Trial of Infrared High Resolution Spectroscopy for Mars and Planets: Current studies

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Mid-high spectral resolution spectroscopy provides us the key information on minor components and dynamics of planetary systems. We have tried to apply this technique mainly by three methods.

The first is the space observations from planetary orbiters (see Aoki et al., in this meeting). We have investigated the Mars Express (MEX) Planetary Fourier Spectroscopy (PFS) data for several years under the collaboration with Italian groups. In 2004, the MEX/PFS team found CH_4 in the Martian atmosphere (Formisano et al., 2004). Associated with its spatial anisotropy and time variations, the loss mechanism by oxidant component becomes important. We analyzed the data and concluded that the oxidant in the atmosphere is insufficient for the support of CH_4 time and spatial variations suggested by several observations. As the next target, we just started to investigate the vertical profile of CH_4 by same instruments.

The second is the ground-based observations (see Aoki et al., in this meeting). We have investigated the SO and SO_2 abundances in the Martian atmosphere by submm observations. In all results, we could not find any signature of gas produced from the crust, which would suggests that the origin of CH_4 is not associated with any volcanic-like crust activities. In Nov 2011, Jan 2012, and Apr 2012, we used SUBARU/IRCS for the detection of Martian CH4 lines. These observations aimed the areas where the enhancement of CH_4 was reported in past observations from ground (low-latitude region) and from MEX/PFS (polar region) in different Martian season. This observation also covered D/H ratio, which can describe the amount of water evaporation from the surface. The analysis is now on going.

The last is the new concept instrument (see Nakagawa et al., in this meeting). We have developed an ultra-high spectral resolution spectrometer, called MILAHI (Mid-Infrared LAser Heterodyne Instrument), for 7-11 um wavelength at a resolution of up to $10^{7\text{-}8}$ and a bandwidth of 1GHz. In Sep 2011 and Jan 2012, the 1st version spectrometer was mounted on the Higashi-Hiroshima 1.5m telescope (Hiroshima Univ.) to perform test observations targeting to Moon, Venus, and stars. Unfortunately, the maximum success was prevented by bad weathers, but the observed S/N told us that we should get the Venus and Mars spectrum with this design. We are now developing the

2nd generation instrument which becomes smaller sized and can be mounted even at the Cassegrain focus. Although a telescope dedicated to this instrument does not exist yet, we expect to attach it to our 60cm telescope moved from Iitate Observatory to the top of Mt. Haleakala, Maui island, Hawaii, in 2013. In 2014, we will also be able to start the operation of the PLANETS telescope at Haleakala, which is now in development with Univ. Hawaii, Tohoku Univ., Kippenhauer Inst., National Univ. of Mexico, Univ. Turku, Harlingten Inovative Optics Co., Stan Truitt Breckenridge Astronomycal Ltd, and collaborators.

赤外高分散分光観測による火星・惑星研究
~ 東北大Gの現状と展望 ~

Trial of infrared high-spectral resolution spectroscopy for Mars and Planets: Current studies in Tohoku Univ.

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[Progress in our Group]

1. from Orbiters $\lambda/d\lambda$ ~ several 10^3

* the Mars Express (MEX) - Planetary Fourier Spectroscopy (PFS)
  Search of Minor components …. Mars H_2O_2 & CH_4 (Aoki)

2. from Ground-based Telescopes $\lambda/d\lambda$ ~ several 10^4

* SUBARU - CIRS & IRTF - CSHELL
  Search of Minor components …. Mars H_2O_2 & CH_4 (Aoki)
  Temperature & Velocity …. Jupiter H_3^+ & H_2 (Uno)
* ALMA <FYI>

3. by 'our' Instruments to 'Haleakala' $\lambda/d\lambda$ ~ several 10^{4-7}

* *Infrared Echelle Spectrometer 1-4 um $\lambda/d\lambda$ ~ 10^{4-5}*
* Infrared Heterodyne Spectrometer 7-12 um $\lambda/d\lambda$ ~ 10^{6-7}
  Temperature & Velocity …. Venus CO_2 (Nakagawa)

Planetary Fourier Spectrometer: onboard MEX

* Spectral range 1.2 to 45 μm
by SWC (1.2 - 5.0 μm) [near infrared]
LWC (5.5 - 50 μm) [thermal]

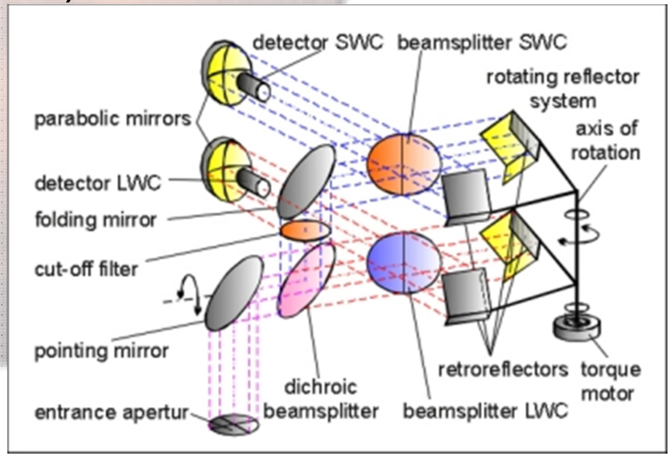
* Resolution $1.3\ cm^{-1}$ [λ/dλ ~ 6400-170] Highest on the Martian Orbit

* Field of View 1.6° for the SWC (7km @ height-250km)
2.8° for the LWC (12km @ height-250km)

* Geometry Nadir and Limb mode

* Operation 8 years (Jan 2004-)
1.5 million spectra

* PI M. Giuranna (IAPS, Italy)



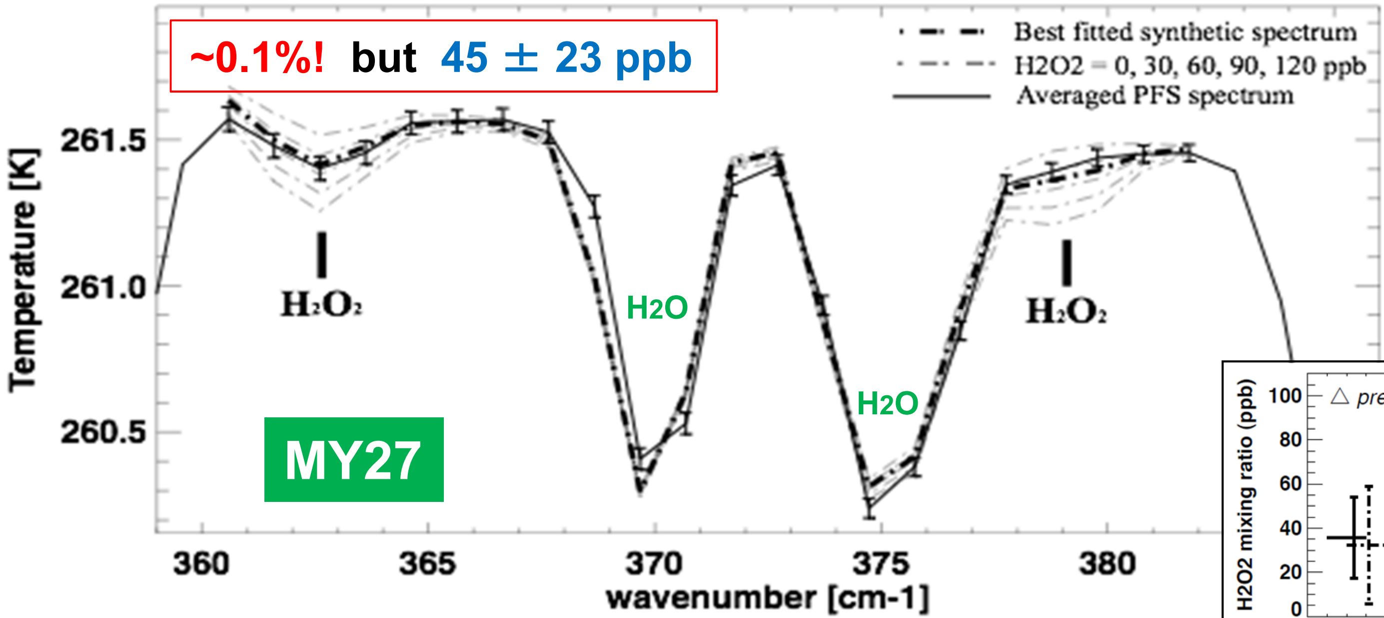
(1) H_2O_2 @ Nadir (2) CH_4, H_2O, CO @ Limb

(1) H_2O_2 with MEX/PFS Nadir data

Submitted! (Aoki et al.)

* ***H_2O_2 is the best tracer of oxidizer in the atmosphere.***
(Only H_2O_2 was detected in the Martian OH_x).
However, previous detections were by a few ground-based observations.

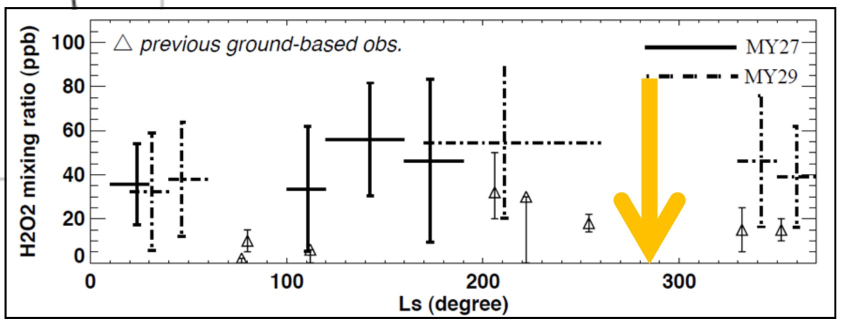
* **We first derived long-term averaged amounts of H_2O_2**
from the spectrum in 360-385 cm^{-1} (26.0-27.8 μm).



[Thick solid]
PFS (14,828 ave.)

[Thick dashed]
best fit

relatively larger, but similar to past ground-based observations

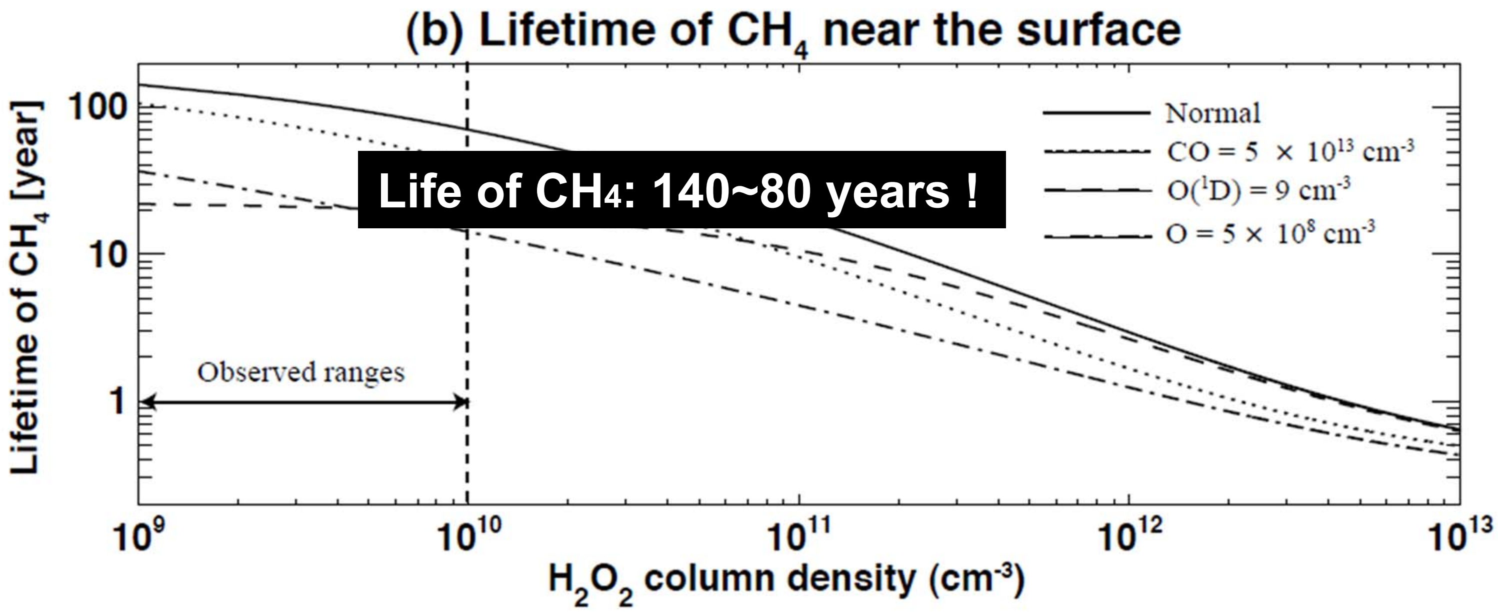


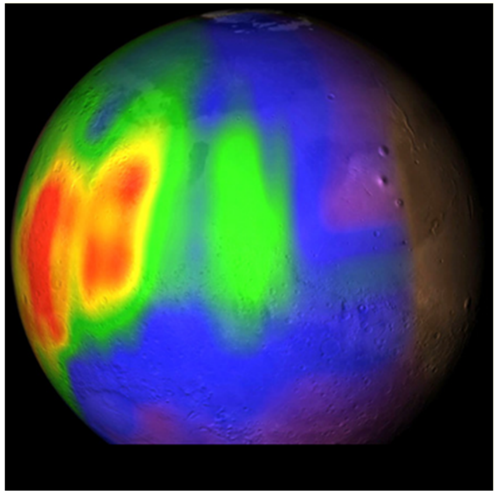
(1) H_2O_2 with MEX/PFS Nadir data

Submitted! (Aoki et al.)

* Oxidation = Lifetime of CH_4 **about weeks or months**

However, **Our 'H_2O_2' (<several 10s ppb) are not sufficient to explain the short lifetime of CH_4.**





Geometrical distribution observed by IRTF/CSHELL http://science.nasa.gov/ [*Mumma et al., 2009*]

Other scenario, like
electro-photochemical loss due to dust storms ?
oxidation loss in regolith ?

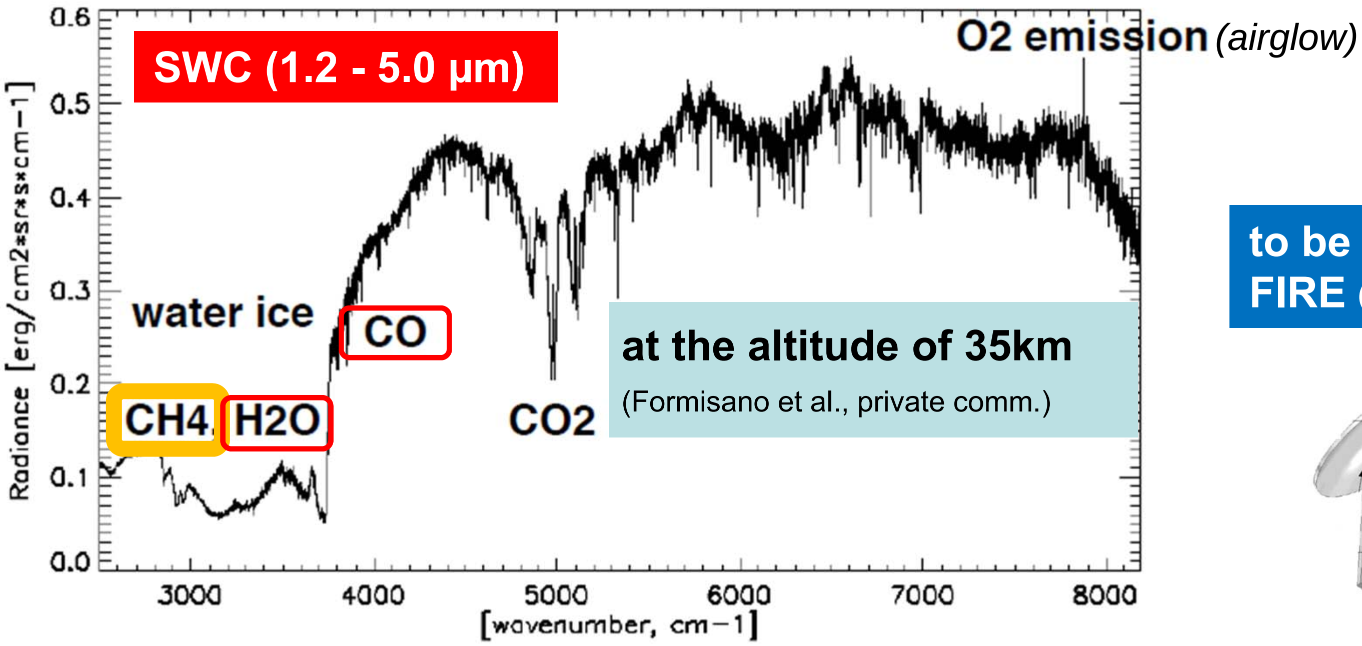
(2) CH_4, H_2O, CO with MEX/PFS Limb data

see **POSTER (Aoki et al.)** --- Introduction will be in this session.

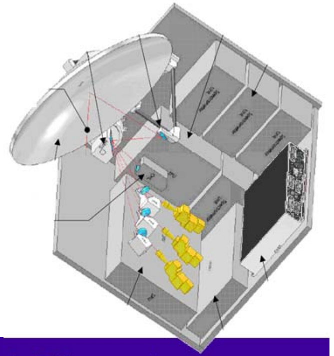
*** Vertical profiles of CH_4, H_2O and CO**

It can potentially constrain their production / loss.

→ The limb data is now combining to a radiative transfer code with multiple scattering.



to be extended to FIRE @ MELOS ?



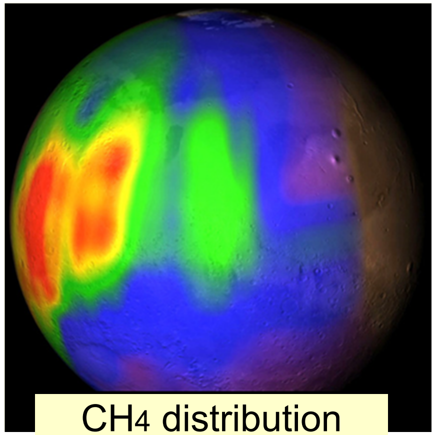
	SUBARU IRCS	*IRTF CSHELL*
		
* Spectral range	0.9 to 5.5 μm	1.1 to 5.5 μm
width	**λ x 2.5%** (with cross-disperser)	λ x ~0.25% (without cross-disperser)
* Resolution	λ/dλ ~ 20000 (2-4um)	**λ/dλ ~ 40000 (2-4um)**
* Slit length	9.4 arcsec	**1 arcmin**
* Guider	**YES!**	no
* with AO?	**YES!**	no

Temperature (line ratio)
High-spatial resolution

Velocity (Doppler shift)
Wide field

(1) CH_4, H_2O, HDO with SUBARU/IRCS

see POSTER (Aoki et al.) --- Introduction will be in this session.



CH4 distribution by IRTF/CSHELL [*Mumma et al., 2009*]

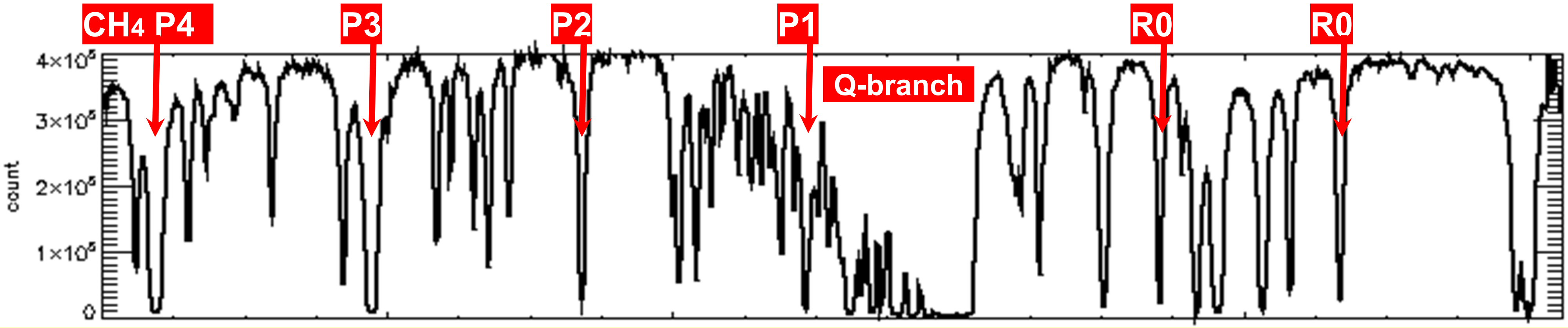
Jan. 2012 & April 2012 (as a part of Campaign)

* Search around the possible source areas of CH_4

(1) the areas with CH_4 extend plumes

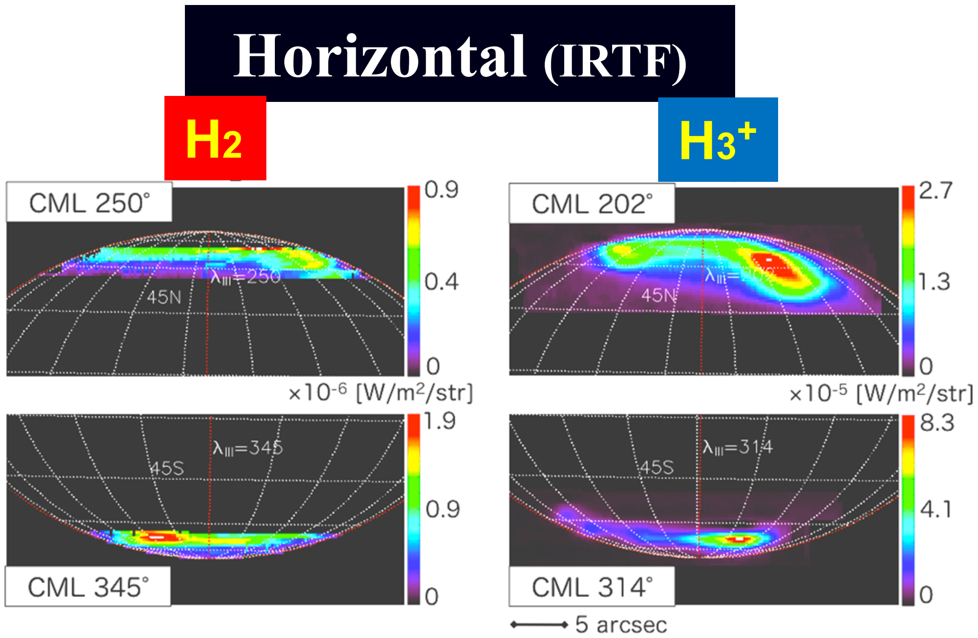
observed by IRTF (mid-latitude) / MEX-PFS (pole)

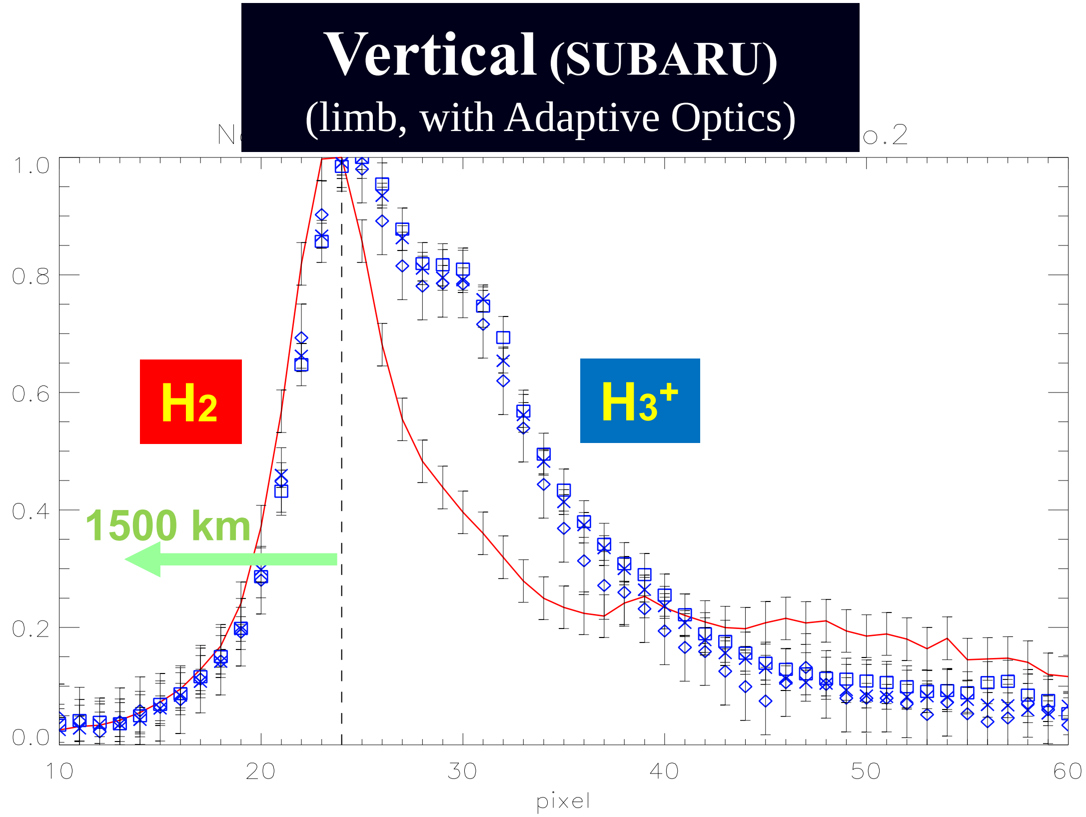
(2) the mud volcanism areas (mid-latitude)



Spectrum on 5 Jan. observed with SUBARU/IRCS **(2970-3050 cm^{-1})**

(2) Difference between Jovian H_3^+ & H_2 aurora





IR-H_2	similar to UV H_2? high-T region?
H_3^+	enhanced at high-T region ?

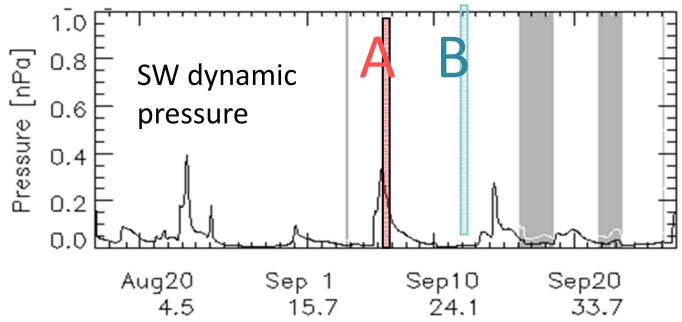
to be submitted (Uno et al.)

Comparison with HST UV-H_2 observations & Exceed UV/EUV is planned !

(2) Temperature & Velocity field: Jovian aurora

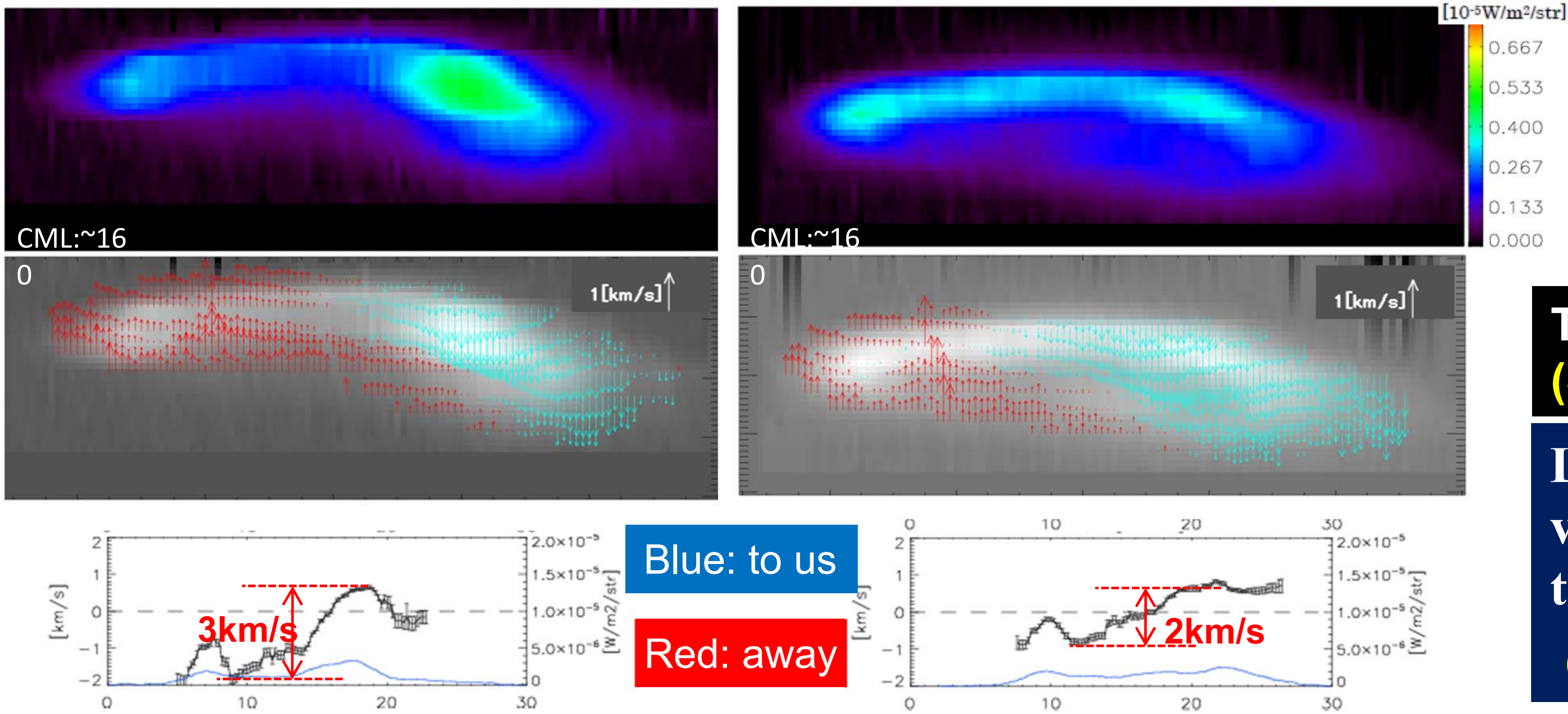
Ion (H_3^+) and neutral (H_2) wind & temperature profiles associated with Jovian aurora at IRTF & SUBARU.

→ **Enhancement of Convection ?**



A: large SW pressure

B: low SW pressure



To be submitted (Sakanoi et al.)

Low-mid latitude velocity is also tried to detect.

(Kita et al., oral)

(3) ALMA --- 'Cycle-0' is going.

see POSTER (Maezawa et al.) --- Introduction will be in this session.

******* In solar system *******

<Chemistry mapping>

Venus — Sulfur and water mapping in the mesosphere of Venus — Encrenaz, Th. (Paris Obs)
(SO, SO_2, HDO)

Titan — Mapping the nitrile chemistry and dynamics of Titan's thermosphere — Moreno, R. (Paris Obs)
(HNC, HCN, HC_3N, CH_3CN, DCN)

<Spatial / Velocity resolved>

Saturn — Probing the vertical structure of Saturn's storm with ALMA — Cavalie, T. (Bordeaux Obs)
(CO, HCS)

Io — Characterizing Io's atmospheric composition and circulation — Moullet, A. (SMA)
(KCl, S_2O, SiO, CO, SO, SO_2)

Comet — A Close-up Look at Comet Elenin — Drahus, M. (Caltech)
(CN, HCN, CO, CH_3OH)

We are defeated ….

Venus (Sagawa et al.)
Mars (Nakagawa et al.)
Jupiter (Maezawa et al.)
Enceladus (Sugita et al.)

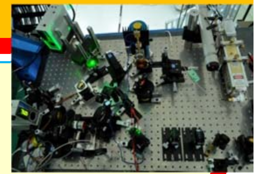
Cycle-1 proposal: 12 July 2012

https://almascience.nrao.edu/news/pre-announcement-for-cycle-1

(Meeting for Solar-System proposal: will be in 15May at Osaka Pref. Univ.)

3. by ‘our’ Instruments toward ‘Haleakala’

Echelle spectrograph

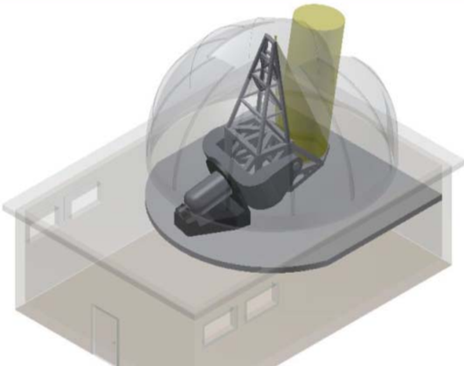


Heterodyne Spectrograph

	Echelle spectrograph	Heterodyne Spectrograph
* Spectral range	2 to 4 μm	7 to 12 μm
* Resolution	**λ/dλ ~ 65000** **[~several km/s]** **(long slit)**	**λ/dλ > 1000000** **[~several 100m/s]** **(spot, like radio observatory)**
* Target	**Jovian auroras** Martian elements	**Venus / Mars / …** **elements &** **velocity field**

see POSTER (Kitami et al.)

1.8m & 0.6m
at Haleakala
(Okano et al., poster)



(2) MIR Heterodyne spectrometer

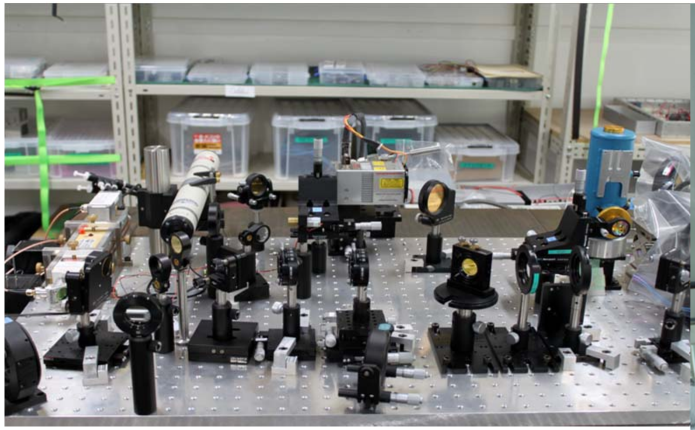
see POSTER (Nakagawa et al.)

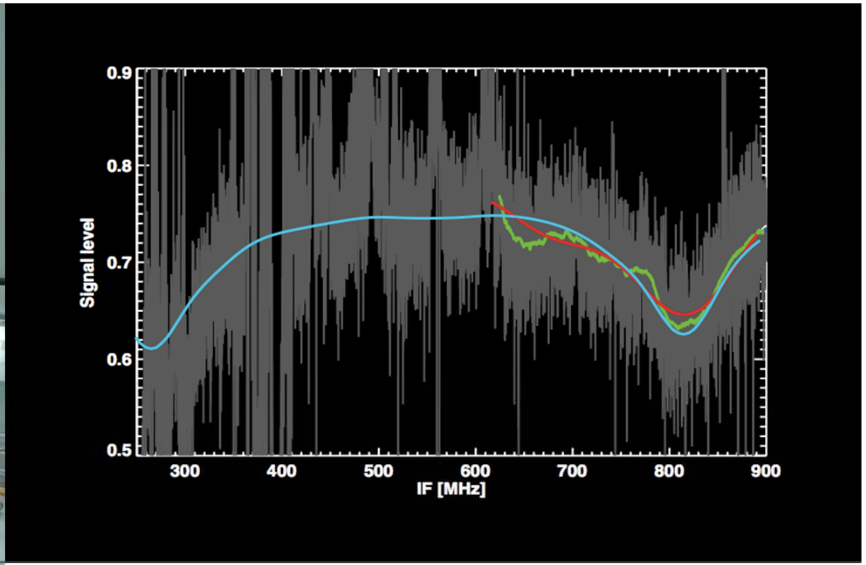
Restart the development end of 2007

Heterodyne signal by a test bench system was established fall of 2008

Success of the test observations at Hiroshima Univ. Obs!

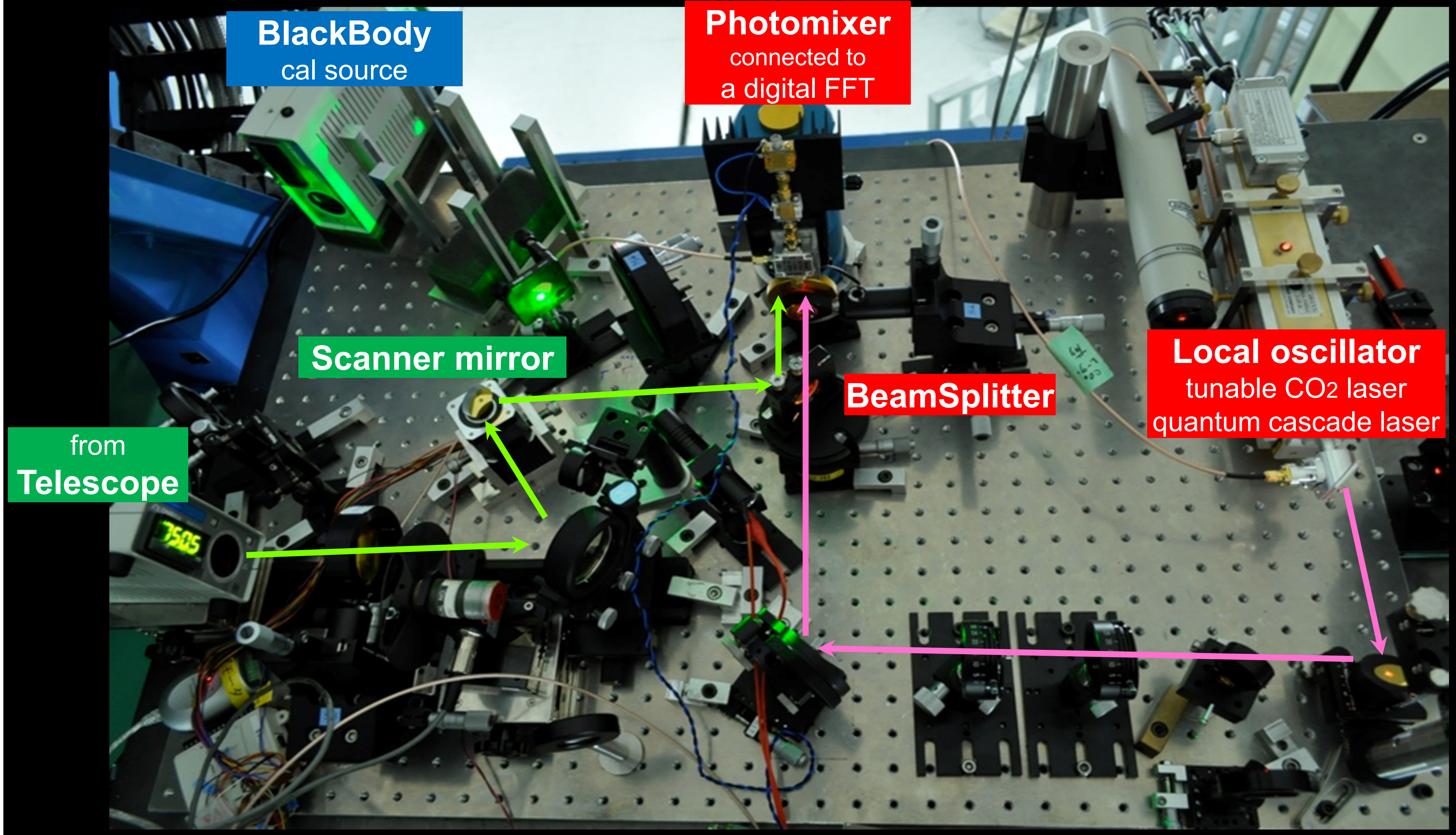
Sep. 2011, Jan. 2012





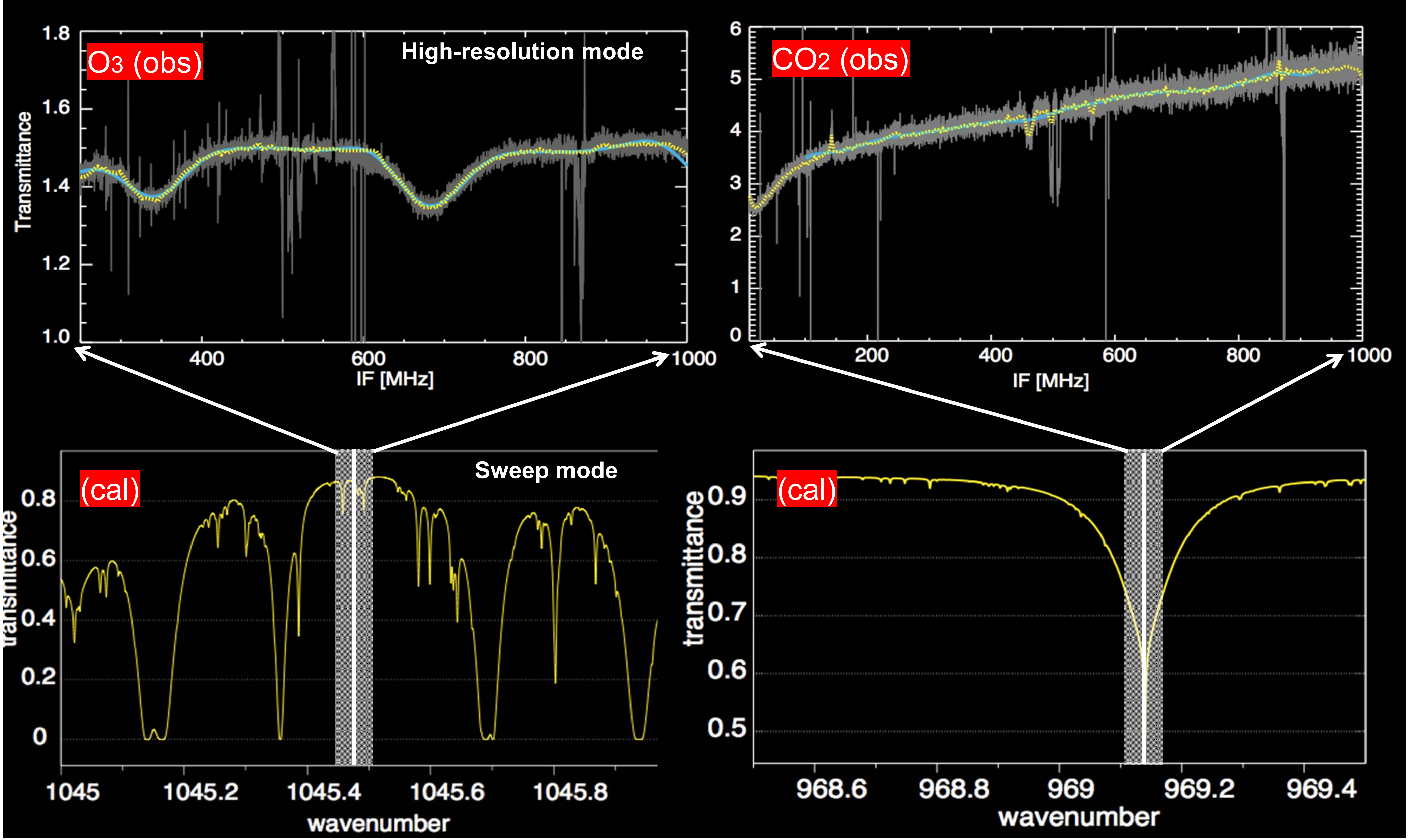
under the collaboration with
G. Sonnabend (U. Cologne)
T. Kostiuk (NASA/GSFC)

- **The 1st Generation instrument ---- very compact!**



3. by ‘our’ Instruments toward ‘Haleakala’ (2) Heterodyne

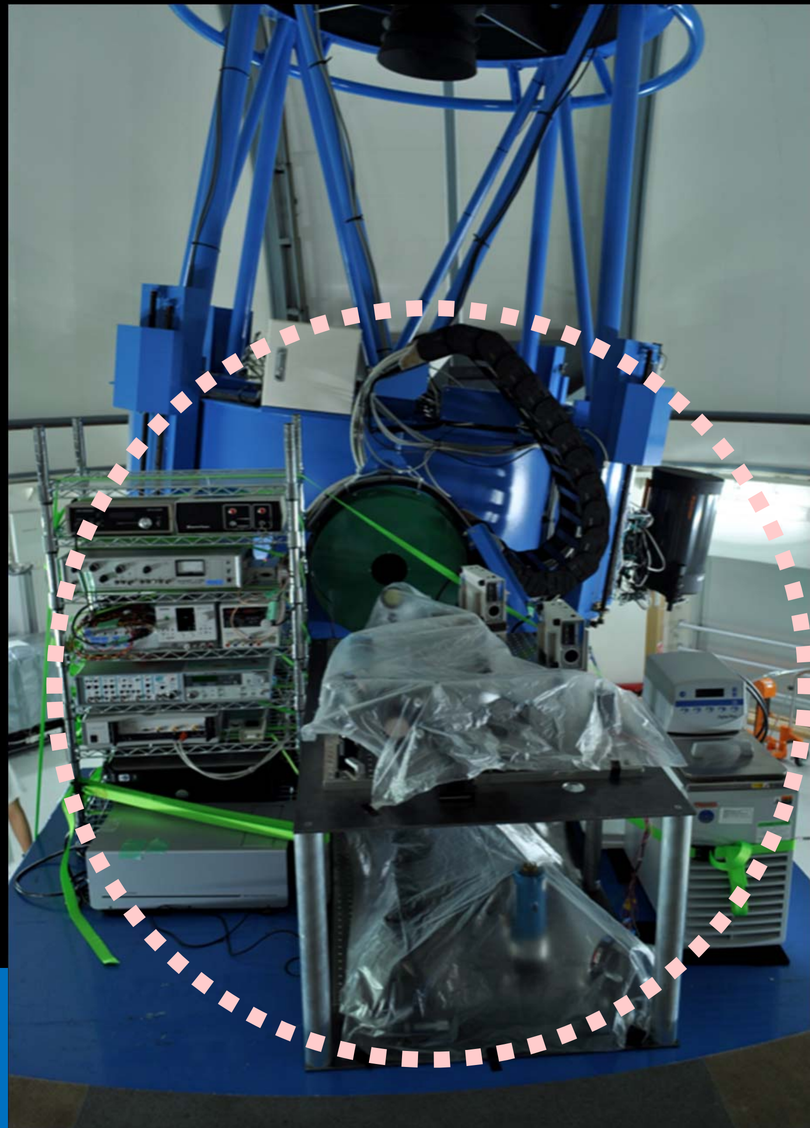
• Test observation: Sun light (terrestrial atmosphere)



• Test observations using Kanata telescope

2012 Jan. 6-20 Higashi-Hiroshima 1.5m

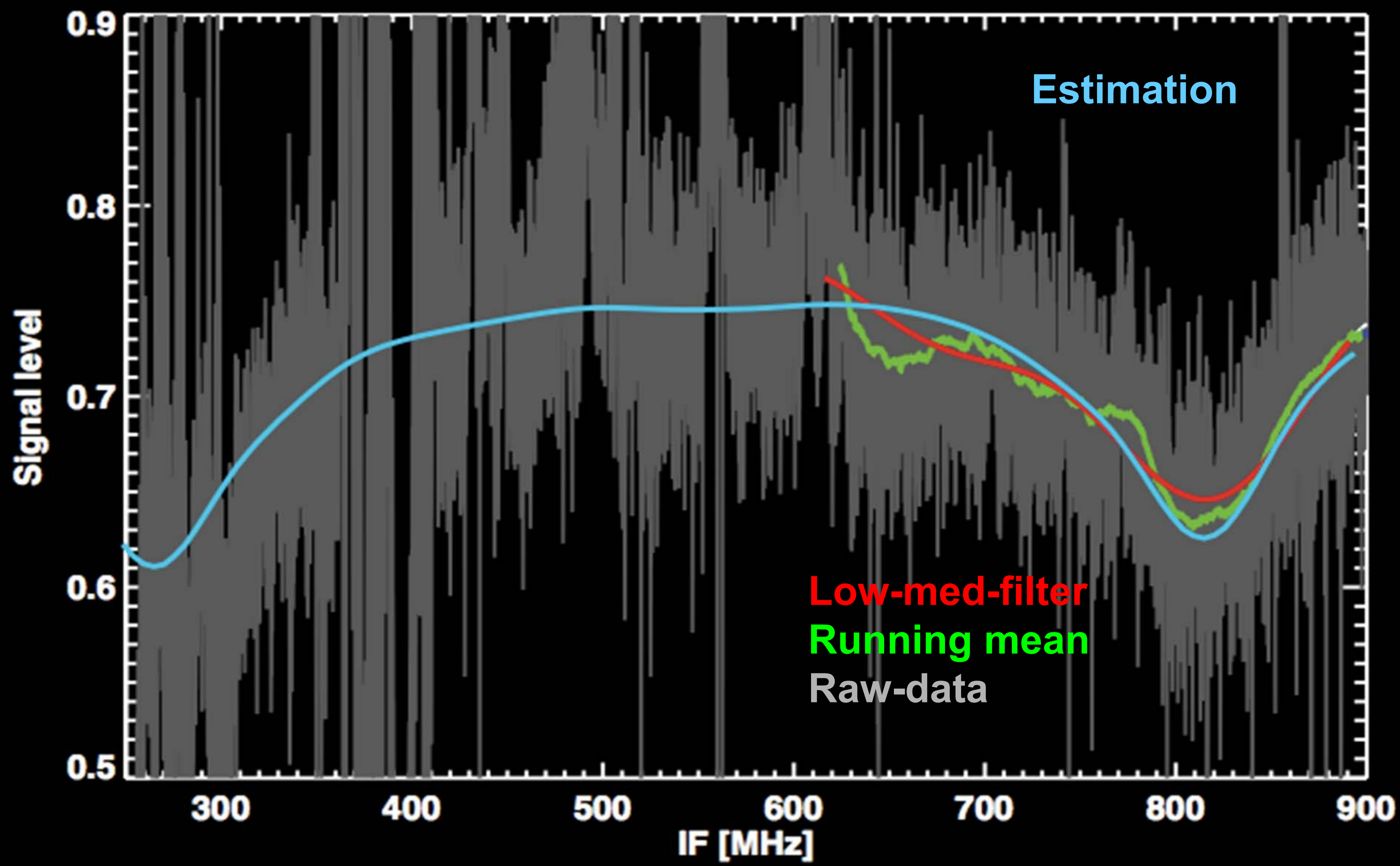
→ successfully obtained
the heterodyne signal with Venus
(a few micro-V)



The heterodyne instrument installed on the Nasmyth focus

3. by ‘our’ Instruments toward ‘Haleakala’ (2) Heterodyne

- **Test observation: Moon light** (terrestrial atmosphere)



Terrestrial O_3 spectra around 1045.6 cm-1
with the moonlight background (Integration: 30 min)

Upper atmospheric wind of Venus

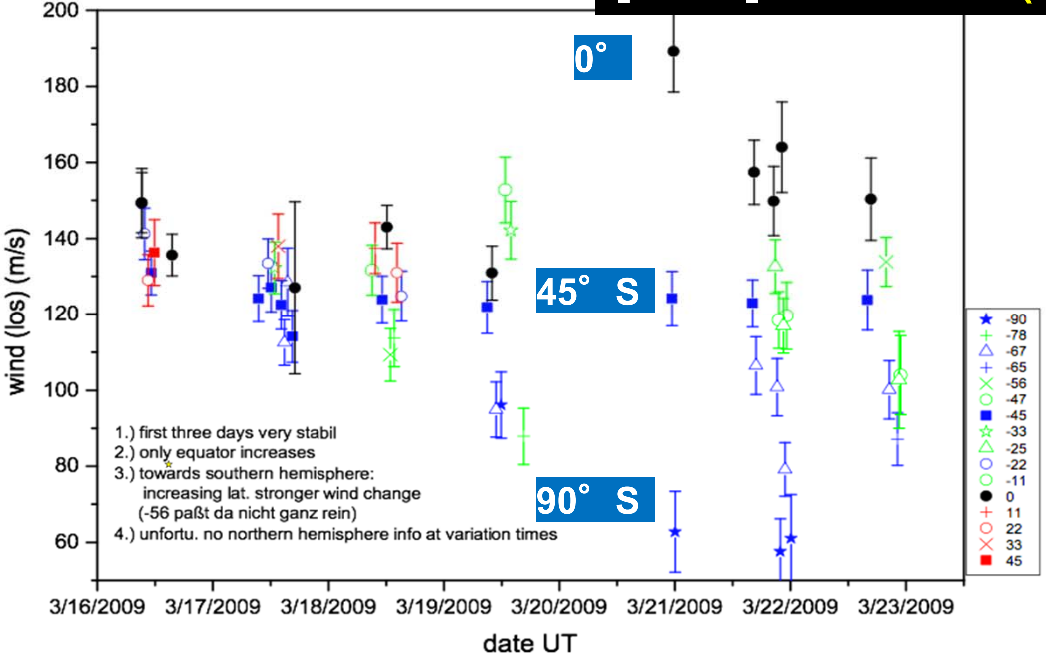
with Univ. Cologne heterodyne observation

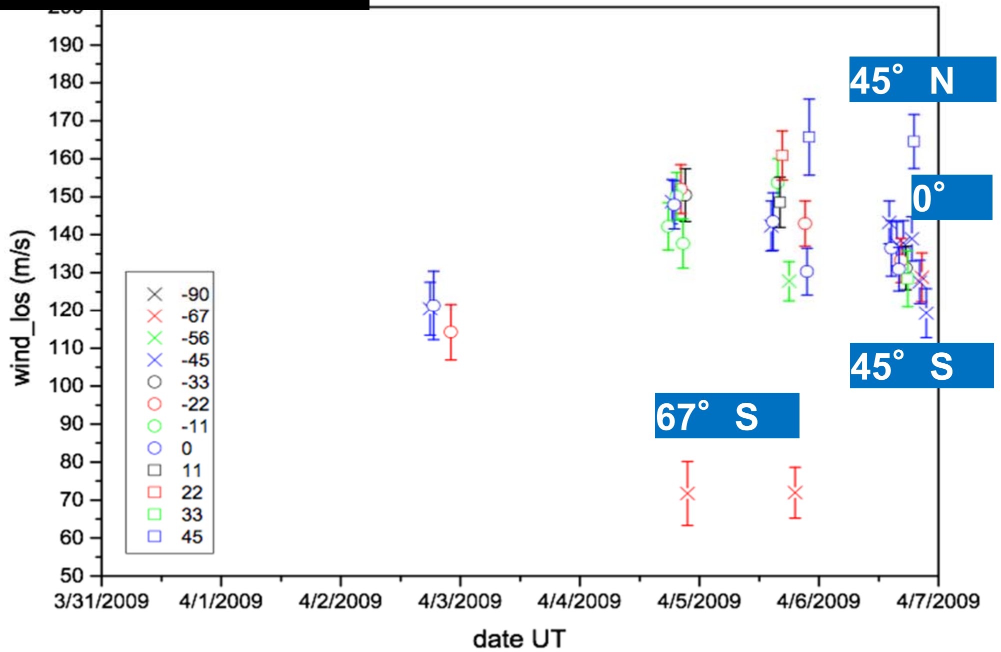
McMath-Pierce Solar Telescope

<u>Observation at Kitt Peak (McMath-Pierce)</u>

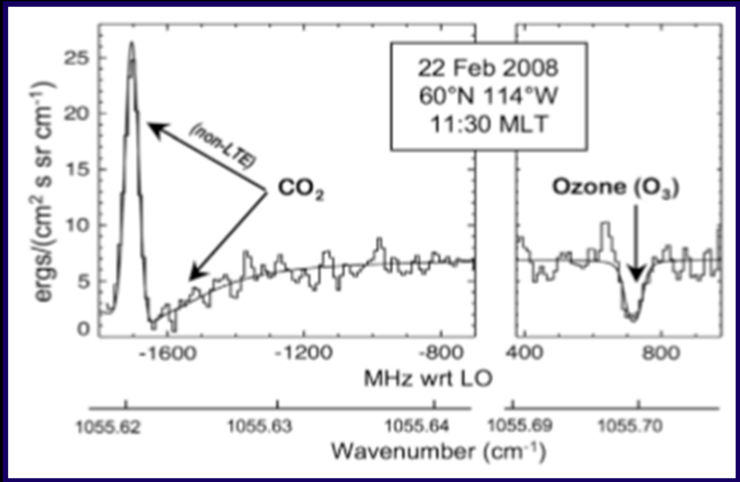
- Strong daily variation of the wind velocity was clarified.
  Amplitudes were larger than predicted by simulations.
  The phase difference was found
  between equator, mid-latitudinal region, and polar region.

[to be] submitted (Nakagawa et al.)

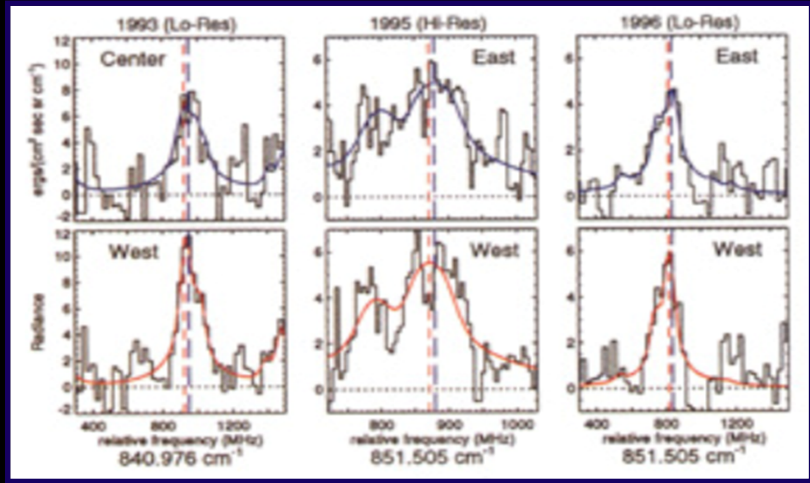




• Scientific applications



Martian O_3 [Fast et al., 2009]



Titan C_2H_6 [Kostuik et al., 2001]

(i) High precise detection of minor constituents

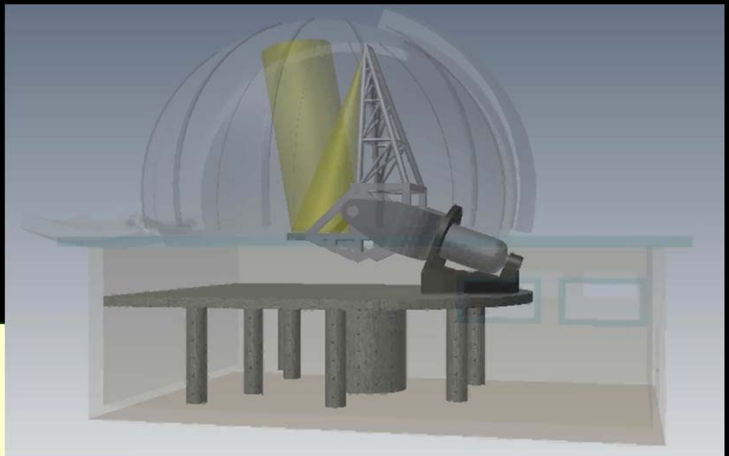
(ii) High accurate detection of dynamics and its vertical profile

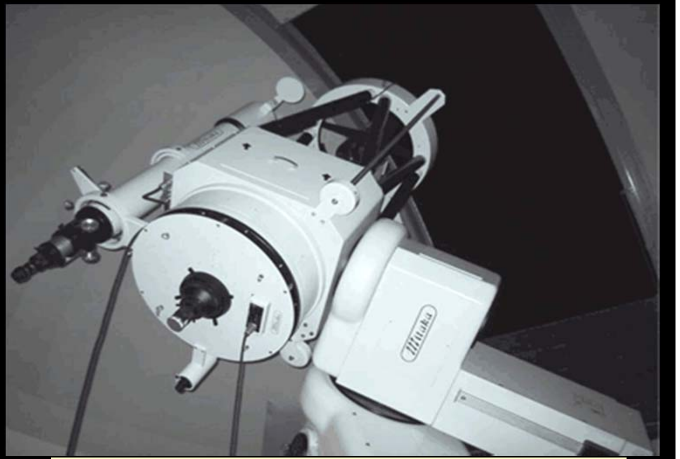
[CO_2]	Mesospheric winds	Mars / Venus
[CO_2]	Dust-storm effect on the dynamics	Mars
[O_3 / H_2O_2]	Photochemistry and oxidant	Mars
[CH_4]	Potential biological or crustal activities	Mars
[H_2O / HDO]	Water cycle & atmosphere-surface coupling	Mars
[C_2H_2 / C_2H_4 / C_2H_6]	Stratospheric dynamics and photochemistry	Jupiter
[SO_2]	Outgassing activities	Mars

end of 2012 60cm
end of 2014 1.8m …. will be available at Haleakala, we expect!

see **POSTER (Okano, Kasaba et al.)**

with linked to Space missions & Simulations





~1.8mφ at Haleakala

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

60cm Vis/IR telescope as Sub-telescope
(Iitate → Haleakala)

http://www.ifa.hawaii.edu/haleakalanew/planets/
http://kopiko.ifa.hawaii.edu/planets/

The site view of Haleakala observatory.