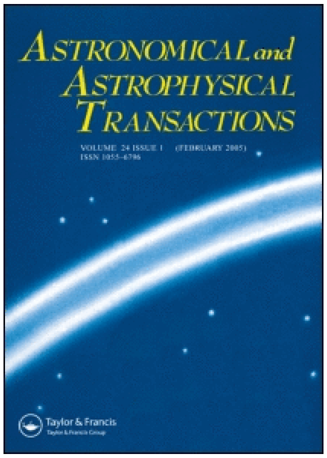

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I. F. Mirabel [a]
[a] Service d'astrophysique, Centre d'études de Saclay, Gif Yvette, France

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GROUND-BASED OBSERVATIONS OF PERSISTENT GAMMA-RAY SOURCES IN THE GALACTIC CENTRE REGION

I. F. MIRABEL†

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The two persistent soft gamma-ray sources in the galactic centre region are black hole candidates of stellar mass with comptonized accretion disks that radiate 10^{37-38} erg s^{-1}. They appear as microquasar stellar remnants from which double-sided radio jets emanate that extend over distances of a few parsecs. One of these sources is the strongest compact annihilator of positrons known so far in the Galaxy, which may be associated with a dense molecular cloud.

KEY WORDS Galaxy center—gamma rays, observations—radio continuum, interstellar—X-rays.

1. THE GALACTIC CENTRE IN SOFT GAMMA-RAYS

The observations with the telescope SIGMA on board of the Russian satellite GRANAT have shown that, contrary to the standard X-ray band (below 20 keV) where many sources have been detected at less than 5° from the galactic centre, at higher energies (35–500 keV) the field is dominated by only two persistent sources: 1E1740.7-2942 and GRS1758-258,[1,2] located respectively at ~50′ and ~5° from Sgr A (see Figure 1). Although variable, these are persistent sources since, unlike transients as the X-ray novae, they are detected most of the time. In the 30–500 keV band these sources radiate a few times 10^{37} erg s^{-1}, near the Eddington limit of a collapsed objects of stellar mass. Since no gamma-ray source was found associated with Sgr A, if there is a super-massive black hole at the dynamic centre of the Galaxy, at present it is in sepulchral silence.

These two sources are likely to be black holes of stellar mass. In their standard state, the shape of the X-ray spectra resembles that of the black hole candidate Cygnus X-1. The intrinsic X-ray luminosity of 1E1740.7-2942 is comparable to that of Cygnus X-1 at the distance of the galactic centre; GRS1758-258 is somewhat weaker.

2. RADIO JETS FROM THE TWO SOFT GAMMA-RAY SOURCES

To clarify the nature of these sources we are carrying out ground-based multiwavelength observations coordinated with the observations by SIGMA from

† Service d'astrophysique, Centre d'études de Saclay, 91191 Gif sur Yvette, France.

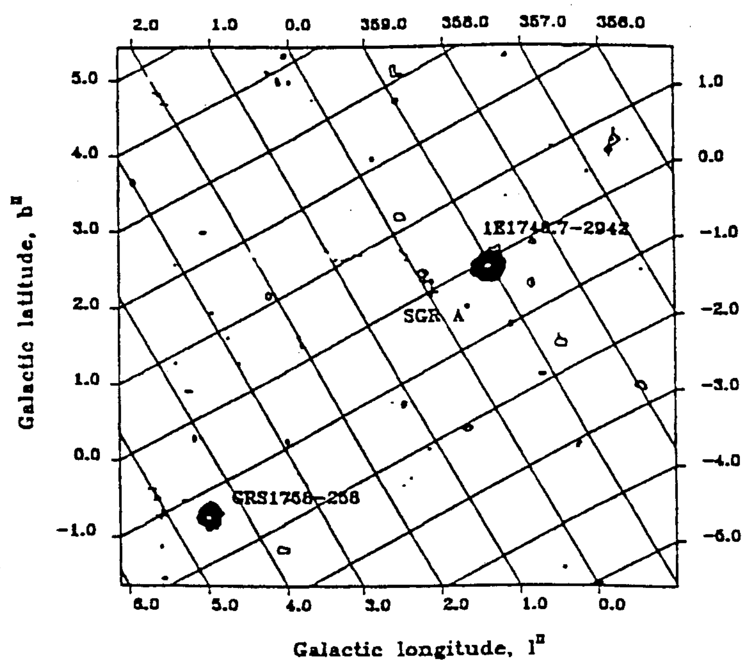

Figure 1 The hard (35–120 keV) X-ray image around the galactic centre obtained by the telescope SIGMA.[1] The two dominant persistent sources are 1E1740.7-2942 and GRS1758-258, respectivly at ~50′ and ~5° from Sgr A.

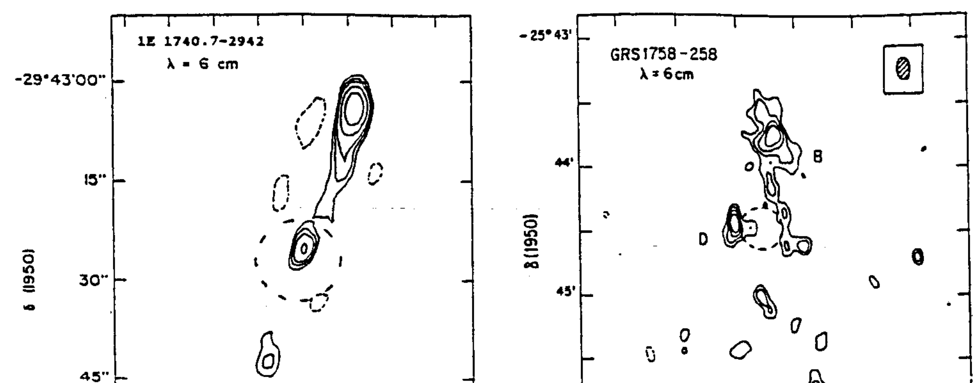

Figure 2 Radio jets associated with the soft gamma-ray sources 1E170.7-2942 and GRS1758-258 observed with the VLA at $\lambda 6$ cm.[3,5] The small dashed circles indicate the position of these sources reported by the soft X-ray satellite ROSAT.

space. Due to the high interstellar absorption along the line of sight to the central region of the Galaxy, optical identification of binary counterparts is very difficult. Therefore, we have undertaken observations at centimeter, millimeter, and infrared wavelengths.

The first result from coordinated VLA-SIGMA observations of these two sources was the identification of the compact radio counterparts with position accuracies $\leq 1''$, namely, 100 times better than the precision obtained with gamma-ray telescopes. Inside the error circles of the X-ray and gamma-ray telescopes we find compact radio sources, with time variations in the radio flux by factors $\gtrsim 4$, which are in the same sense as the soft gamma-ray photon counts by SIGMA.[3,4]

The study of these radio counterparts had an unexpected turn. Radio jets whose centers coincide with the variable sources were soon discovered[3,5] (see Figure 2). Both sources are double-sided and the lobes are aligned with the central, time variable source. The spectral index of the lobes in 1E1740.7-2942 is -0.8. These jets, a few parsecs long, are probably synchrotron sources due to e^+e^- pairs streaming out at high velocities from the high energy sources. Although it is very unlikely that these are extragalactic radio sources in coincidental superposition,[6] we have still to prove the contrary by the detection of time variability in the lobes.

3. THE EXTRAGALACTIC ANALOGY

There are indications that the analogy between these collapsed objects near the centre of the Galaxy and quasars is more than a morphological coincidence, and that perhaps the same basic physical mechanisms can explain these two types of objects. The standard theories in extragalactic research propose that there are three basic ingredients in AGNs and QSOs: a black hole of $10^{6-8}\,M_\odot$, an accretion disk, and radio jets extending to hundreds of kiloparsecs. The same ingredients, but scaled down, are present in 1E1740.7-2942 and GRS1758-258. In the context of the standard model[7] for hard X-ray sources, both sources are black holes of stellar mass with Comptonized accretion disks having temperatures of a few tens of keV. Besides, we find that jets of high energy particles emanate from both objects reaching distances of a few parsecs. Since these appear as quasars at stellar scales we call them "microquasars".

The two persistent soft gamma-ray sources in the galactic centre region are somewhat different from the celebrated microquasar SS433. Although they are more luminous in the X-rays, their radio flux is $\sim 10^{-3}$ that of SS433. Furthermore, the jets from these sources extend up to a few parsec only, whereas the jets in SS433 appear to reach the supernova remnant W50 at distance of ~ 100 pc.

Microquasars with the radio luminosity of SS433 must be rather uncommon since it is the only well collimated stellar radio jet with such a strong flux that is known within distances of several kiloparsecs from the Sun.[8] However, weak radio jets on parsec scales perhaps are commonly associated with hard X-ray sources when embedded in a high-density interstellar environment as that of the galactic centre region.

4. THE COMPACT GALACTIC CENTRE ANNIHILATOR

For two decades gamma-ray astronomers observing the galactic centre region with many balloon and satellite-borne instruments have been reporting intermittent radiation from the annihilation of positrons with electrons. Positrons are electrons of positive charge that annihilate when they meet ordinary matter, producing pairs of photons of 511 keV, the rest-mass energy of the annihilated particles.

The sporadic appearance of this type of gamma radiation in the central region of our Galaxy indicated the existence of a compact object (or objects) capable to produce enormous quantities of positrons in short periods of time. In this context, SIGMA found that 1E1740.7-2942 is a source of 511 keV gammaquanta. On October 13–14, 1990, a powerful annihilation burst around 420 keV was detected,[9,10] and we then came to the realization that this object is the strongest compact annihilation source known in the Galaxy. Since 1E1740.7-2942 can generate 10 billion (10^{10}) tonnes of positrons in just one second, it is now known under the name of the "Great Annihilator".

The broad annihilation line detected by SIGMA from the Great Annihilator should be distinguished from the variable component of the narrow annihilation line observed two decades ago from the galactic centre region. The broad line was observed with a high signal-to-noise ratio on one day only once. This implies that the annihilation took place in a region smaller than 200 astronomical units. If the observed redshift of 20% is gravitational, the annihilation took place in a region closer than 10 Schwarzchild radii from the black hole (for a black hole of stellar mass, the Schwarzchild radius is a few tens of km). This annihilation medium must have a size smaller than a few hundred kilometres in radius, temperatures above 10^8 K, and should be essentially transparent for the 511 keV annihilation photons.

Although the source of positrons at the origin of the broad line and the variable component of the narrow line may be the same, the annihilation medium of the narrow line must be different from that of the broad line. The redshift upper limit of 10^{-5} and the line width smaller than 5% indicate that this narrow line arises in a cold ($\leq 10^5$ K), dense medium ($n \geq 10^4$ cm^{-3}). These properties are consistent with those of molecular clouds which have temperatures below 100 K, and densities greater than 10^4 cm^{-3}. In this context one may ask if the Great Annihilator could be a black hole in a molecular cloud.

5. A BLACK HOLE NEAR A DENSE MOLECULAR CLOUD?

To answer this question we carried out observations of molecular transitions at millimetre wavelengths with the 30-m telescope of the IRAM in Sierra Nevada, southern Spain. The observations revealed the presence of a molecular cloud in the direction of the Great Annihilator.[11,12] The radial velocity indicates that this molecular cloud is in the galactic centre region, has a total mass of 50,000 solar masses, and a mean density of 10^5 cm^{-3}. The absorption in soft X-rays along the line of sight to the Great Annihilator suggests that the compact source could be inside or near the foreground surface of this cloud. Although the physical

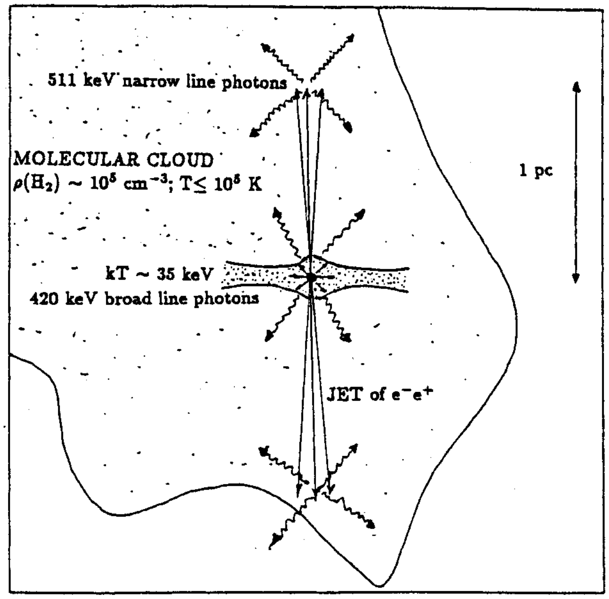

Figure 3 Theoretical model of the Great Annihilator, possibly a stellar-mass black hole in a molecular cloud.[11–13] Electron–positron pairs will annihilate sporadically near the black hole producing the redshifted broad emission line centred at 420 keV, as observed by SIGMA. Some fraction of the pairs will stream out at high velocities up to distances of ~1 pc before they are slowed down in the high density molecular gas, and annihilate giving rise to the 511 keV narrow line.

association of the gamma-ray source and the molecular cloud has not been demonstrated, the probability of a coincidental superposition is less than 7%.

To build up a model of the phenomenological diversity associated with the Great Annihilator, it is useful to employ a Cartesian approach, going from a simple picture to a more complex one. This simple picture, which at present is full of unanswered questions is shown in Figure 3. Instabilities in the accretion disk around a stellar-mass black hole produce an enhancement of gamma photons, which by $\gamma-\gamma$ interactions produce bursts of e^+e^- pairs which will annihilate within a few hundreds of kilometres from the black hole, producing the broad line observed by SIGMA.[13] Some fraction of the e^+e^- pairs will be accelerated by radiation pressure and collimated by magnetic fields. These pairs streaming away at relativistic velocities will produce well-aligned synchrotron radio jets observed with the VLA over a few light years of distance from the central source. The positrons will be slowed down in high-density clumps of the molecular cloud with the subsequent annihilation that gives rise to the time-variable narrow line.

When it is not fed, a black hole remains silent. Besides its gravitational effects, it can reveal its existence as a source of high-energy photons and particules produced at or near the accretion disk built at the expense of matter coming from a binary companion. For instance, Cygnus X-1, one of the best black hole candidates has a blue supergiant companion that feeds the black hole by its strong stellar wind. Other black hole candidates are fed by low-mass stellar companions, which transfer mass through the Roche lobes to the accretion disk of the black hole.

In an attempt to identify a binary companion, P. A. Duc and I went to the Southern European Observatory in the Andes, and used in infrared camera on a 2.2 m telescope. We obtained images in different bands between 1.2 and 2.2 μm of the field centred at the position of the VLA compact source, which we know with a precision better than 1″. We found no infrared counterpart within 1″ of the radio source down to mag 17 at 2.2 μm. This is comparable to the result obtained at Palomar.[14] For an optical absorption of 50 mag along the line of sight to the galactic centre, this infrared magnitude limit implies that the Great Annihilator is not accompanied by a massive star, as it is the black hole in Cygnus X-1. Calculations show that no massive star with optical luminosity brighter than $M_V = -3$ mag is associated with the high energy source.

Since it is difficult to explain the light curve of the Great Annihilator observed by SIGMA in terms of feeding by a low mass companion, it has been proposed that the compact source may be fed directly from the interstellar cloud by a classic mechanism first proposed by Bondi and Hoyle.[15] It has been shown[11,12] that a compact object of stellar mass slowly moving through a dense molecular cloud can accrete more than 10^{-8} solar masses per year, namely, the equivalent of the accretion rate from the stellar wind of a massive companion.

In the context of this hypothesis one may ask why only a single powerful source of high-energy emission and annihilation occurs within the inner few degrees of the Galaxy, where molecular gas is more abundant than anywhere else in the Galaxy, and where there is no reason to expect that massive stellar remnants are rare. According to our hypothesis, the unusual properties of the Great Annihilator are the result of two conditions, each of which has a small probability of being satisfied: first, that the object is located within a dense cloud, and second, that it has a relatively small velocity with respect to that cloud. Our calculations show that only one among the ~40,000 massive remnants within 200 pc from the centre of the Galaxy would satisfy the conditions required to produce a substantial accretion luminosity without a binary companion. Therefore, it is not surprising that despite the large amount of compact objects in the central region of the Galaxy, there is only one Great Annihilator.

Although this is a possible scenario from a theoretical point of view, we have not demonstrated that it also corresponds to reality. Therefore, it still remains an open question how the accretion disk of the black hole is actually fed.

An additional problem is the failure of the attempt to detect high quantum number radio recombination lines from positronium.[16] Recent calculations[17] show that the number of recombination line photons decreases steeply with increasing quantum number. In this context, the proposal by these authors for a search for the positronium H_α line in the near infrared is very interesting.

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