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THE SPECTRUM OF THE CENTRAL LUMINOSITY SPIKE IN M87

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ABSTRACT

A spectrum of the central luminosity spike in M87 has been obtained in 0".75 seeing through a 1" × 1" aperture using the du Pont Reticon Spectrograph at Las Campanas Observatory. A comparison of this spectrum with one taken at $r = 13''$ indicates that less than 20% of the visible and red light comes from a nonthermal component. A Fourier transform analysis of Mg *b* and Na D in the nuclear spectra yields a velocity dispersion $\Delta V = 350 \pm 32$ at an average distance $r \lesssim 0''.35$. These measurements are inconsistent with the 5×10^9 black hole model of Young *et al.* and Sargent *et al.*

A reliable determination of the size of this star cluster is necessary in order to decide if the new data are compatible with models that include a large central mass. A massive black hole ($M \sim 5 \times 10^9 M_\odot$) is consistent with the data presented here if the star cluster is large ($R_{eff} \sim 20$ pc) but is ruled out if the cluster is small ($R_{eff} \lesssim 10$ pc).

Subject headings: black holes — galaxies: nuclei

I. INTRODUCTION

M87 is observed to have a central luminosity spike which appears to be substantially unresolved at 1" (Young *et al.* 1978). Within the core radius of $r \sim 10''$ the velocity dispersion of the stellar component of M87 rises, a behavior unlike the constant ΔV predicted with an isotropic King model (Sargent *et al.* 1978). Young *et al.* (1978) and Sargent *et al.* (1978) (hereafter collectively referred to as Y&S) have fitted their photometric and dynamical data by introducing a $5 \times 10^9 M_\odot$ "black hole" (defined by Young *et al.* 1978) at the center of M87. This mass is sufficient to cause the rise in ΔV from $r = 10''$ to $r = 1''.5$ reported by Sargent *et al.* (1978) and confirmed by Rose and Searle (1980). The large central mass can also explain the departure of the light profile from an isotropic King model in the core, but the spike itself ($r < 1''$) is primarily nonthermal emission (*not* starlight) in the Young *et al.* (1978) model.

This *Letter* presents new dynamical data in the form of a spectrum of the central spike alone, a fivefold improvement in spatial resolution over the Sargent *et al.* (1978) data. The new data, discussed in § II, contradict one feature and one prediction of the Y&S model: (1) the spike is mainly composed of starlight, and (2) the velocity dispersion of the stars fails to rise with decreasing radius as predicted in the Y&S black hole model.

II. THE DATA

A 2000 s integration was taken with the 2.5 m du Pont Reticon Spectrograph at Las Campanas Observatory on 1980 February 10. The spectrum, shown in Figure 1, covers 3300–7000 Å at a scale of ~1 Å pixel^{-1} and a resolution of ~3.5 Å. The seeing was judged by the author to be ~0".75.[1] Acquisition and guiding were done with an aperture-viewing Quantex SEC operated in a real-time mode. The central spike in M87, which contrasted strongly against the galaxy core, disappeared when centered in each of the 1" × 1" apertures used in the observation. The object was alternated between the two 1" × 1" apertures which are separated by 27", with the free aperture collecting sky and M87 starlight (~15% of the object signal). This signal was later subtracted from the spectrum of the central spike. Spectra were also taken with a 1" slit of M87 at $r = 13''$ and a K2 III star, HD 35441, for comparison with the spectrum of the central spike. The spectra were reduced on the PDP 11/34 computer at the Mount Wilson and Las Campanas Observatories using a program written by S. Mochnacki and R. Schommer.

III. INTERPRETATION

a) The Nature of the Spectrum

Figure 1 compares the spectrum of the central spike in M87 to that of the light at $r = 13''$. The spectra contain similar numbers of counts and have been renormalized to the same continuum level in the visible to facilitate the comparison.

The most obvious difference between the two spectra is the presence of broad emission lines in the central spike. The spectrum includes forbidden lines of [O I], [O II], [O III], [N II], and [S II] in addition to the Balmer lines; the relative strengths of these features

[1] A conservative interpretation of this method of judging seeing is that more than 70% of the light in a stellar profile was contained in a 0".75 diameter disk. If the central spike is unresolved and a Gaussian profile is assumed, then more than 90% of the light from the spike entered the 1" × 1" aperture used in the observation.

are indicative of a shock-heated gas (Stauffer and Spinrad 1980). In addition to the more common features, S II (λλ4068, 4076) is seen, and Ne III (λ3968) probably helps Hε fill up the H line of Ca II. The shallowness of the K line and G band (λ4305) are probably due to the contribution of a nonthermal continuum in the blue (~30% at 4400 Å). Because of this dilution of the stellar light by a nonthermal continuum and contamination by the many emission lines, the blue region of the spectrum is poorly suited for determination of the stellar line strength or velocity dispersion.

The Mg *b* triplet (λ5175) and Na D doublet (λ5890) are strong absorption features suitable for the determination of line strength and velocity dispersion (see, e.g., Faber and Jackson 1976) and are uncontaminated by the emission features. Figure 1 demonstrates that the shape of the continuum in the visible and red and the depth of Mg *b* and Na D are identical within the noise in the two spectra. This is strong evidence that there is *very little nonthermal continuum* in the visible and red. If a nonthermal continuum contributed, say, 20% of the light in these regions, then one could explain the similarity of the spectra only by requiring that (1) the nonthermal spectrum have nearly the same color as the stellar continuum, and (2) the line strength γ in the stars increase in proportion to the dilution by the nonthermal source. For example, if half of the light at Mg *b* or Na D were from a nonthermal source, then the line strength in the stars would have to be twice as strong as is normally seen in the spectra of giant ellipticals. The cores of the Na D lines in the stars would have to be nearly black. Since no such stellar population has ever been observed, it seems safe to assume that γ could be at most 40% higher than usual, which limits the contribution of a nonthermal component to $\lesssim$20%.

The spike, therefore, is basically a cluster of stars.

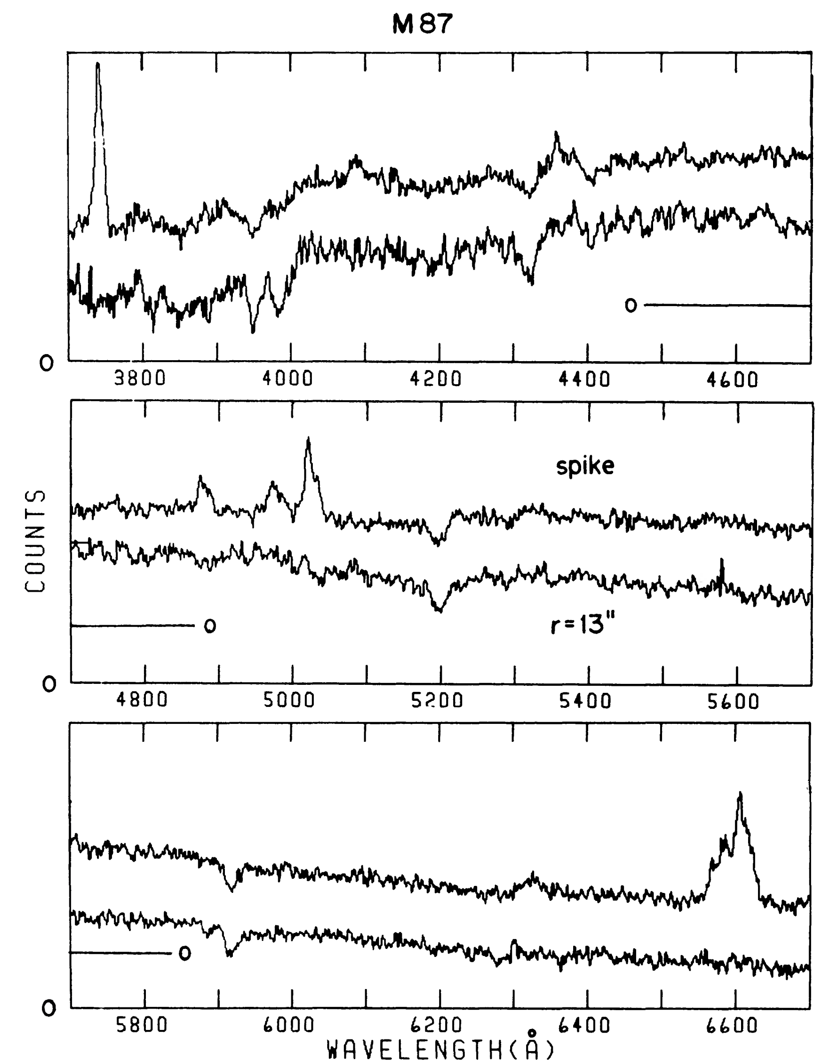

FIG. 1.—The spectra of the M87 central spike and the region at r = 13″. The similarity of the two spectra at Mg *b* and NaD indicate that very little nonthermal continuum is present in the spike. (The M87 spike spectrum has been offset, and a second baseline is indicated.)

The photometry of Young *et al.* (1978) implies $m_v \sim 16.5$ for the spike itself (after correction for the stars along the line of sight), so the cluster has a luminosity $L_v \sim 10^8 L_\odot$. If the cluster had a typical initial mass spectrum, its age is likely to be $\tau \gtrsim 10^9$ years since its light is dominated by K III stars rather than earlier spectral-type dwarfs.

b) The Velocity Dispersion

The spectral regions of Mg *b* and Na D are shown in Figures 4 and 5 for HD 35441, the nucleus of another giant elliptical, NGC 4472, and M87 in the spike and at $r = 13''$. The strong similarity among NGC 4472, M87 at 13", and the M87 spike is easily seen. A Fourier transform technique, discussed in Dressler (1979), was used to determine the line strength and dispersion of the M87 data by comparison with HD 35441. The results are shown in Figure 3. The value of $\Delta V = 275 \pm 23$ km s^{-1} for M87 at 13" is in excellent agreement with Sargent *et al.* (1978). The data for the spike $r \lesssim 0''.35$ were divided into two spectra collected in the two apertures, and the Mg *b* and Na D regions in each were analyzed. These four measurements gave a mean value of $\Delta V = 350 \pm 23$ km s^{-1}. The internal errors of ± 23 must be multiplied by $\sqrt{2}$ in order to account for the uncertainty in comparing these measurements with those on the Sargent *et al.* (1978) system. The excellent fit of these computed models to the data is also shown in Figures 4 and 5.

If the line strength γ for the stars in the spike is normal, that is, the same as in the rest of the core (which is typical of giant ellipticals), then values of $\Delta V > 450$ can certainly be ruled out. Allowing γ to be a free parameter has little effect. For example, if $\Delta V \sim 800$ km s^{-1} in the central star cluster, and if 50% of the light comes from $r \gtrsim 100$ pc ($\Delta V \sim 300$ km s^{-1}, $\gamma_{\rm Mg} \sim 1$, and $\gamma_{\rm Na} \sim 2$), then in order to match the observed depth of Mg *b* and Na D, one must require $\gamma_{\rm Mg} \sim 2.5$ and $\gamma_{\rm Na} \sim 4$ for the $\Delta V \sim 800$ km s^{-1} component. These two components, when combined, yield a model which is virtually identical to the $\Delta V = 600$ km s^{-1} model of Figures 4 and 5, which is a very poor fit to the data. This "minimum hypothesis," therefore, leads to both a poor fit and unreasonable values of γ in the central region. Other models with more of the light in the spike fare even worse.

In summary, the velocity dispersion of the stars in the central spike or star cluster must be $\Delta V \lesssim 600$ km s^{-1}.

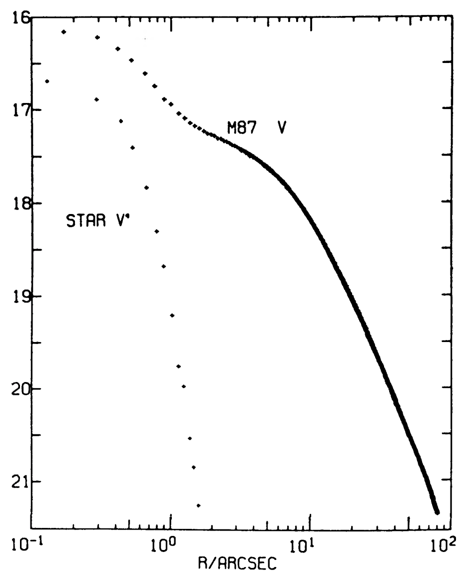

FIG. 2.—The luminosity profile of M87, reproduced from Young *et al.* (1978).

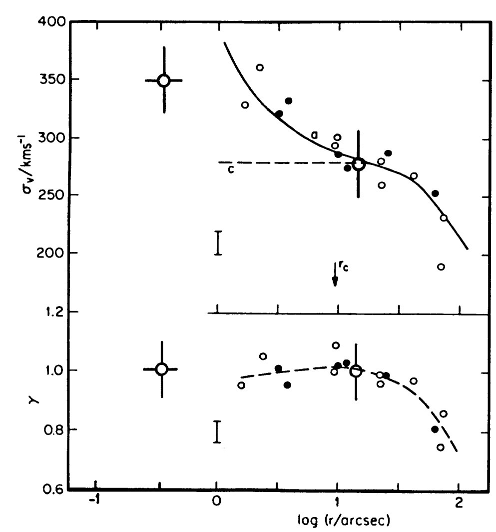

FIG. 3.—The velocity dispersion and line strength data of Sargent *et al.* (1978). The two values found in this study have been added. The solid curve is the Sargent *et al.* (1978) model which assumes a nonthermal spike, and the dashed curve (*c*) represents the isotropic King model. The two new values of γ in the lower panel refer to the Mg *b* region.

c) Discussion

The implications of these new measurements for the black hole model depend critically on the proximity of the stars in the spike to a central massive object. The size of the star cluster that dominates the light of the spike is certainly smaller than $r \lesssim 0''.40$, and speckle interferometry by Boksenberg and Sargent (1980) indicates that a substantial part of the light may be contained within $r \lesssim 0''.02$.

The wide range of central mass distributions consistent with the new data is illustrated by considering two models. In these models, the light distribution of the star cluster is assumed to follow de Vaucouleurs's analytic form and thus to be characterized by an effective radius, $R_{\rm eff}$, which contains half of the light.

If the cluster is large ($R_{\rm eff} \sim 20$ pc; $\Delta V \sim 350$ km s^{-1}) then $M \approx 9.0\, R_{\rm eff}\, (\Delta V)^2/G$ (Rood *et al.* 1972, eq. [8]) implies $M_{\rm cluster} \sim 50$. Any distribution of dark material, including a central, massive black hole, is consistent with this model. Such a massive structure could account for the departure of the light profile and velocity dispersion in the core of M87 ($1''.5 < r < 10''$) from an isotropic King model, as described in Y&S.

If, on the other hand, the star cluster is as small as the speckle measurement suggests ($R_{\rm eff} \lesssim 2$ pc), then $\Delta V \sim 350$ km s^{-1} implies $M_{\rm cluster} \sim 5 \times 10^8 M_\odot$ and $(M/L_v)_{\rm cluster} \lesssim 5$. A massive black hole is thus ruled out. In fact, a black hole massive enough to account for the departures from an isotropic King model can be ruled out if $R_{\rm eff} \lesssim 10$ pc. (The velocity dispersion of the stars within 10 pc of a $5 \times 10^9 M_\odot$ black hole would be $\Delta V \gtrsim 800$ km s^{-1}, which is incompatible with the data presented here.) The star cluster can probably not be smaller than $R_{\rm eff} \lesssim 1$ pc, however, since the extremely high stellar density ($\rho \sim 10^8$ pc^{-3}) results in a relaxation time $t_{\rm rh} \lesssim 10^8$ years (see Spitzer 1975), and the lifetime of dwarf stars against collisions is only $t_{\rm coll} \lesssim 5 \times 10^9$ years. The star cluster is probably older than 10^9 years, as pointed out in § III*a*.

Determination of the size of the star cluster is clearly critical to the development of black hole models. If the star cluster has an effective radius smaller than 10 pc, then less than $10^9 M_\odot$ resides in this region. A less-massive black hole could still have a significant effect on the structure, dynamics, and energetics of M87, but could not account for the departure of the light profile and velocity dispersion from the predictions of an isotropic King model. Duncan and Wheeler (1980) has suggested that anisotropic models might explain this behavior.

IV. CONCLUSIONS

The spectrum of the central luminosity spike in M87 is composed mainly of light from stars with a velocity dispersion $\Delta V \sim 350$ km s^{-1}. These data are

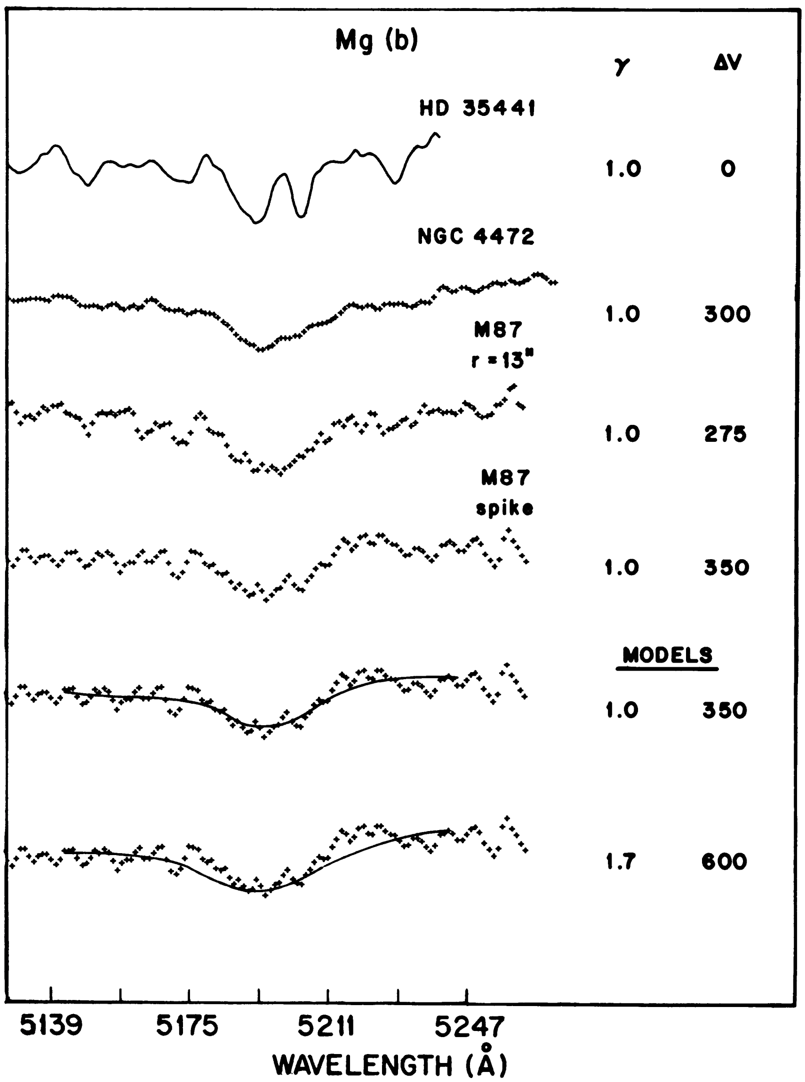

FIG. 4.—A comparison of the Mg *b* region in a star, NGC 4472, M87 at 13″, and the M87 spike. Appropriate values of γ and ΔV are indicated. The good fit of the M87 spike to the standard star broadened to $\Delta V - 350$ km s^{-1} is shown, as well as the excluded $\Delta V = 600$ model. (The wavelength scale refers to the M87 data.)

inconsistent with the Y&S model of a $5 \times 10^9 M_{\odot}$ black hole in the center of M87. A reliable measurement of the size of the spike is necessary to determine if a central mass large enough to account for the departures of the light profile and velocity dispersion from an isotropic King model could be present. If the central star cluster has a characteristic size $R_{\rm eff} \sim 20$ pc, such a large mass ($M \sim 5 \times 10^9 M_{\odot}$) is dictated by the velocity dispersion of the stars. However, if the spike is as small as Boksenberg and Sargent's speckle interferometry suggests ($R_{\rm eff} \lesssim 2$ pc), then a large mass ($M > 10^9 M_{\odot}$) is ruled out. The lifetime of such a cluster, as indicated by its relaxation time ($\lesssim 10^8$ years) and star-star collision time ($\lesssim 5 \times 10^9$ years) may be uncomfortably short. An intermediate size for the cluster (2 pc $\lesssim R \lesssim$ 10 pc) would also exclude the possibility of a massive black hole, but would have dynamical time scales like those of many globular clusters.

Stellar spikes of various sizes seem to be a not too uncommon phenomenon in the nuclei of galaxies, as evidenced by M31, M87, and NGC 5102 (Pritchet 1979). Further study of these structures may disclose something of the nature of star formation at the centers of galaxies, since at least one of these examples (NGC 5102) contains a young stellar component.

It is a pleasure to thank Stephen A. Shectman for his valuable insights, and Peter J. Young and Leonard Searle for several useful discussions.

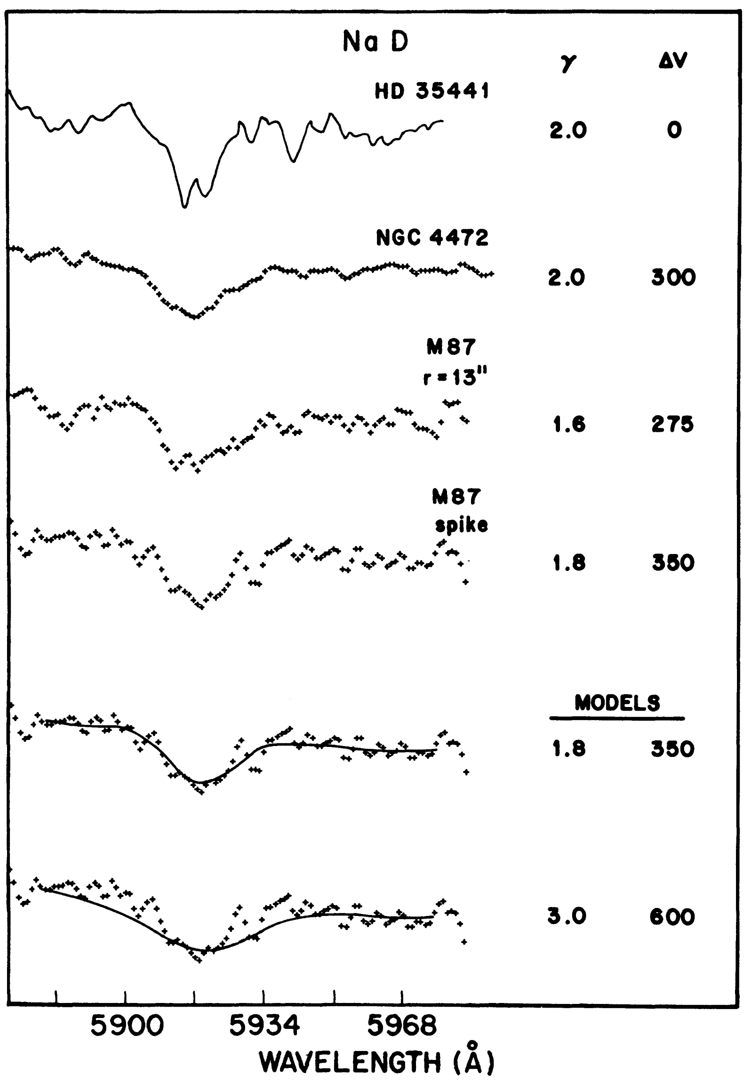

FIG. 5.—Same format as Fig. 4, for Na D

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