Deepest Mid-Infrared Image Throws Doubt on Structure of Active Galaxies

Eric S. Perlman {1,2}, William B. Sparks {3}, James Radomski {4}, Chris Packham {4}, John Biretta {3}, & R. Scott Fisher {5}

Due to the difficulties connected with observing in the mid-infrared, the thermal emissions from active galactic nuclei (AGN) are extremely poorly understood. Yet understanding these same emissions must be considered one of the most important goals for ground-based and upcoming space telescopes which can observe at $\lambda \cong$ 5-30 μm.

Most theorists believe that AGN have a structure consisting of several elements, as shown in Figure 1: a supermassive black hole, orbited by an accretion disk (which radiates in the ultraviolet and X-ray) in its equatorial plane, a dusty region which both obscures high-energy emission and reradiates the energy in the infrared, energetic emission line regions where both broad and narrow emission lines in the optical and ultraviolet are generated. In addition, in radio-loud objects, which comprise about 15% of AGN, one sees powerful jets streaming out at nearly the speed of light. In this model, often called the "unified scheme", the properties of a given object depend strongly on the observer's viewing angle. Several components of this structure are believed to occur in galactic black-hole binary systems as well. However, in AGN, one has the extra task of separating these elements from normal galactic emissions.

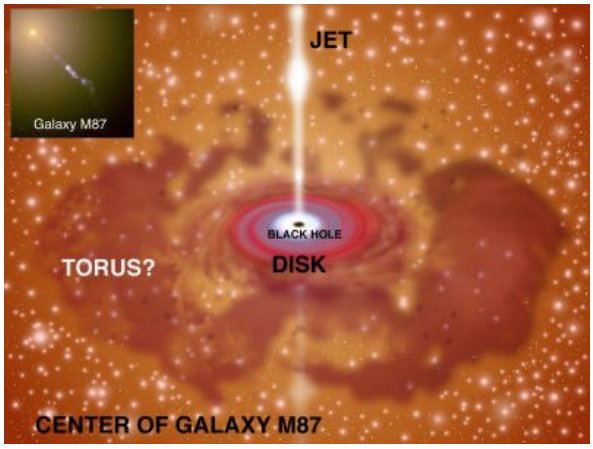


Figure 1. Illustration of a supermassive black hole.

Mid-Infrared observations of AGN give us the opportunity to throw light on the most elusive part of the AGN structure, the obscuring regions. This obscuring region is often called the torus, after the morphology ascribed to it by unified schemes, which also predict a rough size scale of 10^5 - 10^6 times the radius of the black hole's event horizon. Due to its small size, the torus region of an AGN has never before been resolved, so that its real morphology and geometry are not constrained.

It was in the hope of actually resolving the torus region that we observed M87 at a wavelength of 10.8 microns with the Gemini Observatory 8m telescope. M87 is the nearest giant elliptical galaxy, at a distance of 16 megaparsecs, and also the nearest and brightest object with a bright relativistic jet that is seen in the radio, optical and X-rays. Previous observations with the Hubble Space Telescope have revealed that its central black hole is particularly massive: about 3 billion times the sun's mass. The combination of an extremely massive black hole and its small distance would predict that emissions from the torus could be seen at radii of between 0.3-3 arcseconds.

{1} Department of Physics, Joint Center for Astrophysics, University of Maryland-Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, USA. email perlman@jca.umbc.edu

{2} Department of Physics and Astronomy, Johns Hopkins University, 3400 North Charles Street, Baltimore, MD 21218, USA

{3} Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA

{4} Department of Astronomy, University of Florida, 211 SSRB, Gainesville, FL 32611, USA

{5} Gemini Observatory, 670 N. A'ohoku Place, Hilo, HI 96720, USA

We observed M87 on 3 and 10 May 2001 with Gemini-North, using OSCIR, the University of Florida' mid-IR imager/spectrometer. We used a broad filter, centered at a wavelength of 10.8 microns with a bandpass width of 5.3 microns. Because of the small size of the OSCIR detector, we used two pointing centers, to capture emission from the nucleus and jet regions respectively. To subtract out the extremely high (thermal) sky background, which dominates mid-IR observations, we employed the usual strategy of chopping and nodding to a blank field. The observations required seven hours of telescope time, of which five were spent at the nuclear position and two at the jet position.

Figure 2 shows the final, mosaiced Gemini image. For comparison, we also show in Figure 2 images of the M87 jet taken by the VLA (radio) and the Hubble Space Telescope (optical). As can be seen, the very high sensitivity and angular resolution (~0.45") of Gemini have allowed us to for the first time resolve the nucleus of M87, as well as several regions of the jet (labeled on Figure 2). In Figure 3, we show a graph comparing the radial profile of the nucleus of M87 to that of a nearby star, observed the same nights under the same sky conditions. Figure 3 shows that the nucleus of M87 appears to be surrounded by a faint nebulosity accounting for about 7% of the total nuclear flux.

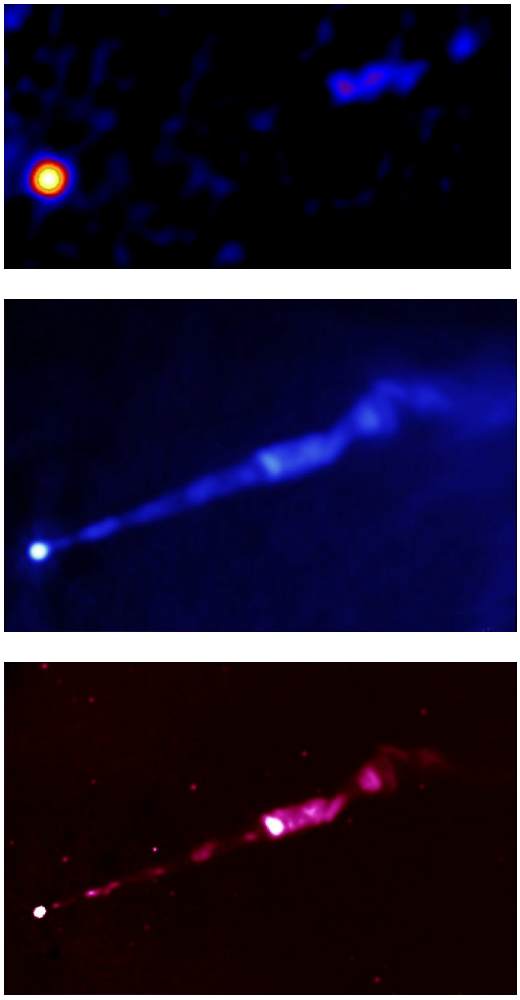


Figure 2: The mosaiced Gemini image (top); a VLA radio image (middle); and an HST optical image (bottom).

Until very recently, mid-infrared observations of M87 had only been able to detect (but not resolve) a faint flux, which included contributions from various nuclear regions, the jet and probably also galactic components such as dust and stars. This mid-IR image of M87 is about a factor of 10 deeper than one taken by the Keck Observatory in 1999, which was recently published by D. Whysong and R. R. J. Antonucci of the University of California, Santa Barbara. The Keck image did not show jet emission and also was not deep enough to resolve the nucleus.

In order to figure out the nature of each emission component, it was necessary to compare the fluxes we detected with those seen in other wavebands. For the nuclear emission, we believed it was possible that several emission components could exist, including stars, synchrotron radiation from the innermost regions of the jet, and warm dust in the torus. Fortunately, each of these components would have a very different broadband spectrum. While the overall shape of stellar and torus emission might be similar, their temperatures would be very different: thousands of degrees for stellar emission compared to a few hundred degrees for dust emission. Synchrotron

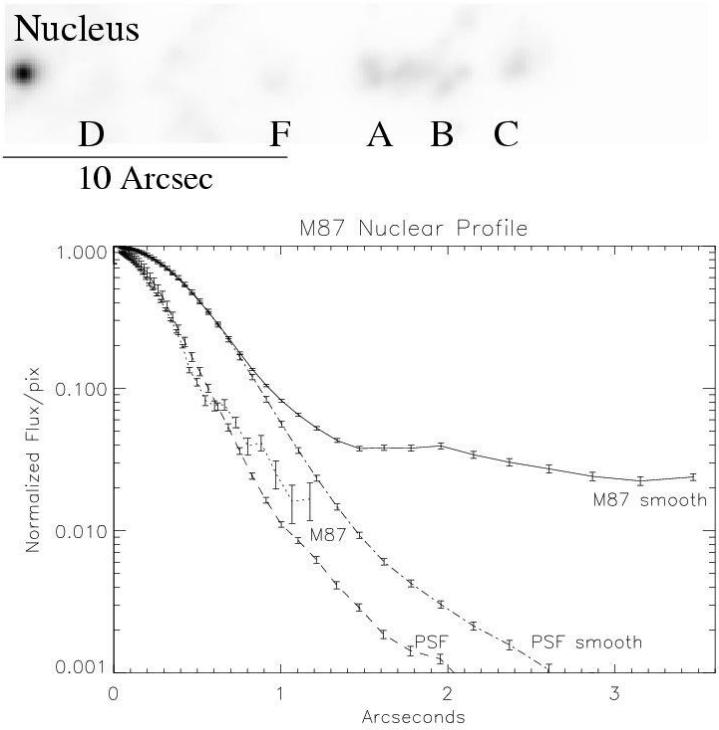


Figure 3. A plot comparing M87's radial profile to that of a nearby star.

emission, by comparison, extends over a much larger range of frequencies, and has a characteristic, nearly power-law shape.

We compared the fluxes of each component to those observed in the radio, optical and X-rays. As expected, the mid-infrared emissions of each jet region we detect agree well with the predictions of synchrotron radiation. But surprisingly, the mid-infrared emissions of the nucleus agree extremely well with the prediction of a synchrotron radiation model fit to the previous radio, optical and X-ray flux measurements. Thus, any thermal emission due to warm dust in the torus must account for only a small fraction of the observed nuclear flux. It is possible that the faint extended emission could be due to torus dust; however, our current image is not deep enough to decipher the origin of this emission, which could also be from galactic stars or dust. Images in additional bands would also help, as they would allow us to fit a rough mid-infrared spectrum.

The Gemini data allow us to set an upper limit on the mid-infrared luminosity of the torus, which is orders of magnitude lower than that observed in other objects. For example in Cygnus A and Centaurus A, two other radio galaxies, the ratio of torus luminosity to jet luminosity is about 1000 times higher. Each of those objects show a tremendous excess of nuclear mid-infrared luminosity over the predictions of synchrotron models. Yet in all other bands, M87 appears intermediate in luminosity between Cygnus A and Centaurus A. Thus the torus of M87, if it exists, must contain far less material than that of either Cygnus A or Centaurus A.

The lack of bright torus emission from M87 in the infrared has important implications for our view of the inner regions of AGN. Is there a class of AGN which do not have significant amounts of obscuring material in their inner regions? If so, what are the characteristics of these objects and how do they differ from other AGN? These questions cry out for deep, high angular resolution mid-IR observations of a large sample of AGN. As a telescope which is optimized for infrared observations, Gemini can make a unique contribution in this area. While R. R. J. Antonucci and his group are already conducting a mid-IR survey of 3CR radio galaxies with the LWS instrument on Keck, the example of M87 shows that those observations will not be deep enough to constrain well the dust emissions from AGN which have either very faint tori or none at all.