15th RHESSI Workshop Graz

Abstracts

Plenary: Review Talks (Wed 27.7.2016)

Battaglia, Marina

RHESSI and EUV observations as diagnostics of accelerated electrons and atmospheric response in solar flares

Observations of flaring processes at EUV wavelengths are highly complementary to RHESSI X-ray observations. They give access to electron energies and temperature ranges to which RHESSI is not sensitive. Modern observatories such as IRIS and SDO provide high spatial, high temporal, and high spectral resolution data over a broad range of UV and EUV wavelengths. Combining RHESSI observations with data from these instruments allows us to study flare accelerated electrons and atmospheric response to flare energy input over a broad energy range and considerably enhances the diagnostic potential of X-ray observations. I will give an overview of some recent results from combined RHESSI and EUV observations of solar flares and will present methods that allow for true simultaneous exploitation of these rich data-sets.

Hannah, Iain

Searching for faint solar HXRs with NuSTAR

Solar flares impulsively release energy in the Sun's atmosphere, with a substantial amount going into accelerating electrons. Hard X-ray (HXR) observations are a crucial tool for understanding the properties of this non-thermal emission and RHESSI is successfully able to study this in large flares down to events many orders of magnitude smaller (microflares). To go beyond RHESSI we require X-ray telescopes with higher sensitivity and dynamic range to probe the faint emission from coronal energy release sites associated with flares and CMEs as well as the weak signatures from even smaller impulsive events (nanoflares). For the latter, X-rays from high temperature (> 5MK) or non-thermal wee events could indicate that they are responsible for maintaining the hot corona. As a step towards a dedicated solar spacecraft an opportunity presents itself with NASA's NuSTAR. Launched in 2012, NuSTAR is an astrophysics mission using X-ray focusing optics to produce highly sensitive imaging spectroscopy. Most of NuSTAR's time is spent on targets outside of the solar system but some is spent on the Sun: solar observations began in late 2014. Here we present NuSTAR's first observations of a variety of occulted, weakly and/or non-flaring active regions. We also present the prospects for detection of HXRs from the smallest flares as we continue through the declining phase of cycle 24 and achieve more optimal observing conditions for NuSTAR.

Plenary: Talks Instrument Session (Sat 30.7.2016)

Caspi, Amir

CubeSats for Solar Soft X-ray Spectroscopy: MinXSS and CubIXSS

The Miniature X-ray Solar Spectrometer (MinXSS), a 3U CubeSat for solar soft X-ray spectroscopy, deployed from the ISS on 16 May 2016 and began taking routine solar spectra on 9 June 2016. MinXSS uses the COTS Amptek X123-SDD spectrometer to observe the Sun from ~0.5 to 30 keV with ~0.15 keV FWHM resolution and ~10 s cadence. These measurements, both during flares and quiescent periods, will help to better understand plasma heating in the solar corona, and the influence of solar X-ray emission on Earth's ionosphere, thermosphere, and mesosphere. We discuss the MinXSS mission and hardware, and present the current state of analysis of MinXSS early-mission flare and quiet Sun observations. We also introduce the next generation instrument for solar soft X-ray spectroscopy, the CubeSat Imaging X-ray Solar Spectrometer (CubIXSS), a proposed 6U mission that includes multiple X123 spectrometers and a novel spectral imager. Using both silicon and CdTe detectors, CubIXSS provides MinXSS-like spectroscopy with improved dynamic range and sensitivity into the hard X-rays, and provides spatially-resolved imaging spectroscopy of flares and active regions in the little-studied ~0.2-5 keV range (~2-60 Å, w/ ~0.25 Å and ~25" FWHM resolutions).

Glesener, Lindsay and the FOXSI team

The first two flights of FOXSI: the Focusing Optics X-ray Solar Imager

The Focusing Optics X-ray Solar Imager (FOXSI) sounding rocket flew in 2012 and 2014, observing microflares, active regions, and the quiet Sun, with a third flight planned for 2018. FOXSI features direct-focusing hard X-ray (HXR) optics, as opposed to the indirect imaging techniques employed on previous solar HXR imagers. With these optics, improved sensitivity and imaging dynamic range are achieved. This talk will present a discussion of the results from the first two flights, along with a preview of plans for the third flight.

Kleint, Lucia

GREGOR Flare Observations

The GREGOR telescope is a 1.5 m optical telescope on Tenerife, Spain that is operational since 2015. It is the currently largest European solar telescope. Observations focus on near-infrared spectroscopy/spectropolarimetry and fast imaging in the visible wavelength range. I will present an overview of the instruments, examples of flare data, and illustrate how GREGOR observations can be used for RHESSI science.

Kontar, Eduard

LOFAR: Low-Frequency Array

The Low Frequency Array (LOFAR) is a powerful next-generation radio telescope offering revolutionary new observing capabilities thanks to its phased-array technology with digital beamforming. The telescope operates in the meter/decameter range allowing detailed studies of the processes in the high corona. I will briefly discuss how the telescope operates, describe possibilities and opportunities, and highlight some interesting observations.

Krucker, Säm

Update on STIX: Spectrometer/Telescope for Imaging X-rays

A short update on the current status of the STIX instrument delivery will be presented.

Martinez Oliveros, Juan C., Lindsay Glesener, Pascal Saint Hilaire, Gordon Hurford, Säm Krucker

MiXI: The Miniature Xray Imager

The Miniature X-ray Imager (MiXI) is an innovative, small, and fully functional solar X-ray observatory concept designed to fit within a 12U CubeSat platform. MiXI will provide the community with X-ray imaging in the energy range from ~6 to 40-50 keV and spectroscopy up to 100 keV of solar flares at a small fraction of the cost of a conventional mission. It includes rotation modulation collimators, providing routine observations of both soft and hard X-ray emission. Coordinated observations between MiXI and the STIX instrument onboard Solar Orbiter will enable solar flare observation from two vantage points, providing new insights into the directivity of flare HXR emission and will allow detailed study of both coronal and footpoint sources within the same flare. These results may have profound implications for theories of flare acceleration processes.

Saint-Hilaire, Pascal and the GRIPS team

First flight of the Gamma Ray Imager/Polarimeter for solar flares (GRIPS)

The Gamma-Ray Imager/Polarimeter for Solar flares (GRIPS) high altitude balloon payload was successfully flown in January 2016 from Antarctica (Jan 19 to Jan 30). During that period, 21 C-class flares occurred on the Sun.

GRIPS provides a near-optimal combination of high-resolution imaging, spectroscopy, and polarimetry of solar-flare gamma ray/hard X-ray emissions from ~20 keV to >~10 MeV. GRIPS's goal is to address questions raised by recent solar flare observations regarding particle acceleration and energy release, such as: What causes the spatial separation between energetic electrons producing hard X-rays and energetic ions producing gamma-ray lines? How anisotropic are the relativistic electrons, and why can they dominate in the corona? How do the compositions of accelerated and ambient material vary with space and time, and why? The spectrometer/polarimeter consists of six 3D position-sensitive germanium detectors (3D-GeDs), where each energy deposition is individually recorded with an energy resolution of a few keV FWHM and a spatial resolution of <0.1 mm^3. Imaging is accomplished by a single multi-pitch rotating modulator (MPRM), a 2.5-cm thick tungsten-copper alloy slit/slat grid with pitches that range quasi-continuously from 1 to 13 mm. The MPRM is situated 8 meters from the spectrometer to provide excellent image quality and unparalleled angular resolution at gamma-ray energies (12.5 arcsec FWHM), sufficient to separate 2.2 MeV footpoint sources for almost all flares. Polarimetry is accomplished by analyzing the anisotropy of reconstructed Compton scattering in the 3D-GeDs (i.e., as an active scatterer), with an estimated minimum detectable polarization of a few percent at 150-650 keV in an X-class flare. GRIPS was also equipped with active BGO shields, and three piggy-back instruments: a solar terahertz radiometer (Solar-T), a hard X-ray spectrometer (SMASH), and a sonic anemometer (TILDAE).

We will present an overview of GRIPS's first flight, the performance of its instruments and subsystems, including the solar pointing and aspect systems, and the current progress of our data analysis.

Veronig, Astrid M., Werner Pötzi

Kanzelhöhe Observatory: Flare observations and real-time detections

Kanzelhöhe Observatory (KSO; Austria) regularly performs high-cadence full-disk imaging of the solar chromosphere in the Hα and Ca II K spectral lines as well as in the solar photosphere in white light. In the frame of ESA's Space Situational Awareness (SSA) program, a new system for real-time Hα data provision and automatic flare detection was developed at KSO. The data and events detected are published in near real-time at ESA's SSA Space Weather portal (http://swe.ssa.esa.int/web/guest/kso-federated). In this talk we give a brief overview on the real-time flare detection system, which is running since July 2013, and its performance.

Contributions to Working Groups

Working Group 1

Battaglia, Marina

RHESSI and IRIS observations of chromospheric evaporation in the 29th March 2014 flare

We present simultaneous RHESSI and IRIS observations of chromospheric evaporation in the flare SOL2014-03-29T17:48 and discuss the likely triggers of evaporation at different locations and different stages during the flare. IRIS observations of the FeXXI line indicate evaporating plasma at a temperature of 10 MK along the flare ribbon during the flare peak and several minutes into the decay phase. RHESSI images show hard X-ray footpoints for two minutes during the peak of the flare. Their locations coincide with the locations of upflows observed with IRIS in parts of the southern flare ribbon consistent with a scenario of beam driven chromospheric evaporation. However, in other parts of the southern ribbon and in the northern ribbon the observed upflows are not coincident with a HXR source in time nor space, most prominently during the decay phase. In this case evaporation is likely triggered due to energy input by a conductive flux that is established between the hot (25 MK) coronal source, which is present during the whole observed time-interval, and the chromosphere. These observations suggest that conduction driven evaporation dominates not only during the decay phase but also during the flare peak.

Fleishman, Gregory D., G.G. Motorina, E.P. Kontar

Joint X-ray and EUV analysis of the 2013 November 5 cold flare

Solar flares demonstrate remarkable variety of the energy partitions between the thermal and nonthermal components. In particular, there are flares, where the nonthermal component clearly dominates over the thermal one. It has recently been recognized that some flares with dominating nonthermal component are in fact ‘cold flares’ (Bastian et al. 2007; Fleishman et al. 2011; Masuda et al. 2013) in which no or so modest thermal plasma response is detected that these events are not even listed as GOES flares. It appears that this modest heating is entirely supplied by the energy losses of the accelerated electrons without any apparent additional heating. Therefore, unlike other flare types, where various mechanisms of the plasma heating are involved and the free magnetic energy is divided in unknown partitions between the thermal and nonthermal components, the nonthermal-energy-dominated cold flares offer, perhaps, the only way of studying the direct effect of the electrons accelerated in flares on the plasma heating, as well as an unbeatably clean way of probing the acceleration itself. Here we analyze a 2013-Nov-05 cold flare with a combination of X-ray (RHESSI), and EUV (SDO) data to understand the relationship between the thermal and nonthermal components in this flare in detail. This is the first example of analysis of cold flares employing both RHESSI and SDO/AIA data, where RHESSI provides information of nonthermal energetic particles, and SDO/AIA characterizes the thermal response at lower temperatures, approximately 0.6 MK – 16 MK. The microwave spectral and imaging data taken from Nobeyama and BBMS/SSRT instruments put significant additional constraints on the magnetic field and number density at the source of the flare. With these data we build a consistent detailed picture of particle acceleration and plasma heating in this cold flare and attempt a 3D modeling of the flaring volume. Based on this analysis, we arrive at important conclusions about the energy release, particle acceleration, and plasma heating in solar flares.

This work was supported in part by NSF grants AGS-1250374 and AGS-1262772 and NASA grant NNX14AC87G to New Jersey Institute of Technology, RFBR grants 15-02-01089, 15-02-03717, 15-02-03835, 15-02-08028, and 16-02-00749, and STFC Consolidated grant project "X-ray and radio diagnostics of energetic solar flare processes," to University of Glasgow.

Gömöry, Peter, A. M. Veronig, Y. Su, M. Temmer, J.K. Thalmann

Chromospheric evaporation flows and density changes deduced from Hinode/EIS during an M1.6 flare

We analyzed high-cadence sit-and-stare observations acquired with the Hinode/EIS spectrometer and HXR measurements acquired with RHESSI during an M-class flare. During the flare impulsive phase, we observe no significant flows in the cooler Fe XIII line but strong upflows, up to 80-150 km/s, in the hotter Fe XVI line. The largest Doppler shifts observed in the Fe XVI line were co-temporal with the sharp intensity peak. The electron density obtained from a Fe XIII line pair ratio exhibited fast increase (within two minutes) from the pre-flare level of $5.01\text{x}10^9$ cm^{-3} to $3.16\text{x}10^{10}$ cm^{-3} during the flare peak. The nonthermal energy flux density deposited from the coronal acceleration site to the lower atmospheric layers during the flare peak was found to be $1.34\text{x}10^{10}$ $erg/s/cm^2$ for a low-energy cut-off that was estimated to be 16 keV. During the decline flare phase, we found a secondary intensity and density peak of lower amplitude that was preceded by upflows of 15 km/s that were detected in both lines. The flare was also accompanied by a filament eruption that was partly captured by the EIS observations. We derived Doppler velocities of 250-300 km/s for the upflowing filament material. The spectroscopic results for the flare peak are consistent with the scenario of explosive chromospheric evaporation, although a comparatively low value of the nonthermal energy flux density was determined for this phase of the flare. This outcome is discussed in the context of recent hydrodynamic simulations. It provides observational evidence that the response of the atmospheric plasma strongly depends on the properties of the electron beams responsible for the heating, in particular the steepness of the energy distribution. The secondary peak of line intensity and electron density detected during the decline phase is interpreted as a signature of flare loops being filled by expanding hot material that is due to chromospheric evaporation.

Kleint, Lucia, P. Heinzel, P. Judge, S. Krucker

Combined IRIS and RHESSI observations to investigate continuum ("white light") emission

Enhanced continuum emission is observed for many flares, yet there is no consensus on its atmospheric formation height. While accelerated electrons are most likely stopped in the chromosphere and deposit their energy in that layer, the photospheric continuum is often enhanced too. The so-called "backwarming", which would transport energy from the chromosphere to the photosphere has been proposed as responsible mechanism. We combine multi-wavelength observations from RHESSI (X-ray), IRIS (UV), HMI (visible), and FIRS (IR) to investigate the spectral shape, the timing, locations and the energetics of continuum emission. We find that the continuum is emitted in both, chromosphere and photosphere, through different mechanisms (hydrogen recombination and H- emission). The timing of continuum emission is nearly immediate with a delay of no more than 15 s after HXR emission at a given location. The energy contained in most electrons >40 keV, or alternatively, of ~10-20% of electrons >20 keV is sufficient to explain the observed continuum emission.

Ning, Zongjun

Evidence of electron-driven evaporation in solar flares

Theoretically, chromospheric evaporation is thought to be caused by two possibilities, such as thermal conduction and nonthermal electron-driven. In this paper, we have explored the relationship between HXR emissions and Doppler shifts caused by the chromospheric evaporation in two flares. IRIS detects these events from the onset to end. And they display the explosive evaporation. We find that the coronal line FeXXI and the chromospheric line CI display their Doppler velocities with an increase-peak-decrease pattern which is well correlated with the rising-maximum-decay phase of HXR light curves. Such anti-correlation between HXR fluxes and FeXXI Doppler red-shifts and correlation with CI Doppler blue-shifts indicates the electron-driven evaporation in these two flares.

Inglis, A.R., J. W. Brosius, A. N. Daw

Quasi-Periodic Fluctuations and Chromospheric Evaporation in a Solar Flare Ribbon Observed by Hinode/EIS, IRIS, and RHESSI (POSTER)

The M7.3 flare ribbon in AR 12036 on 2014 April 18 was observed by multiple instruments including RHESSI, Hinode/EIS and IRIS. Quasi-periodic pulsations were observed in both the EIS (P ~ 75 ± 9s) and IRIS (P ~ 180s, P ~ 90s) slit intensities during the flare's impulsive phase. The profiles of the EIS lines reveal that they were all redshifted during most of the interval of quasi-periodic intensity fluctuations, while the Fe XXIII profile revealed multiple components including one or two highly blueshifted ones. This indicates that the flare underwent ex- plosive chromospheric evaporation during its impulsive rise. Significant redshifts and blueshifts ended near the time of maximum Fe XXIII intensity, indicating the end of chromospheric evaporation during the impulsive phase. Fluctuations in the relative Doppler velocities were detected, but their amplitudes were too subtle to extract significant quasi-periodicities. RHESSI reveals 25-100 keV hard X-ray sources in the ribbon at the location of the EIS slit during the peaks in the EIS intensity fluctuations. The observations are consistent with a series of energy injections into the chromosphere by nonthermal particle beams, sufficient to drive the observed explosive chromospheric evaporation. We speculate that fluctuations are observed in the lower temperature (but not Fe XXIII) lines because at those temperatures the plasma has sufficient time to radiatively cool between successive energy injections.

Rubio da Costa, Fatima, Vahe Petrosian

Data-driven Radiative Hydrodynamic Modeling of the 2014 March 29 X1.0 Solar Flare (POSTER)

A large fraction of energy released during a flare is radiated by coronal and chromospheric plasma. Study the chromospheric flare emission is therefore a key to understand how the flare energy is released, how non-thermal particles are produced and how mass and energy flow via chromospheric evaporation. The X1.0 flare that occurred on March 29, 2014 is one of the few flares that has been observed by all available solar missions simultaneously, allowing the solar community to study it in detail.

We used the RADYN radiative hydrodynamic code to simulate how the atmosphere responds to the energy deposited by the non-thermal electrons. We constructed a multi-threaded flare loop model and used the electron flux inferred from RHESSI as the input to the radiative hydrodynamic code RADYN to simulate the atmospheric response. The temporal evolution of the threads was estimated from the temporal derivative of the GOES 1-8 Å light curve, assuming that each spike corresponds to a single burst.

We synthesized the chromospheric emission in Hα and CaII 8542 Å as a result from the RADYN simulations, and in Mg II h&k as a result from the RH code. Comparing them to observations, we find acceptable fits for Hα and CaII 8542 Å, but the MgII IRIS profiles are broader in the wings than the synthetic ones. To investigate the reasons for the shape discrepancy, we iteratively modified the RADYN atmosphere and simulated the effects with the RH code. We found that a significant level of microturbulence is needed to reproduce the broad line wings from the observations; we increased the microturbulence velocity up to 27 km/s in a narrow region of width ≈800 km in the lower chromosphere, where the core of the line is formed.

Vanninathan, Kamalam, A.M. Veronig, K. Dissauer, M. Madjarska, I. Hannah, E. Kontar, M. Temmer (POSTER)

Plasma Diagnostics of CME related waves and dimmings

Coronal Mass Ejections (CMEs) are often associated with large-scale waves (also known as “EIT waves”) observed in the Extreme-Ultraviolet (EUV) channels as well as coronal dimmings. The globally propagating waves have been observed since the era of the Solar and Heliospheric Observatory/EUV Imaging Telescope instrument but the true nature of these transients has been a topic of speculation for many years. The dimmings are suggested to represent the evacuation of mass that is carried out by CMEs and are a unique and indirect means to study CME properties. While Earth-directed CMEs (on-disk CMEs) are difficult to observe due to the bright background solar disk and projection effects, their corresponding dimmings are clearly discernible and ideally suited for analysis. We use two events as case-studies: an X-class flare of 15 February 2011 and a M-class flare of 9 March 2012. Using data from the 6 EUV channels of Solar Dynamics Observatory/Atmospheric Imaging Assembly for Differential Emission Measure (DEM) diagnostics, we determine the plasma characteristics of the on-disk dimming region as well as the related “EIT wave”. These data are well suited for this kind of study due to the good temperature ranges covered by the multiple passbands of the instrument. Weighted density and temperature for the different regions, as a function of time, are derived from the DEMs. From such an analysis we quantitatively demonstrate that the increase in temperature of the “EIT wave” plasma is due to adiabatic compression at the wave front. This provides support for the case that the event under study is a compressive fastmode wave or a shock. The emission measure calculated in the dimming region reflects the intensity decrease as seen in the filter images but the changes in temperature are not so considerable. These measurements are used to deduce information about the CME as well as understand the relaxation of the coronal plasma after the eruption.

Working Group 2

Benvenuto, Federico, Michele Piana, Gordon Emslie, Richard Schwartz, Ron Murphy, Alec MacKinnon

The determination of high energy particle spectra via gamma ray regularized inversion

One of the most challenging problems in solar physics is the determination of the spectra of high energy particles emitted by the sun during solar flares. Gamma rays produced by high energy particle interactions allow indirect measurements of ambient abundances and spectra of the various accelerated ion species. The estimation can be addressed by applying a sophisticated numerical algorithm which encodes the production of gamma rays detected by RHESSI (and FERMI GBM) in terms of high energy particle reactions. Simulation studies show that when the model describing the production of gamma rays via nuclear reactions well approximates the overall process, the algorithm produces reliable estimates of the ion spectra and their abundances. To apply this method to real data it is necessary to optimally calibrate the model by taking into account other phenomena such as the presence of gamma ray background and nuclear reaction doppler shift. We present some preliminary simulation results and an overview of the possibility of this method in real applications.

Chen, Wei, W. Q. Gan

Time evolution of de-excitation line shapes in solar flare

Solar de-excitation lines are expected to display significant Doppler broadening because the recoiling nuclei de-excite in flight. The energies and widths of these lines provide a wealth of information on the accelerated ions’ directionality and spectra in solar flare. With the calculation of 1.634 MeV 20Ne line as example, we calculated several de-excitation line shapes for various ions spectrum. By analyzing the RHESSI observation data, we also investigated time evolution of de-excitation line shapes in solar flare.

Krucker, Säm, P. Saint-Hilaire, G. Hurford, R. Schwartz, M. Pesce Rollins

RHESSI hard X-ray observations of the Fermi behind-the-limb flare of 01Sep2014

We will report on the RHESSI observations of the highly occulted HXR emissions seen in the Fermi behind-the-limb flare of 01Sep2014. RHESSI standard imaging technique does not show modulations of the rather intense HXR burst seen up to 100 keV indicating a source size in excess of 180 arcsec Using the fan-beam modulation technique, we will derive the location of the HXR source and compare to the FERMI >100MeV source centroid.

Lysenko, Alexandra L., R.L. Aptekar, G.D. Fleishman, L.K. Kashapova, A.A. Kuznetsov, A.E. Tsvetkova, M.V. Ulanov

KWSFD - the Konus-Wind Hard X-ray Solar Flares Database

We present KWSFD, the database of hard X-ray observations of solar flares detected by Konus-Wind instrument. Konus-Wind (KW) is the Russian instrument onboard the US Wind spacecraft operating since November, 1994. The spacecraft is located in the interplanetary space (since July of 2004 - near Lagrange point L1), so the instrument sees the Sun 24 hours a day. KW operates in two modes: waiting mode and triggered mode. In the waiting mode, the light curves in three wide energy bands G1 (now ~ 20 - 80 keV), G2 (now ~ 80 - 300 keV), and G3 (now ~ 300 - 1200 keV) are measured with time resolution of 2.944 s. In the triggered mode, the light curves in the same three energy bands are available with high (from 2 ms to 256 ms) time resolution. In addition, multichannel energy spectra are measured in two partially overlapping energy ranges (now ~20 - 1200 keV and ~250 keV - 15 MeV). During more than twenty years of continuous observations, Konus-Wind detected more than 1000 solar flares in the triggered mode, which constituent the presented database. KWSFD provides spectral data in FITS format as well as light curves in IDL SAV and ASCII formats. The IDL routine for reading and processing KW FITS spectral files has been added to the OSPEX package and now available from SSW. We describe the KW solar data, their advantages and limitations. We illustrate the beauty of the data by presenting some interesting solar events, detected by Konus-Wind.

This work was supported in part by RFBR grants 15-02-01089, 15-02-03717, 15-02-03835, 15-02-08028, and 16-02-00749 and by NSF grant AGS-1262772 and NASA grant NNX14AC87G to New Jersey Institute of Technology.

Pesce-Rollins, Melissa, Nicola Omodei, Rachele Desiante on behalf of Fermi-LAT Collaboration

Fermi Large Area Telescope observations of high-energy gamma-ray emission from solar flares

Fermi LAT >30 MeV observations of the active Sun have increased the number of detected solar flares by almost a factor of 10 with respect to previous space observations. These include detections of impulsive and sustained emission, extending up to ~20 hours in the case of the 2012 March 7 X-class flares. Of particular interest are also the first detections of >100 MeV gamma-ray emission from three solar flares whose position behind the limb was confirmed by the STEREO-B spacecraft. These observations sample flares from active regions originating from behind both the eastern and western limbs and present a unique opportunity to diagnose the mechanisms of high-energy emission and particle acceleration in solar flares. We will present an overview of solar flare detections with Fermi LAT, highlighting recent results and surprising features such the observations from the behind-the-limb flares.

Petrosian, Vahe

Interpretation of On-disk and Behind the Limb Flares Detected by Fermi-LAT and Other Instruments

Observations of solar flares will be described by Pesce-Rollins. I will concentrate on the interpretation of these observations with special focus on the three flares originating from active regions behind the limb of the Sun as viewed from the Earth. I will present models of the radiative, particle transport and acceleration that yield the spatial, temporal and spectral characteristics of the accelerated particles and energetics. This can be useful to distinguish between acceleration in the low corona versus in the environment of the CME-shock' continuous versus prompt acceleration, and electron bremsstrahlung versus decay of pions produced by accelerated ions.

Simoes, P.J.A., <u>A.L. MacKinnon</u>, S. Krucker

The large gamma-ray flare SOL2014-02-25: Time development of gamma-ray emission

The X5.0 flare SOL2014-02-25 occurred near the limb and was observed by many instruments across a wide range of wavelengths, including the Gamma-Ray Burst Monitor on Fermi. It has a nuclear gamma-ray signature that lasted for more than five minutes, with clear identification of the 2.223 MeV neutron capture line and several de-excitation lines. Unusually the flux remained high enough, through several impulsive peaks, to allow a study of the time development of the nuclear line component of the gamma-ray spectrum. We show estimated light curves in individual de-excitation lines.

The many other observations set the gamma-ray emission in detailed context. SDO/AIA images revealed a major filament eruption and extended two-ribbon structure, with STEREO-B images providing a 180 degree view of the eruptive structure. A white light flare was also detected by HMI continuum, appearing as conjugated footprints, well associated with HXR footprints imaged by RHESSI.

Watanabe, Kyoko, Satoshi Masuda, Masanori Ohno

Statistical approach for the origin of white-light emission of white-light flares

Especially, in association with strong solar flares, we sometimes observe enhancements of visible continuum radiation, which is known as a ”white-light flare”. They are still only rarely observed since first being discovered more than 150 years ago, and origin of white-light emission is not still fully understood. Since most of white-light events show a close correlation in time profile and location with the hard X-rays and/or radio emission, there is some consensus that the origin of white-light emission is due to accelerated particles, especially non-thermal electrons.

One model proposes that white-light is emitted from near the photosphere, however, non-thermal electrons are thermalized in the chromosphere - and cannot reach the photosphere. So, still there is a problem concerning how the energy of non-thermal electrons propagates to the photosphere, and/or other accelerated particles - for example, high energy protons - penetrate to the photosphere, and produces white-light emission.

We are performing a statistical analysis of white-light flares which are observed by Hinode/SOT, to understand the conditions that produce enhancements of white-light in solar flares. Hinode/SOT has the capability of observing white-light flares. From white-light flare observations by Hinode/SOT, we found that the power of the white-light emission can be explained by greater than 40keV non-thermal electrons. Moreover, we also found that white-light emission was emitted from the photosphere.

We also compared the WL emission data with GOES soft X-rays, RHESSI hard X-rays, Fermi/GBM gamma-rays, and/or the strength of the photospheric magnetic fields, and investigated the relationships between many physical parameters. In this study, >1MeV gamma-ray were only observed at the X1.8 class flare on October 23, 2012. Not only the RHESSI, but also the Fermi/GBM observed strong gamma-ray emissions from this event. We focused on this flare event and try to impose some constraints on the origin of the white-light emission.

Zucca, P., K.-L. Klein, G. Trottet, G. Share, N. Vilmer, O. Malandraki, R. Miteva, B. Heber, C. Hamadache, J. Kiener, V. Tatischeff, R. Vainio

The role of microwave observations on the nature of high-energy solar gamma-ray events under the HESPERIA –HORIZON 2020 project framework

The FERMI/LAT gamma-ray experiment observed a surprisingly large number of solar events with gamma-ray emission above photon energies of 100 MeV. The emission is likely due to pion-decay photons. This implies that the acceleration of protons in the solar corona to energies above 300 MeV is much more frequent than previously thought. In some cases the emission persists over several hours. In the frame of the HESPERIA project, funded by the Horizon 2020 programme of the European Union, we conduct an extensive study on the relationship between these gamma-ray emissions and electromagnetic signatures of accelerated electrons in the corona with particular attention to the microwave emission on the one hand, and to solar energetic particles (SEPs) detected in space on the other hand. This contribution is to present first results on two subjects, using a sample of 25 gamma-ray events: (1) We search for complementary X-ray and radio signatures of electrons in the solar atmosphere during the high-energy gamma-ray emission, in the attempt to see if long-duration gamma-ray events are accompanied by signatures of long-duration or repeated electron acceleration. (2) We show that electrons near the active regions had rapid access to interplanetary space during and after the impulsive phase of the flares, i. e. at times when the gamma-rays were emitted. We conclude that the some of the same population of protons responsible for the gamma-rays could have escaped the Sun and been detected in interplanetary space.

Working Group 3

Aschwanden M., A. O'Flannagain, A. Caspi, J.M. McTiernan, G. Holman, R.A. Schwartz, E. Kontar

Global Energetics of Solar Flares - Magnetic, Thermal, and Nonthermal Energies

In this global flare energetics project we determine magnetic energies from HMI data, thermal energies from AIA data, and non thermal energies from RHESSI data of 193 M and X-class flare events from the first 3.5 yr of the SDO mission. For the RHESSI spectra we fit a thermal and a nonthermal component, yielding the temperature of the differential emission measure (DEM) tail, the non thermal powerlaw slope and flux, and the thermal/nonthermal cross-over energy e_co. From these parameters we calculate the total non thermal energy E_nt in electrons with two different methods: (i) using the observed cross-over energy e_co as low-energy cutoff, and (ii) using the low-energy cutoff $e_wt predicted by the warm thick-target bremsstrahlung model of Kontar et al. (2015). We find compatible values of the low-energy cutoffs, e_co=21+/-6 keV for the cross-over method, and e_wt=18 +/- 6 keV for the warm-target model. Comparing with the statistics of magnetically dissipated energies E_mag and thermal energies E_th in the two previous studies, we find the following median energy ratios: E_nt = 0.07 * E_mag, and E_th = 0.75 * E_nt, with a standard deviation of approximatly 8. These two inequalities corroborate statistically that the magnetically dissipated energy is sufficient to accelerate electrons in solar flares (most likely by a magnetic reconnection process), and confirm thick-target bremsstrahlung models where the thermal energy in the solar flare plasma is produced by precipitating non thermal electrons in terms of a warm thick-target model.

Awasthi Arun Kumar, Janusz Sylwester and Barbara Sylwester

Differential emission measure distribution and thermal characteristics of a B8.3 flare on July 04, 2009

We investigate the evolution of differential emission measure distribution (DEM[T]) in various phases of a B8.3 flare, which occurred on July 04, 2009. We analyze the soft X-ray (SXR) emission in 1.6-8.0 keV energy range, recorded collectively by Solar Photometer in X-rays (SphinX; Polish) and Solar X-ray Spectrometer (SOXS; Indian) instruments. We make a comparative investigation of the best-fit DEM[T] distributions derived by employing various inversion schemes viz. single gaussian, power-law, functions and Withbroe-Sylwester (W-S) maximum likelihood algorithm. In addition, SXR spectrum in three different energy bands viz. 1.6-5.0 keV (low), 5.0-8.0 keV (high) and 1.6-8.0 keV (combined) is analyzed to determine the dependence of the best-fit DEM[T] distribution on the selection of energy interval. The evolution of DEM[T] distribution, derived using W-S algorithm, reveals the plasma of multi-thermal nature during the rise to the maximum phase of the flare, while of isothermal nature in the post-maximum phase of the flare. Thermal energy content is estimated considering the flare plasma to be of 1) isothermal and 2) multi-thermal nature. We find that multi-thermal energy estimated employing low-energy band of the SXR spectrum result in higher values than that derived from the combined-energy band. On the contrary, the analysis of high-energy band of SXR spectrum lead to lower thermal energy than that estimated from the combined-energy band. The thermal characteristics and the geometry of the flare loop (derived based on EUV images) are used as an input for the Palermo-Harvard hydrodynamic modelling of the event. Results of modelling allows for insight into the dynamics of the plasma in flaring chromosphere-corona transition region during the flare. The flare plasma parameters, derived in the aforesaid manner, are then used to synthesize X-ray emission originating from different heights of solar atmosphere. Further, synthesized X-ray emission as well as other thermal characteristics of the flare plasma is then compared with that obtained from the observations.

Caspi, Amir

Current progress on multi-instrument DEMs using EVE and RHESSI

Solar flare spectra are typically dominated by thermal emission in the soft X-ray energy range, such that the low energy extent of non-thermal emission can only be loosely quantified using currently available X-ray data. To address this issue, we combine observations from the EUV Variability Experiment (EVE) on-board the Solar Dynamics Observatory (SDO) with X-ray data from the Reuven Ramaty High Energy Spectroscopic Imager (RHESSI) to calculate the Differential Emission Measure (DEM) for solar flares. This improvement over the isothermal approximation helps to resolve the ambiguity in the range where the thermal and non-thermal components have similar photon fluxes. This "crossover" range can extend up to 30 keV. We present the current progress on using concurrent EVE and RHESSI observations to calculate flare DEMs and, simultaneously, a high-energy non-thermal component, including spectral break and cutoff. Spectra for both instruments are fit simultaneously in a self-consistent manner. We examine the DEM and non-thermal emission for a sample of large (M/X-class) solar flares observed from 2011 to 2014, and compare the results of the EVE+RHESSI analysis to those using RHESSI alone. We discuss the future directions and goals of multi-instrument DEM analysis.

Cheung, Mark C. M.

A Validated Method for Differential Emission Measure Inversions with SDO/AIA (POSTER)

We present a new method for performing differential emission measure (DEM) inversions on EUV imaging observations of the solar corona taken by SDO/AIA (Cheung et al., 2015, ApJ, 807, 2). We show results from validation tests, including cross comparisons between AIA and Hinode/XRT. We provide examples on how to use the code and illustrate with applications to real data.

Dennis, Brian

Quasi Periodic Pulsations (QPP) in a Long-Duration Flare

QPP are seen in the flare light curves at many wavelengths. They are most prominent during the impulsive phase but sometimes persist for hours afterwards in the decay phase. A modified wavelet analysis technique designed to detect QPP in GOES light curves will be described, and results presented for a long-duration X-class flare on 2013 May 14. QPP were detected for the first two hours of this 8-hour event as the source revealed in RHESSI images rose to an altitude of over 60 km at a rate of 1.6 km/s. The mean QPP time scale increased from ~10 s during the impulsive phase to ~100 s some two hours later. Interpreting the QPP as being produced by vertical kink mode oscillations has allowed estimates to be made of the coronal magnetic field strength as a function of altitude. This uses the measured QPP time scales with the length and densities of the oscillating loops determined from the emission measure and source volume given by the RHESSI imaging spectroscopy observations. Applying this analysis to other events will further test the idea that vertical kink-mode oscillations are the source of QPP during both the impulsive and decay phases. If this origin is established, then QPP can be used as a diagnostic of the conditions in the corona close to the energy release site. In particular, it should be possible to obtain estimates of the Alfven speed, the beta value, and the magnetic field strength in the region of the soft X-ray emitting plasma. During the impulsive phase, other processes presumably connected to the energy release process itself can dominate to produce the more chaotic bursty nature of the emission light curve, but this is still to be established.

Dennis, Brian, Anne K. Tolbert, Andrew Inglis, Jack Ireland, Tongjang Wang, Gordon D. Holman, Laura A. Hayes, Peter T. Gallagher

Long-lived Quasi Periodic Pulsations (QPP) in the X-class Flare of 2013 May 14 (POSTER)

Multiple quasi-periodic pulsations (QPP) seen in the GOES soft X-ray light curves are analyzed for the X3.2 event on 14 May 2013. The pulsations, best seen in the time derivative of the light curve, are apparent for a total of at least two hours from the impulsive phase to well into the decay phase, with a total of 163 distinct pulses evident to the naked eye. Similar pulsations are also seen in the EVE/ESP light curves showing that they are of solar origin and not the result of an instrumental effect. A wavelet analysis shows that the characteristic time scale of these pulsations increases systematically from ~25 s at 01:10 UT, the time of the GOES peak, to ~100 s at 02:00 UT. A second 'ridge' in the wavelet power spectrum, possibly associated with a second coronal X-ray source, shows an increase from ~40 s at 01:40 UT to ~100 s at 03:10 UT. The QPP and their variation during the decay phase of this event are consistent with vertical kink mode oscillations of the newly formed magnetic loops following magnetic reconnection in the current sheet stretching between the CME and the flare. The period of kink-mode oscillations depends on the loop length divided by the Alfven speed, which itself depends on the plasma density and magnetic field strength. We can estimate the loop length from RHESSI and AIA images, and the density from the emission measure and source volume obtained from GOES and RHESSI observations, respectively. Thus, by setting the QPP time scale equal to the kink-mode period, we can get an estimate of the magnetic field strength in the source. Values were obtained in this way ranging from 500 G at an altitude of 24 Mm to 10 - 40 G at 60 Mm, in general agreement with the expected values at these altitudes. Density estimates of 2x1011 cm-3 at 24 Mm and 2x1010 cm-3 at 60 Mm were also obtained. Fast sausage mode oscillations cannot be ruled out as the mechanism producing the QPP.

Dissauer, Karin, M. Temmer, A.M. Veronig, K. Vanninathan, J. Magdalenic

Investigating projection effects in coronal dimming and associated EUV wave event (POSTER)

We investigate the high-speed (v > 1000 km/s) extreme-ultraviolet (EUV) wave associated with an X1.2 flare and coronal mass ejection (CME) from NOAA active region 11283 on 2011 September 6 (SOL2011-09-06T22:12). This EUV wave features peculiar on-disk signatures; in particular we observe an intermittent "disappearance" of the front for 120 s, followed by its reappearance and further propagation in SDO/AIA 171, 193, 211 data. In contrast a continuous evolution of the wave front is clearly visible in the 335 filter, sensitive to hotter plasma (T ~ 2.5 MK). The eruption was also accompanied by the appearance of localized coronal dimming regions.

We exploit the quadrature position of SDO and STEREO-A to study the EUV wave evolution, with respect to its kinematics and amplitude evolution and reconstruct the SDO line-of-sight (LOS) direction of the identified coronal dimming regions in STEREO-A. We show that the observed intensities of the dimming regions in SDO/AIA depend on the structures that are lying along their LOS and are the combination of their individual intensities, e.g. the expanding CME body, the enhanced EUV wave and CME front. In this context, we conclude that the intermittent disappearance of the EUV wave in the SDO/AIA 171,193, 211 filters, which are channels sensitive to plasma with temperatures below ~ 2 MK, is also caused by such LOS integration effects. These observations clearly demonstrate that we need multi-point and multi-wavelength image data to correctly interpret coronal features.

Hayes Laura A., Peter T. Gallagher, Brian R. Dennis, Jack Ireland, Andrew Inglis

Soft X-ray Quasi-Periodic Pulsations in Solar Flares

Quasi-periodic pulsations (QPP) are often observed in the emission from solar flares. These pulsations are typically identified during the impulsive regime in hard X-ray and radio observations from instruments such as RHESSI and Nobeyama. Recently, extensive fine structure QPP have been observed in the GOES/XRS lightcurves with pulsations persisting late into the decay phase in some cases. The observed thermal soft X-ray pulsations can give us a better insight into the nature and origin of the QPP phenomena and can provide a wealth of diagnostic information about the surrounding plasma conditions and heating processes. Here, we present a mulit-instrument investigation of QPP observed in a sample of near limb flares, paying particular attention to the M7.7 flare of 19-July-2012. Focussing on the pulsations observed with GOES/XRS, we relate timescale of these long duration QPP to the Alfvén speed and length scales using spatially resolved observations of RHESSI and SDO/AIA.

Hernandez-Perez, Aaron, J. K. Thalmann, A. M. Veronig, Y. Su

A quadrupolar ribbon flare studied with SDO and RHESSI

A study of the confined M2.1 flare that occurred on 29 January 2015 in AR 12268 has been performed. Observations carried out by analysis of space-based data from the Atmospheric Imaging Assembly (AIA) on board of the Solar Dynamics Observatory (SDO), reveal a quadrupolar ribbon structure in which two primary ribbons are formed followed by the formation of two weaker secondary ribbons. The secondary flare is initiated by plasma travelling along loop structures connecting the main flare site to the secondary flare site. The main flare ribbons are co-spatial with RHESSI hard X-ray sources, whereas no enhanced X-ray emission is detected at the remote secondary flare site. In addition, magnetic reconnection rates and reconnection fluxes are derived and compared to the temporal profile of the hard X-rays measured by RHESSI, which provides an estimate for the flare energy released into high-energy electrons.

Hinterreiter, J., J. K. Thalmann, A. M. Veronig, J. Tschernitz, W. Pötzi

Local reconnection rates of confined and eruptive Hα two-ribbon flares

We present a statistical study of the ribbon separation in Hα two-ribbon flares. The data set consists of 50 confined (62%) and eruptive (38%) flares that occurred in the time range June 2000 to June 2015. The selected flares show a good coverage over the Hα importance and GOES classes, with emphasis to include also powerful confined and weak eruptive flares, and occurred near the center of the solar disk. Hα filtergrams from Kanzelhöhe Observatory for Solar and Environmental Research (KSO) as well as MDI/SOHO and HMI/SDO magnetograms are used to derive the ribbon separation, the ribbon speed and the local reconnection rate. Forbes and Lin (2000) related the magnetic reconnection in the corona to observed signatures of solar flares. Assuming flux conversation, the local reconnection rate (electric field strength) can be estimated using the flare ribbon velocity perpendicular to the polarity inversion line (PIL) together with the line-of-sight (LOS) photospheric magnetic field: $E_C = v \times B_{LOS}$. We find that about 30% of eruptive flares reveal a ribbon separation of >30 Mm, whereas the ribbon separation of confined flares is mostly smaller than 10 Mm (in 75% of the cases). In addition, eruptive flares tend to have higher ribbon velocities than confined flares. Only one confined flare has a maximum electric field strength > 20 V/cm. For the most powerful eruptive flares on October 28, 2003 (X17.2/4B) and October 29, 2003 (X10.0/2B) we obtain the highest electric fields strengths of roughly 65 V/cm.

Holman, Gordon, Karin Muglach

Why X-ray Observations Outside Active Regions Will Advance Our Understanding of SEEs

Until recently, RHESSI X-ray observations have been of flare emission from active regions. These observations have substantially advanced our understanding of the evolution of flares and, more specifically, solar eruptive events (SEEs). The eruption of a quiescent filament, which can be much longer than an active region filament, is a solar eruptive event that does not originate from an active region. X-ray emission observed by RHESSI was recently found to be directly associated with the 2013 September 29 eruption of a quiescent filament (Holman & Foord 2015). A GOES X-ray flare began about 40 min after the beginning of the eruption. The RHESSI emission was found to be a compact thermal source above the western ribbon of the event. A compact dipolar structure with high magnetic field strength was located near the RHESSI X-ray source. Magnetic reconnection between the field of this dipole and the adjacent portion of the magnetic arcade below the erupting filament was deduced to be responsible for the presence of the X-ray emission. It could not be determined whether the gradually emerging dipolar field triggered the eruption.

About 40 eruptions of quiescent filaments associated with RHESSI X-ray emission have now been identified. The RHESSI sources locate the hottest plasma and, presumably, locations of rapid energy release in these slowly evolving events. They display most of the features of active region events. Several of these quiet-sun filament eruptions will be discussed.

Ishikawa, Shin-Nosuke, Sam Krucker, Lindsay Glesener, Steven Christe, Juan Camilo Buitrago-Casas, Noriyuki Narukage

Active region temperature diagnostics with FOXSI-2 and Hinode/XRT

Differential emission measures (DEMs) in solar active regions are important fundamental quantities to understand the physical state and discuss the formation of active regions, and they are estimated by soft X-ray (SXR) and extreme ultraviolet (EUV) observations so far. However, we have shown that EUV and SXR observations have large uncertainties in measuring high-temperature (>10 MK) plasma in a non-flaring active region, while hard X-ray (HXR) observation is extremely sensitive to it (Ishikawa et al. 2014, PASJ). HXR imaging observations during non-flaring time are rarely, if ever, achieved with non-focusing imaging instruments, and higher sensitivity is required for new instruments. On December 11, 2014 the second flight of the Focusing Optics X-ray Solar Imager sounding rocket (FOXSI-2), which has high sensitivity using HXR focusing optics and semiconductor imaging spectroscopic detectors, was done and multiple active regions were successfully imaged. We requested Hinode to perform a co-observation with FOXSI-2 before, during, and after the flight.

The X-ray telescope (XRT) did multi-filter observations to investigate the temperature structure in active regions. With the combination of FOXSI-2 with the highest-ever sensitivity for >10 MK plasma and Hinode/XRT with good sensitivity for <10 MK, a precise DEM with a wide temperature range can be estimated for the first time. We will report results from the combined DEM analysis with FOXSI-2 and Hinode/XRT.

Joshi, Bhuwan, Upendra Kushwaha, Astrid M. Veronig, and Yong-Jae Moon

Large-scale contraction of coronal loops and subsequent confined flux rope eruption observed during the evolutionary phases of an M-class flare

We present a detailed multi-wavelength study of the M6.2 flare which was associated with a confined eruption of a prominence using TRACE, RHESSI, and NoRH observations. The pre-flare phase of this event is characterized by spectacular large-scale contraction of overlying extreme ultraviolet (EUV) coronal loops during which the loop system was subjected to an altitude decrease of ∼20 Mm (40% of the initial height) for an extended span of ∼30 min. This contraction phase is accompanied by sequential EUV brightenings associated with hard X-ray (HXR) (up to 25 keV) and microwave (MW) sources from low-lying loops in the core of the flaring region which together with X-ray spectra indicate strong localized heating in the source region before the filament activation and associated M-class flare. With the onset of the impulsive phase of the M6.2 flare, we detect HXR and MW sources that exhibit intricate temporal and spatial evolution in relation with the fast rise of the prominence. Following the flare maximum, the filament eruption slowed down and subsequently confined within the large overlying active region loops; the event did not lead to a coronal mass ejection (CME). During the confinement process of the erupting prominence, we detect MW emission from the extended coronal region with multiple emission centroids which likely represent emission from hot blobs of plasma formed after the collapse of the expanding flux rope and entailing prominence material. RHESSI observations reveal high plasma temperature (∼30 MK) and substantial non-thermal characteristics with electron spectral index (δ∼5) during the impulsive phase of the flare. The time-evolution of thermal energy exhibits a good correspondence with the variations in cumulative non-thermal energy which suggest that the energy of accelerated particles efficiently converted to hot flare plasma implying an effective validation of the Neupert effect.

Kawate, Tomoko

Non-thermal electron diagnostics in the corona in various wavelength range

Observations of the heating/acceleration processes around the reconnection site are crucial to examine the acceleration mechanisms in solar flares. The major ways to observe the non-thermal electron distribution in the corona are microwave and hard X-rays that are emitted by trapped electrons and thick/thin-target bremsstrahlung, respectively. However, imaging observations of these wavelengths are mainly by the Fourier imaging method and the spatial resolution is not high in most case.

Soft X-ray and EUV lines emitted from highly ionized ions also have sensitivity to several-keV electrons and potentially can detect non-Maxwellian distributions. Especially EUV lines have been observed with relatively high spatial resolutions by focusing optics. However, any electron energy of ~keV can affect these emissions and difficult to derive the electron distribution only by observations especially under non-equilibrium conditions.

To examine detectability of non-thermal electron distribution by these different emissions, we calculate non-thermal electron distributions by 1.5D non-stationary Fokker-Planck equation numerically, and examine emissivities of microwave, hard X-ray, soft X-ray line, and EUV line emissions in space and time. In this presentation, we show our results of the emissivities in multi-wavelengths, and compare how significantly we may observe the electron energy distribution.

Kotrč, Pavel, M. Zapior, P. Heinzel

A new concept of Balmer continuum flux measurement in solar flares

Increase in the Balmer continuum radiation during solar flares was predicted by various authors, but has never been firmly confirmed observationally using ground-based slit spectrographs. We developed a new post-focal instrument, the image selector. The spectral flux including the Balmer continuum in the spectral range 350 - 440 nm can be measured from the whole flaring area, in analogy to successful detections of flaring dMe stars. The system was put into operation at the horizontal solar telescope HSFA2 of the Ondřejov Observatory recently. We measure the total flux by a fast spectrometer from a limited but well-defined region on the solar disk. Using a system of changeable diaphragms a precise selection of observed area is possible. Thus, the disturbing contribution of a bright solar disk can be eliminated as much as possible. Our analysis of the data proves that the described device is sufficiently sensitive to detect variations in the Balmer continuum during solar flares. The angular resolution of the telescope is not crucial for this device. The spectral resolution of the used Ocean Optics spectrometer is 0.35 Angström. It is sufficient to resolve even broader spectral lines in that region like the CaII H & K as well as higher Balmer series ones. Dynamic spectra of one solar flare are presented.

Kuhar, Matej

Detection of the EUV-late phase in X-rays with NuSTAR

We present the NuSTAR observations of the highly occulted (~300 arsecs) post-flare loops one day after the flare. The observations were performed on December 11th 2014, in coordination with SDO/AIA and FOXSI-2. The time evolution of the emission in different AIA channels reveals characteristics of the EUV-late phase event, with NuSTAR observations being the first time that this phenomenon has been observed in X-rays. The NuSTAR spectrum is well represented by an isothermal source of temperature in the range 3.8-4.6 MK and emission measure 0.3-1.7 x 10^46 cm^-3. The above results are consistent with the observed flux level in the Fe XVIII map derived from AIA channels. The flare energetics of the long lasting EUV and X-ray emission are also discussed.

Milligan, Ryan

A method to search for solar flares jointly observed by RHESSI and other instruments

Our current fleet of space-based solar observatories offer us a wealth of opportunities to study solar flares over a range of wavelengths, and the greatest advances in our understanding of flare physics often come from coordinated observations between different instruments. However, despite considerable effort to try and coordinate this armada of instruments over the years (e.g. through the Max Millennium Program of Solar Flare Research), there are frustratingly few solar flares that have been well and truly observed by most or all instruments simultaneously. This is due to a range of factors such as instruments having a limited field of view, satellites in low-Earth orbit going into eclipse, and observing schedules being uploaded days in advance. In this presentation I shall describe a new technique to retrospectively search archival databases for flares jointly observed by RHESSI, SDO/EVE (MEGS-A and MEGS-B), Hinode/(EIS+SOT+XRT), and IRIS. I shall also present a summary of how many flares have been observed by different configurations of these instruments.

Motorina G.G., E.P. Kontar

Temporal evolution of differential emission measure and electron distribution function in solar flares based on joint RHESSI and SDO observations

Diagnostics of coronal flare plasma is typically carried out by means of studying of extreme ultraviolet radiation, while information about the non-thermal plasma component can be obtained from X-ray data. Combination of EUV and X-ray observations is important for inferring plasma parameters over a wide energy range. In this work we combine SDO/AIA (EUV) and RHESSI (X-ray) observations of one near limb flare to determine the differential emission measure (DEM), the mean electron flux spectrum, and plasma parameters (emission measure, temperature, plasma density), where RHESSI is responsible for temperatures above ~10 MK, while AIA places restrictions on lower temperatures. Of special interest is the electron distribution function, which can evolve from a nearly Maxwellian to a distribution with a more complex structure during a solar flare. The exact form of this distribution for low-energies is still poorly understood;

therefore, a detailed investigation is required. Thus, the analysis of temporal evolution of DEM and the mean electron flux spectrum is considered. Assuming that there are two components, which correspond to cold background plasma along the line of sight and hot flaring plasma, the combination of two DEM functions was taken. The results show the detailed evolution of plasma from the early rise to decay in the flare.

Su, Yang, Astrid Veronig, Iain Hannah, et al.

Improved DEM calculation and its applications to flare studies

The Differential Emission Measure (DEM) has been a useful tool in understanding plasma distribution and their temperatures in solar atmosphere. A widely used method to recover DEM from SDO/AIA data is the regularized inversion method developed by Hannah & Kontar 2012. However, in some cases, the method fails to recover reliable result, especially in high temperature range above log T = 6.8. Here we show a simple way to improve the DEM obtained from the inversion method. We will also show some important applications of the more accurate DEMs in studies of plasma heating and RHESSI X-ray sources in solar corona.

Temmer, Manuela

Characteristics of coronal mass ejections and their relation to solar flares (POSTER)

Coronal mass ejections (CMEs) are transient phenomena that abruptly disrupt the continuous outflow of the solar wind. CMEs are defined as huge clouds of magnetized plasma, that are expelled into interplanetary space with speeds of the order of a few hundred to a few thousand km/s. Earth-interacting CMEs having high impact speeds and a strong as well as a long-duration southward magnetic field component, may cause severe geomagnetic effects. The energy release of the CME associated flare, the magnetic field structure of the active region connected to the CME, as well as the initiation height of the CME, for most cases are closely related to the CME speed, size, and mass as measured further out from the Sun. These initial CME parameters mostly determine the propagation behavior of a CME in interplanetary space, and are changed as the CME interacts with the ambient solar medium. In this respect, we present statistical results on CME energetics and their relation to solar flares observed in hard and soft X-rays, as well as case studies on the propagation behavior of CMEs in interplanetary space (propelling versus drag forces) and their impact at the Earth's atmosphere. The results reflect the status of our current understanding of the physical processes of CME evolution from Sun to Earth.

Thalmann, Julia Katharina, A. M. Veronig, Y. Su

Temporal and spatial relationship of flare signatures and the coronal magnetic field

We investigate the plasma and magnetic environment around a CME-associated GOES M1.4 flare (SOL2011-08-02T06:19). We compare coronal emission at EUV and X-ray wavelengths, using SDO AIA and RHESSI images, in order to identify the relative timing and location of reconnection-related sources. We trace flare pixels at UV wavelengths, in order to pin down the intersection of previously reconnected flaring loops with the low solar atmosphere. We aid our analysis with 3D nonlinear force-free magnetic field models, employed from SDO HMI photospheric vector magnetic field maps. With this procedure, we are able to analyze the quasi-static time evolution of the flare/CME-associated coronal model magnetic field. We find that the flare-related SXR flux defines two distinct flare phases. During a first phase, the time evolution of SXR and bright EUV signatures originated from close to the active region core, which hosted a highly twisted/sheared field configuration that was involved in the observed mass ejection. Using our magnetic field models, we provide evidence for an implosion of parts of the model magnetic field during this first flare phase in and around the active region core. During a following second phase, a different part of the active region was involved in the flare process too and the only non-thermal emission signature was observed, in the form of two clearly discernible HXR footpoints. From the model magnetic field rooted in flare pixels we estimate the elevation speed of the current sheet's lower tip, during the on-disk flare, as a few kilometers per second. Comparison to post-flare loops observed above the solar limb seen in STEREO EUVI images, supports this velocity estimate.

Veronig, Astrid M., Jürgen Hinterreiter, Johannes Tschernitz, Julia K. Thalmann

Magnetic reconnection rates in eruptive and confined solar flares

We present a statistical study of magnetic reconnection rates and local reconnection electric fields to study the energy release process in eruptive and confined solar flares. The magnetic reconnection quantities are derived from the flare ribbon evolution studied in Halpha filtergrams from Kanzelhöhe Observatory and co-registered photospheric LOS magnetic field maps from HMI/SDO. Our data set covers 50 flares (19 eruptive, 31 confined) distributed over GOES classes B to >X10. We find a distinct correlation between the total magnetic flux and the peak electric field with the GOES peak flux for both eruptive and confined events. For selected events, we compare the magnetic reconnection rates derived from ground-based Halpha data and seeing-free space-based AIA data with the evolution of the flare energy in accelerated electrons as measured in RHESSI hard X-rays.

Warmuth, Alexander, Gottfried Mann

Flare energetics deduced from X-ray observations: considering some caveats

Recently, we have constrained energy release and transport processes in solar flares by means of a comprehensive characterization of the physical parameters of both the thermal plasma and the accelerated nonthermal electrons, using X-ray observations from RHESSI and GOES. Here, we discuss several issues - or caveats - that influence both thermal and nonthermal energetics. These issues include filling factors, non-isothermality, low-energy cutoff of energetic electrons, and energy input by ions. As these factors can have major effects on the derived flare energetics, they have to be properly assessed before definite conclusions on energy partition and transport can be made.

Working Group 4

Bain, H. M., J. C. Martinez-Oliveros, J. C. Buitrago-Casas

Energy deposition by flare accelerated particles in seismically active solar flares

Solar flares can excite seismic waves that propagate into the solar interior by providing an external impulse. Several mechanisms have been proposed to explain these transient events i.e. “sunquakes” observed in the impulsive phase of solar flares. These include: shock waves, excited as a result of thick-target heating of the chromosphere; photospheric heating or “backwarming”; transfer of energy via the Lorentz force associated with the restructuring of the coronal magnetic field; and energy deposition in the chromosphere by flare accelerated particles. Regardless of the mechanism of generation, it is clear that not all flares induce an acoustic response in the interior of the Sun. Based on the flare list made by Buitrago-Casas et al. (2015) we present a detailed study of RHESSI X-ray observations of X and M class flares with and without a seismic signatures to investigate the energy deposition by energetic particles. This is part of a larger ongoing investigation of the comparative energy deposited by the various proposed mechanisms of seismic excitation and the acoustic energy deduced using holographic techniques.

Carley, Eoin, Nicole Vilmer

Radio counterparts of a behind the limb flare detected by Fermi-LAT

On 2014 September 01, Fermi-LAT detected a bright solar flare occuring from an active region located 36° behind the limb (Pesce-Rollins et al., 2015). We shall report here on the radio observations from Nançay (spectra from ORFEEs and DAM and images from the Nançay Radioheliograh). At the time of the start of the flare, the NRH observations provided evidence for the presence of unusual large radio sources detected from 445 MHz to 150 MHz located above the eruptive loops observed with SDO/AIA. These observations when combined with data from the RSTN network allowed for a rare diagnostic of the magnetic field of the CME in the low corona.

Li Y.P., W. Q. Gan, Y. Su, B.B. Wu, L.M. Song et al.

Hard X-ray Polarization: revisit RHESSI data and prospect future observations

We check the polarization capability (20-100 KeV) based on the original design of RHESSI. A function representing different components of counts is fitted, from which the modulation of the Be-scattered flux could be extracted. The results show that for most cases the Be-scattered flux seems to arise from polarization effects. However, we prove that this look-like phenomenon is untrue in physics. It is almost impossible to get reliable polarization information from the original design of Be-scatter. POLAR is a compact space-borne gamma-ray burst polarimeter, which will be launched in October 2016 on board the Chinese space laboratory Tiangong-2 (TG-2). The capability of POLAR in observing solar flares is discussed.

Glesener, Lindsay, G. Fleishman

Accelerated electrons in a hard X-ray / radio jet

While observations suggest that the vast majority of flare-accelerated electrons travel downwards from their coronal acceleration sites and thermalize in the lower atmosphere, the relatively fewer energetic electrons that travel upward carry a particular importance. Those electrons that have access to “open” field (i.e. field open to interplanetary space) serve as transient, energetic inputs to the heliosphere and are frequently measured in-situ. An especially convenient phenomenon in which to study these electrons is that of coronal jets arising via interchange reconnection with overlying open field; these jets offer a clear “escape route” for electrons to reach interplanetary space. However, hard X-ray (HXR) measurements of accelerated electrons on open field are customarily difficult because of the low densities of the corona and correspondingly low bremsstrahlung yields, and detection is especially difficult in the presence of bright HXR footpoints.

In this work, we combine data from RHESSI, TRACE, and OVSA along with modeling of emission to investigate flare-accelerated electrons in a coronal jet. HXR and microwave data from RHESSI and OVSA, respectively, give complementary insight into electron spectra and locations, including the presence of accelerated electrons in the jet itself. High-time-resolution HXR spectra from the Konus-Wind instrument are used to examine acceleration timescales. We model the energetic electron distributions in the GX Simulator framework using RHESSI and OVSA data as constraints. It is extremely important that the model built using actual magnetic field data yields an excellent match of the simulated and observed radio image and spectrum, thus validating and quantifying the nonthermal electron distribution on the open field flux tube. The result is a modeled distribution, informed and constrained by measurements, of accelerated electrons as they escape the Sun. As far as we are aware, this is the first case in which the microwave gyrosynchrotron emission has been detected from an open, rather than closed, magnetic configuration, and is the most direct constraint to date on the accelerated electron population within a solar jet.

Lesovoi, S.V., A.T. Altyntsev, E.F. Ivanov, V.V. Grechnev, A.V. Gubin, L.K. Kashapova, A.A. Kochanov, A.A. Kuznetsov, N.S. Meshalkina, D.A. Zhdanov

The first results of the flare observations by the Siberian Multiwave Radioheliograph

We present the first results of the flare study obtained with the upgraded Siberian Radio Heliograph supported by spectral observations of the Badary Broadband Microwave Spectropolarimeter within the 4-8 GHz frequency range. The solar flares occurred in March-April 2016 and they were manifestation of the different ranges of the flare activity. The qualitative and quantitative analysis of the events was carried out using the observations the both of the microwave and the X-ray ranges. New possibilities of the heliograph allow getting images with high temporal resolution and carried out localization of the structures observed in microwave spectrum. The results and new possibilities of study are discussed.

Masuda, Satoshi and the ICCON members

Continued Operation of Nobeyama Radioheliograph and height distribution of accelerated electrons in a solar flare

Nobeyama Radioheliograph (NoRH) is a radio interferometer specially designed to observe the full disk of the Sun at 17 and 34 GHz. The spatial resolution is about 10 arcseconds and 5 arcseconds in 17 GHz and 34 GHz, respectively. The time resolution of NoRH is typically 1 second and 0.1 second for the event mode. The National Astronomical Observatory of Japan (NAOJ) has successfully operated NoRH during these two decades. Howevere, from April 2015, Nagoya University started the operation of NoRH as a representative of the International Consortium for the Continued Operation of Nobeyama Raidoheliograph (ICCON; http://hinode.stelab.nagoya-u.ac.jp/ICCON/). ICCON has operated it more than one year with voluntary contributions of world-wide users.

NoRH is a powerful tool to investigate the acceleration/transport/loss processes of high-energy electrons in solar flares. An X-class flare occurred behind the east limb on 13 May 2013. This flare was simultaneously observed with NoRH and RHESSI (The Reuven Ramaty High Energy Solar Spectroscopic Imager). It is a good chance to investigate the height distribution of high-energy electrons in the solar corona. The energy of electrons emitting microwaves is very high (~ MeV), and the mean-energy emitting 34 GHz is higher than that for 17 GHz. Hard X-rays are emitted by relatively lower-energy (~ 100 keV) electrons. So this dataset covers a wide energy range of accelerated electrons. In the framework of the standard flare model based on magnetic reconnection, Minoshima et al. (2011) showed that the height distribution of accelerated/heated electrons depends on their energy. Comparing the observational results and this model, we discuss the electron acceleration/ transport/ loss processes.

Motorina G.G., Y.T. Tsap, A.S. Morgachev, V.V. Smirnova, V.S. Ryzhov, V.G. Nagnibeda, S.A. Kuznetsov

Millimeter thermal emission and soft X-ray observations of solar flares (POSTER)

Musset, Sophie, Eduard Kontar, Nicole Vilmer

Diffusive transport of energetic electrons in the 2004, May 21 solar flare

Solar flares are associated with efficient particle acceleration, in particular with the production of energetic electrons which are diagnosed through the X-ray and radio emissions that they produce when interacting with the solar atmosphere. Particle transport from the acceleration sites to the radiation sites remains of the challenging topic in the field of high energy solar physics and has an important impact on the interpretation of the particle emissions in the context of acceleration models.

In order to address the transport of flare associated energetic electrons in the low corona, we use imaging spectroscopic observations from RHESSI of the 2004 May 21 solar flare which presents together with the usually observed HXR footpoints a well observed coronal non-thermal X-ray source. The number of X-ray emitting energetic electrons in the coronal source is compared to the number of electrons needed to produce the hard X-ray emission in the foot-points and is found twice as large. Such an excess of the number of electrons in the coronal source cannot be explained in the context of the standard model of X-ray emissions in which the dominant electron transport is collisional. In the present flare, an additional process is needed to explain how energetic electrons can be efficiently trapped in the corona.

In the hypothesis of turbulent pitch-angle scattering of hard X-ray producing energetic electrons (Kontar et al, 2014), diffusive transport can indeed lead to a confinement of energetic electrons in the coronal source. Based on this assumption, we estimated for the present event the mean-free path of energetic electrons and found a value of 10^8 – 10^9 meters, much smaller than the size of the observed flaring loop itself. This implies that a diffusive transport of energetic electrons is dominant in this flare which is in good agreement with the results of a previous study based on the gyrosynchrotron emissions from the energetic electrons (Kuznetsov & Kontar, 2015).

Narukage, N., M. Shimojo, T. Sakao

Evidence of Electron Acceleration around the Reconnection X-point in a Solar Flare

Particle acceleration is one of the most significant features that are ubiquitous among space and cosmic plasmas. It is most prominent during flares in the case of the Sun, with which huge amounts of electromagnetic radiation and high-energy particles are expelled into the interplanetary space through acceleration of plasma particles in the corona. Though it has been well understood that energies of flares are supplied by the mechanism called magnetic reconnection based on the observations in X-rays and EUV with space telescopes, where and how in the flaring magnetic field plasmas are accelerated has remained unknown due to the low plasma density in the flaring corona. We here report the first observational identification of the energetic non-thermal electrons around the point of the ongoing magnetic reconnection (X-point), with the location of the X-point identified by soft X-ray imagery and the localized presence of non-thermal electrons identified from imaging-spectroscopic data at two microwave frequencies. Considering the existence of the reconnection outflows that carries both plasma particles and magnetic fields out from the X-point, our identified non-thermal microwave emissions around the X-point indicate that the electrons are accelerated around the reconnection X-point.

Nita, Gelu M., Gregory D. Fleishman, Eduard P. Kontar, Dale E. Gary

Narrowband Gyrosynchrotron Bursts: Probing Electron Acceleration in Solar Flares

We present the results of a statistical analysis performed on a special class of narrowband microwave bursts. These bursts share a common set of characteristics that makes them ideal candidates for direct probing of the acceleration region. These events do not show a significant trapped component and, at the same time, show evidence of the radio source uniformity, which greatly simplifies data analysis. Roughly half of the 21 radio bursts selected for this study have RHESSI data, which allows for detailed, joint diagnostics of the source parameters and their evolution. Based on the analysis of radio-to-X-ray spatial relationships, timing, and spectral fits, we conclude that the microwave emission in these narrowband bursts originates directly from the acceleration regions. These acceleration regions have relatively strong magnetic field, high density, and low temperature. In contrast, the thermal X-ray emission comes from a distinct loop with smaller magnetic field, lower density, but higher temperature. Therefore, these flares occurred likely due to interaction between two (or more) magnetic loops.

Saint-Hilaire, Pascal

CURIE

CURIE, the CUbesat Radio Interferometry Experiment, is a proposed mission to do radio interferometry in space, below the ionospheric cutoff frequency, for the first time. It will investigate primarily CMEs and interplanetary electron beams, but also other heliospherical, ionospheric, magnetospheric, and even astrophysical problems. I will also discuss the instrumental requirements to address these.

White, Stephen

Nobeyama observations in conjunction with RHESSI and FERMI

Working Group 5

Dickson, Ewan, Astrid Veronig, Richard Schwartz, László Etesi, Gordon Hurford, D. Shaun Bloomfield, Nicky Hochmuth, Aidan O'Flannagain, Mel Byrne, Sophie Musset, Samuel Krucker

STIX Flight Software Simulation

The Spectrometer/Telescope for Imaging X-rays (STIX) is the Hard X-ray instrument on Solar Orbiter, an ESA satellite, which will study the physics of the Sun and the inner heliosphere, reaching as close as 0.28 AU. In Graz we are involved in the development of the software for the analysis of STIX data. Simulation of STIX observations is performed both to test the developed software and to understand the instrument performance. This project includes a detailed flight software simulator which reproduces the processes of STIX from detection to telemetry. As STIX data is processed on board, the operation of this software is vitally important. Modules in the flight software simulator include flare detection and coarse flare location – a real time estimate of the position of the flare. A detailed study of the robustness, accuracy and sensitivity of these routines has been performed.

Felix, Simon

Image Reconstruction from Visibilities with Compressed Sensing

Compressed Sensing (CS) is a new approach to reconstruct signals by finding solutions to an underdetermined linear system. We will present the method and a publicly available prototype to reconstruct images from RHESSI and STIX visibilities. We will discuss preliminary results, the potential and limitations of the method, and future directions.

Compressed Sensing is being used successfully in other domains such as medical imaging for MRI/CT, and in astronomy for radio interferometry. The method could be considered specifically in future sensor designs.

Hurford, Gordon

RHESSI imaging – past and future

Massone, Anna Maria, Richard Schwartz

Multi-scale CLEAN and Pixon: an answer to ‘what next in RHESSI imaging'

Multi-scale Clean and a fast implementation of Pixon are probably the most up-to-date imaging algorithms developed within the RHESSI community to model the source image as a collection of Gaussian sources of different sizes and parabolic profiles (pixons or basis functions). Therefore, both methods are essentially multi-scale whereby the main difference between the two approaches is in the fact that Pixon iteratively adjusts to optimize a statistic while CLEAN is unidirectional without any statistical optimization. In this talk we briefly summarize the rationale and the main differences behind the two algorithms and compare their performances on a set of selected events using the current implementations. Finally, we comment on possible future implementations and their computational effectiveness.

Piana, Michele, Federico Benvenuto, Anna Maria Massone

Computational methods for the optimization of spatial and temporal resolution in RHESSI imaging

The way RHESSI performs imaging is rather peculiar: it provides us with both a bunch of Fourier components of the incoming radiation and a set of time modulation profiles and asks us to reconstruct images with spatial and time resolution that, at these wavelengths and at least in principle, are still unprecedented. Now, the main question we should wonder at this stage of the RHESSI story is probably just the following one: did our imaging methods really succeed in approaching such limits in time and resolution power and, if so, with which degree of reliability? This talk would like to address such issue addressing the following two problems:

1) Using the count modulation profile nature of RHESSI data, is it possible to track information on position, size, number, and intensity of the emitting sources with a temporal resolution higher than a few seconds?

2) Using modern mathematical methods designed ad hoc for the analysis of Fourier data, is it possible to reconstruct details of the X-ray sources which are optimally resolved from a spatial viewpoint?

The ultimate aim of this talk is not to provide conclusive solutions to these problems but just to illustrate their main aspects and to show the main difficulties hidden in such topics, using both synthetic and experimental RHESSI observations and defining procedures for the statistical assessment of the reconstructions' reliability

Saint-Hilaire, Pascal

Harmonics

Schwartz, Richard

New Developments in RHESSI Imaging

The tools for RHESSI imaging have been in development since before 1998 and even after 16 years there a few new wrinkles and new requirements as the instrument shows its age. We will be introducing a Pixon algorithm even more enhanced for speed at no cost in precision, a multi-scale variant of the CLEAN procedure, and a true Cartesian basis for the image pixels that is freed from the annular sectors technique introduced in 2000. Another exciting development will be the utilization of visibilities with the heretofore non-visibility algorithms in the toolbox such as Pixons and CLEAN. (Hint: A set of grid visibilities can be expressed as a calibrated eventlist, but compressed by a factor of 12!). And to facilitate a more robust imaging environment we will have tools that report the suitability of the data from each sub collimator for any time in the mission within standard energy ranges. There has also been a fix to the livetime reporting that was problematic for time bins finer than 512 binary microseconds.

Vievering, Juliana

Analysis of Microflares from the Second Flight of the Focusing Optics X-ray Spectral Imager

Observations of the sun in hard x-rays can provide insight into many solar phenomena which are not currently well-understood, including the mechanisms behind particle acceleration in flares. Currently, RHESSI is the only solar-dedicated spacecraft observing in the hard x-ray regime. Though RHESSI has greatly added to our knowledge of flare particle acceleration, the method of rotation modulation collimators is limited in sensitivity and dynamic range. By instead using a direct imaging technique, the structure and evolution of even small flares and active regions can be investigated in greater depth. FOXSI (Focusing Optics X-ray Spectral Imager), a hard x-ray instrument flown on two sounding rocket campaigns, seeks to achieve these improved capabilities by using focusing optics for solar observations in the 4-20 keV range. During the second of the FOXSI flights, launched on December 11, 2014, two microflares were observed. Preliminary analysis of these two flares will be presented, including images of the emission region, light curves, and photon spectra. Through this analysis, we investigate the capabilities of FOXSI in enhancing our knowledge of smaller-scale solar events.

Working Group 6

Alaoui, Meriem, Gordon Holman

Coronal vs chromospheric heating through return currents during the 19 and 20 Jan 2005 solar flares

The high electron flux required to explain the bremsstrahlung X-ray emission observed from solar flares is expected to be accompanied by a neutralizing co-spatial return current. In addition to resupplying the acceleration region with electrons, this return current will both heat the coronal plasma and flatten the electron distribution at lower energies. This flattening in the electron distribution in turn flattens the X-ray spectrum. We have found that return-current collisional thick-target model (RCCTTM) of Holman (2012) provides an acceptable fit to X-ray spectra with strong breaks for 18 flares observed with the Ramaty High Energy Solar Spectroscopic Imager (RHESSI). This is a 1D model similar to the collisional thick-target model (CTTM) with two additional assumptions: (1) electrons lose some of their energy through return current losses along their path to the thick target, where they lose all their remaining energy through Coulomb collisions; (2) the non-thermal beam is streaming in a warm target, which means that electrons will be thermalized at a non-zero energy. We assume this energy to be equal to the analytical value derived by Kontar et al. 2015. We show that return-current heating in the corona is about an order of magnitude higher than the heating at the footpoints at times during the flare.

Brown, John C., Natasha L.S. Jeffrey

Albedo Echo Delay Effects on HXR Burst Light Curves

The photospheric albedo contribution to hard x-rays (HXR) from solar flares, first discussed in the 1970s, has been the subject of intensive study in the past decade, including its effects on the modeling of HXRB spectra, images and even polarization. Here we discuss its effects on HXRB light curves, and particular their energy dependence (dynamic spectra), which have received surprisingly scant attention to date. For a pulse of HXRs from a source at height h above the photosphere, the delay in the albedo contribution from the specular reflection point directly below it is to = 2h/c for the disk centre case. For a typical chromospheric HXR source height h ~ 1000 km to is only 6.7 ms, below noise-limited time resolution for detector sizes to date. However, the albedo echo duration t1 is >> to , since back-scattering extends out to horizon distance d (km) = (2hRsun)^0.5 ~ 37,000 x (h/1000 km) implying a mean pulse echo delays d/c ~

100 ms. Since the albedo fraction peaks around 25 keV photon energy and declines quite steeply thereafter, mean pulse delays should decline in the > 20 keV range.

We illustrate and quantify this effect using analytic approximations and detailed numerical simulations and argue that the energy dependent temporal convolution involved should be taken into account when analyzing HXRB light curves. In particular the energy-dependent HXRB data delays inferred by Aschwanden via cross-correlation studies, and their attribution to declining time of flight (~ 100ms along a 10,000 km loop) with increasing electron energy should be revisited allowing for the echo delay effect.

Browning, P.K., M Gordovskyy, E Kontar

Forward modelling of microwave and other observational signatures of confined flares in twisted loops

Reconnecting twisted coronal loops are a good alternative to the standard model for explaining some types of solar flares. Reconnection may be triggered by the onset of kink instability. This process is a good candidate for interpreting smaller flares observed in isolated coronal loops. Furthermore, twisted magnetic flux ropes play a key role in the "standard flare model". Therefore, it is important to be able to identify twisted magnetic fields in the flaring corona.

We present an overview of various observational features which can be obtained from coupled 3D-MHD and test-particle simulations in reconnecting twisted coronal loops. The temporal and spatial variations of both thermal (EUV and SXR) and non-thermal (HXR and microwave) emission are discussed, and also the properties of turbulent plasma motions which will cause non-thermal line-broadening; these can be used for observational detection of twisted loops. In particular, we discuss the use of the cross-loop circular polarisation gradient of gyrosynchrotron emission as a potential detection tool for twisted magnetic fields and its limitations for different field configurations and loop orientations.

Casadei, Diego

Stereo observations of coronal and footpoint sources with STIX and MiSolFA

STIX is the X-ray imaging spectrometer of the ESA/NASA Solar Orbiter mission, and will observe solar flares from year 2020. As the orbit is highly inclined and with perihelion at 0.3 AU, STIX will observe the Sun from a quite different point of view compared to RHESSI, covering with a similar angular resolution the range 4-150 keV. MiSolFA is a compact X-ray instrument to be flown on a 6-units cubesat in 2020, with the purpose of complementing STIX observations by providing cross-calibrated solar flare measurements from a different point of view. The "stereo" observations by these two instruments allow to get qualitatively new data, which will make it possible to achieve two main science goals: precise estimation of the directivity of X-ray emission as a function of the energy, and simultaneous spectroscopy of coronal and footpoint sources. As both STIX and MiSolFA adopt indirect imaging techniques, the second goal can be achieved by selecting beyond-the-limb flares, whose footpoints are occulted for one of the two instruments, while the other detector measures the footpoint emission. Accounting for the flare statistics and for differences in effective area and distance to Sun, an estimate of the number of observable events is performed, and the expected performance of this stereo configuration is estimated.

Effenberger, Frederic

Particle acceleration and escape from the solar flare loop top

The relation between different timescales of particles in the acceleration region of a solar flare is of critical importance in the analysis of their emission profiles, e.g. in hard X-rays and the characteristics of escaping solar energetic particles (SEPs) . The pitch-angle distribution of particles near the reconnection region at the loop top depends on the scattering properties due to the interaction of the particles with local turbulence. But also the large scale magnetic field can be of significance due to its focusing effect from field-line convergence towards the footpoints of the loop. The shape and evolution of such particle distributions in turn influences the general timescales of particle scattering, acceleration and escape in the loop region. We present results from a detailed model of particle transport and acceleration in a flaring loop based on a Fokker-Planck description and compare to radiation and SEP signatures observed by different space instruments. Commonly, at higher energies the bright footpoint emission from the flare loop prevents a detailed analysis of the weaker loop-top source due to the limited dynamic range. Thus, flares close to the solar limb, where the footpoints are occulted, are interesting events to study because they can reveal the loop-top emission. Results of a survey study of occulted flares observed with the Reuven Ramaty High-Energy Solar Spectroscopic Imager are discussed in the context of our flare modelling efforts.

Emslie, A. Gordon, N.H. Bian, E.P. Kontar

Suppression of parallel transport in turbulent magnetized plasmas and its impact on non-thermal and thermal aspects of solar flares

The transport of the energy contained in electrons, both thermal and suprathermal, in solar flares plays a key role in our understanding of many aspects of the flare phenomenon, from the spatial distribution of hard X-ray emission to global energetics. Motivated by recent *RHESSI* observations that point to the existence of a mechanism that confines electrons to the coronal parts of flare loops more effectively than Coulomb collisions, we here consider the impact of pitch-angle scattering off turbulent magnetic fluctuations on the parallel transport of electrons in flaring coronal loops. It is shown that the presence of such a scattering mechanism in addition to Coulomb collisional scattering can significantly reduce the parallel thermal and electrical conductivities relative to their collisional values. We provide illustrative expressions for the resulting thermoelectric coefficients that relate the thermal flux and electrical current density to the temperature gradient and the applied electric field. We then evaluate the effect of these modified transport coefficients on the flare coronal temperature that can be attained, on the post-impulsive-phase cooling of heated coronal plasma, and on the importance of the beam-neutralizing return current on both ambient heating and the energy loss rate of accelerated electrons. We also discuss the possible ways in which anomalous transport processes have an impact on the required overall energy associated with accelerated electrons in solar flares.

Heinzel, P., J. Kašparová, M. Varady

Evolution of hydrogen continua in solar flares

Using the RHD code Flarix, we model the time evolution of hydrogen recombination continua, accounting for the non-equilibrium hydrogen ionization-recombination which affects the shape of the continuum light-curves. In particular we focus on three observed continua: Lyman (SDO/EVE), Balmer (IRIS, GBO), and Paschen (SDO/HMI, Hinode/SOT). These continua are supposed to be formed in the flaring chromosphere by radiative recombination of hydrogen ions (protons) and they provide a useful diagnostics of the heating and non-thermal processes related to dissipation of the electron-beam fluxes. Balmer continuum is also proven to be an important chromospheric coolant during flares, exhibiting important energy losses which balance the beam heating.

Kašparová, J., M. Carlsson, M. Varady, P. Heinzel

Modelling of solar flare processes: comparison of two RHD codes Flarix and RADYN

This contribution will focus on comparison of two autonomous, methodologically different radiative hydrodynamics codes, Flarix and RADYN, and their use to model the solar flare processes. Radyn code was developed by M. Carlsson at the University of Oslo for chromospheric modelling and has been extended and extensively used for the flare modelling. Flarix code is being developed at the Astronomical Institute of CAS with the primary purpose of the flare processes modelling.

Both codes can compute the time evolution of a 1D flare loop heated by beam electrons propagating from the injection point in the corona down to the lower atmosphere. The codes are based on different numerical approximations. RADYN uses an adaptive spatial grid and implicit scheme to solve linearized equations, whereas Flarix has a fixed grid and is based on explicit and Crank-Nicholson algorithms. Optically thick radiative transitions are treated in non-LTE using accelerated lambda iterations in both codes.

The aim is to present the results of testing the codes for a simplified case of the electron beam heating, including the same physical processes and chemical composition of the initial atmosphere. We will assess the reliability of the codes and compare the time evolution of the atmospheric structure (e.g. temperature, density) and optically thick emission.

Kontar, Eduard P., N.L.S. Jeffrey, A.G. Emslie, N.H. Bian

Non-thermal Electron content in solar flares: Hot-Corona Cold Chromosphere Model

Extending previous studies of nonthermal electron transport in solar flares, which include the effects of collisional energy diffusion and thermalization of fast electrons, we present an analytic method to infer more accurate estimates of the accelerated electron spectrum in solar flares from observations of the hard X-ray spectrum. Unlike for the standard cold-target model, the spatial characteristics of the flaring region, especially the necessity to consider a finite volume of hot plasma in the source, need to be taken into account in order to correctly obtain the injected electron spectrum from the source-integrated electron flux spectrum (a quantity straightforwardly obtained from hard X-ray observations). We present the new model and show that the effect of electron thermalization can be significant enough to nullify the need to introduce an ad hoc low-energy cutoff to the injected electron spectrum in order to keep the injected power in non-thermal electrons at a reasonable value. Hot-Corona Cold Chromosphere Model uniquely provides the upper limit on the power and acceleration rate in solar flares.

Kupriyanova E., L. Kashapova, Z. Xu, H.A.S. Reid

About origin of quasi-periodicities during the circular ribbon flare

We present results of the multi-wavelength study quasi-periodic pulses observed during the two solar flare with circular ribbons. Such type of events imply a fan-spine magnetic topology of the flaring region. The results of the previous study in H-alpha (Xu et al. 2016) revealed uniform and continuous self-rotation of the magnetic fan-spine and formation of twisted flux rope erupted during the flare. We found a series of pulses in hard X-rays and microwaves and H-alpha line which can be interpreted as quasi-periodic pulses. The characteristic time scales of the pulses are 1-3 minutes. The magnetic topology of the flare region assumes a role of the MHD oscillations as trigger and modulation of the observing pulses. We tested periodicity of the pulses in different spectral ranges (from chromosphere emission to radio range) and analysed its correlation on different levels of the solar atmosphere. We also checked possible connection of the flare with emission of the remote source. The diagnostic application of the obtained results is discussed.

Mann Gottfried, H. Önel, A. Warmuth

Electron acceleration at the magnetic reconnection region in the solar corona

Solar flares are considered as the manifestation of magnetic reconnection in the corona. Basically, a flare appears as a local, sudden enhancement of electromagnetic emission on the disc of the Sun. This electromagnetic radiation covers a broad spectrum from the radio up to the gamma-ray range indicating the generation of energetic electrons during flares. RHESSI measurements revealed that 10^36 electrons are accelerated up to energies beyond 30 keV within a second during large flares. According to the standard flare model, the magnetic reconnection happens in the solar corona. There, inflowing magnetic field energy is converted into heating of plasma and generation of highly energetic particles as electrons. We will discuss the heating of electrons at the slow- and fast mode shocks and their subsequent acceleration due to multiple reflections at the fast mode (termination) shocks in order to explain the generation of energetic electrons needed for the hard X-ray radiation as measured with RHESSI during flares.

Melnikov, V. F., Yu. E. Charikov, I. V. Kudryavtsev

Directivity and Polarization Dynamics of Hard X-Ray and Gamma-Ray Emission of a Flare Loop

The peculiarities of the directivity and polarization dynamics of hard X-rays and gamma-rays from different regions of a flare loop were studied based on numerical modeling of the distribution dynamics of energetic electrons in the loop upon their non-stationary but fairly long-lasting injection at the top of the magnetic loop. The modeling results suggest that the degree of directivity and polarization and the variation of these parameters in time depend on the position within the loop and vary fundamentally between cases of isotropic and anisotropic (longitudinal) injection of electrons. The revealed peculiarities of the directivity and polarization dynamics may be used in X-ray and gamma-ray diagnostics of the type of pitch-angle distribution that characterizes the electrons accelerated in a certain specific observed flare.

Oka, Mitsuo

Particle Acceleration in Solar Flares and Terrestrial Substorms: Constraints on Theories

Particles are accelerated to very high, non-thermal energies during explosive energy-release phenomena such as solar flares and terrestrial substorms. While it has been established that magnetic reconnection plays a key role in these phenomena, the precise mechanism of particle acceleration is still being discussed from both theoretical and observational points of view. In order to constrain theories, it is important to characterize the observed forms of energy spectra using quantities such as density, temperature and power-law index. Here we show, based on a compilation of previously reported observations, that the power-law index d may have a lower-limit at d ~ 4 in both solar flares and terrestrial substorms (i.e., d >~ 4), where d is defined in the flux density (differential flux) distribution. This is in stark contrast to the case of particle acceleration at shocks (such as interplanetary shocks and the terrestrial bow shock) whose power-law index often exceeds the limit (i.e., d <~ 4). These results suggest the followings: (1) there may be a common but not-yet-identified physics in these entirely different environment, i.e. the corona and the magnetotail, and (2) explosive energy-release phenomena such as solar flares and terrestrial substorms are not as efficient as shocks in terms of converting upstream energies to non-thermal particle energies, at least in the heliospheric, non-relativistic environment of plasmas.

Reep, J.W., J.C. Brown

Non-thermal Thick Target Recombination in Flares

Brown & Mallik 2008 and subsequent papers presented expressions for non-thermal recombination (NTR) in the collisionally thin- and thick-target regimes, claiming that the process could account for a substantial part of hard X-ray continuum in solar flares usually attributed entirely to thermal and non-thermal bremsstrahlung (NTB). However, we have found the thick-target expression to become unphysical for low cut-offs in the injected electron energy spectrum. We trace this to an error in the derivation, derive a corrected version which is real-valued and continuous for all photon energies and cut-offs, and show that, for thick targets, Brown et al. overestimated NTR emission at small photon energies. The regime of small cut-offs and large spectral indices involve large (reducing) correction factors, and in those parameter regimes NTR/NTB can still be of order unity. Because NTR involves discontinuous jumps in the hard

X-ray spectrum, it is important to include it in spectral fitting and inversion, even when small. We derive simple scaling laws to quickly estimate the contribution of NTR to the non-thermal spectrum.

Varady, M., J. Kašparová, Z. Moravec

Hybrid simulations of chromospheric HXR flare sources

Recent measurements of vertical extents and positions of the chromospheric hard X-ray (HXR) flare sources based on Ramaty High-Energy Spectroscopic Imager (RHESSI) observations show a significant inconsistency with the theoretical predictions based on the standard collisional thick target model (CTTM). Using a hybrid flare code Flarix, we model simultaneously and self-consistently the propagation, scattering and energy losses of electron beams with power-law energy spectra and various initial pitch-angle distributions in a purely collisional approximation and concurrently the dynamic response of the heated chromosphere on timescales typical for RHESSI image reconstruction. The results of the simulations are used to model the time evolution of the vertical distribution of chromospheric HXR source within a singular (compact) loop. Adopting the typical RHESSI imaging times scales, energy dependent vertical sizes and positions as could be observed by RHESSI are presented.

Vršnak, B.

CME-flare relationship (POSTER)

Morphology and evolution of the so-called dynamical flares are often explained as a consequence of reconnection of the arcade magnetic field, taking place below the erupting magnetic flux rope. A tight relationship of the acceleration-phase of the eruption and the flare energy release is evidenced by various statistical correlations between parameters describing coronal mass ejections (CMEs) and flares, as well as by the synchronization of the CME acceleration phase with the impulsive phase of the associated flare. This implies that there must be a feedback relation between the CME dynamics and the flare-related reconnection process. Magnetic reconnection affects the CME dynamics since it: i) reduces the tension of the overlying arcade magnetic field and increases the magnetic pressure below the flux rope, enhancing the CME acceleration; ii) supplies the poloidal magnetic flux to the flux rope, which helps sustaining the electric current in the rope and prolonging the action of the Lorentz force to large distances. In this way, dynamical flares and CMEs are closely related, which is illustrated by employing a simple model, considering the erupting structure as a curved flux rope anchored at both sides in the dense/inert photosphere.

Zimovets, I., A. Artemyev

Electron trapping and acceleration by kinetic Alfvén waves in solar flares

Theoretical models and spacecraft observations of solar flares highlight the role of wave-particle interaction for non-local electron acceleration. In one scenario, the acceleration of a large electron population up to high energies is due to the transport of electromagnetic energy from the loop-top region down to the footpoints, which is then followed by the energy being released in dense plasma in the lower atmosphere. We consider one particular mechanism of non-linear electron acceleration by kinetic Alfvén waves. Here, waves are generated by plasma flows in the energy release region near the loop top. We estimate the efficiency of this mechanism and the energies of accelerated electrons. We use analytical estimates and test-particle modelling to investigate the effects of electron trapping and acceleration by kinetic Alfvén waves in the inhomogeneous plasma of the solar corona. We demonstrate that, for realistic wave amplitudes, electrons can be accelerated up to 10-1000 keV during propagation along magnetic field lines. Here the electric field that is parallel to the direction of the background magnetic field is about 10 to 1000 times the amplitude of the Dreicer electric field. The acceleration mechanism strongsly depends on electron scattering which is due to collisions that only take place near the loop footpoints. The non-linear wave-particle interaction can play an important role in the generation of relativistic electrons within flare loops. Electron trapping and coherent acceleration by kinetic Alfvén wave s represent the energy cascade from large-scale plasma flows that originate at the loop-top region down to the electron scale. The non-diffusive character of the non-linear electron acceleration may be responsible for the fast generation of high-energy particles.