The Material Science for the Solar System Bodies by the NIR Observations

SWIMSで切り拓く太陽系物質科学

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Why do we care small bodies?

Because they are the most suitable storytellers.

They tell us the following things.

Material science

Initial materials of the solar system

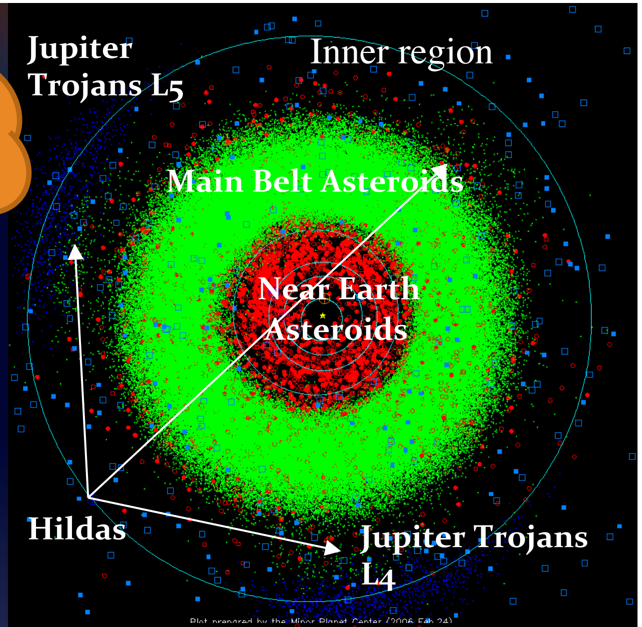
Most of SSSBs were not differentiated, they can be the fossils of the planetesimals which are the building blocks of planets. SSSB's composition reflects materials in early solar system.

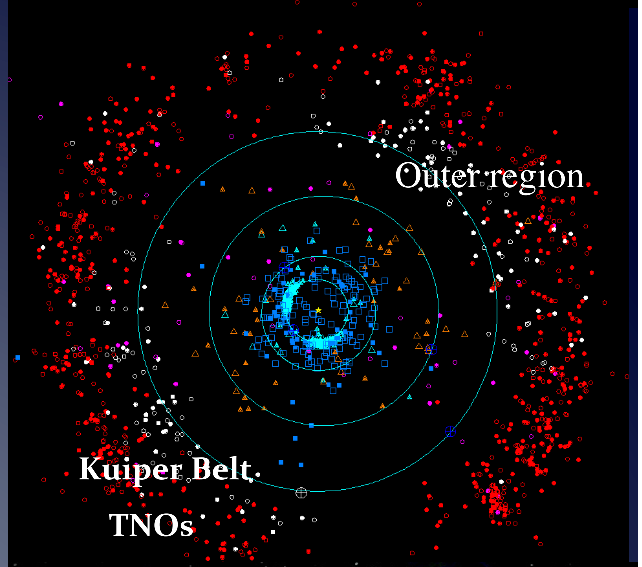
Dynamical evolution

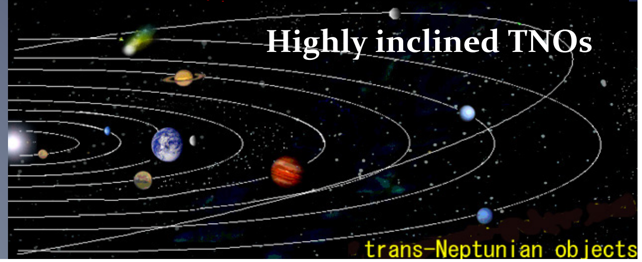
Traces of planet migrations

SSSBs have been affected by planets; they have been scattered, transported, perturbed. Such actions from the planets can remain on the orbital distribution of SSSBs.

Therefore, the investigation of natures of SSSBs leads us to <u>a big picture of early solar system</u>.

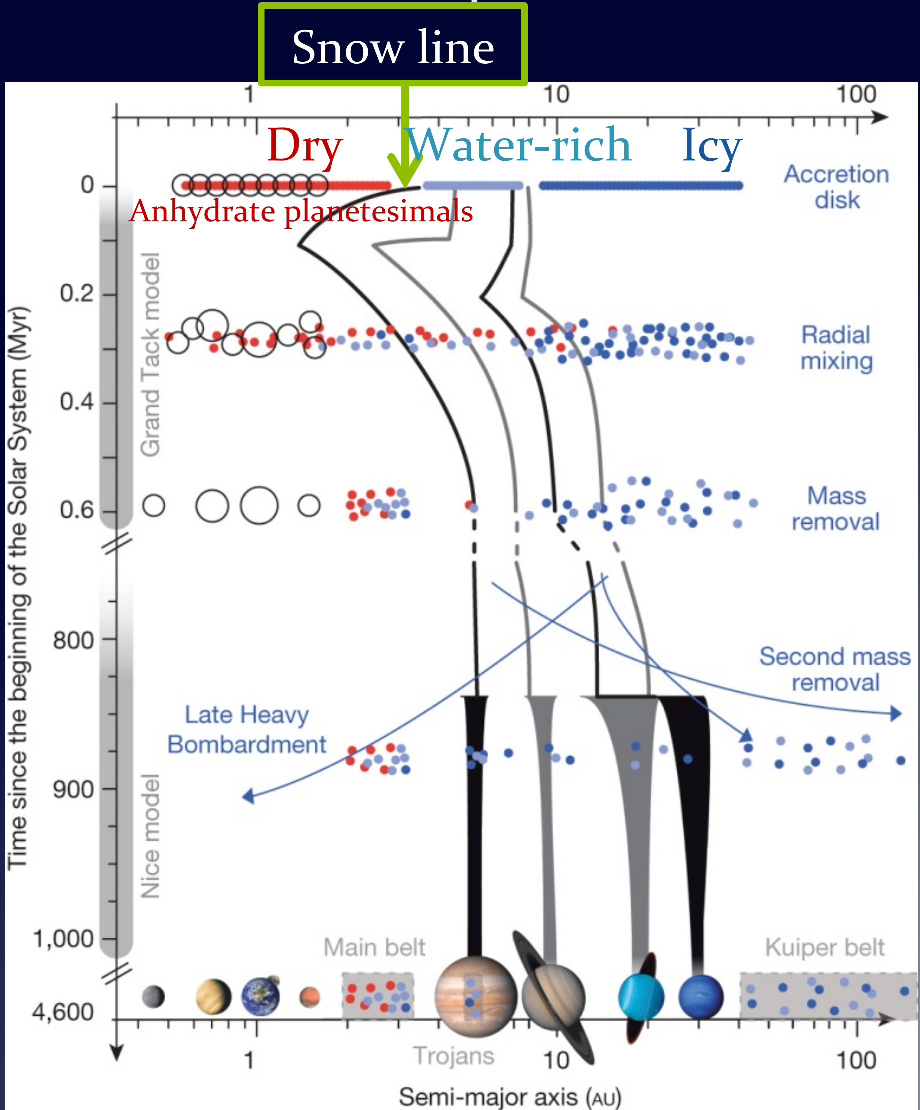






How well do we know about the solar system history? – not so much

The latest planet formation model of our solar system



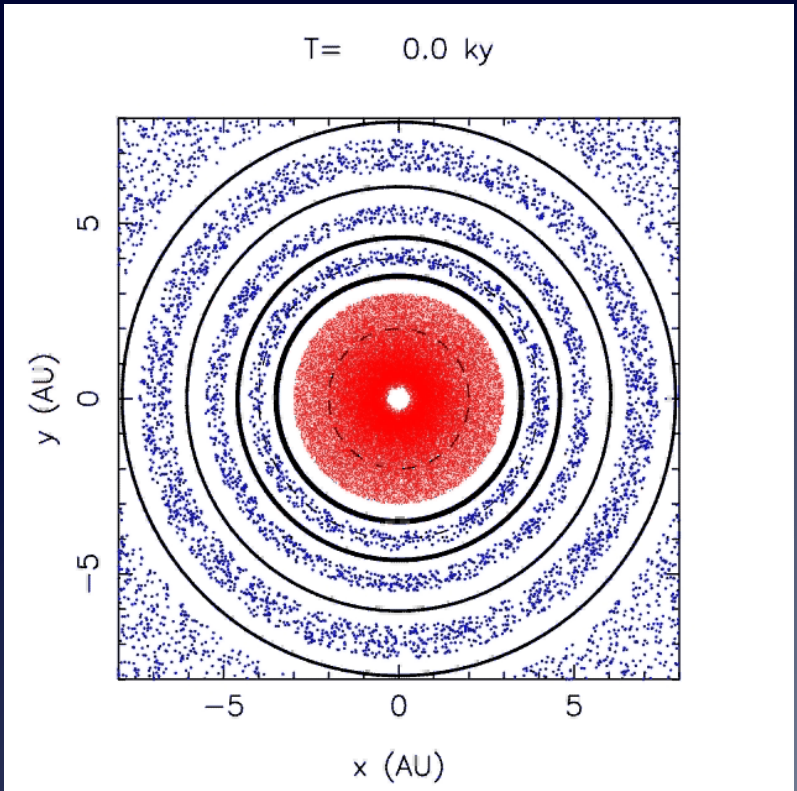
Planets and Small Solar System Bodies (SSSBs) have moved a lot. Such radial mixing brought water all over the solar system.

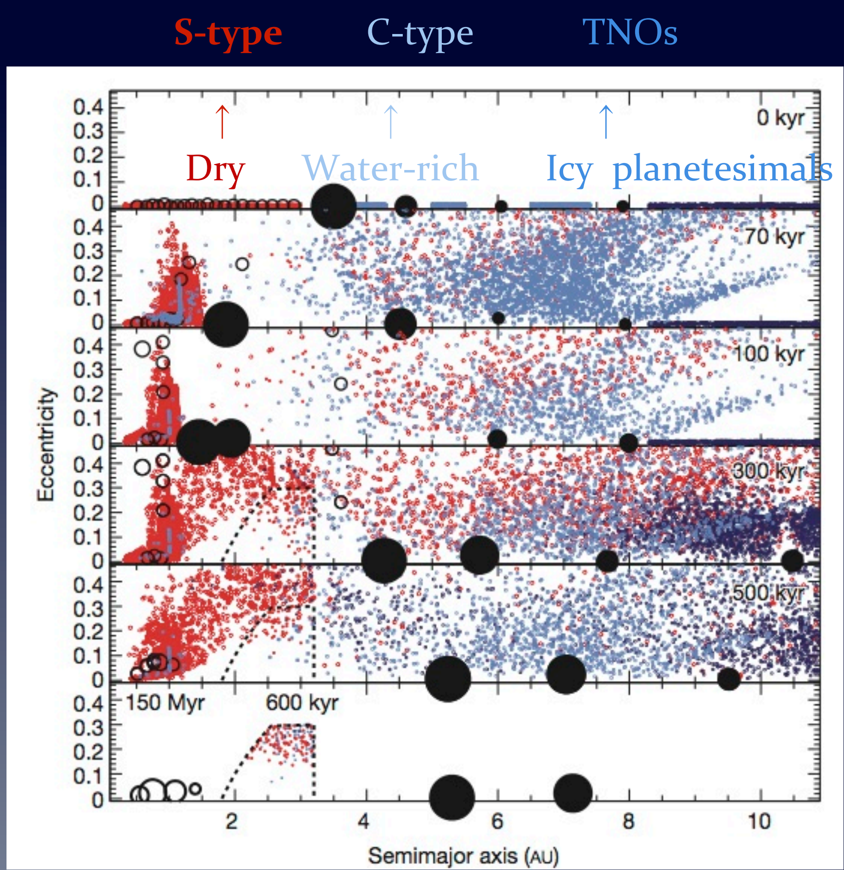
- Grand Tack
  - In solar nebula, the formation of planetesimals and proto-planets started.
  - Jupiter moved inward till ~1.5 AU and outward till ~5 AU due to the interaction with the gas disk
  - This process pushed inner-planetesimals foward the Sun. Water-rich and ice objects migrated into current region of main asteroid belt.
- Nice Model
  - About 800 Myr after the Grand Tack event, Jupiter and Saturn crossed 1:2 MMR, then a catastrophic disturbance happened.
  - Huge amount of objects got into the territorial planet region (Late heavy bombardment). This process provided probably additional water to the Earth.

FE DeMeo & B Carry *Nature* **505**, 629-634 (2014) doi:10.1038/nature12908

Grand Tack Model

”Taxk” is a dedicated maneuver that reverses the direction of the boat. Jupiter and Satan's tack is the main key of this scenario.

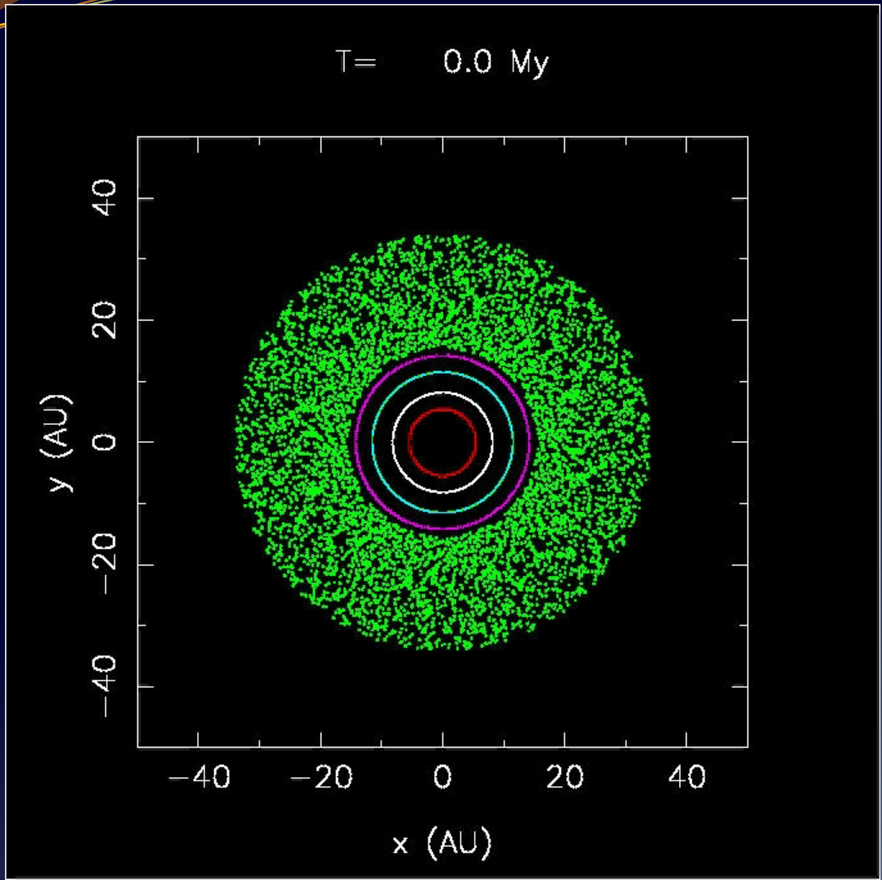


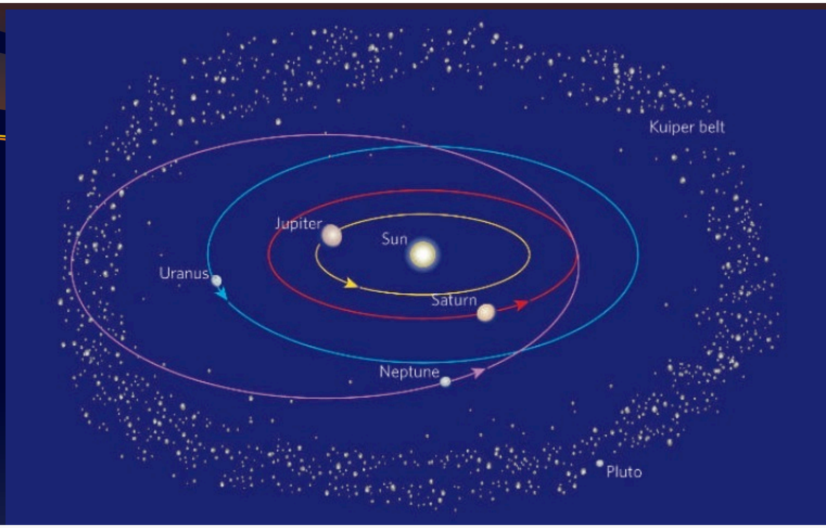


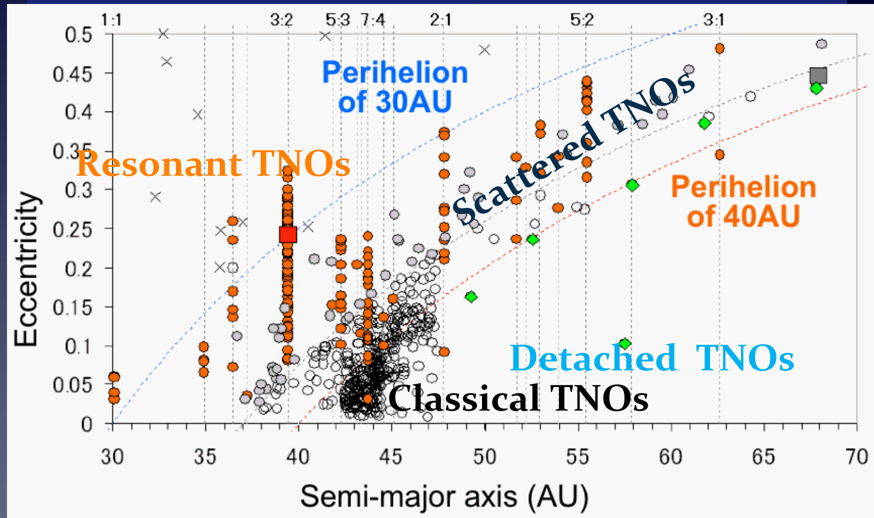
http://www.boulder.swri.edu/~kwalsh/GrandTack.html

This is a simulation of Grand tack done by Kevin Walsh; the first mass removal of the solar system. This model may explain the low mass of Mars and variety of the main belt asteroids, dry, water-rich, even icy objects exist there.

Nice Model







This model may explain

- Complicated dynamical structure of current TNO population,
- Orbital distribution of current Jupiter Trojans
- Period of the Late heavy bombardment.

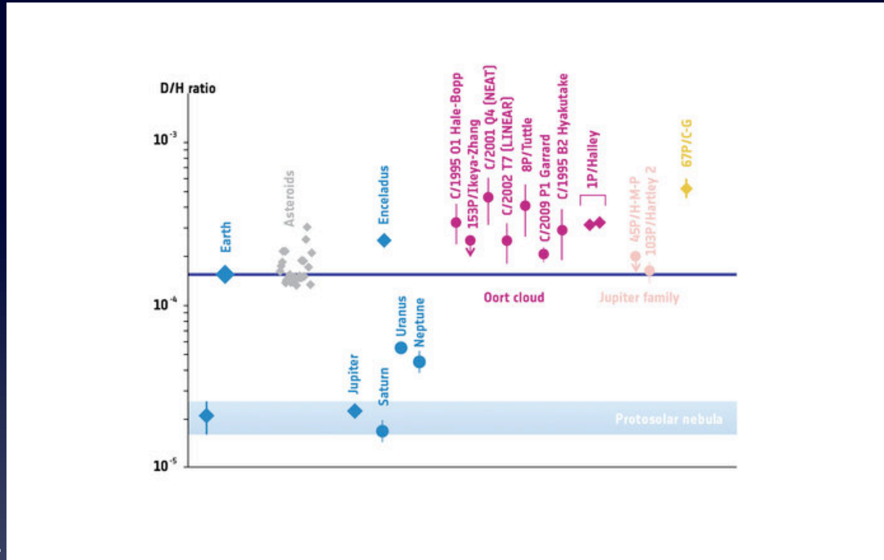
This model predicts

- the same size distributions similar composition in the JT and TNO population.
- Resonant TNOs and Classical TNOs have same size distribution and similar composition.

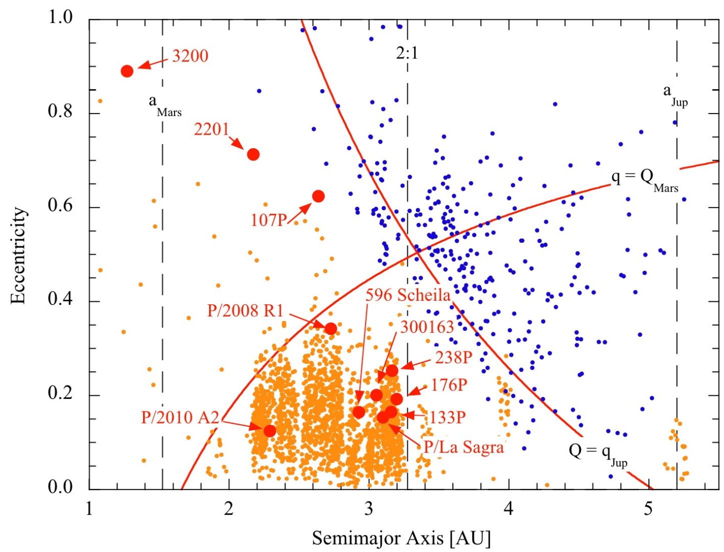
The latest model is still a hypothesis. We must confirm it by observations.

Who delivered water to the Earth?

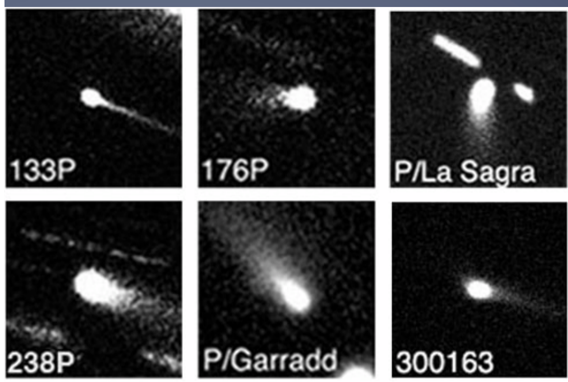
- The origin of water on Earth is not completely understood.
- There are numerous hypotheses. So far no hypothesis can explain the total water amount and the D/H ratio at the same time.
- **Extraplanetary sources**
  - Comets
  - Trans-Neptunian objects
  - <u>Water-rich asteroids (C-complex asteroids)</u> from the outer main asteroid belt



- The D/H ratio in the water on the Earth is very similar to that of carbon-rich chondrites (corresponding to Water-rich asteroids (C-complex asteroids)).



Jewitt 2012, Astron. J.



We think a huge amount of water is hidden in inside of the main belt asteroids.

We want to estimate the water amount in the main belt region.

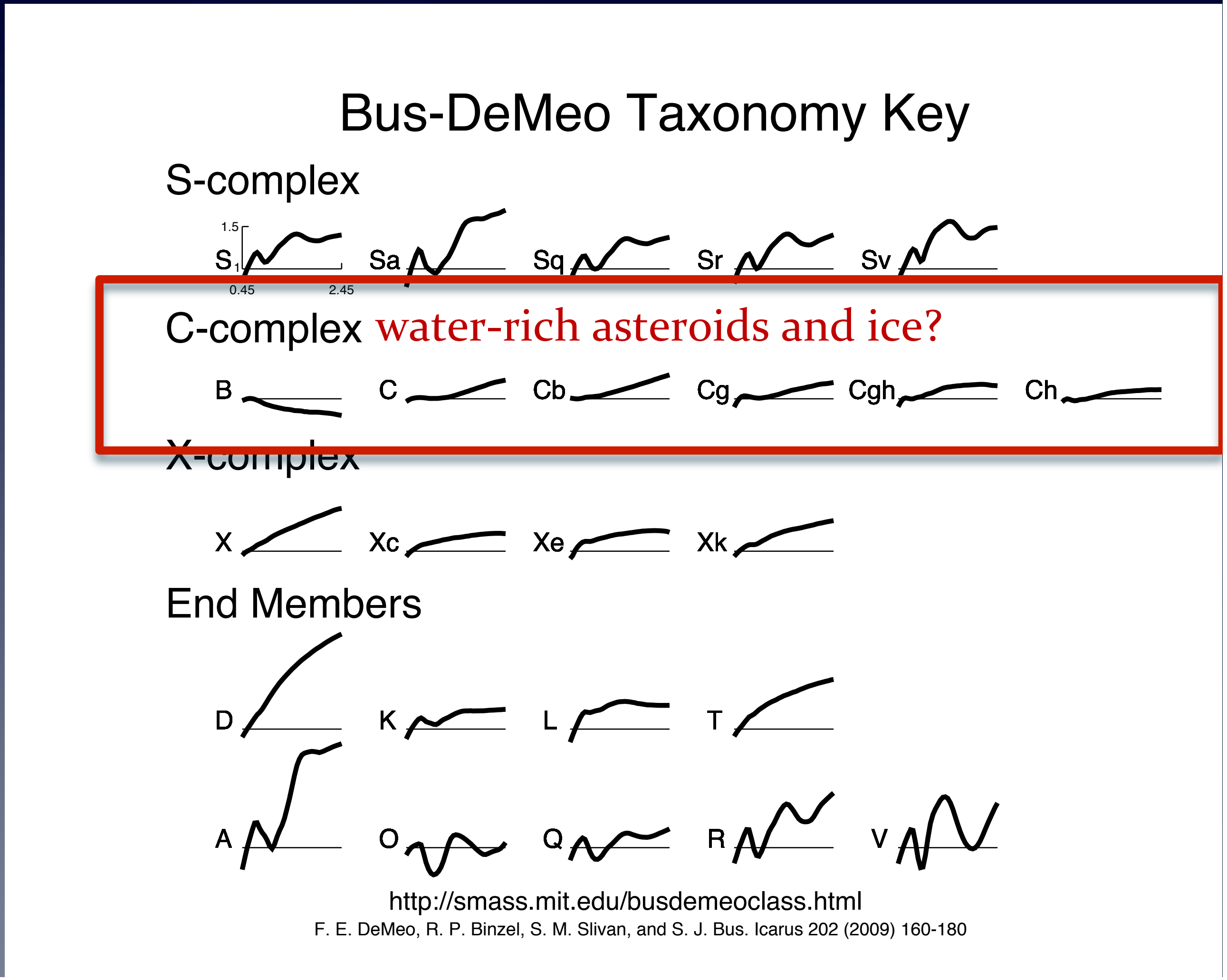
Observations using SWIMS

- Investigation of water content for the water-rich asteroids

- Unfortunately, absorption bands related water appear at 0.7, (0.9, 1.1), 3 μm, outside of the range of SWIMS .
- <u>However, the slope of NIR spectra tell us important information related to water alteration.</u>

- Based on the spectra of water-rich asteroids, it is possible to know the amount of water and the degree of water alteration (by comparison with carbonaceous chondrites)
- There is a detail study for B-type asteroids and carbonaceous chondrites.

NIR spectra of asteroids



Near-infrared spectroscopic survey of B-type asteroids: Compositional analysis

J. de León et al., Icarus 218 (2012) 196–206

by the 3.6 m TNG using NICS

- 6 groups of B-type spectra correspond to the 7 groups of carbonaceous chondrites

CI, CM chondrites:

- 99% water-rich matrix
- Experienced water alteration
- Reddest slope in NIR region

CV, CK chondrites:

- 0% water, dry
- Experienced thermal alteration
- bluest slope in NIR region

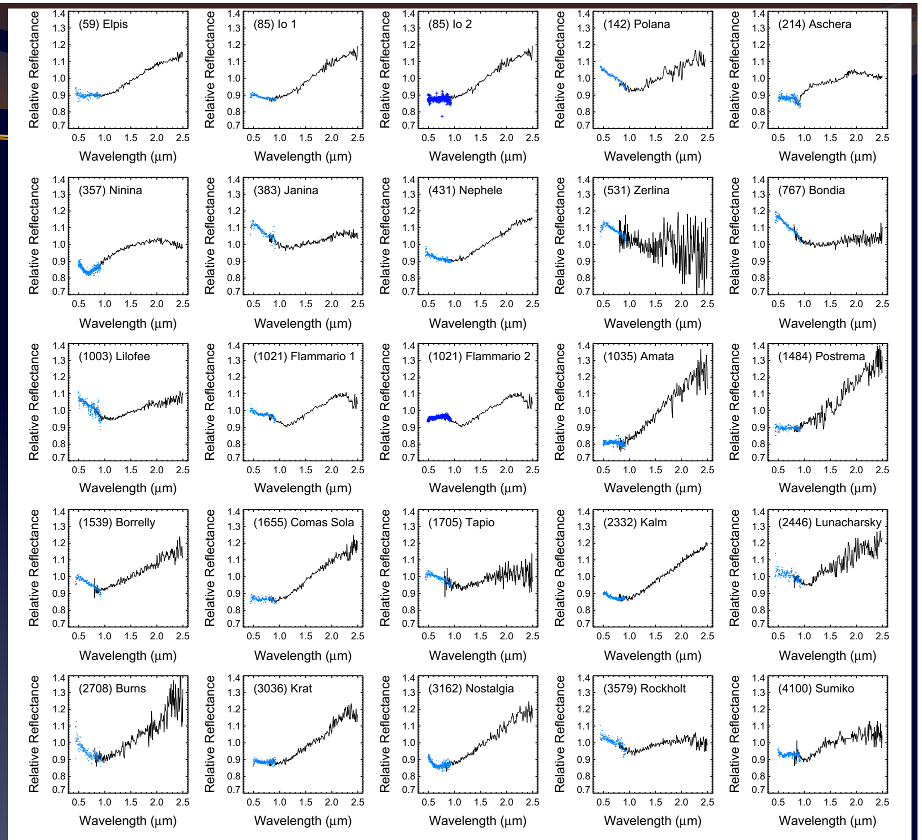


Fig. 1. Near-infrared spectra of B-type asteroids presented in this work (black lines). Visible spectra from other public databases are used to complete our near-infrared spectra and are shown as blue dots and crosses.

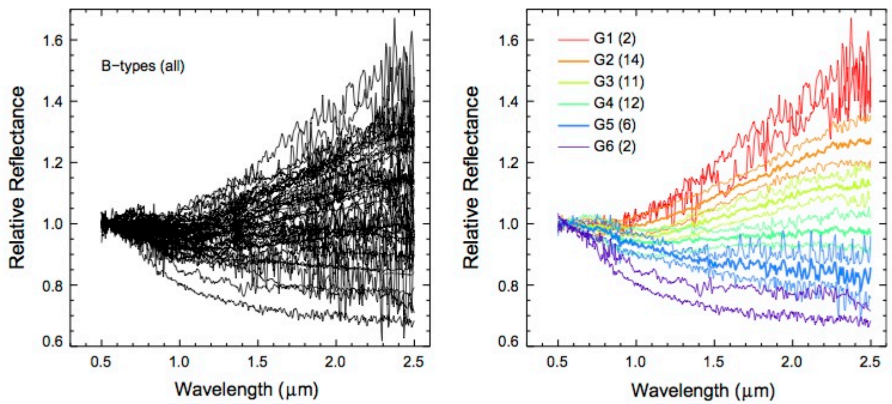
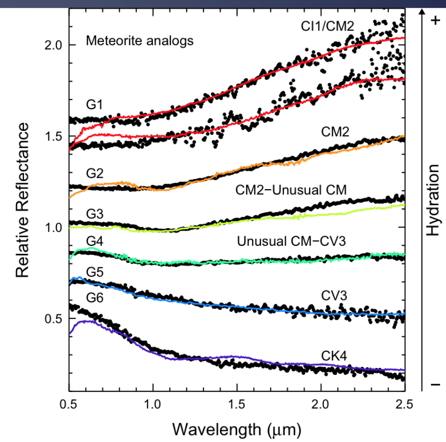


Fig. 4. A total of 47 visible and near-infrared spectra of B-type asteroids are analyzed in this work. The spectra are uniformly distributed filling the gap slopes in the near-infrared (left). The spectra of the centroids of the six groups obtained using the clustering are shown in the right plot. Mean standard in the same color but with thinner lines.



Water-rich

Dry

Fig. 5. Meteorite analogs for clusters G1–G6. The spectral data corresponding to the clusters are shown as black dots. Best meteorite analogs are superimposed using the same color code as in Fig. 4. The spectra are all normalized to unity at 1.25 µm. We show here the spectra of the two asteroids that form the G1 group.

Observation strategy

- Focus on the C-complex asteroids containing of hydrated minerals

- Based on 0.7μm absorption, we can select C-complex asteroids containing of hydrated minerals.
- Since there is a large database of optical spectra of asteroids, it is easy to find the asteroids with 0.7μm absorption.
- 6.5m TAO and Subaru can observe smaller asteroids than previous study. We may be able to investigate the correlation between asteroid size and hydration level.

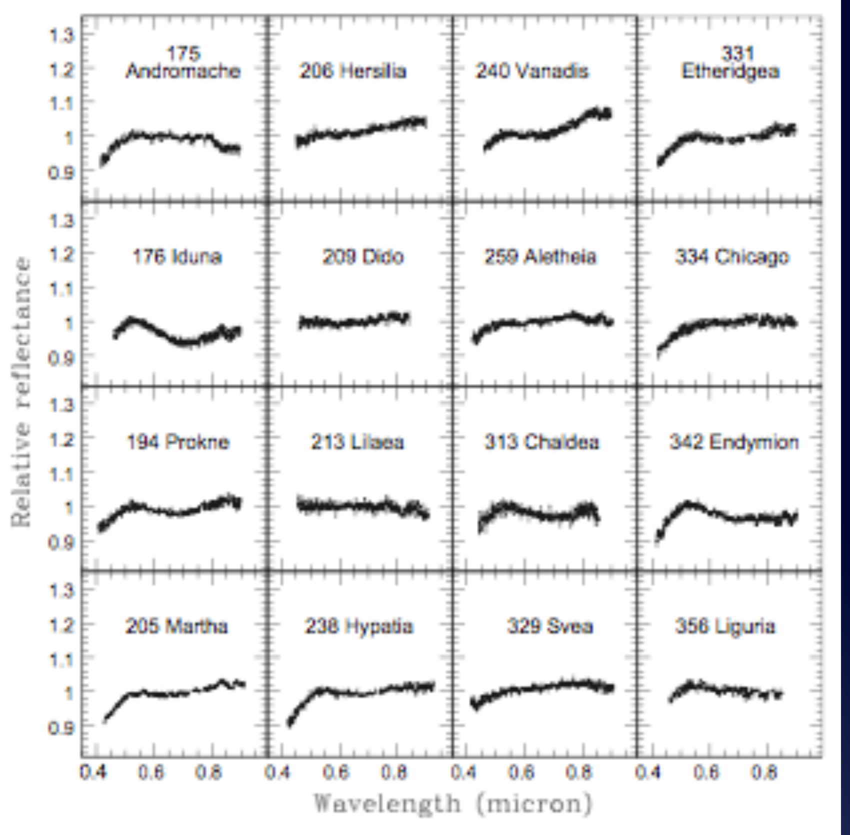


Fig. 3. Reflectance spectra of the observed asteroids. The spectra are normalized at 0.55 μm.

0.7 μm absorption : related to $Fe^{2+} \rightarrow Fe^{3+}$ charge transfer

This absorption is strongly related to 3μm absorption.

Further observation of the thermal alteration through the 3µm absorption

- 95% of the asteroids with 0.7µm absorption show the 3µm absorption

Shapes of the 3µm absorption (Takir and Emery, 2012)

Sharp: hydrated minerals

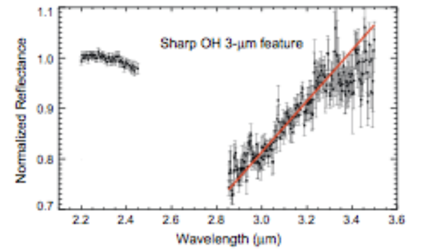


Fig. 5. Isolated sharp 3-µm feature in the spectrum of 121 Hermione. The best fit for this feature is a linear regression across the 2.85–3.25-µm region (in red). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

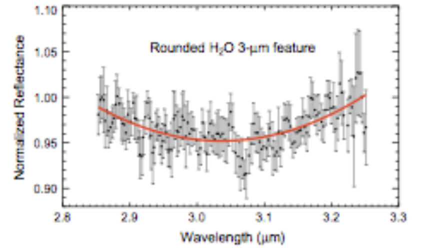


Fig. 6. Isolated rounded 3-µm feature in the spectrum of 361 Bononia. The best for this feature is a second order polynomial across the 2.85–3.25-µm region (in red). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Round: frost of H2O. So far no water alteration and no thermal alteration

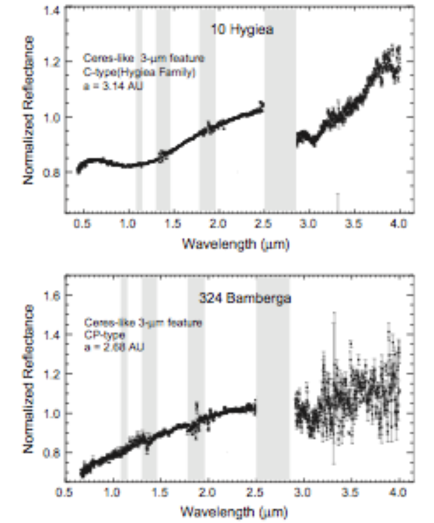


Fig. 9. The Ceres-like group with a 3-µm feature centered at 3.05 ± 0.01 µm. All spectra have been normalized to unity at 2.2 µm. The gray bars on each plot mark wavelengths of strong absorption by water vapor in Earth's atmosphere.

Ceres-like: Water ice, NH4, phyllosilicate, irradiated organic materials, iron-rich clay, hydroxide brucite

Europa-like: Montmorillonite?

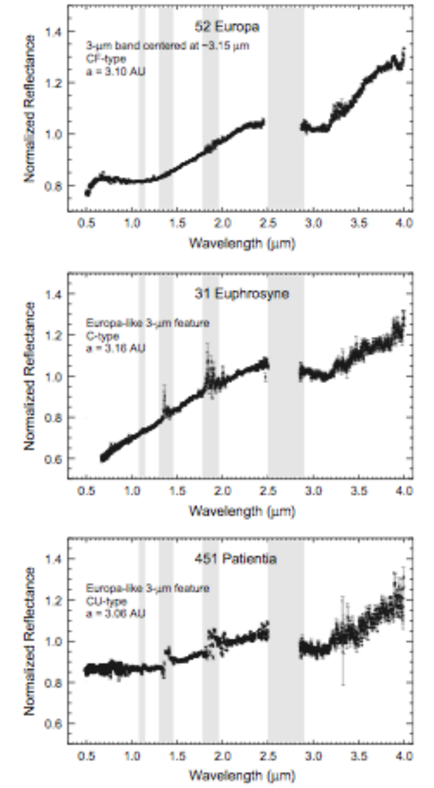


Fig. 10. The Europa-like group with a 3-µm feature centered at 3.15 ± 0.01 µm. All spectra have been normalized to unity at 2.2 µm. The gray bars on each plot mark wavelengths of strong absorption by water vapor in Earth's atmosphere.

Summary

- We will obtain the NIR spectra of water-rich asteroids by SWIMS.
- Based on the slope of the NIR spectra, we can measure the hydration level of asteroids.
- Eventually, we want to estimate the water content in the main asteroid belt region.
- The water content information may be a strong constraint for understanding the planet migration process in the solar system at its early stage.