

What Can We Learn about Compton-thin AGN Tori from Their X-Ray Spectra?¹

© 2023 г. F. Melazzini^{1,2}, S. Sazonov^{1*}

¹Space Research Institute, Russian Academy of Sciences, Moscow, Russia

²Moscow Institute of Physics and Technology, Dolgoprudny, Russia

Поступила в редакцию 21.06.2023

После доработки 21.06.2023; принята к публикации 07.07.2023

We have developed a Monte Carlo code for simulation of X-ray spectra of active galactic nuclei (AGN) based on a model of a clumpy obscuring torus. Using this code, we investigate the diagnostic power of X-ray spectroscopy of obscured AGN with respect to the physical properties and orientation of the torus, namely: the average column density, $\langle N_{\text{H}} \rangle$, the line-of-sight column density, N_{H} , the abundance of iron, A_{Fe} , the clumpiness (i.e. the average number of gas clouds along the line of sight), $\langle N \rangle$, and the viewing angle, α . In this first paper of a series, we consider the Compton-thin case, where both $\langle N_{\text{H}} \rangle$ and N_{H} do not exceed 10^{24} cm^{-2} . To enable quantitative comparison of the simulated spectra, we introduce five measurable spectral characteristics: the low-energy hardness ratio (ratio of the continuum fluxes in the 7–11 keV and 2–7 keV energy bands), the high-energy hardness ratio (ratio of the continuum fluxes in the 10–100 keV and 2–10 keV energy bands), the depth of the iron K absorption edge, the equivalent width of the Fe K α line, and the fraction of the Fe K α flux contained in the Compton shoulder. We demonstrate that by means of X-ray spectroscopy it is possible to tightly constrain $\langle N_{\text{H}} \rangle$, N_{H} and A_{Fe} in the Compton-thin regime, while there is degeneracy between clumpiness and viewing direction.

Keywords: supermassive black holes — active galaxy nuclei — X-ray spectroscopy.

DOI: 10.31857/S0320010823060050, EDN: GPDELE

СПИСОК ЛИТЕРАТУРЫ

1. R. Antonucci, *Ann. Rev. Astron. Astrophys.* **31**, 473 (1993).
2. J. Buchner, M. Brightman, K. Nandra, R. Nikutta, F.E. Bauer, *Astron. Astrophys.* **629**, A16 (2019).
3. J. Buchner, M. Brightman, M. Balokovic, K. Wada, F.E. Bauer, K. Nandra, *Astron. Astrophys.* **651**, A58 (2021).
4. D. Burlon, M. Ajello, J. Greiner, A. Comastri, A. Merloni, N. Gehrels, *Astrophys. J.* **728**, 58 (2011).
5. C.P. Dullemond and I.M. van Bemmell, *Astron. Astrophys.* **436**, 47 (2005).
6. U. Feldman, *Phys. Scr.* **46**, 202 (1992).
7. A. Feltre, E. Hatziminaoglou, J. Fritz, A. Franceschini, *MNRAS* **426**, 120 (2012).
8. S. Furu, Y. Fukazawa, H. Odaka, T. Kawaguchi, M. Ohno, K. Hayashi, *Astrophys. J.* **818**, 164 (2016).
9. I.M. George and A.C. Fabian, *MNRAS* **249**, 352 (1991).
10. M. Guainazzi and S. Bianchi, *MNRAS* **374**, 1290 (2007).
11. R.C. Hickox and D.M. Alexander, *Ann. Rev. Astron. Astrophys.* **56**, 625 (2018).
12. J.S. Kaastra and R. Mewe, *Astron. Astrophys. Suppl. Ser.* **97**, 443 (1993).
13. Y. Liu and X. Li, *Astrophys. J.* **787**, 52 (2014).
14. Y. Liu and X. Li, *IAU General Assembly, Meet.* **29**, 2249494 (2015).
15. A. Malizia, S. Sazonov, L. Bassani, E. Pian, V. Beckmann, M. Molina, I. Mereminskiy, G. Belanger, *New Astron. Rev.* **90**, 101545 (2020).
16. A.G. Markowitz, M. Krumpke, R. Nikutta, *MNRAS* **439**, 1403 (2014).
17. A. Merloni, et al., *MNRAS* **437**, 3550 (2014).
18. M. Nenkova, Z. Ivezić, M. Elitzur, *Astrophys. J.* **570**, L9 (2002).
19. H. Netzer, *Ann. Rev. Astron. Astrophys. Sov. Sci. Rev., Sect. E: Astrophys. Space Phys. Rev.* **53**, 365 (2015).
20. L.A. Pozdnyakov, I.M. Sobol, R.A. Syunyaev, *Sov. Sci. Rev., Sect. E: Astrophys. Space Phys. Rev.* **2**, 189 (1983).
21. C. Ramos Almeida and C. Ricci, *Nature Astron.* **1**, 679 (2017).
22. C. Ramos Almeida, et al., *Astrophys. J.* **731**, 92 (2011).
23. C. Ricci, et al., *Astrophys. J.* **820**, 5 (2016).

* Электронный адрес: sazonov@cosmos.ru

¹ Полная версия статьи публикуется в английской версии журнала (*Astronomy Letters*, vol. 49, № 6, 2023).

24. G. Risaliti, M. Elvis, G. Fabbiano, A. Baldi, A. Zeza, *Astrophys. J.* **623**, L93 (2005).
25. G. Risaliti, M. Elvis, G. Fabbiano, A. Baldi, A. Zezas, M. Salvati, *Astrophys. J.* **659**, L111 (2007).
26. S.Y. Sazonov and M.G. Revnivtsev, *Astron. Astrophys.* **423**, 469 (2004).
27. S.Y. Sazonov and R.A. Sunyaev, *Astrophys. J.* **543**, 28 (2000).
28. S. Sazonov, M. Revnivtsev, R. Krivonos, E. Churazov, R. Sunyaev, *Astron. Astrophys.* **462**, 57 (2007).
29. S. Sazonov, E. Churazov, R. Krivonos, *MNRAS* **454**, 1202 (2015).
30. M. Stalevski, C. Ricci, Y. Ueda, P. Lira, J. Fritz, M. Baes, *MNRAS* **458**, 2288 (2016).
31. A.T. Steffen, A.J. Barger, L.L. Cowie, R.F. Mushotzky, Y. Yang, *Astrophys. J.* **596**, L23 (2003).
32. R.A. Sunyaev and E.M. Churazov, *Astron. Lett.* **22**, 648 (1996).
33. A. Tanimoto, Y. Ueda, H. Odaka, T. Kawaguchi, Y. Fukazawa, T. Kawamuro, *Astrophys. J.* **877**, 95 (2019).
34. Y. Ueda, M. Akiyama, K. Ohta, T. Miyaji, *Astrophys. J.* **598**, 886 (2003).
35. Y. Ueda, M. Akiyama, G. Hasinger, T. Miyaji, M.G. Watson, *Astrophys. J.* **786**, 104 (2014).
36. D.A. Verner and D.G. Yakovlev, *Astron. Astrophys. Suppl. Ser.* **109**, 125 (1995).
37. D.A. Verner, G.J. Ferland, K.T. Korista, D.G. Yakovlev, *Astrophys. J.* **465**, 487 (1996).