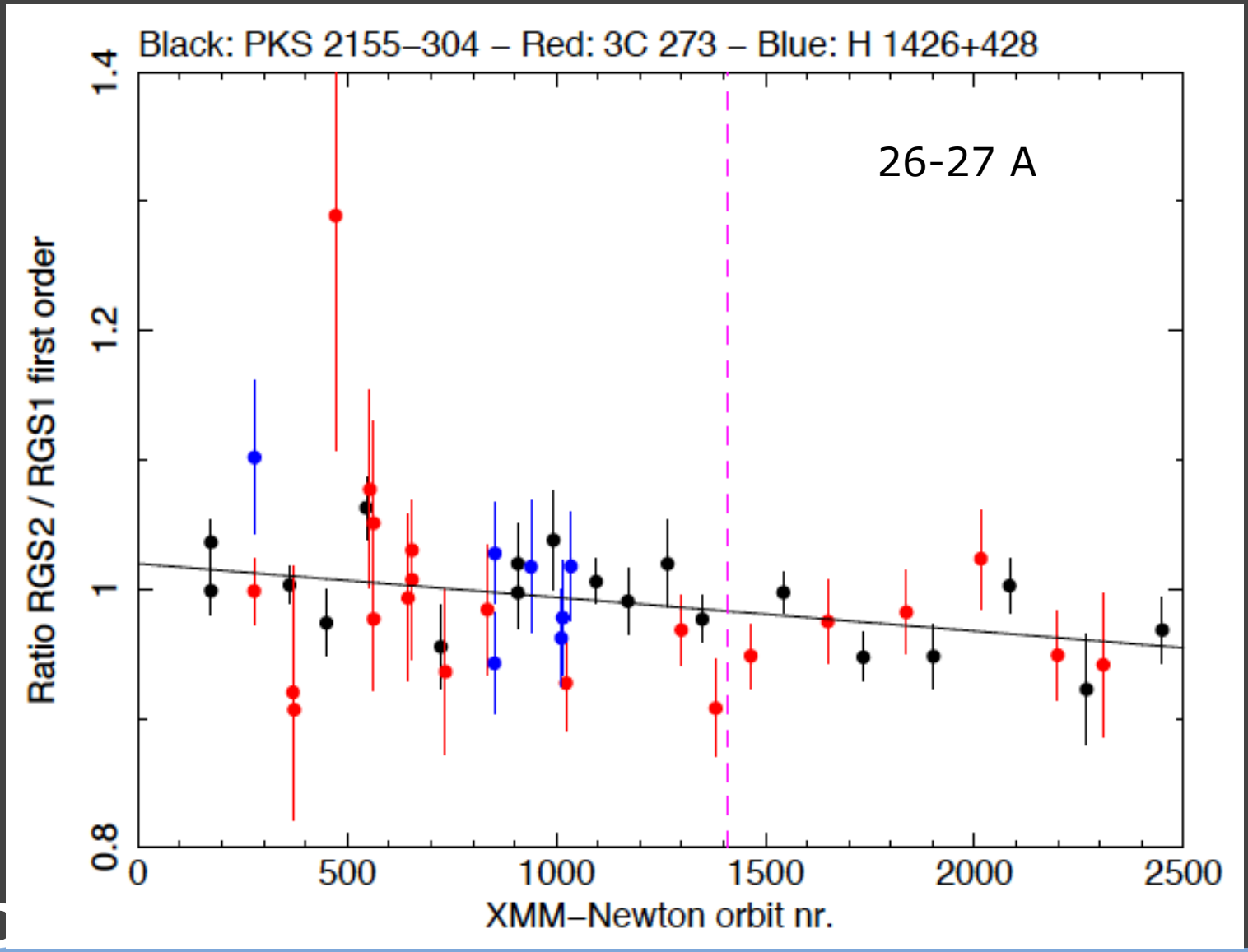
Trend in RGS2/RGS1 in 26-27 A band



Fitting trends to all RGS bands

Table 6: Fits to ratio $R(t)$ of RGS2 over RGS1 flux. Values given are averages over all 28 wavelength bins used. $H(x)$ is the Heaviside function ($H = 0$ for $x < 0$ and $H = 1$ for $x > 0$).

Model	$R(t) = a$	$R(t) = a + bt$	$R(t) = a + uH(t - 1408)$	$R(t) = a + bt + uH(t - 1408)$
χ^2	55.5	52.3	51.0	49.4
d.o.f.	44.6	44.5	44.4	43.6
a	0.987±0.003	1.011±0.004	0.996±0.003	1.006±0.004
$b/10^{-5}$	–	−2.3±0.3	–	−1.4±0.4
u	–	–	−0.031±0.004	−0.015±0.005

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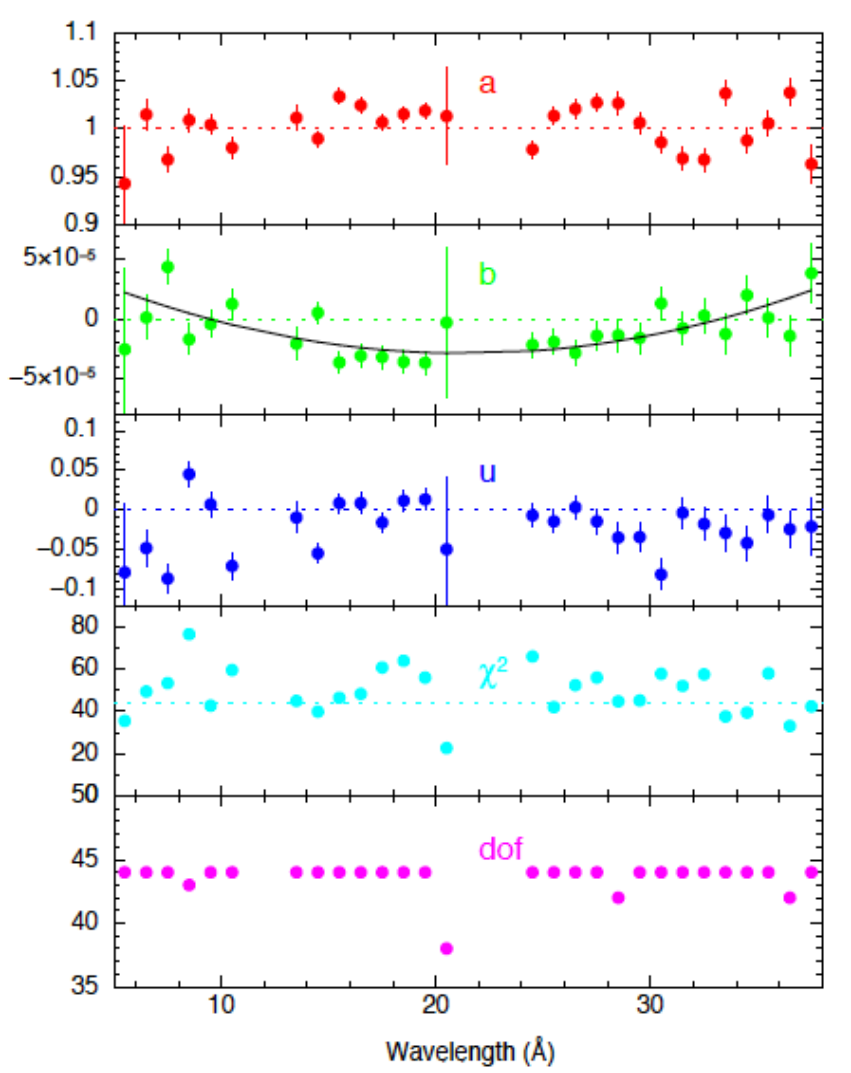
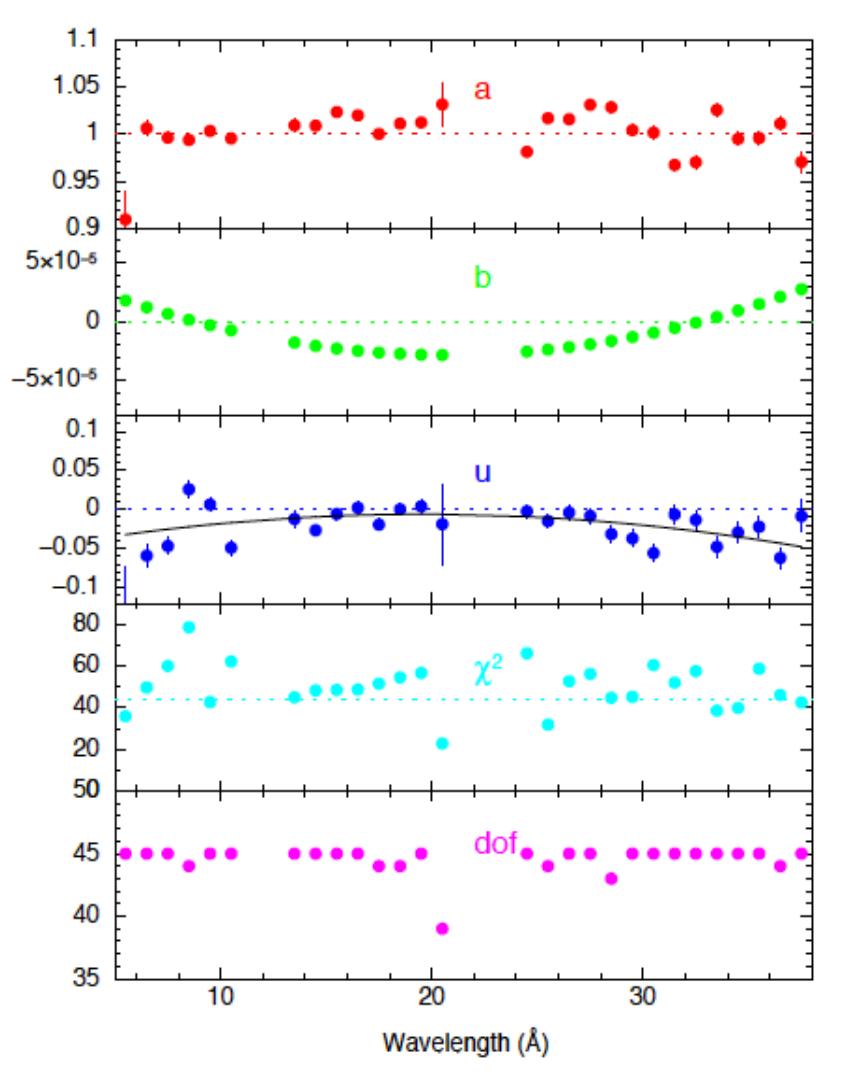
Fitting parameters trend and jump





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High-Resolution fitting

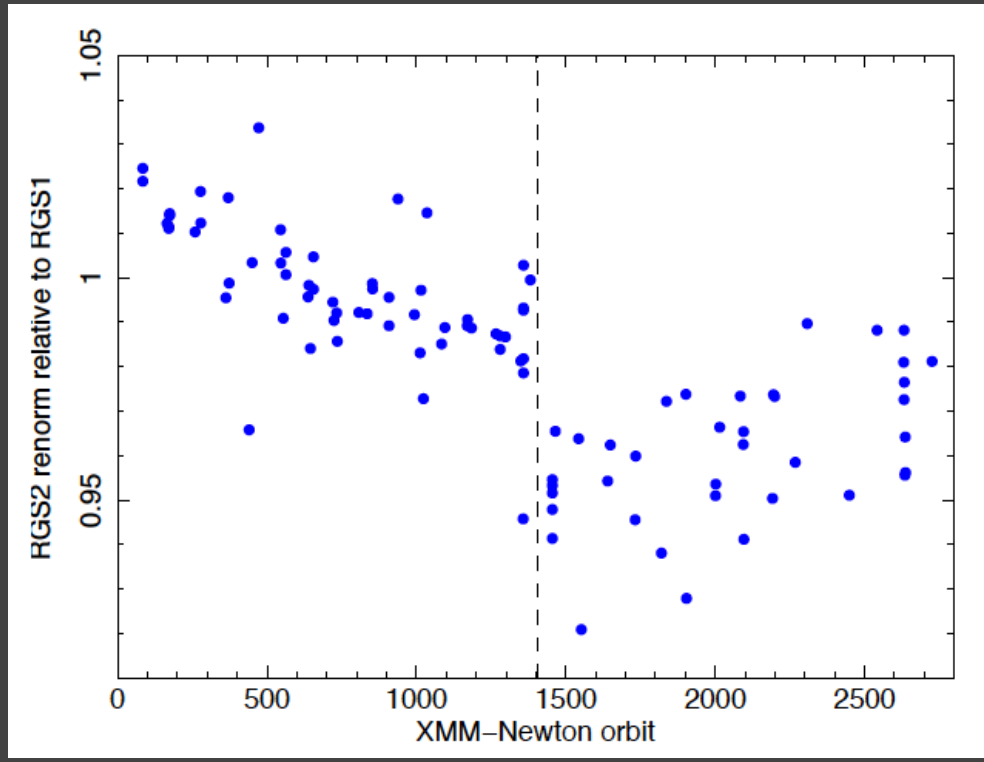
Improvements of the models:

- Including dust absorption in absorption models
- Include spectral curvature in power-law models

Conclusion:

RGS1 is stable with respect to EPIC pn, but RGS2 is not (although within 5%).

New RGS2 norm



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Empirical correction for time dependency

For each 0.05 Å wide bin, we determine the fit residuals for each individual observation relative to the best-fit broken power-law model described in the previous section. We then fit these residuals as a function of time to a simple analytical expression. This is done for first and second order spectra independently.

It the observation epoch is denoted by t, expressed in units of 1000 orbits, then we use the following parameterisation:

- $t < 0.538$: $f = p_1 + (t/0.538)p_2$
- $0.538 < t < 1.408$: $f = p_1 + p_2 + p_6 + ((t - 0.538)/0.870)p_3$
- $1.408 < t < 2.112$: $f = p_1 + p_2 + p_3 + p_6 + p_7 + ((t - 1.408)/0.704)p_4$
- $2.112 < t < 2.816$: $f = p_1 + p_2 + p_3 + p_4 + p_6 + p_7 + ((t - 2.112)/0.704)p_5$

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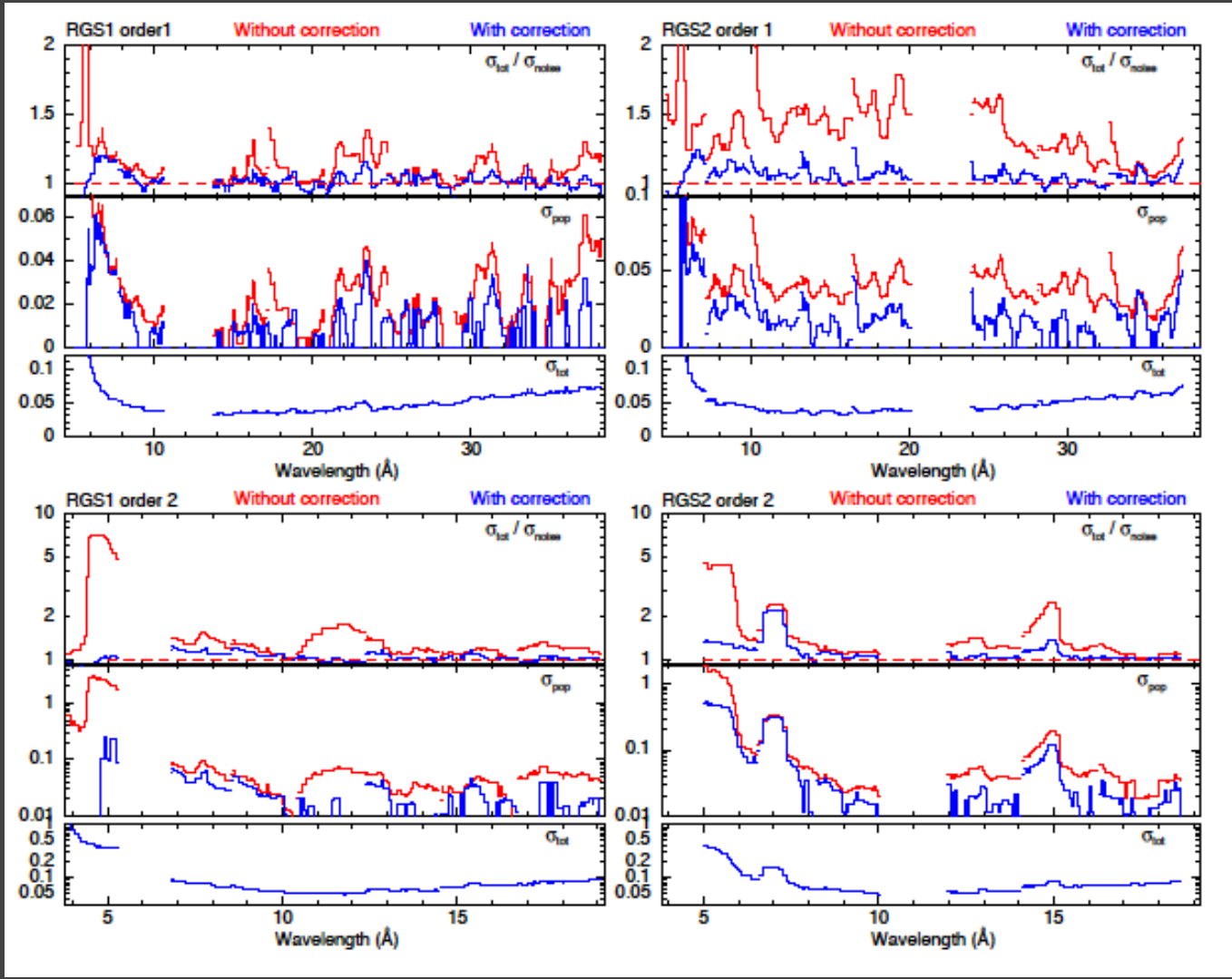
Scatter reduction before and after correction



$\sigma_{tot}/\sigma_{noise}$

σ_{pop}

σ_{tot}

$\sigma_{tot}/\sigma_{noise}$

σ_{pop}

σ_{tot}

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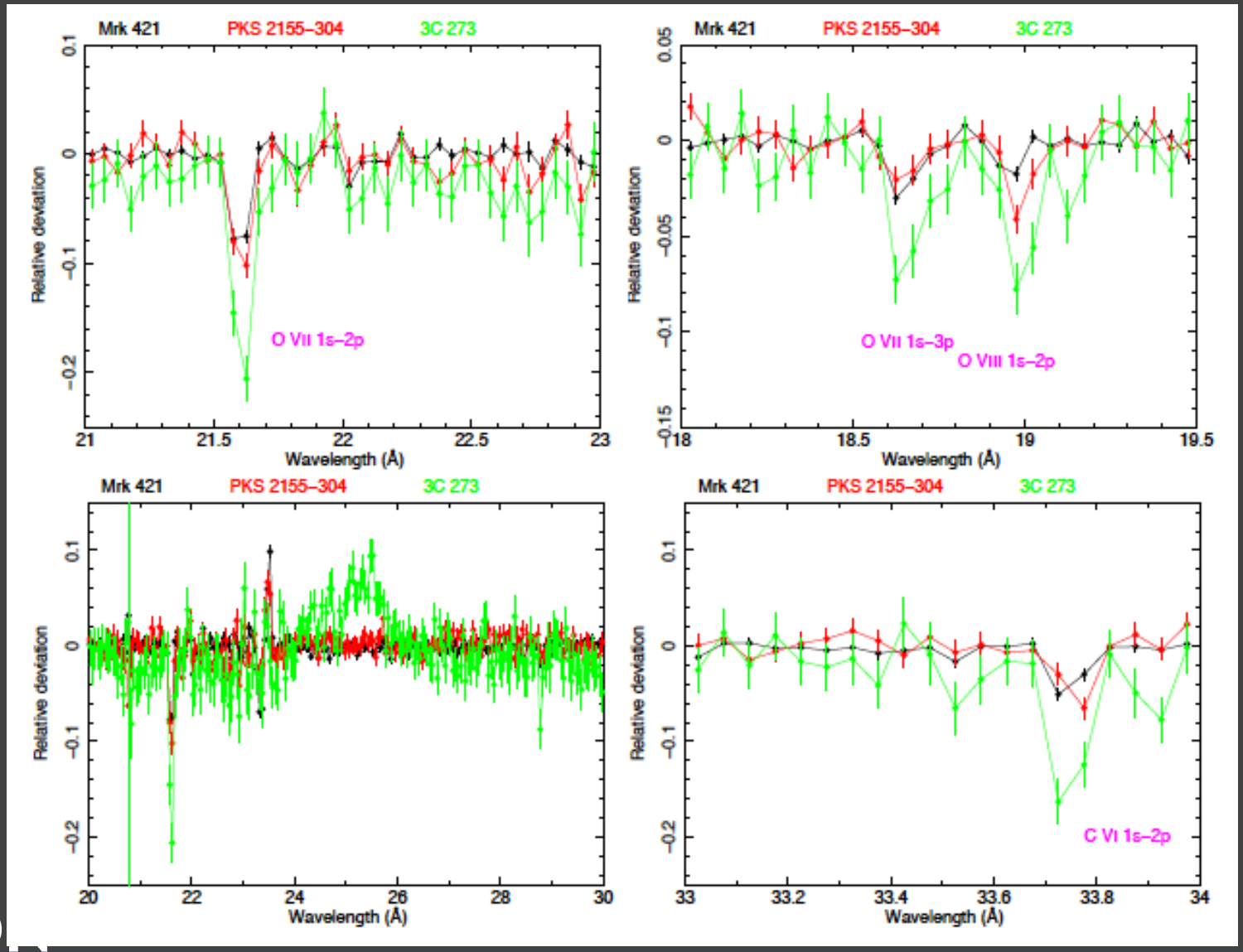
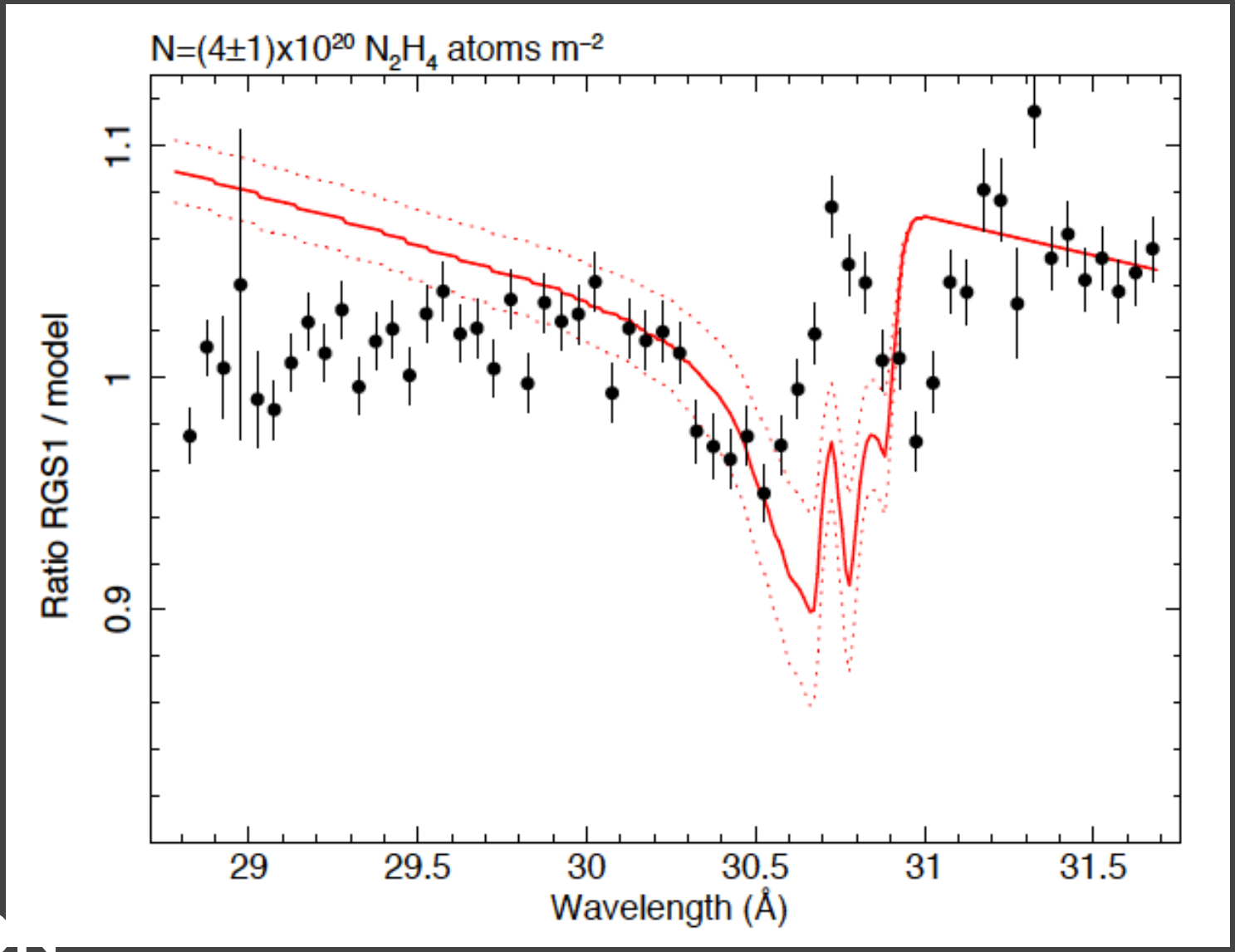
Stacked residuals in bands



Possible hydrazine contamination?



Conclusions

- Effective area of RGS is generally stable within 5%.
- RGS1 is more stable with respect to PN than RGS2.
- Using empirical fits to time dependent behavior of RGS, we can correct the calibration and reduce systematic scatter to 1-2%

- Indications for contamination of Hydrazine detectable near 30-31 A.

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