PG1211+143: a ‘timing’ approach

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**WHY TIMING?**

Timing techniques make use of the rapid variability of AGN to understand their physics.

Variability is observed in different energy bands.

but in the X-ray it occurs on very short time scales, allowing to test the inner regions of AGN.

Arévalo et al. 2009
Close similarities with smaller size systems (BHXRBs) provided the characteristic time scales are re-scaled for the mass.

\[ \log(T_b) = 2.1 \log(M_6) - 0.98 \log(L_{44}) - 2.32 \]

McHardy et al. 2006
**HARD TIME LAGS**

At relatively low frequencies “positive” soft-to-hard lags are detected, having similar Fourier-frequency trend...

Cyg X-1 - Nowak et al. 1999

Ark 564 - Árévalo et al. 2006

...and energy dependence

Cyg X-1-Kotov et al. 2001

1H0707-495 - Zoghbi et al. 2011
HARD TIME LAGS

Origin is debated...

Accretion rate propagation models?? (e.g. Kotov et al. 2001)

Comptonization?? (e.g. Dewangan et al. 2007)
“NEGATIVE” SOFT LAGS

Tentative detections in some AGN, but most significant detection in 1H 0707-495
(see also results in Papadakis talk)

1H 0707-495

High frequency hard-to-soft lag

$M_{\text{BH}} \sim 2 \times 10^6 \, M_{\odot}$ Zhou & Wang 2005 + estimates from PSD break


0.3-1 keV vs 1-4 keV
"NEGATIVE" SOFT LAGS

Represents the hint of a distinct component in the lag frequency-spectrum: plausibly reverberation

(see discussion in Zoghbi et al. 2010, 2011 and Miller et al. 2011)

Reflection from the inner disk

Reflection from a distant medium close to the line of sight
PG1211+143 - light curves

0.3-10 keV

8x10^{12} \text{ erg/s/cm}^2 \quad 1.3x10^{11} \text{ erg/s/cm}^2

Relatively variable source (fvar = 7-10%)

M_{BH} \sim 2.4 \ (\pm 0.7) \times 10^{7} \ M_{\odot} \quad \text{Kaspi et al. 2000, Woo & Urry 2002}

14.6 \ (\pm 4.4) \times 10^{7} \ M_{\odot} \quad \text{Peterson et al. 2004}

10-100 times more massive than 1H 0707-495!
(as well as than MCG-6-30-50 and Mrk 766 - see Papadakis talk)
PG1211+143 - spectra

Analysis of absorption features:
- e.g. Pounds et al. 2003,
- Kaspi & Behar 2006

Time-averaged spectral analysis:
- e.g. Pounds & Reeves 2007
- Reeves et al. 2008

Energy (keV)

keV² (Photons cm⁻² s⁻¹ keV⁻¹)

XMM EPIC-pn

2001
2004
2007a
2007b

Analysis of absorption features:
- e.g. Pounds et al. 2003,
- Kaspi & Behar 2006
Soft (0.3–0.7 keV) -> **Excess**  
Medium (0.7–2 keV) -> **Absorption**  
Hard (2–10 keV) -> **Hard power law**
**PG1211+143 - analysis**

Energy (keV)

- **Soft (0.3-0.7 keV)** -> **Excess**
- **Medium (0.7-2 keV)** -> **Absorption**
- **Hard (2-10 keV)** -> **Hard power law**
$x(t_j)$  \rightarrow  $a(f_k) \exp(-\frac{2\pi i j k}{N})$

**Time domain**

Energy-resolved light curves

**Frequency domain**

Power spectrum
Coherence
Time lags

*PG1211+143 - analysis*
PG1211+143 NEGATIVE SOFT LAG

Negative Lags (=hard leads the soft) detected in all the observations

0.3-0.7 keV vs 2-10 keV

Poisson noise-dominated frequency range
Negative Lags (=hard leads the soft) detected in all the observations in the Poisson noise-dominated frequency range of 0.3-0.7 keV vs 2-10 keV.
COMPARISON WITH 1H 0707-495

Lag frequency $v_{\text{neg}}$

$1H\ 0707-495$

Zoghbi et al. 2010

$PG\ 1211+143$

McHardy et al. 2006

$v_{\text{neg}} \sim 1.5 \times 10^{-3}$ Hz

$M_BH \sim 2 \times 10^6 M_{\text{sol}}$

Zhou & Wang 2005 + estimates from PSD break

$v_2 \sim v_1 M_1/M_2$

$v_{\text{neg}} \leq 1.3 \times 10^{-4}$ Hz
COMPARISON WITH 1H0707-495

Lag magnitude $\tau$

$1H0707-495$

$1H0707-495$

$\tau \sim 30 \text{ sec}$

$\nu_2 \sim \nu_1 \frac{M_1}{M_2}$

$\nu_2 \sim \nu_1 \frac{M_1}{M_2}$

$\tau \sim 30 \text{ sec}$

$PG1211+143$

$\tau \geq 300 \text{ sec}$

$PG1211+143$

$\nu_2 \sim \nu_1 \frac{M_1}{M_2}$

$\nu_2 \sim \nu_1 \frac{M_1}{M_2}$

Zoghbi et al. 2010

Zoghbi et al. 2010

McHardy et al. 2006

McHardy et al. 2006
Lag consistent with being constant over the entire sampled frequency range

\[ \tau \sim 650-740 \text{ sec} \]
(from simulations and after correction from time dilation)
From our lag estimate (i.e. $\tau \sim 650$-740 sec)

$$d<2.2 \times 10^{13} \text{ cm } \iff \text{ few-to-tens } r_g$$
LOW FREQUENCY LAG ENERGY SPECTRA

Shifted so that the minimum lag corresponds to zero

\[ v = 1.6 \times 10^{-4} \text{Hz} \]

![Graph showing log-log plot of lag vs. energy for different years: 2001, 2004, 2007a, and 2007a+b.](image)
LOW FREQUENCY LAG ENERGY SPECTRA

Shifted so that the minimum lag corresponds to zero

\[ \nu = 1.6 \times 10^{-4} \text{Hz} \]

Energy (keV)

Log (s)
LOW FREQUENCY LAG ENERGY SPECTRA

Shifted so that the minimum lag corresponds to zero

\[ \nu = 1.6 \times 10^{-4} \text{Hz} \]

Apparently different trend during higher flux observations
POSSIBLE EXPLANATIONS FOR THE 2007 LAG ENERGY SPECTRA

Secondary Comptonization gas layer?

Disk-corona feedback process that gradually softens the spectrum? (e.g. Malzac & Jourdain 2000)
From PG 1211+143 absorbing gas estimated distance \( r \geq 300 \, r_g \) (Blustin et al. 2005 => \( v_{\text{esc}} = 24000 \, \text{km/s} \), Pounds et al. 2003) and the measured lag:

\[ \theta \leq 10 \, \text{deg} \iff \text{highly collimated structure} \]
CONCLUSIONS

* The observed soft lags in PG 1211+143 resemble the negative lag observed in 1H 0707-495:

  * lags in the two sources (frequency/magnitude) well match after scaling for the mass

  * the lag energy spectra of PG 1211+143 in 2 out of 3 observations are consistent with the high frequency energy lag spectrum of 1H 0707-495

  * same considerations valid for MCG-6-30-15 and Mrk 766 (Papadakis talk)

* The reverberation scenario is favoured, although the 2007 observation lag energy spectrum probably requires contribution from another component

* The fact that 1) the lag is apparently constant in magnitude/frequency over 6 yrs and 2) the need for a highly collimated structure disfavours the distant reflector (e.g. winds, clouds.. etc) scenario
THE END