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DISCOVERY OF BROAD BRACKETT-α EMISSION IN ARP 220

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ABSTRACT

The Brackett-α hydrogen recombination emission from the luminous galaxy Arp 220 is observed to be both weak and very broad, with a FWHM of 1300 km s^{-1}. This line width is not typical of a starburst region but is characteristic of emission lines in Seyfert galaxies.

Subject headings: galaxies: general — galaxies: nuclei — galaxies: Seyfert

I. INTRODUCTION

Many galaxies in the *IRAS* catalog have exceptionally high far-infrared luminosities. The morphologically peculiar galaxy Arp 220 (= IC 4553) is one of the most dramatic examples. At a redshift of about 5400 km s^{-1} (Huchra *et al.* 1983; Mirabel 1982), its *IRAS* flux densities imply a bolometric luminosity of $\sim 2 \times 10^{12}$ $L_\odot$ (Soifer *et al.* 1984; $H_0 = 75$ km s^{-1} Mpc^{-1} is assumed throughout this *Letter*). This is 100 times greater than is typically found for spiral galaxies (de Jong *et al.* 1984) and makes Arp 220 the most luminous galaxy within 100 Mpc at any wavelength.

No consensus has been reached on the source of Arp 220's luminosity. Rieke *et al.* (1985), Joseph and Wright (1985), and Joseph, Wright, and Wade (1984) conclude from infrared photometry and low-resolution infrared spectroscopy that a burst of star formation is primarily responsible. The *IRAS* data are inconclusive, exhibiting characteristics suggestive of both starburst galaxies and Seyfert nuclei (Soifer *et al.* 1984). Radio continuum and ground-based infrared maps, which show that the sizes of the radio and infrared sources are small, lead Norris (1985) and Becklin and Wynn-Williams (1986) to suggest that Arp 220 resembles a Seyfert galaxy more than it does a starburst galaxy.

Velocity-resolved spectroscopy of hydrogen recombination lines in Arp 220 should distinguish between the above two possibilities. Seyfert nuclei have permitted hydrogen lines that are typically broadened by at least 1000 km s^{-1} and often have wings extending to much higher velocities. In a starburst galaxy, however, the nuclear recombination line emission arises in normal H II regions that have low internal velocity dispersions and that are taking part only in galactic rotation. Such emission produces much narrower lines, with widths typically a few hundred km s^{-1} full width at half-maximum (FWHM).

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Observations of the Balmer lines in Arp 220 could, in principle, resolve the question. However, recent studies have indicated that the visual extinction to the nucleus of Arp 220 is ~ 50 mag (see Becklin and Wynn-Williams 1986), so the Balmer emission from Arp 220's nucleus is highly extinguished and unobservable. The Brackett lines, particularly Brα at a rest wavelength of 4.05 μm, are much less affected by extinction and offer the best chance of observing the hydrogen recombination line emission from the nucleus of Arp 220.

II. OBSERVATIONS

Arp 220 was observed in the Brα line at the United Kingdom Infrared Telescope during the nights of 1986 January 17 and 20 and 1986 April 26 and 27. The UKIRT seven-channel cooled-grating spectrometer (Wade 1983) was used with a 300 lines mm^{-1} grating and a 5″ diameter circular aperture to observe the line around its redshifted wavelength (~ 4.125 μm). The beam was centered on the Arp 220's 2 μm continuum peak, which is coincident with the peak of the radio emission (Norris 1985) and was chopped 60″ in an east-west direction in order to cancel sky emission.

The resolution of the spectrometer was ~ 525 km s^{-1}, and the wavelength region near the line was observed every half-resolution element so as to sample the spectrum fully. The spectra were calibrated in wavelength by comparison to argon lamp spectra taken just before and after each observation. The variations in the channel-to-channel response were corrected by dividing each night's data by spectra of photometric standard stars: BS 4983 for the observations of January 17, BS 3188 on January 20, BS 6092 on April 26, and BS 5447 on April 27. No spectral features were found in the standard spectra.

The weighted average of all the data is shown in Figure 1. Each night's data were weighted according to the signal-to-noise ratio (S/N) obtained on the continuum around the line. The final spectrum in Figure 1 represents ~ 15 hr of integration on Arp 220. Flux calibration was accomplished by requir-

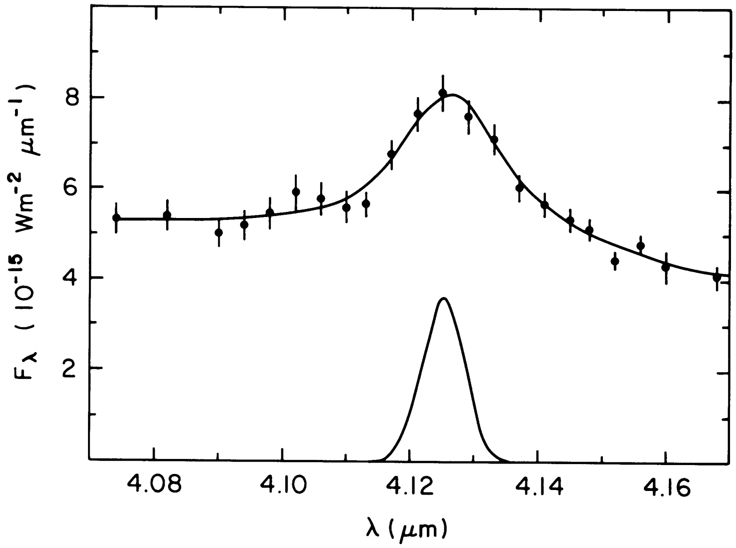

FIG. 1.—Brackett-α spectrum of Arp 220. The dots are the data with $\pm 1\ \sigma$ errors: the solid line is a χ^2 fit to the data of two Gaussians plus a linear continuum. An instrumental profile scaled to the same intensity as the Brα line is shown as a solid line for comparison.

ing that the continuum level in the final spectrum be equal to the continuum level found by comparison with BS 4983 ($L' = 2.87$, $M = 2.87$; Sinton and Tittemore 1984) on the most photometric night, 1986 January 17.

III. RESULTS

The Brα line is readily apparent in Figure 1. The continuum around the line decreases to longer wavelengths, although the slope depends strongly on the reliability of the four longest wavelength data points. The apparently decreasing slope of the continuum may indicate an absorption feature at a wavelength longward or an emission feature shortward of 4.1 μm. The redshift of the line center is 5450 ± 150 km s^{-1}, consistent with previous redshift determinations (Mirabel 1982; Huchra *et al.* 1983).

The FWHM of the Brα line is much greater than the instrumental resolution. In addition, faint wings may be present. To determine the intrinsic FWHM and to test the significance of the wings, the data were fitted with two models, a linear continuum plus a single Gaussian and a linear continuum with two Gaussian components. In each case the slope and offset of the continuum and the position, FWHM, and intensity of the Gaussian components were left as free parameters in a χ^2 fit. The single Gaussian fit returned a FWHM for a single line after correction for the instrumental broadening, of 1300 km s^{-1}; the two Gaussian fit gave for the two lines emitted FWHMs of 1000 km s^{-1} and 3300 km s^{-1}. An F-test (see Bevington 1969) indicated that the additional component is significant at greater than a 99% confidence level. The best-fit centers of the two lines were closely coincident, well within the resolution of the data, again suggesting that the second component is not spurious. The two-Gaussian fit is shown in Figure 1. The very broad wings appear to be a real feature, but a higher S/N spectrum is needed to confirm this result, and in either case the line is well resolved and has a FWHM $\gtrsim 1300$ km s^{-1}.

The integrated Brα line strength for the single Gaussian fit is $3.8 \pm 0.5 \times 10^{-17}$ W m^{-2}. If the wings are real, then the total flux is approximately 4.5×10^{-17} W m^{-2}. Both these results are consistent with the Brα upper limit reported for Arp 220 by Beck, Turner, and Ho (1986). The Lyman-continuum flux implied by the latter value of the line strength is $\sim 7 \times 10^{53}$ photons s^{-1}, assuming case B recombination at $T = 10^4$ K (Osterbrock 1974) and zero extinction at 4.05 μm. If the extinction to the source is $A_v = 50$ mag, as is suggested by the silicate absorption depth (Becklin and Wynn-Williams 1986), the implied Lyman-continuum rate (assuming $A_{Br\alpha} \approx 0.03\ A_v$; Becklin *et al.* 1978) is $\sim 2.5 \times 10^{54}$ s^{-1}. Table 1 compares the latter rate with that of starburst galaxies with measured Brackett line strengths.

The observed Brα line strength allows a prediction to be made of the Brγ line strength in a 5″ beam. Assuming the ratio for case B recombination with $T = 10^4$ K from Giles (1977), the observed Brγ strength should be $\sim 1.6 \times 10^{-17}$ W m^{-2} for $A_v = 0$ mag and 6.5×10^{-19} W m^{-2} if $A_v = 50$

TABLE 1

LYMAN-CONTINUUM FLUX IN ARP 220 AND STARBURST GALAXIES

Object	L_{bol} ($L_\odot$)	N_{Lyc} (s^{-1})	Reference
Arp 220	2×10^{12}	2.5×10^{54} [a]	This work
NGC 3690 ...	5×10^{11}	3×10^{54}	Fischer *et al.* 1983[b]
NGC 1614 ...	4×10^{11}	3×10^{54}	Philips, Aitken, and Roche 1984
M82	3×10^{10}	4×10^{53}	Simon, Simon, and Joyce 1979
NGC 253	3×10^{10}	3×10^{53}	Rieke *et al.* 1980

[a]Assumes $A_v = 50$ mag.

[b]DePoy 1987 measures Brα lines at several positions in NGC 3690/IC 694 and agrees with Fischer *et al.* that most of the luminosity in this object is due to star formation.

mag (assuming $A_{\mathrm{Br}\gamma} \approx 0.10\ A_v$; Becklin *et al.* 1978). The line strength reported by Rieke *et al.* (1985) in an 8″.7 beam, $\sim 3 \times 10^{-17}$ W m^{-2}, is greater than even the predicted zero extinction value. We do not understand the difference between our estimate and Rieke *et al.*'s (1985) measurement. Emission from outside our beam could in principle provide the additional flux, but such a toroid-shaped emission profile seems unlikely, since observations at other wavelengths show a centrally condensed morphology (e.g., Becklin and Wynn-Williams 1986; Neugebauer *et al.* 1987; Joy *et al.* 1986).

IV. DISCUSSION

a) *Line Width*

The most significant result observed in the Brα line measurement is that the line is very broad. The observed instrument-corrected line width is 1300 km s^{-1} (FWHM) for a single Gaussian fit to the spectrum, and faint wings may be present, giving a far greater total width to the line. Several galaxies have had their Brackett emission line profiles determined from high-resolution spectra; the measured FWHMs are given in Table 2 along with each galaxy's classification. Clearly, Arp 220 belongs in the Seyfert galaxy classification on the basis of Brackett emission line width. Additionally, in a sample of galaxies that are luminous at 60 and 100 μm, DePoy (1986) found that only NGC 6240 and the Seyfert 1 galaxy NGC 7469, in addition to Arp 220, have Brα lines with FWHMs > 500 km s^{-1}. It has been suggested that NGC 6240 harbors an active nucleus (DePoy, Becklin, and Wynn-Williams 1986). Those galaxies in the sample with FWHMs < 500 km s^{-1} also seem to have luminosities well explained by a burst of high-mass star formation, based on the strength of the emission lines.

Normal and starburst galaxies have optical line widths that are typically 300 km s^{-1} FWHM (Osterbrock 1985; Balzano 1983) and Seyfert 2 galaxies have optical permitted line FWHMs that range from 300 km s^{-1} to 800 km s^{-1} (Shuder and Osterbrock 1982). Seyfert 1 galaxies, however, tend to have Balmer lines that are much broader, from 1000 km s^{-1} to 6000 km s^{-1} FWHM (Osterbrock and Shuder 1982; Rafenelli 1985). Thus Arp 220 has a Brα line whose FWHM is characteristic of the Balmer emission from Seyfert 1 galaxies rather than those in a starburst or normal galaxy.

Broad spectral lines are the most generally accepted discriminator between starburst and active galaxies (Rieke *et al.* 1985; Khachikian and Weedman 1974). Though supernovae could, in theory, generate the large amounts of kinetic energy required to cause broad line components during exceptionally powerful starbursts (Rieke *et al.* 1985), there is no evidence that supernova-driven broad lines have ever been observed (see, for example, the data in Balzano 1983 and Feldman *et al.* 1982). In fact, galaxies that are thought to be likely candidates for the presence of starbursts have narrow optical and, to the extent that the observations exist, infrared hydrogen recombination lines.

TABLE 2

OBSERVED BRACKETT LINE FWHMs

Object	Type[a]	Line	FWHM (km s^{-1})	Reference
Arp 220	...	Brα	1300	This work
NGC 1068 ...	Sy2	Brγ	1200	Hall *et al.* 1981
	Sy2	Brα	1200	DePoy 1987
NGC 4151 ...	Syl	Brγ	~ 4000	Rieke and Lebofsky 1981
NGC 7469 ...	Syl	Brα	~ 1000	DePoy 1987
M82..........	SB	Brγ	~ 130	Rieke *et al.* 1980
NGC 253	SB	Brγ	< 200	Rieke *et al.* 1980

[a] Sy2 = Seyfert 2 galaxy; Syl = Seyfert 1 galaxy; SB = starburst galaxy.

b) *Line Strength*

The Lyman-continuum photon rate in Arp 220 implied by its Brα line strength is small for the luminosity of the source when compared to starburst galaxies. As shown in Table 1, if Arp 220 had the same ratio of Lyman continuum to bolometric luminosity as observed in starburst galaxies, its Brα strength, corrected for $A_v = 50$ mag as suggested by Becklin and Wynn-Williams (1986), would be ~ 5–10 times larger than what is measured. Only if the visual extinction to the line-emitting region is > 130 mag would the Brα line strength to total luminosity ratio be similar to those of the starburst galaxies.

V. CONCLUSION

The present observations are much more consistent with the presence of an active nucleus than with a starburst. The broad Brα line profile is similar to lines seen in Seyfert galaxies and not to those observed in starburst or normal galaxies. The intensity of the line is probably very low compared to that expected from a burst of star formation. When combined with observations of Arp 220 that indicate a small infrared source size (Joy *et al.* 1986; Becklin and Wynn-Williams 1986; Neugebauer *et al.* 1986), these results strongly suggest that the source of Arp 220's exceptional luminosity is not star formation but a nuclear source with some similarities to those found in Seyfert galaxies.

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