The giant-amplitude X-ray outburst in NGC 5905 – a tidal disruption event?

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Abstract. NGC 5905 is one of the very few galaxies that underwent a giant X-ray outburst, with a change in photon countrate of a factor \(\sim 100\). The outburst spectrum is both, very soft and luminous (Bade, Komossa & Dahlem 1996). Remarkably, the optical pre-outburst emission line spectrum of NGC 5905 is that of an HII-type galaxy, i.e. does not show any signs of Seyfert activity.

One exciting explanation of the X-ray observation is that we may have witnessed the tidal disruption of a star by a supermassive black hole (SMBH) residing in the nucleus of this galaxy. The expected flare of electromagnetic radiation being produced when the stellar debris is swallowed by the black hole was proposed by Rees (1988) as a means of tracing SMBHs in nearby non-active galaxies.

In the present work, we discuss this and other possible outburst scenarios through an analysis of all ROSAT PSPC and HRI X-ray observations of NGC 5905. We also present simultaneous and long-term optical photometry of NGC 5905 as well as follow-up optical spectroscopy.

1. X-ray observations

A giant X-ray outburst of NGC 5905 was discovered during the ROSAT (Trümper 1983) survey observation (Bade, Komossa & Dahlem 1996). NGC 5905 showed a high countrate during this first ROSAT observation. The countrate then declined by at least a factor of several within months and was down by a factor \(\sim 100\) two years later.

The X-ray spectrum during the outburst was very soft (with photon index \(\Gamma_x \approx -4.0\) when fit by a powerlaw). During quiescence, the spectrum is flatter (\(\Gamma_x \approx -2.4\)). The outburst luminosity is of the order of \(L_x \gtrsim \text{several } \times 10^{42} \text{ erg/s}; \) much higher than observed in non-active spiral galaxies (e.g., Fabbiano 1989, Vogler 1997).

New HRI data were taken in 1996 with an exposure time of 76 ksec. These show a further decline by a factor \(\sim 2\) in flux with respect to the last PSPC observation. The long-term X-ray lightcurve is displayed in Fig. 1.

2. Optical observations

Optical observations are an important supplement to the X-ray data. The two most important questions are (i) is there a simultaneous optical outburst, and (ii) does the optical spectrum of NGC 5905 show any signs of Seyfert activity?

2.1. Photometry

We have used photographic plates taken at Sternwarte Sonneberg to produce a long-term optical lightcurve (between years 1962 and 1995) of the nucleus of NGC 5905 and searched the plates taken quasi-simultaneously to the X-ray outburst for a correlated optical outburst. A change in brightness of \(5^m\) is expected if the amplitude at optical wavelengths is the same as in X-rays.

The optical brightness of NGC 5905 is found to be constant within the errors on long terms as well as near the X-ray outburst (Fig. 2), placing strong constraints on outburst scenarios.

2.2. Spectroscopy

We have taken high-resolution post-outburst optical spectra (about 6 years after the X-ray outburst) at the 3.5 m telescope of Calar Alto (Fig. 3). These show the same spectral characteristics as the pre-outburst spectrum of Ho et al. (1995) and classify the galaxy as HII-type. If a high-ionization emission-line component was present during outburst, it had already declined below detectability. We carefully searched for other signs of permanent Seyfert activity – none are revealed. This is another important constraint for outburst models and, at present, makes NGC 5905 the only non-active galaxy among the X-ray outbursting ones.

3. Outburst scenarios

The major characteristics to be explained by outburst models are

\footnote{the other three objects are the Seyfert galaxies IC 3599 (Brandt et al. 1995, Grupe et al. 1995a) E 1615+061 (Piro et al. 1988) and WPVS007 (Grupe et al. 1995b)}
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Fig. 1. X-ray lightcurve of NGC 5905 observed with the ROSAT PSPC and HRI. The dotted curve follows the relation $CR = 0.044(t - t_o)^{-5/3}$ with $t_o = 1990.54$. A time dependence of $\propto t^{-5/3}$ is predicted in the model of tidal disruption of a star (Rees 1988, 1990).

Fig. 2. Optical lightcurve of the nucleus of NGC 5905, based on photographic plates taken at Sternwarte Sonneberg. The abscissa gives the Julian date in JD-2400000 (the data points bracket the time interval 1962 – 1995). The upper panel shows the longterm lightcurve, the lower one the lightcurve in the months around the X-ray outburst. Within the error of about 0.2$m$ the optical brightness is constant.

- short duration, extremely soft spectrum, giant amplitude (a factor $\geq 100$) and huge peak luminosity ($L_x \geq 10^{42-43}$ erg/s) of the X-ray outburst
- no simultaneous change in optical brightness
- the optical spectrum is that of an HII-type galaxy with no signs of permanent Seyfert activity

We in turn discuss several outburst scenarios (for details see Komossa & Bade 1998).

3.1. Supernova in dense medium

The outburst X-ray luminosity by far exceeds that of individual supernovae (those observed in X-rays range between $L_x \approx 10^{35}$ and a few $10^{40}$ erg/s; e.g., Schlegel 1995, Immler & Pietsch 1998).

The possibility of ‘buried’ supernovae (SN) in dense molecular gas was studied by Shull (1980) and Wheeler et al. (1980). In this scenario, X-ray emission originates from the shock, produced by the expansion of the SN ejecta into the ambient interstellar gas of high density. Since high luminosities can be reached this way, and the evolutionary time is considerably speeded up, an SN in a dense medium may be an explanation for the observed X-ray outburst in NGC 5905.

Assuming the observed outburst luminosity of NGC 5905 to be the peak luminosity and using the analytical estimates of Shull and Wheeler et al. for the evolution of temperature, radius and luminosity of the shock,

$$T = E_5^{0.14}n_4^{0.27}(t/t_{\text{rad}})^{-10/7}(2.7 \times 10^7 \text{ K})$$

(1)
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Fig. 3. Optical spectrum of the nucleus of NGC 5905 taken about 6 years after the X-ray outburst. The arrows mark the detected emission lines. The weakness of [OIII]λ5007 compared to Hβ classifies the galaxy as HII-type. The positions of some high-ionization lines, not detected in the spectrum, are marked as well.

\[ R = E_{51}^{0.29} n_4^{-0.43} (t/t_{\text{rad}})^{2/7} (0.29 \text{ pc}) \]  
\[ L = E_{51}^{0.78} n_4^{0.56} (t/t_{\text{rad}})^{-11/7} (9.8 \times 10^{39} \text{ erg/s}) \]

results in a density of the ambient medium of \( n \approx 10^6 \text{ cm}^{-3} \)
but is inconsistent with the observed softness of the spectrum: The expected temperature is \( T \approx 10^8 \text{ K} \), compared to the observed one of \( T \approx 10^6 \text{ K} \). Therefore, an SN in dense medium is an unlikely explanation of the observed X-ray outburst. Additionally, fine-tuning in the column density of the surrounding medium would be required in this scenario in order to prevent the SNR from being completely self-absorbed.

3.2. Gravitational lensing event

Large magnification factors of the source brightness can be reached by gravitational lensing (GL) if the observer, lens, and source ly nearly exactly on a line. Lensing was, e.g., discussed as a possibility to explain the observed variability in BL Lac objects (e.g. Ostriker & Vietri 1985). Being independent of photon energy, GL predicts the same magnification factor at optical wavelengths as in X-rays. Given the non-detection of optical variability simultaneous to the X-ray outburst the GL scenario is very unlikely.

3.3. X-ray afterglow of a Gamma-Ray Burst

As to the question of whether the observations may have represented the X-ray afterglow of a Gamma-Ray Burst (GRB), we note that no GRB has been detected in the time around the X-ray outburst (July 12–15, 1990) of NGC5905 (the 2 reported GRBs nearest in time, of July 8, 1990, have different positions; Castro-Tirado 1994 on the basis of Granat/WATCH data). The possibility remains that the GRB escaped detection or that it was not beamed towards us and only the isotropic afterglow was seen.

3.4. Warm-absorbed hidden Seyfert nucleus

In this scenario, NGC 5905 would host a Seyfert nucleus which is intrinsically slightly variable and usually hidden behind a large cold column of absorbing gas. The nucleus gets visible in X-rays during its flux high-states by ionizing the originally cold column of surrounding gas that becomes a warm absorber, which is transparent to soft X-rays and could also account for the softness of the outburst spectrum (Komossa & Fink 1997a). We find that the model of a (dust-free) warm absorber, calculated with Ferland’s (1993) code Cloudy, successfully fits the X-ray spectrum with an ionization parameter \( \log U \approx 0 \) and a column density of the warm material \( \log N_w \approx 22.8 \). Since there is no evidence for Seyfert activity in the optical spectrum, the nucleus must be hidden. Mixing dust with the warm gas could hide the Seyfert nucleus completely. However, dust with Galactic ISM properties mixed with the warm gas strongly influences the X-ray absorption structure (e.g. Komossa & Fink 1997b, and these proceedings) and a fit of a dusty warm absorber to the X-ray spectrum can only be achieved if we strongly fine-tune the dust properties and the dust depletion factor.
3.5. Accretion-disk instability

If a massive BH with an accretion disk exists in the center of NGC 5905, it usually has to accrete with low accretion rate or radiate with low efficiency, to account for the comparatively low X-ray luminosity of NGC 5905 in quiescence. An accretion disk instability may then provide an explanation for the observed X-ray outburst. Thermally unstable slim accretion disks were studied by Honma et al. (1991), who find the disk to exhibit burst-like oscillations for the case of the standard α viscosity description and for certain values of accretion rate.

Using the estimate for the duration of the high-luminosity state (Honma et al.; their Eq. 4.8), and a duration of the outburst of less than 5 months (the time difference between the first two observations of NGC 5905), a central black hole of mass in the range \(10^4 - 10^5 M_\odot\) could account for the observations. The burst-like oscillations are found by Honma et al. only for certain values of the initial accretion rate. A more detailed quantitative comparison with the observed outburst in NGC 5905 is difficult, since the behavior of the disk is quite model dependent, and further detailed modeling would be needed.

3.6. Tidal disruption of a star

The idea of tidal disruption of stars by a supermassive black hole (SMBH) was originally studied as a possibility to fuel AGN (Hills 1975), but was dismissed later. Peterson & Ferland (1986) suggested this mechanism as possible explanation for the transient brightening of the HeII line observed in a Seyfert galaxy. Tidal disruption was invoked by Eracleous et al. (1995) in a model to explain the UV properties of LINERs, and was suggested as possible outburst mechanism for IC3599 (Brandt et al. 1995, Grupe et al. 1995).

Rees (1988, 1990) proposed to use individual such events as tracers of SMBHs in nearby non-active galaxies. The debris of the disrupted star is accreted by the BH. This produces a flare, lasting of the order of months, with the peak luminosity in the opt-UV, EUV or soft X-ray spectral region.

The luminosity emitted if the BH is accreting at its Eddington luminosity can be estimated by \(L_{\text{edd}} \simeq 1.3 \times 10^{38} M/\odot \text{erg/s.}\) In case of NGC 5005, a BH mass of at least \(10^{4-5} M_\odot\) would be required to produce the observed \(L_x\), and a higher mass if \(L_x\) was not observed at its peak value.

The decline in luminosity after the maximum in the tidal disruption scenario scales as \(L \propto t^{-2}\) (Rees 1990). The observed long-term X-ray lightcurve of NGC 5905 is given in Fig. 1.

We favour the scenario of tidal disruption of a star because it can account for the high outburst luminosity, seems to require least fine-tuning, and the long-term X-ray lightcurve shows a continuous fading of the source over the whole measured time interval.

4. Search for other strongly variable objects

We performed a search for further cases of strong X-ray variability (Komossa 1997) using the sample of nearby galaxies of Ho et al. (1995) and ROSAT survey and archived pointed observations. We do not find another object with a factor \(~\times 100\) amplitude, but several sources are discovered to be strongly variable (with maximal factors ranging between 10 and 20 in the mean countrates): NGC3227, NGC4051, and NGC3516. Another case of this amplitude, NGC3628, was reported by Dahlem et al. (1995).

5. Summarizing conclusions

The most likely scenario to explain the X-ray outburst in NGC 5905 seems to be tidal disruption of a star by a central SMBH; a scenario proposed by Rees (1988) as a tracer of SMBHs in nearby galaxies. We caution, though, that many theoretical details of this process are still rather unclear.

High-resolution optical spectroscopy of NGC 5905 does not reveal any signs of Seyfert activity. At present, this makes NGC 5905 the only non-active galaxy among the X-ray outbursting ones (Komossa & Bade 1998).

The X-ray outburst in this HII galaxy then lends further support to the scenario that all galaxies passed through an active phase (instead of just a few), leaving unfed SMBHs in their centers.

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