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-H₂ ratio)
  • Evolutionary processes
    ◦ E.g.: Titan; CH₄ 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

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Findings at Venus

– Verified radio remote sensing: surface hot (730K) & 92 bar pressure
  • Powerful runaway greenhouse from atmosphere that is ~95% CO₂
  • Temperature lapse rates are close to a dry adiabat
– Atmosphere oxidizing, not reducing (typical of terrestrial planets)
– Precious little hydrogen left, very little H₂O
  • 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 N₂ abundance
– Significant sulfur chemistry
  • H₂SO₄ clouds at ~1 bar, pyrolyzes to H₂O and SO₃ below ~30 km altitude
  • “Surface” visible in telescopes is top of H₂SO₄ 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 CO₂
- Most of the time, atmosphere optically thin at radio, IR, & visible; surface easily detected
- Strongly oxidizing environment; evidence of significant H loss
- CO₂ condenses seasonally at the north pole (H₂O does at both poles)
  - Large seasonal variations in atmospheric pressure, wind directions & speeds, H₂O 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 H₂O and CO₂ 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$_2$O, NH$_3$, H$_2$S, 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
- \( \text{D/H} \sim (5 \pm 2) \times 10^{-5} \)
  - Suggests more D in solar system hydrogen than in local interstellar hydrogen
- \( \text{D/H} \) & \( \text{^3He}/\text{^4He} \) consistent with solar conversion of protosolar D to \( \text{^3He} \)
- 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

- $^{12}$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 $\rightarrow$ $^{40}$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

Huygens landed in *mud* wet with methane and ethane!
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 H₂O ice

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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 ?