Form 8

Research Result Report
ICRR Inter-University Research Program 2022

Research Subject: Understanding the GeV-TeV signatures of star-forming galaxies in the extragalactic gamma-ray background with CTA
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Project summary: During the cosmic 'high noon' (at redshifts of z~2-3), physical conditions and processes in galaxies differ dramatically from those in the local Universe. In particular, cosmic ray (CR) interactions, their associated production of particles and radiation, and their deposition of momentum play an essential role in shaping the evolution of galaxies (Owen et al. 2018, 2019b) as well as producing energetic cosmic backgrounds - including a component of the extra-galactic gamma-ray background, EGB (e.g. Lamastra et al. 2017). Understanding the activities and interactions of CRs in young star-forming galaxies (SFGs) is important to uncover the details of feedback processes influencing their evolution, and spatial analyses of near-future EGB surveys will soon offer an important new opportunity to do this: the continued operation of the *Fermi*-LAT space telescope will reach exposure times sufficient to provide suitable data in the next three years (Owen et al. 2020b), and this will be complemented by the Key Science Projects (KSPs) of the upcoming Cherenkov Telescope Array, CTA (see Science with the Cherenkov Telescope Array, CTA Consortium 2017, in particular, KSP 8: Extragalactic Survey).

This project was initiated in FY2020. Prior to FY2022, work was completed to construct tentative source sub-population models of SFGs, informed by public results from large-scale numerical simulations (EAGLE and IllustrisTNG). These were adapted into a computational code (initially constructed during FY2020, see results in Owen et al. 2021). Modeling work was then completed to investigate signatures of SFG sub-populations in FY2021 using an extension of this code (Owen et al. 2022).

In FY2022, continuation of the project put focus on developing the technical details of SFG prototype models. This was particularly intended to support more meaningful predictions of the EGB signatures imprinted by SFGs in the TeV energy range, which are most relevant to future observations to be conducted with CTA. Certain physical processes (reprocessing of gamma-rays by infrared dust emission in galaxies, and CR transport) had previously been included in the model framework in an approximate fashion. This was tolerable when modeling the EGB at GeV energies, where the impact is marginal. However, proper modeling of the EGB at TeV energies required a refined treatment of these effects. This is because EGB predictions are more strongly dependent on the detailed model configuration at these higher energies.

During FY2022, three specific objectives were identified:

(1) Upgrade TeV prototype emission models for SFGs, accounting for their evolutionary progression, the distribution and properties of their interstellar dust and its associated re-processed infrared radiation field.

Achievement: Work is progressing to augment the existing computational framework. An advanced model accounting for an improved treatment of CR transport has been constructed. Detailed 1-D, 2-D and 3-D MHD simulation codes have been developed to properly capture spectrally-resolved CR transport and flow interactions, accounting for hadronic interactions and multiple CR species. The code has been produced as bespoke modules for the adaptive mesh refinement code, FLASH. Tests have been completed, and production runs will begin in mid-FY2023. This will properly capture the essential aspects of the evolutionary progression of EGB prototype galaxy models, and its impacts on the CR distribution and gamma-ray luminosity from prototype SFGs. Alongside this, theoretical models for dust refinement have been investigated, and a new collaborative initiative has begun with Dr Hiroyuki Hirashita (ASIAA & Osaka University) to develop an advanced treatment of dust evolution under CR irradiation, and its effects on gamma-ray escape in SFGs. Some of these model extensions mark substantial refinements of the physical treatment of SFGs, and will advance the EGB prototype code beyond the current cutting edge of the field. These developments are expected to be completed towards the end of FY2023.

(2) Introduce a prototype CR transport model for SFGs, to properly assess the spectral containment fraction of CRs within a SFG.

Achievement: The model framework has been constructed. A detailed parameter study is underway with various flow configurations and galaxy halo masses. Dedicated computational time on national facilities has been acquired to support numerical modeling and parameter studies (0.2 million cpu-hours) into FY 2023.

(3) Interface refined TeV prototype emission models with the existing computational framework to determine the key features of the EGB anisotropy signatures at energies from 0.01 GeV to 10s of TeV that will be accessible with CTA.

Achievement: This component of the project envisioned substantial interaction with experts at ICRR to gain a detailed understanding of the CTA instrument specifications such that meaningful model predictions could be constructed. Due to the pandemic, an extended visit planned for several weeks was not possible. Instead, only 3 short-term visits could be completed (costing 80,000 JPY). A carry-over request of the un-used 220,000 JPY was approved. This will be used to support a longer planned visiting period during FY 2023 so this aspect of the project can proceed.

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