INVESTIGATION OF SEEING CONDITIONS ON TERSKOL PEAK

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ИССЛЕДОВАНИЕ КАЧЕСТВА ИЗОБРАЖЕНИЙ НА ПИКЕ ТЕРСКОЛ, Андриенко О. – Качество изображений является очень важной характеристикой наблюдательного пункта. Качество изображений определяется атмосферной турбуленцией и характеризуется параметром Фрида. В этой работе представлены результаты недавней попытки определения параметра Фрида на пике Терскол. Для этой цели был применен метод измерения дифференциального движения изображений, построенных небольшими апертурами. Для создания субапертур применялась диафрагма Гартманна. ПЗС-камера была расположена несколько вне фокуса для того, чтобы разделить изображения, построенные различными субапертурами. Каждое изображение оставалось хорошо сфокусированным, поскольку глубина фокуса для небольшой субапертуры больше, чем для главного объектива.

Seeing conditions are a very important parameter of an observational site. Seeing conditions are determined by atmospheric turbulence and are characterized by the Fried parameter r_0. In this work results of a recent attempt to determine the Fried parameter on Terskol Peak are presented. For this purpose the method of measuring of differentional motion of images obtained through small apertures was used. The Hartmann mask was taken as a subapertures producer. A CCD-camera was placed slightly out of focus in order to separate the images produced by different subapertures. Every image was still well focused, as the focus depth for a small subaperture is larger than for the main objective.

INTRODUCTION

Seeing is an important characteristic of an observation site. Along with quantity of clear nights (and/or days), the level of light pollution and atmospheric transparency it serves as a criterion for a choice of an observatory site. There are several works concerning the climate and seeing on Terskol Peak. Information on such characteristics as temperature, pressure, wind, humidity, and nebulosity one can find in [7] and [8]. Atmospheric extinction was investigated particularly in [9]. During 1988–1991 nighttime seeing on the Terskol Peak was investigated by Peretyatko [10]. He used the coherence interferometer designed by Tokovinin [11]. For three observational periods (27.08–19.09.1988, 25.08–14.09.1990, 05.03–22.03.1991) he obtained 8.4 cm as the median value of r_0. For other two periods (09.09–20.09.1989 and 06.12–26.12.1991) it equals 6.3 and 10.1 cm. These values correspond to $1.2''$, $1.6''$, and $1.0''$ $FWHM$ image quality according to $FWHM = 0.98(\lambda/r_0)$ equation (r_0 is the Fried seeing parameter). Daytime seeing was investigated by Troyan and Osipov [12] in 1981. They measured excursions of a small sunspot image built with the 6 cm objective and obtained a mean value of $2.7''$ for the image tremor.

To investigate seeing conditions several methods were developed. We decided to use the method of differentional image motion measurements. In the last decade it is regarded as the most effective and most objective one. This method was realized in the DIMM (differential image motion monitor) facility which was used for site evaluation for NNTT (NOAO) and VLT (ESO) telescopes. DIMM was developed in ESO [5]. In DIMM light beams coming through two small subapertures (separate holes in the aperture diaphragm) are separated with the aid of prisms in such a way that in the focal plane one has two images (of the same star). Their differential motion can be used to measure the seeing.

Indeed, the image quality is directly connected to the statistics of the perturbations of the incoming wavefront which is driven by atmospheric turbulence. For the Kolmogorov turbulence, the phase structure function, *i.e.*, the mean squared differential phase error between two points separated by the distance r in the aperture plane of a telescope, is given by Fried [3]:

$$D_\Phi = 6.88 \left(\frac{r}{r_0}\right)^{5/3}. \tag{1}$$

For apertures smaller than r_0 wavefronts are approximately the planes which are tilted regarding the unperturbed wavefront. A tilt of the wavefront leads to a displacement of the image. Images produced with two separated small apertures display differential motion. In case of the separation that is several times bigger than diameters of apertures the amplitude of the differential motion is bigger than the amplitude of each image motion (wavefronts in front of each aperture become uncorrelated). Differential image motion measurements do not suffer from confusion of the turbulence induced motion with the motion induced by telescope vibrations.

THEORY

Let us follow Sarazin & Roddier [5] and give a short description of the theory used for seeing investigations. The wavefront corrugation $z(x, y)$ is proportional to the wavefront phase error $\Phi(x, y)$:

$$z(x,y) = \frac{\lambda}{4\pi}\Phi(x,y). \tag{2}$$

Since light rays are normal to the wavefront surface, the component α of the angle-of-arrival fluctuation in the x direction is given by:

$$\alpha(x,y) = -\frac{\partial}{\partial x}z(x,y) = -\frac{\lambda}{2\pi}\frac{\partial}{\partial x}\Phi(x,y). \tag{3}$$

Hence, the covariance of the angle-of-arrival fluctuation:

$$B_\alpha(\xi,\eta) = \langle\alpha(\xi,\eta), \alpha(x+\xi, y+\eta)\rangle \tag{4}$$

is related to the covariance $B_\Phi(\xi,\eta)$ of the phase fluctuation by

$$B_\alpha(\xi,\eta) = -\frac{\lambda^2}{4\pi^2}\frac{\partial^2}{\partial\xi^2}B_\Phi(\xi,\eta). \tag{5}$$

Introducing the phase structure function

$$D_\Phi(\xi,\eta) = 2\left[B_\Phi(0,0) - B_\Phi(\xi,\eta)\right] \tag{6}$$

yields:

$$B_\alpha(\xi,\eta) = \frac{\lambda^2}{8\pi^2}\frac{\partial^2}{\partial\xi^2}D_\Phi(\xi,\eta). \tag{7}$$

For the Kolmogorov turbulence at the near-field approximation, the phase structure function is given by the widely used expression (1) where $r = \sqrt{\xi^2+\eta^2}$ and r_0 is the Fried seeing parameter. Putting (1) into (7) gives:

$$B_\alpha(\xi,\eta) = 0.087\lambda^2 r_0^{-5/3}\frac{\partial}{\partial\xi^2}\left[\xi^2+\eta^2\right]^{5/6} = 0.145\lambda^2 r_0^{-5/3}\left[(\xi^2+\eta^2)^{-1/6} - \frac{1}{3}\xi^2(\xi^2+\eta^2)^{-7/6}\right], \tag{8}$$

For $\eta = 0$, we get the longitudinal covariance (in the direction of the tilt) as a function of the separation $\xi = d$:

$$B_l(d) = B_\alpha(d,0) = 0.0968\left(\frac{\lambda}{r_0}\right)^{5/3}\left(\frac{\lambda}{d}\right)^{1/3}. \tag{9}$$

For $\xi = 0$, we get transverse covariance (in the direction perpendicular to the tilt) as a function of the separation $\eta = d$:

$$B_t(d) = B_\alpha(0,d) = 0.145\left(\frac{\lambda}{r_0}\right)^{5/3}\left(\frac{\lambda}{d}\right)^{1/3}. \tag{10}$$

The transverse covariance is exactly 1.5 times larger than the longitudinal covariance and both decrease as the $-1/3$ power of the separation. This was well confirmed experimentally by Borgnino & Vernin [2]. These expressions are valid only within inertial range of the Kolmogorov spectrum. The divirgence at the origin ($r = 0$) is clearly not physical. In practice, the value at the origin is limited by aperture averaging and is given by the expression for the variance of image motion derived by Fried [3, 4], and Tatarski [6]:

$$B_\alpha(0,0) = 0.179 \left(\frac{\lambda}{r_0}\right)^{5/3} \left(\frac{\lambda}{D}\right)^{1/3}, \tag{11}$$

where D is the diameter of the apertures. Because of the slow decrease of the covariance as the $-1/3$ power of the separation d in (9) and (10), aperture averaging does not noticeably modify the covariance function as soon as the separation exceeds at least twice the aperture diameter.

The variance $\sigma^2(d)$ of the differential image motion observed over the distance d is given by:

$$\sigma^2(d) = [B(0) - B(d)]. \tag{12}$$

Putting (9) and (11) into (12) gives the approximate expression for the variance $\sigma_l^2(d)$ of the differential longitudinal motion (for $d \geq 2D$):

$$\sigma_l^2(d) = 2\lambda^2 r_0^{-5/3} \left[0.179 D^{-1/3} - 0.0968 d^{-1/3}\right], \tag{13}$$

whereas putting (10) and (11) into (12) gives the approximate expression for the variance $\sigma_t^2(d)$ of the differential transverse motion (for $d \geq 2D$):

$$\sigma_t^2(d) = 2\lambda^2 r_0^{-5/3} \left[0.179 D^{-1/3} - 0.145 d^{-1/3}\right]. \tag{14}$$

Sarazin & Roddier [5] compared these approximate analytical equations with results of more extensive numerical calculations made by Fried [4]. The agreement is within 4 % in the d/D range of $1 \div 9$ for the longitudinal motion and in the d/D range of $3.5 \div 9$ for the transverse motion.

OBSERVATIONS

To investigate seeing conditions on Terskol Peak (3100 m above the sea level, the Northern Caucasus, Russian Federation) we used a modified DIMM method proposed by Bally *et al.* [1]. They proposed to use images obtained with the Hartmann diaphragm to measure the differential image motion. They called this method H-DIMM. Such a method can be realized virtually at any telescope with a long focus and a sufficiently large objective.

We managed to use H-DIMM method with the guide of Zeiss-2000 telescope placed on Terskol Peak. The guide has 25 cm lens objective with 3 m long focus. The Hartmann diaphragm was made with 37 holes placed at nodes of hexagonal net. The diameter of the holes is 20 mm and the distance between nodes is 37 mm. The diaphragm can be easy attached at the top of the guide tube.

ST-6 CCD-camera was used as a detector. This camera has 375 × 242 pixels with 23 × 27 μm pixel size. To increase slightly downloading time of the frame we used binning in one direction, thus the camera worked in 250 × 242 pixel format (with 34.5 × 27 μm pixel size). ST-6 camera is connected with the computer through COM port and thus downloading time of the frame is pretty long (about 1 min).

The observations were carried out on April 29, 2002 and had a duration of 140 min. We had to select a bright star near zenith. It was Dubhe. The exposure time was 0.1 sec to meet condition of atmosphere "freezing" still providing good S/N ratio in a frame. The detector was placed slightly behind the focus. Thus there were 37 images of the star each built by a different subaperture. Defocusing was small enough to keep each image of the star still well focused. Scale of frames was found with observations of the double star ζUMa (Micar). It is equal to 0.066 μm/arcsec, *i.e.*, 2.3 × 1.8 arcsec/pixel.

Each frame was reduced for the dark current. Then centers of the images of the star were found. After that distances between different pairs of the images as well as their transverse displacements were measured. On each frame variances of longitudinal and transverse displacements were calculated and the Fried parameter r_0 was determined with the help of (14) and (15) equations.

RESULTS AND DISCUSSION

Figure 1 shows variations of the Fried parameter with time. It is easy to see that the parameter r_0 undergoes sufficient variations on a timescale about 1 min. This is typical time of changing the atmospheric turbulence parameters. Unfortunately, it was impossible to obtain frames more frequently because of a slow downloading. The mean value of the Fried parameter during the observations is 7.8 cm. This value of r_0 corresponds to $1.3''$ $FWHM$ (at 500 nm) of a star image obtained with a long exposure according to equation $FWHM = 0.98(\lambda/r_0)$. But in this case the real image quality (for exposures longer then several minutes) could be worse because of strong variations of r_0 at short timescales.

The night on April 29–30, 2002 was the second clear night after several days of bad weather. So, it was far not a good night. There are much better nights with better seeing on Terskol Peak. This was just a first attempt to measure the seeing with DIMM method.

It is planned to continue monitoring of seeing conditions at our observatory and find out typical seeing for different seasons as well as the best possible seeing on Terskol Peak. Measuring of daytime seeing is planned as well. This is a more complicated task because the Sun is not a dot object. Nevertheless, it is possible to use some contrast details on the solar disk (such as spots) for differential image motion measurements. We plan to carry out such observations at the ATsU-26 horizontal solar telescope which is also placed on Terskol Peak.

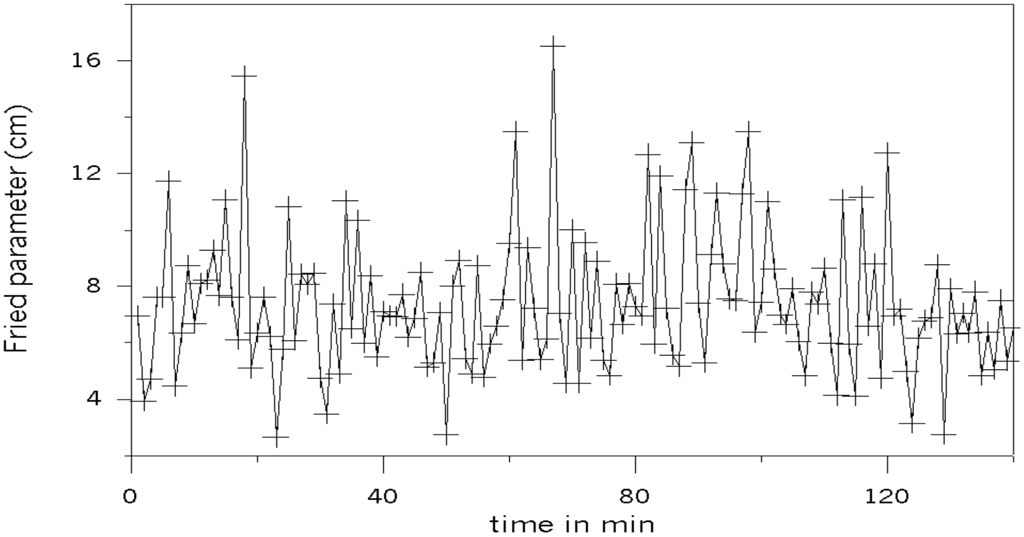

Figure 1. Changing the Fried parameter with time according to the observations on April 29, 2002

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[1] *Bally J., Theil D., Billawala Y., et al.* // Publ. Astron. Soc. Aust.–1996.–**13**.–P. 22.

[2] *Borgnino J., Vernin J.* // J. Opt. Soc. Amer.–1978–**55**.–P. 1056.

[3] *Fried D. I.* // J. Opt. Soc. Amer.–1965.–**55**.–P. 1427.

[4] *Fried D. I.* // Radio Science.–1975.–**10**.–P. 71.

[5] *Sarazin M., Roddier F.* // Astron. and Astrophys.–1990.–**27**.–P. 294.

[6] *Татарский В. И.* Распространение волн в турбулентной атмосфере.–М.: Наука, 1967.

[7] *Кондратюк Р. Р.* // Астрометрия и астрофизика.–1974.–**23**.–С. 98.

[8] *Депенчук Е. А., Кондратюк Р. Р., Койфман А. П.* // Астрометрия и астрофизика.–1975.–**24**.–С. 99.

[9] *Пугач А. Ф., Кондратюк Р. Р., Розенбуш А. Э.* // Астрометрия и астрофизика.–1975.–**25**.–С. 111.

[10] *Перетятко Н. Н.* // Кинематика и физика небес. тел.–2000. –**16**. –С. 470.

[11] *Токовинин А. А.* // Астрон. циркуляр.–1985.–**1356**.–С. 4.

[12] *Троян В. И., Осипов С. Н.* // Астрометрия и астрофизика.–1983.–**49**.–С. 67.