UNIVERSITY OF
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School of Physics
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Correlated X-ray and Optical Variability in Seyfert Galaxies

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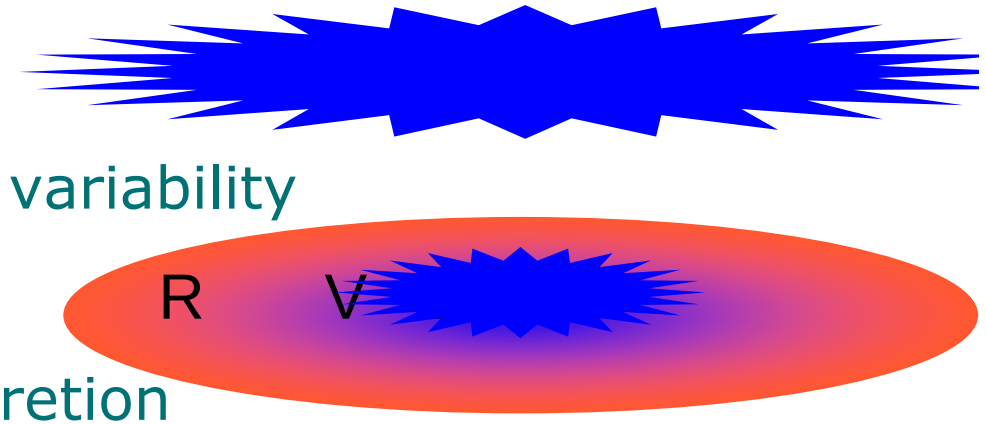
Introduction

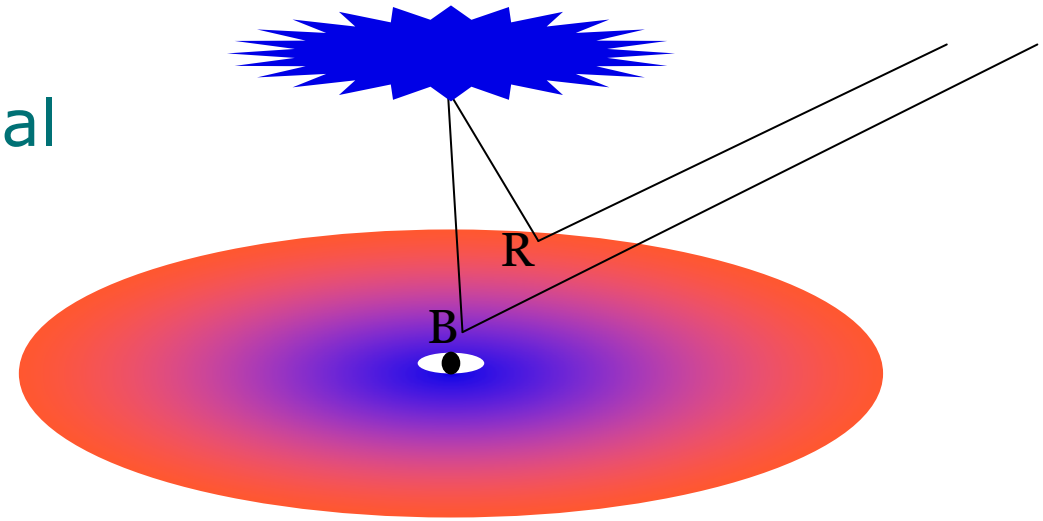
- AGN variable at all wavelengths
- X-rays:
  - From near the BH
  - Rapid (~minutes) variability



- UV / Optical:
  - Optically thick accretion disc
- Interaction:
  - Compton upscattering? – X-ray corona (Haardt&Maraschi 1991)
  - X-ray reprocessing? (Krolik et al 1991)

Reprocessing

- X-rays absorbed and re-emitted thermally by the disc
- Produces short optical lags ~ light crossing time
- Smoothes rapid fluctuations, by dr/c



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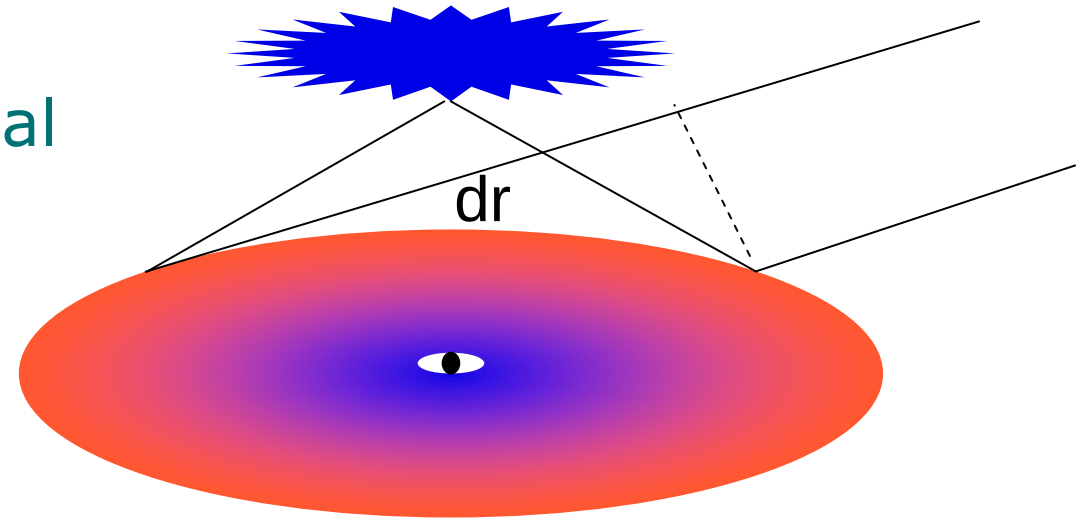
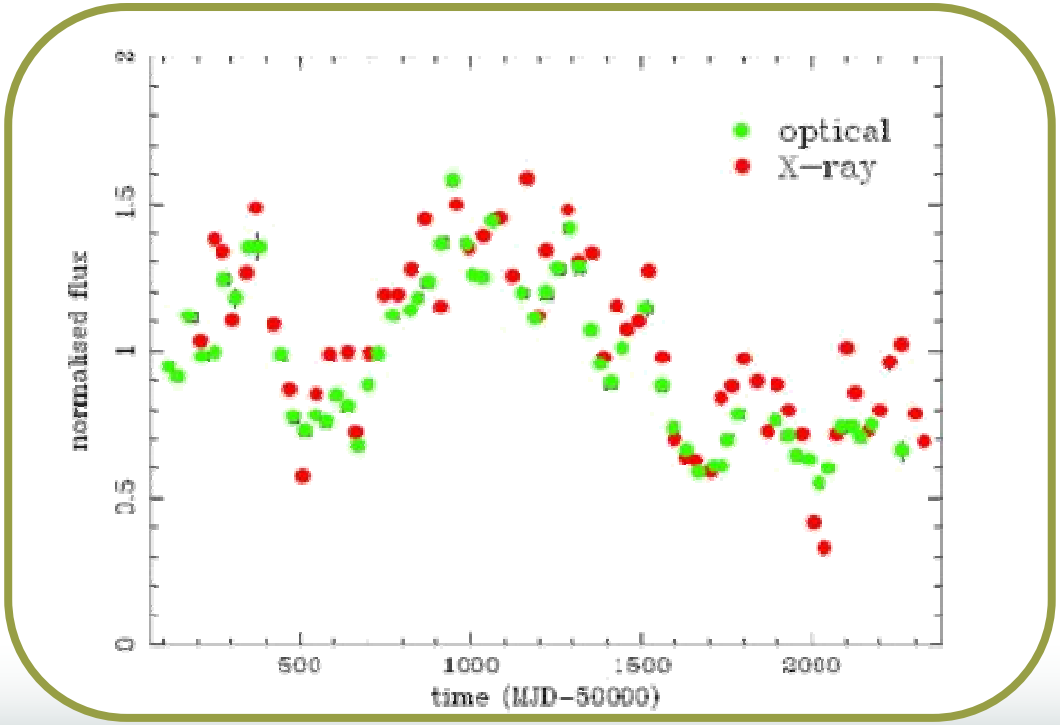


Some previous results

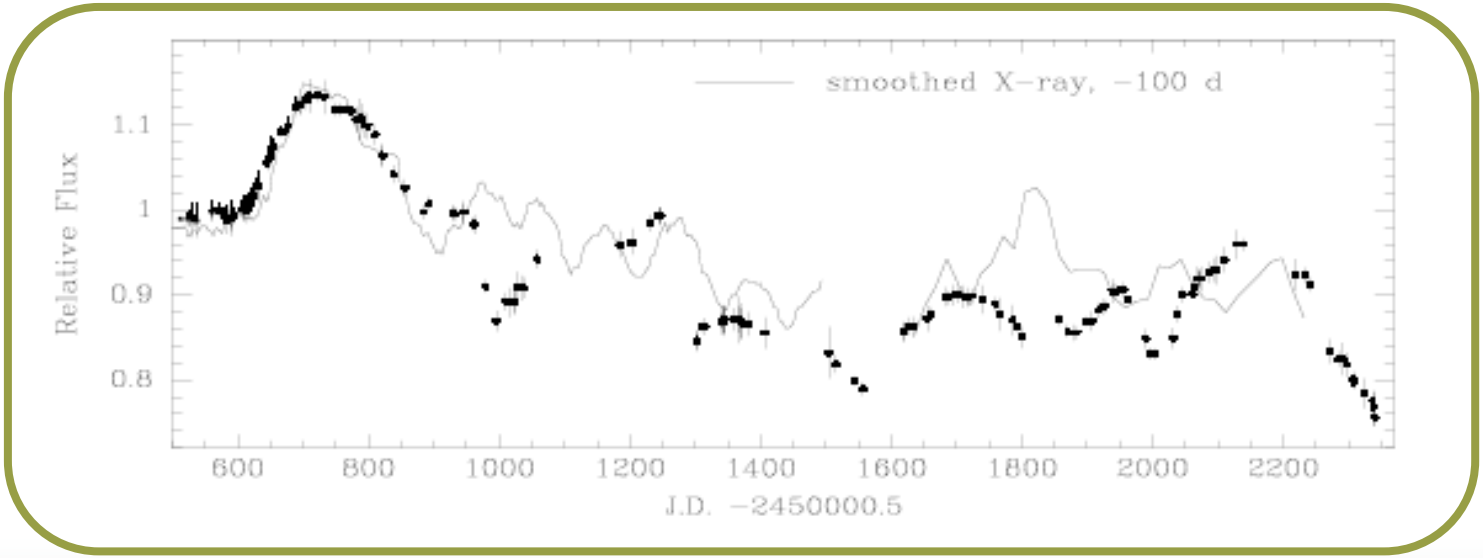
- NGC 4051: 5% UV variation over 1.5 days, delayed w.r.t the X-rays by 0.14 days (Mason et al 2000)
- NGC 4051: Optical leads by 2 days (Shemmer et al 2003)



- NGC 5548: X-ray and optical well correlated on long timescales. Optical amplitude greater than X-ray amplitude (Uttley et al 2003)

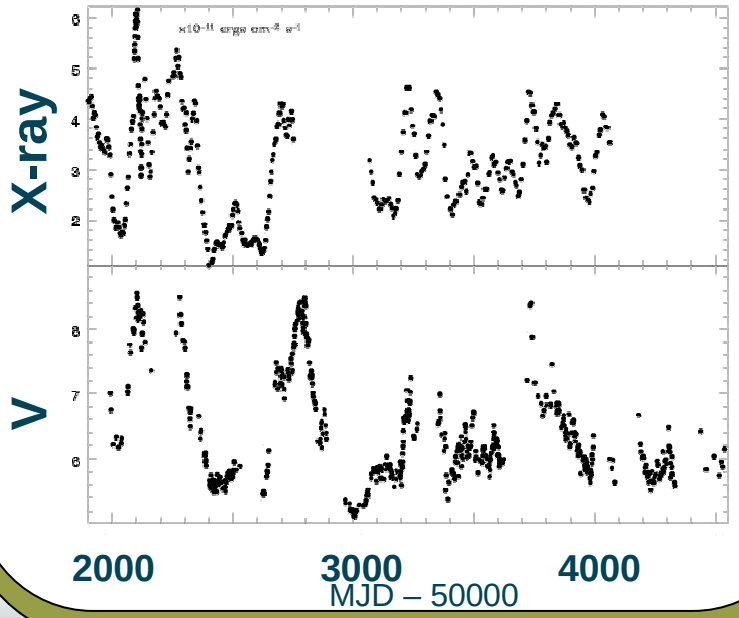
Some previous results

- NGC 7469: No simple flux correlation, but optical correlated with X-ray spectrum (Nandra et al 1998, 2000)
- NGC 3516: No correlation at all? (Maoz et al 2000, 2002)

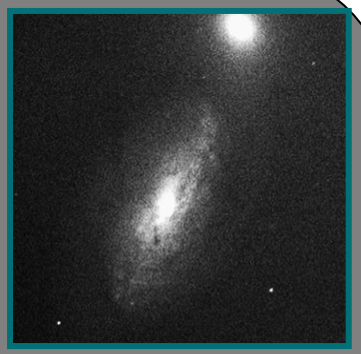


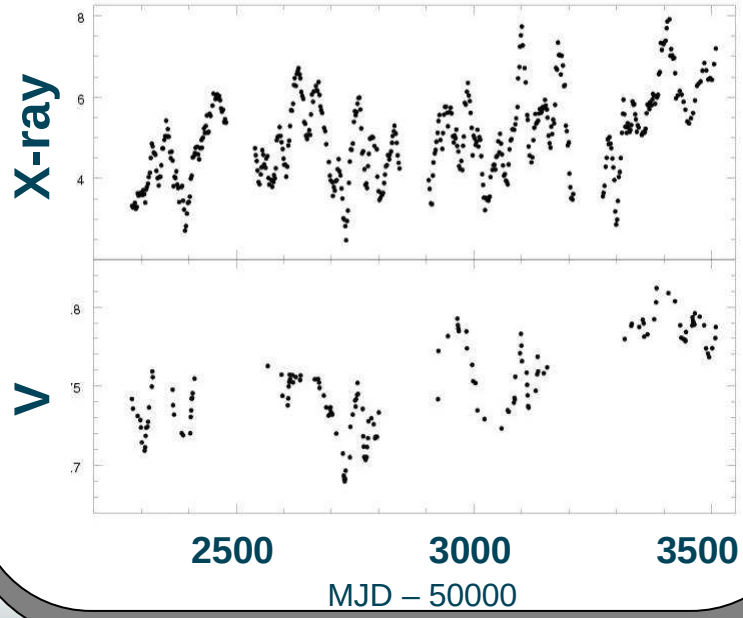
Monitoring

NGC 5548



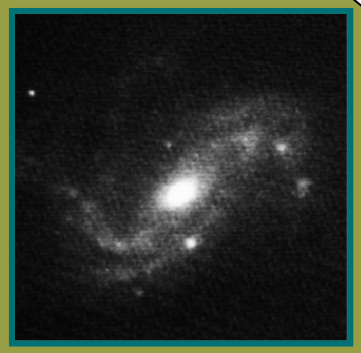
NGC 3227

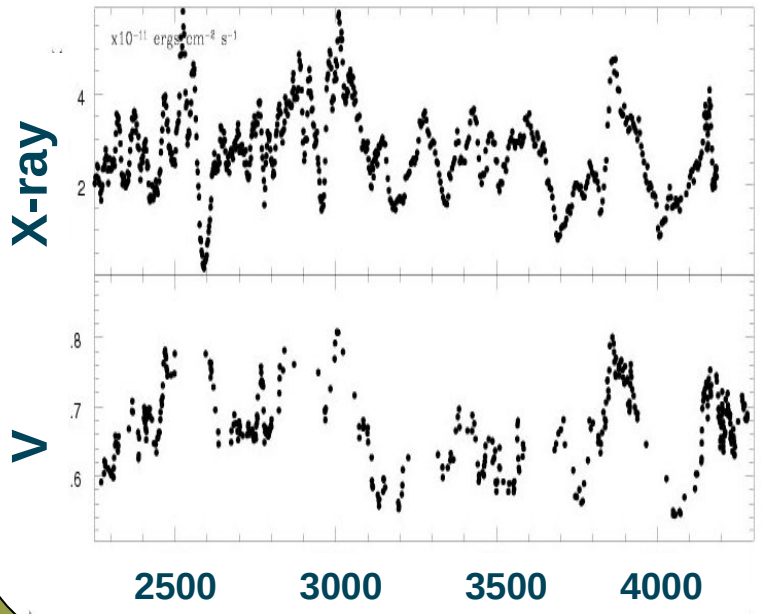




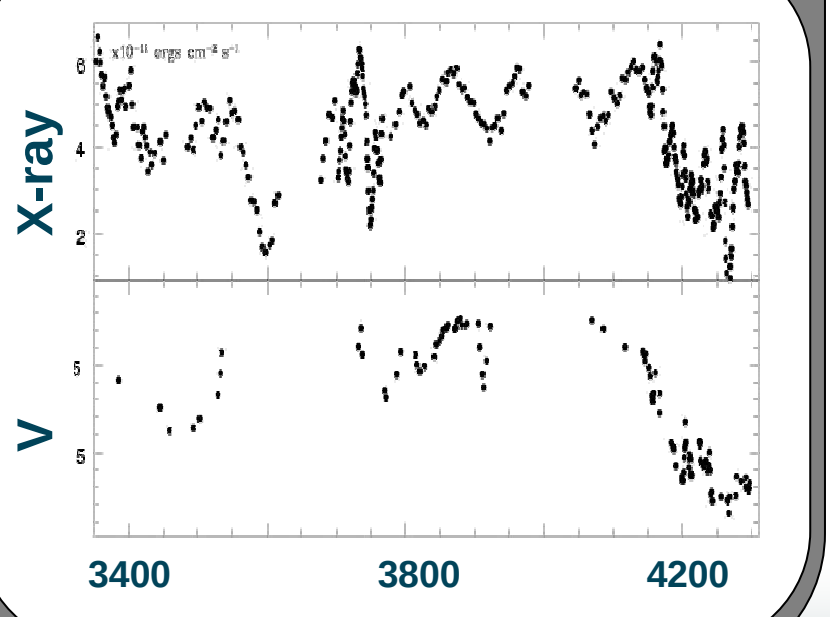
Monitoring

NGC 4051



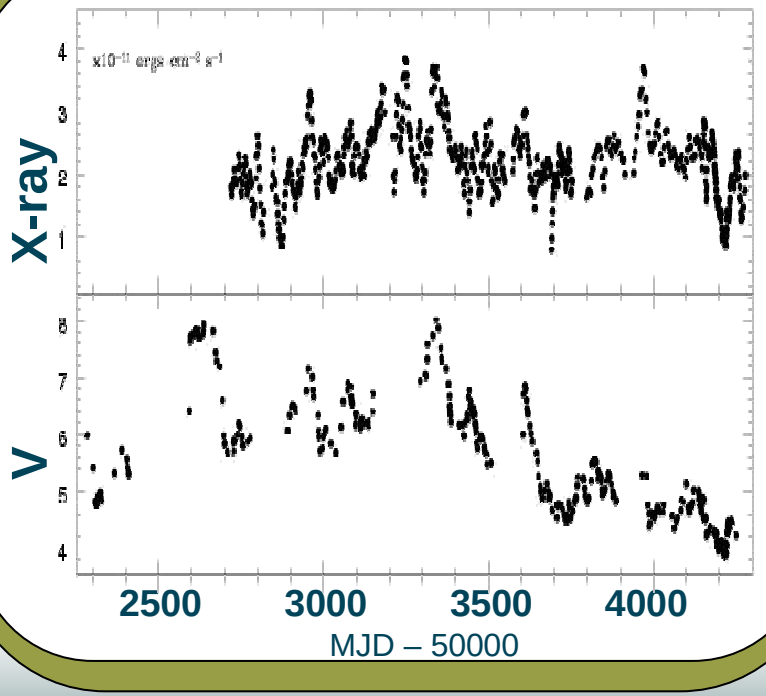


NGC 4593

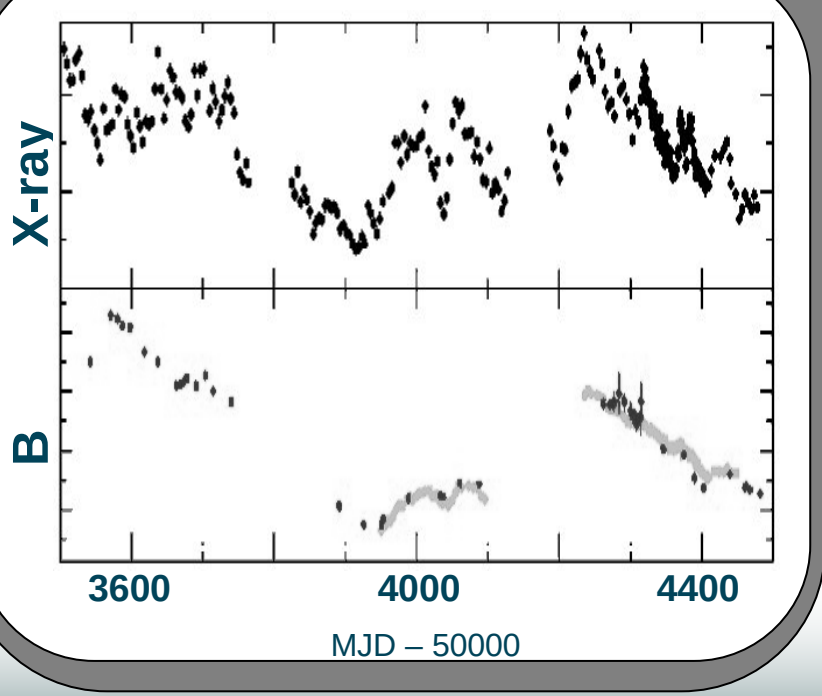


Monitoring

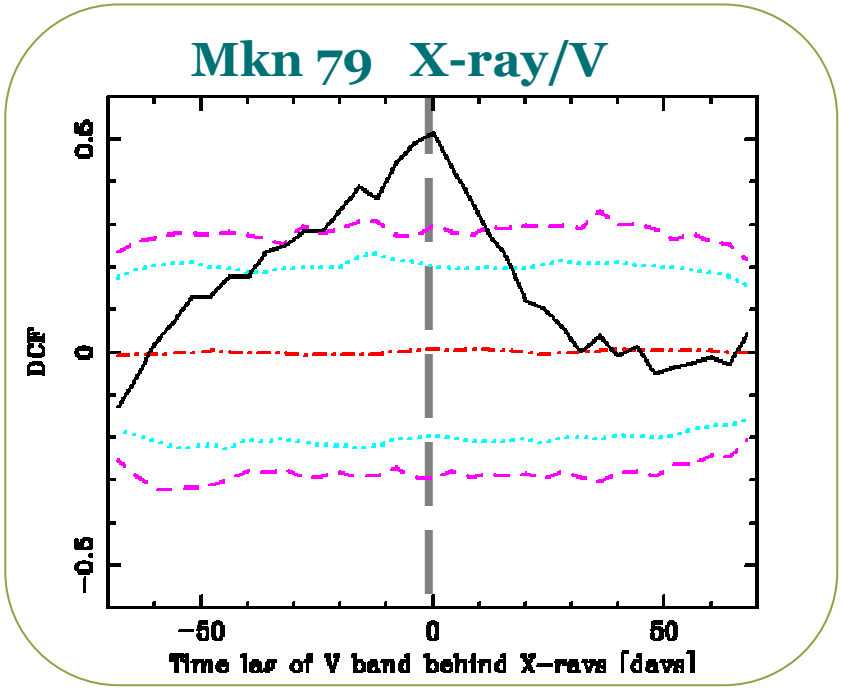
Mkn 79

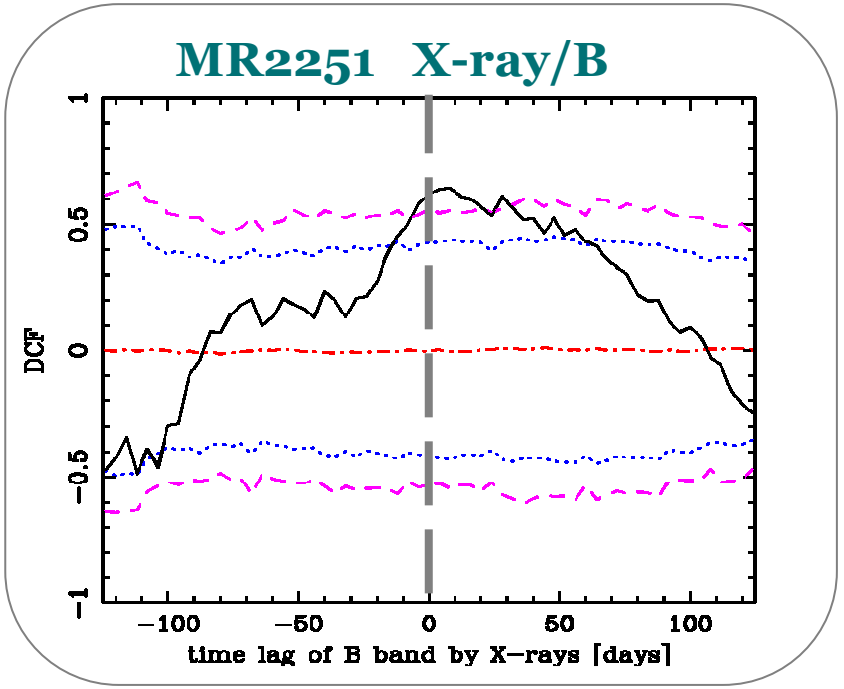


MR2251-178



X-ray/optical cross-correlations





- The variability is correlated at >99% significance.
- Delay consistent with 0 days in both sources (-2±7days and 4±9 days respectively)
- Either both bands ‘see’ each other or both are modulated by the same source

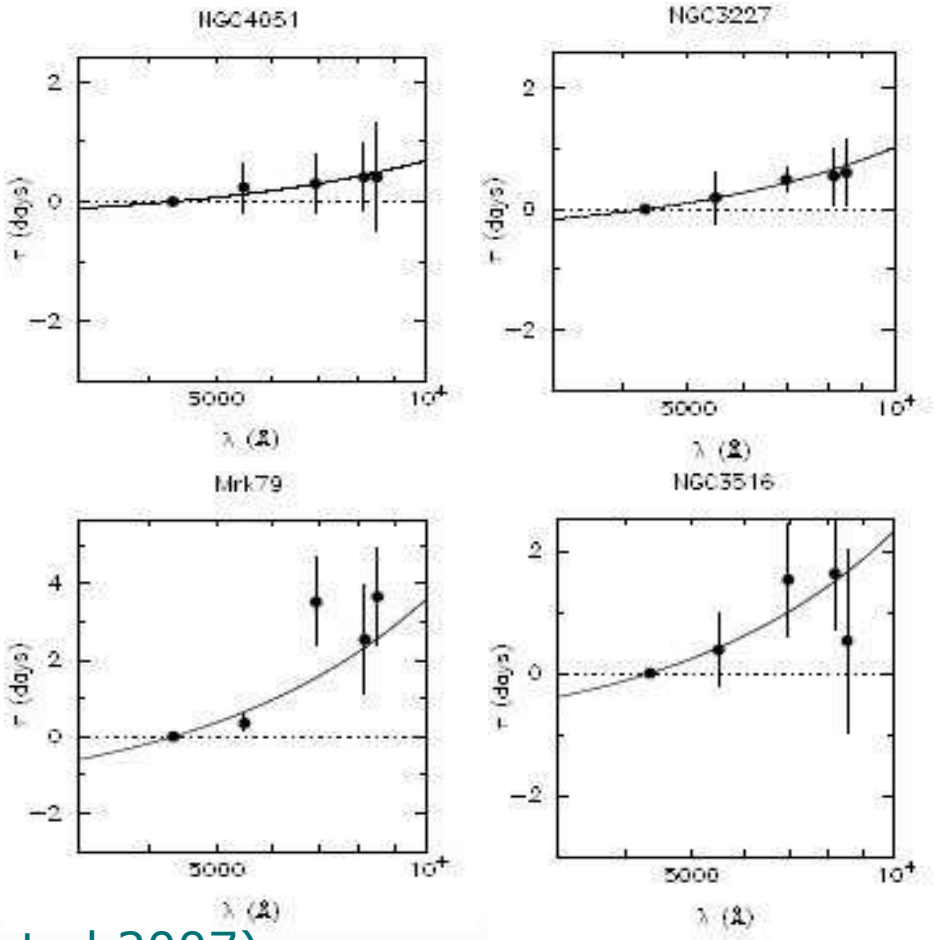
Further support for reprocessing

$$T(R) \propto (MM_{\odot})^{\frac{1}{4}} R^{-\frac{3}{4}}$$

$$\tau(\lambda) = R/c$$

$$\propto T^{-\frac{4}{3}} \propto \lambda^{\frac{4}{3}}$$

$$\left(T \propto \frac{hc}{k\lambda}\right)$$

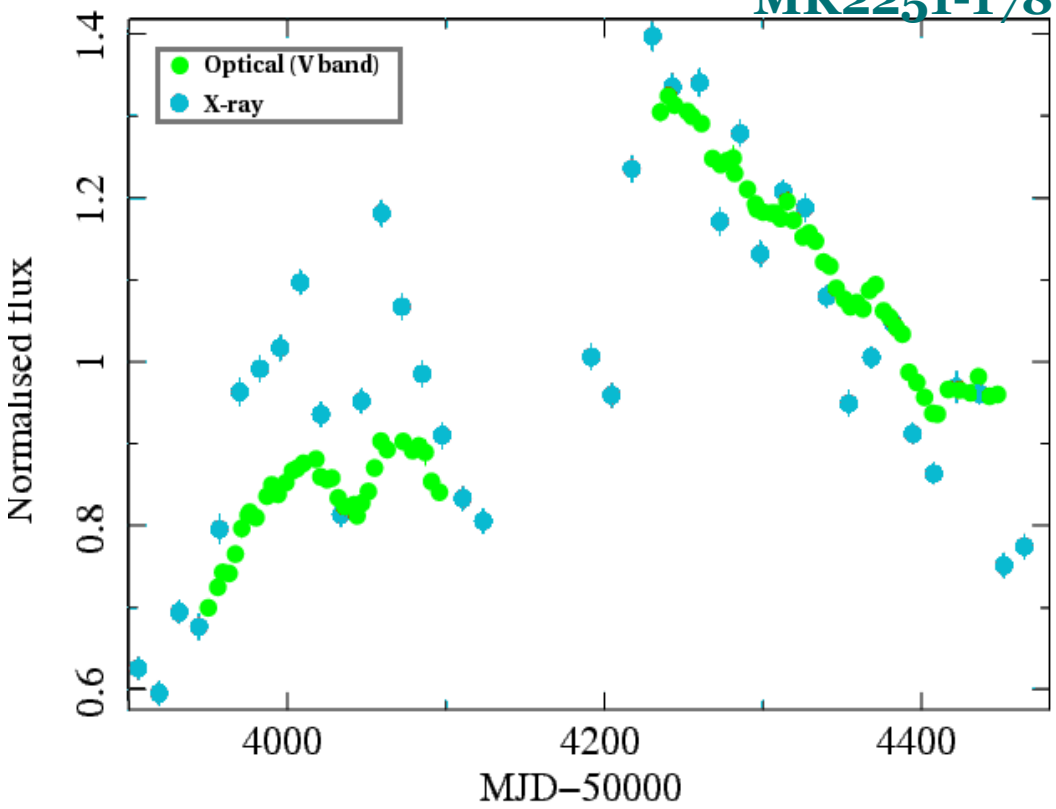


- Short delays
- Smoothing of short timescale fluctuations suggest reprocessing
- $\lambda^{4/3}$ dependence observed

(Cackett et al 2007)

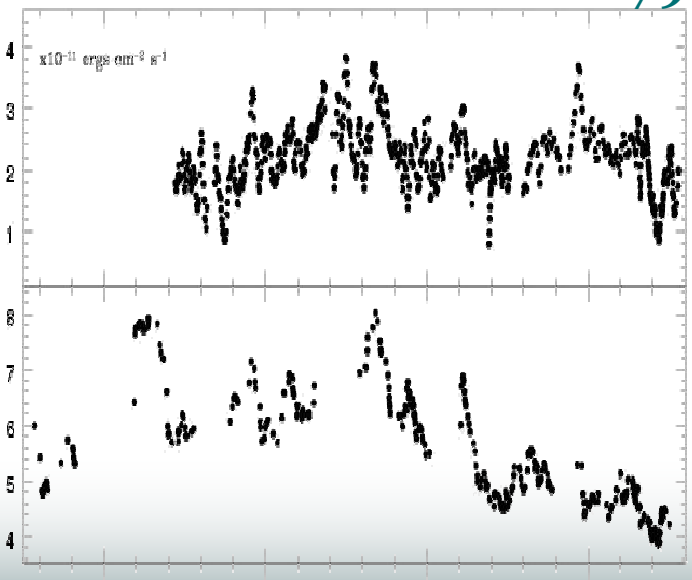
But...

MR2251-178



- *Long term* optical amplitude > X-ray amplitude
- Uncorrelated long term behaviour
- Smoothing by reprocessing not enough

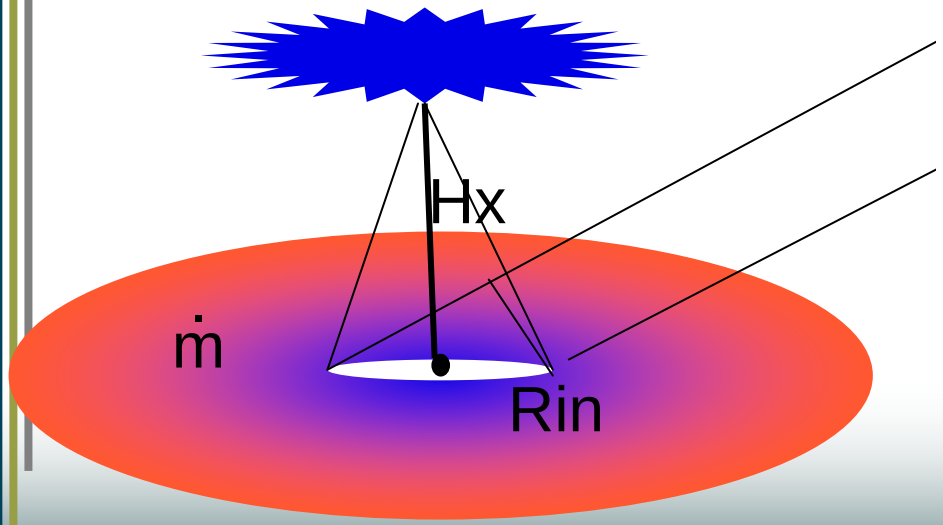
Mkn 79



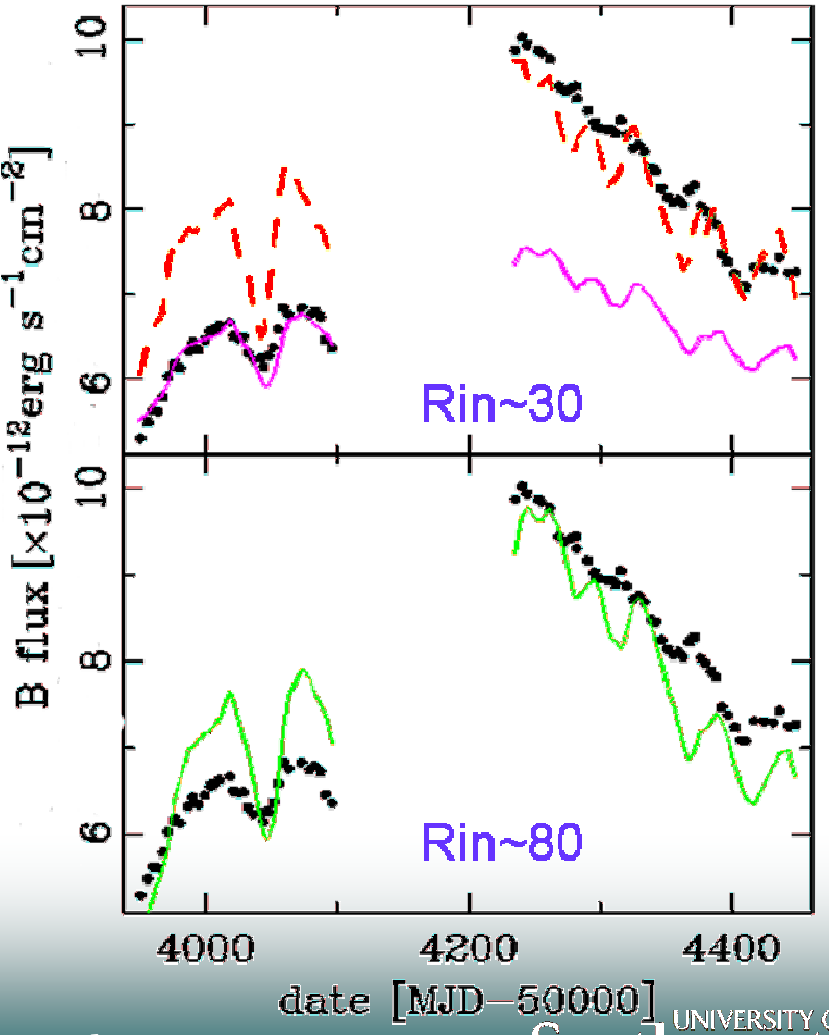
Pure reprocessing can't work

Reprocessing model:
Kazanas & Nayakshin (2001)

Best-fitting accretion rate, source height, inner truncation radius combinations



(Arévalo et al 2008)

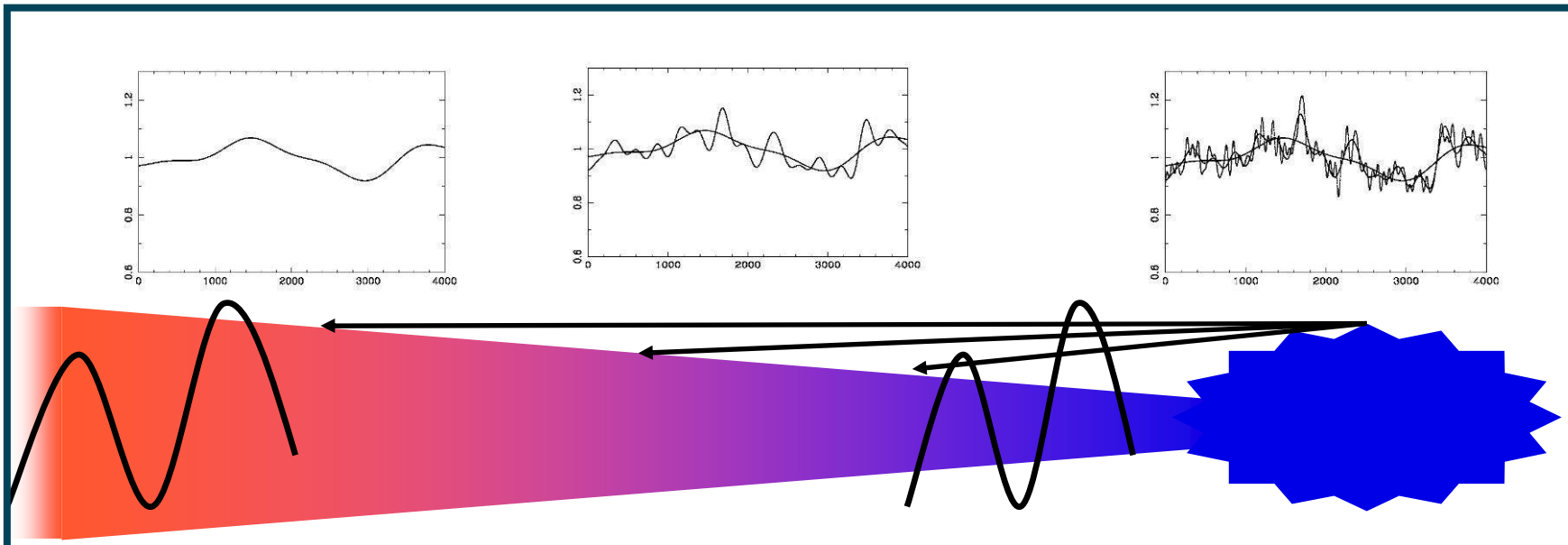


The problem with reprocessing

In order to get the required amount of *smoothing* we see in the optical light curves, we need a *large reprocessor* – this will introduce corresponding *long lags* which are *not observed*.

Adding accretion rate fluctuations

- Accretion rate fluctuations modulating both, thermal and X-ray emission
- X-ray long lags ~ viscous or sound timescale

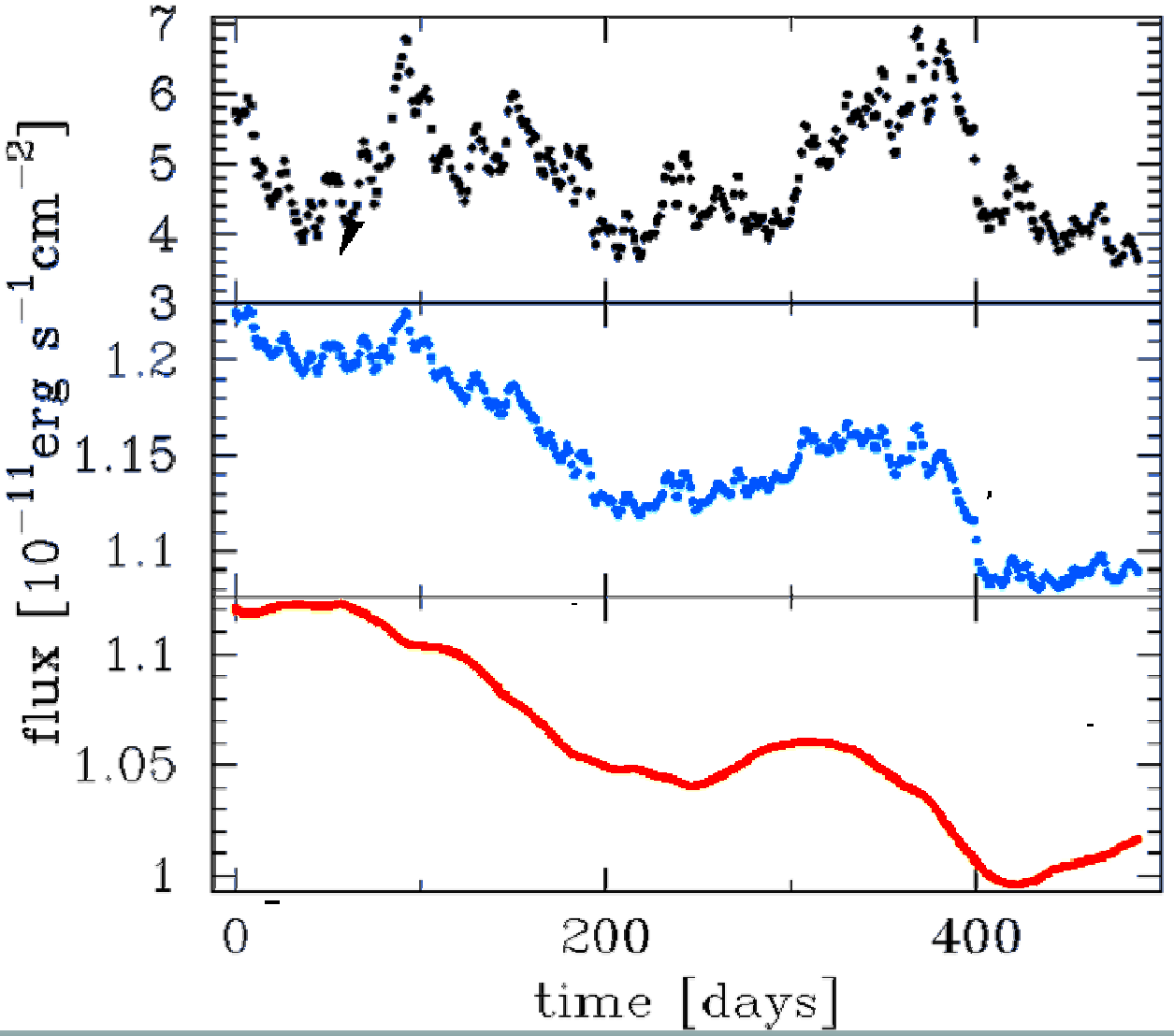


Propagating fluctuations:
Lyubarskii (1997), Arévalo & Uttley (2006)

Reprocessing:
Kazanas & Nayakshin (2001)

Simulated light curves

propagating fluctuations + reprocessing



X-ray

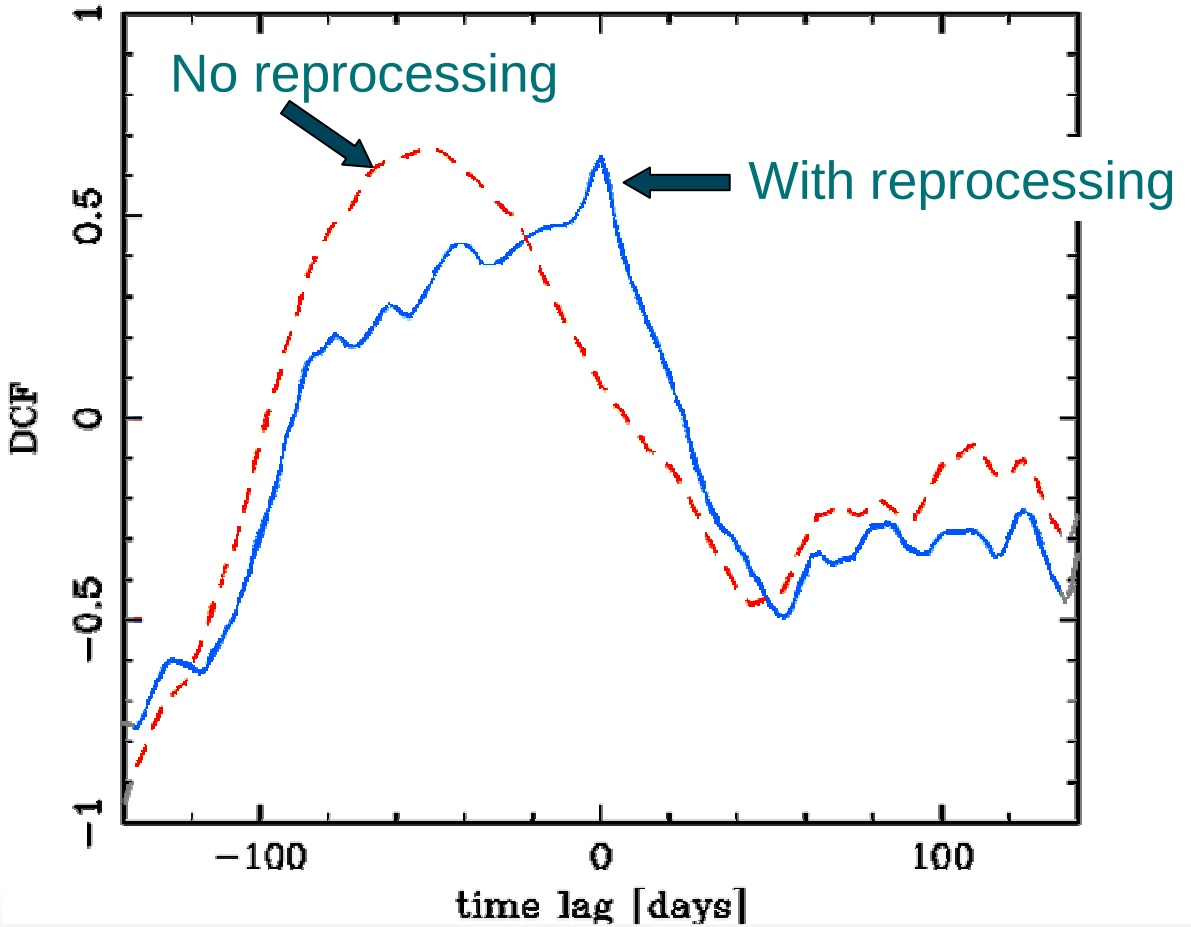
Optical with reprocessing

Optical, accretion fluctuations only

(Arévalo et al 2008)

Simulated light curves

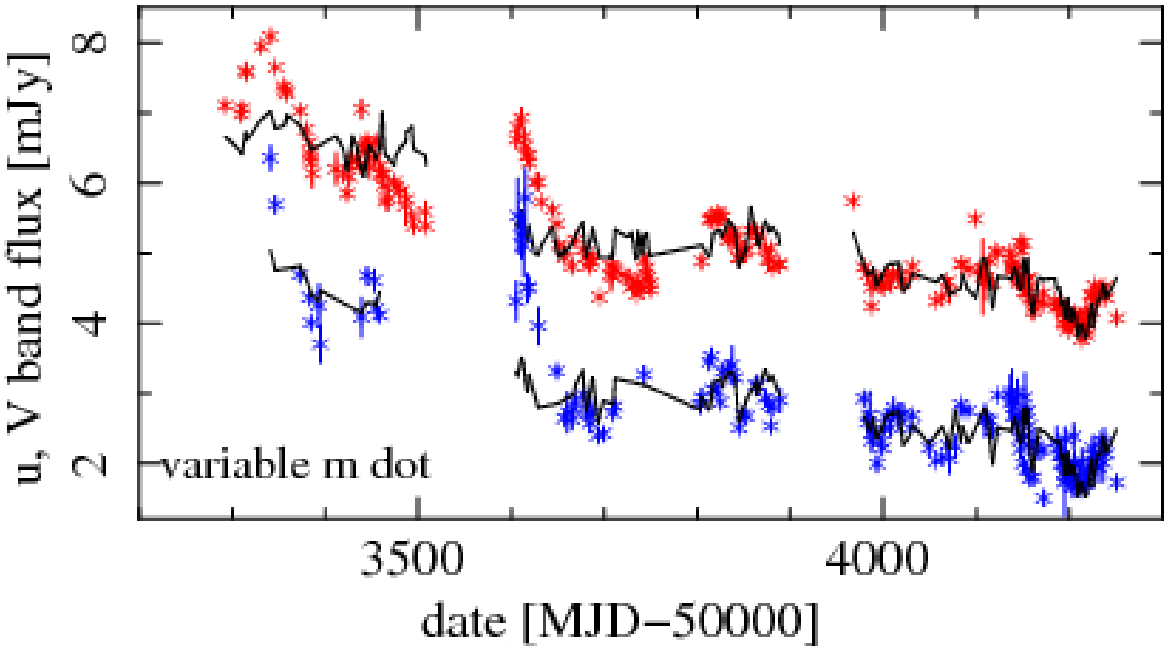
propagating fluctuations + reprocessing



(Arévalo et al 2008)

Reprocessing Mkn 79

Long term trend in the optical light curve well reproduced by accretion rate variations or changes in the geometry of the X-ray source



Observed V band light curve
Observed u band light curve
Optical light curve from reprocessing model

(Breedt et al, *in prep*.)

Conclusions

- X-ray and optical emission in AGN show large amplitude fluctuations.
- Long term monitoring campaigns show *good X-ray/optical correlations* in many objects, with short or no delays.
- Short term variability stronger in X-rays, long term variability stronger in optical bands.
- *Reprocessing* of X-ray is probably responsible for rapid optical fluctuations but another source of intrinsic optical variability must exist, probably *fluctuations in the disc accretion rate*.