Probing Bardeen-Petterson effect in TDEs with spectral line reverberation mapping

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Bardeen-Petterson Effect

- Lense-Thirring precession: test particle at inclined orbit would precess about BH rotation axis (Lense-Thirring effect)
- Bardeen-Petterson effect: for inclined viscous disc around a rotating BH, the inner region would be aligned with BH spin due to LT precession and viscous torque (Bardeen & Petterson 1975); a warped disc is formed

Bardeen-Petterson Effect

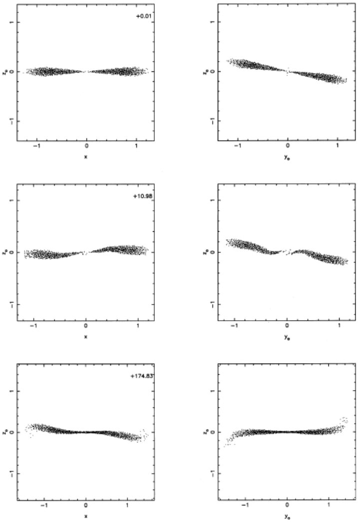


FIGURE: HD simulation of BP effect; Nelson & Papaloizou 2000

Tidal Disruption Events (TDEs)

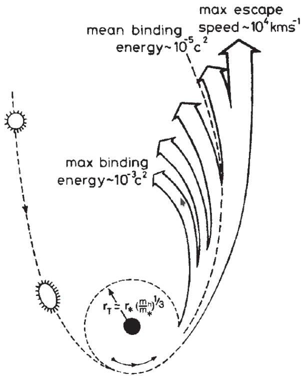


FIGURE: Rees 1988

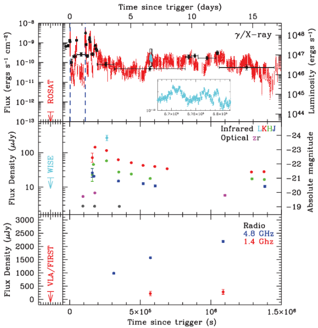


FIGURE: Multiwavelength lightcurve of Sw J1644+57; Levan+2011

- If a star is too close to a SMBH ($\lesssim R_{\rm tidal}$), it will be tidally disrupted
- The bound debris will cool down and form an accretion disc
- No preferred orientation of the stellar orbit → BH spin very probably misaligned with the accretion disc

Iron line reverberation: response of iron line to primary variability

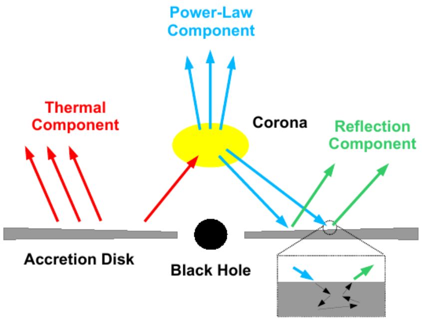


FIGURE: Disc-corona in AGN; Bambi 2018

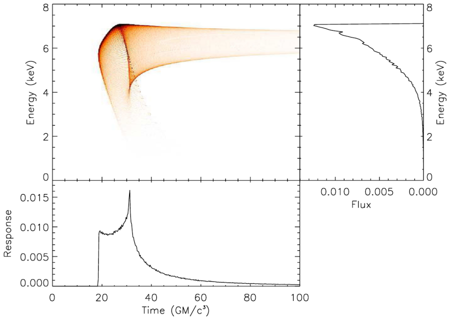


FIGURE: Transfer function of disc; Cackett+2014

- Reverberation can break degeneracies in modelling time-averaged spectrum

Iron line reverberation also found in TDEs

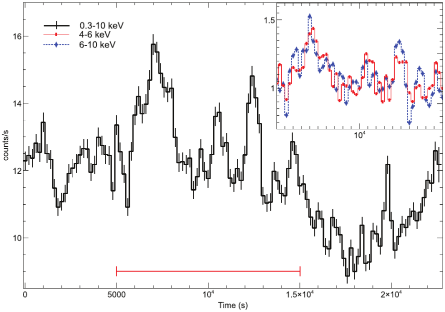


FIGURE: Continuum and Iron K band lightcurves; Kara+2016

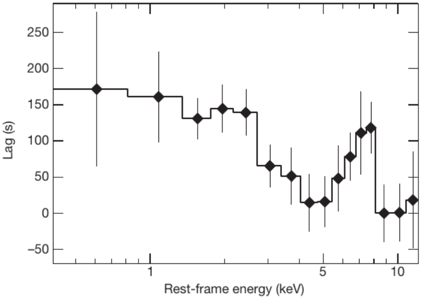


FIGURE: Iron K time lag; Kara+2016

- Iron line reverberation detected in Swift J1644+57; Kara+2016

TDE reverberation for an aligned disc

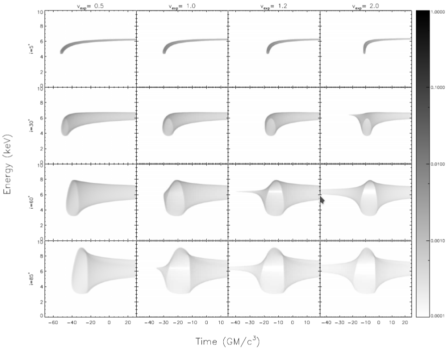


FIGURE: Time-resolved iron line spectrum, $a = 0$; Zhang+2015

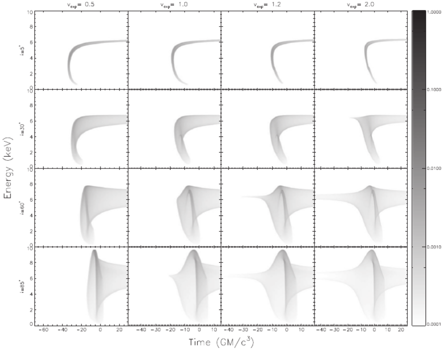


FIGURE: Time-resolved iron line spectrum, $a = 1$; Zhang+2015

- Constraint can be put on black hole spin and inclination with iron line reverberation

Iron line reverberation of Bardeen-Petterson disc

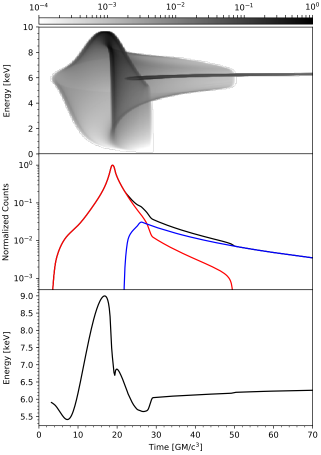
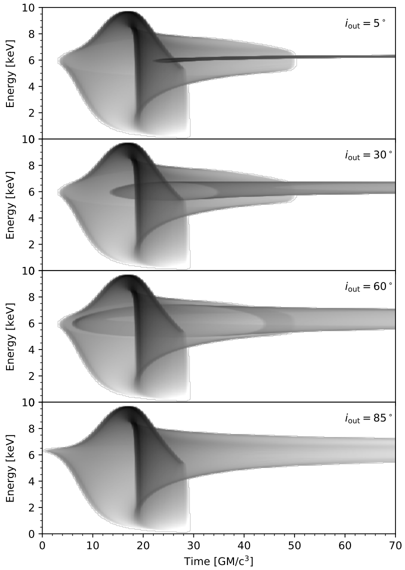


FIGURE: Zhang+2019

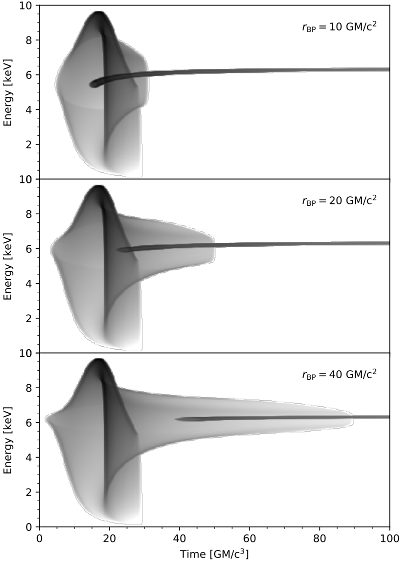
- Inner disc: between r_{ISCO} and r_{BP}; edge-on
- Outer disc: truncated at r_{BP}; face-on
- Sudden decrease of line width at $t \sim 50\ \mathrm{GM/c^3}$: signature of BP disc

Inclination dependence



- Late-time line width increases with outer disc inclination
- Doppler broadening; GR effect not significant

Dependence on transition radius



- As $r_{\rm BP}$ increases, the time when the narrow line dominates the spectrum also increases
- Constraint can be put on $r_{\rm BP}$ with time-resolved spectrum

eXTP/LAD simulation

- eXTP/LAD:
  - eXTP (enhanced X-ray Timing and Polarimetry mission): a Chinese-European X-ray satellite (launch time: 2027)
  - LAD (the Large Area Detector) onboard eXTP: a large-area non-imaging detector onboard eXTP
    - Large effective area: 3.4 m^2 between 6 and 10 keV
    - Energy resolution: better than 250 eV at 6 keV
    - Ideal instrument for iron line reverberation mapping
- Simulation
  - $10^7\ \mathrm{M_\odot}$ BH, 1 $\mathrm{GM/c^3} \sim 50$ s
  - Model: absorbed powerlaw + time-resolved iron Kα line
  - The spectral shape and lightcurve of the powerlaw continuum is the same with Sw J1644+57 during its XMM-Newton observation (obsID: 0678380101)
  - Maximum iron line EW of 70 eV (the same with what is detected by Kara+2016)

eXTP/LAD simulation of a relativistic TDE at low redshift

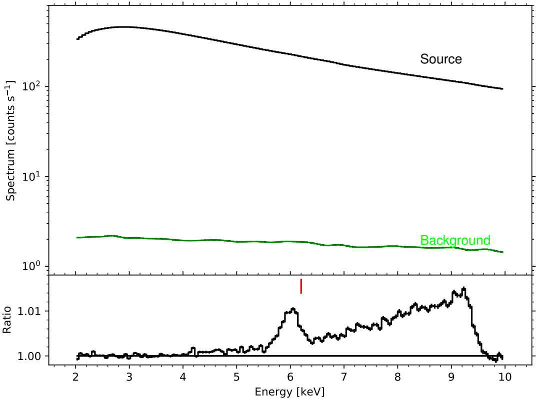


FIGURE: Simulated spectrum and data to continuum ratio

- A relativistic TDE located at $z = 0.032$, the average redshift of ASAS-SN TDEs
- Exposure time: 35 ks
- Spectral features from both inner and outer disc can be detected

eXTP/LAD simulation of a relativistic TDE at low redshift

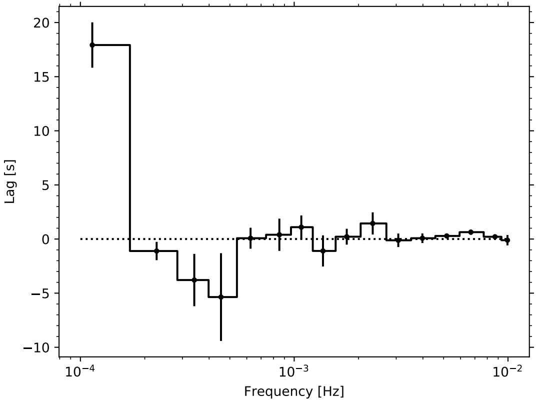


FIGURE: Frequency-dependent time-lag of the 5.75-6.25 keV band (the red wing of the line) vs. the 2-4 keV reference band

- The longest time lag is found at 1.14×10^{-4} Hz
- The time-lag is highly diluted, given that the flux of the emission line is small compared with the continuum

eXTP/LAD simulation of a relativistic TDE at low redshift

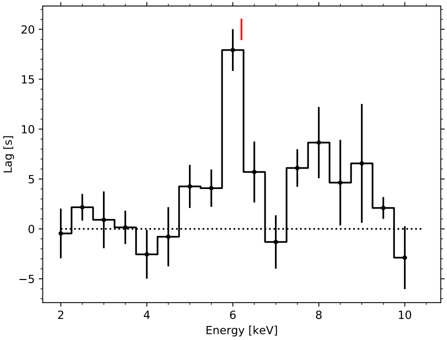


FIGURE: Energy-resolved time-lag at 1.14×10^{-4} Hz

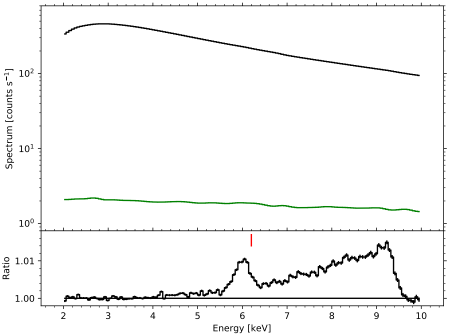


FIGURE: Energy spectrum

- Significant timelags at the energies of the red and blue wings
- The lag of the red wing is longer than the lag of the blue wing
- The ratio of red to blue wings intrinsic lags is even larger as the former is more dilated
- We would be able to detect distinct features of BP disc

eXTP/LAD simulation of Sw J1644+57

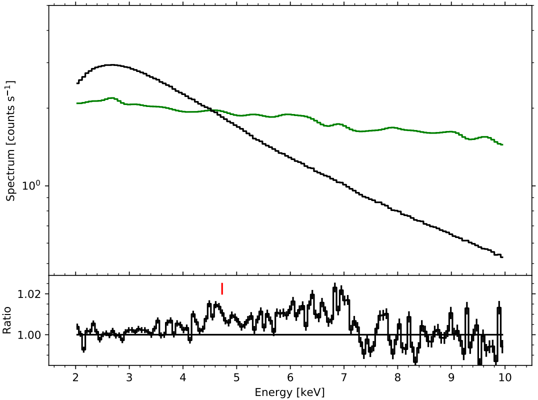


FIGURE: Data to continuum residual

- Background stronger than the source above $\sim$ 4.5 keV

eXTP/LAD simulation of Sw J1644+57

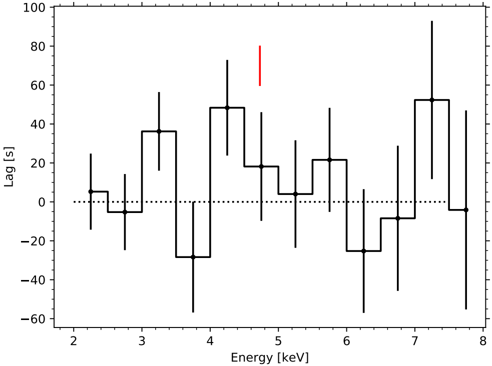


FIGURE: Energy-resolved time-lag

- No time-lag stronger than 2σ detected
- The XMM-Newton observation was taken $\sim$ 14 days after the BAT detection when the source flux has dropped by a factor of $\sim$ 35 from the peak flux.
- Detection and follow-up of TDEs at early stage required

Summary

- TDEs are very probably to have misaligned accretion flows and may contains a warped disc due to Bardeen-Petterson effect
- We calculate time-resolved spectra of BP disc and found that it can be used to put constraint on $r_{\rm BP}$ and outer disc inclination in BP disc
- We simulate eXTP/LAD observation and find that we would be able to detect distinct features of BP disc with time-resolved spectroscopy