Atmospheric Chemistry as a Tool for Mars Exploration and Discovery

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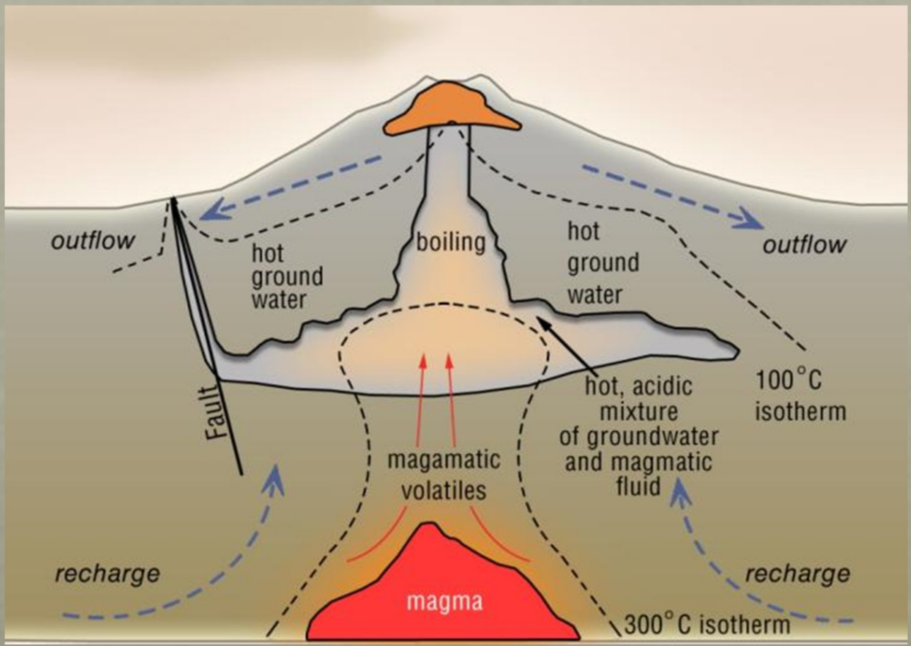
A big question for Solar System exploration

- Mars has long thought to be a cold, dead planet.
- However, new observations open the question

IS MARS ALIVE?

Is Mars alive? Geologically?

- Active geological processes imply extant subsurface habitability

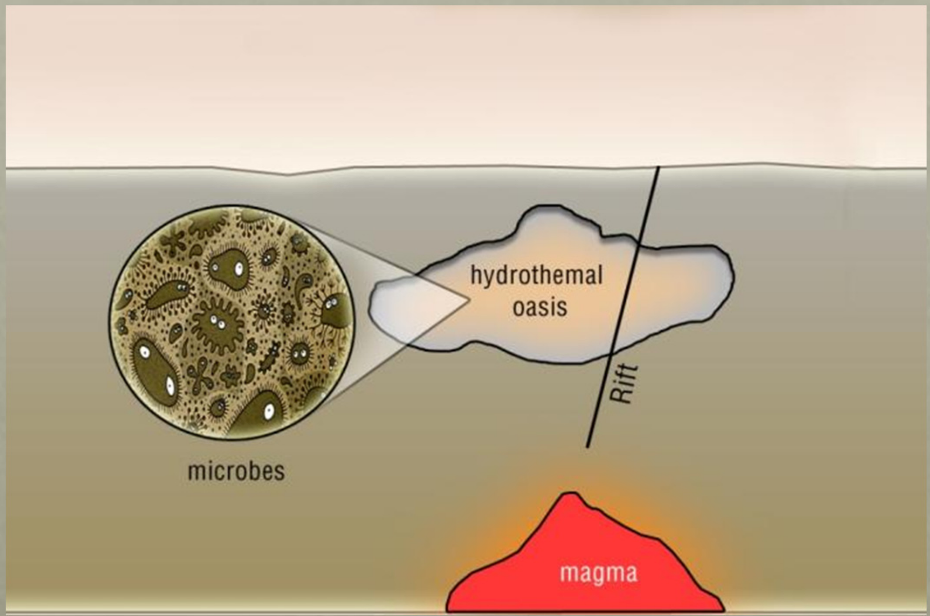


- There is observational evidence for recent volcanic activity
  - Garvin et al. (2000): <1-20 Ma
  - Roberts et al. (2007): < few tens of years ago
- There is observational evidence for recent surface water flows
  - McEwen et al. (2011)

Is Mars alive? Biologically?

- Active geological processes can support extant subsurface life

- Life very persistent if conditions at all hospitable to existence of life
- If Mars ever supported life, there still may exist oases, albeit below surface, habitable and inhabited.



Life detection via atmospheric composition analysis

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Life Detection by Atmospheric Analysis

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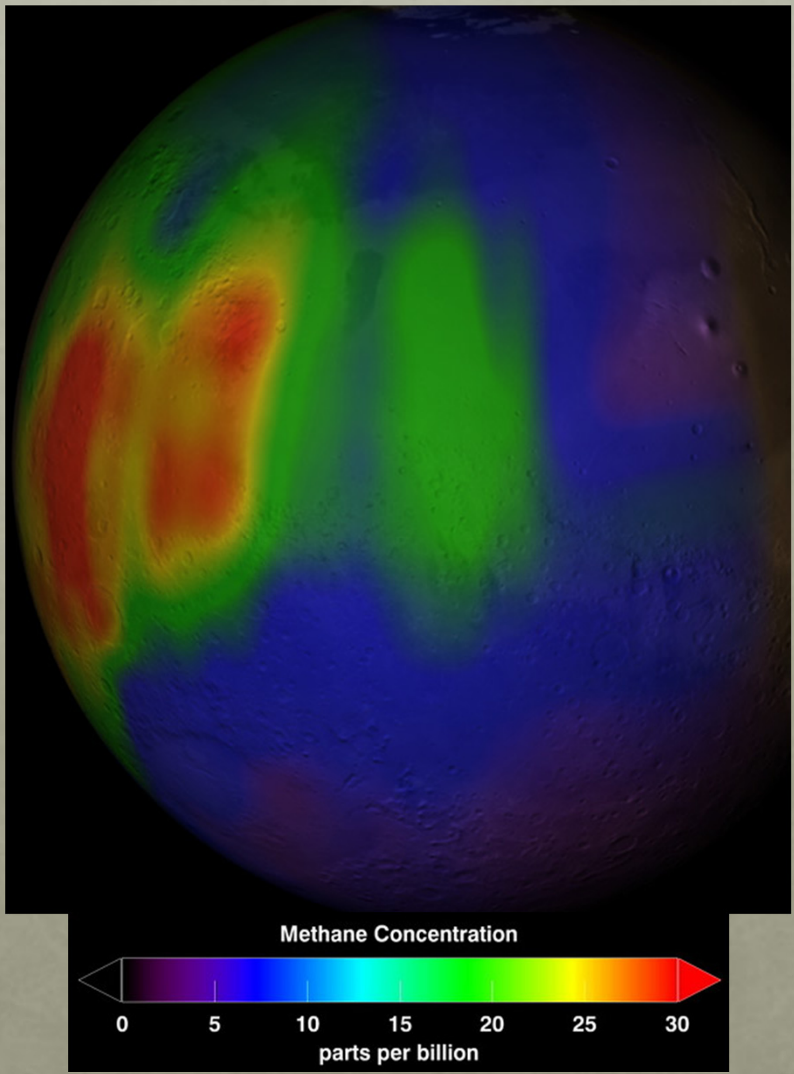
Living systems maintain themselves in a state of relatively low entropy at the expense of their nonliving environments. We may assume that this general property is common to all life in the solar system. On this assumption, evidence of a large chemical free energy gradient between surface matter and the atmosphere in contact with it is evidence of life. Furthermore, any planetary biota which interacts with its atmosphere will drive that atmosphere to a state of disequilibrium which, if recognized, would also constitute direct evidence of life, provided the extent of the disequilibrium is significantly greater than abiological processes would permit. It is shown that the existence of life on Earth can be inferred from knowledge of the major and trace components of the atmosphere, even in the absence of any knowledge of the nature or extent of the dominant life forms. Knowledge of the composition of the Martian atmosphere may similarly reveal the presence of life there.

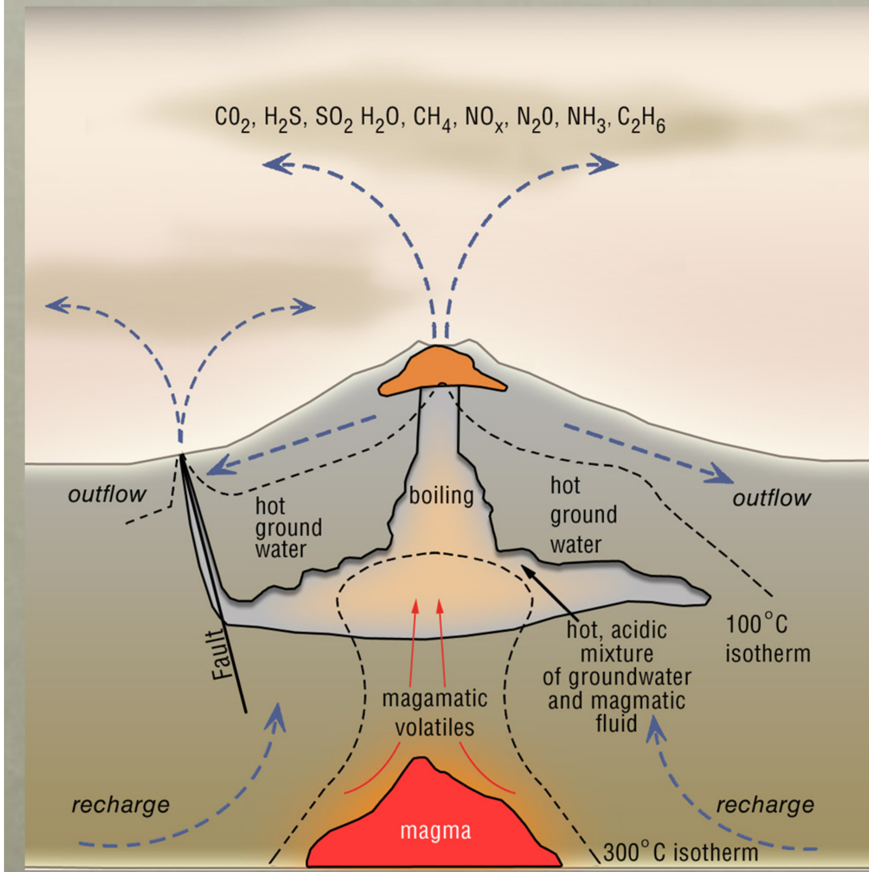
Remote detection of life on another planet was considered over 40 years ago (at JPL in fact) and focused on the analysis of atmospheric composition. Methane was suggested to be a useful atmospheric marker of extant biology.

Modern atmospheric analysis



- Reported detection of methane by Mumma et al. (2009) raises the question of extant active subsurface processes on Mars, heretofore assumed not to be present
- Question: How many different subsurface processes might be active today?
- Search to answer this question not limited to methane: Must necessarily be comprehensive—a broad chemical survey that is global in scale and needs to encompass all climate seasons.

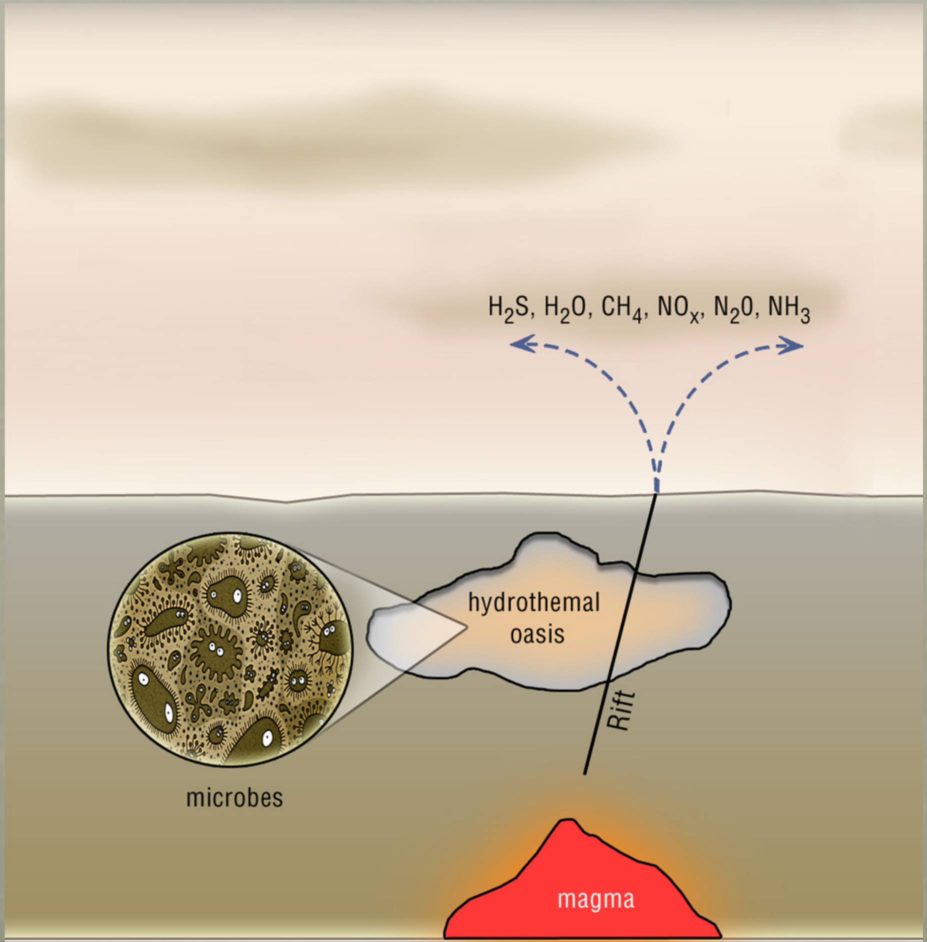
Signatures of geological activity



- Similar to terrestrial counterparts, Martian magmas expected to contain dissolved volatiles that become supersaturated during emplacement in the shallow crust or eruption. Volatiles can be transferred to the atmosphere through several processes:
  - direct degassing
  - degassing into shallow hydrothermal systems
  - interaction of rocks with hydrothermal solutions or ground waters
- Molecular composition of volatiles released from Martian magmas likely differs from terrestrial magmas and will depend on several variables
  - temperature of equilibration
    - high temperature: CO and H_2
    - low temperature: H_2S, S_2, H_2O, CH_4, NH_3
  - pressure of degassing
  - oxidation state
    - oxidized: SO_2

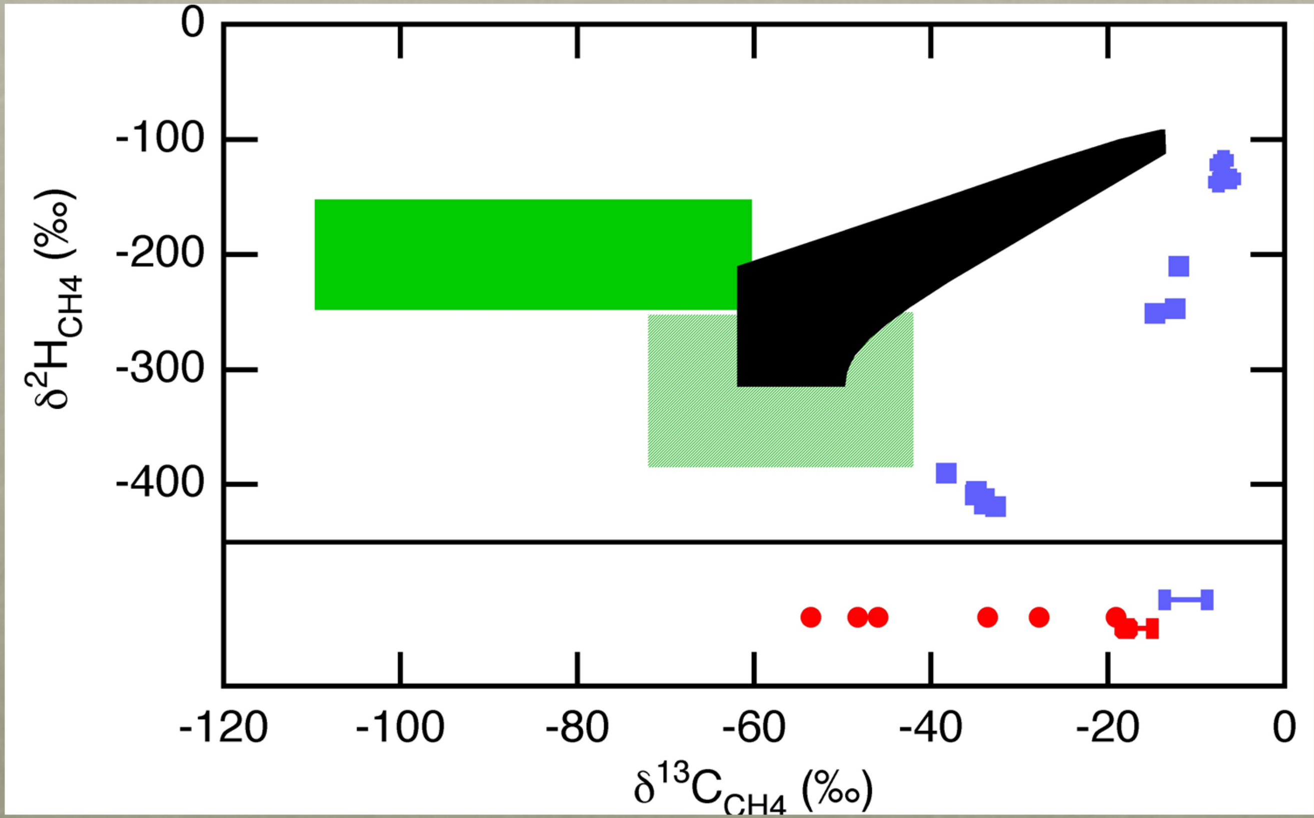
Signatures of biological activity

- Terrestrial microorganisms produce a wide variety of gases as products of both energy-yielding oxidation-reduction (redox) reactions and synthesis and decomposition of organic matter
  - fermentation and anaerobic respiration under strongly reducing conditions: hydrogen-rich compounds, e.g., CH_4, NH_3, H_2S, volatile hydrocarbons, alkylated amines and sulfides
  - nitrogen redox reactions: nitrogen oxides (NO and NO_2), and N_2O
  - thermal decomposition of biogenic sedimentary organic matter: light hydrocarbons
  - microbially-mediated decomposition of sedimentary organic matter using sulfate as an oxidant: H_2S and potentially other reduced sulfur gases



Is methane biogenic or abiogenic?-1

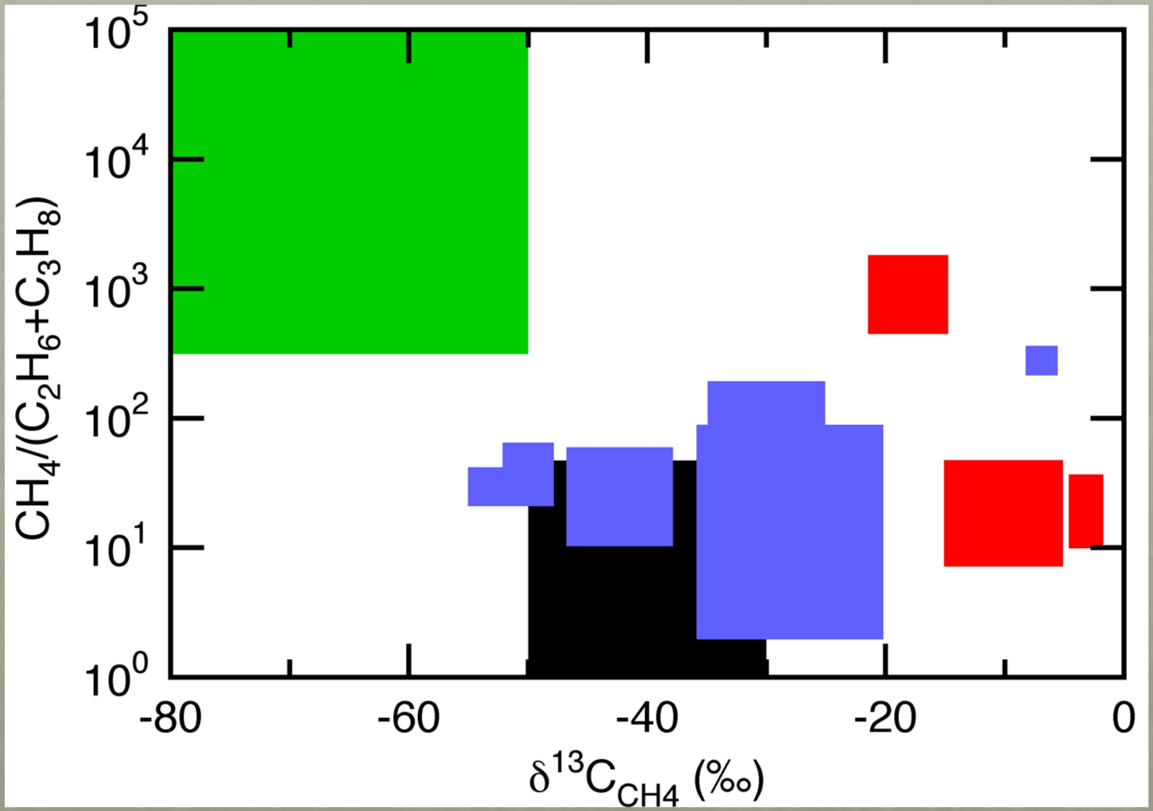
- Ratios of isotopologues can be ambiguous



microbial reduction of CO_2 with hydrogen (dark green), microbial fermentation (light green), thermogenic (black)
hot water-rock (red), cold water-rock (blue)

Is methane biogenic or abiogenic?-2

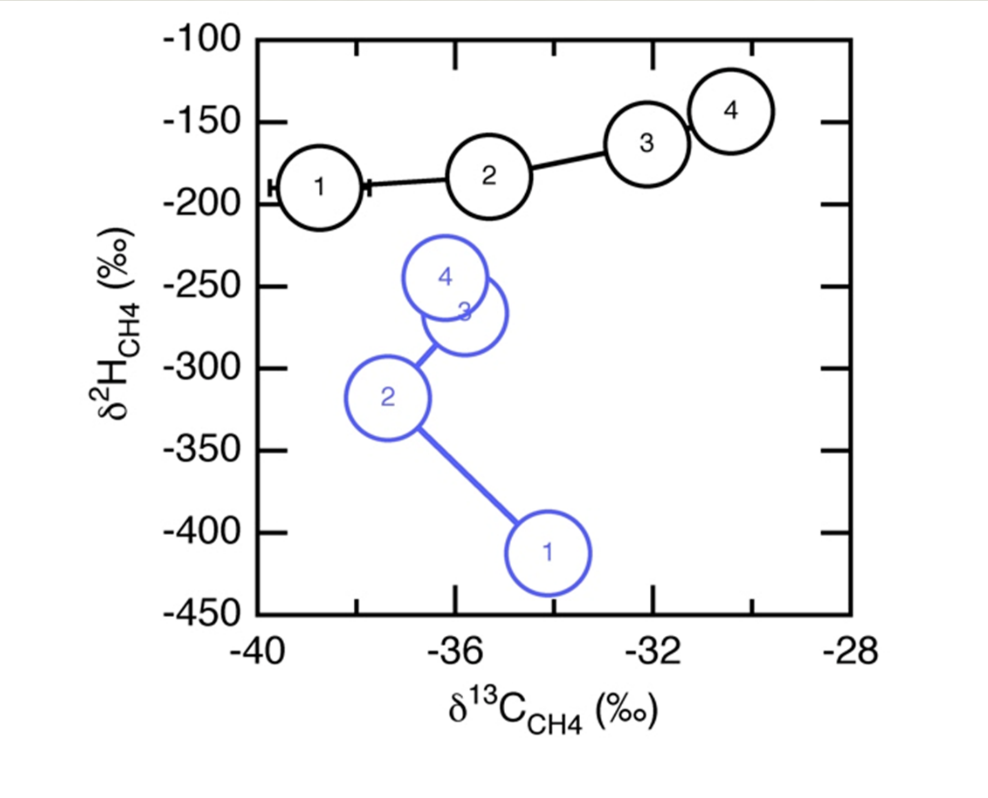
- Ratios of chemical species may be more definitive



microbial reduction of CO_2 with hydrogen (dark green), microbial fermentation (light green), thermogenic (black)
hot water-rock (red), cold water-rock (blue)

Is methane biogenic or abiogenic?-3

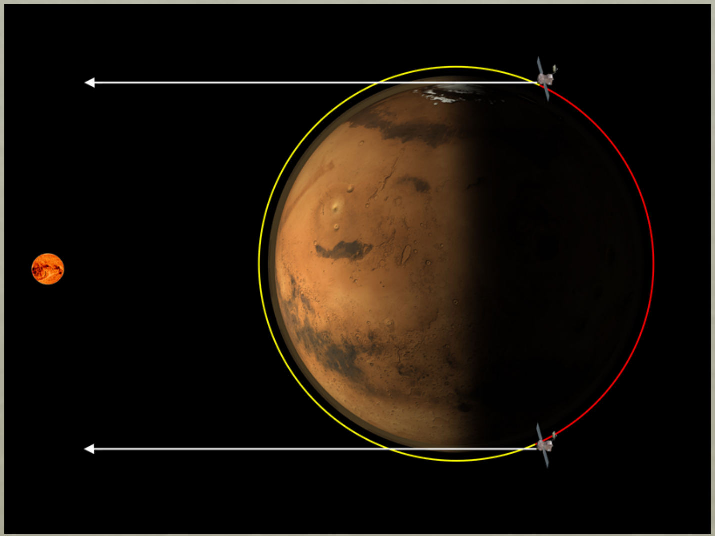
- Isotopic patterns in δ2H and δ13C as a function of alkane carbon number may even be more unique



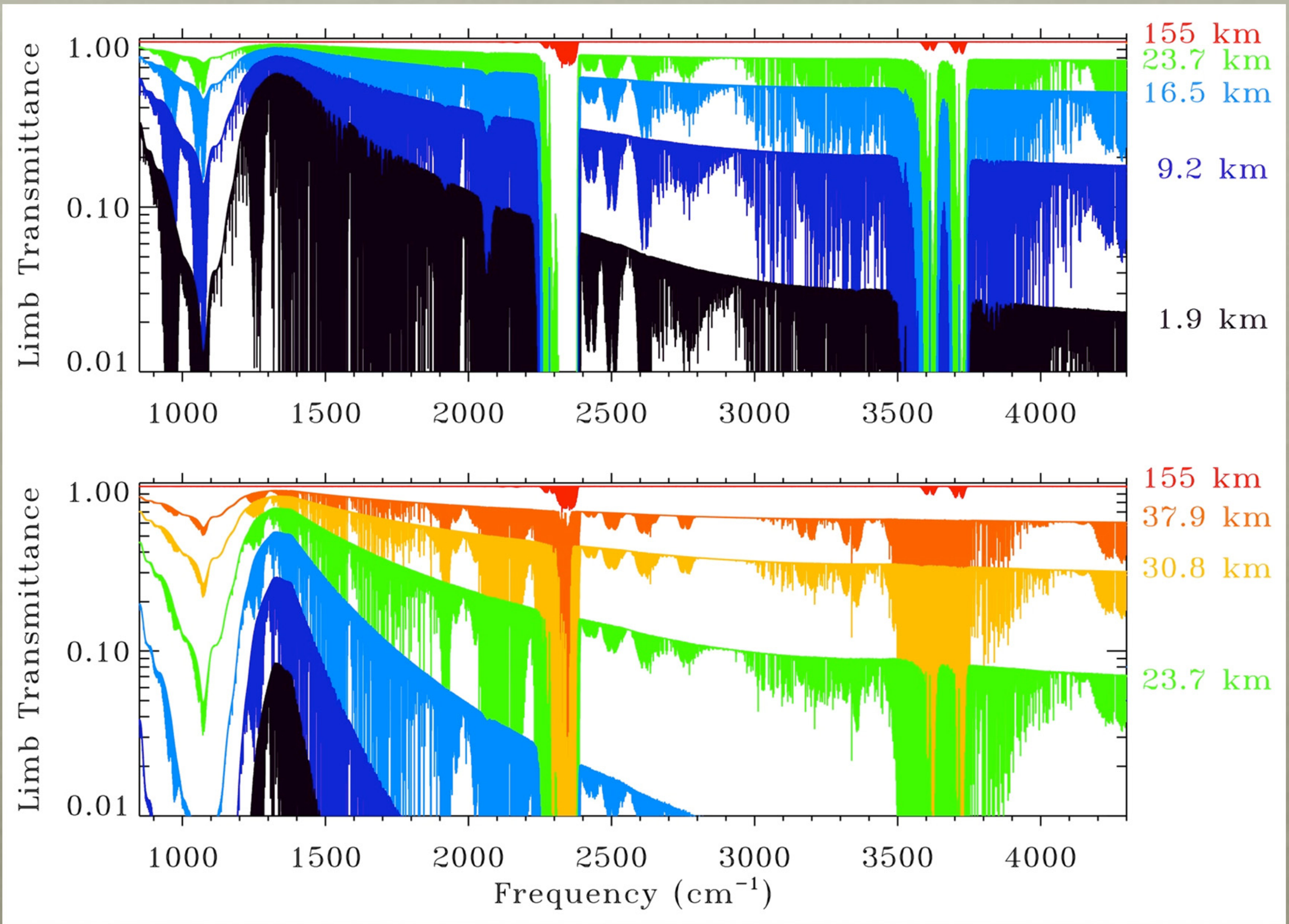
Alkanes derived from thermogenesis (black); abiotic alkanes derived from water-rock reactions (blue)

Solar occultation: signature science measurement

- From an orbiting spacecraft
  - Bright light source
  - Long sample cell
  - 2 latitudes sampled every orbit
- Vertical profiles derived from observing the sun rise and set behind the atmosphere



SIMULTANEOUS MEASUREMENT OF MULTIPLE CHEMICAL SPECIES



Low dust

Moderate dust