SuperMon & Black Hole Tracker

Response to the Questions for SuperMon and Black Hole Tracker

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1. Can more information on the science case be provided? In particular, how do these missions address IXO science objectives?

Essentially, the science case rests on the utility of X-ray continuum spectroscopy in understanding what happens close to a black hole, and, by extension, what happens in all sources with non-thermal continuum emission.

1.1 Black hole Mass measurement:

There are 39 AGNs with black hole mass measurements by reverberation technique (Peterson et al. 2004, ApJ, 613, 682; Denney et al, 2010, ApJ, 721, 715) and 17 X-ray binaries (XRBs) with dynamic black hole mass measurements (Ozel et al. 2010, ApJ 725, 1918; Casares 2006, in "The many scales in the Universe", Springer, p145).

The number distribution in the errors in mass measurement (δM/M) is given in Fig 1.

It can be seen that the black hole masses in XRBs are measured typically upto 10% accuracy and in AGNs upto 30% accuracy.

Based on the current paradigms of accretion theory, the black hole masses are tied to the various observed properties. A few of them are:

a) The fundamental plane of black hole activity: Merloni et al. (2003 MNRAS, 345,10576) derived a correlation between the X-ray luminosity, radio luminosity and the black hole mass.

b) Break time scale: McHardy et al. (2006, Nature, 444, 73) related the black hole mass with the bolometric luminosity and the break time scale in the Power Spectral Density (PSD).

c) X-ray spectral index: Gliozzi et al. (2011, ApJ, 735, 16) scaled up the X-ray spectral index/ intensity correlations to measure the mass of black holes.

In Fig 2. the predicted masses for AGNs with reverberation mass measurements is plotted by a) a simple scaling of X-ray luminosity and b) Merloni et al. relation.

In Fig 3, the predicted masses are plotted for a) spectral index scaling and b) break time scaling.

It can be seen that the best case is the break time scale measurement with 75% rms deviation in mass measurement.

Essentially, our understanding of what happens close to a black hole is not mature enough to make quantitative predictions. The best case (75% rms using McHardy et al. relation) points towards a preferred time scale (ostensibly related to a preferred length scale) in the accretion disk, which scales with mass and luminosity.

A clear understanding of the properties of this length scale, its relation to other observed properties like the QPO generating mechanisms and jet launching mechanisms awaits further observational constraints.

1.2 Black hole Spin measurement:

There are two principle methods to measure black hole spin - 1. by spectral modeling of relativistically broadened Fe-Kα line profile (Brenneman & Raynolds, 2006, ApJ 652, 1028) and 2. by spectral modeling continuum spectra from the accretion disks (McClintok et al. 2011, CQG, 28, 114009). X-ray polarimetry is another promising method to measure black hole spin (Dovciak et al. 2008, MNRAS, 391, 32; Li et al. 2009, ApJ, 691, 847), however it is still a few years into the future. Meanwhile, for the first two methods involving X-ray spectroscopy, galactic black holes provides the best opportunity to accurately measure their spins by combining both methods because of the high S/N measurement of their spectra.

Unfortunately simultaneous modeling of both Fe-line profile as well as thermal continuum runs into difficulty due to a number of reasons -

a) that there are multiple spectral components even in the 'soft state' of black holes (Zdziarski et al. 2005, MNRAS, 360, 825).

b) X-ray detectors having capability of high resolution spectral measurements (so far only CCDs at focal plane of X-ray optics) do not cover sufficient energy range to accurately determine the underlaying continuum.

c) X-ray detectors having broad band coverage do not have sufficient energy resolution to accurately determine Fe-line profile. This futher prevents accurate measurement of continuum itself, as broad part of Fe-line gets mixed up with the continuum.

d) There is always an uncertainty in calibration across multiple instruments so when more then one instrument is used to cover a required energy range, the results carry certain amount of doubt, particularly when there is only marginal overlap in the energy ranges. An example of this is given in Figure 4, which shows a good fit to observed data in broad energy range of 3 - 500 keV with a sophisticated hard X-ray continuum model 'eqpair'. The only irony in this fit is that the data used in this fit is from three different sources - RXTE PCA data of GRS 1915+105, RXTE-HEXTE data of Crab and OSSE data of Cygnux X-3 (!). This highlights the perils and difficulties of X-ray continuum fitting and shows the futility of our present reliance on two different instruments for measuring Fe-line profile and thermal continuum. Hence most of the present galactic black hole spin measurments should be taken with a 'pinch of salt'.

1.3 What needs to be done.

Essentially, the Physics of what happens close to a black hole is reasonably known (I am sure there are no quantum gravity effects !) and the only way to pin down the exact structure of what happens close to a black hole is to make accurate measurements of the radiation coming out from there - measurements of the X-ray continuum spectrum.

In the energy range of $2 - 60$ keV, the X-ray continuum contains many distinct components like a) broad Fe-Kα line, b) X-ray reflection, c) Compton scattering from non-thermal electrons d) Compton scattering from thermal electrons and possibly e) synchrotron radiation. To accurately constrain all of them simultaneously, it is essential to have high energy resolution (< 0.25 keV @ 5.9 keV) measument at low energies (< 10 keV) with simultaneous coverage up to 60 keV from the same detector.

In X-ray astronomy, such measurements are never done !!

Hence, a minimum pre-requisite for a continuum spectroscopy measurement to know what happens close to a black hole is:

sub-keV resolution throughout the energy range 2 – 60 keV with the same detector.

SuperMon's 'Semiwich' configuration offers two unique capablities essential for this endeavour - 1. high detection efficiency at higher energies and 2. effective background rejection in the same background dominated energy range. It further has the potential to augment the BH-spin measurement from X-ray spectroscopy by X-ray polarization measurements as discussed later.

The question of sensitivity can be divided into two steps:

SuperMon: Have a sensitivity for all XRBs above 10 mCrab for spectroscopy in 1000 s (typically 10,000 photons for a good spectrum) and spectroscopy for 2 mCrab sources in 25 ks (a few dozen AGNs) and 5 σ detection for 0.5 mCrab sources in 500 s (enough to track about a hundred AGNs). This will provide time resolved spectroscopy for all transients, black hole sources and neutron stars.

The continuum measurement results can be tied to the polarization measurements (above $\sim$12 keV) for bright sources and the flexibility in pointing will provide enough data to enable time resolved spectroscopy at all time scales. In Figure 5, a plot of expected QPO periods (scaled from 5 Hz for a 10 $M_\odot$ object) for the 39 AGNs with well determined masses is given. A QPO simulation is shown in Figure 6.

It is expected that, with time resolved spectral data catering to the diverse needs of bright XRBs and AGNs, the continuum Physics can be pinned down.

Black Hole Tracker: The SuperMon will make a breakthrough in understanding what happens close to a black hole using continuum fitting methods, and the Black Hole Tracker will push this to fainter sources. With 10 times more area and 10 times more observing time, it can make precise continuum spectral measurements to a select 100 sources spanning the whole gamut of X-ray continuum sources.

Since these sources are inherently time variable and the episodes of interesting activities (like jet emission, state transition, occurrence of QPOs) happen sporadically, a highly sensitive large area (5 m^2) low energy monitor will guide the sensitive spectrometer to the interesting sources.

2. How does the polarimeter work ?

X-ray polarimetry can be measured by a) measuring the directionality of Compton scattered photons b) measuring the directionality of the electrons after the phoro-electric effect and c) measuring the directionality of Thompson scattered photons. The latter two are predominantly used at lower energies. The first method is successfully used at higher energies (> 50 keV) for the Integral data of Cyg X-1.

SuperMon's 'Semiwich' detector configuration offers unique capability to make X-ray polarization measurements using Compton scattering at low energies starting from ∼12 keV. It has three active detectors of increasing atomic number (He, Si and CdZnTe), with mm position resolution. Figure 7 shows estimated sensitivity of the Compton mode X-ray polarimeter with the proposed 'semiwich' detector. It can be seen that ∼1 % polarization can be measured in 100 mCrab source in 10^4 seconds. For bright sources, it may be possible to measure energy resolved polarization due to high energy resolution of CZT detector and knowledge of scattering angle of individual event, which is a distant dream for all other types of X-ray polarimeters.

3. Can you compare these technologies to those of currently operating missions, and missions soon to be launched and under study?

A summary of capabilities of current and future missions, with emphasis on continuum spectral fitting, is given below.

Current Missions

1. Swift: The energy resolution of BAT detector is 3–4 keV at 20 keV and being an open detector, the data is background dominated.

2. Suzaku: There is a crucial gap between 10 keV and 15 keV and the energy resolution is 4 keV at 20 keV.

Future missions

1. Nustar: The sensitivity and energy resolution above 8 keV meets the requirement of continuum spectral fitting. But the lack of low energy data, lack of maneuverability for quick monitoring of transient sources, low count rate ability will be the limitations. Several of the concepts of continuum fitting would be validated and the requirements the Black Hole Tracker can be further refined based on the Nustar data.

2. Astrosat: Again the hard X-ray detector has similar resolution as Swift/BAT, 3–4 keV at 20 keV. But, being a collimated detector, some of the requirements of continuum fitting can be further refined, particularly if a simultaneous observation with Nustar can be attempted.

3. Astro-H: This comes closest to all the requirements of continuum fitting. But, it is unlikely to have the nimbleness to look at a large number of sources. The Astro-H HXI is similar to NuStar and thus comes close to requirement of energy range and energy resolution, but lack of crucial low energy coverage limits its use, particularly for BH-spin measurement. Other Astro-H instruments suffer from the same drawback of non-overlapping energy ranges similar to the present day instruments.

4. Can black hole tracker at 2000kg really be made for 200 MUSD?

Yes.

It is assumed that with SuperMon, the technology will be proven, and hence it is only scaling. This has a huge cost impact. Astrosat, which uses known technologies and has similar size scale (600 – 700 kg payload and ∼2000 kg satellite), has a budget of 50 MUSD. But it does not account for the hidden running costs and the huge delay (10 years and still counting). An appropriate scaling would be Nustar which was made in about 100 MUSD. Hence it is assumed that the launch cost would be about 50 – 60 MUSD, spacecraft cost would be ∼100 MUSD and the instruments could be built in about 40 – 50 MUSD.

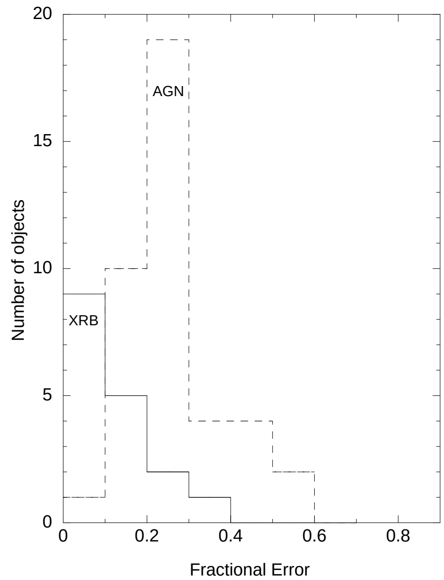

Fig. 1.— The number distribution of errors in black hole mass measurements in AGNs and XRBs.

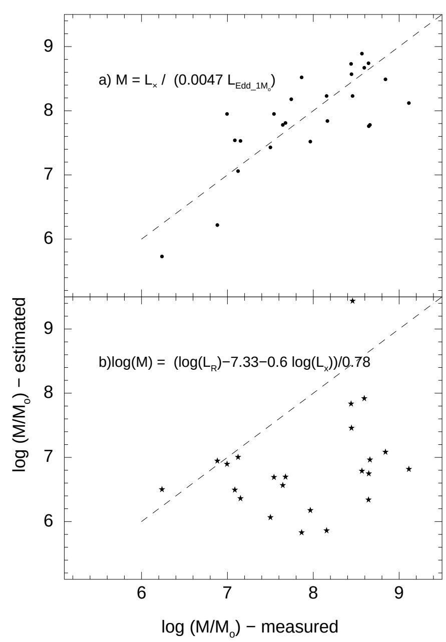

Fig. 2.— The predicted mass of AGNs, based on a) X-ray luminosity is a constant fraction of Eddington luminosity and b) fundamental plane X-ray/radio correlation.

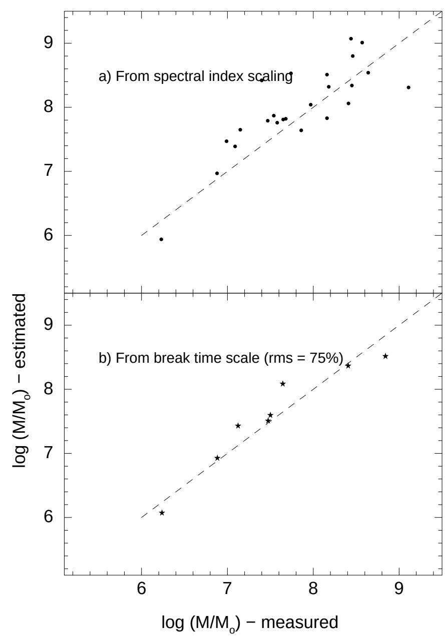

Fig. 3.— The predicted mass of AGNs, based on a) spectral index scaling and b) break time scaling.

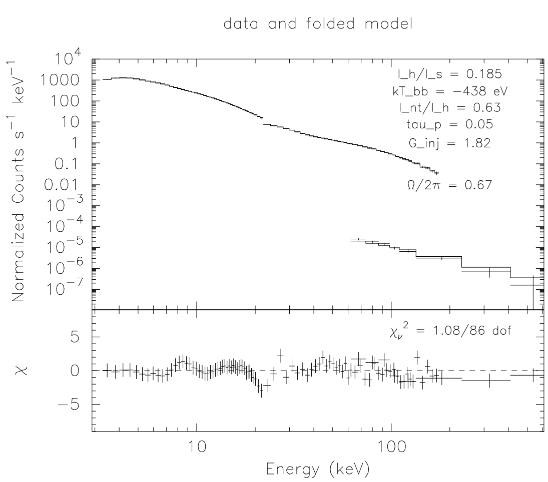

Fig. 4.— A wide band fitting of the eq-pair model for emission from close to black holes.

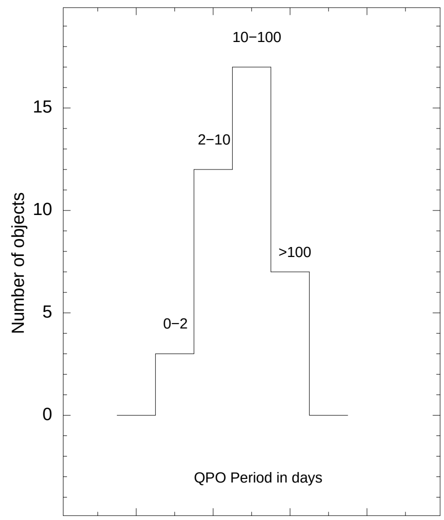

Fig. 5.— The distribution of expected QPOs for 39 AGNs with accurate mass measurement.

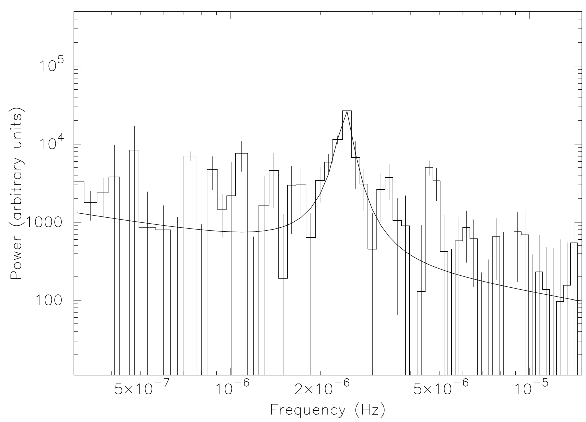

Fig. 6.— A simulation of QPO in AGNs using SuperMon data.

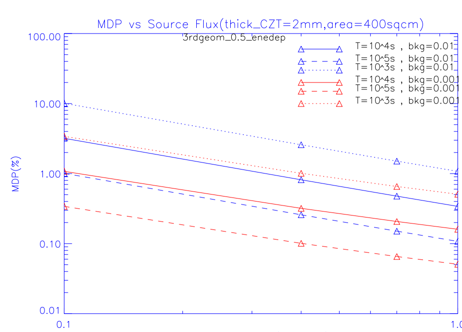

Fig. 7.— The polarization sensitivity of SuperMon.