Calibration uncertainties and thermal line models

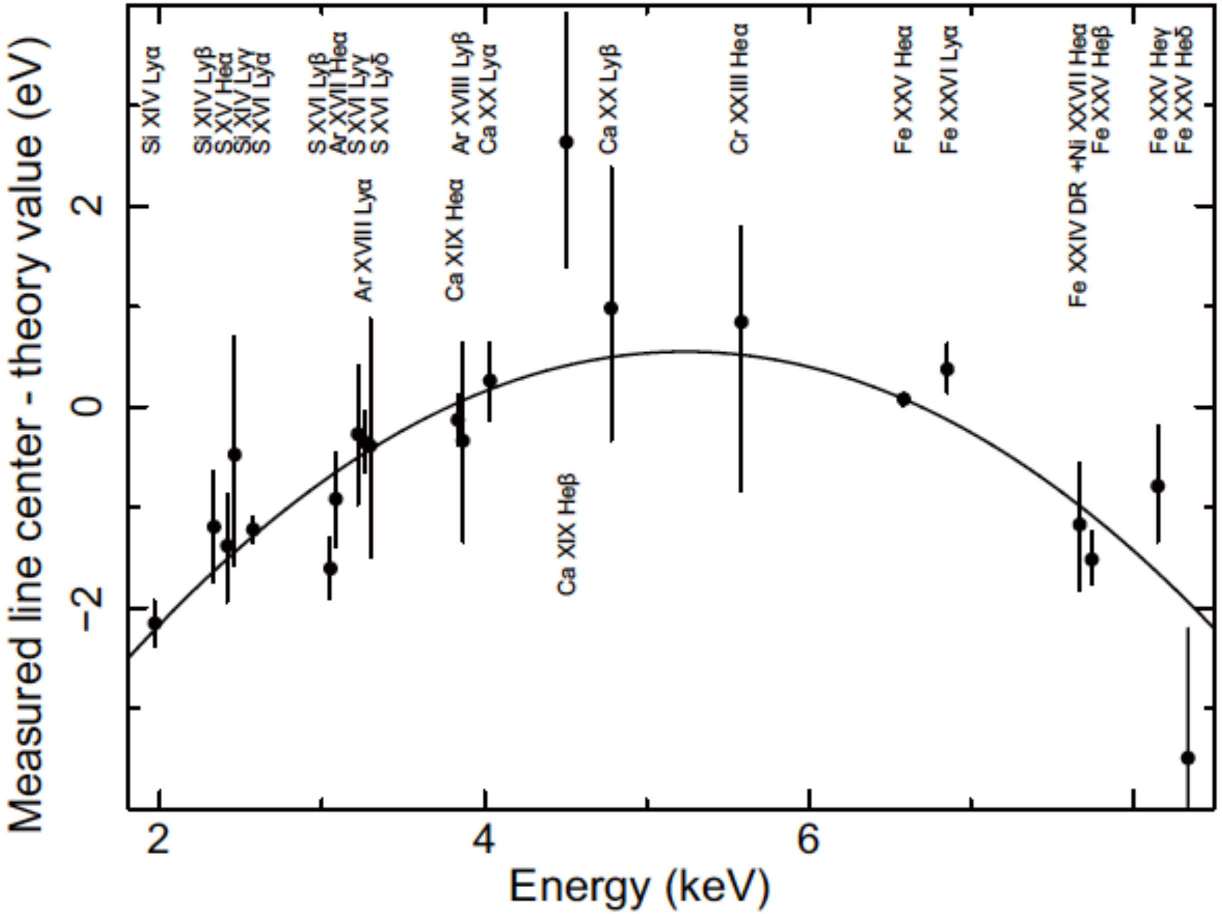
Jelle Kaastra

SRON

Example: Hitomi Perseus spectrum

Intricate relation between calibration and thermal models

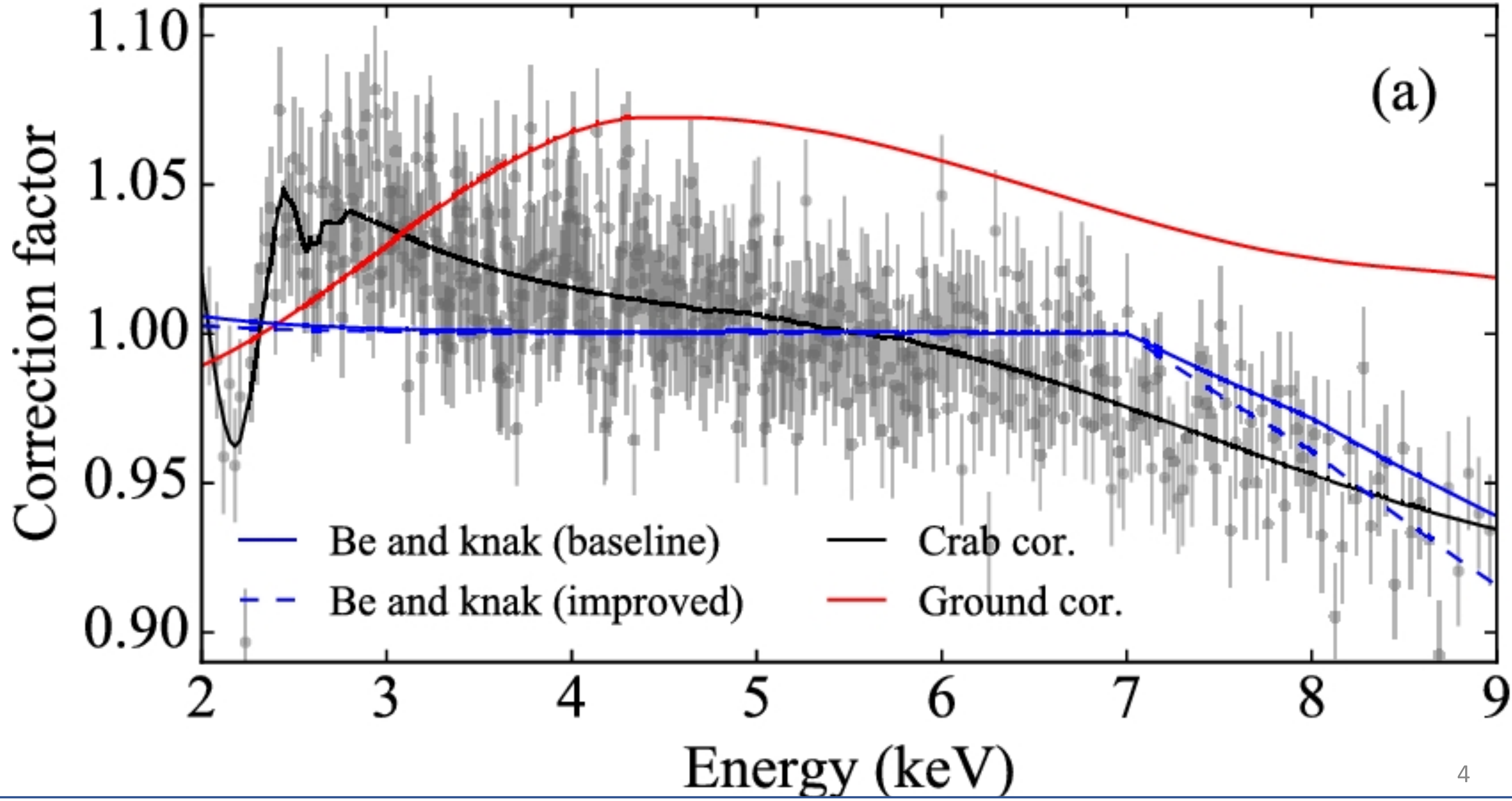
Energy scale corrections



Effective area corrections

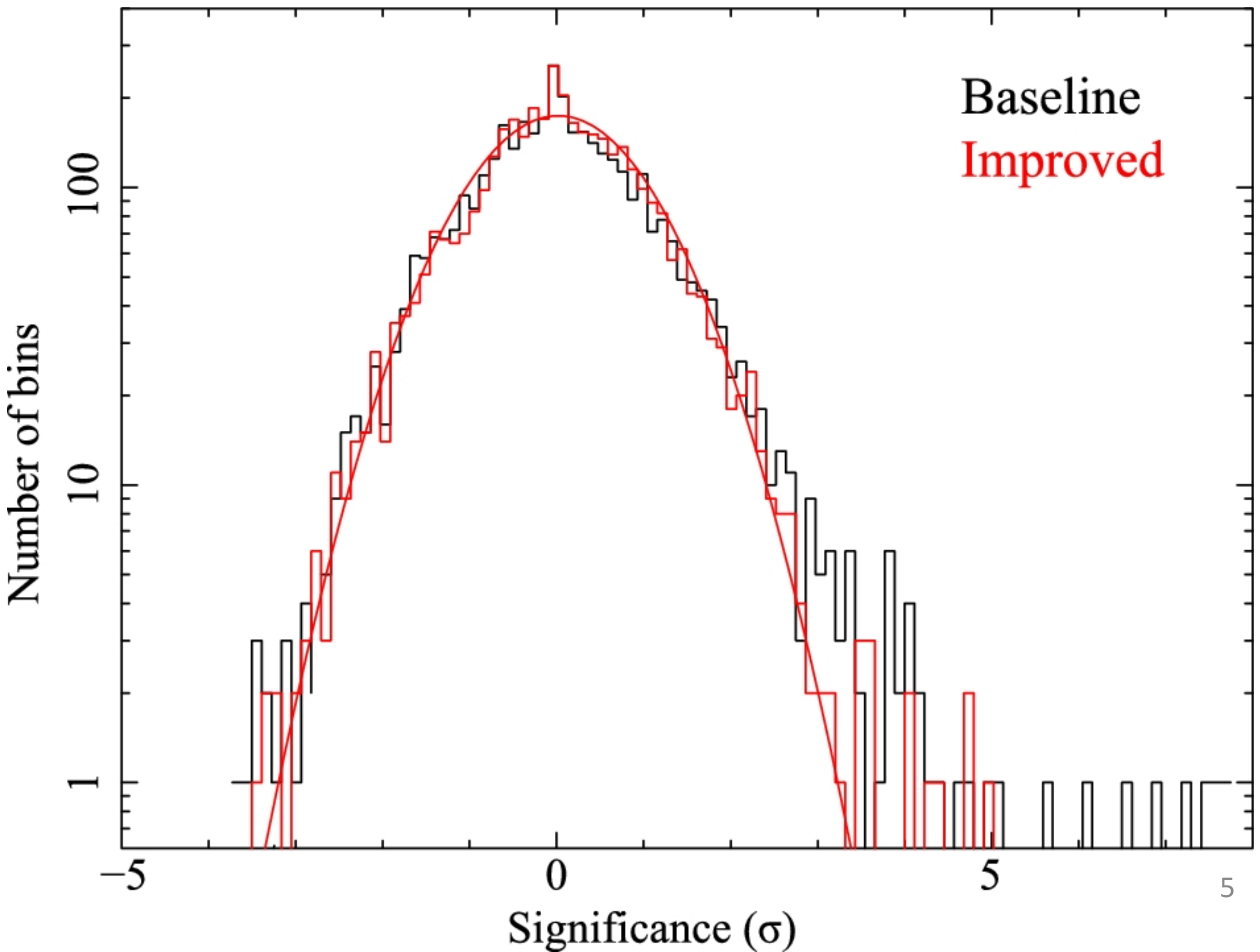
- Empirical correction based on fit of Perseus spectrum
- Correction based upon Crab

➔ *Relative agreement within 3%*



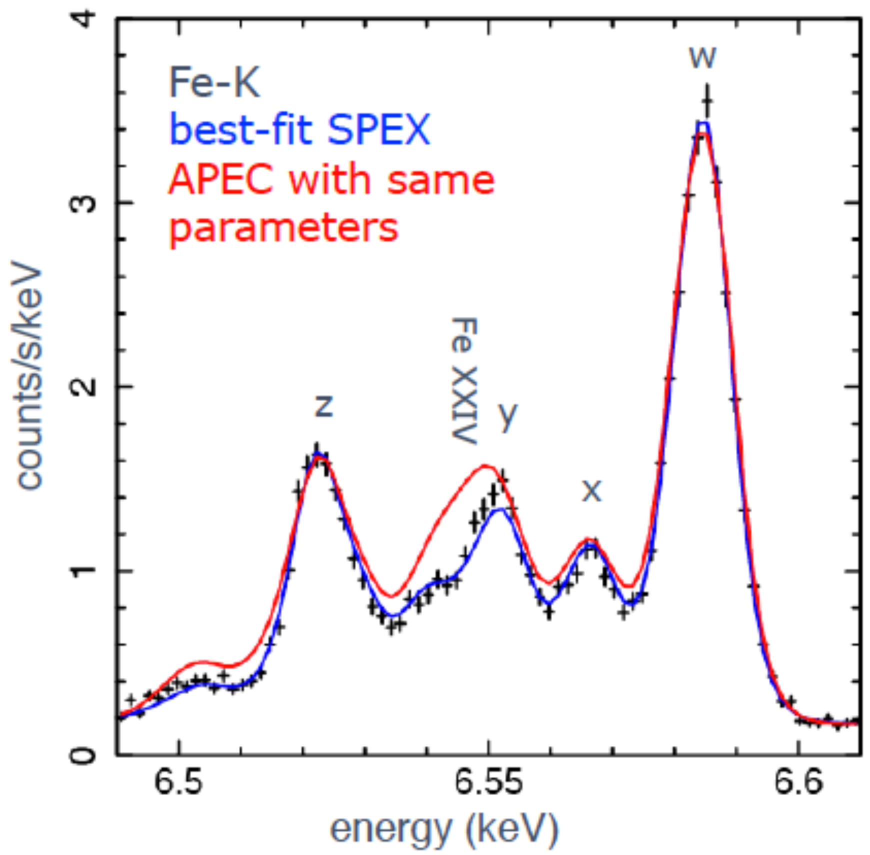
How good are the fits?

- Baseline model: 1T
- Improved model: multi-T structure
- Most residuals consistent with expected statistical distribution
- Outliers caused by errors on predicted line intensities



Details thermal models matter (more than calibration uncertainties?)

Problems to be solved



- state-of-art calculations can differ by up to 70% @ 4 keV
- Fe XXIV inner-shell radiative/Auger rates and branching ratios differ by up to 50%.
- As a result, Fe abundance differ by 16%.
- Similar difference in a few H-like excitations.

H/He/Li-like are the simplest systems!

Can thermal line models help calibration?

Thermal line models and effective area calibration

Can thermal line models help calibration?

NO:

- Source structure is in general more complex (multi-T)
- Source may contain additional non-thermal continuum components
- Line ratios no good alternative (narrow band, model uncertainties)

YES:

Relative stability over time (extended sources). Needs:

- accurate repointing (same part source at same detector part)
- lots of photons
- good enough spatial resolution (to get rid of psf effects)
- no strong contamination by variable point sources through psf
- Interesting for Athena?

Thermal line models and energy calibration

Can thermal line models help calibration?

Yes:

sure for testing stability E-scale, but:

- clusters best targets (calorimeters!) because lines intrinsically stable;
- SNR have intrinsic broader lines but also stable
- stars okay-ish, but up to 100 km/s uncertainty:
  - binary star orbits
  - Binary star rotation (combined with “hot spots”)
  - Flares

Thermal line models and lsf calibration

Can thermal line models help calibration?

Yes:

(with same caveats as E-scale for stars)

But:

- Need to understand intrinsic (source) broadening
- clusters not good (turbulence, position dependent)

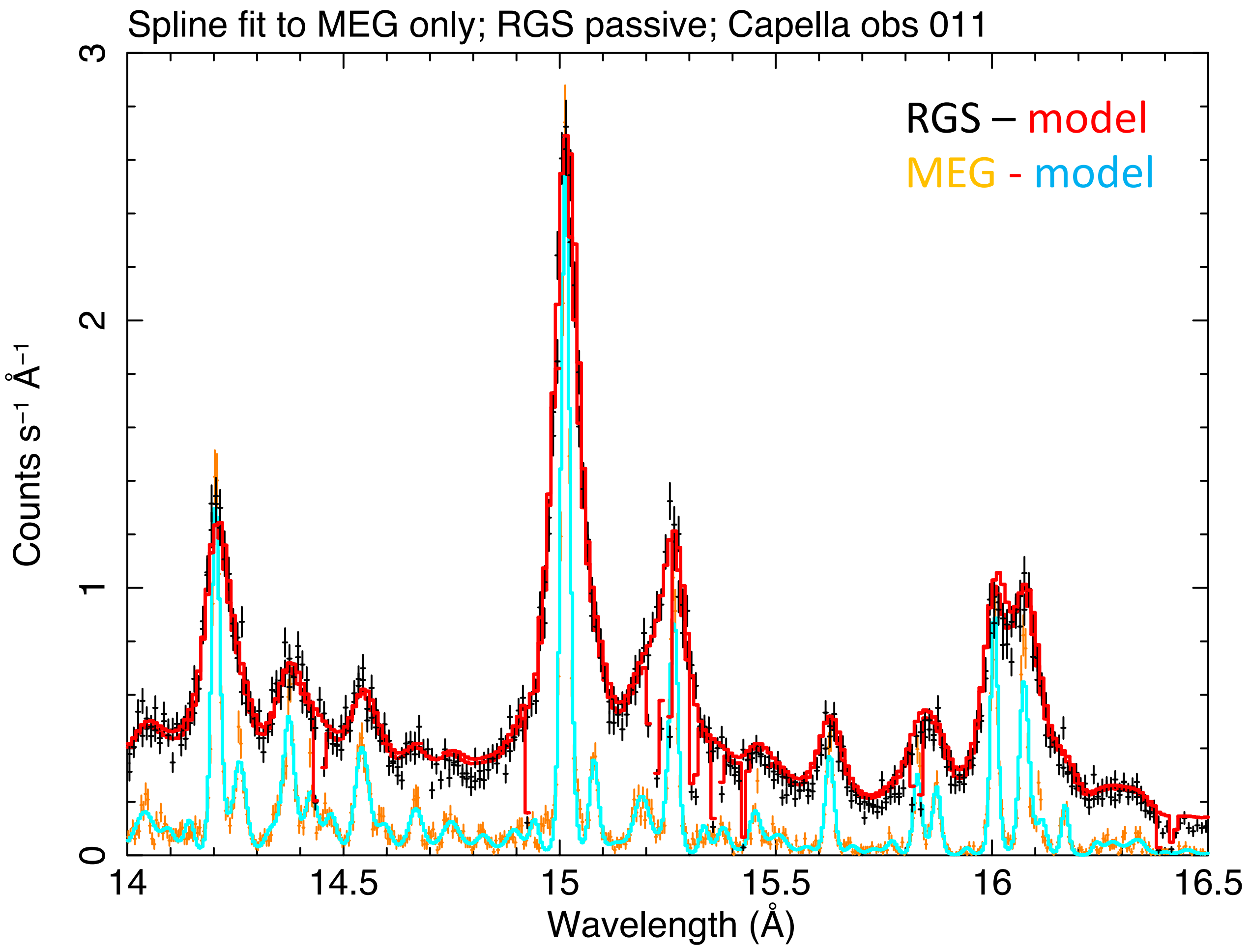
Some aspects of grating spectrometers calibration

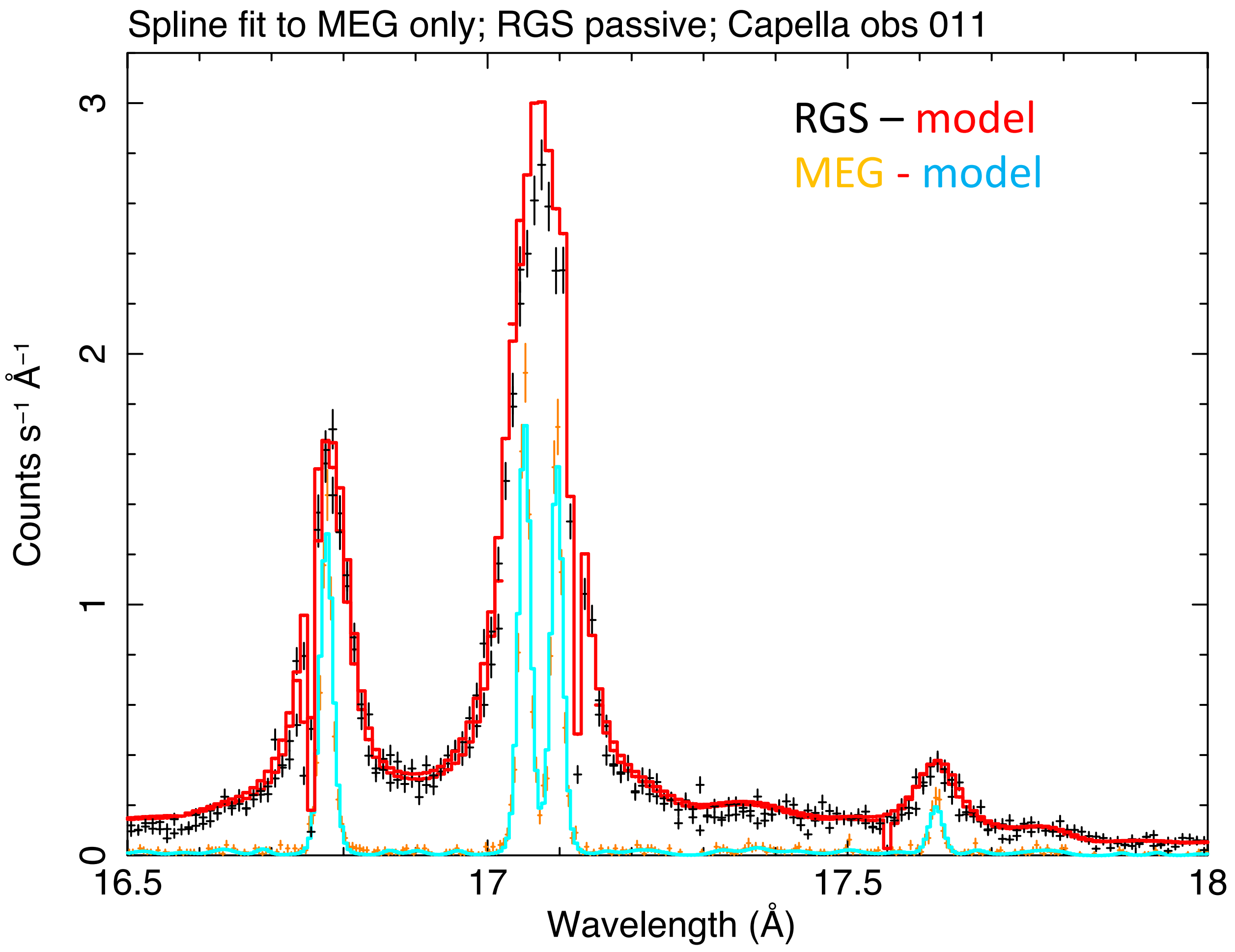
Simultaneous data RGS with Chandra gratings

- Use 76 data sets

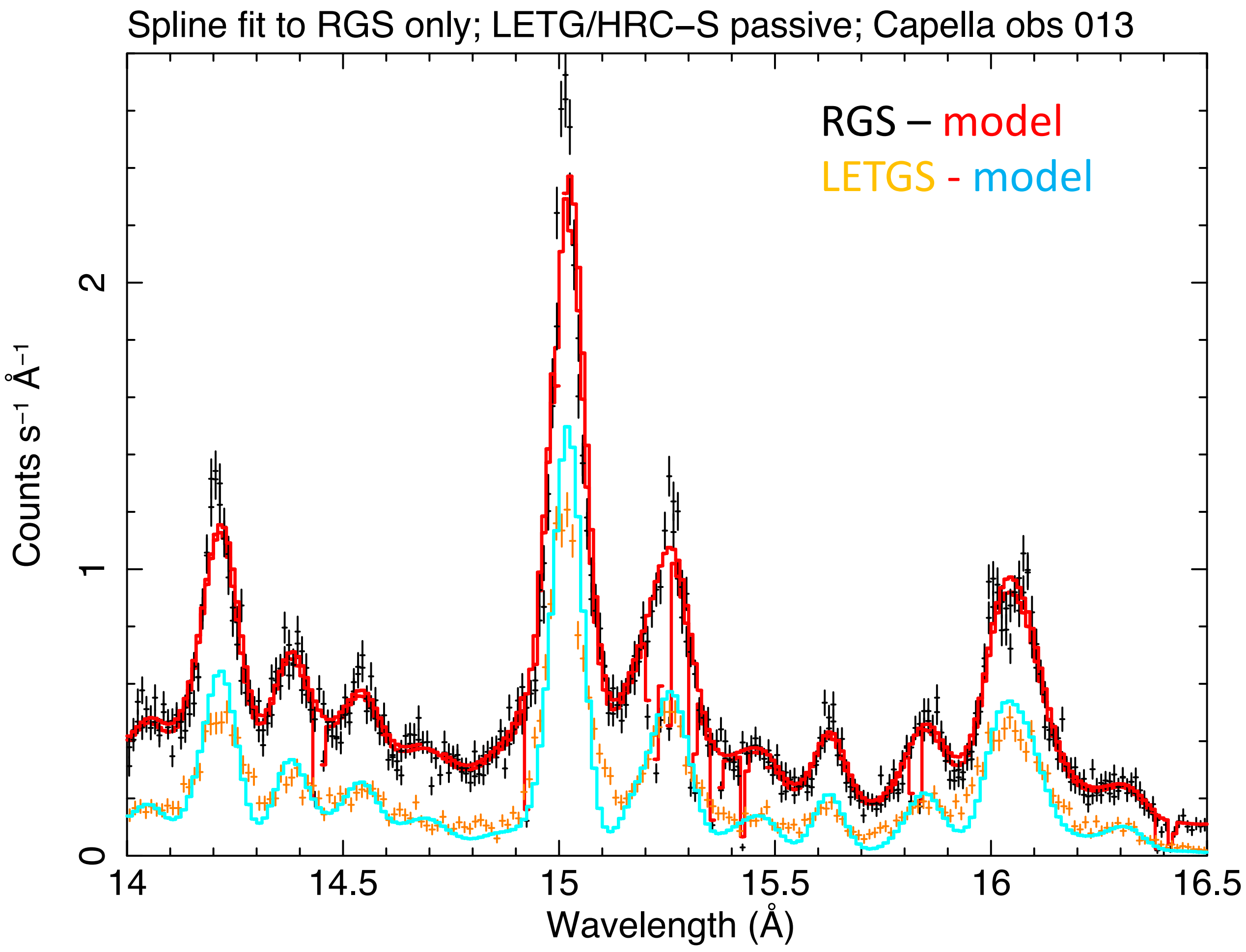
Class/Conf	HETGS	LETG/ACIS-S	LETG/HRC-S
Capella	3	1	3
Other stars	1 (RS Oph)		4 (UX Ari, YY Gem)
Total Stars	4	1	7
3C 273	9	3	1
PKS 2155-304	4	10	8
Other AGN	23	2	
Total AGN	36	15	9
Other	3 (Cyg X1,2,3)		1 (ASASSN-14li)
Total	**43**	**16**	**17**

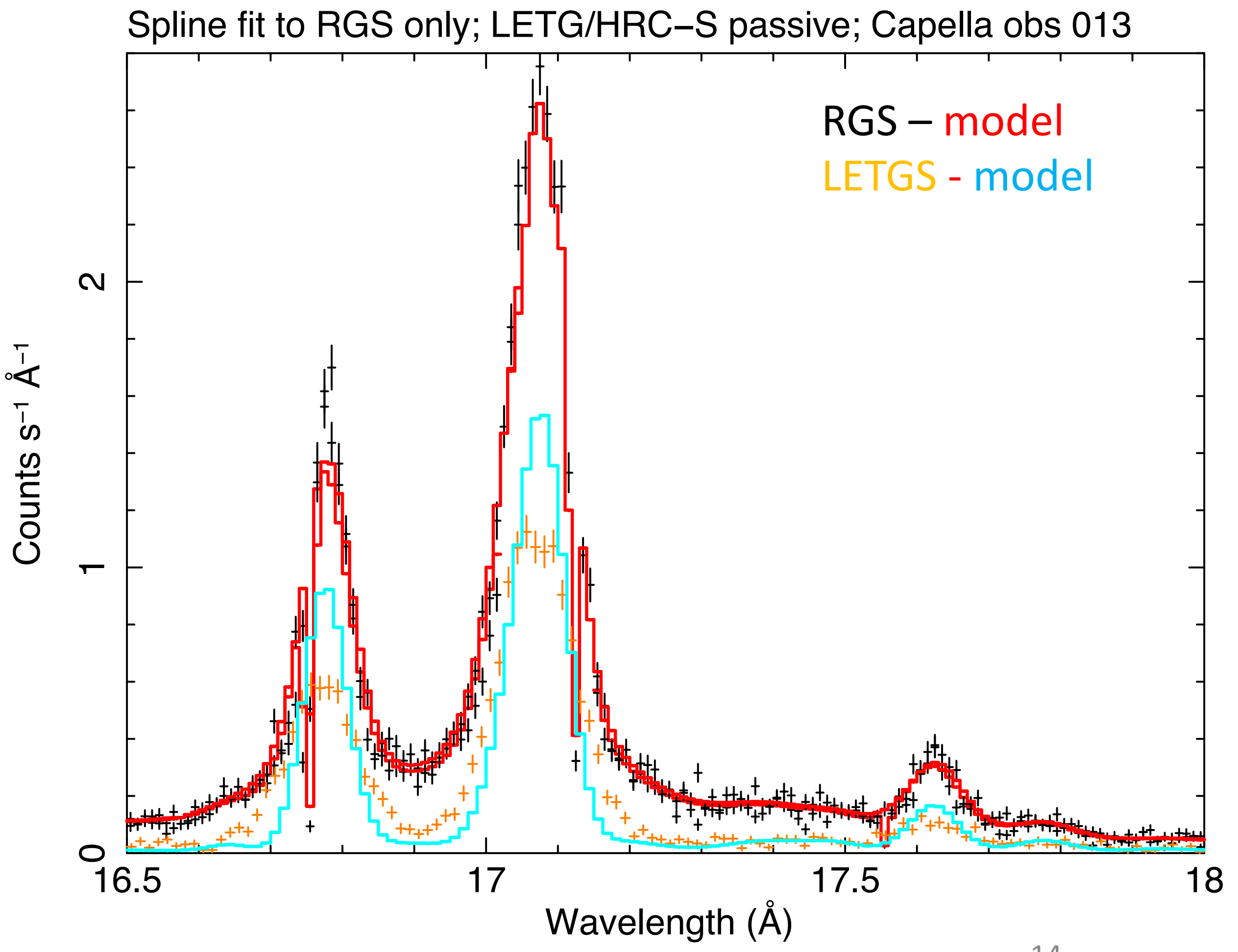
Good match MEG model with RGS data



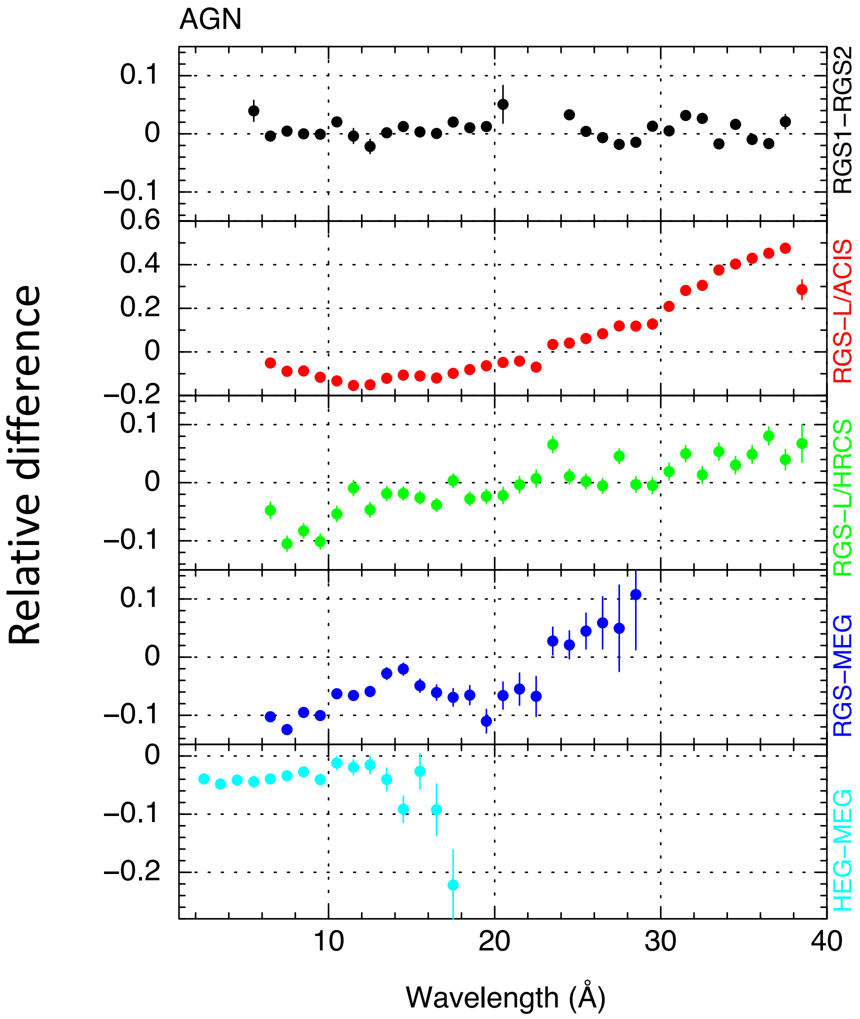


Reasonable results for short wavelength LETG
(quite) different lsf at intermediate λ





Effective area comparisons
using simultaneous AGN (blazar) observations

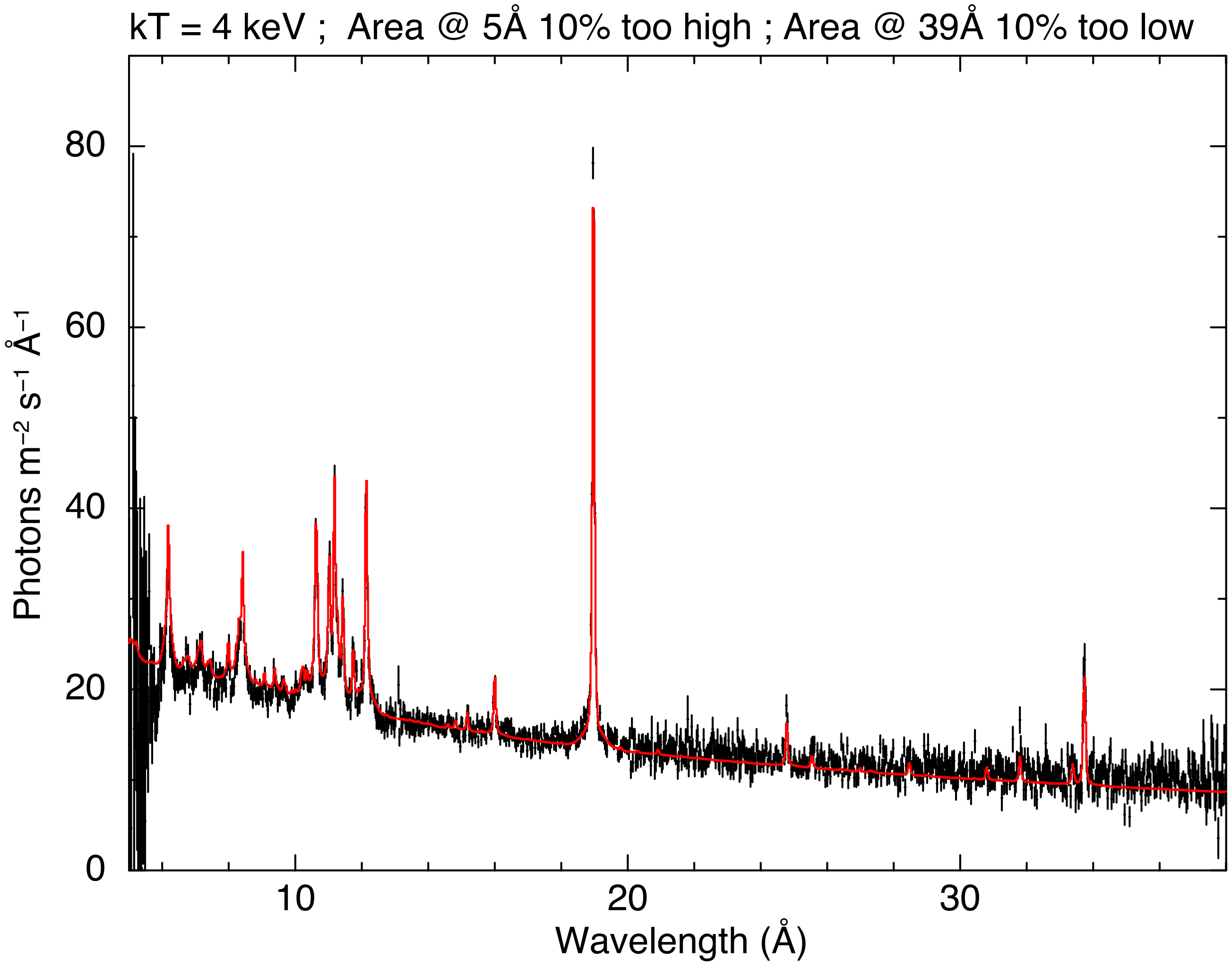


Preliminary conclusions

- LSF's:
  - from MEG-RGS comparison, fair agreement
  - LETG/HRC-S and RGS disagree strongly; issues with LETGS lsf??
- Effective area:
  - Fair agreement RGS and LETG/HRC-S (but 20% gradient from 10-40 Å ….)
  - Strong disagreement RGS with ACIS (MEG, LETG) at long λ : ACIS contamination issues, and/or RGS time degradation?

How do calibration uncertainties affect thermal model parameters?

RGS 1-T model with power law effective area error

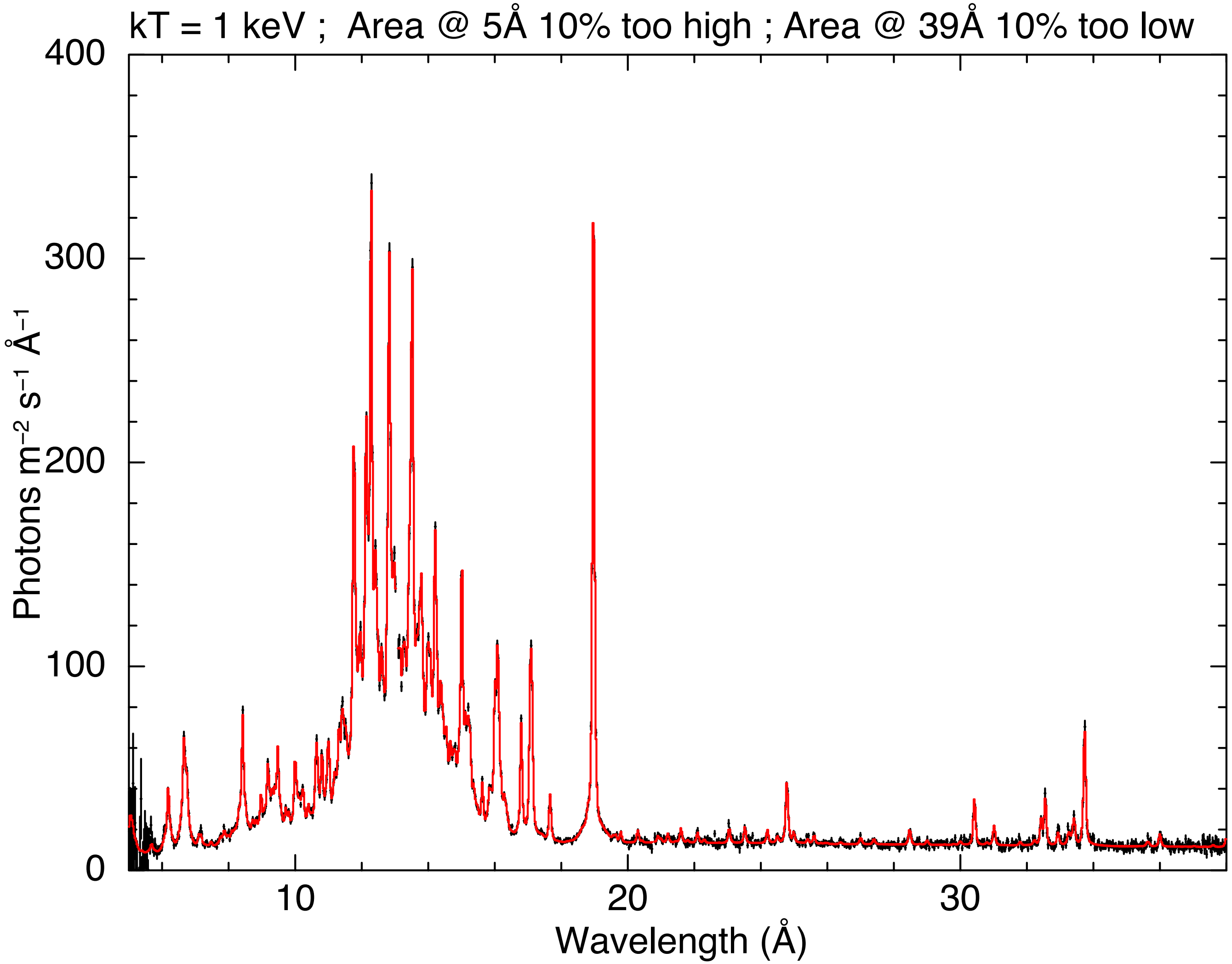


RGS 1-T model with power law effective area error kT = 4 keV

Parameter	Input value	Fit 1	Fit 2	“True” fit
Norm	10000	9964±25	10213±28	10009±30
T (keV)	4	3.88±0.04	2.94±0.05	4.01±0.08
C	1		0.84±0.07	1.04±0.09
N	1		0.62±0.09	0.81±0.12
O	1		0.72±0.02	0.99±0.03
Ne	1		0.64±0.03	1.01±0.05
Mg	1		0.67±0.04	1.05±0.06
Si	1		0.61±0.05	0.93±0.07
Fe	1		0.56±0.02	0.99±0.04
Cstat	1116±47	1582	1177	1087

- Fit 1 not acceptable (too high Cstat)
- Fit 2 (free abundances) would be accepted
- Strong bias in T (> 1 keV!)
- Abundances too low (almost up to 2x)
- Errors on parameters underestimated (almost up to2x)

RGS 1-T model with power law effective area error

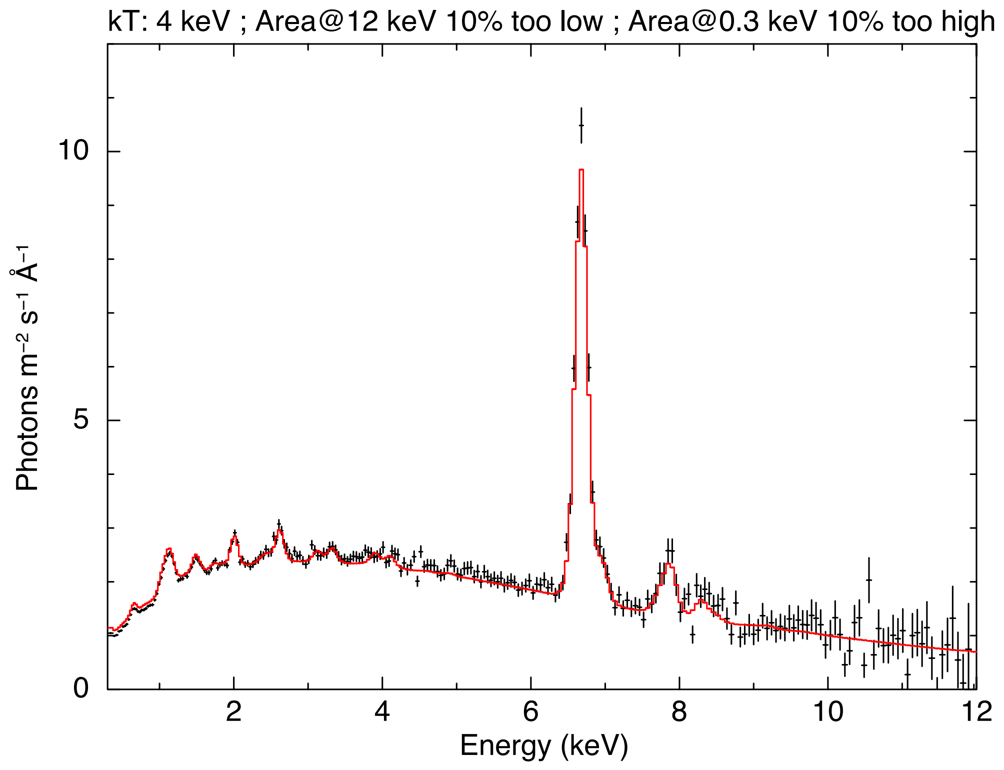


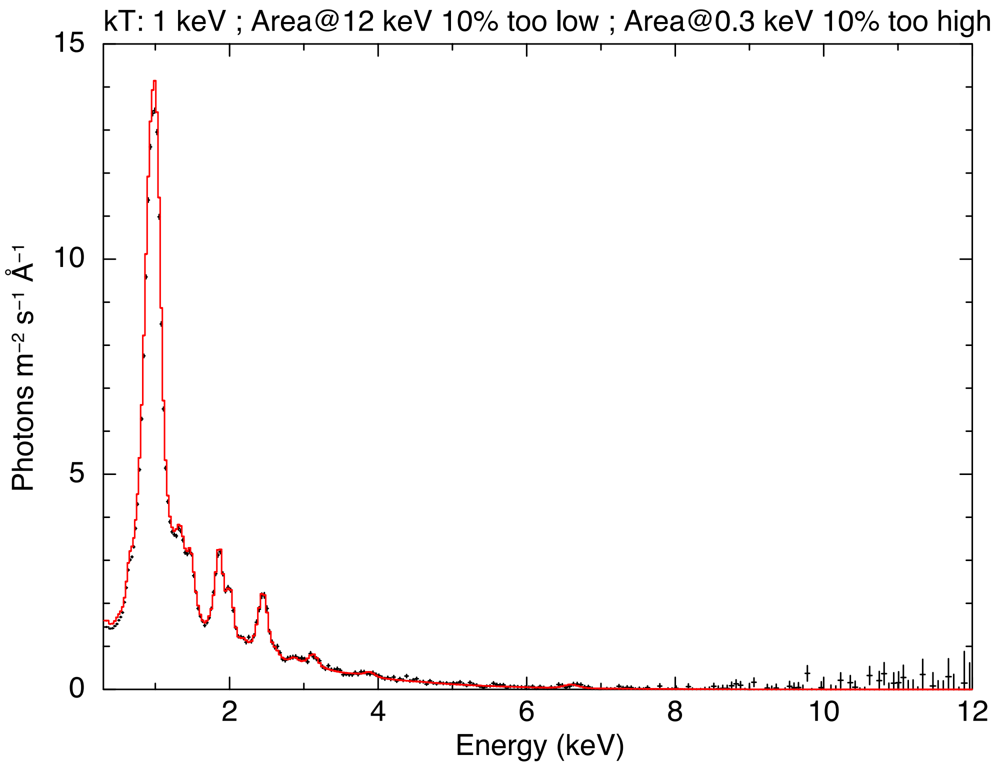
RGS 1-T model with power law effective area error kT = 1 keV

Parameter	Input value	Fit 1	Fit 2	"True" fit
Norm	10000	9942±16	10479±37	10015±36
T (keV)	1	0.998±0.001	0.994±0.001	1.000±0.001
C	1		1.05±0.03	1.00±0.03
N	1		0.97±0.04	0.97±0.04
O	1		0.96±0.01	1.00±0.01
Ne	1		0.90±0.02	0.99±0.02
Mg	1		0.84±0.01	0.98±0.02
Si	1		0.83±0.01	0.93±0.02
Fe	1		0.912±0.005	0.997±0.005
Cstat	1115±47	1808	1305	1086

- Fit 1 not acceptable (too high Cstat)
- Fit 2 (free abundances) would likely be accepted
- Weak bias in T (< 1%)
- Abundances off (up to 15%)
- Errors on parameters OK

Pn 1-T model with power law effective area error





Summary

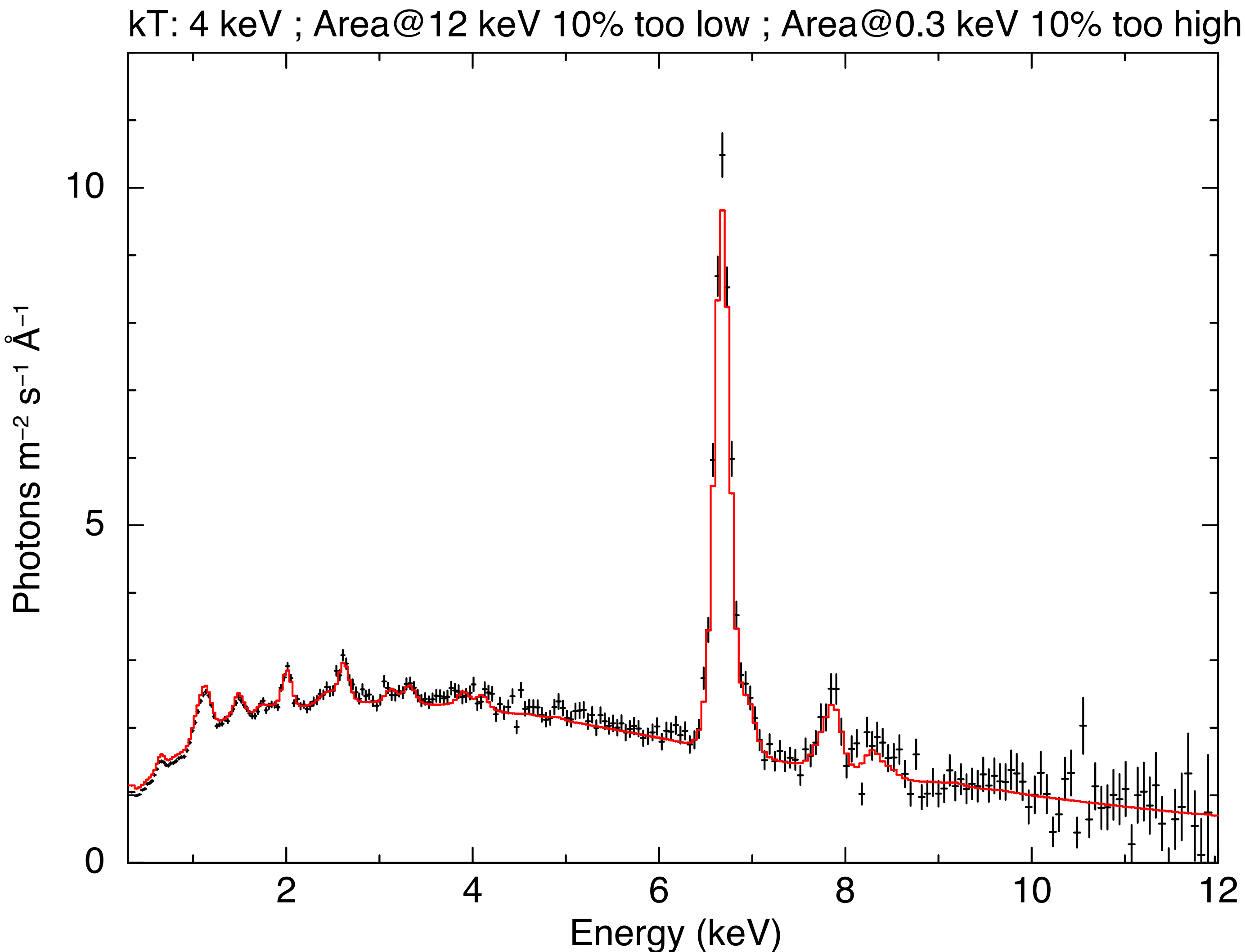
Case	RGS 4 keV	RGS 1 keV	Pn 4 keV	Pn 1 keV
C-stat	no	Modest	Modest	modest
T	25%	No	10%	No
Abundances	50%	15%	50%	15%

Lessons learned:

- Modest effective area uncertainty can give strong bias on derived astrophysical parameters
- Even if the fit is "good", the results can be "wrong"
- Bias depends on:
  - Source model
  - Instrument & energy range
  - Shape of effective area deviations

Backup info

Pn 1-T model
with power law effective area error

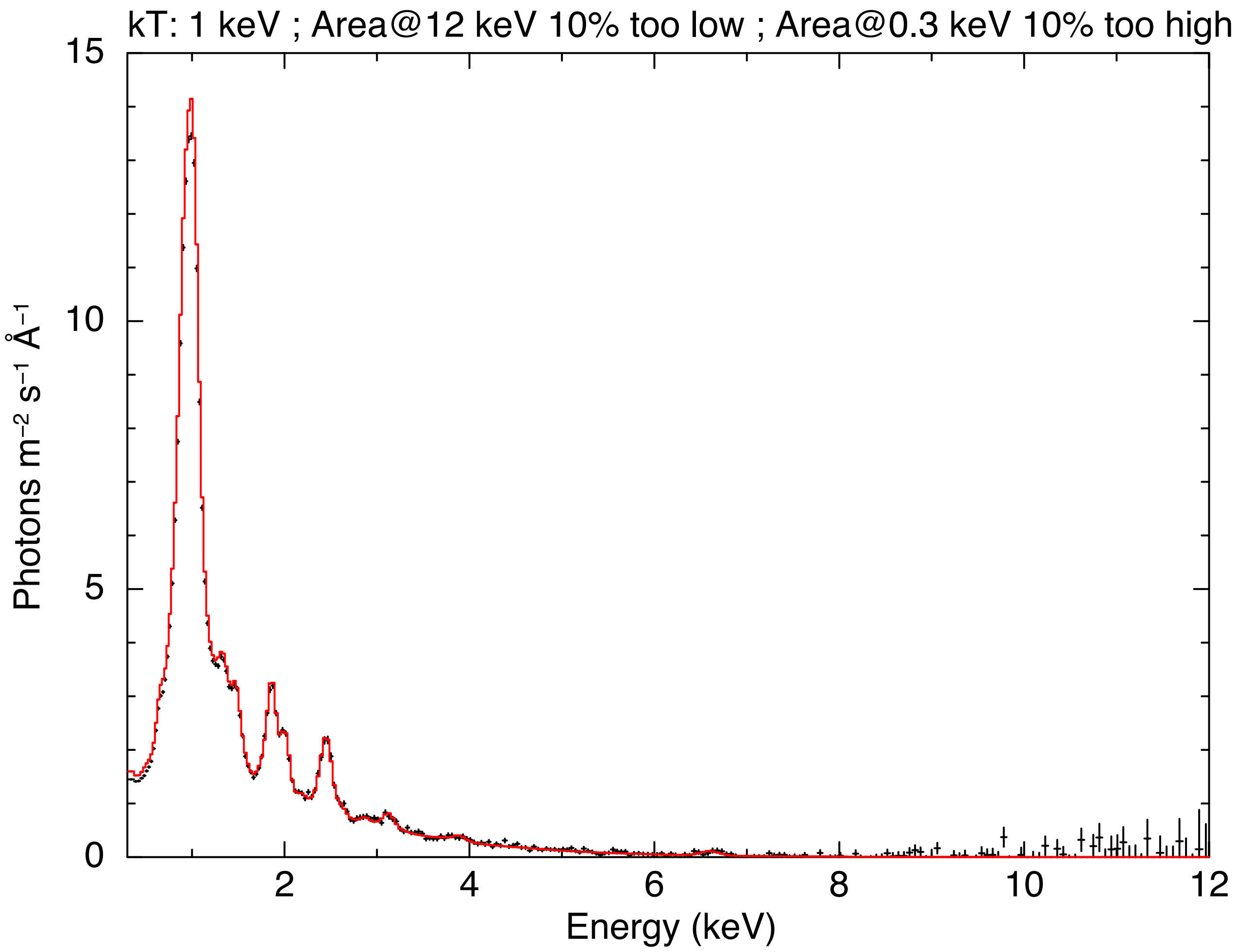


Pn 1-T model with power law effective area error kT = 4 keV

Parameter	Input value	Fit 1	Fit 2	"True" fit
Norm	1000	970.0±1.4	945±5	1004±5
T (keV)	4	4.41±0.02	4.38±0.02	4.04±0.02
O	1		0.95±0.06	0.93±0.06
Ne	1		1.41±0.09	1.00±0.08
Mg	1		1.58±0.11	1.05±0.09
Si	1		1.37±0.06	1.01±0.05
S	1		1.18±0.09	0.81±0.07
Fe	1		1.13±0.02	1.00±0.07
Ni	1		1.06±0.20	0.77±0.17
Cstat	259±23	517	352	227

- Fit 1 not acceptable (too high Cstat)
- Fit 2 (free abundances) would be accepted??
- Bias in T (10 %)
- Abundances too high (up to 50%)
- Errors on parameters slightly over-estimated

Pn 1-T model with power law effective area error



Pn 1-T model with power law effective area error
kT = 1 keV

Parameter	Input value	Fit 1	Fit 2	"True" fit
Norm	1000	959±1	914±5	1002±5
T (keV)	4	1.003±0.001	1.007±0.002	1.002±0.002
O	1		1.04±0.02	0.98±0.02
Ne	1		0.91±0.09	0.87±0.09
Mg	1		1.17±0.02	1.00±0.02
Si	1		1.15±0.01	1.01±0.01
S	1		1.13±0.03	0.98±0.03
Fe	1		1.10±0.02	1.02±0.02
Ni	1		0.85±0.10	0.92±0.10
Cstat	262±23	637	366	266

- Fit 1 not acceptable (too high Cstat)
- Fit 2 (free abundances) would be accepted??
- Weak bias in T (< 1%)
- Abundances too high (almost up to 15%)
- Errors on parameters OK