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Follow-up STIS Spectroscopy of Three Candidate Tidal Disruption Events

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Abstract

Large amplitude, high luminosity soft X-ray flares were detected by the ROSAT all-sky survey in several galaxies with no evidence for AGN activity in their ground-based optical spectra. These flares had the properties predicted for a tidal disruption event by a central supermassive black hole: a soft X-ray spectrum, time-scale of months, and a large X-ray luminosity (10^{42} to 10^{44} erg s^{-1}). In order to evaluate the alternative hypothesis that these flares could have been some form of extreme AGN variability, we obtained follow-up optical spectroscopy of three of the flaring galaxies a decade later with the HST STIS and a narrow slit to search for or place stringent limits on the presence of any permanent Seyfert-like emission in their nuclei. Two of the galaxies, RX J1624.9+7554 and RX J1242.6–1119, show no evidence for emission lines or a non-stellar continuum in their HST nuclear spectra, consistent with their ground-based classification as inactive galaxies. NGC 5905, previously known as a starburst HII galaxy due to its strong emission lines, has in its inner 0.1 arcseconds a nucleus with narrow emission-line ratios consistent with a Seyfert 2 galaxy in the diagnostic diagrams of Veilleux and Osterbrock. The weak Seyfert nucleus in NGC 5905, which was masked by the many surrounding H II regions in ground-based spectra, raises questions about the nature of its X-ray flare.

1.1 Introduction

Dormant, supermassive black holes, suspected to be present in the centers of normal galaxies, should reveal themselves by a UV/X-ray flare when they tidally disrupt a star and some fraction of the tidal debris is accreted. Tidal disruption flares were proposed by Lidskii & Ozernoi (1979) and Rees (1988, 1990) as a probe for supermassive black holes in the centers of inactive galaxies. Such an event is very rare in the nucleus of a galaxy ($< 10^{-4}$ yr^{-1}); however, the ROSAT All-Sky Survey (RASS) in 1990-91 was an ideal experiment to detect these flares since it sampled hundreds of thousands of galaxies in the soft X-ray band. ROSAT detected soft X-ray outbursts from several galaxies with no previous evidence for AGN activity: NGC 5905 (Bade, Komossa, & Dahlem, 1996), RX J1242.6–1119 (Komossa & Greiner 1999), RX J1624.9+7554 (Grupe, Thomas, & Leighly, 1999), RX J1420+5334 (Greiner et al. 2000), and a possible fifth candidate, RX J1331–3243 (Reiprich & Greiner 2001). The flares were distinctive due to their large amplitude of variability (20 – 200), extremely soft blackbody fit temperatures (kT_{bb} = 0.05 -0 .1 keV), and high luminosities (10^{42} – 10^{44} erg s^{-1}). With no previous evidence for permanent AGN

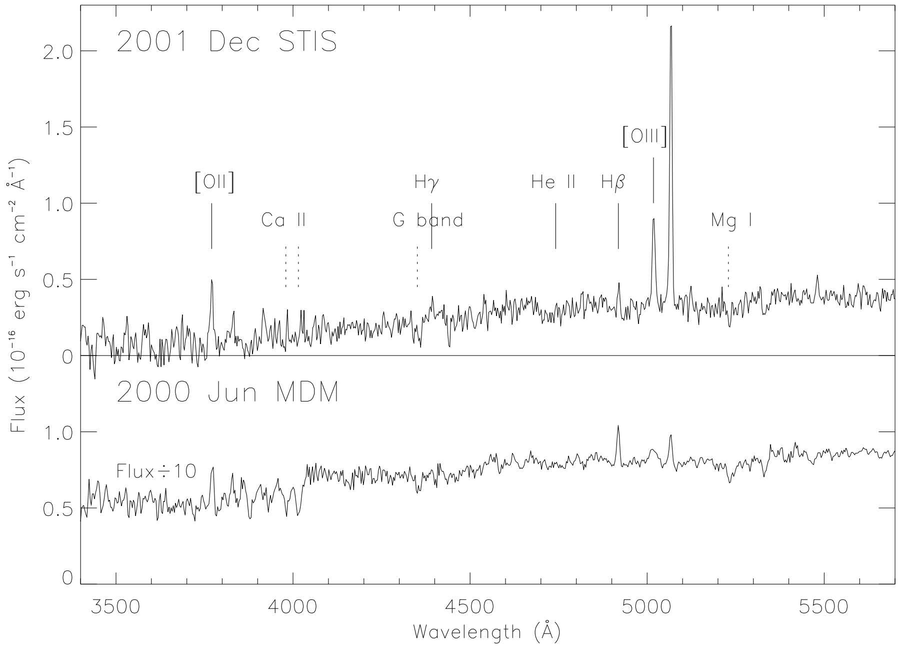

Fig. 1.1. STIS and MDM 2.4m post-flare spectra of the nucleus of NGC 5905, smoothed over one spectral resolution element. The MDM spectrum has been divided by 10 for comparison. Stellar absorption features are shown with dotted lines.

activity in these galaxies, and with flare properties consistent with that predicted for tidal disruption event (Ulmer 1999; Li et al. 2002), the tidal disruption of a star by an otherwise quiescent central supermassive black hole was the most likely outburst scenario. There still remains the possibility that a low-luminosity Seyfert nucleus could reside in the nuclei of these galaxies, undetected in its low-state by ground-based optical observations. In order to establish beyond a reasonable doubt whether these flares were in fact tidal disruption events, as opposed to some form of extreme AGN variability, we present follow-up narrow-slit STIS spectroscopy, up to a factor of 100 more sensitive to nuclear activity than previously obtained ground-based spectra, to search for any weak permanent AGN activity in the centers of these galaxies.

1.2 Results

The STIS spectra of RX J1242.6–11A and RXJ1624.9+7554 demonstrate stellar absorption features, very similar to their ground-based optical spectra. Although the STIS spectra were obtained with a narrow slit, which explains the factor of ~ 5 weaker continuum levels, there appears to be no difference in the spectral features or continuum shape of the STIS spectra compared to the previously obtained ground-based spectra. Thus we find no evidence for permanent Seyfert activity in the nuclei of these galaxies in the form of nuclear emission lines or a non-stellar continuum.

The post-flare ground-based spectra and HST STIS spectra of NGC 5905 (shown in Fig-

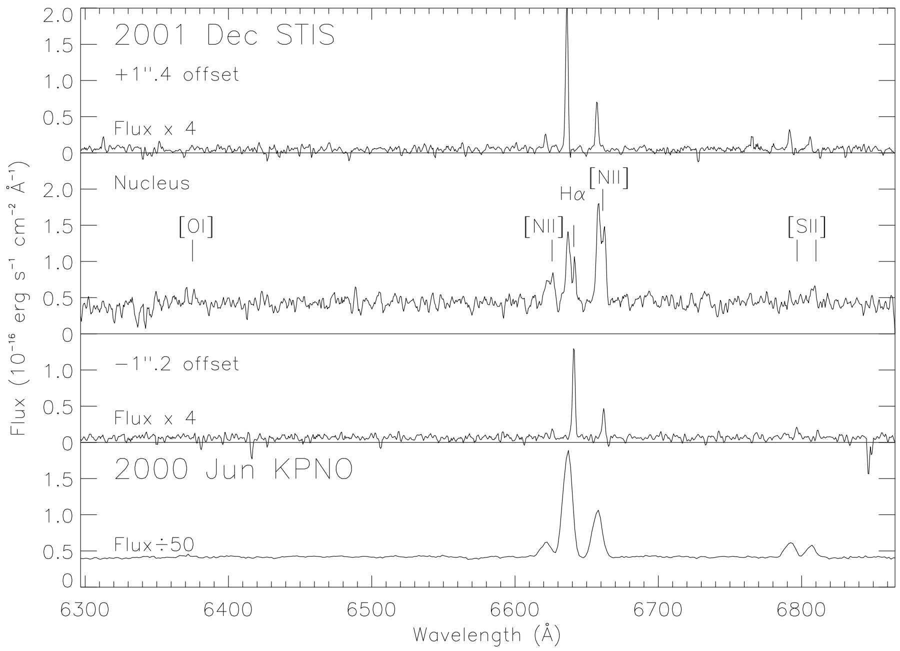

Fig. 1.2. STIS and KPNO 2.1m post-flare spectra of the nucleus of NGC 5905, and STIS spectra centered on peaks of HII emission offset +1".4 and -1".2 from the nucleus, smoothed over one spectral resolution element. The KPNO spectrum has been divided by 50, and the off-nuclear STIS spectra have been multiplied by 4 for comparison.

ures 1.1 and 1.2) differ dramatically. The stellar continuum flux in the STIS spectra are lower than the MDM 2.4m and KPNO 2.1m spectra by two orders of magnitude, and the narrow emission line ratios in the nuclear STIS spectra indicate a higher ionization state for the line emitting gas. The double-peaked Hα and [NII] emission lines in the nuclear STIS spectrum match the velocity shifts of the off-nuclear STIS spectra, centered on peaks of HII emission to the east and west of the nucleus. The off-nuclear spectra and ground-based nuclear spectrum show narrow-line emission consistent with the previous classification of NGC 5905 as an HII/starburst (Ho et al. 1997, Komossa & Bade 1999). The nuclear STIS spectrum, on the other hand, demonstrates narrow emission line ratios that place NGC 5905 in the Seyfert region of the diagnositic diagrams of Veilleux & Osterbrock (see Figure 1.3). These differences in continuum flux and narrow line emission can be understood as a result of the narrower 0".1 slit in the STIS spectra as compared to the $\sim$ 2" slit of the ground-based spectra. The narrow slit effectively reduces the contribution of stellar light and circumnuclear HII nebular emission in the STIS spectrum, making it more sensitive to flux originating from the nucleus itself. The narrow line emission in the STIS spectra is spatially compact compared to the stellar continuum, and has an ionization state different from the ground-based spectra, indicating that the STIS spectra have detected emission from a distinct source

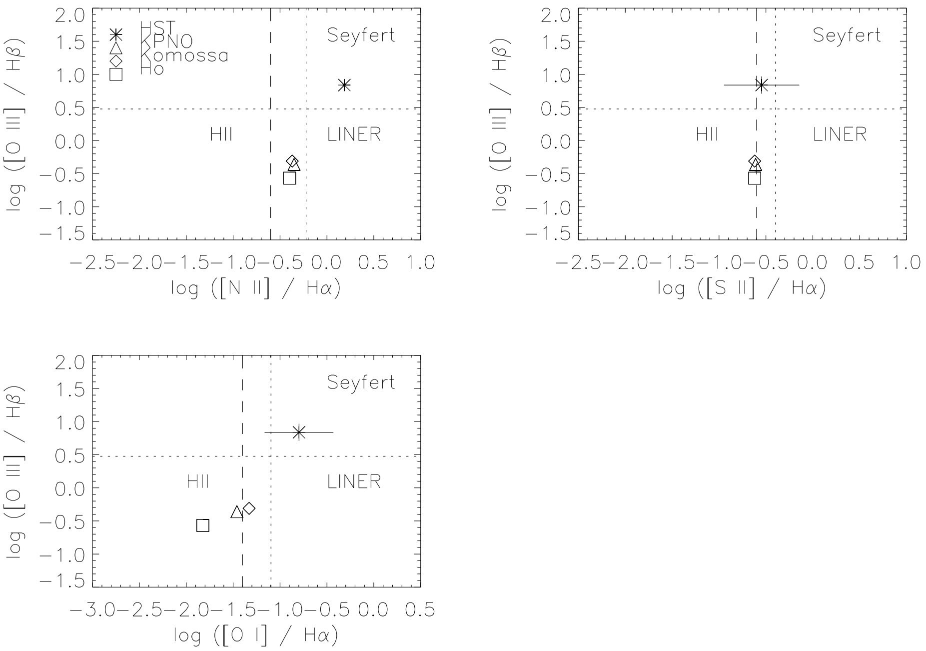

Fig. 1.3. Diagnostic diagrams of Veilleux & Osterbrock (1987). HST measurements shown with 3σ error bars.

in the nucleus, namely a low luminosity Seyfert 2 nucleus that was previously masked by HII regions in the ground-based spectra.

1.3 Discussion

The Seyfert-like narrow emission line ratios in the STIS spectrum require a non-stellar ionizing continuum. Two possibilities for the origin of the line emission exist: narrow-line gas illuminated by a permanent low luminosity Seyfert nucleus, or the fossil nebula of the ionizing soft X-ray flare observed by ROSAT ten years ago. If the emission lines are powered by a Seyfert nucleus, the predicted soft X-ray luminosity of the nucleus using the correlation of soft X-ray luminosity with Hα luminosity derived from observations of low-luminosity AGN ($L_X < 10^{42}$ erg s^{-1}) by Halderson et al. (2001) is only $\sim 10^{39}$ erg s^{-1}, an order of magnitude below the lowest observed soft X-ray luminosity of NGC 5905 (L_X = 4 x 10^{40} erg s^{-1}), which is possibly associated with its nuclear starburst (Komossa & Greiner 1999). A source of 10^{39} erg s^{-1} would not have been detectable by ROSAT in the nucleus of the galaxy during its quiescent state. The presence of stellar absorption features in the STIS spectrum does indicate the lack of a featureless power-law continuum (Figure 1.1), as does the absence of a compact optical source in the nucleus. However, given that no broad Hα emission is detected, this is consistent with the properties of a Seyfert 2 nucleus.

Although a permanent Seyfert nucleus cannot be ruled out as the source of the high excitation emission lines, could the X-ray flare have produced the emission we observe now ten years later? Using the time-dependent photoionization model of Binette & Robinson

(1987), narrow-line emitting gas should continue to emit emission lines after the ionizing source (i.e. X-ray flare) has shut off. Although the [OIII] line responds rapidly to the change in ionizing flux, and decays almost instantaneously due to efficient recombination by charge transfer, the He II and Hβ lines will persist after the flare. The narrow line emission in the STIS spectrum does not have line ratios diagnostic of such a fossil nebula, i.e. [OIII]/He II ≤ 1 (Binette & Robinson 1987). Taking into account light travel-time effects, the STIS spectrum could be detecting gas in the isodelay surface recently ionized by the flare 11.4 yr later, at a minimum distance of 5.7 lyr from the nucleus. This is orders of magnitude larger than the typical scale measured for the broad line region in AGN ($\sim$ light days), thus we do not expect to see broad line emission recently ionized by the flare in the post-flare STIS spectrum. The rapid decay times of the high density broad line clouds would also make fossil broad line emission not detectable in the post-flare spectrum. If however, the narrow line emission in the STIS spectrum is due to gas within the slit (r_{slit} = 35.6 lyr for D = 45 Mpc) currently being ionized by the flare, then the He II line in the spectrum should be strong due to high energy photons in the flare (Ulmer 1999), which is not observed. Thus the narrow line emission in the post-flare STIS spectrum of NGC 5905 does not have the appropriate line ratios for gas ionized by the soft X-ray flare, and must be powered by a steady-state Seyfert nucleus.

1.4 Conclusions

An important question is raised in the case of NGC 5905, of whether its X-ray flare was the result of large amplitude variability of its low luminosity Seyfert nucleus, or the tidal disruption of a star by its central black hole. Further long-term monitoring for variability in the X-ray and optical is necessary to see whether flaring behavior in NGC 5905 recurs, which would indicate variability intrinsic to the Seyfert nucleus, or whether its X-ray flare was a one-time event consistent with the expected frequency of tidal disruption. RX J1242.6–11A and RXJ1624.9+7554 are confirmed to be inactive galaxies from the lack of broad emission lines or a non-stellar continuum in their narrow-slit STIS spectra. The most likely explanation for large amplitude X-ray flares from the nuclei of inactive galaxies is a tidal disruption event by an otherwise dormant central black hole.

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