

1<sup>st</sup> ELSI International Symposium

# Origin of Earth's Ocean

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(Univ. Tokyo → ELSI)

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- ▶ How much water is on the Earth?
- ▶ When did the ocean form?
- ▶ Where did the water come from?

# Earth's Water

How much water?

Ocean:  $1.4 \times 10^{21}$  kg

Earth :  $6.0 \times 10^{24}$  kg

tiny fraction (0.023%)

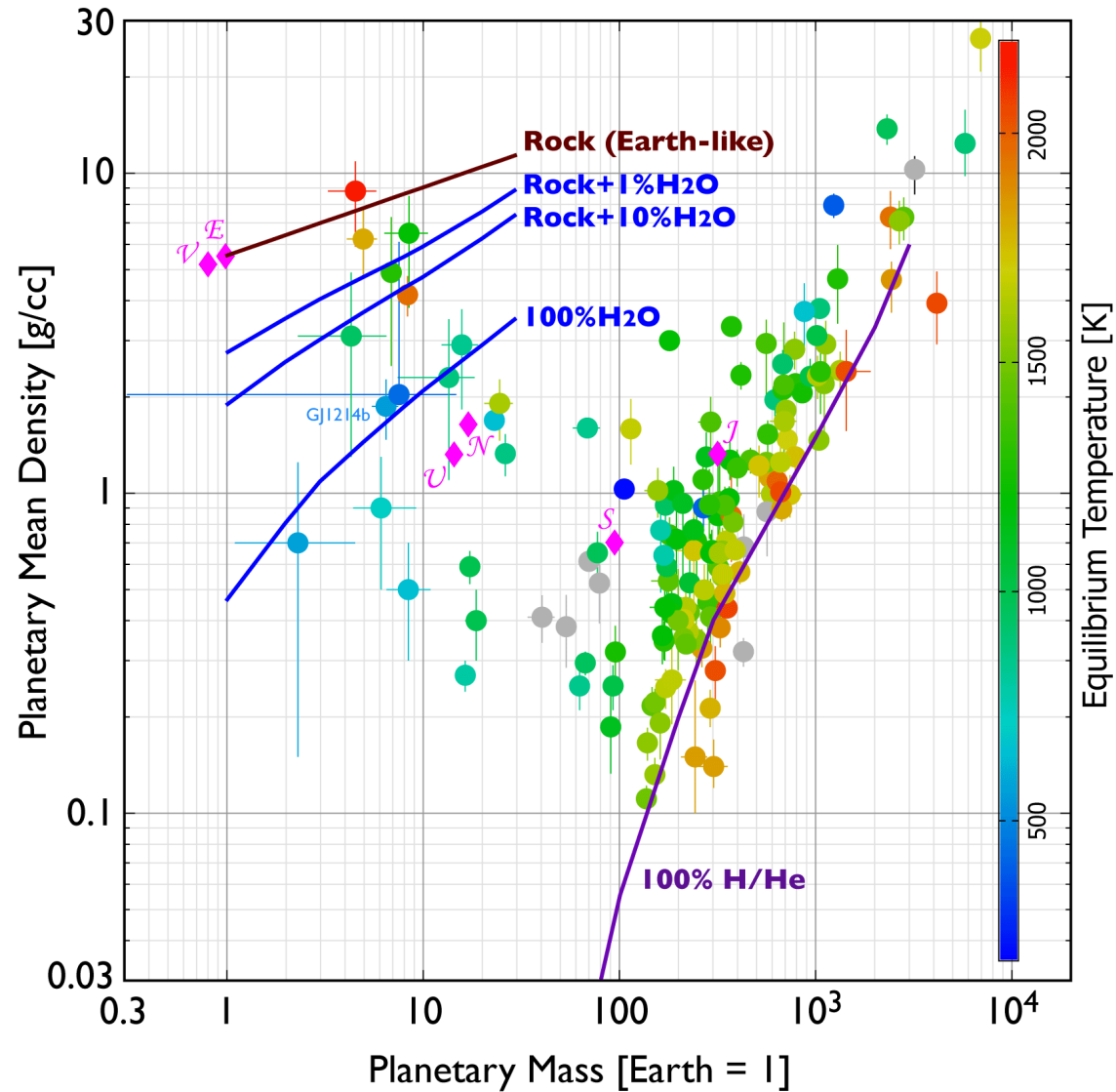
cf. Possibly 5 times ocean mass  
of water in the Earth's interior

Uranus and Neptune are made mainly of  $H_2O$  (60-70%).

A tiny fraction of liquid water on the Earth is  
essential for origin and evolution of life.



# Super-Earths



# How Old is the Ocean?

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- ▶ Isua rocks in West Greenland (3.8 Gyr)

*sedimentary rock*



*pillow-lava*



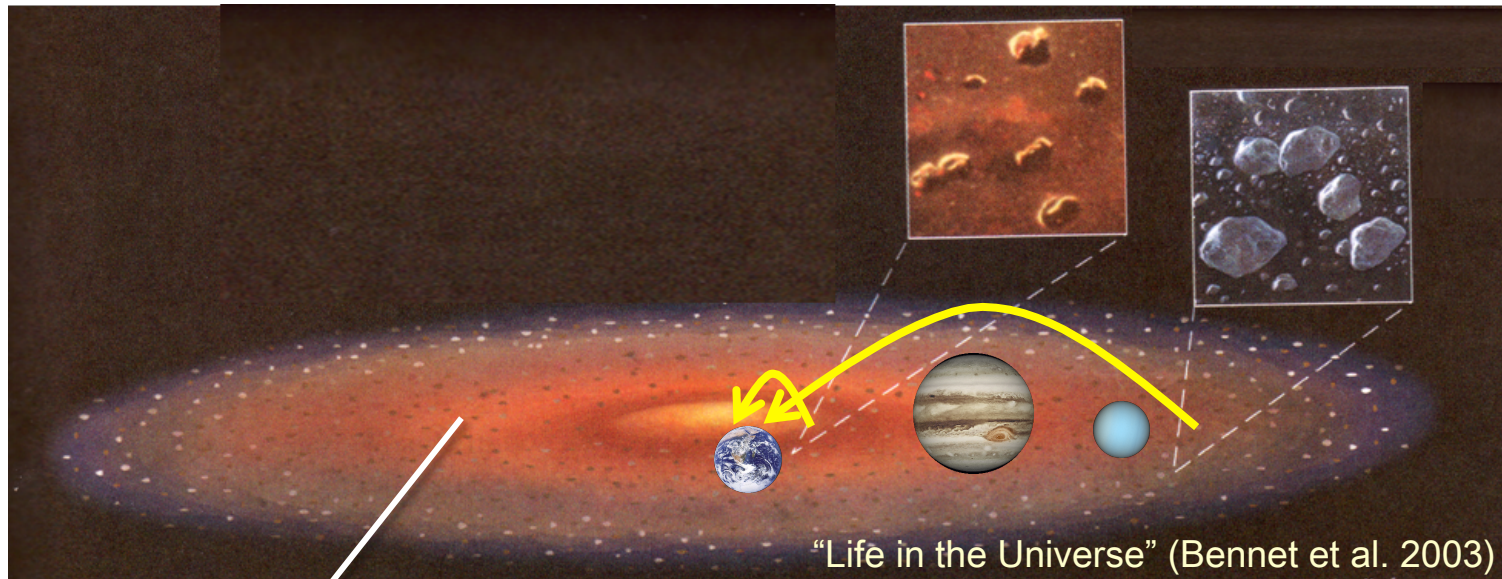
- ▶ Oxygen isotope of zircons (< ~4.3Gyr) *Mojzsis et al. (2001)*

These evidences show that the ocean already existed just after (or during) Earth's formation.

# Possible Water Sources

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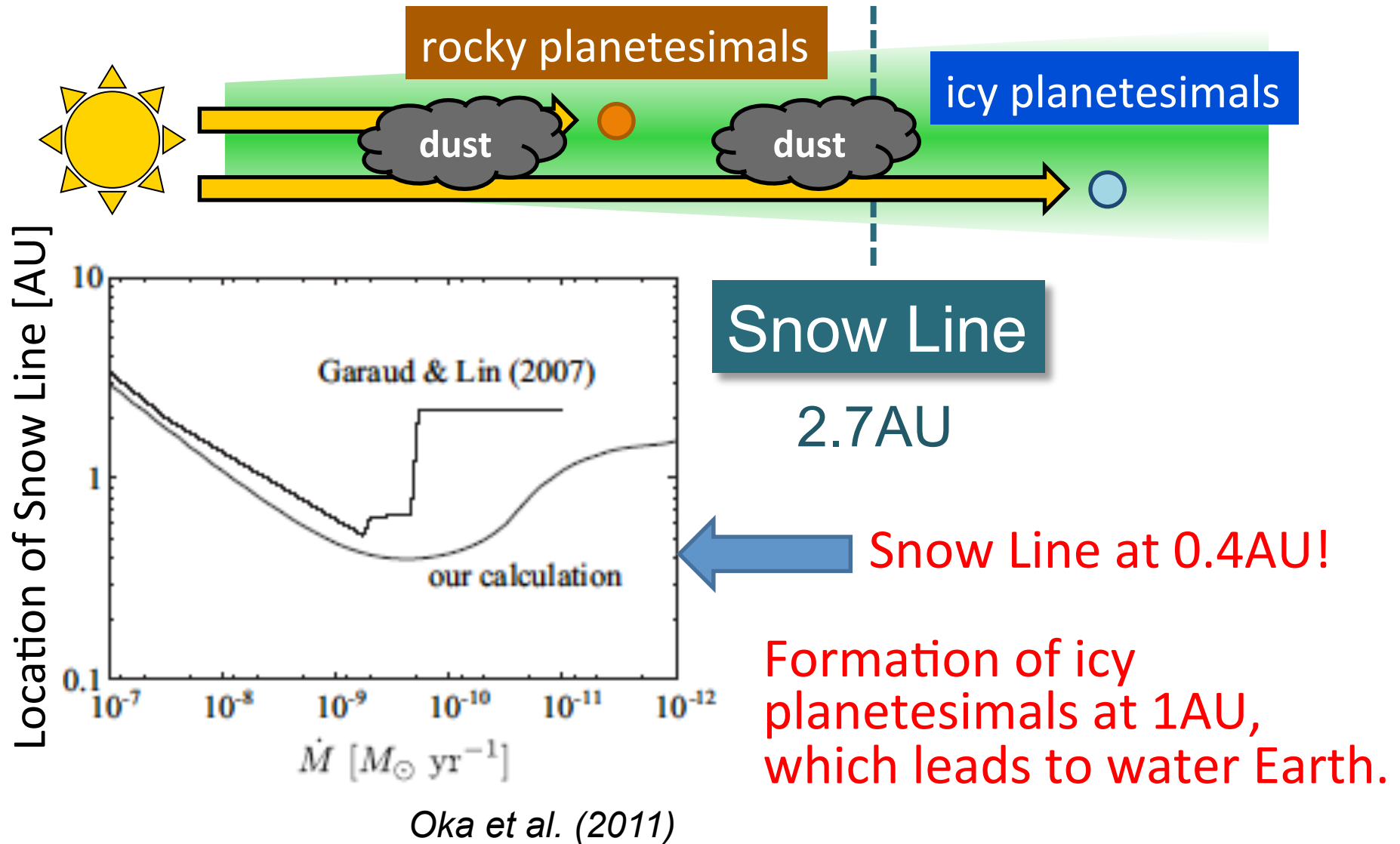
(2) Asteroids, Icy planetesimals  
(e.g., carbonaceous chondrites, comets)



(3) nebular gas

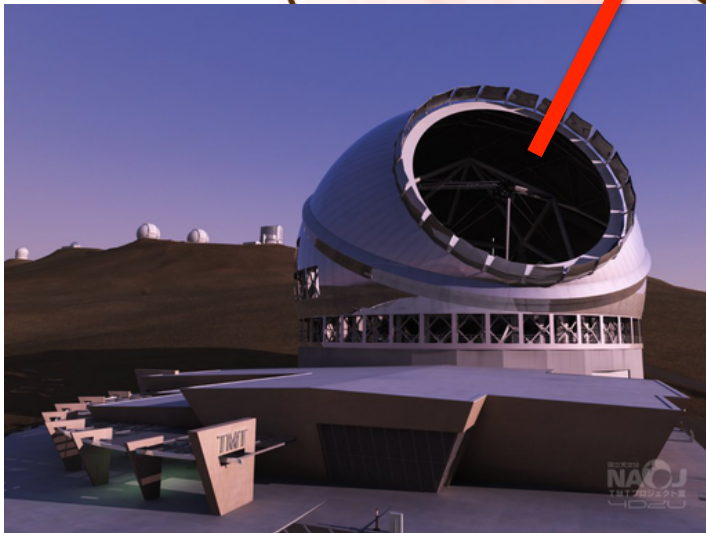
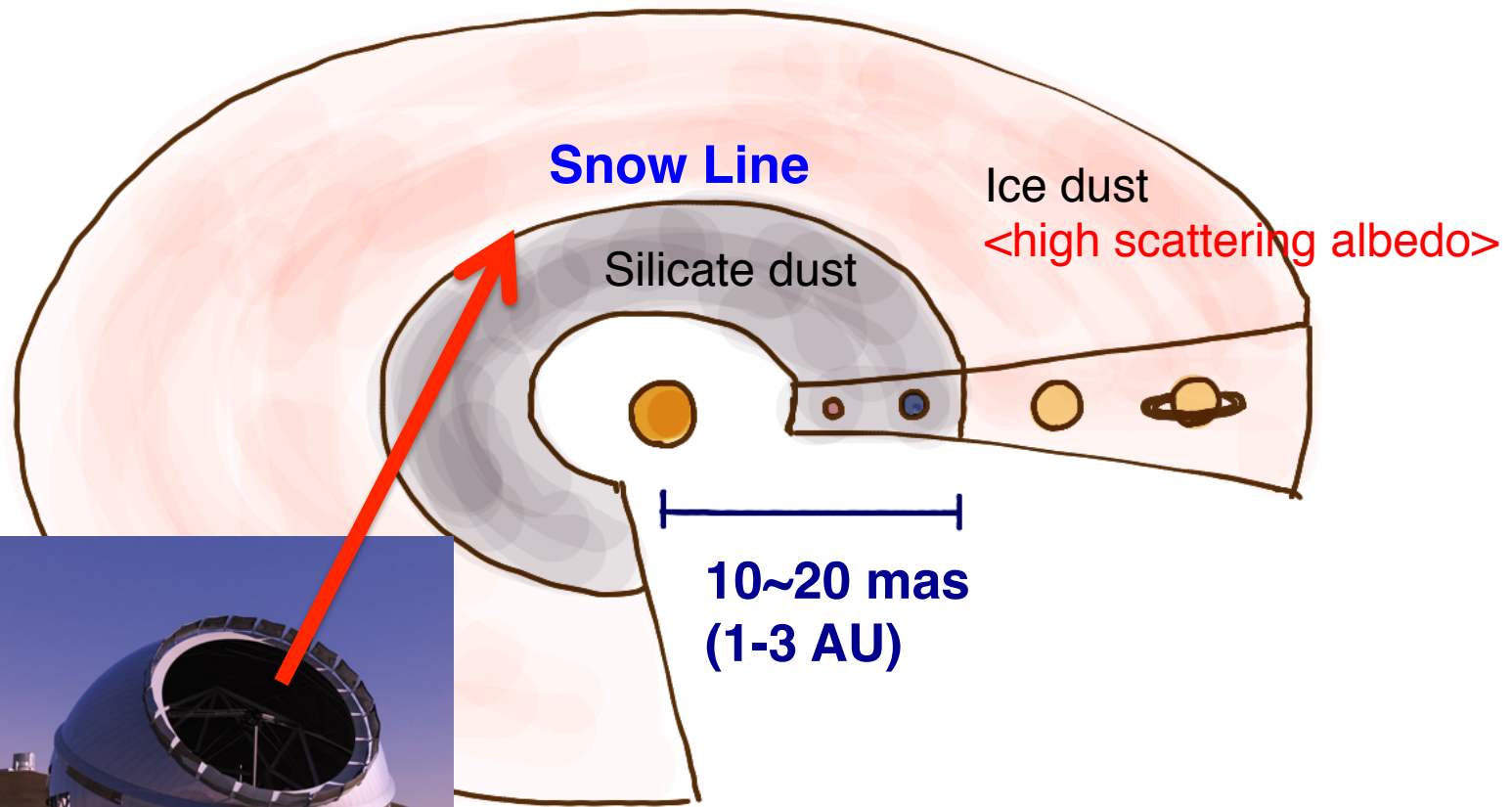
(1) Building block of the Earth  
(planetesimals)

# Building Blocks of Earth





# Obs. of Snow Line

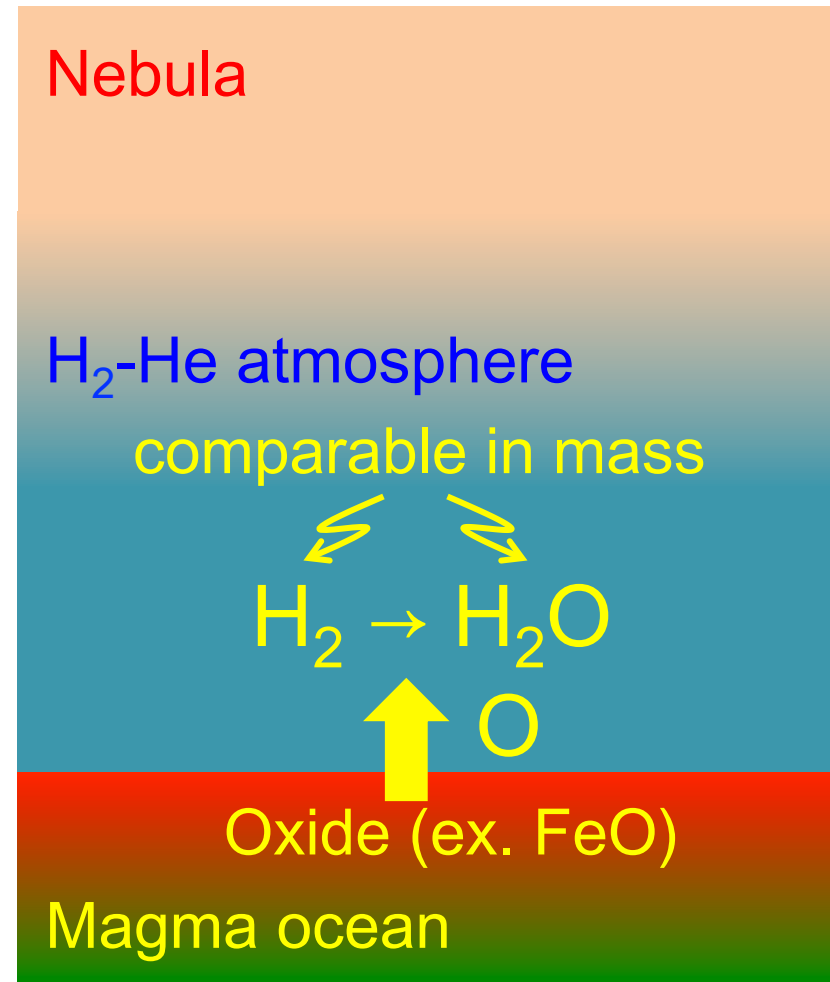
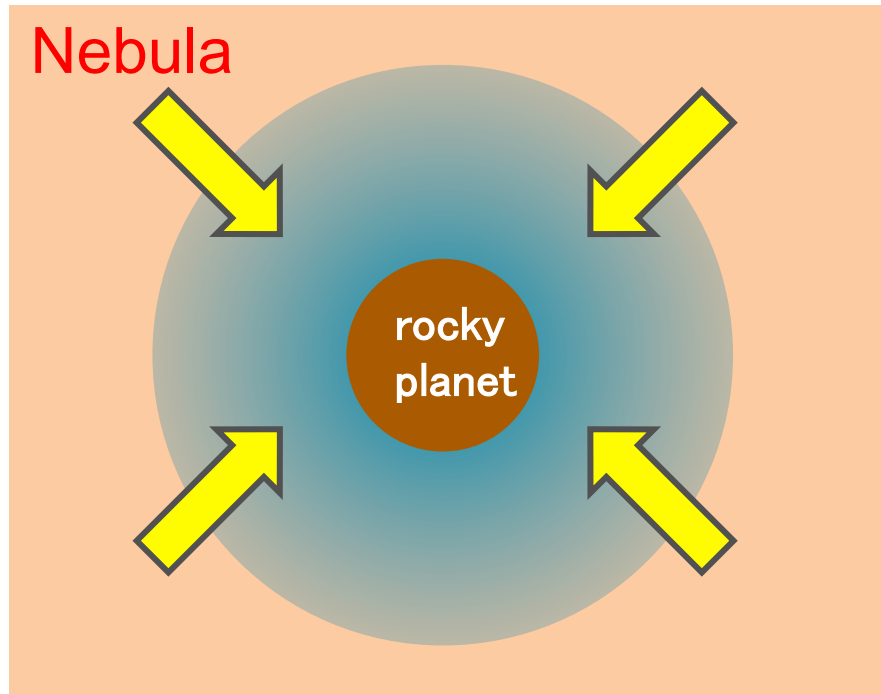


TMT (2021-)  
(Thirty Meter Telescope)

SEIT team

# Nebular Origin of Water

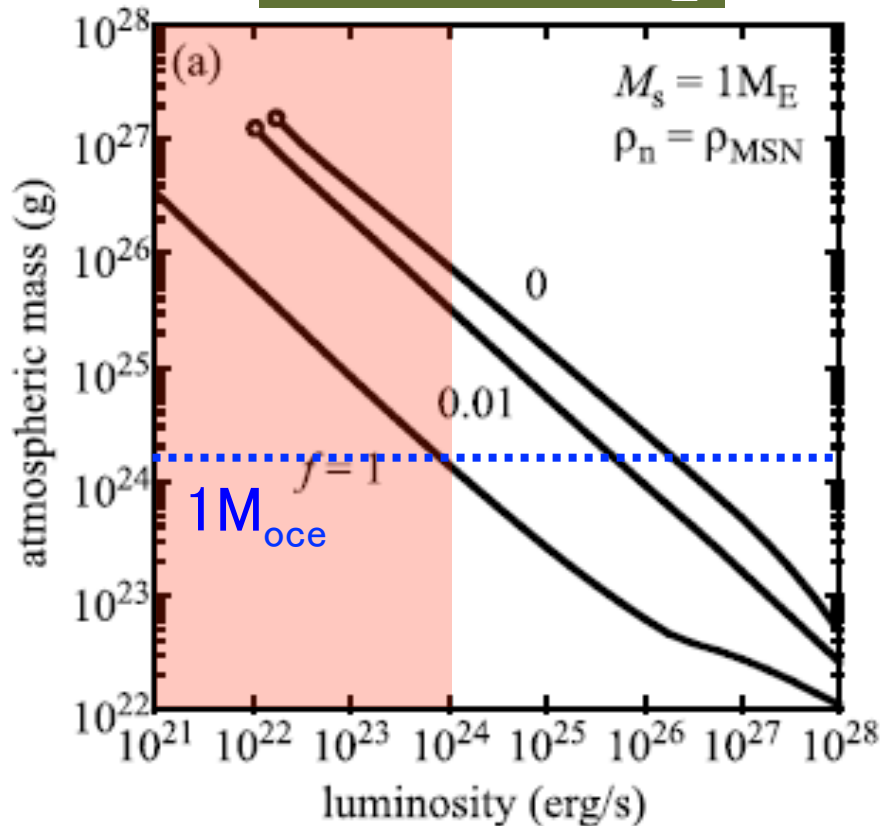
*Sasaki (1990), Ikoma & Genda (2006)*





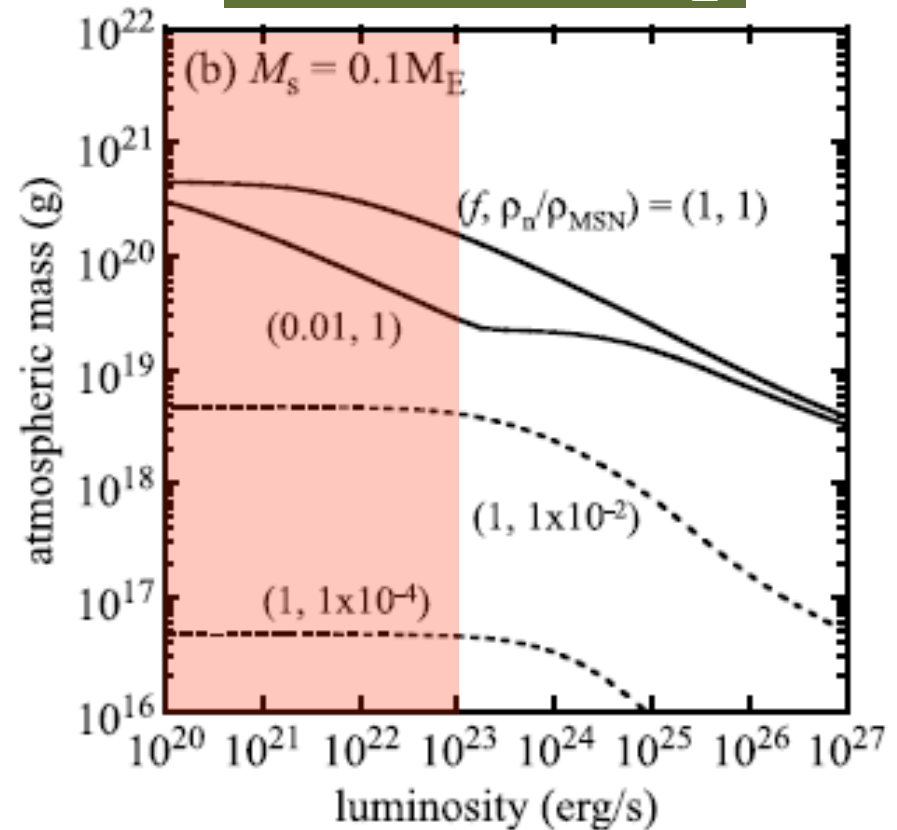
# Captured Atmosphere

Case for  $1 M_E$



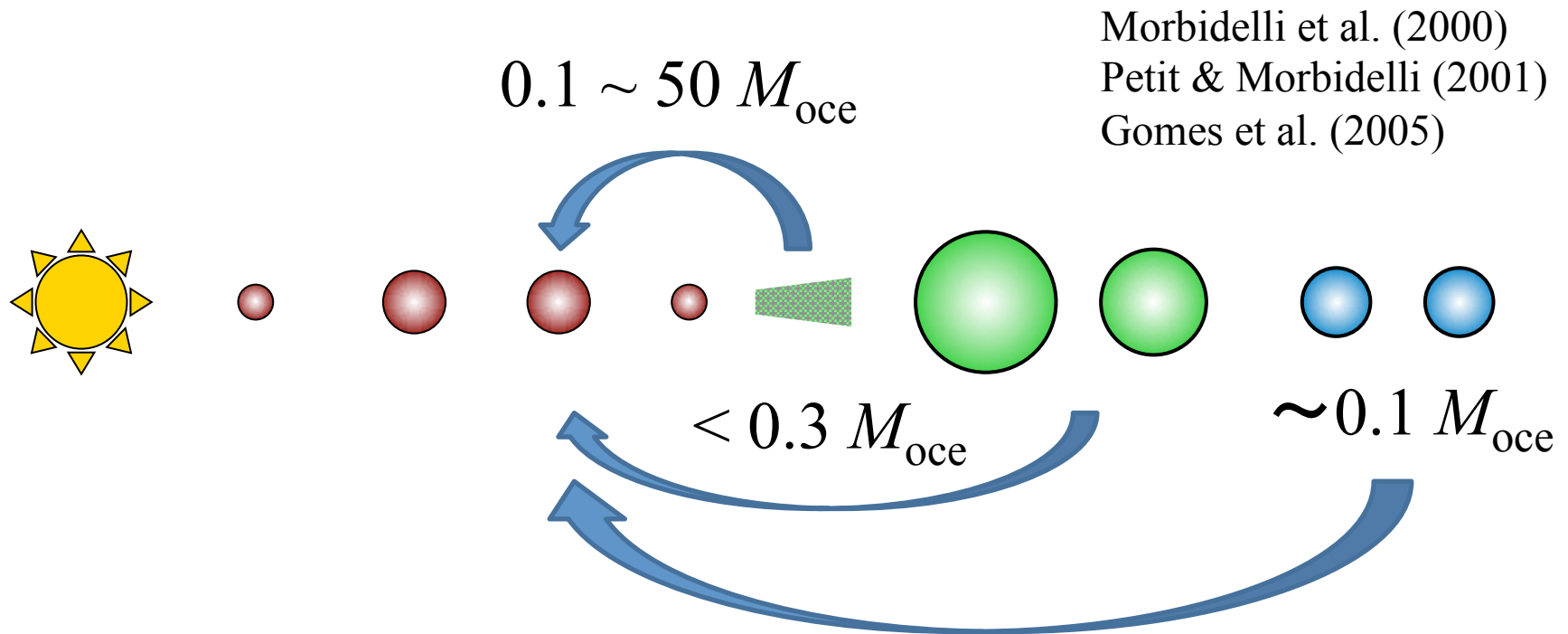
water supply of over  $1 M_{\text{oce}}$

Case for  $0.1 M_E$



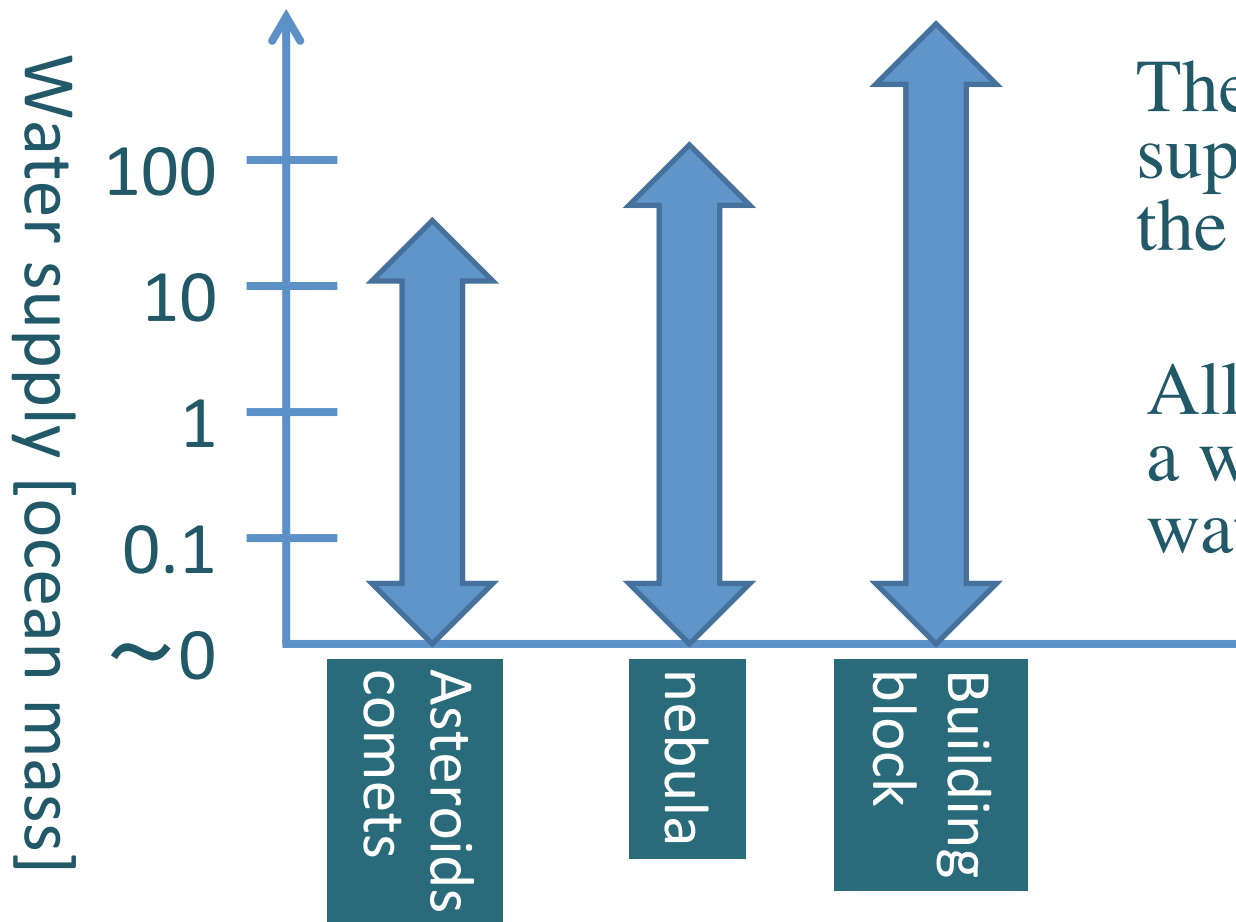
no water supply

# Asteroids and Comets



- ▶ Contribution of comets is low (below  $0.3M_{\text{oce}}$ ).
- ▶ Contribution of asteroids is sometimes huge.

# Water Supply

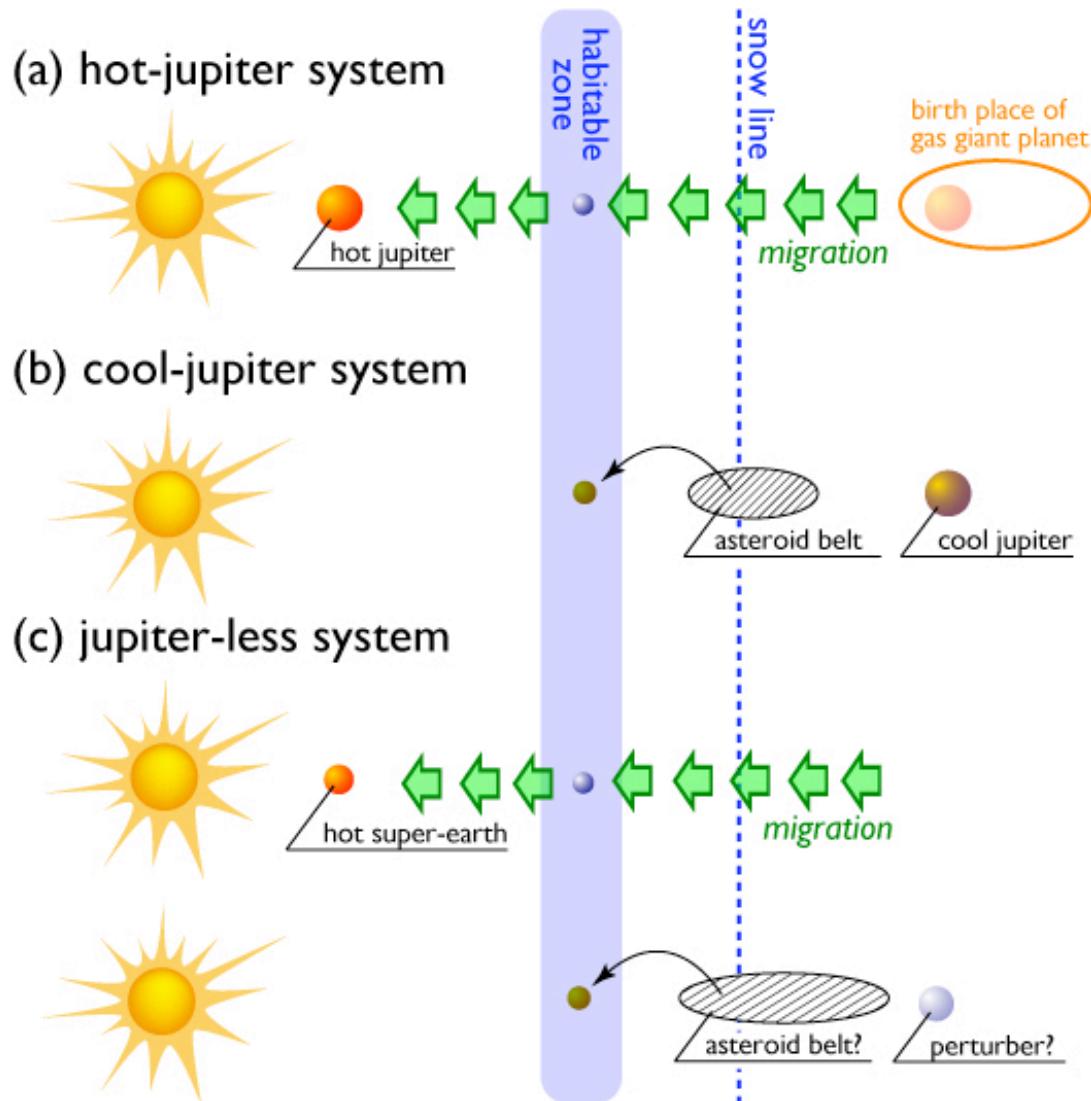


The amount of water supply depends on the water sources.

All water sources have a wide range of water supply.

A wide variety of water amount on extrasolar terrestrial planets

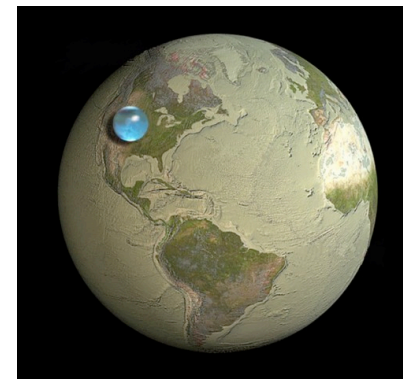
# What controls water amount ?



wide variety in extrasolar planetary systems



Which type is the best for little water supply?



from Maruyama, Ikoma, Genda et al. (2013)

# Summary

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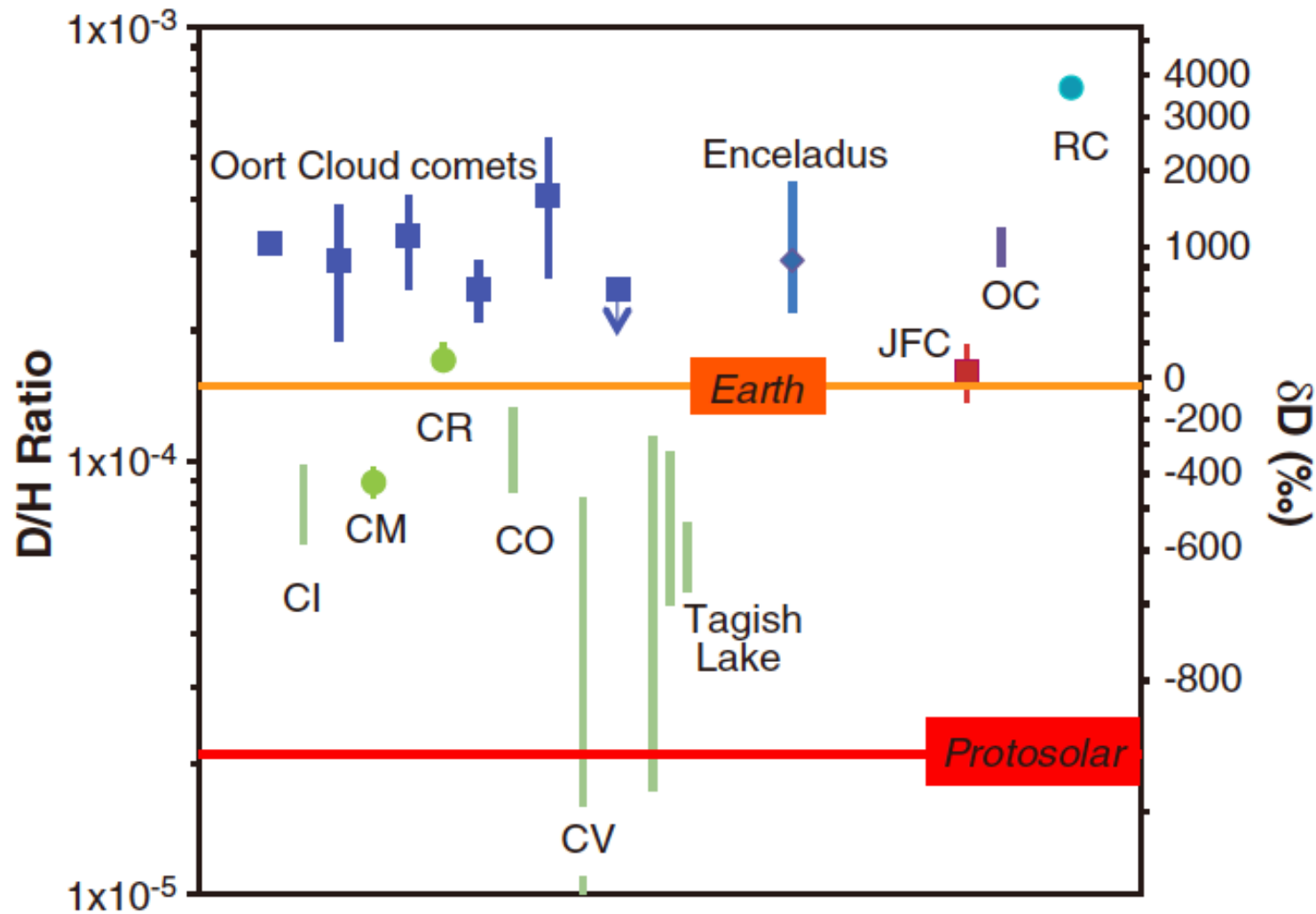
- ▶ A tiny amount of water on the Earth is essential for emergence and evolution of life.
- ▶ Source of water on the Earth is under debate.  
--- Detail investigation of Earth's geology and observation of disks and extrasolar planets will solve this question.
- ▶ The theory of planet formation predicts a wide variety of water amount on extrasolar terrestrial planets.







# D/H in water sources



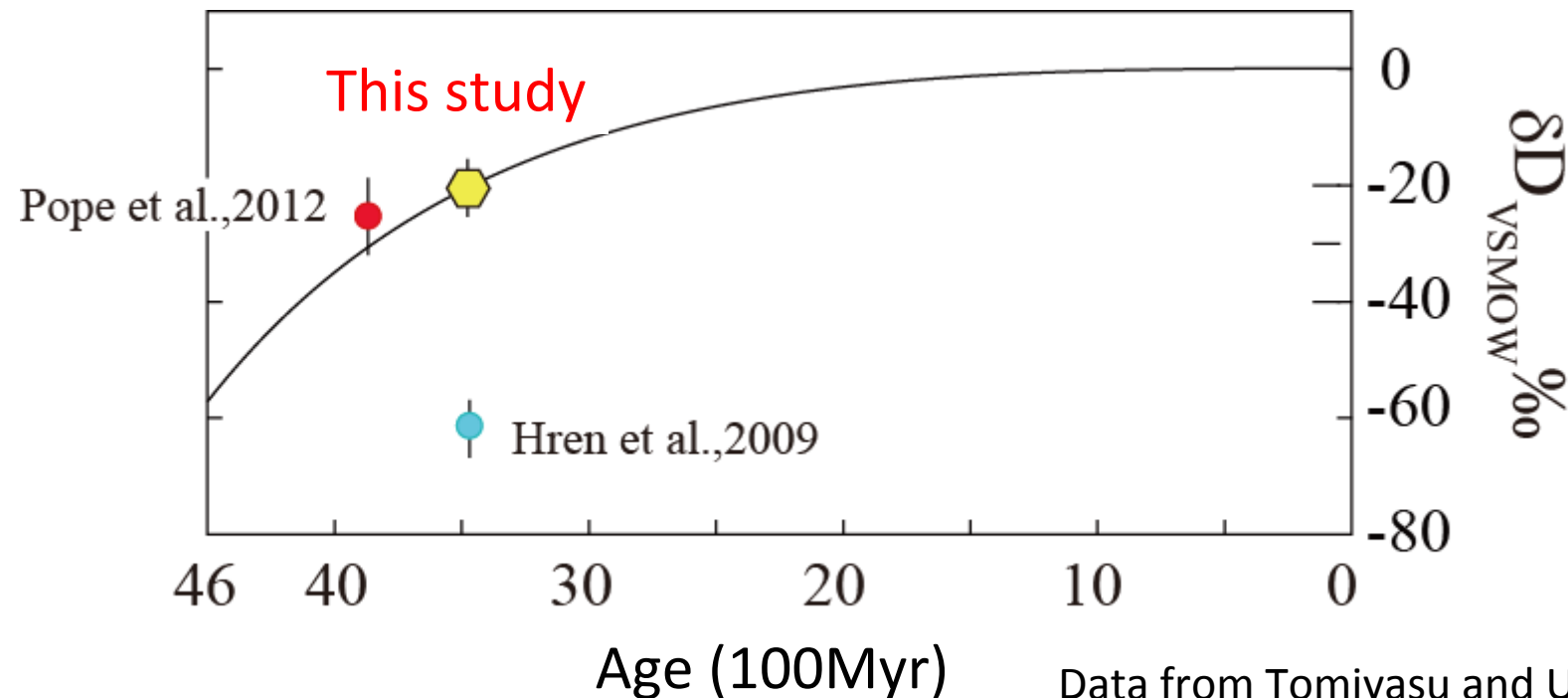
From Alexander et al. (2012)

# Change of ocean D/H

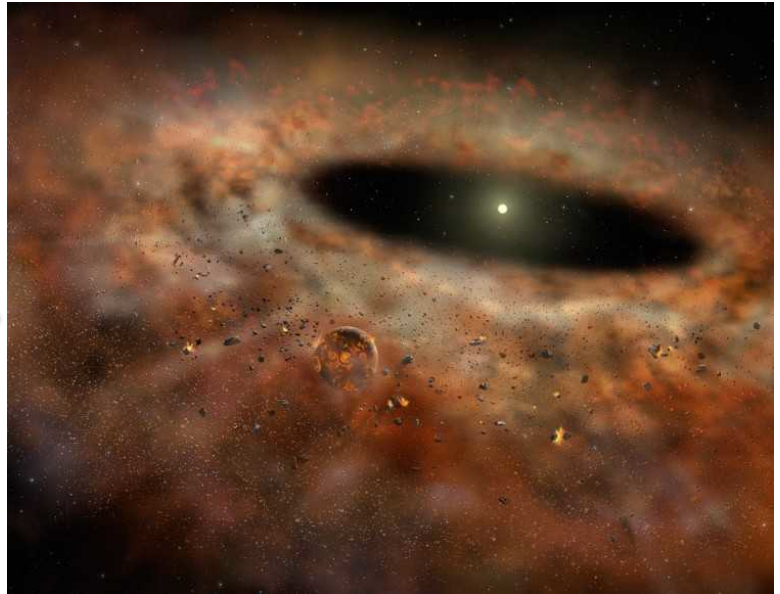
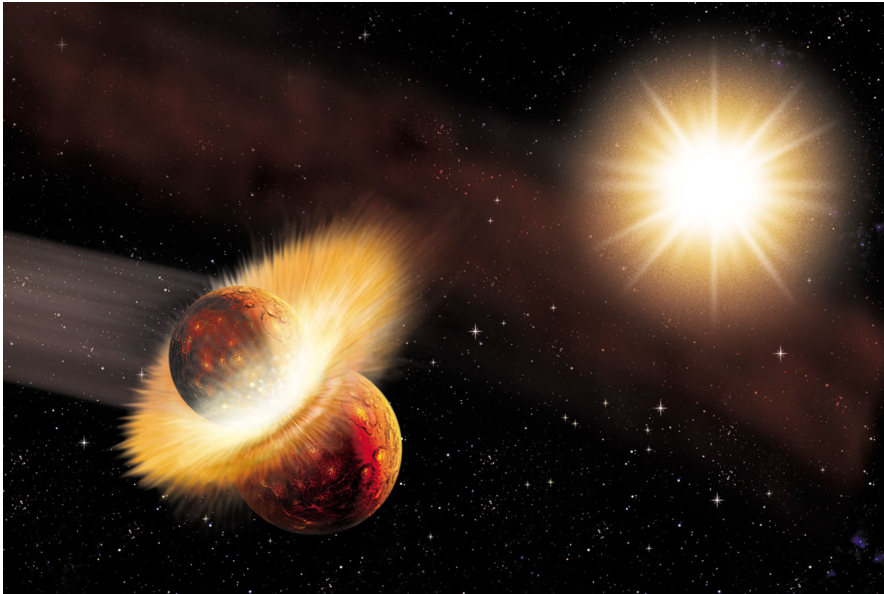
Previous discussion of D/H is based on the assumption that the D/H of ocean has never varied during 4.5 Gyr.

D/H of ocean increases for H<sub>2</sub>-rich proto-atmosphere

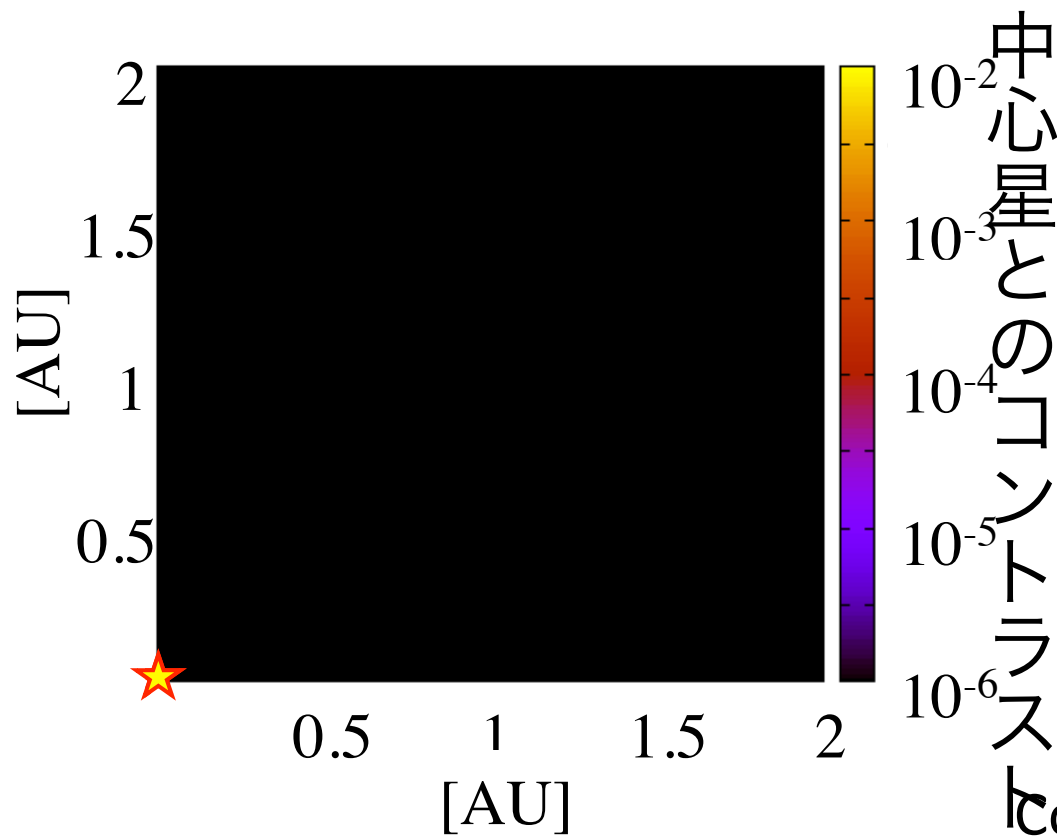
Genda & Ikoma (2008)



Data from Tomiyasu and Ueno in prep.

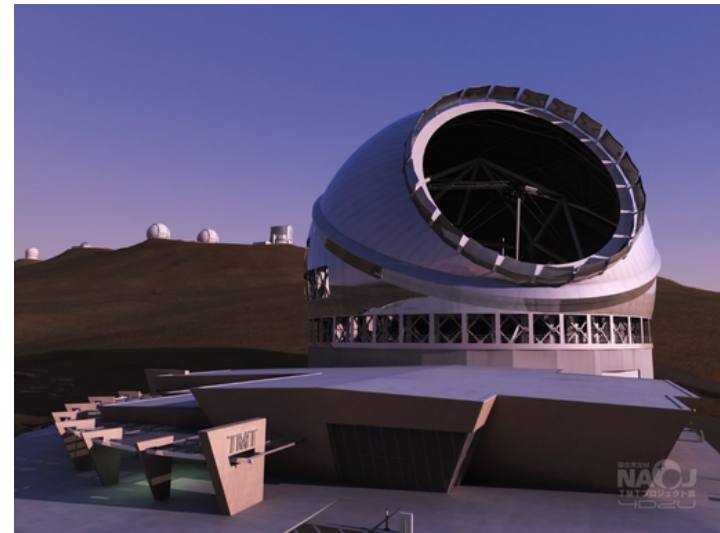


# 次世代望遠鏡による観測



Genda et al. in prep

TMT (2021年～)



Thirty Meter Telescope  
30m望遠鏡

Contrast :  $\sim 10^{-8}$  for SEIT  
(Second Earth Imager for TMT)

# Conditions for Habitable Planet

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Extracting

essential conditions for  
habitable planets  
from Earth's history

- Liquid water
- Amount of water
- Planetary size etc.

Evaluating

these conditions from  
planet formation theory

Universality and  
uniqueness of Earth