RHESSI/Nessie II, Working group 3

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Abstract. This report is a narrative description of the presentations and discussions of Working Group 3 ("From sites of radiation to particle sources") in the second of the RHESSI series of specialized workshops. These have dealt with current work on the distribution functions of the flare-related energetic particles observed via X-ray and γ-ray emissions by RHESSI.

1. Introduction

The RHESSI/Nessie series of workshops have focused on dealing with the concrete problems associated with particles in solar flares, i.e. the behavior of the particles responsible for the X-ray and γ-ray emissions as observed by RHESSI in particular. The three working groups deal respectively with "counts to photons," "photons to particles," and "sites of radiation to particle sources." One can read this neat ordering as "detector response," "inversion of the photon spectra," and "the rest of the problem." Note that "radiation" in the context of the RHESSI/Nessie workshops explicitly means high-energy photons, rather than particles or the more thermal kinds of radiation, for the most part. To keep the scope of Working Group 3 under control, we deliberately avoided discussion data morphology much, while recognizing that within this working group we necessarily had to be aware of the whole array of flare observations. When one notes the huge dynamic range displayed by any given physical parameter in a flare, one realizes that the WG3 domain has to be much less well-defined than the those of the other working groups.

The discussion below just represents the author's understanding of what was discussed and probably includes many misconceptions.

2. The nature of the problem

By almost universal opinion, the X-rays and γ-rays observed in solar flares come from the conversion of magnetic energy in the corona. Thus it is natural, although not necessarily correct, to imagine this happening in a "black box" that can be studied separately. From this black box one imagines the particles to flow along the field lines until they lose energy, partly by the radiation we observe. The radiation sources normally are considered to be “footpoints” or “ribbons” at low altitudes in the solar atmosphere, or “loop-top” if higher up. This division of the physics is a practical matter dictated by the complexities involved in more self-consistent approaches. In this meeting we did not deal with acceleration as such and divided the remaining problem into three compartments (propagation, radiation, and footpoint modeling). In each area we asked specific questions and discussed possible answers to them, and that is the basis of this report.

3. Propagation

The behavior of the particles in the lower solar atmosphere is particularly important, since that is where most of the radiation signatures originate. There is an extensive literature of modeling in the 1-D radiative hydrodynamics limit. Is this ever a valid limit in which to study particle propagation? In other words, does cross-field transport of energy ever permit the modeling of a flare as a single flux tube? This seems to be a dividing line between (a) models involving particle acceleration in large-scale magnetic reconnection, which would probably work like a zipper acting along a series of flux tubes, or (b) particle acceleration acting within a finite flux tube, which might involve a large volume populated by waves.

Either way, the 1-D radiative hydrodynamics models remain extremely relevant, and the discussions in WG3 emphasized many important new inputs into this kind of modeling. In particular, as discussed below, the observations of the 511-keV γ-ray line of positron annihilation (Share et al., 2003).

To what extent are electron footpoints smeared out by drift motions? By drift motions one refers to the non-adiabatic behavior of particle motion in the presence of gradients or external forces. In well-behaved magnetic structures these drifts can be shown to be negligible. However, in solar flares we deal with magnetic structures that by hypothesis behave badly. Thus near a reconnection point one would would expect substantial transport effects; this is being studied by several persons in the “test charge” approximation. The results are quite convincing: accelerated protons and electrons, for example can diverge almost completely. This calls to mind the RHESSI results, which for one flare clearly show a displacement between the 2.223 MeV γ-ray source and the hard X-ray footpoint regions (Hurford et al., 2003). **Answer: Being studied**.

To what extent can ions and electrons be separated spatially? **Answer: Considerably**.

*Do separatrices correspond to ribbons, or (*Metcalf et al.*, *2003*) are they just intriguingly related?* Magnetic energy release probably involves flux transfer between different magnetic domains. To the extent that the flux transfer (magnetic reconnection) itself corresponds to a site of particle acceleration, the particles will then propagate to a radiation source located on the separatrix. Members of the WG3 are working hard to extend the work pioneered by Mandrini and collaborators (e.g., Demoulin et al., 1997) to match RHESSI and TRACE high-energy observations with the best possible modeling of the active-region magnetic field structure. **Answer: Being studied**.

At what time scale does the steady-state approximation break down? **Answer: pending a full understanding of the return current, probably short relative to observed time scales**.

4. Radiation

Flare hard X-ray sources typically occur pairwise in footpoints that are embedded in more extensive ribbons, which can be observed in a variety of chromospheric and transition-region lines. Indeed, the observability of ribbons across different spectral domains is not understood technically at present (see comments above about 1D radiative hydrodynamics models). The RHESSI observations also appear to show more coronal hard X-ray emission than could be inferred from earlier data, perhaps because of improved spectral resolution.

Does trapping and Coulomb loss explain 34-GHz looptop sources? Radio observations at mm radio frequencies, likely to be beyond any radiative-transfer effects, offer an opportunity to study the dynamics of particles directly in the corona that is quite independent of the X-ray observations. In particular the trapping of high-energy electrons may reveal itself much more distinctly than in the “loop-top” or “above-the-loop-top” sources (Masuda et al., 1994) that have been so difficult to understand physically. In particular the Nobeyama 34-GHz observations show an unexpected concentration towards the loop top, as discussed in WG3 by Melnikov. The question is whether ordinary Coulomb collisions can effect this concentration, as trapping continues in time, or whether additional physics is required. This question is also closely linked to the “realistic magnetic modeling” that WG3 is interested in. **Answer: under study**.

Can a coronal loop be dense enough to stop 60 keV electrons? The RHESSI observations reported by Veronig and Brown (2004) strongly suggest this, in that the two flares studied show extremely weak footpoint emission in hard X-rays. The interpretation is that in these events the corona is collisionally thick up to some 60 keV, lending credence to the idea that some flares (probably not most flares) can be described in terms of 1-D flux tubes. **Answer: Yes, at least sometimes**.

Do RHESSI observations suggest a coronal current sheet? The standard reconnection model predicts the existence of a current sheet separating the coronal plasmoid from the flare arcade. Unfortunately the model cannot predict the temperature and emission measure of such a current sheet, and in fact the coronagraphic observations of CMEs strongly suggest that such current sheets are either rare or unimportant at these large altitudes. However Ko et al. (2003) found interesting UV spectroscopic evidence for a current sheet, and RHESSI observations (Sui and Holman, 2003) are also being interpreted in this manner much closer to the flare itself. **Answer: Yes; being studied**.

Can realistic field extrapolations help us to understand flare X-ray sources? Abundant new magnetic data now include routine vector magnetograms and chromospheric line-of-sight magnetograms. These data will soon get better with SDO and Solar-B magnetographs, and with improvements in MHD modeling of the configurations of solar active regions. Strong suggestions of flare-associated perturbations even in the photospheric magnetic field are now appearing in the literature. Unfortunately these are subtle effects, which we must compare conceptually with the drastic restructuring of the active-region field that must be involved in an eruptive flare or CME.

This turned out to be a major activity at the workshop. Three independent "B-cubes" portraying the magnetic volume above active region 10486 (responsible for the October 29, 2003 event) were generated, including one non-linear force-free model. The intercomparison of these reconstructions is already interesting and will be much more so in the context of the RHESSI observations. **Answer: Being studied**.

5. Footpoints

Two prominent problems arose in particular: how do we explain the line width of the 511-keV emission feature due to positron annihilation, and how do we understand the mismatch (overconcentration?) between hard X-ray footpoint sources and ordinary flare ribbons?

Do electron-heated atmospheres produce thick enough transition regions to explain the 511-keV line width? The answer to this question seems to be an unequivocal "no" for traditional 1D models. It is more likely to be "no" for zipper-type (multi-strand) models, since it requires intense heating to maintain a transition-region temperature against radiative losses. **Answer: No**.

Do proton-heated atmospheres produce thick enough transition regions to explain the 511-keV line width? This kind of model is much more attractive, partly because (as pointed out by Emslie at the workshop) we *know* from the γ-rays that the proton heating is present. Furthermore, protons may cause heating in layers, rather than from the top down, so it is not inconceivable that continued heating in the implied few × 10^5 K temperature region could occur. Again, this seems to be possible only in the "macroscopic flux tube" limit. **Answer: Being studied**.

Do we understand footpoint emission-measure distributions sufficiently to explain ribbon radiations? This DEM question is a traditional problem, and (according to my opinion) it depends entirely on additional inputs to the 1D radiative hydro modeling. Do we need to worry about return-current losses? How do we handle two-dimensionality? How do we model magnetic mirroring? What about non-equilibrium plasma effects? And how about waves? **Answer: Being studied, but probably not by enough people**.

Do we understand why hard X-ray footpoint structures are so concentrated in the ribbons? One conjecture is that this is just a spatial analog of the well-known pattern (soft-hard-soft) of thte temporal evolution of flare hard X-ray sources (e.g., Fletcher and Hudson, 2002). **Answer: Being studied**.

6. Summary

This small, specialized workshop seemed to be well focused on important issues. In particular the behavior of energetic particles in solar flares (even if one ignores the fundamental problem of particle acceleration) seems to depend upon a small community of modelers. Who is doing plasma dynamics to understand reverse-current effects, if we are dealing with particle beams? Who is doing adequate modeling of radiative-transfer effects in the all-important lower atmosphere? Who is making use of the newer high-resolution data to understand magnetic structures on more appropriate scales? Who is trying to understand particle acceleration in a self-consistent framework of solar-flare theory? It turned out that key people in all of these areas were present at the RHESSI/Nessie II workshop, and we hope to hear from them in the near future (at the Paris and Sonoma RHESSI workshops, for example).

Appendix

Participants in the discussions included among others, with boldface showing those making presentations: **Joel Allred**, Laura Bone, **Gordon Emslie**, Lyndsay Fletcher, Peter Gallagher, Ross Galloway, **Mikola Gordovskyy**, **Brian Hamilton**, **Iain Hannah**, Gordon Holman, Hugh Hudson (chair), **Gottfried Mann**, **James McTiernan**, **Victor Melnikov**, **Ronald Murphy**, **Vahe Petrosian**, **Gerry Share**, Sigrid Stoiser, **Astrid Veronig**, **Alexander Warmuth**, **Paul Wood**, Valentina Zharkova

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