A DETAILED REFLECTION GRATING SPECTROMETER ANALYSIS OF THE OUTFLOW OF NGC 253

M. Bauer[1], **W. Pietsch**[1], **D. Breitschwerdt**[2], **M. Ehle**[3], **M. J. Freyberg**[1], **A. Read**[4], **and G. Trinchieri**[5]

[1]Max-Planck-Institut für extraterrestrische Physik, Giessenbachstraße, 85748 Garching, Germany
[2]Institut für Astronomie der Universität Wien, Türkenschanzstr. 17, A-1180 Wien, Austria
[3]European Space Astronomy Centre, ESA, P.O. Box 50727, 28080 Madrid, Spain
[4]Department of Physics & Astronomy, University of Leicester, Leicester LE1 7RH, UK
[5]INAF Osservatorio Astronomico di Brera, via Brera 28, 20121 Milano, Italy

ABSTRACT

NGC 253 is an edge-on starburst galaxy in the Sculptor group. Observations in X-rays by *ROSAT*, XMM-Newton and *Chandra* show a mixture of extended and point source emission in disk and halo (Pietsch et al., 2000, 2001; Strickland et al., 2000; Vogler & Pietsch, 1999). Especially interesting is the connection between the starburst driven outflow from the nuclear region into the halo of the galaxy (plume). We analyzed XMM-Newton data, taken with the Reflection Grating Spectrometer (RGS) in 2000 and 2003 with a total low background exposure time of 127.8 ks. We extracted spectra of the outflow for different regions. Depending on the distance to the center along the south-east semi minor axis of NGC 253, the spectra show many individual emission lines with varying intensity. We used line ratios to characterize the temperature and the ionization mechanism in these regions. Furthermore we extracted narrow-band RGS images to map the spatial origin of the different emission lines.

Key words: X-rays: galaxies; Galaxies: individual: NGC 253; Galaxies: spiral; Galaxies: starburst; interstellar medium: jets and outflows.

1. INTRODUCTION AND OBSERVATIONS

The edge-on ($i = 86°$) galaxy NGC 253 is one of the best nearby (2.58 Mpc) examples of a nuclear starburst galaxy. It is well studied in many wavelength regimes. Especially important for sensitive soft X-ray observations is the very low galactic foreground absorption ($N_{\rm H} = 1.3 \times 10^{20}$ cm^{-2}) towards NGC 253 making it a perfect object to study the interaction of the starburst nucleus with the halo.

The nuclear region of NGC 253 was observed with XMM-Newton RGS in 2000 and 2003 with a total low background exposure time of 127.8 ks. The brightest regions in X-rays are the nuclear starburst region and emanating from that, a hollow cone shaped structure (plume) along the south-east minor axis which can be seen as extended bright soft X-ray emission in EPIC PN images. It has been interpreted as an outflow of hot interstellar medium from the starburst nucleus into the halo of the galaxy. Barely visible is an outflow to the north-west, due to high absorption of the intervening NGC 253 disk. The observation geometry led to a RGS dispersion direction that was approximately aligned to the NGC 253 major axis.

2. RESULTS

We extracted high resolution RGS spectra from several regions along the plume of NGC 253. As the galaxy covers the whole RGS detector CCDs, we used the new Science Analysis Software (SAS) task `rgsbkgmodel` to obtain a background spectrum which is not contaminated by emission of the galaxy. The resulting spectra are shown in Fig. 1. The extraction regions have a width of $0.5'$ in the cross dispersion direction and lie parallel to the major axis of the galaxy. We were able to identify many individual emission lines. In region SE 3 however, located farthest from the center, the S/N level is too low to draw reliable conclusions. Region NW is strongly affected by absorption from the disk of NGC 253. The line strength of individual lines changes with distance from the center of the galaxy, i.e. along the outflow. Lines at the shortest wavelengths vanish first from the spectra. Except for the iron lines in the center region the oxygen lines are the strongest lines in all spectra.

We used line ratios from different elements, most of them in their highest ionization state to derive temperatures for the different extraction regions. In contrast to the usual spectral fits we get temperatures free of abundance bias with small errors. The obtained temperatures range from 0.17 to 0.77 keV along the outflow (see Table 1). We did

Table 1. Temperatures of the plasma for different regions of the outflow of NGC 253 derived from line ratios of different elements. For region SE 3 no temperatures could be derived as the lines are too weak.

Region	Temperature in keV			
	Si	Mg	Ne	O
NW		0.40±0.04	0.26±0.06	0.17±0.02
Center	0.77±0.10	0.48±0.04	0.31±0.05	0.23±0.03
SE 1		0.40±0.05	0.23±0.02	0.24±0.03
SE 2			0.22±0.05	0.21±0.02

not include the temperatures derived from Fe XVII in Table 1 as they show errors in the order of 100 %. The broad range of temperatures may be caused by plasma which is not in equilibrium and/or reflects distributions of temperatures in the extraction regions. Narrowband RGS images can help to resolve this issue. Fig. 2 shows a selection of images in the Fe XVII and O VIII lines. A comparison of emission of Fe XVII at $\sim$ 15 Å (2p-3d) and at $\sim$ 17 Å (2p-3s), for example, shows that the emission originates to a certain degree from different regions. In the temperature calculation we assume that the lines emerge from the same region of space. If this is not the case the derived results are wrong. This may be the case for Fe XVII and therefore we obtained the large errors.

The diagnostic lines of Fe XVII are commonly used to derive the ionizing mechanism in plasmas. In the center region of NGC 253 as well as in the regions NW and SE 2 the line strenghts indicate a predominantly collisional ionized plasma. Region SE 1 however shows an inverted line ratio. Here the lines at 17 Å are stronger than the lines at 15 Å. Collisions between electrons and ions seem to be of less importance. This is not expected for an outflow where the X-ray emission is created at the border of the outflow, the region where the ejected gas collides with the surrounding interstellar material. It could be well possible that the strong 2p-3s emission is created in a photoionized region outside of the outflow. A possible region can be seen in Fig. 2 in the Fe XVII image at 17 Å, 0.7′ south of the galactic center. The very bright source coincides with source X33 from Pietsch et al. (2001).

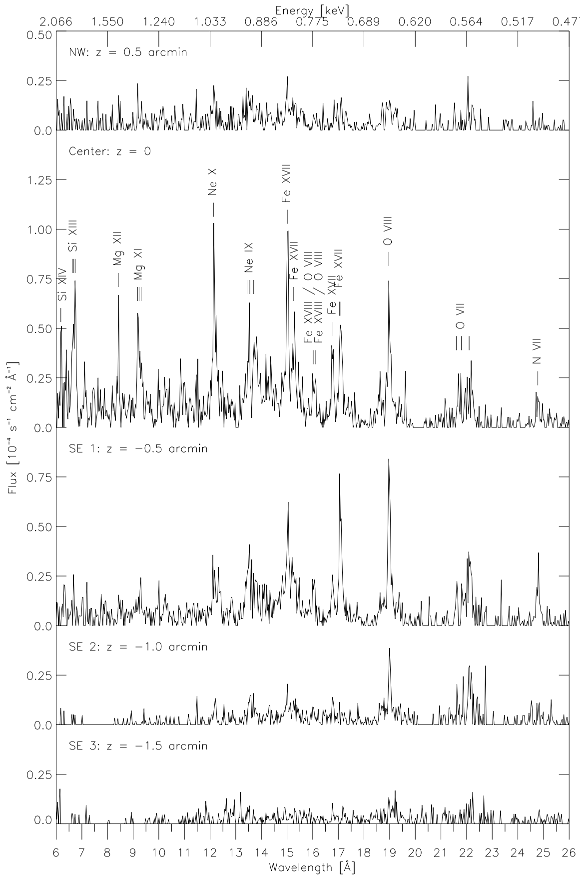

Figure 1. RGS spectra of NGC 253 extracted from different regions along the outflow. The label gives the position of the extraction region along the minor axis relative to the center of the galaxy in arcmin.

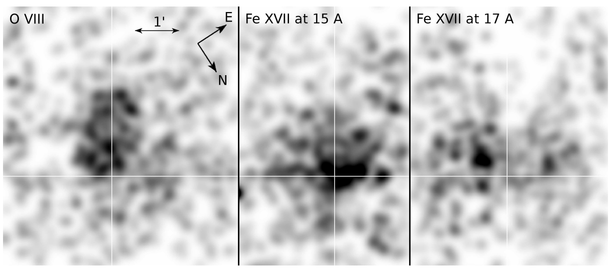

Figure 2. RGS images of NGC 253 in different lines. The RGS data allows to filter for very narrow wavelength bands. Shown here are images in the O VIII and Fe XVII lines. The strong O VIII emission nicely traces the outflow region. The horizontal white line marks the position of the disk of NGC 253. The vertical white line is the direction of the minor axis, i.e. along the outflow.

REFERENCES

Pietsch, W., Roberts, T. P., Sako, M., et al. 2001, A&A, 365, L174

Pietsch, W., Vogler, A., Klein, U., & Zinnecker, H. 2000, A&A, 360, 24

Strickland, D. K., Heckman, T. M., Weaver, K. A., & Dahlem, M. 2000, AJ, 120, 2965

Vogler, A. & Pietsch, W. 1999, A&A, 342, 101