



Mapping AGN Winds
with X-ray reverberation

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Jeekyll Island June 2017

Why AGN winds are so interesting

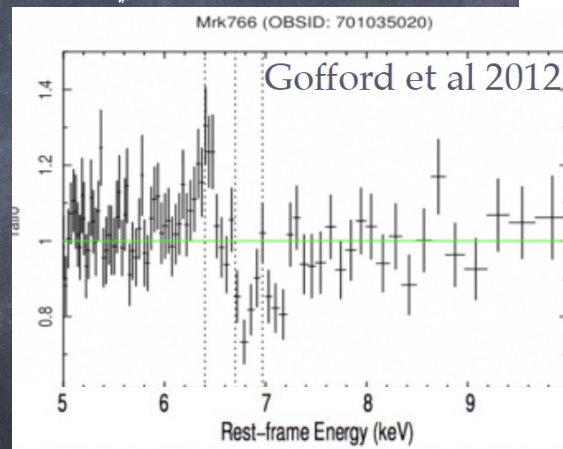
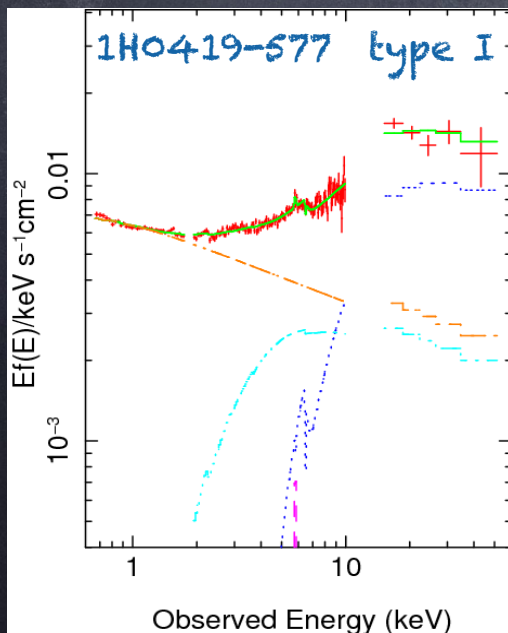
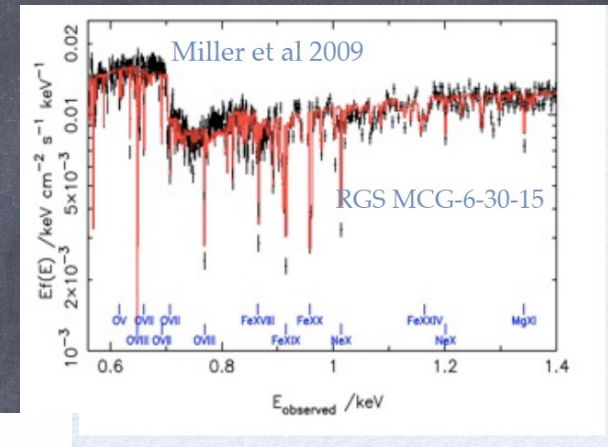
- Wind expected in sources accreting at high fraction of Eddington (e.g. King & Pounds 2003, King 2010)
- Outflows carry mass and energy from the central engine
- Feedback regulates growth of BH and host

X-ray outflows

Innermost zone of wind?

Broad range N_H , ξ and velocity

Blue-shifted absorption lines, 100's km/s - fraction of c (Tombesi et al 2010)

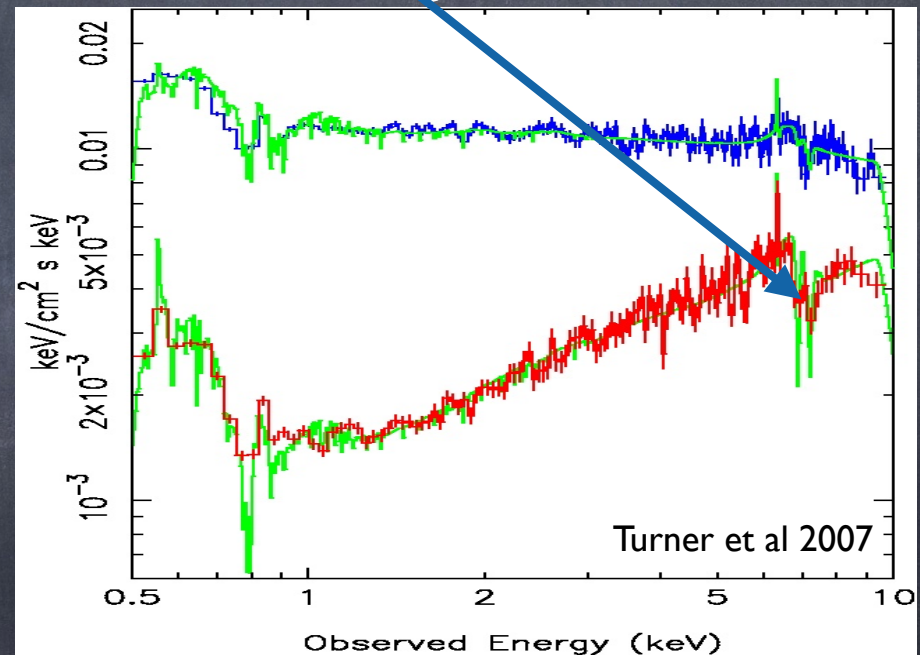


...extending to CT clumps, e.g. Turner et al 2009, Tatum et al 2013, 2016

Variable X-ray absorption on days

Mrk 766: blue shifted
absorption lines - wind
signature

- A source of variability in some AGN on days (e.g. MCG-6-30-15 McKernan et al 1998; NGC 3516 Turner et al 2008)

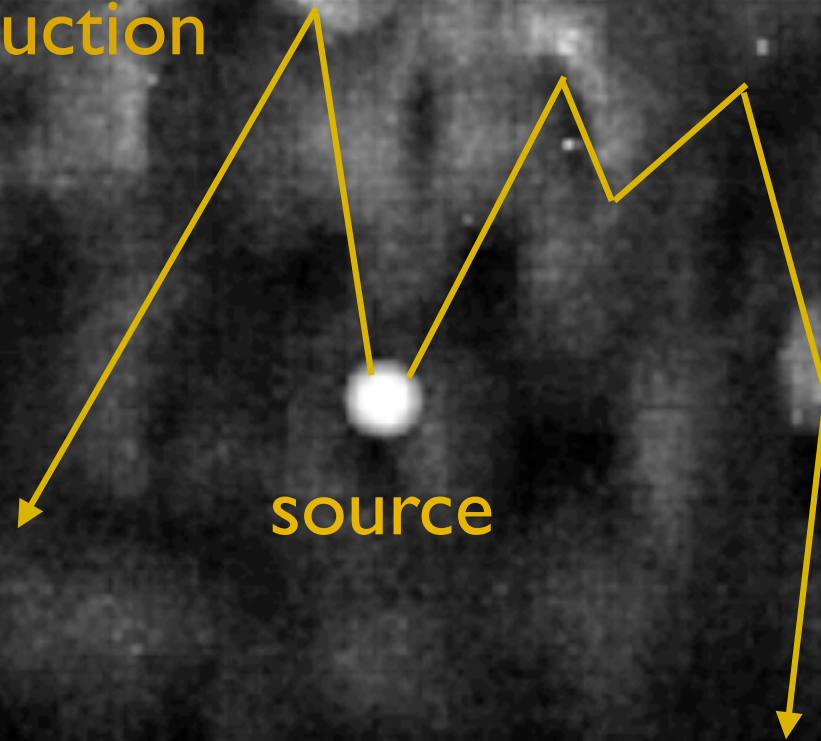


Monte Carlo photon shooting simulated spectra

3D cloud distribution
(1000 interconnected “blobs”)

multiple Compton scattering,
photoelectric absorption &
Fe K line production

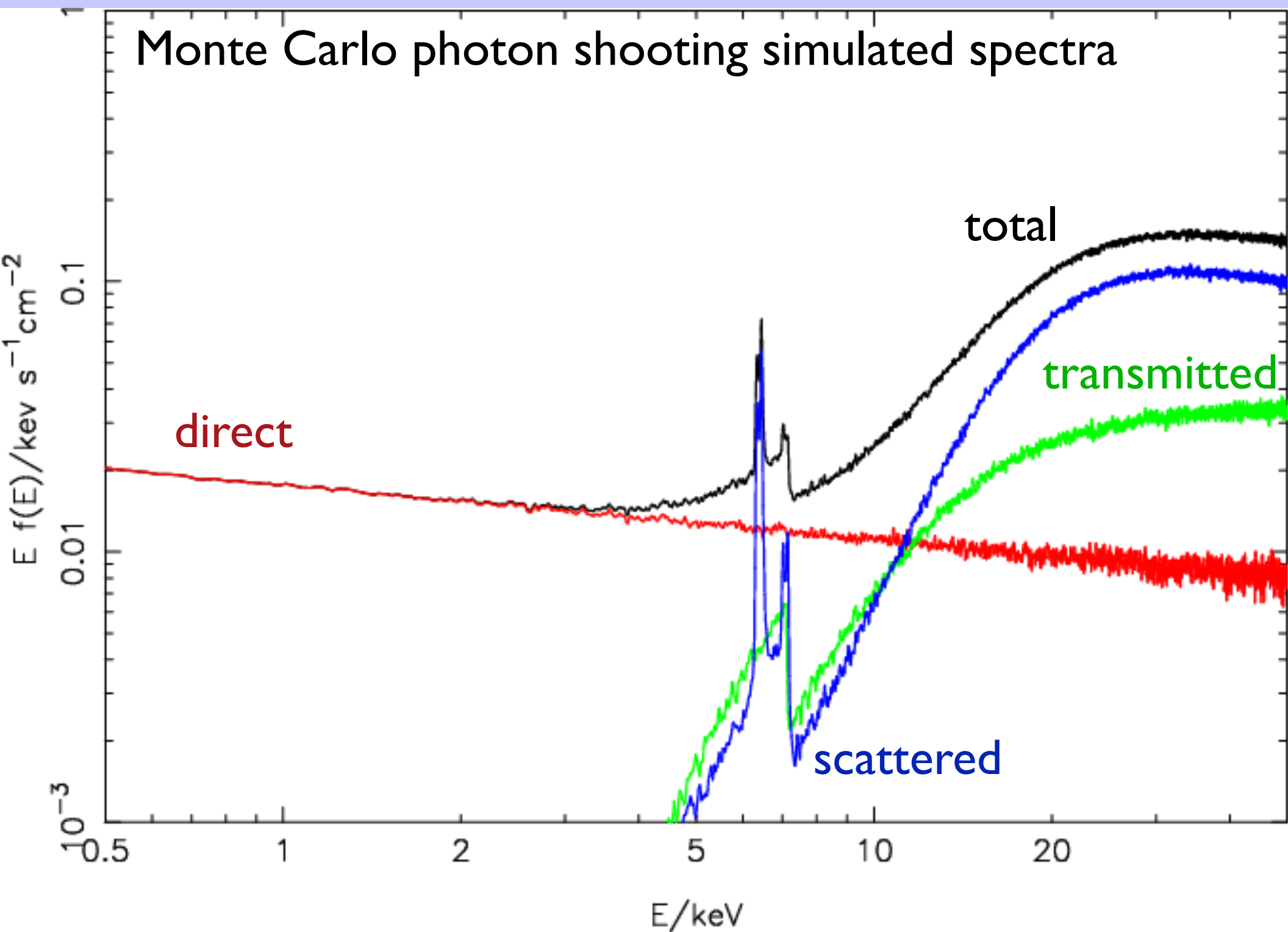
neutral gas only



source

60 billion
photon packets

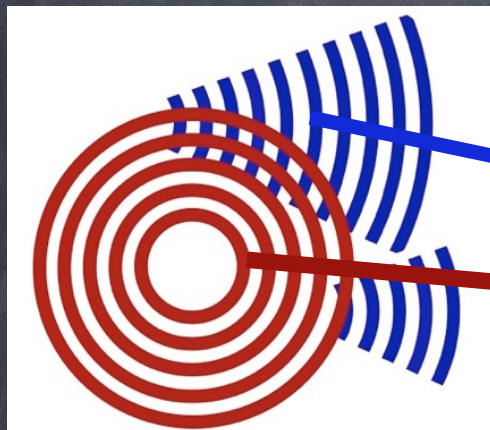
Monte Carlo photon shooting simulated spectra



X-ray time lags

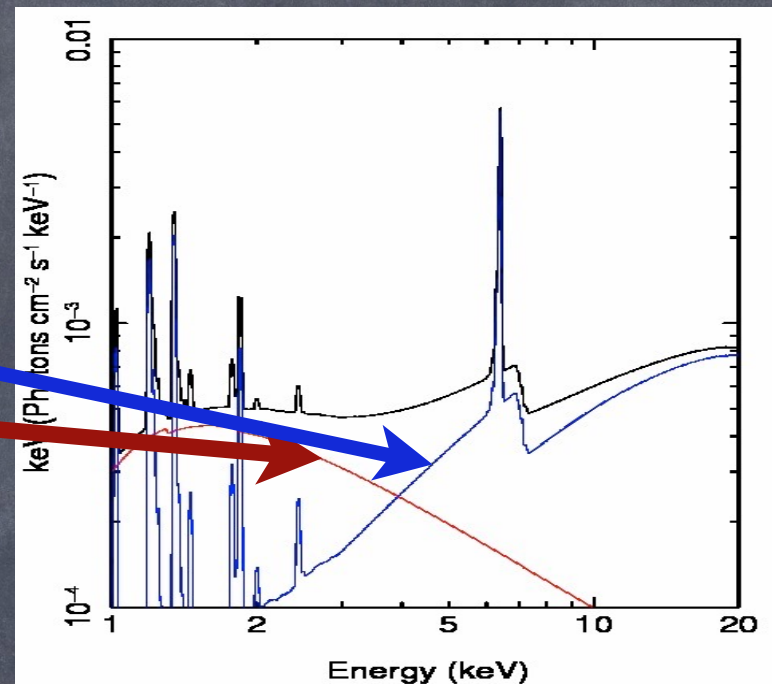
- Lags between hard and soft X-ray photons known in Galactic sources and common in AGN (e.g. DeMarco et al 2013, Kara et al 2016)
- Lags imply not all flux variations caused by absorption events... rapid (ks) events likely intrinsic... X-ray reverberation?

X-ray Reverberation



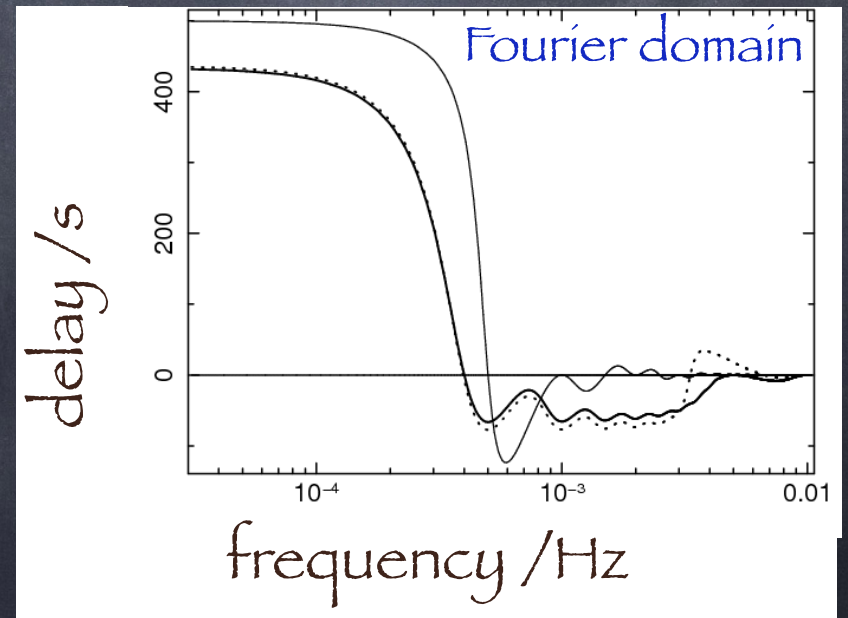
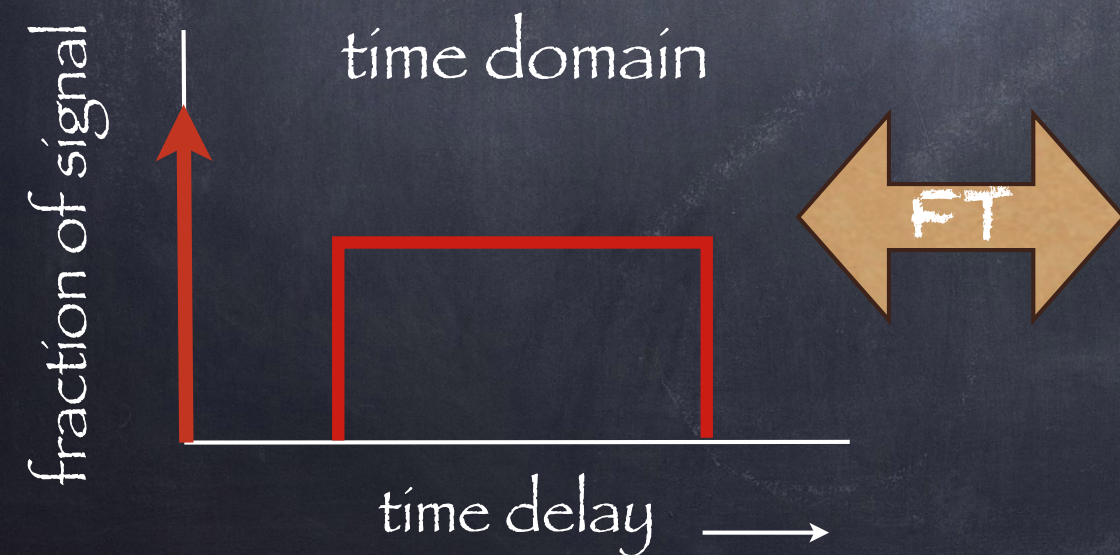
hard spectrum,
scattered,
delayed X-rays

direct X-rays

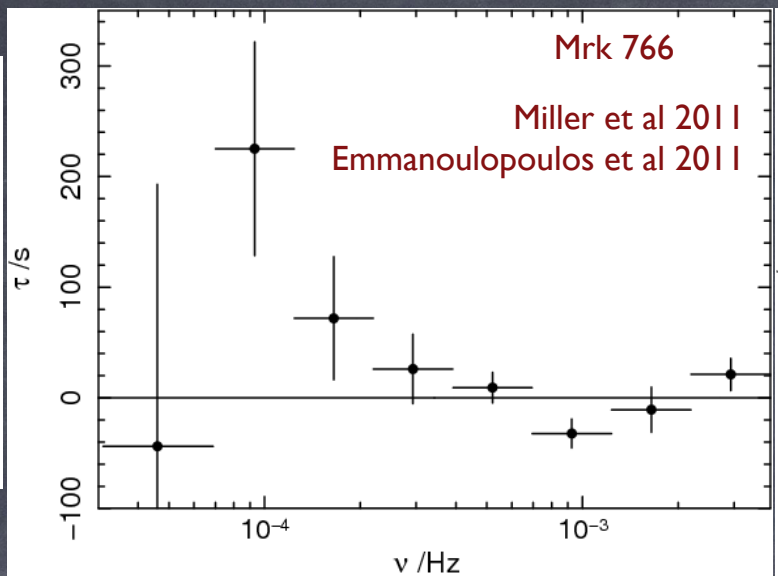


- ⊙ Insufficient counts to separate lines and continuum on short timescales
- ⊙ Measure reverberation between broad bands
- ⊙ Reflected & direct mixed in different fractions in the bands

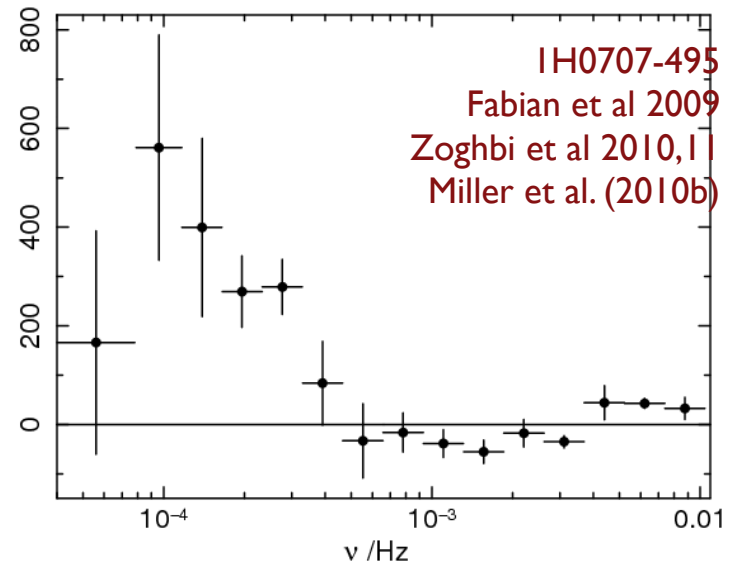
- Estimate cross-band power spectrum (max likelihood) \rightarrow time delay as function of source variations
- Lag spectrum given by phases of Fourier transform of the transfer function which describes spread of time delays in the signal



lag/s

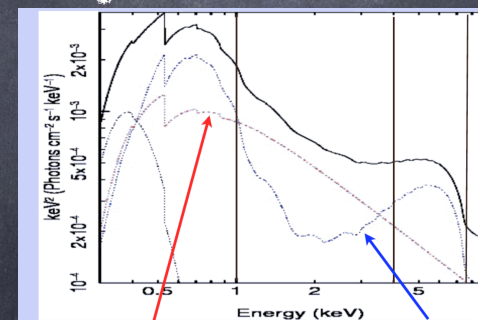


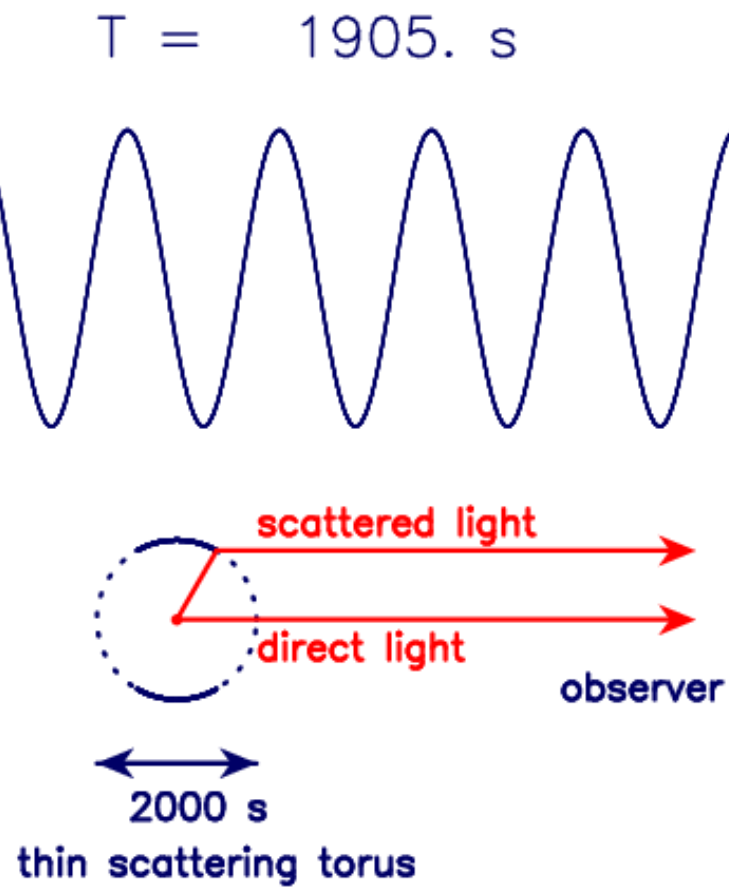
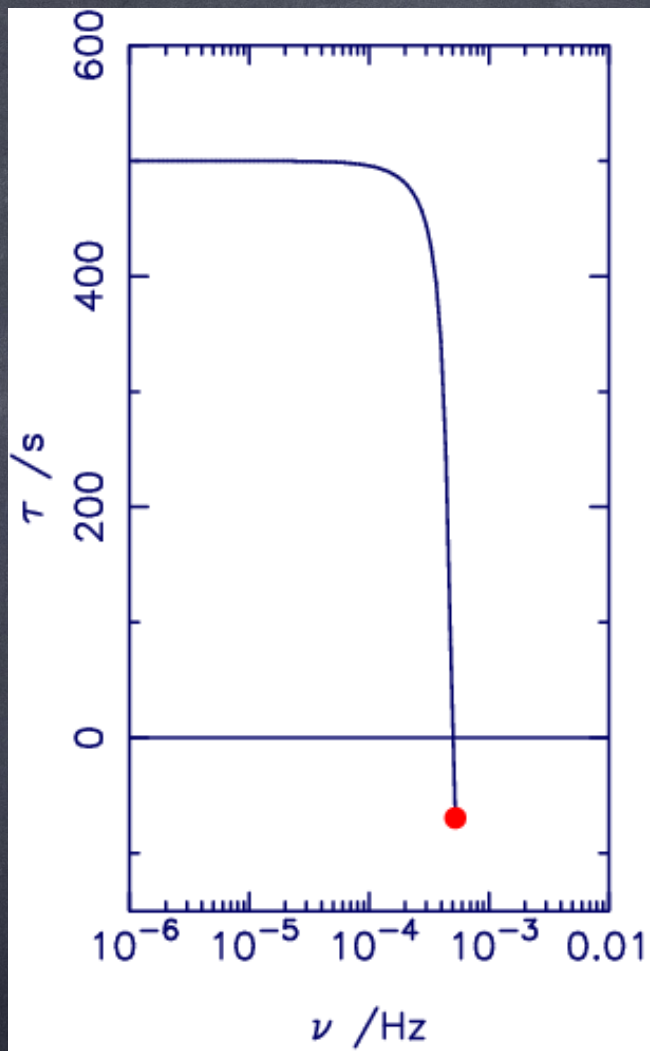
frequency /Hz



frequency /Hz

- Hard X-rays delayed wrt soft defined as **positive lag**
- Two ways to obtain negative lags (soft delayed wrt hard) from reverberation
 - either soft band also has delays (e.g. Zoghbi et al 2010, 2011) **OR**
 - reprocessor is clumpy - negative lags arise from Fourier transform of transfer function

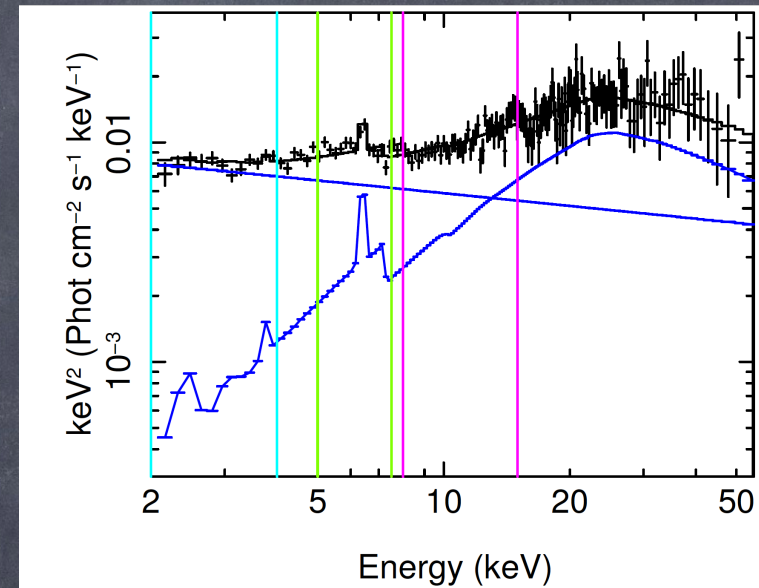
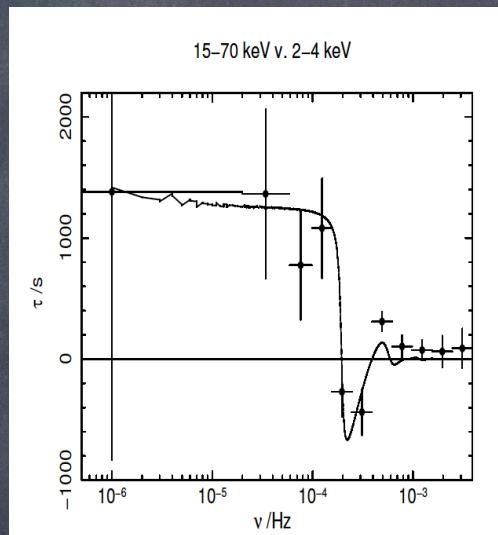
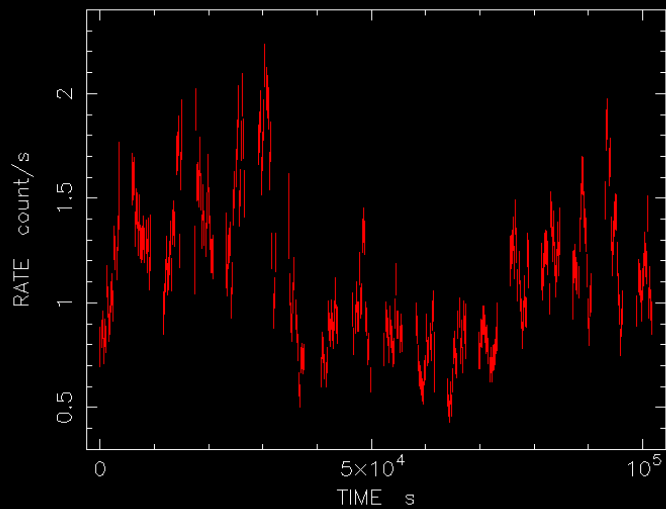




NUSTAR - NGC 4051

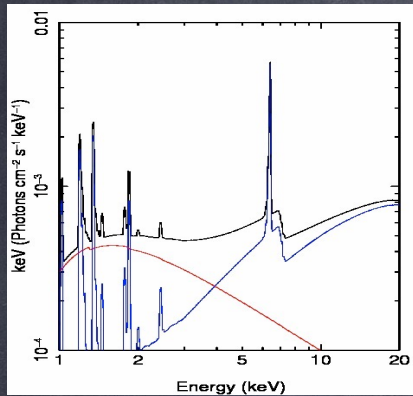
Turner et al 2017

- negative lags not due to reflection in soft band- that band has no reflection!



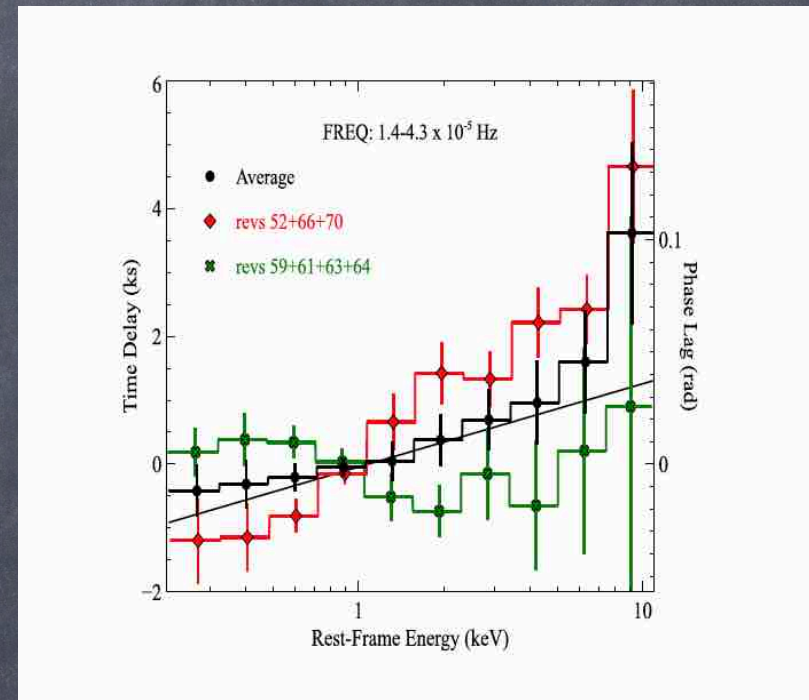
- Light travel time across shell places reprocessor at few hundred r_g

Lag behavior varies



- Green points - lag behavior in low/absorbed state
- Red - lags in high state
- Black is the mean

- Change in lag behavior during heavy X-ray absorption
- N_{H} increase - scattered photons from smaller physical depth in clouds \rightarrow smaller time delay
- X-ray reprocessor dynamic in nature!



PG1211+143

Lobban et al 2017

Conclusions

- Complex X-ray absorption & scattering from outflowing variable wind \rightarrow imprints \sim days variability
- Time lag spectra consistent with reverberation on ks timescales - material lies at 10-100 GM/c^2 , not 1-2 GM/c^2 !
- "Negative" time lags arise from ringing in Fourier transform of hard-band transfer function, not from excess soft band reflection
- Dynamic outflow - changes over time