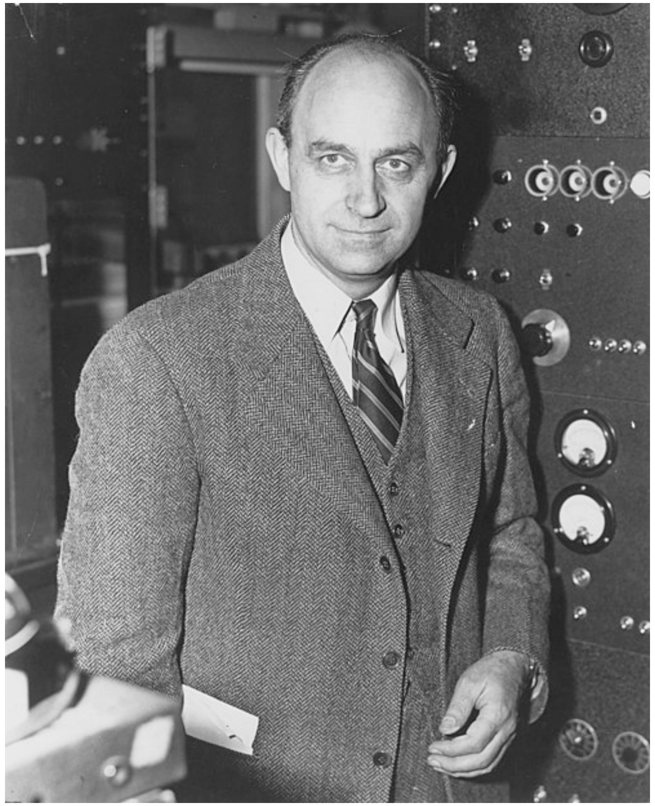
Life in the Universe

Femi’s Paradox (1950, from wikipedia)



Enrico Fermi；1901年9月29日 - 1954年11月28日
恩里科·費米，美籍義大利裔物理學家，美國芝加哥大學物理學教授。 他對量子力學、核物理、粒子物理以及統計力學都做出了傑出貢獻，曼哈頓計劃期間領導製造出世界首個核子反應爐，也是原子彈的設計師和締造者之一，被譽為「原子能之父」

- 1950年，物理学家Enrico Femi 在Los Alamos National Lab 工作。
- 費米悖論源自於他在一次去吃午饭的路上，和同事埃米尔·康佩斯基、爱德华·泰勒、赫伯特·约克有一段普通的交谈。
- 一开始，他们谈论当时流行的UFO报导和阿兰·邓的漫画。漫画把市内垃圾箱的失踪归咎于外星人的掠夺。接着他们谈到未来十年内，人类能够观测到超光速运动的物体的概率大小。泰勒认为是百万分之一，但费米觉得接近于十分之一。然后话题又转向其他方面，
- 直到午餐时费米突然问道“Where are they？”，即“他们在哪里？”（也有说法是“Where is everybody?”，即“其他人在哪里”)。
- 据其中一个在场人士回忆，费米当时用了几个估计的数值做了一系列的快速计算。依靠估算，他当时的结论是地球应该在很早以前被外星人访问过，而且被访问的次数远不止一次。

Femi’s Paradox

宇宙显著的尺度和年龄意味着高等地外文明应该存在。

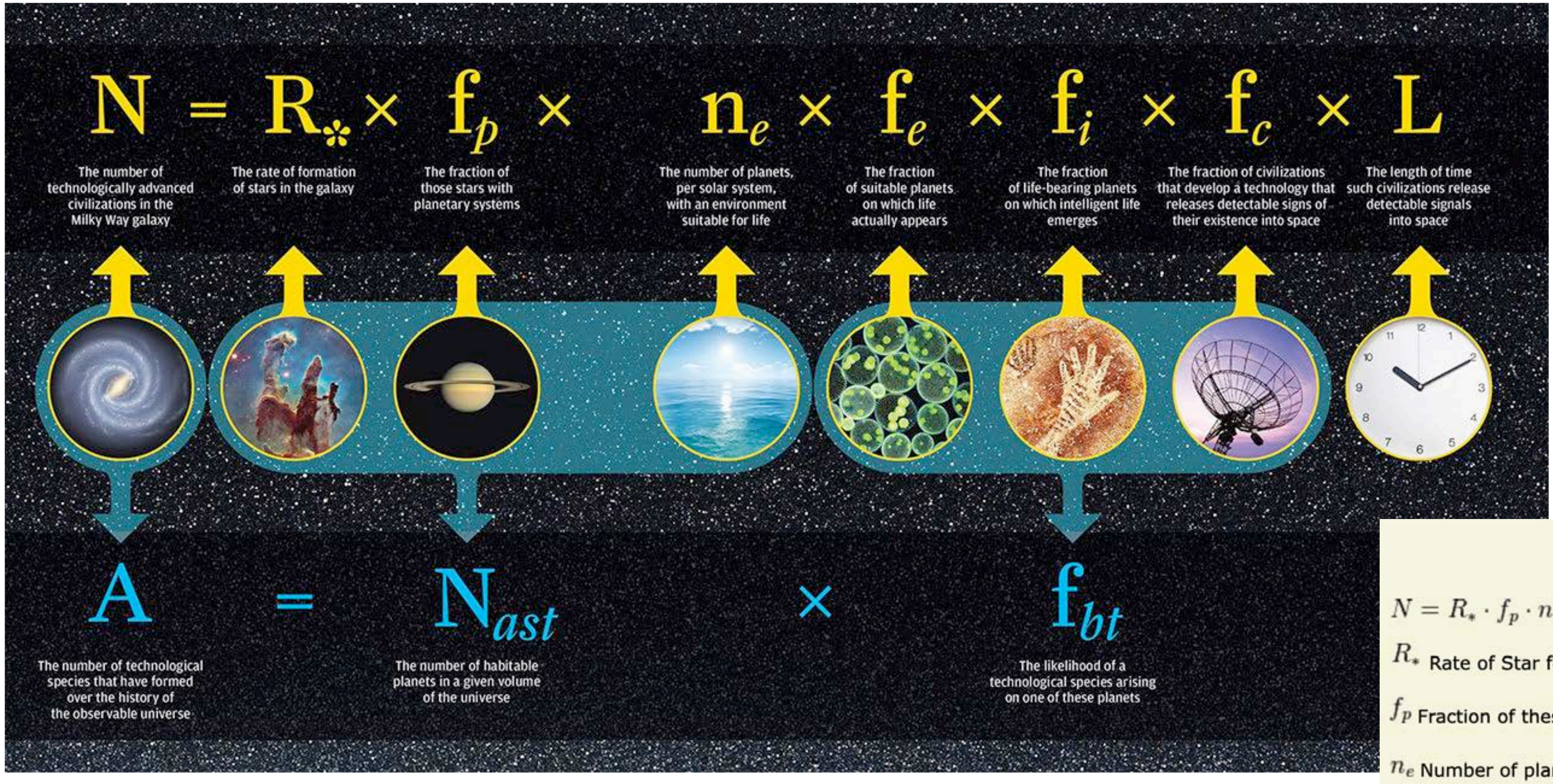
The apparent size and age of the universe suggest that many technologically advanced extraterrestrial civilizations ought to exist.

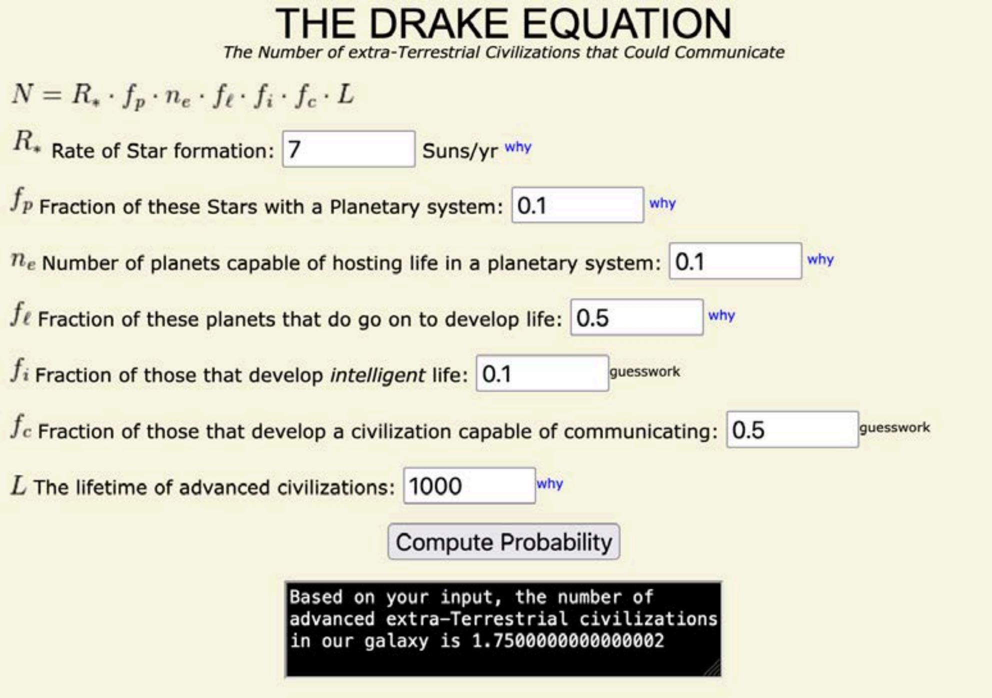
但是，这个假设得不到充分的证据支持。

However, this hypothesis seems inconsistent with the lack of observational evidence to support it.

- 为什么没有地外文明？银河系大约有2500亿（2.5 x 10^{11}）颗恒星，可观测宇宙内则有700垓（7 x 10^{22}）颗。即使智慧生命以很小的概率出现在围绕这些恒星的行星中，那么仅仅在银河系内就应该有相当大数量的文明存在。
- 或者如果地外文明存在的话，为什么我们没有观测到智慧生命的迹象？无线电观测（射电望远镜）、遥感光谱分析均未能提供证据。

德雷克公式 Drake Equation (1961)

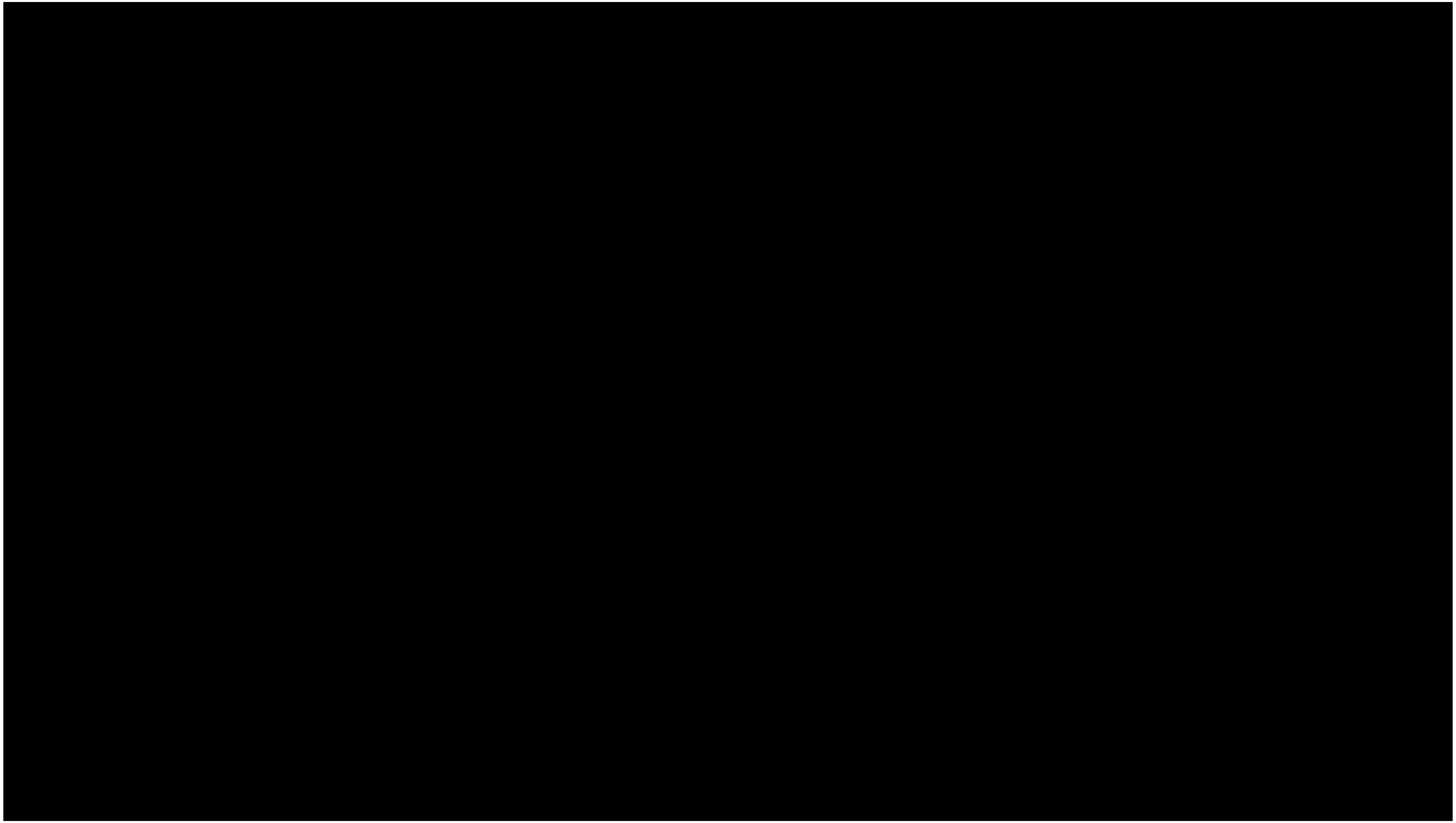




- Drake 参与搜寻地外文明计划（SETI）的第一個技術會議時提出，用于引發科學討論.

http://spacegeek.org/calc/

搜寻地外文明计划 SETI



Michael H. Hart (1975) and afterwards

An Explanation for the Absence of Extraterrestrials on Earth*

MICHAEL H. HART

Are there intelligent beings elsewhere in our Galaxy? This is the question which astronomers are most frequently asked by laymen. The question is not a foolish one; indeed, it is perhaps the most significant of all questions in astronomy. In investigating the problem, we must therefore do our best to include all relevant observational data.

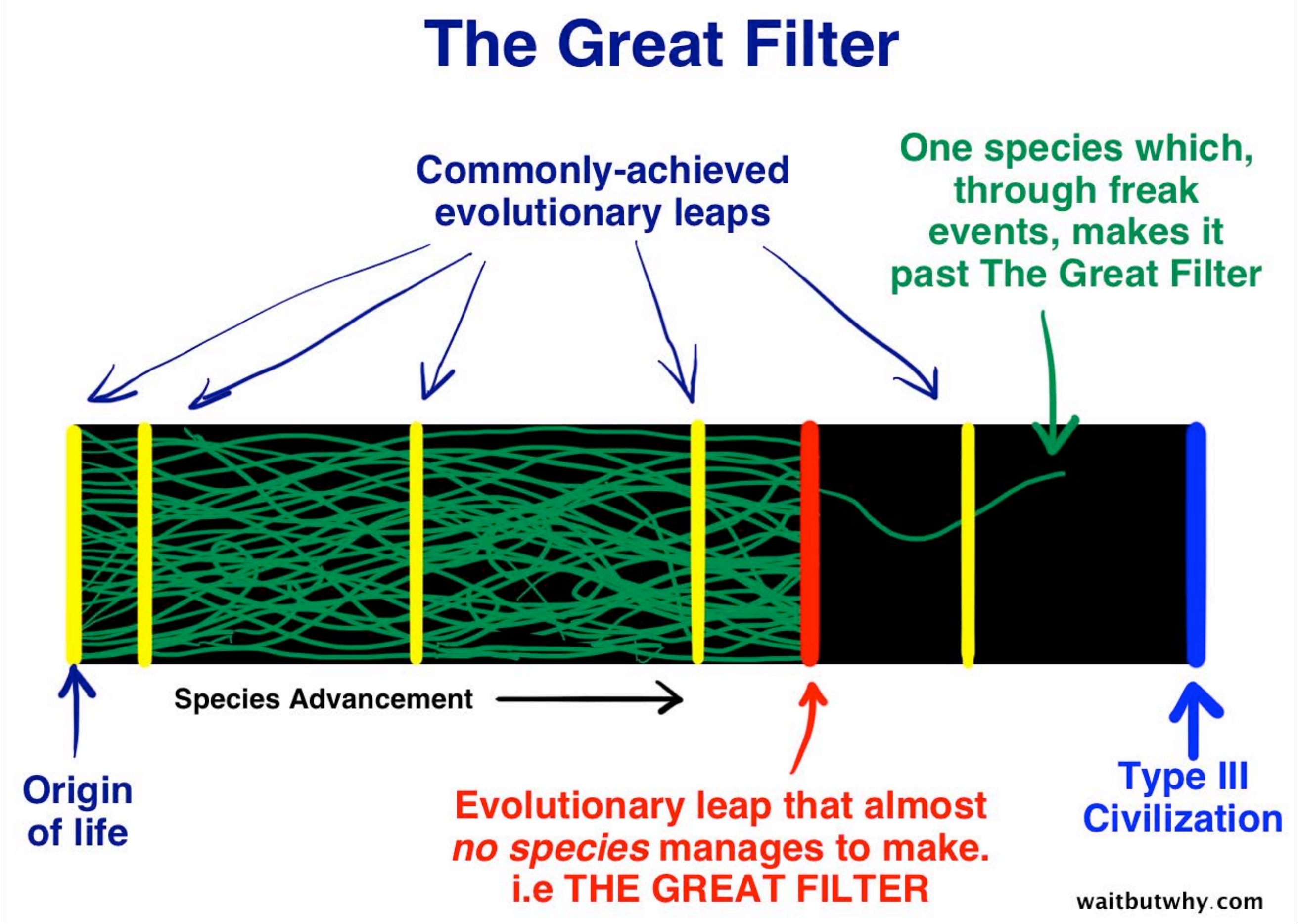
Because of their training, most scientists have a tendency to disregard all information which is not the result of measurements. This is, in most matters, a sensible precaution against the intrusion of metaphysical arguments. In the present matter, however, that policy has caused many of us to disregard a clearly empirical fact of great importance, to wit: *There are no intelligent beings from outer space on Earth now*. (There may have been visitors in the past, but none of them have remained to settle or colonize here.) Since frequent reference will be made to the foregoing piece of data, in what follows we shall refer to it as 'Fact A'.

Fact A, like all facts, requires an explanation. Once this is recognized, an argument is suggested which indicates an answer to our original question. If, the argument goes, there were intelligent beings elsewhere in our Galaxy, then they would eventually have achieved space travel, and would have explored and colonized the Galaxy, as we have explored and colonized the Earth. However, (Fact A), they are not here; therefore they do not exist.

The author believes that the above argument is basically correct; however, in the rather loose form stated above it is clearly incomplete. After all, might there not be some other explanation of Fact A? Indeed, many other explanations of Fact A have been proposed: however, none of them appears to be adequate.

The other proposed explanations of Fact A might be grouped as follows:

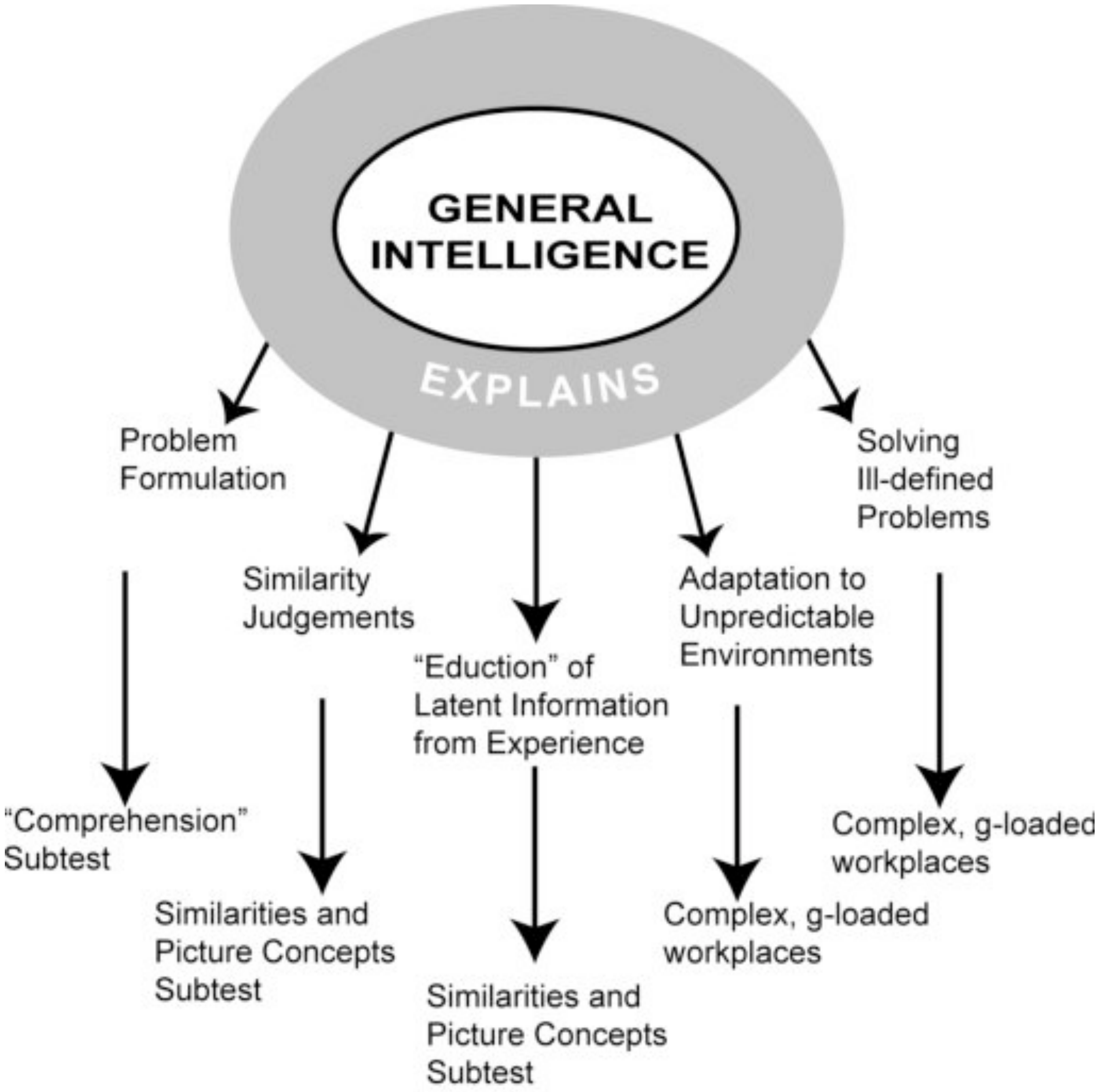
* Reprinted from the *Quarterly Journal of the Royal Astronomical Society*, **16**, 128–35 (1975), with permission of Blackwell Scientific Publications, Ltd.



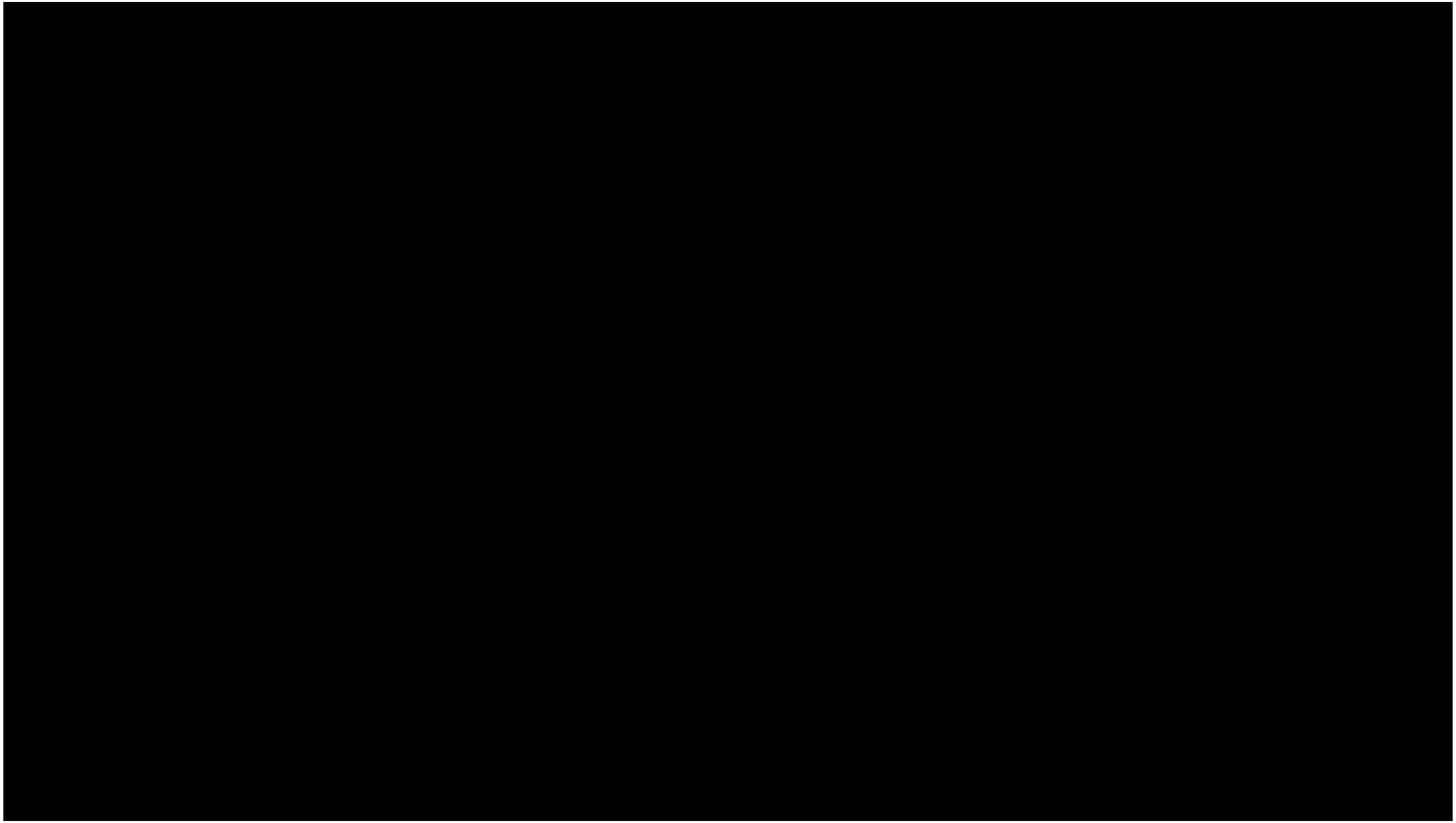
What is life ?

- A system which exchanges matter and energy with the environment AND which reproduces itself and evolves by natural selection
- A system that is capable of making more of itself, by itself, and of evolving (A. Brack)
- An autonomous chemical system that undergoes evolution (NASA)
- Chemical entities that consist of bounded microenvironments in chemical disequilibrium with their environment, capable of maintaining a low entropy state by energy and environment transformation, and capable of information encoding and transfer (Schultz-Makuch & Irwin, 2004)

Intelligent Life



Xenobots (Dec 2021) – is it life?

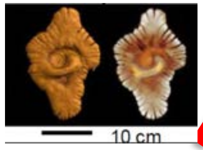


Life in the Universe

- Earth: Origin and Evolution of life
- Mars, Icy Moons, and Elsewhere

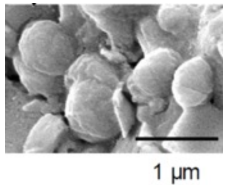
0.1 Ga

Origin of life



0.5 Ga
Diversification
of Life

4.5 Ga
Prebiotic
Soup



3.5 Ga
Oldest Evidence
of Life

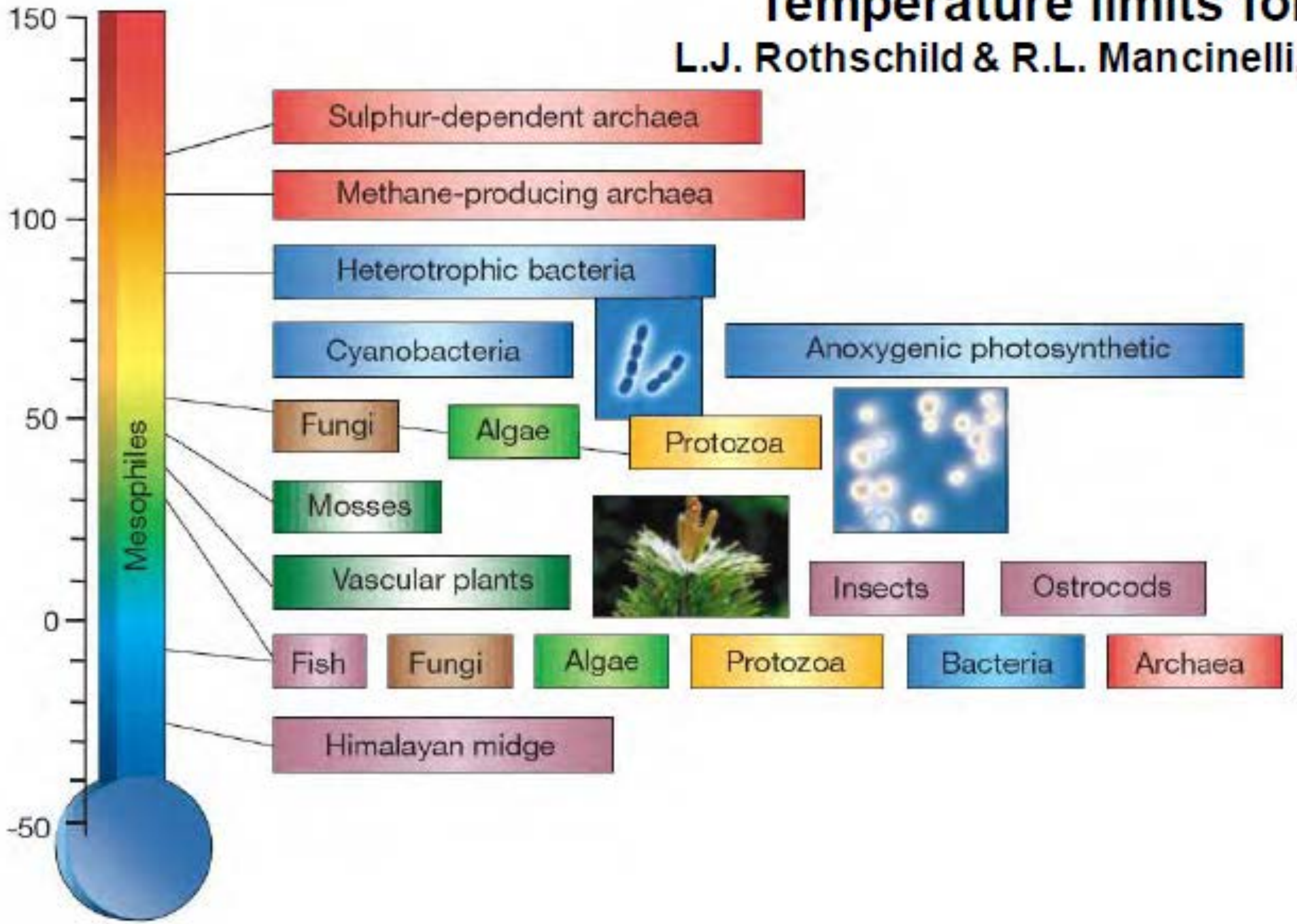
2.5 Ga
Origin of
Eukaryotes?

1.5 Ga
Origin of Multi-
Cellular Life?

Image: SETI
Slide: F. Tian

Temperature limits for life

L.J. Rothschild & R.L. Mancinelli, 2001

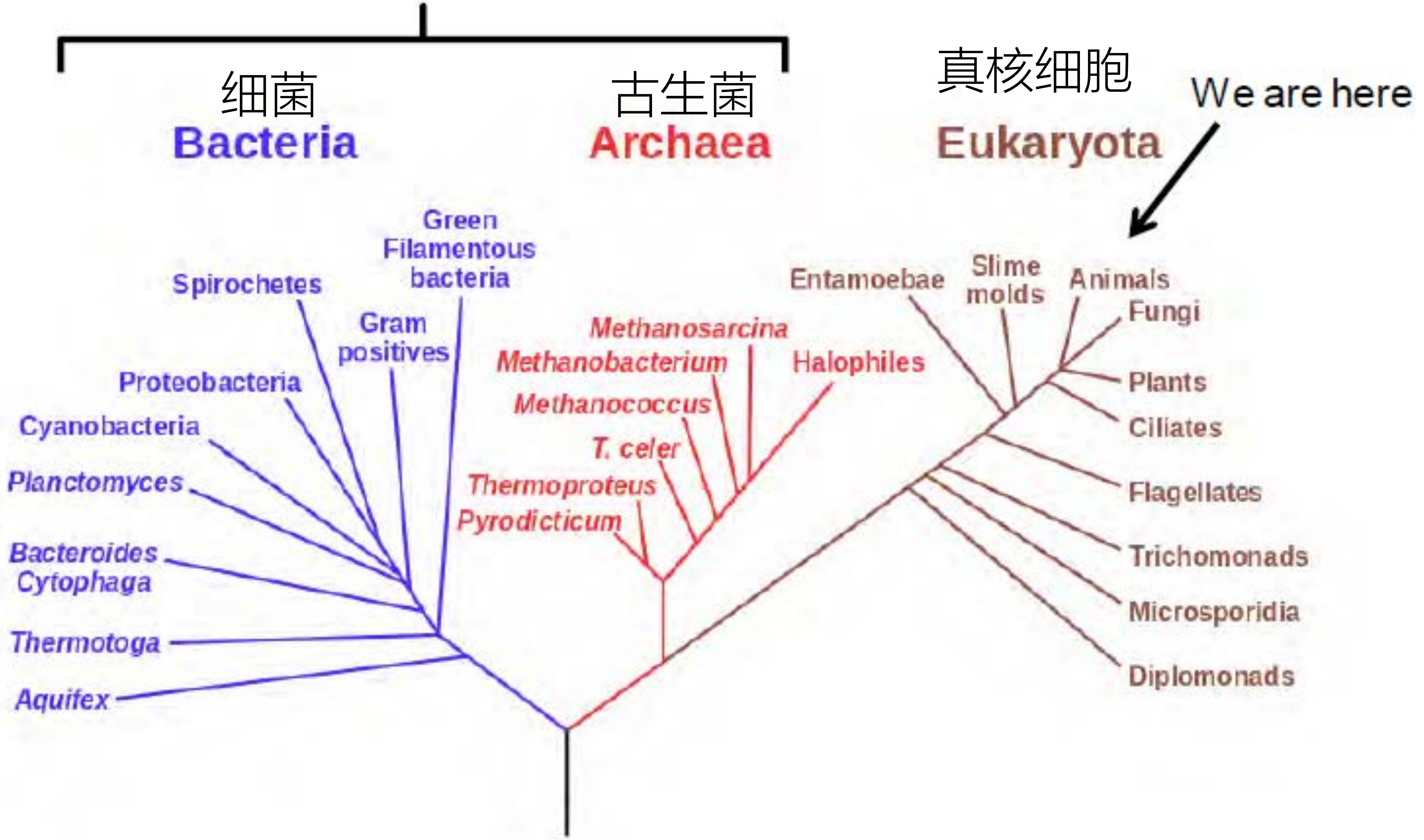


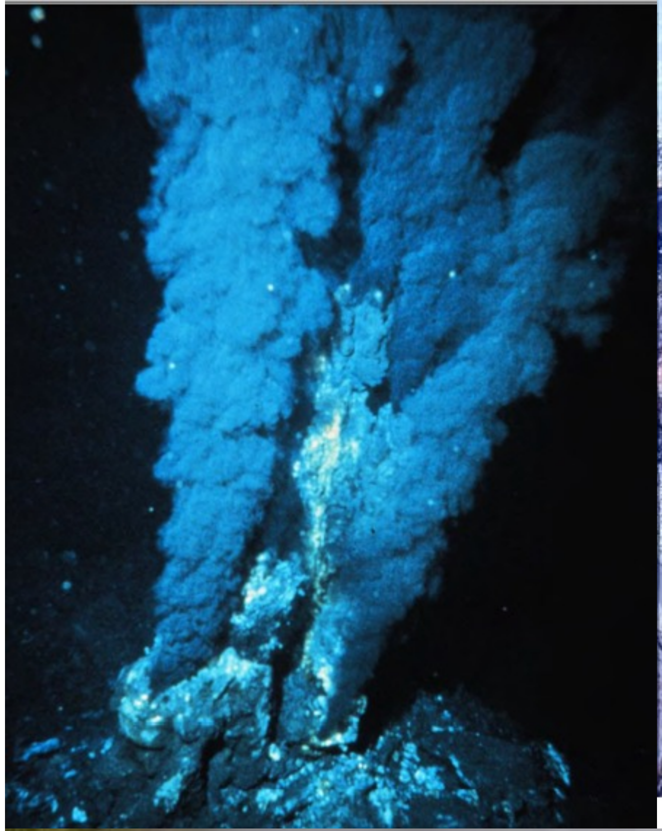
The highest and lowest temperature for each major taxon is given. Archaea are in red, bacteria in blue, algae in light green, fungi in brown, protozoa in yellow, plants in dark green and animals in purple.

The tree of life

Eukaryotes: single/multiple cells
Membrane-bound DNA

原核生物
Prokaryotes: single cells
Free DNA





Extreme Life on our own planet

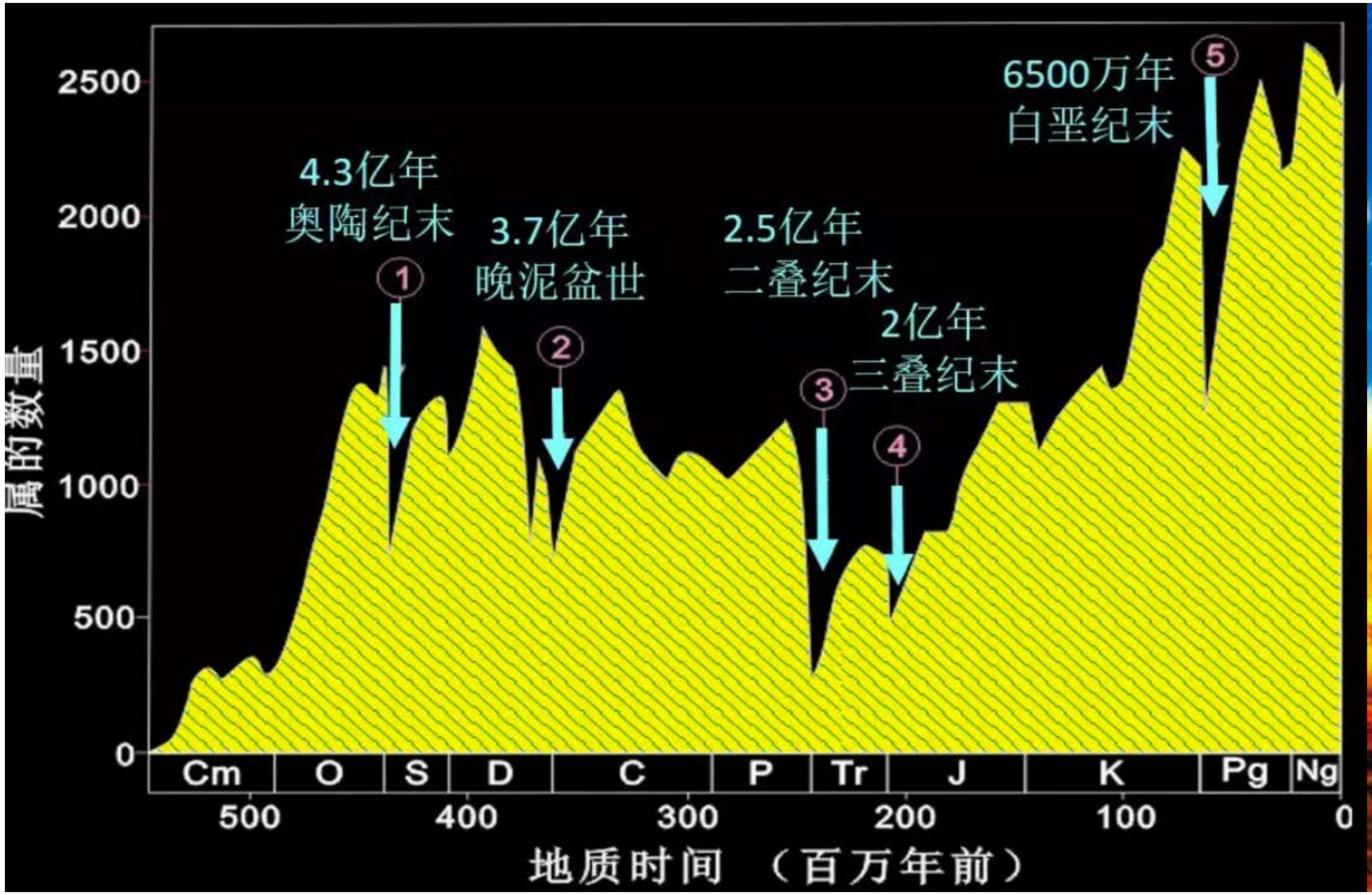
Classfications of Extremphiles

- **Psychrophile or psychrotolerant 嗜冷生物: live in cold environment (deep sea, ice, Tmax=-126 ^{o}C)**
- **Thermophile 嗜热生物: live in hot environment with an optimum growth temperature of 60 ^{o}C**
- **Hyperthermophile 超级嗜热生物: live in very hot environment with optimum growth temperature 90~100 ^{o}C. Recorded max growth temperature 121 ^{o}C. Max survival T~150 ^{o}C?**
- **Acidophile 嗜酸生物: live in very acidic environments (found in pH<1, optimum pH for growth ~3)**
- **Alcaliphile 嗜碱生物: live in alkaline environment (pH optimum for growth >9)**
- **Halophile 嗜盐生物: live in very saline environments (high NaCl)**
- **Barophile or Piezophile 嗜压生物: live in high pressure environment (deep sea, sediments, Mariana Trench -11 km)**
- **Metalotolerant 耐金属生物: live in high metal concentrations (Cu, Cd, As, Zn)**
- **Radioresistant 耐辐射生物: live in high doses of radiation (Deinococcus radiodurans can tolerate >5000 Gy (Gray) while 5 Gy will kill a huma!)**
- **Xerophile 耐旱生物: live in dessicated environment**

地质年代表

宙	代	纪	同位素年龄（百万年）		生物进化阶段	
			距今年龄	持续时间	植物	动物
显生宙	新生代（Kz）	第四纪（Q）	2.5	2.5		人类出现
		第三纪（R）	67	64.5		哺乳动物
	中生代（Mz）	白垩纪（K）	137	70	被子植物	鸟类
		侏罗纪（J）	195	58		
		三叠纪（T）	230	35		
	古生代（Pz）	二叠纪（P）	285	55	裸子植物	爬行动物
		石炭纪（C）	350	65	蕨类植物	
		泥盆纪（D）	400	50		两栖动物
		志留纪（S）	440	40		鱼类
		奥陶纪（O）	500	60	裸蕨植物	
		寒武纪	570	70		无脊椎动物
隐生宙	元古代（Pt）	震旦纪（Z）	2400	1830		
	太古代（Ar）		4500	2100	菌藻类	

五次生物大灭绝事件 Mass Extinction



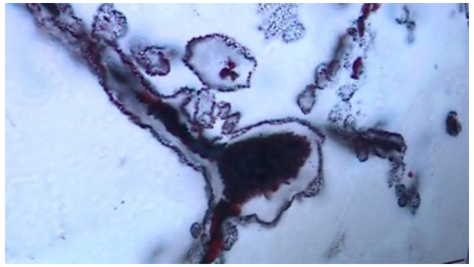
Sepkoski, 1984

Artwork by Peter Arnold, Inc./Alamy

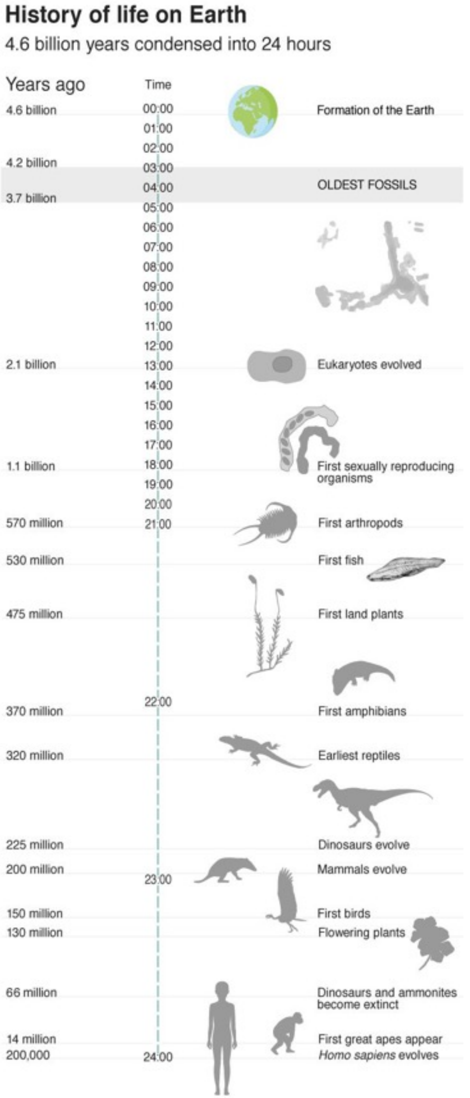
Environment Comparison

	3.5Ga	Now
T	>50 degree C?	15 degree C
pH	~5?	7.2-7.4
Atm Composition	<10^{-5} PAL O2	21% O2
Radiation (UV)	54 W/m2	1 W/m2
Radiation (Total)	1100 W/m2	1360 W/m2
Volcanism	Much	little
Impact	Much (late heavy bombardment 4~3.8 Ga)	little

Based on Westall and Southam 2006; Cockell and Raven 2004



4.28 Ga?



HOW DID LIFE BEGIN?

Panspermia

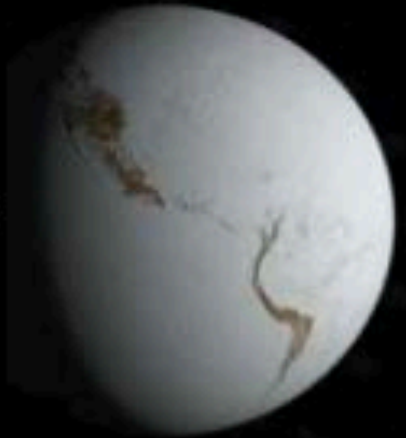
- ✓ Life could have come from outer space in a comet or meteorite.

Community Clay

- ✓ Clay may have provided the foundation for first organic compounds.
- ✓ Mineral crystals in clay could have arranged organic compounds into organized patterns.

Ice Earth

- ✓ 3 billion years ago ice might have covered the oceans.
- ✓ Protected from UV light, organic compounds may have formed and reacted with one another.



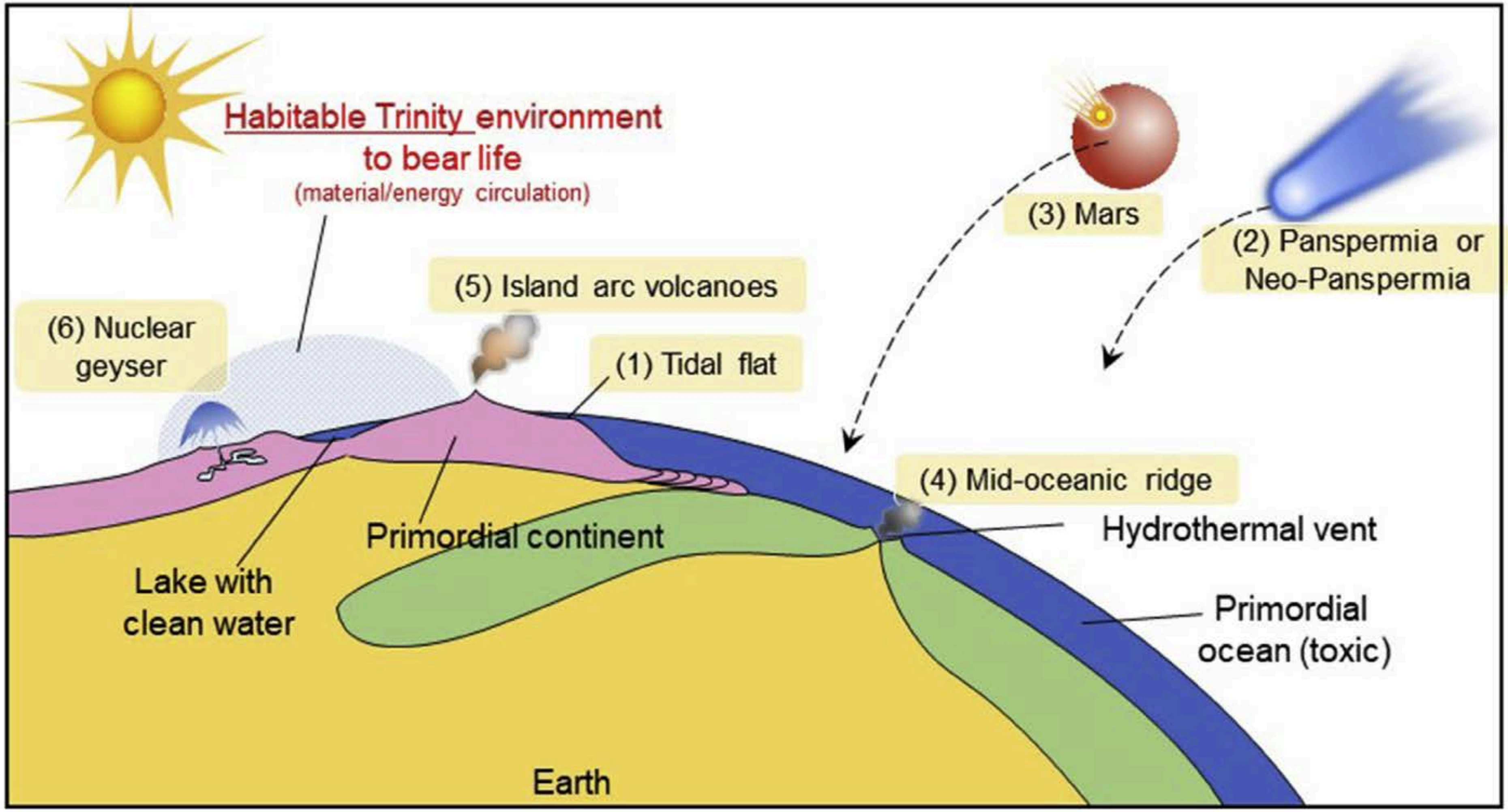
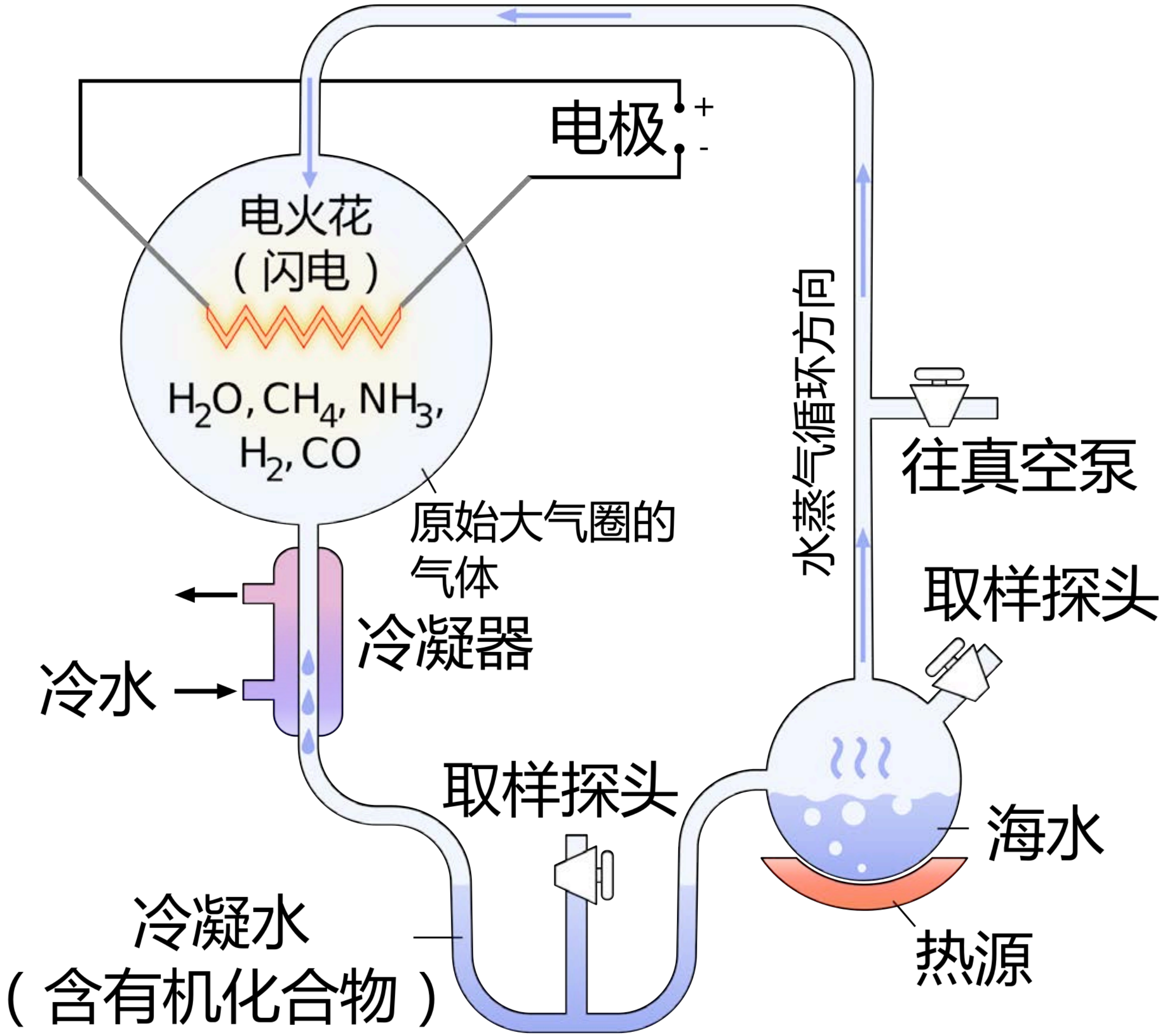


Figure 1. Proposed sites for the birthplace of life on Earth. (1) Classic concepts, including Darwin's warm little pond (Darwin, 1859) with a primordial soup, or a shallow marine tidal flat (Oparin, 1957), (2) Panspermia (Arrhenius, 1908) or Neo-Panspermia (Sutherland, 2016), (3) Mars (Kirschvink and Weiss, 2003), (4) a mid-oceanic ridge hydrothermal system (Corliss et al., 1981) or in an alkaline hydrothermal vent (Kelly et al., 2001), (5) a hydrothermal environment with island arc volcanoes (Mulkidjanian et al., 2012), and (6) a nuclear geyser system on the Hadean primordial continent (Ebisuzaki and Maruyama, 2017).

Maruyama et al., 2019

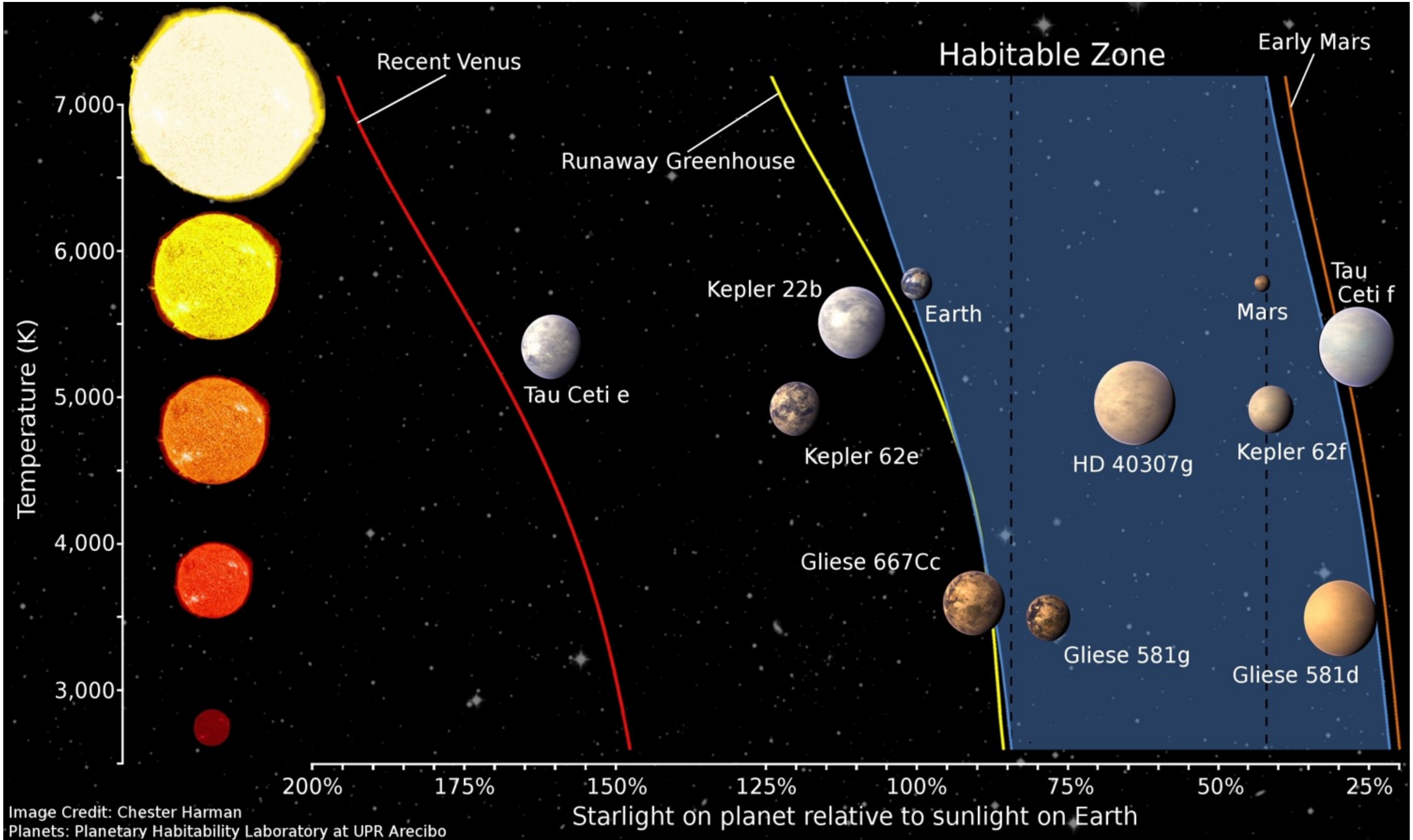
内生学说：Miller-Urey Experiment

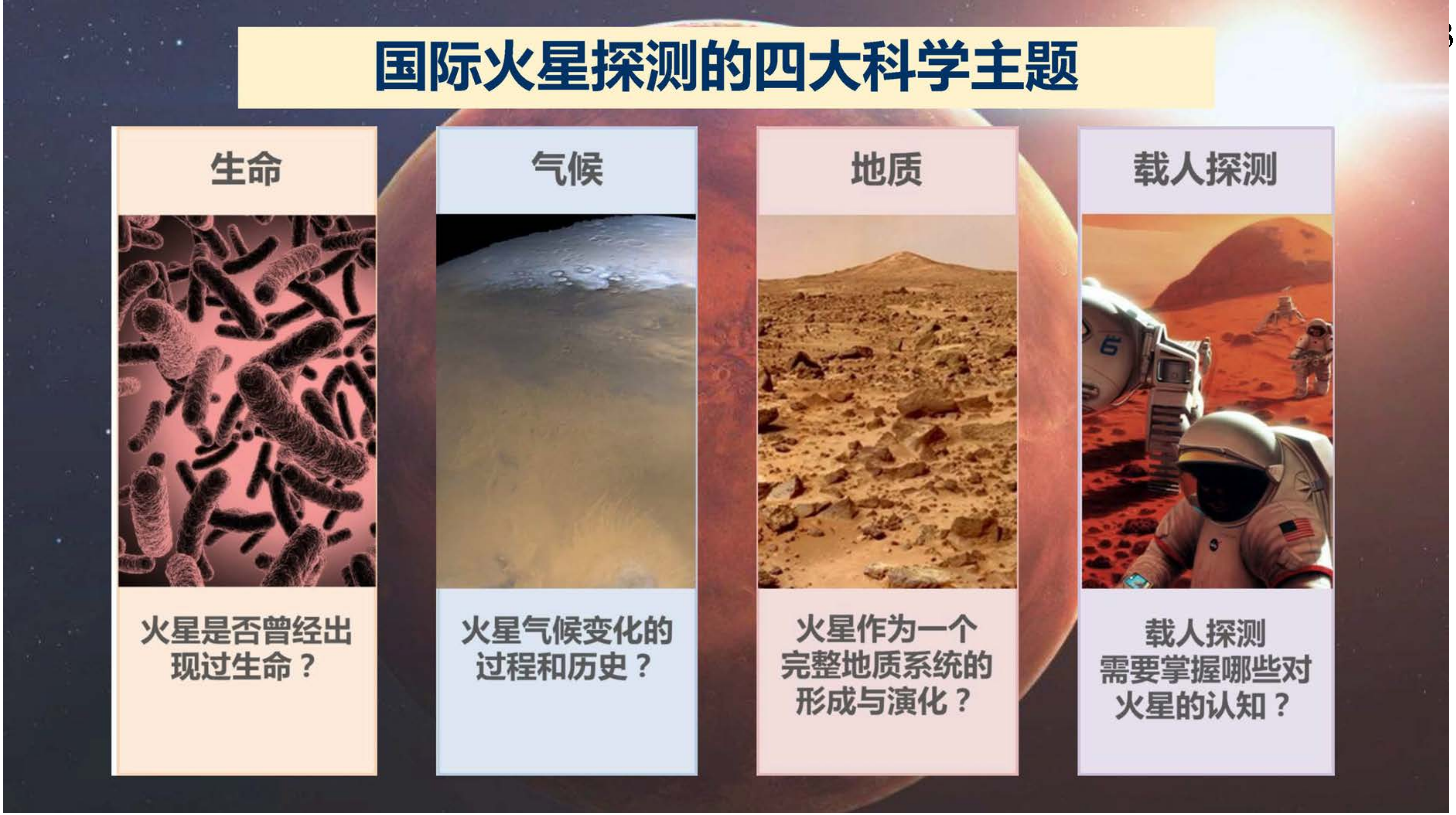


生命化学演化过程可分为四个阶段，难度不断增加：

1. 從無機小分子（即含氫氣、氨氣、甲烷和水蒸氣的原始大氣）生成有機小分子（包括氨基酸、核苷酸）
2. 由有機小分子生成生物高分子（包括原始蛋白質和核酸分子）
3. 由生物高分子組成多分子體系
4. 由多分子體系演變成原始生命。

Life Elsewhere?



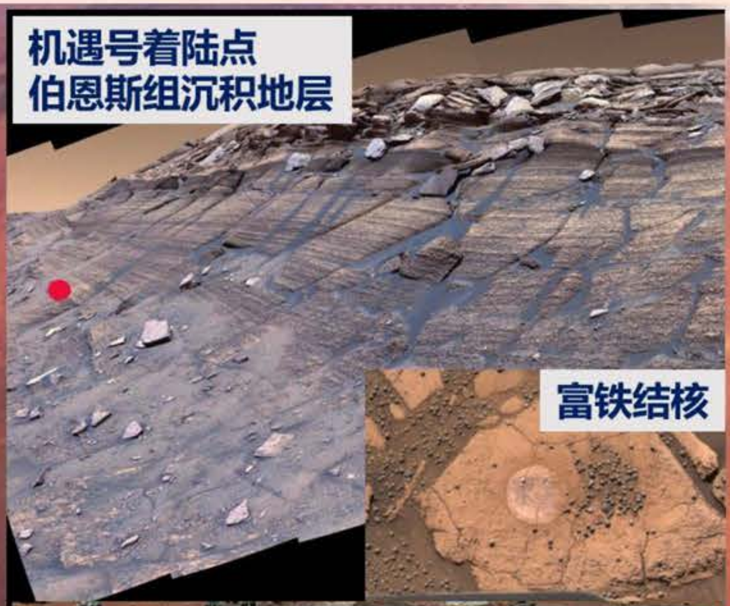


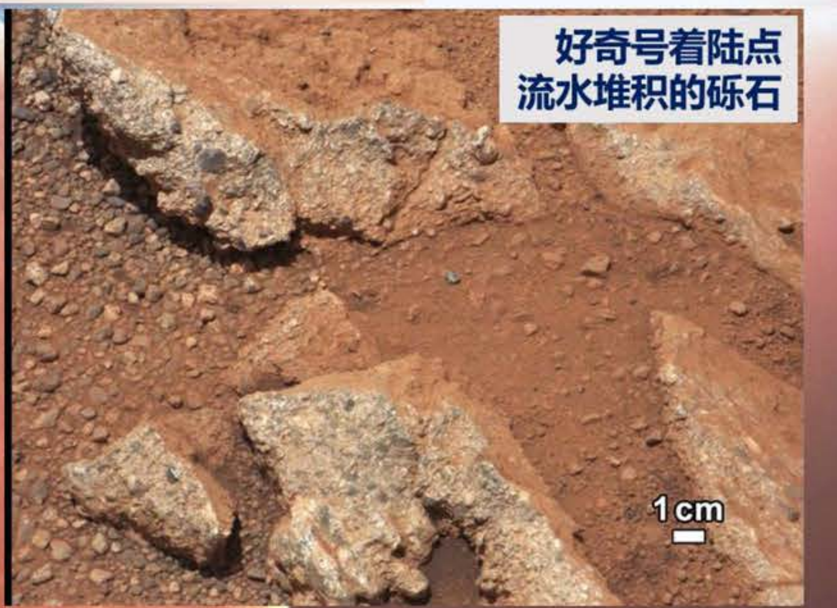
Credit: Yu-Yan Zhao

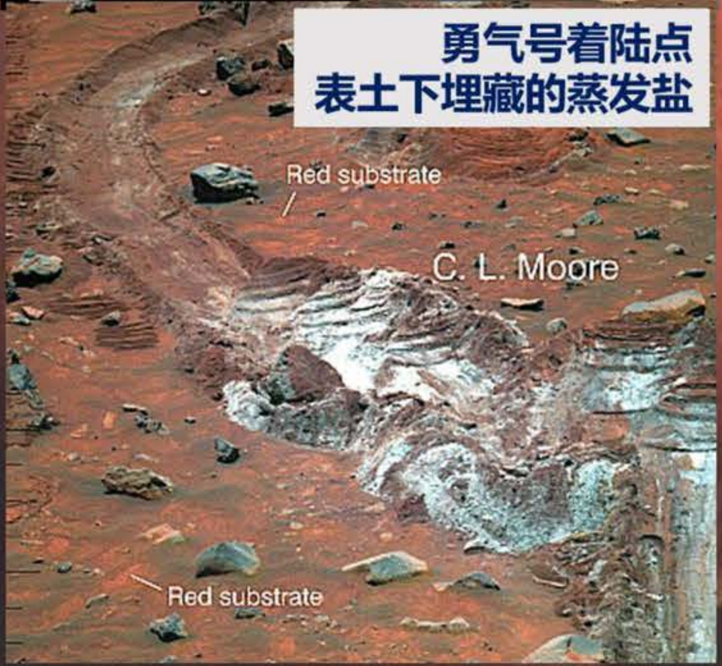
1. 火星早期普遍存在液态水

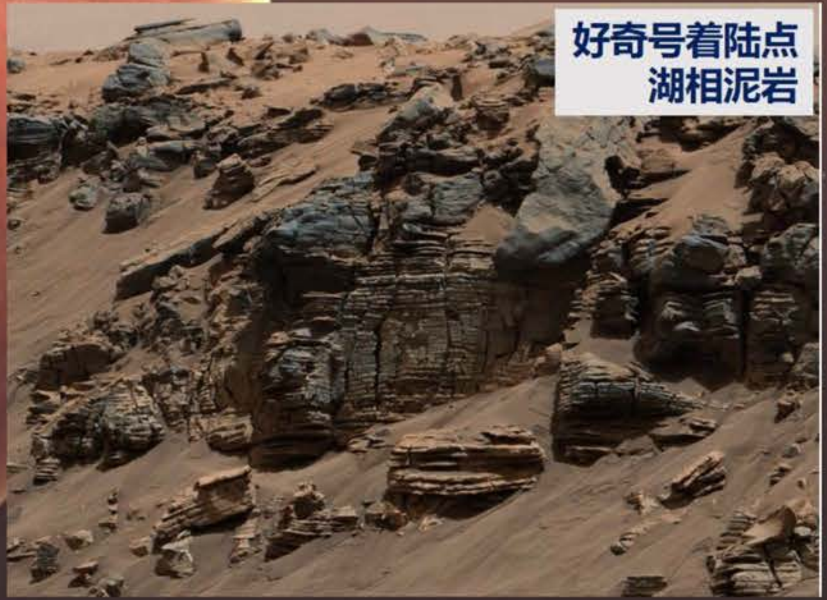
霍顿撞击坑（35 亿年前）
全火星类似冲积扇结构 ＞ 40 个

距今38~35亿年



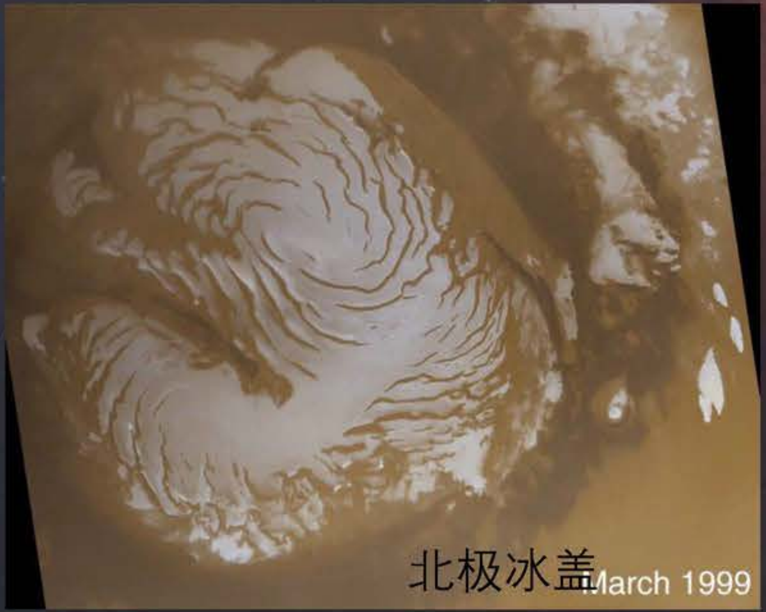


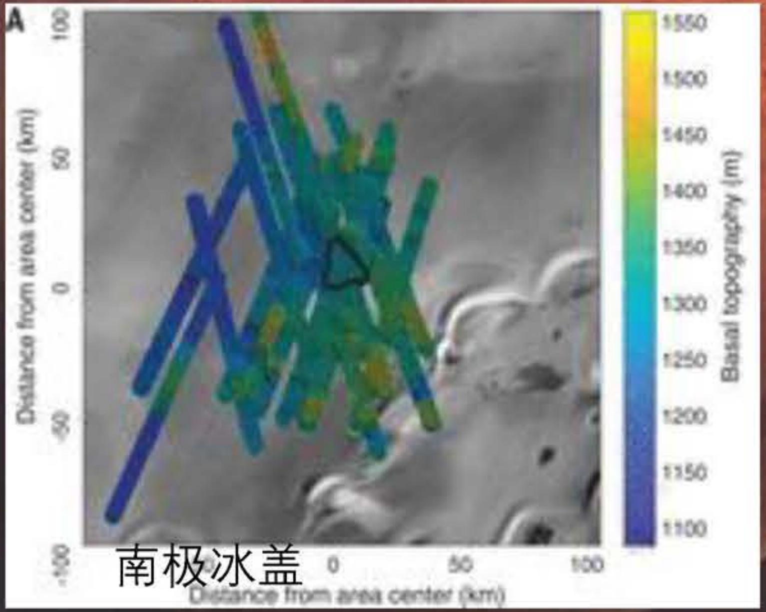


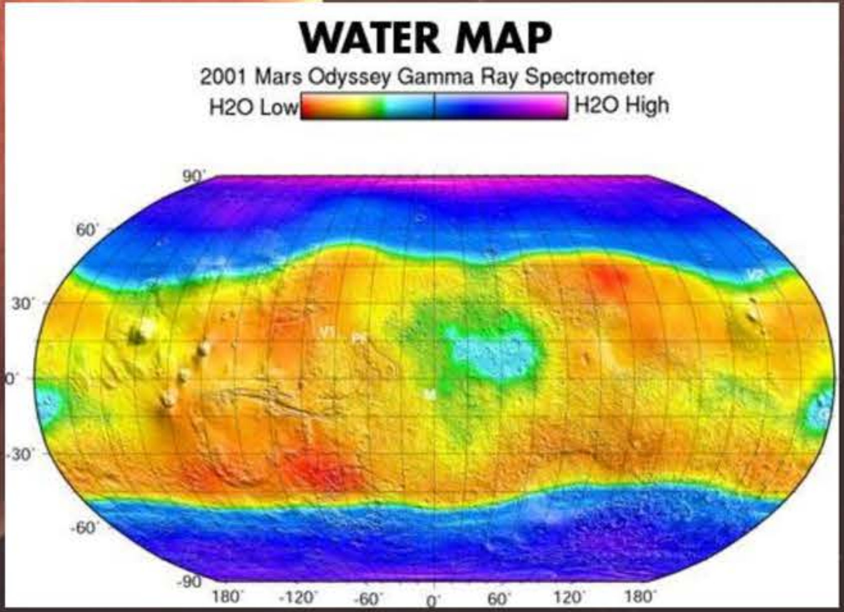


2. 现代火星也有水（冰、汽、霜、矿物里）

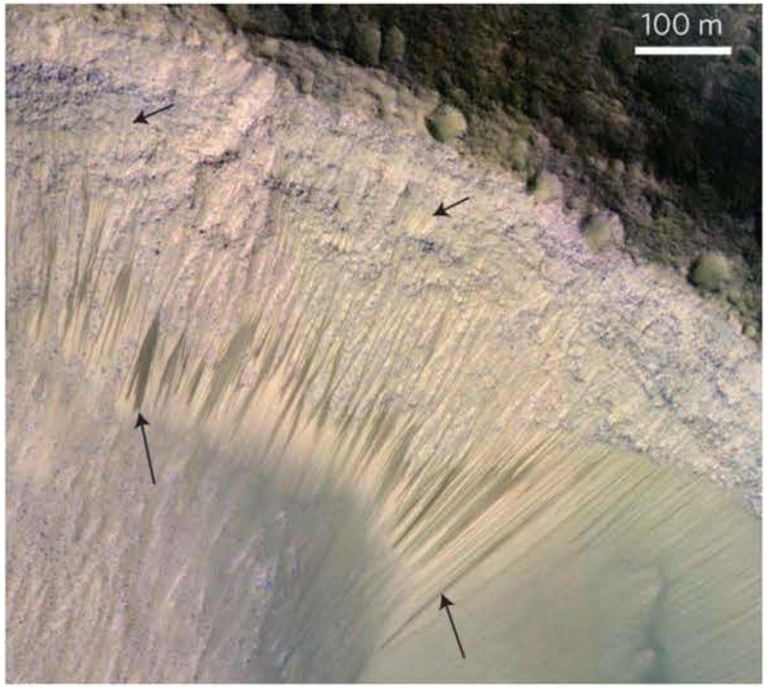
高氯酸盐



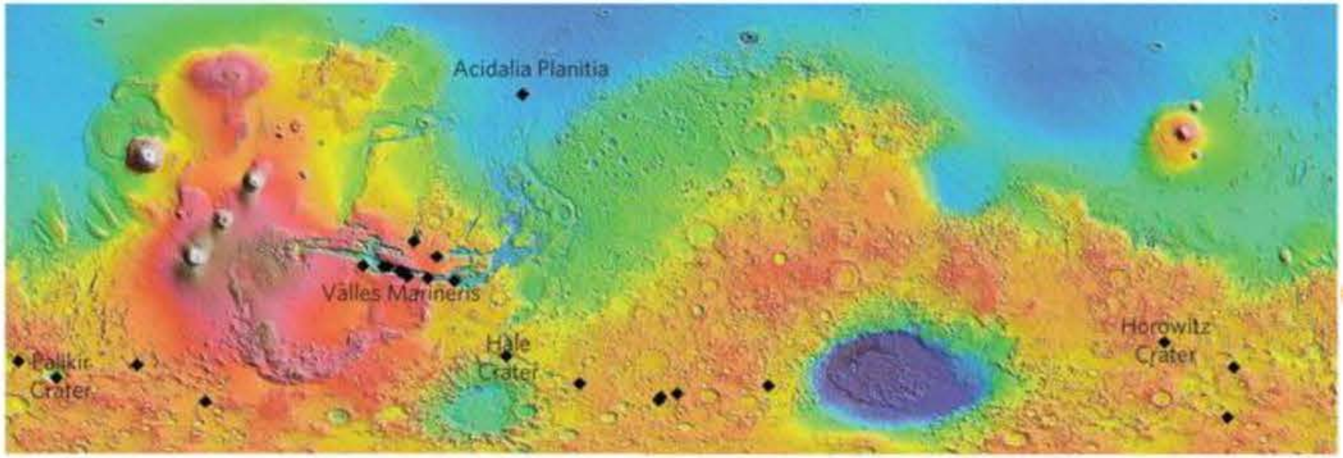


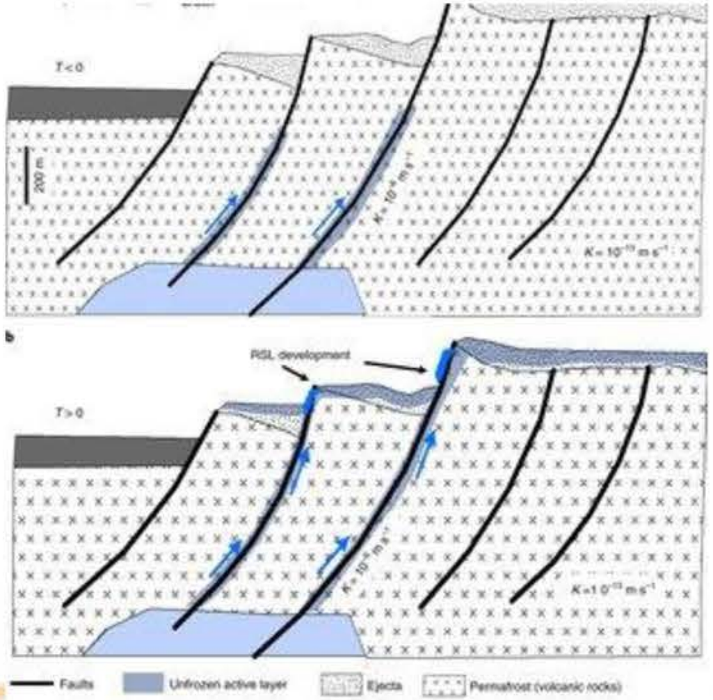


RSL（Recurring Slope Lineae）
是否代表火星现代液态水活动或出露点?



成因争论：融雪、潮解盐水、浅层地下水、深层地下水、二氧化碳霜冻、干颗粒崩塌

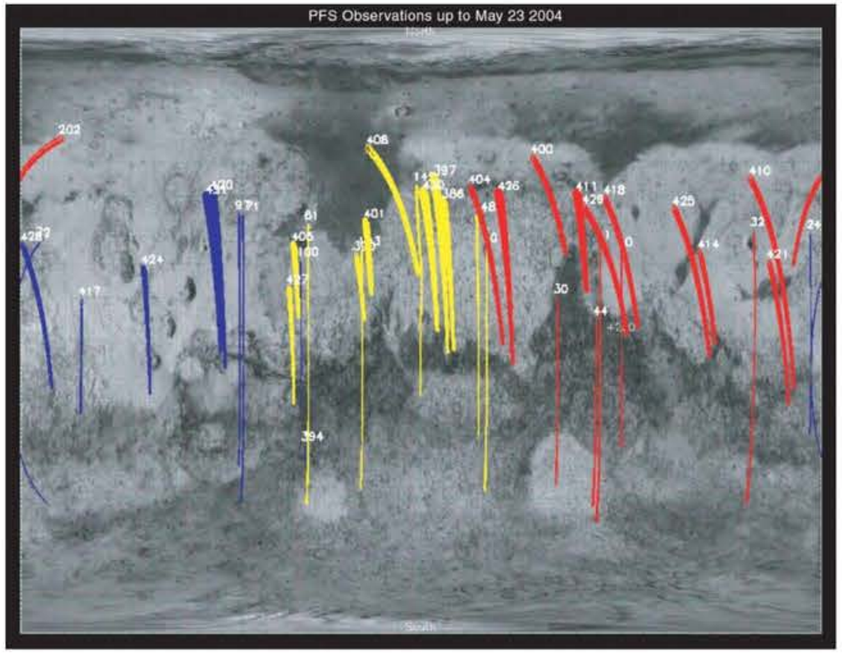


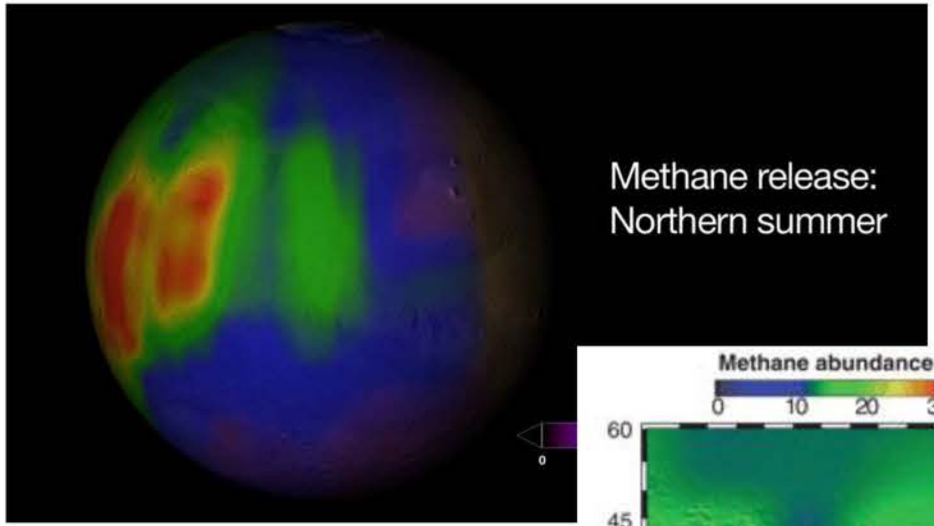


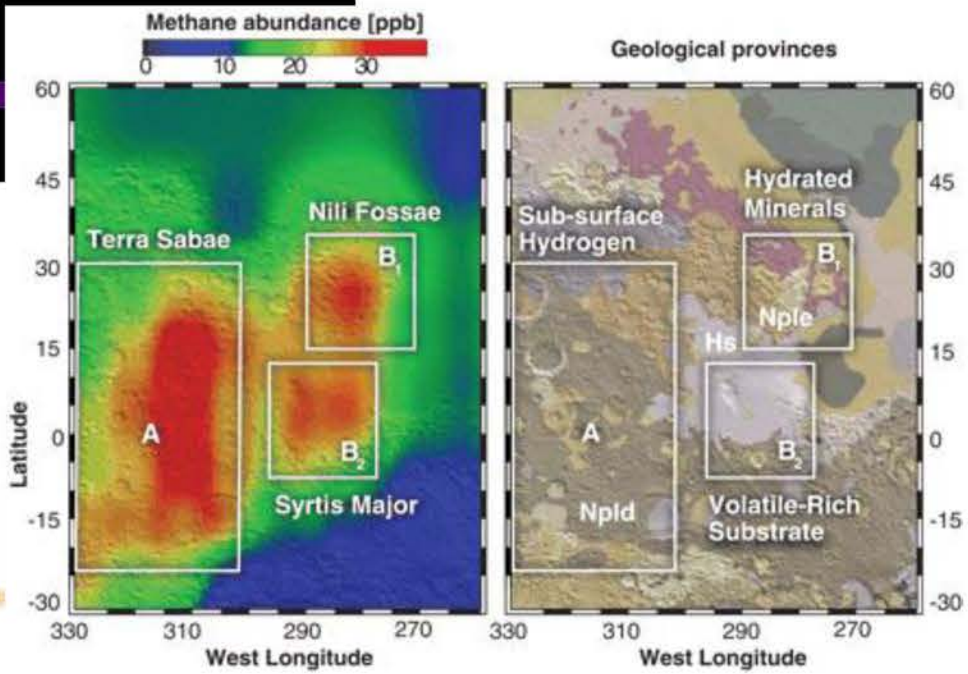
(McEwen et al., 2014； Ojha et al., 2015； Abotalib et a., 2019; NG)

3. 甲烷和有机物的发现

甲烷的产生机制和对生命及早期气候的指示意义是当前研究热点



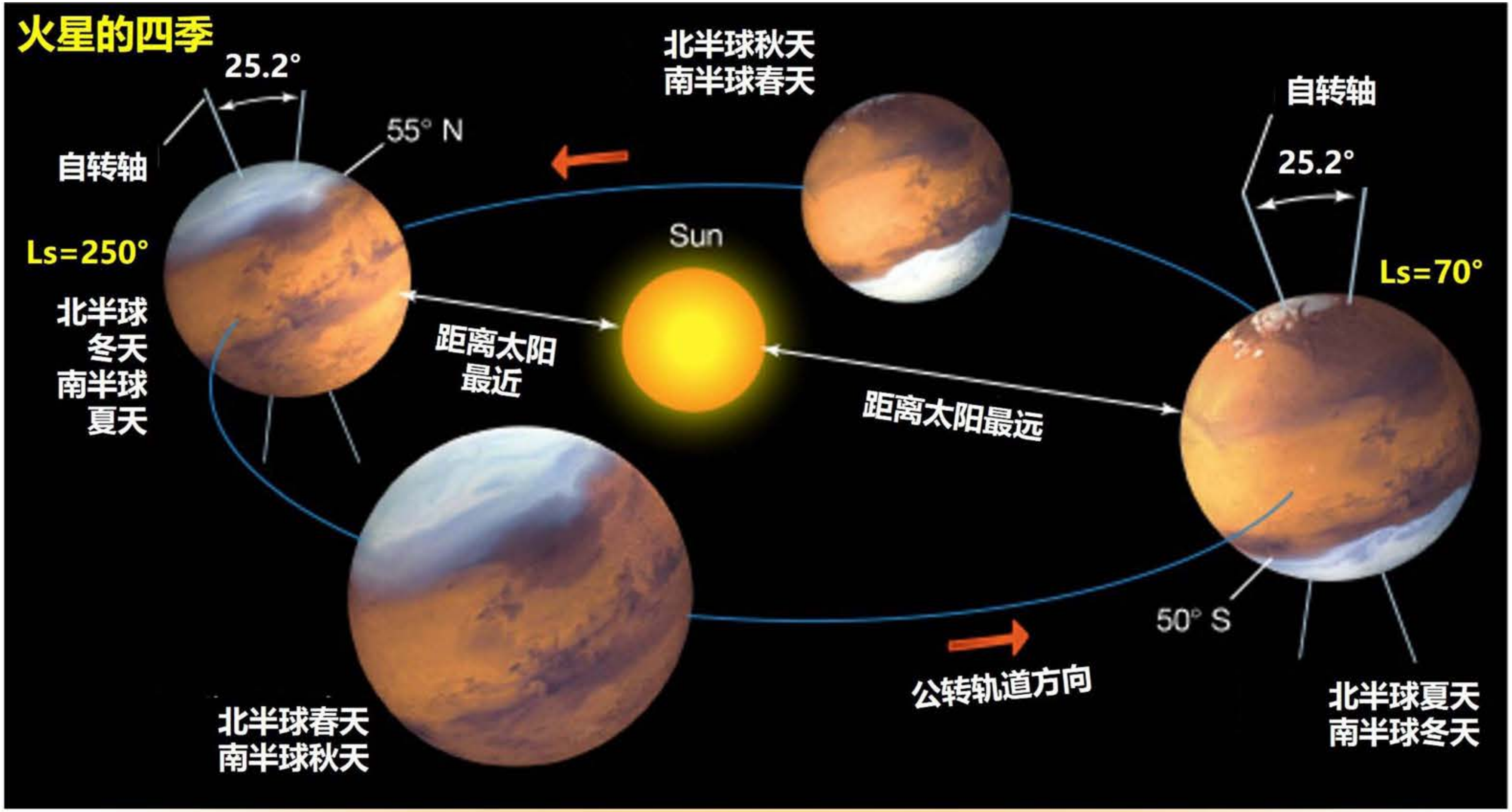




反复观测到火星表面固定区域向大气间歇释放甲烷

(Formisano et al. 2004; Mumma et al., 2009; Science)

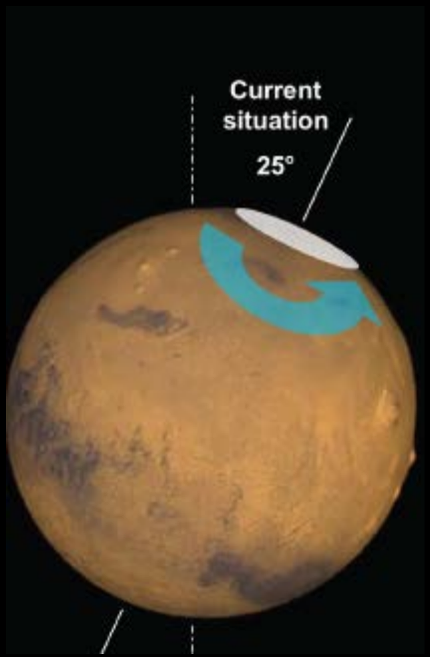
气候变化

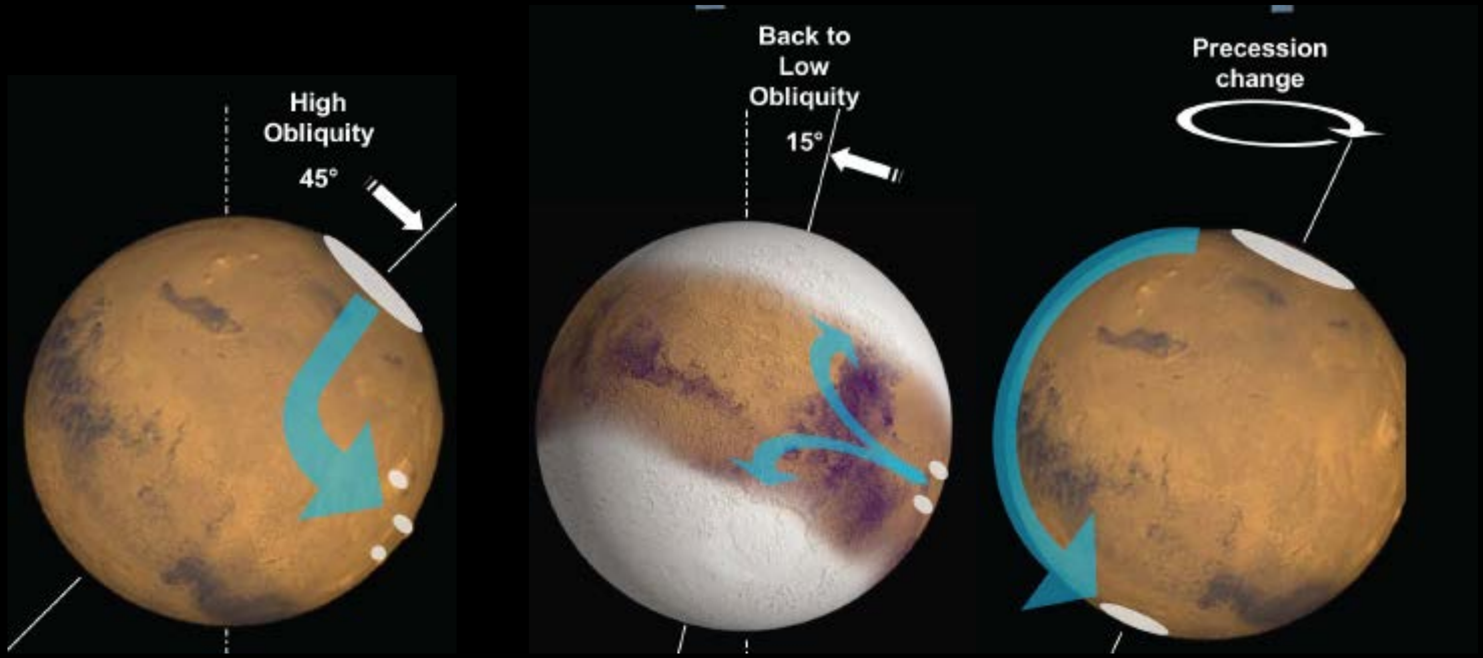


➔ 在近日点（perihelion）运行快；在远日点（aphelion）运行慢

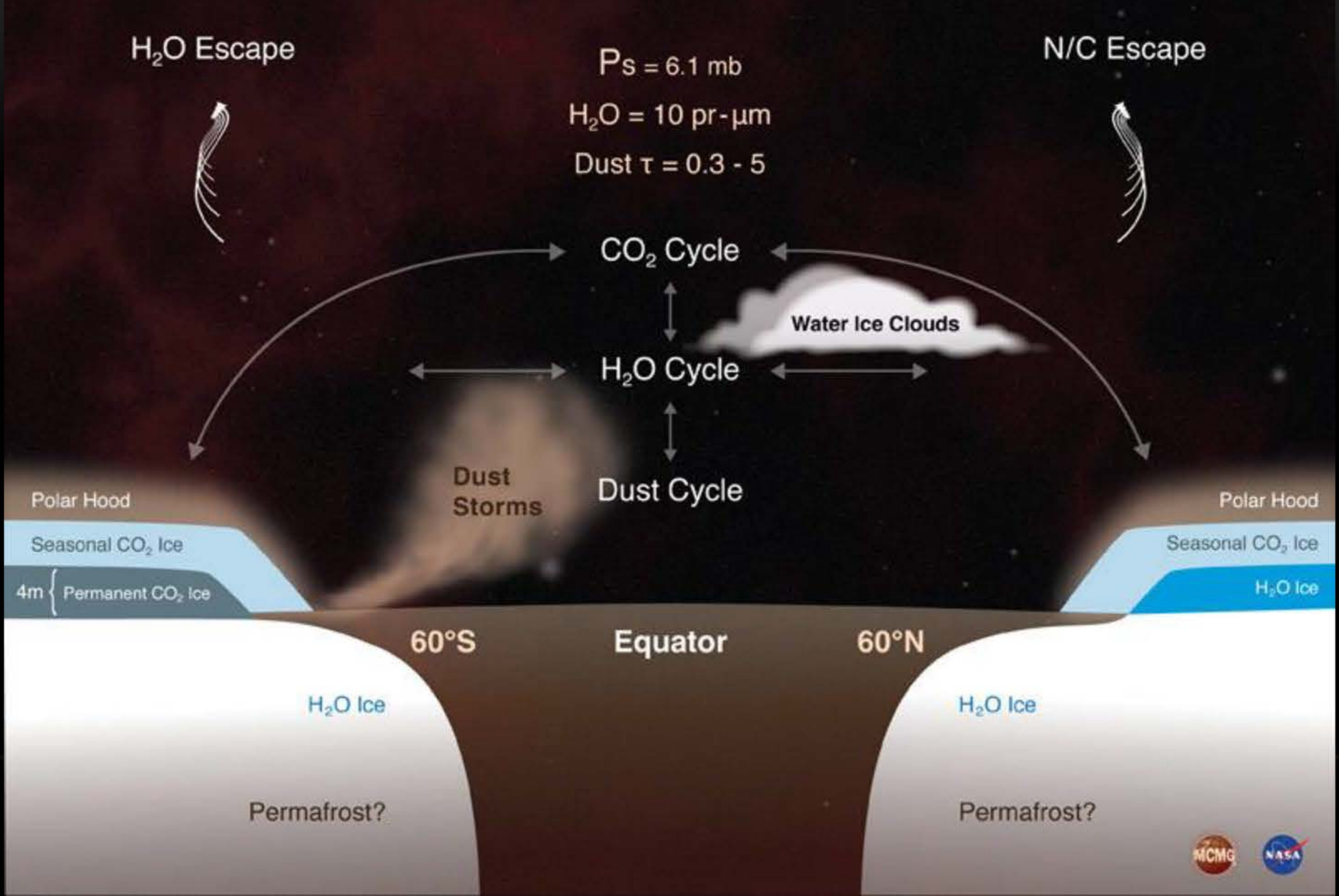
➔ 太阳对行星表面的辐射通量与行星到太阳的距离平方成反比

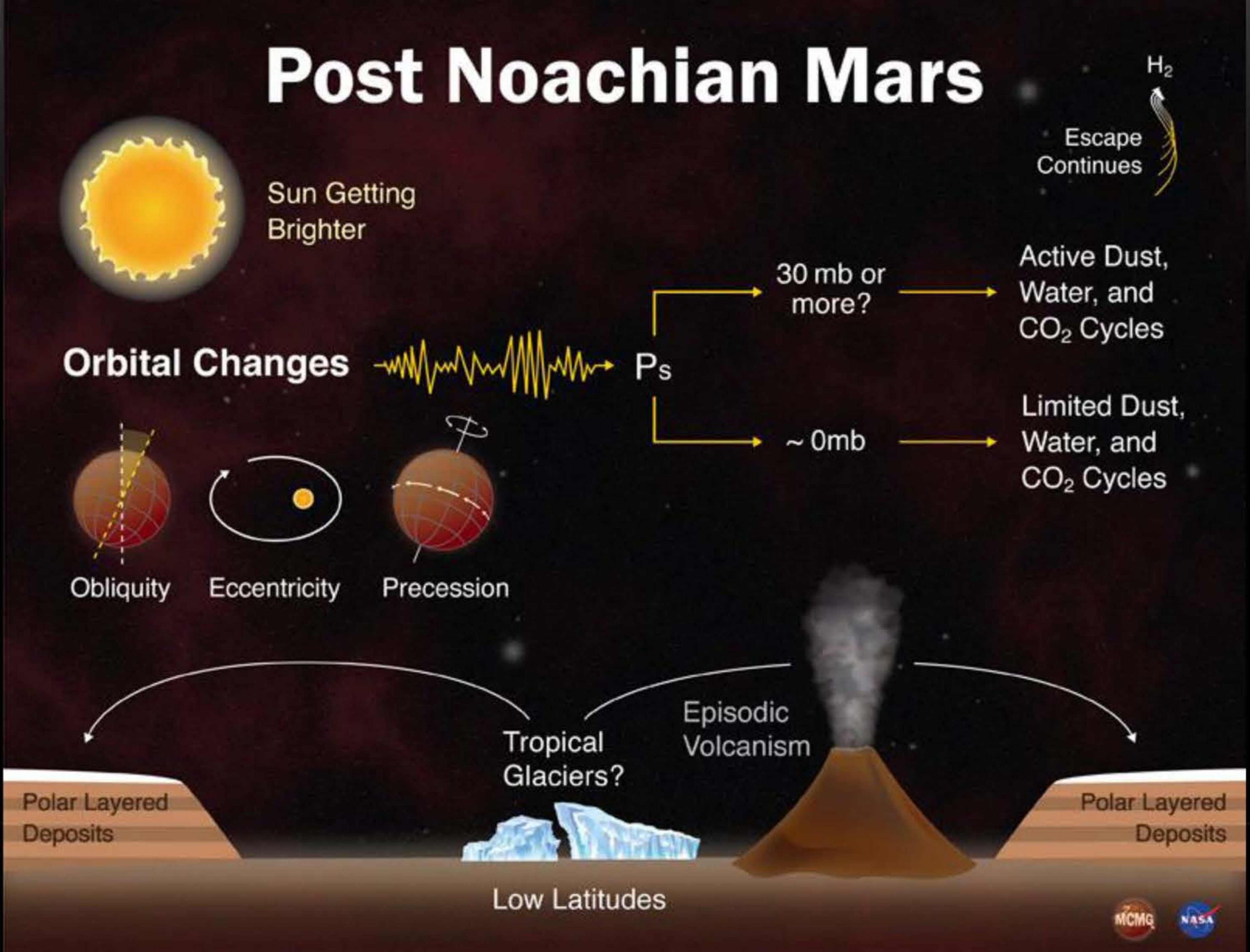
The Climate Change History of Mars

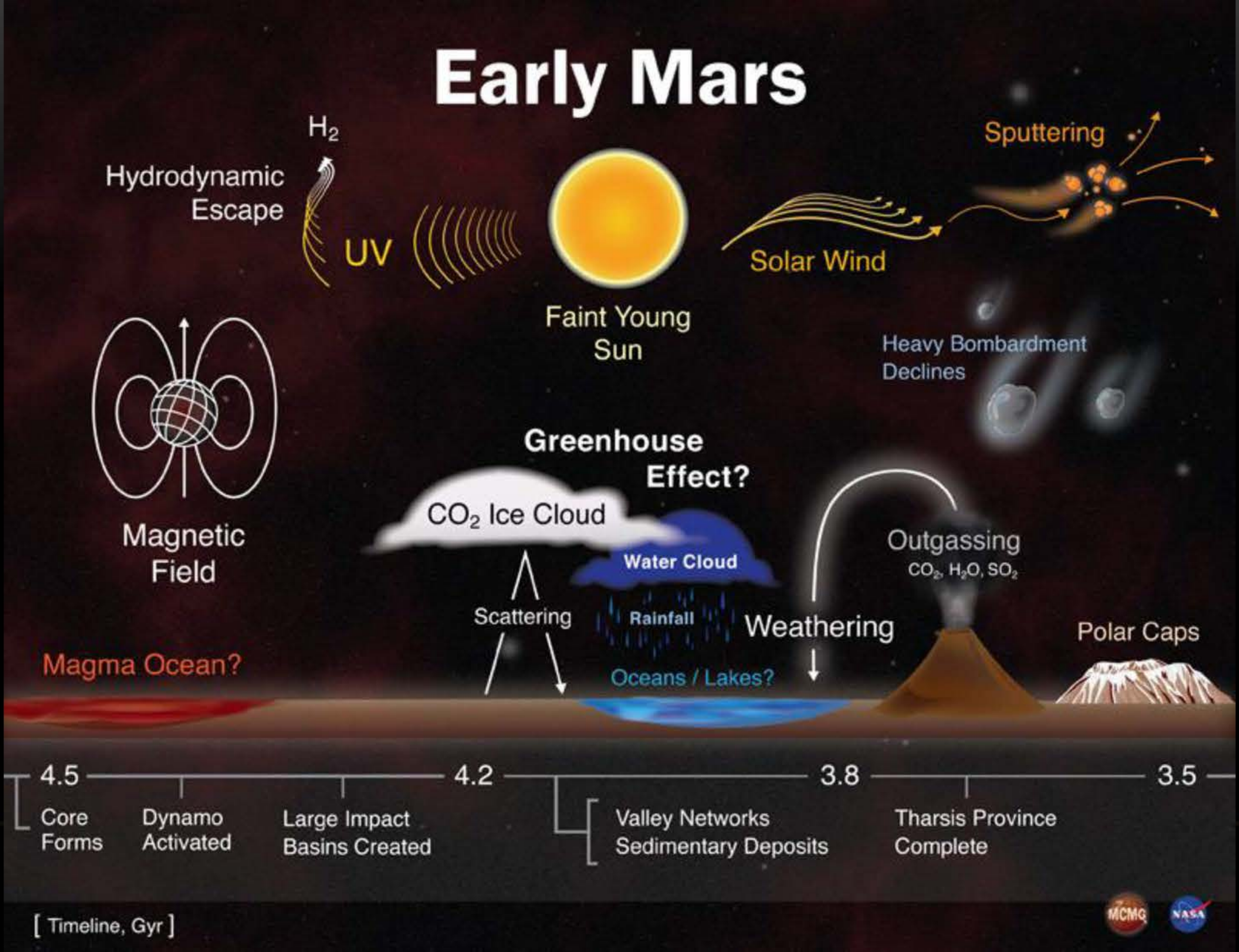




Present Mars




Post Noachian Mars
H2
Escape
Continues
Sun Getting
Brighter
30 mb or
more?
Active Dust,
Water, and
CO2 Cycles
Orbital Changes
Ps
~ 0mb
Limited Dust,
Water, and
CO2 Cycles
Obliquity
Eccentricity
Precession
Episodic
Volcanism
Tropical
Glaciers?
Polar Layered
Deposits
Polar Layered
Deposits
Low Latitudes


Early Mars
H_2
Hydrodynamic Escape
UV
Faint Young Sun
Solar Wind
Sputtering
Heavy Bombardment Declines
Magnetic Field
Greenhouse Effect?
CO_2 Ice Cloud
Water Cloud
Scattering
Rainfall
Weathering
Outgassing
CO_2, H_2O, SO_2
Polar Caps
Magma Ocean?
Oceans / Lakes?
4.5
4.2
3.8
3.5
Core Forms
Dynamo Activated
Large Impact Basins Created
Valley Networks
Sedimentary Deposits
Tharsis Province Complete
[Timeline, Gyr]

宜居性要素与火星宜居性的关联?

次生矿物

矿物形成/改造与早期（水)环境和气候条件的耦合关系?

- 多少水？什么样的水?
- 中性→酸性演化?
- 是否意味着宜居环境?

液态水

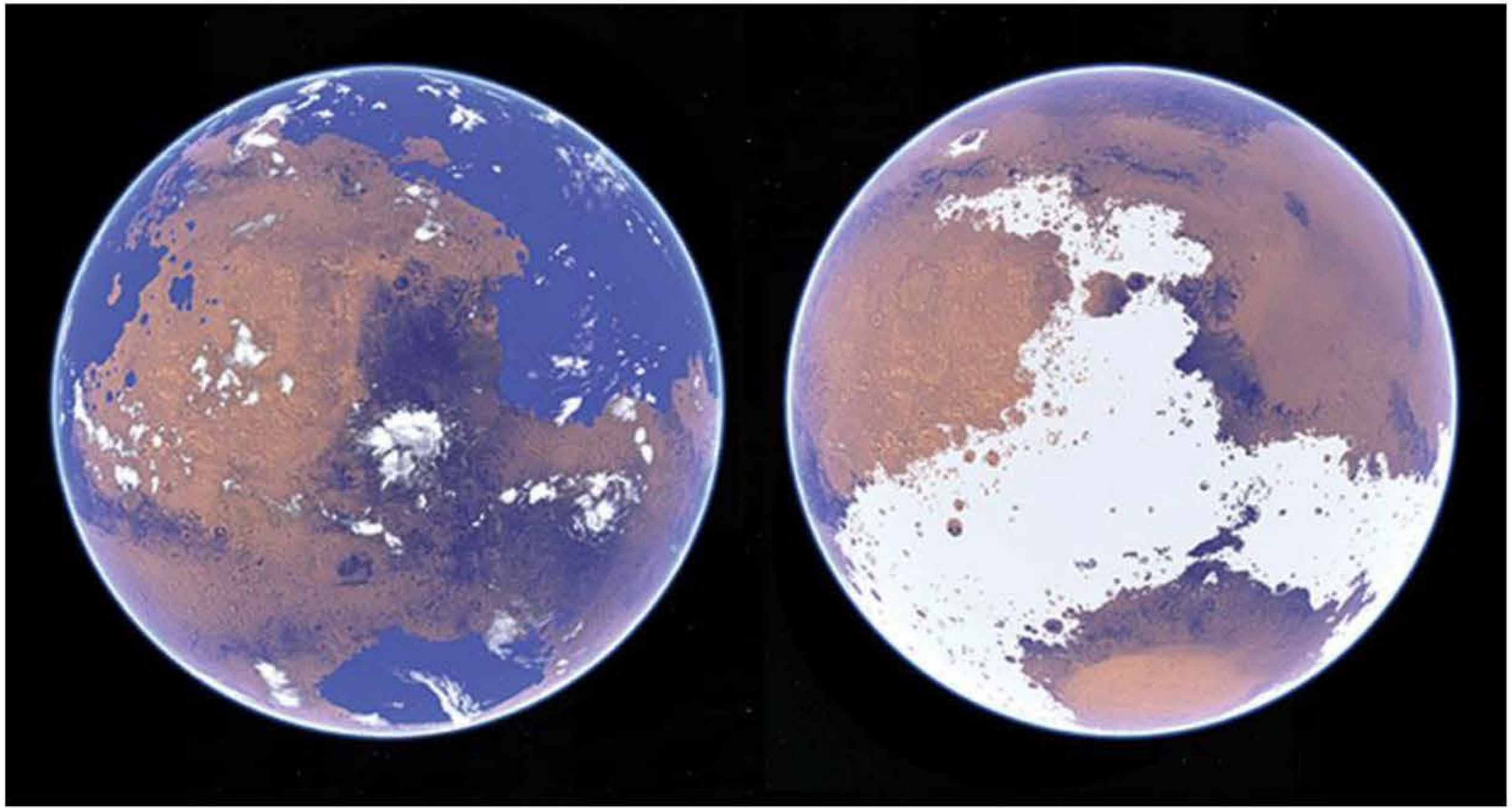
沉积记录

有机物/生命标志物

分布、保存潜力、就位探测?

早期火星气候

Warm and Wet, Cold and Wet, or Cold and Icy?



长期的湿热环境无法解释：

- Faint Young Sun 30% less heat
- CO_2/H_2O无法提供足够的热能保持地表流水活动
- H_2? CH_4? 其它温室气体?
- 沉积岩/沉积物化学风化程度低
- 缺失的碳酸盐是否支持浓密CO_2大气模型?

需要多学科交叉：
地质——水环境条件？持续的时间和水量？降雨？降雪？
地物——火星幔的氧化还原态和去气历史？
大气——气候对撞击、火山和轨道变化的响应？

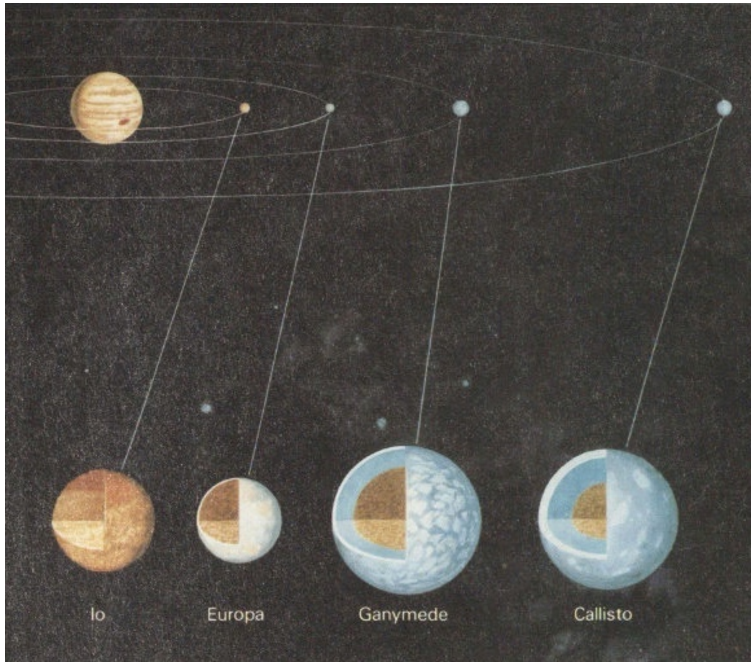
整体低温，间歇性热事件？
撞击、火山、公转轨道变化

冰卫星研究背景

巨行星冰卫星的宜居性是当前行星科学研究和探测的焦点

巨行星的冰卫星

木星的冰卫星系统



- 2024: NASA Europa Clipper
- 2022: ESA JUpiter ICy moons Explorer
- ~2030: 我国木星系统探测计划

表面下可能有海洋

海洋里可能存在生命

轨道共振，潮汐加热

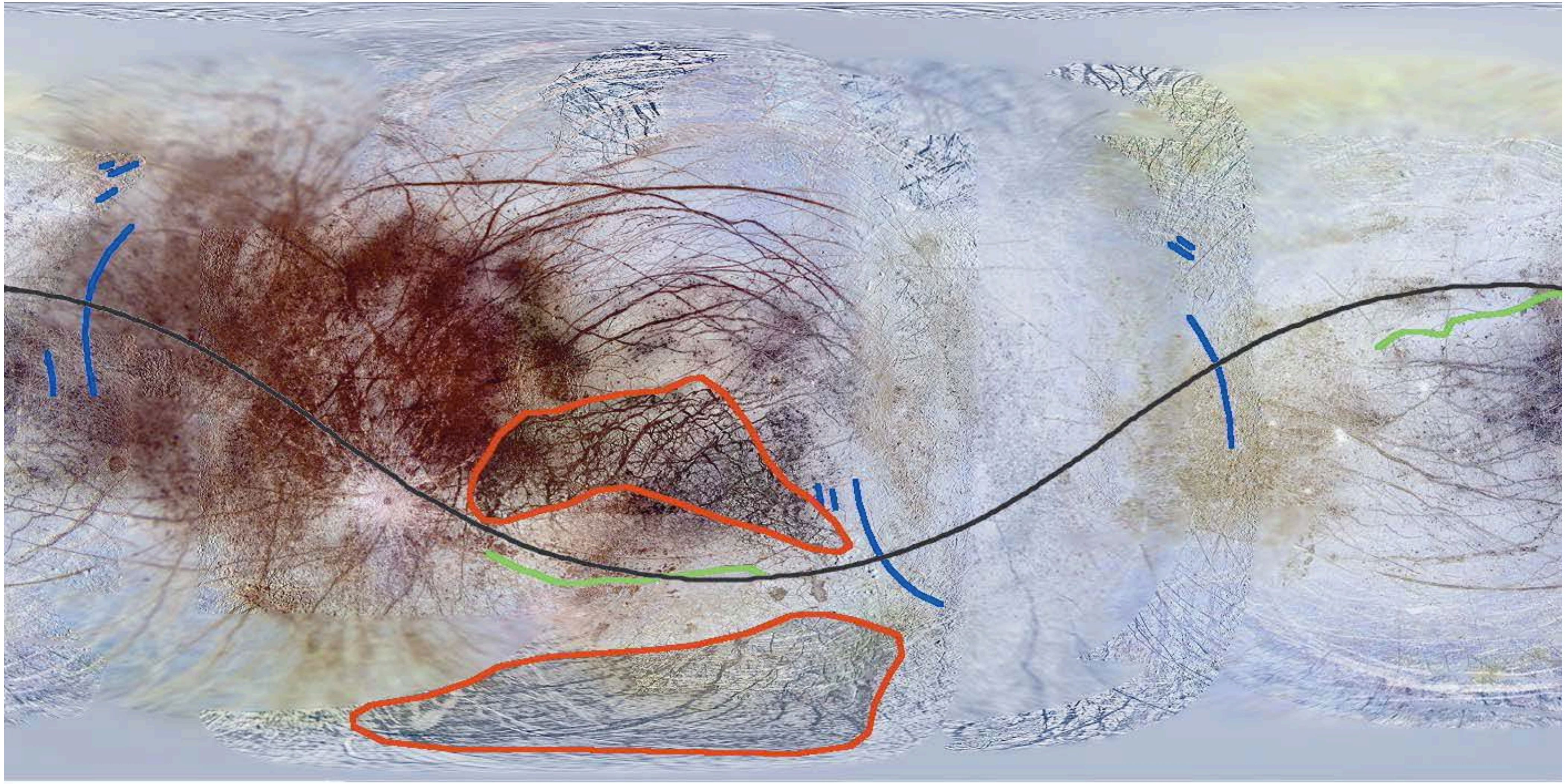
活跃的表面

Ganymede Surface Features

Hubble Space Telescope (1996)

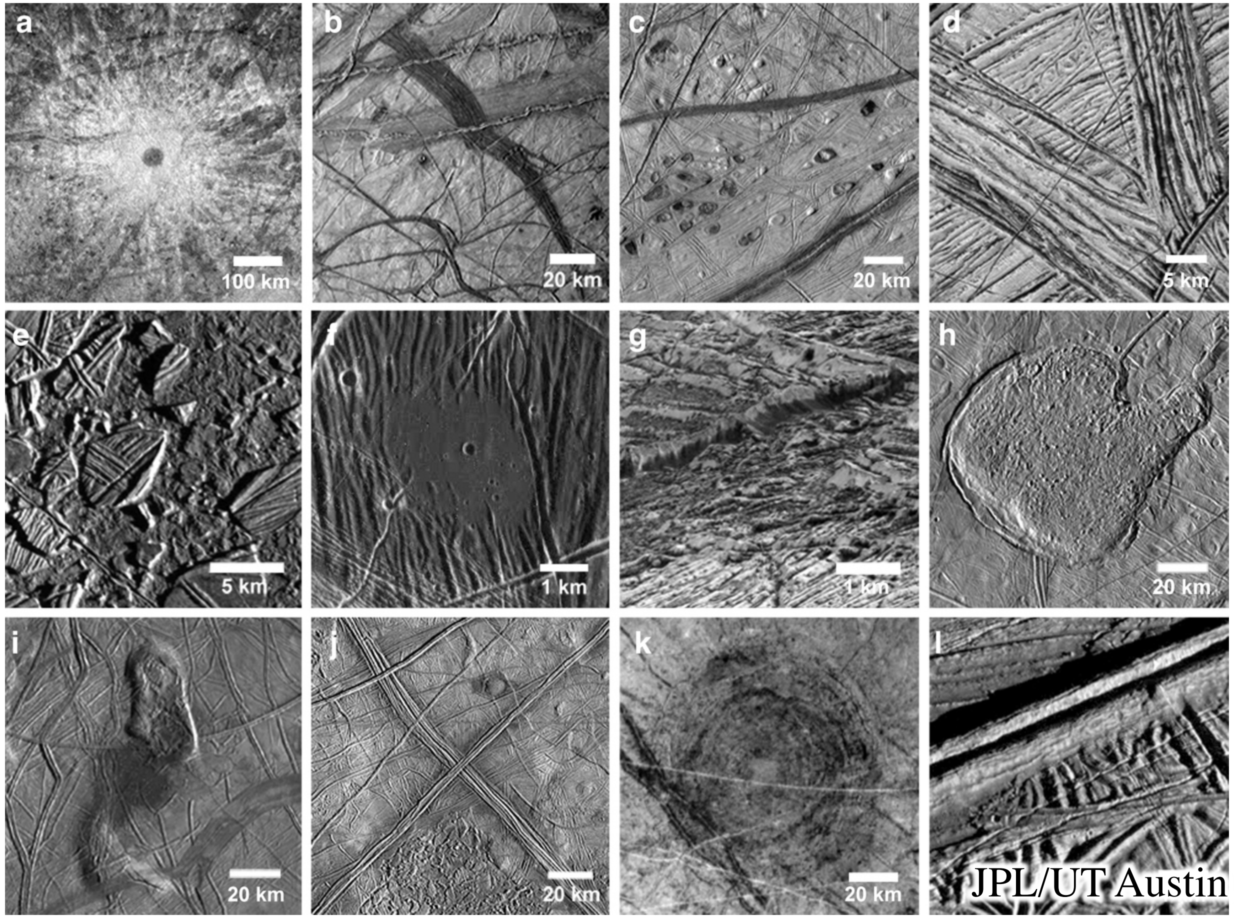
Juno flyby (June 7 2021)
Credit: NASA/JPL/SwRI/MSSS/Kevin Gill/Twitter.

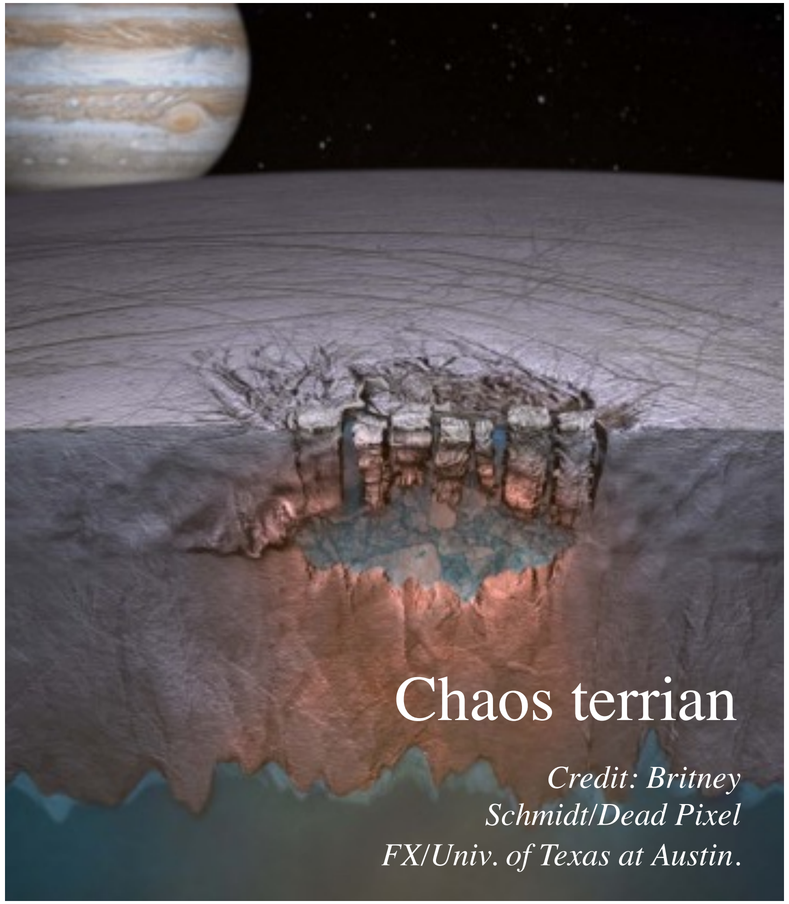
Europa 地质构造



Schenk et al., 2008

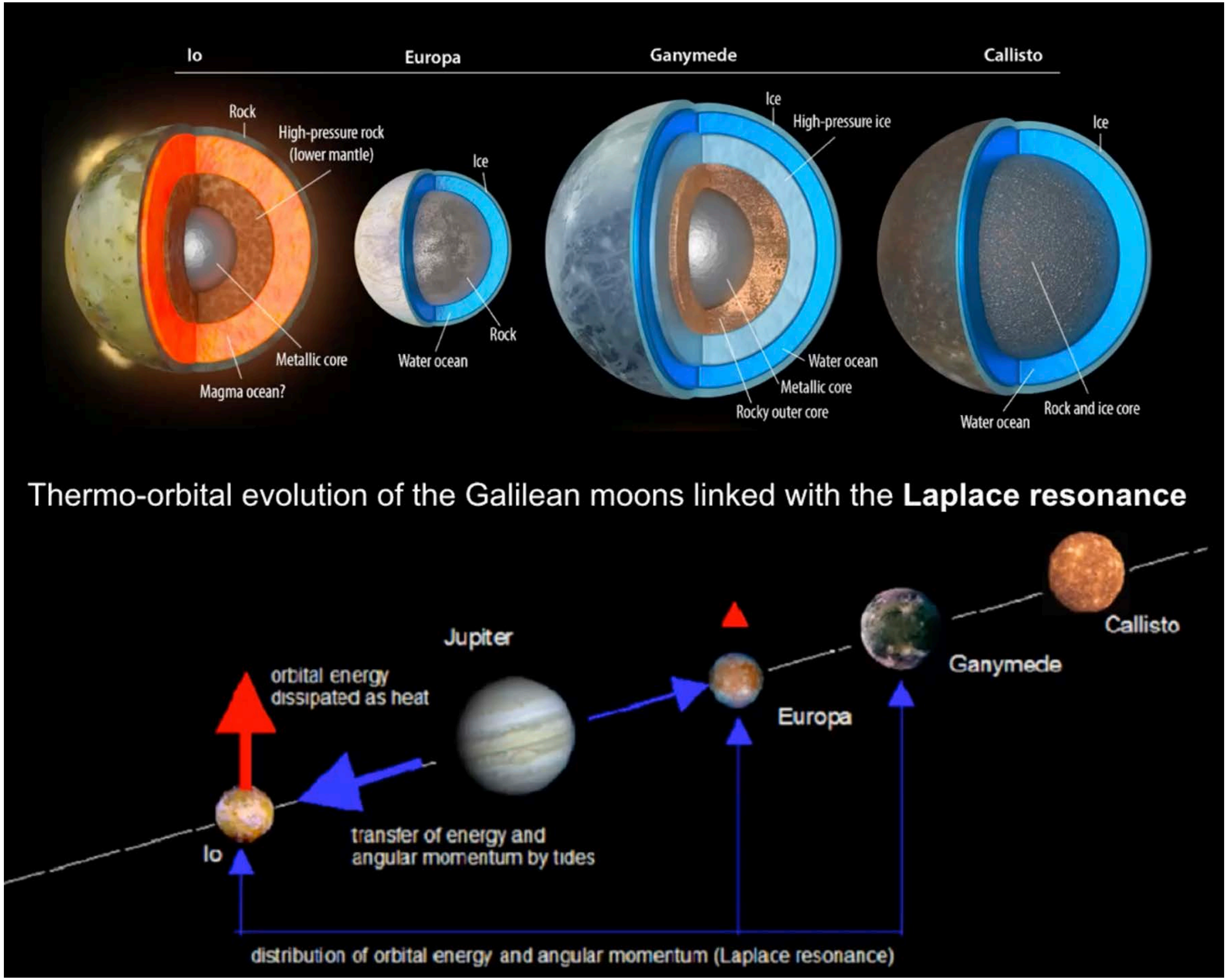
Europa 地质构造

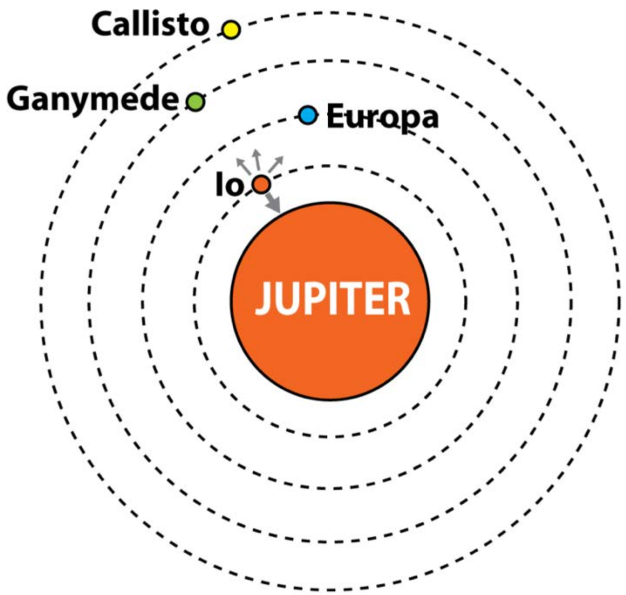


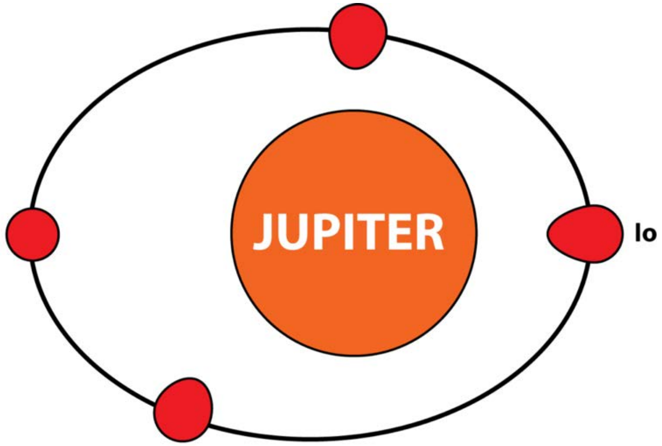


- 潮汐共振对冰圈的影响：冰湖、冰脊、冰断层、冰震等。
- 热演化以及冰圈、水圈和岩石圈的相互作用。

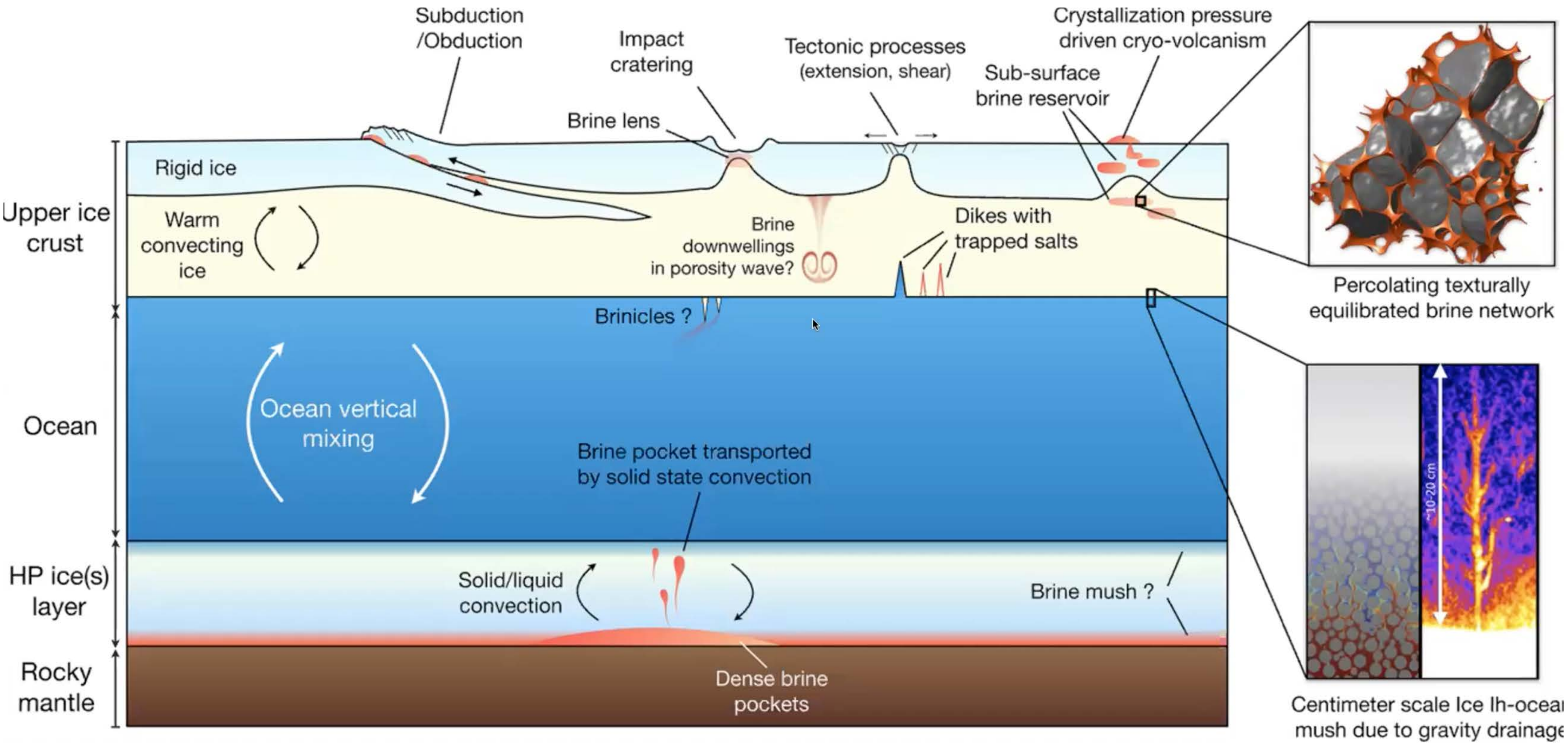
Internal Structure and Tidal Heating





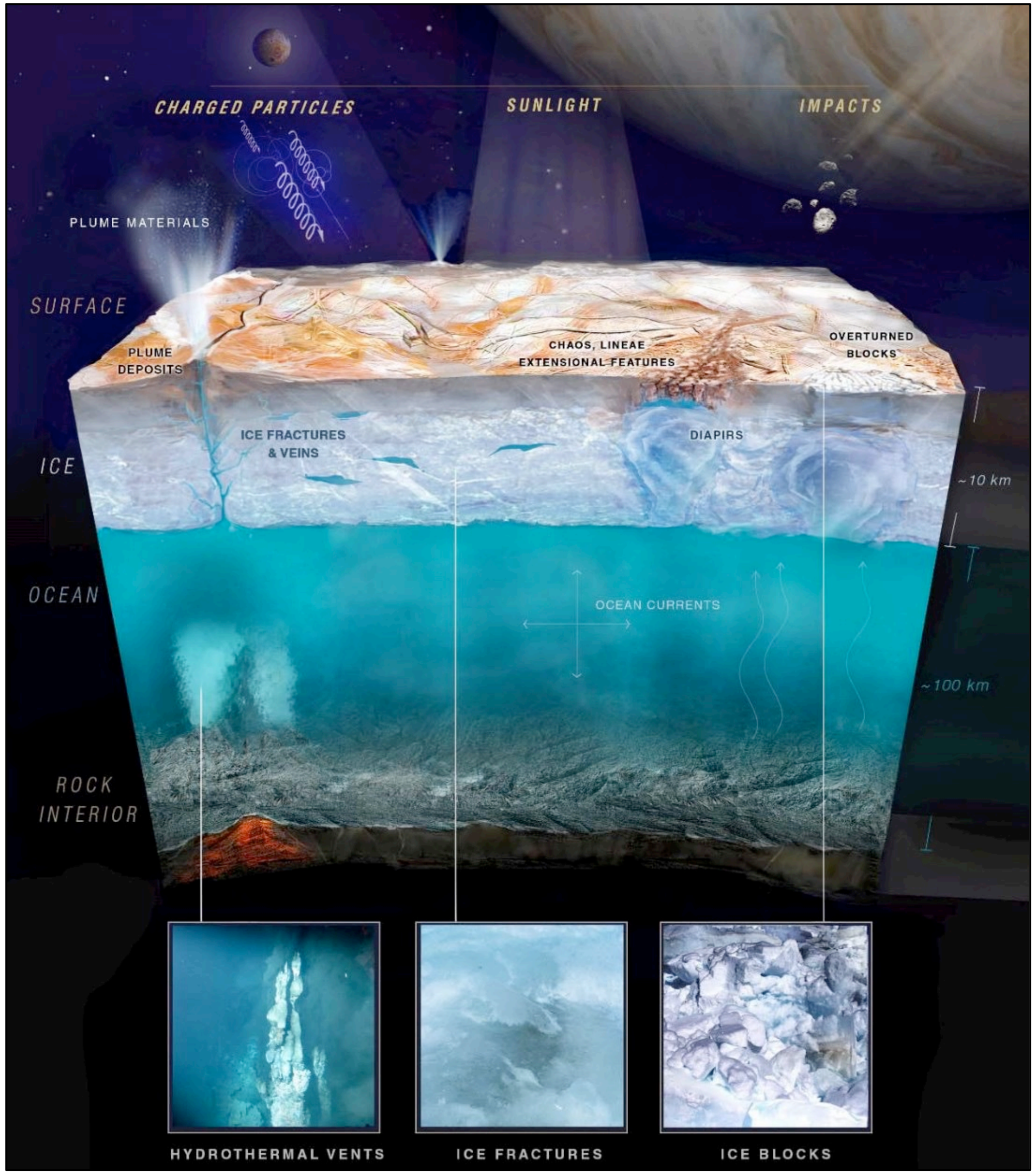


冰卫星“板块运动”

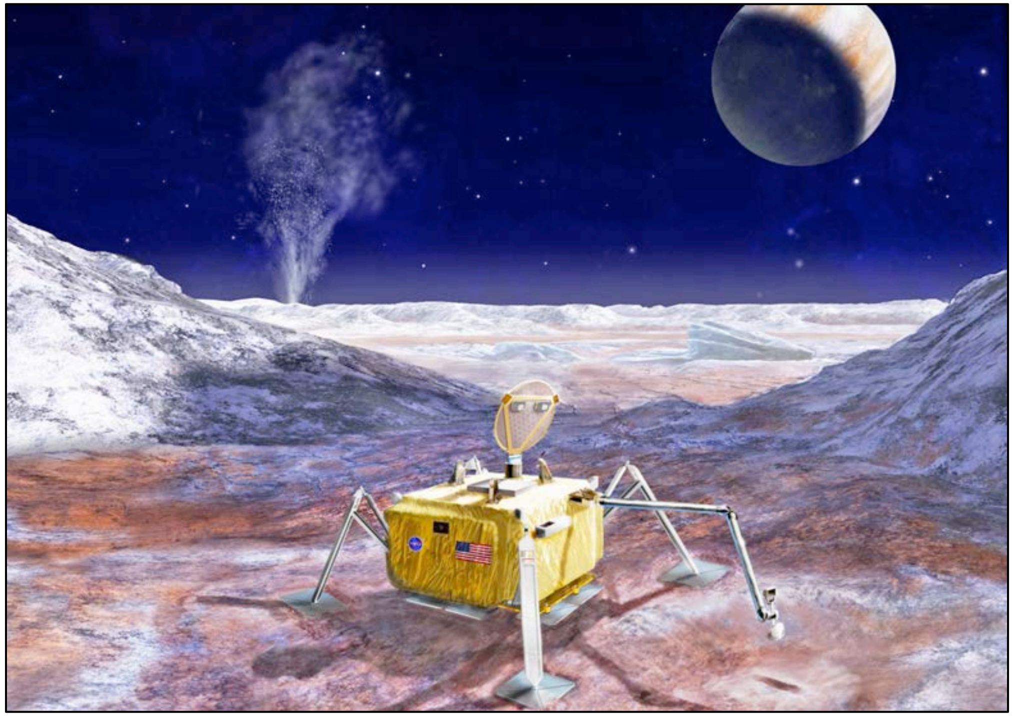


On Europa, Vance+2020

生命存在于深海热液系统？



着陆器？



水底机器人?

Credit: Supplied, Alexander Pawlusik, LERCIP Internship Program NASA Glenn Research Center

有缆观测网?

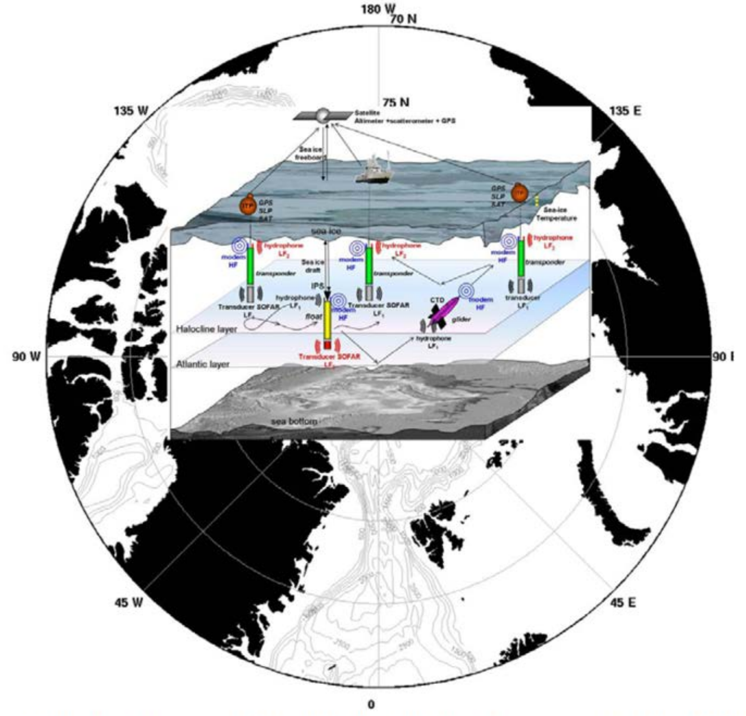
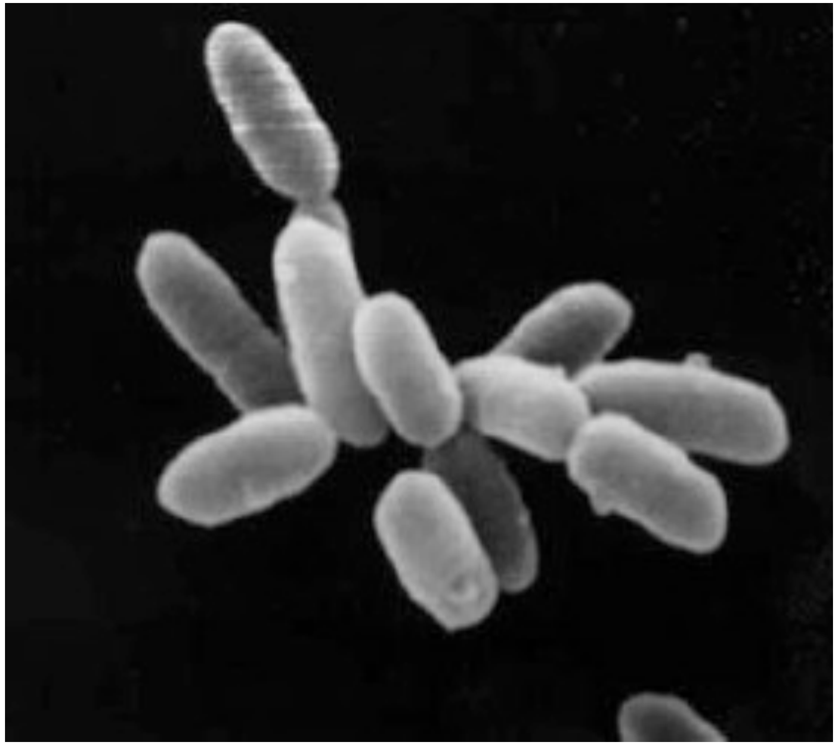


Figure A1.2. Schematic representation of the basic underwater components of the AOOS: (a) Floats (yellow), (b) Gliders (pink) and (c) transponders (green) equipped with SOFAR/RAFOS long-range acoustics capability for underwater navigation and acoustic modem for short-range data transfer. Ice Profiling Sonar will be installed on Floats and CTD on Gliders. Transponders will be ice-tethered and connected to GPS geolocated surface satellite transmitters.

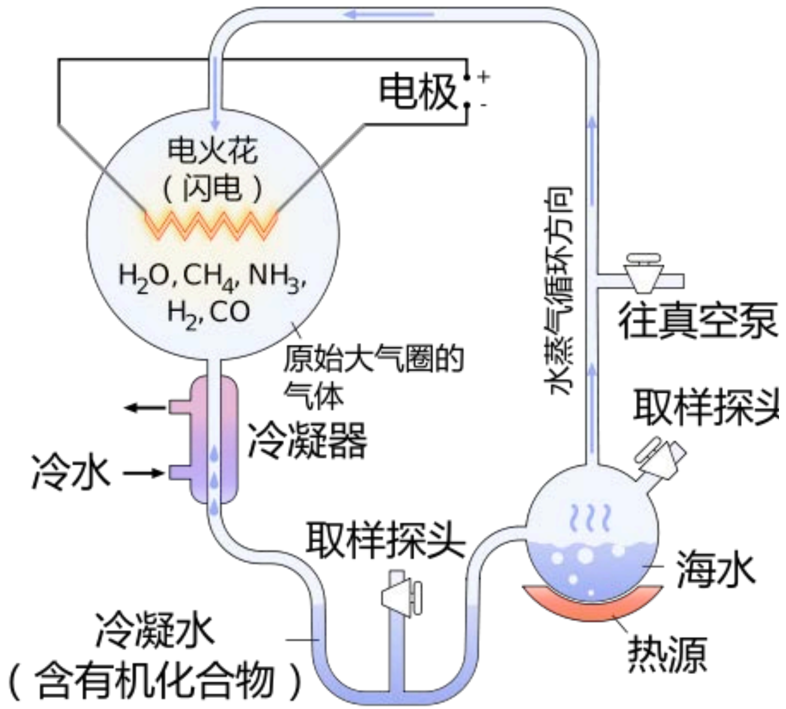
From Arctic Observing Based on Ice-Tethered Platforms Workshop Report

生命是否可能普遍存在？

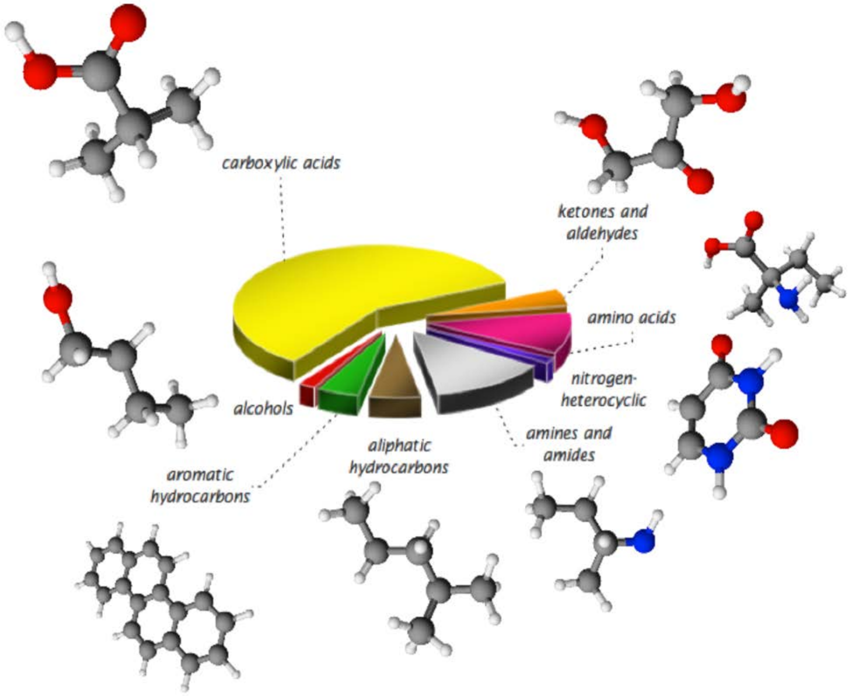
古生菌



米勒实验



外来有机物



- 地球最早的生命形式--古生菌—可能产生于4.41 Ga.
- 原始生命的产生可能非常普遍
- 陨石携带有机物