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Brightness and polarization opposition effects exhibited by Tethys, Dione, and Rhea at low phase angles

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An analysis of phase dependences of the backscattering intensity and polarization state of the radiation scattered by an atmosphereless surface can be especially informative in a narrow phase angle region near opposition, where so-called brightness and polarization opposition effects take place. In this narrow backscattering domain, the scattered light is directly related to the physical characteristics of scattering medium such as packing density, an effective refractive index, sizes and shapes of constituent particles.

The icy Saturnian satellites Tethys, Dione and Rhea are very challenging objects for the investigation of the opposition phenomena because the high albedo surfaces of these satellites, which are covered with nearly pure water-ice, undergo physical and chemical changes due to their interaction with the strong Saturnian magnetosphere and E-ring particles. The latest Cassini observations suggest that the global variation of surface optical properties is caused predominantly by exogenic processes. The analysis of the brightness and polarization behavior near opposition can provide potentially useful information for understanding the distribution of the complex pattern of materials over the satellites' surfaces as well as enlarge the data base for the verification of theories of light scattering in random media. Therefore, the focus of the presented investigation was to find the possible differences in the satellites' upper optically active layers by means of photometric and polarimetric observations, which were collected in the phase angle interval from 5.3 to 0.01 deg and at three different wavelengths, that is, in the blue, red and infrared color bands.

The main findings of the presented analysis are following. The disk-integrated photometric phase curves of Tethys, Dione, and Rhea, corrected for the longitude brightness variations, revealed a steep non-linear intensity growth in the narrow backscatter domain of phase angles less than 2 deg. The measured polarization state was found to be negative, implying that the profiles of polarization phase dependences are most probably irregular with a steep descent and minima at phase angles approximately equal to the angular widths of the corresponding intensity peaks. Both, the profiles of the intensity backscatter peaks and the observed polarization phase dependences provided evidence in favor of the coherent backscatter mechanism as the main contributor to the opposition effects of Tethys, Dione, and Rhea. Surprisingly, the polarization phase dependences demonstrated deep minima of negative polarization at small phase angles with the exception of Tethys' leading hemisphere and the brightest area of Rhea's leading side (W-longitudes are between 100 and 180 deg), which are likely due to very high albedos and low abundances of contaminants in Tethys' leading side and the bright area of Rhea's leading hemisphere. Finally, the comparison of the longitude dependences of the water-ice absorption bands, deduced from Cassini VIMS observations of Rhea and Dione, with the measured polarization in a narrow range of the phase angles around 5 deg, where contribution of a phase angle effect is thought to be reduced, suggest that the larger negative polarizations (in absolute values) correspond to areas, which surface materials are more contaminated and most likely composed of smaller regolith grains.