THE ASTROPHYSICAL JOURNAL, 287:566–570, 1984 December 15

THE LUMINOUS HOST GALAXY AND ANOMALOUS BRACKETT-GAMMA LINE OF MARKARIAN 231

ROC M. CUTRI, G. H. RIEKE, AND M. J. LEBOFSKY
Steward Observatory, University of Arizona
Received 1984 March 7; accepted 1984 July 2

ABSTRACT

New infrared observations have been made of the Seyfert galaxy Markarian 231. Multiaperture photometry reveals that the underlying galaxy is extremely luminous, with $M(K) = -24.7$. This implies that the Seyfert nucleus likely resides in a giant elliptical galaxy, or possibly in a galaxy which is undergoing a massive star-burst. The strengths of the Paschen-alpha and Brackett-gamma lines of hydrogen have been measured using Fourier transform spectroscopy. An anomalously large Paα/Brγ ratio may imply that the electron density in the broad line clouds in Mrk 231 is much higher than that typically quoted for the broad-line regions of other active galaxies. We examine the possible origin of the exceptional activity and the unusual spectroscopic properties in the nucleus of Mrk 231 in the context of the nature of the host galaxy.

Subject headings: galaxies: individual — galaxies: Seyfert — galaxies: structure — infrared: spectra

I. INTRODUCTION

Markarian 231 is unique among Seyfert galaxies. It displays extremely red optical and infrared photometric colors. Strong emission and absorption lines mark the presence of at least three distinct redshift systems in an optical spectrum which is reminiscent of an absorption line QSO (Adams and Weedman 1972; Boksenberg *et al.* 1977). Its exceptionally high luminosity (Rieke and Low 1975) strengthens the analogy with QSOs. A deep 10 μm silicate absorption feature suggests that the nucleus of the galaxy may be obscured by as much as 20 mag of visual extinction (Rieke 1976; Roche, Aitken, and Whitmore 1983), yet the Balmer decrement and the relative strengths of sodium absorption lines indicate only $\sim$2 mag of extinction are present (Boksenberg *et al.* 1977). Mrk 231 also has one of the broadest 21 cm absorption features of any extragalactic source yet observed (Heckman, Balick, and Sullivan 1978).

In this paper we present new photometric and spectroscopic observations which reveal several other exceptional properties of Mrk 231. The most significant result is that the Seyfert nucleus of Mrk 231 apparently lies in a galaxy which is comparable in brightness to first-rank elliptical galaxies. Seyfert nuclei are rarely found in elliptical galaxies (Adams 1977), and such galaxies are typically gas and dust poor. Therefore, the prospect that Mrk 231 resides in a giant elliptical galaxy poses an interesting question as to the source of the large amounts of gas and dust in the system. The underlying galaxy may alternately be an intrinsically less luminous system which is undergoing a massive burst of star formation. In addition, measurements of the Paschen-α line strength, when compared to the Balmer line strengths (Boksenberg *et al.* 1977; Lacy *et al.* 1982), are consistent with the line strengths predicted from case B recombination with $\sim$2 mag of visual extinction. Upper limits to the Brackett-γ line strengths relative to Paschen-α however, fall nearly a factor of 2 below the reddened case B value. Such a large Paα/Brγ ratio has been reproduced by the radiative transfer models of Drake and Ulrich (1980), but to fit the other observed hydrogen line strengths in Mrk 231, extremely high electron densities ($n_e \geq 10^{10}$ cm^{-3}) are required for the broad-line clouds.

We suggest that many of the properties of Mrk 231 can be understood if it is a giant elliptical in the process of assimilating a spiral or irregular galaxy. This interaction appears to have triggered the exceptional level of activity.

II. OBSERVATIONS

Infrared photometry of Mrk 231 was performed with the Steward Observatory 2.3 m telescope on the night of 1981 February 19 (UT). Broad-band measurements at 1.65 and 2.2 μm (H and K) were made using a liquid helium cooled InSb photovoltaic detector system, through apertures with projected beam diameters of 4″ and 8″, corresponding to linear diameters of $\sim$2.5 and $\sim$5 kpc at the galaxy. The measurements were calibrated by alternating observations of Mrk 231 with those of the star GC 18704 made through identical filters and apertures. The H and K magnitudes of Mrk 231 are listed in Table 1; uncertainties in the absolute levels of the measurements are $\leq$0.05 mag. The observed *relative* levels of the magnitudes in each aperture are accurate to $\leq$0.01 mag, however, owing to the exceptional atmospheric stability and frequent measurements of the nearby reference star.

Near-infrared spectra of Mrk 231 were obtained in 1979, 1980, and 1981, also with the Steward Observatory 2.3 m telescope, using the Steward Observatory Fourier Transform Spectrometer. Dual liquid helium cooled InSb detectors were used for these observations which were made through an 8″ circular aperture. Scans were made at a spectral resolution of 16 cm^{-1} over a spectral range determined either by an intervening K broad-band filter (4000–5000 cm^{-1}) or a filter which passes both the H and K bands (4200–6800 cm^{-1}). Each scan of Mrk 231 was corrected for atmospheric absorption by dividing it by a scan of the A type star GC 18704, and all reduced

TABLE 1
INFRARED MAGNITUDES OF MRK 231

Beam Diameter (arcsec)	H	K
4	10.12	8.90
8	10.08	8.87

scans were then averaged together with weightings proportional to the square of the signal-to-noise ratio. The final spectrum, shown in Figure 1, was smoothed to a spectral resolution of 54 cm^{-1}, giving a resolution in velocity space between 2000 and 4000 km s^{-1}. This improves the signal-to-noise ratio in the continuum, yet still allows resolution of the broad hydrogen lines. Insufficient correction for the Brγ absorption line in the standard star's spectrum produced the weak emission feature seen at 4620 cm^{-1}. The 1 standard deviation uncertainty levels for individual resolution elements were estimated from the scatter in the individual spectra around the smooth continuum indicated by the final average. These uncertainties are $\sim$1.5% of the continuum between 4000 and 5000 cm^{-1}, and $\sim$3% of the continuum between 5000 and 6800 cm^{-1}.

The spectrum between 5150 and 5500 cm^{-1} has been omitted in Figure 1 because in this region telluric H_2O absorption reduces the atmospheric transmission to $<50\%$, resulting in a much poorer signal-to-noise ratio. The telluric CO_2 absorptions near 5000 and 4800 cm^{-1} also decrease the signal-to-noise ratio over narrow spectral intervals, although we have still plotted the data in these cases. Inset in Figure 1 is a portion of the spectrum between 4000 and 4400 cm^{-1} at the original 16 cm^{-1} resolution. This resolution is more appropriate for detection of the first-overtone CO bands arising in stars in Mrk 231. The redshifted ($z = 0.041$) positions of the CO bands are marked in the figure.

The most prominent feature in the infrared spectrum of Mrk 231 is Paschen-alpha emission. The peak of the line occurs at 5130 cm^{-1} ($=1.949$ μm) giving a redshift of $z = 0.040$, a value which agrees to within 4% of the redshift of the broad Balmer emission lines found by Adams and Weedman (1972). We measure a line flux of $7.8 \pm 0.3 \times 10^{-13}$ ergs cm^{-2} s^{-1} for Paα which is consistent with the earlier measurements of Lacy *et al.* (1982). Noticeably absent from the spectrum is the Brγ line of hydrogen at 4435 cm^{-1}. The 2 standard deviation upper limit to the Brγ line flux is $\leq 1.8 \times 10^{-14}$ ergs cm^{-2} s^{-1}. Its absence is discussed below. There is little indication of stellar CO absorption, as well. The 2 standard deviation upper limit to the amount of flux removed from the continuum by any CO absorption band is $\leq 8\%$. The remaining parts of the spectrum are essentially featureless continuum, roughly characterized by a $F_\nu \propto \nu^{-2}$ power law. This slope matches that shown by the spectrophotometry of Cutri *et al.* (1981).

III. DISCUSSION

a) The Underlying Galaxy

Because of the immense luminosity of the Seyfert nucleus in Mrk 231, little is known about the underlying galaxy. No obvious stellar features are present in the optical spectrum (Boksenberg *et al.* 1977), yet the object is clearly nonstellar on the Palomar Sky Survey plates. The small but measurable difference between our photometry at 4" and 8" indicates the presence of extended emission, as do the multiaperture measurements of McAlary, McLaren, and Crabtree (1979) and Weedman (1973). If the extended emission is interpreted as starlight from the galaxy, an estimate of the integrated brightness of the galactic component can be made. We have fitted our measurements to the curve of growth for an elliptical galaxy (Sandage 1972) as modified by Lebofsky (1981) to a standard metric (sm) of 32 kpc and $H_0 = 100$ km s^{-1} Mpc^{-1}. Extrapolating the flux increase between 4" and 8" using this growth curve gives magnitudes of $H_{sm} = 11.6 \pm 0.4$ and $K_{sm} = 10.9 \pm 0.8$, where the errors reflect the levels of the observational uncertainties. An identical analysis can be made using the optical photometry of Weedman (1973). These measurements, which were made through apertures of 10", 15", 21", and 35" in diameter, can be fitted to the same curve of growth

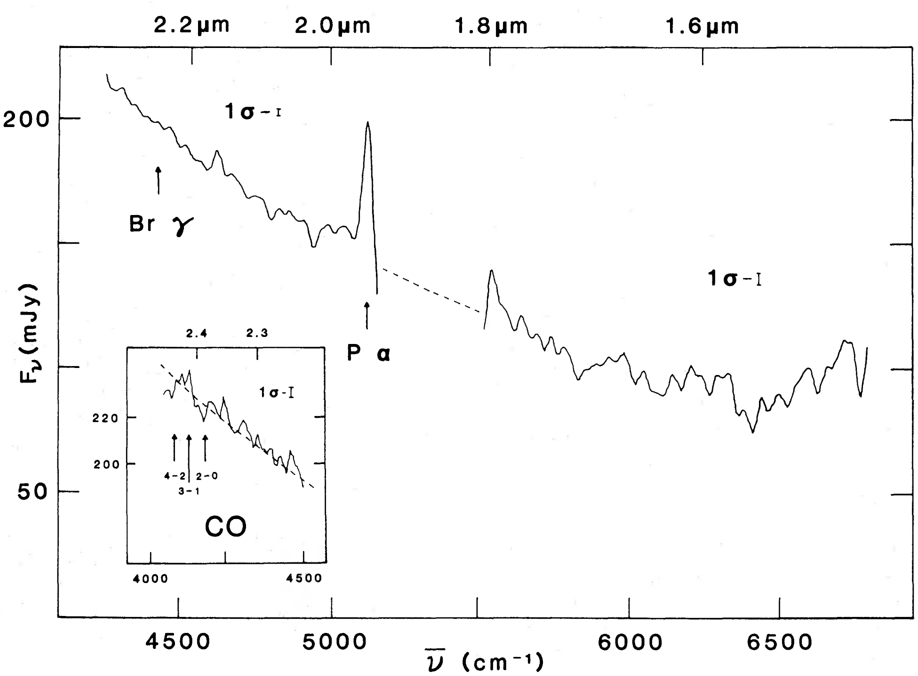

FIG. 1.—The near-infrared spectrum of Mrk 231. These data have been smoothed to a resolution of 54 cm^{-1}. The dashed line represents the portion of the spectrum in which atmospheric transmission drops below 50% and has therefore been omitted. The weak emission feature at 4620 cm^{-1} is the result of insufficient correction for the Brγ absorption line in the A type calibration star GC 18704. (*inset*) The 4000–4400 cm^{-1} region of the spectrum at the original 16 cm^{-1} resolution. The expected locations of the first overtone CO bands have been marked.

because of the similarity of the curve at V and K (Frogel *et al.* 1978). This gives a visual standard metric magnitude of $V_{sm} = 13.93 \pm 0.20$. Adopting a $V-K$ color of ~ 3.3 as a standard elliptical galaxy color (Frogel *et al.* 1978; M. Lebofsky, unpublished) gives $K_{sm} = 10.6 \pm 0.2$, which agrees well with the value derived from our infrared data. This consistency between the results of the small-aperture infrared data and the larger aperture optical data verify that an elliptical galaxy curve of growth is an appropriate representation of the stellar luminosity profile in Mrk 231.

Even a galaxy this bright will contribute only about 8% of the total 2.2 μm light of Mrk 231 in an 8″ aperture and about 5% of the light in a 4″ aperture. An additional upper limit to the contribution of starlight in the near-infrared comes from the lack of CO absorption in the K spectrum as seen in Figure 1. Since a stellar population whose light is dominated by K and M giants should exhibit a CO absorption which removes $\sim 25\%$ of the stellar continuum (Johnson *et al.* 1968; Frogel *et al.* 1978), the absence of CO implies that any galactic component in Mrk 231 cannot provide more than 25% of the total light in an 8″ aperture. This confirms the limit found by Cutri *et al.* (1981).

If there really is an underlying galaxy, the level of the stellar flux at intervening wavelengths can be estimated by interpolating a typical elliptical galaxy spectrum (Frogel *et al.* 1978; Persson, Frogel, and Aaronson 1979; M. Lebofsky, unpublished) from the levels of the stellar emission at V and 2.2 μm. This procedure gives a ratio of the stellar flux to total flux at 6000 Å in a 4″ aperture of ~ 0.4. Boksenberg *et al.* (1977) and Rudy, Foltz, and Stocke (1984) have suggested that the reason that the sodium D lines in Mrk 231 are not black at their center is because there is a component of stellar emission in the integrated light from the nucleus at the wavelength of those lines. The ratio of the flux at the sodium D line center to the flux in the continuum is 0.3 to 0.4, as observed by these authors through 1″ × 3″ and 1″ × 2″ slits, indicating that the stellar emission contributes about 25%–30% of the total flux at 6050 Å. When compensation is made for the smaller apertures, this agrees remarkably well with the value from the interpolation.

Each of these results yields a self-consistent estimate of the starlight in Mrk 231, corresponding to standard metric magnitude $K_{sm} = 10.8$ and normal colors and curve of growth for a giant elliptical. With a Hubble constant of 100 km s^{-1} Mpc^{-1}, the distance modulus of Mrk 231 is 35.5, giving an absolute K magnitude in a standard metric diameter of 32 pc of ~ -24.7. The standard metric absolute magnitude expected for a first rank elliptical galaxy is $M(K)_{sm} = -24.7$, with an intrinsic dispersion of about ± 0.4 mag (Lebofsky and Eisenhardt 1984). The host galaxy of Mrk 231, therefore, has the same luminosity as the average of giant ellipticals. The absolute K magnitudes of the most luminous spiral galaxies in the same metric diameter can be computed from the H band photometry of more than 300 bright spiral galaxies by Aaronson *et al.* (1982). Assuming the Hubble constant as above, *no* galaxy in this sample has $M(K)_{sm} < -24.0$. This comparison is in agreement with optical measurements that show giant elliptical galaxies to be roughly one magnitude more luminous than the brightest luminosity class I spirals (Freeman 1976, and references therein). It is likely, therefore, that the Seyfert nucleus of Mrk 231 resides in a giant elliptical galaxy.

Recent observations by Soifer *et al.* (1984) and Rieke *et al.* (1984), however, have indicated that in some heavily dust enshrouded galaxies star formation can produce exceptionally luminous infrared emission. These "super" starburst galaxies can have a nuclear K magnitude as bright as or considerably brighter than an average giant elliptical galaxy at the same redshift. The curve of growth arguments outlined above tend to favor a giant elliptical as the host of Mrk 231, but we will further examine both of these possibilities in § III*c*. The true nature of the underlying galaxy notwithstanding, the unique position of Mrk 231 high on the luminosity function of both Seyfert nuclei and galaxies in general makes it an important object in understanding both the degree to which the host galaxy affects the active nucleus, and the connection between the host galaxies of Seyferts and QSOs.

b) The Emission Lines

We have compared our hydrogen line measurements of Mrk 231 with those of Lacy *et al.* (1982). The mean of our Paα flux and that of Lacy *et al.* (1982), weighted by the inverse square of the uncertainties, is $7.35 \pm 0.24 \times 10^{-13}$ ergs cm^{-2} s^{-1}. The ratio of the Hα to Paα line strengths is then 3.95 ± 0.32. The Hα/$H\beta$ and Hα/Paα are consistent with those predicted by case B recombination (Lyα:Hα:Hβ:Paα:Brγ = 35.0:2.85:1.00:0.35:0.028, Osterbrock 1974; Giles 1977), reddened by ~ 0.5 mag in $E(B-V)$. The Paα/Brγ ratio of > 41.8, however, cannot be reproduced by the case B value with any amount of reddening. Consequently, as has been established for many active galactic nuclei, the conditions in the broad emission-line regions of Mrk 231 are not like those assumed for the case B calculations, and we cannot be certain of the intrinsic hydrogen line strengths. Brackett-γ has recently been found to be deficient relative to Paα in two other Seyfert galaxies, as well (C. W. McAlary *et al.*, in preparation).

To compare the hydrogen lines with theoretical models, their strengths must be corrected for extinction. An independent reddening estimate comes from the relative strengths of the Ca II and Na I absorption lines. Boksenberg *et al.* (1977) derive a value of >2 mag of visual extinction from these lines, but because they are observed at a different redshift than the hydrogen emission lines, there is no guarantee that this amount of extinction also applies to the broad emission-line region. In the absence of any other reliable reddening indicators, though, we will adopt $A_V = 2$ mag as an approximate value; the extinction is unlikely to be any less in the emission-line region in light of the large amount of dust indicated by the deep 10 μm silicate absorption feature. Correcting the hydrogen lines for 2 mag of visual extinction using the reddening curve of Rieke and Lebofsky (1984) gives line ratios of Hα/Lyα = 0.14 ± 0.03, Hα/Hβ = 2.74 ± 0.43, Hα/Paα = 13.08 ± 0.06 and Paα/Brγ > 45.7.

The Brackett lines are treated in the radiative transfer models of Drake and Ulrich (1980). The dereddened Paα/Brγ ratio in Mrk 231 is reproduced in a number of their examples, but none simultaneously predict the dereddened Balmer decrement or Lyα/Hα or Hα/Paα ratios. Their models which best match the Paα/Brγ ratio require electron densities above 10^{11}–10^{12} cm^{-3} and temperatures of order 10^4 K. These densities are higher than the upper limits usually quoted for broad emission line clouds (see, e.g., Davidson and Netzer 1979). Hubbard and Puetter (1984), however, have argued quite strongly that high densities ($>10^{11}$ cm^{-3}) are necessary to account for the relative hydrogen line ratios in active objects based on their new energy balance calculations, and to explain the observed He I to hydrogen relative line ratios. Hubbard and Puetter reason that the interpretation of such classical density tests as the presence of C III] λ1909 are incorrect because the densities in the emission-line clouds are actually above the critical densities for the forbidden and semiforbidden transitions. Because of these arguments, and if the high densities are needed to suppress the Brγ line flux relative to Paα, as suggested by the radiative transfer models, it appears that the broad emission-line clouds in Mrk 231 could have significantly higher electron densities than are typically assumed for active nuclei.

Considering the implications the Paα/Brγ ratios may have for our understanding of the physical conditions in emission line regions, further observations of Brγ and other higher order hydrogen lines in Seyfert galaxies and QSOs are warranted. Because the Brackett lines are readily measured with current detector systems, it is imperative that these lines be included in more radiative transfer analyses relevant to active nuclei.

c) *Nature of Mrk 231*

The emission from the Seyfert nucleus of Mrk 231 clearly dominates the light from that galaxy. This nucleus, though, resides in an exceptionally luminous stellar system. It is likely that this system is either a giant elliptical galaxy that contains a large amount of gas and dust, or a transient stage in a lower luminosity galaxy, such as a massive starburst.

One possible explanation for the presence of substantial amounts of dust and gas with disturbed velocities in a giant elliptical is an interaction in which a gas and dust-rich system such as a spiral or irregular galaxy is being assimilated. Such an occurrence has been proposed for NGC 5128 (= Centaurus A), another giant elliptical galaxy which shows nuclear activity and contains considerable gas and dust (Dufour *et al.* 1979; Graham 1979).

Galaxy interactions seem to trigger starbursts as well as Seyfert activity. Of particular relevance, starburst activity appears to influence the middle-infrared properties of NGC 5128 (Telesco 1978). With the exception of Mrk 231, strong silicate absorption seems to be typical of starburst, not Seyfert galaxies. It is therefore attractive to model the spectrum of Mrk 231 as a combination of the two types of activity. We have done so, assuming the spectrum to be a combination of that of M82, the prototype starburst galaxy (Rieke *et al.* 1980) and the type 1.5 Seyfert galaxy, NGC 4151. Broadly speaking, the models fit the infrared spectrum satisfactorily only if the starburst has a luminosity 15–20 times as great as that of M82 and the Seyfert activity is about 100 times more energetic than in NGC 4151. The infrared luminosity of $1–2 \times 10^{12}\ L_{\odot}$ (assuming $H_0 = 100$) is then divided roughly equally between starburst and Seyfert activity. Such powerful starbursts have been observed to be occurring in the two violently interacting systems Arp 220 and NGC 6240 (Rieke *et al.* 1984; Soifer *et al.* 1984). Both of these galaxies may, in fact, harbor weak Seyfert nuclei. The large amount of energy in both types of activity in Mrk 231 may be related to the large mass of the host galaxy and to the presence of a substantial amount of interstellar material.

It is becoming increasingly evident that galaxy-galaxy interactions play an important, though poorly understood, role both in starburst and in nuclear activity in galaxies. Larson and Tinsley (1978) first called attention to the apparent correlation between rapid star formation and galaxy interactions. Enhanced radio emission in close pairs of galaxies is well established (Stocke, Tifft, and Kaftan-Kassim 1978; Condon and Dressel 1978; Hummel 1980, 1981; Condon *et al.* 1982). Adams (1977) and Davis (1981) assert that Seyfert nuclei occur more frequently in interacting or disturbed galaxies than in isolated ones. Even QSOs are now being found in interacting systems (Bothun *et al.* 1982; Hutchings, Campbell, and Crampton 1982; Hutchings, Crampton, and Campbell 1984). Mrk 231 may represent one of the most extreme examples of this type of system, containing both a powerful Seyfert nucleus and an intense starburst.

IV. CONCLUSIONS

Our new observations have revealed several more unique properties of Mrk 231. First, the underlying galaxy is extremely luminous, with $M(K) = -24.7$ in a metric diameter of 32 kpc, making it likely that it is a giant elliptical galaxy, or a less luminous galaxy undergoing a massive burst of star formation. The presence of significant amounts of gas and dust in what may very well be an elliptical galaxy suggests that Mrk 231 may be undergoing an interaction with a spiral or irregular galaxy, as has been proposed for NGC 5128, another dusty and gaseous active elliptical. Secondly, the relative hydrogen line strengths cannot be explained by simple case B recombination and reddening. An anomalously large Paα/Brγ ratio may imply that the electron densities in the broad emission line region are greater than 10^{10}–10^{11} cm^{-3}, but further radiative transfer analyses of the Brackett lines are certainly necessary.

The authors would like to express their thanks to Drs. R. Puetter and C. McAlary for their helpful discussions along the course of this work, to Drs. R. Rudy, J. Stocke, and C. Foltz for kindly making their data available to us before publication and to Drs. R. Thompson and H. Thronson for assistance in obtaining the data. This work was supported by the National Science Foundation.

REFERENCES

Aaronson, M., *et al.* 1982, *Ap. J. Suppl.*, **50**, 241.
Adams, T. 1977, *Ap. J. Suppl.*, **33**, 19.
Adams, T., and Weedman, D. 1972, *Ap. J.* (*Letters*), **173**, L109.
Boksenberg, A., Carswell, R., Allen, D., Fosbury, R., Penston, M., and Sargent, W. 1977, *M.N.R.A.S.*, **178**, 451.
Bothun, G., Mould, J., Heckman, T., Balick, B., Schommer, R. and Kristian, J. 1982, *A.J.*, **87**, 1621.
Condon, J., Condon, M., Gisler, G., and Puschell, J. 1982, *Ap. J.*, **252**, 102.
Condon, J., and Dressel, L. 1978, *Ap. J.*, **221**, 456.
Cutri, R., *et al.* 1981, *Ap. J.*, **245**, 818.
Davidson, K., and Netzer, H. 1979, *Rev. Mod. Phys.*, **51**, 715.
Davis, L. E. 1981, Ph.D thesis, University of Toronto.
Drake, S., and Ulrich, R. 1980, *Ap. J. Suppl.*, **42**, 351.
Dufour, R. J., *et al.* 1979, *A.J.*, **84**, 284.
Freeman, K. 1976, in *Galaxies—Sixth Advanced Course of Swiss Society of Astronomy and Astrophysics*, ed. L. Martinet and M. Mayor (Sauverny: Geneva Observatory), p. 1.
Frogel, J., Persson, S., Aaronson, M., and Matthews, K. 1978, *Ap. J.*, **220**, 442.
Giles, K. 1977, *M.N.R.A.S.*, **180**, 57P.
Graham, J. 1979, *Ap. J.*, **232**, 60.
Heckman, T., Balick, B., and Sullivan, W. 1978, *Ap. J.*, **224**, 745.
Hubbard, E., and Puetter, R. 1984, preprint.
Hummel, E. 1980, *Astr. Ap.*, **89**, L1.
———. 1981, *Astr. Ap.*, **96**, 111.
Hutchings, J., Campbell, B., and Crampton, D. 1982, *Ap. J.* (*Letters*), **261**, L23.
Hutchings, J., Crampton, D., and Campbell, B. 1984, *Ap. J.*, **280**, 41.
Johnson, H., Coleman, I., Mitchell, R., and Steinmetz, D. 1968, *Comm. Lunar Planet. Lab.*, **7**, 83.

Lacy, J., *et al.* 1982, *Ap. J.*, **226**, 550.
Larson, R. B., and Tinsley, B. M. 1978, *Ap. J.*, **219**, 46.
Lebofsky, M. 1981, *Ap. J.* (*Letters*), **245**, L59.
Lebofsky, M., and Eisenhardt, P. 1984, *Ap. J.*, submitted.
McAlary, C. W., McLaren, R. A., and Crabtree, D. R. 1979, *Ap. J.*, **234**, 471.
Osterbrock, D. 1974, *Astrophysics of Gaseous Nebulae* (San Francisco: Freeman).
Persson, S. E., Frogel, J. A., and Aaronson, M. 1979, *Ap. J. Suppl.*, **39**, 61.
Rieke, G. H. 1976, *Ap. J.* (*Letters*), **210**, L5.
Rieke, G. H., Cutri, R., Black, J., Kailey, W., McAlary, M., Lebofsky, M., and Elston, R. 1984, *Ap. J.*, in press.
Rieke, G. H., and Lebofsky, M. J. 1984, *Ap. J.*, **287**, 000.
Rieke, G. H., Lebofsky, M. J., Thompson, R. I., Low, F. J., and Tokunaga, A. T. 1980, *Ap. J.*, **238**, 24.
Rieke, G. H., and Low, F. J. 1975, *Ap. J.* (*Letters*), **200**, L67.
Roche, P. F., Aitken, D. K., and Whitmore, B. 1983, *M.N.R.A.S.*, **205**, 21P.
Rudy, R., Foltz, C., and Stocke, J. 1984, *Ap. J.*, submitted.
Sandage, A. 1972, *Ap. J.*, **173**, 49.
Soifer, B. T., *et al.* 1984, *Bull. AAS*, **16**, 470.
Stocke, J., Tifft, W., and Kaftan-Kassim, M. 1978, *A.J.*, **83**, 322.
Telesco, C. 1978, *Ap. J.* (*Letters*), **226**, L125.
Weedman, D. 1973, *Ap. J.*, **183**, 29.

ROC M. CUTRI, M. J. LEBOFSKY, and G. H. RIEKE: Steward Observatory, University of Arizona, Tucson, AZ 85721