

リモート観測による小惑星の含水鉱物探査



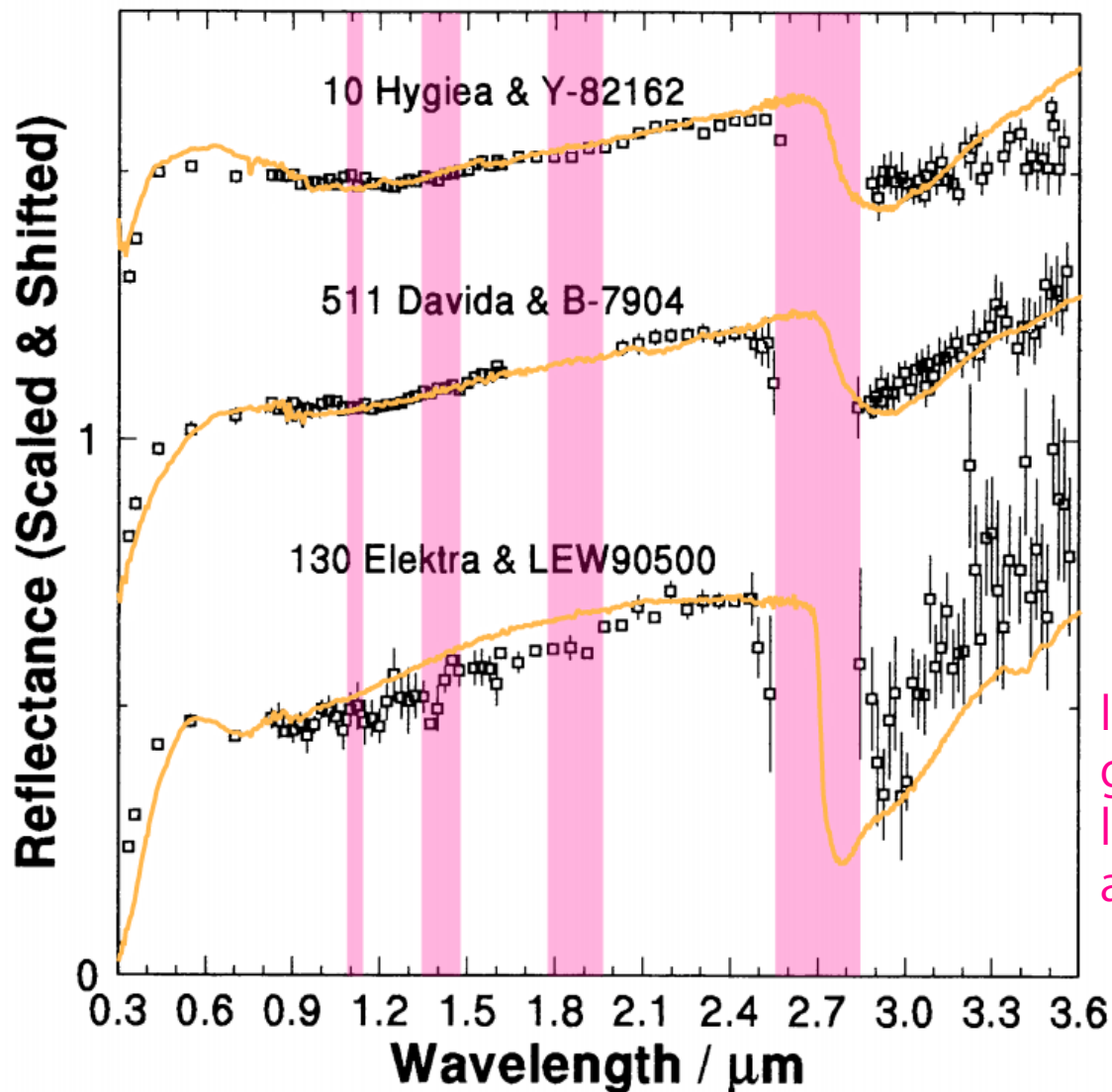
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Existence of “water” in the solar system

- Existence of “water” on asteroids
 - (1) Ceres : hydrated minerals (Rivkin+ 2002)、 water vapor (Küppers+2014)、 etc
 - (4) Vesta : hydrated minerals (Hasegawa+2003, Rivkin+2006, Russel+2015)
 - (24) Themis, (65) Cybele : water ice (Campins+ 2010; Rivkin+2010; Licandro+ 2011)
 - etc
- Hydrated minerals :
 - Any minerals containing OH or H₂O, 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 :
 - ✓ Hydroxyl associated with hydrated mineral (2.7--2.8 μm)
 - ✓ H₂O ice (3.07 μm), etc
 - ✓ Other species (CO, CH₄, NH₃) are not stable on surfaces of asteroids.

Reflectance spectra of asteroids and meteorite (Hiroi+1996)



Observations (dots):

- Zellner+1985
(1.54m Catalina, 2.29m Steward)
- Bell+1988
(NASA/IRTF)
- Jones+1990
(NASA/IRTF)

Meteorite measurements (lines):

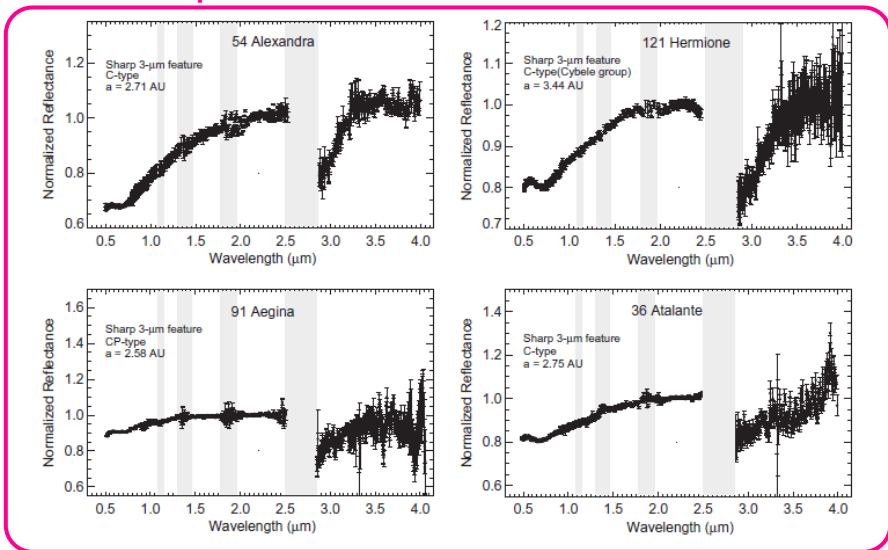
- Carbonaceous chondrites
(RELAB, Brown University)

Infrared observations with ground-based telescopes are limited by atmospheric absorption and thermal emission.

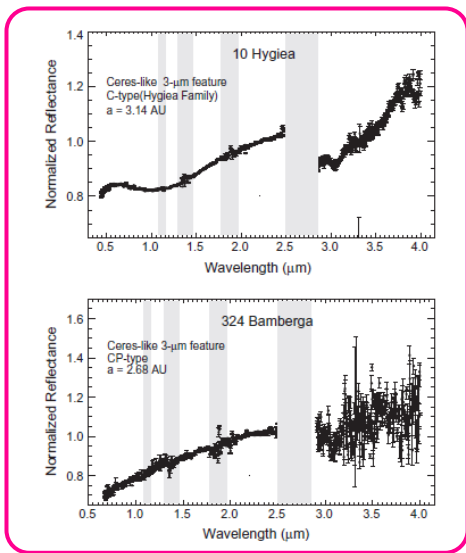
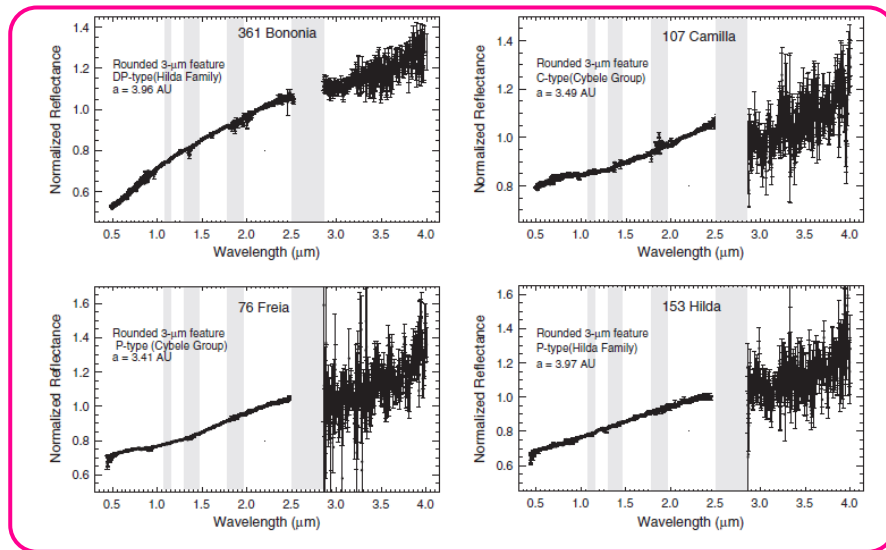
FIG. 3. Three sets of asteroid-meteorite counterparts that have similar overall reflectance spectra. All spectra are scaled to 1.0 at 2.37 μm and offset for clarity.

Vis to near-infrared spectra of C-type asteroids (Takir+2012, 2013)

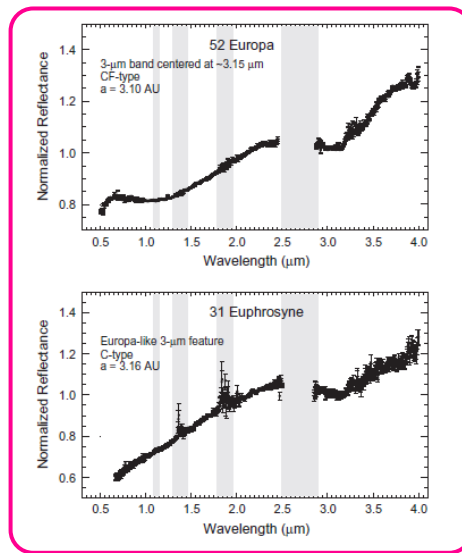
sharp (15)



rounded (8)



Ceres-like
(2)



Europa-like
(3)

Classifying 3 μm -band feature based on observations of 28 asteroids (IRTF/SpeX)

Infrared astronomical satellite "AKARI"

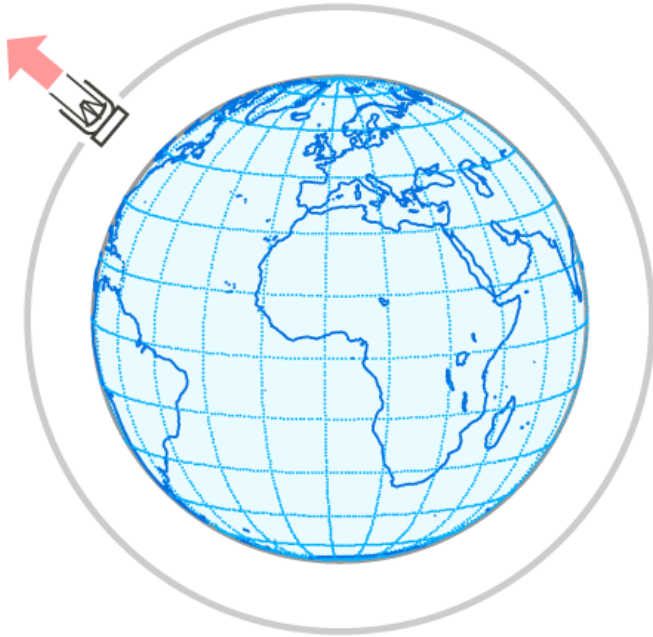
(pre-launch name : ASTRO-F)

- The first Japanese infrared satellite dedicated to all-sky survey
 - Orbit : altitude=700km, sun-synchronous
 - Size : $5.5 \times 1.9 \times 3.7$ m (in orbit)
 - Mass : 952kg (at launch)
 - Telescope : Ritchey-Chrétien, f/6 (68.5cm SiC)
 - Focal plane instruments
 - Infrared Camera (IRC) : 2--26 μm
 - Far-Infrared Surveyor (FIS) : 50--180 μm
 - Cryogenics: liquid helium + mechanical coolers ($< 6\text{K}$)
 - Launched : 2006/02/22 06:28 JST (M-V-8 rocket)
 - Terminated : 2011/11/24 17:23 JST

2 observational modes of AKARI

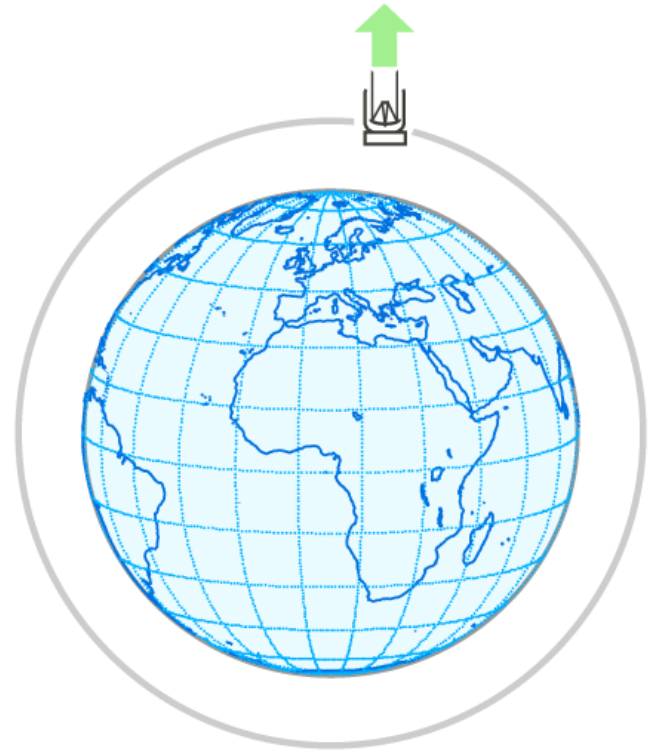
All-sky survey

Continuous survey mode
(scan rate = $3.6''/\text{sec}$)

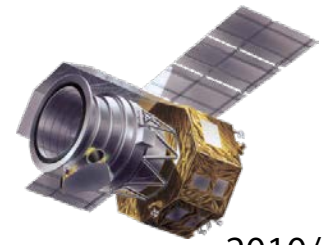


Pointed observations

Targeted observing mode
(about 10 minutes)
for deep imaging and spectroscopy



AKARI observations



2006/02/21 2006/05/08 2006/11/10 2007/08/26 2008/06/01 2010/02/25



Phase 1

Phase 2

Phase 3

Liquid helium + Cryocoolers
(179 ℓ)

Cryocooler

All-Sky Survey

+

5088 pointed observations
(IRC + FIS)

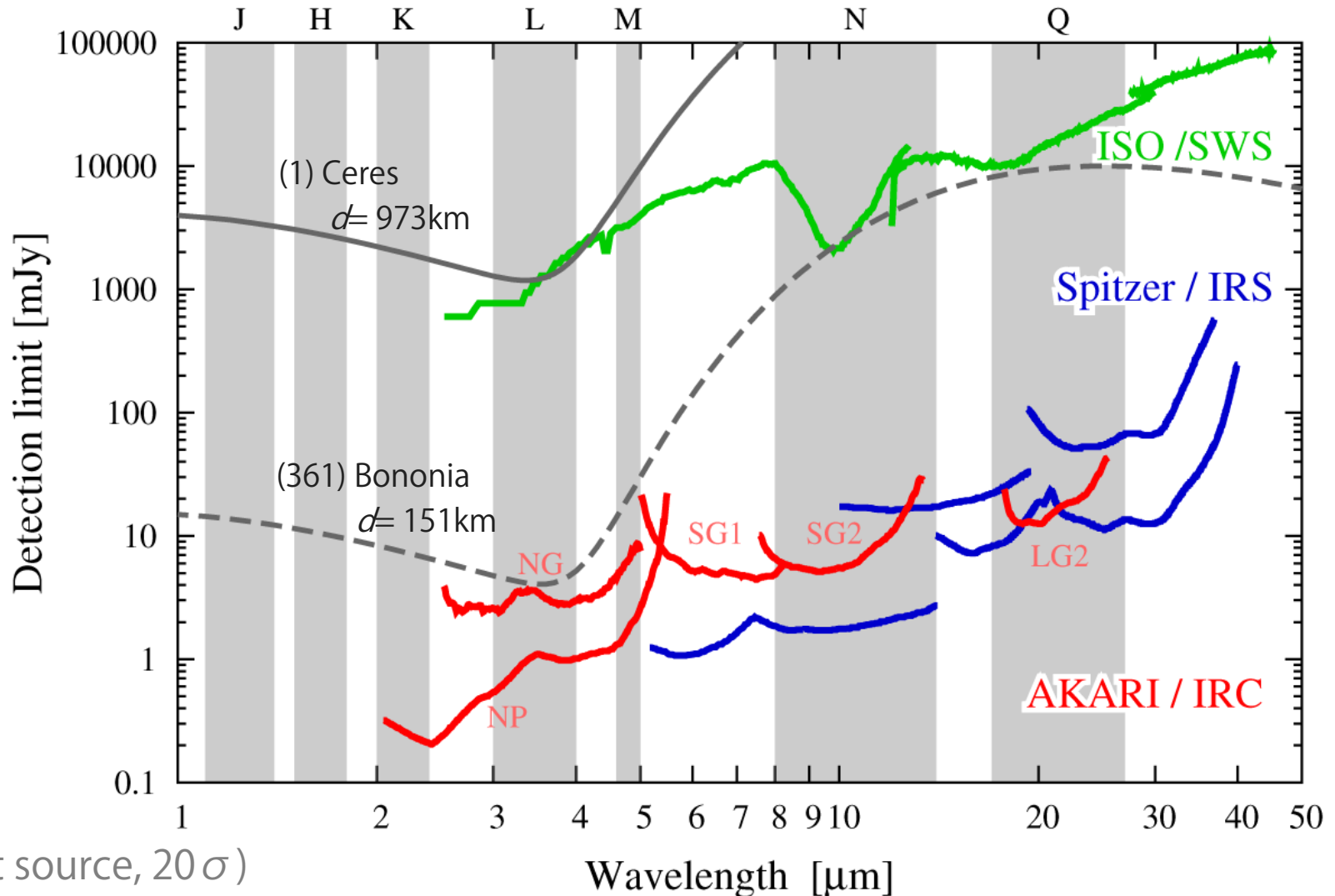
12802 pointed observations
(IRC only)

Asteroid catalog using AKARI
(Usui+2011)

157 asteroid spectroscopy
(Np aperture; 147: NG, 10: NP)

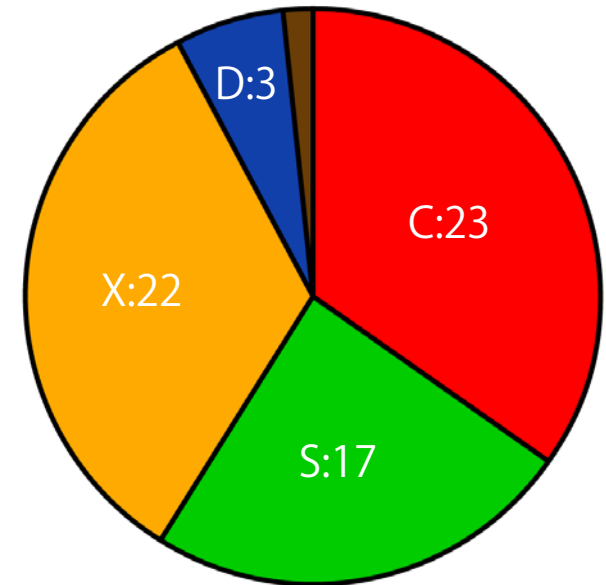
AKARI/IRC spectroscopic observations

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



Near-infrared spectroscopy for asteroids with AKARI

- Observations for 66 asteroids (total 147 times) with IRC/NIR
 - Wavelength coverage : 2.5--5 μm
Spectral resolution : $R=120@3.6\mu\text{m}$
 - Determination of taxonomy :
 - ✓ ECAS (Tholen 1984; Tholen 1989; Tholen+Barucci 1989)
 - ✓ SMASSII (Bus 1999; Bus+Binzel 2002)
 - ✓ S³OS² (Lazzaro+2004)
 - ✓ SDSS-MOC (Carvano+2010)



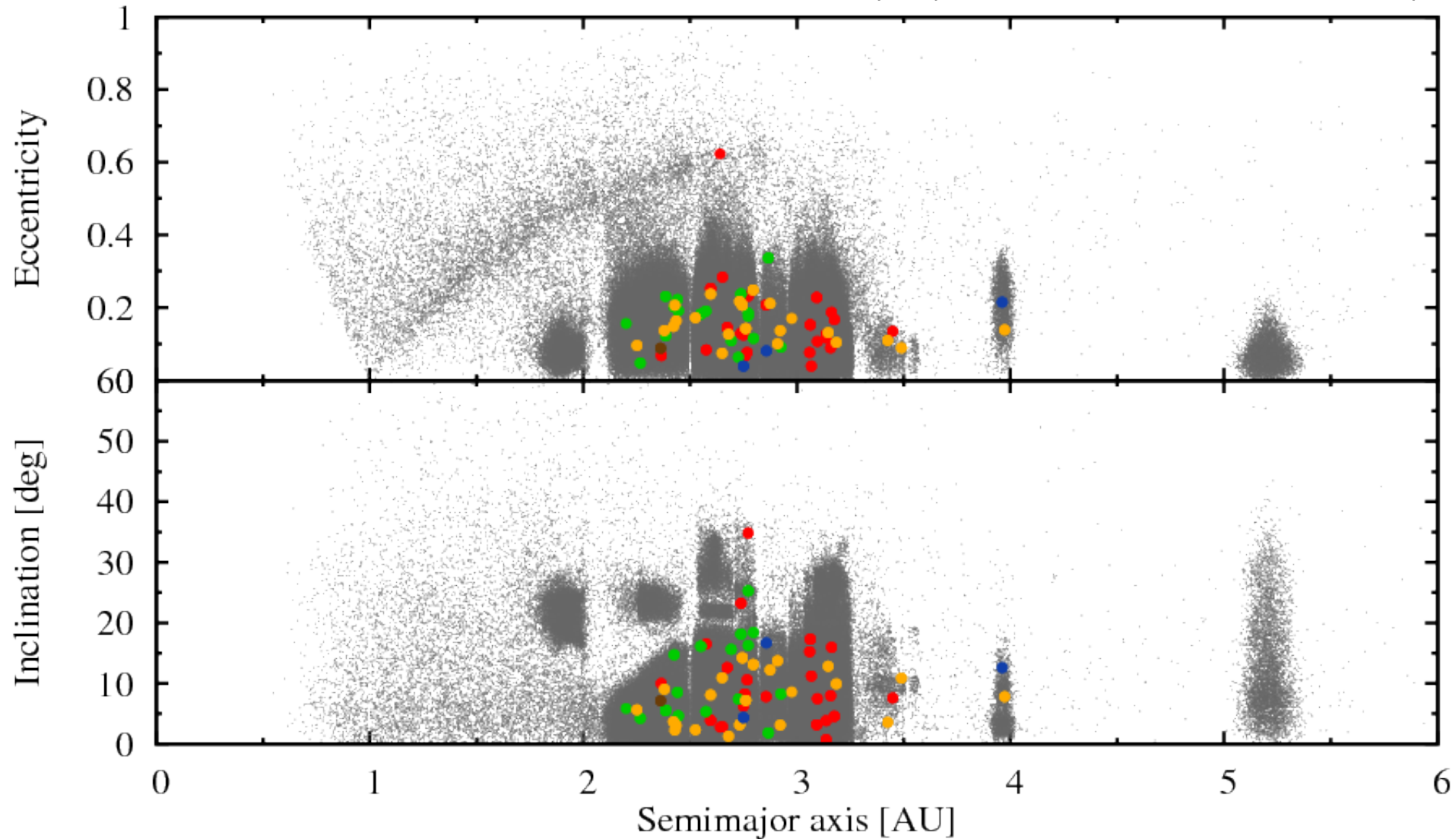
Taxonomy of asteroids for AKARI observations

- Data reduction
 - IRC Spectroscopy Toolkit for Phase 3 Version 20150331
(<http://www.ir.isas.jaxa.jp/ASTRO-F/Observation>)
 - Frame shift-and-add for moving objects (Ootsubo+2012)
 - Object positions : obtained from JPL/Horizons
 - Computed solar spectrum : corrected Kurucz model (Berk+1999)

Distribution of orbital elements of asteroids

C: 23, S: 17, X: 22, D: 3, V: 1 (total: 66 objects)

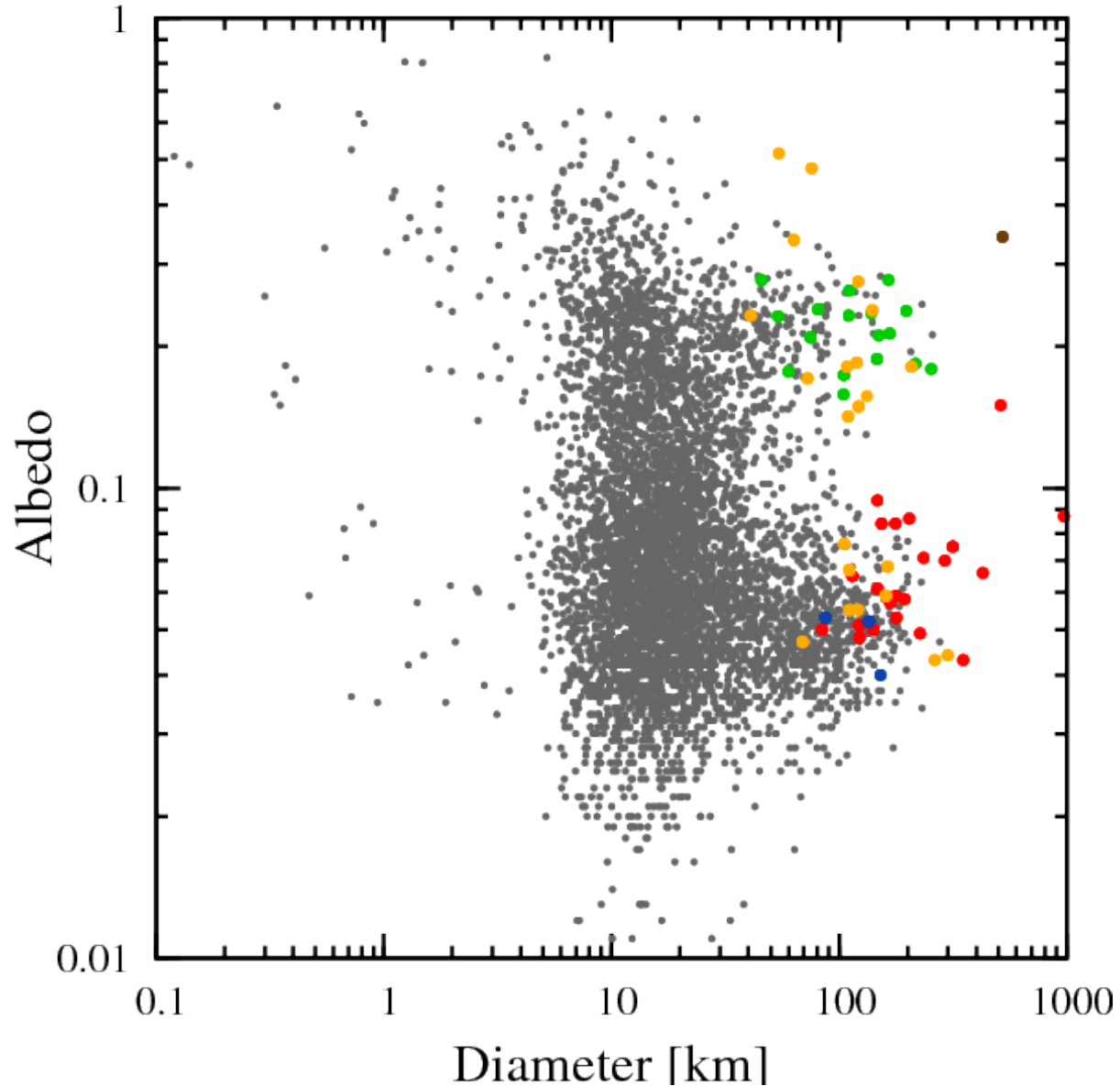
(645,292 asteroids with known orbits)



Distribution of size and albedo of asteroids

C: 23, S: 17, X: 22, D: 3, V: 1 (total: 66 objects)

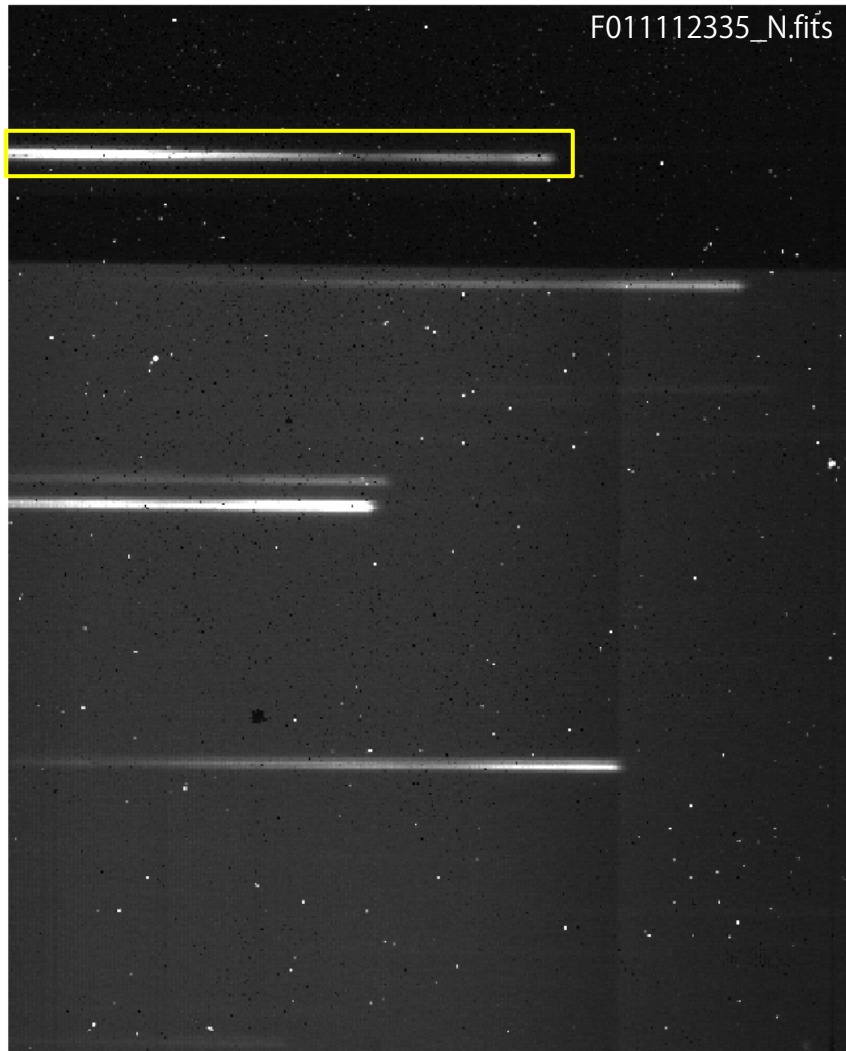
(5,199 asteroids identified with AKARI)



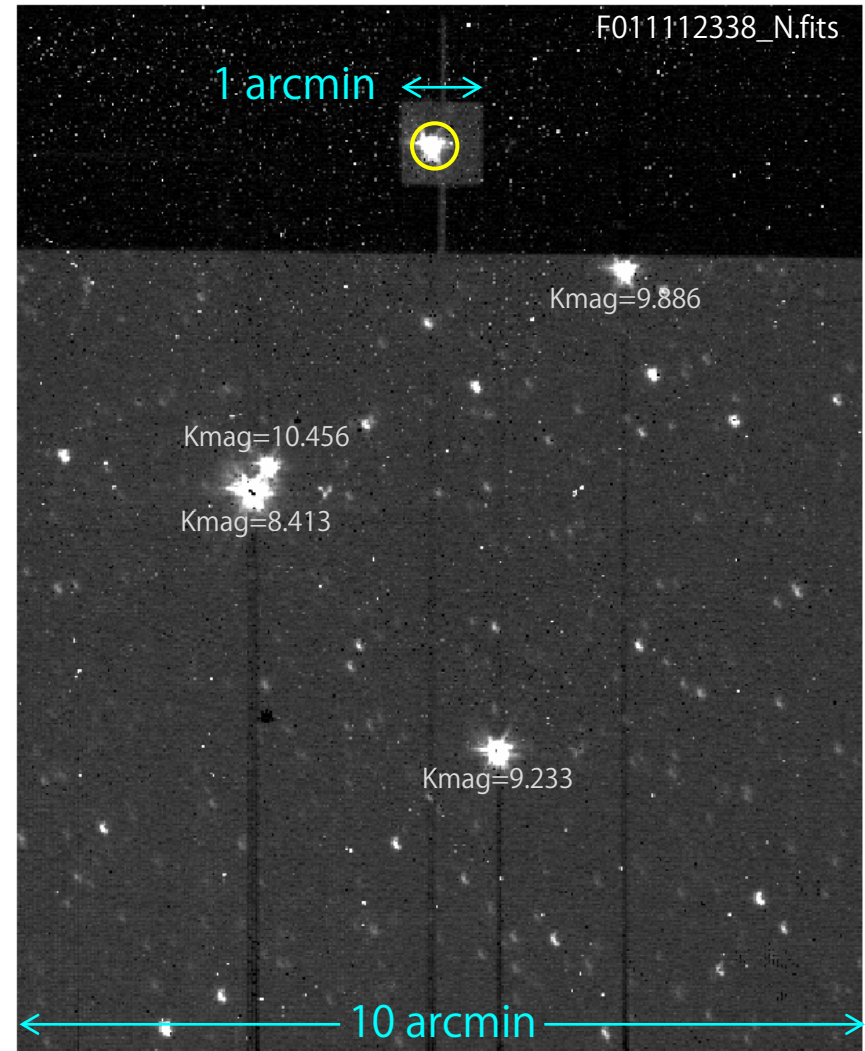
Example of data reduction : (511) Davida

ID=1520065-001, IRCZ4, b;Np, 2008/11/16_11:26:34

spec data (NG; 1/9)

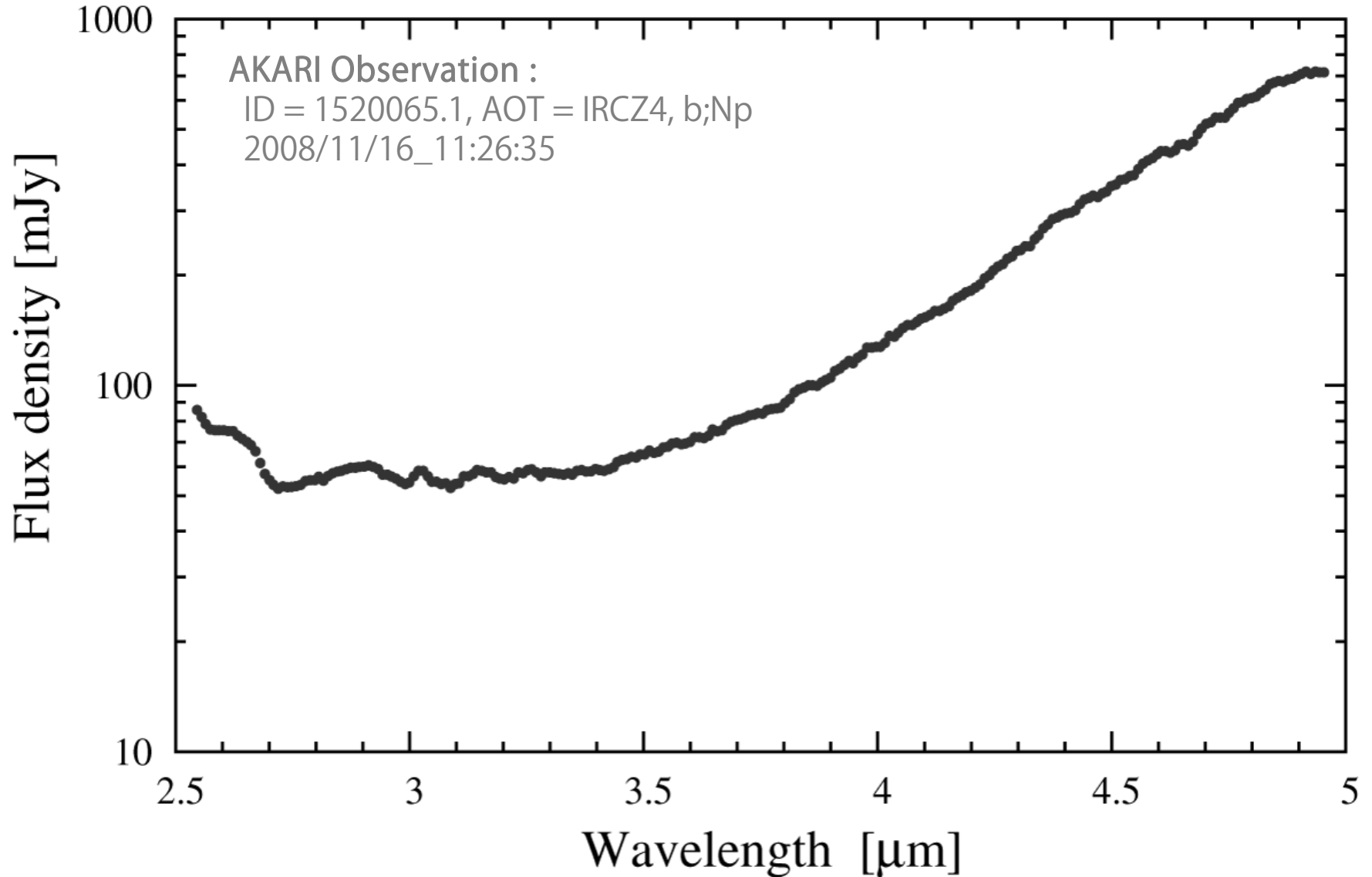


reference image (N3; 1/1)



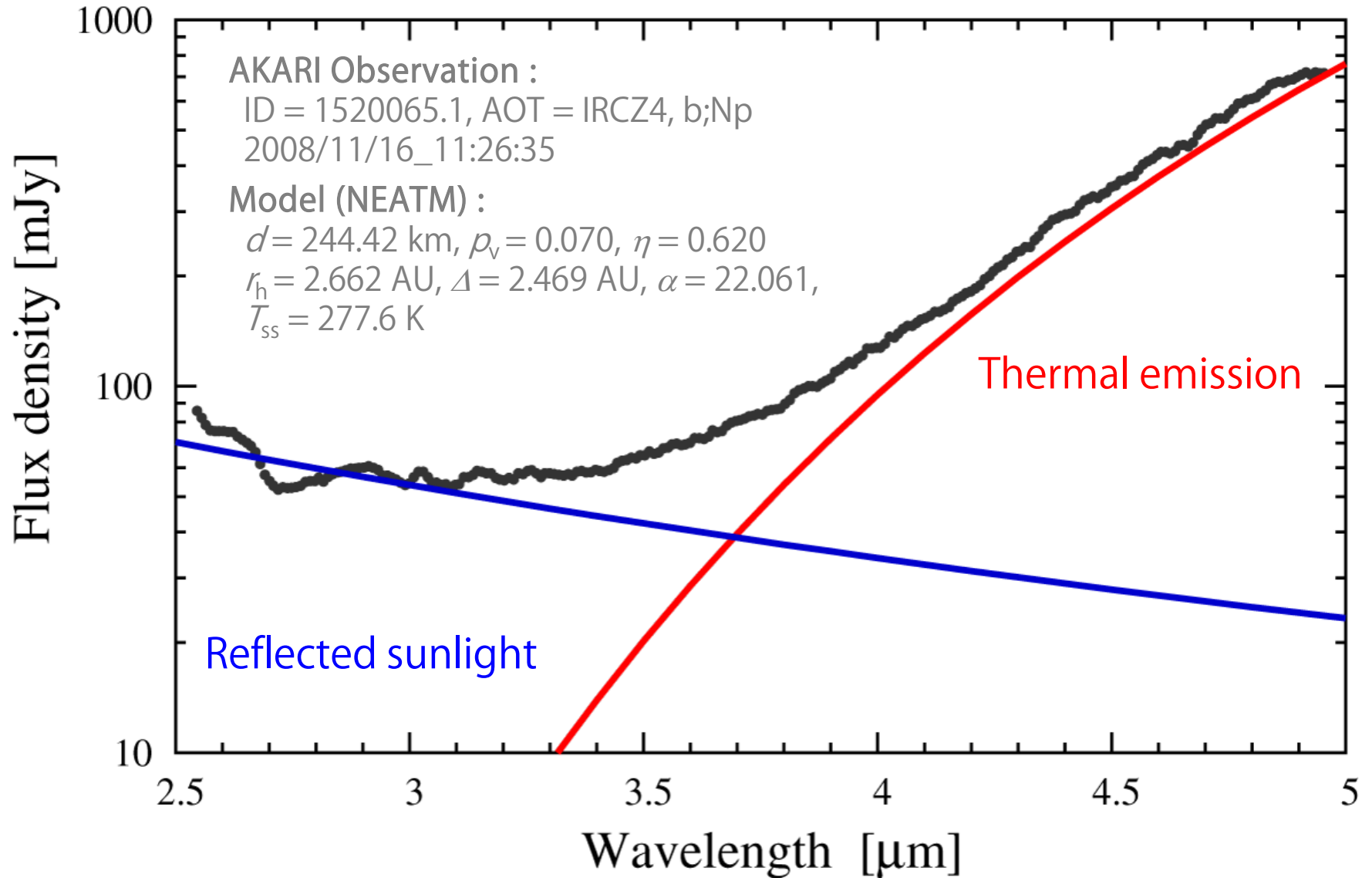
Example of data reduction : (511) Davida

Near-infrared spectrum



Example of data reduction : (511) Davida

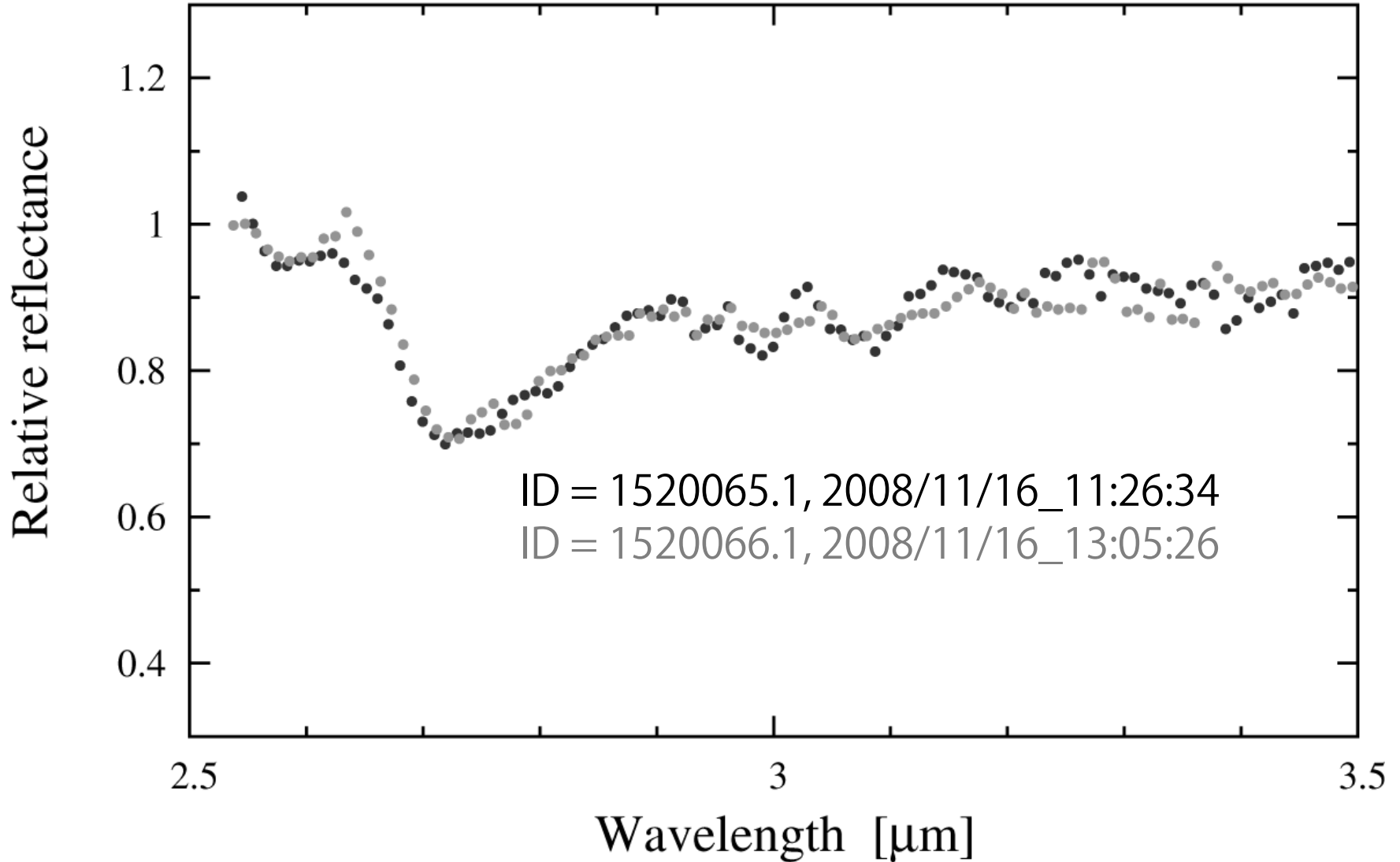
Near-infrared spectrum



Example of data reduction : (511) Davida

Reflectance spectrum

($P = 5.131$ hr)



Near-infrared spectra of C-type asteroids

【PRELIMINARY】

Near-infrared spectra of S-type asteroids

【PRELIMINARY】

Near-infrared spectra of X-type asteroids

【PRELIMINARY】

Albedo v.s. absorption strength of 2.7 μm band

C: 23, S: 17, X: 22, D: 3, V: 1 (total: 66 objects)

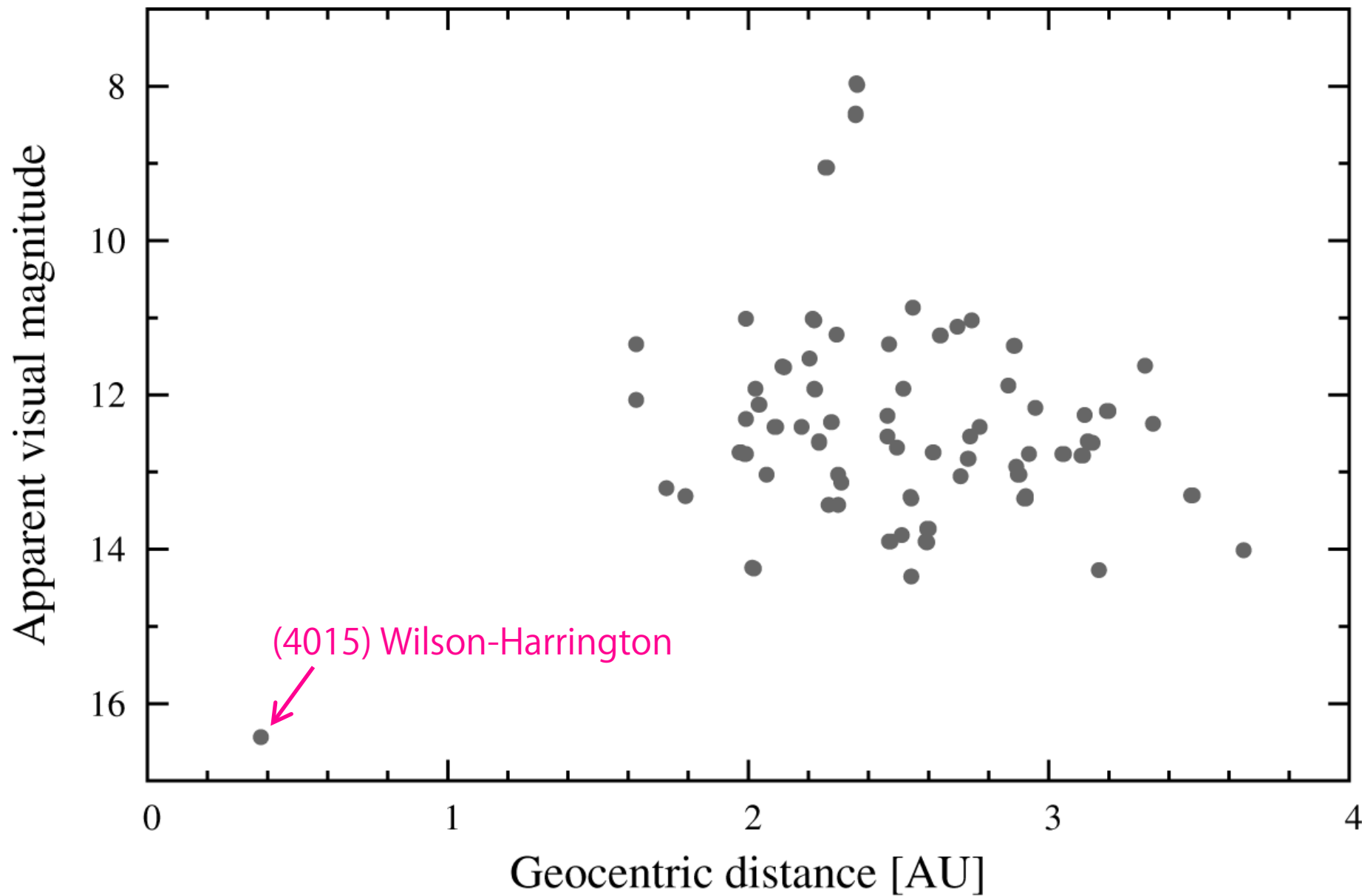
【PRELIMINARY】

Summary

Near-infrared spectroscopy for asteroids with AKARI (Usui+, in prep)

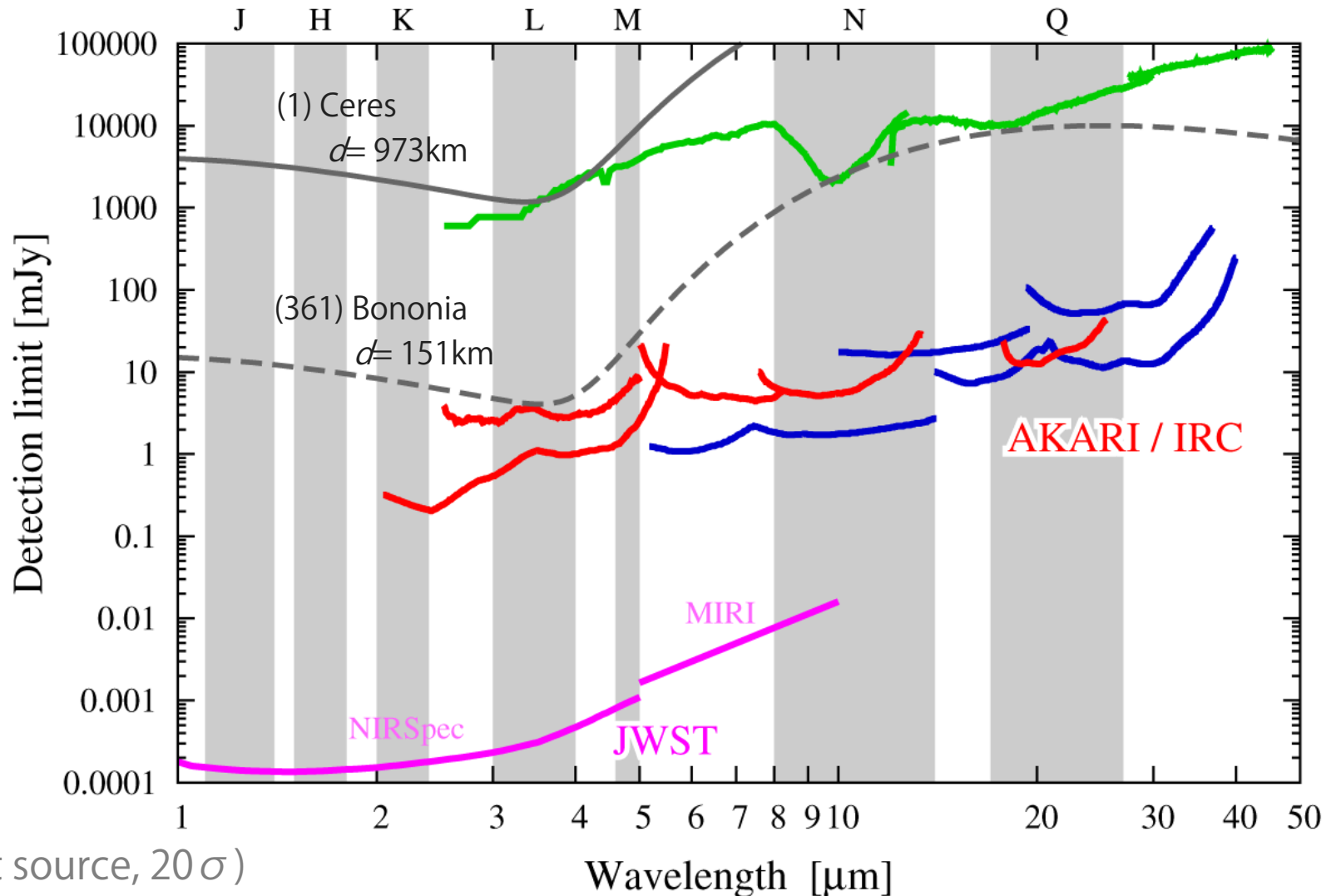
- Spectroscopic observations for 66 asteroids (total 147 times) with IRC/NIR in warm mission phase of AKARI
 - Wavelength coverage : 2.5--5 μm , spectral resolution : $R=120$
- From reduced spectra (in 2.5--3.5 μm range),
 - **Most C-types (16/23)** have clear absorption feature in 2.7--2.8 μm band. (which is considered to be associated with hydrated minerals).
 - **All S-types (17)** have flat spectra, no obvious absorption feature in 2.7--2.8 μm band.
 - **Some X-types (4/22) and D-types (2/3)** have absorption feature like C-types.

あかりで観測した天体の可視等級の分布



AKARI/IRC spectroscopic observations

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



リモート観測による小惑星の含水鉱物探査

- 赤外線天文衛星「あかり」による近赤外線分光観測
 - 「あかり」… 高度 700 km 太陽同期 / 口径 0.7 m
 - 小惑星66天体 (メインベルトで40 km 以上) の近赤外線分光観測を実施した
- 含水鉱物のスペクトルの特徴を統計的に議論するには、より多くのサンプルが必要
(cf. 可視のtaxonomy … ECAS : 589, SMASSII : 1447, S³OS² : 820)
 - 地上もしくは成層圏からの観測：
 - ✓ 現時点で 30 m 級望遠鏡 (GMT, TMT, E-ELT) に3 μm帯の分光機能の計画はない
 - ✓ TAO/MIMIZUKU … 標高 5600 m (チリ・チャナントール山頂) / 口径 6.5 m
 - ✓ SOFIA (Stratospheric Observatory for Infrared Astronomy) … 高度 12 km / 口径 2.5 m
 - ✓ 気球望遠鏡 … 高度 36 km / 口径 0.8 m
 - BOPPS (Balloon Observation Platform for Planetary Science)
 - BRRISON (Balloon Rapid Response for ISON)
 - 宇宙からの観測：
 - ✓ JWST (James Webb Space Telescope) … L2 / 口径 6.5 m
 - ～100天体 (メインベルトで20 km 以下; Norwood+2014)
 - ✓ サブオービタル機、ロケット実験
 - ✓ etc