Form 8

# Research Result Report
# ICRR Inter-University Research Program 2023

Research Subject: Investigating the gamma-ray signatures of feedback microphysics in star-forming environments

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Summary of Research Result: This project aimed to investigate the origin of cosmic rays in and around star-forming environments and construct new tests of cosmic ray interactions and acceleration in and around (1) supernova remnants, (2) star-forming clusters/regions, and (2) galaxy scale systems. During the FY2023 fiscal year, this project was in an initial, exploratory stage. Three specific objectives were planned:

(1) Modeling gamma-ray emission from selected clouds near supernova remnants up to TeV energies under different CR propagation and composition scenarios.
*Achievement: Models were constructed. It was identified that sub-mm data was required, and proposals were submitted to ALMA and JCMT. Discussion with the host group at ICRR led this aspect of the project to be expanded, towards an investigation of star-forming regions as cosmic ray sources. These would seem to be more promising targets for new scientific developments, as our understanding of how cosmic rays are accelerated in detail within these complex environments is incomplete – yet they have been identified as potentially important source of the Galactic cosmic ray flux (possibly comparable to supernova remnants). Increasing gamma-ray data is available to allow for substantial progress to be made in modelling the detailed configurations of these regions, and their individual capability to accelerate cosmic rays through (i) wind interactions, (ii) wind termination shocks, (iii) 2nd order Fermi processes, (iv) bow shocks from escaping O/B stars. During FY2023, preliminary follow-up Fermi analysis was conducted for promising source young massive stellar cluster and other star-forming region candidates (based on their age, O/B stellar population and stellar mass). The properties of these objects were carefully analyzed in conjunction with Gaia DR3 data sets, and initial steps have been made towards constructing physical models of cosmic ray acceleration in winds, bespoke for each target star-forming region. A final determination of selected targets is yet to be made, as more detailed investigations of some star-forming regions to understand why they are gamma-ray bright or dark in the Fermi data is still ongoing. This work will continue as an ongoing collaborative effort in FY2024, although budget for dedicated*

*additional visits to ICRR is not required (project P.I. will move to the Tokyo area for a new position, so this project can freely continue without specific support).*

(2) Population study of starburst galaxies showing indications of an outflow in existing gamma-ray data. Use of their gamma-ray luminosities to set cosmic ray spectral normalizations for specific hydrodynamical flow models to create complete models of circum-galactic flow dynamics suitable for use as feedback testbeds.
*Achievement: A search for extended emission from starburst and main-sequence galaxies detected in gamma-rays was conducted, with follow-up detailed Fermi data analysis. Few sources showed clear evidence of extended gamma-ray emission that could be indicative of emission from an outflow. A preliminary study is instead being conducted first with archival eROSITA data to identify nearby gamma-ray detected galaxies that show X-ray emission signatures from their hot baryons suggestive of cosmic ray dynamical activity. From these, follow-up detailed Fermi analysis will be possible using a more informed morphological model based on the X-ray data. It now appears that this approach will provide a clearer starting point for tests of feedback models, with gamma-ray follow up studies or non-detection limits being useful for additional insights and model constraints. This project objective will therefore be revisited when the eROSITA archival study has been completed.*

(3) Preparation of observational proposals for Galactic star-forming regions in January 2024 for CTA observations at TeV energies to obtain data for model inputs.
*Achievement: Based on estimated fluxes at TeV energies with preliminary models and information at GeV energies with existing Fermi detections of promising targets, it was found that existing archival TeV data obtained with H.E.S.S. would be superior to any observations currently possible with CTA-LST1 alone, for the identified targets worthy of study. A target list and model predictions have been prepared for future observational cycles when more LSTs are online and better data quality can be achieved. This project objective will therefore also be revisited in future, based on the operational status of CTA.*

*Current status & immediate next steps in FY2024:* Overall, this project is now developing from an exploratory stage towards a point where novel scientific returns can soon be achieved. In the next FY2024, the primary focus will be placed the analysis and modeling of star-forming regions in the GeV band to properly understand their currently observed gamma-ray emission properties and the implications for cosmic-ray acceleration depending on the exact configuration of each target object. Dedicated funding for these continuing efforts is not required.

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