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Searching for warped disk AGN candidates

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Abstract. Mapping the maser emission of subnuclear regions of active galactic nuclei (AGN) enable us to determine some interesting details of the geometry of the accretion disks (AD) under the condition that they have “maser skin”. Additional information about disk warp in the innermost zone near the central black hole (BH) can be disclosed by means of modeling the shape of the relativistically broadened iron emission lines in the energy range 6-7 keV. Here we analyze the influence of the AD geometry (warp) on the shape of the set of relativistically broadened emission lines, as well as consider some examples of AGNs identified by maser mapping techinque as warped and having the complex shape of iron lines near 6.4 keV.

Keywords. AGN, accretion: warped accretion disk

It was shown by Bardeen & Peterson (1975) that Lense-Thirring effect in accretion systems with misaligned angular momentum of AD and BH spin leads to the deformation of the disk geometry, so-called disk warp/tilt. Some physical factors which can cause such misalignment were considered recently by Chakraborty & Bhattacharya (2017), including instability due to comparably young age of the system, inhomogeneity or clumpiness of the accretion disk, as well as subnuclear star formation processes.

Following Ingram *et al.* (2016), observational appearances of such warped disks include: 1. if disk is precessing, it is possible to see specific timing features in X-ray lightcurves; 2. if hot surface spots are present, sub-pc scale warp can be traced from VLBI observations (Greenhill 2003, Kartje *et al.* 1999); 3. the shape of emission lines and continuum spectra formed in the vicinity of the central BH depends significantly on the disk geometry (Reynolds *et al.* 2009), that is why the warp can be traced out from X-ray spectral data.

Leaving the explanations of the possible physical reasons of such misalignment, we consider here some observational appearances of AGN with warped accretion disks (WAD) and the methods enabling us to reconstruct the AD geometry in such systems. We analyze the effect of the disk warp on the shape of Fe-K emission lines, using the simplified model of WAD consisting of two flat disks with angle $\Delta\theta$ between them (Fig.1, the left panel). The resulting simulated line profiles are shown on the right panel of the Fig.1, in comparison with the regular one.

We applied this model to fit the observational data on Fe-K lines in several AGNs, where their shape is not interpretable within the regular AD model. These objects are: NGC 1194 (XMM-Newton/EPIC and Suzaku/XIS data were used), NGC 1068, IC 2560, NGC 5506, and the Circinus (XMM-Newton/EPIC data). The results of our fitting, and the information about the megamaser disks and BH masses are shown in the Table.1.

Analysis of the X-ray data on Fe-K lines in AGNs give us the possibility to disclose the peculiarities of the line profile which can be interpreted as a sign of WAD in that AGN. However, one should note that there can be alternative explanations (for instance, NGC 1194, Fedorova *et al.* (2015)) of such peculiarity. Combining the data of Fe-K line observations with the results of maser emission observations enable us to be more

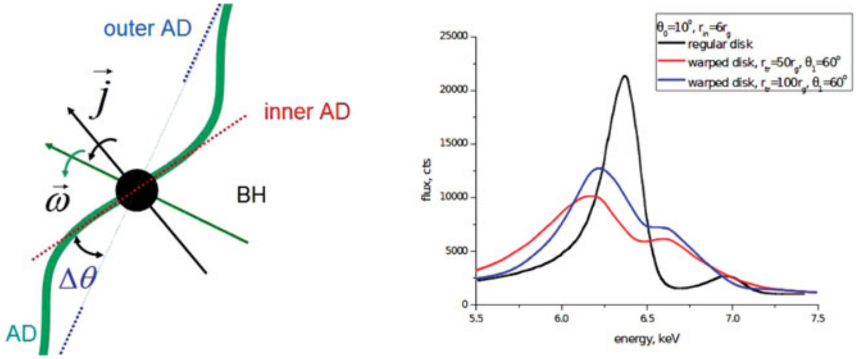

Figure 1. Left panel: WAD Model: two disks with angular momenta. Right panel: Simulated Fe-K line profiles for WADs with different transition radii R_{tr} vs. regular one. θ_0 and θ_1 are inner and outer disk inclination angles, and R_{in} is the inner disk radius.

Table 1. Warped disk candidates and their observational parameters.

Object	megam.disk, pc	M_{BH}, $10^7 M_\odot$	E_α, keV	E_β, keV	R^*_{in}	R^*_{tr}	θ_0	θ_1
NGC 1194	regular, 0.54-1.33[1]	6.6[2]	6.4±0.03	7.01±0.11	7^{+10}_{-3}	500±150	44±10	7^{+10}_{-1}
NGC 1068	warped, 0.57-0.92[1,3]	1.5[4]	6.4±0.02	6.95±0.07	7^{+6}_{-1}	86±5	24±10	14±4
IC 2560	warped, 0.09-0.34[5]	0.44[6]	6.37±0.04	7.02±0.10	8^{+12}_{-2}	140±90	37±10	< 20
NGC 5506	not identified[7]	10[8]	6.40±0.04	–	7^{+22}_{-1}	160±90	40±15	< 10
Circinus	warped, 0.11-0.4[9]	1.7[10]	6.44±0.03	7.07±0.05	9^{+5}_{-3}	101±10	35±1	4±3

Notes: *in units of R_g; [1]Kartje *et al.* (1999); [2]Kuo (2011); [3]Caproni *et al.* (2005) (note that the tilt angle $\Delta\theta = \theta_0 - \theta_1 = 10^o \pm 14^o$ is in a good concordance with the value of $\Delta\theta \approx 11^o$ mentioned there); [4]Greenhill & Gwinn (1997); [5]Yamauchi *et al.* (2012); [6]Graham (2008); [7]Tarchi *et al.* (2011); [8]Uttley & McHardy (2005); [9]Greenhill (2003); [10]Gnerucci *et al.* (2013).

confident considering the WAD hypothesis as the more appropriate one. In the same time, it gives us possibility to reconstruct more detailed map of the AD, where the outer zones are reconstructed from maser emission mapping down to scales of 10^{-2} pc and the inners ones (usually below 10^{-3} pc) are traced out by fitting the Fe-K line profiles.

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