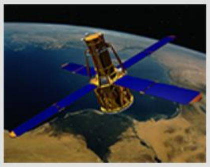

RHESSI-18 Workshop

High-Energy Solar Physics: Building on the RHESSI Legacy

Working group abstracts

WG1 - Radio diagnostics for accelerated electrons

Natsuha Kuroda

Towards Measuring The Energy Content of The Evolving Nonthermal Electron Population in The High Corona

It has been a common practice to probe the acceleration and transport of the accelerated electrons with hard X-ray (HXR) and microwave (MW) observations. In recent years, a new effort has been made in MW domain, comprising new high-resolution, multi-frequency data from The Expanded Owens Valley Solar Array and a breakthrough numerical modeling infrastructure that enables us to study properties of the high-energy electrons in unprecedented cadence and quantitative detail. This study introduces the observation of the M1.2 flare observed on 2017 September 9, and analyzes its high-energy electron properties via the new technique with a focus on the analysis with respect to that from the HXR from the RHESSI. We draw a self-consistent picture of the nonthermal electrons enabled by the direct comparison of the HXR-emitting and the MW-emitting portion of the unified nonthermal electron population. Particularly, we find a rapid increase of the energy contained in the nonthermal electrons partially trapped in the recently found "HXR-invisible" loop. We make quantitative comparison between the trapped and precipitating populations of the nonthermal electrons.

Sijie Yu

Fast plasma outflows associated with impulsive microwave and hard X-ray bursts during the gradual phase of the 2017 September 10 X8.2 flare

The 2017 September 10 X8.2 flare is a spectacular long duration event (LDE) associated with a fast coronal mass ejection (CME). It features an extended gradual phase associated with hard X-ray (HXR) and microwave (MW) bursts that last for at least two hours after the flare peak (at ~1600 UT). We examine the gradual phase using multi-wavelength data recorded by the Expanded Owens Valley Solar Array (EOVSA), RHESSI, Fermi/GBM, SDO/AIA, and MLSO/K-Cor. During the extended gradual phase (~17-18 UT) when the CME already propagates to >10 solar radii, an extremely long and thin plasma sheet is visible in white light (WL) images that extends to at least ~1.5 solar radii above the solar surface. We find evidence of multitudes of fast bi-directional plasma outflows (~300-700 km/s) within the plasma sheet emanating from localized sites at very low coronal heights (0.1-0.2 solar radii above the surface), interpreted as magnetic reconnection occurring in the low corona. The occurrence of the fast plasma outflows correlates very well in time with the intermittent broadband MW emission and HXR enhancements. MW spectroscopic imaging reveals a MW source located at the looptop that coincides with a HXR looptop source. Another MW source is present in the northern leg of the flare arcade, whose temporal evolution seems to correlate with the looptop MW source but shows a time lag characteristic of the Alfvén transit time. We examine the temporal and spatial correlations among the plasma outflows, looptop MW/HXR source, and loopleg MW source, and discuss implications for magnetic energy release, plasma heating, and electron acceleration during the extended gradual phase of the flare.

Säm Krucker

The NoRH/RHESSI Big Flare Catalogue

Solar flares give us a unique opportunity to make spatially resolved observations to study magnetic energy release and particle acceleration in space plasmas. The most direct diagnostics of electron acceleration are provided through radio and hard X-ray observations where we observe synchrotron emissions in the GHz range and non-thermal bremsstrahlung emissions above typically 10 keV. The two leading solar dedicated observatories in these two wavelength ranges are the Nobeyama

Radioheliograph (NoRH) and the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI). We present a statistical study of 35 jointly observed big (>GOES M7) flares. Initial results reveal a linear correlation between the hard X-ray flux above 50 keV and the microwave fluxes at 17 and 34 GHz. These results corroborate earlier findings indicating that the magnetic field strengths in these large flares are all rather similar. In the second part of our talk, we will present imaging results during the flare peak phase to investigate the location of the radio sources relative to the chromospheric footpoints seen in hard X-rays.

Abdallah Hamini

Rhessi and STIX on Solar Radio Monitoring website

Solar Radio Monitoring (secchirh.obspm.fr) is a website for the combined visualization of solar radio data. The main objective of this website is to support multi-wavelength data analysis and space missions dedicated to research on solar activity and on solar-terrestrial relationships, more particularly the SOHO, STEREO and SDO. It produces and provides synthetic data integrating the mapping of sources observed by Nançay Radio Heliograph (NRH) and composite dynamic spectra. The combined survey provided permit to quickly identify and select solar events, to identify the complementary data for the spatial observations and give an overview of the coronal and interplanetary situation.

The energetic electrons that are injected from the low corona to the interplanetary medium are detected via the radio-type radiation they produce in the high corona and the interplanetary medium. On the other hand, the analysis of the spectra observed by X-ray instruments allows obtaining quantitative information on the characteristics of accelerated electrons in the active region and on the thermal energy contained in the plasma. The combination of X-ray instruments data with radio-monitoring surveys is a major asset for scientific research and space weather. Combination results will provide fast visualizations of RHESSI (Reuven Ramaty High Energy Solar Spectroscopic Imager), STIX (Spectrometer/telescope for Imaging X-rays) and ground radio instruments. This combination is also done with the aim of preparing the combination of STIX data with RPW (Radio and Plasma Waves), which in particular contributes to the fundamental questions to which Solar Orbiter bring new answers on the nature of the sources, the mechanisms of acceleration and energy particle transport processes. Therefore, the RHESSI and STIX data will be added in the radio-monitoring website in combination with other space and ground-based instruments in order to facilitate the access to X-ray data for non-expert and to provide to radio-astronomers complementary diagnostics for solar activity.

Brendan Clarke

Evidence for time-dependent magnetic reconnection from X-ray and radio pulsations

A common and perhaps intrinsic feature of solar flare electromagnetic emission is the presence of pulsations in their intensity as a function of time. Known as quasi periodic pulsations (QPPs), these variations in flux appear to include periodic components and characteristic time scales that range from ≤1 s to several minutes. QPPs are typically observed during the impulsive phase of solar flares and have been reported in a broad range of wavelengths from radio to hard X-rays (HXR) and even γ rays. Studying them provides insight into the physical processes operating in the flaring region. To date, the underlying mechanism for the generation of QPPs remains a topic of debate. However, leading theories of QPP generation can be categorised into either oscillatory or self-oscillatory processes. Here, we analyse a GOES M3.7 class flare exhibiting pronounced, oscillatory pulsations in its emission in the X-ray (both soft and hard) and decimetric radio wavebands. It was found that the pulsations within the HXR and SXR light curves yielded two distinct periods of ~106 s and ~37 s. The radio light curve contained a period that matched the long time-scale period of the HXR/SXR curves. Additionally, a time of flight calculation of the electron velocity of the source particles yielded values of $0.3\ c \leq v \leq 0.43\ c$. This indicates that the delay time between the HXR and radio emission is approximately what we would expect if the same population of electrons is responsible for both types of emission. These results suggest that the underlying mechanism producing the QPPs is related to the modulation of the reconnection processes which can explain their presence across the entire spatial range of flaring emission.

Rohit Sharma

Study of the Particle Acceleration in a Weak Solar Flare using JVLA

Solar flares are sudden and massive releases of magnetic energy in the corona. As a consequence, particles are efficiently accelerated to high energies and plasma is heated up to tens of millions K. However, this phenomenon is dynamically and morphologically complex. A characteristic of this complexity is the creation of multiple acceleration sites due to the magnetic field reconfiguration. During the flare, the energetic electrons propagating in the loops emits in high-frequency radio wavelengths via gyrosyntrochton emission mechanism. Some class of energetic particles may undergo plasma instabilities producing intense coherent radio emission. Accelerated electrons and hot plasma also produce X-ray bremsstrahlung. The heated plasma filling the magnetic loops show up as bright emissions in various extreme ultra-violet (EUV) wavelengths. This entire flare process shows complex evolution at fine spatial, spectral and temporal scales. Therefore, a more comprehensive understanding of solar flares requires multi-wavelength analysis with observations that provide high spatial resolution coupled with high frequency and time resolution.

With modern instrumentation, the Jansky Very Large Array (JVLA) provides an opportunity to study solar flares using the broadband imaging spectroscopy at a high spatial resolution. We present an analysis of a GOES B-class flare observed by JVLA on 25th Feb 2012, 20:40 UT to 21:00 UT at 1-2 GHz. This event, despite its small size, displayed a complex morphology with many loop systems suggesting multiple accelerations sites. We perform an event study focusing on the energetics and dynamics of the particle acceleration and heating during this flare. The JVLA observations were coupled with simultaneous X-ray observations from Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) and EUV observations from Solar Dynamic Observatory (SDO). These observations, along with the modelling by gyrosynchroton emission, provide a detailed view of the plasma heating and particle acceleration as a function of space and time.

Marina Battaglia

A series of microflares observed with RHESSI and VLA

On April 23 2013 a series of RHESSI microflares was observed from the same active region over a period of 45 minutes. The Karl G. Jansky Very Large Array was observing the Sun during the same period at a time resolution of 50 ms at frequencies between 1 to 4 GHz. The radio dynamic spectra show a variety of features, like extremely short-lived periodic spikes, drifting bursts, and broad band emission. While some of these emissions were associated with one of the RHESSI microflares, others were not. Equally, not every X-ray burst had a counterpart at radio wavelengths. We present a first exploration and interpretation of this rich data set that demonstrates the big diagnostic potential in simultaneous X-ray and radio observations.

Nicole Vilmer

Extreme narrow-band radio emission associated with a moderate X-ray flare

Very strong narrow-band radio emissions (>10^4 sfu) are sometimes observed in the 1GHz-2GHz range in association with moderate X-ray class flares. One of these extreme events (with a flux >10^5 sfu has been shown recently to be responsible for a disturbance of aeronautical radio navigation (see Marqué et al., 2018) We shall present in this talk another example of a GOES M-class flare (18 November 2003) producing an episode (around 10 minutes) of very strong (>10^4 sfu) narrow-band emission around 1GHz. We will present combined observations from RHESSI, the Radio Solar Telescope Network (RSTN) and the PHOENIX spectrograph to investigate the possible emission mechanisms leading to the extreme narrow-band emissions. We shall also examine the conditions in the flaring active region which could lead to these strong radio enhancements.

Bin Chen

Radio Spectral Imaging of Solar Flare Termination Shock: Co-Spatial Split-band Feature

Solar termination shocks (TSs) can form above the looptop when reconnection outflows that impinge newly reconnected flare arcades exceed the local fast-mode magnetosonic speed. TSs have been suggested as one of the promising drivers for particle acceleration in solar flares, yet observational evidence remains rare. By utilizing radio dynamic spectral imaging of decimetric stochastic spike bursts (SSBs) observed during an eruptive flare event on 2012 March 3 with high spectral, temporal, and spatial resolution, Chen et al. (2015) found that the bursts were associated with a dynamic TS-like feature located at the ending point of fast plasma downflows above the looptop. They also showed evidence for the TS as an electron accelerator. One piece of observational evidence that strongly supports the TS interpretation is the split-band feature: In the radio dynamic spectrum, the SSBs sometimes split into two finer “lanes” in frequency—a phenomenon well-known in type II radio bursts associated with CME-driven shocks. One interpretation for the split-band feature involves the low- and high-frequency lane being produced at the upstream and downstream side of the shock, respectively. We perform detailed spectral imaging analysis of the split-band feature observed in the 2012 March 3 SSB event, and find that the radio centroids of the two split-band lanes each form a co-spatial shock-like surface, which supports the shock upstream-downstream interpretation. We derive spatial and temporal variations of the density compression ratio and Mach number along the surface of the TS, and compare them with recent MHD simulation results.

Yingjie Luo

Dynamic Spectroscopic Imaging of Decimetric Stochastic Spike Bursts in an M8.4 Eruptive Solar Flare: Indication of a Solar Flare Termination Shock

Stochastic spike bursts (SSBs) are characterized by a large number of narrow-band and very-short-duration “spikes” in the radio dynamic spectrum. By imaging a group of SSBs in decimetric wavelengths (1–2 GHz) in an eruptive flare event on 2012 March 3 with high temporal and spectral resolution—a technique known as dynamic spectroscopic imaging, Chen et al. 2015 (Science, 350, 1238) found that they are likely emitted at the front of a dynamic termination shock produced by super-magnetosonic reconnection outflows impinging upon dense, reconnected flare loops. They also showed evidence for the termination shock that served as an electron accelerator. Here we present observations of another SSB event observed by the Karl G. Jansky Very Large Array (VLA) in 1–2 GHz. The event occurred during the extended impulsive phase of a long-duration M8.4 flare on 2012 March 10 that was associated with a fast (>1,200 km/s) halo coronal mass ejection. The flare was observed by the Solar Dynamics Observatory (SDO) against the solar disk and the Solar Terrestrial Relations Observatory Ahead (STEREO-A) from the limb, providing a unique view from two vantage points. In particular, multitudes of supra-arcade downflows (SADs) are seen above the looptop by STEREO-A/EUVI, which are invisible from SDO/AIA. VLA spectroscopic imaging of the SSBs shows that, similar to the case of Chen et al. 2015, the burst centroids form a dynamic surface-shaped structure in the corona. By using 3-D reconstruction of the flare arcades based on EUV imaging data from SDO/AIA and STEREO-A/EUVI, complemented by RHESSI hard X-ray imaging of the flare footpoints, we show that the dynamic surface-shaped structure associated with the SSBs is located above the looptop and below the SADs. The observations are consistent with the interpretation that attributes the SSBs as the radio signature of a solar flare termination shock.

Laura Hayes

Temporal, Spectral and Spatial Analysis of Impulsive Quasi-Periodic Pulsations

One of the key observational features in the emission associated with accelerated electrons is the presence of pronounced modulations and oscillatory signatures known as quasi-periodic pulsations (QPPs). To date, the underpinning mechanisms resulting in the emission modulation remains unknown, and detailed multi-wavelength investigations of flaring QPP events are required to identify the modulation process. Here we will present a detailed temporal, spectral and spatially-resolved investigation of the X1.2 solar flare from May 15 2013 that demonstrate large modulations in its emission. During the impulsive phase, pronounced QPPs with a period of 50s are observed across multiple wavebands including hard and soft X-rays, microwave, UV, EUV - essentially across the whole flaring region. We examine the modulation amplitudes of the different emissions, and in particular focus on the hard X-ray and microwave spectral indices and on the modulation of the degree of polarization of the radio emissions. To further constrain the potential QPP mechanism, we analyse spatially resolved observations of the non-thermal pulsations using both RHESSI and Nobeyama RadioHeliograph data to probe the locations of where the QPP emission is occurring. The results are suggestive of a trap-plus-precipitation model. We will also discuss the QPP modulation in relation to the observed CME eruption. The current theories to explain the presence of QPPs in the context of this event will be presented, along with a discussion of how this type of analysis can be further utilized to probe the mechanisms for electron acceleration and plasma heating.

Nic Bian

Scattering and Fermi Acceleration of Radio Burst Photons in the Solar Corona

Electromagnetic wave scattering off density inhomogeneities in the solar corona is an important process which determines both the apparent source size and the time profile of radio bursts observed at 1 AU. Here we model the scattering process using a Fokker-Planck equation and apply this formalism to several regimes of interest. In the first regime the density fluctuations are considered quasi-static and diffusion in wavevector space is dominated by angular diffusion on the surface of a constant energy sphere. In the small-angle ("pencil beam") approximation, this diffusion further occurs over a small solid angle in wavevector space. The second regime corresponds to a much later time, by which scattering has rendered the photon distribution near-isotropic resulting in a spatial diffusion of the radiation. The third regime involves time-dependent fluctuations and, therefore, Fermi acceleration of photons. Combined, these results provide a comprehensive theoretical framework within which to understand several important features of propagation of radio burst waves in the solar corona: emitted photons are accelerated in a relatively small inner region and then diffuse outwards to larger distances. En route, angular diffusion results both in source sizes which are substantially larger than the intrinsic source, and in observed intensity-versus-time profiles that are asymmetric, with a sharp rise and an exponential decay. Both of these features are consistent with observations of solar radio bursts.

Cynthia Cattell

Understanding the generation of plasma and radio waves by relativistic electron beams: Laboratory plasma experiments

A detailed and experimentally verified understanding of the mechanisms that generate Type II and Type III radio bursts is important to understanding electron acceleration processes in the sun. It is generally accepted that the radio waves are due to a mode conversion involving Langmuir waves excited by electron beams streaming through solar corona and solar wind. How the mode conversion occurs (linear due to density gradient or density fluctuations or non-linear due to three wave interactions) is not known; the radio waves at twice the plasma frequency must include one three wave process. The efficiency (from electron beam energy to Langmuir wave energy to radio wave energy) is also not known. In addition, radio waves may be directly excited. We present preliminary results of a laboratory experiment to address the generation of plasma and radio waves by relativistic electron beams, using the Large Plasma Device (LAPD) at the Basic Plasma Science Facility (BaPSF) at UCLA. This set-up provides highly reproducible, well-diagnosed experiments that may be able to answer key questions about the nature of the generated waves, the efficiency of various conversion processes, and the dependence on plasma parameters in the regime relevant to the solar corona and interplanetary space. Initial experiments were performed with a 20 keV electron beam; future experiments will utilize beams up to ~1 MeV. The initial runs show strong emission at upper hybrid frequency and plasma frequency, both within the plasma column and radiated outside the plasma. Whistler-mode waves were also observed within the plasma column. We will discuss the experimental results and associated simulations and their relevance to our understanding of generation of radio wave by relativistic electron beams in the corona and solar wind. We will also show radio and plasma wave and electron data from STEREO pertinent to the laboratory results.

Eoin Carley

LOFAR for Space Weather (LOFAR4SW): Redesigning the Low Frequency Array as a space weather instrument *(poster)*

The Low Frequency Array (LOFAR) is a phased array interferometer consisting of 13 international stations across Europe and 38 stations surrounding a central hub in the Netherlands. The instrument operates in the frequency range of 20-240 MHz and is used for a variety of astrophysical science use cases. While it is not solar physics or space weather dedicated, a new European Commission-funded H2020 project entitled 'LOFAR for SpaceWeather' (LOFAR4SW) aims at designing a system upgrade to allow the entire array to observe the sun, heliosphere, and ionosphere constantly throughout its observing window. This system upgrade requires a redesign of the entire system, from receiving systems, to back-end computing, to software and scheduling pipelines. Here we describe some of the details of these system upgrade designs as well as an overview of the space weather science and operations that a fully functional LOFAR4SW will perform in the future.

WG2 - Observations of the sun with focusing HXR instruments

Steven Christe

The Focusing Optics X-ray Solar Imager (FOXSI) Explorer

The Focusing Optics X-ray Solar Imager (FOXSI), a SMEX mission concept in Phase A, is the first-ever solar-dedicated, direct-imaging, hard X-ray telescope. FOXSI provides a revolutionary new approach to viewing explosive magnetic-energy release on the Sun by detecting signatures of accelerated electrons and hot plasma directly in and near the energy-release sites of solar eruptive events (e.g., solar flares). FOXSI's primary science objective is to understand the mystery of how impulsive energy release leads to solar eruptions, the primary drivers of space weather at Earth, and how those eruptions are energized and evolve. FOXSI addresses three important science questions: (1) How are particles accelerated at the Sun? (2) How do solar plasmas get heated to high temperatures? (3) How does magnetic energy released on the Sun lead to flares and eruptions? These fundamental physics questions are key to our understanding of phenomena throughout the Universe from planetary magnetospheres to black hole accretion disks.

FOXSI measures the energy distributions and spatial structure of accelerated electrons throughout solar eruptive events for the first time by directly focusing hard X-rays from the Sun. This naturally enables high imaging dynamic range, while previous instruments have typically been blinded by bright emission. FOXSI provides 20–100 times more sensitivity as well as 20 times faster imaging spectroscopy than previously available, probing physically relevant timescales (<1 second) never before accessible. FOXSI's launch in July 2022 is aligned with the peak of the 11-year solar cycle, enabling FOXSI to observe the many large solar eruptions that are expected to take place throughout its two-year mission.

The purpose of this presentation is to provide an update on the result of Phase A concept study.

Milo Buitrago-Casas

Understanding and mitigating stray light for FOXSI's latest flight

The Focusing Optics X-ray Solar Imager (FOXSI) sounding rocket payload is the first solar-dedicated experiment that uses direct focusing to perform imaging spectroscopy in the 4-20 keV range. On September 7, 2018, FOXSI accomplished its latest of three successful flights. The hardware enhancements for the third flight included new CdTe detectors, two new optics modules with increased effective area, a soft X-ray (SXR) CMOS detector, and collimators and aperture plates in front of the optics to reduce stray light background (ghost rays). Here we present an overview of these upgrades, emphasizing on the methods we used to understand and mitigate ghost rays for FOXSI's most recent flight.

FOXSI uses grazing incidence mirrors nested in a collection of seven optical modules. Each mirror consists of two segments, a paraboloid primary and a hyperboloid secondary, that together constitute a Wolter-I ensemble. On-axis X-rays reflect twice on a Wolter-I set to then reach a FOXSI detector on-focus at the focal plane. Nevertheless, some off-axis rays can reflect only once and still end up on a FOXSI detector. These singly reflected rays are known as ghost rays, and if not addressed correctly, they can worsen the overall sensitivity of the instrument. For FOXSI's third flight, a stray light assessment based on a ray-tracing simulation was performed to come up with strategies to mitigate ghost rays. As a result of these assessments, a combination of honeycomb type collimators and bigger aperture plates were attached to the FOXSI optics front to reduce ghost rays. These upgrades enhanced the overall performance of the instrument by reducing stray light reaching the focal plane and by raising the sensitivity of observations across the FOXSI energy range.

Hugh Hudson

Detection Limits for Faint Diffuse Solar X-ray Sources

Focusing optics drastically reduce the background spectral radiance (specific intensity) in the hard X-ray range, a few keV and above, because of the concentration of signal onto a smaller detector area. Thus at disk center we can now go much fainter than was possible with collimator optics. How faint can we see, and what sources might be detectable? The Sun obscures the cosmic X-ray background (CXB) for a well-baffled telescope, but even to detect this component within the solar solid angle will require long integration times. One well-understood but extremely faint limit, well below the intensity of the CXB itself below 10 keV, is imposed by backscattered albedo CXB (Churazov et al., 2008). I discuss various other possible sources such as direct cosmic-ray secondaries, nanoflares, microflares, and even axion conversions.

Matej Kuhar

The role of quiet Sun flares in coronal heating

Coronal heating problem, one of the long-standing unresolved problems in astrophysics, remains to be a source of lively debates in the community. It is yet unclear how the corona (~ million K) remains 3 orders of magnitude hotter than the photosphere (~6000 K). While there is a general agreement that the source of energy lies in the magnetic fields, the mechanisms of this energy conversion are not well understood. One of the proposed explanations is through the impulsive release of magnetic energy by small-scale heating events, which would not be restricted just to active regions, but would make an ensemble across the whole solar disk. In that respect, observing flares outside active regions, in the quiet Sun network, in the X-ray regime, is an important step in understanding the coronal heating problem. Here we present NuSTAR observations of three quiet Sun flares, together with other microflare observations from the active regions. Emphasis is also given on their DEM analysis and potential future observations, also in coordination with sensitive radio instruments such as ALMA.

Kristopher Cooper

NuSTAR observations of a repeatedly microflaring active region

We present several microflares from a recently emerged active region, AR12721, that were observed on 2018 September 9-10. Using both the Nuclear Spectroscopic Telescope Array (NuSTAR) and the Solar Dynamics Observatory's Atmospheric Imaging Assembly (SDO/AIA) the temporal, spatial, and spectral evolution of the microflares can be studied to determine the energy released, and the associated heating of the solar atmosphere. NuSTAR is an astrophysical X-ray telescope, with focusing optics imaging spectroscopy providing a unique sensitivity for observing the Sun above 2.5 keV. The active region microflares were below GOES A1 equivalent level, and the X-ray emission observed by NuSTAR peaks several minutes earlier than the EUV emission seen by SDO/AIA. Heated coronal loops are clearly visible in Fe18 from SDO/AIA, as well as the X-ray images from NuSTAR. From the NuSTAR X-ray spectra, we find that the temperature in some of the microflares reached up to 8 MK but even at the time of peak emission the microflares are multi-thermal.

Jessie Duncan

Hard X-ray Imaging and Spectroscopy of Six NuSTAR Microflares

Hard X-ray (HXR) emission in solar flares can originate from regions of high temperature plasma, as well as from non-thermal particle populations. Both of these sources of HXR radiation make solar observation in this band important for study of flare energetics. NuSTAR is the first HXR telescope with direct focusing optics, giving it a dramatic increase in sensitivity over previous indirect imaging methods. In this work, we present NuSTAR observation of six microflares from one solar active region during a period of several hours on May 29th, 2018. In conjunction with simultaneous data from SDO/AIA, data from this observation has been used to create flare-time images showing the spatial extent of HXR emission. Additionally, NuSTAR lightcurves show time evolution in four different HXR energy ranges over the course of each flare. Finally, spectral fitting of emission at each flare time shows excess high energy emission over an isothermal spectral component in all six flares. The most likely origin of this excess could be either additional volumes of high-temperature plasma, or non-thermally accelerated particles. For each event, characterization of this excess is presented, including determination of upper limits on the non-thermal emission possible in events where it is not directly observed.

Iain Hannah

NuSTAR observations of the quietest Sun

Observing X-rays (above a few keV) from the Sun provides a direct insight into energy release (heating and/or particle acceleration) in the solar atmosphere. Targeting the faintest X-ray emission allows the study of the smallest solar flares, and their contribution to heating the corona. NuSTAR is an astrophysics telescope that uses directly focusing X-rays optics to detect weak X-rays from the Sun. We have observed the Sun many times since the start of solar pointings in Sep 2014 through to our latest observations in 2019. See http://ianan.github.io/nsovr/ for an overview. During the current solar minimum, NuSTAR has observed X-rays from a variety of sources when the Sun is devoid of active regions, during periods of the very quietest conditions. The NuSTAR X-ray images of these weak sources are related to features seen at lower energies, such as in softer X-rays with Hinode/XRT and EUV with SDO/AIA. Crucially, NuSTAR's imaging spectroscopy allows us to obtain and fit the X-ray spectrum from these small events determining the properties. We will present some of the latest solar observations with NuSTAR as we go through the current solar minimum.

Lindsay Glesener

First detection of non-thermal emission in a NuSTAR solar microflare

We report the detection of emission from a non-thermal electron distribution in a small solar microflare observed by NuSTAR. On 2017 August 21, NuSTAR observed a solar active region for approximately an hour before the region was eclipsed by the Moon. The active region emitted several small microflares of GOES class ~A and smaller. In this work, we present spectroscopy demonstrating evidence of electron acceleration in one of these microflares (GOES class A5.7) and we compare energetic aspects of the accelerated distribution to commonly studied larger flares. The flaring plasma observed by NuSTAR, with supporting observation by RHESSI, is well accounted for by a thick-target model of accelerated electrons collisionally thermalizing within the loop, akin to the "coronal thick target" behavior occasionally observed in larger flares. Future observations of this kind will enable understanding of how flare particle acceleration changes across energy scales, and will aid the push toward the observational regime of nanoflares, which are a possible source of significant coronal heating.

Juliana Vievering

Focus on the Extremes: Harnessing the Powerful Capabilities of Hard X-ray Focusing Optics to Explore Solar/Stellar Activity from Sub-A to X10,000 Class Flares

Sensitive measurements of solar and stellar flares in the hard X-ray regime are necessary for investigating energy release and transfer during flaring events, as hard X-rays provide insight into the acceleration of electrons and emission of high-temperature plasmas. The research presented here harnesses the powerful capabilities of two instruments using focusing optics for hard X-rays, the Focusing Optics X-ray Solar Imager (FOXSI), flown on three sounding rocket flights, and the Nuclear Spectroscopic Telescope Array (NuSTAR). With the heightened sensitivity of these instruments, it is finally possible to probe faint events in hard X-rays that have previously been elusive, ranging from small-scale solar events to bright X-ray flares on distant stars. In this presentation, we explore the nature of energy release for flaring events of vastly different magnitudes, including sub-A class solar microflares observed by FOXSI-2 and young stellar object (YSO) flares observed by NuSTAR, and ask whether these events are linked by the common thread of the standard flare model. Additionally, we investigate the complexity of these solar microflares and the impact of ionizing radiation from YSO flares on planet formation, probing some of the most intriguing mysteries of the stars.

WG3 - Reconnection and related acceleration/transport mechanisms

Gregory Fleishman

Magnetic Energy Release and Particle Acceleration viewed through Microwave Eyes

Particle acceleration, one of outstanding problems in solar physics, is unavoidably associated with transformation of excessive magnetic energy in the outermost layer of the solar atmosphere—the solar corona. Broadly speaking, this set of problems can collectively be called “Solar Coronal Magnetism,” which includes emergence of the magnetic flux from the sub-photospheric volume, evolution of the coronal magnetic field, generation and accumulation of a free non-potential magnetic energy, gradual and explosive release of this energy, generation and dissipation of turbulence—the phenomena driving solar flares and other forms of eruptive activity such as jets or coronal mass ejections.

An emerging new remote sensing window—Microwave Imaging Spectroscopy—offers a science-transforming, entirely new look at the coronal magnetism. The foundation of this new capability is sensitivity of the microwave emission to the magnetic field, thermal plasma, and nonthermal electron population. A break-through, however, comes only when this emission is measured at many frequencies with a reasonably high spatial and temporal resolution, which is the case of a new imaging instrument—Expanded Owens Valley Solar Array (EOVSA). In this talk we briefly present the key methodology needed to obtain the target physical parameters, show a few examples of solar flares observed with EOVSA, and discuss main physical findings made with these new data and methodology, in particular—about rapid decay of the magnetic field at the site of the primary energy release in solar flares, associated electric field and accelerated particles, plasma heating, and turbulent magnetic diffusivity. We discuss these new findings in the context of the standard model of solar flare and the contemporary ideas about the magnetic energy release, magnetic reconnection, turbulence generation, and particle acceleration.

Meriem Alaoui

Are runaway electrons significant for the dynamics of the accelerated electron beam/return-current system?

Co-spatial return currents (RCs) have been proposed to balance the electron flux required to explain the observed X-ray bremsstrahlung emission in solar flares. The RC locally neutralizes the charge build-up and cancels the magnetic field induced by the beam of accelerated electrons. This solves the so-called number problem and the associated current stability problem. Based on the results of Alaoui & Holman (2017), that the studied current-driven instabilities are unlikely to explain the enhanced (anomalous) resistivity values, and that the return-current electric field is often relatively close to the Dreicer field, we examine a model where a fraction of the RC carrying electrons are in the runaway regime, and determine whether the need for anomalous resistivity can be abandoned. The non-linear feedback between the beam and RC must be accounted for to most accurately determine the accelerated electron spectrum.

Results: (1) The runaway model can explain the observed spectral flattening without requiring the resistivity to be anomalous (enhanced compared to Spitzer values) in cases where the resistivity was enhanced by less than 3 orders of magnitude in the RCCTTM; (2) the fraction of runaway electrons which stream back into the acceleration region can be up to 70% of the beam flux density; (3) runaway electrons cannot be neglected if the resistivity is classical; (4) When fitting bremsstrahlung spectra using the runaway model, the low-energy cutoff of the injected electron distribution is often tightly constrained.

Joel Allred

The Transport of Flare-Accelerated Electrons and Coupled Return Current

In solar flares electrons are accelerated out of the ambient atmosphere to high energies. These propagate along magnetic loops colliding with and heating the ambient plasma. Details of the flare-accelerated electron spectrum can be determined from observations of the X-ray bremsstrahlung produced as electrons collide with the ambient plasma, predominantly in the footpoints. Electrons moving in a loop produce an electric current which is widely-believed to be balanced by a co-spatial, counter-streaming return current. The return current produces a potential drop acting to decelerate beam electrons over the course of their transport. Inferences of the energy spectrum at the acceleration site, likely near the loop tops, from the bremsstrahlung at the footpoints must account for this deceleration to be most accurate. We have developed a computational tool, FP, which can model the transport of non-thermal electrons from loop top to footpoint. FP solves the Fokker-Planck kinetic equation and self-consistently accounts for the interactions of these electrons with the ambient plasma through Coulomb collisions and return current. We have expanded the Return Current Collisional Thick Target Model (RCCTTM; Alaoui & Holman 2017) to use the FP tool in the X-ray fitting package, OSPEX. Here we report on a study using these tools to fit bremsstrahlung spectra observed by RHESSI during the SOL2013-05-13T 16:03 X2.8 flare. We find that fitting with models that include the effects of return current provides tighter constraints on the elusive low-energy cutoff of the electron distribution and the areas of the footpoints. Additionally, we are able to better constrain the plasma resistivity and find that it is moderately enhanced relative to the Spitzer-predicted value.

Marina Battaglia

Energy release and electron acceleration in magnetic reconnection outflow regions during the pre-impulsive phase of a solar flare

We present observations of electron energization in magnetic reconnection outflows during the pre-impulsive phase of the flare SOL2012-07-19T05:58 during which two X-ray sources, one above the presumed reconnection region and one below, were observed. Imaging spectroscopy X-ray observations from RHESSI are combined with EUV images from SDO/AIA and forward-fitted simultaneously to determine the mean electron distribution function as a function of time over an energy range from 0.1 keV up to several tens of keV. The measured electron distribution spectrum is consistent with a kappa-distribution with $\kappa = 3.5 - 5.5$. The spectral evolution suggests that electrons are accelerated to progressively higher energies in the source above the reconnection region, while in the source below, the spectral evolution suggests density increase due to evaporation and heating. The main mechanisms by which energy is transported away from the source regions are conduction and free-streaming electrons. The latter dominates by more than one order of magnitude, suggesting efficient acceleration even during this early phase of the flare.

Alexandra Lysenko

Catalog of behind-the-limb solar flares registered by the Konus-Wind instrument in hard X-ray range

Emission from accelerated particles observed in the hard X-ray and gamma-ray ranges originates for the most part from the footpoints, although weaker looptop sources can be observed. When flare footpoints are occulted by the solar limb, the so-called behind-the-limb (BTL) flares, we can observe high coronal sources not contaminated by the stronger footpoint emission. The occultation technique long ago revealed a strikingly different morphology of some coronal hard X-ray sources from the non-thermal properties of "ordinary" flares. The properties of these events include very flat hard X-ray spectra, smooth time variations, high altitudes (as inferred from the occultation geometry) and microwave spectra with characteristically low peak frequencies. Such events appear only rarely and are still weakly understood. We undertook a systematic search of such unusual coronal sources in continuous observations of Konus-Wind instrument in hard X-ray range from November, 1994 till nowadays. As Konus-Wind doesn't provide any spatial information the preliminary criterion for BTL candidate selection was low thermal soft X-ray response as compared to prominent nonthermal hard X-ray emission. Afterwards we excluded all on-disc and limb flares from that list based on localization obtained from different instruments at different wavelength. In total we found ~20 BTL flares with the footpoints located at longitudes up to ~40 degrees behind the solar limb. We present an overview of their properties in hard X-ray and radio ranges along with associated phenomena, such as coronal mass ejections and type II/IV radio bursts.

Xiaocan Li

Large-scale particle acceleration during solar flare reconnection

Particle acceleration during solar flare reconnection is an important unsolved problem. Earlier kinetic simulations of magnetic reconnection have identified several acceleration mechanisms that are associated with particle guiding-center drift motions. Here, we show that, for sufficient large systems, the energization processes due to particle drift motions can be described as fluid compression and shear. Based on this result, we then study the large-scale reconnection acceleration by solving the Parker's transport equation in a background reconnection flow provided by MHD simulations. Due to the compression effect, particles are accelerated to high energies and develop power-law energy distributions. The power-law index and maximum energy are consistent with solar flare observations. This study clarifies the nature of particle acceleration in reconnection layer, and may be important to understand particle energization during solar flares.

Evan Tyler

Partitioning of integrated H+ and O+ fluxes in magnetotail reconnection events

We present the partitioning of integrated energy flux from tail reconnection events observed by Cluster and MMS, focusing on the relative contributions of H+ vs. O+ enthalpy flux. Our results indicate that H+ enthalpy flux is often dominant, but that O+ enthalpy flux can contribute significant or greater total energy flux depending on spacecraft location with respect to the current sheet, flow direction, temporal scale, and local conditions. We observe distinct differences in behavior between the H+ and O+ enthalpy fluxes, highlighting the importance of species-specific energization mechanisms. Using the integreated energy fluxes, we are able to probe the size and geometry of the exhaust region of for different ion species which can be compared to heavy-ion acceleration models. These in-situ results in the magnetosphere enhance our understanding of heavy ion acceleration mechanisms near the sun.

Fan Guo

The Acceleration of Particles at Solar Flare Termination Shocks

Standing (but unsteady) solar flare termination shocks can develop when the high-speed reconnection outflow encounters the reconnected post flare loops and accelerates particles to high energy. We investigate the dynamical evolution of the termination shock and its electron acceleration through numerical simulations. Because of the upstream turbulence and plasmoids from the reconnection region, the shock front is likely to be turbulent and rippled at a range of spatial scales, which has a strong implication for electron acceleration. We solve the Parker transport equation for the distribution function of accelerated electrons using the plasma flow velocity and magnetic field obtained from a MHD simulation of a classic Kopp-Pneumann configuration for a two-ribbon flare. We find that the electrons are accelerated rapidly, forming a power-law distribution similar to solar flare observations. Because particles transport crossing the magnetic field is much less than that along the magnetic field, a large fraction of the accelerated electrons are trapped in the region above the top of the post-reconnection loop. These results may explain main features of hard X-ray and microwave observations of solar flares.

Sijie Yu

Short-period Waves in Flare Loops: Possible Vehicle for Flare Energy Transport

Solar flares involve the sudden release of magnetic energy in the solar corona. Accelerated nonthermal electrons have been often invoked as the primary means for transporting the bulk of the released energy to the lower solar atmosphere. However, significant challenges remain for this scenario, especially in accounting for the large number of accelerated electrons inferred from observations. Propagating magnetohydrodynamics (MHD) waves, particularly those with subsecond/second-scale periods, have been proposed as an alternative means for transporting the released flare energy likely alongside the electron beams while observational evidence remains elusive. Here we report a possible observational evidence for these subsecond-period MHD waves in the late impulsive phase of a two-ribbon flare. This is based on ultrahigh cadence dynamic imaging spectroscopic observations of a peculiar type of decimetric radio bursts obtained by the Karl G. Jansky Very Large Array. Radio imaging at each time and frequency pixel allows us to trace the spatiotemporal motion of the source, which agrees with the implications of the frequency drift pattern in the dynamic spectrum. The radio source, propagating at 1000-2000 km/s in projection, shows close spatial and temporal association with transient brightenings on the flare ribbon. In addition, multitudes of subsecond-period oscillations are present in the radio emission. We interpret the observed radio bursts as short-period MHD wave packets propagating along newly reconnected magnetic flux tubes linking to the flare ribbon. The estimated energy flux carried by the waves is comparable to that needed to account for the plasma heating during the late impulsive phase of this flare.

Yang Su

Plasma heating and particle acceleration revealed by the new results from DEM and X-ray Diagnostic of coronal structures

We present new results from detailed studies of X-ray and EUV data that could help us better understand plasma heating in both quiet and flaring corona, acceleration of particles, andevolution of current sheet. The improved Sparse code (Cheung et al. 2015, Su et al. 2018) is used to calculate the DEMs for study of the property and evolution of thermal plasma in a number of coronal phenomena, such as flares, reconnection downflows, cusps, current sheet, coronal holes, and quiet corona. X-ray images and imaging spectra are obtained from both RHESSI data and DEM maps for the study of reconnection events. Together, they provide important clues on the physical processes which require careful consideration in simulations and future studies.

WG4 - Flare thermal response

Mark Cheung

A comprehensive three-dimensional radiative MHD simulation of a solar flare

We present a 2D radiative magnetohydrodynamics (MHD) simulation of a solar flare capturing the process from emergence to eruption. The simulation has sufficient physics for the synthesis of remote sensing measurements to compare with observations at visible, ultraviolet and X-ray wavelengths. This unifying model allows us to explain a number of well-known features of solar flares, including the time profile of the X-ray flux during flares, origin and temporal evolution of chromospheric evaporation and condensation, and sweeping of flare ribbons in the lower atmosphere. The MHD model reproduces the apparent non-thermal shape of coronal X-ray spectra, which is the result of the superposition of multi-component super-hot plasmas up to and beyond 100 million K.

Jeffrey Reep

Constructing a Global Flaring Model

To properly model the entirety of a flare, we must simulate a full arcade of loops whose geometry and heating can change in time. To get away from ad hoc assumptions, we derive heating rates and geometries based on observations of GOES light curves and AIA images. We then construct a model that simulates flaring loops that accounts for time-varying energy, volume, and loop lengths. We validate this model by synthesizing X-ray spectra that are compared with observed MinXSS spectra. By then synthesizing other observables like SDO/AIA lightcurves, we show that we can further constrain the properties of the flare, such as the long duration heating that is known to occur.

Ryan Milligan

Statistical Study of Solar Flares Observed in Lyman-alpha Emission During Solar Cycle 24 Using GOES-15

The chromospheric Lyman-alpha line of hydrogen (Lya; 1216Å) is the strongest emission line in the solar spectrum. Fluctuations in Lya are known to drive changes in the D-layer of Earth's ionosphere (>70km), and recent studies suggest that up to 10% of the energy deposited in the chromosphere by nonthermal electrons is radiated away by the Lya line alone. Despite the energetic importance of Lya there have been relatively few studies in the literature that focus on the behavior of Lya emission during solar flares. This work presents a statistical study of almost 500 M- and X-class flares observed in Lya emission by the EUVS instrument on GOES-15 during Solar Cycle 24. It was found that up to 100 times more energy can be radiated by Lya compared to soft X-rays (also a driver of D-layer fluctuations); that Lya enhancements during flares are comparable to or greater than those measured due to solar rotation variability, albeit on much shorter timescales; and that center-to-limb variations appear to be negligible despite Lya being optically thick.

Gordon Emslie

Warm-target Energetics and a Solution to the Low-energy Cut-off Problem

Solar flare hard X-ray (HXR) spectroscopy serves as a key diagnostic of the accelerated electron spectrum. However, the standard approach using the collisional cold thick-target model poorly constrains the lower-energy part of the accelerated electron spectrum, hence the overall energetics of the accelerated electrons, and consequently their contribution to the overall energetics of the flare, are typically constrained only to within one or two orders of magnitude. In this talk, I will discuss the development and application of a physically self-consistent warm-target approach that involves the use of both HXR spectroscopy and imaging data. The approach allows an accurate determination of the electron distribution low-energy cutoff, and hence the electron acceleration rate and the contribution of accelerated electrons to the total energy released. Using an example solar flare observed by RHESSI, we demonstrate that using the standard cold-target methodology the low-energy cutoff (and hence the energy content in electrons) is essentially undetermined. However, the warm-target methodology can determine the low-energy electron cutoff with ~7% uncertainty at the 3σ level, and hence permits an accurate quantitative study of the importance of accelerated electrons in solar flare energetics.

Natasha Jeffrey

The Role of Energy Diffusion in the Deposition of Energetic Electron Energy in Solar and Stellar Flares

During solar flares, a large fraction of the released magnetic energy is carried by energetic electrons that transfer and deposit energy in the Sun's atmosphere. Electron transport is often approximated by a cold thick-target model (CTTM), assuming that electron energy is much larger than the temperature of the ambient plasma, and electron energy evolution is modeled as a systematic loss. Using kinetic modeling of electrons, we re-evaluate the transport and deposition of flare energy. Using a full collisional warm-target model (WTM), we account for electron thermalization and for the properties of the ambient coronal plasma such as its number density, temperature and spatial extent. We show that the deposition of non-thermal electron energy in the lower atmosphere is highly dependent on the properties of the flaring coronal plasma. In general, thermalization and a reduced WTM energy loss rate leads to an increase of non-thermal energy transferred to the chromosphere, and the deposition of non-thermal energy at greater depths. The simulations show that energy is deposited in the lower atmosphere initially by non-thermal electrons, and later by thermalized electrons over timescales of seconds, unaccounted for in previous studies. This delayed heating may act as a diagnostic of both the non-thermal electron distribution and the coronal plasma, vital for constraining flare energetics.

Galina Motorina

Quantification of thermal response in the 2014 February 16 “cold” flare with joint X-ray and UV analysis

Solar flares are the strongest explosions on the Sun, as a result of which a colossal amount of energy accumulated in a limited amount of the solar atmosphere can be quickly released due to magnetic reconnection. During this process, kinetic, thermal and nonthermal energies release in a priori unknown proportion. In particularly, there are flares with strong nonthermal component while only a weak thermal response, the so-called ‘cold flares’ (Bastian et al. 2007; Fleishman et al. 2011; Masuda et al. 2013; Lysenko et al., 2018). These are perfect for studying flare energization and nonthermal signatures driving the thermal response. For example, in our recent study of 2013-Nov-05 cold flare (Motorina et al., 2018, RHESSI meeting) we have quantified in detail the nonthermal energy conversion to the thermal energy of ambient plasma, which appeared to divide in roughly equal partitions between a cooler and a hotter flaring loops, seen by SDO/AIA and RHESSI spacecrafts respectively.

Here we present a similar analysis of a 2014-Feb-16 “cold” flare with the use of X-ray (RHESSI), EUV (SDO/AIA), and UV (IRIS) data to understand the partition between kinetic, thermal and nonthermal components in detail. To diagnose nonthermal energy we use microwave and X-ray data, while we use (E)UV and X-ray data to probe the thermal and kinetic energy. In particular, with the use of regularized DEM technique we compute evolving maps of temperature, emission measure and thermal energy density based on the SDO/AIA data, which allows us to trace evolution of thermal energy. With the use of this analysis we evaluate the energy partitions between the kinetic / nonthermal / thermal energies and evolution thereof.

Säm Krucker

RHESSI diagnostics of hot plasma in quiescent active regions

This talk discusses RHESSI imaging of a quiescent (non-flaring) active region integrated over long time intervals (up to 40 min). In the absence of detectable microflares, RHESSI imaging reveals a hot component that originates from the entire active region, similar as it is expected for a nanoflare scenario where the entire active region is filled with a large number of unresolved small energy releases. Adding EUV and SXR observations taken by AIA and XRT, respectively, we derive a differential emission measure (DEM) that shows a peak between 2 and 3 MK with a steeply decreasing high-temperature tail, similar to what has been previously reported. The derived DEM reveals that a wide range of temperatures contributes to the RHESSI flux (e.g. 40% of the 4 keV emission being produced by plasma below 5 MK, while emission at 7 keV is almost exclusively from plasmas above 5 MK) indicating that the general approach of fitting an isothermal spectrum to the RHESSI spectrum is inappropriate. We discuss these findings relative hard X-ray microflare observations.

Alexander Warmuth

Thermal-nonthermal energy partition in solar flares: current status and progress

The knowledge of the energetics of thermal and nonthermal particle populations is essential for our understanding of energy release and transport as well as particle acceleration in solar flares. Several recent studies have tried to quantify the thermal-nonthermal energy partition, with various contradicting conclusions. After reviewing these studies, we will address several key aspects that require closer scrutiny before we can come to firm conclusions on energy partition. In particular, we will consider conductive energy losses, nonthermal energy input according to the warm-target model, and the evolution of the energy partition as a function of time.

Sabrina Guastavino

Desaturation of SDO/AIA EUV images of solar flaring storms

SDO/AIA provides a window on multi-wavelength observations of the Solar Corona with unprecedented spatial and temporal resolution. However, a significant amount of AIA images is affected by saturation effects that mainly affect the image core and are particularly dramatic in the case of GOES X-class events. A desaturation method based on inverse diffraction was proposed in 2014 and was implemented in an SSW code (DESAT). However, in order to work, this approach needs information on the background provided by unsaturated maps recorded in between saturated images and therefore this desaturation algorithm cannot be effectively applied in the case of extreme events characterized by a long series of degraded images. Here we propose a new method that overcomes this limitation and is able to automatically restore the information in the saturated region exploiting the diffracted signal contained in the single image and that, therefore, can be applied in the restoration of sequences of saturated images recorded during flaring storms.

Crisel Suarez

Solar Flare Plasma Transport Inferred from Elemental Abundance Changes using soft X-ray Spectra

Solar flares are the most powerful events in the solar system. These eruptive phenomena accelerate particles on timescales of minutes, converting magnetic energy to thermal, radiative and kinetic energy through magnetic reconnections. As a result, local plasma can be heated to temperatures in excess of 20 MK. In addition, plasma flows from the lower chromosphere to the higher corona have been observed. Hence, elemental abundance values similar to chromospheric and photospheric values have been inferred from soft X-ray measurements. Two of the most comprehensive, independent soft X-ray studies on elemental abundance changes in solar flares disagree on the variations of certain low first ionization potential (FIP) elements (Narendranath 2014, Dennis et al. 2015). The Miniature X-ray Solar Spectrometer (MinXSS) CubeSats (Moore et al. 2018) provides new spectrally resolved soft X-ray measurements at higher spectral resolution and broader spectral (0.8 – 12 keV) coverage than the measurements used in Narendranath 2014 and Dennis et al. 2015. These properties allow the MinXSS data set to quantify solar flare variations in Fe, Ca, Si, Mg, S, Ar, and Ni abundances. In the first steps of a larger investigation, here we analyze the M5.0 flare on July 23, 2016 to determine elemental abundance variation derived by MnXSS-1. We recover the traditional abundance evolution, where the low FIP elemental abundance is depleted during the solar flare with respect to quiescent times.

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Tomasz Mrozek

How spatial, time and energy resolutions influence reconstructed RHESSI images and their physical interpretation?

RHESSI has provided 16 years of solar observations in Hard X-Rays and gamma bands. This is a huge data base containing many different features that may be compared with existing models of solar flares. However, the models that we have before our eyes can mislead our scientist's sense and cause misinterpretation or wishful interpretation of the data. I will present three examples of the data interpretation problems which can be addressed maximizing opportunities provided by RHESSI in terms of spatial, temporal and energy resolution, as well as including context observations from other instruments, e.g. SDO/AIA. The problems are: 1. Altitude descent of HXR footpoint sources with increasing of their energy. 2. Shrinkage of flare loops observed in HXRs during impulsive phase of solar flares. 3. The existence of fine structure of HXR loop-top sources. I will present examples of observations and their interpretations that can be found in the literature, and I will show that, with the maximum use of the RHESSI instrument, these examples can be interpreted in a completely different way. Such a revisit of observation will help in near future when completely new Fourier imagers will be operated (STIX, ASO-S/HXI).

Viacheslav Sadykov

Modelling the Behavior of SDO/HMI observables for solar atmosphere heated by precipitating high-energy electrons ***(poster)***

We perform modeling of the line-of-sight (LOS) observables of the Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO) for solar atmospheres heated by precipitating high-energy electrons during solar flares. The radiative hydrodynamic (RADYN) flare models were obtained from the F-CHROMA database. The Stokes profiles for the Fe 6173 A line observed by SDO/HMI were calculated using the radiative transfer code RH, assuming statistical equilibrium and 100 G or 1000 G uniform vertical magnetic fields. The SDO/HMI data processing pipeline algorithm was applied to derive the observables (continuum intensity, line depth, Doppler velocity, and LOS magnetic field). Our results reveal that for the flare models with average deposited energy fluxes of 5.0x10^10 erg/cm^2/s, the deviations of the observables from the actual spectroscopic line parameters can reach 0.6 km/s for Doppler velocities, and about 100 G for the LOS magnetic field. Such deviations decrease significantly for the weaker flare models with average deposited energy flux of < 5.0x10^10 erg/cm^2/s. Although changes of the LOS magnetic field observable for F-CHROMA RADYN models are not accompanied by magnetic field sign reversals, an additional investigation using a higher-energy RADYN simulation (F= 1.0x10^11 erg/cm^2/s) from Kerr et al. (2019) reveals stronger deviations for the observables and the possibility to detect almost zero LOS magnetic field. The results highlight that the sharp magnetic transients observed during the solar flares by SDO/HMI may appear due to rapid heating of the atmosphere by accelerated electrons of high energy fluxes (F >= 5.0x10^10 erg/cm^2/s), and should be interpreted with caution.

WG6 - Connections between accelerated electrons at the Sun and in interplanetary space

Gerald Share

Characteristics of the Hard Electron Continuum Observed in Solar Flares

Combined Solar Maximum Mission (SMM) Hard X-Ray Burst Spectrometer (HXRBS) and Gamma Ray Spectrometer (GRS) spectral data from the 1980 June 4 flare revealed significant hardening in the electron radiation spectrum above a few hundred keV (Dennis 1988). Such hardening appears to be present in several other flares observed since then. The hardening exceeds that expected from relativistic effects and from the contribution of electron-electron bremsstrahlung at high energies. RHESSI imaged what may be the same hard component in three flares and found that the source was distinct from the hard X-ray foot points and was located in the corona (Krucker et al. 2008). With improved understanding of the nuclear contribution to gamma-ray spectra into the MeV range, it is possible to characterize this hard photon continuum. It is best represented by a hard power law (index close to unity) truncated by an exponential rollover with effective energy of a few MeV. We discuss recent studies of the spectra and temporal evolution of this continuum, using data from SMM GRS, RHESSI, and Fermi GBM, and what they imply for the parent electron population and its relationship to MeV electron observed in space.

Vahé Petrosian

Evidence for re-acceleration of flare particles at the CME-shock

It is generally believed that solar energetic particles (SEPs) observed in gradual solar flares are particles accelerated in the coronal mass ejection (CME) and its associate shock environment, escaping the upstream of shock to 1AU. However, the source of seed particles is still debated. I will discuss the possibility of flare accelerated particle as the seeds for this re-acceleration. RHESSI hard Xray and SEP electron observations will be used to test this scenario. This may also account for the difference in spectra and isotopic enhancement of SEP ions in impulsive and gradual events.

Linghua Wang

Solar Energetic Electron Events

Solar energetic electron events are the most common solar particle acceleration phenomenon observed in the interplanetary space. In this paper, I will review the properties of solar energetic electron events, as well as their relationship with other solar phenomena.

Wen Wang

Solar Energetic Electron Events with Related Hard X-ray Flares

We presented a statistical survey of 24 solar energetic electron (SEE) events and related Hard X-ray (HXR) flares from 2002 February to 2016 December measured by WIND/3DP and RHESSI. All the 24 cases showed a double-power-law shape in electron peak spectrum and double-power-law shape is fitted in HXR peak spectrum for cases with >80keV HXR emissions (13 of 24). The spectral energy breaks of SEEs and related HXRs showed a close correlation with cc=0.83. We derived a double-power-law spectrum of HXR-producing electrons from HXR peak spectrum based on observations of SEEs and EUV/HXR imaging at 1AU and we found that: below the energy break, low energy spectral index β1HXR-pro of HXR-producing electrons is larger than β1 of SEEs for most cases (21 of 22). While above the energy break, high energy spectral index β2HXR-pro of HXR-producing electrons agree with β2 of SSEEs for most cases (17 of 22), implying that a secondary acceleration process could exist during downward traveling electrons to the HXR-producing region and be more efficient to electrons at lower energies. After considering energy loss from flare source to 1AU, we found that only the acceleration source region of SEEs with a heliocentric altitude r0 ≧ 1.5Rs could maintain a power-law shape down to ~2keV, consistent with observations at 1AU. We also searched the helium emissions related to SEEs and found that: for cases with 3He/4He > 0.01, 3He/4He showed a close correlation with β1HXR-pro, β2HXR-pro of HXR-producing electrons and β2 of SEEs implying that the acceleration of 3He ions could be associated with source electrons.

Sophie Musset

X-ray emitting electrons in connection with coronal EUV jets

Flare-associated coronal EUV jets outline open magnetic field lines providing an escaping path to the interplanetary medium for particles accelerated during solar flares. Several studies have shown an observational link between coronal jets (observed in EUV or soft X-rays) and type III radio bursts, produced by escaping beams of energetic electrons, or in-situ energetic electron events. In a few events, coronal jets have also been associated with X-ray emitting energetic electrons during flares. However, the likelihood of the association of energetic electrons to coronal jets as well as the link between jet properties and electron properties has not been investigated on a large sample of events. We present here a statistical study of the link between X-ray emitting energetic electrons and the associated coronal EUV jets by looking at their relative timing, and the relation between jet properties and X-ray emitting electron spatial spectral characteristics; and discuss what can be learn from this results for coronal jet modeling and escape of energetic particles.

Anna Maria Massone

Machine learning with feature ranking for flare prediction and its extension to the connection of space weather events

Prediction of space weather events may exploit computational analysis based on machine learning. This approach allows the determination of which data features mostly impact the prediction and possibly the comprehension of which physical properties play the most significant role in the event formation. Here we describe the performances of machine learning with property ranking in the case of flare prediction, using vector and line-of-sight magnetograms provided by SDO/HMI. Our method, developed within the framework of the H2020 FLARECAST effort, utilizes probably the richest set of image features ever (more than 100 properties) and the results allow us to identify which ones, among this large set of properties, contain the richest information related to flare generation. We also illustrate that this approach can be generalized to investigate how observations at the Sun can be connected to CMEs properties and, via their interplanetary propagation, down to magnetosperic, ionospheric and terrestrial impacts.

Aaron West

The role of strong scattering by large-amplitude whistler-mode waves in the evolution of solar wind electron distributions *(poster)*

It is well known that the radial evolution of solar wind electrons is not well-modeled by propagation along the Parker spiral magnetic field while conserving the first adiabatic invariant. The observed strahl pitch angle width is much broader, requiring a scattering mechanism, which is often assumed to be sunward propagating broadband low amplitude whistler-mode waves. In the STEREO satellite waveform capture data, we have discovered large amplitude (~2 orders of magnitude larger than previous observations), narrowband whistler-mode waves propagating in the solar wind. The amplitudes, frequencies, and oblique propagation angles with significant parallel electric fields and their 'close-packing' in solar wind structures suggest these waves can dramatically modify solar wind electron propagation. The waves also have the potential to explain some puzzling aspects of the longitudinal spread and/or radial timing seen in satellite measurements of solar energetic electrons.

To study the potential effect of these waves on solar wind electrons, we have developed a particle tracing code that simulates a single particle's fully 3D interaction with a monochromatic whistler-mode wave through tracing and solving for the phase space evolution at each time step. This allows us to probe the responses of electrons over a full range of initial pitch angle and energy, as well as wave amplitudes and propagation angles. Wave frequency is set using our observed frequencies with respect to the electron gyrofrequency and the whistler dispersion relation, using nominal solar wind values for the background magnetic field strength and density.

Preliminary results show rapid scattering and significant energization (or de-energization) over initial wave angles and energies (from 10 eV to 1 keV) for a range of wave angles, including waves not counterpropagating (in contrast to earlier theoretical work). The simulations suggest that interactions with whistlers may explain strahl broadening and development of the super-halo. Complex structures are seen in phase space that may be explained by resonance overlap and thus stochastic acceleration and nonlinear resonant trapping and scattering. Our results will provide predictions that can be tested the Parker Solar Probe mission.

WG7 - Ion studies and Fermi/LAT

Alexandra Lysenko

Gamma-ray emission from solar flares observed by Konus-Wind

Unlike countless X-ray solar flares, the total number of solar flares recorded in the gamma-ray range is still limited to a few dozen events. For this reason, a detailed analysis of each gamma-ray solar flare is potentially highly valuable to quantify acceleration of ions and electrons up to ultrarelativistic energies. In contrast to the HXR emission from solar flares, which is produced by a single emission process, the bremsstrahlung, solar flare spectrum in the gamma-ray range represent a composition of different components. The bremsstrahlung from relativistic electrons still contributes to the flare gamma-ray continuum, while accelerated ions could manifest themselves through more spectral components via numerous nuclear reactions.

Using the database of Konus-Wind solar flares recorded in the triggered mode, we made a list of events showing significant gamma-ray emission above 1 MeV. Some of those events were observed jointly (or partly jointly) with other high-energy instruments, while others were only covered by the Konus-Wind data. We undertake time-resolved spectral analysis of a few solar flares observed in gamma-ray range and make conclusions about properties of accelerated ions and electrons and their spectral evolution.

Gerald Share

A New View of Solar Flare Gamma-Ray Observations

Now that the latest updates have been completed to various algorithms that calculate nuclear gamma-ray line and continuum emission in solar flares, it is time to begin a systematic reanalysis of our existing gamma-ray flare data base. We focus on observations made by the Solar Maximum Mission (SMM) Gamma Ray Spectrometer (GRS), RHESSI, and the Fermi GBM. Past studies of the GRS spectra used an empirical detector response matrix (DRM) that we updated using a Monte Carlo calculation. We are in the process of incorporating this DRM into the OSPEX SSW package along with spectral files from the GRS archive. The new nuclear studies can address the full range of objectives enabled by gamma-ray observations including: conditions in the ambient flaring atmosphere and characteristics of flare-accelerated particles. We discuss early results from these studies.

Brian Dennis

Extended X-ray sources in Gamma-ray Flares

Evidence will be presented for the existence of hard X-ray sources with extents exceeding the ~3 arcminute limit of RHESSI's standard imaging capability. A novel technique will be used to show that the X-ray source associated with the behind-the-limb flare on 01 September 2014 had an extent of ~5 arcminutes. This event was also detected with Fermi/LAT at >100 MeV. The centroid location of this extended X-ray source is consistent within uncertainties with either a coronal source above the limb or a source on the visible solar disk. The coronal source would be vertically above the over-the limb active region imaged with STEREO thought to be the origin of the event. The source on the disk would be at the same latitude as that active region. The centroid is not consistent with the reported location of the LAT source ~300 arcsec north of the active region latitude. Other events are being studied for evidence of emission from extended sources. The reported narrowing of the 511 keV line during the event on 28 October 2003 will also be discussed.

Nat Gopalswamy

Clustering of SGRE Events Observed by Fermi/LAT: Preconditioning of the Ambient Medium?

It was recently shown that the sustained gamma-ray emission (SGRE) from the Sun lasting for hours beyond the impulsive phase of the associated flare is associated with the same shock that produces interplanetary type II radio burst. The coronal mass elections (CMEs) that drive the shock in the SGRE events are similar to the ones producing ground level enhancement (GLE) in solar energetic particle (SEP) events (Gopalswamy et al. 2018, ApJL 868, L19). It was noticed that more than half of the 19 SGRE events with duration >3 hr occurred in clusters (mostly from the same active region). In another case (2011 June 02 SGRE), the SEP event was almost non-existent, yet there was a type II burst and fast CME; the type II burst was weak and the CME had a speed of only ~1000 km/s. We present an analysis of these events, which suggests that preconditioning of the ambient medium can explain the clustering and the lack of a large SEP event in the 2011 June 02 event. The preconditioning refers to the presence of seed particles and magnetic structures of preceding CMEs.

Vahe Petrosian

Transport of accelerated particles from the CME downstream to the photosphere and production of gamma-rays in solar flares

Localization of long duration >100 MeV gamma-rays from solar flares by Fermi-LAT indicates origins different than their parent active region, in particular in flares with active regions locate behind the limb. This opens the possibility of particles (most likely protons) accelerated in the associated CME can escape its downstream and reach the photosphere. I will discuss under what conditions such a transport will be possible.

WG8 - Future instrumentation

Christopher Moore

Prospects of the SmallSat Solar Activity X-ray Imager (SSAXI)

Detection of soft X-rays from the Sun provides direct information on coronal plasma at temperatures in excess of ~1 MK. The SmallSat Solar Activity X-ray Imager (SSAXI) will combine Miniature lightweight Wolter-I focusing X-ray optics (MiXO) and monolithic CMOS X-ray sensors in a compact package to enable the capability to create solar spectral images from 0.6 – 6 keV. This spectral bandpass is key for observing diverse solar phenomena to constrain various components of coronal heating in the Quiet Sun (QS), Active Region (ARs), and microflares (GOES A and sub A level events). Furthermore, the spectral resolution (resolving power ~10 – 40) will allow determination of Fe, Mg, Ca, Si, S, O, and Ar abundances. The solar science prospects of such an instrument on a future SmallSat platform will be discussed in this talk as well as the proposed mission timeline.

Subramania Athiray Panchapakesan

Alignment and calibration of the Marshall Grazing Incidence X-ray Spectrometer (MaGIXS)

The Marshall Grazing Incidence X-ray Spectrometer (MaGIXS) is a NASA sounding rocket experiment designed to observe the Sun in soft X-rays from 24 - 6.0 ˚A (0.5 - 2.0 keV) expected to be launched in 2020. The experiment is designed to determine the frequency of heating events in coronal structures, including active regions through definitive measurement of the plasma temperature distribution greater than 5 MK. By investigating the differential emission measure (DEM) distribution, MaGIXS measurements can help to discriminate between the high and low frequency coronal heating mechanisms. MaGIXS design is the current state of the art soft X-ray instrumentation to observe the high temperature and low-emission plasma in soft X-rays.

MaGIXS design involves a Wolter-I type telescope and a 3-optic grazing-incidence spectrometer. The spectrometer consists of a finite conjugate mirror pair and a blazed planar, varied line spaced grating, which disperses the rays on to a CCD and provides a high spatial (6"") and spectral resolution (22 mA). MaGIXS will observe a set of high temperature spectral lines, which will have the same optical path and will be detected on the same detector, providing reduced uncertainties and better discrimination than currently existing X-ray/EUV spectrometers/imagers. MaGIXS experiment involves various optical components that are fabricated and tested at various institutions including the Marshall Space Flight Center (MSFC), the Smithsonian Astrophysical Observatory (SAO), the Massachusetts Institute of Technology (MIT) and Izentis LLC. Here we present an overview of the experiment, emphasizing the alignment and calibration for the MaGIXS instrument.

Marek Stęślicki

Small soft X-ray spectrometer support for a imaging hard X-ray spectrometer

Spectrometer for Temperature and Composition (STC) is one of two scientific instruments on-board proposed FOXSI mission. It is designed to monitor solar X-ray flux between 1 keV and 15 with ~0.15 keV energy resolution and provide fast solar X-ray spectroscopy in the entire flux intensity range, variable seven order in intensity form quiet solar conditions to strongest flares. The instrument measurements allow temperature and emission measure analysis of small flares as well as a quiet Sun. The exceptionally wide dynamic range of this instrument as well as its high spectral and temporal resolution and wide plasma temperature coverage will allow STC data to well complement the main FOXSI instrument data resulting in unprecedented measurements, crucial for energy release processes and space weather monitoring.

Noriyuki Narukage

Satellite mission PhoENiX: Physics of Energetic and Non-thermal plasmas in the X (= magnetic reconnection) region

Now, we are studying a new solar satellite mission, ""PhoENiX"", for understanding of particle acceleration during magnetic reconnection, which are ubiquitous features exhibited by a wide range of plasmas in the universe. The main observation targets of this mission are solar flares that are caused by magnetic reconnection and accelerate plasma particles. The sun is a unique target in the sense that it can be investigated in great detail with good spatial, temporal and energy resolutions.

The scientific objectives of this mission are (1) to identify particle acceleration sites, (2) to investigate temporal evolution of particle acceleration, and (3) to characterize properties of accelerated particles, during magnetic reconnection, i.e., during solar flares. In order to achieve these science objectives, the PhoENiX satellite is planned to be equipped with three instruments of (1) Photon-counting type focusing-imaging spectrometer in soft X-rays (up to ~10 keV) demonstrated by FOXSI-3, (2) Photon-counting type focusing-imaging spectrometer in hard X-rays (up to ~30 keV) like FOXSI series, and (3) Spectropolarimeter in soft gamma-rays (spectroscopy is available in the energy range of from > 20 keV to < 600 keV; spectropolarimetry is available from > 60 keV to < 600 keV) like Hitomi/SGD.

We plan to realize this satellite mission around next solar maximum (around 2025).

In this presentation, we will explain the details of science goal and objectives, and instruments of PhoENiX mission. The performance of photon-counting observation in soft X-rays is also given with the FOXSI-3 soft X-ray data.

Trevor Knuth

The IMpulsive Phase Rapid Energetic Solar Spectrometer (IMPRESS)

The Impulsive Phase Rapid Energetic Solar Spectrometer (IMPRESS) is a 3U CubeSat-based hard X-ray spectrometer in development as a collaboration between the University of Minnesota, University of California, Santa Cruz, Montana State University, and the Southwest Research Institute. IMPRESS will observe hard X-ray emission produced by solar flares in the rising phase of Solar Cycle 25 in order to probe electron acceleration. The mission will demonstrate an X-ray detector that will produce a spectrum spanning 1 keV to 256 keV at a cadence of 40 Hz or greater with an effective area of at least 25 sq cm. This detector will allow observation of solar X-ray flux over a vast range.

Michele Piana

Count-based STIX imaging with Expectation Maximization

Similarly to RHESSI, STIX onboard Solar Orbiter is a visibility-based imaging instrument, which will ask for Fourier-based image reconstruction methods. Here we show that, as for RHESSI, also for STIX count-based imaging is possible. To this aim we describe a mathematical model that mimics the STIX data formation process as a projection from the incoming photon flux into a vector made of 120 count components. Then we test the reliability of Expectation Maximization for image reconstruction in the case of several simulated configurations typical of flare morphology

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Shane Maloney

X-ray Image Deconvolution using Neural Networks

X-ray image deconvolution is a difficult problem and has been the subject of numerous studies over the last three decades. Traditional deconvolution algorithms typically use iterative approaches which can be difficult to develop, computationally expensive, and may fail to converge but have proven successful to date. We propose a convolution neural network (CNN) based approach which is significantly faster while at least matching the accuracy of the current methods.

We have developed and applied a CNN approach to the deconvolution of X-ray images. The network is trained on synthetic data, pairs of dirty and clean maps, the CNN learns to remove the artefacts from the dirty map due to the sparse sampling of the u-v plane. The layers of the CNN act as numerous iterations in a traditional scheme with the benefit of the inherent multi-scale nature of the CNN architecture.

Compared to CLEAN the CNN approach is superior in terms of accuracy and speed. The substantial speed increase opens the possibility of new analysis avenues - outlier visibility detection, image confidence maps, source size errors - even if CNN method only matches the accuracy of more complex iterative algorithms (MEM, PIXON, etc.)

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W. Q. Gan

ASO-S Status and HXI Simulations

In the past one year, ASO-S was successfully undertaking its Phase-B studies. By this May the Phase-C will start. The talk will describe the current status of the mission and pay more attentions to the HXI, including the simulations of imaging reconstructions.
