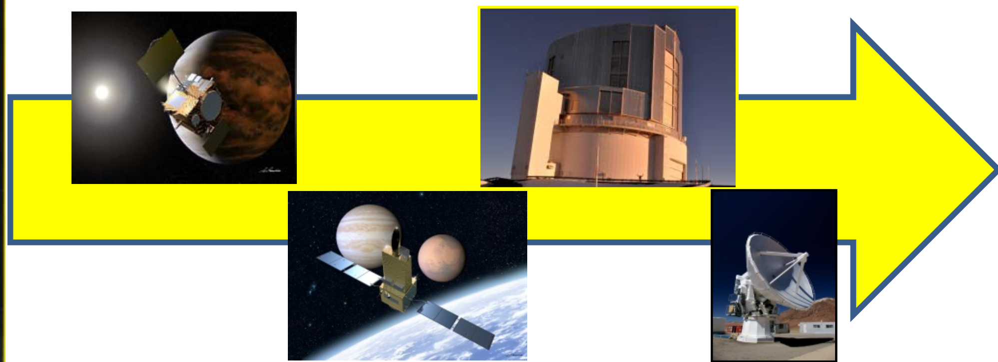
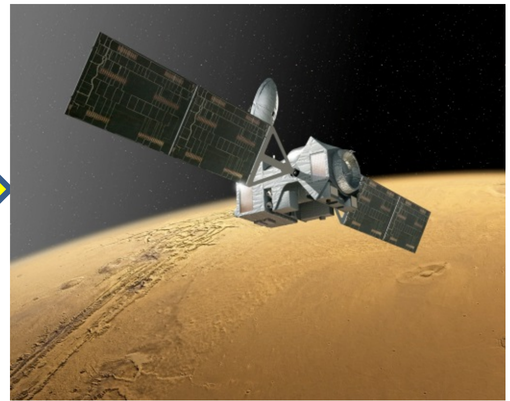
Martian studies
executing & planning at Tohoku Univ. etc.

- Infrared spectroscopic observations
- Numerical modeling studies
- Ground-based & space programs

and expected extensions toward & with TGO / ACS

Y. Kasaba[1], H. Nakagawa[1], T. Sakanoi[1], S. Aoki[1,5], T. Kuroda[1], N. Terada[1], H. Sagawa[2], Y. Kasai[2], T.M. Sato[3], T. Imamura[3], Y. Hirahara[4] (1: Tohoku Univ., 2: NiCT, 3: ISAS/JAXA, 4: Nagoya Univ., 5:IAPS-INAF)





Tohoku University

Sendai (300km north from Tokyo)

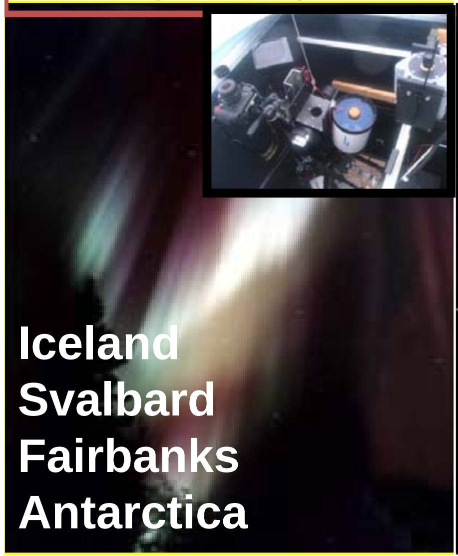
Martian environment studies executing & planning at Tohoku Univ.

Y. Kasaba et al. (IKI, Oct 2013)

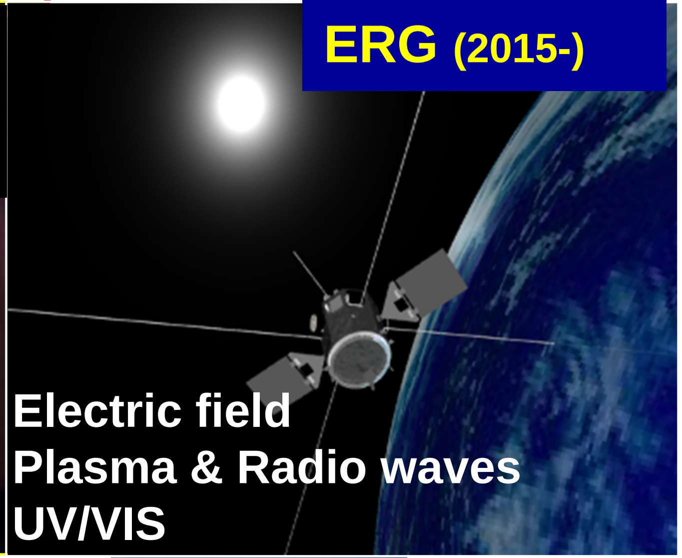
Neutral & Plasma Atmospheres in Solar System

~ Radio / IR / Vis / UV + Numerical studies ~

Terrestrial Aurora & Magnetosphere



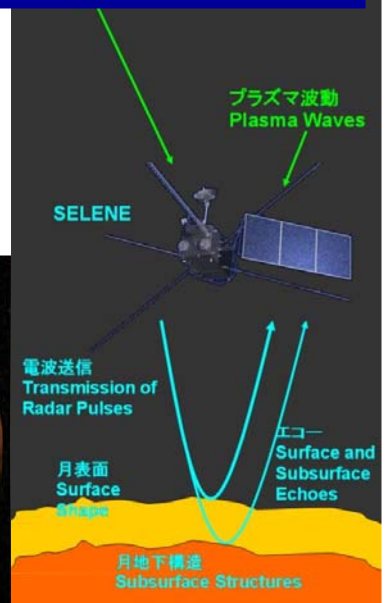
Akebono (1989-)
Geotail (1992-)
Reimei (2005-)
ERG (2015-)



Planetary Atmosphere & Magnetosphere

Sakigake/Suisei (P/Halley: 1984-)

Kaguya (Moon) 2007-



Akatsuki (Venus: 2010-)

Terrestrial Upper atmospheres

ISS-IMAP Airglows

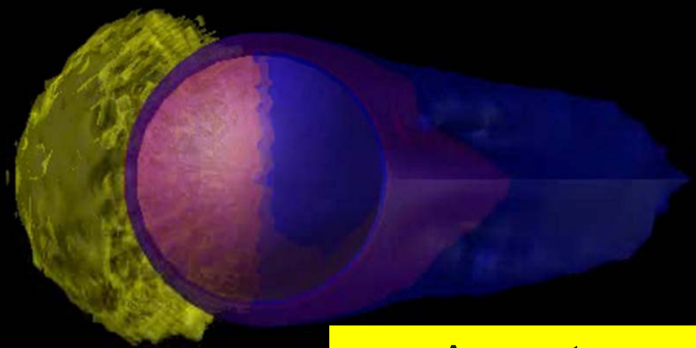
CH4 / O3 in upper atmosphere

BepiColombo

JUICE

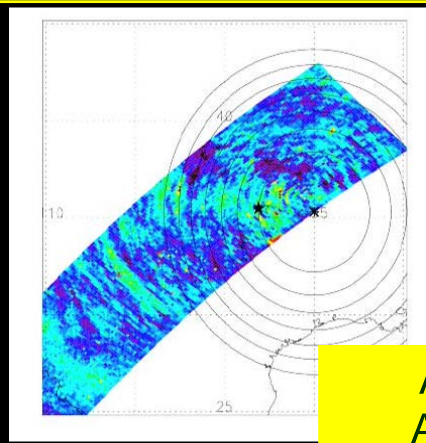
Our current targets for Mars ~ Observations & Simulations ~

Atmospheric Escape



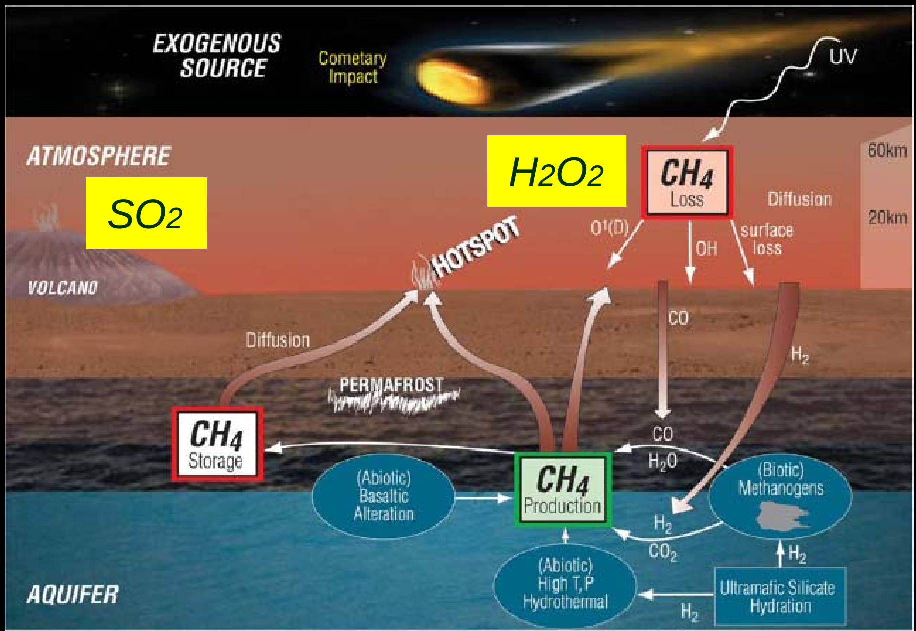
Amount, process,
Solar activity effects

Global dynamics

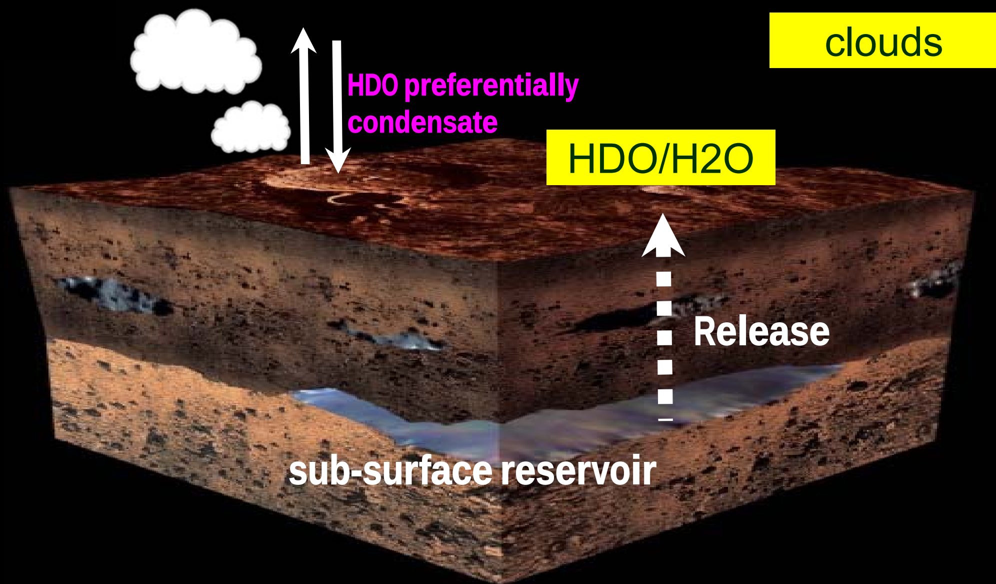


Air glow imaging &
Atmospheric waves

Minor elements:
production / loss / circulation

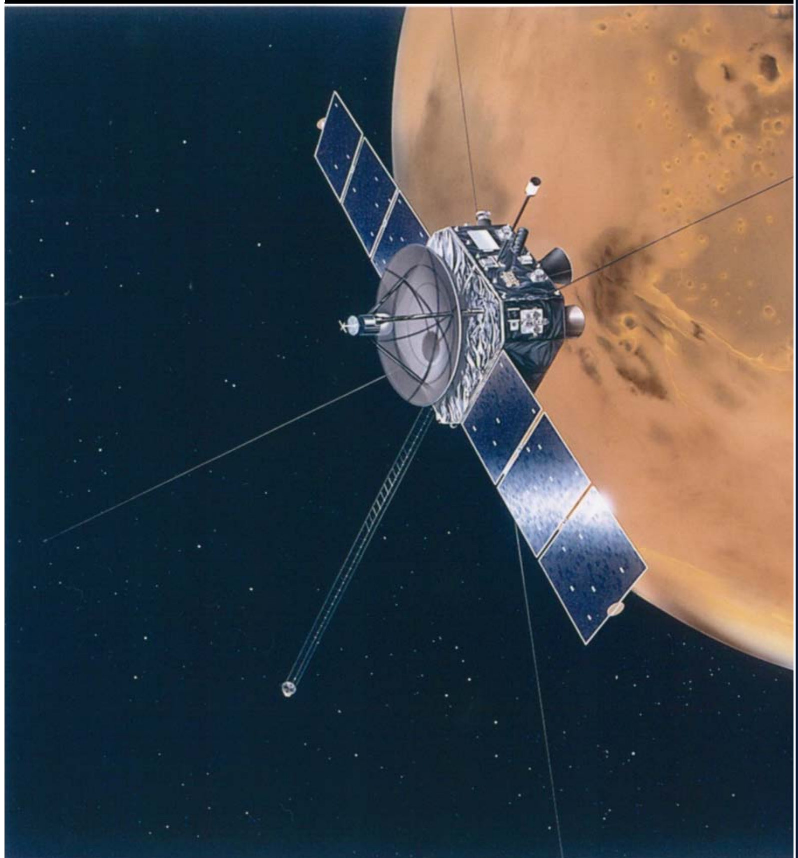


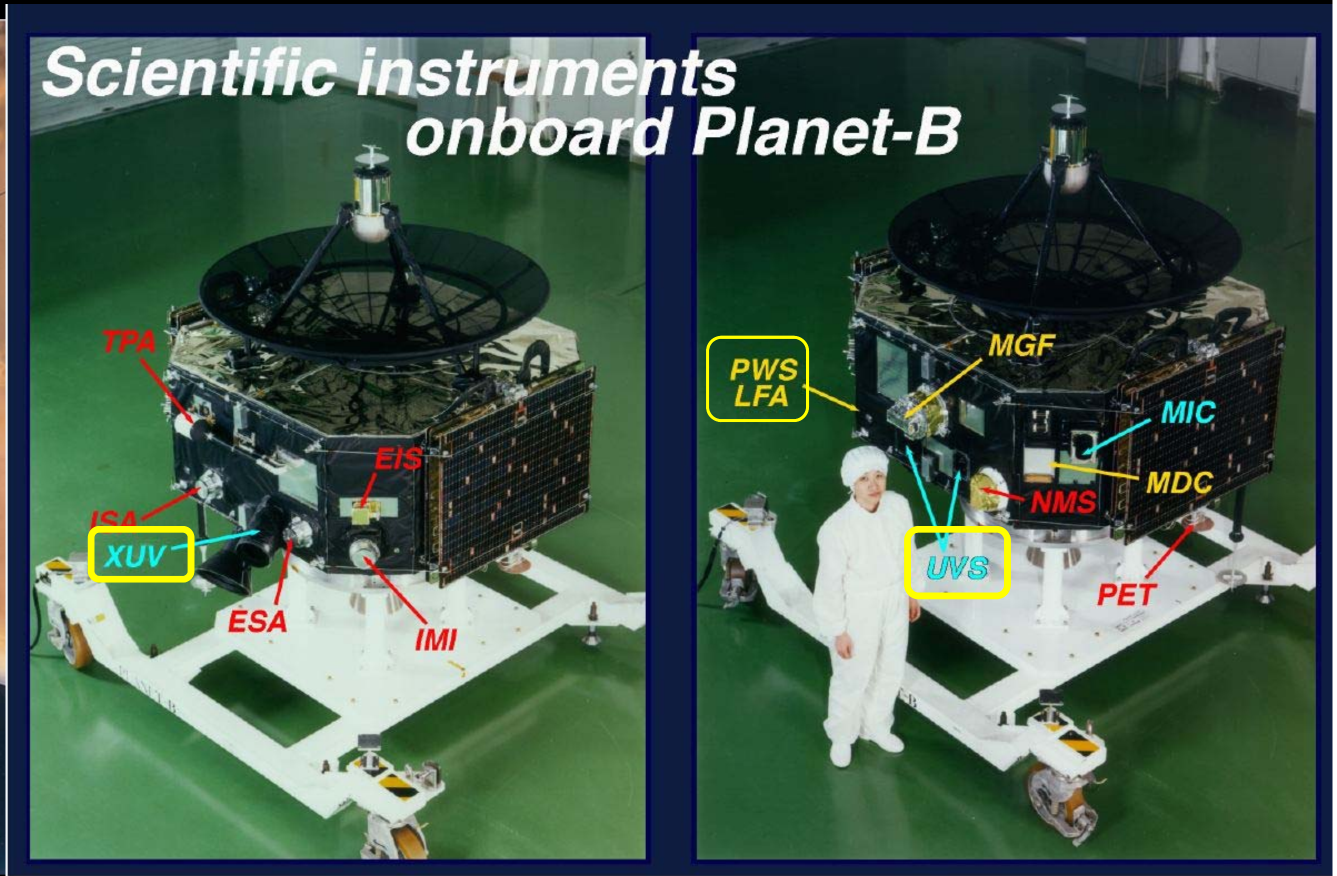
Water & CO_2 Cycles:
Sublimation - condensation



Atmospheric Escape
A mission to Mars: *Nozomi (1998-2004)*

Main target：*to investigate the Martian upper atmosphere*
by the consortium of Imaging & Plasma instruments





The spirits of Nozomi was partially continued to BepiColombo & JUICE, and …

Sprint-A/EXCEED mission

(EXtreme ultraviolet spectrosCope for ExosphEric Dynamics)

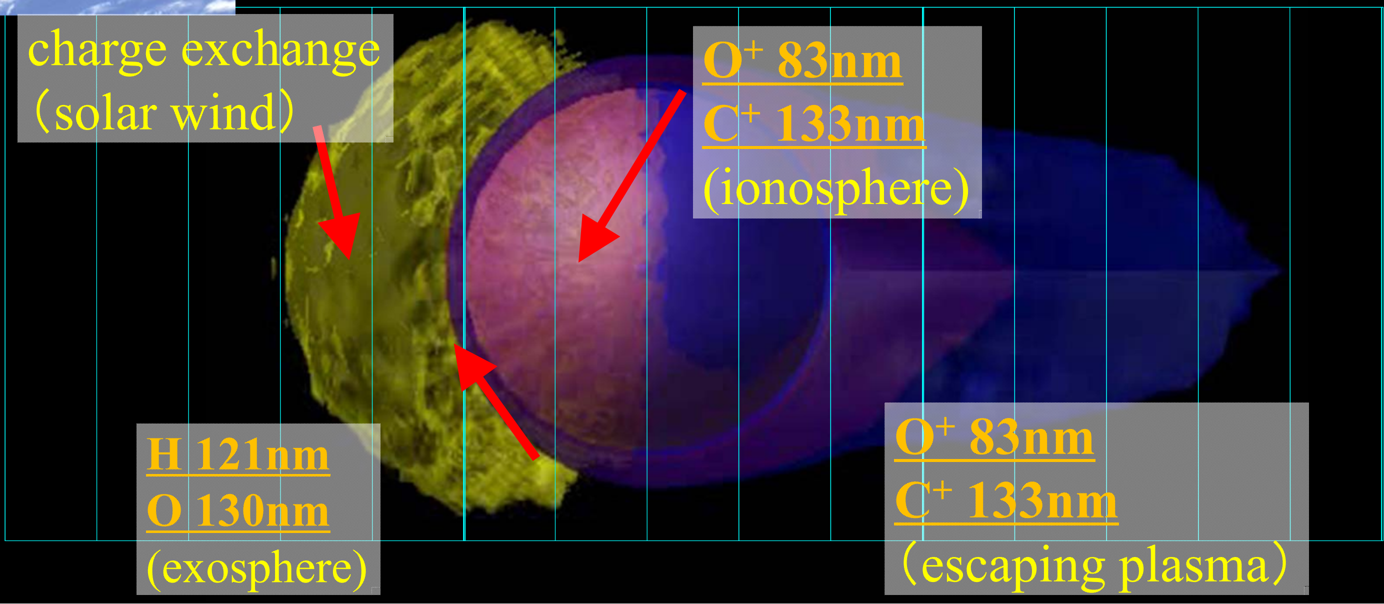
~ Extreme Ultraviolet (EUV) space telescope ~

- Launch 14 Sep 2013
- Observation Nov 2013 ~

A (partial) recovery mission of Nozomi in UV/EUV/XUV plasma imaging

Collaboration with MAVEN is now in planning.

Hybrid Simulation of
Exosphere,
Ionosphere, and
Escaping atmosphere

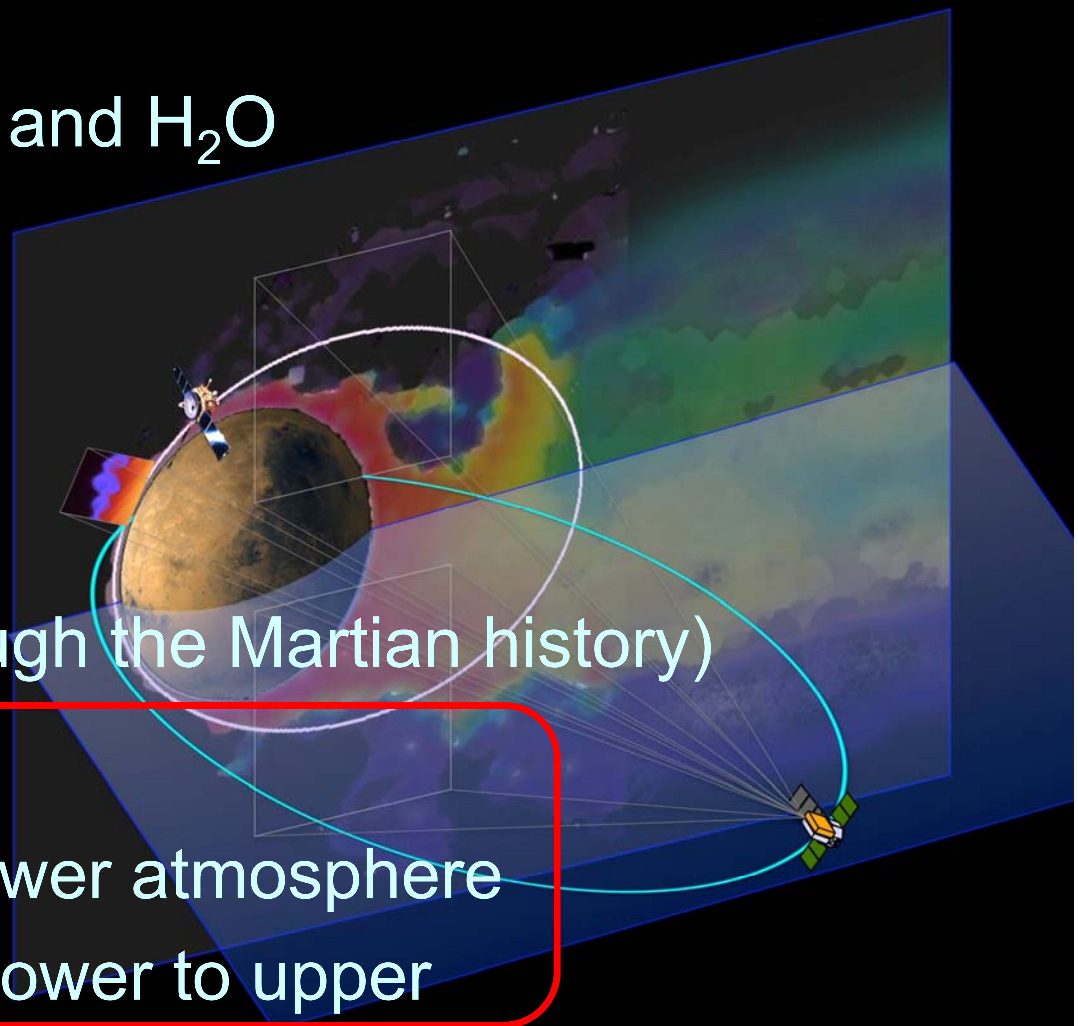


(Terada et al.)

Nozomi-heir *mission (in 2020s?)*

Investigate how and where the Martian CO_2 and H_2O disappeared

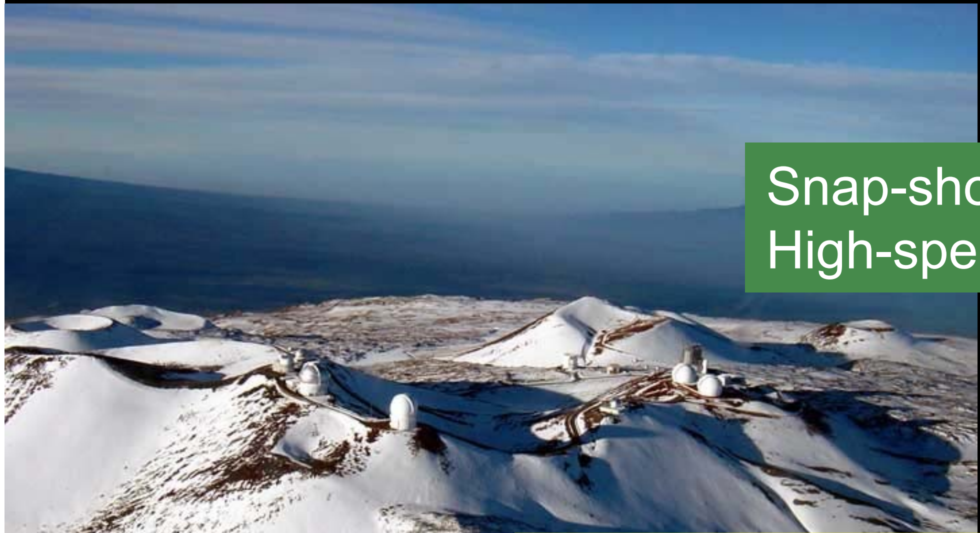
- Target 1:
  Current escape rates of CO_2 and H_2O
- Target 2:
  Escape mechanisms
- Target 3:
  Responses to solar forcing
  (extrapolate backwards through the Martian history)
- Target 4:
  Responses to forcing from lower atmosphere
  → Energy transfer from lower to upper

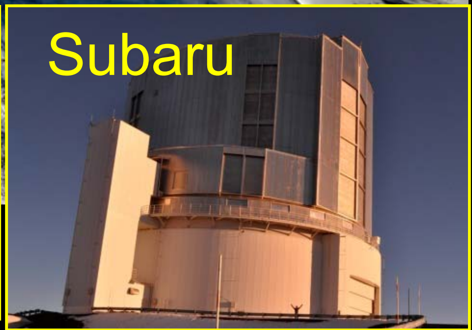


Infrared / Submm studies of Martian Atmosphere

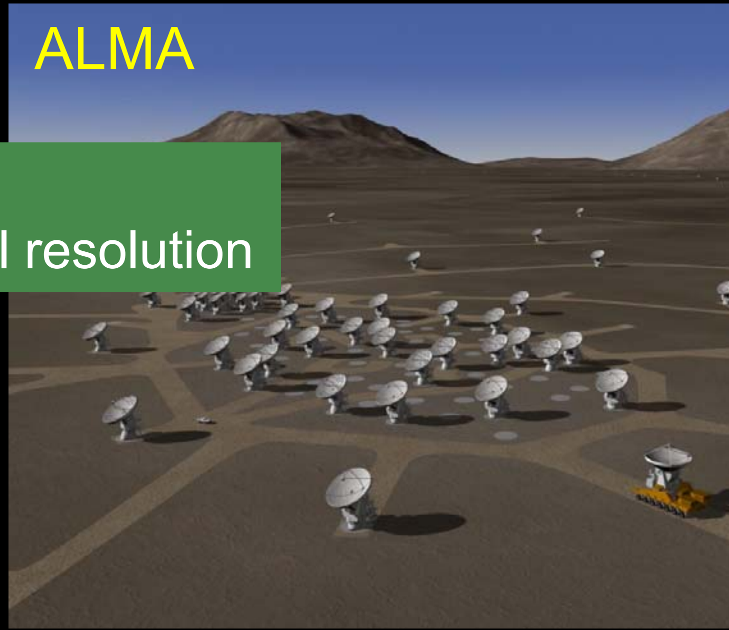
~ with Large-sized facilities ~

Infrared: Mauna Kea

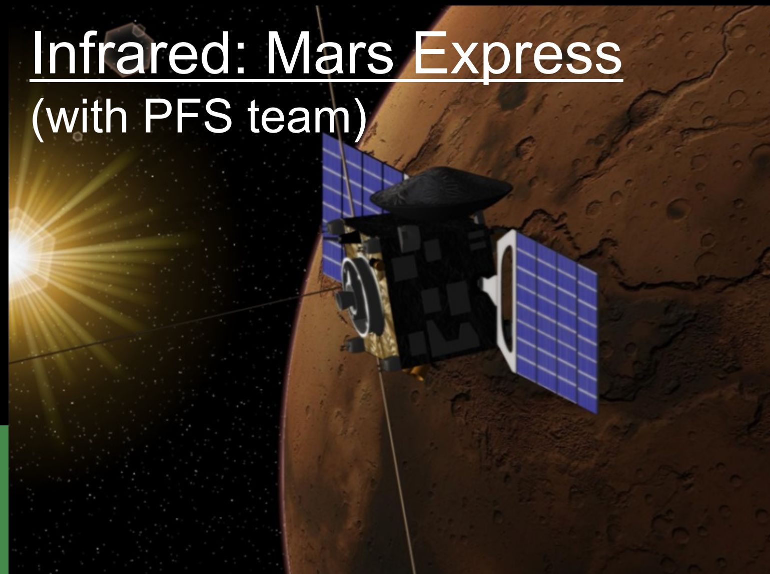




Submm: Atacama



Snap-shot
High-spectral resolution



Continuous &
Long-term Monitoring

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.
(not Mars. 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)

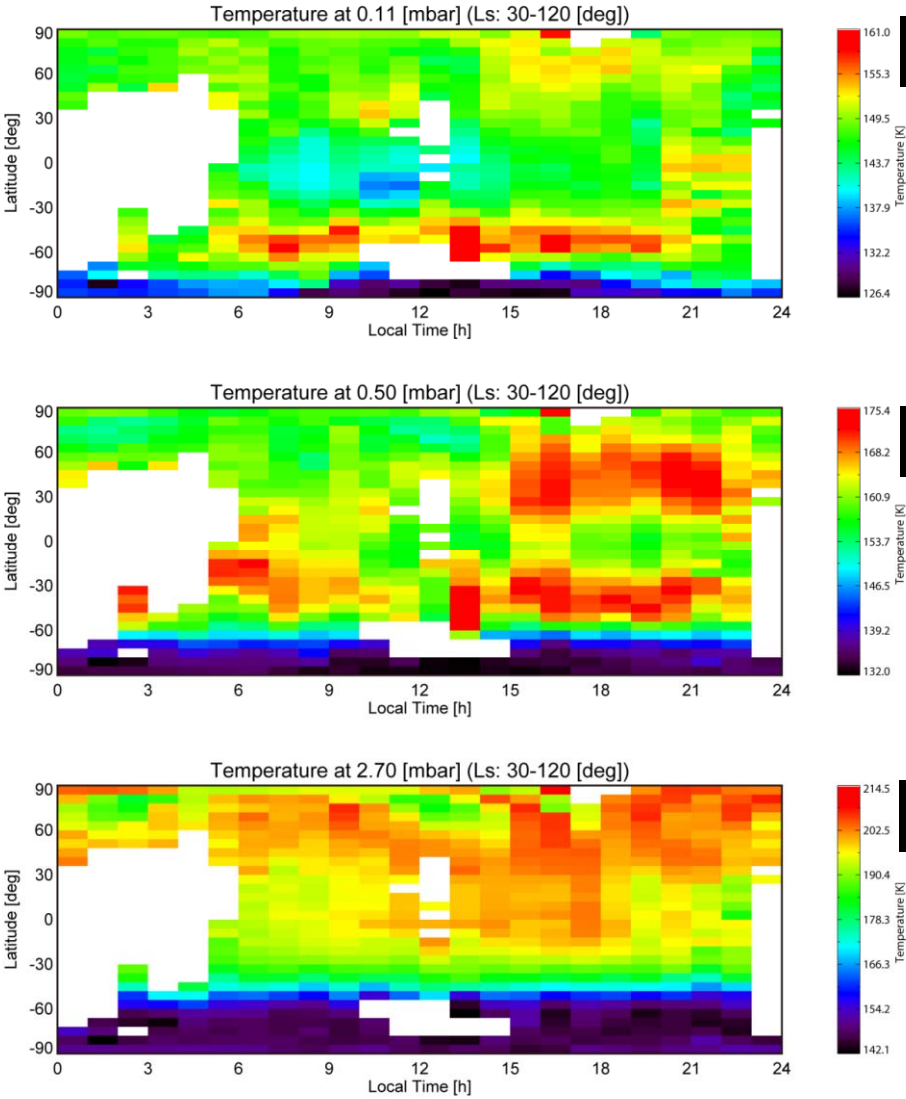
by MEX/PFS
NIR/MIR/TIRVIM: complete exploration !!

with modeling studies & the development of Radiation-Transfer code

Global dynamics: Thermal Tide

(Sato et al.)

by MEX/PFS, thanks to **its wide Local-Time coverage**

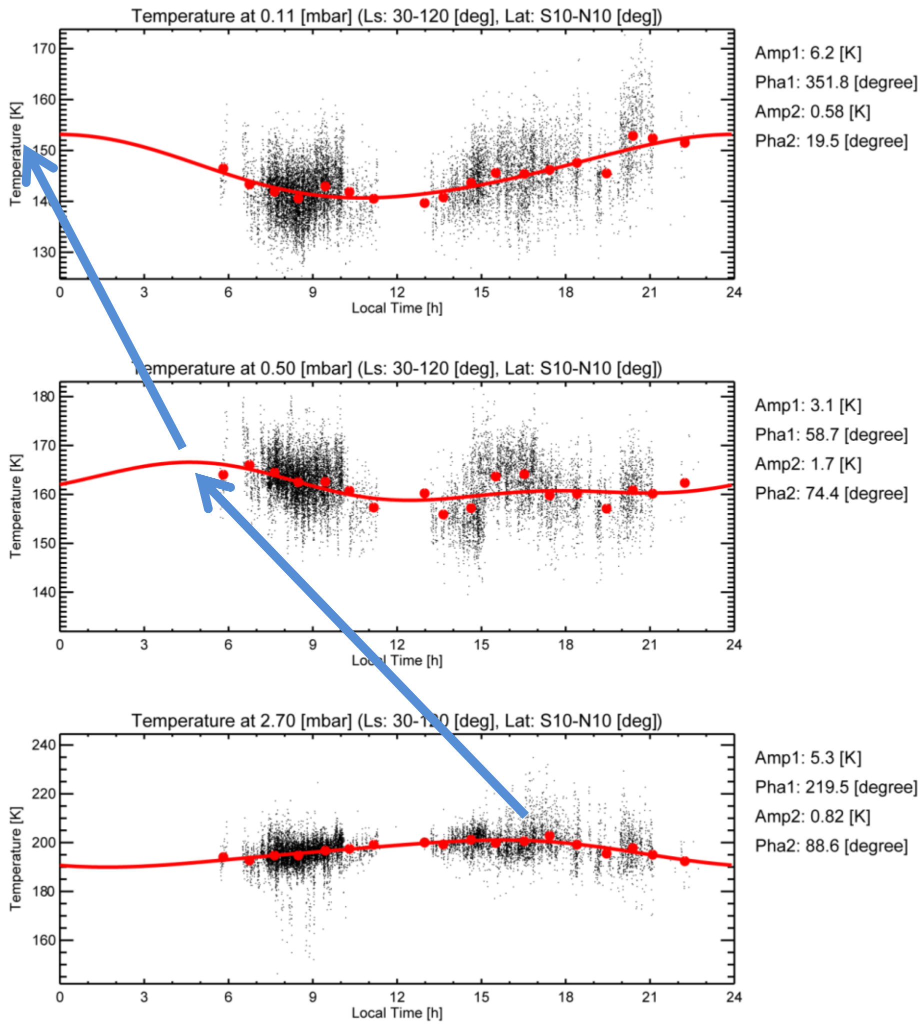


0.11mbar

0.50mbar

2.7mbar

T profile in Local-time - Latitude

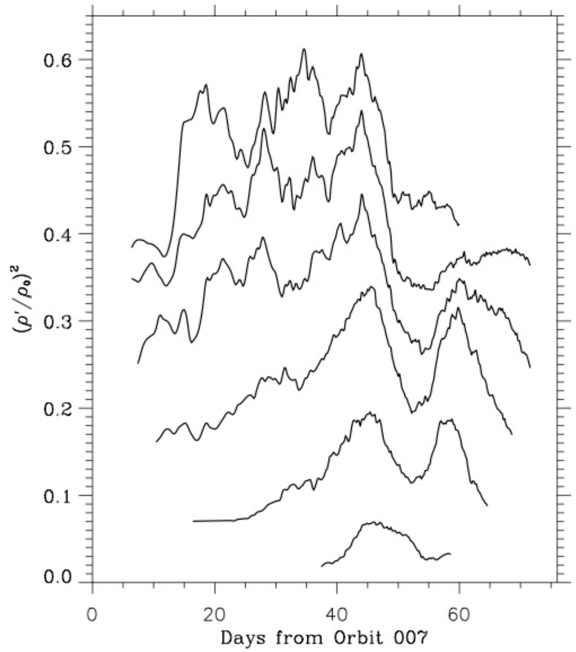


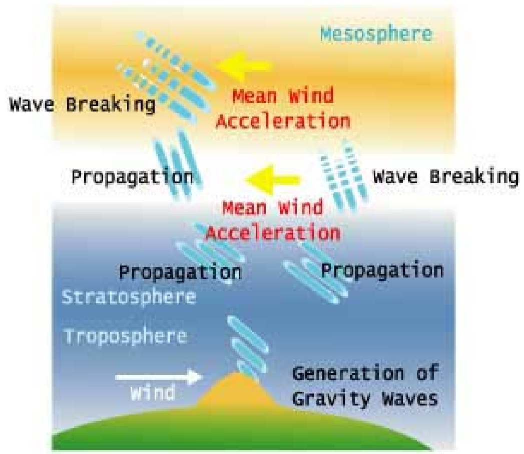
amplitudes and phases of diurnal and semidiurnal migrating tides

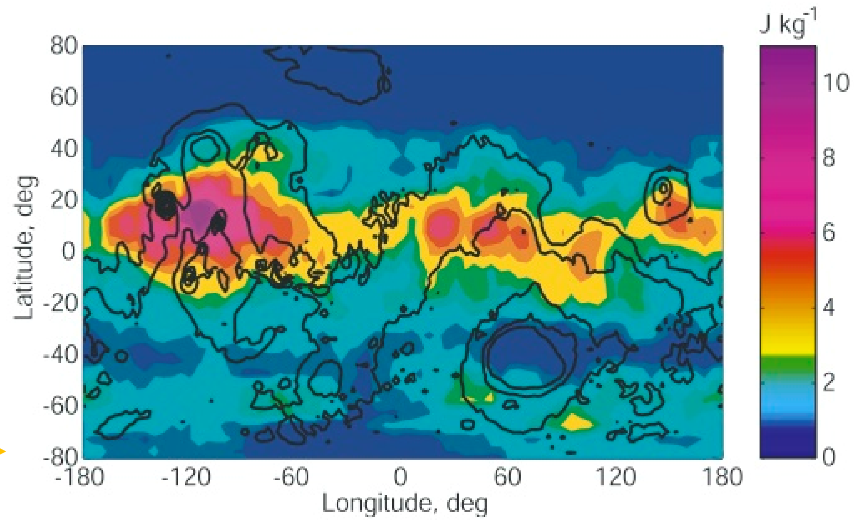
Global dynamics: Gravity Waves

(Sakanoi et al.)

~ Connection from lower to upper atmospheres ~







Martian upper atmosphere

Time variation of GWs observed during aerobraking on MGS and Mars Odyssey [Fritts et al., 2006]

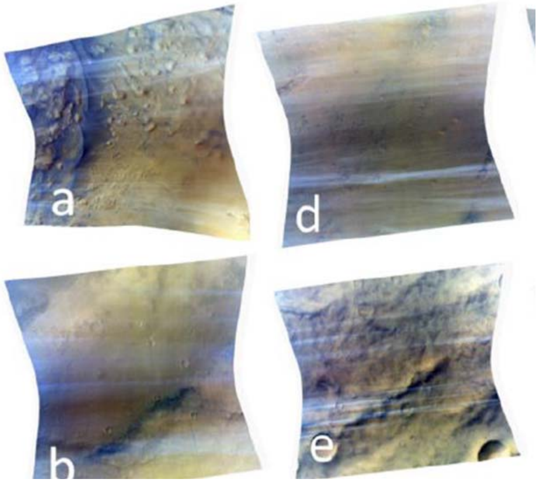
Martian lower atmosphere (10-30 km alt.)

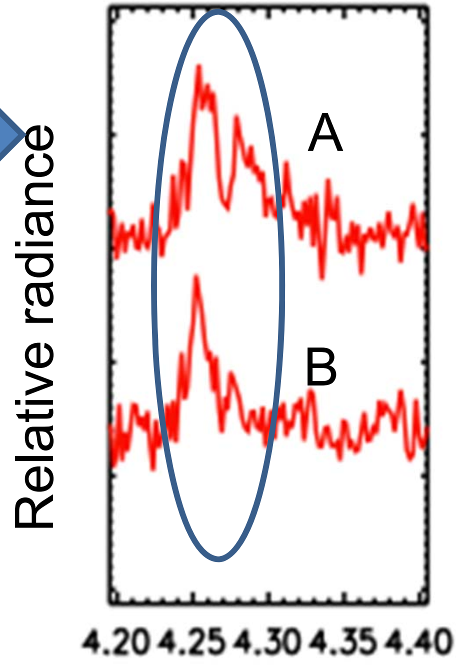
Global distribution of GW potential energy at 10-30 km alt. (vertical wave lengths < 10 km) by the radio occultation of MGS [Creasey et al., 2006]

Gravity waves (GWs) from lower atmosphere are important for main transport (large-scale winds and eddy diffusion) into the thermosphere which could be seen in Airglows

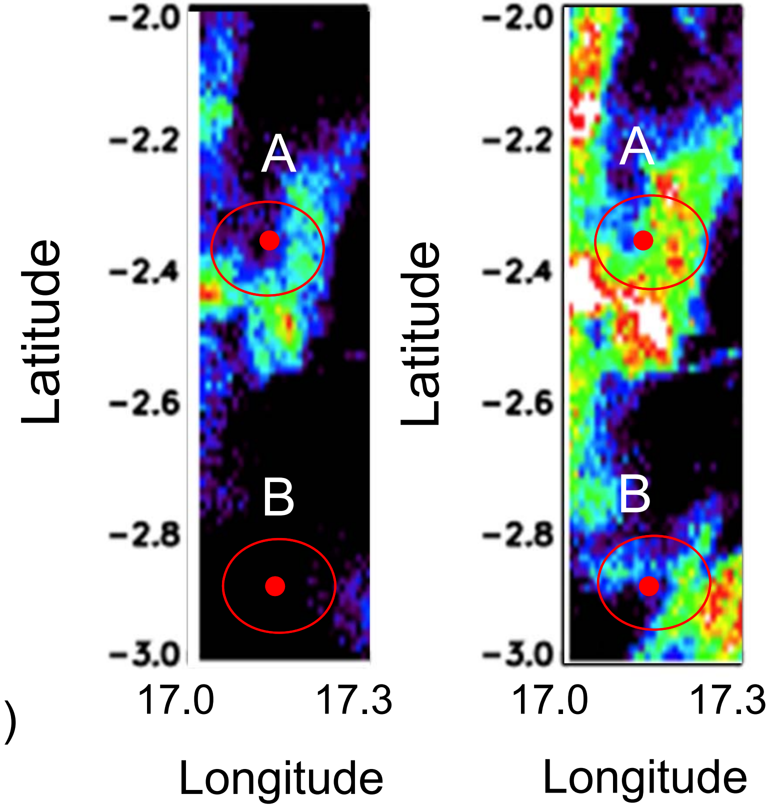
Dynamics & Minor elements: H_2O & CO_2 clouds

CO_2 Cloud features in CRISM & OMEGA





Spectra obtained by MEX/PFS



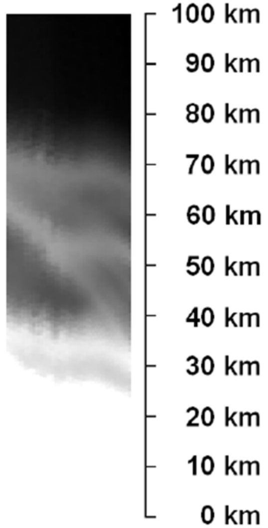
Cloud image by OMEGA

<u>Cloud particle characteristics can be followed</u> by spatial resolution better than PFS & wavelength resolution better than OMEGA.

(Y. Sato et al.)

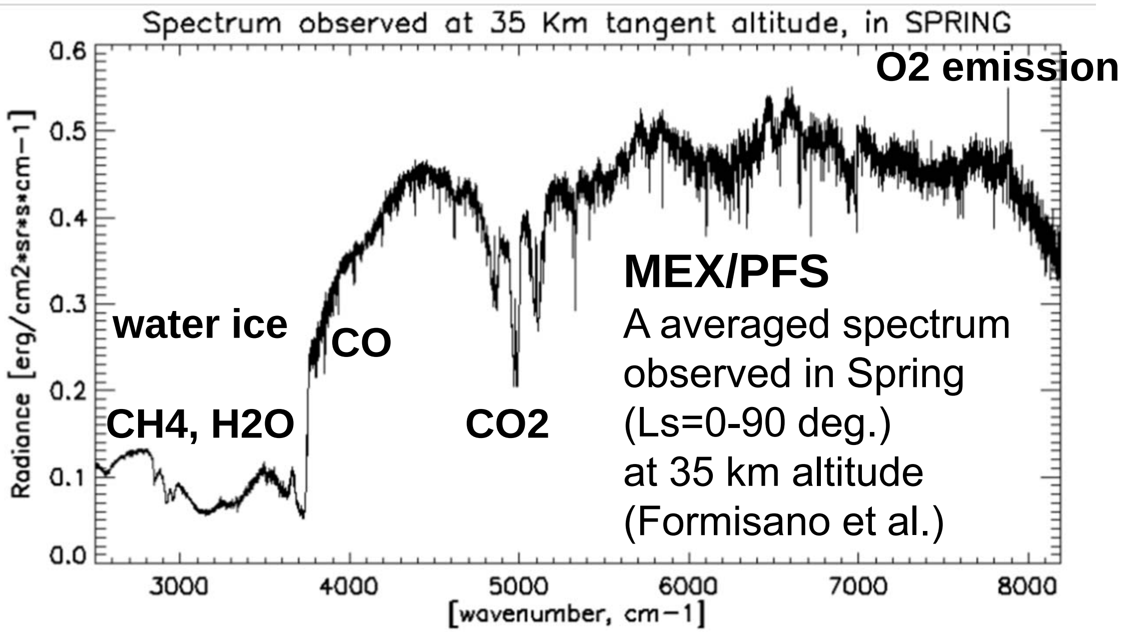
Dynamics & Minor elements: Radiative Transfer

Radiative transfer in Limb

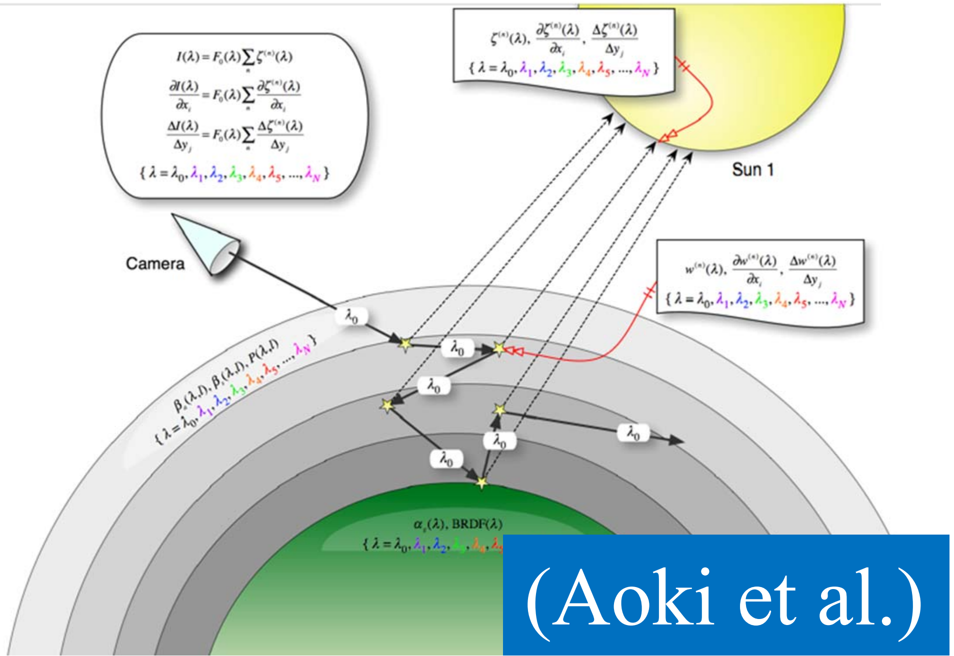


OMEGA limb measurement

(Vincendon+, JGR, 2011)



Development of Monte-Carlo scheme



based on JACOSPAR (Iwabuchi and Suzuki, 2009)

The multiple scattering term is calculated by backward Monte-Carlo method.

very fast calculation.

(Aoki et al.)

DRAMATIC M-GCM (T. Kuroda)

DRAMATIC = Dynamics, RAdiation, MAterial Transport and their mutual InteraCtions [Kuroda et al., 2005-2012]

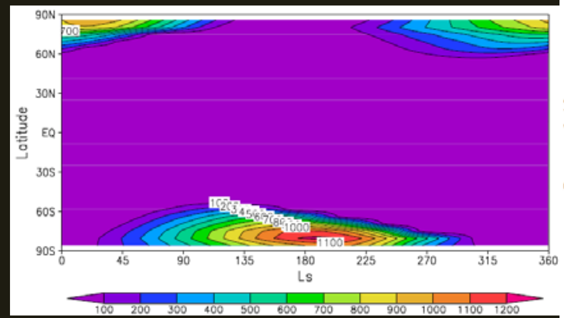
Dynamical core	CCSR/NIES/FRCGC AGCM 5.7b (MIROC 4.0) 3-dimensional primitive equations, spectral solver
Resolutions	Horizontal resolution of ~5.6°×5.6° (T21) (grid interval of ~333km at the equator) 49 layers with σ levels, the model top is at ~100km.
Radiation	CO_2: Absorption and emission in MIR (15μm, 4.3μm) NIR NIR absorption (only LTE effects) Dust: Absorption, emission and scattering in 0.2-200μm
Tracers	Water vapor, water ice, CO_2 ice
Surface	Realistic topography, albedo, thermal inertia and roughness, deposition of CO_2 and water ice

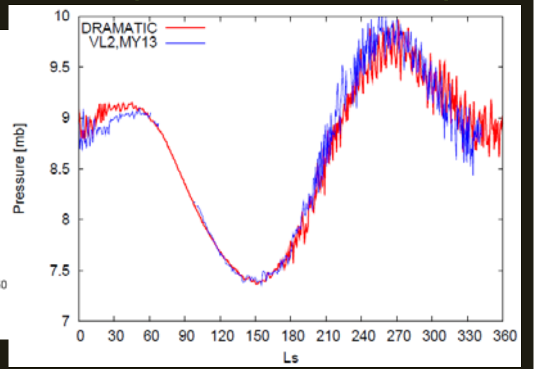
DRAMATIC M-GCM (T. Kuroda)

- Baroclinic waves
  (Kuroda et al., 2007)
- Semiannual oscillations
  (Kuroda et al., 2008)
- Polar warming with global dust storm
  (Kuroda et al., 2009)
- CO_2 snowfall in winter polar atmosphere
  (Kuroda et al., 2013)

.....

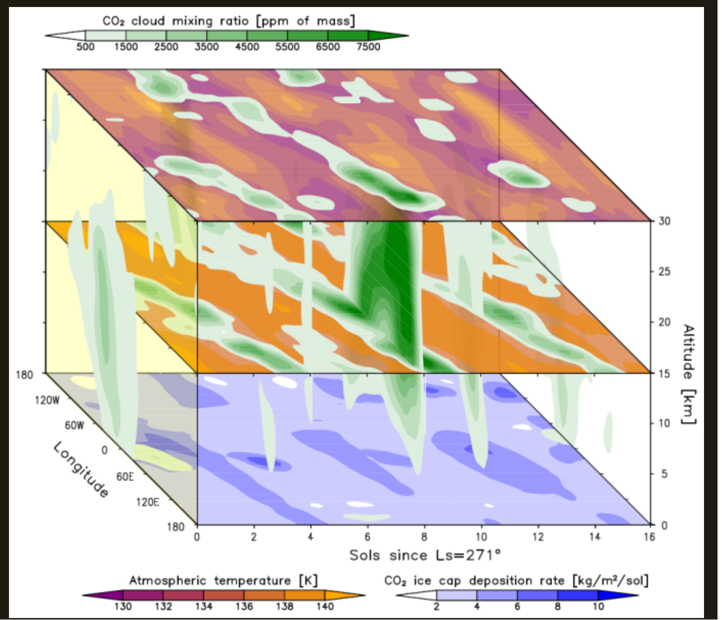
Annual variances of CO_2 polar cap thickness and surface pressure
(in comparison with Viking observation)

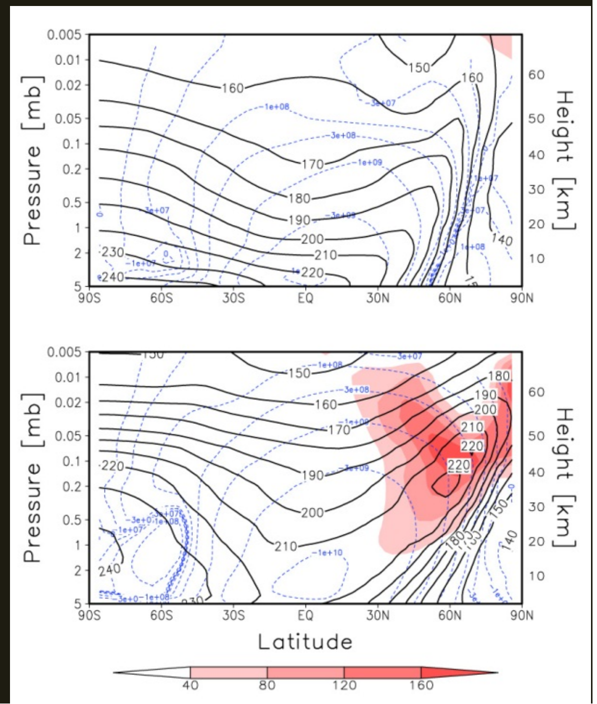




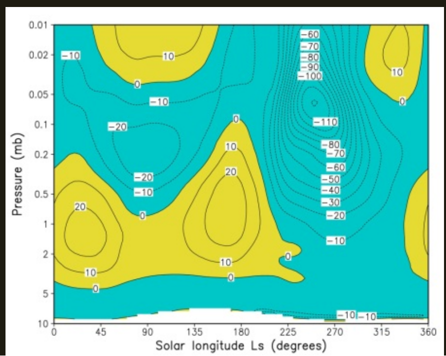
Change of atmospheric fields with global dust storm

Simulated CO_2 Snowfall at 80° N





Semiannual oscillations on equator



HDO/H_2O ratio search by SUBARU/IRCS
[Aoki et al.]

**[benefit]
simultaneous coverage
of wide spectral range
by Cross-Disperser Echelle**

Table. IRCS Instrument parameters (L-band echelle)

	IRCS	CSHELL
Spectral coverage	~80cm^{-1} x 5 bands	~10cm^{-1}
Spectral resolution	~20,000	~40,000
Slit	0.14"x6.69"	0.47"x30"
Pixel Scale	0.06"	0.2"

(1) 2.94–3.01 μm
telluric H2O lines

(2) 3.10–3.18 μm
telluric H2O lines

(3) 3.28–3.36 μm
telluric H2O lines
telluric CH4 lines

(4) 3.49–3.57 μm
telluric CH4 lines

(5) 3.72–3.81 μm
telluric HDO lines
Martian CO2 isotope lines

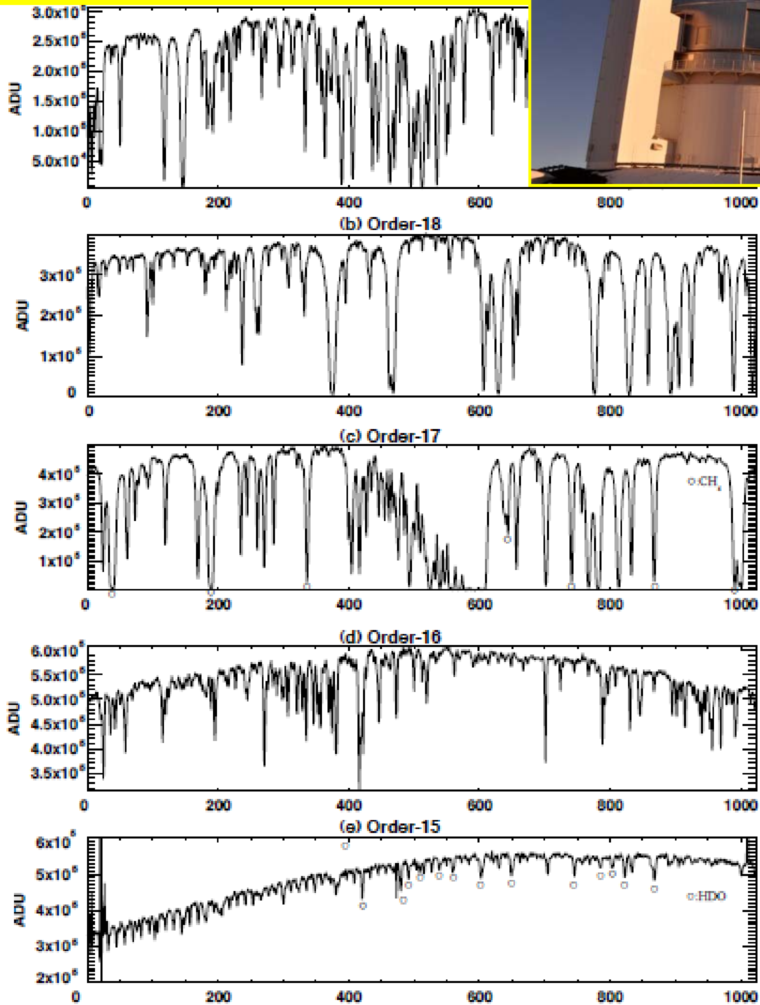


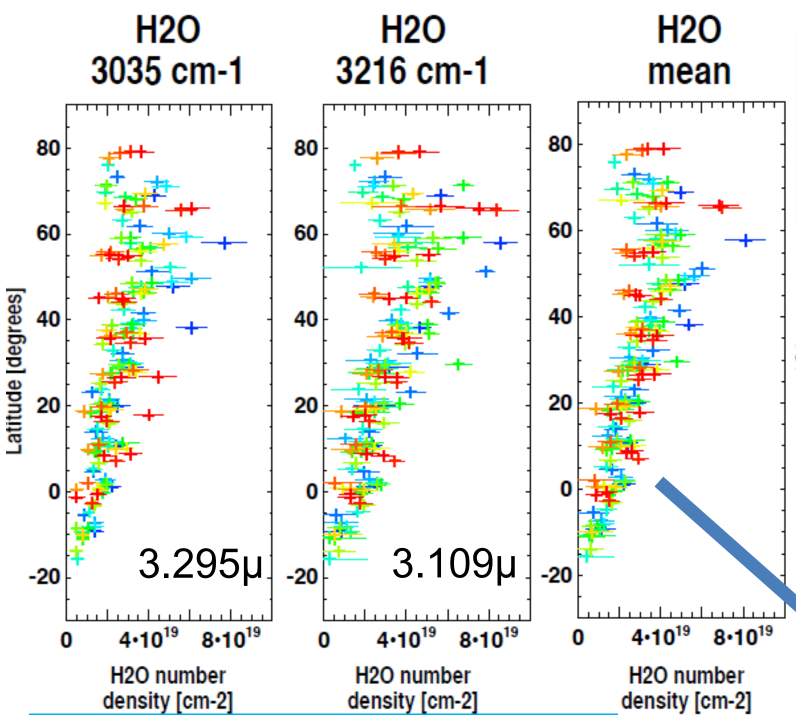
Fig. An example of measured spectrum by IRCS (5-min integration).

Owing to the wide spectral coverage, we could performed absolute simultaneous observations of multiple CH_4, H_2O, HDO, and CO_2 lines.

Martian environment studies executing & planning at Tohoku Univ.

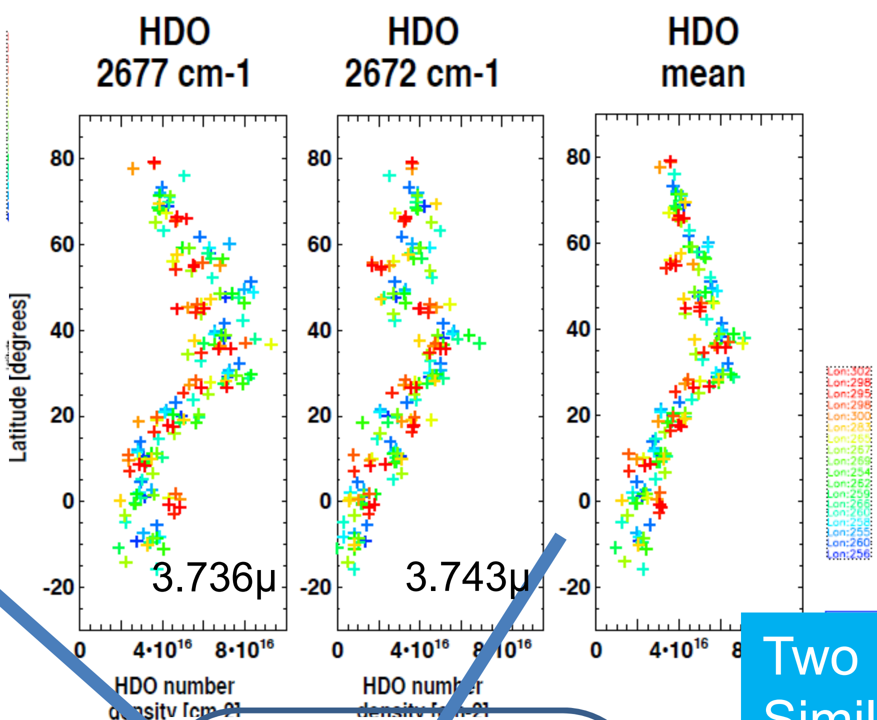
Y. Kasaba et al. (IKI, Oct 2013)

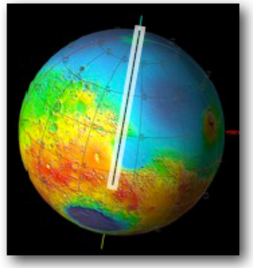
H2O latitudinal distribution



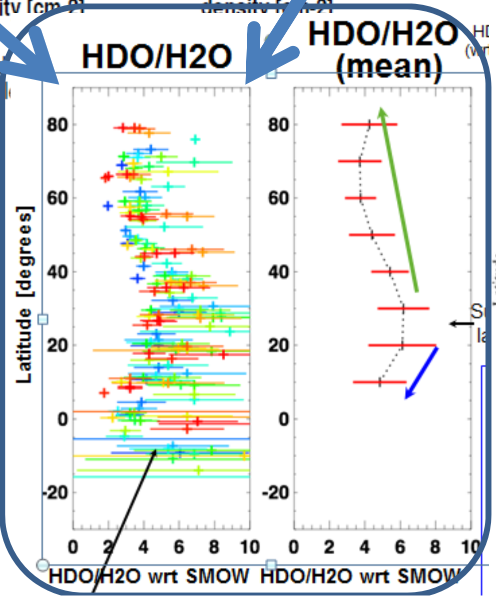
Two H2O lines showed
Similar characterristics

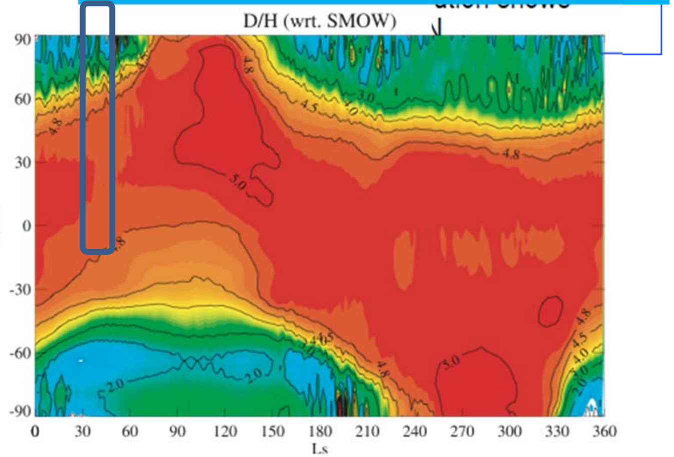
HDO latitudinal distribution (Ls=52)





Two HDO lines showed
Similar characterristics





H2O/HDO ratio,
not far from
Frank's model estimation

HDO/H2O latitudinal distribution (Ls=96)

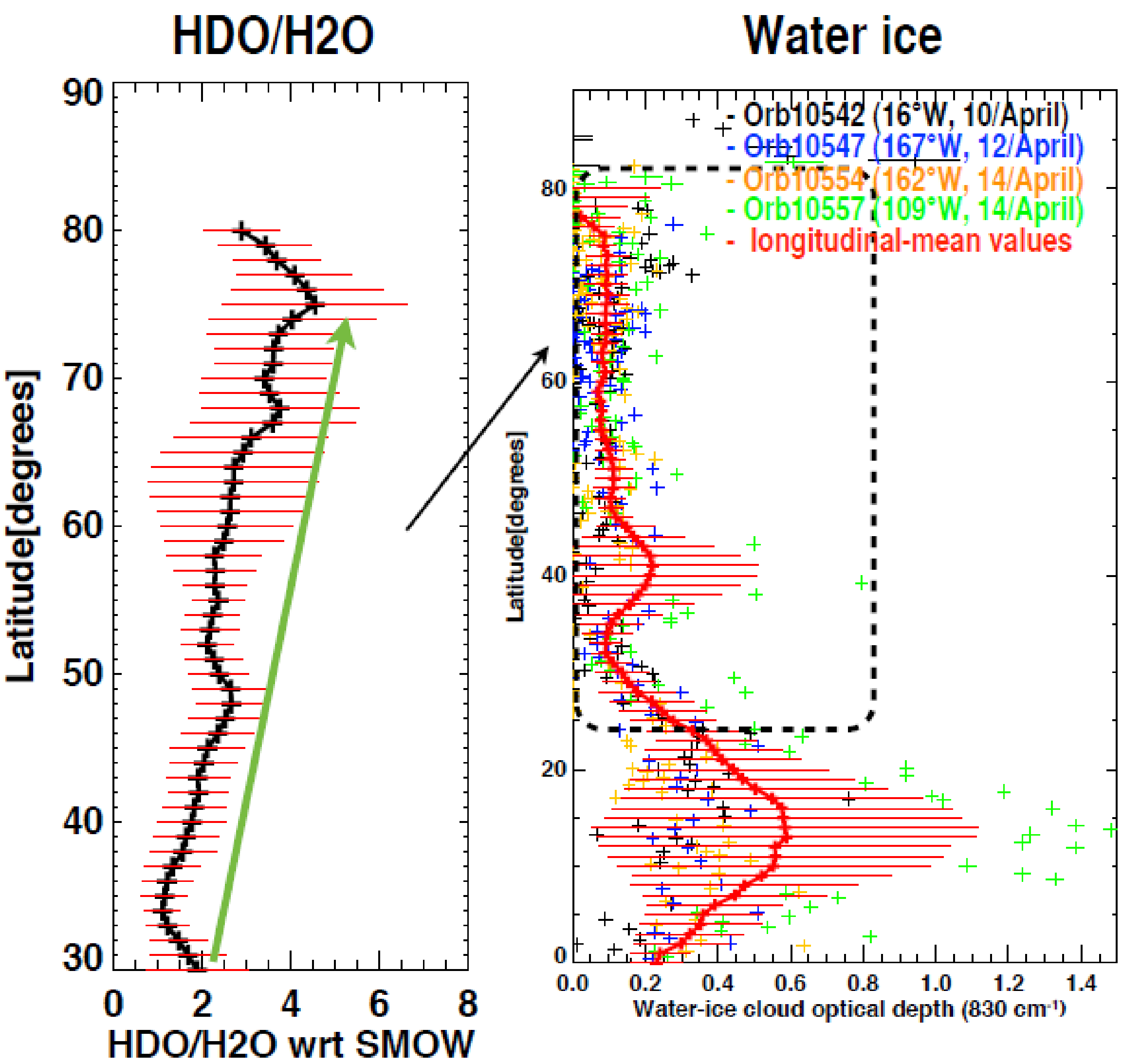


Fig. Latitudinal distributions of HDO/H2O ratio (left) water ice cloud optical depth at 830 cm-1 retrieved from the PFS/LWC observations (right). Differences in color shows the PFS orbits (different date and longitude). The red curve represents their mean values and standard deviation.

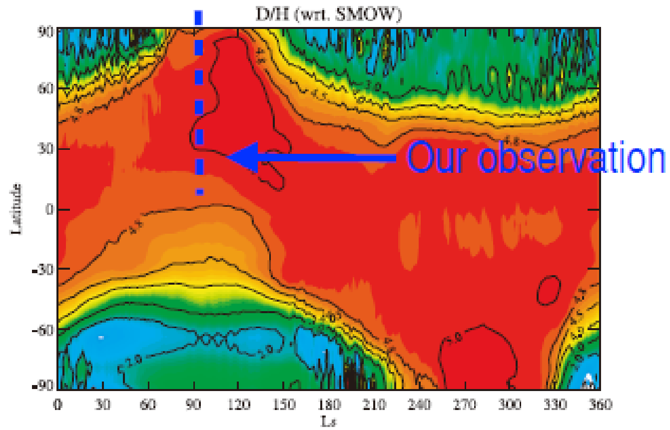


Fig. The predicted annual cycle of HDO/H2O ratio calculated by the GCM (Montmessin et al., 2005).

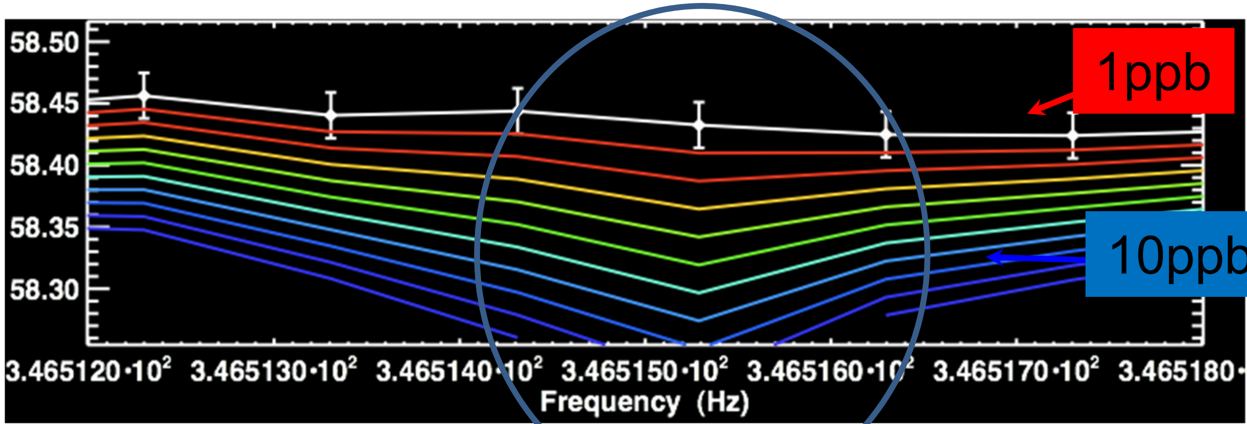
In Ls=96 (northern summer), HDO/H2O shows higher latitudinal dependences to the model.

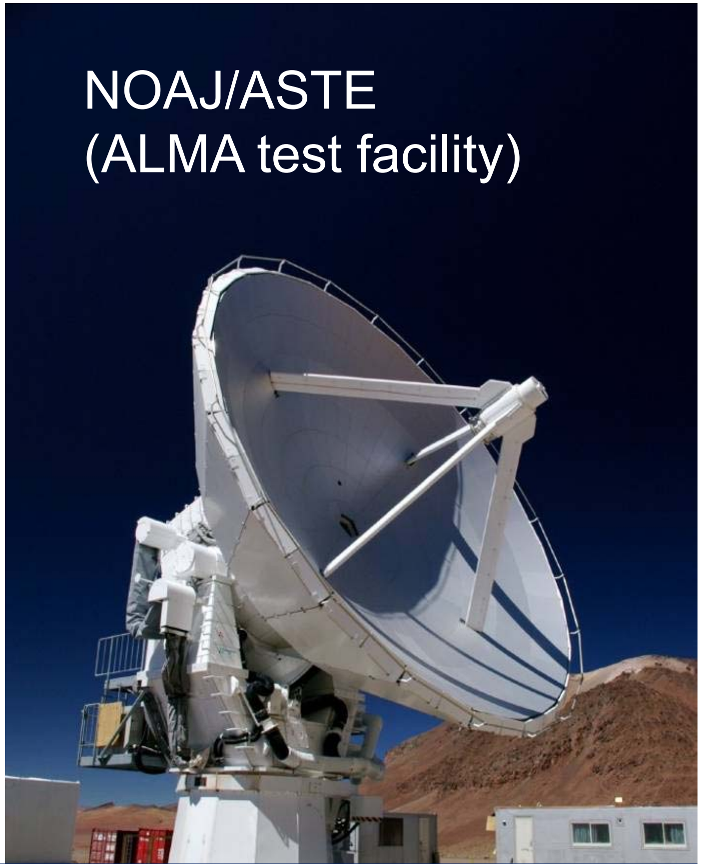
We are considering it with Kuroda's model, but also hope to discuss with Frank.

SO_2 search for the volcanic activity signs

[Nakagawa et al. 2009]

'no sign' --- < 1ppb





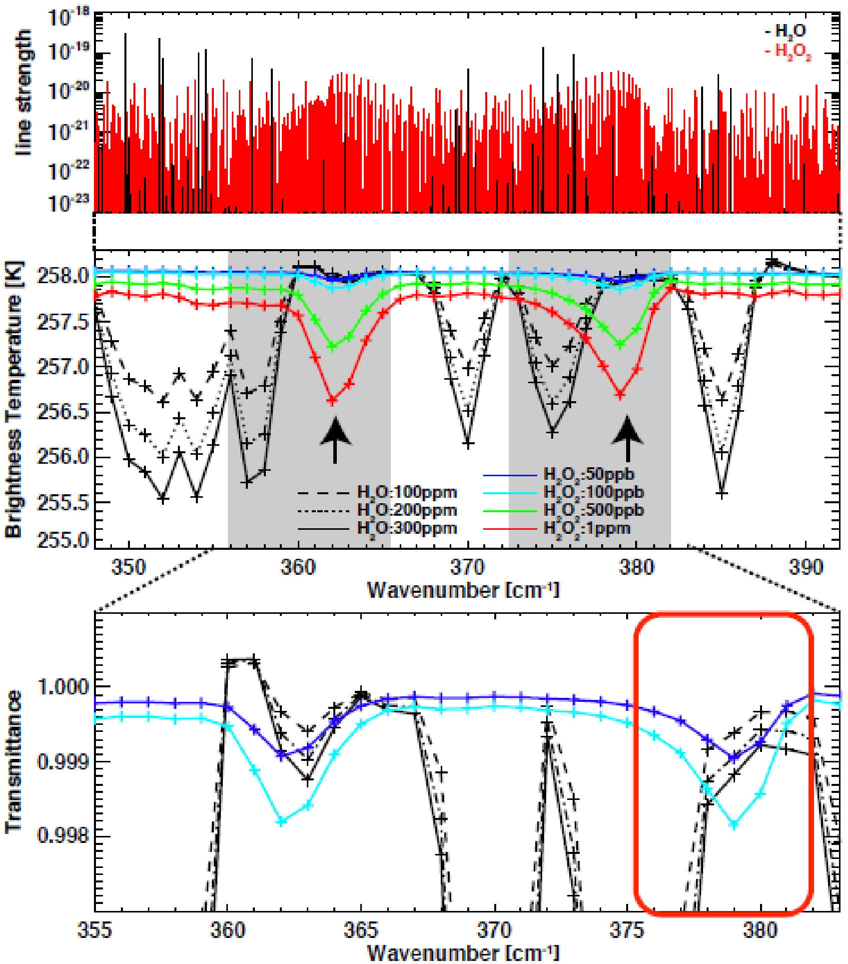
including HDO & H_2O topics,
ALMA & orbiters should override these kinds of issues.

- **Very low level of volcanic gas or the gas dissociated from sulfates for several years & no seasonal variation.**
- **If "CH_4/SO_2" ratio is same as Earth's, CH_4 from the inner crust is much few.**

H_2O_2 search for the CH4 variation factors

[Aoki et al.]

✓This study used the LWC data in the spectral range from 350 to 400 cm^{-1} (25.0–28.5 um), which includes the strong absorption lines of H_2O_2 and H_2O (no CO2, dust features).



←**Line strength (HITRAN 08)**

←**Synthetic spectra (PFS resolution)**

✓ Note that the band around 362 cm^{-1} is overlapped with weak H_2O band (363 cm^{-1}) and strongly contaminated by the side-lobes of water lines (360–361 cm^{-1}). Therefore, we mainly used 379 cm^{-1} band to search of H_2O_2 and investigate its seasonal variation.

Fig. (Top) Line strength of H_2O and H_2O_2 obtained from HITRAN08. (Middle and Bottom) Synthetic spectra for the spectral resolution of the apodized PFS spectrum. The black and color curves show the spectra with

by long-term MEX/PFS data in order to get 'AVERAGED' view.

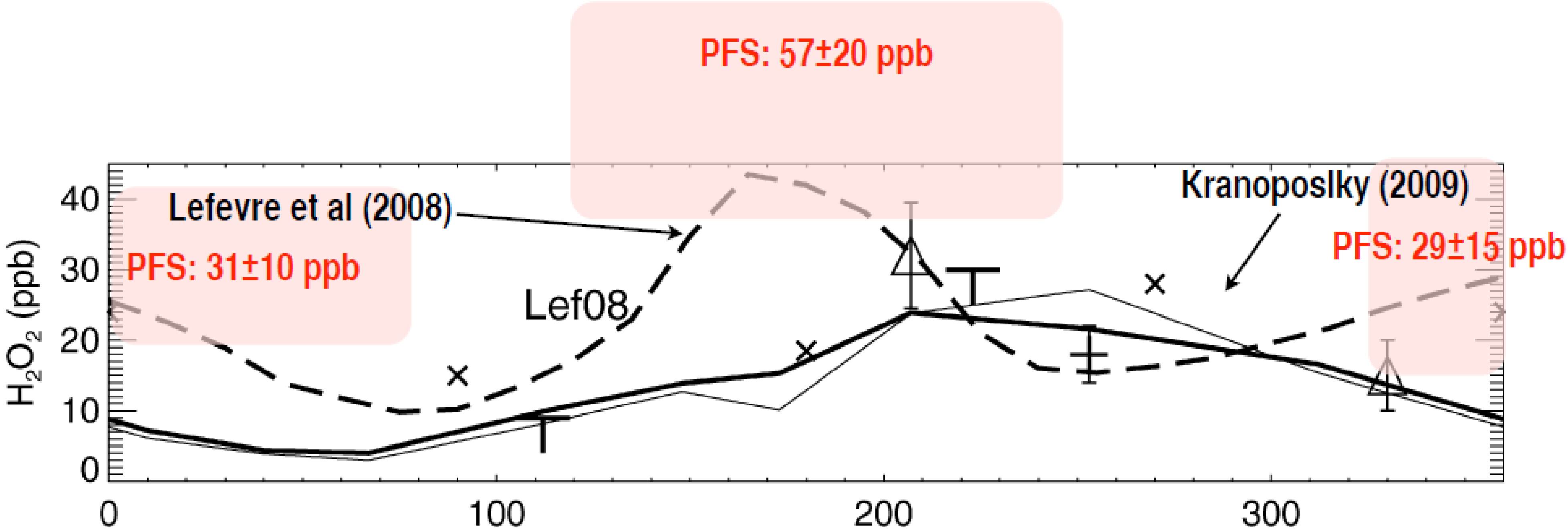
This wavelength was a unique solution in MEX/PFS capability.

H_2O_2 search for the CH4 variation factors

[Aoki et al.]

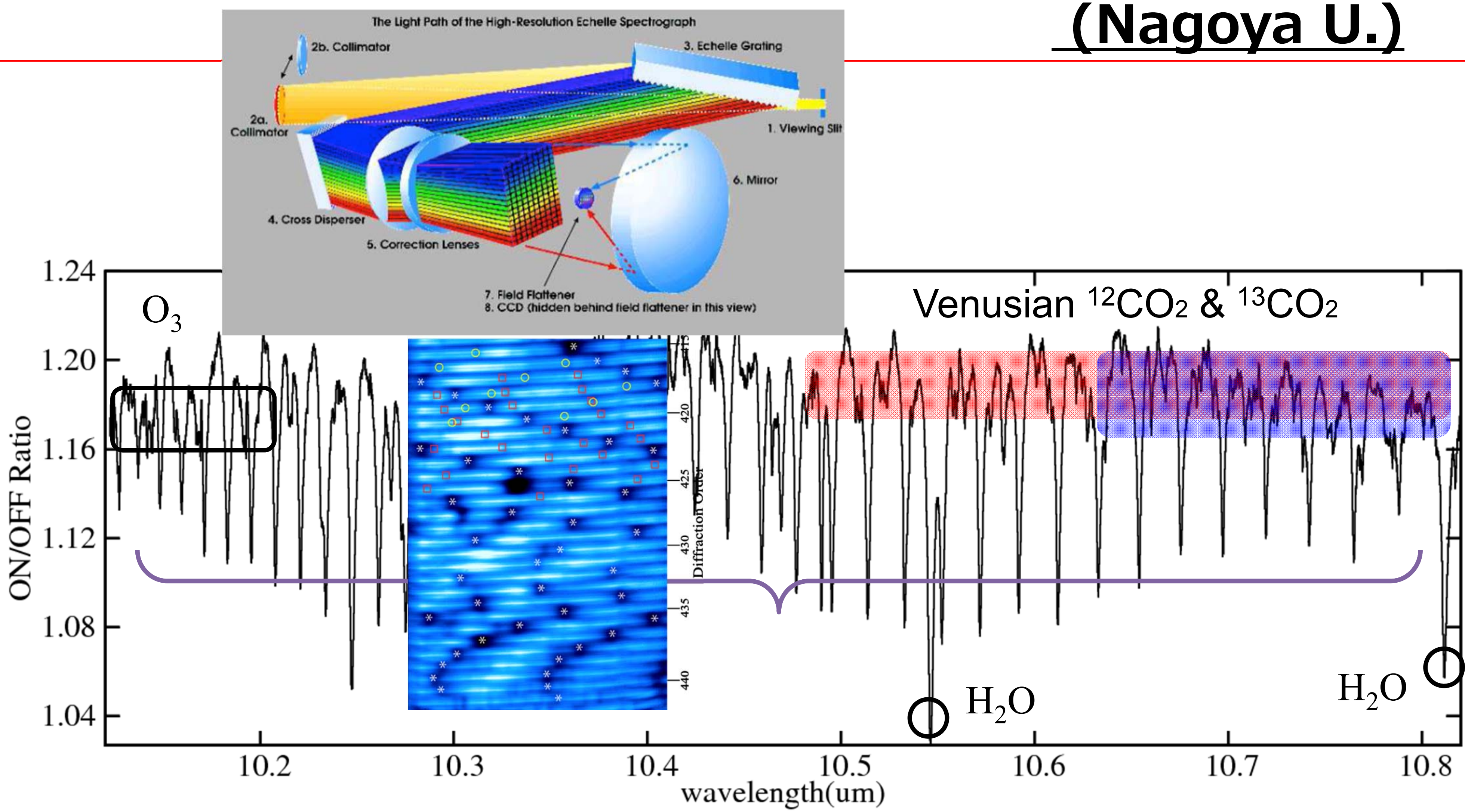
✓ We found that the mixing ratio of H_2O_2 increased at *Ls* = 120–240°, and it is correlated with H2O variation.

* Krasnopolsky (2009). and Lefevre et al (2008) predicted seasonal variation of H2O2.
* The differences between two models are coefficients of (1) H2O2 production (HO2+HO2) and, (2) heterogenous loss (H2O2 + water ice).



The amount of H2O2 is insufficient for CH4 variation.
'Better wavelength resolution' can fix this issue.

$^{12}C/^{13}C$ by GICMICS @ SUBARU: MIR Echelle (Nagoya U.)



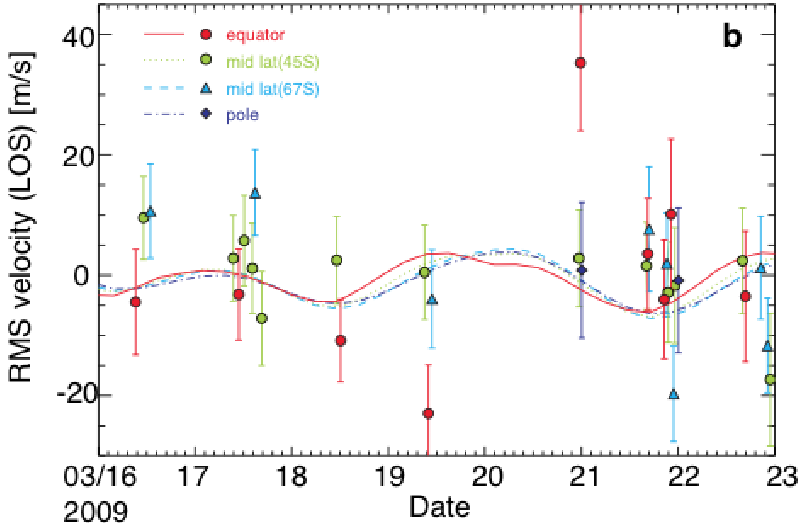
- $^{12}CO_2$ $(\nu_3+\nu_2) \leftarrow (\nu_1+\nu_2)$
- $^{13}CO_2$ $\nu_3 \leftarrow \nu_1$

Test data: Venusian spectroscopy

[10.1-10.8 um, λ/dλ ~ 40,000]

Global dynamics: Velocity field

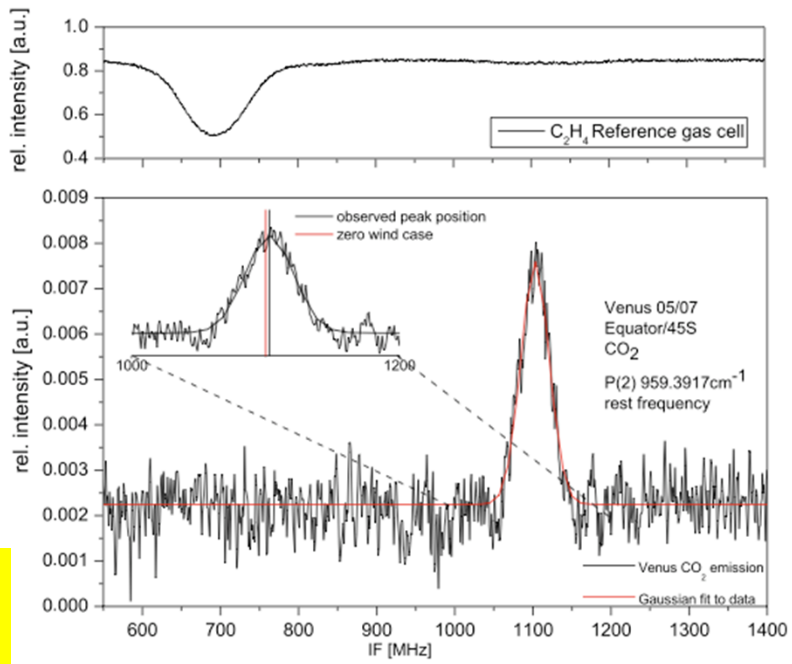
(Nakagawa et al.)



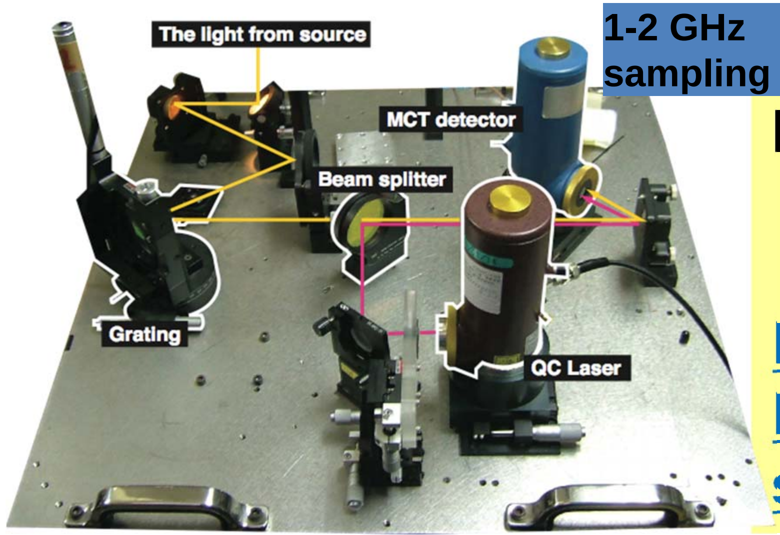
Variation of wind in the Venusian Mesosphere [Nakagawa et al. 2013]

Velocity of Targets
$\lambda/d\lambda > 10^7$
($3 \cdot 10^8$ / 30 [m/s])

Line profile of Targets
$\lambda/d\lambda > 3 \cdot 10^5$
(30THz/100MHz)



Example of the CO_2 non-LTE emission line [Sornig et al., 2008]



1-2 GHz sampling

by Ground-based IR-heterodyne measurement with Univ. Koln group.

It did not have the continuous facility.
But from Summer 2014, we will continuously set it to a telescope @ Haleakala, Hawaii.

Tohoku University Haleakala "Very-Small" Observatory
in Haleakala High-Altitude Observatories (Univ. Hawaii)

Altitude: 3055m
Clear sky rate 80%

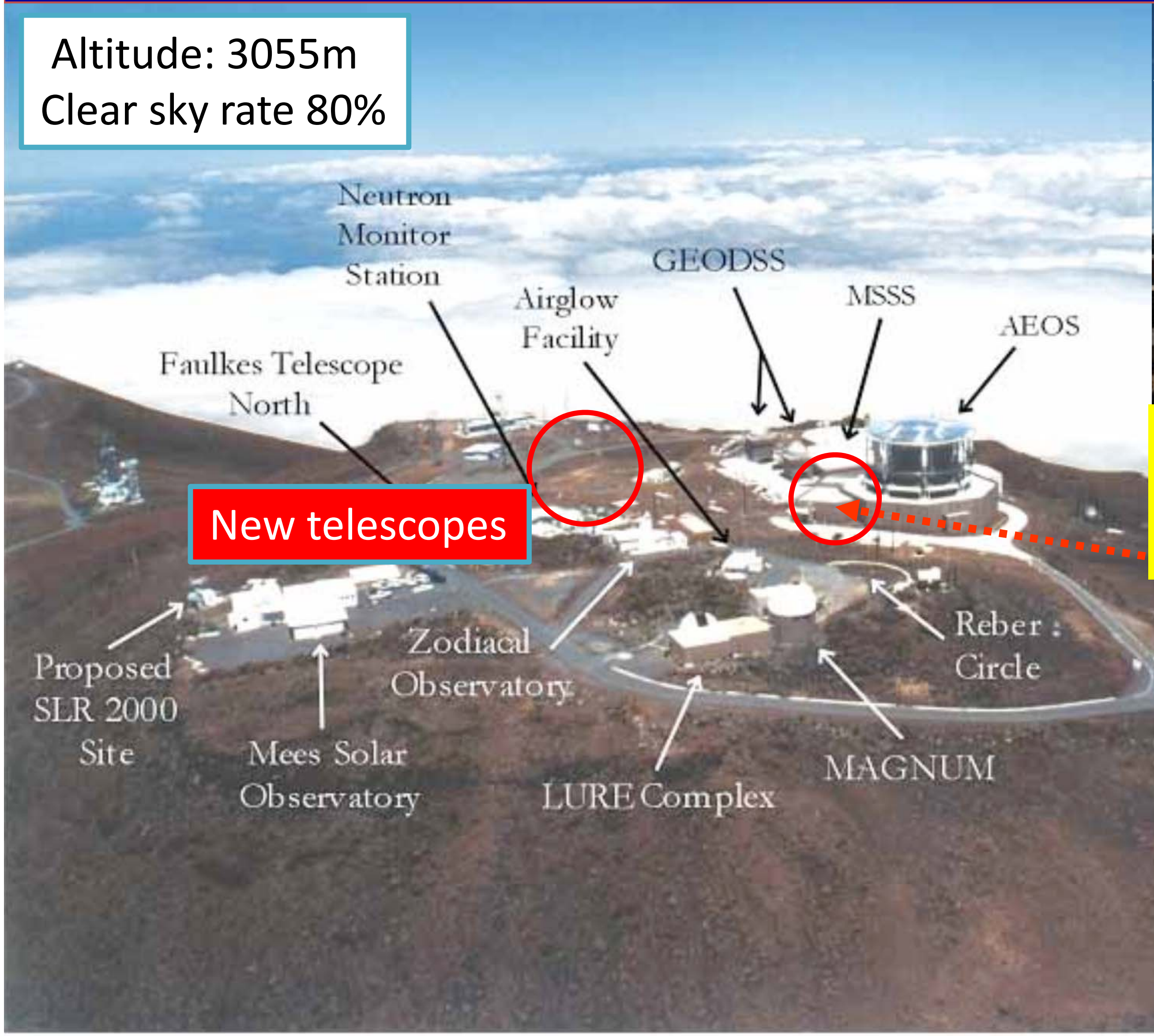
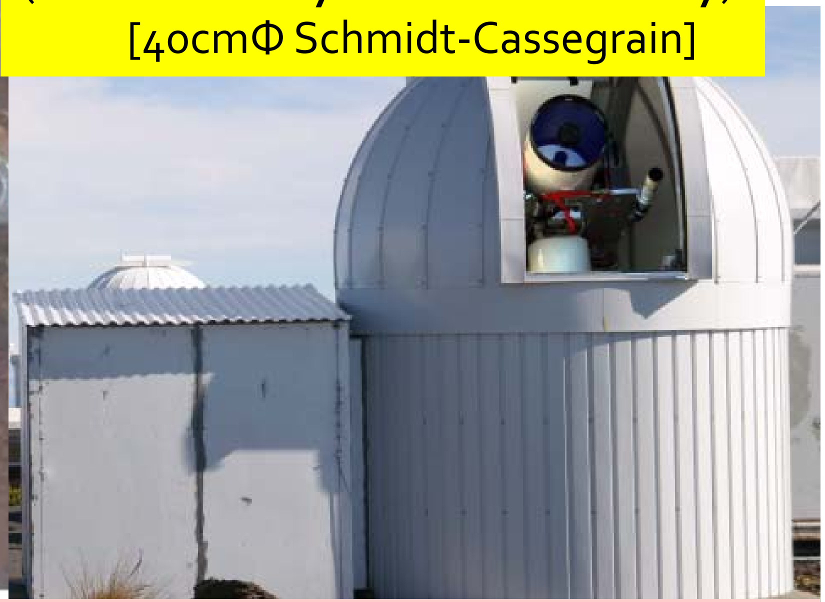


Figure 2-3. Aerial of Haleakalā Observatories Looking

HVSO / Tohoku Univ.
(**Haleakala Very Small Observatory**)
[40cmΦ Schmidt-Cassegrain]

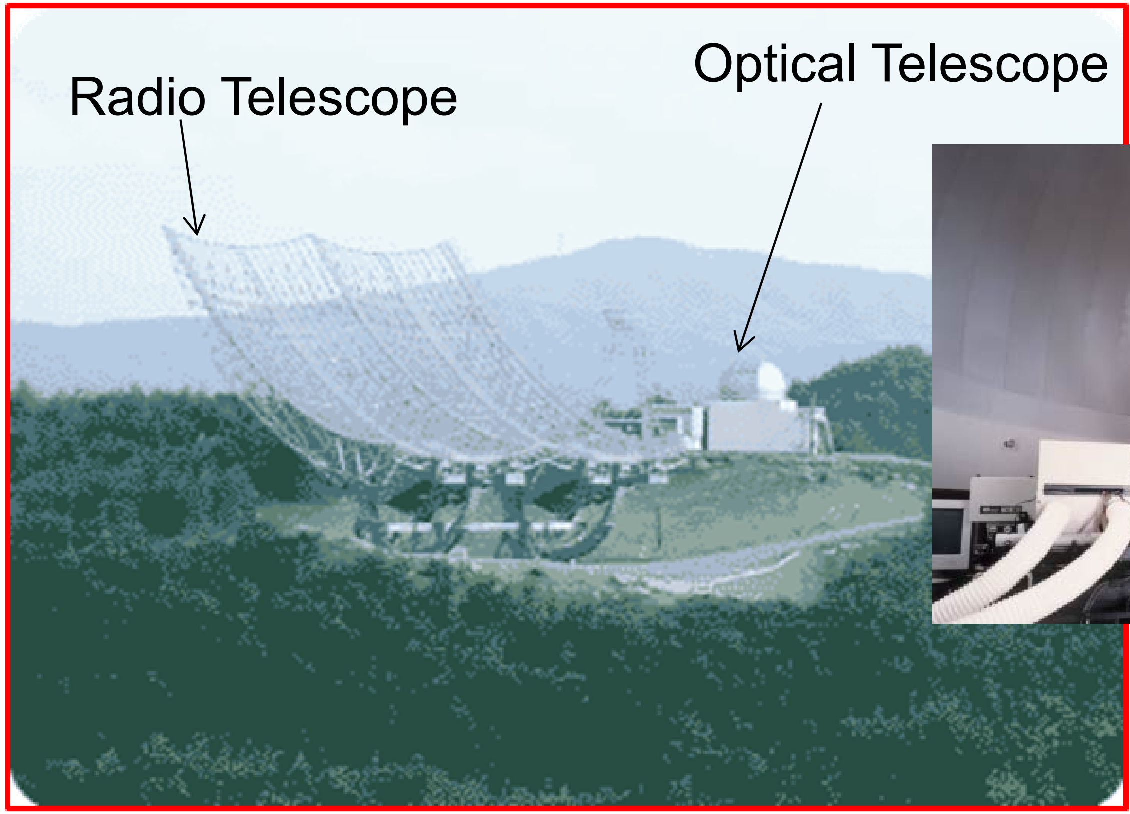


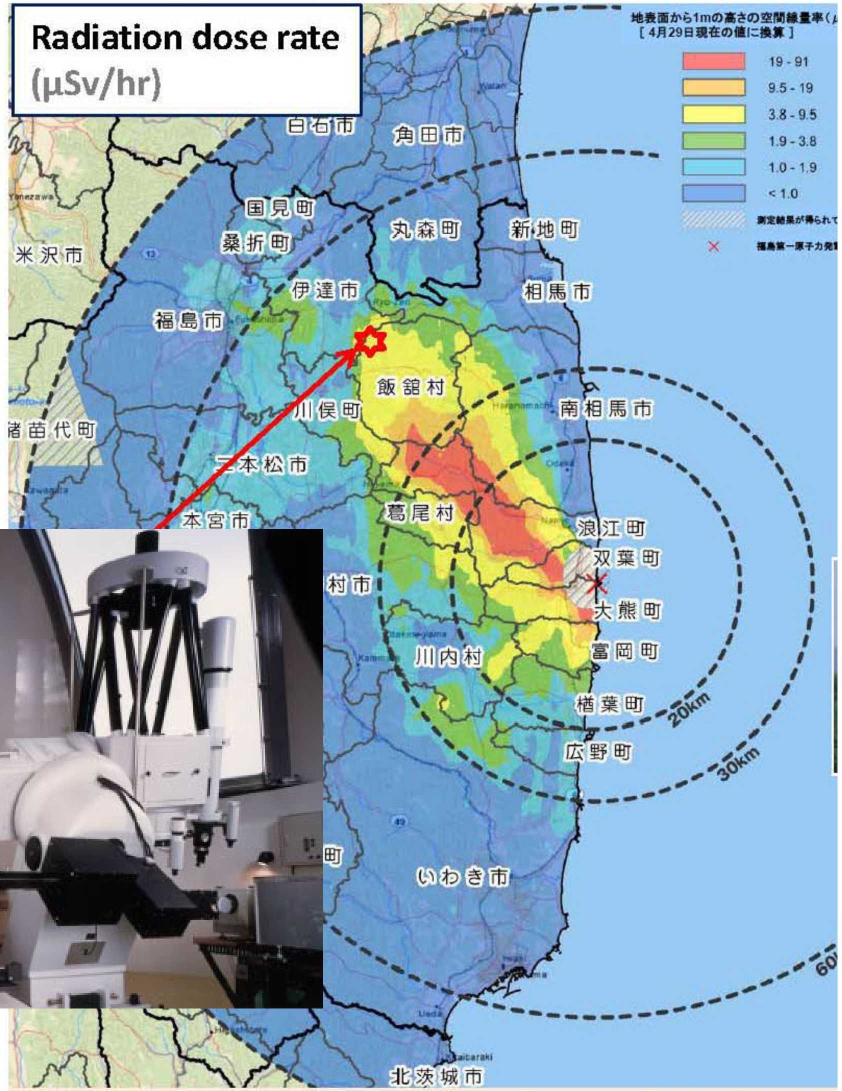
remotely operated from our University

Iitate 60-cm telescope: move to Haleakala, Hawaii

<u>Radiation dose rate</u>

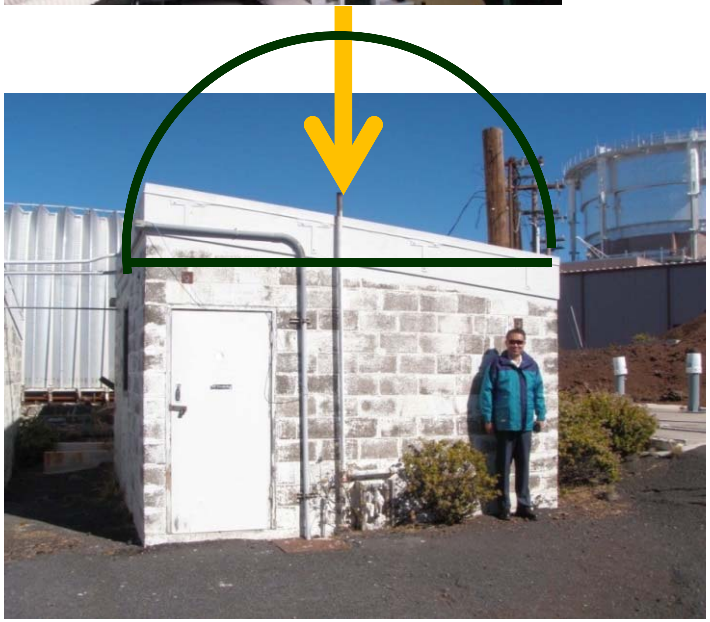
- Current value : 3μSv/hr ~ <u>30mSv/yr</u>
  (5 μSv/hr in 2011)
- Inside a building: 0.2 μSv/hr





http://www.mext.go.jp/component/a_menu/other/detail/

Tohoku Univ. 60cm Observatory moved to Haleakala



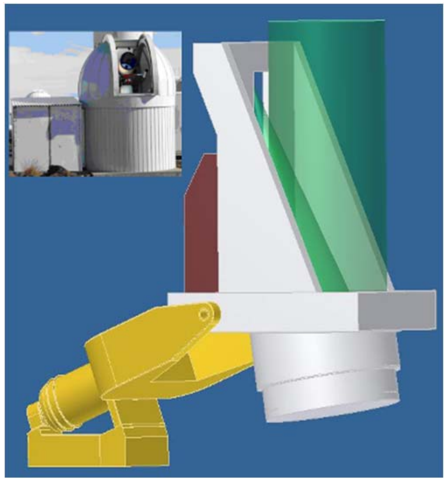
First light: in summer 2014

PLANETS 2m Off-axis Planetary & Exoplanetary telescope

(by institutes from 6 countries)

- Wide dynamic range
  Off-axis with 1/100λ smoothness
- with **Coronagraph & AO**
- Polarization: **Equatorial mount**

PLANETS JapanHawaiiEuropeTelescope



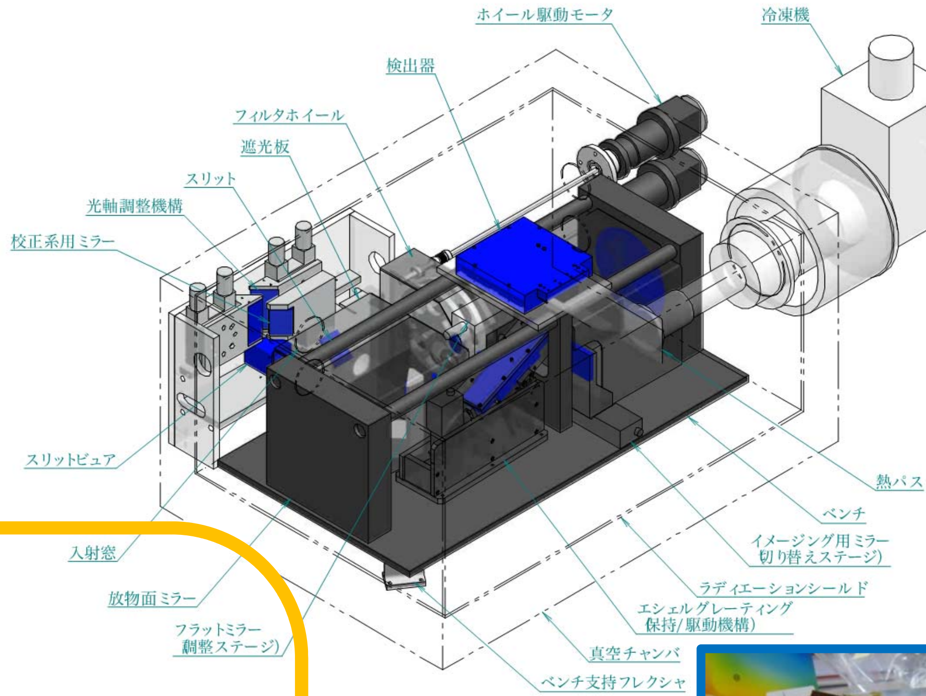
First light: end of 2015 ?

Flexible operations! (Ex) support campaign, Dust storm, ...

Instruments

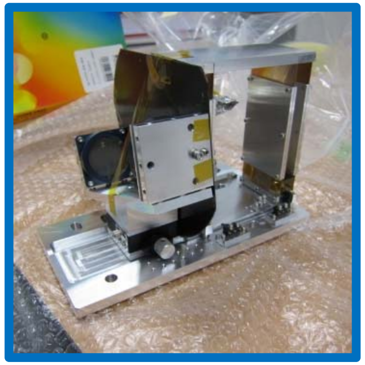
- Near-infrared Echelle imaging spectrograph

Detector:	1k x 1k CCD
FOV:	10’ with optical fiber
Resolution :	~50,000 in 500-900nm



- NIR high-resolution Echelle Spectrograph

Detector	256 x 256 InSb
FOV	50’ or filter imaging
Resolution	~50,000



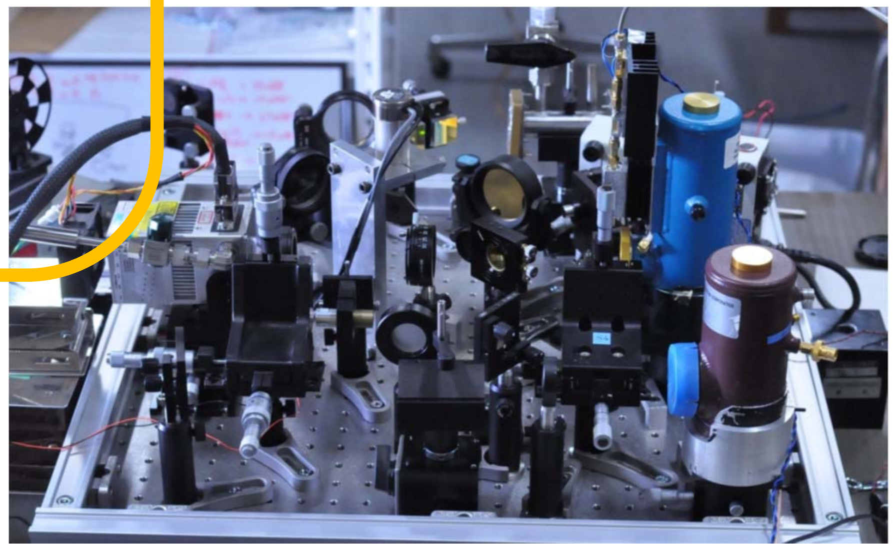
- Mid-infrared heterodyne super high-resolution spectrometer

  Detector: MCT photo-diode

  Resolution : > 1,000,000

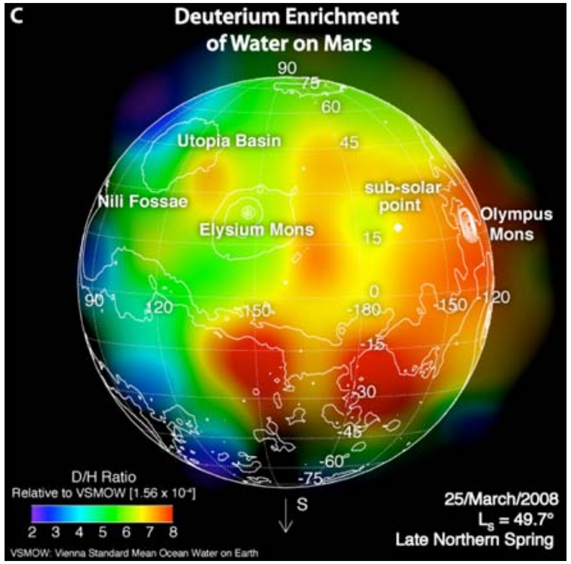
  Wavelength : 7-11 µm

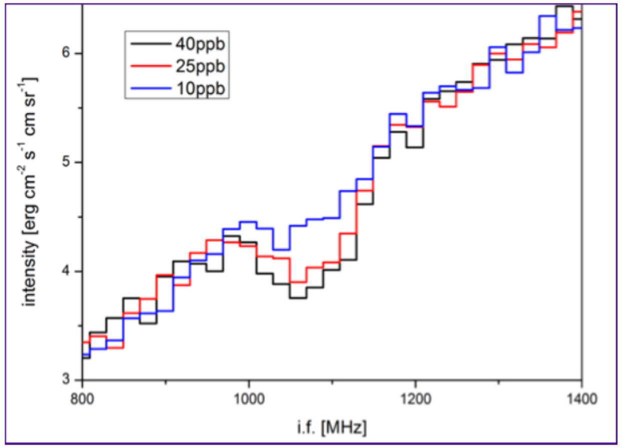
+ MIR Echelle



Heterodyne Target: with R>1,500,000

Isotope map, HDO/H2O (Villanueva+, 2008)

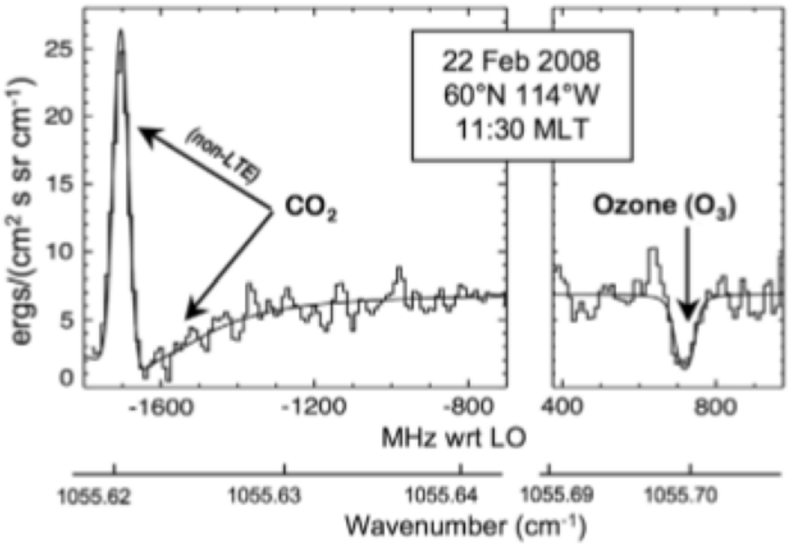


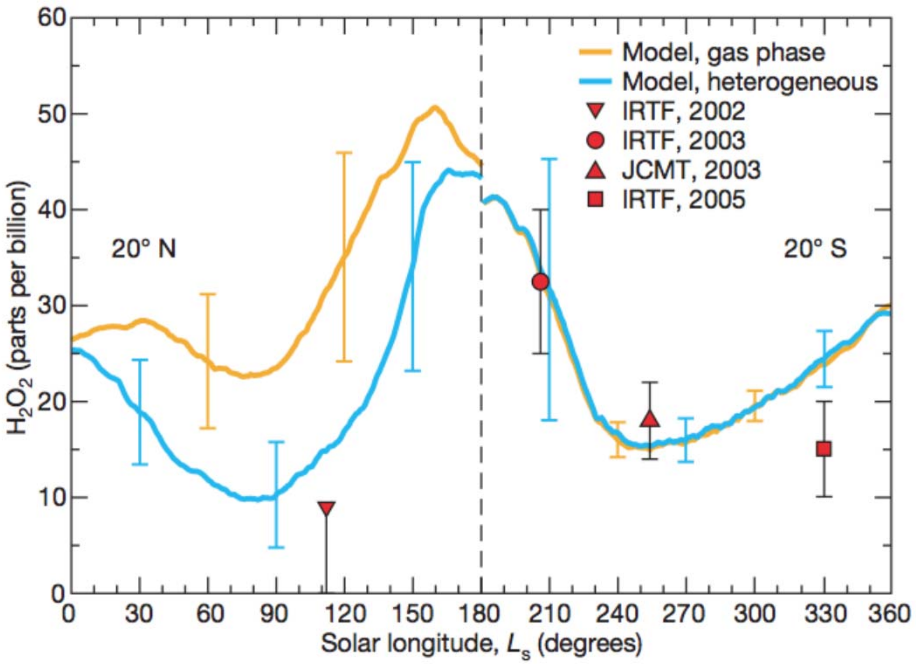


Detection of CH4

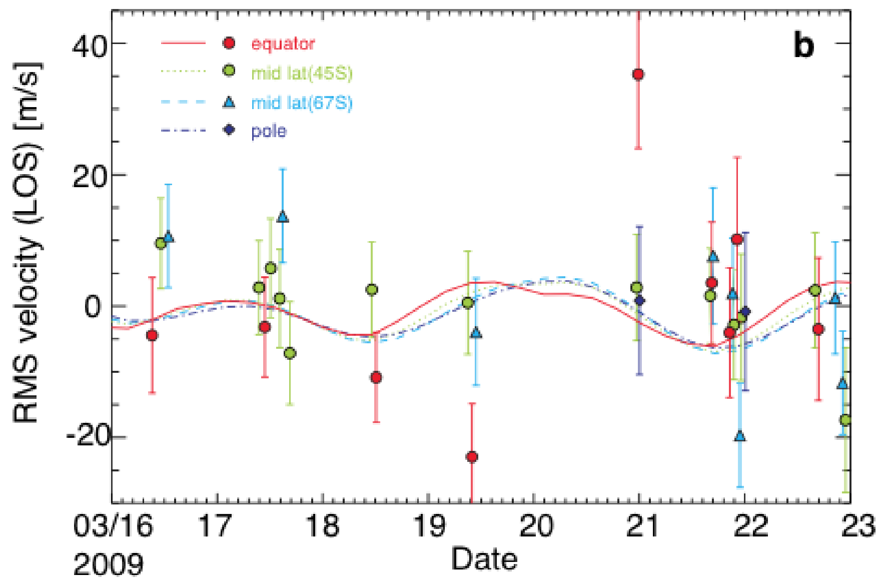
(Sonnabend+, 2009)

IRTF/HIPWAC (Fast+, 2009)





(Nakagawa+, 2013)

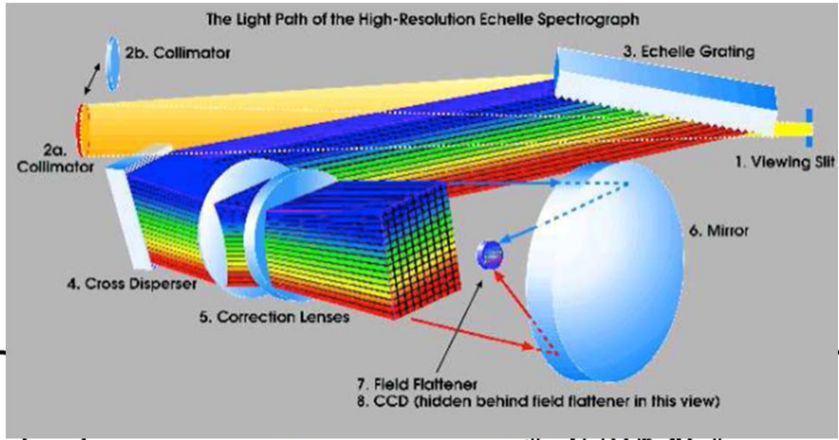


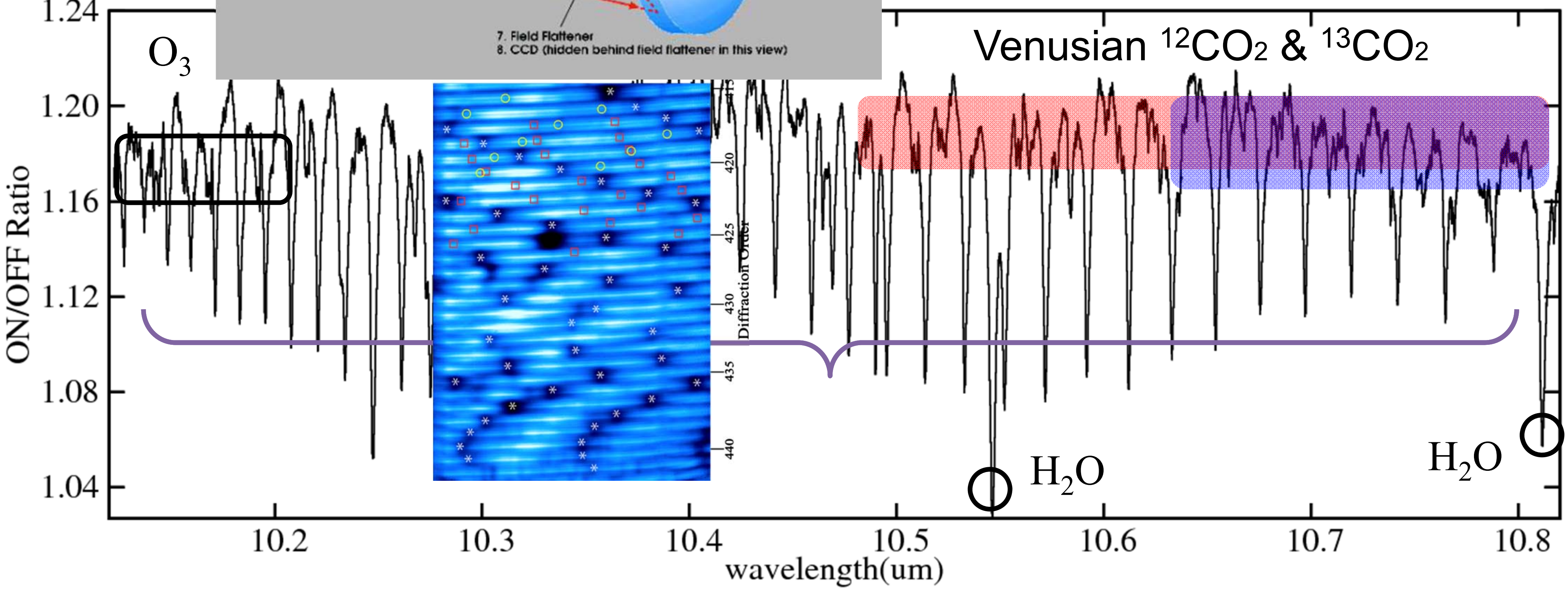
Seasonal var. of trace gas, H2O2 (Lefevre+, 2009)

Mesospheric wind and T

GICMICS @ SUBARU: MIR Echelle (Nagoya U.)

installed to SUBARU-8.2 in this fall as a test



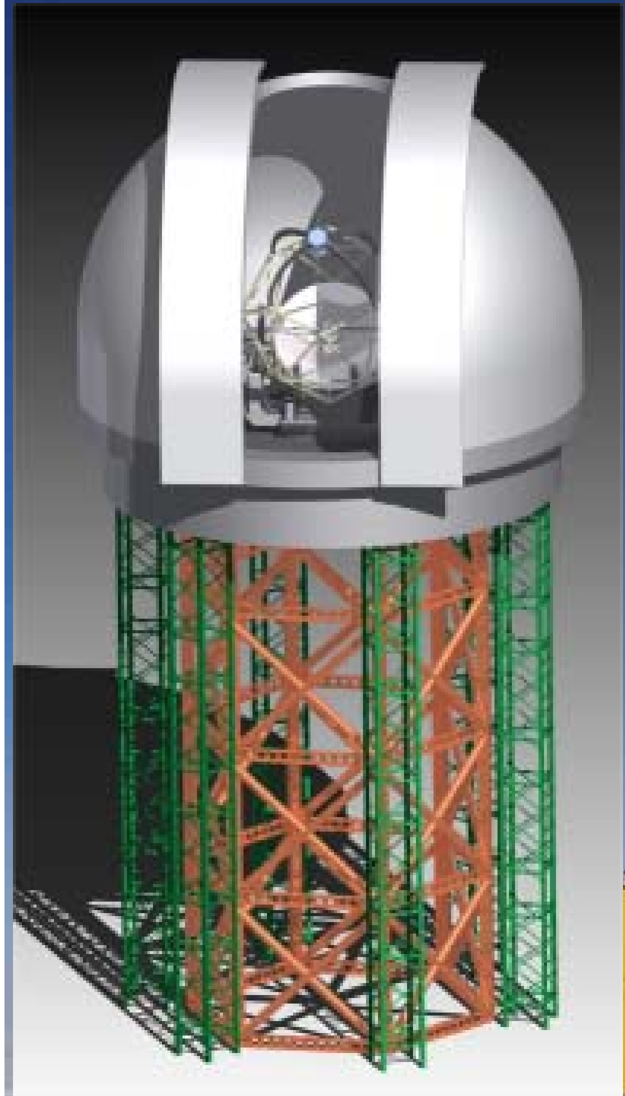


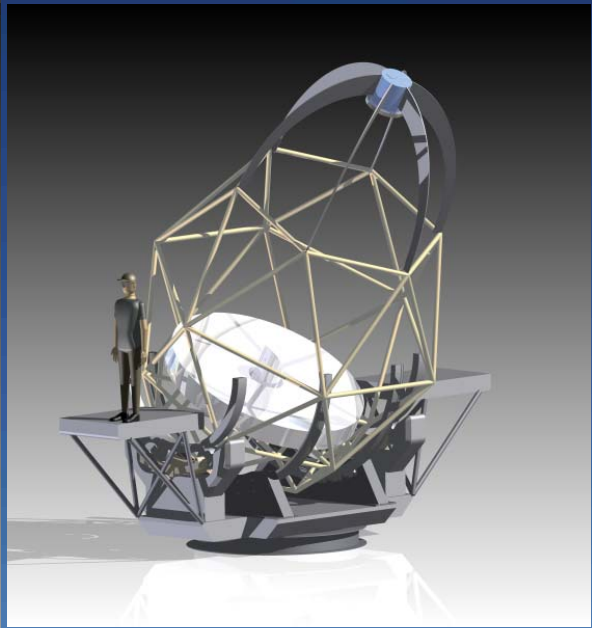
- $^{12}CO_2$ $(\nu_3+\nu_2) \leftarrow (\nu_1+\nu_2)$
- $^{13}CO_2$ $\nu_3 \leftarrow \nu_1$

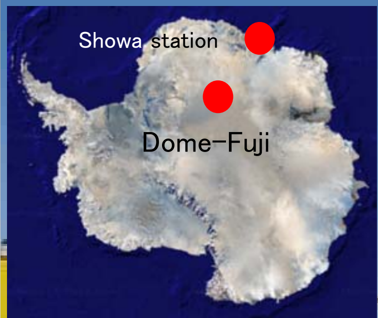
Test data: Venus (in 2012)

[10.1-10.8 um, λ/dλ ~ 40,000]

2.0m telescope @ Antarctica



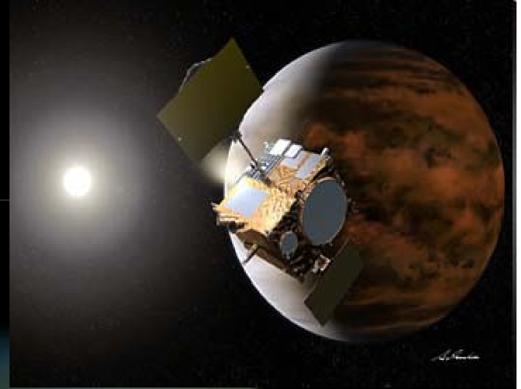




Test facility (2010-)
40cm telescope
at 11m height structure

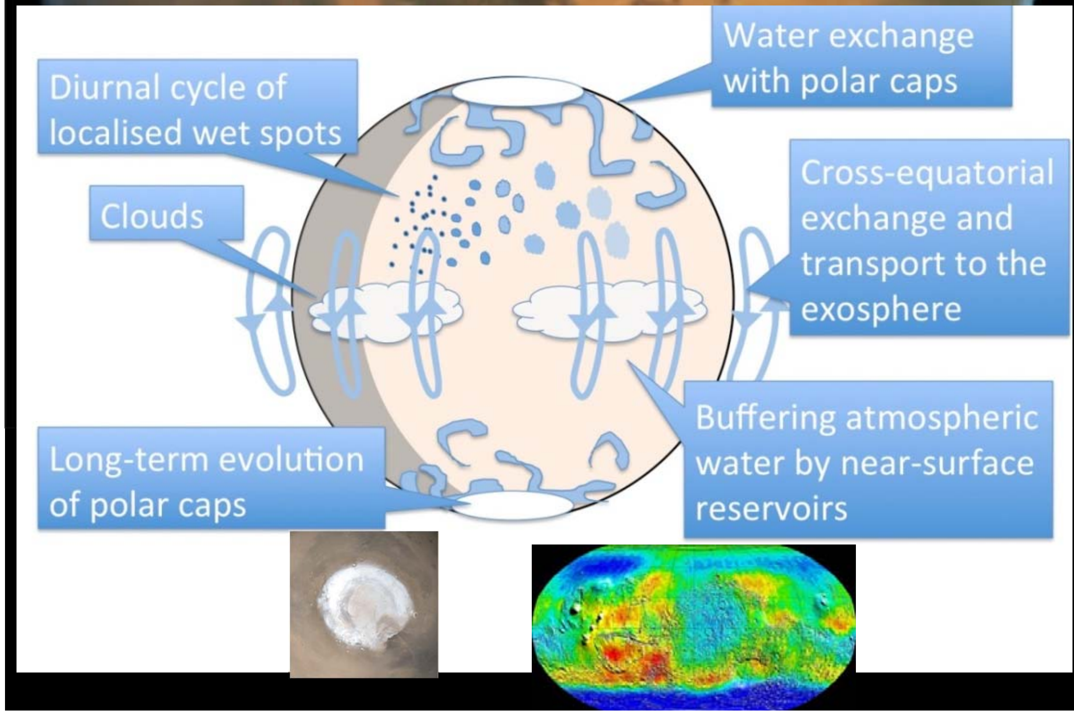
Development from 2015 (tbc)

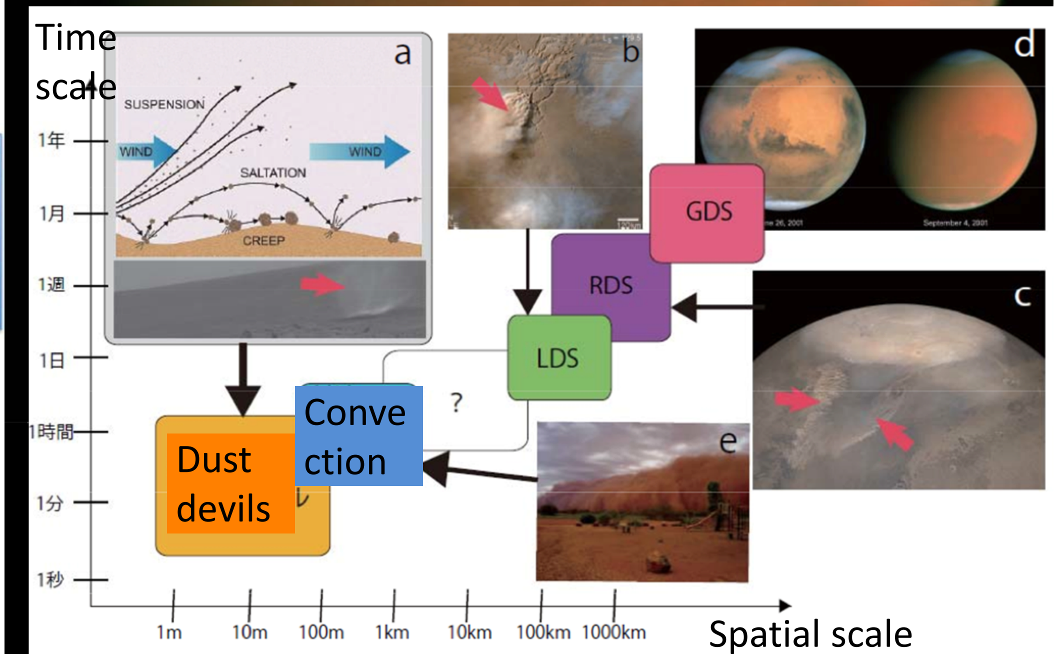
Mars meteorological orbiter concept (in 2020s)



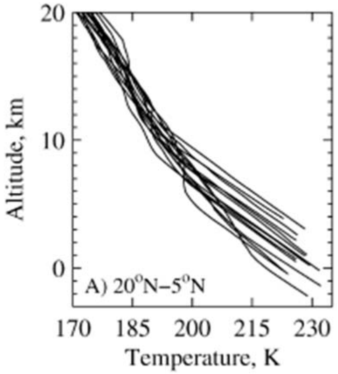
- Nominal mission plan: a medium-size orbiter

The primary target	**Dust meteorology**
Others	**Water cycle**
	Atmospheric chemistry





Nominal plan: Continuous global monitoring from high orbit using a set of dedicated meteorological sensors

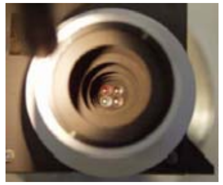


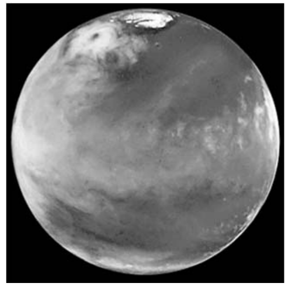
Radio occultation

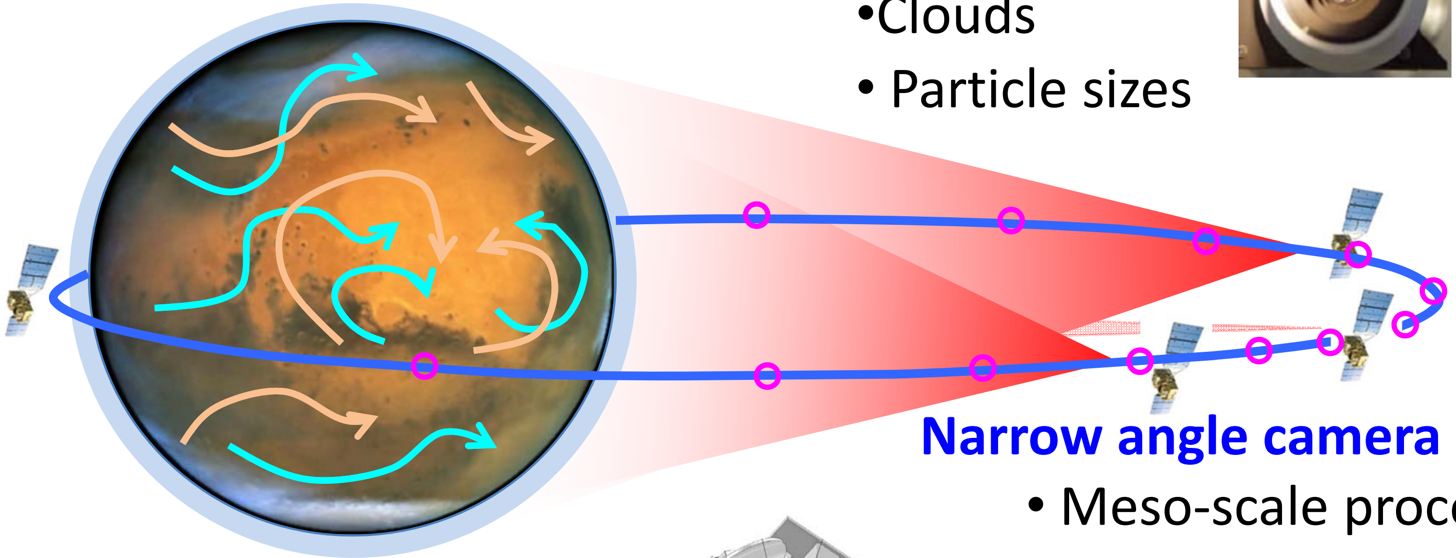
• temperature profile

Polarimetric camera

•Dust
•Clouds
• Particle sizes

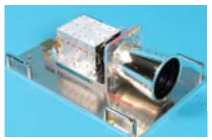






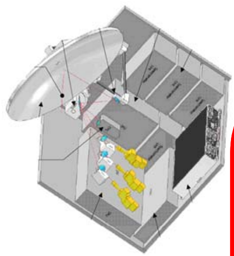
Narrow angle camera (optional)

• Meso-scale processes



Mid-IR camera

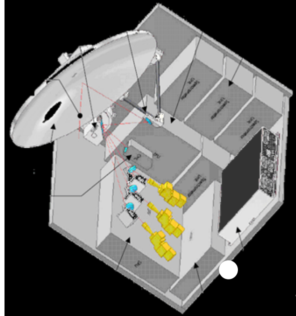
• Dust
• Surface temperature



Sub-millimeter sounder

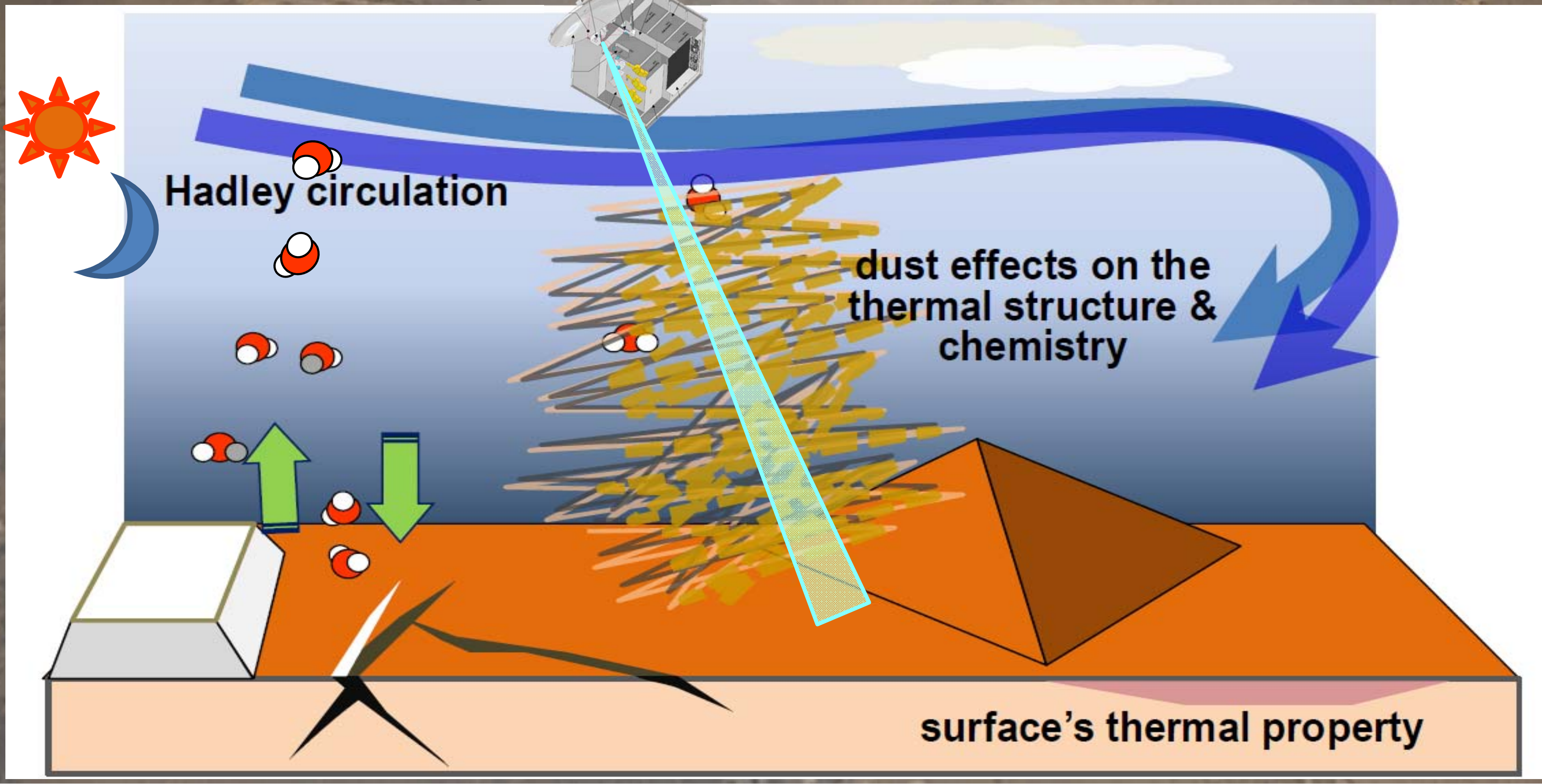
•3-D temperature
•Water vapor
•Trace gases
•Isotopic ratios
•Surface temperature

- Orbital period: 12 hours
- Visualization of transport processes and diurnal cycle by global mapping conducted every one hour



FIRE (Far Infrared Experiment)

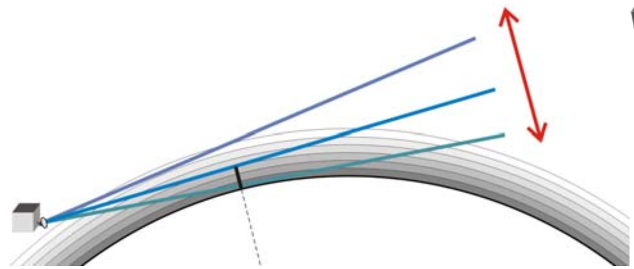
- Atmospheric composition in Sub-mm (550-620 GHz range)
- Key parameters of Meteorological science
  - **3D structure of temperature**
  - **3D observation of water vapor, CO, O3, and its isotopes**
  - **Surface temperature and properties**
  - **Wind velocity**

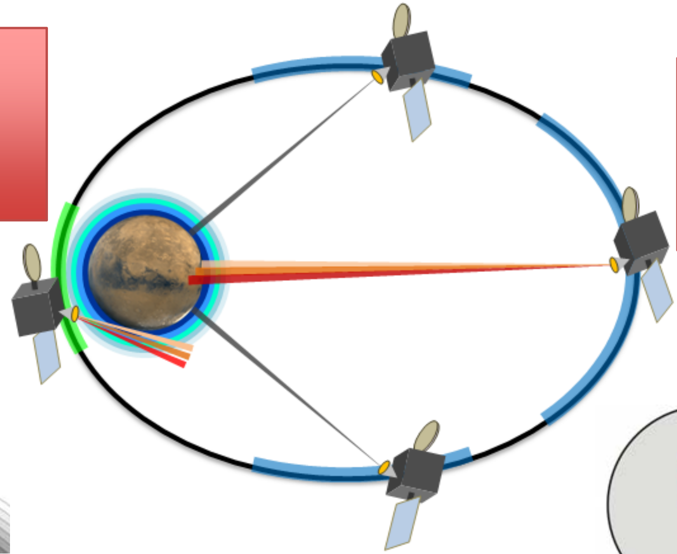


FIRE observation Geometry

Limb observation from near mars points

Vertical scan between 0 – 120 km





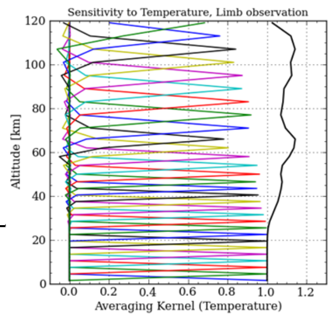
Nadir mapping from far mars points

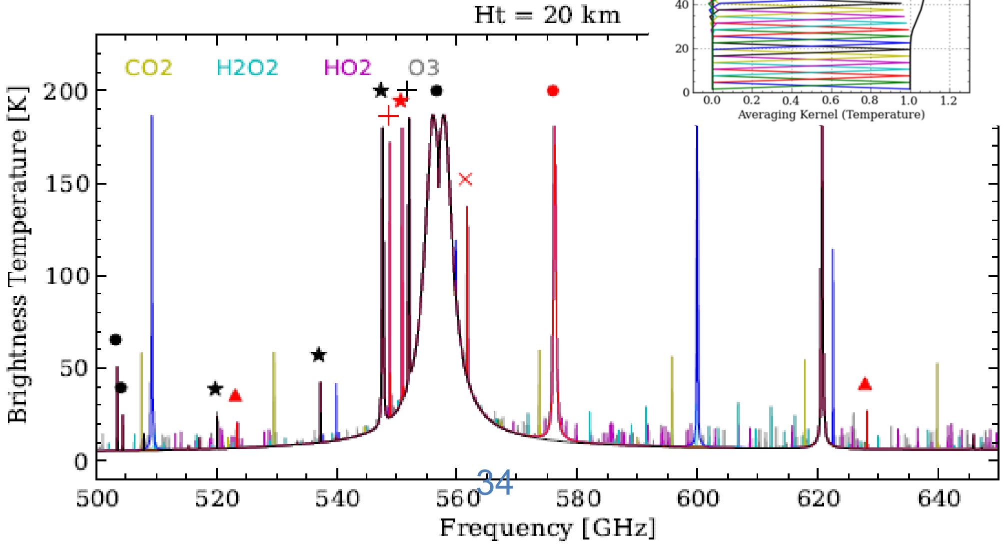
~300 km step mapping for horizontal direction

Temperature（Limb）

Sensitivity up to 120km

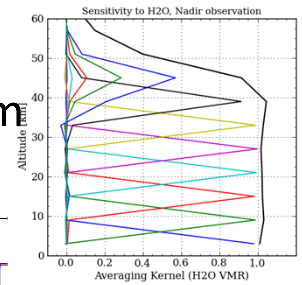
Precision 0.2 - 1 K

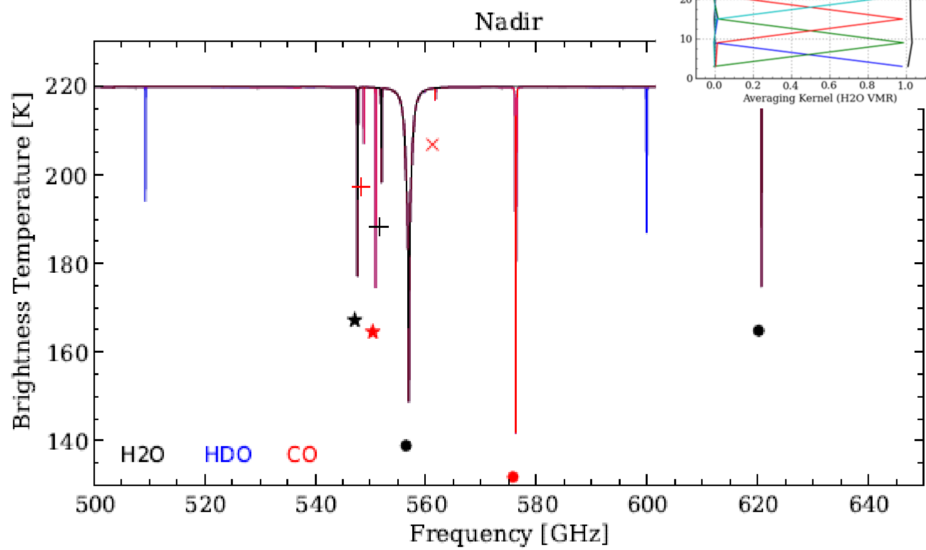




Water vapor（Nadir）

Precision 5 – 15 % @0 – 30 km





We hope to go
as far as possible with TGO,
and extend the outputs
to the next.

Channel	Observation modes	Spectral range	Type of instrument	Resolving power (resolution at mid-range)	SNR	Vertical resolution	Spatial Resolution
NOMAD/SO	Solar Occultation	2.2-4.3 μm 2325-4545 cm^{-1}	Echelle / AOTF spectrometer	20000 (0.15 cm^{-1})	3000	< 1km	--
NOMAD/LNO	Solar Occultation / Limb / Nadir	2.2 – 3.8 μm 2631-4545 cm^{-1}	Echelle / AOTF spectrometer	10000 (0.30 cm^{-1})	1000	< 1km	60-1000km^2
ACS/TIRVIM	Solar Occultation / Nadir	2-25 μm 400-5000 cm^{-1}	FTS	4000 (SO) / 500 (N) (0.15 / 1.6 cm^{-1})	1000 (SO) / 500 (N)	Better than < 10 km	
ACS/MIR	Solar Occultation	2.4 – 4.2 μm 2380-4166 cm^{-1}	Echelle / cross-dispersion	50000 (0.06 cm^{-1})	2000	< 1 km	
ACS/NIR	Solar Occultation / Limb / Nadir	0.7 -1.6 μm 6250-14285 cm^{-1}	Echelle / AOTF spectrometer	20000 (0.5 cm^{-1})	2000 (SO) / 1000 (N)	< 1 km	