Particle Acceleration in Solar Flares and the Plasma Universe – Deciphering its features under magnetic reconnection

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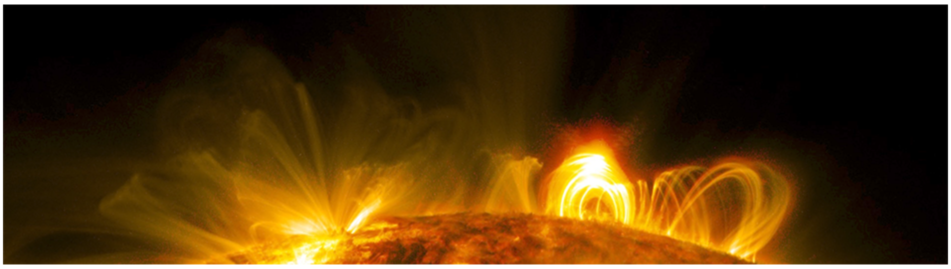
Virtual



Book of Abstracts

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

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We are planning a new solar satellite mission, "PhoENiX", for understanding of particle acceleration during magnetic reconnection. The main observation targets of this mission are solar flares. 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 solar flares. In order to achieve these science objectives, the PhoENiX satellite will obtain the information about individual X-ray and gamma-ray photons (i.e., position, time, energy and polarization) with three instruments of (1) photon-counting type Soft X-ray focusing Imaging-Spectrometer (SXIS; up to ~10 keV), (2) photon-counting type Hard X-ray focusing Imaging-Spectrometer (HXIS; up to ~30 keV), and (3) Soft Gamma-ray Spectro-Polarimeter (SGSP; spectroscopy is available in the energy range of from > 20 keV to < 600 keV; spectropolarimetry is available from >60 keV to < 600 keV). We plan to realize PhoENiX satellite in the Solar Cycle 26 (in 2030s). We emphasize that, thanks to above new observational approach for solar flares, PhoENiX is the first mission that can survey "accelerating" particles in the magnetic reconnection system. To maximize the scientific outputs from the new observations by PhoENiX, we are also promoting the sounding rocket project FOXSI-4 (that aims to observe a solar flare in 2024) as a demonstration of PhoENiX and developing sophisticated numerical approach and interdisciplinary approach. In this presentation, we will introduce the PhoENiX mission and our trinity (observational, numerical, and interdisciplinary) approaches.

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Efficient electron acceleration in compact binary systems

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The gamma-ray binary systems are a new class of compact binary systems established in the middle of the 2000s, owing to the development of GeV/TeV gamma-ray telescopes. They show non-thermal emission peaking above 1 MeV in their SEDs, which is completely different from X-ray binaries. This feature indicates that efficient electron particle acceleration takes place in these binaries, and its physical mechanism has been a long-standing mystery. In this talk, we review the recent observational result of one of the brightest gamma-ray binaries, LS 5039 with Fermi/LAT and NuSTAR, etc. The obtained spectrum indicates that the dominant component peaking 20-30 MeV is different from the soft X-ray component and it has a very hard spectral index. These features are not yet well explained by the proposed models and challenge our understanding of this object. A possible interpretation is that the MeV gamma-ray emission is synchrotron radiation from electrons accelerated by electric fields directly e.g. relativistic magnetic reconnection. In addition, we will explain a new possibility that this gamma-ray binary may contain a magnetar, which is stimulated by hints of pulsation in hard X-rays using Suzaku/HXD and NuSTAR.

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Variability of the Reconnection Guide Field in Solar Flares

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Solar flares may be the best-known examples of the explosive conversion of magnetic energy into bulk motion, plasma heating, and particle acceleration via magnetic reconnection. The energy source for all flares is the highly sheared magnetic field of a filament channel above a polarity inversion line (PIL). During the flare, this shear field becomes the so-called reconnection guide field (i.e., the non-reconnecting component), which has been shown to play a major role in determining key properties of the reconnection including the efficiency of particle acceleration. We present new high-resolution, three-dimensional, magnetohydrodynamics simulations that reveal the detailed evolution of the magnetic shear/guide field throughout an eruptive flare. The magnetic shear evolves in three distinct phases: shear first builds up in a narrow region about the PIL, then expands outward to form a thin vertical current sheet, and finally is transferred by flare reconnection into an arcade of sheared flare loops and an erupting flux rope. We demonstrate how the guide field may be inferred from observations of the sheared flare loops. Our results indicate that initially the guide field is larger by about a factor of 5 than the reconnecting component, but it weakens by more than an order of magnitude over the course of the flare. Instantaneously, the guide field also varies spatially over a similar range along the three-dimensional current sheet. We show that the temporal evolution of the guide field has a profound impact on the number and structuring of plasmoids in the reconnecting current sheet. We discuss the implications of our results for understanding observations of flare particle acceleration.

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X-ray Auroral Flares and Solar Flares from Jupiter

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In 1979, while the Voyager spacecraft were undertaking their paradigm-shifting explorations of the Jovian system, the Earth-orbiting Einstein X-ray observatory was also taking the first X-ray images of the planet (Metzger et al. 1983). Through the 1990s, ROSAT further evolved our understanding of planetary X-rays, differentiating Jupiter's X-ray aurorae from the scattered solar photons dominating the equator (Waite et al. 1995; Gladstone et al. 1998). The year of 1999 ushered in the modern era of X-ray astronomy with the launch of the highly complementary Chandra and XMM-Newton X-ray observatories. These cutting-edge astrophysics platforms uncovered a treasure trove of high energy astrophysical emissions from Jupiter. In particular, at the poles, they revealed a variety of vibrant aurorae: impulsive auroral X-ray flares which can occur with a regular periodic beat every few 10s of minutes (Gladstone et al. 2002); flickering dim ion aurora along the boundary of the swirl region varying on timescales of minutes (Dunn & Yao et al. in review); electron bremsstrahlung aurora from along the main emission (Branduardi-Raymont et al. 2004; 2008) and hints of a transient electron aurora coincident with magnetospheric injection events (Wibisono et al. 2021). Observations of these diverse and spectacular emissions has sparked ground-breaking theoretical work to deduce the magnetospheric processes responsible, suggesting, for example, the presence of now-observed Megavolt potential drops at Jupiter's pole (e.g. Cravens et al. 2003; Clark et al. 2020).

At Jupiter's equator the scattered solar emissions reflect the spectrum and time signatures of solar flares, with XMM-Newton and Chandra offering high energy resolution from 0.2-12 keV, providing insights into solar spectral signatures that potentially cannot be observed by solar observatories.

In this talk, we will showcase the structures and observations discussed above and show how comparisons between remote X-ray observations and in-situ measurements (particularly by Juno) are revealing the processes that lead Jupiter to produce its X-rays (Yao & Dunn et al. 2021). We'll explore how changing solar and solar wind conditions change the planet's X-ray emissions (Dunn et al. 2016; 2020a,b) and how the X-rays connect with UV and radio emissions, magnetic field vibrations and plasma pulsations, to unify Jupiter's pulsed emissions and their source processes. Finally, we'll touch on other exciting X-ray science in the Jovian system: direct imaging of the radiation belts by Suzaku (e.g. Numazawa et al. 2019), Jupiter's magnetar-like X-ray spectra observed by NuSTAR (Mori et al. in review) and the elemental fingerprint fluorescence glow from plasma impacts with surfaces of the moons (e.g. Nulsen et al. 2020).

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Radiative magnetic reconnection near compact objects

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The release of magnetic energy through magnetic reconnection is a major process invoked to model the activity of magnetars, black holes, gamma-ray bursts, and precursors of neutron star mergers. Energy dissipation in these compact objects occurs in a dense radiation field, which impacts the dissipation mechanism and generates copious electron-positron pairs. Radiation spectrum emitted by magnetic dissipation is mainly controlled by the dimensionless compactness parameter set by the ratio of the released power to the object size. Recent simulations of this process demonstrate a reasonable agreement with the observed X-ray spectra of magnetar bursts and the hard state of accreting black holes.

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Direct High-Resolution Imaging of Exoplanets with the Solar Gravitational Lens

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Nature has presented us with a very powerful "instrument" that we are yet to explore and put to use. This instrument is the Solar Gravitational Lens (SGL), which results from the ability of the gravitational field of the Sun to focus light from faint, distant targets. In the near future, a modest telescope with a coronagraph could operate in the focal region of the SGL and, using enormous amplification provided by the Lens, could provide multipixel images of exoplanets. We discuss the imaging properties of the SGL and introduce a mission concept to the SGL focal region that could provide us with direct, high-resolution images and spectroscopy of a potentially habitable Earth-like exoplanet. A meter-class telescope could yield ~(250×250)-pixel images of an "Earth 2.0" at distances up to 30pc with spatial resolution high enough to see its surface features. We address some aspects of mission design and spacecraft requirements, as well as capabilities needed to fly this mission in the next two decades. We also discuss technologies for fast transit through the solar system

that will be demonstrated during our ongoing NIAC Phase III study. For background, please check: https://www.youtube.com/watch?v=NQFqDKRAROI

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Particle Acceleration in Massive Stellar Binary Systems

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The majority of massive stars form a binary system with another massive star. Their strong winds with velocities at 1000-3000 km s^{-1} collide between the two stars and produce stationary shocks. Several so-called colliding wind binary systems (CWBs) within a few kpc from the Sun produce shock-heated plasmas at ~3-5$\times 10^7$ K and emit luminous X-rays up to ~10^{34-35} ergs s^{-1}. The shock should also accelerate a small number of particles to relativistic energies via the Fermi mechanism. In the 2010s, the NuSTAR and Fermi observatories with excellent sensitivities in the extremely hard X-rays (>10 keV) or GeV gamma-rays detected signatures of the accelerated, non-thermal particles from eta Carinae, a supermassive star with the strongest colliding wind activity in our Galaxy. The spectra suggest at least two components, perhaps originating from pion-decay radiation or inverse-Compton radiation of stellar UV radiation upscattered by the accelerated particles. I introduce the current understanding of particle acceleration in massive CWBs.

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The X-ray telescope STIX on Solar Orbiter: first results and future prospects

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Solar Orbiter is an ESA space mission that was successfully launched on February 10th, 2020, from Cape Canaveral. Its purpose is to improve our understanding of how the Sun creates and controls the heliosphere. The Spectrometer/Telescope for Imaging X-rays (STIX) is one of sic remote-sensing instruments on board and provides imaging spectroscopy of the of solar flares in the 4-150 keV range. Thus, STIX is able to measure quantitatively both the parameters of the hot flare plasma and the characteristics of the accelerated electrons. Together with the other instruments on Solar Orbiter as well as with other space-borde and ground based observational assets, STIX will study energy release and particle acceleration in solar flares. IN this talsk, the basic characteristics and capabilities of the instrument will be discussed, and the first results obtained during the cruise phase of Solar Orbiter (2020 and 2021) will be reviewed. Finally, the prospects for STIX in the upcoming science phase will be addressed.

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Hot Plasma Flows and Oscillations in the Loop-top Region During the 2017 September 10 X8.2 Solar Flare

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In this study, we investigate motions in the hot plasma above the flare loops during the 2017 September 10 X8.2 flare event. We examine the region to the south of the main flare arcade, where there is data from the Interface Region Imaging Spectrograph (IRIS) and the Extreme ultraviolet Imaging Spectrometer (EIS) on Hinode. We find that there are initial blueshifts of 20–60 km/s observed in this region in the Fe XXI line in IRIS and the Fe XXIV line in EIS, and that the locations of these blueshifts move southward along the arcade over the course of about 10 minutes. The cadence of IRIS allows us to follow the evolution of these flows, and we find that at each location where there is an initial blueshift in the Fe XXI line, there are damped oscillations in the Doppler velocity with periods of ~400 s. We conclude that these periods are independent of loop length, ruling out magnetoacoustic standing modes as a possible mechanism. Microwave observations from the Expanded Owens Valley Solar Array (EOVSA) indicate that there are nonthermal emissions in the region where the Doppler shifts are observed, indicating that accelerated particles are present. We suggest that the flows and oscillations are due to motions of the magnetic field that are caused by reconnection outflows disturbing the loop-top region.

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Low-energy Cutoff of Non-thermal Electrons estimated from a Spectro-polarimetric Observation

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Low-energy cutoff of the non-thermal electron energy distribution is crucial to derive the total non-thermal electron energy. A flare kernel associated with a C4 class flare was observed in a spectral window including the He I triplet 1083.0 nm and Si I 1082.7 nm with a spectro-polarimeter on the Domeless Solar Telescope at Hida Observatory on 2015 August 9. The observed Stokes profiles of the He I triplet in the flare kernel are well reproduced through inversions considering the Zeeman and the Paschen-Back effects with a three-slab model of the flare kernel. One slab of them produces an absorption, while the others produce emissions with upward and downward velocities. The magnetic field strength inferred from the emission components of the He I line was 1400 G, which is significantly stronger than 690 G that was observed at the same location in the same line 6.5 hr before the flare. In addition, the photospheric magnetic field vector derived from the Si I10827 Å was similar to those of the He I emissions. To explain this result, we suggest that bombardment of non-thermal electrons leaded to the formation of a coronal temperature plasma around a formation layer of the photospheric Si I line, and then the emission in the He I triplet was produced in the deep layer. Assuming an umbral atmospheric model and a power-law index of non-thermal electron energy distribution, we derived the low-energy cutoff of the non-thermal electron as 20-30 keV from the location where the He I emissions were formed.

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Particle Acceleration in high-beta ICM Shocks

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Weak shocks are induced by mergers and/or supersonic flow motions in the hot tenuous intracluster medium (ICM) of galaxy clusters. Cosmic ray (CR) protons are expected to be accelerated at quasi-parallel shocks via diffusive shock acceleration (DSA), whereas CR electrons are expected to be accelerated preferentially at quasi-perpendicular shocks. Reflection of incoming particles, and ensuing self-excitation of plasma waves via microinstabilities, and scattering of backstreaming particles back to the shock by those upstream waves play important roles in particle injection to DSA. Pre-accelerated particles can participate in the Fermi-I process and be accelerated further to relativistic energies. We review these kinetic processes operating in ICM shocks.

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Study of particle acceleration and plasma heating in solar flares with X-ray and EUV data: a progress report

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Particle acceleration and plasma heating are key aspects of energy release in solar flares. They are closely related to magnetic reconnection process. Evidence of non-thermal emissions are found not only in large flares, but also in microflares and even nanoflares, suggesting that energetic electrons play a central role in energy release and plasma heating in at least a large fraction of flares. However, how plasma is heated in various coronal phenomena, including active regions, flares, coronal loops, hot channels, bright points, and quiet corona, is still an open question. In this talk, I will present recent studies using X-ray and EUV data which revealed new features of energetic electrons and particle acceleration in corona. The calculation of differential emission measure (DEM) for quiet Sun has been further improved recently and was used in the analysis of energetic particles and full corona. I will also introduce a flare detection code (RFD) and new database for studies of long-term coronal evolution and flaring activities during a full solar cycle. The database will provide us with essential info for both statistical studies and case studies. Preliminary statistical results suggest that microflares and nanoflares may help solve the coronal heating problem. The significance of these results for future studies and solar missions is discussed.

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Particle acceleration in black hole accretion flows

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The hard X-ray emission seen from accreting black holes shows that some fraction of the gravitational energy is not thermalised in optically thick material, so gives a more direct view of the particle acceleration mechanism(s) in strong gravity. I will review how we can use these data to understand more about how particles are accelerated in the vicinity of the black hole.

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Electron acceleration in solar flares

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Magnetic reconnection is a significant driver of energetic particles in flares both on the sun and the broader universe. Single x-line models fail to explain the large number of energetic electrons seen in flares. However, simulations reveal that reconnection becomes turbulent in the flare environment, consistent with observations of non-thermal broadening of spectral lines. Magnetic energy release and particle acceleration therefore take place in a multi-x-line environment. A major surprise is that the energy gain of the most energetic electrons is dominated by Fermi reflection in growing and merging magnetic flux ropes rather than parallel electric fields. The implication is that the kinetic scale boundary layers that control the parallel electric field are not important in flare energy release where the separation of scales can reach 10^{10}. A new computational model, $kglobal$, has been developed that blends MHD dynamics with electron particles but eliminates all kinetic scales. Feedback of the energetic electrons on the MHD is included. Simulations of reconnection in a macro-scale system reveal electron powerlaw distributions that extend nearly three decades in energy and that the dominant control parameter is the ambient out-of-plane (guide) magnetic field. PIC models fail to produce such spectra because of inadequate separation of scales. The electron spectral indices match those measured by RHESSI and EOVSA for the September 10, 2017, flare. Major challenges are to understand how relativistic electrons are "confined" as they gain significant energy. The results suggest that modeling of particle acceleration in realistic macro-scale flare geometry will be possible.

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Non-thermal electron acceleration by magnetically driven reconnection in the laboratory*

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Magnetic reconnection is a ubiquitous astrophysical process that rapidly converts magnetic energy into some combination of plasma flow energy, thermal energy, and non-thermal energetic particles, including energetic electrons. Various reconnection acceleration mechanisms in different low-beta and collisionless environments have been proposed theoretically and studied numerically. However, none of them have been heretofore confirmed experimentally, as the direct observation of non-thermal particle acceleration in laboratory experiments has been difficult. Here we report the direct measurement of accelerated non-thermal electrons from low-beta magnetically driven reconnection in experiments using a laser-powered capacitor coil platform. The angular dependence of the measured electron energy spectrum and the resulting accelerated energies, supported by particle-in-cell simulations, indicate that the mechanism of direct electric field acceleration by the out-of-plane reconnection electric field is at work. Scaled energies using this mechanism show direct relevance to astrophysical observations. Our results therefore support one of the proposed acceleration mechanisms by reconnection, and establish a new approach to study reconnection particle acceleration with laboratory experiments in relevant regimes.

*A. Chien, L. Gao, S. Zhang, H. Ji, E. Blackman, W. Daughton, A. Stanier, A. Le, F. Guo, R. Follett, H. Chen, G. Fiksel, G. Bleotu, R. Cauble, S. Chen, A. Fazzini, K. Flippo, O. French, D. Froula, J. Fuchs,

S. Fujioka, K. Hill, S. Klein, C. Kuranz, P. Nilson, A. Rasmus, R. Takizawa, "Direct measurement of non-thermal electron acceleration from magnetically driven reconnection in a laboratory plasma", submitted (2021).

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The Interplay of Magnetically Dominated Turbulence and Magnetic Reconnection in Accelerating Particles

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Nature's most powerful high-energy sources are capable of accelerating particles to high energy and radiate it away on extremely short timescales, even shorter than the light crossing time of the system. It is yet unclear what physical processes can produce such an efficient acceleration, despite the copious radiative losses. By means of fully-kinetic particle-in-cell simulations that include self-consistently the radiation reaction force, we investigate the acceleration and cooling of particles in turbulent plasmas subject to strong synchrotron cooling. We show that reconnecting current sheets, which develop self-consistently in the turbulent plasma, inject particles with a hard power-law distribution and low pitch angle. Particles cool down by increasing their pitch angle, which affects the cooled particle distribution. Due to the low pitch angle of the accelerated particles, significant synchrotron radiation is emitted above the synchrotron burnoff limit. Synchrotron radiation from the accelerated particles give rise to a synchrotron energy flux with a power-law range $\nu F_\nu \propto \nu^s$ with $s \sim 1$, up to the peak frequency $\nu_{\rm peak}$. Our findings have important implications for understanding the nonthermal emission from high-energy astrophysical sources, most notably the prompt phase of gamma-ray bursts and gamma-ray flares from the Crab nebula.

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The Magnetic Connection Between Flares, Rotation, and Age for the Volume-Complete Sample of Fully Convective M Dwarfs within 15 Parsecs

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Fully convective M dwarfs display a diversity of magnetic phenomena, motivating questions of how these stars generate and sustain large scale coherent magnetic fields. We present an observational study that characterizes the relationship between age, stellar rotation, flares, and chromospheric activity for the volume-complete sample of M dwarfs with masses between 0.1 and 0.3 solar masses that reside within 15 parsecs. We found that these stars fall into two groups: The first set has ages less than 3 Gyr, flares frequently, and has short rotation periods, while the second group has ages in excess of 6 Gyr, with rotation periods exceeding 90 days, and flares very rarely. We find that all mid-to-late M dwarfs display the same slope for the frequency of flares as a function of energy, with an index sufficient to explain coronal heating.

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Particle Acceleration in Magnetic Reconnection Events Observed by MMS

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The NASA Magnetospheric Multiscale (MMS) mission uses four closely-spaced spacecraft to investigate magnetic reconnection in the boundary regions of the Earth's magnetosphere by measuring charged particles and electric and magnetic fields at the electron scale for the first time in space. Magnetic reconnection involves the conversion of magnetic energy to heat and charged particle kinetic energy. Particle energization is manifested in several different ways including jets of ions streaming away from X lines, electron jets streaming both toward and away from X lines, out-of-plane flows of electrons accelerated by the reconnection electric field, and high-energy ions and electrons produced by induced electric fields and Fermi acceleration. MMS encounters both asymmetric reconnection at the dayside magnetopause and symmetric reconnection in the magnetotail. Particle densities are much lower in the tail so that the available magnetic energy per particle is much higher than on the day side. The sources of accelerated electrons are also different being primarily magnetosheath electrons on the day side and neutral-sheet electrons on the night side. Meandering trajectories are important in both regions, which allows for cross-field acceleration by the reconnection electric field. The long-term puzzle of the acceleration of particles to energies of hundreds of keV during magnetic reconnection events in the geomagnetic tail has been solved by MMS, which observes acceleration by turbulent electric fields in the region surrounding the X line.

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Reconnection-Driven Particle Acceleration in High-Energy Astrophysics

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Nonthermal particle acceleration (NTPA), including to ultra-relativistic energies, plays an extremely important role in astrophysics. Some of its most spectacular manifestations come from high-energy astrophysics, where we routinely observe very bright and often rapidly-varying flaring emission with broadband power-law spectra from a rich variety of objects, including the exotic environments around accreting black holes and neutron stars. Magnetic reconnection has been increasingly often invoked in recent years as the most viable mechanism for driving NTPA in many high-energy astrophysical contexts, powering the most violent, most extreme events, especially in relativistic plasmas. In this talk I will review some of the most remarkable examples of nonthermal high-energy astrophysical flares and will explain why magnetic reconnection presents the most natural explanation for them. I will also describe the recent theoretical and numerical progress in our understanding of reconnection-driven relativistic NTPA, highlighting the key differences and similarities with solar-flare reconnection. I will also outline the most important and promising directions for future research.

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Spectroscopic observations and modeling of solar flares

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Recent spectroscopic instruments such as Hinode/EIS and IRIS have enabled significant advancements in our understanding of some of the physical mechanisms at play during the impulsive phase of flares, including details of how the non-thermal energy is released and propagated from the corona to the low-atmosphere through accelerated particles. At the same time, the new discoveries have brought to light new unsolved questions and challenges for current models. This talk will provide some examples of the unique contributions to our understanding of flares from these instruments and in particular how state-of-the-art heating models of flares can be constrained by their rich spectral diagnostics. I will also discuss the path forward to solve some of the outstanding problems in preparation for the next generation of solar mission concepts such as PhoENiX.

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HXI onboard ASO-S

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Advanced Space-based Solar Observatory (ASO-S) was officially approved in the end of 2017. The primary scientific objectives are to study the relationships between solar magnetic field, solar flares and coronal mass ejections. The are three payloads on it. By now the mission is in the stage of flight model and is planed to be launched in 2022. This talk will describe the general progress of the mission, with a focus on the payload of Hard X-ray Imager (HXI).

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Numerical approaches for the understanding of particle acceleration during magnetic reconnection

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TBD

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Magnetic reconnection as a key phenomenon in clusters of galaxies

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The Intra-Cluster Medium (ICM), i.e., the ideal classical plasmas associated with individual cluster of galaxies (CLGs), is the most dominant known form of cosmic baryons. Within the ICM, the member galaxies move at transonic velocities, and their motion was long believed to be unaffected by the ICM. However, through a series of X-ray observations (from Makishima et al. 2001 to the latest one, Gu, Makishima, Matsumoto et al. 2020), we have revealed that the galaxies strongly interact with the ICM, and transfer a fraction of their kinetic energies to the ICM on cosmological time scales. Our grand scenario (Gu+20) can explain; (1) the vitally needed heating source for the ICM to stop its radiative cooling; (2) the stable balance between the heating and cooling ; (3) the turbulence velocity of ~160 km/s measured with Hitomi; and (4) the uniform metal distributions in the ICM out to the CLG periphery. At the same time, it provides natural explanations to; (5) the radial distributions of the three components (galaxies < Dark Matter < ICM) in nearby CLGs ; and (6) the observed cosmological infall of galaxies towards the CLG centers (Gu+13,+16). We further expect that the scenario ultimately explains; (7) the particle acceleration in the intra-cluster space, and (8) the long sought origin of the environmental effects working on galaxies. Since the galaxy motion through the ICM is transonic and super Alfvenic, we do not expect the creation of either strong shocks or slow shocks. Instead, magnetic reconnection is considered to play a key role when the kinetic energies of galaxies are transferred to the ICM, and the galaxies are dragged and decelerated by the ICM as a back reaction.

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Constraints on the acceleration region of type III radio bursts from radio bursts and X-ray bursts

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During the gradual phase of flare SOL2017-09-09T10:50, a faint increase of non-thermal X-ray emission has been detected by Fermi/GBM, and is associated with radio decimetric spikes and type III radio bursts detected by the ORFEES radio-spectrograph, the LOFAR radio-telescope, and the Wind/WAVE instrument. These signatures indicate that a faint acceleration event was the source of electron beams propagating to the heliosphere. We show that the non-thermal X-ray bursts and radio decimetric spikes correlate on short time scales, which support the idea that the fragmentation of the radio emission into spikes is linked to the fragmentation nature of the acceleration process itself. The combination of HXR and radio diagnostics in the corona is used to provide strong constraints on the density of the acceleration site. Using spectroscopic imaging of the radio emission at lower frequencies using the LOFAR observations, and the constraints on the acceleration site derived from the X-ray and higher frequency radio emission, we show that the observed radio source sizes are much larger than the expected size of the electron beam in the high corona, confirming that radio source properties are strongly affected by radio-wave scattering due to turbulent density fluctuation of the ambient plasma.

Day 3 / Session 2 / 67

Multiple Boris integrators for particle-in-cell (PIC) simulation

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Particle-in-cell (PIC) simulation has long been used in theoretical plasma physics. In PIC simulation, the Boris solver is the de-facto standard for solving particle motion, and it has been used over a half century. Meanwhile, there is a continuous demand for better particle solvers. In this contribution, we introduce a family of Boris-type schemes for integrating the motion of charged particles. We call the new solvers the multiple Boris solvers. The new solvers essentially repeat the standard two-step procedure multiple times in the Lorentz-force part, and we derive a single-step form for arbitrary subcycle number n. The new solvers give n^2 times smaller errors, allow larger timesteps, but they are computationally affordable for moderate n. The multiple Boris solvers also reduce a numerical error in long-term plasma motion in a relativistic magnetized flow.

Day 3 / Session 2 / 4

Electron energy partition in solar flares and Earth's magnetotail

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Electrons are accelerated to non-thermal energies during explosive energy-release in solar flares and Earth's magnetotail. To understand the origin of energetic electrons, magnetic reconnection and associated kinetic structures have been studied extensively. However, it still remains unclear how the electron energy spectrum evolve during magnetotail reconnection and how energies are partitioned between thermal and non-thermal electrons. Here we show, based on in-situ observations by NASA's Magnetospheric Multiscale (MMS) mission, that electron energy spectra during reconnection are generally represented by the kappa distribution with the typical power-law index δ of 3-4, regardless of preconditioning (or activity level) of the magnetotail. However, an additional Maxwellian distribution is often necessary to better fit the data, indicating there might be an additional plasma population in the plasma sheet. The resultant non-thermal fraction of electron energy ranges from ~20% to ~60%. These values are consistent with those obtained in solar flares or, more specifically, the above-the-looptop hard X-ray coronal source. We envision that the observed properties facilitate comparative studies of particle acceleration during explosive energy-release in solar and terrestrial plasma environment.

Day 3 / Session 2 / 6

The study of an extended recovery of an ICME induced extreme geomagnetic storms

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Geomagnetic storms are crucial phenomena during severe space weather conditions, which directly or indirectly affects us. Temporal evolution of the storm is investigated using Dst or SYM-H index.

Usually, CIR generated storms are weaker but have quite a longer recovery phase than ICME generated stronger storm recovery phase. In the investigation of specific storm events, we noticed that ICME induced storm recovery phase is quite longer than usual. We observed the presence of strong Alfvenic fluctuations during the recovery phase of the storm. Thus we indicated that Alfvenic fluctuations could be a possible reason behind this extended recovery phase. Further, we have investigated the fast and slow recovery of extreme storms that occurred in the last three decades. We used exponential, hyperbolic, and linear decay functions to fit the fast and slow recovery of the storms. We observed that exponential and hyperbolic functions are well explained only for fast recovery while slow recovery is well explained by a linear function.

Day 3 / Session 2 / 8

Large Microwave Flare Sources with Multi-loop Magnetic Reconnection observed by EOVSA Imaging Spectroscopy

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We present the imaging spectroscopy of C-class flare SOL2017-04-04 observed by Expanded Owens Valley Solar Array (EOVSA) to investigate the source morphology of the low-frequency microwave emission. At the low frequencies, the microwave flare source showed an extended emission almost ten times as large as the usually observed high-frequency and hard X-ray flare emission. The source area seems to decrease steeply by more than an order of magnitude as we move from low to high frequencies. Unlike a single and straightforward loop "standard solar model" type flare, this event in the microwave emission shows the contribution of the multiple flux loops in different sizes with the "three-dimensional loop-loop interaction" scenario, resulting in the flare eruption. The emission at other wavelengths barely shows any sign of particle transport at the secondary sites where we see the low-frequency source centroids. These high-resolution microwave observations indicate that, after the main reconnection process, the accelerated particles have access to a much larger volume of the flaring region through the overlying loops. These results highlight the diagnostic potential of the microwave frequencies through which the physical conditions during the flares can be directly interpreted.

Day 3 / Session 2 / 11

Behaviour of neutrino near to sun spot

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The solar phenomenon are of varied synthesis process whereas the actual process of sunspot and inside the sunspot with neutrino oscillation give a new glimpses of understanding the present research.

Day 3 / Session 2 / 19

Principal Acceleration Process for High-Energy Particle Event

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The physical links between CMEs and solar storms were well understood, but the CMEs were not still confirmed for particle acceleration at the Sun. It was observed that CME associated shocks accelerate particles in the interplanetary (IP) space, but it was not understood at what distance from the Sun such acceleration becomes important. Although m-type II bursts, indicative of MHD shocks low in the corona, are clearly associated with the majority SEP events, such shocks were not found ahead of CMEs. Some researchers found that the speeds deduced from the drift rates of m-type II bursts have differed greatly from the speeds of accompanying CMEs, thus suggesting that the m-type II bursts are not caused by shocks driven by CMEs. The m-type bursts are most likely caused by flares, not by CMEs. Recently, we investigated that the flare initial onset is always earlier than the CME initial onset and suggested that the flare is probably the main reason of the high energy particle events. When we assumed the particle onset at nearly 1 au, it was found that the high energy particle event onset is close to the onsets of the flare components and obviously if we consider the particles are not scatter free and trace nearly close to the Sun, the flare appears to be the principal acceleration that causes high-energy particle events (MeV; GeV). Current space missions, such as Solar Orbiter and Parker Solar Probe located in the inner heliosphere, will surely shed more light into this topic.

Day 3 / Session 2 / 21

Hard X-ray upper limits of the quiet Sun with new FOXSI observations

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Solar nanoflares are small eruptive events releasing magnetic energy in the quiet corona. If nanoflares follow the same physics as their larger counterparts, they should emit hard X-rays (HXRs) but with a rather faint intensity. A copious and continuous presence of nanoflares would result in a sustained and persistent emission in HXRs, which in turn would deliver enormous amounts of energy into the solar corona, possibly accounting for its high temperatures. To date, there has not been any direct observation of such sustained and persistent HXRs from the quiescent Sun. However, Hannah et al. in 2010 constrained the quiet Sun HXR emission using almost 12 days of quiescent solar-off-pointing observations by RHESSI. These observations set 2σ upper limits at 3.4×10^{-2} photons^{-1} s^{-1} cm^{-2} keV^{-1} and 9.5×10^{-4} photons^{-1} s^{-1} cm^{-2} keV^{-1} for the 3-6 keV and 6-12 keV energy ranges, respectively. Observing feeble HXRs is challenging because it demands high sensitivity and dynamic range instruments in the HXR energy band. The Focusing Optics X-ray Solar Imager (FOXSI) sounding rocket experiment excels in these two attributes when compared with RHESSI. Particularly, FOXSI completed its third successful flight (FOXSI-3) on September 7th, 2018. During FOXSI-3's flight, the Sun exhibited a fairly quiet configuration, displaying only one aged non-flaring active region. Using the entire $\sim$6.5 minutes of FOXSI-3 data, we constrained the quiet Sun emission in HXRs. We found 2σ upper limits in the order of $\sim 10^{-3}$ photons^{-1} s^{-1} cm^{-2} keV^{-1} for the 5-10 keV energy range. FOXSI-3's upper limit is consistent with what was reported by Hannah et al., 2010, but FOXSI-3 achieved this result using $\sim$1/2640 less time than RHESSI. A

possible future spacecraft using FOXSI's concept would allow enough observation time to constrain the current HXR quiet Sun limits further or perhaps even make direct detections.

Day 3 / Session 2 / 36

Electroformed X-ray Optics Development for the FOXSI-4 Rocket Project

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We have been developing X-ray optics for a fourth FOXSI (Focusing Optics X-ray Solar Imager) sounding rocket experiment, FOXSI-4, which will be launched in 2024 and part of a flare campaign to elucidate of the acceleration / heating mechanism of solar flares. Because much brighter X-ray emissions are expected, high imaging performance rather than effective area is essential. To achieve the requirement of FOXSI-4 on the angular resolution, we introduced our original electroforming technique. Our idea is to apply our original ultra-precise electroforming technique which has been developed for X-ray focusing systems in synchrotron radiation facilities to X-ray optics for astrophysics. Technologically, to fabricate larger mirrors in diameter and height (typically 10 /100 mm in diameter / height for ground X-ray focusing systems) is the most difficult challenge. As a first step, we fabricated a Wolter- I full-shell Ni test sample with height, diameter, and, thickness of 60, 60, and, 1 mm whose design parameters are optimized for FOXSI-4. We conducted X-ray irradiation tests at 15 keV and obtained focused images from the entire area successfully for the first time. Even though the resultant angular resolution in HPD is >30 arcsec due to remaining low- / mid-frequency figure errors in an axial direction, a sharp inner core with an FWHM value of ~4 arcsec is observed because of a very low figure error in a circumferential direction as expected from the inner surface profiles. It is also found that spot scan measurements with a beam size of 1 mm x 5 mm reveal a spatial variation in their performances and some of the areas achieved ~20 arcsec in HPD. Design, fabrication, and evaluation of the mirror module assembly are currently in progress and the impact of the mounting process will also be evaluated using Xray. We will show recent status of our development and future plans.

Day 3 / Session 2 / 39

Effects of magnetic fields on primordial abundance evolution

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Various effects of primordial magnetic fields (PMFs) on nuclear abundances are reported. It has been known that a strong PMF enhances the cosmic expansion rate and distribution functions of electrons and positrons in the early universe. Therefore, primordial nuclear abundances are a probe of the PMF during the big bang nucleosynthesis (BBN). A fast expansion due to the magnetic field energy density results in more abundant relic neutrons at the primordial helium synthesis than in standard BBN. This large neutron abundance results in a stronger destruction of 7Be via the 7Be(n,p)7Li(p,alpha)

reaction sequence [1]. Although the primordial Li abundance is reduced by the efficient 7Be destruction, the degree of the reduction is limited by significant effects on D and 4He abundances. A recent calculation of BBN under inhomogeneous PMFs shows that the effects on nuclear abundances significantly depend on the spatial distribution of the PMF amplitude [2]. Long after the BBN, the cosmological structure formation progresses. If there is a PMF with a comoving intensity of nano-Gauss over small structure scales, it affects motions of charged particles including Li+ ions [3]. As a result, abundances of chemical species as well as the baryonic density can evolve inhomogeneously under PMFs. This can give a solution to the cosmic Li problem, that is, a discrepancy in Li abundance between observations of metal-poor stars and the standard BBN prediction [3,4].

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Day 3 / Session 2 / 32

Search for neutrinos associated with solar flares in the Super-Kamiokande detector

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Search for neutrinos produced during solar flares has been discussed for the last 60 years while clear signals of neutrinos associated with solar flares (solar flare neutrinos) have not been identified yet. Since neutrinos are not affected by the interplanetary magnetic field, solar flare neutrinos may give a hint of particle acceleration mechanism in solar flares. According to some theoretical predictions, the flux of the solar flare neutrino depends on the releasing energy and the location, where solar flares occur on the surface of the Sun. To minimize the background for the solar flare neutrino searches, data of solar satellites (GOES, RHESSI, and Geotail) were analyzed and windows for solar flare neutrino searches on the visible side were defined. In addition, coronal mass ejection event catalogs were used to determine the search windows for solar flare neutrinos on the invisible side of the Sun. The Super-Kamiokande (SK) is the world's largest underground water Cherenkov detector in Japan. The SK experiment has been started in 1996 and its data set covers the period of solar cycles 23 and 24. In this presentation, the results of solar flare neutrino searches using data set from 1996 to 2018 are presented.

Day 3 / Session 2 / 44

Introduction to STIX Spectroscopy

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The Spectrometer/Telescope for Imaging X-rays (STIX) onboard the Solar Orbiter is dedicated to the study of solar flares. STIX measures HXR spectra in the range 4 to 150 keV with up to 1 keV resolution, binned on board into 30 scientifically useful energy bins over 32 pixellated detectors. These spectra are also binned in time between 20 seconds, at standard background level, down to 0.5 seconds during the peak of moderate flares. Interesting events can then be downloaded to Earth at up to this stored resolution based on the scientific rationale and available telemetry. The collection and format of our main science data products will be described along with the available and upcoming analysis software. Examples of spectra observed during the Near Earth Commissioning and Cruise Phases of Solar Orbiter demonstrating the initial capabilities of STIX will also be shown.

Day 3 / Session 2 / 50

Efficient Nonthermal Ion and Electron Acceleration in 3D Magnetic Reconnection

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Solar flare and magnetotail observations show simultaneous acceleration of ions and electrons into power-law energy distributions extending to high energy. This suggests a common reconnection acceleration process but the underlying physics is not well understood. During magnetic reconnection, energetic particles undergo a universal Fermi acceleration process involving the curvature drift of particles. However, the efficiency of this mechanism is limited by the trapping of energetic particles within flux ropes. Using 3D fully kinetic simulations, we demonstrate that the flux-rope kink instability leads to field-line chaos in weak-guide-field regimes where the Fermi mechanism is most efficient, thus allowing particles to transport out of flux ropes and undergo further acceleration. As a consequence, both ions and electrons form clear power-laws which contain a significant fraction of the released energy. The low-energy bounds, which control the nonthermal energy contents, are determined by the injection physics, while the high-energy cutoffs are limited only by the system size. These results have strong relevance to observations of nonthermal particle acceleration in both the solar corona and magnetotail.

Day 3 / Session 2 / 52

The Acceleration of Energetic Electrons by the Reconnection-driven Termination Shock

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Solar flares are the most powerful energy release phenomena and important sites for particle acceleration in the solar system. Although many particle acceleration mechanisms have been proposed, it remains controversial which process plays a dominant role and can explain various observational signatures of particle energization. In solar flares, HXR and radio observations provide primary diagnostics of the acceleration and transport of energetic electrons. Nonthermal looptop sources have suggested that particle acceleration takes place above the top of flare loops and the flare termination shock is one of the promising candidates as the acceleration mechanism. Here we investigate the acceleration of energetic electrons in solar flares by combining a large-scale MHD simulation of a solar flare with a particle acceleration and transport model. We find that the accelerated electrons are concentrated in the looptop region due to the acceleration at the termination shock and confinement by the magnetic trap structure, in agreement with HXR and microwave observations. Numerous plasmoids can be produced in the reconnection current sheet and interact dynamically with the shock. We find that the energetic electron population varies rapidly in both time and space due to plasmoid-shock interactions. We also present the first numerical modelling of nonthermal double coronal X-ray sources based on electron acceleration by a pair of termination shocks. Our simulations have strong implications to the interpretation of coronal nonthermal emission sources.

Day 3 / Session 2 / 14

Suprathermal electrons in Earth's magnetotail: What can they teach us about flare electron energization?

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The large-scale magnetic configuration and plasma beta in solar flares are similar to those in the magnetotail during reconnection. Studies of suprathermal electrons in the magnetotail may thus shed light on suprathermal electron production during flares. We will discuss statistical and case studies of MMS magnetotail measurements. In particular, we will assess: (1) whether primary electron energization occurs at the reconnection X-line or downstream, and (2) roles of magnetic field configurations and fluctuations (including magnetic islands) in energizing electrons to suprathermal energies.

Day 3 / Session 3 / 43

The role of plasma physics, shocks, and magnetic fields in the intra-cluster medium

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Although commonly approximated as an ideal fluid in cosmological simulations, the hot tenuous gas permeating clusters of galaxies is known to be a magnetized collisionless plasma sharing some similar physical properties with, e.g., planetary magnetospheres, the solar atmosphere and solar wind, and accretion discs around compact objects. I will discuss the current knowledge and challenges in constraining and understanding the process of particle acceleration in galaxy clusters, as well as the cosmic evolution of large-scale magnetic fields. At the moment, most studies revolve around observations of shock- and turbulent (re)acceleration, however there are a few instances where magnetic reconnection has also been hypothesized to play a role.

Day 3 / Session 3 / 38

Solar Spectroscopy in X-rays and EUV, and Future Prospects

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Solar flares are the most powerful explosions in the solar system, impulsively releasing stored magnetic energy to heat coronal plasma to tens of MK and accelerating electrons to hundreds of MeV and ions to tens of GeV. Even within quiescent (non-flaring) active regions, ambient plasma is impulsively heated to 5-10 MK, well above the "quiet corona" temperatures of 1-3 MK. Despite many decades of study, the fundamental question of how magnetic energy is stored in the corona and impulsively released to drive these processes remains open. Spectroscopic observations of the Sun offer unique probes into energy release processes. X-ray and extreme ultraviolet (EUV) wavelengths, in particular, provide critical diagnostics of plasma temperatures, densities, and elemental abundances, as well as accelerated electron populations and associated energy deposition. Measurements of these various properties and their evolution over time provide insight into the underlying physical mechanisms of plasma heating and particle acceleration. Each wavelength range offers unique access to specific processes and/or temperature regimes, and combined observations enable a comprehensive picture of impulsive energy release in solar flares and within quiescent active regions. A number of recent and ongoing missions have made significant advancements in answering this question, including with spatially integrated spectroscopy, filtergram imaging, and spectral imaging in X-rays and EUV using various techniques. We provide a brief review of some of these missions and their contributions to the field, including RHESSI, SDO (EVE and AIA), Hinode (XRT and EIS), and MinXSS. We then discuss upcoming missions that will break new ground with novel observations, including the IMPRESS and CubIXSS CubeSats. We close with a long-term outlook for making transformative progress on this question, including the COMPLETE mission concept that aims to finally close this longstanding and fundamental question.

Day 3 / Session 3 / 56

Particle acceleration in the Earth's magnetotail

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Magnetic reconnection is a fundamental universal energy conversion process which converts magnetic energy into particle energy including heating and non-thermal acceleration. In the low Beta plasma of the Earth's magnetotail magnetic energy is released quasi-regularly by the reconnection process, leading to explosive energy release similar to the energy build-up and release process in solar flares. We present recent in-situ Magnetospheric MultiScale (MMS) observations of reconnection-associated particle heating and acceleration in the low Beta, high Alfvén speed regime of Earth's magnetotail. The degree of heating observed in different events vary greatly, suggesting that the characteristics of electron heating depend strongly on plasma parameter regimes. The non-thermal electron energy content, on the other hand, does not show any such dependence.

Day 4 / Session 1 / 25

Magnetic reconnection in the partially ionized low solar atmosphere

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The plasmas in the low solar atmosphere are highly stratified and the total hydrogen density decreases about 6 orders of magnitude within a thin layer of 2 Mm. The temperature in this region is generally only several thousand K and the plasmas are partially ionized. Thanks to the high resolution telescopes, plenty of small scale reconnection events at different altitude in this region have been observed. The interactions between ions and neutrals may strongly affect the reconnection process and make the reconnection mechanisms to be very different from those in fully ionized plasmas. What's more, the radiative transfer and cooling process make the studies of magnetic reconnection in this region to be more difficult. In this talk, we will review the recent progresses on theoretical and numerical studies of magnetic reconnection in the low solar atmosphere , and discuss the mechanisms which lead to fast reconnection rate and heating in different reconnection events.

Day 4 / Session 1 / 45

Accelerations of energetic electrons in the Earth's inner magnetosphere: Arase observations

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In the terrestrial inner magnetosphere, the energetic electron is highly variable during magnetic disturbance such as substorms and magnetic storms. The wave-particle interactions play important roles on accelerations, transportations, and loss of the energetic electrons through the cross-energy couplings. Interactions with MHD fast mode waves cause the betatron accelerations through drift resonance, while whistler mode waves cause the acceleration of electrons through cyclotron resonance. The Arase satellite has observed the inner magnetosphere and provided the direct measurements about these interactions with waves. In this presentation, we will give an overview of the Arase observations about the energetic electron accelerations and discuss what processes are essential to generate ultra-relativistic electrons.

Day 4 / Session 1 / 27

Magnetic Reconnection and Electron Acceleration: Recent Insights from Microwave Imaging Spectroscopy Observations of Solar Flares

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Solar flares involve the catastrophic release of magnetic energy through magnetic reconnection. Solar flares are also highly efficient particle accelerators, capable of accelerating a large number of charged particles to high energies within a short time. The unique sensitivity of microwave emission to both the dynamic coronal magnetic field and the flare-accelerated high-energy electrons makes

it an excellent tool for probing the key physical processes underlying magnetic reconnection and particle acceleration. Recently, we have enjoyed a major transition in solar microwave observing as it has evolved from imaging at a few discrete frequencies to true broadband imaging spectroscopy. In this talk, I will highlight some of our recent results based on this new technique, using data from the Expanded Owens Valley Solar Array and the Karl G. Jansky Very Large Array.

Day 4 / Session 2 / 68

Identification of periodicities in solar wind parameters using empirical mode decomposition and Lomb S periodogram

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Sun shows short and long term periodicity in various kinds of solar phenomena. 11 year cycle is very common in many solar activity parameters, 22 year cycle in magnetic polarity reversal and also slowly varying component of solar radio emission shows periodicity of 27 days. Studies of periodicities in these parameters provide information about physical state of the sun i.e. it quit or in disturbed. Apart from that study of periodic behavior of sun helps us to understand the various mechanisms involved in the different processes happening inside the sun. In the present study we apply empirical mode decomposition and Lomb S periodogram method for the identification of periodicities in solar wind parameters. These parameters show short periodicity of nearly 13.5 days as well as days. It provides very important information regarding the solar dynamics related to the development of dipole tilt. Keywords: EMD, Lomb S periodogram, periodicity, solar wind parameters

Day 4 / Session 2 / 35

Soft X-ray Spectral Diagnostics of Multi-thermal Plasma in Solar Flares with Chandrayaan-2 XSM

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Solar flares result from impulsive energy release due to magnetic reconnection in the solar atmosphere. Observational evidence suggests that the flaring plasma consists of a thermal distribution of particles heated to higher temperatures during the process and a non-thermal distribution of particles. As this hot plasma emits copiously in the X-ray wavelengths, X-ray spectral measurements provide a wealth of information on the physical conditions of the flaring plasma providing insights into the particle acceleration process in magnetic reconnection. Solar X-ray Monitor (XSM) onboard Chandrayaan-2 mission provides broad-band disk integrated soft X-ray solar spectral measurements in the energy range of 1-15 keV with high resolution and time cadence. We model the X-ray spectra obtained with XSM to investigate the evolution of the plasma parameters during a sample of C and M class flares. Using the soft X-ray spectra consisting of the continuum and well-resolved line complexes of major elements like Mg, Si, and Fe, we investigate the consistency of isothermal and multi-thermal assumptions on the higher temperature components of the flaring plasma. We will also discuss the diagnostic potential of combined analysis of soft to hard X-ray spectra of solar flares using XSM along with other instruments in the context of plans for future solar X-ray observatories.

Day 4 / Session 2 / 55

Pitch-angle distribution of accelerated electrons in 3D current sheets with magnetic islands

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We present diagnostic tools for particle energy and pitch angle distributions at acceleration in 3D Harris-type reconnecting current sheets with a single or multiple X-nullpoints taking into account the ambient plasma feedback to the presence of accelerated particles. We explore accel- eration of particles during their passage through 3D reconnecting current sheets occurring in the interplanetary space using particle-in-cell (PIC) approach with single and multiple X-nullpoints (magnetic islands). We consider coalescent and squashed magnetic islands formed in the current sheets with different thicknesses, ambient density and mass ratios, and simulate energy, density and pitch-angle distributions of accelerated particles. We report distinct populations of two groups of particles: transit and bounced ones, which have very different energy and asymmetric pitch-angle distributions associated with the magnetic ffield parameters. The simulated pitch angle distributions of accelerated particles are presented for different angles of the spacecraft paths through reconnecting current sheets. The outcomes are compared with some in-situ observations of solar wind particles from Ace, Wind and Parker Probe. This comparison indicates that locally generated superthermal electrons can account for the counter-streaming 'strahls' often observed in the pitch-angle distribution spectrograms of the satellites crossing local current sheets.

Day 4 / Session 2 / 22

Cold-chain Comptonization in black hole coronae

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What powers the hard, non-thermal X-rays from the coronae of accreting black holes—against the strong inverse Compton cooling losses due to the scattering by soft accretion disk photons—is an unsolved mystery in astrophysics. We perform 2D particle-in cell simulations of reconnection in magnetically dominated (σ»1) electron-positron and electron-ion plasmas subject to strong Compton cooling. We find that the particle energy spectrum is dominated by a peak at trans-relativistic energies, which results primarily from the bulk motions of 'plasmoids' laden with cooled-down particles. Its peak has a quasi-Maxwellian shape with an effective temperature of ~100 keV, which depends only weakly on the flow magnetization and the strength of radiative cooling. We complement our particle-in-cell studies with Monte-Carlo calculations of the transfer of seed soft photons through the reconnection layer of our simulations, and we produce synthetic X-ray spectra. We demonstrate that Comptonization by the bulk motions of a chain of Compton cooled plasmoids can naturally explain the hard-state spectra of accreting black holes.

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Effect of Magnetic Field Dissipation on Primordial Li Abundance

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The standard Big Bang Nucleosythesis (BBN) model predicted the abundances of light elements that led to one of the main observational supports of the Big Bang theory. However, current observational data no longer confirm the standard BBN (SBBN) confidently. Measurements of Li abundances in metal-poor stars clearly contradict the SBBN value by more than a factor of 3-4 [1,2]. In addition, a possible discrepancy has been pointed out between observed D abundances in absorption systems of quasars and the SBBN value [3]. We investigated dissipation effects of primordial magnetic fields on primordial elemental abundances, and show one probable way to solve the problems of primordial abundances based on the mechanism for acceleration of charged particles by field dissipations. When a magnetic field reconnects, its energy is converted to kinetic energies of charged particles as observed as solar energetic particles arriving on earth. If it happens in the early Universe, it accelerates cosmic background nuclei, and energetic nuclei induce nonthermal reactions. We solve how low-energy cosmic rays come to be, after generation, by including a quick energy loss in a dense cosmic plasma. A constraint on the dissipation is then derived from a theoretical calculation of the nonthermal reactions during BBN. We find that observations of the Li and D abundances can be explained if 0.01-0.1 % of cosmic energy density was utilized for nuclear acceleration after the cosmological electron-positron annihilation epoch. Also, we evaluate that this size of magnetic field energy density explains an acceleration of plasma particles up to kinetic energies suitable for nonthermal nuclear reactions. Therefore, the acceleration of cosmic background nuclei associated with a primordial magnetic dissipation is a possible generation mechanism of soft CRs that has been suggested as a solution to the Li problem [4]. Only the dissipating magnetic field model suggested here simultaneously explains observations of both low Li and high D abundances without assuming nonstandard physics. Therefore, signatures of strong magnetic fields in the early Universe have possibly been observed in primordial elemental abundances.

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Day 4 / Session 2 / 33

Radiative turbulence in magnetically-dominated jets

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Relativistic jets from Active Galactic Nuclei (AGN) are likely magnetically-dominated, i.e. the magnetic energy per particle exceeds the rest mass. Since there is a huge separation of scales between the transverse size of the jet and the Larmor radius of the particles that emit the observed radiation, the dissipation of the magnetic energy is mediated by a turbulent cascade.The advent of large-scale Particle-In-Cell simulations makes it possible to study turbulent energy dissipation in magnetically-dominated plasmas from first principles. I will show that turbulence is able to accelerate non-thermal particles, even when the radiative losses are severe. The accelerated particles are strongly anisotropic, and move nearly in the same direction of the local magnetic field. As an effect of the anisotropy, the synchrotron emission is severely suppressed with respect to the standard case of isotropic particles. I will discuss the implications of the particle anisotropy for the modelling of non-thermal radiation from AGN jets.

Day 4 / Session 2 / 9

Particle-in-cell simulation of sub-ion cyclotron frequency spectrum of circularly polarized dispersive Alfven waves in inhomogeneous solar flaring plasmas.

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The observed soft X-ray flux during solar flares is produced by electron bremsstrahlung, when accelerated electrons that move from magnetic loop top to the footpoints slow down by dense layers of the sun. In order to explain the observed soft X-ray flux during solar flares, if electron acceleration happens at loop top, nearly 100% electrons need to be accelerated. No acceleration mechanism is known with such high efficiency. This problem can potentially be solved by postulating [Fletcher & Hudson, Astrophys. J. 675, 1645 (2008)] that flare at loop top creates dispersive Alfven waves (DAWs) which then propagate towards the footpoints, and as they move in progressively denser parts of the loop (due to natural gravitational stratification) the aforementioned high percentage is no longer needed. It has been known that, in homogeneous plasma, when perpendicular wavelength of Alfven wave (AW) approaches kinetic scales such as e.g. ion-inertial length, it acquires magnetic-field-aligned (parallel) electric field, which can efficiently accelerate electrons [Stasiewicz et al Space Sci. Rev. 92, 423 (2000)]. Further, Tsiklauri, Sakai, & Saito, Astron. Astrophys. 435, 1105 (2005) have shown that if DAW propagates in plasma with transverse (with respect to external magnetic field) density inhomogeneity, the generated parallel electric field is orders of magnitude higher than (i) homogeneous plasma case and (ii) Dreicer electric field (one that triggers electron run-away acceleration). Subsequently Tsiklauri Phys. Plasmas 19, 082903 (2012) has revisited the problem with full 3D particle-in-cell approach. Ofman JGR 115, A04108 (2010) considered similar set up as in Tsiklauri, Sakai, Saito (2005) but instead of considering one DAW harmonic with 0.3 ω_{ci} he considered f^{-1} AW cascade and added He++ ions and used Hybrid simulation model. Note that our approach uses PIC code so it can resolve electron-scale physics contrary to Ofman who used Hybrid code, which can resolve only ion-scale physics. Now in the present work we essentially revisit Ofman's set up run it for two cases 1. when transverse density gradient is ~c/ω_{ci} (as in Tsiklauri, Sakai, Saito (2005) and Tsiklauri (2012)), i.e. on "electron"-scale; 2. when the gradient is on ion scale circa 40 c/ω_{ci} (as in Ofman (2010)) i.e. on "ion"-scale; In this presentation novel numerical simulation results will be presented. Including the scaling of the magnetic fluctuations power spectrum steepening in the higher-density regions, and the heating channelled to these regions from the surrounding lower-density plasma due to wave refraction, as originally found by Ofman (2010).

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Multiple wavelengths observation of large stellar flares on the active RS CVn-type star UX Ari with MAXI, NICER, Ibaraki-Yamaguchi radio interferometer, and CAT

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The study of stellar flares has been greatly advanced by MAXI (Monitor of All-sky X-ray Image), which started its operation in 2009. MAXI observes a large area of the sky once per 92-minute orbital cycle and makes it possible to search for stellar flares effectively. All these flares are found

to be at the upper ends for stellar flares with the total energy of 10^{34-39} erg (e.g, Tsuboi et al. 2016). However, the geometry, state of stellar surfaces, and the decay process of these giant flares are not known in detail as opposed to the Sun because stars cannot be image-resolved. Therefore, it is important to analyze the differences in the light curves at multiple wavelengths, the state of the plasma, and the time evolution of the elemental abundances to provide observational constraints on the understanding of the stellar flare picture. We have conducted multi-wavelength observations of the RS CVn-type star UX Ari for about two months using MAXI, NICER (Neutron star Interior Composition Explorer; 0.2–12 keV), Ibaraki-Yamaguchi radio interferometer (6.7 GHz, 8.3 GHz), and CAT (Chuo-university Astronomical Telescope; V-band). As a result, two flares are detected in total in the X-ray and the radio bands. The first flare has a total energy of ~10^{37} erg in the 2-10 keV band, and the second one, of which the peak has not been detected, has ~10^{37} erg at least in the same band. This means the flares are both 10^5 times or larger than the largest solar flares. The flares had the long e-folding times of ~20 days in the radio band, and where along with the rotational modulation with the same period as the spin period of the binary system. Such phenomena have been reported in huge flares (Elias et al. 1995), though such long decay time can never be explained by just one impulsive supply for the accelerated electrons, as discussed in Catalano et al. (2003). On the other hand, the X-ray flux shows no obvious sinusoidal variation in these flares. The NICER spectra in the 0.3-8 keV are well reproduced by an absorbed two-temperature optically thin thermal plasma model when we set the elemental abundances of O, Ne, Si, S, and Fe to be free. The time variation of the abundance indicates that the high-FIP elements (< 10 eV) are more enhanced as compared to the low-FIP elements throughout our observation period, having the "FIP bias" of -0.8 ~ -0.5; i.e. inverse FIP effect. The negative values (inverse FIP effect) are consistent with the flares on other, magnetically active stars. The noteworthy thing in our observation is that the FIP bias shows sinusoidal variation, anti-correlating with the variation in the radio flux. This indicates that the radio-loud region is compact and is essential to the inverse FIP effect.

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Solar Flare Plasma Temperature: Relating GOES-XRS Flux to Chandrayaan-2 XSM Spectra

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Solar flare plasma temperatures are fundamental to our understanding of flare dynamics and energy transport. GOES-XRS broadband flux ratios are often used to estimate flare temperature. Though an approximation, a single temperature isothermal plasma is still a reasonable approximation for many applications. We compare the flare temperatures (single or two temperatures) derived using spectra from the Solar X-ray Monitor (XSM) onboard Chandrayaan-2 and that from GOES-16 XRS in order to derive a possible empirical relation that can be used to refine the GOES-XRS temperature estimate. XSM operates at 1-15 KeV overlaps the energy range of the GOES X-ray Spectrometers (XRS), enabling a comparison between the two instruments. Flares, of GOES class A and above, seen on-disk for both instruments are considered. We obtain the disk-integrated flux values for the duration of the flares from the GOES '1-minute average flux' products and temperature from the spectral fitting of the XSM flare data using a chianti based model. We find a strong correlation between the two parameters, thus providing us with a method to derive temperature estimates for even low classes of flares from the GOES broadband flux values. Previous studies have shown that the temperature of flares scales with the GOES class, for M and above. Even though GOES detects low-class of flares, due to the contribution of high background at low flux, temperature calculated from current models, such as the SolarSoft routine 'goes_chianti_tem', saturates to the instrumental limit value. XSM spectra through this empirical relation enable using GOES XRS flux to derive flare temperatures over a larger dynamic range.

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Transport of stellar energetic particles in the habitable zones of young active stars

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Charged particles energized by coronal flares or travelling shocks at young active stars may significantly impact the habitability of exoplanets. We used test-particle simulations to investigate the diffusive transport of ~GeV protons throughout turbulent active astrospheres, from stellar corona to planet atmosphere. The 3D turbulent and magnetised stellar wind of a TRAPPIST-1-like system has been reconstructed by using observed magnetograms and overlapping a synthetic magnetic turbulence with a given power spectrum. We find that only a few percent of particles injected within half a stellar radius from the stellar surface can escape, and that the escaping fraction increases strongly with increasing injection radius. Particles injected further out by travelling shocks strongly focus onto two caps within the fast wind regions and centered on the equatorial planetary orbital plane. Due to the very close-in orbit of Trappist-1e (0.03 AU) and the very high activity of the host star, on the basis of a scaling relation between far-UV emission and energetic protons for solar flares, we found that the innermost putative habitable planet, TRAPPIST-1e, is bombarded by a proton flux up to 6 orders of magnitude larger than experienced by the present-day Earth. We present preliminary results of the chemical response of the upper planetary atmosphere to the particle flux at various phases of its orbit around the star.

Day 4 / Session 2 / 10

The physics of wave particle interaction in Lower Hybrid Oscillation

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Lower Hybrid Oscillation (LHO) is a coupled oscillation between ions and electrons under cyclotron motion by coulomb force. The condition for LHO is the presence of a local electric field in a weakly magnetised plasma. A theoretical study shows that, in a collision less magnetised gravitational plasma, this condition is satisfied where the Lower Hybrid (LH) coupling is made possible by an electric field induced by the gravitational drift of ions. Analysis of the dispersion relation shows that the LHO is an effective mechanism for wave particle interaction in which both the electrons and ions are absorbing photons (electromagnetic waves) via cyclotron resonance. It is also noted that the electron cyclotron damping is a multi-wavelength absorption, which strengthens the LH coupling while the ion cyclotron damping is a multi-photon absorption which leads to the multiple ionisation and results in the emission of high energy radiation. A general formula for the ion cyclotron resonant emission has been derived from the dispersion relation, which is truly reflecting the mechanism of the LHO and found to be useful for analysing any spectral emission from the gravitational plasma. An attempt is made to analyse the EUV emission lines of solar and aurora spectrum and found to be very interesting. In a conclusive note, "the LHO seems to be a very fundamental oscillation, which is holding the truth about particle acceleration by cyclotron resonance and more study would be very significant".

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Modeling Large-scale Electron Acceleration in Solar Flare Magnetic Reconnection Region

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Recent multi-wavelength observations (e.g., by EOVSA, RHESSI, and STIX) show that nonthermal emissions could fill up a significant portion of the solar flare reconnection region. The electrons responsible for these emissions contain a substantial fraction of the released magnetic energy and often develop power-law energy tails. In this study, we model the large-scale electron acceleration by solving the energetic particle transport equations using background MHD fields. Due to flow compression, electrons are accelerated to hundreds of keV and develop nonthermal power-law distributions, both of which are consistent with the observations. The model-generated spatially and temporally dependent electron distributions can be used for producing synthetic radio or hard X-ray emission maps, which can be directly compared with radio and hard X-ray observations. These results have important implications for understanding large-scale electron acceleration during impulsive flares.

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New, focused views of the high energy Sun

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In the past decade, the capability to focus hard X-rays from the Sun has become a reality. Though no solar-dedicated space observatory yet exists, glimpses of the Sun at hard and soft X-ray energies from the FOXSI sounding rocket and the NuSTAR spacecraft have opened windows to show us what can be explored. Most notably, these missions have investigated solar flares down to far smaller scales than could be explored with previous, indirect hard X-ray instruments, observing fluxes fainter than RHESSI microflares by multiple orders of magnitude. These studies evaluate the ability of small flares to act as powerful particle accelerators and explore how energy release scales with flare magnitude. An upcoming sounding rocket flight will apply this method to a large flare for the first time, and will demonstrate the type of measurements that can regularly be performed once a dedicated spaceborne platform is realized.

Day 4 / Session 3 / 53

Multiscale Modeling and Simulations of Particle Acceleration in Solar Flares

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We present recent highlights of particle acceleration and transport in solar flares with modeling tools that cover a range of relevant scales. 3D kinetic simulations in the nonrelativistic regime have uncovered the injection process of thermal particles and early stage of nonthermal acceleration of both ions and electrons. The flux-rope kink instability and oblique tearing instabilities lead to a turbulent reconnection region, allowing particles to transport out of flux-ropes and undergo further acceleration. We model large-scale acceleration of electrons by solving a transport model in the MHD simulation of solar flares. Consistent with fully kinetic simulations, electrons are accelerated to hundreds of keV and develop clear nonthermal power-law spectra. The spatially and temporally dependent electron distributions have been used for producing synthetic radio and hard X-ray emission maps, which can be made to closely compare with observations.

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Extreme particle accelerators

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I will talk about the perfectly designed by Nature machines - Cosmic Ray Factories accelerating particles - electrons and protons - with a rate close to the theoretical margin allowed by classical electrodynamics and magnetohydrodynamics. For a long time, we suspected the Crab Nebula as an extreme electron accelerator. After the recent detection of PeV gamma-rays from the Crab, we have direct evidence that it operates as an extreme electron accelerator. The highest-energy particles of 10^20 eV observed in cosmic rays provide the most convincing case of extreme proton accelerators linked, most probably, to relativistic jets driven by supermassive Black Holes. I will discuss the role of these objects in the context of the origin of galactic and extragalactic cosmic rays.

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Summary

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