Commitment to European Mars Missions
~ via Infrared Spectroscopic Sciences ~

欧州次期火星探査機への日本からの参加
~ 赤外線分光観測に絡んで ~

from Ground-based & Mars Express
to Trace Gas Orbiter [CrossDrive]

News - Tohoku Univ. 60cm (T60)

- **Flexible** Conjugated operations with large telescopes & space missions
- **Continuous** Temporal variabilities in diurnal, seasonal, solar cycle
- **Unique instruments** including 'Infrared' (not covered by T40 = 40cm Schmidt camera)


T60 Open Ceremony
[8 Sep. 2014]

[First instrument – to **Venus/Mars**]
Mid-Infrared LAser Heterodyne Instrument (MILAHI)

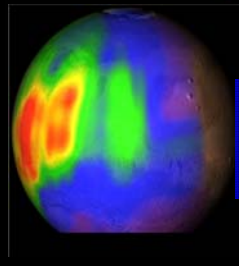
… with large-sized telescope sciences

2008 - now

Collaboration with Italian Team
for Mars Express --- Planetary Fourier Spectrometer

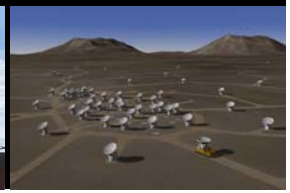
*** Methane !**
[search of]
- SO_2 (for Crust activity -- CH_4 production ?)
- H_2O_2 (for Oxidization -- CH_4 loss ?)

*** H_2O & Aerosol cycles !**
[search of]
- HDO/H_2O ratio (water cycle)
- CO_2 cloud (gravity waves)



… contributing
- **CAL**
- **Retrievals**

*** Local Time variations**
[search of]
- **Thermal tides** (planetary waves)
- **Dust** (daily variation)



[Italy] **Vittorio Formisano**
Marco Giuranna
Shohei Aoki (Nov. 2014-)

Our current targets for Mars ~ Observations & Simulations ~

Global dynamics

- **GCM/Thermal Tides etc.** — by MEX/PFS
- **Gravity Waves etc.** (at Earth/Venus/Jupiter) — by VEX Radio-Sci., ISS/AirGlow (Earth), IRTF (Jup.)
- **Mesospheric wind** — by MIR heterodyne, mm/submm (ground based MIR/mm/submm + Models)

Water & CO_2 Cycles
Minor elements

- **H_2O & CO_2 clouds** — by MEX/PFS, comparing OMEGA data
- **H_2O/HDO** — by SUBARU (+ submm)
- **$^{12}CO_2/^{13}CO_2$** — by SUBARU (+ MEX/PFS)
- **H_2O_2** (with CH_4) — by MEX/PFS

with modeling studies & the development of Radiation-Transfer code

2009-2010

Proposal from Russian & French Team
to 'our ORBITER' ~ based on VEX/SOIR ~

Target: Solar Occultation (& nadir/limb survey) for

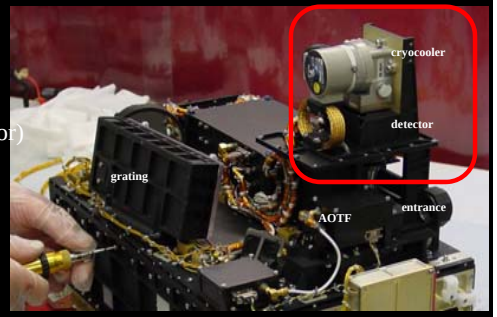
Circulation of Major Atmospheric components — CO_2, H_2O, CO + Aerosols
Follow up of Minor Atmospheric components — HDO, CH_4, other species

Design: High-dispersion Near-infrared Spectrometer with

Wavelength	2.2 ~ 4.4 μm [4500 ~ 2200 /cm]
Resolution	λ/Δλ: 30000 [0.1 /cm]
Bandwidth	λ/λ_{band}: 150 [20 /cm]
FOV :	2' x 30' (+ Pointing Mirror)
Disperser:	AOTF (no moving part)

Specifications

Mass	**5.5 kg + 1.5 kg** (Pointing Mirror)
Power:	**25 W**



[Russia] Oleg Korablev
[France] Franck Montmessin

ExoMars Project

- Orbit: 120 min (40 min eclipse: 12 times / day)
  Altitude 400 km, Inclination 74 deg
  Wide LT coverage

2016 Jan. Launch (MOI: Oct)

ExoMars

2018 Launch

Trace Gas Orbiter

EDL Demonstrator Module (EDM)

The Rover

Landing Platform

ExoMars Project

ESA + NASA TGO → **ESA + Roscosmos TGO**

NOMAD — High resolution occultation and nadir spectrometers — *Atmospheric composition (CH_4, O_3, trace species, isotopes) dust, clouds, P&T profiles*

UVIS (0.20 – 0.65 μm)	λ/Δλ ~ 250	SO Limb Nadir	
IR (2.3 – 3.8 μm)	λ/Δλ ~ 10,000	SO Limb Nadir	
IR (2.3 – 4.3 μm)	λ/Δλ ~ 20,000	SO	

MATMOS — High-Resolution FT spectrometer — *Vertical distribution of water, methane and trace species*

Infrared (2.3 – 12 μm)	λ/Δλ ~ 130,000	SO

EMCS — Limb radiometer — *Monitoring of atmospheric structure, water and aerosols*

MAGIE — Wide-angle camera — *Monitoring of clouds and ozone*

HiSCI — High-resolution camera — *Mapping of sources; landing site selection*

NOMAD [Belgium & Italy] — High resolution occultation and nadir spectrometers — *Atmospheric composition (CH_4, O_3, trace species, isotopes) dust, clouds, P&T profiles*

UVIS (0.20 – 0.65 μm)	λ/Δλ ~ 250	SO Limb Nadir	
IR (2.3 – 3.8 μm)	λ/Δλ ~ 10,000		
IR (2.3 – 4.3 μm)	λ/Δλ ~ 20,000	SO	

ACS [Russia & France] — Suite of 3 high-resolution spectrometers — *Atmospheric chemistry, aerosols, surface T, structure*

Near IR (0.7 – 1.7 μm)	λ/Δλ ~ 20,000	SO Limb Nadir
IR (Fourier, 2 – 25 μm)	λ/Δλ ~ 4000 (SO)/500 (N)	SO Nadir
Mid IR (2.2 – 4.5 μm)	λ/Δλ ~ 50,000	SO

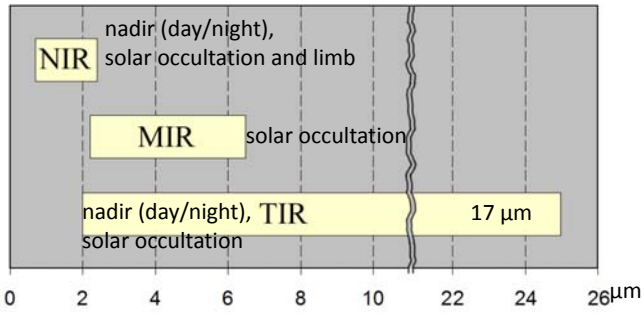
CaSSIS — High-resolution camera — *Mapping of sources; landing site selection*

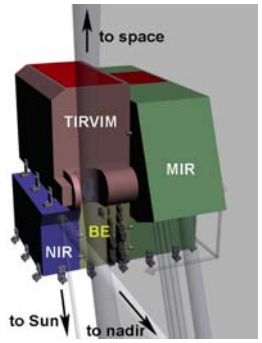
FREND — Collimated neutron detector — *Mapping of subsurface water*

Key questions of Mars science and ACS

- Internal structure/Volcanism
  By measuring minor gases of potential volcanic origin
- Climate: present and evolution
  By characterizing atmospheric state, climate, and isotopic ratios (D/H in particular)
- Past and present habitability
  By measuring minor gases of potential biological significance

	Spectral range	Inst. range	resolution
NIR	0.73-1.6 μm	~0.17 μm	>20 000
MIR	2.3-4.3 μm	0.28-0.32μm	>50 000
TIRVIM	2-17 μm	full range	0.2cm^{-1} occ 0.2-1.6 cm^{-1} nadir





* Chemical Composition of the Martian Atmosphere
* Mars Climatology and Seasonal Cycles
* Sources and Sinks of the Martian Atmosphere

Species	Current Knowledge	Detection limits	
		Solar Occultation	Nadir
CH_4	0-60 ppb [14-16]	14 ppt	0.8 ppb
H_2O	< 300 ppm (variable)	2.5 ppb	8 ppb
CO	700-800 ppm	20 ppb	2.5 ppm
HDO	D/H =5.6 SMOW	1.7 ppb (i.e. 6 ppm H_2O)	5 ppb (i.e. 17 ppm H_2O)
$^{13}CH_4$ CH_3D		20 ppt (i.e. 2 ppb CH_4) 70 ppt (i.e. 100 ppb CH_4)	0.78 ppb (i.e. 70 ppb CH_4)
CO, CO2 isot		2 % accuracy	2 % accuracy
HCN	3 ppb	0.06 ppb	6 ppb
H_2CO	< 3 ppb	0.1 ppb	1.5 ppb
HO_2		6 ppb	75 ppb
H_2S	< 100 ppb	4 ppb	0.2 ppm
C_2H_2	< 2 ppb	0.3 ppb	2 ppb
C_2H_4	< 500 ppb	3 ppb	40 ppb
C_2H_6	< 400 ppb	0.03 ppb	1.25 ppb
OCS	< 70 ppb	0.5 ppb	18 ppb
N_2O		7 ppb	10 ppm
NO_2		0.03 ppb	8.5 ppb
SO_2	< 2 ppb	0.1 ppb (UVIS)	1 ppb (UVIS)
O_3		50 ppt (UVIS)	1 ppb (UVIS)

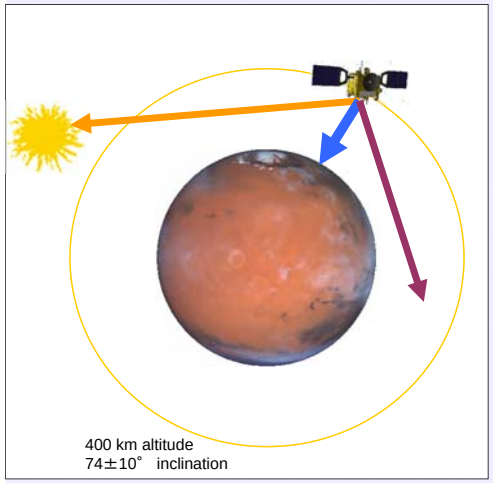
< MSL >

~10ppb or less

D/H~3

NOMAD

Modes of Operation



- **Solar Occultation**
  - SO (+LNO)
    - fov:1km
    - vertical sampling: 180m - 1km
  - UVIS
    - fov:1km
    - vertical sampling: 300m
- **Nadir**
  - LNO
    - fov:0.2km x 12 km (HR)
    - 2.3km x 6 km (LR)
  - UVIS
    - fov:5km x 5km
- **Limb**

NOMAD

Our current targets for Mars ~ Observations & Simulations ~

Global dynamics

- GCM/Thermal Tides etc. — by MEX/PFS: TIRVIM - YES by wide Local-Time coverage
- Gravity Waves etc. (at Earth/Venus/Jupiter) — by VEX Radio-Sci., ISS/AirGlow (Earth), IRTF (Jup.): NIR – YES, in vertical [in horizontal ???]
- Mesospheric wind — by MIR heterodyne, mm/submm (ground based MIR/mm/submm + Models)

Water & CO_2 Cycles

Minor elements

- H_2O & CO_2 clouds — by MEX/PFS, comparing OMEGA data: TIRVIM: YES by higher spectral res. & sens. in Vertical (with photometer ch?) [horizontal ?]
- H_2O/HDO — by SUBARU (+ submm)
- $^{12}CO_2/^{13}CO_2$ — by SUBARU (+ MEX/PFS)
- H_2O_2 (with CH_4) — by MEX/PFS: NIR/MIR/TIRVIM: complete exploration !!

with modeling studies & the development of Radiation-Transfer code

EU Project CROSS DRIVE

Interactive Planetary Science Data Exploration

- CROSS DRIVE: Collaborative Rover Operations and Satellites Science in Distributed Remote and Interactive Virtual Environments
- Exploitation of produced huge datasets of potential immense value for research as well as planning and operating future missions
- Aims at:
  - ESA ExoMars 2016 (TGO) and
  - ESA ExoMars 2018 (Rover) missions
- Use cases:
  - Landing Site Characterization
  - Atmospheric Data Analysis
  - Rover Target Selection

CROSS DRIVE

CROSS DRIVE
Rover Target Selection

ALTEC THALES

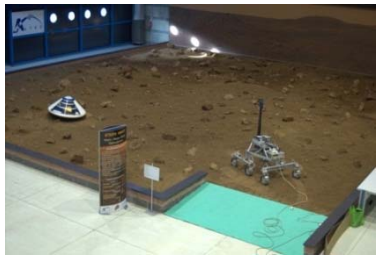
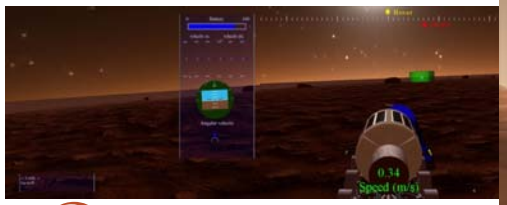


Fig.: ALTEC will operate Mission Control Center (MCC) for ExoMars; Operative Rover scenario definition in Mars and Moon Terrain Demonstrator (MMTD) at ALTEC

Fig.: Brian Cooper and colleague, lead driver for MSL Curiosity, he wrote the software to drive it.

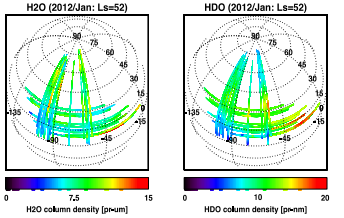
Fig.: Veritas – Spacecraft and Rover Simulation at TAS-I



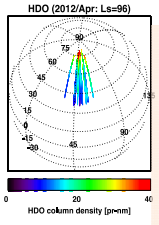
CROSS DRIVE

CROSS DRIVE
Atmospheric Data Analysis
[ExoMars 2016 TGO]

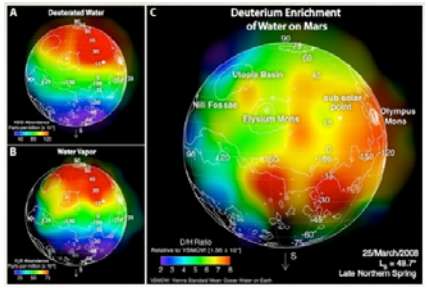
- Science objectives: Chemical composition (e.g. trace gases)
- NOMAD instrument: spectrometer for UV, visible, and IR spectral regions



東北大学 TOHOKU UNIVERSITY



* **Subaru – H_2O & HDO map** [route for Ground-based data]
* **MRO - CRISM – H_2O map** (from JHU/APL)
* Heterodyne
* ALMA
* M-GCM



HDO/H2O ratio
[Villanueva et al., 2008]

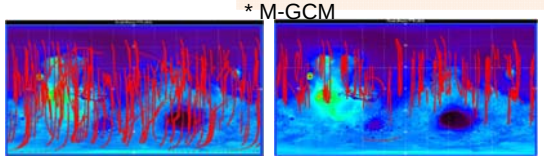


Fig.: Sparse measurement of methane (biology or geology?) in Martian atmosphere [INAF]

CROSS DRIVE INAF

Task 6.5 (& D6.9) - Definitions

To provide the test platform for the comparison with other Mars missions outside of ESA (orbiters & landers) and ground-based telescopes (from the Earth & on its orbit) from outside of PDS, PSA, etc.

[Task 6.5.1: Ground based observations of Mars]

- Tohoku Univ. Haleakala observatory: 60cm Cassegrain telescope with MIR heterodyne spectrometer (, NIR Echelle spectrometer / Imager)
(dedicated to continuous planetary monitoring - Test observations started from fall 2014.)

- Open-use large size telescopes: SUBARU 8m(, IRTF 3m, ALMA, …).

[Task 6.5.2: Other Mars missions outside of ESA]

- CRISM on NASA/MRO (originally, by JHU)
Surface characteristics, aerosols, densities of selected species, etc. will be provided for the tools developed under T6.3 (Analysis Tools)

… They are complementary to T6.1 (Level-1/2 data).

Q. What target do we perform the comparison (and visualization by VR system) ?
→ to focus on water vapor (H_2O and its isotope) by its high scientific interests.
<< They can potentially be expanded by requests from Use cases. >>

Deliverable 6.9 from Task 6.5: Summary

<Ground-based> SUBARU/IRCS data in Jan & Apr 2012.
L1 data [spectra]
L2 data [retrieved column density of H_2O, HDO, and the HDO/H_2O ratios)

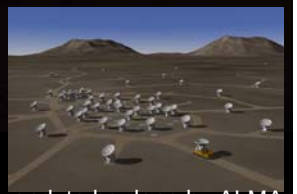
<Space> MRO/CRISM data in 2006-2011
L2 data [retrieved column density of H_2O]

as the test platform for space (from orbiters & landers) and ground-based (from Earth incl. space telescopes).
on the Cross-Drive projects.

… and, two projects are on going at Haleakala

60cm telescope with IR heterodyne (2014~)

1.8m telescope 'PLANETS' (2016~)



… and, to be done by ALMA