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Ongoing Cosmic ray acceleration in the supernova remnant W51C revealed with the MAGIC Telescopes

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Abstract. The supernova remnant (SNR) W51C interacts with the molecular clouds of the star-forming region W51B, making the W51 complex one of the most promising targets to study cosmic ray acceleration. Gamma-ray emission from this region was discovered by Fermi/LAT and H.E.S.S., although its location was compatible with the SNR shell, the molecular cloud (MC) and a pulsar wind nebula (PWN) candidate. The modeling of the spectral energy distribution presented by the Fermi/LAT collaboration suggests a hadronic emission mechanism. Furthermore indications of an enhanced flux of low energy cosmic rays in the interaction region between SNR and MC have been reported based on ionization measurements in the mm regime. MAGIC conducted deep observations of W51, yielding a detection of an extended emission with more than 11 standard deviations. We extend the spectrum from the highest Fermi/LAT energies to ~ 5 TeV and find that it follows a single power law with an index of $2.58 \pm 0.07_{\text{stat}} \pm 0.22_{\text{syst}}$. We restrict the main part of the emission region to the zone where the SNR interacts with the molecular clouds. We also find a tail extending towards the PWN candidate CXO J192318.5+140305, possibly contributing up to 20% of the total flux. The broad band spectral energy distribution can be explained with a hadronic model that implies proton acceleration at least up to 50 TeV. This result, together with the morphology of the source, suggests that we observe ongoing acceleration of ions in the interaction zone between the SNR and the cloud.

Keywords: acceleration of particles, gamma rays, supernova remnants, molecular clouds, cosmic rays

PACS: 98.58.Mj, 98.58.Db, 98.70.Sa, 95.85.Pw

INTRODUCTION

The here presented results summarize the results published in Aleksić et al. [1]. Located at the tangential point ($l = 49^\circ$) of the Sagittarius arm of the Galaxy, the W51 region lies at a distance of ~ 5.5 kpc [2]. The three main components consisting of the star forming regions W51A and W51B and the supernova remnant W51C are identified according to radio continuum observations. The age of W51C is estimated to be 30 kyrs [3]. Several observations [4, 5, 6] provide evidence that the shock wave of W51C collides with the giant molecular cloud complex W51B and thus direct interaction between them. Moreover, recent measurements [7] showed over-ionization of the gas in W51B in certain locations close to W51C coinciding with the shocked gas. They conclude this excess in ionization implies the existence of an intense flow of freshly accelerated

cosmic rays (CRs) that, through proton-proton collisions, ionize the hydrogen in the adjacent cloud. Furthermore, a hard X-ray source CXO J192318.5+140305 is detected, representing possibly a pulsar wind nebula [8, 9] (PWN) associated with the SNR. An extended source of gamma rays was first detected by the H.E.S.S. telescopes reporting an integral flux above 1 TeV of about 3% that of the Crab Nebula [10]. However, the presented morphological and spectral information was not enough to attribute the origin of the emission to any particular object in the field of view. Also, the Large Area Telescope (LAT) on board the *Fermi* satellite detected an extended source between 200 MeV and 50 GeV coincident with the H.E.S.S. source [11], favoring an hadronic origin of the observed emission. Moreover, MILAGRO reports a 3.4σ excess with median energy of 10 TeV coincident with the *Fermi*/LAT source [12]. MAGIC observed the source to determine the spatial origin of the emission, the spectral behavior in the very high energy regime and thus constraining the possible acceleration of cosmic rays in the system.

MAGIC DATA, RESULTS AND THEIR INTERPRETATION

MAGIC observed W51 in 2010 and 2011 resulting in a total amount of 53 h effective dark time. An extended source has been detected with more than 11 standard deviations above an energy threshold of 150 GeV. The centroid of the emission is spatially coincident with the region where the shock of the SNR interacts with the molecular complex W51B. We obtain the intrinsic source extension defined as the σ of a two dimensional Gauss function as $0.12 \pm 0.02_{\text{stat}} \pm 0.02_{\text{syst}}$ degrees. The obtained spectrum ranges from 75 GeV up to 5.5 TeV and follows a power law with a spectral index of $\Gamma = 2.58 \pm 0.07_{\text{stat}} \pm 0.22_{\text{syst}}$, and a normalization constant at 1 TeV of $N_0 = (9.7 \pm 1.0_{\text{stat}}) \times 10^{-13} \text{cm}^{-2} \text{s}^{-1} \text{TeV}^{-1}$. The spectral slope is in agreement with the one obtained by [11] above ~ 10 GeV and the flux above 1 TeV is in agreement with the value obtained by [10]. Furthermore we performed morphological studies in two energy ranges: 300–1000 GeV and above 1000 GeV. Figure 1 shows the obtained skymaps from MAGIC in the context of multi wavelength data. The main aspects in both energy ranges are as follows: the centroid of the emission always coincides with interaction region between remnant and cloud. No significant gamma ray emission is observed from the outer parts of W51B, challenging the interpretation that escaped CRs produce the observed emission by illuminating W51B from the outside. Instead the interpretation that the emission arises from CRs being accelerated in the interaction region explains the observed morphology and is supported by the enhanced CR ionization measured in this region [7]. In both energy ranges we see a feature of the emission extending towards the position of the possible PWN. From the available data it is not clear if the PWN is an independent source in very high energies. However we determine that its contribution to the overall observed flux by MAGIC would be only $\sim 20\%$ not showing any significant dependence on energy. Thus we interpret all emission to have a common origin.

We model the observed multi wavelength radiation assuming a broken power law spectrum of highly relativistic protons and electrons. No simple one-zone leptonic scenario (Bremsstrahlung or Inverse Compton) can explain both the radio and the gamma ray emission, in agreement with results obtained previously by [11]. In addition the

FIGURE 1. Relative flux maps: From 300 GeV to 1000 GeV (top) and > 1000 GeV (bottom). On the left hand side the MAGIC data are combined with the ^{13}CO ($J=1-0$) intensity maps from the Galactic Ring Survey (see http://www.bu.edu/galacticring/new_index.html) integrated between 63 and 72 km s^{-1} shown as thin contours. On the right hand side the thin contours represent the 21 cm radio continuum emission from [5]. In all maps the diamond represents the position of CXO J192318.5+140305 and the cross the position of the OH maser emission [9, 4]. The dashed ellipse (with a cross in the center) represents the region of shocked atomic and molecular gas [6, 5]. The 3 counts contour above 1 GeV determined by *Fermi*/LAT is displayed by the single thick contour. In each picture the gaussian sigma of a point-like source (PSF) after the applied smearing is shown. The grey scale represents the relative flux as measured with MAGIC. In addition the test statistics contours of MAGIC are shown starting at 3 and increasing by one per contour. Credit: J. Aleksic et al. A&A, 541, A13, 2012, reproduced with permission ©ESO

FIGURE 2. Model of the multi-wavelength SED in the hadronic-dominated scenario. The dashes with error bars are 21cm radio continuum, circles represent *Fermi*/LAT data, squares are the data obtained by MAGIC and the star represent the MILAGRO data point. The upper limit in the X-ray regime is obtained from *ROSAT* data. Credit: J. Aleksic et al. A&A, 541, A13, 2012, reproduced with permission ©ESO

upper limit presented at this conference (Solicited talk by: A. Giuliani, AGILE study of Supernova Remnants) at energies ~ 100 MeV challenges a leptonic interpretation of the gamma ray data. We find that the multi-wavelength data can be well described in a hadronic scenario where $\sim 16\%$ of the kinetic energy of the remnant has been transferred into cosmic rays (see Fig. 2). The model assumes an ambient density of $10 \text{ particles cm}^{-3}$, a magnetic field strength of $53 \mu\text{G}$, and an electron to proton ratio of 0.0125. The electron and proton spectra are described by a broken power law of slope -1.5 before the break at 10 GeV and a slope of -2.7 afterwards, which is compatible to similar objects [13, 14]. The measurement by MILAGRO is not explained in this scenario and would require an additional component at higher energies.

CONCLUSIONS

MAGIC extends the gamma ray spectrum of the supernova remnant W51C almost without gap from the *Fermi*/LAT energies to ~ 5 TeV. The centroid of the emission is pin pointed to the interaction region of the supernova shock wave (W51C) and the molecular cloud (W51B). From the here determined morphology and the available multi-wavelength data it is suggested that we observe ongoing ion acceleration at least up to 50 TeV in a medium age supernova remnant interacting with a molecular cloud.

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