C. R. Physique 16 (2015) 686–703

Contents lists available at ScienceDirect

Comptes Rendus Physique

www.sciencedirect.com

Gamma-ray astronomy / Astronomie des rayons gamma

# Gamma rays from the Galactic Centre region

## *Rayons gamma de la région du centre galactique*

Meng Su [a], Christopher van Eldik [b]

[a] *Kavli Institute for Astrophysics and Space Research, Massachusetts Institute of Technology, Cambridge, USA*
[b] *ECAP, University of Erlangen-Nürnberg, Erwin-Rommel-Str. 1, 91058 Erlangen, Germany*

A R T I C L E  I N F O

*Article history:*
Available online 9 October 2015

*Keywords:*
Gamma rays
Observations
Galactic Centre
Fermi bubbles

*Mots-clés :*
Rayons gamma
Observations
Centre galactique
Bulles de Fermi

A B S T R A C T

During the last decades, increasingly precise astronomical observations of the Galactic Centre region at radio, infrared, and X-ray wavelengths laid the foundations for a detailed understanding of the high-energy astroparticle physics of this most remarkable location in the Galaxy. Recently, observations of this region in high energy (HE, 10 MeV–100 GeV) and very high energy (VHE, > 100 GeV) $\gamma$-rays added important insights into the emerging picture of the Galactic nucleus as a most violent and active region where acceleration of particles to highest energies and their transport can be studied in great detail. We review the current understanding of the $\gamma$-ray emission emanating from the Galactic Centre.


R É S U M É

Pendant les dernières décennies, la région du centre galactique a fait l'objet d'observations astronomiques de plus en plus précises en radio, en infrarouge et en rayons X, qui ont fourni les bases de l'étude des phenoménes de haute énergie à l'oeuvre dans cette partie remarquable de notre galaxie. Récemment, les observations de cette région dans le domaine des rayons gamma de haute et de très haute énergie (HE, 10 MeV–100 GeV, et VHE au-dessus de 100 GeV) ont apporté d'importantes informations, donnant du noyau galactique l'image d'une région active et violente où l'on peut étudier en détail l'accélération des particules aux très hautes énergies et leur transport. Cet article présente les interprétations actuelles des émissions gamma issues du centre galactique.


## 1. Introduction: the Galactic Centre environment

The innermost part of the Milky Way, including the Galactic nucleus with its multi-million solar mass black hole (BH), cannot be observed with the naked eye or with classical optical telescopes, because it is obscured by a thick layer of dust present along the Galactic Plane. It was therefore only in the 1950's that the Galactic nucleus was discovered by detection of intense radio emission from the barycentre of the Milky Way [1,2]. It is its relative proximity to Earth that makes the Galactic nucleus an ideal laboratory to study the astrophysics of galactic nuclei in general: the Galactic nucleus is located

*E-mail addresses:* mengsu@space.mit.edu (M. Su), christopher.van.eldik@physik.uni-erlangen.de (C. van Eldik).

http://dx.doi.org/10.1016/j.crhy.2015.09.001

about 8.5 kpc (or roughly 27,000 light years) away from Earth (the distance to our neighbour galaxy Andromeda, which also hosts a supermassive BH is about 770 kpc). Today, the central Galaxy is studied in a broad range of the electromagnetic spectrum, as the Galactic dust torus is mostly transparent to low-energy (radio and far infrared) radiation as well as to high-energy photons (X-rays up to multi-TeV γ-rays).

The dynamics of the inner (roughly 300 pc in radius) region of the Galaxy is largely driven by the presence of the supermassive BH, identified with the strong radio source Sgr A* [3]. Besides the BH, there is a wealth of other interesting phenomena observed in this region, such as places where new stars are being born (star formation regions), the remnants of massive explosions of stars terminating their life (supernova remnants, SNRs), rotating neutron stars that release tremendous energy into their surroundings, thereby forming pulsar wind nebulae (PWNe), and populations of high-mass X-ray luminous binary stars (for a review, see, e.g., [4,5]). The density of the interstellar medium (ISM) is on average about an order of magnitude larger than in other parts of the Galactic disk, and the region is pervaded by strong magnetic fields, probably by far exceeding the level of 5 nT [6] (as compared to typically a few hundred pT in the Galactic disk), leading to the observation of radiation from large-scale filamentary structures.

While far-infrared (IR) emission traces sites of ongoing star formation, non-thermal radio, X-ray and γ-ray emission indicate populations of charged particles that underwent acceleration to supra-thermal energies in cosmic accelerators such as SNRs, PWNe, in the vicinity of the supermassive BH or in colliding winds driven by massive stars in star-forming regions. It is therefore clear that observing the Galactic Centre (GC) region at these photon energies gives access to a completely different view of the inner Galaxy than the one expected to be seen by an optical telescope. In this context, observation of γ-rays at energies of a few GeV and beyond are key to characterise the high-energy astrophysical phenomena at work, as they trace the most violent phenomena at place in the GC region. Since about a decade, a new generation of sensitive HE and VHE γ-ray telescopes is in place, which give unprecedented access to the various high-energy processes in the GC: the Large Area Telescope (LAT, [7], onboard the Fermi satellite) and the ground-based telescope arrays H.E.S.S. [8], MAGIC [9] and VERITAS [10] enable detailed spectral, morphological and temporal studies of Galactic and extragalactic γ-ray-emitting sources in an energy range of 20 MeV to several 10 TeV. In the GC region, several new sources of high-energy γ-ray emission have been discovered and characterised by these instruments, thereby significantly advancing our knowledge about the astrophysical phenomena taking place in this region. Still, the angular resolution of these instruments is relatively moderate compared to instruments at other wavelengths: while X-ray telescopes routinely achieve arcsecond resolution, and infrared observations with a resolution of few 10 milliarcsecond are possible, the detection of HE and VHE γ-ray telescopes currently allows for a resolution of $\sim 0.05°$–$0.2°$ only (strongly dependent on the γ-ray energy). For the GC region, this means that the smallest physical structures that can be probed are of size $\sim$10 pc, limiting the direct comparison of γ-ray sources to possible counterparts observed at smaller energies via their morphology or spatial coincidence.

In this article we give an overview, based on γ-ray observations, of our current understanding of the high-energy astrophysics of the inner few 100 pc region of the Milky Way and summarise the progress made in the last years.

### 1.1. *The Central Molecular Zone and inner 50 pc region*

The first large-scale image of radio observations of the GC region is shown in Fig. 1, covering a sky area of several degrees across. The bulk of the emission is aligned with the Galactic plane and extends over about 300 pc in Galactic longitude, a region which is called the Central Molecular Zone (CMZ). The emission is largely dominated by non-thermal synchrotron radiation, suggesting that acceleration of electrons to supra-thermal energies takes place throughout the region, possibly to energies of a few 10 TeV and beyond. Within the CMZ, numerous sites of radio emission can be observed, which are at least partly connected to sites of ongoing particle acceleration. Several structures have clearly been identified as SNRs, and also the PWN inside the SNR G 0.9+0.1 is well visible. The regions denoted by Sgr B1, Sgr B2, Sgr C and Sgr D contain large concentrations of ionised or molecular material, with gas densities of more than $10^4$ cm$^{-3}$, exceeding by far the density of clouds at other locations in the Galaxy. Several thread-like filaments, notably the GC arc, are oriented perpendicular to the Galactic plane. The Galactic nucleus itself is located within the complex radio structure Sgr A.

The molecular cloud content of the CMZ has been mapped by measuring excitation lines from different molecules, most importantly *CO* [12,13] and *CS* [14]. From these measurements, the CMZ is estimated to host about 10% of the total molecular material of the Galaxy. Based on models of gas kinematics in the inner Galaxy [15] or OH absorption measurements [16], the measured Doppler shifts of the emission lines (which encode the radial velocity of the gas with respect to the observer) have been translated into distance information. Because the interaction of cosmic ray particles with ambient gas is a source of diffuse γ-ray emission, the resulting 3-dimensional maps are an important input to study cosmic ray transport. The gas maps suggest that the bulk of the gas content is located within a line-of-sight distance of 200 pc from the GC, with the eastern part containing the Sgr B complex being located in front, and the western part behind the position of the Galactic nucleus.

The inner 50 pc region of the CMZ is dominated by the Sgr A radio complex (see Fig. 1), which can be substructured [17] into (i) the bright compact radio source Sgr A* at the dynamical centre of the Galaxy, (ii) the extended, non-thermal source Sgr A East (at a projected distance of 2.5 pc from the centre), which encloses in projection (iii) Sgr A West, a three-armed H II region (the *minispiral*) which rotates around the GC and exhibits a thermal radio spectrum. Sgr A West itself is surrounded by the so-called (iv) Circum Nuclear Disk of molecular gas of mass $\sim 10^4 M_{\odot}$. Based on X-ray [18–20] and radio [21,22] observations, Sgr A East is nowadays identified as the remnant of a supernova event that took place about