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NARROW-BAND FABRY-PEROT OBSERVATIONS OF THE COMPOSITE Sy2/STARBURST GALAXY NGC 7679

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Валери Голев, Иванка Янкулова. ТЕСНОИВИЧНИ НАБЛЮДЕНИЯ С ФАБРИ-ПЕРО НА КОМПОЗИТНАТА Sy2 ГАЛАКТИКА NGC 7679 С ВЗРИВНО ЗВЕЗДО-ОБРАЗУВАНЕ

С 2m RCC телескоп на Украинската национална обсерватория на пик Терскол, Кавказ, е наблюдавана галактиката NGC 7679. Тесноивичните висококонтрастни изображения са получени в настройваем Фабри-Перо режим с двуканалния фокален редуктор на MPAe в Линдау, Германия. Композитната Sy2 галактика NGC 7679 = Mark 534 с взривно звездообразуване и висока IR светимост е сравнително близък обект от тип SB0, в който активното ядро и мощните процеси на звездообразуване съществуват едновременно. Йонизационната структура в близките до центъра области (≤ 2.5 kpc) се поддържа от AGN-континуума, а извън тези области източникът на йонизация е взривното звездообразуване. NGC 7679 показва анизотропия на йонизацията и фотонен дефицит, който се интерпретира като горещ прахов абсорбер в рентгеновата област на спектъра. Тези особености не позволяват да се обясни сложната физична природа на NGC 7679 с общоприетия Обединен модел на галактиките от сийфъртов тип.

Valeri Golev, Ivanka Yankulova. NARROW-BAND FABRY-PEROT OBSERVATIONS OF THE COMPOSITE Sy2/STARBURST GALAXY NGC 7679

NGC 7679 was observed with the 2m RCC Telescope of the Ukrainian National Astronomical Observatory at peak Terskol, Caucasus. The two-channel Focal Reducer of the MPAe in Lindau, Germany, was used for narrow-band imaging of the galaxy in tunable Fabry-Perot mode. The composite Starburst/Seyfert high-luminous IR galaxy NGC 7679 = Mark 534 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 nuclear spectral energy distribution from IR to X-rays is typical for Seyfert type 2 (or Sy2) AGN-galaxies. Meanwhile the NGC 7679 is an unabsorbed X-ray source (i.e. possesses low X-ray column density). The maximum of ionization of the starburst region is displaced by $\sim$ 13 arcsec eastward from the nucleus. All these pecularities do not allow to apply the simple formulation of the common Unified Model of Seyfert-type AGNs for this galaxy. The inferred 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.

Keywords: galaxies: active, galaxies: Seyfert, infrared: galaxies, starburst: galaxies, galaxies: individual: NGC 7679 (Mark 534)

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1. INTRODUCTION

Clear consensus about the energy source of active galactic nuclei (AGN) already exists. The gravitational energy released through matter accretion onto a "central engine" (supposed to be a supermassive black hole up to $10^9 M_\odot$) is responsible for the enormous electromagnetic radiation observed in AGN. Progress in unveiling, analyzing and modeling the different components in AGN from pc up to 10 kpc scales—the accretion disk, the relativistic jets, the X-ray absorber very close to the central engine, the "torus" which funnels the ionizing radiation, the surrounding clouds of dense material in Broad-line Region (BLR) and Narrow-line region (NLR), the jet induced effects on larger scales, and so on.

In spite of today's remarkable insights into the AGN phenomenon, some key questions remain open, as for instance (1) "energy budget problem" or the large discrepancy between the energy output required from the observed emission and that one extrapolated from observed continuum spectral energy distribution (SED), and (2)AGN fuelling or how the accreted matter is carried inwards.

NGC 7679 as an unusual Seyfert galaxy in the sense of both above written points. The high-luminous IR galaxy NGC 7679 is nearby (z = 0.0171) nearly face-on SB0 Sy2 galaxy in which starburst and AGN activities co-exist [1].

Composite Seyfert-starburst galaxies have been recently studied by Levenson et al. [2]. A significant part of the observed emission in the far IR (or FIR) spectral domain 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 (see [2], and references therein). NGC 7679 belongs to a small sample of unabsorbed (Compton-thin or "transmission-dominated") 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 [3].

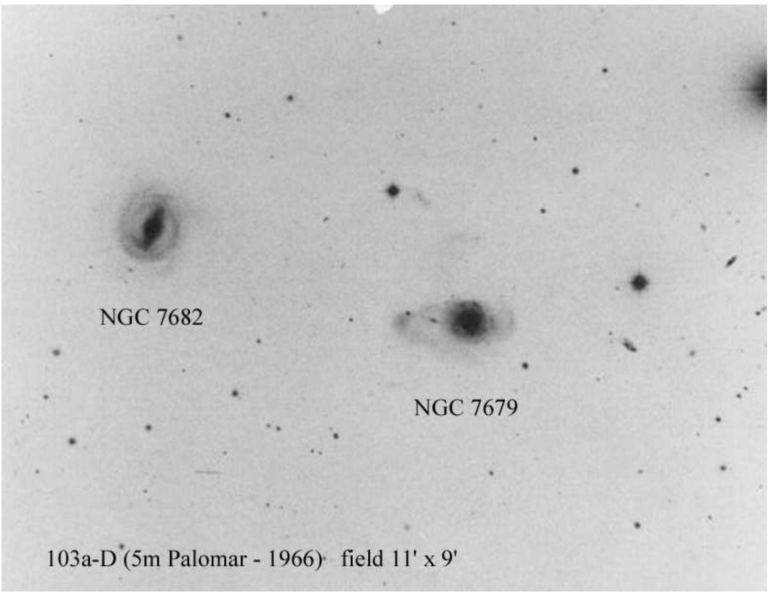

Fig. 1. The field of Sy2 galaxy pair NGC 7679 and NGC 7682. This DSS broad-band image was downloaded from the image archive of the NED Extragalactic database (http://nedwww.ipac.caltech.edu/). Hereafter North is up and East is to the left as it is accepted worldwide in astronomy

NGC 7679 is physically associated by a common stream of ionized gaz with the Sy2 galaxy NGC 7682 at $\sim$ 4.5 arcmin eastward. There are also signs of tidal disruption due to the interaction with the faint compagnion that lies $\sim$ 50 arcsec at eastern direction also (see Fig. 1). Together with the existence of a bar in NGC 7679 this could enhance the gas flow towards the nuclear regions and possibly trigger the starburst processes observed [4].

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

2. OBSERVATIONS AND DATA REDUCTION

NGC 7679 was observed by K. Jockers, T. Bonev, and T. Credner with the 2m RCC 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-Institut für Aeronomie (MPAe), Germany, designed by K. Jockers. This instrument was primarily intended for cometary studies but it has repeatedly been used for observations of active galactic nuclei (see for example [5], [6], and [7]). The technical data and the present capabilities of the MPAe Focal Reducer are described in [8] and [9].

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. Two exposures of NGC 7679 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.

Table 1. NGC 7679—Details on observations

Image frame	Interference filter[a) $\lambda_c/\Delta\,\lambda$	Fabry-Perot tuned wavelength $\lambda_{\rm FP}$, Å	Frames $\times$ exposure time, s
Red channel:			
H$\alpha\lambda$6563	6662/55	6674.8	1×1800
			2×900
[N II]λ6548	6662/55	6659.9	1×900
continuum	6719/33	6720.0	1×1800
			1×900
[O III]λ5007	5094/44	5092.4	2×900
continuum	5002/41		1×1200
Gunn r[b)	6800/1110	–	1×60
Blue channel:			
[O III]λ4363	4432/44	4437.7	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

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 λ_{FP} at which the Fabry-Perot was tuned, and the exposures are listed.

The images were reduced following the usual reduction steps for narrow-band 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 Point-Spread Functions (PSFs) of each line – continuum pair which unavoidably degrades the final FWHM of the images to the mean value about 3–3.5 arcsec. At the distance of NGC 7679 one arcsec corresponds to a distance of about 340 pc assuming $H_0 = 75$ km sec^{-1} Mpc^{-1}.

3. RESULTS

The analysis of 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 a "double nucleus" otherwise unseen in the known broad-band images. The separation between the nuclear counterparts (in fact one is the active nucleus itself and the other is the brightest extremely powerfull starburst region close to the nucleus at P.A. $\approx 315°$ in NW direction) is ≤ 3 arcsec.

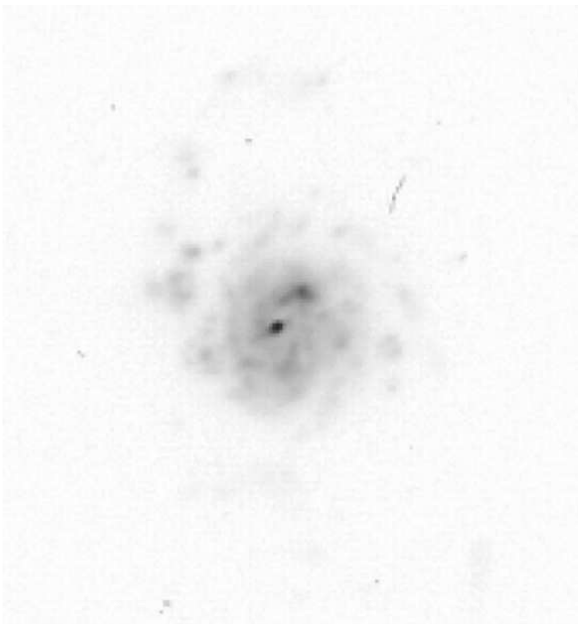

Fig. 2. Hα image of the nuclear parts of NGC 7679 extracted from the archive of 3.5m NTT ESO telescope at La Silla, Chile. The separation between the nucleus and the brightest extremely powerfull starburst region at P.A. $\approx 315°$ is about 3 arcsec

In Fig. 2 we present the pure Hα emission from the nuclear parts of NGC 7679 extracted from archive images taken with the 3.5m ESO NTT at La Silla, Chile, where the powerfull circumnuclear starburst regions are seen.

An indication of such "double nucleus" could be seen in at very different wavelength range on 6-cm high-resolution VLA radiomap of NGC 7679 published without comments by P. Stine (see [10]) in 1992. The angular distance between two counterparts is quite the same. During his study of radio and infrared emission from Markarian starburst galaxies Stine concluded that the radio spectral index steepens away from the center which indicates that nonthermal emission leaks out of the starburst region.

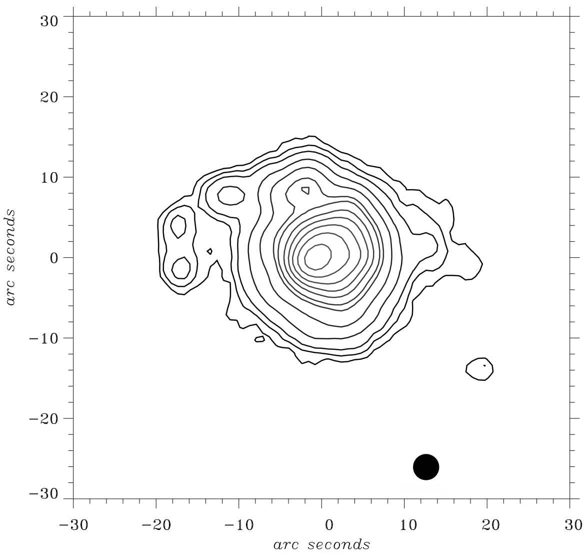

Fig. 3. The logarithmicaly spaced contours of continuum-subtracted deep high-contrast narrow-band Hα -image of the regions around the nucleus of NGC 7679. Hereafter the image center (0,0) denotes the optical position of the nucleus of NGC 7679 (as given in NED). The resulting FWHM of the seeing after all reductions is shown

In Fig. 3 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 NGC 7679 could enhance the gas flows towards the nuclear regions and possibly trigger the starburst processes.

The analysis of the [O III]λ5007 emission shows both clear East-West elongation and two extrema decentered of about $\sim$ 4 arcsec from the position of the nucleus (Fig. 4). 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

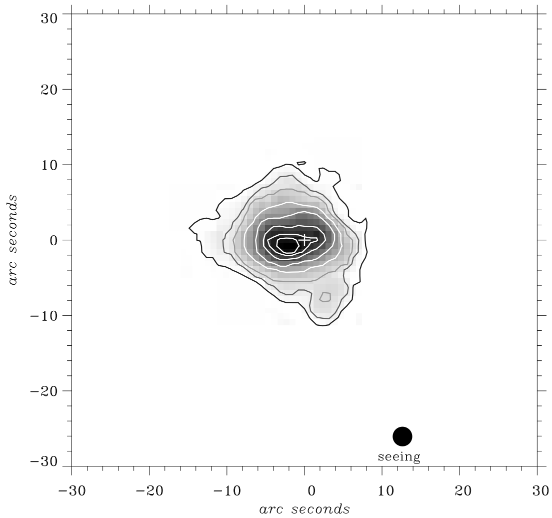

Fig. 4. The contours of continuum-subtracted narrow-band [O III]λ5007-image superimposed on the gray-scale [O III]λ5007-emission distribution of the regions around the nucleus of NGC 7679. Note East-West elongation and two extrema decentered of about $\sim$ 4 arcsec from the position of the nucleus

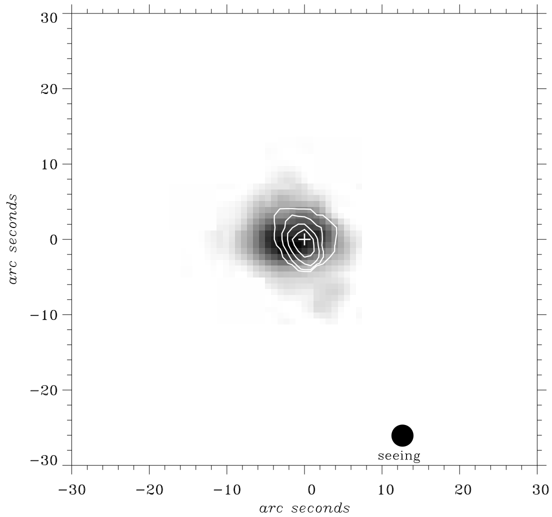

Fig. 5. The contours of [O III]λ4363/[O III]$\lambda\lambda$4959 + 5007 ratio superimposed on the gray-scale [O III]λ5007 halftone image of the regions around the nucleus of NGC 7679. The maximum of [O III]λ4363 emission arises in the innermost nuclear region situated in the valley between both maxima of the [O III]λ5007 emission

any preferred direction. The contours of the [O III]λ4363/[O III] $\lambda\lambda$4959+5007 ratio are elongated along the direction perpendicular to the extension of the [O III]λ5007 emission (see Fig. 5). Note the shift of the [O III]λ4363/[O III]$\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 [O III]λ5007/Hα ratio or the ionization map (Fig. 6) 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. Adopting $T_{\rm e}$ between 1.0×10^4 K and 2.0×10^4 K the observed [O III]λ4363/[O III]$\lambda\lambda$4959 + 5007 ratio shows very high electron densities at the direction of the nucleus ($\log N_{\rm e}$ varies between 6.2 and 7.8).

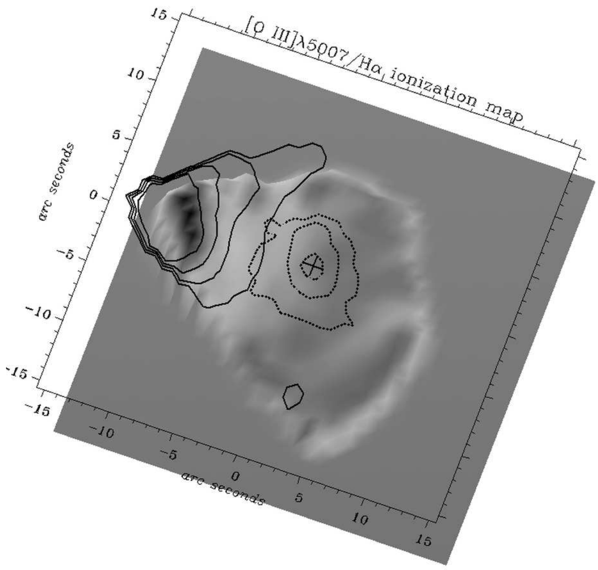

Fig. 6. The contours of [O III]λ4363/[O III]$\lambda\lambda$4959 + 5007 ratio superimposed on the gray-scale and contours of the ionization map (or [O III]λ5007/Hα ratio)

4. DISCUSSION

The luminous IR SyGs, in the framework of the AGN simple unification model featuring a thick dusty torus around the nucleus, represent the same population as usual optically selected far-IR emitting AGNs but viewed edge-on to the disk. Thus the active nucleus is obscured [11], and the FIR emission is due to a centrally heated torus [12, 13]. It should be mentioned that there are still very little direct evidences for the existence of the torus itself in the centers of SyGs.

On the basis of the emission-line fluxes extracted from the central 2 kpc region of NGC 7679 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 $\rm s^{-1}$. On the other hand the number of ionizing photons $N_{\rm Xray}$ provided by the central AGN and estimated from the measured flux in soft X-rays ($0.1 - 2$ keV band) is $N_{\rm Xray} \approx 10^{53}$ photons $\rm s^{-1}$).

The complex physical nature of the Sy2 nucleus of NGC 7679 is outlined by following pecularities:

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

(ii) The [O III]λ5007 emission of the regions around the nucleus of NGC 7679 is elongated in East-West direction and two extrema decentered of about $\sim$ 4 arcsec from the position of the nucleus. The [O III]λ4363 emission arises in the innermost nuclear region between both maxima of [O III]λ5007 emission. Thus 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 temperatute $T_{\rm e}$.

(iii) Both the dense ionized gas in the innermost region (probably dust-mixed) and the inferred ionization anisotropy of the radiation field together with the photon deficiency of ionizing photons $N_{\rm Xray}/N_{\rm opt} = 0.1 - 0.5$ (where $N_{\rm opt}$ is the number of ionizing photons needed to maintain the observed ionization structure, and $N_{\rm Xray}$ 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 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 (see e.g. [14]).

(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 eastward from the nucleus.

5. 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. Meanwhile 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 ($\leq$ 2.5 kpc) is maintained by the AGN-type continuum whereas outside this region the source of ionization has a starburst origin. 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 $N_{\rm opt}/N_{\rm Xray} \approx 0.1 \div 0.5$

we conclude that the central AGN source is observed trough the dust-gas clouds which could be in relation with a dusty torus. This picture deviates from the widely accepted simple Unified Model for Seyfert-type active galactic nuclei.

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