Oil and natural gas on Mars

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ABSTRACT

On Earth, according to conventional theory, the largest, by mass and volume, identifiable trace of past life is subsurface oil and natural gas deposits. Nearly all coal and oil on Earth and most sedimentary source rocks associated with coal, oil, and natural gas contain molecules of biological origin and is proof of past life. If Mars possessed an Earth-like biosphere in the past, Mars may contain subsurface deposits of oil and natural gas indicating past life. Life might still exist in these deposits. Subsurface oil and natural gas on Mars would probably cause seepage of hydrocarbon gases such as methane at favorable locations on the Martian surface. Further, if Mars contains substantial subsurface life, the most detectable signature of this life on the Martian surface would be gases generated by the life percolating up to the surface and venting into the Martian atmosphere. In this paper, systems that can detect evidence of subsurface oil and gas, including ground penetrating radar and infrared gas sensors are explored. The limitations and future prospects of infrared gas detection and imaging technologies are explored. The power, mass, and volume requirements for infrared instruments able to detect venting gases, especially methane, from an aerobot is estimated. The maximum range from the infrared sensor to the gas vent and the minimum detectable gas density or fraction of the Martian atmosphere – as appropriate for the instrument type – is estimated. The bit rate and bit error rate requirements for transmitting the data back to Earth are also estimated.

Keywords: oil, natural gas, Mars, mass spectrometer, infrared spectrometer, aerobot, rover, methane

1. INTRODUCTION

Finding traces of current or past life on Mars may be extremely difficult. If life never developed to multicellular organisms such as plants or animals, conventional fossils will not be present. It may be difficult to prove beyond a reasonable doubt that fossils of single-celled organisms are biological in origin. Even if fossils exist, nearly all will be buried beneath the surface and thus undetectable. Fossils on the surface will be rare and may have been eroded away by the Martian dust storms, meteorite impacts, and other forces. Neither manned landings nor stationary or slow moving, short range robotic probes such as Mars Pathfinder can explore the surface area of Mars, 144 million square kilometers comprising as much surface area as all the continents and islands of Earth[1]. Even one-centimeter or better resolution optical imaging of the entire surface of the planet either from a high resolution imaging satellite or low altitude aerobots, or even high speed rovers, may be unable to detect past or present life since surviving traces are likely to be beneath the surface of the planet. Excavation or drilling into the surface of Mars can only be undertaken at a few locations and thus will probably miss traces of past or present life unless these traces are extremely common and easily identifiable.

On Earth, according to conventional theory, the single largest, by mass and volume, identifiable trace of past life is subsurface coal, oil, and natural gas deposits, generally believed derived from compressed and degraded dead plants, animals, algae, or bacteria. Nearly all oil on Earth contains molecules of unequivocal biological origin and thus constitutes proof of life. If Mars possessed an Earth-like biosphere at one time in the past, Mars may contain sub-surface deposits of oil and natural gas which would constitute evidence of past life. Life might still exist in these deposits. It has been suggested that Mars once

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supported large bodies of standing water such as lakes or oceans[2,3]. It has also been suggested that Martian meteorites contain evidence of past Martian life, especially single-celled organisms[4]. The ancient Martian oceans may have teemed with single-celled organisms. Prevailing theory attributes crude oil deposits on Earth specifically to prokaryotes, algae and other simple single-celled organisms, trapped in sediments from lakes, rivers, and oceans. Some data and theories suggest that Mars may have been warm and wet as recently as 300 million years ago, within the 400 million year geological time frame of rocks on Earth where most commercial deposits of oil have been found[5]. Evidence for geologically recent groundwater seepage and surface runoff on Mars has recently been reported[6].

An alternate theory, the non-biological theory of oil and gas, holds that oil and natural gas on Earth are derived from primordial hydrocarbons from the initial formation of the Earth[7,8,9,10,11,12]. This theory almost certainly predicts large deposits of oil and natural gas beneath the Martian surface. Some variants of the non-biological theory suggest that life originated in the subsurface hydrocarbon deposits and might also be present in Martian hydrocarbon deposits. In either case, subsurface oil and natural gas on Mars would probably give rise to seepage of hydrocarbon gases such as methane at favorable locations on the Martian surface.

Regardless of whether oil and natural gas can be found on Mars, if Mars contains substantial subsurface life, the most detectable signature of this life on the Martian surface would be gases generated by the life percolating up to the surface and venting into the Martian atmosphere. A search for oil and gas on Mars would probably concentrate on surface emissions of methane. On Earth, essentially all emissions of methane into the atmosphere are attributed to current or past life, primarily the anaerobic decay of recent organic matter[13,14,15].

The reported anaerobic subsurface lithoautotrophic microbial ecosystem (SLiME) in the Columbia River Basalt Group is frequently suggested as a model for subsurface life on present day Mars[16]. The archaebacteria in the Columbia River Basalt Group are believed to produce substantial amounts of methane from hydrogen (H_2) and carbon dioxide (CO_2). The hydrogen is thought derived from reactions between water and ferrous silicates in the basalt. Natural gas was commercially exploited at the Columbia River Basalt Group early in the twentieth century. The origin of this natural gas is uncertain. The basalt is volcanic rock, not sedimentary rock, and has negligible organic content. Thus, natural gas would not be expected based on conventional theory. It has been suggested that this natural gas derived from the methanogenic archaebacteria. A subterranean ecosystem similar to the Columbia River Basalt ecosystem would seem likely to produce surface seeps of methane.

Oil fields on Mars would be an excellent place to seek surviving life. Oil and natural gas would provide unoxidized carbon fuel for bacterial life. On Earth, methanotrophic bacteria have been found at oil seeps and have even been found as symbiotic bacteria in the tissues of marine invertebrates living near seeps[17]. On Earth, thermophilic bacteria and hyperthermophilic archaea have been found growing, even thriving, in several oil reservoirs[18,19,20,21,22]. It is not clear if these bacteria derive from recent contamination from injection of oil production fluids, from burial of bacteria with the original sediments, or some other source. It is clear these bacteria can live in oil fields and utilize crude oil for food. Mars appears to contain large quantities of iron oxides, primarily various forms of Fe_2O_3, that provide loosely bound oxygen that could be used to oxidize the hydrocarbon fuel[23]. Since any oil is likely to have originated from microbial Martian life, some of this life may have survived within the oil deposits.

Petroleum frequently shows optical activity where the plane of polarization of polarized light is rotated when passed through the fluid. This indicates a preference for one handedness or chirality of the complex hydrocarbons in oil. This is a characteristic of biology and absent in fluids of non-biological origin. Some petroleum exhibits a clear preference for molecules with an odd number of carbon atoms over those with an even number. This effect may be due to the breakdown of biological substances. Most petroleum contains molecules such as phytane, pristane, and hopanoids of probable or unequivocal biological origin. Large quantities of hopanoids that appear to be derived from biohopanoids such as bacteriohopanetetrol have been found in most oils and coal. Geohopanoids, derivatives of the hydrocarbon hopane ($C_{30}H_{52}$) have been found in every sediment or fossil fuel that has been analyzed for them. Biohopanoids are major constituents of the membranes of prokaryotes, single cell organisms without a nucleus, such as algae and bacteria[24,25]. They are not used in the membranes of eukaryotes such as plants and animals. This strongly suggests that oil derives from simple single-celled organisms, rather than plants or other complex organisms, that would have existed early in the history of the Earth and might have developed on Mars before the warm and wet conditions disappeared. Hopanoids trapped in sedimentary rocks have been proposed as a biomarker for detecting past life on Mars and other planetary bodies[26].

Of the 20 kg/cm^2 of surface area of carbon on Earth, about one fifth, 4 kg/cm^2 is estimated to be in subsurface hydrocarbon deposits[27]. Since the amount of oil, natural gas, and other subsurface deposits of hydrocarbons is vast, far exceeding the quantity of carbon incorporated in current surface life, the geological and chemical processes that convert biological matter into oil, natural gas, and other hydrocarbons must be simple and ubiquitous. To account for the great quantity of oil and natural gas and the widespread distribution through all eras and types of rocks, no special kinds of life or unusual geological conditions can be evoked. If the biological theory of oil and natural gas is correct, almost certainly any biological debris buried and pressure cooked for several million years will convert to oil, natural gas, or other common subsurface hydrocarbon deposits. This conversion is also likely to have occurred on Mars and other planetary bodies if life developed there.

Oil on Earth is generally thought to be geologically young because oil is thermodynamically unstable when subjected to elevated temperatures over long periods of time in open systems[28]. It is believed that oil deposits at temperatures in the region of 100 − 150° C, the range at which oil is believed to be generated, degrade into natural gas, primarily methane, over geological time periods. Some observations, experiments, and theories contradict this and suggest that oil can be stable for billions of years at 150° C [29]. Almost all petroleum production on Earth comes from rocks younger than 400 million years[30]. However, commercial oil and gas fields exist in Proterozoic (Precambrian) rocks in the former Soviet Union, Oman, and China[31,32,33,34,35]. The oldest known oil occurs in rocks 1,650 million years old in the McArthur Basin of northern Australia[36]. However, oil has recently been reported preserved in inclusions in Archaean sandstones dating back about 3,000 million years from the Superior craton, Canada, the Kaapvaal craton of southern Africa, and the Pilbara craton, Australia [37]. Although oil is rare in Precambrian rocks on Earth, kerogen, a graphitized material often associated with oil and gas and believed to be the precursor or remains of the precursor of oil and gas, is common[38]. The Precambrian kerogen has a deficiency of the ^{13}C isotope believed to indicate biological origin. Kerogen and molecular fossils of cellular and membrane lipids have been reported in 2,700 million year old shales from the Pilbara Craton, Australia[39].

Evidence exists that hydrocarbon generation by thermal maturation of biogenic kerogen was extensive in Archaean sedimentary basins[40]. Similar processes may have occurred on an ancient warm and wet Mars. Whether oil and other hydrocarbons produced on an ancient wet and warm Mars could survive to the present is unclear. Much of the surface of Mars is thought to be of great age. The Noachian system, covering most of the Southern Hemisphere, which contains the most extensive and convincing evidence of water is thought to date to circa 3.8 billion years ago[41]. Rocks of such age are extremely rare on Earth, e.g. the Isua rocks in Greenland. On Earth, such rocks were buried by sedimentation and ground up by plate tectonics processes. Any oil deposits that formed on the ancient Earth presumably converted to natural gas within a few hundred million or billion years as burial raised temperatures and pressures to the point where oil converts to gas. The natural gas probably migrated upwards into more recent sediments or outgassed to the surface in the absence of a caprock, leaving only the solid kerogen and the membrane lipid biomarkers frequently found in the Precambrian sedimentary rocks. Mars however lacks most signs of plate tectonics. Volcanic activity on Mars is thought to have been much less than on Earth[42]. Burial of ancient rocks through sedimentation appears to have been much less extensive than on Earth. On Mars, hydrocarbon deposits formed billions of years ago may have survived near the surface.

2. PROSPECTING FOR OIL AND NATURAL GAS ON MARS

Ground penetrating radar and trace gas detectors may be able to detect subsurface deposits of oil and natural gas on Mars. In principle, ground penetrating radar can directly probe beneath the surface of Mars and may be able to detect oil and gas reservoirs as anomalous reflections of radar signals. Trace gas detectors can detect, determine the chemical composition, and measure the concentration of gas seeps. Trace gas detectors include infrared detectors and mass spectrometers.

2.1 GROUND PENETRATING RADAR

Ground penetrating radar, either mounted on orbiting satellites or mobile surface or near-surface platforms, may be able to see beneath the surface of Mars and detect oil fields or gas fields. Ground penetrating radar detects subsurface features through reflections caused by changes in the dielectric permittivity of the ground. An orbiting Mars Subsurface Radar Mapper has been proposed[43]. The Mapper would be powered by a 6.0 kWe Topaz II nuclear reactor and operate at 20 MHz. It is estimated to be able to see 180 – 375 meters into the surface. The Mapper was designed primarily to look for subsurface ice. Ice has a dielectric constant similar to the Martian regolith and the radar was estimated to be unable to unambiguously identify a sub-surface feature as ice. Subsurface ice would be tentatively identified based on the shape of the sub-surface features. The Mapper could probably detect an oil field and possibly gas fields on Mars. However, it seems likely that it would be unable to unambiguously identify the sub-surface feature as oil, rather than water, ice, or a density variation. Hydrocarbons have a dielectric permittivity in the range of 2.0 to 3.0, similar to both water ice and the Martian regolith, making unambiguous identification of oil or gas reservoirs extremely unlikely. Further the Martian regolith appears to contain large amounts of iron in various forms. The iron and iron oxides on Mars are likely to interfere with ground penetrating radar in unpredictable ways. Ground penetrating radar appears to be a poor means to locate oil and gas reservoirs on Mars. Surface seeps of methane and other hydrocarbons seem to be the most promising detection method.

2.2 SURFACE SEEPS OF OIL AND NATURAL GAS

On Earth, oil and natural gas were initially found through surface seeps of oil and natural gas. Natural gas, primarily methane, is frequently associated with other subsurface hydrocarbon deposits such as oil and coal. This method does not require drilling, excavation, or other methods that are impractical on Mars. This method is also likely to preferentially find large deposits near the surface that will be the easiest to study.

Prolific natural hydrocarbon seepage occurs offshore of Coal Oil Point in the Santa Barbara Channel, California[44]. Both oil and natural gas seep at this location. It is estimated that natural seeps off Coal Oil Point introduce about 50 to 70 barrels (approximately 8,000 to 11,000 liters) of oil per day into the Santa Barbara Channel[45]. There have been large seeps of natural gas at this location. Oil companies established seep tents that have typically collected 30,000 m^3 (1,050,000 cubic feet) of natural gas per day since 1983. The seep tents are steel pyramids covering 1900 m^2 of sea floor. The mass emission rate at the seep tents is about 0.34 kg/second. Coal Oil Point is one of the larger and best documented surface seeps of both oil and natural gas. Surface seeps seem to exhibit a log normal distribution on Earth[46]. Most seeps tend to be small. However, the large seeps dominate and are the source of the bulk of natural gas emitted into the atmosphere. A mission to Mars would initially seek a large easily identifiable seep such as the Coal Oil Point seep.

Detection of gas seeps, methane or otherwise, on Mars would require a thorough survey of the planet by long range robotic rovers, long duration balloons, or long-endurance Mars Aircraft unless far higher spatial resolution trace gas detectors for Mars satellites are developed. Several mobile robotic missions have been proposed[47,48]. The percentage of the Martian surface that a probe can cover depends on the surface speed of the probe, the maximum range from the probe to a detectable gas seep, and the duration of the mission. To set the scale, a mission duration of 100 days is chosen. A surface speed of 1-10 meters/second would be typical of a long duration rover or a balloon driven by the Martian winds. A surface speed of 100 m/sec would correspond to a long-endurance Mars aircraft.

Table 1. Coverage of Mars Surface by Gas Seep Probes

Surface Speed	**Maximum Range to Gas Seep**	**Square Kilometers Covered in 100 Day Mission**	**Percentage of Martian Surface**
1 m/sec	100 m	1,728	0.0012 %

10 m/sec	100 m	17,280	0.012 %
100 m/sec	100 m	172,800	0.12 %
1 m/sec	1,000 m	17,280	0.012 %
10 m/sec	1,000 m	172,800	0.12 %
100 m/sec	1,000 m	1,728,000	1.2 %
1 m/sec	10,000 m	172,800	0.12 %
10 m/sec	10,000 m	1,728,000	1.2 %
100 m/sec	10,000 m	17,280,000	12.0 %

The maximum range to a surface seep will be determined by the minimum detectable concentration (MDC) of the gas sensor, the gas flux at the seep, and the dispersion of the gas in the Martian atmosphere. An additional important design parameter for mobile probes is the response time or averaging time of the gas sensor. A fast moving probe will need a response time less than the duration that the probe is within range of the seep. The dispersion will be governed by the mean wind velocity in the region of the seep and turbulent diffusion in the Martian atmosphere. Continuous surface seeps are considered because transient releases are unlikely to be detected. The minimum detectable concentration (MDC) of a trace gas sensor will be expressed in parts per billion (ppb) by volume or mole fraction at standard atmospheric temperature and pressure (STP) on Earth. One part per billion by volume or mole fraction at STP is roughly a concentration 1×10^{-9} kg/m^3. The average density of the Martian atmosphere is about 0.016 kg/ m^3.

Atmospheric dispersion of trace gases has been extensively studied both theoretically and experimentally on Earth. The most common model for transport and diffusion of a neutrally buoyant or passive gas cloud from a continuous source is a Gaussian plume model.

$$C / Q = 1 / (\pi \sigma_y \sigma_z \mu) \exp(-(y - y_0)^2 / 2 \sigma_y^2) \exp(- h^2_p / 2 \sigma_z^2) \quad (1)$$

where C is the concentration of gas and Q is the mass emission rate (kg/sec) for a continuous plume. μ is the wind velocity. x is the distance along the wind. $(y - y_0)$ is the crosswind distance from the cloud axis. h_p is the vertical elevation. σ_y is the standard deviation of the lateral distribution of gas concentration. σ_z is the standard deviation of the vertical distribution of gas concentration. On Earth, σ_y and σ_z are functions of the along wind direction x. The functions vary with atmospheric conditions and the local environment, such as rural versus urban conditions[49]. Mars winds have typical speeds of 6-8 meters per second[50]. A design value of 20 meters per second is frequently used since Martian winds rarely exceed 20 meters per second[51].

A Gaussian plume model has implications for searching for gas seeps on Mars using point or open path trace gas detectors. With a point detector, the probe must pass through the gas plume to detect the gas. With an infrared open path detector, the path of the beam from the source to the detector must pass through the plume to detect the gas. A Gaussian model means that the concentration of the gas will be high within a few standard deviations of the main axis of the plume. Beyond this, the concentration drops off rapidly. It is necessary for the sensor to traverse the core of the plume to detect the gas. Secondly, the higher the altitude of the probe, the further down wind from the gas source the probe must pass to detect the gas and the more sensitive a trace gas detector must be to detect the gas. For example, a rover on the surface will be able to detect the seep by passing directly over the seep. An airplane at 500 meters elevation could not detect a plume if it flew directly over the source unless the Martian winds had subsided long enough for the plume to diffuse to 500 meters. At 500 meters elevation, the probe would probably need to be several thousand meters downwind of the seep to traverse the core of the plume and detect the gas (see Figure 1). A wind sensor able to measure the speed and direction of the Martian winds during the measurements would greatly enhance the ability of a probe to locate the source of the gas plume.

Figure 1 shows the gas concentration in parts per billion of Earth atmosphere at standard temperature and pressure with a gas mass emission rate of 0.34 kg/sec, an ambient wind of 8 meters per second, a sensor at an altitude of 500 meters, and $\sigma_y = 0.04 \times x$ and $\sigma_z = 0.04 \times x$. This is representative of an airplane. Figure 2 shows similar results for an altitude of 100 meters, a low flying plane or balloon. Figure 3 shows the results for an altitude of 1 meter, a rover.

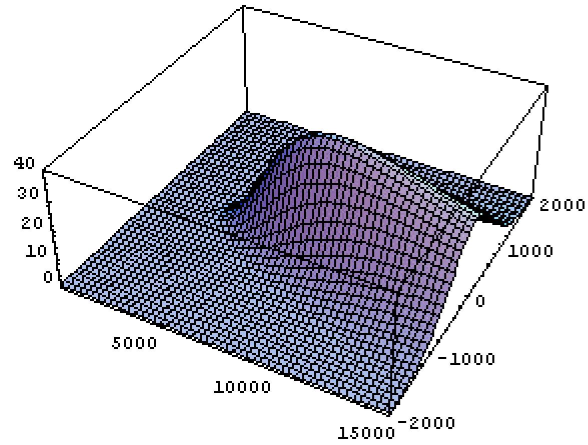

Figure 1. Gas Concentration at 500 Meters (Airplane)

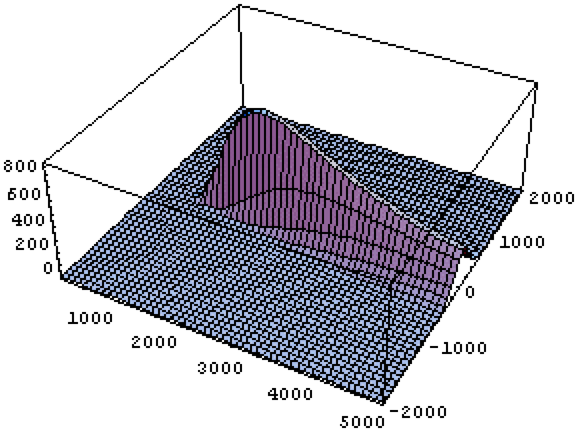

Figure 2. Gas Concentration at 100 Meters (Balloon).

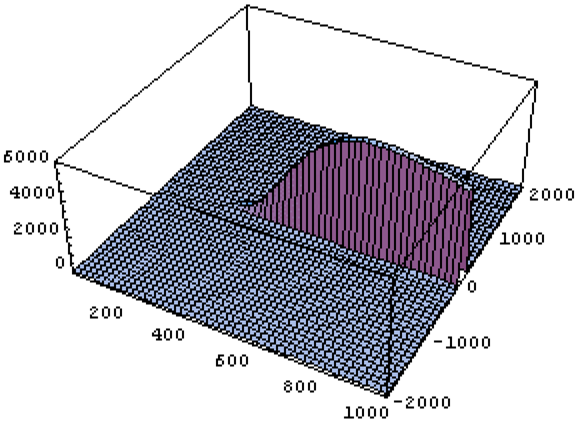

Figure 3. Gas Concentration at 1 Meter (Rover)

Thus, a trace gas sensor with a sensitivity in the tens of parts per billion can detect a gas seep at considerable distance – from hundreds to thousands of meters – and an altitude of hundreds of meters if necessary. The effectiveness of the probe increases exponentially with decreasing altitude. The optimum search strategy appears to be for the probe to traverse Mars perpendicular to the direction of the Martian wind.

The ideal probe would be able to navigate to the source of the gas plume, the surface seep, once a gas plume was detected. A wind sensor giving the speed and direction of the Martian wind would probably make this easier. A video camera would allow the probe to visually inspect the surface seep and observe transient phenomena such as bubbles, eruptions, or disturbances of the Martian dust associated with the seep. A video camera might be able to locate oil on the Martian surface. Oil on the surface is likely to be very short lived due to the ultraviolet light, the oxidizing properties of the Martian soil, and the low pressure of the Martian atmosphere. The ideal probe would contain a sensor such as a gas chromatograph able to detect and identify the hopanoids or other molecular fossils of cellular membranes either in oil on the surface or in the Martian rocks at the seep. The detection of hopanoids would likely be accepted as unequivocal proof of past life on Mars.

2.3 TRACE GAS DETECTORS

Mass spectrometers (MS) and integrated gas chromatograph mass spectrometers (GCMS) have traditionally been used to determine the composition of planetary atmospheres including trace gases. The Viking lander missions to Mars, for example, used a GCMS with a sensitivity in the parts per billion. In addition to proven designs, many compact, lightweight, very low power mass spectrometers are under development for future space missions.

Most compounds other than simple diatomic molecules such as molecular hydrogen (H_2) have characteristic infrared absorption lines in the range of 2 to 5 microns. Methane has an absorption line at 3.3 microns. Many organic molecules and other gases of interest such as hydrogen sulfide have nearby absorption lines. This forms the basis of a variety of infrared gas sensors. Currently these sensors are used to detect dangerous gas leaks in factories, on oil wells, and other settings. Some sensors are used or under development for detecting and measuring atmospheric pollutants and trace gases in the atmosphere.

Trace gas detectors come in three families: point detectors, open path detectors, and remote sensors. Point detectors sample the atmosphere at the location of the probe. A typical point detector will contain a gas cell that the atmosphere circulates through. The trace gas concentration is measured in the gas cell. Open path detectors contain either an infrared source that projects an infrared beam and an infrared detector that are separated by an open path through the atmosphere or an infrared source, a retroreflector (a mirror that reflects the projected infrared beam back to the source), and a detector adjacent to the source that measures the reflected infrared beam. Open-path detectors can measure the integrated trace gas concentration along the path of the beam. Both point detectors and open path detectors rely on turbulent diffusion of trace gases in the Martian atmosphere to detect trace gas sources, typically surface seeps, at a distance from the sensor. In addition, the ambient Martian winds, typically 6-8 meters/second, will carry the gas plume downwind.

Active remote sensors rely on backscatter of infrared light from the trace gas clouds. The intensity of the backscattered infrared varies depending on whether the infrared has the characteristic absorption frequency of the gas. Such sensors can directly probe the trace gas concentration at the surface and at a distance from the sensor. A passive sensor such as an ultra-sensitive infrared imaging array would rely on differential absorption of infrared light from natural sources such as the Sun or the Martian surface. Table 2 lists a number of commercial and laboratory gas detectors.

Table 2. Trace Gas Detectors

Technology	**Size**	**Weight**	**Power**	**MDC**	**Response Time**
Difference Frequency Generation	45 cm by 45 cm by 12 cm	25 Kg	60 W	23 ppb (CH_4)	2.1 seconds

(DFG) Infrared Sensor[52]					
Rosemount Analytical Non-Dispersive Infrared Analyzer Model 880A (IR lamp with IR frequency filter)[53]	22 cm by 48.3 cm by 48.3 cm	25 Kg	150 W	1 ppm	0.5 – 20 seconds
Aircraft (ER-2) laser infrared absorption spectrometer (ALIAS)[54]	200 cm by 50 cm by 50 cm (at least)	72 Kg	400 Watts (at least)	50 pptv	10- 30 seconds
European Spectrometry Systems (ESS) ecoSys-P (Man Portable Mass Spectrometer System)[55]	53 cm(W) by 45 cm (H) by 23 cm (D)	26 Kg	170 Watts	2 ppb (standard) 2 ppt (with TDS) for Volatile Organic Compounds	100 msec (capillary) 1 second (membrane) 90 sec (TDS)
Viking Lander Gas Chromatograph – Mass Spectrometer (GCMS)[56,57]	much less than 100 cm by 100 cm by 100 cm	much less than 600 Kg (total weight of Viking)	much less than 140 W (total power of Viking)	10-50 ppm (on Mars? means 100 – 500 ppb on Earth)	At least 10.24 seconds (time for one mass spectrometer scan)
Viking Instruments Corporation Spectra Trak 672[58]	14 in (H) by 21 in (W) by 32 in (D)	145 lbs	1,300 W (startup) and 1,000 W (during analyses)	Down to low ppm for direct injection Down to 5 ppb for air preconcentration	Direct injection, soil vapor 10-15 minutes
Galileo Probe Mass Spectrometer Experiment[59]	18.4 cm (Diameter) by 37 cm (Length)	13.2 Kg	13 W (instrument) 12 W (pumps and heaters)	10 ppmv H_2O 1 ppbv (Kr, Xe) 100 – 500 more sensitive for hydrocarbons *with sample enrichment*	Nominal 75 second scan (2 – 150 amu); 0.5 seconds per mass step

A robotic mission such as a rover, balloon, or airplane would probably require a smaller, lightweight trace gas sensor than the current state of the art trace gas detectors. A variety of small, light, low-power mass spectrometers are under development. A group at Johns Hopkins University and the University of Maryland has developed a small time of flight (TOF) mass spectrometer, TinyTOF, with a size of 30 cm by 15 cm by 15 cm, a weight of 5 Kg, and a power dissipation of 50 Watts for medical applications[60]. A group including Mahadeva Sinha at Jet Propulsion Laboratory is developing a MS with a weight of 1 Kg and a power dissipation of 2 Watts[61]. Another group at JPL including Ara Chutjian is developing a MS with dimensions of 4 in. by 6 in. by 8 in. and a weight of 1.1 Kg. Other researchers at JPL have proposed a MS with a mass of only 0.6 Kg[62]. The MS for the Cassini-Huygens Gas Chromatograph – Mass Spectrometer has a target minimum detectable concentration of 10 ppb[63]. The COSAC Gas Chromatograph and Hi-resolution TOF Mass Spectrometer has a planned weight of 4.3 Kg (2 Kg for MS alone) and a power dissipation of 15 Watts (10 Watts for MS alone)[64]. Miniaturized solid-state Fourier Transform Infrared Spectrometers (FT-IR) and gas chromatographs with volumes of less than 2 cm^3 have recently been reported[65,66]. It seems likely that compact, lightweight, portable single-chip or few chip trace gas sensors can be developed for Mars missions in the next few years. Such instruments would also be useful for oil and gas prospecting on Earth, monitoring trace gases for safety purposes, and monitoring environmental releases of trace gases.

The bitrate requirements for point and open-path trace gas detectors are modest. If the trace gas detector takes one measurement each second and each measurement consists of a spectrum of 256 samples, a typical size for a mass spectrometer spectrum, with 16 bit samples, the total bitrate will be 16×256 or 4096 bits per second. One measurement per second is certainly reasonable for a rover or balloon travelling a few meters per second. Airplanes may require a higher rate of measurements. This bitrate is well within current Mars to Earth bit rates. Remote trace gas sensors such as scanning IR lasers or IR imaging arrays mounted on mobile probes may have substantial bitrate requirements, such as megabits per second. The usual Mars to Earth design bit error rate (BER) of 10^{-5} should be acceptable for point and open-path detectors. This equates to an error in 1 out of 25 spectra. If the error does not occur on a peak in the spectrum, the error should be easily identifiable and can be ignored.

3. CONCLUSION

A trace gas sensor for high-speed robotic Mars probes such as rovers, balloons, or airplanes will probably need to meet the following parameters. For mobile probes, the response time of the instruments becomes an important design parameter.

SIZE: 1000 cm^3
WEIGHT: 2 kg
POWER: 20 Watts
RESPONSE TIME: 1 second
MINIMUM DETECTABLE CONCENTRATION (MDC): 10 ppb (ppt preferred) of Earth atmosphere at standard temperature and pressure (STP)
BITRATE: 4096 bits per second
BIT ERROR RATE: 10^{-5}
TARGET GASES: CH_4 (required), other hydrocarbon gases, H_2S, H_2O

The altitude of a point or open-path trace gas detector is a major determinant of the likelihood of detecting a gas seep. A surface probe such as a rover will have the best chance of detecting a gas plume. A probe travelling perpendicular to the wind direction will be able to achieve maximum coverage of the Martian surface. These results suggest either a rover on the surface or a balloon with a guide wire dropping near the surface would have the best chance of locating a gas seep. A balloon could carry either a point gas sensor at the end of the guide wire or an open-path detector with a retroreflector at the end of the guide wire. The balloon would need some mechanism such as a sail or small propeller to achieve motion at a significant angle to the wind direction. A surface or near-surface probe may be able to detect gas seeps at a range of several thousand meters downwind of the seep.

A wind sensor able to measure the speed and direction of the Martian wind would greatly enhance the ability of a probe to locate the source of a gas plume once detected. A video camera on the probe would permit visual inspection of the seep and detection of transient phenomena such as bubbles, eruptions or disturbances of the Martian dust associated with the seep. The video camera might also be able to locate oil or other hydrocarbons on the surface at the seep. The ideal probe would have a means to unambiguously identify hopanoids or other molecular fossils of cellular membranes in the rocks or in any hydrocarbons at the seep. The detection of hopanoids would probably be accepted as proof of past life on Mars.

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