# NGC 6212: AN X-RAY-SELECTED ACTIVE ELLIPTICAL GALAXY

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*Received 2 December 1985; revised 3 February 1986*

## ABSTRACT

Optical observations of the elliptical galaxy NGC 6212 show it to be a type 1 Seyfert galaxy at $z = 0.030$, not a BL Lac object as suggested by Biermann, Strom, and Bartel (1985). The x-ray luminosity in the 0.3–3.5 keV band varies between $2\times10^{42}$ and $8\times10^{42}$ erg s$^{-1}$ over a period of months. Broad Balmer emission lines in the nucleus are possibly variable in one year. Narrow emission lines extend to at least 11 kpc from the nucleus. The optical continuum is dominated by starlight, with no evidence for a nonthermal component, although one is undoubtedly present at a very faint level. The x-ray, optical, and radio properties are typical of low-luminosity, x-ray-selected Seyfert galaxies. In the past, the vast majority of objects with x-ray and radio properties like those of NGC 6212 have turned out to be Seyfert galaxies, not BL Lac objects. Nevertheless, x-ray selection is a promising technique for choosing candidates for the hypothesized categories of radio-quiet or "mini" BL Lacs.

## I. INTRODUCTION

Biermann, Strom, and Bartel (1985, hereafter referred to as BSB) reported the detection of x-ray and radio emission from the elliptical galaxy NGC 6212. They suggested that the nucleus might contain a BL Lac object, and called for optical spectroscopy. Several groups, including ourselves, had previously studied the *Einstein Observatory* data. The identification of the x-ray source NGC 6212 was first reported by Margon (1983), together with a redshift for the "abnormal" galaxy. We also had an optical spectrum which showed NGC 6212 to be a Seyfert galaxy at $z = 0.030$, not a BL Lac object (Halpern and Biretta 1985). In this paper, we present the optical and x-ray data. The x-ray flux varies by a factor of 4 on a time scale of months. The optical spectrum shows broad Balmer emission lines and narrow forbidden lines which are typical of low-luminosity x-ray-selected Seyfert galaxies. The continuum is predominantly stellar, with no evidence for a nonthermal contribution. Narrow emission lines extend at least 11 kpc from the nucleus and are used to derive a rotation curve.

One purpose of this paper is to emphasize that the x-ray variability and relatively weak radio emission of NGC 6212 are *not* unusual for Seyfert galaxies. In the absence of optical spectroscopy, the *a priori* probability that an object with the x-ray and radio properties of NGC 6212 will turn out to be a BL Lac object is much smaller than the probability that it will be a Seyfert galaxy.

## II. X-RAY ANALYSIS

An x-ray source coincident with NGC 6212 appeared in four *Einstein* Imaging Proportional Counter (IPC) observations of the quasar 3C 345. The dates, exposure times, and fluxes are listed in Table I. The observations in 1980 February and March were combined, as no significant variation was found between them. Fluxes were derived from the observed counts inside a circle of radius 3′ about the x-ray centroid. The background was obtained in an annulus between radii of 8′ and 15′ about the field center in order to exclude 3C 345, which is only 5′ from NGC 6212. The flux increased by almost a factor of 4 between 1979 August and 1980 January. The data from the IPC observations in 1980 were combined in order to constrain the parameters for a standard power law continuum with absorption. A total of $236 \pm 20$ counts were fitted in the energy range 0.1–4.5 keV. The best fit was found for $\alpha = 0$ (energy index) and $N_H = 1\times10^{20}$ cm$^{-2}$, although $N_H$ as large as $7\times10^{21}$ and $\alpha$ as large as 2 cannot be excluded. Figure 1 shows the confidence contours of allowed spectral parameters. A spectral index of 0.5 and $N_H = 3\times10^{20}$ cm$^{-2}$, consistent with the 21 cm column density of Heiles (1975), has been adopted for the derivation of integrated flux. The x-ray luminosity in the 0.3–3.5 keV band varies between $2\times10^{42}$ and $8\times10^{42}$ erg s$^{-1}$ (for $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$, used throughout this paper). The 1979 August observation had only 43 counts detected in the source, too few to permit a spectral fit. One observation by the *Einstein* High-Resolution Imager (HRI) in 1980 August failed to detect NGC 6212. The upper limit corresponds to a luminosity of $4\times10^{42}$ erg s$^{-1}$ for the assumed spectrum, which is within the range observed by the IPC.

## III. OPTICAL OBSERVATIONS

A spectrum of NGC 6212 was obtained on 1984 April 5 UT using the Double Spectrograph (Oke and Gunn 1982) on the 5 m Hale telescope at Palomar Observatory. The CCD detectors covered the wavelength range 3200–9000 Å, and a dichroic filter split the beam at 4700 Å. Instrumental resolution was 8 Å in the blue spectrum and 12 Å in the red. A long slit of width 1″ was oriented at position angle 90°, close to the major axis of the galaxy. Spectra having moderate resolution (2.5–4.5 Å) were obtained on the night of 1985 June 28 UT with the same instrument. This time, a long slit of width 2″ was oriented along the major axis (P. A. = 82°). The integration times were 1000 and 2500 s for the low- and moderate-dispersion spectra, respectively.

### *a) Continuum*

The low-dispersion spectrum of the nuclear region ($1'' \times 3\overset{''}{.}9$) is shown in Fig. 2. Broad H$\alpha$ emission, and nar-

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TABLE I. *Einstein* observations of NGC 6212.

| Day | Exposure time (s) | $F_x$ (0.3–3.5 keV) ($10^{-13}$ erg cm$^{-2}$ s$^{-1}$) | $L_x$ (0.3–3.5 keV) ($10^{42}$ erg s$^{-1}$) | Instrument |
|---|---|---|---|---|
| 1979 Aug. 27 | 1960 | 5.3 | 2.0 | IPC |
| 1980 Jan. 24 | 2038 | 20.8 | 7.9 | IPC |
| 1980 Feb. 12/Mar. 5 | 3280 | 10.1 | 3.8 | IPC |
| 1980 Aug. 18 | 1360 | < 10.6 | < 4.0 | HRI |

row emission lines of [O III], Hα, [N II], [S II], and possibly [O II], are present at a redshift of 0.030. The emission-line properties are discussed below. The continuum is characteristic of a normal elliptical galaxy. There is no evidence for a nonstellar component, and the equivalent widths of the absorption lines are normal (e.g., 3.6 Å for Na D). The strength of Ca H and K and the "4000 Å break" are particularly sensitive indicators that any nonstellar contribution to the total flux must be small, even in the blue region of the spectrum.

In Fig. 3, we compare the spectrum of NGC 6212 with the continuum flux distribution of the average giant elliptical galaxy (Yee and Oke 1978), normalized at 5500 Å. No adjustments or fits were made. Even though the spectrum of NGC 6212 was obtained through a narrow slit, effects of atmospheric dispersion should be negligible since the airmass was 1.02. To the extent that reddening intrinsic to NGC 6212 can be neglected, no reddening correction is necessary for the small Galactic column of $N_H = 3\times10^{20}$ cm$^{-2}$. The match between the spectra is striking, both in overall slope and in the strength of the 4000 Å break. Aside from the emission lines in NGC 6212, the only detectable difference occurs in the strengths of the TiO bands between 6200 and 7100 Å. Those are stronger in the standard galaxy spectrum. It is obvious that no improvement in the agreement can be obtained with the addition of a power law continuum. Therefore, we conservatively estimate that any nonstellar component must contribute less than 30% of the flux at 4000 Å.

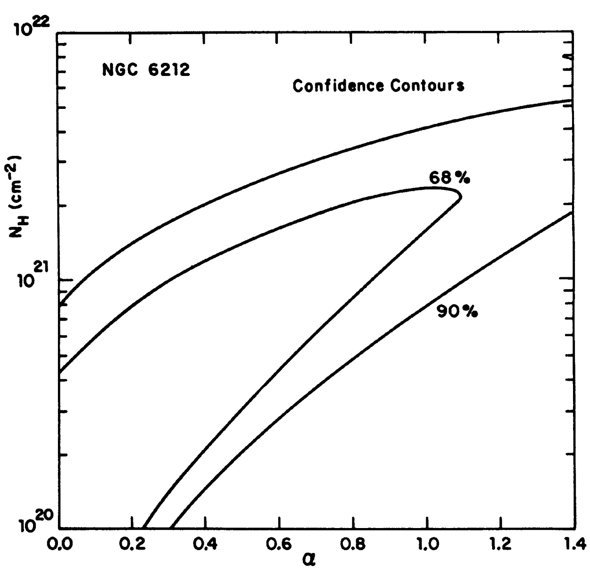


FIG. 1. Contours of acceptable power law fits to the *Einstein* IPC spectrum of NGC 6212. The data from the observations in 1980 have been combined. The best fit falls at $\alpha = 0.0$, $N_H = 1.0\times10^{20}$ cm$^{-2}$. Contours of 68% and 90% confidence are determined using the prescription of Avni (1976) for two interesting parameters.

### *b) Nuclear Emission Lines*

The presence of Hα emission that is much broader than the forbidden lines reveals the Seyfert 1 nature of the nucleus. Figure 4 shows that the FWZI of Hα is roughly 15 000 km s$^{-1}$, and the FWHM is ~6050 km s$^{-1}$. The forbidden lines in the nucleus have FWHM between 400 and 500 km s$^{-1}$. Figure 5 reveals the presence of broad Hβ emission after subtraction of the S0 galaxy IC 4889, which has been used as an absorption-line template in previous studies (see Filippenko and Halpern 1984 and Filippenko 1985 for a description of the method). As often occurs in Seyfert galaxies, the broadline Balmer decrement is much steeper than case B. The emission-line fluxes are listed in Table II. Both the broadline and narrowline fluxes refer to the nuclear region (2″×4″.7) depicted in Figs. 4 and 5. The level of ionization in the narrow lines is rather low as measured by the small [O III]/Hβ and large [N II]/Hα intensity ratios. This is true even though the measurement of narrow Hβ is hampered by the underlying stellar absorption line. A systemic velocity of 9080 ± 20 km s$^{-1}$ is derived from the narrow Hα and [N II] lines. This is in agreement with an unpublished velocity of $v = 9054 \pm 33$ km s$^{-1}$ from the Center for Astrophysics redshift survey (T. Beers, private communication).

### *c) Extended Emission*

The double-peaked Hα profile in Fig. 4 is a result of the rotation curve plus the fact that narrow Hα increases in strength away from the nucleus. In Fig. 6, we show ten spectra extracted from consecutive intervals of 0″.58 (500 pc) along the major axis. All are on the same intensity scale, but with arbitrary offsets. One can see the broadening of the narrow lines and the presence of very broad Hα in the nucleus. The reversal of [N II]/Hα in the nucleus is quite striking. The [N II] flux decreases away from the nucleus, while the Hα flux actually increases. Emission lines can be seen at least as far as 13″ (11 kpc) from the nucleus. It is not obvious what the ionization mechanism is outside the nucleus. The [N II]/Hα ratio of 0.5 falls on the boundary between power law photoionization and H II regions, but is closer to the average of Seyfert galaxies (Halpern and Steiner 1983).

The rotation curve (Fig. 7) derived from the narrow emission lines is very flat both near and far from the nucleus. The strong lines enable very accurate relative-velocity measurements to be made, so that the error bars are no larger than the size of the points. It is also possible to derive a rotation curve for the stars using the low-dispersion spectrum, but only over a smaller region near the nucleus. The Na D and Ca II λ 8542 lines show that the stellar rotation curve agrees

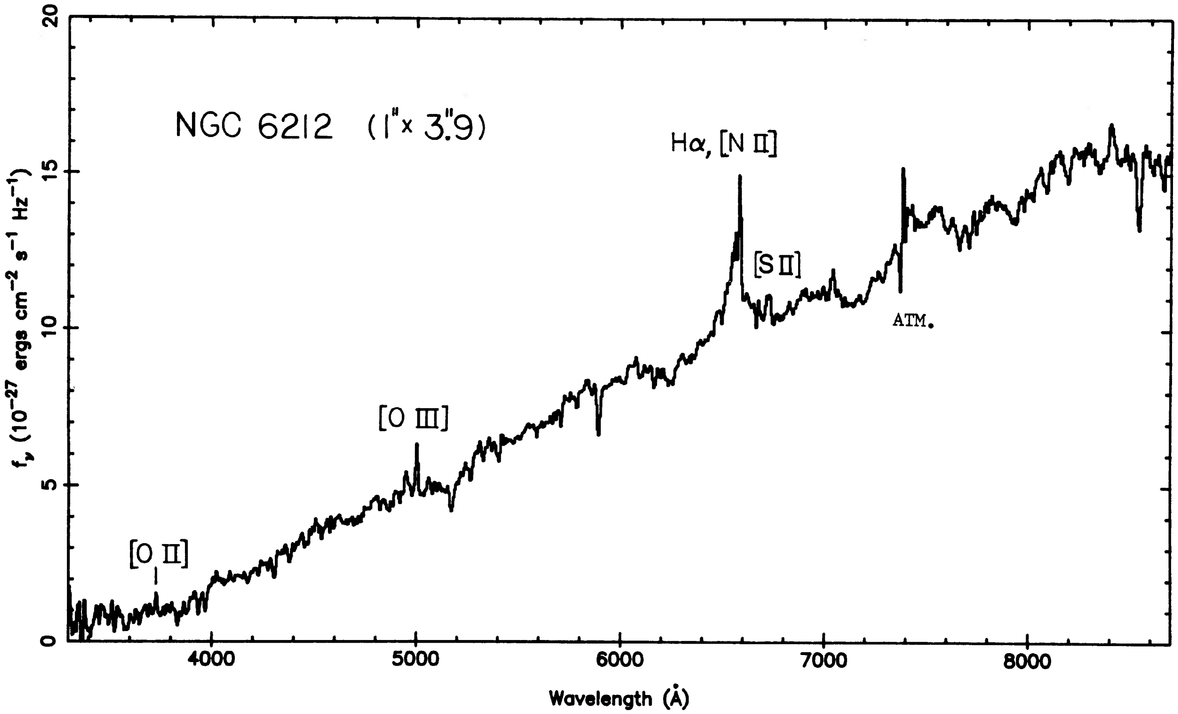


FIG. 2. Spectrum of the nucleus of NGC 6212 obtained through a 1" × 3."9 aperture. Rest wavelength is plotted. Resolution is 8 Å blueward of 4500 Å and 12 Å redward. No adjustments were necessary to match the spectra at the crossover wavelength of the dichroic.

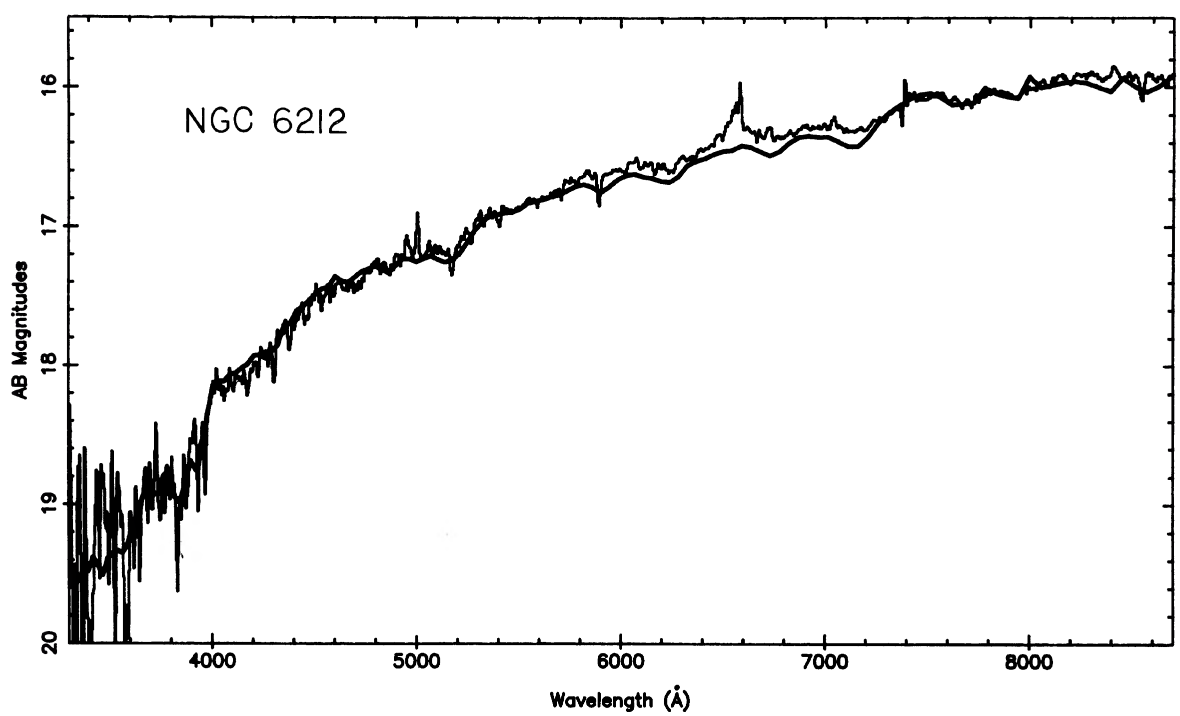


FIG. 3. Comparison of the spectrum of NGC 6212 (light line) with the average giant elliptical galaxy (heavy line) of Yee and Oke (1978). The normalization was chosen to match at 5500 Å. There is no evidence for an additional, nonstellar contribution to the continuum. TiO bands between 6200 and 7100 Å are slightly stronger in the standard galaxy.

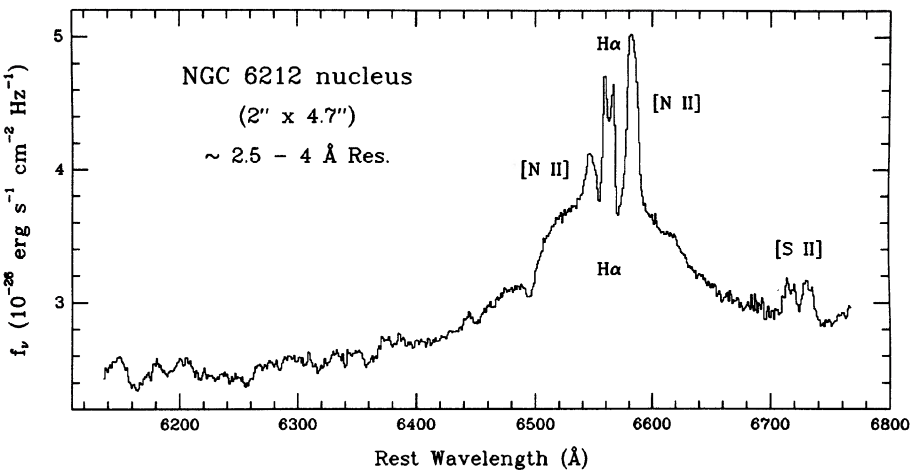


FIG. 4. Spectrum of the central $2'' \times 4''.7$ region near Hα. The resolution is 2.5 Å at the red end and 4 Å at the blue end. Broad Hα has FWZI = 15 000 km s$^{-1}$. The double-peaked narrow Hα line is a result of the rotation curve (see Fig. 6). Stellar absorption lines, including Hα, are prominent.

very well with that of the emission-line gas. The projected rotation velocity is 200 km s$^{-1}$. Asymmetries in the off-nuclear emission lines, easily seen in Fig. 6, can be understood in terms of a classical rotation-curve analysis. A maximum in the amount of material per unit radial velocity occurs at the tangent point, where the radial velocity is largest. This accounts for the peak and sharp cutoff of the line on the high-velocity side.

### *d) Possible Hα Variation*

Comparison of Figs. 2 and 4 reveals a possible change in the equivalent width of broad Hα, but first we must caution that a direct comparison of fluxes is difficult because of the different slit widths and dispersions. The continuum level differs by a factor of 3 because of the different apertures used. The higher flux (Fig. 4) more accurately represents the true value. Also, it is impossible to separate out the narrow Hα and [N II] lines in the low-dispersion spectrum. Nevertheless, the equivalent width of a spatially unresolved line is much less sensitive to these effects. The FWZI of Hα seems to be the same in both spectra. Measuring the equivalent width of all the emission between 6400 and 6700 Å, we find that it is 30 Å in the earlier, low-dispersion spectrum, and 66 Å in the high-dispersion spectrum taken 1.2 years later. Since broad Hα accounts for 85% of the 66 Å equivalent width, this is evidence for an increase in the flux of broad Hα by about a factor of 3. Note that the equivalent width is greater through the wider slit than the narrower one. We would expect any instrumental effect to go in the opposite direction, since the wider slit admits more starlight relative to nuclear emission lines.

There are, however, other systematic errors which could produce a spurious variation. Very poor atmospheric seeing, for example, could reduce the Hα flux in a 1" slit to a greater degree than the starlight. Poor guiding could also reduce the equivalent width of Hα. We cannot be certain that Hα has varied until more observations are made. Emission-line variations are not unexpected, however, since the ionizing continuum is highly variable as seen at x-ray energies.

### *e) Imaging*

An image of NGC 6212 was obtained through an *r* filter (Thuan and Gunn 1976) using a CCD on the Palomar 1.5 m telescope. The radial surface-brightness profile is well fit by an elliptical galaxy $r^{1/4}$ law with effective radius $7''.8$ (6.8 kpc) and effective surface brightness of 22.2 mag arcsec$^{-2}$. The integrated *r* magnitude is 14.35. We used the colors and *K* corrections of Oke and Sandage (1968), and the magnitude conversions of Kent (1985), to derive an absolute visual magnitude of $M_V = -21.75$. This is 1.4 mag fainter than

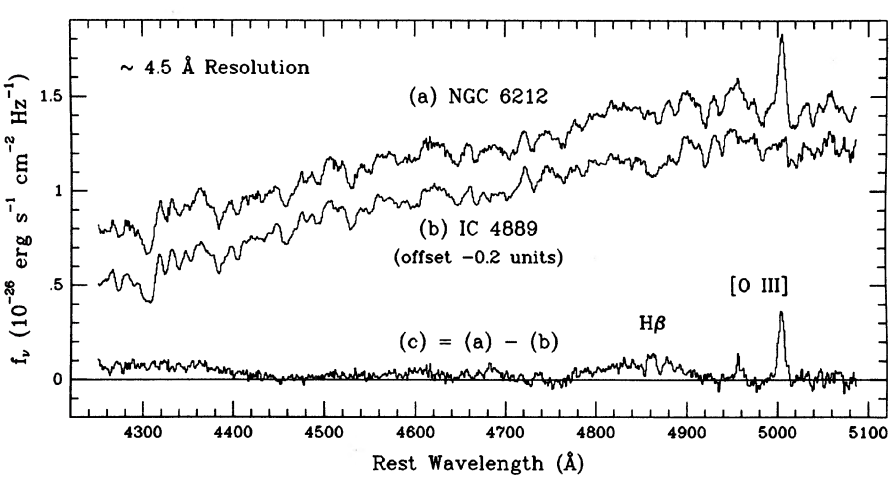


FIG. 5. Spectrum of the central $2'' \times 4''.7$ region covering Hβ and Hγ. A suitably scaled spectrum of a normal S0 galaxy was subtracted to reveal the presence of faint, broad Hβ emission.

TABLE II. Optical properties of NGC 6212.

| Line | Flux[a] ($10^{-15}$ erg cm$^{-2}$ s$^{-1}$) | FWHM (km s$^{-1}$) | FWZI (km s$^{-1}$) |
|---|---|---|---|
| Hβ (broad) | 10: | | 8 600: |
| Hβ (narrow) | 2: | | |
| [O III] λ 4959 | 1.1 | | |
| [O III] λ 5007 | 3.6 | 400 | |
| [O I] λ 6300 | <1 | | |
| [N II] λ 6548 | 2.8 | | |
| Hα (broad) | 109 | 6050 | 15 000 |
| Hα (narrow) | 6.6 | | |
| [N II] λ 6583 | 9.9 | 400 | |
| [S II] λ 6716 | 1.6 | | |
| [S II] λ 6731 | 1.9 | | |
| $L$(Hα) | $4.2\times10^{41}$ erg s$^{-1}$ | | |
| E.W. (Hα + [N II]) | 66 Å | | |
| $v_{\rm heliocentric}$ | $9080\pm20$ km s$^{-1}$ | | |
| $v_{\rm rot}$ | ~200 km s$^{-1}$ | | |
| $r_e$ | 7″.8 | | |
| $I_e$ | 22.2 mag arcsec$^{-2}$ | | |
| $m_r$ | 14.35 | | |
| $M_V$ | −21.75 | | |

[a] Line flux in the central 2″ × 4″.7 region.

the brightest elliptical galaxies in clusters. There is no evidence in the image for a central excess of light from a nonstellar continuum source, in agreement with the results of the spectroscopy. However, the seeing in the image was poor, and the red filter is not the optimum one for this purpose.

## IV. DISCUSSION

We have shown that NGC 6212 is an active elliptical galaxy with x-ray and optical properties that are indistinguishable from those of some well-known x-ray-selected Seyfert galaxies. The steep Balmer decrement, stellar continuum, and low-ionization lines have been found in NGC 526a, NGC 5033, NGC 7213, Arp 102 B, NGC 2110, and several sources from the *Einstein* serendipitous surveys (e.g., Gioia *et al.* 1984). It is clear that x-ray surveys are able to detect weak Seyfert nuclei which would not have been found by ultraviolet-excess or objective-prism techniques.

It is important to realize that the energy distribution in the nucleus of NGC 6212 is not unusual among Seyfert galaxies. Even though an optical nonthermal continuum has not been detected, there is no particular problem with the quantity of ionizing flux. The ratio of x-ray to Hα luminosity varies between 5 and 20, which is within the observed range for Seyfert galaxies and is in agreement with standard photoionization calculations. There is undoubtedly an optical nonstellar continuum, but it is hidden by the dominant starlight contribution even in a small aperture. Malkan and Sargent (1982) found that an extrapolation of the typical optical spectrum, described by the power law $f_\nu \propto \nu^{-1.1}$, falls within a factor of 2 of the observed x-ray flux in Seyfert 1 galaxies. By inverting this argument, we find that an extrapolation of the observed x-ray flux to optical wavelengths leads to an expected power law flux of $1\text{–}2\times10^{-27}$ erg cm$^{-2}$ s$^{-1}$ Hz$^{-1}$ at 4500 Å. The observed starlight (Fig. 5) falls at least a factor of 5 above this, in part because NGC 6212 is a fairly compact galaxy (for comparisons, see Hoessel and Schneider 1985). The effective spectral index $\beta_{\rm ox}$ between x-ray and blue wavelengths is about 1.35, consistent with values obtained for Seyfert 1 galaxies and x-ray-selected active

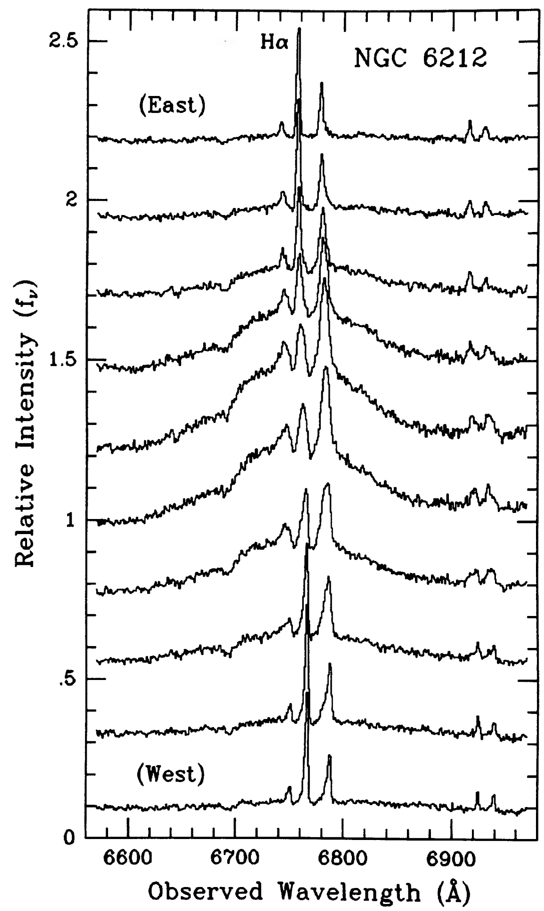


FIG. 6. Consecutive, spatially resolved spectra separated by 0″.58 (500 pc) along the major axis. Observed wavelength is plotted. All are on the same intensity scale, in units of $10^{-26}$ erg cm$^{-2}$ s$^{-1}$ Hz$^{-1}$, but with arbitrary offsets. The narrow lines are broader in the nucleus, where the [N II]/Hα ratio reverses. Hα absorption is also present. Broad Hα is confined to the nucleus. The asymmetry of the off-nuclear lines can be understood in terms of the maximum velocity coming from the tangent point (see the text). The [S II] line ratio indicates a decrease in density away from the nucleus.

galaxies by Kriss (1982). Of course, since the optical emission is dominated by starlight, the effective $\beta_{\rm ox}$ of the nucleus itself is somewhat smaller.

In speculating that NGC 6212 may be a BL Lac object, BSB asserted that "x-ray variability and radio emission are not common for most active galactic nuclei." This statement is wrong for two reasons. First, x-ray variability *is* common among Seyfert galaxies. Although *rapid* variability may be rare, numerous x-ray studies of quasars, Seyfert galaxies, and broadline radio galaxies have shown that large amplitude variations are ubiquitous on time scales of days to months (e.g., Marshall, Warwick, and Pounds 1981; Halpern 1982; Mushotzky 1984; Reichert *et al.* 1985). In particular, the amplitude of variability $\Delta L/L$ is inversely correlated with absolute luminosity, so that the low-luminosity Seyfert galaxies like NGC 6212 experience the largest excursions. It was shown by Halpern (1982) that virtually every Seyfert galaxy with $L_x < 10^{43}$ erg s$^{-1}$ varies by more than a factor of 2.

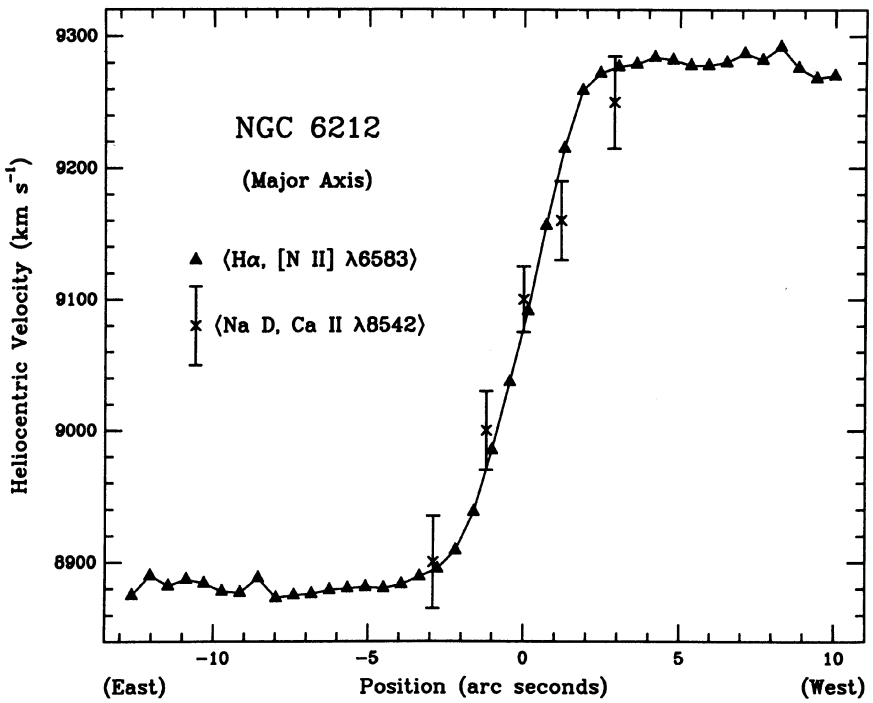


FIG. 7. Rotation curve measured from the narrow emission lines. A heliocentric systemic velocity of $9080 \pm 20$ km s$^{-1}$ is found. The error includes a possible systematic offset of 10–15 km s$^{-1}$. The stellar rotation curve measured from the low-dispersion spectrum matches that of the emission lines. Uncertainties in the emission-line measurements are so small that the slight "kinks" at 8".6 E and 8".2 W may be real.

With respect to the radio emission, it is clear from the many surveys of Seyfert galaxies that compact components are often detected. The Westerbork survey of Markarian Seyfert galaxies (Meurs and Wilson 1984) showed that over 50% are detected at a flux level exceeding 5 mJy at 1.4 GHz. In this regard, NGC 6212 is not a strong radio source (3.3 mJy according to BSB). More significant, perhaps, is that the ratio of x-ray to radio flux is no different from that detected in a complete sample of x-ray-selected Seyfert galaxies. Figure 12(b) of Meurs and Wilson (1984) shows that a radio power of $1 \times 10^{22}$ W Hz$^{-1}$ is typical for those objects from the Lawrence and Elvis (1982) sample that have x-ray luminosities of several times $10^{42}$ erg s$^{-1}$. This is exactly what is observed in NGC 6212.

How does NGC 6212 compare with other objects selected by the same instrument? A complete sample of extragalactic objects selected by the IPC was observed with the VLA (Gioia *et al.* 1983). Excluding clusters of galaxies, 60 objects were observed and 16 were detected at 6 cm at the level of 1 mJy or higher. Of these 16 detections, four were BL Lac objects, two were "normal galaxies," and ten were emission-line active galaxies. The fluxes of the BL Lacs were between 6 and 18 mJy. By contrast, the expected flux density of NGC 6212 at 6 cm, extrapolated from longer wavelengths, is only 1.2 mJy. Therefore, it may be said that the *a priori* probability that an x-ray-selected galaxy that is also a 1 mJy radio source or weaker (e.g., NGC 6212) will turn out to be a BL Lac object is at best 13% (2 out of 16), and only if each of the two normal galaxies in the Gioia *et al.* survey are really harboring BL Lac objects.

## V. ARE THERE ANY RADIO-QUIET OR MINI BL LACS?

Although NGC 6212 appears not to be a BL Lac object, it is interesting to speculate about the capability for detecting new types of BL Lacs. To date, the x-ray-selected BL Lac objects are all high-luminosity sources with $L_x \geqslant 3 \times 10^{44}$ erg s$^{-1}$ (Stocke *et al.* 1985; Feigelson *et al.* 1986; Halpern *et al.* 1986). If NGC 6212 had turned out to harbor a nucleus with a featureless, polarized continuum, it would have been of great interest as an example of a "mini" BL Lac. If such objects exist, they are extremely hard to find since the principal distinguishing feature, the optical continuum polarization, is hidden by the dominant stellar spectrum. Highly luminous host galaxies can even hinder the detection of the average BL Lac object (Halpern *et al.* 1986). It was pointed out by Chanan *et al.* (1982) that x-ray selection may be the most promising way to find candidates, especially since the radio emission of x-ray-selected BL Lacs is relatively weak. NGC 6212 has an effective spectral index $\alpha_{rx}$ between radio and x-ray energies of $\sim 0.5$, which is smaller than in all but one known BL Lac (Ledden and O'Dell 1985). That one object is 1218 + 304 ($\alpha_{rx} = 0.48$), another x-ray-discovered BL Lac. In this sense, x-ray selection is also capable of detecting, should they exist, BL Lac objects that are radio quiet at the 1 mJy level. The record so far is 1E 1207.9 + 3945, with $S(6\,\mathrm{cm}) = 6.1$ mJy (Stocke *et al.* 1985). Given the fact that new BL Lacs with x-ray fluxes of $> 0.3\,\mu$Jy continue to be discovered (Halpern *et al.* 1986), it is in principle possible to reach $\alpha_{rx}$ values of 0.33 with radio sensitivities of 0.1 mJy.

Finally, we should point out that the detection of broad H$\alpha$ emission does not in itself rule out a BL Lac classification. We are aware of at least one case (Ulrich 1981) in which a transient broad H$\alpha$ line appeared in an elliptical galaxy previously classified as a BL Lac because of its optical polarization (PKS 0521 − 36). In this regard, it is extremely important to try to confirm the suspected variation of H$\alpha$ in NGC 6212. Of course, the radio flux of NGC 6212 is negligible in comparison with that of PKS 0521 − 36. Nevertheless, if the principal defining characteristic of a BL Lac is taken to be polarized nonthermal continuum, then it is still conceivable that sensitive polarization measurements will show that objects like NGC 6212 are closely related to BL

Lacs. Until then, active elliptical galaxies with broad emission lines and weak radio emission should be called Seyferts.

We are grateful to G. Bothun, who did the surface-photometry reductions. We thank J. Carrasco and J. Henning for assistance at Palomar Observatory. J. B. Oke and W. L. W. Sargent shared their observing time with us. A. V. F. is supported by a postdoctoral fellowship from the Miller Institute for Basic Research in Science, U. C. Berkeley. J. P. H. acknowledges support from NASA Grant No. NAG 8-497. This is Columbia Astrophysics Laboratory Contribution Number 308.

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