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ROSAT X-RAY OBSERVATIONS OF CENTRAL GALACTIC STARBURSTS

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RESUMEN

Presentamos observaciones espectroscópicas de las galaxias NGC 4569 and NGC 4303 hechas con *ROSAT*. Ambos objetos son miembros del cúmulo de Virgo y tienen compañeras cercanas más pequeñas con quienes probablemente han tenido un encuentro. Los espectros en rayos-X suaves (0.1–2.4 keV) pueden ser ajustados con un modelo de dos componentes, consistentes en una ley de potencias para la emisión del núcleo activo y un modelo de Raymond-Smith para el gas caliente originado en el brote de formación estelar. Las luminosidades en rayos-X están en el rango de 10^{40} erg s^{-1}. La fuente central de NGC 4569 es compacta y no puede ser resuelta con el detector HRI de *ROSAT*, pero hay emisión extendida tanto en el disco como arriba de él. Los rayos-X de NGC 4303 son dominados por el núcleo activo, pero también se observan varias fuentes en el disco asociadas con regiones H II.

ABSTRACT

We present spatial and spectral results of *ROSAT* observations of two galaxies: NGC 4569 and NGC 4303. Both objects are members of the Virgo Cluster and have nearby smaller companions with which they have probably gone through an encounter. Both soft X-ray spectra (0.1–2.4 keV) can be fitted with a two-component model consisting of a power-law component from a non-thermal emission of a compact active nucleus and a Raymond-Smith model for a hot thin thermal plasma originating from starbursts. The X-ray luminosities are in the range of 10^{40} erg s^{-1}. The central source of NGC 4569 is very compact and can not be resolved with the *ROSAT* HRI detector, while there is extended soft X-ray emission in the galactic disk as well as above it. NGC 4303 is dominated by the active nucleus in the X-ray. But several additional disk sources associated with H II regions can be observed.

Key Words: **GALAXIES: ACTIVE — GALAXIES: INDIVIDUAL (NGC 4303, NGC 4569) — GALAXIES: STARBURSTS — X-RAYS: GALAXIES**

1. INTRODUCTION

The phenomenon of galactic nuclear activity is strongly connected with starbursts, especially in galaxies with low luminous active nuclei, like LINERs and Seyfert galaxies. Besides UV and optical observations the analysis of X-ray data reveals composite spectra, indicating non-thermal nuclear activity and soft thermal emission from the hot gas of a central starburst. One main aspect of interest is the triggering mechanism of galactic activity in different morphologies, like interacting systems (Tschöke, Hensler, & Junkes 1999) and bars.

Here we investigate luminosity and spectral distribution of the soft X-ray emission from two nearby barred galaxies with nuclear starburst activity. In both nearby galaxies the X-ray emission can be clearly distinguished between different galactic components: the center, the disk, and, in the case of NGC 4569, the halo. Both galaxies have been classified as LINERS from optical spectroscopy (NGC 4569: Willner, Elvis, & Fabbiano 1985; NGC 4303: Huchra, Wyatt, & Davies 1982).

NGC 4569 is a bright early-type spiral in the Virgo Cluster, one of the few blue-shifted galaxies outside the local group. It is gas-deficient in the outer spiral arms, the neutral hydrogen content is strongly concentrated in the inner region (Cayatte et al. 1990). The bright nucleus, embedded in a normal stellar bulge, is probably the result of a recent star formation episode (Stauffer, Kennedy, & Young 1986).

NGC 4303 is a barred late-type spiral galaxy and also member of the Virgo Cluster. Indications for a high star formation rate in NGC 4303 are the high density of H II regions (Hodge & Kennicutt 1983; Martin & Roy 1992) and three observed supernovae (van Dyk 1992). It shows also strong radio emission distributed over the entire disk (Condon 1983). Two nearby galaxies, NGC 4303 A (Condon 1983) and NGC 4292 (Cayatte et al. 1990), are possible candidates for a past interaction with NGC 4303.

2. SPATIAL DISTRIBUTION, X-RAY SPECTRA AND LUMINOSITIES

2.1. *NGC 4569*

The global X-ray spectrum of NGC 4569 can be described by a two-component fit consisting of a power-law component (predominantly from the nucleus) and a thermal plasma component (hot gas from SNRs and superbubbles). The resulting value of hydrogen absorption is in agreement with the Galactic foreground, supporting the observed H I deficiency (Cayatte et al. 1990). The total luminosity in the *ROSAT* band for NGC 4569 amounts to $\sim 2\times10^{40}$ erg s^{-1}.

Two interpretations for the emission of the compact nucleus in the HRI image seem possible: either X-ray emission from an unresolved compact nuclear source, to be associated with the LINER-type nucleus of NGC 4569 in the optical, or a slightly extended nuclear starburst region, similar to the one found in NGC 1808 (Junkes et al. 1995) at a scale of $\sim$ 1 kpc. With the spectral resolution of the *ROSAT* PSPC it is not possible to clearly determine the nature of the central source. The power-law represents either the contribution from high-mass binaries in the central starburst, or an AGN component with a spectral distribution in the *ROSAT* band which could be described by a power-law fit.

X-ray emission from the disk of NGC 4569 is clearly visible in the PSPC image (Fig. 1). The total disk emission in X-rays from either side (NE vs. SW) is comparable. Their spectral energy distributions, however, differ significantly. The contribution from the northern part is significantly harder. This may indicate either higher absorption in the north, or an intrinsically harder X-ray spectrum caused by the cumulative impact of several SNRs or high-mass X-ray binaries. Higher internal absorption towards the northern part of NGC 4569 seems difficult to explain since the H I content of that galaxy is strongly confined to the central part (Cayatte et al. 1990).

NGC 4569 has an inclination of $\sim 65°$. The galaxy appears extended in soft X-rays; the X-ray emission in the *ROSAT* band shows contributions from areas outside the nucleus and outside the disk. In contrast to edge-on galaxies, where emission components from disk and halo can be quite easily distinguished, it is more difficult to disentangle these components in the case of NGC 4569.

The overall distribution of the soft X-ray emission appears to be very asymmetric with a spur extending from the galaxy center and some additional diffuse patches west of the galaxy. The source northwest of the galactic center is probably not connected to NGC 4569. A further source southwest of the nucleus of NGC 4569 can be identified with a background galaxy visible in the optical. We derived a hardness ratio (0.5–2.0 keV vs. 0.1–0.4 keV) of 0.1 for the area west of NGC 4569, excluding both these independent X-ray sources. The total number of counts after background subtraction for this area is only 50, hence no meaningful spectrum could be derived. The hardness ratio is compared with the results from model spectra. A value of HR = 0.0 results for a thermal plasma spectrum (e.g., Raymond & Smith 1977) with a plasma temperature of 0.2 keV. Hence, the X-ray emission from the area outside the disk can be explained with hot gas of a temperature of approximately 2×10^6 K.

An additional argument in favor of diffuse X-ray emission in the halo of NGC 4569 comes from the very good spatial correlation of the soft X-ray (0.1–0.4 keV) emission with a large diffuse Hα spur (Fig. 1). Similar correlations were observed in a number of nearby starburst galaxies (e.g., M82: Shopbell & Bland-Hawthorn 1998; NGC 3628: Dahlem et al. 1996; NGC 4666: Dahlem et al. 1997) and are interpreted as a signature for an outflow of hot gas from the starburst center. Our X-ray data are fully consistent with such an interpretation in the case of NGC 4569.

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2.2. *NGC 4303*

Obvious differences between NGC 4303 and NGC 4569 are that (1) NGC 4303 has a much lower inclination (27°; Guhathakurta et al. 1988) and (2) the amount of H I is more distributed over the total galactic disk and much higher in the outer parts than in NGC 4569, which is closer to the Virgo Cluster center. Consequently, the first point allows better observation possibilities to distinguish between disk and central source. Vice versa, it is not possible to observe a soft halo component above the galactic disk, as can be seen in NGC 4569 or in more details in edge-on starburst galaxies (e.g., Vogler, Pietsch, & Kahabka 1995).

Another difficulty in the X-ray observations of NGC 4303 is that no spatial distribution can be obtained from the PSPC data due to the fact that the galaxy is $17'$ off-axis in the field of view. This degenerates the spatial resolution of the observation to $\sim 67''$.

The global X-ray spectrum of NGC 4303 can be described by a similar fit to that of NGC 4569 with a non-thermal power-law component and a Raymond-Smith component. The resulting value of hydrogen absorption is 3.4×10^{20} cm^{-2}, a factor of 2 higher than the Galactic foreground. This is in agreement with the distribution of H I gas over the whole galactic disk of NGC 4303. The total luminosity of NGC 4303 in the *ROSAT* band is $\sim 5\times10^{40}$ erg s^{-1}.

The HRI image reveals a dominant central source and several additional sources distributed along the spiral arms (Fig. 2). UV observations (Colina & Arribas 1999) result in an unresolved ($\leq$ 8 pc) active nucleus (compact stellar cluster or AGN) and a surrounding spiral-shaped region of very young massive star forming clusters (2–3 Myr). This picture leads us to attribute a power-law component to the nuclear source, contributing more than 80% to the total spectrum. This is in agreement with the results from the HRI observation, where the main part originates from the center of the galaxy. The coincidence of the disk sources with H II regions in the spiral arms is in favour of several star forming regions with SNRs to be the origin of the observed X-ray emission. The sources at the ends of the bar are in agreement with expected gas flows and accumulation within the bar. The eastern spiral feature in the optical and Hα with the X-ray source at its bend suggest a past tidal disturbance in the gas dynamics leading to enhanced star formation.

Further contribution to the X-ray flux from HMXBs in the disk sources and from a circumnuclear starburst at a distance up to $\sim$ 1 kpc from the center cannot be excluded from the HRI observation.

3. CONCLUSIONS

A comparison of the total luminosities of NGC 4569 and NGC 4303 in the soft X-ray with a larger sample of normal and active galaxies (Green, Anderson, & Ward 1992) shows good agreement with the galaxies (including LINERs and starburst galaxies) in that sample. Most of the soft X-ray emission in both galaxies comes from their nuclear regions, but additional components from the disk and, in the case of NGC 4569, possibly from the halo, can be distinguished. The existence of a central superwind in NGC 4569 is supported by two facts: First, the extended emission component is predominantly at one side coincident with an Hα feature at high z. This one-sided geometry would be expected in an ambient medium with a density gradient along the z-direction and a starburst region slightly above the galactic plane. Second, its spectral distribution (hardness ratio) can be explained with a hot plasma of a temperature of a few 10^6 K, which would be expected in the halo of starburst galaxies.

The nature of the nuclei in NGC 4569 and NGC 4303 is still unknown. X-ray images and spectra indicate a coexistence of a dominating AGN and a starburst in both galaxies. Both harbour a compact central source, emitting most of the soft X-rays. Nevertheless, massive nuclear stellar clusters with enhanced star formation can not be excluded to account for the sources.

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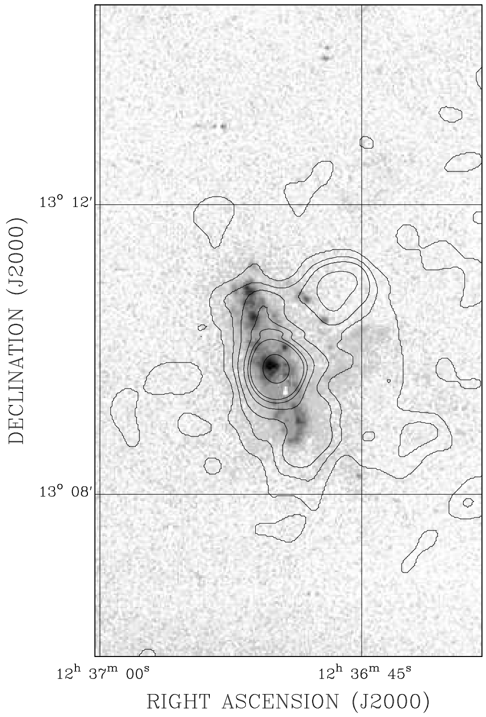

Figure 1. NGC 4569: PSPC X-ray contours over Hα image.

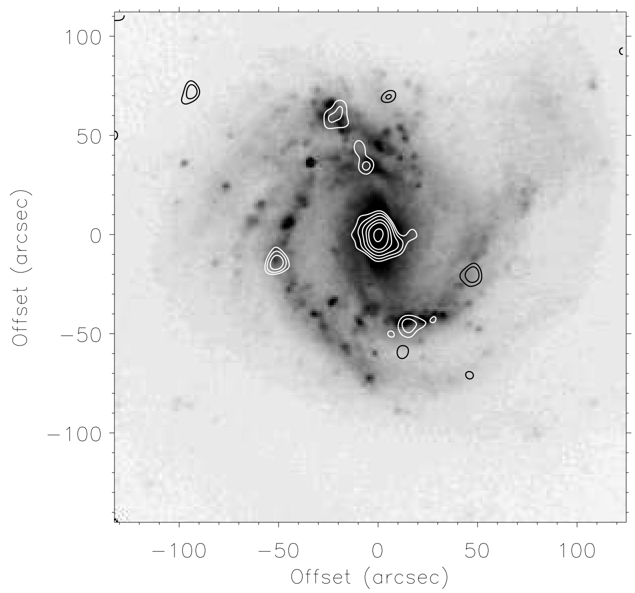

Figure 2. NGC 4303: HRI X-ray contours over R band image (Frei et al. 1996).

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