Measuring strong field gravity effects in AGN observed with LOFT

Alessandra De Rosa

INAF/Institute for Space Astrophysics and Planetology

Outline

- **LOFT**: Large Observatory For X-ray Timing

  LAD background knowledge: scientific constraints

- **BH diagnostic**

  1. **Phase resolved spectroscopy of the iron line**
     - ✓ **Step 1**: WARNING Models: absorption vs reflection

       IF Reflection is the right answer ..
     - ✓ **Step 2**: The broad relativistic "average" Fe line (disc line): measuring the spin
     - ✓ **Step 3**: iron line from hot spot around SMBH (HS line): measuring the mass
  2. **Reverberation:** measuring the lag and distance

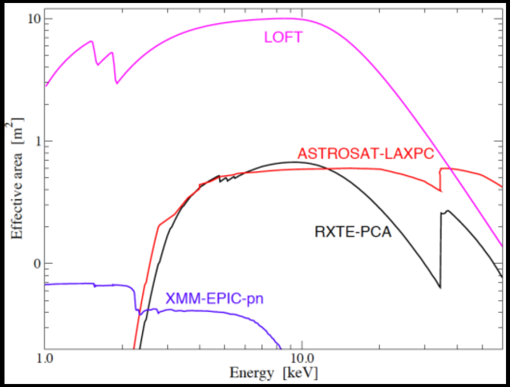
- **Conclusions and future**

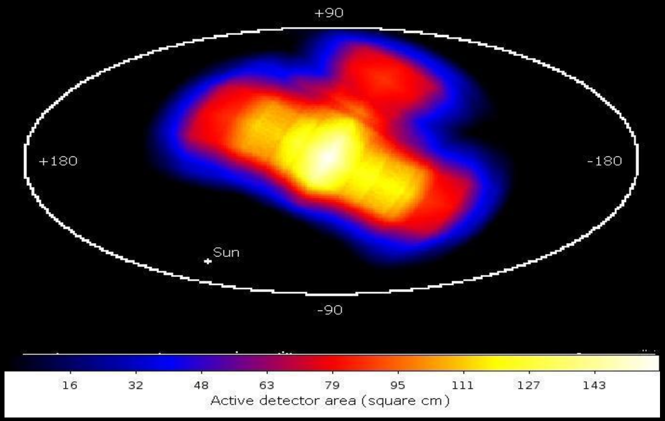
LOFT
Large Observatory For x-ray Timing

A mission proposal selected by ESA
as a candidate Cosmic Vision M3 mission
devoted to X-ray timing
and designed to investigate
the space-time around collapsed objects

ESA Member States currently involved in the payload development:
Czech Republic, Denmark, Finland, France, Germany, Italy, Netherlands, Poland, Spain, Switzerland, United Kingdom

The LOFT Instruments (today)





LAD – Large Area Detector

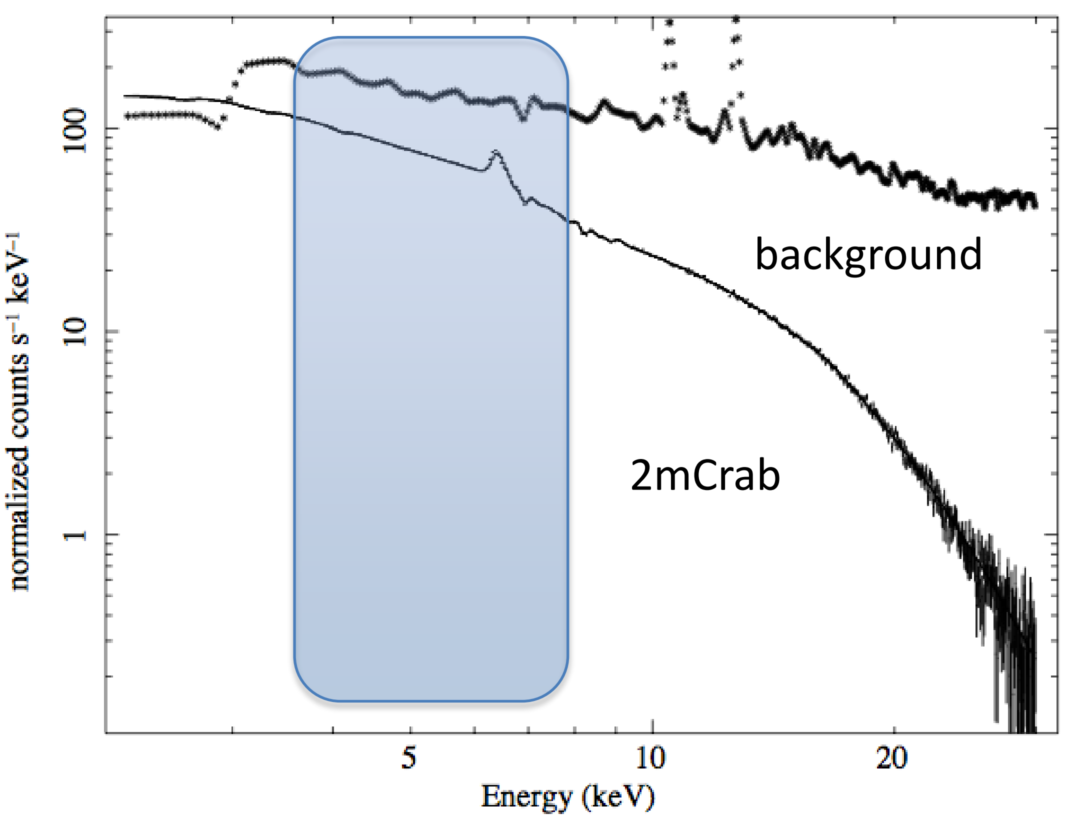
Effective Area	4 m^2 @ 2 keV 8 m^2 @ 5 keV 10 m^2 @ 8 keV 1 m^2 @ 30 keV
Energy range	2-30 keV primary 30-80 keV extended
Energy resolution FWHM	260 eV @ 6 keV 200 eV @ 6 keV (45% of area)
Collimated FoV	1 degree FWHM
Time Resolution	10 μs
Absolute time accuracy	1 μs
Dead Time	<1% at 1 Crab
Background	<10 mCrab (<1% syst)
Max Flux	500 mCrab full event info 15 Crab binned mode

WFM- Wide Field Monitor

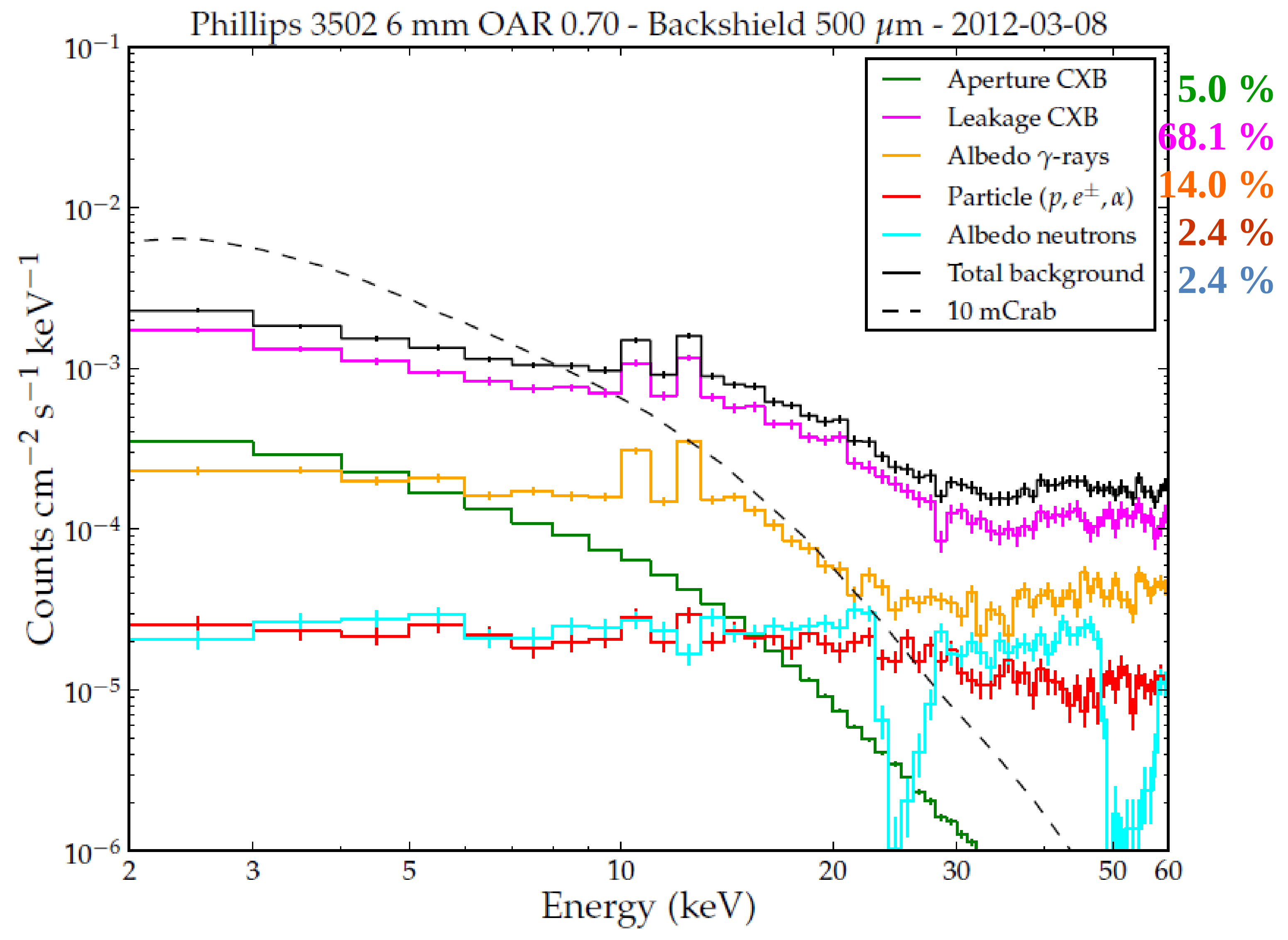
Energy range	2-50 keV primary 50-80 keV extended
Active Detector Area	1820 cm^2
Energy resolution	300 eV FWHM @ 6 keV
FOV (Zero Response)	180°x90° + 90°x90°
Angular Resolution	5’ x 5’
Point Source Location Accuracy (10-σ)	1’ x 1’
Sensitivity (5-σ, on-axis) Galactic Center, 3 s Galactic Center, 1 day	 270 mCrab 2.1 mCrab
Standard Mode	5-min, energy resolved images
Trigger Mode	Event-by-Event (10μs res) Realtime downlink of transient coordinates

The LAD background

- How accurately we know the total bkg ?
- How/how much variable are the bkg components (Orbital phase)?



LAD Background modelling



5.0 %
68.1 %
14.0 %
2.4 %
2.4 %

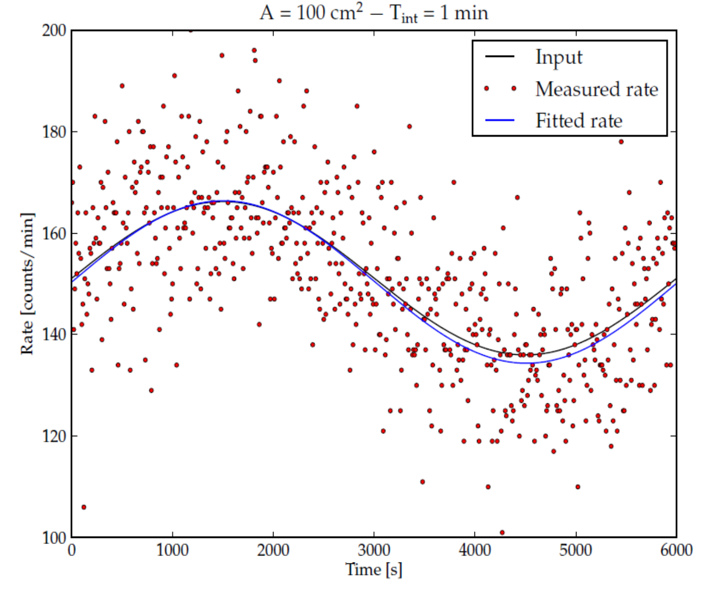
LAD Background modelling

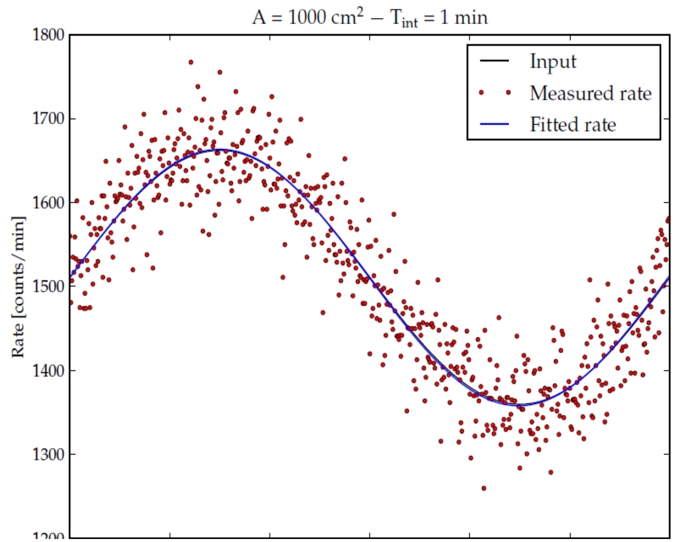
- 82% of the LAD background is due to CXB and Albedo photons leaking through the collimator walls; 8% due to ^{40}K radioactivity; additional 4.8% is due to particles and albedo neutrons: <u>92% of the LAD background is due to “mass effects”</u>
- Residual bkg (5%) due to CXB.
- Expected largest background variability (<20%) due to the geometrical combination of “intrinsically stable” CXB and Albedo (total of 82%): a geometrical model describing the satellite position and orientation in this “stable” environment will account for the detected variation.
- The variation is smooth, on the orbital timescale.

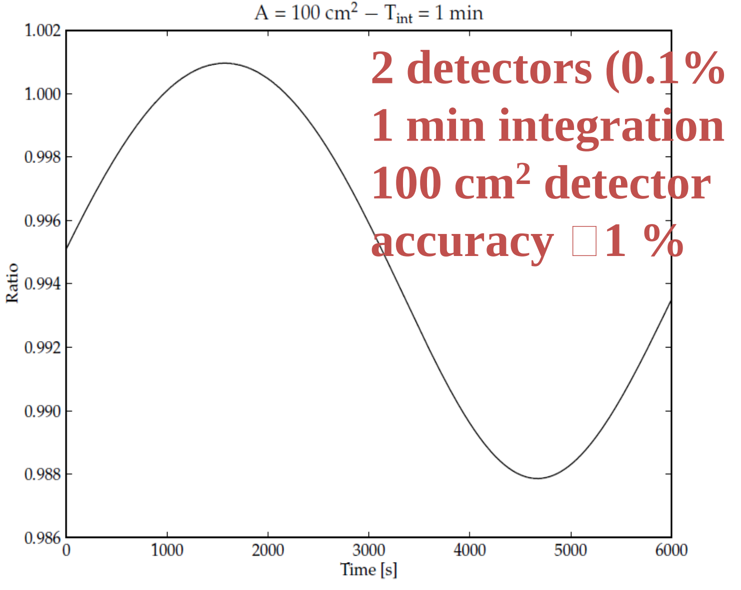
Active Background monitoring

- As the largest variable bkg component is "mass-driven", a mass-representative blocked collimator will be able to follow the smooth variations of the largest fraction of the overall background (leakage+particles+albedo=87%). The rest is stable (aperture+radioactivity).
- SDDs covered with a closed collimator (no open channels) of reduced thickness (same mass per unit surface) will receive the same leakage background as "real" SDDs.
- We can use these "blocked" detectors to monitor the background variability and support its geometrical modeling; variation is smooth along the orbit, allowing for a minute-scale integration times.
- A trade-off between required accuracy for background modelling and area of these "blocked" detectors is ongoing (subtracted or added to the overall LAD area???).

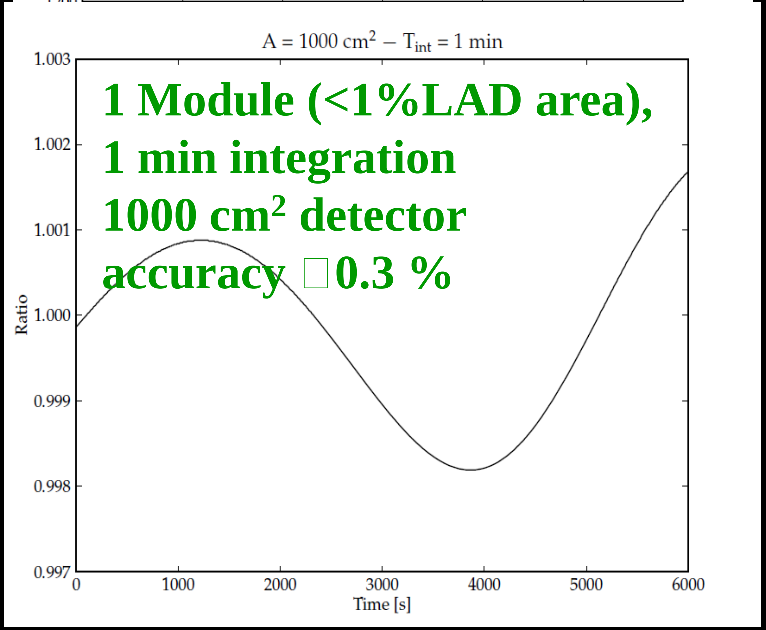
Preliminary simulations on active bkg modelling







2 detectors (0.1% LAD area)
1 min integration
100 cm^2 detector
accuracy □1 %



1 Module (<1%LAD area),
1 min integration
1000 cm^2 detector
accuracy □0.3 %

LOFT-STRONG FIELD GRAVITY

AGNs: Black Hole Diagnostic

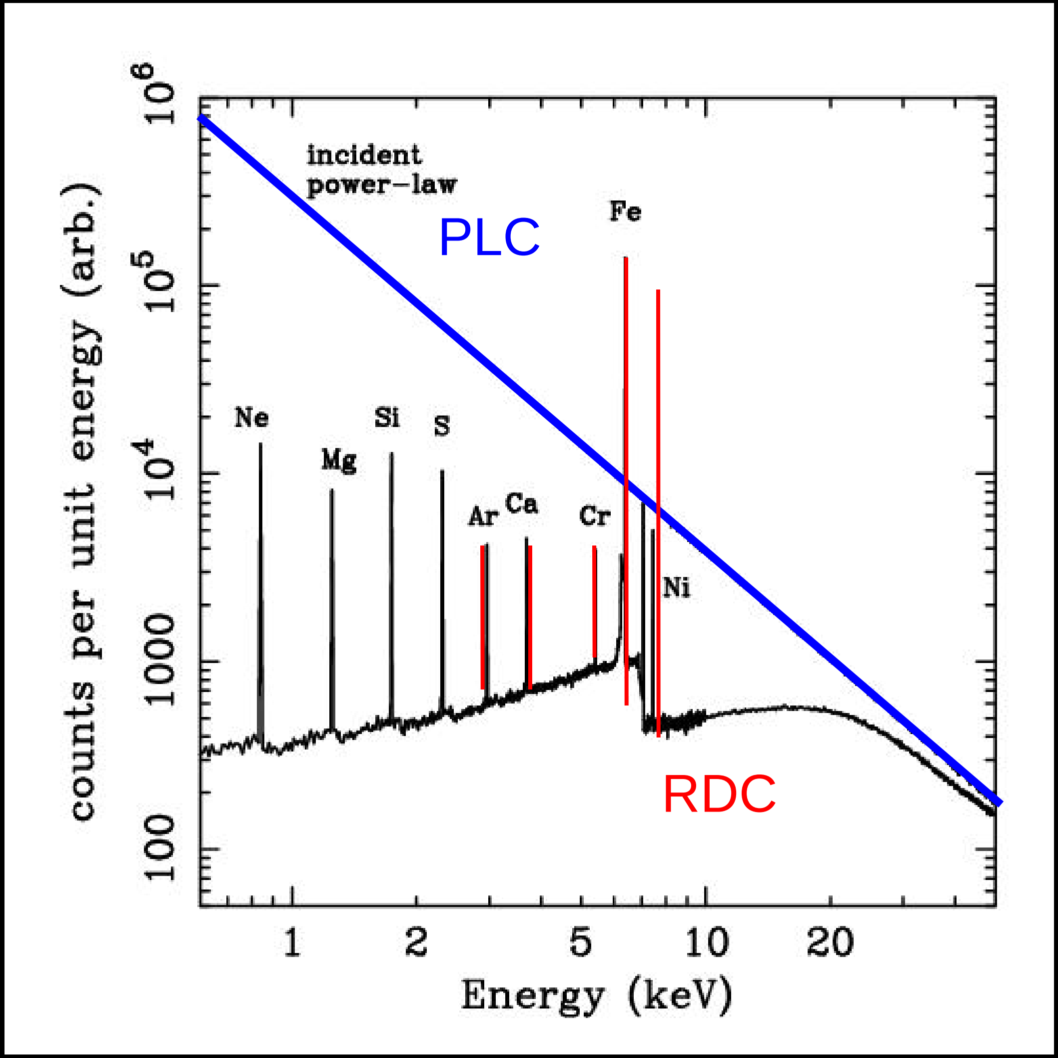
1. Phase resolved spectroscopy
2. Reverberation (credits Phil Uttley)

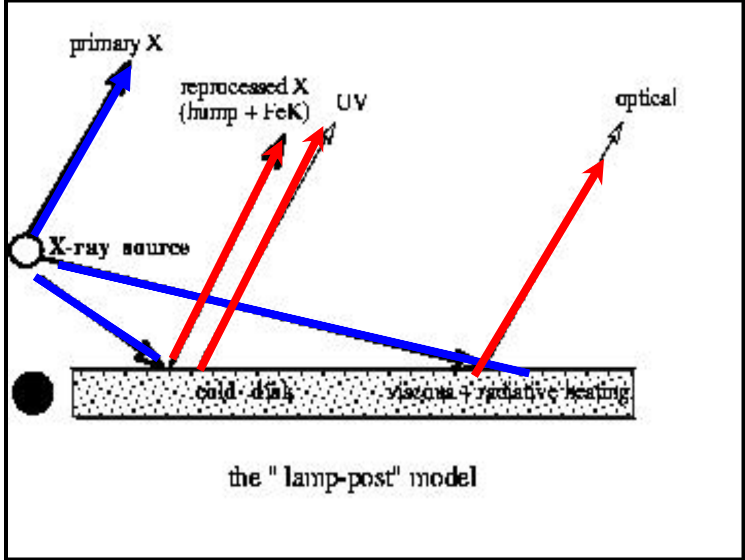
From the LOFT Scientific Requirements Document

SFG5: De Rosa, Fabian, Reynolds, Miniutti, Nowak, Uttley, Matt, ...

Broad Fe Line	**Hot-spot (variable) Fe Line** **Reverberation mapping**
Measure the Fe-line profile of 30 AGN, and carry out reverberation mapping of 8 brightest AGNs, to provide BH spins to an accuracy of 20% of the maximum spin (10% for fast spins)	*Measure AGN masses with 30% accuracy, constraining fundamental properties of supermassive black holes and of accretion flows in strong field gravity*

The X-ray reflection spectrum





the " lamp-post" model

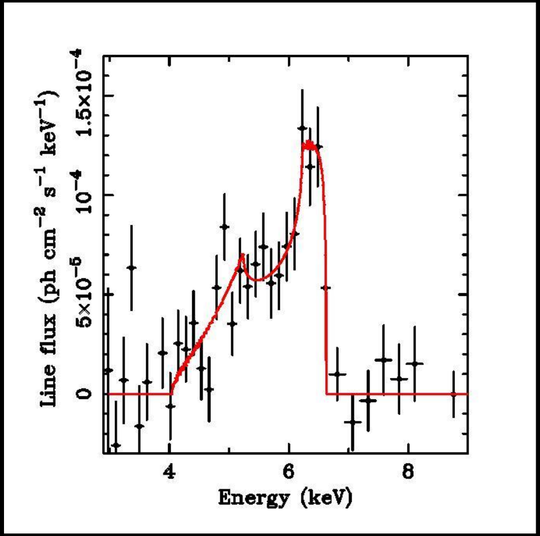
$\propto$ Inclination

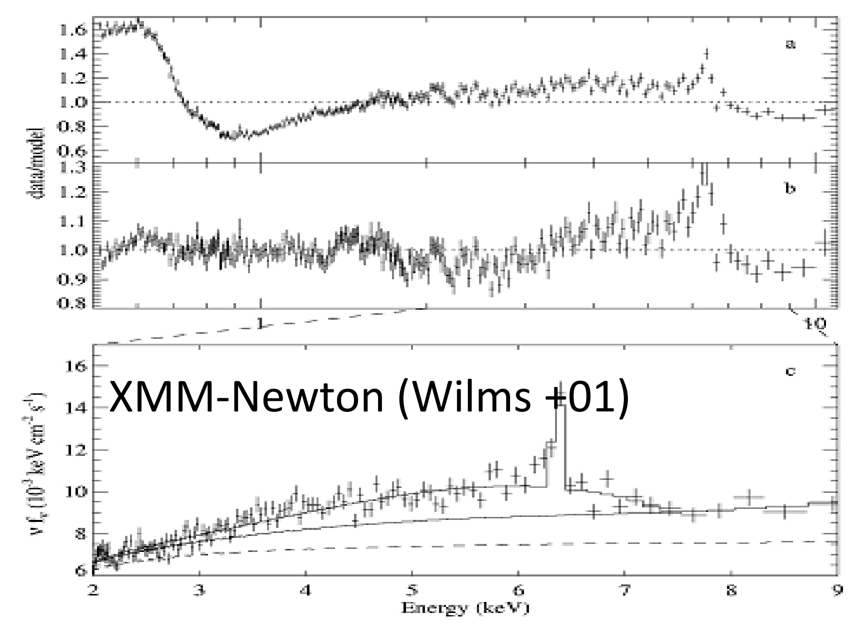
$\propto$ $\Omega/2\Pi$ (coverage, isotropy)

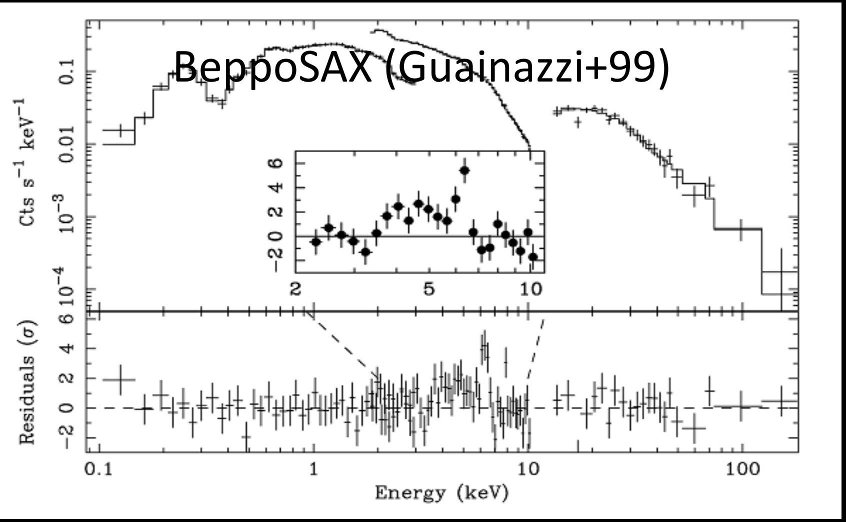
$\propto$ Ab

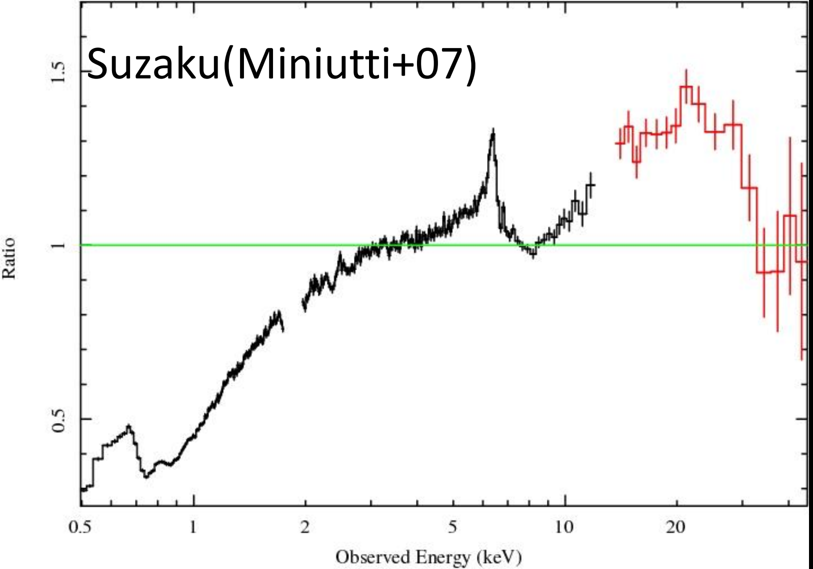
Reynolds 96

THE relativistic Fe line in MCG-6-30-15




XMM-Newton (Wilms +01)


BeppoSAX (Guainazzi+99)


Suzaku(Miniutti+07)

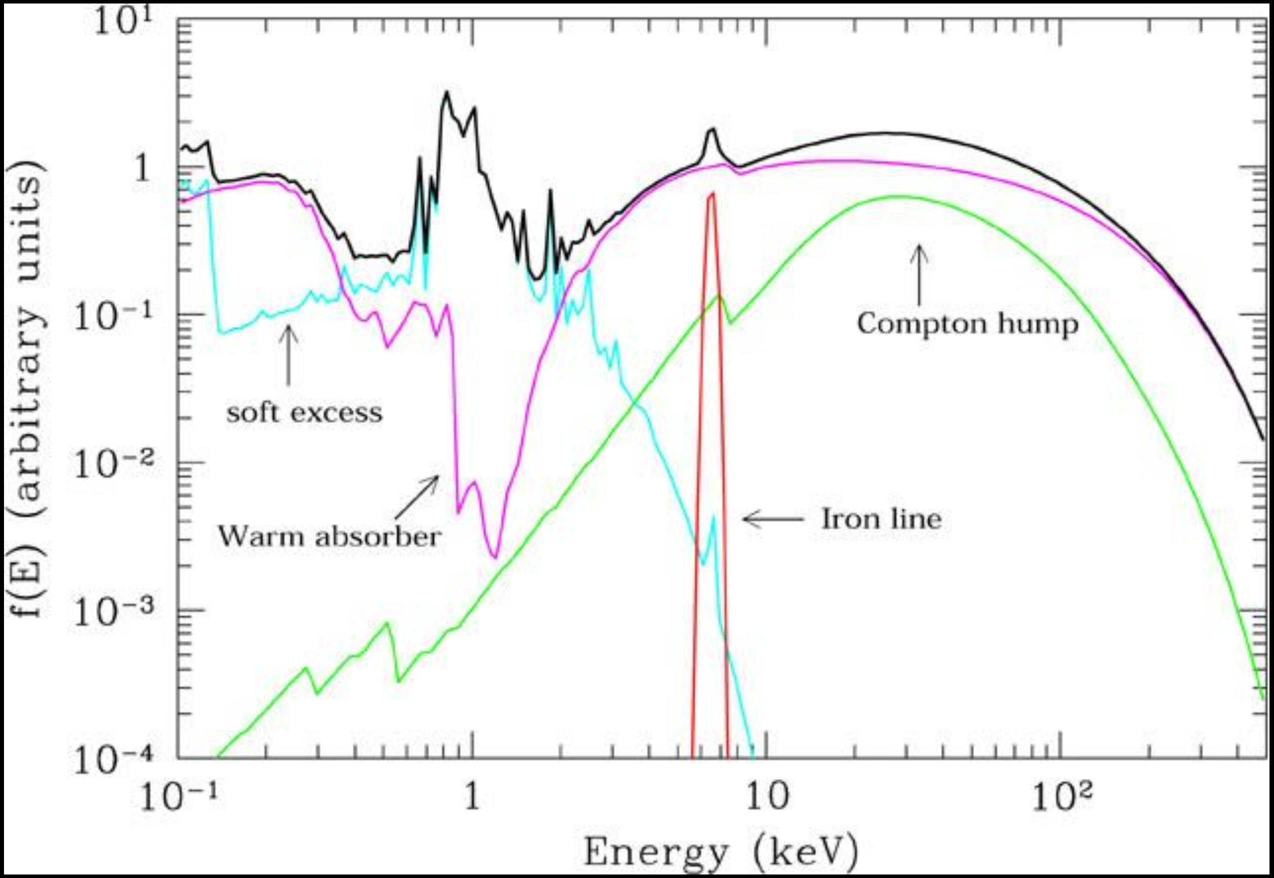
Step 1

Is really the reflection nearby a SMBH the right answer?

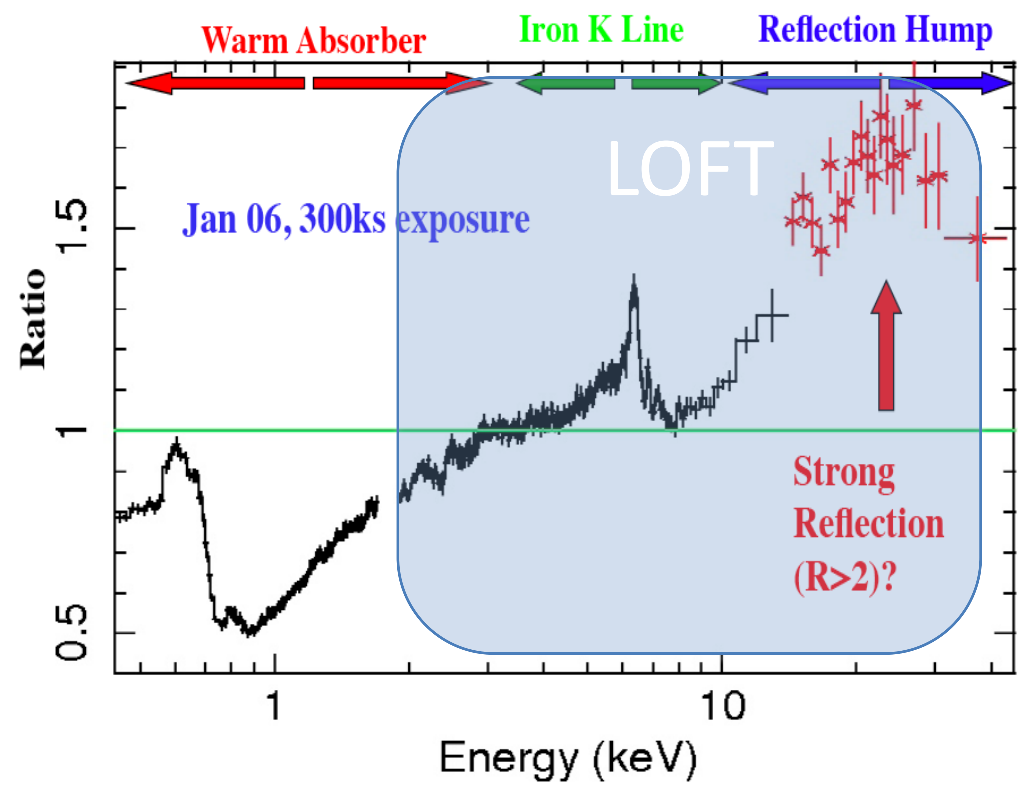
Complex ionized absorption has be proposed as a viable alternative (Miller+08)

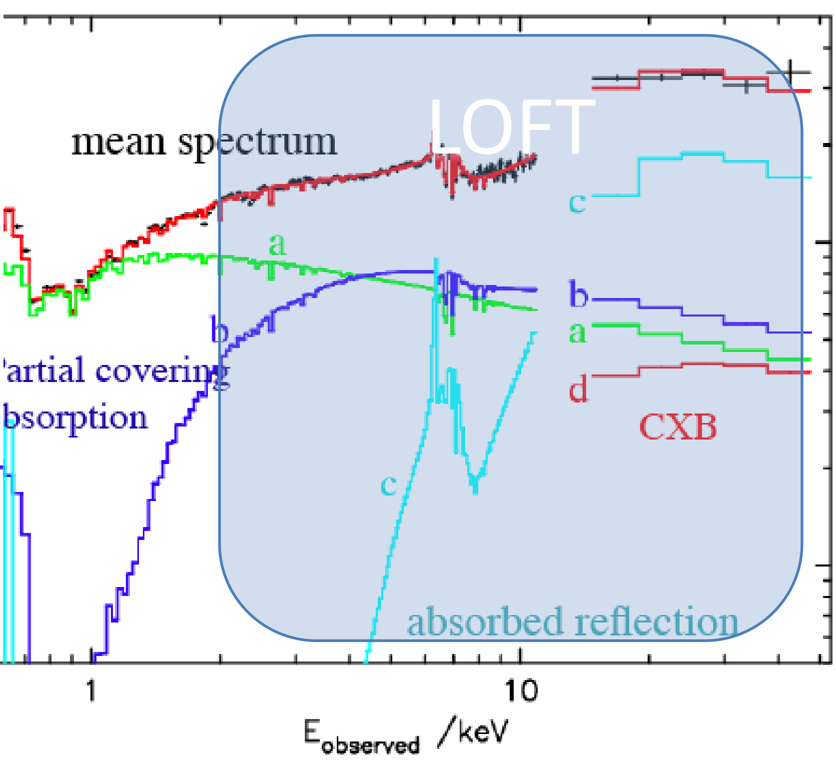
Can we distinguish between the two?

Miniutti vs Miller scenario



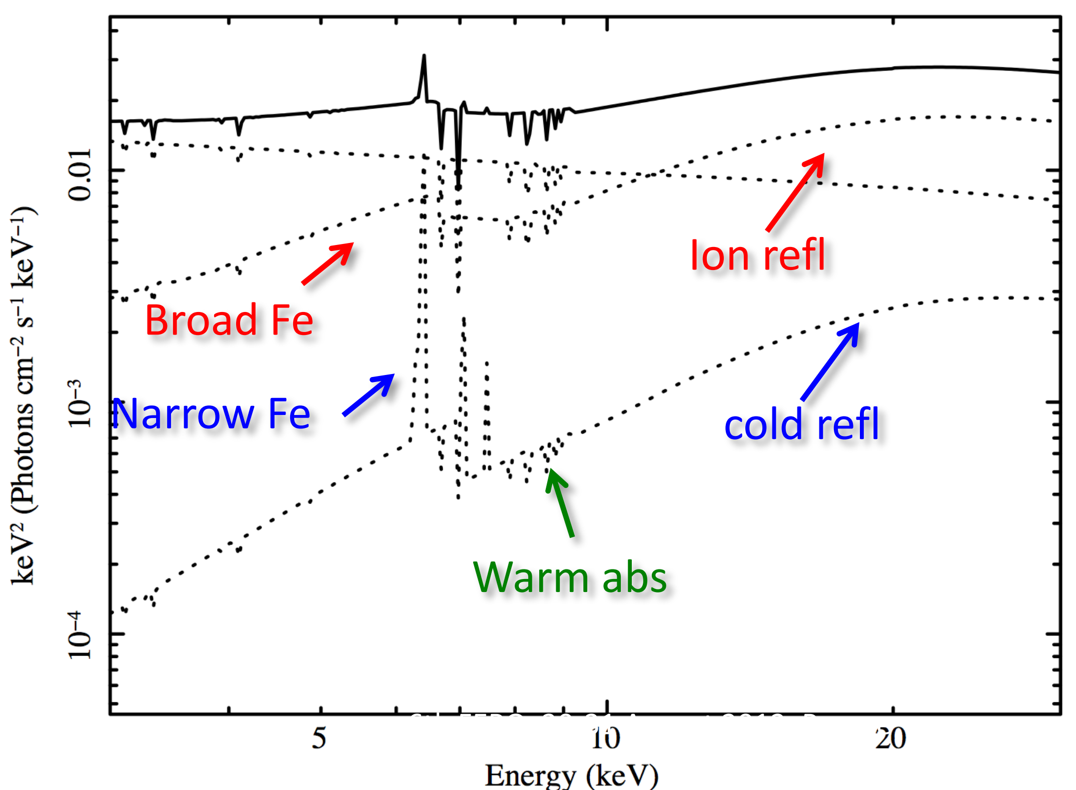
Miniutti vs Miller scenario





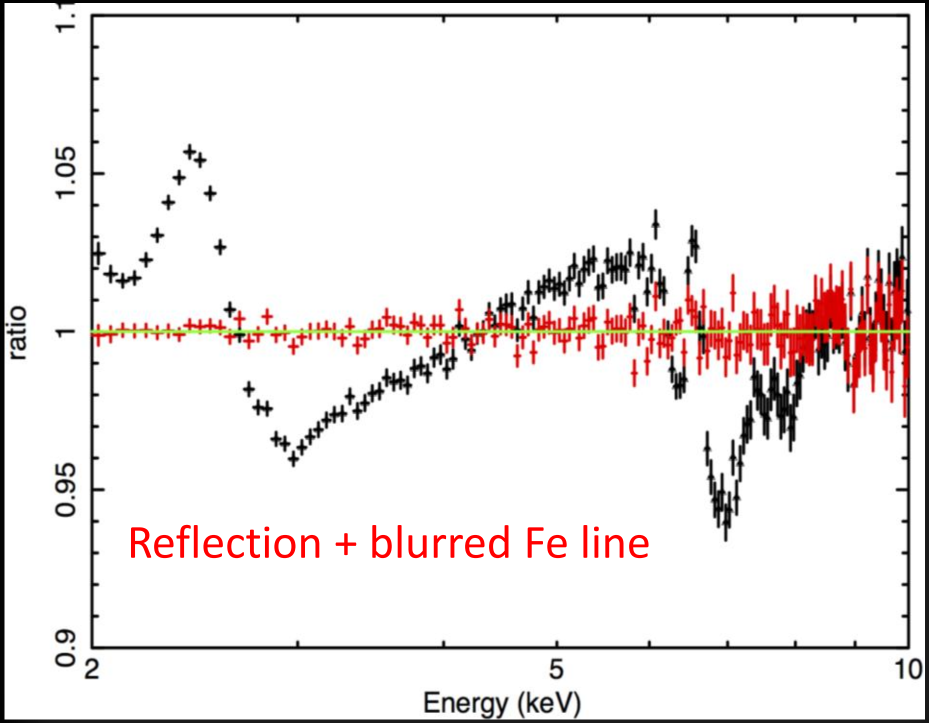
MCG6-30.15: 1 warm absorber+2 reflecting media

	Flux (2-10 keV)	Flux (3-30 keV)
Continuum	3.1e-11	3.7e-11
Ionized refl	1.3e-11	3.5e-11
Cold refl	1.2e-12	4.8e-12



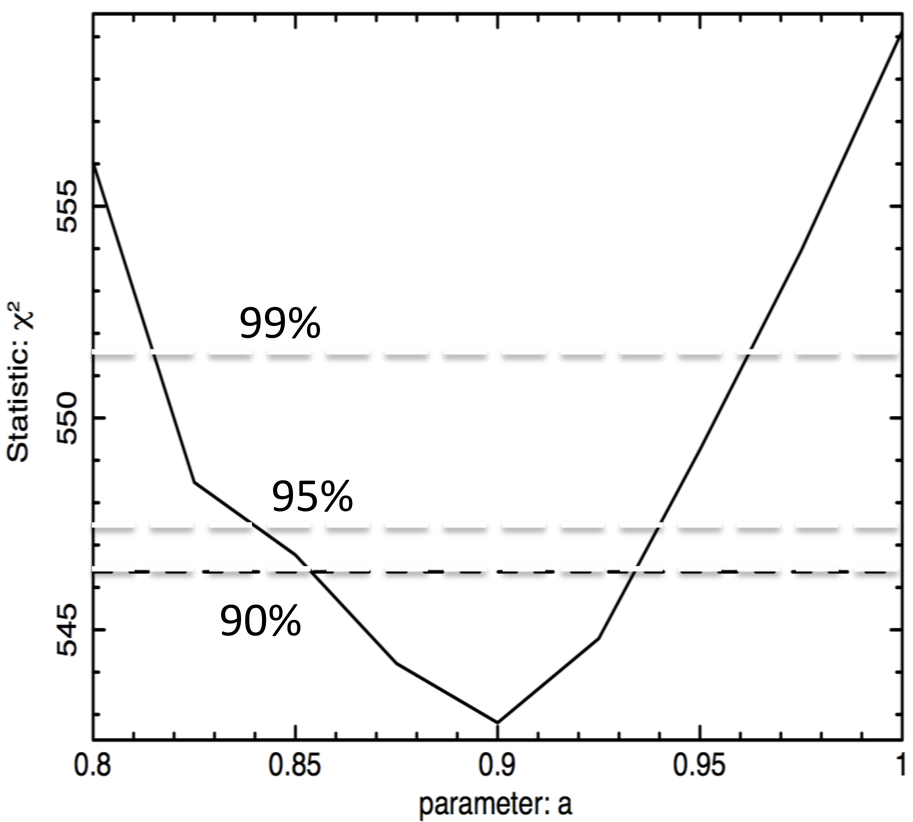
A. De Rosa

Reflection *vs* complex absorption model

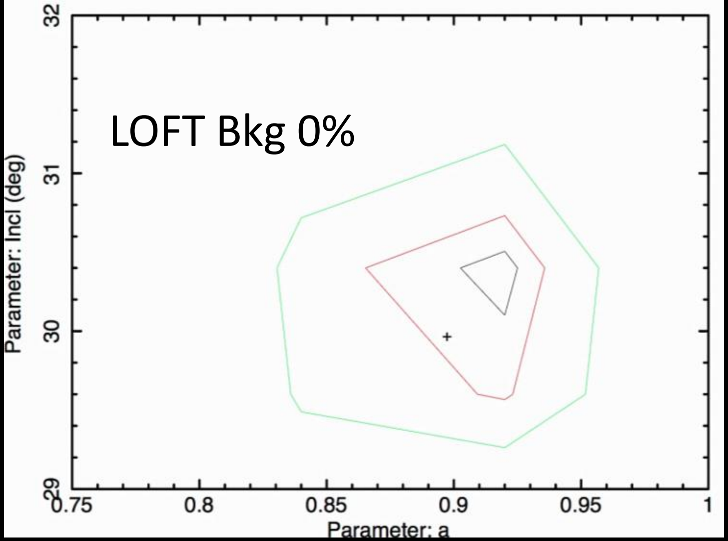


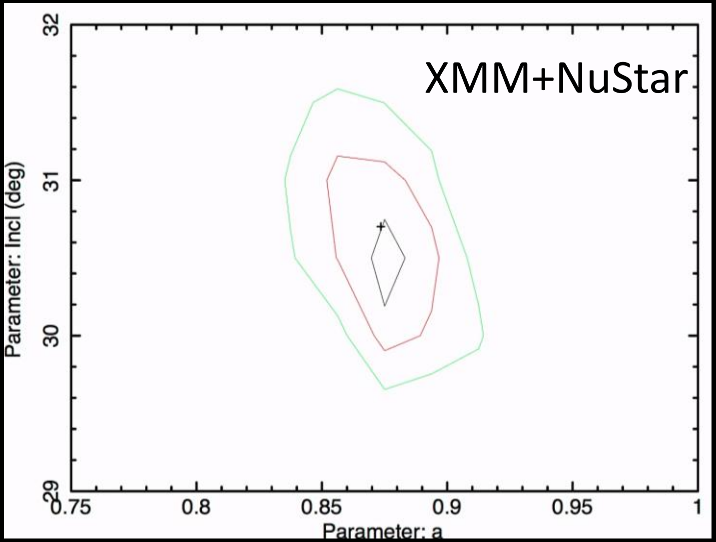
MCG-6-30-15

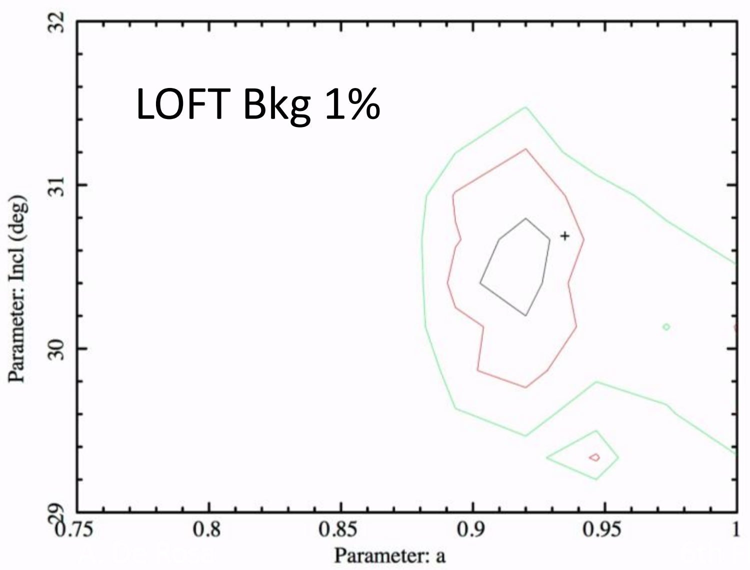
150 ks LOFT simulated observation

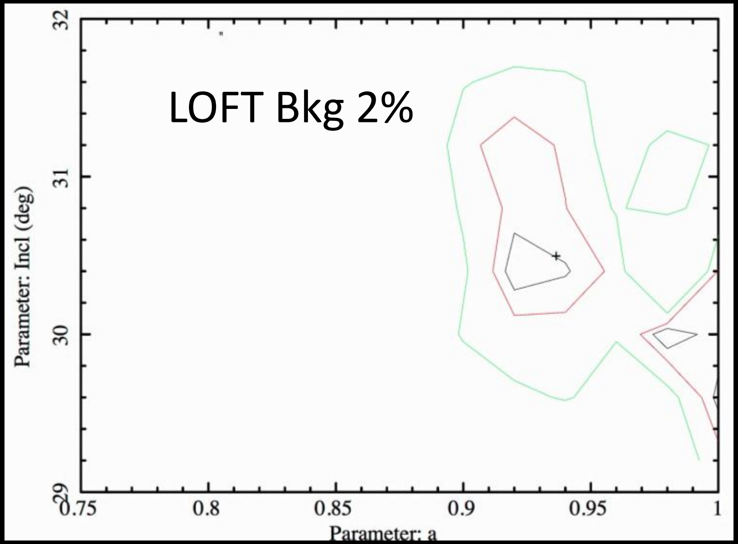


MCG6: 1wa+2refl. a=0.9

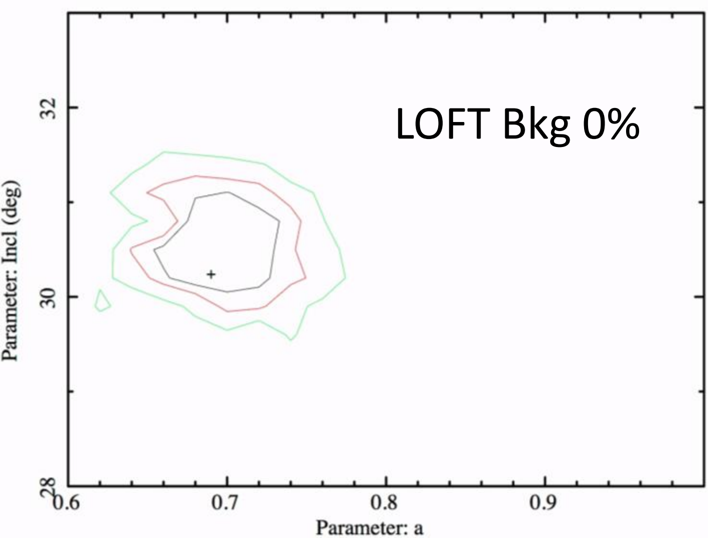


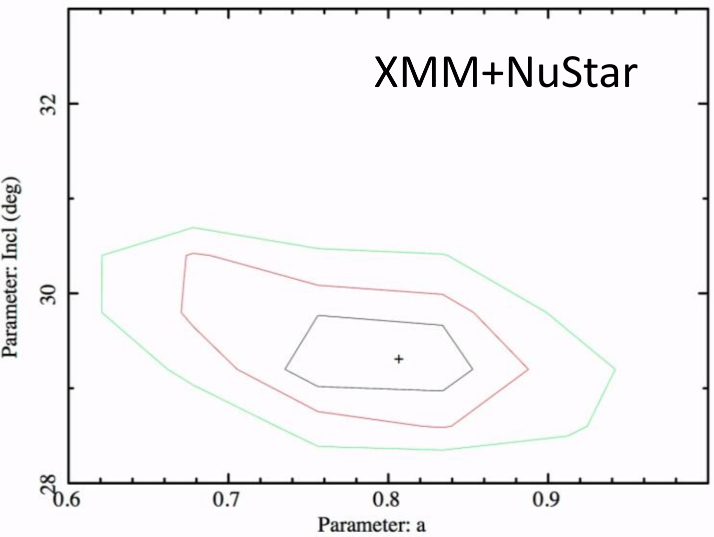


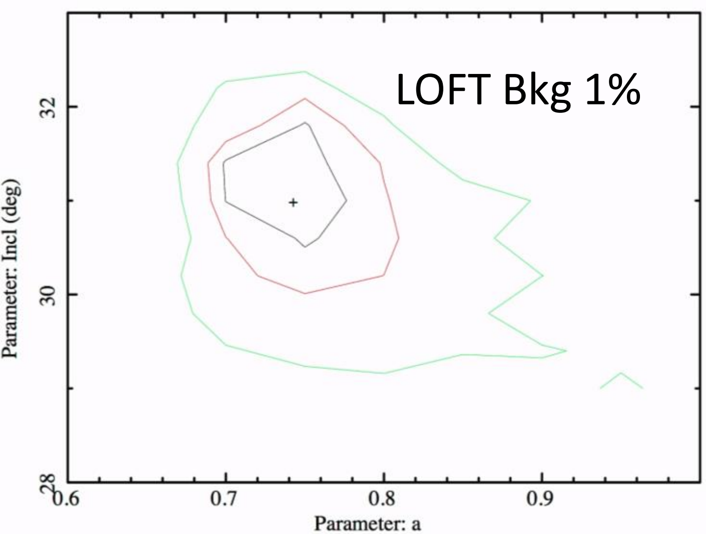


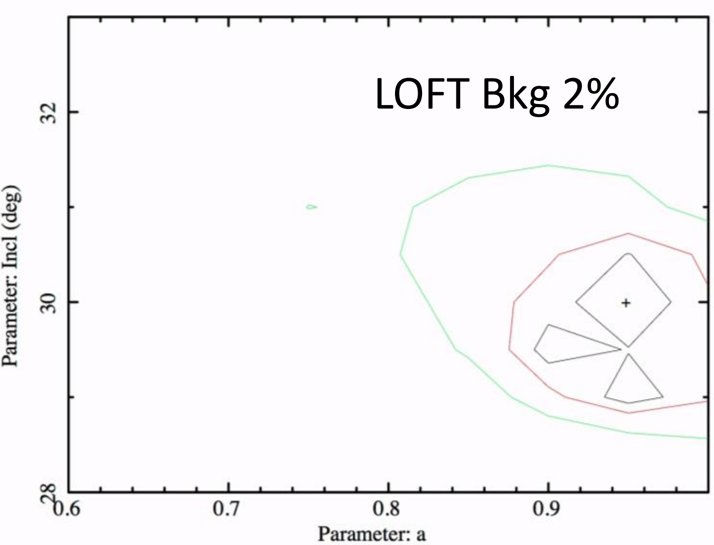


MCG6: 1wa+2refl. a=0.7


LOFT Bkg 0%


XMM+NuStar


LOFT Bkg 1%

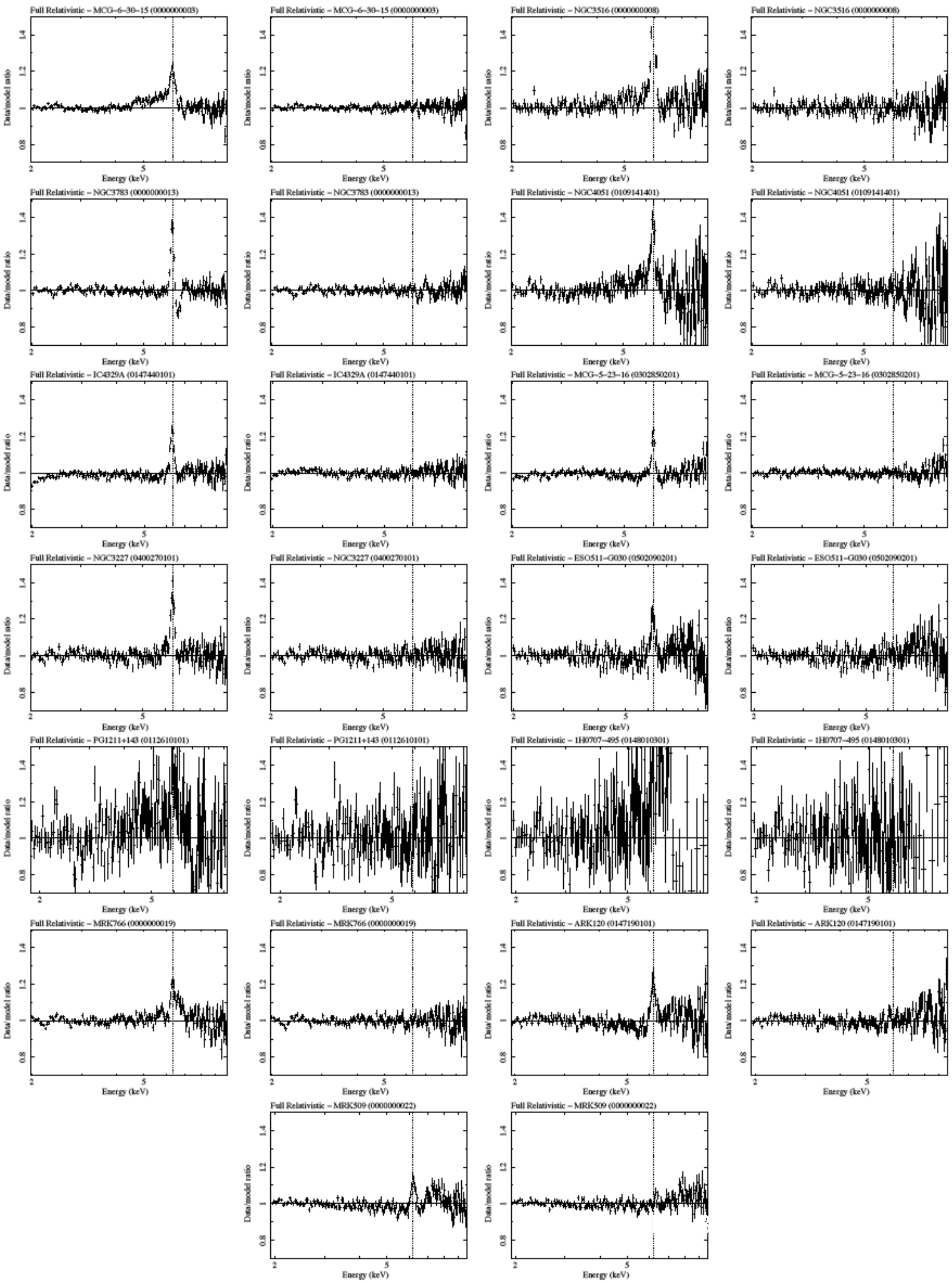

LOFT Bkg 2%

Step 1 ☑

Reflection as a probe of the innermost accretion flows: BH diagnostic with LOFT.

Step 2 ☐

Measuring spin: average disc Fe line



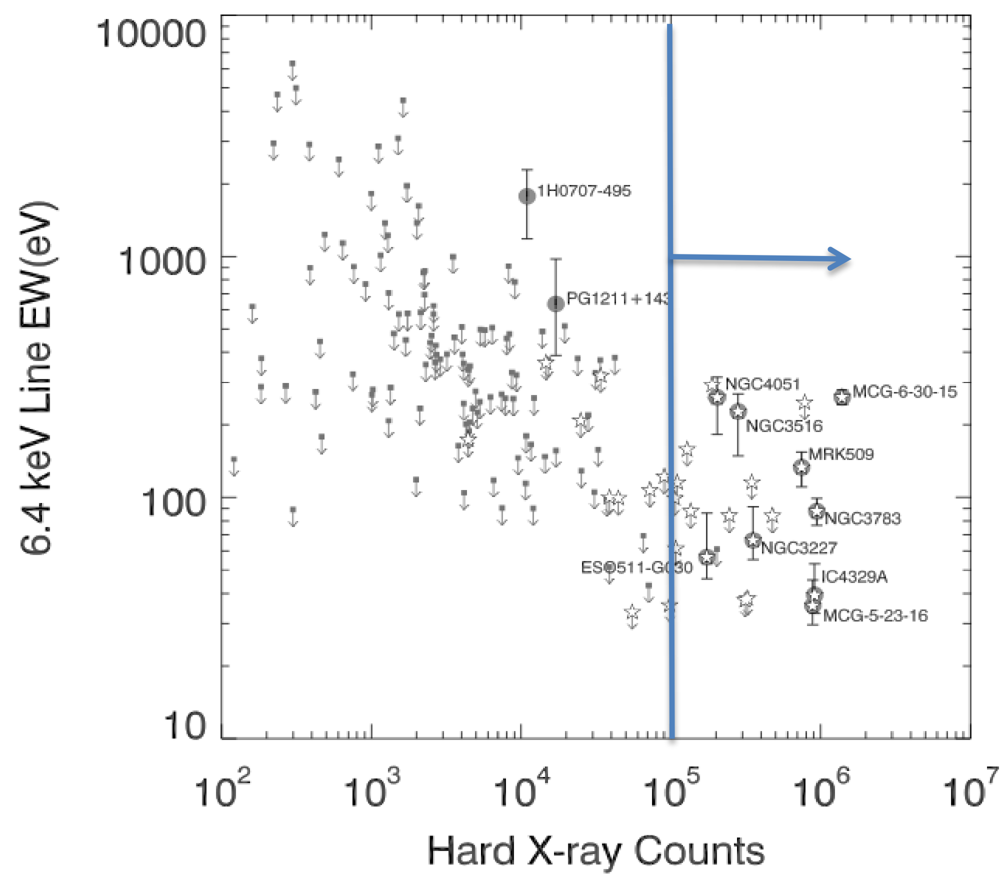
FERO sample

de la Calle-Perez+2010

- The fraction of relativistic Fe lines detected a flux limited XMM sample (FERO, de la Calle Pérez, 2010) is 36% (11/31).

- HOW MANY AGN with relativistic Fe line will be observed with LOFT with Nσ>5?

EW vs hard X-ray counts



FERO being made of spectra of disparate quality and by the unavailability of a well-defined complete AGN sample. Nevertheless, *__the observed detection fraction can be considered as a lower limit for the intrinsic number of AGN that would show a broad Fe line__* if, for example, all sources were observed with the same signal-to-noise.

☐ 5σ detection

↓ upper limit (90% c.l.)

☐ above 1ct/s in RXTE Slew Survey *(Revnivtsev+ 04)*

de la Calle Perez+ 2010

Hard X-ray counts

t_{exp}=10 Ks

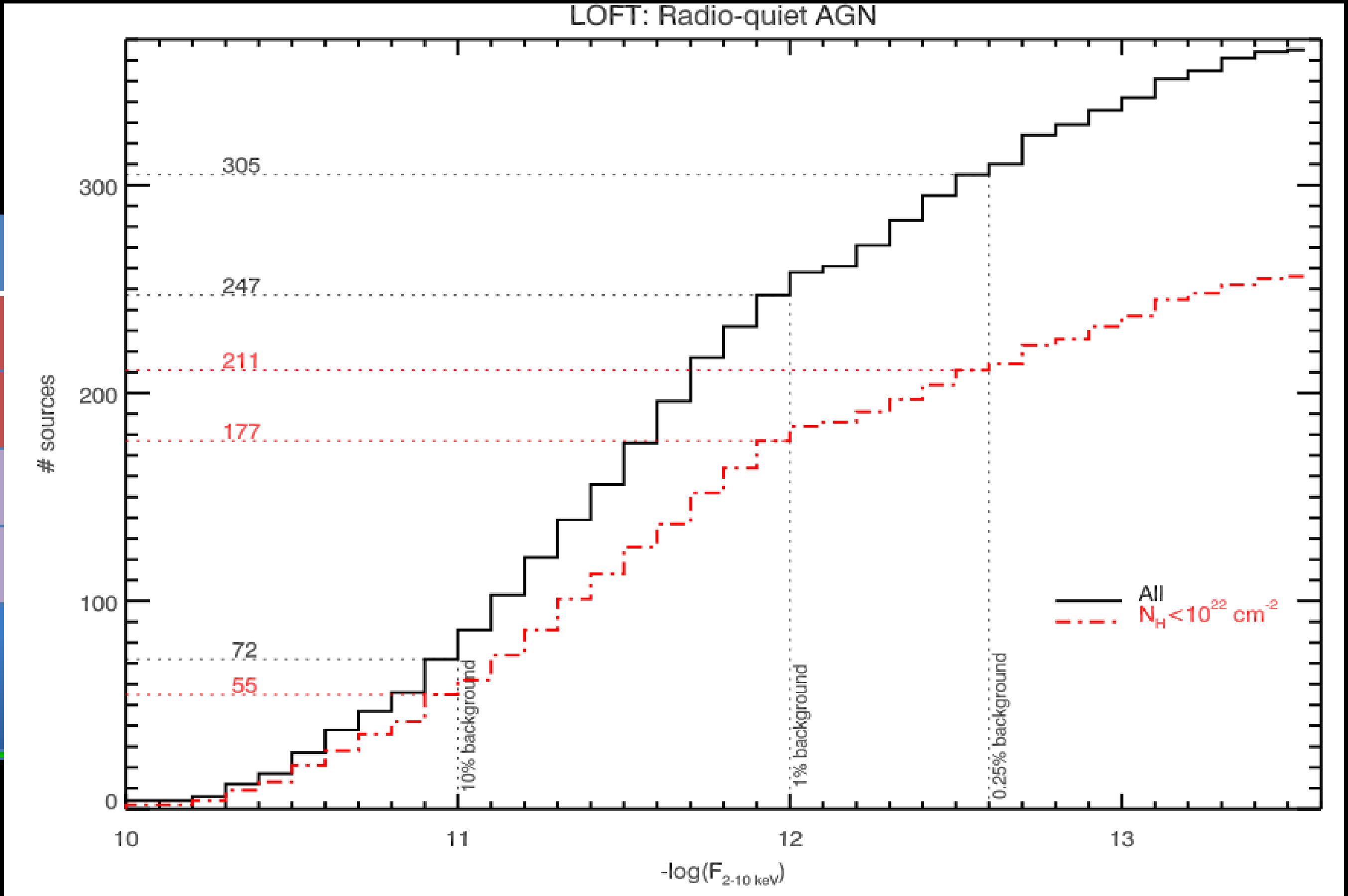
	3mCrab	**1mCrab**	**0.1mCrab**
LOFT cts(2-10keV)	1e7	3.4e6	3.4e5
LOFT S/N	1700	650	71
XMM cts (2-10keV)	8.1e4	2.7e4	2.7e3
XMM S/N	284	160	50

More than 10 AGN above 2mCrab
More than 30 AGN above 1mCrab

Hard X-ray counts

t_{exp}=10 Ks

LOFT cts(2-10keV)
LOFT S/N
XMM cts (2-10keV)
XMM S/N



More than 10 AGN above 2mCrab

More than 30 AGN above 1mCrab

Credits S. Bianchi

Step 1 ☑

Reflection as a probe of the innermost accretion flows: BH diagnostic with LOFT

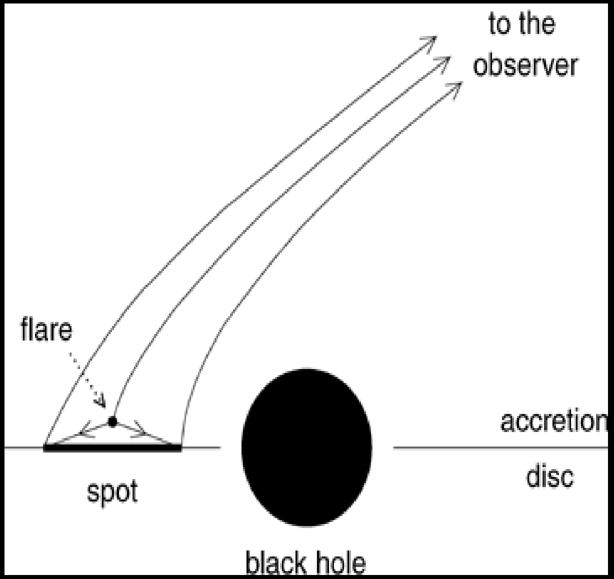
Step 2 ☑

Measuring spin: average disc Fe line

Step 3 ☐

Measuring mass: hot spot disc Fe line

X-ray Fe line from hot spot around SMBH

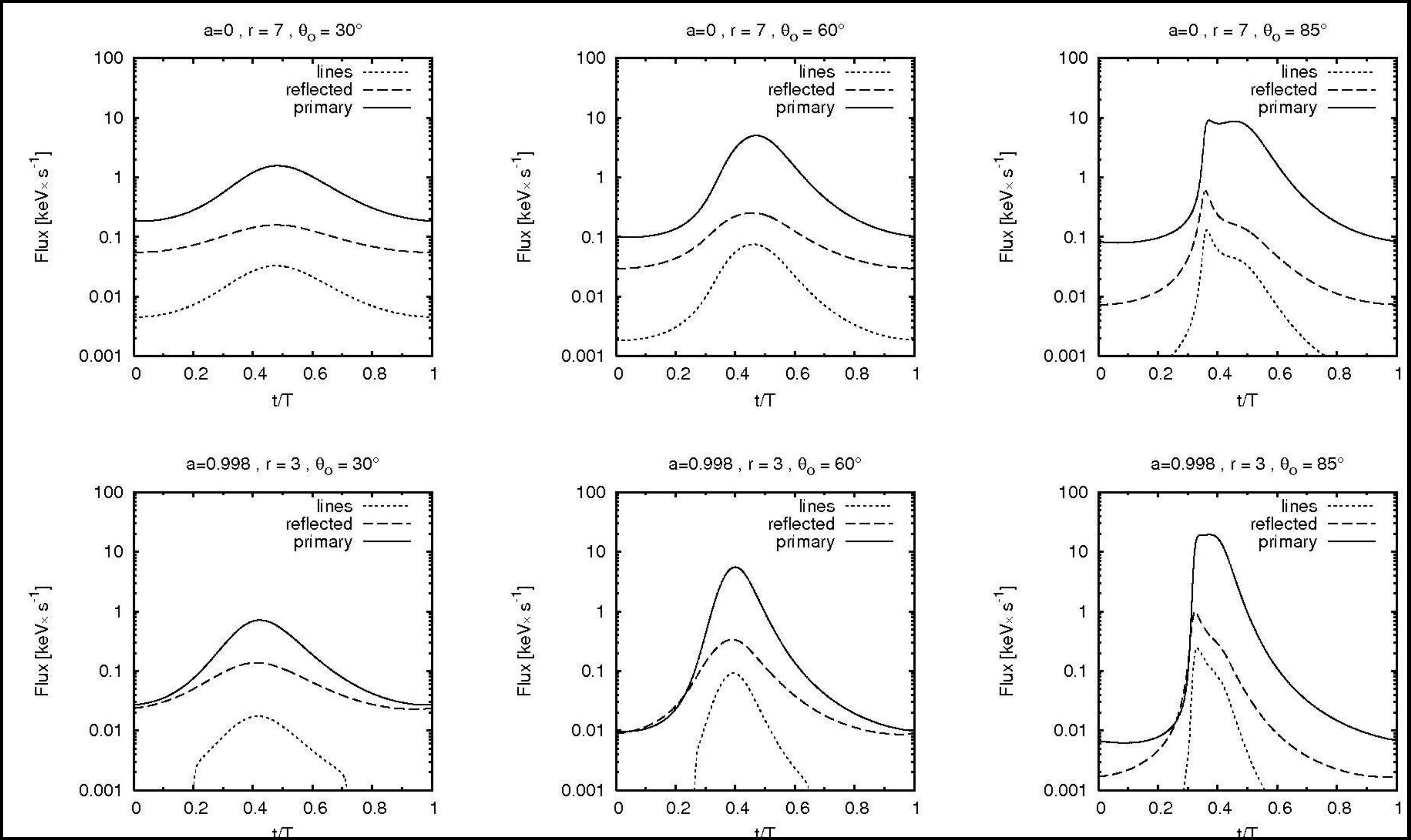


- AGN variability is likely associated to “activation” of the X-ray regions above the accretion disc. These flares will produce an echo in the observed reflection components from the disc (Fe line & Compton hump) on time-scales comparable light-crossing of a gravitational radii

  $t_{cr}=r_g/c=GM/c^3 \sim 50\ M_7\ s.$

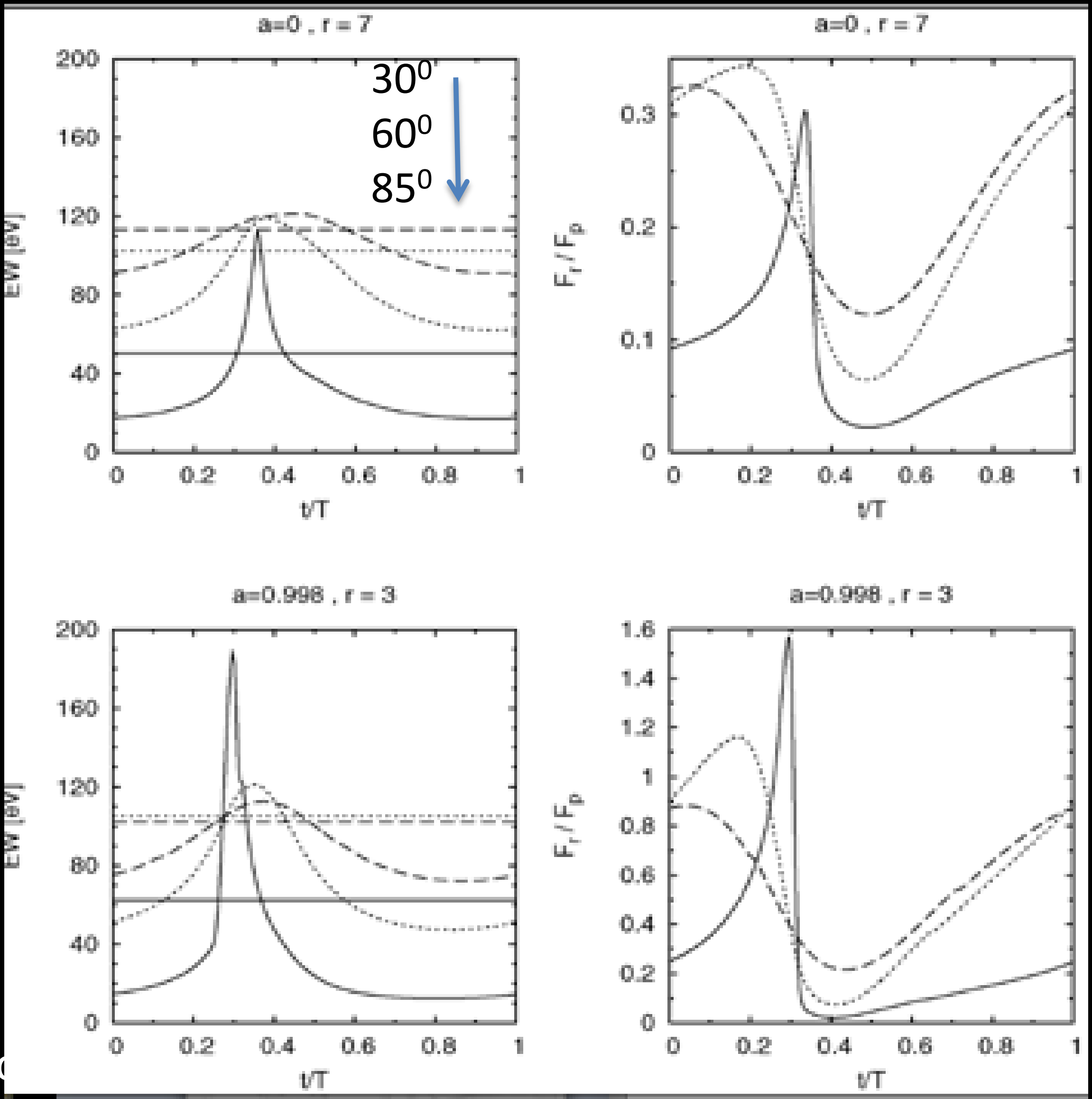
- While *time averaged* Fe profiles can be expressed in terms of $r_{g,}$ losing any information about black-hole mass, assuming the ‘hotspot’ corotating with the disc with a Keplerian rotation, the orbital period can be measured $T_{orb}=310\ (r^{3/2}+a)M_7$ s, and then the BH mass.

Orbiting spots



Dovciak+08

Orbiting spots



30°
60°
85°

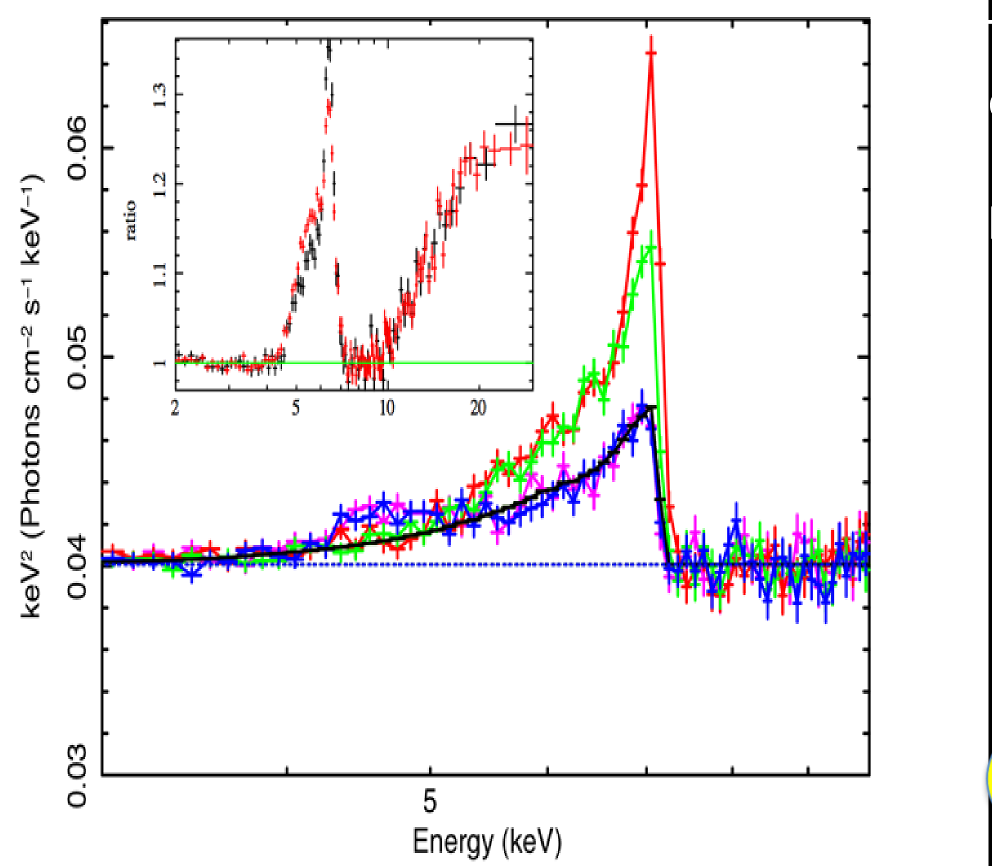
Do

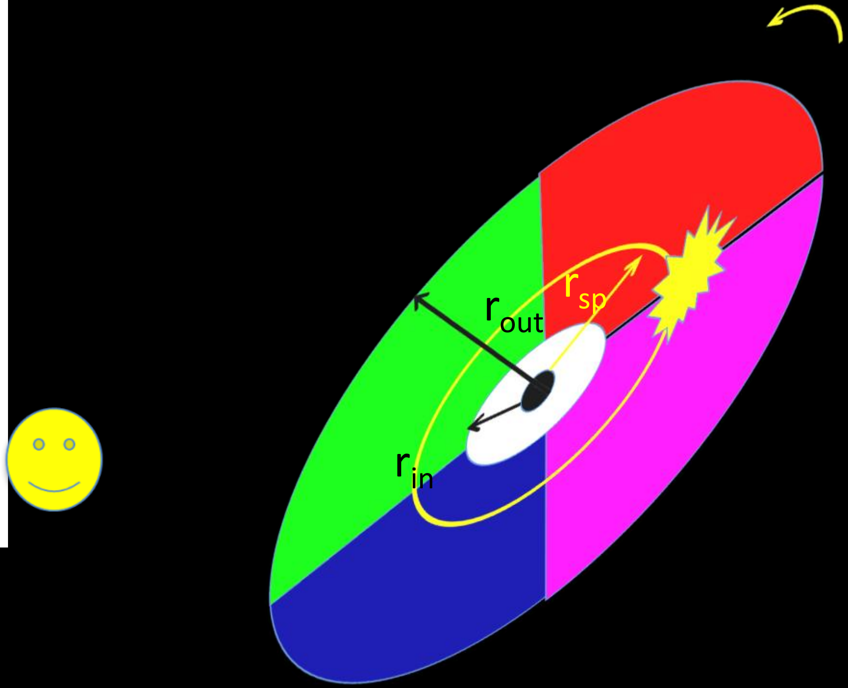
LOFT 16 ks simulation of a steady and *variable* Fe line

MCG-6-30-15

F=3mCrab, a=0.99, r_{in}=1r_g, r_{out}=100$r_{g,}$
θ=45°, $\varepsilon \sim r^{-3}$, r_{sp}=10r_g, T_{orb}=4 ks
T_{exp}=16 ks → mapping 4 phases (1000 s each) in four cycles

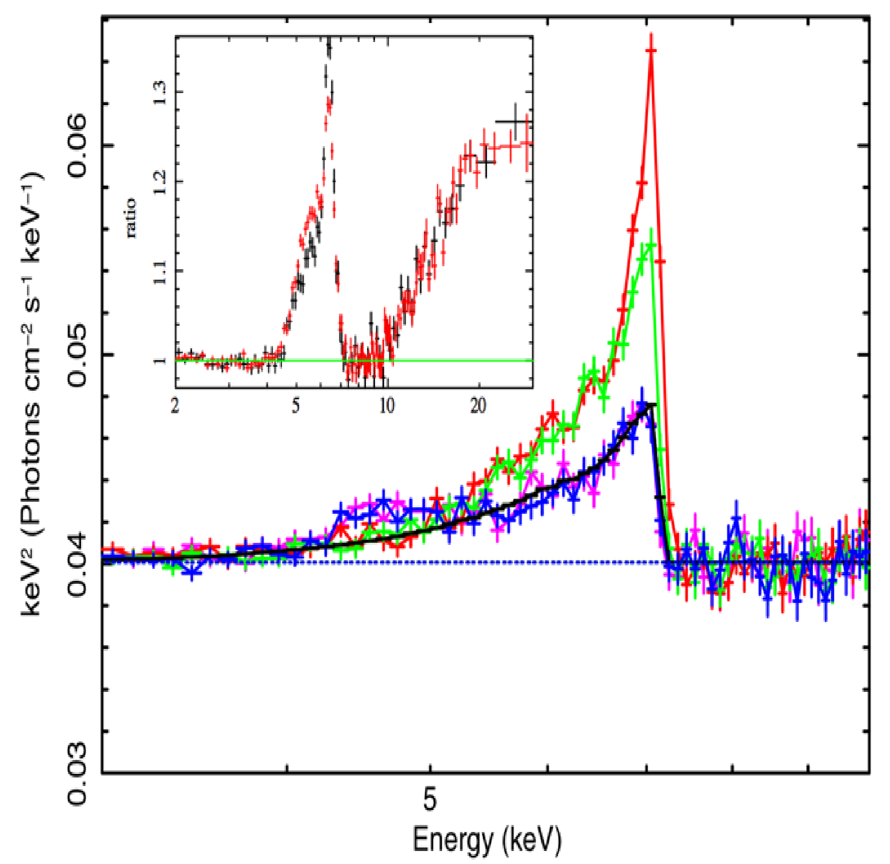
M=3-4 10^6 M_{sun}, a=0.93-0.99, R=0.98(0.02



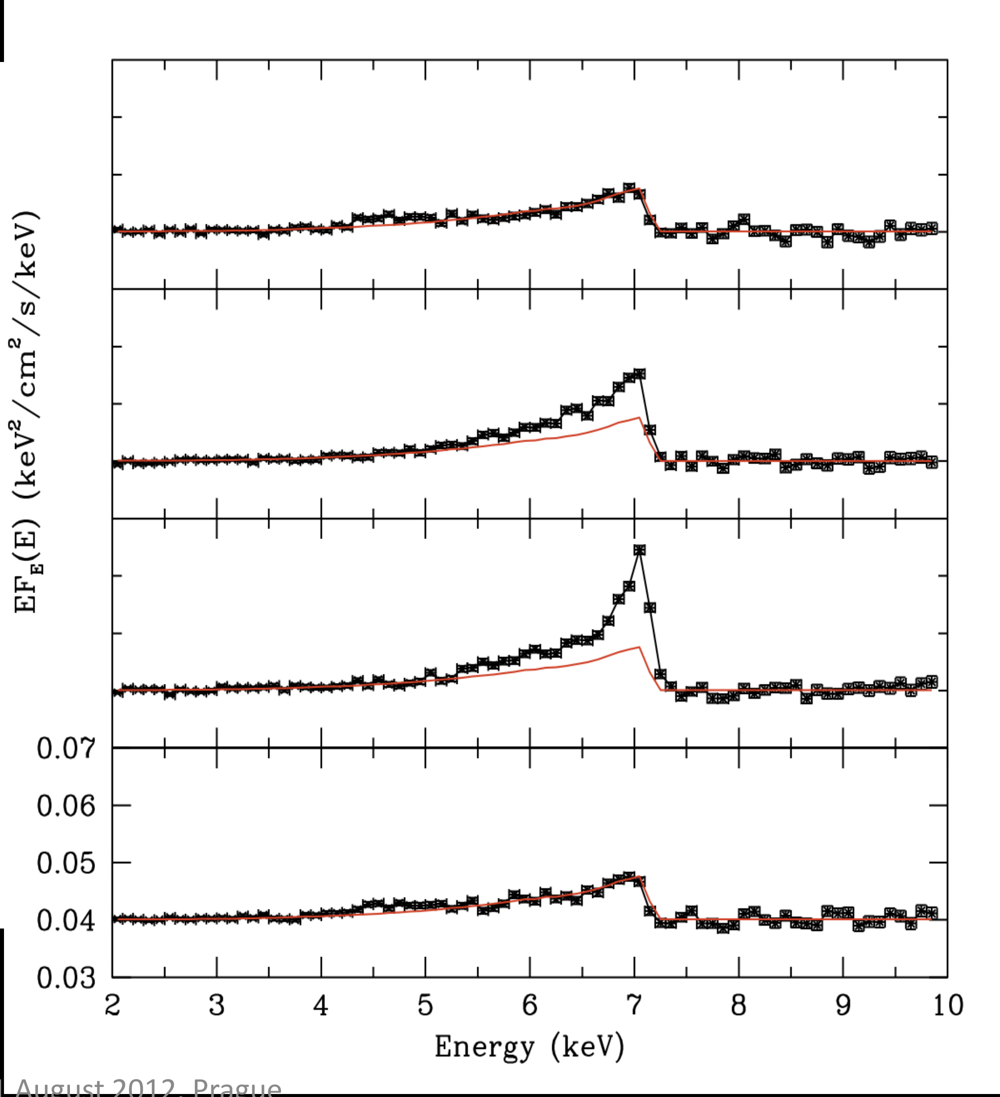


LOFT 16 ks simulation of a steady and *variable* Fe line

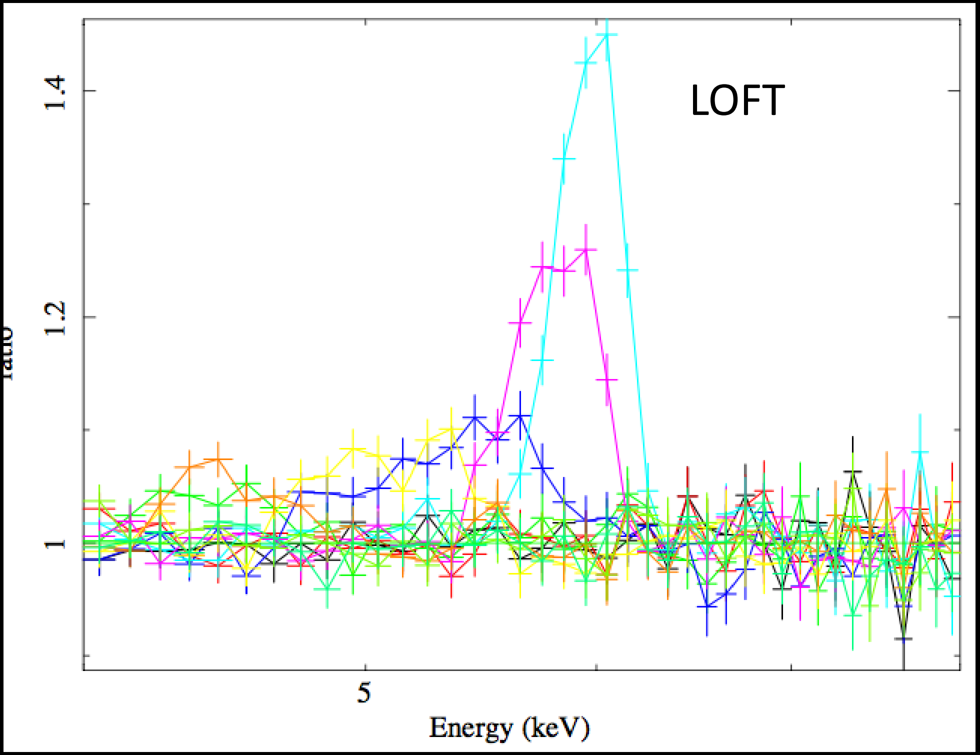
MCG-6-30-15



F=3mCrab, a=0.99, r_{in}=1r_g, r_{out}=100r_g

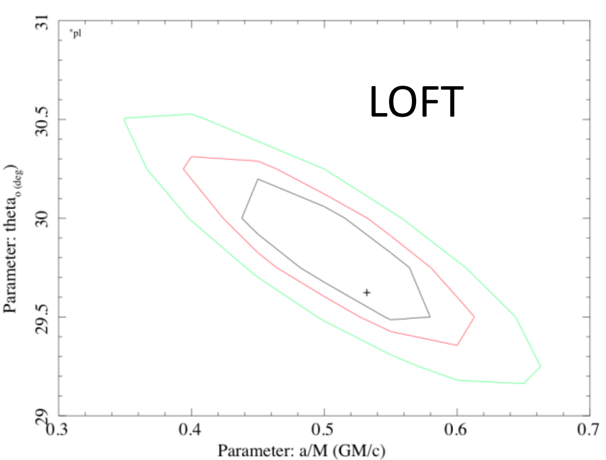


1mCrab. 5ks. 2orbits. a=0.5, r=6

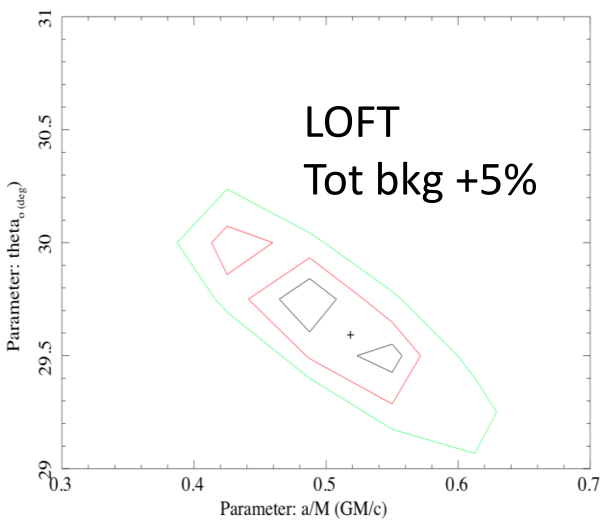


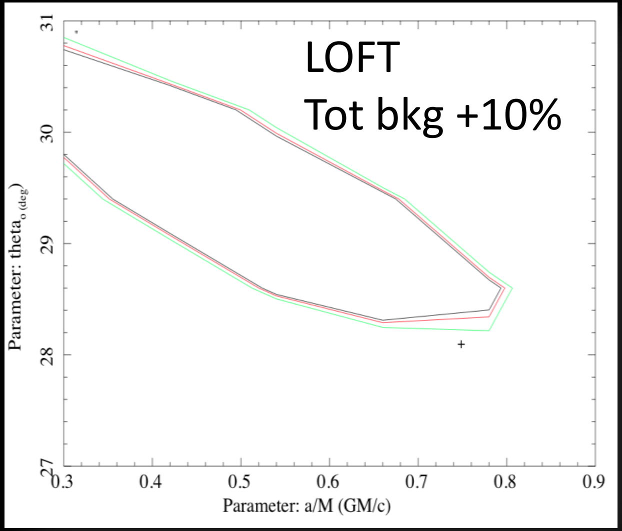
- 2 orbits
- 10 phases: 5e3 s each
- $R_{sp}=R_{isco}$
- $\text{Theta}=30^0$
- a=0.5

Hot-Spot variable Fe line. 1mCrab

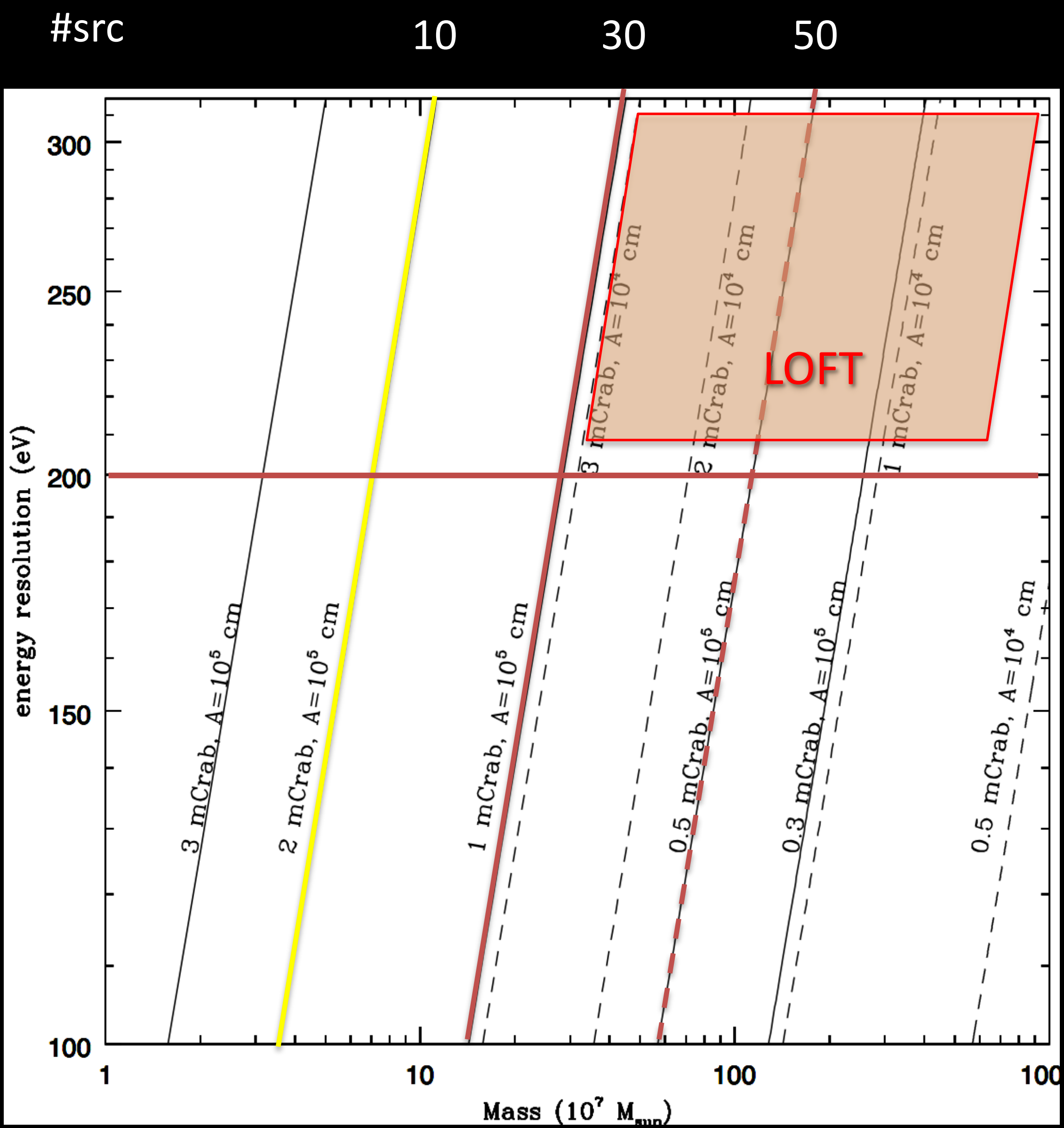


- 2 orbits: 5e3 s
- $R=R_{isco}$
- $Theta=30^0$
- a=0.5





Effective area vs Energy resolution



2 orbits, 10 phases

a=0

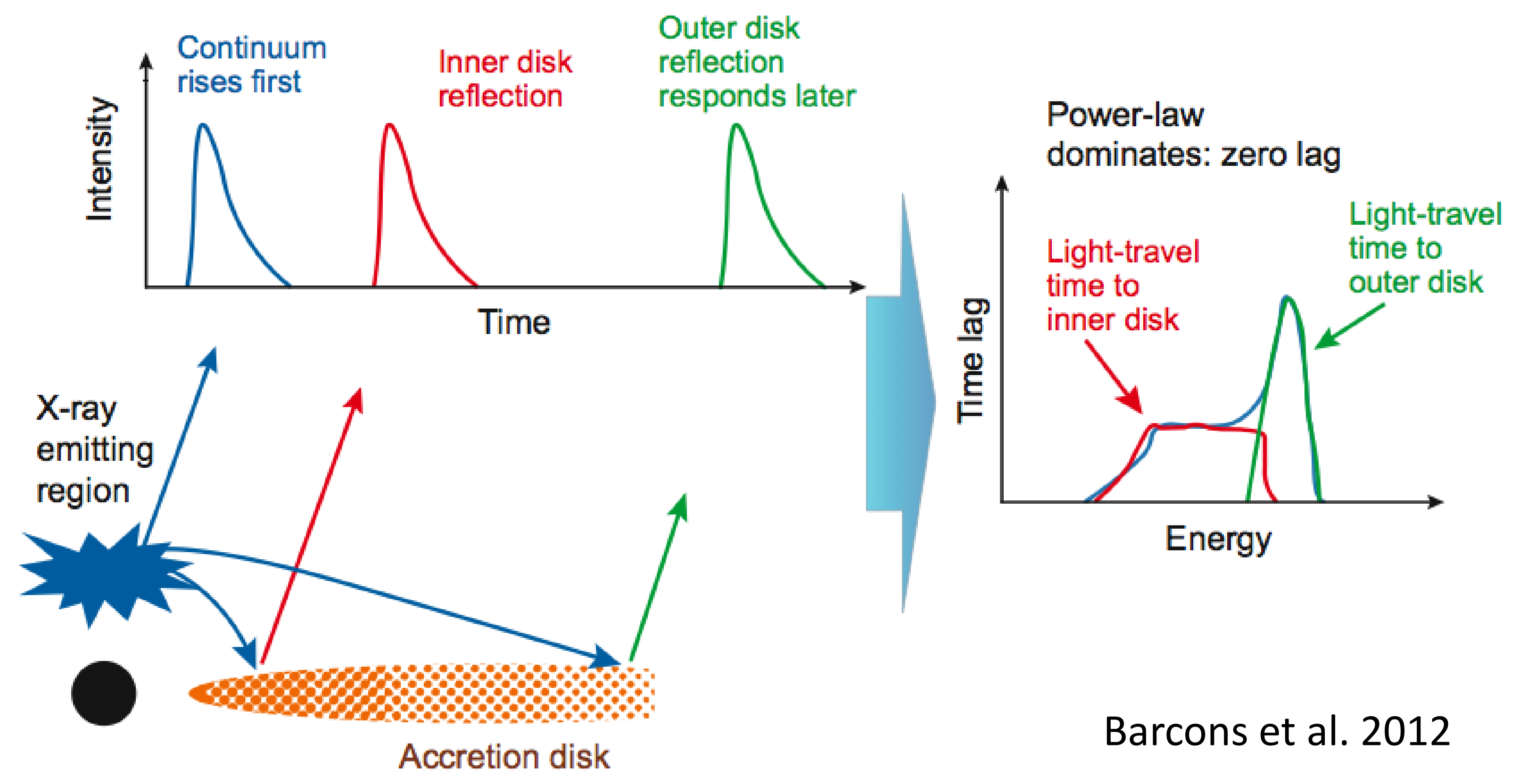
$R_{in}=R_{isco}$,

S/N=3

EW=30 eV

σ=100 eV

Reverberation: basic idea



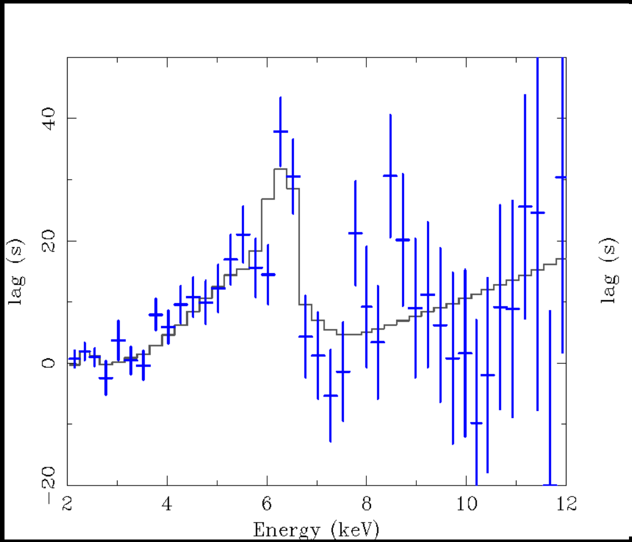
Barcons et al. 2012

By modeling the lags we can measure the light travel times from the continuum emitting region and the disc, and so determine R

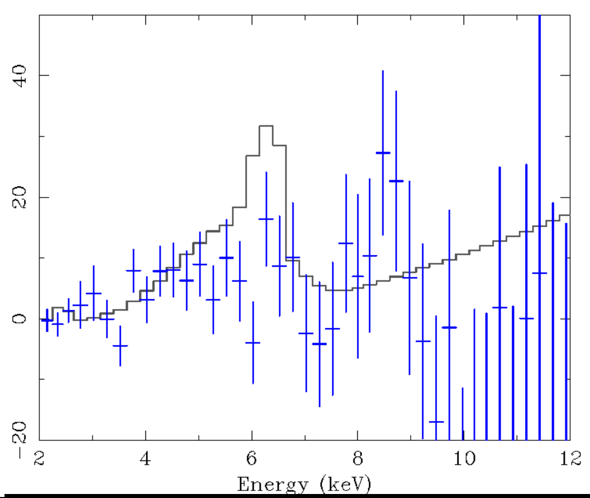
Expected results and effects of uncorrected background fluctuations

Assume 1% rms fluctuation of **total** bgd spectrum, which is not corrected by bkg modelling

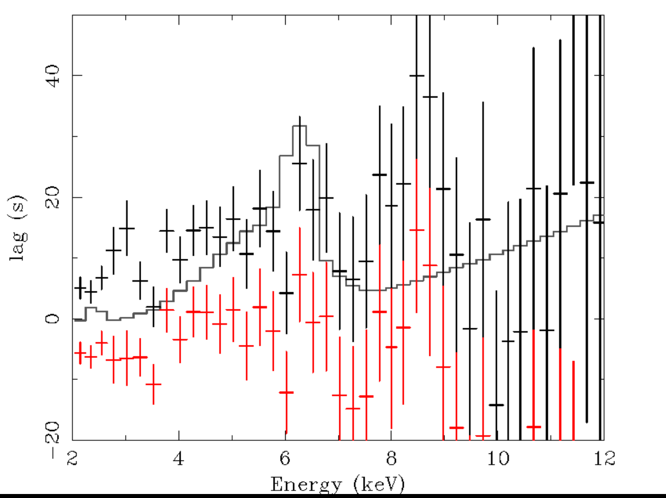
- 3 effects: bias, extra noise and systematic error:
- Bgd contributes an extra correlated variable component with its own lag (zero lag?) – dilutes/shifts the intrinsic source lags
- Bgd variations correlate randomly with Poisson noise to add extra noise term
- Bgd variations also correlate randomly with source variations, adds an extra systematic shift, but in a random direction!



No uncorrected fluctuations



1% uncorrected fluctuations: bias (assume zero bgd lag) + extra noise



1% uncorrected fluctuations: systematic shifts (upper and lower 68% probability)

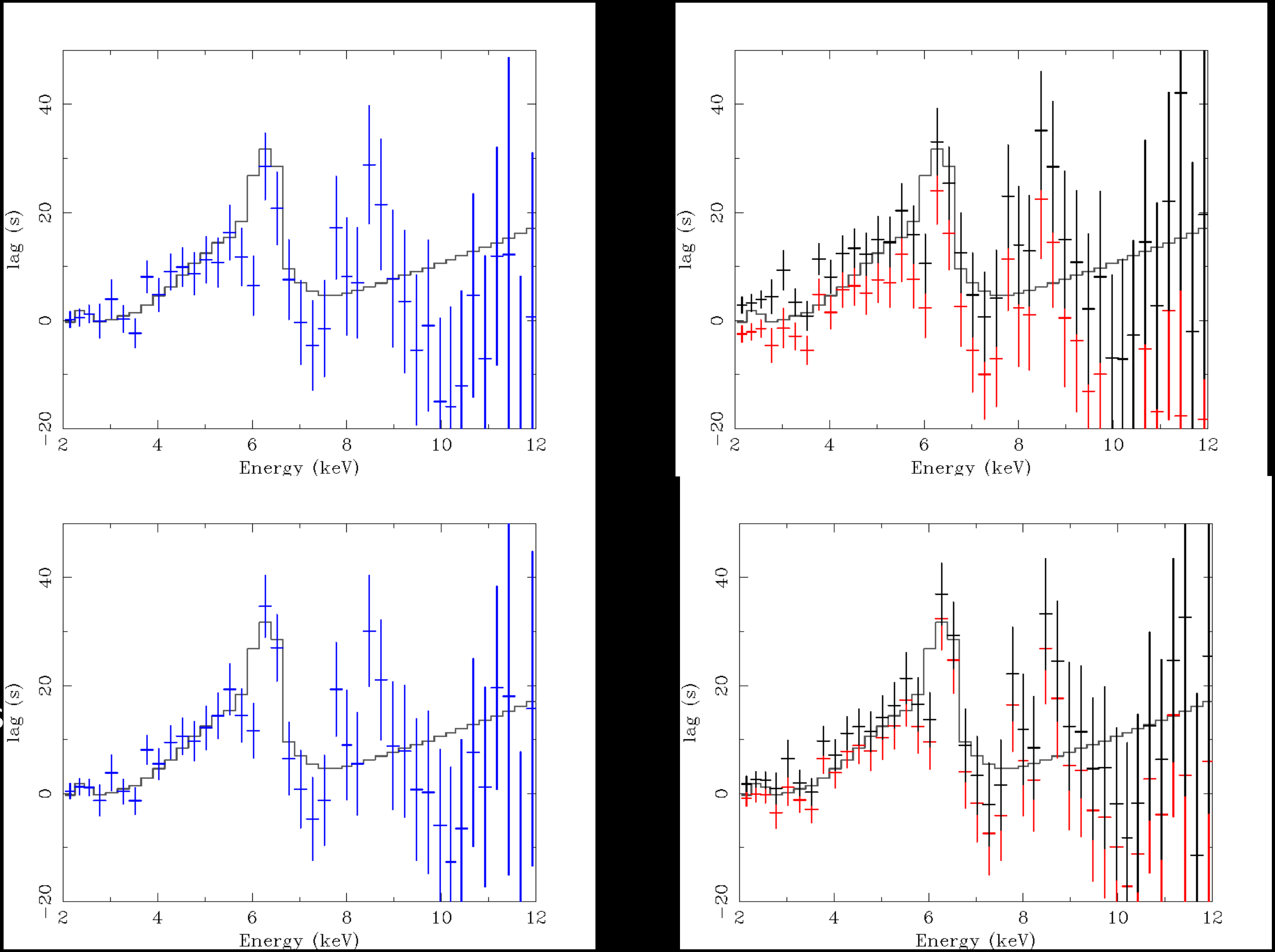
Dependence on BKG fluctuation amplitude

Bias+extra noise

Systematic error +/-68% range

0.5% fluctuations

0.25% fluctuations



Dependence on BKG fluctuation amplitude

- Constant background increases errors through additional Poisson noise and dilution of variable signal, but these are not catastrophic effects

- The lag measurements are very sensitive to background variations: ***errors scale approx. linearly with amplitude of uncorrected bgd fluctuations!***

- Both effects could be reduced by net reduction of background (e.g. leakage), since amplitude of fluctuations also scale with background rate.

Summary and next steps

- Although it has been primary conceived for timing studies, detailed simulations have shown that LOFT will provide a major step forward in the study of GR in the strong filed regime by observing with unprecedented accuracy transient features in X-ray spectra of AGNs
- SFG studies impose strict requirements to the uncorrected variations of the LAD background: between <1% for phase resolved spectroscopy, < 0.25 % for reverberation mapping;
- Mostly of the LOFT-LAD bkg variability is “geometrically” dominated. Use of blocked SDDs to monitor and model the modulation is under evaluation; alternative hardware (collimators) are currently under study

- ESA M3 missions Assessment study extended. Yellow Book due Sept. 2013