Probing the accretion disk in Seyfert 1 galaxy NGC 4593

Sachindra Naik
Physical Research Laboratory, India
Outline of the Presentation

- Introduction : Central engine
- Broadband X-ray spectroscopy
- X-ray/UV/Optical light curves
- Cross-correlation between light curves
- Accretion disk and X-ray reprocessing
- Lag-Spectrum profile
- Flux-Flux profile
- Summary and results
**Introduction:** Unified Model

Antonucci 1993
Introduction: Unified Model

Antonucci 1993
Introduction: Artistic representation of central engine and spectrum in Seyfert 1 AGN.
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NGC 5548: Fausnaugh et al 2015
Introduction: Artistic representation of central engine and spectrum in Seyfert 1 AGN
Correlation between UV/optical and X-ray emission

Observed variability in X-ray/UV/optical emission from AGN is in wide time range -- days to years.

**Case-I** : Delay in fluctuation in UV/optical radiation compared to X-ray implies **X-ray reprocessing**

**Case-2** : Fluctuation in UV/optical band is independent of the X-ray band implies fluctuations are local to the disc.

**Case-3** : Rare rapid changes in optical band compared to X-ray band implies **distinct regions of origin**.

Correlation between UV/optical emission & X-ray emission is complex. Hence, intensive exploration is required.
NGC 4593

- NLS1, $z=0.009$
- $M = \sim 10^7 \, M_{\text{sun}}$
- Variable in X-ray and UV/optical on long and short timescale

Log of observation of NGC 4593 with Swift XRT/UVOT

<table>
<thead>
<tr>
<th>Observation ID</th>
<th>00092353001–00092353201</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of Observations</td>
<td>2016 July 13 - 2016 August 5</td>
</tr>
<tr>
<td>MJD</td>
<td>57582.8 - 57605.4</td>
</tr>
<tr>
<td>No. of IDs for XRT</td>
<td>185</td>
</tr>
<tr>
<td>No. of IDs for UVOT</td>
<td>160-184</td>
</tr>
</tbody>
</table>
- Powerlaw plus blackbody model modified by Galactic absorption
- No Intrinsic absorption required
X-ray spectroscopy - results

- Reduced $\chi^2$ is close to unity
- Photon index does not vary significantly - no significant Comptonization

There seems no variation in seed photon flux.
Swift XRT/UVOT light curve
After removing data-points of low sensitivity patches, bad tracking

Count rate (cnts s⁻¹)

Time (MJD)
Linear fit for soft band and hard band \((y = mx + c)\)

Positive intercept \(C\): Slowly variable component i.e. disk emission
Cross-correlation lags

**Javelin**: Zu et al. 2011

<table>
<thead>
<tr>
<th>Lags in days</th>
<th>Soft</th>
<th>W2</th>
<th>M2</th>
<th>W1</th>
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</thead>
<tbody>
<tr>
<td>Javelin</td>
<td>0.22±0.02</td>
<td>0.56±0.88</td>
<td>0.91±0.27</td>
<td>1.1±0.5</td>
</tr>
<tr>
<td>ZDCF</td>
<td>0.11±0.18</td>
<td>0.36±0.35</td>
<td>0.38±0.36</td>
<td>1.45±0.70</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lags in days</th>
<th>U</th>
<th>B</th>
<th>V</th>
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</thead>
<tbody>
<tr>
<td>Javelin</td>
<td>0.76±1.0</td>
<td>0.9±1.3</td>
<td>1.3±0.5</td>
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<tr>
<td>ZDCF</td>
<td>1.94±0.44</td>
<td>1.62±0.35</td>
<td>1.14±1.62</td>
</tr>
</tbody>
</table>

**ZDCF**: Alexander 1997
X-ray reprocessing model

Timescale \( \sim \) light travel time \( \sim \) hours to days
Optical/UV emission lag the X-rays

\[ T \sim R^{-3/4} \]

Optical/UV emission lag the X-rays (Krolik et. al 1991)
Lag profile of standard disk

- Gravitational heating + X-ray illumination on the disc ($H << R$, $R_{in} << R$), temperature

$$T(R) = \left( \frac{3GM\dot{M}}{8\pi\sigma R^3} + \frac{(1 - A)L_X H}{4\pi\sigma R^3} \right)^{1/4}$$

- Lag with respect to $\lambda_0$

$$\tau - \tau_0 = \left( \frac{1}{c} \right) \left( \frac{\lambda_0}{k} \right)^{4/3} \left( \frac{3GM\dot{M}}{8\pi\sigma} + \frac{(1 - A)L_X H}{4\pi\sigma} \right)^{1/3}$$

$$\left[ \left( \frac{\lambda}{\lambda_0} \right)^{4/3} - 1 \right].$$

- Functional form of the lag

$$\tau = \alpha \left[ \left( \frac{\lambda}{\lambda_0} \right)^\beta - 1 \right]$$
Power law model?

Std. Disk model: dashed line

Functional form of disk lag: Blue

$\tau = (2.01 \pm 0.28) \times 10^{-4} \left(\frac{\lambda}{\lambda_0}\right)^{4/3} - 1$

$\chi^2_{dof} = 0.85/6$

$\tau = (0.61 \pm 0.13) \left(\frac{\lambda}{\lambda_0}\right)^{4/3} - 1$

$\chi^2_{dof} = 0.7/6$

$M = 10^{**7} M_{\odot}$, Accretion rate = 0.04*Eddington rate; $h = 6r_g$; $R_{in} = 6r_g$; $L_x = 10^{**43.7}$ ergs s$^{-1}$

Real disk seems larger than expected from standard disk
Other two examples of similar results

Fairall 9

\[ \tau = \alpha \left( \frac{\lambda}{\lambda_0} \right)^\beta - 1 \]

\[ 2.9 \pm 0.4 \times [(\lambda/192.8)^{1.36\pm 0.13} - 1] \]

\[ -3.0 \pm 0.4 + 0.020 \pm 0.001 \times \lambda \]


NGC 5548

\[ \beta = 1.23 \pm 0.31 \]


Real disk seems larger than expected from standard disk
Summary

- Existence of slowly and highly variable components
- X-rays and UV/optical emission are strongly correlated
- Variability observed in the UV/optical emission is due to the reprocessing of X-ray emission
- Lags are longer than that predicted from standard disk theory
- Longer lags infer larger size of real accretion disk
Ongoing work on AGN with AstroSat

- NGC 4748: Simultaneous X-ray/UV (AstroSat) and Infrared (Mount Abu Telescope) observations are over.
- Mrk 359, UGC 06728, NGC 424, NGC 4388, NGC 4945

Thank you for Your Attention