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Letter to the Editor

Detection of an extremely soft X-ray outburst in the H II-like nucleus of NGC 5905

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Abstract. NGC 5905 was observed with ROSAT five times, three times during the ROSAT all-sky survey (RASS) and twice in the pointed observing mode. The soft X-ray properties of the nucleus of NGC 5905 derived from the RASS observations, namely high-amplitude flux variability on timescales of days, the extremely soft spectrum (photon index $\Gamma = 4$), and high peak luminosity of $L_X = 7 \cdot 10^{42}$ ergs s^{-1}, are all inconsistent with its optical classification as HII-type, i.e. starburst galaxy. During the pointed observations taken two years later, the X-ray luminosity was down by a factor of > 80. Possible mechanisms, which can produce the high state, are discussed. Tidal disruption of a star near a central black hole is in good agreement with the observations.

Key words: Galaxies: general - galaxies: starburst - galaxies: individual: NGC 5905 - quasars: general - X-rays: galaxies

1. Introduction

X-ray observations have revealed distinct differences between nuclei of normal spiral galaxies, starburst galaxies, and active galactic nuclei (AGN). The latter object class has X-ray luminosities in excess of 10^{42} ergs s^{-1}, typically (Seyfert 1 galaxies, Maccacaro et al. 1991, Moran et al. 1995). They have complex multicomponent X-ray spectra which can be described in first approximation with a power law. In many AGN strong variability has been observed with doubling time scales down to 1000 seconds (e.g. IRAS 13224−3809, Boller et al. 1993), which imposes hard constraints on the size of the emitting region. The most popular theory to account for these observations is that of a massive black hole surrounded by an accretion disk (Mushotzky et al., 1993). In the optical wavelength region AGN are recognized by their emission line spectra. The relative emission line strengths cannot be described by single thermal components and need complex multifrequency continua. The high intrinsic velocities inferred from the line widths are considered as evidence for the existence of a deep potential well near the central black hole.

On the other hand, nuclei of normal spiral galaxies can be explained as central condensations of stars and interstellar gas. X-ray luminosities of up to 10^{40} ergs s^{-1} can be produced by large numbers of X-ray binaries, presumably mostly high mass X-ray binaries (HMXRBs), and supernova remnants (SNRs) in the central condensation (Fabbiano 1989). However, in many cases the presence of a weak AGN with a luminosity considerably below 10^{40} ergs s^{-1} cannot be ruled out entirely. If no or little soft X-ray variability is observed, its contribution to the total luminosity must be small, though.

Starburst nuclei show properties similar to those of normal galaxies, with soft X-ray luminosities of up to $\sim 10^{41}$ ergs s^{-1}, due to the comparatively larger number of HMXRBs and SNRs in the central condensations (Fabbiano 1989). The optical emission line spectra of these nuclei can be considered as upscaled versions of HII region spectra. Velocities derived from the line widths do not exceed 800 km s^{-1}.

Recent ROSAT results have challenged this rather consistent distinction between starburst nuclei and AGN based on their optical and X-ray emission characteristics. Boller et al. (1994) claimed the discovery of strong X-ray variability in an exceptionally X-ray luminous (> 10^{42} ergs s^{-1}) HII type galaxy However, Halpern et al. (1995) have doubts about the classification of the optical spectrum. Another galaxy with unusual properties is IC3599 (Brandt et al., 1995 and Grupe et al., 1995). 1990/91 it had X-ray luminosities above 10^{44} ergs s^{-1}, with an extremely steep X-ray and EUV spectrum and a peculiar optical spectrum similar to narrow-line Seyfert 1 galaxies. In the next years the X-ray flux faded by a factor of 100 and the high excitation lines in the optical spectrum disappeared.

In this paper we present X-ray timing and spectral properties of NGC 5905 (see Fig. 1), a galaxy with similarities to these objects. Because of its unusual properties one section describes in detail the optical identification of the X-ray source and its reliability. Afterwards, the X-ray observations and the optical classification are described. The discussion deals with the possible source of the X-ray emission and on the implications on the AGN – starburst nuclei dichotomy.

2. X-ray observations and optical classification

In Tab. 1 details about the ROSAT observations are given. For the following X-ray analysis source photons were extracted

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within a radius of 300". The background was determined within a source free cell along the scanning direction of the telescope for the RASS data and for a source free cell near the target for the pointed observation. The data were corrected for vignetting.

2.1. X-ray variability

NGC 5905 was already observed in the test phase of the RASS in July 1990 for 1250 sec with a maximal count rate of 0.6 cts s^{-1}. This first observation is spread over 6 days. A timing analysis is possible for the central four days of this period and reveals a count rate increase by a factor of ~ 3 (Fig. 2). During the RASS NGC 5905 was observed twice, in December 1990, and January 1991, respectively. Already the upper limits indicate stronger variability than during the RASS test phase observations. Since the effective exposure times for the RASS II and III observations are very short the resulting upper limits give no strong constraints. The pointed observations allow much more stringent statements about high amplitude variability. The observed count rate of 0.007 cts s^{-1} in the 1993 data represents a minimal difference in the count rate compared to the early RASS test phase of a factor of 80. For the first pointed observation, only an upper limit can be given. However, in this pointed observation NGC 5905 is located near the edge of the field of view and is hidden partially by the detector grid structure. It should be noted that NGC 5905 was in a high state only in one out of five observations, thus suggesting an outburst in the RASS test phase.

2.2. X-ray spectral properties

The hardness ratio given in Tab. 1 is defined as HR = (hard − soft)/(hard + soft) with soft and hard count rates in the energy bands 0.1 − 0.5 keV and 0.5 − 2.4 keV, respectively. A power law fit with absorption fixed to the Galactic foreground value, $N_{H,gal} = 1.5 \cdot 10^{20}$ cm^{-2}, yields a photon index of $\Gamma = 3.97 \pm 0.39$ (Γ defined as $N_{ph} \propto E^{-\Gamma}$, the quoted errors are for the 68% confidence level). To simplify comparisons of the resulting L_X with other sources we use this common model in the discussion. Leaving N_H as a free parameter in the power law fit leads even to $\Gamma > 5$. These values from the RASS observations characterize NGC 5905 as an extremely soft X-ray emitter compared to other galactic nuclei. Parameters of several model fits are given in Tab. 2. The low count rate in the second pointed observation does not allow a detailed spectral analysis. Nevertheless the hardness ratio of -0.65 ± 0.11 and the photon index of 2.41 ± 0.69 show a significant hardening in comparison to the high state in the RASS.

2.3. Reliability of identification

The emission properties of the source presented here are so extraordinary that its correct identification is crucial for an interpretation of our results. Fig. 1 shows the ROSAT pointing error circle for our RASS observations overlaid on a digitized sky survey image of NGC 5905, after correction for boresight errors. In Tab. 1 we list the positions of the X-ray source and the optical nucleus of NGC 5905. This shows suggestively that the X-ray source has to be located within a few arcseconds of the centre of NGC 5905. Since the observed X-ray emission is extremely soft we can be sure that no emission was picked up from a background source behind the galaxy. Below 0.4 keV, where the emission maximum lies in our observations, galaxy disks, with typical HI column densities of $> 5 \cdot 10^{20}$ cm^{-2}, are opaque. Galactic foreground objects with the observed strong variability are rare. Only extremely flaring M dwarfs and cataclysmic variables can be considered, but they have shorter variability timescales and no such object was optically detected in front of NGC 5905.

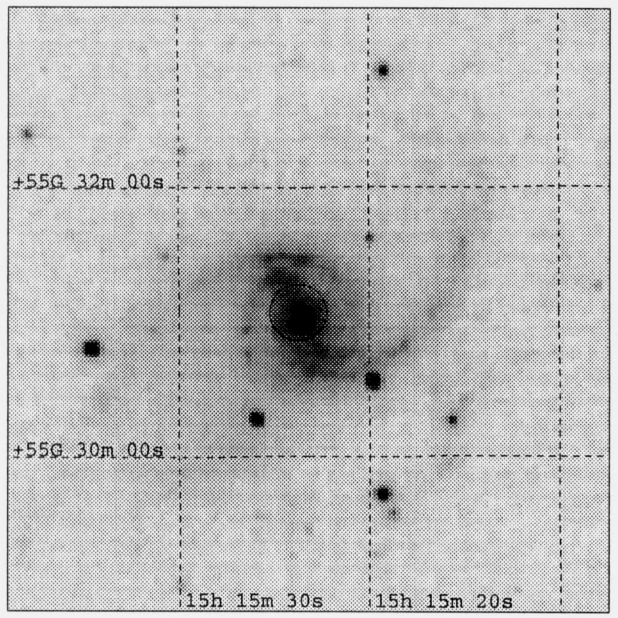

Fig. 1. Digitized POSS image of NGC 5905 with RASS error circle.

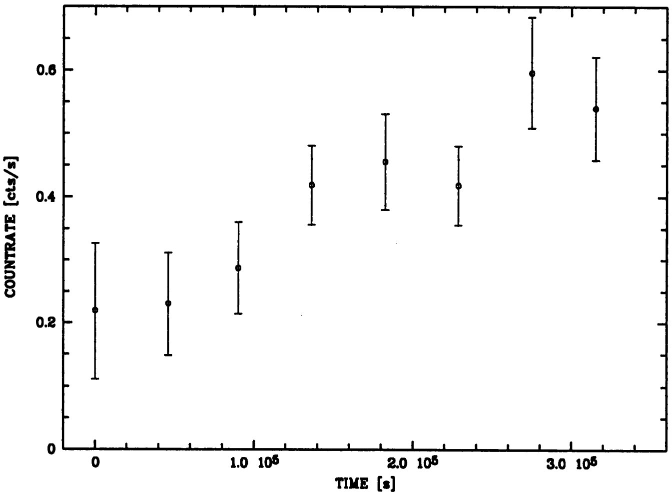

Fig. 2. X-ray light curve of NGC 5905 in the RASS test phase (July 12-15, 1990)

2.4. Optical classification of NGC 5905

NGC 5905 is a large barred spiral galaxy with B = 12.3 and an optical diameter $D_{25} = 7'$ (Romanishin, 1983). Sandage (1993) gives a recessional velocity of 3769 km s^{-1} corrected for local motions of our own Galaxy. With $H_0 = 50$ km s^{-1} Mpc^{-1} the distance is 75.4 Mpc and D_{25} corresponds to a diameter of 153 kpc so that NGC 5905 has to be considered as one of the physically largest spiral galaxies known so far.

	date	R.A.	declination	p. u.	exposure [s]	photons	count rate [s^{-1}]	HR
RASS I	11-16/07/1990	15 15 23.7	+55 31 04	13"	1250	400 ± 47	0.40 ± 0.03	-0.86 ± 0.03
RASS II	21/12/1990				100		< 0.09	
RASS III	15/01/1991				50		< 0.10	
point. obs. I	06/01/1992				3000		< 0.004	
point. obs. II	18/07/1993	15 15 23.5	+55 31 02	14"	10200	70 ± 10	0.007 ± 0.001	-0.65 ± 0.11
Optical pos.		15 15 23.2	+55 31 05	2"				

Table 2. Best-fit spectral parameters for the RASS observations and the second pointed observation of NGC 5905. f_X is given in units of 10^{-13} ergs cm^{-2} s^{-1}, N$_\mathrm{H}$ in 10^{20} cm^{-2}, and L_X in 10^{41} ergs s^{-1} (L_X calculated for D = 75.4 Mpc).

	RASS						pointed observation II		
Model	N$_\mathrm{H}$	Γ	kT(eV)	χ^2/ν	f_X	L_X	Γ	f_X	L_X
power law free	2.9 ± 1.9	5.1 ± 1.1		13.5/13	326 ± 497	225			
power law	1.5	4.0 ± 0.4		17.7/14	69 ± 12	48	2.4 ± 0.7	0.7 ± 0.4	0.4
blackbody	1.5		56 ± 12	16.1/14	37 ± 5	26			
bremsstrahlung	1.5		137 ± 33	15.9/14	47 ± 5	32			

A moderate resolution optical spectrum of the nucleus of NGC 5905 can be found in the spectral atlas of nuclei in nearby galaxies (Ho et al., 1995). The spectrum was taken in 1985 and shows strong similarities to the spectrum of M82 (Ho et al., 1995), a prototype starburst galaxy. Therefore, NGC 5905 appears to belong to the same class of objects. In the emission line diagnostic diagrams of Veilleux and Osterbrock (1987) NGC 5905 is placed in the region of HII-galaxies. With a width of 300 km s^{-1} the Balmer emission lines have the same FWHM as the forbidden lines visible in the spectrum ([O III] 4360, [O III] 4959, [O III] 5007, [O I] 6300, [N II] 6548, [N II] 6584 and [S II] 6717 + 6731). No broad wings in the Balmer lines and no Fe II emission lines are detectable in the high signal-to-noise spectrum by Ho et al. (1995). Giuricin et al. (1991) derived the same classification independently with different optical spectra.

3. Discussion

3.1. Starburst vs. AGN – observational constraints

The following four observational results constrain model scenarios of the nucleus of NGC 5905:

X-ray luminosity. The highest observed count rate in the RASS is 0.6 cts s^{-1} on July 15, 1990. Using the conversion factor following from the power law fit with N$_\mathrm{H}$ fixed to the Galactic value (Tab. 2), a soft X-ray luminosity in the 0.1–2.4 keV band of $L_X = 7 \cdot 10^{42}$ ergs s^{-1} is calculated. Tab. 2 illustrates that the value of f_X and therefore L_X depends strongly on the choice of the spectral model that we fit to the data. The absolute value of L_X is therefore not well defined. Based only on photon statistics, none of the models in Tab. 2 can be excluded. The free power law fit can probably be ruled out because of an unphysically steep rise of the power law component at the lowest energies.

X-ray spectral variability. In the low state the soft X-ray spectrum of NGC 5905, although not well-constrained by our data, is considerably flatter than during the X-ray outburst. The low-state luminosity of $4.4 \cdot 10^{40}$ ergs s^{-1} and the shape of the soft X-ray spectrum during the pointed observations are consistent with earlier results on other starburst galaxies (e.g. Watson and Stanger 1982). From this it follows that the additional flux observed in the high energy state of NGC 5905 is presumably in the extremely soft X-ray energy range and the maximum of the emission must lie in the extreme ultraviolet (EUV) spectral range.

Duration of the X-ray outburst. The high luminosity quoted above was observed over a period of 6 days, while 5 months later it had already declined to below our detection limit. Therefore, we can estimate the total energy released in the high state to be of the order of 10^{49-50} ergs.

The optical spectrum. Another observational result, which must be taken into account for the discussion of the emission mechanism is the optical spectrum of the nucleus. It exhibits all characteristics of an HII-type nucleus. The strengths of the emission lines can be explained by the ionizing continuum of hot young stars; no low luminosity AGN has set its footprints via broad wings in the Balmer lines.

Putting all our results together it is unlikely that NGC 5905 hosts an X-ray loud Seyfert 1 nucleus, which might just be hidden by foreground interstellar gas (as found e.g. in NGC 1808 and NGC 4945; Awaki and Koyama, 1993). The observations rather suggest that the high luminosity X-ray event was a short-lived outburst. This outburst is the first observed in such a galaxy which is simultaneously so soft and luminous.

X-ray observations of another galaxy which are similar to ours on NGC 5905, were obtained by Boller et al. (1994), who observed high-amplitude X-ray variability with doubling timescales of about 1500 sec and a peak $L_X > 10^{42}$ ergs s^{-1} in IRAS 15564+6359, a galaxy classified in the optical domain as HII-type. However, in this case the quality of the optical spectrum is too poor to be conclusive and other authors (Moran et al. 1995, Yegiazarian and Khachikian 1988) have classified this galaxy as Seyfert 1 type. Perhaps IRAS 15564+6359 is another example for a Seyfert 1 galaxy with variable optical spectrum.

3.2. Character of the outburst

No stellar objects are known with the above quoted X-ray luminosities. HMXRB's are the most powerful permanent X-ray emitters and are highly variable, but luminosities above 10^{40} ergs s^{-1} are far beyond observed values (Nagase 1989). Non catastrophic X-ray sources cannot explain the luminosity of the high state of NGC 5905 and its outburst character also excludes a large ensemble of such objects.

Based only on total energy considerations, a supernova with a typical total energy output of order 10^{51} ergs is capable of creating an outburst as observed. However, previous supernovae had peak luminosities below 10^{40} ergs s^{-1} and emitted a harder X-ray spectrum. This would dismiss supernovae, but it has to be kept in mind that only four have been observed in soft X-rays so far (Schlegel, 1993).

The soft X-ray emissivity of an SNR is, again, too low. The possibility of an SNR expanding into an optically thick high-density medium (in which a large fraction of the kinetic energy could be converted into radiation in the UV and X-ray regime, see Shull (1980) and Wheeler et al. (1980)) is also ruled out by the observations. Neither the expected X-ray photons at energies of a few keV arising from the shock-heated gas at temperatures in the range 10^{8-9} K nor strong X-ray absorption in excess of the Galactic value are detected.

Other known mechanisms which emit as much energy as observed in the outburst of NGC 5905 involve high-mass central black holes. The image of a Seyfert nucleus accreting close to its Eddington limit and hidden by foreground interstellar gas has been excluded above, although further observations, e.g. in radio wavelengths and hard X-rays, are needed for a strict rejection. If a black hole were responsible for the observed outburst, it would of course also exist in phases when the soft X-ray emission of NGC 5905 is in its low state. Then, however, the black hole would be quiescent and thus invisible, because no broad line region is detectable in the optical spectrum. In this scenario, the ionizing continuum, producing the optical emission lines, is of stellar origin.

The idea of quiet black holes in normal galaxies is not new. AGN activity seems to have undergone a maximum around $z = 2$ (Hartwick and Schade, 1990). The black holes must still exist. However, the decreased level of activity indicates that many of them might be dormant. This is probably due to the lack of large surrounding disks at the present epoch. On the other hand, black holes do not only accrete gas and dust, but also stars. When a star is falling towards the black hole it experiences a gravitational torque which in the end leads to its tidal disruption (Rees 1990). After disruption about half of the mass of the star forms an accretion torus around the hole. The luminosity of the accretion disk should be a substantial part of the Eddington luminosity, $L_{\rm Edd} = 1.3 \cdot 10^{38}\, M_{\rm H}$ ergs s^{-1} (where $M_{\rm H}$ is the black hole mass in solar masses). The time scale of this event can be estimated to be of the order of months. Sembay and West (1993) suggest a thermal bremsstrahlung spectrum with $kT = 0.02 - 0.05$ keV for the accretion torus. For the outburst of IC 3599 tidal disruption has also been proposed as emission mechanism (Brandt et al., 1995; Grupe et al., 1995). Although in this case no low state optical spectrum is available, the spectral properties become more and more like a HII-type nucleus with increasing time distance to the outburst.

The observed properties of the outburst event in NGC 5905 are close to the proposed scenario of Sembay and West, 1993. However, there is a difference to the assumptions of these two authors: NGC 5905 is not really a normal galaxy, but hosts a central starburst. Starburst nuclei have high star densities and their velocity fields are not in equilibrium due to frequent supernova explosions. Both peculiarities increase the probability for capturing stars into a central black hole, thus favouring our proposed scenario.

In summary, the model invoking the tidal disruption and subsequent accretion of a star by a central black hole can explain our observations of NGC 5905 most naturally. All other models fail to explain at least one aspect of our data. However, large uncertainties remain. An optical spectrum of moderate resolution and high signal to noise exists for the quiescent state of NGC 5905, from which it can be classified unequivocally. For the outburst time or shortly afterwards no spectrum exists. This also makes the comparison of the optical emission properties of NGC 5905 and IC 3599 a bit speculative. Although not discussed any further here, such outburst events are of great interest for studies of AGN evolution and of the relation between AGN and starburst nuclei.

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References

Awaki H., Koyama K., 1993, Adv. Space Res. 13, 221

Boller T., Trümper J., Molendi S., et al., 1993, A&A 279, 53

Boller T., Fink H., Schaeidt S., 1994, A&A 291, 403

Brandt W. N., Pounds K. A., Fink H. H., 1995, MNRAS 273, L47

Fabbiano G., 1989, ARA&A 27, 87

Giuricin G., et al., 1991, MNRAS 247, 444

Grupe D., Beuermann K., Mannheim K., et al., 1995, A&A 299, L5

Halpern J. P., Helfand D. J., Moran, E. C., 1995, ApJ 453, 611

Hartwick F. D. A., Schade D., 1990, ARA&A 28, 437

Ho L. C., Filippenko, A. V., Sargent, W. L. W., 1995, ApJS 98, 477

Maccacaro T., Della Ceca R., Gioa I. M., et al., 1991, ApJ 374, 117

Moran E. C., Halpern J. P., Helfand D. J., 1994, ApJ 433, L65

Mushotzky R., Done C., Fabian A. C., 1993, ARA&A 31, 717

Nagase F., 1989, PASJ 41, 1

Rees M. J., 1990, Science 247, 817

Romanishin W., 1983, MNRAS 204, 909

Sandage A., 1993, ApJ 402, 3

Schlegel E. M., 1993 in AIP Conference Series 313, p. 195, editors Schlegel E. M., Petre R.

Sembay S., West R. G., 1993, MNRAS 262, 141

Shull J. M., 1980, ApJ 237, 769

Veilleux S., Osterbrock D. E., 1987, ApJS 63, 295

Watson M. G., and Stanger V., 1982, ApJ 286, 144

Wheeler J. C., Mazurek T. J., Sivaramakrishnan A., 1980, ApJ 237, 781

Yegiazarian and Khachikian, 1988, Soob. Byurakan, Spets. Astrofiz. Obs. 60, 3

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