International collaboration of European and Japanese Mars exploration missions
新たな同位体観測による火星大気進化の解明
：日欧火星探査ミッションの国際協力

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Abstract

Mars had experienced dramatic climate change from a warm and wet environment that held large amounts of water in the past to a dry and cold environment in the present. Understanding the evolution of the Martian atmosphere is an important research topic that leads to our understanding of a habitable planetary environment. Isotopic analysis of the Martian atmosphere has long been used to estimate the amount of water and atmosphere in the past. However, the estimates of previous studies have large uncertainties and remain unresolved. In this study, carbon and oxygen isotope ratios and fractionation factors will be derived for the first time using new observation methods from the atmosphere to the space. The water and volatile inventory will be clarified to answer “Was Mars a habitable environment?”. The mass spectrum analyzer (MSA) onboard MMX could provide in-situ isotope analysis in the escaping ions from the Martian atmosphere at Phobos orbit (Yokota et al., EPS, 2021). Development the instrument progressing on-time, aiming for launch in 2024 and stat its observation from 2025. NOMAD presents the carbon isotopic ratio in CO at 20-50 km altitudes show a strong ^{13}C depletion (Aoki et al., under review). Such a strong depletion in CO in attributed to the CO_2 photolysis-reduced fractionation, as predicted by the model (Yoshida et al., Planetary Science J., 2023: https://doi.org/10.3847/PSJ/acc030). The plan is to strengthen international collaboration with the ExoMars TGO/NOMAD and MMX/MSA leads the comparative data analysis collaboration.

New isotope observations of Mars atmospheric evolution: International collaboration of European and Japanese Mars exploration missions

P-22

20-21 February 2023, Symposium on Planetary Sciences, Tohoku University

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1.1 New isotope ratio observations

Abstract, Key points of this project

- We will elucidate the volatile inventory and the mechanism of atmospheric loss on Mars, by achieving a new isotope ratio observations for carbon (C) and oxygen (O), considering the interaction between space, upper atmosphere, and lower atmosphere as the mutual system.
- High-resolution mass spectrometer MSA onboard MMX is first capable to *in-situ* detect isotope ratio of escaping atmosphere (C, O, N, and potentially H).
- High-resolution remote-sensing spectroscopy NOMAD onboard TGO also potentially provide isotope ratio in the middle atmosphere (H, C and O). **See Poster P-21 Shiobara et al., this symposium**
- The fractionation between two isotope ratio could constrain the volatile inventory and the mechanism of atmospheric loss on Mars.

1.2 Introduction: Why we care?

Open question of Mars evolution

- Previous studies have failed to explain how Mars could have retained sufficient atmosphere to explain its warm and wet environment in the past.
- Cannot distinguish between volatile (CO_2) and water inventory.
- Large uncertainty of the impact of extreme solar wind condition in the past.

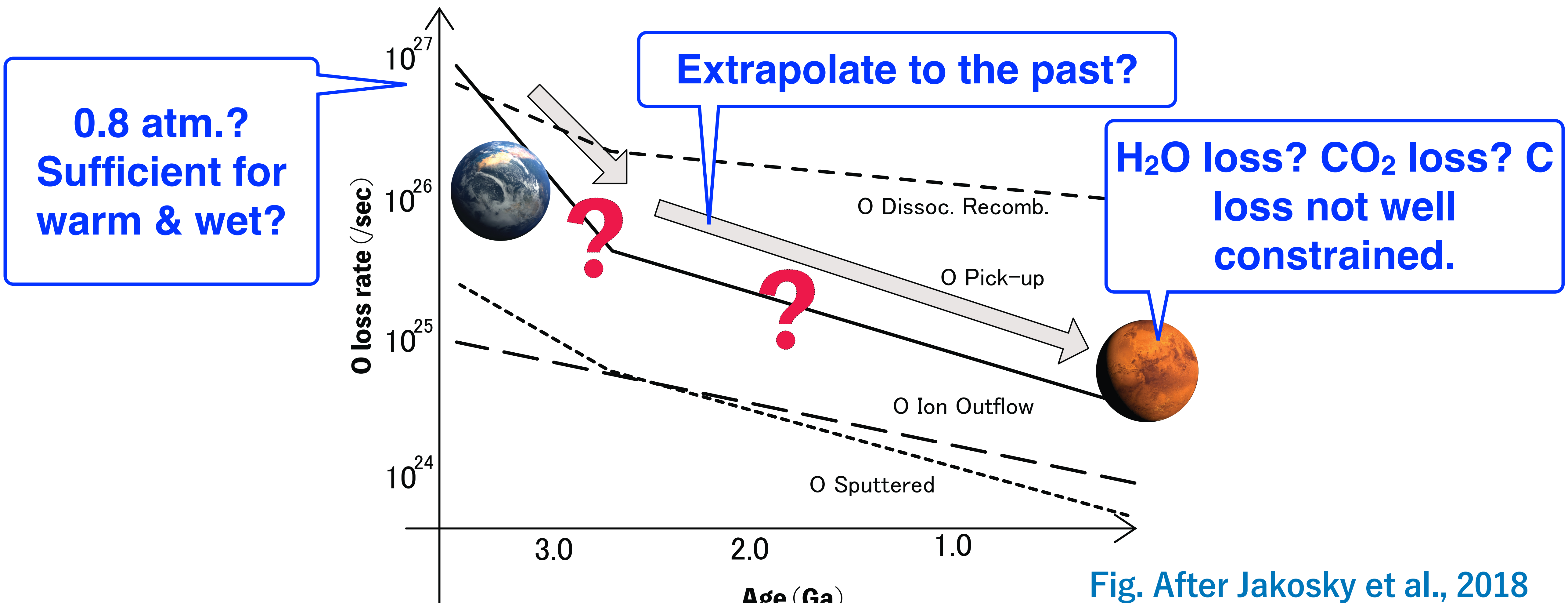


Fig. After Jakosky et al., 2018

1.3 New findings by recent studies suggests possible upward revision of loss.

Solar forcing and effective coupling from below

- Notable variation of atmospheric loss by extreme solar event [Jakosky+15]
- Atmospheric escape driven by lower atmosphere [Chaffin+21]

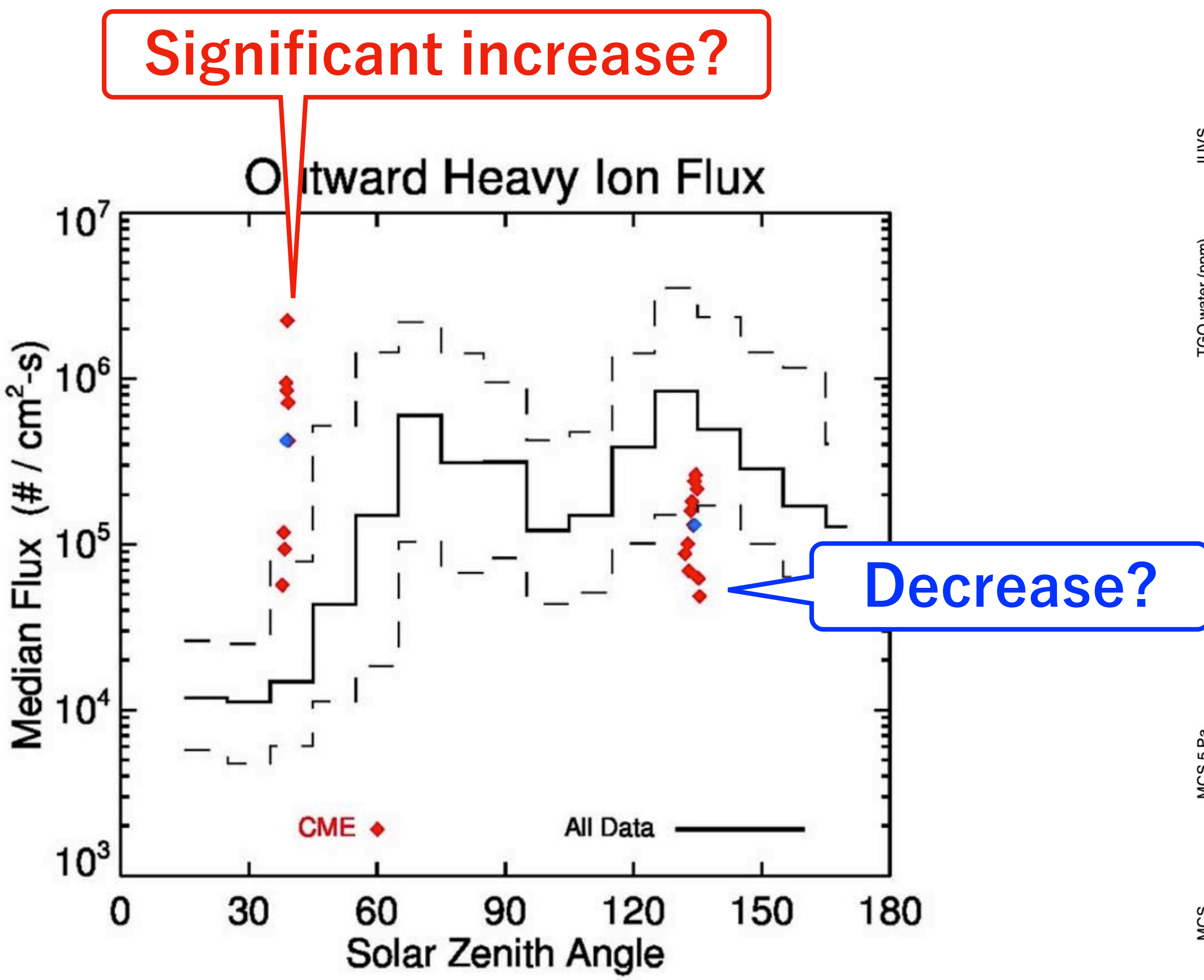


Fig. Jakosky et al., 2015

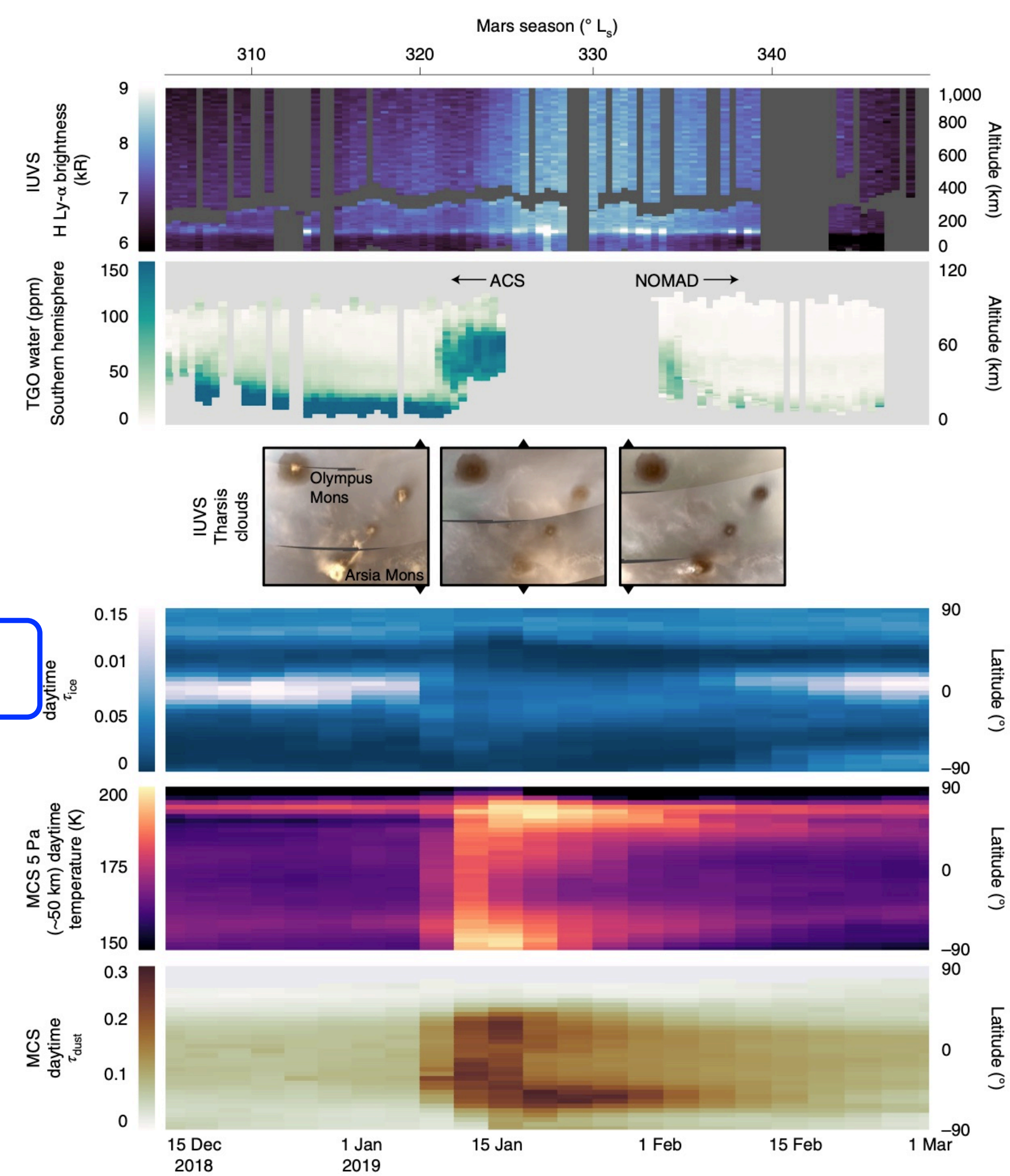
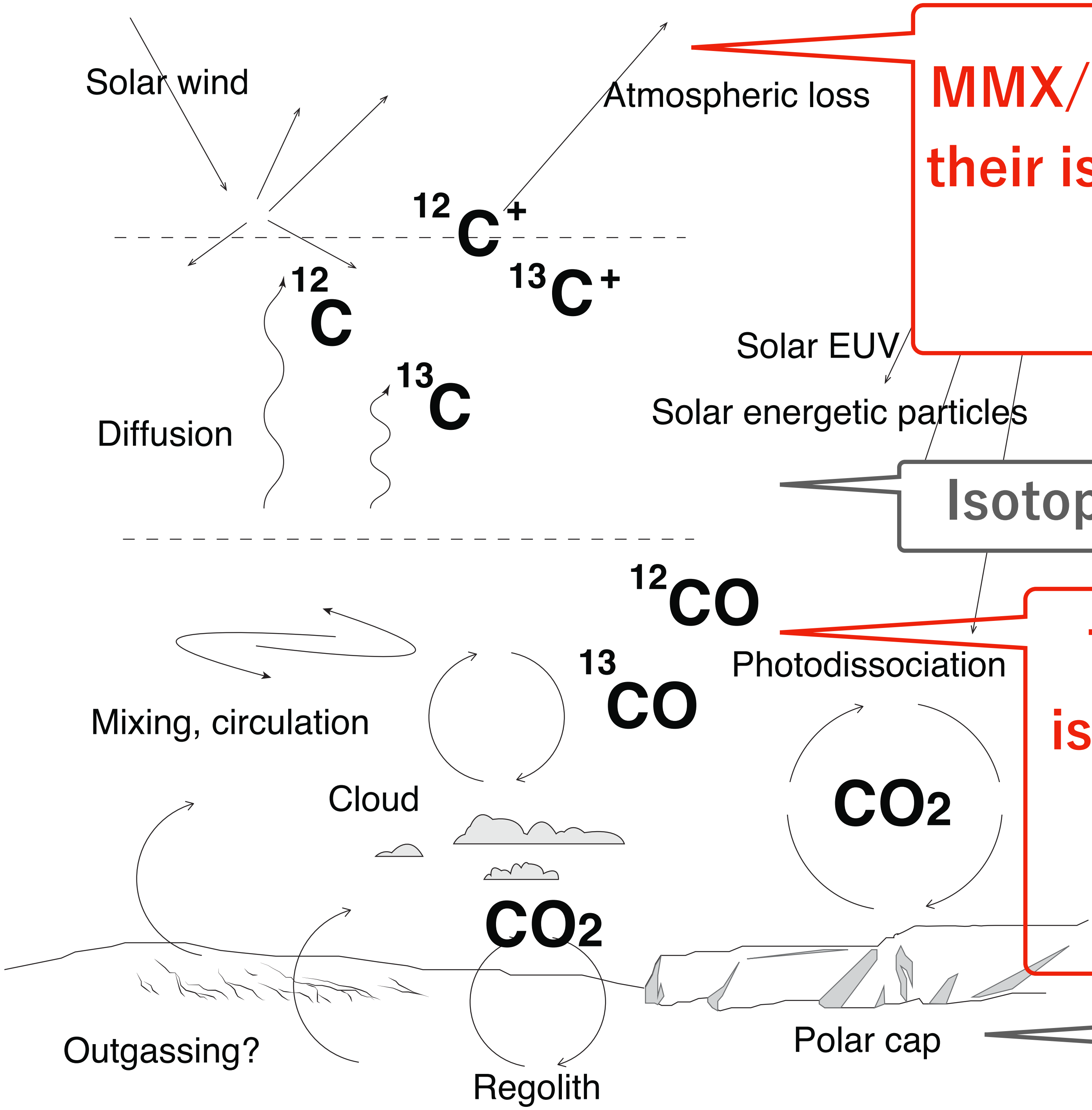


Fig. Chaffin et al., 2021

1.4 New and unique advantage

New constrain by MMX/MSA and TGO/NOMAD



MMX/MSA observes O^{+}, C^{+}, N^{+}, Ar^{+} and their isotopes [Yokota+21; Ogohara+21], starting from 2025

Isotopes in CO_2 by MAVEN [Stone+EPSC]

TGO/NOMAD observes CO and its isotopes $^{13}C/^{12}C$ $^{18}O/^{16}O$, & HDO/H_2O
[Aoki+22; Aoki+under review]
See Poster P-21 Shiobara et al.

Isotopes by Curiosity [Webster+13]

Fig. After Nakagawa, 2019

1.5

New and unique advantage 2

Models that link observations

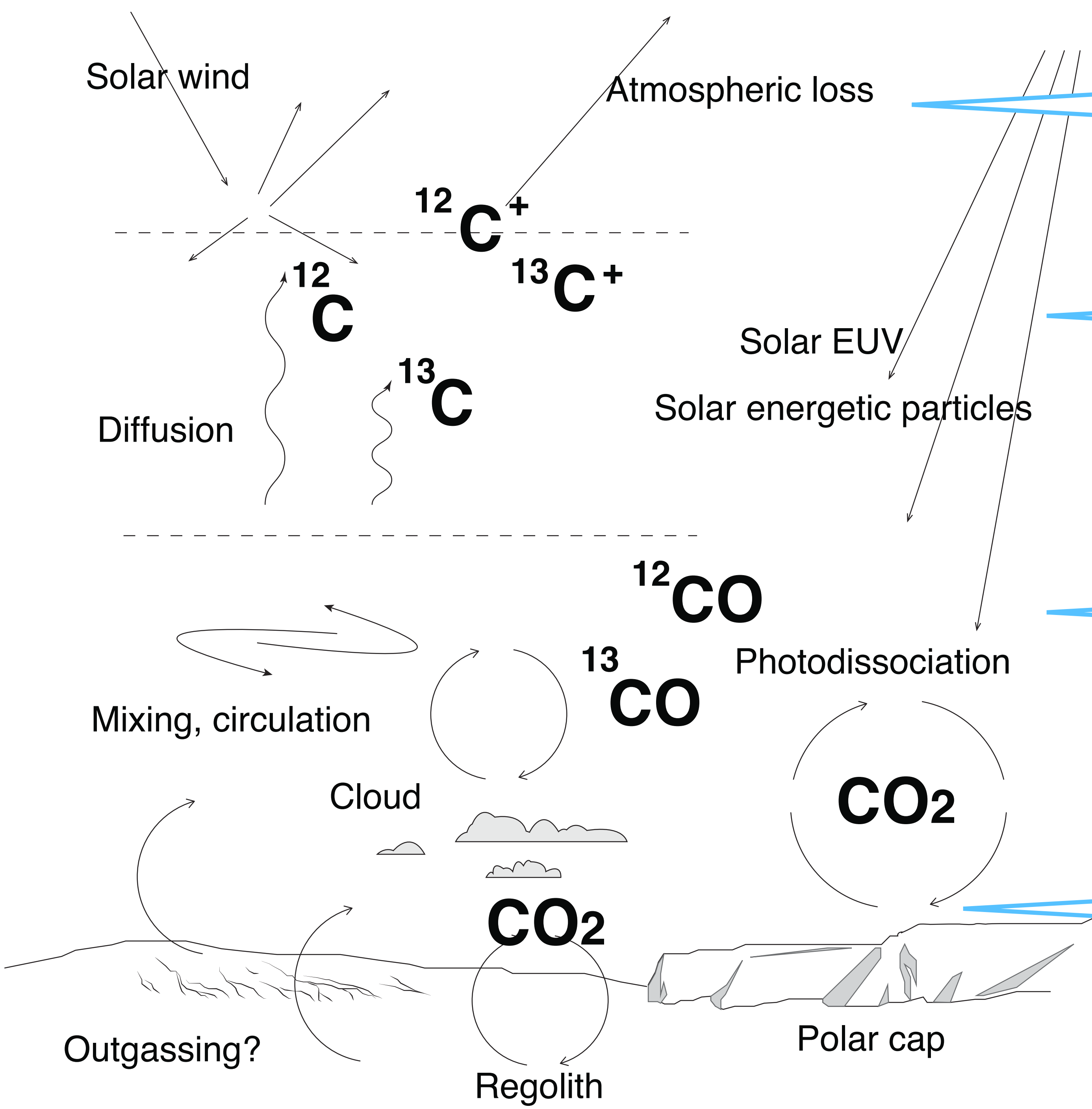


Fig. After Nakagawa, 2019

MHD simulation
[Terada+09; Sakai+under review]

Monte Carlo model
[Nakamura+2022]
See 0220-PM10 on 20 Feb.

1D photochemical model
[Yoshida+,under review]
See 0220-PM11 on 20 Feb.

General Circulation Model
[Daerden+22; Kuroda+; Kobayashi+]
See Poster P-20 Kobayashi et al.

New and unique advantage 2

1.6 Models that link observations

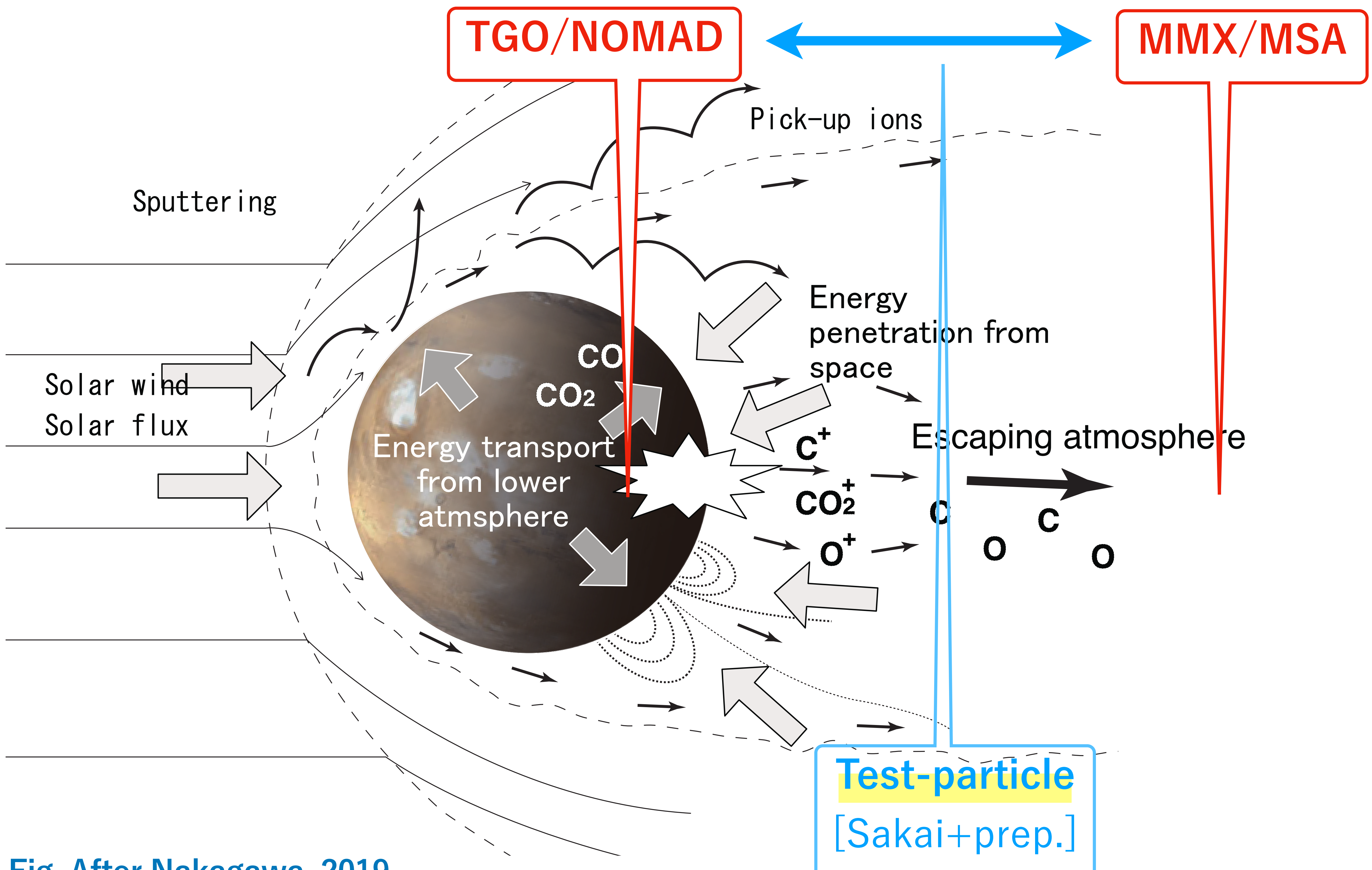
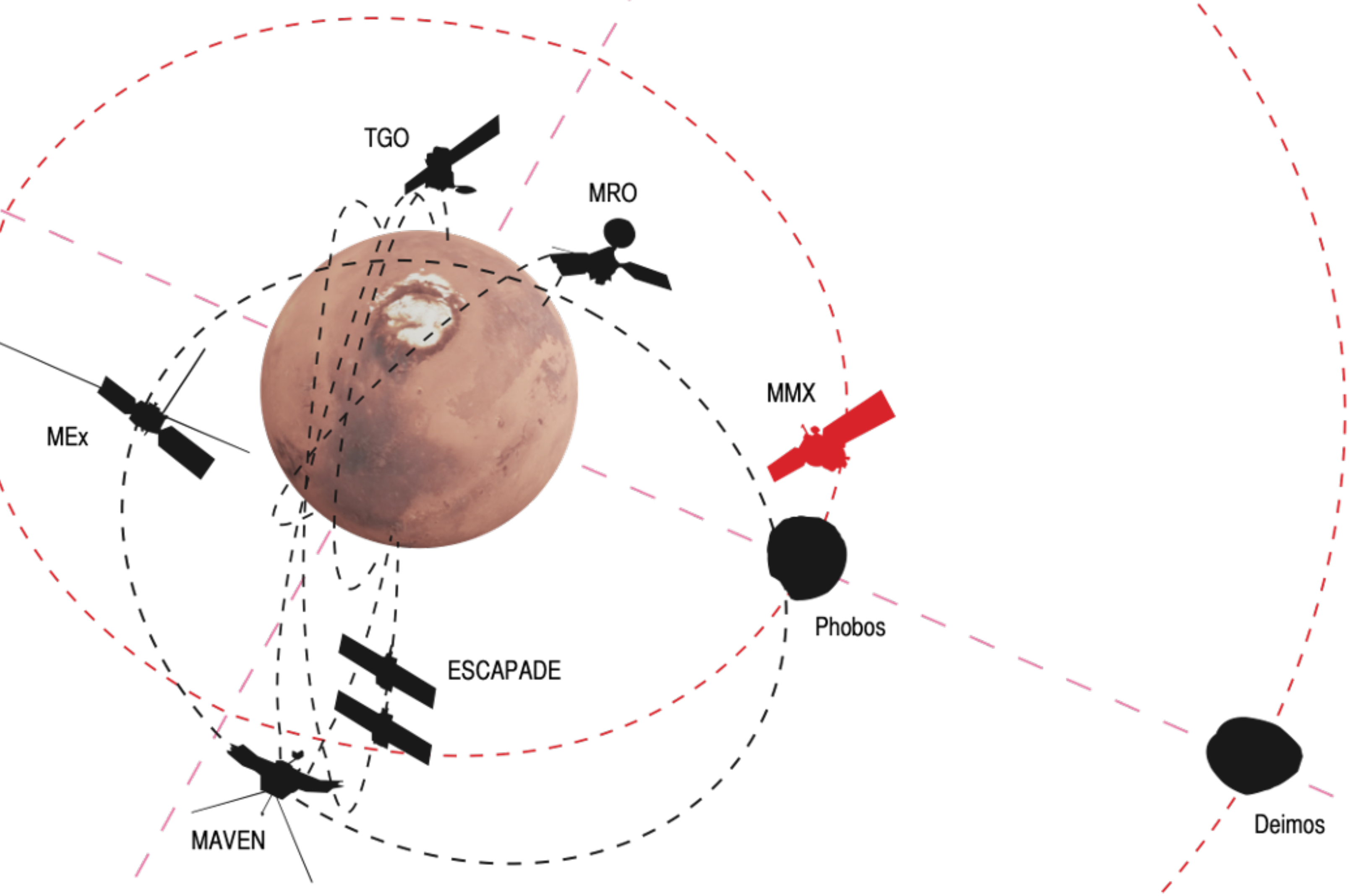


Fig. After Nakagawa, 2019

1.7

Advantage of MMX atmospheric observation

How to monitor the lower atmosphere?



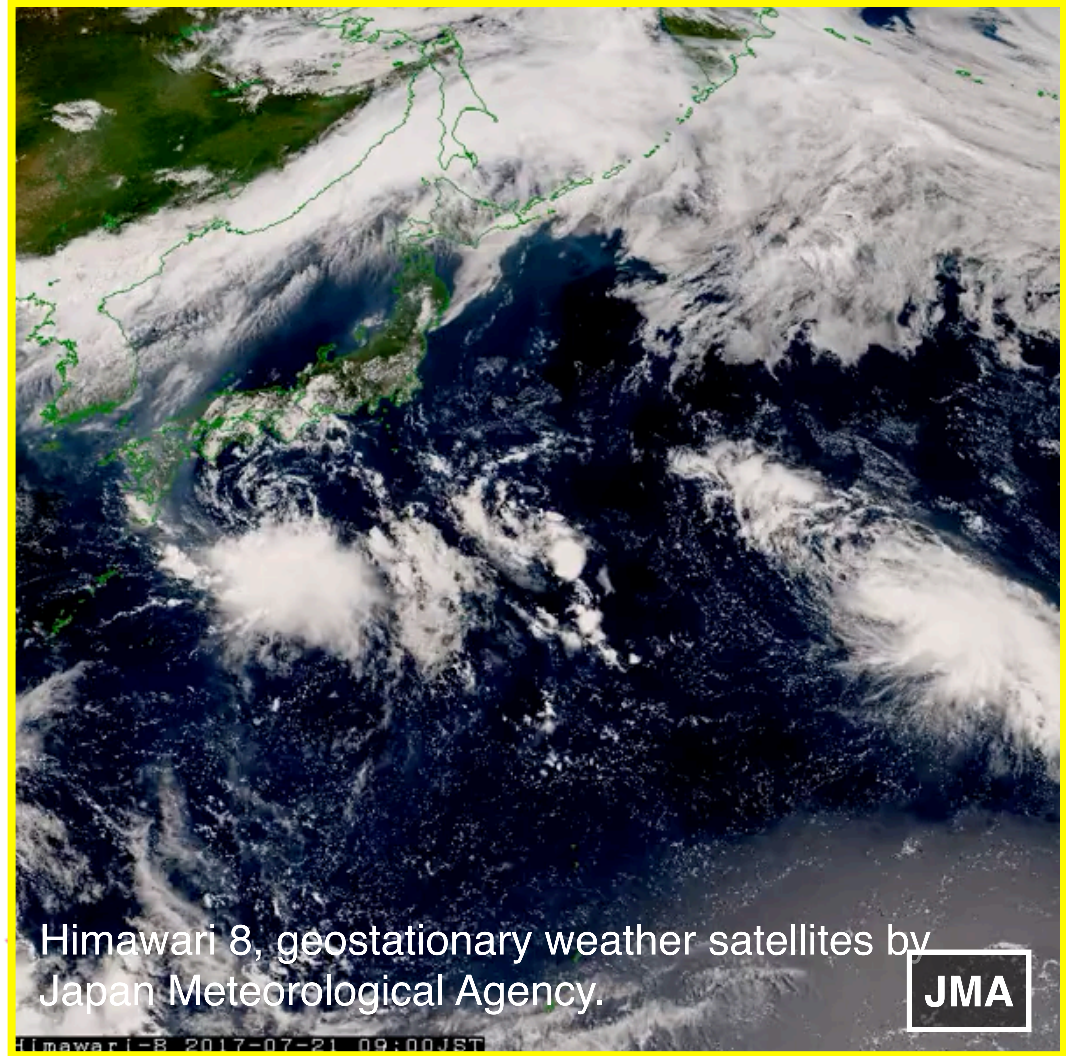
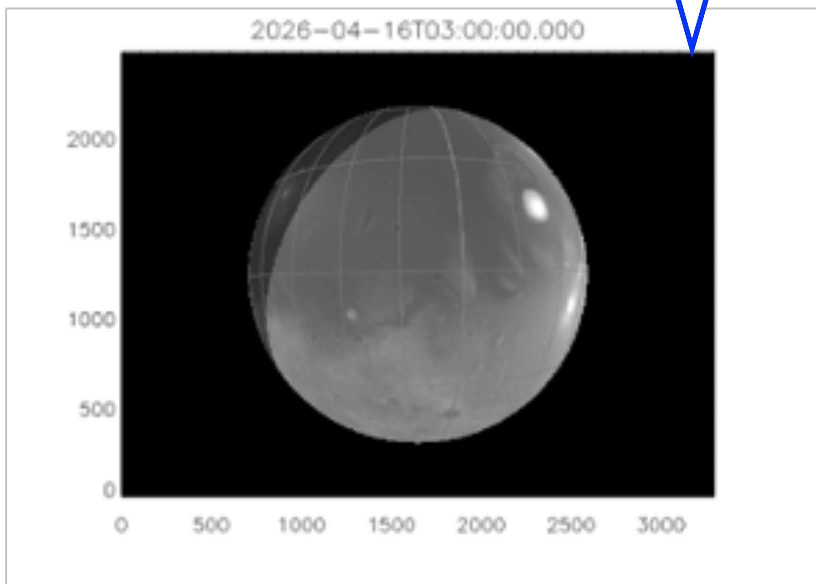


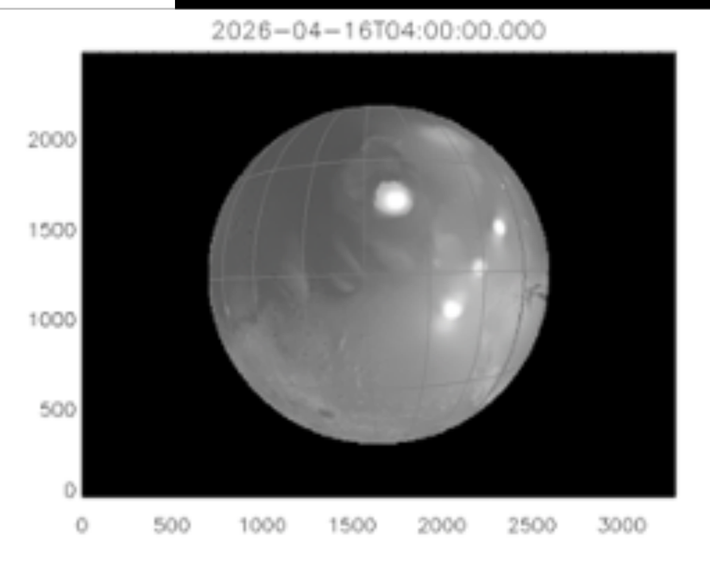
Fig. Ogohara et al., 2021.

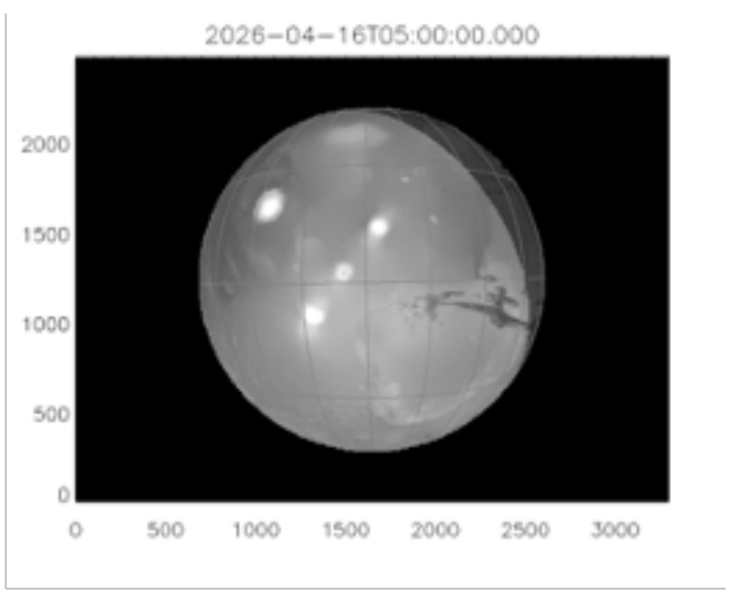
1.8 MMX atmospheric observation from Phobos equatorial orbit

Hourly monitoring in VIS (7-ch.) to NIR (0.9-3.6)

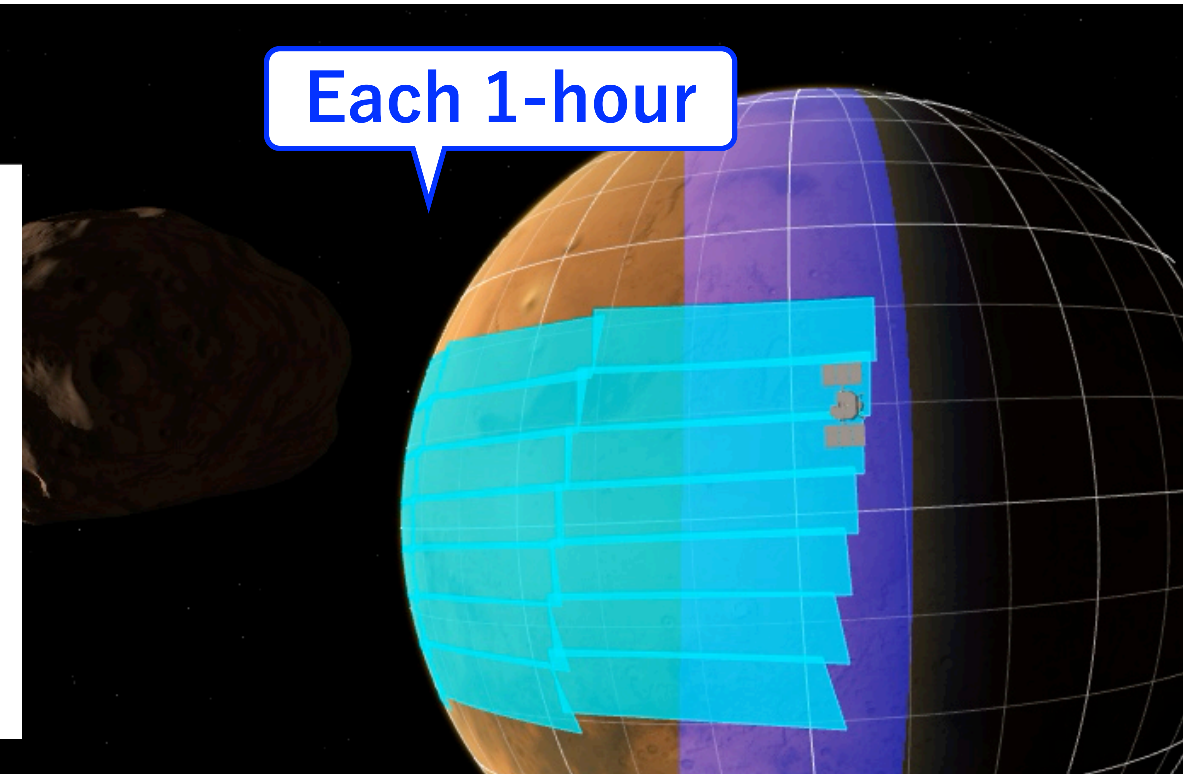
Each 15min

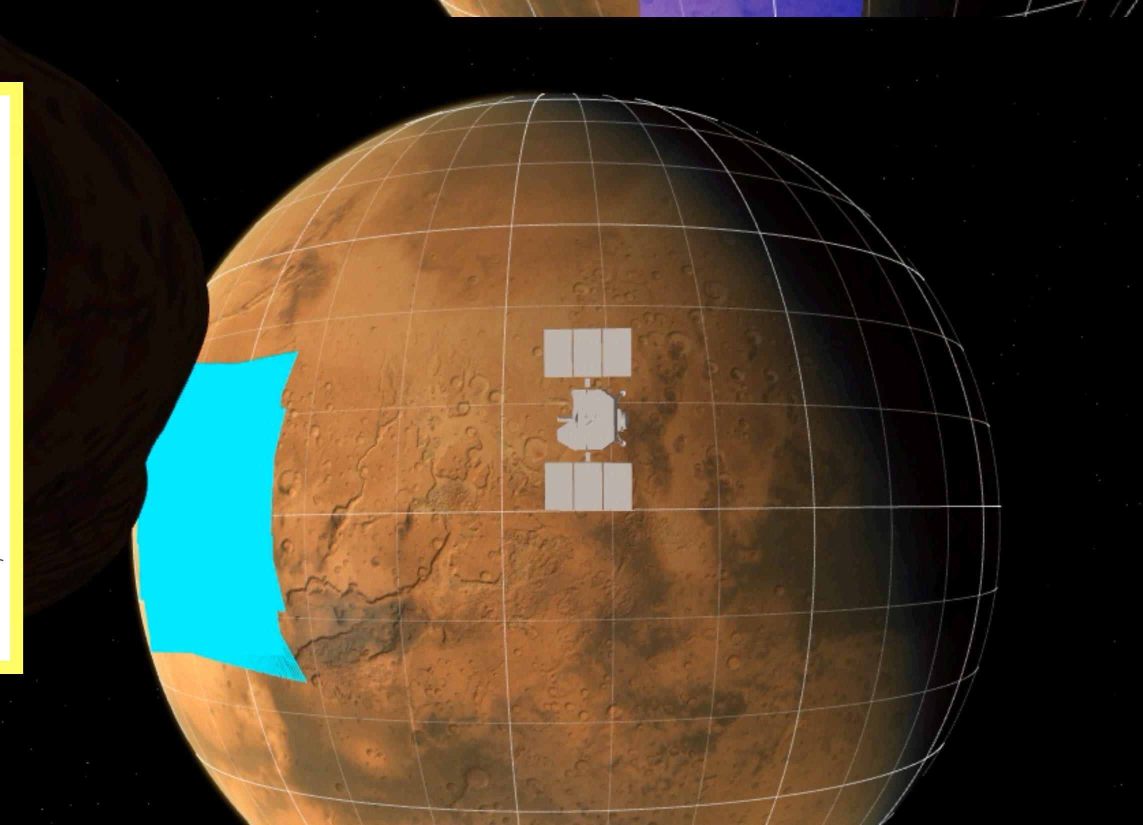






Each 1-hour





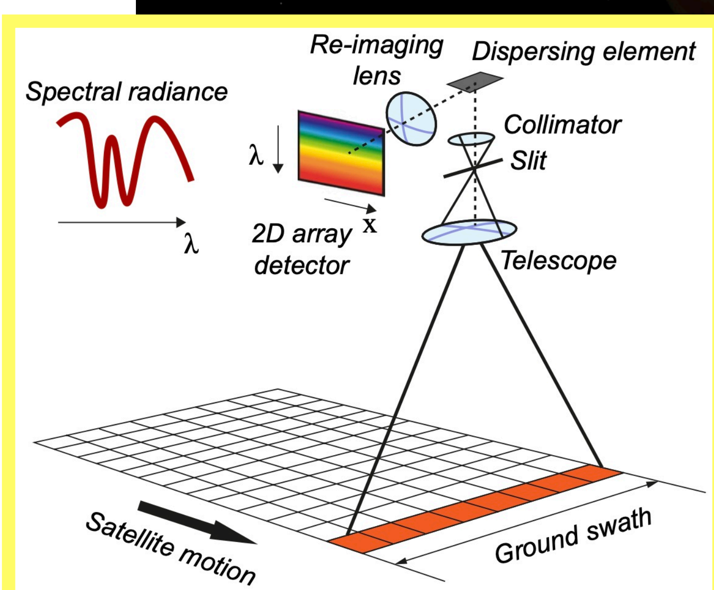


Fig. Kameda+21; Barucci+21

1.9

MMX operation plan

Atmospheric observation campaigns

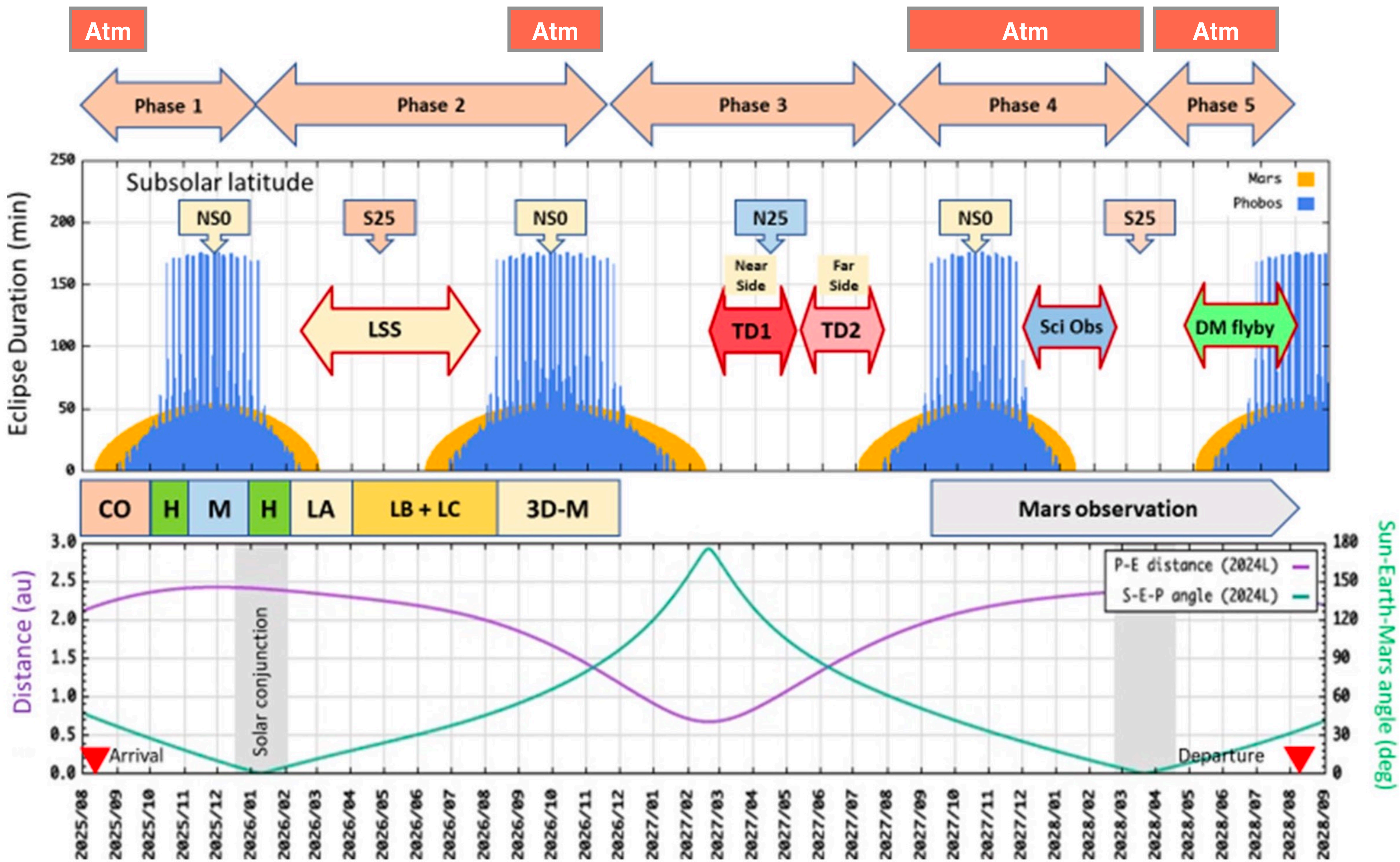


Fig. Nakamura et al., 2021.

2.0 Summary of our preliminary results

- In this study, carbon and oxygen isotope ratios and fractionation factors will be derived for the first time using new observation methods from the atmosphere to the space.
- The water and volatile inventory will be clarified to answer "Was Mars a habitable environment?".
- The mass spectrum analyzer (MSA) onboard MMX could provide in-situ isotope analysis in the escaping ions from the Martian atmosphere at Phobos orbit (Yokota et al., EPS, 2021). Development progressing on-time, aiming for launch in 2024 and start its observation from 2025.
- NOMAD presents that the carbon isotopic ratio in CO at 20-50 km altitudes show a strong ^{13}C depletion (Aoki et al., under review).
- Such a strong ^{13}C depletion in CO in attributed to the CO_2 photolysis-induced fractionation, as predicted by our model (Yoshida et al., under review).