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

D. W. G. SEARS

Bay Area Environmental Institute/
NASA Ames Research Center,
Space Science and Astrobiology Division,
Mountain View
California 94035, USA.
(derek.sears@nasa.gov)

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

Abundant regolith

→ Thermal history, cratering mechanisms, operations

<10 km
Annefrank
Braille
Gaspra
Itokawa
Toutatis
3. **What was new?**

- Grooves on *Gaspra* (Veverka 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?

The Eros “ponds” – subsurface water?
6. How did we do linking meteorites with asteroids?

Itokawa, an LL chondrite asteroid
6. **How did we do linking meteorites with asteroids?**

*Itokawa, an LL chondritic asteroid*
6. How did we do linking meteorites with asteroids?

Gaffey et al., 1993, with modifications

Sarafian et al., 2013

Wilkening, 1973

Vesta and the HEDs
6. How did we do linking meteorites with asteroids?

Vesta and the HEDs
<table>
<thead>
<tr>
<th>S(IV)</th>
<th>Olivine + orthopyroxene</th>
<th>Opx-bearing ureilites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(+/- FeNi metal)</td>
<td>Lodranites</td>
</tr>
<tr>
<td></td>
<td>(0.20 &lt; opx/(ol+opx) &lt; 0.50)</td>
<td>Winonites &amp; IAB irons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H, L, LL Chondrites</td>
</tr>
</tbody>
</table>

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

Gaffey et al., 1993, with modifications

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?
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2. Search for Water
3. Study the Interior