A New Mission Concept:
The Search for Trace Gases in the Mars Atmosphere

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Scientific Motivation

- ***Methane has been detected in the atmosphere of Mars***
  - *First indications were from orbit (MEX: Formisano et al., 2004)*
  - *Confirmed by Earth-based telescopic spectrometers (Krasnopolsky et al., 2004; Mumma et al., 2009)*

  ⇒ ***Presence indicates a surface/subsurface source***

- ***Data indicate spatial & temporal—perhaps seasonal—variability***
  - *Inconsistent with present photochemical and atmospheric transport models*

  ⇒ ***Variability indicates a different photochemical sink of methane, perhaps on aerosols or at the surface***

- ***Present photochemical models of the Mars atmosphere cannot explain these observations***

Scientific Goals

- **The scientific need is for new missions at Mars to:**
  - Confirm the presence of methane and its variability over all Mars seasons
  - Survey trace gases and their isotopologues in the Mars atmosphere in order to understand the nature of their subsurface/surface sources: Biochemical and geochemical?
  - Characterize the processes by which methane, other trace gases, and aerosols interact and are possibly removed from the atmosphere
  - Locate atmospheric source regions to further characterize the surface/ subsurface sources
  - Identify possible locales for future surface/subsurface exploration

  => These needs can be summarized as: Detection, Characterization, Localization

- **A 2016 orbiter mission could conceivably also provide essential telecommunications and monitoring support to future missions landing on Mars**

ESA-NASA Conceptual Program

- ***The 2016 Orbiter***
  - ***Science focus:*** *Understand presence and variability of atmospheric trace gases and their implications for Mars habitability*
  - ***Programmatic focus****: Carry telecommunications package for relay to/ from future landed assets, including…*
- ***The 2016 EDL Demonstrator***
  - ***Technological goals:*** *entry, descent, touch-down, survival with batteries, a few scientific sensors.*
- ***The 2018 Rover(s)***
  - ***Science focus:*** *habitability and exobiology at and below the Martian surface;*
  - ***Programmatic focus:*** *Prepare a sample cache for future return to Earth.*
- ***The 2020 Option: Network***
  - ***Science focus:*** *simultaneous investigations of Mars interior and local surface environment from 4-6 surface stations, coordinated with an orbiter.*

Joint Instrument Definition Team (JIDT) Charter

- ***Review the mission requirements (payload, orbit, data return) needed to implement a 2016 science orbiter mission focused on:***
  - *Detection of a broad suite of atmospheric trace gases (with high sensitivity)*
  - *Characterization of their spatial and temporal variation*
  - *Localization of sources of key trace gases?*
- ***Discuss the measurement requirements, including***
  - *Payload: Instrument types, mass, power, data rate, required fields of view, observation cycles*
  - *Note: total payload mass (with contingency) not to exceed TBD kg*
  - *Orbit: Inclination, altitude/period*
- ***Endorse, refine, and/or augment the current requirements. Key questions to be addressed:***
  - *Should/can (within resources) a mapping capability be included?*
  - *What are the observation modes that must be accommodated?*
  - *What are the associated orbit requirements?*
- ***Provide a report that might be used in the formulation of a Joint Announcement of Opportunity for instruments on a 2016 orbiter.***

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

NASA Participants

- Richard Zurek, JPL (Mars Program Office) - co-chair
- Mark A. Allen, JPL
- R.Todd Clancy, Space Science Institute
- Jim Garvin, NASA Goddard Space Flight Center
- Michael Smith, NASA Goddard Space Flight Center

Technical Support Leads

- Albert Haldemann, EXM/ESA
- Tomas Komarek, JPL (Mars Program Office)

Sponsors

- Marcello Coradini, ESA
- Michael Meyer, NASA

Trace Gas (TG) Science Objectives

Detection:

- *Requires very high sensitivity to the following molecules and their isotopomers:* H_2O, HO_2, NO_2, N_2O, CH_4, C_2H_2, C_2H_4, C_2H_6, H_2CO, HCN, H_2S, OCS, SO_2, HCl, CO, O_3
- *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 hetereogeneous chemistry)*

Localization:

- *Inverse modeling to link observed concentration patterns to regional transformations (e.g., in dusty air) and to localized sources requires simulations using circulation models constrained by dust and temperature observations*
- *Mapping of multiple tracers (e.g., aerosols, water vapor, CO,* CH_4*) 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 may require tracing molecules at the ~1 part per billion concentration*

JIDT Activities

April – June 2009

- ***Mission concept: Carrier to deploy ExoMars from Mars orbit would also carry a science payload (NTE 70 kg)***
  - *ESA: ExoMars Descent Module and Rover*
  - *NASA: Launch Vehicle and Carrier*
  - *Both: Science payload to be selected in response to a joint AO*
- *JIDT held several telecons and a face-to-face meeting in early June*
  - *Endorsed Trace Gas objectives*
  - *Raised doubt that the needed payload could fit a 70-kg mass allocation*

August – October 2009

- ***Mission concept: Orbiter bus to deploy EDL Demonstration Module on direct entry and carry a science payload (~110 kg)***
  - *ExoMars Descent Module and Rover to be launched in 2018*
  - *ESA: Orbiter & EDL Demo* *NASA: Launch Vehicle*
  - *Both: Science payload to be selected in response to a joint AO*
- *JIDT reconvened and held several telecons*
  - *Preliminary report in October; Final report in November*

JIDT Findings (1 of 4)

- ***JIDT endorsed 3 Science Goals for the conceptual 2016 Mission with the following priority order:***
  - *Detection: Emphasize broad survey and sensitive detection of trace gases and isotopologues, including methane, higher-order hydrocarbons, and other photochemical families: HOx, NOx, SOx, etc.*

    ⇒Solar Occultation techniques with high spectral resolution
  - *Characterization: Effects of dust and ice aerosols, variation over the globe and on many time scales (diurnal to seasonal)*
    - *Map selected gases (e.g., methane) and precursur species (e.g., H2O) over the globe and as a function of local time and season, preferably unaffected by aerosols*
    - *Map atmospheric state (e.g., temperature, aerosol concentration, clouds)*

    ⇒Mix of thermal infrared and microwave/sub-mm instruments

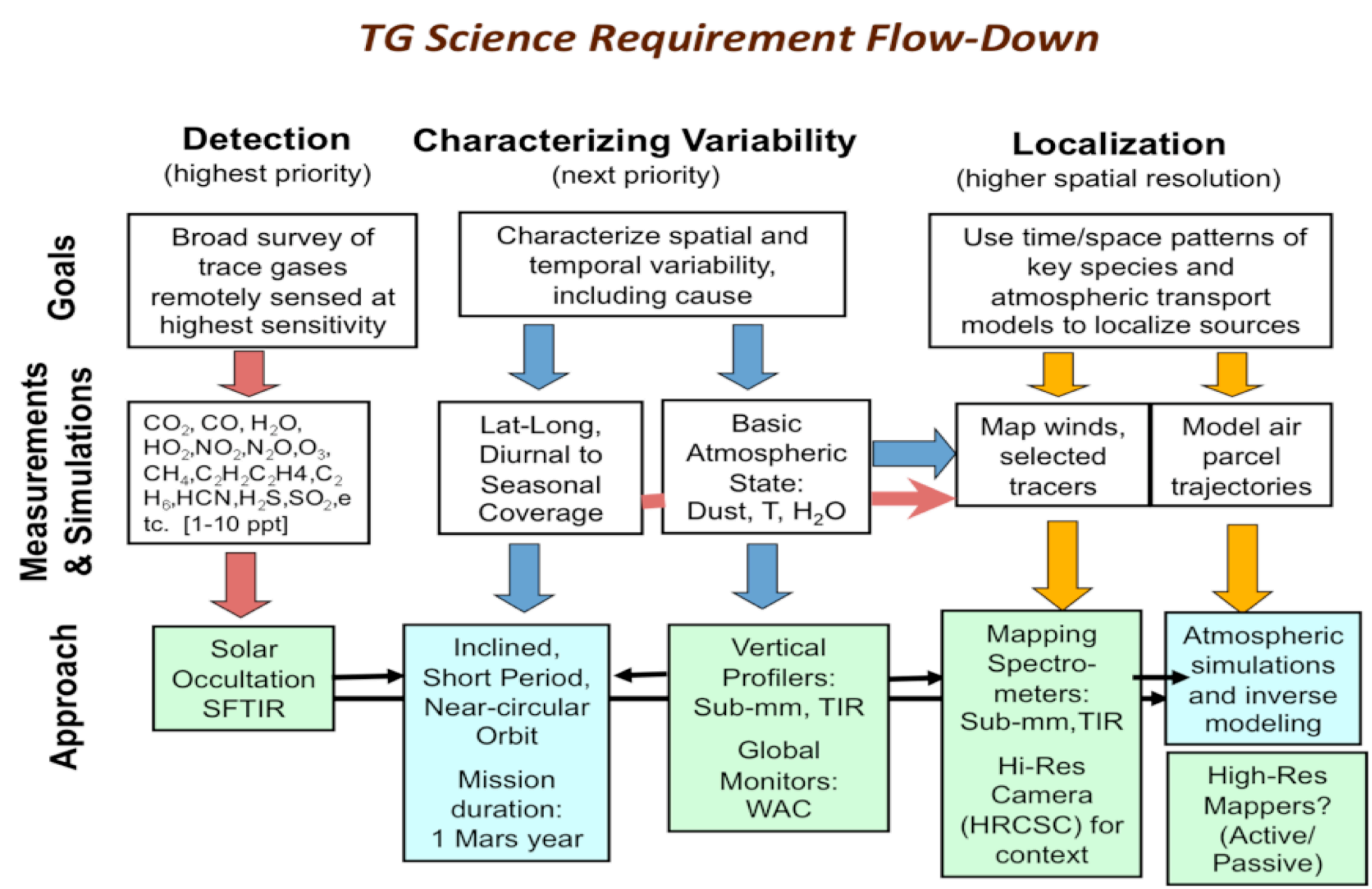
    ⇒Wide-angle camera for observing atmospheric weather

    ⇒Combination of nadir, limb and cross-track observation modes
  - *Localization: Identify broad source regions and attempt to isolate*
    - *Validate models of atmospheric transport and inverse modeling for sources*

    ⇒Direct observations of horizontal winds would provide a powerful check on these
    - *Characterize potential source regions*

    => High-resolution imaging or mapping of localized areas

From Goals to Approach



Example Measurement Approaches
(Actual Instruments Selected thru AO)

#	Acronym	Description	View Modes	Observation Modes	
1	SFTIR	Solar Fourier Transform IR Spectrometer: **Broad survey** of trace gases with high precision	Solar Occultation only; passive radiative cooler	2 Solar Occultations per orbit (~24/day); processing interferorgrams throughout orbit	
1	SLNIR	Solar-Nadir IR Mapper: Detection and mapping of **specific** trace gases	Solar occultation; nadir and limb viewing; heat sink required (assumed to be provided by s/c)	2 solar occultations + dayside nadir/limb (60 min) on each orbit	
2	Sub-mm	Sub-mm Spectrometer profiler/mapper **Atmospheric temperature & winds** plus **H2O and specific** trace gases	Nadir and limb, including away from velocity vector	Continuous operations switching between nadir, space, different limb; observe both sides of ground track	
2	TIR	Thermal IR profiler/mapper spectrometer or radiometer for atmospheric **temperature and dust**, plus **H2O and some** trace gases	Nadir and limb views, including away from velocity vector	Continuous operations switching between nadir, space, different limb; observe both sides of ground track	
2	WAC	Wide Angle Camera imaging **atmospheric phenomena** for discriminating between surface, dust clouds, & ice clouds	push-frame operation with .GE. 2 color bands; requires alignment with ground track motion	Cross-track (nearly orthogonal to velocity vector) horizon-to-horizon	
3	HRCSC	High Resolution Color Stereo Camera: **Surface imaging**	~1 m/pixel ground sampling (at nadir) with TDI; fore/nadir/aft views	Designated targets of opportunity; requires alignment with ground track motion (mitigation needed)	

JIDT Findings (2 of 4)

The resources available for a possible 2016 joint ESA-NASA mission are still being explored. Actual resources and approach would be outlined in the AO and related materials.

The JIDT made the following recommendations:

- ***Payload mass and (orbital average) power allocations of 125 kg and 190 W***
- ***The proposed mission baseline should include downlink to two ground-based deep space stations***
  - *Even then, this will greatly restrict the utility of high-resolution imaging or mapping instruments*
- ***The proposed mission should make nominal observations (occultation, profiling, mapping, monitoring, and imaging) for at least one Mars year***
  - *Ensures seasonal coverage*

Example Instrument Allocations
(Actual Instruments Selected thru AO)

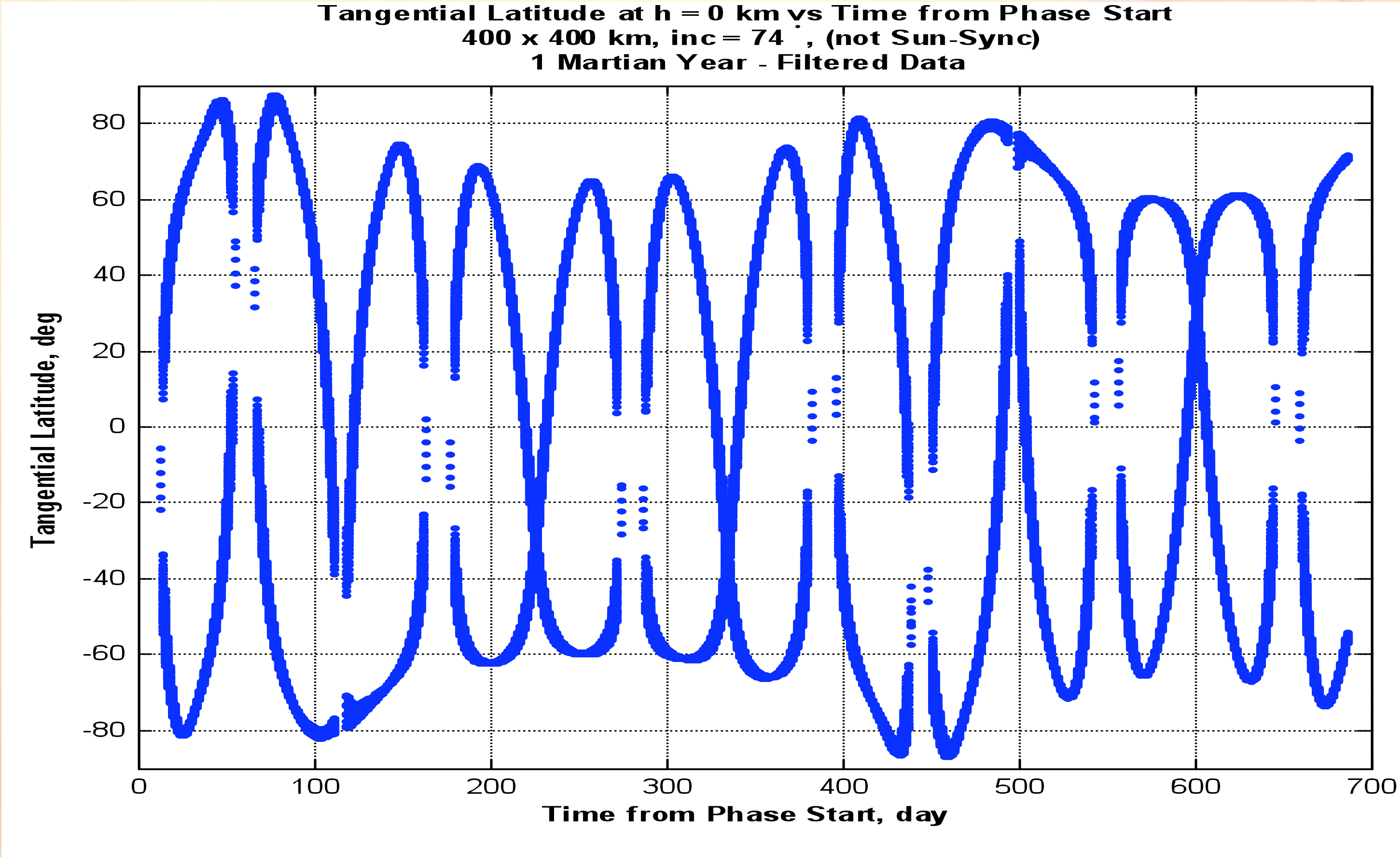
		MASS (kg)	Accommodation Issues	Power (W, avg.)	Power (W,Peak)	Data Vol. (Mbits/day)	Comments
	SFTIR	40	Anti-sun radiator a critical component	50	50	1900	On-board processing of interferograms;
	SLNIR	20	Includes 5 kg for radiator not previously included	20	30	900	Formerly labelled TGM/SOIR; Radiator too large to place on instrument; assumed on s/c
	Sub-mm	27	Power estimates reflect heritage technologies	80	99	800	Instrument includes ability to slew to view direction; some indications that power need could be cut in half
	TIR	10	Data volume assumes mapping of selected trace gases	20	20	1000	Assumed 100 interferograms per orbit; T/dust/ice sounders typically return less data
	WAC	3	Onboard processing (e.g., image compression) done in instrument (not on spacecraft computer); gimbal to stay cross-track?	5	5	500	Typically framing cameras, some with spectral filters so direction important
	HRCSC	25	5 kg added to account for low design maturity; 5 kg added for camera positioning platform; assumed 10 min/orbit peak power and 10 W standby	15	50	3000	1.6 Gb/image (compressed) Requires velocity vector alignment during imaging; if s/c slews, other instrument radiators must be protected
	Totals	125		190	254	8100	At max range/aphelion power
	Allocations	110	Aug-09	140		3000	150 kbps for single station pass

JIDT Findings (3 of 4)

With regard to the orbit of the conceptual mission, the JIDT recommended:

- ***A proposed low-altitude (~400 km) nearly circular orbit***
  - *Enables viewing from any and all parts of the orbit*
  - *Low altitude enables good vertical resolution and reasonable latitude-longitude sampling*
- ***An orbital inclination of 74° ±10°***
  - *Lower inclinations shrink latitudinal coverage*
  - *Higher inclinations move too slowly through local time, convoluting diurnal and seasonal effects*
- ***Ground-track should not precisely repeat but should be optimized for mapping coverage by the profiling instruments***

Orbital Considerations



Solar occultation tangential latitudes versus time over a Mars year in a 380 km orbit with a 74° inclination. This shows one possible combination of altitude and inclination that provides latitudinal coverage each season (colors) for this observational mode.

JIDT Findings (4 of 4)

The conceptual mission design presented to the JIDT had the spacecraft essentially pointing to the sun and nadir at all times

The JIDT noted:

- ***A sun-pointed spacecraft provided a good viewing geometry for solar occultation instruments and for instrument radiative coolers***
- ***Might require augmented viewing capabilities for profiling and low-resolution mapping instruments***
  - *Such instruments already have mechanical means of scanning the limb, but might have to add another degree of actuation (e.g., azimuth as well as elevation scanning)*
- ***Would require turn-tables or other devices for imaging instruments***
  - *Wide-angle cameras (which views orthogonal to the ground track) could probably tolerate this*
  - *Such an approach likely will not work for high resolution instruments requiring precise pointing along the ground track*
  - ***JIDT did not agree on an alternate approach***

Next Steps

- ***ESA and NASA are continuing to explore opportunities for possible joint missions launched in the 2016, 2018, and 2020 opportunities***
- ***Preliminary engineering studies for concepts for the 2016 mission continue; this mission concept has a scientific/telecommunications orbiter dropping off an EDL Demonstration Module continue***
- ***If the 2016 joint orbiter mission is to move forward to realization, the release of an Announcement of Opportunity for the scientific payload needs to occur very early in 2010, with instrument selection by late summer***
- ***Once selection is made, the mission design can be refined appropriately with the resources allocated by ESA and NASA***

Summary

- *The Joint Instrument Definition Team chartered by ESA and NASA believes that that a scientifically exciting and credible mission could be conducted within the evolving capabilities of the current mission concept for a 2016 science/telecom orbiter delivering an EDL demonstrator on direct entry to Mars.*
- *Some lingering issues need to be addressed, but these are viewed by the JIDT to be technically workable.*
- *The JIDT endorses the selection of the science payload through an open, competitive Announcement of Opportunity and looks forward to this appearing soon.*
- *Such a mission will surely reveal new aspects of Mars, while addressing the key issue of the nature of biogeochemical activity on Mars today*