

# Mars Trace Gas Mission Science Rationale & Concept

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Presentation to the NRC Decadal Survey  
Mars Panel

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## Background (1 of 2)

### MEPAG Science Analysis Group Activities (2006-2007)

- Science Analysis Group (SAG-1), chaired by C.B. Farmer  
*Strategic Mission to study atmospheric photochemistry and aeronomy, following up on Solar System Exploration Decadal Survey recommendation*  
⇒ **MAVEN and TGE selected to compete for 2011 launch as a Mars Aeronomy Scout**
- Science Analysis Group (SAG-2), chaired by W. Calvin  
*Defined 3 mission concepts, one of which was a Trace Gas mission to follow up on potential exchanges of methane between the atmosphere and subsurface, implying a dynamic Mars with the possibility of a biochemistry*  
⇒ **NASA forms Science Definition Team for a Mars Science Orbiter focused on trace gas detection and mapping**

### 2013 MSO Science Definition Team (SDT)

- Telecons/meetings October–December 2007
- Final written report January 2008  
⇒ **Aeronomy Mars Scout (MAVEN or TGE) slipped to 2013 launch**
- Report to MEPAG February 2008  
⇒ **MAVEN selected for launch in 2013**

## Background (2 of 2)

### 2016 MSO SDT Telecon Update:

⇒ *Earth-based observations confirm methane detection, report variability*

- Focused on minimum payload required to follow up on reported methane discoveries, for possible low-cost NASA mission or joint ESA-NASA mission
- Telecon held February 17, 2009
- Briefing to NASA MEP and to MATT-3

### ESA-NASA discussions on Joint 2016 Mission (2009)

Joint Instrument Definition Team (JIDT) studies Trace Gas instruments for ExoMars orbiter/carrier; re-affirms need for both detection of broad suite of gases in atmosphere and mapping of key trace gases

⇒ *Earth-based observations confirm methane detection, report variability*

⇒ *ExoMars slips to 2018 opportunity*

Study of joint mission combining Trace Gas orbiter with technology drop-off package is initiated (August, 2009)

## Agenda

- Science Rationale & Objectives for a Trace Gas Mission
- A Mission Concept (NASA only) to Achieve those Objectives

# What Science Questions are Raised by Methane Detection?

*Current photochemical models cannot explain the presence of methane in the atmosphere of Mars and its reported rapid variations in space and time. Neither appearance nor disappearance can be explained, raising the following scientific questions:*

- Is there ongoing subsurface activity?
    - Are there Surface/near-Surface Gas Reservoirs (particularly ice)? Where are they?
  - What is the nature of gas origin: geochemical or biochemical?
    - Are other trace gases present? What are the isotopic ratios?
    - Nature of the methane source requires measurements of a suite of trace gases in order to characterize potential biochemical and geochemical processes at work
  - What processes control the lifetimes of atmospheric gases?
    - Time scales of emplacement or activation and modification (seasonal, annual, episodic, longer term)
    - Role of heterogeneous chemistry: reactions on surface or airborne dust and ice
    - Atmospheric-surface exchange and atmospheric transport
- ⇒ ***What is the inventory, transport, and photochemistry of the Mars atmosphere? Note: It's not just about methane!***

## A Trace Gas Mission must provide:

- A *comprehensive survey of both known gases* ( $\text{H}_2\text{O}$ ,  $\text{H}_2\text{O}_2$ ,  $\text{CO}$ , etc.), as well as to *improve detection limits by an order of magnitude or more* on gases not yet observed.
- A *definitive statement* about whether or not methane is still present in the atmosphere and characterize whatever variability it has. However, a detailed inventory of atmospheric gases and their isotopologues will be a *major advance* in our understanding of the recent history and climate of Mars *whether or not methane is detected*.
- Characterization of the *roles that aerosols and temperature play* in controlling atmospheric composition.
- All atmospheric fields required (temperature, density/pressure, wind, aerosol concentration) to enhance our ability to *understand and to simulate for science and engineering* the Mars atmosphere.

# Atmospheric Composition

*Atmospheric evidence for present habitability*

## Key measurement objectives:

Photochemistry ( $\text{H}_2\text{O}_2$ ,  $\text{O}_3$ ,  $\text{CO}$ ,  $\text{H}_2\text{O}$ )

Transport ( $\text{CO}$ ,  $\text{H}_2\text{O}$ )

Isotopic Fractionation (isotopomers of  $\text{H}_2\text{O}$  and  $\text{CO}_2$ )

Surface exchange ( $\text{CH}_4$  and  $\text{H}_2\text{O}$ )

Inventory ( $\text{HO}_2$ ,  $\text{NO}_2$ ,  $\text{N}_2\text{O}$ ,  $\text{C}_2\text{H}_2$ ,  $\text{C}_2\text{H}_4$ ,  $\text{C}_2\text{H}_6$ ,  $\text{H}_2\text{CO}$ ,  $\text{HCN}$ ,  $\text{H}_2\text{S}$ ,  
 $\text{OCS}$ ,  $\text{SO}_2$ ,  $\text{HCl}$ )

## Measurement goals:

Solar occultations to obtain sensitivity of 1–10 parts per trillion

Limb-geometry mapping at sensitivity of 1–10 parts per billion with  
latitude/longitude/altitude/local time coverage

⇒ Will significantly improve knowledge of atmospheric composition  
and chemistry

⇒ Could lead to identification of source regions

## Atmospheric State

*Climate processes responsible for seasonal / interannual change*

### Key measurement objectives:

Wind velocity

Water vapor and atmospheric temperature without influence of dust

Diurnal coverage of all parameters

Vertical profiles of all parameters

Continue climatology monitoring

### Measurement goals:

2-D wind velocity, temperature, aerosol optical depth, water vapor at

5 km vertical resolution over broad height range

diurnal coverage twice per martian season

85% or better coverage along orbit

⇒ Extend record of climatology to characterize long-term trends

⇒ Validate and significantly improve models of transport and state



## Surface Change Science

*Recent processes of surface-atmosphere interaction*

### Key measurement objectives:

Geologic context of potential localized trace gas sources  
Aeolian features (dust devil tracks, streaks, dust storm changes)  
Gullies, avalanches, dune motions  
Formation of small impact craters over time

### Measurement goals:

1 meter resolution sufficient for these goals

- ⇒ Understanding active processes and the role of volatiles
- ⇒ Exchange of volatiles between high latitudes and atmosphere

# *Trace Gas Measurement Objectives*

## **Detection:**

- Would require very high sensitivity to the following molecules and their isotopomers: H<sub>2</sub>O, HO<sub>2</sub>, NO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, C<sub>2</sub>H<sub>2</sub>, C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, H<sub>2</sub>CO, HCN, H<sub>2</sub>S, OCS, SO<sub>2</sub>, HCl, CO, O<sub>3</sub>
- Detection sensitivities of 1-10 parts per trillion

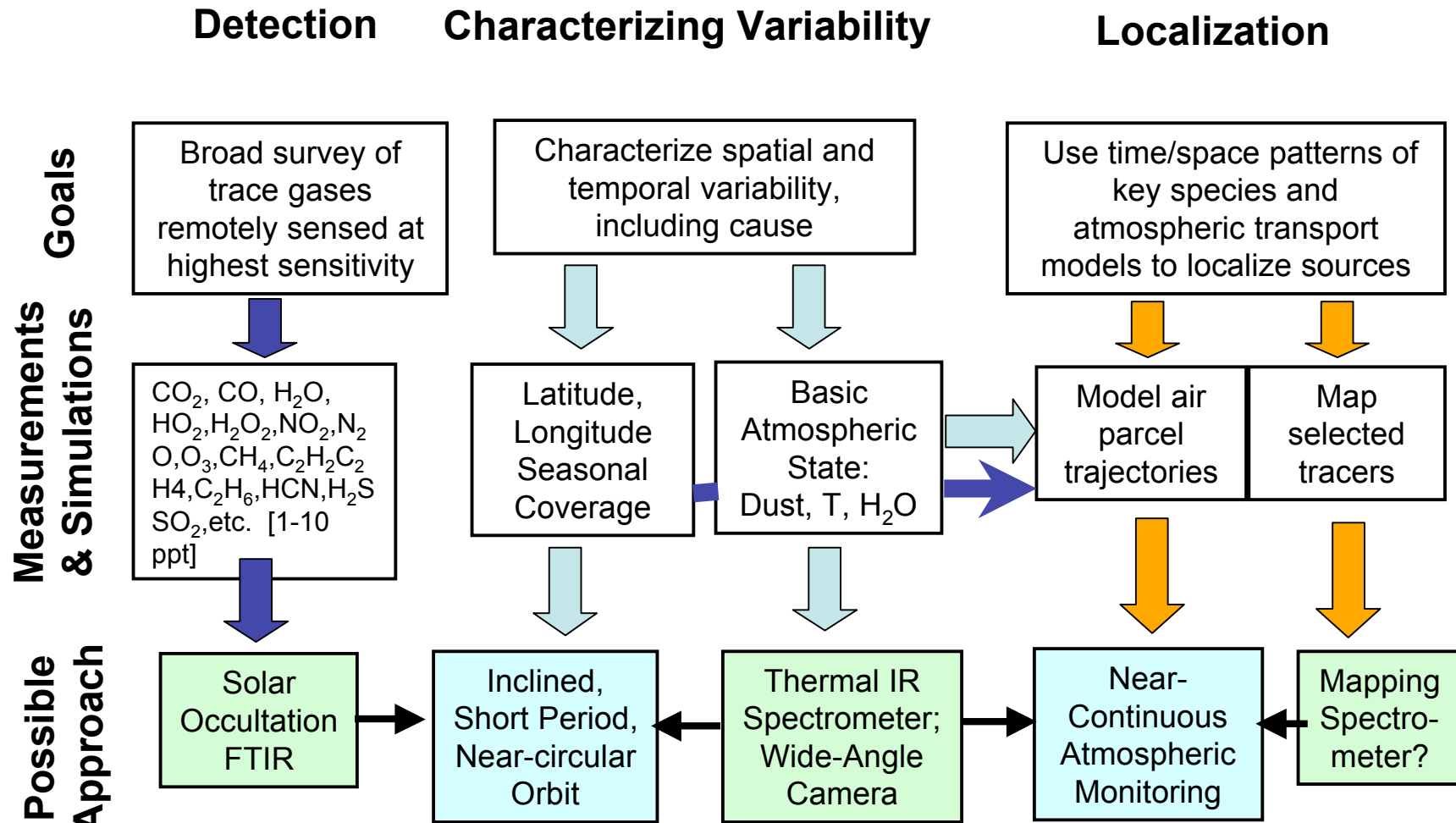
## **Characterization:**

- Spatial and Temporal Variability: Latitude-longitude coverage multiple times in a Mars year to determine regional sources and seasonal variations (reported to be large, but still controversial with present understanding of Mars gas-phase photochemistry)
- Correlation of concentration observations with environmental parameters of temperature, dust and ice aerosols (potential sites for heterogeneous chemistry)

## **Localization:**

- Mapping of multiple tracers (e.g., aerosols, water vapor, CO, CH<sub>4</sub>) with different photochemical lifetimes and correlations helps constrain model simulations and points to source/sink regions
- To achieve the spatial resolution required to localize sources might require tracing molecules at the ~1 part per billion concentration
- Inverse modeling to link observed concentration patterns to regional transformations (e.g., in dusty air) and to localized sources would require simulations using circulation models constrained by dust and temperature observations

# Trace Gas Measurement Requirement Flow-Down



## Sample “strawman” Payload (existence proof)

- Solar occultation spectrometer(s)

  - Atmospheric composition (broad spectral range and high resolution)
  - Mapping key species (narrower spectral range)

- Sub-millimeter spectrometer

  - Wind velocity through Doppler shift
  - Water vapor, temperatures, etc. without influence from dust
  - Map key species

- Wide-angle camera (MARCI-like)

  - Daily global view of surface and atmospheric dust and clouds

- Thermal-IR spectrometer

  - Daily global observations of temperature, dust, ice, water vapor
  - Direct comparison to previous climatology record

- High-resolution camera (as resources permit)\*

  - Imaging of possible local sources and active surface processes

    - \*Prime difference between TGM concept and earlier MSO*

## Orbit characteristics:

### Near-circular at low altitude (300-400 km)

- Allows best *coverage mapping*
- Allows most solar occultation opportunities (*most sensitive detection*)
- Orbit altitude may be increased at some point for planetary protection

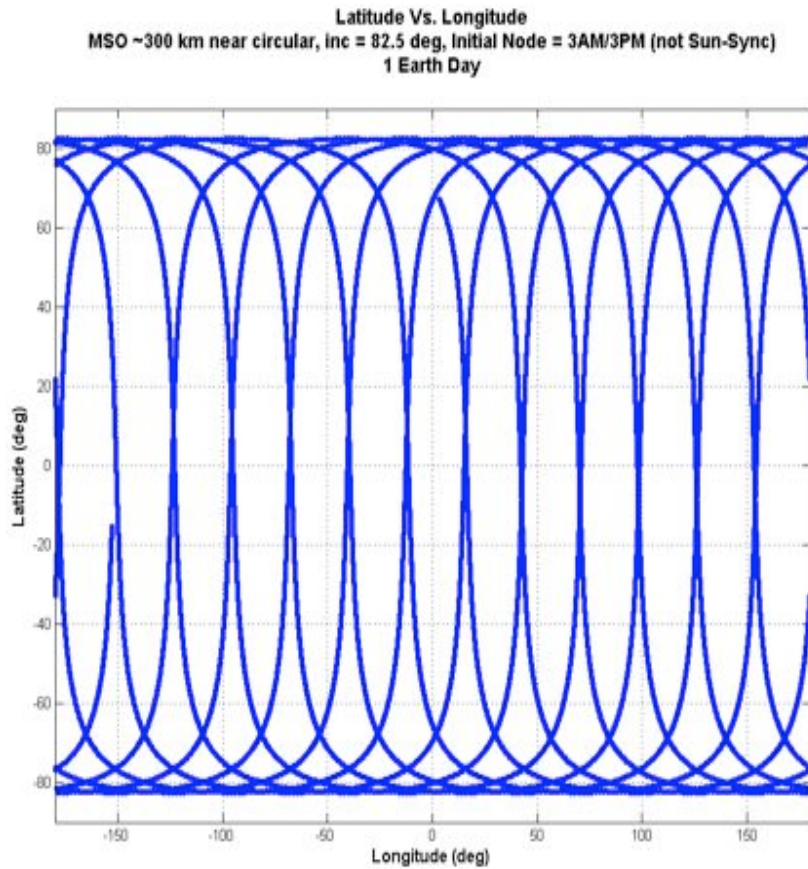
### High inclination ( $\sim 74^\circ \pm 10^\circ$ )

- Compromise between *global coverage* and faster *precession of local time* and more uniform latitude distribution of solar occultation points
- Science requires *full diurnal cycle* in less than a Martian season

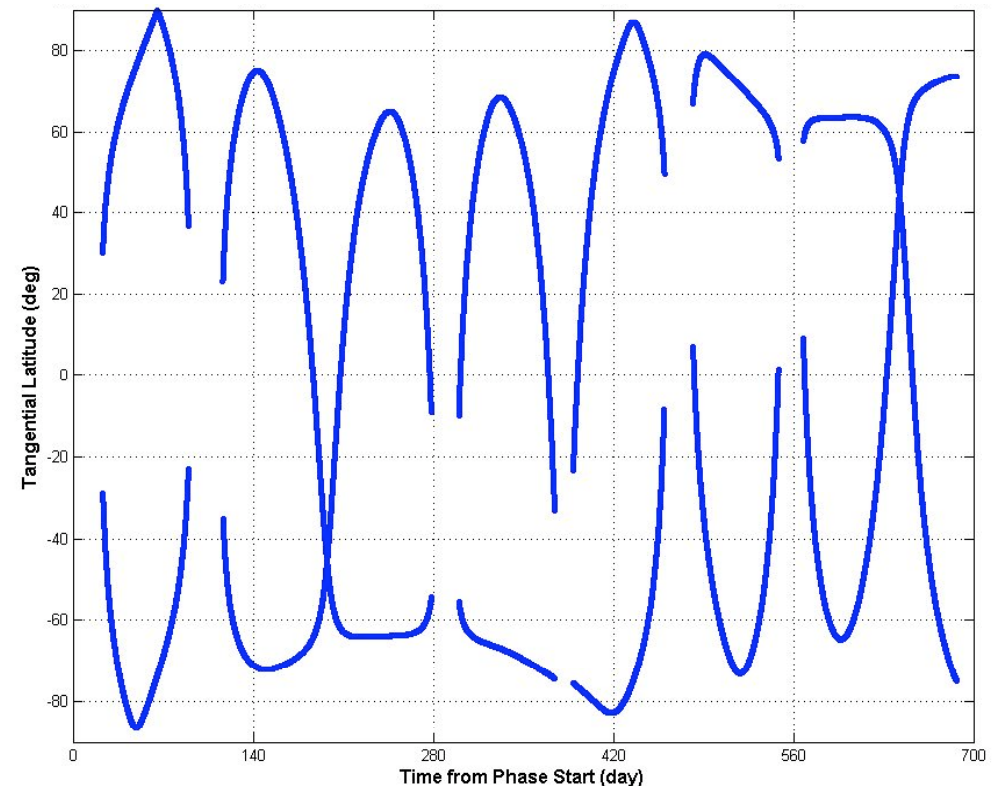
### Mission duration (1 Mars year)

- Full seasonal coverage

## Orbit tracks for one day Good global mapping



## Solar occultations for one year Good latitude distribution





# 2016 TGM Mission Implementation Concept

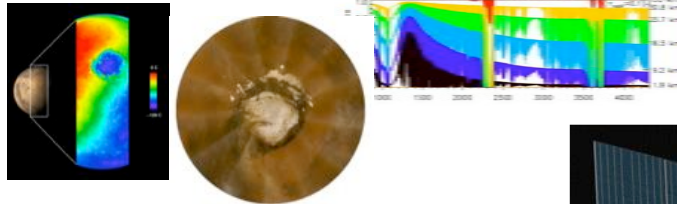
OBJECTIVES

## Perform Trace Gas / Mapping (TGM) Science

*Atmospheric Composition and State  
Detection, Mapping, and Characterization*

## Telecom Infrastructure for future missions

*Proximity UHF and deep space X band links*



**Nadir- and limb-pointing capability**  
UHF proximity telecom 250 Mb/sol  
X-Band deep space telecom > 2 Gb/day  
Data storage 64 Gb  
EOL power 1500 W  
Cost effective monopropellant propulsion  
5 year lifetime, 10 years consumables

FLIGHT SYSTEM

PAYLOAD

## Notional Instruments\*

### Solar occultation (FTIR spectrometer)

*Atmospheric composition*

### Wide-angle camera (MARCI-like)

*Global view of surface, dust and clouds*

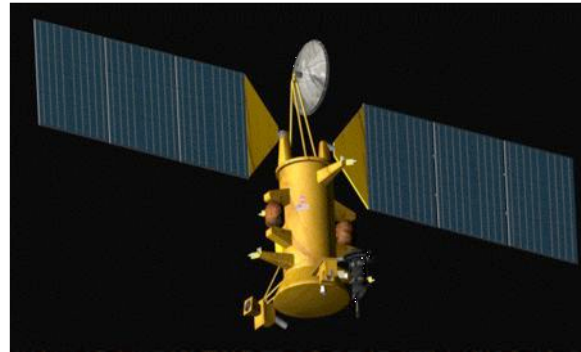
### Thermal-IR spectrometer (TES-like)

*Temperature, dust, ice, water vapor climatology*

### Mapping Spectrometer (Multiple Spectrum

### Measurement Approaches)

*Water vapor, Wind, Temperature*



**S/C Bus Dry Mass** 1100 kg  
**Science Payload\*** 115 kg  
**Propellant** 1915 kg  
**Total Wet Mass** 3130 kg  
**LV Capability** 3330 kg  
*(Atlas-V 411)*

MASS SUMMARY

MISSION DESIGN

**Launch Date** January 2016  
**Launch C<sub>3</sub>** 13.9 km<sup>2</sup>/s<sup>2</sup>  
**V<sub>inf</sub>** 3.8 km/s  
**Aerobraking Duration** 6 to 9 months  
**Start Science Observation** March – June 2017\*  
**Science Orbit** Walking, Inclination 74°  
**Science Emphasis Phase** ~2 yrs, 400 x 400 km  
**Relay Emphasis** ~2 yrs, 400 x 400 km



## Notional Cost through Launch (RY \$M)\*

**Development Cost** 500 – 530  
**Launch Vehicle** 215  
**Cost-through-Launch** 715 – 750

## Key Milestones

**Mission Concept Review** ~Sept 2010  
**PDR** Dec 2012  
**CDR** Sept 2013  
**Sys Integration Review** July 2014  
**Fight Readiness Review** Dec 2015/Jan 2016

COST & SCHEDULE

**\*Several partnering approaches are being considered**

*Pre-decisional for planning and discussion purposes only*

## Summary:

- TGM would enable *significant new science* and provide *key infrastructure* elements
- TGM science objectives *not covered* by any other proposed mission (including MSR)
- 2016 is *avored launch opportunity* for TGM:
  - Provide needed telecom support for other future missions
  - Minimize gap in atmospheric monitoring
  - Possible synergy with MAVEN extended mission



**Back-Up**

## MSO SDT Membership:

Michael Smith, Chair, NASA Goddard Space Flight Center

Don Banfield, Cornell University

Jeff Barnes, Oregon State University

Phil Christensen, Arizona State University

Todd Clancy, Space Science Institute

Phil James, University of Toledo (retired)

Jim Kasting, Pennsylvania State University

Paul Wennberg, Caltech

Daniel Winterhalter, JPL

Michael Wolff, Space Science Institute

Rich Zurek, JPL (Mars Program Office)

Janis Chodas, JPL (MSO Project Manager)

Tomas Komarek, JPL (MSO Mission Concept Manager)

## JIDT Membership:

### ESA Participants

- Augustin Chicarro
  - *ESA - Co-Chair*
- Jean-Loup Bertaux
  - *Service D'Aeronomie, CNRS*
- Frank Daerden
  - *BIRA/IASB*
- Vittorio Formisano
  - *IFSI Roma (I)*
- Gerhard Neukum
  - *Freie Universitaet Berlin*
- Albert Haldeman
  - *EXM/ESA*

### NASA Participants

- Richard Zurek
  - *JPL (MPO) - Co-Chair*
- Mark Allen
  - *JPL*
- R.Todd Clancy
  - *Space Science Institute*
- Jim Garvin
  - *NASA GSFC*
- Michael Smith
  - *NASA GSFC*
- Tom Komarek
  - *JPL (MPO)*