Solar system observations with ALMA: Understanding the dynamics and chemistry of Venus atmosphere

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Venus, a neighbor planet of the Earth, has atmosphere significantly different from that of our planet. It is covered by a dense CO2 atmosphere and thick H2SO4 clouds. Although the planet itself rotates with a very slow speed (1.4 m/s), the Venus atmosphere moves about 60 times faster than the surface. Such a zonal wind (a.k.a. “super-rotation”) governs the dynamics of Venus atmosphere below the cloud layer. On the other hand, different characteristics in the wind pattern appear in the upper atmosphere. One of the most predominant components of the atmospheric dynamics in the upper atmosphere is the sub-solar-to-anti-solar (hereafter, “SSAS”) flow, driven by the thermal gradient between the dayside and nightside. It is considered that the superimposition of these two (zonal and SSAS) wind patterns is the key to describe the dynamics in the middle atmosphere (mesosphere) of Venus [Lellouch et al., 1997].
The wind in the Venus middle atmosphere has been investigated through the Doppler shift measurements of submm/mm CO absorption lines. Recent observations [e.g., Clancy et al., 2010, Moullet et al, 2012] revealed that the strengths of the zonal and SSAS flows (in a global scale) are highly time variable, and also localized significant inhomogeneity exists. Such temporal and spatial variability may be induced by activities of waves (gravity wave, for example), as predicted by GCM numerical simulations [e.g., Hoshino et al., 2012]. To advance the understanding on Venus dynamics, observational information with “high spatial resolution” and “high temporal resolution” are most required. Using single-dish submm/mm telescope often has a limitation in the spatial resolution (~10 arcsec, typically). Some improvement in the spatial resolution has been achieved by previous submm/mm interferometric observations but at the expense of the time resolution (~one day). Considering these facts, it can be said that ALMA is one of the most favorable facilities to study the atmospheric dynamics in Venus: ALMA provides a spatial resolution of sub-arcsec level with only a couple of minute’s data integration, i.e., “snap-shot” of Venus map in submm/mm wavelengths.
In addition to the scientific interest on the atmospheric dynamics, understanding the chemistry (including the chemistry related to H2SO4-cloud formation) in the Venus atmosphere is also a scientific subject which has been debated for years. ALMA can be a very powerful tool for this scientific interest as well. Its high sensitivity enables the observations of minor species such as SOx and HDO, and also its capability of observing at higher frequencies opens a door to the mapping of newly observed species such as HCl. HCl is an important reservoir for highly reactive chlorine (ClO*x*) species. While HCl was detected from ground for the first time in 2010 at 625 GHz [Sandor and Clancy, 2012], its spatial and diurnal variations are still left unrevealed.
In this study, we review the new findings with respect to the atmospheric dynamics and chemistry of Venus during the ALMA early science operations. Encrenaz et al. (2015) successfully observed Venus with ALMA in the Cycle-0 semester. They obtained the distribution maps of CO, SO, SO2, and HDO. The SO and SO2 maps showed significant local variations and also day-to-day temporal variation. From their CO data, the wind map can be also derived [Encrenaz, in private communications].
Subsequently, in the Cycle-2 semester, we challenged Venus HCl mapping using Band-9 (625 GHz) configuration. Unfortunately the quality of observation was severely limited due to the very low elevation angle of Venus. Careful data reduction is on-going, and we will present the first results

obtained from the ALMA Band-9 observations.

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