High spectral resolution observations of AGN

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SRON

Overview

- Importance of AGN outflows
- The zoo of AGN: characteristic examples of outflows observed with RGS
- Importance of reverberation studies
- The need for larger samples of high quality spectra
- Conclusions

1. Importance of AGN outflows

Important for:

- Growth of supermassive black holes
- Enrichment of the intergalactic medium
- Evolution of the host galaxy
- Cluster cooling flows
- Magnetisation of cluster and galactic gas
- AGN luminosity function

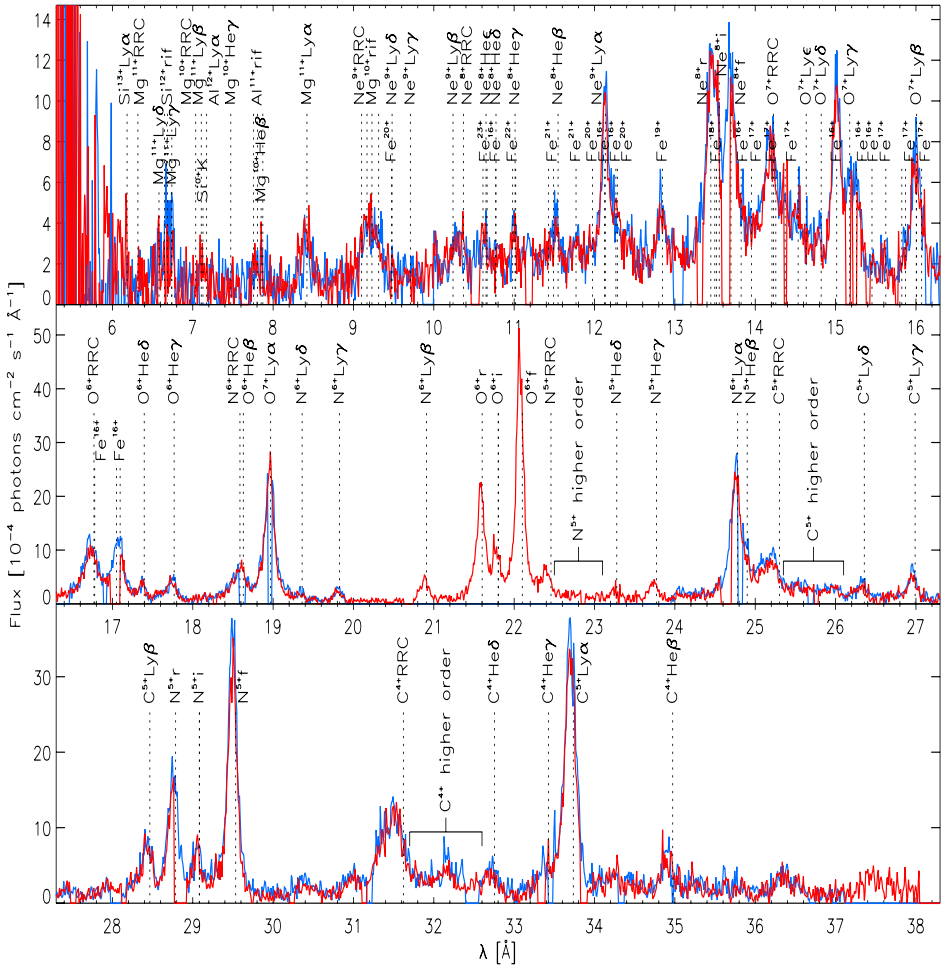
More about this in talk Arav

2. The zoo of AGN: lots of different BiRDs

Prototype Seyfert 2: NGC 1068

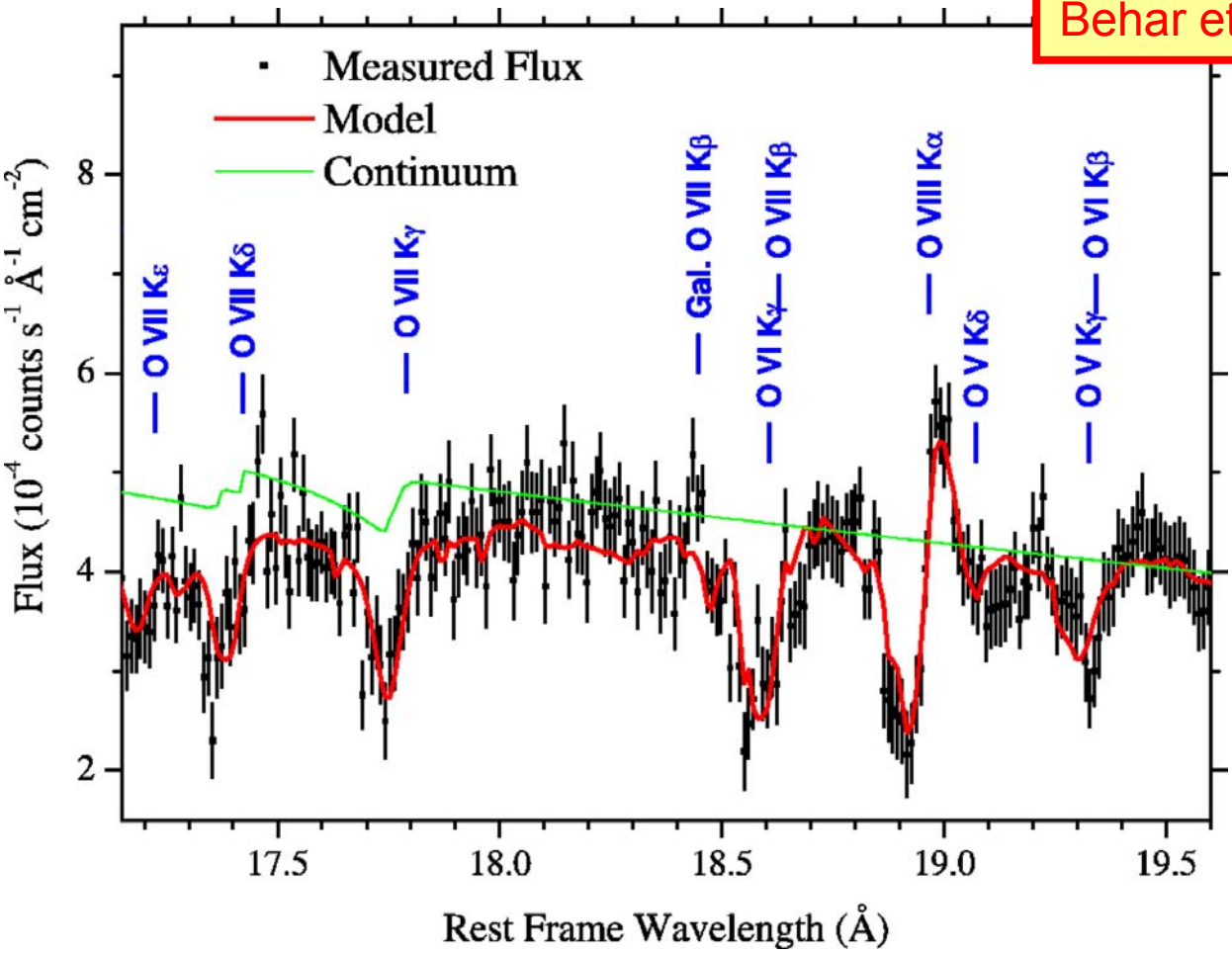
Kinkhabwala et al. 2002

- Strong emission lines and RRC from photoionised gas
- See the outflow in emission
- More about Seyfert 2 in talk Guainazzi



Seyfert 1: absorption spectra

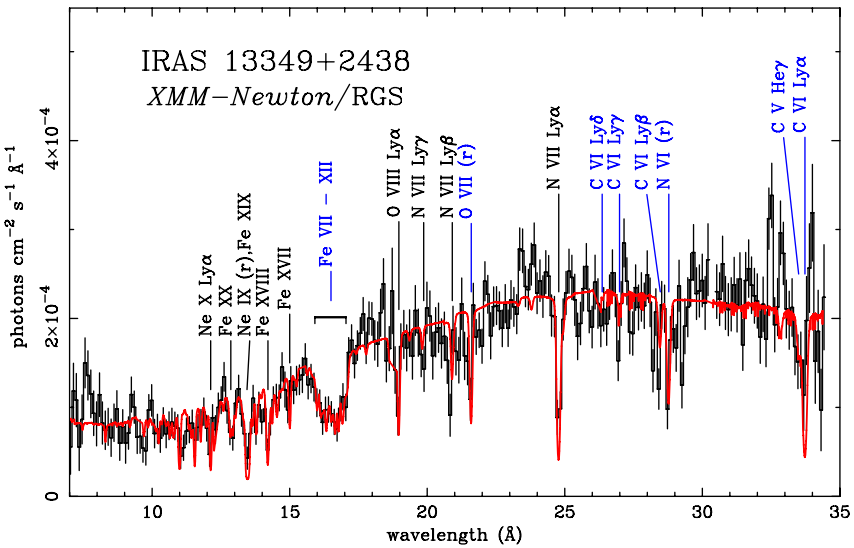
NGC 3783, XMM/RGS,
Behar et al. 2003



IRAS 13349+2453: UTA of iron

Sako et al. 2001

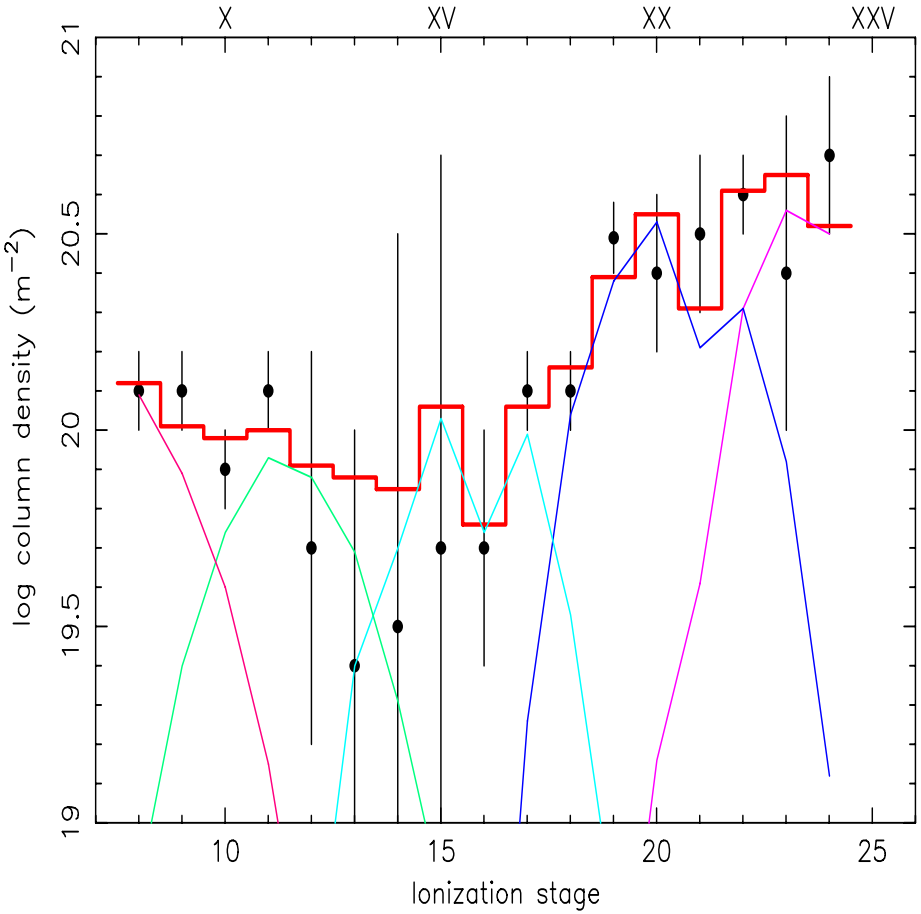
- IRAS 13349+2453
- Broad absorption lines (σ_v=600 km/s)
- Lines show outflow 200 km/s
- No clear edges
- Strong UTA near 16-17 Å (2p-3d)



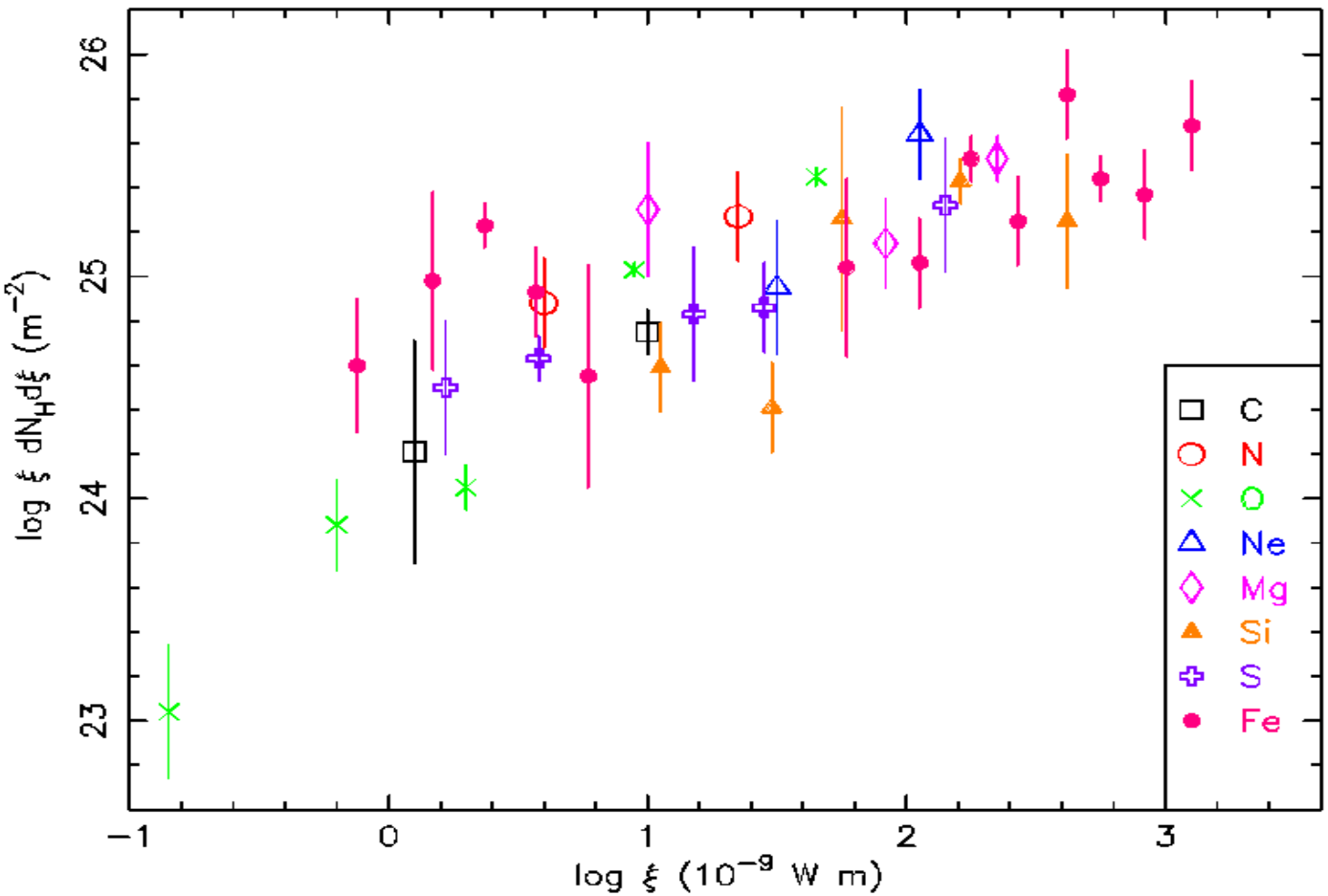
Complex absorber: NGC 5548

Steenbrugge et al. 2003

- Use column densities Fe ions from RGS, 137 ks spectrum
- Measured N_{ion} as sum of separate ξ components
- Need at least 5 components



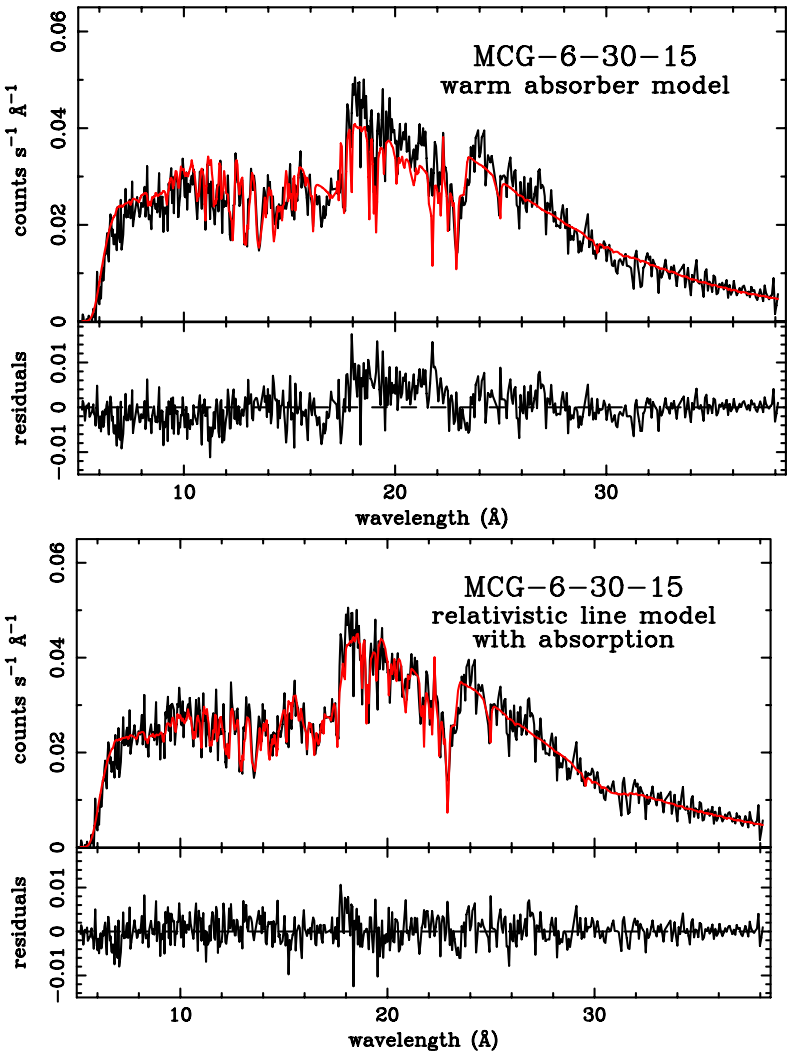
NGC 5548: continuous versus discrete column density distribution



Relativistic lines: MCG -6-30-15

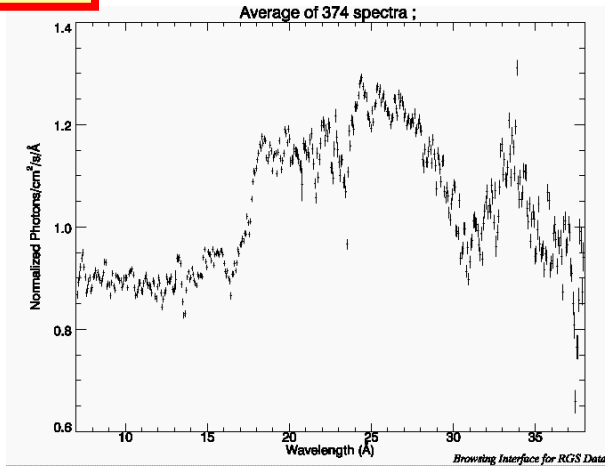
Branduardi-Raymont et al. 2001; Sako et al. 2003

- Need to understand warm absorber in order to understand continuum and vice versa
- High spectral resolution only way to resolve this

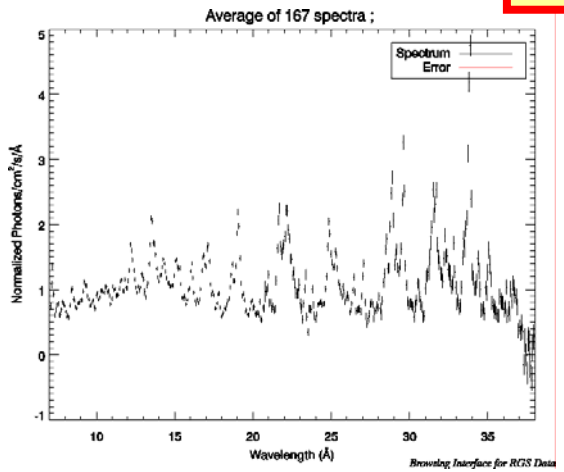


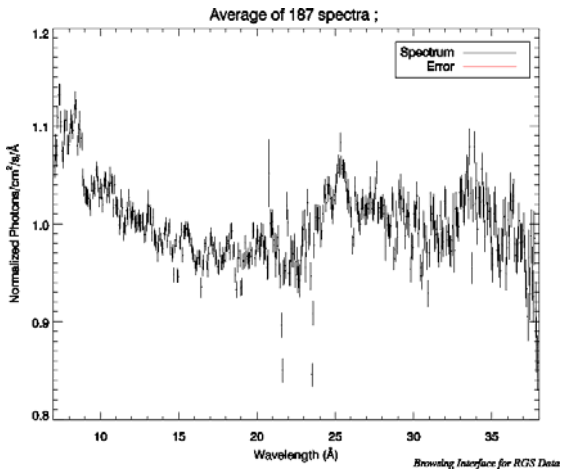
Average redshift, N_H corrected RGS spectra (BiRD)

Seyfert 1

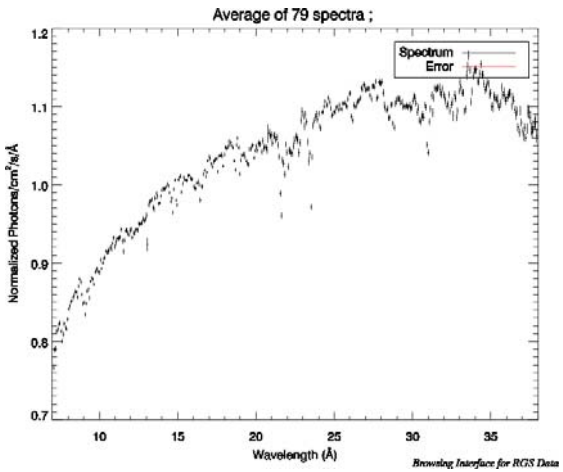


Seyfert 2





Quasar



BL Lac

3. Importance of reverberation studies

Spherical shell:

Kinetic luminosity ~½ $\Omega r N_H m_p v^3$

$\Omega = O(\pi)$ from fraction of S1 with absorber

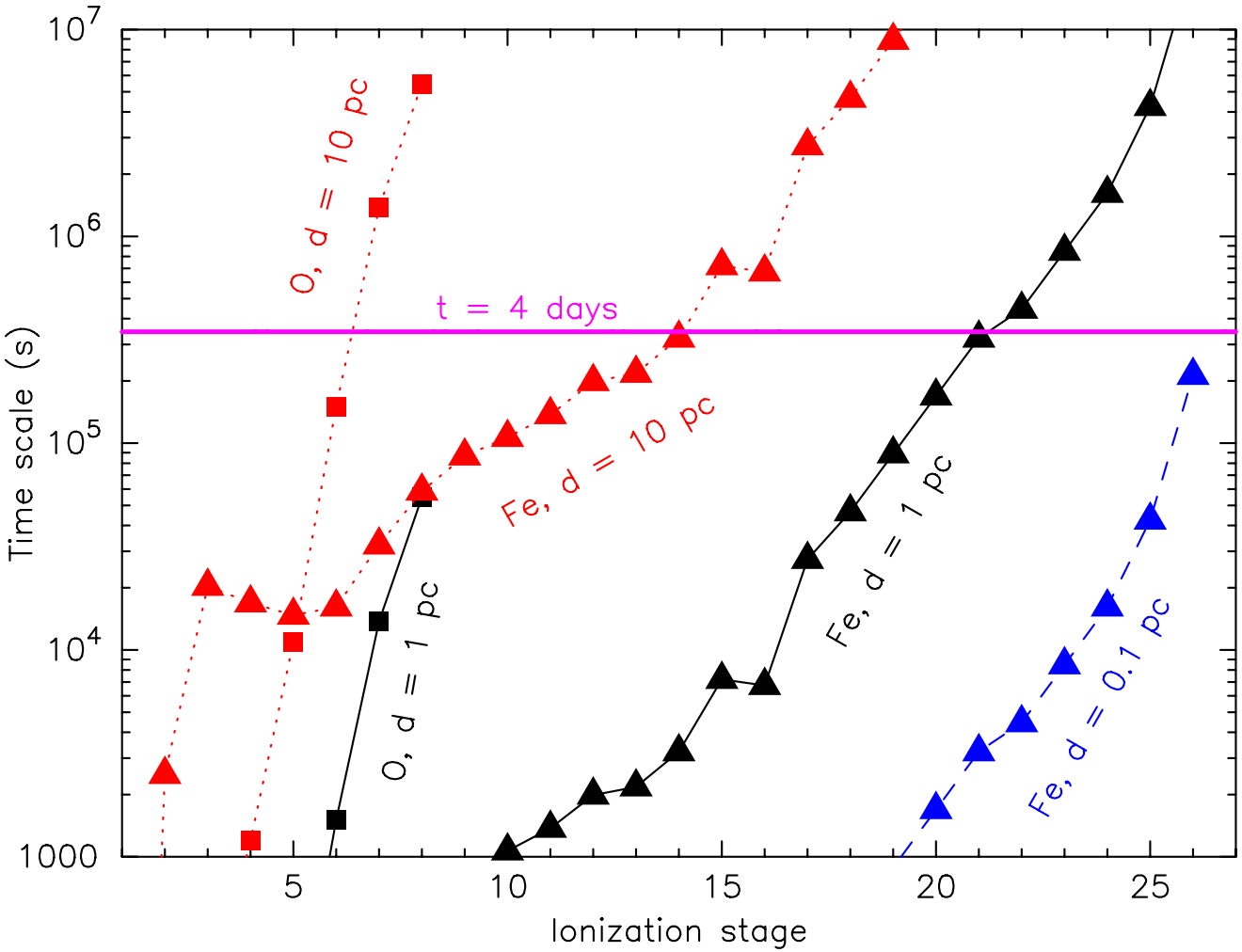
V measured from spectrum

N_H measured from spectrum

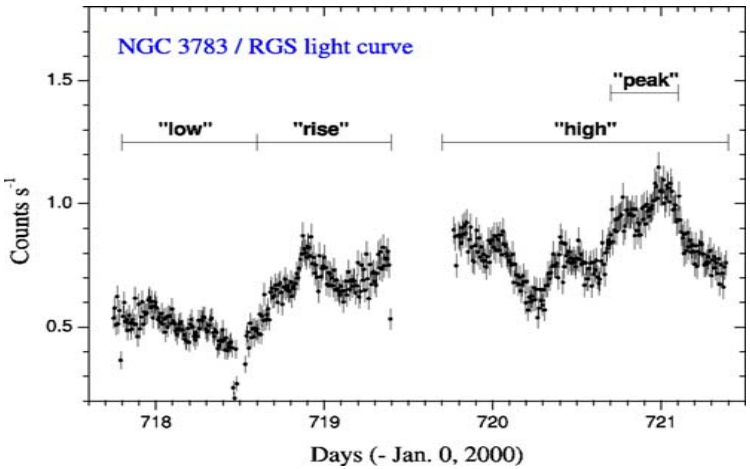
r unknown

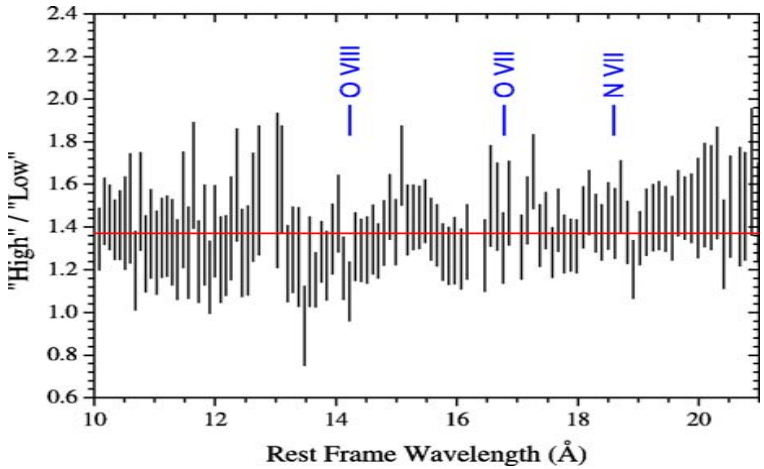
How to estimate R: reverberation

- If L increases for gas at fixed n and r, then $\xi = L/nr^2$ increases
- → change in ionization balance
- → column density changes
- → transmission changes
- Gas has finite ionization/recombination time t_r (density dependent as ~1/n)
- → measuring delayed response yields $t_r \rightarrow n \rightarrow r$


Time scale (s)
Ionization stage
t = 4 days
O, d = 10 pc
Fe, d = 10 pc
O, d = 1 pc
Fe, d = 1 pc
Fe, d = 0.1 pc

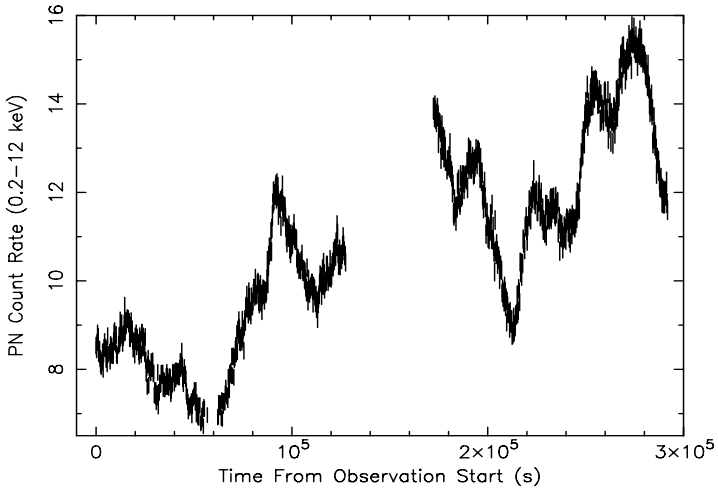
Reverberation: NGC 3783

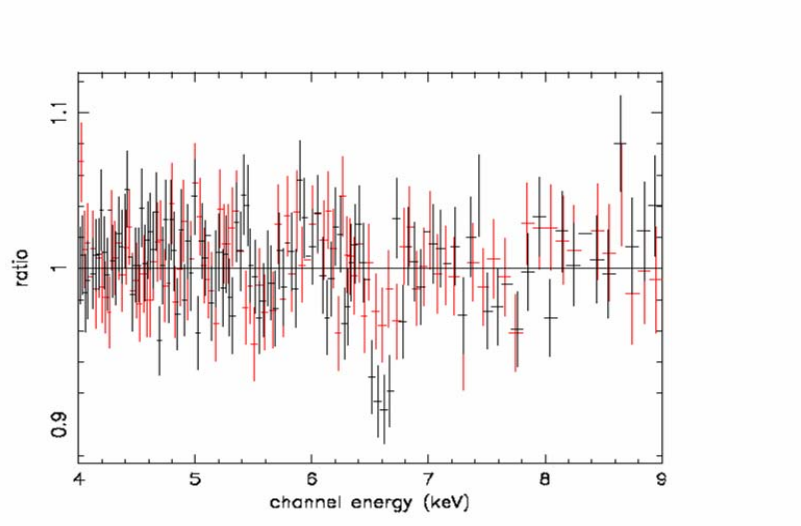




- RGS data (Behar et al. 2003): no change in Warm absorber ➔ n<300 cm^{-3}, r>10 pc.

Reverberation II: NGC 3783





- EPIC data (Reeves et al. 2003): change in

Warm absorber (larger columns) ➔ $n>10^8$ cm^{-3}, $r<0.02$ pc.

➔ What to make out of this?

➔Urgent need of more data!

4. The need for larger samples of high quality spectra

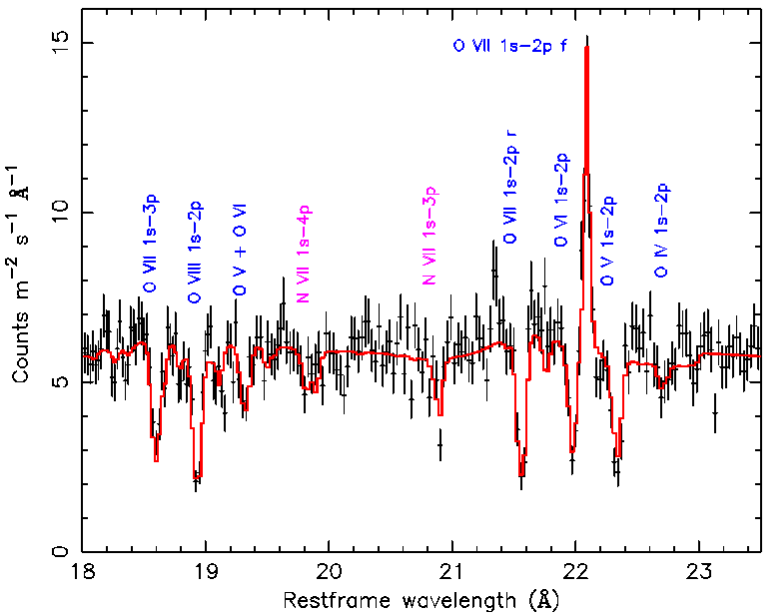
Large variety of AGN:

- warm absorber yes/no
- Relativistic lines yes/no
- “Normal” broad lines
- Dust yes/no
- Luminosity differences
- Orientation angles

➔ Need sizeable sample of good spectra to understand the population

Tool: the oxygen region

- Oxygen region: why important?
- Good diagnostic region:
- For almost any ξ there is a diagnostic ion
- Oxygen is the most abundant metal
- RGS best instrument for oxygen studies



Magic equation

- @ oxygen, $N_H=10^{20}$ cm^{-2} ⟷ tau=0.1
- Eff area RGS @ 23 Å ≈ 40 cm^2 (1 RGS)
- FWHM RGS @ 23 Å ≈ 0.07 Å
- S/N=10 per FWHM (minimum requirement for good spectrum) reached at 100 counts/FWHM

$$t_{\rm exp}\,({\rm ks}) = \frac{114}{F_{2-10\,{\rm keV}}}\,e^{0.1N_{20}}$$

$F_{2-10\,{\rm keV}}$ in 10^{-14} W or 10^{-11} erg cm^{-2}s^{-1}

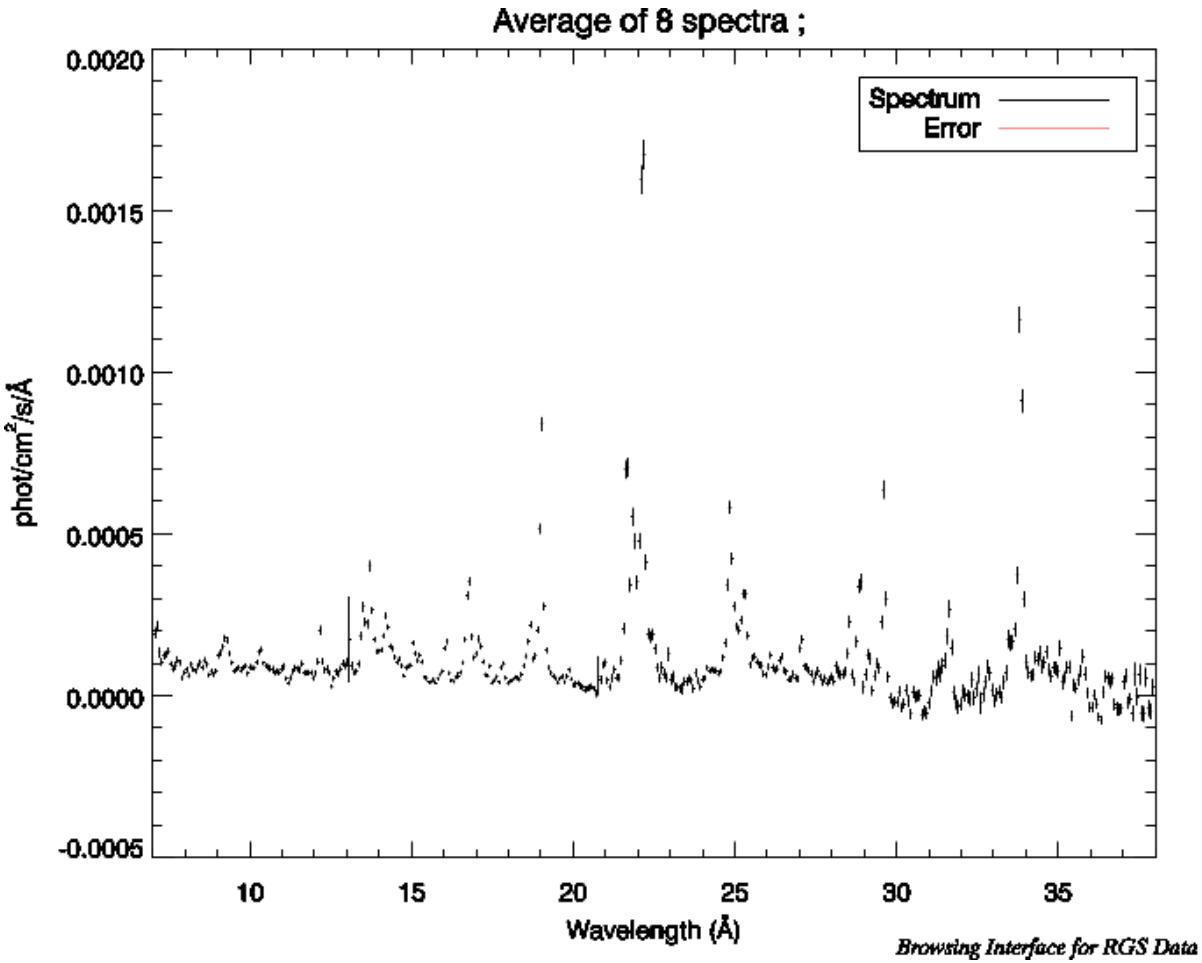
Brightest 15 Seyfert 1-like

Flux	t_{exp} (ks)	S/N	Flux	t_{exp} (ks)	S/N
9.0	182	5	4.5	452	39
8.9	149	9	4.3	60	20
8.8	559	50	4.1	46	8
6.5	103	0	4.1	154	22
5.5	58	0	3.8	22	6
4.6	38	3	3.6	0	0
4.6	233	16	3.5	77	13
4.6	132	22			

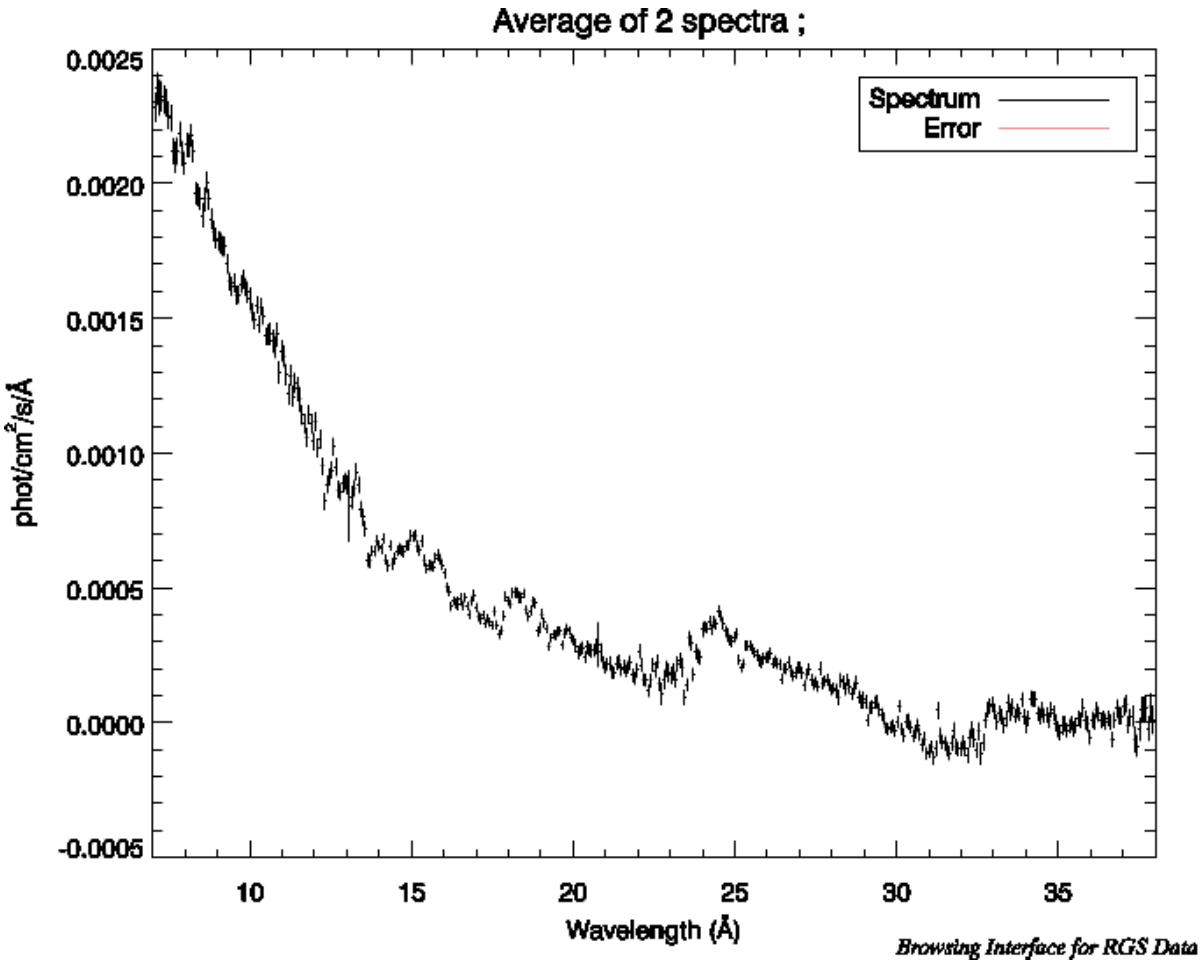
Flux in 2-10 keV band, 10^{-14} W (10^{-11} cgs)

S/N at 23 Å for FWHM of RGS

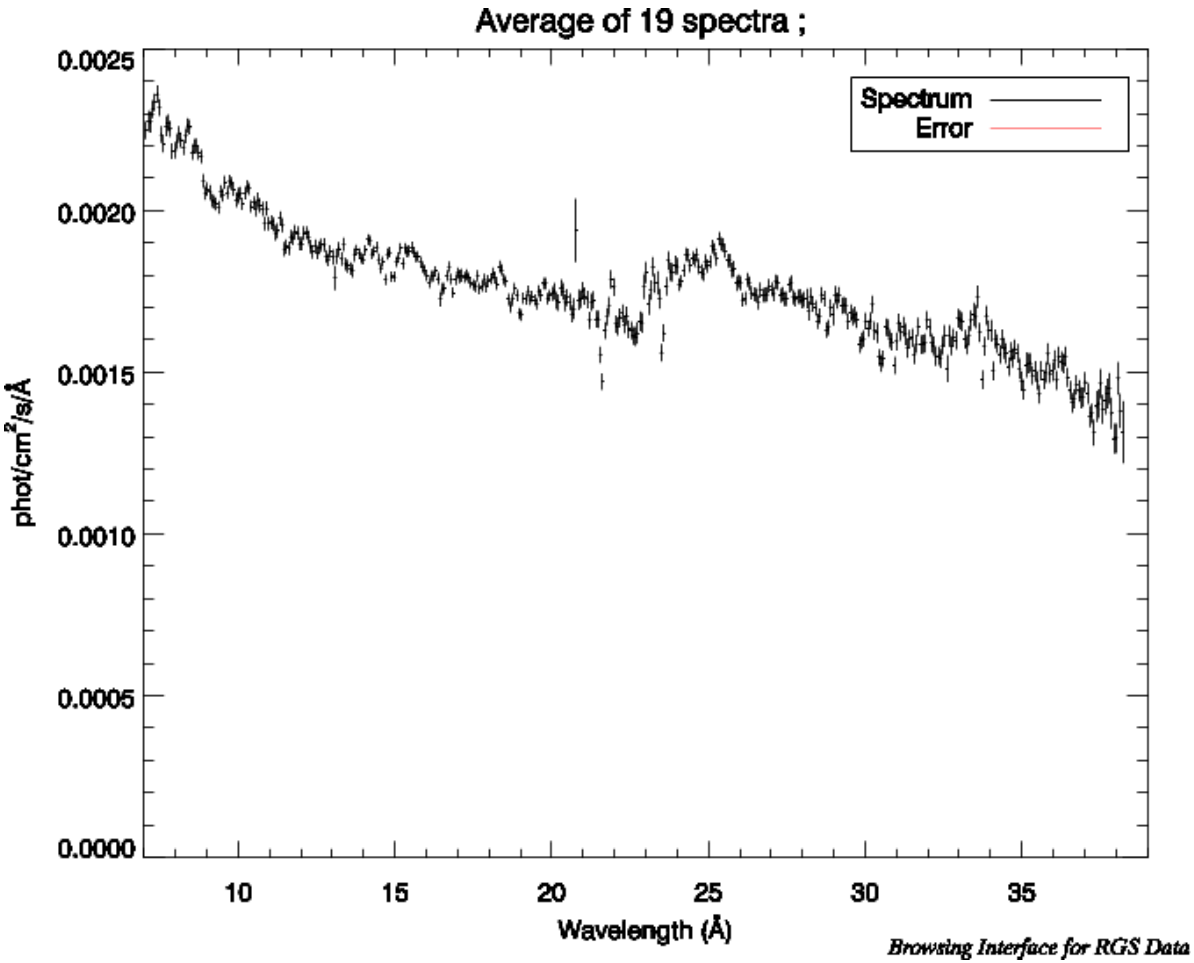
1. NGC 4151 (t=182 ks, S/N=5): more S2-like



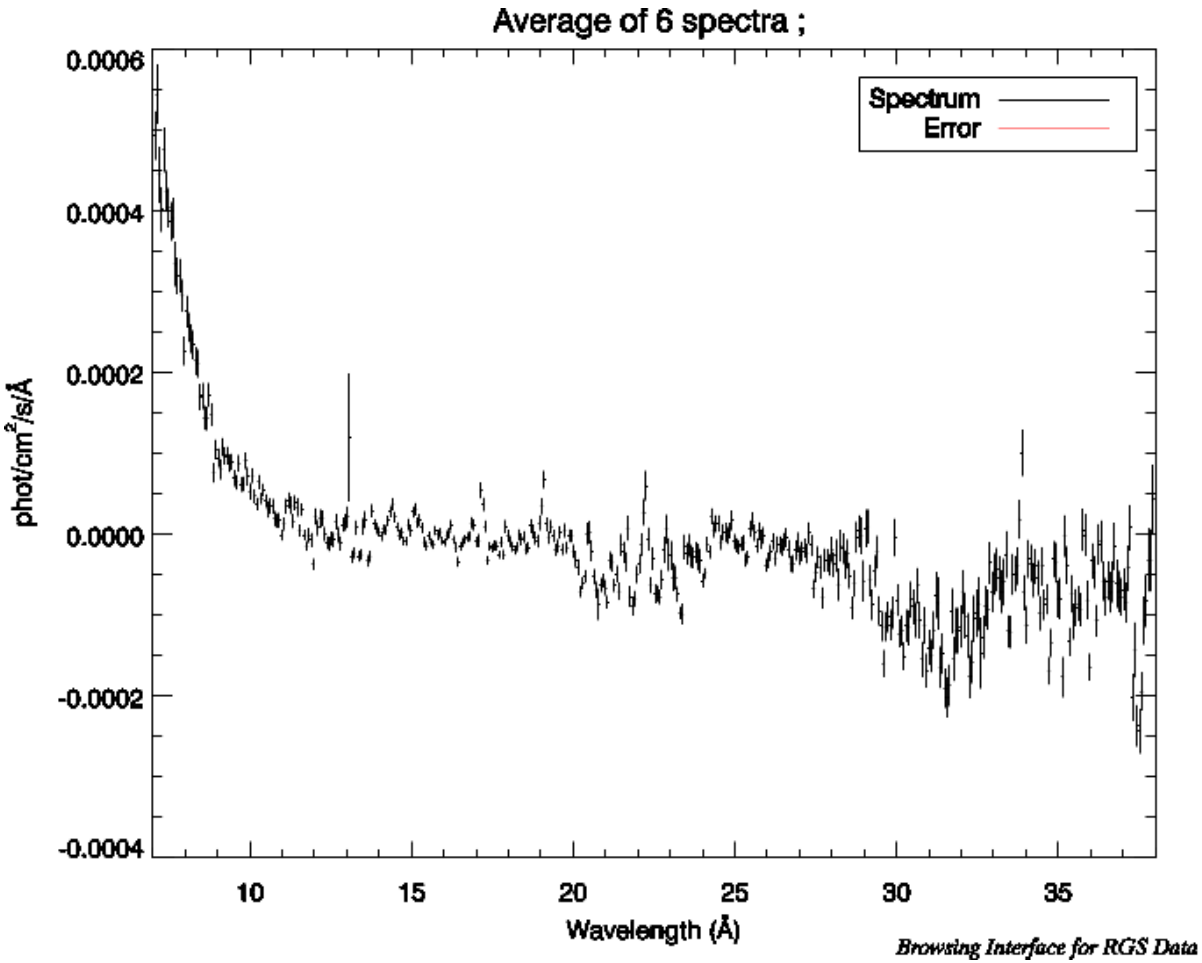
2. IC 4329A (t=149 ks, S/N=9): intrinsic absorption



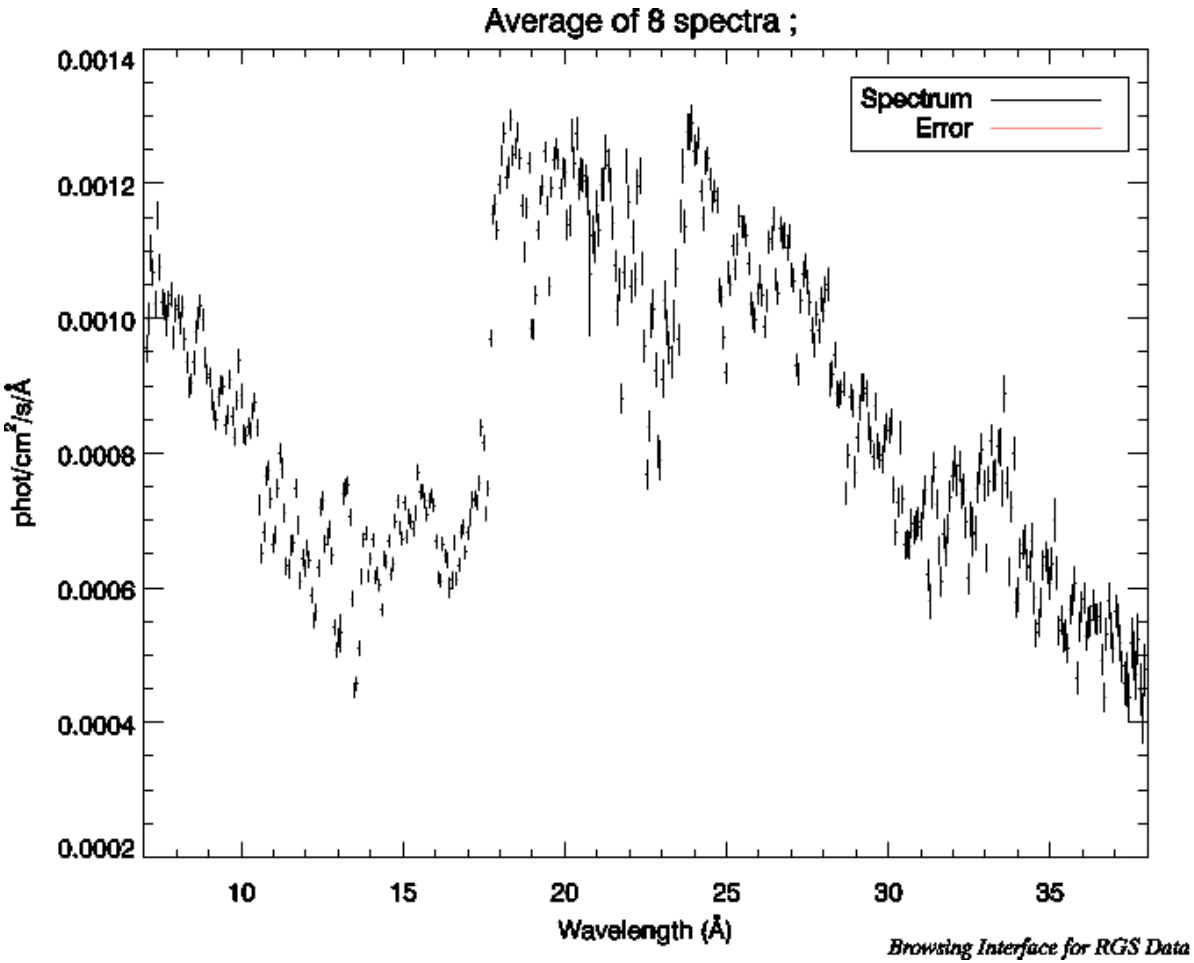
3. 3C 273 (t=559 ks, S/N=50): at most weak spectral features



4. NGC 5506 (t=103 ks, S/N=0): misclassification (S2)



9. MCG -6-30-15 (t=452 ks, S/N=39): as it should be…



Brightest 52-66 Seyfert 1-like

Flux	t_{exp} (ks)	S/N	Flux	t_{exp} (ks)	S/N
1.5	0	0	1.1	13	4
1.5	0	0	1.1	14	2
1.4	8	2	1.0	0	0
1.4	572	30	1.0	0	0
1.3	16	3	1.0	0	0
1.2	0	0	1.0	0	0
1.2	163	15	1.0	22	2
1.2	12	4			

Mrk 766

NGC 4051

Flux in 2-10 keV band, 10^{-14} W (10^{-11} cgs)

S/N at 23 Å for FWHM of RGS

Conclusion: Legacy program XMM-Newton

- Reverberation: 3 or 4 well sampled sources, each about 1 Ms
- Sample S1-like sources: ~50 brightest, at 100-130 ks on average each, about 5 Ms

Mass outflow rate

(Blustin et al. 2005)

- Assumption 1: solid angle 1.6 sr
- Assumption 2: momentum outflow = absorbed momentum radiation
- ➔Outflowing mass comparable to accreted mass