Disk-Integrated Thermal Properties of Ceres Measured at Millimeter Wavelengths

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Introduction: Recent Dawn observations suggested a water-ice-rich subsurface of Ceres. Understanding the thermal conditions of Ceres is important for constraining the present-day distribution of subsurface water ice and the related geology on Ceres to support future in-situ explorations. We report the disk-integrated thermal modeling of Ceres based on three epochs of observations of Ceres with the Atacama Large Millimeter/submillimeter Array (ALMA) at 265 GHz. In addition, water outgassing has been mysterious on Ceres, with a couple detections but more searches with non-detections. We searched for HCN around Ceres with the ALMA compact array (ACA) in October 2017 and did not detect it.

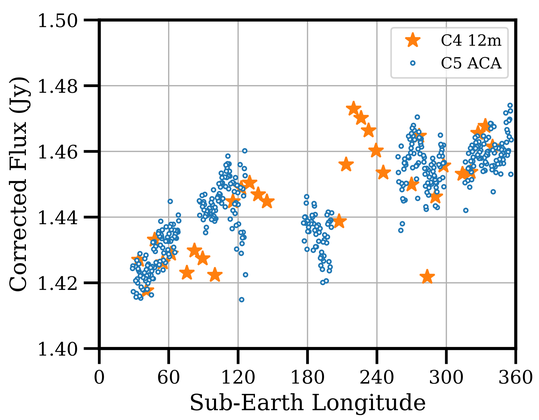

Fig. 1. Rotational lightcurve of Ceres at ~1.1 mm wavelength from ALMA Cycle 4 12 m data (C4) and Cycle 5 ACA data (C5), corrected to the mean geocentric distance. Our thermal lightcurve of Ceres is similar in shape and phasing as the visible lightcurves of Ceres from the literature. The thermal flux variations due to rotation is about 0.05 Jy, or about 6 K in brightness temperature. Our modeling suggested that the observed thermal lightcurve variation is due likely to the variations in subsurface thermal properties or dielectric properties, or both.

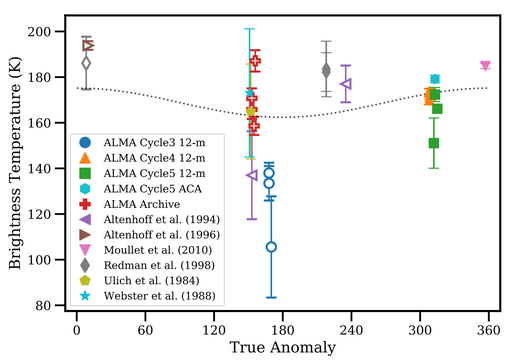

Fig. 2. Brightness temperature measurements of Ceres at 200 – 300 GHz from our data and from historical observations. The dotted line marks the expected annual temperature curve based on an STM assuming an emissivity of 0.8 with no infrared beaming. Overall our ALMA data agree with historical data, although the Cycle 3 measurement and the data from Cycle 5 12 m appear to be lower than the overall trend and could be due to artifacts. A seasonal trend is evident, with a thermal delay of 60° – 90° in true anomaly with respect to STM.

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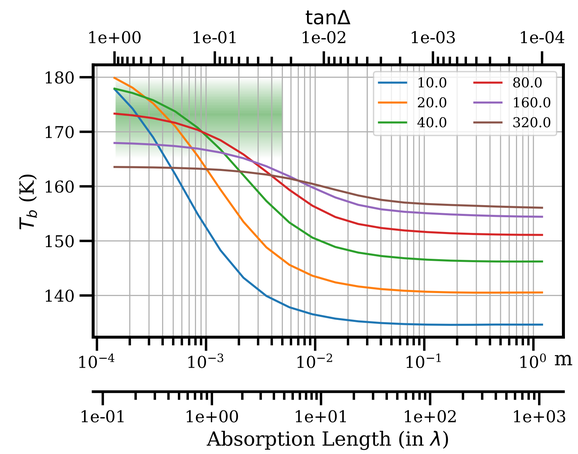

Fig. 3. Modeled disk-averaged brightness temperature plots for Ceres for the geometry of our October 2017 observations with respect to electrical absorption parameters. Different curves correspond to different thermal inertia from 10 to 320 SI unit. The green shaded area marks the range of our measured brightness temperatures centered at about 173 K. The upper x-axis is loss tangent. The two lower x-axes are absorption length in meters and in units of wavelength (1.13 mm), respectively. Our modeling suggests a loss tangent of >~0.02, and a thermal inertia likely between 40 and 160 in SI unit for Ceres.

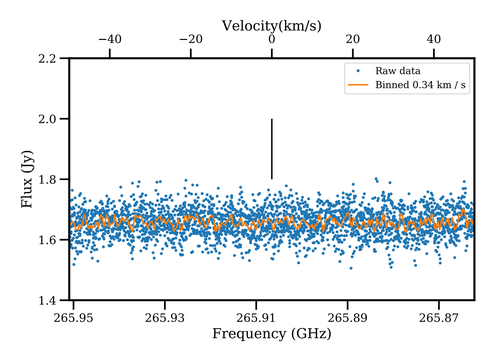

Fig. 4. Spectrum of Ceres observed with ACA centered at the HCN J=3-2 line. The vertical bar shows the expected position of the line. No emission line is detected. The corresponding 3-sigma upper limit Q_{HCN} is $2x10^{24}$ s^{-1}, assuming LTE and optically thin condition.

Conclusions:

1. Rotational variations in the subsurface thermal emission are detected for Ceres, due likely to variations in thermal inertia, or dielectric absorption, or both.
2. Seasonal temperature variations exist on Ceres, possibly with a large thermal delay from the perihelion/aphelion.
3. The electric absorption of Ceres top layer regolith at 1 mm wavelength is much higher than those of lunar-like material and asteroidal and cometary materials previously measured. Combined with previous radio observations at other frequencies, the frequency characteristics of dielectric absorption on Ceres is unique and probably correlate to its phyllosilicate and/or salt composition.
4. No HCN J=3-2 emission line is detected, suggesting a 3-sigma upper limit production rate of $2x10^{24}$ s^{-1}, assuming LTE and optically thin.
5. The constraints on the global average thermal inertia and dielectric properties are inputs to our follow-on disk-resolved thermal mapping analysis of Ceres that is currently ongoing. Both thermal maps and dielectric absorption maps will be useful for future in-situ explorations including radar experiments.