

# The Discovery of a Giant $H\alpha$ Filament in NGC 7213

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## ABSTRACT

The nearby Seyfert galaxy NGC 7213 has been imaged in  $H\alpha$  and HI with the CTIO 1.5 m telescope and with the Australia Telescope Compact Array (ATCA), respectively. Optically NGC 7213 looks undisturbed and relatively featureless but the continuum-subtracted  $H\alpha$  image shows a 19 kpc long filament located approximately 18.6 kpc from the nucleus. The  $H\alpha$  filament could be neutral gas photo-ionized by the active nucleus, as has been suggested for the Seyfert galaxy NGC 5252, or shock-ionized by a jet interacting with the surrounding HI, as has been suggested for the radio galaxy PKS 2240-41. The HI map reveals NGC 7213 to be a highly disturbed system suggesting a past merging event.

*Subject headings:* galaxies: Seyfert — galaxies: individual (NGC 7213) — galaxies: peculiar — galaxies: spiral

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## 1. Introduction

NGC 7213 is a face-on Sa (Tully 1988) galaxy located at a distance of 22.0 Mpc ( $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ) (Tully 1988) and hosts an active nucleus. Its nuclear activity was first discovered in follow-up optical spectroscopy of X-ray sources observed by the HEAO-A2 satellite (Phillips 1978) and is in the Piccinotti *et al.* (1982) sample of X-ray selected active galaxies.

The nucleus of NGC 7213 has been classified as a Seyfert 1 (Phillips 1979, Filippenko and Halpern 1984) based on the broad optical emission lines, strong blue continuum and emission lines from such highly ionized species as  $\text{Ne}^{+4}$ . Its nuclear spectrum also exhibits narrow low ionization emission lines that define the LINER class which may originate from diffuse ionized gas surrounding the nucleus. This extended nuclear emission line region (ENER) has been observed in several spirals (e.g. M81, M31, N1398 etc.) and its ionization may be attributed to shock heating or photo-ionization by the bulge post asymptotic giant branch (PAGB) stars (Heckman 1996; Devereux, Ford, and Jacoby 1997).

The optical continuum image of the galaxy is dominated by an almost featureless bulge and shows no sign of any recent interaction (see Figure 5 of Hameed & Devereux 1999). An unsharp masking of the continuum image shows dust lanes sinuously winding into the central region which are also visible in the photograph of NGC 7213 in the *Carnegie Atlas of Galaxies* (Sandage and Bedke 1994). The continuum-subtracted  $\text{H}\alpha$  image shows a ring of H II regions surrounding the nucleus that has been studied in detail by Storchi-Bergmann *et al.* (1996). However, the present paper is motivated by the discovery of a giant  $\text{H}\alpha$  filament located approximately 18.6 kpc (in projection) south of the nucleus. This filament is roughly 19 kpc long, has no counterpart in the optical continuum image and lies well outside the optical diameter of the galaxy (Hameed & Devereux 1999).

An HI map of NGC 7213, obtained as part of an HI survey of nearby Seyfert galaxies (Blank 1999), reveals NGC 7213 to be a highly disturbed system with tidal tails. The  $\text{H}\alpha$  filament is, in fact, a small part of an HI tail located south of the nucleus. Contrary to the optical continuum image, the disturbed HI morphology suggests that NGC 7213 has gone through a merger or an interaction. In this paper we present details of neutral and ionized hydrogen gas morphology of NGC 7213.

## 2. Observations

## 2.1. H $\alpha$ Observations

An H $\alpha$  image of NGC 7213 was obtained on October 25, 1997, using the Cassegrain-Focus Imager (CFCCD) on the CTIO 1.5m telescope. CFCCD uses a  $2048 \times 2048$  Tektronics chip and has a pixel scale of  $0.43'' \text{pixel}^{-1}$  at f/7.5, yielding a field of view of  $14.7' \times 14.7'$ . The galaxy was imaged using the narrow band H $\alpha$  + [NII] filter at  $6606\text{\AA}$  ( $\Delta\lambda = 75\text{\AA}$ ) and a narrow band line free continuum filter at  $6477\text{\AA}$  ( $\Delta\lambda=75\text{\AA}$ ). Three exposures of 900 seconds each were obtained through the line and the continuum filters. Details of the data reduction process and calibration are described in Hameed & Devereux (1999).

## 2.2. HI Observations

NGC 7213 was observed in the 21cm, HI spectral line with the Australia Telescope Compact Array (ATCA) in its 1.5 D, 750 D, and 750 C configurations on October 9, 1993, and October 2 and 15, 1995, respectively. The shortest and longest baselines used were 31 m and 1454 m respectively which resulted in a synthesized beam size of  $42'' \times 52''$ . Further details of the HI observations will be presented in a later paper.

## 3. Results

Figure 1 shows contours of continuum-subtracted H $\alpha$  image of NGC 7213 overlaid on grey-scale HI map of the same region. Despite a relatively short integration time (900 sec), the H $\alpha$  image reveals remarkable structure in the ionized gas. The giant filament is located  $2.9'$ , or 18.6 kpc south of the nucleus (in projection). In comparison, the diameter ( $D_{25}$ ) of the galaxy extends out to only  $2.1'$  (Tully 1988). The H $\alpha$  filament is roughly 19.0 kpc long ( $3.0'$ ) and has a total H $\alpha$  flux of  $F_{H\alpha} = 1.1(\pm 0.2) \times 10^{-13} \text{ergs}^{-1} \text{cm}^{-2}$ , which corresponds to  $L_{H\alpha} = 6.4 \times 10^{39} \text{ergs}^{-1}$  at our assumed distance of 22 Mpc (Tully 1988). The total H $\alpha$  luminosity of NGC 7213 is  $L_{H\alpha} = 1.7 \times 10^{41} \text{ergs}^{-1}$  (Hameed & Devereux 1999).

NGC 7213 has been observed in H $\alpha$  before. Storchi-Bergmann *et al.* (1996) obtained H $\alpha$  imaging and spectroscopy of the circumnuclear H II regions, but the giant filament was located outside of their field of view. The filament is, however, barely visible in the H $\alpha$  image of NGC 7213 obtained by Evans *et al.* (1996).

The grey-scale map in Figure 1 shows the neutral gas morphology and reveals NGC 7213 to be a highly disturbed system. The central region has a high concentration of HI and the giant H $\alpha$  filament appears to be a small part of an HI tail located southwest of the

nucleus. This HI tail has a peak surface density of  $5.1M_{\odot}pc^{-2}$ . There appears to be a lack of HI emission in a region that is  $40'' \times 60''$  in size lying about  $2'$  southwest of the nucleus and is not due to HI absorption (For details, see Blank 1999).

Figure 2 shows a close-up of the H $\alpha$  filament and the region surrounding it. Overall the filament has a bow-like structure with a discontinuity towards the eastern end. The filament does not have any counterpart in the optical continuum image (Hameed & Devereux 1999). There is some low level diffuse H $\alpha$  emission that connects the filament with a ring of H II regions surrounding the nucleus.

Figure 3 reveals the total extent of neutral gas which extends far beyond the optical radius. The azimuthally averaged column density falls to  $1 \times 10^{19}cm^{-2}$  at a radius of about 9 arcminutes (58 kpc), and the azimuthally averaged surface density of HI is  $1M_{\odot}pc^{-2}$  at a radius of 3.5 arcminutes. The overall HI distribution is clumpy and roughly oval in shape with a position angle of about  $110^{\circ}$ . There is a prominent HI tidal tail in the north-western region of the galaxy. The total HI mass of the NGC 7213 system is  $4.6 \times 10^9 M_{\odot}$ .

The velocity field of NGC 7213 is shown in Figure 4. The velocity field becomes increasingly disordered further away from the center and is likely to be the result of a merger.

#### 4. Discussion

*What is the source of ionization for the giant filament?* It is unlikely that the filament is foreground galactic emission since our H $\alpha$  image was obtained with a redshifted H $\alpha$  filter and any foreground emission would have been subtracted out. In addition, the H $\alpha$  morphology and its correlation with HI strongly suggests a connection with NGC 7213. The lack of clumpy HII regions in the filament also rule out local star formation as the ionization source. Similarly, there is no continuum emission from the filament, ruling out field OB and post-asymptotic Giant Branch stars as a source of ionization.

There are at least two possible mechanisms which might explain the large H $\alpha$  filament. One possibility is a starburst-related superwind. Devine & Bally (1999) found a 3 kpc long ionized “cap” located 11 kpc above the plane of M82. Fainter H $\alpha$  was also detected between the H $\alpha$  cap and M82. Devine and Bally have suggested that the H $\alpha$  in the cap traces ambient material that is being shocked by a superwind and/or photoionized by radiation from nuclear starburst. Massive star formation in NGC 7213 is confined to a ring of HII regions surrounding the nucleus and is much weaker than the starburst in M82. Our calculations suggest that it is very unlikely that the filament in NGC 7213, which is much

larger than the “cap” in M82(Table 1), is being ionized by the leakage of UV photons from the star forming ring.

A more likely explanation is that the filament is either being photo-ionized by UV photons escaping from the central AGN or shock-ionized by a jet interacting with the surrounding medium. Observations of Seyfert galaxies have identified galactic scale minor outflows in a number of galaxies (e.g. Wilson & Tsvetanov 1994; Colbert *et al.* . 1996). The presence of broad emission lines (Filippenko & Halpern 1984), along with the detection of X-rays(Piccinotti et al. 1982; Fabbiano, Kim, and Trinchieri 1992) and an unresolved UV point source (Rokaki & Boisson 1999) in the nucleus of NGC 7213, strongly suggest the presence of an AGN. Lyman continuum photons from the central engine may ionize part of the extensive HI which surrounds NGC 7213. Such a situation exists within the type 1 Seyfert galaxy NGC 5252, which hosts a biconical structure of ionized gas that extends up to a distance of 18 kpc from the nucleus and consists of a complex network of filaments(Prieto & Freudling 1996; Tsvetanov *et al.* 1996; Morse *et al.* 1998). The largest of these filaments is located about 7 kpc from the nucleus and is approximately 3.6 kpc in length (Table 1).

In the case of NGC 7213, the  $H\alpha$  luminosity of the nucleus is  $4.7 \times 10^{40} \text{ergs}^{-1}$ . If the filament in NGC 7213 is photoionized by the nucleus, then, at least, 14% of ionizing photons have to escape from the nucleus to provide the observed  $H\alpha$  luminosity of the filament:  $6.4 \times 10^{39} \text{ergs}^{-1}$ . We can obtain a rough estimate as to whether or not the source responsible for  $H\alpha$  emission in the nucleus has enough energy to ionize the filament. Lets consider a simple case where ionizing photons are leaking isotropically from the nucleus. The flux at the distance of of the filament (18.6 kpc),  $F_{nf}$ , can be calculated by  $F_{nf} = L(H\alpha)_{nuc}/4\pi D^2$ , where  $L(H\alpha)_{nuc}$  is  $H\alpha$  luminosity of the nucleus and D is the distance of the filament from the nucleus. Using the above values, we get  $F_{nf} = 1.1 \times 10^{-6} \text{ergs}^{-1} \text{cm}^{-2}$ . Assuming the filament to be a 2-dimensional sheet, we can get the luminosity of the filament,  $L_{nf}$ , by multiplying  $F_{nf}$  by the surface area of the filament,  $165'' \times 55''$  or  $5.9 \times 10^{22} \text{cm} \times 1.8 \times 10^{22} \text{cm}$ . This gives  $L_{nf} = 1.2 \times 10^{39} \text{ergs}^{-1}$  which is about 6 times smaller than the observed luminosity of the filament (Table 1). It should be noted, however, that the  $H\alpha$  luminosity of the nucleus is not an accurate measure of the ionizing flux, and represents only those ionizing photons that have been absorbed by hydrogen near the nucleus. The covering factor for the broad line region in AGNs is quite uncertain, but some studies (e.g. Peterson 1997) estimate the covering factor to be around 0.1, suggesting that only 10% of the ionizing photons are being absorbed. If this is the case in NGC 7213, then the nucleus can easily provide the photons required to ionize the filament. In addition, our calculations above used the simplest case of isotropic emission. Even a modest beaming of the ionizing photons towards the filament can potentially provide

enough energy to ionize the filament.

On the other hand, the radio galaxy PKS 2250-41 provides an example where a giant emission line arc is shock ionized by a radio jet (Tadhunter *et al.* 1994). It should be noted, however, that the emission line arc in PKS 2250-41 has been observed only in [OIII] and no H $\alpha$  observations for the galaxy exist in the literature. The arc in PKS 2250-41 is located 37 kpc from the nucleus and has a total length of about 50 kpc (Clark *et al.* 1997). Such jet interaction induced ionization could be the case in NGC 7213, albeit on a smaller scale. In the study of star forming regions of NGC 7213, Storchi-Bergmann *et al.* (1996) found velocity dispersions near the nucleus suggesting a collimated outflow or other non-circular motions. Furthermore, Harnett (1987) and Blank (1999), found extended radio emission in low resolution images that might also indicate the presence of a radio jet.

Understanding the kinematics of the ionized gas could help distinguish between these two possibilities. If ionized gas is produced by UV photons escaping from the nucleus, then we might expect the ionized gas to have the same radial velocity as the neutral gas at the same location. On the other hand, if the ionized gas is produced by shocks, its velocity should be significantly different from the neutral gas. In addition, optical spectroscopy can also provide diagnostic line ratios that may determine whether the filament is shock-ionized or photo-ionized. Shock-ionization is expected to produce high ratios of [NII](6548+6584Å)/H $\alpha$ , [SII](6716+6731Å)/H $\alpha$ , and [OIII](5007Å)/H $\alpha$  relative to photo-ionization (Shull & McKee 1979; Dopita & Sutherland 1995).

The identity of the progenitor galaxy, responsible for the disturbed HI morphology of NGC 7213, is also unclear. There is a nearby elliptical galaxy of unknown redshift located at 5' north-east of NGC 7213. If that system is a close companion, it is unlikely to be responsible for the disturbed HI morphology. While the anomalous HI arms could be produced by a small galaxy tidally removing HI gas from its larger companion (e.g. the M 51 system), the elliptical companion of NGC 7213 is located in the middle of the northern arm, not at the end of the arm as one would expect, if it was drawing out the HI. It is more likely that NGC 7213 is a merger remnant, as Blank (1999) has identified an inner HI disk counter-rotating with respect to the larger HI disk in NGC 7213. This notion is further supported by the presence of “shells” in an unsharp mask of the Digital Sky Survey image of NGC 7213 (Hibbard, private communication). However, we cannot rule out the presence of another perturber, as there is a bright foreground star to the north-west of NGC 7213 that may be masking any nearby galaxy.

The giant filament in NGC 7213, one of the largest among nearby active galaxies, joins an increasing number of galaxies that have galactic scale ionization features. It is difficult to estimate how common these objects are, as very few studies of Seyfert galaxies exist that

have focused on large scale features. In a study of 22 edge-on Seyfert galaxies, Colbert et al. (1996) find  $\sim 1/4$  of galaxies with good evidence for minor axis outflows, but none at scales comparable to NGC 7213 and NGC 5252. Similarly, Baum et al. (1993) found kpc-scale extended features in seven out of ten Seyfert galaxies they studied. A large, wide field, systematic study of nearby Seyfert galaxies will provide information about the importance of these filaments and their relationship to AGNs and their host galaxies.

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Table 1. Comparison of Filaments in 3 galaxies

| Galaxy   | Filament size<br>(kpc) | Distance from the nucleus<br>(kpc) | H $\alpha$ luminosity<br>( $ergs^{-1}$ ) | Possible ionization source | Reference             |
|----------|------------------------|------------------------------------|--|----------------------------|-----------------------|
| M 82     | 3                      | 11                                 | $2 \times 10^{38}$                       | Starburst wind             | Devine & Bally (1999) |
| NGC 5252 | 3.6                    | 7                                  | $5.3 \times 10^{39}$                     | Active nucleus             | Morse et al. (1998)   |
| NGC 7213 | 19.0                   | 18.6                               | $6.4 \times 10^{39}$                     | Active nucleus             | This paper            |

Fig. 1.— Contours of Continuum-subtracted  $H\alpha$  image of NGC 7213 overlaid on HI map of the same region. North is at the top and east is to the left of the image. The giant  $H\alpha$  filament is located on the southern HI tail located  $3'$  south of the nucleus. The contours are 13, 26, 40, 66, 198, 594, and 1782 Emission Measure ( $\text{pc cm}^{-6}$ ). Assuming a distance of 22.0 Mpc,  $1\text{kpc} = 9.4''$ . Coordinates in the image are accurate to  $\sim 2$  arcsec. The ellipse in the lower-left corner of the HI image shows the resolution(FWHM) of that image.

Fig. 2.— Image showing the complicated structure of the filament and other ionized features near the nuclear region. The black bar in the bottom left corner of the image represents 1 kpc in length.

Fig. 3.— HI contours overlaid on grey-scale of integrated HI distribution. The contours are 10,20,30,40,50,60,70,80,90 percent of the peak, which is  $6.6 \times 10^{20}$  H atoms  $\text{cm}^{-2}$ . Note that the optical image of NGC 7213 would cover just the central  $2.1'$  of the HI map.

Fig. 4.— The isovelocity curves. The contours are from 1508 to 2028  $\text{kms}^{-1}$  in intervals of  $40 \text{kms}^{-1}$ .

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