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Icy satellites of Saturn: disk-integrated observations of the brightness opposition surge at low phase angles

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The surfaces of most atmosphereless bodies exhibit two interesting optical phenomena at small phase angles, namely a strong brightness increase and negative values of the degree of linear polarization. Of particular interest is the appearance a nonlinear growth of the surface brightness and a second narrow minimum of polarization at phase angles less than 1-3°. These features of brightness and polarization in the narrow phase angle range near opposition are called the photometric and polarimetric opposition effects. These phenomena have attracted increased attention from the perspective of theories of light scattering in random media and their application to the determination of properties of the upper optically active regolith layers on the atmosphereless bodies. However, up to now photometric and especially polarimetric observations conducted at small phase angles are rare. In order to enlarge the amount of available observational data we have conducted photopolarimetric observations of the major icy Saturnian satellites. The observations were performed at the 2m-telescope of the Bulgarian National Observatory with the Two-Channel Focal Reducer of the Bulgarian Academy of Sciences built at the Max-Planck-Institute for Solar System Science. This instrument incorporates a two-channel imaging polarimeter which can be used in coronagraph setup. The light of Saturn and its rings is almost fully absorbed by a black glass and its diffraction pattern is eliminated by a Lyot stop. The photopolarimeter records intensity and degree of polarization of the satellites in two colors simultaneously. In this study, we present the first results of the disk-integrated photometry of Enceladus, Tethys, Dione, and Rhea in the red (center wavelength 694 nm, FWHM 79 nm) and near-infrared (center wavelength 888.5 nm, FWHM 29 nm, methane absorption band) spectral bands at phase angles between 5.6° and 0.01°. The resulting magnitudes can be represented as a sum of two terms, one describing the solar and the other one the rotational phase dependence. The satellites Enceladus, Tethys, Dione, and Rhea demonstrate a sharp brightness increase in the narrow backscattering domain at phase angles between 0.7° and 0.01° and reveal the presence of a narrow component of the brightness opposition effect, which has not been recorded previously for these moons except for Enceladus. The slopes of the low phase angle portion of the moon's phase curves, particularly of the phase curves of Tethys and Rhea, are extremely high and exceed the slope of Europa's phase curve at opposition. The shape of the phase curves as well as the strength of the opposition effects both indicate that the mechanism of constructive wave interference is a strong contributor to the opposition effects of the high albedo Saturnian satellites. At the same time, Enceladus' backscattering peak is broader and weaker despite of the satellite's extremely high albedo. This may be caused by the fact that the warmer ice grains on the surface of this satellite are larger and have a smoother surface. Therefore coherent effects related to scales comparable to the wavelength are suppressed. The rotation curves of the satellites confirm that the leading/trailing albedo asymmetry known from previous visual observations extends into the red and near infrared wavelength range. The amplitudes of hemispherical asymmetries in the red and near infrared are quite similar and amount to 4%, 8%, 38%, and 18% for Enceladus, Tethys, Dione, and Rhea respectively.