Simulation of Chinese Giant Solar Telescope

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ABSTRACT

Chinese Giant Solar Telescope is the next generation ground based solar telescope of china. Due to the characteristics of ring aperture in polarization detection and thermal control, the current design of CGST is an 8 meter ring solar telescope. The simulation of science cases and the current observations from 1m class solar telescopes indicated the necessity of such a big aperture especially in infrared bands. The integrated simulation of optical system and imaging ability such as optical design, MCAO, active maintenance of primary mirror were carried out in this paper. The results of simulation and analysis showed that the current design could meet the demand of most science cases not only in infrared band but also in near infrared band and visible band.

Key words: Solar telescope, ring aperture, simulation, infrared

1. INTRODUCTION

Chinese Giant Solar Telescope (CGST) is the next generation infrared and optical solar telescope. It is a very large ground based solar telescope first 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. In order to meet the requirements of scientific goals, CGST was designed to an 8 meter RIT (Ring Interferometric Telescope) [1, 2]. As a typical ring telescope, the resolution diameter of CGST is 8 meters and the collecting area is 22 square meters equal to the collecting area of a traditional 5 meter telescope (Fig.1).

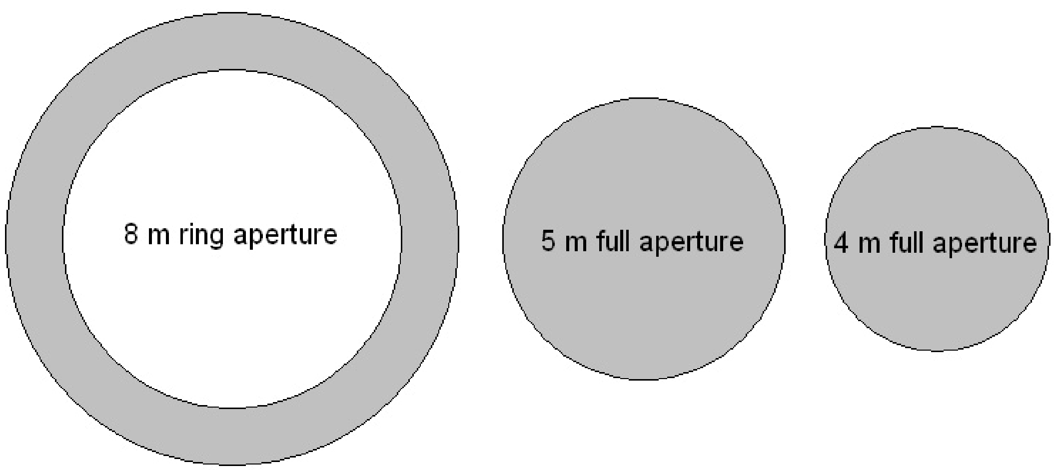

Fig.1. Clear aperture of 8 meter CGST, the width of ring is 1 meter

The site of ATST (Advanced Technology Solar Telescope) is on Haleakala mountain of Hawaii. EST (European Solar

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Telescope) will be installed on the mountain of Canary Islands. The potential site of CGST is located in the plateau of Southwest China. CGST could fill the vacancy between ATST and EST. This means the three large solar telescopes could observe the sun continually.

As a communal project of Chinese solar field, CGST is currently supported by National Natural Science Foundation of China (NSFC), Chinese Academy of Sciences (CAS) and all the participated units.

2. SCIENCE CASE AND SIMULATION

The solar magnetic field is the key factor of solar activity. In order to predict the solar eruption such as flare and CME, it is necessary to observe the fine structures of solar magnetic field and the fine features of solar dynamic field. About thirty years ago, many solar physicists believe the fundamental structure of solar magnetic field was around 0.1 arc-second equivalent to 70km on the sun. This is also the reason why the aperture size of current big solar telescopes is around 1 meter. With the development of new technologies include the adaptive optics and new manufacturing technologies of solar telescope, fine structures smaller than 100km (0.15 arc-second) on the sun can be resolved by ground based solar telescope in the last ten years (Fig.2). The new observations indicated there should be many fine structures smaller than 0.1 arc-second not only in magnetic field but also in dynamic field. These fine features and their evolution are the decisive factors of solar magnetic field and solar activities. But one meter scale telescope unable to resolve these fine features such as micro magnetic reconnection, the structure of bright points and the evolution of tiny flux tubes. The fine structures around 0.03 arc-second (about 20km on the sun) are also predicted by recent numerical simulation [3, 4]. It is the main reason why ATST and EST chose 4 meters as their aperture size.

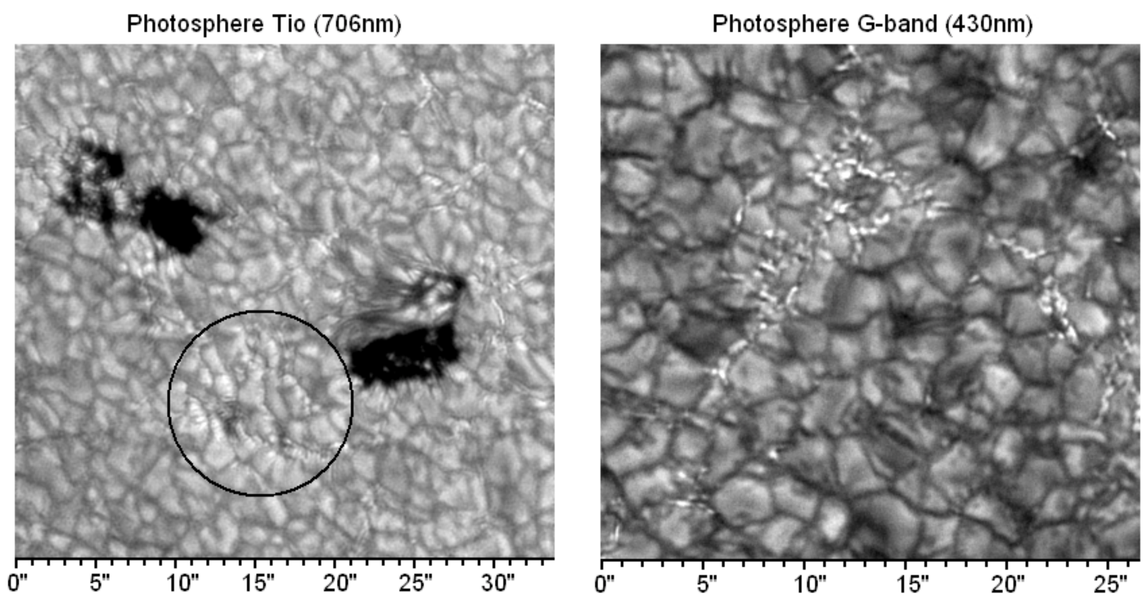

Fig.2. Left image shows some uncertain micro magnetic reconnection structures (inside black cycle). The right pattern shows many bright points on quite sun. These images are both taken by 1 meter New Vacuum Solar Telescope (NVST, Yunnan Astronomical Observatory).

As the outer diameter of CGST is two times bigger than 4 meters, CGST can observe the fine structure in near infrared bands as ATST and EST do in visible bands. For example, a 4 meter solar telescope can resolve 0.04 arc-second at 706 nm (TiO) but the 8 meter CGST can also reach the same resolution at 1.56 micron and shows more information from deep photosphere.

The scientific goals of CGST can be briefly expressed by several cases. The first one is the high resolution imaging for photosphere and chromospheres with 1s temporal scale. Based on our simulations[5], this case needs very good seeing up to 10cm or more in visible bands. The diffraction limited imaging in near infrared bands (about 1 micron) is the main objective and we will also give consideration to high resolution imaging in visible bands. Adaptive optics and two dimension spectrometers are the key techniques in this field. The second sciences case of CGST is the high precision measurement of vector magnetic field. This case can be combined with the high resolution imaging. But the key point is to measure the Zeeman split directly with high dispersion grating spectrometer in far infrared region. In this case, Zeeman split is proportion to the square of wavelength. For example, the Zeeman split is 400 times wider at 10 micron compare with the Zeeman split at 0.5 micron. Another important case is synchronal multi channel observation. This mode is very important to understand the transportation process of solar energy and mass flow from the lower photosphere to solar corona. It is also the best way to discover the heating mechanism of corona.

3. MODELING AND SIMULATION OF CGST

3.1. Discussion of solar telescope

In order to reduce the air turbulence inside the telescope tube, traditional solar telescope tend to use vacuum tube. The diameter of vacuum window is larger than pure aperture. It is very difficult to manufacture vacuum window when the diameter of primary mirror increase to 2 meters or more. On the other hand, the turbulence before thick window is worse compare with the thin one (Fig.3). For these reasons, most modern large solar telescopes will be designed as open structure.

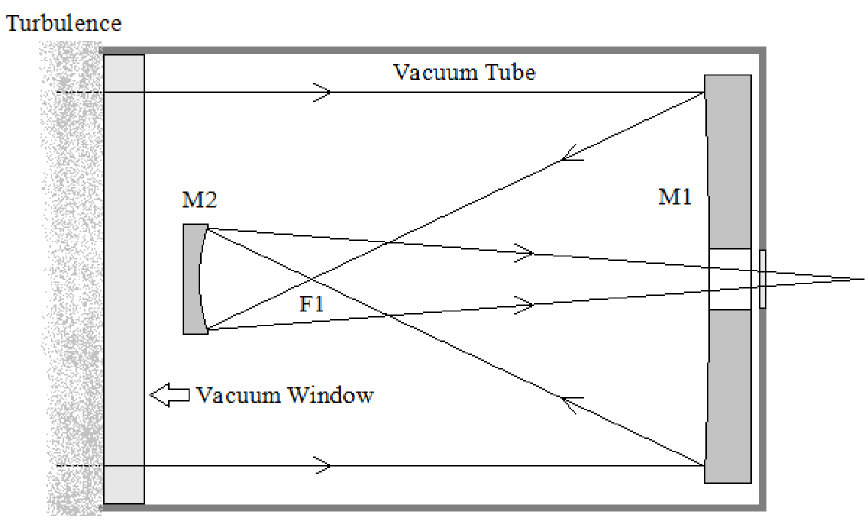

Fig.3. Diagram of a traditional vacuum solar telescope

One key point of open solar telescope is thermal control as the sun is a hot spread source. The normal optical system of solar telescopes is Gregorian system or modified Gregorian system as these systems have a primary focus (F1) before secondary mirror. A field diaphragm (arc-minute scale for high resolution observation) on F1 can prevent more energy enter into following system to minimize the thermal problems. In such a case, there should be a serious temperature gradient near F1. Although the wave-front distortion is not so serious on F1 but the temperature gradient will bring a serious influence to the wave-front on entrance pupil. One solution to this problem is to design telescope to an off-axis system (Fig.4). It is easy to insert a large size thermal control box at F1 and will not block the light rays. A disadvantage of this kind off-axis system is that the unsymmetrical structure will result in serious cross talk between the polarization parameters. It is an obstacle for high precision magnetic field measurement.

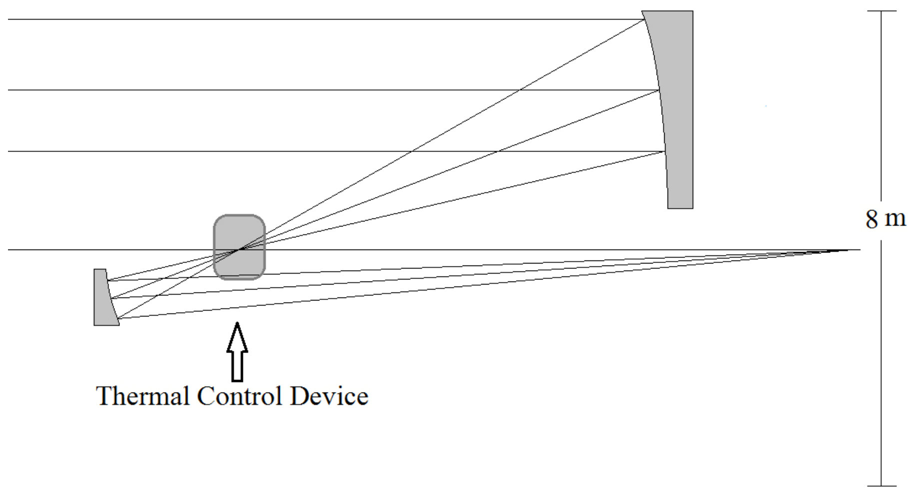

Fig.4. Diagram of an off-axis system with thermal control box

3.2. Properties of Ring Solar Telescope

Compare with the off-axis system, ring telescope is a symmetrical system and no instrument polarization. It is also easy to insert a large size thermal control box at F1 as same as off-axis telescope. In fact, revolve an off-axis system around its virtual axis will shape a ring structure (Fig.5).

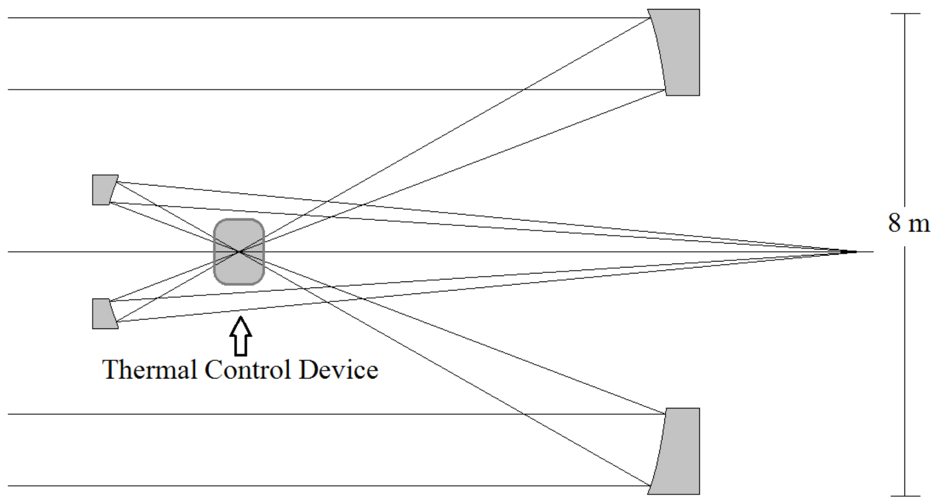

Fig.5. Diagram of a ring telescope with thermal control box

The most important optical property of a ring aperture is it can cover all the baselines smaller than its outer diameter. This means the ring telescope has a complete U-V coverage[1]. The PSF of a ring aperture is different from Airy disk (Fig. 6). But it is easy to transform ring aperture PSF to Airy disk without any information loss since the full U-V coverage property. The PSF and its transformable properties were discussed and simulated in references [2] not only in theory but also considerate the real mode with finite photons. The more properties such as small spherical aberration, fast F-ratio and low wind resistance were also analyzed in references [1, 2].

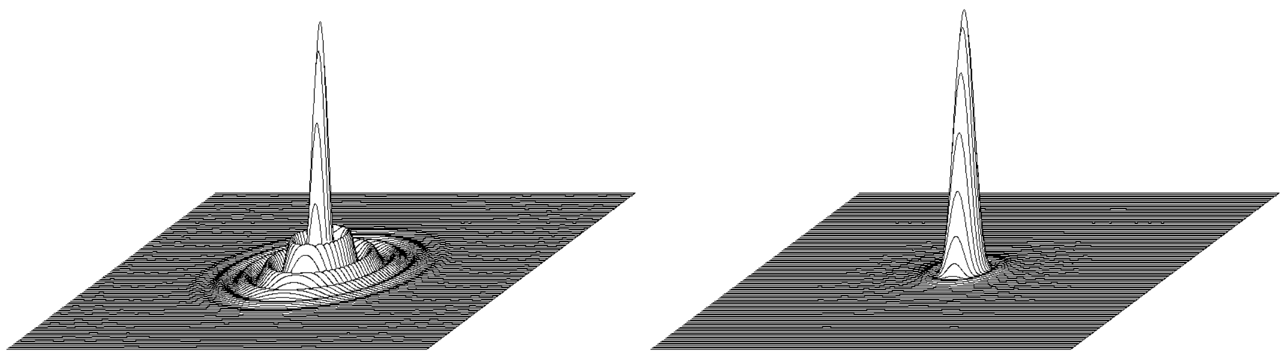

Fig.6. Comparison between ring aperture PSF (left) and Airy disk

Another very interesting property of RST (Ring Solar Telescope) is about wave plate. For normal full aperture telescope, the wave plates include liquid crystal wave plate and narrow band filters could not insert into concentrate light path since there is a big Optical Path Difference (OPD) between central ray and edge ray. But for ring system this problem is minimized as the central part of ring aperture is vacant (Fig.7). This property gives more conveniences in solar telescope designing.

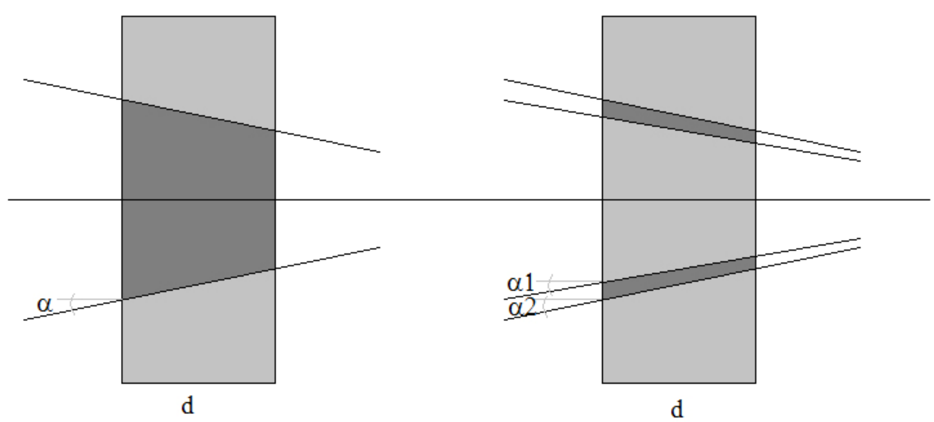

Fig.7. Left pattern shows wave plate or filter in full aperture light path. The right one shows ring case.
As α >> (α2-α1), the maximum OPD in left pattern is much bigger than the right one.

3.3. Optical simulation and modeling

CGST is also a modified Gregorian optical system as figure 8 shows. The diameter of primary ring mirror is 8 meters. The width of primary ring mirror is decided by two factors. The first one is Signal to Noise Ratio of each spatial frequency components. The second is to keep enough central vacancy to install thermal control device. Increase the SNR of spatial frequency components means enlarging the width of ring and also means reducing the size of central vacancy. According to our rough estimation, a good thermal control device needs one meter scale central vacancy near F1. Consider the balance of these two factors, one meter size was confirmed as the width of the ring aperture. Figure 9 is the MTF comparison between 4 meter full aperture and 8 meter CGST. The SNR of most frequency components of 8m CGST are higher than 4 meter full aperture telescope. Table 1 shows the main optical parameters of CGST.

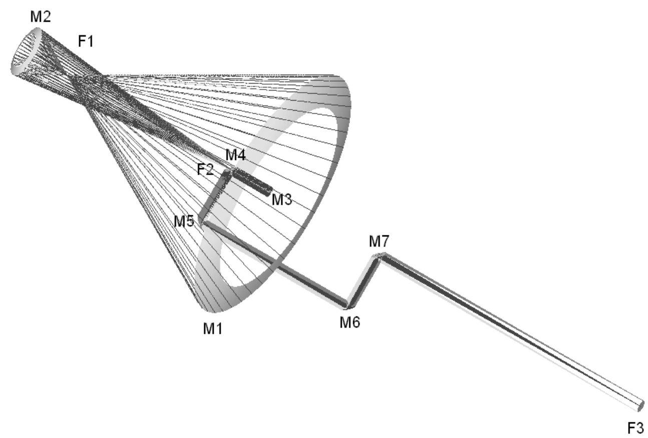

Fig.8. Modified Gregorian system of CGST

Tab.1.The main optical parameters of CGST

Diameter	8 m
Width of ring	1 m
Collecting area	22 m^2
Field of view	~3’
F/D of primary	~1
Spectral range	0.3~15 micron
Spatial resolution	0.03”
Polarization accuracy	$2x10^{-4}$

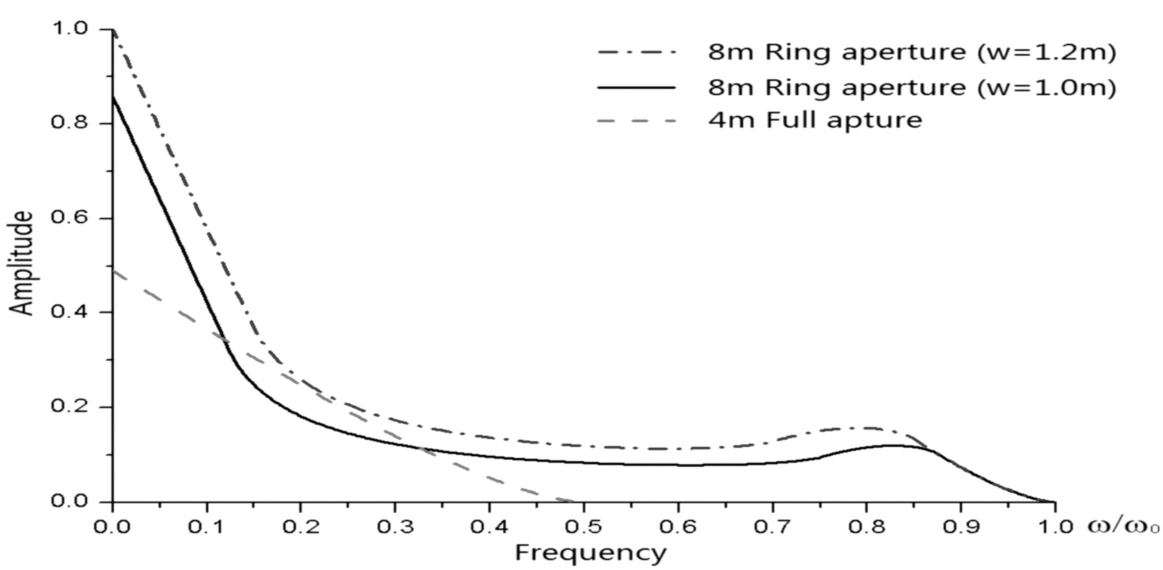

Fig.9. MTF comparison between 8m CGST and 4m full aperture telescope

3.4. Active maintenance and adaptive optics

There are two types of primary ring mirror, the whole ring or the segmented ring. The active maintenance of segmented ring is quite different from segmented full mirror. The segmented ring mirror of CGST consists of 24 1m × 1m trapezoid-shaped segments (almost square-shaped). In such a structure the surface shape can’t be kept just use edge sensors. Only 2/3 modes in surface shape error can be corrected[6] since the tip errors of segments can't be detected by edge sensors. Therefore, some kinds of sensors able to detect the tip should be used. High precision tip detection similar to SH wave-front sensor was simulated by Yuan et.al.[7]. It shows a very good result by using inner light source instead of natural stars. All the simulations indicated that the segmented primary ring mirror can be active maintained by edge sensors combine with tip sensors. Whole ring need no active maintenance but it may difficult to manufacture.

Adaptive optics of ring telescope was also simulated by Dai et.al.[5]. Annular orthogonal polynomials were used to fit the ring wave-front instead of classical Zernike polynomials. Even so, the fitting result is still not so good. In order to increase the fitting accuracy, classical fitting sequence was adjusted to match a narrow ring case. Then the residual error was reduced to a reasonable value and the Strehl Ratio of reconstructed PSF was increased to 0.32.

Professor J.M. Beckers also did some calculations and analysis of CGST's MCAO (Multi Conjugate Adaptive Optics). His brief conclusions are the following. 1, MCAO can also enlarge the high resolution FOV in ring case. For example, TCAO (Triple Conjugate Adaptive Optics) can enlarge high resolution (0.3 arc-second) FOV to full solar disk (about 0.5 degree) at 12.3 micron (Mg I). 2, Traditional TCAO of CGST requires more (~ 3x) sub-areas (as guide stars) on sun than full aperture telescope.

3.5. Structure and figures

There is no formal mechanical design and structure simulation of CGST. The structure shown in figure 10 is just a schematic diagram to express our idea. The right pattern of figure 10 is another alternative design very similar to GMT (Giant Magellan Telescope). It is a 6 meter multi mirror solar telescope proposed by NIAOT (Nanjing Institute of Astronomical Optical Technology).

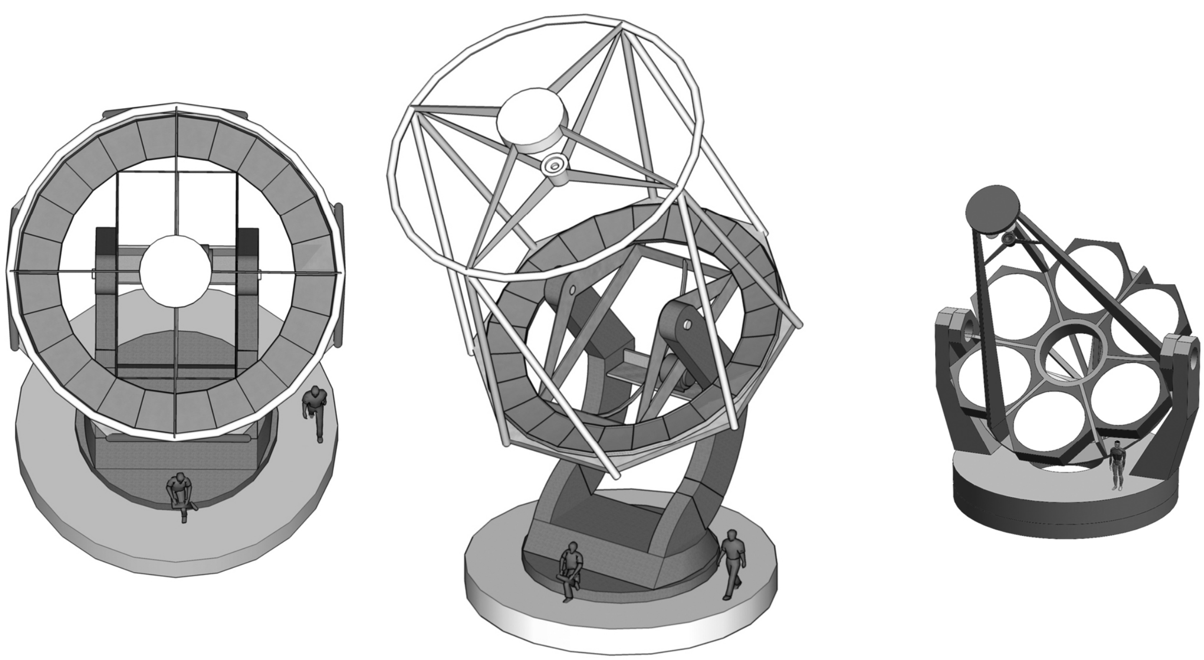

Fig.10. 3D sketch of CGST. The right pattern is another alternative design of CGST.

4. CURRENT SITUATION OF CGST

In order to drive CGST forward to an approved National Science Project, three committees and several working groups were established in 2010. The three committees are Advisory Committee, Scientific Committee and Promotion Committee. The working groups include Scientific Group, Designing Group, Instruments Group and Site Survey Group. In the same year, CGST was selected and recommended to National Development and Reform Commission (NDRC) as a project of "National major basic scientific project for 2016-2030". It was also selected by National natural Science Foundation of China (NSFC) as an astronomical project for 2016-2020. Up to now, there are 1.2 million US$ for paper work and site survey of CGST given by NSFC and CAS (Chinese Academy of Sciences).

A site survey group is working on the plateau of Southwest China. The potential regions are two parts (Fig.11). One part is near the border between Yunnan province and Sichuan province. Another is in the western Tibet. The site survey instruments include small image motion monitor, Solar Differential Image Motion Monitor, Sky Brightness Monitor, scintillometer, integrate water vapor detector, robot weather station and the other useful instruments.

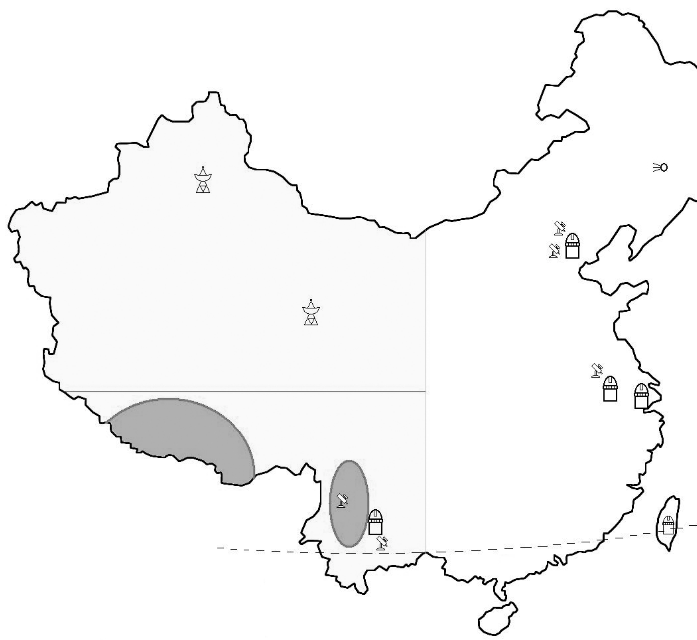

Fig.11. Site survey map of CGST. The potential regions are the two black parts.

5. ACKNOWLEDGEMENTS

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