ISSI Visiting Scientists Programme

THE RHESSI MISSION: INVERSION METHODS FOR IMAGING SPECTROSCOPY.

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Final Report

This project was the continuation of a previous one (with title *The RHESSI Mission:* X-Ray Spectra and Image Analysis by Means of Inversion Methods), funded by ISSI for the period 2005-2006. Both projects were devoted to the formulation of inverse methods for the analysis of solar X-ray data recorded by the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), launched by NASA on February 5, 2002.

In particular this second project was focused on the integration of 2D spatial imaging with 1D high resolution spectroscopy into an *imaging-spectroscopy* approach for the analysis of hard X-ray emission during solar flares. We developed a new method for imaging spectroscopy that avoids the "traditional" noise-sensitive step of stacking independent images made in different count-based energy intervals. Rather, it involves regularized inversion of the count visibility spectra (i.e., the two-dimensional spatial Fourier transforms of the spectral image) to obtain smoothed (regularized) forms of the corresponding electron visibility spectra. Application of conventional visibility-based imaging algorithms then yields images of the electron flux that vary smoothly with energy. The results of this study have been published in [3] and presented during international conferences [9,10,11].

In the meantime we continued the work, started under the first project ISSI support, focused on the development of robust, rigorously-tested algorithms to determine the source electron spectrum from observations of the emitted hard X-ray spectrum. We have explored different forms of the kernel cross-section, such as through including electron-electron bremsstrahlung [4], and anisotropic emission [1,2]. We have studied the solar bremsstrahlung inverse problem in a rigourous mathematical framework [6]. We have analyzed both source-integrated spectra [1,2,4,7] and imaged spectra [3,5]. Finally, our work has also been included in a RHESSIinspired book in preparation for submission to *Space Science Reviews* [8].

The team composition reflected the multidisciplinary flavor of the project: it comprised experts in electron acceleration and propagation in solar flares, data analysis and mathematical inversion techniques. We had also the opportunity to invite Dr. Richard A. Schwartz (NASA Goddard Space Flight Center, Greenbelt Maryland, USA) to join us during the last meeting (January, 28 - February, 3 2008). Dr. Schwartz is responsible for the integration of the RHESSI data analysis software into the Solar SoftWare (SSW) package and his expertise was very useful in order to make available our new developed techniques to the community through the Solar SoftWare tree.

List of Publications Resulting from the Project

Journal Papers

[1] E. P. Kontar & J. C. Brown, "Stereoscopic Electron Spectroscopy of Solar Hard X-Ray Flares with a Single Spacecraft," *The Astrophysical Journal*, **653**, L149-L152 (2006).

[2] J. Kašparová, E. P. Kontar, J. C. Brown, "Hard X-ray spectra and positions of solar flares observed by RHESSI: photospheric albedo, directivity and electron spectra," *Astronomy & Astrophysics*, **466**, 705-712 (2007).

[3] M. Piana, A. M. Massone, G. J. Hurford, M. Prato, A. G. Emslie, E. P. Kontar, & R. A. Schwartz, "Electron Flux Spectral Imaging of Solar Flares through Regularized Analysis of Hard X-Ray Source Visibilities," *The Astrophysical Journal*, **665**, 846-855 (2007).

[4] E. P. Kontar, A. G. Emslie, A. M. Massone, M. Piana, J. C. Brown, & M. Prato, "Electron-Electron Bremsstrahlung Emission and the Inference of Electron Flux Spectra in Solar Flares," *The Astrophysical Journal*, **670**, 857-861 (2007).

[5] Y. Xu, A. G. Emslie, & G. J. Hurford, "RHESSI Hard X-ray Imaging Spectroscopy of extended sources and the physical properties of electron acceleration regions in solar flares," *The Astrophysical Journal*, **673**, 576-585 (2008).

[6] A. M. Massone, M. Piana, & M. Prato. "Regularized solution of the solar Bremsstrahlung inverse problem: model dependence and implementation issues," *Inverse Problems in Science and Engineering*, in press (2008).

[7] J. C. Brown, J. Kašparová, A. M. Massone, & M. Piana, "Fast Spectral Fitting for Hard X-ray Bremsstrahlung from Truncated Power-Law Electron Spectra," *Astronomy & Astrophysics*, submitted (2008).

[8] E. P. Kontar, J. C. Brown, A. G. Emslie, W. Hajdas, G. D. Holman, G. J. Hurford, J. Kašparová, P. C. V. Mallik, A. M. Massone, M. L. McConnell, M. Piana, M. Prato, E. J. Schmahl & E. Suarez-Garcia. "Deducing Electron Properties form Hard X-ray observations," *Space Science Reviews*, in preparation (2008).

Conference Proceedings

[9] A. M. Massone, M. Piana, M. Prato, A. G. Emslie, G. J. Hurford, E. P. Kontar, & R. A. Schwartz. "Electron flux maps of solar flares: a regularization approach to RHESSI imaging spectroscopy," In: Modelling and Simulation in Science. Proceedings of the 6th International Workshop on Data Analysis in Astronomy Livio Scarsi. Erice, Italy 15 - 22 April 2007. Eds. V. Di Gesù, G. Lo Bosco & C. Maccarone. ISBN 978-981-277-944-1 (2007).

[10] A. G. Emslie, M. Piana, A. M. Massone, G. J. Hurford, M. Prato, E. P. Kontar, & R. A. Schwartz. "Determination of Electron Flux Spectrum Images in Solar Flares using Regularized Analysis of Hard X-Ray Source Visibilities," In: Bullettin of the American Astronomical Society. American Astronomical Society 210th Meeting. Honolulu, Hawaii. 27-31 May 2007. vol. 39, # 037.04. ISBN/ISSN: 0002-7537. (2007).

[11] A. M. Massone, M. Piana & M. Prato. "Imaging spectroscopy of hard x-ray sources in solar flares using regularized analysis of source visibilities," In: Proceedings of AIP2007. Conference on Applied Inverse Problems 2007: Theoretical and Computational Aspects. June 25-29, 2007. University of British Columbia, Vancouver, Canada. In press.