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SPECTROPHOTOMETRY OF BRACKETT LINES IN VERY LUMINOUS IRAS GALAXIES

D. L. DePoy
University of Hawaii, Institute for Astronomy
Honolulu, Hawaii 96822 USA

ABSTRACT. Observation of the Brackett-α and Brackett-γ hydrogen recombination lines have been made in a sample of galaxies chosen from the IRAS catalog to have high luminosities at infrared wavelengths. Most have strong Brackett line emission indicating large numbers of high mass stars; the formation of these stars may hence be the underlying source for the galaxies' luminosities. However, there are at least two exceptions that may not be explained in this manner: NGC 6240 and Arp 220. Additional evidence indicates that each of these exceptions may be more closely related to Seyfert-type galaxies or other active galactic nuclei.

INTRODUCTION

IRAS has shown that there are many galaxies that have high luminosities at wavelengths around 80 μm. This luminosity can be extremely high, sometimes greater than 10^{12} $L_\odot$, which is similar to that of Seyfert galaxies and other active galactic nuclei (AGN).

The cause of this luminosity is subject to debate. One possibility is that very intense episodes of star formation are producing large amounts of ultraviolet radiation from high-mass stars that subsequently is absorbed and reradiated at longer wavelengths by dust associated with the star formation sites (Rieke et al. 1985; Joseph et al. 1985). Another is that an AGN underlies the galaxy and whatever powers an AGN is powering the infrared emission (see DePoy, Becklin, and Wynn-Williams 1986). Other causes have been postulated (e.g., Harwit in these proceedings).

If high-mass stars are the source of the luminosity, then observations similar to those made in galactic star formation regions should reveal their presence. These can include observations from X-ray to radio wavelengths. However, severe limitations hamper many techniques. For example, X-ray observations are curtailed by the lack of a satellite, radio studies are complicated by nonthermal processes, and submillimeter data are limited by beam sizes that require stringent assumptions about filling factors. Observations of hydrogen recombination lines are useful in quantitatively measuring the number of hydrogen ionizing photons, but optical lines are obscured by dust and, until recently, infrared lines have been difficult to detect.

Advances in infrared instrumentation have been made, however, that allow the infrared lines to be more easily detected. The Brγ (n = 7 to 4) and the Brα (n = 5 to 4) lines offer the best observational possibilities because both are situated in unobscured portions of the atmosphere and, especially Brα, are at wavelengths long enough to be only slightly affected by dust extinction.

Presented here are the results of a study of Brα and Brγ line strengths in a number of galaxies specifically chosen to have high luminosities in the infrared.

SAMPLE AND OBSERVATIONS

The galaxy sample was chosen from the IRAS Point Source Catalog (IRAS Explanatory Supplement 1985). The objects from the catalog had to have been detected in the 12 μm and 25 μm bands and have the sum of the fluxes in the 60 μm and 100 μm bands greater than 35 Jy. This limit was chosen so that if the object had a ratio of 100 μm plus 60 μm flux to Brackett line strength similar to that found in M82 and NGC 253, it would be possible to detect with a signal-to-noise ratio >5 in a 1 hr integration. Each object also had to be an optically cataloged galaxy with a redshift greater than 2000 km s^{-1}. Finally, the declination limits of the sample were -40° to +60°.

There were 25 galaxies that met the above criteria. They range in luminosity from 5 x 10^{10} $L_{\odot}$ to 2 10^{12} $L_{\odot}$. Four of the sample galaxies have been detected in one or both of the Brackett lines previous to this study: NGC 1614 (Aitken, Roche, and Phillips 1981), NGC 3690 (Fischer et al. 1983), Arp 220 (Rieke et al. 1985), and NGC 6240 (DePoy, Becklin, and Wynn-Williams 1986; Rieke et al. 1985).

All of the observations have been made on the United Kingdom Infrared Telescope (UKIRT) with a seven-element cooled grating spectrometer (CGSII). A 633 lines mm^{-1} grating was used that gave a resolution of about ~550 km s^{-1} around Brα and ~1200 km s^{-1} around Brγ. The 5.5" beam was always centered on the peak of each galaxies' 2 μm continuum.

RESULTS

The data on 15 galaxies were collected during two observing runs (January and April 1986). Of the 15, 13 were detected in the Brα line and 7 in Brγ. A run in September 1986 is planned to complete the sample.

A convenient measure of the amount of star formation in a galaxy is the "Infrared Excess" (IRX), defined as

$$(L_{bol}/L_{Ly\alpha}) - 1,$$

where L_{bol} is the bolometric luminosity of the source and $L_{Ly\alpha}$ is the luminosity of the Lyα line (Jennings 1975). The bolometric luminosity of a galaxy can be estimated from the IRAS data (IRAS Explanatory Supplement 1985) and the luminosity of the Lyα line from an extinction corrected hydrogen line strength and recombination theory (see Wynn-Williams 1984).

In H II regions the IRX is typically 5-10 (Jennings 1975); in starburst galaxies such as M82 and NGC 253 the IRX is slightly higher, closer to 20 or 30 (Simon et al. 1979 and Rieke et al. 1980, respectively). In AGN, however, the IRX is usually much higher, partly because for a given amount of luminosity the much flatter UV spectrum of an AGN produces far fewer photons near the ionization energy of hydrogen (see Cutri, Rieke, and Lebofsky 1984).

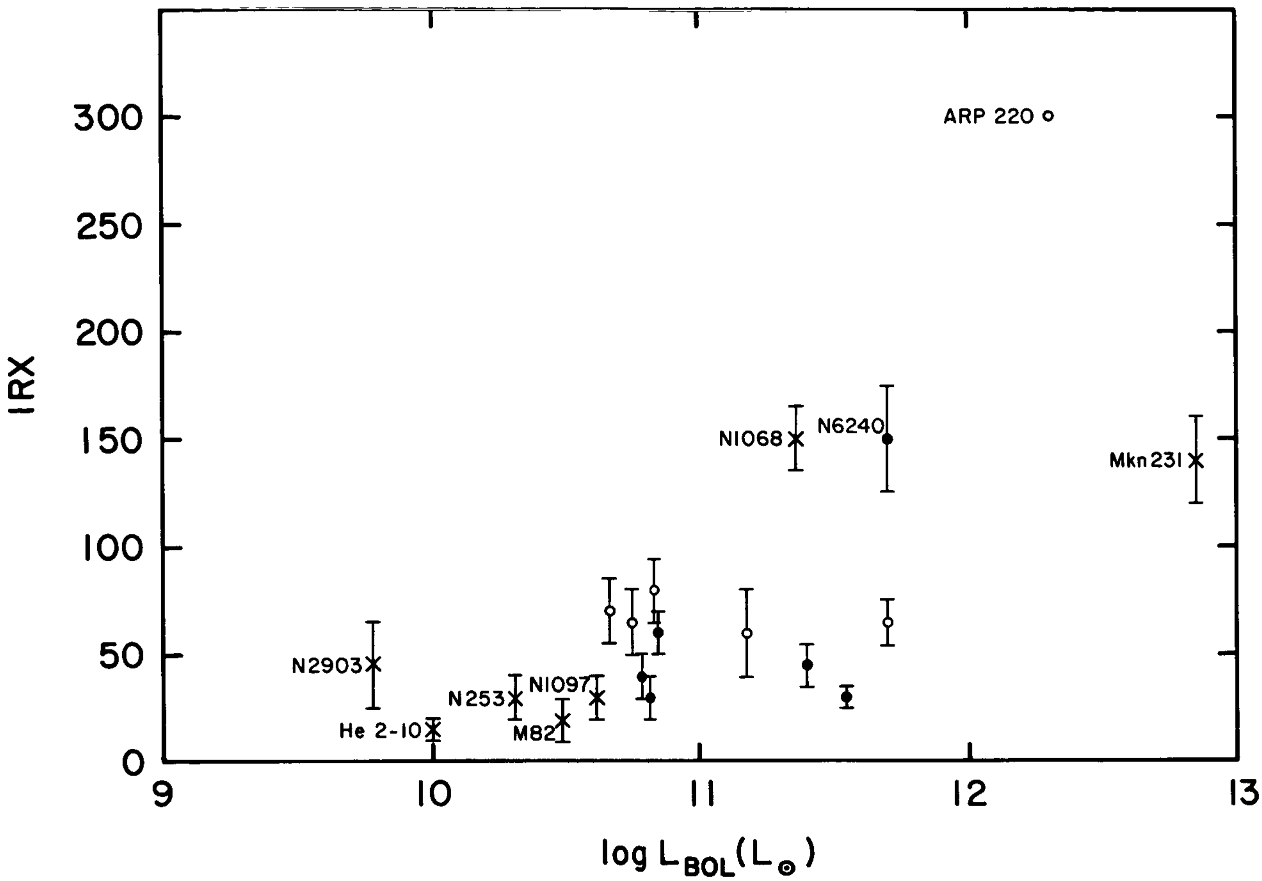

Figure 1. The infrared excess (IRX) vs. the bolometric luminosity of various objects and the sample galaxies. X's are from the literature, closed circles are program galaxies with both Brα and Brγ measured (and hence with extinction derived), and open circles are program galaxies with only the Brα measured.

Figure 1 shows the IRX of the program galaxies versus their bolometric luminosities. Also shown are the positions of some other galaxies whose Brackett lines have been reported in the literature (Beck, Beckwith, and Gatley 1984; Cutri, Rieke, and Lebofsky 1984; Hall et al. 1981; Phillips et al. 1984; Rieke et al. 1980).

Typically, the program galaxies have IRXs that are similar to or slightly higher than the starburst galaxies. In general, the galaxies with the IRXs that are slightly larger than the starburst galaxies are those with poorly determined extinctions or that are at the low redshift end of the sample. This may imply that the IRX in those cases has been overestimated, since either larger extinction or extended emission would give a larger intrinsic line strength and, hence, a lower IRX. Therefore, it appears that most of the program galaxies may be similar to starburst galaxies in their ratio of Lyman-α luminosity to bolometric luminosity. In any case, the implied hydrogen ionizing photon flux indicates a large number of high-mass stars; therefore the luminosities of the program galaxies may arise from the formation of these stars.

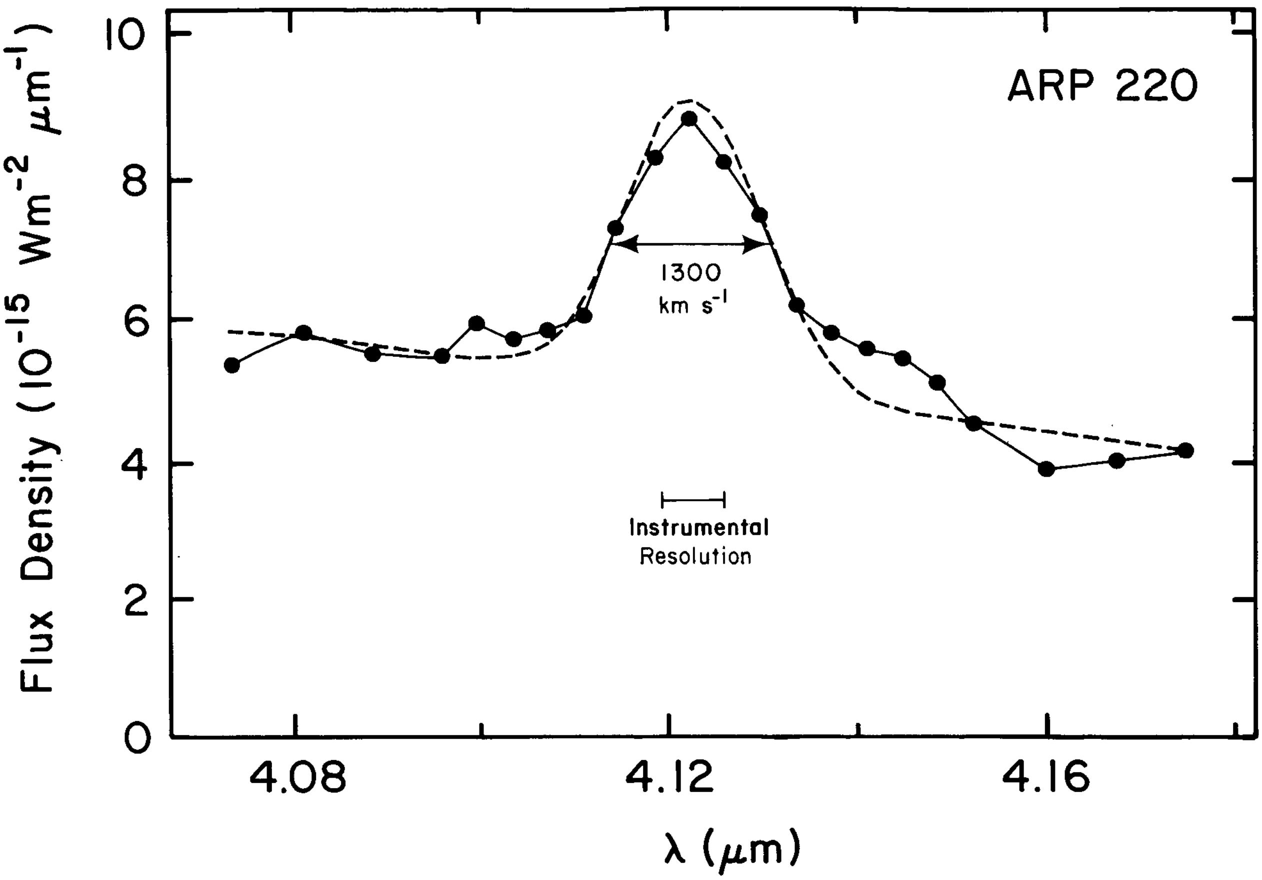

Figure 2. Brα line data on Arp 220. The dots and connecting line are the data smoothed with a three-point running mean; the dashed line is a χ^2 fit of a Gaussian and a linear continuum to the data. The Gaussian fit has a FWHM of ~1300 km s^{-1}.

There are, however, two notable exceptions, NGC 6240 and Arp 220. A thorough discussion of the data on NGC 6240 can be found in DePoy, Becklin, and Wynn-Williams (1986), in which it is argued that NGC 6240 has many properties similar to AGN. Arp 220, in addition to its very high IRX, has at least two other pieces of information that indicate that it is likely to be an AGN. First, the detected Brα in this source is very broad, about 1300 km s^{-1} FWHM (see Figure 2). Second, the 10 and 20 μm emission is unresolved spatially (see Becklin's paper in these proceedings). Therefore, Arp 220 may harbor an AGN.

CONCLUSIONS

A sample of 14 galaxies luminous in the IRAS bands have been observed for Brα and Brγ emission. The results indicate that, in general, the program galaxies have luminosities that are probably explained by the formation of high-mass stars. Two of the galaxies, however, do not fit the pattern. They may be more easily understood as AGN.

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