A new constraint on HCl abundance at the cloud top of Venus by IRTF/iSHELL observations

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The atmosphere of Venus can be vertically divided into three regions with different chemical conditions. Thermodynamic equilibrium reactions are dominant in the lower atmosphere up to 60 km under high temperature and pressure conditions. The middle atmosphere between 60 and 110 km is controlled by photochemistry driven by solar UV radiation. In the upper atmosphere above 110 km, dissociation, ionization, and ionospheric reactions are important processes.
HCl is the primary chlorine reservoir in the Venus' atmosphere below 110 km. Highly reactive chlorine species (ClO_x), which is produced by solar UV photolysis of HCl, has been proposed to play an important role in catalysis of CO and O recombination to CO_2, thereby stabilizing the CO_2 atmosphere. Chlorine chemistry is also linked to the source and sink of SO_2, and its understanding is necessary to explain the observed vertical distribution of SO_2.
Interestingly, there is a large inconsistency between the HCl abundances measured by spacecraft and ground-based telescopes. The SOIR instrument onboard Venus Express measured its abundance as less than ~50 ppb at the cloud top (~70 km) increasing with altitude, reaching to 1 ppm in the upper atmosphere (~110 km) [Mahieux et al., 2015]. Such a vertical trend conflicts with the results obtained by sub-mm ground-based observations which inferred a vertically constant profile (up to ~80 km) [Sandor and Clancy, 2012]. Near-infrared ground-based observations also showed the HCl abundance at the cloud top as ~500 ppb [Iwagami et al., 2008; Krasnopolsky, 2010], which was nearly one order of magnitude larger than the SOIR results. The reason for this inconsistency has not been understood yet.
In order to revise the HCl abundance at the cloud top, we carried out a high-resolution spectroscopy of Venus' dayside at wavelengths of 3.580-3.934 μm with IRTF/iSHELL on August 5-7, 2018 and August 18-20, 2020 (UT). Venus was near its greatest eastern and western elongations, respectively, in the observation periods. Taking the full advantages of iSHELL's high spectral resolution of R ~ 75,000 with a high relative Doppler-shift of Venus seen from the Earth, iSHELL enabled us to observe individual HCl lines with less contamination by terrestrial lines. We analyzed two cross-dispersed echelle orders (orders 142 and 144) which contained retrievable lines of $H^{35}Cl$, $H^{37}Cl$, and $^{16}O^{12}C^{18}O$. With using radiative transfer modeling, $H^{35}Cl$ and $H^{37}Cl$ abundances were derived after cloud top altitude was retrieved from several $^{16}O^{12}C^{18}O$ lines.
HCl abundance at the cloud top showed neither significant latitudinal nor local time dependence and its average value was 0.39±0.01 ppm. The value supported previous ground-based measurements [Krasnopolsky et al., 2010; Sandor and Clancy, 2012]. The isotopic ($H^{35}Cl/H^{37}Cl$) ratio also had no remarkable trend and was 3.05±0.17, which was a similar value to that for the Earth (3.13).
In this presentation, we will show HCl abundance and its isotopic ratio at the cloud top, retrieved from the iSHELL spectra and compare them with the previous studies. Finally, we will discuss a possible reason why there is an inconsistency between spacecraft and ground-based observations.

Keywords: Venus, atmosphere, ground-based observation, radiative transfer

