Observations of Starburst Galaxies

T. Nagai,[1,2] V.V. Vassiliev, I.H. Bond, P.J. Boyle, S.M. Bradbury, J.H. Buckley, D. Carter-Lewis, O. Celik, W. Cui, M. Daniel, M. D'Vali, I.de la Calle Perez, C. Duke, A. Falcone, D.J. Fegan, S.J. Fegan, J.P. Finley, L.F. Fortson, J. Gaidos, S. Gammell, K. Gibbs, G.H. Gillanders, J. Grube, J. Hall, T.A. Hall, D. Hanna, A.M. Hillas, J. Holder, D. Horan, A. Jarvis, M. Jordan, G.E. Kenny, M. Kertzman, D. Kieda, J. Kildea, J. Knapp, K. Kosack, H. Krawczynski, F. Krennrich, M.J. Lang, S. LeBohec, E. Linton, J. Lloyd-Evans, A. Milovanovic, P. Moriarty, D. Muller, S. Nolan, R.A. Ong, R. Pallassini, D. Petry, B. Power-Mooney, J. Quinn, M. Quinn, K. Ragan, P. Rebillot, P.T. Reynolds, H.J. Rose, M. Schroedter, G. Sembroski, S.P. Swordy, A. Syson, S.P. Wakely, G. Walker, T.C. Weekes, J. Zweerink

(1) University of Utah, 115S 1400E suite 201, Salt Lake City, UT 84112, USA

(2) The VERITAS Collaboration–see S.P.Wakely's paper "The VERITAS Prototype" *from these proceedings for affiliations*

Abstract

The search for TeV gamma-ray radiation from starburst galaxies (SBGs) has been conducted by the Whipple 10-m gamma-ray telescope from January 2001 to March 2003. The regions with high star formation rates (SFRs) observed in SBGs are frequently accompanied by high density clouds of interstellar matter (ISM). This seems to create nearly perfect conditions for generating diffuse gamma-ray radiation as high energy cosmic rays interact with the ISM. If the current paradigm that supernovae are the origin of high energy cosmic rays is valid, then star forming regions rich in type Ib/c, II supernovae may become the laboratories to test the hypothesis. Using the Whipple telescope we have conducted a survey of several plausible SBGs selected based on their distance, density of gas clouds, age of star forming regions, SFRs, and magnetic fields, as well as the presence of radio flux and X-ray point sources. We discuss the selection criteria based on gamma-ray flux estimates, as well as the results of a novel spectrum dependent analysis (to be reported during presentation) of SBG observations for which a total exposure of 10-30 hours per source have been accumulated.

1. Introduction

It is believed that star formation activity in SBGs is ignited in regions of high ISM density by large scale interactions such as multiple galaxy interaction

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or strong accretion near the core of the galaxy. Due to high SFRs, SBGs produce high supernova rates. The typical age of starburst regions in our study is on the order of $\sim 10^7$ years, and therefore, most of the SNe would be type Ib/c or Type II, because the region is not old enough to host Type Ia SNe. If the region is older, there is a high probability that the gas is blown away from the starburst region by cumulative SNe explosions and stellar winds. Supernova remnants are believed to be prime candidates of high energy cosmic rays' (CRs) acceleration sites. Besides the simple model of CR acceleration in a supernova remnant in uniform ISM, more effective acceleration scenarios, such as SNRs expanding into wind bubbles, or large scale mechanism with more complicated gas distribution such as OB star and SN association, have been recently studied [2,3]. These acceleration scenarios are likely to exist in SBGs. Although SBGs might be rich with energetic CRs inside the starburst region, their escape from these regions is disfavored by high density ISM and relatively large magnetic fields. In spite of the difficulty of obtaining direct evidence of SN origin of CRs in SBGs, it might be possible to detect indirect evidence via secondary strong gamma-ray emission, resulting from interaction between high energy hadronic CRs and dense interstellar medium (ISM), or leptonic CRs with dense photon fields from many massive stars, CMB, and FIR. For gamma-ray emission, dense ISM and large magnetic fields are advantages to enhance the interactions. The hadronic interaction (p-p collision) produces gamma-ray emission via neutral pion decay. Another mechanism of TeV gamma-ray emission in SBGs might be the interaction of relativistic electrons with low energy photons by inverse Compton (IC) scattering. It might be very difficult for high energy CR electrons to escape from the starburst region because of the synchrotron cooling effect from relatively large magnetic fields. If there exist some reacceleration mechanisms of electrons, such as combined shocks from multiple SN explosions, the IC scenario may become effective. The existence of relativistic electron halos around starbursting regions in some SBGs are suggested by radio continuum observations, e.g. [4,5]. In either case, SBGs seem to provide a number of possibilities for high energy gamma-ray emission.

SBGs are new TeV gamma-ray source candidates. Only one detection of this type has been reported (from NGC253, by CANGAROO group, [1].) The gamma-ray emission from NGC253 is claimed to be due to IC mechanism by relativistic electron cloud which extends to the scale of 10 kpc in the galactic halo.

2. Source selection

We reviewed published data on all nearby SBGs and selected M82, M81, IC342 and NGC3079 for the Whipple observations. Their characteristic parameters are summarized in table 1. The Milky Way galaxy data are given for comparison purposes. For all sources we made a simplified gamma-ray flux estimation from pion decay in which we assumed uniform ISM distribution over the starburst region. The CR density in the starbursting region was evaluated either as a low limit from the equipartition assumption between CR energy density and magnetic field energy density, or from supernova rate estimates found in publications, e.g. [6]. The X-ray and radio emission presence were checked to decide on the final selection. All of these sources are luminous in radio (extended region), FIR and X-ray (multiple point sources may indicate recent post stellar evolution.) Because distance has a crucial effect on the observable flux for SBGs, only nearby sources were considered.

3. Observation

The Whipple instrument is a ground-based atmospheric Čerenkov gamma-ray telescope with a 10m aperture. The camera has 379 PMTs used for imaging the 2.6 degree field of view. The star fields for all of the sources are relatively quiet, with no bright stars in the field of view, except one in the OFF region of NGC3079 (mag 4.84.) A summary of Whipple observations is shown in table 2. All data were taken in either pair (ON, OFF) or TRACKING modes. For the detailed description of observational method with the Whipple telescope, see e.g. [7].

4. Preliminary results and Discussion

No solid detection has been found with standard analysis, in which Čerenkov shower image parameter cuts (so called Hillas parameters: light intensity, width, length, distance between source position on camera and image center, image rotation angle) are optimized for TeV sources with gamma-ray differential spectral index close to 2.5, such as the Crab Nebula. The preliminary upper limits on the differential photon flux per logarithm of energy obtained in such analysis are shown in table 2. Since the gamma-ray production mechanisms of SBGs are not well understood, we have extended our investigation over a wider range in spectral indices. Spectral index dependent cut optimization is now in development with index range from 1.0 to 4.0. The main motivations for this include an index of 3.74 ± 0.27 reported for NGC253 by the CANGAROO group [8], and success of similar analysis approach developed by us and applied for detection of H1426 ([7], confirmed with [9].)

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Table 1. Observed sources.

Source	Distance (Mpc)	P density (cm^3)	B field (μG)	Size of SB (kpc)	Age of SB region (10^6yrs)
M82	∼3.5	$\sim 10^4$	∼25	∼0.1	∼30
M81	∼3.5	$\sim 10^2$	∼37	∼5	∼30
IC342	∼3.0	$\sim 10^4$	∼75	∼1	∼10
NGC3079	∼16	$\sim 10^3$	$\sim 10^5$	∼1	∼30
MilkyWay	-	∼1	∼3	-	$\sim 10^4$

Table 2. A summary of the observations. The flux upper limits are preliminary and correspond to 650 GeV photons, which provide a maximum detection rate of the telescope for observations at 35 degree zenith angle.

Source	Exposure (sec)	Typical zenith (degree)	2 σ upper limit (photon cm^{-2} s^{-1})
M82	29753	38	8.84×10^{-12}
M81	36507	38	7.05×10^{-12}
IC342	22604	37	7.17×10^{-12}
NGC3079	36468	26	1.58×10^{-11}

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