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THE REMARKABLE INFRARED GALAXY ARP 220 = IC 4553

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ABSTRACT

IRAS observations of the peculiar galaxy Arp 220 ≡ IC 4553 show that it is extremely luminous in the far-infrared, with a total luminosity of $\sim 2 \times 10^{12}\ L_{\odot}$. The infrared-to-blue luminosity ratio of this galaxy is ~ 80, which is the largest value of the ratio for galaxies in the UGC catalog, and places it in the range of the "unidentified" infrared sources recently reported by Houck *et al.* in the *IRAS* all-sky survey. Other observations of Arp 220, combined with the luminosity in the infrared, allow either a Seyfert-like or starburst origin for this luminosity.

Subject headings: infrared: sources — galaxies: photometry — galaxies: Seyfert

I. INTRODUCTION

Observations with the *Infrared Astronomical Satellite*[6] of the peculiar galaxy Arp 220 ≡ IC 4553 show that it is extremely luminous and that 99% of the galaxy's luminosity is emitted at infrared wavelengths. Of the galaxies in the UGC catalog detected in the *IRAS* survey for $|b| > 30°$, A220 has the largest ratio of infrared to blue luminosity. This *Letter* reports the *IRAS* observations of this galaxy system and discusses their implications.

II. *IRAS* OBSERVATIONS

A220 was scanned on four separate "hours-confirming" scan sets in the course of the *IRAS* all-sky survey (Neugebauer *et al.* 1984) and was detected as a strong pointlike source at 25, 60, and 100 μm. The signal-to-noise ratio of the observations at these wavelengths is always well over 100. Table 1 gives the observed position of the infrared source and the flux densities at all four infrared wavelengths observed by *IRAS*. The source strength at 12 μm was obtained by co-addition of 13 individual detector scans. The uncertainties in the average flux densities listed in Table 1 reflect the uncertainty in the absolute calibration of the *IRAS* data (Neugebauer *et al.* 1984). Corrections to the observed flux densities for effects of the broad bandpasses would change the observed flux density by less than 15% at 12 μm, and much less than 10% at 25, 60, and 100 μm, and were not applied since they depend on the shape of the unknown energy distribution.

The angular size of A220 was estimated by comparing scans of A220 with those of NGC 2623, a point source at the *IRAS* angular resolution. At 25 μm, the upper limit to the angular diameter of A220 was determined to be 25″ for a uniform disk model. No emission lines were detected in the single scan of A220 using the low-resolution spectrometer aboard *IRAS*.

III. OTHER OBSERVATIONS

Arp 220 (UGC 9913 = IC 4553 = Zw 136.017 = MGC +04-37-005) was originally classified as a "galaxy with adjacent loops" in the *Atlas of Peculiar Galaxies* (Arp 1966). The optical image from this atlas (Fig. 1 [Pl. L1]) shows a double structure with faint extended loops or tails. Its appearance suggests that A220 may be the remnant of the recent merger of two galaxies. A220 was detected in a radio survey of isolated pairs of galaxies (Stocke, Tifft, and Kafftan-Kassim 1978) and in the Arecibo 2380 MHz survey of optically bright galaxies (Dressel and Condon 1978). Condon and Dressel (1978) determined the optical and radio position of A220 (Table 1) and its spectrum between 3.4 and 11.1 cm. The infrared and radio positions, which agree within the uncertainties, are illustrated in Figure 1, where it is seen they fall between the two bright optical condensations. Condon (1980) reported a determination of the size of the radio source of 1″.3 × 0″.5. The location of the infrared and radio sources in the minimum between the two optical cores is suggestive that the minimum in optical brightness is due to an obscuring dust lane.

Condon (1980) found A220 to be the most luminous radio source in his sample; an upper limit on the fraction of thermal emission contributing to the radio flux at 2380 MHz is 30%. The neutral hydrogen spectrum at 21 cm (Mirabel 1982) is quite peculiar, showing no evidence for emission, and a very broad (740 km s^{-1}) absorption-line width. The observed column density of hydrogen is by far the largest in the galaxies sampled by Mirabel. The breadth and profile of the H I feature are indicative of strong noncircular motions in the line of sight to the nucleus of A220.

Optical spectra of A220 have been reported by Tifft (1982) and Heckman *et al.* (1983). Tifft reports the presence of Hα

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[6] The *Infrared Astronomical Satellite* (*IRAS*) was developed and is operated by the Netherlands Agency for Aerospace Programs (NIVR), the United States National Aeronautics and Space Administration (NASA), and the United Kingdom Science and Engineering Research Council (SERC).

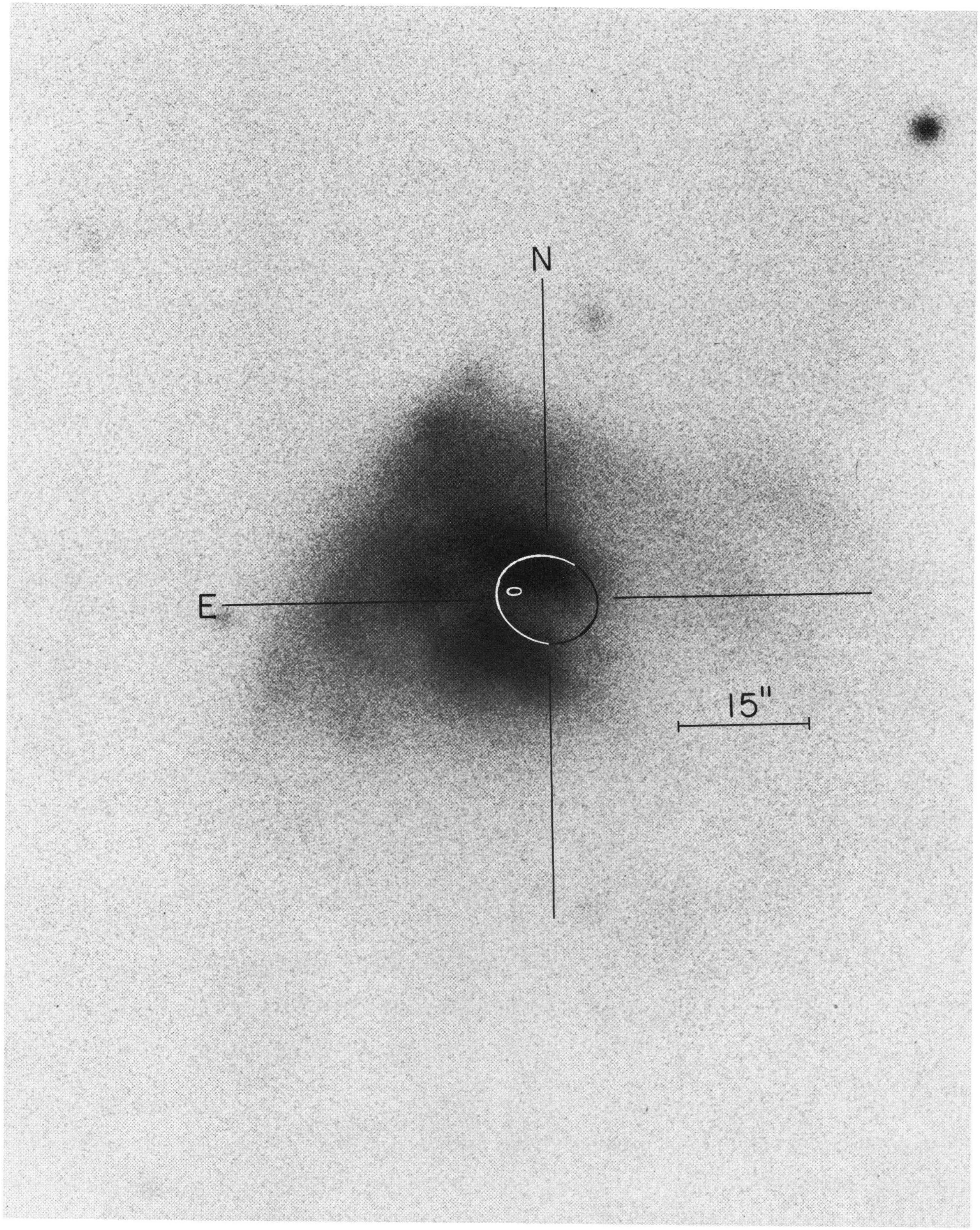

FIG. 1.—The visible image of A220 (©1966, California Institute of Technology) taken from Arp (1966) showing the infrared and radio source positions. The large ellipse is the 1 σ error ellipse of the infrared source position, with the cross indicating the infrared position. The small ellipse shows the radio source size at its position from Condon (1980).

SOIFER *et al.* (*see* page L1)

TABLE 1

PROPERTIES OF ARP 220

A. POSITION

Wavelength	R.A.	Declination	Notes[a]
Infrared	$15^h32^m46\overset{s}{.}6 \pm 0.4$	$+23°40'07'' \pm 5$	1
Radio	15 32 46.92	+23 40 07.9	2
Optical:			
(N)	15 32 47.0	+23 40 17	3
(S)	15 32 47.1	+23 40 02	3

B. FLUX DENSITY

Wavelength (μm)	Flux Density (Jy)	Notes[a]
12	0.48 ± 0.06	4
25	8.5 ± 1.2	4
60	124 ± 19	4
100	149 ± 22	4

NOTES.—(1) This work. (2) Condon and Dressel 1978. (3) Stocke, Tifft, and Kaftan-Kassim 1978. (4) The quoted *IRAS* uncertainties reflect the uncertainty in the absolute calibration and are set at 15% of the flux.

and weak [O II] 3727 emission. Heckman *et al.* (1983) found strong (6 Å equivalent width), broad (20 Å FWHM) Hβ absorption, and broad [O III] 5007 emission (480 km s^{-1} FWHM).

Baan, Wood, and Haschick (1982) have detected very strong OH main-line emission from this galaxy at 5375 km s^{-1} with a full width at half-maximum of 108 km s^{-1}, and a luminosity in the 1667 MHz line of 350 $L_{\odot}$. The heliocentric velocity of A220 has been determined as 5369 km s^{-1} in the optical by Huchra *et al.* (1983), and as 5420 km s^{-1} from 21 cm atomic hydrogen absorption by Mirabel (1982). For a Hubble constant H_0 of 60 km s^{-1} Mpc^{-1}, the velocity of 5400 km s^{-1} corresponds to a distance of 90 Mpc.

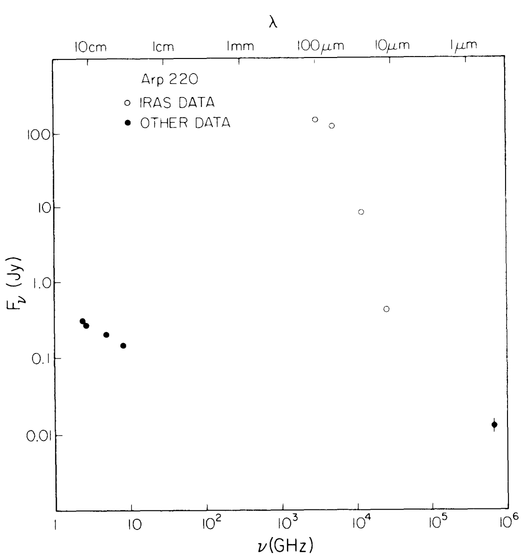

FIG. 2.—The energy distribution of A220, plotted vs. frequency from the data in Table 1 and the cited references. The open circles are the *IRAS* data, while the filled circles represent data from other observations (see text).

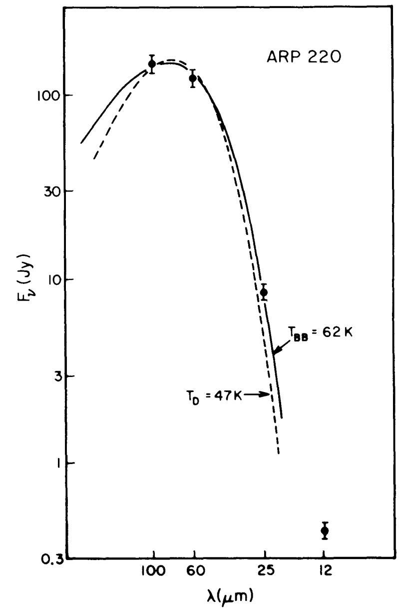

FIG. 3.—The *IRAS* observations of A220, plotted vs. wavelengths. For comparison the solid curve is the best fit blackbody curve fitted to the data at 25, 60, and 100 μm and is labeled $T_{\rm BB}$. The dashed curve labeled T_D shows the fit of a modified blackbody with an emissivity proportional to frequency fit to the 60 and 100 μm data.

IV. DISCUSSION

a) *Emission Mechanism*

The overall energy distribution for A220 from the visible through radio wavelengths is shown in Figure 2. This shows a strong peak in the infrared with a 100 μm to 5 GHz flux density ratio of roughly 1000. This ratio is typical of bright infrared galaxies, such as M82 and NGC 1068, and implies that the mechanism for producing the infrared emission is thermal emission by dust. The ratio of 100 μm to 12 μm flux density, 300, is higher than for any other known object of this class and suggests an extremely high optical depth at 12 μm. Of course, a nonthermal origin to the infrared emission cannot be immediately dismissed, but we regard this possibility as very unlikely since the energy distribution as shown in Figure 3 is so well represented by thermal models.

b) *Luminosity*

The observed infrared flux for A220 leads to an extreme luminosity. Fitting the infrared data by a blackbody gives a temperature $T_{\rm BB} = 62$ K and a total infrared flux of 8.7×10^{-12} W m^{-2}. This fit to the infrared data is shown in Figure 3 and provides an acceptable fit to the observed fluxes at 25, 60, and 100 μm. An equally acceptable fit using an emissivity proportional to frequency is also shown in Figure 3 and gives a fit to the 60 and 100 μm data of $T_D = 47$ K with a total flux of 8×10^{-12} W m^{-2}. Taking the latter flux and a distance to A220 of 90 Mpc leads to an infrared luminosity of 1.8×10^{12} $L_{\odot}$. This luminosity is a factor of 6 larger than the extreme Seyfert galaxy NGC 1068 and is about that of the most luminous Seyfert galaxy known, Mrk 231 (Rieke and Low 1975).

Soifer *et al.* (1984) have used the infrared-to-blue luminosity ratio as a measure of the infrared activity in galaxies found to be bright in the *IRAS* observations. The flux per logarithmic frequency internal (νF_ν) in the blue is 9×10^{-14} W m^{-2}, giving an infrared-to-blue luminosity ratio of 80; the Zwicky magnitude of $m_Z = 14.4$ mag (Arp 1966) has been converted to a blue magnitude $B_T = 13.8$ mag using the prescription of Auman, Hickson, and Fahlman (1982). This ratio is more extreme for A220 than for any of the galaxies found by Soifer *et al.* (1984).

Houck *et al.* (1984*a*) have reported the discovery of infrared sources which have either a faint or no visual counterpart on the Palomar Sky Survey. Aaronson and Olszewski (1984) and Houck *et al.* (1984*b*) have obtained CCD images of some of the "blank" fields and have found faint galaxies with infrared-to-blue luminosity ratios as great as 200 in the positions of nearly all the sources. If A220 were sufficiently distant to be detected at the *IRAS* survey limit of 0.5 Jy at 60 μm, it would correspond to such a "blank" field source at a redshift of $z \approx 0.3$. Thus A220 could well represent a very nearby example of this class of extremely infrared active galaxies. For A220 the large infrared-to-blue flux ratio is due to an extremely large infrared luminosity. This suggests that some of the "unidentified" sources are likely to be highly luminous infrared sources, rather than highly extinguished sources of more modest luminosity.

c) Limits on Angular Size

From the observed flux and temperature we can establish lower limits on the angular size of the infrared source. If the emission mechanism is thermal radiation by dust, the minimum angular diameter is given by assuming the emissivity is unity. This leads to a diameter of 1''.3 if $T = 62$ K. The minimum size of the infrared source is comparable to but slightly larger than the size of the radio source as measured by Condon (1980).

A crude maximum angular size of the infrared source can be derived if we assume the heating is from a central luminosity source and the emitting grains view the central source directly. If $T_D \approx 47$ K, consistent with optically thin emission with emissivity varying as wavelength^{-1}, the source diameter is 12''. This is consistent with the observed upper limits on the source size derived from the *IRAS* observations, but it is measurable by other techniques.

d) Is A220 a Seyfert Galaxy or a Starburst Galaxy?

Two obvious candidates for powering the infrared luminosity of A220 are a Seyfert-type galaxy or an extreme burst of star formation, such as seen in galaxies like NGC 3690 and M82. These two classes are characterized by a central, presumably nonthermal, luminosity source surrounded by matter that absorbs and reradiates the luminosity in the infrared in the former case, and multiple sites of active star formation, presumably spread throughout the inner galaxy, in the latter case.

The optical spectroscopy (Heckman *et al.* 1983) provides conflicting evidence. The presence of strong, broad Hβ absorption shows that hot stars are present, while the broad [O III] 5007 Å emission is suggestive of Seyfert-like properties.

TABLE 2

COMPARISON OF OBSERVED PROPERTIES OF EXTREMELY INFRARED LUMINOUS GALAXIES

Property	A220	M82	Mrk 231
L ($L_\odot$)	2×10^{12}	3×10^{10}	2×10^{12}
L_{IR}/L_B................	80	10	25
S(100 μm)/S(12 μm)..	300	30	20
S(100 μm)/S(6 cm) ...	750	400	250

Indeed, Heckman *et al.* (1983) were unable to distinguish between classifying this galaxy as an H II region, Seyfert, or "liner."

Unfortunately, the infrared observations add little help to this rather confusing situation but rather, as with the other observations, show that A220 exhibits some properties of both Seyfert nuclei and starburst galaxies. This is demonstrated in Table 2, which compares the observed properties of A220 with those of extreme examples of the starburst and Seyfert nuclei, M82 and Mrk 231.

While the luminosity of A220 is ~ 60 times that of the starburst galaxy M82, the ratio of 100 μm to 6 cm flux densities, i.e., the quantity that, in principle, measures the ratio of young star luminosity to supernova luminosity, is quite comparable in the two galaxies. The ratio of infrared-to-blue luminosity in Arp 220 is a factor of ~ 10 greater than in M82. If the starburst model obtains in A220, a much greater fraction of the galaxy is undergoing the starburst. The 100 μm to 12 μm flux density ratio is much greater in A220 than in M82. In a starburst model, this would have to be explained as viewing the star formation through a much greater mean optical depth, suggestive of significant silicate absorption at 12 μm.

In the case of M82, the size of the infrared source is quite similar to that of the radio source. This cannot be the case for A220, since the minimum blackbody diameter of the infrared source of 1''.3 is already larger than the observed radio size of 1''.3 × 0''.5. Furthermore, if the infrared source in M82 were scaled to the luminosity of A220, while keeping the luminosity per unit volume the same, the linear size of the infrared source would be roughly 3 times the size of the radio source.

Just as the model of a starburst galaxy cannot be simply scaled to the luminosity of A220 without some modification, neither can the Seyfert-type model as exemplified by Mrk 231. The lack of clear evidence in the visible images for a bright nucleus argues that in the Seyfert models the central source must be heavily obscured. The visible "dust lane" could provide this screen. While the luminosities of the two galaxies are quite similar, the infrared-to-blue luminosity ratio in Mrk 231 is a factor of 3 less than in A220, suggestive of a higher optical depth to the luminosity source in A220. Such a greater optical depth is suggested also by the much greater ratio of 100 μm to 12 μm flux densities in A220. An alternative explanation of this latter discrepancy is simply a significantly different inner radius of material being heated by the luminosity source. A further difference between the two sources comes in a comparison of the 100 μm to 6 cm flux density ratios, where A220 shows a significantly larger value for this ratio.

The importance of this discrepancy is not clear, since the meaning of this ratio is not clear for Seyfert nuclei.

V. SUMMARY

The peculiar galaxy A220 has been found to be extremely luminous in the infrared and has an infrared-to-blue luminosity ratio of 80, typical of some "unidentified" far-infrared sources found by *IRAS*. Both starburst and Seyfert-like origins to the activity of A220 are possible. The infrared luminosity of A220 is comparable to that of the brightest Seyfert galaxies and many quasars. The high infrared luminosity in A220, combined with the relatively normal value for the visual luminosity, demonstrates that in this system, at least, the high infrared-to-visual luminosity ratio is due to an excess of infrared luminosity rather than a highly extinguished source of more modest visual luminosity.

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