宇宙科学特別研究 I

偏光撮像装置 “**HOPS**” で探る金星上層ヘイズ

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総合研究大学院大物理科学研究科宇宙科学専攻
所属研究室 佐藤毅彦研究室

学籍番号 20121151
榎本孝之

概要

Venus has very thick cloud of which optical depth is large enough to obscure the ground in visible light. Hansen and Hovenier [1974] analyzed the polarization data obtained by ground–based observations during 1960', based on the multiple light scattering theory including polarization effect, and proposed that the cloud particles of Venus are composed of H_2SO_4 droplets whose effective radius and effective variance are 1.05μm and 0.07 respectively. This fact was verified again by Orbiter Cloud Photopolarimeter (OCPP) onboard Pioneer Venus Orbiter (PVO). OCPP can map spatially-variable polarization of reflected sunlight from Venus, and it was newly found that many sub micrometer sized particles "hazes" were distributed mainly on polar regions. In addition, the optical depth of the haze layer had declined exponentially during the mission period [Sato et al., 1996]. Similar trend of the SO_2 abundance was also reported from PVO [Esposito, 1985]. The variation of the optical depth of the hazes has not been studied since PVO, so it is not clear that there is a similar correlation between them.

To monitor the distribution of the Venusian upper hazes, we developed an imaging-polarimetry system "HOPS" (Hida Optical Polarimetry System) and performed observations by attaching it to the 65cm refracting telescope at Hida Observatory of Kyoto University. As HOPS provides pixel-by-pixel polarization map, polarization in an arbitrary area can later be obtained just by summing up the corresponding pixels for comparison with previous measurements. This is the biggest advantage of imaging polarimetry against the aperture measurements. Additionally, there were no monitoring research through the ground based observations since PVO, so our study provides the latest information about microphysical properties of hazes continuously.

The observations were carried out at solar phase angles around 39° (Jul., 2013), 56° (Aug., 2013), 58° (Oct., 2012), 85° (Aug., 2012) and 129° (May, 2012) at 4 selective wave lengths 438nm, 546nm, 650nm and 930nm; 546nm and 930nm data can be compared with PVO data. HOPS is a "two beam type" polarimetry instrument which enables high accurate measurements against variable atmospheric conditions. The effect of variable atmospheric transparency, non-uniformity of sensitivities over the CCD pixels and different throughputs of two beams can be corrected through arithmetic operations in image processing. However, the time variable image blurring due to atmospheric turbulence remains source of errors. The estimated errors using artificial polarization maps, whose polarization degrees are 5% at polar regions, are around ±1% (relative error: ±20%). The position angle of the fast axis of a half–wave retarder in HOPS were determined by observing standard polarized and unpolarized stars. The polarization data of actual observations were corrected by considering the orientation of the Sun–Venus plane and instrument rotator, and this angle.

We compared the data with PVO data at wavelength 930 and 546nm directly. The clear differences appear at polar regions in 930nm. The neutral point of our data is found to be at around 75° while the point of PVO is around 40°. This difference may indicate the different situation of the distribution of hazes. In addition, several days of data taken in a single observing run (the solar phase angle can be considered the same) indicate possible oscillation of polarization. Previously, Nagata et al. [1984] reported oscillation of polarization, in infrared, with a period of 4.5 days. The cause may be either changes of aerosol properties or changes of low-latitude boundary of the haze. Because the date at phase angle 129 exhibits a large north-south asymmetry (the northern polar haze appears much more confined near the pole than the south), such oscillating polarization may possibly be a manifestation of longitudinal variation of the haze boundaries.

We developed a radiative transfer calculation code using Adding–Doubling model [de Haan et al., 1987, Hovenier et al., 2004] to analyze the polarization data. This calculation code introduces "Super Matrix" for integrating several matrix products for the purpose of good efficiencies of the numerical integration processes. The accuracy of the code has been verified for model atmospheres including particles whose scattering properties are isotropic [van de Hulst, 1980], Henyey–Greenstein

functions [van de Hulst, 1980], Rayleigh scattering and Mie scattering [de Haan et al., 1987]. The accuracy is perfect for non–conservative isotropic scattering atmosphere and conservative and non–conservative Henyey–Greenstein functions. However, for conservative isotropic scattering semi infinite atmospheres the relative error of the calculations are around 0.02%. Additionally, the errors of the calculation is less good (max $\sim$ 3%) for the atmosphere including Mie scattering particles. These errors must be reduced in the future, but the current accuracy is good enough compared with the errors caused by atmospheric turbulence during observations.

The comparisons of the theoretical polarization degrees with observation data are performed by calculating the averages of sum of squared residuals (SSR) for three wavelengths 930nm, 650nm and 546nm. We treated cloud particles effective radius $r_{\mathrm{eff,c}}$, effective variance $v_{\mathrm{eff,c}}$, refractive index n_r and haze particle effective variance $v_{\mathrm{eff,h}}$ as fixed parameters, and haze particle effective radius $r_{\mathrm{eff,h}}$ and optical depth τ_{h} as free parameters, respectively. The resultant parameters for northern polar region are $r_{\mathrm{eff,h}} = 0.22\mu$m, $\tau_{\mathrm{h}} = 0.09$ and for southern polar region $r_{\mathrm{eff,h}} = 0.20\mu$m, $\tau_{\mathrm{h}} = 0.05$ at 930nm. The optical depth is smaller compared with the initial observations of PVO $\tau_{\mathrm{h}} = 0.25$ but comparable with those observed during the declininig phase. Such declination of the abundance of SO_2 is also observed by Venus Express orbiter [Marcq et al., 2012], so our results are consistent with the report of the correlation with it.