LOFT Large Area Detector
Scientific requirements to the LAD Background variation and systematics

	Name	Date	Signature
Prepared by	A. De Rosa. P. Uttley R. Campana E. Del Monte M. Feroci, G. Fraser, M. Nowak, M. Orlandini, E. Perinati, S. Vaughan, D. Walton (the Background Working Group)	2013-09-23	
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1 Introduction

The LAD is a collimated and non-imaging instrument, its background cannot be simultaneously measured, and then subtracted, during the source observation, as usually happens in imaging instruments, but it has to be carefully "a priori" modelled and calibrated (see details in Campana et al. 2013).
Preliminary evaluations already indicated that the uncertainty on the knowledge of the LAD background has to be reduced below a few percent in order to efficiently exploit the performance of the instrument in the Strong Gravity Studies (SFG), one of the two main scientific objectives of the LOFT mission. In fact, the average background level will be subtracted from the signal but its fluctuations, if not properly modelled, may affect the observation of faint sources like Active Galactic Nuclei (AGNs, of few mCrab flux). Given the huge throughput of the LAD and the high statistics that can be accumulated even with short integrations, particular care must be taken in the evaluation and reduction of all the systematic effects that will ultimately affect the instrument capabilities in these type of studies. The systematic effects derive from the un-modelled and uncorrected variations of the background that are consequently not properly subtracted from the signal of faint sources. Therefore specific activities have been devoted to address a full characterisation of the LAD background, to study its variability and define models to describe it, and finally to estimate the resulting accuracy of the estimation and subtraction (see LOFT_LAD_BkgSys_20130918).
In this note we describe the scientific objectives that drive the requirement on the LAD background systematics.

The background level and residual systematics requirements are driven by one of the five science goals (level 1) of the Strong Field Gravity part of the LOFT science case regarding the faint (1–10 mCrab) sources like most Active Galactic Nuclei (AGNs)

The relevant science goal is:

> SFG5: constrain fundamental properties of supermassive black holes and of accretion flows *in* strong field gravity by measuring (a) the Fe-line profiles of <u>20 AGNs</u> and, for 6 AGNs: (b) carry out <u>reverberation mapping</u> and (c) tomography, providing BH spins to an <u>accuracy of 20%</u> of the maximum spin (10% for fast spins) and measuring their masses with 30% accuracy.

2 Fe-line profile in 20 AGNs and determination of spin and masses

The relativistically broadened Fe-line profile that is seen in a number of AGNs (with a flux of a few mCrab) provides a powerful tool to probe the accretion flows in a region where the motion is determined by General Relativity (GR).
The observation and modeling of the broad Fe line profile in the weak sources like an AGN require a good spectral accuracy to disentangle all different emission/absorption contributions that may be present in the Fe K band (3-8 keV), namely: warm absorption gases, narrow neutral and ionized lines (Fe Kα, Fe Kβ, Ni Kα) plus broad Fe K line with the goal of determining accurately the broad line parameters to recover the BH's spin. These components are illustrated in Figure 1.

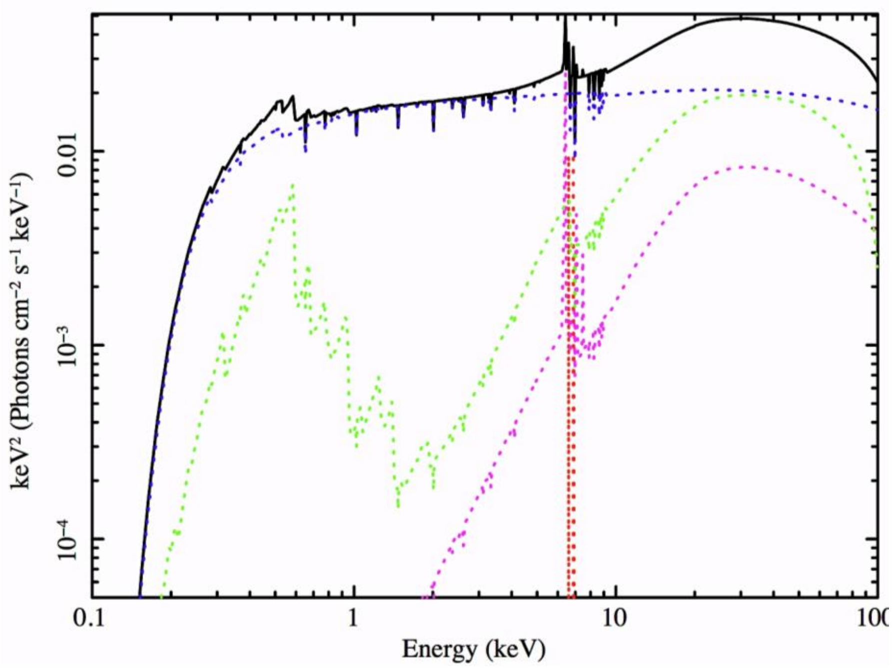

Figure 1: The different components of an AGN spectrum including the continuum and ionized absorber (blue), the cold reflection and narrow Fe line Kα, Fe-Kβ and Ni-Kα (magenta), the ionized lines FeXXV and Fe XXVI (red) and the blurred ionized reflection component (green). The total emission is given in black.

The sample of AGNs accessible to the LAD for SFG studies has been collected taking into account X-ray catalogues of present X-ray missions.
In particular, the XMM targeted observations of unabsorbed AGNs (CAIXA sample, Bianchi et al. 2009), the Suzaku sample of Seyfert 1-1.9 AGNs (Patrick et al. 2012), the identified AGNs from BAT and INTEGRAL surveys (Bird et al. 2010, Baumgartner et al. 2013).
Among this LAD SFG-AGNs sample we identified the so-called “bare” Seyfert 1, i.e. sources without evidence of warm/complex absorbers.
For the bare AGNs, due to the absence of emission/absorption features in addition to the broad Fe line, it will be easier to get the goal fulfilled, and already with a S/N~250 in 2-10 keV will be possible to observe the Fe line profile with unprecedented accuracy and measure the BH’s spin with 20% of error.
The remaining sources are known to be characterized by complex absorption with presence of prominent absorption/emission components in their spectrum. For these AGNs a minimum S/N~400 is needed to disentangle all the spectral features, resolve (possible) model ambiguity and observe the Fe line profile with a the good accuracy to achieve the goal of 20% of error on the measurement of the BH’s spin.

Figure 2 shows the sensitivity limits of the LAD for S/N=250 and 400 in 2-10 keV and different levels of background systematics, 0.2%, 0.25% and 0.5% (from left to right) of the mean background level, constant over the energy band.
The effect due to the uncorrected background variations (background systematics) will add an extra statistical noise component significantly increasing the limiting flux attainable for each given S/N.
The sensitivity limit for S/N~400 (250) ranges from 7(4) to 18(10)x10^{-11} erg cm^{-2} s^{-1} depending on the background systematics.
With the main goal to collect 20 good candidates for SFG studies among the AGNs sample, we require a limiting flux above 4,9 x10^{-11} erg cm^{-2} s^{-1} for bare and complex AGNs, respectively. This implies a requirement for the LAD Background systematics of 0.25% (or below)

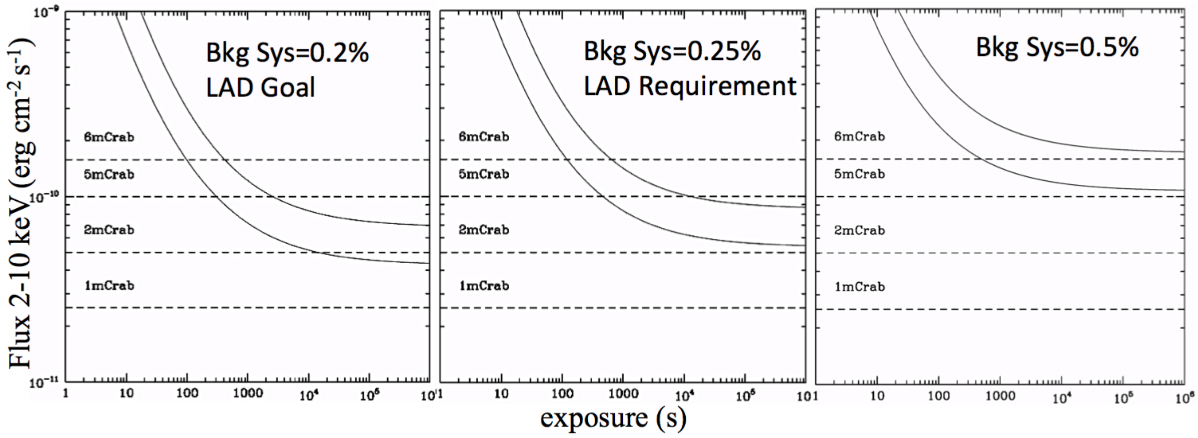

Figure 2: LAD Sensitivity limit curves for three levels of unaccounted for background variation: 0.2% (LAD goal), 0.25% (LAD requirement) and 0.5% (from left to right) of the mean background level. The solid lines refer to a S/N=250 (lower curves) and 400 (upper curves) in 2-10 keV energy range.

3 Reverberation mapping and tomography of BHs

Reverberation (radiation 'echoing') of the variability of an incident hard continuum off the disk leads to time lags between energy bands.
These energy-dependent time lags are caused by the different light-travel times from the variable continuum emitting region to different parts of the accretion disc, where the continuum signals are reprocessed into reflection and thermal emission components. The time lags can be modeled to determine the absolute length scale (km) between the different emitting regions, and in combination with spectral measurements, key parameters such as the disc inner radius and black hole mass can be determined.
The time lags will be measured for both X-ray binaries for which they will be <1ms, and for AGN for which they will be tens of seconds, e.g. as observed in 1H0707-495 (Fabian et al. 2009, Zoghbi et al. 2010, 2011). For the X-ray binaries, background is small compared to source counts and the time-scales of background variability are long compared to the time-scales of source variability, so background effects are negligible. In the case of AGNs the residual background variations which cannot be corrected for by modeling may be comparable in amplitude, and on similar time-scales, to the expected source variability. Thus un-modelled background variability can cause significant systematic and statistical errors in the reverberation lag measurements.

The background has a number of different negative consequences for the precise measurement of time lags:

i. The background level effectively dilutes the intrinsic source variability, which reduces the signal-to-noise (S/N) of any lag measurements.
ii. Any fluctuations in the background, which are not accounted for by background subtraction will contribute a fluctuating spectral component which is uncorrelated with the true source variations. This component has its own time-lag contribution (which may be zero), which is added to the true source signal, systematically degrading it. Furthermore, the background systematics add an extra statistical noise component to the lag measurements, significantly increasing the error bars and also adding a further (randomly-directed) systematic shift due to the spurious correlation of the background and source variations.

The latter set of effects is by far the most severe, since the signal-to-noise of the lag measurements degrades roughly *linearly* with the amplitude of the unaccounted-for background fluctuations. Therefore, fluctuations in the background need to be well-modeled in order to permit the reverberation measurements of weak source, such as mCrab AGN.
Figure 3 shows the effects of the un-modeled background variations on lag measurements for three cases, corresponding to levels of Bkg systematics in the frequency range 0.3 to 1 mHz (i.e. time-scales

of a few ks to 1 ks) which are 1%, 0.5% and 0.25% of the mean background level, constant over the energy band. The assumed model is shown as a solid line and is chosen to match expectations for 1H0707-495 (Fabian et al. 2009, Zoghbi et al. 2010, 2011), the first AGN shown to possess reverberation lags, and one of the key targets of the AGN strong gravity core programme.
The data points show two cases corresponding to the 1-sigma upwards or downwards systematic shift that is caused by the background fluctuations (the background fluctuations also worsen the statistical errors, as is shown by the size of the error bars). **These simulations suggest that it is necessary to model the background variations on time-scales of a few ks to a level of 0.25% (or smaller) of the mean background level, so that the reverberation mapping of AGN can be carried out.**

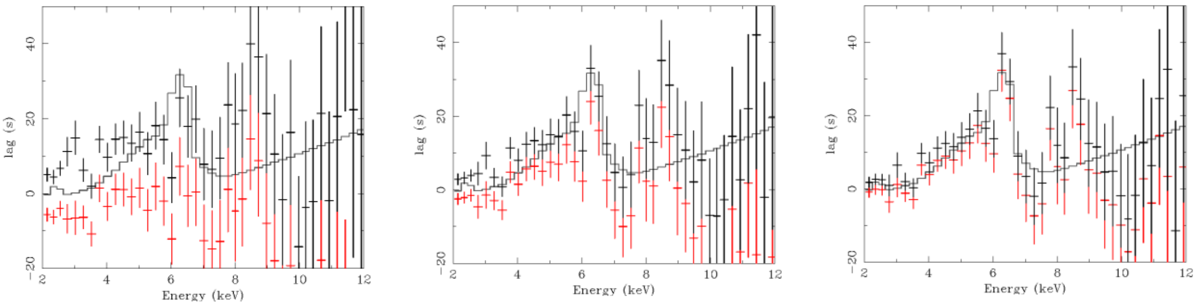

Figure 3: Effects of the un-modeled background variations on lag measurements in the frequency range 0.3 – 1 mHz (i.e. time-scales of a few ks to 1 ks) for three levels of unaccounted for background variation: 1%, 0.5% and 0.25% (from left to right) of the mean background level. The solid line is the model for the AGN 1H0707-495.

4 Conclusions

The background level and residual systematics are driven by the science goal (level 1) of the Strong Field Gravity, SFG5, regarding the relatively faint (1–10 mCrab) sources like most Active Galactic Nuclei (AGNs)
The main effects due to the uncorrected background variations (background systematics) will add an extra statistical noise component significantly increasing (1) the limiting flux attainable for each given flux (2) the error bars of the lag measurements.

Detailed simulations suggest that it is necessary to model the background variations on time-scales of a few ks to a level of 0.25% of the mean background level, this requirement will allow us to (1) observe a sample of 20 AGNs to measure their BH spin with an accuracy of 20%, (2) to carry out reverberation mapping measurement on AGN.

5 References

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