NEAR–INFRARED PHOTOMETRIC OBSERVATIONS OF THE INNER JOVIAN SATELLITES

I. Kulyk[1], **K. Jockers**[2], **N. Karpov**[3], **A. Sergeev**[3]

[1] *Main Astronomical Observatory, NAS of Ukraine*
27 Akademika Zabolotnoho, 03680 Kyiv, Ukraine
e-mail: `leda@mao.kiev.ua`

[2] *Max-Planck-Institut für Aeronomie*
D-37191 Katlenburg-Lindau, Germany
e-mail: `jockers@linmpi.mpg.de`

[3] *International Center for Astronomical and Medico-Ecological Research*
27 Akademika Zabolotnoho, 03680 Kyiv, Ukraine

The Galileo spacecraft observations reveal the inner moons of Jupiter as sources for the Jovian ring. Therefore, the question of existence and nature of regolith on the surface of these moons should paid more attention. We present the first results of an attempt to observe the opposition surge of these satellites with the 2-m Zeiss RCC telescope of the Terskol Observatory in October and November 1999. Images of Amalthea, Thebe, and Metis were acquired at solar phase angles from –3.3 to +2.5 degrees.
We present the results of the analysis of about 50 images obtained in the methane absorption band and provide absolutely calibrated magnitudes for these three satellites at small solar phase angles.

1. INTRODUCTION

During the Voyager mission, three of four small inner Jovian satellites were discovered.

Following the spacecraft observations, the main Jovian ring and small satellites were detected from the Earth, but these observations were limited because of difficulties caused by the light scattered by Jupiter (Beclin and Wynn-Williams, 1979; Jewitt *et al.*, 1981; Neugebauer *et al.*, 1981; Nicholson *et al.*, 1991). Spacecraft observations were continued with Galileo and HST and our knowledge about sizes, shapes, reflectances of these satellites and the ring structure was improved (Ockert-Bell *et al.*, 1999; Thomas *et al.*, 1998; Meier *et al.*, 1999).

Nevertheless, many specific problems connected with the alteration of the satellite surfaces by interaction with magnetospheric plasma, meteoroid impacts or by implantation of the sulfur ions from Io remain unresolved (Veverka *et al.*, 1986; Thomas *et al.*, 1998). An investigation of the inner moons brightness near their opposition can indicate the differences in their regolith and thus provide information about their environment. We present the first results of photometric CCD observations of Amalthea, Thebe, Metis made at small phase angles from –3.3 to 2.5 degrees.

2. OBSERVATION

We used the 2-m Telescope of the Terskol Observatory equipped with the Two–Channel Focal Reducer of the Max-Planck-Institute for Aeronomy (Küppers and Jockers, 1997). The number of images, the phase angles, and the orbital longitudes covered by the satellites are presented in Table 1.

All observations were performed with red channel of the device. The red channel has a CCD array with 576×406 pixel, the image scale is approximately $0\farcs83$ per pixel for an overall field of view of $7\farcm8\times5\farcm2$. To reduce the flux from Jupiter and the Galilean satellites, a filter consisting of Schott glasses NG1 (1 mm thick) and BG39 (0.3 mm thick) was placed in the Cassegrain focus to cover whole Jupiter's disk (see Küpper and Jockers, 1997). The observations were performed in the methane absorption band at 0.89 μm where the disk of Jupiter is comparatively dark. Each night, the spectrophotometric reference stars ζ Pegasi, $\pi2$ Orioni, $\xi2$ Ceti were observed at different airmasses in order to make the absolute photometric calibration as well as to measure extinction coefficient. Twilight sky was acquired for the flatfield frames. The integration time was from 120 to 300 sec for the frames with satellite images.

The satellite precise positions for the purpose of image identifications were taken from the Horizons Ephemeris System (*horizons@ssd.jpl.nasa.gov*).

Table 1: Summary of Images

Satellite	Date (UT, 1999)	Number of images	Phase angle (deg)	Longitudes covered (deg)
Thebe	23 October	7	0.31	102.9–115.3
	25 October	6	0.57	91.2–106.1
	2 November	5	2.25	290.1–310.1
	2 November	5	2.30	43.9–62.0
Amalthea	13 October	7	–2.27	46.7–82.4
	23 October	2	0.31	110.9–112.8
	2 November	6	2.27	57.2–72.9
Metis	8 October	7	–3.30	90.9–111.31
	2 November	1	2.26	263.1
	2 November	3	2.30	101.0–113.4

3. PROCESSING AND RESULTS

At the first step of image processing we made bias subtraction and flatfield correction for each frame. As it is well known, one of the main difficulties in observing the inner satellites and processing their images is the scattered light from the planet. The light diffracted by the support structure of the secondary mirror was removed by a Lyot stop that placed at the exit pupil of the focal reducer. The remaining aureole has circular symmetry and its brightness depends on the angular distance from the Jupiter's center. To account this part of the scattered light we recalculate each image into polar coordinates. Afterwords the linear interpolation was performed along diameters connecting the background fields on either side of the ring's system with the satellites. Interpolated background was transformed back in to rectangular coordinates and removed from the original image.

For each frame we examined how the total intensity of satellite's or star's image varies as a function of the distance from their center. The center of any image was estimated by two-component Gaussian fit. Aperture photometry was performed on all satellite and reference star images. A round aperture, 10 pixels in the radius, is the most suitable for stars, satellites Amalthea and Thebe. For the innermost satellite Metis it was necessary to decrease the aperture to a radius of 4 pixel. After this we estimated a residual background from an annular aperture with inner and outer radii 12 and 14 pixels respectively and subtracted this background from the total number of counts of a satellite. We performed an absolute photometry by comparing the integrated brightness of each moon image with the brightness of the standard star. The variation of the satellite/star atmospheric extinction is taken into account by means of the extinction coefficient.

The absolute energy distribution for reference stars was taken by Bessel (Bessel, 1999). To account for the filter width, the area of the stellar spectrum under the filter transmission curve was integrated and divided by the width of the filter's pass band.

The satellite magnitudes were reduced to the $r = 1\,AU$. They are given in Table 2. The internal standard error was calculated by averaging the several frames obtained in the same night neglecting the satellite orbital variations. These errors are included in the table too.

Table 2: Absolute magnitude for Thebe, Amalthea, Metis

Satellite	Elongation	Phase angle (°)	$M(1,\varphi)$ (mag)	rms (mag)
Thebe	E	0.31	7.86	0.05
	E	0.57	7.83	0.06
	W	2.25	8.31	0.10
	E	2.30	7.92	0.08
Amalthea	E	–2.27	6.19	0.04
	E	0.31	6.11	–
	E	2.27	6.24	0.03
Metis	E	–3.30	8.24	0.15
	W	2.26	8.56	–
	E	2.30	8.22	0.17

To derive the phase coefficients of satellite brightness we used all the data available for Amalthea and the images of Thebe obtained near the eastern elongation of the satellite.

The value of the phase coefficient for Amalthea 0.046 ± 0.015 mag/degree is in a good agreement with that obtained by Voyager images for phase angles 0.8–40 degrees and an effective wavelength near 0.48 μm (Veverka *et al.*, 1981). The phase coefficient for Thebe is 0.043 ± 0.021 mag/degree. Both values are comparable with those measured for other objects with rough, very dark surfaces (Clark *et al.*, 1999).

We did not estimate the phase variations of brightness of Metis because lack of the data near opposition. The absolute magnitudes for Metis indicate that the leading side for this satellite is brighter then the trailing one in agreement with Galileo data, but our estimates of the absolute magnitudes point to a higher geometric albedo for 0.89 μm then those derived from Galileo images (Thomas *et al.*, 1998).

4. CONCLUSIONS

Our results are in a good agreement with early measurements that indicate on the increase of a brightness of Thebe and Amalthea from the visible to 0.9 μm (Pascu *et al.*, 1992; Thomas *et al.*, 1998). The phase dependences of brightness at small solar phase angles are similar for Thebe and Amalthea.

The estimations of the brightness of Metis have a preliminary character due to insufficient photometric data for this satellite.

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