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The Large Vacuum Solar Telescope on the Way to High Resolution

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Abstract. The Large Vacuum Solar Telescope (LVST) is distinguished by its high theoretical optical parameters. We have carried out spectropolarimetric observations in various spectral bands, particularly in the HeI 10830Å line region (especially since 1997, when a new CCD system was obtained). The results cause us to conclude that only by means of adaptive optics will we be able to approach the theoretical resolution of the LVST. The possibility of using some kind of adaptive optics system is considered.

1. Introduction

One of the most important goals of solar astronomy is to understand the interaction of solar magnetic fields with the solar atmosphere. Supposing that such interactions occur on scales down to sizes near 50 km, resolution to $0.''05$ is required for studying such processes. Good resolution is required also for spectroscopic observations with narrow-band filters, since they require exposures longer than the temporal scale of the image motion that powerfully distorts these observations. Velocity fluctuation measurements in the upper atmosphere require repetitive scanning of one area for minutes to hours, and spatial registration must be maintained with high accuracy.

Modern ground-based telescopes are not capable of reaching such performance. In consequence of atmospheric turbulence, the resolution of ground-based solar telescopes is limited to an average value of about $1''$, with short periods of higher resolution in sites with the best seeing. In actual instruments it is important to suppress disturbances to the wave front (both inside the telescope and outside of it) that reduce resolution and consequently the information value of observations.

In the last decade progress in adaptive optics (AO) has raised the possibility of using such systems to improve the resolution of ground-based telescopes enough to study processes on the Sun at the angular scale required for their understanding.

The main difficulty in using AO, for solar observations particularly, is the small area over which it is possible to correct an image (isoplanatism), which in turn depends on the height distribution of turbulence in the Earth's atmosphere. It is very important for us to have the isoplanatic angle as large as possible in order to study extended scenes such as active regions and supergranular cells. For

Figure 1. View of the telescope.

imaging such extended objects, CCD arrays are used everywhere. For successful operation of AO systems with CCDs, where real-time correction of fast disturbances in the wave front arriving from the object is required, it is necessary to know the current and expected atmospheric parameters at each instant in order to optimize a disturbance compensation algorithm. This requires a careful study of seeing parameters. Under poor seeing an AO system simply will not be able to work.

In our article we will present some results of our efforts to achieve high resolution with the Large Vacuum Solar Telescope at Baikal Astrophysical Observatory.

2. Observations

2.1. Telescope

The Large Vacuum Solar Telescope (LVST) of the Baikal Astrophysical Observatory is situated near the shore of Lake Baikal in Listvianka village about 70km from Irkutsk. Its top is about 700 meters above sea level. The solar chromosphere and its fine structure are a main object of scientific studies at this telescope. In Fig 1 a view of the telescope is presented.

The LVST uses a single-mirror polar siderostat with a diameter of about 1 meter. The height of the siderostat tower is 25m. The diameter of the objective lens in the vacuum pipe is 76cm, the focal length is 40m, and the diameter of the solar image is 38cm. The theoretical spatial resolution is 0.18 arcseconds. The optical performance of the telescope is described by Skomorovsky & Firstova (1996). The telescope is equipped with a spectrograph. The good features of

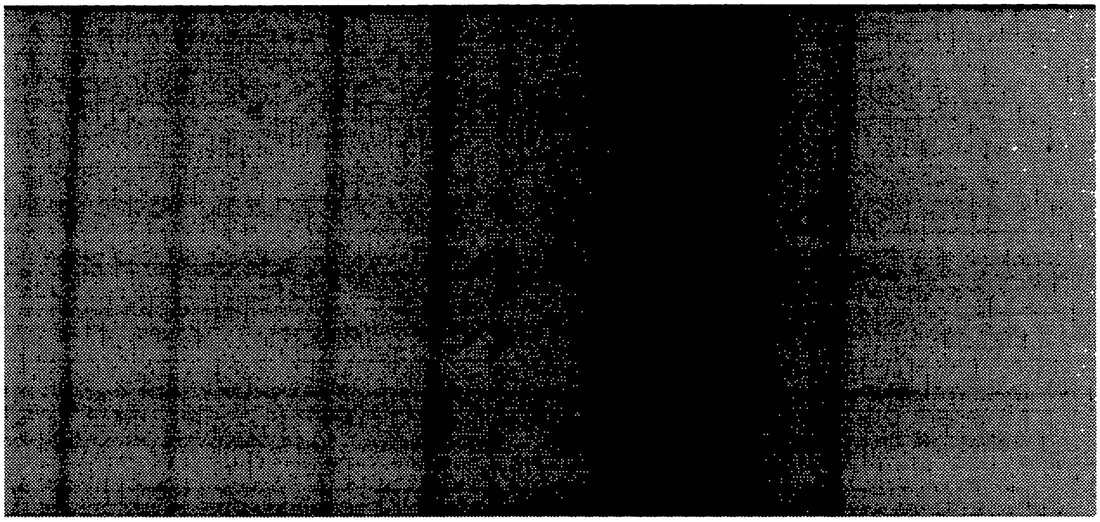

Figure 2. Raw CCD image of solar spectral lines in the H_α line region. The vertical size corresponds to 40 arc seconds

this spectrograph and particularly its diffraction grating allow the LVST to be used to study the fine structure of spectral lines.

2.2. Imaging system

Before 1995 imaging was performed only by photographic camera. In that year two CCD cameras were obtained: an ST-6 from Santa Barbara Instrument Group, and a special camera from a Russian manufacturer (St-Petersburg) with changeable camera heads (800×400 and 370×290). Toward the end of 1997 the first and still only commercial CCD system was installed in our observatory, a TEK 512×512 CCD from Princeton Instruments Company with a ST-130 controller. A new system with 2K×2K CCD camera will be installed in 1999.

During our observations the main objects of interest usually are flares and mustaches. As seen in Fig 2), we still do not reach optimal image quality.

3. Attempts to Improve Image Quality

What can we do to improve the solar image quality and its spatial resolution? Below we present short descriptions of our steps.

3.1. Image selection

Real-time selection of best frames with a seeing monitor has been used. The seeing monitor works on the basis of the contrast of granulation images (Karpinsky & Malyn 1983). Measurements have been performed at the Kislovodsk Solar Station, capturing exposures during the best quality moments with a photographic camera (Karpinsky & Bulatov 1983).

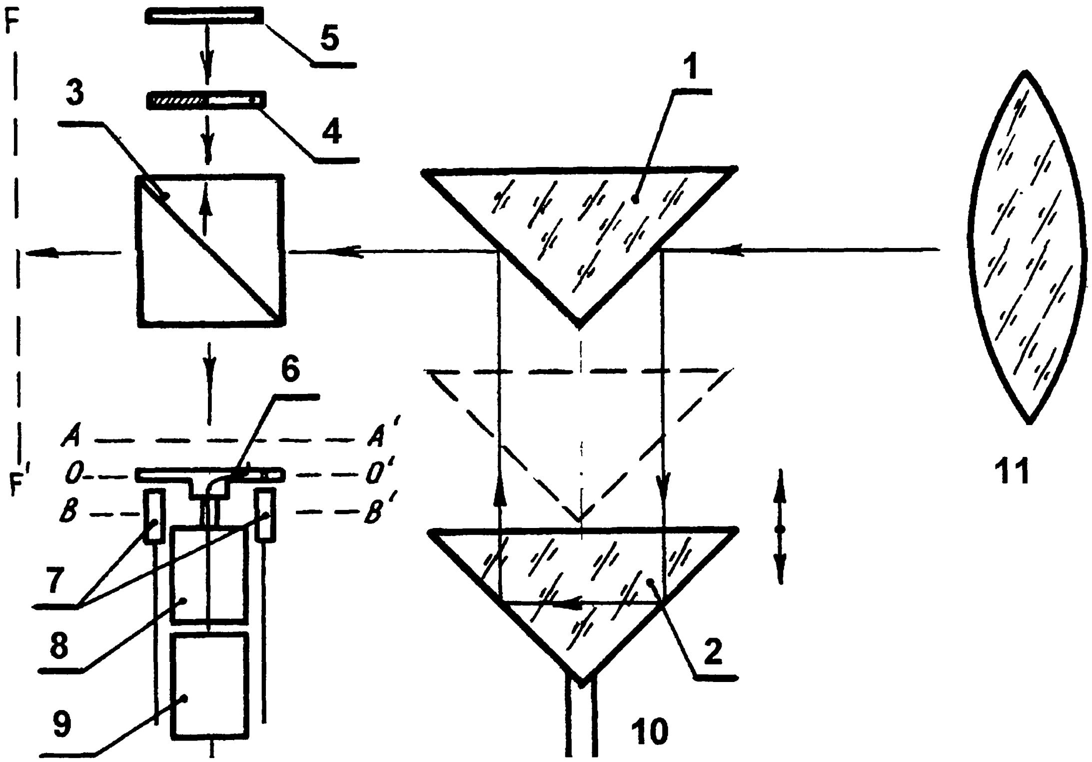

Figure 3. Optical scheme - focus stabilization system, indicating: 1 – fixed prism; 2 – movable prism; 3 – prism beamsplitter; 4 – shutter (mirror semi-circle); 5 – mirror; 6 – fiber; 7 – synchronizing elements; 8 – engine; 9 – photo-multiplier; 10 – rod to potentiometer; 11 – objective lens.

3.2. Focus stabilization

Combining the granulation contrast seeing monitor with the focus guiding system of the LVST has led to the development of an auto-focusing device. Fig 3 (Bulatov & Palachev 1988) is a sketch of the optical scheme. This defocusing compensation tool was designed to process both slow and comparatively quick variations of the focus position. The system worked only under very good seeing conditions. With poor quality images the correct position of focus was not defined. In summary, the system worked well in good seeing conditions, compensating both slow thermal and fast turbulence-induced variations in focus position.

3.3. Sunspot guiding

We have used a sunspot guider since 1987 for our observations (Druzhinin et al. 1988; Bulatov et al. 1991). A quadrant photodiode is used as a sensor. Regrettably, the inertia of the mirrors limited the image motion compensation to a frequency of 10 Hertz. We also met with performance problems for sunspots with asymmetrical form. A similar system at NSO/SP is the well-known spot tracker (von der Lühe 1988).

3.4. Site testing for large telescope project

At the same time we led the work to choose a place for the new large solar telescope. A suitable place was found in Central Asia (Bulatov et al. 1992) after investigation of seeing for several years (1987-1990) in different regions of the USSR.

3.5. Corrections inside the telescope

As a prototype for such a new generation telescope we considered the Large Vacuum Solar Telescope. In the LVST a thermal control system compensates the distortion of objective lens caused by non-uniform heating from the Sun. It is essential to control image motion, image rotation, and scattered light. The best method for correcting the image distortion is adaptive optics. As an initial stage we plan to install a correlation tracker, similar to schemes successfully working on several other solar telescopes (Von der Lühe et al. 1989, Rimmele et al. 1993, Ballesteros et al. 1996)

4. Current Status

In August 1998 a series of atmospheric turbulence measurements were conducted to evaluate the Fried parameter and isoplanatic angle on the top of the LVST. As is well known, these parameters must be taken into account in the design of an adaptive optics system or a tip-tilt mirror system like the correlation tracker. For more detailed information about seeing variations we usually monitor the image motion of the solar limb. An example of such a diagram is shown in Fig 4. This information also helps us define more optimal characteristics for future adaptive optics systems.

The following stage, planned for 1999, will be to test on the LVST a flat 3-cm active mirror driven by piezo ceramics. It will be part of a future adaptive optics system, which will have bimorph mirrors mounted on a base of piezo ceramics. The upper limit of the frequency response will be increased from 200 Hz to 2 kHz. A model of the AO system will be built with the servo supply system, allowing varying actuator configurations and contact points to the mirror. The computer model will calculate the accuracy of reproducing the Zernike polynomials, representing atmospheric aberrations. Work with such mirrors, mostly for night-time objects, has been led by the Tomsk Institute of Atmospheric Optics (Lukin 1994). We also hope for collaboration with Solar Adaptive Optics Teams from SVST, NSO/SP and IAC.

We are also going to improve observational data at the Large Vacuum Solar Telescope using filters for the BaII 4554$\mathring{A}$ (FWHM=0.08$\mathring{A}$) and H_β 4861$\mathring{A}$ (0.09$\mathring{A}$) lines, and a new two-bandpass birefringent filter for the HeI 10830$\mathring{A}$ (0.48$\mathring{A}$) and H_α 6563 (0.3$\mathring{A}$) lines (Kushtal & Skomorovsky 1998). Example of filtergrams are presented in Fig 5

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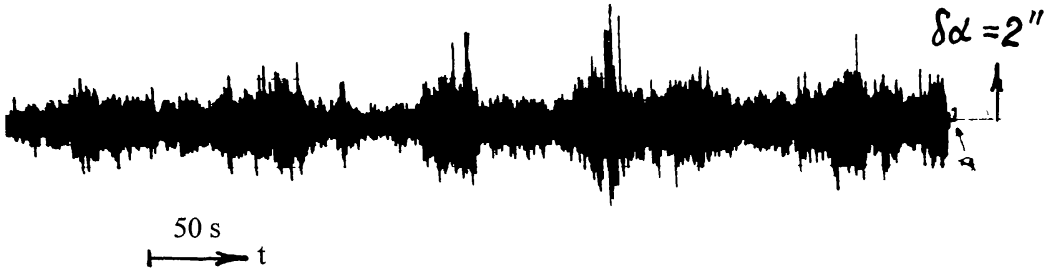

Figure 4. Solar limb image motion - temporal diagram.

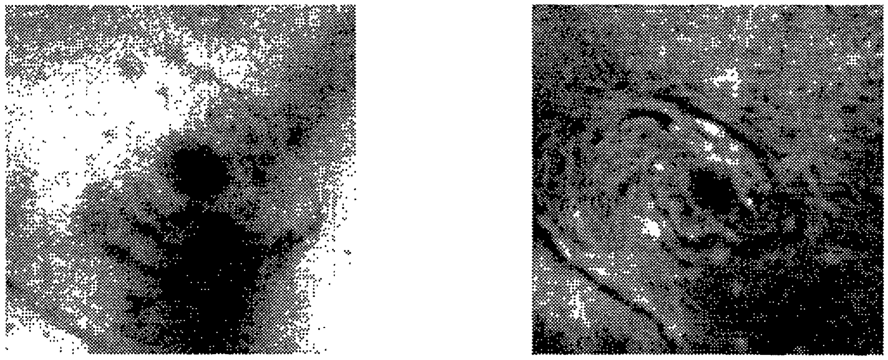

Figure 5. Filtergrams: left) obtained 8 July 1998 at 12:11 LT, centered on wavelength HeI 10830Å - 0.2Å, size = 205″; right) obtained 8 July 1998 at 12:29 LT, centered on wavelength H_α + 0.2Å, size = 266″

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