DISK-INTEGRATED THERMAL PROPERTIES OF CERES MEASURED AT MILLIMETER WAVELENGTHS. Jian-Yang Li[1], A. Moullet[1], T.N. Titus[1], H.H. Hsieh[1], M.V. Syke[1], [1]Planetary Science Institute, [2]SOFIA/USRA, [3]US Geological Survey (jyli@psi.edu).

Introduction: Recent Dawn observations suggested a water ice-rich subsurface of Ceres [1-4]. Understanding the thermal conditions on Ceres is especially important for constraining the present-day distribution of subsurface water ice on Ceres. We observed Ceres at mm wavelengths with the Atacama Large Millimeter/submillimeter Array (ALMA) to ascertain its temperature and subsurface thermal properties. We also searched for HCN species around Ceres in light of the detection of water vapor on Ceres [5]. The ultimate goal of our observations is to map the thermal inertia on Ceres. In this abstract, we report the results derived from the disk-integrated brightness temperature measurement that constraints the average thermal inertia and dielectric properties of Ceres regolith.

Observations: We observed Ceres in three epochs in 2015 October 31 to November 12, 2017 September 26 to 31, and 2017 October 15 to 26. All observations were performed with the 12-m array targeting the thermal continuum at an average frequency of 265 GHz. We also included the ALMA Compact Array in the 2017 October epoch, in order to precisely measure the total flux of Ceres, but with one sideband tuned to detect the emission line of HCN J=3-2 transition. All observations used Band 6. Each observation is composed of three tracks on Ceres and covers one full rotation of Ceres.

All data were calibrated using ALMA's automated science pipeline package. In order to obtain reliable absolute flux calibration, we used a common quasar available in our data in the two 2017 epochs. The flux calibrate is good to 10%.

Lightcurve: The rotational lightcurve of Ceres at 265 GHz has an amplitude of 4% with double peaks. The flux density is relatively low in the eastern hemisphere compared to that in the western hemisphere. Both the amplitude and the overall shape and phasing of the lightcurve from our data are consistent with previous observations at similar frequencies [6,7]. Given the low Bond albedo of Ceres of about 3% [8], the small rotational variations in reflectance lightcurve [9], and the almost oblate shape of Ceres [10], the variations in the 256 GHz lightcurve are most likely caused by variations in thermal inertia or dielectric properties of the top regolith of Ceres.

HCN Search: We did not detect any emission line at the expected frequency of HCN J=3-2 transition. The noise level of our spectrum after binning to a velocity resolution comparable to ~2/3 of the thermal velocity on the surface of Ceres is about 54 mJy. Based on this noise level, assuming a global production and a Haser model for HCN distribution, we derived an upper limit production rate $Q_{HCN}=2\times10^{24}$ molecules/s.

Thermal Modeling: We performed thermal modeling of Ceres to interpret the disk-averaged brightness temperature of Ceres. The thermal flux at 265 GHz, or about 1.3 mm in wavelength, is affected by both the surface temperature, and the subsurface temperature profile and the dielectric properties of Ceres. The dominant factor, loss tangent, which characterizes the absorption length of subsurface emission, is completely unknown for Ceres. We therefore assumed a series of values for thermal inertia, and calculated the expected brightness temperature with respect to loss tangent (Fig. 1).

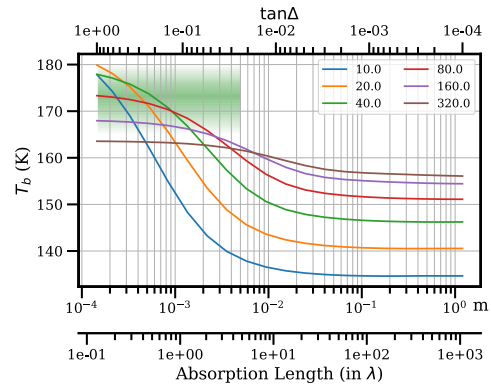

Fig 1. Modeled brightness temperature for Ceres with respect to electrical absorption characteristics and thermal inertia. Different curves correspond to different thermal inertia. The green shaded area marks the range of our measurement. The measured range of brightness temperatures allows for a range of loss tangent >~0.02, or electrical absorption length <~5 mm or ~5 wavelengths regardless of thermal inertia.

Our modeling suggests that the loss tangent of Ceres top regolith is much higher than those of lunar-like materials and of some asteroids such as Vesta, which is in the order of 10^{-3}. We attribute this difference to the unique clay mineral composition of Ceres [11]. The thermal inertia of Ceres is probably between 40 and 160 in the SI unit, which is also much higher than previous results derived from the thermal infrared [12], although most recent work from Dawn suggested higher thermal inertia for some regions [13]. This might suggest variations in thermal inertia with respect to depth.

We acknowledge SSERVI-TREX grant to PSI.

References: [1] Ruesch et al. 2016; [2] Hiesinger et al. 2016; [3] Sizemore et al. 2017; [4] Prettyman et al. 2017; [5] Küppers et al. 2014; [6] Altenhoff et al. 1996; [7] Moullet et al. 2010; [8] Li et al. 2019; [9] Li et al. 2006; [10] Russell et al. 2016; [11] De Sanctis et al. 2016; [12] Spencer et al. 1989; [13] Rognini et al. 2020.