

SECTION II.7

THE GALACTIC NUCLEUS

Wednesday 1 June, 1115 - 1310

Chairman: B.F. Burke



Students of the Galactic Nucleus: Schwarz and Oort in the garden of Lauswolt.

LZ

THE GALACTIC NUCLEUS

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ABSTRACT

The ionized gas within 2 parsec from the centre region is distributed in spiral-like features which appear to emanate from a nucleus. This nucleus is close to the ultra-compact radio source and the infrared source IRS 16, but does not exactly coincide with either. The spiral is strongly inclined to the galactic plane. The arms are clumpy. The spiral appears to rotate, but there appear to be also large radial motions.

The phenomena show some resemblance to what is observed on a very much larger scale in the nuclei of radio galaxies and quasars.

An exceptionally powerful, variable source of hard X- and gamma-rays, GCX, has been found in the direction of the centre. This may be the true galactic nucleus. Strong, variable emission of the 511-keV electron-positron annihilation line has also been observed to come from the central region.

The evidence for a central black hole is discussed. It is not compelling. The energy required for the strong infrared radiation emitted by the central few parsecs is probably coming from a large number of luminous stars, and due to a recent burst of star formation. The observed state of ionization indicates the burst to have occurred about one million years ago.

The distribution of the dense molecular clouds within 300 pc from the centre is very asymmetric: practically all lie at positive longitudes. Their motions differ radically from circular motions. The layer of clouds is tilted relative to the galactic plane. The so-called "+40-km/s cloud" lies in front of the nuclear spiral, and is therefore moving towards the centre. Different interpretations of the systematic motions are considered. The outspoken asymmetry excludes a static condition. If the "molecular ring" at $R \sim 150$ parsec is actually an expanding feature, its origin might be sought in the same burst of star formation proposed to explain the state of ionization and the infrared radiation of the nuclear region.

THE MINI-SPIRAL

An extremely interesting insight into the nucleus of the Milky Way System has recently been obtained from high-resolution observations at wavelengths between 2 and 20 cm. The region within $\sim 40''$, or 2 pc, from the centre is shown in Figs 1 and 2. Fig. 1, from an investigation by

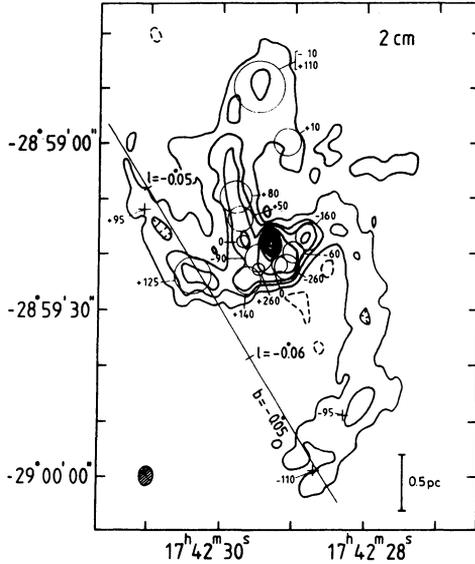


Fig. 1. Contour map at 2 cm of spiral structure in the galactic nucleus.

Half-power beamwidth $2'' \times 3''$ (Ekers *et al.* 1983). The circles indicate positions and diameters of $[\text{NeII}]$ clouds; the numbers are velocities in km s^{-1} , determined by Lacy *et al.* (1980).

Ekers, van Gorkom, Schwarz & Goss (1983), shows the distribution at $\lambda = 2$ cm measured with the VLA with a half-power beamwidth of $2'' \times 3''$. Fig. 2 gives observations with the same instrument at 6 cm, and a still higher resolution ($1'' \times 2''$), recently obtained by Lo and Claussen (private communication). Main features are a striking spiral-like pattern, with a strong central bar. The dense concentration near the centre in Fig. 1 is that around the compact radio source. The pictures suggest ejections of jets from the nucleus, principally in a nearly East-West direction, and turning into a North-South pattern at about $1/2$ pc from the centre. It resembles the structures observed near the nuclei of radio galaxies and quasars. The structure is clumpy. The clumps are unstable, with half-lives of about 10^3 yr as estimated from their internal velocity. The average density in the spiral is about $4 \times 10^3 \text{ cm}^{-3}$. Its total mass is estimated at some tens of solar masses. Per year a mass of the order of $0.001 M_{\odot}$ appears to have been ejected. The denser parts had been observed in the $[\text{NeII}]$ line at $12.8 \mu\text{m}$ by Lacy *et al.* (1980) at Berkeley; these provide much information concerning the velocities in different parts of the pattern; part of their data are indicated in Fig. 1. High velocities (of $+260$ and -260 km s^{-1})

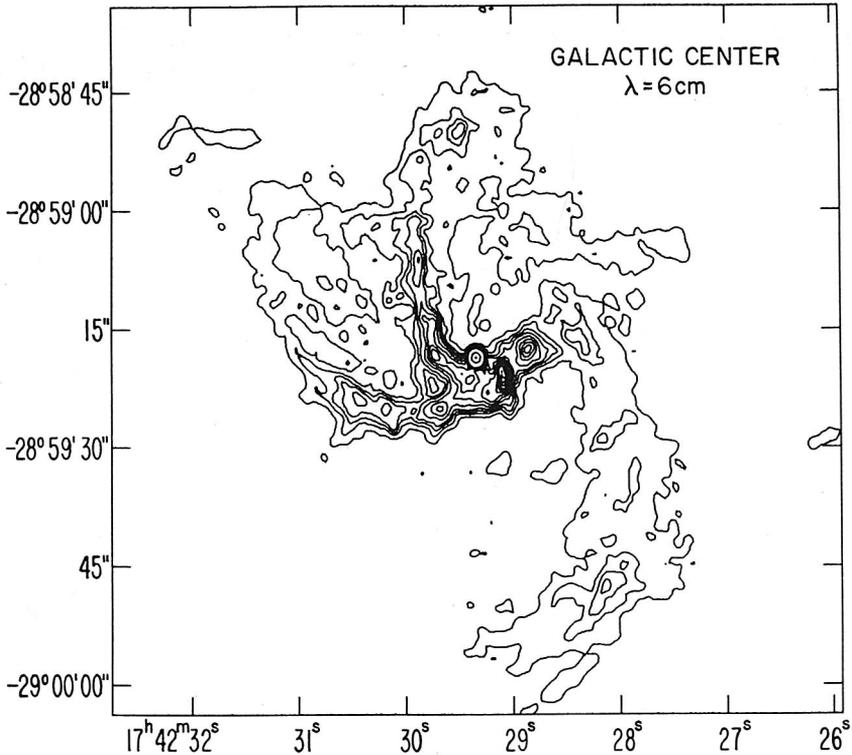


Fig. 2. Contour map at 6 cm. Resolution $1''.1 \times 1''.3$ (Courtesy of K.Y. Lo & M.J. Claussen).

occur in the immediate vicinity of the nucleus; at the ends of the "EW bar" they have dropped to $+125 \text{ km s}^{-1}$ on the E side and -160 km s^{-1} on the W side. In the N arm as well as in the NE arm the velocities are roughly $+100 \text{ km s}^{-1}$, in the S arm -100 km s^{-1} ; these velocities are in the same direction as the general rotation of the Galaxy, giving the impression that expelled gas is being swept along by gas already previously present in a rotating disk. Observations of hydrogen recombination lines at both Westerbork and the VLA (van Gorkom, Schwarz & Bregman 1985) have confirmed and extended the [NeII] velocities. If we are indeed witnessing ejection, its direction must evidently have made a large angle with the galactic plane. The hypothetical disk must therefore also have made a large angle with this plane.

The velocities do not furnish unambiguous evidence for outward motion. They can equally well be fitted to infalling clouds. But in order to come so close to the centre the clouds must have had extremely small initial transverse velocities, and it is a somewhat improbable accident that three clouds should be falling in simultaneously, two of which appearing to come from opposite directions. It is also difficult to see how the highly unstable clumps observed in the [NeII] lines could have formed in the infalling clouds.

Infall is strongly favoured by K.Y. Lo & M.J. Claussen, who are preparing an article on the subject. They suggest that a supernova exploded a few times 10^4 years ago and that clumps of swept-up gas are now falling back and are ionized by a concentration of OB stars near the centre.

Brown (1982), who first observed the spiral-like shapes (Brown *et al.* 1981), has proposed ejection from a rotating nozzle. Like the infall model this avoids the problem of having a pre-existing dense rotating disk.

The velocities observed at the positions nearest the centre ($+260$ km s^{-1} and -260 km s^{-1} respectively, at $R \sim 0.1$ pc) furnish a rough indication of the mass near the centre required to obtain such infall velocities, or, alternatively, the mass required to explain the decrease of expulsion velocities from ~ 260 km s^{-1} at 0.1 pc to ~ 100 km s^{-1} at 1 pc. This is of the order of $10^6 M_{\odot}$.

A CENTRAL BLACK HOLE?

It has variously been suggested that the bulk of this mass might be in a black hole. The evidence, however, is rather indirect, and cannot be considered as compelling. It rests principally, on the one hand, on observations of the systematic motion of the interstellar neutral hydrogen in the central 500 pc, and on the other hand, on the distribution of population II stars inferred from the near-infrared radiation, the latter combined with an $M/L_{2.2\mu}$ inferred from the nucleus of M31 (cf. Oort 1977). The observations give some evidence that the star distribution does not provide a sufficiently large mass to explain the motions, and that therefore an additional mass of the order of a few million solar masses may be required. But the arguments are not conclusive (cf. also Isaacman 1981, who has derived a value for the mass within $R = 1$ kpc from the distribution and motions of planetary nebulae).

It should be noted that a star concentration should have a density of $2 \times 10^8 M_{\odot} pc^{-3}$ to reach such a mass in a volume of 0.1 pc radius, while a density of 10^{10} hydrogen atoms per cm^3 would be needed for a gas clump of the same mass. Both values are improbably high. Whether a black hole at the centre would be observable depends among other factors on its present rate of accretion.

There are three peculiar objects which have been considered as possible candidates for the actual nucleus: (1) an ultra-compact radio source, (2) a sharp concentration of $2\text{-}\mu m$ radiation, called IRS 16, and (3) a source of X- and γ -rays called GCX. I shall deal with each of these in succession.

THE COMPACT RADIO SOURCE

VLBI observations have shown that the radio source is extremely small. The most recent measures at a wavelength of 1.3 cm, reported by K.Y. Lo, appear to have resolved it, and to have overcome the influence of interstellar scattering. These observations yield a diameter of $0''.0035$, or 5×10^{14} cm = 30 A.U. (Lo & Claussen, private communication). Previously Kellermann *et al.* (1977), observing at 3.8 cm, found a core

$\leq 0''.001$; this core has not been seen in later observations. The main source is variable with amplitudes of 20 to 40% on time scales ranging from days to years (Brown & Lo 1982). The variations are larger at 3.7 cm than at 11 cm; the 11-cm flux has increased systematically by a factor 1.5 in three years.

THE SOURCE IRS 16

This lies at the centre of a general concentration of 2- to 3- μ m emission, and has been thought to be the core of the distribution of population II (cf. Bailey 1980). This is now doubted on the ground that its spectrum does not show the CO absorption typical for late-type giants; cf. Wollman *et al.* (1982) who conclude: "If it is a central condensation of stars, the population is abnormal". Recent observations of a 1500 km s⁻¹ wide He emission line in this source, and the total absence of a similar H line (Hall *et al.* 1982) also indicate that something quite different is involved in IRS 16. Finally, IRS 16 does not coincide with the dynamical centre suggested by Fig.'s 1 and 2, but lies about 4", or 0.2 pc, NE of it. The ultra-compact radio source lies at a similar distance, but apparently does not coincide exactly with IRS 16; it lies 1".8 W of it (Ekers, private communication).

GCX

In the 0.5 - 4.5 keV energy range observations with the Einstein satellite at a resolution of 1' have located 12 sources within 0.5' from the centre, one of which coincides with Sgr A West. This is a relatively weak source, and has not varied in brightness between two observations 6 months apart (Watson *et al.* 1981). Observations with HEAO-1 in the 10-100 keV range have given particularly interesting information (Levine *et al.* 1979). The resolution, of $\sim 1.6'$, is much less than for the Einstein satellite, but a central source is found which in the higher half of this energy range surpasses all other sources in a field between $\ell -40^\circ$ and $+40^\circ$, $b -20^\circ$ and $+20^\circ$ except for a transient source Nova Oph 1977. This central source is variable on a time scale of the order of half a year. Fig. 3, taken from Matteson (1982), illustrates the nature of the source in comparison to the other sources in the field. The maximum luminosity in the 10 keV to 10 MeV range is $\sim 3 \times 10^{38}$ erg s⁻¹, and at these energies is the largest of any known galactic source (Matteson 1982). Although the positional uncertainty is considerable ($\sim 0.5'$), the unique nature of this source, and its probable coincidence with the more accurately located Einstein X-ray source, make it likely that it is the galactic nucleus itself (cited from Matteson 1982). The source was observed in three periods separated by half-year intervals, and was found to vary considerably, in particular at the highest energies, indicating a diameter of 0.2 pc or less. The variation has been confirmed and extended by other observations, notably by the HEAO-3 satellite. At 300 keV variations by factors 4 to 8 have been found. At the still higher energies (10 MeV - 1 GeV) observed by the COS-B satellite, with $\sim 1^\circ$ resolution, there is a source, 2CG359-00,

GALACTIC CENTER REGION

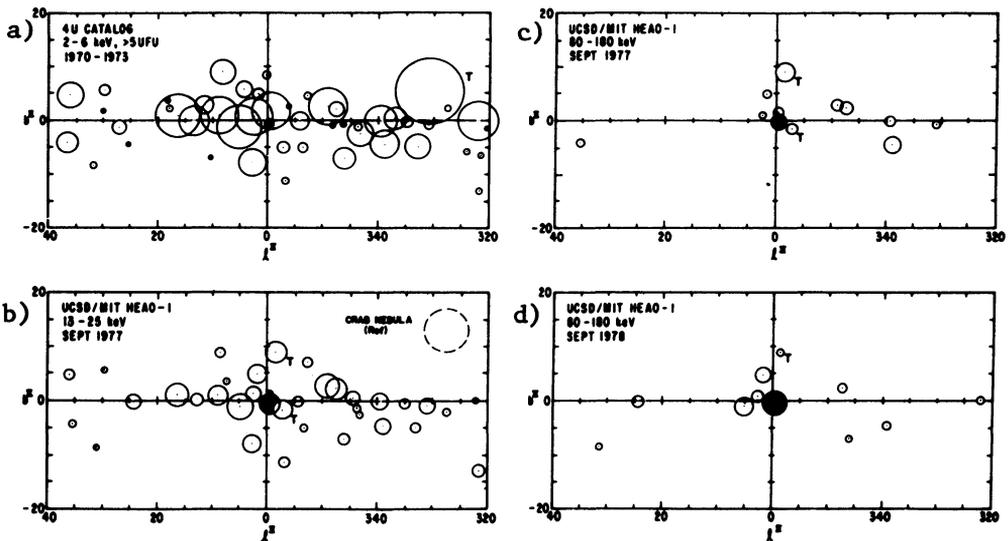


Fig. 3. X-ray maps of the galactic-centre region, with l^{II} , b^{II} in degrees. The area of a circle is proportional to a source's luminosity per logarithmic energy band (Matteson 1982).

at l° from the centre, but this is not unique in strength, and cannot yet with certainty be identified with the galactic nucleus.

It may be concluded from the above observations that the nucleus produces energetic particles corresponding with a maximum effective temperature of $\sim 10^{10}$ K, and varying in intensity in a period estimated to be of the order of 1 to 2 years.

THE POSITRON-ELECTRON ANNIHILATION LINE AT 511 keV

Beside continuum emission, wide-angle instruments have also detected line emission at a wavelength corresponding to 511 keV, coming from the general direction of the centre. Like the continuum the line emission is variable, and on a similar time scale. This proves that it probably comes from a single object with a diameter of the order of 0.2 pc or smaller. It is tempting to believe that it must in some way be connected with the nucleus itself. The line results from the annihilation of positrons. The narrowness of the line shows that the positrons must have been effectively cooled before recombination. The gas contained in the nuclear spiral could well provide the appropriate medium for this. According to Lingenfelter & Ramaty (1982) the positrons are most likely produced by photon-photon collisions in the vicinity of a compact source in the galactic centre. These authors conclude that the diameter of the positron source must be $\sim 3 \times 10^8$ cm and the mass of the black hole be $\sim 500 M_{\odot}$. Blandford (1982)

has, however, suggested that the positrons could be produced in the magnetosphere of a $\sim 10^6 M_{\odot}$ black hole, while Novikov *et al.* (preprint) have proposed interaction of a γ -ray beam from a massive black hole with an interstellar cloud as a possible mechanism. It is still unclear what relation, if any, exists between the variable X- and γ -ray source, the positron source and the minispiral of ionized gas.

ENERGETICS AND SOURCE OF IONIZATION IN THE CENTRAL FEW PARSECS

Lacy *et al.* (1980) have extensively discussed the state of ionization of the gas. This is considerably lower than in other known HII-regions, and indicates an ionizing source of about 30 000 K. Such a source could be provided by a burst of star formation about one million years ago.

For a 3' region centred on the galactic nucleus we have the following requirements:

From far-IR radiation and from grain temperature we conclude that $> 1.5 \times 10^{50}$ Ly_{cont} photons per sec are needed, while the state of ionization shows that the effective temperature of the ionizing stars must be less than 35 000 $^{\circ}$. From the presence of more than 7 red supergiants it is expected that there will be more than 80 blue supergiants. With a normal distribution in spectral type and luminosity these would give a luminosity exceeding $1.5 \times 10^7 L_{\odot}$, a Ly_{cont} flux of more than $1.9 \times 10^{50} \text{ sec}^{-1}$ and a Ly_{cont} temperature of ~ 35 000 K.

Rieke & Lebofsky (1982) conclude: A star burst causing rapid star formation up to about 10^6 years ago can entirely explain the energetics in the inner few parsecs. The galactic centre is therefore similar to the star-burst powered nuclei of many spiral galaxies.

SUPERNOVA REMNANT CLOSE TO THE CENTRE

There is one more phenomenon which should be mentioned in connection with the region within 5 pc from the centre, viz. a shell-like structure of non-thermal radiation, which is clearly shown in Fig. 4 as an elliptical ring with a diameter of roughly 9 pc along the galactic plane and 6 pc perpendicular to it. This is most likely a supernova remnant. In earlier studies the brightest part on the Eastern side has been called Sgr A East. The centre lies at an apparent distance of roughly 50", or 2 pc, from the centre of the small spiral, and is probably also spatially close to it. There is no clear evidence that the shell has interacted with the gas in the spiral.

SUMMARY CONCERNING THE COMPACT NUCLEUS

The motions within 1 pc from the centre indicate the presence of a mass of at least one million solar masses which may plausibly be ascribed to a black hole, though the evidence is not yet convincing. A magnetized black hole of this order may also provide a mechanism for creating the large number of positrons which produce the strong, variable radiation in

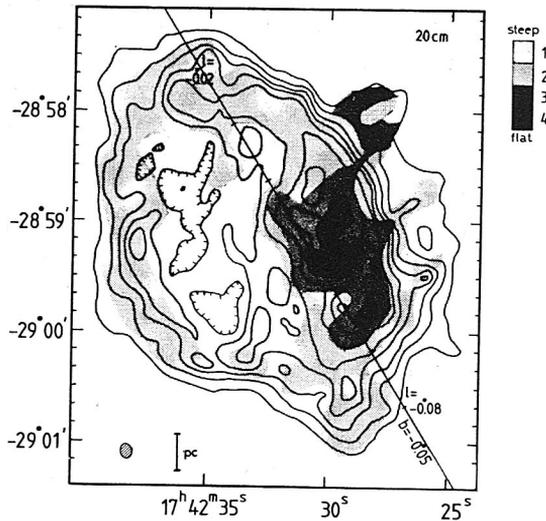


Fig. 4. Spectral index distribution superimposed on 20-cm map. Four intervals are given: 1. $\alpha < -1$; 2. $-1 < \alpha < -0.5$; 3. $-0.5 < \alpha < 0.0$; 4. $\alpha > 0.0$ (Ekers *et al.* 1983).

the 511 keV electron-positron annihilation line. A black hole may furthermore be needed for the production of the curious spiral features observed in the central 2 pc.

It is likely that the exceptionally strong and variable source of X- and γ -rays in the 50 keV to 10 MeV range called GCX coincides with the nucleus; this is corroborated by the close coincidence with Sgr A West of the accurately positioned, but less energetic point source observed in the 0.5 - 4.5 keV range.

Both the ultra-compact radio source and IRS 16 (whose positions appear to differ by $1''.8$) might coincide with the X- γ ray source; they are situated well within the uncertainty range of its position; but neither of them may qualify for the actual nucleus, because they lie about $4''$ away from what appears to be the dynamical centre of the spiral features.

THE WIDER SURROUNDINGS OF THE CENTRE

The General Mass Distribution

This can best be derived from the radiation in the near infrared, which may be assumed to come from population II stars. For the region within $\sim 1^\circ$ from the centre the most relevant observations are those of Becklin & Neugebauer (1969) at $2.2\mu\text{m}$. They have been discussed most extensively by Sanders & Lowinger (1972) and have been confronted with observations of HI velocities and with observations of the infrared and optical brightness in the nucleus of M31 to derive the mass distribution and the gravitational field (cf. also Oort 1977). The density varies

approximately as $R^{-1.8}$. Recent observations by Matsumoto *et al.* (1982) with a resolution of $0.5''$ and $0.8''$ at 2.4 and $3.4\mu\text{m}$ have given a valuable extension to $\sim 10''$ from the centre. Their Fig. 1 shows the distribution at $2.4\mu\text{m}$ corrected for extinction. They also give a comparison of the rotation curve derived from these data with that derived from HI velocities.

HII REGIONS WITHIN $0.25''$ (40 PC) FROM THE CENTRE

Fig. 5 shows the distribution (due to Pauls *et al.* 1976) of these regions. There are two peculiar circumstances: Firstly, all the ionized gas lies at positive longitudes. It forms a structure which has been

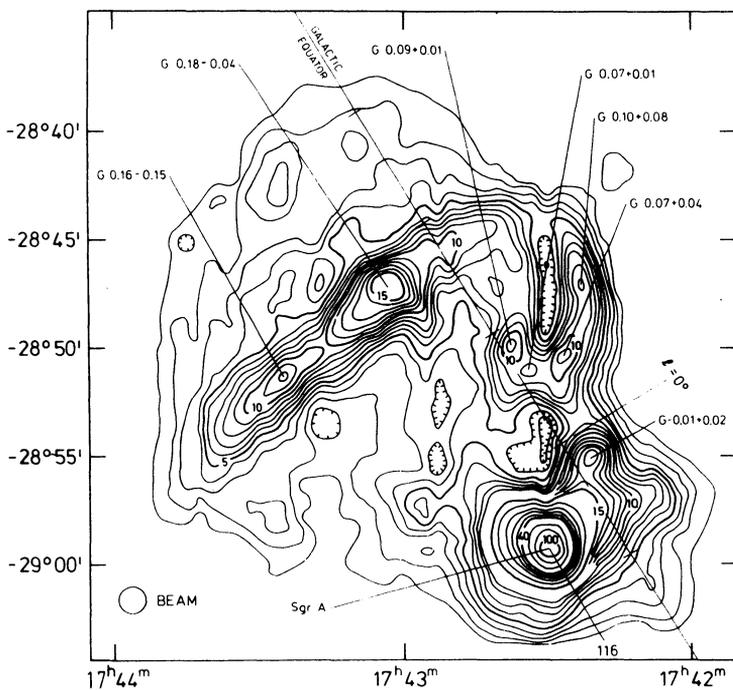


Fig. 5. Map of the continuum emission at 10 GHz within $15'$ of the centre, made with the Bonn 100-m telescope (Pauls *et al.* 1976).

called the Arc by the discoverers in Bonn. Secondly, the radial velocities of all clouds, as derived from hydrogen recombination lines, are remarkably small, ranging from -48 km s^{-1} at the longitude of the centre to -20 km s^{-1} at the sharp bend in the North, and smaller still along the North band of the arc. These velocities are much smaller than the circular velocities of $100\text{--}150 \text{ km s}^{-1}$ at the same distance from the centre, inferred from the distribution of the infrared radiation. If the latter values for the circular velocity are correct the clouds clearly do not move in circular orbits. They might have been expelled from the nucleus and be near their

apocentres. Westerbork observations have indicated that there is considerable fine-structure in these features.

MOLECULAR CLOUDS

Large-beam observations of the absorption lines of OH and H_2CO in Sgr A show two overpowering features, at ~ -130 and $\sim +40$ km s^{-1} , respectively; both are very wide, with half-intensity widths of ~ 70 km s^{-1} (Fig. 6). The first appears to be part of a large expanding feature extending to nearly 1° (150 pc) on either side of the centre, and has a counterpart of comparable mass on the far side of the centre, moving away from it at about 160 km s^{-1} , as inferred from observations of CO emission. Together, these features give the impression of a massive expanding ring; but other interpretations have also been suggested.

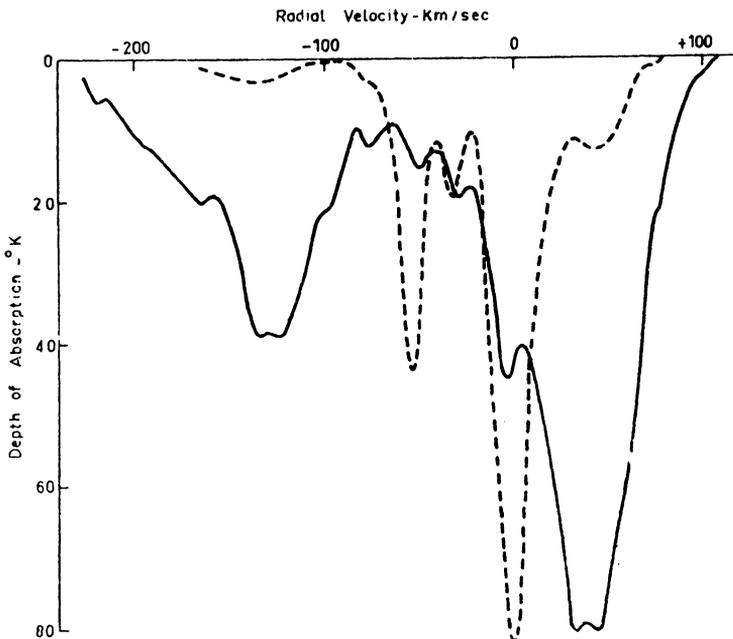


Fig. 6. Absorption profile of Sgr A observed with the Parkes telescope (Bolton *et al.* 1964). Full curve: OH; dashed curve: HI.

THE $+40$ KM S^{-1} CLOUD

The feature at $+40$ km s^{-1} is likewise part of an extended structure, as may be seen from Fig. 7 showing the HCN emission at 3.4 mm. Its main mass lies at positive longitudes, where it extends to $\sim +0.2$ (Fukui *et al.* 1977 and 1980). The cloud has a total mass estimated to be between 10^6 and 10^7 M_\odot . There has been considerable controversy concerning the question whether it moves inward towards the centre, as would be suggested by its

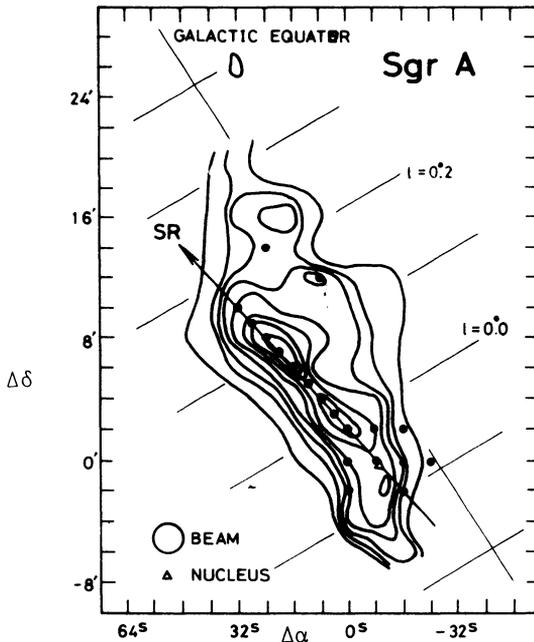


Fig. 7. The HCN emission from the "+40 to +50 km s⁻¹ cloud" (Fukui *et al.* 1980; cf. also Fukui *et al.* 1977).

being seen in absorption against Sgr A; or whether it lies behind the centre and is seen in absorption against Sgr A East, which might lie beyond the centre, in which case it could be moving outward from the true centre. Recent VLA observations by Whiteoak *et al.* (1983) appear to have settled the problem. These observations with a beam of 3.5" show H₂CO at velocities between +40 and +45 km s⁻¹ in absorption against the small nuclear spiral discussed in the first part of this lecture. As the latter is presumably connected with the real nucleus, we must conclude that at least the part of the +40 km s⁻¹ cloud covered by the VLA observations is moving inward towards the centre. A similar conclusion has earlier been stated by Sandqvist (1982). As the phenomena observed in the molecular clouds of the central region appear to require expulsion and subsequent falling back of these clouds, the observation of inward moving features should cause no surprise.

Most interesting information concerning in- and outward moving gas clouds has come from an investigation by Liszt *et al.* (1983), who have observed HI absorption against a region of about 3" diameter around Sgr A West. The observations were made with the VLA at an angular resolution of 12". The authors found absorption features over the range from -200 to +140 km s⁻¹. Only the gas at velocities larger than +150 km s⁻¹ is unabsorbed and must lie beyond the centre.

An interesting detail is that, with their very small beam, Whiteoak *et al.* did not see any sign of absorption of the +40 km s⁻¹ cloud against

the compact radio source, although they did see the cloud in absorption against the small spiral at this position.

Must we conclude that the point source lies in front of the $+40 \text{ km s}^{-1}$ cloud? This is implausible, because the large size of the cloud would then place it at least 10 pc in front of the centre, while its lateral distance is only 0.1 pc or less. Liszt has drawn my attention to the extreme clumpiness of the H_2CO distribution in general, and that as a consequence the number of clumps of the $+40 \text{ km s}^{-1}$ cloud expected to lie directly in front of the point source might be sufficiently small for the line of sight to the point source not to cross any.

OTHER PHENOMENA OF THE GAS IN THE CENTRAL REGION

Let us now briefly consider some other phenomena observed in the distribution and motion of the gas in the nuclear region.

Three main peculiarities have to be explained: 1. the large radial components observed in the gas motions, 2. the striking asymmetry in the distribution of the molecular clouds (cf. Fig. 8), and 3. the fact that the high-velocity gas within the central 1-2 kpc lies in a tilted layer. The latter phenomenon has been studied most extensively by Liszt & Burton (1980), who concluded that between $\sim 1^\circ$ and $\sim 6^\circ$ from the centre the gas disk is tilted by as much as 24° to the galactic equator. In the inner few hundred parsecs the tilt is still present but is much less.

EXPANDING FEATURES?

I have mentioned the "expanding molecular ring" which, at a distance of 190 pc from the centre, appears to have an average radial component away from the centre of 150 km s^{-1} . If this gas has been expelled from the centre it has been decelerated by sweeping up gas from a rotating disk, as indicated by its having a transverse velocity of about 50 km s^{-1} in the direction of the general rotation. The mass of the ring is estimated at about $10^7 M_\odot$.

Liszt & Burton (1980) have proposed a different interpretation of the feature. They proposed an alternative description of this as well as all features farther from the centre that had been ascribed to expanding gas. In their model the gas is supposed to move in central ellipses of considerable excentricity, with major axes in a direction making a considerable angle with the line of sight, as well as with the galactic plane. The model describes sufficiently well all observed velocity contours, but no satisfactory dynamical interpretation has yet been given.

The most straightforward interpretation of the molecular ring would still seem to be that it is ejected from the nucleus, although the mechanism causing the ejection is still obscure. The ejection should have taken place about a million years ago. It is possible that the star burst which has supposedly formed the late O stars required to explain the observed state of ionization of the nuclear gas clouds has been responsible for this ejection.

Güsten & Downes (preprint 1983) have recently drawn attention to formaldehyde at still higher velocity ($\sim -190 \text{ km s}^{-1}$) which is seen in absorption against Sgr A. They believe that it has been ejected. It extends

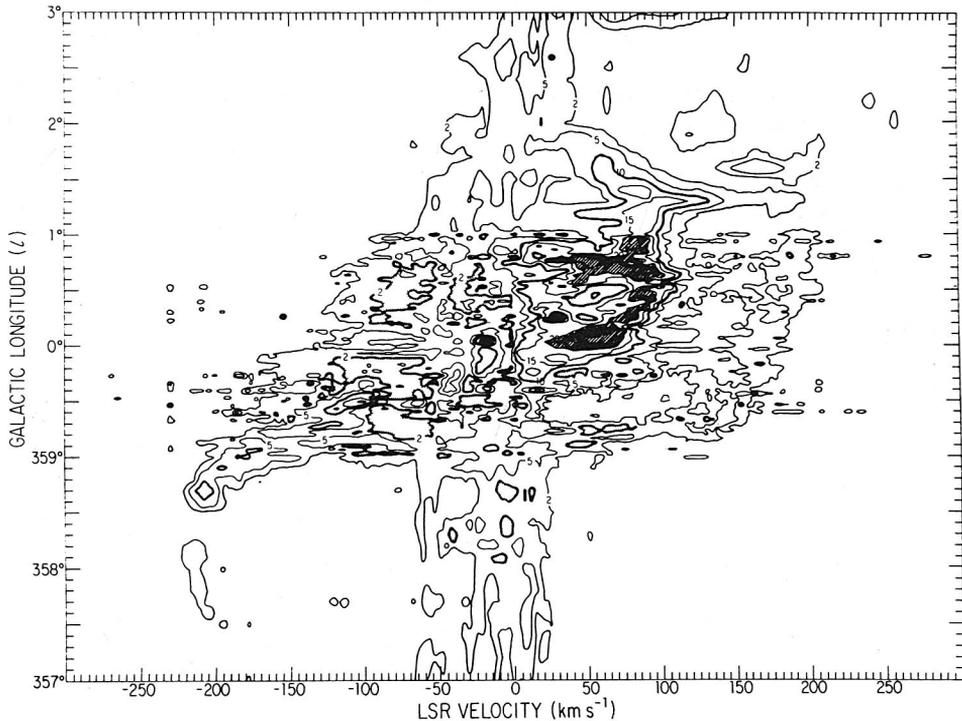


Fig. 8. Longitude-velocity map of ^{12}CO emission at $b = 0^\circ$. From observations with the 11-m NRAO telescope on Kitt Peak (Bania 1977). The part between $l = 359^\circ$ and $l = 1^\circ$ is from a study by Liszt *et al.* (1977). Contour levels are drawn at $T^* = 2, 5, 10, 15, 20, 25, 30 \text{ K}$. Heavy line: 10 K contour; hatched areas are above 20K; black is above 30K.

to at least 5 pc from the centre.

ASYMMETRY AND LOW ROTATION OF THE BULK OF THE MOLECULAR GAS

The distribution of the molecular gas as observed in the CO emission at 2.6 mm is extremely asymmetric, cf. Fig. 8. All dense clouds are situated at positive longitudes. The strongest concentration, Sgr B2, at $l = +0^\circ.67$ has been the subject of numerous investigations. It is a strong radio source, containing at least 7 giant compact HII regions, as well as some dense molecular and dust clouds; the CO clouds have a velocity range from +45 to +100 km s^{-1} . There is an apparent bridge at +70 to +90 km s^{-1} between the dense feature at $l = 0^\circ$ (which is mostly due to the +40 km s^{-1} cloud) and Sgr B2. Some fairly dense features continue to +1 $^\circ.5$ longitude, beyond which there is a fairly rapid drop. The "+40 km s^{-1} cloud" itself lies also almost completely at positive longitudes.

A similar preference for positive longitude has been described above for the "Arc" of ionized gas near the centre.

The molecular gas at positive longitude exhibits a systematic motion

in the same direction as the general rotation, but the velocity is considerably less than the circular velocities corresponding to the assumed gravitational field.

Clearly, the distribution and motions are widely different from equilibrium conditions. As the time of revolution in the region concerned is only a few million years, the disturbance which has caused the anomalous distribution and motions must have been quite recent. Its nature is unknown. In view of the large masses involved (of the order of $10^8 M_{\odot}$) it must have been powerful.

A brief reference must be made to the anomalous motions of some large features at greater distances from the centre, the most massive of which is the 3-kpc arm, which at the longitude of the centre has an outward velocity of 53 km s^{-1} . There are half a dozen other extended features between ~ 1 and 4 kpc from the centre which at $l = 0^{\circ}$ show outward motions between ~ 100 and $\sim 150 \text{ km s}^{-1}$. (Cf. a summary by Oort (1977), based on discussions by van der Kruit (1970) and Cohen & Davies (1976)). All these may be interpreted as expanding structures pushed out by gas expelled from the centre, or, alternatively, as gas moving in excentric orbits in a bar-like potential field, as supposed by Liszt & Burton (1980). The expulsion theory would require a state of nuclear activity far greater than what is observed at present. The phenomena observed in Seyfert galaxies, and, in particular, those in the seemingly normal spiral NGC 4258, show that activity of the scope required does occur in spiral galaxies.

However, the most direct indication of violent activity - in a relatively nearby past - is shown by the molecular clouds within 250 pc from the centre, by the "Arc" within 40 pc , and by the minispiral of ionized gas within 1 pc from the centre.

The hard X- and γ -ray source at the centre shows that activity is continuing at the present time.

THE TILT OF THE GAS LAYER

This might or might not be connected with the same "disturbance" that caused the phenomena discussed above, but most likely this is mainly due to a triaxial distribution of the central mass. The nature of the motions to be expected in a triaxial gravitational field in the central region is being investigated extensively by W.A. Mulder and T. de Zeeuw in Leiden.

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DISCUSSION

B.F. Burke (Chairman): We are used to subjects getting larger and larger. This one becomes smaller and smaller as we proceed.

Oort: Not quite: Lo has now found the limit and resolved the source.

A. Blaauw: A fundamental, almost philosophical, point is whether there

is a "true Nucleus" of the Galaxy, if one goes to smaller and smaller scales. Ambartsumian and his associates think there is something of primordial, even fundamental, significance in the Nucleus. But is it not true that, if one goes to smaller and smaller dimensions, of the order of parsecs, the notion of "the Nucleus" vanishes? A gravitational pit there one could only notice if one orbited around it. Do you think there is more to it than this?

Oort: I can answer that briefly: a black hole.

Blaauw: Yes, but is that not a secondary phenomenon? A black hole may have formed in the course of the Galaxy's evolution, but it was not primordial in the formation of the Galaxy.

Oort: I do not know that at all. It may have formed in the course of time, but there are now several phenomena which one would like to explain with a black hole. One might say: The fundamental thing is the black hole.

H. van Woerden: It seems to me that the real question is whether there is a spike in the mass distribution at the Centre.

Oort: Yes, certainly - but one cannot see that well enough. The source IRS 16 has been suggested to represent the actual condensation in the general distribution of Population II stars. But it is doubtful whether it is really a central cluster. On a larger scale, one cannot define the centre well enough.

J.P. Ostriker: If the "central pit" in the galactic stellar density distribution has a size of parsecs, then perhaps a variety of interesting constituents can collect in this small region, including massive clusters, black holes dragged in by dynamical friction, and gas shed during normal stellar evolution. Could we not be witnessing the complex interaction amongst these constituents in "the pit", with no one of them being properly called the "true Centre" of the Galaxy?

R.H. Sanders: I wish to make a point about the central point source at the "true Nucleus". Backer and Sramek have measured the proper motion of this object at the VLA, and they find a proper motion consistent with the rotation of the Sun around the centre of the Galaxy. The error at present is about 100 km/s, but this will get better with time. If the object is a massive one, one would expect that it has settled to the "true Galactic Centre", and that it has no additional, peculiar motion in addition to the reflex of the Sun's rotation around the Centre.

H.S. Liszt: Even though we observe HI absorption over a very wide range of velocities, its behaviour is not at all chaotic and it can all be related to the molecular-cloud emission that we observe on arcminute scales. We do not understand it fully, but it is not chaotic.

Another point is that the +50 km/s HI cloud is seen in absorption

against the central point source, and that is important to stress. Absorption by H_2CO may be absent, but in HI it is strong: 20%.

Oort: But your HI observations have a much wider beam than Whiteoak's 3.5 arcsec for H_2CO . His narrow beam shows the minispiral absorbed at +40 km/s, but there is no sign whatever of absorption against the compact source.

Liszt: The thermal and nonthermal fluxes are much more heavily tangled at 20 cm than at 6 cm, hence the sources are difficult to separate. We should probably reobserve the source with the VLA, but I think the measured optical depth of 0.2 is too high for that to arise from absorption of the nonthermal emission.

Oort: That would be sympathetic, because it is very difficult to imagine the point source to be so far in front of the Centre as would be required if it really lies outside the +40 km/s cloud.

Liszt: I agree, but I think - HI is an atom, it samples atomic gas, hence can exist at lower densities; H_2CO and other things are molecules, which require different conditions for their existence. Hence it is important to consider chemical as well as geometric and kinematic factors.

The Chairman: Lynden-Bell.

Oort: Don't ask too difficult questions! (Laughter.)

D. Lynden-Bell: How definite do you regard a) the positron annihilation line itself, and b) its variability?

Oort: To me the line itself seems very convincing, but I am not an X-ray specialist and cannot judge well enough. Its wavelength fits perfectly. As to its variability, the earlier suggestion by HEAO results has been confirmed by recent balloon observations: it has disappeared more or less, so it has varied from a fairly strong line to nothing at present.

Lynden-Bell: But it did not go through an intermediate phase: it was just on once, off twice, right?

C.J. Cesarsky: Since HEAO it has been observed twice from balloons.

The Chairman: We must bring this discussion to a close. Several people still want to be heard, but it is better to be unfair to several, and at least give duty to the speakers.



Oort and Mrs. Oort (right), with Mrs. Borgman, at the Kapteyn-Van Rhijn exhibition. Background: official academic portrait of Kapteyn CFD