Millimeter-Wave Bands Monitoring Observations of Planetary Atmospheres with a Ground-Based 10-m Radio Telescope

太陽系惑星大気観測　SPARTプロジェクト

－太陽活動(G型星)惑星大気環境に与える影響　－

Solar Planetary Atmosphere Research Telescope

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Landscape of SPART operation

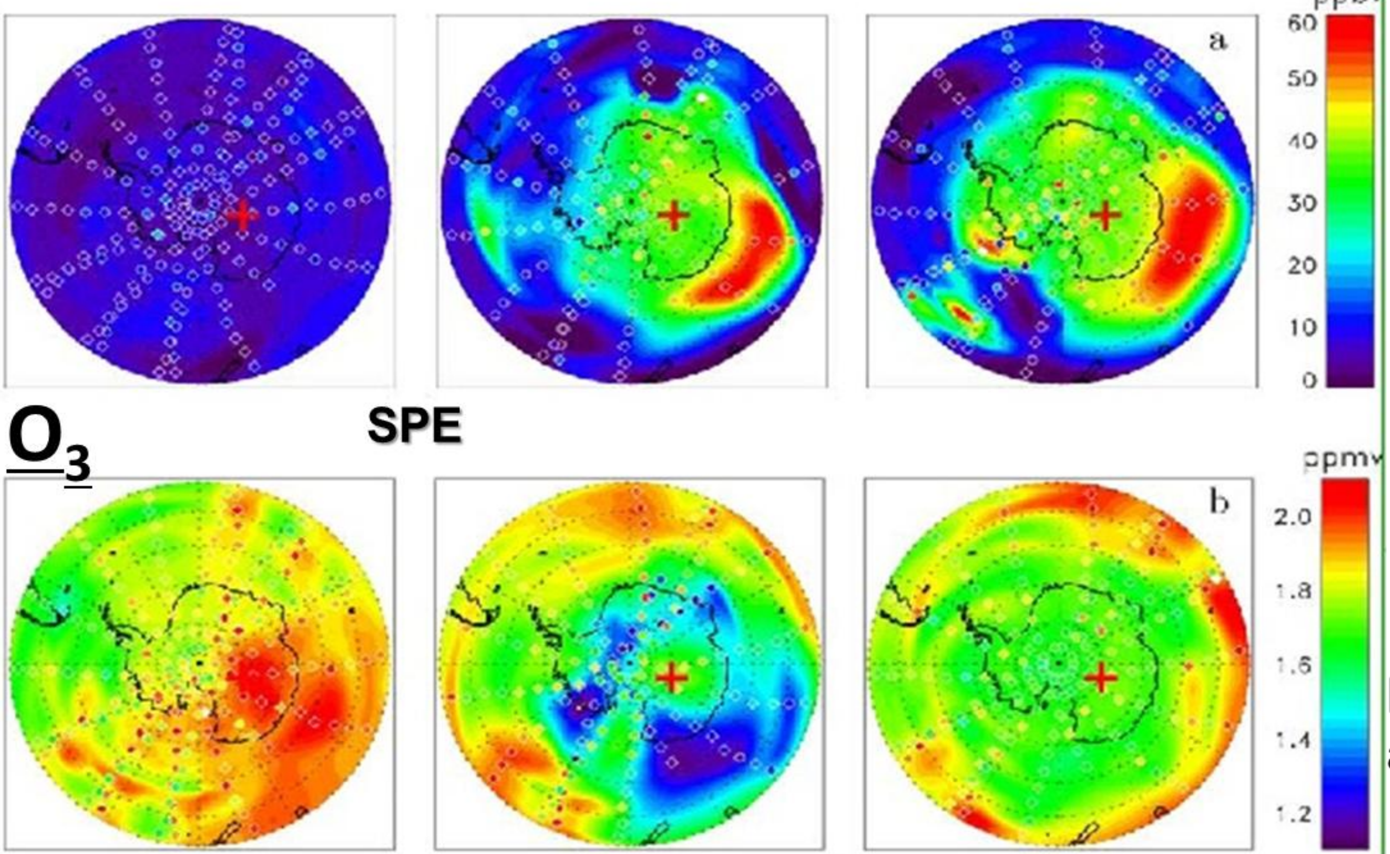
Influence of Solar Proton Events (SPE) on Planetary Atmosphere

Earth

MIPAS Satellite

NO_x **27-OCT 2003** **29-OCT** **30-OCT**

O_3 **SPE**



$N(^2D) + O_2 \rightarrow NO + O$

$N(^4S) + O_2 \rightarrow NO + O$

Middle/upper mesosphere

$H + O_3 \rightarrow OH + O_2$

$OH + O \rightarrow H + O_2$

$O_3 + O \rightarrow O_2 + O_2$

Lower mesosphere and upper stratosphere.

$OH + O_3 \rightarrow HO_2 + O_2$

$HO_2 + O \rightarrow OH + O_2$

$O_3 + O \rightarrow O_2 + O_2$

Lopez–Puertas et al. 2005, JGR

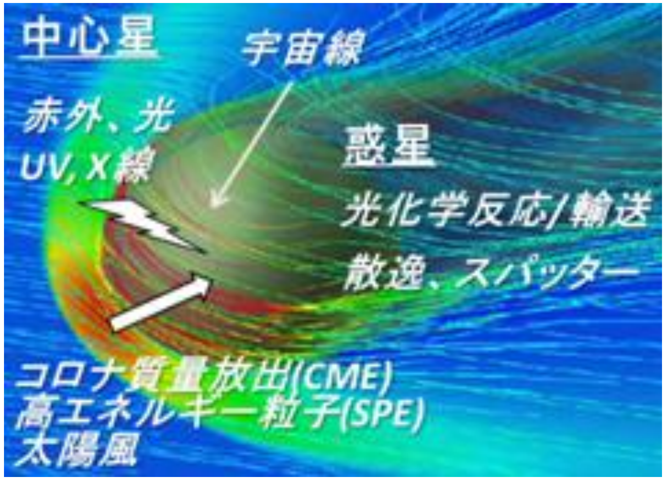
Introduction

Influence of activities of a G-type star, the Sun on Planetary middle Atmospheres

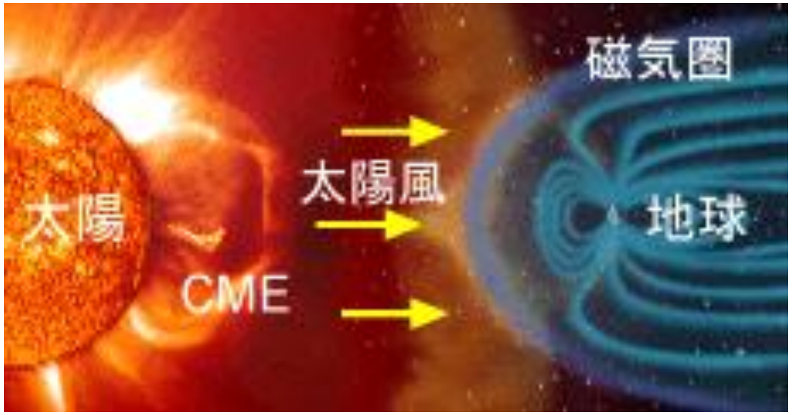
Solar activities such as solar wind, solar flares, solar proton events (SPEs) have affected the environments and evolutions of planetary atmospheres.

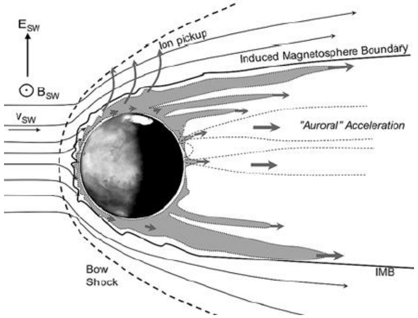
To further understand the habitable zone and atmospheric physical and chemical balance of solar and extra-solar planets, it is important to study the influence of activities of our Sun, which is a typical G-type star, on the atmospheres of Venus and Mars as well as of Earth.

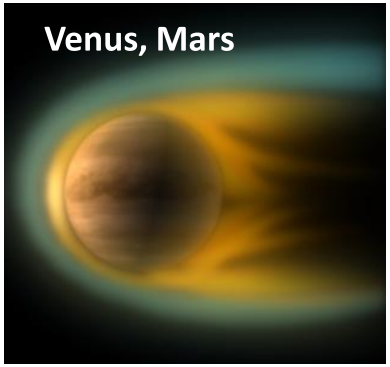
The Earth is protected by its geomagnetic field, whereas Mars and Venus are directly exposed to solar activities because of the absence of such an intrinsic geomagnetic field.



Magnetic Storm, Airglow, Aurora







Mm/Submm Wave Band Heterodyne Spectroscopy With Ground Based Telescope

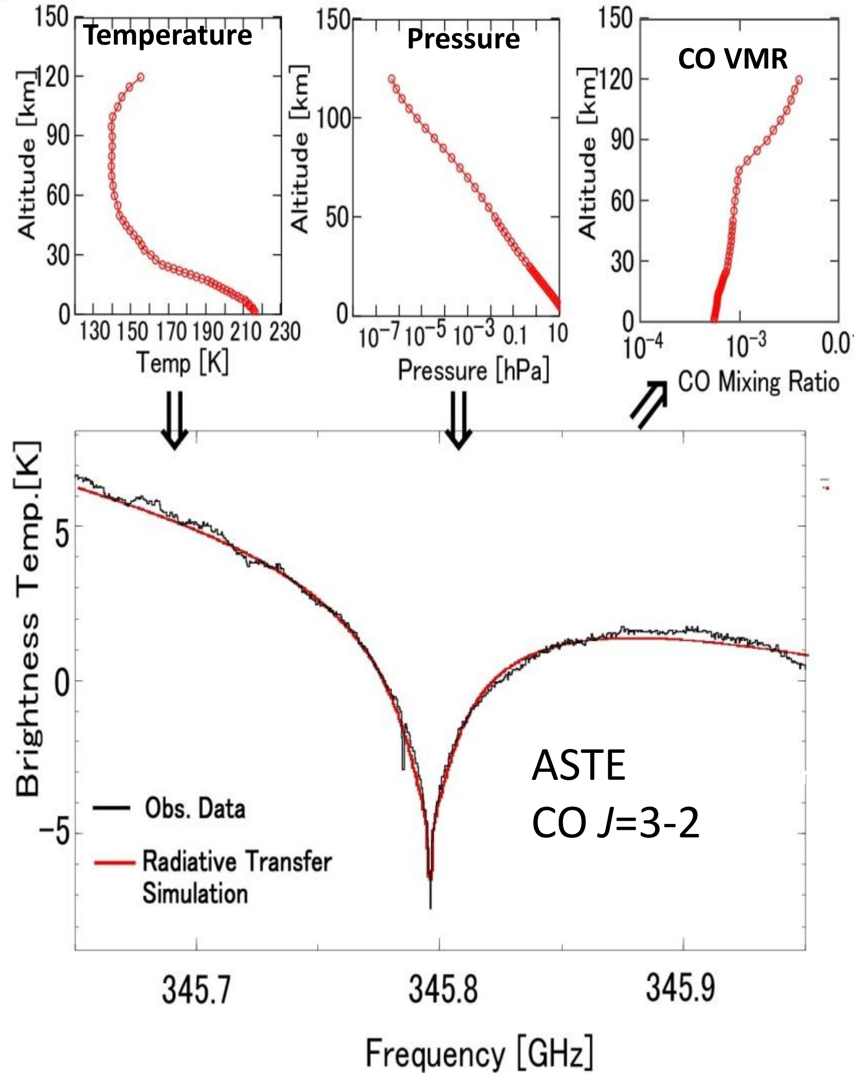
Atacama Submillimeter Telescope Experiment (ASTE) Alt. 4860m

Asdvantage

- less affected by absorption/scattering of aerosols

- high frequency resolution
  ($f/df \sim 10^7$)
  -> Vertical distributions of minor constituents and/or temperature in <u>middle atmosphere</u>, which can be derived by retrieval analysis.

- Systematic long-term and ToO observations with various spectral lines



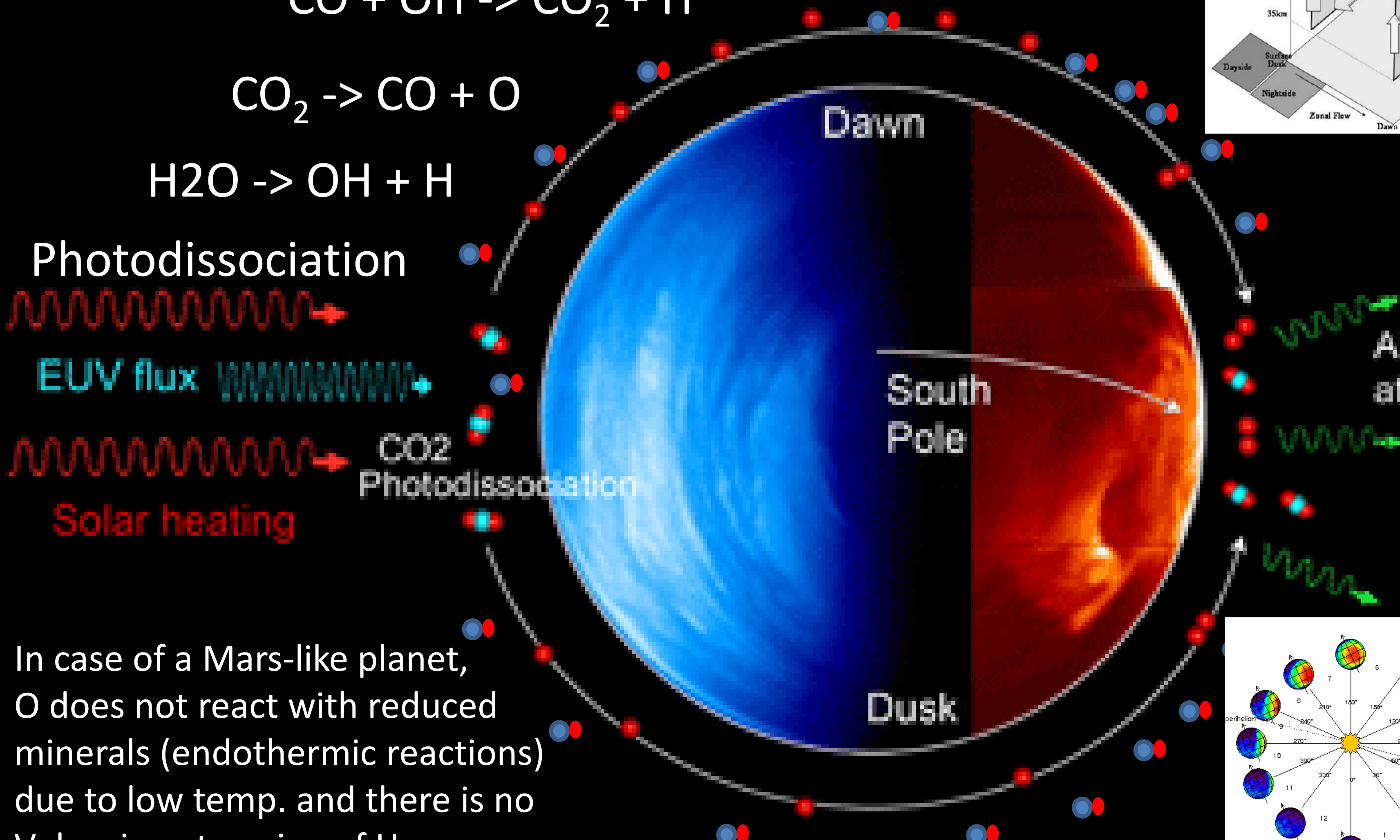
Formation & Destruction Processes of CO, CO_2, O_2

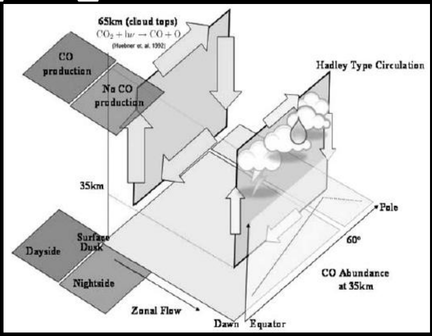
$CO + OH \rightarrow CO_2 + H$

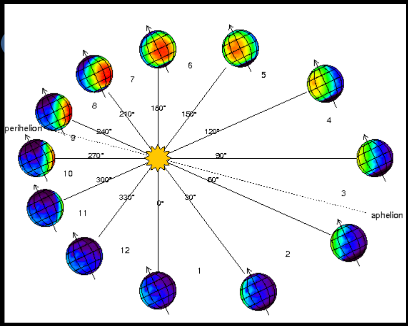
$CO_2 \rightarrow CO + O$

$H2O \rightarrow OH + H$

Photodissociation

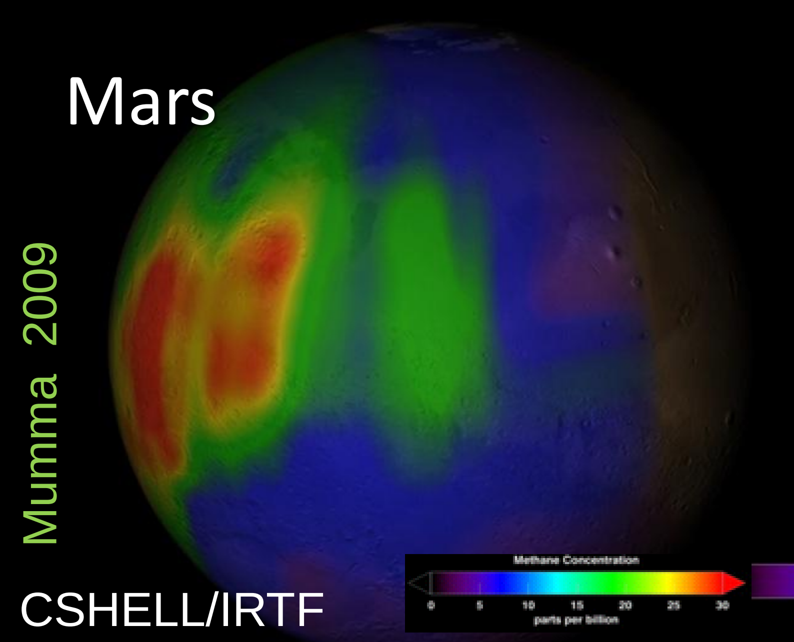


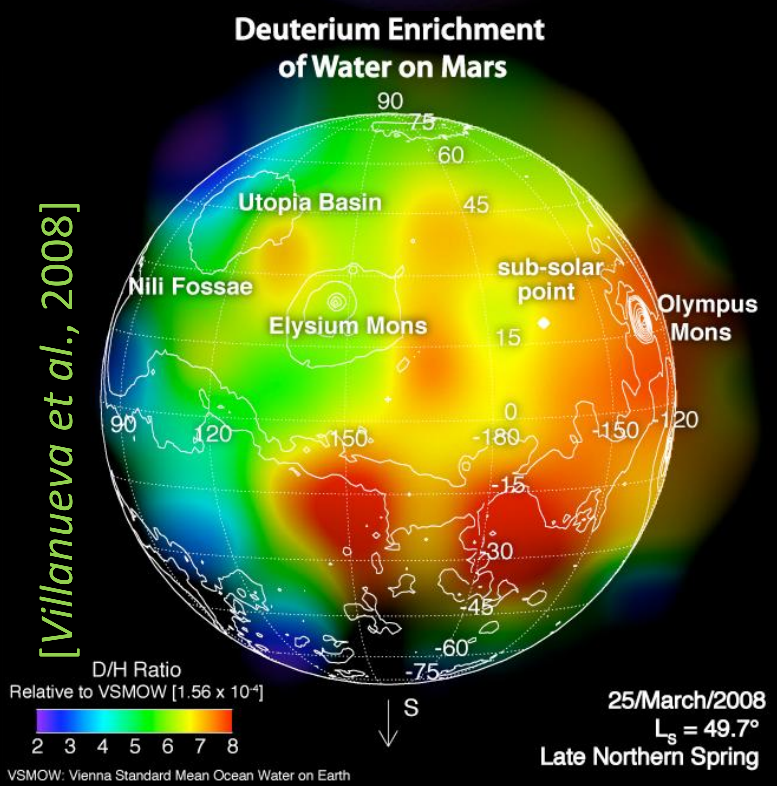




In case of a Mars-like planet, O does not react with reduced minerals (endothermic reactions) due to low temp. and there is no Volcanic outgassing of H_2

WEBPAGE: ESA (modified)





CH_4 Methane

Life Time of CH_4 : ～340 yr on gas phase chemistry
We can not explain the abundance and localized distribution

- Cometary Impacts, fireball
- Geologic sources
  Volcanism, Hydrothermal Activity, Hot Spots, Gas Seepage

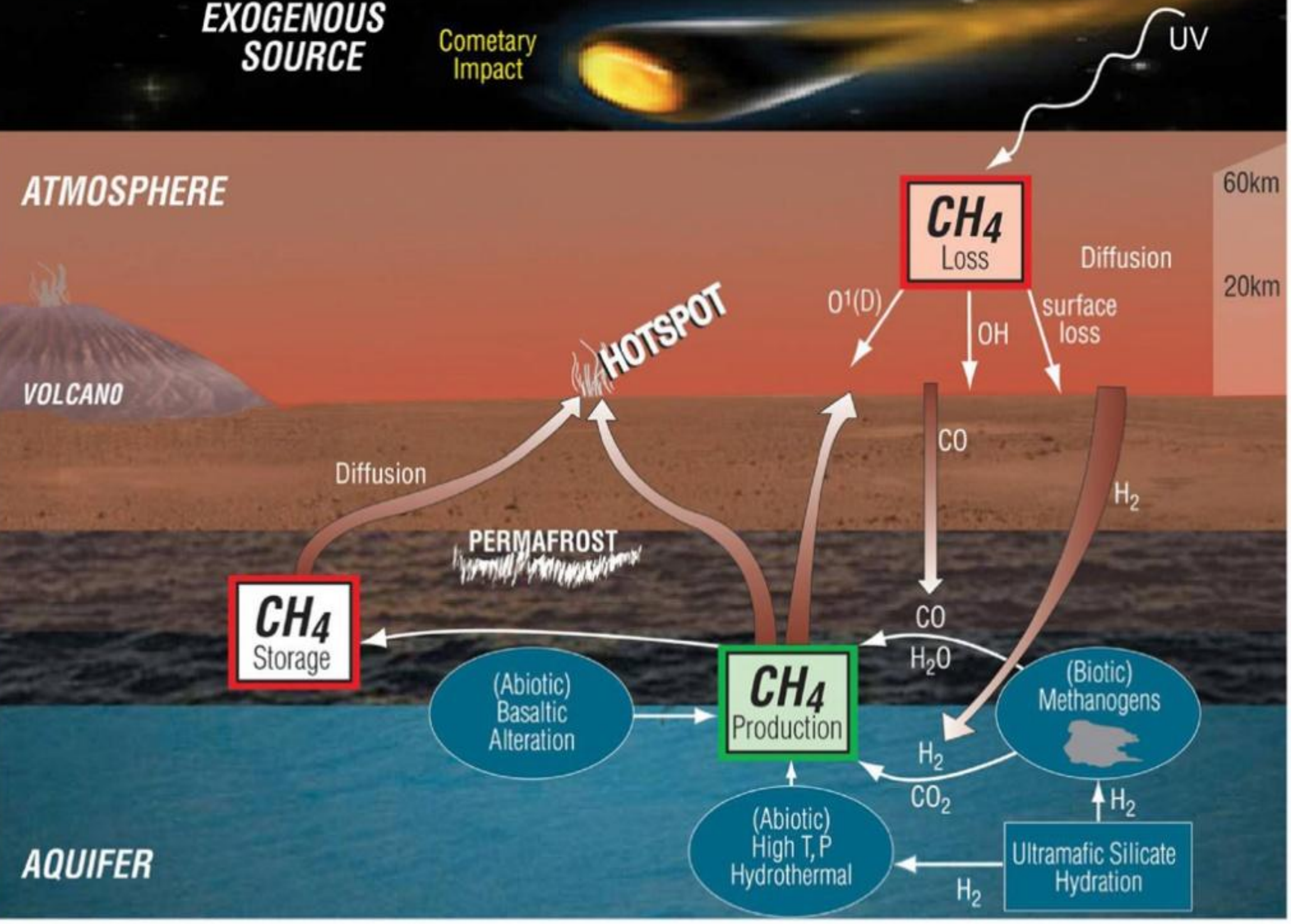
CO_2 Depletion Problem

HDO/H_2O ratio (D/H artio)

The vapor pressure of HDO is slightly lower than that of H_2O. Deuterium is enriched in condensed phase. →Deuterium depletes in gas phase
→ D/H ratio provide us an important information about the atmospheric circulation, atmospheric Escape, and Evolution of Planetary Atmosphere

Spatial Resolution: 0.1” = 70 km @1AU

Atreya et al. 2007

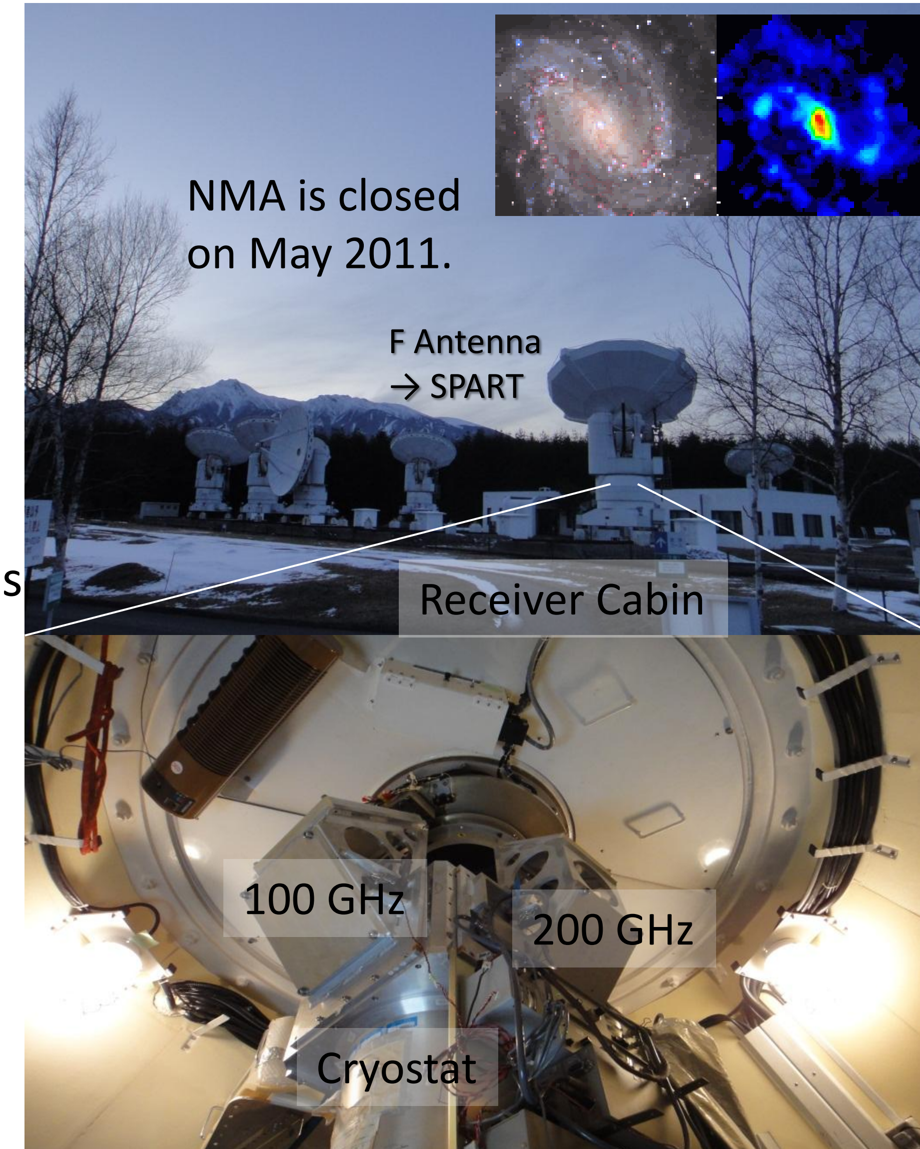


SPART Project
Solar Planetary Atmosphere Research Telescope

Nobeyama Millimeter Array (NMA) of Nobeyama Radio Observatory, Japan

- Alt. 1350 m
- 6 antennae, 10m aperture
- 100/200 GHz bands

NMA was closed on May 2011. After that, F-antenna was improved as a single dish telescope for exclusive use of observations. Beam size of the SPART is ***68 arcsec*****.**



Improvements for SPART

New IF Syetem

- 1^{st} IF (center: 6 GHz) → 2^{nd} IF (center: 0.5 GHz)
- Good linearity
  (gain compression is better than 2 %)
- Stabilization of IF output power: ±0.1 dB

New Spectrometer

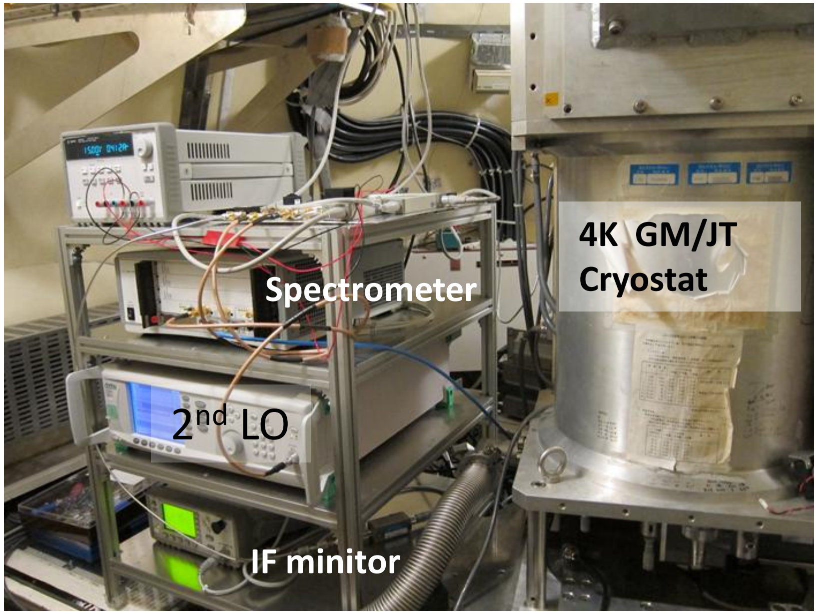
Field programmable gate array (FPGA) based Fast Fourier Transform Spectrometer（Acqiris/Agilent）

- Band Width：1 GHz
- Channels：16384 ch
- Frequency resolution ：61 kHz
- Allan variance of Spectrometer：2000 sec

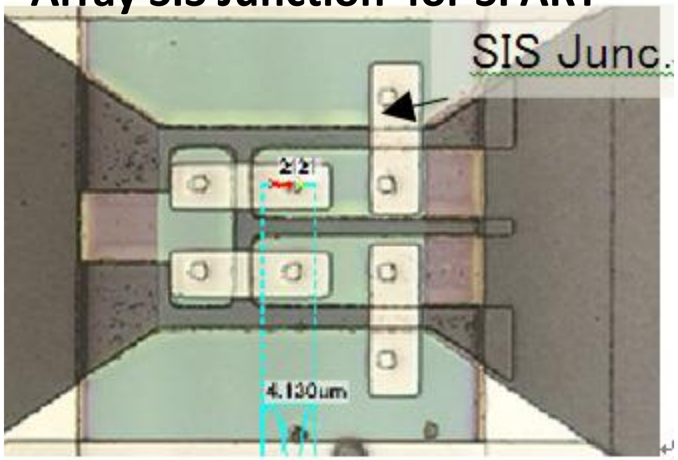
Improved Environment Monitoing

- Room & Receiver Temperature （Yokogawa DA100）
  Chopper, LO, IF, 4k-SIS mixser, Spectrometer
  Synthesizer etc
- Weather condition
  Wind velocity/direction, temp., humidity, rain
- SIS bias current/voltage, Total Power

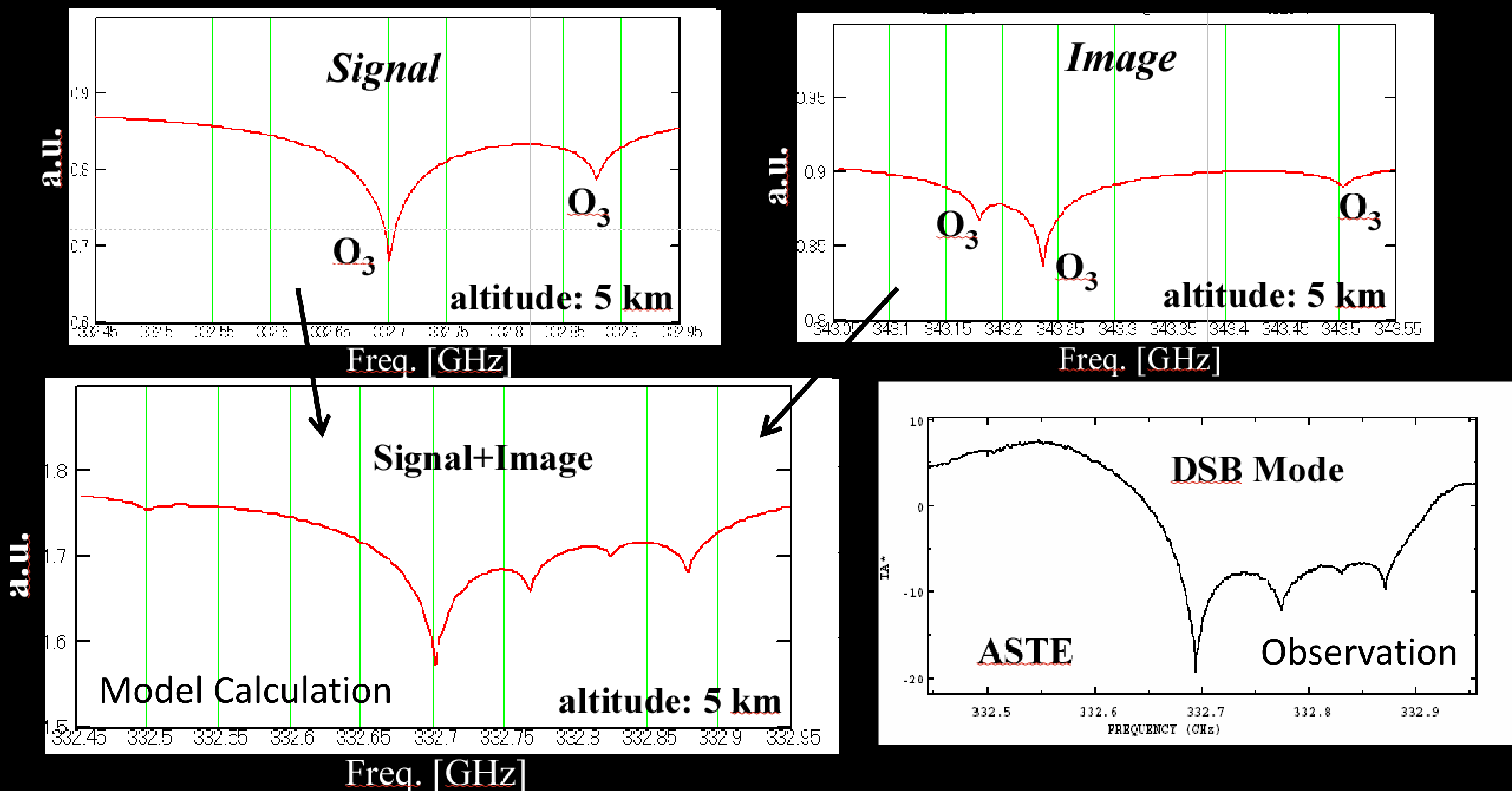
New backend system was installed in Receiver Cabin



Array SIS Junction for SPART



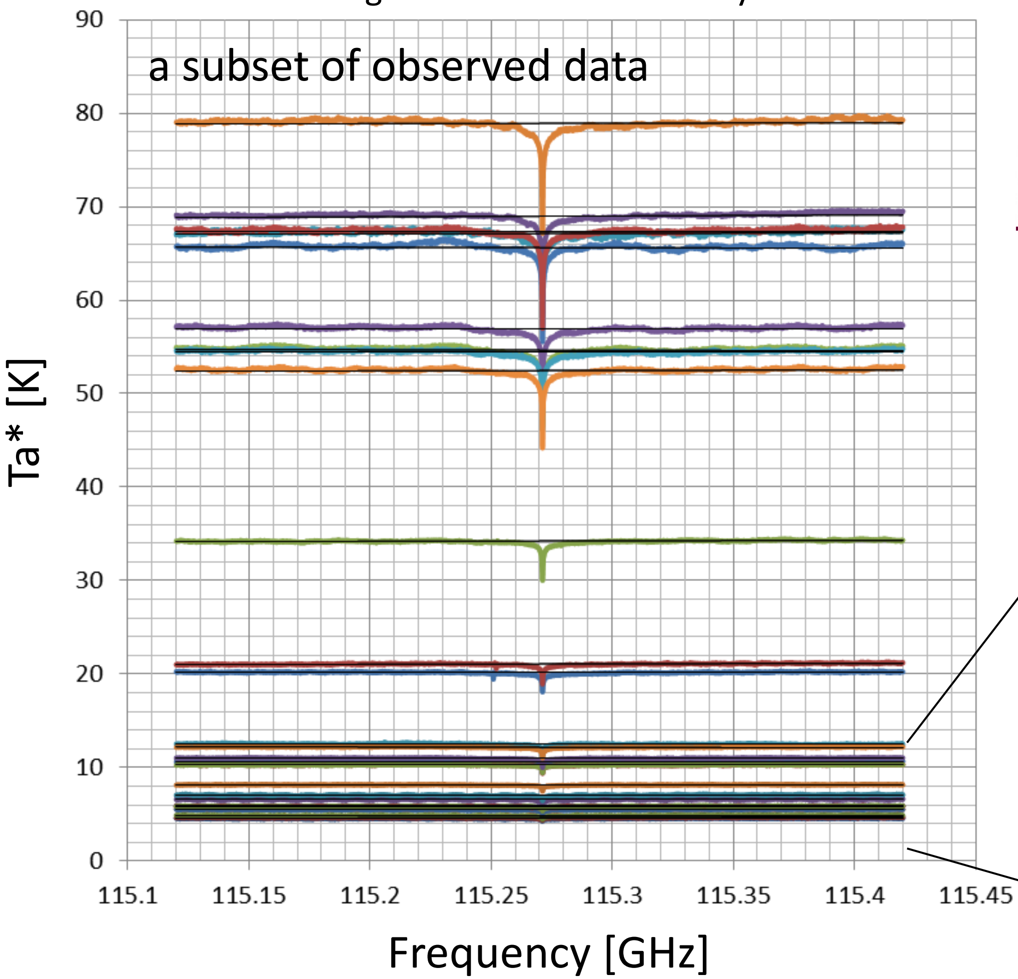
Strong Line Intensity of Ozone from Image Band

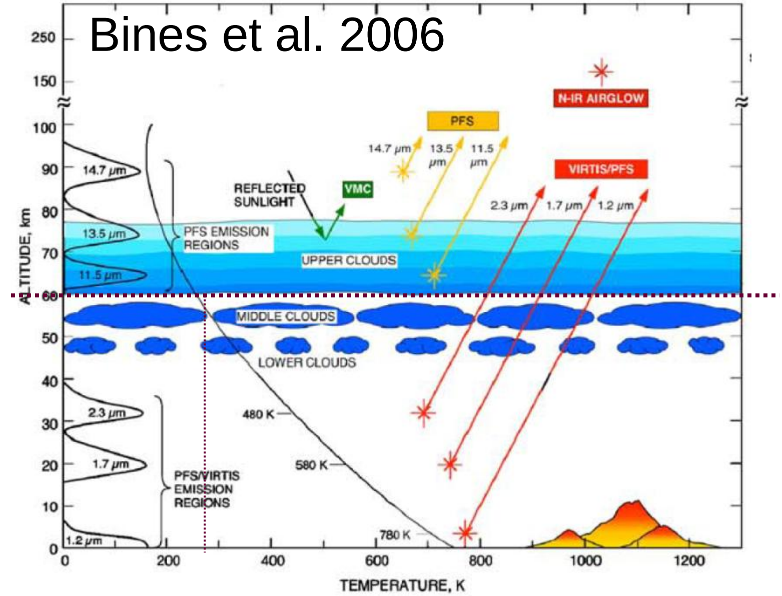


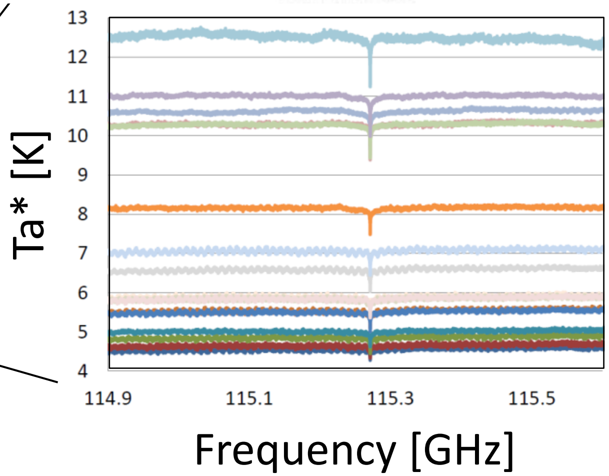
Monitoring Observations toward Venus with SPART

Spectral lines of ^{12}CO J=1-0 115.2712018

Observing Period: Dec. 2011 – July 2012

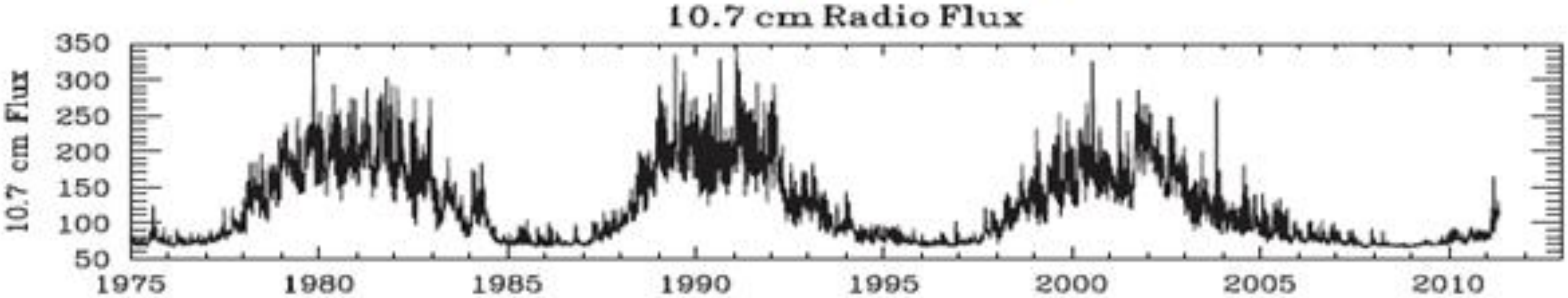




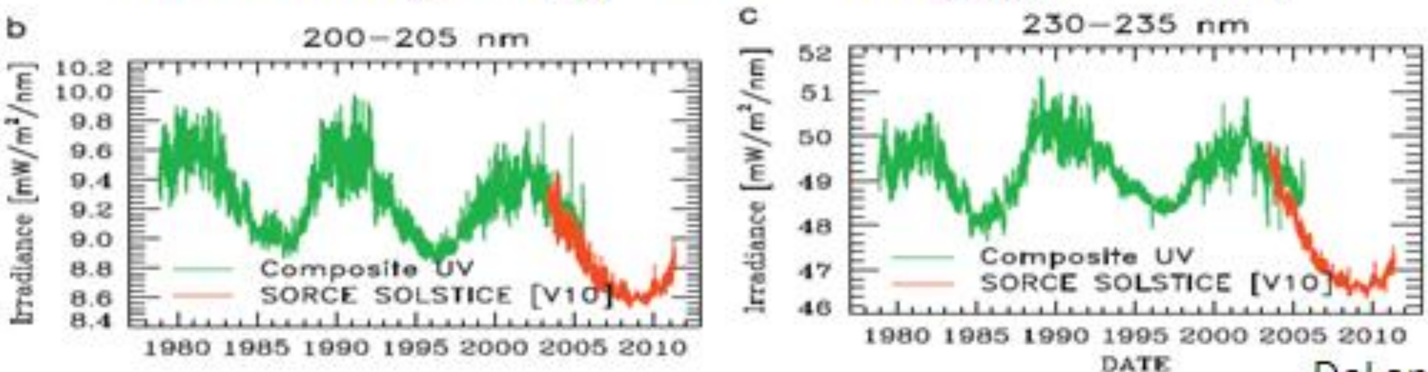


Variability in continuum level is due to the change in the apparent diameter of Venus.

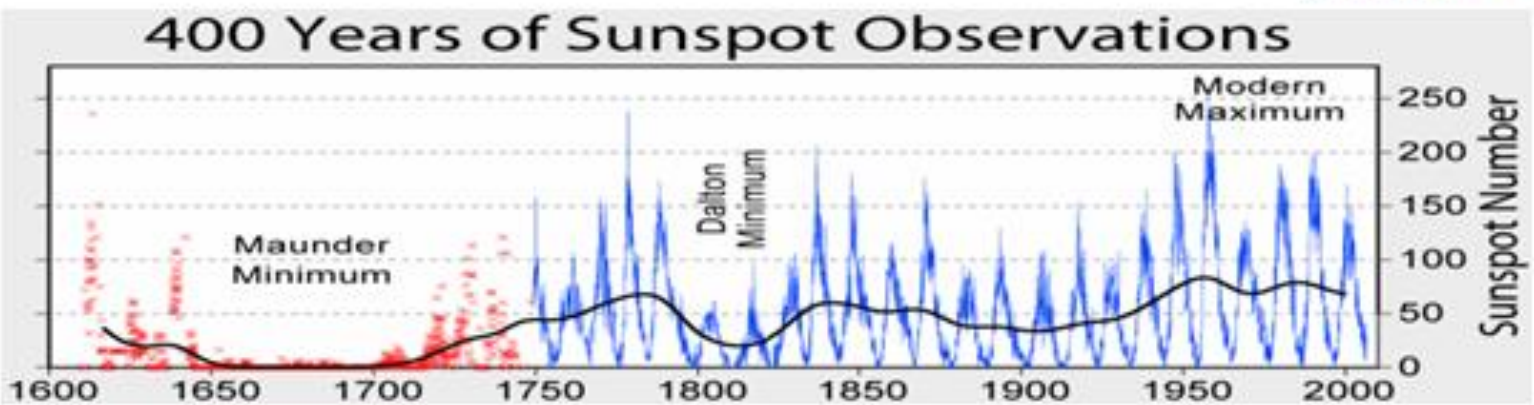
Recent Solar Activities



The bonding energy: CO-O 5.52 eV (224.7 nm)

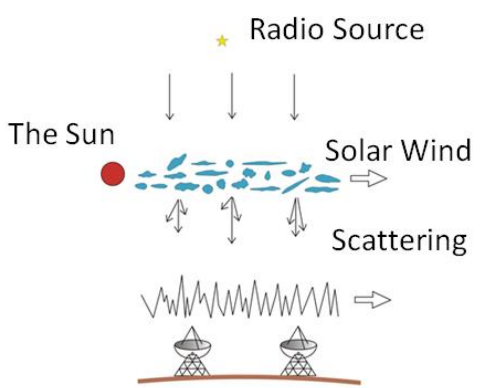


DeLand et al. 2012

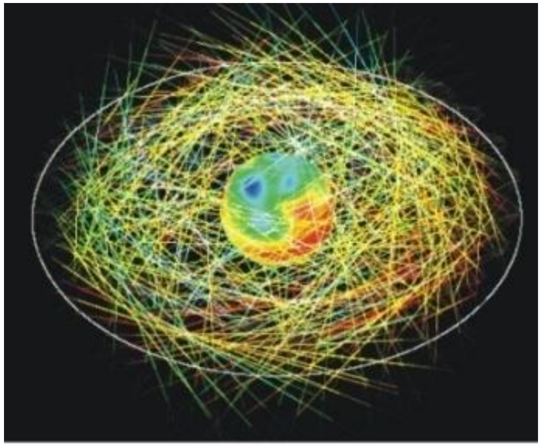


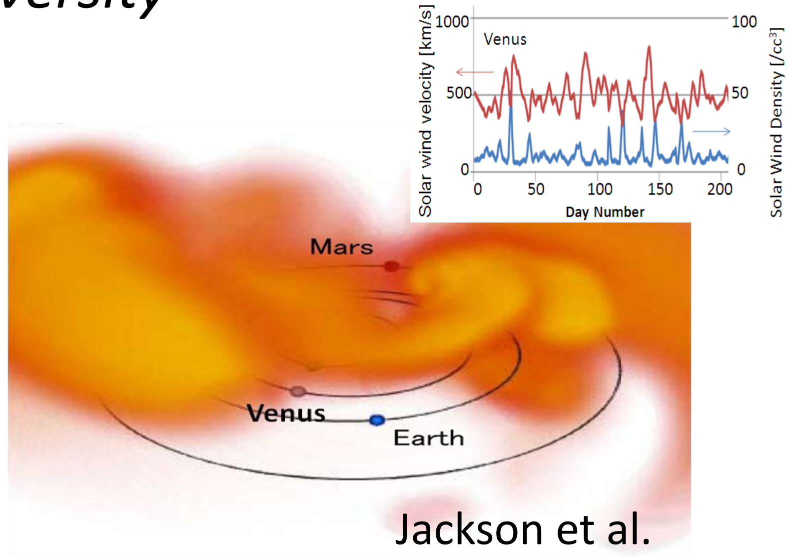
Interplanetary Scintillation Observation/ENLIL

Tokumaru Group of STEL/Nagoya University

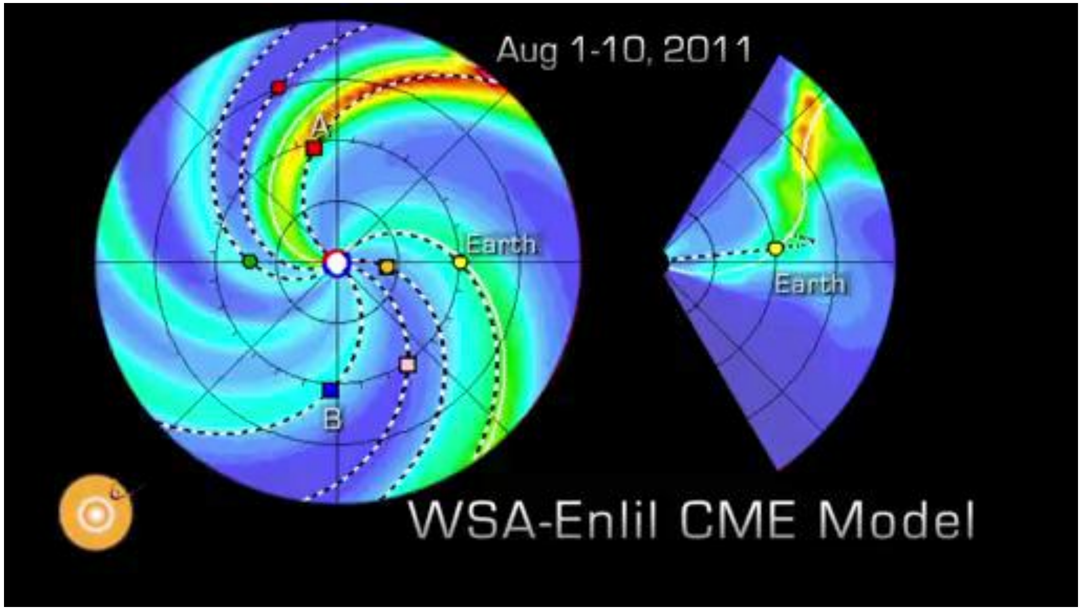


http://stsw1.stelab.nagoya-u.ac.jp/study/sub4.htm

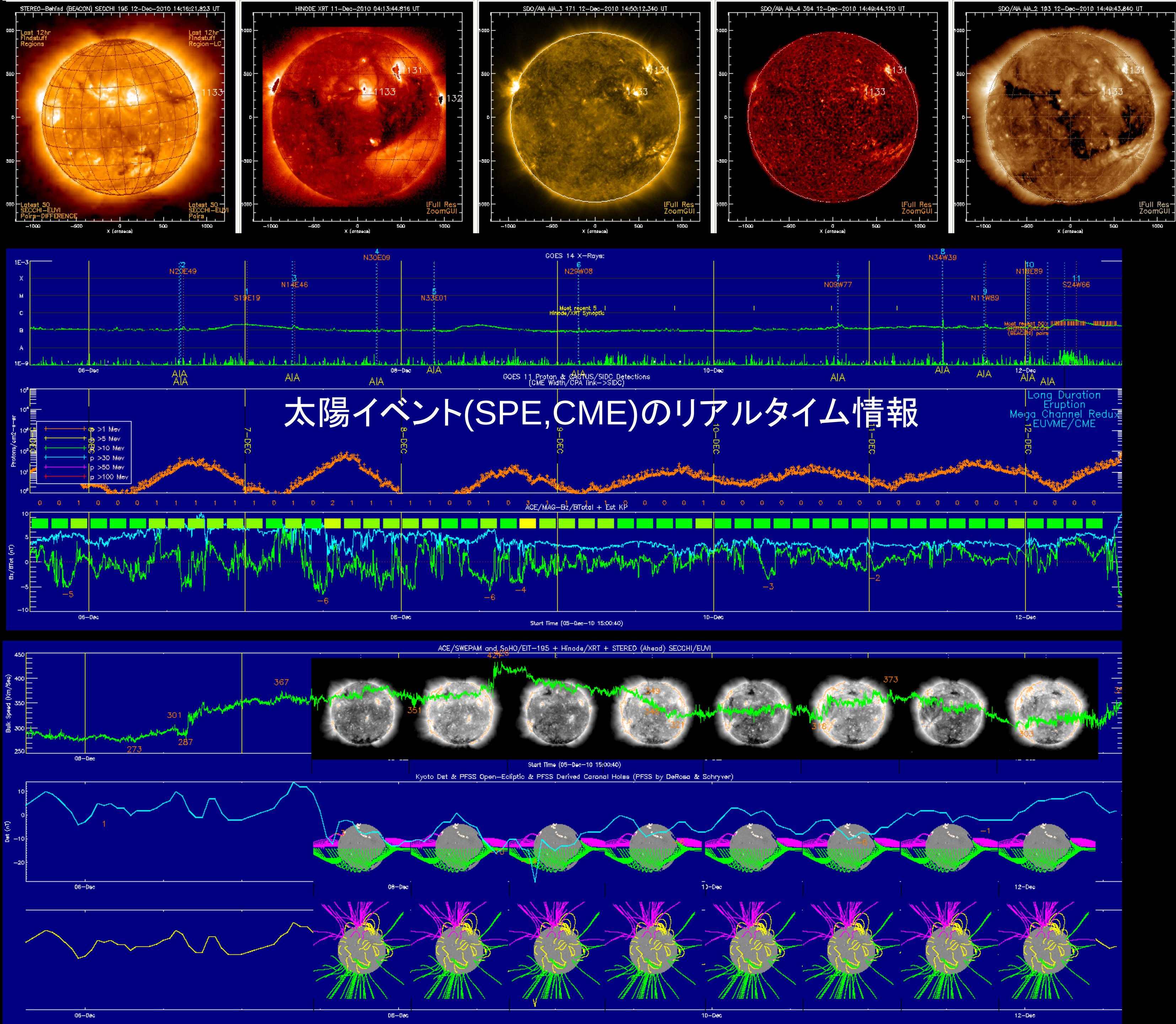




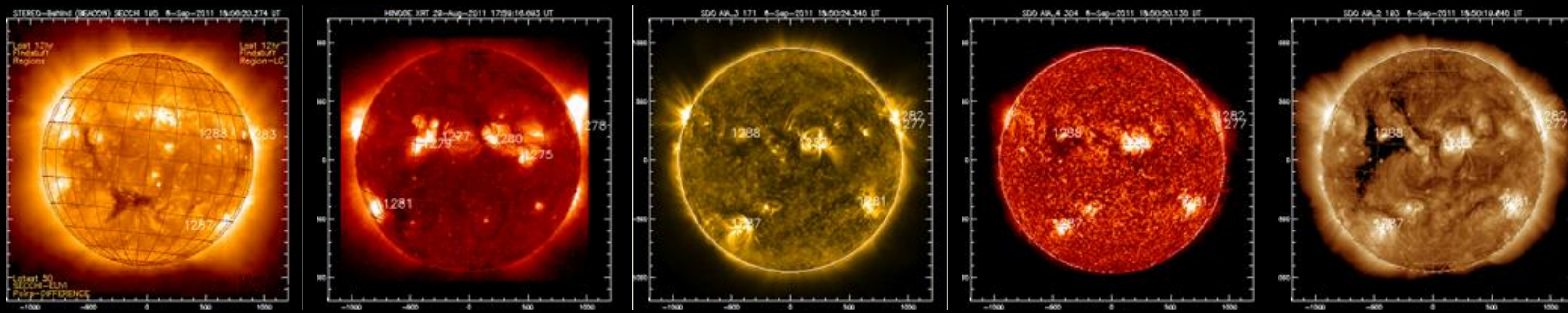
NASA 3D magnetic hydrodynamics model

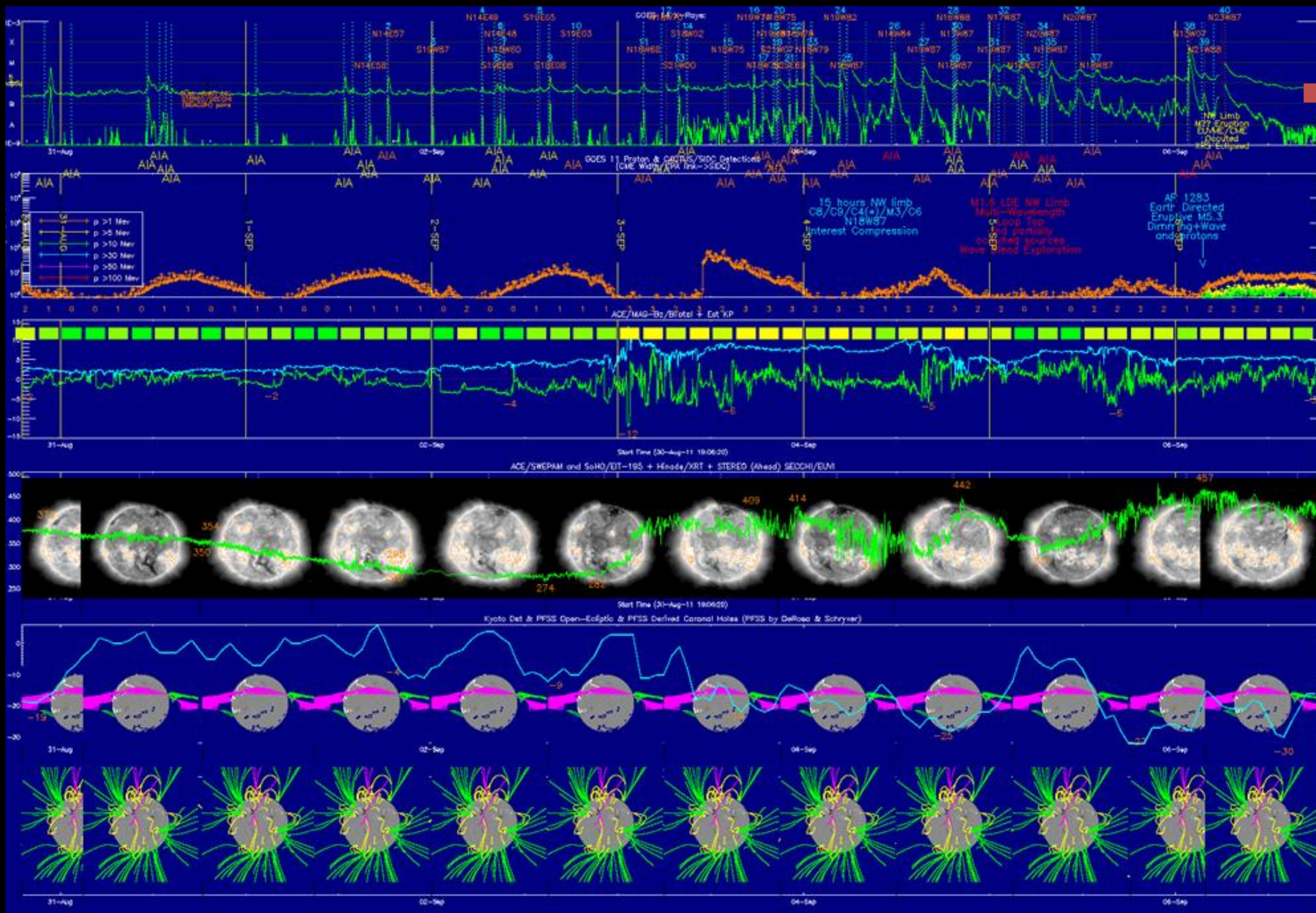


太陽イベント(SPE,CME)のリアルタイム情報



Lockheed Martin

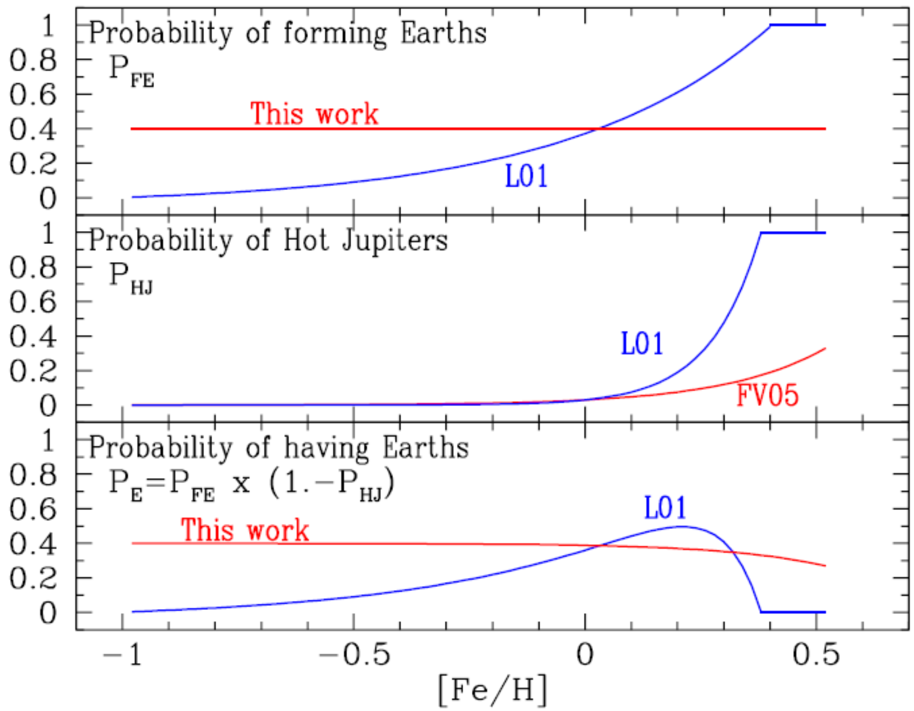




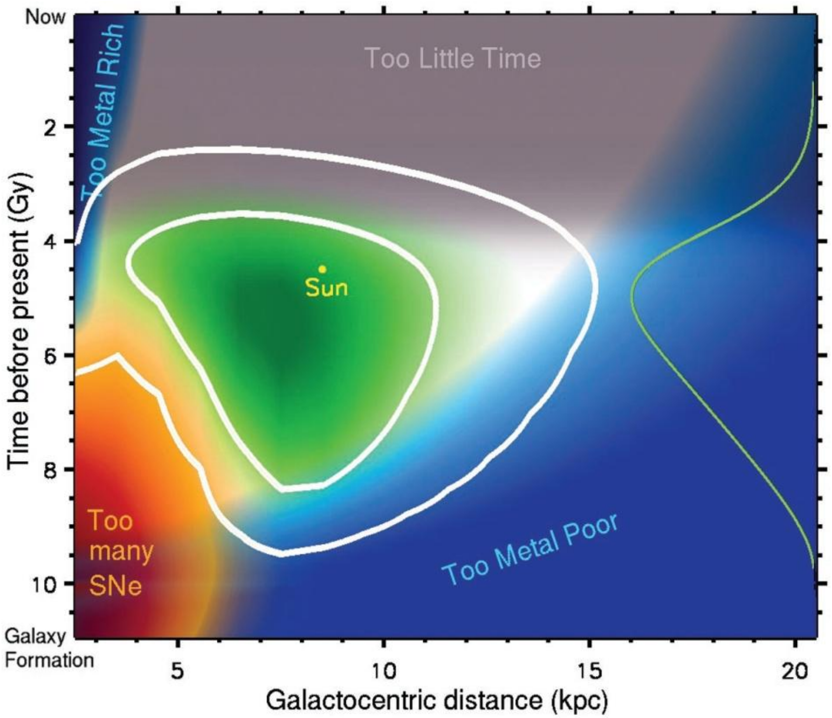
ALMA

Lockheed Martin

Probability of Having Earths

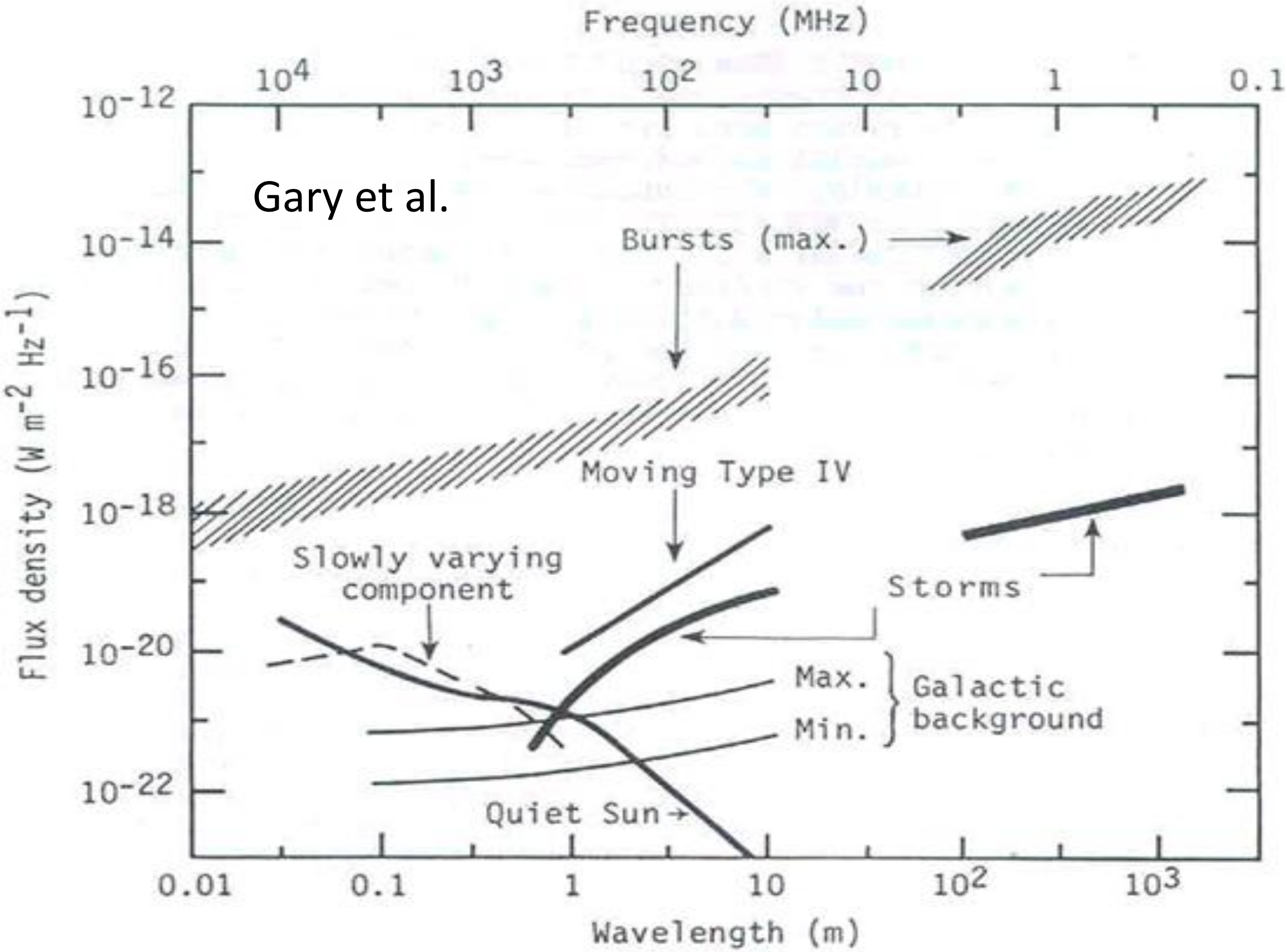


Prantzos 2008



Lineweaver 2004

Radio-Band Spectrum of the Sun



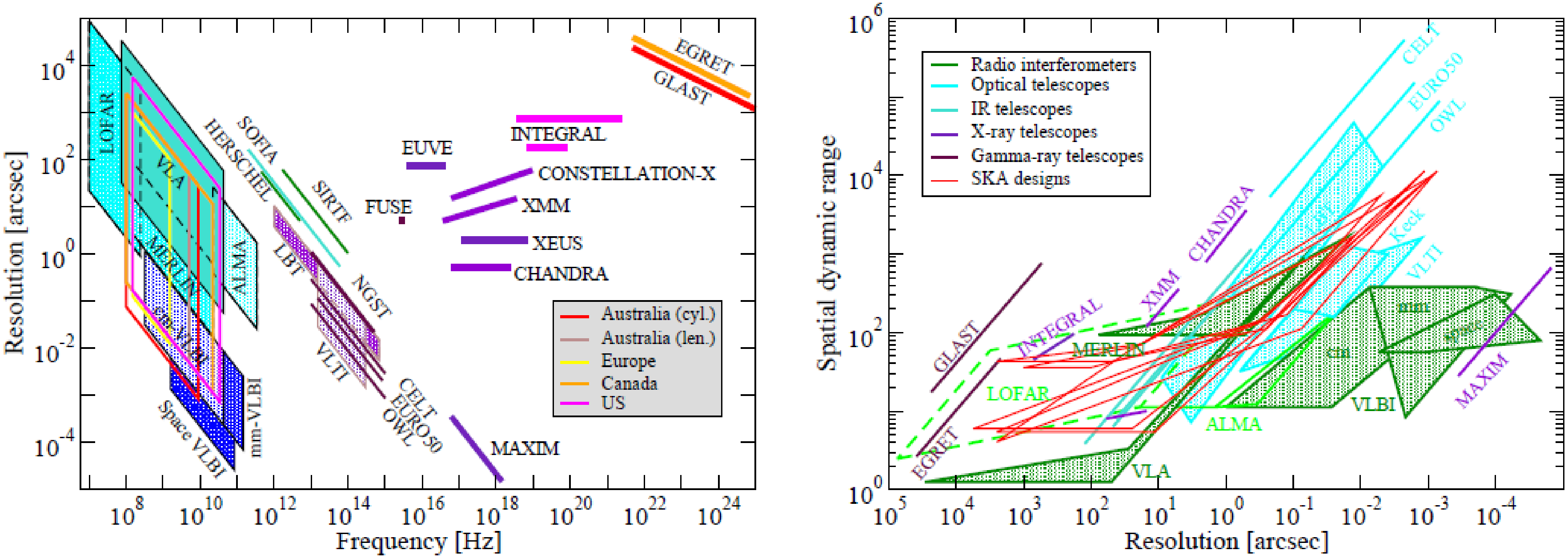
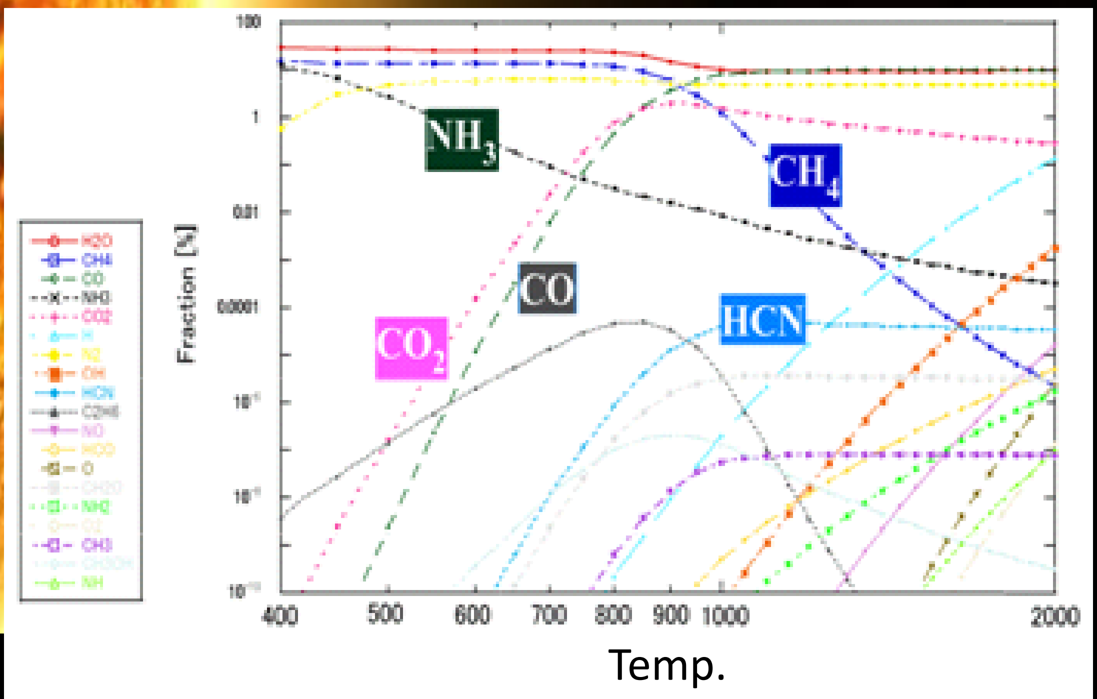
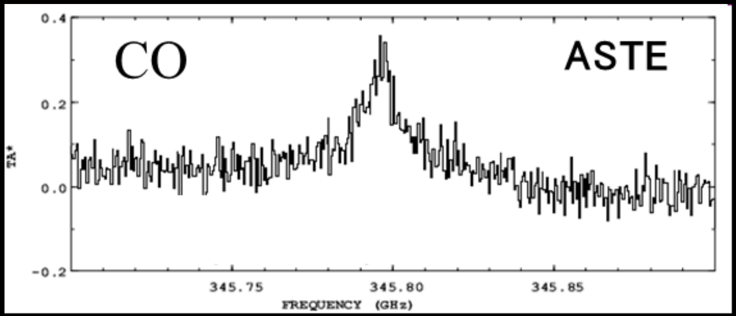


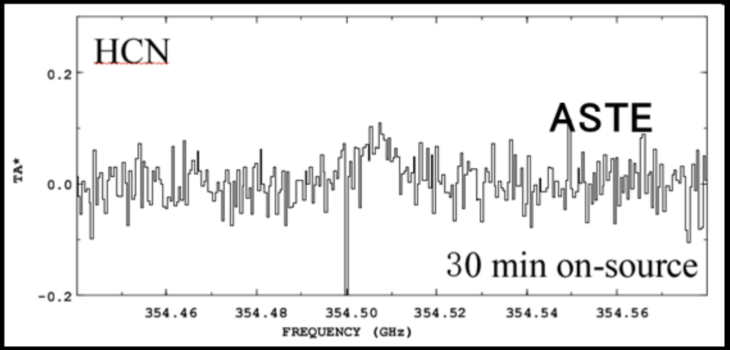
Fig. 1. Left: Resolution of the SKA compared with the resolution of other main existing and future astronomical instruments. **Right:** Spatial dynamic range of the SKA designs for observations with $\Delta\nu = 1\,\mathrm{MHz}$ and $\tau = 1\,\mathrm{s}$) compared to other major instruments [1].

Lobanov's SKA memo

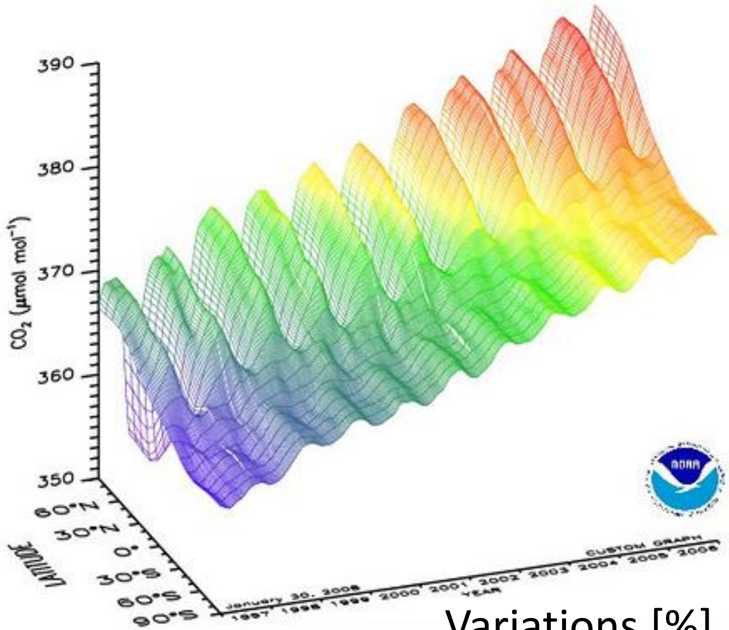
Chemical Compositions

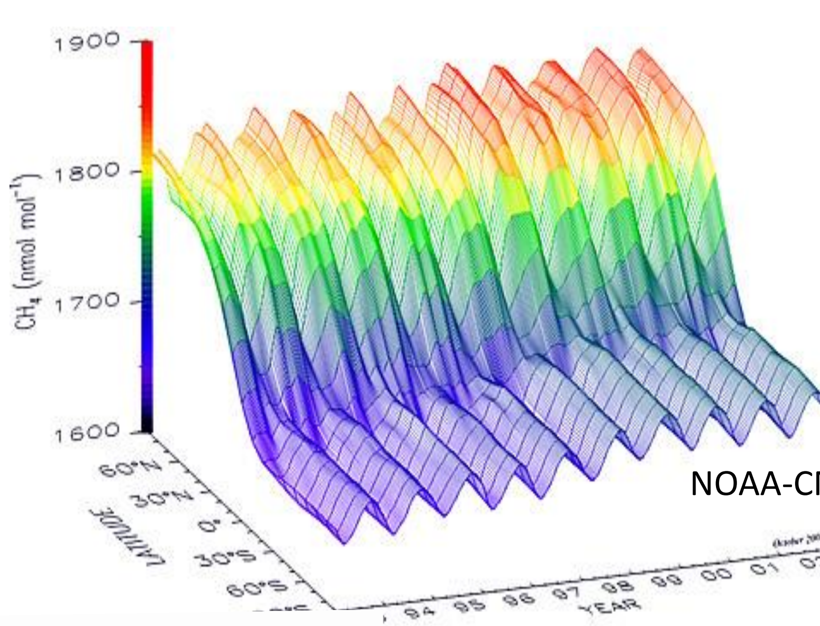






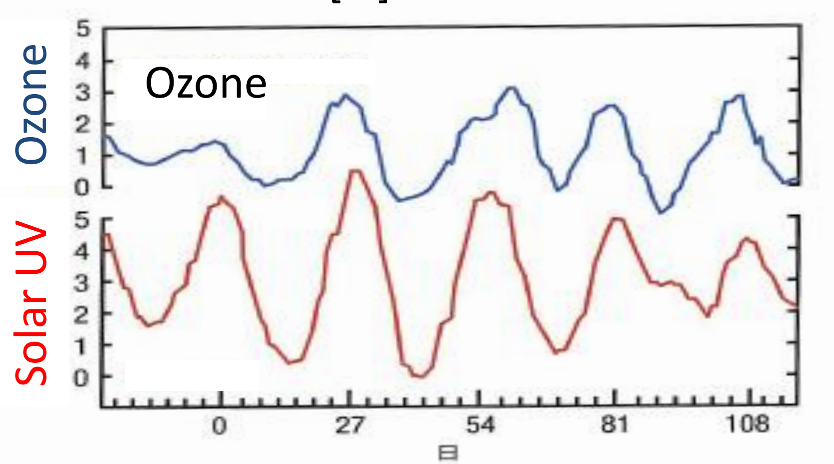
Global Distribution of Atmospheric Carbon Dioxide and Methane



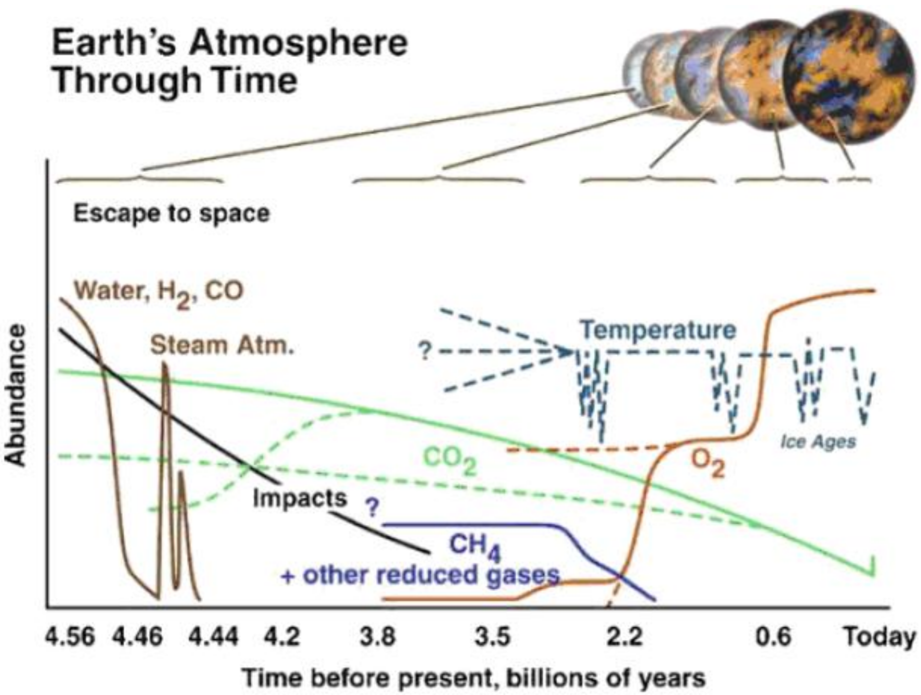


NOAA-CMDL

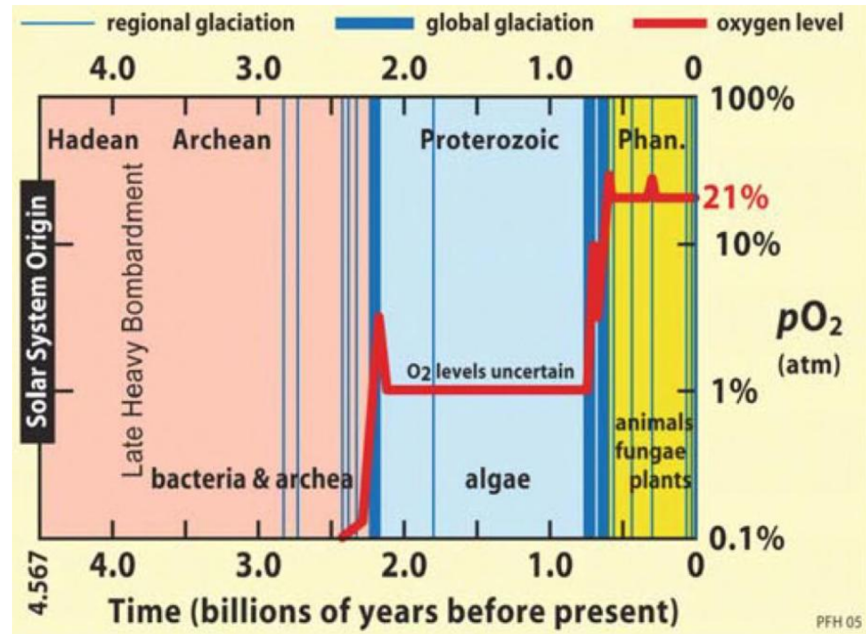
Variations [%]



Evolution of chemical compositions in the earth’s atmosphere

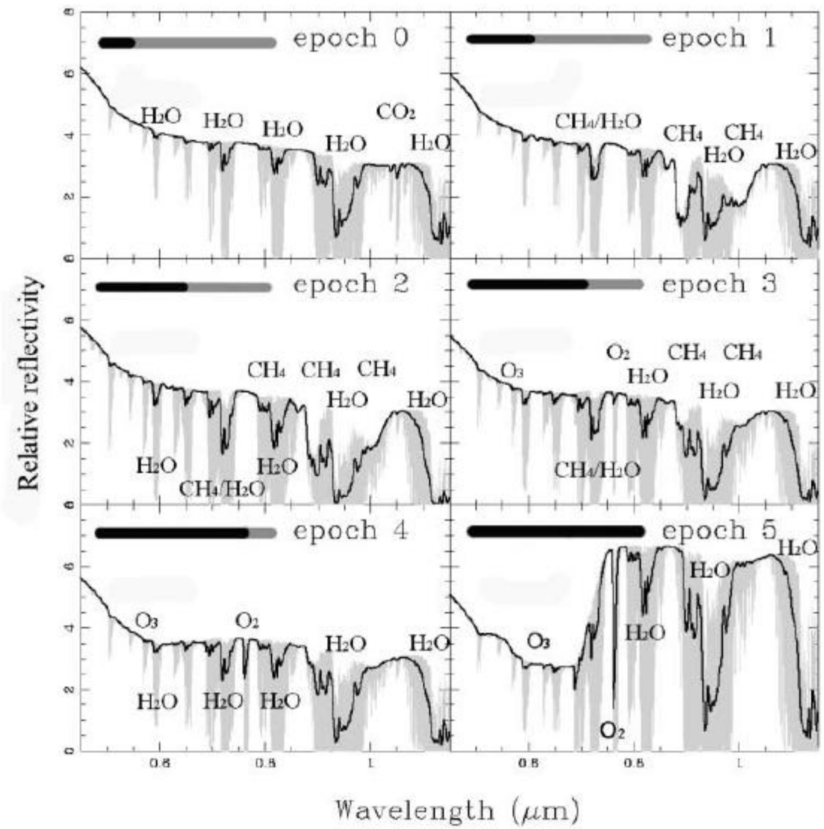


Vazquez et al.
Original:D.D.Marais & K.J.Zahnle



Courtesy: Paul F. Hoffman

without clouds



with clouds

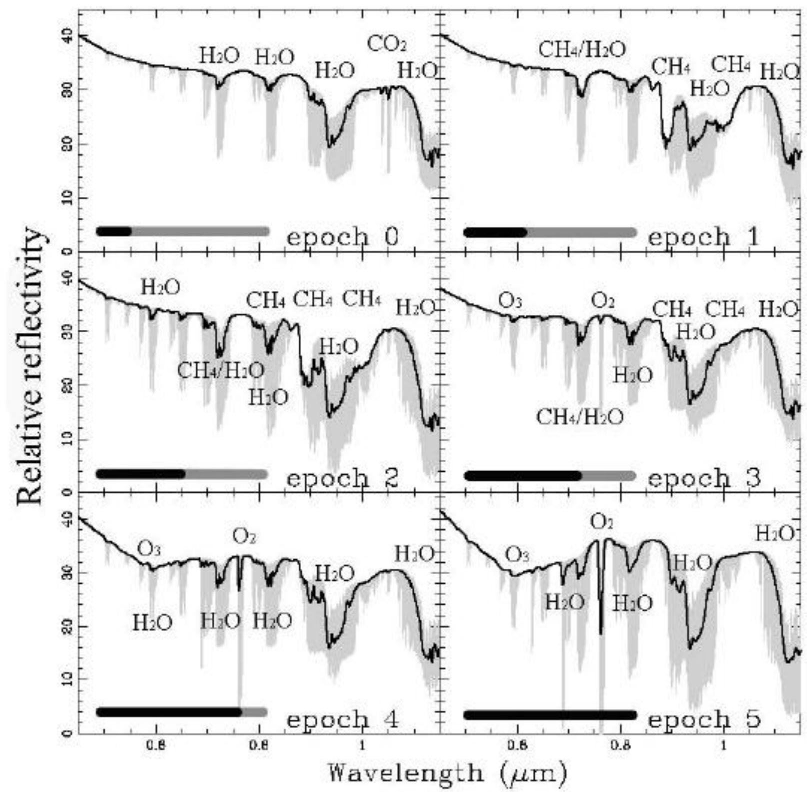


TABLE 1

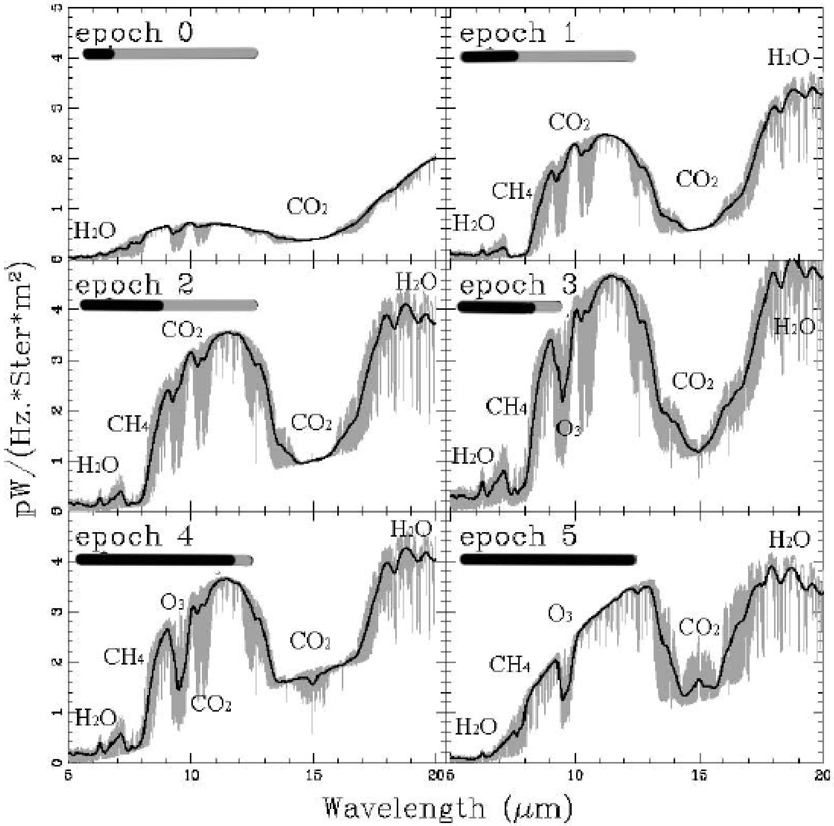
Evolution of Surface Abundances over Geological Time

Epoch	Age (Gyr ago)	Mixing Ratios				
		CO_2	CH_4	O_2	O_3	N_2O
0............	3.9	1.00E−01	1.65E−06	0	0	0
1............	3.5	1.00E−02	1.65E−03	0	0	0
2............	2.4	1.00E−02	7.07E−03	2.10E−04	8.47E−11	5.71E−10
3............	2.0	1.00E−02	1.65E−03	2.10E−03	4.24E−09	8.37E−09
4............	0.8	1.00E−02	4.15E−04	2.10E−02	1.36E−08	9.15E−08
5............	0.3	3.65E−04	1.65E−06	2.10E−01	3.00E−08	3.00E−07

Note.—Based on Kasting (2004).

Kaltenegger et al. 2007

without clouds



with clouds

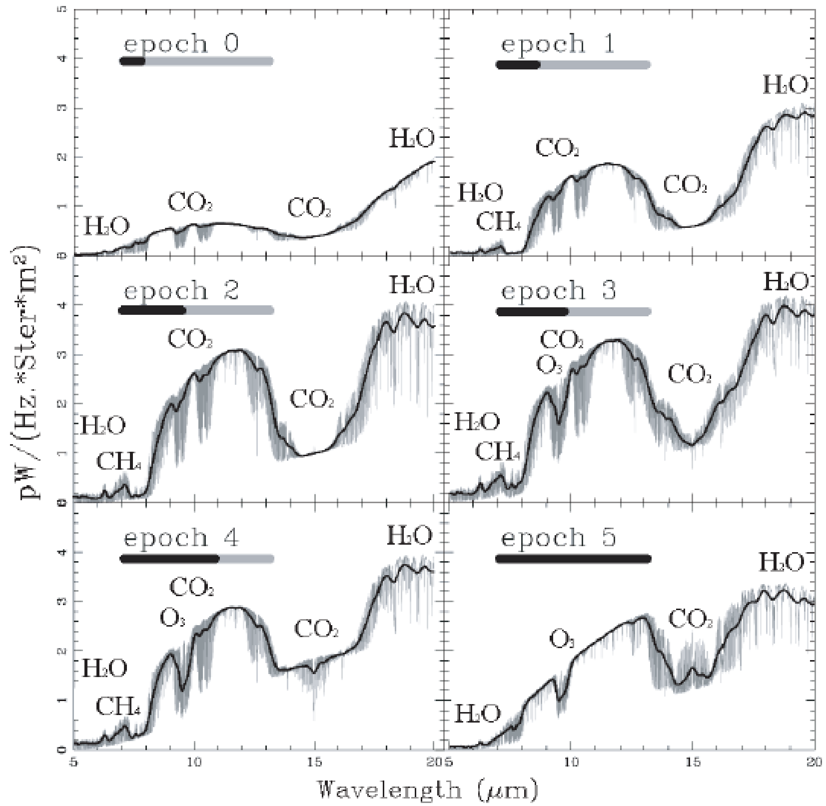


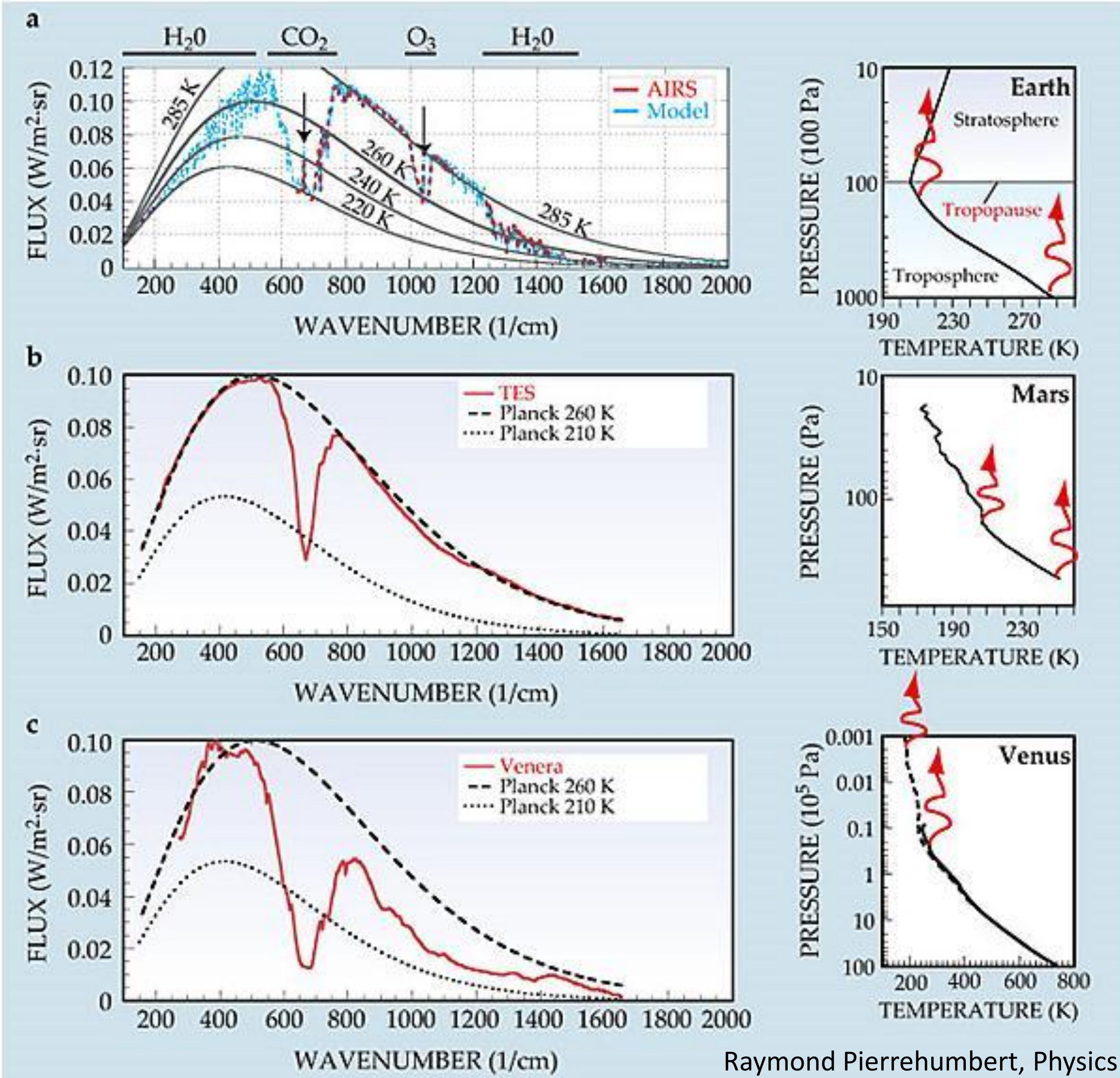
FIG. 10.—Same as Fig. 9, for the thermal infrared with a resolution of 20.

Kaltenegger et al. 2007

Earth

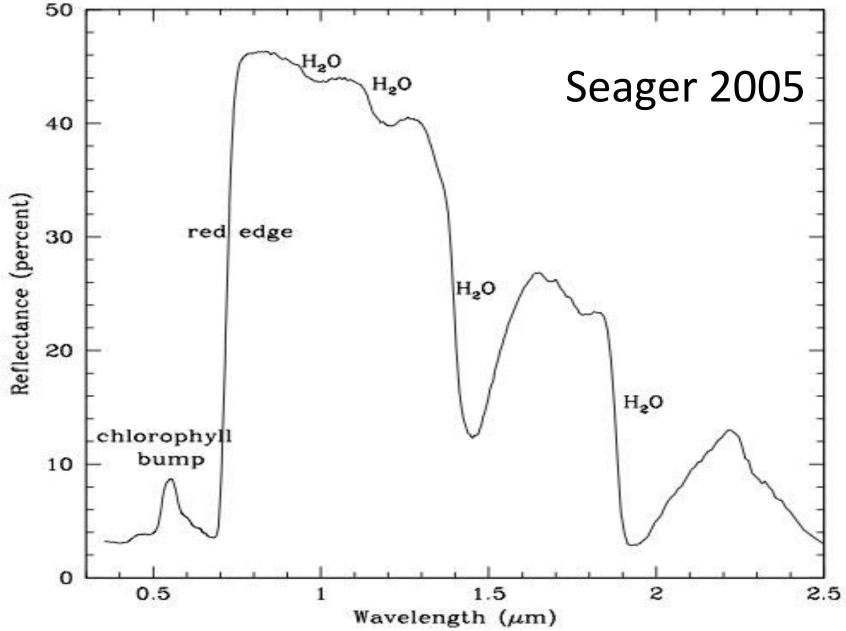
Mars

Venus

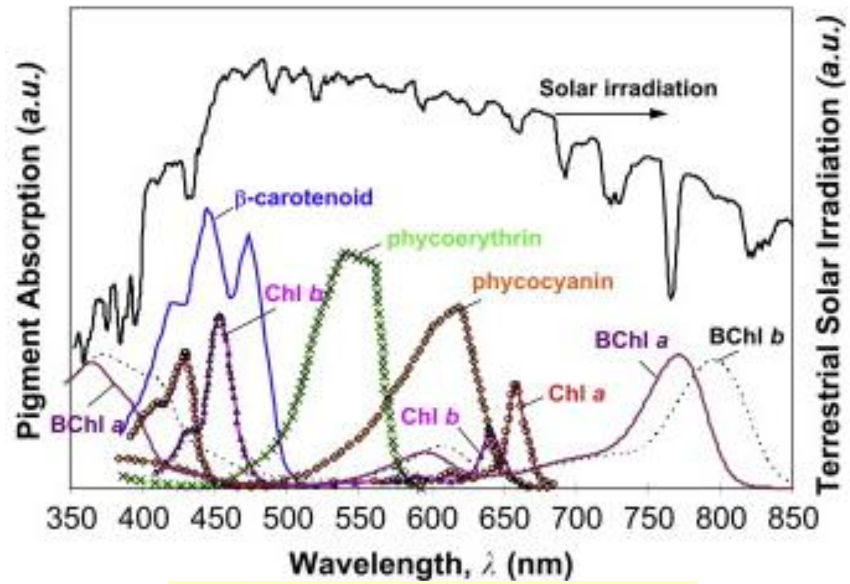


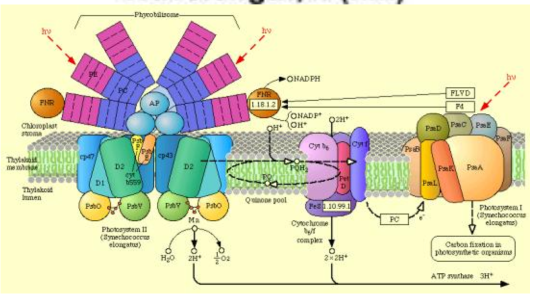
Raymond Pierrehumbert, Physics Today, 2011

Red Edge



Pilon et al. 2011





Venus, Earth (1 AU away) @230 GHz,10m ---- Intensity ~ 30 K

Super-Earth (10 pc away) @345 GHz,18 km ---- ~1.4mK
@1.5 THz, 18 km ---- ~ 26 mK

Super-Earth (50 pc away) @1.5 THz, 18 km ---- ~1 mK
@1.5 THz, 50 km ---- ~1 mK

(integration time !?)

ALMA + Japanese next-generated Satellite !?