Extended X-ray emission from the face-on spiral galaxy M83: a galactic halo produced by an active star-forming disk?

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ABSTRACT

ROSAT PSPC investigations of M83 (Ehle et al. 1998) show complex X-ray emission from the extended hot interstellar medium as well as from point-like X-ray sources in this nearby face-on spiral galaxy. Several observational results support the existence of a huge spherical gas halo in addition to emission from the galaxy's disk.

A comparison of X-ray and radio observations of nearby galaxies with high levels of star-formation supports the hypothesis that a high energy input rate in the galactic disk triggers the outflow of hot gas and the halo formation.

The XMM satellite can be used to spatially disentangle the emission from galactic disks and halos. Future spectral investigations performed with XMM will help to unravel the excitation conditions of the hot X-ray emitting gas.

1. Introduction

While there is increasing evidence that star forming activity in the disks of spiral galaxies is related to the existence and structure of radio halos, further studies are needed to test the correlation between the energy input by supernovae in the disk and the surface brightness and evolution of X-ray halos. It is important to observe edge- as well as face-on orientated galaxies: the face-on orientation minimizes absorption of point sources and – given the angular resolution of the telescope is high enough – allows a clear separation of point-like sources and diffuse emission. In edge-on galaxies it is possible to map the extended halo emission.

2. Separation of Emission Components

2.1. Point-like Sources

We detected 13 point-like sources in M83, 10 of which were previously unknown, down to a limiting sensitivity of $\sim 0.8 \cdot 10^{38}$ erg s^{-1}. Eight of them are positionally correlated with HII regions and/or HI voids and could be giant bubbles of hot gas in star-forming regions, young supernova remnants, ultraluminous X-ray binaries or a combination of all these components (Williams & Chu 1995). A detailed discussion of time variability, properties of individual sources and a comparison with HI channel maps is in preparation and will make use of sensitive ROSAT HRI observations. A preliminary contour map of this 48 ksec HRI exposure is given in Fig. 2.

2.2. The Nuclear Region

Spectral modelling tells us that the nuclear X-ray emission is complex. A comparison of the observed spectra of the nuclear and the disk area (Figs. 3) shows that the nuclear emission is harder than the extended disk and halo emission of M83. The soft X-ray emission of the nucleus is clearly extended and shows a ridge-like structure pointing approximately in the direction of the optically visible bar. However, the reason for the strong asymmetry of the hard nuclear X-ray radiation (dominating the broad band emission visible in Fig.1) could not be found from the PSPC observations alone. Only the sensitive ROSAT HRI observations (Fig. 2) show that part of the 'extended' nuclear emission indeed originates from point-like sources.

2.3. Extended Emission

A discovered agreement of the galactocentric scale length of the hard-band diffuse X-ray- and of the thermal radio emission favours the idea that the hard diffuse emission is due to hot gas produced by star-forming regions in the galactic disk. This hypothesis is further supported by the fact that a 'hump' in the radial profile at ~ 5 kpc radius is also visible in the optical light where it indicates the presence of active and recent star formation. On the other hand, the smooth profile of the soft, diffuse X-ray emission together with its shallow radial descent supports the idea that this X-ray emission component is related to a different distribution and place of origin of the emitting sources. The asymmetric distribution of the soft X-rays supports the existence of a spherical gas halo: the galactic disk is opaque to soft X-rays so that we only see the emission from the front hemisphere.

The existence of several hot gas components is further supported by the spectral characteristics of the diffuse emission: Our best fit to the data (Fig. 3, right) is a two-temperature Raymond-Smith plasma ($T_1 = 2.1$ and $T_2 = 5.7 \cdot 10^6$ K) with both internal and external (galactic foreground) absorption. Actually, we expect the gas to have a continuous temperature distribution. More sophisticated spectral models in combination with the new XMM telescope will allow a better description of the hot interstellar medium.

3. Comparison with other galaxies

The luminosity of the diffuse X-ray emission in M83 of $3.6 \cdot 10^{40}$ erg s^{-1} in the broad ROSAT energy band is very high. The (distance-independent) mean surface brightness I_x of the soft diffuse emission alone is about twice that of NGC 253 (Table 1). In edge-on view the X-ray halo of M83 would probably look even more spectacular than that of NGC 253 (Fig. 4).

To search for a common reason for this difference between M83 and NGC 253 we compare them with other galaxies where diffuse X-ray emission is detected. This is done in respect to the

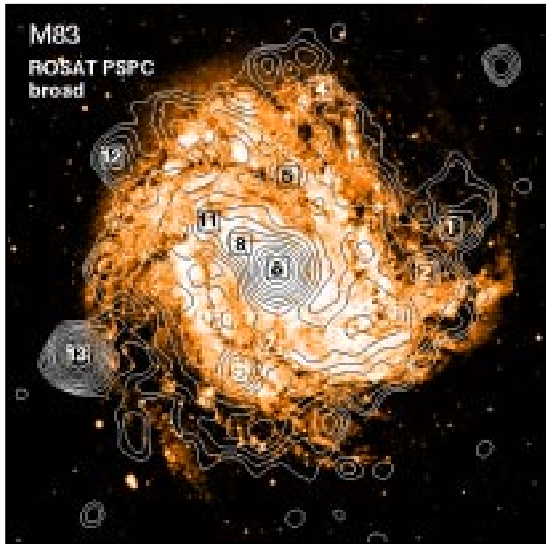

Fig. 1.— Broad-band (0.1-2.4 keV) ROSAT PSPC contours of M83 overlaid onto a deep optical image from the 3.9m Anglo Australian Telescope, kindly provided by David Malin. Here we are showing only the central part of the PSPC field of view. ROSAT-detected sources in M83 are marked as squares (Ehle et al. 1998). The image has been combined from subimages in the individual energy bands which have been smoothed with the FWHM of the average PSPC point response function and exposure-corrected for the respective energy bands. Contour levels increase by $2^{n/2}$. Contours are $(1, 1.4, 2, 2.8, 4, ...) \times 1 \cdot 10^{-3}$ cts s^{-1} arcmin^{-2} above the background.

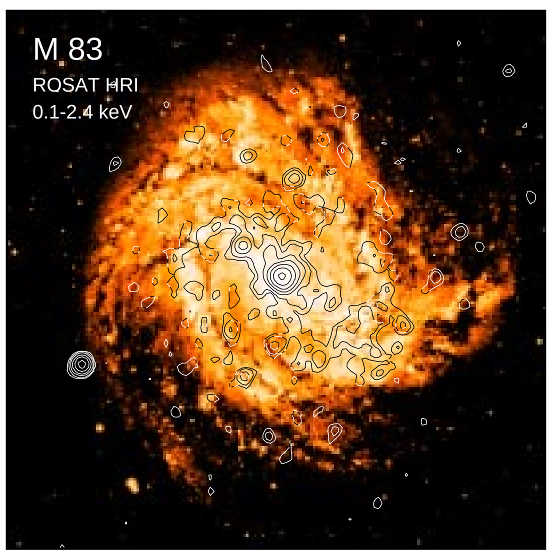

Fig. 2.— Contour map of the ROSAT HRI image of M83 (energy band 0.1-2.4 keV) smoothed to a FWHM of 12". Contour levels are $(3, 5, 10, 20, 40, 80, 160) \times 2.5 \cdot 10^{-2}$ cts s^{-1} arcmin^{-2} above the background.

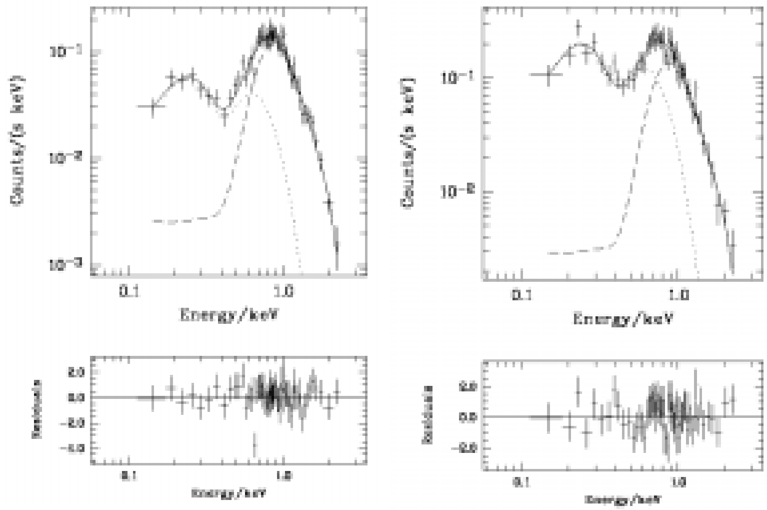

Fig. 3.— Observed ROSAT PSPC spectrum of the nuclear area (left) and extended emission (right) of M83 between 0.1 and 2.4 keV together with the two-temperature fits. The contribution of the low-temperature component is indicated separately as the dotted and that of the high-temperature component as the dashed curve. The lower part of the diagram shows residuals in units of standard deviations.

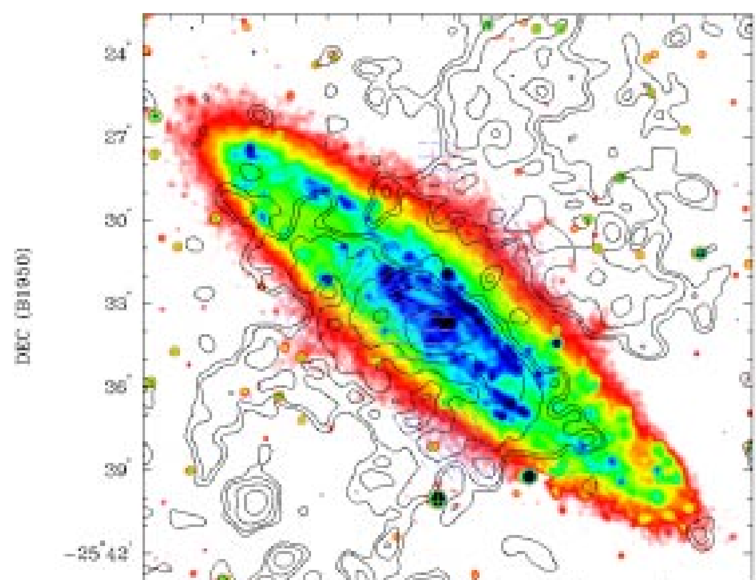

Fig. 4.— A multispectral view of NGC 253 (Ehle et al., in prep), in which the ROSAT soft PSPC band (0.1-0.4 keV) contour map (Pietsch 1993) has been superposed onto an HII image. Vectors show the magnetic field orientation deduced from observations of the linearly polarized nonthermal radio emission (Beck et al. 1994).

supernova rates and distance-independent parameters like the X-ray surface brightnesses I_x and the energy input per surface area, $\dot{E}_A^{tot}$, a quantity that measures the activity in the galactic disk which seems to be important for the evolution of galactic radio halos (Dahlem et al. 1995, Golla 1997). Results for four galaxies are presented in Table 1.

Table 1: Comparison of M83 and other galaxies with diffuse X-ray emission

Galaxy (1)	D (2)	r_{SF} (3)	ν_{SN}^{nt} (4)	ν_{SN}^{FIR} (5)	$\dot{E}_A^{tot}$ (6)	I_x (7)
M83	8.9	9.9	0.29	0.49	3.2	2.9
NGC 253	2.58	7.7	0.11	0.15	1.9	1.5
		2.3†			22.7	
NGC 3628	6.7	7.0	0.04	0.06	0.9	1.0
NGC 4565	9.7	16.9	0.02	0.04	0.1	0.5

†in NGC 253 most of the star formation is limited to the inner disk

(2) assumed distance in Mpc

(3) radial extent of star-forming disk in kpc, estimated from IRAS CPC observations (van Driel et al. 1993)

(4) supernova rate in yr^{-1}, calculated from the power of nonthermal radio emission

(5) supernova rate in yr^{-1}, calculated from FIR luminosities

(6) mean energy input rate per unit surface area (as defined in Dahlem et al. 1995) in 10^{-3} erg s^{-1} cm^{-2}

(7) X-ray surface brightness in 10^{-6} erg s^{-1} cm^{-2}, calculated over the area of soft halo emission in NGC 253, NGC 3628 and NGC 4565 and over the extent of the soft diffuse emission in M83, respectively

The supernova rates and consequently the energy input rates into the interstellar medium are well correlated with the X-ray surface brightnesses. The energy input rate in case of M83 is very high and even higher than that for NGC 253 (if averaged over the whole area of star formation). The energy input rate from the inner star-forming disk of NGC 253 alone is by far the highest, a result that might explain the extreme vertical extent of the X-ray halo emission of that galaxy.

An important finding of our study is that outflow models for the transport of hot gas up into the halo should not be restricted to nuclear starbursts and superwinds (Suchkov et al. 1994), but should include the whole star-forming galactic disk. M83 is likely to be a good example of a X-ray halo produced by an active star-forming disk.

4. How XMM can help...

Further studies are needed to test the correlation between the energy input by supernovae in the disk and the surface brightness and evolution of galactic X-ray halos.

The XMM satellite with its high sensitivity will help us to detect the low surface brightness

X-ray halos that we expect to find in spiral galaxies if the energy input in the underlying galactic disk is above a certain level. The good spatial resolution of XMM will allow us to disentangle the emission of hot gas components in galactic disks and halos. The high spectral resolution will make it possible to investigate the excitation conditions of the hot X-ray emitting gas over a wide energy range.

A recently started radio investigation (Dahlem, Ehle, Haynes et al.) to search for previously unknown cosmic ray halos will allow us to test if galactic radio and X-ray halos are related phenomena. Investigations of the linearly polarized radio emission and the structure of galactic magnetic fields can address the question on how magnetic fields channel the gas outflow and on how they affect the halo structure. A first glimpse of an interesting link between hot gas, cosmic rays and magnetic fields has been found in case of NGC 4666 (Dahlem et al. 1997) and NGC 253 (Fig. 4; Ehle et al., in prep.)

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