Existence of “water” in the solar system

- Existence of “water” on asteroids
  - (1) Ceres: hydrated minerals (Rivkin+ 2002), water vapor (Küppers+2014), etc
  - (24) Themis, (65) Cybele: water ice (Campins+ 2010; Rivkin+ 2010; Licandro+ 2011)

- Hydrated minerals:
  - Any minerals containing OH or H$_2$O, which are formed in environments where anhydrous rock and liquid water are together (aqueous alteration).
  - They are found within chondrite matrix of meteorites.
  - Hydrated minerals are stable above the sublimation temperature of water ice.
  - Knowledge of the hydrated mineral is important for deducing the origin of Earth's water, and unraveling the processes in the earliest times of the solar system.
  - Diagnostic absorption features in 3 µm band
    (e.g., Takir & Emery 2012, Takir+2015, Rivkin+2015, etc, etc, …)
    - Hydroxyl associated with hydrated mineral (2.7--2.8 µm)
    - H$_2$O ice (3.07 µm), etc

Infrared observations with ground-based telescopes are limited by atmospheric absorption. → Need to send telescopes into space!
Infrared astronomical satellite “AKARI”
(AKARI means “light” in Japanese.)

The first Japanese infrared satellite dedicated to all-sky survey

- Orbit: 700km altitude, sun-synchronous
- Size: 5.5 x 1.9 x 3.7 m (in orbit) / Mass: 952kg (at launch)
- Telescope: Ritchey-Chretien, 68.5cm SiC (f/6)
- Launched: 2006/02/22 06:28 JST (JAXA M-V-8 rocket)
- Terminated: 2011/11/24 17:23 JST
Asteroid observations with AKARI

- **All-sky survey data (9, 18 µm)**
  - Size and albedo catalog of 5120 asteroids: Asteroid catalog using AKARI (AcuA) (Usui+2011, 2013)
  - Larger asteroids are fully covered. (H < 9, >40 km in main belt; Usui+2014)

- **Pointed observations (7-24 µm)**
  - Studying mission target asteroids (Hasegawa+2008, Müller+2014, 2017, etc)
  - Serendipitous survey (Hasegawa+2013, Deyama+ in prep.)

- **Archived photometric data of observed asteroids**
  - Available at JAXA website: [http://www.ir.isas.jaxa.jp/AKARI/Archive/](http://www.ir.isas.jaxa.jp/AKARI/Archive/)
  - Àlí-Lagoa+2018
  - Szakáts+ talk (this morning)
AKARI/IRC spectroscopic observations

- AKARI provides valuable spectroscopic data because of its high sensitivity and unique wavelength coverage (2.5--5 µm).

![Graph showing detection sensitivity vs. wavelength with data points for Ceres and Bononia]
Near-infrared spectroscopy for asteroids with AKARI

- Spectroscopic observations at wavelengths from 2.5 to 5 µm.
  - Spectral resolution : R=120@3.6 µm
- Warm mission phase data (2008/05 - 2010/02)
- One pointed observation: ~10 min.
  - Effective exposure time: 350-400 sec
- Targets : 66 asteroids
  - Main-belt to Hildas (d > 40 km)
  - Classification : Bus-DeMeo taxonomy (compiled by Hasegawa+2017)

- Data reduction
  - IRC Spectroscopy Toolkit for Phase 3 Version 20170225RC (IDL-based package)
  - Frame shift-and-add for moving objects (Ootsubo+2012)
  - Object positions : obtained from JPL/Horizons
  - Computed solar spectrum : corrected Kurucz model (Berk+1999)
Example of data reduction: (511) Davida

Near-infrared spectrum

AKARI Observation:
ID = 1520065.1, AOT = IRCZ4, b;Np
2008/11/16_11:26:35

Model (NEATM):
- $d = 238.6$ km, $p_v = 0.070$
- $r_h = 2.662$ au, $\Delta = 2.469$ au, $\alpha = 22.061$,
- $T_{ss} = 268.1$ K

Flux density [mJy] vs. Wavelength [μm]

- Thermal emission
- Reflected sunlight
Reflectance spectra of asteroids (vis - near IR)

Ground-based observations

(511) Davida (C-type)
No clear feature

(6) Hebe (S-type)
Significant absorption

Wavelength [µm]
Relative reflectance

AKARI
This work

Significant absorption
No clear feature
Near-infrared spectra of C-complex asteroids
Band depth at 2.7 µm vs peak wavelength (C-complex)

Laboratory experiments (Yamashita+ in prep)

Heating experiments of meteorites

Abundance of phyllosilicate decreases

Mg/Fe ratio increases

Dehydration process

(R = 0.88)
Summary
Near-infrared Asteroid Spectroscopic Survey with AKARI

- Spectroscopic observations for 66 asteroids (total 147 times) with IRC/NIR in the warm mission phase of AKARI
  - Wavelength coverage: 2.5--5 µm, spectral resolution: R~100
  - Time variation of the spectra is not examined at present.
    (two or three spectra are averaged for each object)

- From the reduced spectra (in 2.5-3.5 µm range),
  - Most C-complex (17/22) have clear absorption feature at around 2.75 µm.
    (which is associated with hydrated minerals).
  - Correlation between peak wavelength and band depth of 2.7 µm feature can be understood as dehydration process of C-complex asteroids.
  - Combination of the absorption features at 0.7 µm and 2.7 µm can be diagnostic of aqueous alteration / dehydration history of C-complex asteroids.
AKARI/IRC near-infrared asteroid spectroscopic survey: AcuA-spec

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Abstract

Knowledge of water in the solar system is important for the understanding of a wide range of phenomena, from the origin of life to the evolution of the planets.