THE SPEKTROSAT MISSION

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ABSTRACT

High resolution spectroscopy will be an important diagnostic tool in future X-ray astronomy. SPEKTROSAT, the follow-up mission to ROSAT will be equipped with a transmission grating spectrometer with a spectral resolution of 0.2 Å over the wavelength range between 6 Å and 300 Å. Third order aberations are minimized by a mounting of the grating elements according to the Rowland-torus geometry. The ROSAT mirror system will be slightly changed by a redesign of the optical stops in order to reduce the field of view. The Focal Instrumentation has to be modified for a better match with the spectroscopic requirements. Since SPEKTROSAT is almost identical to ROSAT, this concept offers a large amount of science at relatively low costs. Its limiting line sensitivity will be about 20 times better than that of the EINSTEIN-OGS.

1. SCIENTIFIC RATIONALE

ROSAT will perform the first all-sky survey in X-rays using focussing optics. After the ROSAT survey about 10^5 individual sources are known with a position better than 1 arcmin but low spectral resolution. Detailed investigations on a subset of these sources will be carried out after the sky survey in the pointing phase of the mission. The spectral resolution is limited by the intrinsic energy resolution of the focal instrumentation detectors. A logical next step would be high throughput, high resolution spectroscopy. By using dispersive methods, a mirror system with a quality of at least that of the ROSAT mirror system is required in order to avoid unfeasable grating ruling densities and very large focal plane detectors. According to that mirror, SPEKTROSAT will be a 'soft' instrument dedicated to a wavelength band between 6 and 300 Å.

The soft energy bandpass (below 2 keV) especially is important for the study of stellar coronae. Almost all types from 'normal' (like the sun) to strong variable stars (e.g. cataclysmic variables) are interesting objects. Luminous sources like X-ray binaries and supernova remnants can be observed spatially resolved also in the Magellanic Clouds and even in the Andromeda Nebula. The hot gas in clusters of galaxies can be investigated. The non-thermal character of sources like the Crab

Nebula or the emission from Active Galactic Nuclei can be verified only be means of spectroscopy.

The absorption due to the Interstellar Medium produces prominent edges in the (continous) spectrum of background sources. The investigation of the strength of these edges leads to a knowledge about the abundances of the lighter elements (C, N, O, Ne, Mg and Al).

In this context, the spectral range between 90 and 200 Å is especially interesting, because it contains very intense lines from highly ionized iron (Fe XVIII - Fe XVII) as well as lines produced in a cooler plasma (Fe IX - XII). Therefore temperature and density diagnostic of heterothermal plasmas as likely parts in stellar coronae are possible (Schmitt, 1988).

In addition, the XUV part of the spectra is of particular interest for the photosperic X-ray radiation of hot white dwarfs as well as X-ray and XUV radiation from hot stars whis is - presumably - produced by numerous shocks in their winds.

Summarizing, SPEKTROSAT is the only proposed mission, dedicated purely to high resolution X-ray spectroscopy. It is particularly important for studies of stellar coronae, hot white dwarfs and low N_h AGN.

2. THE SPEKTROSAT CONCEPT

The use of transmission gratings as dispersive elements in X-ray telescopes with an angular resolution in the arcsec range is preferable to the use of reflection gratings, because a transmission grating spectrometer can be incorporated into an existing telescope without major changes of the overall design.

SPEKTROSAT will be an almost identical copy of ROSAT except for the inclusion of a transmission diffraction grating and a modified focal plane instrumentation. As a baseline it carries two high resolution imagers and one proportional counter (the ROSAT focal instrumentation contains two PSPC and one HRI, Pfeffermann, 1986). Minor changes will also be made in the mirror system: in order to avoid spectral confusion by having more than one X-ray source in the direction of dispersion, the field of view is reduced from 2 degrees to 45 arcmin by a redesign of the optical stops. From the ROSAT experience it seems to be feasible to improve the on-axis angular resolution from 3" to 2" (half energy width) thereby increasing the spectral resolving power (Beckstette, 1988).

This concept takes advantage from the fact that most of the S/C-hardware as well the management experience can be carried over from ROSAT thereby reducing costs drastically. Moreover, the extensive ROSAT data analysis system can be used with only minor modifications. The ground operations concept differs from that of ROSAT if SPEKTROSAT is launched into an orbit with 28° inclination (wich is the baseline for Shuttle launches). On the other hand, the scientific performance is enhanced, because the loss due to the belt passages is reduced.

In addition to its main telescope, ROSAT contains also a 'passenger payload', the XUV Wide Field Camera. The possible replacement on SPEKTROSAT by another instrument is investigated currently in industry. Several proposals from the U.S. are already made in order to extend the energy bandpass of the grating spectrometer.

The design of the spectrometer is determined by the environment of the (modified) ROSAT-telescope and by the scientific requirements regarding spectral resolution and the wavelength band to be covered. A resolving power $\lambda/d\lambda = 100$ is needed in order to separate the individual lines of the O VII triplet at 22 Å. The wavelength range should extend at least 200 Å for reasons mentioned above.

According to the grating formula $\sin \alpha = \lambda/d$ (d=grating period) the achievable spectral resolution and the wavelength range are complementary. At a given angular resolution of the telescope, the spectral resolution is determined by the ruling density of the grating. Increasing the ruling density requires a larger focal plane detector (or the wavelength band is reduced).

The environment for the spectrometer is given by the geometry of the telescope (Aschenbach, 1986 and Table 1). The on-axis resolution is affected not only by the mirror-detector combination, but also by other spacecraft subsystems, e.g. the attitude measurement and thermal control (Table 2). The error budged leads to a half energy width of 4.8 arcsec (3.8 arcsec design goal) for the worst case of faint sources. By observing bright sources, where autocorrelation methods within the data analysis can be applied, some of the errors are reduced (or even neglected) leading to only 2.5 arcsec on-axis resolution. This value corresponds to 0.18 Å spectral resolution assuming a grating ruling density of 1000 l/mm and a distance of 1700 mm between the grating and the focal plane.

TABLE 1: Geometry of the (SPEKT-)ROSAT telescope

entrance diameter paraboloids	(mm)	834.9, 695.7, 573.0, 466.1
interface diameter par./hyp.	(mm)	785.5, 653.2, 537.1, 436.4
exit diameter hyperboloids	(mm)	660.0, 548.8, 451.2, 366.6
length of all mirror shells	(mm)	500
total collecting area	(mm)	1141
focal length	(mm)	2400
distance grating focal plane	(mm)	1700
detector size	(mm)	< 120

TABLE 2: Subsystem error budged (68% encircled energy)

Subsystem	ROSAT	SPEKTROSAT	
	(verified)	(baseline)	(goal)
Mirror Assembly	1.9	1.28	1.28
Thermal Control Mirr.	0.9	0.9	0.9
Structure Telescope	2.2^1	-	-
Thermal Control Struc.	1.15^2	1.15	1.15
Fiducial Light System	1.5	1.5	1.5
Focal Plane Instrument	2.0	0.64	0.64
Attitude Measurement	1.75	1.75	0.9^3
RMS (half energy width)	8.1	4.8	3.8

$^{1)}$: bias only; $^{2)}$: random only; $^{3)}$: noise only

Since the grating is mounted in the convergent beam behind the mirror, it is exposed to nonparallel light. A plane mounting would produce optical aberrations thereby reducing the spectral resolution. This effect is dominant over the intrinsic resolution given by the mirror-detector combination. Therefore, the grating is required to have an appropriate curvature, the so-called Rowland torus. This geometry is approximated by a

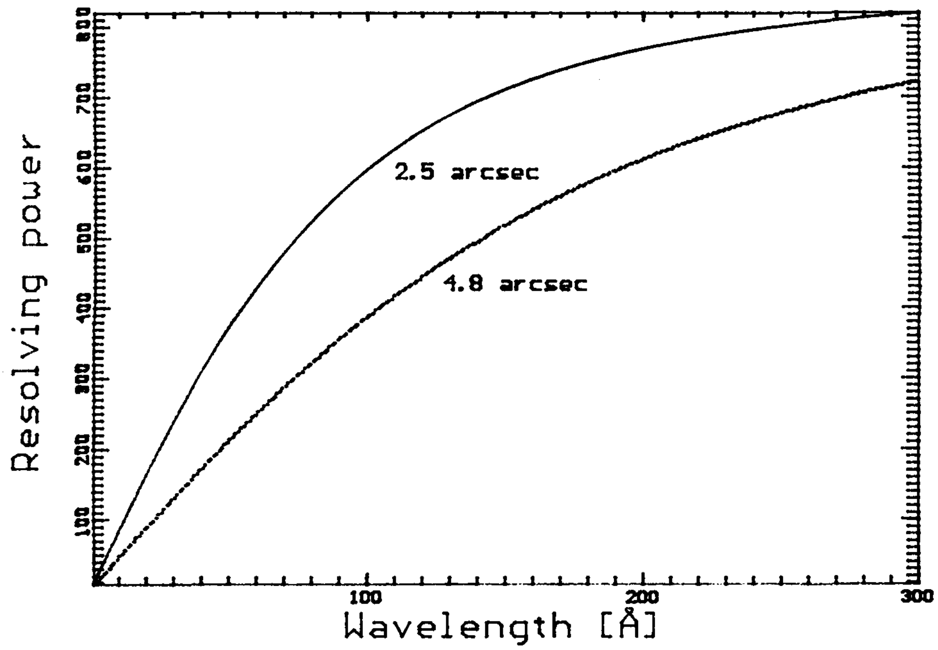

Figure 1: Spectral resolving power of the SPEKTROSAT instrument for faint sources (worst case) and strong sources (best case).

large number of (flat) individual grating facets and also by a curvature of the detector. Residual optical aberrations result from the finite size of the elements, which reduce the resolution at longer wavelengths (Predehl, 1988 and Figure 1). A small extension of the spectrum perpendicular to the direction of dispersion (astigmatism) does not affect the spectral resolution but extends the size of the resolution elements thereby increasing the sensitivity against background (intrinsic detector noise, particles, also diffuse X-ray's).

3. SPECTROMETER PERFORMANCE

The sensitivity of the telescope without grating is quite similar to that of ROSAT (with the HRI in focus). Differences arise from the fact that the wavelength band is extended and therefore modified filters have to be used. For spectroscopy, at least 100 events are required in an individual line. On the other hand, typical observation times will range from several hours to a day. Table 3 contain the sensitivy of SPEKTROSAT for a number of different spectral lines in terms of 100 counts per 10000 seconds. The background is always less than 1 count per resolution element.

TABLE 3: Line sensitivity (100 cts / 10^4 s)

Element	λ (Å)	S (erg/cm2/sec)
C VI	33.7	$2.1 * 10^{-13}$
N VII	24.8	$4.2 * 10^{-13}$
O VII	21.6	$5.8 * 10^{-13}$
O VIII	18.6	$7.2 * 10^{-13}$
Ne IX	13.5	$10. * 10^{-13}$
SI XII	44.1	$1.3 * 10^{-13}$
S XII	39.9	$1.5 * 10^{-13}$
Fe XVI	50.5	$1.2 * 10^{-13}$
	63.7	$1.1 * 10^{-13}$
	66.4	$1.0 * 10^{-13}$
Fe XXII	135	$0.8 * 10^{-13}$
Fe XXIV	192	$0.6 * 10^{-13}$

The quality of a transmission grating can be characterized by its first order efficiency and the degree of higher order supression. For a classical amplitude grating, both depend only on the bar-slit ratio within the grating period. An optimum is achieved at a ratio of 1:1. Then, the first order efficiency reaches its maximum of about 10% (for each of both sides of the symmetric spectrum) and all even orders are cancelled out. At shorter wavelengths, the efficiency depends also on the wire thickness due to transparency effects, which can be used in order to increase the efficiency up to 20%. A long term development-program at MPE lead to gratings having an efficiency very close to this theoretical optimum (Predehl, 1986 and Figure 2).

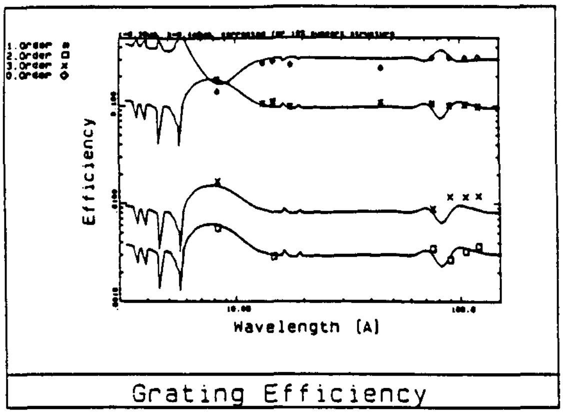

Figure 2: Measured and calculated efficiencies for a grating with 1000 gold wires per mm. These are one-side efficiencies, corrected for the obstruction due to the support grid (18%).

The quality of a grating produces spectrum does not only depend on the geometry of the spectrometer and the bar slit ratio. Any distortion of the grating itself would be reflected in a degradation of the spectrum. Possible sources of distortion may be: broken or missing bars, deviation of the grating foil from the plane, varying grating period, or a 'scatter' of the bars around their nominal positions. These effects reduce the efficiency and (more seriously) the spectral resolution.

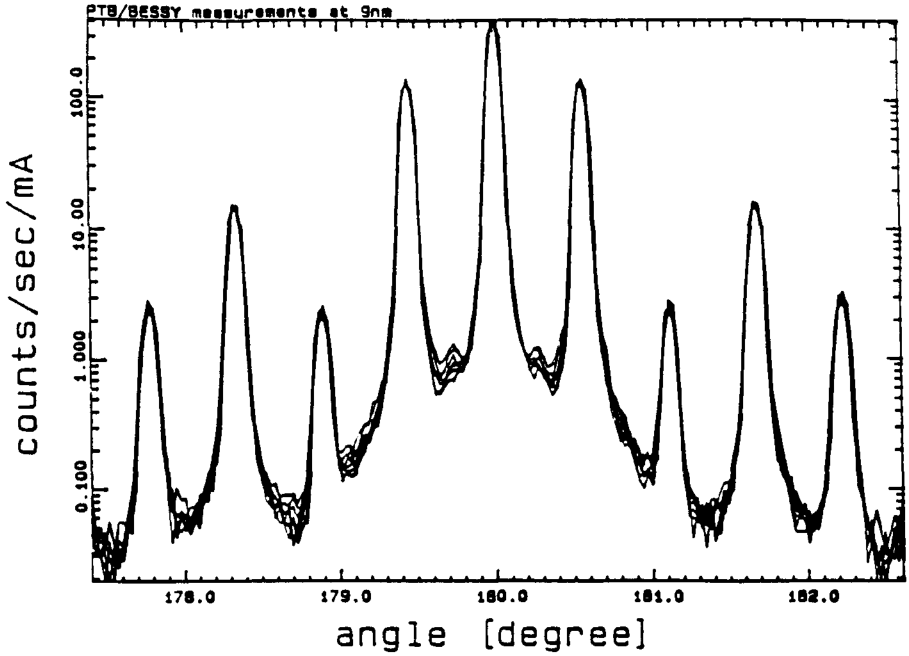

Figure 3: Spectra obtained at different locations on the grating. The wavelength is 90 Å, the intensity is normalized to the synchrotron storage ring current.

Measurements in the visual wavelength range yielded resolving powers $\lambda/d\lambda > 6000$ for our gratings, limited by the non-flatness of the grating foil. Deviations of the order of μm are sufficient to distort the diffraction pattern. Due to the diffraction geometry, this effect can be neglected in the X-ray region, because a remarkable fraction of a mm is needed in order to produce the same effect. Unfortunately, there is no way to measure the spectral resolution directly in X-rays, because no focussing optics with an angular resolution in the arcsec range is available at the present time.

For SPEKTROSAT, several hundred individual facets will be assembled to the torus. All facets have to be identical within very narrow tolerances. Figure 3 demonstrate the excellent degree of uniformity achieved so far.

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