Modeling the thermal reverberation in AGN

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Observations – NGC 5548

- Observations: UV/optical delays with respect to X-rays that increase with wavelength

- This may be due to reprocessing of X-rays in the accretion disc:
  - part of the X-rays is reflected off the disc
  - part is absorbed in the disc where it is thermalized and causes temperature increase
  - thus the disc UV/optical emission will increase
  - X-rays variations must be followed by the variations in the reprocessed UV/optical emission with lags increasing with wavelength
UV/optical time lags in NGC 5548

- Observed UV/optical time lags vs. wavelength $\lambda$

- The shape agrees well with the predictions of a Shakura-Sunyaev $\alpha$-disc.

- The amplitude is too large.

- The disc appears larger.

Fausnaugh et al (2016)
Model assumptions for NGC 5548

**black hole:** \( M = 5 \times 10^7 M_\odot, \ a = 0.1 \)

**primary isotropic power-law emission with energy cut-offs:**
\[ h, \ L_X(2-10\text{keV}) = 0.0034 \ L_{\text{Edd}}, \ \Gamma = 1.5 \]
\[ E_0 = 0.1 \text{keV}, \ E_c = 300 \text{keV} \]

**Novikov-Thorne accretion disc:**
\( \dot{M}, \ r_{\text{in}} = \text{ISCO}, \ r_{\text{out}} = 10000 \ r_g, \ f_c = 2.4 \)

**Other parameters:**
\( \text{incl} = 40^\circ, \ D = 75 \text{Mpc} \)

\[ F_{\text{abs}}(r, \varphi) = F_{\text{inc}}(r, \varphi) - F_{\text{refl}}(r, \varphi) \]

\[ T_{\text{new}}(r, \varphi) = \left[ \frac{F_{\text{abs}}(r, \varphi) + F_{\text{NT}}(r)}{\sigma} \right]^{1/4} \]

\[ \Psi(\Delta \lambda, \tau_{\text{obs}}) = \frac{F_{\text{rev}}(\Delta \lambda, \tau_{\text{obs}}) - F_{\text{NT}}(\Delta \lambda)}{F_{X_0} \Delta t} \]

*\( F_{\text{refl}} \) – given by XILLVERD (Garcia et al. 2016)*

**KYNXILREV model**
– all relativistic effects included
Black body properties

- flux decreases with decreasing temperature much faster for small $\lambda$
- the temperature decreases with radius ($\sim r^{-3/4}$) and with time
The response:

- start rising at the same time for all $\lambda$
  - close to the BH the temperature is high enough for the BB to be emitted at all studied $\lambda$

- is shorter for smaller $\lambda$
  - BB with smaller temperature at larger radius does not contribute to smaller $\lambda$

- is higher for lower accretion rate
  - disc temperature is lower thus $F_{NT}$ is smaller, the same $F_{abs}$ will cause larger change in BB

- is shorter for lower accretion rate
  - disc temperature is lower thus response diminishes earlier
Delay dependence on accretion rate

As a consequence the delay:

- is shorter for smaller $\lambda$  
  → since response is shorter

- increases with accretion rate  
  → since response is longer

\[
\langle \tau \rangle = \frac{\int_0^\infty t \Psi(\lambda, t) \, dt}{\int_0^\infty \Psi(\lambda, t) \, dt}
\]
Response dependence on height

The response:

- starts earlier and is shorter for smaller height
  → light travel time is shorter

- is higher for larger heights
  → incident flux is proportional to the cosine of the incident angle – by increasing the height cosine increases leading to a larger incident flux and thus larger $F_{\text{abs}}$
Delay dependence on height

As a consequence the delay:

- is higher for higher height
  \( \rightarrow \) since the response starts later and lasts longer
Fitted delay

- 0.65-day delay between X-rays and HST $\lambda_{1367}$ added

- fit in the grid of different accretion rates and heights

- U-band point excluded from fitting due to an additional delay probably caused by the Balmer jump in BLR (Korista & Goad 2001)

$$\langle \tau \rangle = \frac{\int_0^\infty t \Psi(\lambda, t) \, dt}{\int_0^\infty \Psi(\lambda, t) \, dt}$$

$\chi^2$/dof = 10.8/7 for $a = 0$
$\chi^2$/dof = 10.7/7 for $a = 1$
Summary

• The disc response in all UV/optical bands increases when the source height increases and the accretion rate decreases.
  → Therefore, we do not expect a strong thermal reverberation signal in objects with high accretion rate and strong X-ray reflection signatures like, for example, the X-ray bright narrow-line Seyfert-1 galaxies.

• The delays between X-rays and optical/UV bands increase with increasing source height and increasing accretion rate.

• We have successfully fitted the delays with NT disc for NGC 5548 with reasonable accretion rates, $\dot{m} = 0.01 \dot{m}_{\text{Edd}}$, and height, $h \sim 60 \, r_g$ which is consistent with X-ray reflection fitting by Brenneman et al (2012) where height, $h \sim 100 \, r_g$.

• We have used our reverberation code KYNXILREV model.

• More details in: Kammoun, Papadakis & Dovčiak (2019).

• Future plans:
  → study the effect of other parameters: M, $L_X$, $\Gamma$, $E_0$, $E_c$, inclination, non-razor thin discs
  → fit other AGN with observed UV/optical lags (NGC4593, NGC4151, Mrk 509)
  → study the connection of UV/optical light curves with X-ray ones
Additional material
Thermal reverberation is highly non-linear.

Response function depends on $L_X$.
Delay dependence on $L_X$
Delay dependence on $L_X$