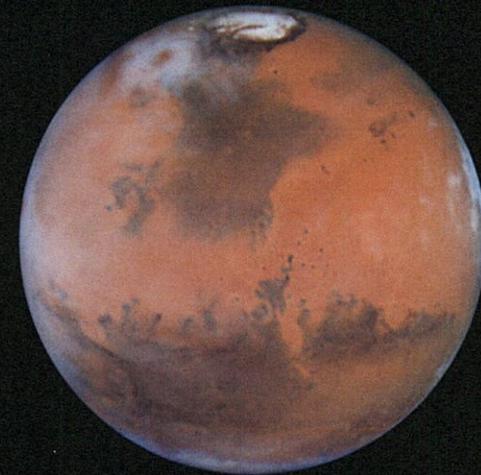


The Faint Young Sun Problem How to warm up early Earth and Mars?



Feng Tian

Center for Earth System Science

Tsinghua University

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Outline

- 1. Archean Earth faint young Sun problem
- 2. Late Noachian/Early Hesperian Mars faint young Sun problem
- 3. Early Noachian Mars Atmosphere Stability
- 4. Atmospheres and Climate of some known exoplanets

Era	Period	Epoch	Duration in millions of years	Millions of years ago
GENOZOIC	Quaternary	Holocene	0.01	0.01
		Pleistocene	1.8	1.8
	Tertiary	Pliocene	3.5	5.3
		Miocene	18.5	23.8
		Oligocene	9.9	33.7
		Eocene	21.1	54.8
		Paleocene	10.2	65
MESOZOIC	Cretaceous		79	144
				206
	Jurassic	62	248	
PALEOZOIC	Triassic		42	290
				323
	Carboniferous	Pennsylvanian	33	354
		Mississippian	31	417
		Devonian	63	443
	Silurian		26	490
				443
			490	
Cambrian		53	543	
			543	
PRECAMBRIAN			543	4600

Ice age (Pleistocene)

Dinosaurs extinction

Warm

First dinosaurs

Ice age

First vascular plants

Ice age

Age of fish

First shelly fossils

EON	ERA	Duration in millions of years	Millions of years ago
PHANEROZOIC	CENOZOIC	65	65
	MESOZOIC	183	248
	PALEOZOIC	295	543
PROTEROZOIC	LATE	357	900
	MIDDLE	700	1600
	EARLY	900	2500
PRECAMBRIAN	LATE		500
			3000
	MIDDLE		400
			3400
EARLY		400	
		3800	
HADEAN		800	4600

First shell fossils
Snowball Earth

Warm

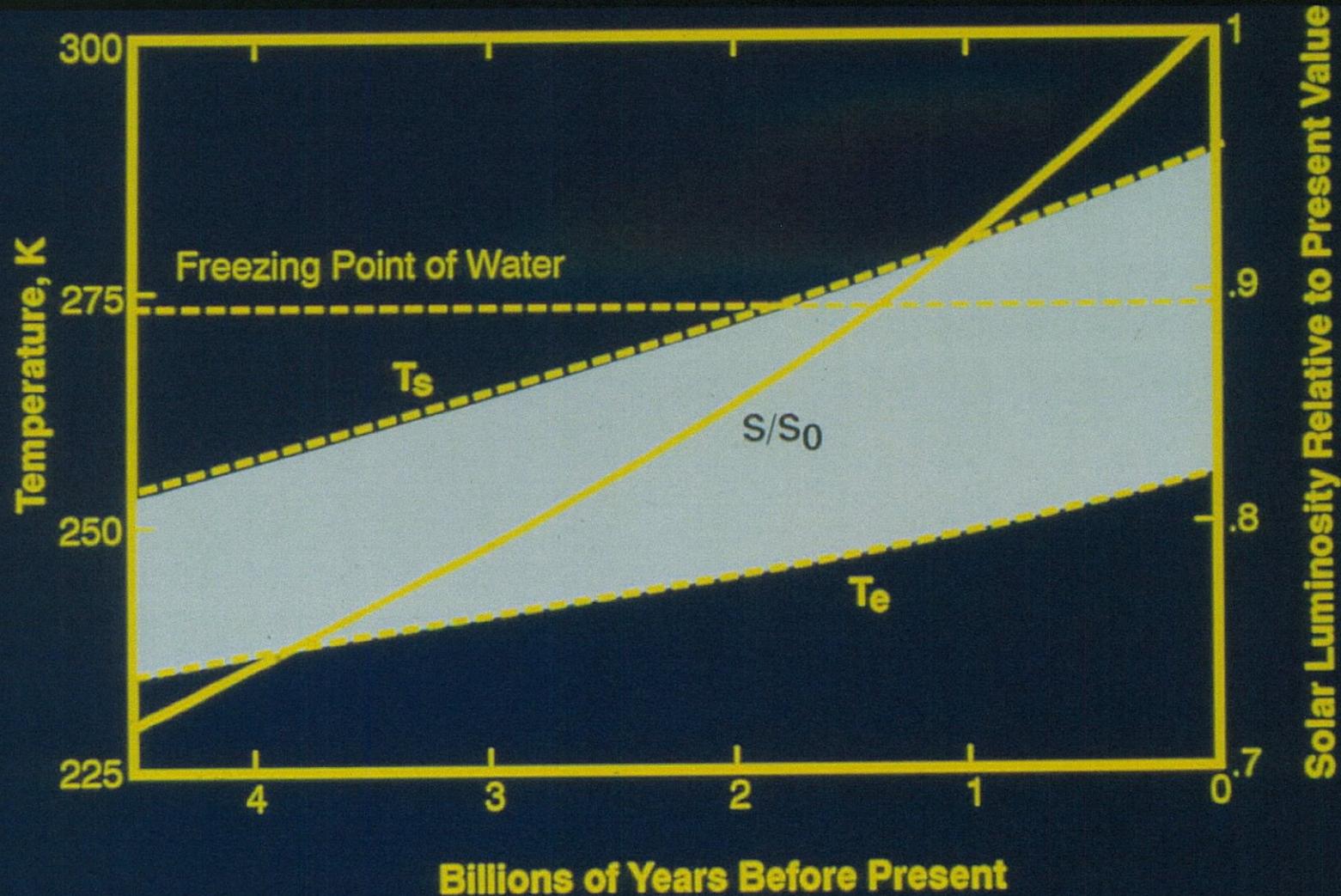
GOE (Great Oxidation Event)

Ice age

Warm (?)
Origin of life

s. based on the principles of

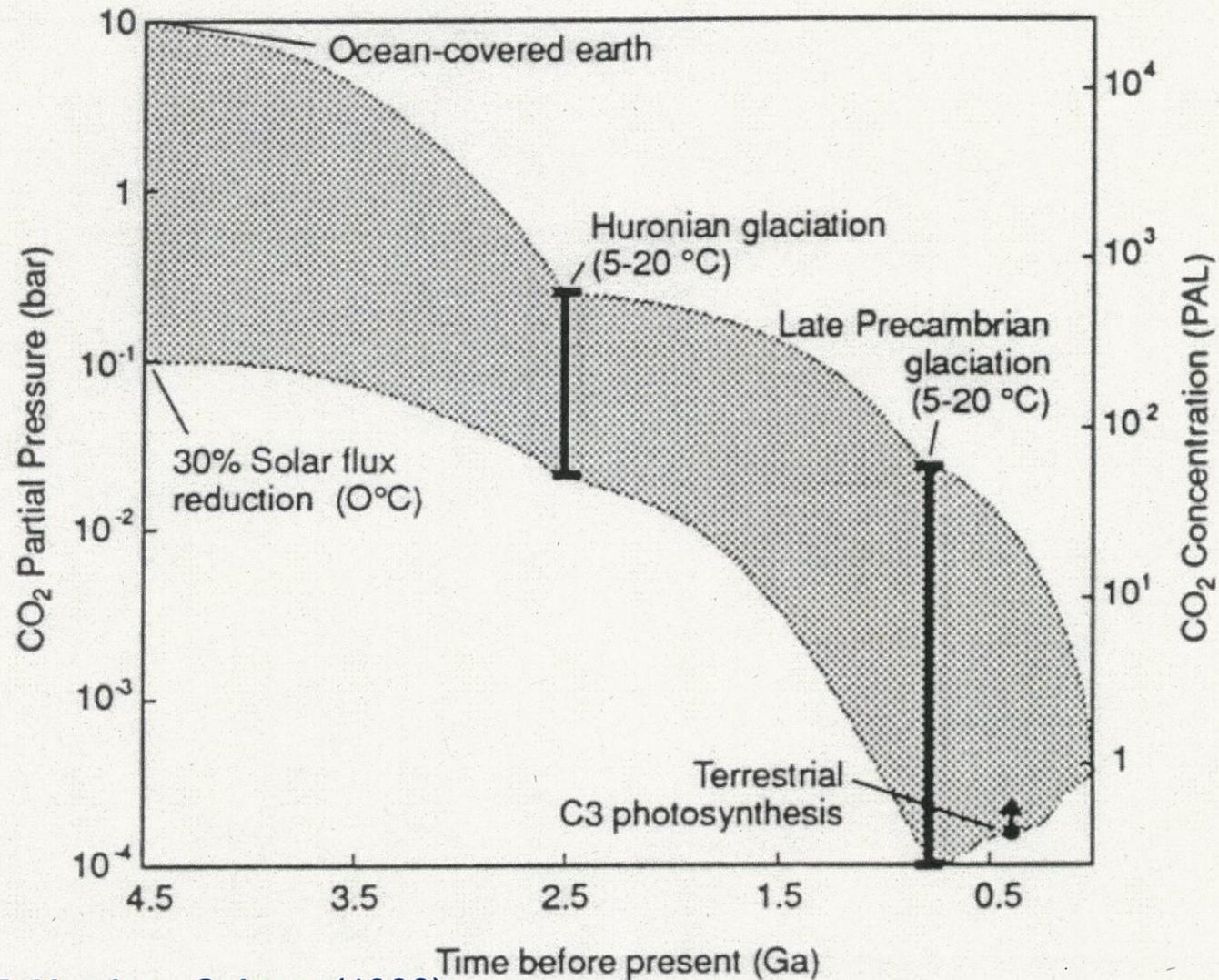
The faint young Sun problem



Kasting et al., *Scientific American* (1988)

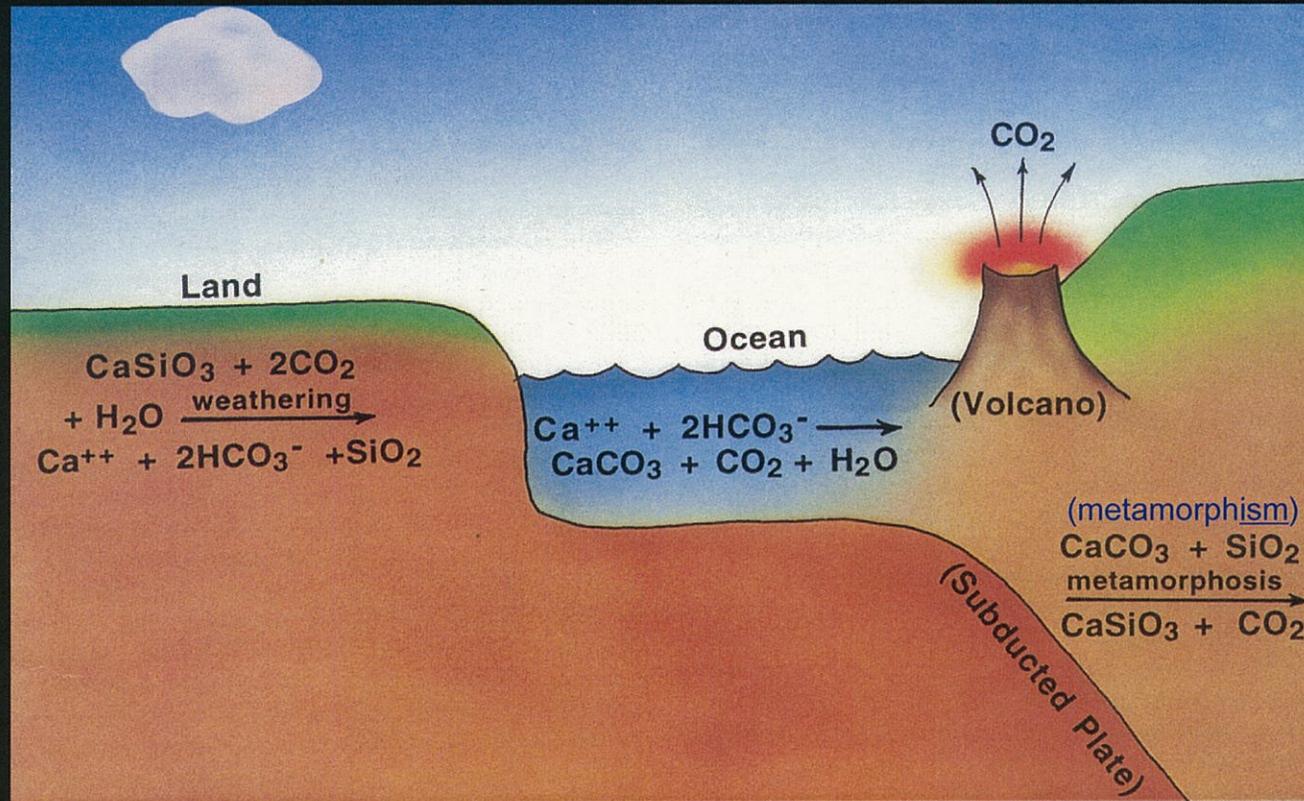
effective temperature: $\sigma T_e^4 = S(1-A)/4$

CO₂ vs. time *if* no other greenhouse gases (besides H₂O)



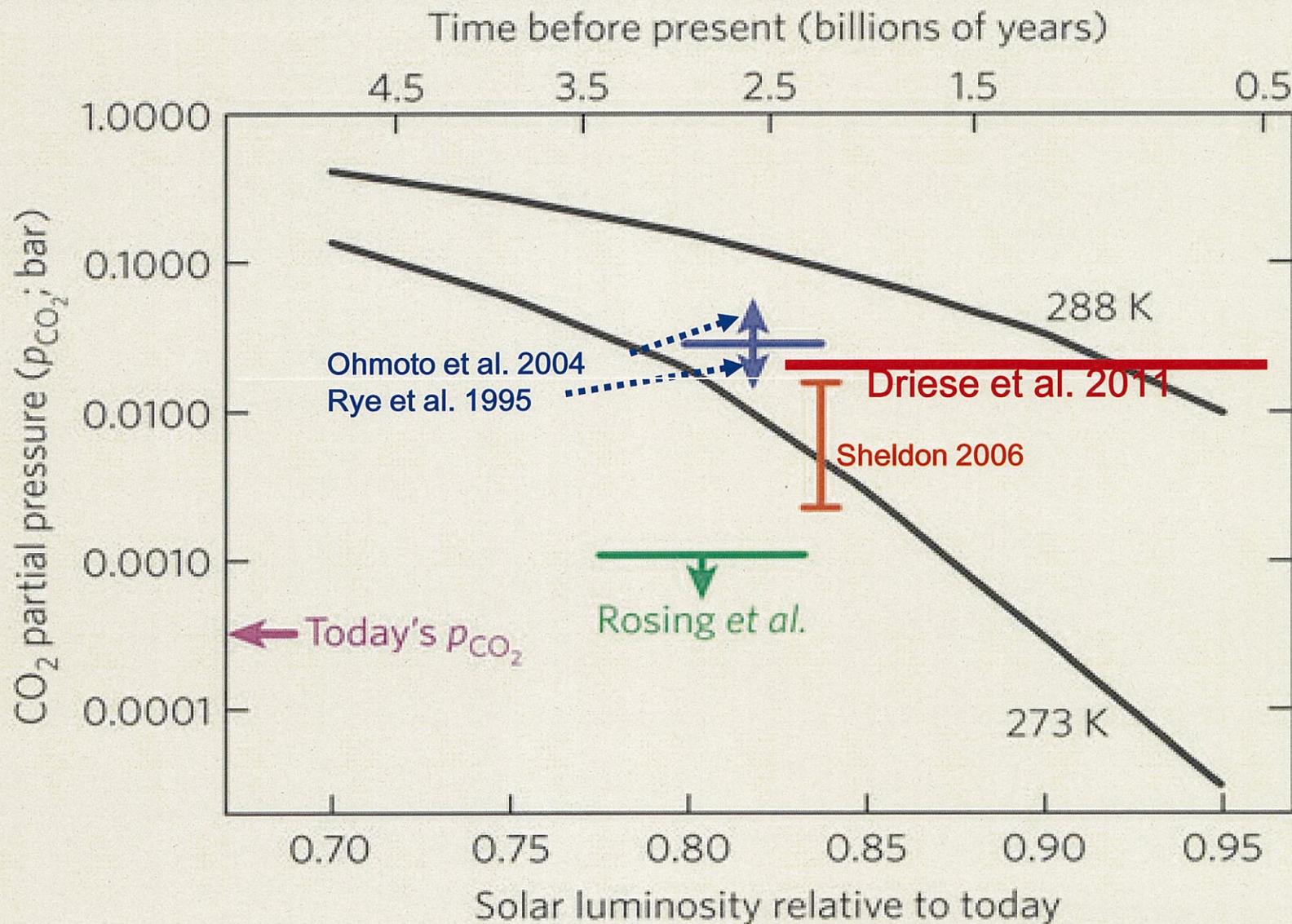
J. F. Kasting, *Science* (1993)

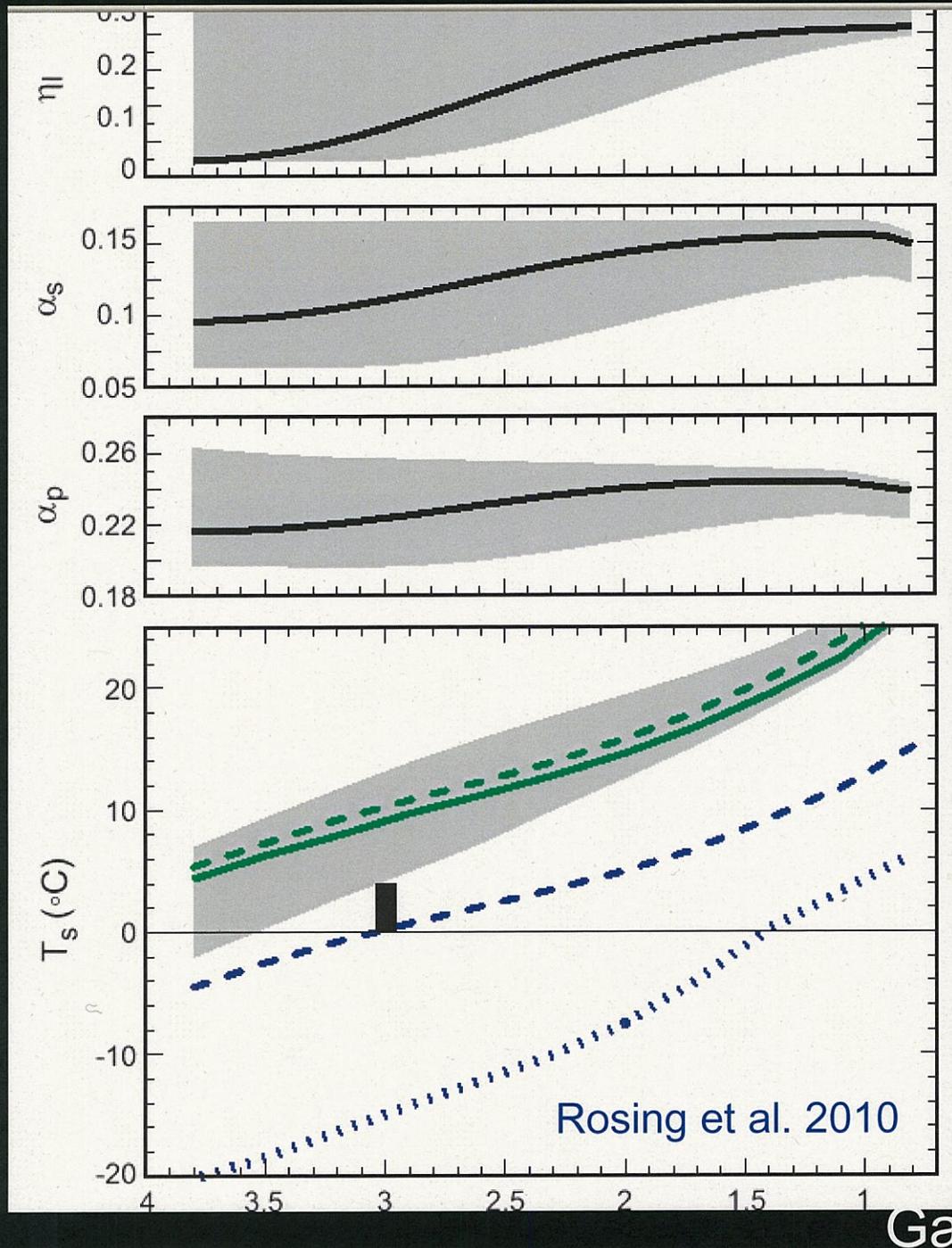
The carbonate-silicate cycle



- Yes! CO_2 could have been higher because of the carbonate-silicate cycle
- This cycle regulates Earth's atmospheric CO_2 level over long time scales and has acted as a planetary thermostat during much of Earth's history, because CO_2 builds up as the climate cools

But the geologists provides limits on atmospheric CO₂ for early Earth

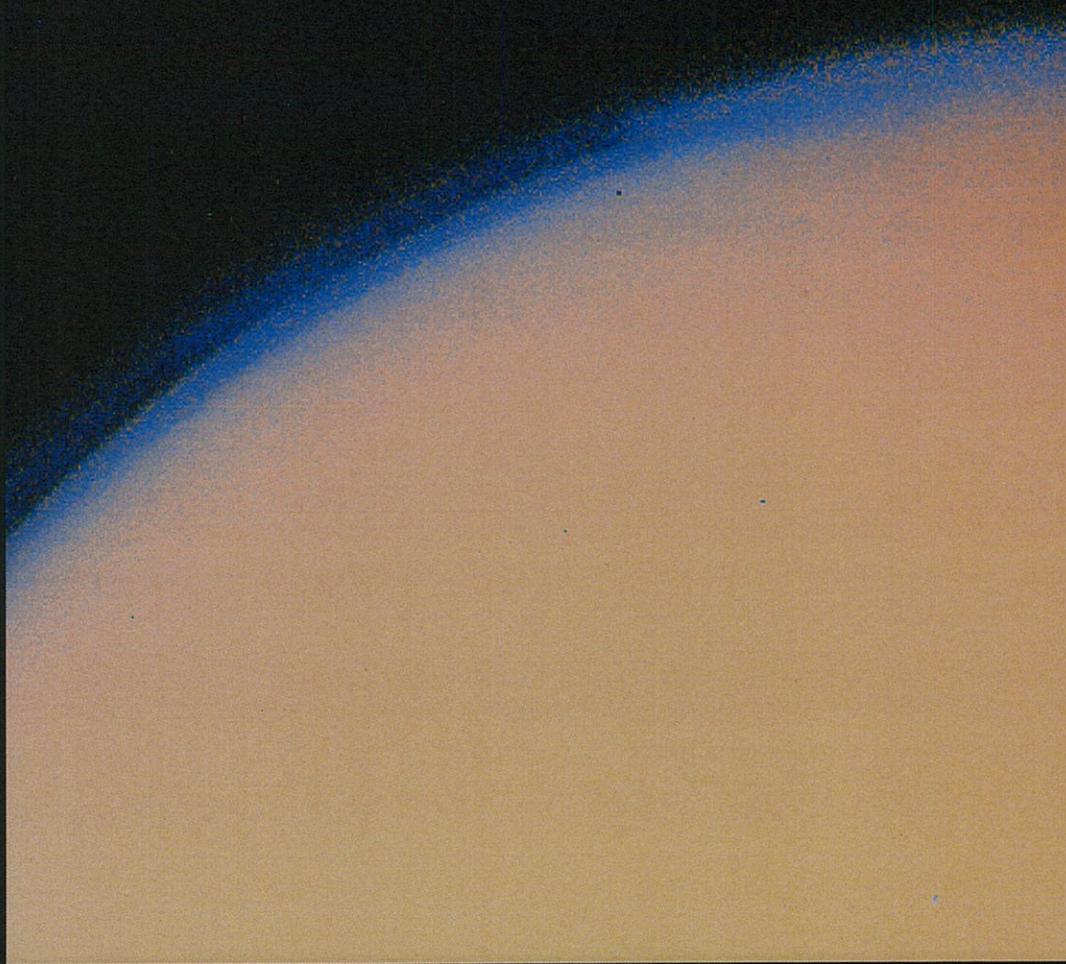




By adjusting cloudiness, surface albedo, and using 900 ppmv of CO_2 and CH_4 , Rosing et al. can bring surface $T \sim 10$ K above freezing temperature.

But $\text{CH}_4/\text{CO}_2 \sim 1$ should produce haze...

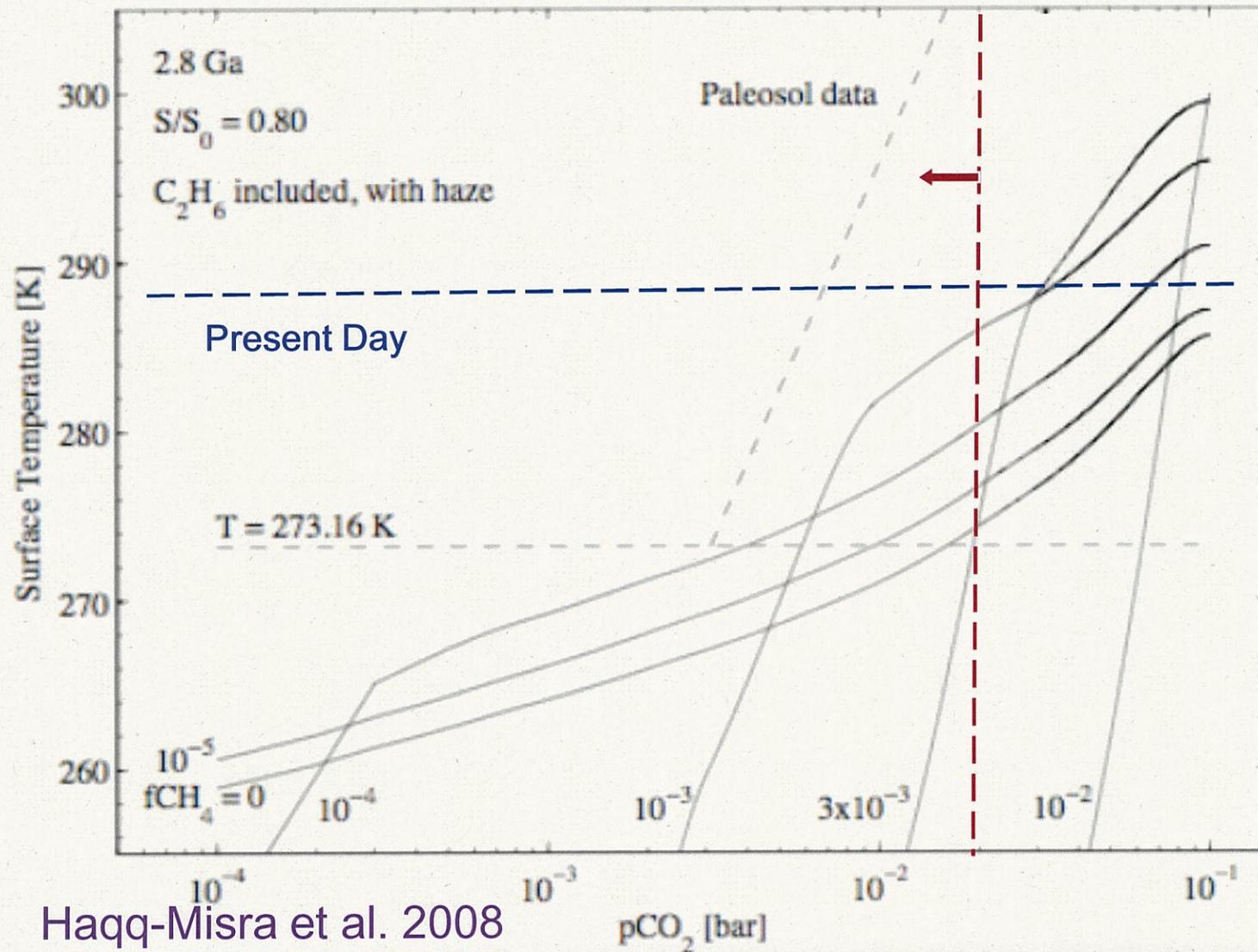
Titan's organic haze layer



- Haze is thought to form from photolysis (and charged particle irradiation) of CH_4
- It can produce an *anti-greenhouse effect*

(Picture from
Voyager 2)

CH₄/CO₂/C₂H₆ greenhouse with haze



Haqq-Misra et al. 2008