Optical and infrared measurements of planetary atmospheres with the T60 telescope and the future PLANETS mission at Haleakala, Hawaii

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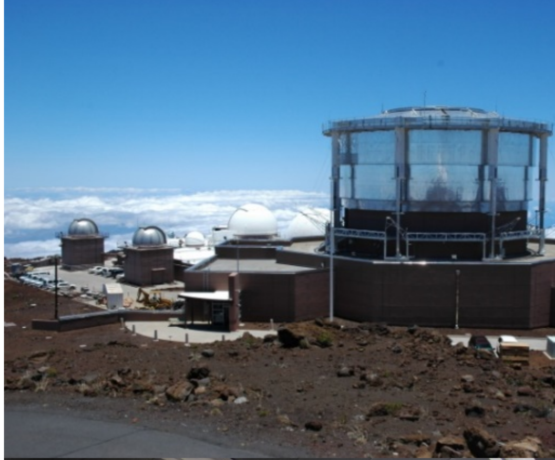
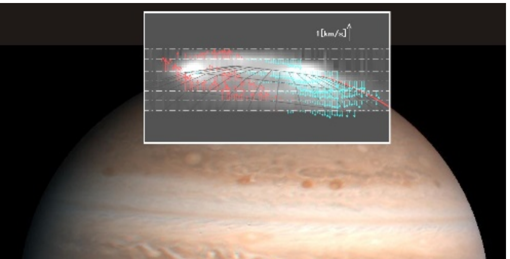
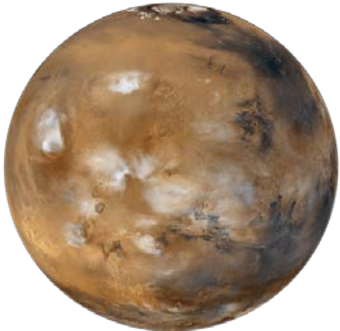
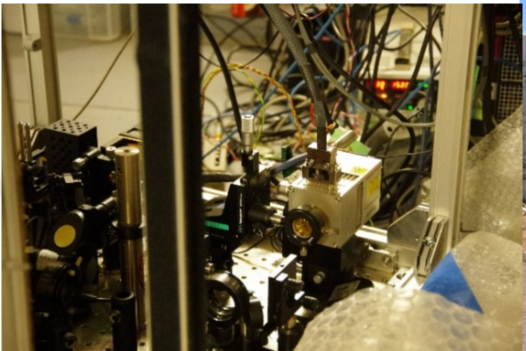


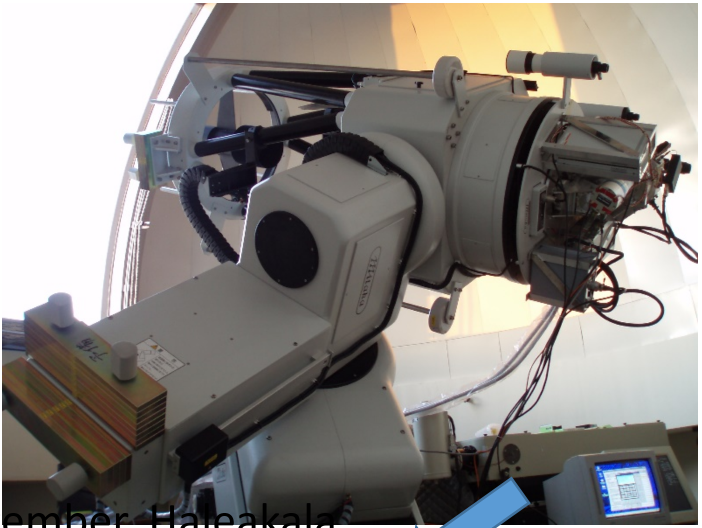




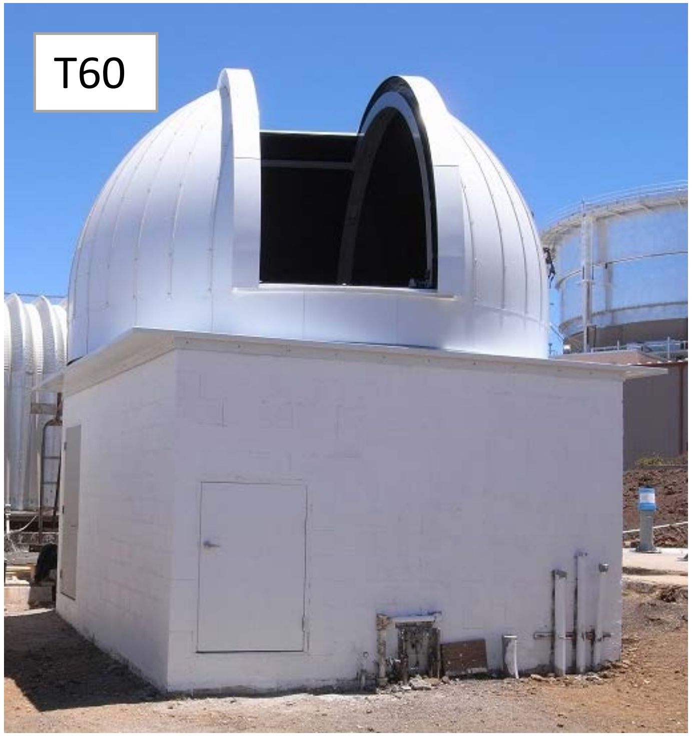


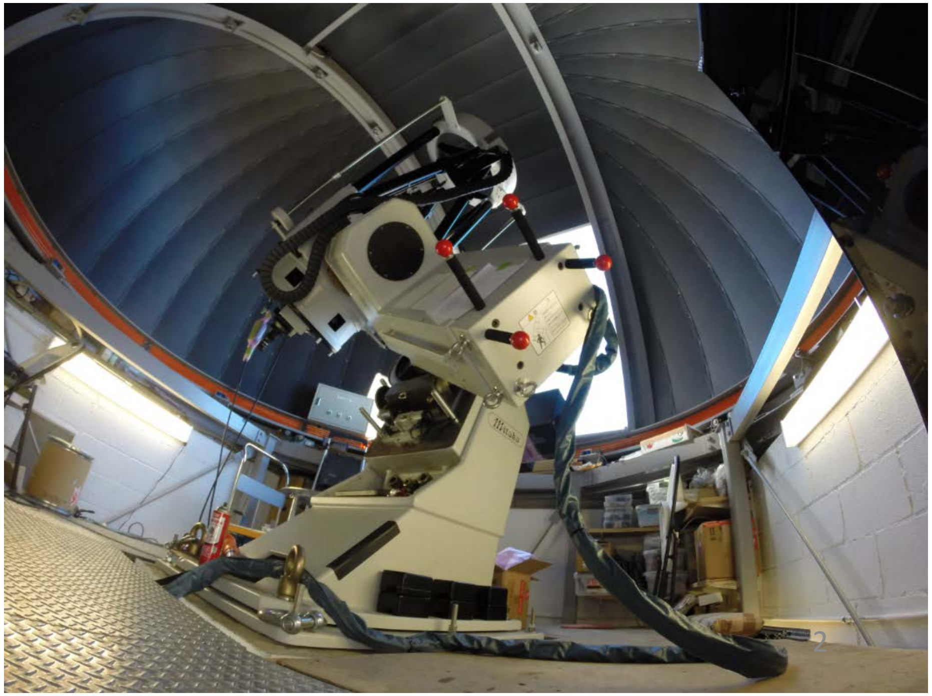
Relocation of T60 from Iitate to Haleakara

2013 June, Iitate

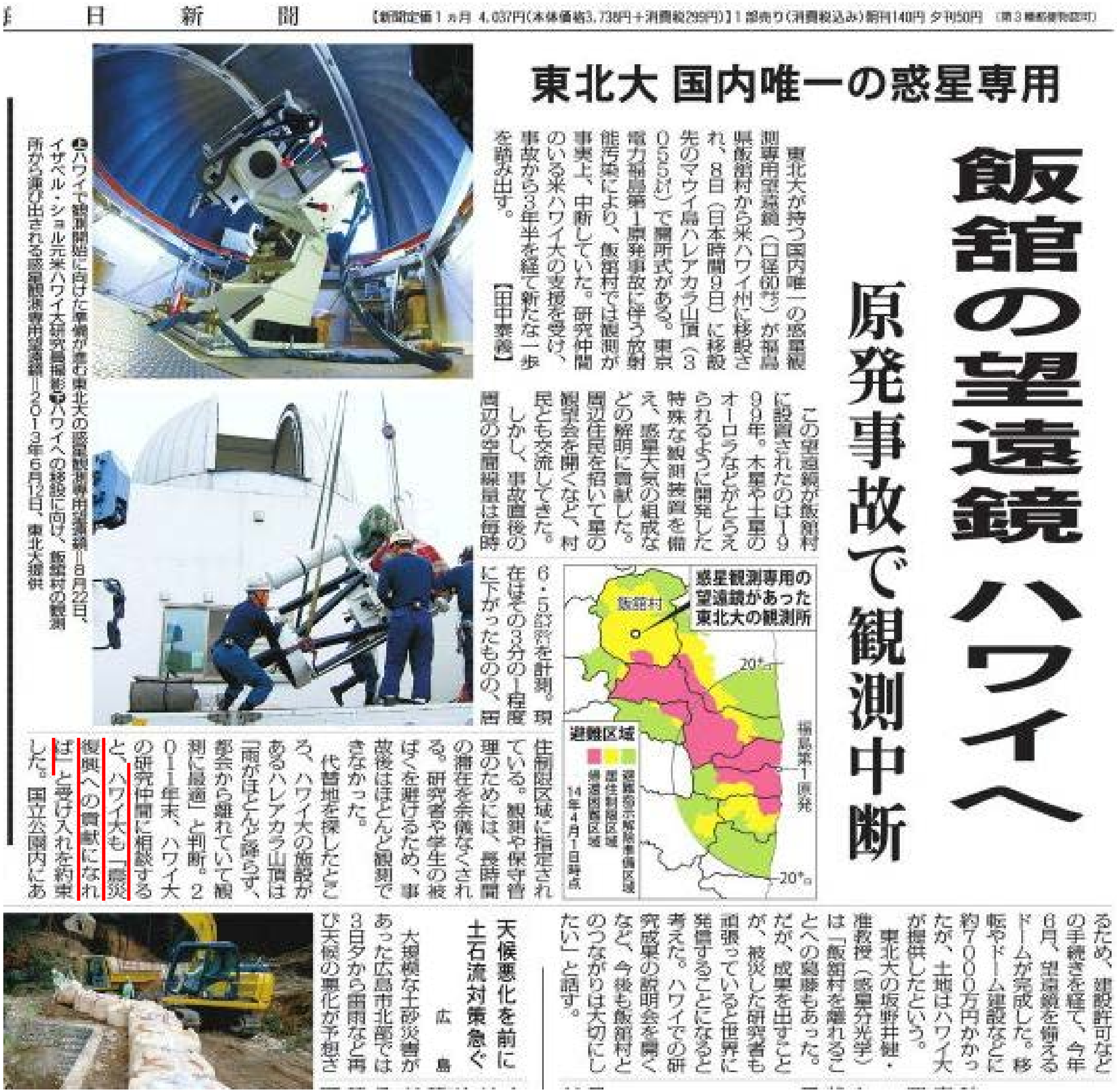


2014 September, Haleakala





T60 Open Ceremony - 8 Sep. 2014



東北大 国内唯一の惑星専用

飯舘の望遠鏡 ハワイへ

原発事故で観測中断

東北大が持つ国内唯一の惑星観測専用望遠鏡（口径60㌢）が福島県飯舘村から米ハワイ州に移設され、8日（日本時間9日）に移設先のマウイ島ハレアカラ山頂（3055㍍）で開所式がある。東京電力福島第1原発事故に伴う放射能汚染により、飯舘村では観測が事実上、中断していた。研究仲間のいる米ハワイ大の支援を受け、事故から3年半を経て新たな一歩を踏み出す。【田中泰義】

この望遠鏡が飯舘村に設置されたのは1999年。木星や土星のオーロラなどがとらえられるように開発した特殊な観測装置を備え、惑星大気の組成などの解明に貢献した。周辺住民を招いて星の観望会を開くなど、村民とも交流してきた。

しかし、事故直後の周辺の空間線量は毎時6・5マイクロシーベルトを計測。現在はその3分の1程度に下がったものの、居住制限区域に指定されている。観測や保守管理のためには、長時間の滞在を余儀なくされる。研究者や学生の被ばくを避けるため、事故後はほとんど観測できなかった。

代替地を探したところ、ハワイ大の施設があるハレアカラ山頂は「雨がほとんど降らず、都会から離れていて観測に最適」と判断。2011年末、ハワイ大の研究仲間に相談すると、ハワイ大も「震災復興への貢献になれば」と受け入れを約束した。国立公園内にあるため、建設許可などの手続きを経て、今年6月、望遠鏡を備えるドームが完成した。移転やドーム建設などに約7000万円かかったが、土地はハワイ大が提供したという。

東北大の坂野井健・准教授（惑星分光学）は「飯舘村を離れることへの葛藤もあった。だが、成果を出すことが、被災した研究者も頑張っていると世界に発信することになると考えた。ハワイでの研究成果の説明会を開くなど、今後も飯舘村とのつながりは大切にしたい」と話す。

㊤ハワイで観測開始に向けた準備が進む東北大の惑星観測専用望遠鏡＝8月22日、イザベル・ショル元米ハワイ大研究員撮影 ㊦ハワイへの移設に向け、飯舘村の観測所から運び出される惑星観測専用望遠鏡＝2013年6月12日、東北大提供

天候悪化を前に 土石流対策急ぐ

広　島

大規模な土砂災害があった広島市北部では3日夕から雷雨など再び天候の悪化が予想さ

2014/9/3　毎日新聞

NIPPON SERIES 2013

東北大惑星プラズマ・大気研究センター

望遠鏡、ハワイへ移設

福島・飯舘から 14年秋完了予定

観測体制強化

東北大惑星プラズマ・大気研究センターが、飯舘観測所（福島県飯舘村）にある口径60㌢の光学望遠鏡を、ハワイのマウイ島に移設する計画を進めている。設置場所は標高3055㍍のハレアカラ山頂で、2014年9月に移設を完了する予定。観測の支障となる大気や水蒸気の影響が少なく、晴天率の高さから計画的な観測が可能になる。センターは「観測条件の良さは世界トップクラス。惑星の大気や気象などに関する謎の解明につなげたい」と説明している。

マウイ島の隣のハワイ島には世界最大級の「すばる望遠鏡」があるが、使用希望が殺到し、申請しても1年間に1日使えるかどうかの状態。自前の望遠鏡を持つことで、惑星の季節変化や気候変動など長期的な観測が必要な現象のデータを毎日取得できるのも利点だ。

協力関係を結ぶハワイ大の敷地を使う。敷地には既設の口径40㌢の光学望遠鏡がある。同大などと資金を出し合って15年に完成する口径1・8㍍の光学望遠鏡と合わせ、観測体制が大幅に強化される。

作業は6月、光学望遠鏡の取り外しを終えた。移設後は仙台市のセンターから遠隔操作できるシステムを視野に入れる。飯舘観測所の約30㍍四方のアンテナを備える大型電波望遠鏡は残し、今後も観測を継続する。

移設に合わせ、惑星から出る可視光と赤外線を詳細に分析する機器を新たに開発する。地球の大気に吸収されるため観測が難しい赤外線を調べることで、惑星の大気の組成のほか、温度や風向、風速などの気象現象が分かるという。

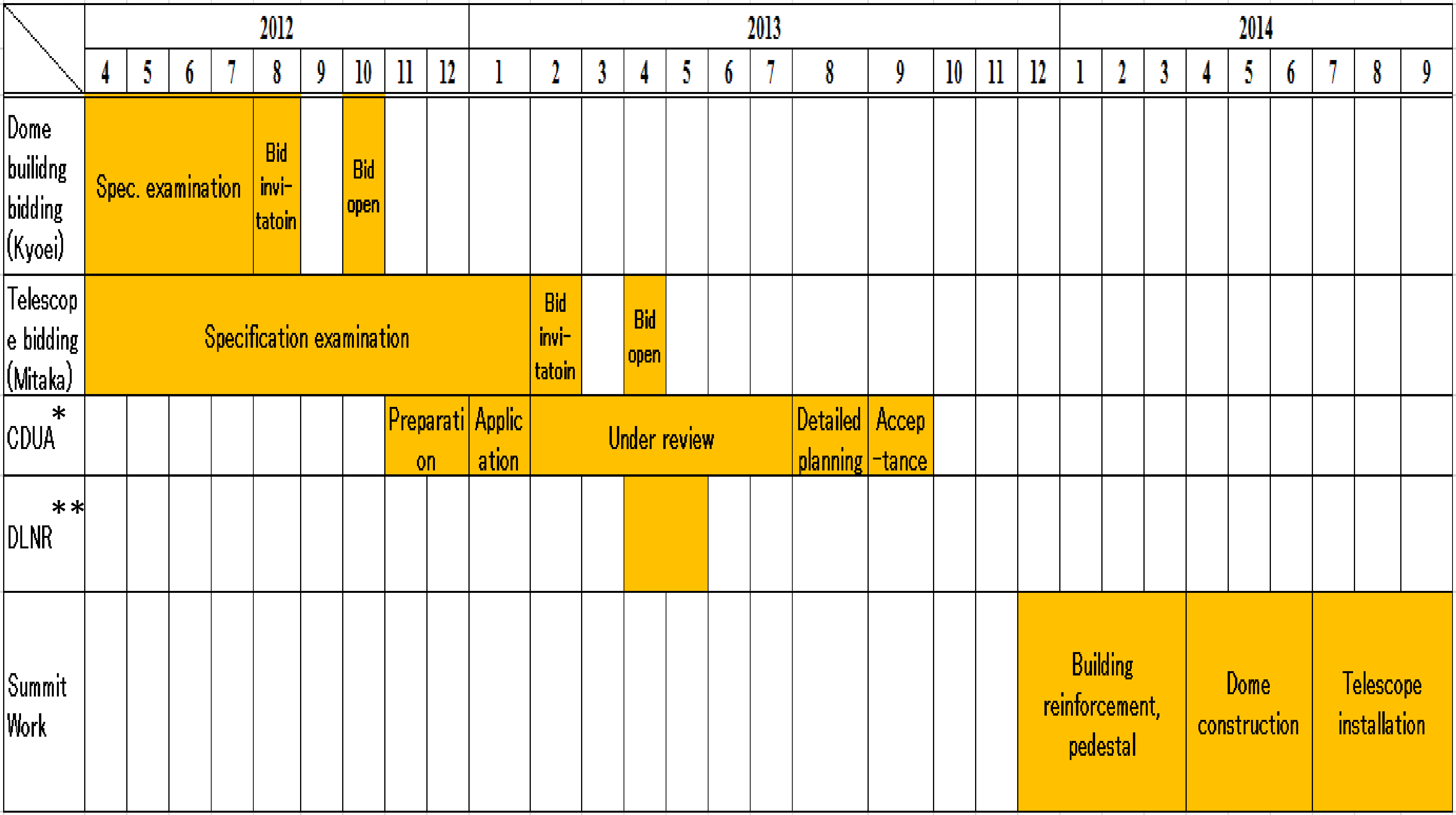
オーロラの研究に取り組む坂野井健准教授（惑星超高層大気物理学）は「高速で自転する木星ではピンクの強力なオーロラが発生している。どのような現象が大気と宇宙空間の接点で起きているのか精密な観測で確かめたい」と意気込む。

光学望遠鏡の移設先となるマウイ島ハレアカラ山頂

2013/11/3　河北新報（一面）

Timeline of T60 installation

2011.11 UH/IFA and Tohoku agreed the relocation of T60

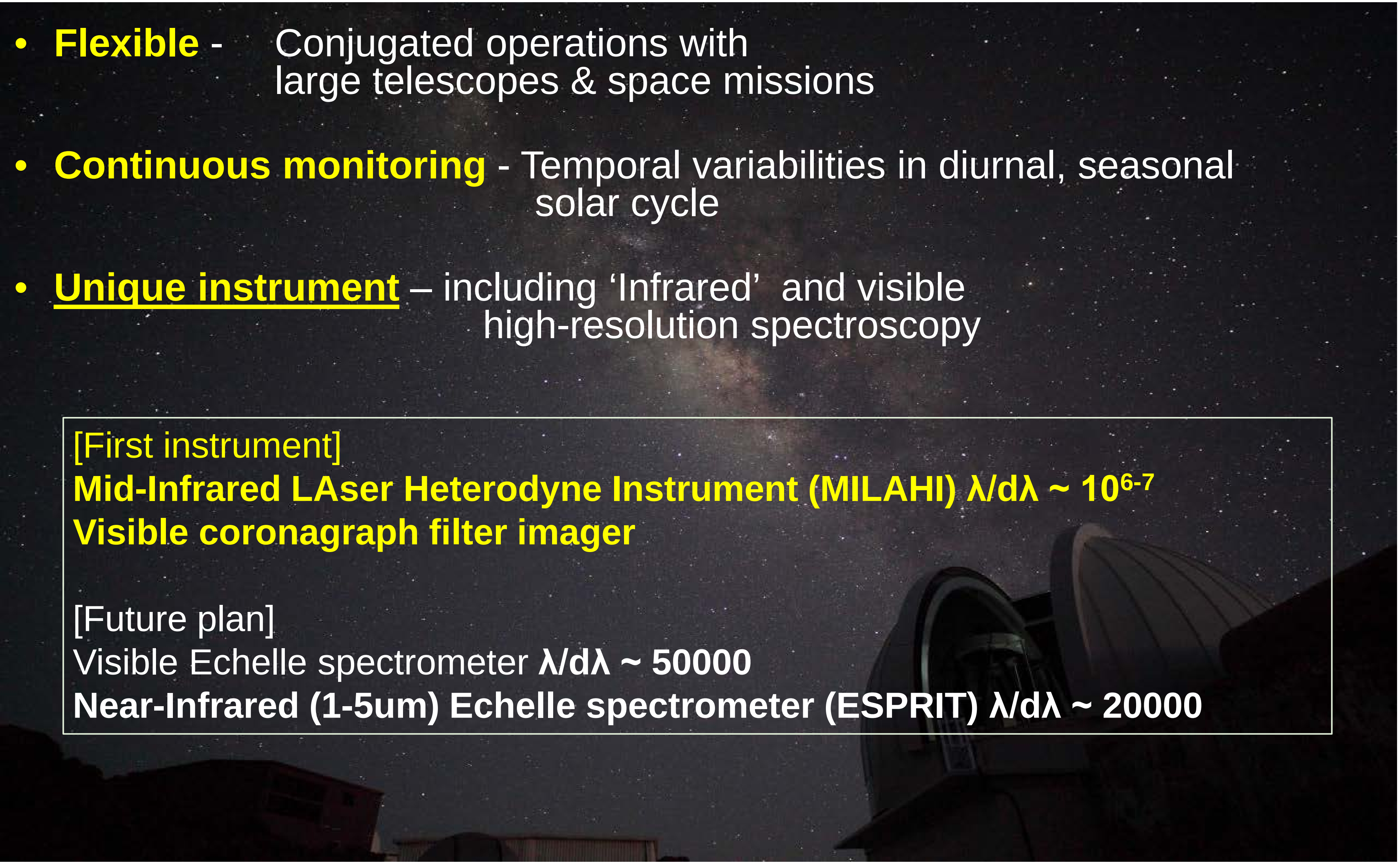


	2012									2013												2014								
	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
Dome builidng bidding (Kyoei)	Spec. examination	▨	▨	▨	Bid invitatoin		Bid open																							
Telescope bidding (Mitaka)	Specification examination	▨	▨	▨	▨	▨	▨	▨	▨	▨	Bid invitatoin		Bid open																	
CDUA*								Preparation	▨	Application	Under review	▨	▨	▨	▨	▨	Detailed planning	Acceptance												
DLNR**													▨	▨																
Summit Work																					Building reinforcement, pedestal	▨	▨	▨	Dome construction	▨	▨	Telescope installation	▨	▨

*CDUA: Conservation District Use Application

**DLNR: Department of Land and Natural Resources

Purpose of Tohoku Univ. 60cm (T60)



- **Flexible** - Conjugated operations with
  large telescopes & space missions

- **Continuous monitoring** - Temporal variabilities in diurnal, seasonal
  solar cycle

- **Unique instrument** – including 'Infrared' and visible
  high-resolution spectroscopy

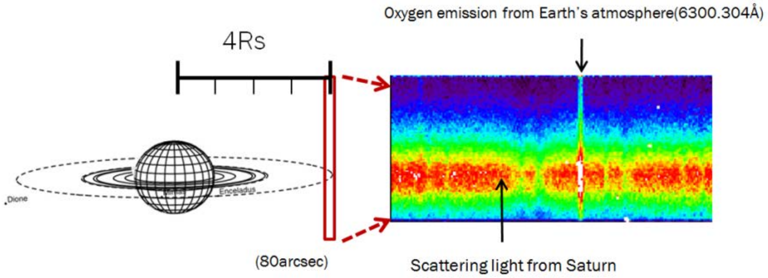
[First instrument]
Mid-Infrared LAser Heterodyne Instrument (MILAHI) λ/dλ ~ 10^{6-7}
Visible coronagraph filter imager

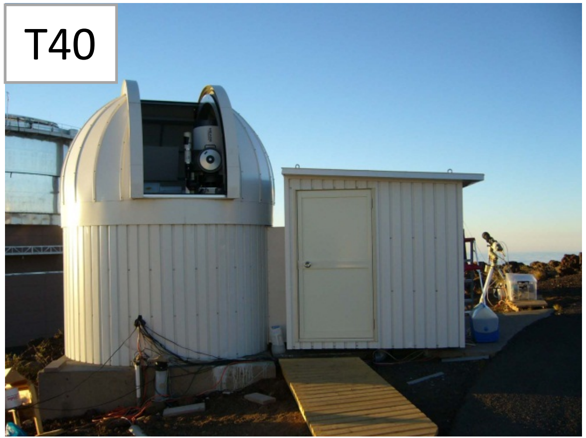
[Future plan]
Visible Echelle spectrometer **λ/dλ ~ 50000**
Near-Infrared (1-5um) Echelle spectrometer (ESPRIT) λ/dλ ~ 20000

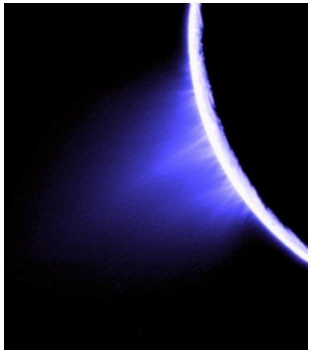
Requirements to detect faint emissions

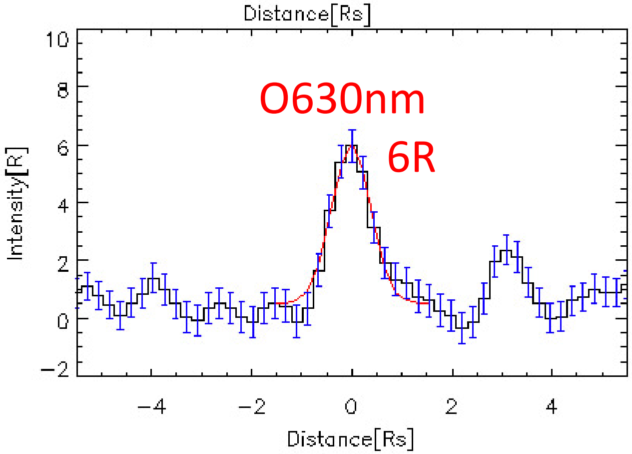
We have operated our 40-cm telescope at Haleakala since 2006.
Solid small body objects are not quiet like;
- **Jupiter's satellite Io torus (S+, Na, etc)**
- **Saturn's satellite Enceladus torus (O)**
- **Mercury's sodium tail (co. Kameda et al.)**

∗ To obtain 1 dataset of Saturn's Enceladus emission, we need integration time for a few days.
∗ To understand the time variation and satellite-phase angle dependence, we need larger aperture and fast optics.









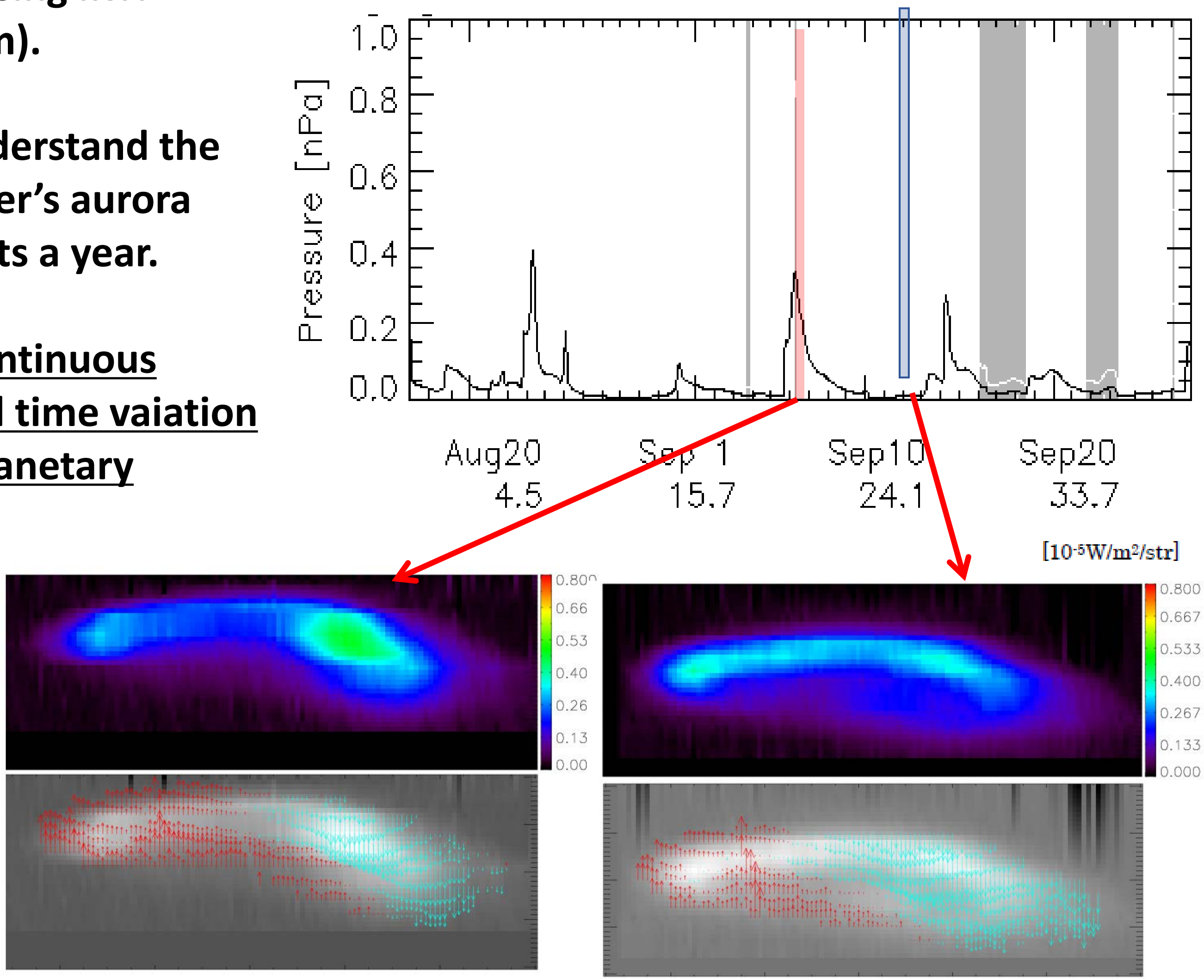
Requirement to understand time variations

Proposal measurements of Jupiter's infrared aurora since 2007 using IRTF（Φ3m）and SUBARU (Φ8.2m).

However, it is difficult to understand the solar wind response to Jupiter's aurora from the data for a few nights a year.

<u>It is essential to carry out continuous measurement to understand time vaiation and causal relationship in planetary atmospheres.]</u>

Solar wind dynamic pressure



Jupiter's infrared aurora at 3.9 μm

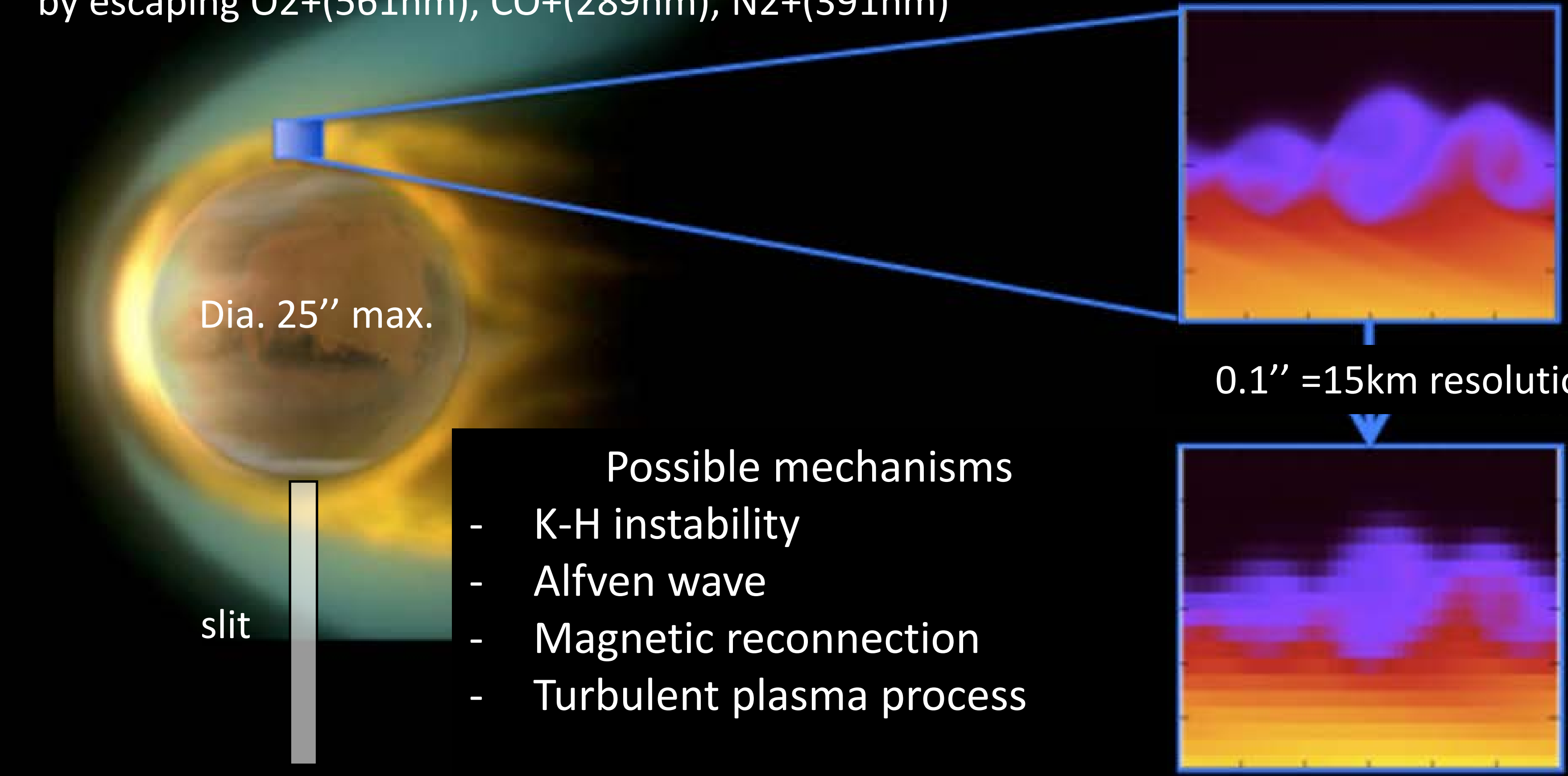
away in red, toward in blue

IRTF

Atmospheric Escape process from Mars

Ion pick up by solar wind

Feasible to detect emissions of resonant scattering by escaping O2+(561nm), CO+(289nm), N2+(391nm)



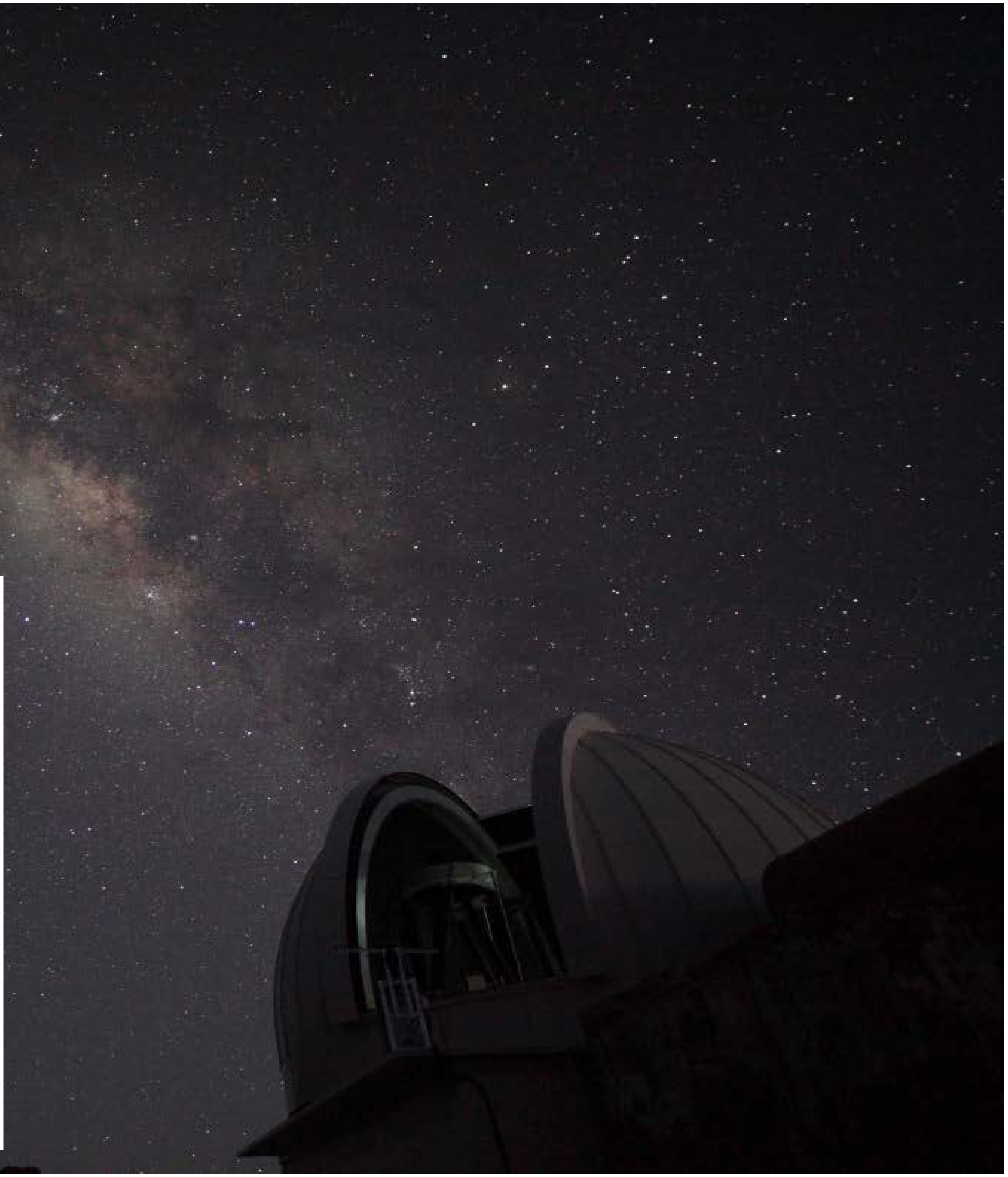
Possible mechanisms

- K-H instability
- Alfven wave
- Magnetic reconnection
- Turbulent plasma process

Why do we need high-resolution spectroscopy to measure planetary atmospheres?

- Detection of emission/absorption (including non-LTE) of planetary atmosphere and satellite, distinguishing from emission/absorption of terrestrial gasses and strong background continuum,
- Detection of tracer gases, such as Martian Methane and H2O/HDO, for dynamics and chemical processes,
- Measurement of Doppler velocity and number density as well as height-profile of gasses.

Night View of Tohoku Univ. 60cm (T60)



晴天率0.6～0.7

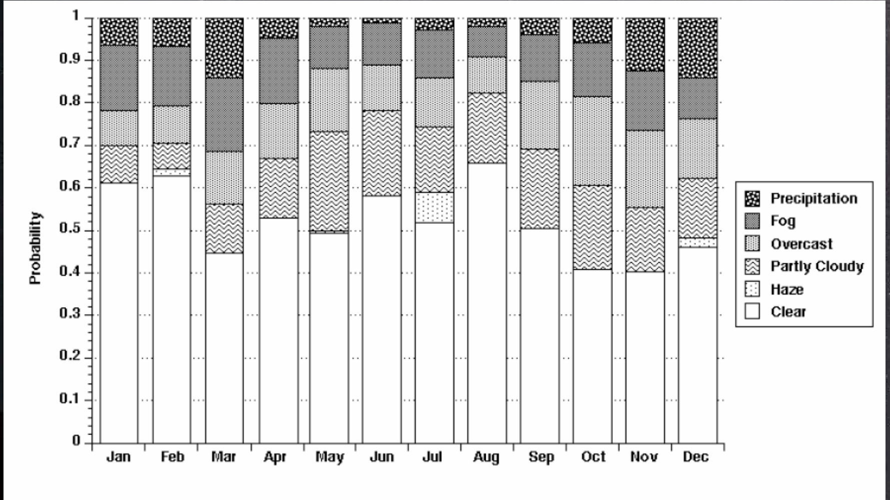
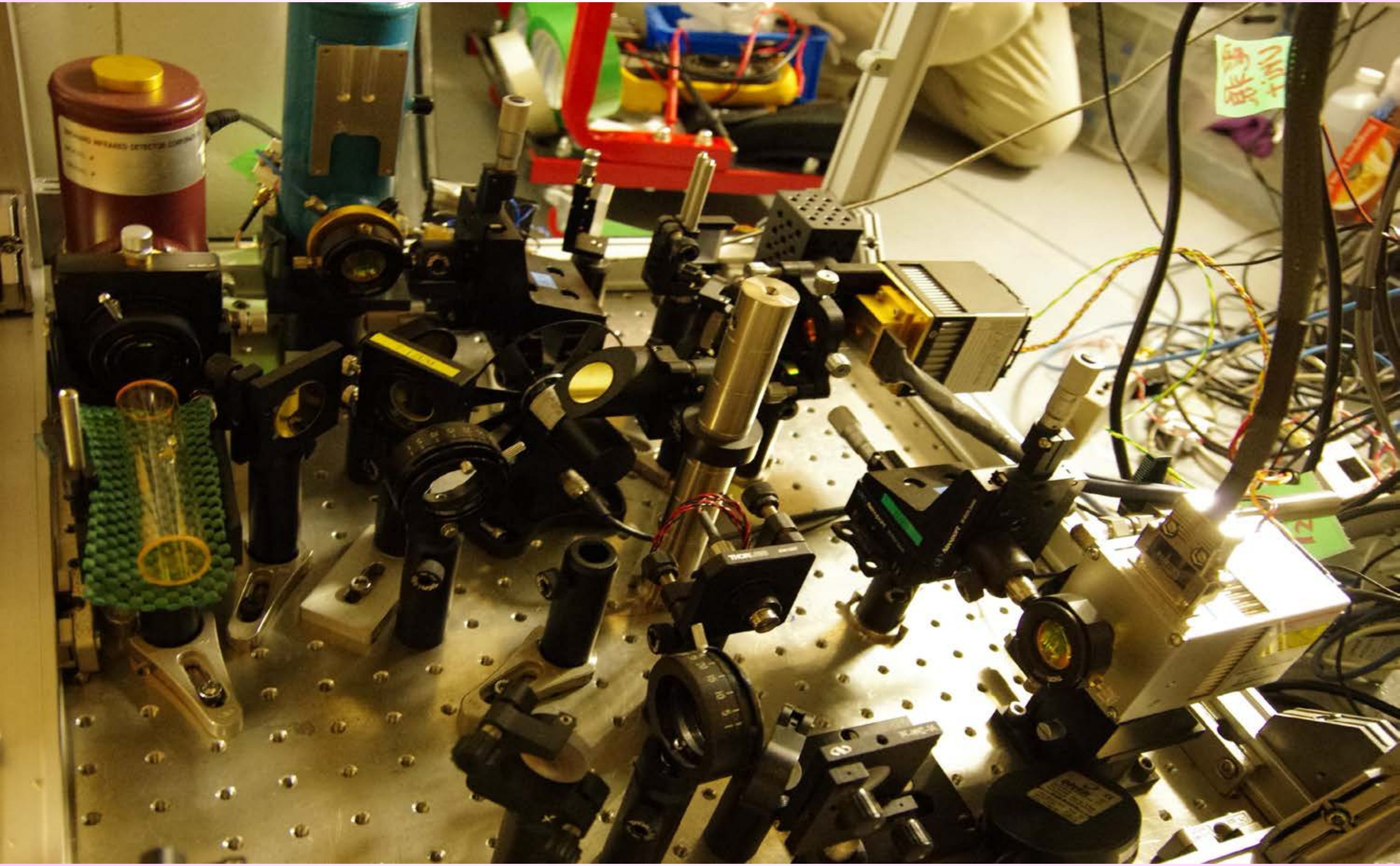
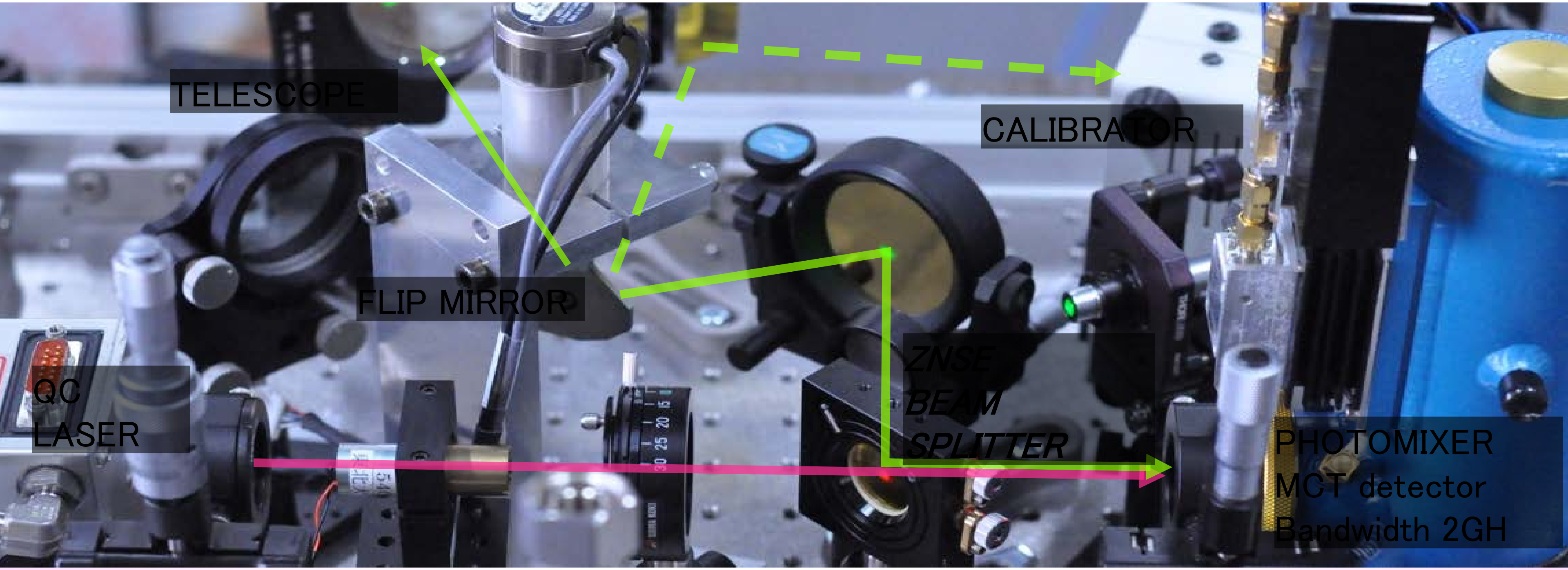


Figure 2-1. AMOS Weather Observations, 5-yr Average

IR Heterodyne instrument on T60 (Sep. 2014) [Credit: Ohkusa]



IR heterodyne: Principle



$$R_{TOA} = \varepsilon_B(T_{surf})\, e^{-\tau} + R_{UW}$$

IR flux from the planet through its atmosphere ...

$$I_{het} = R_{TOA} \otimes R_{LO}$$

… is combined with IR from local (laser) and focused on Photomixer.

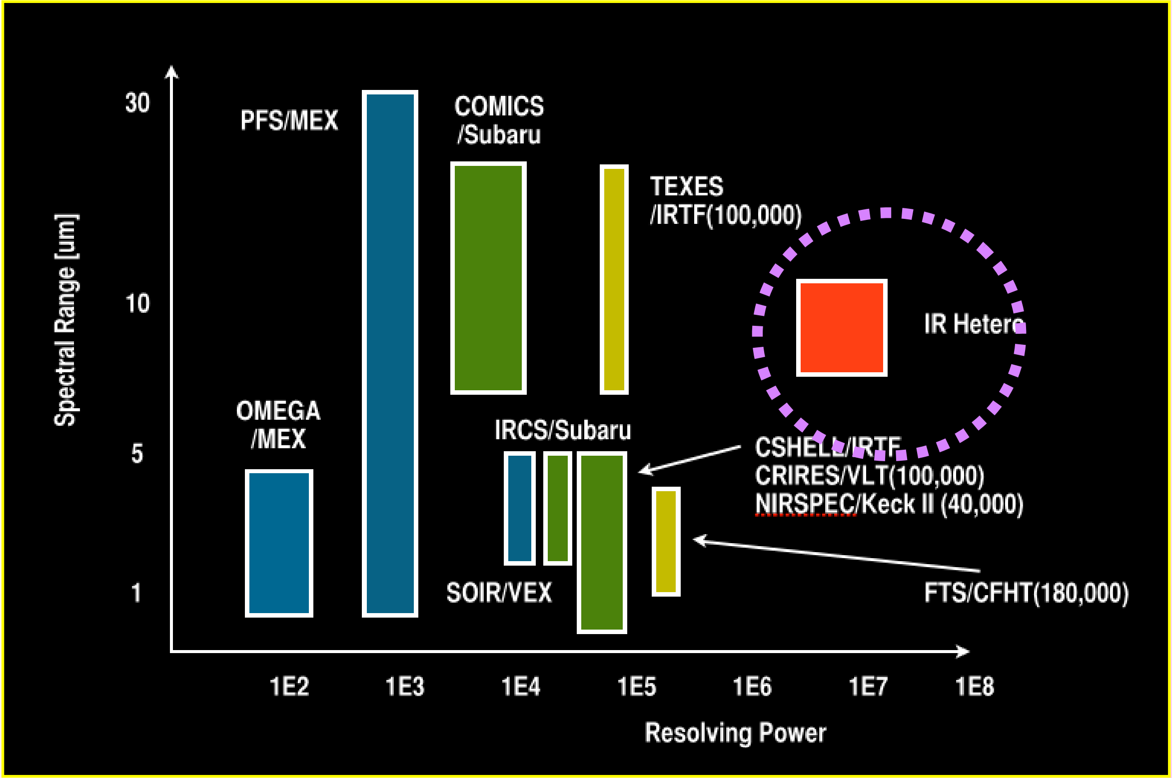
$$I_{het} = I_{DC} + I_{IF} = P_S + P_L + 2\sqrt{P_S P_L}\cos(2\pi \gamma_{IF} t - \varphi)$$

Output is in Radio region (Bandwidth: ~2 GHz) of the electromagnetic spectrum.

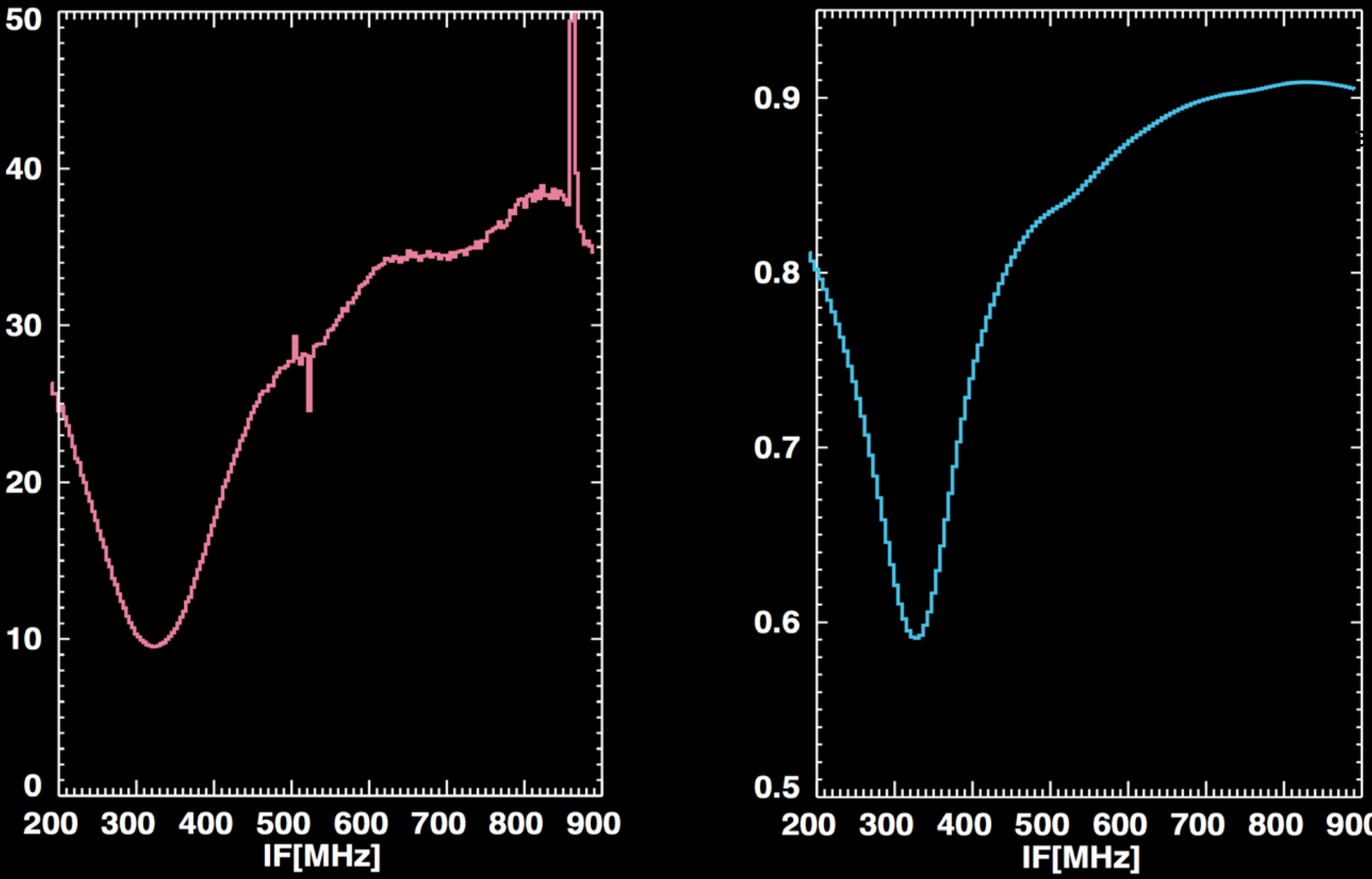
Advantage of IR heterodyne

- **Sensitive detection** of minor trace gases
- **Wind and temperature** (10 m/s & 10K accuracy)
- **Mapping** with **vertical profiles** (3D structure)
- Many **organic** molecules
- **Small-sized**
  (good for space-,
  balloon- applications)

IR Heterodyne instrument onboard T60 on September 2014. [Credit: Ohkusa



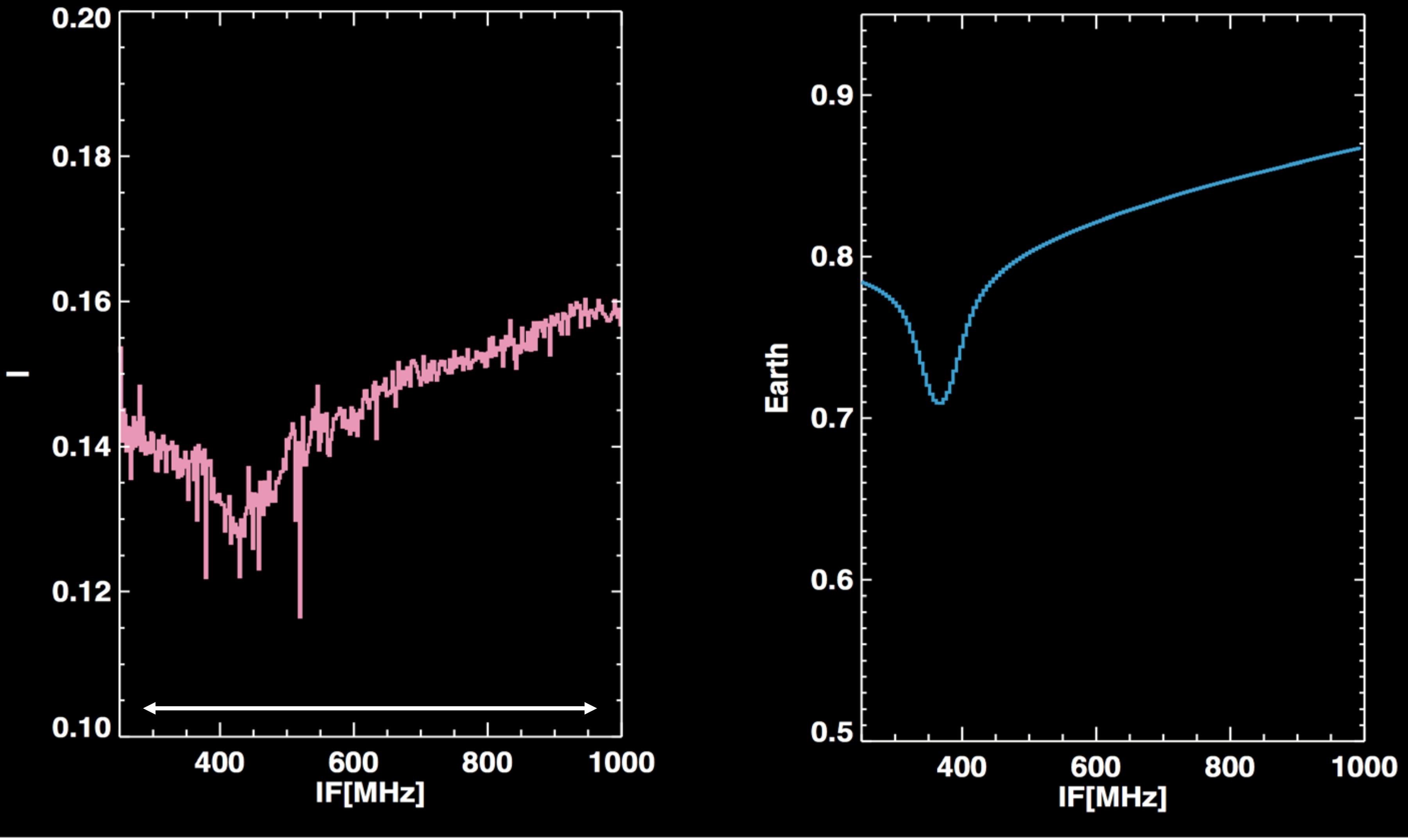
Data at Laboratory with Sun light (ATRC, Univ. Hawaii)



Observed terrestrial O_3 at Laboratory in coelostat sunlight at 1043.864 cm^{-1}
(1GHz bandwidth, 1MHz res., 10min integration time on Mar. 2014)

Reduced sunlight is led into the instrument.

Sun (terrestrial atmosphere) at T60 !

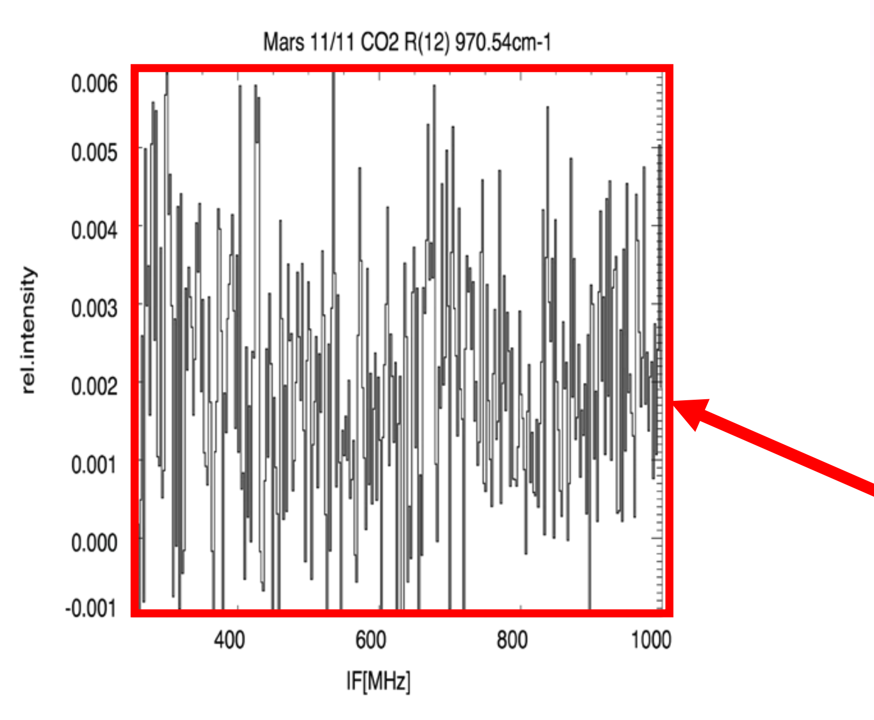


Observed terrestrial CO_2 spectrum with T60 at 970.532 cm-1

(1GHz bandwidth, 2MHz res., 5min integration time on 3 Sep. 2014)

First detection of Mars non-LTE emission with T60 !

(ref) Previous study
[Sonnabend et al., 2006].



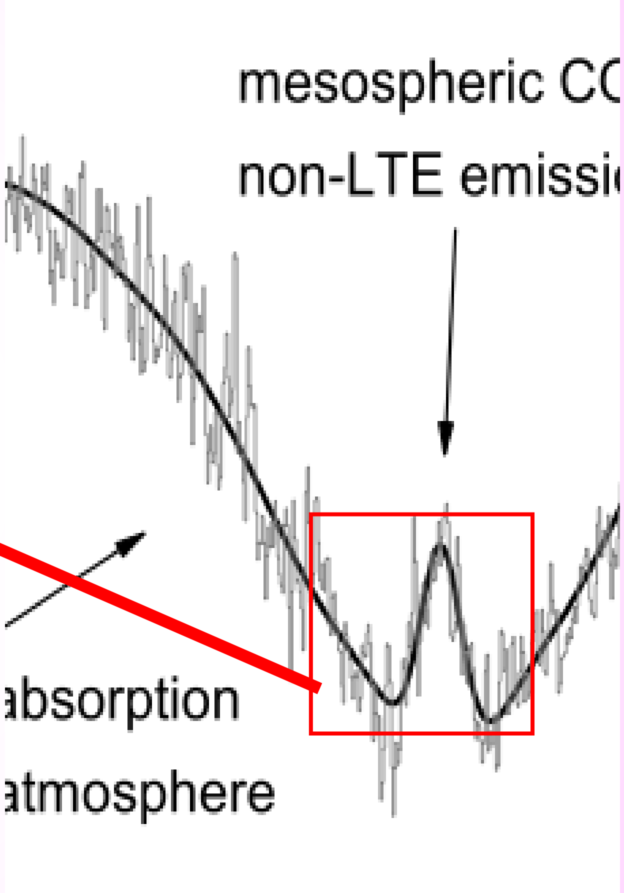
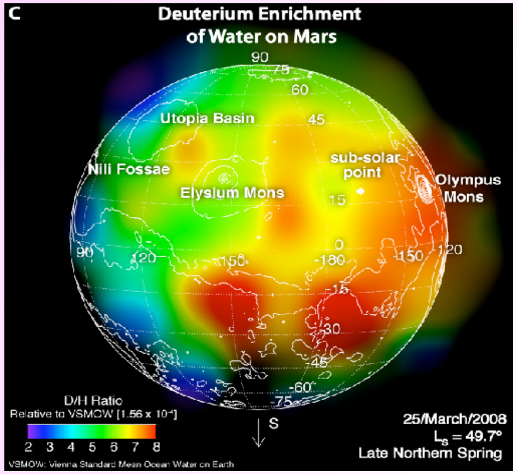


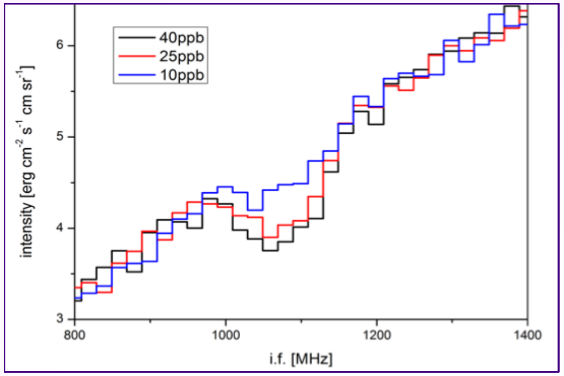
Fig. Mars CO2 non-LTE emission spectrum obtained by IR heterodyne instrument onboard T60 on 11 November 2014. Integration time is 10min. FOV is located at the center of Martian disk.

Observed Martian CO2 spectrum by T60 ***at 970.532 cm^{-1} (2MHz res.)***
on 14 Nov. 2014

Heterodyne Target: with λ/dλ>1,500,000

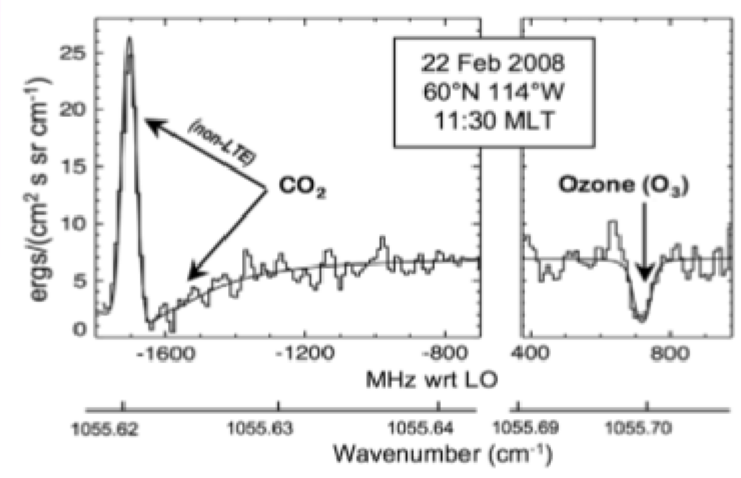
Isotope map, HDO/H_2O (Villanueva+, 2008)

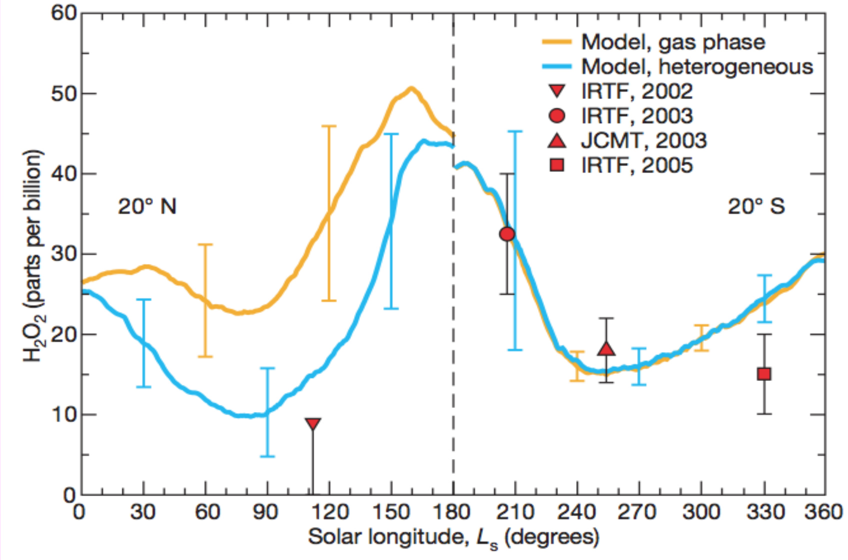




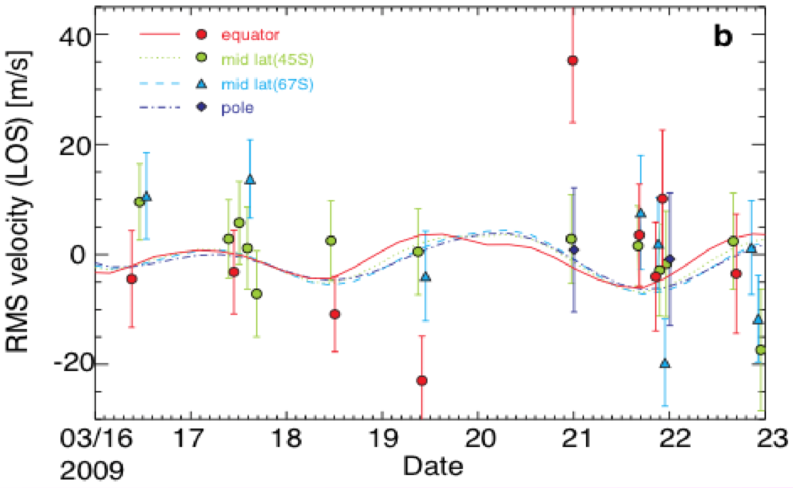
Detection of CH_4 (Sonnabend+, 2009)

IRTF/HIPWAC (Fast+, 2009)





Seasonal var. of oxidisor, H_2O_2 (Lefevre+, 2009)



Mesospheric Wind and T (Nakagawa+, 2013)

Spatial Resolution of MILAHI with T60

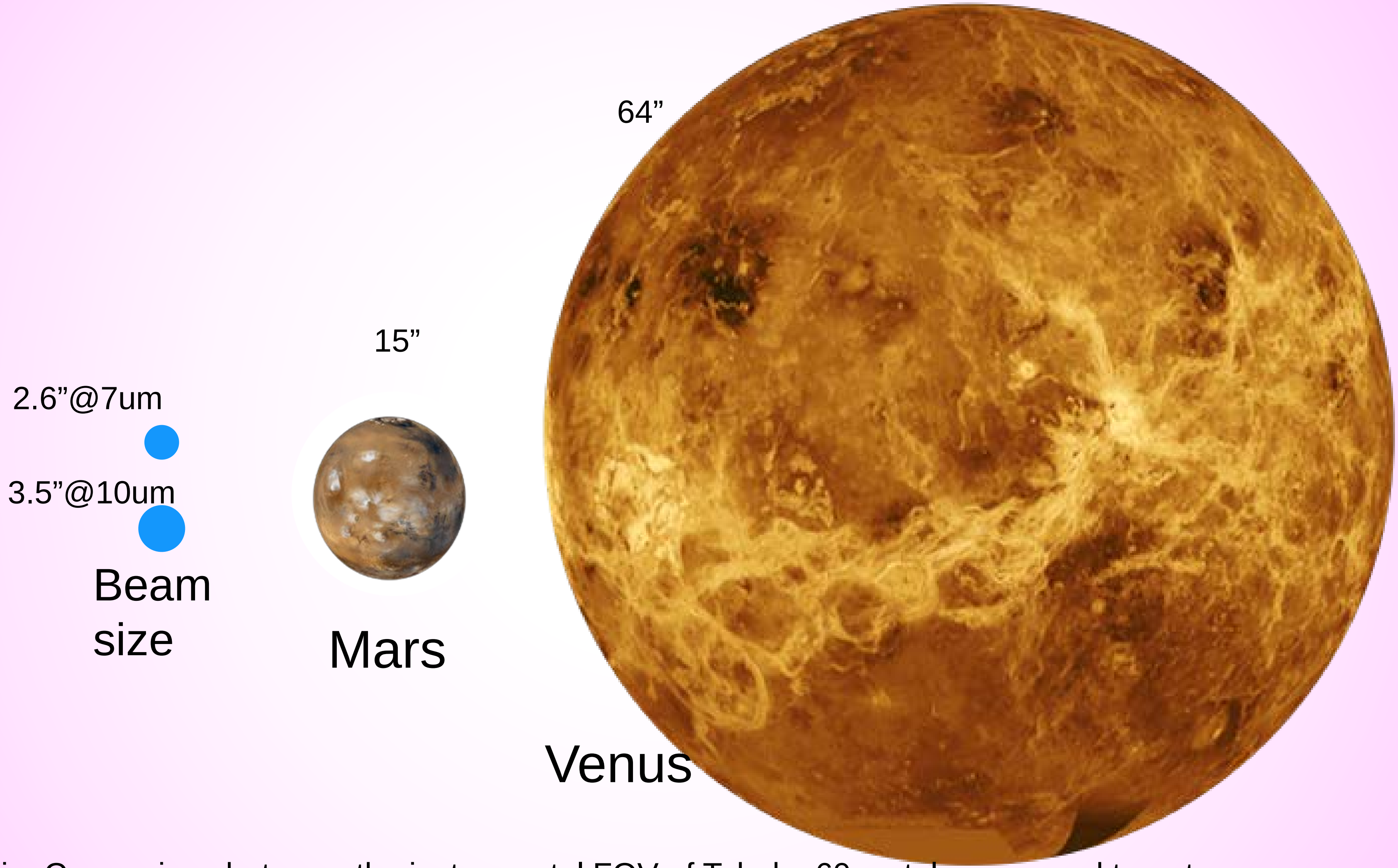
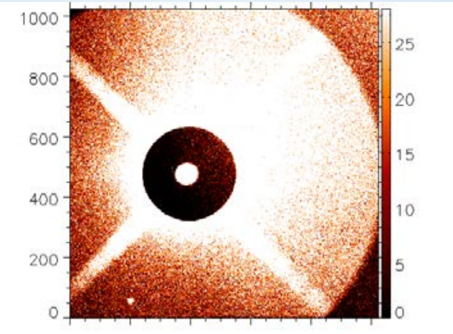


Fig. Comparison between the instrumental FOV of Tohoku 60cm-telescope and targets. Resolved disk image can be obtained to investigate global distributions of physical parameters.

Optical Layout and an Occultation mask for coronagraphy



ND4 filter

1st focal plane

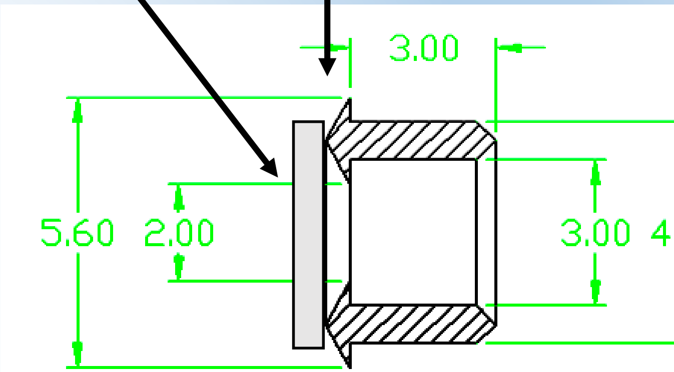
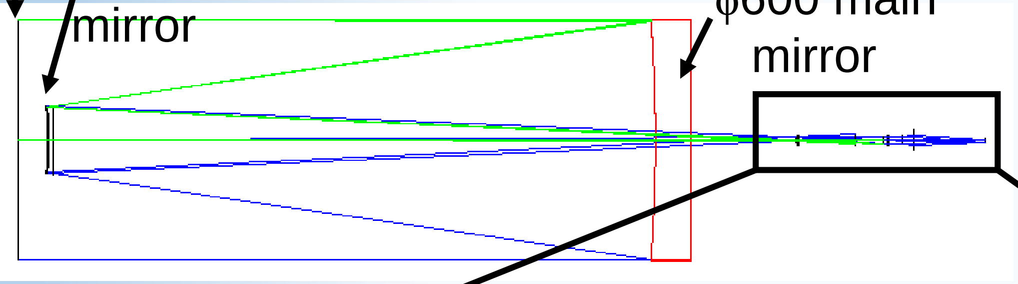


Fig. Crosssection of an occulting mask

Entrance pupil

ϕ220 secondary mirror

ϕ600 main mirror

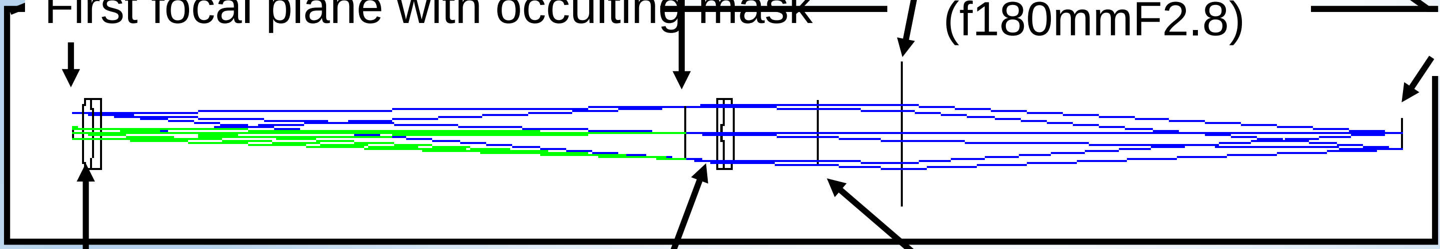


Lyot stop (pupil mask)

Camera lens (f180mmF2.8)

First focal plane with occulting mask

Final focal plane (ccd)



Collimating lens (f250mm achromatic)

Narrow-band filter

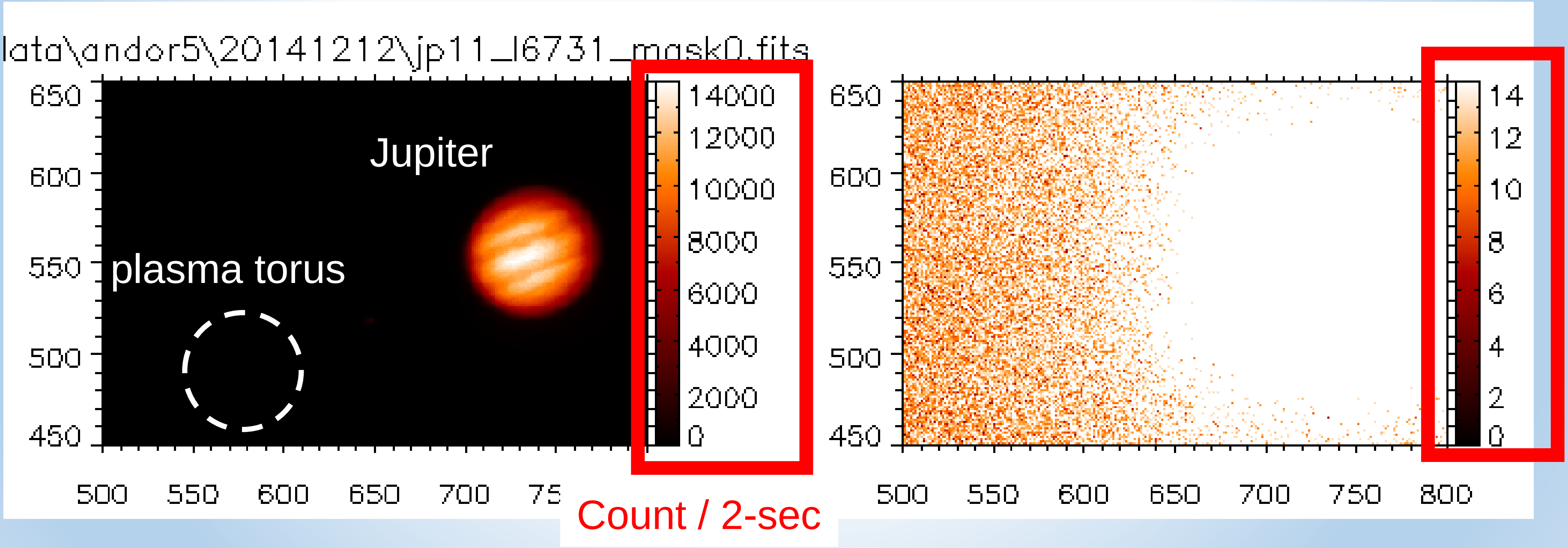
Field lens (f200mm achromatic lens)

Fig. Optical layout of new monochromatic imager attached on Tohoku 60cm telescope at Haleakala

High-dynamic range observation 2

Tab. 1 Brightness of targets and contamination sources

Targets	**Separation from bright objects**	Brightness of targets	Brightness of bright objects	**Brightness ratio (obj/tar)**
Jupiter plasma torus	**50-100”**	500 R	50MR/nm	**10^5**
Enceladus torus	**5” from Rings 15” from disk**	5 R	20 MR/nm (Ring) 15 MR/nm (Disk)	**>10^6**
Escaping spices from Venus	**10-100”**	1-100 R	>500/nm MR	**>10^6**



Count / 2-sec

Fig2. Contamination by Jupiter disk continuum

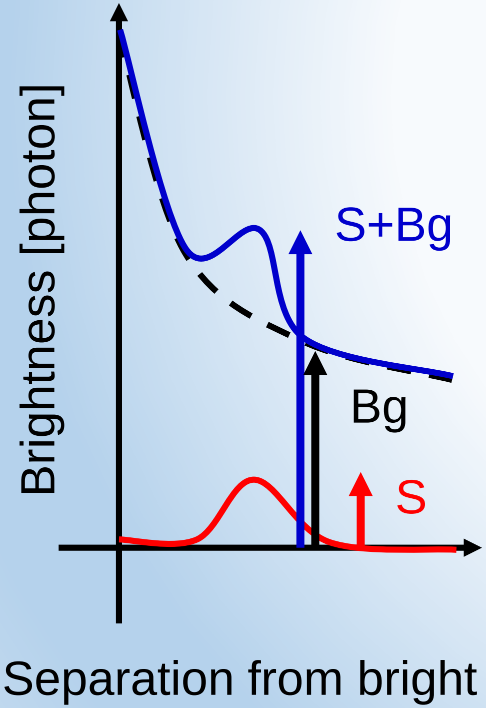
Improving Signal / Noise Ratio

Signal Noise Ratio,

$$S/N = \frac{S}{\sqrt{S+Bg}} \begin{cases} = \sqrt{S} & \text{(where S>>Bg)} \\ = \sqrt{S}/\sqrt{Bg} & \text{(where S<<Bg)} \end{cases}$$

s is number of signal photon,
Bg is number of background photon

Under the terms of S << Bg, reducing Bg mainly improves S/N.



Target + Background
Background (contamination)
Target

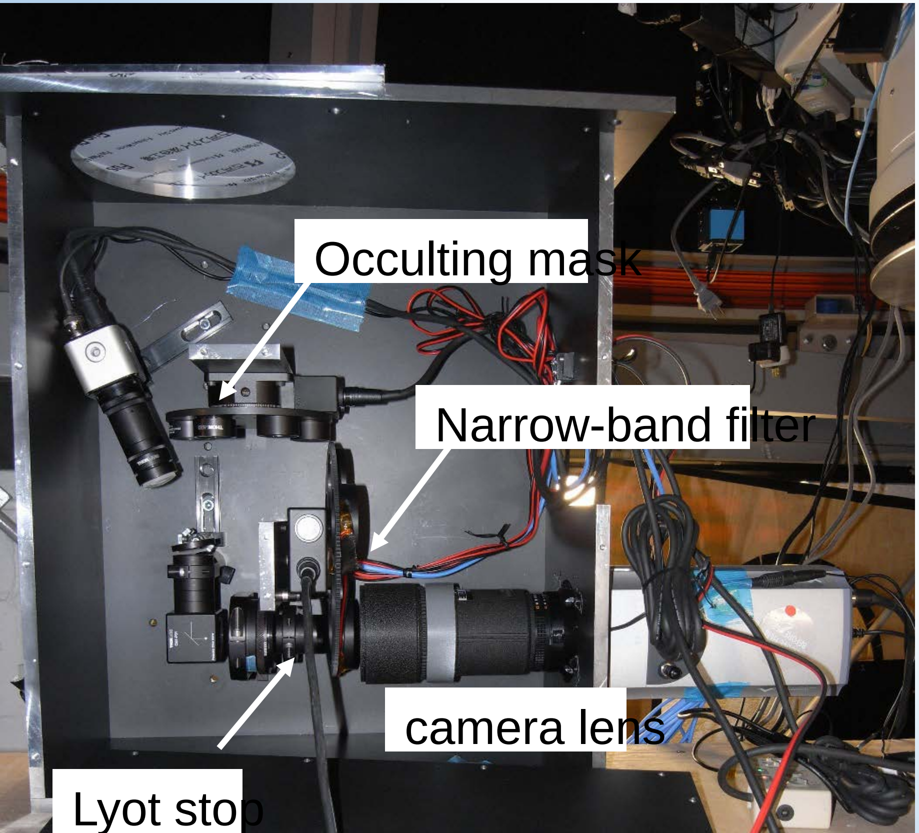
A new monochromatic imager has been developed for Tohoku 60-cm telescope (T60) at Haleakala observatory

What does make “Background Contamination”?

Scattering and Diffraction mainly cause background contamination.

For reducing scattered light, we put a mask on the first focal plane which occults or reduces light from bright main body. The mask decreases scattering by optics after the mask.

For reducing diffraction, we put a pupil mask called ***“Lyot stop”. …***

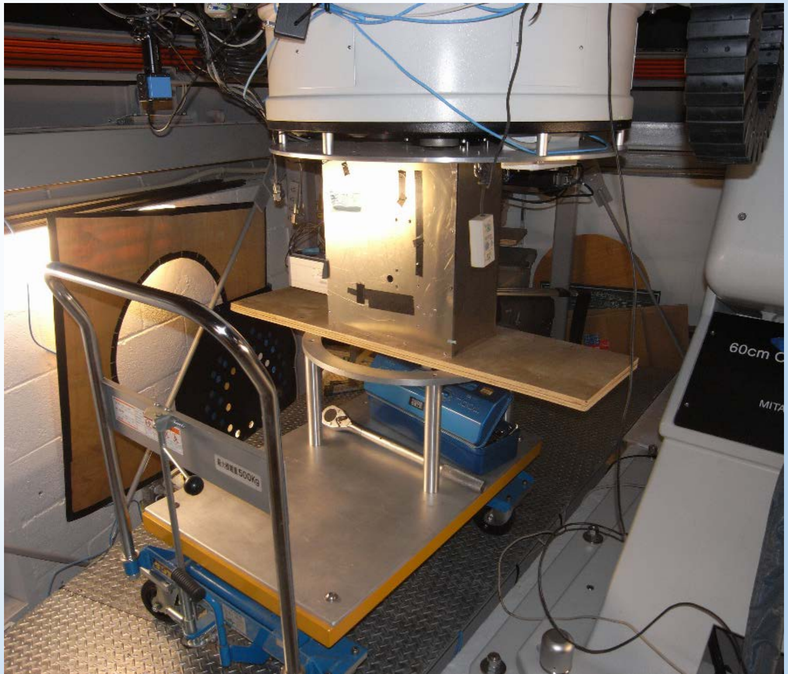


Occulting mask

Narrow-band filter

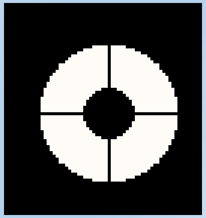
camera lens

Lyot stop



Reducing diffraction using Lyot stop

Entrance pupil image



FT

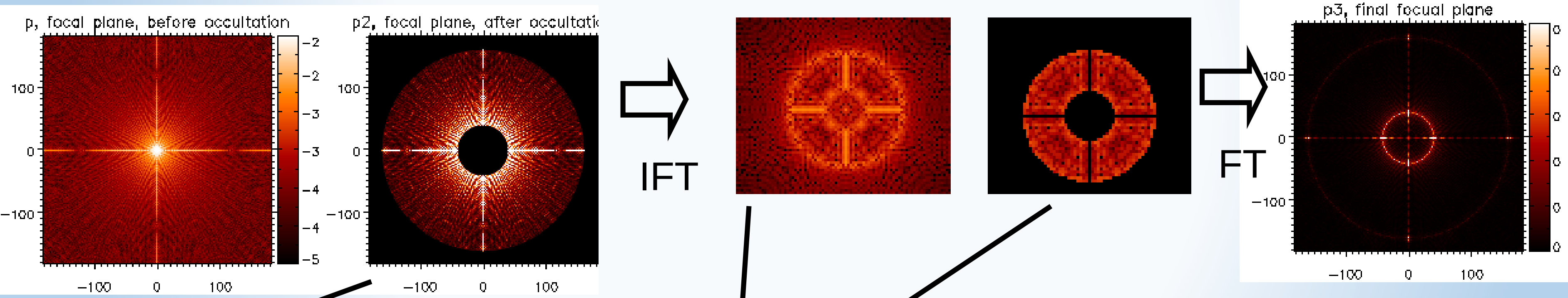
Secondary support structure (spider)

produces cross-shaped diffraction pattern
which is the most critical for detecting fain
emission spreading around the bright body.

Before / after occulting mask

Before / after Lyot stop

Final image at CCD



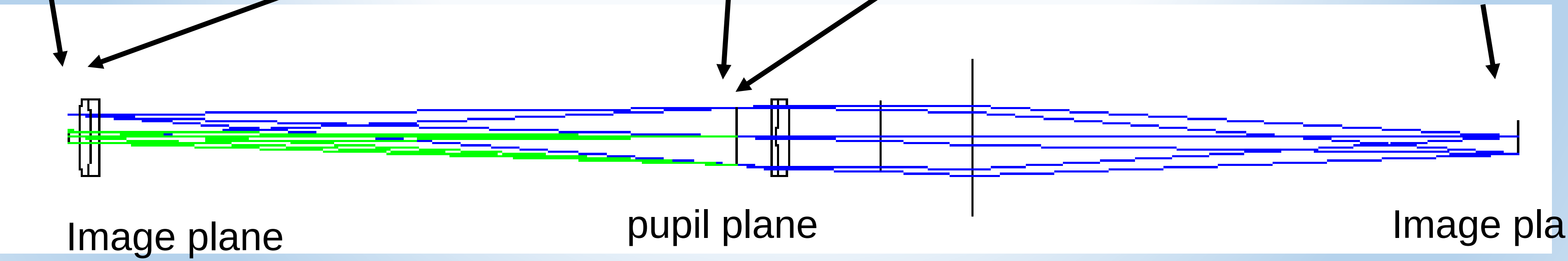


Fig. Model calculation of diffraction pattern using Lyot stop

Preliminary result of Jupiter plasma torus observation

Brightness on the dusk ansa increases when λIII~200 degrees.

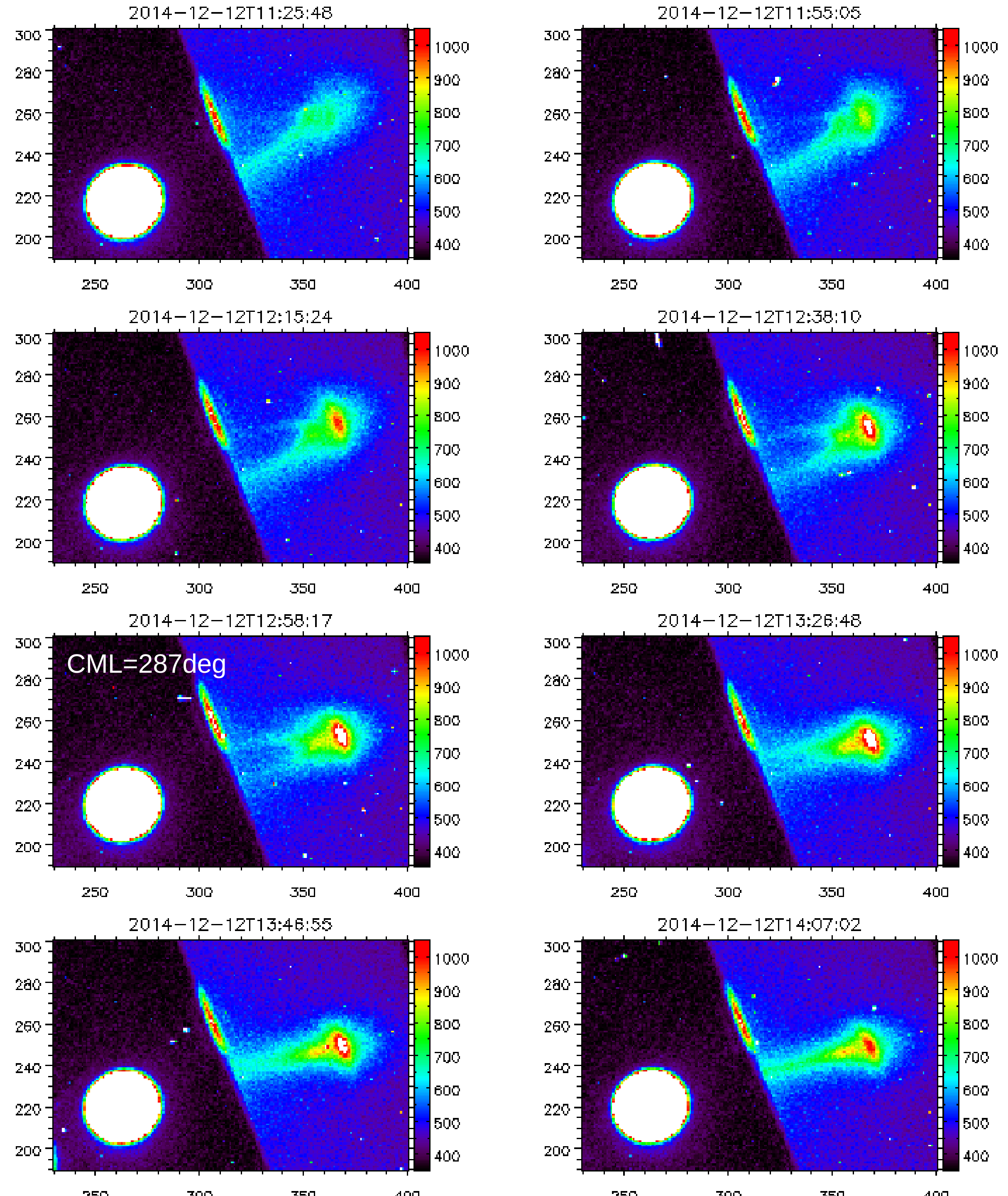


Fig. a seriel of [SII] 6731A images of Jupiter plasma torus on 2014-12-12 UT. Exposure time is 20-

Summary

- **MILAHI, a new infrared heterodyne instrument with λ/dλ ~ 10^{6-7}** finally started its initial run attached to Haleakala T60.

- **Feasibility on T60 was demonstrated by solar observations** (terrestrial and solar atmospheres).

- **We are going to Martian observations** in Nov 2014 and March-September 2015 for the monitor of lower atmosphere just below MAVEN observations.

- **A new monochromatic imager with an Occulting mask and a Lyot stop** was been developed for Tohoku 60cm telescope (T60).

- **The imager successfully decreases diffraction** from bright main body by factor of 2-3 for axisymmetric background contamination as well as by order of 1 for cross-shaped background contamination.

- **Long-term monitoring of faint emissions close to the planets**, e.g. Jupiter plasma torus, Enceladus torus, will be achieved using this high-dynamic imaging capability with high-spectral resolution.