Timing Properties of Accreting Black Hole Systems

Ranjeev Misra

(IUCAA)

Shurti Triparthi, Gulab Dewangan , Archana Bora

Energy Dependent Time-lags in AGN

Ranjeev Misra

(IUCAA)

Shurti Triparthi, Gulab Dewangan, Archana Bora

Variability in black hole binaries

- The Epicyclic frequency at R = 8 GM/c^2 for a 10 solar mass black hole is ~ 80 Hz

Variability in black hole binaries

- The Epicyclic frequency at R = 8 GM/c^2 for a 10 solar mass black hole is ~ 80 Hz
- However, the observed high frequency break is f_B ~ 10 Hz (e.g. Cyg X-1 soft state)

Variability in black hole binaries

- The Epicyclic frequency at $R = 8\ GM/c^2$ for a 10 solar mass black hole is ~ 80 Hz
- However, the observed high frequency break is $f_B \sim 10$ Hz (e.g. Cyg X-1 soft state)
  - Associate f_B with viscous timescale (e.g. Lyubarskii 1997, Arevalo et al. 2006, Titarchuk et al. 2007, Ingram & Done 2011)

Variability in black hole binaries

- The Epicyclic frequency at R = 8 GM/c^2 for a 10 solar mass black hole is ~ 80 Hz
- However, the observed high frequency break is f_B ~ 10 Hz (e.g. Cyg X-1 soft state)
  - Associate f_B with viscous timescale (e.g. Lyubarskii 1997, Arevalo et al. 2006, Titarchuk et al. 2007, Ingram & Done 2011)

    OR

  - Low value of f_B is due to heavy damping of the Epicyclic oscillations (Misra & Zdziarski 2008)

Variability in AGN

- The Epicyclic frequency at $R = 8\ GM/c^2$ for a 10^7 solar mass black hole is $\sim 8 \times 10^{-5}$ Hz

Variability in AGN

- The Epicyclic frequency at $R = 8\ GM/c^2$ for a 10^7 solar mass black hole is $\sim 8 \times 10^{-5}$ Hz
- The observed high frequency break is $f_B \sim 10^{-5}$ -- 10^{-4} Hz, depending on Luminosity. So at high accretion rate either:
  - Viscous time-scale ~ Epicyclic time-scale

    or
  - Damping is less important.

Time lags in black hole binaries

- For thermal Comptonization the expected time lag between two energy bands E_1 and E_2 is $\Delta T \sim R/c \log(E_2/E_1) \sim 10^{-3}$ secs $\log(E_2/E_1)$

Time lags in black hole binaries

- For thermal Comptonization the expected time lag between two energy bands E_1 and E_2 is $\Delta T \sim R/c \log(E_2/E_1) \sim 10^{-3}$ secs $\log(E_2/E_1)$
- However, the observed time lags is (e.g. Cyg X-1 hard state, Nowak et al. 1999)

$$\Delta T \sim 10^{-3} \text{ secs } (f/10 \text{ Hz})^{-0.7} \log(E_2/E_1)$$

$$\Delta\Phi = 2\pi f \Delta T \sim 0.02 \log(E_2/E_1)$$

Time lags in black hole binaries

- Waves propagating in a cylindrical geometry

  (Nowak et. al. 1999)

Time lags in black hole binaries

- Waves propagating in a cylindrical geometry

  (Nowak et. al. 1999)

  - Spectra hardens towards the inner regions

    (Kotov et. al. 2001, Arevalo & Uttley 2006)

Time lags in black hole binaries

- Waves propagating in a cylindrical geometry (Nowak et. al. 1999)
  - Spectra hardens towards the inner regions (Kotov et. al. 2001, Arevalo & Uttley 2006)

    OR

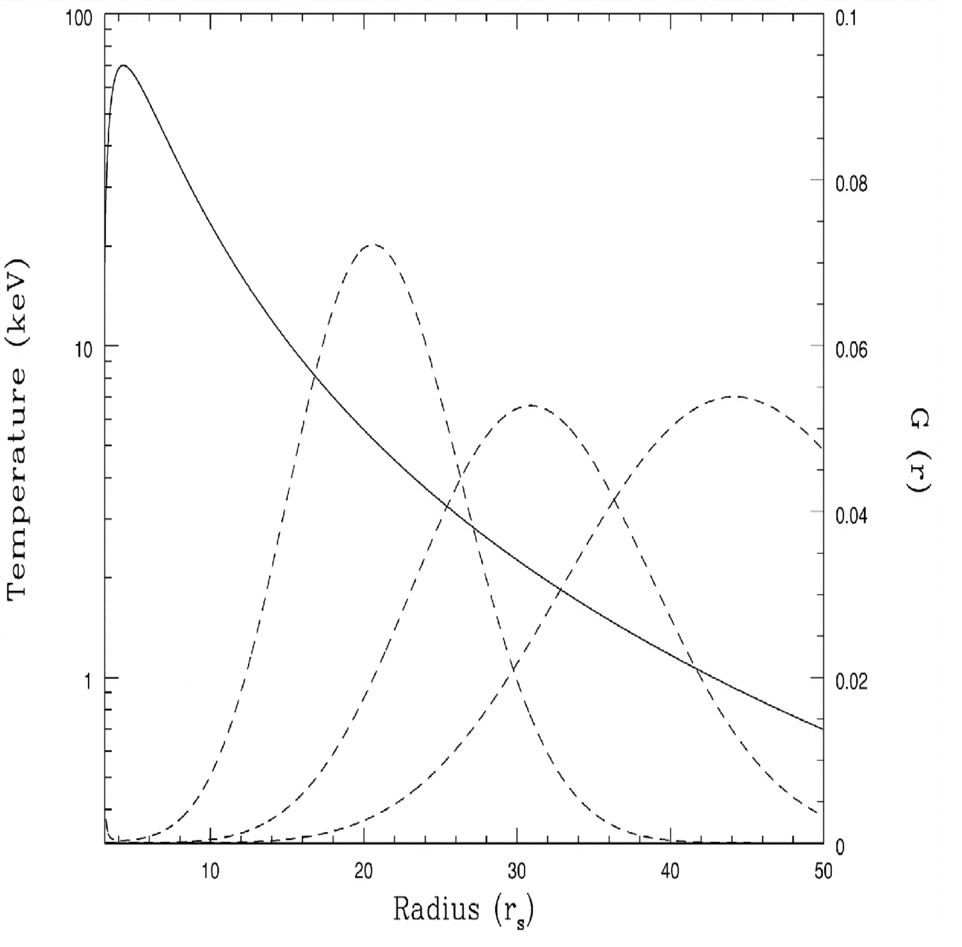
  - Transition disk, where temperature increases steeply towards the inner radius (Misra 2000)

Transition disk model for Cygnus X-1

Transition disk model

Temperature profile calculated from accretion disk structure

Explains the broad band spectrum and time lags.



(Misra, 97, 98, 00)

Time lags in black hole binaries

- The observed time lags: (e.g. Cyg X-1 hard state)

$$\Delta T \sim 10^{-3} \text{ secs } (f/10 \text{ Hz})^{-0.7} \log(E_2/E_1)$$

- Spatial separation of regions producing different energy photons
- For thermal Comptonization, the size of the emitting region is $<< c\,\Delta T_{min} \sim 20\ GM/c^2$

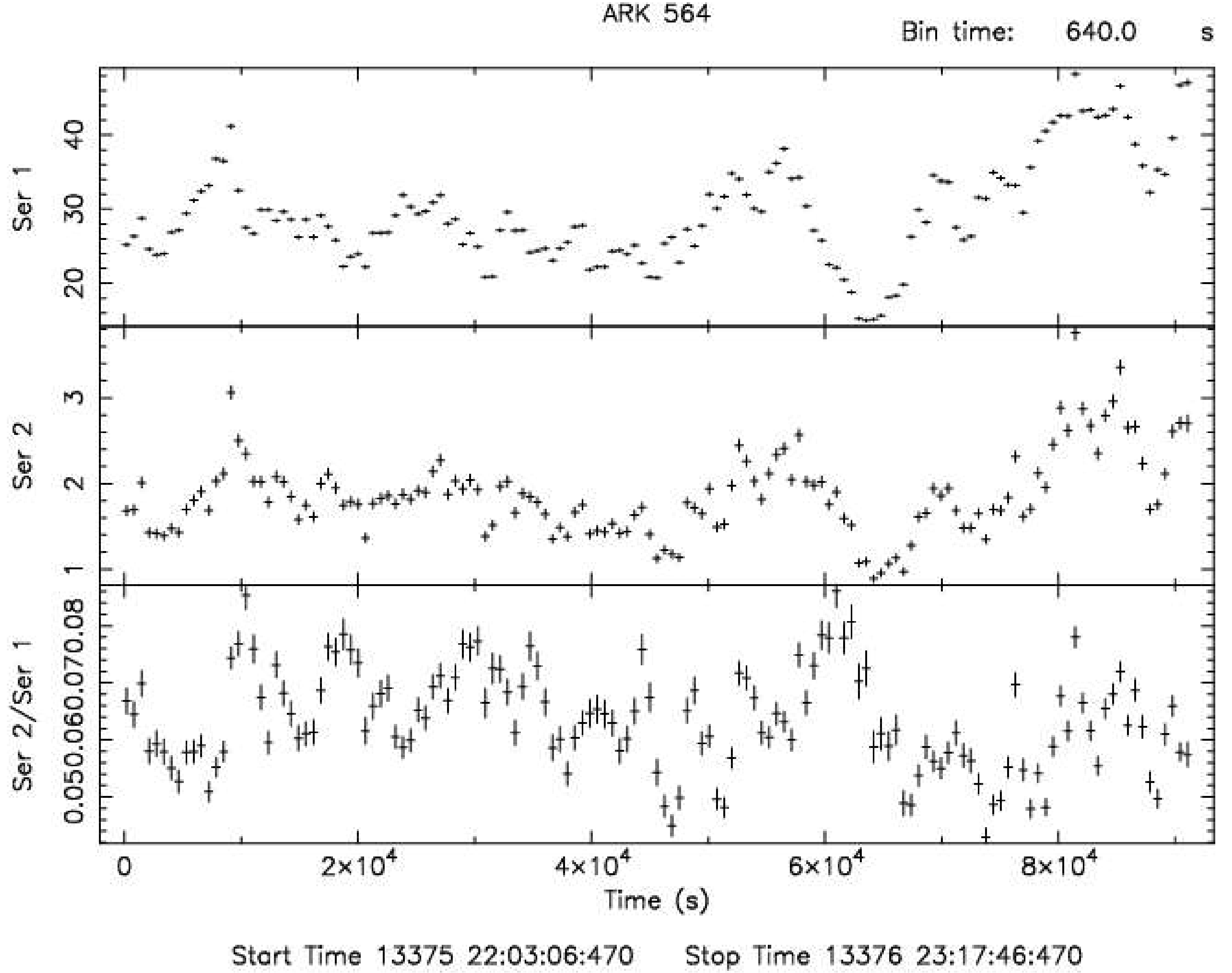
Time lags in AGN

- The lower count rate for AGN, does not allow for detailed frequency dependent time-lags as for black hole binaries.
- For some highly variable and bright sources, frequency dependent time lags can be obtained, but which require to be verified by simulations.

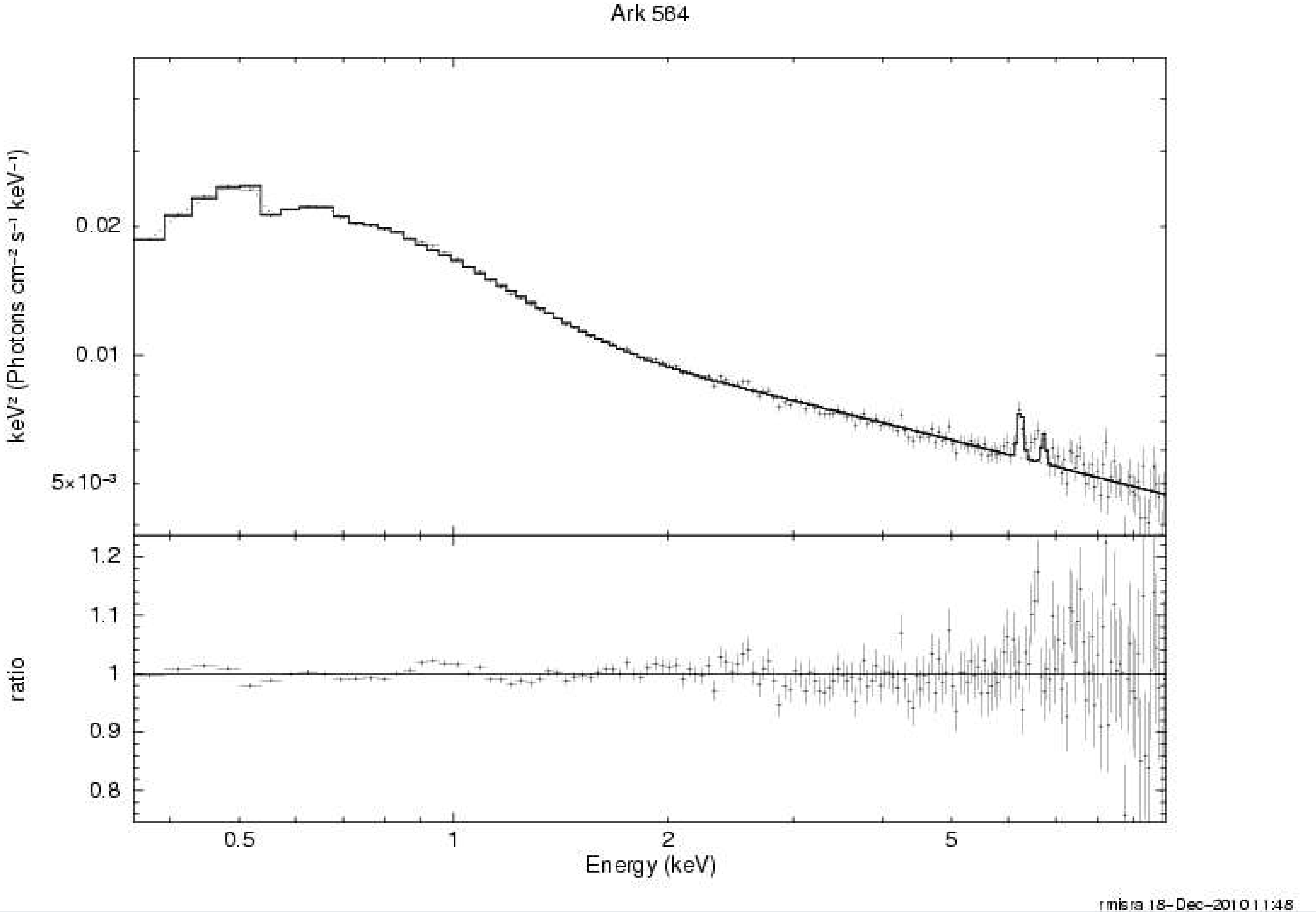
Time lags in AGN

- We have developed an analytical scheme to estimate the errors of the cross-correlation and frequency averaged time and phase lags (Misra, Bora & Dewangan 2011)
- Scheme has been tested using simulations.

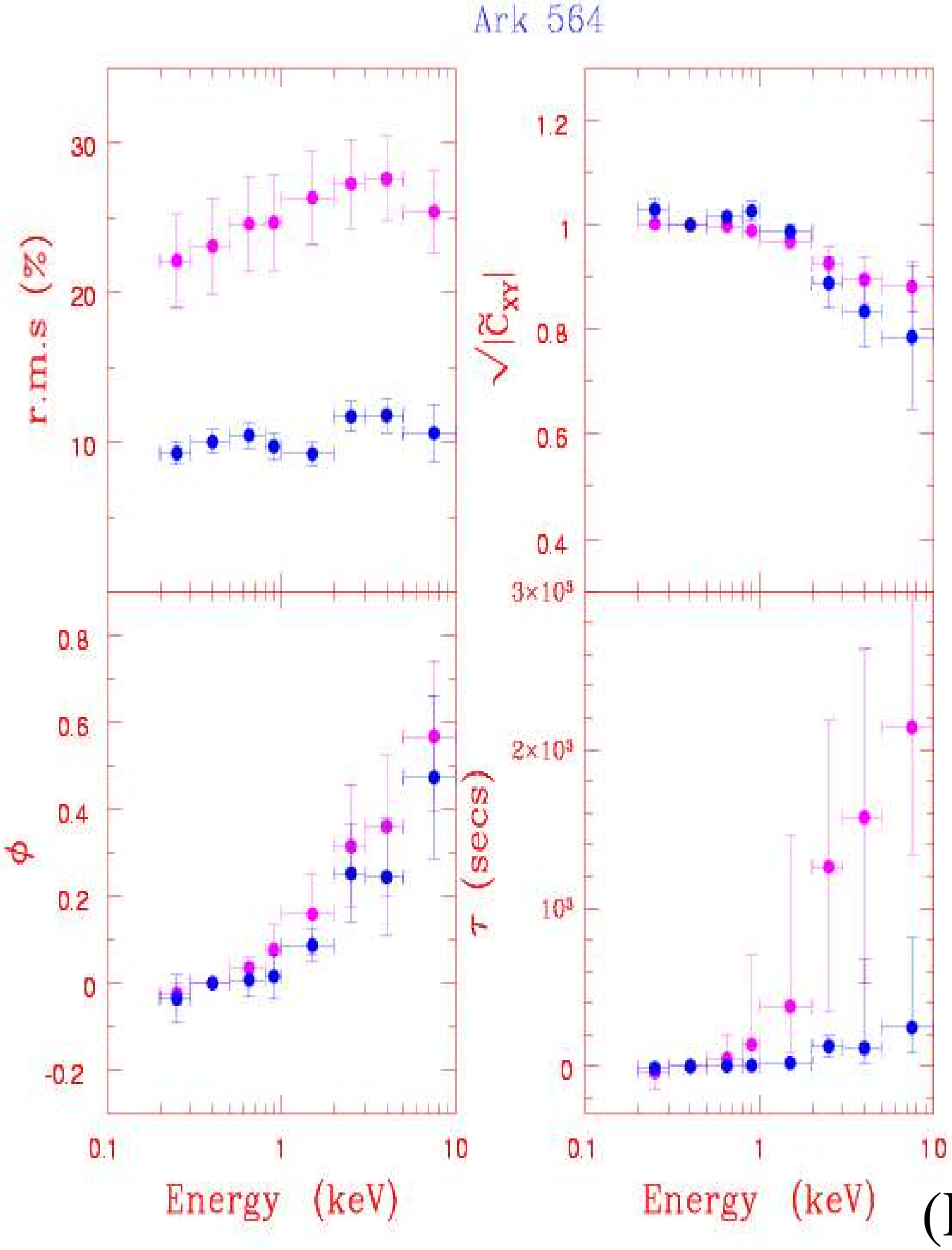
XMM-Newton Light curves of ARK 564



XMM-Newton Spectrum of Ark 564



XMM-Newton timing analysis of Ark 564



- Complete Light curves T = 10^5 s
- Light curves divided into ten segments T = 10^4 s

$$\Delta\Phi \sim 0.13 \log(E_2/E_1)$$

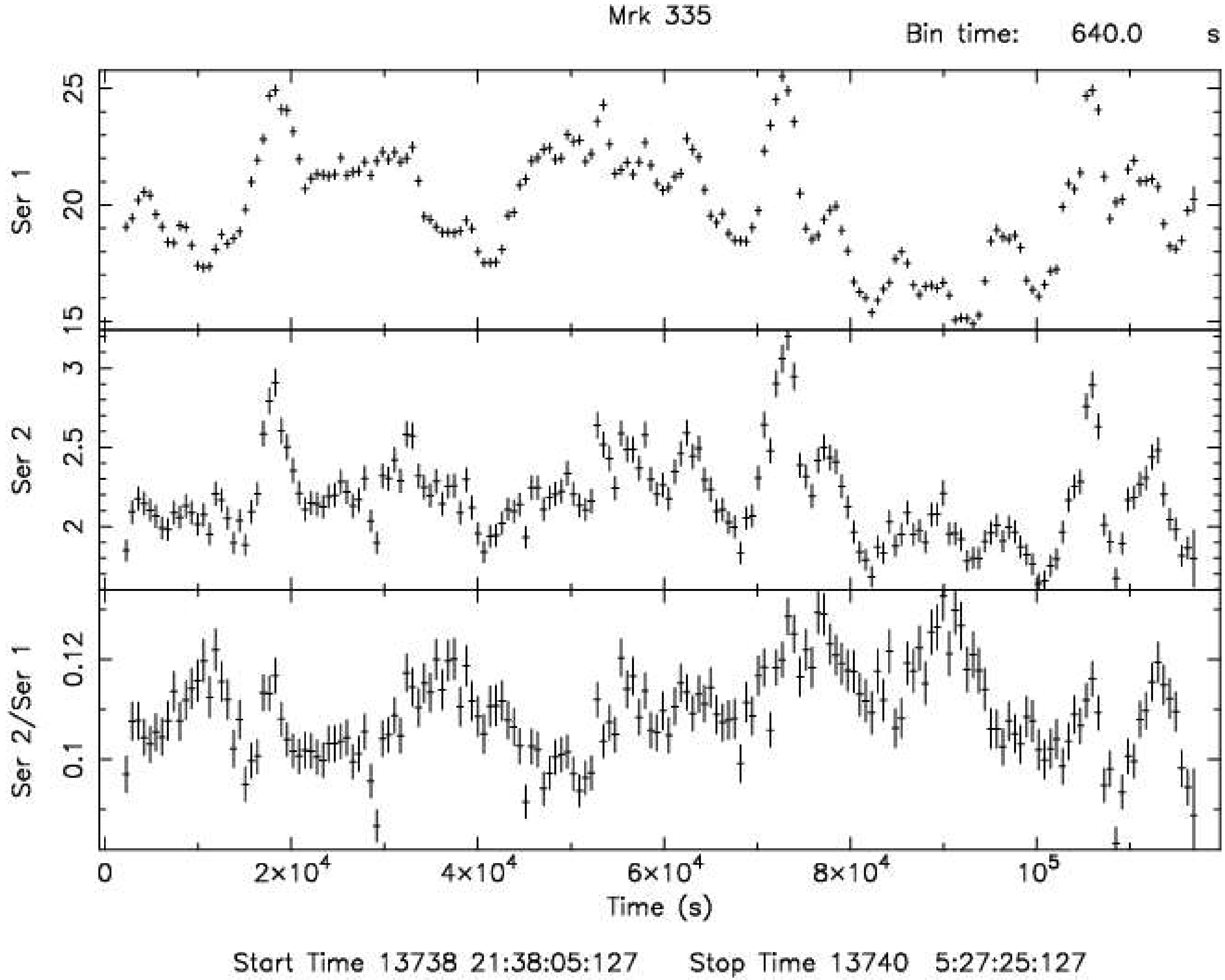
$$\Delta T_{min} \sim 40 \text{ s} \log(E_2/E_1)$$

Size L < 1.2 x 10^{11} cm

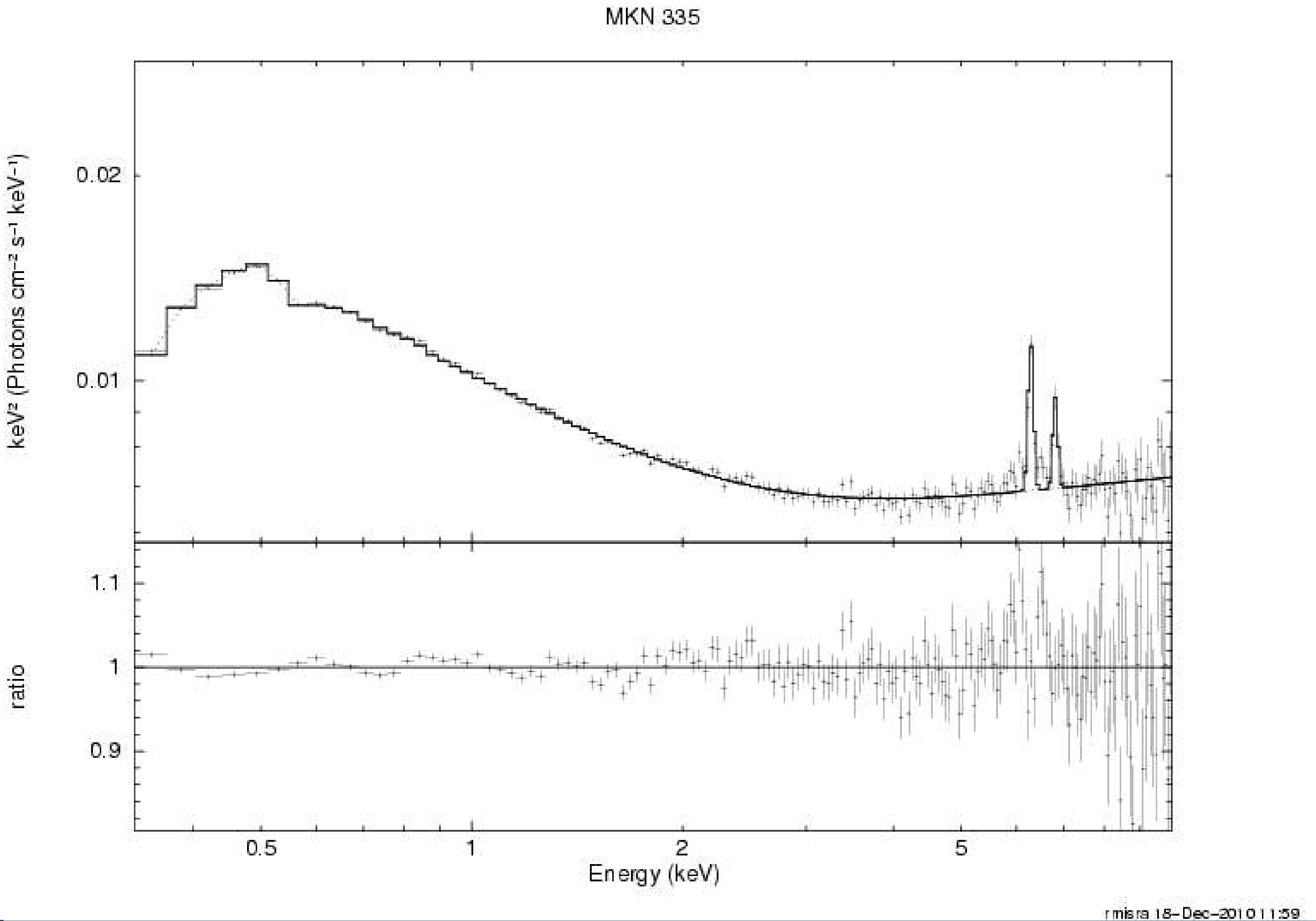
$\sim$ 2 GM/c^2

(Results consistent with Arevalo et al. 06)

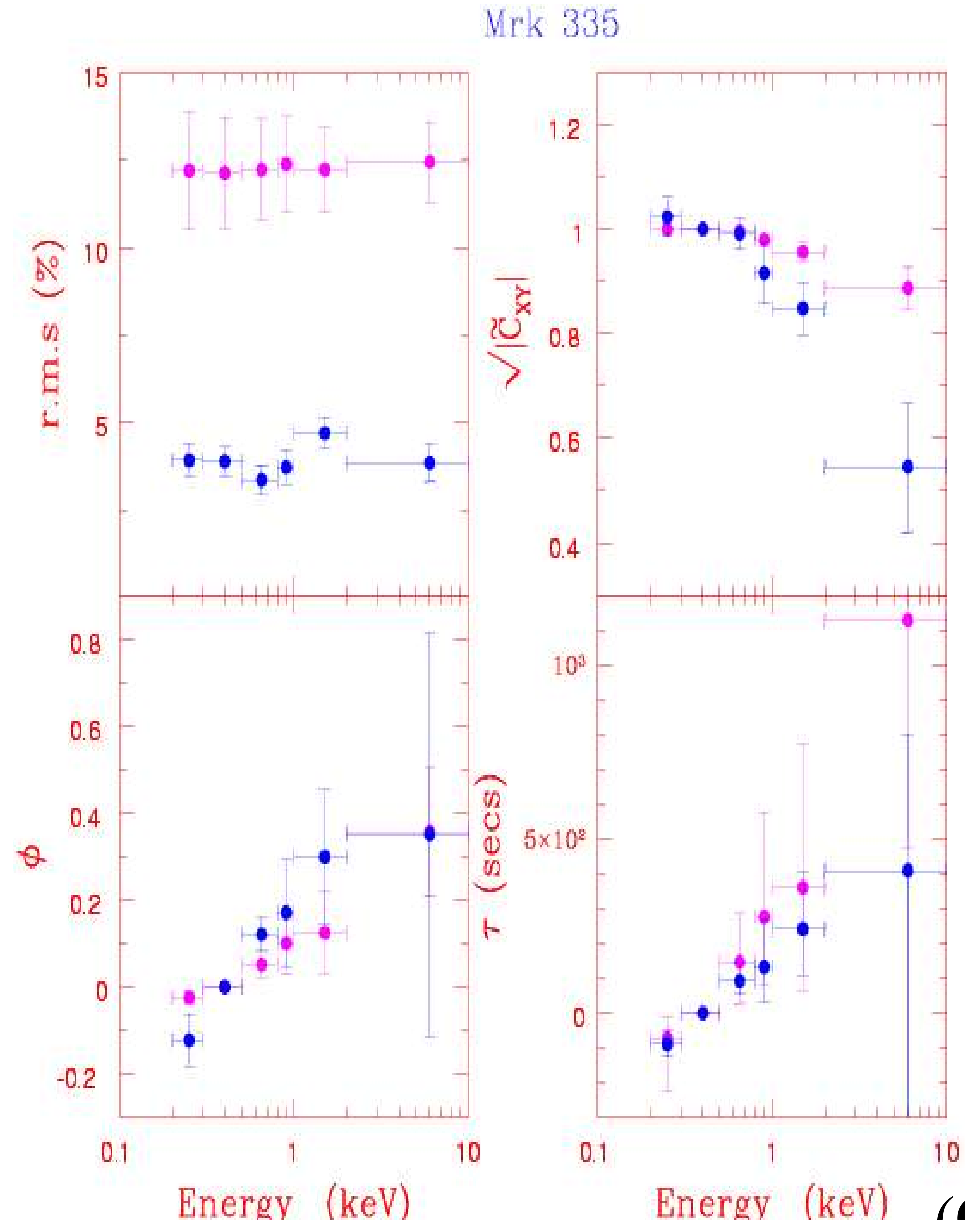
XMM-Newton light curves of MRK 335



XMM-Newton Spectrum of MRK 335



XMM-Newton timing analysis of Mrk335



- Complete Light curves T = 10^5 s
- Light curves divided into ten segments T = 10^4 s

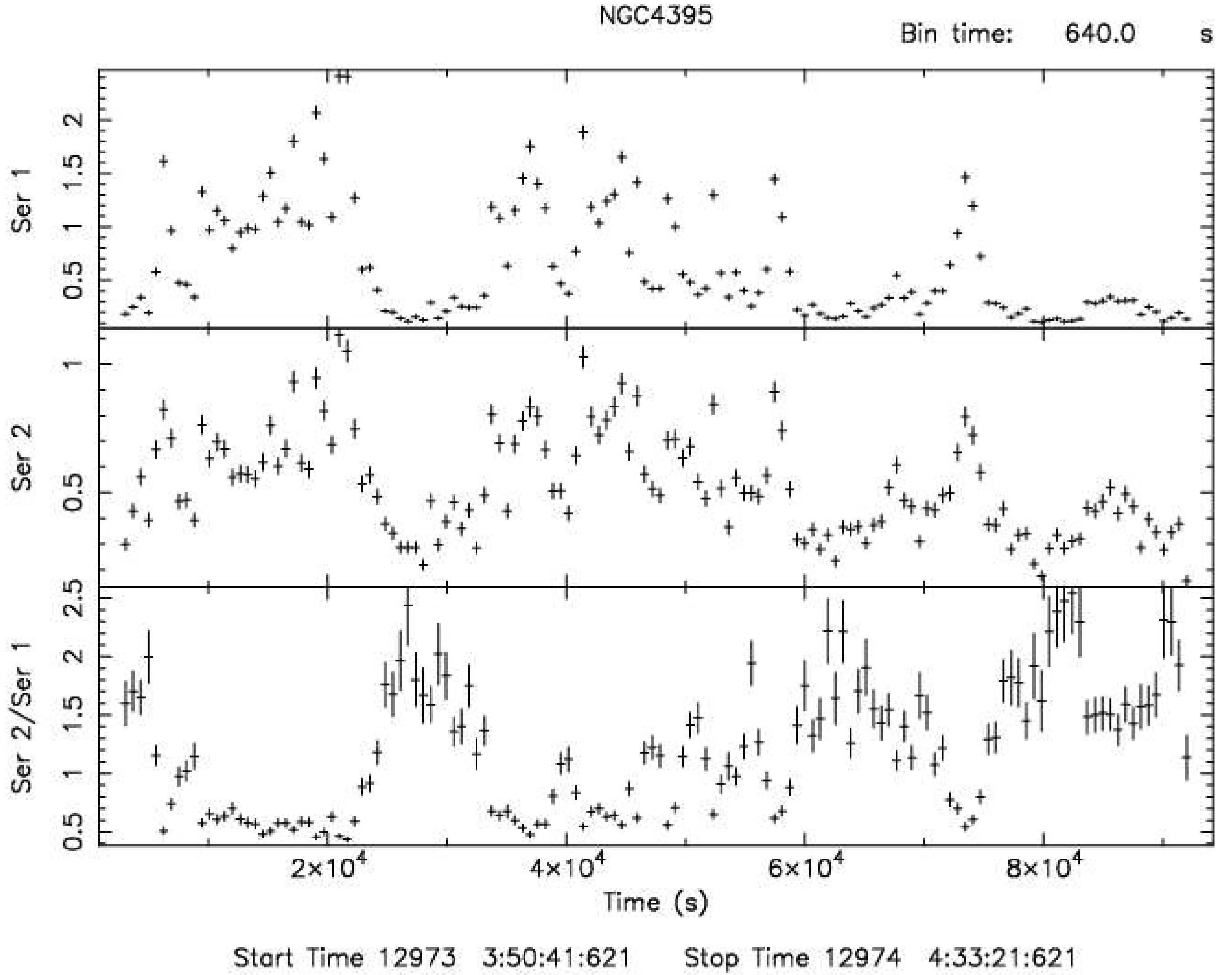
$\Delta T_{min} \sim 250$ s $\log(E_2/E_1)$

Size L < 7.5 x 10^{12} cm

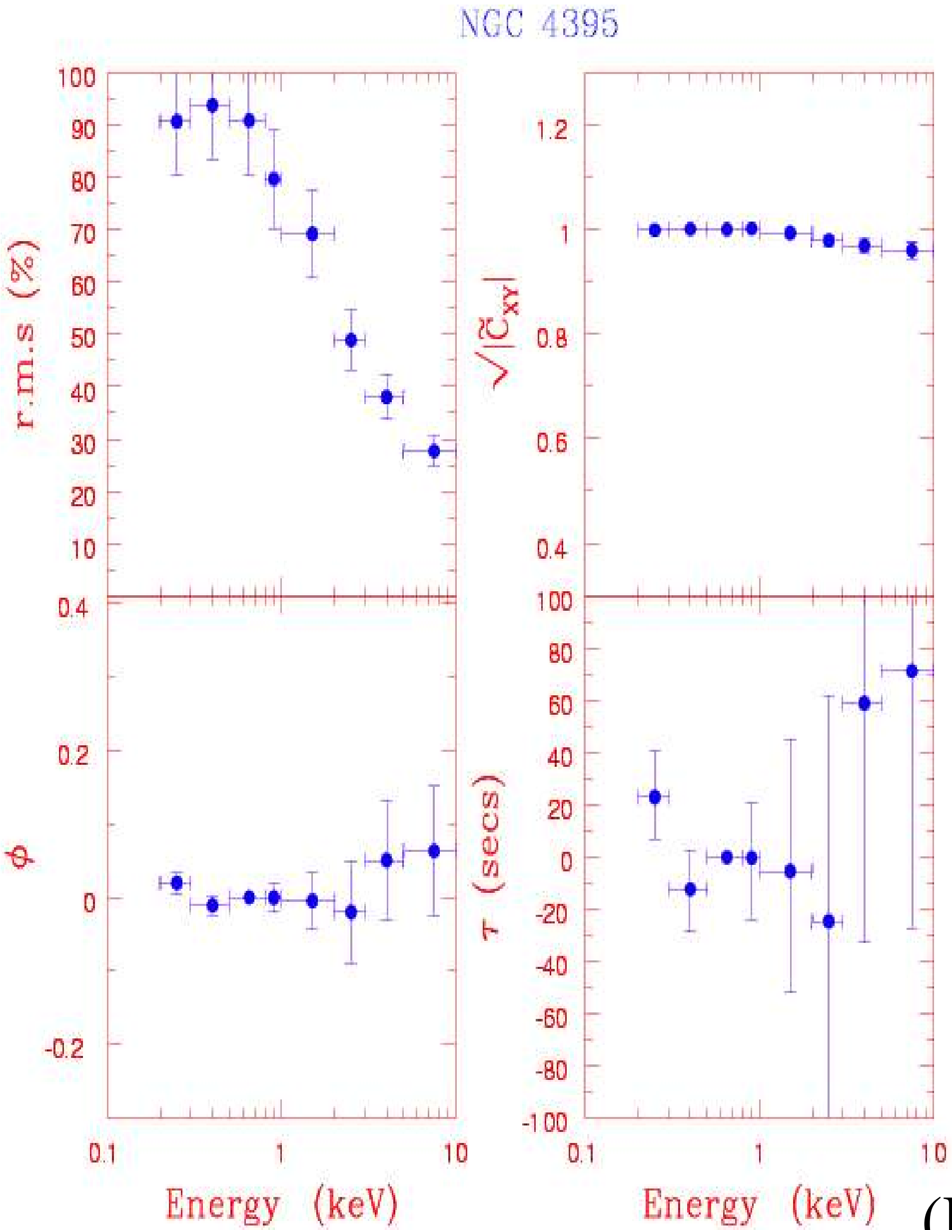
~ 4 GM/c^2

(Comparison with Arevalo et al. 08)

XMM-Newton light curves of NGC 4395



XMM-Newton Timing analysis of NGC 4395



- Complete Light curves T = 10^5 s

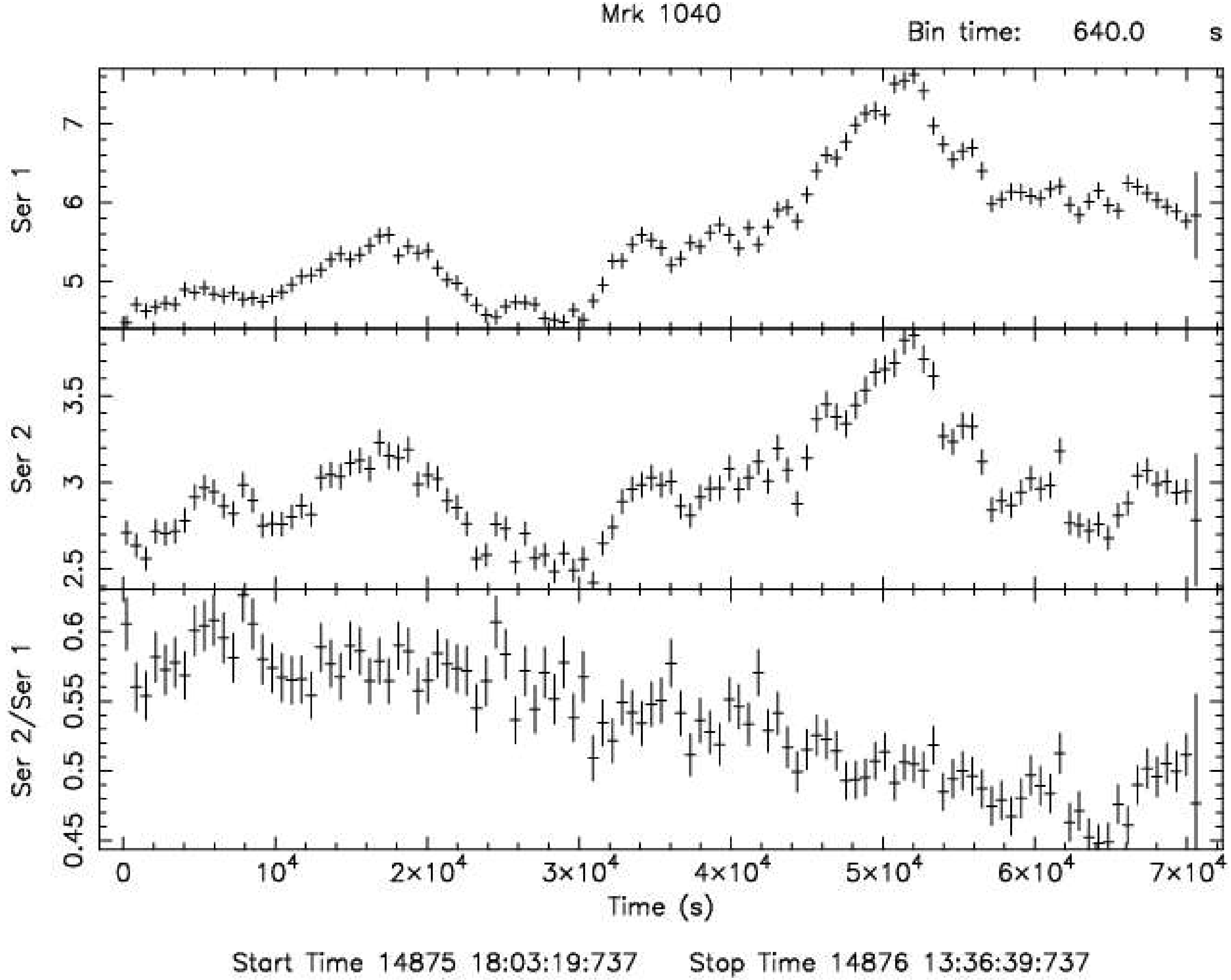
Highly Variable and highly coherent

Consistent with zero time-lag < 20 sec

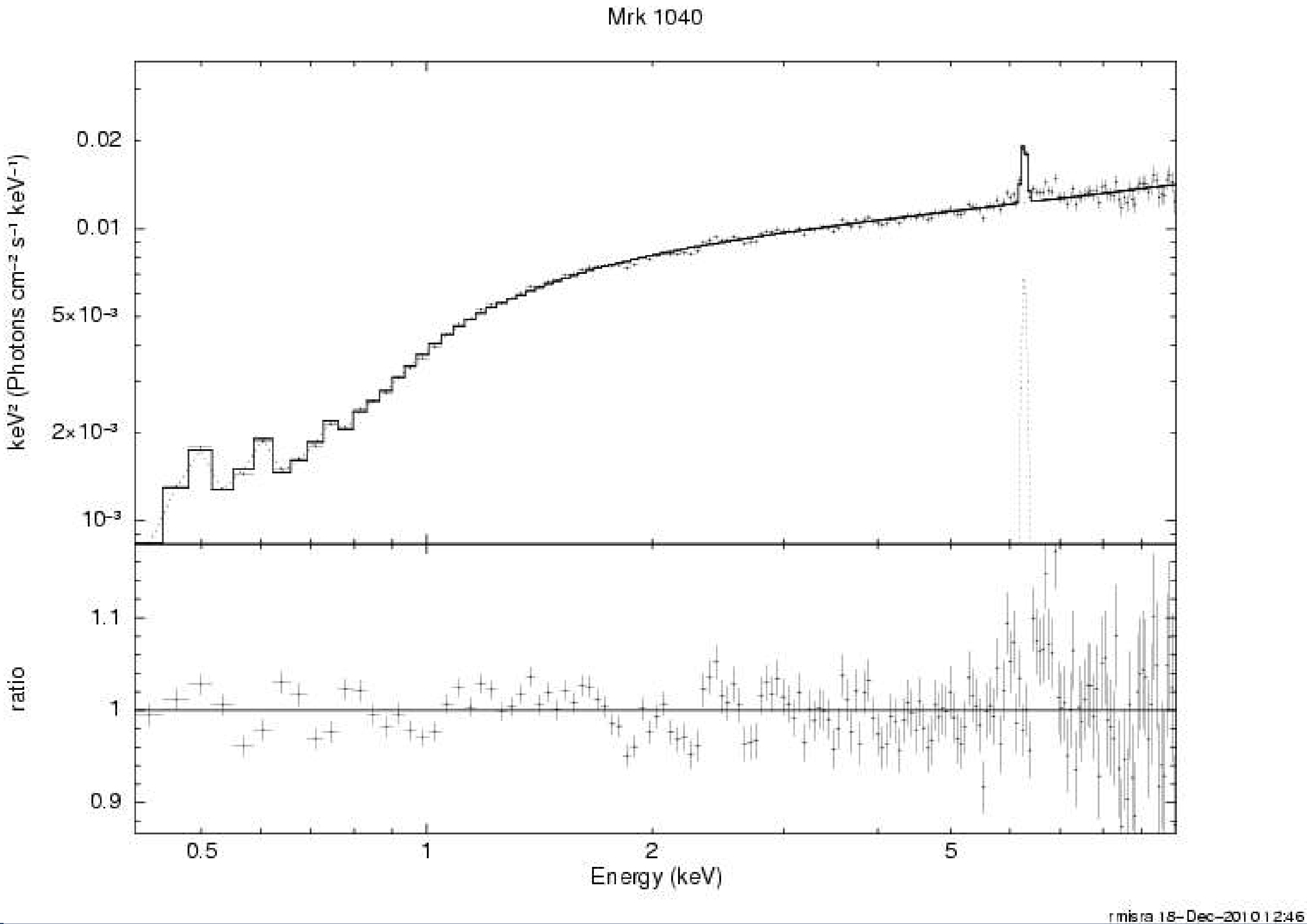
Variable absorption model?

(Results consistent with Vaughan et al. 04)

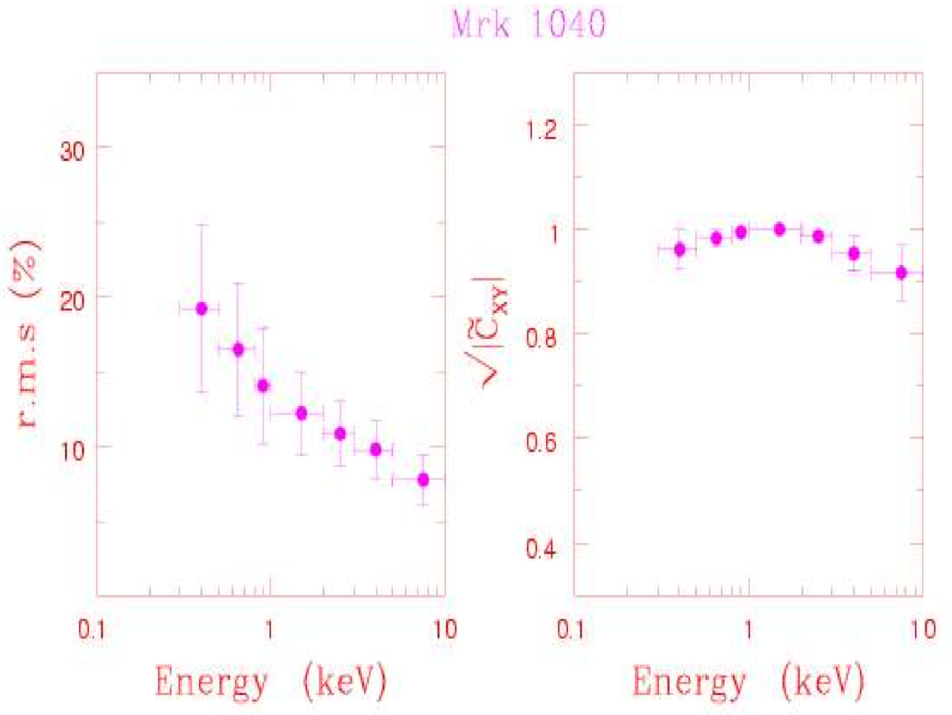
XMM-Newton Spectrum of MRK1040



XMM-Newton Spectrum of MRK 1040

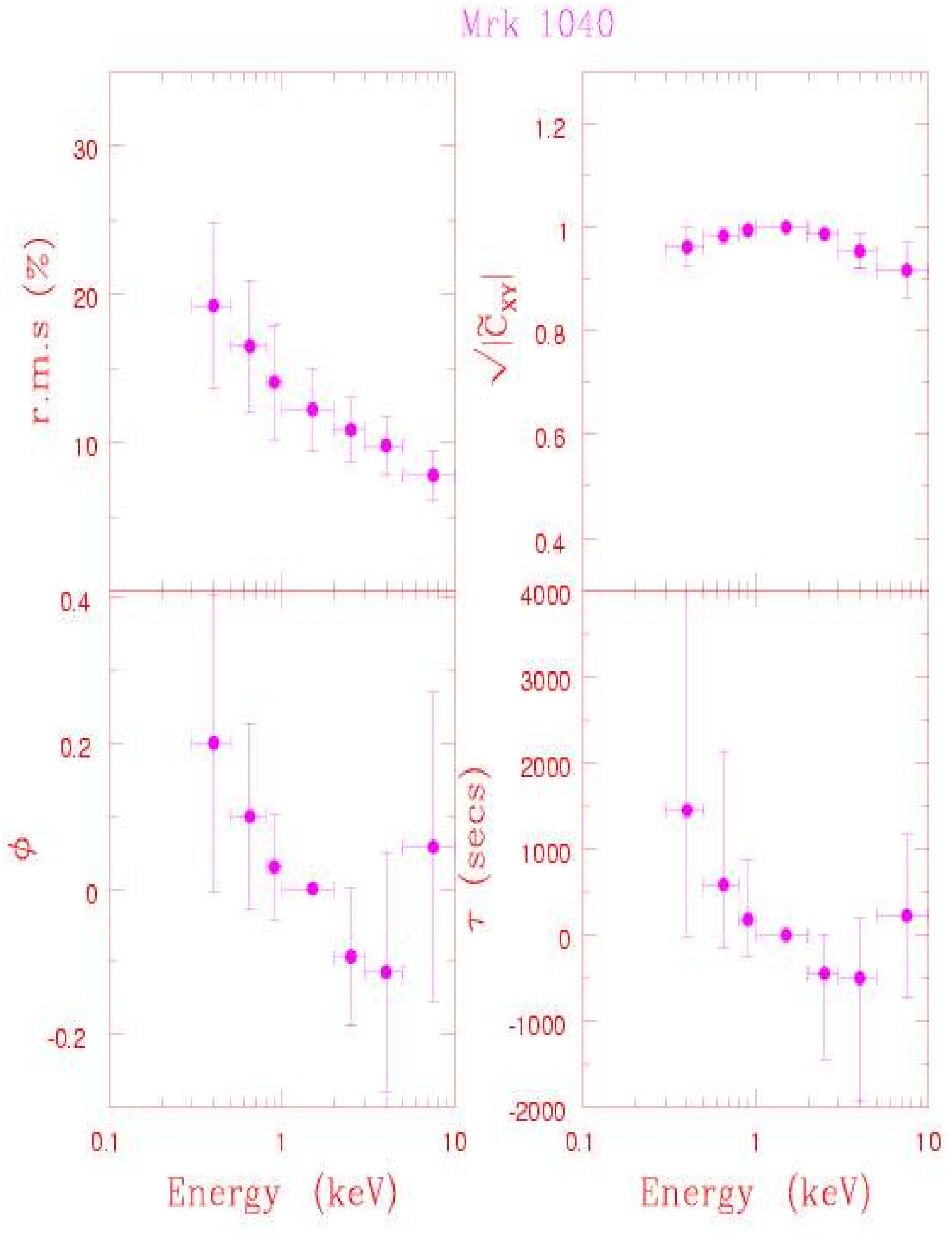


XMM-Newton Timing analysis of MRK 1040



- Complete Light curves $T = 10^5$ s

XMM-Newton Timing analysis of MRK 1040



- Complete Light curves T = 10^5 s

SOFT LAGS!

Hard x-ray vary before the soft x-rays.

Summary

- The high frequency breaks for AGN can be close to the Epicyclic frequency at 8 GM/c^2.
- For optically thin, thermal Comptonization models, the observed time lags in AGN imply a size less that < 2 GM/c^2
- The phenomenology of time-lags is complex with one AGN showing the possibility of soft lags.