# End to end testing of RHESSI spectroscopy data product

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## Introduction

### STIX Spectrogram

Spectrograms, that is a regular or irregular grid of counts or photons as a function of energy and time are a fundamental data type in x-ray astronomy. The STIX spectrogram data product consists of the measured counts summed over detectors (and pixels) for all 32 standard energy channels at a variable time resolution based on the interval selection procedure. As standard all the counts in all detectors are combined to make the spectrogram but a detector mask may be applied to remove given detectors.

One of the most widely used tools for solar X-ray data analysis is OSPEX (Object Spectral Executive). This is an object-oriented interface for X-ray spectral analysis of solar data. This software is part of the SSW distribution and has been used extensively in the analysis of the data from previous solar X-ray instruments such as RHESSI. The OSPEX package has been extended and adapted in order to handle data from multiple instruments including STIX. OSPEX allows complete spectral analysis (display, manipulation and interpretation of the data) of STIX flare data to be performed.

The count data in the spectrogram can be interpreted as the result of a photon spectrum, modelled as number of simple functional components, interacting with the STIX CdTe detector, modeled by the response matrix. This model spectrum can then be fit to the observed count data and the parameters found can then be interpreted scientifically e.g. the temperature of the emitting thermal plasma.

### End to End Testing procedure

In order to ensure the full pipeline from simulation of synthetic data to analysis software functions as expected, end to end testing is performed starting with RHESSI flare data. The RHESSI data for a selected flare is analyzed in OSPEX in the standard manner to determine the photon spectrum for all time bins over the flare. The background is estimated separately for each energy band and then subtracted. Parametric fits are then performed on the background subtracted count spectrum for each time bin. For consistency each spectrum is fit with two components, a thermal (f\_vth) and non-thermal (f\_1pow).

The procedure stx\_sim\_rhessi\_flares was then used to generate a scenario file for the specified flare using the fit parameters. A background component with an energy profile generated by stx\_bkg\_continuum\_mdl is also included with a constant time profile that extends slightly longer than the period of the flare.

Starting with the scenario file the data simulation software (DSS) is run to generate FITS files with the eventlist of detected counts for the full flare scenario. This contains the detector, pixel, energy ad channel and time of every count which reaches the detector. Time filtering is then applied to this to account for the influence of deadtime and pileup produce a list of triggers and detected counts.

This eventlist is then processed flight software simulator (FSWS). A spectrogram of the count data is created from the level 1 output of the STIX interval selection algorithm. This has the full resolution of 32 energy channels and a time binning determined by the interval selection algorithm to ensure that each bin has a duration long enough to contain a useful amount of counts. A detector response matrix using the same standard 32 STIX energy channels in count space, with a high energy extension in photon space, is also generated. Response matrices for all RCR states are scaled to the total area of the pixels used and the presence of the attenuator is accounted for. This data is then written into spectrum and DRM FITS files.

An OSPEX object is created and the generated files are loaded into it. The OSPEX anyspecfile method, along with STIX reader routines, then allows the files to be interpreted correctly and therefore to be analysed using the full capabilities of OSPEX. Light curves, spectra and spectrograms can then immediately be plotted. Background time intervals are selected before the beginning and after the end of the flare as the input background has a constant time profile at all energies.

Parametric fitting of the count spectrum, using the same components as was used to fit the RHESSI data (f\_vth and f\_1pow) is then performed. The values at each time are compared with the input parameters derived from the RHESSI data.

A range of RHESSI flares were analysed from GOES class B to X. Two weak flares were studied on 5th October 2005 and on 12th February 2002, these flares are mostly thermal with very little nonthermal component apparent. Two moderate flares are studied on 31st December 2007 and 24th February 2011 these flares show notable non-thermal emission in the impulsive phase of the flare but not much non-thermal in the rest of the flare. Two large flares are also simulated, 23rd July 2002 and 2nd November 2003 these flares show notable non-thermal emission throughout the flare time and also require multiple rcr changes to accommodate the high flux.

## Small Flares

### 5-October-2005



Figure 1 : Input information from OSPEX fits to RHESSI data for the B9.6 flare on 5th October 2005. Top:. Total thermal photon flux for each time bin. Bottom: location of the observed flare on the solar disk



Figure 2 : Input photon lightcurve in standard quicklook bands (4-7keV (black), 7-11keV (blue), 11-16keV (red), 16-40keV (green), and 40-150keV (yellow)) including both the thermal and non-thermal components for the flare on 5th October 2005



Figure 3 : Count flux lightcurve including background in STIX quicklook bands displayed in OSPEX read in from the stx\_spectrum FITS file for the flare on 5th October 2005



Figure 4 : Comparison between input parameters fit from RHESSI data and output parameters determined by the OSPEX fit to the STIX simulated data for the same time bins for the flare on 5th October 2005. Top: Emission measure Bottom: Plasma temperature.

### 12-February-2002



Figure 5: Input information from OSPEX fits to RHESSI data for the flare on 12th February 2002. Top:. Total thermal photon flux for each time bin. Bottom: location of the observed flare on the solar disk



Figure 6 : : Input photon lightcurve in standard quicklook bands (4-7keV (black), 7-11keV (blue), 11-16keV (red), 16-40keV (green), and 40-150keV (yellow)) including both the thermal and non-thermal components for the flare on 12th February 2002



Figure 7 : : Count flux lightcurve including background in STIX quicklook bands displayed in OSPEX read in from the stx\_spectrum FITS file for the flare on 12th February 2002



Figure 8 : : Comparison between input parameters fit from RHESSI data and output parameters determined by the OSPEX fit to the STIX simulated data for the same time bins for the flare on 12th February 2002. Top: Emission measure Bottom: Plasma temperature.

## Moderate Flares

### 31-December-2007



Figure 9 : Input information from OSPEX fits to RHESSI data for the flare on 31st December 2007. Top:. Total thermal (black) and non-thermal (red) photon flux for each time bin. Bottom: location of the observed flare on the solar disk



Figure 10 : : Input photon lightcurve in standard quicklook bands (4-7keV (black), 7-11keV (blue), 11-16keV (red), 16-40keV (green), and 40-150keV (yellow)) including both the thermal and non-thermal components for the flare on 31st December 2007



Figure 11 : Count flux lightcurve including background in STIX quicklook bands displayed in OSPEX read in from the stx\_spectrum FITS file for the flare on 31st December 2007



Figure 12 : Comparison between input parameters fit from RHESSI data and output parameters determined by the OSPEX fit to the STIX simulated data for the same time bins for the flare on 31st December 2007. Top Panel: Emission measure from f\_th fit. Second Panel: Plasma temperature from f\_th fit. Third Panel: Normalization of f\_1pow fit. Bottom Panel: spectral index of f\_1pow fit

### 24-February-2011



Figure 13 : Input information from OSPEX fits to RHESSI data for the flare on 24th February 2011. Top:. Total thermal (black) and non-thermal (red) photon flux for each time bin. Bottom: location of the observed flare on the solar disk



Figure 14 : Input photon lightcurve in standard quicklook bands (4-7keV (black), 7-11keV (blue), 11-16keV (red), 16-40keV (green), and 40-150keV (yellow)) including both the thermal and non-thermal components for the flare on 24th February 2011



Figure 15 : Count flux lightcurve including background in STIX quicklook bands displayed in OSPEX read in from the stx\_spectrum FITS file for the flare on 24th February 2011



Figure 16 : Comparison between input parameters fit from RHESSI data and output parameters determined by the OSPEX fit to the STIX simulated data for the same time bins for the flare on 24thFebruary 2011. Top Panel: Emission measure from f\_th fit. Second Panel: Plasma temperature from f\_th fit. Third Panel: Normalization of f\_1pow fit. Bottom Panel: spectral index of f\_1pow fit

## Large Flares

23-July- 2002

Figure 17 : Input information from OSPEX fits to RHESSI data for the flare on 23rd July 2002. Top:. Total thermal (black) and non-thermal (red) photon flux for each time bin. Bottom: location of the observed flare on the solar disk



Figure 18 : : Input photon lightcurve in standard quicklook bands (4-7keV (black), 7-11keV (blue), 11-16keV (red), 16-40keV (green), and 40-150keV (yellow)) including both the thermal and non-thermal components for the flare on 23rd July 2002



Figure 19 : Count flux lightcurve including background in STIX quicklook bands displayed in OSPEX read in from the stx\_spectrum FITS file for the flare 23rd July 2002. The attenuator status change is visible at approximately 00:28



Figure 20 : Comparison between input parameters fit from RHESSI data and output parameters determined by the OSPEX fit to the STIX simulated data for the same time bins for the flare on 23rd July 2002. Top Panel: Emission measure from f\_th fit. Second Panel: Plasma temperature from f\_th fit. Third Panel: Normalization of f\_1pow fit. Bottom Panel: spectral index of f\_1pow fit

### 2-November-2003



Figure 21 Input information from OSPEX fits to RHESSI data for the flare on 2nd November 2003. Top:. Total thermal (black) and non-thermal (red) photon flux for each time bin. Bottom: location of the observed flare on the solar disk

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Figure 22 : Input photon lightcurve in standard quicklook bands (4-7keV (black), 7-11keV (blue), 11-16keV (red), 16-40keV (green), and 40-150keV (yellow)) including both the thermal and non-thermal components for the flare on 2nd November 2003



Figure 23 : : Count flux lightcurve including background in STIX quicklook bands displayed in OSPEX read in from the stx\_spectrum FITS file for the flare on 2nd November 2003. Rate control regime status changes are visible in the count rate.



Figure 24 : Comparison between input parameters fit from RHESSI data and output parameters determined by the OSPEX fit to the STIX simulated data for the same time bins for the flare on 2nd November 2003. Top Panel: Emission measure from f\_th fit. Second Panel: Plasma temperature from f\_th fit. Third Panel: Normalization of f\_1pow fit. Bottom Panel: spectral index of f\_1pow fit

## Results

The time profiles for the parameters match well between the input values derived from RHESSI data and the fit values from the STIX data simulation particularly for the thermal component. The magnitude shows some slight bias – for the thermal component the emission measure is often underestimated and there is a slight, probably compensatory overestimate for the plasma temperature. For the power law component the normalization usually shows good agreement however there is also a tendency to underestimate the spectral index.