DEEP RGS OBSERVATIONS OF CLUSTERS

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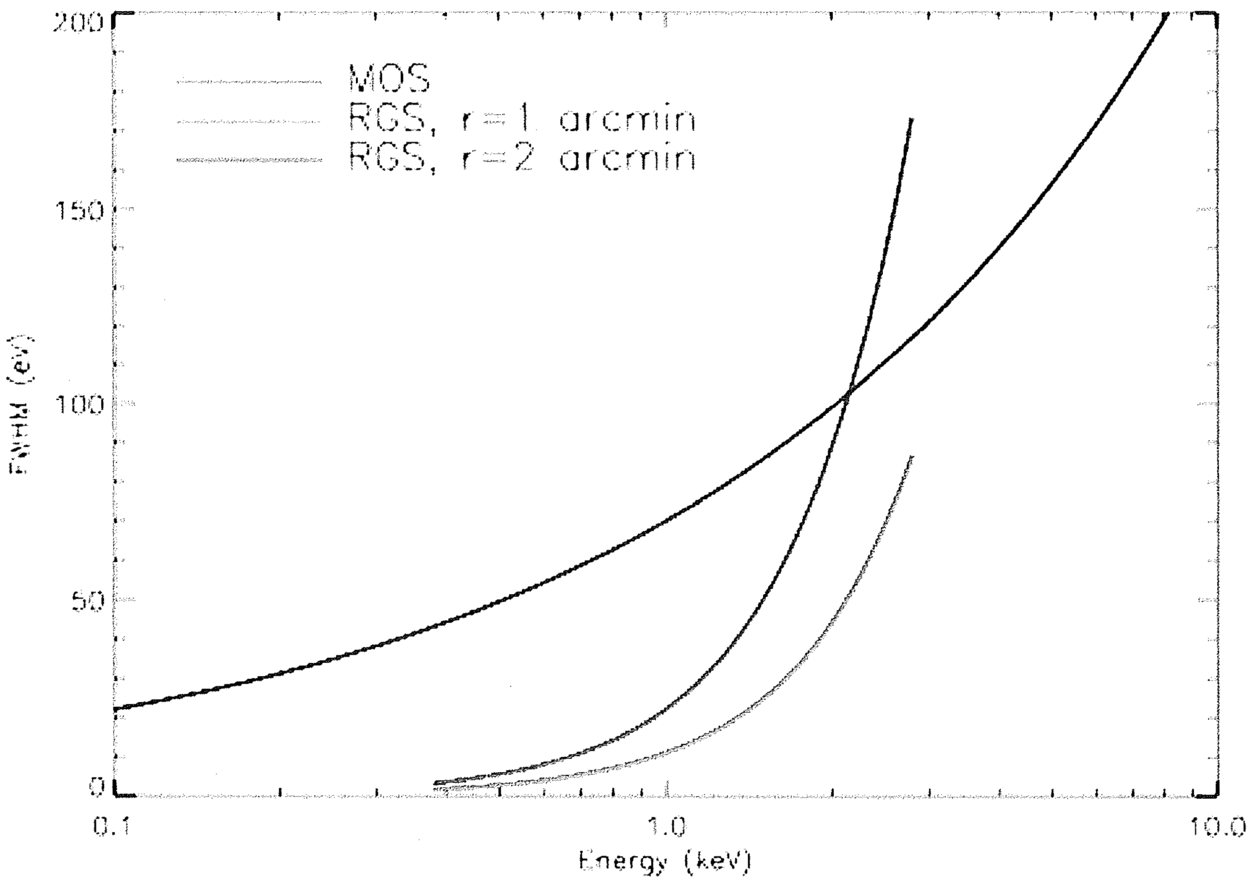
Goals for High Resolution Observations

- Basics (*i.e.*, published results)
  - Measured (core) cluster temperature
  - Measured cluster abundances

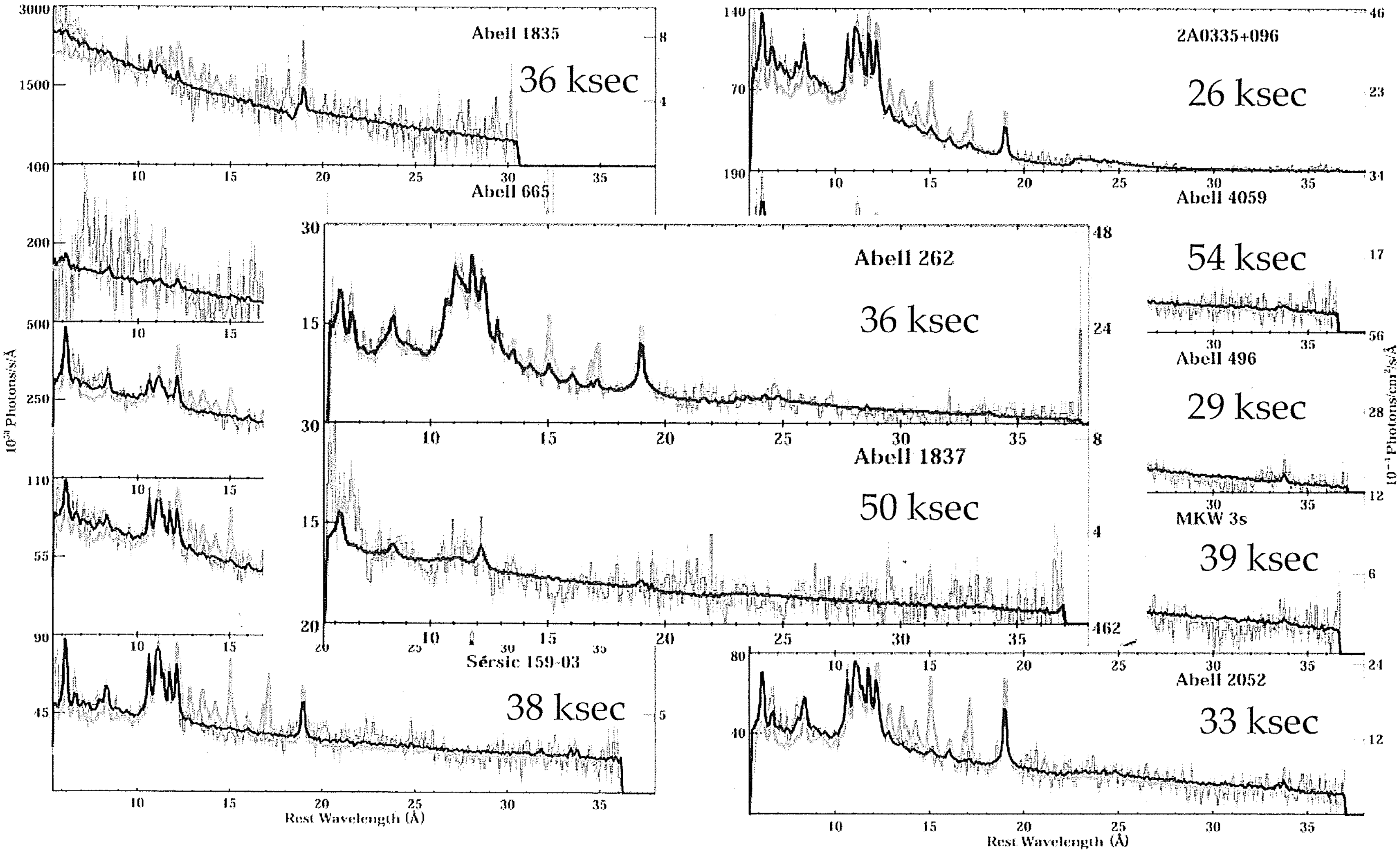
- Advanced (*i.e.*, more data needed?)
  - Detect line broadening due to turbulence
  - Detect resonant scattering

Resolution: RGS vs EPIC



$$\Delta\lambda = 0.138\,\text{Å}\,\frac{r_{arcmin}}{\text{order}}$$

(Partial) Review of Existing Observations/Results



Peterson et al 2003: Cluster cooling flows don't cool.

(Partial) Review of Existing Observations/Results

Clusters with Published RGS Observations

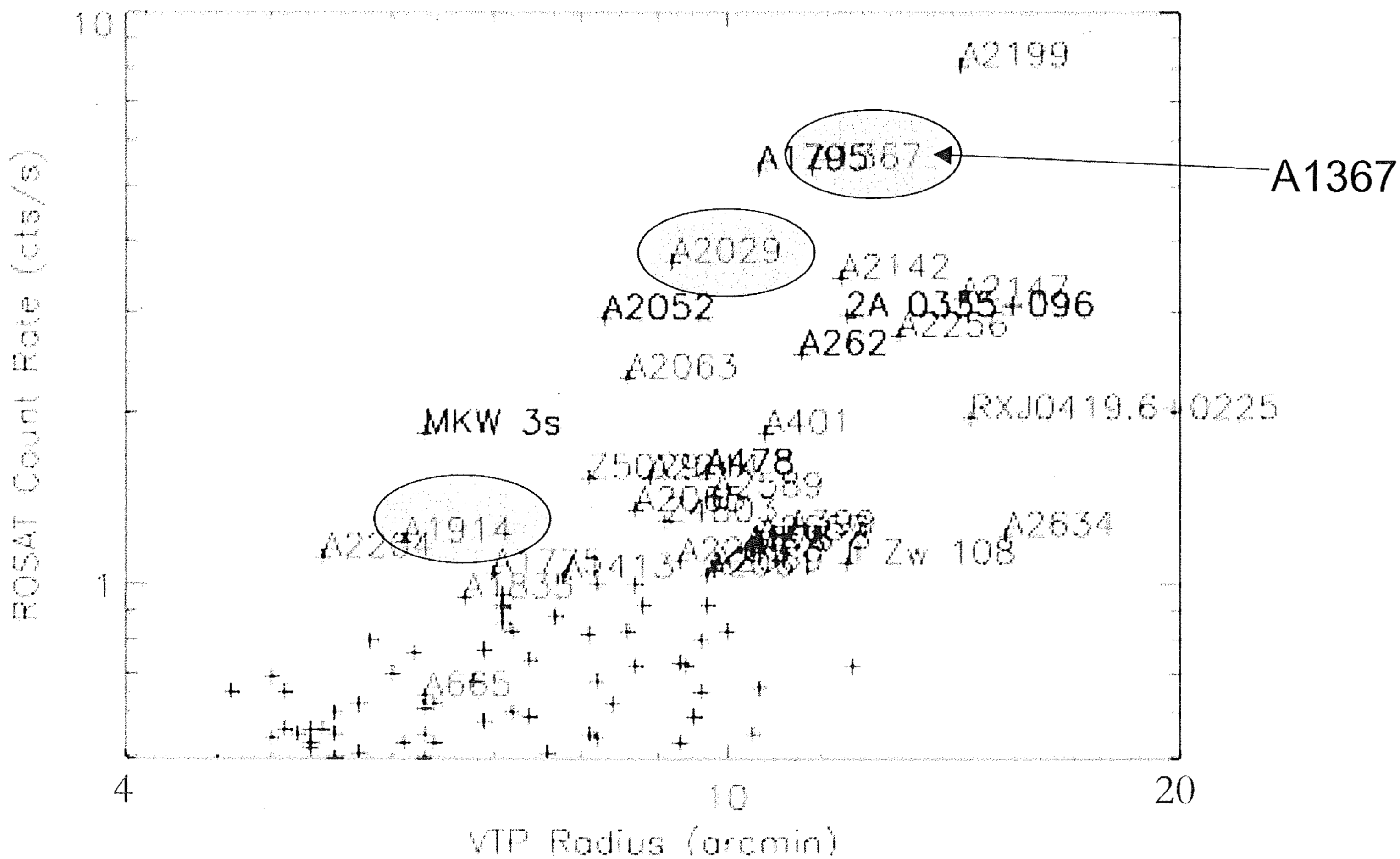
Cluster	z	Time ksec	F_X(0.1-2.4) cgs,unabs	kT keV	R_{core} (″)	Results
A1835	0.2541	36	1.5e-11	14.8	79	T_{ion}, Ab(O,*Ne*,*Mg*,Fe)
A665	0.1818	20	2.4e-11	~8	53	T_{ion}, Ab(Fe)
A1795	0.0639	40	6.8e-11	5.3	147	T_{ion}, Ab(O,Ne,Mg,Si,Fe)
Hydra A	0.0550	38	4.8e-11	3.8	138	T_{ion}, Ab(O,Ne,Mg,Si, Fe)
Ser 159-03	0.0572	38 (121)	2.4e-11	2.4	72	T_{ion}, **Radial[**Ab(O,Ne,Mg,Si, Fe)**]**
2A0335+096	0.0344	26 (130)	8.1e-11	3.0	156	T_{ion}, **Radial[**Ab(O,Ne,Mg,Si, Fe)**]**
A4059	0.0466	54	3.1e-11	3.5	72	T_{ion}, Ab(O,Ne,Mg,Si, Fe)
A496	0.0322	29	7.5e-11	3.9	380	T_{ion}, Ab(O,Ne,Mg,Si, Fe)
MKW 3s	0.0455	39	3.0e-11	3.0	111	T_{ion}, Ab(O,Ne,Mg,Si, Fe)
A2052	0.0356	33	4.7e-11	3.1	258	T_{ion}, Ab(O,Ne,Mg,Si, Fe)
A262	0.0155	36	4.9e-11	2.4	163	T_{ion}, Ab(O,Ne,Mg,Si, Fe)
A3112	0.0756	24	3.6e-11	4.1	22	*T_{ion}, Ab(O,Ne,Mg,Fe)*
A478	0.0881	119	4.1e-11	6.5	62	*T_{ion}, Ab(O,Ne,Mg,Fe)*
A2597	0.0822	74	2.0e-11	2.6	18	T_{ion}, Ab(O, Fe)

Peterson et al. (2003); *Tamura et al. (2004)*, Morris & Fabian (2005), *de Plaa et al. (2004)*, **de Plaa et al.(2006), Werner et al. (2006)**

(Partial) Review of Existing Observations/Results

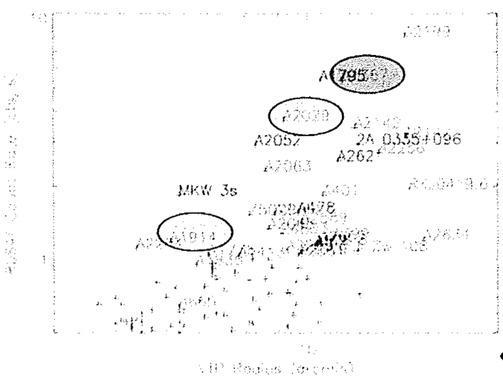
But what about unpublished data?

Using the ROSAT BCS, a number of sources pop up as being potentially interesting.



(Partial) Review of Existing Observations/Results

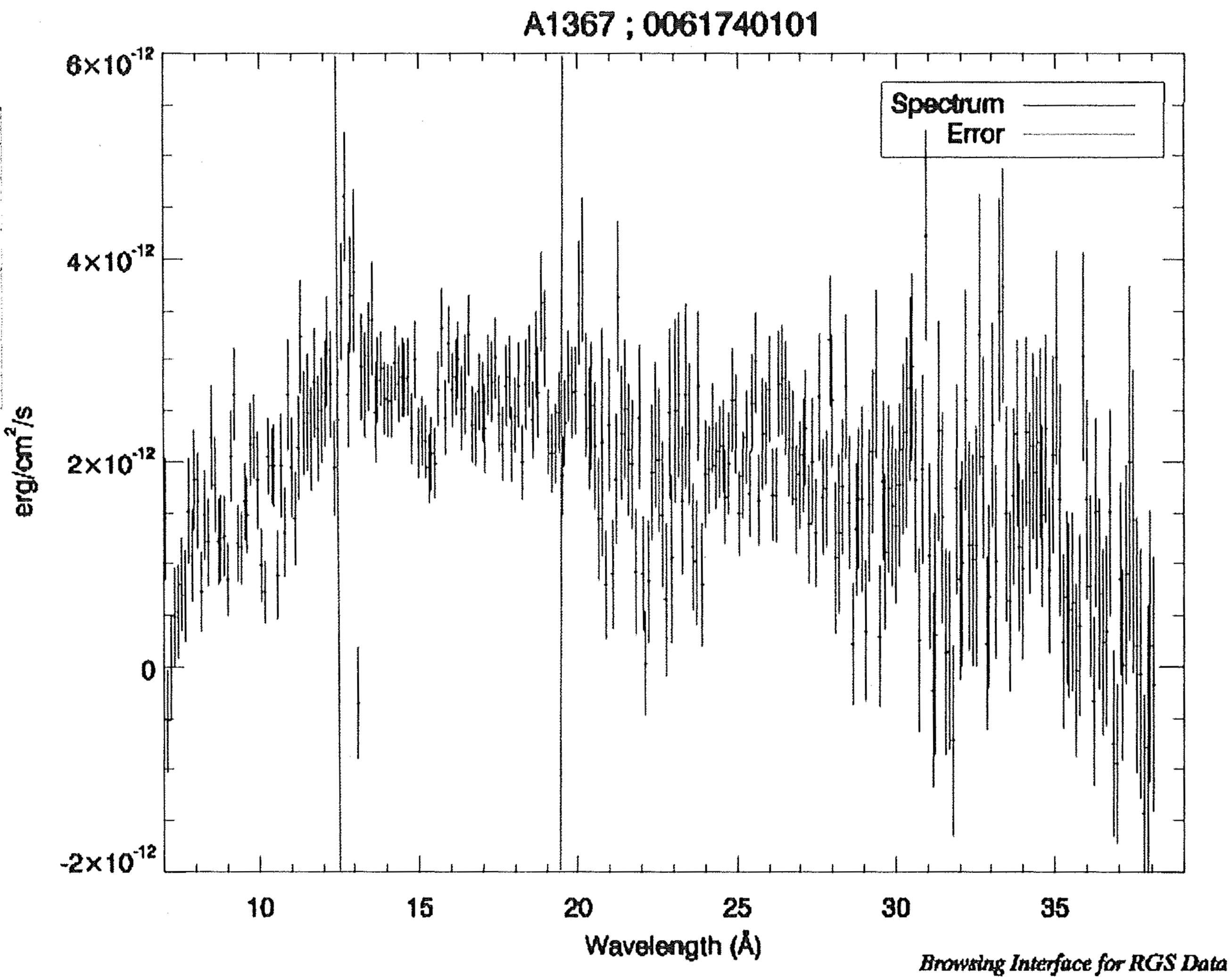
A1367, 33 ksec



z=0.021562

O VIII, 19.39Å

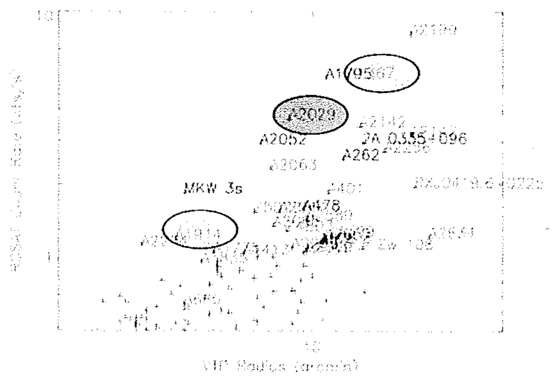
Ne X, 12.393Å

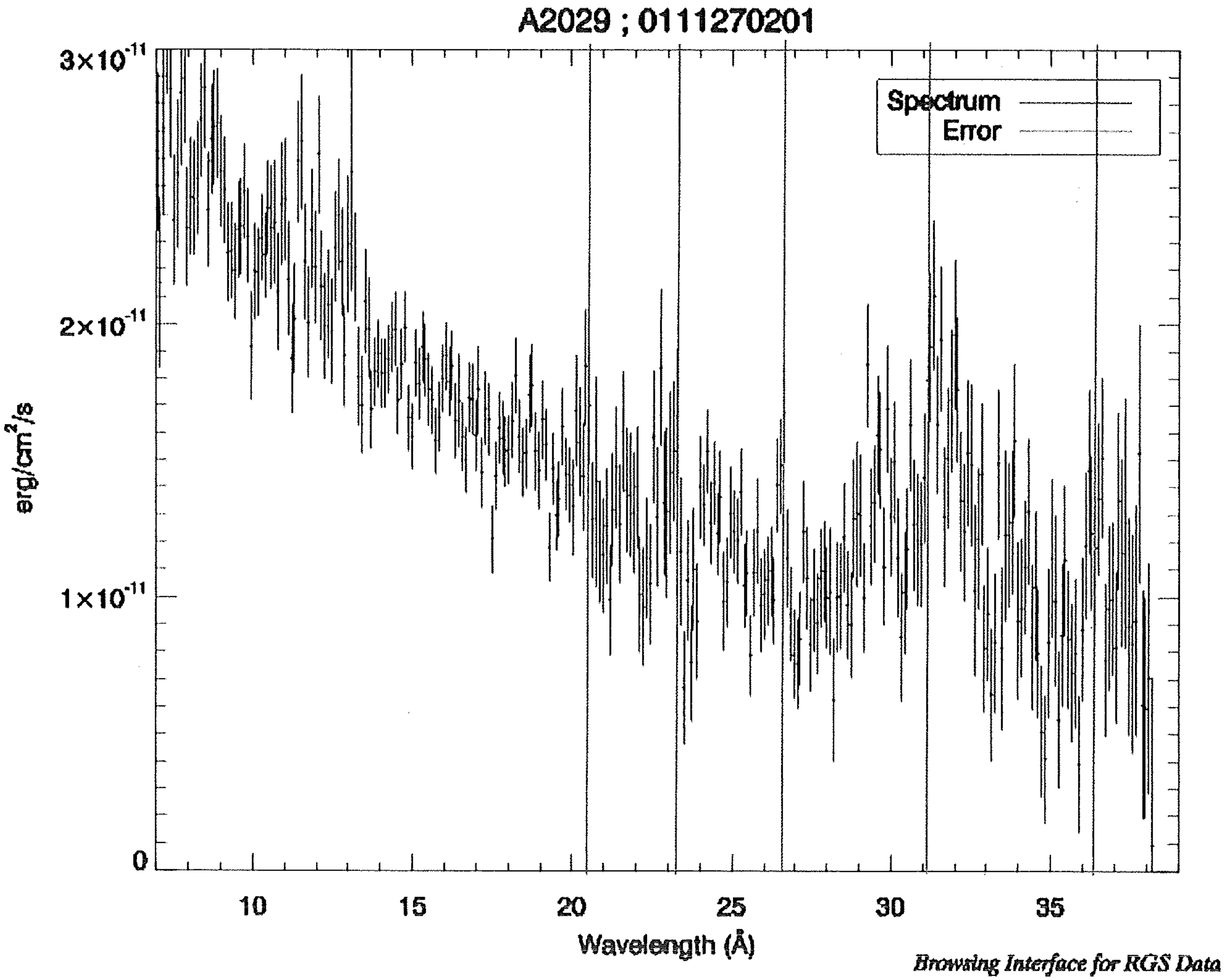


http://xmm.esac.esa.int/BiRD/

(Partial) Review of Existing Observations/Results

A2029, 20 ksec





z=0.077454

C VI 36.35 Å

N VI 31.01 Å

N VII 26.72 Å

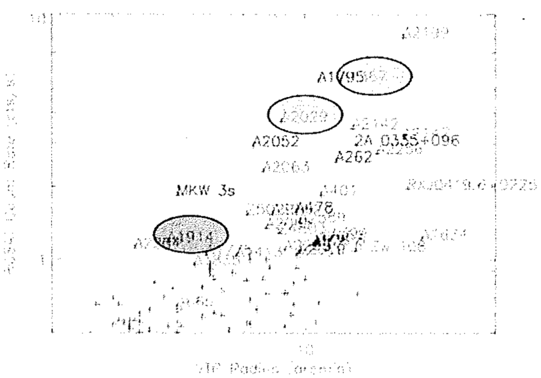
O VII 23.27 Å

O VIII 20.44 Å

http://xmm.esac.esa.int/BiRD/

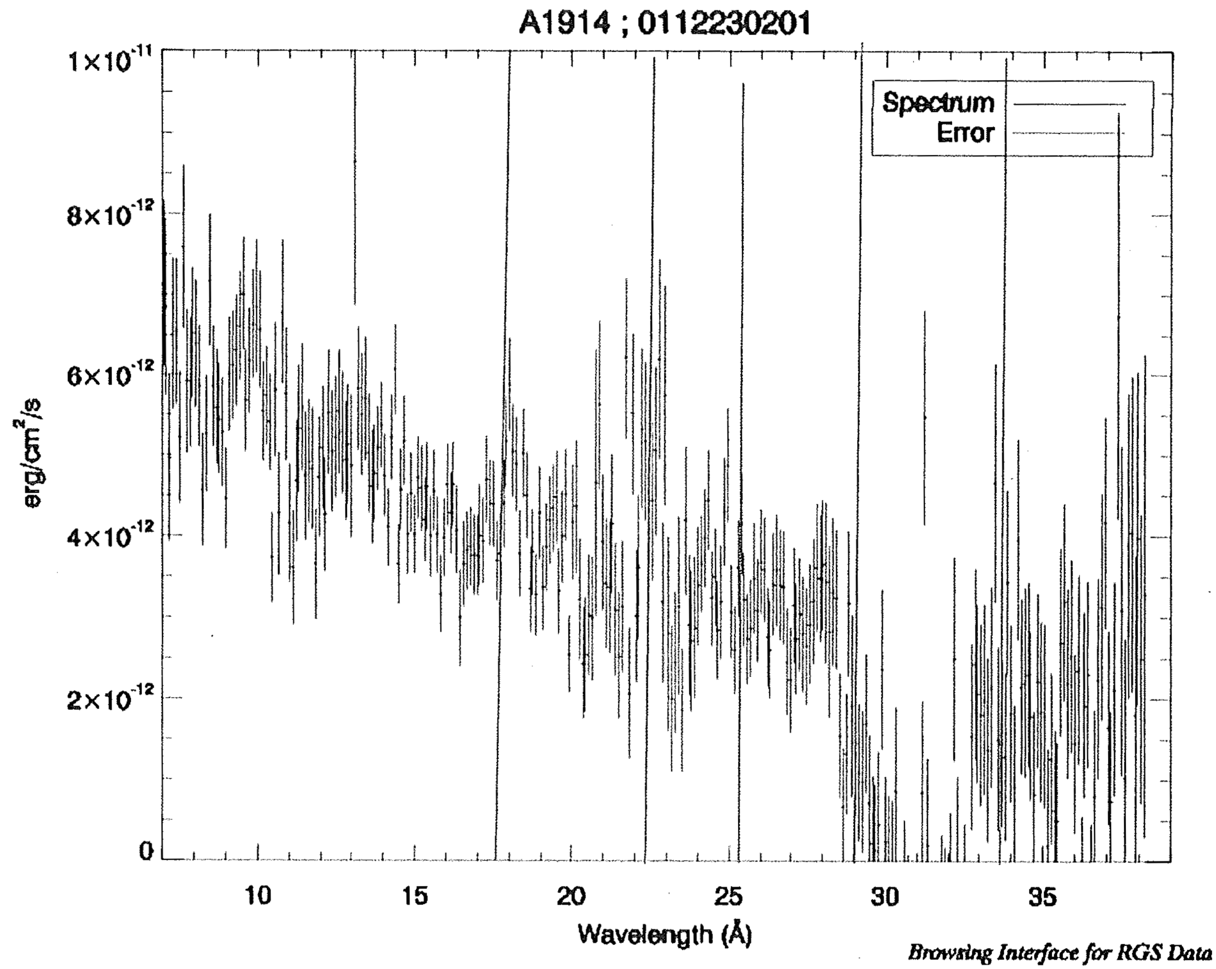
(Partial) Review of Existing Observations/Results

A1914, 26 ksec



z=0.171

N VI 33.71 Å
N VII 29.02 Å
O VII 25.29 Å
O VIII 22.21 Å
Fe XVII 17.58Å



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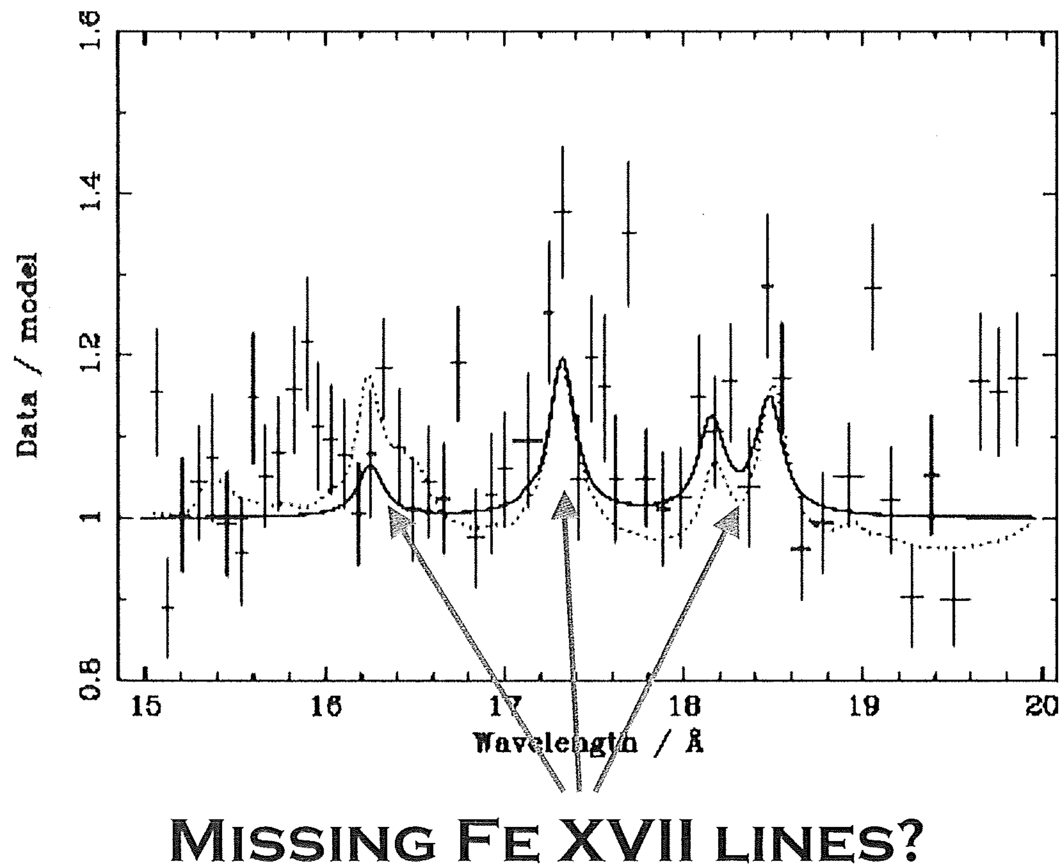
(Partial) Review of Existing Observations/Results

A2597, 74 ksec (Morris & Fabian 2005)

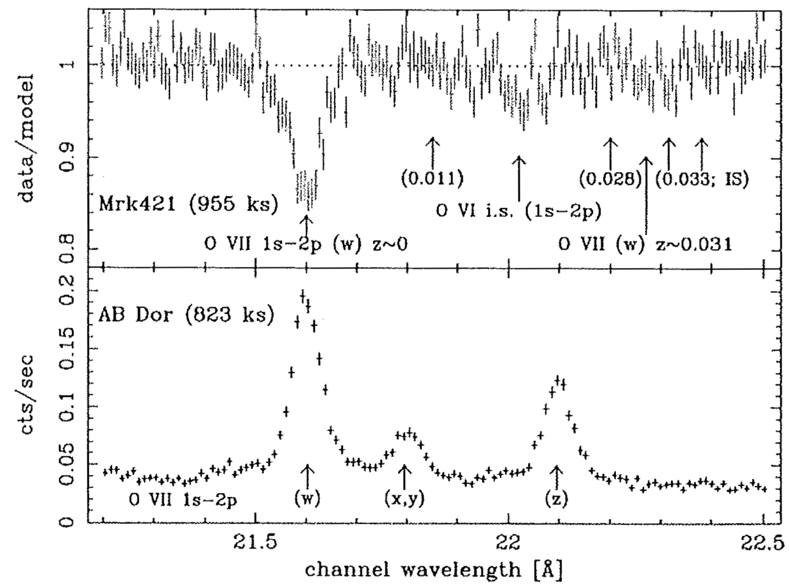
Peterson et al. (2003) showed that cooling flow clusters have an apparent temperature "cutoff" at ~T/3.

However, A2597 shows *hints* of Fe XVII cooling lines that are not statistically significant, but which – *if real* – will affect our understanding of cooling flow clusters.



Limits on Observation Length: Systematics

A search for the WHIM via Mkn 421, compared to a deep observation of the bright star Capella. The upper curve has **~5.2x10^5 cts/Å** at 21.6Å and thus requires special attention to handle calibration uncertainties.



Compare: 100 ksec on a ***cool bright cluster:***

~750 cts/Å at 21.6Å;

peak of **~1.5x10^4** cts/Å at 12Å.

T_X = 1.5 keV
F_X(RGS) ~ 10^{-11} cgs
N_H=10^{20} cm^{-2}

⇒ **3.5 Msec** needs to reach similar values!

Why spend 300+ ks on Clusters?

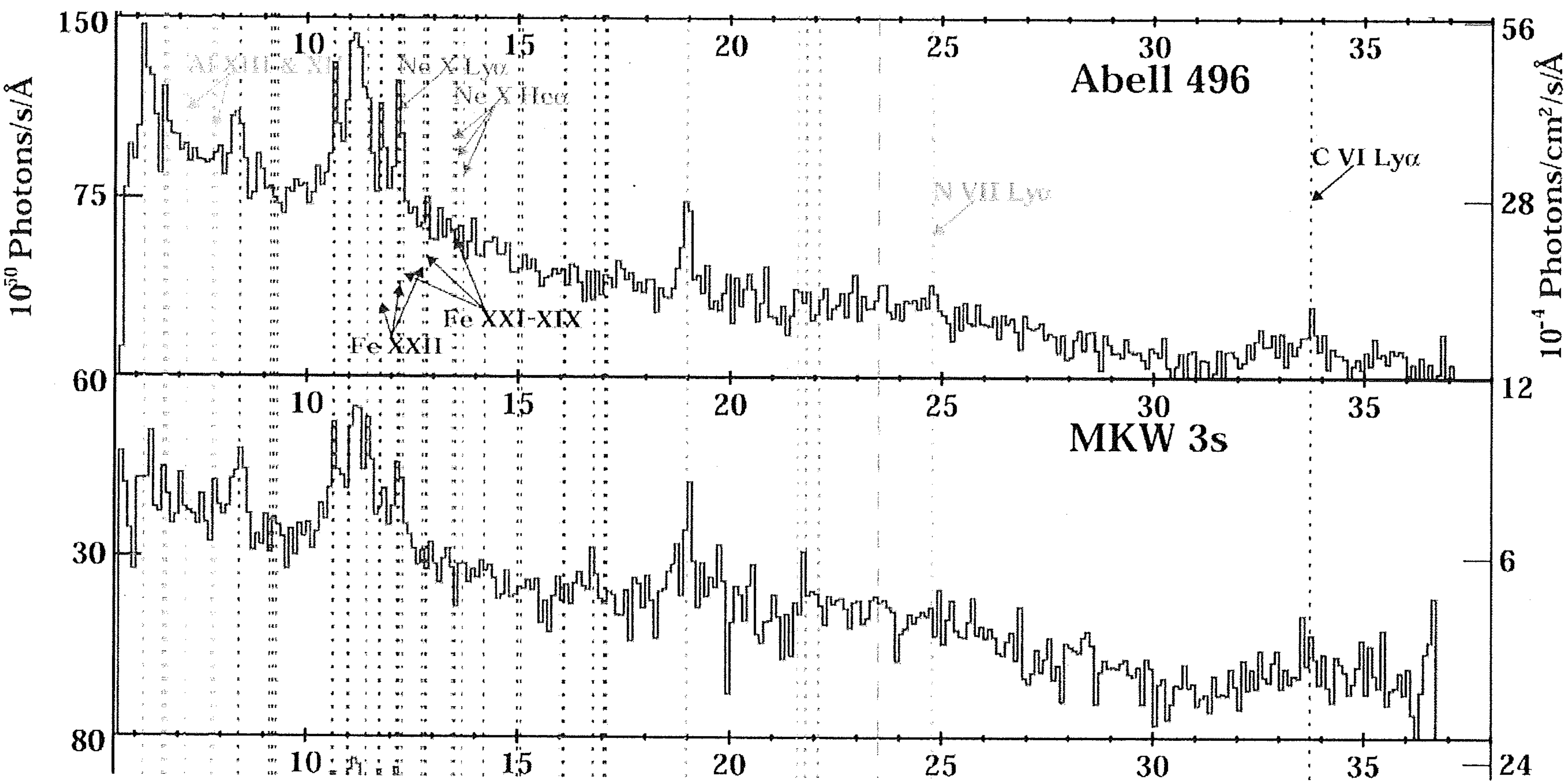
- The RGS is the **only** existing high-resolution X-ray spectrometer for extended sources.
- All RGS Cluster observations are dominated by statistics.
- The *earliest possible* calorimeter mission will not launch before 2011:

$\Rightarrow$126 Msec from today $\Leftarrow$

What would 300+ ks observations find?

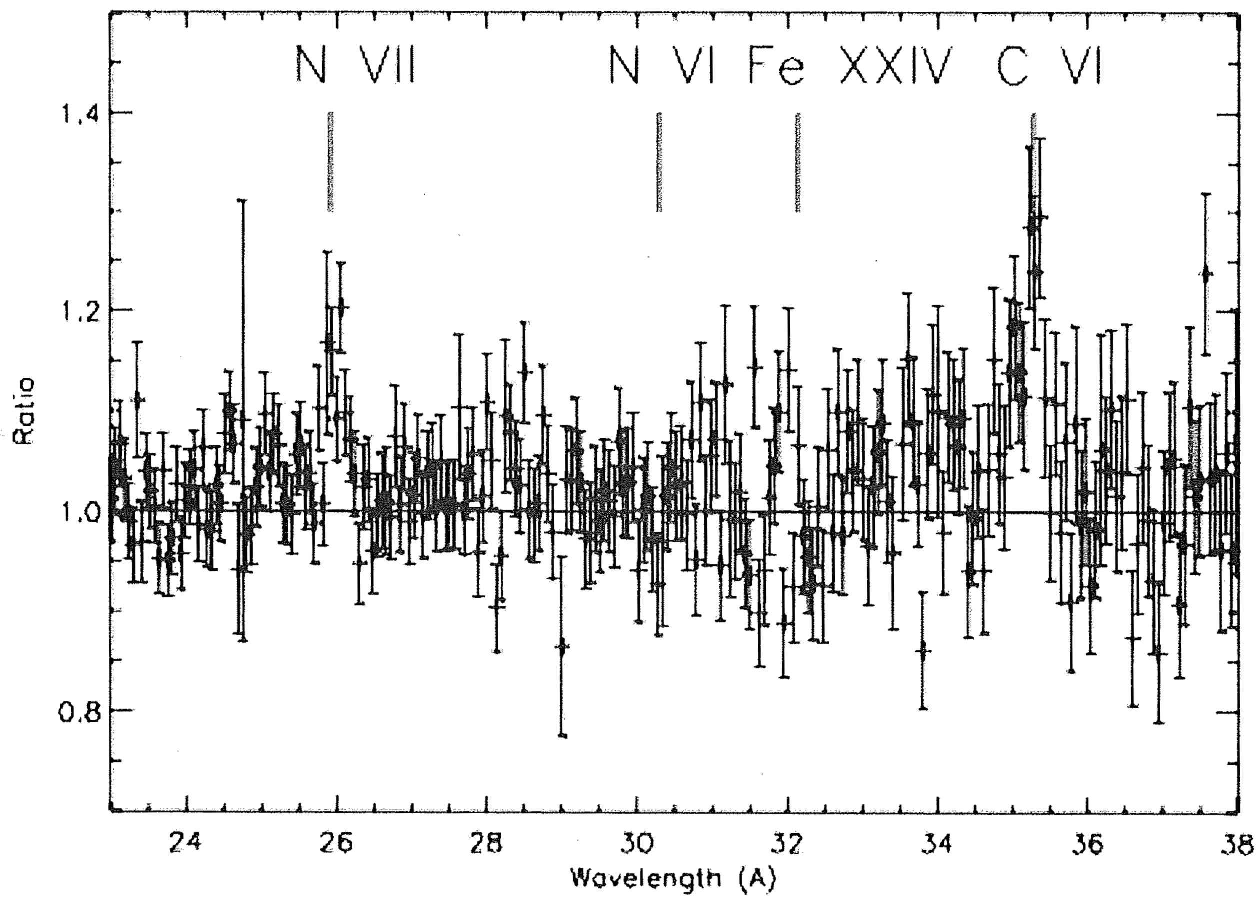
- Carbon & Nitrogen abundances
  - Even in hot clusters, recombination creates detectable hydrogenic emission lines.
  - Nitrogen in particular comes primarily from intermediate mass stars (~4-8$M_{\odot}$), not supernovae
  - C (and O) comes from massive (>8$M_{\odot}$) stars, so comparisons will tell us about the stellar IMF led to the enrichment of the ICM.

- Proof of concept: Peterson et al. (2003)



C VI detected in A496 in only 29 ksec!

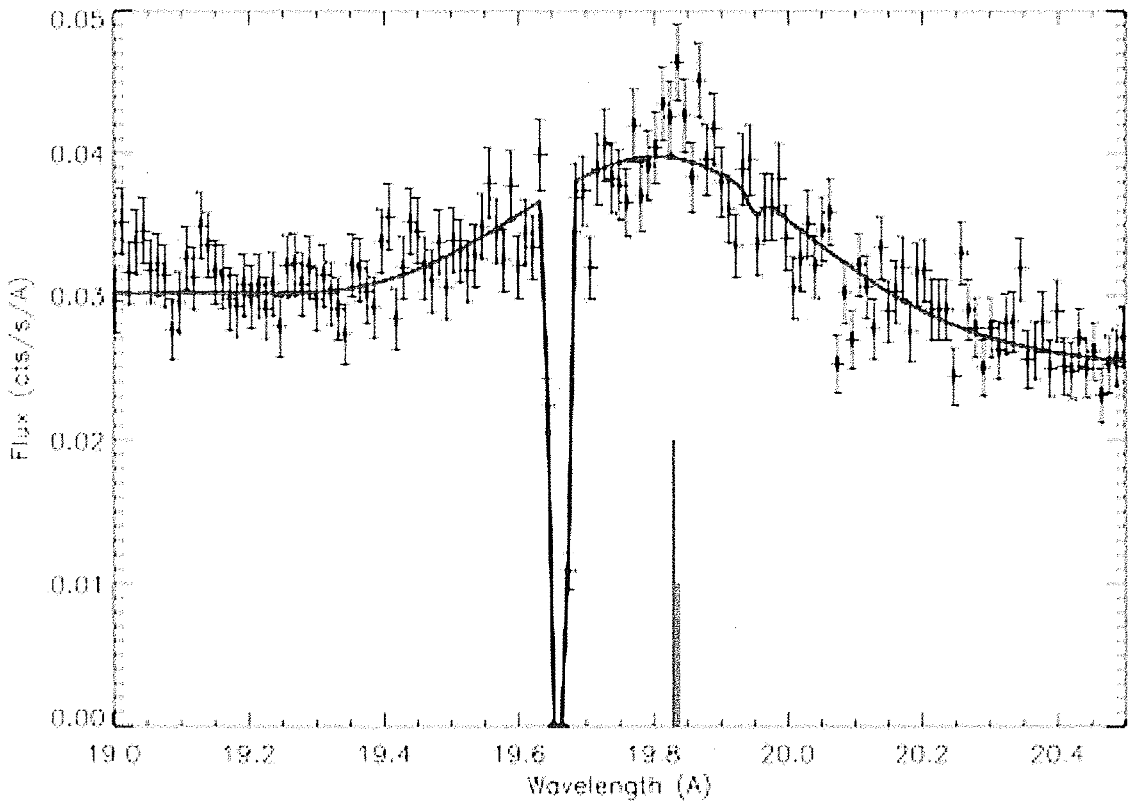
- Detecting Carbon & Nitrogen lines
  - 300 ks on MKW3s with RGS1+2 (assuming solar abundances; 3-4σ detection of N VII, C VI):



Line Position

MKW 3s, 300 ks, O VII:

- Line Centroid:
  ±260 km/s (90%)
- Line Intensity:
  ±4% (90%)



Conclusions

- Practically all XMM cluster observations are underexposed relative to the RGS
- Unique science capability of XMM
- Data analysis challenging, but with RGSXSRC not impenetrable
- Deep observations open new possibilities with both guaranteed science (e.g. C, N abundances) and speculative possibilities.