CONSIDER THREE MAJOR QUESTIONS:

1. HOW DID EARTH GET ITS VOLATILES?
2. HOW DID GIANT PLANETS GET ATMOSPHERES?
(3. IS THERE EXTRATERRESTRIAL LIFE IN THE SOLAR SYSTEM?)
1. HOW EARTH GOT ITS VOLATILES

• ENDOGENIC

• EXOGENIC
  – ICY PLANETESIMALS AKA COMETS
  – ROCKY PLANETESIMALS AKA ASTEROIDS, METEORITES

  – COURIERS MUST HAVE
    a) Deuterium/Hydrogen \( (D/H) = 1.6 \times 10^{-4} \) (IN WATER)
    b) Krypton/Xenon=Kr/Xe >100
EXOGENOUS SOURCE

• **ICY (NOT ROCKY) PLANETESIMALS**

  **WHY?**
  ONLY on MARS Kr/Xe ~ EARTH Kr/Xe

  Not So in Meteorites!!
  or in sun, or in Jupiter

  Common Bombardment by Comets??
COMETS AS SOURCE OF EARTH’S WATER??

- TWO PRINCIPAL COMET FAMILIES:
  - OORTCLOUD ORIGIN: KUIPER BELT
  - JUPITER FAMILY (JFC) ORIGIN: URANUS<>_NEPTUNE

- TEST THAT ICE IN AN IMPACTOR MUST PASS:
  - DEUTERIUM/HYDROGEN (D/H) IN A COMET’S ICE
  - MUST = D/H IN OCEANS, ICE, YOU, ETC. D/H =1.6 X10^-4
    (SAME VALUE FOUND IN WATER IN METEORITES)
  - MANY VALUES EXIST IN SOLAR SYSTEM: e.g, Jupiter 2.6 X10^-5
## THE COMETS WITH KNOWN D/H

<table>
<thead>
<tr>
<th>FAMILY</th>
<th>DESIGNATION</th>
<th>YEAR</th>
<th>D/H</th>
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<tbody>
<tr>
<td>HALLEY</td>
<td>HALLEY</td>
<td>1986</td>
<td>3.2 x10^{-4}</td>
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<td>OORT</td>
<td>AVERAGE OF FIVE</td>
<td>MSC</td>
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<tr>
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<td>45 P H-M-P</td>
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THE RIDDLE OF THE MARBLE JAR:

IMAGINE A JAR FILLED WITH MARBLES.
YOU CAN’T SEE INSIDE THE JAR.

NOW REACH IN AND TAKE OUT ONE
MARBLE—IT’S BLACK!

“A HA!” YOU EXCLAIM, “THE MARBLES IN
THE JAR ARE BLACK”

NOW YOU TRY AGAIN. THIS TIME THE
MARBLE IS WHITE.” IT’S A MISTAKE, AN
ACCIDENT,

IT’S NOT REALLY A MARBLE.” BUT THE
NEXT ONE IS ALSO WHITE. “MAYBE THE
BLACK ONE
IS THE MISTAKE” ETC., ETC.
CONCLUSIONS

• DID COMETS BRING THE OCEANS TO EARTH?
  • MAYBE YES, MAYBE NO
  • Need more observations!!

======================================

TO PROGRESS:
RETURN TO HARTLEY 2—Study Noble gases Plus compare all with Chur-Ger

NEED STATISTICS: MINI-ROSETTA FLOTILLA
JFC PLUS OORT? (STORE S/C IN “GARAGE”.... WAIT)
DESIGN VERSATILE LANDER=> SMALL, LIGHT, TOUGH, CHEAP
INCLUDE STUDY OF ORGANICS
Comet relatives: MBCs, Trojans, Hildas, Satellites, Kuiper Belt

INTERNATIONAL COLLABORATION ESSENTIAL !!
GIANT PLANETS
JUPITER

Planetary Enhancement

Direct Gravitational Capture

Interior Processes

Hot Spot Meteorology

Ratio of Jovian to Solar Abundances
(Relative to Hydrogen)
JUPITER

Conundrum:

• Enrichment of C, N, S, Ar, Kr, Xe mixing ratios
  
  — CHALLENGES CLASSICAL MODEL FOR GIANT PLANET ORIGIN:
    — ABUNDANCES SHOULD ALL BE SOLAR
    — Solution
      — Deplete H₂ => No enrichment

CLASSICAL MODEL PRESERVED
Saturn Probe

--Now know C/H = 10x solar

--Consistent with SmallerMass ratio H2/Core than Jupiter

--Need to know N/H, Ar/H

Also He/H, D/H, Ne/H  $^{15}\text{N}/^{14}\text{N}$

And Probe gives much more!
Uranus and Neptune

- Shallow Probes: ~ 5 bars, μ-wave ?? bars
  Bolton and Owen 2001

- MEASURE CARBON, ARGON, NEON, KRYPTON: ISOTOPES AND ABUNDANCES (H/He, D/H, H2S? N2? 15N/14N?)

- ENRICHMENT VS. DEPLETION

- INTERNAL STRUCTURE ATMOSPHERE VS. “CORE”,
OTHER LIFE IN SOLAR SYSTEM?

• DISTINGUISH ORIGIN FROM ADAPTATION
• STRANGE FORMS OF LIFE IN WATER ON EARTH $\neq$ LIFE ON EUROPA

• BEWARE MICROBIAL CONTAMINATION!!
GIANT PLANETS
1. ENDOGENIC
2. EXOGENIC

HOW TO DISTINGUISH?
Noble gases on Mars ~ Earth

A) Icy Planetesimals aka comets
B) Rocky planetesimals aka asteroids, => meteorites

HOW TO DISTINGUISH (IN WATER)
DEUTERIUM/HYDROGEN MUST MATCH

EARTH:

ON EARTH (OCEANS)  \[ \text{D/H} = 1.6 \times 10^{-4} \]

ELSEWHERE?
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<td>2014</td>
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WATER IN COMETS

ICY PLANETESIMALS, AKA COMETS
WHY? MARS NOBLE GASES => NOT IN ROCKS

TEST THAT ICE IN A COMET MUST PASS:

DEUTERIUM/HYDROGEN (D/H) IN A COMET’S ICE

\[
\text{MUST} = \quad \text{D/H IN OCEANS, ICE, YOU, ETC.} \\
\text{D/H} = 1.6 \times 10^{-4}
\]
(SAME VALUE FOUND IN WATER IN METEORITES)

MANY VALUES IN SOLAR SYSTEM
HOW TO DISTINGUISH (IN WATER) DEUTERIUM/HYDROGEN MUST MATCH EARTH:

ON EARTH (OCEANS) \[ \text{D/H} = 1.6 \times 10^{-4} \]

ELSEWHERE?
ENDOGENIC

EXOGENIC:
- HOW TO DISTINGUISH? MARS NOBLE GASES ~ EARTH NOBLE GASES
- Icy Planetesimals aka comets
- Rocky planetesimals aka asteroids, => meteorites

- HOW TO DETERMINE SOURCE (IN WATER)
- DEUTERIUM/HYDROGEN MUST MATCH EARTH:

- ON EARTH (OCEANS) \[ D/H = 1.6 \times 10^{-4} \]

- MORE
1. Icy Planetesimals aka comets
2. Rocky planetesimals aka asteroids, => meteorites

HOW TO DISTINGUISH (IN WATER)

DEUTERIUM/HYDROGEN MUST MATCH

EARTH:

ON EARTH (OCEANS) \[ \text{D/H} = 1.6 \times 10^{-4} \]

ELSEWHERE?
1. HOW EARTH GOT ITS VOLATILES => WATER

- ENDOGENIC
- EXOGENIC:
  - HOW TO DISTINGUISH? MARS NOBLE GASES ~ EARTH NOBLE GASES
  - Icy Planetesimals aka comets
  - Rocky planetesimals aka asteroids, => meteorites

- HOW TO DETERMINE SOURCE (IN WATER)
- DEUTERIUM/HYDROGEN MUST MATCH EARTH:

- ON EARTH (OCEANS) $D/H = 1.6 \times 10^{-4}$

- ELSEWHERE?
1. SOURCES OF VOLATILES

- **ENDOGENIC**

- **EXOGENIC**
  - HOW TO DISTINGUISH? MARS NOBLE GASES ~ EARTH NOBLE GASES
  - Icy Planetesimals aka comets
  - Rocky planetesimals aka asteroids, => meteorites

- HOW TO DETERMINE SOURCE (IN WATER)
  - DEUTERIUM/HYDROGEN MUST MATCH EARTH:

- ON EARTH (OCEANS) \[ \text{D/H} = 1.6 \times 10^{-4} \]

- ELSEWHERE?
1. HOW EARTH GOT ITS VOLATILES => WATER

1. HOW EARTH GOT ITS VOLATILES => WATER

A) ENDOGENIC
B) EXOGENIC  Hint from Mars
   a) Icy Planetesimals aka comets
   b) Rocky planetesimals aka asteroids, => meteorites

HOW TO DISTINGUISH (IN WATER)
DEUTERIUM/HYDROGEN MUST MATCH EARTH:

ON EARTH (OCEANS)  D/H = 1.6 X 10^{-4}

ELSEWHERE?
EXOGENOUS SOURCE OF VOLATILES