Answers to the submitted questions for Xenia:

1. Are there ways Xenia could address the IXO science objectives not discussed in the RFI response?

The prime goals of the Xenia mission include the evolution of metals from high red-shift (z>7) using Gamma-Ray Bursts (GRBs) up to the recent past (the metal contents of clusters of Galaxies and the Warm Hot Intergalactic Medium; WHIM). In our response to the RFI we concentrated on those topics where the return of Xenia could be ranked as comparable to IXO. For the other IXO science objectives Xenia will also provide crucial information although not always covering the same part of the observational parameter space. The IXO science objectives we did not discuss in our response were (directly quoted below from the RFI):

“What happens close to a black hole?

Measurement: time resolved high resolution spectroscopy of the relativistically broadened features in the X-ray spectra of stellar mass and supermassive black holes”

Clearly, the expected science return for IXO for this question is focused on the 6 keV Iron line which is above the Xenia energy window. Xenia has been optimized for its field of view, low energy response and fast repointing. This resulted in a small area of 25 (goal 100) cm^2 area for the moderate resolution instrument (HARI) which is not comparable to the area and resolutions provided by IXO and Athena at 6 keV (6500 cm^2 with TES resolution of IXO and 5000 cm^2 for Athena equally distributed over high resolution (few eV) and moderate CCD-like resolution). However, in a similar proposal submitted to ESA in 2011 (ORIGIN) the focal length of the CRIS instrument was increased resulting in a > 100 cm^2 at 6 keV with high spectral resolution which shows that *there is room for optimization.*

More importantly in this context is that relativistic lines are not limited to the Fe-line. Early in the XMM-Newton mission claims have been made about low energy relativistic lines (e.g. Branduardi-Raymont, 2001). This has been disputed and alternative explanations have been provided. More recently the O-lines at 0.7 keV were also found in another object with XMM/RGS (see Madej et al. 2010). These observations indicate that, although less common, effects of strong gravity can also be studied at lower energies and although these features are less well studied than for the Fe line complex, there is no fundamental limitation and one could expect possibly more new insights when this part of the observational parameter space is studied systematically.

When interpreting the question "what happens close to a black hole" not in terms of relativistic lines, but as feedback from SMBHs, *Xenia will be excellent to study* *outflows of AGNs*. A key question in galaxy evolution (or galaxy and core BH co-evolution) is the role of AGN feedback. This can be addressed if the distance of outflows can be determined by measuring the response (delay due to recombination) of the transmission of absorbing gas to continuum variations. Xenia is well suited for this task, utilizing monitoring programs, combined with sufficient effective area and excellent spectral resolution.

"When and how did supermassive black holes grow?"

Measurement: Measure the spin in supermassive black holes; distribution of spins determines whether black holes grow primarily via accretion or mergers.

IXO would perform a deep survey at CCD resolution, to carry out statistical analysis on the (relativistic) iron line profiles to determine the spin of black holes. For this task, one often ignores potential problems associated with narrow line subtraction. Comparing IXO (WFI) with HARI, both have the same energy resolution (CCD). Although the effective area of IXO is about 65 times higher than that of HARI. the respective FoVs are 18 arcmin diameter for IXO versus 90 arcmin for HARI (goal). This means that the grasp, which is the figure of merit that matters most in this context, is 25/65, for HARI/IXO, so not much less. As long as the sources are not close to the confusion limit, HARI will be able to recover a lot of this kind of survey science. The X-ray background per PSF in HARI can be 4 times larger than for IXO assuming a 10 arcsec resolution for HARI and a 5 arcsec resolution for IXO (note that for Athena this has been relaxed to a requirement of 10 arcsec). On the other hand the particle background is much lower due to the LEO orbit, and at the Fe-K line the particle background is more important than the X-ray background. Therefore we expect that IXO and Xenia will have a similar performance. In addition, for a given source, the lower effective area for Xenia is compensated to a large extent by longer exposures. A more precise determination of the Xenia capabilities in that objective depends on fine-tuning of instrument parameters, especially the spatial resolution of the mirror: going from 10 to 5 arcmin, doubles the number of sources found, and pushes the flux detection limit down by a factor of about 4.

References:

1. Madej, O. K., et al. 2010, MNRAS 407, L11.
2. Branduardi-Raymont. G. et al. A&A 365L, 140, 2001

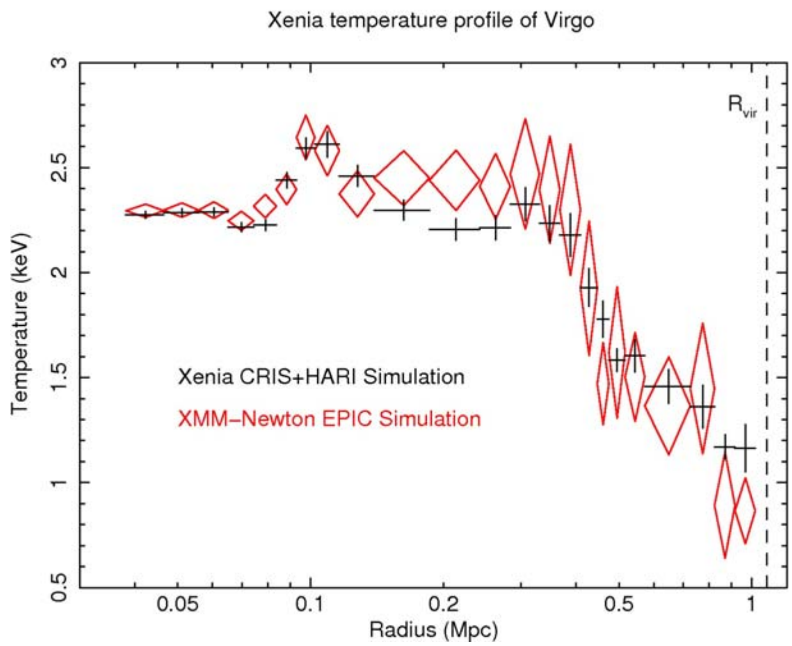
2. Can additional information be provided about the plan to "map temperatures, masses and abundances of clusters beyond the virial radius"? (If results of some simulations were presented at the Workshop it would be very useful.)

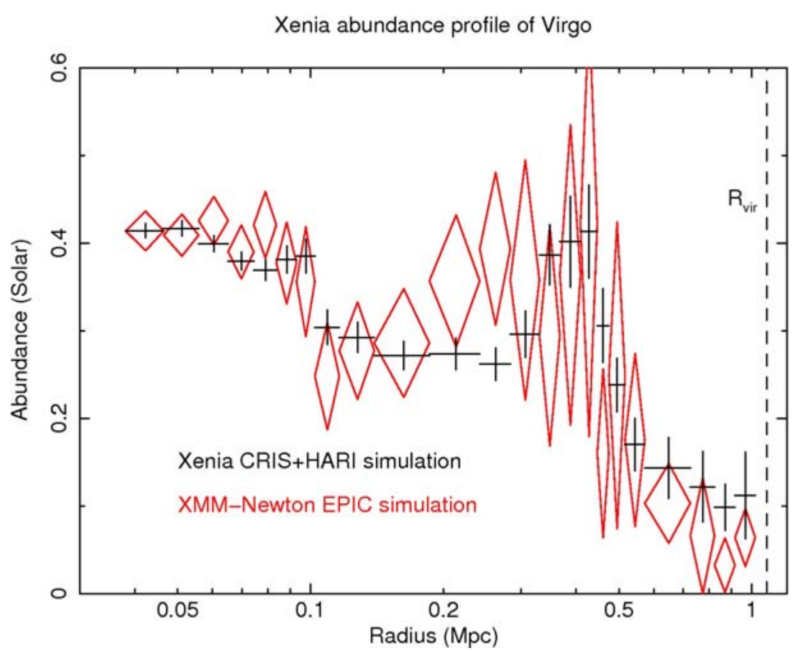
Explain how the combination of the CRIS and HARI instruments might provide data that are much better than we can currently acquire with XMM

(aside from the obvious exception of the calorimeter's spectral resolution). The RFI response states that both will have low background primarily due to the satellite being in low Earth orbit. Both CRIS and HARI have relatively low effective areas. CRIS has a rather large PSF of 4/2.5 arcmin HPD requirement/goal that will hinder any mapping effort. HARI would appear to be the preferred instrument for mapping, but it has CCD-like spectral resolution with less effective area than XMM. It is hard to see how these instruments can do better, especially for high Z clusters. Detailed simulations could support the argument.

To address the above request, we simulated a CRIS+HARI temperature and abundance profile for a radial scan of the Virgo cluster up to R_{200} (based on XMM-Newton data by Urban et al., 2011, MNRAS, 414, 2101). This simulation is based on the same total exposure time as XMM (~200 ks), but since Xenia has a larger FoV, the number of pointings was smaller than XMM (6 Xenia vs. 14 XMM pointings), which allowed for a higher exposure per pointing for Xenia.

The attached plots show a comparison between the Xenia and XMM EPIC simulations. *It is clear that Xenia provides a significant improvement with respect to XMM at all radii of the Virgo cluster*. Since the same input values were used (only the EPIC normalizations were corrected for the smaller XMM-Newton field of view), this is a fair comparison of the error bars obtained with the two observatories. A HARI-only simulation at the same radii gives errors which are ~5 times higher than the published XMM points. However, the high spectral resolution of CRIS allows us to resolve the Fe-L complex and other lines, which leads to a more precise determination of the metal abundance and temperature. Further, the low particle background in HARI is mainly noticeable at energies >2 keV. In this simulation, the instrumental background was not modeled (we are assuming that the cosmic (sky) background dominates). The lower background at high energies allows a more precise determination of the thermal-Bremsstrahlung continuum, and thus the temperature. The combination of both instruments therefore yields errors which are smaller than the ones with XMM.





Simulations of the Virgo cluster (see text for details)

3. Very little is said about the optics for the HARI instrument. The RFI response says that they use polynomial approximations to a Wolter I to reduce off-axis aberrations and provide excellent imaging performance over a wide field of view. It would be useful to see more details on the design of these optics. Are there prototypes that demonstrate this off-axis performance?

First of all, we would like to stress that there is nothing complicated about the wide-field (= polynomial approximation; for the concept please see Burrows, Burg & Giacconi 1992) prescription in contrast to any other prescription for an X-ray optic. Indeed, as many authors have shown (*e.g.*, Elsner et al. 2009, 2010, 2011) the wide-field optic is, for all practical purposes, a simple perturbation of a Wolter I optic. None of the differences lead to any problems or complications insofar as manufacturability is concerned.

As to the question of existence, there have been two prototypes optics built and tested. The Brera group has previously demonstrated the feasibility of large-size wide-field grazing-incidence polynomial mirrors made in SiC. They calibrated prototypes under full illumination at MSFC/XRCF and at MPE/PANTER. They achieved the best results with a prototype having a 2-mm thickness, 60-cm diameter and 24-cm (2-surface) height. The optic used a Chemical Vapor Deposition (CVD)-SiC carrier and a super-polished polynomial mandrel for epoxy replication. The shell had a HPD of ~10″, almost constant across a 60º wide offset scan, and measured at MSFC in X-rays. While this technology may perhaps be obsolete at this time, the Brera team has recently constructed another wide-field optic using polished glass. As reported by Dr. Murray at the PCOS Workshop, the optic achieved about 17" averaged over the field of view before final polishing. Please see the presentation by Dr. Murray for more details.

References:

1. "Optimal grazing incidence optics and its application to wide-field X-ray imaging", Burrows, C.J., Burg, R., & Giacconi, R. 1992, Astrophysical Journal, **392**, 760.
2. "On the design of wide-field x-ray telescopes", Elsner, R. F., O'Dell, S. L., Ramsey, B. D., & Weisskopf, M. C. 2009, Proceedings of the SPIE, **7437**, 13.
3. "Methods of optimizing x-ray optical prescriptions for wide-field applications", Elsner, R. F., O'Dell, S. L., Ramsey, B. D., & Weisskopf, M. C. 2010, Proceedings of the SPIE, **7732**, 83.
4. "Mathematical formalism for designing wide-field x-ray telescopes: mirror nodal positions and detector tilts", Elsner, R. F., O'Dell, S. L., Ramsey, B. D., & Weisskopf, M. C. 2011, Proceedings of the SPIE, **8147**, 35.