X-ray continuum−iron line time-lags in AGN

The case of MCG−6-30-15, Mrk 766 and NGC 4051

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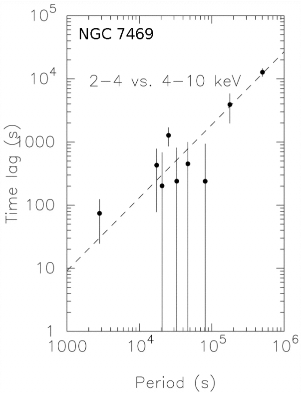
Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ ΚΑΙ ΘΡΗΣΚΕΥΜΑΤΩΝ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

Krakow, 28-30 August 2014

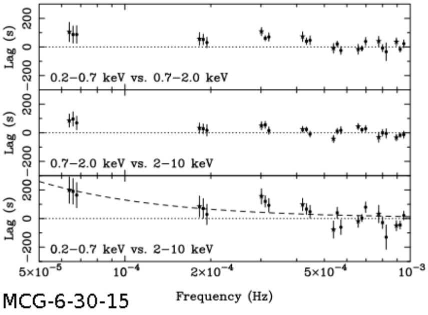
Overview

1. Time-lags in AGN X-ray light-curves
   - "Hard lags"
   - "Soft lags"
   - "Fe Kα lags"
2. Our work
   - Outline and methods
   - Preliminary results
   - Concluding remarks

Early studies: "Hard lags"



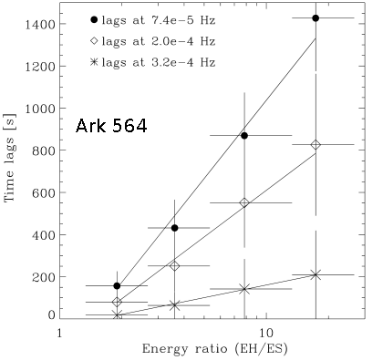
Papadakis *et al.* (2001)



Vaughan *et al.* (2003)

- High energy variations lag behind low energy variations
- Time-lags increase with increasing time-scale

Early studies: "Hard lags"



Arevalo *et al.* (2006)

- At a given time-scale, time-lags increase with increasing energy separation

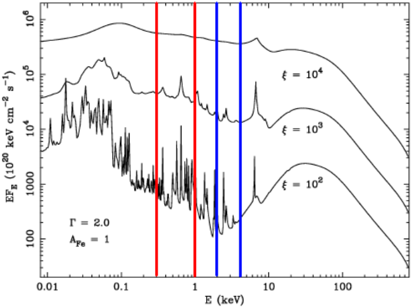
The quest for reverberation lags

Primary source
+ surrounding material → reflection

Choose energy bands representative of "continuum" and reflected emission

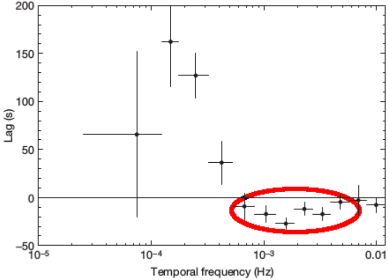
- "Continuum": $\sim 2-4$ keV
- Reflected: $\sim 0.3-1$ keV

"Soft" band variations delayed w.r.t. the "continuum" ("soft lags")

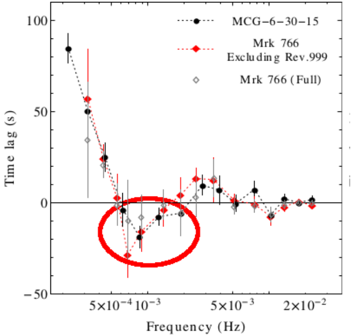


Ross & Fabian (2005)

Detection of "soft lags"



Fabian *et al.* (2009)



Emmanoulopoulos *et al.* (2011)

Detection of "soft lags"

"Soft lags" detected in several sources so far:

- 1H 0707-495 (Fabian *et al.* 2009; Zoghbi *et al.* 2010)
- Mrk 766 (Emmanoulopoulos *et al.* 2011)
- MCG−6-30-15 (Emmanoulopoulos *et al.* 2011)
- PG 1211+143 (De Marco *et al.* 2011)
- Mrk 1040 (Tripathi *et al.* 2011)
- RE J1034+396 (Zoghbi & Fabian 2011)
- NGC 3516 (Turner *et al.* 2011)
- IRAS 13224-3809 (Fabian *et al.* 2012)

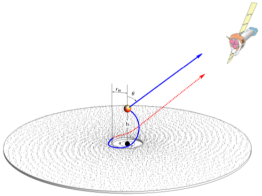
+7 sources: NGC 4395, NGC 4051, NGC 7469, Mrk 335, NGC 6860, NGC 5548, Mrk 841 (De Marco *et al.* 2013)

Detection of "soft lags"

Main results for maximum "soft lag" (De Marco *et al.* 2013):

- $\sim 10 - 600$ s at frequencies $\sim 0.07 - 4 \times 10^{-3}$ Hz
- Linear scaling with black hole mass
- Lag magnitudes indicate sizes $\sim 1 - 10\ R_g$

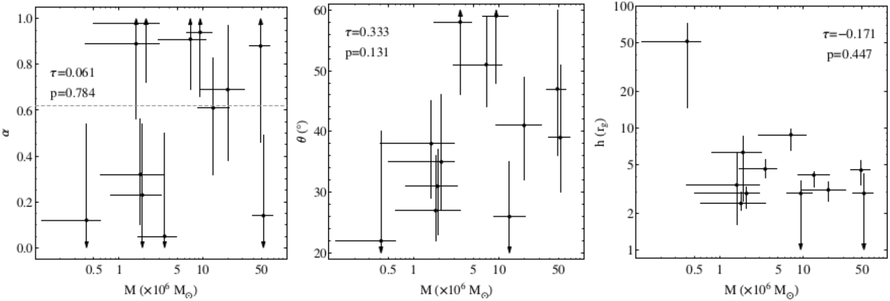
Modelling “soft lags” – the “lamp-post” model



Emmanoulopoulos et al. (2014): “Soft” ($0.3 - 1$ keV) vs “continuum” ($1.5 - 4$ keV) lags

- *XMM-Newton*, 12 “unobscured” AGN
- Fully relativistic disc response functions (Fe Kα; Dovciak *et al.* 2004)
- Free parameters: $\{h, i, a, M_{\rm BH}\}$
- Assumptions: 1) No reflection in “continuum” band, 2) “soft” band response $\sim$ Fe Kα response

Modelling "soft lags" – the "lamp-post" model



Emmanoulopoulos *et al.* (2014)

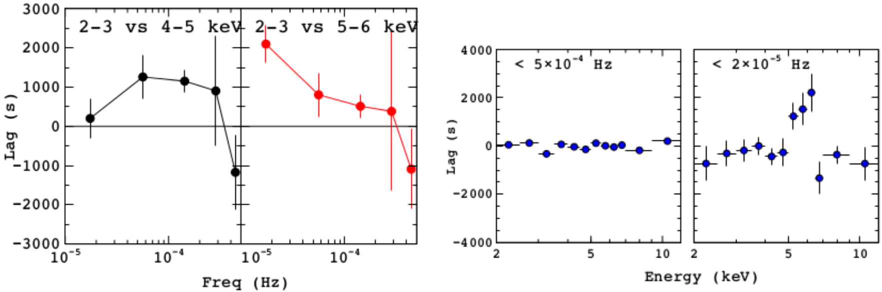
- $\langle a \rangle = 0.62$, $\langle i \rangle = 40^{\circ}$, $\langle h \rangle = 3.7\ \mathrm{R_g}$

“Continuum” −iron-line lags

Growing sample of sources with detected “continuum” −iron-line lags

- NGC 4151 (Zoghbi *et al.* 2012)
- Ark 564, Mrk 335 (Kara *et al.* 2013)
- PG 1244+026 (Kara *et al.* 2013)
- 1H 0707-495 (Kara *et al.* 2013)
- IRAS 13224-3809 (Kara *et al.* 2013)
- MCG−5-23-16, NGC 7314 (Zoghbi *et al.* 2013)
- SWIFT J2127.4+5654 (Marinucci *et al.* 2014)

"Continuum"—iron-line lags in NGC 4151



Zoghbi *et al.* (2012)

- "Lag-frequency" spectra show expected behaviour
- "Lag-energy" spectra mimic shape of broad iron-line

Our work: Outline

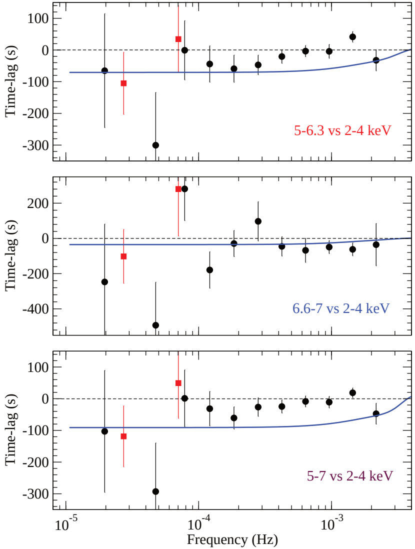
- **Goal**: Detailed study of "continuum"−iron-line lags
- **Plan**: Study a sample of "unobscured" AGN with all available archival *XMM-Newton*, *Suzaku* and *ASCA* data
- Sample selection criteria:
  - X-Ray bright and variable
  - ≥ 0.5 Ms of available archival data
  - $M_{\rm BH} \leq 2 \times 10^7\ {\rm M_\odot}$ (orbital period at ISCO $\lesssim 2$ ks → short *Suzaku* & *ASCA* segments)
- **The sample**: 13 sources

Our work: Methods

- Standard Fourier techniques
- Study sampling properties of time-lags (bias, analytic error prescriptions, **prob. distributions**) as a function of
  - Time-lag shape (constant delay, power-law, "top-hat" response)
  - Sampling properties of typical *XMM-Newton*, *Suzaku* and *ASCA* light-curves
  - Frequency binning
  - Light-curve signal-to-noise
- Focus on lags between "continuum" ($2 - 4$ keV) and three iron-line bands: $5 - 6.3$, $6.6 - 7$ and $5 - 7$ keV
- Model lags using fully relativistic response functions in "lamp-post" geometry (as in Emmanoulopoulos *et al.* 2014), **including reflection in "continuum" band**

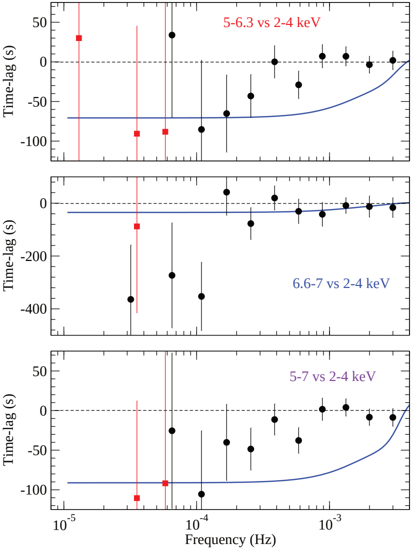
Preliminary results: MCG−6-30-15

- **Circles**: *XMM-Newton* data (100 s bins)
- **Squares**: *Suzaku* data (orbital period bins)
- **Cont. line**: Reverberation with $M_{\rm BH} = 2 \times 10^6\ \rm M_{\odot}$, $a = 0.676$, $h = 3.6\ \rm R_g$ and $i = 40^\circ$



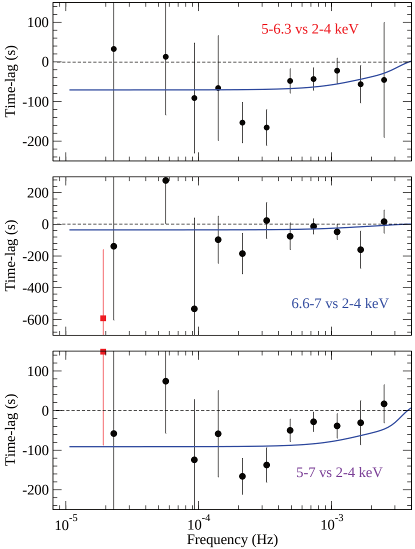
Preliminary results: NGC 4051

- **Circles**: *XMM-Newton* data (100 s bins)
- **Squares**: *Suzaku* data (orbital period bins)
- **Cont. line**: Reverberation with $M_{\rm BH} = 2 \times 10^6\ {\rm M}_\odot$, $a = 0.676$, $h = 3.6\ {\rm R_g}$ and $i = 40^\circ$



Preliminary results: Mrk 766

- **Circles**: *XMM-Newton* data (100 s bins)
- **Squares**: *Suzaku* data (orbital period bins)
- **Cont. line**: Reverberation with $M_{\rm BH} = 2 \times 10^6\ {\rm M}_\odot$, $a = 0.676$, $h = 3.6\ {\rm R_g}$ and $i = 40^\circ$



Concluding remarks: Status

- Data reduction complete
- Study of time-lag sampling properties using Fourier techniques almost complete
- Detailed model fitting of lags pending
- Future extensions: Detailed study of time-lag sampling properties using Maximum Likelihood method (e.g. Miller *et al.* 2010)
    - Crucial for high-frequency input from *Suzaku* and *ASCA* light-curves