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Nature of Prominence and their role in Space Weather
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The Chinese Giant Solar Telescope

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Abstract. Chinese Giant Solar Telescope is the next generation ground-based solar telescope. The main science task of this telescope is to observe the ultra fine structures of the solar magnetic field and dynamic field. Due to the advantages in polarization detection and thermal controlling with a symmetrical circular system, the current design of CGST is a 6∼8 meter circular symmetrical telescope. The results of simulations and analysis showed that the current design could meet the demands of most science cases not only in infrared bands but also in near infrared bands and even in visible bands. The prominences and the filaments are very important science cases of CGST. The special technologies for prominence observation will be developed, including the day time laser guide star and MCAO. CGST is proposed by all solar observatories and several institutes and universities in China. It is supported by CAS and NSFC (National Natural Science Foundation of China) as a long term astronomical project.

Keywords. Telescopes, High angular resolution, Magnetic fields, Prominence, Filaments

1. Introduction

Chinese Giant Solar Telescope (CGST) is the main facility of a future solar observatory, the Chinese Advanced Ground-based Solar Observatory. The Chinese Advanced Ground-based Solar Observatory consists of two huge facilities, the CGST and a large aperture coronagraph. The large coronagraph is a 1m refracting telescope similar to COSMO. According to the current plan, this 1m refracting coronagraph will be developed by a Sino-American cooperation group. This paper mainly introduces the CGST which is proposed by Yunnan Astronomical Observatory CAS, National Astronomical Observatories CAS, Purple Mountain Observatory CAS, Nanjing University, Nanjing Institute of Astronomical Optical Technology and Beijing Normal University.

The primary science goals of the next generation solar telescopes are similar, that is to push the human's understanding of the sun and the space weather to a new level. As is well known, the knowledge of the sun strongly depends on the very high precision observations of the solar magnetic and dynamic fields. That is the reason why solar physicists wish to develop the next generation solar telescopes, such as Solar-C, ATST (Keil *et al.* 2003), EST (Schmidt *et al.* 2012) and CGST. As large ground-based solar telescopes are more powerful in very high resolution and can do more complex observations, the ongoing space solar telescopes such as Solar-C and Chinese DSO cannot replace the ground-based solar telescopes in the near future.

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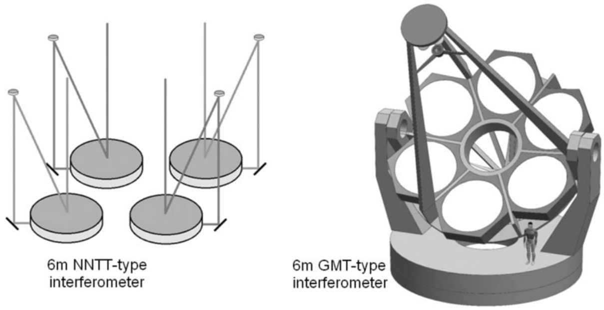

Figure 1. Sketches of NNTT-type CGST and GM- type CGST.

2. Current conceptual designs of CGST

Although the vacuum telescopes have many advantages in solar observation, it is very difficult to manufacture a vacuum solar telescope if the aperture diameter increases over 1 meter. Another disadvantage of vacuum solar telescope is the opaqueness of the vacuum window in the infrared range. So the next generation large solar telescopes are all designed to be open telescopes. The open solar telescopes are roughly classified into two kinds, off-axis and on-axis telescopes. An off-axis telescope is comparatively easy to do thermal control, but its unsymmetrical structure will result in polarization cross talk. It is a trouble for magnetic field measurements.

The CGST will focus on the ultra fine structures of magnetic and dynamic fields in different layers of the solar atmosphere. Many sciences cases were suggested to observe and study the physical phenomena from convection zone to corona. Compared with the current Chinese solar telescopes, the spectral range of CGST will be expanded to 15 micron or even farther. In order to meet the requirements of scientific goals, Chinese solar astronomers (Fang 2011) wish to combine the advantages of both off-axis and on-axis systems. Several symmetrical off-axis systems have been proposed. The first conceptual system consists of four telescopes. Each telescope is an independent off-axis solar telescope with 2 or 3 meters diameter. All the four telescopes need co-phasing with each other. As it looks like the former NNTT telescope, we named it NNTT-type. The second system consists of more primary sub-mirrors. The diameter of each mirror is 2 meters. All the mirrors are off-axis parabolic and are combined into a circular co-phasing interferometric telescope. It looks like the GMT telescope without the central mirror. We call it Aperture Ring Telescope or simply GMT-type.

The third design is an 8 meter ring telescope (Liu *et al.* 2012). In this design, the primary mirror is an 8 meter ring mirror with 1 meter width (Table 1, Figure 2). This telescope is named Ring Solar Telescope (RST). As a typical RIT (Ring Interferometric Telescope) (Liu *et al.* 2006), the resolution diameter of RST is 8 meters and the collecting area is 22 square meters, just equal to the collecting area of a traditional 5 meter telescope. No matter a whole ring or a segmented ring, the primary mirror will reach its diffraction limit at least at 1 micron band. We have done many simulations of the 8 meter RST, such as the PSF properties (Liu *et al.* 2011), the finite element analysis of the mechanical structures (Dai *et al.* 2012), the active optics and adaptive optics (Dai *et al.* 2011; Yuan *et al.* 2011). High resolution solar observations by using a real ring aperture (Figure 4) were also carried out on the 1 meter New Vacuum Solar telescope (Liu & Xu 2011). All the above simulations and experiments indicate the feasibility of the 8 meter RST. Now, the 8 meter RST is the relatively most complete conceptual design in all the proposed candidates of CGST.

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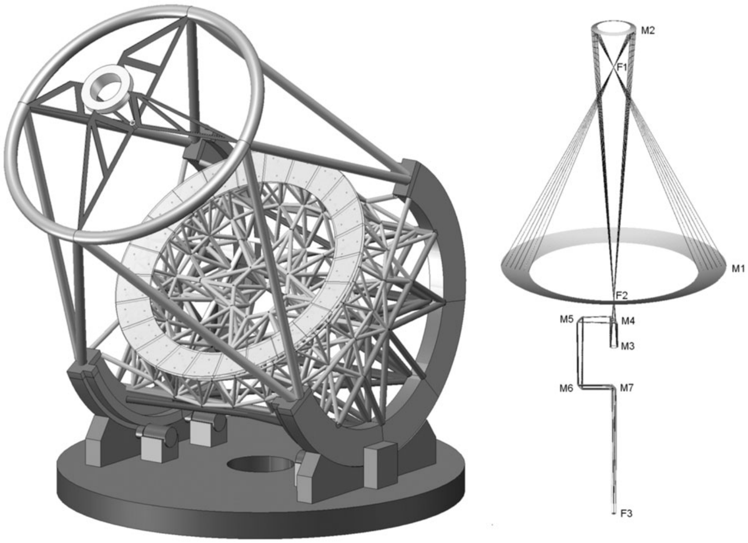

Figure 2. 3D sketch of 8m RST, the primary mirror is an 8 meter ring with 1 meter width.

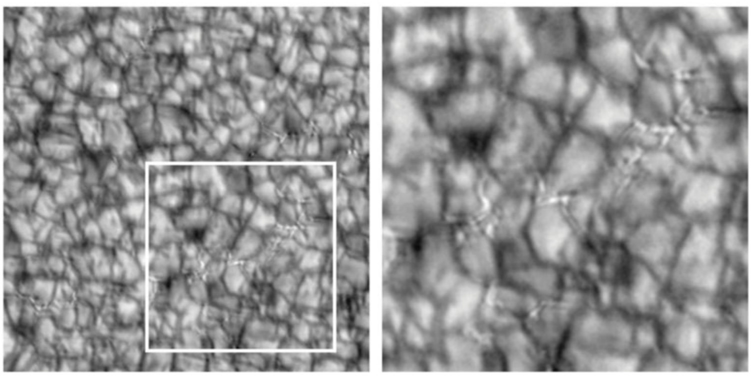

Figure 3. High resolution imaging by ring aperture, the diameter of the ring is 1 meter, the width is 0.15m.

3. Prominence observation with CGST

With the progress of modern solar observations and the developments of new technologies, fine structures smaller than 10 0km can be resolved by current ground-based solar telescopes. The recent researches also indicate that there should be ultra fine structures smaller than 0.1 arc-second in the solar photosphere. These ultra fine structures are not only statistically significant fundamental structures but also a part of solar activity itself. New observation results from NST showed the inherent relationship between the photosphere bright points and the obvious activities in solar corona (Ji *et al.* 2012). The recent simulations also predicted 20 km significant structures in the photosphere (Stein *et al.* 2006; Stein *et al.* 2011). The current solar telescopes cannot resolve these ultra fine features and their evolutions, such as the micro magnetic reconnection, the structure of bright points and the evolution of the tiny flux tubes. So, the next generation large solar telescopes all chose 4 meter or more as their aperture size. The scientific goals of CGST will be introduced in other papers. In this paper, prominence observations with CGST are introduced as an important case.

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Table 1. Optical parameters of CGST.

Diameter of primary mirror	8m
Width of primary mirror	1m
F/D of primary mirror	1
Collecting area of primary mirror	$22m^2$
Diameter of secondary mirror	1.6m
Spectral range	0.3 $\sim$ 15 micron
Spatial resolution	0.03 arc sec
Polarization accuracy	$\sim 10^{-4}$

Many cases of prominences and filaments have been discussed in CGST science group. Some of them are based on the high resolution observations from the 1 meter NVST (Liu & Xu 2011). Figure 4 shows the obvious changes of active filaments during a flare eruption. After flare, an active filament connected with another one in a short time and exchanged some mass and energy. Some observation data from SDO and the other solar telescopes also showed the filament reconnections (Jiang *et al.* 2013). Are these real reconnections between filaments or only visual effects? The deeper problems in such a case include the fine magnetic structures of filaments, the reconnection process between filaments, the magnetic energy transmission and storage. Although a one meter telescope could resolve many details inside a filament, it is still too small to resolve the individual flux structures and their evolutions. Direct evidences are needed to demonstrate these reconnections result from more fundamental magnetic reconnections or consist of more fine combinations of tiny structures. The relationship between filaments reconnection and the reconnection of flux ropes or flux tubes (Linton *et al.* 2001) is still open. It is one of the key problems in filament eruption and is also an important science case of prominence high resolution observation. According to the simulations, CGST will be able to observe filament reconnection with very high angular resolution and very high polarization accuracy.

Another important case is a perennial open question, that is, the quiescent prominences. We don't know well the structures and the origin of the quiescent prominence, especially the magnetic field in it or below it. Some works, such as the dynamic structures of quiescent prominence could be done by using a current 1 m-class telescope. Figure 5 shows a high resolution quiescent prominence taken by the 1 meter NVST. As the magnetic field of quiescent prominence is very weak, most problems are waiting for more powerful observational facilities. For example, some current observations showed that quiescent prominences do not have obvious footpoints in the photosphere. On the other hand, the recent observations and simulations demonstrate that tornados are related to the photospheric magnetic field and have obvious footpoints in the photosphere (Wedemeyer-Bohm *et al.* 2012). The relationship between quiescent prominences and tornados implies that many quiescent prominences may have footpoints in the photosphere and the photospheric magnetic field. Only a large aperture telescope with high polarization sensitivity could give the final answer. In all the remaining problems of quiescent prominence, the magnetic field is the most important part. It is directly relevant to the nature of prominence.

Unlike the objects on the solar disk, the observations of prominence need some special methods and new technologies. For example, the normal adaptive optics could not observe the prominence on the edge of the solar disk as it is very difficult to do the wave-front

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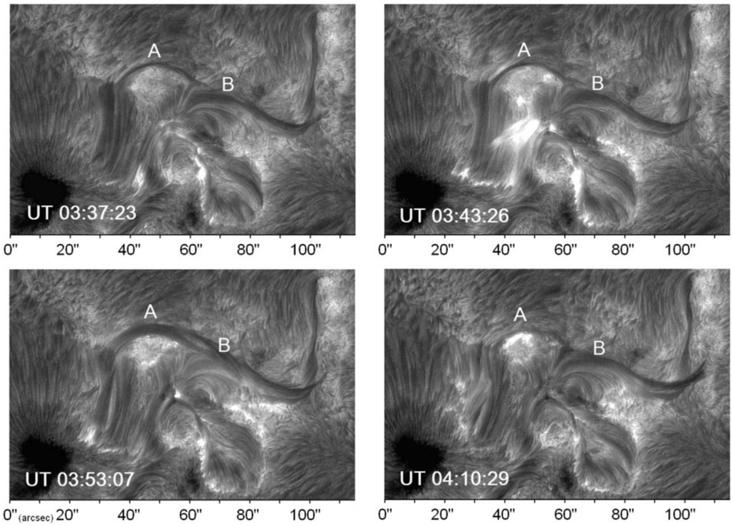

Figure 4. The change of active filaments during a flare on October 25, 2012 (AR11598).

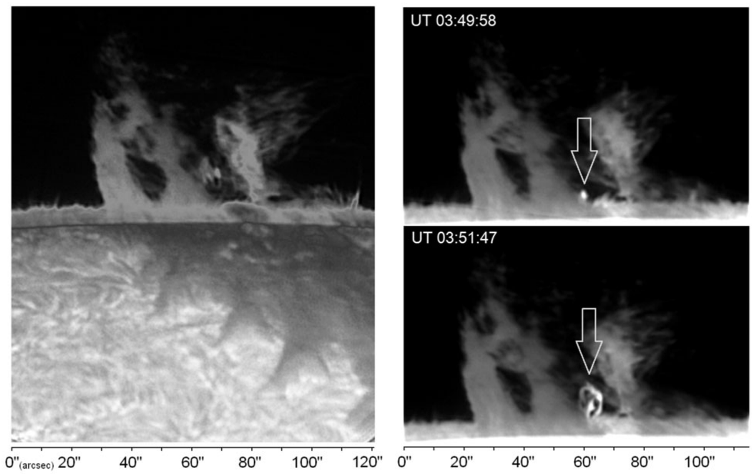

Figure 5. Quiescent prominence on January 15, 2013.

sensing. Normally, we could do wave-front sensing in photosphere bands and do AO observations in the weak chromosphere bands. But prominences on the edge of solar disk do not have such a photosphere background. The idea of using a chromospheric wave-front sensor encounters the problem of low photon numbers. An alternative choice is to use the Day-time Laser Guide Star (LGS) to do wave-front sensing, for example the sodium LGS. MCAO (Multi Conjugated Adaptive Optics) is also a very important technology for prominence observations, as the size of a prominence is much larger than the isoplanatic area of the Earth atmosphere.

4. Current situations of CGST

A site survey group is working on the plateau of southwest China. This work began in 2010 not only for CGST but also for the big aperture Sino-American cooperative coronagraph. GIS (Geography Information System) and the satellite meteorological information

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have been used in the general survey. The testing instruments include the portable image motion monitor, solar differential image motion monitor, sky brightness monitor, scintillometer, integrated water vapor detector, robot weather station and other useful instruments. Now, after three years' hard work, the site survey group has reduced the candidates from dozens to several lake sites and mountain sites.

Besides the progress in science and technology, CGST also got some progress for project approval. In 2010, a committee has been set up to push CGST to be a normal National Science Project. In the same year, CGST has been selected and recommended to the National Development and Reform Commission (NDRC) as a "National major basic scientific project for 2016–2030". In 2012, CGST was confirmed as one of the major national science projects by NDRC of China. The first budgets for preliminary research work and site survey are mainly funded by NSFC (National natural Science Foundation of China) and CAS (Chinese Academy of Sciences).

5. Acknowledgements

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