Water on Asteroids? A Spitzer-IRS Search, to be Continued with MIRI

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Questions?
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One-Minute Summary:

- It's reasonable to expect water vapor, and possibly other volatiles, around certain asteroids. Diagnostic features are in the MIR.
- We started re-analyzing all IRS spectra of asteroids (~5—30 μm).
- So far, we found no evidence for water vapor. Given the low gas temperature, this is not surprising.
- We will look for other gas features, though.

- Will MIRI see water vapor from asteroids? Probably not.
- HCN, H_2C_2, and CO_2 (all in MRS channel 3b) may be observable (abundance permitting) if SNR in the thousands can be reached. We'll know more in 2018 thanks to space missions Hayabusa-2 and OSIRIS-REx.

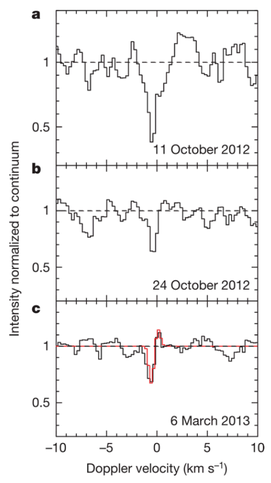
Background

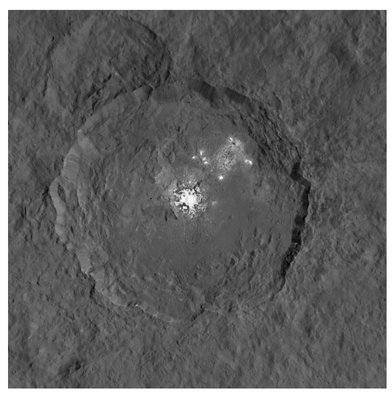
Earth's water appears to have an extraterrestrial origin, with comets and asteroids being possible sources. Isotope measurements favor asteroids (e.g., Sarafian et al., 2014), especially C-class asteroids, the parent bodies of the water-rich carbonaceous chondrite meteorites.
(1) Ceres is the largest C-class asteroid. As shown on the right, water vapor emanating from Ceres can be observed in the far-IR. Another C-class asteroid, (24) Themis, shows water-ice features in the NIR (Rivkin & Emery, 2010; Campins et al., 2010). This motivated us to search the Spitzer archive for serendipitous water vapor detections around asteroids in IRS spectra (~5—30 μm).
The next instrument to cover this wavelength range, at improved spectral resolution and greatly improved sensitivity, will be JWST-MIRI.

Water on Ceres

Left panel: Herschel-HIFI detection of the ~557GHz 1_{10}–1_{01} line of ortho-water (Küppers et al., 2014)

Right panel: bright surface spots imaged by Dawn may be water ice
(Image credit: NASA/JPL-Caltech/ UCLA/MPS/DLR/IDA).





Spitzer-IRS data analysis

Spectroscopic asteroid observations were identified based on the filtered observing log for Solar System Objects provided by the Spitzer Science Center: NAIF ID > 2000000 and AOTs irsstare and irsmap. This resulted in a list of 358 AORs.
For each AOR, we downloaded the Basic Calibrated Data (pipeline version S18.18.0) from the SHA. We ran the C2D pipeline (Lahuis 2007) for de-fringing and spectral extraction (both aperture photometry and PSF fitting are used).
Resulting spectra were examined for correlation with water vapor. No significant match was found.

Using MIRI, what volatiles can be observed off asteroids?

We coarsely estimate expected column densities and compare them with models of line depth for MRS's spectral resolving power. We consider C-class asteroids, the most volatile-rich class.

- Ceres' column density of water vapor is ~10^{14} cm^{-2} (see Fig. 1).
- Once off the surface, gas cools down quickly; it will be seen in absorption against the thermal emission of the asteroid. Water lines in MIRI's wavelength range are sensitive to warm gas (T ~ 100's K; see van Dishoeck et al., 2014). We don't expect MIRI to detect water vapor around asteroids. This is consistent with our non-detection (so far) of water in IRS data.
- Other volatile species that show potentially observable absorption lines in MIRI's wavelength range include C_2H_2, CO_2, HCN, HNC, NH_3, C_4H_2, C_6H_6 (Bast et al., 2013; absorption features for cold gas and R=3,000 are deeper than 1% for column density 10^{16} cm^{-2}; see also Fig. 2 on the right). For column densities matching that of H_2O @ Ceres (10^{14} cm^{-2}), they would result in absorption features that are observable, in principle, for brighter asteroids where SNR in the thousands can be reached easily.
- On comets, water is the most abundant volatile species (e.g., Bockelée-Morvan et al., 2005), with relative abundances of ~10% for CO and CO_2; ~1% for CH_4, C_2H_6, CH_3OH, H_2CO, NH_3, H_2S. If both Ceres' water column and cometary relative abundances are valid proxies, volatiles evaporating from asteroids will be unobservable by MIRI.
- However, we should be ready to be surprised in 2018, when the space missions **Hayabusa-2 and OSIRIS-REx** arrive at their C-class near-Earth asteroid targets. If any indication for high volatile abundance is found, MIRI-MRS is in a good position to check it.

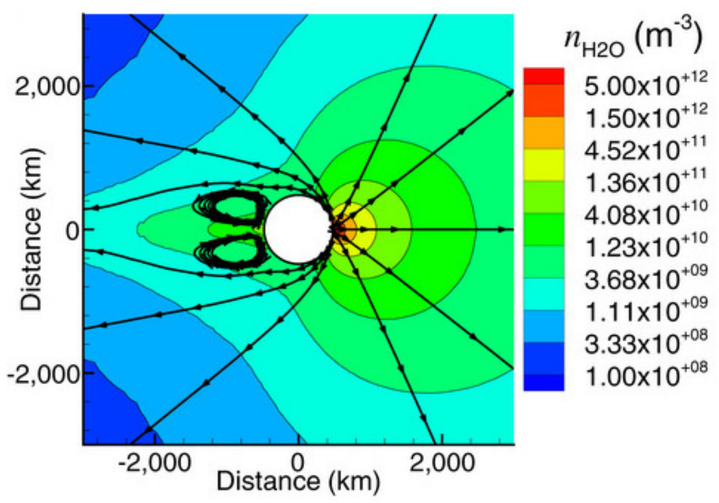


Fig. 1: Modeled water-vapor density around Ceres (Küppers et al., 2014, Extended Data Figure 2a; Sun is right). Integrating towards the Sun, we estimate the column density toward the observer (co-aligned with the Sun to within 20°) to be **~10^{14} cm^{-2}**.

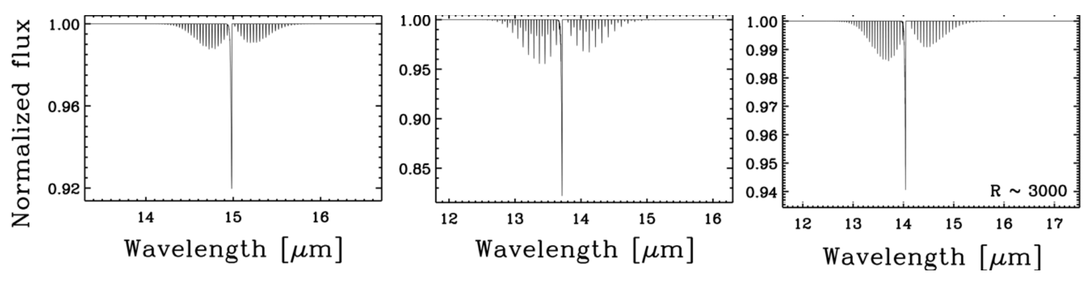


Fig. 2: Absorption spectra (taken from Bast et al., 2013, appendix B) of **CO_2, C_2H_2, and HCN** (left to right) for T=200 K, R=3,000 (appropriate for MIRI-MRS), and column density of 10^{16} cm^{-2}. For 10^{14} cm^{-2}, lines would be ~100 times less deep.
Note that the CO_2, C_2H_2, and HCN features lie in the same MIRI-MRS channel (3b), so they could be observed simultaneously.

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