METHANE ON MARS: MEASUREMENTS AND POSSIBLE ORIGINS. Michael J. Mumma[1], Geronimo L. Villanueva[2], Robert E. Novak[3], Yana L. Radeva[2], H. Ulrich Kaufl[4], Alan Tokunaga[5], and Therese Encrenaz[6], and Paul Hartogh[7], [1]NASA-Goddard Space Flight Center USA 20771 (michael.j.mumma@nasa.gov), [2]NASA-GSFC (geronimo.l.villanueva@nasa.gov), [3]Iona College (rnovak@iona.edu), [4]European Southern Observatory (hukaufl@eso.org), [5]University of Hawaii (tokunaga@ifa.hawaii.edu), [6]Observatoire de Paris (therese.encrenaz@obspm.fr), [7]Max Planck Institute – Solar System Research (hartogh@linmpi.mpg.de).

Introduction: The presence of abundant methane in Earth's atmosphere (~1.6 parts per million) requires sources other than atmospheric chemistry. Living systems produce more than 90% of Earth's atmospheric methane; the balance is of geochemical origin. On Mars, methane has been sought for nearly 40 years because of its potential biological significance, but it was detected only recently [1-5]. Its distribution on the planet is found to be patchy and to vary with time [1,2,4,5], suggesting that methane is released recently from the subsurface in localized areas, and is then rapidly destroyed [1,6].

Before 2000, searchers obtained sensitive upper limits for methane by averaging over much of Mars' dayside hemisphere, using data acquired by Mars-orbiting spacecraft (*Mariner 9*) and Earth-based observatories (Kitt Peak National Observatory, Canada-France-Hawaii Telescope, *Infrared Space Observatory*). These negative findings suggested that methane should be searched at higher spatial resolution since the local abundance could be significantly larger at active sites. Since 2001, searches for methane have emphasized spatial mapping from terrestrial observatories and from Mars orbit (*Mars Express*).

Results: The first definitive detections and spatial maps were achieved using high-dispersion infrared echelle spectrometers at three ground-based observatories (NASA's IRTF, W. M. Keck Observatory, and Gemini South). To 2006, we detected four spectral lines of the CH_4 ν_3 band near 3.3 µm, along with H_2O and HDO [1,5,7]. Our observational campaign resumed in August 2009, using CRIRES/VLT along (Table 1). For the first time, image correction was employed using adaptive optics (AO) at Keck and at VLT-UT1.

For a typical observation, the spectrometer's long entrance slit is held to the central meridian of Mars (Fig. 1, right) while spectra are taken sequentially in time. For each snapshot in time, spectra are acquired simultaneously at contiguous positions along the entire slit length, sampling latitudinally resolved spatial footprints on the planet (35 footprints, for the geometry shown in Fig. 1). Successive longitudes are presented as the planet rotates, and the combination then permits partial mapping of the planet. Our study of methane on Mars now extends over five Mars years, sampling a wide range of seasons (L_s) with significant spatial coverage. Here, we present absolute extractions of methane for our database spanning 1999-2006 and a brief snapshot of preliminary results from the recent campaign (Table 2).

A series of such measurements taken in Mars' Northern Summer 2003 found that methane varied significantly in abundance over the surface of Mars, and in time (Fig. 2) [1,5]. In 2005, additional active regions were found in early Southern Spring [5].

In Northern summer, methane was notably enriched over several localized areas (Fig. 2): A (East of Arabia Terra, where water vapor is also greatly enriched), B_1 (Nili Fossae), and B_2 (southeast quadrant of Syrtis Major). The combined plume contained ~19,000 metric tons of methane, and the estimated source strength ($\geq$ 0.6 kilogram per second) was comparable to that of the massive hydrocarbon seep at Coal Oil Point in Santa Barbara, California. By vernal equinox about one-half the released methane had been lost. When averaged over latitude and season, spectral data from *Mars Express* also imply an enhancement in methane in this longitude range [4].

Unusual enrichments of hydrated minerals (phyllosilicates) were identified in Nili Fossae from Mars Express, and from the Mars Reconnaissance Orbiter (Fig. 2). The observed morphology and mineralogy of this region suggests that these bedrock outcrops, might be connecting with reservoirs of buried material rich in volatile species. The characteristic arcuate ridges in the southeast quadrant of Syrtis Major were interpreted as consistent with catastrophic collapse of that quadrant, perhaps from interaction with a volatile-rich substrate. This collapse could provide conduits connecting the substrate with the atmosphere.

The most compelling results from these searches are: 1) the unambiguous detection of multiple spectral lines of methane, 2) Evidence for spatial variations that imply active release in discrete regions, and 3) Evidence for seasonal variations that imply a CH_4 lifetime of months rather than the 300-plus years implied by photochemistry. The short lifetime may be the result of reaction with strong oxidants such as peroxides located in the soil and/or on airborne dust grains [1,6,8].

The possible origins of Mars methane will be discussed in the context of geologic and biologic terrestrial analogues. Mars-analogue sites on Earth range from sub-permafrost zones that might be accessed seasonally at scarp faces, to tundra sites where its release from the near-surface photic zone is activated thermally. Key measurements needed to test its origin on Mars (biotic vs. abiotic) include fractionation (hydrogen, carbon) among isotopologues, abundance ratios of methane homologues (C_nH_{2n+2}), and tests of other possible biomarker gases (e.g., H_2S, N_2O, NH_3).

Instruments on the ExoMars-Trace Gas Orbiter mission, intended for launch in early 2016, target these measurements. Meanwhile, we targeted many of these gases in the 2009-2010 campaign, and will continue to do so in future years.

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Current Campaign: Completed runs – 2009B

Dates	Instrument	Mode	Diameter arc-sec	Velocity km/s	Season L_s
19 - 24 Aug	CRIRES	AO	5.6"	- 9.7	325°
05 -10 Sept	CRIRES	AO	6.0"	-10.6	334°
29 Oct - 1 Nov	CRIRES	AO	7.8"	-13.8	1.9°
6 – 7 Nov	CSHELL	–	8.2"	-13.8	5.4°
10 - 11 Nov	NIRSPEC	non-AO	8.5"	-13.8	7.3°
19 - 23 Nov	CRIRES	AO	9.2"	-13.9	11.7°
23 Nov	CSHELL	–	9.4"	-13.9	13.6°
25 Nov	CSHELL	–	9.4"	-13.9	14.5°
1 - 2 Dec	NIRSPEC	non-AO	10.0"	-13.5	17.4°
11 - 12 Dec	NIRSPEC	AO	10.8"	-12.6	22°
12 -15 Dec	CSHELL	–	11.0"	-12.3	23°
15 - 16 Dec	NIRSPEC	non – AO	11.1"	-12.2	24°

Current Campaign: Completed runs – 2010A

Dates	Instrument	Mode	Diameter arc-sec	Velocity km/s	Season L_s
27 - 28 March	CSHELL	–	9.6"	14.5	69°
29 March	NIRSPEC	non-AO	9.5"	14.6	70°
3 - 4 April	NIRSPEC	AO	9.0"	14.9	73°
13 - 14 April	*CRIRES*	*AO*	*8.3"*	*15.3*	*77°*
24 - 25 April	NIRSPEC	non-AO	7.6"	15.4	82°
27 April	NIRSPEC	non-AO	7.5"	15.4	83°
1 – 2 May	*CRIRES*	*AO*	*7.25"*	*15.3*	*85°*
6 - 7 May	CSHELL	–	7.0"	15.2	88°
12 - 13 May	*CRIRES*	*AO*	*6.7"*	*15.0*	*90°*
1 – 2 June	*CRIRES*	*AO*	*6.0"*	*14.1*	*99°*
8 - 9 June	CSHELL	–	5.7	13.7	102°

Table 1. Mars Trace Gas Campaign August 2009 – June 2010.

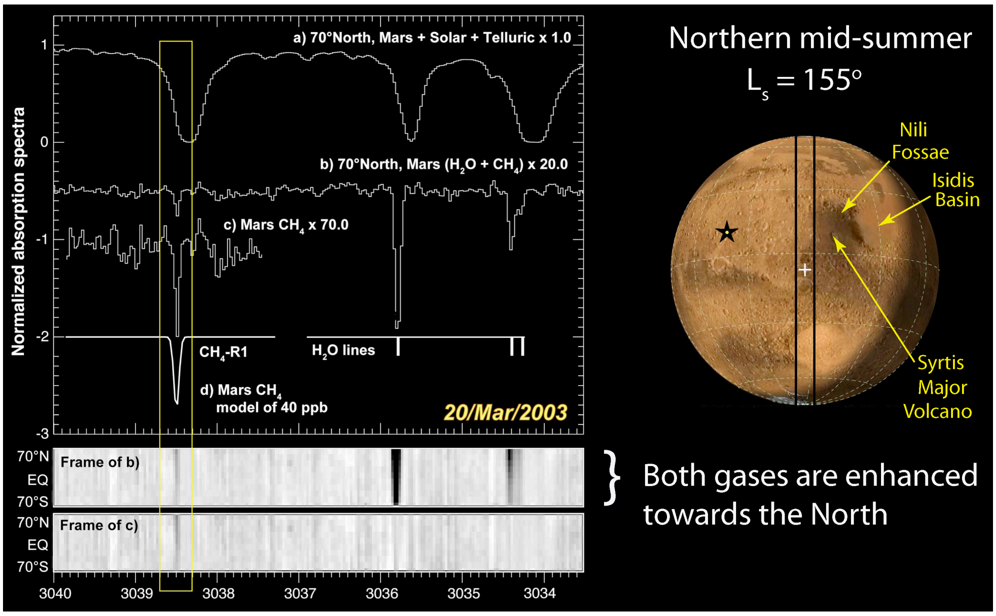

Figure 1. Right. Mars' aspect in March 2003; sub-solar (☆) and sub-Earth (+) points are marked. The spectrometer entrance slit (CSHELL/IRTF) is shown to scale (vertical lines). Spectra were acquired simultaneously for 35 spatial footprints along the slit. **Left.** The spectrum at 70° N latitude (top). (b, c) Spectral signatures of Mars methane (CH_4) and water (H_2O) after subtraction of terrestrial and solar signatures. Spectral lines of water (three lines) and methane (one line) are strongest in the northern hemisphere (frame of 'b'). The latitudinal distribution of methane alone appears after subtracting a synthetic model of H_2O (frame of 'c').

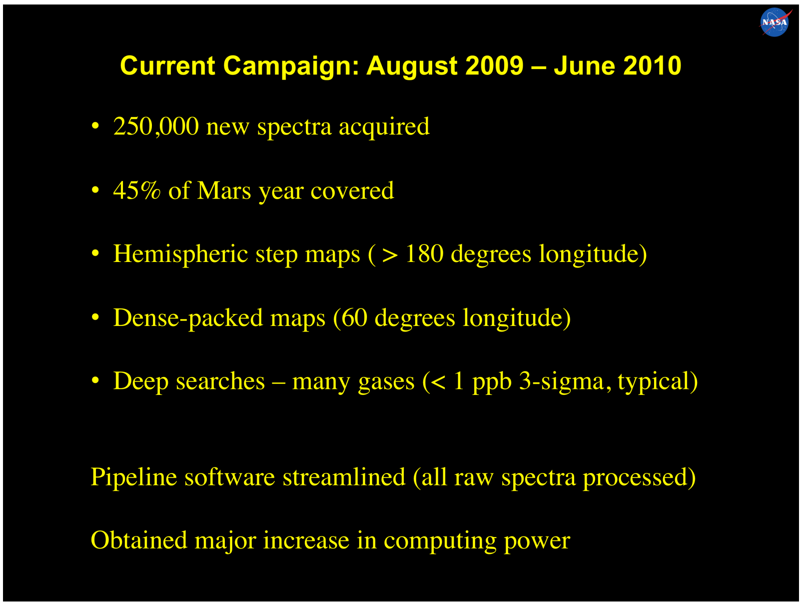

Table 2. Overview of Mars Trace Gas Campaign August 2009 – June 2010.

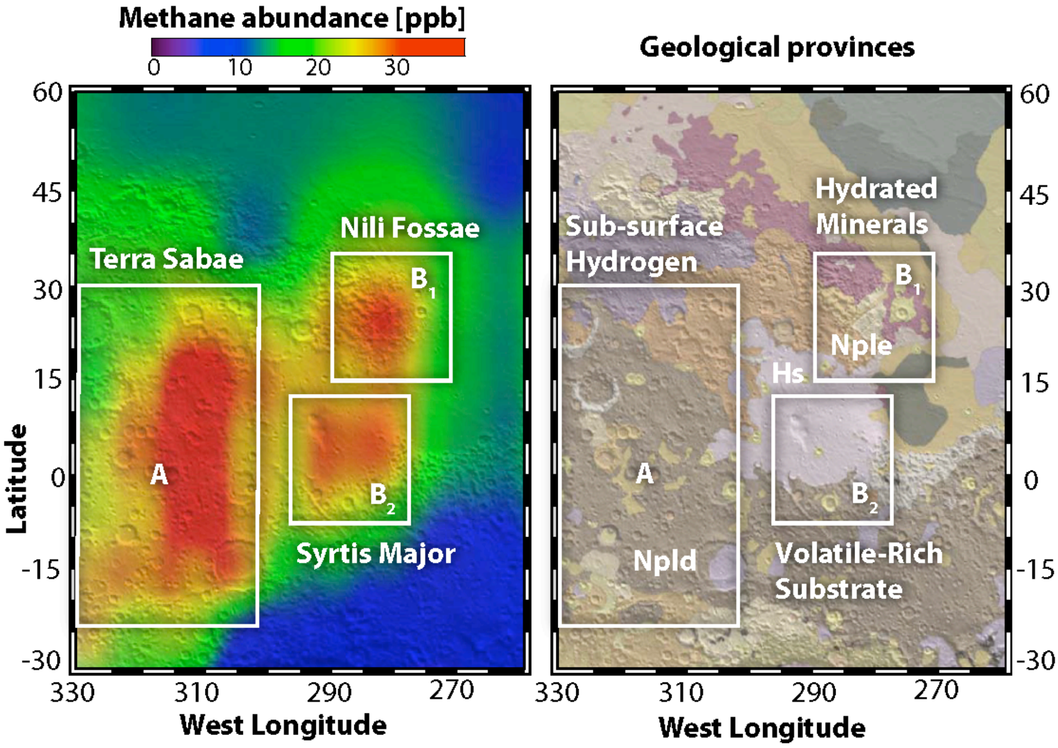

Figure 2. Regions where methane appears notably localized in Northern Summer (A, B_1, B_2), and their relationship to mineralogical and geo-morphological domains. **Left.** Observations of methane near the Syrtis Major volcanic district. Region A (Terra Sabae) is rich in sub-surface hydrogen, B_1 (Nili Fossae) displays minerals that formed in water, and B_2 (southeast quadrant of Syrtis Major shield volcano) overlaps a region that appears to have collapsed. **Right.** Geologic map (Greeley and Guest) superimposed on MOLA topographic shaded-relief. Distinct terrain types are coded by color. The most ancient terrain [dissected (Npld) and etched (Nple) plateau material] is Noachian in age (~3.6 - 4.5 billion years old, an era when Mars was wet), and is overlain by volcanic deposits of Hesperian age (light grey) from Syrtis Major (Hs, ~3.1 - 3.6 billion yrs old). After [1].