C.3.4 High Energy Telescope (HET)

C.3.4.1 Measurement Objectives

The High-Energy Telescope (HET) is designed to make measurements of the intensity and energy spectra of H, He, and electrons accelerated in solar energetic particle (SEP) events. In addition, it will provide limited measurements of the elemental composition of Z > 2 nuclei with > 30 MeV/nucleon, thereby extending the energy range of LET. It will use on-board analysis techniques to provide real time fluxes of key species important to space weather applications, including H and He with ~13 to ~100 MeV/nucleon, and electrons with 1 to 5 MeV.

The single-ended design described here (which we label HET2) differs in minor respects from the double-ended design originally proposed in order to make use of existing detectors and to thereby reduce cost (see Appendix F). However, the species and energy coverage are essentially the same as originally proposed, and the geometry factor of this design (2.2 cm^2sr) is essentially identical to the 2.4 cm^2sr of the original design.

C.3.4.1.1 Ion Measurements. Using the standard dE/dx-E technique implemented using silicon solid-state detectors, HET identifies particles which stop in depths of silicon ranging from 1 to 8 mm. The corresponding energy range for H and He is ~13 to ~40 MeV/nucleon. Particles with longer ranges penetrate the instrument. Up to ~100 MeV/nucleon H and He can be identified using multiple dE/dx measurements. For these higher energies HET responds to particles incident from either end of the instrument, providing some anisotropy information (forward/backward along the mean magnetic field direction).

HET will also identify heavy nuclei up through iron. In the penetrating mode only the major species such as C, O, Ne, Mg, Si, and Fe can be reliably identified.

C.3.4.1.2 Electron Measurements. Although the response of HET to electrons is more complex than the response to nuclei because of electron scattering, experience with similar telescopes flown on IMP-7 & 8, Pioneer 10 & 11, Voyager 1 & 2, and SAMPEX has shown that with a combination of suitable simulations and (if available) calibration data, HET can provide accurate measurements of the intensity and energy spectra of ~1 to ~5 MeV electrons during both solar particle events and quiet times (interplanetary Jovian electrons). The separation between protons and electrons, both of which are singly charged, is possible because electrons are relativistic even at low energies and therefore have lower rates of energy loss than protons of the same energy.

C.3.4.1.3 On-board Particle Identification. During large SEP events the telemetry allocation to HET will allow for the transmission of pulse-height data for only a small fraction of the particles triggering HET. Therefore on-board processing algorithms will be used to identify the charge and energy of up to several thousand particles per second. Each identified particle will be accumulated in a species versus energy matrix that can be telemetered once per minute (coarse energy grid for real time data) or once per 15 minutes (finer energy grid). This approach will ensure that high-time-resolution statistically accurate data will be available for both space weather applications and SEP acceleration/transport studies. It is presently anticipated that the HET species to be identified in real time will include electrons, H, ^3He, ^4He, CNO, $10 \le Z \le 14$, and Fe. In addition, penetrating H and He will be identified in real time with energies up to ~100 MeV/nucleon, and it should be possible to identify the element groups $6 \le Z \le 8$, $10 \le Z \le 14$, and $24 \le Z \le 28$ ("Fe") in real time.

C.3.4.1.4 Beacon Data. Real-time space-weather data from HET is of special interest for identifying large solar proton events that can endanger astronauts on the Space Station, as well as damage satellite hardware. Depending on location, STEREO may observe high-energy particle fluxes many hours before they reach Earth (if one of the two spacecraft is initially better connected to the shock than Earth is). Fluxes of H, He (~13 to > 100 MeV/nucleon), as well as electrons, will be available from HET in real time (within 5 minutes) on a continuous basis. Table C.3.4-1 and Figure C.3-8 show the species and energy intervals that have been identified from HET for transmission in the Beacon data.

Table C.3.4-1 HET Beacon Data

Species	Energy Range (MeV/nuc) E_{min}	E_{max}
Hydrogen	13	30
Hydrogen	30	50
Hydrogen	50	100
Helium	13	30
Electrons	1	5

C.3.4.1.5 Data Products. The following data products will be provided from HET.

- Real Time Fluxes of Key Species: See the description of Beacon Data products in Section C.3.4.1.4.
- Matrix Rate Data: Ten species in ~5 energy intervals each. H, He and electron data reported every minute, heavier ions every 15 minutes (see description in C.3.4.1.3 and IMPACT summary Table A.1).
- Pulse Height Data: The HET bit rate will allow the pulse-height data for ~1 – 2 particles/second to be transmitted in their entirety. These data will be used to identify rare species and to check the operation of the onboard algorithms. The pulse-height data for a typical particle requires ~50 bits. The priority system will ensure that all particle classifications will be sampled.

- Engineering Rates: Singles rates will be recorded for each of the individual detectors, including all the discriminator levels. These are useful for monitoring instrument health. Also included will be coincidence rates of various detector combinations that are needed for normalizing the event rates.
- Housekeeping Data: These include detector leakage currents, temperatures at selected points in the instrument, and various power supply voltages.

C.3.4.2 Approach.

HET will resolve elements using energy loss (ΔE) versus residual energy (E') implemented with the arrangement of detectors illustrated in Figure C.3.4-1. In the primary mode of operation an energetic particle passes through the H1 detector, enters the following H2 detector, and comes to rest either in that detector or in one of following three detectors (H3, H4, or H5). The absence of a signal in the H6 detector indicates that a "stopping particle" has been detected. Total energy is obtained from the sum of the detector signals, and the nuclear charge, Z, is identified based on response tracks in the two dimensional ΔE versus E' plane. For particles stopping beyond H2, two or more separate determinations of Z are obtained, improving resolution and permitting a consistency check, which can be used to suppress backgrounds.

Particles which penetrate into the H6 detector ("penetrating particles") are analyzed with a lower priority. For these particles, only a portion of the total energy is measured. Over a range of energies extending to approximately twice the maximum stopping particle energy, the change of the particle's ionization rate as it slows can be used to estimate the total energy and then to identify the charge of the particle.

Penetrating particles incident from the back end of HET (the bottom in Figure C.3.4-1) can also satisfy the coincidence requirements for analysis. Over the range of energies where there is a measurable change of ionization rate as the particle slows in the instrument, the sense of this change (increasing or decreasing from front to back of the detector stack) can be used to determine which end of the telescope the particle entered.

C.3.4.2.1 Detectors. All of the detectors used in HET are ion-implanted silicon PIN diodes. The sizes and configurations of these detectors are summarized in Table C.3.4-2. The H1 detector contact is segmented into a small circular center area surrounded by a larger-area annular region. These two areas are separately instrumented. The smaller area will have a lower count rate, which will help to minimize pulse pile-up in the largest energetic particle events.

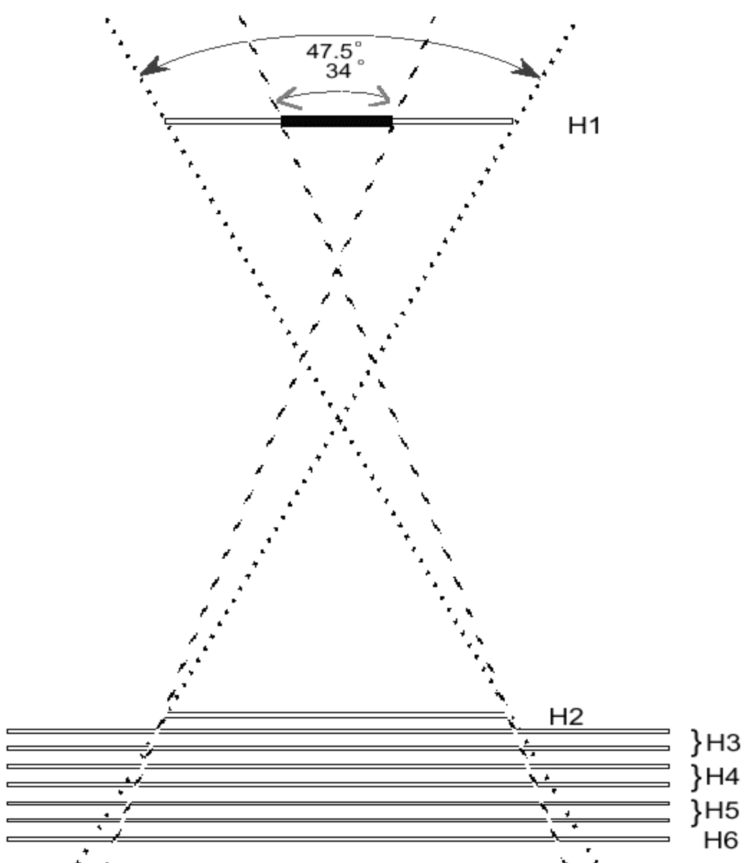

Figure C.3.4-1. The High Energy Telescope (HET).

C.3.4.2.2 Field of View and Angular Resolution. The HET instrument is designed to be oriented with its symmetry axis along the mean direction of the Parker spiral magnetic field with the H1 end facing generally sunward (see Figure B.1). HET has a field of view covering a full angle of 47.5° around the mean Parker spiral direction in both the forward hemisphere and, for penetrating particle analysis, the backward hemisphere. These view cones should be unobstructed.

The current Field of View accommodation issues for HET are described in section C.3.0.1.

C.3.4.2.3 Front-End Electronics. The ionization charge signal from each hit detector element is processed with a linear electronics chain comprising a charge-sensitive preamplifier, shaping amplifier (1 μs peaking time), linear gate, peak detector, and Wilkinson rundown ADC. This design, which is based on front-end electronics designs successfully used on a long series of previous space missions, is being implemented in a custom VLSI circuit to reduce mass, power, and volume requirements.

Table C.3.4-2 HET Detectors

Detector ID	Number of Units	Shape and Dimensions	Active Area (cm^2)	Thickness (μm)	Contact Arrangement
H1	1	Circular 4.8 cm. Diam.	18	1000	TBD cm^2 central area surrounded by annular area
H2	1	Circular 4.8 cm diam.	18	1000	Identical to H1except center and annuar contacts connected at PHA input
H3-H5	3	Circular 9.1 cm diam.	65	2000	Each 2000 µm "detector" implemented as two 1000 µm devices connected in parallel
H6	1	Circular 9.1 cm diam.	65	1000	Identical to 1000 µm devices connected in parallel to form H3-H5

Digital circuitry for controlling the VLSI pulse height analyzers (PHAs), performing coincidence logic, accumulating rates, buffering event data, and interfacing with the SEP common electronics will be implemented in programmable gate arrays. Discriminators for each electronics chain are implemented by digital comparisons between the Wilkinson rundown count and programmable digital values. Simple logic equations based on the states of these discriminators allow rapid classification of detected particles as electrons, H, He, or Z > 2 ("HiZ") nuclei. The processing of each of these categories of events will be separately throttled under the control of the SEP microprocessor to optimize the mix of processed events. In addition, trigger rates will be accumulated for each category to allow absolute flux normalizations of the processed events.

C.3.4.2.4 Interface with Common Electronics. The interface between the HET front end circuitry and the SEP common electronics will be via a small number of digital signals. These include control lines for enabling the processing of electrons, H, He, and HiZ events, an interrupt line signaling when attention is needed from the SEP DPU, and serial lines for transferring data to the DPU and control bits (e.g., discriminator levels, enable/disable for coincidence terms, test pulse amplitude) to the front-end logic.

The front end electronics will also provide a multiplexed analog line to the common electronics carrying DC housekeeping voltages representing such quantities as detector leakage currents. The interface will also carry conditioned DC power at the voltages required by the front end and bias voltages for the silicon detectors.

C.3.4.2.5 Expected Performance. Figure C.3.4-2 shows results of simulating the response of the HET instrument to selected elements and isotopes satisfying its various trigger conditions. Electrons (not shown) populate a region in the lower-left corner of the response matrix, below the H track. .can be used under the control of the SEP microprocessor to perform functional tests of the electronics as well as to monitor the gain and offset stability of the analog front end.

C.3.4.2.6 HET Resource Requirements. In the IMPACT proposal the HET telescope, including the detectors, was to be supplied by Waseda University. When they did not receive funding for STEREO it became necessary to consider alternate designs for HET that could meet the science requirements for lower cost (see Appendix F). The HET2 design presented here has the advantage that it satisfies the science requirements for lower cost by making use of spare detectors from ACE. The one disadvantage of this option is that the larger area of these detectors will require a mass increase of ~300 grams. Studies of the HET design during Phase A have also led to other refinements in the design and to improved definition of the required resources. The net result is a HET2 design that will satisfy the science requirements with significantly reduced risk.

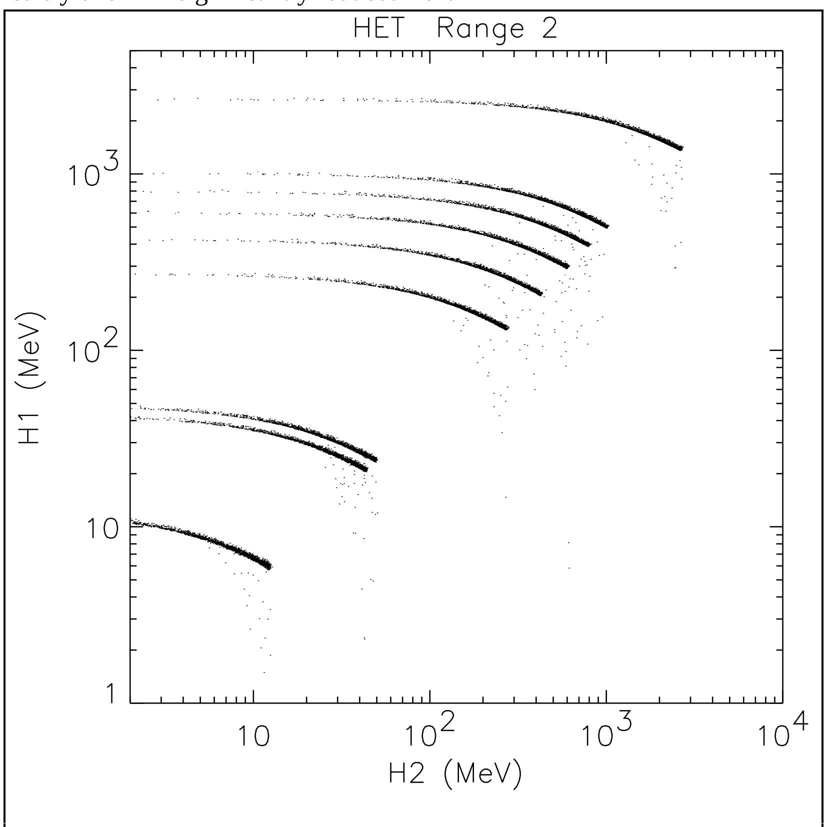

Figure C.3.4-2. Simulated response of the HET instrument to selected elements and isotopes.

Table C.3.4-3 HET Mass Requirements

	Proposal (grams)	Phase A Estimate* (grams)	Change (grams)	Explanation
HET Sensor	235	600	365	Use existing, larger-area detctors from ACEt
HET electronics	32	92	60	Fewer PHA channels per chip than assumed moved 1 Acetel from logic board to front end
TOTAL:	267	692	425	

*Assumes HET2 design that employs existing ACE detectors

Table C.3.4-4 HET Power Requirements

	Proposal (mW)	Phase A Estimate* (mW)	Change (mW)	Explanation
HET Sensor	0	0	0	0
HET electronics	36	70	34	Fewer PHA channels per chip than assumed Moved 1 Acetel from logic board to front end
TOTAL:	36	70	34	

*Assumes HET2 design that employs existing ACE detectors

C.3.4.2.6.1 Segmented H1 Detectors. The STEREO science goals require that HET be able to measure accurately the fluxes of high energy H, He, and electrons in the largest SEP events that may be encountered, and that HET also be capable of measuring small, impulsive events. A survey of ACE data over the past 2.5 years has shown that the maximum count rates of >0.6 MeV protons expected for the H1 detector could reach ~100,000 per second, too great to ensure that accurate measurements will be made using current electronic designs. At the same time the minimum count rates of interest are likely to be < 10^{-3} per second. To handle this wide dynamic range in intensity requires that HET have a variable geometry factor. This has led to the adoption of a detector design for the H1 detectors in which there is a small, separately-instrumented, central "bulls-eye" region with <10% of the full detector area. This smaller central region would be used during periods with the greatest particle intensities. HET will also achieve its best resolution for particles detected in the center region.

C.3.4.2.6.2 Custom VLSI Circuitry. In the IMPACT proposal it was assumed that there would be 16 VLSI pulse height analyzer circuits per chip requiring 4 mW for each channel. The VLSI design is now much farther along and the first prototype circuits have been fabricated by MOSIS. Two separate VLSI package designs are now envisioned, one with 10 channels per chip (for LET L1 and L2) and a second with a single channel per chip (for the HET detectors and for LET L3). It is now also recognized that there will be an "overhead" power requirement in each of these chips (~2 mW each), and that the power per channel will depend somewhat on the dynamic range requirements (4 mW for L2 and L3; 3 mW for L1). One additional small change in the HET power and mass is due to a change in bookkeeping - one Actel chip originally bookkept with the SEP common electronics is now considered part of the HET front end.

The above considerations have led to small increases in the required mass and power (see Tables C.3.4-3 and C.3.4-4). On the other hand, the power requirements are now much better known, and the chip design is more conservative than was assumed in the proposal. The net result is that schedule and cost risk have been reduced.

C.3.4.2.6.3 HET Bit Rate Requirements. After discussions with STEREO Project management it was decided to ask for an increase in the IMPACT bit rate allocation. The portion of this new allocation assigned to HET will increase its bit rate by a factor of four. This increase will improve the science return from HET and reduce the time required for functional testing throughout the program. It will also reduce data-compression requirements. The totals in Table C.3.4-5 reflect the new HET bit rate.

Table C.3.4-5 HET Bit-Rate Requirements

	Proposal	Phase A Estimate (bps)	Change (bps)	Explanation
HET	30	120	90	Reduce testing time during I&T and improve science return

C.3.4.3 Development plan

C.3.4.3.1 Trades in progress. With the dropout of the Waseda University collaborator who was to have provided the HET telescopes (also see section C.3.0), we have had to investigate ways to provide the HET science in a cost effective manner. In the system described in this Phase A report, we plan to use spare ACE/SIS detectors in a single-ended telescope design. This appears to be the most cost-effective way of preserving essentially all of the science provided by the original HET design. Other possibilities for HET are discussed in Appendix F.

We are also pursuing a trade study involving the implementation of the signal processing ASIC. This study is discussed in section C.3.3.3.1.

C.3.4.3.2 New technology development; descope options. The only new technology development item for HET is the signal processing ASIC, which will also be used in LET and SIT. The status of the development this circuit is described in C.3.3.3.2.

The HET telescopes were originally to be provided by Waseda University. However, this collaborator could not get funding, which led to a study to find a way to replace some or all of the HET science.

Various options were considered and are described in Appendix F. The baseline we are describing in this report represents a descope of the original HET design. It uses primarily existing spare detectors from the ACE/SIS instrument. As such, further descoping of HET will probably not result in significant cost savings.

C.3.4.3.3 Long lead items. Long lead items for HET include the H1 and H2 solid state detectors and the ASICs. The status of the special integrated circuits for signal analysis is described in C.3.3.3.3. The adopted HET design uses primarily spare solid-state detectors from the ACE/SIS instrument, all of which are in hand. The front two detectors will be obtained from Micron Semiconductor and definition discussions are currently underway.

*C.3.4.3.4 Breadboard, engineering model plans.*The HET electronics is not as complex as that of LET, and due to fewer detector signal channels it will fit on a single PCB. Otherwise, the same approach as described in C.3.3.3.4 will be employed here.

C.3.4.3.5 Fabrication plan. The fabrication plan for HET will be very similar to that for LET described in C.3.3.3.5.

C.3.4.3.6 Calibration Plan. The HET front-end electronics will be calibrated on the bench over a wide range of operating temperatures using a pulser and calibrated test capacitors. Based on our experience with similar circuitry on ACE it is expected that they will be linear to a high degree of precision, requiring only two numbers, the gain and offset, to characterize the response of a given ADC at a given temperature.

A full functional test of HET prior to delivery will require exposure to heavy ion beams at the Michigan State University Cyclotron. While the primary purpose of this exposure is to test the functionality and response of HET over its full dynamic range, including high-rate conditions such as will be encountered in a large SEP event, this exposure will also provide valuable calibration data on the location of the tracks of ions from H to Ni.

Calibration of the response of HET to electrons will rely mainly on simulations and on experience with previous telescopes of similar design. For reasons of schedule and cost, it is not presently planned to take HET to an electron accelerator. However, HET will also be tested with cosmic ray muons and with radioactive sources that include ^{106}Ru, which produces beta-decay electrons up to 3.5 MeV. HET will also be tested with gamma-ray sources that include ^{137}Cs, ^{60}Co, and ^{228}Th. These sources provide information on the response of HET to gamma-ray induced Compton electrons, which provide a steady source of background for electron measurements in flight.

C.3.4.3.7 Ground Support Equipment (GSE). Ground support equipment will be developed at Caltech/JPL under the direction of M. Wiedenbeck. It will be based on a PC or workstation running an appropriate variant of the Unix operating system and will have the capability of collecting data either via Ethernet or RS232 in the formats provided by several alternative sources: the SEP DPU or DPU simulator (supplied by Caltech), the IMPACT DPU (IDPU) simulator (supplied by UC Berkeley), or the Berkeley IMPACT GSE. The GSE will format and archive test data, perform limit checking of selected quantities, and provide a variety of data displays. It will be capable of processing data either in real time or during playback from previously stored files.

The GSE computer and core software will be identical for LET and HET, with different subroutines as needed to process the different data formats and to make instrument-specific displays. In addition, the GSE software will include routines to extract and display SIT and SEPT data from the IDPU and S/C data streams.

C.3.4.3.8 Special facility plans. Most of the integration and test activities will take place in Room 5 of Downs Laboratory at Caltech. This large laboratory was developed for the integration and test of the CRIS and SIS instruments on ACE. It is not a certified clean room; however, it contains two clean benches, on which most of the assembly operations will take place. For environmental tests, we will use facilities at JPL and/or GSFC. We plan to do an end-to-end functional test of HET at the Michigan State University Cyclotron accelerator.

C.3.4.3.9 Outstanding Issues. The revised description of HET described here has not yet been approved by the Project.

C.3.4.3.10 Concerns. We are assuming that the contamination control plan will allow us to develop our hardware using the same facilities and using the same processes that we used for developing our CRIS and SIS instruments on ACE. We assume that upon delivery, our instrument will be cleaned externally using ethanol.

We are concerned about the shortening of the schedule, which occurred since our proposal was submitted and accepted. Measured from the beginning of Phase B to instrument delivery, we have lost 3 to 7 months, depending on whether IMPACT delivers at the beginning or end of the current delivery window. We are very concerned about ITAR issues as discussed in section C.3.5.7.

C.3.4.4 Operational constraints

C.3.4.4.2 Areas of concern. HET may be powered on at ambient pressure or in a good vacuum but must not be powered on in a partial vacuum (10^{-5} Torr < pressure < ambient). For vacuum operation, HET must be in a vacuum of < 10^{-5} Torr for 24 hours before being initially powered on.

C.3.4.4.1 Special bus requirements. Not applicable to HET.

C.3.4.4.3 Special requirements for I&T. In order to functionally test HET it will be desirable to stimulate the front detectors with radioactive sources (alphas, gammas, and betas). It is necessary to purge HET continuously with dry nitrogen (purity of LN2 boil-off), except for brief periods. Solvents should be used sparingly around HET, and only while it is being purged.

C.3.4.4.4 Special requirements for commissioning. HET should be allowed to outgas for at least 24 hours after launch, before turn-on.

C.3.4.4.5 Special requirements for operations. There are no special requirements for HET with regard to operations. Occasional commanding is all that is required.

C.3.4.5 Management processes

C.3.4.5.1 Roles and responsibilities. The roles and responsibilities for the development of HET are the same as those for LET and are described in C.3.3.5.1.

C.3.4.5.2 Heritage. The HET sensor system has a heritage which goes back to similar solid-state detector telescopes flown on Voyager, ISEE, and ACE. Much of the electrical design will be based on designs executed for the ACE/CRIS and ACE/SIS instruments. The microprocessor will be the same as the one used in the CRIS and SIS instruments. One particularly strong heritage aspect is the personnel. Almost all of the same people will be working to produce HET who worked on ACE/SIS.

C.3.4.5.3 Product assurance plans. Caltech, JPL, and GSFC will follow the Performance Assurance Implementation Plan for the STEREO IMPACT Instrument Suite.

C.3.4.5.4 Planning and interface with IMPACT team. W. Cook will work directly with D. Curtis on issues involving the electrical interface with the IMPACT DPU. T. von Rosenvinge of GSFC will be the point of contact for mechanical and administrative issues. Regular IMPACT conference calls and meetings are scheduled to ensure the coordination between the groups.