First Asia-Pacific Solar Physics Meeting
ASI Conference Series, 2011, Vol. 2, pp 9–17
Edited by Arnab Rai Choudhuri & Dipankar Banerjee

1-meter near-infrared solar telescope

Z. Liu* and J. Xu
Yunnan Astronomical Observatory, Chinese Academy of Sciences, Yunnan, China

Abstract. In order to observe the fine structure of solar dynamical field and magnetic field, a 1-meter near-infrared solar telescope was developed by Yunnan Astronomical Observatory, Chinese Academy of Sciences. The telescope is located by the Fuxian Lake in southwest China. In this paper, we will introduce some details of the telescope such as scientific goals, structures, instruments and the parameters of the site. First light observation of high resolution photosphere is introduced too.

Keywords : Sun: general – telescopes

1. Introduction

As the ground partner of Chinese Space Solar Telescope (Deng et al. 2009) a new one meter solar telescope was proposed by Chinese solar physicists in 90s of last century. The original scientific goals of this telescope focused on the spectrum of solar active region including the magnetic field measurement based on Zeeman Effect. Then the site survey started in 1996 in the southwest of China because of the high altitude and low latitude of this region. In 1999, Fuxian lake was confirmed as the final site from many candidates. Due to the excellent seeing (Lou et al. 2001) of the new site, the high resolution imaging became another main goal of this telescope. Finally, the goal of this solar telescope was described as: observe the sun by high resolution image instruments and multi-wave spectrometer (including polarization analyzer) in visible and near infrared bands.

The whole project is mainly charged by Yunnan Astronomical Observatory. NIAOT (Nanjing Institute of Astronomical Optics & Technology) is the main participant and the most important collaborator. Several Chinese observatories and institutes are also involved in this project (see acknowledgements). In order to match the good

*email: lz@ynao.ac.cn

Figure 1. New Vacuum Solar telescope and its wind screen.

seeing and reduce the instrument polarization, the telescope was designed as a vacuum type with symmetrical optical system. Mechanical part was designed and manufactured by NIAOT. Main optical elements were produced by LZOS, Russia. Control system and most instruments including a huge vertical spectrometer were developed by Yunnan Astronomical Observatory itself. The telescope was installed on the site in 2010 by NIAOT and Yunnan Astronomical Observatory. In the same year, first light observation was carried out on September 1. The formal name of this one meter solar telescope is New Vacuum Solar Telescope (NVST) and the name of the new solar observatory is Fuxian Solar Observatory (FSO).

2. Telescope and building

An optical window (W1) with 1.2 meter diameter is placed on the top of the vacuum tube to keep inner air pressure low than 70 Pa. The optical system after W1 is a modified Gregorian. There is a 3 arcmin field diaphragm (heat stop too) on primary focus (F1) to prevent more energy enter into following system. After primary mirror (M1), the secondary mirror (M2) converge light rays to F/9 and focus at F2. For fear of polarization crosstalk, polarimeter can be inserted into the light path near F2 before the turning point of light rays. The M4 is a small flat mirror and reflects light rays to horizontal direction. As focusing mirror, M3 converge light rays to final focus through reflector M5 M7.The pure aperture of telescope is 985 mm and the effective focal length before instruments is 45 meters.

The mounting of NVST is an alt. & az. structure. It is more compact compared with the equatorial mounting. The alt. & az. mount means stabilization and small wind resistance as well as image rotation and blind area. Blind area of NVST is about 2 degrees on the zenith. As the latitude of FSO is 24.5°N, there is almost no blind

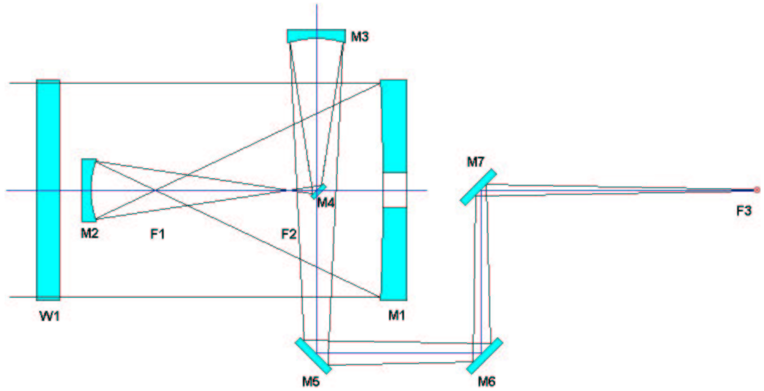

Figure 2. The optical diagram of NVST.

area effect in normal solar observation. Image rotation on focus can be offset by active rotating device such as a derotator. Pointing accuracy of NVST is high enough to point any region of solar disk in several arcsec. Tracking system can track the sun steadily with about 0.5 arcsec tracking accuracy in half an hour. The high tracking accuracy is supported by two closed loops. Inner loop depends on two high accuracy circular inductive synchronizers installed on mechanical axes. Another one is individual small guiding telescope with a 4k by 4k CMOS sensor and banding on main telescope tube. In order to keep the good local seeing, telescope works on the open air and has no traditional dome. At this situation, an active wind screen was built to reduce the wind pressure on telescope. Wind screen can move automatically according to the wind direction (Fig.1). The thermal control system of NVST consists of two parts: water cooling for F1 and W1 (Fig.3). The left heat is still very harmful to F1 diaphragm although the most energy outside the view of field is reflected off vacuum tube. The water cooling system brings the left energy via a heat pipe connected to F1 diaphragm. With the same reason a circular water tunnel around W1 edge is designed to avoid the image degradation caused by hot deformation of W1.

The tower is a building with 16 meter height. There are two independent foundation piers inside the building. The inner pier support vertical spectrometers and a rotating platform. The outer one is for telescope. The moveable dome can be opened and moved to the opposite side on the top of building (Figs 4 & 5).

3. Instruments of NVST

The instruments of NVST can be roughly classified into two groups. The first group consists of imaging instruments and 2D spectrometers including multi-wave high resolution imaging system, adaptive optics (AO) system, Fabry Perot filter and magnetograph etc. Imaging instruments are placed on a big rotating platform. The second group contains two traditional grating spectrometers: multi-wave spectrometer and

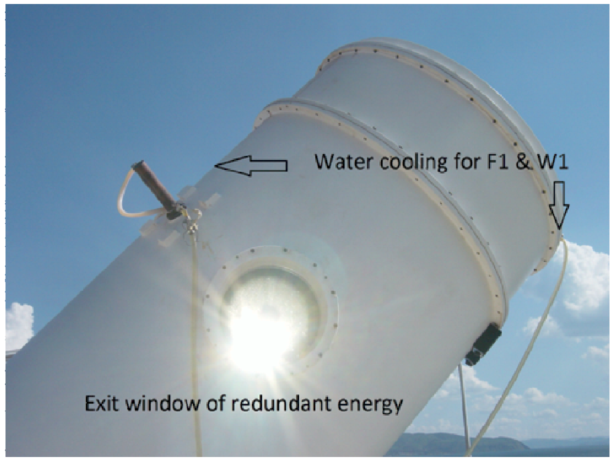

Figure 3. Cooling system of NVST.

Figure 4. Full view of NVST building.

high dispersion spectrometer. Multi-wave high resolution imaging system has two branches, one for photosphere imaging another for chromosphere imaging. The photosphere branch can take G band and TiO images with very high angular frequency and high temporal frequency depending on the performance of cameras. Speckle masking is adopted as the normal method to reconstruct solar images to diffraction limit. The chromosphere branch can take different chromosphere images depending on the central wavelength of filter. We normally use a 0.25 angstrom H alpha Lyot filter to get the solar atmosphere images. These two imaging branches can work simultaneously and can also follow the AO system. The current AO system is a low order 37 elements system. A high order AO system with 127 elements funded by NSFC (National Nature Science Foundation of China) is being constructed by IOE (Institute of Optics and Electronics, CAS). The AO system also has independent imaging cameras such

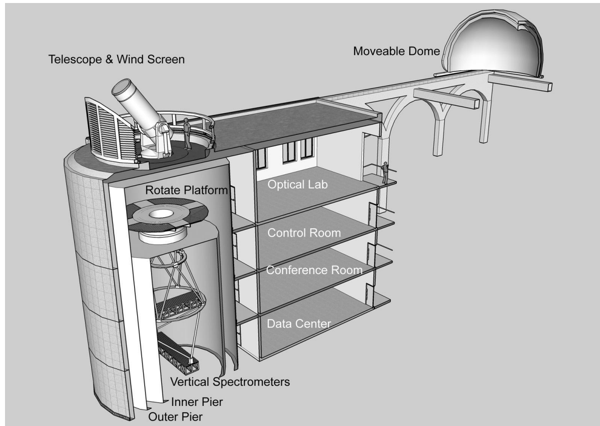

Figure 5. View inside NVST building.

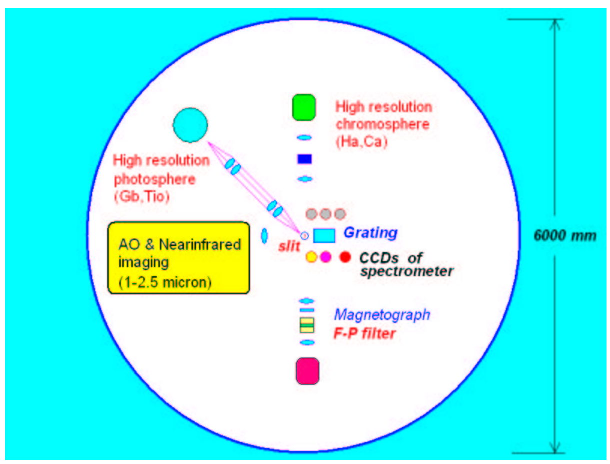

Figure 6. Diagram of rotating platform and instruments.

as 1.56 micron photosphere camera. A near infrared Fabry Perot filter and a magnetograph are still being designed and will be equipped in the next two years. The different imaging instruments can be switched quickly by using a rotatable 45 degree mirror on the center of the rotating platform.

Two grating spectrometers are both placed on a vertical hanging bracket. The bracket is a rigid frame fixed under the rotating platform. It rotates synchronously with rotating platform to offset the image rotation. The bracket has two levels, multi-wave spectrometer on the first level and high dispersion spectrometer on the second level. Slit is also on the center of rotating platform under the 45 degree mirror. Two spectrometers use the same collimating mirror but different gratings. The grating of multi-wave spectrometer is a 1200 lines/mm blazed grating for 0.05 angstrom resolution at Hα line (6563Å). The grating of high dispersion spectrometer is a 316 lines/mm echelle grating. Resolution of high dispersion spectrometer at 1.56 micron is 0.05 angstrom too. The first light lines of multi-wave spectrometer are Hα, Ca II (8542Å) and He I (10830Å). He I is also the line of high dispersion spectrometer. Another important spectral line of high dispersion spectrometer is Fe I (1.56 micron) for measurement of photosphere magnetic field.

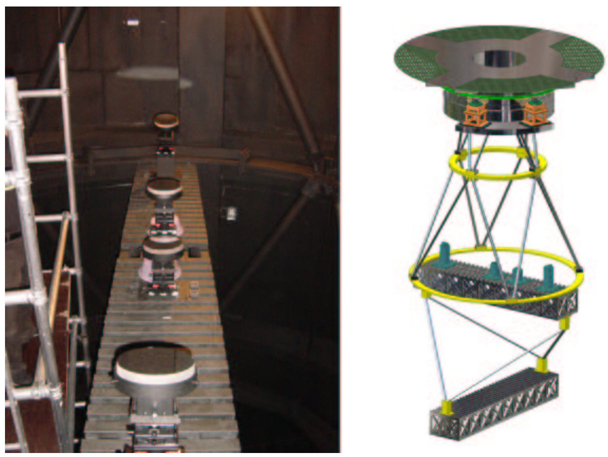

Figure 7. The rotating platform and vertical spectrometers.

Although polarization analyzer is not included in above two groups as an independent instrument but it is really a very important part of NVST. The basic structure is rotating wave-plate system. Polarization analyzer is the key to get stokes parameters for both spectrometers and imaging instruments. It is placed near F2 and before M4 (Fig.2) in order to reduce the cross talk of I, Q, U and V. Due to the stability of the glass wave-plate the liquid crystal wave-plate is not adopted in current design. The polarization analyzer of NVST is still being developed and will be installed into NVST tube at the end of 2011.

4. Some observation results

The site installation of the telescope and the high resolution imaging system was finished in June 2010. Then the main optical system of NVST was tested by an optical interferometer on site. The whole control systems include tracking and pointing were tested at the same time. The final testing before the formal first light was carried out by using only 40cm sub aperture to observe the central part of the quiet photosphere. Testing results indicate that NVST meets the design requirements (Fig.8).

On September 1, 2010, the telescope was guided to point a small sunspot to do

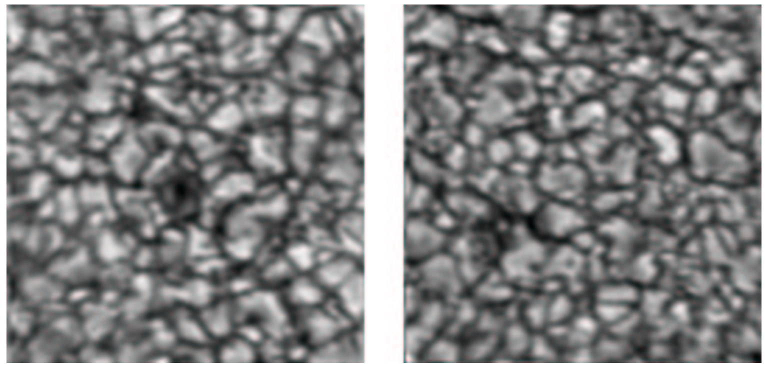

Figure 8. Quiet sun observed by 40 cm sub aperture, without any reconstruction.

the formal first light observation by using full aperture. The filter is 10 Å bandwidth near 7057 Å(titanium oxide) to show photosphere structure (Goode et al. 2010). The exposure time is 5 milliseconds. Thousands of speckle images were taken by a 2048 $\times$ 4096 PI CCD camera with 4 fps. Every 50 or 100 speckle images were calculated to reconstruct one high resolution image by Speckle Masking (Weigelt 1977) and ISA (Liu et al. 1998). Fig 9 is a typical reconstructed high resolution image of active region. In this image, fine structures of sunspot and quiet sun such as granulations, penumbral filaments, magnetic bright points and umbra bright points are all very clear. Resolution of this image is better than 0.2 arcsec and this means 120 km details on the photosphere can be resolved.

5. Introduction to FSO and site parameters

Fuxian Lake is in the southwest China, 60 km from Kunming City. The area of this lake is about 210 square kilometers. The average depth is more than 90 meters. The altitude is 1712 meters above sea level. FSO (Fuxian Solar Observatory) is on the northeastern lakeside located at $24°34'$N and $102°57'$E. Usual monsoon comes here via the lake with the same direction as the lake wind. Large water body cools the air very well and keeps the balance between water temperature and air temperature. It is the reason that local daytime seeing of FSO is quite good (Liu et al. 2001). Average seeing is up to 10 cm a year but is better in rainy season (Fig.10). The wind is mostly (68%) blowing from the lake with mean velocities no more than 6 m/s. The sunshine duration is about 2,200 hours per year.

FSO is belongs to Yunnan Astronomical Observatory, CAS. There are two solar facilities in FSO besides NVST. One is an optical telescope another is a radio telescope. The optical telescope is a multi-tube Optical and NIR Solar Eruption Tracer (ONSET). ONSET has four vacuum tubes, three for solar observation one for guiding. It is developed by Nanjing University and operated by FSO. A 10 meter radio dish is

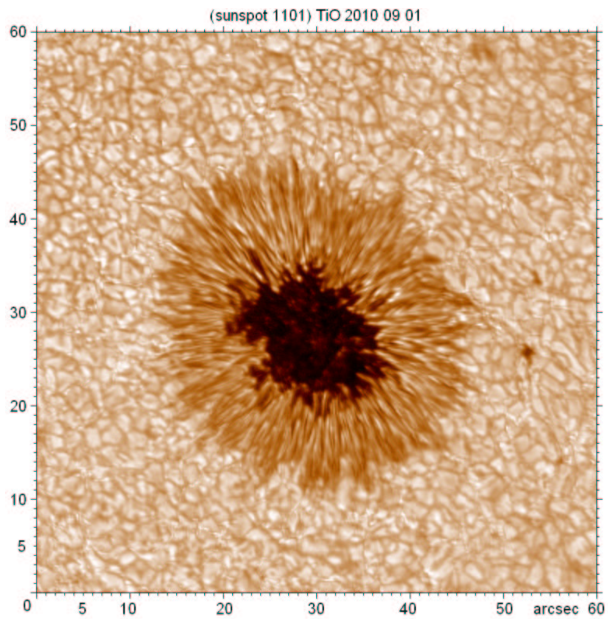

Figure 9. The first light of NVST, fine structure of AR 1101.

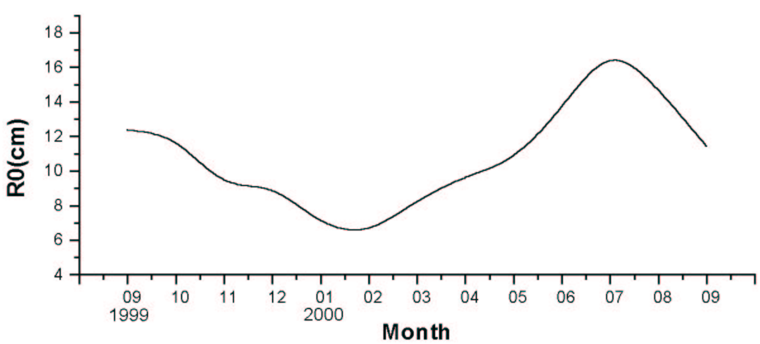

Figure 10. Profile of seeing in one year (from Sept. 1999 to Sept. 2000).

also placed on FSO to record the various radio bursts from solar corona. This radio facility is developed and operated by the radio group of Yunnan observatories.

Acknowledgements

This project was firstly proposed by Professor Guoxiang Ai, Professors Cheng Fang, Jianqi You, Longxiang Shen and Mingchan Wu. They are the pioneers of NVST. NIAOT is the main collaborator with Yunnan Astronomical Observatory in this project.

Contributors also include NAOC CAS, PMO CAS, NAIRC CAS, IOE CAS and LZOS. The authors thank Professor Jacques M. Beckers for his valuable suggestions about the size of the vacuum window and his participation in site testing. The authors also thank the NVST team members for their outstanding efforts.

NVST are currently funded by CAS (KJCX2-EW-T07) and MOST (2011CB 811401) of China.

References

Deng Y. Y., Zhang H. Q., 2009, Science in China Series G: Physics Mechanics & Astronomy, vol.52(11), 1655

Lou K., Liu Z., Zhang R. L., Lu R. W., Wu M. C., 2001, Progress in Astronomy, vol.19(2), 147

Goode P. R., Yurchyshyn V., Cao W., Abramenko V., Andic A., Ahn K., Chae J., 2010, ApJ Letter, 714, L31 (ADS)

Weigelt G., 1977, Opt. Commun., 21(1), 55

Liu Z., Qiu Y. H., Lu R. W., 1998, Proc. SPIE., vol. 3561, 326

Liu Z., Beckers J.M., 2001, Solar Phys., 198(1), 197