A radio and near-infrared mini-survey of the MGRO J2019+37 complex

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Abstract.

MGRO J2019+37 is an unidentified source of very high energy gamma-rays originally reported by the MILAGRO collaboration as the brightest TeV source in the Cygnus region. Despite the poor angular resolution of MILAGRO, this object seems to be most likely an extended source or, alternatively, a superposition of point-like TeV sources.

In order to contribute to the understanding of this peculiar object, we have mosaiced it with the Giant Metrewave Radio Telescope (GMRT) in Pune, India, at the 610 MHz frequency covering a field of view of about 6 square degrees down to a typical rms noise of a few tenths of mJy. We also observed the central square degree of this mosaic in the near infrared Ks-band using the 3.5 m telescope and the OMEGA2000 camera at the Calar Alto observatory (Spain). We present here a first account of our observations and results, together with a preliminary cross correlation of the radio and infrared source catalog as well as a correlation with the available X-ray observations of the region.

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MGRO J2019+37

The galactic very-high-energy (VHE) γ-ray sources discovered during these last years by the new generation of Čerenkov telescopes (H.E.S.S., MAGIC, MILAGRO) are currently a hot topic in modern high-energy Astrophysics. Among the ~75 detected sources, nearly one third of them still remain unidentified.

A recent addition to the population of extended and unidentified TeV sources has been reported by the MILAGRO collaboration, with the discovery in the Cygnus region of the most extended TeV source ever known [1]. The TeV emission from this area covers several square degrees and includes diffuse emission and at least a new source, MGRO J2019+37. The origin of these emissions and their association to any astrophysical counterpart is unknown. Although a possible connection with anisotropy of the galactic cosmic rays has been proposed [2], the TeV γ-ray flux as measured at 12 TeV from the diffuse emission of the Cygnus region (after excluding MGRO J2019+37) exceeds that predicted from a conventional model of cosmic ray production and propagation [1]. This strongly suggests the existence of high-spectrum cosmic-ray sources and/or other types of TeV γ-ray sources in the region.

To better understand this peculiar object, we have performed a multi-wavelength campaign comprising a radio survey at 610 MHz and infrared observations in the Ks band. Recent X-ray observations are being analyzed.

RADIO SURVEY

The region has been observed with wide-field deep radio imaging at 610 MHz (50 cm) using the GMRT in Pune (India) on July 2007. A total of 19 pointings cover the region of about 2.5° × 2.5° centered on the MGRO J2019+37 peak of emission. The final combined image has an rms of ~0.2 mJy/beam with a 5 arcsecond resolution thanks to the long baselines of the GMRT antennas. Standard flagging and calibration procedures were used to process the GMRT data using the AIPS software package. For illustration purposes, in Fig. 1 we show a low-resolution version of the GMRT mosaic produced using a restoring beam of 30 arcsecond in order to better enhance the extended radio sources in the field.

The AIPS task SAD was applied for source extraction in the high-angular resolution version of Fig. 1. As a re-
FIGURE 1. Radio map obtained with the GMRT radiotelescope at 610 MHz (greyscale) convolved with a circular restoring beam of 30 arcsecond. The red cross and box indicate the Center of Gravity and uncertainty region of the TeV emission from the source MGRO J2019+37. The conspicuous radio sources located inside this box correspond to an extended HII region and a bright compact radio source also detected with the VLA as NVSS J202032.97+363158. Overlayed are the position probability contours (50%, 68%, 95% and 99%) of the Third EGRET Catalog sources 3EG J2021+3716 and 3EG J2016+3657, as well as the GeV source GeV J2020+3658 (blue ellipse). Recently EGRET data has been reanalyzed by [5], resulting in a single source named EGR J2019+372, located approximately between the two 3EG sources.
result, a total of 358 radio sources were detected above 2 mJy. Among them, 255 are fainter than 10 mJy and the majority were previously undetected at radio wavelengths. In Fig. 2 we show their distribution histogram as a function of log $S_{\text{Peak}}^\nu$. Apart from the already known extended bright sources, we have been able to detect new extended mJy sources displaying arcsecond structure. Further studies on the relevant radio sources are being conducted to explore possible counterparts or particle accelerators related to the TeV source.

**INFRARED SURVEY**

We have also carried out an infrared survey of the central square degree of the region using the OMEGA2000 wide field camera on the 3.5 m telescope at the Centro Astronómico Hispano Alemán (CAHA) in Almería (Spain) on 25 September 2007. This instrument consists of a Rockwell HAWAI2 HgCdTe detector with 2048 × 2048 pixels sensitive within 0.8 to 2.5 $\mu$m. A pattern of $4 \times 4$ pointings was performed in the $K_s$-band (2.15 $\mu$m) in order to minimize the interstellar absorption. Individual frames were sky-subtracted, flat-field corrected and then combined into a final mosaic using the AIPS task FLATN. A low-resolution view of this mosaic is presented in Fig. 3. A catalog of $\sim 3 \times 10^5$ near infrared sources was produced using the SEXtractor package.

**CATALOG CROSS-CORRELATION**

We have performed a preliminary cross-correlation of the radio and infrared source catalogs. Out of the 358 detected radio sources, 40 of them lie inside the central squared degree imaged in the near infrared. A total of 7 of these sources have an infrared counterpart within less than 1 arcsecond of their radio position.

We have also obtained source lists of all X-ray observations of the region performed by *Chandra* and *XMM-Newton*, computed through the celldetect and edetect_chain tasks. A total of 22 of the 358 radio sources are located in fields observed in X-rays, which cover an area of $\sim 4 \times 10^5 \text{arcmin}^2$. We have found that 5 of them have a radio counterpart within 5 arcseconds. Extrapolating the fraction of X-ray counterparts to the rest of the radio observation, we expect that about 82 of the detected radio sources have an X-ray counterpart.

**CONCLUDING REMARKS**

The analysis of both the infrared and radio observations has very recently been finished. Having this kind of data for the MGRO J2019+37 field will be a very useful information by the time the *Fermi* satellite provides more accurate information about the gamma-ray sources in this remarkable region of the Galactic Plane. The physical understanding of the most relevant sources in the field is currently work in progress, as well as the analysis of new *XMM-Newton* and AGILE observations.

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FIGURE 3. Appearance of the full near infrared mosaic in the $K_s$-band obtained with the CAHA 3.5 m telescope and the OMEGA2000 camera. The ensemble of 16 pointing covers almost completely the Center of Gravity and uncertainty region of the TeV emission from the source MGRO J2019+37. The limiting magnitude is $K_s \sim 17$ and the total field of view is about 1 squared degree. North is up and East is to the left. Astrometric solutions on the final frames were determined within $\pm 0.1$ arc-second by identifying about twenty reference stars in each pointing for which positions were retrieved from the 2MASS catalog.