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Database of satellite polarimetry

S. V. Zaitsev[*], *V. K. Rosenbush, N. N. Kiselev*

Main Astronomical Observatory of the NAS of Ukraine, Akademika Zabolotnoho Str. 27, 03680, Kyiv, Ukraine

We present the electronic database (EAR-SA-COMPIL-3-SATPOL-V1.0, NASA Planetary Data System), involving 2355 published and 105 unpublished results in planetary satellite polarimetry. The database contains 2460 measurements of linear polarization of planetary satellites, including fifteen measurements of polarization for the Martian satellites (Phobos and Deimos), 2318 measurements for five Jovian satellites (Io, Europa, Ganymede, Callisto, and Himalia), 127 measurements for two Saturnian satellites (Titan and Iapetus). Broad-band measurements within the spectral region 233–850 nm are presented. The range of phase angles is 0.1°–154°. The geometric conditions of observations (phase angle, planetographic longitude and latitude of the target disk centre seen by the observer, and position angle of the scattering plane) are calculated for given moments of time according to the JPL Horizons ephemeris system. We have compiled nineteen references to the published papers and some unpublished sources. The data are provided in a tabular ASCII format. The database can be used as the observational basis for detailed theoretical modelling, interpretation of the phase-angle and spectral dependence of polarization, and for selecting future space-mission targets.

Key words: polarization, planets and satellites: surfaces, database

INTRODUCTION

Polarimetry is a very powerful remote-sensing method for studying distant solar system bodies. The characteristics of phase-angle and wavelength dependence of polarization for these bodies are sensitive to the mechanisms of light scattering, as well as the albedo, composition, and structure of the particulate surface, or physical properties and scattering parameters of the satellite's atmosphere. Observations of polarization of the planetary satellites, especially combined with simultaneous photometry, provide information which may reveal physical properties of the satellite surface or atmosphere by modelling the light scattering in terms of corresponding mechanisms.

In the 1920s Lyot carried out the first polarimetric observations of solar system objects [11]. During lunar observations he discovered a phenomenon of negative polarization of light scattered by the Moon surface at small phase angles, which was the logical interpretation. It triggered the intense study of physical properties of solar system objects by means of polarimetry. In the 1960s and 1970s detailed sets of measurements of linear polarizatioin of the Galilean satellites performed by Dollfus [6] and Veverka [17] allowed to determine the main polarization parameters of satellites of the outer planets of the Solar System for the first time. At about the same time, Zellner carried out the first polarimetrical observations of Deimos [22] and Iapetus [23]. Since then, polarimetrical observations of planetary satellites have been carried out using various polarimetric equipment and methods.

The Database of Satellite Polarimetry was initiated with the aim to catalogue all existing data on the linear polarization of planetary satellites. In this paper, we provide a short description of the database.

DATABASE DESCRIPTION

We define a measurement of linear polarization of a satellite as: the single determination of the degree of linear polarization, at a given date and time, corresponding to a specific phase angle of the object, the specific locations of the object and the observer (earth-based or spacecraft-based), and the specific spectral band. For example, if an instrument provides a measurement of polarization simultaneously in the U, B, V, R, V bands, one act of measuring gives us 5 measurements in terms of values as defined above (one measurement for each spectral band).

The currently available version [21] of the catalogue can be downloaded via Web[1]. It contains 2460 measurements of linear polarization of planetary satellites, including fifteen measurements of polarization for the Martian satellites (Phobos and

[*]sergio908@rambler.com

[1]`http://sbn.psi.edu/pds/resource/satpol.html`

Deimos), 2318 measurements for five Jovian satellites (Io, Europa, Ganymede, Callisto, and Himalia), 127 measurements for two Saturnian satellites (Titan and Iapetus). The data obtained from 1966 till 2012 were collected from all accessible published sources. Some unpublished data available to us were included in the database as well. The presented observations were carried out using various telescopes and various ground-based and space-based polarimetric equipment, and methods including photoelectric and imaging techniques. The information about the observations is listed in Table 1. It includes authors of paper, names of the filter bandpass or effective wavelength of the bandpass as given in the paper, aperture of instruments used (or spacecraft name in case of spacecraft-based observations), average value of errors of linear polarization measurements, and the list of objects observed.

The database consists in two ASCII files. The first file contains the basic data of the catalogue in table form, while the second one contains references to the papers. The main table includes 23 columns, which are described in Table 2. There are the main observed characteristics of polarized light from planetary satellites (the degree of linear and circular polarization, the position angle of the polarization plane and their errors) as they are given in the original papers. Geometric observational circumstances (phase angle, the position angle of scattering plane, planetographic latitude and longitude of the sub-observer point) are calculated using the JPL Horizons ephemeris system[2]. Deviation θ_r of the plane of polarization θ from the direction perpendicular to the plane of scattering φ was calculated according to expression:

$$\theta_r = \theta - (\varphi \pm 90^\circ), \qquad (1)$$

where the sign in the brackets is chosen to fulfil the condition

$$\varphi \pm 90^\circ \leq 180^\circ, \qquad (2)$$

according to [3]. The negative and positive sign of linear polarization means that the angle θ_r is close to 90° and 0°, respectively.

Most of the observations were obtained with UBVRI, the standard wide photometric band system [9], and standard wide photometric band system VRI [5], but some measurements of polarization were obtained with no filters, or with wide-band filters, or with special filters described in corresponding papers. Some authors did not provide their papers with tables of polarimetrical observations results, and presented their results in figures instead. For such sources, polarization and phase angle values were obtained directly from figures. In many cases necessary geometric observational circumstances were absent in the original papers, and therefore are calculated using the JPL Horizons ephemeris system for all measurements of polarization, except spacecraft observations and values obtained from paper figures. There are no measurements of circular polarization for planetary satellites in the period of time covered by the compilation, but it is planned to carry out such observations and include them in a future update of the database.

For a more detailed description of the observations, equipment used, and data reductions, one is referred to the source reference, the list of which is given in the Database of Satellite Polarimetry table of references.

[2] `http://ssd.jpl.nasa.gov/horizons.cgi`

CONCLUSIONS

2460 measurements of linear polarization of planetary satellites are currently collected in the Database of Satellite Polarimetry (EAR-SA-COMPIL-3-SATPOL-V1.0, NASA Planetary Data System) [21]. The Database of Satellite Polarimetry is presented and described. The database can be used as the observational basis for detailed theoretical modelling, interpretation of the phase-angle and spectral dependence of polarization of planetary satellites, studying circumplanetary space, and selecting future space-mission targets.

It is planned to include polarimetry results for Saturn's Rings, as well as our not yet published results for satellites of Saturn and Uranus, in a future update of this data set.

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Table 1: Information about observations included in the Database of Satellite Polarimetry.

Authors	Spectral band or wavelength, Å	Instruments	Average error, %	Objects
Bolkvadze [1]	4000–7000	40-cm	0.10	Io, Europa
Botvinova & Kucherov [2]	3900–6850	60-cm	0.05	Io, Ganymede, Callisto
Chigladze [4]	4200–7000	40-cm	0.05	Io, Europa, Ganymede, Callisto
Degewij et al. [7]	B, G, V	91-cm, 208-cm	0.20	Himalia
Dollfus [6]	5500	60-cm, 100-cm, 107-cm	0.10	Io, Europa, Ganymede, Callisto
Ejeta et al. [8]	B, V, R, I	4×820-cm	0.02	Iapetus
Kiselev et al.[10]	V	70-cm	0.05	Io, Europa, Ganymede, Callisto
Morozhenko [12]	U, B, V, R	60-cm	0.03	Io, Europa, Ganymede, Callisto
Noland et al. [13]	5700	Mariner 9	4.00	Phobos, Deimos
Rosenbush et al. [14]	U, B, V, R	60-cm	0.06	Io, Europa, Ganymede, Callisto
Rosenbush & Kiselev [15]	U, B, V, R, I	70-cm	0.02	Io, Europa, Ganymede, Callisto
Tomasko & Smith [16]	Blue, Red	Pioner 11	0.30	Titan
Veverka [17]	3000–8000	40-cm, 154-cm	0.10	Io, Europa, Ganymede, Callisto
Veverka [18]	3000–8000	154-cm	0.20	Titan
Zellner & Gradie [19]	5500, G	154-cm	0.10	Io, Europa, Ganymede, Callisto, Iapetus
West et al.[20]	2640, 7500	Voyager 2	0.05	Titan
Zaitsev et al. (unpubl.)	U, B, V, R, I	125-cm, 260-cm	0.04	Io, Europa, Ganymede, Callisto
Zellner [22]	2330	154-cm, 229-cm	0.05	Deimos
Zellner [23]	G	154-cm	0.15	Iapetus
Zellner [24]	3600, 5200, 8300	61-cm, 224-cm, 226-cm	0.06	Titan

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Table 2: Description of the Database of Satellite Polarimetry file.

Position	Format	Label	Designation of column
1-9	A9	SATELLITE_NAME	Name of satellite
11-15	A5	SATELLITE_ID	IAU satellite designation
17-20	I4	OBS_YEAR	Year of observation
22-23	I2	UT_MONTH_OBS	Month of observation
25-26	I2	UT_DAY_OBS	Day of observation, UT
28-29	I2	UT_HOUR_OBS	Hour of observation, UT
31-32	I2	UT_MINUTE_OBS	Minute of observation, UT
34-35	I2	UT_SECOND_OBS	Second of observation, UT
38-46	A10	BAND_ID	Name of the filter bandpass
49-52	I5	CENTRAL_WAVELENGTH	Effective wavelength of the bandpass, Å
55-61	F8.3	PHASE_ANGLE	Phase angle, degree
64-68	F6.1	SUB_OBS_LONGITUDE	Planetographic longitude, degree
70-74	F5.1	SUB_OBS_LATITUDE	Planetographic latitude, degree
77-81	F6.1	SCA_ANGLE	Position angle of the scattering plane, degree
83-88	F6.3	LINEAR_POL	Degree of linear polaDegree of circular polarization, %
91-95	F6.3	LINEAR_POL_ERR	Error in linear polarization degree, %
98-102	F6.1	POL_ANGLE	Position angle of the polarization plane, degree
105-108	F5.1	POL_ANGLE_ERR	Error in the position angle, degree
111-116	F7.3	CIRCULAR_POL	Degree of circular polarization, %
119-123	F6.3	CIRCULAR_POL_ERR	Error in circular polarization degree, %
126-130	F6.1	POL_SCA_ANGLE	Deviation of the polarization plane, degree
133-138	F7.3	SCA_LINEAR_POL	Percent of linear polarization, refered to the perpendicular to the scattering plane, %
140-160	A21	REFERENCES	References according to references file