

ASO-S: Advanced Space-based Solar Observatory

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ABSTRACT

ASO-S is a mission proposed for the 25th solar maximum by the Chinese solar community. The scientific objectives are to study the relationships among solar magnetic field, solar flares, and coronal mass ejections (CMEs). ASO-S consists of three payloads: Full-disk Magnetograph (FMG), Lyman-alpha Solar Telescope (LST), and Hard X-ray Imager (HXI), to measure solar magnetic field, to observe CMEs and solar flares, respectively. ASO-S is now under the phase-B studies. This paper makes a brief introduction to the mission.

Keywords: solar magnetic field, coronal mass ejection, solar flare, solar space mission

1. INTRODUCTION

It has been a long trek to develop space missions to study the Sun in China¹. The earliest effort could be dated back to 1976, when the first solar mission proposal, named ASTRON-1, was accepted. In 1990s, some solar payloads² on manned spacecraft series "Shenzhou" were implemented. SST (Space Solar Observatory)³ was also proposed in 1990s. In 2000s, Small Explorer for Solar Eruptions (SMESE, a joint Chinese-French mission)⁴, Kuafu⁵, and others were proposed and promoted. But none of them had gone into the engineering stage, except some solar payloads on "Shenzhou-2". In order to better organize the space science missions, in 2011, Chinese Academy of Sciences (CAS) opened a new domain named as "Strategic Priority Research Program of Space Science". It in particular supports the development of scientific satellites at three different levels: conception study (Phase-0/A), background study (Phase-A/B), and mission engineering study (Phase-C/D).

The conception study of Advanced Space-based Solar Observatory (ASO-S) was carried out from September 2011 to March 2013. Its background study was started in January 2014, and will be completed by the end of 2015. In following sections we describe separately ASO-S's scientific objectives, payloads, mission profiles, and contexts. The prospect is made in the last section.

2. SCIENTIFIC OBJECTIVES

Solar flares and coronal mass ejections (CMEs) are two most powerful eruptive phenomena in the Sun. The energies of these eruptions are believed to come originally from the solar magnetic field. The ASO-S mission is exclusively proposed to understand the relationships among the solar magnetic field, solar flares, and CMEs. Its major scientific

objectives could be abbreviated as '1M2B': one Magnetism plus two Bursts (flares and CMEs), to study their physical formation and mutual interactions. More explicitly, four major goals can be described as follows:

1) **Simultaneously observe non-thermal images of flares in hard X-rays, and the formation of CMEs, to understand the relationships between flares and CMEs.**

The origin and initiation of solar flares and CMEs remain unsolved and are still a hot topic in solar physics. It is generally accepted that flares originate locally, but CMEs can originate either in small scale or in large scale. The relationship between flares and CMEs is still in debate. Is there any cause-effect relationship between flares and CMEs? Does a flare trigger a CME or *vice-versa*, or there is no link between them? Statistically there is a rough 70% link. Why are some flares accompanied by CMEs, and others not, and how is this behavior determined? The Sun has an activity cycle of 11 years. It is predicted that cycle 25 would eventually start from 2020 and peak around 2022 to 2025⁶. Close to the solar maximum, the occurrence of flares and CMEs is more frequent. ASO-S is planned to launch in 2021 and to make imaging observations of the source region of these two types of eruptions in white light, UV, X-ray, and γ -ray. ASO-S will be able to follow the eruptions from the photosphere to the corona and from their initiation to full development.

2) **Simultaneously observe full-disc vector magnetic field, energy build up and release of solar flares, and the initiation of CMEs, to understand the causality among them.**

A consensus has been reached that solar flares and CMEs are driven by the magnetic field, and the energy involved in these two eruptions comes from gradual build-up of stresses (the "non-potential energy") stored in the coronal magnetic field. What magnetic configuration is favorable for producing flares and CMEs remains to be one of the most important issues in solar physics. For example, the following questions need to be answered. What roles do the magnetic field shearing and magnetic flux emergence play to store the pre-flare energy and to trigger eruptions? What quantitative relationship can we establish between the magnetic field complexity and the productivity of CMEs? Are CME triggered locally (e.g., by magnetic reconnection) or globally on a large scale (e.g., by ideal MHD instabilities or loss of equilibrium)? The full-disk vector magnetograph onboard ASO-S will provide detailed information on the magnetic context of eruptions. HXI is dedicated for flare observations, LST for CME observations. Simultaneous observations of solar magnetic field, solar flares, and CMEs will help us to disentangle the relationships among them, and most importantly to establish quantitative relationships between the magnetic field and the eruptions.

3) **Observe the response of solar atmosphere to eruptions, to understand the mechanisms of energy release and transport.**

When flares and CMEs occur, huge numbers of energetic electrons and ions are accelerated. These accelerated particles can travel swiftly in the direction of the magnetic field, penetrate the lower atmosphere, and heat the plasma there. ASO-S is designed to observe the lower corona, chromosphere, photosphere simultaneously. The observations in X-ray and γ -ray can reveal properties of accelerated electrons and ions. Thus the energy transport process during the eruptions in the solar atmosphere can be understood. The diagnostics of the energy transport is a key to understand the energy release process, and to reveal the properties of the energetic particles escaping from the Sun. Meanwhile, contrary to H-alpha line studies, Lyman-alpha line has seldom been studied before. The pioneering systematic observations of the Lyman-alpha line will bring us an almost completely new window.

4) **Observe solar eruptions and the evolution of magnetic field to provide clues for forecasting space weather.**

The space environment near the Earth is greatly influenced by flares and CMEs, which are two most intensive phenomena in the Sun. From flare observations by ASO-S, we can predict the arrival of energetic particles tens of minutes in advance. From the CME observations by ASO-S, we can determine their morphology and propagation direction, then predict the arrival of a CME at the Earth tens of hours or a few days in advance. If we can obtain the relationships between the magnetic field configuration and the eruptions from the observations made by ASO-S, the predictions can be made even earlier according to the magnetic field quantities.

3. PAYLOADS

To fulfill the scientific objectives, three payloads are proposed: a Full-disc vector MagnetoGraph (FMG), a Lyman-alpha Solar Telescope (LST), and a Hard X-ray Imager (HXI). An overview of the mass, size, power requirement and data rate of three instruments can be seen in Table 1. An outline sketch of the ASO-S configuration appears in Figure 1.

Table 1. Mass, size, power requirements and data rate of the three payloads.

Instrument	Mass (kg)	Size (mm)	Power (W)	Data rate(GB/day)
FMG	85	1200×600×450	55	140
HXI	50	1200×400×400	70	5
LST	60	950×842×400	110	150
Structure	25			
Sum	220		<250	295

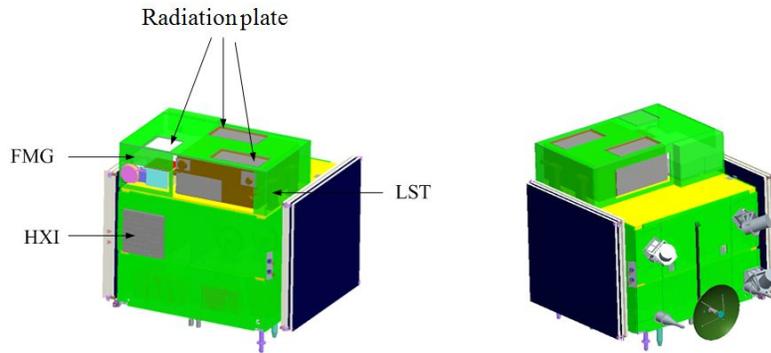


Figure 1. Sketch of one of the ASO-S configurations based on the satellite platform SAST-1000.

1) Full-Disc Vector Magnetograph (FMG)

FMG measures the magnetic fields of the photosphere over the entire solar disk. Compared with the magnetograph onboard Hinode⁷, FMG has a larger field of view and higher time cadence. Comparing to the magnetographs onboard SDO⁸ and SOHO⁹, FMG has a simpler observation mode and a higher measurement precision. The main performance parameters of FMG and the corresponding parameters of the magnetograph of PHI (Polarimetric and Helioseismic Imager) onboard Solar Orbiter¹⁰ are listed in Table 2.

Table 2. Key performance parameters of FMG and PHI. HRT: high resolution telescope; FDT: full disk telescope.

	FMG	PHI/HRT	PHI/FDT
Wavelength	Fe I 532.4nm	Fe I 617.3±0.06nm	Fe I 617.3±0.06nm
Accuracy	$B_{LOS} \approx 5G$	$B_{LOS} < 10G$	$B_{LOS} < 10G$
Spatial resolution	0.5''	~200 km at 0.28 AU	~730 km at 0.28 AU
Temporal resolution	2 minutes	45-60s	45-60s
Field of view	33'	16.8'*16.8'	2.1°

FMG consists of an imaging optical system, a polarization optical system, and a CCD image acquisition and processing system. Its optical system is delineated in Figure 2.

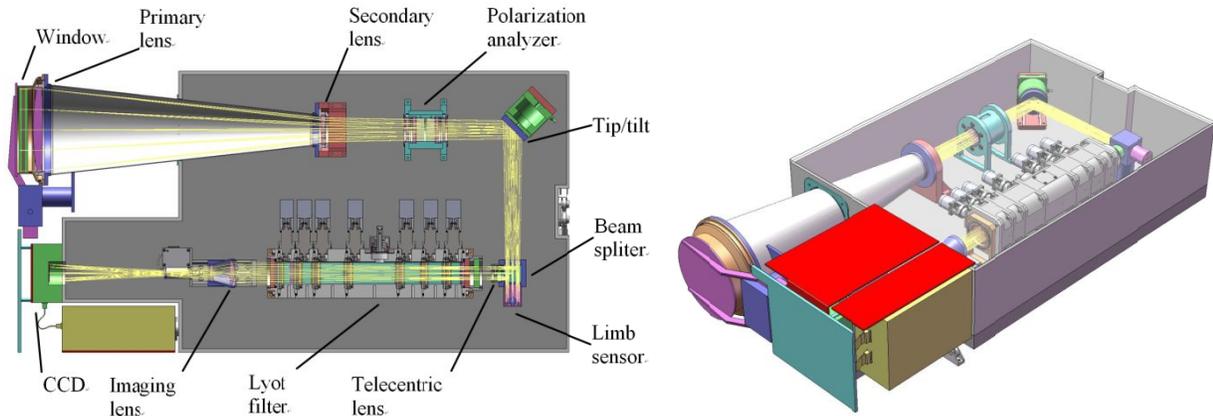


Figure 2: Optical and mechanical system of FMG.

2) Hard X-ray Imager (HXI)

HXI aims to image the full solar disk in the high-energy range from 30 keV to 300 keV, with good energy resolution and high time cadence. It is designed for flare observations. The principle of HXI is the same as HXT¹¹ (hard X-ray telescope) on board YOHKOH using indirect imaging of spatial modulation. Unlike HXI and HXT, another high energy imaging mission RHESSI¹² adopts the indirect imaging technique by rotational modulation. STIX (Spectrometer Telescope for Imaging X-rays) onboard Solar Orbiter takes the indirect imaging of spatial modulation as well. The key parameters of HXI and STIX are summarized in Table 3. The telescope structure including collimators, detector, and electronics box, etc., is presented in Figure 3.

Table 3. Key parameters of HXI and STIX.

	HXI	STIX
Energy range	30-300 keV	4-150 keV
Energy resolution	3%@662keV	~1 keV, less at higher energies
Angular resolution	< 6 ''	7 ''
Field of view	1°	2.5° for spectroscopy, 1.5° for imaging
Temporal resolution	0.5 s	Up to 0.1 s
Effective area	100 cm ²	~6 cm ²

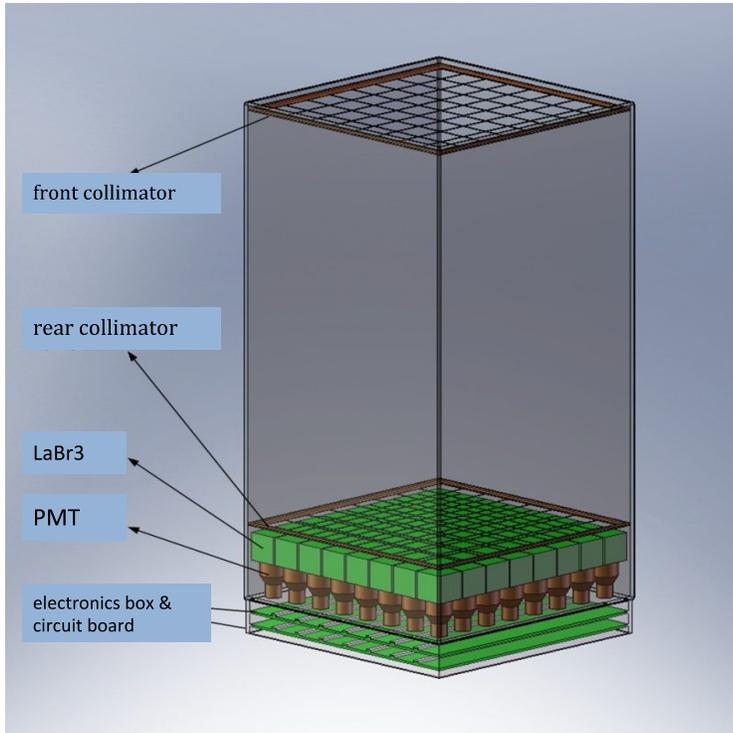


Figure 3. Design of the HXI structure.

3) Lyman-alpha Solar Telescopes (LST)

To observe CMEs continuously from solar disk to a few solar radii, another payload LST will be on board. It comprises three telescopes observing in Lyman-alpha and white light: SDI (solar disk imager), SCI (solar coronagraph imager), and WST (full-disk white-light solar telescope) for the purpose of calibration. WST can also be used to observe white-light flares, a fundamentally important aspect of flare physics. SDI works in the same wavelength band as the HRI (High Resolution Imager) of EUV (Extreme Ultraviolet Imager) onboard Solar Orbiter; And SCI shares some common features with METIS (Multi Element Telescope for Imaging and Spectroscopy) onboard Solar Orbiter. The key parameters of these four instruments are presented in Table 4.

The hydrogen Lyman-alpha line is the brightest line in the UV and is formed all through the chromosphere and the bottom of the transition region. Comparing with the conventional white-light coronagraph images, Lyman-alpha coronagraph observations will provide new discoveries of CMEs. The light ray-tracing diagrams of the SCI and SDI are delineated in the left and right panels of Figure 4, respectively.

Table 4. Key parameters of LST/SCI, METIS, LST/SDI, and EUV/HRI.

	LST/SCI	METIS	LST/SDI	EUV/HRI
Wavelength	121.6±10nm	visible: 580-640nm HI Ly α 121.6±10nm	121.6±5nm	H I Ly α 121.6nm 17.4 nm
Field of view	1.1 – 2.5 R $_{\odot}$	1.4 -2.9 R $_{\odot}$ (0.27 AU) 2.1 -4.35R $_{\odot}$ (0.4AU)	0.0 – 1.2 R $_{\odot}$	1000''*1000''
Spatial resolution	4.6''	20''(2*2 binning)	1.12''	1''
Temporary resolution	4 - 10s	Visible: 5 min UV/EUV: 15-20 min	1-5s	can reach sub second

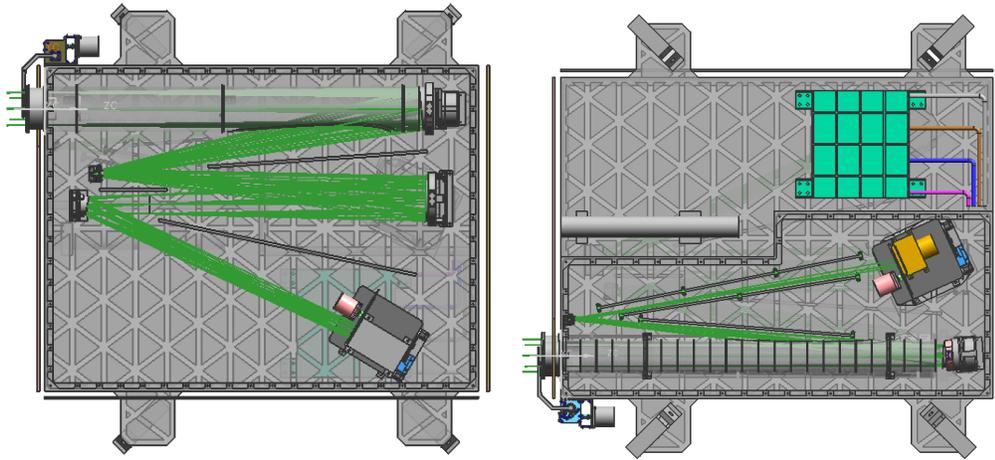


Figure 4. Ray-tracing diagrams of SCI (left) and SDI (right).

4. MISSION PROFILE

ASO-S has a solar synchronous orbit at an altitude of 720 km. The selection of the altitude takes into account both the lower particle background along the orbit for HXI and the lower scattered light level for LST. It has an inclination angle of around 98.2° .

One candidate of the satellite platform is the FengYun series SAST1000 from Shanghai Academy of Space Technology. Another is CS-L3000A from China Academy of Space Technology. Both platforms are mature and have a 100% success in the past missions. The altitude control uses the three-axes stability technology. The platform attitude pointing accuracy is designed to be $\leq 0.01^\circ$, measurement accuracy $\leq 1''$, stabilization accuracy $\leq 0.0005^\circ/s$. The payload attitude pointing accuracy is designed to be $\leq 20''$, and stabilization accuracy $\leq 0.25''/30s$ for FMG and $1-2''/10s$ for LST. The launch vehicle is Long March-2D rocket, which has a capability to carry 1000 kg mass into the orbit of 720 km. The satellite room of Long March-2D is showed in Figure 5.

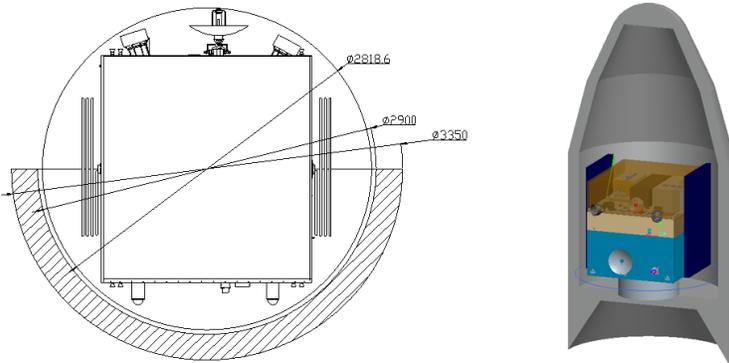


Figure 5. The satellite room of Long March-2D.

5. CONTEXT

In comparison with current and future missions (see Table 5), e.g., STEREO¹³, Solar Dynamic observatory (SDO), Solar Orbiter (SO), Solar Probe Plus (SPP)¹⁴, Interhelioprobe (IHP)¹⁵, especially concerning the observations of solar magnetic field, solar inner corona, and solar hard X-ray imaging, the instruments onboard ASO-S have their own characteristics. Only Solar Orbiter and ASO-S have such a capability to observe simultaneously the magnetic field, inner

corona, and hard X-ray imaging. Certainly both missions have some differences in instrumental parameters, e.g., the field of view of coronagraphs, energy window of hard-ray imagers, and others shown in Section 3. In the future, ASO-S will work together with other available missions complementarily, and will play an irreplaceable role.

Table 5. Mission comparisons for the observations of solar magnetic field, inner corona, and X-ray imaging

Observations	STEREO (2006-)	SDO(2010-)	SO (2017)	SPP (2018)	IHP(2022)	ASO-S (2021)
Magnetograph	×	√	√	×	×	√
Coronagraph	√ (WL)	×	√	?	√ (WL)	√
X-ray imaging	×	×	4-150 keV	×	5-100 keV	√

6. PROSPECT

As mentioned in Section 1, ASO-S will finish its Phase-B study by the end of 2015. In 2016, ASO-S might have a chance to compete with other candidate missions for the engineering Phase-C study. If selected, ASO-S is expected to finish the whole engineering stage within 4 years, and to launch in 2021, so that it can cover the entire 25th solar cycle peak years, although the life time is designed to be 4 years.

By now there are four solar-related mission proposals in China¹⁶: DSO(Deep Space Solar Observatory, an updated version of SST), Kuafu, SPORT(Solar Polar Orbit Telescope), and ASO-S. It is really hard to predict at moment which mission is more possible to obtain final approval to enter the engineering phase. However, what we can say is that ASO-S is a relatively simple and small mission. It is economical in cost and has a higher technology readiness level. Besides, in terms of the scientific objectives, as evaluated in a forum organized by the International Space Science Institute in Beijing, ASO-S is advanced not only in solar physics researches but also in applications, such as, space weather forecast¹⁷. To our knowledge, there has not been any previously existing single mission, which focused exclusively on 1M2B. Most importantly, for quite a long time the Chinese solar physics community has been dedicated to the research on solar magnetic field, solar flares, and CMEs. ASO-S will for certain bring a wide involvement of the community. Hopefully, with great effort ASO-S could become the first Chinese solar mission into the orbit.

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