THE GALACTIC CENTER
Introductory Review: Outstanding Puzzles and Challenges

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Over the last two decades, the refinement of radio and infrared techniques, as well as work in space, have provided a remarkable amount of information about the center of our galaxy. Much of it fits into a more or less understandable and increasingly well-defined pattern. However, some of this information seems to represent phenomena we do not yet understand, and still other measurements appear to challenge us with inconsistencies. Much of the material to be presented at this conference represents new results which will add both to our information and our understanding. It is hoped this first discussion will properly introduce the overall subject, paying particular attention to those areas which are still puzzling or under debate. Because of the wealth of material, the complexity of the subject, and my own limitations, not all of the many important points and questions will be treated, nor treated equally. Fortunately, the many gaps which I must leave will be filled by others, since there are review talks on most of the various, more specific aspects of the field.

Radio radiation from the galactic center on a scale of about 50 parsecs is illustrated by figure 1. This shows the remarkable arcs or filaments discovered by Yusef-Zadeh, Morris, and Chance (1984), as well as the so-called bridge region composed of elongated and arched structures which extend from the Sagittarius A region towards these elongated filaments. On a still larger scale, Sofue and Handa (1984), have discovered what is known as the "galactic center lobe", a region of ionized gas extending a few hundred parsecs approximately perpendicular to the galactic plane. These and other observations of structures a short distance (10-100 pcs.) from the center clearly suggest magnetic fields because of their long, narrow nature. The required field would be generally poloidal, or perpendicular to the galactic plane. Faraday rotation in these regions agree with expectations that magnetic fields are of some importance. While magnetic fields are thought to be very important for many of these more distant structures, how important they may be close to the center where densities and gas velocities are higher is one of the unanswered questions.

M. Morris (ed.), The Center of the Galaxy, 1–20.

ENCLOSED MASS^a AS A FUNCTION OF RADIUS AROUND SAGITTARIUS A*

Radius (pc)	N	Linear Orbits	Isotropic Velocities	Circular Orbits	Molecular Ring
		Dominant Central Mass			
<0.5.........	10	4.2 ± 1.8	2.1 ± 0.9	1.4 ± 0.6	...
<1.0.........	21	6.8 ± 2.0	3.4 ± 1.0	2.3 ± 0.7	...
<2.0.........	33	10.6 ± 2.6	5.3 ± 1.3	3.5 ± 0.9	5.6–7.9
<6.5.........	54	40 ± 8	20 ± 4	13 ± 3	
		Self-Gravitating System			
<0.5.........	10	8.4 ± 3.8	4.2 ± 1.9	2.8 ± 1.2	...
<1.0.........	21	14 ± 4	6.8 ± 2.1	4.5 ± 1.4	...
<2.0.........	33	21 ± 5	10.6 ± 2.6	7.1 ± 1.7	5.6–7.9
<6.5.........	54	81 ± 16	40 ± 8	27 ± 5	...

^{a} Units of mass are 10^6 $M_\odot$.

Table 1. Mass enclosed within a given radius about the galactic center determined from velocities of 43 stars and on the basis of various assumptions listed (Rieke and Rieke 1988)

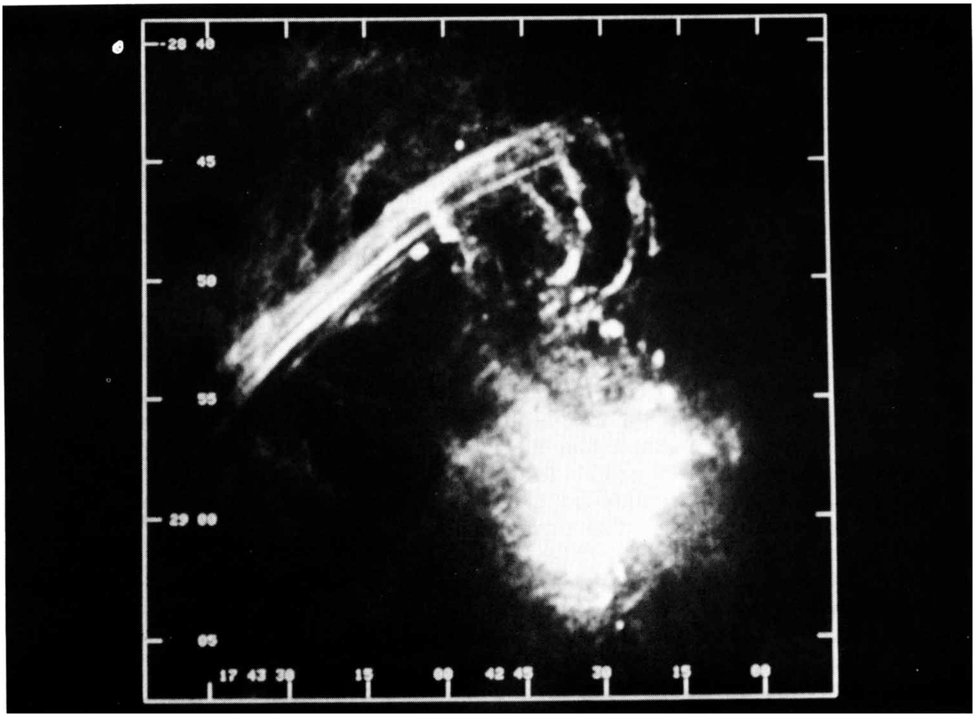

Figure 1. Large scale (60pc x 60pc) features of ionized gas around the galactic center. From Yusef-Zadeh, Morris, and Chance (1984)

Heyvaerts, Norman, and Pudritz (1988) have constructed a synoptic model of the entire region based on magnetic fields dominating most of the dynamics. Their model involves a rotating structure of 10^5 to 10^6 solar masses within 1/4 parsec from the center which throws off magnetic loops, which in turn expand and produce most of the observed characteristics. They note that this magnetic engine cannot be made of stars. Further, a gas containing this much mass and spread over a region which can be resolved by normal telescopes would have been seen because it would be rather opaque. Hence, such material must be confined to circulation in a very small volume, presumably around a black hole. This model provides a good basis for discussion. We have no real measure of the magnetic field strengths themselves, but the model provides some predictions which can be tested experimentally.

Recent studies, to be reported in more detail here by Erickson et al. (1988) and by Genzel et al. (1988) of the "bridge region" between Sagittarius A and the elongated filaments appear to test the proposal of Heyvaerts et al. (1988) that ionization in this region has been produced by shocks associated with expanding magnetic loops. Erickson et al.(1988) have measured spectra of ions such as CII, OIII, SiIII, and SIII, as well as OI in this region at a number of different positions. The high ionization potential required to produce some of these ions seem clearly to indicate an ultra-violet ionization consistent with radiation coming from a source at a temperature of about 36,000K. A map of this region in CII by Genzel et al. (1988) is shown in figure 2. CII clearly follows the general outlines of molecular clouds and ionized gas in this region. The abundance of CII, the ratio of CII to the emission measure, as well as the relative ionic abundances found by Erickson et al. (1988) all indicate ultra-violet excitation. Very likely some shocks are also present, and these results do not rule out magnetic fields having some important role; they do indicate that this ionization is not primarily produced by magnetic shocks. The sources of the ultra-violet radiation are not presently known; it is hoped they can be located.

We do, fortunately, have some direct measurements of magnetic fields, although it is very difficult to determine the field magnitude with any precision. Aitken et al. (1986) have measured the polarization of radiation in the 10 μm region at a number of points in ionized gas immediately around the central region. Figure 3 shows the direction and relative magnitude of the polarization superimposed on contours of the 10 μm radiation in a region about 1.5 x 2.5 parsecs. The pattern observed is quite understandable. Measurements of NeII fine structure radiation and of radio radiation show that the "northern arc", that is, gas going northward from the center, represents a dense stream of ionized gas moving at velocities of 50 to 100 km per second along the line of sight, and fitting an orbit which can be represented by materials either falling towards or being expelled from the center. The magnetic field, believed to be perpendicular to the direction of polarization, can be seen from figure 3 to lie along the direction of

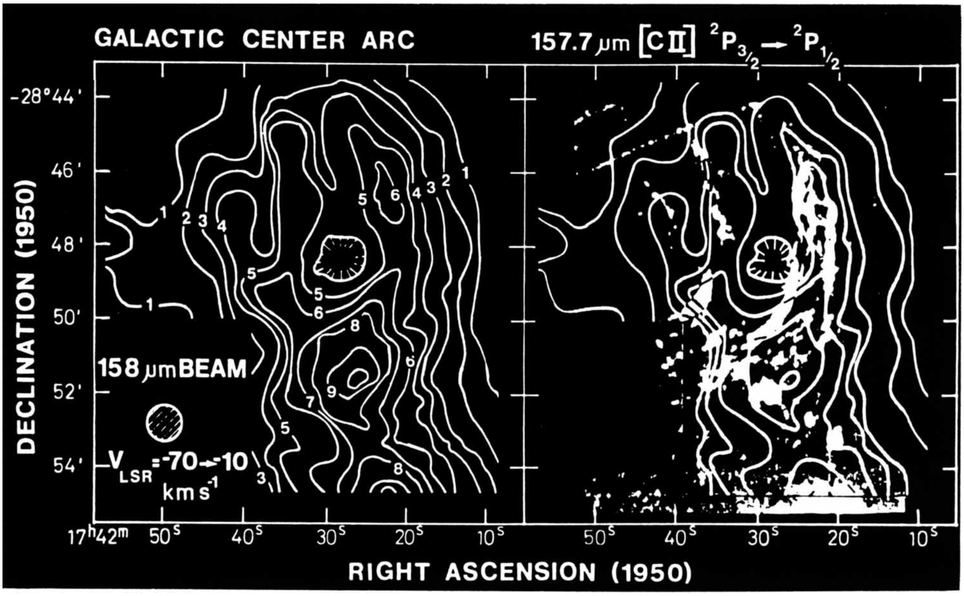

Figure 2. [CII] map of the "bridge region" for velocities V_{LSR} = -70 to -10 km s^{-1} (Stacey et al. this conference). Right-hand diagram are contours superimposed on the thermal radio continuum emission (Morris and Yusef-Zadeh 1985).

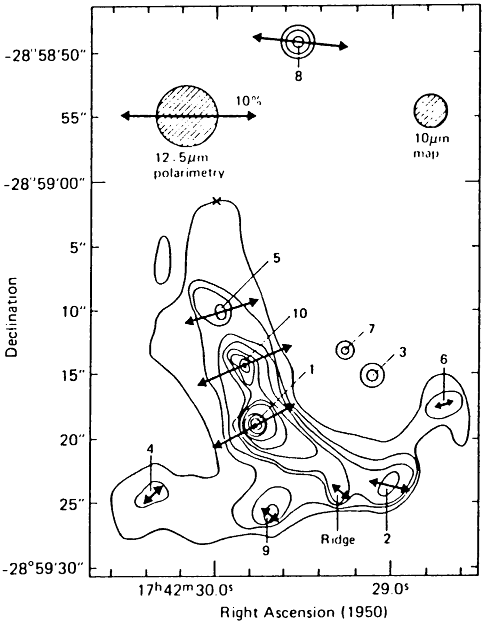

Figure 3. Polarization of 12.5 μm continuum radiation in the galactic center (Aitken et al 1986) superimposed on 10 μm continuum contours (Becklin et al. 1978).

flow of this ionized material. Aitken et al. (1986) estimate that the field must be as large as about 10 milligauss from standard theory of polarization by dust grains. The bar of material running east and west contains many different velocities, and generally higher velocities than those found in the northern arc and with more chaotic motions. Hence it is not surprising that the magnetic field directions vary throughout this bar and that they do not seem quite as large. Recent results of Hildebrand et al. (1988) on the polarization of 100 µm radiation are shown in figure 4. The dust involved in this case is partly within the same ionized clouds measured by Aitken et al. (1986), but most of it is in the orbiting neutral material outside of the ionized ring of 1.7 parsecs radius. Figure 4 implies a magnetic field of more or less uniform direction and magnitude, and approximately along the direction of the galactic plane. The magnitude deduced, again from standard arguments about dust grain orientation and polarization, is also about 10 milligauss. These results are more difficult to understand than those within the inner region; in fact, there seems no immediate way to reconcile a more or less uniform magnetic field in the plane of the galaxy extending over such a large region with evidence that the dust emitting this 100 µm radiation is circulating in a disk whose plane is more or less in the line of sight. Most of the radiation should come from dust at a radius considerably less than the extent of the measurements and hence moving perpendicular to the field. It is also somewhat surprising that the field does not appear, even on the outer limits, to be merging into a poloidal field perpendicular to the plane of the galaxy, which is expected from indications of the poloidal field mentioned earlier in connection with the elongated structures on a larger scale.

How important magnetic fields are for the dynamics of this central region is still uncertain. The magnetic field suggested by Aitken et al. (1986) has an energy density about 1/3 to 1/4 that of the kinetic energy in the gas, and hence would not be dominant. However, this represents only a rough estimate of a lower limit of the magnetic field and does not provide a value on which we can rely. In addition, the morphology generally looks more like orbital motion than motions controlled by magnetic fields. Serabyn and Lacy (1985) and Serabyn et al (1988) have fitted most of the ionized gas in the inner region to rather convincing gravitational orbits about the center. Nevertheless, even if magnetic fields do not dominate in this inner region, as seems likely, they may still have a substantial effect on motions in the central region.

Interesting and suggestive information has been obtained from high energy radiation. However, measurements in this energy range are not yet complete enough nor well enough understood to provide very clear evidence about critical problems of the galactic center. I shall omit discussions of x-rays completely; they will be reviewed by Skinner later in this meeting. The most striking gamma-ray radiation is $e^+ - e^-$ annihilation radiation at 511 kilovolts energy (Cf. Leventhal, 1987). At least a substantial part of this radiation comes from a small

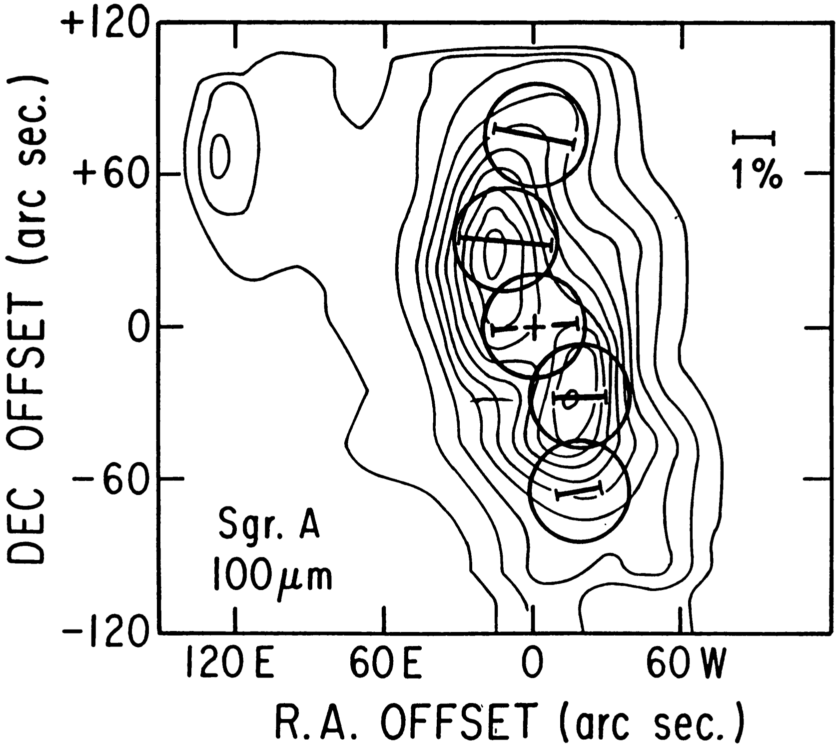

Figure 4. Polarization of 100μm continuum emission from the galactic center (Hildebrand et al. 1988).

source, since it has varied over a period of about 8 years. Its intensity corresponds to the annihilation of about 10^{10} tons of positrons per second, but it has recently dropped below detectability for the last available detection system. Since the distribution and variation of the annihilation radiation promises to be important for study of the galactic center, it is hoped that further equipment and occasions for precise work on it from space will become available. Ozernoy (1987) has concluded that the source of this radiation may be material around a black hole, but that it would be one not heavier than a few hundred solar masses. Kluzniak et al. report at this conference that the source could be an x-ray binary. Lingenfelter and Ramaty will discuss its nature at greater length.

Another very striking observation has been made in the detection of 1.8 MeV gamma rays from ^{26}Mg, a decay product of ^{26}Al. The latter has a lifetime of about 10^6 years. The intensity of this radiation corresponds to approximately 3 solar masses of ^{26}Al. Von Ballmoos et al. (1987) suggest that much of the source is concentrated in the galactic center, while Webber et al. (1986) propose that this radiation may also be connected with the electron-positron annihilation radiation. McCallum et al. (1987) argue that it is a diffuse source. In the latter case, it is too intense to be produced by normal supernovae; novae have been suggested as a source of this ^{26}Al by Clayton (1984).

Much information has now been accumulated about the relative positions of various clouds and other objects in the galactic center. In two dimensions this is determined, of course, by good angular resolution and mapping. Relative positions of objects in the third dimension, along the radial direction, has recently been determined by a number of emission and absorption measurements, many of which are being reported at this conference. We now know, for example, from the work reported here by Mezger et al., Pedlar et al., and Goss, that Sagittarius A West is surely in front of Sagittarius A East. There are many other valuable geometrical relations which are now known and whose description I must leave for more detailed reports.

Characteristics of the molecular gas outside of the ionized ring at 1.7 parsecs have been extensively studied. Figure 5 shows, for example, the distribution of HCN at radii out to a few parsecs, from the work of Wright et al. (1987). The contours immediately demonstrate a substantial clumping of the gas clouds. We know also from the velocities and velocity dispersions within clumps that there is substantial turbulence, and that the clouds are not gravitationally bound. Their density is in the range of a few times 10^4 to a few times 10^5 hydrogen atoms per cm^3. The temperature is typically 300-400K. However, shocked hydrogen, first discovered by Gatley et al. (1984) is widespread in this region, and shows temperatures up to about 2,000K. The orbital period, and also the time of relaxation for these clumpy clouds, is about 10^5 years. Hence, unless there is an inherent instability in their motions which causes such turbulence, the

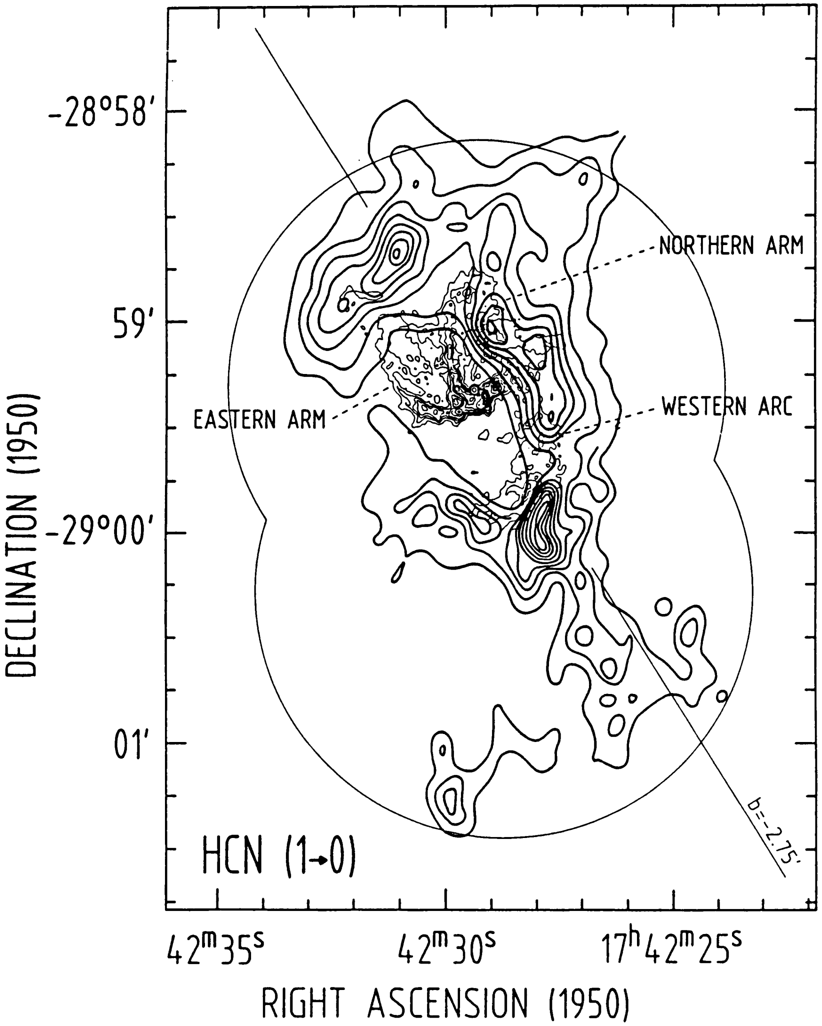

Figure 5. Contours of HCN 1→0 emission from the galactic center (Güsten et al. 1987) superimposed on the radio continuum.

considerable turbulent energy of about 2 x 10^{50} ergs must have been caused by a large outburst of energy about 10^5 years ago - either emerging from the center or possibly due to an influx of gas. The rather highly evacuated central region (density $\leq 40/\text{cm}^3$) makes the former case, an explosion, the more likely source of this energy. Ultraviolet radiation floods much of this region, producing ions such as CII and a good deal of heating. Shocks also must contribute to the heat.

One of the more discussed uncertainties in the behavior of the molecular gas has been the distribution of velocity as a function of radius. CII spectra, measured by Lugten et al. (1986), indicate a velocity beginning near the ionized ring of about 110 km per second which decreases somewhat at larger radii. On the other hand, measurements of the $1\to0$ transition of CO by Güsten et al. (1987) have been interpreted to indicate a velocity which does not change very much with radius, in addition to a rather wide distribution of velocities. Of course, the CII is expected to come from warmer clouds ionized by ultra-violet radiation and hence regions close to the galactic center, whereas the $1\to0$ transition of CO can come from cooler clouds, including those some distance from the galactic center, and its radiation can be reabsorbed. That CII probably comes from warm gas is reinforced by observation of the $3\to2$ transition of CO by Serabyn et al. (1986) and of the $7\to6$ transition of CO by Harris et al. (1985), which show that these more excited states of CO have velocity distributions essentially like that of CII. Nevertheless, the velocity distribution is complex enough that details of its radial behavior are not especially clear.

Ionized gas within the 1.7 parsec radius is now quite well measured as to both distribution and velocities. Killeen and Lo report in this conference on a VLA map made with a resolution as fine as 0.7 arcsec by 0.4 arcsec. Yusef-Zadeh, Ekers, and Morris also report on high resolution work on this gas and certain special and striking structures within it. Extensive velocity measurements have been made with high angular resolution on the ionized gas by Lacy and others (1979, 1980, 1987), using the fine structure transition of NeII at 12.8 µm. Lacy et al. will report on some of the latest measurements. Velocities have also been measured by Van Gorkom et al. (1985, 1988) using the 67α recombination line of hydrogen.

While we know a great deal about the gas distribution and velocities, the source of the gas is still under discussion. Is it due to infall or ejection, and if ejection what type of machine can possibly provide the characteristics observed? Infall seems the more likely, and some evidence pertinent to this is represented by the stream of ammonia, to be reported by Ho et al. at this meeting, which comes in from a distance as far as 10 parsecs to a point near the ionized ring. Generation of gas by stellar disruption has also been suggested. However, there seems to be too much gas for most of it to have been so produced, based on theoretical calculations of the probability of disruption by a central black hole. Another suggested source has been wind. However, there is not enough wind observed to produce as much gas as is seen, nor is it clear what kind of object could blow out the large dense clumps of clouds which are observed.

The ionized gas in the central region is quite turbulent, showing line widths of 50 - 100 km/sec. Unfortunately, we do not know the scale of this turbulence because dimensions of the clouds themselves are as large as one light year. Hence, even though angular resolution may be much better than this, we do not know whether the turbulence is on a small scale, simply represents gravitational gradients, or is possibly associated with Alfvèn waves.

There is at least one other puzzle which concerns the ionized gas, the intensities of the recombination lines. Van Gorkom et al. (1985, 1988) report a strong decrease in the relative intensity of the recombination lines to the radio continuum as one goes from the 1.7 parsec ring in towards the center of the galaxy. They have suggested that this decrease is due to a temperature increase. However, the decrease is much too large to be due to any expected variation in temperature and hence some other phenomena must also be present. One suggestion has been that much of the continuum radiation is non-thermal. Wright et al. (1987) have reported that about 1/3 of the radiation is non-thermal, but this is much too small a fraction to allow an easy explanation for the very small ratio of recombination line to continuum intensity near the center.

The short infrared radiation (2.2 μm) in the galactic center indicates the intensity of stellar radiation - or at least of red giant radiation - and has been used to determine the stellar distribution beginning with the very early measurements of Becklin and Neugebauer (1968). Their measurements yielded a stellar density proportional to $1/r^{1.8}$, or in other words a stellar mass within an enclosed radius proportional to $r^{1.2}$. Allen, Hyland, and Jones (1983) have examined the same radiation at small radii with high angular resolution and find that this distribution law applies into distances so close that the inner core radius of the cluster is indicated to be less than 0.1 parsec. Rieke and Lebofsky (1987) have also studied the short infrared radiation intensity in this region as a function of radius, but by carefully following a path where no bright stars appear to exist so that the intensity distribution from weaker and perhaps more average stars could be obtained. From this, they suggest that there is an inner core radius of about 1 parsec. Additional studies of stellar distribution using detector arrays will be reported here by Gatley, DePoy, and Fowler, as well as by Catchpole, Glass, and Whitelock.

Recent pictures of the short infrared intensity taken with an array type detector have been obtained by Genzel et al. (unpublished). These pictures appear to show clearly that there is substantial obscuration of the short infrared intensity by molecular material and dust just outside the ionized ring at 1.7 parsecs. Reike and Lebofsky (1987) have previously pointed out the importance of patches of obscuration, but this particular pattern had apparently not been previously recognized. On the other hand, such a result is not surprising in view of the fact that the column density of gas estimated from other measurements indicates optical depths greater than 6 magnitudes for some of the clouds in this region. In fact, the infrared intensity at 2.23 μm drops in the observed regions, according to the measurements of Genzel et al.(unpublished), by a factor of about 100. Thus, it is clear that considerable care needs to be taken in making estimates from the short infrared intensity of the stellar density as a function of radius, particularly in the regions where molecular clouds occur. Whatever errors this obscuration may have introduced in the past would appear to be in the direction of producing an apparently steeper variation with radius than is actually the case. In addition, it seems very likely that the heavier stars, including the brighter red giants, would have concentrated towards the center of the stellar distribution since the relaxation time for stellar motions in this cluster is estimated to be only about 10^8 years. It is thus reasonable to expect that the measurements of Becklin and Neugebauer (1968) and of Allen et al. (1983) may be influenced by a red giant concentration towards the center and may be indicating more stellar density towards the center than is actually the case. Thus, there is no necessary inconsistency between those measurements and the measurements of Reike and Lebofsky (1987), which indicate a flattening of the distribution inside a core radius of about 1 parsec.

There has been a steady accumulation of information and ideas about the distribution of mass within the region of the galactic center. The most extensive measurements of gas velocity in this region, of Lacy et al. (1980) and Serabyn et al. (1985, 1988) have used the fine structure of NeII. While essentially all of the ionized gas within a radius of about 2 parsecs has been measured, Serabyn and Lacy (1985) have discussed two especially interesting features, measured in considerable detail with 6 arcsec and 3 arcsec beams. Velocities of the western arc measured by this method, and also with recombination radiation by Van Gorkom et al.(1985, 1988) , indicate that velocities correspond quite well to those of a circle rotating at an approximately uniform velocity of about 120 km per second. Velocities of circulation are not entirely uniform, however, but vary by about 20 km per second indicating that in addition to an average circular motion there is some turbulence. Molecular gas velocities just outside this western arc give rather similar results. These measurements, as well as the stellar velocities which will be discussed later, all indicate that within a radius of about 30 arcsec (or about 1.7 parsecs) there is a mass of $4.7 \pm 1 \times 10^6$ solar masses. In the northern arc, velocities have been shown to fit rather smoothly a parabolic orbit coming much closer to the galactic center, which is presumed to be located in the region of IRS 16 and Sgr A*. This parabolic orbit, if it is primarily due to gravitational forces, indicates 3.5×10^6 solar masses within a radius of 0.5 parsecs and also shows that the center of mass is located at Sgr A* within a precision of about 5 arcsec. Figure 6 shows velocities of ionized gas in the bar extending from east to west across the galactic center. This

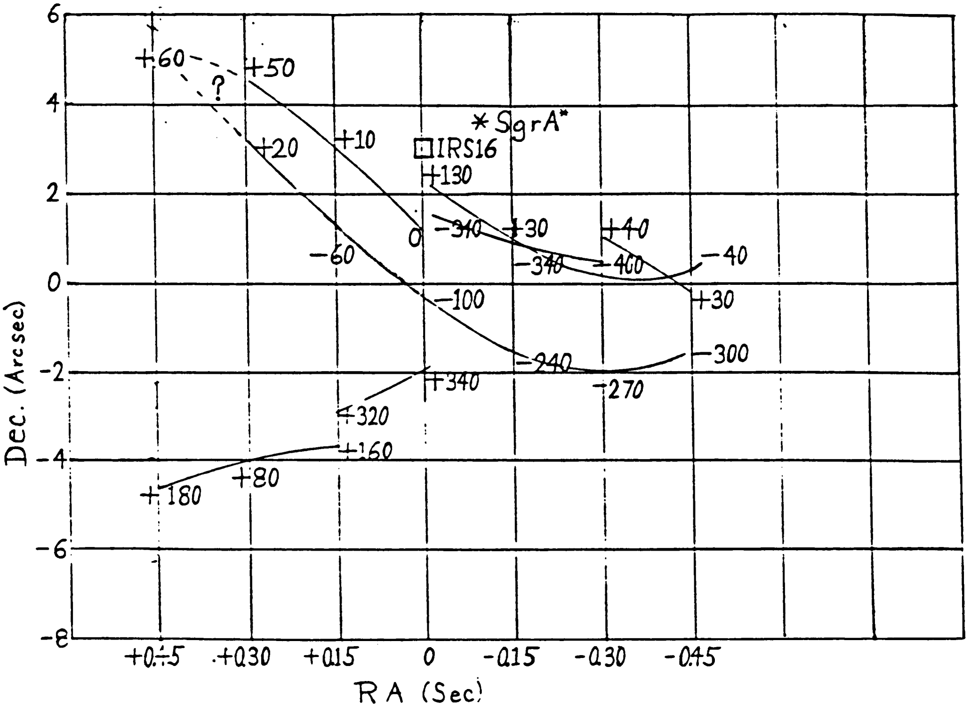

Figure 6. Ionized velocities close to Sgr A*, showing a somewhat confused and dense distribution of gas clouds of relatively high velocity. (Adapted from Serabyn et al. 1988) The numbers represent measured velocities in km s^{-1}. The arcs connect more-or-less continuous distributions of gas into apparent orbits about the center.

includes a good deal of rather high velocity gas. Serabyn et al. (1988) have also fitted some of this gas to orbits about the center and found results consistent with a concentration of a few million solar masses. Such orbits are represented by shorter arcs and are somewhat less convincing than those of the western arc and northern arm. Nevertheless, the simple presence of so much gas at high velocities in itself indicates a concentration of mass if motions are dominated by gravitational forces. In fact, the velocities are somewhat too high to be associated simply with circular orbits about a central mass, but could be explained by material falling in from a radius of about 2 parsecs if there is a concentration of a few million solar masses at the center. The distribution of velocities in figure 6 also gives some mild indication that perhaps the center of mass is south of Sgr A* by about 5 arcsec, because the highest velocities occur in that region. However, this indication may be due only to an accidental distribution of gas.

It is clear from the gas velocities that a few million solar masses must be concentrated near the center if these velocities are dominated by gravitational forces. Hence, this poses the question whether there can be any other explanation for the overall characteristics and high velocities of ionized gas observed.

An increasing gas velocity towards the center, still influenced essentially by gravitational forces, could indeed alternatively be obtained if the stellar density increases more rapidly towards the center than the equilibrium value, $1/r^2$. For example, a $1/r^3$ distribution rather than the $1/r^{1.8}$ deduced from near IR observations would provide an adequate fit to most of the gas behavior. For such a distribution to be real, there would need to be additional dark matter concentrated towards the center, and it has been suggested that possibly dark stars might provide such an explanation. However, unless there are types of stars with which we are yet unfamiliar, the darkest stars should be the lighter ones, and it is difficult to understand why the lighter rather than the heavier stars would concentrate towards the center in view of the rather short relaxation time for stellar motions in the cluster. Intense radiation could provide accelerations of gas clouds. However, we have reasonably good information about radiation intensity and it is less than 1/10 of what would be required.

It has been suggested that winds emanating from the center might accelerate the ionized clouds. However, there is at present not enough wind to provide the necessary acceleration. In addition, the morphology of these clouds does not seem appropriate for acceleration by this method. For example, a wind blowing from the center should produce the highest velocity clouds further away from the center rather than close in, since the further clouds would have been subjected to an acceleration over a longer distance. This is of course contrary to observations. In addition, the rather blobby clouds present do not have the appearance of having been strongly accelerated from one side by winds rather than simply being in a gravitational orbit.

Another possibility for high velocity clouds which has been suggested is that the ionized clouds have been ejected at high velocity from some central object. This is of course a "deus ex machina" which would need an explanation in itself. Furthermore, it would not eliminate the necessity for strong gravitation since the clouds, if they are ejected, appear to be slowed as they orbit away from the center; the dynamics for motion outward is identical with the dynamics for motion inward, so that the same gravitational forces would be required.

The possibility that the higher velocity clouds have fallen in from some distance is still another suggestion, and is qualitatively plausible. However, such an explanation does not work very well quantitatively. For example, an infall from a distance of 2 parsecs into a radius as close as 0.25 parsecs (5 arcsec) would give velocities of 411, 224, and 203 km per second if the mass distribution corresponded with that of a black hole, $1/r^2$ or $1/r^{1.8}$ respectively. Thus, such an infall would not give the observed velocities if we accept the measured stellar distribution as the only mass present. In fact, an infall from an initial distance greater than 60 parsecs would be required for the high velocities observed. One would expect gas falling in from that distance to collide with other gaseous material, and to be strung out into an elongated cloud rather than have the more compact shapes seen in many cases.

The possiblity that magnetic fields have had a substantial influence on the dynamics is one that cannot be treated with any completeness at this point because we do not know the magnitudes of the fields present. The magnitudes estimated from polarization measurements are not sufficiently high to dominate the kinetic energy of the ionized gas in the regions of very high velocity and high density. However, these estimates cannot set a firm upper limit on the magnetic fields, which might in fact be larger. As noted earlier, Heyvaerts et al. (1988) have explored an interesting scenario for how magnetic fields could have a major influence on the dynamics of the entire region. But this scenario also seems to require a special object towards the center, namely 10^5-10^6 solar masses of material orbiting rather tightly around some other massive object.

Figure 7 represents the mass distribution in the galactic center assuming that gas motions are in fact dominated by gravitational effects. It also plots the mass as determined from the motions of the thirty-three OH stars, measured by Winnberg et al. (1985) and six stars measured at infrared wavelengths by Sellgren et al.(1987). This stellar information agrees with information from the gas, but does not extend far enough towards the center to give a critical determination of whether there is a mass concentration. Rieke and Rieke (1988) have recently substantially extended the infrared measurements of stellar velocities, using CO bandheads, and have accumulated velocity measurements for forty-three stars. They note that the velocity dispersion is almost constant with radius, which might simply indicate

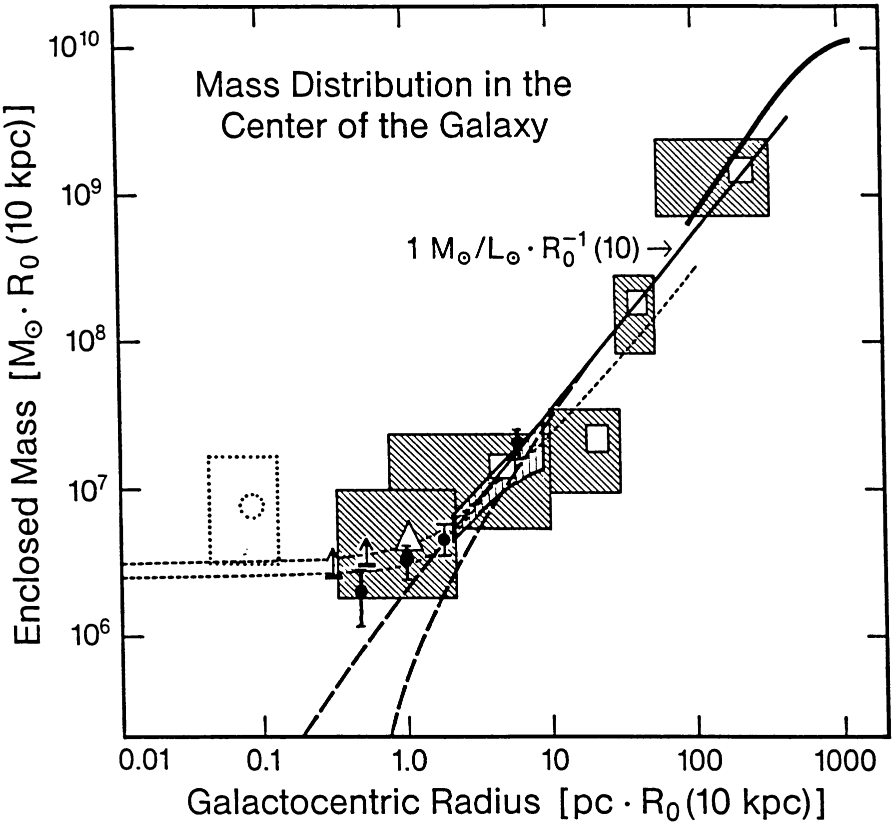

Figure 7. Mass contained within a radius R_o about the galactic center (After Genzel and Townes 1987). The heavy solid curve is from observed HI velocities. The thin solid line is the mass variation deduced from 2.2μm intensities. The vertical striped region is from velocities of the circumnuclear molecular ring. The black dot at 1.7 pc and lower limits come from ionized gas velocities. The dotted box is a mass estimate assuming that fast gas near IRS 16 is in orbit (which is questionable). The long dashed curves apply if the stellar distribution determined from 2μm is extended to short radii, the upper one being for a core radius of 0.1pc and the lower for a core radius of 1.0pc. Except for that at 1.7 pc; the black points with error bars are from stellar velocity measurements by Rieke and Rieke (1988) assuming a random distribution of velocities. The shaded boxes represent masses inferred from velocities of stars with OH masers.

a stellar density distribution proportional to $1/r^2$. However, details of the positions and velocities of the individual stars mean that a concentration of mass is in fact indicated. Table 1 shows their estimates of mass enclosed within various radii. This table uses standard theory for computing the enclosed mass, but several possible assumptions about the distribution of stellar orbits. The various assumptions about stellar motions show that uncertainties could still remain even if an extensive catalog of stellar velocities were known. There is, in fact, an indication of some ellipticity in the distribution of stars about the galactic center. However, this apparent ellipticity is not so great that it prevents a random distribution from being a reasonable representation so far as an estimate of mass distribution is concerned; the best and perhaps most natural assumption is then one of a random distribution, shown in column 3 of the table. The resulting masses are plotted on Figure 7, which shows that the mass distrbution determined from stellar velocities fits that determined from the gas motions fairly well, indicating a centralized mass, presumably a black hole, of a few million solar masses. While not the best fit, the mass distribution proportional to $1/r^{1.8}$ indicated by present stellar measurements is also not very far outside of the probable errors of Rieke and Rieke (1988), as shown by the bars on Figure 7. However, if there is a core radius of about one parsec as suggested by Rieke and Lebofsky (1987) and which seems reasonable, particularly after the demonstration of obscuration by Genzel et al. (unpublished) mentioned above, then the stellar velocity distribution would be quite unexplainable from the stellar distribution alone.

Fortunately, Sellgren et al. will report other measurements of stellar velocities at this conference, measured by a still different technique. Instead of measuring individual stars, they used an 8 arc second field of view in order to measure the CO bandheads from the average of a large number of stars within the field of view, thus very much reducing the statistical uncertainty by using more stars. Their results should give further important information about the mass distribution.

Some of the most intriguing questions about the galactic center have to do with the nature of peculiar objects found there, and just where the center is actually located. The gaseous orbits analyzed by Serabyn et al. (1985, 1988) indicate that the dynamic center is within 5 arc seconds of Sgr A*. Sellgren et al. report in this conference that from the stellar measurements it is at least within 10 arc seconds of Sgr A*. The velocities shown in Figure 6 indicate that it might be about 5 arc seconds south of this object. Sgr A* is certainly a candidate for the center, or for a black hole. The striking measurements of Backer and Sramek (1982, 1987) show that the motion of Sgr A* perpendicular to the line of sight has not been greater than about 25 km s^{-1}. In view of the high velocities generally found in this region, and Sgr A*'s likely proximity to a black hole if there is one, this indicates that Sgr A* must be the heaviest object in the region unless it happens to be on an orbit which moves directly along the line of sight. The probability of the latter case is less than about 10%.

Ionization patterns within the central region indicate that much of the ionizing radiation comes from the very central region, and it would be natural to presume that it had an origin in material falling into the black hole if such exists. In this case, there should also be infrared present of detectable intensity, making the same object which is the origin of most of the ultraviolet radiation visible in the short infrared. So far, it is not clear which object, if it is a single one, has appropriate characteristics to fit this type of model. There have been many measurements of the relative position of Sgr A* with respect to IRS 16 and various other objects manifest in the short infrared. Figure 8 shows maps due to Forrest et al. (1986) and to Allen and Sanders (1986) which locate Sgr A* with respect to various components of IRS 16. It is not coincident with any of these infrared sources.

IRS 16 is in itself an interesting and puzzling object. Adams, Becklin et al, (1988) as well as a paper by Simons et al in this conference, show from lunar occultation that IRS 16 is composed of a number of point sources. Any one of these or their collection might be the source of the ultraviolet radiation. However, since from Figure 8 Sgr A* does not agree with any of them nor with any detected short infrared source, it would be difficult to make Sgr A* both a massive black hole and the primary source of the ultraviolet radiation. IRS 16 itself is generally very blue and bright, and difficult to identify with any normal object. Gas of velocity up to 1,000 km/sec has also been discovered in the region of IRS 16. It is extended over 1 or 2 arc seconds and does not appear to have the velocity distribution expected of orbiting material. Present evidence makes perhaps the best guess that Sgr A* is indeed a heavy black hole, but most of the ionizing photons come from components of IRS 16. However, the nature of Sgr A* and these various components of IRS 16 remain to be clarified.

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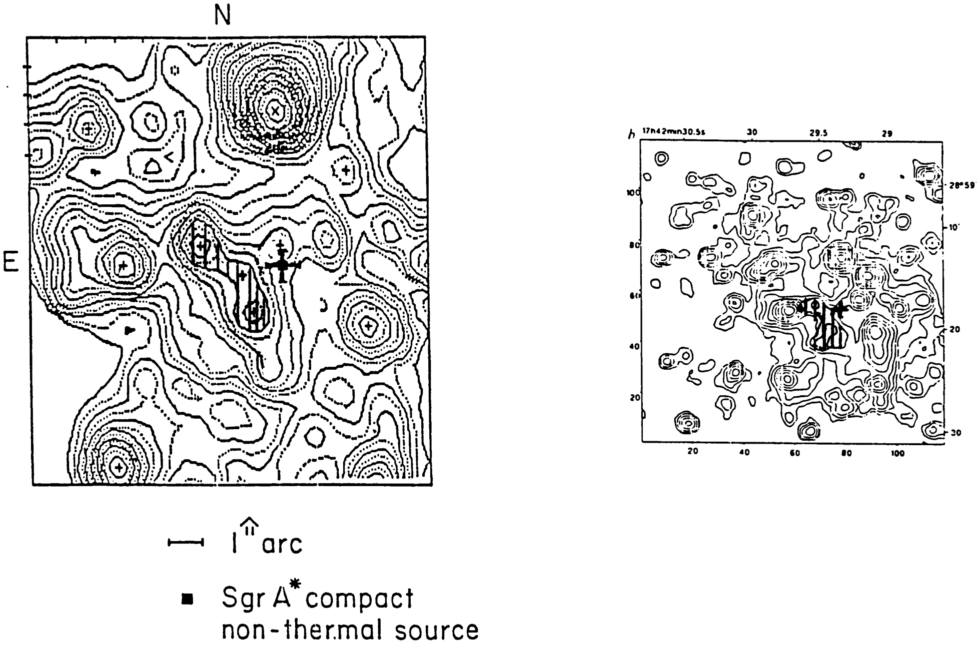

Figure 8. Infrared intensity contours of the region near Sgr A*. The left-hand figure is a map at 2.2μm by Forrest et al. (1986) and the right-hand one at 3.8μm by Allen and Sanders (1986). The crosses represent the position of Sgr A* and the regions covered with vertical lines the region of IRS 16.

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