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Spectro-temporal diagnostics to evaluate physical structure around NGC 4051

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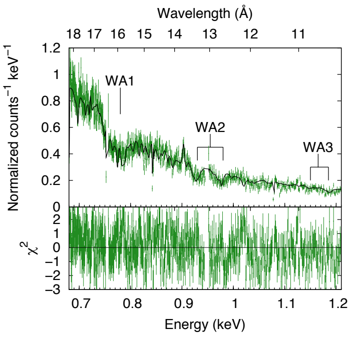
Abstract

We calculate the root-mean-square (RMS) spectra of NGC 4051 with high energy resolution of RGS on XMM-Newton. Its energy spectrum has a number of emission/absorption lines, and the absorption features are explained by three blueshifted warm absorbers. Its RMS spectra has sharp peaks and dips, which are explained by variable absorption features and non-variable emission lines. A lower-ionized ($\log \xi = 1.5$) absorber shows large variability, whereas higher-ionized ($\log \xi = 2.5, 3.2$) absorbers shows little variability. The lower-ionized absorber is calculated to locate at $\sim 10^3 R_s$, assuming Kepler motion. It may partially cover the central region. On the contrary, the higher-ionized ones locate at $>10^5 R_s$, or uniformly extend.

1. About NGC 4051

- Narrow-line Seyfert 1 galaxy with z=0.0023
- $M_{BH}=(1.7\pm0.5)\times10^6 M_{solar}$ [1]
- Observed by XMM in 2009 with ~600 ks exposure time [2]
- Have a number of absorption/emission lines

2. Spectral fitting



- We used a grid table model made by running XSTAR to explain absorption features.
- Three absorbers and several narrow emission lines are needed.
- WA1 makes a deep Fe-L UTA feature.

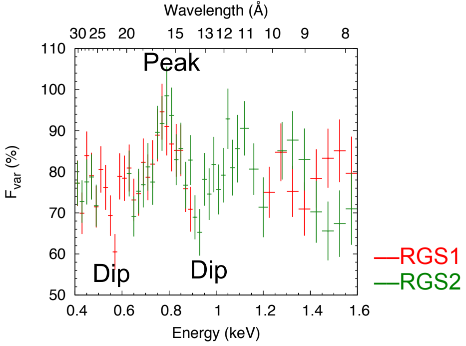
	N_H (cm^{-2})	log ξ	v (km/s)
WA1	2.5×10^{21}	1.5	–650
WA2	8.7×10^{21}	2.5	–4000
WA3	6.7×10^{23}	3.4	–6100

3. RMS spectra

- F_{var} : Variation amplitude fraction, the long-timescale variability across the whole observation period [3]

$$F_{var} = \frac{1}{\langle X \rangle}\sqrt{S^2 - \langle \sigma_{err}^2 \rangle}$$

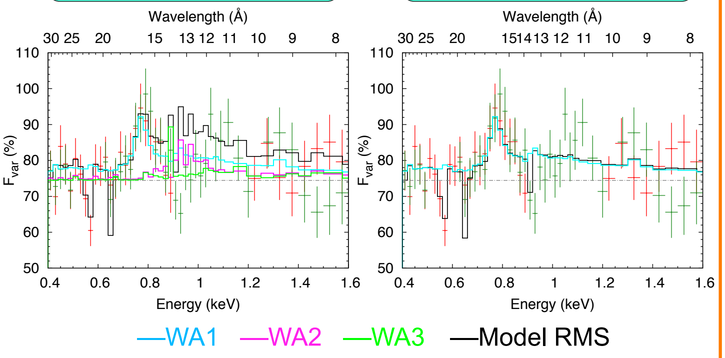
where $\langle X \rangle$ is the mean count rate, S^2 is the variance of the light curve, and $\langle \sigma_{err}^2 \rangle$ is the mean error squared.



- A peak at ~0.8 keV is due to variation of WA1
- Dips at ~0.6 and ~0.9 keV are due to the O VII and Ne IX lines

ALL absorbers are variable

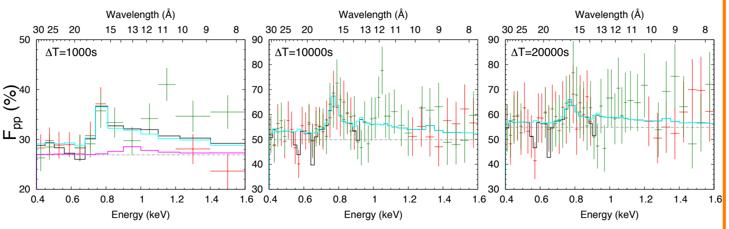
Only WA1 is variable



- If all the three absorbers had the same variability, additional F_{var} peaks at 0.9–1.0 keV could be seen.
- Only WA1 varies, whereas WA2 and WA3 do not vary.

- F_{pp} : Point-to-point fractional variability, the short-timescale variability at a given timescale [3]

$$F_{pp} = \frac{1}{\langle X \rangle}\sqrt{\frac{1}{2(N-1)}\sum_{i=1}^{N-1}(X_{i+1}-X_i)^2 - \langle \sigma_{err}^2 \rangle},$$



	500 s	800 s	1000 s	3000 s	5000 s	10000 s	15000 s	20000 s
WA1	22 ± 6 %	30 ± 7 %	28 ± 8 %	37 ± 7 %	41 ± 8 %	41 ± 10 %	49 ± 11 %	26 ± 13 %
WA2	0^{+11} %	7 ± 18 %	9 ± 20 %	0^{+4} %	0^{+9} %	0^{+16} %	0^{+17} %	0^{+21} %
WA3	26 ± 28 %	0^{+29} %	0^{+95} %	0^{+33} %	10 ± 40 %	0^{+114} %	0^{+116} %	0^{+141} %
Constant	19.8 ± 0.8 %	24.0 ± 1.0 %	26.9 ± 1.1 %	35.0 ± 1.0 %	37.9 ± 1.2 %	49.9 ± 1.5 %	55.5 ± 1.7 %	55 ± 2 %
χ^2_ν (dof)	0.62 (16)	0.49 (16)	1.39 (16)	1.50 (68)	1.44 (68)	0.51 (68)	0.46 (68)	0.44 (68)

- We calculated the F_{pp} spectra at 500s-20000s, to find that all of them are similar to the F_{var} spectra.
- WA2 and WA3 do not vary at all the examined timescales.
- WA1 shows the largest variability at ~10000s.

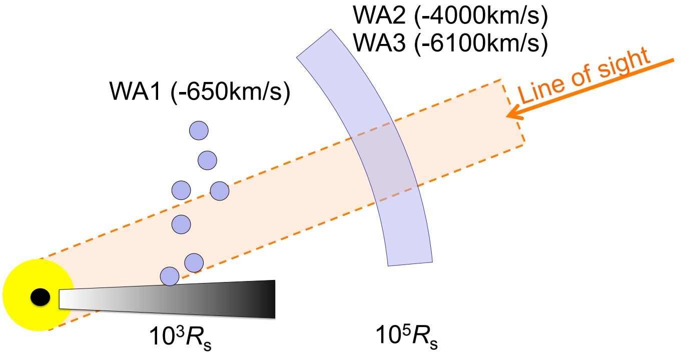
4. Geometry of warm absorber outflows

- Assuming an X-ray absorber follows Kepler motion, the location of the absorber (r) is calculated to be

$$\frac{r}{R_s} = 2\times10^3\cdot\left(\frac{\Delta T}{10^4\,\mathrm{sec}}\right)^2\left(\frac{a}{10R_s}\right)^{-2}\left(\frac{M_{BH}}{1.7\times10^6 M_{solar}}\right)^{-2},$$

where R_s is the Schwarzschild radius, ΔT is the variability timescale, and a is the size of the X-ray emission region.

- WA1 is variable, and locates at $\sim10^3 R_s$.
- We propose that WA1 partially cover the X-ray source, and that the partial covering fraction varies.
- On the contrary, WA2 and WA3 show no variation.
- We propose that they locate at $>10^5 R_s$, which is consistent with Compton cooling shocked wind gas proposed by [4].



<References>
[1] Denney, K. D., Watson, L. C., Peterson, B. M., et al. 2009, ApJ, 702, 1353
[2] Pounds, K. A. & Vaughan, S. 2011, MNRAS, 413, 1251
[3] Edelson, R., Turner, T. J., Pounds, K., et al. 2002, ApJ, 568, 610
[4] Pounds, K. A. & King, A. R. 2013, MNRAS, 433, 1369

【 XMM-Newton: The Next Decade (ESAC, 2016.5.9-11) 】