OBSERVATIONS OF STELLAR IMAGE MOTIONS WITH THE SYNCHRONOUS NETWORK OF TELESCOPES

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НАБЛЮДЕНИЯ ДВИЖЕНИЯ ИЗОБРАЖЕНИЙ ЗВЕЗД С СИНХРОННОЙ СЕТЬЮ ТЕЛЕСКОПОВ, Жиляев Б., Романюк Я., Святогоров О., Верлюк И., Тарадий В., Сергеев А., Карпов В., Ловкая М. – Обнаружение движения изображений звезд стало возможным благодаря использованию Синхронной сети удаленных телескопов, которая открывает новый путь для детектирования маломасштабной переменности звезд. Точность звездной фотометрии на уровне 0.001 зв. вел. и миллисекундная точность координатных измерений в оптике кажутся отдаленными перспективами для большинства наземных наблюдателей. Движения изображений звезд во время экспозиции может служить источником дополнительных фотометрических ошибок и ограничивать точность позиционных измерений. Главная цель этой работы состояла в том, чтобы обнаружить эффект движения изображений звезд в фокальной плоскости нескольких удаленных телескопов, работающих синхронно. Отметим, что такой эффект, составляющий несколько десятых долей угловой секунды, находится на пределе обнаружения при ординарных измерениях с одиночным телескопом.

Stellar Image Motions (SIM) discovery became possible due to the use of the Synchronous Network of distant Telescopes (SNT), which presents an exciting new way for detecting the small-scale variability. The millimagnitude precision of ground-based stellar photometry and the milliarcsecond accuracy in coordinates of position measurements in the optics seem to be distant summits for most practitioners. SIM during the integration time can cause photometric errors and frustrate the exact position measurements. The main goal of this work was to detect the effect of image motions in the focal plane of several distant telescopes operating synchronously. Note that such an effect amounting to a few tenth arcsecond may be only marginally detected in the trivial round measurements.

INTRODUCTION

Our primary goal was to attain the highest possible precision of ground-based stellar photometry. Giant planets and their satellites were selected as photometric targets with an *a priori* constant irradiance for short length of time. Surprisingly, they revealed short-period brightness oscillations. This raises a question: where do oscillations occur? Following this way we found that the variability observed is due to image motions in the focal plane of telescopes. Our findings based on the many-site synchronous monitoring allow us to conclude that stellar image motions are of a global nature.

Here we report first results of detection of stellar image motions. The impact of SIM on the precision of ground-based stellar photometry and position of coordinate measurements is one of the most important aspects of the phenomenon. In this context the SNT project supplies the capabilities to highlight this new exciting observational effect in astrophysics.

OBSERVATIONS OF BRIGHTNESS OSCILLATIONS OF GIANTS PLANETS AND THEIR SATELLITES WITH THE SNT

SNT has given us decisive evidence of correlated brightness variations of Jupiter and its satellite Europa. In common opinion the Sun is a constant star. Data provided by ground and space experiments demonstrate only non-radial oscillations with amplitudes of no more than a few parts per million at frequencies below 5 mHz. A surprising result was that Jupiter and its satellites glowing in sunlight showed the presence of apparent small-amplitude periodic variations in the optical. This raises, however, the question of whether these oscillations are generated in the Earth's atmosphere or originated from a faulty operation of the equipment. These doubts may be settled only by the simultaneous use of several distant telescopes.

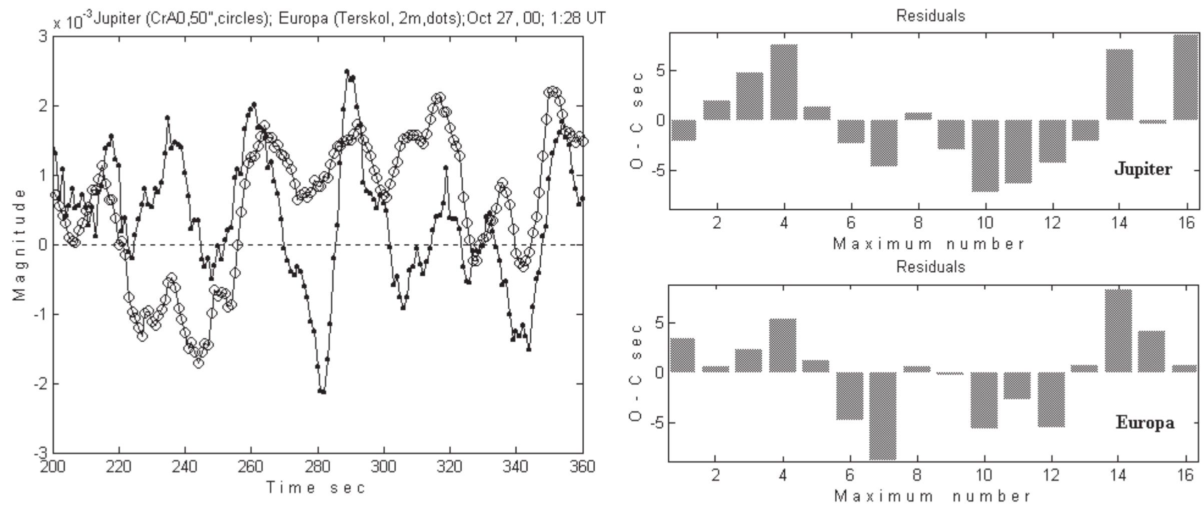

Figure 1. Left panel: Portions of the Jupiter (circles) and Europa (dots) light curves as seen simultaneously by the Crimean 50-inch and the Terskol 2-m telescopes, respectively, on October 27, 2000, 1:28:43 UT. Right panel: Changes in the oscillation period value obtained from the observed times of maxima both on Jupiter and on Europa over about seven minutes

The many-site monitoring of Jupiter and its satellites had been carried out on October 27, 2000. The instruments used were the 2-m Ritchey-Chretien telescope at Terskol Peak in the Northern Caucasus and the 50-inch reflector at the Crimean Observatory. Both these instruments are equipped with the high-speed two channel photon-counting stellar photometers. Observations were obtained in the U band with 0.01 s sampling time. The simultaneous operation of the telescopes was synchronized to an accuracy of 0.1 s. Fig. 1 shows the Jupiter (circles) and Europa (dots) light curves as seen simultaneously by the Crimean 50-inch and the Terskol 2-m telescopes, respectively. The many-site high-speed monitoring revealed the oscillations with a frequency around 0.04 Hz and amplitudes of some thousandth. A well-defined oscillation with a mean period of 22.7 s is obvious from this picture. This harmonic is found coincided in amplitude, frequency and phase. It is great surprise that the two-site data agree in the finest details. They show good fit of modulation properties shown in Fig. 1 (the right panel). A mean period of 22.7 s was obtained from an analysis of the observed times of maxima. This period appears to be constant in the average only. The O–C data show significant correlated changes in the period value both on Jupiter and on Europa over about seven minutes. The result lends additional support to the reality of the high-frequency brightness oscillations observed.

A similar situation holds on Saturn and its satellite Rhea. Fig. 2 shows the light curves of Saturn and Rhea as seen at the same time by the Terskol 2-m (diamonds) and Crimean 50-inch (dots) telescopes, respectively. Their amplitudes and shifting properties are coincided within experimental errors. No explanations for this exist yet. Note that the oscillation amplitudes are quite small and are about of 0.01 mag. Such low amplitude variations lie usually below the detection limit for ordinary photometric data. Their discovery became possible by use of the Synchronous Network of distant Telescopes.

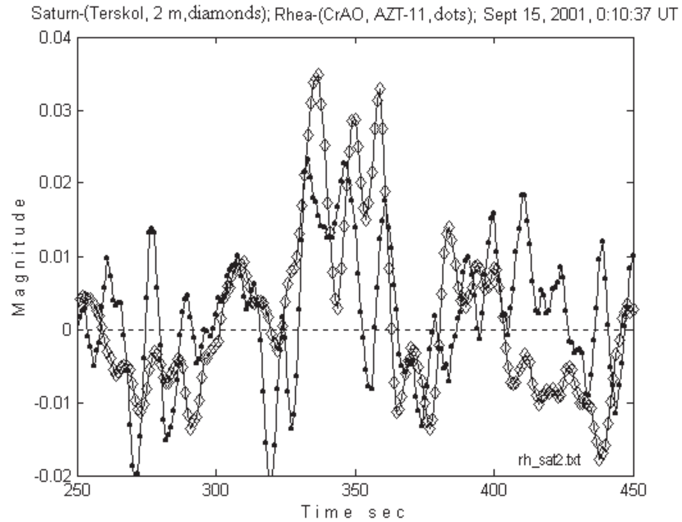

Figure 2. Portions of the light curves of Saturn and Rhea as seen at the same time by the Terskol 2-m (diamonds) and Crimean 50-inch (dots) telescopes, respectively, on September 15, 2001, 0:10:27 UT

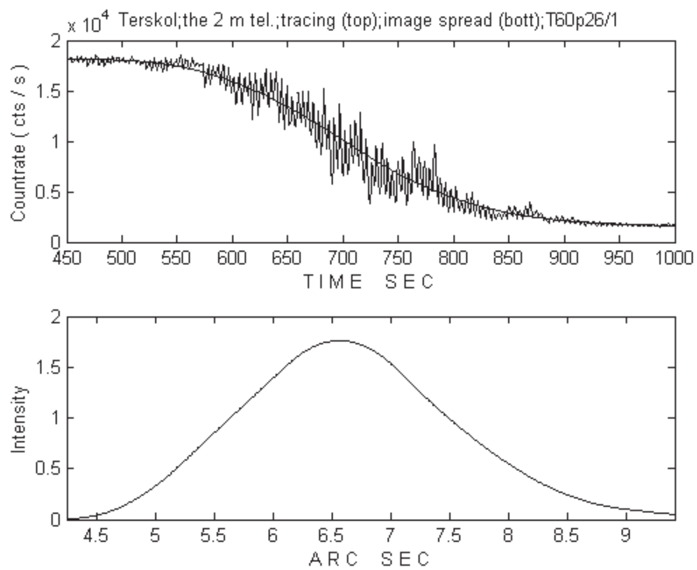

Figure 3. An image tracing by diaphragm-edge (upper plot) and star's image spread (lower plot, arbitrary units). Observations of the field star PPM119406 were made with the Terskol 2-m telescope on October 28, 2000

IMAGE MOTION AS A CAUSE OF BRIGHTNESS VARIATIONS

It is appropriate to quote here from experienced observers: *"As spectroscopic observers know, low-frequency image motions mean that good centering cannot be done quickly. If we look at a star just a second, and center on its average position during that time, a minute later it may be several arc-seconds away from the set position."* [2]. Image motions may cause a measurable variability due to extended image wings or varying background around bright objects.

Image motions reveal itself in the tracing a bright star across the diaphragm. Fig. 3 shows an image tracing by diaphragm-edge (upper plot) and star's image spread (lower plot, arbitrary units).

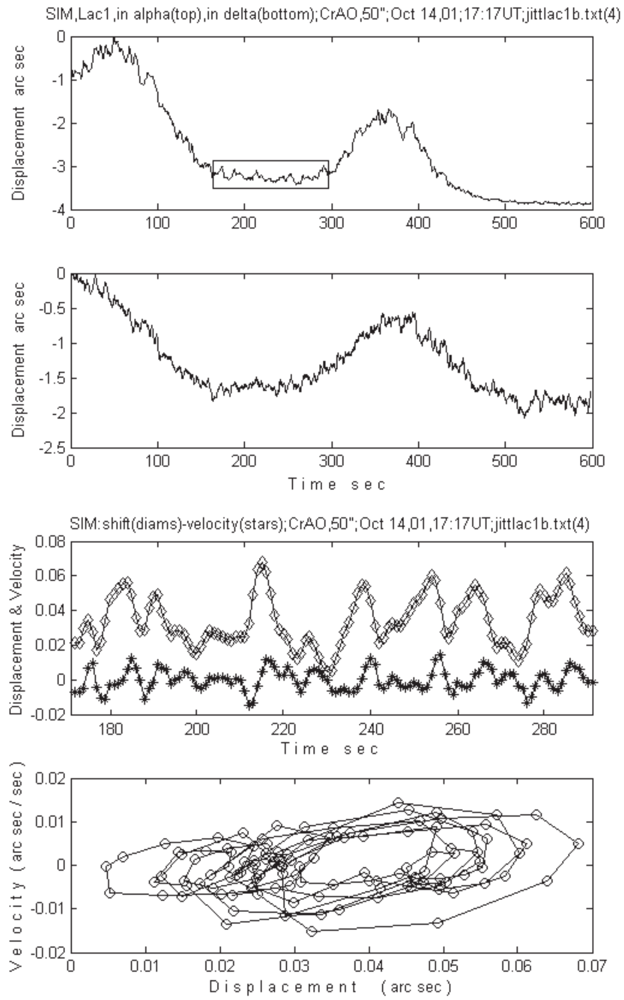

Figure 4. Two upper plots show stellar image motions by diaphragm edge area at the 50-inch Crimean reflector in the both alpha- and delta-direction over ten minutes. This gives reliable evidence of that SIM are 2-D in character. Two lower plots exhibit two-dimensional evolution of SIM through the phase space diagram

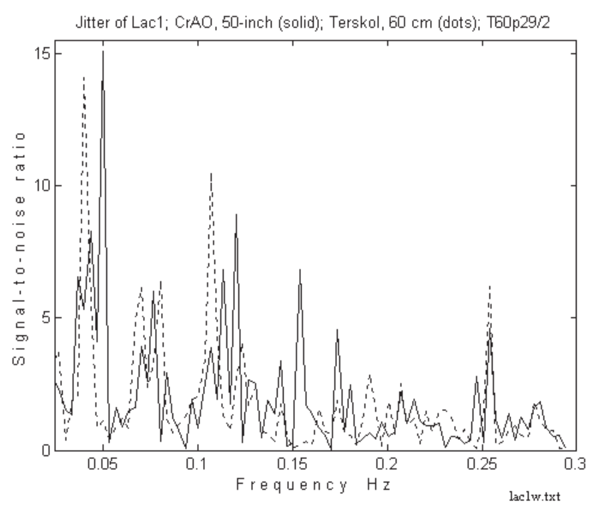

Figure 5. The power spectra of image motions of the field star PPM119406 obtained with the Terskol 60-cm telescope and the Crimean 50-inch telescope on October 1 and October 13, 2001, respectively

The upper plot presents the tracing light curve smoothed by spline with the 100-point boxcar to average the short scale oscillations. The star image spread was determined by numerical differentiation of the tracing light curve. As can be seen the star has a FWHM about of 2 arcseconds. The intensity drops to about 1 % at a circle of 4-arcsec diameter. From this image motion may be evaluated in amplitude as large as of the order 0.2 arcsecond.

Fig. 4 proves that stellar image motions could not be connected to errors in drive rate of telescopes. A two channel high-speed photometer was used to measure a transmission tracing by diaphragm-edge in the both right ascension and declination directions. Cassegrain reflectors with equatorial mounting (the Zeiss-600 at Terskol Peak and the 50-inch telescope in Crimea) and the 2-m Zeiss RCC telescope at Terskol Peak were used. One may suppose that errors in drive rate cause telescope displacements in the R.A. direction only. The upper plots show stellar image motions by a diaphragm edge area at the 50-inch Crimean reflector in the both alpha- and delta-direction over ten minutes. These data enable us to conclude that SIM are 2-D in character. Two bottom plots result from analysis of SIM using the phase space diagram approach [1]. The numerical computation of the Poincare map was performed by differentiation of the tracing light curves. The Poincare surface of section $(R, dR/dt)$, derived from the light curve portion shown in upper panel, demonstrates a trajectory which is typical for the quasi-harmonic process. Complex dynamics of SIM makes impossible now to test whether motions is deterministic or stochastic phenomenon. What really is: Order or Chaos, closed or only bounded path? These questions have to be examined in the future. As this is seen from the plots, the oscillation amplitudes of SIM are typically from some hundredth to some tenth arcsecond. The speed of SIM is of a few hundredth arcsecond per second.

Far distant telescopes show similar patterns in stellar image motions. Fig. 5 presents the power spectra of image motions of the field star PPM119406 obtained with the Terskol 60-cm and the Crimean 50-inch telescopes on October 1 and October 13, 2001, respectively. Both telescopes reveal similar features at about 0.04, 0.08, 0.12 and 0.25 Hz.

CONCLUSION

We have every reason to formulate The Stellar Image Motion Theorem:

Every star traces a bounded path round of its average position. The image motions are multiperiodic in character, their periods are in the range of a few seconds to a few minutes. Their amplitudes are of a few tenth arcsecond.

Physical interpretation of the SIM phenomenon encounters considerable difficulties. One may interpret it as an atmospheric effect connected to the oscillations in the stratified Earth's atmosphere. This poses, however, a challenging problem, in view of the maintenance of high phase coherence and zero time delay between complex photometric variations observed simultaneously at telescopes separated by a distance of thousands kilometers from each other.

[1] *Moon F. C.* Chaotic Vibrations. An Introduction for Applied Scientists and Engineers.–New York, Chichester: John Wiley & Sons, Inc., 1987.

[2] *Young A. T., Genet R. M., Boyd L. J. et al.* Precise Automatic Differential Stellar Photometry // Publs Astron. Soc. Pacif..–1991.–**103**.–P. 221–242.