

# Science Activity Plan (SAP)

The latest version (v0.1, 10 July 2017) of the full SAP document can be downloaded [here](#).

*N.B.: The individual Confluence pages might contain more recent information than the full SAP document.*

- Solar Orbiter detailed science objectives
  - Objective 1: What drives the solar wind and where does the heliospheric magnetic field originate?
    - 1.1 What are the source regions of the solar wind and heliospheric magnetic field?
      - 1.1.1 Source regions of the fast solar wind
        - 1.1.1.1 Low FIP fast wind origins
        - 1.1.1.2 Origin of the small-scale X-ray and UV jets in polar coronal holes
      - 1.1.2 Source regions of the slow solar wind
        - 1.1.2.1 Does slow wind originate from the over-expanded edges of coronal holes?
        - 1.1.2.2 Does slow and intermediate solar wind originate from coronal loops outside of coronal holes?
        - 1.1.2.3 Abundance of minor ions as a function of height in the corona as indicator of slow or fast wind
        - 1.1.2.4 Study of density fluctuations in the extended corona as a function of the outflow velocity of the solar wind while evolving in the heliosphere
        - 1.1.2.5 Structure and evolution of streamers
        - 1.1.2.6 Disentangle the spatial and temporal variability of the slow wind
        - 1.1.2.7 Trace streamer blobs and other structures through the outer corona and the heliosphere.
        - 1.1.2.8 Determine the velocity, acceleration profile and the mass of the transient slow wind flows
      - 1.1.3 Source regions of the heliospheric magnetic field
        - 1.1.3.1 Full characterization of photospheric magnetic fields and fine structures
        - 1.1.3.2 How does the Sun's magnetic field link into space?
          - 1.1.3.2.1 How does the Sun's magnetic field change over time?
          - 1.1.3.2.2 How is the heliospheric current sheet (HCS) related to coronal structure?
          - 1.1.3.2.3 How does the heliospheric magnetic field disconnect from the Sun?
        - 1.1.3.3 What is the distribution of the open magnetic flux?
      - 1.1.4 Transverse themes
        - 1.1.4.1 Reconnection
          - 1.1.4.1.1 Interchange reconnection between open and closed field lines and its role in slow wind generation
          - 1.1.4.1.2 Identify coronal reconnection sites by measuring impulsive event material
          - 1.1.4.1.3 Identify reconnection exhausts in the solar wind
          - 1.1.4.1.4 Current sheets inferred by determining the magnetic field geometries at local chromospheric heating sites
          - 1.1.4.1.5 Identify and characterise the solar wind reconnection physics in current sheets with thickness down to the ion scales and smaller
          - 1.1.4.1.6 Photospheric reconnection
          - 1.1.4.1.7 Electron acceleration in coronal reconnection regions
          - 1.1.4.1.8 Formation of flux ropes/CMEs via magnetic reconnection in the corona
    - 1.2 What mechanisms heat the corona and heat and accelerate the solar wind?
      - 1.2.1 What mechanisms heat the corona?
        - 1.2.1.1 Energy flux in the lower atmosphere
        - 1.2.1.2 Energy and mass flux in the corona.
        - 1.2.1.3 Contribution of flare-like events on all scales
        - 1.2.1.4 Observe and explore flare-like 'heating events' from the quiet corona
        - 1.2.1.5 Determine whether coronal heating is spatially localized or uniform, and time steady or transient or impulsive for a wide range of magnetic loops with different spatial scales.
        - 1.2.1.6 Resolve the geometry of fine elemental loop strands
        - 1.2.1.7 Detect and characterise waves in closed and open structures
        - 1.2.1.8 Investigate the role of small scale magnetic flux emergence in energizing the above laying layers
        - 1.2.1.9 Multi-temperature diagnostics of flaring coronal loops
        - 1.2.1.10 Heating in flaring loops vs heating in active regions
      - 1.2.2 What mechanisms heat and accelerate the solar wind?
        - 1.2.2.1 Determine where energy is deposited in the solar wind
        - 1.2.2.2 What drives the evolution of the solar wind distribution functions in situ?
        - 1.2.2.3 What is the nature and origin of waves, turbulence and small-scale structures?
        - 1.2.2.4 Solar wind reconnection physics
        - 1.2.2.5 Magnetic reconnection in the chromosphere, the transition region and the corona
        - 1.2.2.6 Study fast plasma flows from the edges of solar active regions discovered with Hinode/EIS
        - 1.2.2.7 Study the correlation degree between velocity and magnetic field fluctuations in the interplanetary space
        - 1.2.2.8 What determines the azimuthal flow of the near-Sun solar wind?
    - 1.3 What are the sources of solar wind turbulence and how does it evolve?
      - 1.3.1 Solar and local origin of Alfvénic fluctuations
      - 1.3.2 How is turbulent energy dissipated and how does turbulence evolve within the heliosphere?
      - 1.3.3 Plasma turbulence variability
      - 1.3.4 Plasma turbulence anisotropy
  - Objective 2: How do solar transients drive heliospheric variability?
    - 2.1 How do CMEs evolve through the corona and inner heliosphere?
      - 2.1.1 What are the global structure, initiation, and evolution of CMEs?
        - 2.1.1.1 CME initiation
        - 2.1.1.2 CME structure
        - 2.1.1.3 CME evolution
    - 2.2 How do CMEs contribute to solar magnetic flux and helicity balance?
      - 2.2.1 How do CMEs contribute to the global evolution of magnetic flux in the heliosphere?

- 2.2.2 What is the role of ICMEs in the Sun's magnetic cycle?
  - 2.3 How and where do shocks form in the corona and in the heliosphere?
    - 2.3.1 Coronal shocks
    - 2.3.2 What are the properties and distribution of heliospheric shocks?
      - 2.3.2.1 Understand coronal conditions under which the shocks form and determine the interplanetary conditions where they evolve
      - 2.3.2.2 Identify interplanetary shocks and characterise their spatial and temporal evolution
      - 2.3.2.3 Study heating and dissipation mechanisms at shocks with radial distance
      - 2.3.2.4 Identify mechanisms that heat the thermal solar wind particle populations near shocks and determine their energy partition
    - 2.3.3 Resolve the interplanetary shock field and plasma structure down to the spatial and temporal scales comparable and smaller than the typical ion scales.
    - 2.3.4 Shock-surfing acceleration mechanism
    - 2.3.5 Understand the radio emissions from the ICME driven shocks
    - 2.3.6 Identify shock accelerated particles
  - Objective 3: How do solar eruptions produce energetic particle radiation that fills the heliosphere?
    - 3.1 How and where are energetic particles accelerated at the Sun?
      - 3.1.0 Explore in depth the SEP properties
      - 3.1.1 CME and shock associated SEP sources
        - 3.1.1.1 Where and when are shocks most efficient in accelerating particles?
        - 3.1.1.2 Why are gradual SEP events so variable?
          - 3.1.1.2.1 Intensity variability
          - 3.1.1.2.2 Composition variations
          - 3.1.1.2.3 Warped shock fronts
          - 3.1.1.2.4 Turbulence and inhomogeneities
        - 3.1.1.3 How are superhalo particles accelerated continuously in the corona and solar wind?
        - 3.1.1.4 How can SEPs be accelerated to high energies so rapidly?
        - 3.1.1.5 Do proton-amplified Alfvén waves play a role in accelerating particles at shocks?
        - 3.1.1.6 What causes SEPs' spectral breaks?
        - 3.1.1.7 Are there favourable environments for particle acceleration?
      - 3.1.2 SEPs associated with flares, coronal loops and reconnection regions
        - 3.1.2.0 Impulsive SEP event sources
          - 3.1.2.0.1 Measure the enhancements of trans-iron elements in impulsive SEPs (to be deleted - trans-iron SEPs cannot be detected by EPD)
        - 3.1.2.1 Understand energy release and particle acceleration process
        - 3.1.2.2 Evaluate how significantly large flares contribute directly to gradual SEP events
        - 3.1.2.3 Flare seed particles
        - 3.1.2.4 Explore the fact that only some of the hard X-ray peaks are related to escaping electrons, while others are not
        - 3.1.2.5 X-ray prompt events
        - 3.1.2.6 Delayed events (between X-ray peak and electron release time)
        - 3.1.2.7 How are so many electrons accelerated on such short time scales to explain the observed hard X-ray fluxes?
        - 3.1.2.8 Explore the type III radio bursts delays
      - 3.1.3 Relativistic electron acceleration
        - 3.1.3.1 How shocks can accelerate electrons to relativistic energies (never observed for shocks near 1 AU)?
        - 3.1.3.2 Double-power law spectra
      - 3.1.4 Other high sensitivity X-ray studies
        - 3.1.4.1 Hard X-ray emission of escaping electron beams (thin-target emission)
        - 3.1.4.2 X-ray emission from electrons accelerated at CME shocks
    - 3.2 How are energetic particles released from their sources and distribute in space and time?
      - 3.2.0 What controls the escape of the particles to the heliosphere?
      - 3.2.1 How do energetic particles scatter and move along the interplanetary magnetic field?
        - 3.2.1.1 Map the power spectrum of the turbulent magnetic field as a function of heliocentric distance in order to provide ground-truth for transport models
        - 3.2.1.2 Measurements of SEP events time profiles and anisotropy in order to probe solar wind turbulence
        - 3.2.1.3 Identify dropouts and measure scattering of SEPs by turbulence.
      - 3.2.2 Latitudinal and longitudinal transport of SEPs
      - 3.2.3 Properties and distribution of near-Sun shocks, their fluctuations and particle acceleration
      - 3.2.4 How do large and small-scale structures modulate particle fluxes?
      - 3.2.5 Shock-surfing acceleration mechanism
      - 3.2.6 Effects of energetic particles propagating downward in the chromosphere
    - 3.3 What are the seed populations for energetic particles?
      - 3.3.1 What are the properties and distribution of suprathermal seed populations?
        - 3.3.1.1 Characterization of the suprathermal population
        - 3.3.1.2 Characterize the suprathermal elemental and charge-state composition as a function of energy, time and location.
        - 3.3.1.3 Role of shocks in generating SEPs
- Objective 4: How does the solar dynamo work and drive connections between the Sun and the heliosphere?
  - 4.0 Overall remarks and feasibility concerning Objective 4 observations with Solar Orbiter
  - 4.1 How is magnetic flux transported to and re-processed at high solar latitudes?
    - 4.1.1 Study the detailed solar surface flow patterns in the polar regions, including coronal hole boundaries.
    - 4.1.2 Study the subtle cancellation effects that lead to the reversal of the dominant polarity at the poles
    - 4.1.3 Explore the transport processes of magnetic flux from the activity belts towards the poles and the interaction of this flux with the already present polar magnetic field.
    - 4.1.4 Study the influence of cancellations at all heights in the atmosphere
  - 4.2 What are the properties of the magnetic field at high solar latitudes?
    - 4.2.1 Probability density function (PDF) of solar high-latitude magnetic field structures.
    - 4.2.2 Basic properties of solar high-latitude magnetic field structures

- 4.2.3 Probe the structure in deep layers of the Sun
    - 4.3 What is the nature of magnetoconvection?
    - 4.4 Are there separate dynamo processes acting in the Sun?
    - 4.5 How are coronal and heliospheric phenomena related to the solar dynamo?
  - 5. Additional science objectives
    - 5.1 Additional Science Objectives of EUI
    - 5.2 Additional Science Objectives of EPD
      - 5.2.1 Energetic particles in Venus and Earth environment.
      - 5.2.2 Galactic and anomalous cosmic rays. Long-term and short-term modulation and spatial variation.
      - 5.2.3 Energetic neutral atoms.
      - 5.2.4 Jovian electrons.
    - 5.3 Additional Science Objectives of MAG
    - 5.4 Additional Science Objectives of METIS
      - 5.4.1 Hydrogen Ly- emission by the atmosphere of planets (e.g. Venus, Jupiter)
      - 5.4.2 Study of Sungrazing comets
        - 5.4.2.1 Understand cometary properties and evolution by mapping the hydrogen Ly- emission, proportional to the outgassing rate, along its trajectory close to the Sun
        - 5.4.2.2 Investigate the fragmentation of the cometary nucleus from the variation with the heliocentric distance of the outgassing rate and from the splitting of the cometary tail
    - 5.5 Additional Science Objectives of PHI
    - 5.6 Additional Science Objectives of RPW
    - 5.7 Additional Science Objectives of SoloHI
    - 5.8 Additional Science Objectives of SPICE
    - 5.9 Additional Science Objectives of STIX
    - 5.10 Additional Science Objectives of SWA
      - 5.10.1 What is the temporal variability of 3D thermal particle distributions?
      - 5.10.2 How are proton and helium temperatures related to their relative drift, is there any evidence for resonant heating?
      - 5.10.3 How common are proton beams, where do they come from and what impact do they have on ambient conditions (wave generation, heating)?
      - 5.10.4 Identify and characterise the various forms of free energy in the particle distribution functions
      - 5.10.5 Fully characterise the radial and latitudinal variability of 3D thermal particle distributions under different solar wind conditions
      - 5.10.6 Electron halo population
      - 5.10.7 How do the combined electron strahl and composition signatures vary across reconnecting solar wind current sheets?
  - Bibliography
  - Sub-objectives not yet attached to SOOPs
- SOOP pages
  - L\_DEFAULT
  - L\_IS\_STIX
  - L\_IS\_SoloHI\_STIX
  - L\_FULL\_LRES\_MCAD\_Coronal-Synoptic
  - L\_FULL\_LRES\_MCAD\_Probe-Quadrature
  - L\_FULL\_MRES\_MCAD\_CME-SEPs
  - L\_FULL\_HRES\_LCAD\_MagnFieldConfig
  - L\_FULL\_HRES\_MCAD\_Coronal-He-Abundance
  - L\_FULL\_HRES\_HCAD\_Eruption-Watch
  - L\_FULL\_HRES\_HCAD\_Coronal-Dynamics
  - L\_SMALL\_MRES\_MCAD\_Ballistic-connection
  - L\_SMALL\_MRES\_MCAD\_Connection-Mosaic
  - L\_SMALL\_HRES\_HCAD\_Fast-Wind
  - L\_SMALL\_HRES\_HCAD\_Slow-Wind-Connection
  - L\_BOTH\_LRES\_MCAD\_Pole-to-Pole
  - L\_BOTH\_MRES\_MCAD\_Farside-Connection
  - L\_BOTH\_MRES\_MCAD\_Flare-SEPs
  - L\_BOTH\_HRES\_LCAD\_CH-Boundary-Expansion
  - L\_BOTH\_HRES\_HCAD\_Major-Flare
  - R\_FULL\_LRES\_LCAD\_Transition-Corona
  - R\_FULL\_LRES\_HCAD\_Full-Disk-Helioseismology
  - R\_FULL\_HRES\_HCAD\_Density-Fluctuations
  - R\_FULL\_LRES\_LCAD\_Out-of-RSW-synoptics
  - R\_SMALL\_MRES\_MCAD\_AR-Long-Term
  - R\_SMALL\_HRES\_LCAD\_Composition-vs-Height
  - R\_SMALL\_HRES\_LCAD\_Fine-Scale-Structure
  - R\_SMALL\_HRES\_MCAD\_Polar-Observations
  - R\_SMALL\_HRES\_HCAD\_Atmospheric\_Dynamics\_Structure
  - R\_SMALL\_HRES\_HCAD\_AR-Dynamics
  - R\_SMALL\_HRES\_HCAD\_PDF-Mosaic
  - R\_SMALL\_HRES\_HCAD\_RS-burst
  - R\_SMALL\_HRES\_HCAD\_Wave-Stereoscopy
  - R\_SMALL\_HRES\_HCAD\_Ephemeral
  - R\_SMALL\_HRES\_HCAD\_Granulation-Tracking
  - R\_SMALL\_HRES\_HCAD\_Local-Area-Helioseismology
  - R\_BOTH\_HRES\_HCAD\_Nanoflares
  - R\_BOTH\_HRES\_HCAD\_Filaments
  - SOOP prototemplate: I/R/L\_FULL/SMALL\_L/M/Hres\_L/M/Hcad\_freefield
  - SOOPs To Be Cleaned-Up
    - L\_SMALL\_HRES\_MCAD\_Suprathermal\_Popul

- R\_SMALL\_HRES\_HCAD\_ModePhysics
  - Summary of SOOPs
- General Planning strategy for first version SAP v0
  - Example Planning periods (from October 2018 Option E)
    - Remote Sensing Window Properties
    - MTP05 - 2021/01/01 - 2021/07/01
    - MTP06 - 2021/07/01 - 2022/01/01
    - MTP07 - 2022/01/01 - 2022/07/01
    - MTP08 - 2022/07/01 - 2023/01/01
    - MTP09 - 2023/01/01 - 2023/07/01
    - MTP10 - 2023/07/01 - 2024/01/01
    - MTP11 - 2024/01/01 - 2024/07/01
    - MTP12 - 2024/07/01 - 2025/01/01
    - MTP13 - 2025/01/01 - 2025/07/01 (EMP)
    - MTP14 - 2025/07/01 - 2026/01/01
    - MTP15 - 2026/01/01 - 2026/07/01
    - MTP16 - 2026/07/01 - 2027/01/01
    - MTP17 - 2027/01/01 - 2027/07/01
    - MTP18 - 2027/07/01 - 2028/01/01
    - MTP19 - 2028/01/01 - 2028/07/01
    - MTP20 - 2028/07/01 - 2029/01/01
    - MTP21 - 2029/01/01 - 2029/07/01
- Science Planning !NEW!
  - Roadmap for Planning Activities & Related Work
  - Trajectory Overview - 10 February 2020 Launch
  - Solar Orbiter / Bepi Colombo Opportunities for Coordinated Measurement Campaigns
  - Cruise Phase
    - MLP of Cruise during SOWG#11 (Jan 2018)
    - MLP of Cruise during SOWG#13 (mini-SWT, 23 Jan 2019)
      - SOWG 13 Cruise Phase MLP: Questions to be answered
    - MLP of Cruise during SWT#24 (April 2019)
      - Summary of changes made to original Cruise Phase plan for RS payload
      - Summary of Plan Optimisation for the In Situ Payload
    - MLP of Cruise during SWT#25 (Oct 2019)
    - MLP of Cruise during SWT#26b (Mar 2020)
      - Simulation results MLP for LTP3
    - LTP01 May 2020-June 2020
      - LTP01 Schedule
        - STP-100 and -101 Schedule
    - LTP02 July 2020-Dec 2020
      - LTP02 Schedule
        - STP-102 Schedule
        - STP-103 Schedule
        - STP-104 Schedule
        - STP-105 Schedule
        - STP-106 Schedule
        - STP-107 Schedule
        - STP-108 Schedule
        - STP-109 Schedule
        - STP-111 Schedule
        - STP-112 to 127 Schedule
    - LTP03 Jan 2021-June 2021
      - Changes made to LTP03 post-SOWG 16
      - LTP03 Schedule
        - STP-127 to 131 Schedule
        - STP-132 to 136 Schedule
        - STP-137 to 141 Schedule
        - STP-142 to 145 Schedule
    - LTP04 July 2021-Dec 2021
  - NMP Segment 1: Jan-Dec 2022
    - LTP05 Jan 2022-June 2022
    - LTP06 July 2022-Dec 2022
  - NMP Segment 2: Jan-Dec 2023
  - NMP Segment 3: Jan-Dec 2024
  - NMP Segment 4: Jan-Dec 2025
    - LTP12 July 2025-Dec 2025
  - Early STPs Debriefing - 21 July 2020