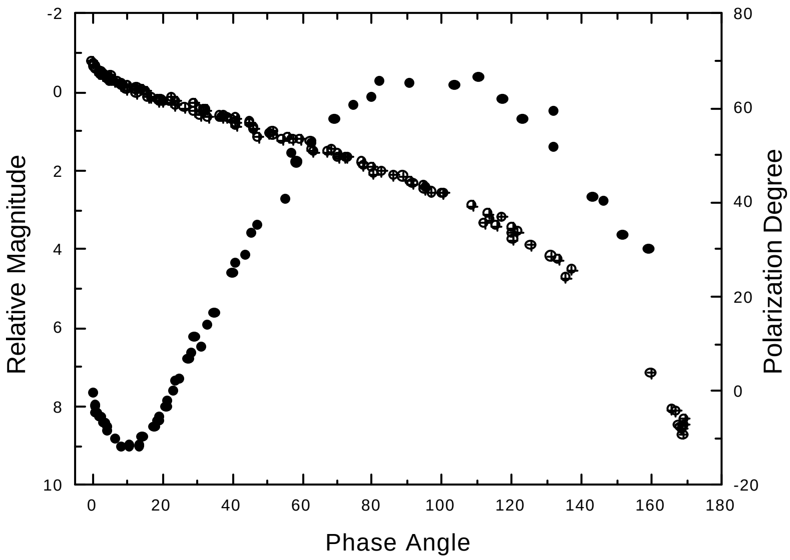
PHOTOMETRY AND POLARIMETRY OF ASTEROIDS: IMPACT ON COLLABORATION

Abstracts


The International Workshop



June 15–18, 2003, Kharkiv, Ukraine

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PHOTOMETRY AND POLARIMETRY OF ASTEROIDS: IMPACT ON COLLABORATION

The International Workshop
June 15–18, 2003
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A B S T R A C T S

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Contents

OPPOSITION POLARIMETRY AND PHOTOMETR Y OF ASTEROIDS

I.N. Belskaya[1], V.G. Shevchenko[1], Yu.S. Efimov[2], N.M. Shakhovskoj[2], N.M. Gaftonyuk[2], Yu.N. Krugly[1], V.G. Chiorny[1]

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Interest to observations of the atmosphereless Solar System bodies at small phase angles has greatly increased last decade due to a progress in theoretical studies of the opposition phenomena. To interpret this effect two main mechanisms are involved: traditional shadow hiding and recently recognized coherent backscattering. The mechanism of coherent backscattering predicts the simultaneous existence of both the negative linear polarization and brightness opposition effect (e.g. Shkuratov 1985). According to Mishchenko (1993) the backscattering intensity peak is accompanied by a sharp asymmetric peak of negative polarization at very small phase angles. Only simultaneous study of both photometric and polarimetric opposition phenomena may lead to a further progress in understanding and interpretation of opposition phenomena.

In 1997 we initiated a long-term observational program to investigate opposition phenomena simultaneously by means photometry and polarimetry (Belskaya et al., 2002; 2003). The purpose was to obtain in the same apparition both brightness and polarization phase curves for asteroids of different composition. The observations were carried out using 0.7 m telescope of Chuguev Observational Station near Kharkiv, and the 1 m and 1.25 m telescopes of the Crimean Astrophysical Observatory. The main idea was to study phase curve behavior down to extremely small phase angles (less that 0.3 deg) where mechanism of coherent backscattering should play a dominant role. We focused our efforts on observations of S and E-type asteroids which are characterized by the largest opposition effect among asteroids, and on observations of low albedo asteroids for which the absence of the opposition effect has been reported. Obtained observational results can be summarized as the following:

- a noticeable very narrow opposition surge was found in the magnitude phase curve of F-type asteroid 419 Aurelia with a geometric albedo of only 0.05. This surge was not detected by the previous observations down to phase angles of 0.6 deg (Harris, Young, 1989) because of its unusual narrowness (less than 0.6 deg). It is a first evidence of an existence of narrow opposition effect for dark asteroids.

- larger amplitude of the opposition effect of moderate albedo asteroids as compared to high albedo objects has been confirmed. The previous conclusion was made by analyzing the observational data down to 0.3 deg (Belskaya and Shevchenko 2000). However, a possibility remained that the observed difference could disappear at zero phase angle due to steeper phase curve slope of E-asteroids. Our observations of asteroid 20 Massalia down to phase angle of 0.08 deg have proved that phase curves of the S-type asteroids are also characterized by a steep slope. The opposition effect amplitude measured at á=0.1 deg is more than 0.1 mag larger for the S-asteroids as compared to the E-type. It is hardly explained by the mechanism of coherent backscattering which should be more effective for high albedo surfaces.

- a sharp peak of negative polarization at small phase angles was not found. The value of polarization at phase angle α<1deg is less than 0.5% in the BVRI bands for all observed objects, namely 20 Massalia (S-type), 214 Aschera (E-type), and 419 Aurelia (F-type).

- negative polarization branches of the S and E-asteroids have an asymmetrical shape. The phase angle at which the polarization minimum occurs is close to the angle of opposition effect beginning.

- a decrease both the depth and width of negative polarization branch has been found for the F-type asteroid 419 Aurelia as compared to other dark asteroids. The depth of polarization minimum is equal to 1.0±0.1% in the V band and the inversion angle is less than 18 deg. The corresponding mean values for the C-type asteroids are the following: 1.7% and 20.3 deg. Our observations of 419 Aurelia is the first evidence of so-called "saturation" of the amplitude of negative polarization previously observed for very dark laboratory samples (Zellner et al., 1977; Shkuratov et al., 2000).

The significance of the obtained results and their correspondence to available theoretical models are discussed.

This research was partly supported by the Ukrainian foundation of fundamental research (grant N 02.07/379).

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SPECTROPHOTOMETRIC OBSERVATIONS OF ASTEROIDS IN THE CRIMEAN ASTROPHYSICAL OBSERVATORY.

Bochkov V.V., Prokof'eva V.V. (Crimean Astrophysical Observatory, Ukraine)

Facilities of digital television complex of 0.5-meter meniscus telescope have been successfully used to perform spectrophotometric observations of asteroids from 7^m up to 12^m in the Crimean astrophysical observatory. Accuracy of spectra energetic calibration has been update up to 1-2%. Accuracy of relative measurements of intensities in individual spectra is equal 1% for brightness of asteroids from 7^m up to 10^m. More than 2500 asteroid spectra have been obtained during last three years. Database of special structure has been created to store and treat spectral information. Prototype of database application has been developed to calculate absolute spectral distributions of asteroids and their magnitudes B, V and color-indexes B-V. As an example, B, V, B-V magnitudes calculated from spectral observations of the asteroid 4 Vesta is presented.

ESTIMATES OF ROTATION PERIODS OF ASTEROIDS DERIVED FROM CCD-OBSERVATIONS IN ANDRUSHIVKA ASTRONOMICAL OBSERVATORY

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In March – April 2003, CCD-observations of 4 Critical List Objects 2003 AJ73, 2003 EO16, 2003 FH1, 2002 RH52 and one NEO 35107 were carried out in the prime focus of the Zeiss-600 astrograph of Andrushivka Astronomical Observatory (ÀÀÎ, Long. = 28.9973, ρ cos φ = 0.64407, ρ sin φ = +0.76245). Besides the astrometric positions, we obtained the rotation phase curves and derived the estimates for the rotation periods of the objects.

METHOD OF ACCURACY ESTIMATION OF ASTEROID' POSITIONAL CCD OBSERVATIONS AND RESULTS ITS APPLICATION WITH EPOS SOFTWARE.

O.P. Bykov, V.N. L'vov (Pulkovo astronomical observatory, Russia, oleg@OB3876.spb.edu)

During last five years an accuracy of the CCD observations obtained by amateurs and professional astronomers all over the World was investigated with Pulkovo EPOS Software. We used the MPC database and considered various NUMBERED MINOR

PLANETS observed during several months per year (more 50-150 positions) for each observatory having the MPC code.

The main idea of our method of an estimation of an accuracy of the NMP observations is to use these (O-C) irregularities when we calculate the mean value of (O-C) and its mean error for the considered NMP. The values of (O-C) may be very different for various NMPs, but the mean error of these (O-C)s shows a reliability of "atmosphere + telescope + CCD matrix + catalogue" system in the middle observational conditions and is an indicator of accuracy of the CCD positional observations for considered observatory. The theory of NMP' motion is very good known and all perturbations are accurate calculated with EPOS.

Pulkovo EPOS software package for observations of the Solar System bodies was created by Drs. V.N. L'vov, R.I. Smekhacheva and S.D. Tsekmejster. It is multi-purpose application which helps to prepare and test positional observations of major planets and natural satellites, asteroids and comets. It contains the efficient tools for data storage, accurate calculation of various ephemerides, planning and testing the observations and visualization of objects' motion. We would like to describe that only EPOS can accurately calculate not only coordinates of the Solar System bodies but also their the first and the second derivatives and so called Pulkovo Apparent Motion Parameters (AMPs), namely an angular velocity and acceleration, position angle and a curvature of topocentric or geocentric object's trajectory. Several star catalogs distributed on CD-ROM's are available: Hipparcos, Tycho, ACT, USNO. It means the improved capacity of ephemeris calculation and visualization of objects motion on the stars background. It is possible to use two time scales (UT1, DT) and two coordinate systems (equator and equinox of J2000.0 and B1950.0). We use the EPOS software package for express analysis of observations, (namely their accuracy estimation and rejecting the erroneous data), for identification of the observed objects with the catalog ones and searching the new objects and for precalculation of any approachings and occultations of celestial bodies.

With the help of the EPOS an accuracy of the modern CCD positional asteroidal observations were investigated for more than 300 amateur and professional observatories in the years 1999-2002, the new method for a real time identification of any moving celestial object by means of the Pulkovo Apparent Motion Parameters was elaborated, direct methods of the fast preliminary orbit determination were developed and successfully applied to the calculations of asteroids and comets orbits. We also are testing CCD amateur asteroidal observations in "hot-line" regime.

The authors hope that the EPOS software package may be useful for near Earth space control and for a search of the moving celestial objects on the old and new CCD frames obtained by any telescope at amateur or professional astronomical observatories.

Modern CCD observations in Astronomy carried out in the benefit of Astrophysics or Astrometry among numerous objects fix the images of Small Solar System bodies. These images are the "by product" of all CCD observations but they are not properly used by observers themselves, especially by astrophysicists, due to underestimation of such information and absence of convenient software for analysis of moving celestial objects in a real time. We are sure that each CCD frame must be analyzed, with the EPOS Software particularly, for searching the moving objects in interactive mode.

POLARIMETRIC OBSERVATIONS OF ASTEROIDS WITH THE TORINO UBVRI PHOTOPOLARIMETER

A. Cellino, R. Gil Hutton, M. Di Martino, E.F. Tedesco, Ph. Bendjoya

Since 1995 the Torino photopolarimeter is attached at the 2.15 m telescope of the El Leoncito Observatory (San Juan, Argentina). This instrument is capable of obtaining simultaneous UBVRI measurements of the degree of linear or circular polarization of objects brighter than V=15, approximately. A long-term project of observations of minor planets is currently under way. We present a set of unpublished results obtained during the last observing runs. The main purposes of the observations are to obtain albedo estimates to be compared with previous IRAS radiometric determinations, and the measurement of the degree of linear polarization at very small phase angles (less than 1 degree). The latter observations are a very useful input for modern theoretical models of light scattering from asteroidal surfaces.

PHOTOMETRY OF ASTEROIDS: NEW LIGHTCURVES OF 16 ASTEROIDS OBTAINED IN 1993-2001.

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Ground-based observations are the main source of our knowledge of the physical properties of the asteroidal population. For example the photometric lightcurves may be used to determine rotation periods, pole coordinates, and shapes of asteroids. We are presenting photometric data and lightcurves of 16 asteroids of the main belt, which were obtained in 1992 - 2001 during 47 nights at 0.7 m telescope of Institute Astronomy of Kharkiv National University and 1-m telescope Crimean Astrophysics Observatory in Simeiz.

Photometric observations of asteroids were carried out using a photoelectric photometer and ST-6 CCD-cameras. The photoelectric data reduction methods were described by Shevchenko *et al*. (1992). The method of CCD observations is explained in Krugly *et al*. (2002). CCD-images were reduced with the synthetic aperture photometry package (ASTPHOT) developed at DLR by S. Mottola (Mottola *et al.*, 1995). The observations were obtained in the V and R bands of the standard Johnson-Cousins spectral system. The absolute calibrations of the data were performed with standard sequences from Landolt (1992) and Lasker *et al*. (1988). The accuracy of absolute photometry is equal to 0.02-0.03 mag.

The results of observations are summarized in the Table, which includes year of observations, IRAS-albedo and diameter, taxonomic type, rotation periods, and results of determination rotation periods of asteroids**.**

Asteroid	Opposition	Albedo	D (km)	Type	Period (hrs)	Ampl. (mag)
24 Themis	1995	0.101	234	C	8.374	0.13
51 Nemausa	1994	0.093	147	CU	7.784	0.16
89 Julia	1993	0.176	151	S	11.387	0.20
173 Ino	1999	0.064	154	C	6.163	0.05
225 Henrietta	1995	0.040	120	F, C0	7.360	0.22
387 Aquitania	1998	0.190	100.	S	24.14	
423 Diotima	1993	0.048	208	C	4.7754	0.20
505 Cava	1993	0.054	108	FC	8.1789	0.21
543 Charlotte	1995	0.260	34		10.718	0.23
670 Ottogebe	1995	0.183	34		8.37	0.34
679 Pax	2000	0.165	51	I	8.452	0.11
694 Ekard	1998	0.046	90	CP	5.922	0.39
713 Luscinia	1996	0.041	109	C	8.505	0.12
800 Kressmania	1997	0.160	15.8	S	4.464	0.12
1369 Ostanina	1995	0.102	41.6		8.397	0.84
4908 Ward .	2001				10.96	0.93

As a result of analysis observation data the new rotation periods of five asteroids were determined for the first time: 543 Charlotte, 670 Ottogebe, 713 Luscinia, 1369 Ostanina, and 4908 Ward.

The lightcurves of asteroids 24 Themis, 51 Nemausa, 423 Diotima, and 694 Ekard confirmed unambiguity of known periods of these asteroids. The incomplete lightcurves of the asteroids 89 Julia, 173 Ino, and 800 Kressmania presented with the earlier determined periods.

Krugly Yu. N., et al. 2002. *Icarus* **158**, p. 294-304.
Landolt, A. U. 1992. *Astron. J.* **104**, 340-371.
Lasker B. M., et al. 1988. *Astrophys. J. Suppl. Ser.* **68**, 1-90.
Mottola, S., et al. 1995. *Icarus* **117**, 62-70.
Shevchenko V. G., et al. 1992. *Icarus* **100**, 295-306.

PHYSICAL CHARACHTERIZATION OF NEAR EARTH ASTEROIDS FROM THERMAL INFRARED SPECTROPHOTOMETRY

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Even though more than 2200 near-Earth asteroids (NEAs) have been discovered to date, our knowledge of their sizes and albedos is limited to very few objects, resulting in a large uncertainty on the distribution of these parameters for the whole population. Observations in the thermal infrared, combined with optical photometry, enable albedos and sizes of asteroids and other atmosphere-less objects to be derived and can give some insight into the thermal properties of the target.

We present a summary of results to date from an on-going extensive program of thermal-IR and simultaneous visible observations of NEAs using the ESO 3.6-m, the ESO-Danish 1.5m and the ESO/MPI 2.2m telescopes at La Silla, Chile.

Accurate modeling of the observed thermal emission from an irregularly shaped asteroid at a high phase angle (e.g., 90°) is a complex task that requires knowledge of parameters such as thermal inertia, surface roughness, and rotation vector, beside shape. The use of simple thermal models to derive reliable diameters and albedos of NEAs is discussed.

SEASONAL VARIATIONS OF JUPITER POLAR HAZE POLARIZATION

O. S. Goryunova, L. A. Akimov, V. V. Korokhin, O. M. Starodubtseva, E. V. Shalygin, and Yu. I. Velikodsky

Polarimetric observations of Jupiter were carried out using different technique and different telescopes during the period from 1981 to 2003. Seasonal changes in the north-south (N-S) asymmetry of polarization at high latitudes of Jupiter have been revealed by these observations at blue wavelengths. The average seasonal difference in the polarization degree between north and south (on the latitudes ±60°) is positive and equal to about 0.5%. There is some relationship between seasonal variations in the observed difference and the seasonal north-south asymmetry in solar radiation incident on Jupiter's atmosphere (see Fig.). There are two maxima on observed seasonal curve falling on the jovian spring and autumn and coinciding correspondingly with positive and negative maxima of heliocentric latitude of Jupiter (Starodubtseva et al., 2002). The new data of observations in 2000-2003 with an imaging CCD–polarimeter confirm the hypothesis of influence of insolation on the seasonal fluctuations of north-south asymmetry of jovian polarization.

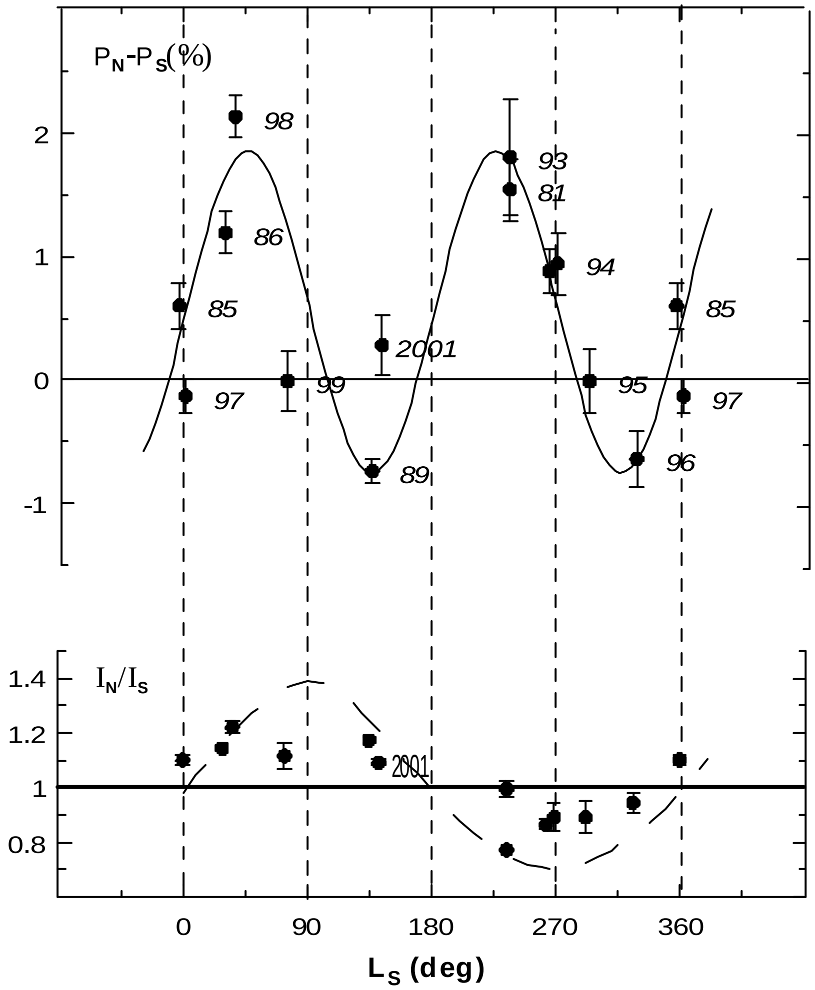

Fig. Polarization degree difference between North (N) and south (S) regions at planetocentric latitudes +/-60° (the upper dots), and ratio of measured intensities for these regions (the lower dots), as a function of planetocentric orbital longitude of the Sun

As is well known, polarization data throughout the visible and ultraviolet range are sensitive to aerosol haze in the high atmosphere (from a few mbar to a few tenths of mbar) (West, Tomasko, 1980; Smith, Tomasko, 1984). This stratospheric polar haze is high enough for its formation and characteristics to be plausibly influenced by external factors, such as planetary magnetic field, dust component in the magnetosphere, charged particles impacts, cycle changes in solar activity, and orbital motion.

As we found (Starodubtseva et al., 1994; Starodubtseva et al., 2002), there are some longitudinal variations of polarization at high latitudes, which are organized in System III and IV related to the rotation of the magnetosphere. It is likely to imply magnetospheric control over stratospheric aerosol formation in the polar regions. These facts suggest that the strong jovian magnetic field, which is asymmetric in its structure and magnitude with respect to the planet’s equator, is the initial factor of the observed N-S asymmetry in polarization.

Thus, we discuss two possible explanations of seasonal variations of the N-S asymmetry of the linear polarization degree: seasonal changes in insolation and/or time-variable magnetospheric effect on the polar events.

Smith P. H., Tomasko M. G. 1984. *Icarus*, **58**, 35-73
Starodubtseva O. M. et al. 1994. *In Lunar and Planetary Science Conf. XXV, March 14-18, Houston, Texas, USA*, 1331-1332.
Starodubtseva O. M. et al. 2002. *Icarus*, **157**, 419-425
West R. A., Tomasko M.G. 1980. *Icarus*, **41**, 278-292

ASTROMETRY AND PHOTOMETRY OF SMALL BODIES OF THE SOLAR SYSTEM AT BNAO-ROZHEN

V. Ivanova, Vl. Shkodrov. (Institute of Astronomy, Bulgarian Academy of Sciences)

A short description of all the telescopes, 2m RCC, 50/70cm Schmidt and 60cm Cassegrain of Bulgarian National Astronomical Observatory-Rozhen, is presented. All the three telescopes are used for investigation of small bodies of the Solar System. Recent observational programs and the most important results, some of them in collaboration with astronomers from USA, Germany, Poland, Belgium, Ukraine, Russia, Macedonia, Serbia are summarized. Some collaborations continue nowdays. But a new cooperative program and consolidation of common efforts is of great importance for more successful future investigations.

PHOTOMETRIC EVIDENCES OF BINARY ASTEROIDS.

L. G. Karachkina, V.V. Prokof’eva (Crimean Astrophysical Observatory, Ukraine)

29 binary asteroids are known as Solar system members. Asteroidal moons discoveries were obtained by photometric observations, with help of adaptive optics, radar and spacecraft images. The part of photometric works especially among NEAs is rather high. We discuss the peculiarities of frequency analysis that allowed to find the binarity of some asteroids and assumed the existence of small moon around 1620 Geographos.

PHOTOMETRIC EVIDENCES OF BINARY ASTEROIDS, MODELS AND AFFINITY WITH FAMILIES

L. G. Karachkina, V.V. Prokof’eva, N.M. Gaftonyuk (Crimean Astrophysical Observatory, Ukraine)

21 satellite systems are known among main belt asteroids and NEAs, as well as 8 - among Centaurus and TNO. Moon's discoveries were received by photometric

observations (light curves analysis and eclipses), with help of adaptive optics, radar and spacecraft images. The part of photometric works is rather high. We discuss the properties of light curves analysis, that permitted to find the composite structure of some asteroids. The construction of rough models of binary system is presented. The families were found, genetically affined with six binary asteroids.

ON A DARKENING OF ASTEROIDS

Anatoly Kazantsev (Astronomical Observatory of Kyiv Taras Shevchenko University, Ukraine)

The IRAS - albedo of 2228 asteroids (Tedesco E. F. et al. 2002) were analyzed depending on belonging to asteroid families and their orbit elements. It was obtained that the average brightness of asteroids of all main families are higher in compare with background ones – the asteroids on orbits with neighbor values of semimajor axes. The differences of average brightnesses are various for various families.

It is possible to explain the pointed feature as a darkening of background asteroids caused by covering with dust of them. Consequently, the difference between the brightness of family's asteroids and the background ones may be a some characteristic of the family's age. On the base of this the conclusion was made that the Maria and Koronis families should were younger in compare with families Eos, and especially Themis.

Tedesco E. F. et al. 2002, Astron. J., 123:1056-1085

POLARIMETRY OF NEAR-EARTH ASTEROIDS

Kiselev Nikolai (Institute of Astronomy of V.N. Karazin Kharkiv National University, Ukraine)

At present polarimetric data are available for more than 100 asteroids (http://PDS.jpl.nasa.gov/.). Unfortunately, most data relate to the main-belt asteroids (MBAs) that cannot be observed from the Earth at phase angles $\alpha>30$ deg. A favorable possibility to obtain the most complete phase dependence of polarization including the maximum of positive polarization is allowed by near-Earth asteroids (NEAs). NEAs provide data that, in many respects, supplement the data for the MBAs. Beginning in 1968, polarimetric observations were carried out only for 12 NEAs, listed in the table, 7 of which were studied in the Institute of Astronomy, with four of them, - 1036 Ganymed, 1627 Ivar, 2100 Ra-Shalom and 1998 WT24 (33342), - being observed for the first time.

NEAs studied with polarimetry

NEA	Type	Apparation	α_{max}, deg
433 Eros	S	1968, 1972, 1975	53.2, 32.9, 44.3
1566 Icarus	U	1968, 1996	83.5, 57.7
1620 Geographos	S	1969, 1994	78, 23.5
1685 Toro	S	1972, 1988	78.5, 106.3
1036 Ganymed	S	1972, 1989,1998	42.0, 37.7, 14.8
4179 Toutatis	S	1972/1973, 1996	101.3, 111.0
887 Alinda	S	1973/1974	27.5
1580 Betulia	C	1976	38.8
2062 Aten	S	1976	Unpublished data
1627 Ivar	S	1990	64.1
2100 Ra-Shalom	C	1997	59.7
33342 (1998 WT24)	E	2001	83.4

This review answers the questions:

i) why it is necessary to carry out the polarimetry of NEAs;
ii) what results were obtained;
iii) what we should do in the future.

IMAGING PLANETARY CCD-PHOTOPOLARIMETER

V. V. Korokhin, V. V. Konichek, and I. E. Sinelnikov (Institute of Astronomy of Kharkiv University, Ukraine, e-mail: dslpp@astron.kharkov.ua)

CCD-camera. The basis of the device is a b/w high-resolution CCD-videocamera Mintron OS-65D. Photosensor is a Sony 1/3” CCD 752x582 pixels. The camera has been modernized in such a way, that the operational frame rate, 25 Hz may be 2, 4 or 8 times reduced This allows to increase the maximal exposure and, accordingly, a threshold sensitivity of the device. Moreover, this allowed to decrease information flow and to use a relatively simple interface unit for digitizing and inputting the images to an IBM PC compatible personal computer (PC). The device uses a standard parallel port working in EPP (Enhanced Parallel Port) mode for connecting to PC.

Optical and mechanical unit. A polarization filter PF-40.5 is used as a polarization analyzer. In observations, the analyzer rotates sequentially through 45° under PC control, with each rotation lasting for 0.1 sec. Signal measurements are made with the immovable analyzer. Several tens of rotations are made in each measurement cycle. Such a technique permits to reduce the atmosphere instability during the observations. Each observational dataset consists of 20 to 60 frames for every Polaroid position, which are superposed and averaged in the further processing. A computer controlled turret of 6 filters is used in changing spectral band. The photopolarimeter is capable of imaging all the parameters of linear polarization for the observed objects.

Software. The "x_CCD" program has been developed to control the device and observational process. We use the "IRIS" program system (http://www.cyteg.com) for data processing, which was also developed by us (Korokhin et al., 2000). The software runs under Microsoft Windows OS.

Practical application. During the last 4 years, the photopolarimeter was used for: studying the temporal and spatial variations of the degree of linear polarization of Jupiter (Starodubtseva et al., 2002), studying the fine effects in negative branch of phase dependence of polarization by observations of Galilean satellites of Jupiter (Rosenbush et al., 2000), and for studying the positive branch of phase dependence of polarization of the lunar surface. The accuracy of measurements of the degree of linear polarization is estimated to be 0.10..0.15%. Instrumental polarization varies within 0.05..0.15% for different telescopes. No significant instrumental depolarization has been detected.

Korokhin V. V. et al. 2000. *Kinematika i Fizika Nebesnykh Tel*, **16**, 80-86
Rosenbush V. K. et al. 2000. *Kinematics and Physics of Celestial Bodies. Supplement Series*, **No3**, 227-230
Starodubtseva O. M. et al. 2002. *Icarus*, **157**, 419-425

DEPENDENCE OF PHASE ANGLE OF MAXIMUM POSITIVE POLARIZATION ON ALBEDO

V. V. Korokhin, and Yu. I. Velikodsky (Institute Astronomy of Kharkiv University, Ukraine, e-mail: dslpp@astron.kharkov.ua)

The surface of the Moon is a good sample of athmosphereless cosmic bodies' surface. Due to the facts that albedo of the Moon varies in wide range and the lunar surface is available for observations from the Earth in practically full range of phase angles it is possible to study different dependences of optical parameters. For example, degree of positive polarization (and maximum of positive polarization P_{max} in particular) – albedo dependence is studied well. But the distribution of phase angle α_{max} of P_{max} over the lunar disk and correlation with other optical parameters are not practically investigated.

Therefore the maps of maximum of positive linear polarization degree P_{max} and of its phase angle α_{max} have been constructed for the eastern hemisphere of the Moon, based on a set of polarimetric observations of lunar surface at a wide range of phase angles, varying from 8° to 123°. The observations were carried out at Kharkov Observatory in 2 wavelengths λ_{eff}=461 nm ($\Delta\lambda$=106.4 nm) and λ_{eff}=669 nm

($\Delta\lambda$=125.0 nm) with an imaging CCD–polarimeter (Korokhin et al, 2000) and a camera lens of 3 cm diameter, and 30 cm focal length.

The P_{max} and α_{max} maps are represented in the external perspective projection (distance=221.1739 R_{Moon}, image radius=225 pix) and are accessible at http://www.univer.kharkov.ua/astron/dslpp/polar/ as FITS-files. A pixel size is equal to about 8 km on lunar surface.

A histogram of P_{max} distribution over the lunar disk has distinct maximum, – P_{max}=7.3% for λ_{eff}=461 nm and P_{max}=5.25% for λ_{eff}=669 nm, – corresponding to highlands. Distribution of P_{max} for mares is more diffuse. The range of P_{max} variations is 4.0..21.0% for λ_{eff}=461 nm and 3.0..15.0% for λ_{eff}=669 nm.

A histogram of α_{max} distribution is distinctly bimodal, with the first peak at α=99.7° (highlands), and the second one at α=104.1° (mares) for λ_{eff}=461 nm. For λ_{eff}=669 nm we have α=96.8° and α=101.2°, respectively. The histogram is in a whole more narrow in blue light, – 94.0°..106.0°, - as compared to red (90.0°..105.0°). As a rule, the maximum of polarization occurs at larger phase angles in the blue band.

Correlation diagrams α_{max} (in degrees) versus albedo ρ were plotted (fig.1 – for λ_{eff}=461 and fig.2 – for λ_{eff}=669 nm), having given α_{max} = (-141.91±0.03) ρ + 110.45±0.42) for λ_{eff} =461 nm, and α_{max} = (-110.14±0.03) ρ + 108.58±0.31) for λ_{eff} =669 nm. Correlation coefficient is equal -0.893 for λ_{eff} =461 nm and -0.877 for λ_{eff} =669 nm, i.e., a significant anticorrelation is observed.

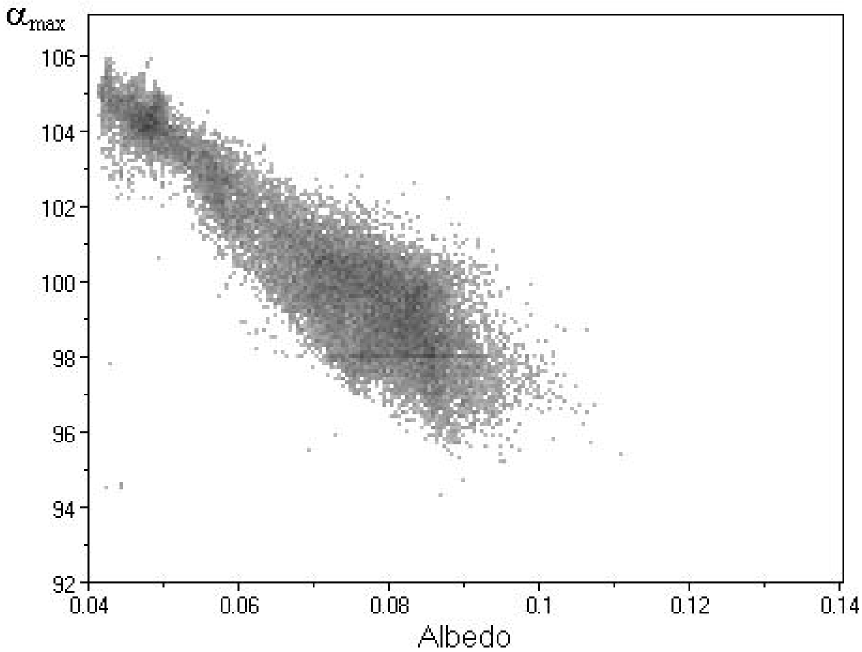

Fig.1. Correlation diagrams α_{max} (in degrees) versus albedo for λ_{eff}=461 nm

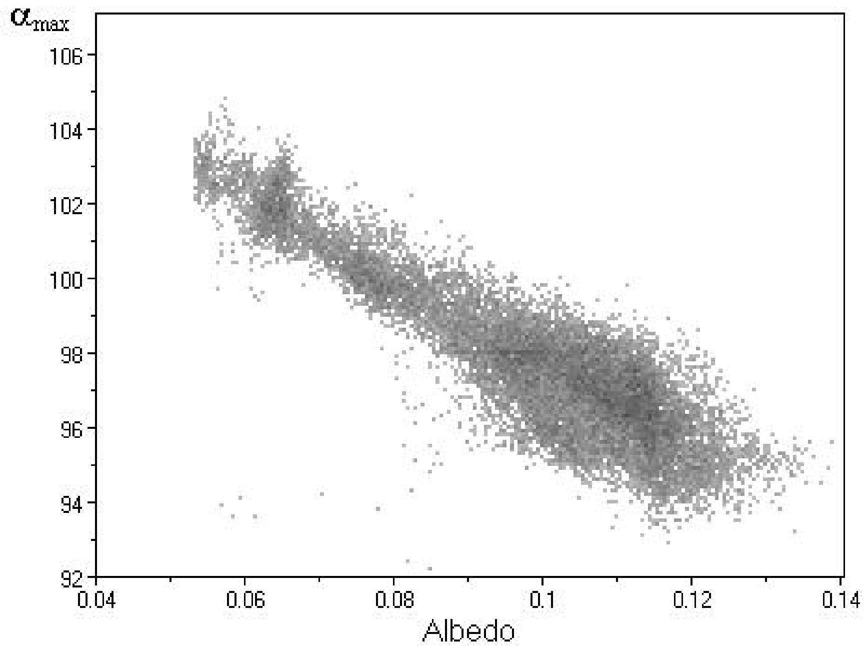

Fig.2. Correlation diagrams α_{max} (in degrees) versus albedo for λ_{eff}=669 nm

The analysis of these data, especially combined with other optical parameters, is helpful in obtaining more information about the fine structure of the regolith of athmosphereless cosmic bodies (Shkuratov, Opanasenko, 1992).

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DISCOVERY OF BINARY ASTEROIDS BY PHOTOMETRIC OBSERVATIONS

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Since 1970's many theoretical works were devoted to predict the existence of binary asteroids and to model their lightcurves (Van Flandern et al. 1979). Photometric lightcurves of some asteroids were interpreted as indication of binary systems (Cellino et al. 1985). The only asteroid 216 Kleopatra was found to be a contact binary from a long list of supposed binaries.

In recent years binary objects have been revealed in orbits over all Solar System. The binaries have been found among near-Earth asteroids (14 objects), Mars crossers (1), main belt (7), Cybele group (3), Trojan (1) asteroids and also among Kuiper belt (8) objects. They have been detected by different observing techniques such as radar, adaptive optics, direct CCD imaging both using Hubble Space Telescope and ground-based telescopes (Merline et al. 2003). The discoveries started with 243 Ida's satellite, Dactyl, which was detected in the images by Galileo spacecraft in 1993 (Chapmen et al. 1995). During 1994-1999 several near-Earth asteroids (NEAs) were supposed to be binaries from lightcurve observations (Mottola et al. 1995; Pravec, Hahn 1997; Mottola 1997; Pravec et al. 2000). In 2000 the first radar binary 2000 DP107 was reported among near-Earth objects (Ostro et al. 2000). The asteroid was also studied by photometry, which showed a two-periodic lightcurve. The lightcurve looks like previously suspected "photometric" binaries. Estimated parameters of the binary system from the lightcurves were found to be in the agreement with the radar results. Several attempts have been made to pick out different frequencies in asteroid lightcurves by Prokof'eva et al. (Prokof'eva, Demchik, 1994; Prokof'eva et al. 1995; Prokof'eva et al. 2001). Among asteroids for which they found several different rotational periods in lightcurves there is asteroid 87 Sylvia, which has a small satellite according to the data by adaptive optics technique (Brawn, Margot, 2001).

Two different models could be used in order to explain the observed complex lightcurves of asteroids. First, we may suppose that asteroid is in an excited rotation state and its spin vector is not fixed in space (precessed body). There are several asteroids assumed to be in precessing state (253 Matilda, 1220 Crocus, 4179 Toutatis). Another posibility is based on the assumption that the asteroid is a binary object. It assumes the existence of two bodies rotated around the common center. NEA 1994 AW1 could be considered as the first binary asteroid detected by photometry (Mottola et al. 1995; Pravec, Hahn 1997). The method of analysis of complex lightcurves is described in Pravec, Hahn (1997). The core of the method is based on hypothesis that the primary body (larger, central) of the binary system is not synchronous with the orbit period of secondary body (satellite). In such case the asteroid rotation spectrum shows two different frequencies. Apart from eclipse/occultation events we observe a light-periodicity connected with primary's rotation (short period component). After removing primary's lightcurve, remaining brightness variations look like an eclipse/occultation curve (long period component). Analysis of lightcurves of a supposed binary asteroid permits to estimate the following values: rotation period of the primary body, orbital period and eccentricity, separation between bodies, size ratio and density of bodies. Numerical modeling puts constrains on binary system and gives more real parameters of the bodies and extra data for the system orbit (Mottola, Lahulla, 2000). Mainly such photometric binaries are discovered among NEAs, which are young enough systems to be synchronous. Now we understand some common properties of binary NEAs. The primary component is usually not much elongated body with a short rotation period (close to 3 hours), while the orbital period of the secondary small component is longer than 12 hours.

There is some limitation for discovery of a binary asteroid from photometric observations. The main feature of a binary object is its two-periodic lightcurve. The photometric precision puts a limit for maximum diameter ratio of the bodies, which can be distinguishable from their lightcurves. We can hope to registry a binary system with a diameter down to ratio of 1:5, if the accuracy of photometry is within 0.01 mag. Searching for binary system by means of photometry demands both a high photometric accuracy and a long continuous lightcurve, which is possible in the frame of observatory cooperation.

Six photometric binary asteroids were observed in Kharkiv Observatory (Pravec et al. 2000; Mottola et al. 1997; Pravec 2002; Krugly et al. 2002). The observations were carried out in cooperation with Ondrejov Observatory and Germany Aerospace Center DLR. In the past two years there have been some improvements in our observing abilities, and we expect the new binary discoveries during new observations of NEAs.

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TWENTY FIVE YEARS OF ASTEROID INVESTIGATIONS AT THE INSTITUTE OF ASTRONOMY OF KHARKIV NATIONAL UNIVERSITY (REVIEW)

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The studies of physical properties of asteroids at the Institute of Astronomy (before 2001 it was called the Astronomical Observatory) started in 1977 by photometric observations of asteroid 17 Thetis at Gissar Observatory (Tajikistan) together with the colleagues from the Institute of Astrophysics in Dushanbe. Most of the observations were curried out with 0.7 m reflectors of the Institute of Astrophysics (Dushanbe) and of the Institute of Astronomy (Kharkiv), 1.0 m reflectors of Sanglok Observatory (Tajikistan) and of the Crimean Astrophysical Observatory (Simeiz, Crimea, Ukraine), 1.25 m reflector of Crimean Astrophysical Observatory (Nauchny, Crimea, Ukraine) and others.

Since 1977 many research programs have been undertaken such as: photometric studies of asteroid shapes and rotations; magnitude-phase and color-phase dependences; photometry and polarimetry of M-type asteroids and laboratory modeling of their optical properties; polarimetry of CMEU-asteroids and their taxonomic classification; polarization-phase dependences; spectral dependence of asteroid polarization; scattering properties of asteroid surfaces; opposition effect of asteroid brightness; opposition effect of asteroid polarization; optical properties and rotation of near-Earth asteroids and others.

Many observational programs are carried out in the frame of collaborations with our colleagues in the Crimean Asrophysical Observatory, Sternberg Institute of Astronomy in Moscow (Russia), Astronomical Observatory of Poznan University (Poland), Astronomical Institute of Czech Academy of Sciences (Czechia), Torino Astronomical Observatory (Italy), Uppsala Astronomical Observatory (Sweden), Planetary Institute DLR (Berlin) and Jet Propulsion Laboratory (USA).

Now asteroid studies are carried out by methods of photometry, polarimetry, laboratory and numerical modeling. This review presents the principal results and achievements obtained by the asteroid group of the Institute of Astronomy of Kharkiv National University.

ASTEROID ROTATIONS

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Photometric lightcurves can provide the most abundant data on asteroid rotation. We review the methods of determination of poles, shape models, senses of rotation and sidereal periods of the asteroids. The data obtained for about 1000 objects allow us to present the distribution of rotation rate versus size of the asteroids. Spin vectors have been determined for about 100 bodies and the lack of asteroid poles close to the ecliptic plane is apparent.

ECLIPSING BINARY ASTEROID 90 ANTIOPE

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Asteroid 90 Antiope was observed on four nights in December 1996 (Hansen et al. 1997). A composite lightcurve with an amplitude of 0.70 mag was constructed with a rotational period of 16.509 hours. This lightcurve was very similar to the lightcurve of an eclipsing binary star. The binarity of this asteroid was confirmed by direct imaging with adaptive optics in August 2000 (Merline et al. 2000). They deduced that Antiope was a double asteroid with similar-sized components, separated by 170 km. The orbital period was about 16.5 hours, consistent with the period derived from the 1996 photometric observations. If we accept Antiope's diameter of 120 km as determined by IRAS satellite and assume that it is binary system of two spherical objects, we can found the diameter of each component to be 85 km.

Photometric obswervations of Antiope were also carried out on 14 nights in September through November 2000 (Micha³owski et al. 2001). The brightness of the asteroid varied with an amplitude of about 0.08 mag within the period of 16.496 hours (consistent with earlier reported periods). This small amplitude was due to the non-spherical shapes of the components rather than to mutual occultations

Antiope was observed again on 26 nights between 19 October 2001 and 7 February 2002 (Micha³owski et al. 2002). These data showed two-component lightcurve with each showing the same period of 16.505 hours. The observed amplitudes of both of them linearly depended on phase angle. The first component (with amplitude 0.05-0.10 mag) was associated with the rotation of two non-spherical bodies; the second one, showing two sharp minima (with amplitude 0.05-0.12 mag) was due to mutual occultation/eclipse events in the binary system. The lightcurves have suggested that the rotational periods of both bodies are equal to the orbital period, which is characteristic for synchronous rotation.

We also observed this asteroid on 27 nights between 9 December 2002 and 7 April 2003. The lightcurves were similar to those from previous apparition but with smaller amplitudes: 0.04-0.09 mag due to the rotation and 0.01-0.05 caused by occultation/eclipse events. All available lightcurves have allowed us to predict the eclipsing amplitudes during future oppositions of Antiope.

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PHOTOMETRIC AND POLARIMETRIC OPPOSITION EFFECTS IN ASSBS: ASTEROIDS

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The presented paper covers several closely related subjects: (i) a brief review of the existing photometric and polarimetric data for ASSBs including asteroids at small phase angles; (ii) a discussion of how to determine the parameters of the BOE and negative polarization; (iii) a study of correlations among observable parameters and a more detailed discussion of the obtained results for asteroids; (iv) conclusions and future directions.

Objects of different nature such as asteroids, satellites, planets, planetary rings, comets, and interplanetary dust particles exhibit one common property as they approach the opposition, namely a nonlinear brightness increase and negative linear polarization (Rosenbush et al. 2002 and references therein). These phenomena are known as the brightness (BOE) and polarization (POE) opposition effects and are believed to contain information about the surface composition, texture, and particle size. The observed characteristics of the BOE and POE can also, in principle, contain information about different scattering mechanisms. Presently, the coherent backscattering mechanism (CBM) and the mutual shadowing mechanism (SM) are believed to be the primary candidates to explain the observed opposition phenomena. Although the SM can play an important role in the formation of the BOE, it is unable to describe the negative polarization effect (Hapke 1993). Within the framework of the CBM it is possible to explain both the photometric opposition effect and negative polarization simultaneously. Quite recently, the POE was discovered for some high-albedo objects such as Io, Europa, Ganymede, and 64 Angelina at phase angles less than 1–2^{o} (Rosenbush et al. 2002). This discovery has corroborated the remarkable theoretical prediction that the BOE should be accompanied by the POE (Mishchenko 1993).

There are numerous data potentially indicating different behavior of brightness and polarization near opposition for bodies with different albedos and chemical composition (Rosenbush et al. 2002). The observed photometric phase curves show a great diversity and range from a very narrow spike-like opposition brightness peak for some high-albedo objects (icy satellites, Saturn's rings, asteroids 44 Nysa and 64 Angelina) to only the linear part of the phase curve (e.g., some C- and P-type asteroids). The shape of the polarization phase curve near opposition (phase angles less than 2°) had not been studied well until quite recently. Recent analyses of observational data show a bimodal phase angle dependence of polarization of light reflected by such high-albedo objects as Saturn's rings, the Galilean satellites of Jupiter, and asteroid 64 Angelina. There is a separate peak of negative polarization superposed on the regular (perhaps slightly asymmetric) negative polarization branch. Therefore, the resulting polarization curve at backscattering angles can have different shape – from a single POE spike to a single, nearly parabolic negative polarization branch. Strong relationships between different parameters of the BOE as well as between the characteristics of the BOE and the negative polarization branch based on a large volume of data for objects with different physical and chemical properties have been found. This result is important because it suggests the common origin of the photometric and polarization opposition phenomena. Furthermore, these relationships show an obvious segregation of all ASSBs studied into two groups of high-albedo and low-albedo objects. The results obtained indicate unequivocally the different roles played by the CBM and the SM in the formation of the photometric and polarimetric opposition phenomena for high- and low-albedo objects, respectively.

However, the available observations of the photometric and, especially, polarimetric opposition effects are insufficient to derive definitive conclusions as to the contribution of different mechanisms to their formation. In particular, the shape of the phase dependence of polarization at extremely small phase angles is not studied in detail for various objects (planetary satellites, asteroids of different types). The dependence of the BOE parameters on the wavelength may be a good test of whether CBM can explain the opposition spikes exhibited by high-albedo objects (Mishchenko 1992b; Hapke et al. 1998). Unfortunately, the spectral dependence of these parameters has not been investigated at all. Detailed observations of high-albedo objects, which reveal a bimodal phase-angle dependence of linear polarization and a very narrow opposition brightness peak as well as those of low-albedo objects (C-, P-, D-type asteroids) not showing the BOE, are especially important.

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SPECTRAL DIAGRAMS OF THE S-ASTEROIDS AND METEORITES: MODELING OPTICAL MATURATION OF CHONDRITE-LIKE SURFACES

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Recently we showed by spectral simulation (Golubeva, Shestopalov, 2003) that optical parameters of the unweathered material (presented by achondrites and ordinary chondrites) on the albedo (750 nm) - color (950 nm/750 nm) diagram move through the S-asteroid region to the Moon region owing to increasing concentration of the submicroscopic metallic iron grains (SMFe) in the rims of the particles of the meteorite samples. Now we attempt to reply to such question: is it possible to find near relations between S-asteroid and H-, L-, LL-chondrite spectra when calculating effect of the optical maturation of the OC-like surfaces? For this aim we used ECAS and 52-color survey for Main Belt S-asteroids (Zellner et al., 1985; Bell et al., 1998) and meteorite spectrum dataset (Gaffey, 1976). Based on the author comments we selected meteorite samples with pure surfaces.

The following illustrations for meteorites and asteroids were constructed: the diagram (D1) of the maximum reflectance position near 750 nm (ë$_{max}$(750 nm)) versus minimum absorption band position near 950 nm after removing linear continuum (^{2}ë$_{min}$(950 nm)), the diagram (D2) of the spectral curvature in ECAS system (u+w-2v) versus ^{2}ë$_{min}$(950 nm), and diagram (D3) of ECAS color-index (u-x) versus ^{2}ë$_{min}$(950 nm).

Diagrams before space weathering simulation. Regions occupied meteorites and asteroids are apparently separated on the D1 and D2 diagrams. Regions for these objects are slightly recovered on the D3 diagram. There are significant statistical correlations between asteroid spectral parameters on all diagrams, on the contrary, dispersion of the meteorite dots on diagrams is essential and correlation coefficients are small.

Diagrams under the space weathering simulation. Modeling optical maturation of the chondrite-like surfaces we attempted to coincide meteorite and asteroid regions on all diagrams. The same suppositions as in case of albedo-color diagram (see above) and theory from (Shkuratov et al.,1999; Hapke,2001) were used. Variations of the meteorite spectral parameters were studied under the following conditions: i) increasing SMFe concentration in the particle rims when particle sizes are constant; ii) growth and diminution of the particle sizes in the presence of invariable SMFe concentration; iii) various correlations between SMFe concentration and size of particle are examined too.

In result we cannot find any transformations of the meteorite spectral parameters caused by maturation of chondrite-like surfaces to coincide the meteorite and asteroid regions on all diagrams simultaneously. It takes place owing to different speeds and directions of the displacement of the meteorite dots on diagrams. We studied also spectral parameter transformations for individual meteorite samples and found only LL-chondrite Parnellee and asteroid 115 Thyra (S III-IV) whose scaled reflectance spectra are satisfactorily fitted. Visual albedo of the asteroid and chondrite-like surface is 0.25 and 0.29 correspondingly.

So we come to conclusion that optical effects of chondritic surface maturation don't allow overcoming the distinctions between spectra of ordinary chondrites and Main Belt S-asteroids. We assumed in the present numerical experiment that iron grains are introduced into upper thin layer of *crystal* particles. It is possible that some share of particles on asteroid surfaces is vitrified and this circumstance causes additional alterations of the S-asteroid spectra. Besides, one should not rule out the possibility that S-asteroid surfaces have not a chondritic composition.

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INVESTIGATION OF ASTEROID PHASE DEPENDENCES OF BRIGHTNESS AT THE INSTITUTE OF ASTRONOMY OF KHARKIV NATIONAL UNIVERSITY

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Investigation of lightscattering from planetary surfaces at Kharkiv Observatory is a traditional direction of research started at the beginning of the last century by N. P. Barabashov. The disk-integrated brightness as a function of phase angle is one of the basic sources of information on physical properties of planetary surface (albedo, particle size, roughness and porosity of surface, probable mechanisms of lightscattering from regolith layer, etc.). Because of the small angular sizes of asteroids we cannot measure the distribution of brightness over their disks from the ground-based observations, the integral phase dependences of brightness are one of the main sources of information on asteroid physical characteristics. First of all it is the absolute magnitude which allows us to do an estimation of asteroid size.

The brightness of an asteroid corrected for the amplitude of the lightcurve and for the distances to the Earth and to the Sun decreases linearly in the phase-angle range 7-30 deg. There is nonlinear increasing of brightness with decreasing of phase angle less than 7 deg. This phenomenon is named “opposition effect” (OE). Gehrels (1956) was the first who discovered the opposition effect in asteroid 20 Massalia. In the following years the data were accumulated for the investigation of the asteroid phase dependences in more detail. It has been known that the phase dependences are different for low and moderate albedo asteroids (Bowell, Lumme 1979), and “spike-effect” was discovered by Harris *et at.* (1989) for hight albedo asteroids. Because of the deficit of data on brightness behavior in range of opposition effect it was supposed that the opposition effect is the same for all asteroid types.

The first observations of the asteroid phase dependences at the Kharkiv Observatory in cooperation with Dushanbe Observatory were performed in 1977. The phase dependences for asteroid 17 Thetis in UBV bands was obtained (Lupishko *et al.* 1979). In the next ten years the magnitude-phase relations for about ten asteroids were obtained at the Kharkiv Observatory (Lupishko *et al.* 1979, Lupishko and Belskaya 1983, etc.). But the regular photometric observations to investigate asteroid phase dependences have been carried out since 1989. We concentrated our efforts on observations of brightness behavior both as in range of opposition effect including phase angles down to zero and as in range of linear part of phase dependence. During the next ten years we obtained in cooperation with other observatories the phase dependences of brightness for about twenty asteroids of different composition types in a wide range of phase angles including subdegree region (Shevchenko et al., 1996; Shevchenko et al., 1997, etc.).

We have analyzed our and all available data and have discovered that the amplitude and the width of OE depend on asteroid albedo in a non-monotonic way with the maximum for the moderate-albedo asteroids. Relative to this maximum, the amplitude of the OE decreases both for low and high albedo asteroids (Belskaya, Shevchenko 2000). The phase coefficient defined in the range of 10-25 deg correlates linearly with geometric albedo of asteroids (the coefficient of correlation is equal to 0.93). The existence of such a strong correlation strongly suggests that the main factor influencing on the slope of asteroid phase curves in linear part is albedo.

Recently our attention has been devoted to opposition phenomena in brightness behavior for low albedo asteroids. The low albedo asteroids show the smallest amplitudes of opposition effect and the largest dispersion of them as compared to asteroids of other types. To investigate this fact in more detail and to improve data set, we have carried out new observations of the phase dependences of brightness for low albedo asteroids. We have found three groups of objects for low-albedo asteroids (Shevchenko *et al.* 2003): a) the asteroids without opposition effect down to 0.1 deg of phase angle; b) the asteroids for which the opposition effect begins at phase angles less than 3 deg; c) the asteroids for which the opposition effect begins at phase angles close to 7 deg.

We have also begun CCD-observations of asteroid phase curves in BVRI bands to investigate the OE amplitude dependence with wavelength for different composition types of asteroids. This can help us to indicate possible lightscattering mechanisms from asteroid surfaces.

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PHOTOMETRIC AND POLARIMETRIC OBSERVATIONS OF (216) KLEOPATRA

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T. Mukai (Graduate School of Science and Technology, Kobe University)

The main-belt asteroid (216) Kleopatra has been frequently observed by ground based photometric technique because its drastic amplitude changes attracted many observers. The variations of amplitudes are between 0.09-1.2 mag. at different geometries and these phenomena suggest that the shape of Kleopatra must be too elongated or contacted binary. Tanga et al. (2001) showed its elongated figure by HST/FGS interferometric observations, while Hestroffer et al. (2002) resolved two bodies for the first time with the adaptive optics system, ADONIS, installed on the 3.6m ESO telescope and the MISTRAL deconvolution technique in 1999.

We have observed the (216) Kleopatra by both photometric and polarimetric techniques simultaneously using a visible spectro-photo-polarimeter, HBS (Kawabata et al. 1999), installed at Dodaira Observatory astronomical observatory of Japan in November 1999.

We found that amplitude was 0.12 mag.. This small value, compared with the largest 1.2 mag. was caused by an almost pole-on view, however polarimetric data show slight difference with rotation. We simulated the lightcurve and degree of polarization curve based on Roche binary model and estimated density of Kleopatra. Hestroffer et al. (2002) have already estimated the density of Kleopatra as 4-5 g/cm^3, assuming to be the Roche binaries, however, their value is the first approximation because thay did not account for the scattering effects of the asteroids (Leone et al. 1984). We tried considering scattering model and improved the value of the density.

In this workshop we will present the results of observations using the HBS and lightcurve simulations accounted for light scattering based on the Roche binary model and report the improved density of Kleopatra.

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POLE DETERMINATION OF ASTEROIDS AND INTERPRETATION OF DATA

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Asteroid rotation and shape are fundamental characteristics related to dynamical processes taking place in the asteroid belt. On the other hand, asteroid rotation, described by its spin vector is accessible for the ground-based observations and can be used for checking the proposed theories and hypotheses. Detailed studies of asteroid spin vector distribution can provide the initial data necessary for the solution of a wide range of tasks, such as the process of growth of bodies in the protoplanetary nebular and their collisional evolution during postaccretion period, the shape of asteroids and their interiors, the strength of asteroid matter, and so on. Therefore, determination of the spin vectors of asteroids is one of the most important and principal problems of asteroid studies.

The spin vector of an asteroid can be determined from different observational data, such as visual and infrared photometry, thermal radiometry, radar and occultation observations. The photometric amplitude and magnitude method (AM-method) is based on the assumption that the observed lightcurve of an asteroid is primarily caused by changing projected area of a rotating object. In this case, the asteroid magnitude and lightcurve amplitude will depend on the spin vector, shape, visible and illuminated geometry. This method models the asteroid as a three-axial ellipsoid rotating around its shortest axis. For the AM-method we used the numerical photometric asteroid model based on ellipsoidal asteroid shape, homogeneous albedo distribution over the surface, and Akimov's scattering law. The method allows to determine spin axis orientation (λ_0, β_0) and ellipsoidal shape of the body (*a/b*, *b/c*), but it can not distinguish between a prograde and retrograde sense of rotation. The epoch method (E-method) is based on the analysis of variations in the observed synodic rotation period (P_{syn}) of the asteroid, caused by changes in the relative geometry Sun - Earth - asteroid and measured for different time intervals. The method does not depend on the shape of asteroid and determines the sidereal period (P_{sid}), the direction of the spin axis (λ_0, β_0) and the sense of asteroid rotation.

The combined method (the amplitude-magnitude method plus the epoch method) used in this study gives all the above-mentioned parameters of asteroid shape and rotation and requires the solution of the system of nonlinear equations with the six unknowns:

$$F_i\,(P_{sid}\,,\ l_0\,,\ b_0\,,\ a/b\,,\ b/c\,,\ V_0) = 0$$
$$i = 1, 2, \ldots k, k+1, \ldots k+m$$

where: k - number of equations from AM-method; m - number of equations from E-method.

Using the combined method (AM-method plus E-method) the pole coordinates, sidereal rotation periods, senses of rotation, and axial ratios of three-axial ellipsoid figures of 34 asteroids were determined, namely: 22 Kalliope, 75 Eurydike, 93 Minerva, 97 Klotho, 105 Artemis, 113 Amalthea, 119 Althaea, 158 Koronis, 167 Urda, 201 Penelope, 208 Lacrimosa, 211 Isolda, 263 Dresda, 268 Adorea, 270 Anahita, 277 Elvira, 311 Claudia, 321 Florentina, 338 Budrosa, 344 Desiderata, 347 Pariana, 369 Aeria, 462 Eriphyla, 480 Hansa, 487 Venetia, 534 Nassovia, 631 Philippina, 674 Rachele, 720 Bohlina, 776 Berbericia, 887 Alinda, 951 Gaspra, 1223 Neckar, and 4954 Eric.

Analyzing the new and previous determinations of pole coordinates and shapes (~190 asteroids) some quality interpretation can be done. In the spin vector distribution there is a significant predominance of asteroids with prograde rotation (~2/3 for the whole sample of asteroids). But this predominance depends on asteroid diameter: among the small asteroids (D<50 km) the ratio prograde to retrograde rotation is equal to 1:1, among the objects with 50<D<125 km it is equal to 3:2, and for the large objects (D>125 km) it is equal to 2:1. The characterization of the spin properties is different for asteroids with both senses of rotation. The distribution of pole ecliptic latitudes is anisotropic for asteroids with prograde rotation but in case of retrograde rotation it is almost isotropic. Among the objects of prograde rotation the axis orientation is becoming more perpendicular while asteroid diameter increases, that is, the spin vectors of large asteroids are concentrated to be moderately perpendicular to the ecliptic plane. These results agree with the hypothesis that asteroids on the stage of accumulation acquired mainly prograde sense of rotation and spin orientation perpendicular to the ecliptic plane, and subsequent collisional evolution changed their initial relict orientation to the currently observed one.

The fraction of asteroids (D<200 km) with retrograde rotation depending on their diameters shows a clear minimum of the dependence at D≈125 km. It is well known that the similar minimum takes place in the dependencies of rotation rates and lightcurve amplitudes of asteroids on their diameters. Analysis of this dependence for the asteroids of C, S and M taxonomic classes separately gives the new result: a depth of minimum depends on the taxonomic class and increases from the less dense C-asteroids to the most dense M-objects. That is, asteroid diameters of 125 km is some cosmogonic peculiarity of asteroids and its quantitative explanation can give new and important information about dynamical evolution in asteroid belt.

POLARIMETRY AND PHOTOMETRY OF THE M-TYPE ASTEROID 216 KLEOPATRA

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Simultaneous polarimetric and photometric observations for the M-type main-belt asteroid 216 Kleopatra were obtained during its 1999-2000 apparition. The observations were carried out using 70-cm reflector of Chuhuev Observation Station near Kharkiv. Telescope was equipped with a single-channel photoelectric photometer-polarimeter that worked on the modulation principle with a rapidly rotating polaroid and with a photon counting photomultiplier. Linear polarization and brightness of the asteroid were measured in the standard V-band.

The obtained polarization data and Asteroid Polarimetry Database (http://pdssbu.astron.umd.edu/SBNapd/archive/APD/opd.tab. 2003) have made it possible to composite the phase dependence of linear polarization of the asteroid 216 Kleopatra. Minimal degree of negative polarization in the V-band is P_{min}=-1.1% and lies at a phase angle of α=8°.6, α_{inv}=20°.9 and h=0.107. As it's known the asteroid shows variation of polarization with rotation [$\Delta P \approx 0.3\%$ at α=8°.3 (Shinokawa et al. 2002)]. The presented observations show amplitude of the variation about 0.4% at the phase angle of 25°.1. It can be caused by a structure unhomogeneous of the asteroid surface. The lightcurve of the asteroid has amplitude of $0^m.18$. The polarization peculiarity does not correlate with the lightcurve extrema.

Shinokawa K. et al. 2002. *Mem.S.A.It.*, **73**, 658-661.

A MODEL OF POSITIVE POLARIZATION OF REGOLITH

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Polarimetric observation is one of powerful methods of remote sensing of solid surfaces of planets and asteroids. A lot of works on studying the negative polarization recently have appeared, while the positive branch of polarization, observed at the large phase angles, is investigated worse. There is no yet satisfactory model of formation of a positive branch with a maximum of polarization at phase angles about 90-110°. Hence, it is no absolutely clear, what information on surface properties can be obtained with polarimetry. There is a hypothesis that the positive polarization is formed as result of Fresnel's reflection from large (~50 μm) particles (Shkuratov, Opanasenko, 1992). This hypothesis meets difficulties, connected to searching the causes of observed decreasing an angle of polarization maximum in comparison with value, predicted by Fresnel's law. In (Shkuratov, Opanasenko, 1992) some such mechanisms are considered. However, it is probable, that mature regolith contains too small quantity of large (in comparison with a wavelength) facets giving Fresnel's reflection. Therefore there is an idea to consider a model, which is based mainly on light scattering inside the large particles – i.e. on scatterers, smaller or comparable with wavelength. At the same time a small contribution of Fresnel's reflection may be also exist. In our opinion, this model more precisely corresponds to particles of regolith, which during a long time was exposed to powerful micrometeoric bombardment.

We assume, that polarization arises mainly at single scattering on large particles of regolith. However these particles are the conglomerates formed as a result of shock and microshock processes. These conglomerates can be treated as a random nonhomogeneous medium with fluctuations of a refractive index. Such fluctuations approximately can be treated as small scattering particles which sizes varying from mach smaller than wavelength to some larger than wavelength. We approximately can apply the theory of radiative transfer to such medium, considering light scattering by a layer of such small particles.

The approximate solution of this problem was considered. It is based on separate approximate description of single and multiple scattered light. For the description of scattering on a single small particle Reyleigh-Gans approximation (Bohren, Huffman, 1983) was used. It has allowed to obtain phase dependence of polarization degree in analytic form. This phase dependence provides a good description of our polarimetric observation data (for the Moon) in wide range of phase angles and in different parts of spectrum. The model has a good agreement with observed behaviour of polarization maximum and phase angle of this maximum at changing albedo and wavelength. At increasing the albedo the maximum of polarization decreases (this is known as Umov's law), and the angle of the maximum decreases too. The last can be explained that at increasing the albedo there increases the contribution of multiple scattering, which has polarization maximum at smaller angles than single scattering in a combination with multiple scattering.

Distributions of the model parameters over lunar surface are obtained. The possibility of using these results for prediction of physical properties of regolith particles is discussed. In more detail these results are presented on our site: http://www.univer.kharkov.ua/astron/dslpp/moon/polar/.

Bohren C. F., Huffman D. R. 1983. *Absorption and Scattering of Light by Small Particles* (Wiley, New York)

Shkuratov Yu. G., Opanasenko N. V. 1992. *Icarus,* **99**, 468-484.

THE CATALOGUE OF POTENTIALLY HAZARDOUS ASTEROIDS AND COMETS

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The Catalogue of potentially hazardous cosmic objects has been prepared for print. The aim of its publication is to create a handbook for professional astronomers and experts in other fields of knowledge. An additional objective is to outline the astronomical knowledge that is required for understanding and usage of the data included in the Catalogue.

The Catalogue contains data on 500 potentially hazardous asteroids (MOID is less or equal to 0.05 a.u., H is less or equal to 22 mag) and on 50 periodic comets with orbits approaching to that of the Earth. The data on each object embrace information at its discovery circumstances, orbit, photometric parameters, rotation, albedo, diameter, color-indexes, taxonomic class, velocity of collision and its energy in case it should happen. Detailed description of the data is also given. Special attention is paid to a number of problems connected with the origin of NEAs, to the dynamical structure of the asteroid belt and processes of delivering the asteroid matter to the inner part of the Solar system, to the search of encounters of asteroid and comets with the Earth and to estimation of collision probability, to the description of Torino and Palermo scales.

IS THE (469) ARGENTINA A BINARY SYSTEM?

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From the lightcurves of asteroid (469), observed on March 9-11 2002 at Yunnan Observatory, China, we can identify the light variation of light with at least two periods. The analysis to relation between different periods suggests that the asteroid (469) is a binary system, in which the light variation of the secondary caused by rotation cannot be ignored. Using periods of 17.00 hours and 3.00 hours, the observed lightcurves can be fitted well.

NEAR-EARTH OBJECT RADAR RESEARCH

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At present there are only two countries in the world, which have powerful transmitters and large dishes, and therefore can conduct the NEO radar research – U.S. and Ukraine. The comprehensive reviews of U.S. results, which were obtained, respectively, in the asteroid and comet radar investigations, were stated in Asteroids III (Ostro et al, 2002) and by Harmon et al (1999). Here the results, which were developed at the Ukrainian radar telescope in Evpatoria Space Center, along with some proposals on future international radar astronomy collaborations and on first dedicated European NEO Radar (Zaitsev, 2002), will be presented.

Harmon, J. K., et al. 1999. Radar observations of comets. *Planet. Space Sci., 47, 1409-1422.*
Ostro, S. J., et al. 2002. Asteroid radar astronomy. In *Asteroids III, Arizona Press, 151-168.*
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RESEARCH OF BINARY ASTEROID 1996 FG3

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This paper is devoted to research of binary asteroid 1996 FG3. We have considered model of binary asteroid in which the components of the system are approximated by homogeneous triaxial ellipsoids moving under the influence of the Sun and mutual gravitation. The force function of gravitational interaction of components was approximated by the sum of force functions of great number of elementary masses, which are packed in both ellipsoids.

The equations of prograde-rotational motion were integrated by Everhart's method. Computed values of coordinates of components and Euler's angles of their orientation in space were used for simulation of lightcurves. To simulate model lightcurves the method developed by Zheleznov (Zheleznov, 1999) has been used. This method based on the technique of approximation of ellipsoid surface by great number of small plane facets simulate lightcurves taking into account the mutual shadowings and occultations of components.

These algoritms have been used for approximation of lightcurves of binary asteroid 1996 FG3 (Pravec et al., 2000). Assuming coincidence of orbital plane of the satellite with equatorial plane of the primary, acceptable agreement between the real lightcurves and model ones has been achieved. Satellite orbit, density and mean diameters of components have been determined. Parameters of ellipsoids representing primary and satellite have been found, too.

The research of prograde-rotational motion of the system allowed one to estimate precession of satellite orbit and to draw some conclusion about influence of this precession on lightcurves. Stability of this system during more than 1000 revolutions of satellite has been researched, too.

The problem of more complex motion of components including oscillations of satellite orbit inclination has been considered briefly.

Pravec P. et al. 2000. *Icarus*, **146**, **2,** 190-203.
Zheleznov N. 1999. *Preprint of IAA of RAS*, **131**. (in Russian)

A FORMATION MECHANISM FOR BIMODAL NEGATIVE POLARIZATION OF THE HIGH-ALBEDO ATMOSPHERELESS CELESTIAL BODIES

Evgenij Zubko and Yuriy Shkuratov (Institute of Astronomy of Kharkiv National University, Ukraine)

Introduction. Atmosphereless celestial bodies exhibit the negative polarization branch (NPB) of light scattered at small phase angles. Usually, the NPB has a parabolic shape, but for some cases, e.g., Jupiter's moon Europa, it is bimodal (pluses in Fig. 1) [1]. Similar feature has also been found in laboratory measurements [2]. It was shown that the bimodal shape of NPB is caused by albedo spottiness of the scattering surface [2]. We consider here another mechanism. The NPB of regoliths is believed to be due to superposition of a single and coherent multiple light scattering, e.g., [3, 4]. If NPBs of single and multiple scattering have different widths, we can anticipate the total NPB to be bimodal. Here, we test this idea with our computer model of light scattering by particulate media. Also, we test a possibility of the bimodal NPB for the case when a single light scattering has no its own NPB.

Model. We simulate light scattering by regolith-like surfaces with a semi-infinite random particulate media having a macroscopically flat boundary. The model uses a ray-tracing method, which accounts for electromagnetic phases of direct and time-reversal trajectories, e.g., [3,4]. Our method takes into account both the shadow-hiding effect and the coherent enhancement of backscattering. The packing density of the model medium studied is 0.1.

To simulate single light scattering we use the data of the laboratory measurements for irregular particles of the Locon volcanic ash [5] and calculation results for cubes, which are obtaned with the Discrete Dipole Approximation (DDA) [6].

Results and discussion: Dark points in Fig. 1 present NPB of the "average" particle of the Locon volcanic ash [5]. For our convenience we made a smoothing of the experimental data [5]. The size parameter of the particles is $x \approx 90$ ($x = 2\pi r/\lambda$, where r is the radius of particles and λ is the wavelength). Solid line in Fig. 1 shows results of our simulation for the model medium composed of irregular particles of the Locon volcanic ash. As one can see, our simulation qualitatively reproduces the bimodality of Europa's NPB. Thus, if single particles of a medium possess own NPB and the multiple scattering in the medium is strong, then the shape of resulted NPB can be bimodal.

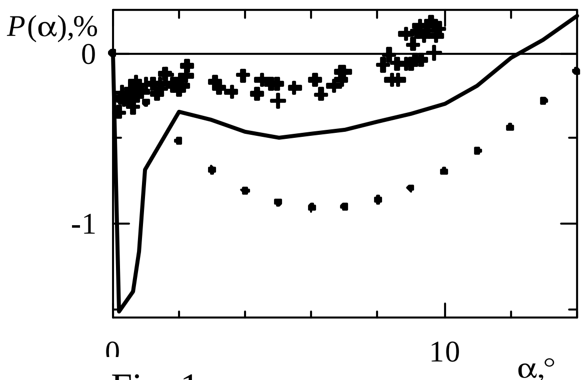

Fig. 1

One could expect that if single particles have no their own NPB, but NPBs of low and high orders of scattering are of strongly different widths, then the resulted NPB shape can also be bimodal.

To simulate such a case we used single scattering of cubical particles with the size parameter of the equivalent volume sphere $x = 1.49$ and refractive index $m = 1.5 + 0i$ (albedo of the single scattering is $\omega = 1$), which have no their own NPB. Thin solid line in Fig. 2 is the polarization curve of the cubes. Dashed line in Fig. 2 shows results of our simulation for second order of light scattering by the medium composed of cubes. Dotted line in Fig. 2 shows our results for sum from third up to twelfth orders of light scattering by the medium composed of cubes. One can see a drastic difference between dashed and dotted

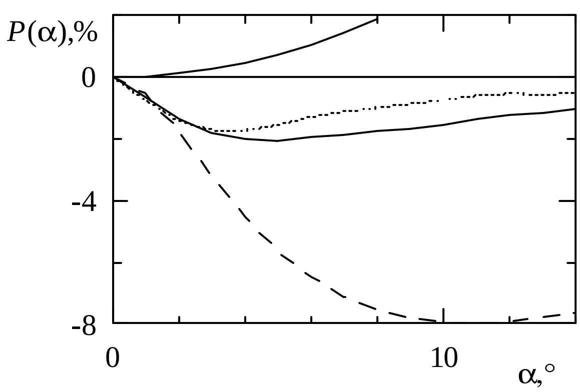

Fig. 2

curves. In particular, the phase angle of polarization minimum of the second scattering order is 10.5° versus 3.5° for the sum from third up to twelfth scattering orders. Nevertheless, general NPB of the medium is not bimodal (see thick solid line in Fig. 2). Thus, if the single particles have no their own NPB and the NPBs of the second and higher orders of scattering (sum from third up to twelfth) have a different widths, then the resulted NPB shape is not bimodal. Maybe, involving of more numbers of scattering orders (higher then twelfth) will do produce a bimodal NPB.

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