High Energy Solar Physics Data in Europe
(HESPE)

Grant Agreement no.: 263086

Beneficiaries

- **Università di Genova (UNIGE)**
- **Fachhochschule Nortwestschweiz (FHNW)**
- **University of Glasgow (UNIGLA)**
- **Universitaet Graz (UNIGRA)**
- **Centre National de la Recherche Scientifique (CNRS)**
- **University of California at Berkeley (UCB)**

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Second Year Report
(December, 1 2011 – November, 30 2012)

1. Project objectives for the period

The rationale of the 'High Energy Solar Physics Data in Europe (HESPE)' project is to formulate and implement computational methods for solar high-energy data analysis, and to utilize Information and Communication Technology (ICT) tools for providing algorithms and science-ready products to the solar physics community.

HESPE wants to be a home for state-of-the-art high-energy solar data and science-ready products, which helps to initiate original, challenging solar, helio and space science. To accomplish this goal, HESPE utilizes computational and technological tools whose conception is driven by theoretical models formulated within the framework of solar flare physics. More specifically, HESPE is realizing a computational corpus containing numerical algorithms for spectral fitting, spectral inversion, image reconstruction, edge detection, image segmentation, spectral and image classification. Further, HESPE aims at: defining and realizing a database of optimized data products that are interoperable with standard data analysis software; setting up a standard catalogue of science-ready products that automatically allow fast searching and browsing; and, finally, integrating these products into e-infrastructures (like HELIO or SOTERIA) that are already active in the EU solar, helio and space weather communities.

In the following objectives concerned with the Research and Technology Development (RTD) work packages during the second year are described. The activity of the Management (MGT) Work Package (WP 1) and the 'Other Activities' Work Package (WP 2, mainly devoted to dissemination) will be described in the last section of this report

1.1 Work Package 3: Theory

The objectives of WP 3 for this second year were to capitalize on the improved techniques in X-ray and gamma-ray data analysis and diagnostics; to develop the background theory of particle acceleration and to study how the efficiency of X-ray diagnostics can be improved by integration with appropriate datasets. The achievement of such objectives has been the result of the following tasks foreseen in the HESPE 'Description of Work':

Task 1: Parameters of accelerated particles:

- *Derivation of the characteristic parameters of the accelerated particle populations in solar flares and use X-ray and gamma-ray diagnostics to measure the electron angular distributions and X-ray source structures.*
- *Combination of the analysis of SEP events at the Earth and at the Sun using X-ray and gamma-ray data, to identify the propagation properties of energetic particles in turbulent plasma media of the solar corona and interplanetary space.*

Task 2: Study of the energy release sites and particle acceleration mechanisms:

- *Combination of X-rays and other wavelengths to derive the physical conditions of the energy release sites and to better understand particle acceleration mechanisms: with radio observations related to geo-effective factors (space weather); optical, SXR and EUV (SDO mission).*

Task 3 Development of paradigms for generating synthetic data:

- *Design of physical/geometric configurations for flaring events; formulation of simulation paradigms for producing calibrated event lists, hard X-ray visibilities, count spectra and images.*

Task 4 Development of particle acceleration and propagation models:

- *Based on the results obtained in previous tasks, we will undertake theoretical development of particle acceleration models, and particle propagation models.*

1.2 Work Package 4: Computation

The general aim of WP 4 for the second year was to keep on constructing a computational corpus for the analysis of data provided by hard X-ray and gamma-ray observations. Specifically the idea was to formulate, develop and implement algorithms for spectroscopy, imaging and imaging spectroscopy and to validate such computational methods against synthetic data of plausible physical significance and real observations provided by currently operating hard X-ray and gamma-ray instruments. The roadmap to the achievements of such goals has been based on the following tasks, specific for the HESPE second year activity:

Task 1: Imaging:

- *From visibilities: interpolation/extrapolation approaches by means of Fourier methods*
- *From dirty maps: deconvolution and multiple-deconvolution methods based on iterativeregularization techniques exploiting a priori information on the solution and on the statistical properties of the data.*

Task 2 Spectroscopy:

- *Improvement of Tikhonov regularization techniques already implemented in SSW by including automatic computation of the error and resolution bars by means of a Monte Carlo approach.*
- *Implementation of Expectation-Maximization approaches to spectral inversion*

Task 3 Imaging spectroscopy:

- *Formulation and implementation of method for spatially resolved spectroscopy which provides electron maps of the source at many different electron energies starting from count visibilities.*
- *Validation of the approach against both synthetic data and real observations.*

Task 4 Validation of the algorithms against both synthetic data and observations.

1.3 Work Package 5: Technology

The main objective pursued by WP 5 during this second year has been the realization of the HESPE processing framework and the publication of the visibility database. This objective pertains to Task 1 according to the HESPE 'Description of Work':

Task 1: From Telemetry Data to Visibilities:

- *Design and Implement the Interval Selection Algorithm: Develop a "generic" algorithm for flare detection, based on methods that are not only valid for RHESSI data. Develop a method to divide the detected flare into energy and time sub-intervals that are optimal for generation of visibilities.*
- *Generate Visibilities: Apply the interval selection algorithm to the RHESSI Level-0 and generate the instrument-independent visibility database.*

The accomplishment of this objective is crucial for the generation of the science product database, which is the main objective of Task 2 for the third year of HESPE activity:

Task 2: Generate Science Ready Products:

- *Code the algorithms delivered by WP3, according to the interface provided by the RHESSI data analysis software.*
- *Integrate the coded visibility algorithms into the RHESSI data analysis software framework.*
- *Generate images (both electron and X-ray), dynamic and spatially resolved Spectra (electron and X-ray).*
- *Validate the data products for quality.*

The integration of these database services into already existing EU e-infrastructures will be pursued during the third year of HESPE activity according to the following:

Task 3: Interface the data products to the European Infrastructure:

- *Create metadata services for the virtual observatories: Generate a schema describing the data products and their relationships, implement the schema into a database and ingest the metadata describing the products.*
- *Integrate services into EU e-Infrastructures, by making the access HELIO compatible.*
- *Deploy database queries as web services for easy integration in any VxOs.*
- *Implement data mining algorithms to support flare predictions.*

1.4 Work Package 6: Future

The main objective of WP 6 is to make the deliverables of WP 3, WP 4 and WP 5 accessible to future missions. This objective will be accomplished through an activity based on the following tasks:

Task 1: Generation of synthetic data for future visibility-based instruments
Task 2: Validation of algorithms against synthetic data
Task 3: Generation of computational tools for processing generic visibility data

2. Work progress and achievements during the period

The RTD work packages Theory (WP 3), Computation (WP 4) and Technology (WP 5) have been always active during these second twelve months of HESPE activity, while the RTD work package Future (WP 6) has started at month 20. It follows that most of the results obtained during this second year are concerned with WP 3, WP 4 and WP 5 while WP 6 has considered just some preliminary aspects of its tasks. Furthermore, HESPE is an interdisciplinary project and indeed most results have been obtained thanks to intense inter-connections among the different work packages. In the following of this section we will synthetically mention the main results obtained for the period by the HESPE WP 3, WP 4 and WP 5 activity. Then we will discuss in more details what we consider the most significant achievements among these results. A systematic discussion of the work progress during this second year will be offered in sub-section 2.3.

2.1 Overview of HESPE results for the period

The following itemization contains all the results obtained during the second year by the HESPE Theory, Computation and Technology work packages.

- **Creation of a distributed and autonomous HESPE processing framework.** The framework is a Java program that allows for autonomous and distributed processing of flare data (collected by either RHESSI or any other instrument for high energy measurements based on modulation profiles). It manages all the necessary steps from reading raw data and flare-specific configurations, to processing the data and publishing the visibility database and science products. To increase processing speed, all the above steps can be executed on a distributed group of servers in parallel.
- **Publication of an optimized visibility database.** At the URL http://hsp.cs.technik.fhnw.ch/webgui-0.6-SNAPSHOT a web-GUI allows users to browse the list of events that have been processed by the HESPE framework to extract the corresponding optimized visibilities. Eventually each GOES classified flare from the RHESSI Event List will be processed by HESPE.
- **Formulation and implementation of image reconstruction methods from visibilities.** HESPE has developed several regularization methods that take as input visibilities corresponding to different time and energy intervals and provide as output reconstructed images at the same time and energy intervals.
- **Development and implementation of a method for the construction of electron maps from visibilities.** The construction of electron maps of a flaring event was one of the main original goals of the RHESSI mission and is currently one of the major goals also for the STIX mission in Solar Orbiter. A very optimized visibility-based optimized code based on the idea described in (M. Piana, A. M. Massone, G. J. Hurford, M. Prato, A. G. Emslie, E. P. Kontar, and R. A. Schwartz ApJ, 665 846 2007) is now included in the GUI of the SSW tree.
- **Formulation and implementation of image reconstruction methods from count modulation profiles.** HESPE has showed that the classical Lucy-Richardson approach to image deconvolution can be extended to image reconstruction from count modulation profiles (Benvenuto et al 2012; Benvenuto et al 2013). The generalization of this approach to the solution of the spatially integrated spectroscopy inverse problem and to the construction of an imaging spectroscopy approach from counts (instead of from visibilities) is under construction.
- **Spatially integrated spectroscopy.** HESPE scientists (Emslie and Massone 2012) pointed out that the expectation values of the source brightness and its variance in a given photon energy bin are in general not (as has been assumed in prior works) equal to the number of counts observed in that energy bin. From this viewpoint they developed a new method for computing the confidence strip associated to the reconstructed electron flux spectrum. Further, the Lucy-Richardson approach has been generalized to spectroscopy. The validation of this algorithm is in progress.
- **Validation of models for particle acceleration mechanisms.** HESPE has worked at several observational aspects of flares that are relevant to particle acceleration. As far as models involving magnetic reconnection are concerned, UV and HXR evidence for a

coronal null and quasi-separatrix layers exhibiting slip-running reconnection has been found by Reid et al. (2012) in a specific flare on 16-Nov-2002; further, recent observations by Su et al. (2012) provide probably the strongest evidence yet of magnetic reconnection in the solar corona. As far as models involving turbulence and waves are concerned, Guo et al. (2012a,b) have carried out studies of electron flux maps for coronal loop flares, with the aim of constraining the volume filling factor and electron acceleration efficiency in these events. Also focusing on strong coronal loop sources, in a study of 4 flares using RHESSI imaging spectroscopy, it was found by Simoes and Kontar (2012) that, during the impulsive phase, the electron rate at the coronal source is a factor of 1.6-7.9 higher than the electron rate at the foot-points. Finally, Reid and Kontar (2012) carried out specific investigations of wave-particle processes from both a theoretical and an observational standpoint.

- **Theoretical studies on turbulent acceleration processes.** A major study of the properties of wave-particle acceleration processes (Bian et al 2012) involving low-frequency waves in a strongly-magnetized plasma introduces a classification scheme for such acceleration models. The results of wave-particle interactions on energetic electrons in the heliosphere, both for the case of electrons propagating from a coronal acceleration site outwards into the heliosphere, and downwards into the lower atmosphere, have been further examined by Kontar et al. (2012) and Ratcliffe et al. (2012). A specific wave energization model involving the progression of a single Alfvenic wave pulse from the corona into the chromosphere has also been studied by Russell and Fletcher (2012).
- **Studies on ion acceleration mechanisms.** An extensive review of energetic particles in solar flares has been written by Vilmer (2012), which includes a discussion of ions. The information about ions comes primarily from gamma-ray radiation, which is weaker and more difficult to measure than X-ray radiation - however alternative diagnostics such as charge-exchange continuum have also been investigated (Hudson et al 2012).
- **Observational study of energy release rate in flares.** This activity has been carried out by Torre et al (2012) again using electron maps obtained from RHESSI visibilities.

2.2 Main HESPE achievements for the period

The creation of the HESPE processing framework (see Figure 1) has been the main realization of WP 5, under the leadership of FHNW but with the support of all the units in the HESPE consortium. There are three main modules making up the HESPE framework:

- **The Database Module** allows other modules to write data to the database through a unified interface. This is an advantage as it is allowing for flexibly changing the underlying database or database structure without requiring rewriting major parts of other modules, e.g. when reacting to feedback from researchers.

- **The Cloud Computing Manager** manages the distributed processing, the communication between Java and the IDL-written SSW library and the correct invocation of the RHESSI software in IDL. There are two main components that have been developed for the HESPE framework:

  - ➢ The Cloud Service Manager manages the data processing, orchestrates the distribution of tasks among all active Processing Towers (see below) and collects and integrates the processed data products.
  - ➢ The Processing Towers are also independent services receiving ad executing processing tasks. They also allow for connecting the non-Java based applications).

  All processing steps involved in the Framework are organized in the Processing Pipeline (see Figure 2) that calculates the visibilities and creates quick-look images (the current version of the Framework utilizes uv_smooth as image processing method: the reason for this is in the fact that this interpolation/extrapolation algorithm is strongly FFT-based and therefore extremely fast). The pipeline reads the data from a selected event, calculates information needed by the Interval Selection Algorithm, applies the Interval Selection Algorithm to create the optimized time-energy intervals, reconstructs the uv_smooth images for each interval and publishes all the computed data in the visibility database and web server. The Interval Selection Algorithm is the computational core of the Framework. It finds optimal time-energy intervals that allow for the generation of optimal sets of images covering an entire flare. The detailed description of the algorithm is given in the HESPE deliverable D5.1 (Month 12), can be downloaded at the URL http://www.hespe.eu/software/installation/demonstration-packages/ and produces outputs as the one in Figure 3.
- **The Web Interface Module** at the URL http://hsp.cs.technik.fhnw.ch/webgui-0.6-SNAPSHOT is a web GUI that allows users to browse the processed event list, view images and download the visibilities for each event.

The final outcome of the HESPE Processing Framework (and, ultimately, of the whole HESPE effort) is the creation of an optimized visibility database and of a database of science ready products. The HESPE visibility database has been already published as HESPE deliverable D5.2 and currently contains all 800 X-type and M-type events (but the database is currently being filled). For these flares it is possible to download the visibilities for an individual data analysis or to explore the event by analyzing the pre-processed spectrograms of the corresponding quick-look images.

A second important result obtained by HESPE thus far has been the creation of a significant computational corpus made of regularization methods for image reconstruction from visibilities. In fact, we now have an updated version of uv_smooth (Allavena et al 2012) that improves the previous version insofar as it reduces the artifacts showing up in the case of specific flaring configurations (namely, for significantly separate compact sources) but preserving the computational effectiveness of the original method; we have implemented a visibility-based CLEAN algorithm which is now available in SSW (and soon in the GUI); we are validating a new maximum entropy method that does not suffer of the over-resolving behavior of the algorithm currently available in SSW; and we are working at the realization of a Bayesian method representing a powerful generalization of the forward fitting approach to image reconstruction (preliminary results of this method have been presented at the conference 'Solar in Sonoma', November 27 - December 2 2012, Petaluma, CA, USA). In the second part of the year we have focused on reconstruction techniques taking count modulation profiles as input. The Expectation Maximization (EM) algorithm described in (Benvenuto et al 2012; Benvenuto et al 2013) is able, at the same time, to minimize the C-statistics, encode a positivity constraint in the reconstruction process and avoid over-resolving artifacts thanks to a very effective stopping rule. The results of the validation process under construction seem to show that EM can become the algorithm of choice for image reconstruction from RHESSI data. Finally, as far as imaging is concerned, a key aspect of HESPE has been to deliver electron flux maps straight from visibilities (Massone and Piana 2013), without the transition step of photon maps and this has been used to great effect. This method is now available at the SSW GUI (see Figure 4) and furthermore, a new (and probably even more effective) approach to the generation of electron maps is now under construction using the Expectation Maximization technique already introduced for the production of photon images. This approach will directly takes count modulation profiles as input.

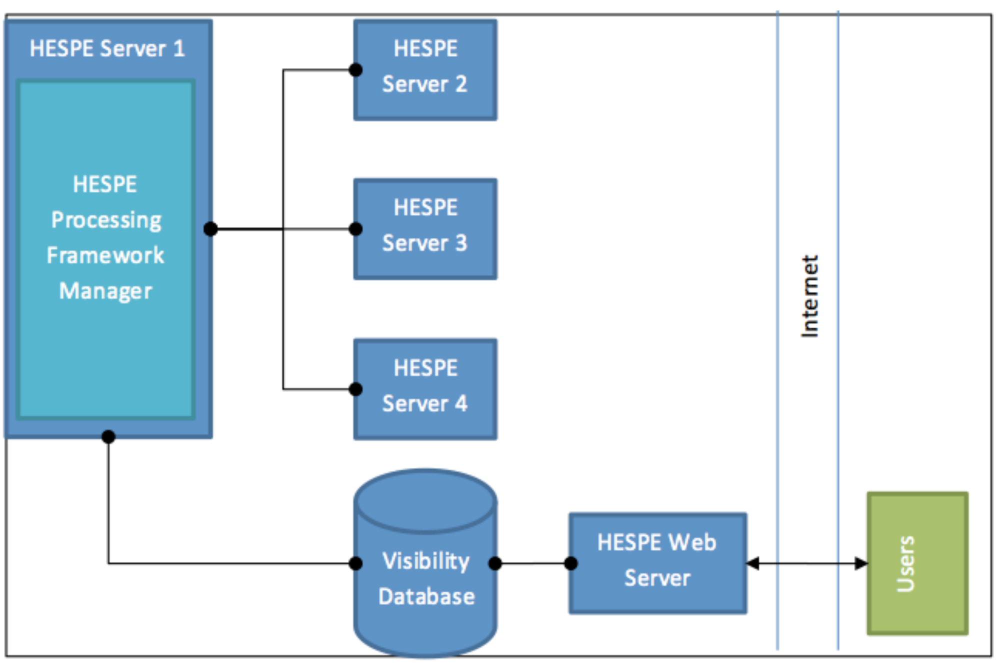

Figure 1. HESPE processing framework.

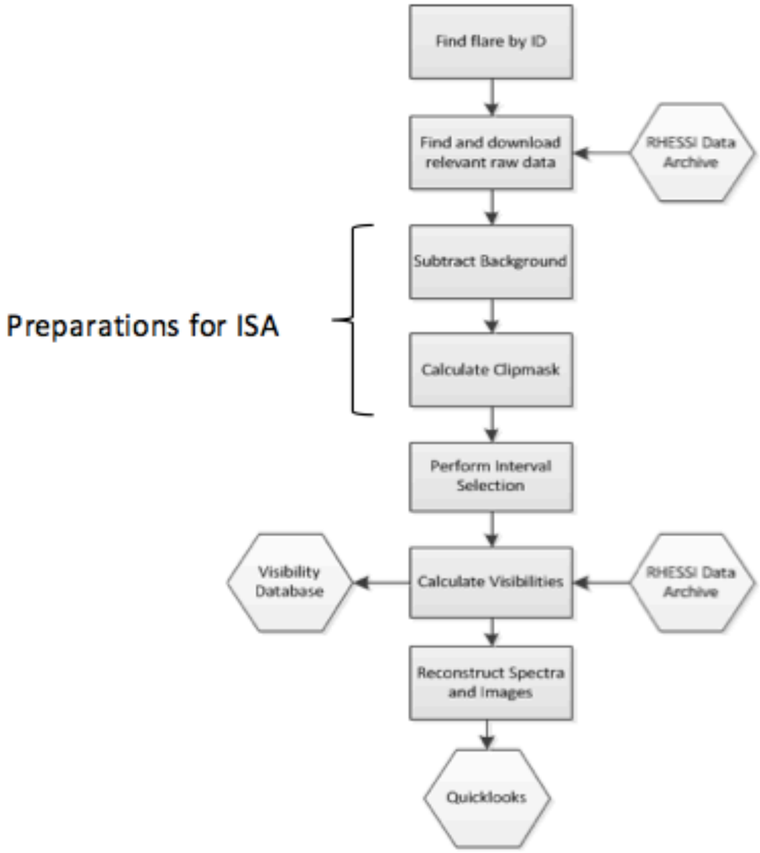

Figure 2. HESPE processing pipeline.

HESPE is mainly a technology and computation project, but the technological and computational tools thus far realized have been utilized within the HESPE framework itself to obtain important results in terms of the theoretical comprehension of solar flare physics and, specifically, for the selection of the most reliable models for particle acceleration and energy transport. Specifically, in the first two years HESPE researchers have obtained two main results utilizing RHESSI observation:

- Su et al (2012) report the most direct observations of magnetic reconnection in the solar corona that produced a GOES C2.3 flare on August 17, 2011 (see Figure 5). The SDO/AIA EUV data clearly showed how coronal loops flow into the reconnection region to form new, hot loops that are relaxing. Simulataneously, RHESSI observed X-ray sources at locations expected from the magnetic reconnection process. The inflows, observed over a wide range of temperatures, have initial locations far from the reconnection site (up to 40 arcsec) but expanded and accelerated as the approach to the reconnection site. The final observed inflow speed range from 20 to 70 km per second and the outflow speeds from 90 to 440 km per second.

- Guo et al (2012a,b) analyzed electron flux maps for 22 extended coronal loop flares. For each event they fit a collisional model with an extended acceleration region to the observed variation of loop length with electron energy, resulting in estimates of the plasma density in, and longitudinal extent of, the acceleration region. These quantities in turn allowed inference of the number of particles within the acceleration region and of the filling factor. The mean values obtained for the filling factor and specific acceleration rate over the 22 events have implications for both the global electrodynamics associated with replenishment of the acceleration region and the nature of the particle acceleration process.

The most important results obtained by the HESPE Theory work package (WP 3) was probably the realization of a classification scheme for stochastic acceleration models involving low-frequency plasma turbulence in a strongly magnetized plasma (Bian et 2012). This classification takes into account both the properties of the accelerating electromagnetic field, and the nature of the transport of charged particles in the acceleration region. In this work the acceleration processes are grouped as either resonant, non-resonant or resonant-broadened, depending on whether the particle motion is free-streaming along the magnetic field, diffusive, or a combination of the two. Stochastic acceleration by moving magnetic mirrors and adiabatic compressions are addressed as illustrative examples. They also obtained expressions for the momentum-dependent diffusion coefficient, both for general forms of the accelerating force and for the situation when the electromagnetic force is wave-like, with a specified dispersion relation. Finally, for models considered, they calculates the energy-dependent acceleration time, a quantity that can be directly compared with observations of the time profile of the radiation field produced by the accelerated particles, such as those occurring during solar flares.

2.3 Work progress for the period

This sub-section describes the activities performed by the RTD work-packages during the second HESPE year.

<u>Work Package 3: Theory</u>

Task 1: Parameters of accelerated particles
- Derivation of the characteristic parameters of the accelerated particle populations in solar flares and use X-ray and gamma-ray diagnostics to measure the electron angular distributions and X-ray source structures.

- Combination of the analysis of SEP events at the Earth and at the Sun using X-ray and gamma-ray data, to identify the propagation properties of energetic particles in turbulent plasma media of the solar corona and interplanetary space.

Task 2: Study of the energy release sites and particle acceleration mechanisms
Combination of X-rays and other wavelengths to derive the physical conditions of the energy release sites and to better understand particle acceleration mechanisms: with radio observations related to geo-effective factors (space weather); optical, SXR and EUV (SDO mission).

Hard X-ray emission from high energy electrons is the principle diagnostic for accelerated particles. Observational measurements or estimations of the properties of this emission - its intensity, spectrum, shape, time evolution - constrain the possible parameter space of acceleration models. Some of these properties can be difficult to measure, in particular those to do with the shape and size of non-thermal sources. However HESPE team members have developed robust methods for extracting the maximum information about source shapes from the data, and have used these to good effect in certain classes of flares to obtain constraints on the properties of the accelerator. Common views hold that flare particle acceleration takes place in the corona, and the resulting fast particles propagate down towards the lower atmosphere (chromosphere), as well as out into the heliosphere. Testing models of this type requires observations of coronal non-thermal X-ray sources, either with or without accompanying chromospheric sources. Radio observations are also valuable in constraining properties of electrons propagating outwards into space. At present there are relatively few flares which simultaneously show both coronal and chromospheric sources, because of the limited dynamic range of RHESSI (i.e. the fact that it is not possible to see faint sources in the same image as bright ones, where the ratio between the two surface brightness is more than about 10). Thus, the flare use in the studies carried out as part of HESPE are only a subset of all flares observed by RHESSI and this must be born in mind when assessing the generality of the results obtained. However the ideas and analysis methods developed in this WP will be equally applicable when observations deliver better dynamic range.

The main results obtained by these two tasks are concerned with models involving reconnection and models involving turbulence and waves and are described in both HESPE deliverables D3.1 and D3.2.

As far as Task 2 is concerned:

- As already pointed out, Su et al (2012) used SDO/AIA and RHESSI data to provide the first evidence of magnetic reconnection in the corona.
- Multi-wavelength observations with the SDO/AIA, GOUES and RHESSI instruments have been used by Fletcher et al (2012) to investigate early flare evolution in an M-class flare on August, 7 2010.

- Reid et al (2012) analyzed the X-ray and 1600 Angstrom UV emission from the flare on November 16, 2002 in the context of magnetic field modeling previously done by Masson et al (2009).

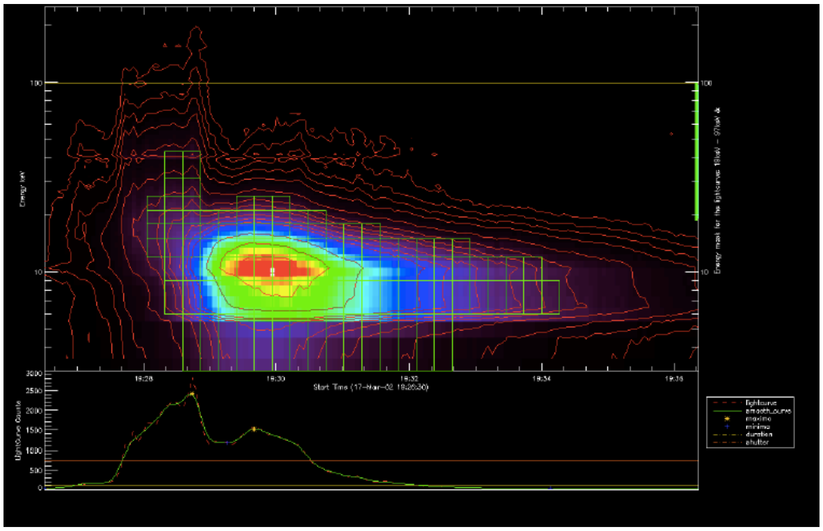

Figure 3. Output of the Interval Selection Algorithm with the found intervals.

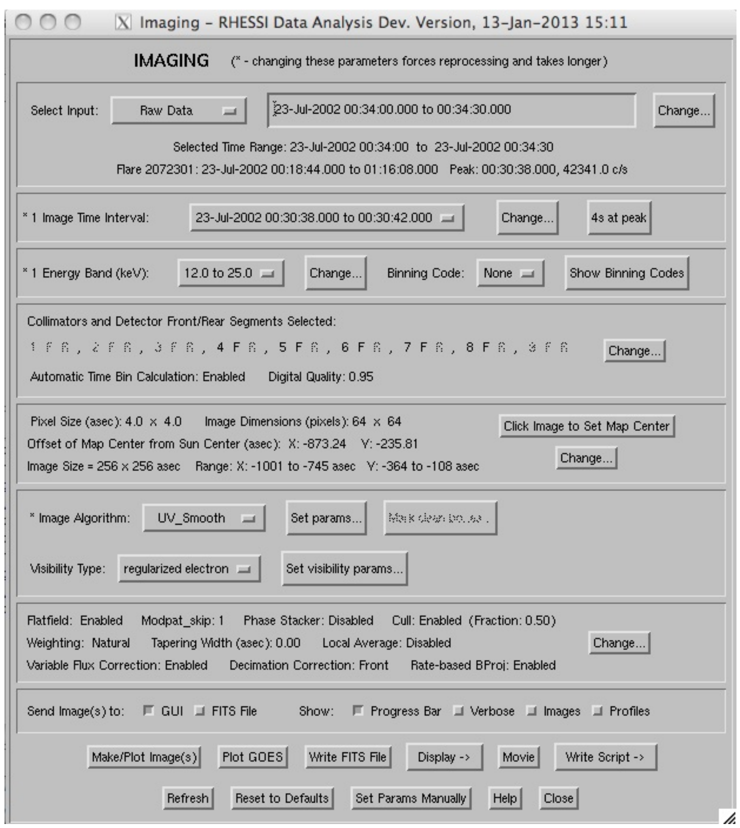

Figure 4. SSW GUI snapshot showing the interface for running the electron map code.

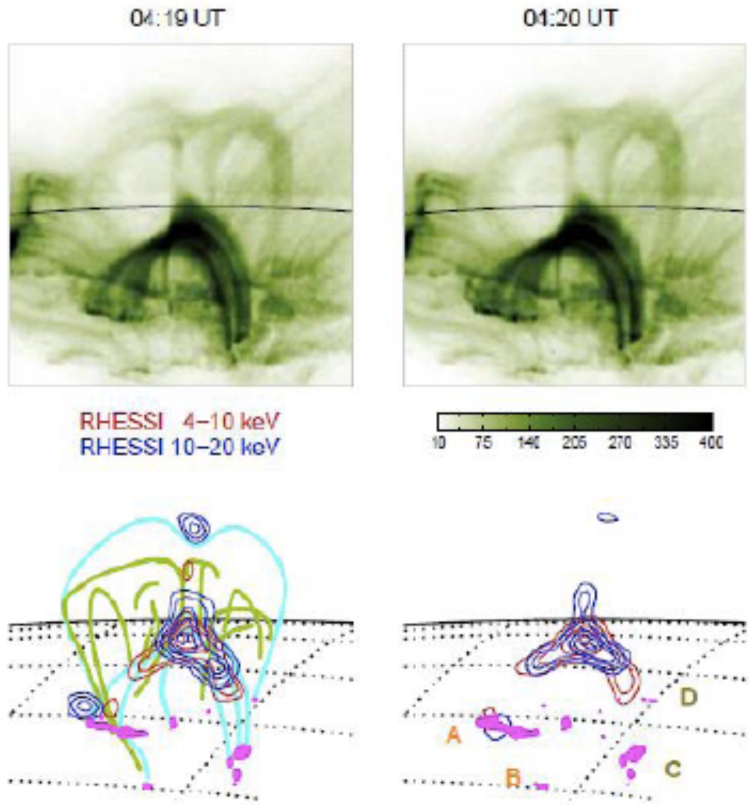

Figure 5. Flare loop configuration investigated by Su et al (2012).

All these studies prove that multi-wavelength techniques in which high energy data are complemented with different regimes (like EUV or radio-data) provide the most effective methodological framework for this kind of analysis.

As far as observational studies involving turbulence:

- As already pointed out, Guo et al 2012 applied the electron maps procedure to determine estimates of the size of the acceleration region together with filling factor and specific acceleration rate in the case of a number of coronal loop flares.
- Simoes and Kontar (2012) focused on four strong coronal loop sources and found with RHESSI imaging spectroscopy that, during the impulsive phase, the electron rate at the coronal source is significantly higher than the electron rate at the foot-points (this is consistent with a picture where electrons in the flare are accelerated in the corona and then subject to magnetic trapping and/or pitch-angle scattering, thus pointing to a scenario in which a turbulent accelerator operates in a substantial fraction of the loop

volume and accelerated particles are trapped for some time by their interaction with turbulence).

- Reid and Kontar (2012) observationally investigated wave-particle processes in which the propagation of beams of electrons through the coronal plasma excites Langmuir waves also with re-acceleration phenomena.

An observational study of energy release rate in flares has been carried out by Torre et al (2012) again using electron maps obtained from RHESSI visibilities. Such a study concerns the April 15, 2002 event and utilize the electron continuity equation to show that the energy loss rate obtained is consistent with a form for electrons suffering Coulomb collisions in a ionized hydrogen target with a finite temperature, provided that one also allows for continuous injection of fresh electrons along most of the length of the source.

Task 1 and Task 2 also required studies of important aspects of energy transport in solar flare-CME events and of relation between flare particle acceleration and CME dynamics. Such studies are described in details in deliverable D3.2. Specifically, Hudson et al (2012) qualitatively explored the consequences of momentum conservation on several aspects of solar flares and CMEs, in particular describing the relative importance of vertical impulses that could contribute to the excitation of seismic waves. Finally, Berkebile-Stoiser et al (2012) derived the initial dynamics of CMEs low in the corona and compared it to the particle acceleration in the associated flare.

Task 3 Development of paradigms for generating synthetic data
- Design of physical/geometric configurations for flaring events; formulation of simulation paradigms for producing calibrated event lists, hard X-ray visibilities, count spectra and images.

The results concerning this task are described in the HESPE deliverable D3.3. The report associated to such deliverable contains the description of a possible general paradigm for the simulation of synthetic hard X-ray solar data. Such paradigm is based on two conceptual steps. First, a systematic study of the flare morphology at different energies and time intervals allows the determination of typical number and spatial disposition of loop-top and foot-point sources. Second, synthetic high energy data are generated by means of 'ad hoc' routines using as input data flaring configurations inspired by the outcome of the first step study.

Constructing synthetic simulation data requires a robust understanding of the characteristic distributions of flare sources at different energies. Although some guidance about this exists from previous work, so far no systematic study of the number and the spatial disposition (i.e., spacing, orientation) of flare foot-points or loop-top sources has been carried out. HESPE WP 3 and WP 4 worked at this by using CLEAN, visibility-based maximum entropy and uv_smooth as image reconstruction methods. Our conclusion is that 27.2% of flares on our sample of 690 events have a single detectable high energy source (at a nominal spatial resolution of about 7 arcsec), 40.1% have two sources and the remaining part has three or more sources (Simoes and Kontar 2013).

The crucial advantage of having at disposal sets of realistically simulated synthetic data is that these data sets can be utilized to validate algorithms of analysis, either already implemented in SSW or currently under development.

Task 4 Development of particle acceleration and propagation models
- Based on the results obtained in tasks 2.1 and 2.2, we will undertake theoretical development of particle acceleration models, and particle propagation models.

During this second year HESPE focused mainly on two theoretical studies. Vilmer (2012) wrote an extensive review on energetic particles which includes a discussion on the models for ion acceleration. Further, as previously discussed, Bian et al (2012) performed a major study of the properties of wave-particle acceleration processes involving low-frequency waves in a strongly magnetized plasma. This study introduces a classification scheme for such acceleration models: resonant, non-resonant or resonant-broadened, depending on the character of the interaction between the particles and the magnetic field.

<u>Work Package 4: Computation</u>

Task 1: Imaging
- From visibilities: interpolation/extrapolation approaches by means of Fourier methods
- From dirty maps: deconvolution and multiple-deconvolution methods based on iterative regularization techniques exploiting a priori information on the solution and on the statistical properties of the data

HESPE has worked at both methods utilizing visibilities and deconvolution algorithms starting from count modulation profiles. In the visibility domain, HESPE developed uv_smooth with the aim of enhancing the performance of both the interpolation and the extrapolation steps (Allavena et al 2012). Then a visibility-based CLEAN algorithm has been implemented and is now in SSW. Finally, we are working at an optimized modification of the maximum entropy approach in which a new and effective minimization algorithm is applied and a new stopping rule is used to avoid over-resolving effects.

HESPE devoted most of the second year activity to develop an Expectation Maximization (EM) scheme with positivity constraint and an optimal stopping rule (Benvenuto et al 2012). In practice, this method realizes the traditional Lucy-Richardson approach for image deconvolution in the case of Rotating Modulation Collimators imaging. The technical difficulty here is in the fact that this latter inverse problem is extremely under-determined and therefore a new ad hoc regularizing algorithm has been developed to stop the scheme. An example of the reliability of this method is given in Figure 6, where EM is compared to Pixon. We point out that EM is notably more effective from a computational viewpoint: analogous levels of C-statistics are obtained by EM within fractions of the computational time employed by Pixon.

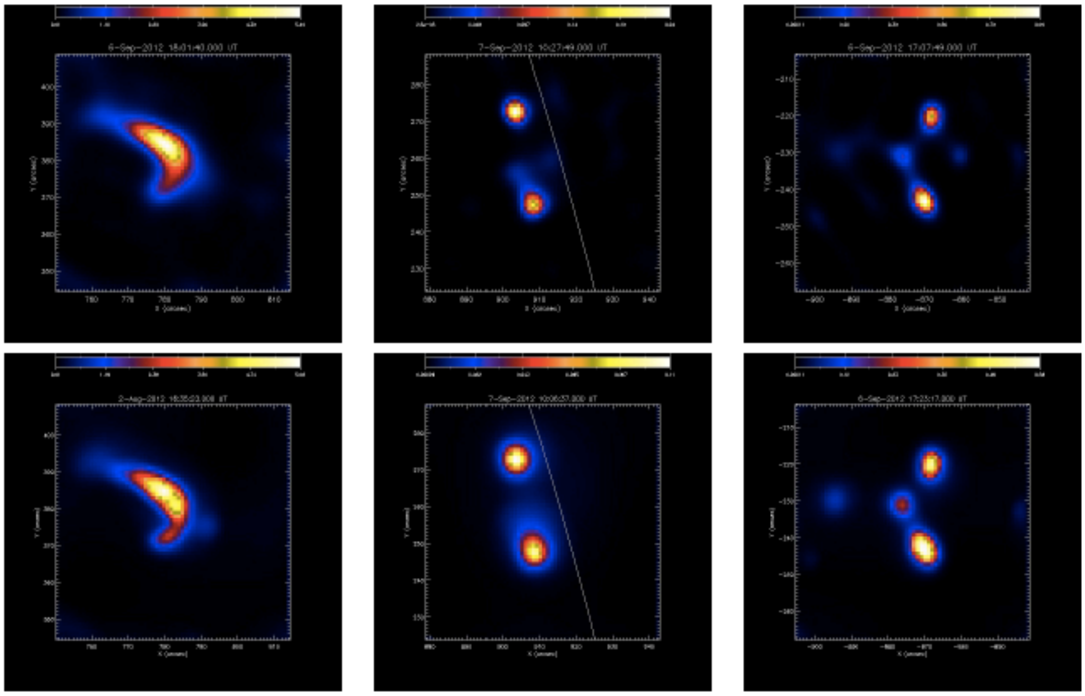

Figure 6. Expectation-Maximization for RHESSI imaging (first row): comparison with Pixon outputs (second row) in the case of the April 15 2002 (first column), February 20 2002 (second column) and 23 July 2002 (third column) events.

Task 2 Spectroscopy
- Analytical and semi-analytical approaches for fast spectral fitting in the case of general forms of the bremsstrahlung cross-section
- Improvement of Tikhonov regularization techniques already implemented in SSW by including automatic computation of the error and resolution bars by means of a Monte Carlo approach
- Implementation of Expectation-Maximization approaches to spectral inversion

Using Bayesian statistics (Emslie and Massone 2012), HESPE provided explicit formulas for determining the confidence strip (in the sense of a Bayesian credible region) for the average electron spectrum reconstructed by mean of a regularized inversion procedure. This approach provides rigorous bounds on the intensity and shape of the accelerated electron spectrum.

EM has been generalized to the spectroscopy problem to obtain a very effective approach. Specifically, here we have considered this inverse problem as a particular case of the image reconstruction problem in which the unknown is the photon distribution in a unique pixel whose size is equal to the whole field of view. In this way the conditioning of the linear system dramatically decreases and EM becomes extremely accurate. The validation of this approach is under construction but preliminary results obtained with synthetic data simulated by means of a blind experiment show that it is able to reproduce short wavelengths features with impressive fidelity.

Task 3 Imaging spectroscopy
- Formulation and implementation of method for spatially resolved spectroscopy which provides electron maps of the source at many different electron energies starting from count visibilities
- Validation of the approach against both synthetic data and real observations

From a physical viewpoint, it is well-established that X-ray emission is the bremsstrahlung radiation signature of the phase-space distribution of electrons in the plasma and that this electron distribution is the information of central interest in the study of solar flares. Some years ago scientists now belonging to the HESPE consortium have developed a computational method for the synthesis, at different electron energies, of maps of the event whose pixel content is related to the averaged electron flux in situ. WP 4 has written a review on this method (Massone and Piana 2013) and implemented this approach as an IDL code in SSW. This package can now be utilized from the Graphical User Interface by all the solar and heliophysicists that want to infer spatially resolved information on the electron behavior in the flaring loop.

We are currently working at the generalization of EM for the construction of electron maps from count modulation profiles.

Task 4 Validation of the algorithms against both synthetic data and observations

Within the HESPE framework, for the first time, a systematic validation of all the imaging methods existing in the Solar SoftWare tree is under construction. A group of HESPE researchers, led by G J Hurford (UCB) and A M Massone (UNIGE, HESPE WP 4 leader) has set up a complex test already described in the report concerning the first year of HESPE activity. The report describing the first year HESPE activity discusses the paradigm of this. An example of the approach has been utilized by Benvenuto et al (2013) to validate the new Expectation-Maximization algorithm for maximizing the likelihood of RHESSI count modulation profiles.

The realization of this test is under construction; first results for a specific imaging algorithm are in Benvenuto et al (2013) where the synthetic data realized according to this test have been utilized to validate the Expectation Maximization approach.

Work Package 5: Technology

Task 1: From Telemetry Data to Visibilities

a. Design and Implement the Interval Selection Algorithm: Develop a "generic" algorithm for flare detection, based on methods that are not only valid for RHESSI data. Develop a method to divide the detected flare into energy and time sub-intervals that are optimal for generation of visibilities.

b. Generate Visibilities: Apply the interval selection algorithm to the RHESSI Level-0 and generate the instrument-independent visibility database.

Task 2: Generate Science Ready Products

a. Code the algorithms delivered by WP3, according to the interface provided by the RHESSI data analysis software.

b. Integrate the coded visibility algorithms into the RHESSI data analysis software framework

c. Generate images (both electron and X-ray), dynamic and spatially resolved Spectra (electron and X-ray).

d. Validate the data products for quality.

Task 3: Interface the data products to the European Infrastructure

a. Create metadata services for the virtual observatories: Generate a schema describing the data products and their relationships, implement the schema into a database and ingest the metadata describing the products.

b. Integrate services into EU e-Infrastructures, by making the access HELIO compatible.

c. Deploy database queries as web services for easy integration in any VxOs.

d. Implement data mining algorithms to support flare predictions.

The main objective achieved by WP 5 during this second year has been the realization of the HESPE processing framework and the publication of the visibility database. This objective pertains to Task 1 and has been described in details in the HESPE deliverable D5.2. This result is crucial for the generation of the science product database (the main objective of Task 2). The creation of this database, together with the integration of these database services into already existing EU e-infrastructures (Task 3) are in due course and will be the core of the third year of HESPE activity.

Work Package 6: Future

Task 1. Generation of synthetic data for future visibility-based instruments

Task 2. Validation of algorithms against synthetic data

Task 3. Generation of computational tools for processing generic visibility data

The activity of WP 6 has begun at month 20 of HESPE GANTT chart. HESPE researchers are currently working at the synthesis of simulated visibilities that will be recorded by the Solar Telescope for Imaging X-rays (STIX) as part of the ESA Solar Orbiter mission that will be launched in January 2017. An example of the location of STIX visibilities in the spatial frequency plane as obtained by HESPE researchers working at UNIGE, UCB and FHNW is given in Figure 7.

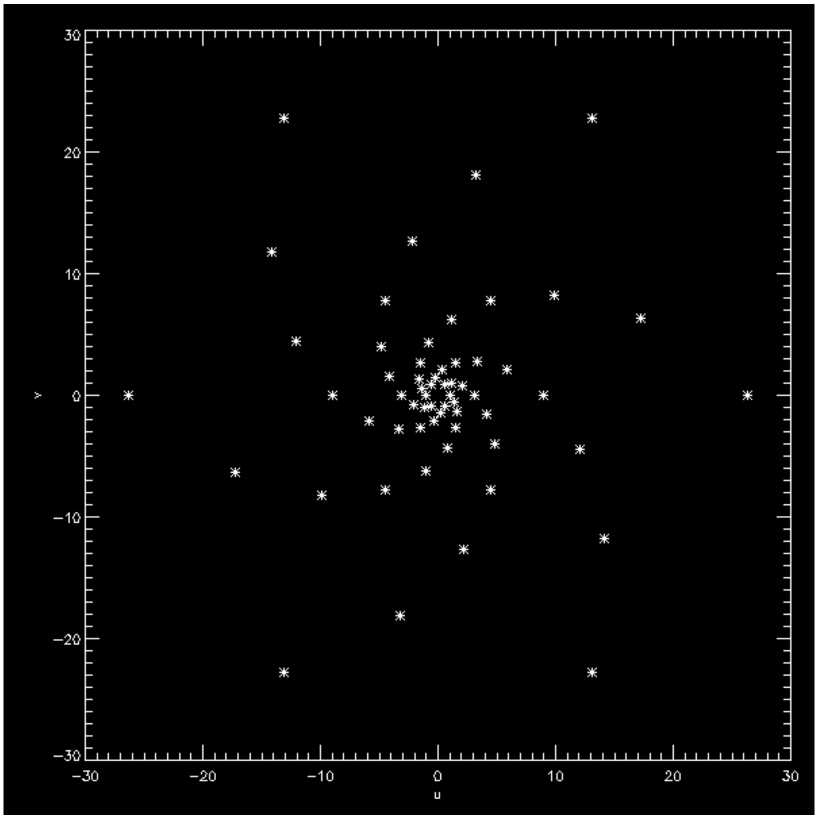

Figure 7. Position of STIX visibilities in the spatial frequency plane.

3. Project management during the period

HESPE management effort essentially focused on coordinating the activities of the project beneficiaries by monitoring schedules, organizing work package meetings, monitoring the hiring of new HESPE personnel, establishing and maintaining email lists, establishing and maintaining relation with REA. In the following a description of these activities is itemized in detail:

- During this second year activity, the persons (either partly or totally) supported by HESPE funds are:

- ✓ Federico Benvenuto, post-doc (UNIGE)
- ✓ Jingnan Guo, post-doc (UNIGE)
- ✓ Alberto Sorrentino, post-doc (UNIGE)
- ✓ Gabriele Torre, PhD student (UNIGE)
- ✓ Andre Csillaghy, university professor (FHNW)
- ✓ Laszlo Etesi, post-doc (FHNW)
- ✓ Nicky Hochmuth, post-doc (FHNW)
- ✓ Hanna Sathiapal, public outreach (FHNW)
- ✓ Roman Boutelier, post-doc (FHNW)
- ✓ Marina Battaglia, post-doc (FHNW)
- ✓ Lyndsay Fletcher, university professor (UNIGLA)
- ✓ Eduard Kontar, university professor (UNIGLA)
- ✓ Paulo Simoes, post-doc (UNIGLA)
- ✓ Ewan Dickson, post-doc (UNIGLA)
- ✓ Yang Su, post-doc (UNIGRAZ)
- ✓ Relindis Rott, PhD student (UNIGRAZ)
- ✓ Christoph Miksitis, PhD student (UNIGRAZ)
- ✓ Hamish Reid, post-doc (CNRS)

- As for the first year, also in this second one, the project coordinator organized some work package meetings in order to improve the effectiveness of the scientific activity of the project. The aims of such one- or two-day workshops were to allow the coordinator to have a clear picture of the status of the topics addressed by the HESPE crew at the different work package levels and to envisage and implement contingency plans in case the achievement of some results promised in the HESPE proposal were under risk of accomplishment. In detail

  - ✓ A WP 3-WP 4-WP 5 meeting took place at CNRS (Paris) on May 8-9 2012
  - ✓ One WP 4-WP 5 meeting took place at FHNW (Brugg) on September 5-7 2012

  Furthermore, the second year full HESPE meeting took place in Graz, October 2-3 2012. The slides presented at that meeting and summarizing the second year HESPE activity are available at the HESPE webpage at http://www.hespe.eu

The 'Other activities' work-package WP 2 is mainly devoted to dissemination purposes. In this context, the organization, realization and maintenance of the HESPE Web Site represent a notable support both for the management of the RTD activities and for dissemination of HESPE results.

HESPE Web Site Resources

The HESPE webpage at http://www.hespe.eu is regularly updated and contains both dissemination materials and demos, data and codes that are used by HESPE researchers for their scientific activity.

Software Development Support

The software written for HESPE is based on and integrated into the SolarSoftware (SSW) library. To allow for distributed development a software versioning system was set up that manages the HESPE source code. Once the source code has been tested and is stable, the system automatically replicates the source files into SSW. This software versioning system helps keeping track of changes to source files and lowers the source code management overhead due to e.g. code conflict resolution support, etc.

The selected software versioning system is Apache Subversion (SVN). The HESPE SVN repository is hosted and maintained by FHNW at

https://project.technik.fhnw.ch/projekte/i4ds/HESPE/svn/trunk (login required).

Instruction on how to work with SVN can be found at

http://www.hespe.eu/software/documentation/for-developers/.

Dissemination

The representation of HESPE by means of presentations at conferences and meetings has been the major way of dissemination. It has been complemented by many science publications. The meetings attended are:

- SIMAI, Turin, Italy, June 2012
- SIPWORK VI, Montana State, USA, August 2012
- Solar in Sonoma, Petaluma, USA, November 2012
- AGU Meeting, San Francisco, USA, December 2012
- COSPAR, Mysore, India, July 2012
- NAM UK, Manchester, March 2012
- Solar Orbiter V, Bruges, September 2012
- PNST, La Londre, France, March 2012
- French Reconnection, Paris, September 2012
- June 29th 2012, Cool Stars 17, Barcelona
- August 20th 2012, IAU XXVIII general assembly, Joint Discussion 3, Beijing, China
- 8th October 2012, 'Rocks'n'Stars', Goettingen, Germany

- 19th November 2012, Solar Physics with Radio Observations: 20 years of Nobeyam Radioheliograph and Beyond, Nagoya Japan
- 7th December 2011 Colloquium, Royal Observatory Belgium
- 23 May Queen's University Belfast
- 16th August 2012, Colloquium, Purple Mountain Observatory, Nanjing, China
- 16th October 2012, Seminar, MSSL
- 4th February 2012; Glasgow Science Centre
- 23 March 2012: Airdrie Astronomical Society
- 7th September 2012: Moray Astronomers Group

The Public Outreach "Solar-lab" activities has been integrated in the efforts already started with the HELIO and CASSIS EU-Projects as well as national public outreach programs. This way, we present a global picture on the solar activity and its influence on the earth instead of presented fragmented efforts for each specific project. Nevertheless, in the global program, specificities of each project are emphasized. For instance, HESPE has provided the possibility of emphasizing the role of X-rays in our understanding solar activity.

Solar-lab is divided into three modules:

- The Helio-lab for families (www.heliolab.eu): a web-site for families, with an uncommon design and format, in English, French, Italian and German.
- the Expo-lab for scientists at public events: a hands-on model of current research in heliophysics designed to support scientists communicating their science.
- The School-lab for elementary schools: in co-operation with the Pedagogical University FHNW, developing educational material relating direct observations to satellite data.

Planned is also a youtube video presenting the results of the project, which will be delivered by the end of the project.

Papers written under the HESPE support, submitted, accepted or published during the second year of HESPE activity

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