THE MISSION ASTEROIDS: SCIENCE AND EXPLORATION IN THE SPACE AGE*

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**Space Science Reviews (in revision)*

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THE MISSION ASTEROIDS
A Personal Perspective

Review

1. *Missions*
2. *Discovery*
3. *Sizes*
4. *Maps*
5. *Spectra*

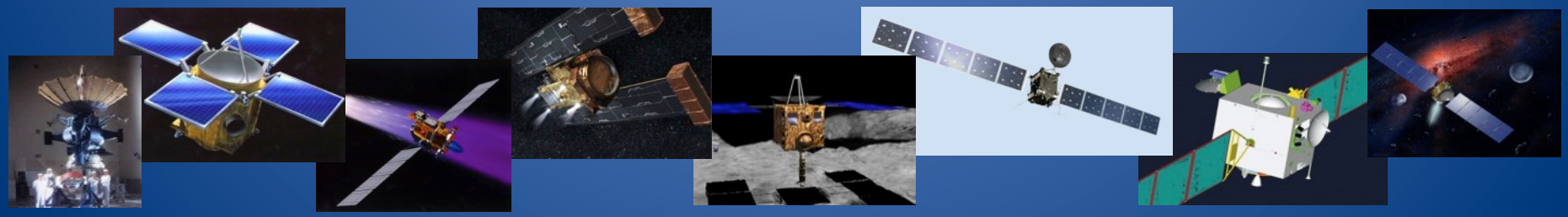
Themes of present talk

1. *What was confirmed?*
2. *What was new?*
3 *How abundant is water inside the snow-line?*
4. *How did we do linking meteorites with asteroids?*

What's next?

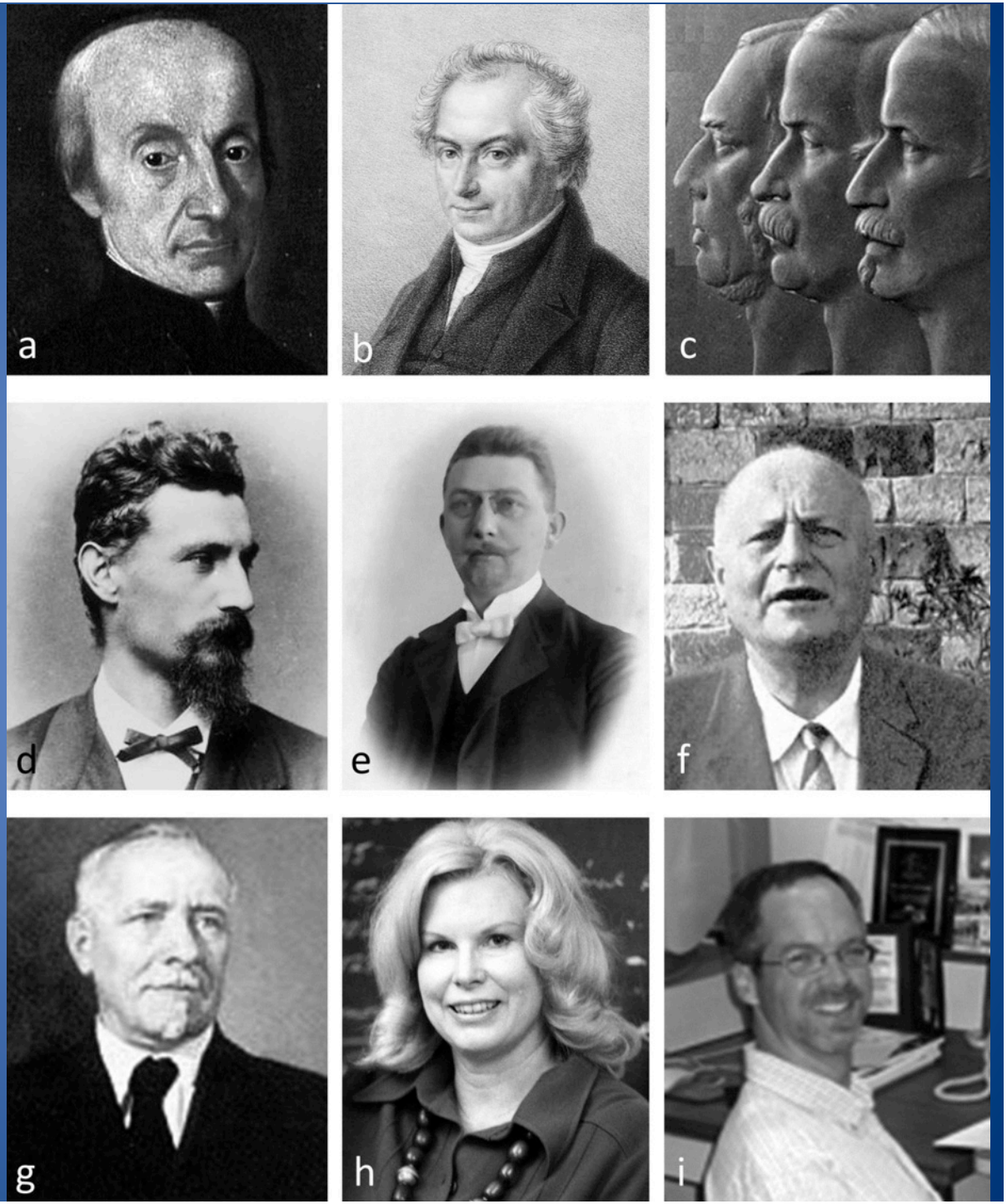
Missions

Asteroid	Spacecraft	Encounter Dates	Mission Type
951 Gaspra (1916 S45)	Galileo	Oct 29, 1991	Flyby
243 Ida (1988 DB1)	Galileo	Aug 28, 1993	Flyby
Dactyl (243 Ida 1)	Galileo	Aug 28, 1993	Flyby
253 Mathilde (1949 OL1)	Shoemaker-NEAR	June 27, 1997	Flyby
9969 Braille (1992 KD)	Deep Space 1	July 29, 1999	Flyby
433 Eros (1898 DQ)	Shoemaker-NEAR	Feb 14, 2000 to Feb 12, 2001	Orbit
5535 Annefrank (1942 EM)	Stardust	Nov 2, 2002	Flyby
25143 Itokawa (1998 SF36)	Hyabusa	Sept 15, 2005 to April 25, 2006	Touch and Go
2867 Steins (1969 VC)	Rosetta	Sept 5, 2008	Flyby
21 Lutetia	Rosetta	July 10, 2010	Flyby
4 Vesta	Dawn	July 16, 2011 to Sept 5, 2012	Orbit
4179 Toutatis (1989 AC)	Chang'e 2	Sept 12, 2012	Flyby
1 Ceres	Dawn	March 6th, 2015 to present	Orbit

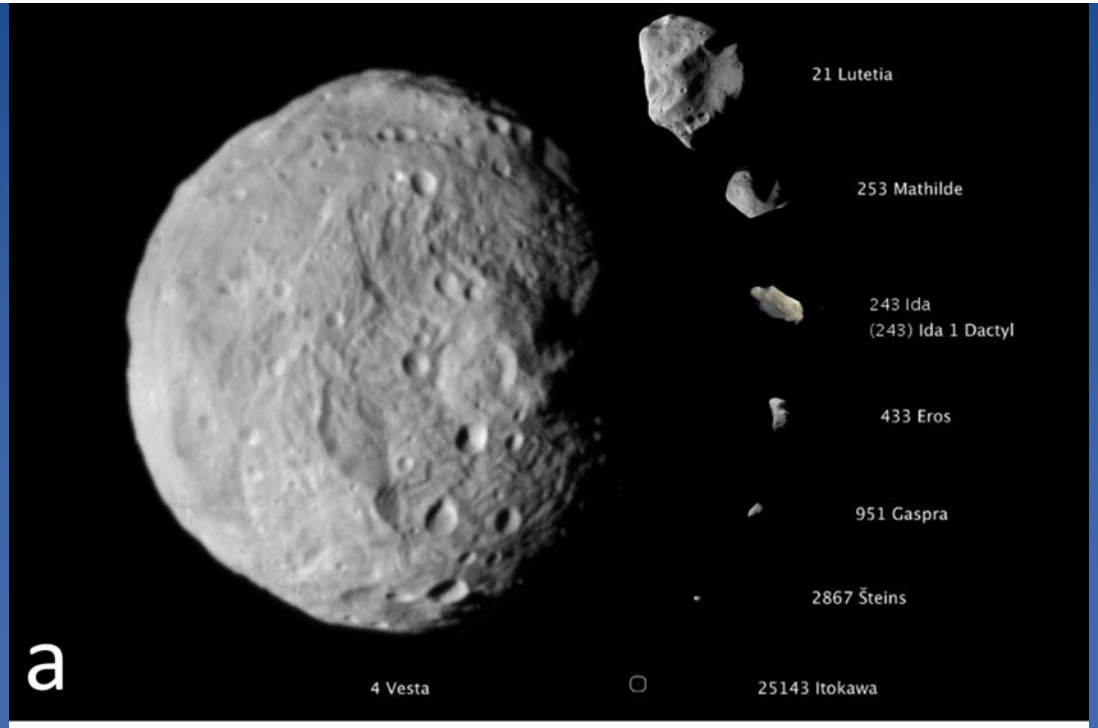


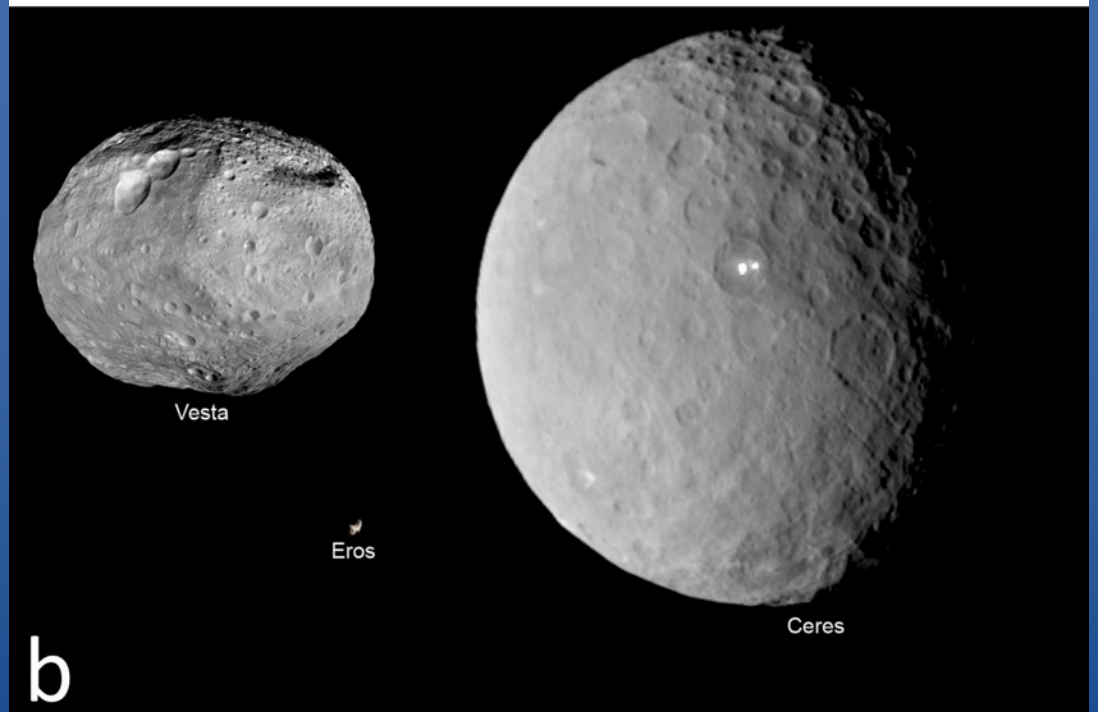
Discoverers

a. Piazzi, Ceres, 1801
b. Olbers, Vesta, 1807
c. Goldschmidt, Lutetia, 1885
d. Palisa, Ida, 1884, Mathilde, 1885
e. Witt, Eros, 1898
f. Nuejmin, Gaspra, 1916
g. Reinmuth, Annefrank, 1942
h. Helin, Braille, 1992
i. Lawrence, Braille, 1992



Sizes

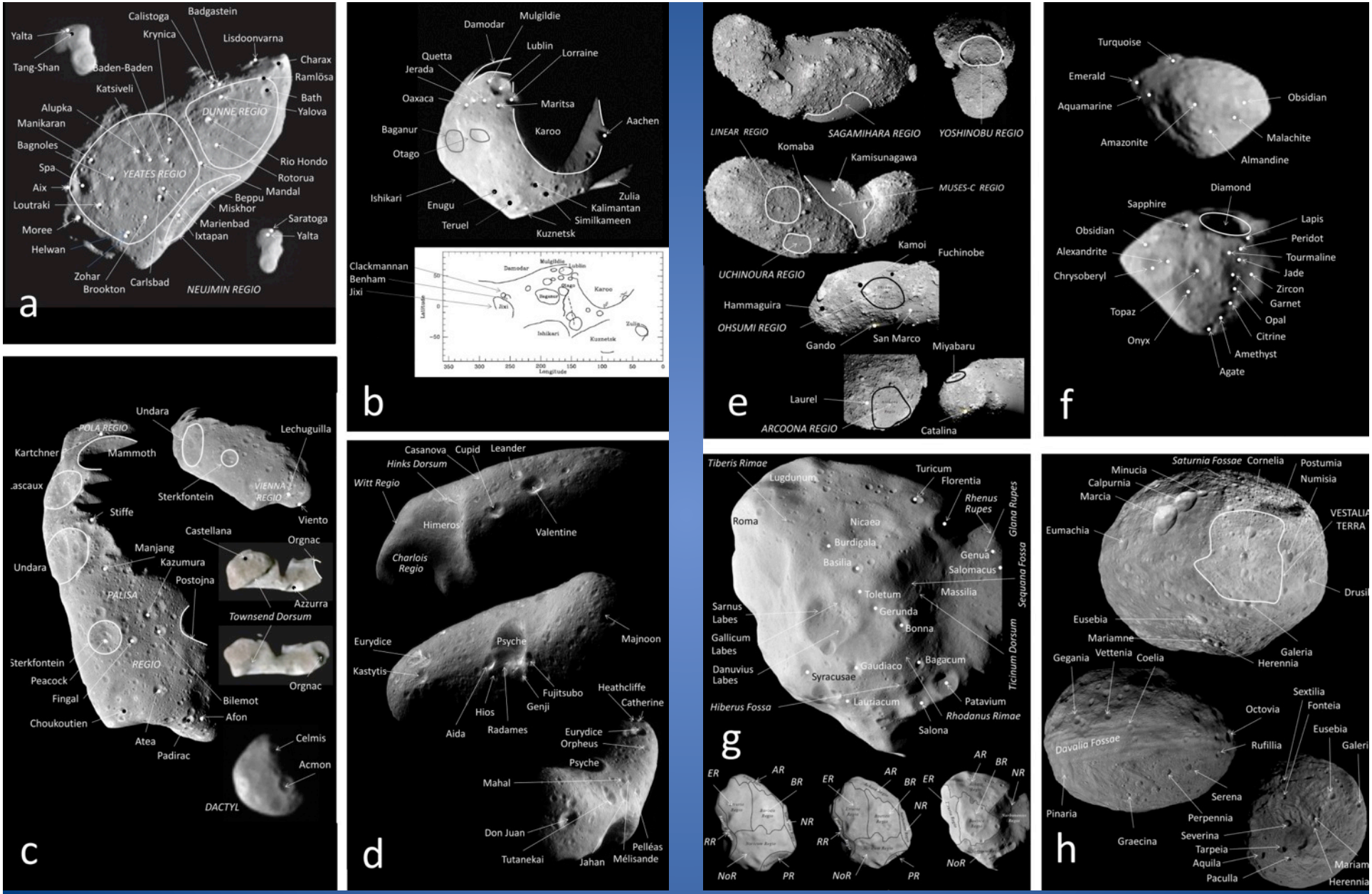




Max dimension

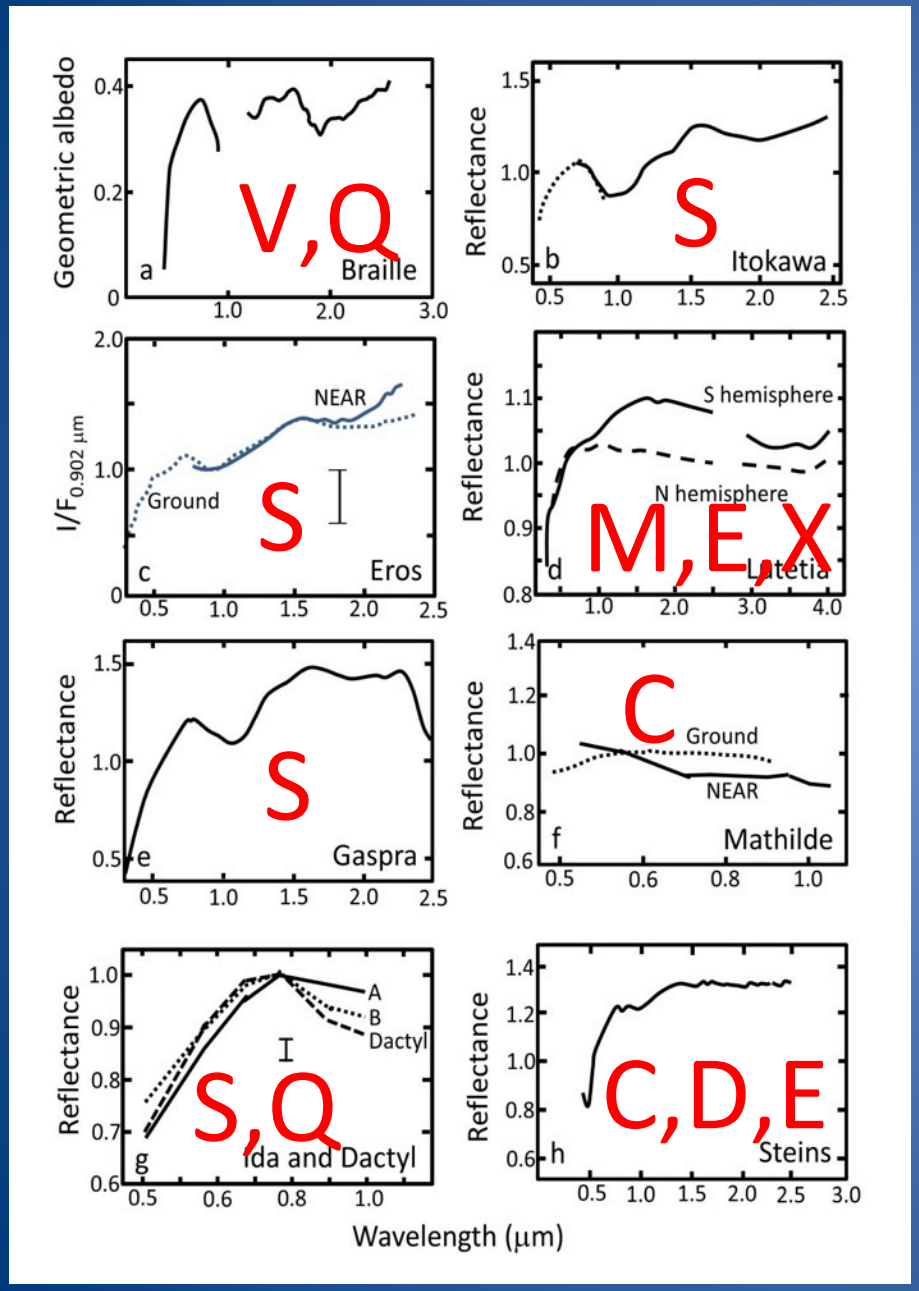
Vesta	573 km
Lutetia	121 km
Mathilde	66 km
Ida	60 km
Eros	34 km
Gaspra	18 km
Steins	6.7 km
Itokawa	0.54 km

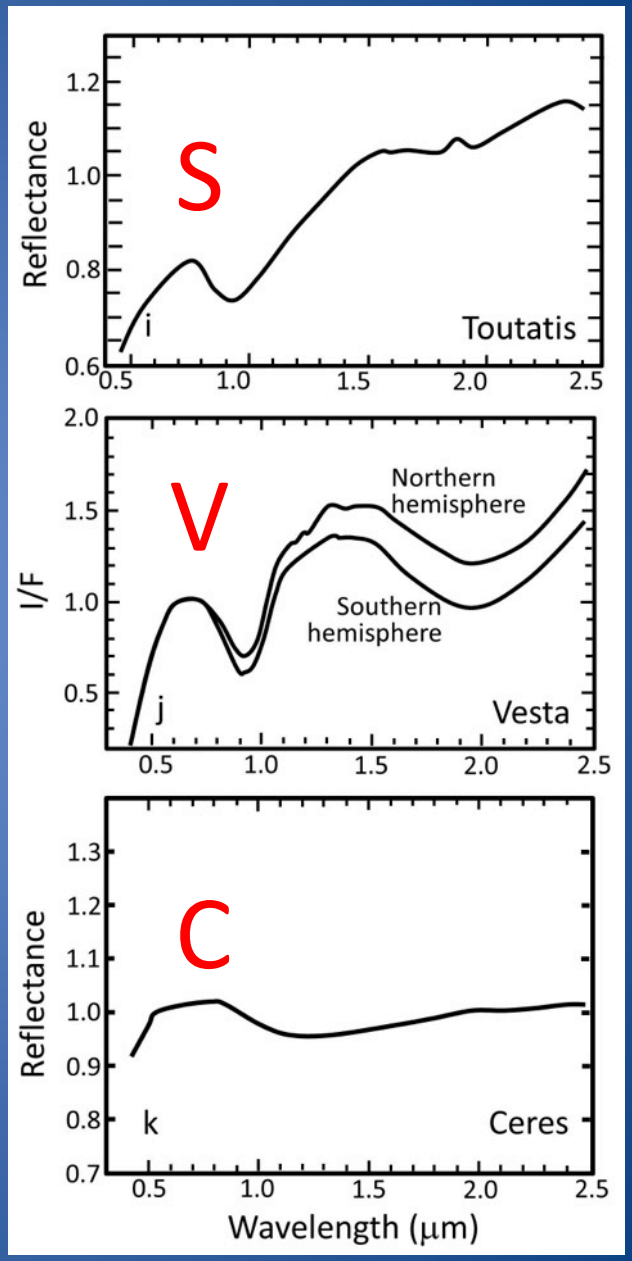
Vesta	573 km
Ceres	958 km
Eros	34.4 km



Maps Gaspra, spa towns (34), Mathilde, coal fields, (23), Ida, caves (25), Dactyl (2), Eros, lovers (41), Itokawa, space centers (17), Steins, gems (24), Lutetia, Roman cities (37), and Vesta, vestal virgins (106).

Spectra

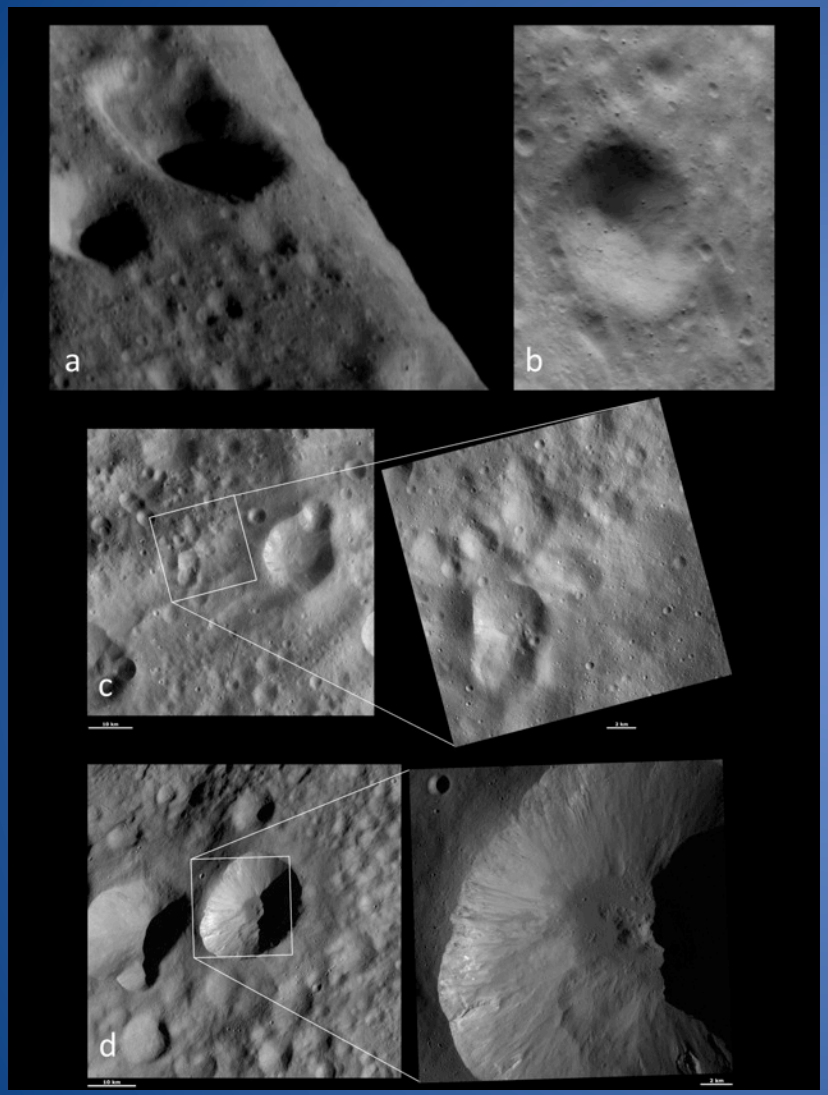

Geometric albedo
V,Q
a
Braille
Reflectance
S
b
Itokawa
I/F0.902 μm
NEAR
Ground
S
c
Eros
Reflectance
S hemisphere
N hemisphere
M,E,X
d
Lutetia
Reflectance
S
e
Gaspra
Reflectance
C
Ground
NEAR
f
Mathilde
Reflectance
A
B
Dactyl
S,Q
g
Ida and Dactyl
Reflectance
C,D,E
h
Steins
Wavelength (μm)

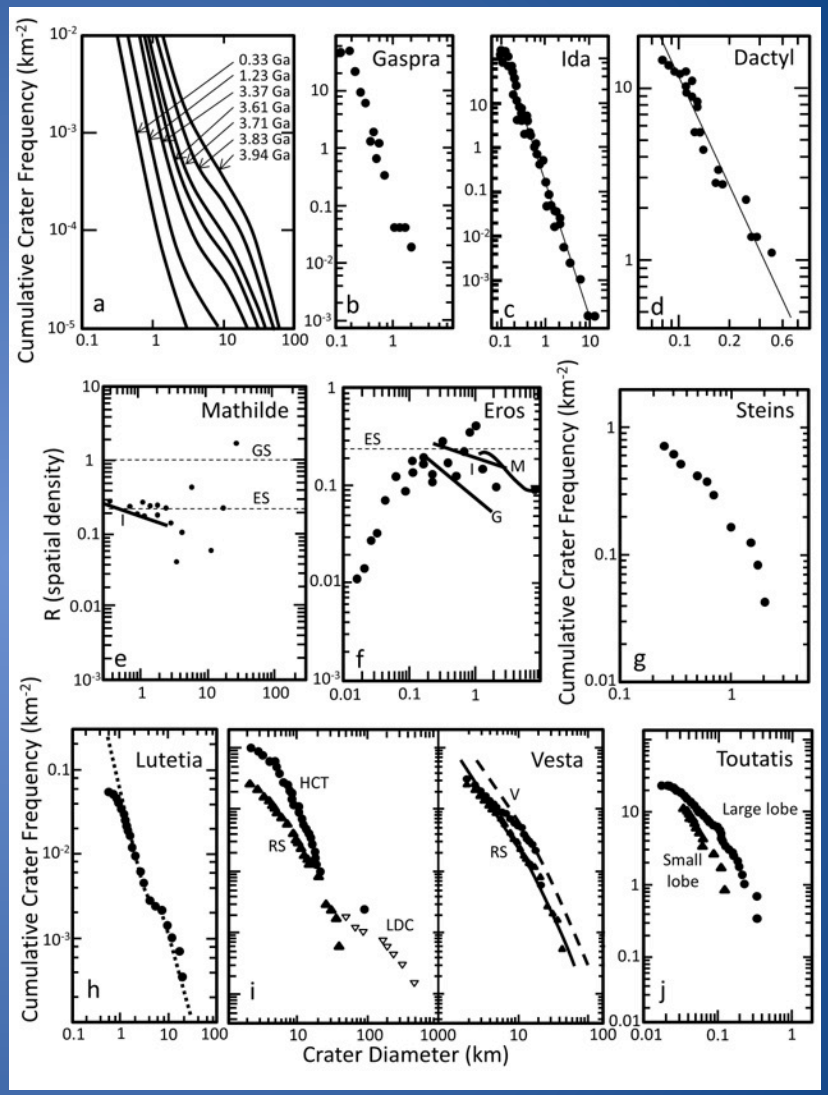

Reflectance
S
i
Toutatis
I/F
V
Northern hemisphere
Southern hemisphere
j
Vesta
Reflectance
C
k
Ceres
Wavelength (μm)

FOUR TOPICS FOR TODAY
A Personal Perspective

1. *What was confirmed?*
2. *What was new?*
3. *How abundant is water inside the snow-line?*
4. *How did we do linking meteorites with asteroids?*

1. *What was confirmed?*

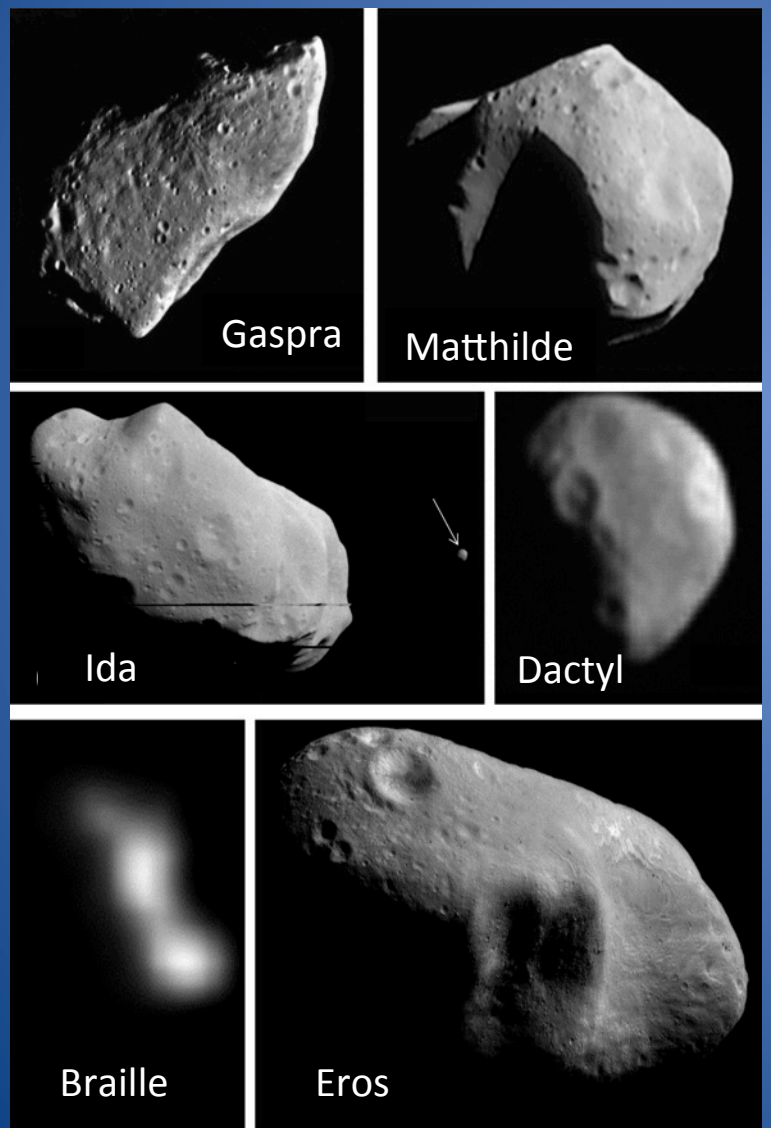


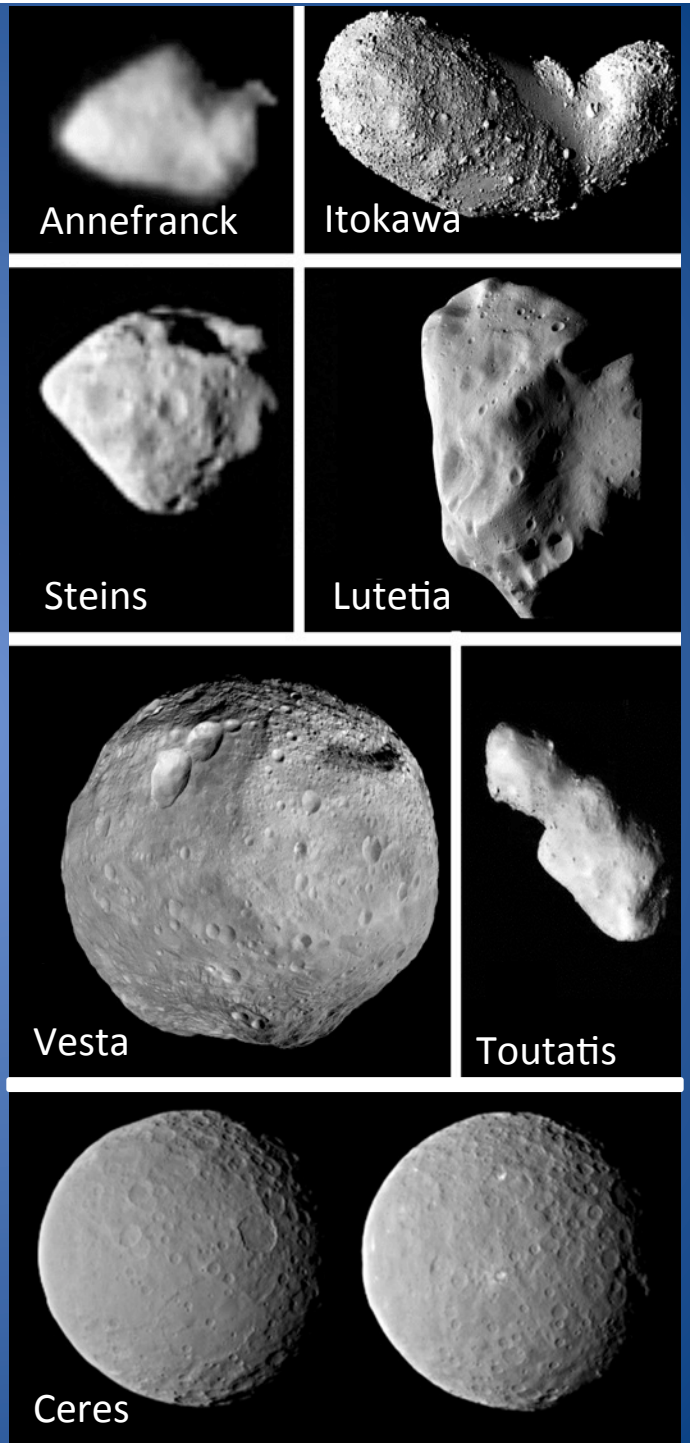


Dry, heavily cratered, ancient surfaces

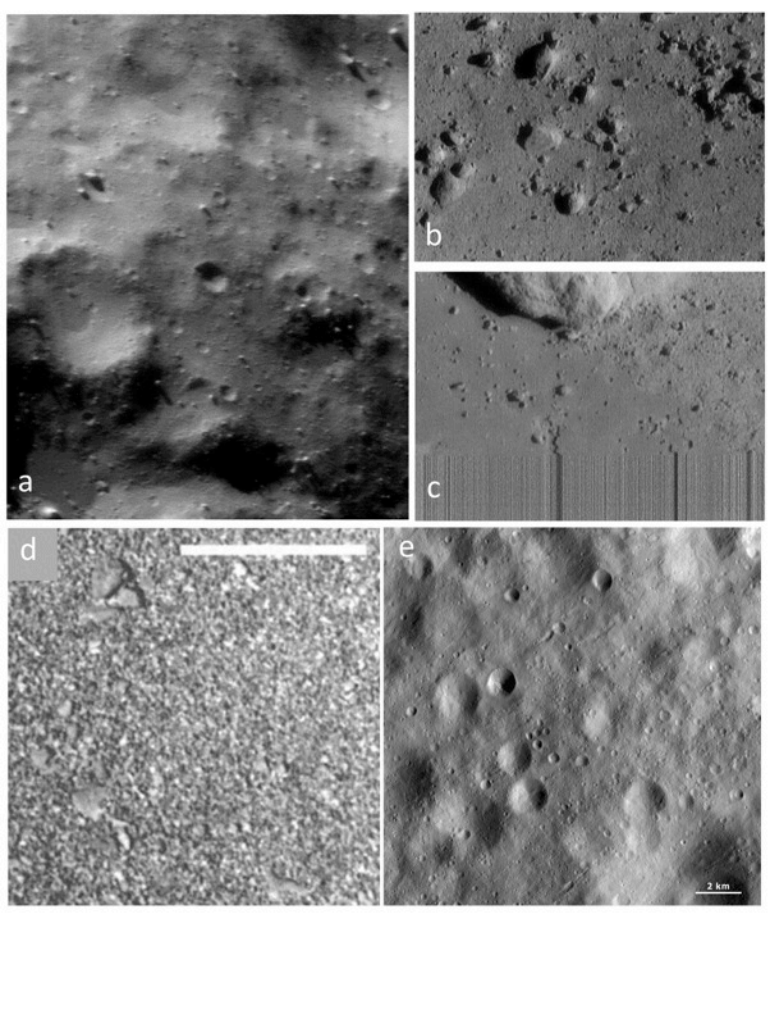
1. *What was confirmed?*

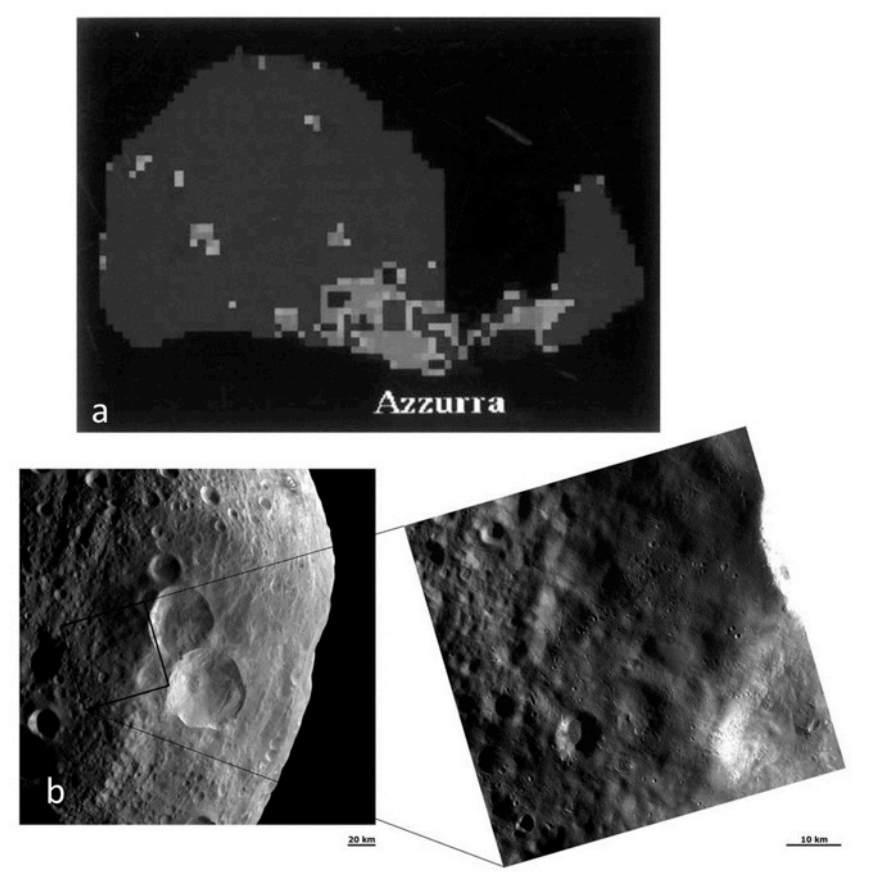
Most are irregular, dwarf planets are essentially spheres

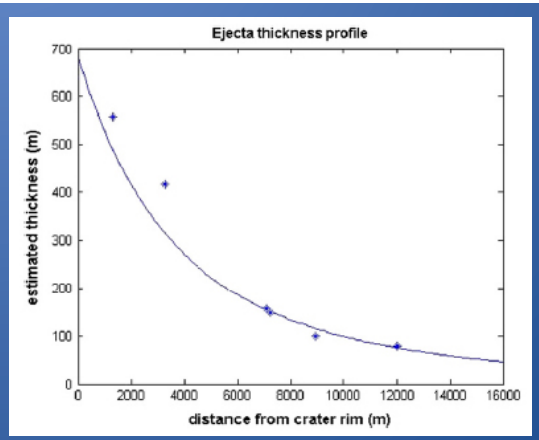




2. *What was new?*







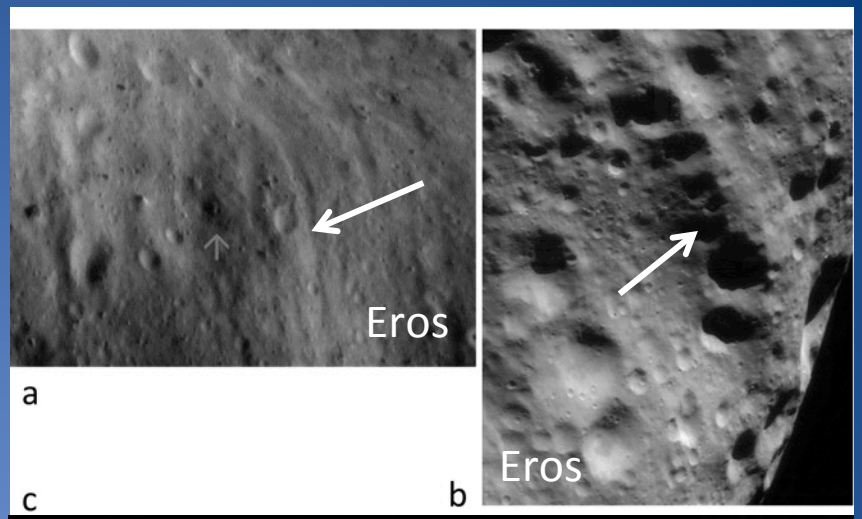
<u><10 km</u>
Annefrank
Braille
Gaspra
Itokawa
Toutatis

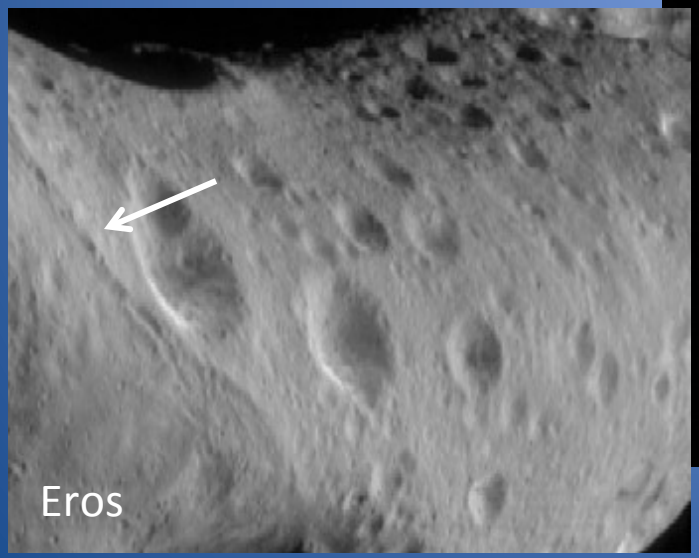
Abundant regolith

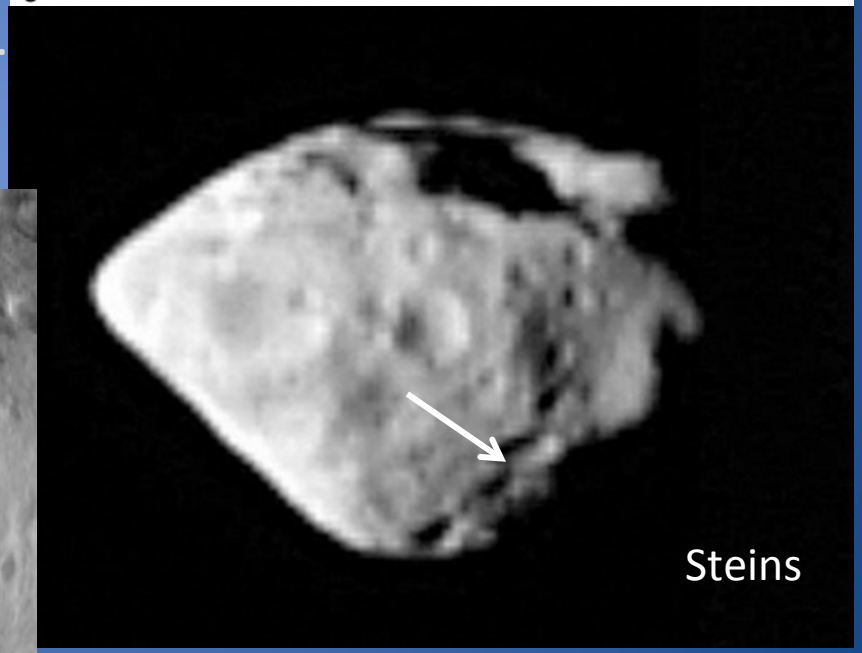
➔Thermal history, cratering mechanisms, operations

3. *What was new?*

- Grooves on Gaspra (Ververka et al., 1994b).
- Fractures in the Pola Regio region of Ida (Asphaug et al., 1996), opened by the Azzurra crater impact?
- Rahe Dorsum and many smaller grooves on Eros (Proctor et al., 2002).
- The catena on Steins (Keller et al., 2010)

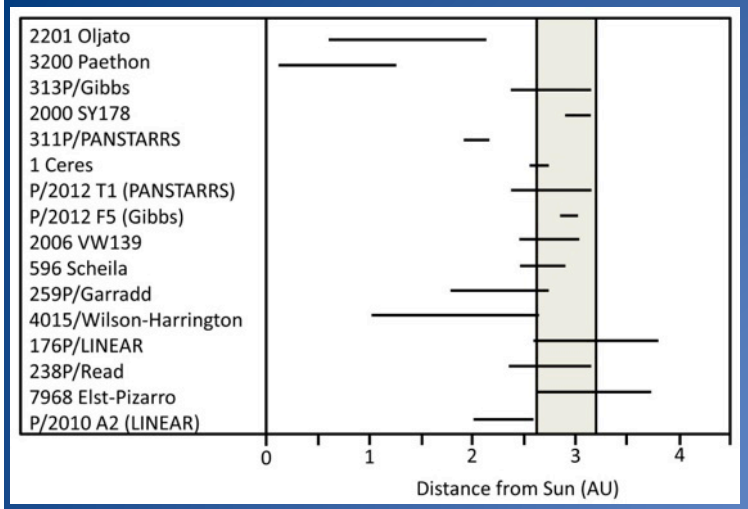




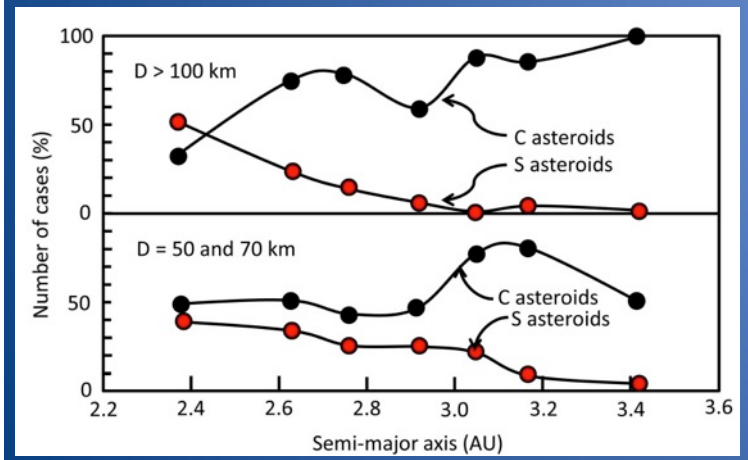


Ridges, grooves, catenas – coherent bodies?

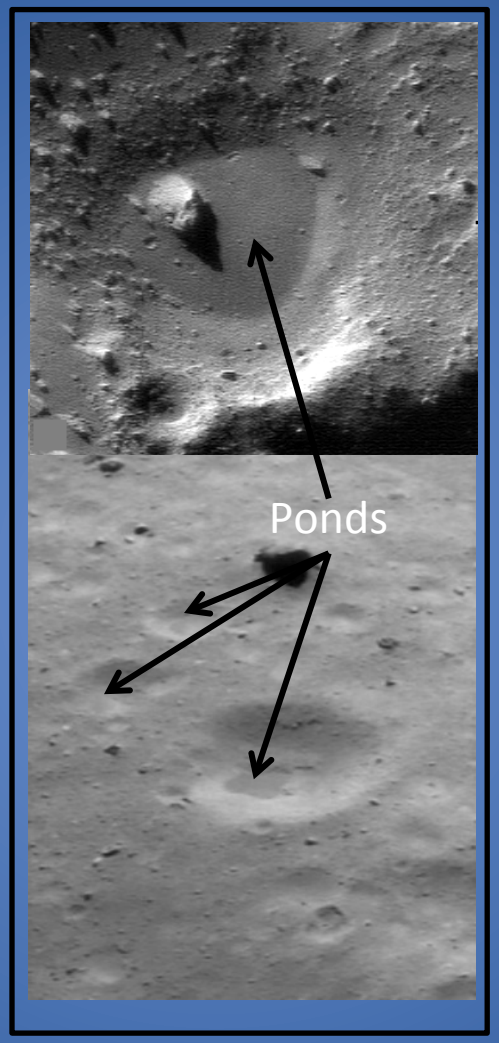
4. How abundant is water inside the snow-line?

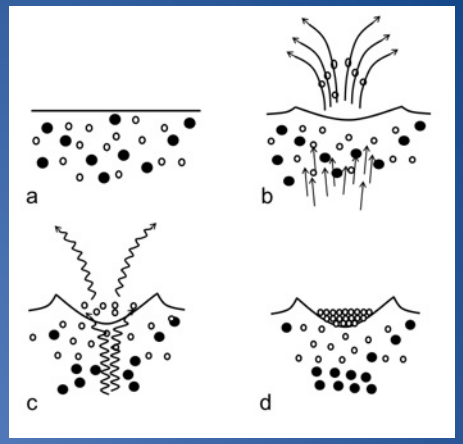


(Data from Jewitt, website)

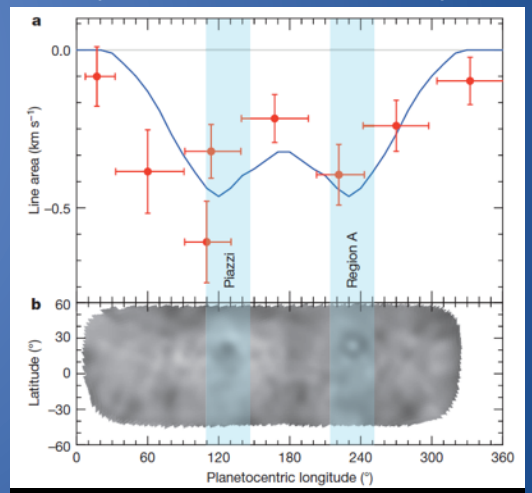


(Redrawn from Chapman, 1976)

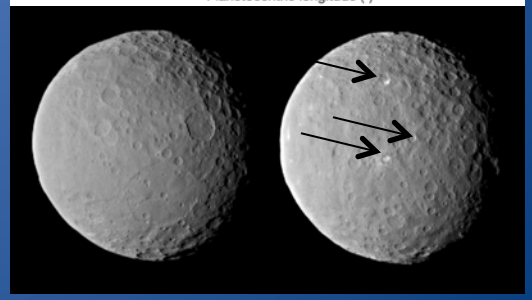




(Sears et al., 2015)

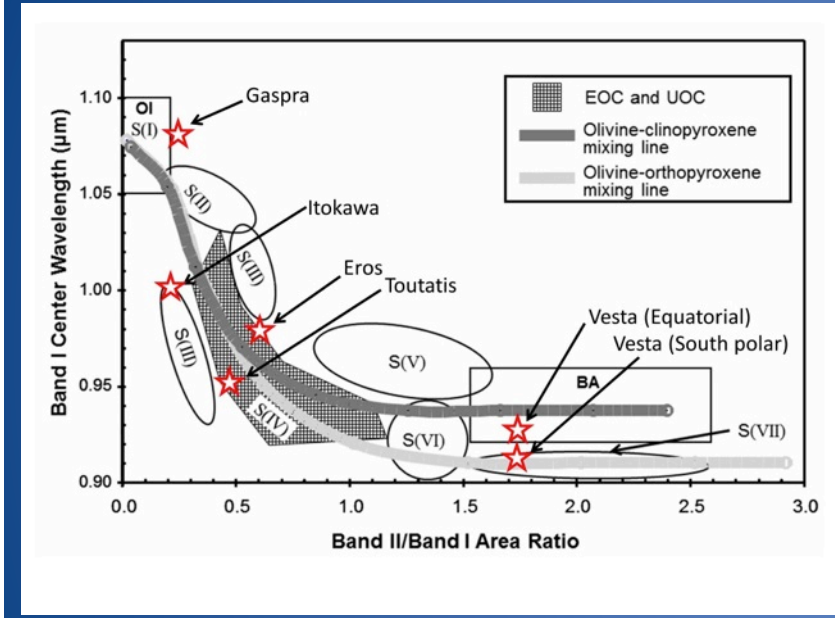


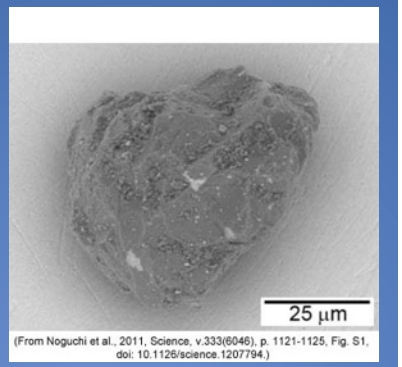
(Kueppers et al., 2014)



The Eros "ponds" – subsurface water?

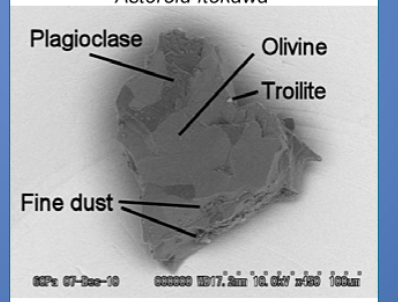
6. How did we do linking meteorites with asteroids?



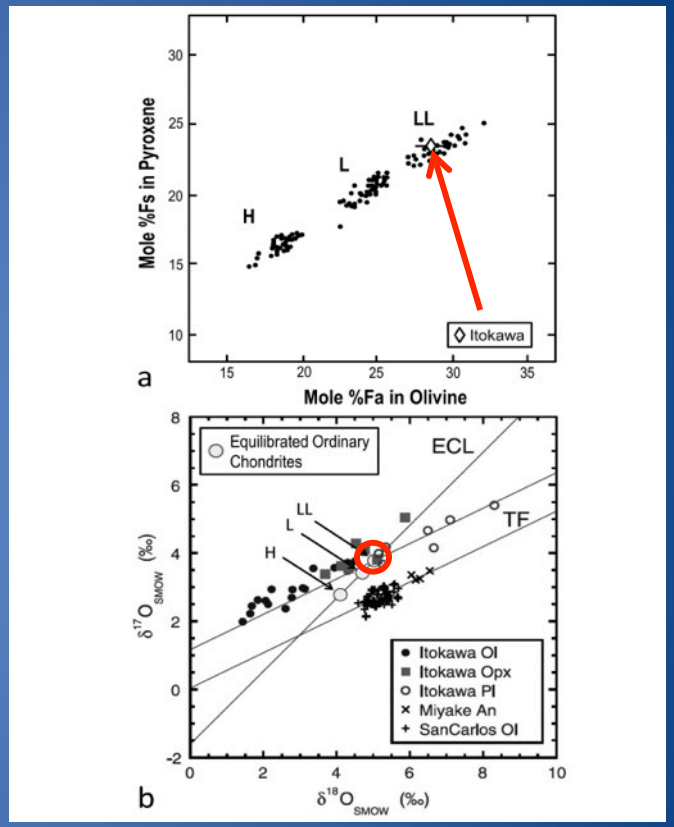


(From Noguchi et al., 2011, Science, v.333(6046), p. 1121-1125, Fig. S1, doi: 10.1126/science.1207794.)

Particle from Muses-C Regio on the Asteroid Itokawa

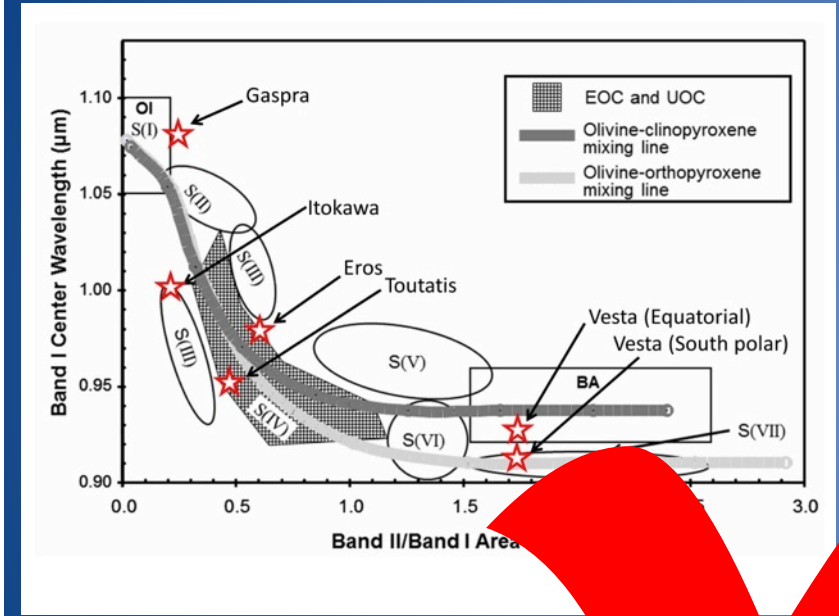


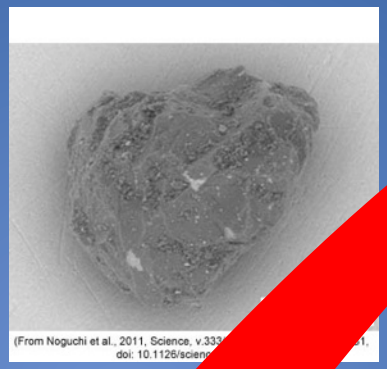
(From Nakamura *et al.*, 2011, *LPSC* abstract 1766.)

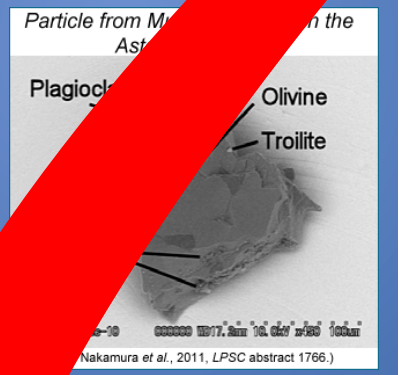


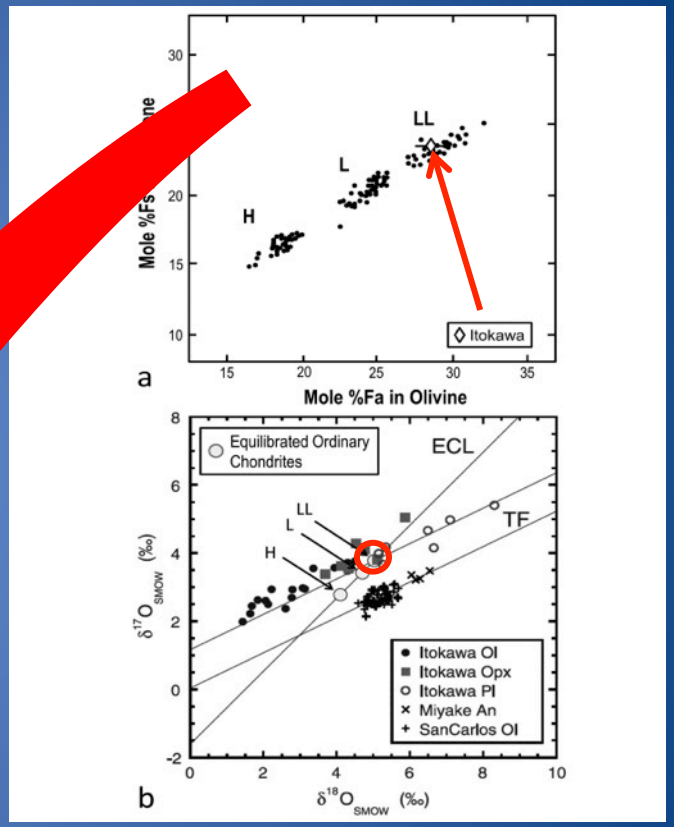
Itokawa, an LL chondrite asteroid

6. How did we do linking meteorites with asteroids?









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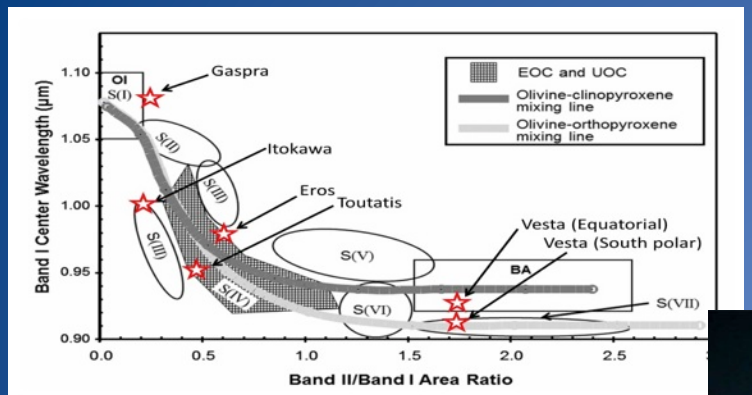
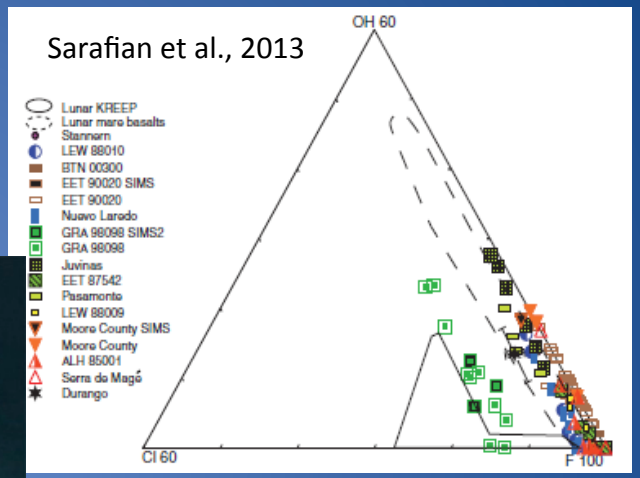
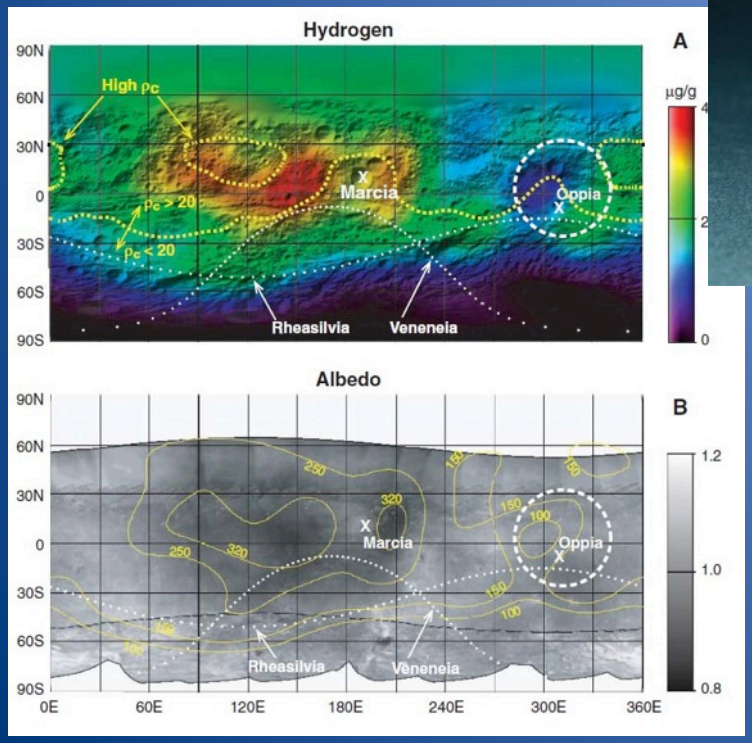


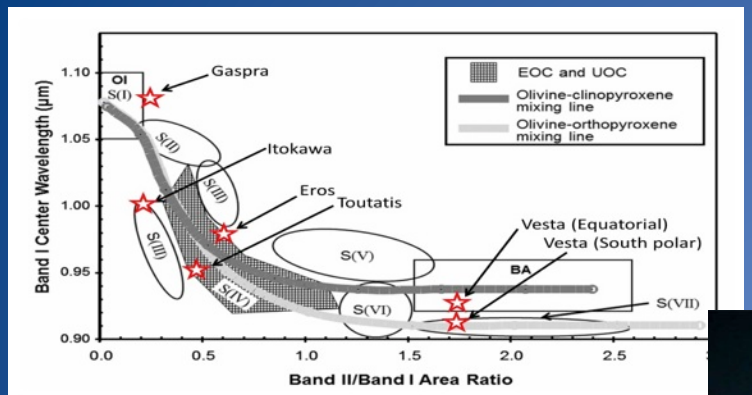
Gaffey et al., 1993, with modifications





Vesta and the HEDs

6. How did we do linking meteorites with asteroids?



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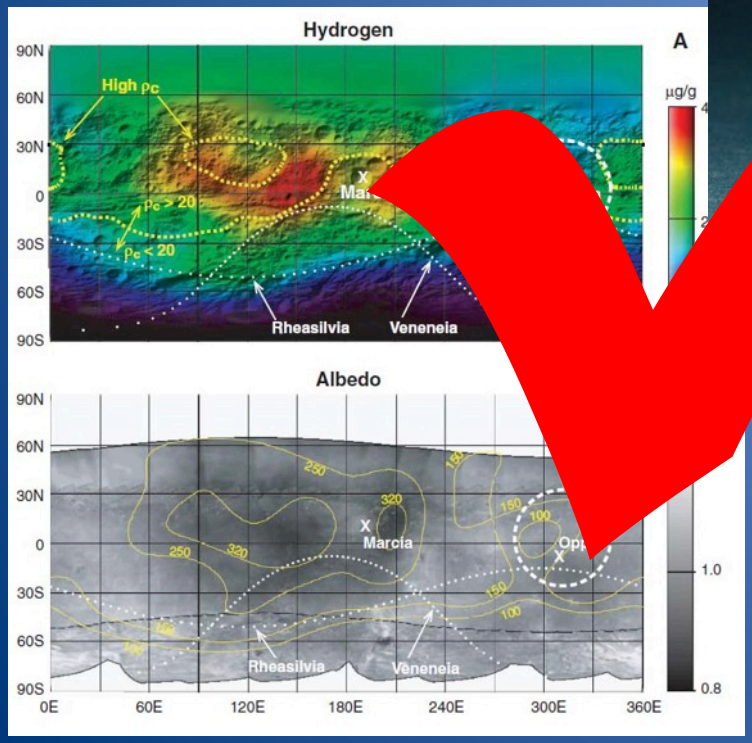
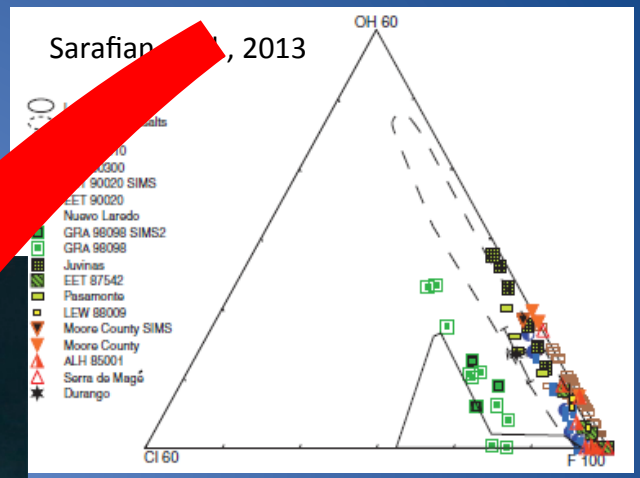
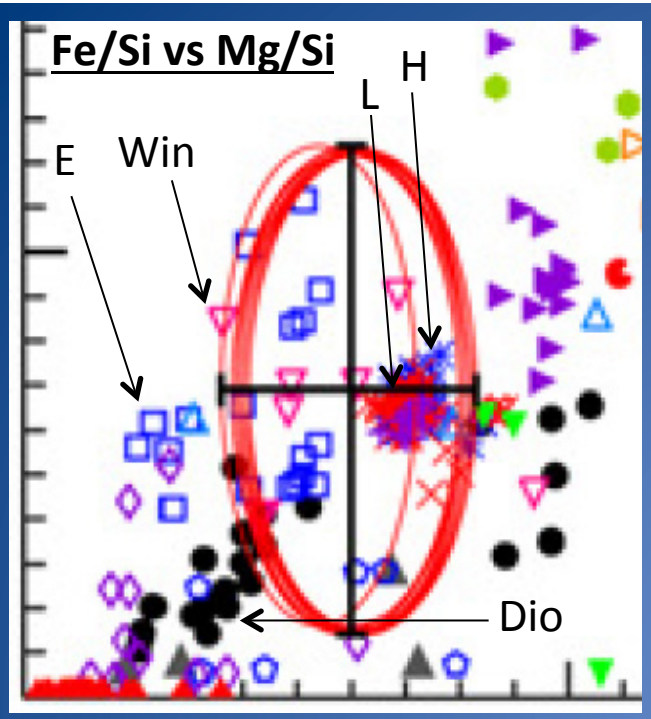
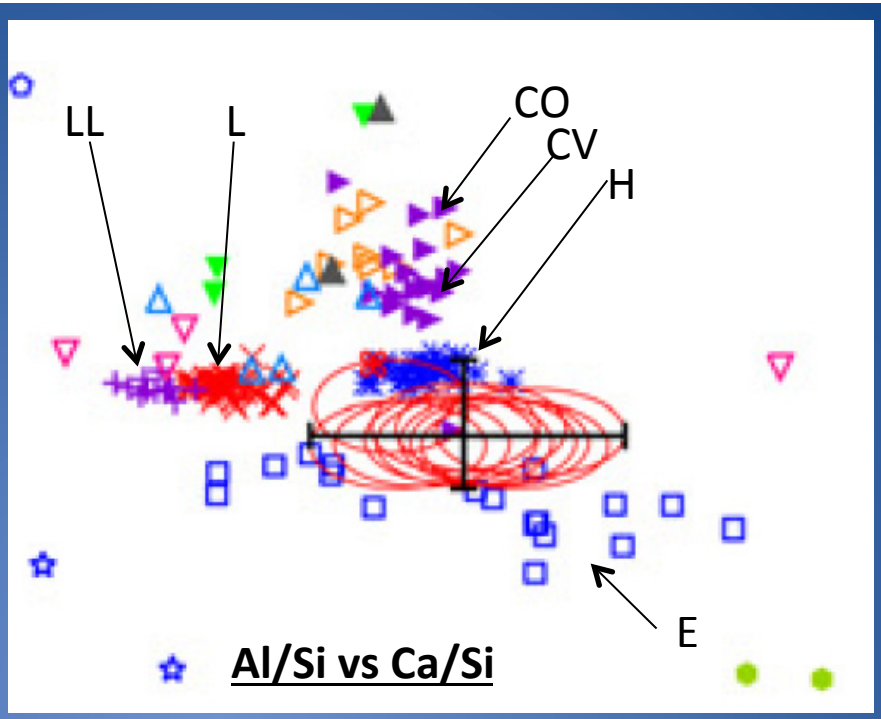


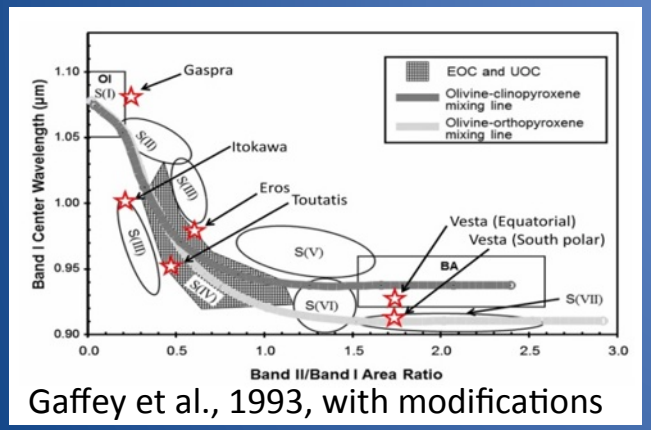


Vesta and the HEDs

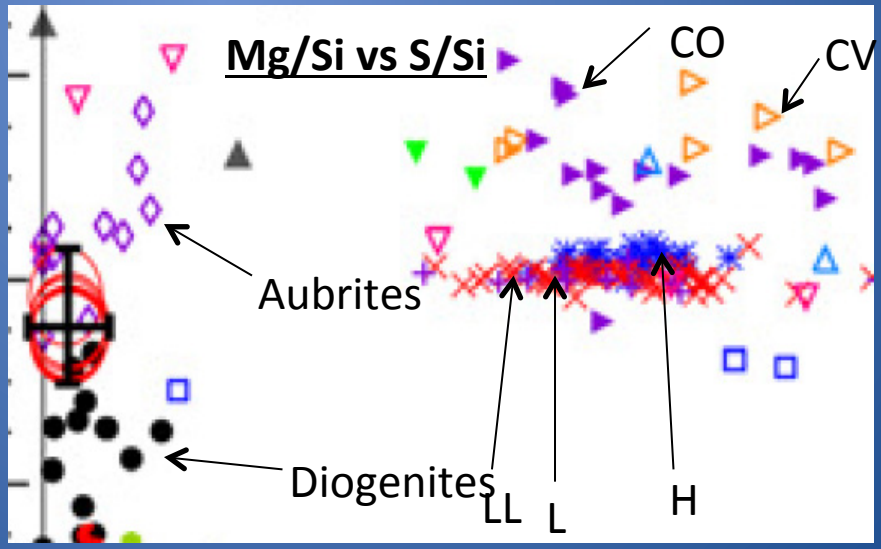




Shoemaker -NEAR XRS results (Lim and Nittler, 2013)

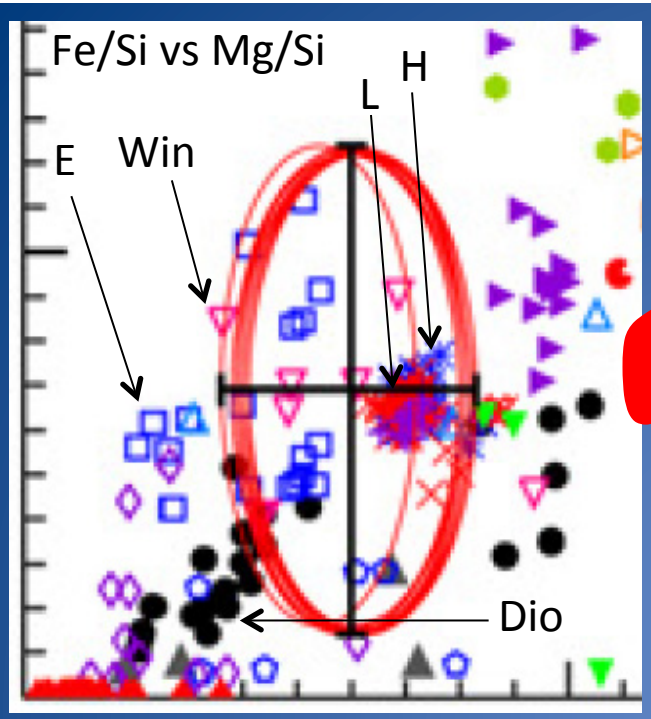


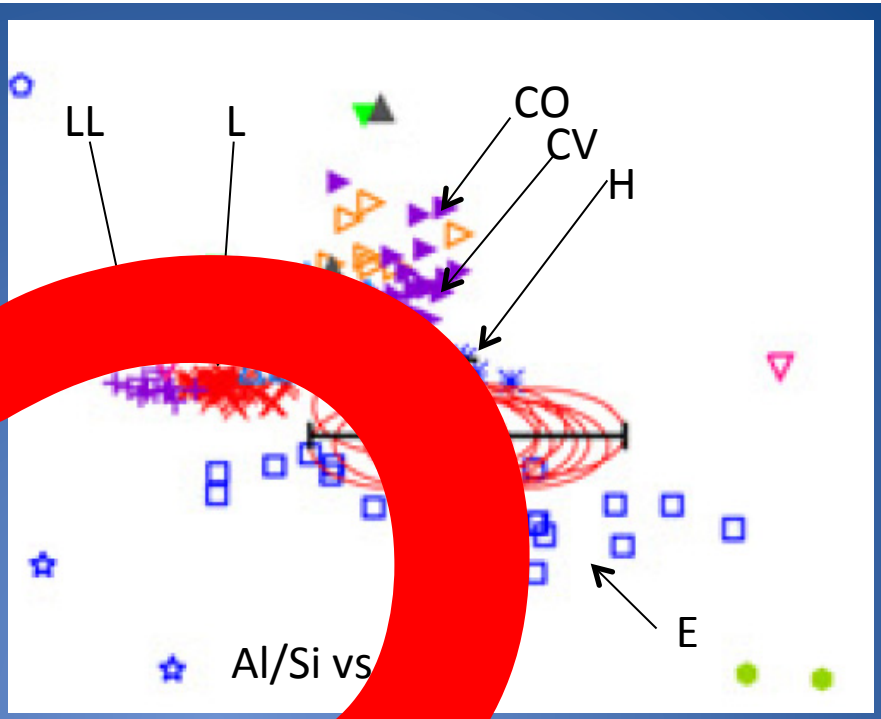
Gaffey et al., 1993, with modifications



S(IV)	Olivine + orthopyroxene (+/−FeNi metal)‡ (0.20 < opx/(ol+opx) < 0.50)	Opx-bearing ureilites Lodranites Winonites & IAB irons H,L,LL Chondrites

Eros and the ordinary chondrites





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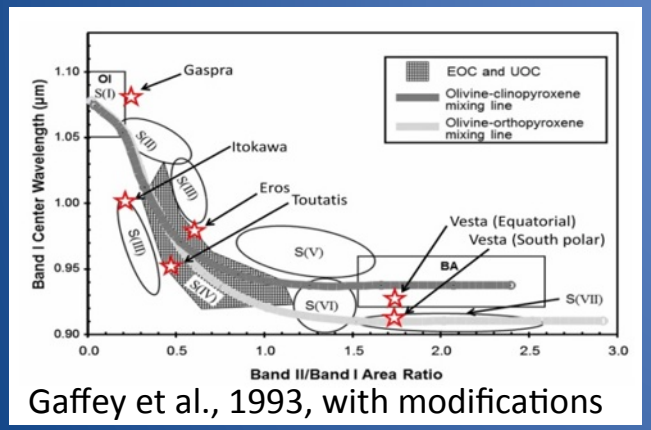

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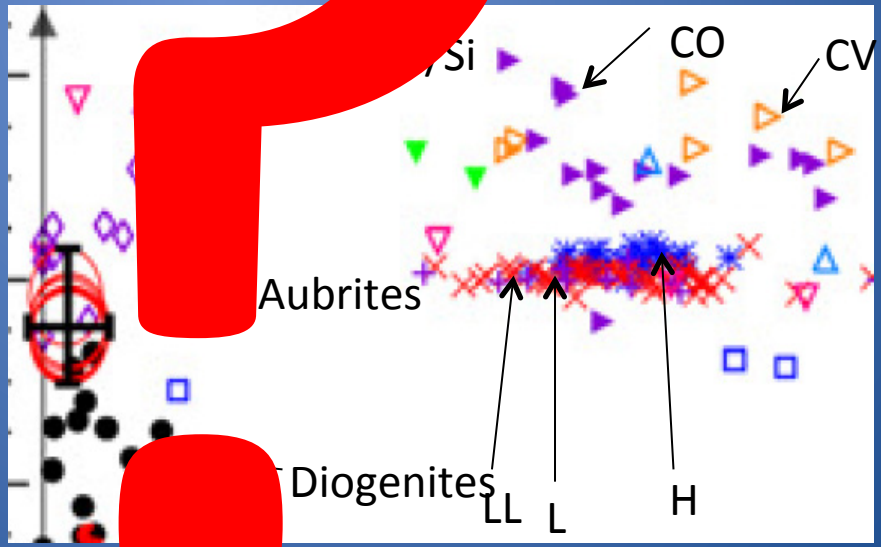

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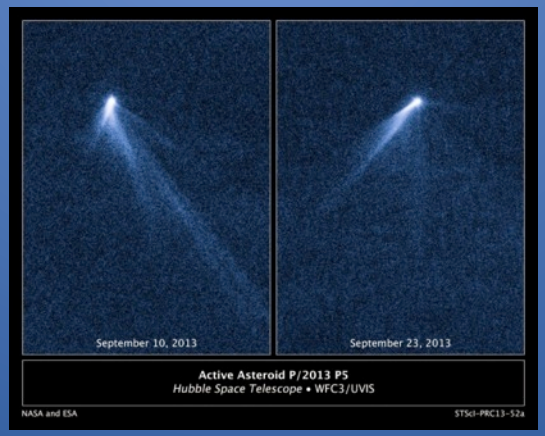
Eros and the ordinary chondrites

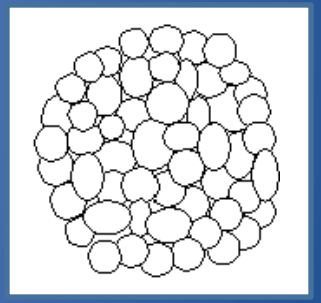
WHAT NEXT?
A Personal View

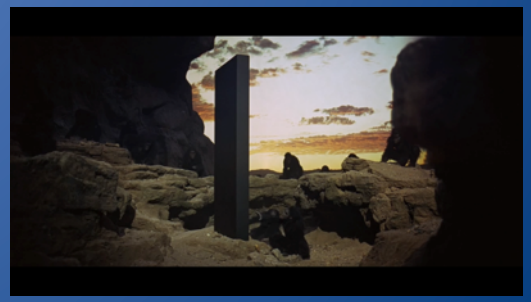
1. *Return Samples*
2. *Search for water*
3. *Geophysical studies of the interiors*

Hayabusa 2, launched Dec 2014, will return samples Dec 2020



Active asteroids inside the snowline





Rubble piles, monoliths, something else?

THE MISSION ASTEROIDS
A Personal Perspective

Review

1. *Missions*
2. *Discovery*
3. *Sizes*
4. *Maps*

Themes of present talk

1. *What was confirmed?*
2. *What was new?*
3 *How abundant is water inside the snow-line?*
4. *How did we do linking meteorites with asteroids?*

What's next?

1. *Return samples*
2. *Search for Water*
3. *Study the Interior*