2. Scientific Requirements

2.1 Scientific Requirements

2.1.1 Requirements for Helioseismology Observables

The success of global helioseismology, which is centered at precise measurement of the solar eigenfrequencies and inversion of these frequencies, is well documented. In particular, mapping the solar differential rotation (Figure 7) and meridional flow (Figure 8) throughout the low- to mid-latitude convection zone had a great impact on our understanding of the solar dynamo.

One inherent limitation of global helioseismology comes from inverse analysis based on the linear perturbation theory, and the symmetry of the global eigenfunctions; the structure inversion is primarily about estimating the spherically symmetric component of the thermal structure of the sun (even inversions for aspherical components of the thermal structure of the sun is accessing only those components that are axisymmetric and north-south symmetric), and the rotation inversion is about measuring the axisymmetric, north-south symmetric component of the solar internal flow. Moreover, the sensitivity kernels for rotation inversion, derived from the eigenfunctions, do not have large amplitude in higher latitude region.

Local helioseismology, based on local measurement of wave propagation, particularly wave travel times, is better suited for revealing local structure free of any kind of symmetry that are mentioned in the above. Local helioseismology has already been successful in measuring near-surface component of meridional flow (Figure 8), which is the key ingredient in flux-transport dynamo, up to around 60° latitude (Giles et al. 1997). Extending the measurement to higher latitudes is one of the main scientific targets of SOLAR-C Plan-A.

Thus there are two main objectives of heliseismology observations from an inclined orbit: 1. *High-latitude local helioseismology*: measure local wavefield in high-latitude region better than from within the ecliptic place, for local-helioseismology analyses of various flows in the near-surface (and if possible, deeper) layers, such as meridional flow. 2. *Multi vantage-point helioseismology*: in combination with observing facilities in the ecliptic plane, observe waves with large skip angles better, for helioseismology analyses of deep interior, such as mid-latitude tachocline regions. The first objective is more promising in producing important results, whereas the second objective is more challenging.

Helioseismology requires long continuous observing periods at a high time cadence in order to resolve the various spatial and temporal scales associated with processes of generation and dissipation of solar magnetic fields. These scale range from supergranulation, which defines the magnetic network and is a primary source for magnetic field diffusion and has a typical spatial scale of 30 Mm and lifetime of about 1 day, and larger-scale dynamics of active regions occupying 50-100 Mm and evolving on the scale of a week, to the global meridional and zonal flows occupying the whole convection zone 200 Mm deep and varying with the solar cycle on the time scale of a year.

These three fundamental scales of solar dynamics and activity define three basic observing patterns that are needed to achieve the primary objective above: relatively short (8 hour long) but high-resolution (512×512 pixels) time series to investigate the structure and dynamics on the supergranular and magnetic network scales; longer (7-14 days) and high-resolution (512×512 pixels) series to follow the evolution of individual active regions (particularly, on the far side of the Sun in conjunction with Earth-side observations), and long time period (36-72 day) low resolution (256×256 pixels) observations to investigate the global dynamics and circulation of the convection zone down to the tachocline by both local and global helioseismology techniques.

All these observing programs require a 1 minute cadence for the Dopplergrams. However, a strict temporal continuity requirement (95% coverage) is required for 8-hour chunks of these programs. The longer observing programs may have gaps. However, the total coverage should be at least 70-80%, in particular, for the global helioseismology 36-72-day runs in order to prevent the aliasing problems in the measurements of mode frequencies and frequency splitting. The precision of the frequency measurements is inverse proportional to the square root of the observing time. Currently, 72-day runs are used in the SOHO/MDI Structure program that is similar to the low-resolution (256×256 pixels) SOLAR-C program. These runs provide inversion results for solar structure, asphericity and rotation through the whole convection zone, tachocline and outer radiative zone. Shorter, 36-day runs will still provide new results for the convection zone sufficient for studying the torsional oscillations and other global variations. However, the ability to resolve the tachocline structure and dynamics will be greatly reduced. The investigation of the solar-cycle variation in the tachocline region may require 12-month long averaging of the frequency measurements. The minimum science requirement for exploring the solar-cycle variations in the polar regions is to have two or three 36-day runs per year.

Table 2. Helioseismology Observing Requirements

Measurement Objective(s)	Technique	Length of observation	Image size (pixels)	Image cadence
Differential rotation and torsional oscillations at high latitudes, sub-surface polar jets	Global	36-72 days	256×256	1 min
	Local	8 hrs	512×512	1 min
Meridional circulation, latitudinal and longitudinal structures, secondary cells, relationship to active longitudes, magnetic flux transport	Local	8 hrs	512×512	1 min
Supergranulation and large-scale convection patterns in polar regions (super-rotation, wave-like behavior, network, flux transport, relationship to coronal holes)	Local	8 hrs	512×512	1 min
Structure and dynamics of the high-latitude tachocline (oblateness, flows)	Local	36 days	256×256	1 min
Tomography of the deep interior: stereoscopic observations (SOLAR-C-SDO, SOLAR-C-GONG)	Local (time-distance, holography)	36 days	256×256	1 min

The different measurement objectives, the observing technique and the observing requirements are listed in Table 2. Global helioseismology, which assumes symmetry about the rotation axis of the Sun, requires a very accurate determination of the frequencies of the Sun's acoustic modes of to determine the longitudinal rotation as a function of depth; the longest observation times (36-72 days of continuous, 70-80% coverage data) are needed to determine the frequency and frequency splitting of solar oscillation p-modes of low angular order, m. These modes, in particular, zonal m=1 modes, propagate into the polar regions and provide the information about the polar structure and dynamics. The current ecliptic-viewpoint observations do not provide measurements sufficiently accurate for helioseismic inversion of the solar structure and rotation in the polar regions. It is important to complement the SOLAR-C observations with ecliptic-viewpoint data in order to infer the structure and dynamics of the whole Sun, from the equator to the poles.

It can be seen from the table that some of these measurements require high latitude viewing for many days at a time. This was the driving requirement for choosing an orbit inclination with the highest possible inclination. The high-latitude viewing will provide a unique opportunity to study the dynamics of meridional flows and rotation in the polar regions and search for deep longitudinal structures in the tachocline by local helioseismology. In addition, the high-latitude orbit will allow us to obtain better coverage of the deep polar regions using the observing scheme with two vantage points, SOLAR-C and ecliptic viewpoint helioseismology instrument.

The required telemetry for the helioseismic observations is case dependent. However, it is obvious that the reduction of the data by on-board processing is mandatory. For a measurement of Doppler velocity map with a simultaneous measurement of line-of-sight magnetic fields, two polarization states of I +V and I-V need to be observed at four wavelength positions for a good estimate of the line-of-sight magnetic fields. This methodology was used in *Hinode* filtergram observations. The eight images obtained at eight observing times can be reduced to two index maps by simple arithmetic operations, each can be converted to Doppler velocity and line-of-sight magnetic field by a known non-linear function. If we need Doppler velocity maps of 512×512 imaging points every 1 min, ~13 kbit/s data rate is required for the data compression efficiency of 3 bit/s (512 ×512 pixel × 3 bit/pixel /60 s =13,107 bit/s) that is achieved in *Hinode*. For the case of local helioseismology that requires both a large field of view and high-spatial resolution, 1024×1024 imaging points may be necessary, and the required data rate becomes ~51 kbps (1024×1024 pixel × 3 bit/pixel /60 s =52,429 bit/s).

2.1.2 Requirements for Magnetic Fields Observables

Along with the Dopplergrams, full-disk line-of-sight magnetograms of 1024x1024 pixels will be taken every 5 (TBD) minutes to observe the response of the magnetic field to the surface, sub-surface and interior flows. Together, these observations will be used to study phenomena such as the evolution of active regions, flux transport and the solar cycle field reversal. SOLAR-C, complemented by near-Earth magnetograph observations, will enable us to follow the evolution of active regions continuously for much longer than the half-solar rotation now possible. Full-sun vector magnetic field observations shall be done every 60 min (TBD) or high-cadence observations of vector magnetic fields shall be possible for a 4×4 (TBD) arcmin field of view.

The required data rate for line-of-sight magnetograms of 1024x1024 pixels of 5 minutes cadence is about 10 kbps (1024 ×1024 pixel × 3 bit/pixel /300 s =10,486 bit/s). When four Stokes polarization states of I, Q, U, V are obtained at four wavelength positions, 16 imaging data need to be downloaded to the ground. 2048×2048 pixel vector magnetograms every 2 hours requires ~27 kbps (2048 ×2048 pixel × 3 bit/pixel × 16 images/7200 s =27,962 bit/s). For the active region monitor by vector magnetic fields of 256×256 pixel imaging points, the data rate of 51 kbps (256×256 pixel × 3 bit/pixel × 16 images/60 s =52,429 bit/s) is required for cadence of 1 minutes.

2.1.3 Requirements for TSI Observations

The fastest approach to reach the science goals for TSI measurements is to compare a latitudinal scan of the solar irradiance to contemporaneous measurements from in-ecliptic spacecraft from the long-term TSI monitoring programs, such as SORCE/TIM and PICARD/PREMOS or their successors. A slightly more demanding approach consists in a self-contained statistical analysis of several latitudinal scans to detect latitudinal trends in irradiance. Both approaches would benefit form observations at higher heliographic latitudes but extrapolation of trends in the SOHO/VIRGO measurements, which cover ±7°, suggests that 30° is sufficient to answer the above questions.

The SOLAR-C TSI instrument produces the on-source and off-source irradiance data by the periodic operation of a shutter located in front of one of cavities. The average and peak data producing rates are ~2 kbits/s and ~4 kbits/s after the data compression. The full FOV is about 5° and there is a 15 arcmin pointing tolerance. This instrument is assumed to be continuously operated in the SOLAR-C out-of-ecliptic orbit after the nominal operation. There may be a request of a special operation to do an intentional offset pointing for instrument calibration.

2.1.4 Requirements for EUV imaging and Spectroscopy Observables

For the imaging of transition-region (TR) dynamics, a band at 304 Å is suitable. Polar plumes are visible in a band at 171 Å and 195 Å. Hotter coronal plasma components in coronal bright points and active regions are observed in a band at 335 Å. These are observed by a telescope consisting of multilayer mirrors that has a spatial resolution of ~2 arcsec by ~1 arcsec spatial sampling. The field of view covers the whole Sun when the spacecraft points to the disk center. One of these bands is observed at a time. Wide slit observations of EUV scanning spectrometer may supplement the imaging of the TR and corona, but the images obtained with the wide slit are not sharp due to the blurring in the spectral direction. The wide slit observation cannot be used for the stereoscopic observations with a similar telescope in other line-of-sight directions. In the case of selecting a grazing-incidence telescope as a SOLAR-C coronal imager, observations of polar plumes may be performed in a low-contrast condition and the TR observations become impossible. A nominal operation is a combination of the full-disk observation at ~1 hr interval low cadence and smaller field-of-view observations with a higher cadence of few min. A fast observation consuming all allocated telemetry in a short time needs to be supported. ~20 kbps data recording rate is necessary when a data compression of 1.5 bits/s is considered.

Emission line spectroscopy with focusing optics is required to measure flows of solar-wind source region and to detect a signature of Alfvén waves that is a promising candidate to accelerate fast solar wind. A candidate of wavelength is in EUV. Although EUV instruments are relatively heavy, the SOLAR-C EUV scanning spectrometer needs to be achieved in a lighter weight condition because the total payload mass is limited. It is possible to enhance the instrument sensitivity of a small EUV spectrometer that is better than that of SOHO/SUMER (*Hinode*/EIS) by reducing the number of reflections (or reducing the filter components that shut the visible light). A higher sensitivity by more than a factor of 5 increase from the current space instruments is required. In addition to measurement of emission-line intensity, a spectral resolution similar to EIS and SUMER is needed to evaluate the dynamics of hot plasmas. The FOV center needs to be changed by moving an internal optics like SUMER, which could change the FOV in the north-south direction to investigate the outer region of polar coronal holes. A nominal image size of 256x256 pixel data points with 10 sec cadence produces ~20 kbps data when the data are compressed in a 3 bit/pixel lossy data compression like JPEG2000.

2.1.5 Observables of inner heliospheric imaging (Optional)

The imaging data of the inner heliosphere in the visible-light range are obtained by periodic exposures that produce a huge data volume. The exposure duration of ~1 min is a typical exposure, and the on-board summation of 60 frames, so that the image producing rate is one imager per 60 min. The final image size after the binning is 1024x1024 with 16 bit depth at each image point. Assuming 40 percent data compression, the final data producing rate is about 2 kbps. The FOV size is 60° to cover a large inner heliosphere and the FOV center point to a point above the solar south pole with an offset angle of ~45° (TBD) from the disk center. This setting of the instrument gives an overhead view of the Sun-Earth space in the ecliptic plane when the spacecraft is in the northern heliosphere. The spacecraft needs to rotate by 180° around the spacecraft Z axis if the Sun-Earth space in the ecliptic plane should also be observed when the spacecraft is in the southern heliosphere.

The following objects are contained in the observed data: solar wind structures and CME (via scattered light by electrons in the heliosphere), diffuse Zodiacal light (via scattered light by dust particles in the heliosphere), stars, planets of our solar system, comets, and asteroids. The brightest object is planets as a point source and scattered light by dust particles as a diffuse source. To determine a dust distribution from the measurement of Zodiacal-light brightness, a special observation in which the spacecraft Z axis is largely offset to the disk center may be required. Since it is strongly related to the safety operation of spacecraft, a risky attitude maneuver shall be avoided.

2.1.6 Observables of in-situ measurements (Optional)

Not studied in detail. The measurement of solar wind velocity for main elemental species will be mandatory. The in-situ magnetic field will also be a basic parameter, but the level of ~1 nT magnetic field at 1 AU may not be measured by the strong magnetic fields from permanent magnets used in ion engines when the SOLAR-C orbit is formed with help of solar electric propulsion system.

2.1.7 Summary of Required Data

Table 3 summarizes the data required for SOLAR-C Plan-A.

Table 3. Data required for SOLAR-C Plan-A

	Measurement	Wave-length (Å)	Spatial sampling	Image Size (Pixels)	Number of images transmitted	Cadence	Data rate (kbps)
1	Photospheric line-of-sight Doppler velocity: Global Helioseismology	Visible	4.0 arcsec	512×512	1	1 min	*13
2	Photospheric line-of-sight Doppler velocity: Local Helioseismology	Visible	1.0 / 2.0 arcsec	1024 ×1024	1	1 min	*51
3	Photospheric line-of-sight magnetic field	Visible	1.0 arcsec 2.0 arcsec	2048×2048 1024 ×1024	1	10 min	*10 *5
4	Photospheric vector magnetic field	Visible	1.0 arcsec	2048×2048 256×256	16	8 hours 10 min	*7 *5
5	Imaging of Chromosphere	Visible (TBD)	1.0 arcsec	2048×2048	1	1 hour	#3
6	Imaging of TR and Corona	EUV/X-ray	~1.2 arcsec ~2.4 arcsec	2048×2048 1024×1024	2	1 hour 5 min	#3 #20
7	Imaging spectroscopy of Chromosphere, TR, and Corona	EUV	~1.0 arcsec	spatial×spectral 256×256	1	10 sec	*19
8	Monitoring TSI	-	-	-	-	1 min	2
9	Heliospheric imaging [option]	visible	0.03°	1024 ×1024	1	1 hour	*1
10	In-situ (TBD)	-	-	-	-	-	~1

*(#)Data compression down to 3 (1.5) bit/pixel is assumed

2.2 Science Payload

Table 4 shows candidate payloads for SOLAR-C. The description of each payload is shown in the following subsections.

Table 4. SOLAR-C Plan-A Model Payload

HAI (Helioseismic Activity Imager)		MDI+electronics 57 kg
Weight	65 kg	HMI+electronics
Aperture: 12.8 cm		+ harness 73.5 kg
Detector: APS or Backside illuminated CCD		
Sampling: 0.5 arcsec/pixel (TBD)		
Detector format: 4K×4K (TBD)		
Wavelength: 5000-8700 Å		
LIM (Luminosity and Irradiance Monitor)		2 PMOD+electronics in
Weight	5.0 kg	VIRGO: ~5 kg
Number of cavities	≥3	TIM(4 cavities): 10 kg
EAI (EUV Activity Imager)		STEREO EUVI
Weight	12 kg	telescope alone: 7.7 kg
Ritchey-Chretien telescope with Mo/Si mirrors		
Detector: APS or Backside illuminated CCD		
Sampling: 1.2 arcsec/pixel		
Detector format: 2K×2K (TBD)		
Wavebands: 171, 195, 304, 335 (all TBD) Å		
ESS (EUV Scanning Spectrometer)		
Weight	30 kg	
Two reflection system: offset parabola + concave grating		
Spectrometer with a factor of 4 (TBD) magnification		
Detector: intensified APS or intensified CCD detector		Use of MCP
Sampling 0.75 arcsec/pixel (TBD)		148cm focal length
Detector format: 4K(spectral)×1K(spatial) TBD		
Waveband (TBD):		
IHI (Inner Heliospheric Imager; **Optional)**		STEREO HI-1+HI-2
Weight	8.0 kg	+Electronics: 13.8kg
Detector: APS or Backside illuminated CCD		
Sampling: 0.03 deg/pixel		
Detector format: 2K×2K (TBD)		
Others (In-situ Measurements etc.)		
Weight	α kg	
Mission data processor if required		
Weight	β kg	
Total weight (130 kg tentatively allocated for payload)	$120+\alpha+\beta$ kg	

2.2.1 Helioseismic and Activity Imager

This instrument observes the Sun in the visible light for imaging the Sun in the continuum and at absorption lines, for acquisition of the helioseismic information from Doppler velocity observations, and for mapping the photospheric magnetic fields. It consists of a refractive telescope, a polarization modulator, a tip-tilt mirror, a narrow band tunable filter, and a mechanical shutter, and a 2D imaging camera. The narrow bandpass filter has a bandpass of 100-200 mÅ in full width at half maximum (FWHM), and its central wavelength can be tuned in 5000-8700 (TBD) Å. A similar type filter with a wider bandpass of 1 Å FWHM was operated for imaging the green-line (5303) corona for 10 years at a ground-based observatory in Japan.

The baseline detector is a large-format CCD camera with 4K×4K (TBD) pixels. When a scientific grade CMOS detector is available, it is better to be adopted from the viewpoint of radiation hardness in the space environment.

The whole-sun area has to be observed in most of the time because the Doppler velocity observations for helioseismology will mostly be running except for some special operations.

The baseline data recording rate of this instrument is 50 kbps. When one of data is compressed to 3 bits/pixel average, three types of data of 512×512 pixels, magnetograms, Dopplergrams, and continuum image, can be obtained every 1 min.

Figure 17 shows the schematic optical diagram of the instrument. One of programmatic difficulties in developing this instrument is to realize a narrow band tunable Lyot filter that is being developed to raise TRL. When it is difficult to be developed , the use of Michelson interferometer with a wider band Lyot filter like SOHO/MDI and SDO/HMI observing a single absorption line or a Fabry-Perot filter may become a fallback plan.

The selected line for the Doppler and magnetic field measurement is a TBD line at TBD Å. Ni I 6768 Å (Fe I 6173Å) was selected for SOHO/MDI (SDO/HMI).

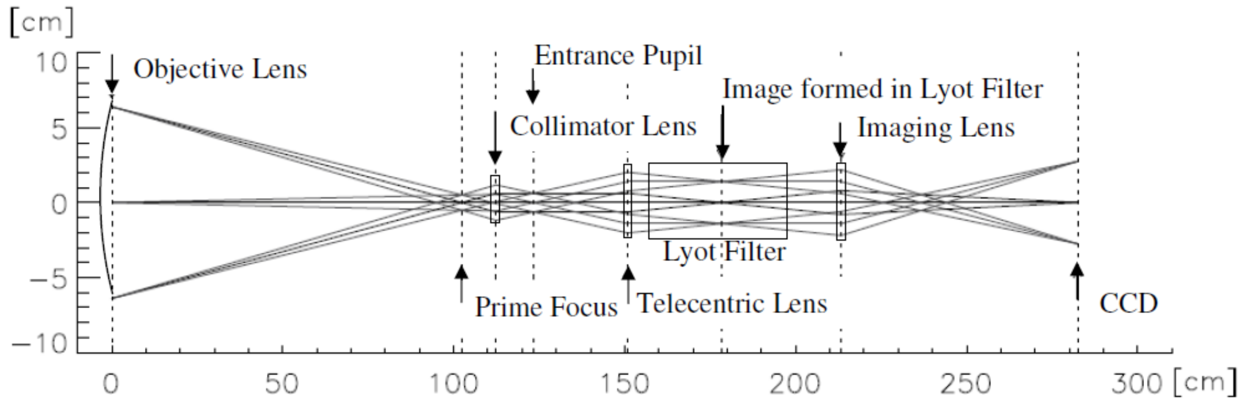
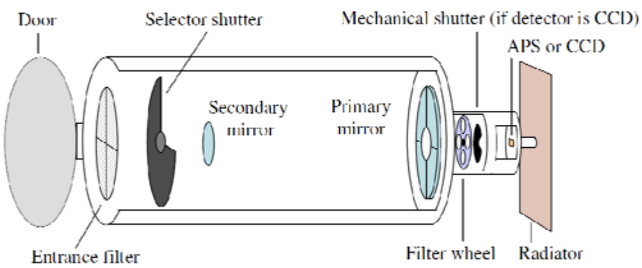


Figure 17. Schematic optical diagram of HAI conceptual design.

2.2.2 EUV & X-ray Spectroscopic Imaging Telescopes

A fast cadence imager is needed for tracking the evolution of dynamic events in the outer solar atmosphere. The SOLAR-C Plan-A is not a mission targeting to resolve elementary structures. It will be sufficient to cover the whole Sun corona with a range of extended corona above the limb of the Sun by an imaging system that resolves a few arcsec structures. Observations of solar polar region from an out-of-ecliptic view are new issues and a telescope to observe the structures near the polar region is required. A whole Sun imager of ~1 arcsec spatial sampling is proposed here. The whole Sun with extended corona can be covered by a 2D imaging device of 2K × 2K pixels at the distance of 1 AU from the Sun. An EUV imaging telescope like STEREO EUVI may be more suitable than the X-ray telescope to observe polar plumes and inter-plume regions in polar coronal holes. In the late 2010's and early 2020's whole Sun EUV imagers are planned in Solar Orbiter and GOES spacecrafts and the presence of these imagers needs to be considered for the selection of the telescope bandpass. The SOLAR-C Plan-A EUV Activity Imager (Figure 18) is a Ritchey-Chretien telescope consisting of two hyperboloid mirrors. Each mirror is coated with Mo/Si multi-layers to enhance the reflectance of EUV light. The full width at half maximum of the reflectance as a function of wavelength is 10–15 Å around a central wavelength of each bandpass. Currently selected wavelength bands are 171, 195, 304, and 335 Å for their central wavelengths. A stereoscopic observation with SO will be possible at 171, 304, and 335 Å bands because the same EUV band with SO is selected. The CMOS APS is a primary candidate for the detector and the fall back plan is a back-illuminated CCD that was used in *Hinode*, STEREO, and SDO imagers. The imager on STEREO with a different selection of wavelength band can be a model payload.



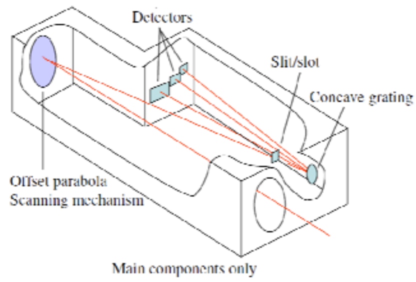


Figure 18. (left): SOLAR-C EUV Activity Imager
Figure 19. (right): SOLAR-C EUV Spectrometer

The imaging spectroscopy is a key instrument to detect the source of fast solar wind flows from polar coronal holes. The following performance is required: (1) the higher-throughput than SOHO SUMER and *Hinode* EIS for both quiet sun (QS) and active regions (AR), (2) 1 arcsec or slightly better spatial sampling, (3) a scanning rage of ±4 arcmin in the scanning direction, and (4) simultaneous observations of emission lines formed in the chromosphere, transition region, and corona. The SOLAR-C Plan-A science payloads have to be set at the side of the Sun, that is the spacecraft +Z direction, to the bus module because the surface of side bus panels located in the spacecraft ±X and ±Y directions are all used as radiators. Hence, the length of this imaging spectrometer must not be long like *Hinode* EIS, which is longer than 3.2 m in the Z direction. In order to realize a short instrument length without adding another reflection, the spectrometer needs to have a magnification using a single concave grating. The design of this type of spectrometer was first found by Roger Thomas (Thomas 2003). The instrument, SOLAR-C EUV Spectrometer (Figure 19), consists of a single off-axis parabola as a primary mirror of the telescope, a slit/slot selector, a toroidal (or ellipsoidal) concave grating with varied line space as a disperser, and solar-blind intensified CMOS detectors. Three wavelength bands are chosen to observe the chromosphere, transition region, and corona simultaneously: one is 310-340 Å (TBD), and 760-800 Å (TBD), and 1000-1100 Å (TBD).

The main body of these telescopes and imaging spectrometer are made of CFRP because of the weight reduction. In addition to the stringent contamination control of used materials including sufficient material bakeout, one point of note is that temperatures of all optical components should slightly be higher than that of the main body by the thermal design for a long-term stable instrument performance.

In the imaging spectroscopy with a grating spectrometer, there are two specific directions in the plane of the sky, that is, a slit direction and a scanning direction perpendicular to the slit direction. The direction along the slit will be in the north-south direction in the imaging spectrometer. It will be good to rotate the spacecraft around its Z axis for a specific observation to set the slit for any direction.

2.2.3 Solar Irradiance Monitor

The SOLAR-C total solar irradiance monitor is an absolute radiometer with cone-shape cavities. In front of each cavity there is a mechanical shutter to control the radiation input from the Sun. Each cavity has a heater and a thermal sensor, so that each can be a reference cavity. One of cavities is periodically exposed to the Sun. During the exposure, one of remaining cavities unexposed to the Sun is heated by the heater attached until the electrical heat input balances the solar input. For this operation there needs two cavities in this instrument at least. The cadence of periodic exposure is 1 min (TBD). There is degradation of the cavity surface by being exposing to the space environment, mainly due to solar UV illumination. To calibrate the degradation of the cavity surface, an infrequent exposure of a reference cavity to the Sun is needed. Probably, there will be another TSI instrument in low-Earth orbit at that time, so the SOLAR-C TSI monitor will also be calibrated to the other monitor when the SOLAR-C spacecraft is located in the ecliptic plane. There are a few groups to have heritage on developing the space TSI monitor, PMOD, JPL, LASP, and so on. A cross calibration to a cryogenic absolute radiometer is required before the flight.

2.2.4 Inner Heliospheric Imager (Optional)

A slightly-modified heliospheric imager on STEREO can be an optional candidate payload. The lens unit consisting of multiple optical lens has a large field of view (FOV) of about 60° and the FOV center to the Sun is offset by 45° around the spacecraft X-axis looking at space above the solar south pole when the spacecraft is in the ecliptic plane (Figure 20). When the spacecraft is located at the northern heliosphere, the heliospheric imager can look at the interplanetary space between the Sun and Earth. The spacecraft needs to rotate 180° around the spacecraft Z axis when the same interplanetary space is observed in the southern heliosphere.

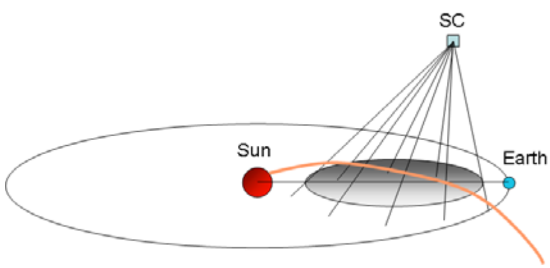


Figure 20. Field of View of Inner Heliospheric Imager

The scatted light level is reduced by the multiple baffles located in front of the wide-field lens unit. A 2D imaging device of 2K × 2K pixels that is cooled down to -60° is placed at the focal plane.

The brightest component is from planets in the solar system as a point source and the zodiacal light as diffused background. The bandpass is 5000-8000 Å (TBD) in the visible range. In order to avoid the blooming due to a bright object in FOV, a CMOS device will be preferable. Each image is obtained by ~1 min exposure duration. A multiple set of exposures is summed together by an on-board processing to enhance the component originating from electron scattering. The processed data are reformed into a telemetry data.

If the FOV of this instrument can point to the opposite side of the ecliptic plane by the spacecraft maneuver, a basic data set for determining the interplanetary dust distribution may be obtained for the first time.

2.2.5 In-Situ Instruments (Optional)

The role of in-situ instruments has not been discussed in detail in the SOLAR-C Plan-A working group. The out-of-ecliptic in-situ measurements were performed in the Ulysses mission. The orbit inclination is about 80°, which mostly covers the whole heliocentric latitude. The orbit is highly elliptical, so that the there is a period of a fast and a slow latitudinal scan for the heliosphere with different distances from the Sun. One major point of the SOLAR-C Plan-A orbit is that the spacecraft periodically travels between northern and southern maximum latitudes in a half year at nearly 1AU distance from the Sun. It is possible to do a research on the heliospheric physics that strongly depends on the solar cycle. A transport of cosmic rays in a solar cycle may become a target of SOLAR-C Plan-A regarding the production of cosmogenic isotope like ^{14}C and ^{10}Be, which are used as indices of the past long-term solar activity.

2.2.6 Other Instruments (Optional)

Since the SOLAR-C Plan-A spacecraft travels in a unique orbit, some instrumental proposals may arise from non-solar physics community. Although it may be important to consider them here to maximize a rare opportunity, it is beyond the scope of this proposal.

2.3 Spacecraft Requirements given from the Science Objectives

2.3.1 Attitude Control Requirements

On the SOLAR-C Plan-A there are imaging instruments that require periodic exposures in a long period of time, so that the spacecraft +Z axis is basically pointed to the Sun by a three-axis stabilized attitude control system (ACS). Since one of main payloads, which has marginally cover the whole Sun in the field of view, points to the Sun center for a day, a week, a month or a few months for the purpose of helioseismic and magnetic field observations, the nominal pointing direction is the center of the solar disk, so that the pointing coordinates of the other instruments with narrower field of view is restricted by the condition. Thus, when the other payload needs to look at a different location on the Sun outside its narrow field of view, the payload has to have a mechanism to change its own field of view. The tracking of the differential rotation of the Sun by the spacecraft attitude control is not required for observations with a small field of view.

Yohkoh and *Hinode* also have three-axis stabilized ACS and the spacecraft Y-axis is stabilized to point to the solar north. The functionality to rotate the spacecraft around the Z axis at any angle is to be requested, and provides a unique opportunity to observe scientific targets for the EUV scanning spectrometer that has a specific orientation in the plane of the sky. It is the slit direction. If the inner heliospheric imaging is adopted, the spacecraft rotation of 180° around the Z axis becomes mandatory and a step-by-step rotation of the spacecraft may sample the scattered photons from dusts in the solar system.

Table 5. Requirements for Attitude Control Stability (TBD)

<table>
<tr><th>Payload</th><th>Duration</th><th>ΔX, ΔY (arcsec)</th><th>ΔZ (arcsec)</th><th>Unit</th></tr>
<tr><td rowspan="5">- Imager
- Spectrometer</td><td>1 sec</td><td>0.6</td><td></td><td>3σ</td></tr>
<tr><td>10 sec</td><td>0.8</td><td></td><td>3σ</td></tr>
<tr><td>5 min</td><td>1.6</td><td></td><td>0-p</td></tr>
<tr><td>1 hr</td><td rowspan="2">*2.0</td><td rowspan="2">400</td><td rowspan="2">0-p</td></tr>
<tr><td>24 hr</td></tr>
</table>

*: will be better than *Hinode* due to no external disturbance except for solar radiation pressure in the interplanetary orbit. An exceptional period happens during the operation unloading the angular momentum of reaction wheels.

The spacecraft pointing stability achieved in *Hinode* completely satisfies the SOLAR-C Plan-A requirement. The long-term stability for an order of hour, a few arcsec per hour, will automatically be improved in SOLAR-C Plan-A, because the disturbance due to the thermal distortion disappears in the interplanetary space. Table 5 shows requirements for the attitude control system.

2.3.2 Time management

Except for the helioseismic instrument, the ISAS time tag system that was used in *Hinode* is applicable to SOLAR-C Plan-A. An additional requirement is given from the helioseismic instrument that requests a regular interval of exposure sequences. Table 6 summarizes the requirement for the time tag. The information of the time tag is distributed from the spacecraft data handling unit to the instrument controller of the helioseismic payload.

Table 6. Requirement of Spacecraft Time Tag (TBD)

Short term stability (1 – 100 sec)	± 0.5 ppm TBD	Requirement in SOHO
Long term stability (1 year)	± 1.0 ppm TBD	Requirement in SOHO
Duty cycle	0.5±0.05 sec	Requirement in SOHO

2.3.3 Data Compression and Data Storage

Since the telemetry should effectively be used, all the data need to be compressed on-board the spacecraft. The 12-bit lossless DPCM and lossy JPEG image compression were adopted in *Hinode* and a similar type of image compression is required in SOLAR-C Plan-A mission. It is efficient to compress the data in one box that is connected to all payloads, but the alternative is that each payload produces the compressed data to the spacecraft. The selection of the scheme is TBD.

The spacecraft is accessible from the Earth every day and the downlink will be periodically performed. But the total telemetry rate at the most distant location is not high and it is the bottle neck in the high-cadence observations. The following design philosophy will be applicable.

- Each payload can send the data to the spacecraft at any time.
- The data storage area is divided into small number of volume and each payload can send the data by a specified data storage volume.
- When the data are sent to the ground, one of data storage volume is dumped according to a planned schedule.

Some payload can do a high-cadence observation easily under this system, and the issue is the largest data size of a data storage volume that is related to the longest duration of the high-cadence of observation.

When the science data are produced in the rate of 100 kbps at the most distant part in the orbit during the science operation phase, total data volume per day is 8.2 Gbits (100 kbps × 1024 bit/kbit × 86400 s = 8.85×10^9 bits). However, the data rate can be higher when the distance to the spacecraft is shorter or when the Ka-band link condition is more stable than expected. When the 100 kbps data rate is possible at spacecraft position of 40° from the solar equatorial plane, the data rate can be 2.0 (3.3) times larger at 30° (25°). The capacity of the data recorder should be selected for an observing case of the maximum data rate condition. The tentative number may be 32 Gbits (TBD) including the spacecraft housekeeping data.

It will be useful from the operational point of view if the data recorder storage is divided into several independent volumes or partitions and if each payload can send the data by selecting one of volumes.