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The Cold, the Dense and the Energetic: Cosmic Ray Bombardment of Molecular Cores Near Supernova Remnants

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0.1 Abstract

One of the oldest unsolved mysteries in astrophysics is the origin of cosmic rays, particles that travel at speeds close to the speed of light. A plausible theory to explain the acceleration of these particles is shock-acceleration in the expanding shells of supernova remnants (SNRs) within our galaxy. In this thesis, the interstellar medium towards supernova remnants that display indicators of particle acceleration, ie., gamma-ray emission, are investigated. More specifically, results from mm-wavelength molecular gas surveys towards two gamma-ray emitting SNRs, RX J1713.7−3946 and CTB 37A are presented. Chapter 1 summarises astrophysics at high energies, including what cosmic rays are, how they may be accelerated, their connection to gamma-ray emission and how gamma-ray astronomy is performed from the ground.

On the opposite (low-energy) side of the energy spectrum, Chapter 2 describes some of the theory of single dish radio astronomy, which allows us to probe molecular environments. By tuning the receiver to home-in on particular molecular species, different interstellar environoments can be targeted. Some specific molecular species are outlined in Chapter 3, before utilising these species in following chapters.

The bulk of chapters 4 and 5 are composed of published articles presenting interstellar gas observations and investigation. Chapter 4 is an in-depth analysis of the molecular environment towards the supernova remnant RX J1713.7−3946 (in 3 articles) using several independent molecular gas tracers, including transitions of the CS, NH_3 and N_2H^+ molecules. In addition to various specific mm-phenomena, the presence of dense gas was confirmed via our observations. The issue of cosmic ray transport into dense star-forming cores was then addressed. Due to enhanced magnetic turbulence, cosmic ray propagation may be slower than the galactic average, so predictions for several slow-diffusion scenarios are made. Through modeling, scenarios where low energy cosmic rays are excluded from the centres of molecular cores were identified. Such cases may result in a lower proportion of low energy gamma-rays coming from core centres relative to higher energy gamma-rays (ie. a hardening of the gamma-ray spectrum).

Chapter 5 is an overview of the molecular gas towards the entire gamma-ray emission region of the supernova remnant CTB 37A (in 1 article), allowing the estimation of the mass of cosmic-ray target material, found to be $\sim 10^4\,M_\odot$. In a hadronic scenario for gamma-ray emission, this corresponds to a cosmic ray density of ∼80-1100 times that seen Earth. This may have implications for the supernova remnant energetics, distance and age, which are discussed.

Finally, in Chapter 6, an investigation of the subtleties of cosmic ray diffusion near supernova remnants is carried out, and techniques to simulate effects that may result from diffusion into molecular gas are outlined. Hard conclusions concerning the spectrum of gamma-rays resulting from molecular cores are left for future work.

0.2 Declaration of Originality

I, Nigel Maxted, certify that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968. The author acknowledges that copyright of published works contained within this thesis (as listed below*) resides with the copyright holder(s) of those works. I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library catalogue and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

*Published works contained within this thesis:

- Maxted N., Rowell G., Dawson B., Burton M., Nicholas B., Fukui Y., Walsh A., Kawamura A., Horachi H. & Sano H., 2012, MNRAS, 419, 251-266
- Maxted, N., Rowell G., Dawson, B., Burton, M., Kawamura, A., Walsh, A., Sano, H., Lazendic, J., 2012, eds. F. Aharonian et al., AIP Conf. Proc. Vol. 1505, High Energy gamma-ray Astronomy Am. Inst. Phys., New York, p. 253
- Maxted N., Rowell G., Dawson B., Burton M., Nicholas B., Fukui Y., Walsh A., Kawamura A., Horachi H., Sano H., Yoshiike S. & Fukuda T., 2013, MNRAS, *in press*
- Maxted N., Rowell G., Dawson B., Burton M., Nicholas B., Fukui Y., Lazendic J., Kawamura A., Horachi H., Sano H., Walsh A., Yoshiike S. & Fukuda T., PASA, *Manuscript being finalised*

Signature_____ Date_____

0.3 Acknowledgements

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