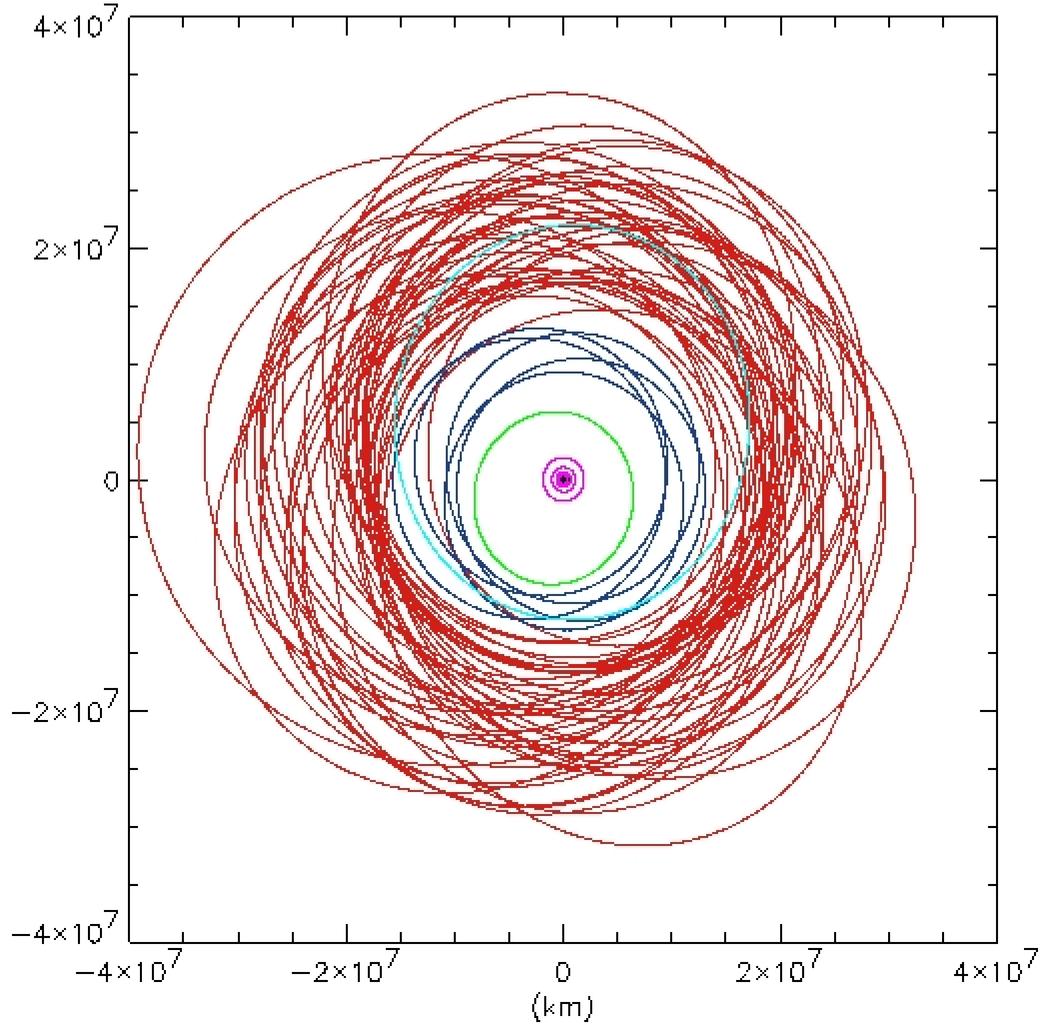
惑星系研究会＠定山渓渓流層
2013．08．07－09

スペクトル型から見た木星小衛星とヒルダ・トロヤ群との関係

高遠徳尚（国立天文台ハワイ観測所）

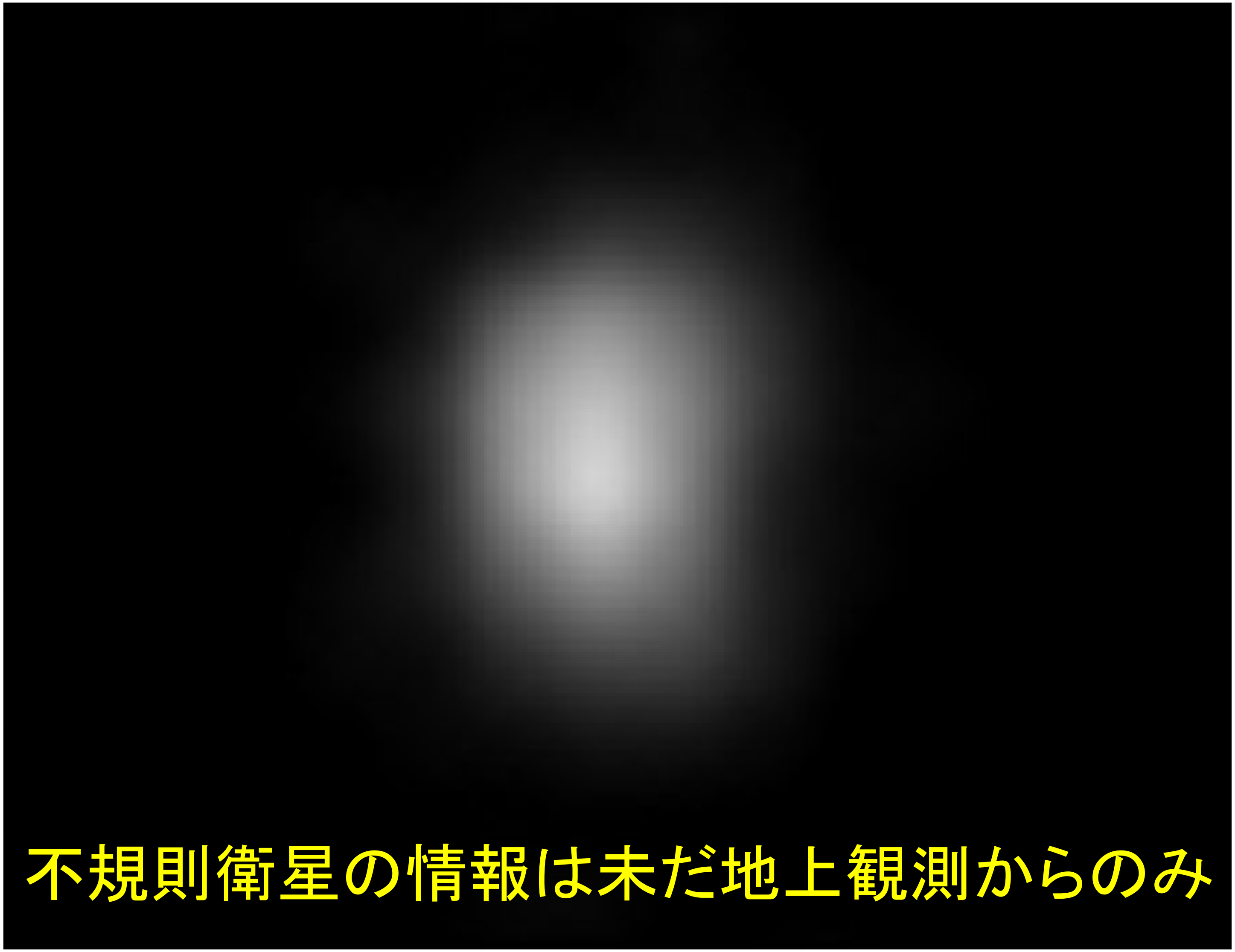
木星の衛星

Inner small satellites: 4
Galilean satellites : 4
Irregular satellites
- prograde : 7
- retrograde: 52

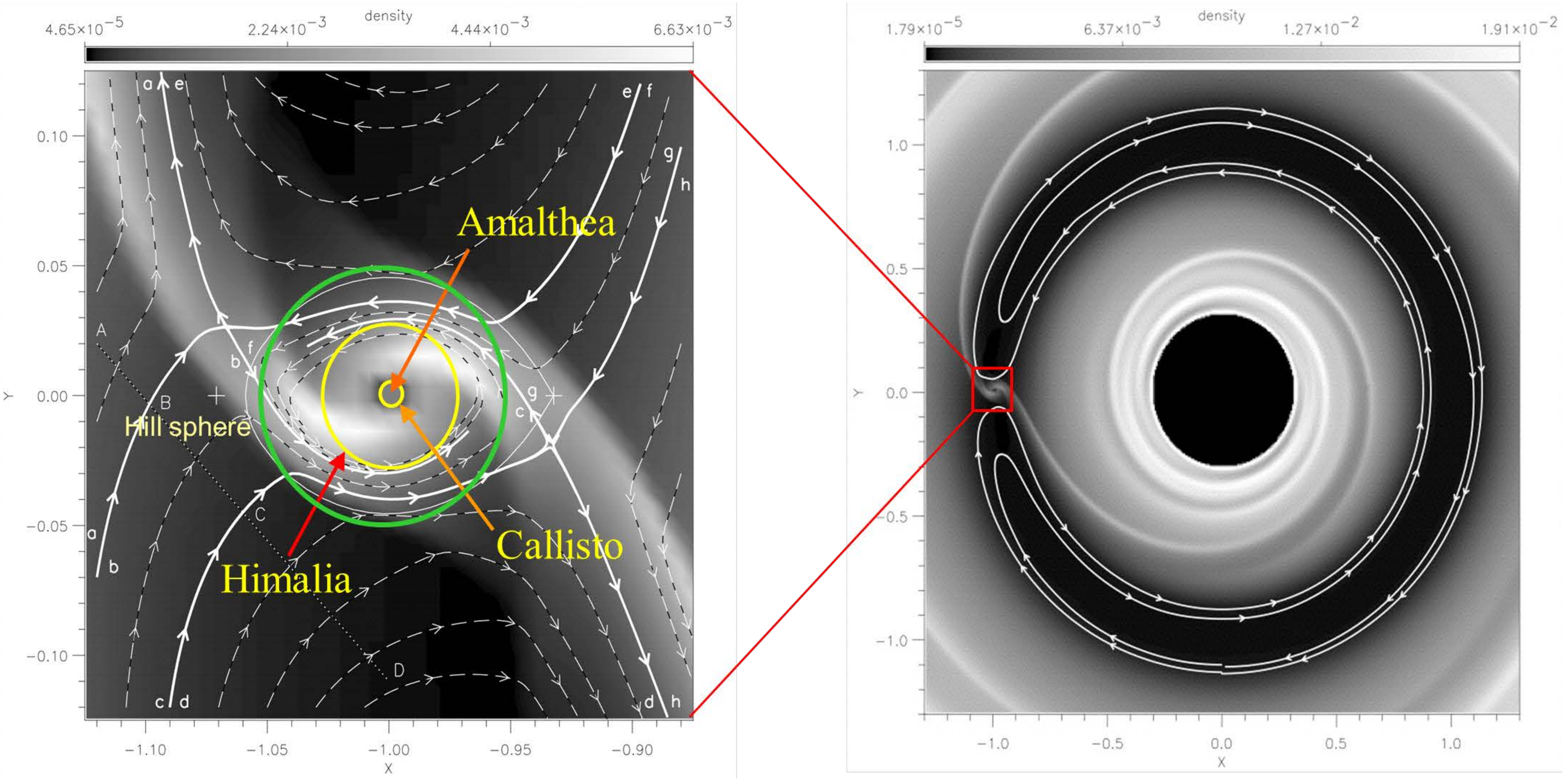


Sheppard

Himalia pictured by Galileo

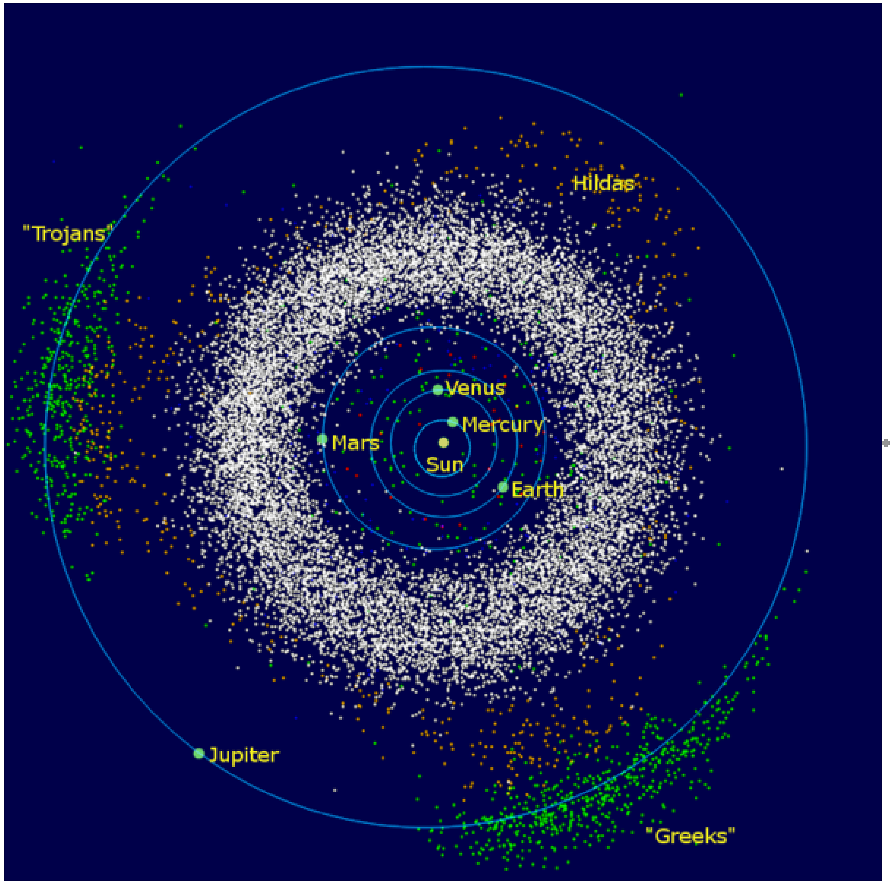


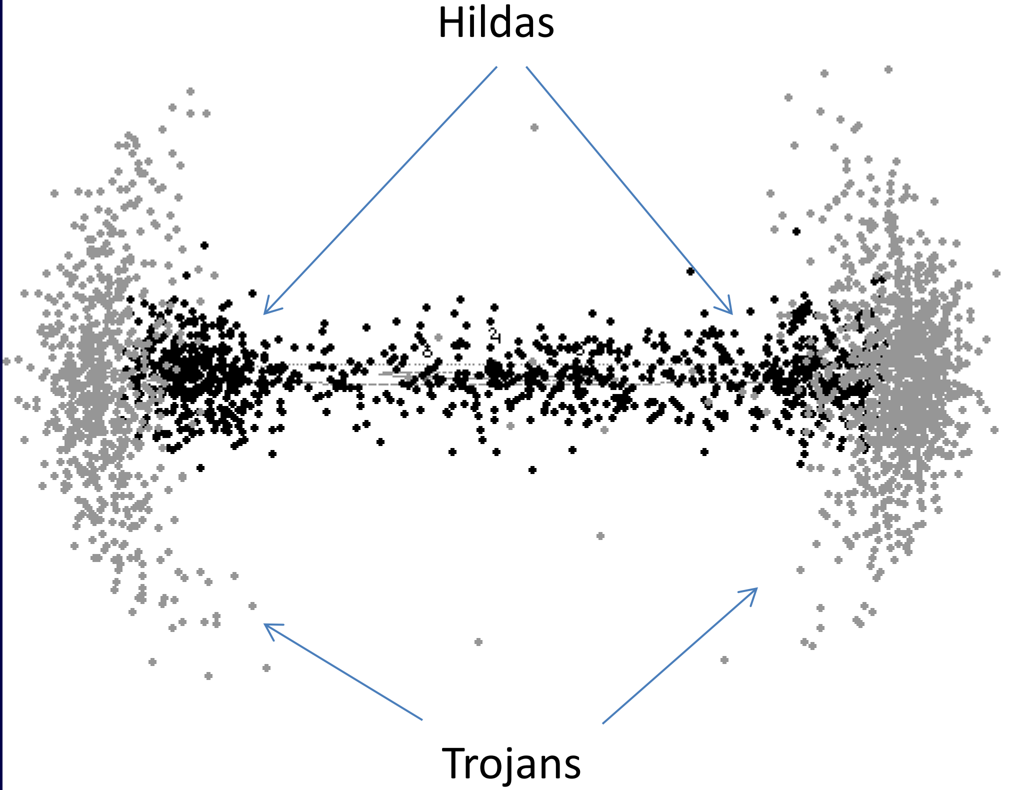
周木星円盤との位置関係



Canup & Ward

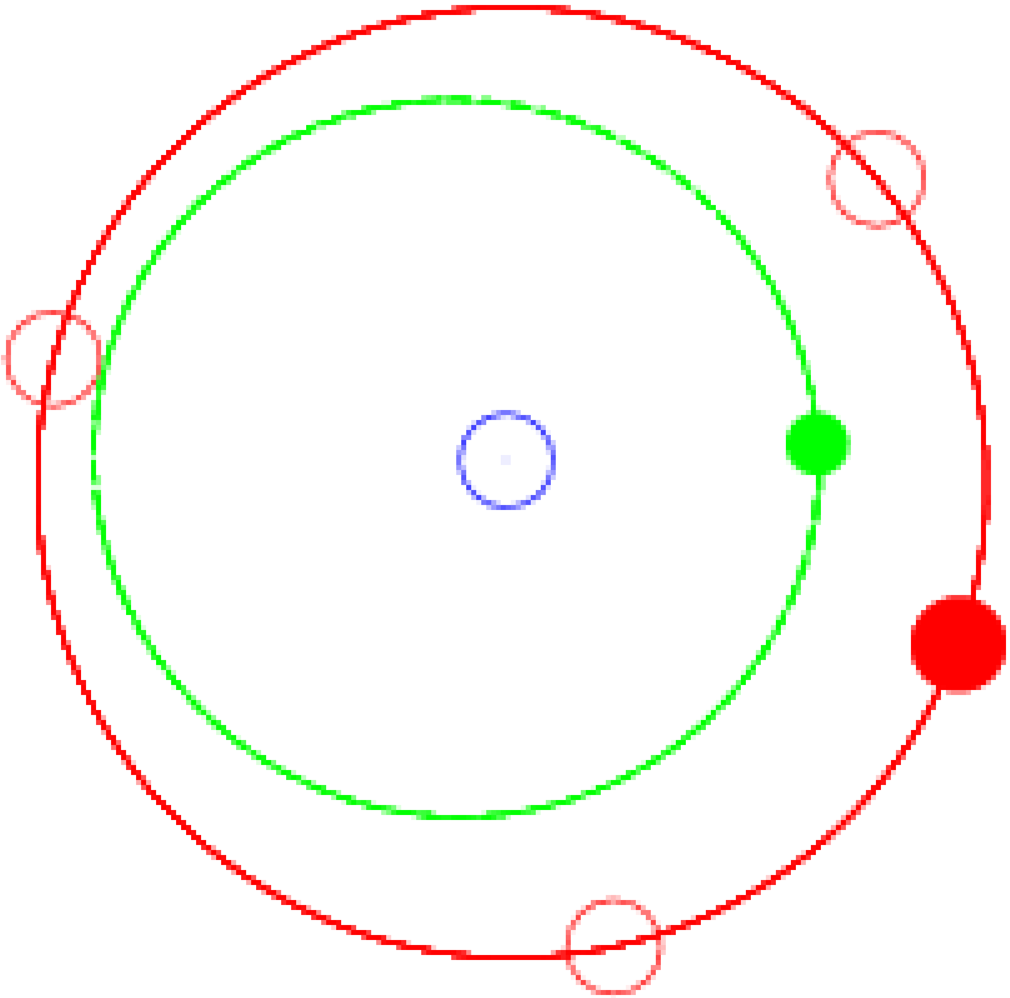
ヒルダ群、トロヤ群





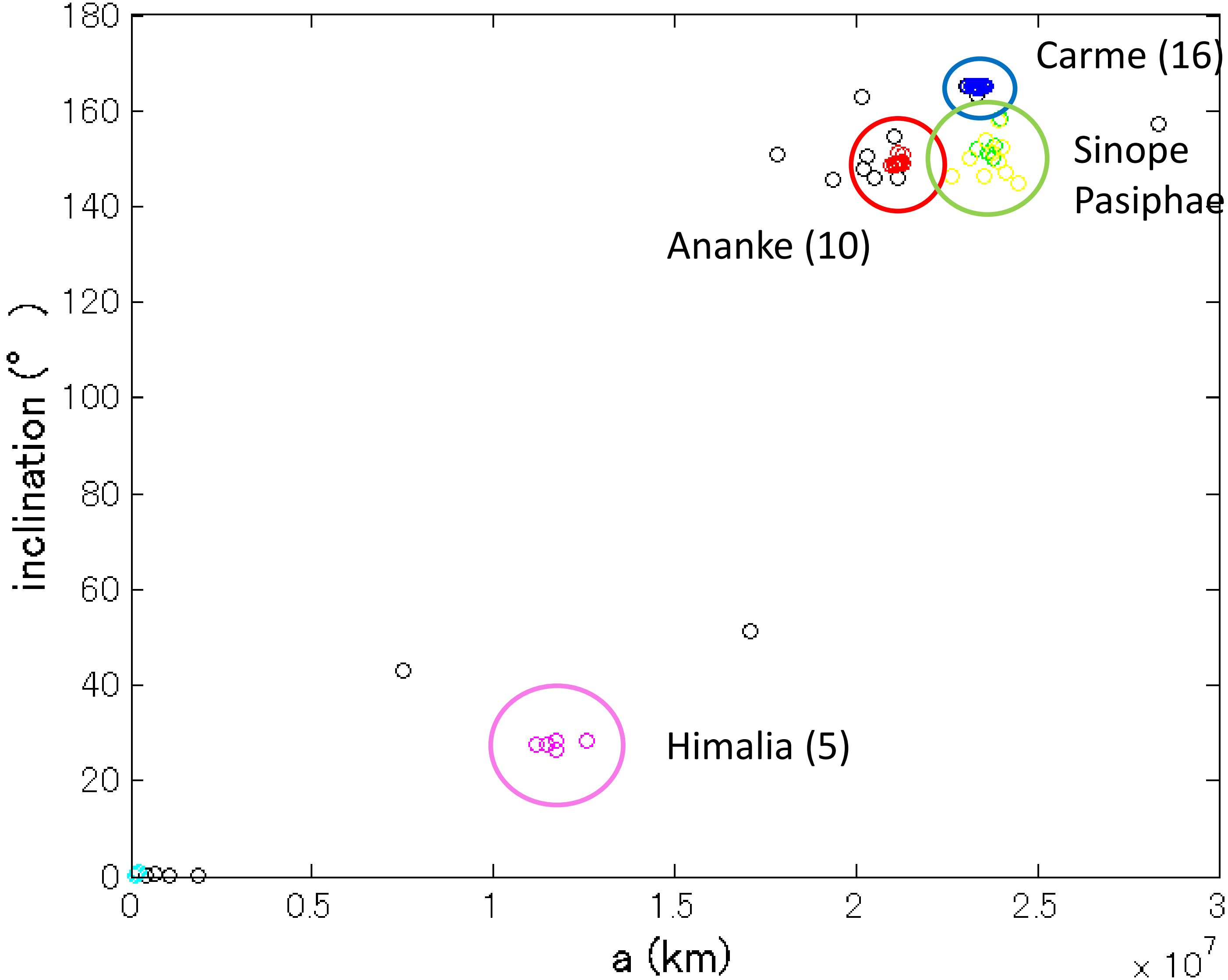
黄道面から見た図

Hilda

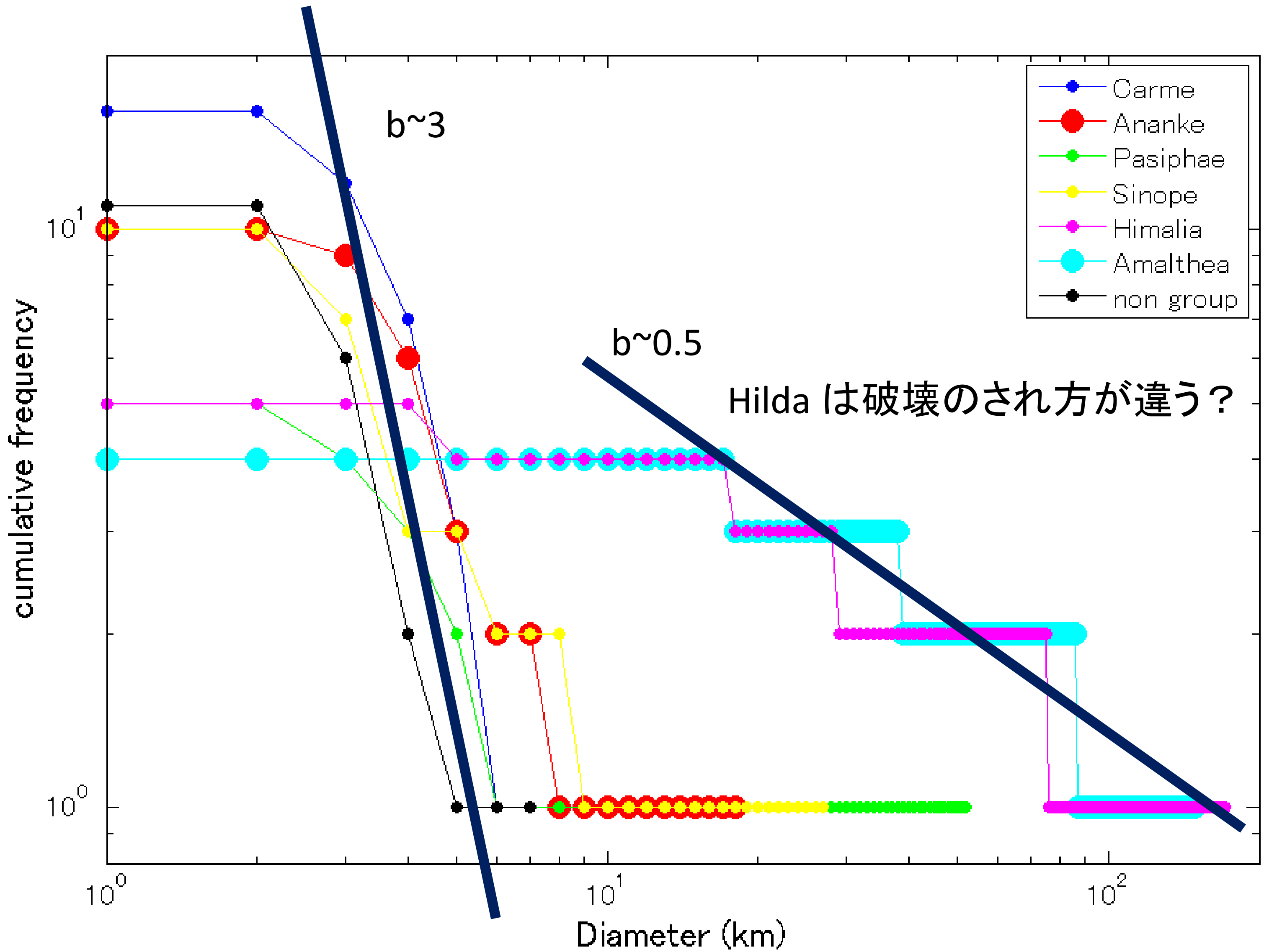


3 : 2

不規則衛星の軌道要素

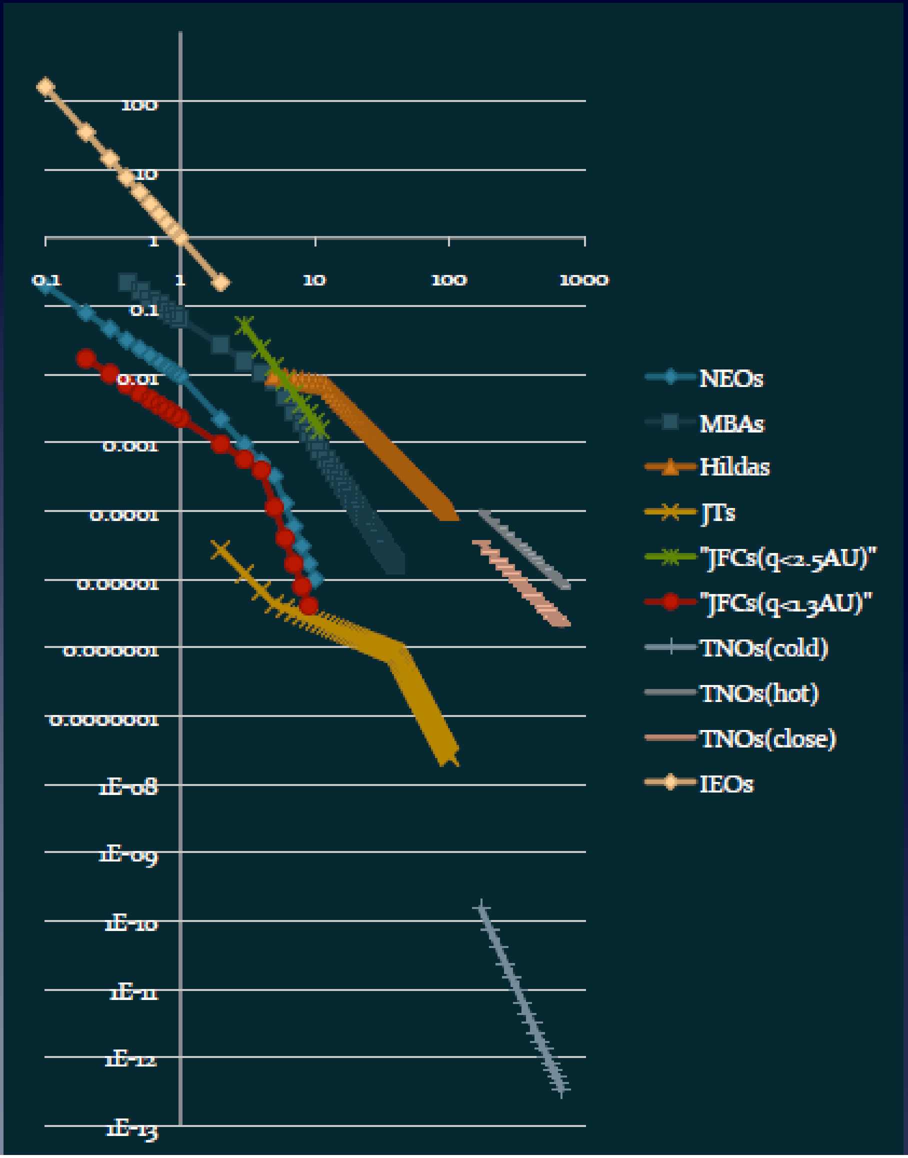

Carme (16)
Sinope
Pasiphae
Ananke (10)
Himalia (5)
inclination (°)
a (km)
× 10^7
180
160
140
120
100
80
60
40
20
0
0.5
1
1.5
2
2.5
3

Cumulative size-frequency distribution of each satellite group



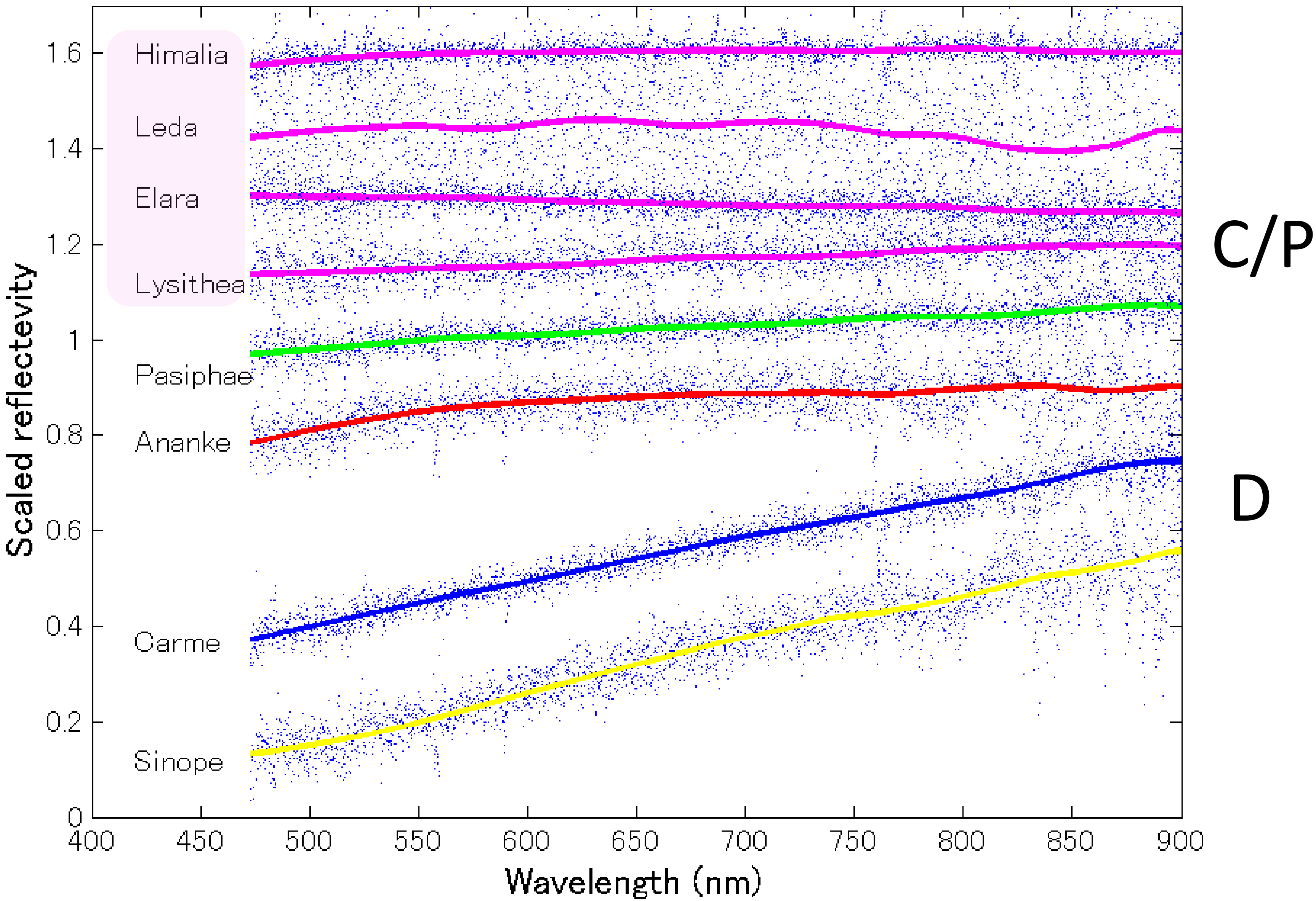
Summary of SSSB's size distribution

Group	b	Size range (km)
IEOs	2.2	0.03<D<1.6
NEOs	5 2.1 1.32	D > 5 1.5 < D < 5 D < 1.5
MBAs	3 1.3	5 < D< 40 0.4 < D < 5
Hildas	2.0 0.37	D > 12 5 < D < 12
JTs	3.8 0.8 2.0	D > 40 5 < D < 40 D < 5
JFCs (q<2.5AU)	2.7	3 < D < 11
Near Earth JFCs (q<1.3AU)	5.65 1.25	4 < D < 9 0.2 < D < 4
TNO(cold)	4.4	170 < D < 670
TNO(hot)	1.8	170 < D < 670
TNO(close)	2.0	170 < D < 670



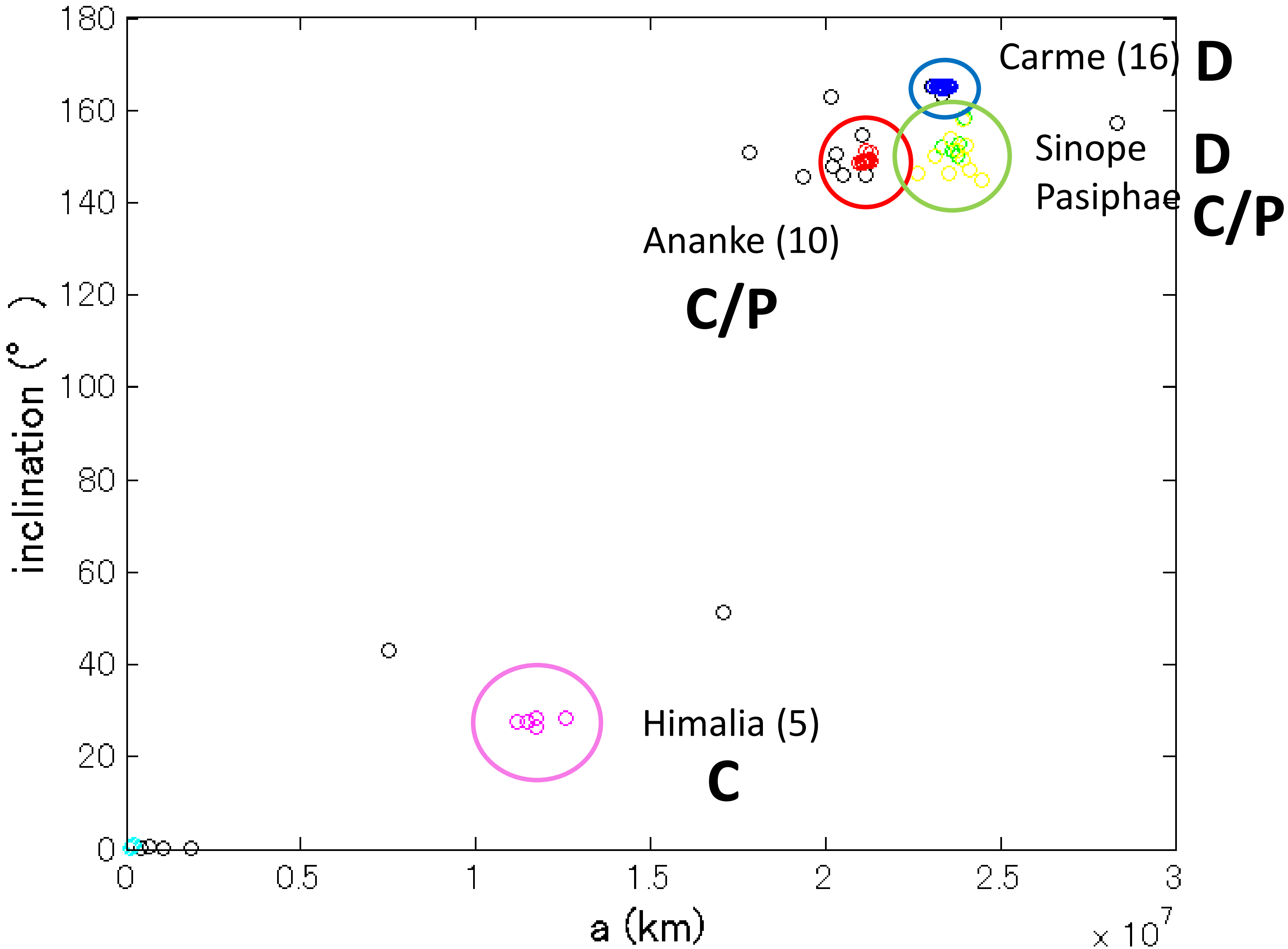
Yoshida ACM2012

木星不規則衛星の可視スペクトル



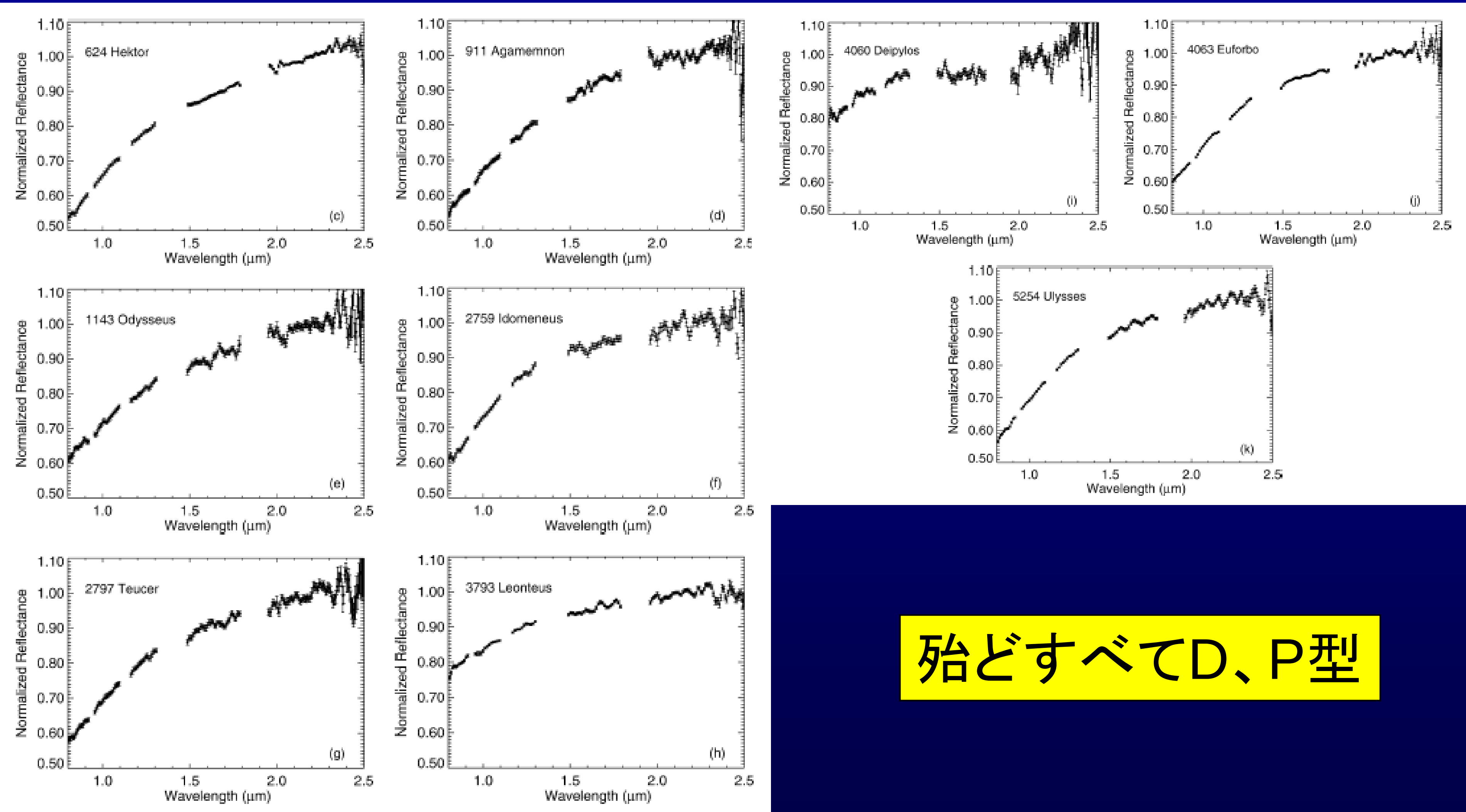
Takato/Subaru 2012

不規則衛星の軌道要素



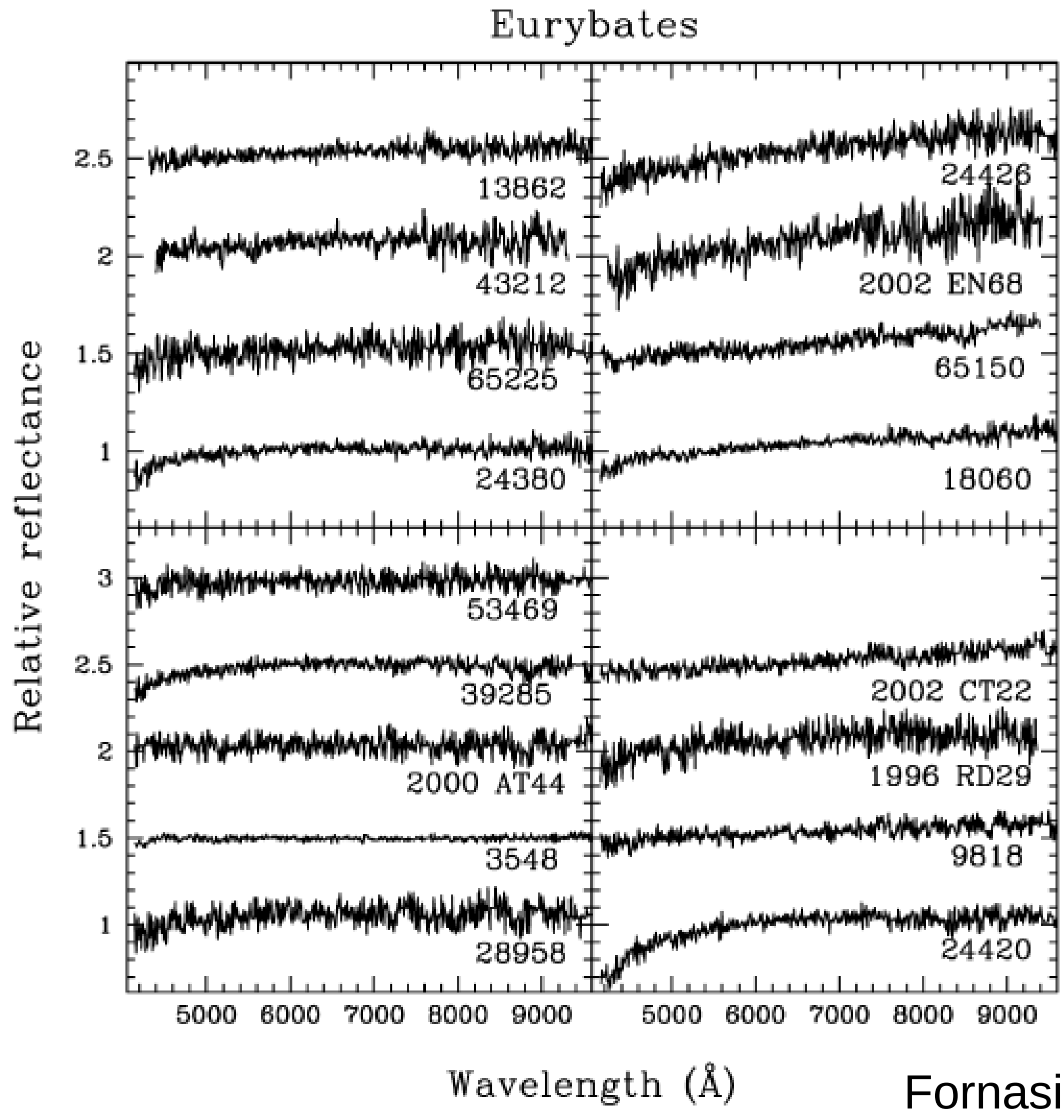
Carme (16)
D
Sinope
D
Pasiphae
C/P
Ananke (10)
C/P
Himalia (5)
C
inclination (°)
a (km)
× 10^7
180
160
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3

トロヤ群天体の反射スペクトル(Emery & Brown 2003)



殆どすべてD、P型

L4のFamilyはC，P型が多い



Fornasier et al. 2007

Fig. 5. Reflectance spectra of the 17 Eurybates family members (L4 swarm). Spectra are shifted by 0.5 in reflectance for clarity.

トロヤ群とのスロープの比較

Family member　　Background　　Total

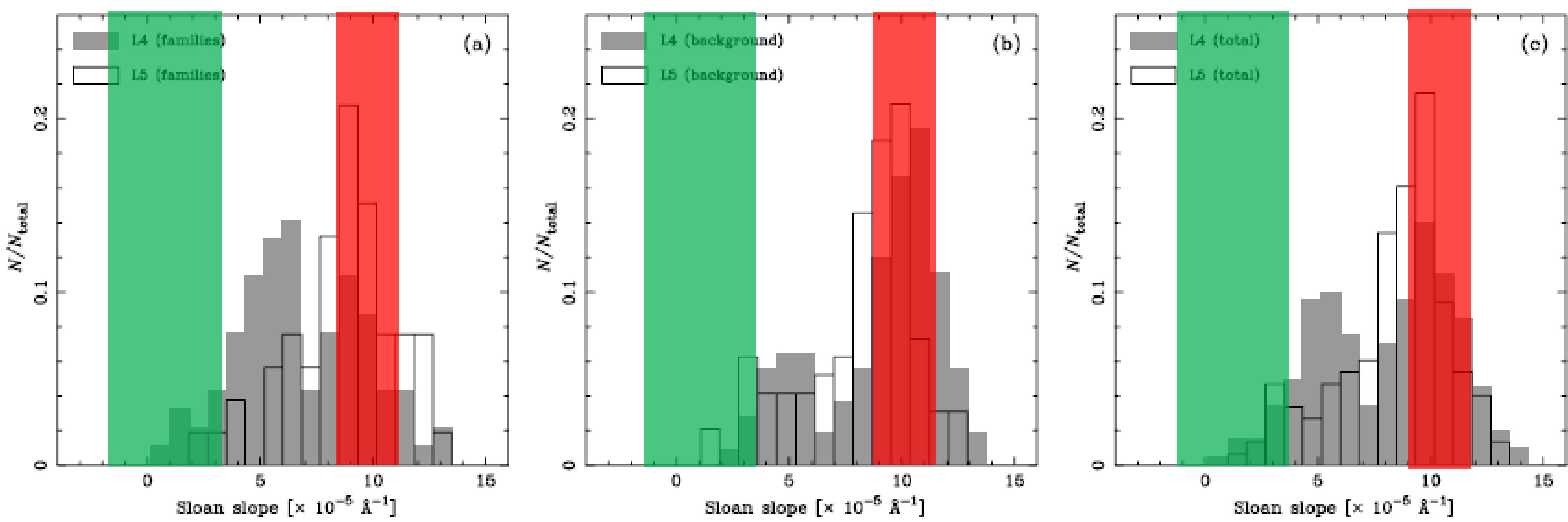
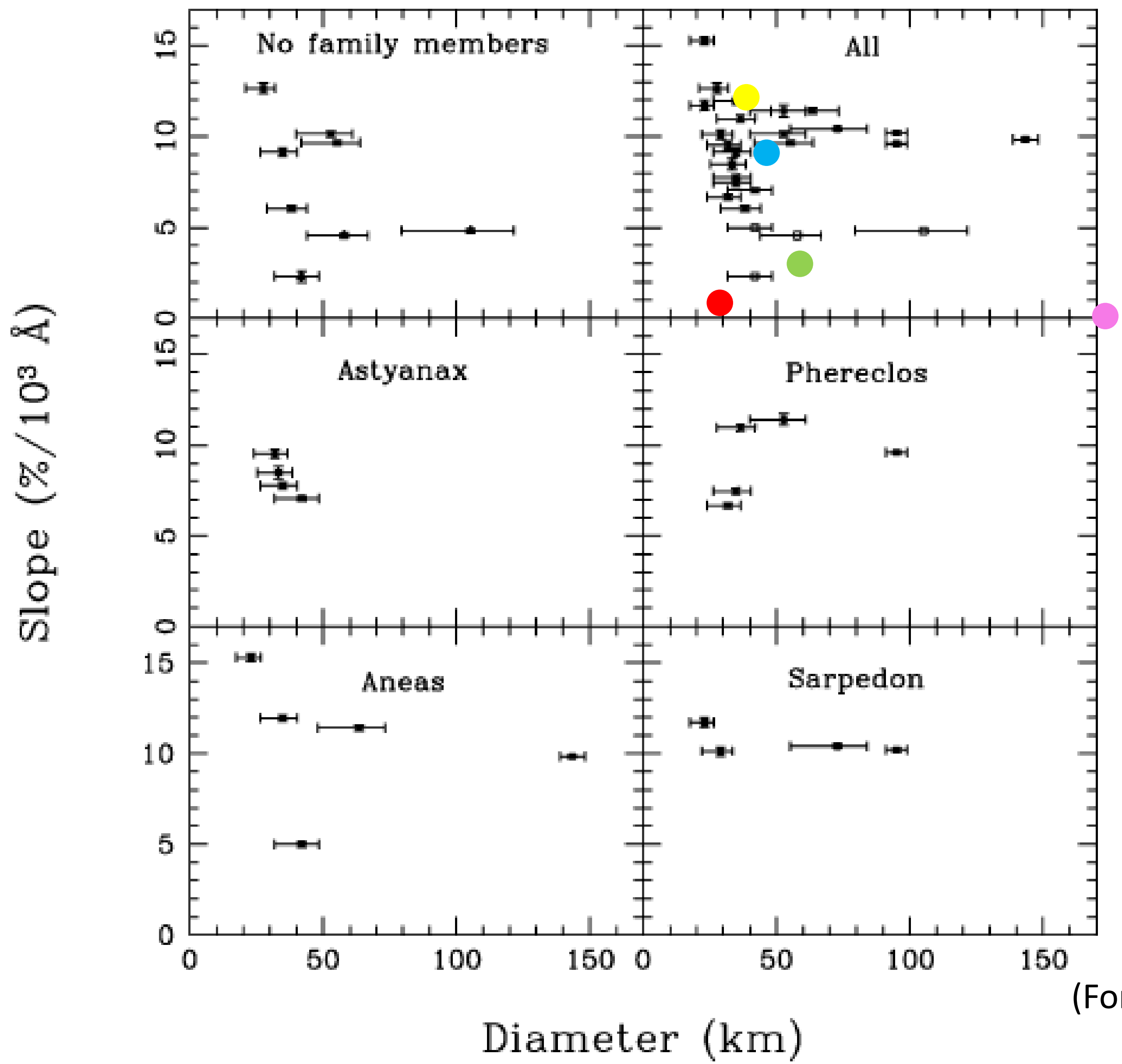


Fig. 6. a) Distribution of the Sloan slopes of family members only. The gray histogram corresponds to the L4 swarm and the outlined histogram to the L5 swarm. b) Same as a), but for the background asteroids only. c) Same as a), but for both family members and background asteroids together. Each histogram has been normalized such that its area is 1.

Roig et al. 2008

トロヤ群：サイズと赤さ(optical slope)の関係



(Fornasier et al. 2004)

軌道傾斜角が小さいと
大きなサイズの天体が少ない

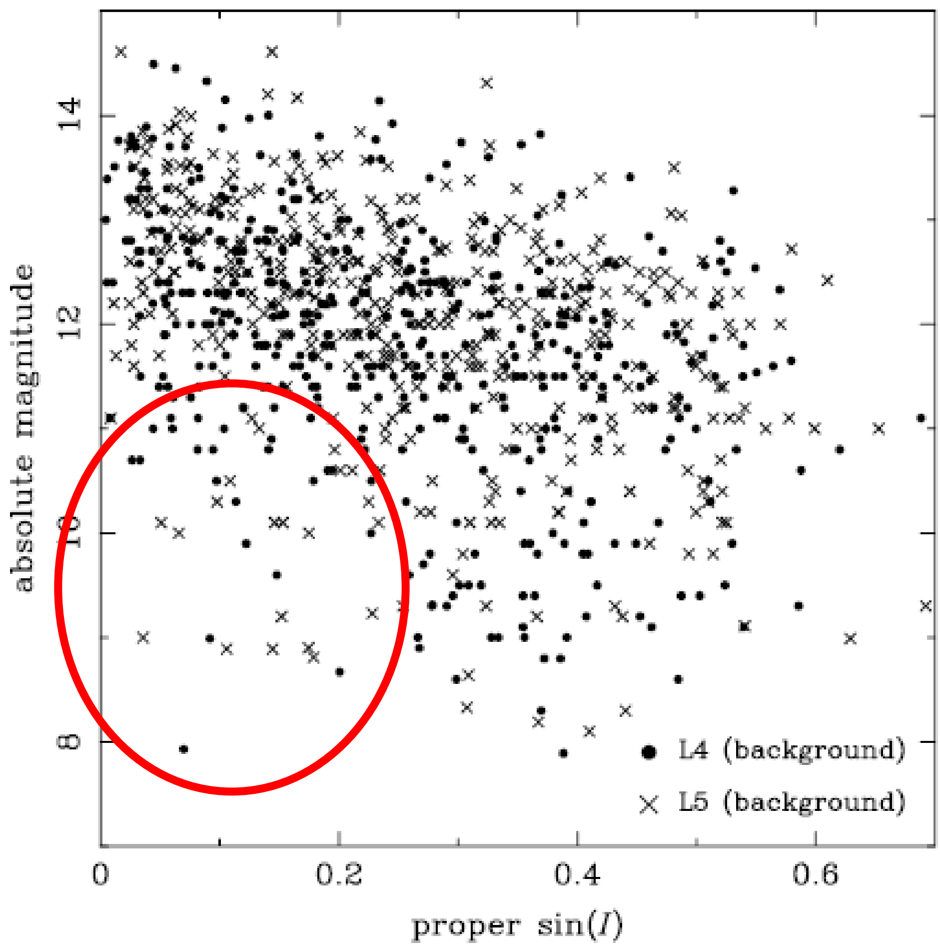


Fig. 10. Distribution of proper inclinations in terms of absolute magnitude for 913 known background Trojans. Dots correspond to the L4 swarm and cross to the L5 swarm. Note the relative lack of large asteroids with small inclinations.

Roig et al. 2008

Centaurs

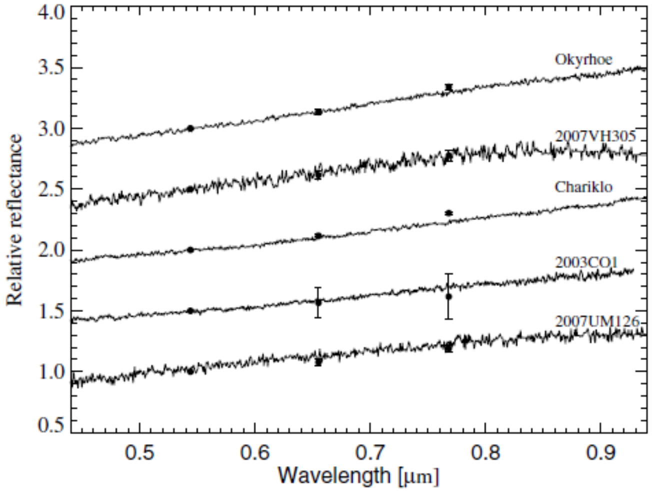


Fig. 1. Visible spectra of Centaurs. Spectra are shifted by 0.5 for clarity. The colour indices converted to spectral reflectance are also shown on each spectrum.

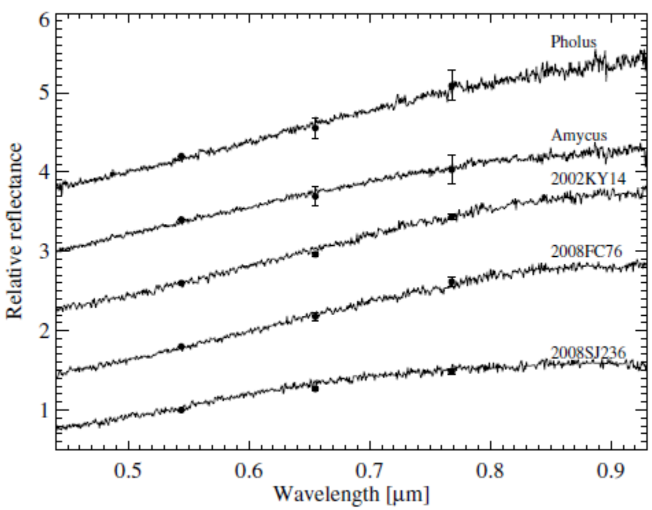


Fig. 2. Visible spectra of Centaurs. Spectra are shifted by 0.8 for clarity. The colour indices converted to spectral reflectance are also shown on each spectrum.

Classical TNOs

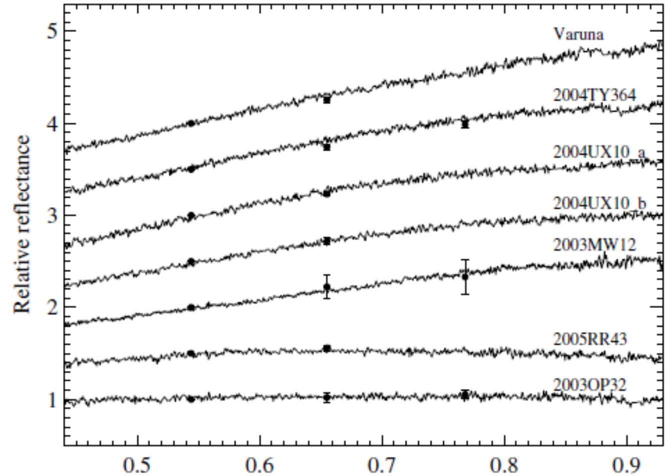


Fig. 3. Visible spectra of Classical TNOs. Spectra are shifted by 0.5 for clarity. The colour indices converted to spectral reflectance are also shown on each spectrum. 2004 UX10 was observed during two different nights: the spectrum labelled "a" was taken on 4 Dec. 2007, the one labelled "b" on 5 Dec. 2007.

SDOs

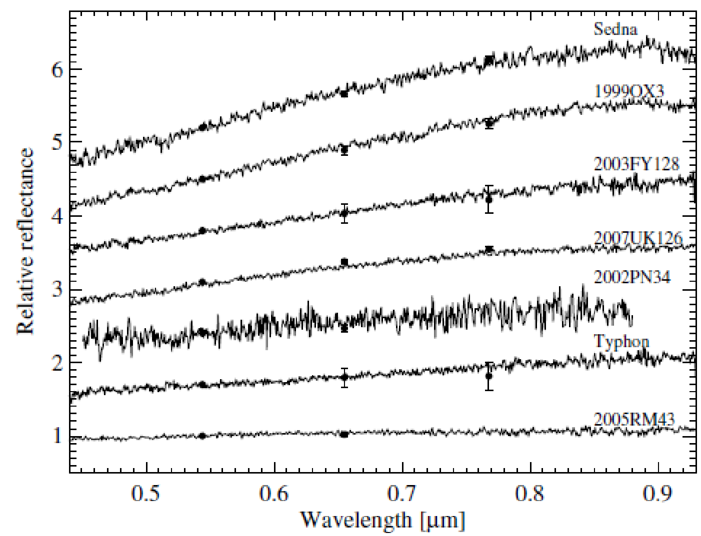


Fig. 5. Visible spectra of SDOs and detached objects (Sedna and 120132 2003 FY128). Spectra are shifted by 0.7 for clarity. The colour indices converted to spectral reflectance are also shown on each spectrum.

Fornasier+2009

Resonant TNOs

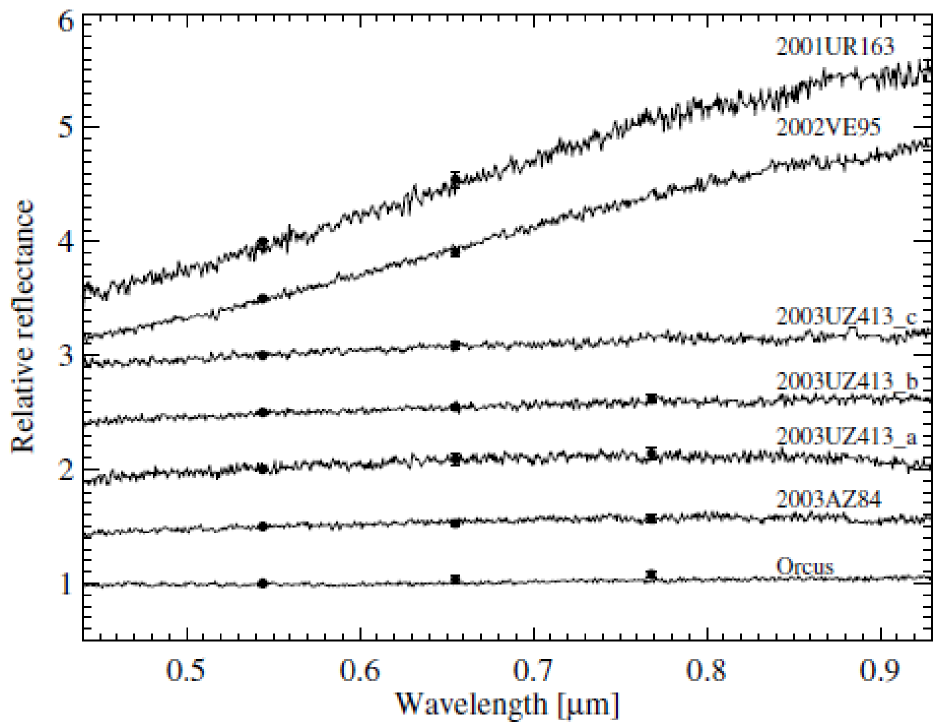


Fig. 4. Visible spectra of resonant TNOs. All are plutinos except 42301 (2001 UR163) which is in the 9:4 resonance with Neptune. We observed 2003 UZ413 during 3 different runs: the spectrum labelled "a" is from Sep. 2008, "b" from Nov. 2008, and "c" from Dec. 2007. Spectra are shifted by 0.5 for clarity. The colour indices converted to spectral reflectance are also shown on each spectrum.

Fornasier+2009

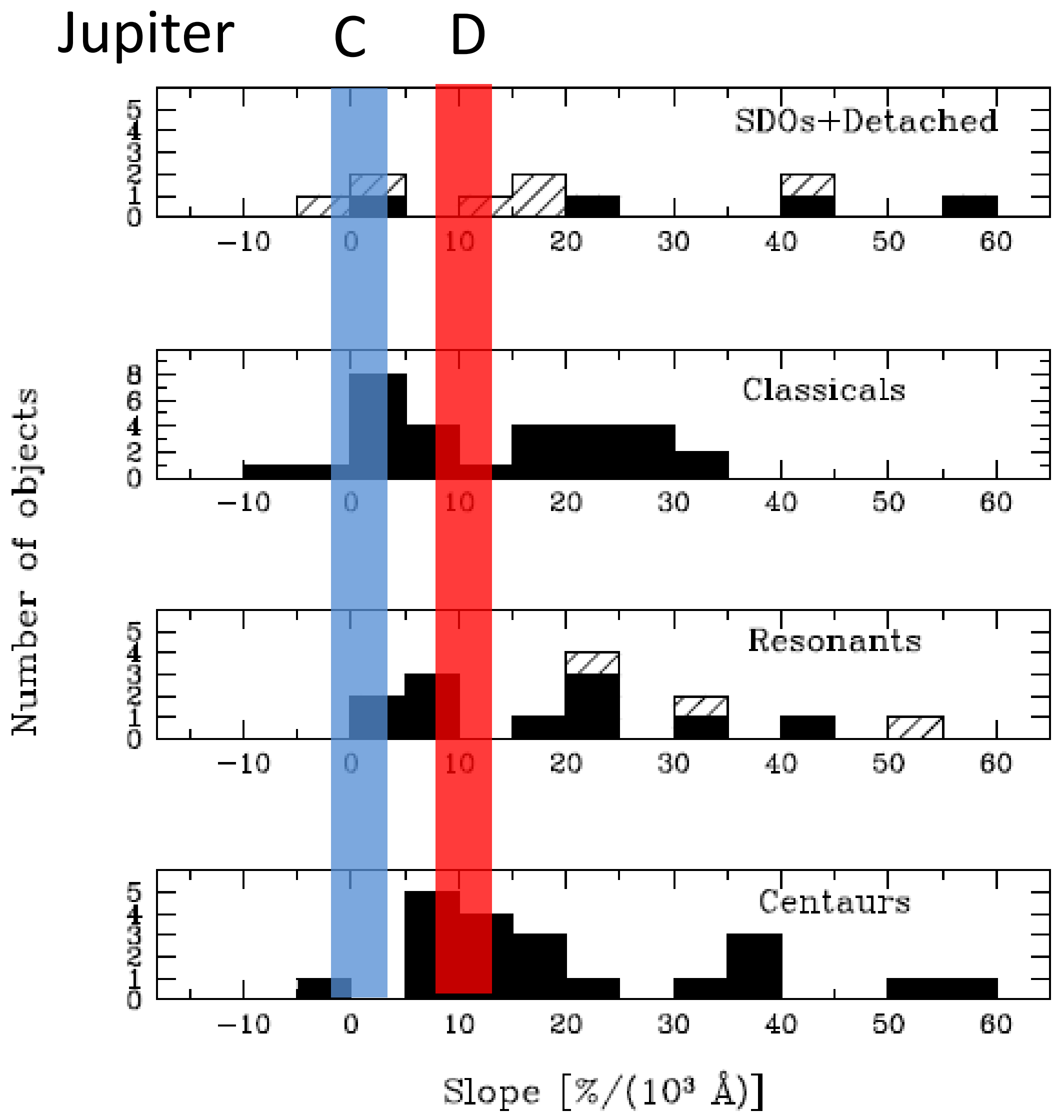
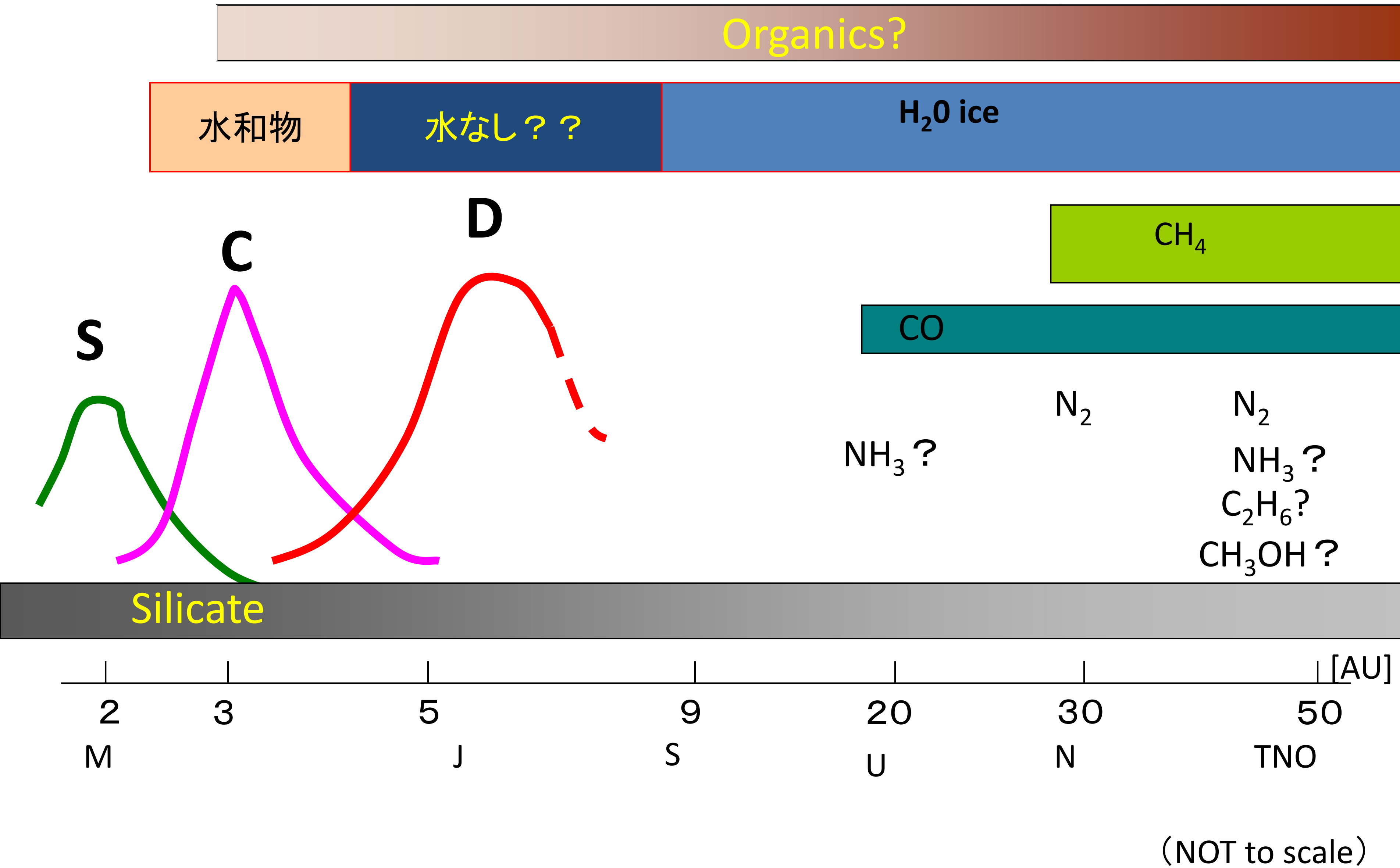


Fig. 7. Distribution of TNOs and Centaurs as a function of the spectral slope. The sample comprises 20 Centaurs, 14 Resonants of which 11 are plutinos (black histogram), and 3 are in the resonances 11:2, 5:2 and 9:4 with Neptune (hatched areas), 29 Classicals, 6 SDOs (hatched areas) and 4 detached bodies.

Fornasier+2009

太陽系内小天体の表面物質



C,D型小惑星（トロヤ群・ヒルダ群）

≒　TNO, Oort 彗星（の一部）

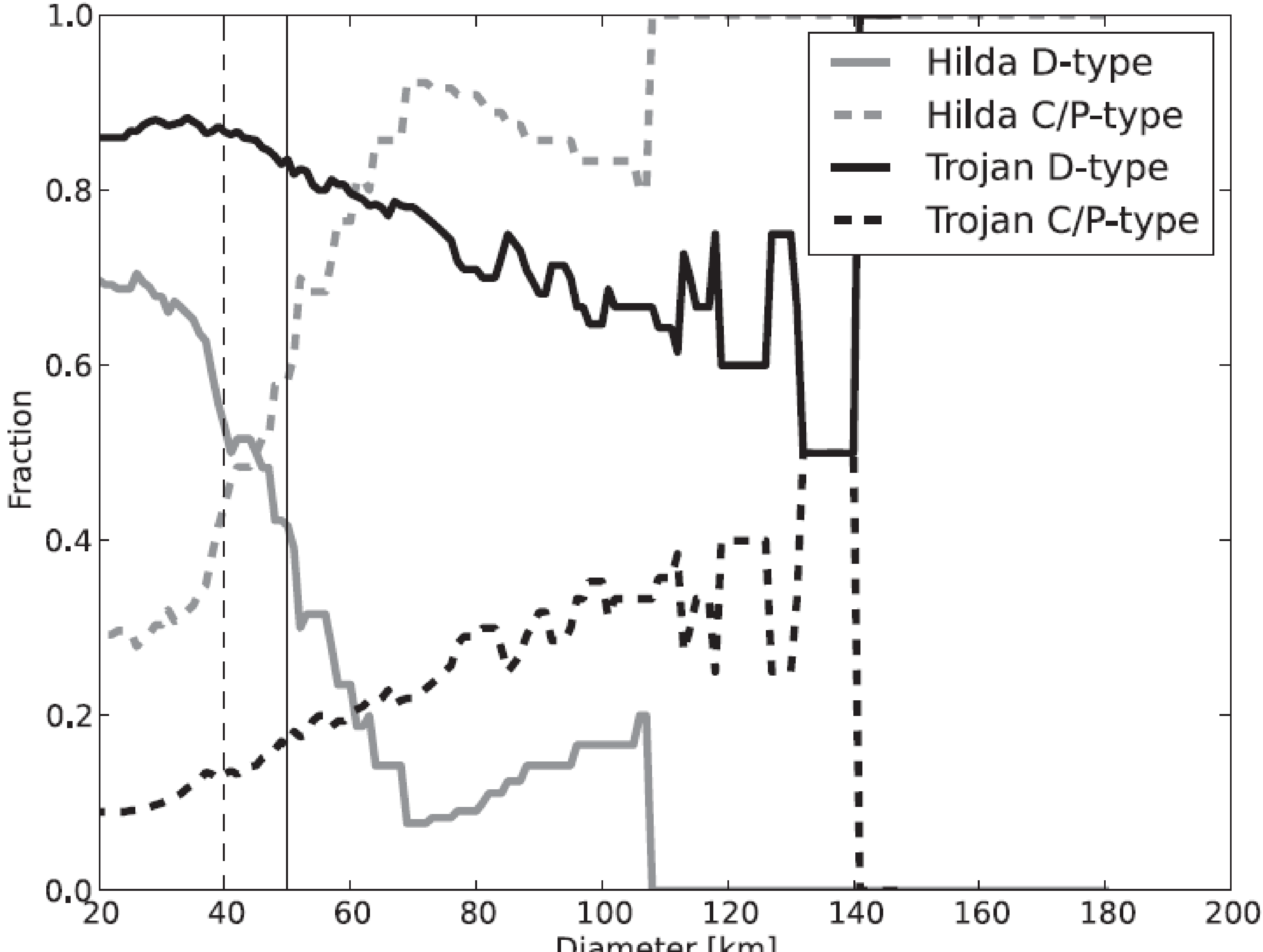
≒　木星の不規則衛星

≒　ガリレオ衛星の構成物質

見かけの違いは、その後に置かれた環境の違い？

出生地を現在の反射スペクトルから同定できるか？

ヒルダ群･トロヤ群のC/P とDの割合



Grav+ 2012

各グループの母天体直径

D			C/P		
Carme	＞	46 km	Ananke	＞	28 km
Sinope:	＞	38 km	Pasiphae	＞	60 km
			Himalia	＞	178 km

Himaliaグループはヒルダ群orトロヤ群起源として矛盾は無いか？

（1） 1つの母天体が捕獲後分裂したと想定した場合

＊母天体の直径は178km 以上で、現在の割合ではヒルダ群のCは100%、トロヤ群では50%なので、Cが捕獲されたとしても矛盾は無い。

＊しかし、**なぜもっと小さな天体が捕獲され残っていないのか？**

=> ガス抵抗で落ちた？

（2） 5天体が別々に捕獲されたと想定した場合。

＊各天体の直径は大きい順に 175, 86, 36, 20 km (スペクトルがわかっている4天体）。

＊全部ヒルダ群から捕獲されたとすると、4つがすべてC/P である確率は

～1*0.9*0.5*0.3 = 0.2 (もっとも確からしいのは4天体中2.7天体がC/P）

＊全部トロヤ群から捕獲されたとすると、4つがすべてC/Pである確率は

～0.5*0.3*0.1*0.1 = 0.002(もっとも確からしいのは4天体中1天体がC/P）

Carme, Sinope, Ananke, Phasiphae： 4母天体中2天体がC/P型

すべてヒルダ群と同じ起源と考えて矛盾は無いか？

=> **4天体中2天体がC/P**であるのが期待値

(0.7 + 0.5 + 0.5 + 0.3 = 2)

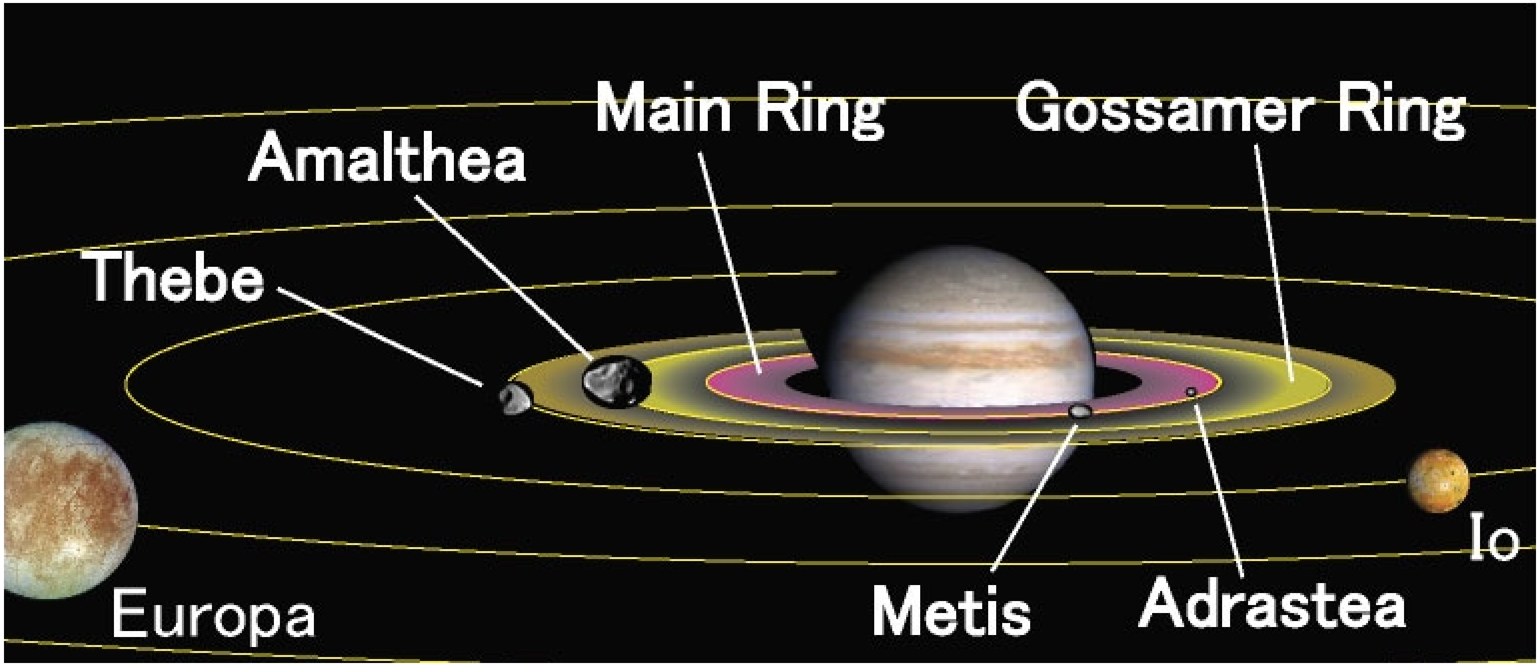
すべてトロヤ群と同じ起源と考えて矛盾は無いか？

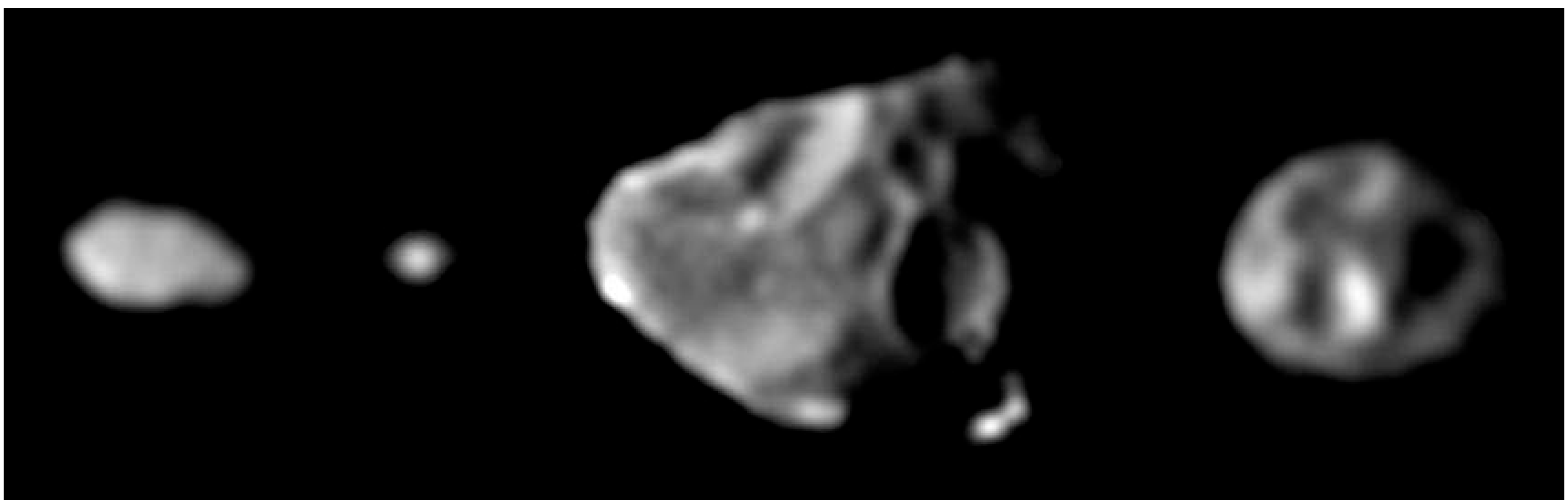
=> **4天体中0.6天体がC/P**であるのが期待値

(0.2+ 0.15 + 0.15 + 0.1 = 0.6)

確率的にはヒルダ群と同一起源と考える方が、
スペクトルタイプ比と整合的
ただし、それぞれが違う起源であることは否定しない。

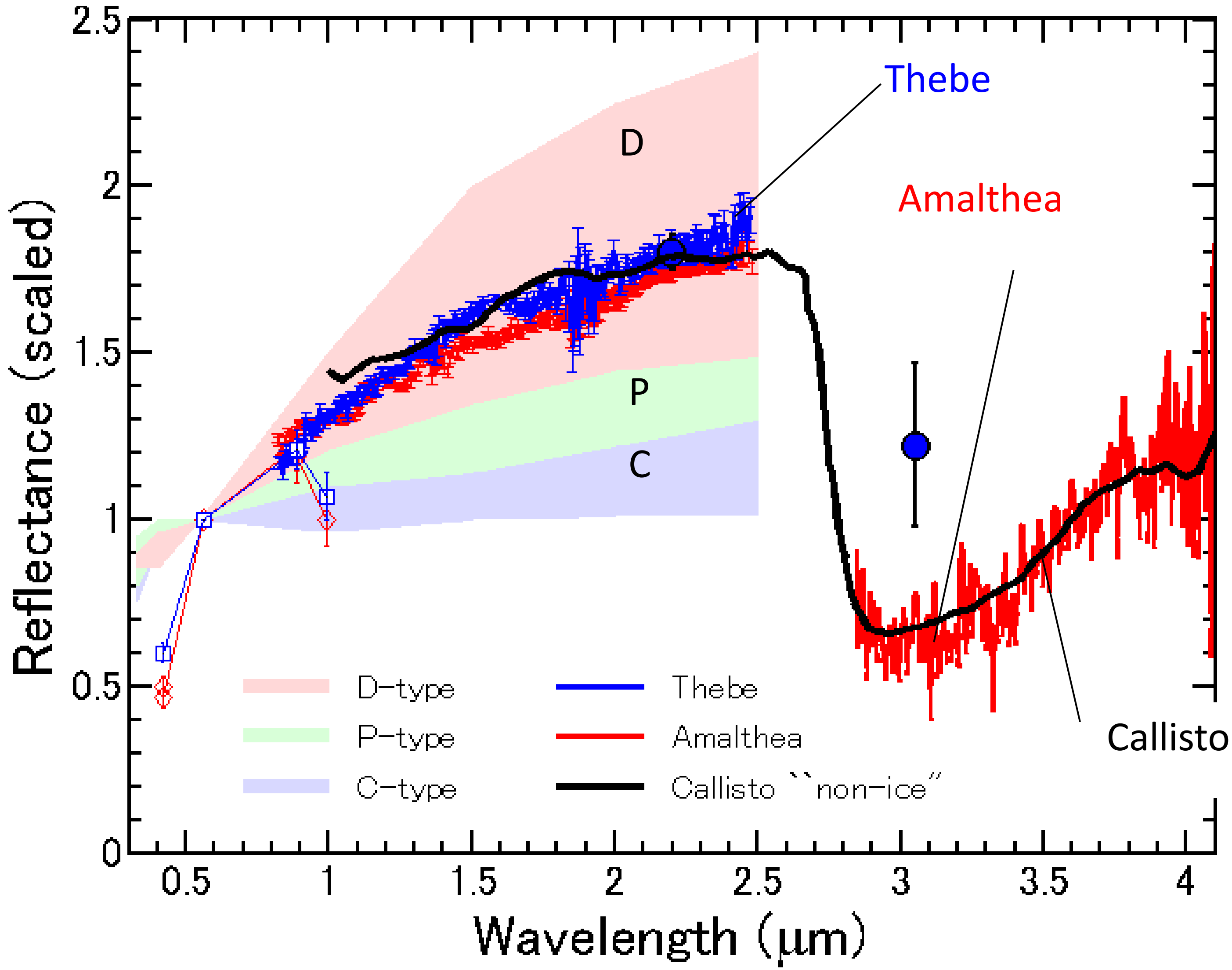
Inner small satellites の起源



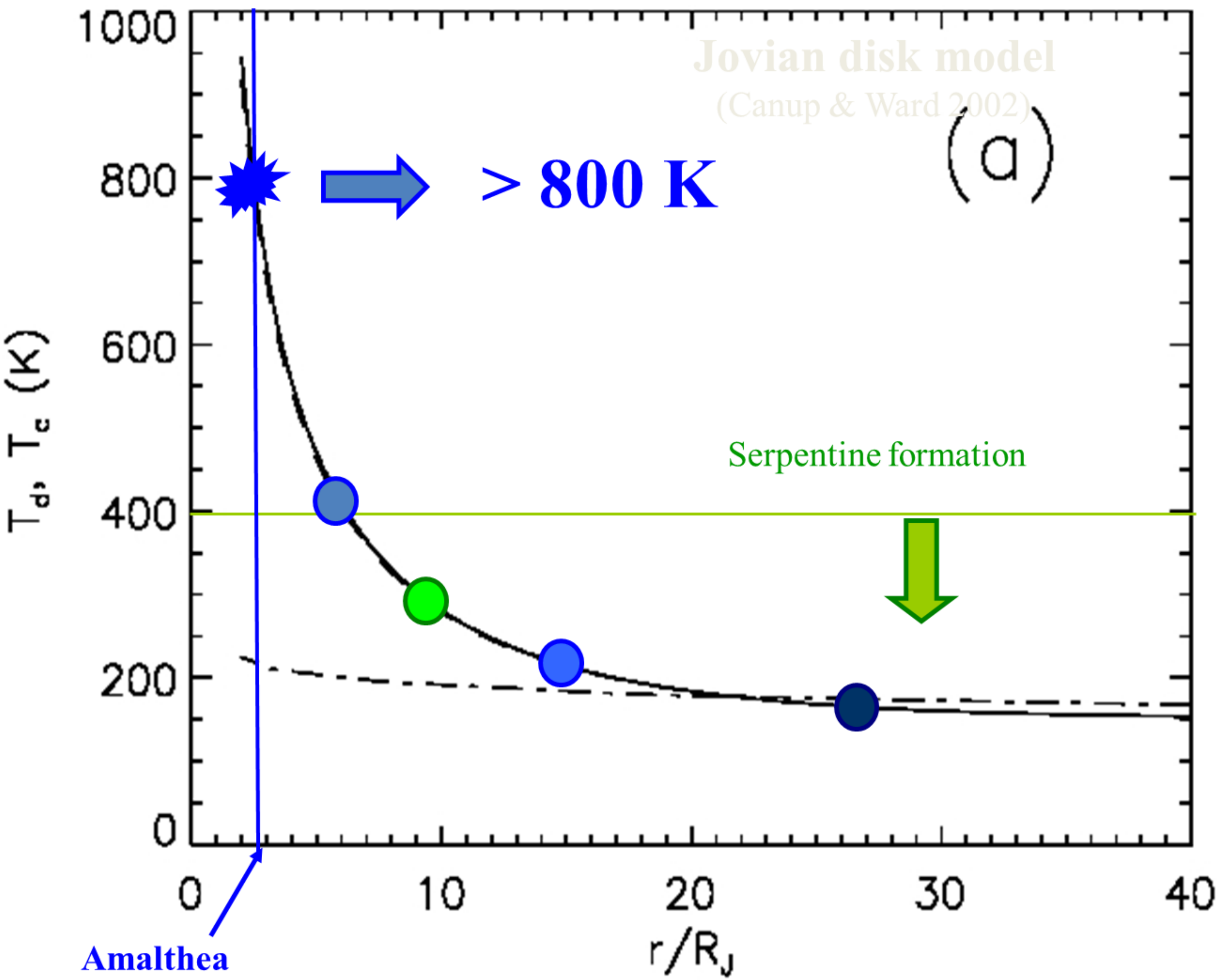


Metis Adrastea Amalthea Thebe

水質変性鉱物（だと思う）



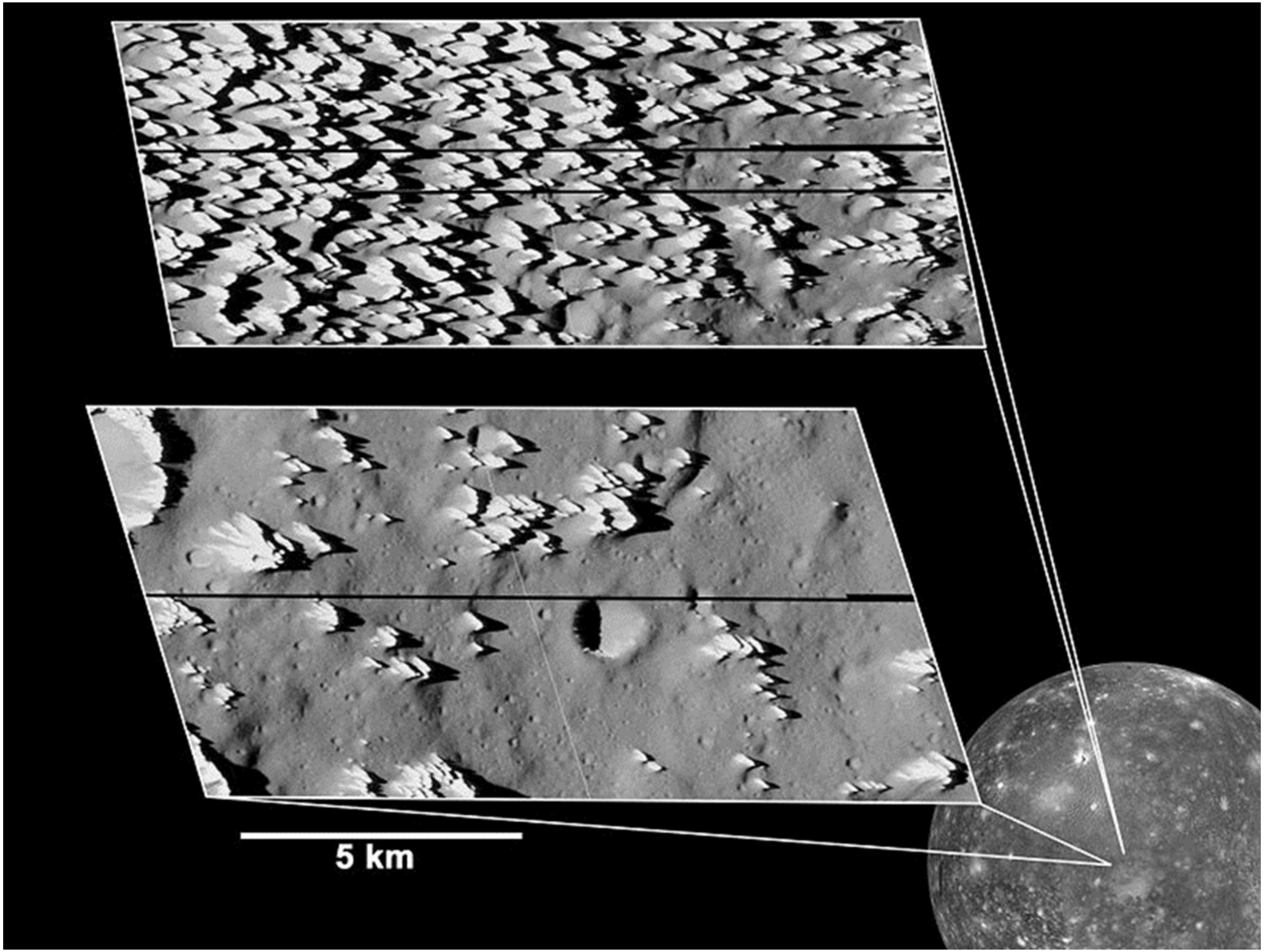
(Takato et al. 2004)



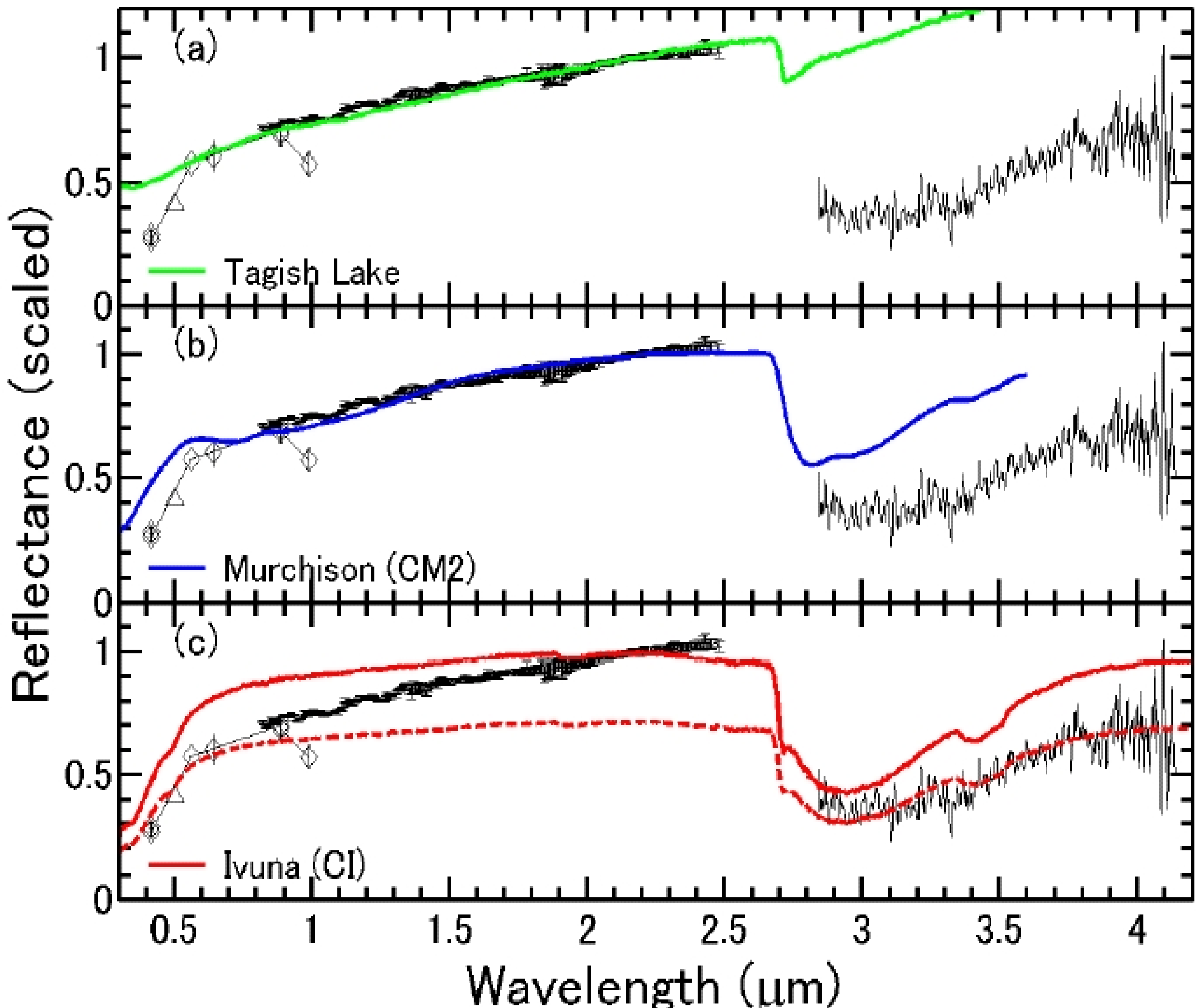
Jovian disk model
(Canup & Ward 2002)
(a)
> 800 K
Serpentine formation
Amalthea
T_d, T_c (K)
r/R_J
1000
800
600
400
200
0
0
10
20
30
40

Callisto

Callisto non-ice



隕石との比較



Tagish Lake

Murchison
(CM2)

Ivuna (CI)

Dタイプ小惑星のアナログ隕石（？）

Tagish Lake

The grid is millimeters.

				
# TAG-114	**# TAG-117**	**# TAG-118**	**# TAG-119**	**# TAG-126**
Weight: **114 mg**	Weight: **117 mg**	Weight: **118 mg**	Weight: **119 mg**	Weight: **126 mg**
Features: **Fragment**	Features: **Fragment**	Features: **Fragment**	Features: **Fragment**	Features: **Fragment**
$68	$70	$70	$71	sold

Click here to put your selection on our order form.

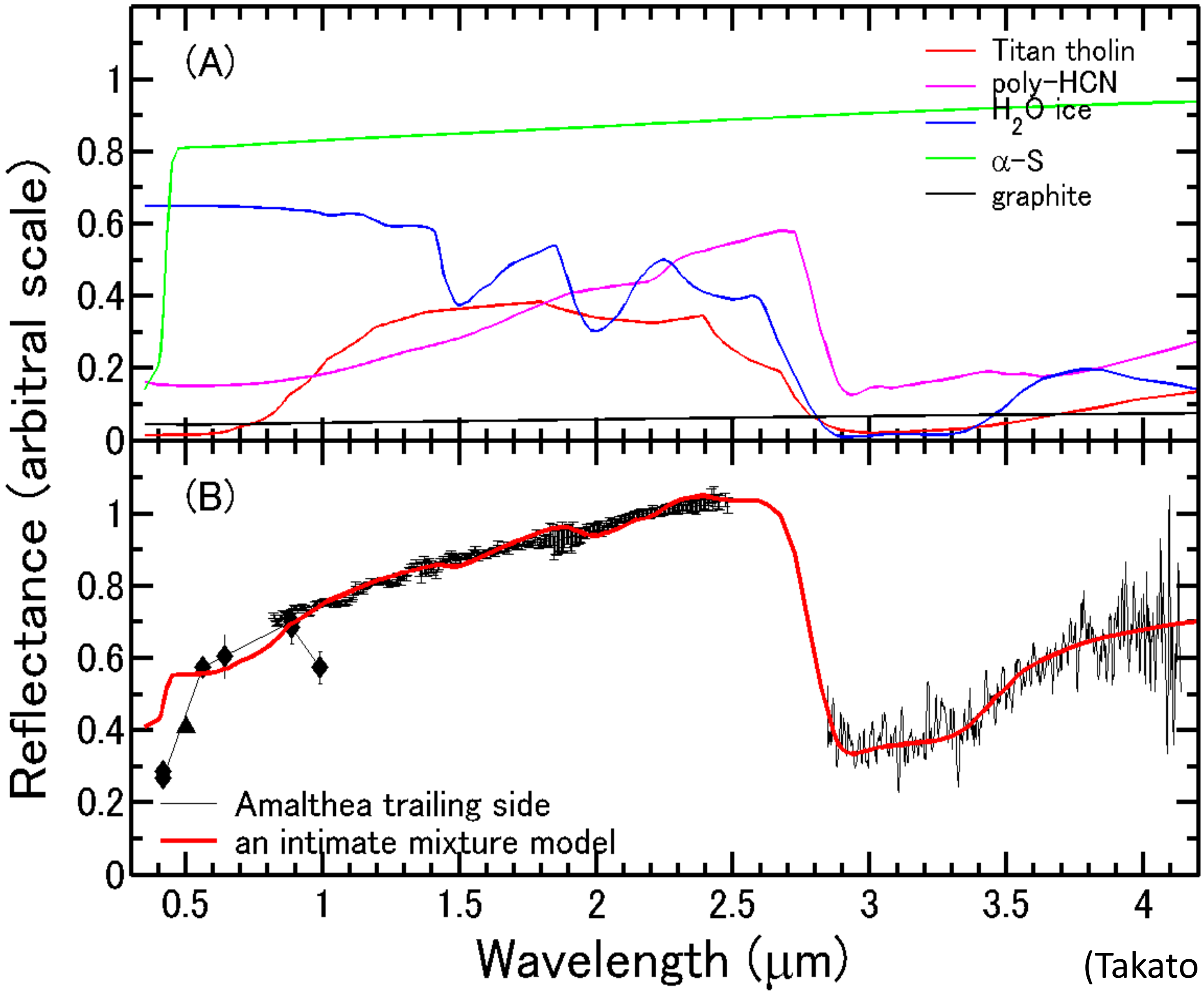
The grid is millimeters.

				
# TAG-130	**# TAG-134**	**# TAG-142**	**# TAG-144**	**# TAG-152**
Weight: **130 mg**	Weight: **134 mg**	Weight: **142 mg**	Weight: **144 mg**	Weight: **152 mg**
Features: **Fragment**	Features: **Fragment**	Features: **Fragment**	Features: **Fragment**	Features: **Fragment**
$78	$79	$85	sold	sold

www.meteoritemarket.com

Organic material ?

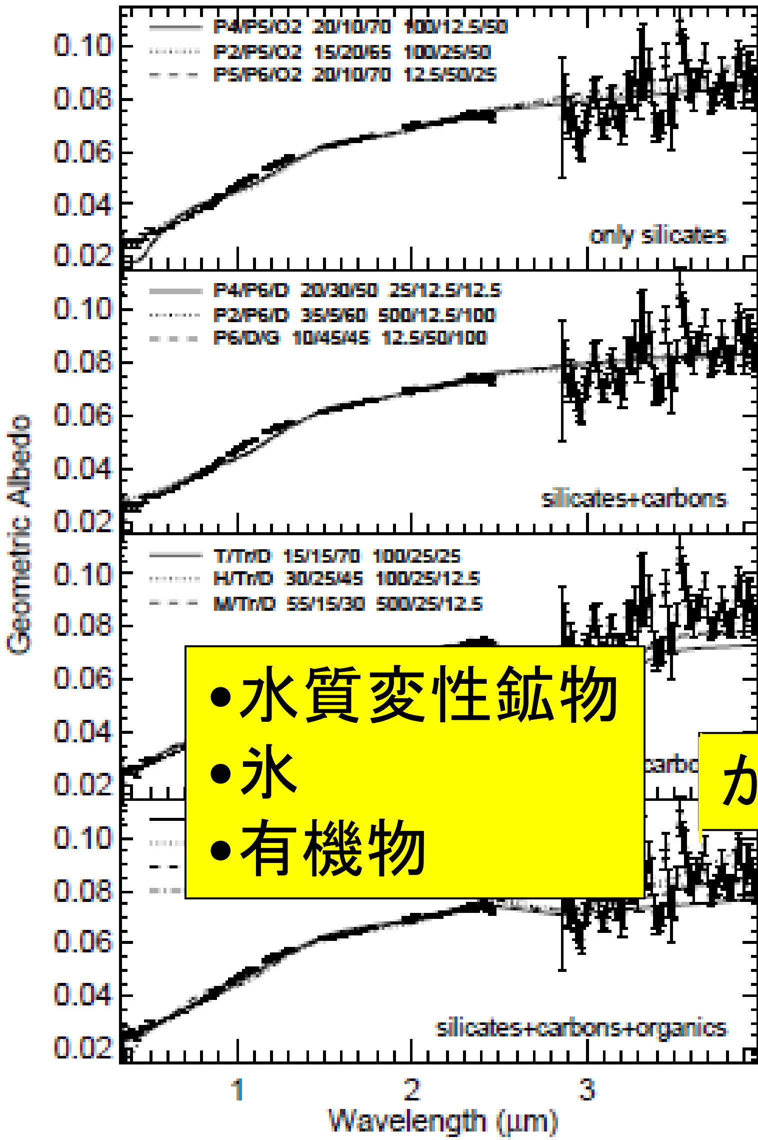
ではないと思うが・・・

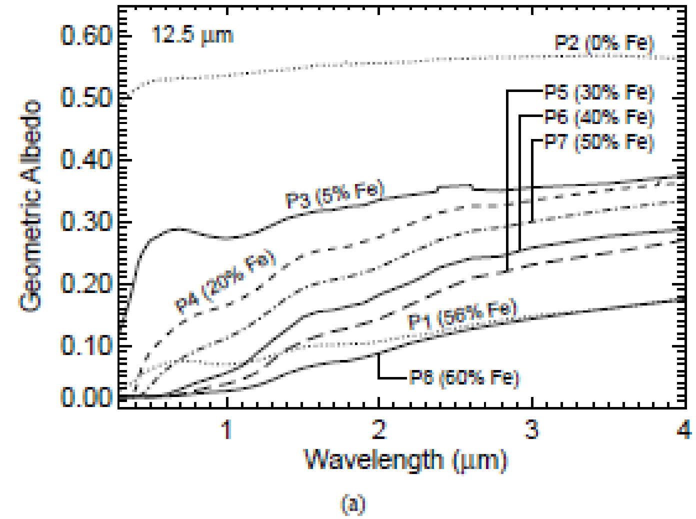


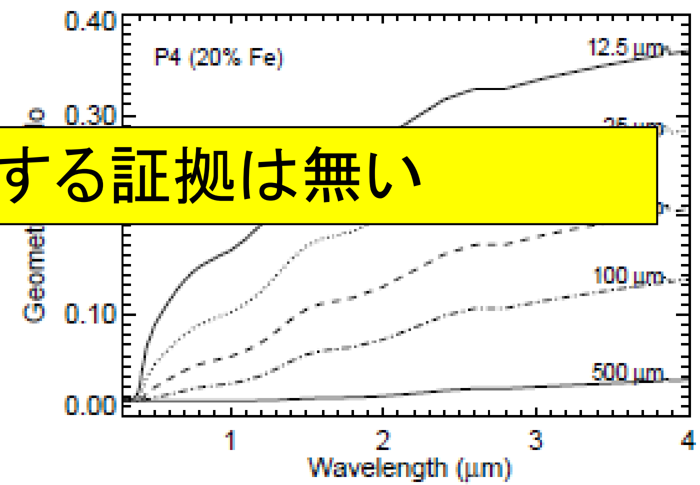
(Takato et al. 2004)

Dタイプ小惑星のモデルフィット

(Emery & Brown 2004)

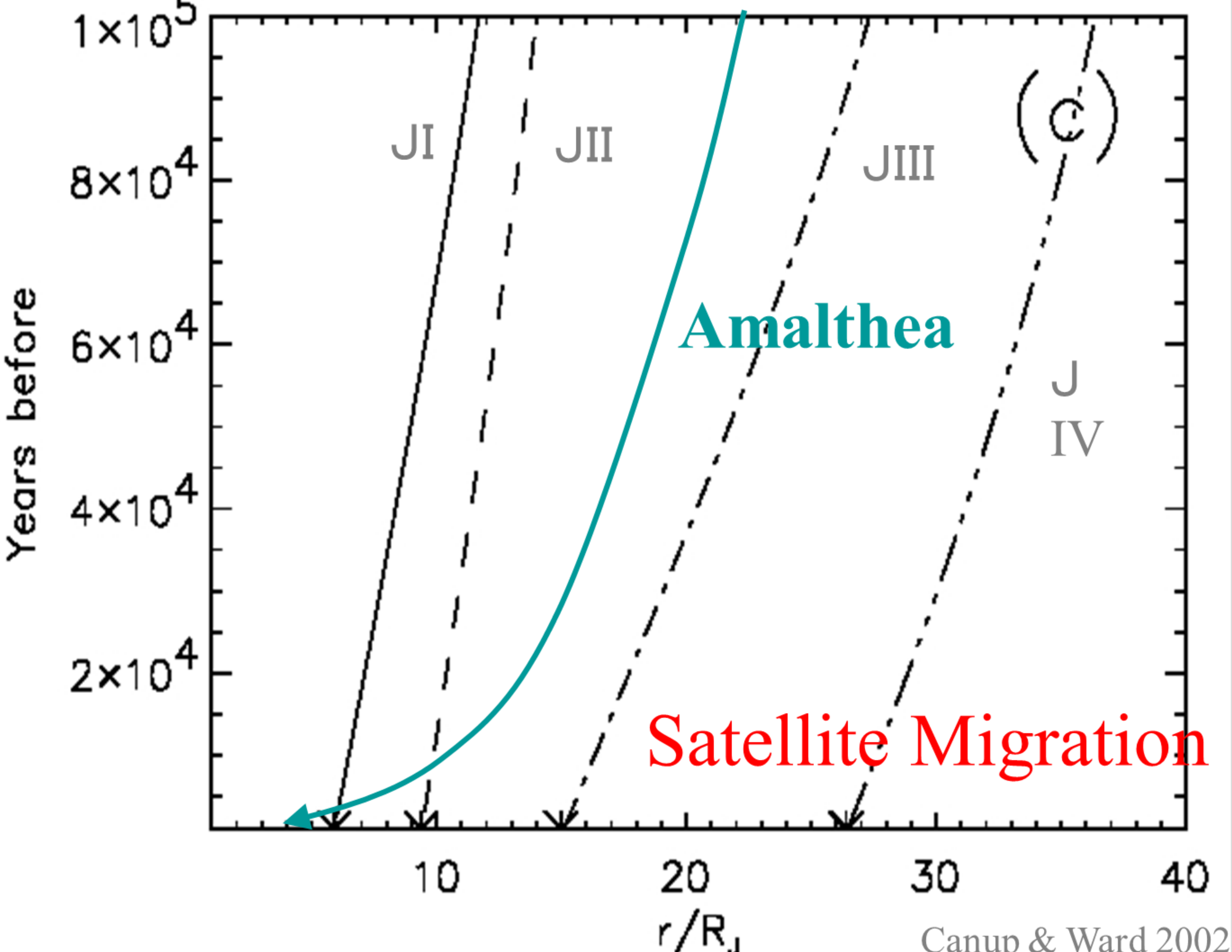






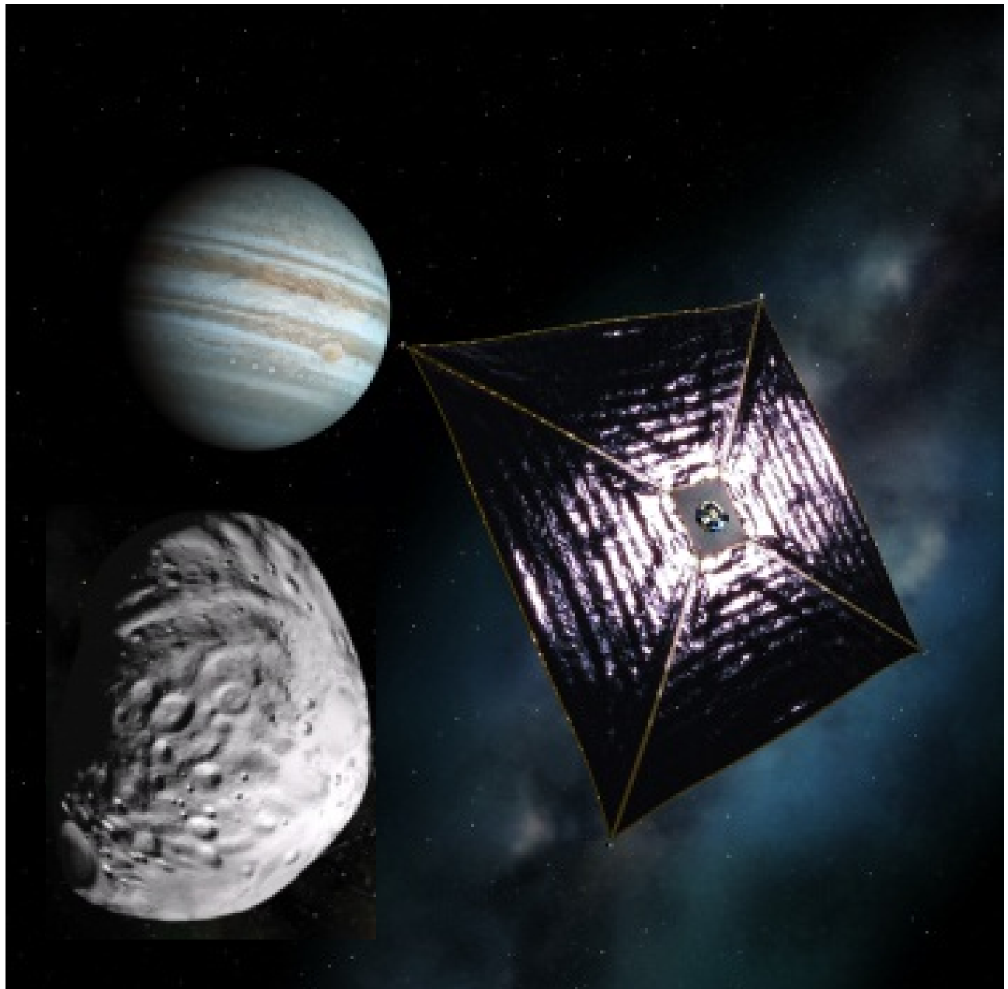
- 水質変性鉱物
- 氷
- 有機物

が存在する証拠は無い



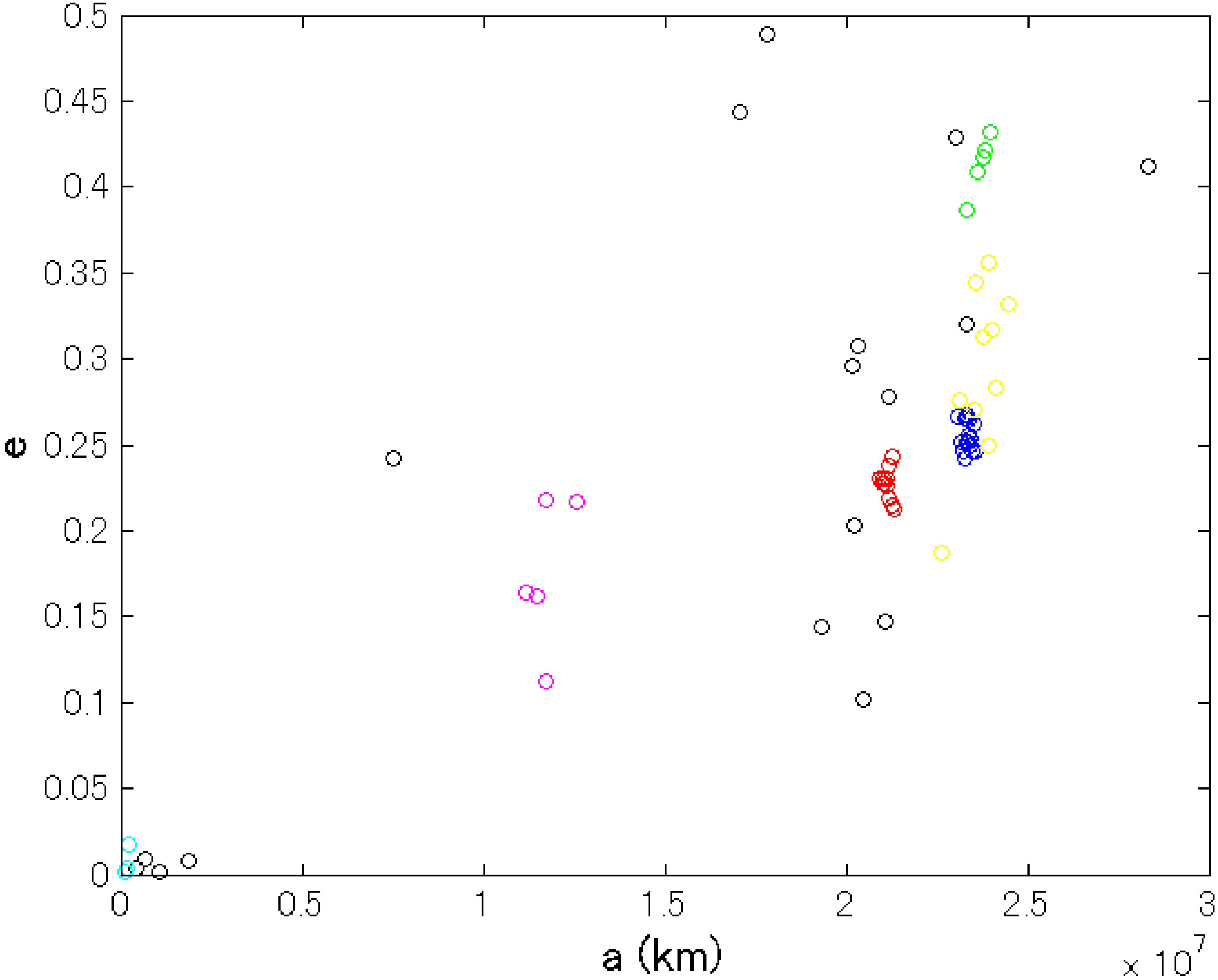
Amalthea
Satellite Migration
JI
JII
JIII
J
IV
(c)
Years before
1×10^5
8×10^4
6×10^4
4×10^4
2×10^4
10
20
30
40
r/R_J
Canup & Ward 2002

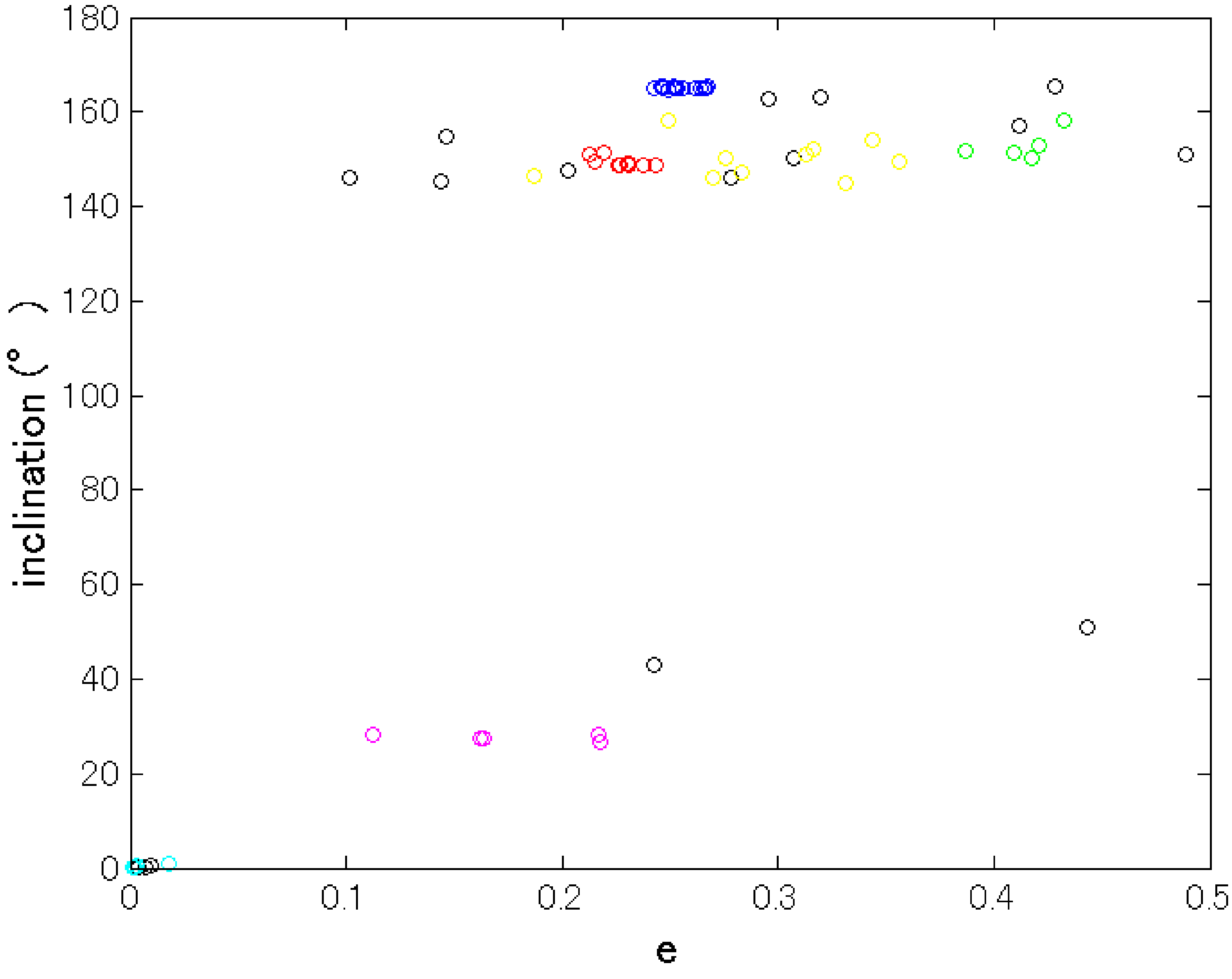
ソーラー電力セイルによる
外惑星領域探査計画



森　他2013

以下、予備

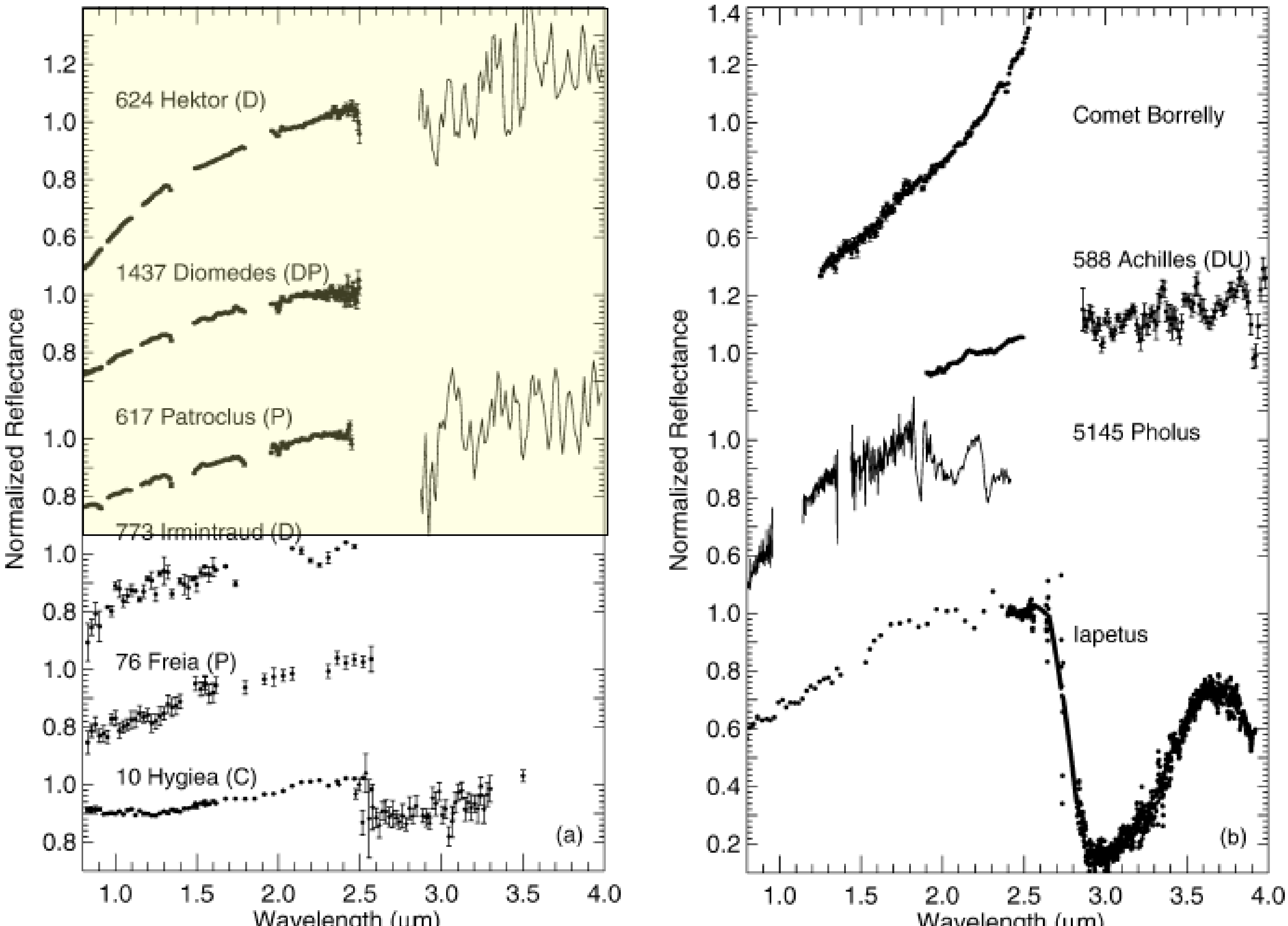

0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
e
0
0.5
1
1.5
2
2.5
3
a (km)
× 10^7

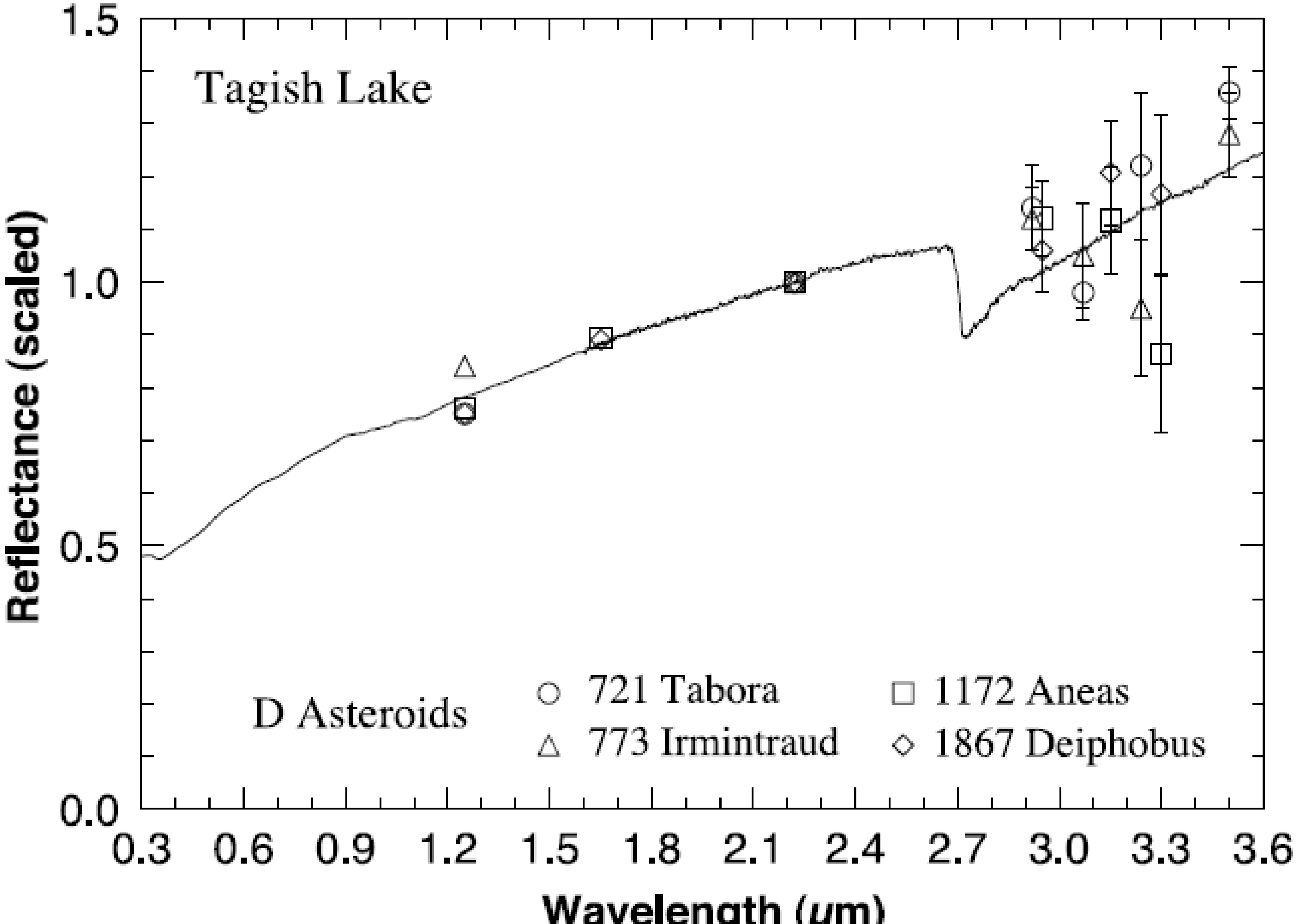


inclination (°)
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
e

トロヤ群天体の反射スペクトルと他天体の比較
（3μm帯）

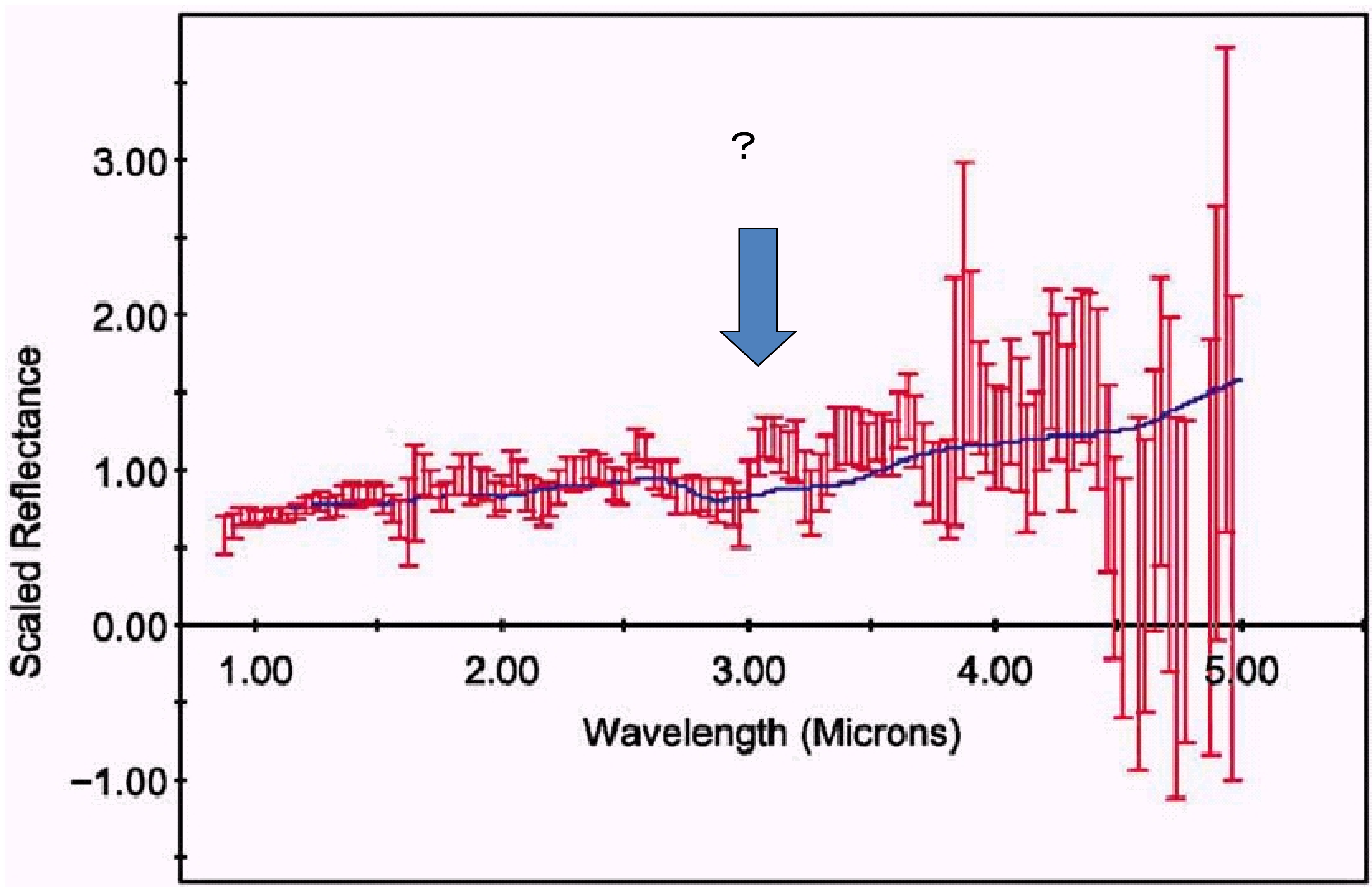
(Emery & Brown 2003)





(Hiroi et al. 2001)

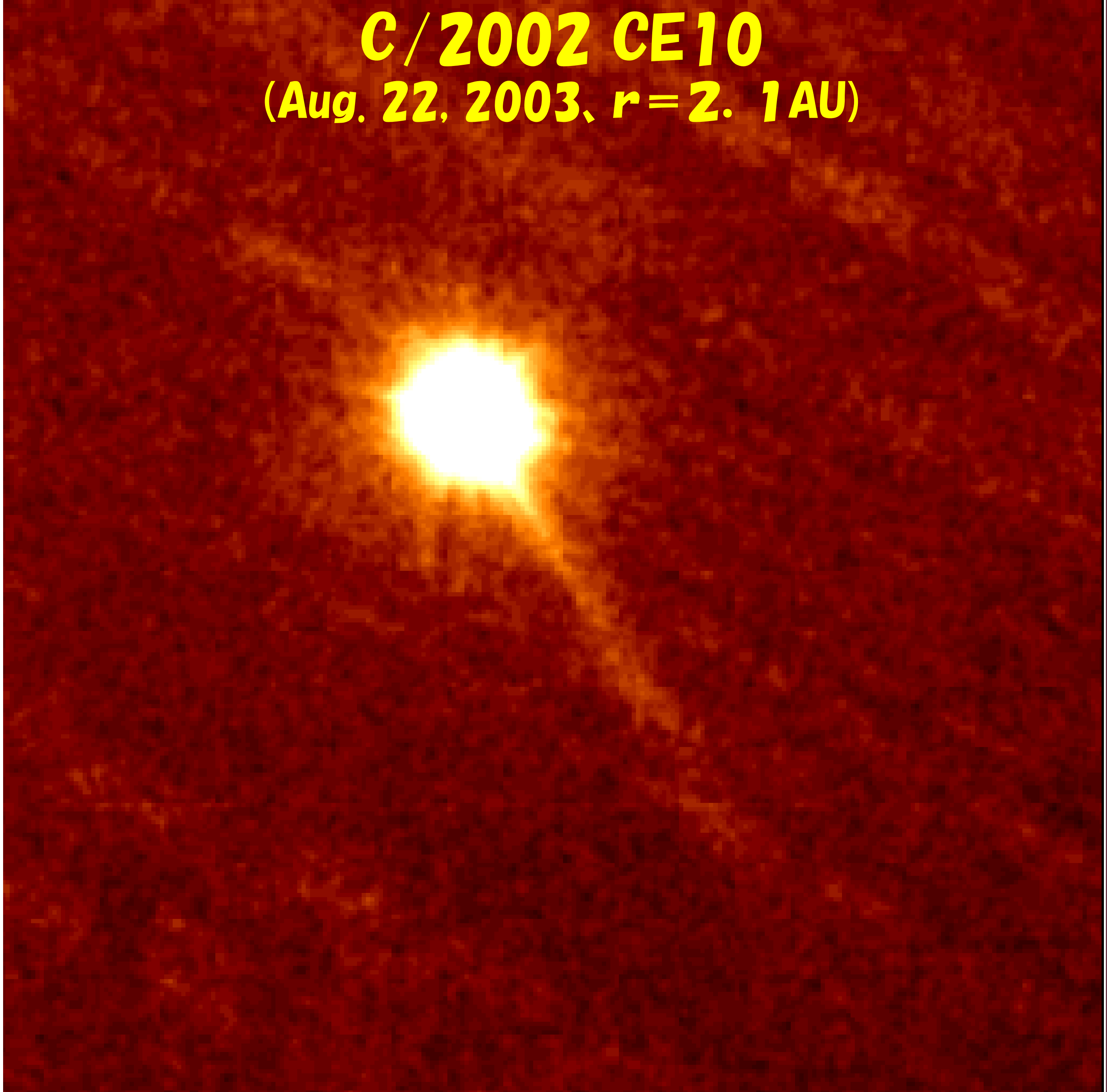
Himalia のスペクトル

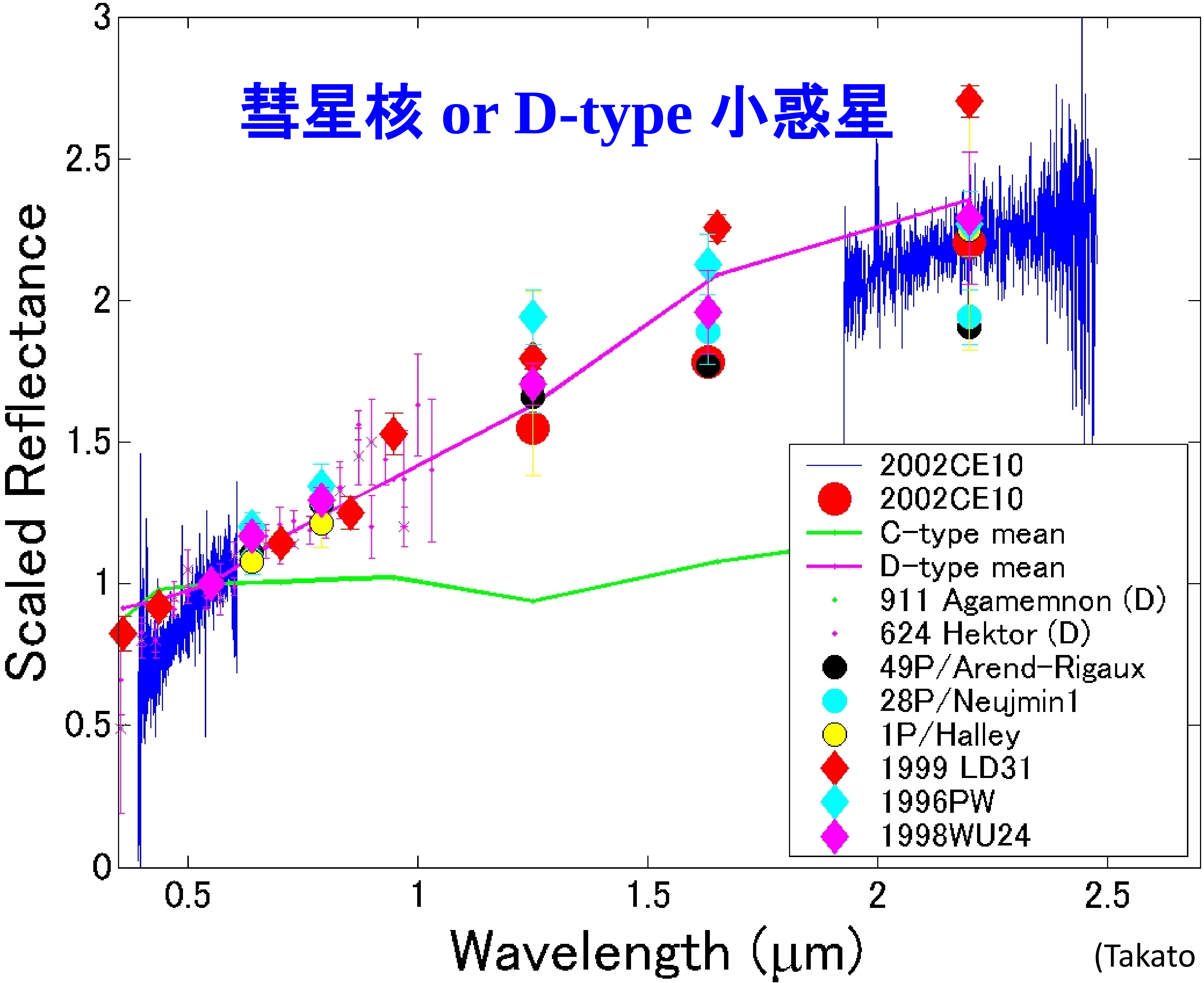


C/2002CE10

- LINEARによって「**小惑星**」として発見
- 軌道傾斜角 i=145. 5°（**逆行**）
- 離心率 e=0. 79
- q＝2. 05AU、Q=17.6AU

⇒
- Halley タイプ
- Oort雲起源（？）

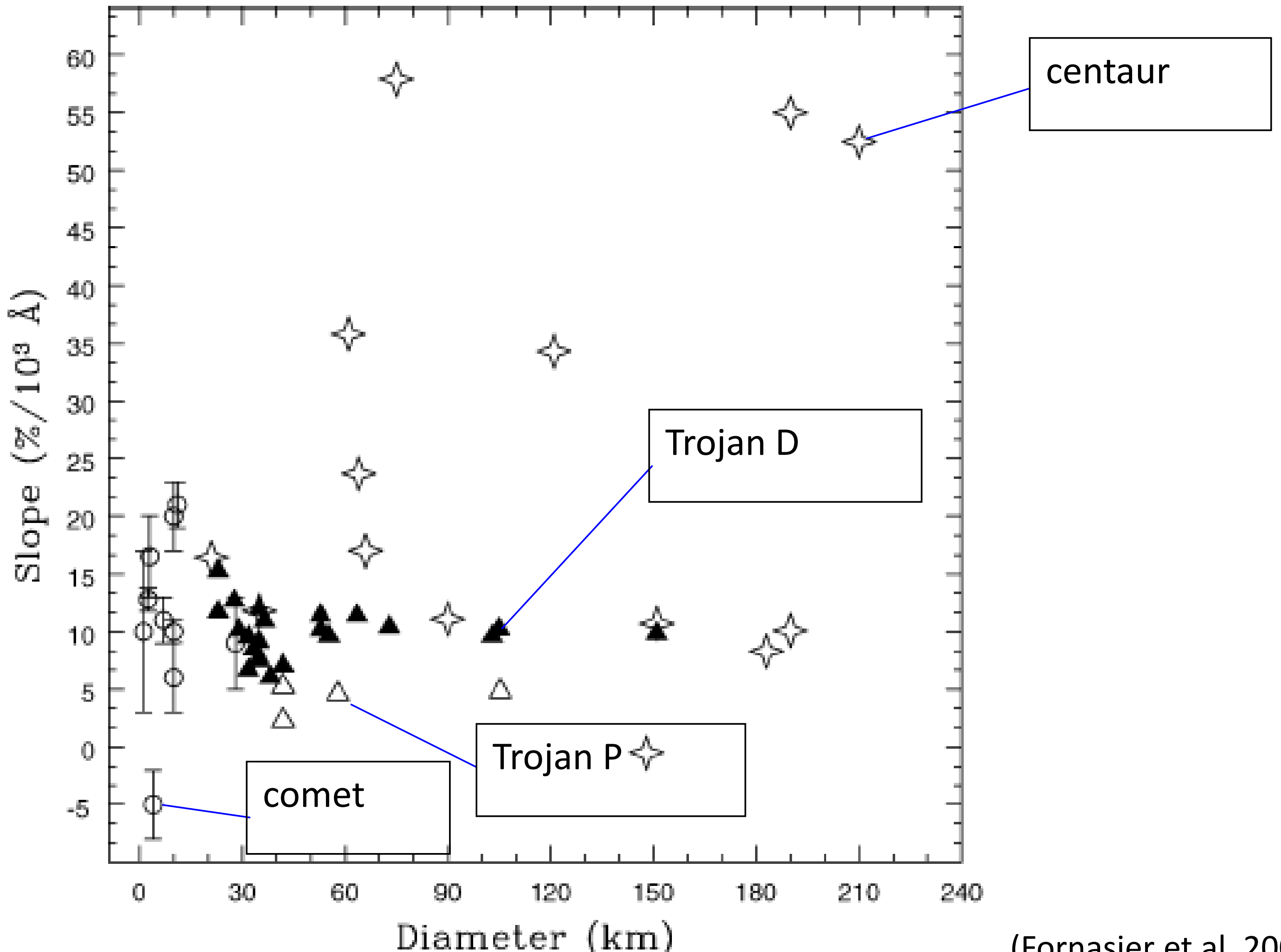

C/2002 CE10
(Aug. 22, 2003, r=2. 1AU)



彗星核 or D-type 小惑星
Scaled Reflectance
Wavelength (μm)
0
0.5
1
1.5
2
2.5
3
0.5
1
1.5
2
2.5
2002CE10
2002CE10
C-type mean
D-type mean
911 Agamemnon (D)
624 Hektor (D)
49P/Arend-Rigaux
28P/Neujmin1
1P/Halley
1999 LD31
1996PW
1998WU24

(Takato et al.)

サイズと赤さとの関係(他天体との比較)



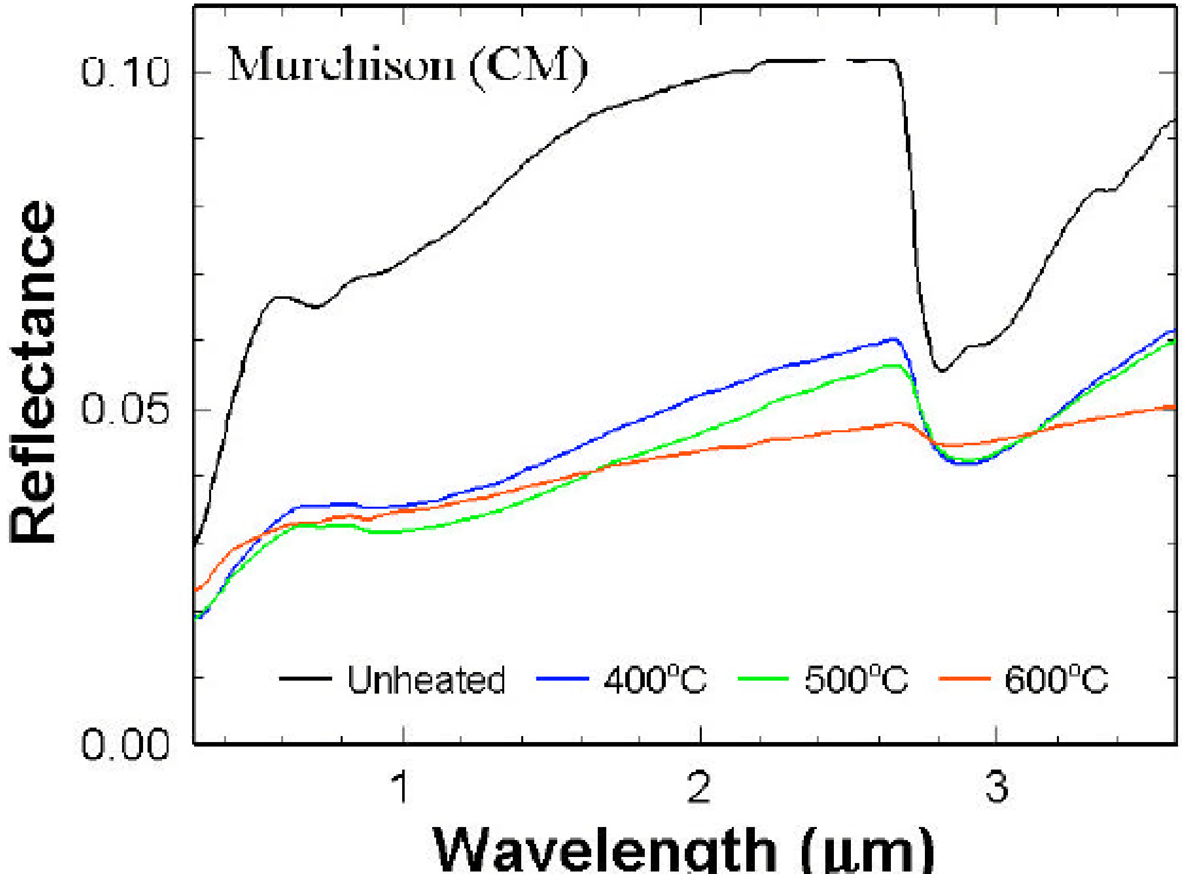
(Fornasier et al. 2004)

なぜ3μmの吸収（氷、水質変性物、有機物）が見えないのか？

- 水質変性が起こるほど高温にならなかった？
- 表面の氷は昇華、スパッタリング(by UV, CR,MM)された？
- カーボン系の微粒子で覆われている？
- 有機物の量はそれほど多くない？
- 宇宙風化？
- etc.

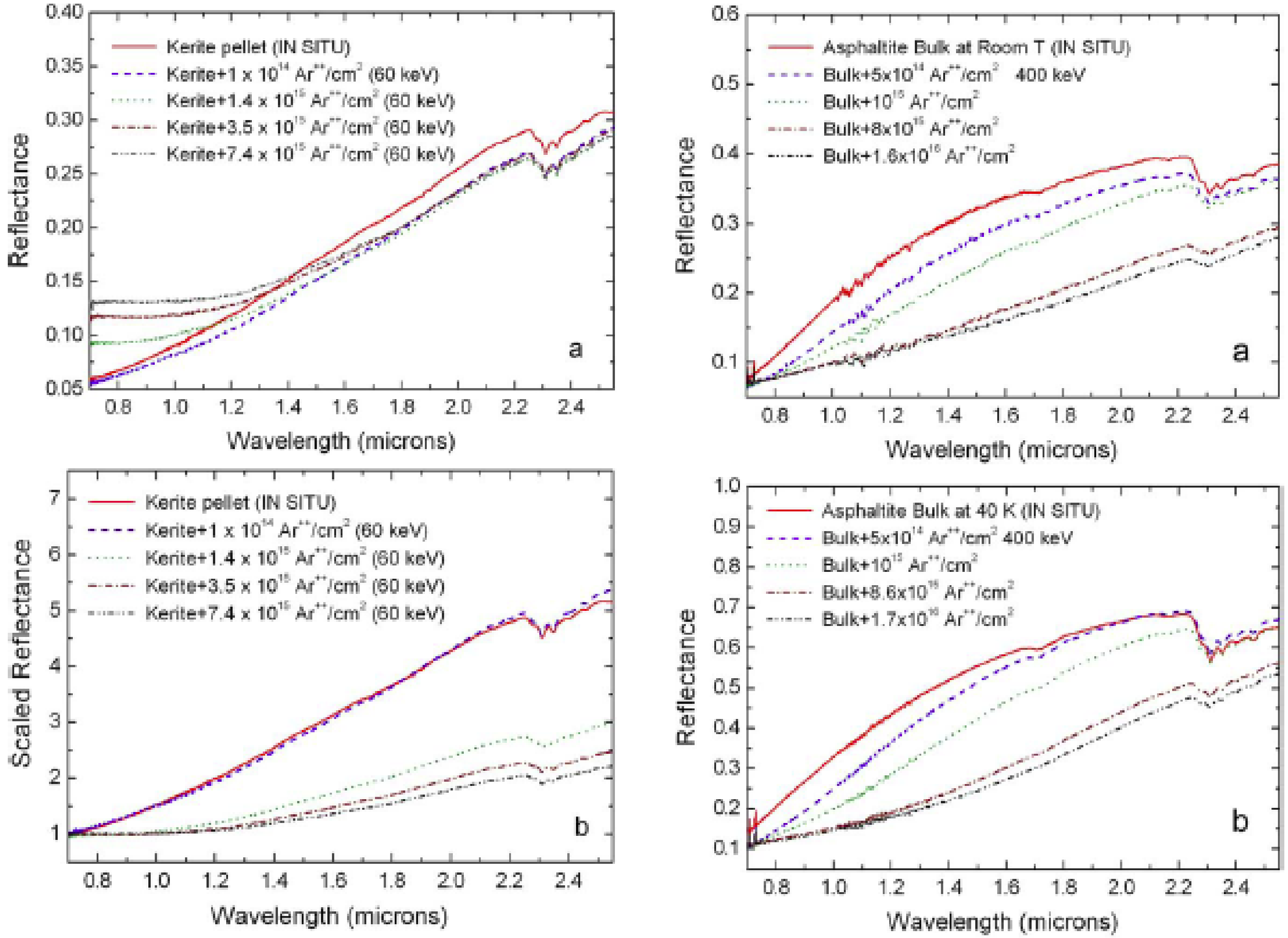
中身は氷＋シリケート＋有機物が詰まっている？

加熱 or 宇宙風化？



(Hiroi et al. 2003)

UV光,宇宙線照射？



(Moroz et al. 2004)

C，P，Dの関係:
有機物の宇宙風化？

- C → P → D？
- C ← P ← D？
- 組成の違いで風化度とは無関係？

表面に氷は検出されていない

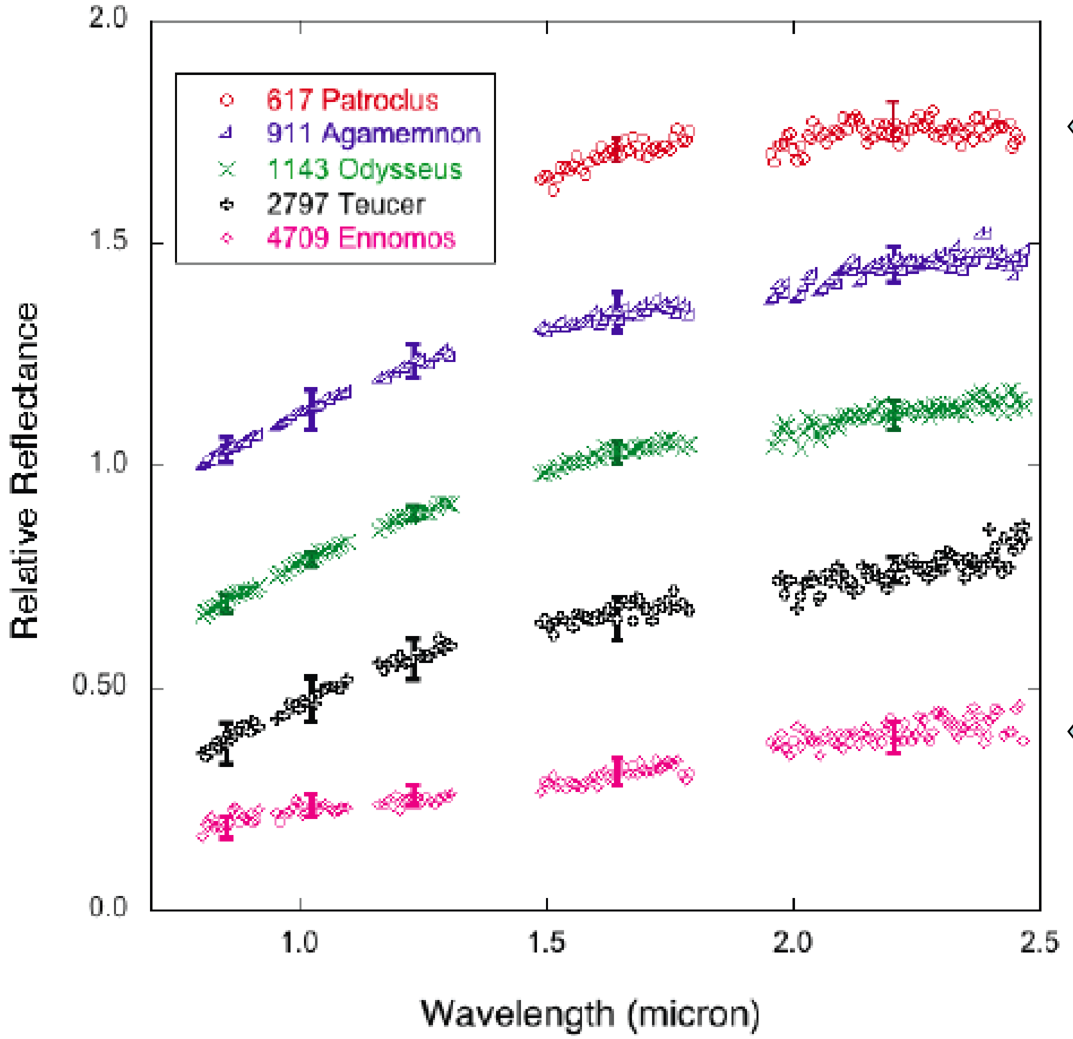


FIG. 1.—Average spectra of (4709) Ennomos, (617) Patroclus, (911) Agamemnon, (1143) Odysseus, and (2797) Teucer. All spectra are normalized at 2.2 μm and vertically offset for clarity.

Binary

高アルベド
(p=0.13)

Yang & Jewitt 2007

Fine-grain silicate

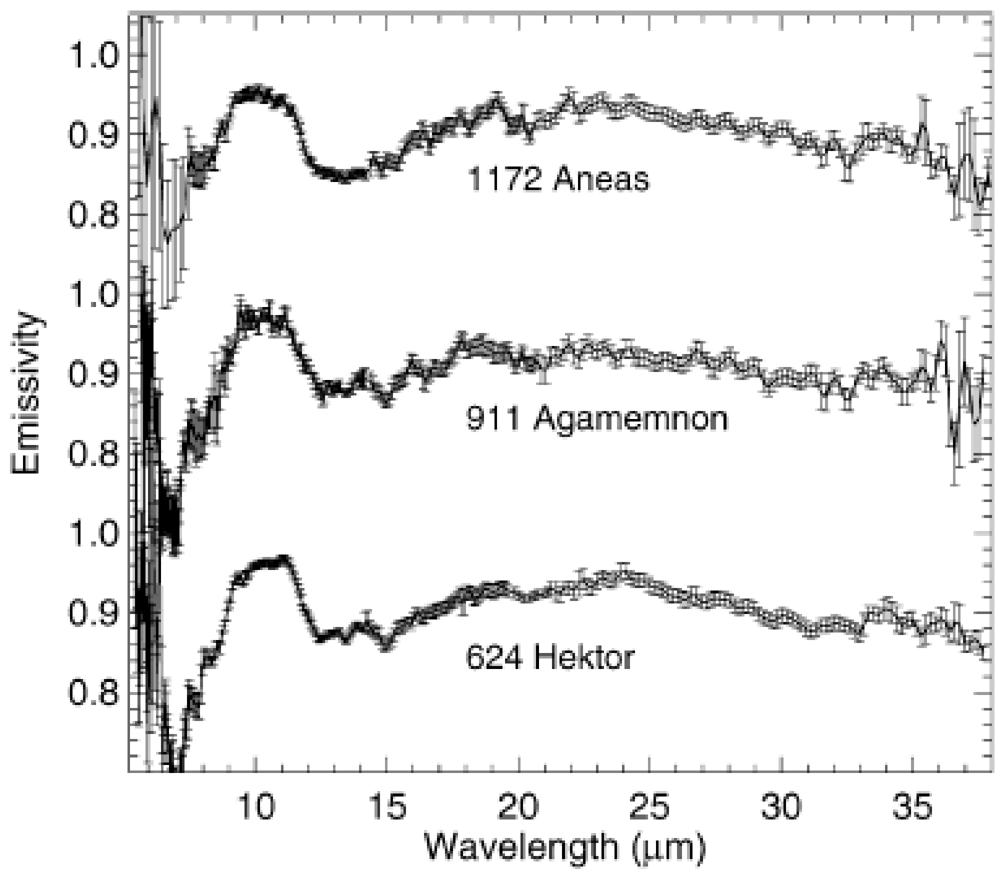
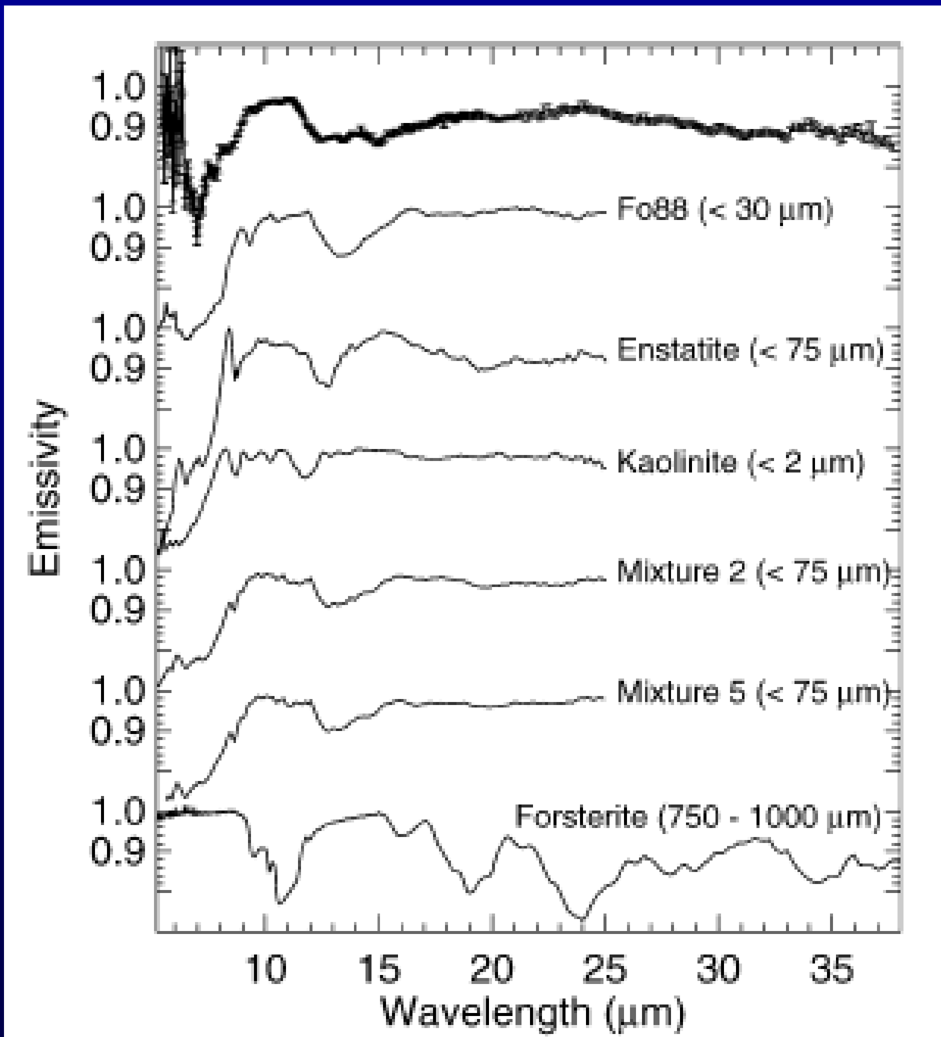
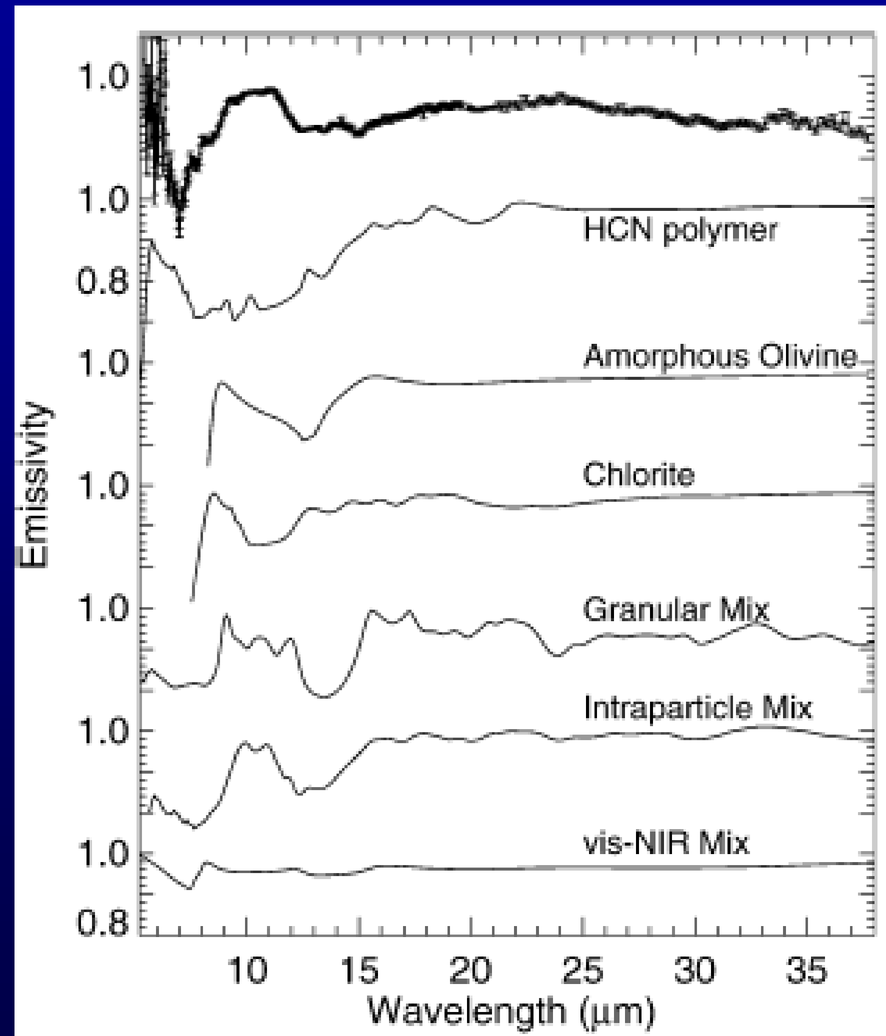


Fig. 4. Emissivity spectra of Hektor, Agamemnon, and Aneas created by dividing the measured SED by the best-fit STM for each object. The shortest wavelength portion ($\lambda < 7.5$ μm) of the Aneas spectrum has been binned by a factor of five to improve the S/N.

Emery et al. 2006

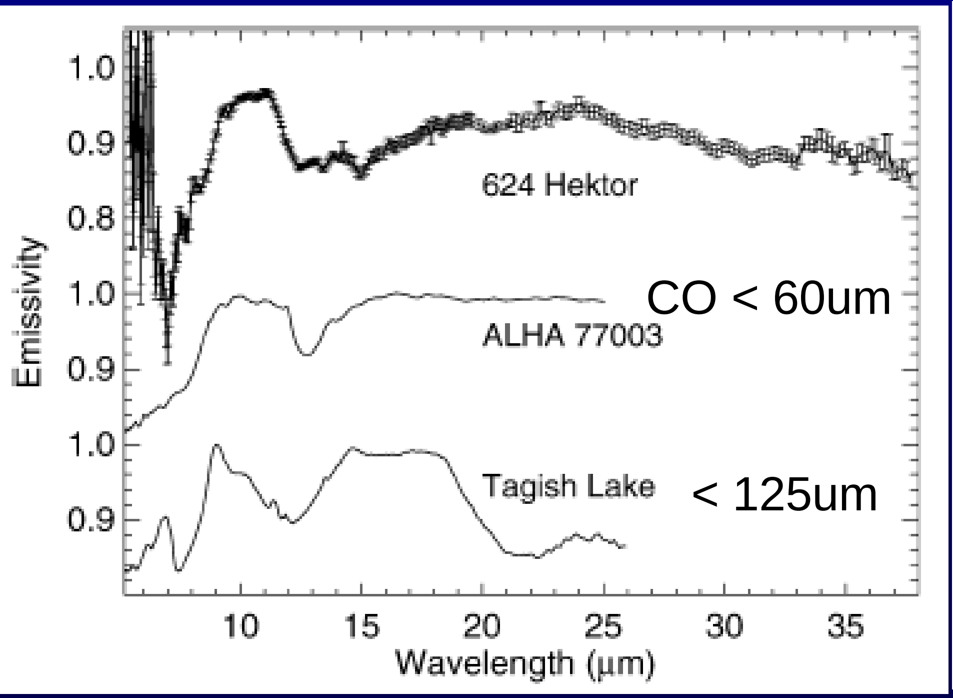


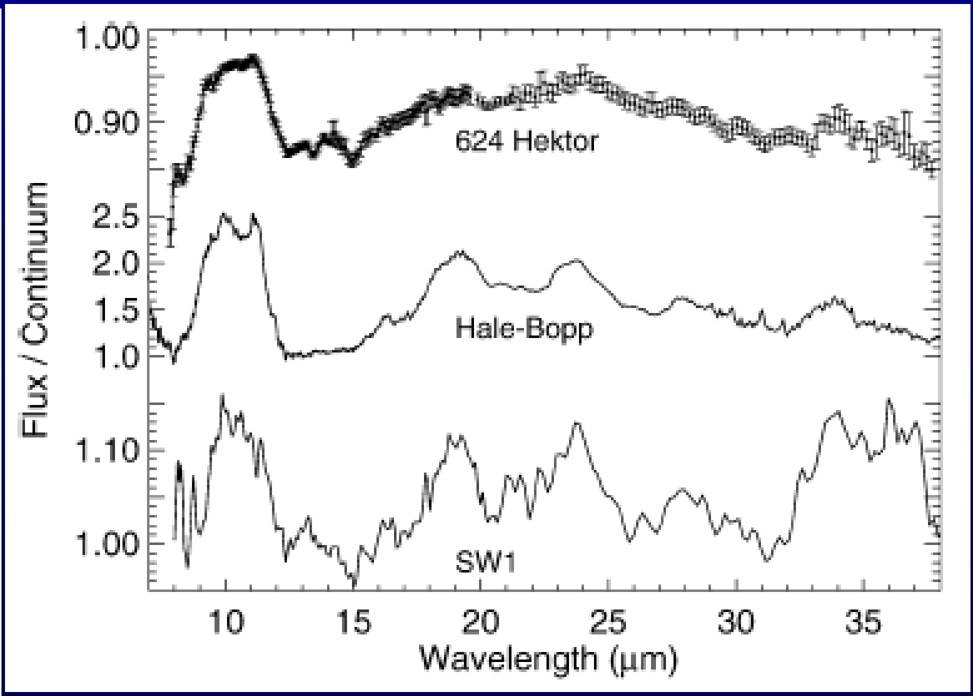
1.0
0.9
Fo88 (< 30 µm)
Enstatite (< 75 µm)
Kaolinite (< 2 µm)
Mixture 2 (< 75 µm)
Mixture 5 (< 75 µm)
Forsterite (750 - 1000 µm)
Emissivity
10
15
20
25
30
35
Wavelength (µm)



1.0
0.8
HCN polymer
Amorphous Olivine
Chlorite
Granular Mix
Intraparticle Mix
vis-NIR Mix
Emissivity
10
15
20
25
30
35
Wavelength (µm)

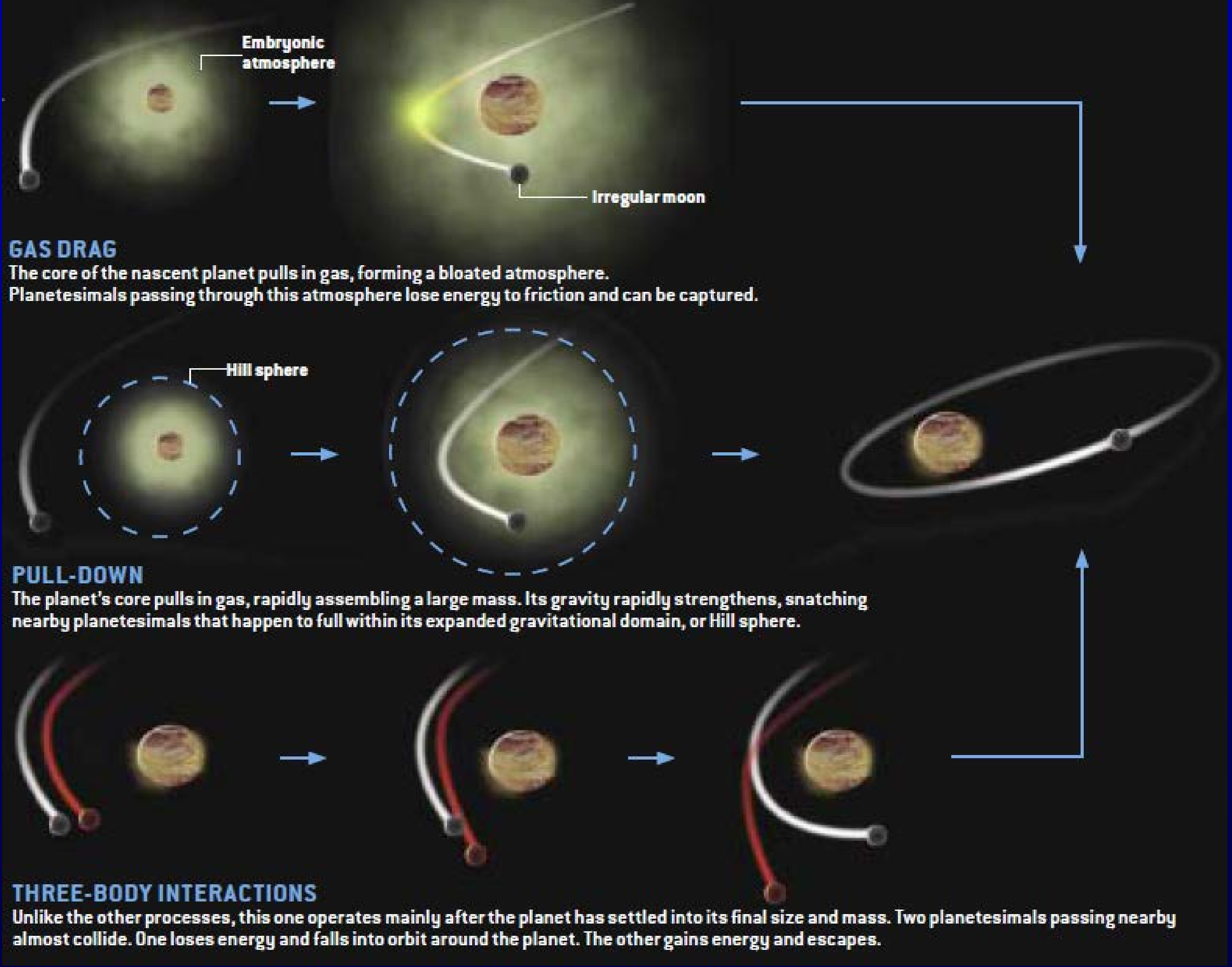
彗星コマのスペクトルに類似





Emery et al. 2006

Jewitt / Scietific America



波長0．7μmの吸収の有無

(Valis et al. 2006)

Presence/absence of 0.7-μm feature in jovian outer irregular satellites

JVI Himalia prograde (28° inclination) cluster:		
JVI Himalia	Y (6)[1,2,5], N (1)[3]	g
JVII Elara	Y (3)[5] N (2)[1,5]	g
JX Lysithea	Y[4]	g
J XIII Leda	N[3]	g
JVIII Pasiphae retrograde (149° inclination) cluster:		
JVIII Pasiphae	Y (2)[5], N (2)[1,4]	g
JXII Ananke	Y[4]	g/r
JXVII Callirrhoe	Y[4]	r
JXIX Megaclite	Y[4]	r
JXXII Harpalyke	N[4]	g
JXXIV Iocaste	N[4]	g
JXXVII Praxidke	Y[4]	g
JXI Carme retrograde (165° inclination) cluster:		
JXI Carme	Y (2)[3,4], N[1]	r
JXX Taygete	N[4]	r
JXXIII Kalyke	N (2)[4]	R
Other satellites:		
JIX Sinope	Y[4], N[3]	r
JXVIII Themisto	Y[4]	r

1 Tholen and Zellner, 1984.
2 Jarvis et al., 2000a.
3 Luu, 1991.
4 Grav et al., 2003.
5 Degewij et al., 1980.

なぜD型には3μmの吸収（氷、水質変性物、有機物）が見えないのか？

- 水質変性が起こるほど高温にならなかった？
- 表面の氷は昇華、スパッタリング(by UV,
-
-
-
- etc.

ぜひとも、表面を掘り起こして！

（何かをぶつけるだけでも良い）

中身は氷＋シリケート＋有機物が詰まっている？

まとめ

- D型とくにトロヤ群へ
- 枯渇彗星も
- 3μm帯分光器＋カメラ（水）
- ３－１0μm帯分光器＋カメラ（有機物）
- 表面を掘り起こして！
- まわりの環境調査も(eg. Dust flux)