Origins of ^{3}He-Rich Solar Energetic Particles

Abstract

Particle acceleration is ubiquitous in the universe; however, our Sun provides a rare opportunity to observe energetic particles and their sources jointly. The acceleration mechanism in solar flares, tremendously enhancing (up to factors of ten thousand) abundances of rare elements like ^{3}He and ultra-heavy nuclei (like ^{197}Au and ^{207}Pb), has been puzzling for more than 50 years. Flares associated with ^{3}He-rich solar energetic particles have been commonly observed in jet-like forms indicating acceleration in magnetic reconnection on field lines open to interplanetary space. The goal of the team is to advance our understanding of the ion enhancement mechanisms by combining scientists with knowledge in different disciplines and research methods. The proposed team includes experimentalists with expertise regarding *in-situ* heliospheric and remote solar observations, as well as theoreticians and modelers of ion acceleration. The aims of the team are to 1) summarize the properties of ^{3}He-rich solar sources, gathered with the recent high-resolution, extreme ultraviolet and photospheric magnetic field observations, 2) determine how these properties correlate with the *in-situ* energetic particle observations, and 3) conclude how these properties could constrain different models of particle fractionation and acceleration. It is a very timely topic, with the forthcoming launch of Parker Solar Probe scheduled for August 2018 and of Solar Orbiter scheduled for February 2020, carrying instrumentation for both solar *in-situ* and remote-sensing observations. The ISSI Team will be essential for promoting this area as a key focus of these missions with new discoveries being discussed during the Team meetings.

Scientific rationale

Solar energetic particles (SEPs) are produced directly in flares on the Sun by some ambiguous mechanisms or by CME driven shocks traveling through the corona and interplanetary space (Reames 2017). Particle acceleration in solar flares is characterized by an anomalous elemental composition as evidenced by the *in-situ* observations of the escaping population (Kocharov & Kocharov 1984; Mason 2007) or by remote observations of the magnetically trapped population via ɣ-ray lines (Vilmer et al. 2011). In contrast, the particle acceleration at the CME shocks is characterized by a nearly coronal abundance (Desai & Giacalone 2016). The most striking feature of the flare acceleration is the enormous enhancement of the rare isotope ^{3}He by factors of up to 10^4 above the coronal abundance. It presents one of the most extreme fractionations known to occur in astrophysical sites. Heavy (Ne-Fe) and ultra-heavy nuclei (mass > 70 amu) are enhanced by a factor of 3-10 and >100, respectively, independently of the amount of ^{3}He enhancement. It has been interpreted as evidence that different mechanisms are involved in the acceleration of the ^{3}He and the heavy ions. There are other abundance anomalies like enhancements of the heavier isotopes of ^{20}Ne and ^{24}Mg (^{22}Ne, ^{26}Mg; Mason et al. 1994; Dwyer et al. 2001; Wiedenbeck et al. 2010) or recently reported S-rich SEPs (Mason et al. 2016).

Discovered more than 50 years ago (Schaeffer & Zähringer 1962), ^{3}He-rich SEPs are still poorly understood. It is mainly because of their low intensities and the association with minor flares (Reames et al. 1988a; Reames & Ng 2004; Nitta et al. 2006; Wang et al. 2012; Bučík et al. 2016b). Some events even have no X-ray increase (Reames et al. 1988a; Bučík et al. 2016b) and show only a small EUV brightening. Furthermore, flares producing ^{3}He-rich SEPs observed at Earth come from a limited region on the western hemisphere of the Sun which is magnetically well-connected to the observer (Reames et al. 1988a). The energetic ions do not show clear flare signatures as energetic electrons through the hard X-ray (HXR) bremsstrahlung and/or radio emissions. Nuclear ɣ-ray lines were observed only in major flares (Vilmer et al. 2011) and generally not in ^{3}He-rich events (but see Van Hollebeke et al. 1990; Kartavykh et al. 2007 for few exceptions). ^{3}He-rich SEP events are a ubiquitous phenomenon with the rate of occurrence corresponding to >10^3 events/yr on the solar disk at solar maximum (Reames et al. 1994).

Goals

The goal of the ISSI Team is to advance our understanding of the peculiar ion enhancement mechanism of ^{3}He-rich SEPs addressing the following areas: 1) morphology of ^{3}He-rich flares, 2) EUV line spectroscopy of ^{3}He-rich flares, 3) underlying photospheric magnetic field, 4) source plasma characteristics in ^{3}He-rich flares and 5) models of ion acceleration and fractionation in ^{3}He-rich flares. The work program is divided into the corresponding five Work Packages (WPs).

WP1: Constraining ion acceleration and injection by exploring the morphology of ^{3}He-rich flares

Flares associated with ^{3}He-rich SEPs have often been found in a jet-like form (Fig. 1a) (Kahler et al. 2001; Wang et al. 2006; Nitta et al. 2006, 2008; Bučík et al. 2014; Chen et al. 2015), indicating acceleration on open field lines during magnetic reconnection. Despite recent extensive research on solar jets (Raoufi et al. 2016; Innes et al. 2016), the jet features have not been investigated alongside the acceleration and the escape of ^{3}He-rich SEPs. The standard/erupting dichotomy of jets (Moore et al. 2010) has now started to be addressed in ^{3}He-rich events (Kahler et al. 2015; Bučík et al. 2018a). The events with high ^{3}He and Fe enrichments have been found to be associated with twisted jets and/or mini filaments (Kahler et al. 1987; Mason et al. 2016; Innes et al. 2016; Bučík et al. 2018a). The unwinding motions in the jets have been associated with the generation of Alfvén waves (Fig. 5a) (e.g., Liu et al. 2011; Lee et al. 2015). Surprisingly, in many ^{3}He-rich events, jets have been found to be accompanied by large-scale propagating EUV waves (Fig. 1c) (Bučík et al. 2015a; Nitta et al. 2015). It has been discussed that the shock associated with these MHD fast-mode waves may affect the ion energy spectra (Bučík et al. 2016a) or that the waves may be responsible for broad longitudinal distributions measured in several ^{3}He-rich events (Wiedenbeck et al. 2013; Nitta et al. 2015; Bučík et al. 2016b). Kocharov & Torsti (2003) and Torsti et al. (2003) have suggested that high-energy (>10 MeV/n) ^{3}He-rich SEPs may be due to re-acceleration in coronal shocks.

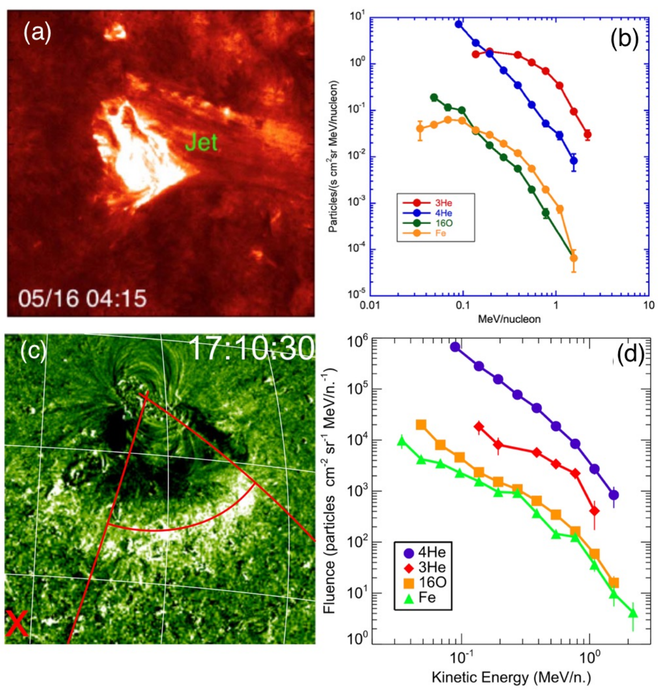

Figure 1. (a) 304 Å EUV image of a solar source (an erupting helical jet) in 2014 May 16 ^{3}He-rich SEP event (Mason et al. 2016), (b) corresponding energy spectra (Nitta et al. 2015). (c) 195 Å EUV image of a solar source (a blast wave) in 2010 Jan 26 ^{3}He-rich SEP event, (d) corresponding energy spectra (Bučík et al. 2015a).

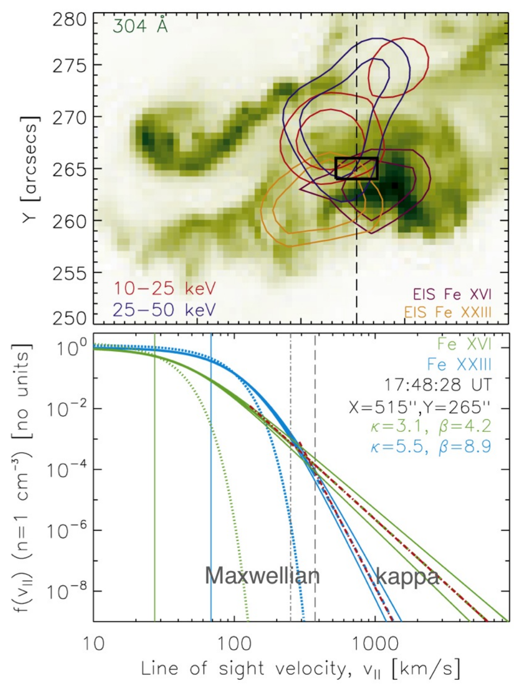

Figure 2. Top: 304 Å EUV image of 2014 Mar 29 X-class flare. Bottom: The kappa line profiles for Fe XVI and Fe XXIII converted to the velocity distribution in one region marked by a black rectangle in top panel; β – power law index (Jeffrey et al. 2017). (Fe with 2000 km/s~20 keV/n)

To assess the importance of the jets, EUV and MHD waves for ion acceleration and injection into interplanetary space we will explore how characteristics in the remote source (e.g., speed, acceleration of the EUV wave/jet) correlate with the in-situ measured features of ^{3}He-rich SEPs (e.g., abundance, energy spectra).

WP2: Uncovering ion acceleration signatures using EUV line spectroscopy in ^{3}He-rich flares

Remote observations of ion acceleration in solar flares are quite limited. There are theoretical predictions for a formation of non-thermal broadened profiles in H I Lyα (1216 Å) and He II Lyα (304 Å) (e.g., Orrall & Zirker 1976; Peter et al. 1990; Laming et al. 2013) caused by accelerated protons and α-particles, respectively, that capture electrons due to charge-exchange with thermal neutral hydrogen. However, so far, no clear evidence of Dopplerbroadened Lyα from energetic ions in solar flares has been observed (Brosius 2001; Hudson et al. 2012). The authors discuss that strong chromospheric heating during the flare may reduce or mask the charge-exchange mechanism. Jeffrey et al. (2016, 2017) have found the Fe XVI 262.98 Å and Fe XXIII 263.76 Å line profiles in two flares consistent with a kappa distribution of emitting ions with kappa values corresponding to the highly-accelerated ion distribution (Fig. 2). The excess line broadening could also be a signature of wave turbulence (Moortel & Nakariakov 2012). Winglee (1989) has developed an acceleration mechanism related to the bulk flow evaporation (manifested in line blueshift). Reames et al. (1994) have doubted the mechanism as the events with chromospheric evaporation did not correlate with ^{3}He-rich flares. Small field-of-view of EUV spectrographs may be a limiting factor for systematic investigation of EUV line profiles in ^{3}He-rich SEP sources, but the intentional pointing to the magnetically connected flares may be helpful.

We will discuss plans for observing proposals for current spectrometers EIS/Hinode, IRIS and forthcoming SPICE/SOLO. We plan to explore the relation between non-thermal line profiles and charge-to-mass ratio (Q/A) ratio of emitting ions. The importance of chromospheric evaporation will be delineated.

WP3: Role of underlying photospheric field on ion acceleration in ^{3}He-rich flares

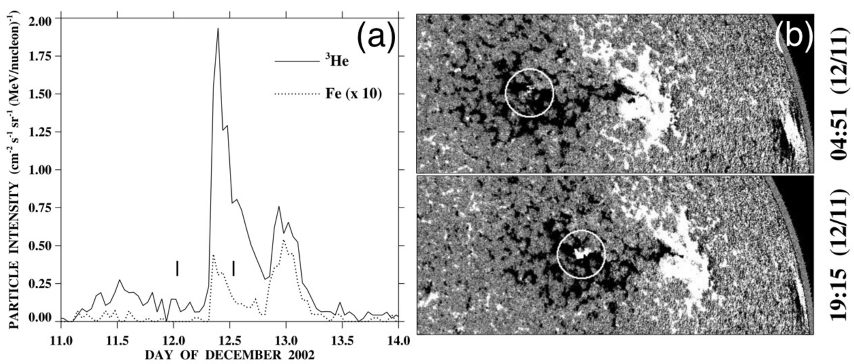

Figure 3. 2002 Dec 12 ^{3}He-rich SEP event. (a) 385 keV/n ^{3}He, Fe intensities. (b) magnetograms showing the emergence of a positive-polarity flux near coronal hole preceding the ^{3}He-rich SEP injection (Wang et al. 2006).

Photospheric sources of low energy (< 1 MeV/n) ^{3}He-rich SEPs have often been attributed to small compact active regions lying next to a coronal hole (Wang et al. 2006; Bučík et al. 2014, 2018a), where magnetic field lines open to the heliosphere. Indeed, ^{3}He-rich events often occur in the slow solar wind preceding high-speed wind from the coronal hole (Zwickl et al. 1978; Kocharov et al. 2008). A plage region from dispersed sunspots can also be the source of low-energy ^{3}He-rich SEPs (Chen et al. 2015; Bučík et al. 2015b). So far only one event has been reported arising directly from a sunspot, at the edge of the sunspot umbra (Nitta et al. 2008). Surprisingly, there have been no reports on ^{3}He-rich SEP events originating from so-called magnetic moving features near the sunspots that are sources of strong jets (Chifor et al. 2008). The photospheric sources of high-energy ^{3}He-rich events (Reames & Ng 2004; Nitta et al. 2006) have not been addressed. Bučík et al. (2018b) have reported a strong, high energy (>10 MeV/n) ^{3}He-rich event from the boundary of a large sunspot. Several previous works reported delayed ion injection, by about 1 hr relative to the solar electrons in some ^{3}He-rich SEP events (e.g., Wang et al. 2016). The source at the coronal-hole may guarantee direct escape of SEPs.

We plan to examine the relation between in-situ characteristics of ^{3}He-rich SEPs and the nature of the photospheric source.

WP4: Relation between source plasma characteristics in ^{3}He-rich flares and energetic ion abundances

Early direct measurements of high ionization states (Luhn et al. 1987) indicated very hot (>10 MK) plasma sources of ^{3}He-rich SEPs. However, detection of charge states increasing with kinetic energy (DiFabio et al. 2008) has suggested ion stripping after acceleration. The pattern of heavy-ion enhancements on Q/A (Fig. 4a) along with the temperature-dependent pattern of the ion charge Q (Fig. 4b) suggests that the temperature of the source plasma that is accelerated (~3 MK) is not a flare-like. In a very hot plasma, all elements up to Fe would be fully ionized with nearly the same A/Q as ^{4}He. Ions such as ^{4}He, ^{12}C, ^{14}N, and ^{16}O are unenhanced in ^{3}He-rich events, while all heavier species like ^{20}Ne, ^{24}Mg, ^{28}Si, ^{32}S show enhancement. This rules out very high temperatures. On the other hand, if the plasma is too cold, some lighter elements (like ^{12}C, ^{14}N) would not be fully ionized, implying their enhancement. However, this has not been generally observed, although few events have been reported with enhanced ^{14}N indicating temperature <1.5 MK (Mason et al. 2002b). S-rich SEPs suggest even lower temperatures (0.4 MK; Mason et al. 2016). Furthermore, the measurements of low energy ^{3}He-rich events show different enhancement pattern for key ion species (Ne, Mg, S, Si; Mason et al. 2004) compared to the observations of high energy ^{3}He-rich events. Earlier works speculated that abundance variations in source material may affect the anomalous composition of ^{3}He-rich SEPs (Mason et al. 1986; Reames et al. 1990). Winglee (1989) have suggested that variations in the source material can be discernable with EUV spectral line observations. A relation between element abundances in ^{3}He-rich SEPs and plasma characteristics (temperature, emission measure) determined from the soft X-ray observations have been studied by Reames (1988b) and Reames et al. (1988a). The authors have shown that in the relatively narrow and high-temperature range, the heavy-ion abundances correlate with the temperature but $^{3}He/^{4}He$ does not.

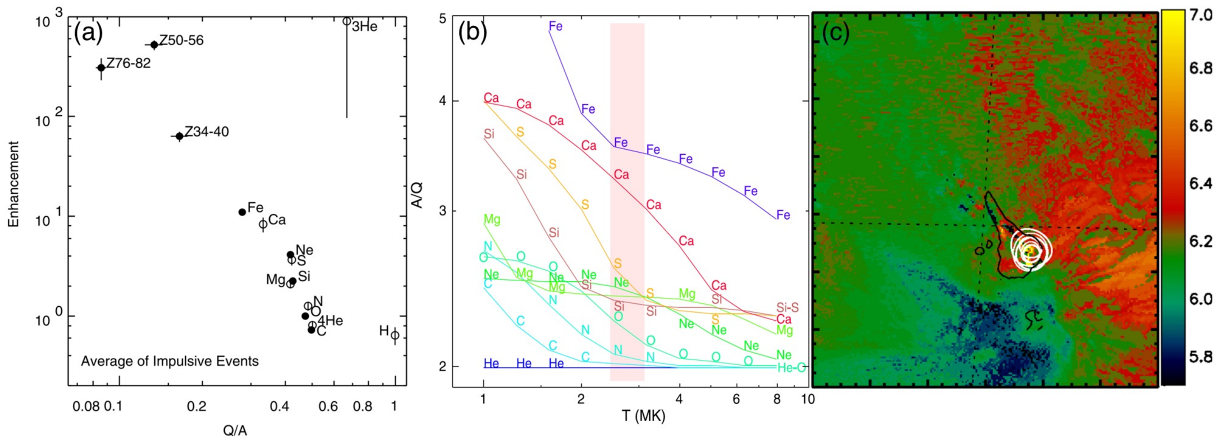

Figure 4. (a) Abundance enhancement in 2-10 MeV/n ^{3}He-rich events relative to coronal abundances vs. Q/A (Reames & Ng 2004) (b) A/Q vs. the theoretical equilibrium temperature T. The region of most likely T for 2-10 MeV/n ^{3}He-rich SEPs is shaded pink (Reames et al. 2015). (c) log T in the ^{3}He-rich flare; the white contours mark the HXR sources; the black outlines the jet shape (Chen et al. 2013).

We plan to examine the relation between the temperature (Chen et al. 2018), density, and abundances of the source plasma (determined from EUV observations; Fig. 4c) and elemental enhancement in ^{3}He-rich SEPs.

WP5: Modeling of ion acceleration and fractionation in ^{3}He-rich flares

The anomalous composition of ^{3}He-rich SEPs suggests unique acceleration processes operating at the flare sites. ^{3}He-rich SEPs exhibit puzzling energy spectral shapes varying from rounded forms to power laws (Fig. 1b-d) (Möbius et al. 1982; Reames et al. 1997; Mason et al. 2000, 2002a; Nitta et al. 2015; Bučík et al. 2016a). The ^{3}He and ^{4}He spectra are well-fitted by the model of cyclotron resonance with turbulence in the proton cyclotron branch (Liu et al. 2006), and the heavy-ion spectra by the model of cyclotron resonance with cascading Alfvén waves (Miller 1998; Mason et al. 2002a) where ions with low Q/A are accelerated with a faster rate (Eichler 2014; Kumar et al. 2017). An efficient acceleration of ^{3}He by electromagnetic ion cyclotron waves (Roth & Temerin 1997) in two-component (H-^{4}He) plasma (Fisk 1978) has been recently shown to work in nuclear fusion devices (Kazakov et al. 2017). In addition to models based on the cyclotron resonance, other non-wave mechanisms have been suggested. These include fractionation 1) by reconnection outflows followed by Fermi acceleration on magnetic islands (Fig. 5b) (Drake et al. 2006, 2009) and 2) by helical DC electric fields (Fleishman & Toptygin 2013). The former model, providing power-law energy spectra (Drake et al. 2013), is consistent with the observed pattern of heavy-element abundance enhancements as a function of Q/A (Fig. 4a) (Mason et al. 2004; Reames & Ng 2004), and the latter, with recently reported untwisting motions in ^{3}He-rich jets (Bučík et al. 2018a). Magnetic islands have been observed in the reconnection sites through the temperature analysis (Li et al. 2016). The turbulence and reconnection pictures of ion acceleration in ^{3}He-rich flares are now merging into a single picture in which reconnection in the corona is intrinsically turbulent (Daughton et al. 2011; Dahlin et al. 2015, 2017). The consequence is that the acceleration ions with a range of Q/A can be studied simultaneously with the release of magnetic energy.

We plan to explore the self-generation of turbulence during reconnection, including both the intrinsic turbulence associated with reconnection in 3D systems as well as that associated with beams and pressure anisotropy. The impact on multi-species in heating can then be explored to establish the relative roles of the various mechanisms proposed.

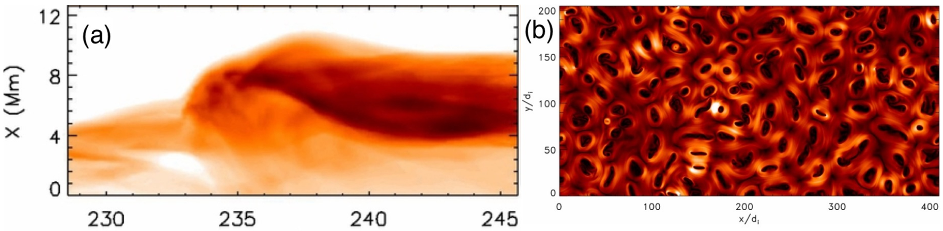

Figure 5. (a) Alfvén waves in the distance-time diagram of the plasma density across the simulated jet (Lee et al. 2015). (b) Magnetic islands in the x-y plane of the field strength in the simulation of current-sheet reconnection (Drake et al. 2013).

Added value of ISSI Team & Timeliness

The elemental and isotopic abundances in our solar system (Gloeckler & Geiss 1998) have been a traditional area of research at ISSI Bern. Thus, the interaction with members of ISSI would be beneficial for the Team. We believe that the best way to advance our understanding of ^{3}He-rich SEPs lies in a cross-disciplinary approach where energetic ions measured *in-situ* and solar images of their sources are simultaneously investigated. Such effort has started relatively recently when multi-point high spatiotemporal resolution imaging observations of a full solar disk (STEREO and SDO) became available to properly identify and examine small ^{3}He-rich flares. Significant progress has been made in the effort to understand particle heating and acceleration during magnetic reconnection. The focus, however, has been on protons and electrons rather than the various ion species. For the first time, modelers are now able to include multiple ion species in simulations. Thus, the time is ripe to bring together remote and *in-situ* observers with modelers to make progress and plan for the upcoming Solar Orbiter (SOLO) and Parker Solar Probe (PSP). An ISSI Team would provide a unique opportunity to make this happen.

^{3}He-rich SEPs are thought to be an important source of suprathermal ions that can be further accelerated by CME driven shocks, which may explain the variability of space-weather-hazardous gradual SEP events. The science goal of the Team corresponds to one of the four SOLO science questions (how do solar eruptions produce energetic particle radiation?) and to one of the three PSP science objectives (explore mechanisms that accelerate and transport energetic particles). Since the main reason for our current lack of understanding of the ^{3}He-rich SEPs is the small size of the events at 1 AU, the upcoming missions to close distance of the Sun will revolutionize our view on mysterious processes responsible for ion acceleration in solar flares.

Outputs & Schedule

The ISSI Team will answer the following outstanding research questions: **1)** Are there separate mechanisms that accelerate ^{3}He, heavy and ultra-heavy ions? [WP1, 5] And then, under which conditions different mechanisms dominate? [WP4] **2)** Is the anomalous enhancement mechanism fundamental for all solar flares? Is there a depletion of enhanced species in gradual SEP events? [WP2, 4] **3)** Is the injection into interplanetary space associated with ion acceleration/fractionation? And, how is the injection realized? [WP1, 3] **4)** Is the mechanism which accelerates and fractionates different ion species operating more continuously, and not necessarily related to the flaring activity? [WP3, 5 discussion new PSP data]

Expected outcomes from the ISSI team: 1) a review paper summarizing the state-of-the-art in ^{3}He-rich SEP science; 2) identifying open questions that will be addressed in future common projects/studies of the ISSI team members; 3) proposing coordinated studies on this topic at SOLO, PSP, and other observatories at 1 AU (the focus area in WP3 is included in the ESA SOLO Observing Program); 4) organization of a session at an international conference

We plan two one-week meetings at ISSI Bern; one meeting in Autumn 2018 and another in Summer 2019. We require the standard financial support, which includes living expenses for all team members and travel support for the team coordinator.

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ANNEXE I

Bibliography

Bučík R., Fludra A., Gómez-Herrero R., et al. 2018b, A&A (submitted)
Bučík R., Innes D.E., Chen N.H., et al. 2015b, JPCS 642, 012002
Bučík R., Innes D.E., Guo L., Mason G.M., Wiedenbeck M.E. 2015a, ApJ 812, 53
Bučík R., Innes D.E., Mason G.M., Wiedenbeck M.E. 2016a, JPCS 767, 012002
Bučík R., Innes D.E., Mason G.M., Wiedenbeck M.E. 2016b, ApJ 833, 63
Bučík R., Innes D.E., Mall U., et al. 2014, ApJ 786, 71
Bučík R., Innes D.E., Mason G.M., et al. 2018a, ApJ 852, 76
Brosius J. W. 2001, ApJ, 555, 435
Chen N.-H., Bučík R., Innes D.E., Mason G.M. 2015, A&A 580, A16
Chen N.-H., Bučík R., Kim R.-S. 2018, Proc. IAU Symposium 335, Cambridge Uni Press (in press)
Chen N.-H., Ip W.-H., Innes D.E. 2013, ApJ 769, 96
Chifor C., Isobe H., Mason H.E., et al. 2008, A&A 491, 279
Dahlin J.T., Drake J.F., Swisdak M. 2015, PhPl 22, 100704
Dahlin J.T., Drake J.F., Swisdak M. 2017, PhPl 24, 092110
Daughton, W., Roytershteyen V., Karimabadi, H., et al. 2011, Nature Phys. 7, 539
Desai M., Giacalone G. 2016, LRSP 13, 3
DiFabio R., Guo Z., Möbius E., et al. 2008, ApJ 687, 623
Drake J.F., Cassak P.A., Shay M.A., Swisdak M., Quataert E. 2009, ApJ 700, L16
Drake J.F., Che H., Shay M.A., Swisdak M. 2006, Nature 443, 553
Drake J.F., Swisdak M., Fermo R. 2013, ApJL 763, L5
Dwyer J.R., Mason G.M., Mazur J.E., et al. 2001, ApJ 563, 403
Eichler D. 2014, ApJ 794, 6
Fleishman G.D., Toptygin I.N. 2013, MNRAS 429, 2515
Fisk L.A. 1978, ApJ 224, 1048
Gloeckler G., Geiss J. 1998, SSRv 84, 275
Hudson H.S., Fletcher L., MacKinnon A.L., Woods T.N. 2012, ApJ, 752, 84
Innes D.E., Bučík R., Guo L.-J., Nitta N.V. 2016, AN 37, 1024
Jeffrey N.L.S., Fletcher L., Labrosse N. 2016, A&A 590, A99
Jeffrey N.L.S., Fletcher L., Labrosse N. 2017, ApJ 836, 35
Kahler S.W., Lin R.P., Reames D.V., Stone R.G., Liggett M. 1987, SoPh 107, 385
Kahler S.W., Reames D.V., Cliver E. 2015, PoS (ICRC2015) 049
Kahler S.W., Reames D.V., Sheeley N.R.Jr. 2001, ApJ 562, 558
Kartavykh Y.Y., Dröge W., Klecker B., et al. 2007, ApJ 671, 947
Kazakov Y., Ongena J., Wright J.C., et al. 2017, Nature Phys. 13, 973
Kocharov L., Laivola J., Mason G.M., Didkovsky L., Judge D.L. 2008, ApJS 176, 497
Kocharov L.G., Kocharov G.E. 1984, SSRv 38, 89
Kocharov L., Torsti J. 2003, ApJ 586, 1430
Kumar R., Eichler D., Gaspari M., Spitkovsky A. 2017, ApJ 835, 295
Laming J.M., Moses J.D., Ko Y.-K., et al. 2013, ApJ 770, 73
Lee E.J., Archontis V., Hood A.W. 2015, ApJL 798, L10
Li L.P., Zhang J., Peter H., et al. 2016, Nature Phys. 12, 847
Liu W., Berger T.E., Title A.M., Tarbell T.D., Low B.C. 2011, ApJ 728, 103
Liu S., Petrosian V., Mason G.M. 2006, ApJ 636, 462
Luhn A., Klecker B., Hovestadt D., Möbius E. 1987, ApJ 317, 951
Mason G.M. 2007, SSRv 130, 231
Mason G.M., Dwyer J.R., Mazur J.E. 2000, ApJL 545, L157
Mason G.M., Mazur J.E., Dwyer J.R. 2002b, ApJ 565, L51
Mason G.M., Mazur J.E., Dwyer J.R., et al. 2004, ApJ 606, 555

Mason G.M., Mazur J.E., Hamilton D.C. 1994, ApJ 425, 843
Mason G.M., Nitta N.V., Wiedenbeck M.E., Innes D.E. 2016, ApJ 823, 138
Mason G.M., Reames D.V., Klecker B., Hovestadt D., von Rosenvinge T.T. 1986, ApJ 303, 849
Mason G.M., Wiedenbeck M.E., Miller J.A., et al. 2002a, ApJ 574, 1039
Miller J.A. 1998, SSRv 86, 79
Moore R.L., Cirtain J.W., Sterling A.C., Falconer D.A., 2010, ApJ 720, 757
Moortel I.De., Nakariakov V.M. 2012, RSPTA 370, 3193
Möbius E., Scholer M., Hovestadt D., Klecker B. 1982, ApJ 259, 397
Nitta N.V., Mason G.M., Wang L., Cohen C.M.S., Wiedenbeck M.E. 2015, ApJ 806, 235
Nitta N.V., Mason G.M., Wiedenbeck M.E., et al. 2008, ApJL 675, L125
Nitta N.V., Reames D.V., DeRosa M.L., et al. 2006, ApJ 650, 438
Orrall F.Q., Zirker J.B. 1976, ApJ, 208, 618
Peter Th., Ragozin E.N., Urnov A.M., Uskov D.B., Rust D.M. 1990, ApJ, 351, 317
Raouafi N.E., Patsourakos S., Pariat E., et al. 2016, SSRv 201, 1
Reames D.V. 1988b, ApJL 325, L53
Reames D.V. 2017, LNP 932 (Springer)
Reames D.V., Barbier L.M., von Rosenvinge T.T., et al. 1997, ApJ 483, 515
Reames D.V., Cane H.V., von Rosenvinge T.T. 1990, ApJ 357, 259
Reames D.V., Cliver E.W., Kahler S.W. 2015, SoPh 290, 1761
Reames D.V., Dennis B.R., Stone R.G., Lin R.P. 1988a, ApJ 327, 998
Reames D.V., Meyer J.P., von Rosenvinge T.T. 1994, ApJS 90, 649
Reames D.V., Ng C.K. 2004, ApJ 610, 510
Roth I., Temerin M. 1997, ApJ 477, 940
Schaeffer O.A., Zähringer J. 1962, PRL 8, 389
Torsti J., Kocharov L., Laivola J., Chertok I., Thompson B.J. 2003, SoPh 214, 177
Van Hollebeke M.A.I., McDonald F.B., Meyer J.P. 1990 ApJS 73, 285
Vilmer N., MacKinnon A.L., Hurford G.J. 2011, SSRv 159, 167
Wang L., Krucker S., Mason G.M., Lin R.P., Li G. 2016, A&A 585, A119
Wang L., Lin R.P., Krucker S., Mason G.M. 2012, ApJ 759, 69
Wang Y.-M., Pick M., Mason G.M. 2006, ApJ 639, 495
Wiedenbeck M.E., Cohen C.M.S., Leske R.A., et al. 2010, ApJ 719, 1212
Wiedenbeck M.E., Mason G.M., Cohen C.M.S., et al. 2013, ApJ 762, 54
Winglee R.M. 1989, ApJ, 343, 511
Zwickl R.D., Roelof E.C., Gold R.E., Krimigis S.M. 1978, ApJ 225, 281

ANNEXE II

<table>
<tr><th colspan="24">Schedule</th></tr>
<tr><td colspan="6">2018</td><td colspan="12">2019</td><td colspan="6">2020</td></tr>
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<tr><td colspan="3">Preparation for the 1st meeting

Setting up web-page of the ISSI Team

Nomination 1-2 young scientists to the Team</td><td colspan="3">1st meeting at ISSI Bern</td><td colspan="7">Implementation of specifics tasks

Monitoring of progress

Preparation for the 2nd meeting (presentations, refining schedule)</td><td colspan="3">2nd meeting at ISSI Bern</td><td colspan="2">Monitoring of progress</td><td colspan="3">Finalize & submit review paper</td><td colspan="3">Submit final report to ISSI</td></tr>
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Tentative agenda for a Team meeting

Day	Morning sessions	Afternoon sessions	
1	WP1 state-of-the-art presentations	WP1 discussions	Joint analysis of ion composition (ACE, SOHO, STEREO) and imaging (SDO, STEREO) data from current experiments
2	WP2	WP2	Ion composition data from PSP; Plans for PSP, SOLO
3	WP3	WP3	Plans for spectrometers on Hinode, IRIS using Hinode EIS flare catalog (http://solarb.mssl.ucl.ac.uk/SolarB/eisflarecat.jsp) and IRIS Data Search (http://iris.lmsal.com/)
4	WP4	WP4	Work on a review paper
5	WP5	WP5	Wrap-up

ANNEXE III

List of confirmed members

Name	Institute	Role
Radoslav Bučík	Institute for Astrophysics, University of Göttingen & Max Planck Institute for Solar System Research, **Germany**	Team Leader; *STEREO observations of ^{3}He-rich SEPs and their solar sources*
Nai-Hwa Chen	Korea Astronomy and Space Science Institute, **Republic of Korea**	*temperature diagnostic of ^{3}He-rich sources*
James F. Drake	Institute for Physical Science and Technology, University of Maryland, **USA**	Team Co-Leader; *modeling of heavy ion acceleration*
David Eichler	Department of Physics, Ben-Gurion University, **Israel**	*theory of heavy ion acceleration*
Raúl Gómez-Herrero	Space Research Group, University of Alcalá, **Spain**	*SEPs observations – propagation, anisotropy – STEREO/SEPT, SOLO/EPD*
Georg C. Ho	Applied Physics Laboratory, Johns Hopkins University, **USA**	*observation of suprathermal ^{3}He-rich SEPs – ACE, SOLO*
Natasha L. S. Jeffrey	School of Physics & Astronomy, University of Glasgow, **UK**	*EUV line spectroscopy – signatures of ion acceleration*
Stephen Kahler	U.S. Air Force Research Laboratory, **USA**	*magnetic connectivity to ^{3}He-rich sources*
Rahul Kumar	Department of Astrophysical Sciences, Princeton University, **USA** & Department of Physics, Ben-Gurion University, **Israel**	*modeling of heavy ion acceleration*
Siming Liu	Purple Mountain Observatory, Chinese Academy of Sciences, **China**	*modeling of ^{3}He acceleration*
Nariaki V. Nitta	Lockheed Martin Advanced Technology Center, **USA**	*observation of ^{3}He-rich sources - STEREO, SDO, Hinode*
Mark E. Wiedenbeck	Jet Propulsion Laboratory, California Institute of Technology, **USA**	*observation of high-energy ^{3}He-rich SEPs – ACE, STEREO, PSP*

Self-supported experts

Name	Institute	Role
Gregory D. Fleishman	Center for Solar-Terrestrial Research, New Jersey Institute of Technology, **USA**	*theory of ^{3}He-rich SEP acceleration*
(John) Martin Laming	Naval Research Laboratory, **USA**	*remote signatures of ion acceleration*
Wei Liu	Lockheed Martin Solar and Astrophysics Laboratory, **USA**	*EUV imaging of flare acceleration, EUV waves, jets – SDO, IRIS*

Ilan Roth	Space Science Laboratory, University of California, **USA**	*theory of ^{3}He acceleration*
Notes Remote observers: 4 (Team)/5 (Total) *In-situ* observers: 4/4 Modelers: 4/7 Countries (Team): *DE* (1), *KR* (1), *US* (6), *IL* (1), *ES* (1), *UK* (1), *CN* (1)		