Chapter 3

What is the Nature of the Center of the Galaxy?

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IS THERE A COMPACT CENTRAL MASS CONCENTRATION IN OUR GALAXY?

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1. Introduction

Since the center of our own galaxy is the closest region of this type, it should provide a proving ground for our understanding of such regions. And fortunately, recent developments in radio, infrared, and x-ray astronomy allow us to look at the center of our galaxy in considerable detail – a privilege not possible in the visible region because of the rather dense dust clouds surrounding it. We find there many complex and interesting phenomena, including evidence for a compact central mass of a few million solar masses from the dynamics of stars and gases. However, its existence has been doubted because the radiant energy coming from the very center is much less than normal theoretical expectations for a black hole of such a mass. This discrepancy has led to speculation whether the velocity measurements could be misleading, whether the concentrated mass is in some form other than the expected black hole, whether the radiation might be taking place in an exotic form, being directed away from us or happening to be low at the moment, or whether our theories of such radiation are as yet incomplete. The general characteristics of the very central region of our galaxy will be reviewed along with the dynamic evidence for a large concentrated mass and comparison of the radiation it emits with that of various theoretical models.

2. The Central Region of our Galaxy and Sgr A*

Radiation from the center of our galaxy was first seen in the radio region in 1932 by Jansky (1932), but it was only in the recent few decades that the growing fields of radio interferometry and infrared astronomy have allowed

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us to see details of composition and structure in this region. Plate 1 provides high resolution radio maps of the region made with the VLA, showing four panels of different intensity levels. The blue color is used to indicate synchrotron type radiation and red color for thermal radiation from ionized gas. At the lowest exposure, the intense point source known as Sagittarius A* shows up very prominently. This point source is a strong candidate for a black hole, and is possibly the heavy black hole indicated by dynamical measurements. However, its radiated intensity is orders of magnitude weaker than first expectations for such an object.

Surrounding the ionized region of Plate 1 is relatively warm molecular gas, of temperature about 200-300K. Figure 1 shows a map by Güsten et al. (1987) of the HCN $0 \rightarrow 1$ transition in this warm, dense, and clumpy gas. Large variations in density are indicated on the map. The dark central region in its center contains very few molecules, but is occupied by the ionized gas shown in Plate 1 along with some atomic material. At increasing radii from the center of the galaxy, the HCN radiation fades out. This does not mean that no HCN is present, but rather that the temperature and densities are too low for this particular transition of HCN to be strongly excited. In fact, clumpy clouds and somewhat turbulent motion continue for some distance from the center, as shown by observations of CO and other molecules.

The hole in the center of the molecular cloud immediately raises the question as to how it was formed. The energy required to form it has been estimated to be as large as about 10^{53} ergs. While the clouds containing HCN are in general circulating around the center, they do not all move at the same speed, and hence should collide with each other and make a more uniform motion and distribution after a period of time of about 100K years. Hence, some very energetic phenomenon must have occurred within the last 100K years, quite possibly the same one which produced the central hole. While this may immediately suggest infall of material into a black hole and a subsequent explosion, it might instead be due to a series of supernovae, or an intense starburst.

Sagittarius A* is unique in our galaxy in terms of its intensity and radio characteristics, and has been intensively examined since its discovery. Rogers et al. (1994) have found it's size to be about 1.4×10^{13} cm at 3 mm wavelength. Position measurements over a period of about 10 years shows that is velocity across the field of view is smaller than about 15km s^{-1} (Backer, 1994). This rather low velocity, compared to the velocity of the many stars nearby of about 150 km s^{-1} or more, indicates that it must be substantially heavier than the average such star. The probability of its having such a low cross-field velocity is less than about 1% if its mass is equal that of the average nearby star, but about 25% if its mass if 40 time

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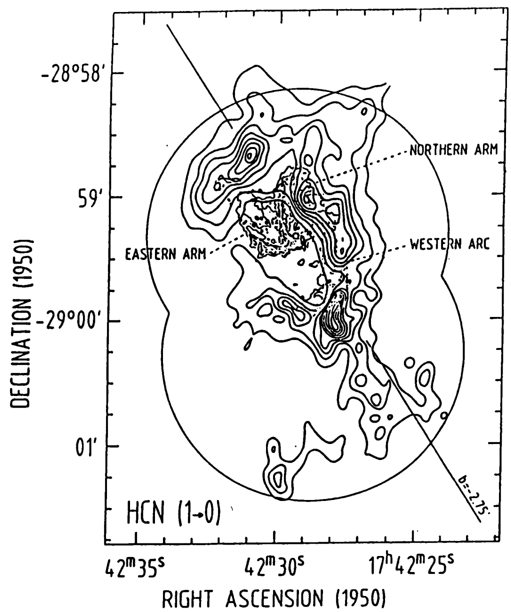

Figure 1. **A map of the HCN 1 → 0 transition, with contours representing successively higher intensity, superimposed on thin-line contours of the radio continuum. The latter is intense in the central hole where there is no HCN radiation and also borders the cloud of molecular gas surrounding the hole. (After Güsten et al., 1987).**

larger. Thus, one can say that its mass is large, but while it may indeed by very massive, there is no overwhelming case that its mass is larger than a star of some tens of solar masses. Clearly it is a special object from the point of view of its characteristics and its location, which is not further from the exact dynamic center than a couple of arcsecs, the probable error in such a determination. It is a strong candidate for the putative massive black hole.

Considerable effort has been directed towards detecting Sgr A* in the infrared, since an accreting black hole is expected to radiate strongly in the infrared. Eckart et al. (1993) have succeeded in obtaining excellent resolution of an object coinciding in position with Sgr A*, as shown in Figure 2. The object appears to have an effective temperature about 35,000K, a luminosity of $10^{5.4\pm.5}$ $L_\odot$ (Eckart et al., 1993), and is elongated. However, there are enough bright stars in the vicinity to make some of the apparent elongation and even any certain identification with Sgr A* open to some question in the absence of other identifying characteristics because of the possible coincidence of other stars.

Nearby phenomena also indicate something special about Sgr A*. Figure 3 shows a map of radio radiation around the infrared star IRS 7, which is

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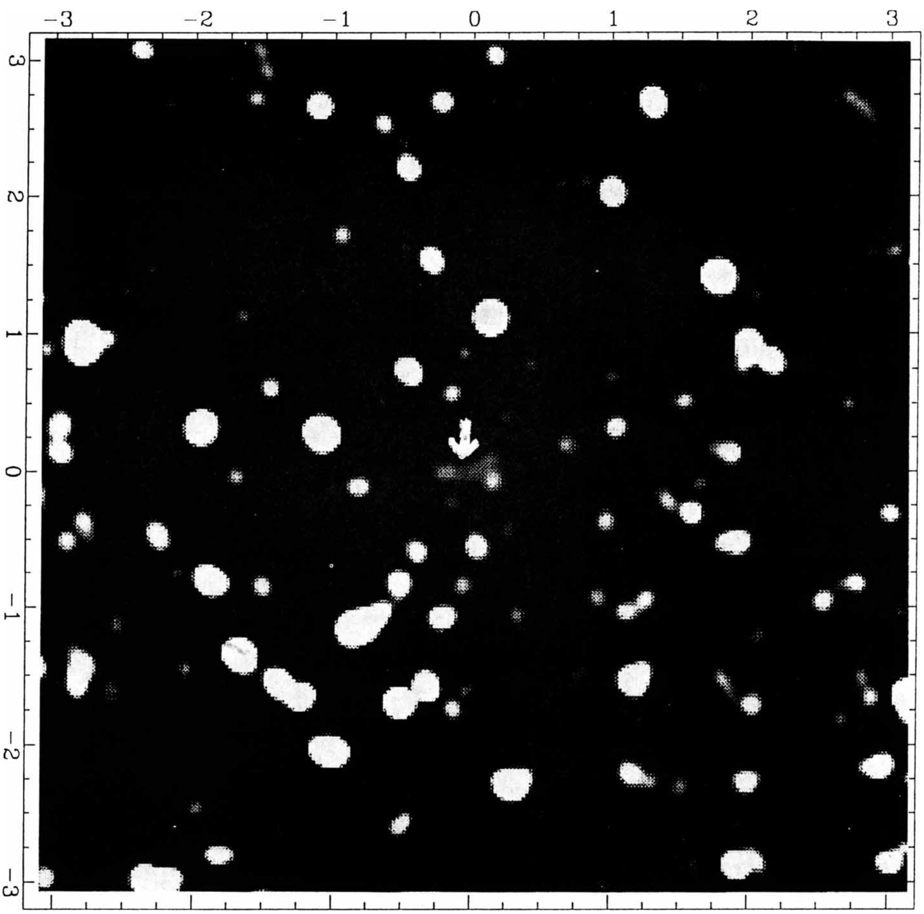

Figure 2. A high resolution near IR image of the galactic center showing an elongated object (marked by arrow) at the position of Sgr A*. Resolution is approximately 0.15 arcsec. (Courtesy Eckart, A., Genzel, R., Hofmann, R., and Tacconi-Garman, L.E.).

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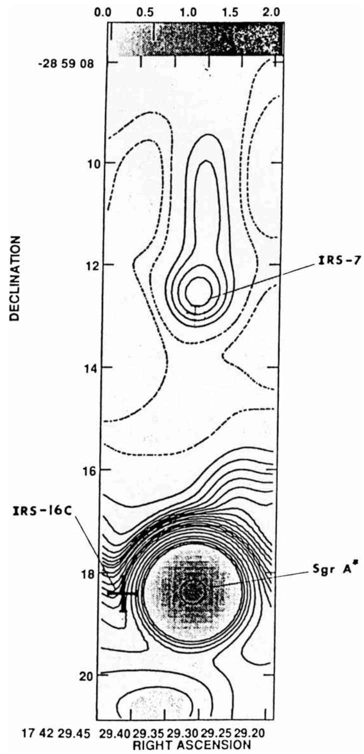

Figure 3. **IRS7 and the vicinity of Sgr A* at 2 cm wavelength. The intensity contours show a tail on the star IRS7 pointed away from Sgr A*, indicating a wind from the direction of the latter source (Yusef-Zadeh and Morris, 1991).**

near Sgr A*. There is a tail of material leaving IRS 7 pointing exactly away from Sgr A*, and hence indicating a strong wind from that object. Figure 4 shows what is known as the "minicavity" in nearby ionized material. This represents a remarkably circular region low in ordinary ionized material. Its opening is not precisely in the direction of Sgr A*, but velocities in the region may have moved this "minicavity" about 2 arcsecs in a few hundred years. Hence it might have been more centered on Sgr A* not too long in the past.

Figure 5 is a cartoon to provide an overall view of the central region. This shows the circulating molecular clouds, the hole in the center, Sgr A*, ionized streamers, IRS7 and its tail, the "minicavity", and an aggregate of some rather unusual bright blue stars very near the center. Many of these stars are rich in helium and emit stellar winds of velocities near 1000 km s^{-1}. Clearly, they are short-lived, and their type is very rare in any region far from the galactic center.

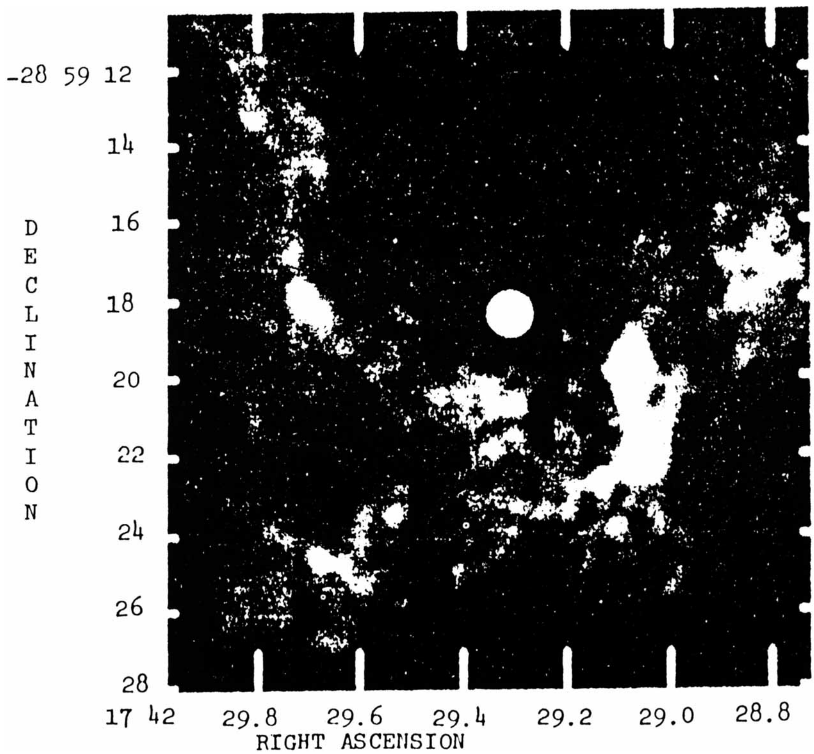

Figure 4. The "minicavity" , a circular pattern with an opening, in the radio continuum radiation (at 2 cm) near Sgr A*. The latter point source is the bright circular object near the "minicavity" (Morris and Yusef-Zadeh, 1987).

3. Dynamic Evidence for a Strong Central Gravitational Field

While some of the features already discussed certainly suggest that Sgr A* may be a massive black hole, the evidence discussed so far is only qualitative and not conclusive. More specific evidence comes from dynamics of the region. Initial measurements of velocities of ionized gas near the galactic center were made by a several students at Berkeley, including Lacy and Serabyn who have also done more recent work of this type (Serabyn et al., 1985). The fine structure transitions of the ground state of NeII and AIII were first measured, since they provide convenient lines in the ionized material from which excitation temperature and densities as well as velocities can be determined. Other measurements have been made of hydrogen recombination lines (Roberts et al., 1993) at radio frequencies and of the Brγ line (Herbst et al., 1993). Figure 6 shows positions where velocities of NeII were measured by Serabyn et al. (1985). These include an examination of the ionized ellipse which is clearly evident on the western side of the cavity

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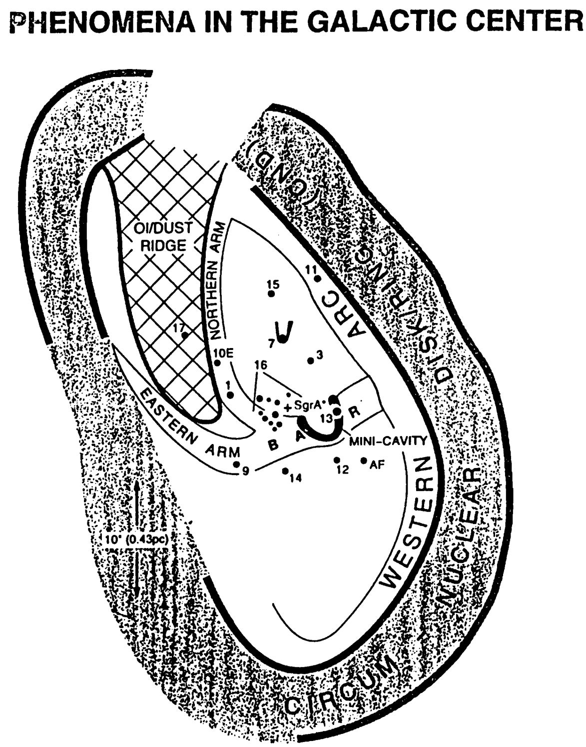

Figure 5. A cartoon diagram showing phenomena near the galactic center, including the circumnuclear disk of molecular gas, the ionized western arc, and eastern and northern arms. The northern arm is probably part of an atomic cloud shown to the east of it. Also shown are the radio point source Sgr A*, IRS7 and its ionized tail, the "minicavity" in ionized gas, and a number of bright stars. Distance from top to bottom of the circumnuclear disk shown here is approximately 65 arcsec, or 2.7 pc. (After Genzel and Townes, 1994).

and which can be traced somewhat further around the center, and even more detailed measurements of the "northern arm", or streamer running north and south within this cavity. Figure 7 is a plot of velocities in this elliptical structure as a function of north-south displacement from the center. To a good approximation these velocities vary linearly from north-to-south and are near zero at the center. This is easily interpreted as the projection of a circular distribution of ionized gas around the center with a velocity of rotation about 110 km s^{-1}. Since the distance from the center of the ellipse is approximately 1.4 parsecs, the mass enclosed within its radius is found to be 4.0×10^6 $M_\odot$. Variations in velocity from an ideal constant rotation can be seen from Figure 7 to be about 20 km s^{-1}. This is one of the observations which indicates that the clouds have been recently disturbed since this nonuniformity would tend to be smoothed out by collision in the

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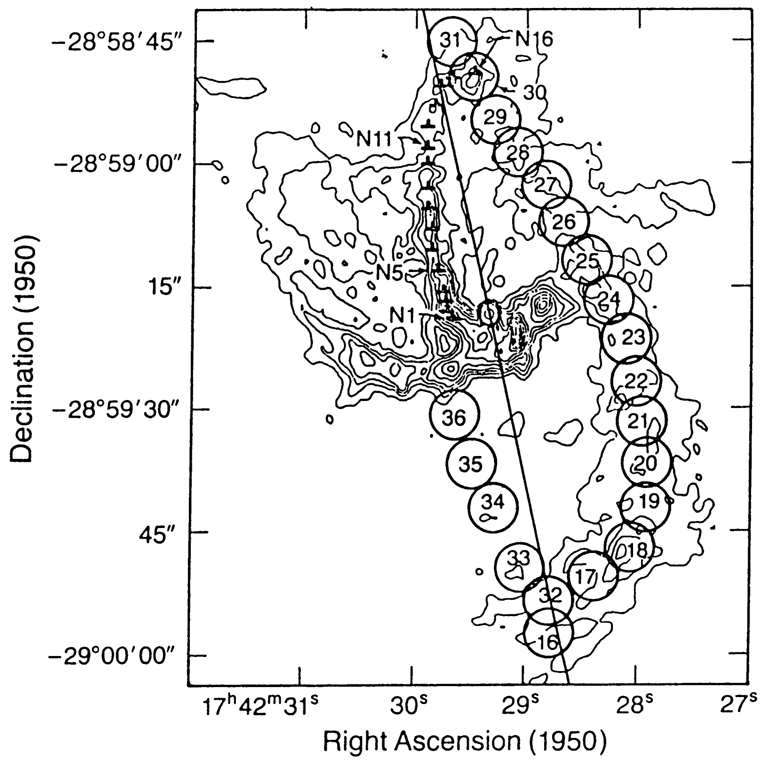

Figure 6. **Radio intensity contours of the western arc and the northern northern arm with positions where the NeII spectra were measured by Serabyn and Lacy (1985).**

course of about 50K years.

The "northern arm" has a very different pattern of velocities. It has been fitted by Serabyn and Lacy (1985) to a parabolic orbit, representing infall of material towards a central mass of about 4×10^6 $M_\odot$, and the orbit indicates that this mass is still enclosed within a radius as small as 0.5 parsecs. Herbst et al. (1993) have recently made measurements of this northern arm in the Brγ line. Their measurements agree well with those of Serabyn et al. (1985), but they were able to extend the velocity measurements still closer to the center and find that the orbit corresponds to a parabolic one about a mass of 4×10^6 $M_\odot$ even as close as 0.2 parsecs. The attractive center for this orbit is within one arcsec of Sgr A*, a distance about equal to the uncertainty in location of this center.

Although the northern arm provides a very strong suggestion that there is a large concentrated mass and also a measurement of its magnitude, an important question can be raised about the rigor of such a conclusion. Jackson et al. (1993) have found a large cloud of atomic gas to the northeast

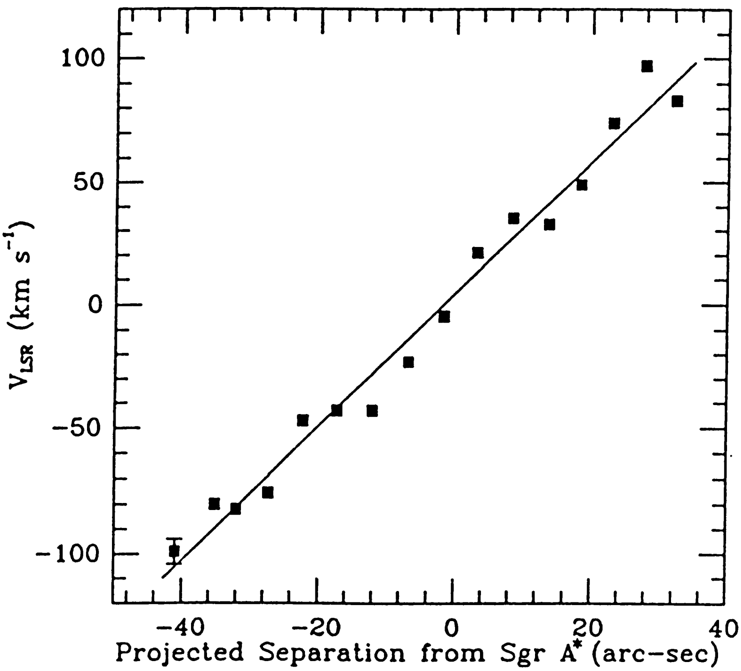

Figure 7. Plot of NeII velocities along the western arc versus the offset in declination from Sgr A* (Serabyn and Lacy, 1985).

of the northern arm, as if in fact a large amount of material has been falling towards the center and the northern arm is simply its edge, ionized by UV radiation from the center. This is also taken as an explanation why the ionized ellipse is not seen to the northeast, since the atomic cloud is dense enough to shield the molecular ring from ionizing radiation coming from the center. If the northern arm is thus the edge of infalling material, its pattern does not necessarily represent an orbit of free falling material. The fact that it fits a parabolic orbit so well is impressive and may correctly represent the gravitational field, but this pattern could be accidentally produced by rather more complex motions of the entire cloud.

There is considerable additional high velocity gas very near the galactic center. Most of this other gas does not clearly fit any recognizable orbit, but may simply represent blobs of gas which are moving in the gravitational field. One can see from Figure 8 that there is a considerable amount of rather high velocity gas, with velocities frequently 200-300 km s^{-1} and becoming as high as 400 km s^{-1}. These are substantially larger than ve-

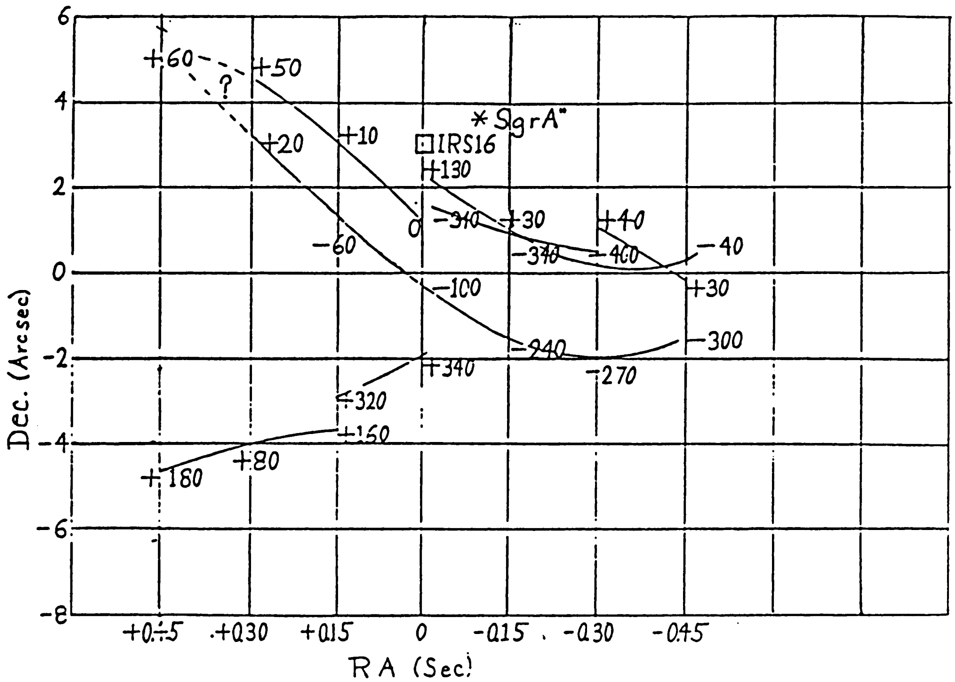

Figure 8. Velocities in km s^{-1} of ionized gas near Sgr A* as determined from NeII spectra (Adapted from Serabyn et al., 1988). Lines connect what may be parts of various gas flows, though the presence of gas flows rather than simply motion of individual batches of gas is uncertain.

locities of typical material found in the circulating molecular clouds, and appear to represent motions of gas in a rather strong gravitational field, corresponding again to a central mass near 4×10^6 $M_\odot$.

Gas velocities can be misleading indicators of gravitational fields since gas may be accelerated by a variety of mechanisms such as variable magnetic fields and winds, or the gas may fall in from a long distance. However, we now have reasonable evaluations of magnetic fields in this general region from polarization measurements (Aitken et al., 1991) and Zeeman effects (Roberts and Goss, 1993). While they are strong enough to somewhat effect the motion of ionized gas found in the galactic center, they are not strong enough to dominate the kinetics or produce the velocities observed. There are also high winds present; some emanate from the hot blue stars near the center and some may come from Sgr A*. These can have effects on the velocities of gas clouds but the present winds would not be strong enough to give the observed cloud velocities and patterns. Neither can infall from a long distance produce the particular patterns and velocities seen, since such an infall would be expected to produce long streamers, such as the northern arm, and in any case for the high velocities involved, if there were no large central mass the infall would have to come from such a long distance that there would be many collisions to impede the accumulation of the observed velocity.

While gas measurements appear to give substantial information about strong gravitational fields, and possible questions about their interpretation do not discount the essence of this information, stellar velocities are open to somewhat fewer questions than those of the ionized gas. For that reason the stellar measurements of Sellgren et al. (1990), Haller (1992) and Haller et al. (1992) have been particularly valuable. Both of these groups have measured the near IR lines of CO in the atmospheres of red giants. Haller et al. have measured individual red giant stars. Sellgren et al. have measured the average velocity of a collection of stars within a given field of view, so that somewhat weaker stars could be utilized. The velocities obtained by Sellgren et al. as a function of distance from the center are shown in Figure 9 where the velocity is seen to increase toward the center rather than remaining constant as would be expected for a normal cluster of uniform stars. The evidence that there is a substantial increase in velocity as one approaches the center can be described as approximately a 6σ result. In presenting the evidence for a concentration of dark mass, Sellgren et al. also note that the mass to luminosity ratio increases towards the center to a value of about 10. They find $5.5 \pm 1.5 \times 10^6$ $M_\odot$ within the radius of 0.6 parsecs. Haller, Rieke, and Rieke (1992), not only have proceeded with their measurements in a rather different way, they have also made an independent analysis of results. They conclude there is evidence for a mass of $2.0 \pm .4 \times 10^6$ $M_\odot$ within a radius 0.17 parsecs and obtain a signal to noise ratio of 6σ.

An additional method for obtaining information on motions near the center is now becoming available through the measurement of proper motions of the peculiar bright blue stars near Sgr A*. These stars appear, from Doppler shifts of gases near their photospheres, to have velocities of the order of 1,000 km s^{-1} but the Doppler shifts may be produced primarily by stellar winds rather than stellar motion. Careful measurement of stellar positions, using a high resolution near-IR camera, has been used by Eckart et al. (1994) to show that two of these stars appear to have proper motions corresponding to velocities near 1,000 km s^{-1}. They are substantially closer to the very center than most of the other stars observed, and this high velocity of course again indicates a large concentrated mass. At present one can still claim some uncertainty in these results: one possible objection is that since stars are very dense in this region and some of them are of vari-

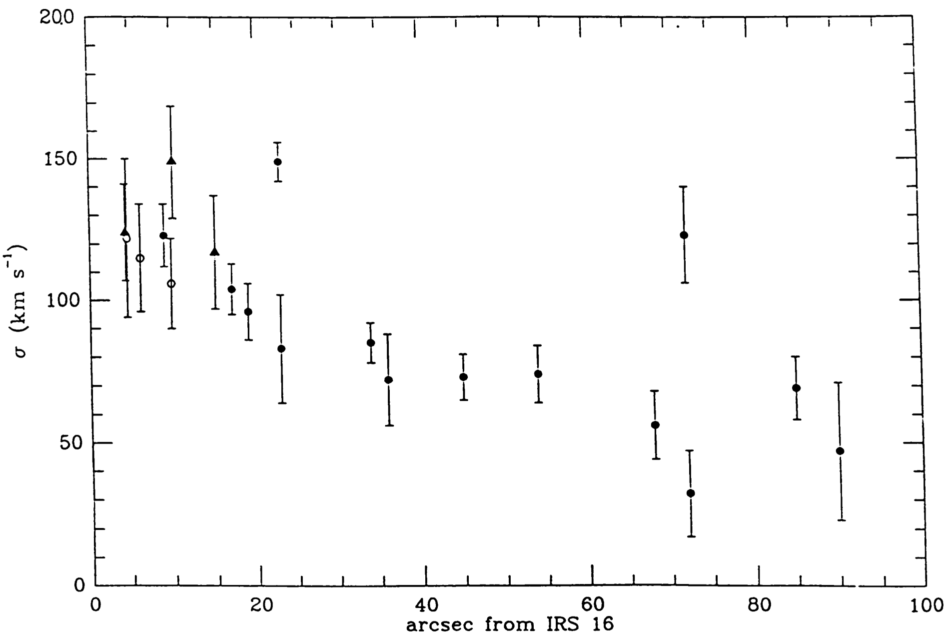

Figure 9. Stellar velocities as a function of distance from IRS16, and hence also approximately distance from Sgr A* (Sellgren et al., 1990).

able luminosity, the apparent proper motion might be caused by a near coincidence along the line of sight of two stars and the variable intensity of one of them. This type of measurement has only recently been realized, but it does appear that in the long run measurement of a number of stars should provide conclusive results. So also may very precise measurement by radio interferometry of the position of gaseous components near the center.

As an overall summary of these dynamic results, Figure 10 shows the mass which would be inside a given radius from the center, using the velocity results for the various components which have been measured. The data include spectra of OH maser stars, most of which are at some distance, CO spectra of red giants, and IR spectra of gaseous components. The results are compared with curves representing a normal cluster of stars. Two such curves are shown, with the two possible core radii of the cluster of stars near the galactic center which have been estimated by Rieke et al. (1988) and by Eckart et al. (1993). It is clear that observations do not fit these ideal stellar clusters, but instead indicate a concentrated central mass of

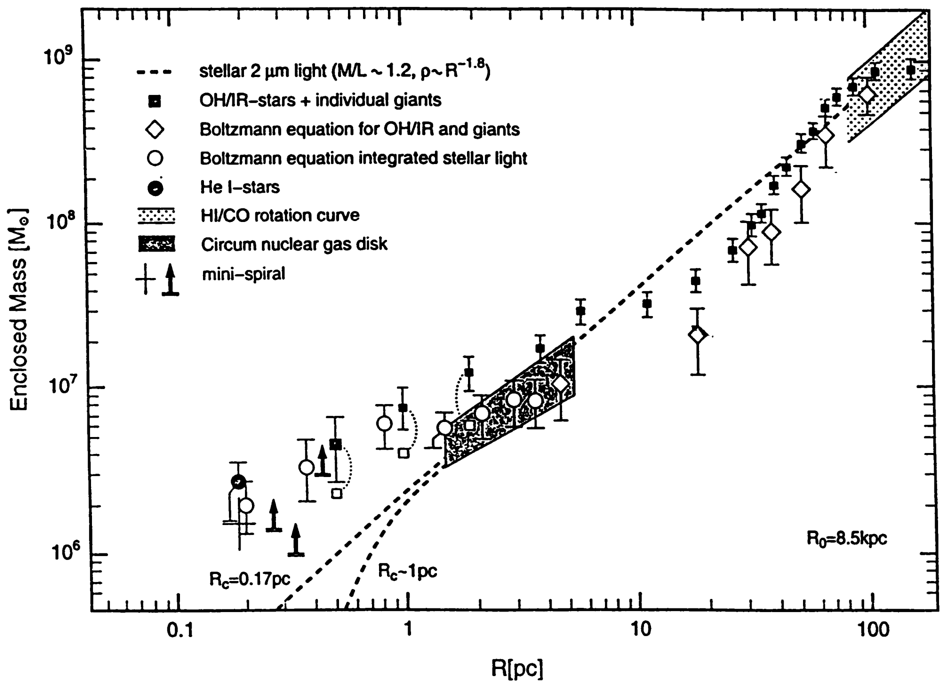

Figure 10. Mass inside a given radius from the galactic center as judged from velocities of gas and stars. The two dotted lines are the expected values for stellar clusters with core radii of 0.17 pc and 1.0 pc respectively (Genzel et al., 1994).

$2 - 3\times\ 10^6\ M_\odot$. Furthermore, a wide variety of measurements appear to consistently indicate such a value.

4. Radiation from the Central Region

The Eddington luminosity limit of a black hole having the mass indicated by dynamics in the galactic center is about 3×10^{44} ergs s^{-1}. But the actual radiation observed in the x-ray region is only about 2×10^{36} ergs s^{-1}, in the radio region about 10^{34} ergs s^{-1}, and in the infrared about 10^{38} ergs s^{-1}, more than six orders of magnitude below the Eddington limit. Of course, the Eddington limit need not be reached. However, considerable ionized gas is found in the immediate region near Sgr A* and it has been estimated from this and from the local stellar winds that there should be a mass infall of about 10^{-3} $M_\odot$ per year (Lacy et al., 1982) which, for 10% energy conversion efficiency, would produce a luminosity within two orders of magnitude of the Eddington limit.

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One reason the apparent black hole in the galactic center may not be radiating as much as is expected at present is that the amount of mass infall can be variable. It has been estimated that a star would fall into the central mass once every few thousand years (Lacy et al., 1982), and Rees (1988) has pointed out that such an infall might last only a few years. Hence there may be a probability as low as about 10^{-3} that infall into the black hole would be radiating actively at any one time. However, some evidence against such episodic radiation has been given by Sunyaev et al. (1993), who have examined Compton scattering of x-rays in the 9-20 keV range from gas in the galactic plane. They give an upper limit to the x-ray radiation scattered a certain distance from the galactic center, and conclude that there has been no x-ray radiation from the center in the wavelength range measured with an intensity greater than about 10^{38} ergs s^{-1} averaged over the last 400 years, and that the Eddington limit could not have been in effect for as much as one day during this time. With somewhat less restrictive numbers, their work indicates that no intense x-ray radiation has been emitted over the last few thousand years, requiring any strong emission episode to have been rather far in the past.

Ozernoy (1989) models infall of material into a black hole and finds that, for the amount of gas present and the radiation seen in the radio and infrared regions, the black hole must have a mass less than a few hundred $M_\odot$ rather than $2 \times 10^6 M_\odot$. Falcke et al. (1993) model the radiation with a rotating black hole of mass $\leq 2 \times 10^6$ $M_\odot$ and the very low infall rate of $< \ 10^{-7}$ $M_\odot yr^{-1}$. Melia (1992) has calculated a model of a uniform wind striking a black hole of $1 - 2 \times 10^6 M_\odot$ which, because the angular momentum is very small, accretes into the black hole with relatively little radiation. In fact, he fits the observed radiation throughout the spectral region observed with just such a gas falling into the black hole at a rate of about 10^{-3} $M_\odot$ per year. Radiation is produced in part because of turbulence in the accretion, which effectively provides some angular momentum, and produces variations in the intensity of radiation consistent with the minor variations which have been seen. Of course, the actual flow of gas will not be completely uniform. Ruffert and Melia (1994) have refined Melia's model to allow an inflow of gas from about 30 stars surrounding the black hole which are emitting stellar winds and providing about a 3% gradient in the velocity over the accretion radius of 10^{16} cm. They find the radiation in this case more or less consistent with what has been observed, but about twice as large as that for the uniform flow. The Falcke et al. model may be satisfactory as a model at this particular time, but with an improbably small inflow which cannot be typical. The Ozernoy model does not at present appear consistent with the Melia or Ruffert and Melia models, and the discrepancy must remain open until further work is done.

There have been a number of suggestions that perhaps the concentrated mass indicated by dynamics in the central region is not a black hole, but another form of dark mass, such as neutron stars, other small black holes, or even some new form not yet envisaged. Morris (1993) has calculated that if the region within about 10 parsecs of the galactic center produces stars at a normal rate, there should in the past have been a number of rather heavy, short-lived stars which in their supernova stage produced black holes of about 10 $M_\odot$. A large fraction of these black holes would migrate much closer to the center of the galaxy and Morris suggests they might form the concentrated heavy mass, as well as perhaps some of the unusual stars found there by their merger with more ordinary stars. These proposals also have difficulties. The lighter stars such as neutron stars should be evicted from the center by collision and in addition, either neutron stars or black holes should be expected to form some binaries and capture material to produce individual x-ray sources in the central region – sources which are not observed. A large concentration of 10 solar mass black holes with density about 10^8 per pc^3 which is suggested has been shown by Goodman and Lee (1989) and by Lee (1994) to be unstable, and in fact to collapse into a large black hole. Morris' estimate of a large number of black holes migrating towards the center as the result of local supernova is, however, not easy to dismiss and the lack of evidence for them in the form of mergers or x-ray sources suggests either very little stellar formation in the region during the last 10^9 years or that black hole formation by heavy supernovae explosions is much less frequent than expected.

There should indeed be merger stars in the neighborhood of the galactic center, since the density there is quite high. Mergers with some neutron stars or small black holes could produce types of stars which are not otherwise very familiar. Since there are some few tens of unusual intense blue stars near the galactic center it has been suggested that at least some of these may be merger stars, which is an attractive suggestion. However, a group of rather similar stars has been found about 100 parsecs away from the galactic center near the radio continuum striations to the northeast where the density is not particularly high. This gives credence to the more every-day suggestion that these stars have been produced by a starburst. On the other hand, this explanation also leaves questions because at least at present the region near the galactic center is quite unsuitable for much stellar formation.

We are thus left with rather convincing evidence based on velocity measurements that there is indeed a concentrated mass in the center of our galaxy of about $2 \times 10^6 M_\odot$ but with the puzzle that it does not radiate as much as it expected, considering the amount of material surrounding it. A similar dilemma occurs in a number of nearby galaxies for which there

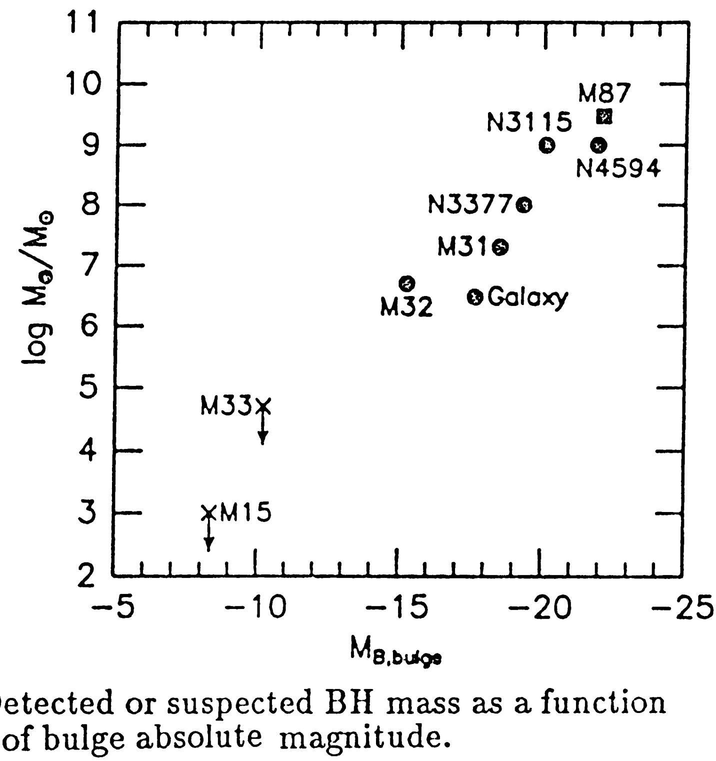

Figure 11. Magnitude of the apparent black hole mass at the center of nearby galaxies as a function of the bulge absolute magnitude (Kormendy, 1994).

appears to be good dynamic evidence for heavy black holes but which are emitting even less radiation than the center of our own galaxy. Among the local galaxies which have been studied, Kormendy (1993) has shown that the mass of the apparent central black hole, as judged from velocity measurements, is closely related to the luminosity of the galactic bulge, as shown in Figure 11. It can be seen from this figure that the apparent black hole mass in the center of our own galaxy and its luminosity are rather consistent with this plot of the black hole masses and bulge luminosities for other galaxies. The black hole in M87 has recently been confirmed by Ford et al. (1994), with measurements of high velocity gas surrounding its center. Figure 12 provides a plot of velocities for the galaxy NGC 3115, showing rather good evidence that in fact the velocity increases sharply near the center, indicating a central black hole of mass about 10^8 $M_\odot$. Evidence for the other galaxies also seems reasonably convincing. Of the five nearby galaxies for which there appears to be reasonable evidence of heavy black holes in their central regions only two, the Sombrero Galaxy

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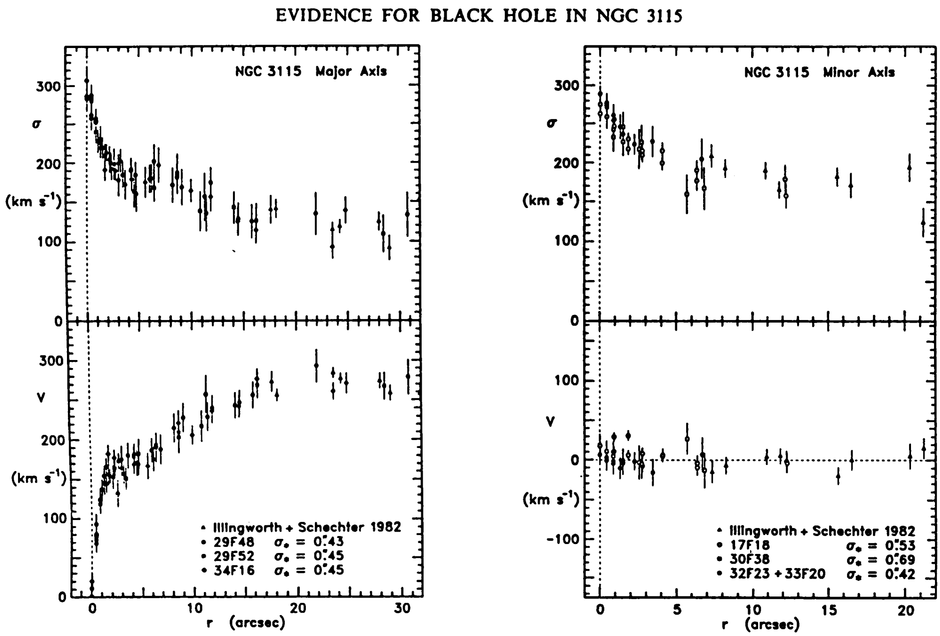

Figure 12. Stellar velocity dispersion (upper diagrams) and rotational velocities (lower diagrams) as a function of distance from the center of NGC 3115 (Kormendy and Richstone, 1992). The velocity dispersion strongly indicates a massive central black hole.

(NGC 4594) and M87, are producing intense radiation. The others produce even less than does our own galaxy, though their black holes as judged from dynamics near their centers are substantially larger. One can appeal to the argument of episodic behavior for these galaxies which are not emitting strongly, that is, the supposition that not much material is presently falling into the black holes. Unfortunately, we cannot study the nature of the very centers of these galaxies as well as we can the center of our own galaxy. However, M31 has recently been found by Lauer et al. (1994) to have a double nucleus which is thought to indicate a merger of two galaxies, and this would lead one to expect that substantial material would be falling into the two nuclei.

5. Summary

Despite the great amount of detailed information which has been accumulated by many different research groups about the center of our galaxy, we are left with several dilemmas:

1) There is a sizable group of bright blue and unusual stars, many of them with a high He abundance, in the center of our galaxy whose origin is unclear.

2) One would expect a number of black holes of size of about 10 $M_\odot$ to have migrated towards the galactic center if such black holes are formed by the supernova explosions of heavy stars as is expected (Brown and Bethe 1994), but the lack of x-ray sources in the center indicate that these are missing. Does this indicate that the formation of black holes by supernova explosions is not as abundant as has been expected, or instead that there has been no recent stellar formation near the galactic center other than possibly the peculiar stars mentioned above?

3) Finally, there seems to be positive dynamic evidence indicating a large central mass in our galaxy and also in a number of nearby galaxies, masses so concentrated that there are no models for them other than black holes. Yet the radiation expected from these black holes, according to most of the accepted theoretical models, is not observed. Is the dynamic information misleading us about heavy central masses, or do we simply not yet understand sufficiently well the many complex phenomena connected with infall of material into massive black holes?

My personal inclination is to believe the apparent results of the kinetic information, which are in the case of our own galaxy indicated by several different types of measurements of reasonable surety and involve a somewhat simpler use of theory than does the possibly complex dynamics of infall into a black hole and energy conversion during infall. However, further measurements will be needed to settle this question in a really satisfactory way. Fortunately, there are methods envisioned, particularly measurements of proper motions, which in time should allow a convincing settlement of this question.

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DISCUSSION

W. Kundt: Before calling SgrA East a "SNR", one should notice that it is some 10 times too small, and some 10^2 times too energetic for a SNR, and may instead be part of the outflow phenomenon from SgrA* through the pc-scale sets into the Gal-Center Chimney; see A & SS 172, 109 (1990). And: when trying to distinguish between an unresolved nuclear mass of a few 10^6 $M_\odot$ via stellar velocities, care should be taken at radii $\lesssim 1$ lyr that their line-opaque windzones may have large relative velocities, as indicated by IRS 7,10, 6, and 21.

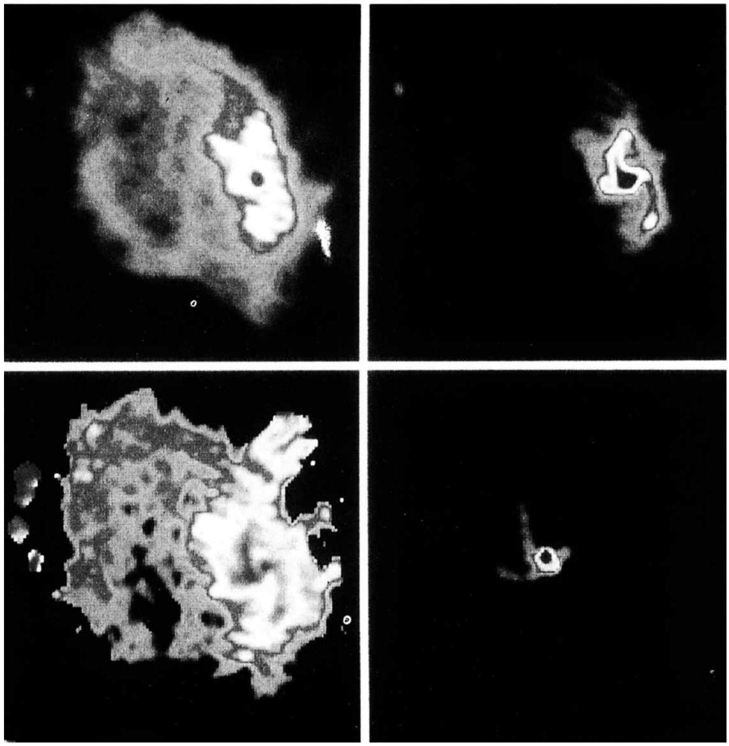

Figure Radio continuum maps from the VLA of the central 10×10 pc^2 of our galaxy. Lower left: Spectral index map from images at 20 and 6 cm with 8 arcsec resolution. The blue region represents synchrotron radiation, the yellow and red various intensities of free-free thermal emission. Upper left: 20 cm image with 8 arcsec resolution. Upper right: 6 cm image. lower right: 2 cm image, resolution 4 arcsec. (Courtesy Ekers, R.D., Schwarz, U.J., Goss, W.M., and van Gorkom, J.H.).

(For colour plate of figure see page xviii)

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