

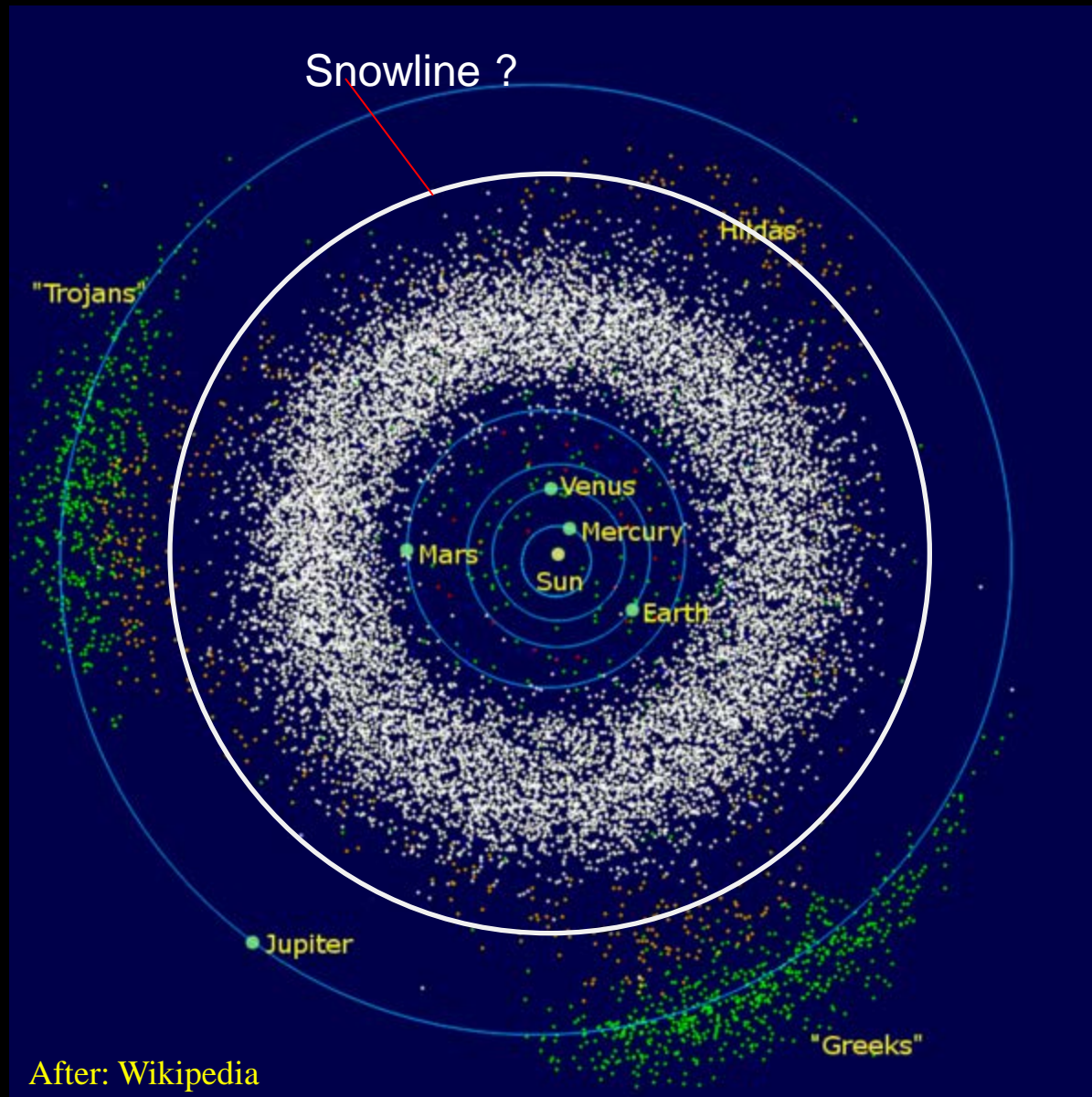
How is water released from Ceres ?

M. Küppers¹, L. O'Rourke¹ and the MACH-12 and various other teams

¹ESA/ESAC, Villanueva de la Cañada, Spain

- 1) Introduction
- 2) What do we know about water release from Ceres?
- 3) Which models do agree with the observations

Volatile rich and inert (rocky) bodies



Classical picture:
Snowline in the solar system somewhere between asteroid main belt and Jupiter's orbit:

- Giant planets and comets are icy
- Terrestrial planets and asteroids are dry
 - Earth oceans come from outer solar system !?

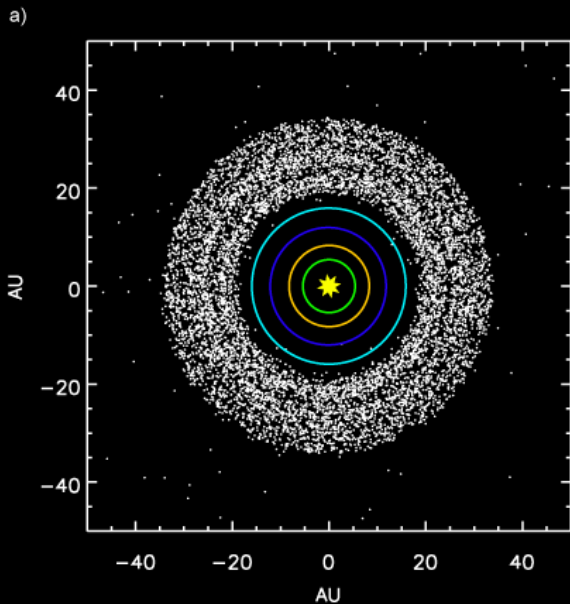
After: Wikipedia

Ceres: General Properties

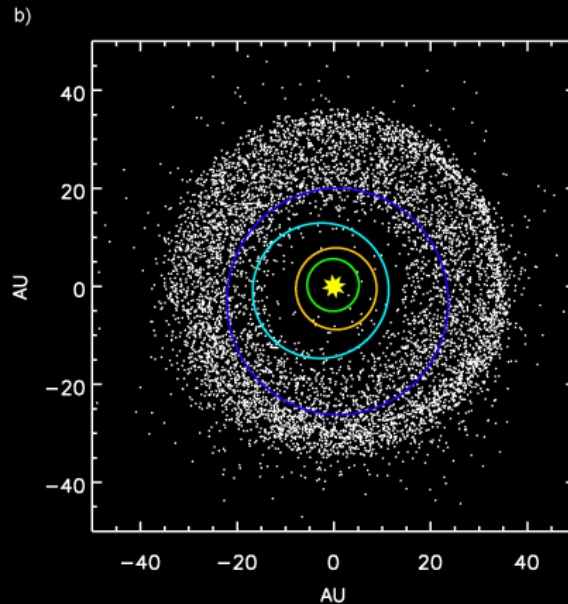
- First detected (Piazzi 1801) and largest main belt object
 - ❑ Mean diameter 945 ± 23 km, mass 9.44 ± 0.06 kg, density 2.13 ± 0.05 g/cm³
 - ❑ Ceres constitutes ~30 % of the mass of the main belt
- Obliquity slightly too low for a homogeneous body
 - ❑ Ceres is suggested to be differentiated (Thomas et al. 2005)
- Ceres low density suggests that 17-27 % of its mass are water ice
 - ❑ If composed of silicates and ice
 - ❑ If neither compression nor porosity are important
 - ❑ A subsurface ocean is a possibility (McCord and Sotin 2005)

Limitations of the classical picture: Planetary Migration (Nice model)

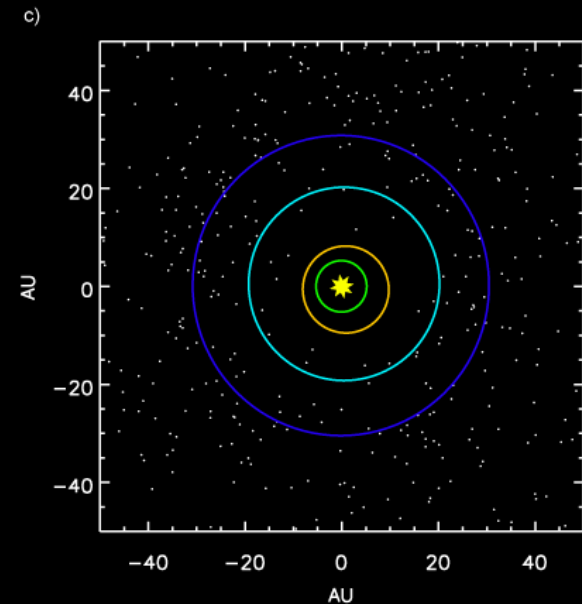
Before migration



3 Mys after start of migration



200 Mys after start of migration



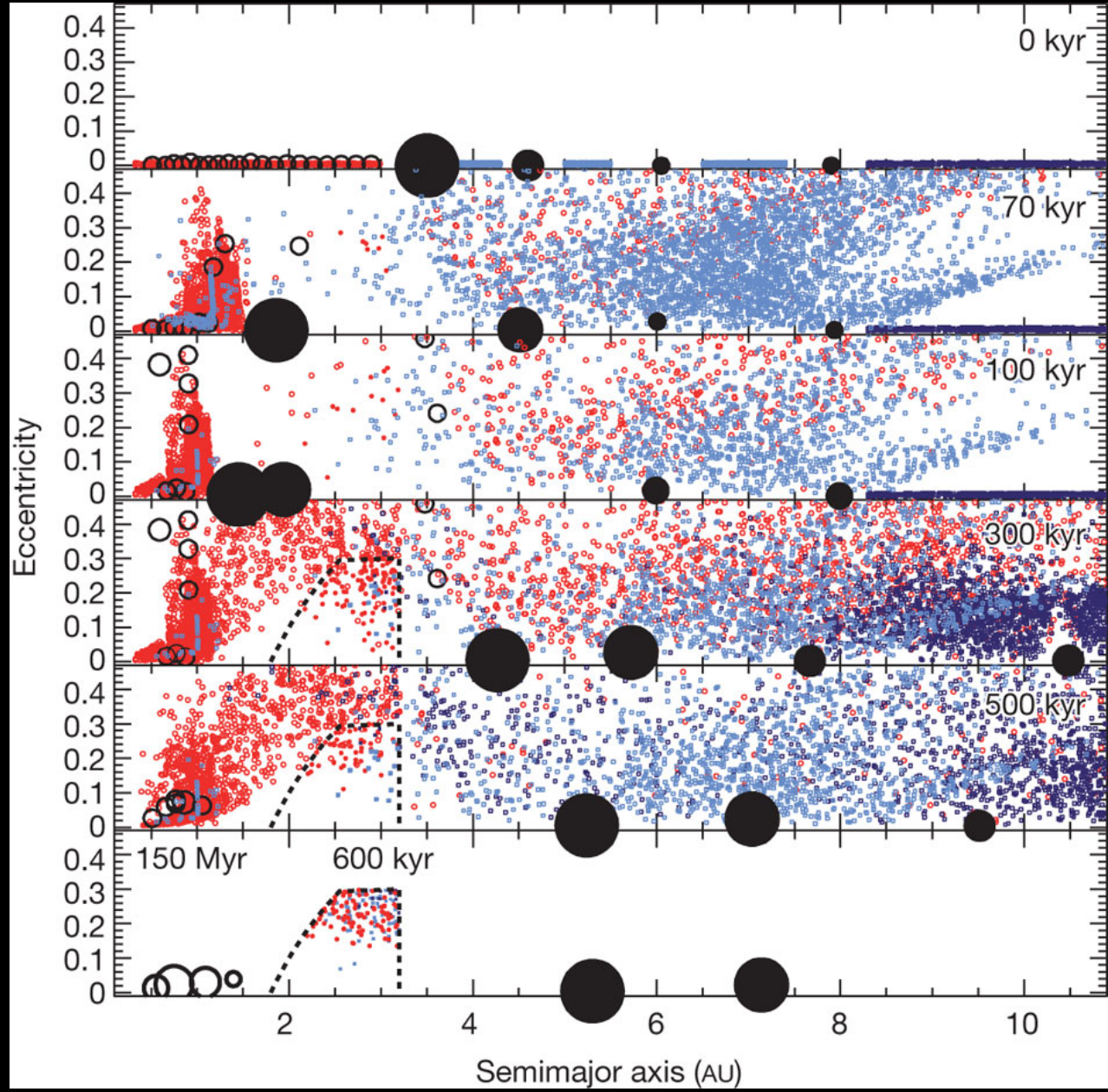
Source: Wikipedia, after Gomez et al. 2005

Migration implies that objects may cross the snow line

Evolution over time

Some minor bodies may cross the snow line!

Ice may then survive until today in the interior of those bodies



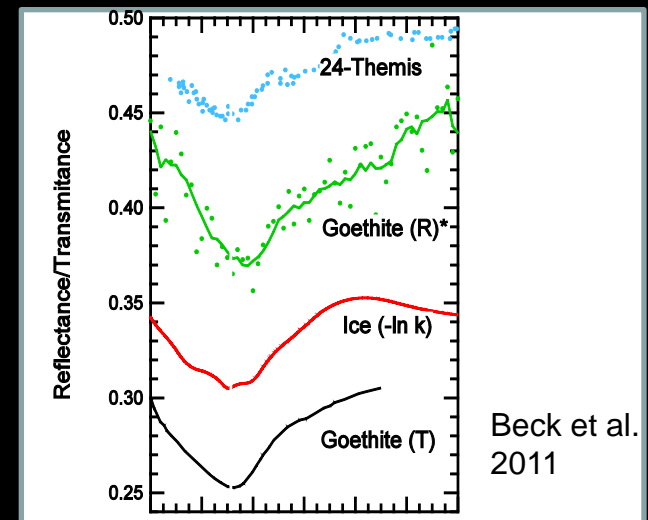
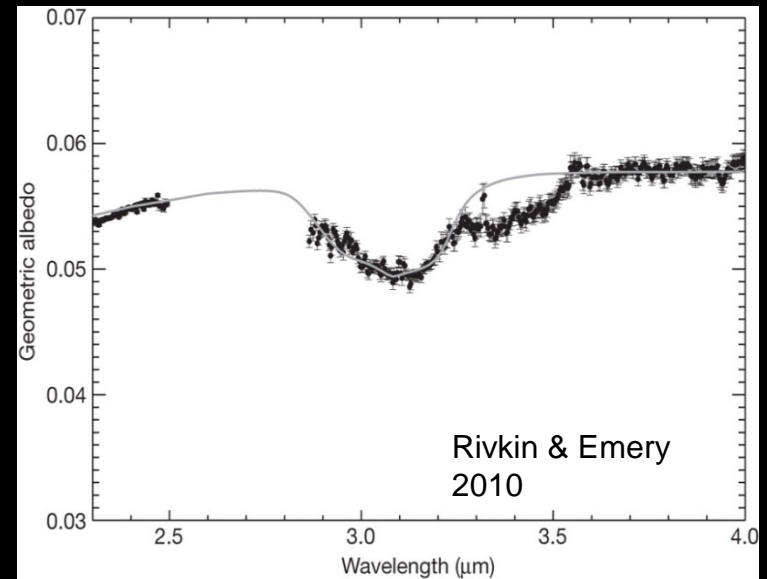
From: Walsh et al. 2011



Transition objects or: Water in the asteroid belt

I Hydrated features in asteroid spectra

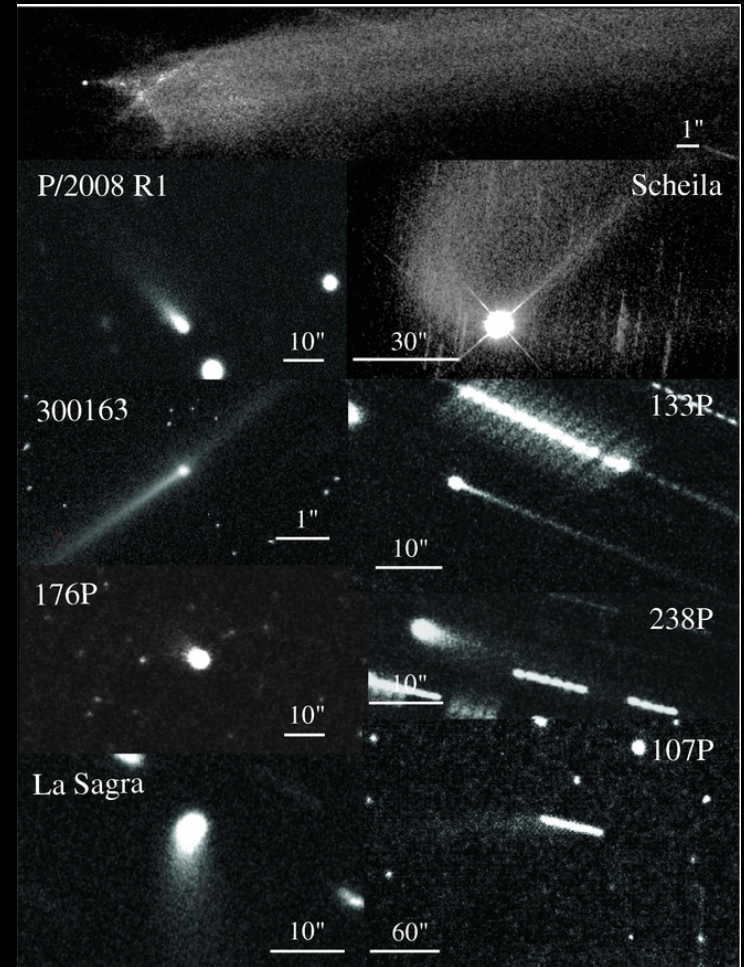
- 3 micron absorption in spectra of some asteroids is indicative of hydrated minerals
- It is claimed that the spectrum of 24 Themis cannot be explained by hydrated minerals alone, but requires water ice on the surface (Campins et al. 2010, Rivkin & Emery 2010)
- The mineral goethite (FeO-OH) has been suggested as an alternative to water ice (Beck et al. 2011)



Water in the asteroid belt?

II Active asteroids or main belt comets

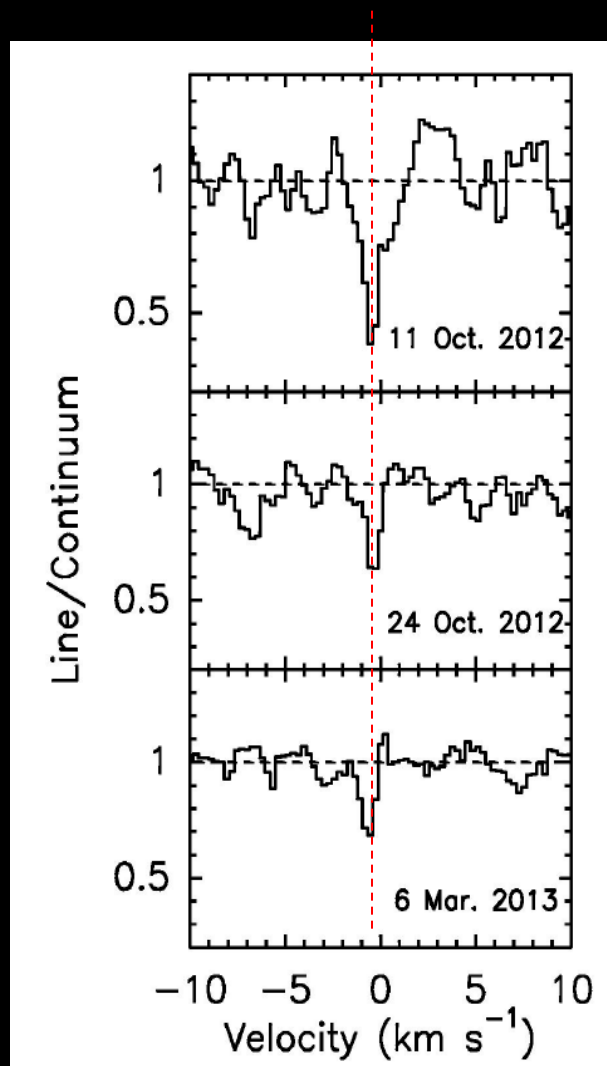
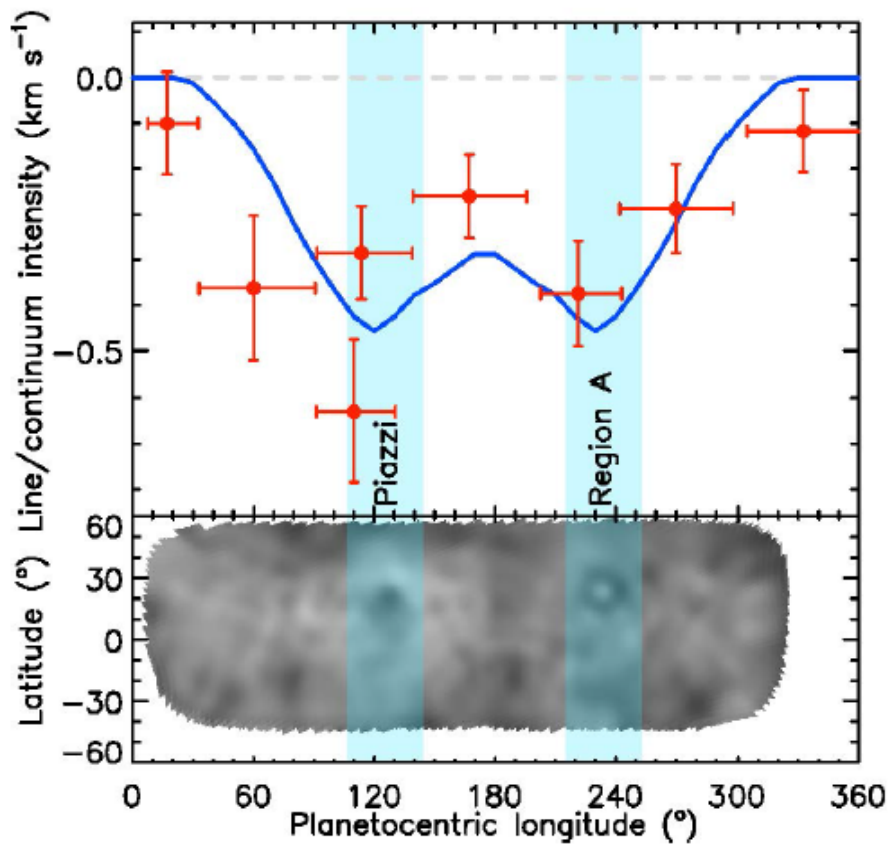
- While some of them are most likely driven by impact or fast rotation, some show recurrent activity around perihelion (133P and 238P)
 - Comet-like activity driven by water sublimation is the most natural explanation
- Several main-belt objects exhibit a dust coma and/or tail
 - No water or other volatiles detected so far



Jewitt 2012

Water detected on Ceres!

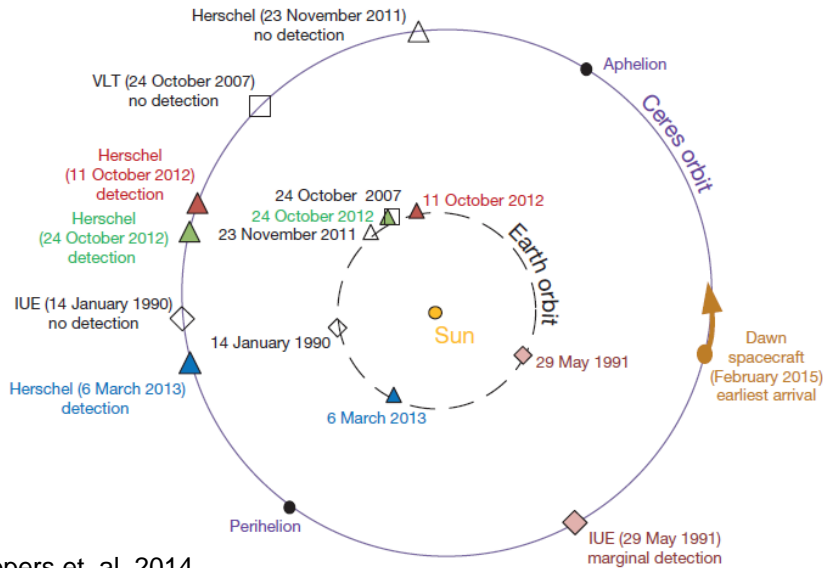
- Water vapour detected with high resolution spectroscopy from Herschel Space Observatory



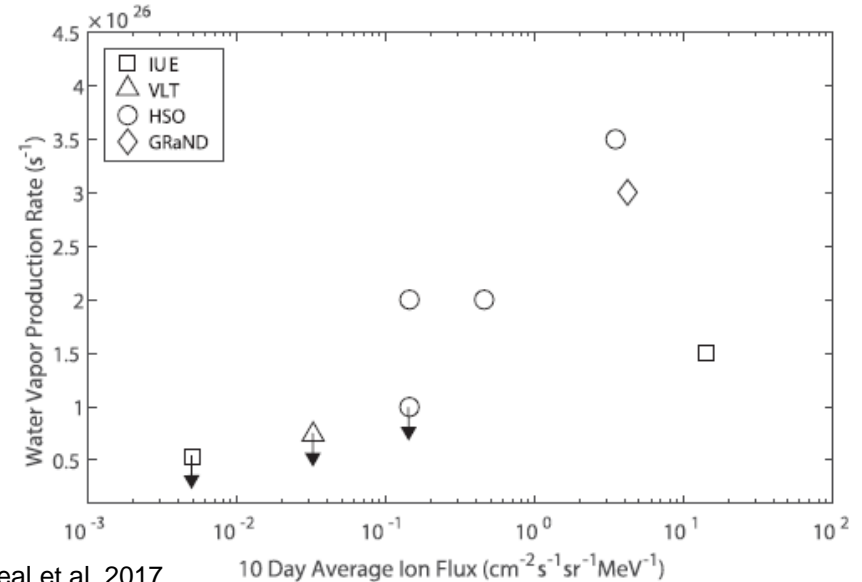
Küppers et al. 2014



Water vapour from Ceres



Küppers et al. 2014



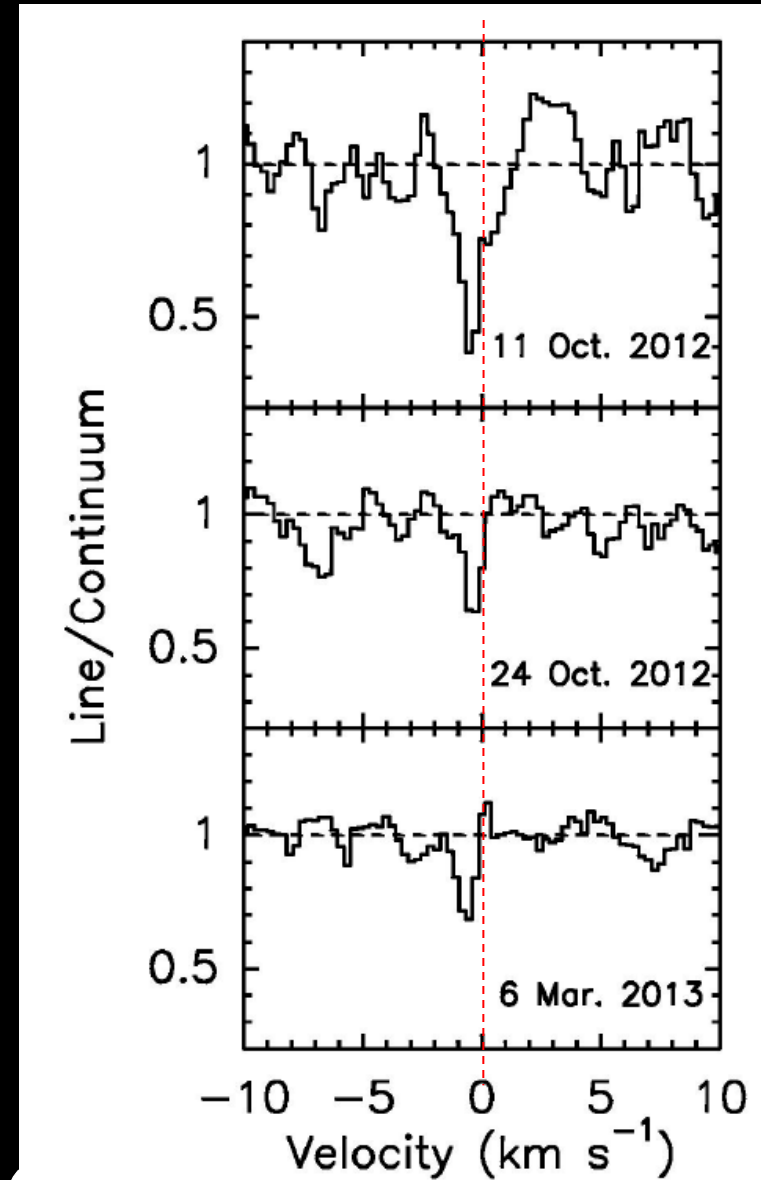
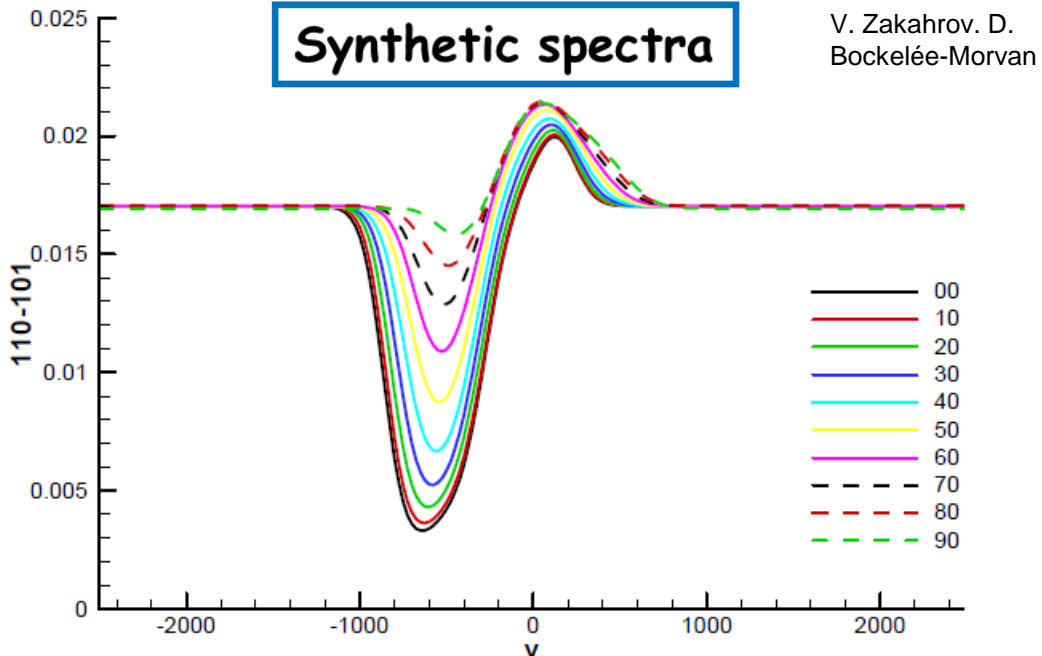
Villarreal et al. 2017

- Roughly half of the detection attempts found water vapour from Ceres
- If found, production rate is a few 10^{26} s^{-1}
- Correlation of water production with solar energetic proton flux

Water vapour from Ceres (2)

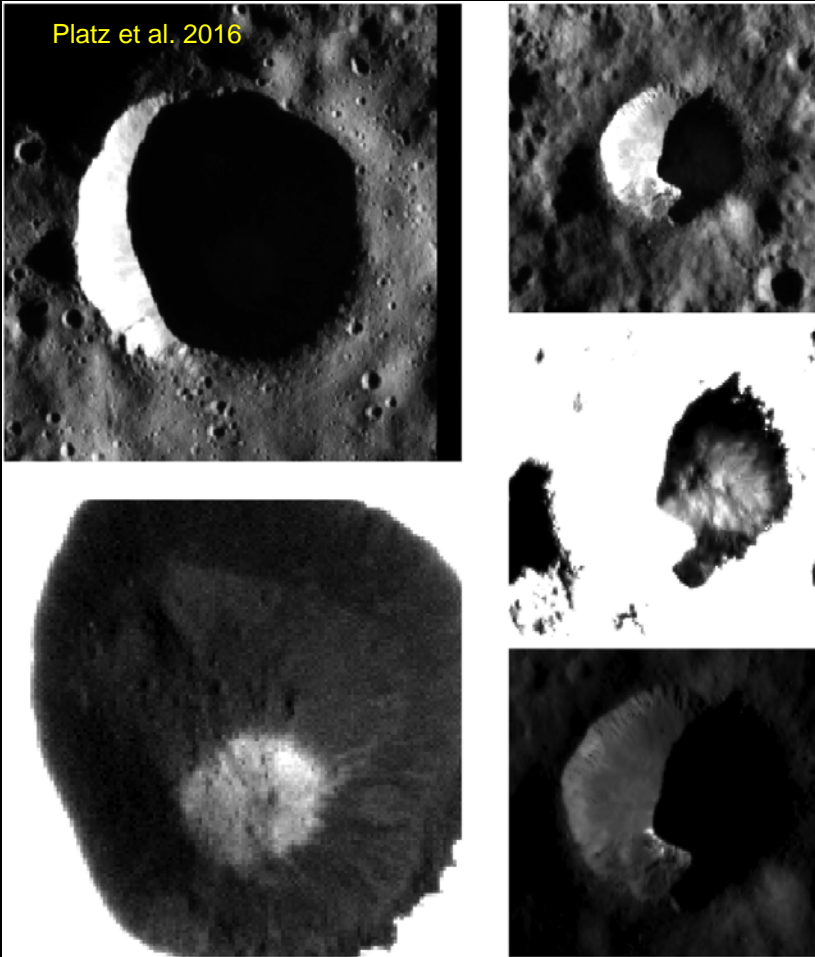
Küppers et al. 2014

- Water observations show absorption line, no or little emission
 - **The sources of most of the water vapour are not polar regions**
- **Expansion velocity $\sim 400 - 700$ m/s**
- **Thermal velocity ~ 700 m/s**

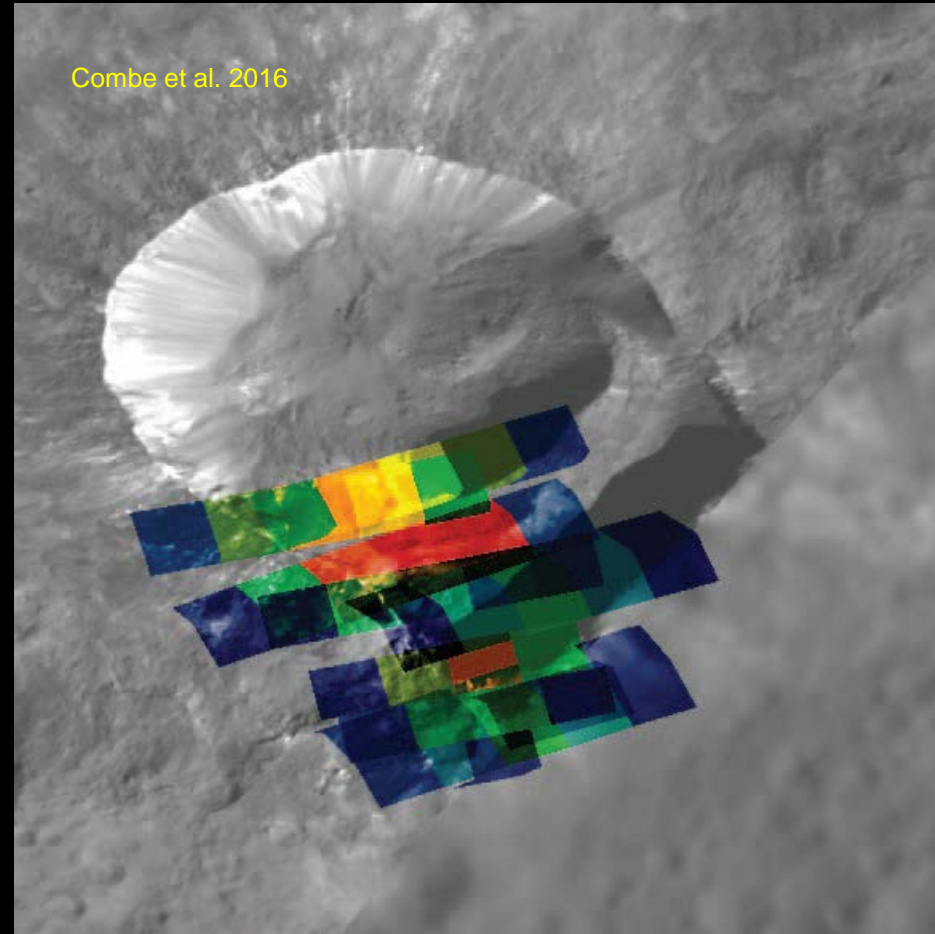


Water ice on Ceres: DAWN

Platz et al. 2016



Combe et al. 2016

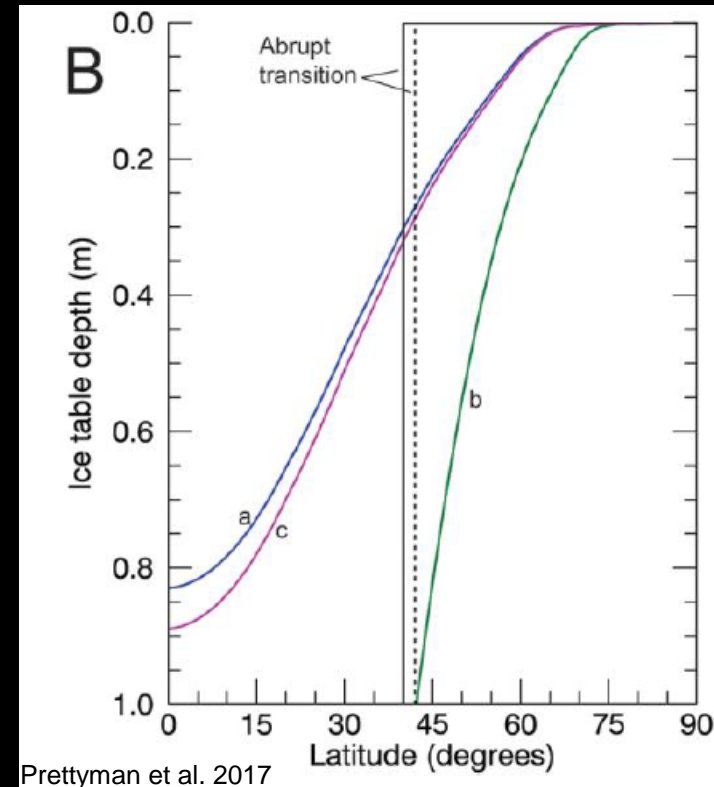


Surface ice detected at isolated locations, but not enough to explain water production

Water ice on Ceres: DAWN (2)

- Water ice globally present at a depth of decimeters
- Production rate of 10^{26} s^{-1} during 4 billion years corresponds to a layer of 135 m removed from Ceres' surface

=> Either ice is continuously transported from the interior towards the surface or the surface layer is continuously removed by the sublimating ice (cometary activity)

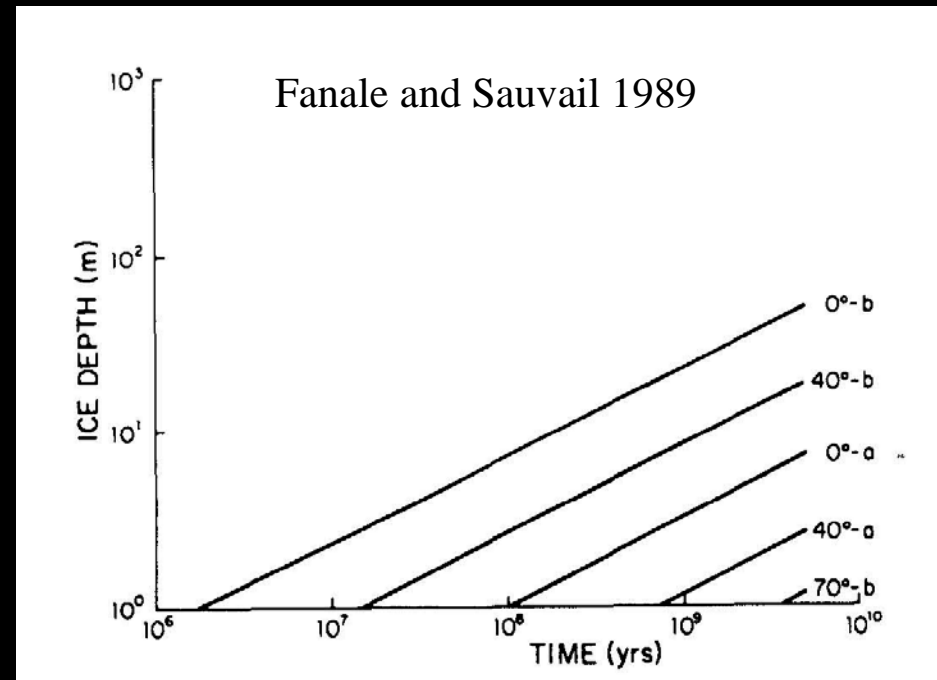


Possible mechanism of water emission on Ceres: I Receding ice layer

Idea: Sublimation removes ice layer to increasing depth below the surface

X Excluded

- Emission should be mostly polar
- With the production rates observed today, sublimation would have ceased long ago

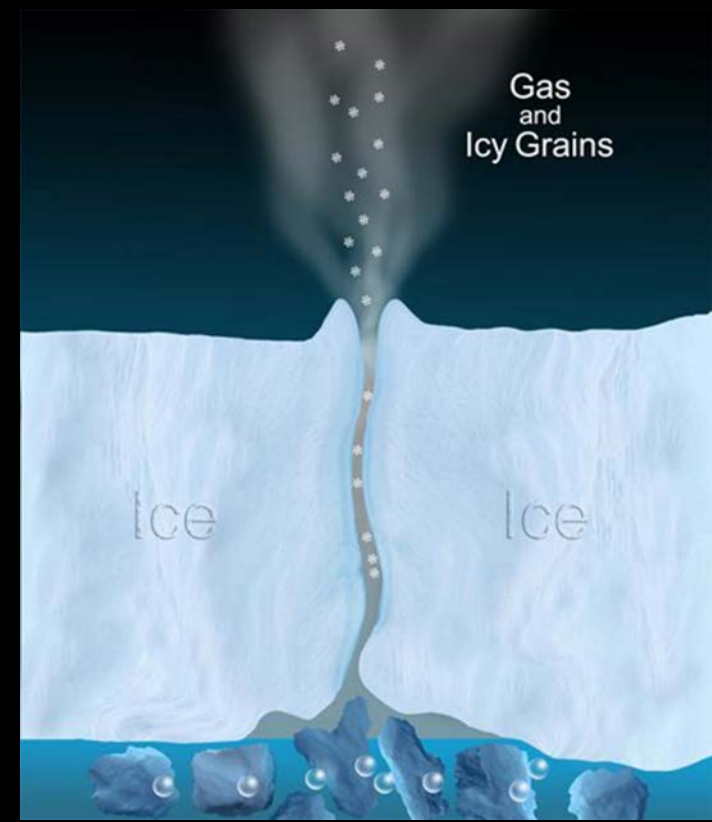


Possible mechanism of water emission on Ceres: II Spectacular events (big impact setting free ice layer, Cryovolcanism,..)

X Excluded

- Not seen be DAWN

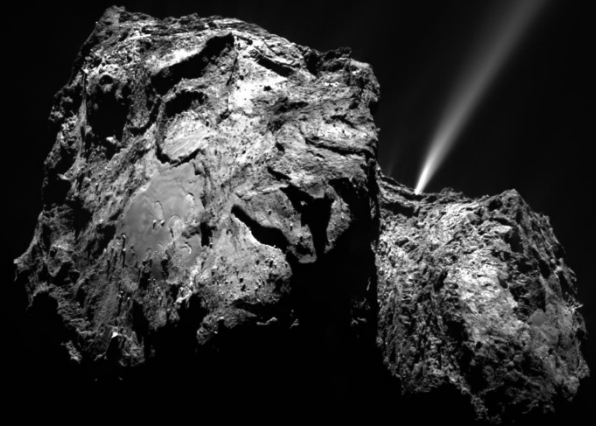
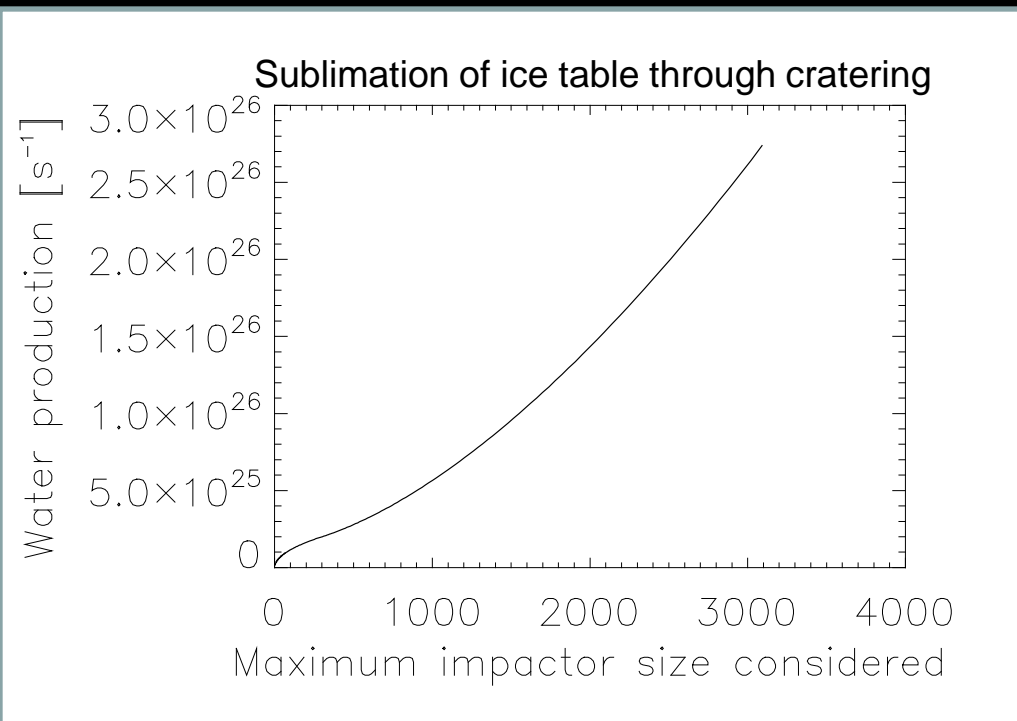
Model of cryovolcano on Enceladus



Possible mechanism of water emission on Ceres:

III Cometary sublimation

- Water ice sublimation from the (or from just below the) surface
- Sublimation from ice table is negligible, but can increase due to local sublimation from small craters



Source: OSIRIS/Rosetta

Possible mechanism of water emission on Ceres:

III Cometary sublimation (2)

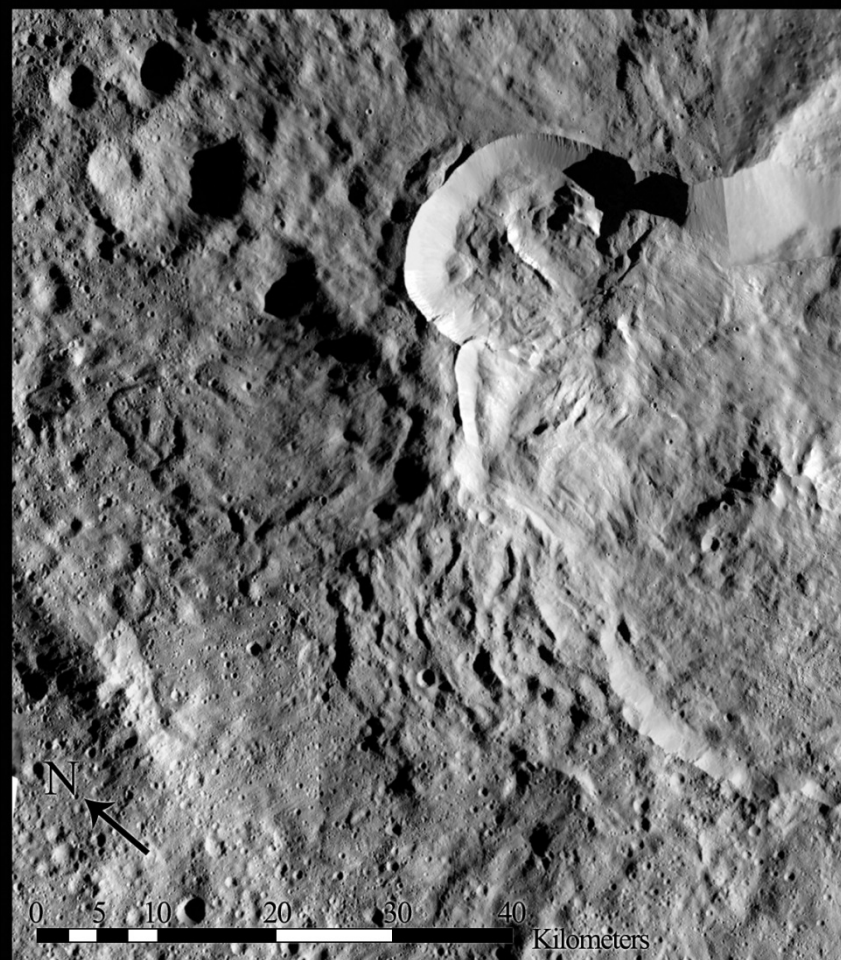
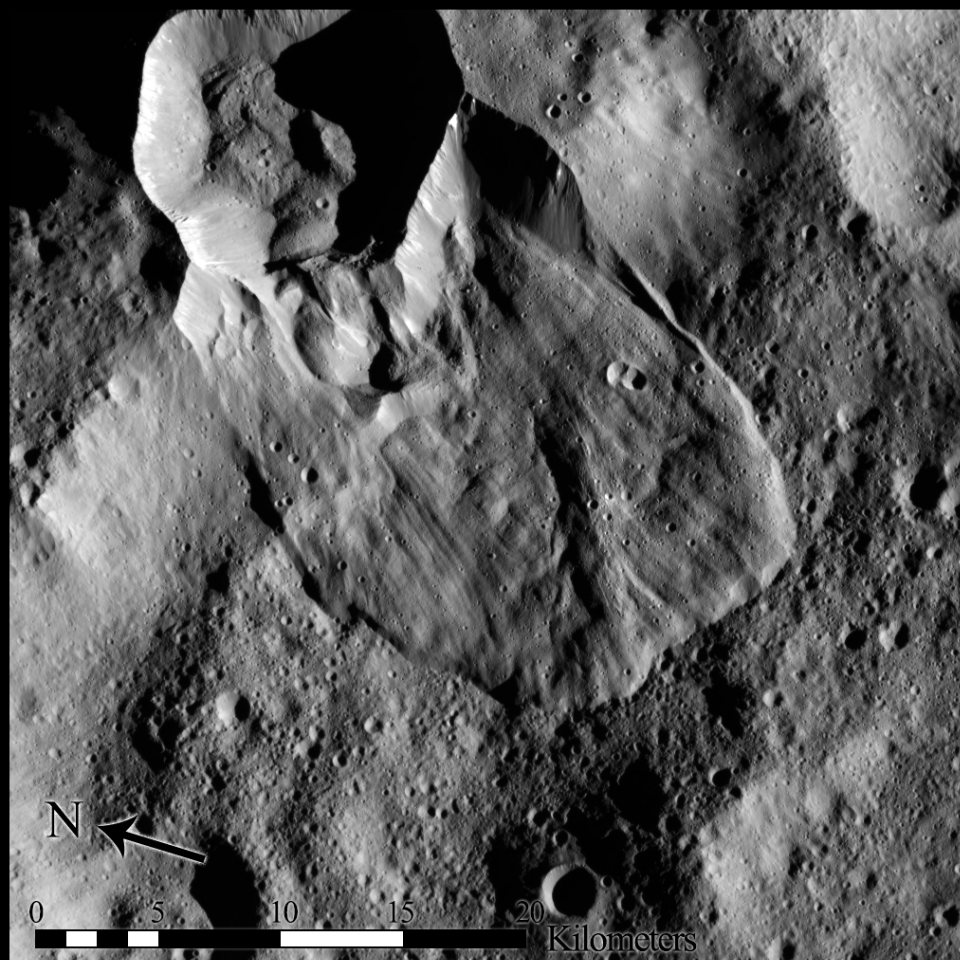
- ❑ Impact excavation of the ice table and subsequent sublimation may explain the water vaporization (preliminary calculations)
- ❑ As generally small areas are involved and ice may be covered or mixed with dusty regolith, this may be consistent with DAWN observations

Issues:

- ❑ How to get rid of the dust? Water sublimation alone will deplete the ice in the near-surface layer. Ceres escape velocity too high for dust escape.
- ❑ Largest impacts required happen ~once in a million years.
Duration of sublimation? Does model overestimate impactor sizes?
- ❑ Does not explain correlation of water production with solar particles
 - Maybe solar particles increase excitation, not production?

Possible mechanism of water emission on Ceres: III Cometary sublimation (3)

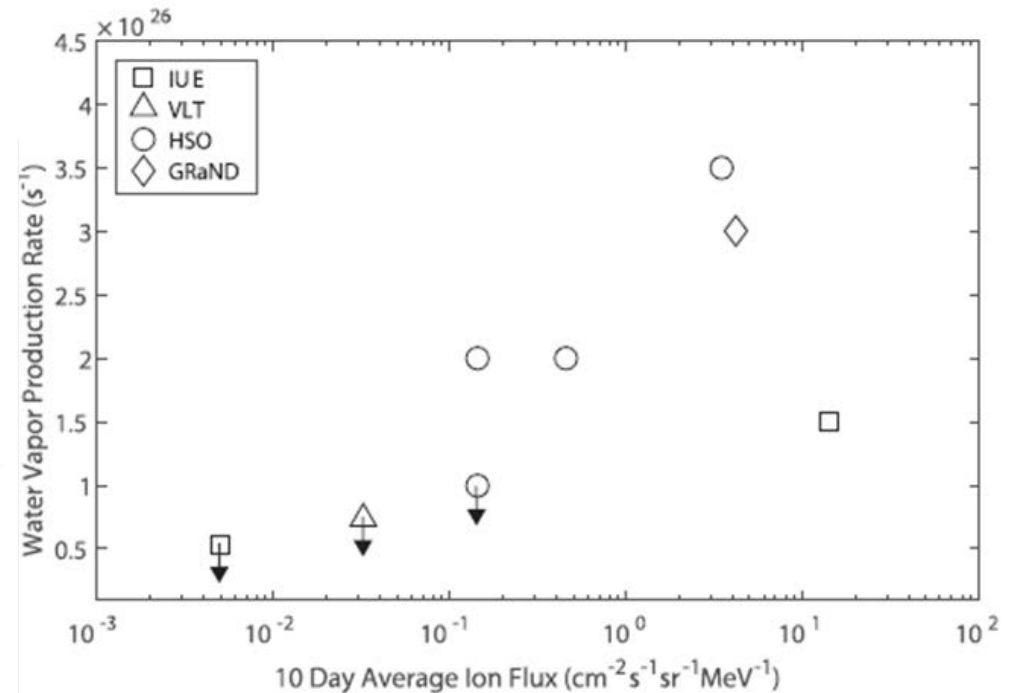
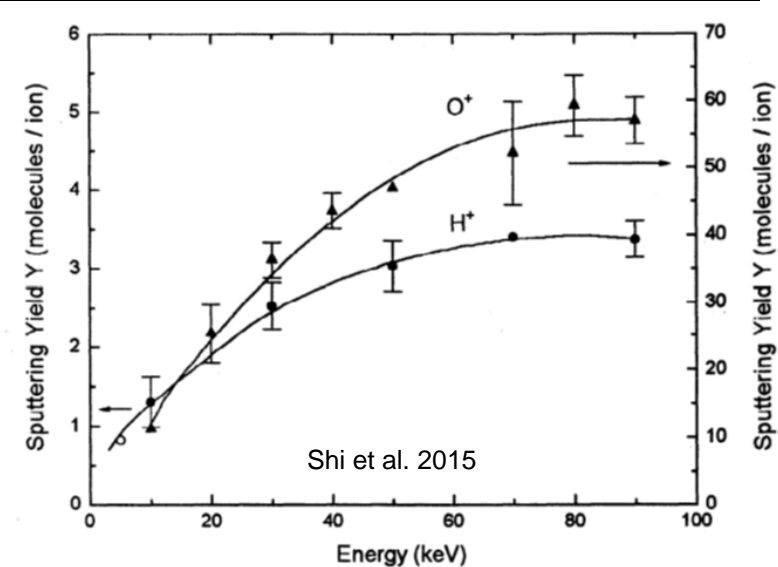
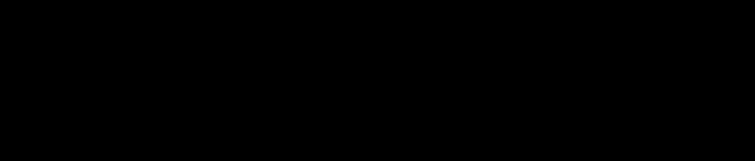
- Landslides initiated by impacts may solve problems 1 and 2



Possible mechanism of water emission on Ceres:

IV Sputtering by solar energetic protons

- ❑ Correlation between water production and solar energetic particle flux was shown (Villarreal et al. 2017)
- ❑ Energetic particles are near-isotropic and can reach unilluminated areas
- ❑ Variability of SEPs may explain pseudo-random time variability of water production



Possible mechanism of water emission on Ceres:

IV Sputtering by solar energetic protons (2)

Issues:

- Sputtering efficiency too low. Even assuming that each SEP particle hits water ice, production rates are orders of magnitude lower than measured.
 - Indirect effect of SEPs through heating and sublimation?
- Velocities of sputtered molecules higher than measured
 - Indirect process?
- If the process is efficient, the ice deposits in unilluminated areas should be depleted quickly. Also, observations show that polar areas do not dominate the water emission.

Conclusions

- Explaining simultaneously a near-surface ice table and significant ongoing sublimation is not trivial
- Most promising processes:
 - Exposure of ice table by impacts, prompting landslides, followed by sublimation
 - Water sputtered or heated by SEPs
- No process can currently explain all observations
 - Combination of various effects?

General Considerations

- Ceres contains water and organic material (DAWN, de Sanctis et al)
- Interior heat and possible sub-surface ocean (past or even today (?))

Ceres is a possible target for Astrobiology

- **Easier to reach for space missions than moons of Jupiter or Saturn**