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eROSITA on SRG

A X-ray all-sky survey mission

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Abstract. eROSITA (extended ROentgen Survey with an Imaging Telescope Array) is the core instrument on the Russian Spektrum-Roentgen-Gamma (SRG) mission which is scheduled for launch in late 2012. eROSITA is fully approved and funded by the German Space Agency DLR and the Max-Planck-Society. The design driving science is the detection of 50 - 100 thousands Clusters of Galaxies up to redshift z 1.3 in order to study the large scale structure in the Universe and test cosmological models, especially Dark Energy. This will be accomplished by an all-sky survey lasting for four years plus a phase of pointed observations. At the time of writing the instrument development is currently in phase C/D.

Key words. Stars: abundances – Stars: atmospheres – Stars: Population II – Galaxy: globular clusters – Galaxy: abundances – Cosmology: observations

1. Mission overview

The Russian Spectrum-Roentgen-Gamma (SRG) satellite will fly on a medium class platform ("Navigator", Lavochkin Association, Russia). The launch will be in 2012 using a Soyuz-2 rocket from Bajkonur into an orbit around L2. The payload consists of the X-ray instruments eROSITA (extended ROentgen

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Survey with an Imaging Telescope Array) and ART-XC (Astronomical Roentgen Telescope – X-ray Concentrator).

The seven eROSITA telescopes are based on the existing design launched on the ABRIXAS mission plus an advanced version of the pnCCD camera successfully flying on XMM-Newton. In order to optimize eROSITA for the Dark Energy studies, the effective area is increased by a factor of five, the angular resolution is improved by a factor of two, and the field of view is also increased by a factor of two with respect to ABRIXAS. Such a design has been drawn to match the outcome of the most recent calls for ideas on Dark Energy observations (like e.g. by NASA, DOE, ESA, ESO and others).

Similarly to eROSITA ART-XC contains 7 telescopes working in the energy range between 6 and 30 keV. The telescopes are conical approximations of the Wolter-I geometry with CdTe detectors in their focal planes (Pavlinsky et al., 2010, this Volume)

2. Design Driving Science

2.1. Dark Energy

One way to test cosmological models and to assess the origin, geometry, and dynamics of the Universe is through the study of the large-scale structures Indeed galaxy clusters are strongly correlated and thus they are good tracers of the large-scale structure on very large scales by sampling the most massive congregates of matter. The galaxy cluster population provides information on the cosmological parameters in several complementary ways:

1. The cluster mass function in the local Universe mainly depends on the matter density Ω_m and the amplitude of the primordial power spectrum σ_8.
2. The evolution of the mass function f(M,z) is directly determined by the growth of structure in the Universe and therefore gives at the same time sensitive constraints on Dark Matter and Dark Energy.
3. The amplitude and shape of the cluster power spectrum , P(k) and its growth with time, depend sensitively on Dark Matter and Dark Energy.
4. Baryonic wiggles due to the acoustic oscillations at the time of recombination are still imprinted on the large scale distribution of clusters (i.e. in their P(k) and the Autocorrelation function) and thus can give tight constraints on the curvature of space at different epochs.

The constraints provided by the different cosmological tests with clusters are complementary in such a way, that degeneracies in the parameter constraints in any of the tests can be broken by combinations. The simultaneous constraint of Ω_m and σ_8 by combining method 1 and 3 above is one such example Schuecker et al. (2003). In addition the combination of several tests provides important consistency checks as explained below. In addition to the above applications, galaxy clusters have been used as cosmological standard candles to probe absolute distances, analogous to the cosmological tests with supernovae type Ia. The assumption that the cluster baryon fraction is constant with time combined with observations of this quantity provides constraints on Dark Matter and Dark Energy, e.g. Allen et al. (2004)). In a very similar way, combined X-ray and Sunyaev-Zeldovich-measurements provide a mean for absolute distance measurements and constraints of the geometry of the Universe, e.g. Molnar et al. (2004).

Large, well defined and statistically complete samples of galaxy clusters (which are dynamically well evolved and for which masses are approximately known) are obvious prerequisites for such studies. A substantial progress in the field requires samples of tens to hundreds of thousands of clusters. Surveys at several wavelengths are used or planned to be used to achieve this goal. More in general, in X-ray surveys, galaxy clusters are detected by the radiation of the hot intracluster medium and X-ray observations are still the most efficient tools to select clean cluster samples. In addition X-ray observations provide accurate estimates of the cluster physical parameters. Indeed the X-ray luminosity is tightly correlated to the gravitational mass, temper-

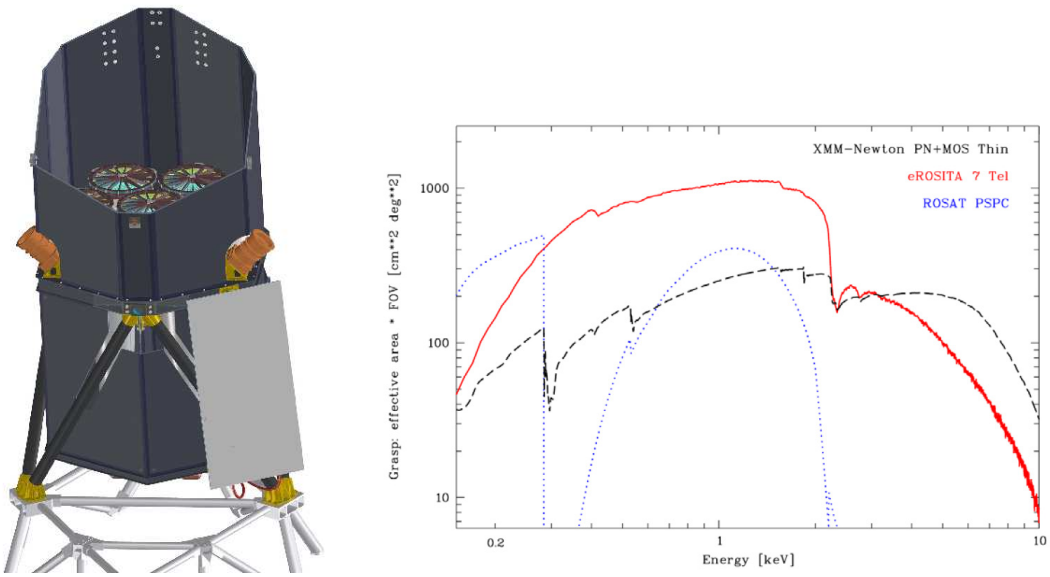

Fig. 1. *Left Panel* : The eROSITA telescope on board SRG. *Right Panel* : The grasp of eROSITA compared with ROSAT-PSPC and XMM-Newton.

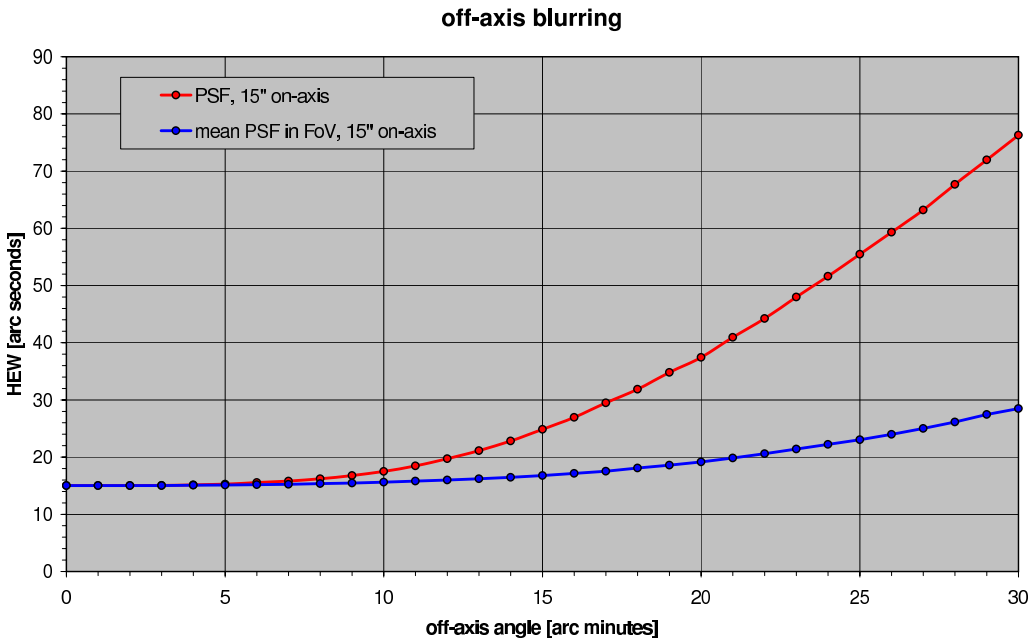

Fig. 2. *Red Curve*: the PSF HEW as function of the offaxis angle in pointing mode. *Blue Curve*: the PSF HEW within an encircled off-axis angle during a scan. Basically the value at 30′, is the cumulative PSF in the survey.

ature and core radius Reiprich et al. (2002). Therefore most cosmological studies involving galaxy clusters are based on X-ray surveys (e.g. Henry (2000), Henry (2004), Böhringer et al. (2000), Vikhlinin et al. (2003).

3. Instrument

The mirror replication technique was developed for XMM-Newton and has then been applied to the small satellite mission ABRIXAS, which had scaled the XMM-Newton telescopes down by a factor of about 4. The ABRIXAS optical design and manufacturing process are adopted for eROSITA partially because the inner 27 mirror shells and therefore the focal length are kept the same. The mirror system consists of 7 mirror modules with 54 mirror shells each and a X-ray baffle in front of each module. Unlike on ABRIXAS, the seven optical axes are co-aligned. Compared to a large single mirror system, the advantages of a multiple mirror system are: shorter focal length (reduced instrumental background) and reduced pileup when observing bright sources. This configuration allows a more compact telescope and multiple but identical cameras which automatically provides a 7-fold redundancy. The capabilities of the X-ray mirror system are described by effective area, vignetting function, and PSF. The production of the flight mirrors has already started. The eROSITA-CCD Meidinger et al. (2009) have 384 × 384 pixels or an image area of 28.8 mm × 28.8 mm, respectively, for a field of view of 1.03° diameter. The 384 channels are read out in parallel. The nominal integration time for eROSITA will be 50 msec. The integrated image can be shifted into the frame store area by less than 100 msec before it is read out within about 5 msec. CCD together with the two CAMEX and the (passive) front-end electronics are integrated on a ceramic printed circuit board (CCD-module) and is connected to the "outer world" by a flexlead. The flight-CCDs have already been fabricated. For operation the CCDs have to be cooled down to -80 °C by means of passive elements (heatpipes and radiator). Fluorescence X-ray radiation generated by cosmic particles is minimized by a graded shield consisting of aluminum and boron carbide. For calibration purposes, each camera housing contains a radioactive Fe^{55} source and an aluminum target providing two spectral lines at 5.9 keV (Mn-K_α) and 1.5 keV (Al-K_α). The mechanism ("Filter Wheel") for moving the calibration source into and out of the field of view is designed and qualified. Also the telescope structure is qualified. The optical bench connects the mirror system and the baffles on one side with the focal plane instrumentation on the other side. Additionally, it forms the mechanical interface to the S/C bus. The flight model manufacturing is on-going. The dimensions of the telescope structure is of the order 1.9 m diameter x 3.2 m height. The total weight of eROSITA is 735 kg Predehl et al. (2007). The instrument design is shown in Figure 1.

4. Sensitivity

Figure 1 shows the grasp of eROSITA, i.e. the product of effective area and solid angle of the field of view. The effective area of eROSITA is about twice that of one XMM-Newton telescope in the energy band below 2keV, whereas it is three times less at higher energies. This is a consequence of the small f-ratio (focal length vs. aperture) of the eROSITA mirrors. An advantage of the short focal length is also larger field of view. The eROSITA angular resolution is 15 arcsec on-axis. Due to the unavoidable off-axis degradation of a Wolter-I telescope, the angular resolution averaged over the field of view is of the order of 28″ (Fig. 2). We will scan the entire sky for four years (ROSAT 1/2 year). Therefore the eROSITA sensitivity during this all-sky survey will be approximately 30 times ROSAT. With the current scanning strategy, we expect an average exposure of ∼3 ks in the all-sky survey, with two deep fields at the ecliptic poles with an exposure of the order of 20-40 ks, depending on the actual mission strategy.

We have performed simulations of the radiation environment in L2 and determined, by including the cosmic components, a background intensity of 5.63 cts s^{-1} deg^{-2} and 3.15 cts s^{-1} deg^{-2} in the 0.5–2 keV and 2–10 keV energy bands, respectively.

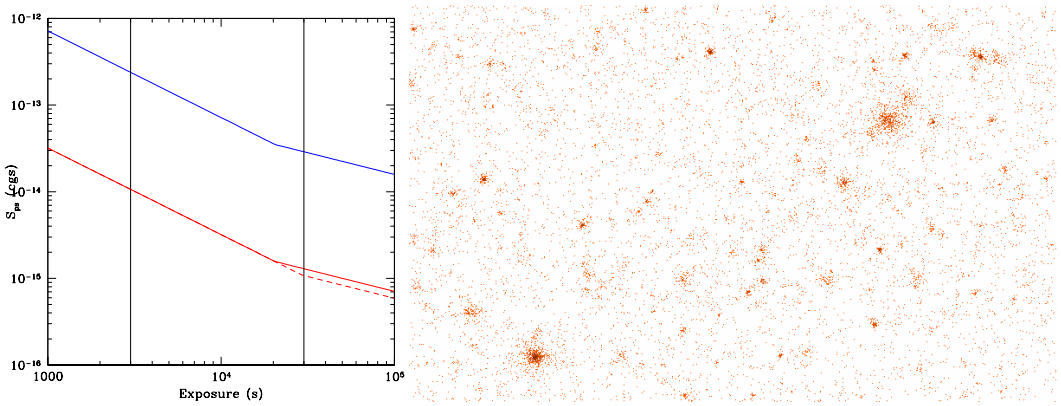

Fig. 3. *Left Panel* : the 5σ point-source sensitivity vs. exposure in the 0.5–2 keV (*red*) and 2–10 keV (*blue*) energy bands by assuming a PSF HEW of 30″ and 40″, respectively. The dashed lines is the sensitivity achieved with an average PSF-HEW of 25″. *Right Panel* : A simulation of a 3ks observation of a 1°×1.6° of eROSITA in survey mode. The simulations includes cosmis+particle background, randomly distributed AGN and clusters extracted from Hydrodinamical simulations.

The 0.5-2 keV flux limit for clusters will be, on average, of the order of 3×10^{-14} erg cm^{-2} s^{-1} and 5×10^{-15} erg cm^{-2} s^{-1} in the all-sky survey and in the ecliptic poles, respectively. In Figure 3 we plot the eROSITA 5σ point source flux limit of the survey in the 0.5–2 keV and 2–10 keV energy bands as function of the exposure time. In the all-sky survey the typical flux limit will be $\sim10^{-14}$ erg cm^{-2} s^{-1} and $\sim3\times10^{-13}$ erg cm^{-2} s^{-1} in the 0.5-2 keV and 2–10 keV energy band, respectively. At the poles we expect to reach flux limits of the order of $\sim2\times10^{-15}$ erg cm^{-2} s^{-1} and $\sim3\times10^{-14}$ erg cm^{-2} s^{-1} in the 0.5-2 keV and 2–10 keV energy band, respectively. Note that the observation will be photon limited up to exposures of ∼20 ks. In the 0.5–2 keV band, the confusion limits of 1 source every 10 beams will be reached in about 20-30 ks. At this fluxes the X-ray sky is dominated by clusters and AGN, which can be separated with an angular resolution of 25″–30″. The logN-logS of clusters is well known to the proposed depth (Gioia et al. (2001), Rosati et al. (2002), Finoguenov et al. (2007)). The proposed survey will identify 50,000 100,000 clusters depending on the capabilities in disentangle moderately-low extended sources from AGN. Concerning the number of AGN we can use the logN-logS measurement in moderately wide field surveys, like XMM-COSMOS Cappelluti et al. (2007), Cappelluti et al. (2009), to predict the detection 3-10×10^6 sources, up to z∼7-8, depending on the detection threshold. A simulation of a 3 ks eROSITA observation of a typical extragalactic field is shown in Figure 3. Multi-band optical surveys to provide the required photometric and spectroscopic redshifts are already in the planning stages, and will be contemporaneous with or precede our survey. The cluster population will essentially cover the redshift range z = 0 - 1.3 and will reveal all evolved galaxy clusters with masses above $3.5\times10^{14}h^{-1}M_{\odot}$ up to redshifts of 2. Above this mass threshold the tight correlations between X-ray observables and mass allow direct interpretation of the data.This sample size is necessary for example to precisely characterize the cluster mass function and power spectrum in at least ten redshift bins, to follow the growth of structure with time.

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