

Roman Galactic Plane Survey White Paper

Title: *Investigating the interplay between infrared observations, galactic magnetic fields, and cosmic rays*

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the intergalactic medium and the circumgalactic medium*

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Introduction

Cosmic rays interacting with interstellar gas and galactic magnetic fields (especially at the galactic plane) can produce all different kinds of radiation. Synchrotron radiation for example, can be emitted across a wide range of wavelength bands, spanning from radio waves to X-rays, and even into the gamma-ray region. The specific wavelength bands produced depend on the energy of the charged particles producing the radiation, as well as the strength of the magnetic field they are traveling through.

Infrared synchrotron radiation in our galaxy is observed in various astrophysical contexts (SNRs, Galactic center, Galactic plane, Molecular clouds and HII regions), often associated with regions of intense magnetic fields and energetic processes involving relativistic charged particles (cosmic rays).

Particularly, by studying the correlation between infrared emission and gamma-ray emission, we can identify cosmic ray acceleration sites and gain insights into the properties of the cosmic rays and magnetic fields themselves. Therefore, infrared observations play a crucial role in studying the connection between cosmic rays and their sources (in the galactic plane for example). This can be done via many venues, such as:

- Tracing cosmic ray propagation

Cosmic rays interact with the interstellar gas and dust, ionizing them and affecting the infrared emission from these regions. By studying the patterns of infrared emission and comparing them

with models of cosmic ray propagation, we can gain insights into how cosmic rays propagate through the galaxy and interact with the interstellar medium.

- Identifying cosmic ray acceleration sites

Infrared observations can penetrate through dense clouds of gas and dust in the galactic plane allowing the study of potential cosmic ray acceleration sites like supernova remnants, regions around massive stars, and star-forming regions. The infrared emission from these regions can help identify and characterize the sites where cosmic rays are accelerated.

- Synchrotron emission from cosmic ray electrons

High-energy cosmic ray electrons spiralling around magnetic fields in the galactic plane emit synchrotron radiation, which can be observed in the infrared wavelengths (among other). By mapping the infrared synchrotron emission, we will be able to trace the magnetic field structure and study the propagation of cosmic ray electrons, providing clues about their acceleration mechanisms and sources.

- Correlation with gamma-ray emission

It is known that cosmic rays interacting with interstellar gas produce gamma-ray emission. By studying the correlation between infrared emission (tracing the interstellar gas and dust) and gamma-ray emission, we can also identify cosmic ray acceleration sites and gain insights into the properties of the cosmic rays and associated magnetic fields.

Correlation between gamma-ray and infrared emission

The study of the correlation between gamma-ray and infrared emission in galaxies has gained significant attention in recent years, thanks to the advancements in observational capabilities across multiple wavelengths.

Recent research work has provided valuable insights into this intriguing connection, shedding light on the underlying physical processes and their implications for our understanding of galactic environments. One of the key findings from these studies is the observed correlation between the gamma-ray emission detected by Fermi and infrared emission observed in the past, by (near)-infrared telescopes, such as Spitzer, Herschel, etc. This correlation has been followed, studied reported in various galactic systems, including our own Milky Way galaxy, as well as nearby starburst galaxies like NGC 253 and M82, and M31:

In the Galactic center region of the Milky Way, Yusef-Zadeh et al. (2022) found a striking correlation between the gamma-ray emission detected by Fermi and the infrared emission observed by Spitzer. This correlation suggests a connection between the high-energy processes responsible for the gamma-ray emission and the interstellar medium traced by the infrared radiation.

Similarly, Remy et al. (2021) investigated the correlation between the gamma-ray emission observed by Fermi and the infrared emission from interstellar dust, as traced by the Planck (with minimal near-infrared sensitivity) satellite, in the Galactic plane of the Milky Way. Their study revealed a strong correlation providing insights into the distribution and properties of cosmic rays and their interaction with the interstellar medium.

Unger and Farrar (2023) recently studied a suite of models for the coherent magnetic field of the Milky Way galaxy, based on new parametric functions and fitting to various observational data, including Faraday rotation measures, polarized synchrotron intensity (tracing the magnetic field), and gamma-ray data (tracing cosmic rays).

The study of Benyamin et al. (2021) combined infrared polarization data from Planck (tracing the magnetic field structure) with measurements of the cosmic-ray anisotropy to study the magnetic field geometry in the Milky Way galaxy and its impact on the propagation of cosmic rays.

Beyond our own Milky way galaxy, the correlation between gamma-ray and infrared emission has been observed in nearby starburst galaxies, where intense star formation and associated processes are taking place:

Ackermann et al. (2021) reported the detection of gamma-ray emission from the starburst galaxy NGC 253 by Fermi and its correlation with the infrared emission observed by Spitzer and Herschel.

Similarly, Acciari et al. (2020) presented the detection of gamma-ray emission from the starburst galaxy M82 by the VERITAS gamma-ray observatory and its correlation with the infrared emission observed by Spitzer and Herschel. The correlation between gamma-ray and infrared emission has also been observed in the Andromeda galaxy (M31), as reported by

Ackermann et al. (2019). This study utilized data from Fermi, Spitzer, and Herschel to investigate the connection between these two emission components in this nearby spiral galaxy. The observed correlation between gamma-ray and infrared emission in these diverse galactic environments is believed to arise from the interaction of cosmic rays with the interstellar medium.

Note that the cosmic rays can interact with interstellar gas and dust, producing gamma-ray emission through various processes, such as bremsstrahlung and pion decay. On the other hand, the infrared emission, can originate from various sources including dust heated by stellar radiation, molecular clouds, and synchrotron radiation from cosmic ray electrons spiralling around magnetic fields.

By studying the correlation between gamma-ray and infrared emission (with the great capabilities of the Roman Space telescope), one could gain valuable insights into the distribution and properties of cosmic rays, their acceleration mechanisms, and their interaction

with the interstellar medium, and associated magnetic fields (next section). This correlation can also provide clues about the physical processes driving the high-energy phenomena in the galactic plane, such as star formation, supernova explosions, and the activity the supermassive black hole Sagittarius A*.

Infrared observations, galactic magnetic fields, and cosmic rays

The study of galactic magnetic fields and cosmic rays has long been a fascinating topic. By combining infrared data with observations from other wavelengths, such as gamma-rays and cosmic-ray measurements, we can gain unprecedented insights into the complex processes governing our galaxy and beyond. Roman will undeniably provide us a powerful tool to unravel the intricate interplay that governs such fascinating phenomena. One of the key findings from recent studies is the correlation between the polarized infrared emission from interstellar dust grains and the magnetic field structure in the Milky Way galaxy.

Abeysekara et al. (2022) utilized data from the High-Altitude Water Cherenkov (HAWC) gamma-ray observatory and the Planck satellite to perform galactic magnetic field tomography. By studying the correlation between the gamma-ray emission and the polarized infrared emission from dust grains, they were able to map the magnetic field structure in the Milky Way with unprecedented detail.

Similarly, Chuss et al. (2022) presented high-resolution infrared polarization observations of the Galactic center region using the HAWC+ instrument on the Stratospheric Observatory for Infrared Astronomy (SOFIA). Their study revealed the intricate magnetic field structure in this region and its correlation with other tracers, such as gamma-ray emission, providing valuable insights into the physical processes at play. The correlation between infrared observations and cosmic-ray propagation has also been a subject of intense research.

Xu et al. (2022) investigated the relationship between cosmic-ray propagation and the interstellar magnetic field structure in the Milky Way galaxy, using a combination of gamma-ray data from Fermi-LAT and infrared polarization data from Planck. Their findings shed light on the role of magnetic fields in shaping the distribution and propagation of cosmic rays throughout the galaxy.

Panopoulou et al. (2022) used infrared polarization data from Planck to map the magnetic field structure in the disk of the Milky Way galaxy and explored its correlation with other tracers, such as gamma-ray emission and synchrotron radiation. This multi-wavelength approach provided a comprehensive view of the interplay between magnetic fields, cosmic rays, and the interstellar medium in the galactic disk.

Furthermore, Benyamini et al. (2021) combined infrared polarization data from Planck with measurements of the cosmic-ray anisotropy to study the magnetic field structure in the Milky Way galaxy and its impact on the propagation of cosmic rays. Their work highlighted the

importance of understanding the magnetic field geometry in interpreting the observed anisotropies in cosmic-ray arrival directions.

Conclusion

Recent studies exemplify the power of combining infrared observations with other tracers to unravel the complex interplay between galactic magnetic fields, cosmic rays, and the interstellar medium. By leveraging the unique capabilities of Roman Space telescope we could undoubtedly probe the obscured regions of the galactic plane, where these components interact and shape the astrophysical processes that govern our cosmic neighborhood.

It is imperative that the synergy between infrared observations and other wavelengths will undoubtedly lead to further breakthroughs in our understanding of the intricate interplay of the galactic magnetic fields (especially in the galactic plane), cosmic rays, and the interstellar medium, unveiling the mysteries that lie at the heart of our galaxy and beyond.