INTEGRAL/IBIS search for e$^-$e$^+$ annihilation radiation from the Galactic Center Region

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Abstract

Electron-positron annihilation radiation from the Galactic Center region has been detected since the seventies, but its astrophysical origin is still a topic of a scientific debate. We have analyzed data of the gamma-ray imager IBIS/ISGRI onboard of ESA’s INTEGRAL platform in the e$^-$e$^+$ line. During the first year of the missions Galactic Center Deep Exposure no evidence for point sources at 511 keV has been found in the ISGRI data; the 2σ upper limit for resolved single point sources is estimated to be $1.6 \times 10^{-4}$ ph cm$^{-2}$ s$^{-1}$.

Key words: Gamma-rays: observations, Galaxy: bulge, INTEGRAL, IBIS

1 Introduction

In the seventies, balloon instruments provided first evidence for e$^-$e$^+$ annihilation from the Galactic Center region. As the line was discovered at an energy of $476 \pm 26$ keV (Johnson B., et al. 1972), the physical process behind the emission was initially ambiguous and had to await for the advent of high resolution spectrometers. In 1977, germanium semiconductors, flown for the first time on balloons, allowed to establish the identification of the narrow annihilation line at 511 keV, its width turned out to be of a few keV only (Albernhe et al. 1981, Leventhal et al. 1978). The eighties were marked by ups and downs in the measured 511 keV flux through a series of observations performed by the balloon-borne germanium detectors (principally the telescopes of Bell-Sandia and GSFC). The fluctuating results were interpreted as the signature of a compact source of annihilation radiation at the Galactic Center.
(see e.g. Leventhal 1991). Additional evidence for this scenario came initially from HEAO-3 (Rieger et al. 1981) reporting variability in the period between fall 1979 and spring 1980. Yet, during the early nineties, this interpretation was more and more questioned, since neither eight years of SMM data (Share et al. 1990) nor the revisited data of the HEAO-3 Ge detectors (Mahoney et al. 1993) showed evidence for variability in the 511 keV flux. Throughout the nineties, CGRO’s Oriented Scintillation Spectrometer Experiment (OSSE) measured steady fluxes from a galactic bulge and disk component (Purcell et al. 1997) and rough skymaps became available based on data from OSSE, SMM and TGRS. A possible third component at positive Galactic latitude was attributed to an annihilation fountain in the Galactic center.

Amongst the different models that have been proposed to explain the origin of positrons in the GC let us only mention a few: radioactive nuclei produced by nucleosynthesis (Ramaty R., et al. 1979), neutron stars or black holes (Lingenfelter R.E., Ramatay R. 1983), pulsars (Sturrock P.A. 1971), cosmic ray interaction with the interstellar medium (Kozlovsky B., et al. 1987), gamma-ray bursts (Lingenfelter R.E., Hueter G.J 1984) and light dark matter physics (Boehm C., et al. 2004).

Since the launch of INTEGRAL in October 2002, ample observing time of the mission’s core program has been devoted to the Galactic Center Deep Exposure (GCDE). A map obtained by SPI during the first year GCDE shows an extended 511 keV emission $(8_{-2}^{+3} \text{deg FWHM})$ centered symmetrically on the Galactic Center (Jean et al. 2004, Weidenspointner et al. 2004). The corresponding bulge flux is $0.96^{+0.21}_{-0.14} \times 10^{-3} \text{ ph cm}^{-2} \text{ s}^{-1}$, with the uncertainty being dominated by the width of the Gaussian intensity distribution. Spectroscopy of 511 keV line emission from the bulge resulted in a best fit energy of 511.02$^{+0.08}_{-0.09}$ keV and an intrinsic line width of 2.67$^{+0.30}_{-0.33}$ keV FWHM (Lonjou et al. 2004).

SPI has not detected emission from positive latitudes, and the Galactic plane emission - if existent - must be on a lower level than reported by OSSE. The GC emission at 511 keV can not be explained by a single source, yet the contribution of a number of point sources can not be excluded. The simple bulge morphology of the 511 keV emission observed by SPI is suggestive for a e$^+$ origin in the Galaxie’s old stellar population.

In the future, additional exposure and improved knowledge of background systematic will refine SPI’s image of Galactic e$^-$$e^+$ annihilation, and better constrain the many models proposed for its origin.

Also, an important contribution for constraining the models is expected to come from INTEGRAL’s imager IBIS. With its superior angular resolution and good sensitivity for point sources, IBIS will help to decide whether the
extended bulge emission is of genuinely diffuse origin or the result of a number of blended compact sources. In this article we present preliminary results of an ISGRI data analysis in the 511 keV band during the first year of the missions Galactic Center Deep Exposure. This analysis uses the IBIS Standard Analysis pipeline and is therefore optimized for - and limited to - point sources detection. For the diffuse emission detection, a so called “light bucket” data analysis technique has been performed for SPI 511 keV data analysis and at lower energies for IBIS/ISGRI (Lebrun F., et al. 2003). The light bucket analysis at 511 keV for IBIS is in progress and will be presented elsewhere.

2 Data analysis

The IBIS instrument (Ubertini P., et al. 2003) on board of the INTEGRAL satellite (Winkler C. et al., 2003) is an X and Gamma-ray coded mask telescope with a large field of view (29° × 29°) and a good angular resolution (12′). IBIS has also spectral capabilities in the wide energy band from 15 keV to 10 MeV, with a reasonable energy resolution. The position sensitive detector is based on two layer, ISGRI (Lebrun F., et al. 2003), a CdTe pixelated low energy 128 × 128 matrix, covering the range from 15 keV to 1 MeV, and PICsIT (Labanti C., et al. 2003), a CsI 64 × 64 matrix, covering the range from 175 keV to 10 MeV. The IBIS detectors Quantum Efficiencies (QE) (De Cesare G., et al. 2001) and the background count rate depend on the photon energy. The
Fig. 2. Two IBIS/ISGRI mosaic images of the Galactic Center Region in different energy bands. The low energy map on the left shows the mosaic in the energy band 18 keV - 40 keV. The image on the right shows the ISGRI mosaic in the energy band 120 keV - 250 keV. At high energies, six sources are clearly detected: 2 NS LMXBs (Ginga 1826-24, 4U 1812-12), 3 BH LMXBs (Granat 1758-258, 1E 1740.7-2942, IGR J17464-3213), 1 NS or BH HMXB (4U 1700-377)

ISGRI Quantum Efficiency (QE) is equal to 2.0 % at 511 keV, due to the low thickness (2 mm) of the CdTe detectors, but the background rate (fig. 1) is quite low. Below 100 keV the ISGRI background spectrum show the emission lines due to the lead and tungsten fluorescence photons generated in the IBIS telescope. The 511 keV line, mainly caused by the high energy particles interaction with the INTEGRAL materials, is also present.

The IBIS standard analysis (Goldwurm A. et al., 2003) is optimized for detection and spectral extraction of point sources, also in crowded region. The IBIS data and the Off-line Scientific Analysis (OSA) software are delivered by the Integral Science Data Center (ISDC) (Courvoisier T. J. L., et al., 2003).

3 Results

Eight ISGRI mosaic images have been obtained, from revolutions 46 to 123 in the following energy intervals: [18 keV, 40 keV], [40 keV, 60 keV], [60 keV, 120 keV], [120 keV, 250 keV], [250 keV, 435 keV], [435 keV, 485 keV], [485 keV, 535 keV], [535 keV, 585 keV]. While at low energies the GC is a very crowded region, only six hard X-ray sources are detected in the 120 keV - 250 keV energy band (fig. 2). Some of these sources could in principle give a contribute at 511 keV.
Fig. 3. The standard processing of the GCDE ISGRI data has not shown any evidence for 511 keV point sources. The image on the left shows the mosaic in the energy band 485 keV - 535 keV. The large structure that appears is due to the overlap of the dithering points. After the correction for these effects (image on the right panel), the systematic structures in the image are strongly reduced.

The figure 3 show the IBIS/ISGRI mosaic at 511 keV, in the energy band 485-535 keV, with an exposure time equal to 1.5 Msec in a large part of the Galactic Center Region. The left panel in the figure show the mosaic image as obtained by the standard pipeline without any correction; the large structure in the image is mainly due to the overlapping of the dithering pointings. After the subtraction of the mean value of the maps in the adjacent bands (435-485 keV and 535-585 keV), this systematic noise is reduced from 36 % to 8 %, but the statistic noise is increased by a square root of 2 factor.

Despite the deep exposure, no 511 keV point sources have been found. Starting from the ISGRI sensitivity that we have estimated from the Crab calibration data ($2.9 \times 10^{-4} \text{ph cm}^{-2} \text{s}^{-1}$, at $3 \sigma$ for an exposure time of 1 Msec), we obtain the flux upper limit $1.6 \times 10^{-4} \text{ph cm}^{-2} \text{s}^{-1}$, at $2\sigma$ of confidence level for an exposure time equal to 1.5 Msec.

4 Conclusions

At the present state of the IBIS/ISGRI GCDE data analysis we have not found any evidence for 511 keV point sources in the Galactic Center Region. Taking in account of the ISGRI sensitivity, the data set an upper limit (at $2\sigma$ confidence level) of $1.6 \times 10^{-4} \text{ph cm}^{-2} \text{s}^{-1}$ on the 511 keV flux for any point source in the Galactic Center region. The sensitivity improvement provided
by the PICsIT data analysis and by the analysis of a more extended data set will give more constraints on the 511 keV flux, or we will found a sample of new sources.

For a diffuse radiation the IBIS standard pipeline is not appropriate. Dedicated data analysis strategy and methods for this purpose are in progress.

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