Broad-band spectral analysis of the gamma-ray binary system LS 5039 and its strong MeV gamma-ray emission†

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With the development of GeV/TeV gamma-ray observation techniques, since the 2000 s it was established that several high-mass X-ray binary systems emit strong non-thermal emissions. They are called gamma-ray binary systems, and so far, approximately ten sources have been identified.[1)] Their spectral energy distributions (SEDs) have a peak typically beyond 1 MeV. Such non-thermal emissions indicate that efficient particle acceleration takes place in them, and they are considered a new particle accelerator in the Universe. However, the nature of compact objects and the acceleration mechanism in these systems are not well understood, and this has been a long-standing question.

LS 5039 is one of the brightest known gamma-ray binary systems in our galaxy.[2)] Its companion star is an O star with a mass of 23 $M_{\odot}$, but it is not known whether its compact object is a black hole or a neutron star. From X-ray and TeV gamma-ray observations, it is suggested that this object accelerates TeV electrons on the time scale of seconds, with an extremely high efficiency.[3)] Recently, by reanalysis of the COMPTEL data, strong MeV gamma-ray emission has been found from this source.[4)] These findings imply that it is essential to understand its broad-band spectrum from X-rays to TeV gamma-rays. In this report, we present our results of the spectral analysis using the latest data.[5)]

By using 11 years of Fermi-LAT GeV gamma-ray data and hard X-ray data of the NuSTAR observation, we updated the SED of LS 5039 with the highest available statistics (see Fig. 1). The obtained SED and its spectral modulation along the orbital phase suggest that LS 5039 has at least four spectral components from the X-ray to TeV band: (1) an X-ray component up to 100 keV, (2) a spectral component that is dominant above 100 keV up to a few tens of MeV, (3) a GeV gamma-ray component that is almost independent of the orbital motion, and (4) a TeV gamma-ray component. Existing theoretical models can interpret the first and fourth components, *e.g.*, particle acceleration at the pulsar wind termination shock. However, we found that the second and third components are not explained well. When the MeV emission is interpreted as synchrotron emission, we can constrain the acceleration efficiency parameter as $\eta < 10$. This result suggests that particle acceleration operating in LS 5039 is different from the diffusive shock acceleration (DSA) assumed in many models because DSA yields $\eta > 10$.

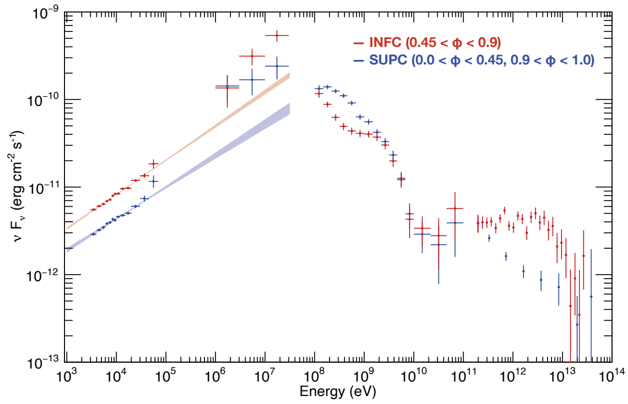

Fig. 1. The SED of LS 5039 with the NuSTAR and 11 years of Fermi LAT data. The red points represent the spectra in orbital phases around the inferior conjunction (INFC) when the compact star is in front of the companion star from the observer's perspective. The blue points denote the spectra around the superior conjunction (SUPC) when the compact star is behind the companion star. See Ref. 5) for details.

We have performed a broad-band spectrum analysis of the gamma-ray binary LS 5039 and summarized the features of the emission components in each band. The emission components from MeV to GeV remain uncertain, and further studies on this energy band are key to understanding this object's nature. The MeV gamma-ray satellite COSI will be launched in 2025.[6)] Moreover, towards MeV/subGeV gamma-ray observation in the 2030s, the GRAMS project with an unprecedentedly large effective area has been proposed.[7)] We expect that these future observations will further deepen our understanding of the mysterious gamma-ray binary systems.

References
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