Modelling broad Fe Kα reverberation

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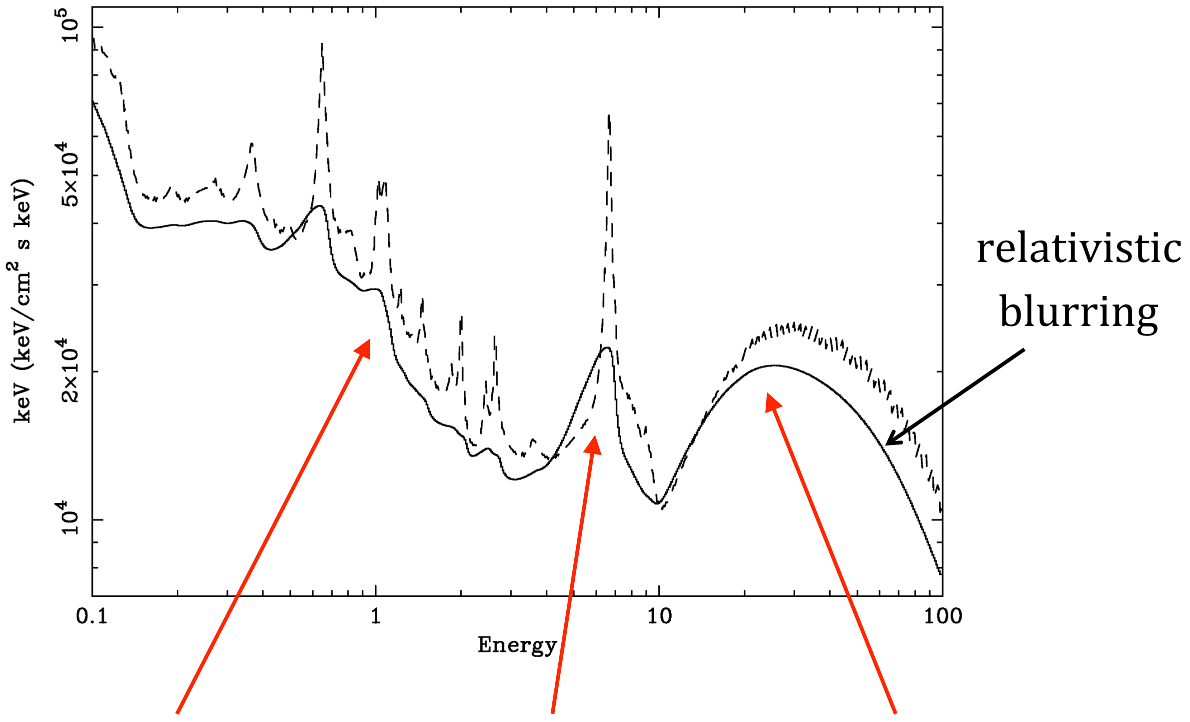
For the paper:
Cackett et al. 2014, MNRAS, 438, 2980

For a review:
Uttley, Cackett, Fabian, Kara & Wilkins
2014, A&ARv, 22, 72

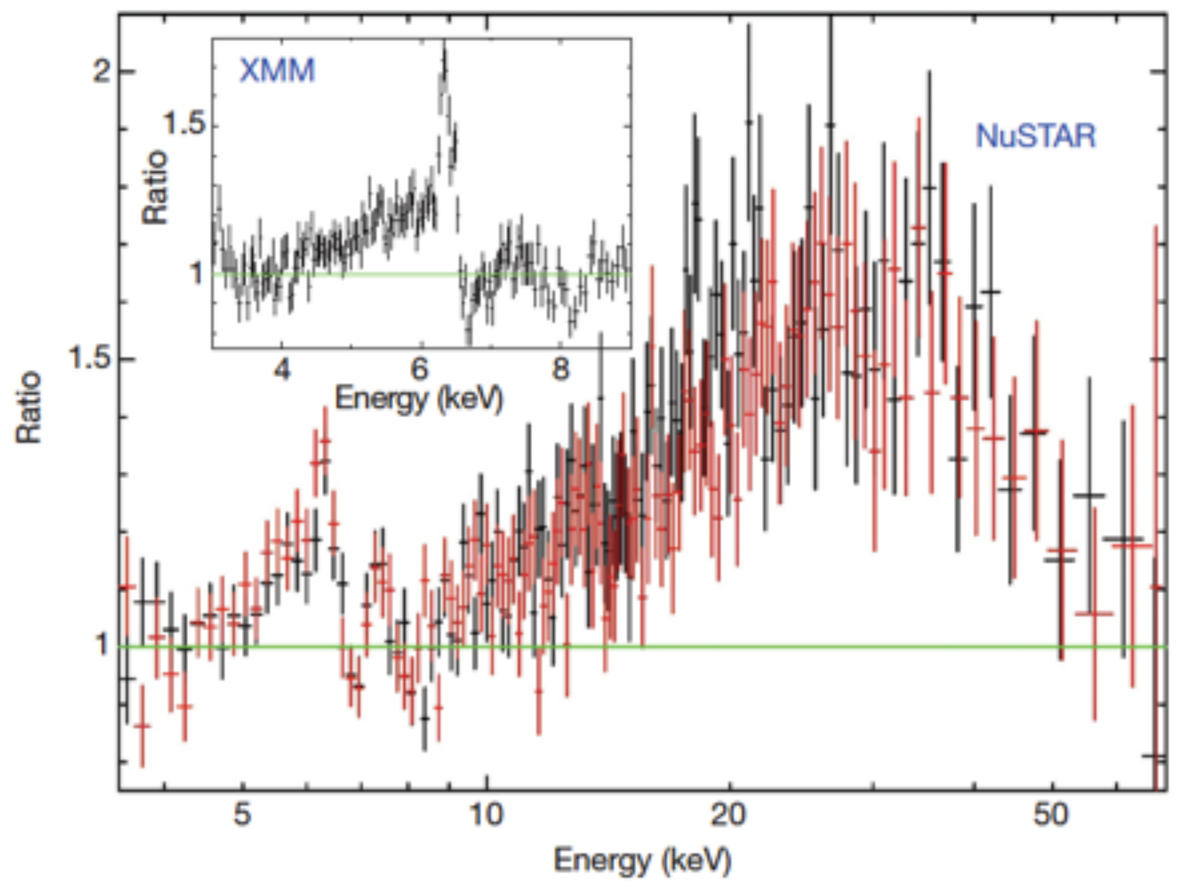
Collaborators: *Abdu Zoghbi, Chris Reynolds, Andy Fabian, Erin Kara, Phil Uttley, Dan Wilkins*

Relativistic reflection in AGN



relativistic blurring

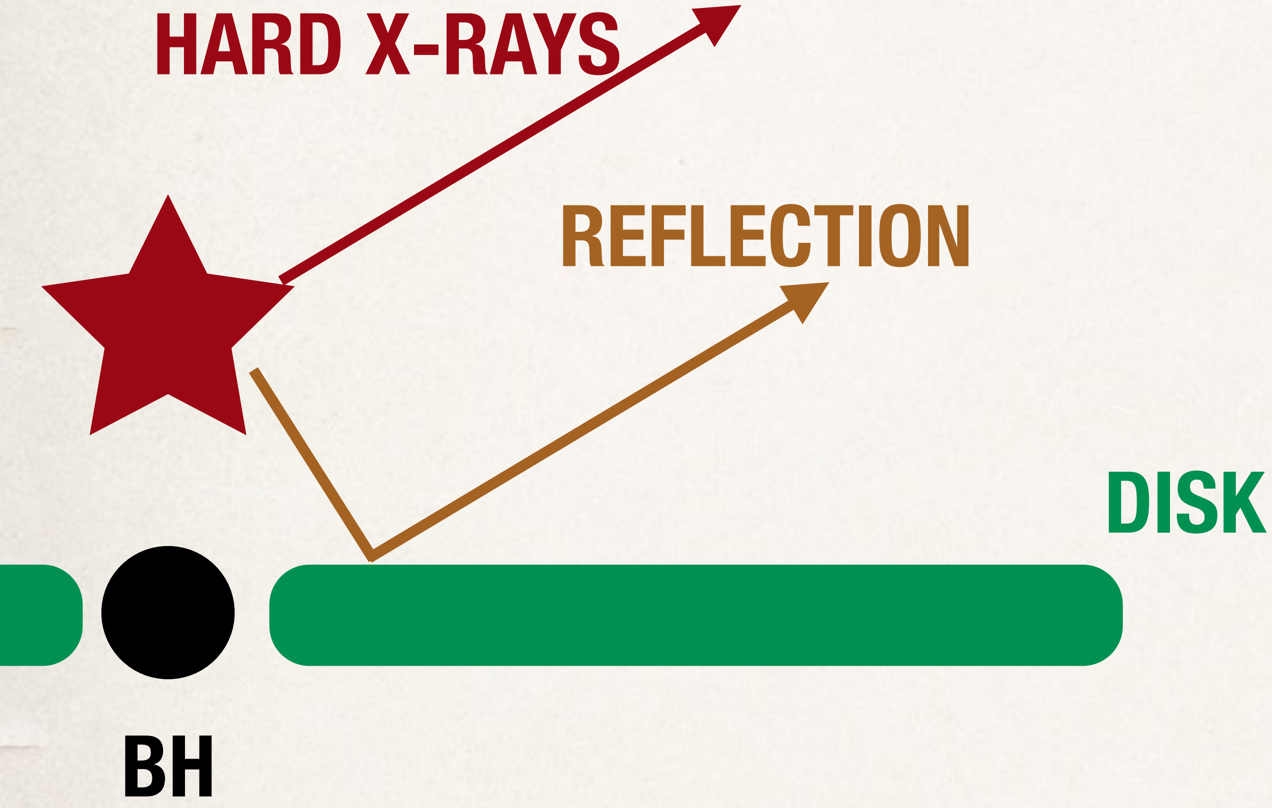
Soft excess – broad iron line – Compton hump



NGC 1365: Risaliti+13

- Reflection predicts lags between the continuum and reflected components

Reflection predicts reverberation lags



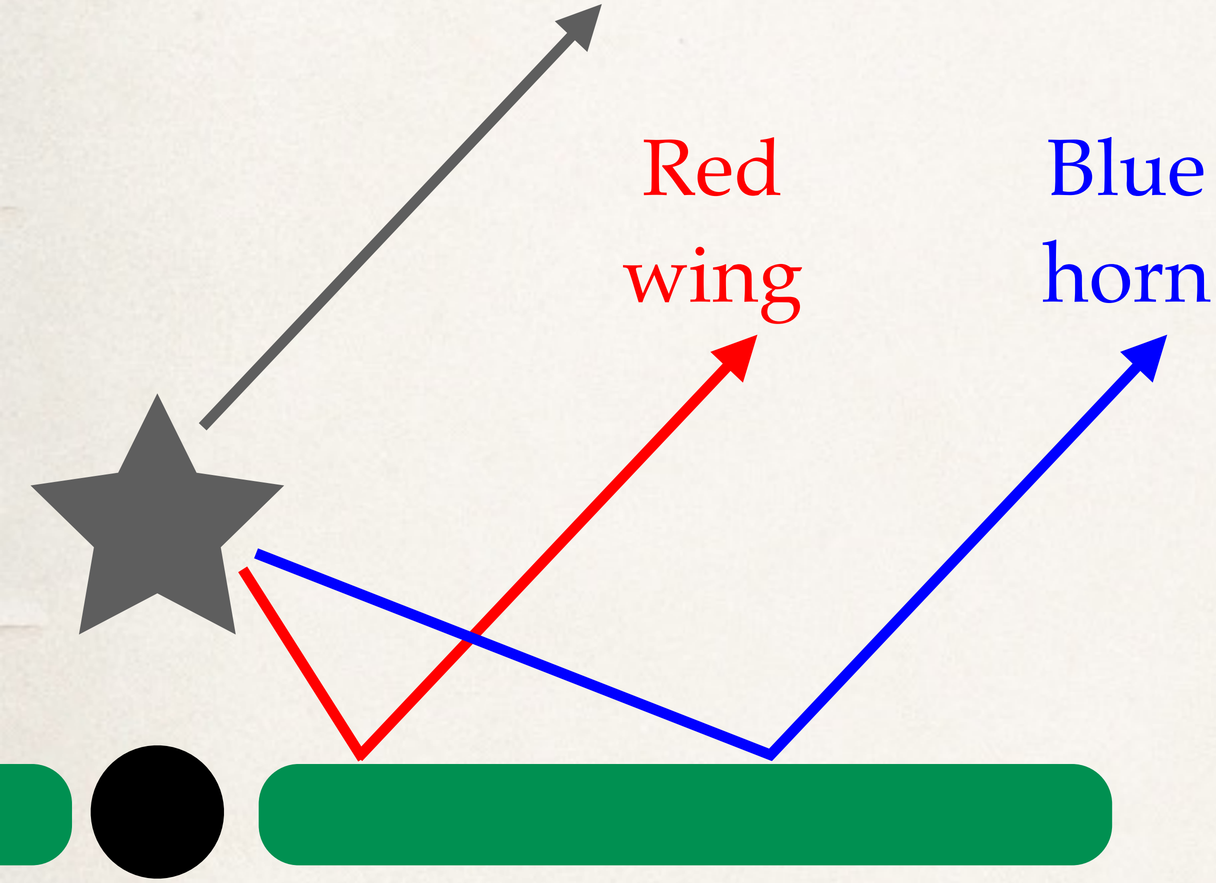
- Path-length difference between continuum and reflected photons will lead to a time lag

- Lag will depend on geometry and kinematics of region

- Determine lags between lightcurves in different energy bands using Fourier techniques (see Uttley+14 for detailed description)

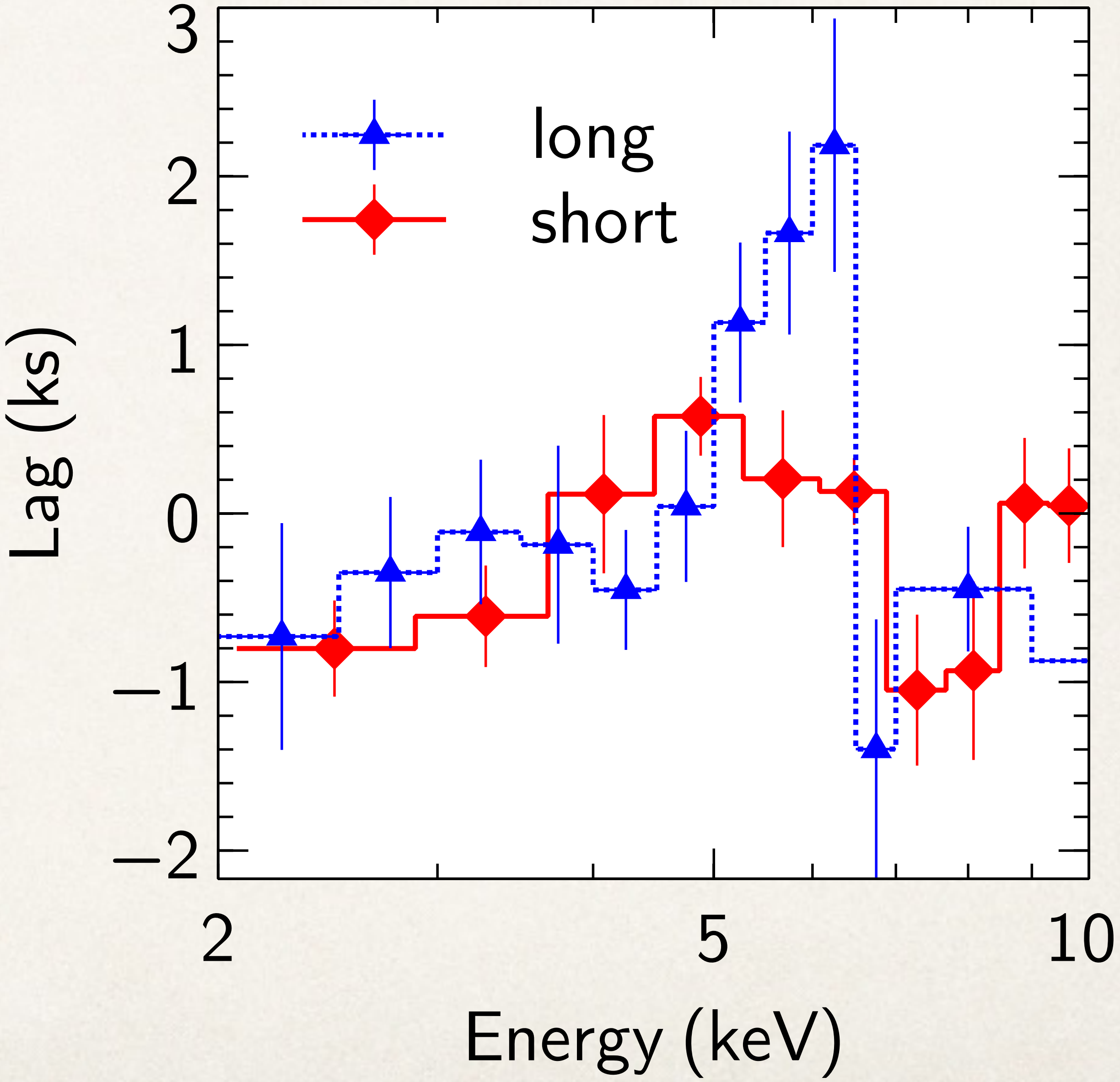
- So can look at lags vs frequency (timescale) and energy

First Fe Kα lag: NGC 4151


Red wing

Blue horn

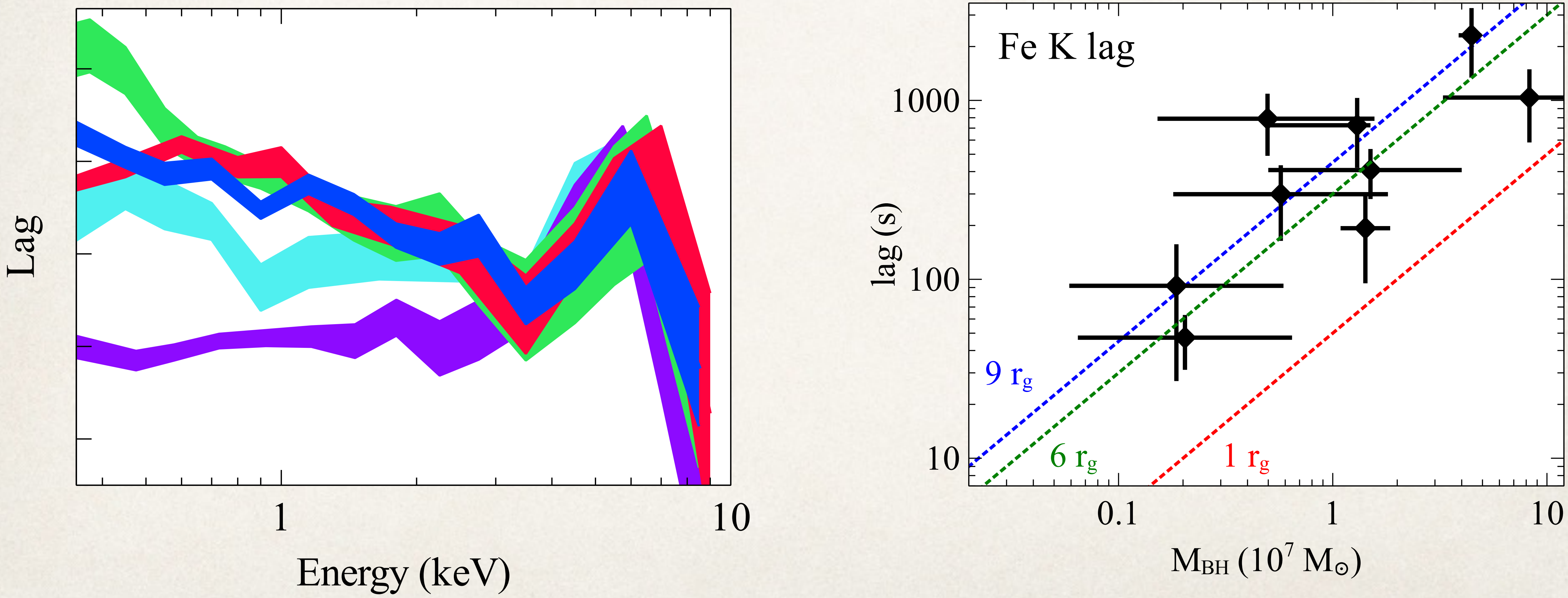
Zoghbi+12



NGC 4151

More Fe K lags

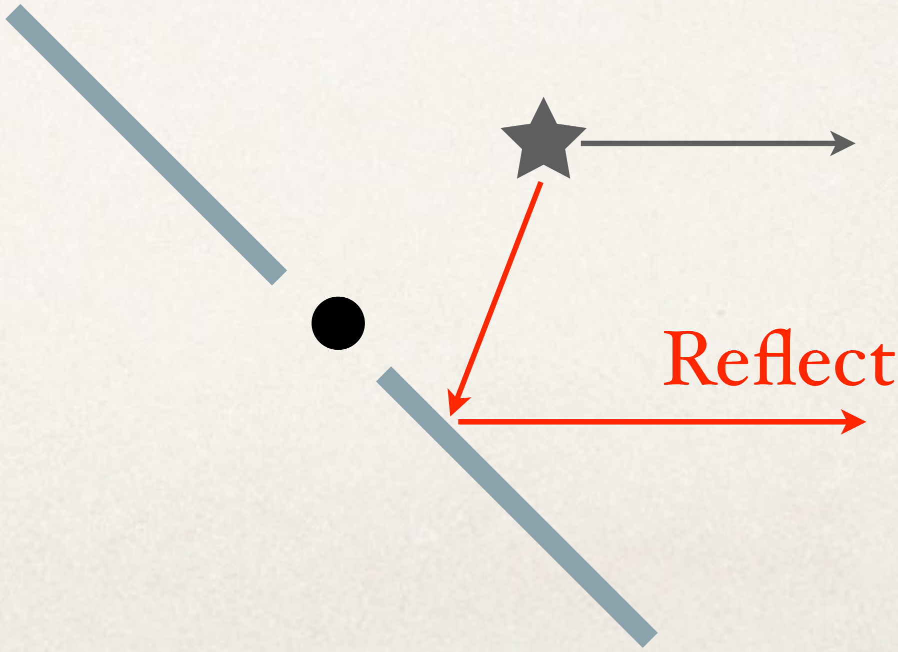
- Now detected in >9 objects (Zoghbi+12, 13; Kara+ 13a, b, c, 14a, b; Marinucci+14)
- Fe K lag scales with black hole mass



Uttley+14, after Kara+13c

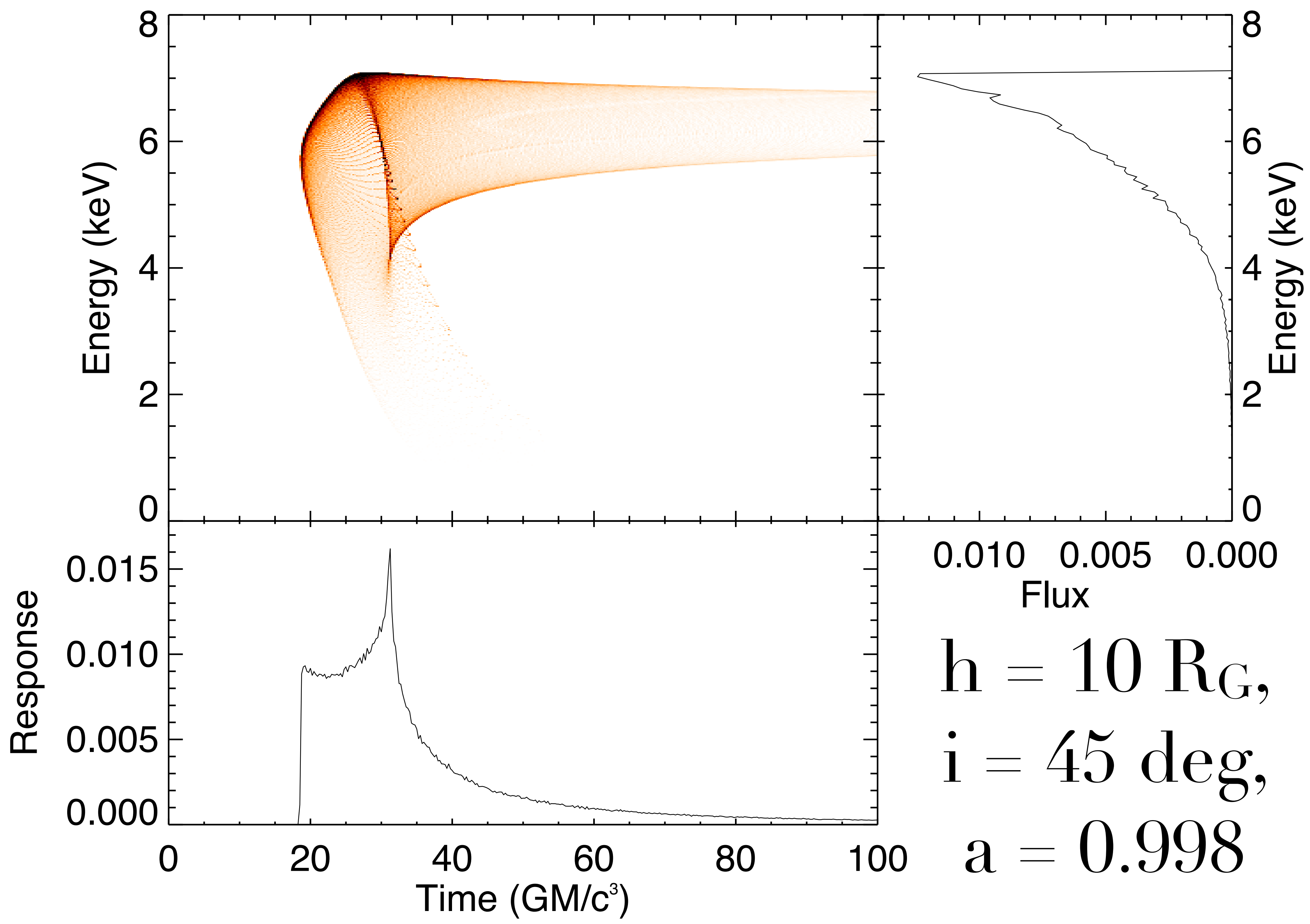
Time-dependent model for an irradiated disk

- *Transfer function (or impulse response function)* - describes the link between the direct and reflected lightcurves (blurring kernel)
- Time-dependent disk transfer functions explored by, e.g. Reynolds+99
- Here, we assume simple lamp-post type geometry

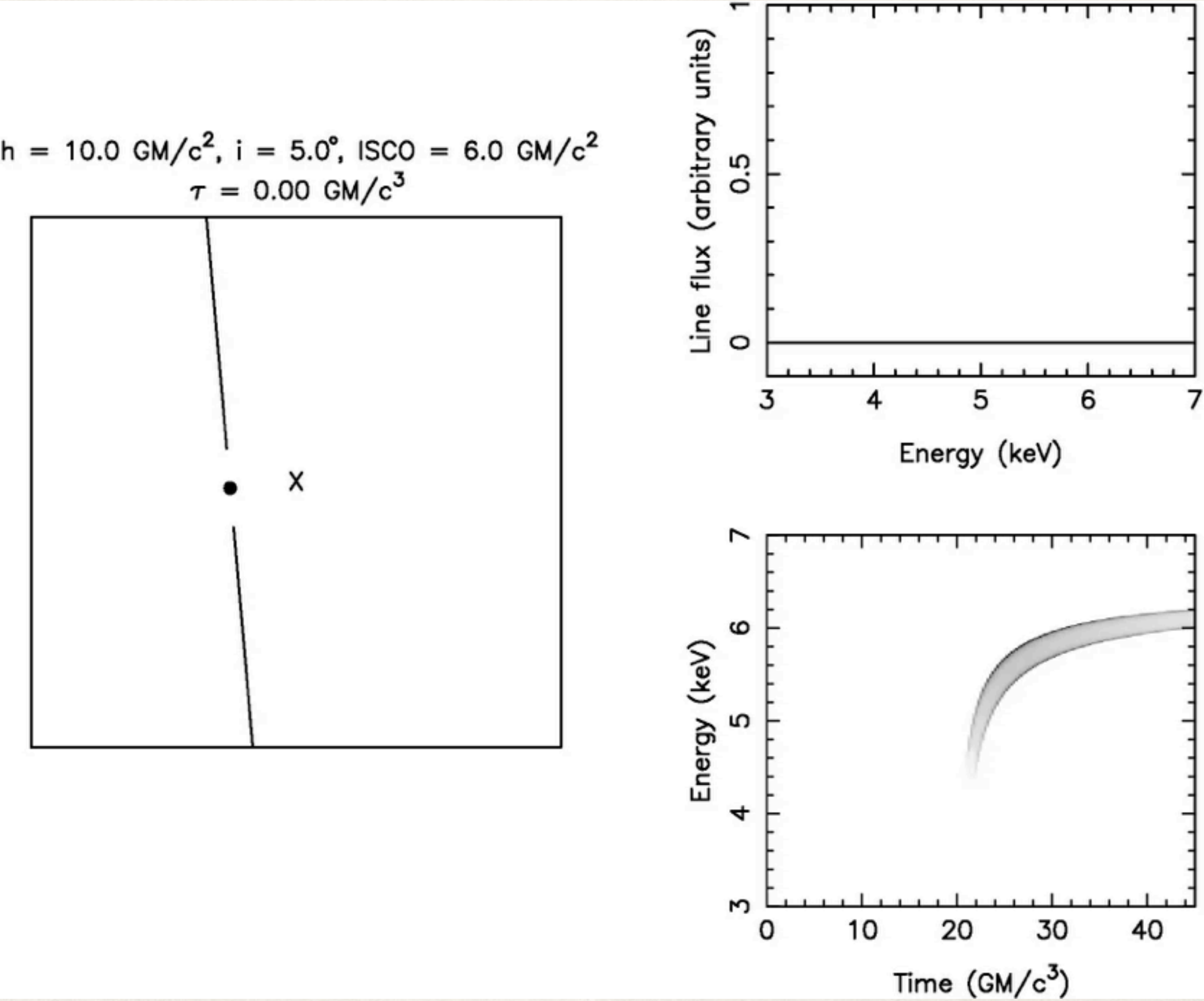


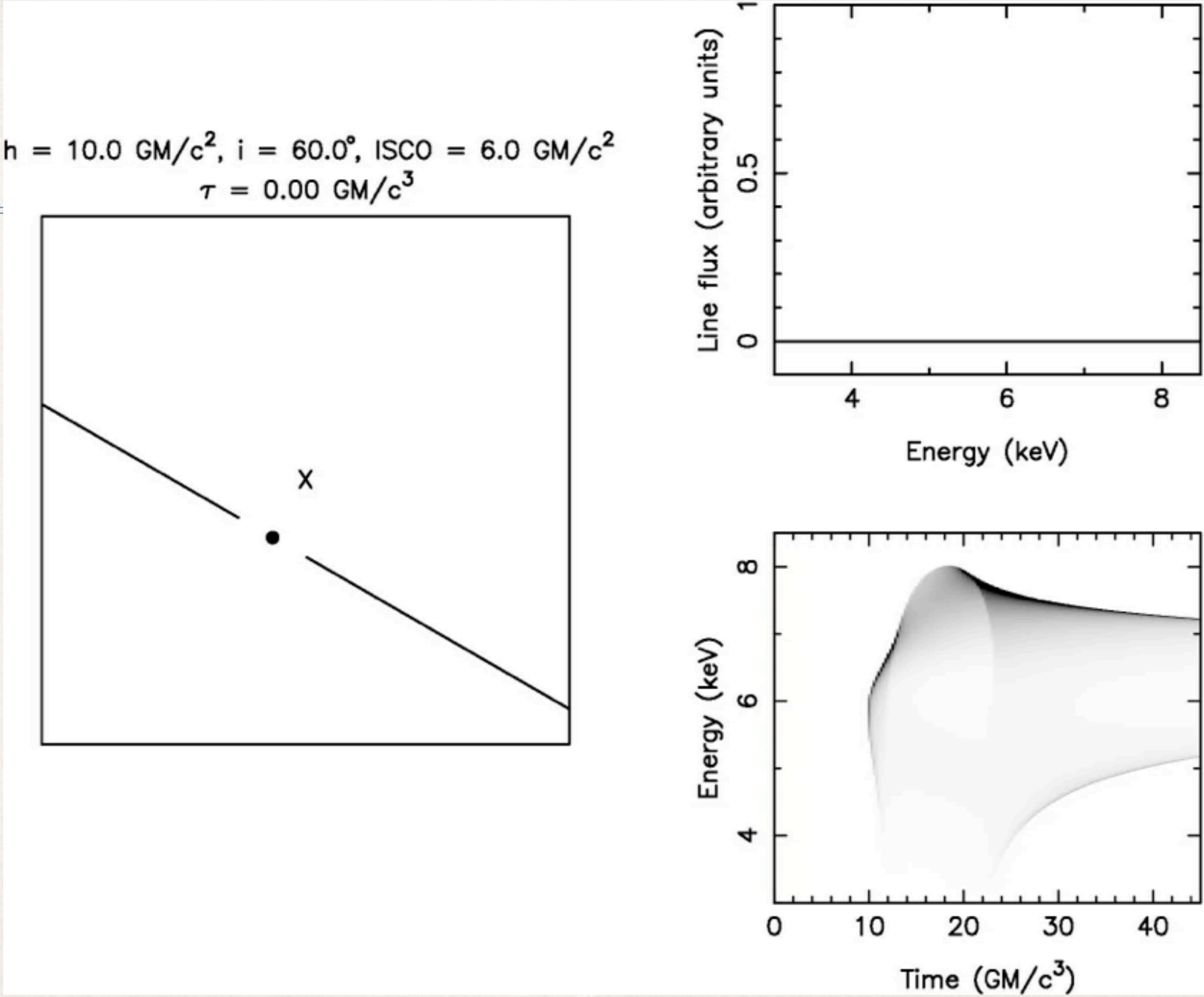
Reflected

Time-resolved Fe K emission from a disk



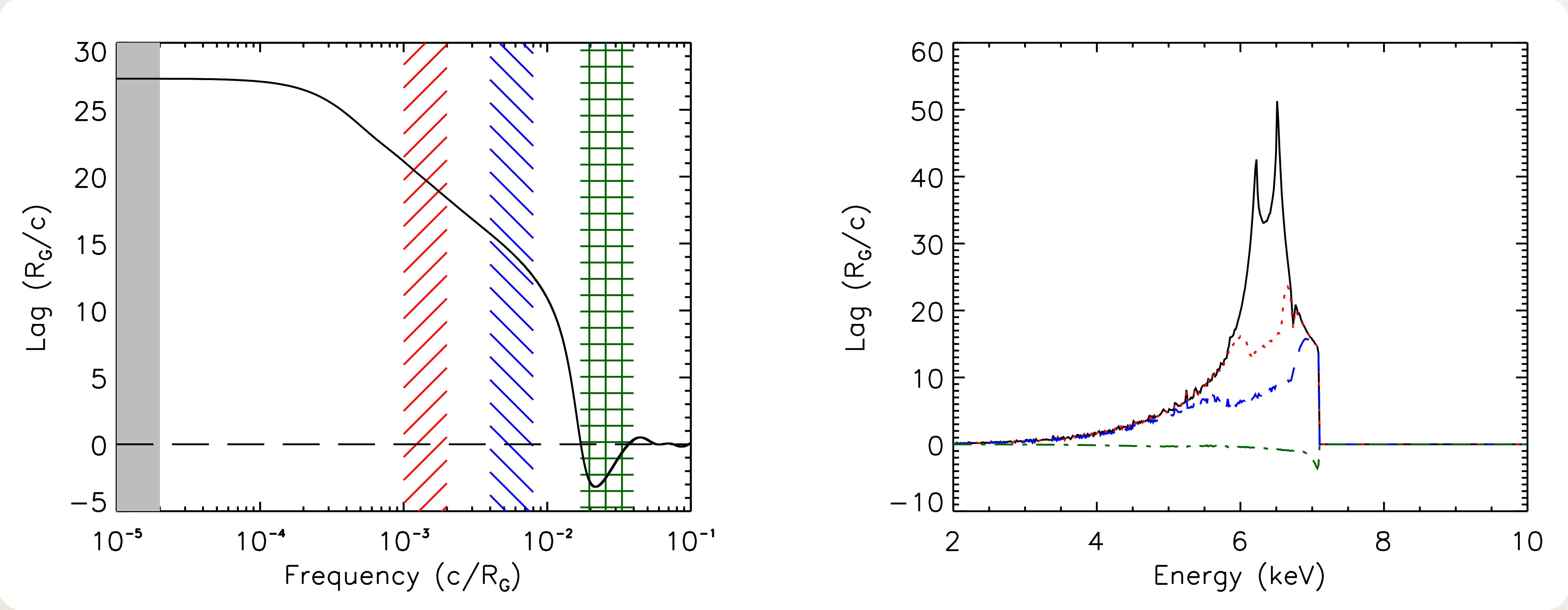
$h = 10\ R_G$,
$i = 45$ deg,
$a = 0.998$


h = 10.0 GM/c², i = 5.0°, ISCO = 6.0 GM/c²
τ = 0.00 GM/c³
X
Line flux (arbitrary units)
0
0.5
1
3
4
5
6
7
Energy (keV)
Energy (keV)
3
4
5
6
7
0
10
20
30
40
Time (GM/c³)


h = 10.0 GM/c², i = 60.0°, ISCO = 6.0 GM/c²
τ = 0.00 GM/c³
X
Line flux (arbitrary units)
0
0.5
1
4
6
8
Energy (keV)
Energy (keV)
4
6
8
0
10
20
30
40
Time (GM/c³)

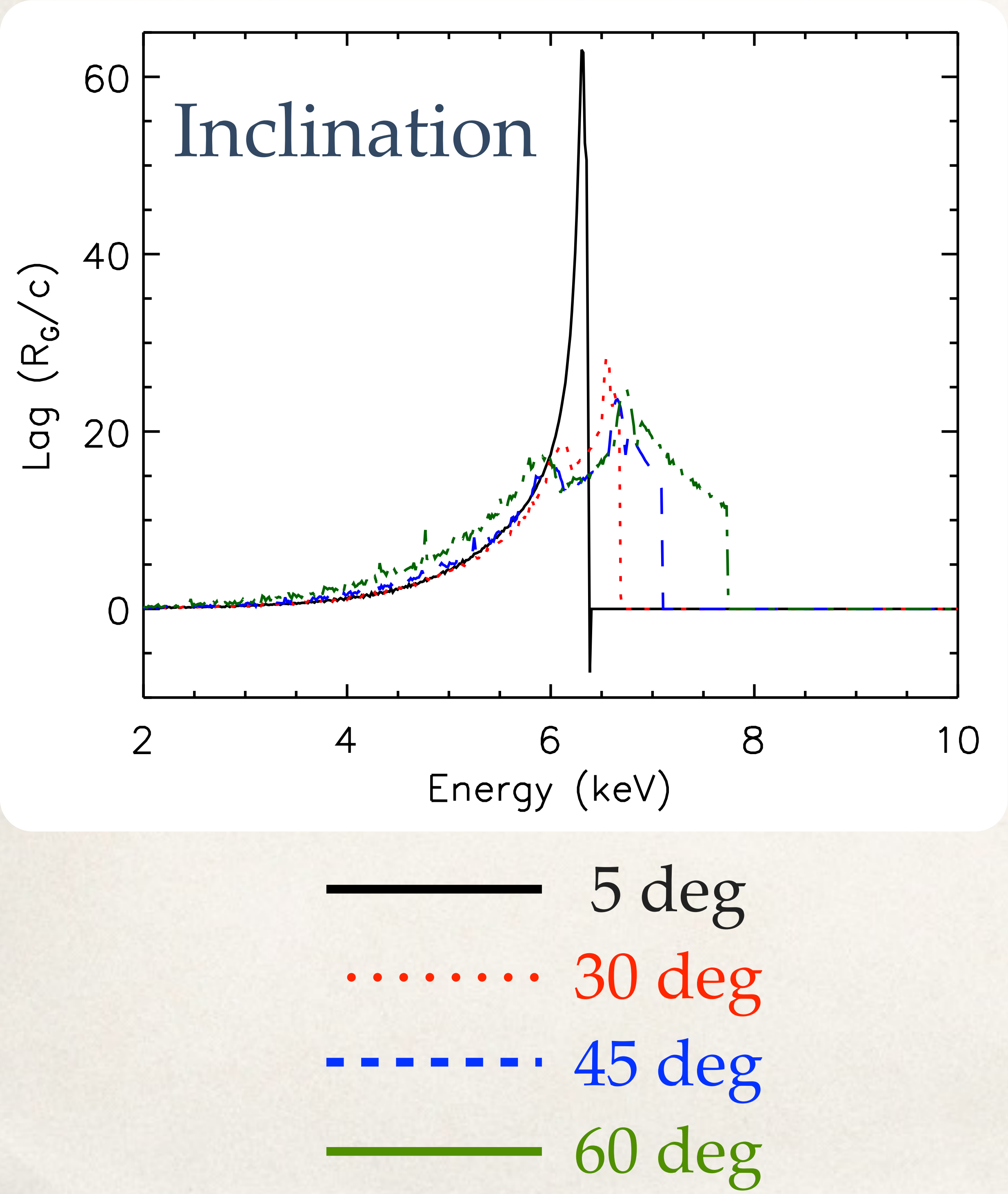
Frequency and energy dependence of lag

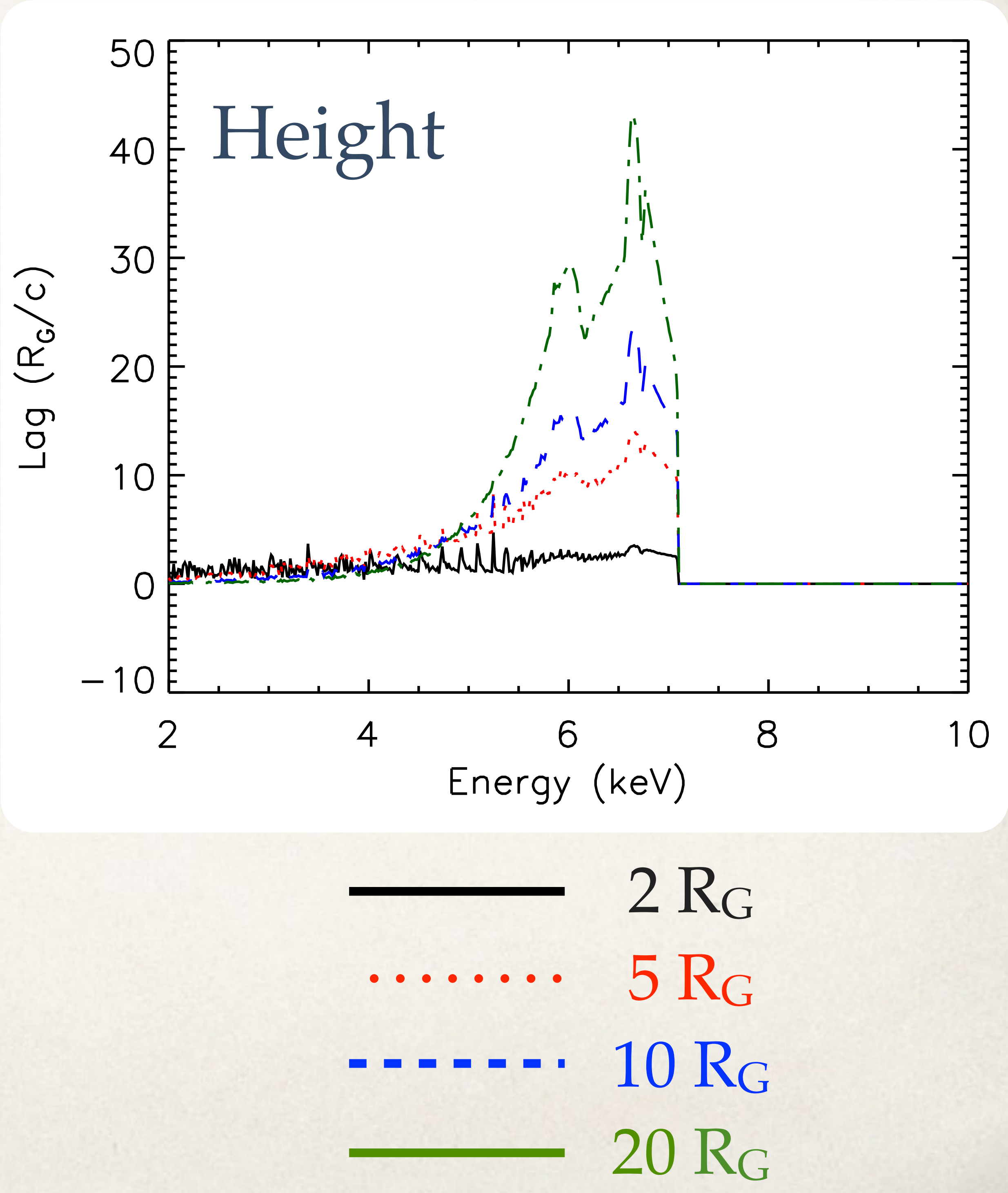
- Fe K lag you see depends on the frequency you look at
- High frequencies filter against the largest size-scales



Cackett+14

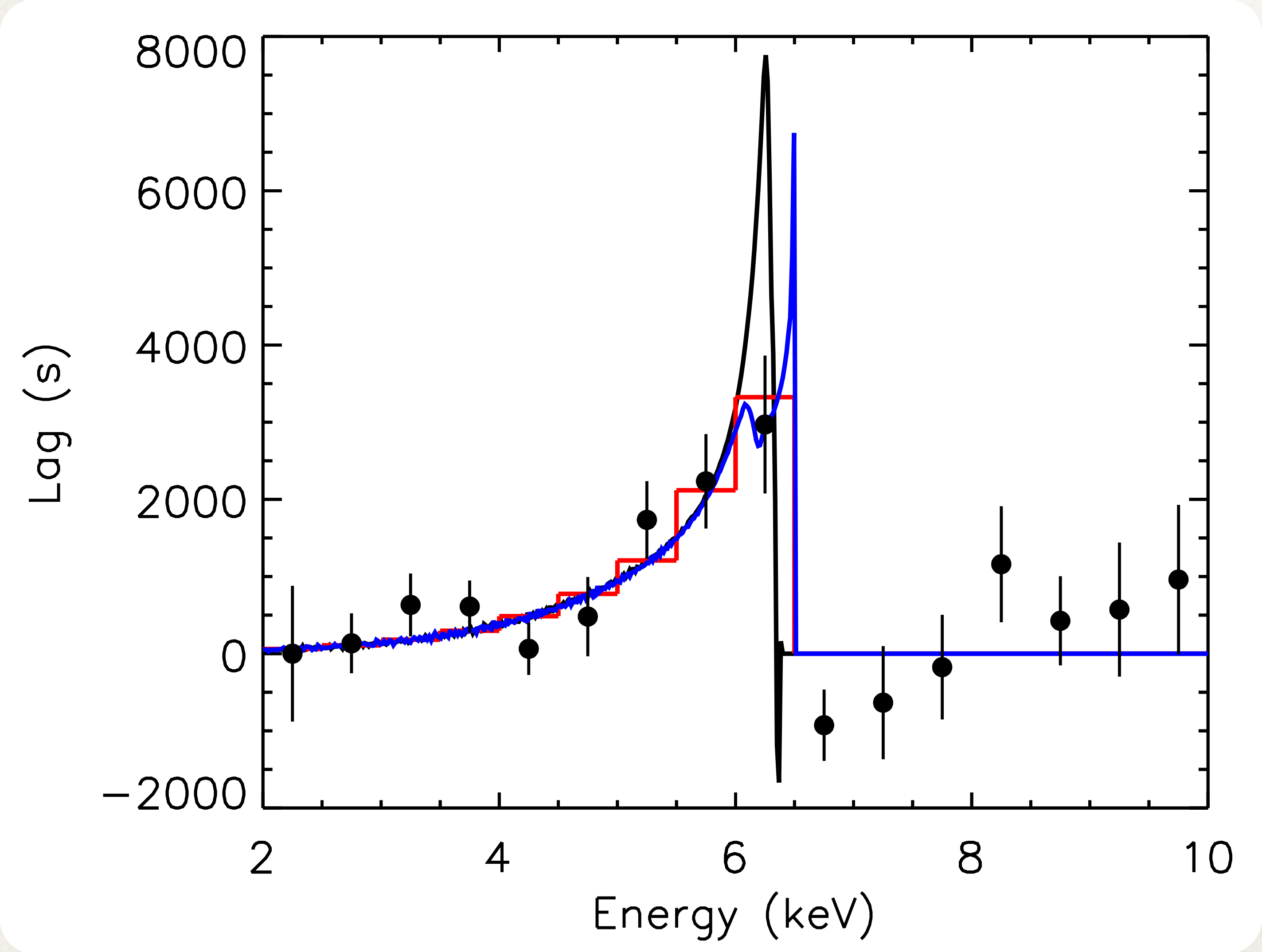
Dependence on geometry





Fitting NGC 4151

- We assume optical reverberation mapping mass, $M = 4.6 \times 10^7 M_\odot$
- Best-fit: X-ray source at height 7 ± 3 R_G above the black hole
- Low inclination required by zero lag above 6.5 keV

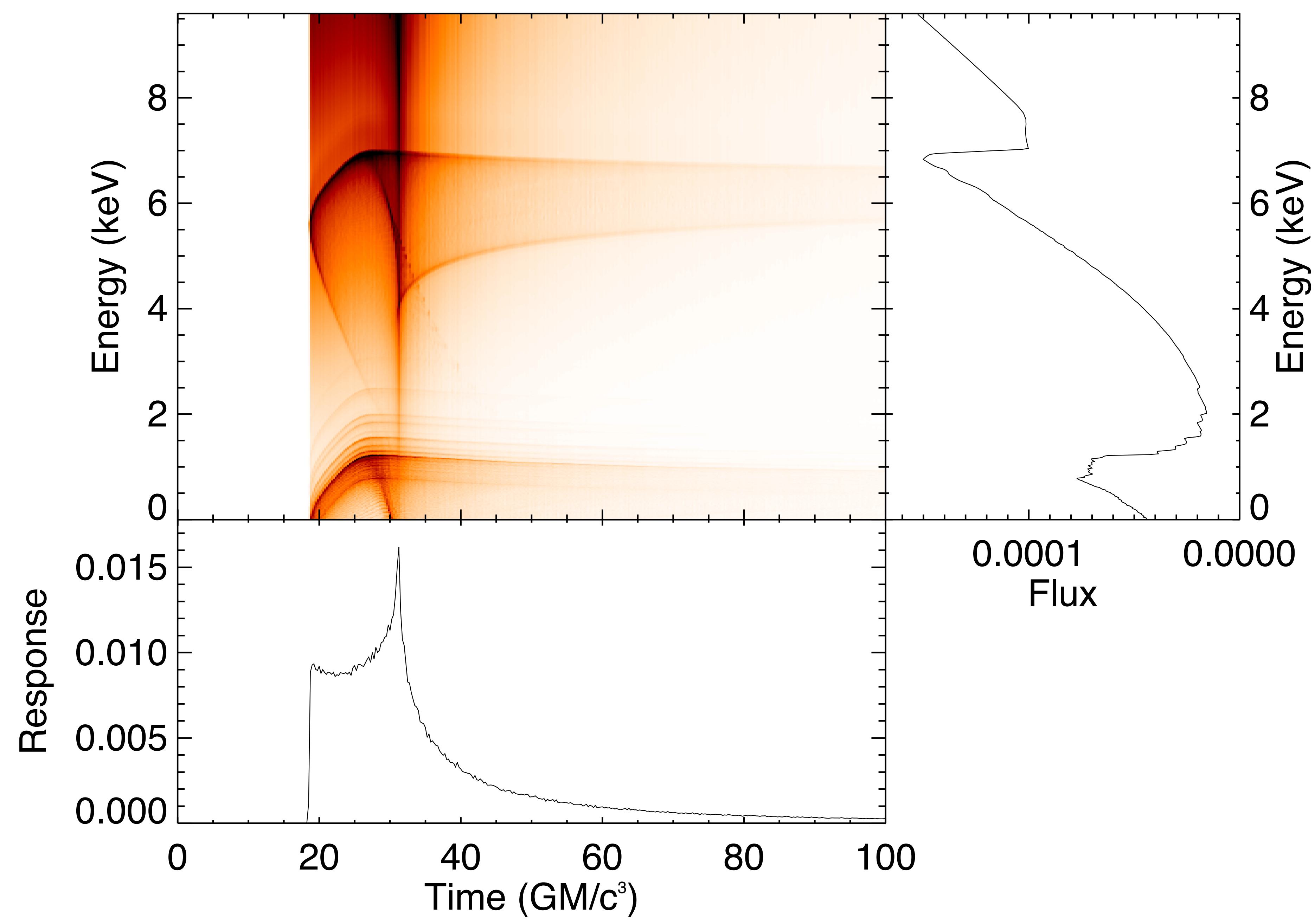


i = 5 deg

i = 20 deg

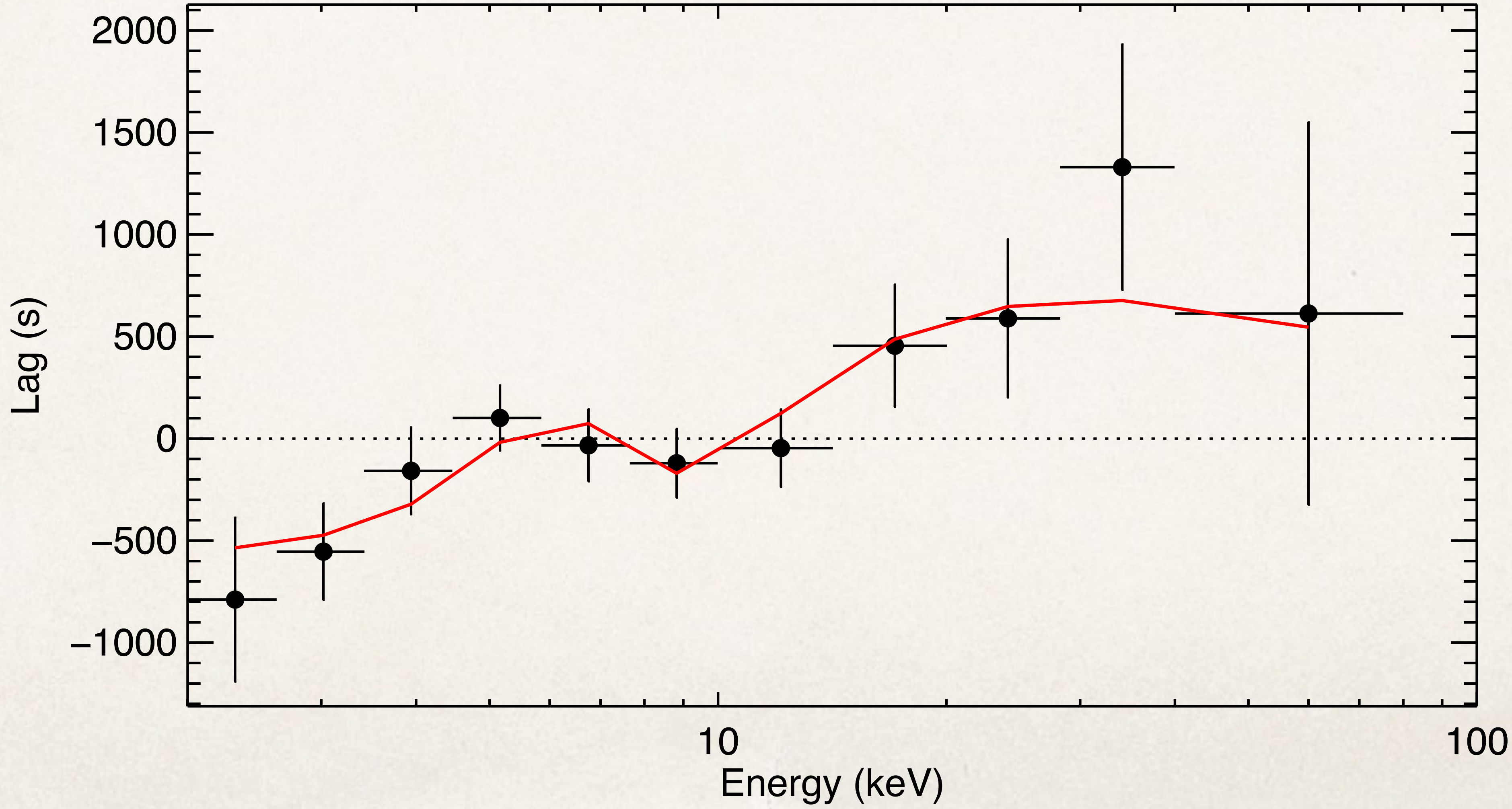
Cackett+14

Including full reflection (not just Fe K)



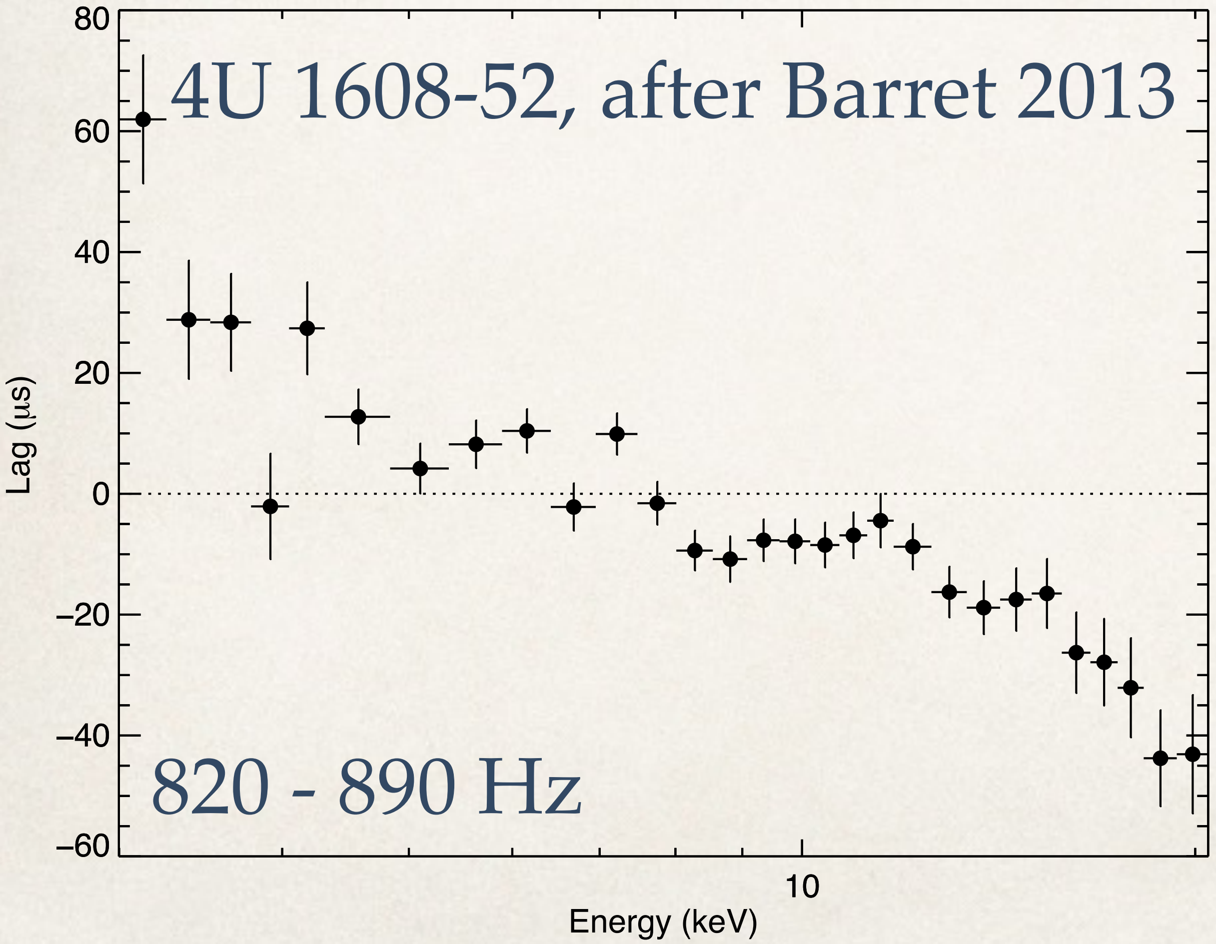
MCG-05-23-16

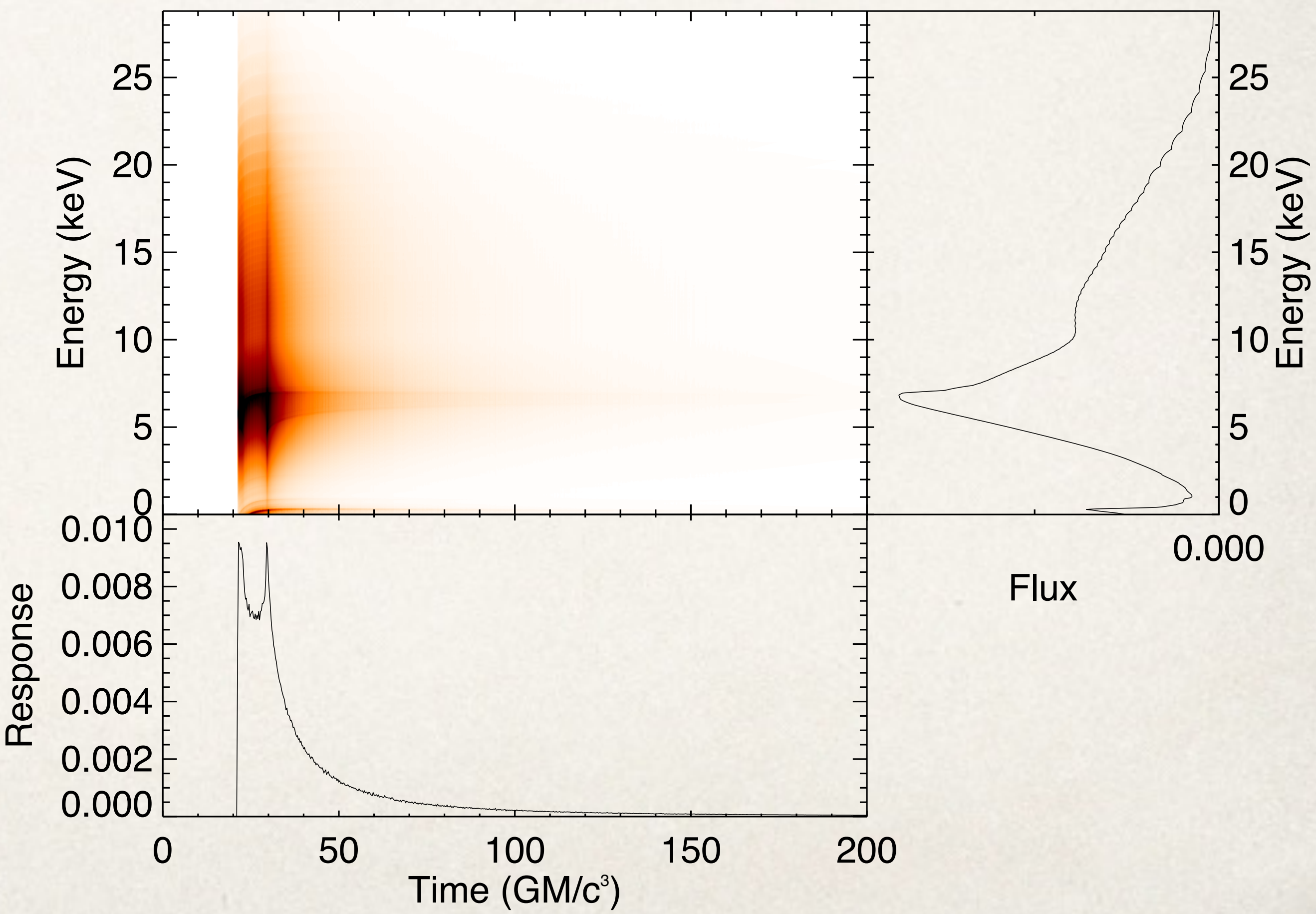
- Fe K lag (Zoghbi+2013) and Compton hump lag with NuSTAR (Zoghbi+2014)
- Preliminary look at reflection model fits well (h = 10 R_g)



Lags in neutron stars

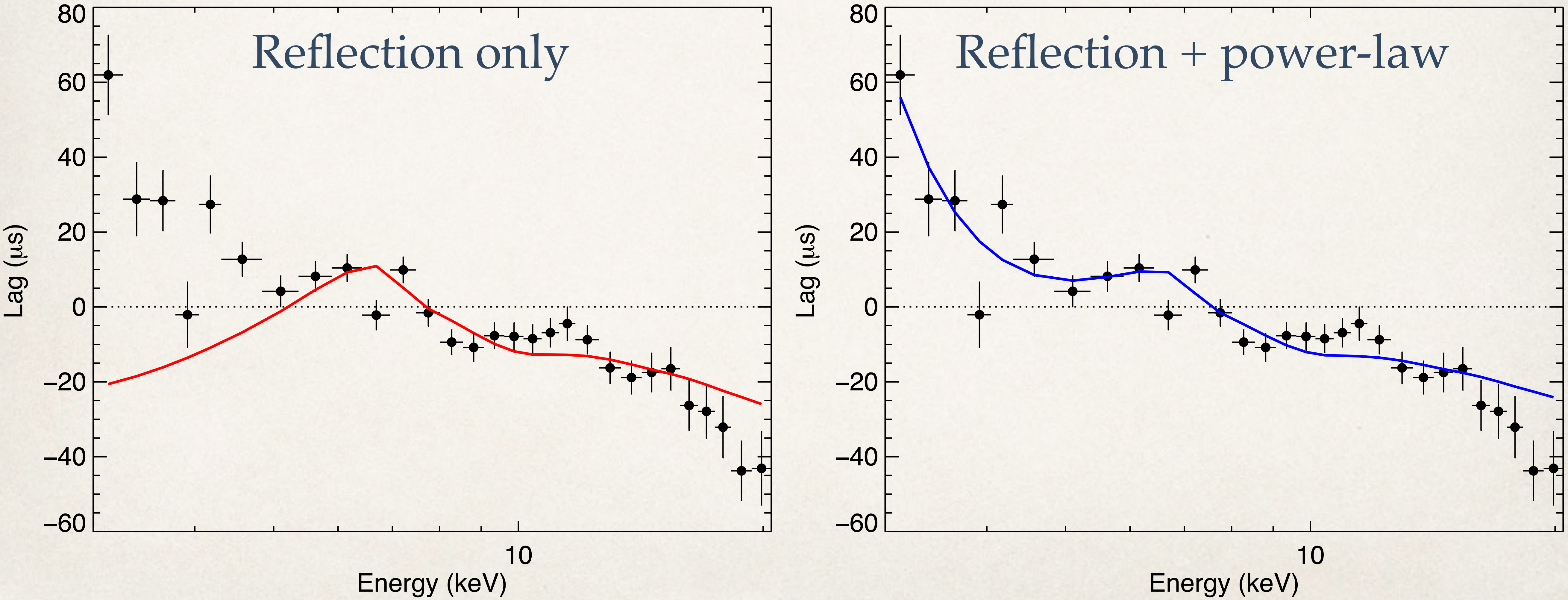
- Barret (2013) reported possible reverberation in neutron star LMXB 4U 1608-52, looking at lower kHz QPO lags
- Are they consistent with reverberation?
- Convolve TF with best-fitting reflection model (irradiated by blackbody)





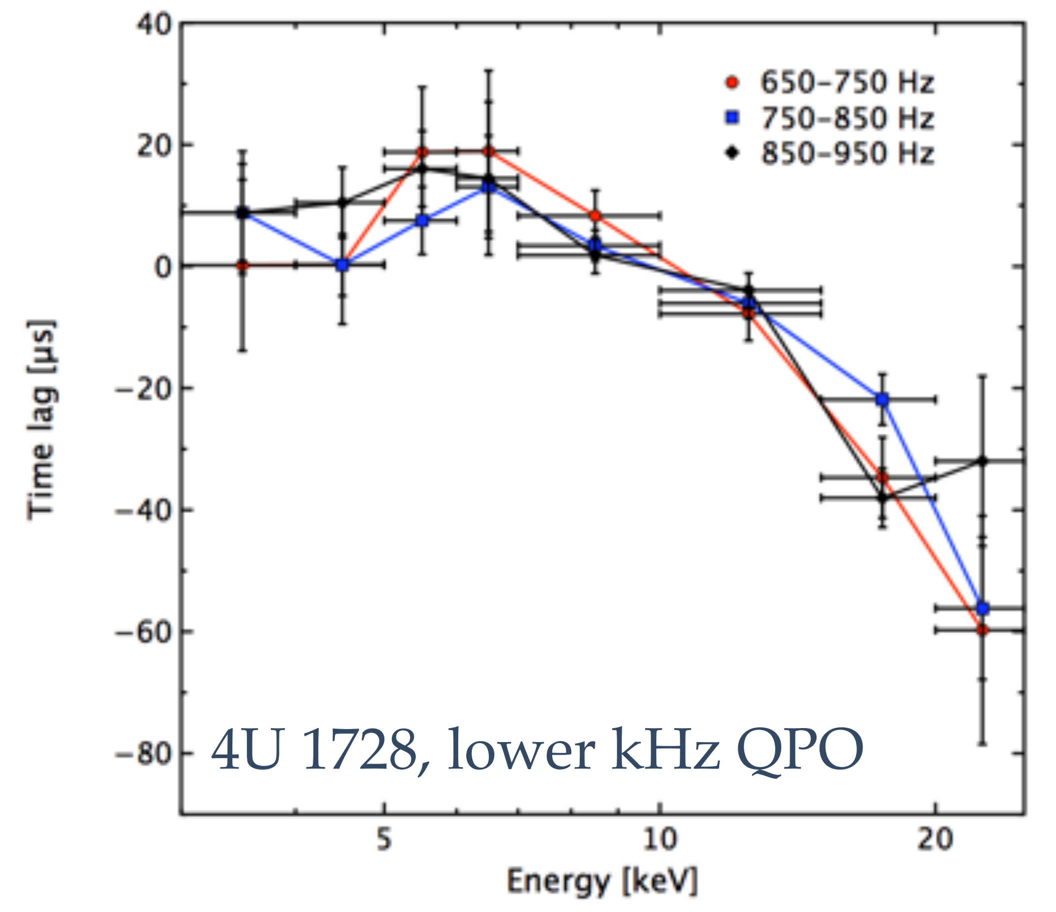
Does the model fit?

- Reverberation only provides poor fit
- Including intrinsic power-law lags does better, but still poor fit above 10 keV

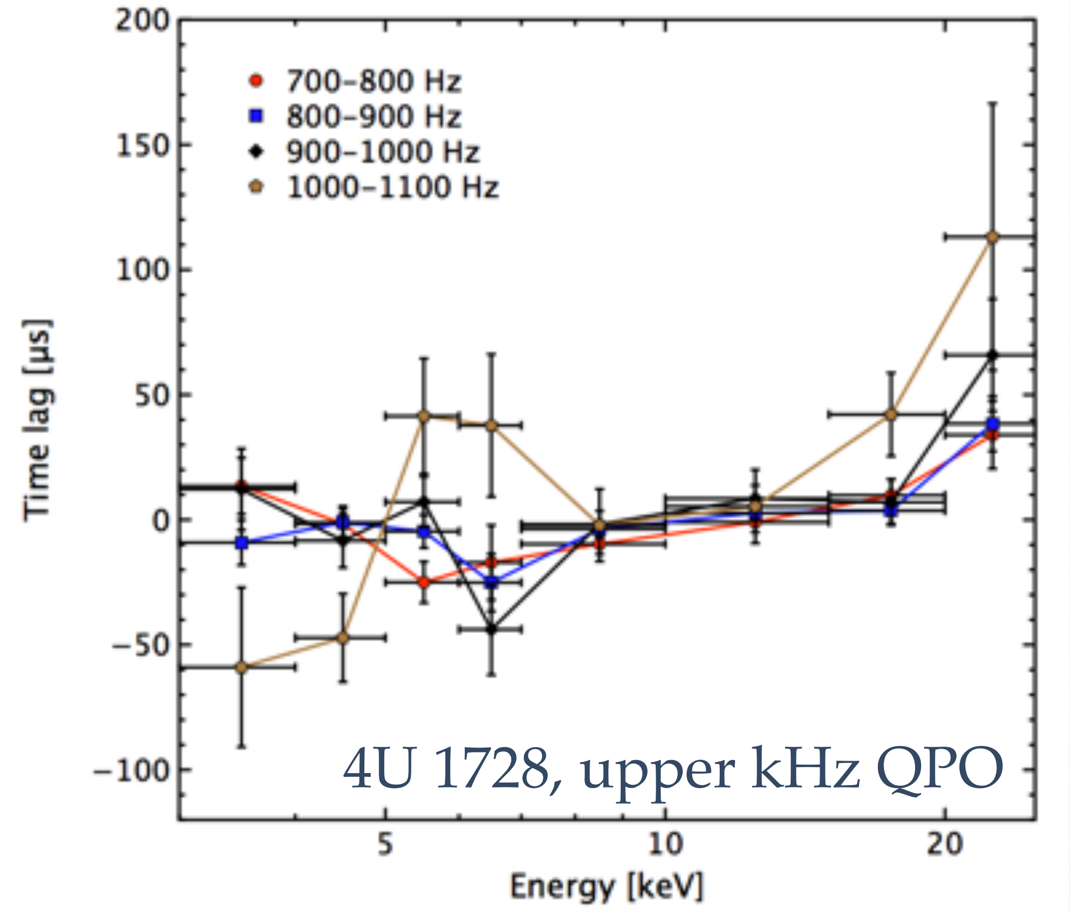


Reverberation may be in upper kHz QPO

- Reflection models predict flatter lags than seen in 4U 1608-52
- This is more consistent with results when looking at both the upper kHz QPOs in 4U 1728-34 (Peille, Barret & Uttley 2015)



4U 1728, lower kHz QPO



4U 1728, upper kHz QPO

Summary

- Fe Kα lags now detected in a handful of AGN
- Energy and frequency dependence of lags depends on geometry and kinematics of the region
- Fitting Fe Kα lag in NGC 4151 we imply a **compact corona**
- *Lots more to do:*
    - more full reflection spectrum fitting (not just Fe Kα line)
    - extended corona models