VII. COMPARISONS OF OUR GALAXY WITH OTHER GALAXIES

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THE GALACTIC NUCLEUS COMPARED TO THOSE OF OTHER GALAXIES

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ABSTRACT: Observations at various wavelengths are considered for extragalactic nuclei and are compared to how our galaxy would appear at comparable distances. The starlight from our nucleus is similar to that from the spirals in the Virgo Cluster. Our nucleus would show no sign of activity to a distant observer, neither unusual color, nor emission lines, nor excess infrared radiation. For example, the luminosity in Hβ emission is about 10^{38} ergs s^{-1}, which is 100 times fainter than that in the faintest Seyfert galaxy or emission line galaxy. It is also emphasized that there is no evidence from X-ray data for a massive, condensed object in the Galactic nucleus.

I. INTRODUCTION

This review is painful for an observer, because the observations of the nucleus of our own galaxy are so good that most of them have to be thrown out. In order to measure our own nucleus with absolute resolution comparable to that obtainable even for M31, we would need, for example, 21 cm observations with a 5 foot telescope. For optical observations, we have only a few results for the nuclei of other galaxies with 1" resolution; this corresponds to 100 pc at 20 Mpc, the nominal distance of the Virgo Cluster. 100 pc in our own nucleus would subtend 34'. There are excellent observations at many wavelengths that map our nucleus on a much finer scale than this, as reviewed comprehensively by Oort (1977). Because of the vastly different scales observed, it is rarely clear just what is meant by a "galactic nucleus". It won't be clear in this paper, either. Table 1 illustrates the different scales implied by references to various sorts of "galactic nuclei". For conciseness, the nucleus of our Galaxy is referred to as the GN.

II. STARS

One of the more reasonable comparisons that can be made is between the starlight from the GN and that from comparable regions in other galaxies. A substantial amount of small aperture photometry

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TABLE I

Scale Sizes of 'Galactic Nuclei'

Source	Absolute size
GN(infrared)	1 pc
GN(Sag. A)	10 pc
GN(thermal radio)	100 pc
Seyfert Nucleus	0.1 pc - 1000 pc
M31 Nucleus	10 pc
Nuclear magnitude (Virgo)	1000 pc

exists for galaxies giving what are termed "nuclear magnitudes". From the distribution of 2.2μ light, Oort (1977) deduced a table of the stellar mass contained within various distances from the GN, assuming $M/L_V = 15$. This tabulation can be transformed to give the absolute magnitude of the GN within a given diameter. For comparison, the most complete data set for nearby galaxies is Tifft's (1969) photometry of Virgo Cluster galaxies, done with apertures as small as 9".7. Comparing the GN to those in Virgo depends on the adopted Virgo Cluster distance modulus. Results are given in table 2 for two alternatives. One adopts the Sandage-Tammann modulus of 31.5 (corresponding to $H_o = 55$ km s^{-1} Mpc^{-1}); the other uses the modulus 30.5 ($H_o = 85$ km s^{-1} Mpc^{-1}) preferred by several workers and most recently defended by Hanes (1977). (We have ignored small Galactic absorption corrections). For each modulus, table 2 shows the m_V that would be observed for the GN at that distance using an aperture of 1 kpc projected diameter, taking the mass within a 500 pc radius from Oort's table. The alternative aperture sizes, for the different moduli, are 16" and 10". Fortunately, these correspond to apertures used by Tifft (1969) to observe Virgo galaxies. His results are given in table 2 for all spirals which he observed that are considered by de Vaucouleurs and de Vaucouleurs (1973) to be Virgo Cluster members.

These results show that the nuclear magnitude of our Galaxy is certainly comparable to Virgo spirals, and the values are closer for the lower distance modulus. For now, this is not meant as a meaningful statement on the value of H_o, but it might someday be an interesting approach. In table 2, the GN most closely resembles NGC 4192 (SABab), 4421 (SBa) and 4651 (SAc).

III. GAS AND DUST

We know from 21 cm, high level recombination line, molecular and continuum radio emission that there is a substantial amount of gas in the GN. While there are many interesting details of this radio emission, the radio power of the GN is weaker than that detected from the nucleus of any other galaxy except M31 and M101 (Ekers 1974). The

Table II

Magnitudes for Central kpc of GN and Virgo Spirals

	m - M = 30.5 m_v(16")	m - M = 31.5 m_v(10")
NGC 4192	13.2	13.7
4216	12.1	12.7
4254	13.1	13.9
4321	12.7	13.5
4421	13.5	14.0
4450	12.7	13.2
4501	12.6	13.2
4535	13.9	14.3
4548	13.0	13.6
4569	12.2	12.6
4651	13.2	13.8
4654	14.0	14.7
Virgo mean	13.0±0.6	13.6±0.6
GN	13.4	14.4

most effective technique for optical detection of gas in galactic nuclei is looking for emission lines. In this respect, how would our nucleus appear? To decide, it is necessary to know the amount of ionized gas in the GN. From observations of H109α, Pauls, Mezger and Churchwell (1974) deduced that the highest density ionized gas is in Sgr A West, which they conclude has M(HII) ≃ 600 $M_\odot$ and $N_e \simeq 1.4 \times 10^3 cm^{-3}$. They also decided that if the extended H 109α emission comes from H II, there is ~ $10^4 M_\odot$ with N_e ~ 200. (Wollman et al. 1977 concluded that ~ $10^2 M_\odot$ of H II was needed to explain the [Ne II] 12.8μ emission line.) This entire H II complex has an extent of about 4' so it would be unresolved in an extragalactic system. Knowing the volume, density and temperature of an H II region, the total Hβ emission can be calculated (Osterbrock 1974). For a T_e of 6000°K deduced by Pauls et al., Osterbrock's table for case B interpolates to an Hβ emissivity of $1.6 \times 10^{-26} N_e^2$ ergs cm^{-3} s^{-1}. Therefore, the complex of gas responsible for the H 109α emission would produce an Hβ luminosity, L(Hβ), of 5×10^{37} ergs s^{-1}. There could also be Hβ emission from a much lower density but more extended ionized gas producing the thermal radio continuum. This gas fills a volume of 260 x 90 pc with a mean N_e = 16, if the 3.75 cm continuum is all thermal in origin (Oort 1977, table 4). Were such gas of comparable temperature to that producing H 109α, it would have L(Hβ) = 6×10^{38} ergs s^{-1}. Therefore, on a scale size of 100 pc - like that observed for the nuclei of other galaxies - the GN would have 5×10^{37} ergs $s^{-1} <$ L(Hβ) $< 5 \times 10^{38}$ ergs s^{-1}.

Compared to many other galaxies, this is very weak emission. The faintest Seyfert nuclei or emission line galaxies from the Markarian and Tololo lists have L(Hβ) ≃ 10^{40} ergs s^{-1} (Weedman 1977); the brightest Seyferts have L(Hβ) ≃ 10^{44} ergs s^{-1}. The faintest emission line measured in the nucleus of another spiral galaxy would correspond to L(Hβ) = 2 x 10^{38} ergs s^{-1}, for M81 (Peimbert 1968). Even here, the Hβ is not visible - only deduced from the Hα strength. Given that there seems to be plenty of H I (about $10^7 M_\odot$) in the GN, the lack of ionized gas has to be caused by a deficiency of ionizing photons. The L(Hβ) limits calculated above could be accounted for by 17 to 170 main sequence 07 stars. (This comes from the relation $N_* = 3.4 \times 10^{-37}$L(Hβ) in Osmer, Smith and Weedman 1974.) Krugel and Tutukov (1978) recently carried through a detailed synthesis of the GN in order to reproduce the observed infrared data. The infrared radiation is attributed to a combination of that from 4000°K giant stars and that from dust heated by the ultraviolet radiation from 06 V stars; the relative contributions depend on the wavelength observed. Their model requires about 100 such O stars within 50 pc radius from the GN, comparable to that deduced from our L(Hβ). In a review of their observations, Mezger, Churchwell and Pauls (1974) decide that the total thermal radio emission from a 300 pc by 150 pc volume in the GN, including giant H II regions embedded in a lower density extended H II region, could be accounted for by the ionization from 77 06 stars. All these estimates indicate that at the distances of galaxies beyond the local group, the GN would not show emission lines or an unusually blue continuum in the visible spectrum. The rate of star formation in the GN is orders of magnitude lower than that in objects called "active galaxies".

In the early days of infrared astronomy, radiation at far infrared wavelengths (λ≥10μ) was sometimes attributed to exotic non-thermal mechanisms, but it is now considered that in most cases this radiation is from heated dust. This heating arises primarily from absorption of ultraviolet photons. A small core about 1 pc (20") in diameter stands out at 10μ in the GN (Becklin and Neugebauer 1969). This is superposed on a more extended source whose extent is not well determined because of the limited chopper throw of infrared telescopes. Consequently, it is difficult to compare the 10μ luminosity of the GN with that observed for other galaxies. Aumann and Low (1970) feel that the far infrared luminosity of the GN arises within a diameter of less than 3' and assign the GN a 10μ flux of 10^3 Janskys. The most extensive data for other galaxies is in Rieke and Lebofsky (1978) who observed with a 5".7 beam. An important result is that M31 has an absolute 10μ flux that is a factor of ten fainter than the GN; in fact, all of the 10μ radiation from the nucleus of M31 can be explained as starlight. Because the absolute diameter observed at 10μ for M31 would correspond to 6'.6 at the GN, this result for M31 indicates a real and important difference between the GN and that of M31. However, the difference can be accounted for by the O stars in the GN which are needed anyway to explain the presence of ionized gas. The only galaxy detected with an absolute flux at 10μ comparable to that of the GN is NGC 3031. All of the other normal spiral galaxies detected at 10μ

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Table III
Some Normal Spiral Galaxies Detected at 10μ

Galaxy (NGC)	3627	4258	4303	4536	4569	4736	4826	5055
Type	Sb	Sbc	Sbc	Sbc	Sab	Sab	Sab	Sbc
Flux Ratio*	58	40	330	840	400	50	34	64

*This gives the ratio of the absolute 10μ flux of the galaxy listed to that of the GN, using the distance and detection in Rieke and Lebofsky (1978).

have much brighter absolute fluxes, as shown in Table 3. Therefore, while the GN is sometimes cited as part of an "infrared galaxy phenomenon", the activity in the GN is very mild compared to some other spiral galaxies.

IV. BLACK HOLES?

Existing X-ray observations are especially important because they show that there is not an X-ray source in the GN. Though there is an X-ray source centered about 20' from the GN (Giaconni et al. 1974), and known as GCX, this is an extended source (Kellogg et al. 1971). From the Uhuru catalog (Giaconni et at. 1974), it is possible to estimate the limit on luminosity for any discrete X-ray source in the GN. The catalog limit corresponds to about 2×10^{-11} ergs $cm^{-2}s^{-1}$ in the 2-6 kev band for representative spectra. Therefore, any source at the GN has an X-ray luminosity less than 2×10^{35} ergs s^{-1}. This is a factor of 10 to 100 fainter than the X-ray sources identified in some globular clusters (e.g. Cominsky et al. 1977, Clark, Markert and Li (1975). The X-ray sources associated with the nuclei of Seyfert galaxies approach 10^{45} ergs s^{-1} (Tananbaum et al. 1978). Lightman, Giaconni and Tananbaum (1978) analyze the properties needed for a hypothetical black hole to explain the X-ray emission from the Seyfert NGC 4151. They conclude that $0.07L_{44} < M_7$ where L_{44} is the X-ray luminosity in units of 10^{44} ergs s^{-1} and M_7 is the black hole mass in units of $10^7 M_\odot$. For analogous circumstances in the GN, the luminosity limit would require a black hole mass less than $1.4 \times 10^{-3} M_\odot$. A rule of thumb for energy generation by black hole accretion, derived from the Eddington limit whereby the energy released acts against further accretion, is 10^{38} ergs s^{-1} per accreting solar mass. This gives a limit for a GN black hole of $2 \times 10^{-3} M_\odot$. These limits, while very uncertain, do indicate that there is no evidence from X-ray astronomy of a significant accreting object in the GN. In this case, the absence of evidence is meaningful evidence of absence, because there seems to be sufficient interstellar matter in the nucleus to power accretion. Knowing confidently that our galactic nucleus does not contain a dormant black hole would rule out suggestions that all galaxies once went through a quasar or Seyfert stage, powered by a massive black hole.

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DISCUSSION

Sanders: Can you exclude the possibility that our Galaxy is a Seyfert for about 2% of the time?

van den Bergh: Dr. Sanders' suggestion that galaxies might become Seyferts for a short time every $\sim 5\times10^6$ years can be excluded because about half of all Seyferts have a peculiar "washed out" spiral structure. This suggests that typical Seyferts have been in their "on" stage for a period comparable to, or longer than, their rotation period ($\sim 10^8$ yr).

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