Search for high energy $\gamma$-rays from the direction of the candidate electromagnetic counterpart to the binary black hole merger gravitational-wave event S190521g

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Abstract

The gravitational-wave event S190521g — a likely binary black hole merger in the accretion disk of an active galactic nucleus — was accompanied by an optical counterpart. Such dense environments around luminous energy release regions are favourable for high energy $\gamma$-ray production. We report on a search for high energy $\gamma$-rays from the direction of the candidate electromagnetic counterpart to the S190521g event using publicly-available data of the Fermi-LAT space $\gamma$-ray telescope. No significant signal was found. We present upper limits on the spectral energy distribution of the source in the $100 \text{ MeV} - 300 \text{ GeV}$ energy range. We discuss the importance of studying S190521g-like transients in the context of cosmic ray acceleration, $\gamma$-ray and neutrino production in such sources.

Keywords: black hole mergers, high energy $\gamma$-rays, Fermi-LAT space $\gamma$-ray telescope

1. Introduction

Very recently, the first detection of a plausible optical electromagnetic counterpart to a candidate binary black hole merger S190521g was reported in [1]. Namely, an optical flare with the duration of $\sim 50$ days was detected with the Zwicky Transient Facility, indicating that this merger occurred inside the accretion disk of J124942.3 + 344929 — an active galactic nucleus situated at the redshift of $z = 0.438$.

This observation is interesting in the context of $\gamma$-ray astronomy for the following two reasons: 1) a very high value of the estimated bolometric luminosity of the flare $L_{\text{bol}} \sim 10^{45} \text{ erg/s} \sim 10^{57} \text{ eV/s}$ and the luminosity distance to the source $d_L \sim 3 \cdot 10^3 \text{ Mpc}$, typical for quasars [2] the expected energy flux could be as high as $F_E \sim L_{\text{bol}}/(4\pi d_L^2) \sim 1 \text{ eV/(cm}^2\text{s)}$, if the power transferred to high energy (HE, $E > 100 \text{ MeV}$) particles is comparable with $L_{\text{bol}}$. $F_E \sim 1 \text{ eV/(cm}^2\text{s)}$ is still within the capabilities of the Fermi-LAT space $\gamma$-ray telescope [4], motivating the search for HE $\gamma$-rays from this source.

In the present paper we perform a search for HE $\gamma$-rays from the direction of J1249 + 3449 on a month – year timescale using publicly-available data of the Fermi-LAT space $\gamma$-ray telescope. We note that no significant signal was found with Fermi-LAT over a short time period of 10 ks [5].

2. Fermi-LAT data analysis

Here we derive upper limits on the observable spectral energy distribution (SED = $E^2dN/dE$) of J1249 + 3449. We select Fermi-LAT data within two time windows: 1) 2019, May 19, 00:00:01 UTC — 2019, September 1, 00:00:01 UTC; 2) 2019, May 19, 00:00:01 UTC — 2020, June 30, 00:00:01 UTC. The region of interest (ROI) is

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1hereafter called J1249 + 3449 for simplicity

given that the estimated mass of the final black hole is $\sim 100$ solar masses

2the estimated gas density in the accretion disk is $\sim 10^{-10} \text{ g/cm}^3$

3neglecting cosmological effects

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We calculate the value of the test statistic $TS$ corresponding to the hypothesis of the J1249 + 3449 emission being present in the dataset against the null hypothesis of it being absent. We obtain $TS \ll 1$, i.e. no significant $\gamma$-ray flux was detected from this object. Then we derive upper limits (95% confidence level) on the SED, using likeSED.py \cite{2}. These upper limits for both considered time intervals are shown in Fig. 1. We also performed an independent binned analysis using the fermipy package \cite{3} and derived upper limits with the $gta.sed$ method implemented in this package, but the obtained limits are weaker than for the case of the unbinned analysis.

3. Discussion

There are many possible explanations for the negative results of the search for HE $\gamma$-rays reported above, including the following ones:

1) the bolometric luminosity $L_{bol}$ and/or the power transferred to HE particles could have been significantly over-estimated;
2) HE $\gamma$-ray production efficiency could be significantly lower than unity (especially for the case of primary protons or nuclei);
3) HE $\gamma$-rays could have been beamed out away from the line-of-sight;
4) HE $\gamma$-rays could have been absorbed by the material of the accretion disk, or photon fields of the accretion disk corona and/or thermal photon field created by hot gas around the merger. The absorption of $\gamma$-rays on photon fields of the BLR is usually significant at $E > 10 – 30$ GeV (e.g. \cite{4}). This might impair the prospects of detecting S190521g-like transients with imaging atmospheric Cherenkov telescopes such as H.E.S.S. \cite{10,11}, MAGIC \cite{12,13}, VERITAS \cite{14,15}, or CTA \cite{16,17}.

A detailed study of these effects is underway and will be published elsewhere. X-ray data may be helpful in constraining some models, especially those that include the process of electromagnetic cascade development in the source (both in matter and photon fields) with subsequent synchrotron emission of cascade electrons.

Of course, other multiwavelenght/multimessenger data could also be helpful, in particular, very high energy (VHE, $E > 100$ GeV) neutrino searches from the direction of J1249 + 3449. S190521g-like transients could be copious sources of two components of VHE neutrinos: 1) “hadronuclear” neutrinos coming from interactions of accelerated protons or nuclei with the material of the accretion disk, or photon fields of the accretion disk corona and/or thermal photon field created by hot gas around the merger. The absorption of $\gamma$-rays on photon fields of the BLR is usually significant at $E > 10 – 30$ GeV (e.g. \cite{4}). This might impair the prospects of detecting S190521g-like transients with imaging atmospheric Cherenkov telescopes such as H.E.S.S. \cite{10,11}, MAGIC \cite{12,13}, VERITAS \cite{14,15}, or CTA \cite{16,17}.

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![Figure 1: Upper limits on the SED of J1249 + 3449 over the time period of 105 days from 19th of May, 2019 till 1st of September, 2019 and over the time period of 408 days from 19th of May, 2019 till 30th of June, 2020.](image-url)

Figure 1: Upper limits on the SED of J1249 + 3449 over the time period of 105 days from 19th of May, 2019 till 1st of September, 2019 and over the time period of 408 days from 19th of May, 2019 till 30th of June, 2020.
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