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THE COMPOSITE Sy2/STARBURST COMPTON-THIN GALAXY NGC 7679 = Mark 534

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Abstract. The Starburst/Sy2 galaxy NGC 7679 (Mrk 534) was observed with the 2m RCC Telescope of the Ukraine National Astronomical Observatory at peak Terskol, Caucasus. The two-channel focal reducer of the MPAe in tunable Fabry-Perot mode was used. The high-luminous IR galaxy NGC 7679 is a low-redshift face-on SB0 galaxy in which starburst and AGN activities co-exist. The ionization structure in the inner central region (≤ 2.5 kpc) is maintained by the AGN continuum whereas outside this region the source of ionization has a clear starburst origin. The SED from IR to X-rays is typical for Sy2 galaxies. NGC 7679 is an unabsorbed X-ray source (i.e. possesses low X-ray column density) for which the simple formulation of the Unified Model for SyGs is not applicable. The maximum of ionization of the starburst region is displaced by 12 arcsec east from the nucleus. The infered ionization anisotropy of the radiation field and the photon deficiency of ionizing photons are suggestive that the central AGN source is observed through dense dusty-gaseous clouds. Such dusty warm absorbers have already been invoked to explain the discrepancy between the amount of X-ray cold absorption and the optical reddening in some SyGs.

1. INTRODUCTION

The high-luminous IR galaxy Mrk 534 is nearby ($z = 0.0171$) nearly face-on SB0 Sy2 galaxy in which starburst and AGN activities co-exist (Della Ceca et al, 2001). Composite Seyfert-starburst galaxies have been recently studied by Levenson et al. (2001). A significant part of the observed FIR-emission of these composites could be associated with circumnuclear starburst events. The circumnuclear starburst should also play a major role in the obscuration processes around the AGN (Levenson et al, 2001, and references therein). NGC 7679 is included in a small sample of unabsorbed Sy2 galaxies (i.e. Seyferts which have an X-ray column density lower than 10^{22} cm^{-2}) for which the simple formulation of the Unified Model for Seyferts is not applicable (Panessa and Bassani, 2002).

NGC 7679 is physically associated by a common stream of ionized gas with the Sy2 galaxy NGC 7682 at $\sim 4.5'$ east. There are also signs of tidal disruption due to the interaction with the faint compagnion that lies $\sim 50''$ at east direction also (see Fig. 1). Together with the existence of a bar in Mrk 534 this could enhance the gas flow towards the nuclear regions and possibly trigger the starburst processes observed (Gu et al, 2001).

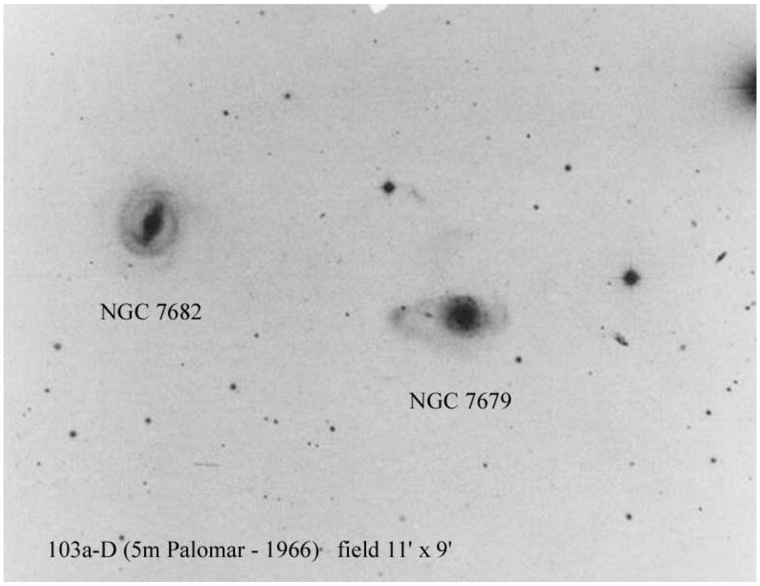

Figure 1: The field of Sy2 pair NGC 7679 and NGC 7682. This broad-band image was downloaded from NED.

NGC 7679 shows quite high IRAS luminosity in the far IR (log $L_{\rm FIR}/L_{\odot} \approx 11.10$), a ratio $L_{\rm farIR}/L_B \sim 1$, and IR colors typical of a classical starburst galaxy.

2. OBSERVATIONS AND DATA REDUCTION

NGC 7679 was observed by K. Jockers and T. Bonev with the 2m reflector of the Ukraine National Astronomical Observatory at peak Terskol, Caucasus. The observations were carried out on October 1996 with the Two-channel Focal Reducer of the Max-Planck-Institute for Aeronomy (MPAe) designed by K. Jockers and described in Jockers (1997) and Jockers et al. (2000). This instrument was primarily intended for cometary studies but it has repeatedly been used for observations of active galactic nuclei (Yankulova, 1999; Golev et al, 1995, 1996). The technical data and the present capabilities of the MPAe Focal Reducer are described in the paper of Jockers (1997) and Jockers et al. (2000).

All observations are taken in two-channel Fabry-Perot (FP) mode using tunable FP narrow-band imaging with spectral FWHM of the Airy profile $\delta\lambda$ in order of 3 - 4 Å. The overall "finesse" of the system (or $\Delta\lambda/\delta\lambda$) is $\approx$ 15 which enables quite high contrast of the FP images.

The details of observations are presented in Table 1 where the central wavelengths λ_c and the effective width $\Delta\lambda$ of the interference filters used to separate the Fabry-Perot interference orders, the wavelength $\lambda_{\rm FP}$ at which the Fabry-Perot was tuned, and the exposures are listed. At the distance of Mrk 534 one arcsec corresponds to a

Table 1: NGC 7679 – Observiation details

image frame	interference filter[a)] $\lambda_c/\Delta\,\lambda$ (Å)/(Å)	Fabry-Perot tuned wavelength $\lambda_{\rm FP}$ (Å)	frames × exposure time (s)
red channel:			
H$\alpha\lambda$6563	6662/55		1 × 1800
			2 × 900
[N II]λ6548	6662/55		1 × 900
continuum	6719/33		1 × 1800
			1 × 900
[O III]λ5007	5094/44		2 × 900
continuum	5002/41		1 × 1200
Gunn r[b)]	6800/1110		1 × 60
blue channel:			
[O III]λ4363	4432/44		1 × 900
			1 × 1200
continuum	4253/32		3 × 900
BG 39/2[b)]	4720/700		2 × 1500

[a)] Used to separate Fabry-Perot working orders.

[b)] Broad-band image taken without Fabry-Perot.

distance of about 340 pc assuming $H_0 = 75$ km sec^{-1} Mpc^{-1}.

Two exposures of Mark 534 were obtained through each filter to eliminate cosmic ray events and to increase the reliability of the measurements. Between exposures the telescope was slightly offset to avoid permanent defects of the CCD. Flatfield exposures were obtained using dusk and dawn twilight for uniform illumination of the detector. No dark correction was required.

The images were reduced following the usual reduction steps for narrowband imaging. After flatfielding the frames were aligned by rebinning to a common origin. The final alignment of all the images was estimated to be better than 0.1 px (the scale is 1 px = 0.8 arcsec). A convolution procedure was performed in order to match the PSFs of each line – continuum pair which unavoidably degrades the final FWHM of the images to the mean value about 3 - 3.5 arcsec.

3. RESULTS

The unpublished Hα images taken from the archives of the Isaak Newton Group of telescopes at La Palma and from the ESO La Silla NTT revealed in the light of pure Hα emission a "double nucleus" unseen in the known broad-band images. The separation between the nuclear counterparts (in fact one is the nucleus itself and the other is an extremely powerfull starburst region close to the nucleus) is $\leq$ 3 arcsec. In Fig. 2 we present our very deep and high-contrast Hα image with numerous starburst regions where because of both seeing and pixel size we are able to see only elliptical central isophotes instead of the "double nucleus". The existence of this "double nucleus" in Mark 534 could enhance the gas flows towards the nuclear regions and possibly trigger the starburst processes.

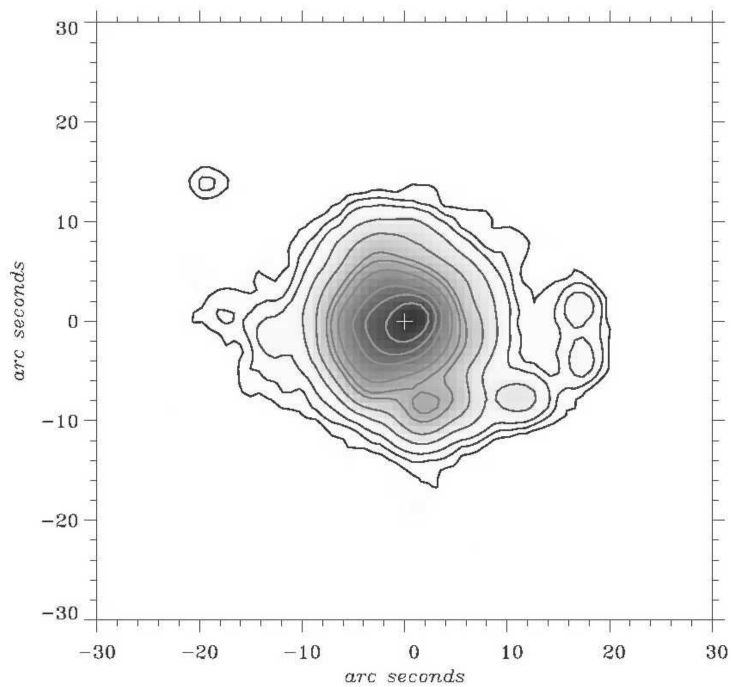

Figure 2: The contours of Hα superimposed on the gray-scale Hα image of the regions around the nucleus of NGC 7679. The image center (0,0) denotes the optical position of the nucleus of NGC 7679 (as given in NED). The resulting FWHM of the seeing after reductions is shown.

The contours of [O III]λ5007 superimposed on the gray-scale [O III]λ5007 image of the regions around the nucleus of NGC 7679 are presented in Fig. 3. The E-W elongation of [O III]λ5007 emission is clearly seen as well as the two extrema decentered of about $\sim$ 4 arcsec from the position of the nucleus.

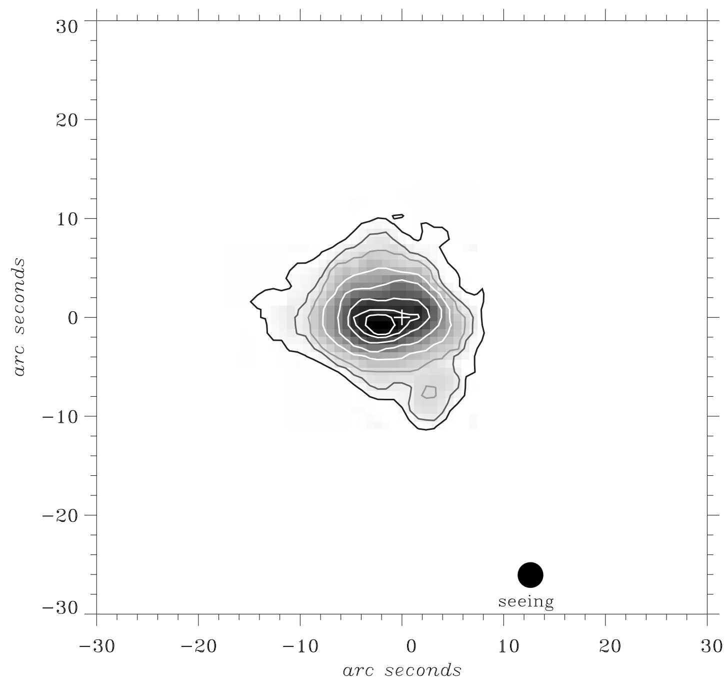

Figure 3: The contours of [O III]λ5007 superimposed on the gray-scale [O III]λ5007 image of the regions around the nucleus of NGC 7679. The image center (0,0) denotes the optical position of the nucleus of NGC 7679.

The [O III]λ4363 emission arises in the innermost nuclear region situated in the valley between both maxima of the [O III]λ5007 emission and does not show any preferred direction. The contours of the [O III]λ4363/[O III]$\lambda\lambda$4959 + 5007 ratio are elongated along the direction perpendicular to the extension of the [O III]λ5007 emission (see Fig. 4). Note the shift of the [O III]λ4363/[O III]$\lambda\lambda$4959+5007 maximum comparing to the maximum of the [O III]λ5007 emission. The former grows between two [O III]λ5007 extrema and reaches its maximum at the position of the nucleus.

The analysis of the [O III]λ4363/[O III]$\lambda\lambda$4959 + 5007 ratio (adopting $T_{\rm e}$ between 1.0×10^4 K and 2.0×10^4 K) shows very high electron densities at the direction of the nucleus ($\log N_{\rm e}$ varies between 6.2 and 7.8 depending on $T_{\rm e}$ adopted).

The [O III]λ5007/Hα ratio or the ionization map (Fig. 5) is a well known idicator of the mean level of the ionization and temperature in the emission-line regions. The E-W elongation with an offset of the peak value is clearly seen. The [O III]λ5007/Hα flux-calibrated ratio infers the highest ionization $F_{5007}/F_{H\alpha} \approx 2.1$ shifted to the east of about 13 arcsec with respect to the nuclear position defined by the images in the light of the continuum adjacent to Hα. The [O III]λ4363/[O III]$\lambda\lambda$4959 + 5007 ratio

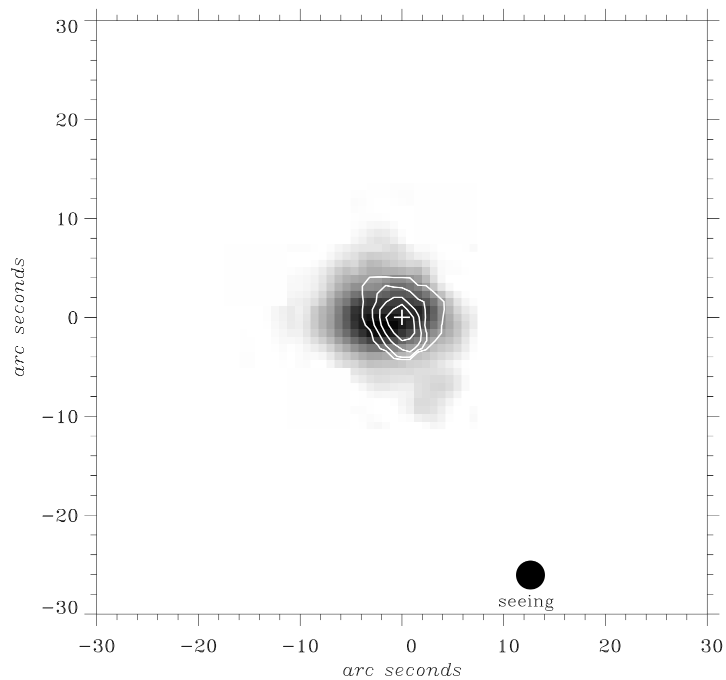

Figure 4: The contours[O III]λ4363/[O III]$\lambda\lambda$4959 + 5007 ratio superimposed on the gray-scale [O III]λ5007 halftone image of the regions around the nucleus of NGC 7679. The image center (0,0) denotes the position of the nucleus.

(dense matter) coincide with the galactic nucleus and the ionization grows to the east of the nucleus.

On the basis of the emission-line fluxes extracted from the central 2 kpc region we estimate the number of the ionizing photons $N_{\rm opt}$ which have to be available in order to exist the observed ionization structure to be $N_{\rm opt} \sim 10^{54} \div 5 \times 10^{54}$ photons s^{-1}. On the other hand the number of ionizing photons $N_{\rm X-ray}$ provided by the central AGN and estimated from the measured flux in soft X-rays (0.1 - 2 keV band) is $N_{\rm X-ray} \approx 10^{53}$ photons s^{-1}).

The morphology both of the inner part of the [O III]λ5007 image and of the [O III]λ5007/Hα ratio suggests an anisotropy of the radiation field. Taking into consideration also the photon deficiency $N_{\rm opt}/N_{\rm X-ray} \approx 0.1 \div 0.5$ we conclude that the central AGN source is observed trough the dust-gas clouds which could be in relation with a dusty torus.

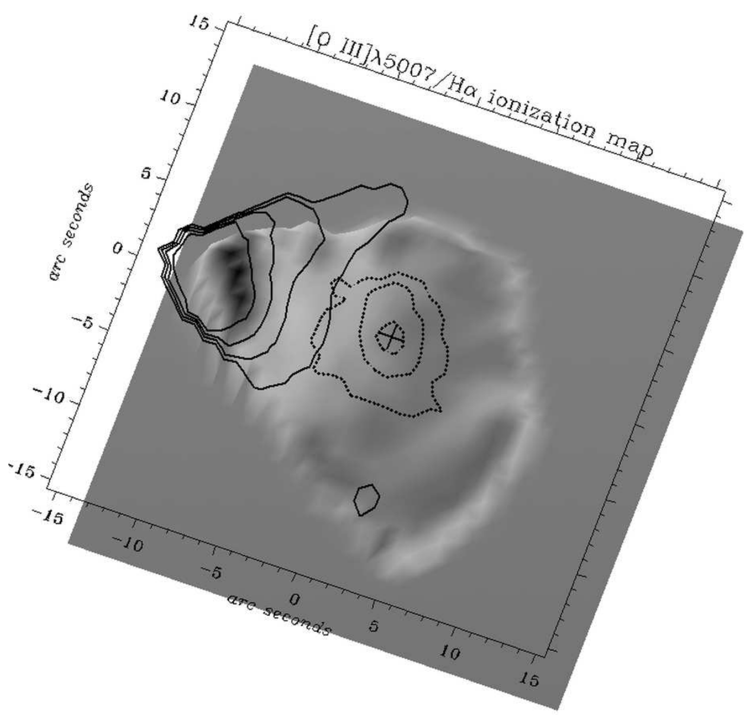

Figure 5: The contours of [O III]λ4363/[O III]$\lambda\lambda$4959 + 5007 ratio superimposed on the gray-scale and contours of the ionization map (or [O III]λ5007Hα ratio). The image center (0,0) denotes the position of the nucleus.

4. CONCLUSIONS

The complex physical picture of NGC 7679 is revealed. Its high FIR luminosity and its IR colors are typical for a classical starburst galaxy. The Hα images show a double nucleus and an extended envelope with bright knots which resembles a starforming ring at about 5 kpc from the center of NGC 7679. The ionization structure in the inner central region (about 3 kpc) is maintained by the AGN-type continuum whereas outside this region the source of ionization has a starburst origin. The SED from IR to X-rays is typical for classical Sy2 galaxies.

(i) The maximum of ionization of the starburst region is displaced by $\sim$ 13 arcsec east from the nucleus.

(ii) The high values around the nucleus of the [O III]λ4363/[O III]$\lambda\lambda$4959 + 5007 ratio are tightly connected with the presence of dense ionized gas with high electron temperature $T_{\rm e}$.

(iii) Both the dense ionized gas in the innermost region (probably dust-mixed in and outlined by the ratio) and the inferred ionization anisotropy of the radiation field and the photon deficiency of ionizing photons $N_{\rm X-ray}/N_{\rm opt} = 0.1 - 0.5$ (where $N_{\rm opt}$ is the number of ionizing photons needed to maintain the observed ionization structure, and $N_{\rm X-ray}$ is the number of quanta provided in soft X-rays by the central AGN), are suggestive that the central AGN source is observed through dense dust-gas clouds. Such "dusty" warm absorbers have already been invoked to explain the discrepancy between the amount of X-ray cold absorption and the optical reddening in some SyGs (Reynolds 1997).

(iv) There could be a "hole" in the warm absorber of the nuclear source so that the X-ray emission from the accretion disk is unabsorbed and pointed out to the region of the observed [O III]λ5007/Hα maximum at $\sim$ 13 arcsec eastern from the nucleus.

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References

Della Ceca, R., Pellegrini, S., Bassani, L., Beckmann, V., Cappi, M., Palumbo, G.G.C., Trinchieri, G., Wolter, A.: 2001, *Astron. Astrophys.* **375**, 781.

Golev, V., Yankulova, I., Bonev, T., Jockers, K.: 1995, *Mon. Not. Roy. Astron. Soc.* **273**, 129.

Golev, V., Yankulova, I., Bonev, T.: 1996, *Mon. Not. Roy. Astron. Soc.* **280**, 29.

Gu, Q.S., Huang, J.H., de Diego, J.A., Dultzin-Hacyan, D., Lei, S.J., Benitez, E.: 2001, *Astron. Astrophys.* **374**, 932.

Jockers, K.: 1997, *Experimental Astronomy* **7**, 305.

Jockers, K., Credner, T., Bonev, T., Kiselev, N., Korsun, P., Kulik, I., Rosenbush, V., Andrienko, A., Karpov, N., Sergeev, A., Tarady, V.: 2000, *Kinematika i Fizika Nebesnykh Tel*, Suppl. No. 3, 13.

Levenson, N., Weaver, K., Heckman, T.: 2001, *Astrophys. J.* **550**, 230.

Panessa, F., Bassani, L.: 2002, *Astron. Astrophys.* **394**, 435.

Reynolds, R.: 1997, *Mon. Not. Roy. Astron. Soc.* **286**, 513.

Yankulova, I.: 1999, *Astron. Astrophys.* **344**, 36.