

Exploration for Habitability and Life in the Solar System and Beyond: an Earth Analogue

Mark Allen^{1,2*}, Charles Miller¹, Christopher Webster¹, Paul Wennberg²

¹*Jet Propulsion Laboratory, California Institute of Technology*

²*Division of Geological and Planetary Sciences, California Institute of Technology*

*Email: Mark.Allen@jpl.nasa.gov, Voice: 818 354-3665

The chemical composition of Earth's atmosphere is profoundly influenced by the existence of life. Life on another planet might similarly be revealed in the composition of its atmosphere. Recognizing this fundamental concept, NASA's Terrestrial Planet Finder (TPF) will seek to identify signatures of the presence of biological activity in the atmospheres of extrasolar planets. Such signatures may include the presence of biogenic gases in disequilibrium and/or characteristic isotopic markers of life.

Recent geological evidence supports the hypothesis that Mars was once both warm and wet. Such conditions are thought to be conducive to the emergence of life. Given the apparent adaptability of life on Earth, we should not rule out the possibility that life might still exist on Mars. Obviously such a discovery, however remote, would significantly alter our understanding of our place in the universe. A careful examination of the Martian atmosphere with highly sensitive instruments based on the terrestrial experience is in order.

The presence of methane (CH₄) in a primarily oxidized atmosphere has long been considered a possible signature of life. Methane, a component of the Earth's atmosphere produced almost entirely by biological activity, is a classic "disequilibrium" biosignature. The recent tentative detections of methane in the Martian atmosphere by ground-based telescopes and Mars Express have potentially profound implications. There are many possible sources of methane in the Martian atmosphere, some of which are related to extant domains of habitability and some related to the presence of life.

To fully understand the implications of the Mars methane discovery requires drawing from astrophysics, planetary science, and Earth science. An interdisciplinary and multidisciplinary program of research is needed to understand these implications, guide future robotic exploratory activities, and thereby provide an intellectual framework for the search for life in other solar systems. One starting point is the Earth's atmosphere.

- Are there unknown abiotic homogenous gas-phase reactions that can produce or destroy methane?
- Are there yet-to-be-identified abiotic heterogeneous processes on atmospheric dust/aerosols or present at the atmosphere-surface interface that either produce or destroy methane?

To what extent, might the observed methane be introduced from outside the Martian atmosphere or arises from the Martian interior?

Poorly known at present are possible external sources of methane to the Martian atmosphere, which also may operate to some degree in the terrestrial atmosphere. The influx of meteoroids to either atmosphere introduces complex carbon materials, so for both Earth and Mars:

- To what extent is carbon converted to methane during ablation events?

While comets strike planetary bodies intermittently, a cometary impact on Mars a thousand years ago—which can furnish the observed level of methane currently detected—cannot be precluded.

- Would methane from a comet have a distinctive isotopic signature or would other compounds still be present in the Martian atmosphere that would not be "native" to Mars and be indicative of a comet impact in the recent geologic past?

Alternatively, the observed methane could originate from deep within Mars. We could be seeing methane that was trapped in the Martian interior during its accretion. A more likely possibility is that primordial carbon in the Martian interior is being reduced to methane in an extant magma zone and is being degassed from a magmatic finger rising close to the Martian surface. Another likely possibility is that magma created hydrothermal systems in which abiotic chemistry can generate methane.

- To what extent would methane in these scenarios show unique H/D or $^{12}\text{C}/^{13}\text{C}$ isotopologue abundances or would a unique composition of other chemical species be cogenerated?
- How much methane may be degassed from what level of subsurface volcanic or hydrothermal activity?
- What do field studies of terrestrial magmatic zones and hydrothermal systems show about local compositions and isotope abundances?

The methane present in the Martian atmosphere might be leaking out of extant subsurface clathrates that could have been formed in the past from biotic or abiotic processes or are being formed in modern times. But why would methane be leaking out now from these clathrates?

- To what extent were clathrates in the near Mars subsurface stable in the past or are stable during current Martian conditions?

Investigations of terrestrial methane clathrates provide a basis for evaluating clathrate stability on Mars.

If the observed methane arises from the Martian interior, either directly outgassing from extant volcanism or being trapped in clathrates and later released, the presence of methane indicates that Mars was habitable in the past and might reveal extant habitability. If habitable at present, does life then exist on Mars?

So there is the dramatic possibility that the observed methane is biogenic: either the effluent of past life trapped in ice clathrates and leaking out at present, or directly leaking out of extant oases of life.

- From field and laboratory studies of terrestrial biology, what unique H/D or $^{12}\text{C}/^{13}\text{C}$ isotopologue abundance ratios might arise from biotic processes?
- Is there a unique composition of other cogenerated chemical species?

Even if the observed methane is from an abiotic process, it is possible that other, non-methanogenic life forms exist on Mars today and have introduced into the atmosphere other chemical signatures indicative of their subsurface presence.

- What would be potential biosignatures and characteristic isotopologue abundance ratios from other potential Martian lifeforms?

Finally, if any life exists on Mars,

- What amount of gas emission of any biosignature comes from a specific level of biological activity?

Terrestrial studies support the general search for habitable and inhabited extrasolar planets. However the recent observations of methane in the Martian atmosphere provide an immediate motivation for expanding such studies with profound implications for the Vision for Space Exploration.