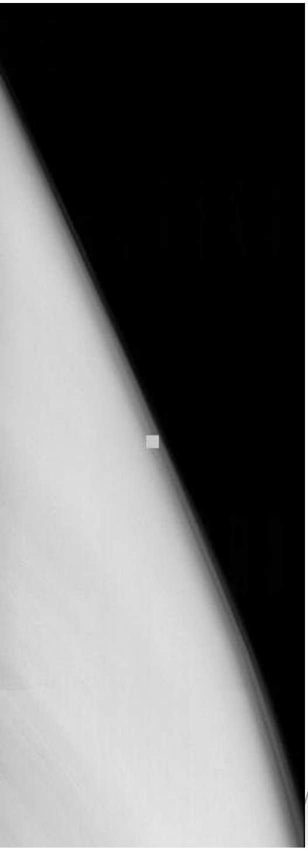
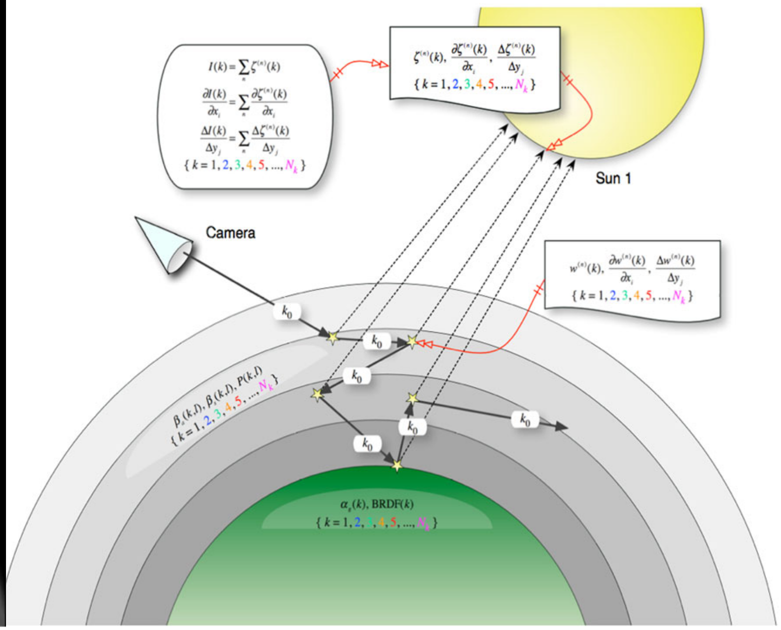
米欧火星探査機群観測データによる 新大気リトリーバル技術の検証

～ 欧ExoMars Trace Gas Orbiter および 日MMXへの応用展開準備～

<2019-2021>





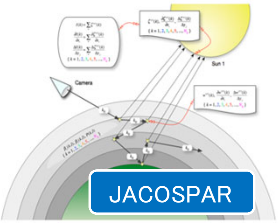
笠羽 康正[1], 小暮 李成[1](M2: M論案件), 中川　広務[1], 青木 翔平[2,3],
Arnaud Mahieux[3], 岩渕 弘信[1], 出村 裕英[2]
+ 佐藤 隆雄[5], 吉田 奈央[1](D2:ベルギー), 風間 暁[1](M1)

1. 東北大学・理, 2. JAXA-ISAS, 3.ベルギー IASB,
4.会津大, 5. 北海道情報大

<青字：定例的に活動しているメンバー>

月惑星探査アーカイブサイエンス拠点集会2021 (2021/10/11 Mon: 1400-1420)

2018 (H30)	2019(H31)	2020(H32) – 2021(H33)	2022(H34) – 2023(H35)



MMX打上 (2024予定)

- 研究全体の戦略立案および国内・海外協力者との調整
- MMX計画への接続と「次の国際共同研究」への発展

笠羽(代表)
中川・寺田(分担) + 今村(東大:協力)

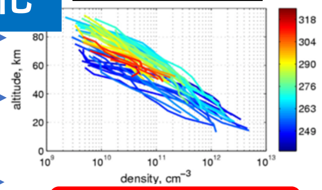
欧米探査機との協働で追う火星大気環境の変動と進化

本開発の位置

(A) 下層大気の鉛直構造観測

- JACOSPARの開発・検証 — 岩渕(分担) / 笠羽(代表)・中川(分担)
- MEX等のリム観測データの総合解析 — MEX: Guranna, Bröring (協力)
- TGOの太陽掩蔽・リム観測データの総合解析 — 青木・中川(分担)+笠羽(代表) / TGO: Vandaele, Korablev (協力)

対流圏–中間圏

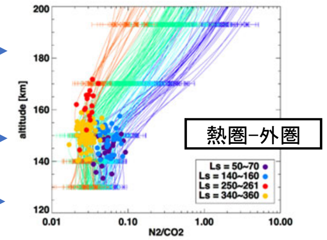


鉛直分布構造観測 (from Orbiters)

(B) 上層大気の鉛直構造観測

- MAVEN・粒子観測データの総合解析 — 寺田(分担) / MAVEN: Mahaffy (協力)
- MAVEN・紫外観測データの総合解析 — 中川(分担) / MAVEN: Schneider (協力)
- Hisakiの全球ダストストーム時紫外観測データの解析 — 山崎 (協力)
- TGO・紫外観測データの総合解析 — 中川・青木(分担)+笠羽(代表) / TGO: Vandaele (協力)

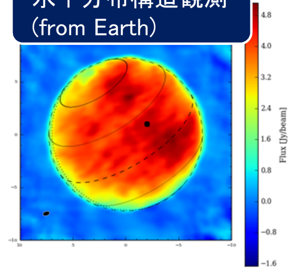
熱圏–外圏



(C) 全球大気の水平構造観測

2018	2020	2022	
ALMA 2018観測解析	ALMA 2020観測解析	ALMA 2022観測解析	佐川・青木 (分担)
SOFIA 2018観測解析	SOFIA 2020観測解析	SOFIA 2022観測解析	青木・佐川 (分担)
ハレアカラ 2018観測解析	ハレアカラ 2020観測解析	ハレアカラ 2022観測解析	中川(分担)・笠羽(代表) / 村田・坂野井(協力)

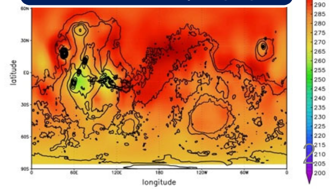
水平分布構造観測 (from Earth)



(D)大気鉛直輸送・結合モデル研究

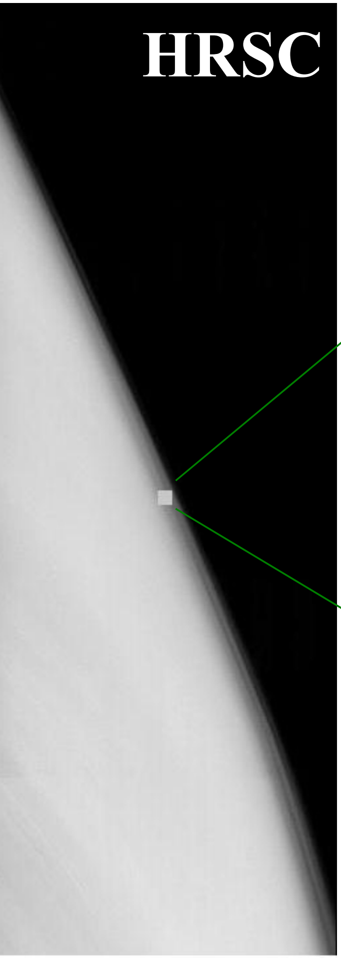
- モデルへの波動・拡散/化学・鉛直輸送プロセス導入
- 平常時・擾乱時の鉛直構造観測量の再現・検証 — 黒田・寺田 (分担) / 高橋・Medvedev・Leblanc(協力)
- 水平メゾスケール観測量の再現・検証 (MMXへの展開)
- 火星古環境・太陽系初期想定モデルへ成果反映と、火星大気進化の追跡

数値モデルによる現・過去火星環境評価

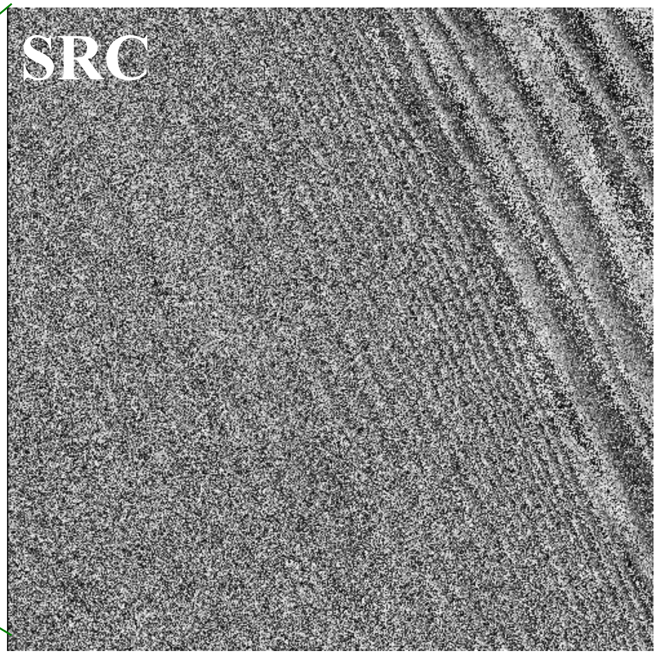


Martian Limb structure

“Layered dust” can be identified in high altitude !

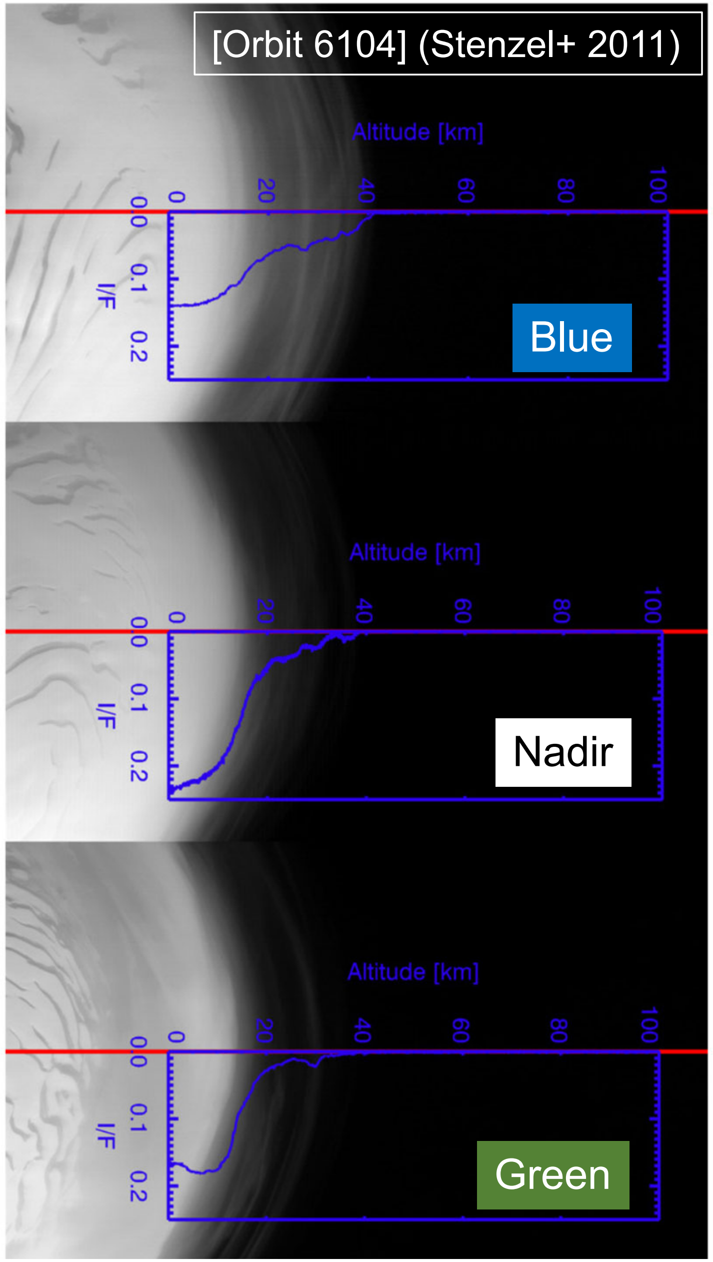


170 km



7.5 km

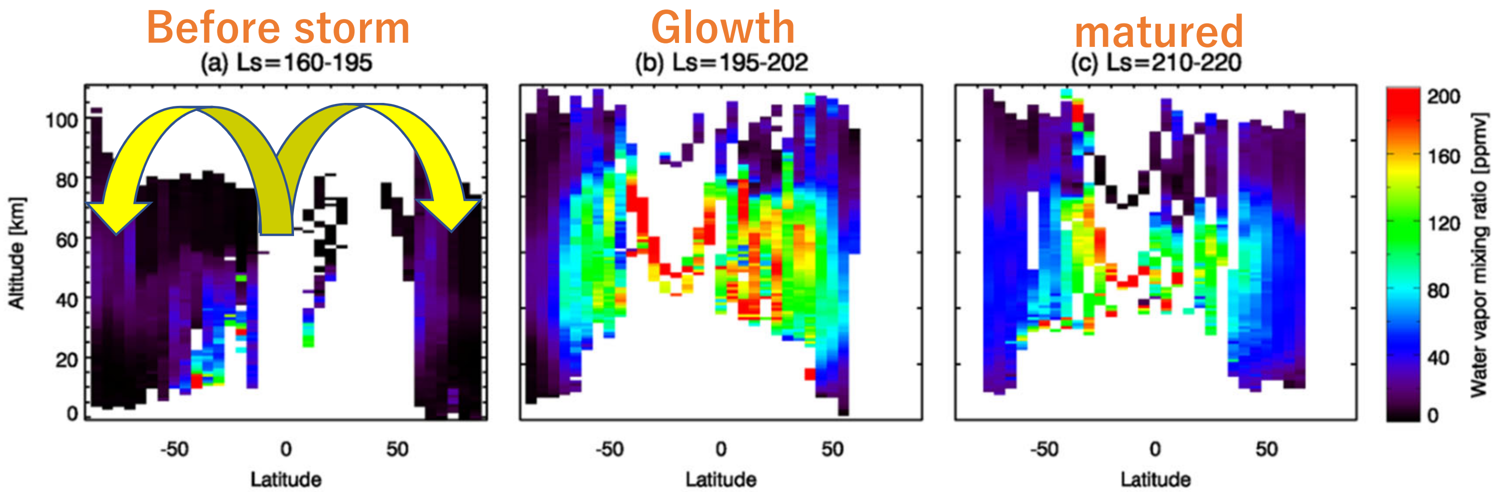
(h0044_0009.nd2)



High-Resolution Stereo Camera / Mars Express

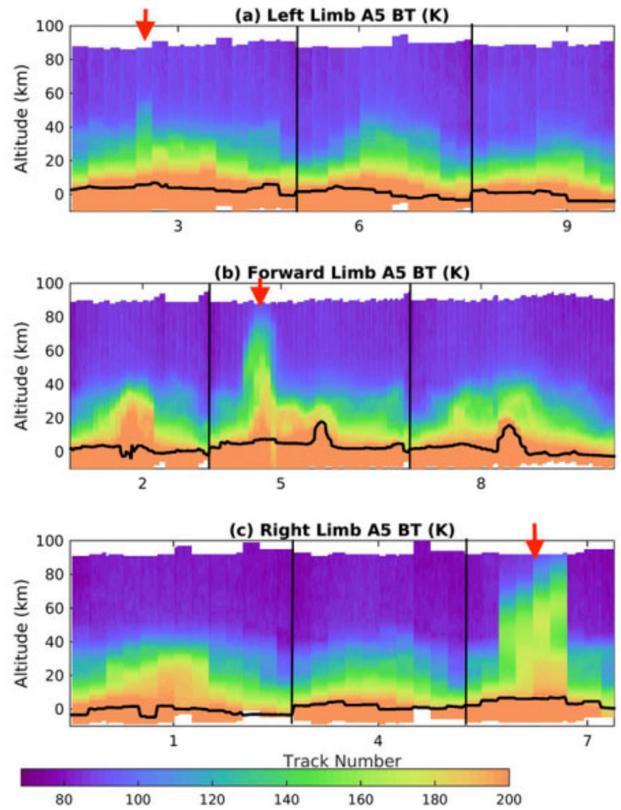
Water & Dust vertical transportation -- Recent discoveries

- **Water vapor & Dust** are transported to 50-90 km (mesosphere) by Global Dust Storm !



ExoMars/TGO NOMAD observation in Solar Occultation above limb:
Water vapor distribution before, during the storm. (Aoki et al. 2019)

- Dust can be transported to ~70 km in 2-h !



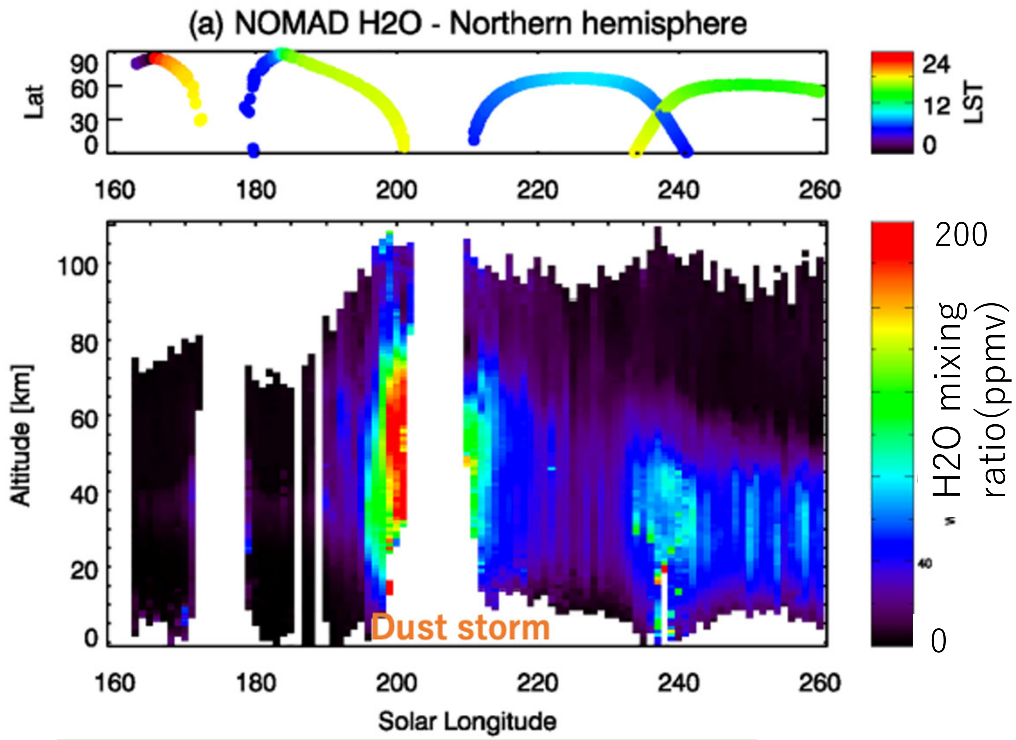
MRO MCS observations at 463 cm^{-1} above eastern Tharsis in limb observations (Heavens et al. 2019)
Ls=190 in MY 30 [0813–1233 UTC 30 Nov 2010])

Four explanations: (Vandaele+ 2019)

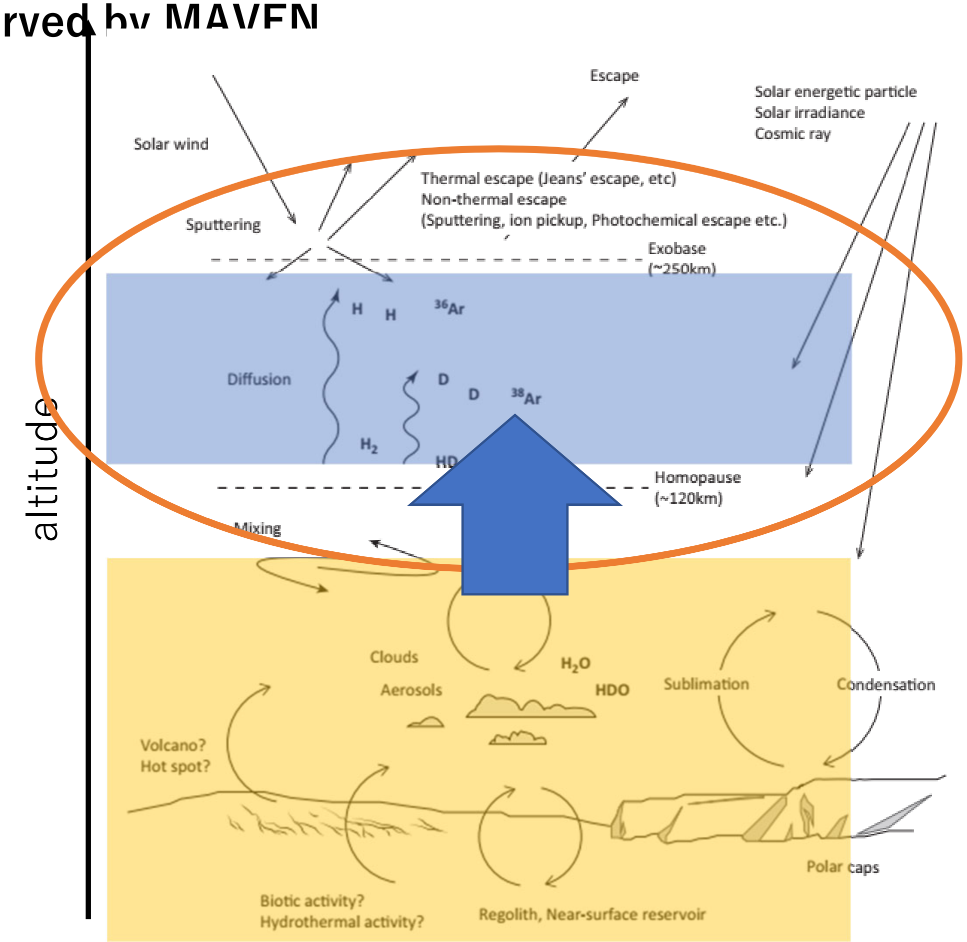
1) **Dust absorbs solar radiation**, increasing saturated vapor pressure at high altitudes
2) **Hadley circulation** is strengthened by dust warming the atmosphere. → Vertical mixing occurs
3) **Local deep convection** due to heating of dust
4) **Large-scale rise** of dust layer due to dust heating

Water & Dust vertical transportation -- Recent discoveries

- **Water vaper** (transported with dust?) **in the mesosphere (50~90 km) can be dissociated by Solar UV.**
  ⇨ **It can be linked to the escape to space observed by MAVEN**



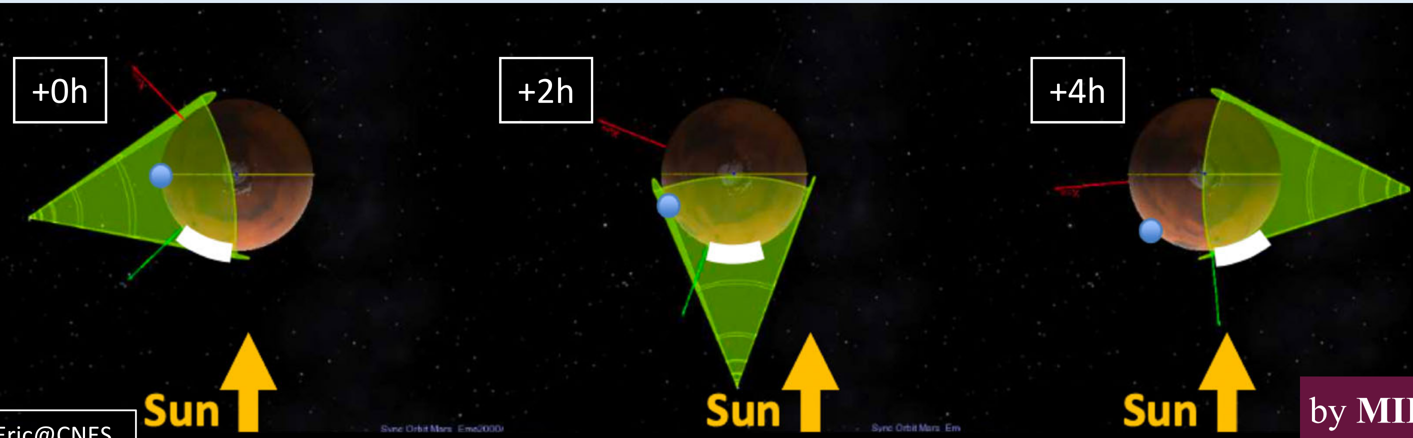
H_2O vertical transportation during the storm (Aoki et al., 2019)



[Vertical / Horizontal distributions of "dust / water ice / H_2O gas"]
Their variations & correlations are important for those transportations.

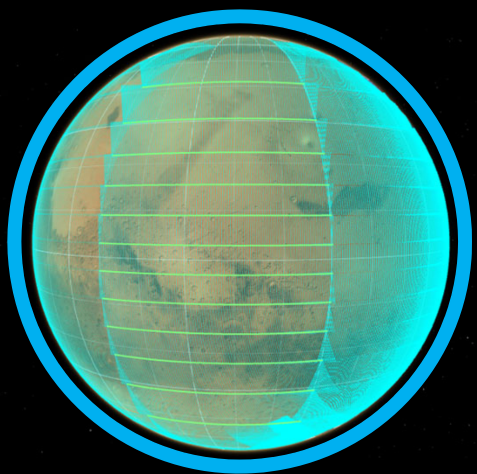
A possibility of JAXA MMX – Global disk + limb observations

<Requirement> "gases and aerosols" simultaneously with practical calculation time by fitting multiple wavelengths

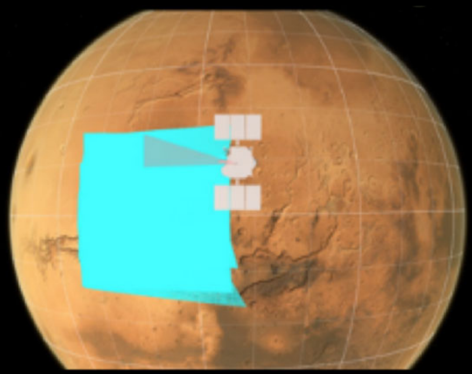


Sawyer Eric@CNES

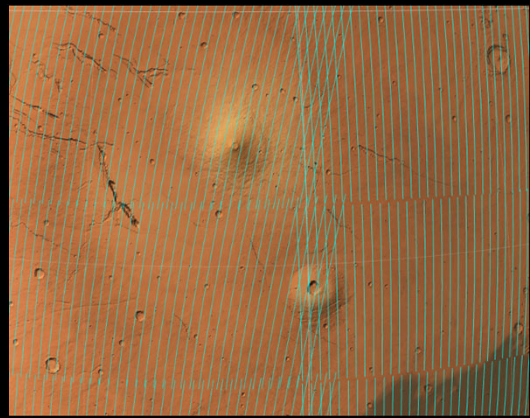
by **MIRS**: NIR spectrometer (0.9-3.6 μm) with **TENGOO**: Vis multiband imager



Global mode
4 km res. (36 stripes, 6,598 images)
8 km res. (36 stripes, 14,149 images)



Tracking mode
(6 stripes 3 times, 32,191 images)



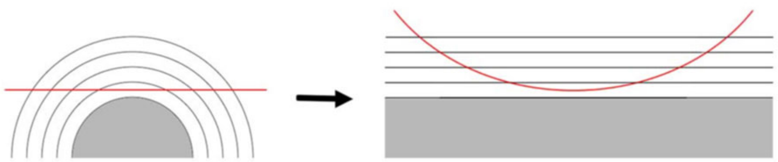
Expanded view of slit positions

"Pre-JACOSPAR" -- Retrieval of aerosols profile in Martian atmosphere

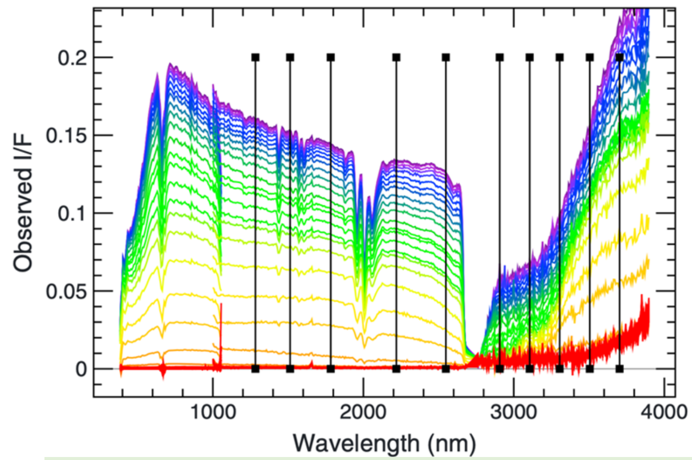
<Requirement> "gases and aerosols" simultaneously with practical calculation time by fitting multiple wavelengths

Case-1: Limb retrieval of "Dust and Water ice aerosols" with MRO/CRISM (Smith+ 2013)

- *pseudo-spherical* approximation due to reduce the calculation costs
  → Retrieval was conducted for **10 lines** of wavelength



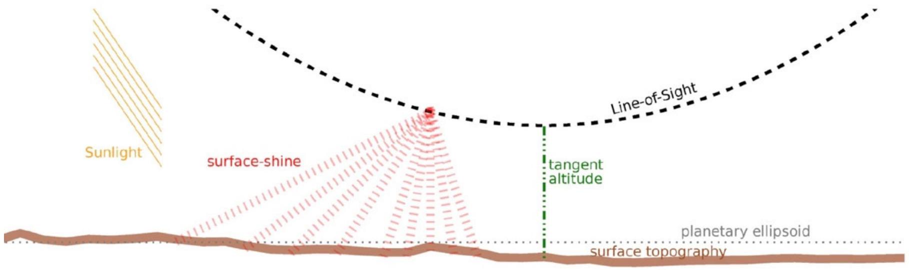
Pseudo-spherical approximation
= The atmosphere plane-parallel
The optical path "curved", assuming the limb observation.

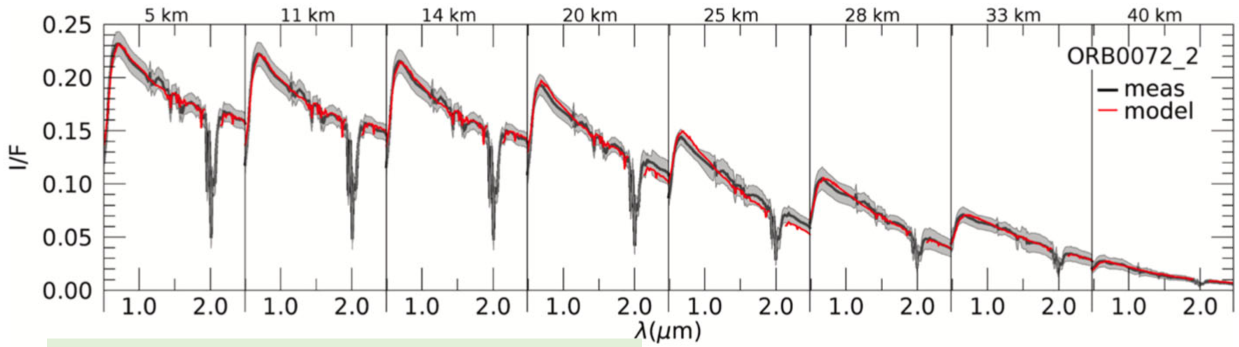


"10 wavelengths" (black vertical lines) are only used.

Both: No absorptions by gases

Case-2: Limb retrieval of "Dust"
with MEx OMEGA (D'Aversa+ 2022)





Best fits of the OMEGA 0.5–2.5 μm limb scans

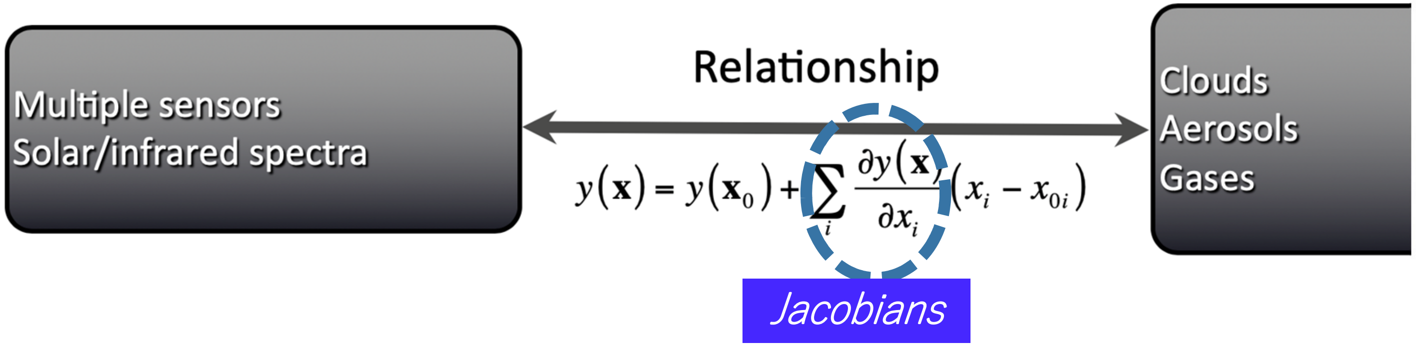
"JACOSPAR" -- Retrieval of aerosols profile in Martian atmosphere

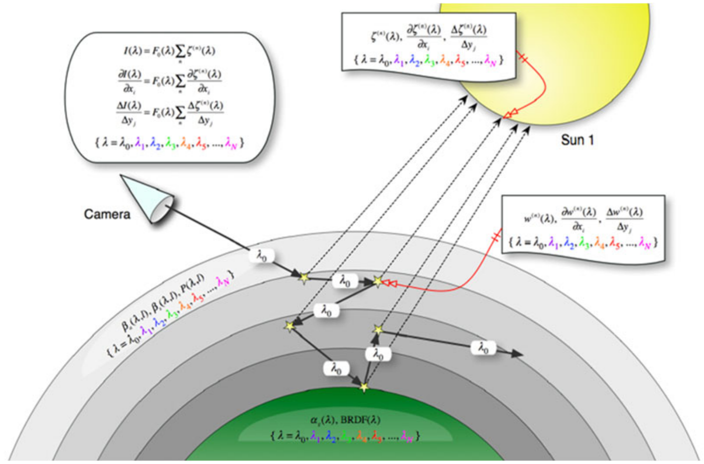
A fast atmospheric radiative transfer model using "Backward Monte Carlo" & "Dependent Sampling"

- Efficiently calculate the **spherical atmosphere** and **multiple scattering**
- Covering in "UV ~ far-IR" (solar radiation + planetary thermal radiation)

Input parameters: Optical properties -- Albedo / Scattering / Absorption / Phase function
Solar direction

--> Calculation for Radiance & Jacobian ➔ Retrieval !!





[Backward Monte Carlo (BMC)]

To spread the photons backward (from the observation point to the radiation source).
→ more efficient than forward MC (Asano+ 2010)

[Dependent Sampling] (Marchunk et al., 1980)

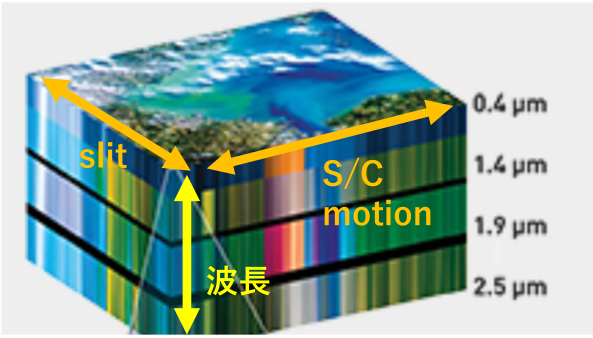
To calculate the radiance for optically-average system k_0, and
→ to simulate the measurement signals of other thousands of systems by using 'Weight factor'

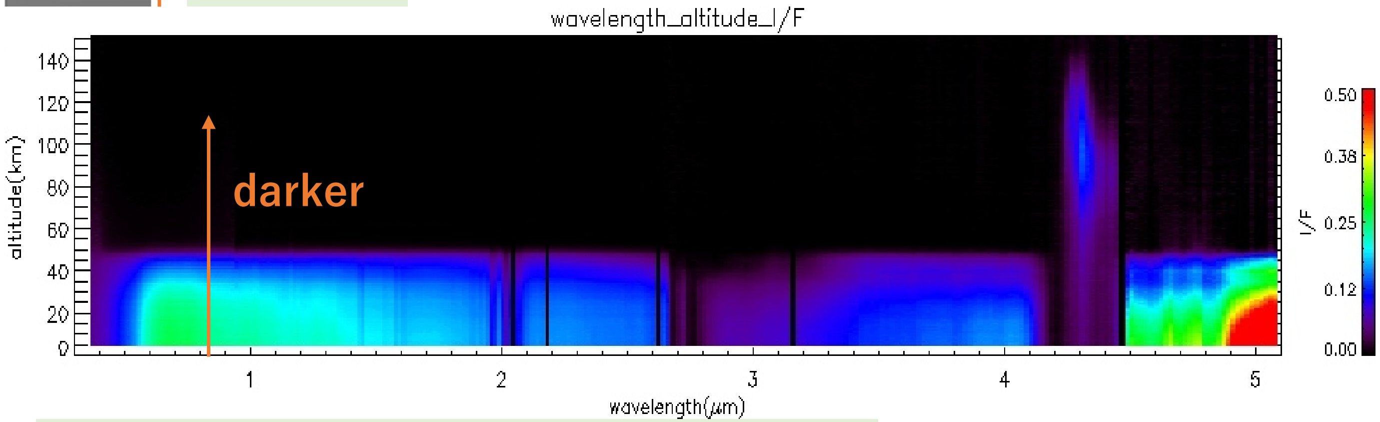
"JACOSPAR" -- Retrieval of aerosols profile in Martian atmosphere

applied to **MEx OMEGA** (Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité)

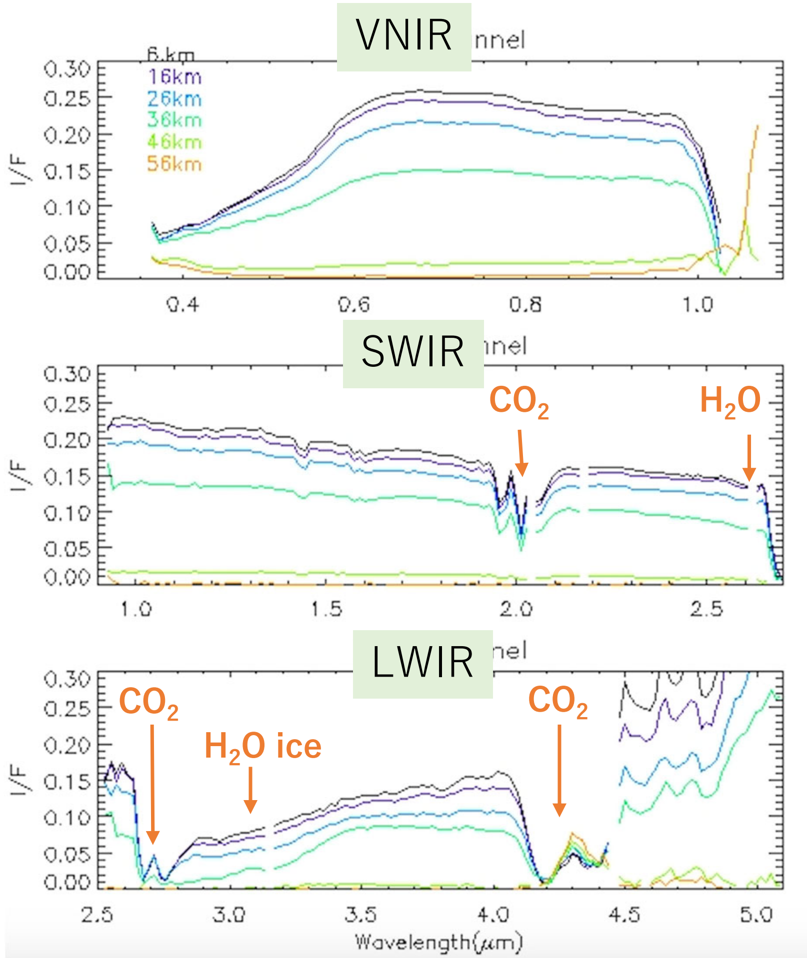
λ	0.35~5.2 μm (res.: 13~20 nm)
$\lambda/d\lambda$	350~10000 (IFOV 1.2mrad)
Mode	dadir & **limb**
Data	2004~ (SWIR : 2004~2008)

OMEGA
Limb image
(in blue)





OMEGA limb spectrum ---- darker at higher altitudes



まず “Dust + Ice” --- Validation of JACOSPAR “Forward model”

Validation for Forward model – Compare with DISORT (past trial by Italian team) + **“some real OMEGA observations”**

・Geometry : Limb (Phase angle = 90° Incidence angle = 0° Emission angle = 90° Tangential height = 20 km)

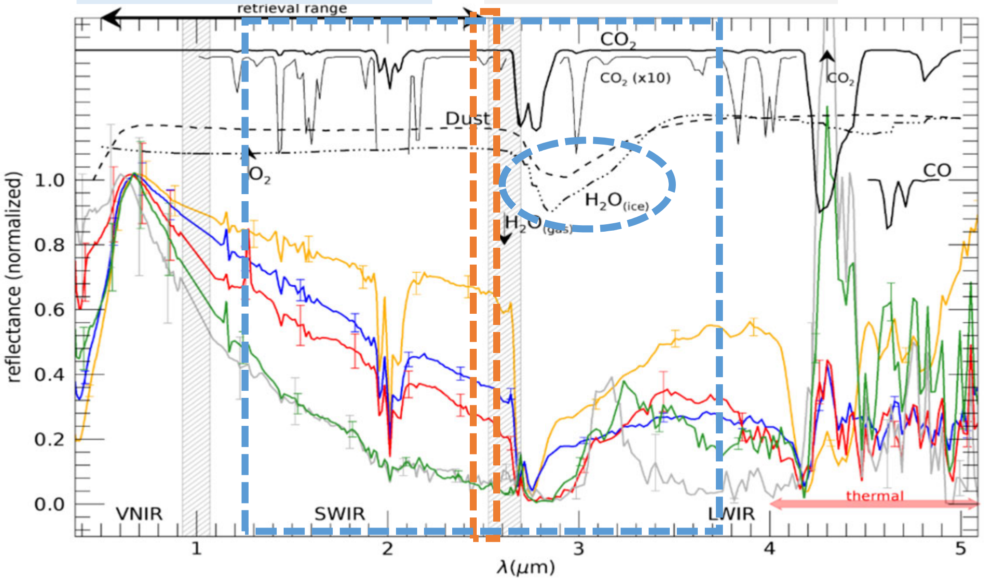
・Input aerosols : Dust (R_m=1.5μm, R_s = 0.3) / Water Ice Dust (R_m = 1.5μm, R_s = 0.3)

τ : Dust = **0.218** at 1075cm^{-1} / Water ice = **0.06** at 830 cm^{-1}

gases : H_2O, CO_2 (Gas databases need to be fixed) **Next step**

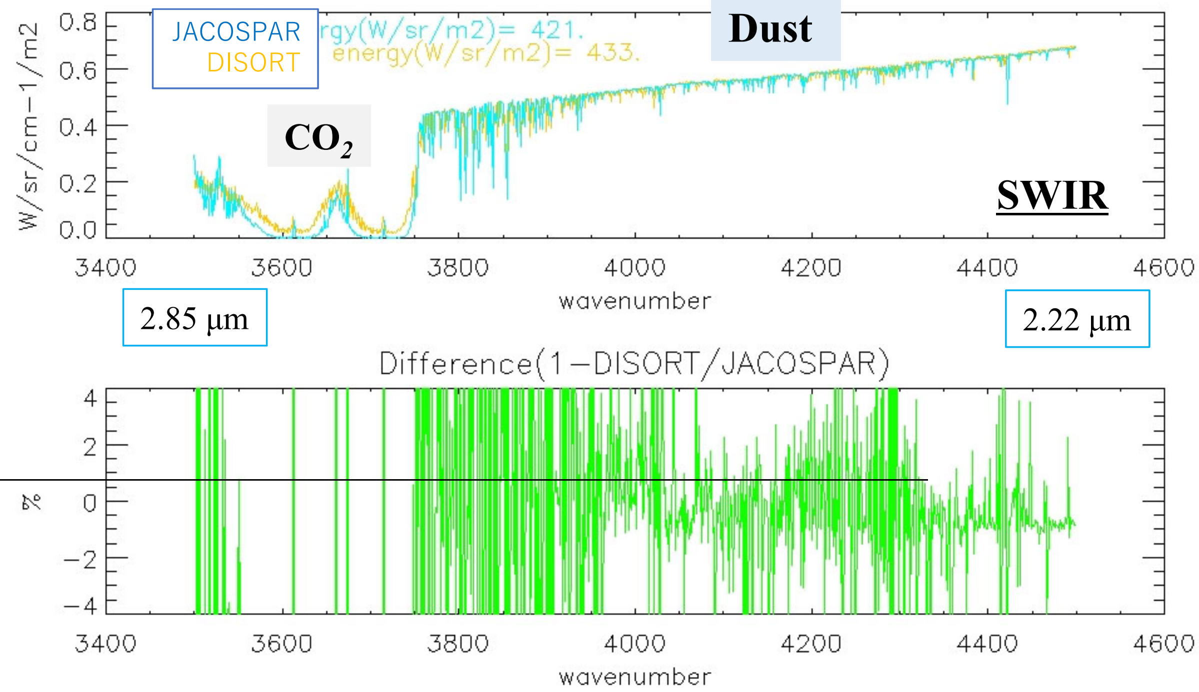
Dust
derived from continuum in wide range

Gas
derived from absorption in narrower range



MEx OMEGA spectrum
(used in D'Aversa+ 2022)

Dust density : 2.44 ~ 2.5 μm
Dust & Ice density : 1.27 ~ 3.7 μm
Particle size : 0.70 ~ 3.7 μm



Agreement: < 1% for continuum

まず "<u>Dust</u> + Ice" --- Validation of JACOSPAR "Inversion"

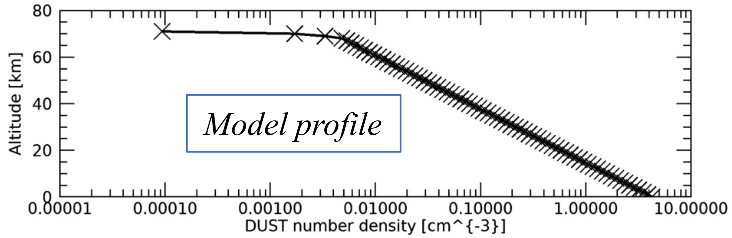
- **Model dust profile → Synthetic spectrum** (not observed one: **2.44 ~ 2.5 μm**) → **Retrieved dust profile**

Geometry : Limb (Phase angle = 5.2° Incidence angle = 74.6° Emission angle = 90° Tangential height = 7-56 km, dz = 7km)

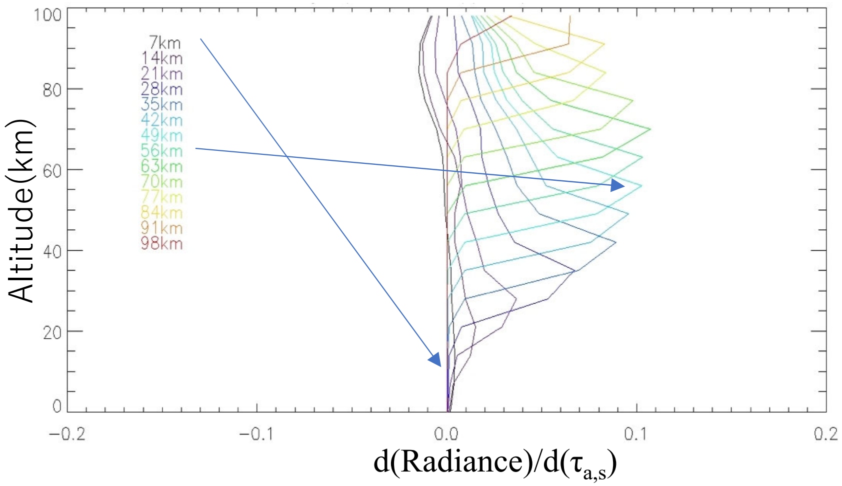
Composition dust (R_m = 1.5 μm, R_s = 0.3, optical depth = 0.218 at 1075 cm^{-1})

→ Retrieved for **"Dust density"**

[A priori] "model dust density" x 2 [R_m = 1.5 μm, R_s = 0.3]



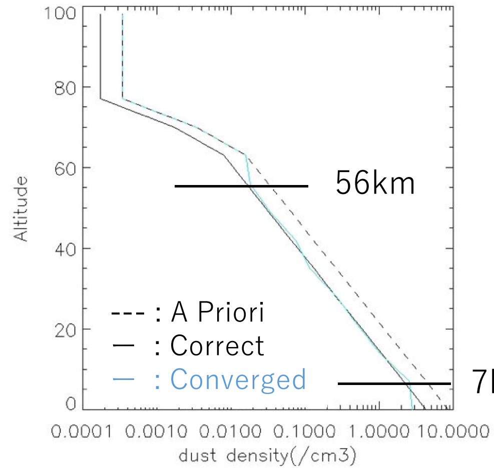
<u>Jacobian</u>



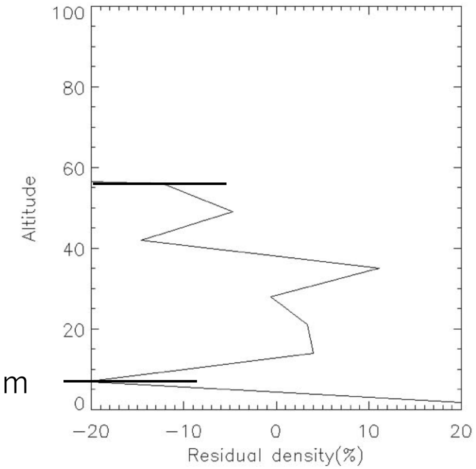
+: その高度のdustが増えると
特定optical pathでのfluxが増大

<下の高度は、dust 吸収で情報が得難い>

<u>Dust density profile</u>



<u>Residual dust density</u>



Accuracy for dust density < ±20%

開発中の数値’解析’ツール：潜在的連携テーマ

～ 火星 & beyond, linked to simulations ～

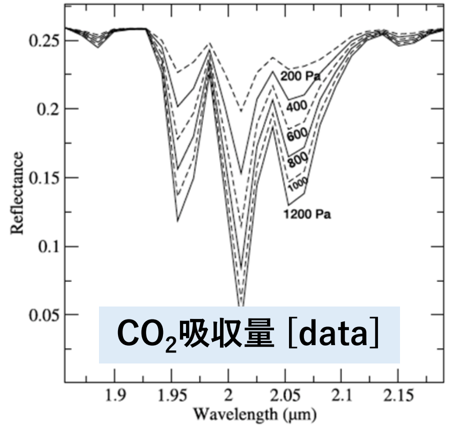
[大気]

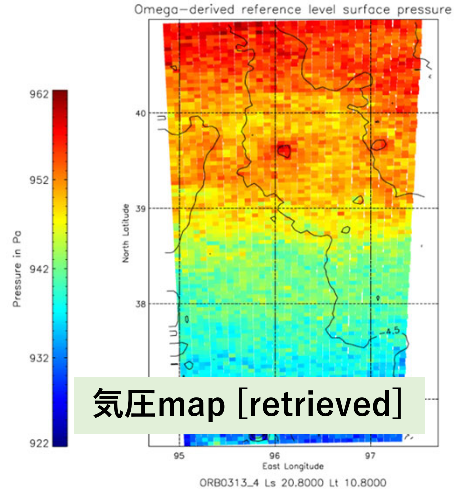
* 大気リトリーバル技術　（本テーマ）

Spectrum shape → Dust & Gas 水平・垂直空間分布

* 気圧map導出技術　　　（開発中）

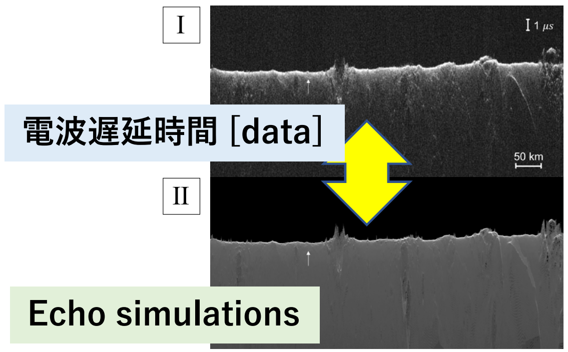
CO2吸収量　　　→ 地上気圧マップ

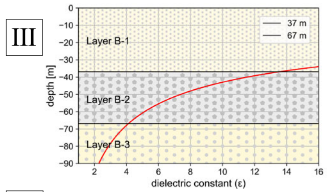


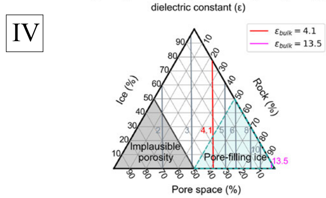


[地下]

* 電波反射情報　　　→ 地下情報map







数値ツールは広く使われてなんぼ。またその「開発」には蓄積とheritageが必要。
これを担う「宇宙機関」は存在しないわけで、重要なインフラとして会津大にはご活躍を期待したい。