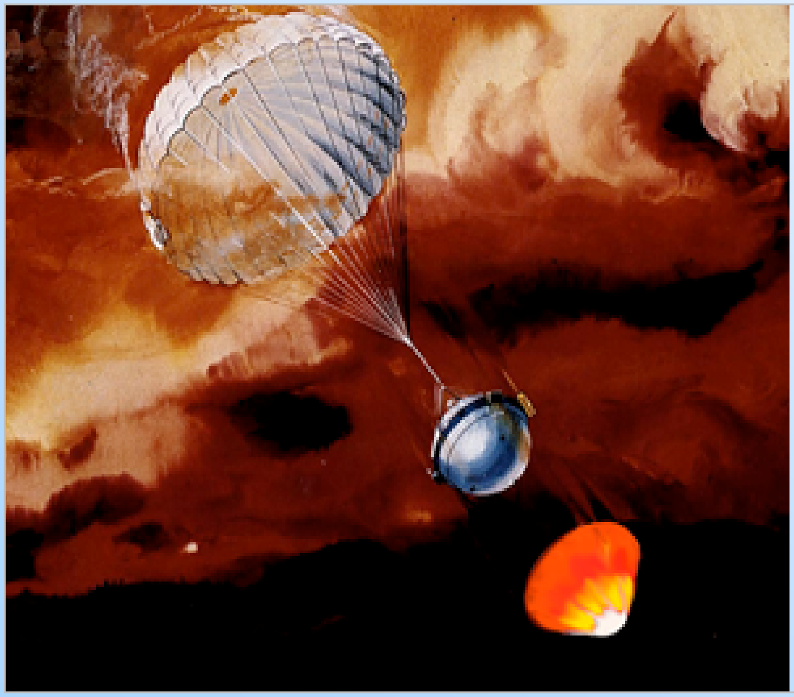
What We Have Learned from Atmospheric Entry Probes



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Where Have We Delivered Entry Probes?

– Venus
  - Pioneer Venus Probes (1 large, 3 small)
  - Many Soviet Venera probes with brief (~1 hr) landed operations
  - Two Soviet Vega balloons
– Mars
  - NASA Mars landers/rovers
    - Viking, Mars Pathfinder, Mars Exploration Rovers (Spirit/Opportunity), Phoenix
– Jupiter
  - Galileo Probe
    - Outer solar system
– Titan
  - ESA Huygens probe, delivered by NASA’s Cassini Saturn orbiter

What Unique Measurements Can Entry Probes Provide?

– Remote sensing techniques

- Many remote sensing techniques can see into optically thin regions
  - There are a variety of techniques using spectral, polarization, and other data
- Interiors of optically thick regions are often inaccessible
  - Seen from outside, atmospheres become optically thicker with depth
- Some remote sensing techniques have relatively large uncertainties
- Materials that are spectrally inactive are often invisible to remote sensing

– *In situ* techniques

- Very accurate measurements of a wide range of parameters & characteristics
  - Entirely different approaches from remote sensing, different physics
- Measurements inside optically thick regions
- Measurements of spectrally inactive constituents

What Unique Measurements Can Entry Probes Provide?

–Composition and chemistry

- Bulk planetary composition for key species (clues to formation processes)
  - Elemental ratios: H & He, “ices”, noble gases
  - Isotopic ratios to high accuracy
  - Diagnostic species (e.g., CO, ortho- to para-H_2 ratio)
- Evolutionary processes
  - E.g.: Titan; CH_4 is irreversibly converted to higher hydrocarbons, nitriles, etc.

–Atmospheric structure and energy balance

- Vertical temperature, pressure, and density profiles; lapse rates, stability
- Depths at which solar energy is deposited; upwelling radiant energy

–Atmospheric dynamics

- Lateral (winds) and vertical transport of matter and energy

–Processes at the seams of these disciplines

- Clouds: condensation regions of volatiles
- Atmospheric electricity: dynamics-generated processes can cause chemical evolution

Potential Problems With Entry Probe Observations

- Sampling a non-representative region of the atmosphere (or surface)
  - Galileo probe at Jupiter
- Instrumentation inappropriate for the sampled environment.
  - Viking biology experiment
  - Pioneer Venus Large Probe mass spec inlet plugged by aerosol droplet
- Equipment malfunctions: lost observations
  - Galileo probe
    - Backwards-wired accelerometer delayed heatshield deploy, 410 mb instead of 100
    - Planned measurements from tropopause to 420 mb level lost
  - Huygens
    - “Spin vanes” malfunction, spun backward during critical period
    - Channel A receiver on Cassini not turned on; lost Doppler Wind Experiment data and half of images
- Just plain bad luck
  - Venera mineralogy instrument sensor landed on top of imager lens cap

Findings at Venus

–Verified radio remote sensing: surface hot (730K) & 92 bar pressure

- Powerful runaway greenhouse from atmosphere that is ~95% CO_2
- Temperature lapse rates are close to a dry adiabat

–Atmosphere oxidizing, not reducing (typical of terrestrial planets)

–Precious little hydrogen left, very little H_2O

- D/H ~100 x Earth value, implies significant loss of H from upper atmosphere (would not happen to a Jupiter-like planet at this heliocentric distance)

–Roughly Earthlike N_2 abundance

–Significant sulfur chemistry

- H_2SO_4 clouds at ~1 bar, pyrolyzes to H_2O and SO_3 below ~30 km altitude
- “Surface” visible in telescopes is top of H_2SO_4 clouds
- Venus still active volcanically?

–Surface sampled so far looks like basalt

- Fe, Mg, Al, Si, O
- Some regions yet unsampled suggest very different composition
  - E.g.: Maxwell Montes

Findings at Mars

- –Surface pressure <1/10,000 that at Venus, and much colder
  - But still mostly CO_2
- –*Most of the time*, atmosphere optically thin at radio, IR, & visible; surface easily detected
- –Strongly oxidizing environment; evidence of significant H loss
- –CO_2 condenses seasonally at the north pole (H_2O does at both poles)
  - Large seasonal variations in atmospheric pressure, wind directions & speeds, H_2O content
- –High-speed sun-driven seasonal winds cause planet-scale dust storms
  - Increased atmospheric absorption of sunlight can "inflate" atmosphere
  - Atmosphere becomes optically thick above surface, obscuring it
- –Surface composition varies greatly with location
  - Much Fe, Mg, Al, Si, O in igneous rocks & weathering products
  - Water-processed minerals in sediments: hematite, salts, perchlorate
  - Poles can be covered in H_2O and CO_2 frosts and/or snows

Findings at Jupiter - 1

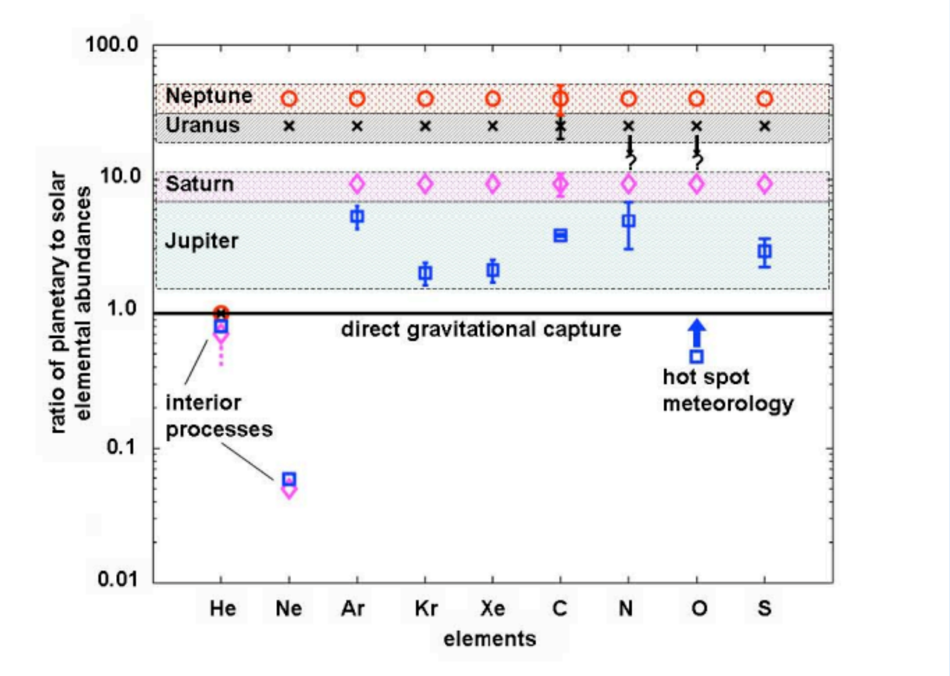
–No surface, so no “surface pressure”; entire planet is gaseous

–Strongly reducing environment; nearly everything is bonded to H

–He abundance very nearly solar (significant error in Voyager rem sens)

–Large number of volatile species (“ices”) in troposphere

- CH_4, H_2O, NH_3, H_2S, minor PH_3
- C, N, O, S all ~4 x solar, ± ~30-40%, *after correcting for hot-spot entry*
  - Expect greater enrichments at Saturn, much greater at ice giants



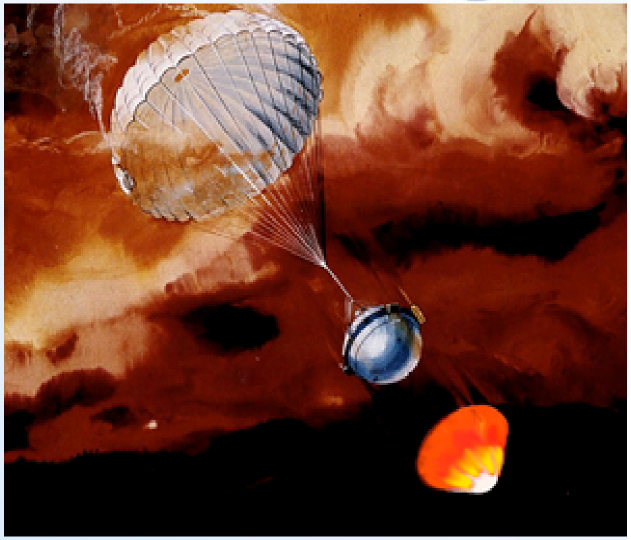
Findings at Jupiter - 2

–Large variations in noble gas abundances

- Suspect interior processes
- Noble gas isotopic ratios close to solar values

–D/H ~$(5 \pm 2) \times 10^{-5}$

- Suggests more D in solar system hydrogen than in local interstellar hydrogen



–D/H & $^{3}He/^{4}He$ consistent with solar conversion of protosolar D to ^{3}He

–Great majority of solar energy deposited above 4-bar level; ~none at 10

- Winds above 3-bar level are slower (150 m/s) than below (>180 m/s)
- Suggests winds are mostly *not* sun-driven

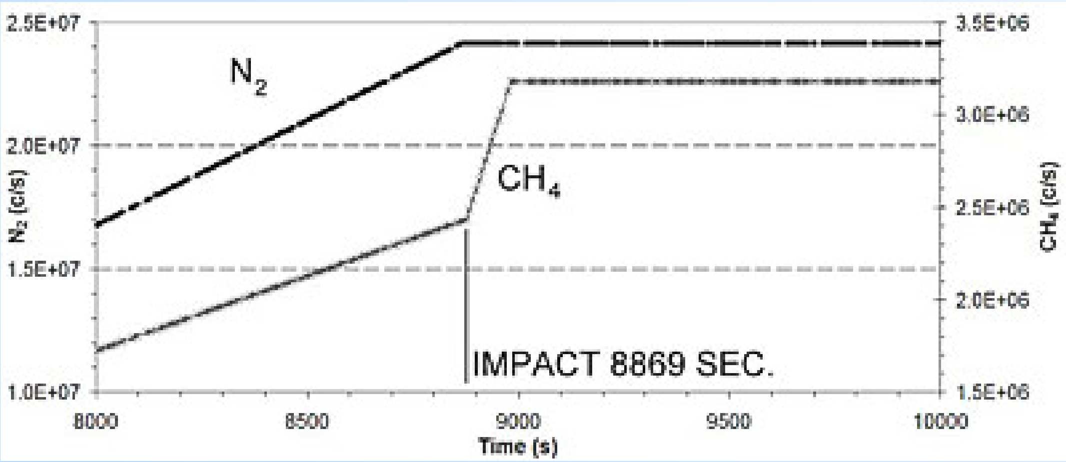
–Stable atmospheric structure

- Lapse rates in 5-15 bar levels average -1.8 K/km; adiabatic would be -1.95
- Would not expect convection in a hot spot

Findings at Titan - 1

–Not a planet; a planet-sized icy satellite w/ deep, extended atmosphere

- Atmosphere ~98% N_2, 1.5% CH_4 except near the surface where it is higher



Huygens landed in *mud* wet with methane and ethane!

–$^{12}C/^{13}C$ implies continuous/periodic replenishment of atmospheric CH_4

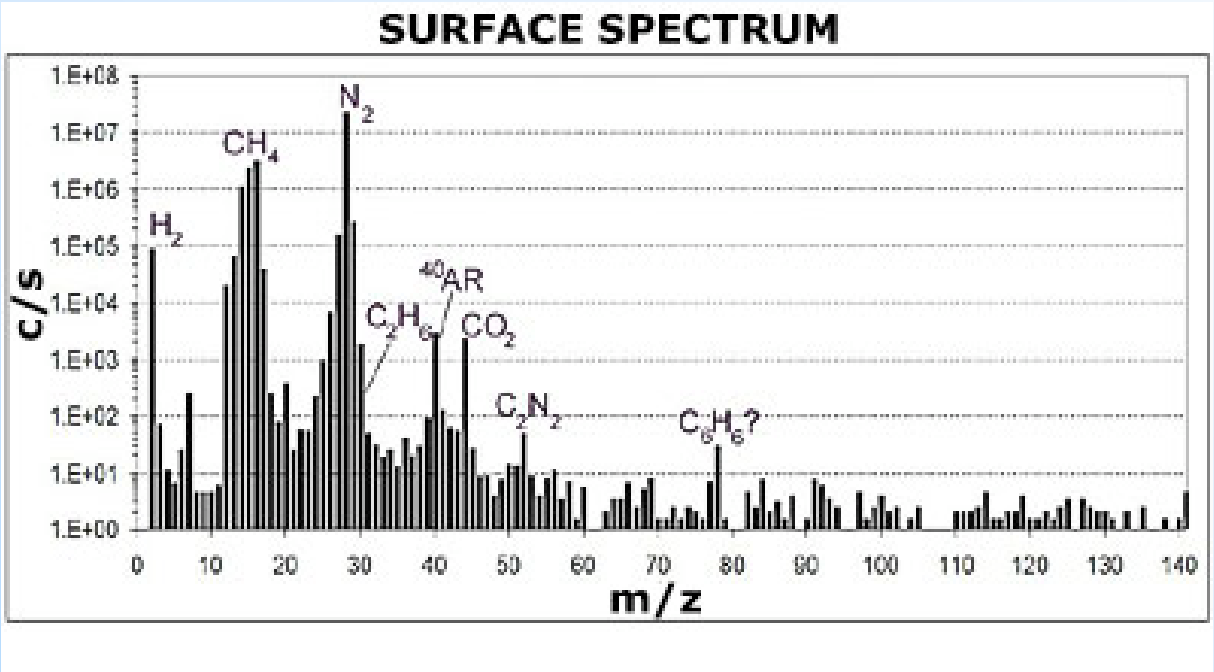
- Suggests Titan might still be geologically active
- Detection of ^{40}Ar also suggests geologic activity
  - Product of rocky interior radioactive decay: ^{40}K -> ^{40}Ar

–Low general abundance of Ar indicates N_2 in atmosphere began as NH_3

- Planetesimal temperatures low enough to bring in N_2 should also bring in Ar

–Absence of detectable quantities of other noble gases is puzzling

Findings at Titan - 2



– Confirmation of complex organic chemistry in atmosphere & on surface!
  - Molecules with C, H, O, & N (astrobiologists take note!)
  - CAS CDA detected organics (single molecules?) w/ mass up to *8,000 Daltons*
– Imager saw a mixed rock-and-sediment surface deeply modified by fluvial activity: erosion, sediment deposition
  - Most likely from methane rain (ethane mixed in?)
  - Rocks are mostly H_2O ice

Where Else Do We Need To Go?

–Saturn

- Compare to Jupiter
- Test solar system formation theories with enriched abundances of ices

–At least one ice giant planet

- Uranus or Neptune
- Much higher enrichments of ices expected (formation theory test)
- CO vertical abundance profile at Neptune could verify interior source of CO

–Triton? Pluto?

- Ice abundances, noble gases, D/H for Kuiper Belt Objects would be key

Questions ?