The Bardeen-Petterson effect

Unique evidence in Swift J2058+0516

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- Bardeen-Petterson (B-P) effect
- Iron line as a probe of B-P effect
- Iron lines reverberation mapping to probe BH mass and spin
- Evidence of B-P effect in the TDE X-ray flare Swift J2058
  - complex line feature
- Discussions: probing dormant SMBH spins with the B-P effect
The Bardeen-Petterson (BP) effect

- A tilted accretion disk around a spinning black hole to warp into the equatorial plane of the spinning black hole.

- Combination of two effects: differential Lense-Thirring precession and internal viscosity of the accretion flow.

The BP radius is estimated as a few tens Rg

Information of both the BH and the accretion flow
Disk line profile sensitive to disk inclination within 100 Rg

Relativistic line profiles around a spinning BH
(Laor 1991)

Sensitive probe of the innermost BP disks could be from disk lines.
Iron line as a probe of the Bardeen-Petterson disks

- inner disk deep in the potential, angular momentum aligned with the BH spin
- outer disk less affected by the BH spin
- broad, relativistic iron line turns into multiple peaks, depends on inclinations as well as the angle $\phi$

The line emission is primarily from two disk components

Fragile et al. 2005
Iron line profile of a Bardeen-Petterson disk

The B-P disk line profile is not very sensitive to spin $a$. 

Fragile et al. 2005
Iron line profiles of Bardeen-Petterson disks

Multiple or triple-peaked line profile often shows up! - signature of BP disks

in contrast: double or blurred line profile seen in AGNs
Reverberation mapping with the iron lines due to illuminating X-ray flares

- proposed for the study of the iron line response to the illuminating flares in AGNs (before the Chandra era)
- model based on hard X-ray irradiation of cold, dense matter in the innermost disk inside ~ 100 Rg
- broad, relativistic iron lines to probe black hole mass and spin

Young & Reynolds 2000
A $\delta$-function illumination flare:

- A circle of illumination in the rest frame
- Expanding with light speed

Region passed by ionization circle
Evolution of Iron line profile from an expanding ionization circle

Young & Reynolds 2000
A characteristic double-horn profile dominated by photons having energy around the maximum or the minimum of the allowed range

Karas et al. 2010
Reverberation mapping: Schwarzschild BHs

Young & Reynolds 2000

Separation between the double line peaks become narrower with time due to 1) reduced gravitational redshift 2) reduced Doppler effect

part of the ionization circle is seen because of light travel effect

Young & Reynolds 2000

FIG. 6.—Panel a shows the theoretical transfer function for a Schwarzschild case with an inclination of 60° and an on-axis flare at a height of 10GM/c². Note the “loops” in the transfer function corresponding to fluorescence from the ionized regions of the disk within the innermost stable orbit. The horizontal line shows the time delay between the initial response and the “re-emergence” which may be used to estimate the black hole mass. Panel b shows the simulated observed transfer function. The loops are still visible. The data have been rebinned to produce these figures with improved signal-to-noise ratio.
Reverberation mapping: Kerr BHs

Different from the Schwartzchild BH case:

A "red-ward moving bump"

Young & Reynolds 2000
Focus on the iron line in AGNs

- incident power-law component irradiates the cold disk
- the accretion disk is ionized, generating the disk lines
- Iron line is the strongest; details depend on the ionization state

X-ray reflection from an illuminated slab

Iron disk lines will form in a large luminosity range including super-Eddington regimes

Zhou et al. 2010
Iron line reverberation mapping of the innermost disks
AGNs vs. Previously dormant SMBHs (TD flares)

**AGN**
- Coupling between the iron line and the ionization flux
- Illuminations by both persistent flux and flares exist!
- Only recently results are obtained by averaging flares

**TD flares**
- a newly formed disk has not been ionized
- X-ray flare illuminates and ionized the fresh disk
- Rising edge of the luminous TD (X-ray) flare serves as the “δ-function” illumination

TD flares from previously dormant SMBHs are perfect targets
Tidal Disruption Events: Swift J2058

Similar to Swift J1644: a long-lived, super-Eddington event, luminous radio counterpart, faint optical emission

see Cenko et al. 2012, but out mass estimate is different (see below)
X-ray observations Swift J2058

- **triple-peaked lines** probably due to highly ionized line Fe XXVI at around 7.0 keV; **line flux** gives the lower limit on $M_{\text{BH}}$: $\sim 10^8$ solar masses

- probably detection of the Bardeen-Petterson disk, $R_{\text{BP}}$ ~ a few tens $R_g$

- implying a spinning SMBH

Average results of the first few observations

$\sim 6$ sigma & 8 sigma

$Z = 1.185$

Yu & Zhang, 2012, submitted
Conclusions

• We have detected complex line emission from Swift J2058, which we interpret as a triple-peaked iron line from an innermost warping disk (line emission first occurred ~ 10 days after the first detection)

• The evolution of the line profile is consistent with that the line emission from an expanding ionization circle in a Bardeen-Petterson (BP) disk. The line profile maps the gravitational field in relation to the distance to the BH. The SMBH is therefore a spinning SMBH.

• Simple modeling of the data gives the SMBH mass of the order of $10^9$ solar masses (then $L_{\text{peak}}$ ~ a few times $L_{\text{E}}$ measured on time scales shorter than the dynamic time scales at the ISCO), but lower SMBH mass can be obtained if assuming slower expansion. This is larger than the SMBH mass expected for TD of giant stars for non-spinning SMBH, but a rapidly spinning SMBH up to $7 \times 10^8$ solar masses would allow TD flares for sun-like stars (Kesden 2012) - An extraordinary massive SMBH would explain its uniqueness among TDEs.

• Line spectroscopy (not limited to iron line) during the very early stages of TD flares is essential for probing the SMBH spin and the innermost flow with the Bardeen-Petterson effect - good to know for future missions targeted at TD flares.