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)**

Coordinator: prof. Michele Piana (UNIGE)

First Year Report
(December, 1 2010 – November, 30 2011)

1. Summary description of project context and objectives

On 28 October 2003, the Earth experienced one of the most dramatic effects of solar eruptive events for many years. Following an intense flare, a halo coronal mass ejection was directed straight towards the Earth, with a velocity of 8 million km/hour. 19 hours after the explosion, strong geomagnetically induced currents caused blackouts of the power distribution grid; the accuracy of satellite navigation systems was degraded; airliners scheduled for trans-polar flights were rerouted to lower latitudes. This one event brought home the reality that modern technology-based societies are becoming increasingly vulnerable to this type of natural threat. And it clearly demonstrated that understanding the physics of these most powerful events is a necessary prerequisite to predict their occurrence and their potentially damaging effects in space and on the Earth.

It has been recognized since the early days of space investigation that high-energy observations play a crucial role in understanding the basic mechanisms of solar eruptions. Unfortunately, the peculiar nature of this radiation makes it so difficult to extract useful information from it that nonconventional observational techniques together with complex data analysis procedures must be adopted. 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 sophisticated Information and Communication Technology (ICT) tools for providing algorithms and science-ready products to the solar physics community.

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

2. Description of the work performed since the beginning of the project and the main results achieved so far

The first year of HESPE activity had two main scientific goals. First, we aimed at designing a HESPE framework to allow for pipelined processing of high-energy data. Second, we wanted to start the realization of a notable corpus of computational methods for the analysis of high-energy data in the case of spectroscopy, imaging and imaging spectroscopy. Both goals have been fully achieved.

Specifically, as far as the first goal is concerned, we have based the HESPE framework on the idea that data processing can be modeled as a sequential execution of processing routines. Every routine takes an input and returns values (data structures, arrays, etc.), which themselves serve as input for the next processing step. The structure of this framework is represented in the horizontal pipeline in Figure 1. During this first year, HESPE scientists fully realized the first module of the pipeline, i.e. the interval selection step (red pipeline in Figure 1). Specifically, we have realized an automatic pipeline for the creation of a visibility database that, by means of an interval selection algorithm transforms measured counts into optimized visibility bags. In this specific case, the first step of the pipeline is data acquisition; the second step is background noise removal; the third step is interval selection and the last step is visibility creation. This pipeline can be eventually integrated with the SolarSoftWare (SSW) library, which is required for our IDL-based software to work.

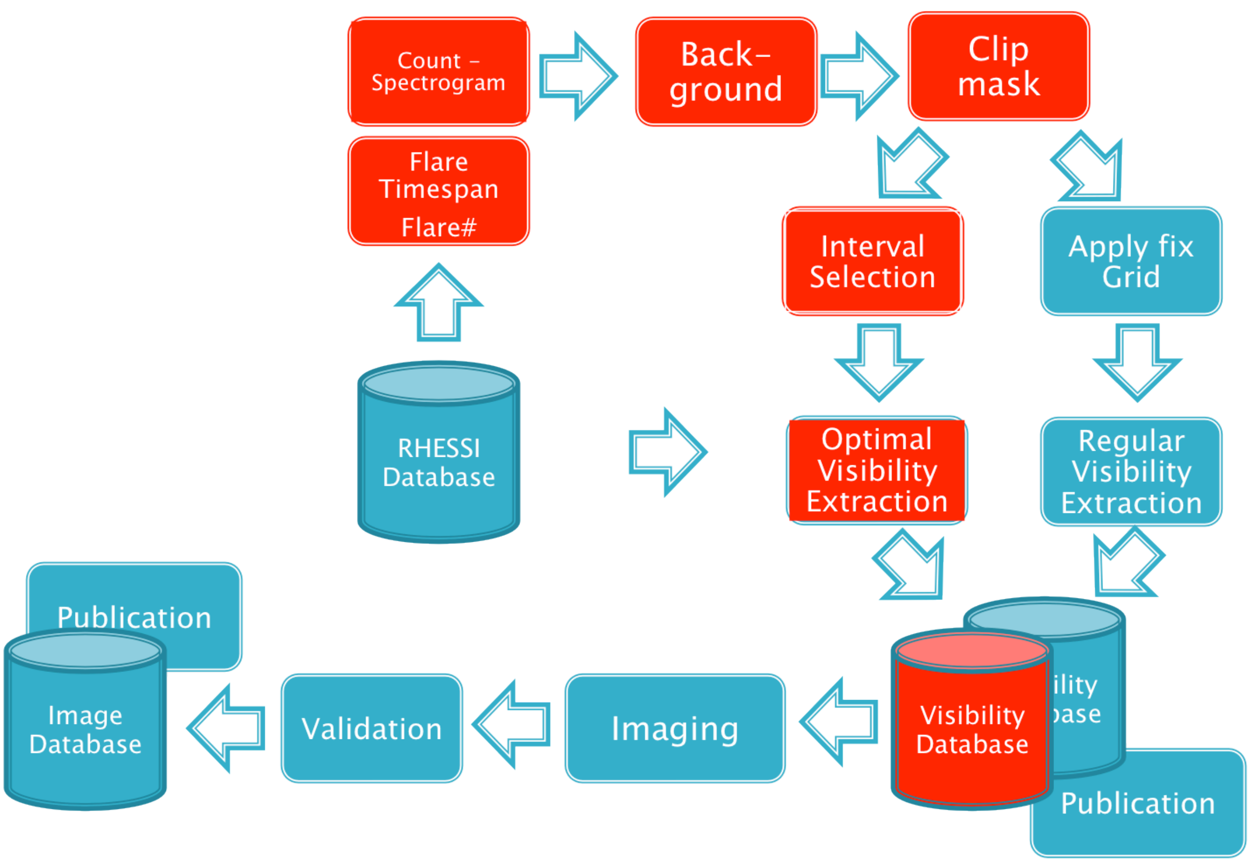

Figure 1. *The HESPE framework and, in red, realization of the interval selection pipeline*

We firmly believe that this technological realization may have an impressive impact on current and future solar physics research. Just as an example, this pipeline will allow, for the first time, statistical analyses of high-energy data according to a fully automatic manner: eruptive events can be classified according to different parameters (e.g., position on the solar disk, peak flux, dynamic phase) and optimized visibility datasets can be created for each class and reached by means of simple database queries.

As far as the second goal is concerned, we have based the approach to the computational activity on two complementary strategies: the implementation of brand new or newly optimized algorithms in spectroscopy, imaging and imaging spectroscopy; and the validation of existing methods in order to assess their reliability when applied to experimental measurements. HESPE has implemented new statistical methods for best fitting the different parameters of a hard X-ray spectrum and for reconstructing electron flux spectra from count data; has produced a new, optimized version of the *uv_smooth* routine for image reconstruction from visibilities by means of interpolation/extrapolation procedures; and has provided the SSW tree with a software package able to reconstruct maps of the flaring events whose pixels are related to the electron flux spectrum in situ, at different electron energies. But the most notable conceptual result obtained so far by HESPE in this context is the achieved consciousness that not all the imaging methods typically utilized in solar physics (and typically implemented in SSW) are reliable for the reconstruction of images of flaring events of all possible physical or geometrical properties. On the contrary, the preliminary results of the imaging test realized by HESPE scientists during this first year activity clearly shows that, for each event, it is possible to point out a specific imaging method that best reconstructs a specific event property (overall configuration, shape, size, absolute and relative intensities). HESPE is providing solar astronomers with a general strategy, implemented by means of a lookup table suggesting the optimal method for each data set under analysis and therefore enhancing the level of reliability of the physical models drawn after the processing of X-ray data.

3. Description of the expected final results and their potential impacts and use

HESPE will provide crucial results in the theory of solar flare physics, in the development of computational methods for high-energy data analysis and in the technological exploitation of science products consequence of such data analysis.

From the theoretical viewpoint, HESPE will provide

- a general paradigm for the selection and classification of the events according to their morphological and physical properties;
- a general paradigm for the generation of realistic, physically plausible synthetic data (calibrated event lists, counts, visibilities...);

- a description and interpretation of all up-to-date theoretical models for particle acceleration mechanisms during solar flares and the role that, in these models, is played by physical and geometrical parameters to be reconstructed by the computational algorithms developed by HESPE;
- a general paradigm for the integration of information extracted from data of different wavelengths (X-rays, gamma-rays, radio,...).

On the other hand, and even more importantly, the computational power that HESPE will put at disposal of the solar physics community will allow first investigation in important theoretical issues involving: (i) advances in the theory of solar flare particle acceleration and transport (due to the availability of large databases of data analyzed with the most powerful processing techniques); (ii) advances in solar physics as a whole (due to the greatly improved accessibility of the best X-ray data, from present and future missions, to the whole solar and heliospheric community, for easy integration into their ongoing analyses); (iii) better understanding of the sources of high energy particles escaping and transport from the Sun to the Earth, which is essential component of space weather.

The advances proposed by HESPE in computational solar physics will change the perspectives of high-energy solar data analysis and will systematically involve activities in imaging, spectroscopy and imaging spectroscopy. Indeed HESPE will put a coherent corpus of computational algorithms at disposal of the solar physics, heliophysics and space weather European communities. This computational framework will be realized according to a two-fold methodological approach:

- the formulation of the algorithms will be systematically performed according to rigorous mathematical paradigms that will involve interpolation and extrapolation methods, regularization techniques for the solution of linear inverse problems, machine learning methods for data and image processing;
- a validation step realized with the support of physically plausible synthetic data will allow HESPE to establish rigorous procedures for data analysis, where each observational condition (energy channel involved, time interval selected, position and overall shape of the event) will be associated to the data processing algorithms, thus guaranteeing optimality, effectiveness, accuracy, robustness and reliability.

The effectiveness of these methods will be first assessed against data observed by the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), which certainly represents the current hardware ground truth for high-energy solar data. However the kind of implementation adopted makes these algorithms easily applicable to data from other past and future missions.

Finally, HESPE technological results will be the generation of two databases that, to many extents, represent the most impressive outcome of this project:

- HESPE data generation algorithms will allow the creation of a database of high energy visibility sets for all possible flaring events on the Sun. Owing to their intrinsically abstract nature and thanks to the compressed characteristics of the information they carry, visibilities represent the *perfect* way to represent X-ray observations. HESPE visibility database will contain bags of visibilities corresponding to time intervals and energy bins that have been optimized according to rigorous mathematical criteria.
- Just because of this abstract nature, visibilities do not most probably fit the needs of a wide community. To make the information contained in visibilities accessible, science ready data products are needed. By science ready data products, we understand calibrated high-level products that are independent on the instrument, such as sets of images of a flare event corresponding to different time and energy intervals; sets of full Sun and spatially resolved calibrated spectra and sets of physical and morphological parameters that best allow the interpretation of the mechanisms at the basis of the emission. Of course HESPE technology will associate quick look products of these images, spectra and parameters that allow prompt visualization of the data contents.

The generation of these two databases will rely on a software infrastructure able to deal with the sheer amount of data available. Such an infrastructure will not be instrument specific. Using adequate programming skills, based on object-orientation, refactoring, and component-based software construction, we will design an infrastructure that will not only be able to deal with RHESSI data products but also prepare the accessibility of data from further high energy missions (it will therefore, prepare the integration into the European e-Infrastructures).

At a more strategic, even societal level, HESPE will allow a better understanding of the sources of Coronal Mass Ejections. This will eventually help to forecast geomagnetic storms associated to solar eruptions and to reduce their effects on our technology-based society. HESPE will put the potential of high-energy solar data at disposal of the European solar, helio and space weather scientists and will guarantee a stable and long term positioning of Europe in the sustainable exploitation of this data products. Finally, at a cultural level, HESPE will implement a research collaboration where solar physicists, computer scientists and mathematicians integrate their skills and knowledge with the aim of realizing a highly interdisciplinary scientific program. The result of this virtuous interaction will be a new and still quite rare way to deal with fundamental physical open problems, where practices in solar physics make use of technological competences of computational scientists and mathematical research can validate its power on applied problems of notable practical impact.

4. **Project research and technology objectives for the period**

In the following the Research and Technology Development (RTD) work packages are described. The Management (MGT) work package and the 'Other Activities' work package (mainly devoted to dissemination) will be described in the following section.

Work Package 3: Theory

The objectives of WP3 are 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 improve the efficiency of X-ray diagnostics by integration with appropriate datasets. In the following the main achievements obtained by WP3 are described, according to the foreseen tasks. The references included in this discussion correspond to papers that have been compiled during this first year activity.

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 1 and Task 2 mix up research themes that can be dealt with according to an inter-task approach. Indeed the bulk of solar flare emission originates from very compact sources located in the lower solar atmosphere and observable at a broad range of wavelengths such as near optical, UV, EUV, soft and hard X-rays, and gamma-rays. Nevertheless, very few spatially resolved imaging observations have been performed to determine the structure of these compact regions. Within HESPE an intense research activity is inferring reliable information about the morphological properties of the emitting source and their impact onto the energetic and temporal development of the emission and even onto the occurrence of larger-scale phenomena.

The results obtained by WP3 in addressing such topics are:

- studies of size and structure of flaring regions both in the case of X-ray wavelength (Battaglia M and Kontar E P 2011a) and by means of a multi-wavelength analysis (Battaglia M and Kontar E P 2011b). Such studies allow the formulation of general paradigms for the determination of physical parameters characterizing the flaring loop and for the selection of models describing energy transport phenomena before and during the emission;
- studies concerning the comprehension of the acceleration mechanisms by means of turbulence arguments (Kontar et al 2011) or focused on specific events that can be interpreted according to ‘ad hoc’ models (Fleishman et al 2011);

- a study concerning the role of momentum conservation in processes related to solar flares and Coronal Mass Ejections (CMEs), with specific emphasis on the importance of impulses that could contribute to the excitation of seismic waves (Hudson, Fletcher, Fischer et al 2011);
- a multi-wavelength analysis of an eruptive event utilizing RHESSI and TRACE X-ray and EUV/UV data (Joshi et al 2011). This study may have a significant impact on the comprehension of the dynamics of the event (for example, from the pre-flare to the main-flare phase) also with respect to the evolution toward larger-scale phenomena;

This last item focuses on a very important theoretical issue whose development could be a core research aspect of future projects, i.e. the problem of integrating data from different instruments in order to integrate information on eruptive events. In the second and third years of HESPE activity we will certainly develop such issue and, specifically, we will formulate procedure paradigms for such data integration. Finally, within HESPE activity a review paper has been realized and submitted to a Guest Issue of the *Philosophical Transactions of the Royal Society* A, entitled "Astrophysical Process in the Sun" (Vilmer 2011). The focus of such paper is on the relation between solar flares and solar energetic particles and on the information, describing this connection, that can be extracted from high-energy data.

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 tasks 2.1 and 2.2, we will undertake theoretical development of particle acceleration models, and particle propagation models.

Also in the case of these two tasks the activity is strongly correlated and therefore it is described together in the following.

The idea of WP3 is to gather together our current best understanding of 'solar flare theory' and use it as a motivation/input for both forward modeling experiments and interpretation of data. There is an immense amount of literature on solar flare theory and we must beware of 'reinventing the wheel', e.g. we do not want to waste time writing unnecessary reviews (though we could consider whether there are gaps that we can fill in). Note also, that HESPE does not specifically deal with solar flare theory, but rather, in WP3, with the theoretical aspects of the technical developments necessary for the success of the HESPE project. Therefore, in this first year activity we have specified how the different aspects of solar flare theory can inform our computational/technological work. The main issues we have pointed out are:

- how particle/kinetic theory treatments can make predictions about the spectral and temporal characteristics of non-thermal particles, and how these depend on the ambient conditions (magnetic field, temperature, density etc). Thus they may help to rule out/in certain locations for acceleration (e.g., it is hard to accelerate in a cold dense plasma);

- magnetohydrodynamics (MHD) considerations lead us to the overall magnetic geometry, suggesting possible source locations, and the slower temporal evolution, and may motivate typical values for the plasma parameters of the environment (though these are probably less reliable than those available from e.g. spectroscopic measurements);
- cartoon 'theory' is mostly a conceptual framework for integrating different ideas rather than having any predictive power. But the published cartoons may help with general ideas about relative locations and temporal evolution of sources.

On the basis of these theoretical paradigms, next year WP3 will work at evaluating the constraints placed by available theoretical models on the choice of parameters for the Computation work package; evaluating the ability of the observational constraints to distinguish between theoretical models; identifying the gaps in the literature above.

Finally, HESPE WP3 has begun compiling a file containing a list of papers related to specific flaring events. For each paper the file provides the event data, the publication details, the keywords and a link to the paper file in the SAO/NASA Astrophysics Data System. The file, that does not contain references to conference proceedings, statistical studies and review papers, is now available at http://www.hespe.eu.

Work Package 4: Computation

The general aim of WP4 is the construction of a computational corpus for the analysis of data provided by hard X-ray and gamma-ray observations. Specifically the idea is 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. During the first year of HESPE activity all these issues have been addressed, with particular emphasis given to the processing for hard X-ray visibilities in imaging and imaging spectroscopy. In the following the main achievements obtained by WP4 are described, according to the foreseen tasks. The references included in this discussion correspond to papers that have been compiled during this first 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 iterative regularization techniques exploiting a priori information on the solution and on the statistical properties of the data

In this first year WP4 focused mainly on the development of imaging methods that process count visibilities recorded by RHESSI or by other instruments whose technology is based on Rotating Modulation Collimators. Specifically an important result in this topic has been the development of an updated version of the *uv_smooth* algorithm. A first version of this method is already part of the SSW tree and realizes a two-step imaging strategy: first an interpolation of the visibilities in the frequency space provides a visibility surface which, in the second step, is inverted by means of an iterative constrained algorithm to obtain out-of-band extrapolation. HESPE developed "uv_smooth" with the aim of enhancing the performance of both the interpolation and the extrapolation steps (Allavena et al 2011). Specifically, in the first step, the interpolation process is optimized by representing the measured visibilities according to specific coordinates that make optimal the sampling of the frequency plane. In the second step, we implemented two different kinds of constraints on the solution in order to obtain super-resolution effects. A systematic validation of this approach by means of synthetic and real visibilities allowed us to show the advantages of this algorithm, which are numerous and rather clear: it is an FFT-based procedure and therefore it is notably rapid; it does not need any data pre-processing such as background subtraction; it is very robust with respect to different source configurations and, thanks to its flexibility and speed, can be used for bootstrap analysis. The implementation of the algorithm in the Solar SoftWare (SSW) tree of the RHESSI mission is under construction.

A second, very intriguing imaging problem addressed by HESPE has been concerned with the problem of separating the albedo flux from primary emission in RHESSI data. A fresh study has been developed utilizing a Green's function approach to modify the expected count rates of a point source and to determine the true visibilities from the measured X-ray visibilities. The effectiveness of this approach has been tested by searching for evidence of the expected albedo flux from below the hard X-ray footpoints seen with RHESSI in two events to energies in excess of 100 keV (Schwartz et al 2011).

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

During the first year of HESPE activity we have begun working at Bayesian methods for both forward-fitting electron spectra and inversion of count-rate spectra to obtain electron flux spectra. Specifically:

- a Bayesian analysis approach has been implemented for the forward fitting of electron and/or photon spectra to the RHESSI measured count-rate spectra. A Markov chain Monte Carlo method was used to sample the complete parameter space and determine the posterior probability distribution. The main advantage of this approach is that it provides detailed confidence intervals for the parameters, not just their best-fit values. This method has been compared with the results of the standard chi-squared minimization routine, and extensive analysis using chi-squared-mapping and Monte Carlo simulations has supported and facilitated the interpretation of the Bayesian results.

- an expectation-maximization approach typically used in image deconvolution has been introduced in the case of spectroscopy, whereby the electron flux spectrum is reconstructed from the count flux spectrum by iteratively maximizing a likelihood function according to a specific topology. The strength of this approach is in the fact that expectation-maximization explicitly accounts for the Poisson nature of the noise on the count observations.

The validation of all these methods is in progress with respect to both synthetic and real measurements. In particular, in the case of the expectation-maximization algorithm, we are testing the reliability of the algorithm against simulated count spectra that had been used in a *blind* test for the validation of traditional forward-fitting, zero- and first-order regularization and an adaptive matrix inversion method.

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. In the first year of the HESPE project WP4 has written a review on this method (Massone and Piana 2011) and implemented this approach as an IDL code in SSW. This package can 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.

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 WP4 leader) has set up the following complex and sophisticated test:

1. Ten different configurations of the flaring region have been invented, characterized by very different topographical and physical properties (size, position, number and distance of disconnected components, relative intensity of the components) (see Figure 2);
2. for each flaring configuration, three different synthetic visibility sets have been realized, characterized by three different levels of statistics (low, medium, high). This simulation

has been performed utilizing the properties of the RHESSI imaging system but an extension to any other hard X-ray device is straightforward;

3. the following imaging algorithms have been applied to each visibility set: a forward-fit routine where the source models are one or two ellipses; a maximum entropy method; the first release of *uv_smooth*; an implementation of CLEAN; an implementation of Pixon;
4. a set of routines has been implemented, for the quantitative assessment of the algorithms' performances. These routines compare the topographical and physical properties of the original configurations with the ones of the reconstructions;
5. based on the results of this assessment, lookup tables are under construction, in which the reliability of each algorithm will be assessed with respect to the recovery of different physical, geometrical and computational parameters.

This experiment is still under construction (in particular, we are still processing the results in step 5 and collecting all the information obtained in a systematic fashion). The results of this test have been discussed at the twelfth RHESSI workshop (Nanjing, China, October 16-21 2011).

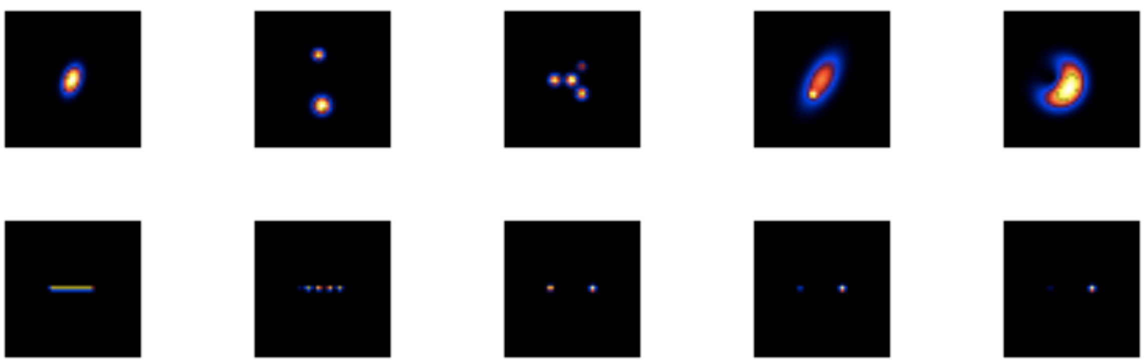

Figure 2. *HESPE imaging test: the ten flaring configurations utilized to produce the synthetic visibility sets*

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.

During the first year WP5 has been entirely devoted to Task 1, i.e. to the implementation of the pipeline that creates the visibility database within the HESPE framework. Such pipeline is described in Figure 1 where the cyan boxes account for the path from reading data to publishing science products (the overall goal of HESPE), while the boxes in red account for the path from data to visibilities (it is very likely that the interval selection pipeline will be broken up and reorganized to work more efficiently with the horizontal processing pipeline).

In the following the main features of each box of the vertical pipeline are described in detail.

<u>Data Reading:</u> the pipeline starts by reading from the RHESSI data archive. For a given time interval or flare number the RHESSI routine/object *hsi_spectrum* locates and downloads the required FITS files. The result is an *hsi_spectrum* with counts over time and energy. The time axis is binned into time intervals with length of the roll period. The energy axis is constructed using pseudo logarithmic bins from a predefined energy binning schema. At this point the *hsi_spectrum* is transformed into an *hsp_spectrum* for simplicity reasons.

<u>Background subtraction:</u> for a clear separation of the event from the Sun activity, the background in the spectrum is eliminated by a simple background removal algorithm. The background removal only influences the clip mask finding process (see next step). It does not, however, change the data on which visibility extraction algorithm operates.

<u>Clip mask finding:</u> determining the correct start and end time of a flare, and finding energy boundaries minimum/maximum) in the spectrum of the flare are crucial to defining interesting time-energy bins for image reconstruction, etc. Following the background subtraction, the clip mask module tries to find the border of an event within the spectrum. The clip mask finding algorithm performs the following steps:

- set the event start time at the lowest energy band;
- avoid convex shapes in the direction of the energy axis;
- smooth mask borders;
- add an additional space into the energy direction (telescopes) at time points with high vertical dynamic (fluxes).

If distinct shapes are detected in time, the algorithm separates them into sub events that are processed individually. Figure 3 shows the clip mask borders with the two sub events in yellow.

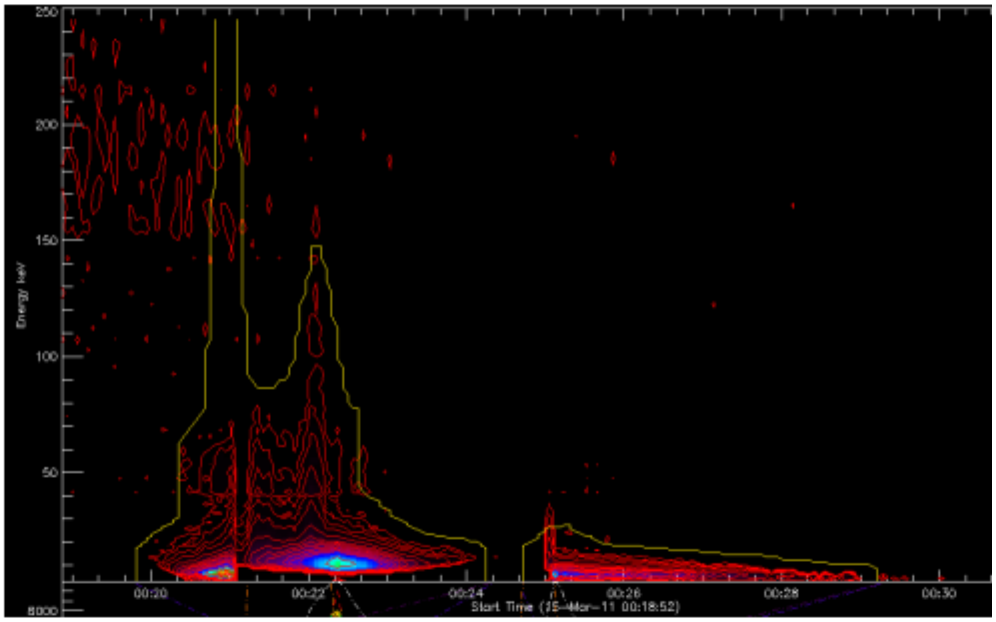

Figure 3. *The clip maks borders: two sub-events are highlighted in yellow*

Visibility creation: the goal of the interval selection algorithm is to find a contiguous time-energy grid for events. Each time-energy bin of the grid allows for the reconstruction of meaningful science products, e.g. images with good quality and resolution. The contiguous grid allows for a comparative analysis in time and/or energy. Uniformity is not required; however, the grid must be homogeneous, that is the time duration is the same for all intervals and the energy bands are the same over the complete event. The current version of the interval selection algorithm processes an event as follows:

a) use the mask to identify sub events. Process each sub event separately;
b) calculate a light curve for the event for a given energy range (sum of counts over time):
    i. find significant maxima and minima in the lightcurve;
    ii. ensure correct identification of maxima and minima on the curve (no two successive maxima/minima);
c) bring the clip mask for this sub event into the shape of a rectangle (start time, end time, energy min, energy max);
d) for each maxima, select the maximum as a starting point for the calculation of this initial column:
    i. set the initial time interval (T is one roll period) around this maximum;
    ii. subdivide the energy column for this time interval into fractions as follows:
        1. start at the maximal energy boundary and proceed towards the minimum energy boundary;
        2. shift the lower-energy border in dependence of the energy-binning and sum the counts until a certain minimum count is reached;

3.start with a new split contiguously;

iii. propagate this column contiguously around the initial column for the rest of the event (time axis);

iv. for the initial column, for each time-energy bin within, the counts constraint is fulfilled. This is necessary for the reconstruction of science products. However the same is not guaranteed for the propagated columns for the rest of the event;

v. a score function calculates the performance of the whole grid. At this time, the score is the number of cells in the grid that pass the minimum counts criterion;

vi. save the grid with the best performance;

vii. increase T by one roll period and alternatingly grow initial time interval to the left and right. Continue with ii;

e) compare the highest scoring grids for each maximum and return the best grid.

Due to the centered time intervals around the seed points the approach tries to ensure that no fluxes or other interesting points (maxima at the light curve) are split into two intervals.

Figure 4 shows a possible result of the interval selection. The mask was enlarged to a rectangle and the grid divided the event into uniform time intervals and homogeneous energy bands. The green line on the bottom shows the light curve. The time steps are centered on the maximum of the curve. The green bordered cells fulfill the count criterion and the turquoise ones to a high degree and may also be used to reconstruct good images.

The contiguous and homogeneous grid allows for the reconstruction of comparative images. The event can be analyzed for a specific energy range over uniform time intervals or for the same time interval over different energy bands. For each time-energy bin in the grid an image can be reconstructed and stored in a database for publication. Since the interval selection is an optimization algorithm, not all time-energy bins yield good images. However, the grid with the highest number of good time-energy bins (the criterion is minimum counts) is selected to guarantee good coverage of the event. The extracted visibilities or the visibility database can be used with image reconstruction algorithms such as *uv_smooth*. The very fine grid used for the visibility extraction process allows users of the visibility database to configure the interval selection algorithm to reconstruct sets of images that meet their specific needs.

As a comparison with Figure 4, Figure 5 shows a rejected grid from the optimization process. The number of valid intervals is only 75% of the final result. This demonstrates that different time intervals lead to different energy intervals.

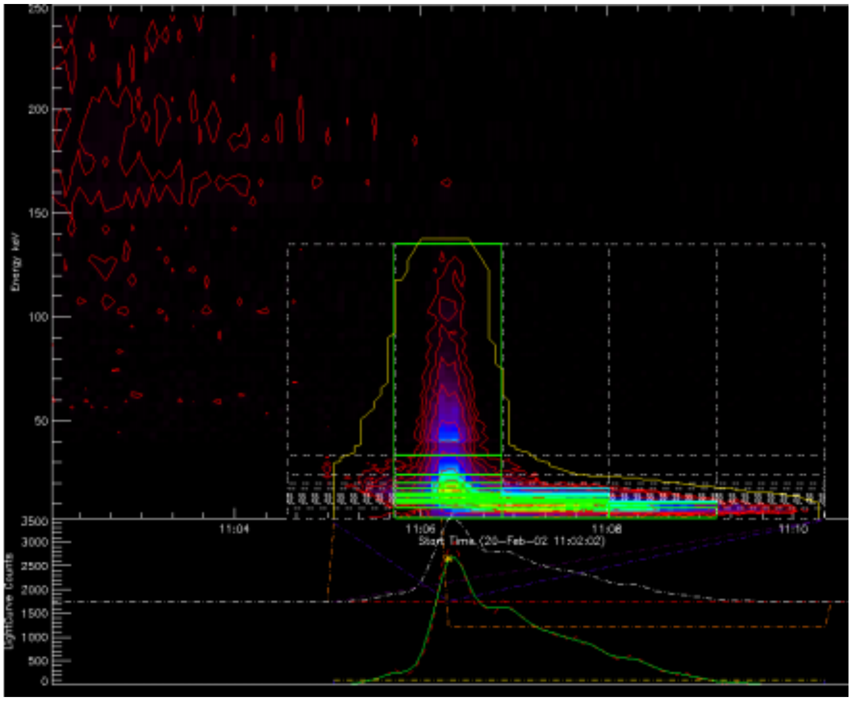

Figure 4. *Result of the interval selection algorithm when the optimization process accepts the result*

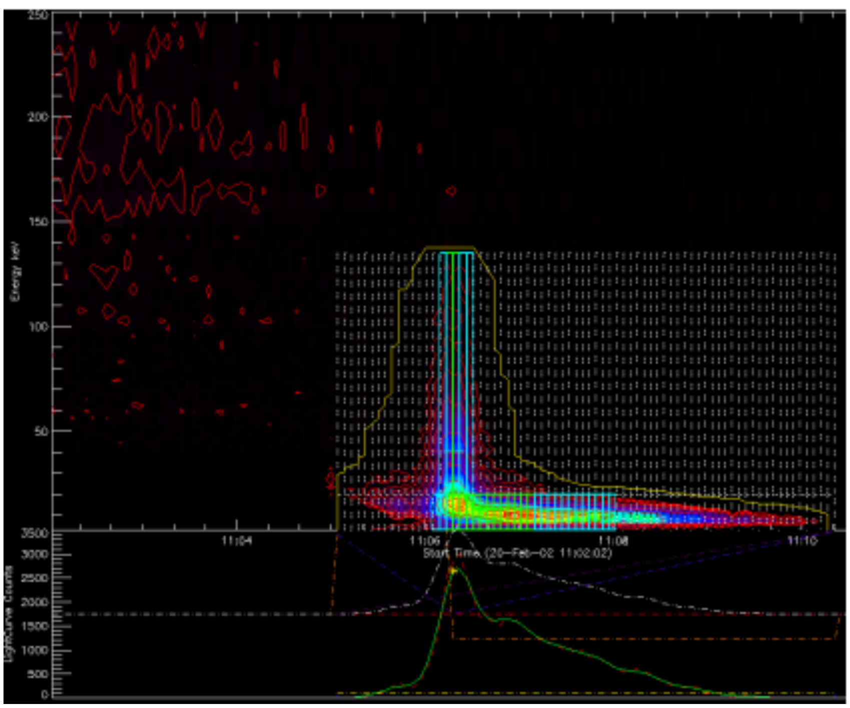

Figure 5. *Result of the interval selection algorithm. Example of grid rejected by the optimization process*

5. Project management during the period

HESPE management activity 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 first year ten persons have been hired thanks to HESPE financial support. They are:
  - ✓ Jingnan Guo, post-doc (UNIGE)
  - ✓ Federico Benvenuto, post-doc (UNIGE)
  - ✓ Rosita Timossi, administration (UNIGE)
  - ✓ Laszlo Etesi, post-doc (FHNW)
  - ✓ Nicky Hochmuth, post-doc (FHNW)
  - ✓ Hanna Sathiapal, public outreach (FHNW)
  - ✓ Paulo Simoes, post-doc (UNIGLA)
  - ✓ Yang Su, post-doc (UNIGRAZ)
  - ✓ Relindis Rott, PhD student (UNIGRAZ)
  - ✓ Hamish Reid, post-doc (CNRS)
- UNIGE and UNIGRAZ found some difficulties in the hiring of two post-docs of Chinese nationality, owing to burocratic reasons: in both cases, the university offices required the submission of numerous official forms and the fulfillment of such requirements notably slowed down the hiring process. This reflected in postponing the starting date for the contract of these two post-docs, who began their activity within HESPE in June (for the UNIGE researcher) and in September (for the UNIGRAZ researcher).
- In order to improve the effectiveness of the scientific activity of the project, the project coordinator organized some Work Package meetings. 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 WP 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 WP3 meeting took place at CNRS (Paris) on March 3-4 2011
  - ✓ A WP5 meeting took place at FHNW (Brugg) on June 1-2 2011
  - ✓ A WP4-WP3 meeting took place at CNRS (Paris) on July 7-8 2011

  Furthermore, at the end of the eleventh RHESSI meeting, which took place in Glasgow in the period 4-7 April 2011, we organized a one-day plenary HESPE meeting which took advantage from the fact that representatives of all beneficiaries were present on that occasion, and that could point out the status of the activities around the half time of HESPE first year.

HESPE foresees the help of a work package, named 'Other Activities' (WP 2) mainly devoted to dissemination purposes. In this context, the organization, realization and maintainance 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

During the first year we have developed the HESPE Web Site at http://hespe.eu. The domain "hespe.eu" is owned and maintained by the Fachhochschule Nordwestschweiz (FHNW), representing all other participating institutions. The web server and software development resources (see below) are also located at the FHNW, and maintained by FHWN ICT support staff. All data, i.e. web framework, web content, source code, etc. are automatically backed up each night and stored on separated servers. The HESPE Web Site is a portal for the HESPE team, for scientists, EU officials, and the public, serving as a platform for data and information exchange. All contents, except the section "Internal Resource" are publicly available.

The basic framework behind the HESPE web platform is an open source Content Management System (CMS) called Typo3 (http://typo3.org). CMS allows for fast implementation of web sites and come with built-in support for web content editing (forms, WYSIWYG editors, etc.). Typo3 is entirely written in the script language PHP and runs on an Apache webserver with access to a local MySQL database. After a few initialization steps, the site configuration, setup, and maintenance are performed online through the Typo3 backend.

The data contained in the web site are organized according to the general structure described in Table 1. HESPE Web Site is of course a dynamic framework whose contents are changing together with the development of the project and the accomplishment of the different deliverables. At the moment of the submission of the project report, the different areas contain:

- *Project*: general description of the project; description of the main scientific objectives for each one of the R&T HESPE work packages; discussion of the main scientific issues that represent HESPE cultural background; description of the instruments involved in HESPE research activity and of the technical characteristics of the data.
- *News and Resources*: list of the positions opened with HESPE financial support; list of HESPE meetings; list of meetings with scientific contents useful to HESPE scientific activity.
- *Data Access*: link to the RHESSI data center and to the Quick Look browser for RHESSI data.
- *Software*:
  - ✓ *requirements for the HESPE framework*; setup of the demonstration package for the interval selection algorithm;
  - ✓ *documentation concerning the HESPE framework.*

- *Internal Resources* (login required): minutes describing the discussion performed at work package meetings.

Area	**Purpose**	**Target Audience**
Project	General information on the HESPE project and the HESPE structure	Everyone
News and Resources	Contains a news section and information on events, papers, and presentations	Everyone
Data Access	Gives links to the data (i.e. RHESSI data)	Scientists, HESPE Team
Software	Documentation of algorithms and data processing software	Scientists, HESPE Team
Public Outreach	Presentations of HESPE for the public	Public
Internal Resources	Login required. Internal data exchange and information on the current status, on the project plan, etc.	EU officials, HESPE Team

Table 1. *The content of the HESPE webpage at http://hespe.eu*

Software Development Support

The software written for HESPE will be based on and integrated into the SolarSoftware (SSW) library. However, 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 will automatically replicate the source files into the 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 main dissemination occasions for HESPE activity during this first year have been the two RHESSI meetings. Specifically, during the eleventh RHESSI meeting (Glasgow, April 4-7 2011) the main objectives of HESPE have been illustrated to an audience made of most high-energy solar physics scientists. During the twelfth RHESSI meeting (Nanjing, October 16-21 2011) the results obtained by HESPE in its first year activity have been extensively described. Specifically, one entire session of the workshop has been devoted to illustrate the results of the test for the validation of imaging methods by means of synthetic hard X-ray data while representatives of all HESPE units have provided talks on the main results obtained during their activity within the HESPE framework.

Very interestingly, on October 31 2011 the Festival of Science taking place every year in Genova, Italy, hosted a round table about the rationale, objectives and first results of the HESPE project. During this meeting, coordinated by the HESPE Principal Investigator, Gordon Hurford (UCB) and Anna Maria Massone (UNIGE) described to a non-specialist audience the main issues concerning the acquisition and analysis of solar high energy data. Furthermore, A Gordon Emslie, from West Kentucky University and member of the HESPE Steering Committee, discussed the main open problems related to the physics of solar flares and explained why a project like HESPE is crucial for the unveiling of the most secret aspects of these mysterious explosive phenomena. The Festival of Science in Genova is a very renowned event for the dissemination of science and we believe that this round table on HESPE science was a perfect occasion for disseminating the content of our project and its impact on the astrophysical community.

References (papers written under the HESPE support)

Allavena S, Piana M, Benvenuto F and Massone A M 2011 An interpolation/extrapolation approach to X-ray imaging of solar flares *Inverse Problems and Imaging* (submitted)

Battaglia M and Kontar E P 2011 Height structure of X-ray, EUV, and white-light emission in a solar flare *Astronomy and Astrophysics* **533** L2

Battaglia M and Kontar E P 2011 Hard X-ray footpoint sizes and positions as diagnostics of flare accelerated energetic electrons in the low solar atmosphere *Astrophysical Journal* **735** 42

Bian N, Kontar E P and MacKinnon A 2011 Turbulent cross-field transport of non-thermal electrons in coronal loops: theory and observations *Astronomy and Astrophysics* **535** A18

Fleishman G D, Kontar E P, Nita G M and Gary D E 2011 A cold, tenuous solar flare: acceleration without heating *Astrophysical Journal Letters* **731** L19

Hudson H S, Fletcher L, Fisher G H, Abbett W P and Russell A 2011 Momentum distribution in solar flare processes *Solar Physics* 10.1007/s11207-011-9836-0

Hudson H S, Fletcher L, MacKinnon A L and Woods T N 2011 EVE limits on low-energy alpha particles in solar flares *Solar Physics* (submitted)

Hudson H S, Woods T N, Chamberlin P C, Fletcher L, Del Zanna G, Didkovsky L, Labrosse N and Graham D 2011 The EVE Doppler sensitivity and flare observations *Solar Physics* **273** 69

Joshi B, Veronig A M, Lee J, Bong S C, Tiwari S K, Cho K S 2011 Pre-flare activity and magnetic reconnection during the evolutionary stages of energy release in a solar eruptive flare *Astrophysical Journal* (in press)

Kontar E P, Hannah I G and Bian N H 2011 Acceleration, Magnetic Fluctuations, and Cross-field Transport of Energetic Electrons in a Solar Flare Loop *Astrophysical Journal Letters* **730** L22

Massone A M and Piana M 2011 The use of electron maps to constrain some physical properties of solar flares *Solar Physics* (in press)

Schwartz R, Kontar E P, Jeffrey N and Massone A M 2011 Accounting for the albedo flux in RHESSI image reconstructions SPD *Meeting 2011*, Las Cruces, NM USA, June 12-16 2011

Vilmer N 2011 Solar flares and energetic particles *Philosophical Transactions of the Royal Society* A (submitted)