从系外行星到天体生物学

杨毅

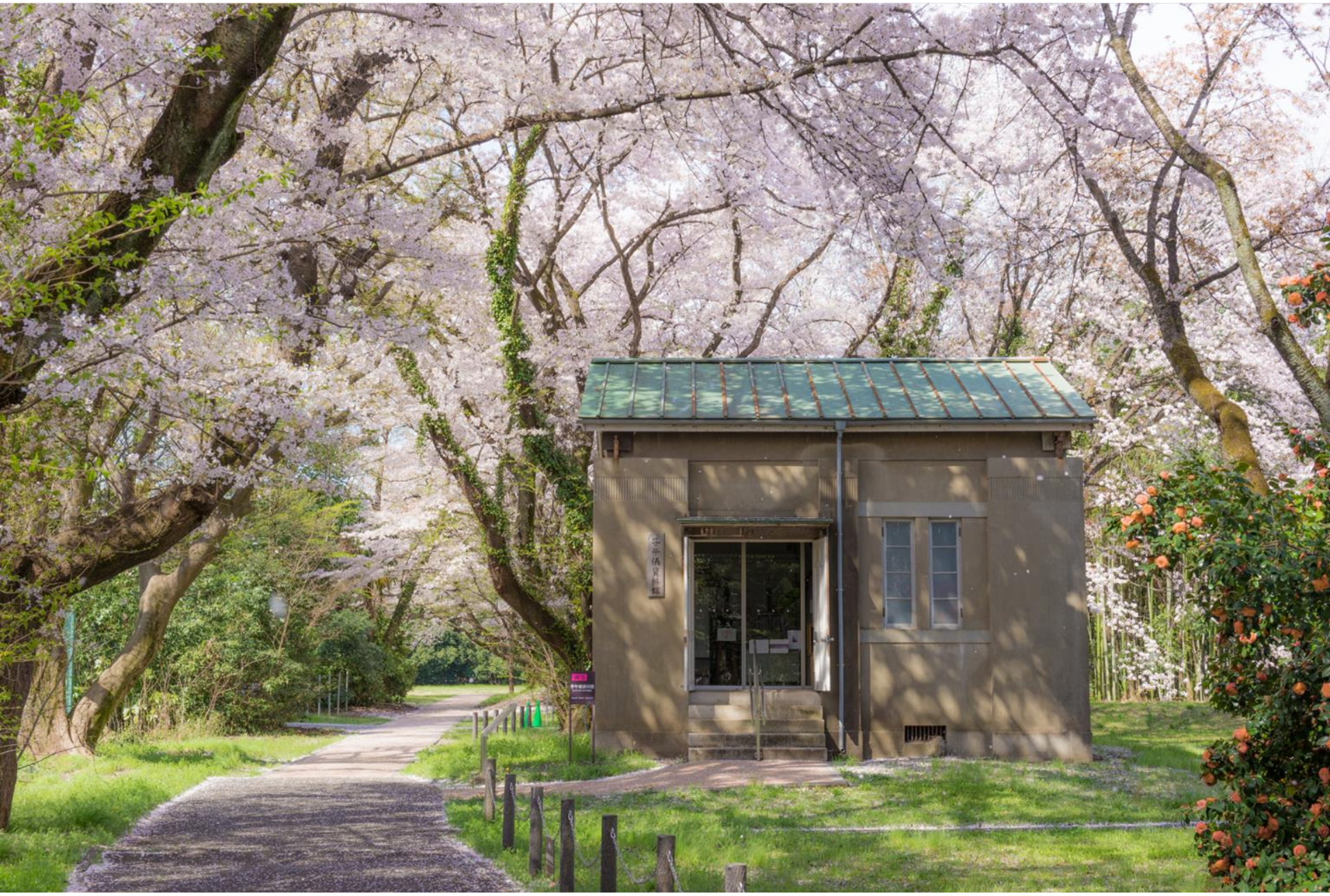
杭高天文社20周年纪念演讲

2023年1月29日

个人经历

- 2005-2008年: 杭州高级中学
- 2008年-2012年: 北京大学
- 2012-2018年: 日本综合研究大学院大学/国立天文台(NAOJ)
- 2018-2019年: 国立天文台-天体生物学中心
- 2019-2022年: 东京大学
- 2022-: 国立天文台-天体生物学中心

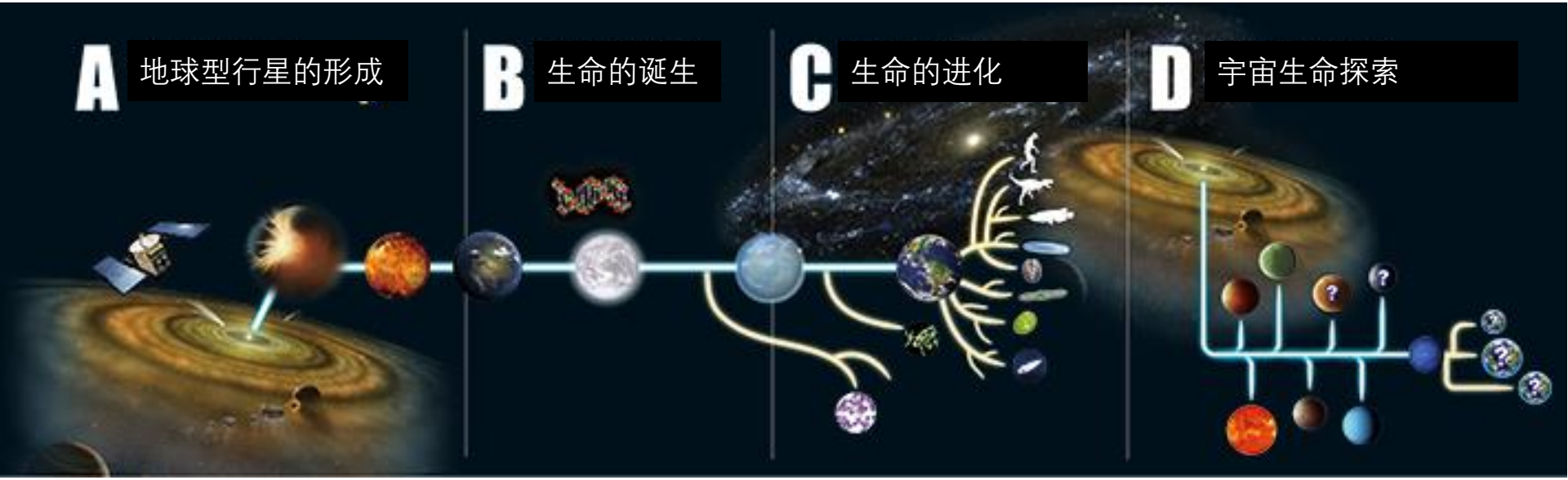

国立天文台

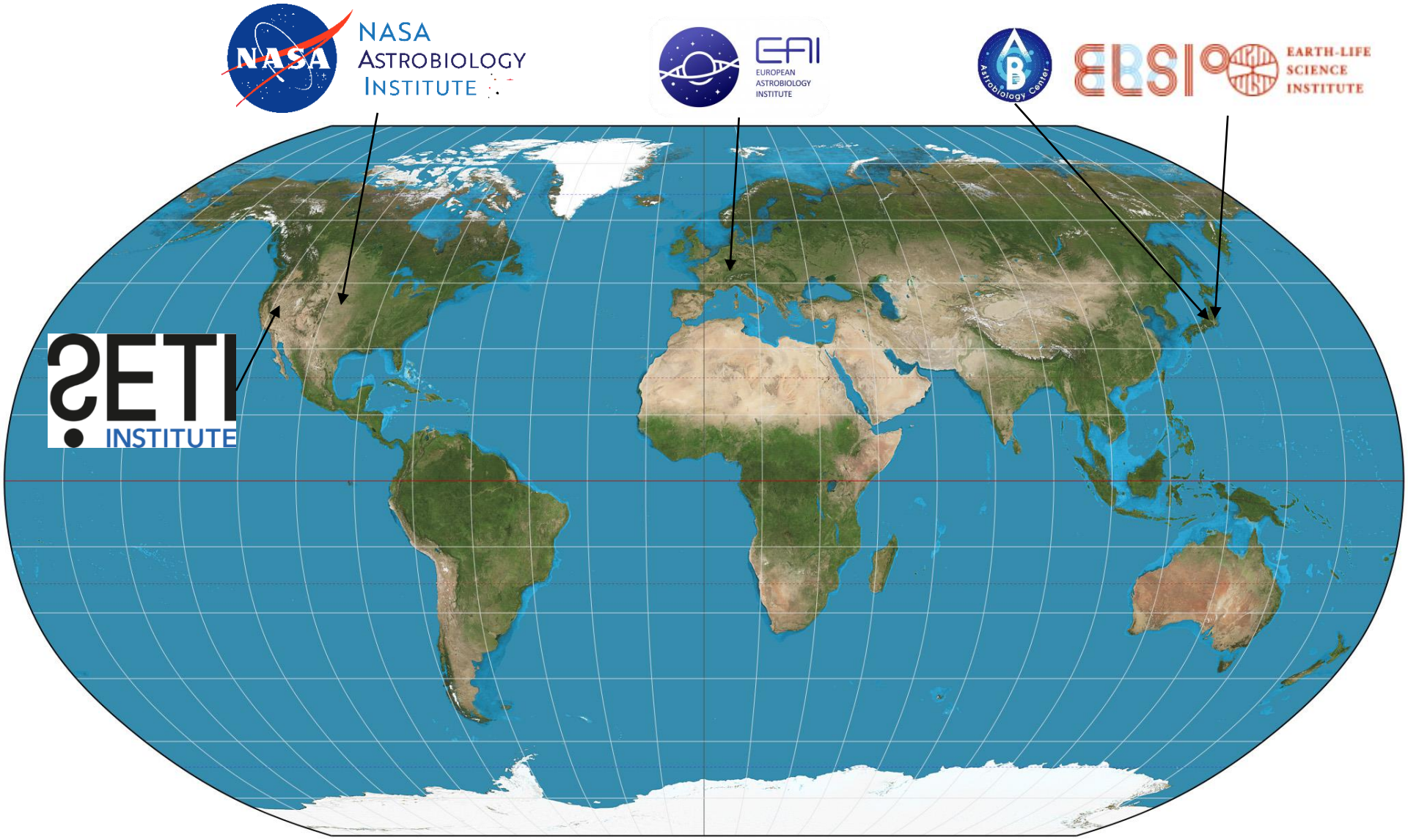


天体生物学的研究内容

研究宇宙中生命的起源，进化，分布和未来的交叉学科

–NASA天体生物学研究所




NASA
NASA ASTROBIOLOGY INSTITUTE
EAI
EUROPEAN ASTROBIOLOGY INSTITUTE
Astrobiology Center
EARTH-LIFE SCIENCE INSTITUTE
SETI INSTITUTE

本次报告的内容

太阳系外行星

生命起源

地外生命探索

太阳系外行星

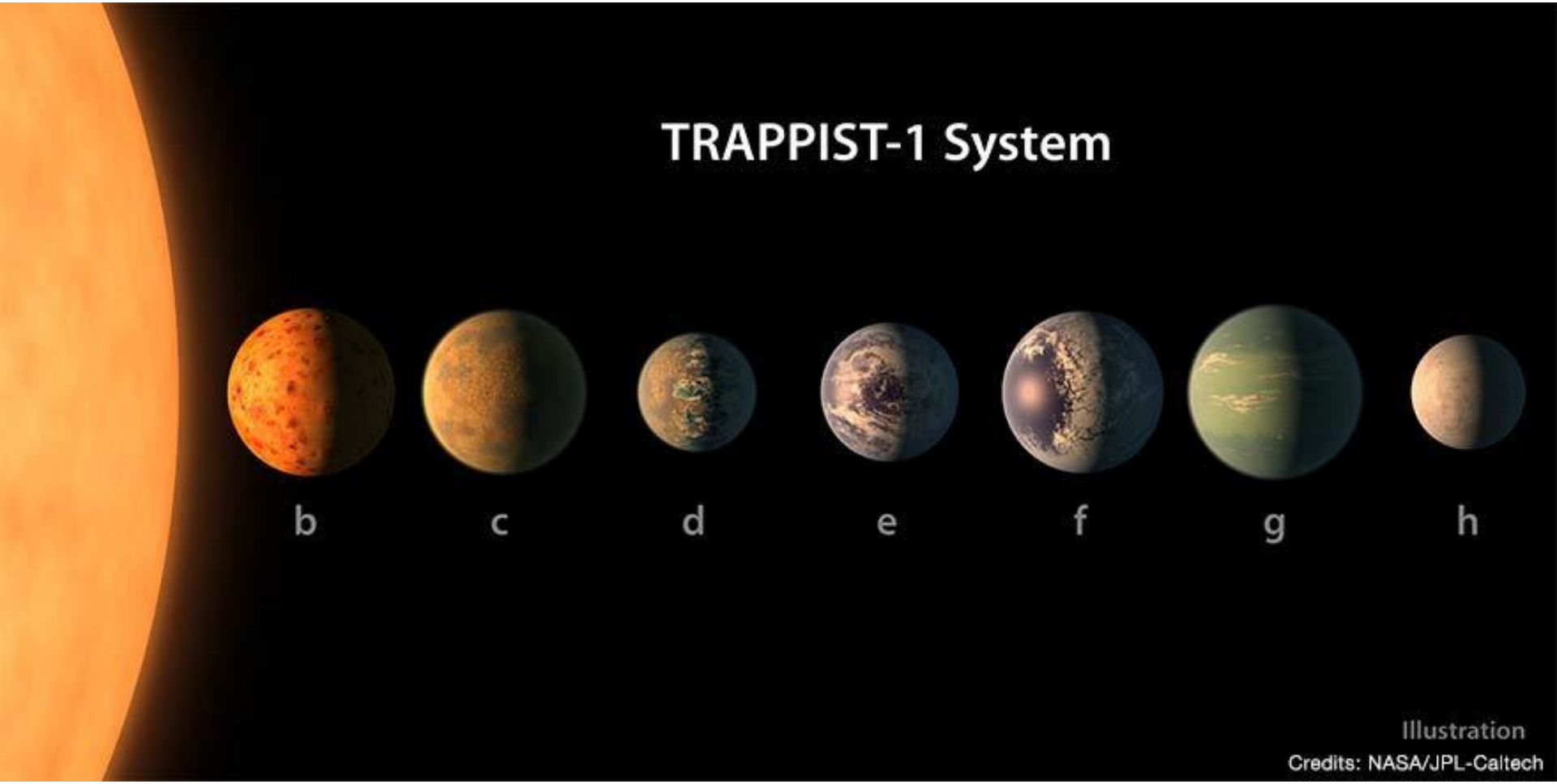

TRAPPIST-1 System
b
c
d
e
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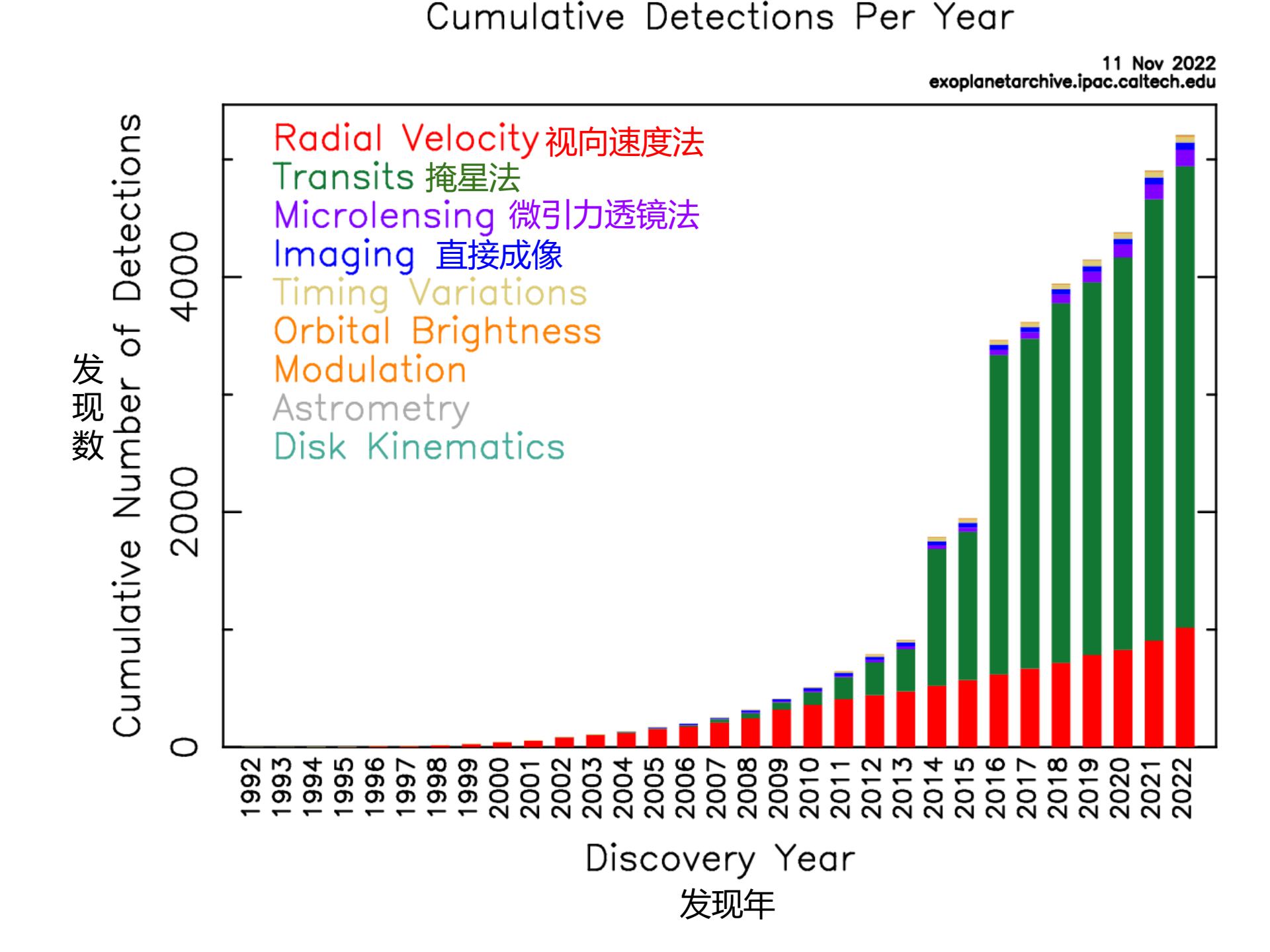
Illustration
Credits: NASA/JPL-Caltech


Cumulative Detections Per Year
11 Nov 2022
exoplanetarchive.ipac.caltech.edu
Radial Velocity 视向速度法
Transits 掩星法
Microlensing 微引力透镜法
Imaging 直接成像
Timing Variations
Orbital Brightness Modulation
Astrometry
Disk Kinematics
Cumulative Number of Detections
发现数
0
2000
4000
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Discovery Year
发现年

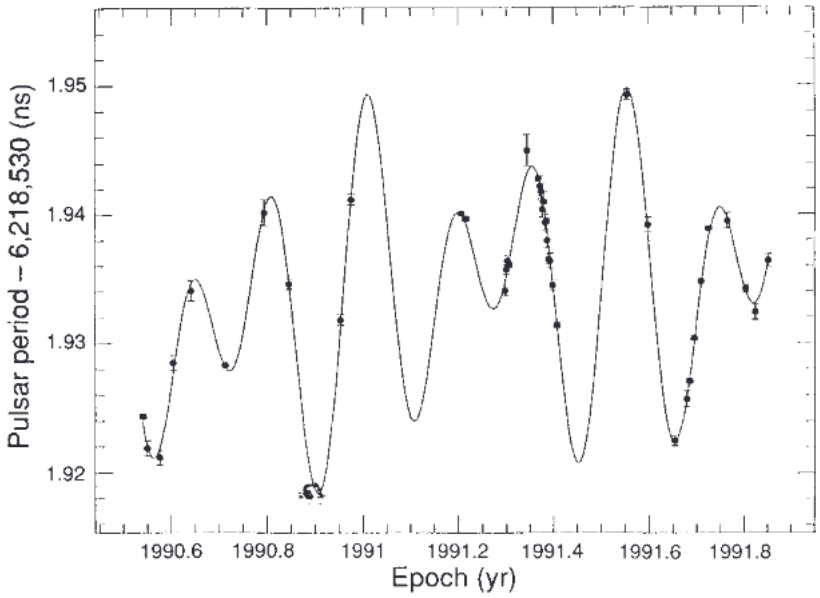
首次发现：脉冲星周围

A planetary system around the millisecond pulsar PSR1257+12

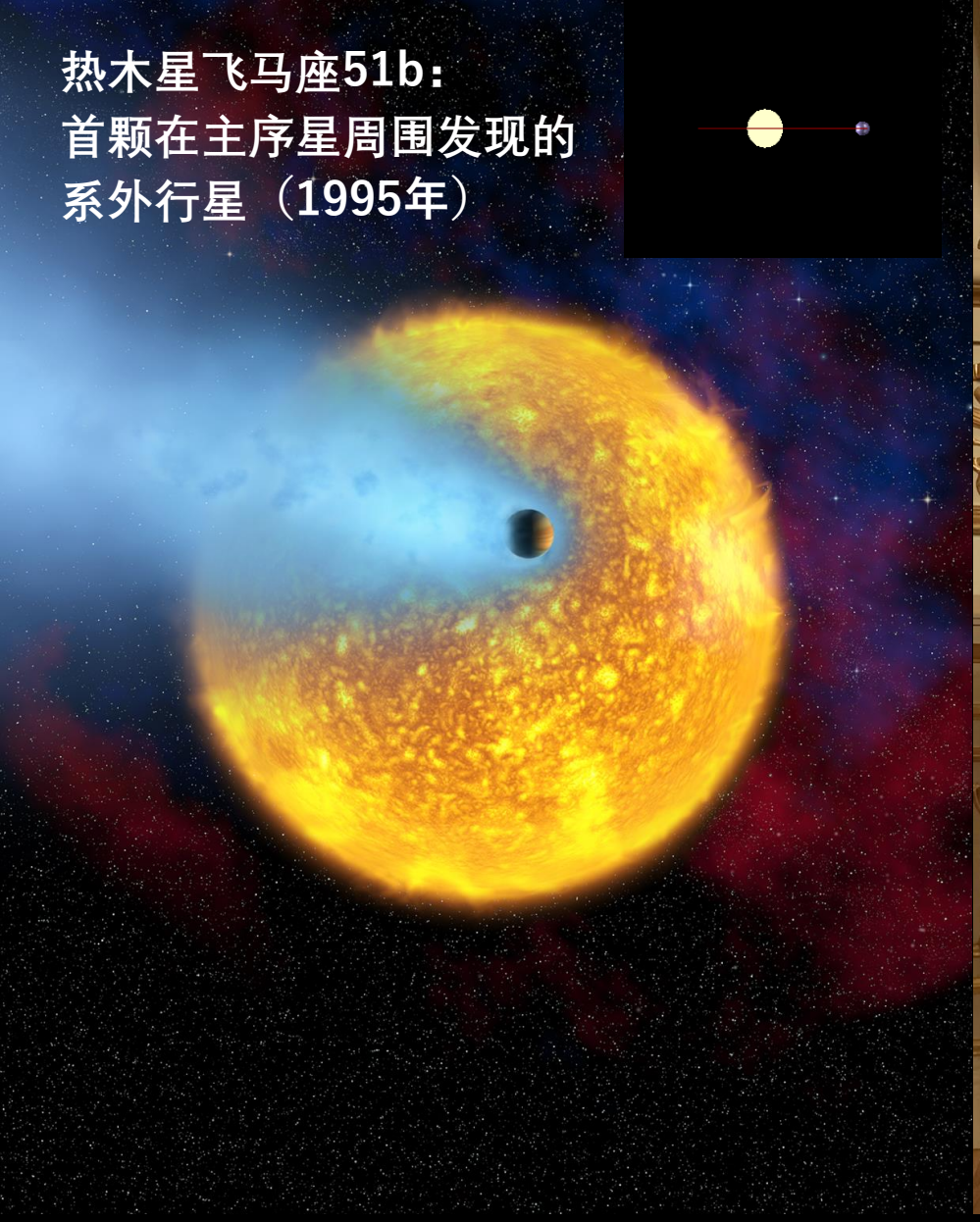
A. Wolszczan* & D. A. Frail†

* National Astronomy and Ionosphere Center, Arecibo Observatory, Arecibo, Puerto Rico 00613, USA
† National Radio Astronomy Observatory, Socorro, New Mexico 87801, USA

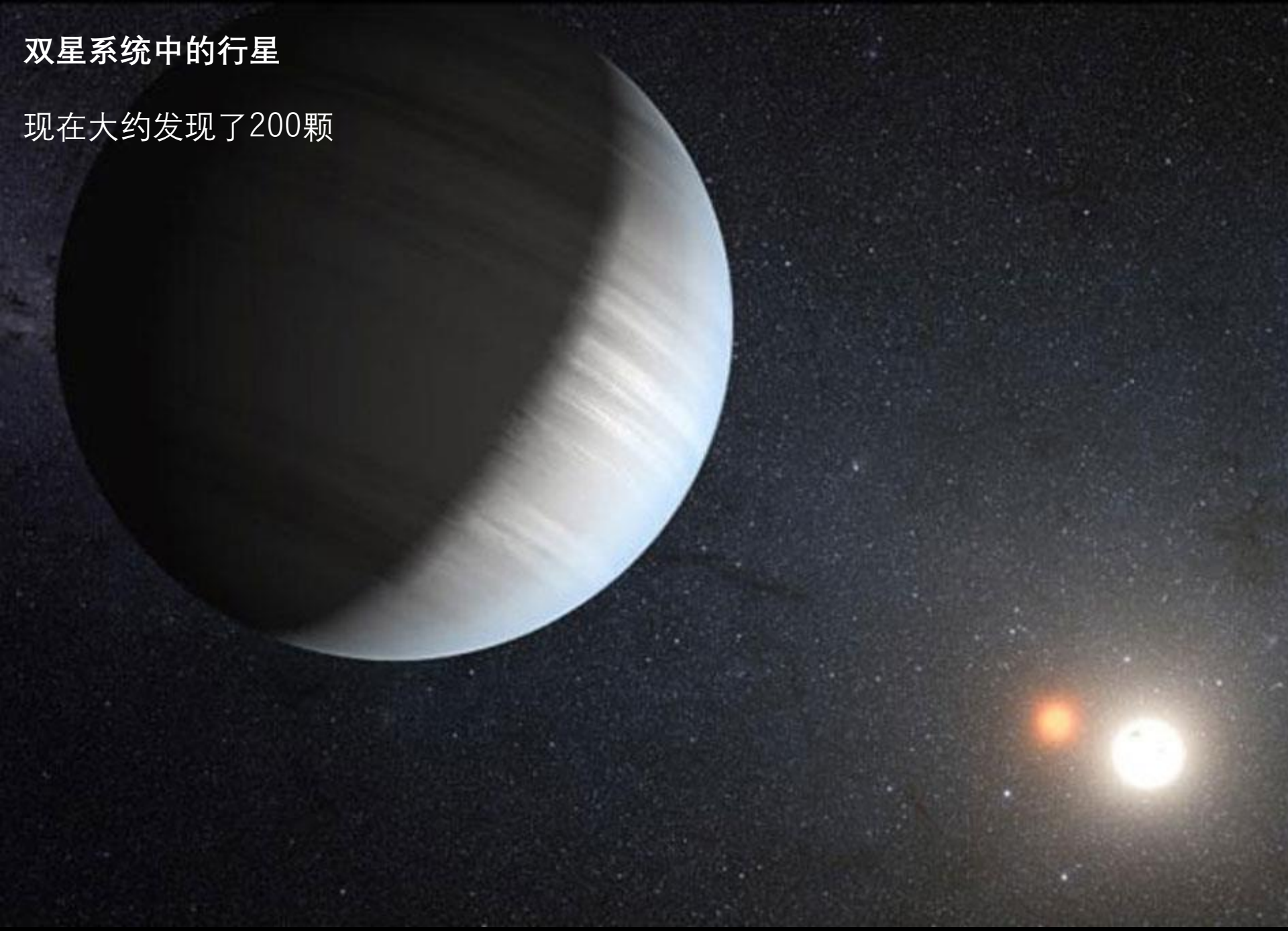
MILLISECOND radio pulsars, which are old ($\sim 10^9$ yr), rapidly rotating neutron stars believed to be spun up by accretion of matter from their stellar companions, are usually found in binary systems with other degenerate stars[1]. Using the 305-m Arecibo radiotelescope to make precise timing measurements of pulses from the recently discovered 6.2-ms pulsar PSR1257+12 (ref. 2), we demonstrate that, rather than being associated with a stellar object, the pulsar is orbited by two or more planet-sized bodies. The planets detected so far have masses of at least 2.8 $M_\oplus$ and 3.4 $M_\oplus$, where $M_\oplus$ is the mass of the Earth. Their respective distances from the pulsar are 0.47 AU and 0.36 AU, and they move in almost circular orbits with periods of 98.2 and 66.6 days. Observations indicate that at least one more planet may be present in this system. The detection of a planetary system around a nearby (~ 500 pc), old neutron star, together with the recent report on a planetary companion to the pulsar PSR1829−10 (ref. 3) raises the tantalizing possibility that a non-negligible fraction of neutron stars observable as radio pulsars may be orbited by planet-like bodies.



热木星飞马座51b：
首颗在主序星周围发现的
系外行星（1995年）

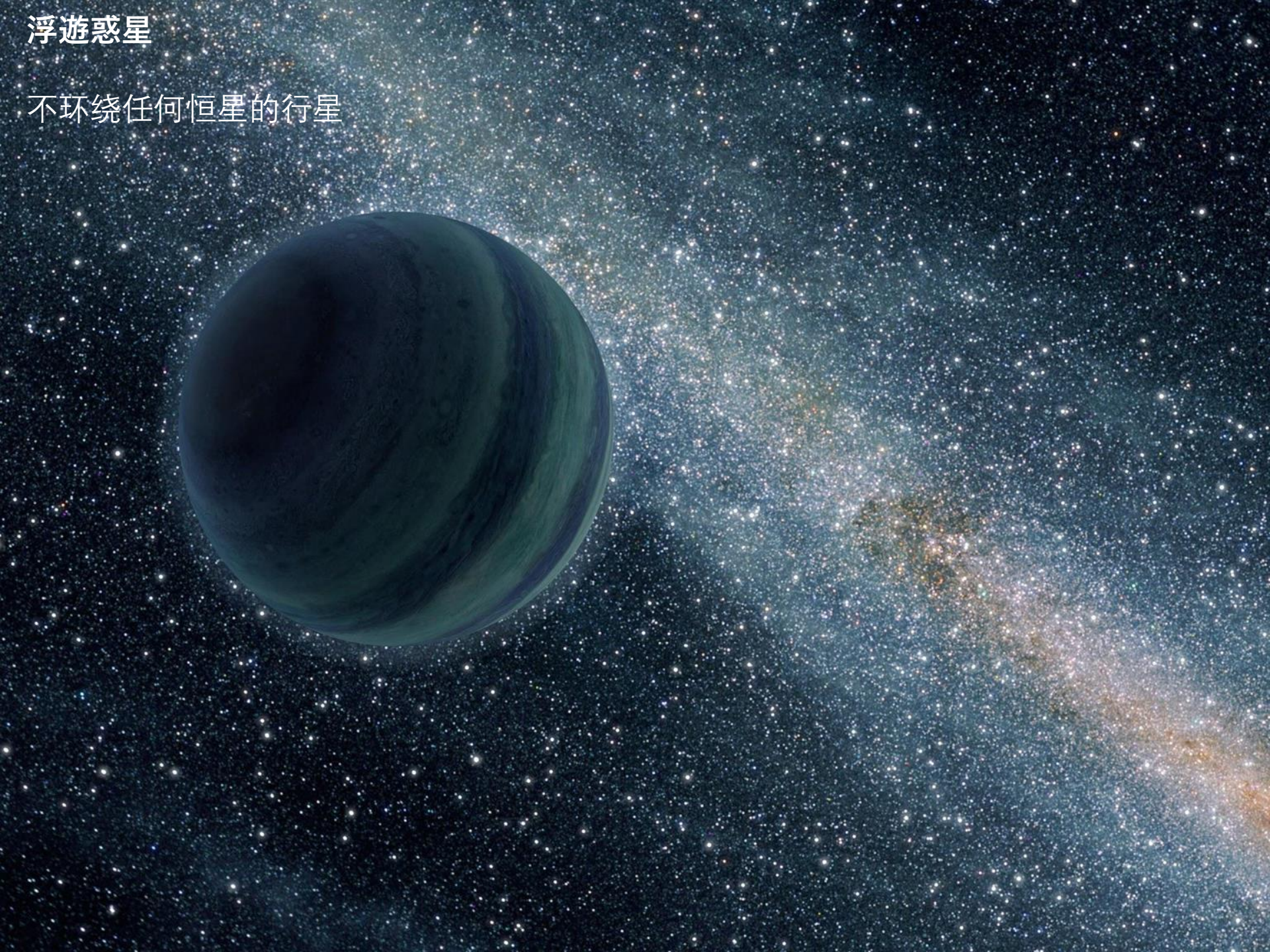


2019年诺贝尔奖
麦克·梅耶和迪迪尔·奎洛兹

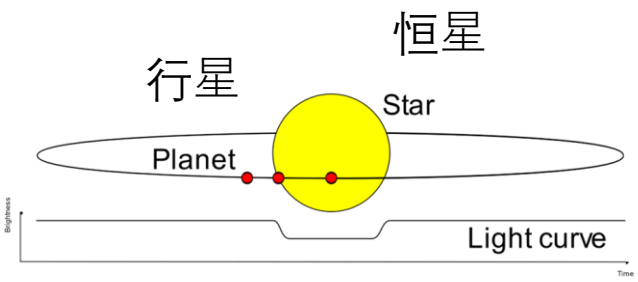

双星系统中的行星
现在大约发现了200颗

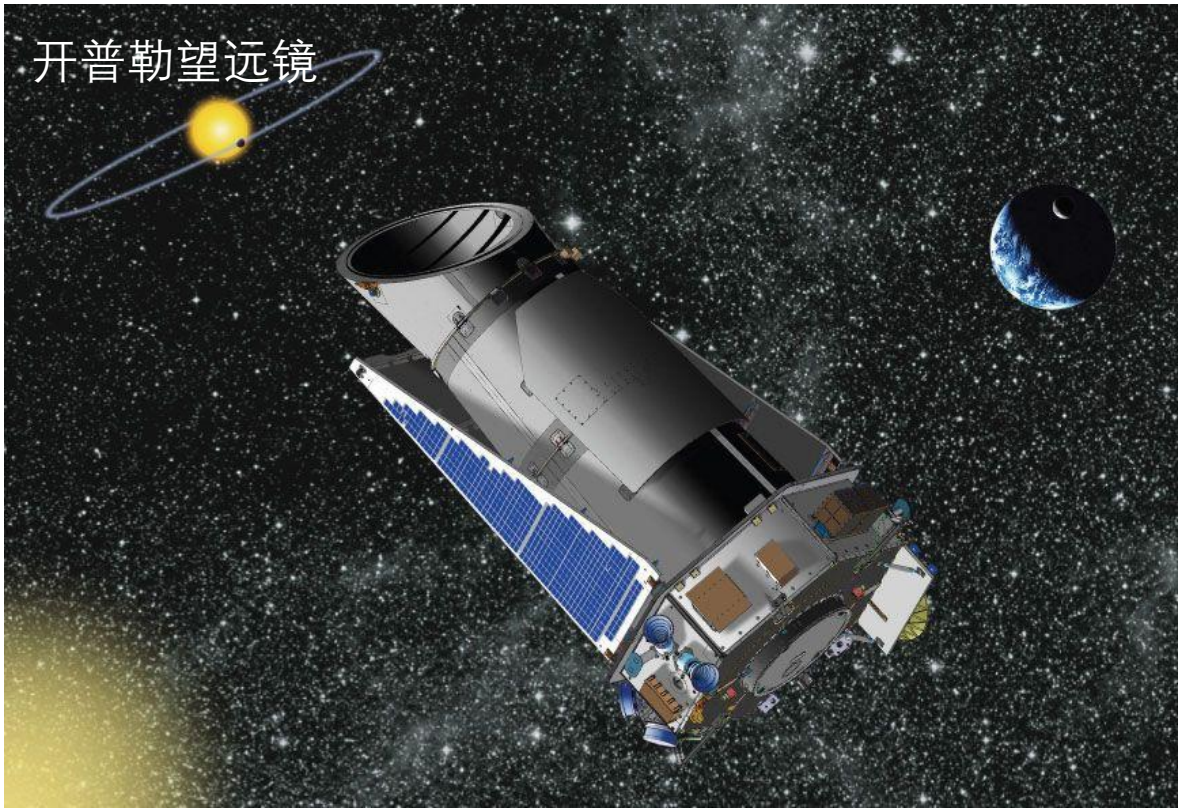
浮遊惑星

不环绕任何恒星的行星



探测方法：掩星法

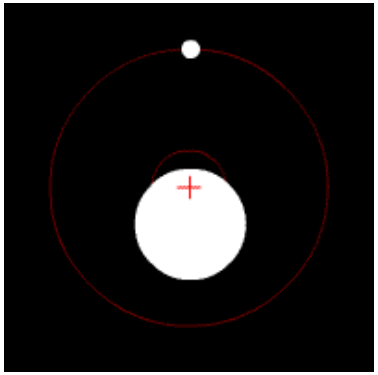


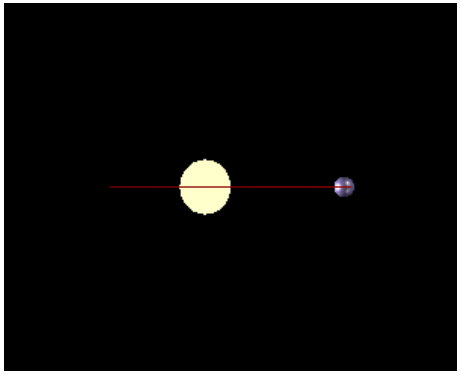


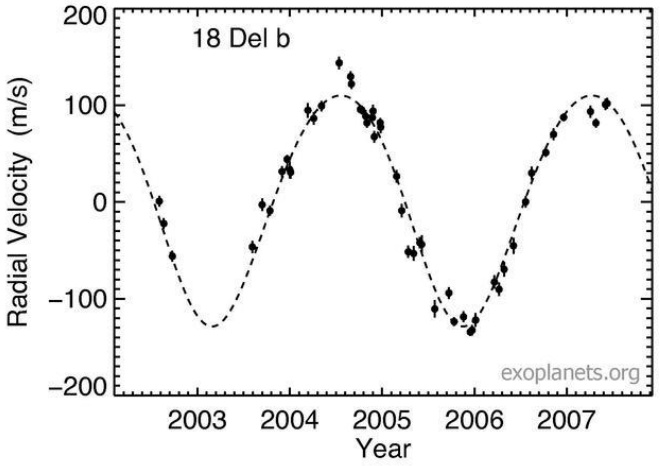
视向速度法

- 精度: 0.1m/s
- 地球大小的行星可以被探测到

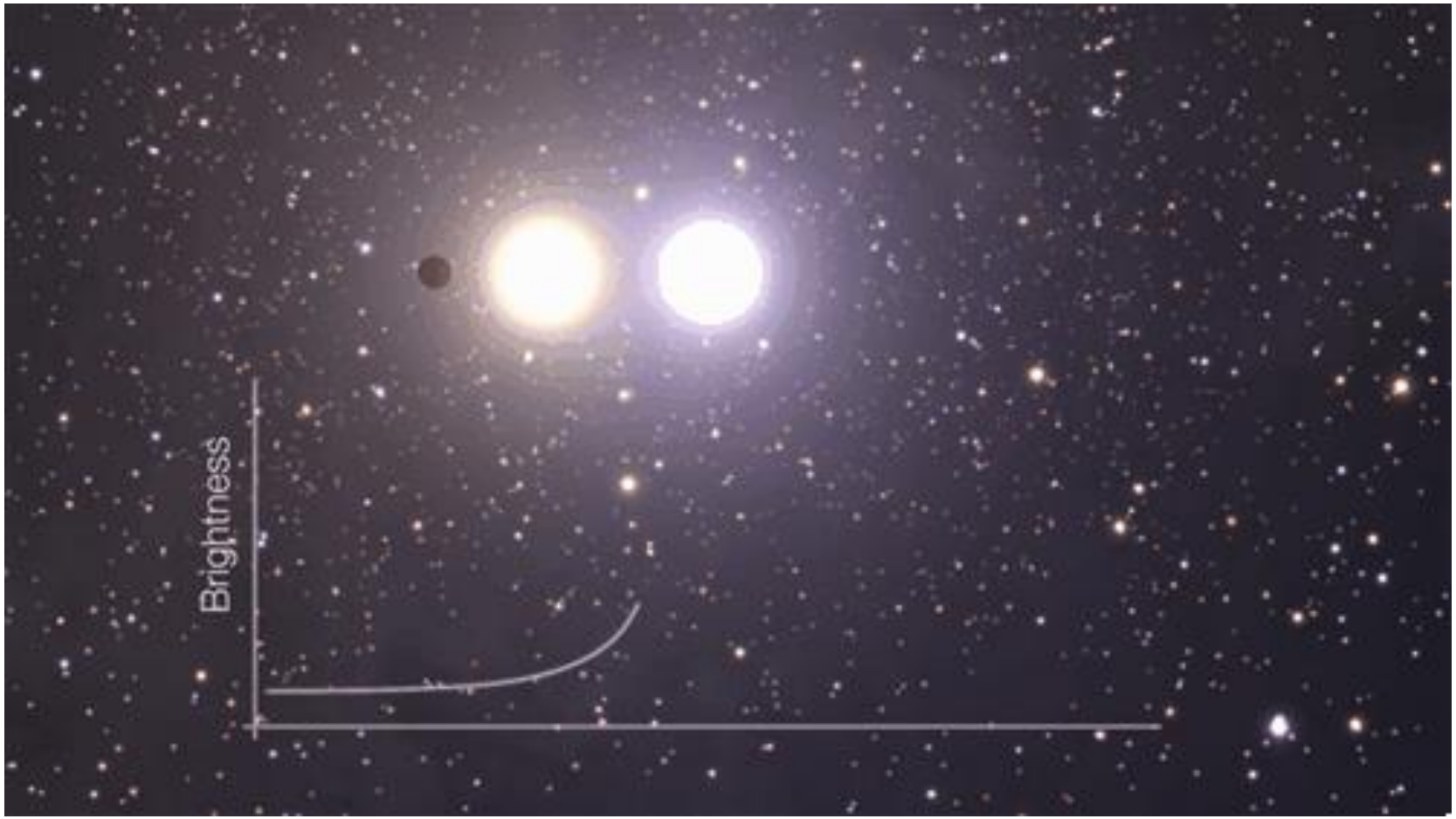
- 天体测量法:
- GAIA: 海王星质量的行星



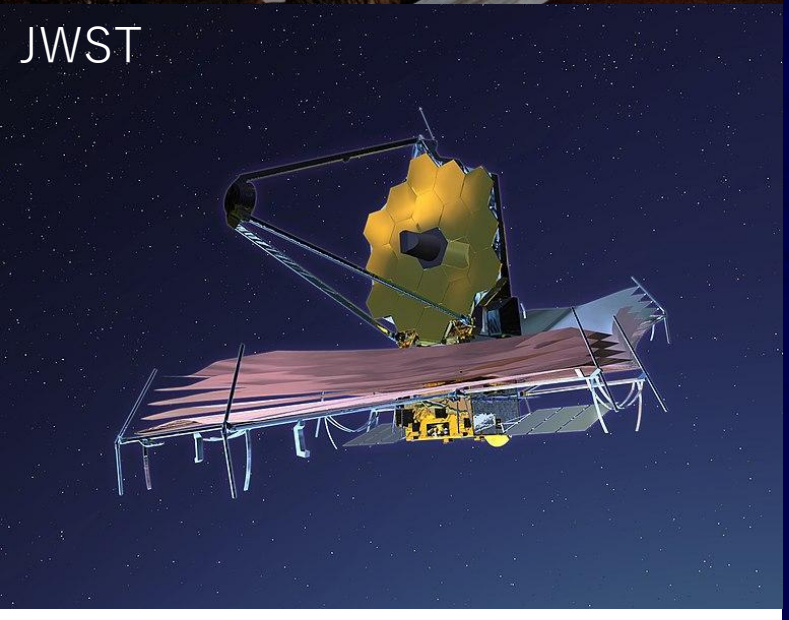


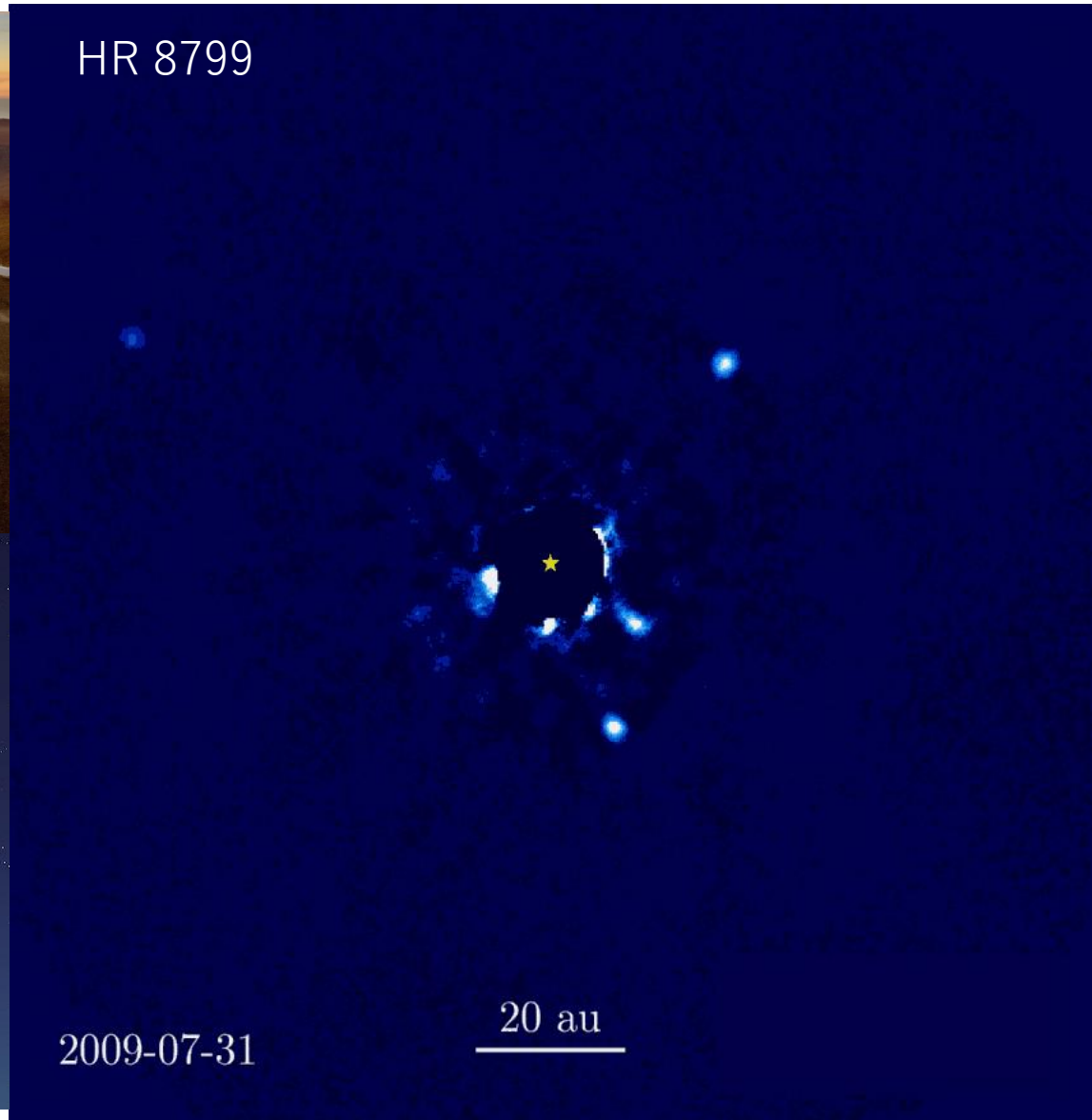


微引力透镜法



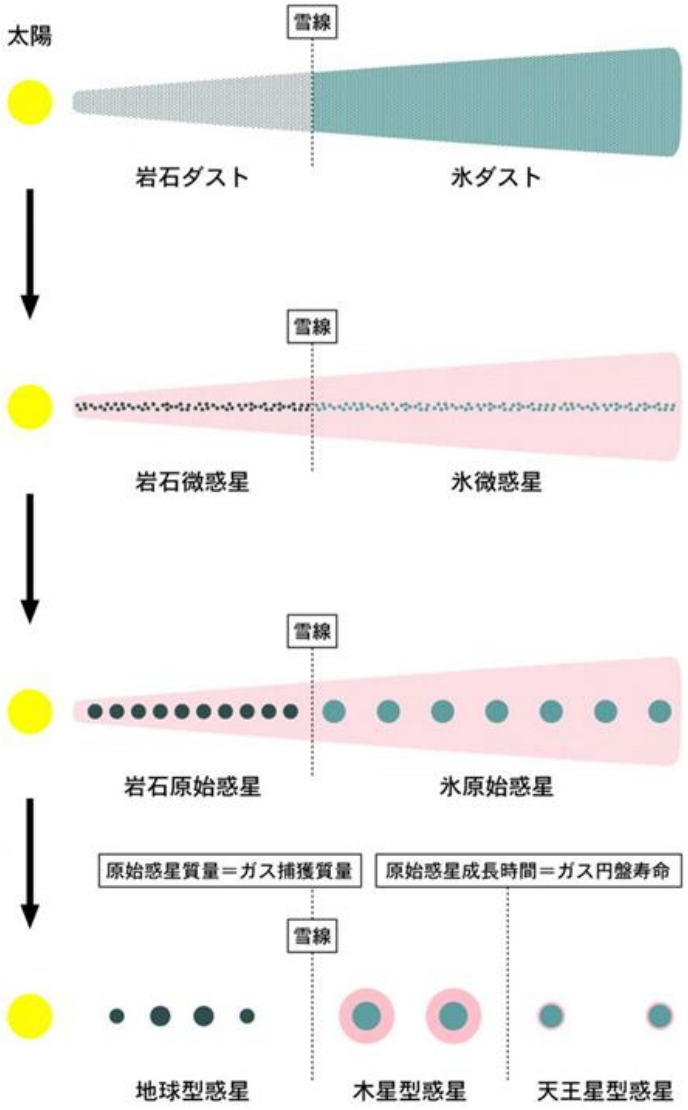
系外行星的直接成像



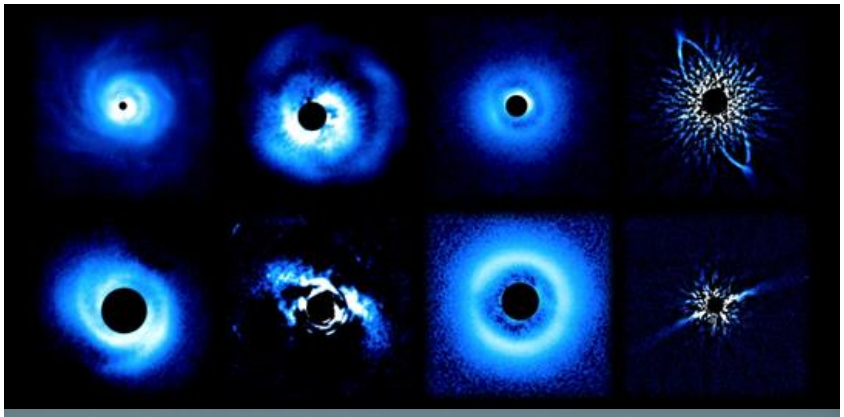


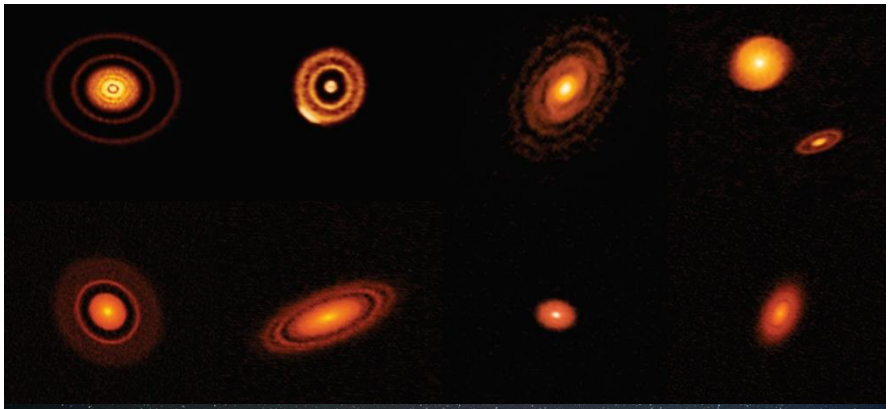
行星的形成

- 核吸积模型：
  - 可以解释大部分行星的形成
  - 问题：核心如何形成，时间可能不够
- 重力不稳定模型:
  - 时间足够 (约1000年)
  - 问题：需要大质量的原行星盘，远离中心恒星



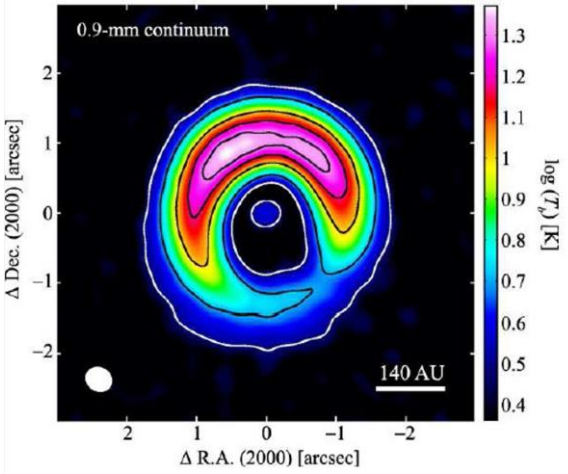
行星的摇篮：原行星盘



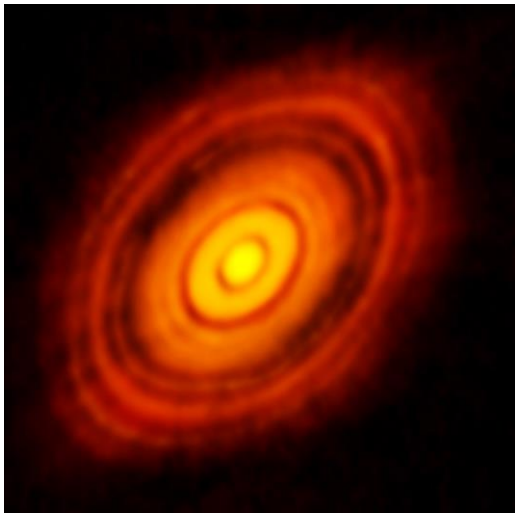


原行星盘结构

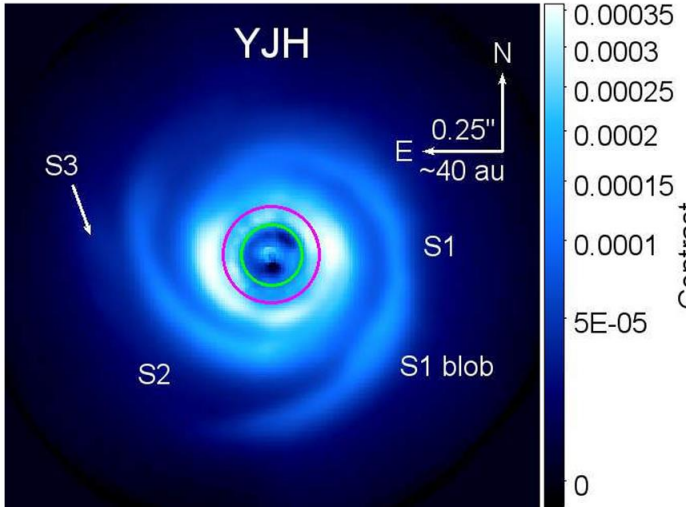
- 可能与行星形成有关



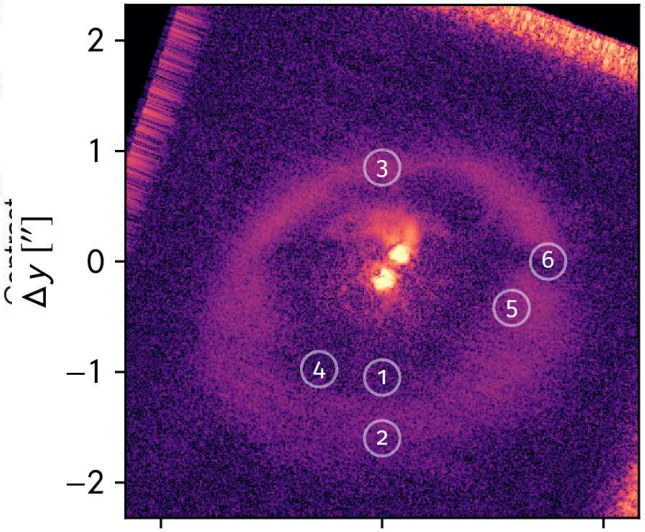
非对称结构



环

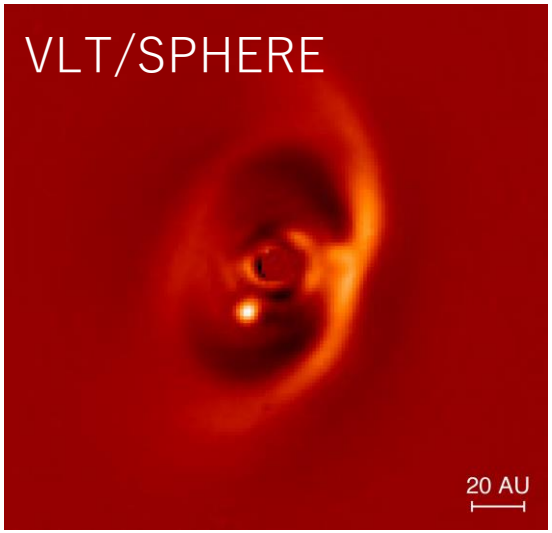


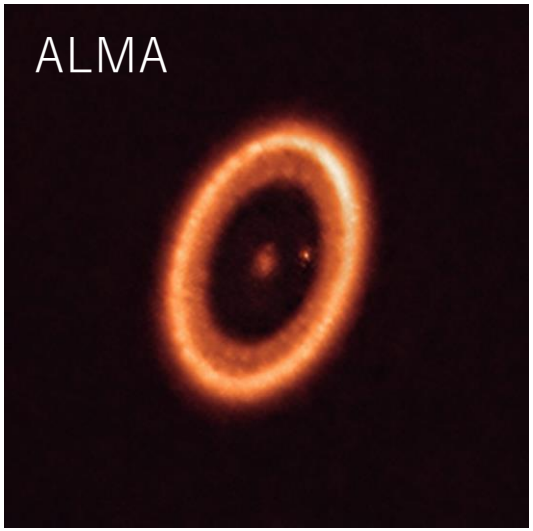
旋臂



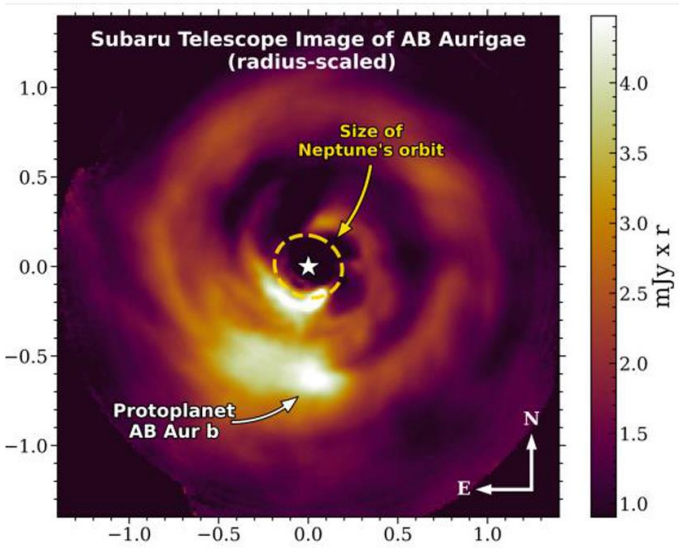
双星系统

形成中的行星





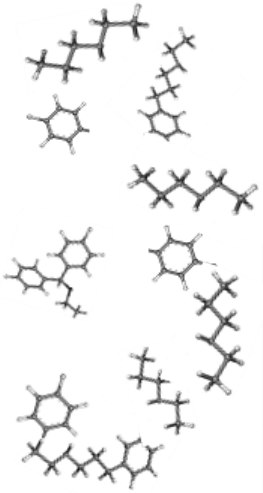
PDS 70



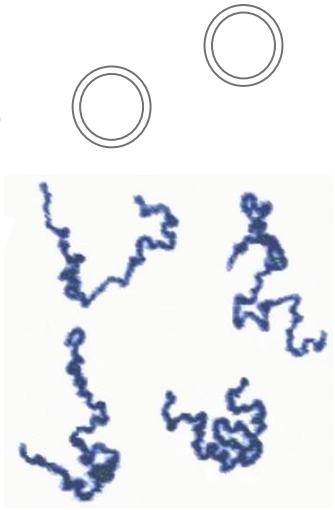
AB Aur

生命的起源

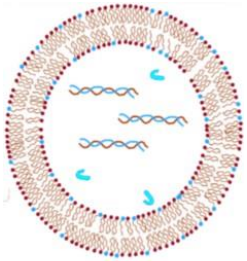
Habitable world



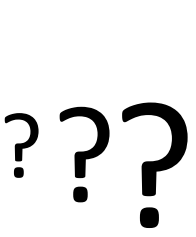
Prebiotic synthesis



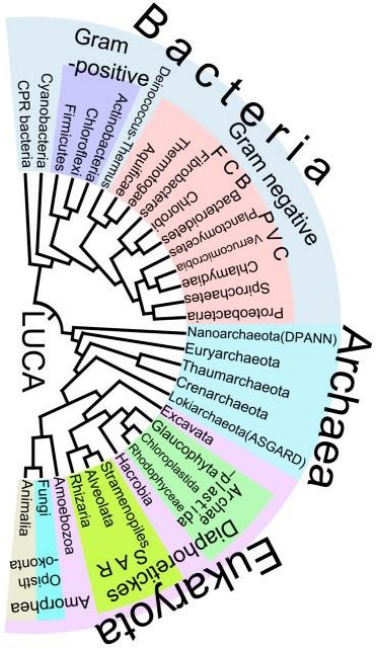
Polymers, vesicles



… Protocells? …



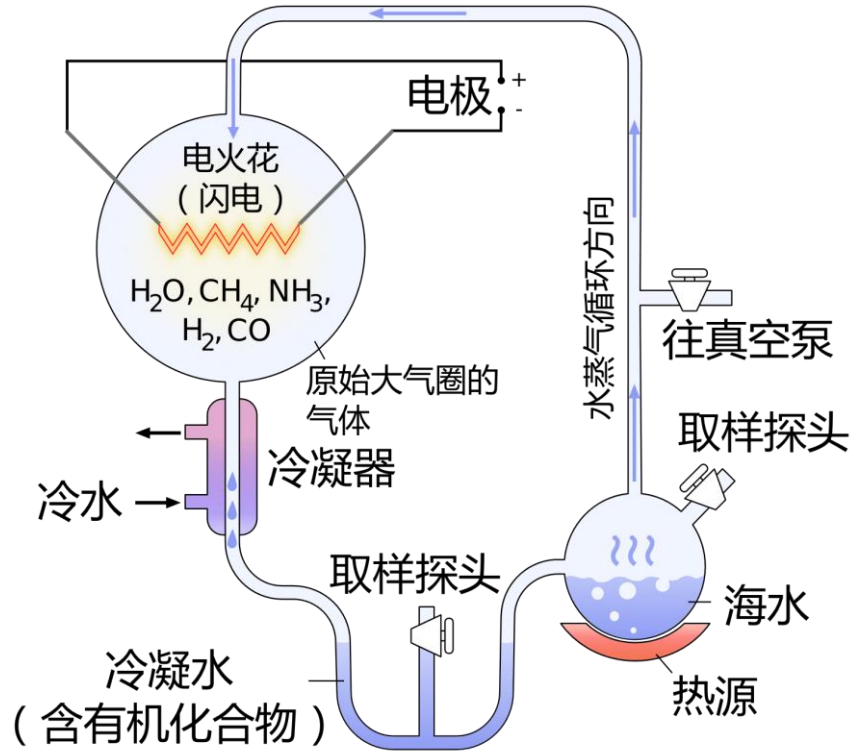
LUCA

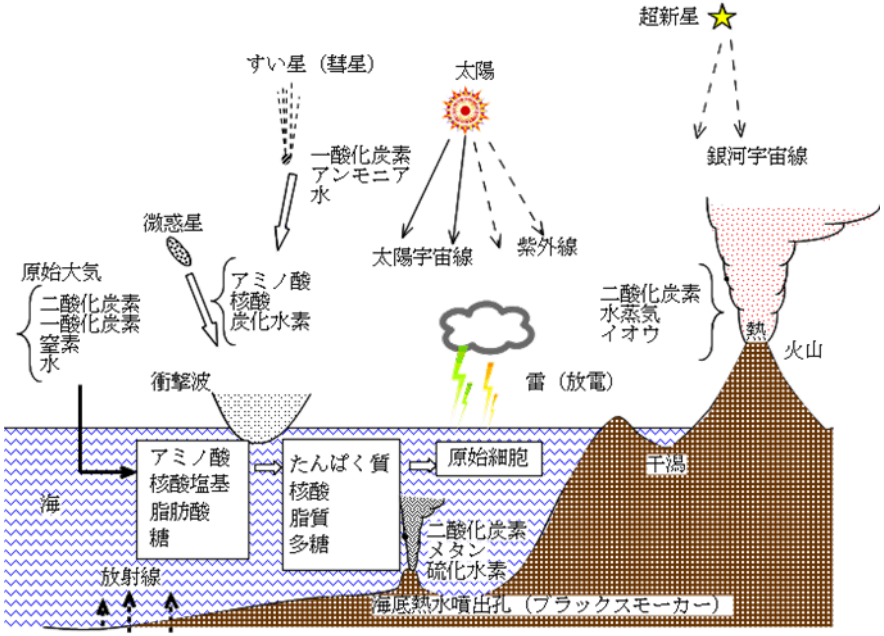


Diversity of life

生命起源：化学进化

尤里-米勒实验(1950s)

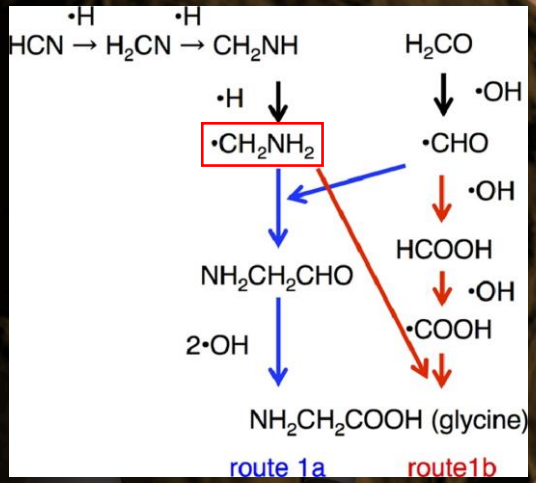




生命形成的环境

星际有机分子

- 陨石中存在嘌呤，嘧啶和氨基酸
- 生命大分子可能先在太空中形成？

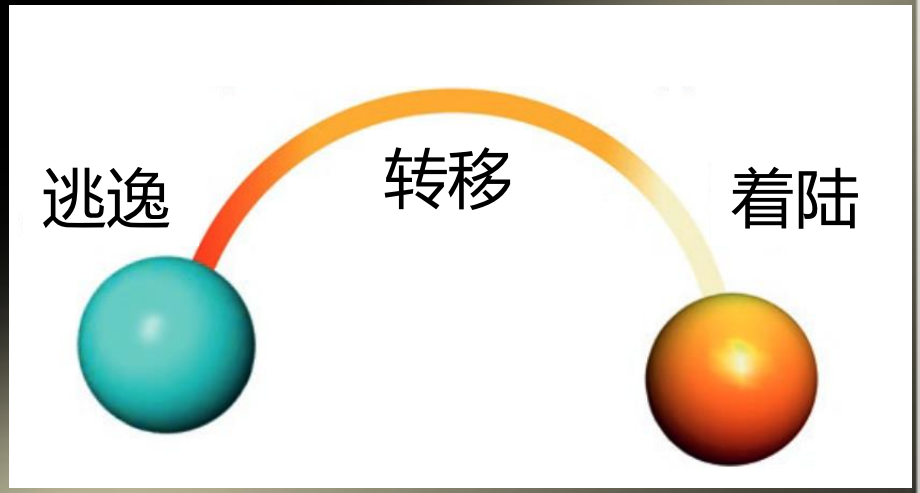


合成甘氨酸的路径

Table 1.2 Molecules found in interstellar clouds

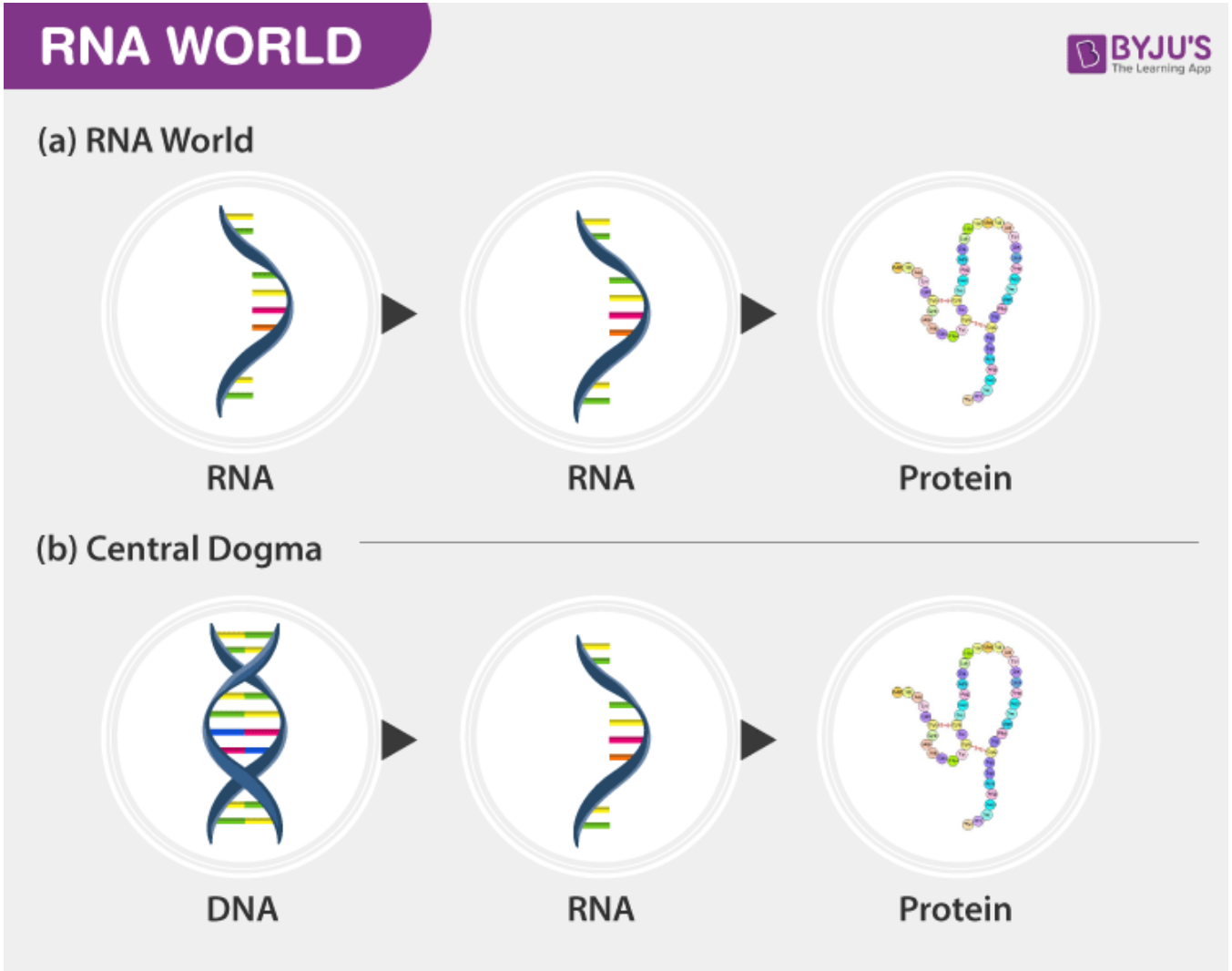
Simple neutral molecules
H_2, CH, CN, CO, HCl, NH, NO, NS, OH, PN, SO, SiO, SiS, CS, HF, O_2, SH, CH_2, HCN, HCO, H_2O, H_2S, HNC, HNO, N_2O, OCS, SO_2, CO_2, NH_2, HO_2, NH_3, H_2CO, H_2CS, CH_3, H_2O_2, CH_4
Ionic species
(Cation)
CH^+, CO^+, SO^+, CF^+, OH^+, SH^+, HCl^+, ArH^+, HCO^+, HCS^+, HOC^+, N_2H^+, H_3^+, H_2O^+, H_2Cl^+, OH_3^+, $HCNH^+$, HCO_2^+, C_3H^+, H_2COH^+, NH_4^+, H_2NCO^+, HC_3NH^+
(Anion)
C_4H^-, C_6H^-, C_8H
Carbon-chain molecules and their isomers
C_2, C_3, C_2H, C_2O, C_2S, c-C_3H, l-C_3H, C_3N, C_3O, C_3S, C_2H_2, C_5, C_4H, l-C_3H_2, c-C_3H_2, HC_3N, HCCNC, HNC_3, C_5H, l-C_4H_2, C_5N, C_6H, CH_3CCH, HC_5N, CH_3C_3N, C_6H_2, CH_2CCHCN, CH_3C_4H, HC_7N, CH_3C_5N, HC_9N, CH_3C_6H, $HC_{11}N$
Complex organic molecules
HCOOH, CH_2CO, CH_3CN, CH_3NC, CH_3OH, CH_3SH, HC_2CHO, c-C_3H_2O, CH_2CNH, HNCHCN, CH_2CHCN, CH_3CHO, CH_3NH_2, c-C_2H_4O, H_2CCHOH, $HCOOCH_3$, CH_3COOH, CH_2OHCHO, CH_2CHCHO, NH_2CH_2CN, CH_3CHNH, CH_3CH_2CN, $(CH_3)_2O$, CH_3CH_2OH, CH_3CONH_2, C_3H_6, CH_3CH_2SH, $(CH_3)_2CO$, $(CH_2OH)_2$, CH_3CH_2CHO, C_2H_5OCHO, CH_3OCOCH_3, $C_2H_5OCH_3$, n-C_3H_7CN
Other molecules
FeO, HNCO, HNCS, H_2CN, HCNO, HOCN, HSCN, CH_2CN, H_2CNH, NH_2CN, HCOCN, HNCNH, CH_3O, NH_2CHO

地球生命外来假说

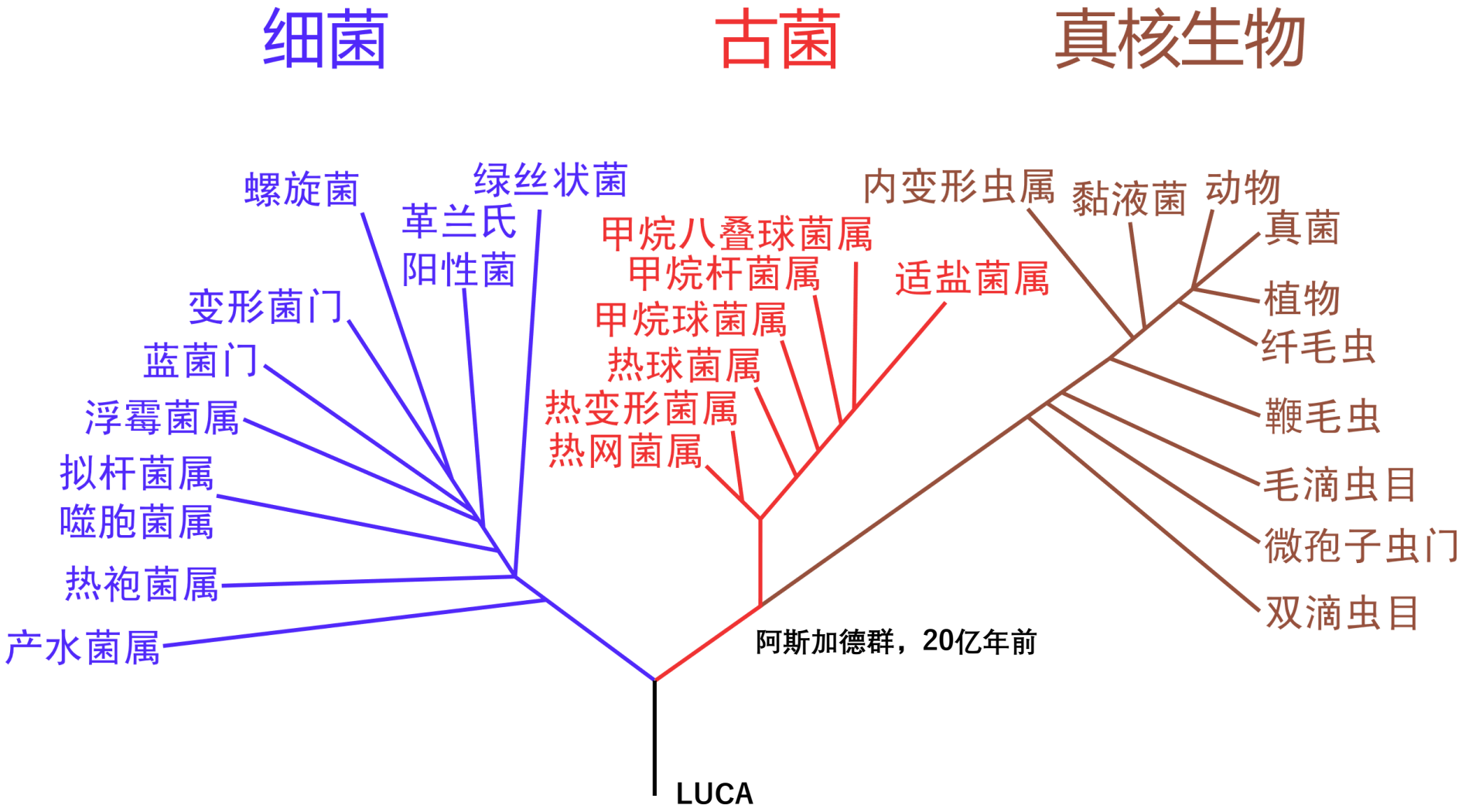


RNA世界假说

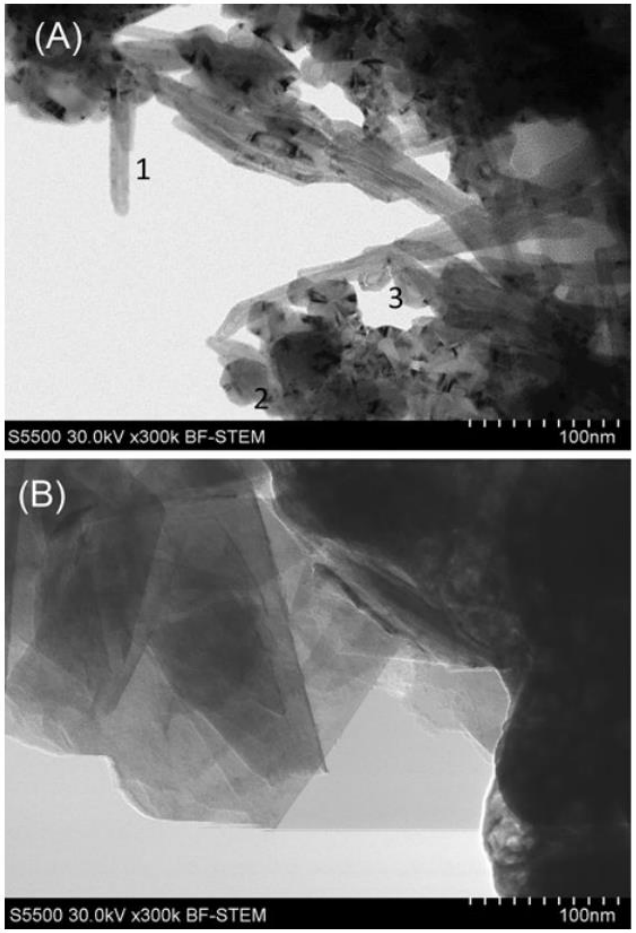
“分子生物学家之梦”：实验室下合成可自我复制的RNA



生物的进化

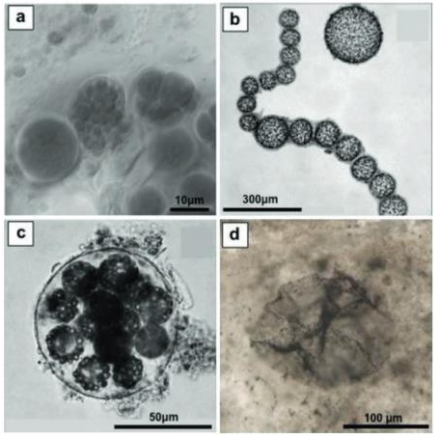

细菌
古菌
真核生物
螺旋菌
绿丝状菌
革兰氏
阳性菌
变形菌门
蓝菌门
浮霉菌属
拟杆菌属
噬胞菌属
热袍菌属
产水菌属
甲烷八叠球菌属
甲烷杆菌属
甲烷球菌属
热球菌属
热变形菌属
热网菌属
适盐菌属
内变形虫属
黏液菌
动物
真菌
植物
纤毛虫
鞭毛虫
毛滴虫目
微孢子虫门
双滴虫目
阿斯加德群，20亿年前
LUCA

最早的生命：~38亿年前



石墨

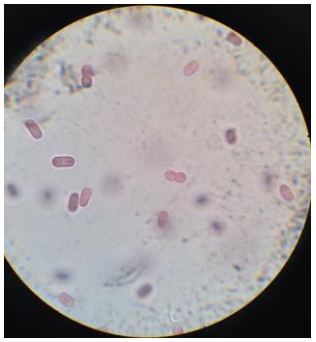
叠层石



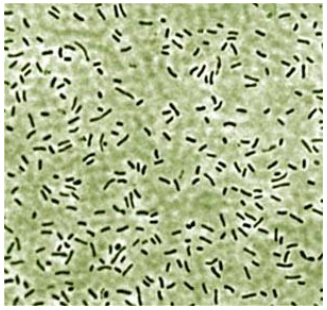
微化石

光合作用的出现大氧化事件（24亿年前）

34亿年前：
无氧光合作用：H_2S->S

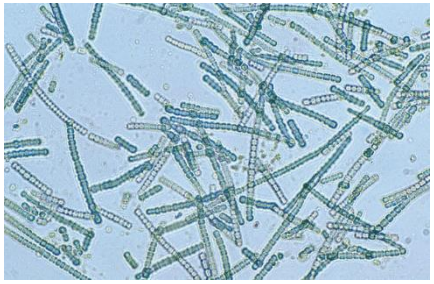


紫硫细菌（PS II）



绿硫细菌（PS I）

30亿年前：
产氧光合作用：H_2O->O_2

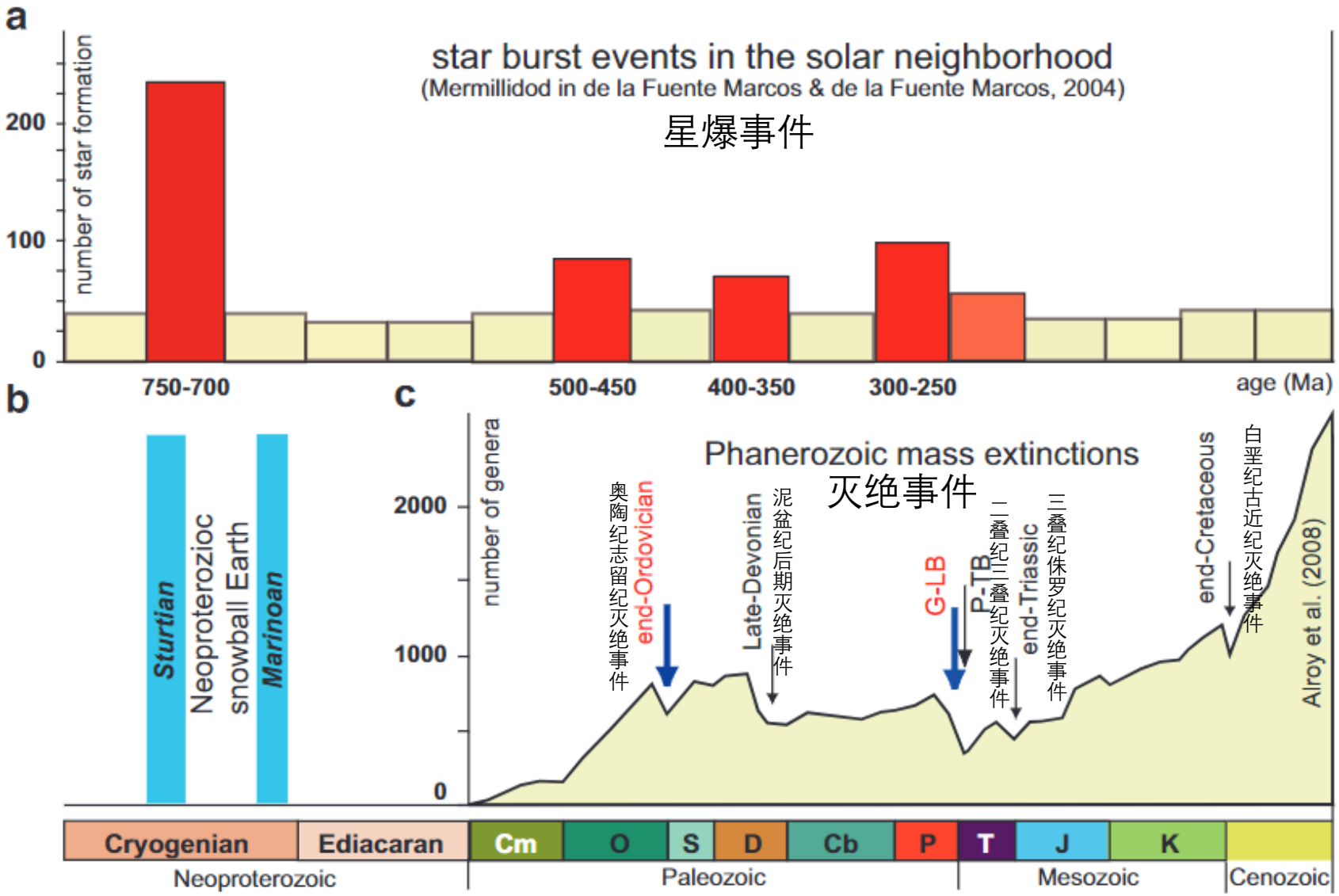


蓝细菌（PS I+PS II）

24亿年前：
大氧化事件，雪球地球

寒武纪生命大爆发：5.4亿年前

大灭绝和宇宙环境


a
star burst events in the solar neighborhood
(Mermillidod in de la Fuente Marcos & de la Fuente Marcos, 2004)
星爆事件
number of star formation
200
100
0
750-700
500-450
400-350
300-250
age (Ma)
b
Sturtian
Neoproterozioc
snowball Earth
Marinoan
c
number of genera
2000
1000
0
Phanerozoic mass extinctions
灭绝事件
奥陶纪志留纪灭绝事件
end-Ordovician
Late-Devonian
泥盆纪后期灭绝事件
G-LB
P-TB
二叠纪三叠纪灭绝事件
end-Triassic
三叠纪侏罗纪灭绝事件
end-Cretaceous
白垩纪古近纪灭绝事件
Alroy et al. (2008)
Cryogenian
Ediacaran
Cm
O
S
D
Cb
P
T
J
K
Neoproterozoic
Paleozoic
Mesozoic
Cenozoic

地外生命探索

最早的尝试：火星

interest. For example, the *Hellas* region comes out very bright in Martian colors, strikingly so as compared with the polar cap, which is strong in the blue of the spectrum. The so-called "Seas" or large dark regions are much darker in the longer wave-lengths than in the green and blue, as has been shown by the direct photographs. It is hoped that some assistance in these studies will be got from spectral comparisons of variously colored terrestrial landscapes.

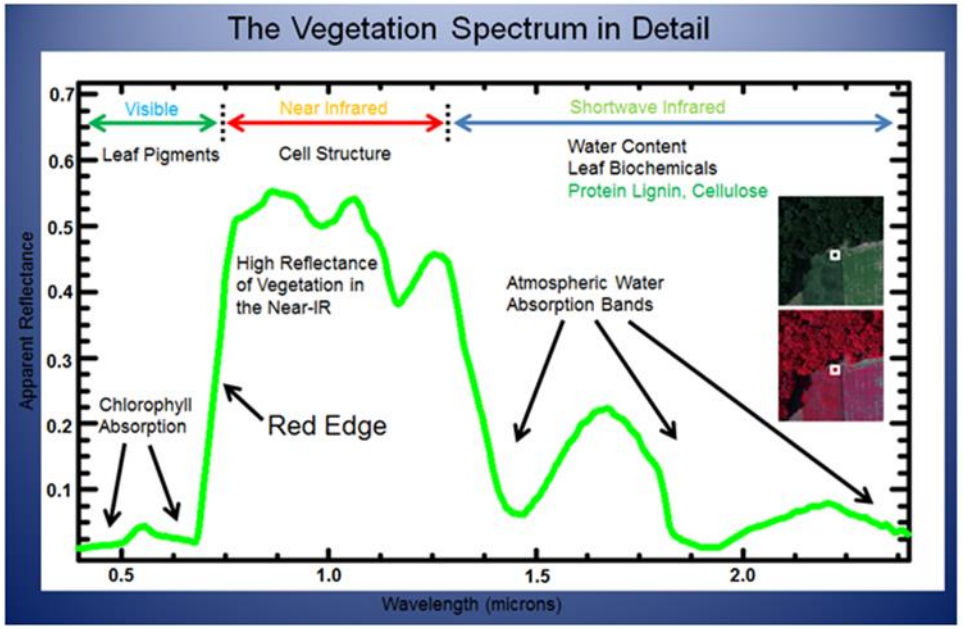
An interesting observation concerned with these large dark areas is the test for chlorophyl. Some such tests for chlorophyl were made here several oppositions ago, but not under very favorable conditions either as regards quality of the spectrograms or the seasonal conditions of the regions observed, hence the negative evidence could not be given much confidence.

Terrestrially the chlorophyl spectrum may be studied in two ways: one is by using chlorophyl in solution and getting the spectrum by transmitted light, the other, by observing the spectrum of sunlight reflected by vegetation. The two spectra are very different. The solution spectrum is much the more definite showing strong blue and violet absorption and the well-known dark band about λ6600. It is the one commonly described and published and so is best known. The reflection spectrum from vegetation is not at all definite visually as its most distinctive feature is its brilliancy in the deep red, beyond the sensitivity of the eye. From this point it is faint until the blue is reached where it again brightens somewhat. Obviously the solution spectrum is no guide to what to look for in the spectrum of chlorophyl in light reflected by vegetation, which is much the more difficult to recognize.

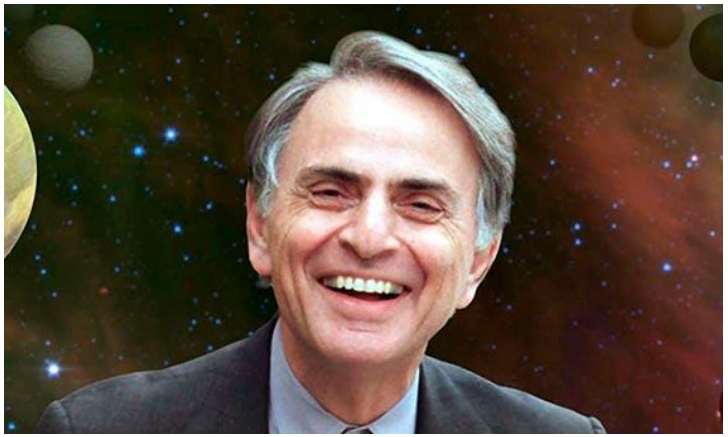
In the case of *Mars*, of course, we are dealing with the reflection spectrum. The Martian spectra of the dark regions so far do not give any certain evidence of the typical reflection spectrum of chlorophyl. The amount and types of vegetation required to make the effect noticeable is being investigated by suitable terrestrial exposures.

维斯托·斯里弗（1924）

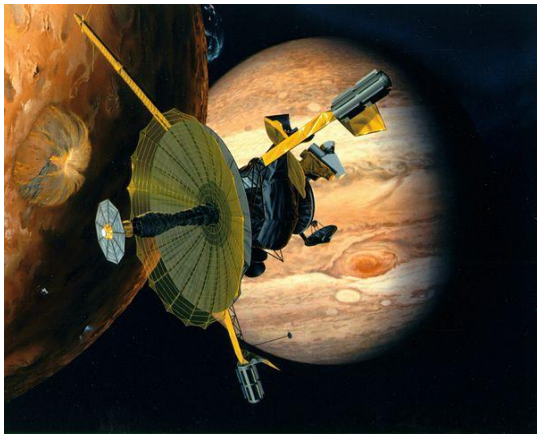
叶绿素的红边



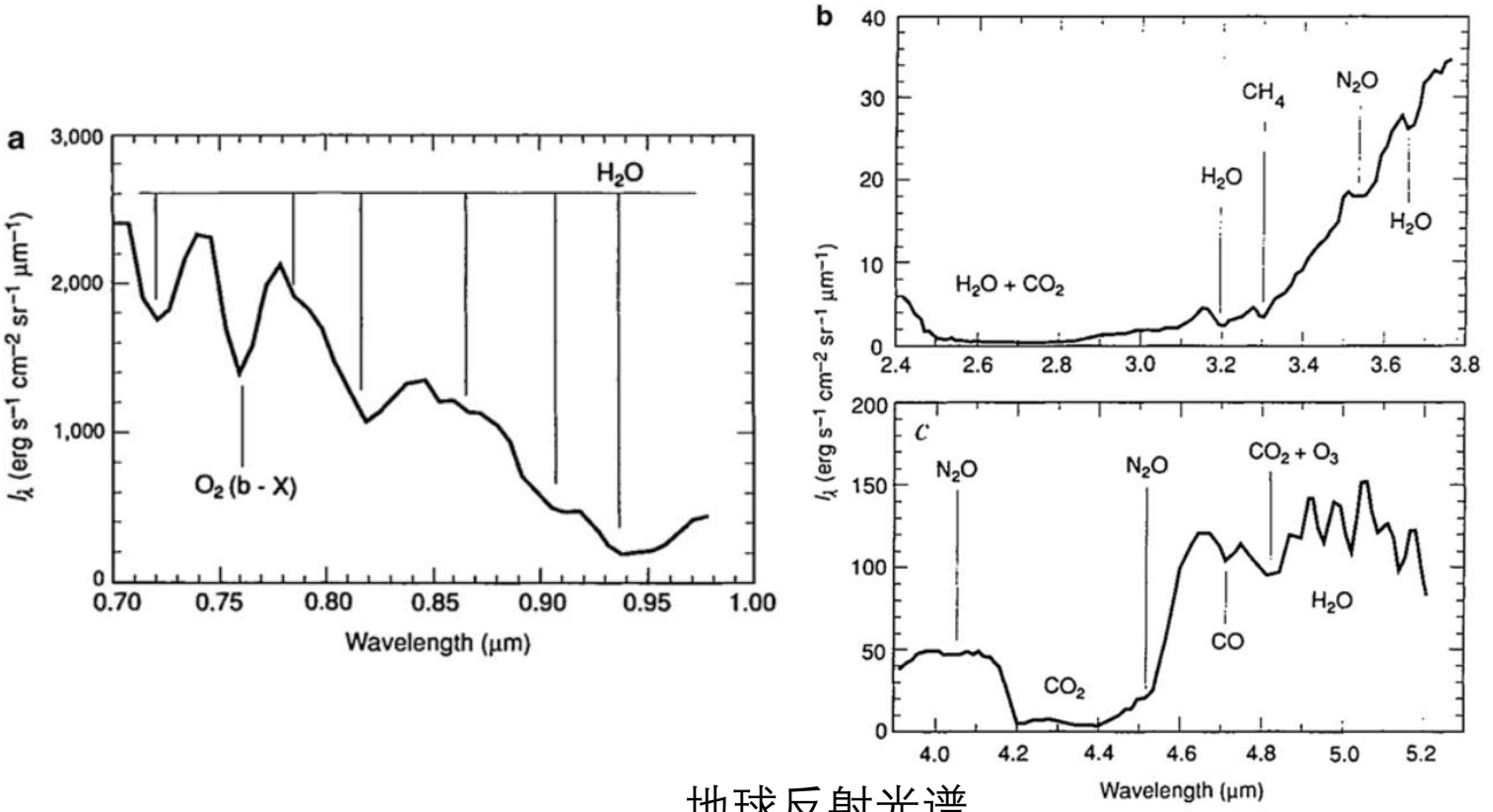
对地球的观测（1990年）



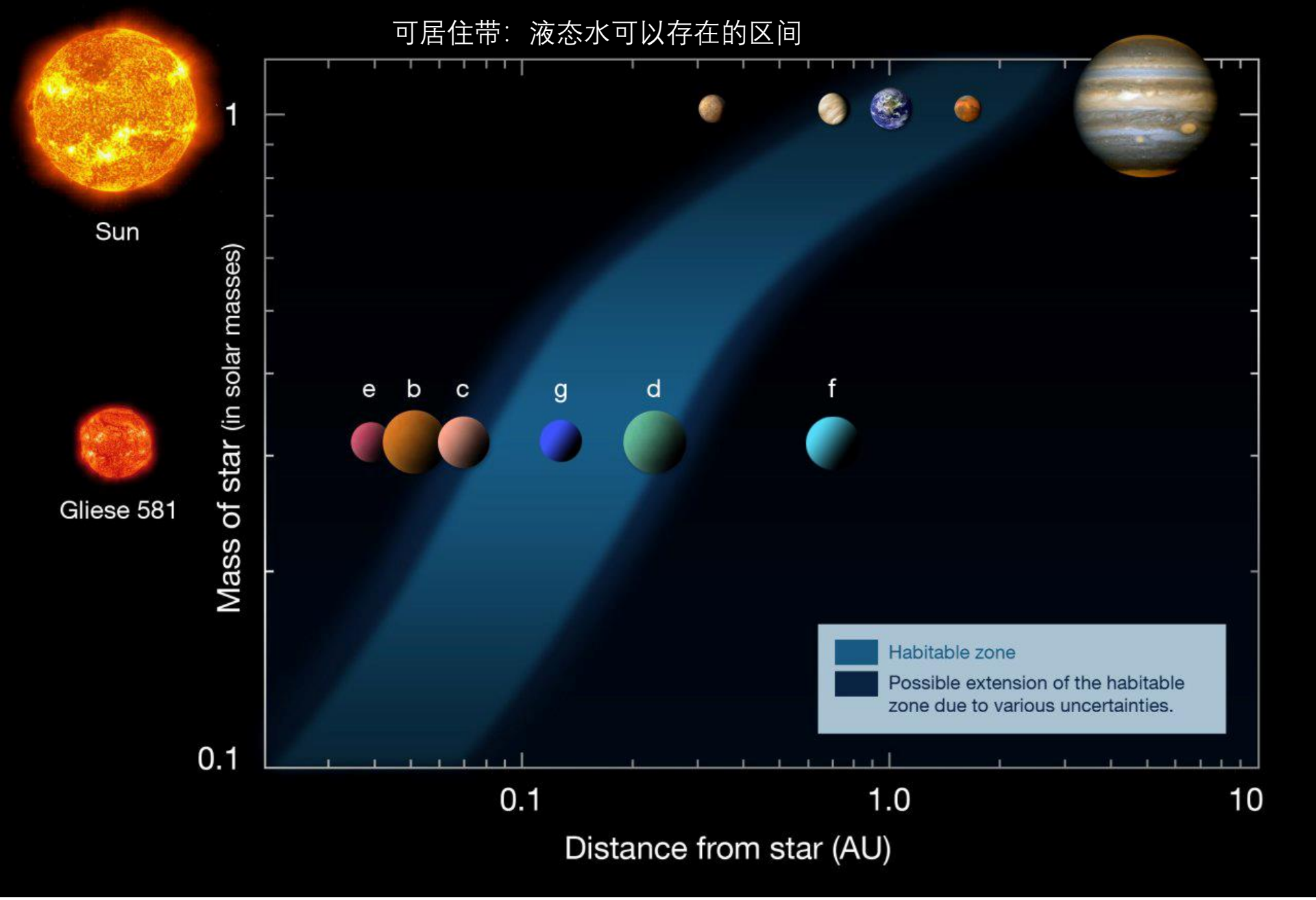
卡尔·萨根



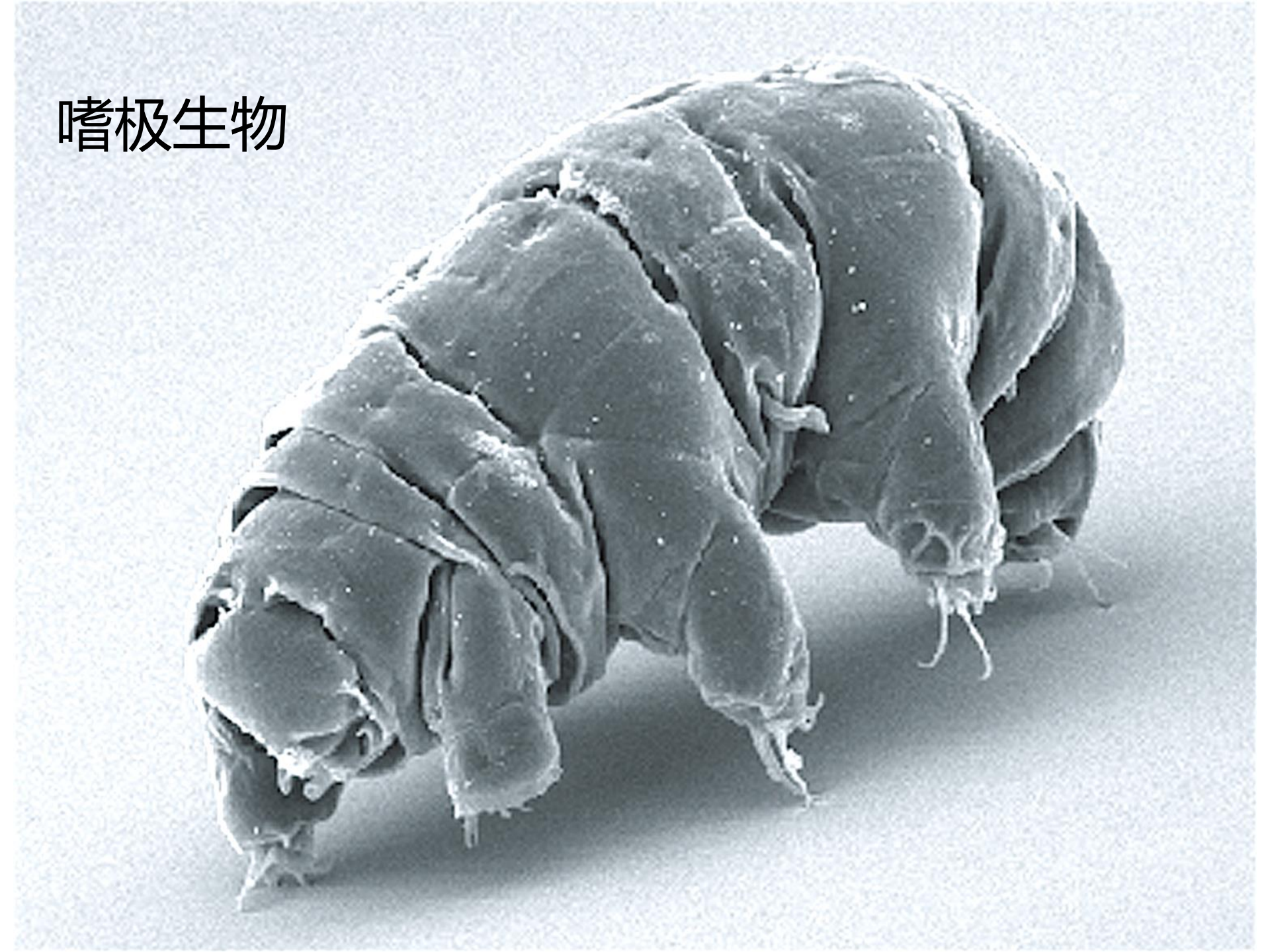
伽利略号



地球反射光谱

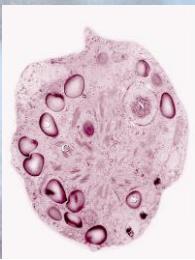

可居住带：液态水可以存在的区间
Sun
Gliese 581
Mass of star (in solar masses)
1
0.1
e
b
c
g
d
f
Habitable zone
Possible extension of the habitable zone due to various uncertainties.
0.1
1.0
10
Distance from star (AU)

嗜极生物



管状蠕虫
深海

冰雪藻

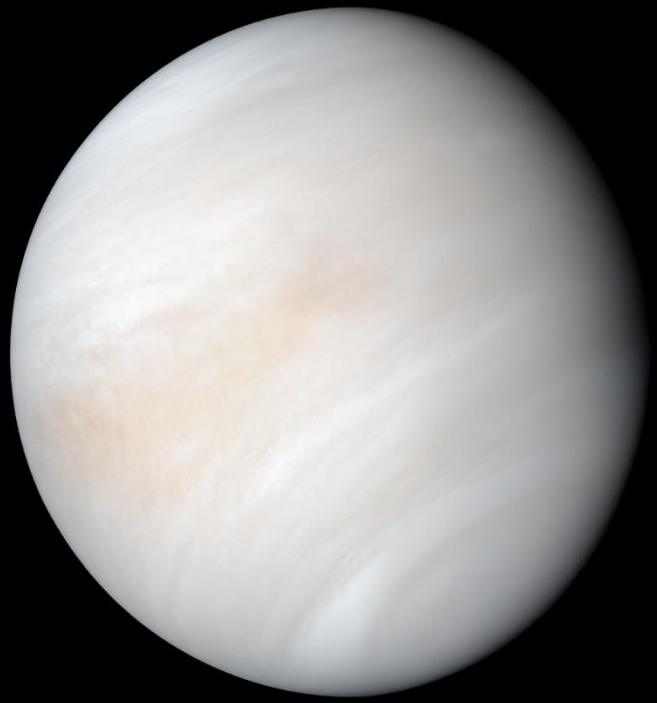


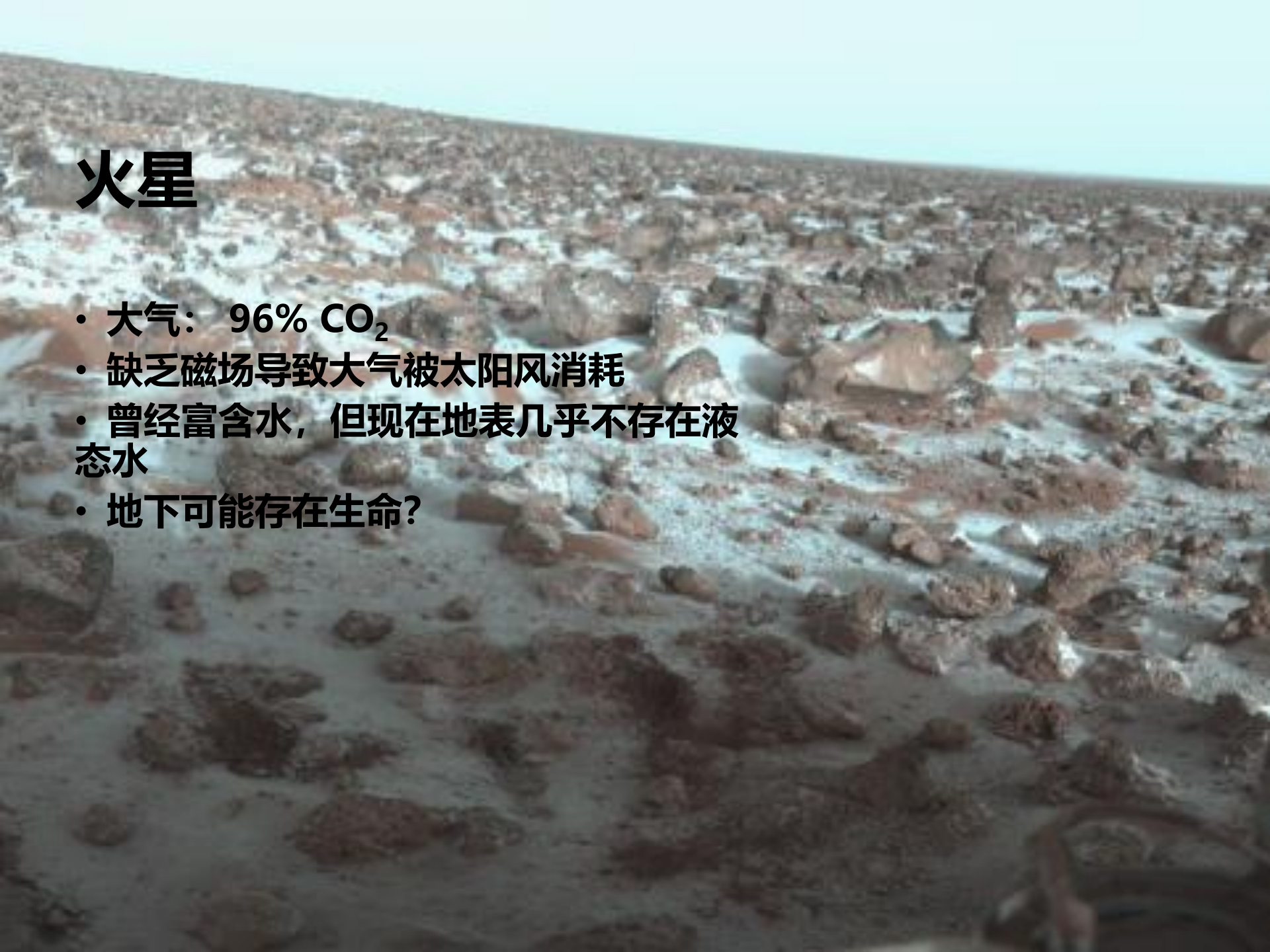
嗜热菌

	生长繁衍的极限	存活极限
最低温度	<0°C，藻类，地衣等耐寒生物	<0°C，许多细菌和古菌
最高温度	122°C，20-40Mpa 甲烷嗜高热菌	130°C，30Mpa，180分钟 甲烷嗜高热菌
最大压强	140Mpa，6°C *Colwellia marinimaniae*	1.4 Gpa, 120°C 肉毒杆菌芽孢
最低pH	0 星名氏嗜酸菌	<0
最高pH	12.4 Alkaliphilus transvaalensis	可能大于14
最高盐度	饱和盐水 嗜盐菌	结晶中，2.5亿年 *Lysinibacillus sphaericus*
紫外辐射	不明	10^{-5}生存率 $2000J/m^2$ 抗辐射奇异球菌
电离辐射	不明	10^{-5}生存率，20KGy伽马射线 抗辐射奇异球菌

金星

浓密的大气：96.5% CO_2, 3.5%N_2
地表温度>400°C
云层中可能存在生命?

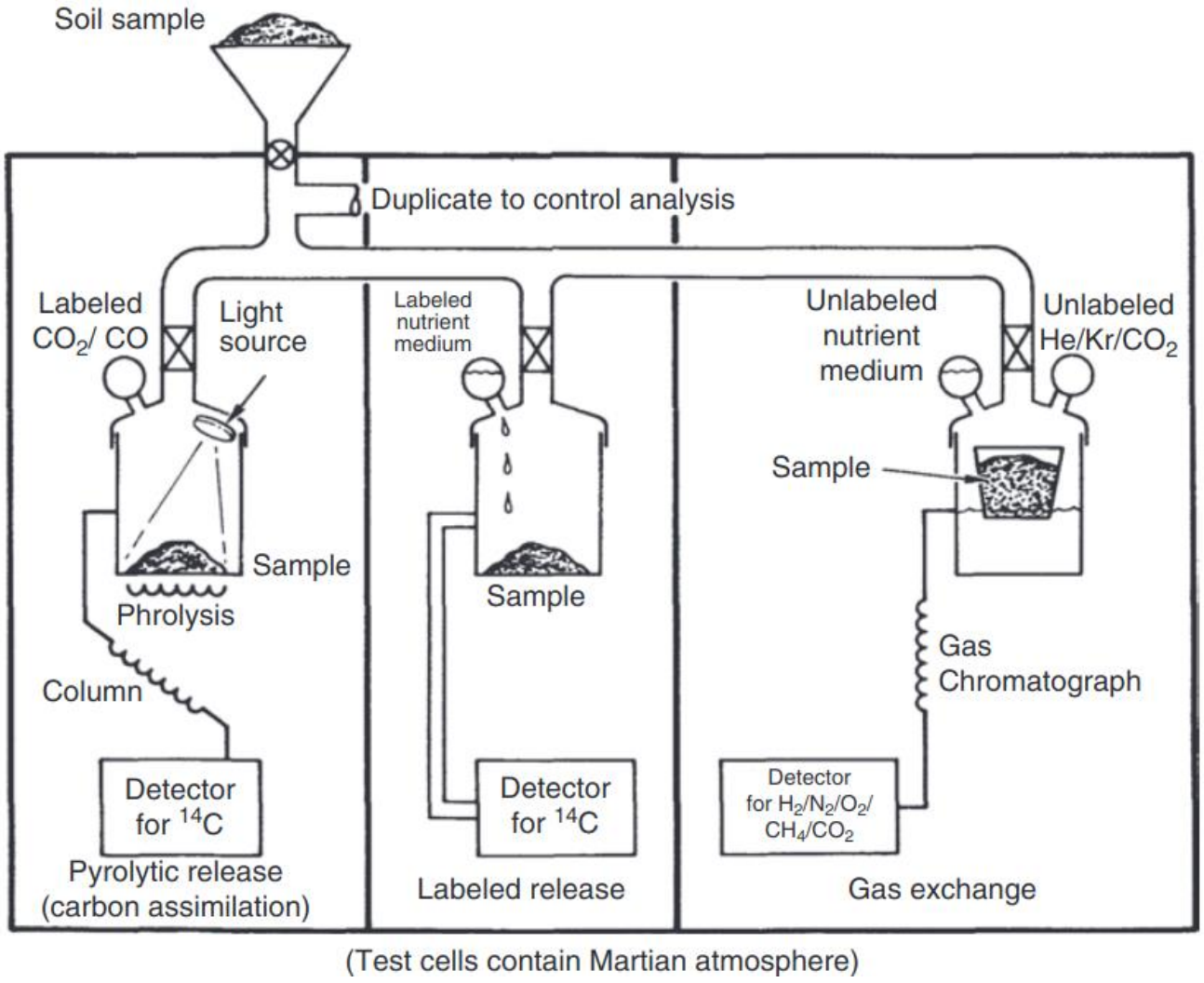




火星

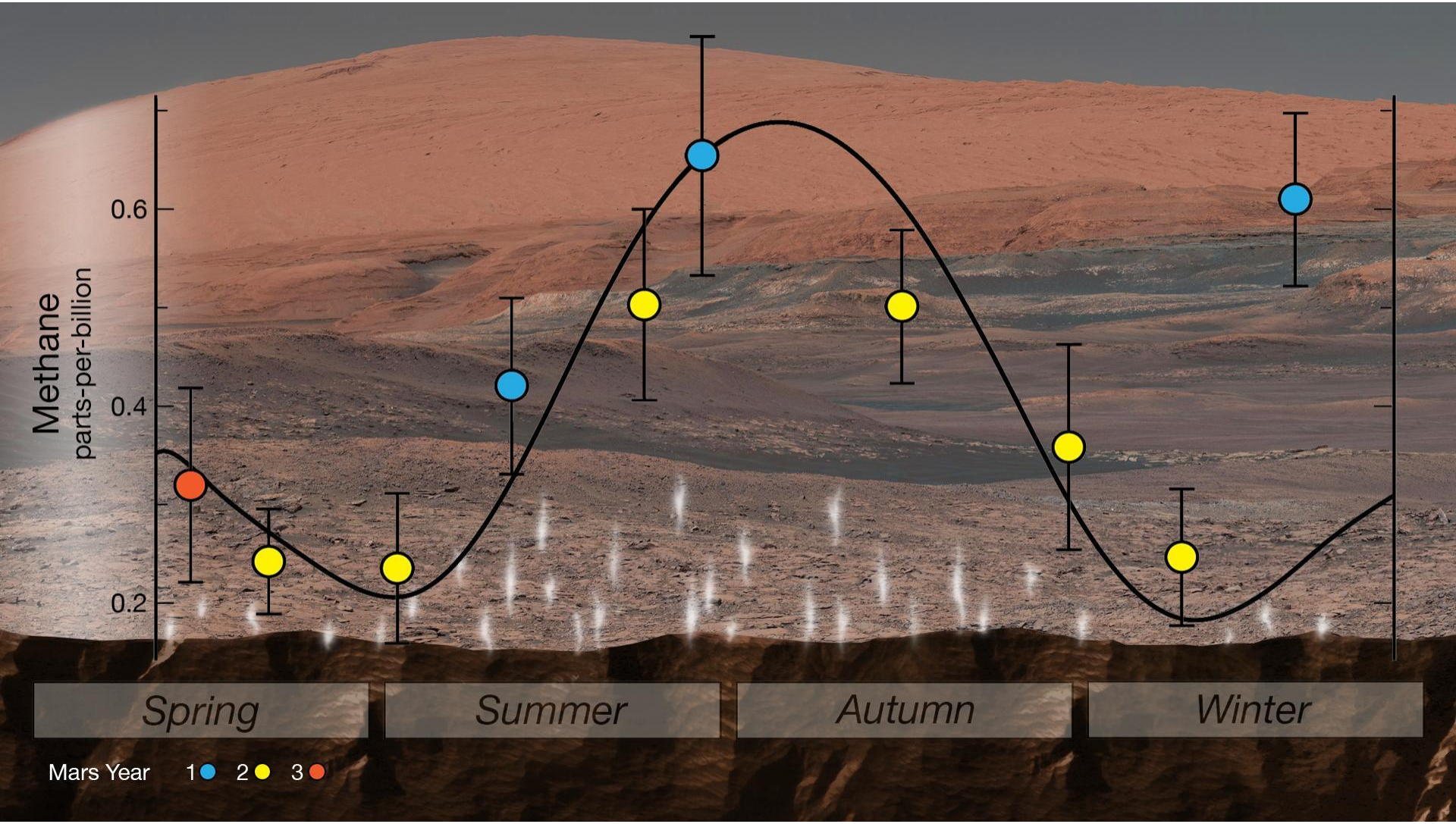
- 大气： 96% CO_2
- 缺乏磁场导致大气被太阳风消耗
- 曾经富含水，但现在地表几乎不存在液态水
- 地下可能存在生命?

海盗号的实验



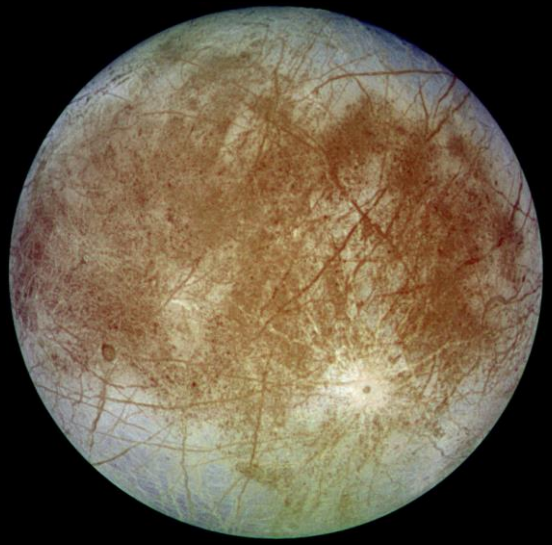
热解释放　　显踪释出　　气体交换

火星上的甲烷释放量一年中的变迁

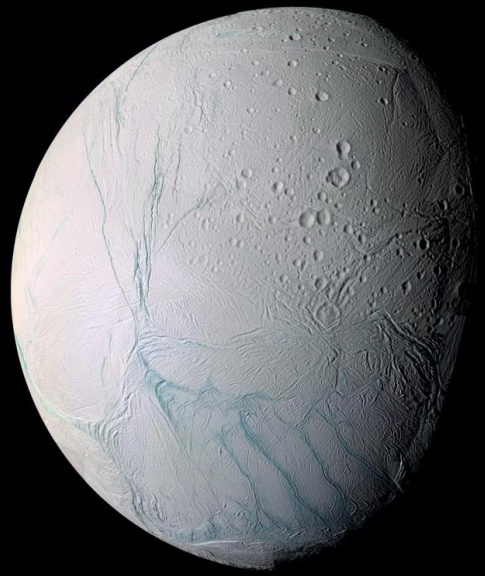


可能存在生命的卫星

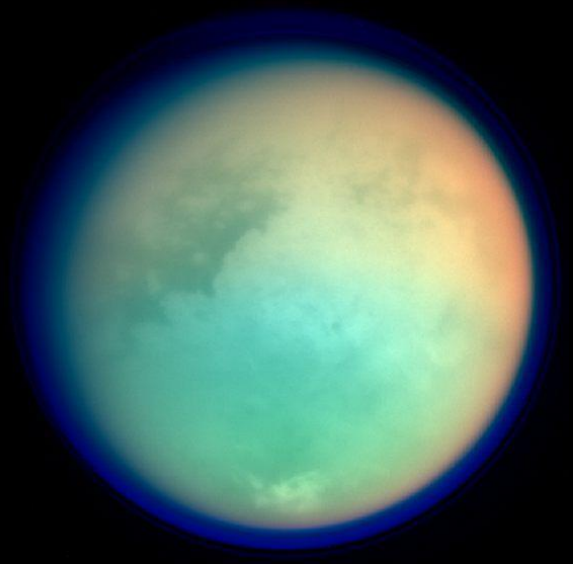
木卫二



土卫二



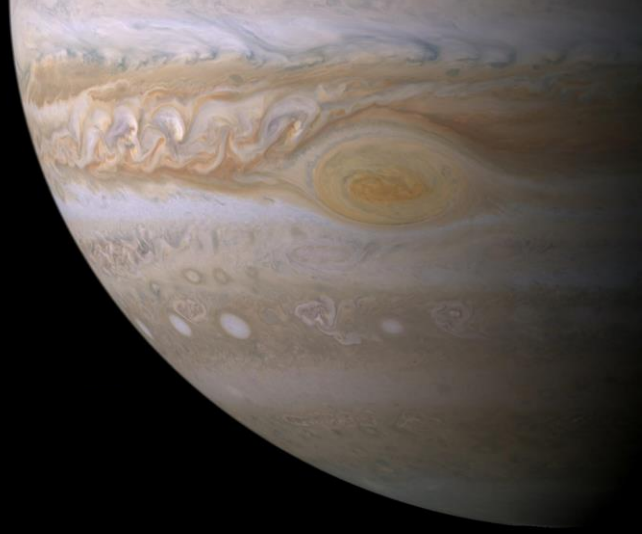
土卫六



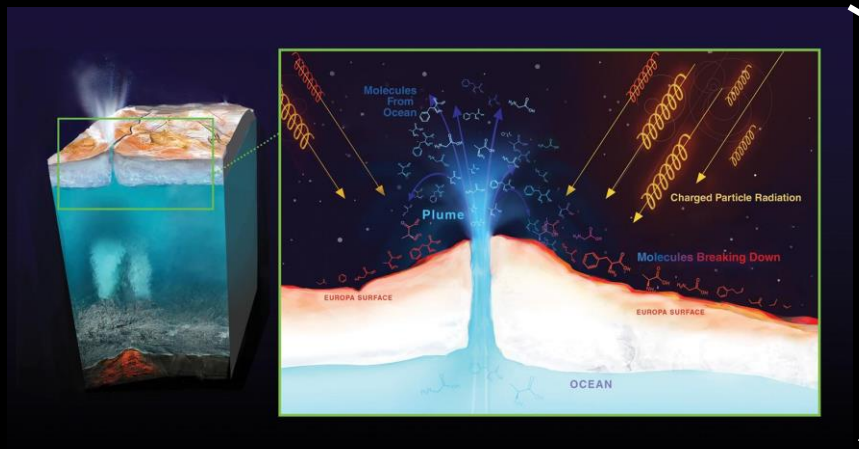
木卫二

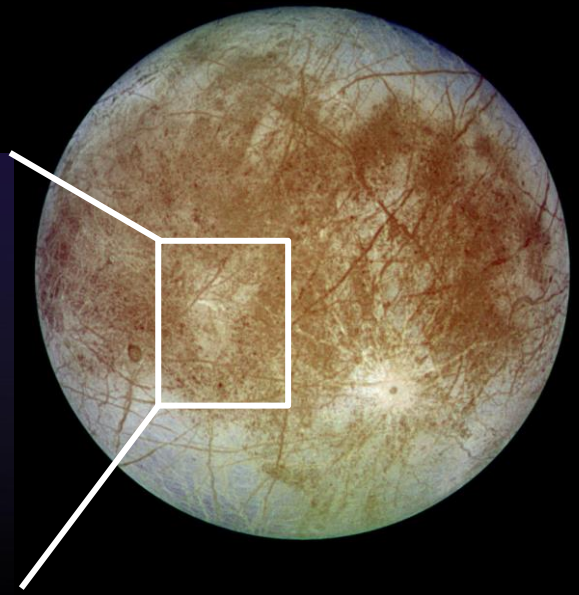
Europa Clipper

计划2024年发射



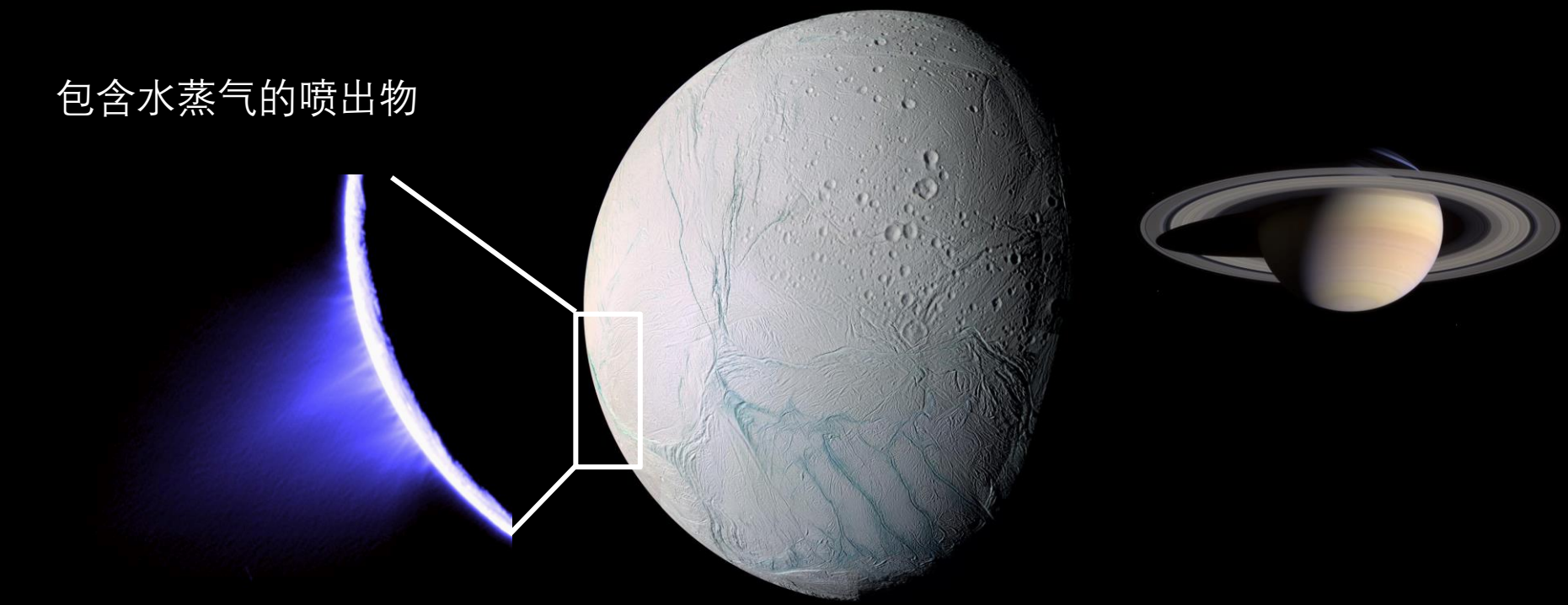
冰下可能存在生命

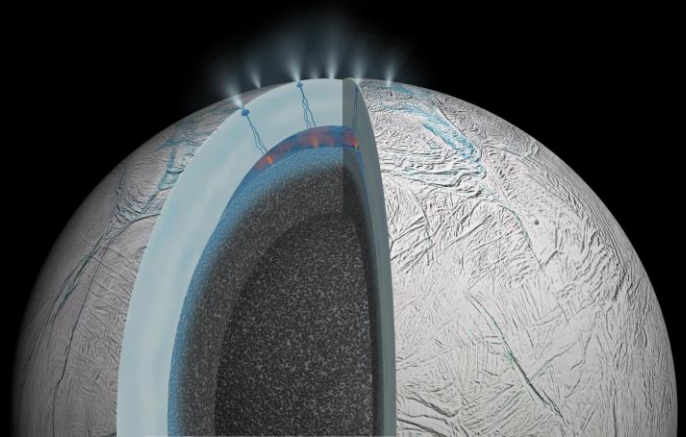




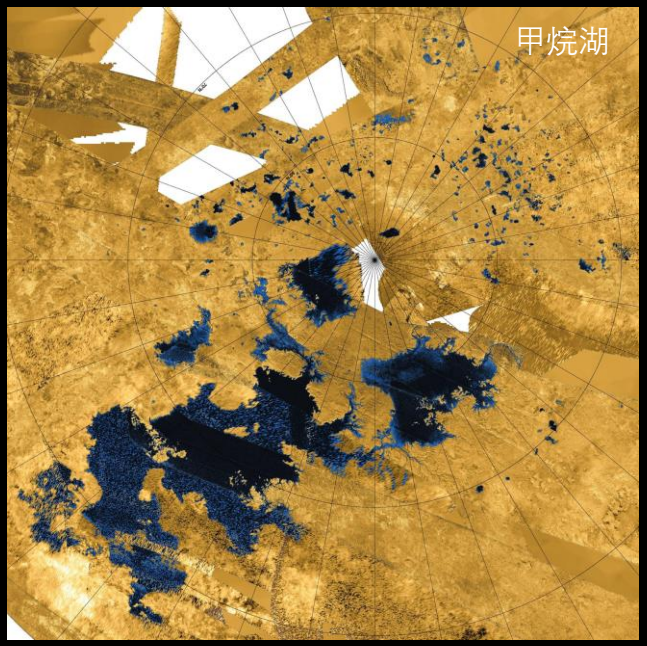
土卫二

包含水蒸气的喷出物



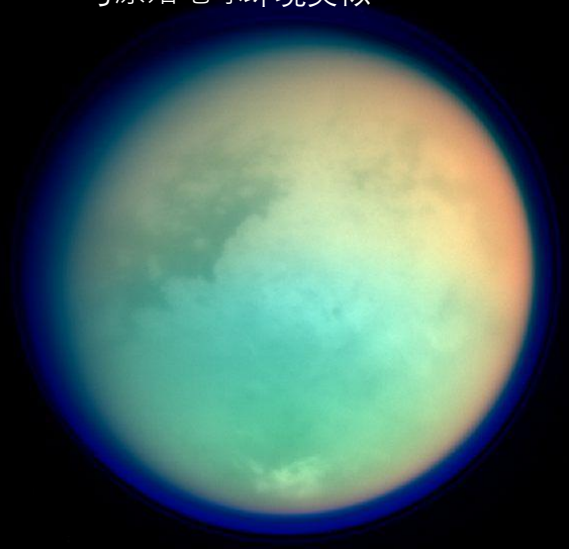


土卫六



大气成分：氮（97%）、甲烷（2.7±0.1%）

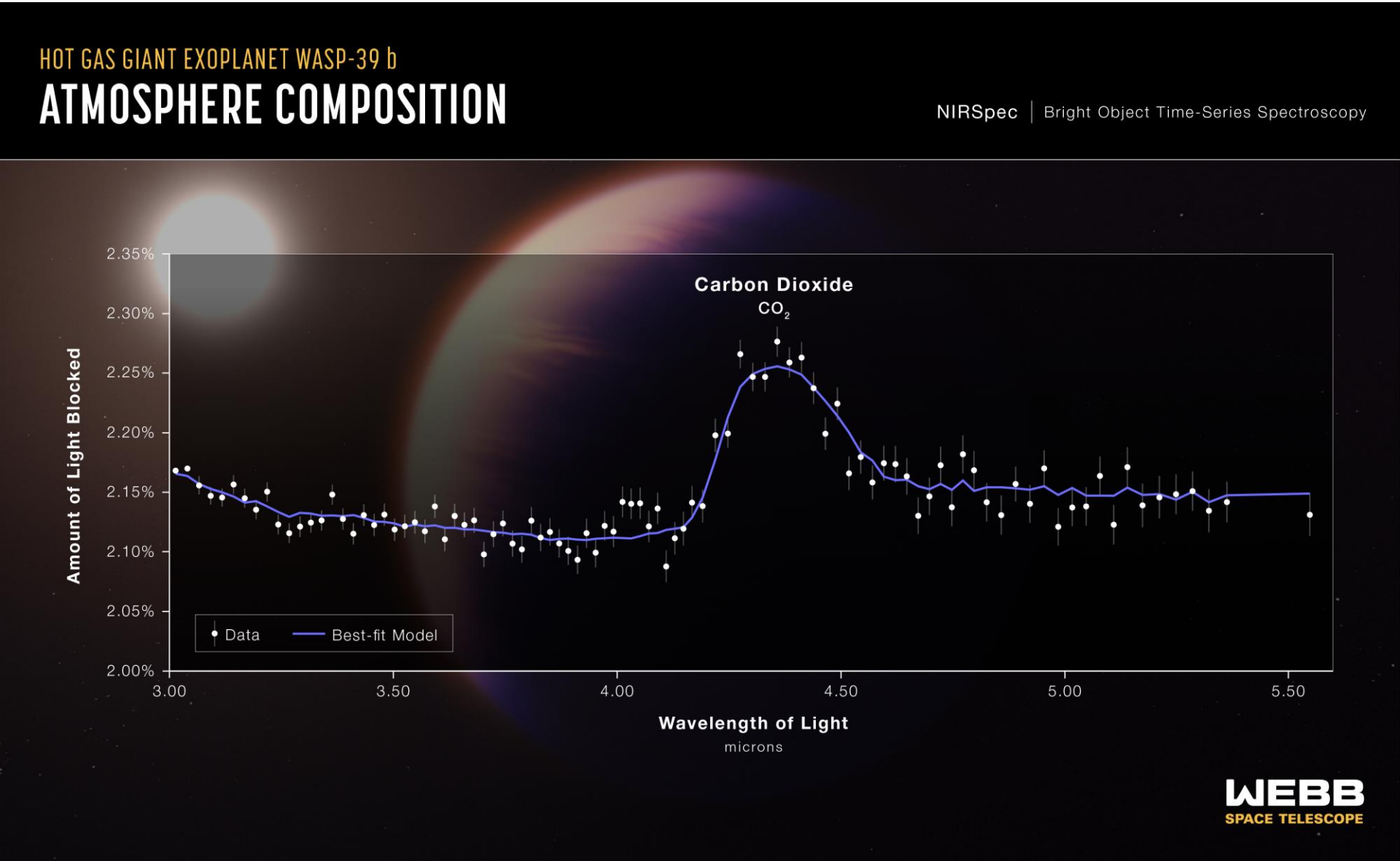
与原始地球环境类似



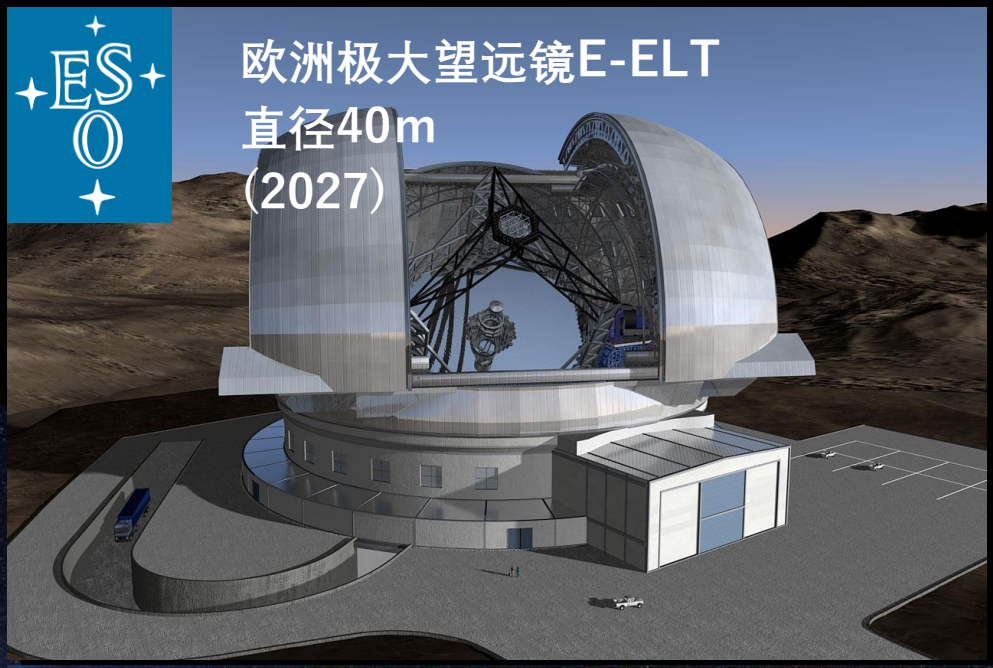
土卫六探测无人机：蜻蜓
2027年发射预定

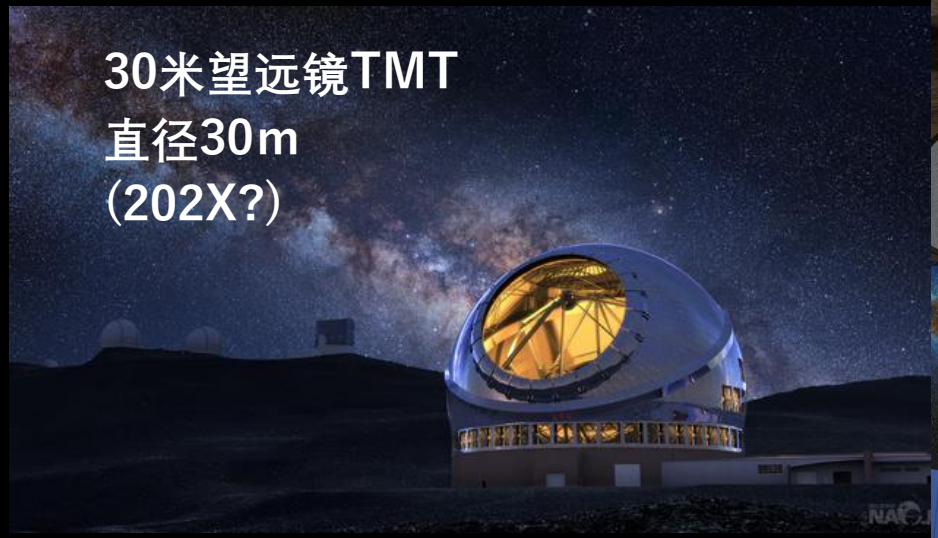
可能存在与地球生命不同类型的生命?

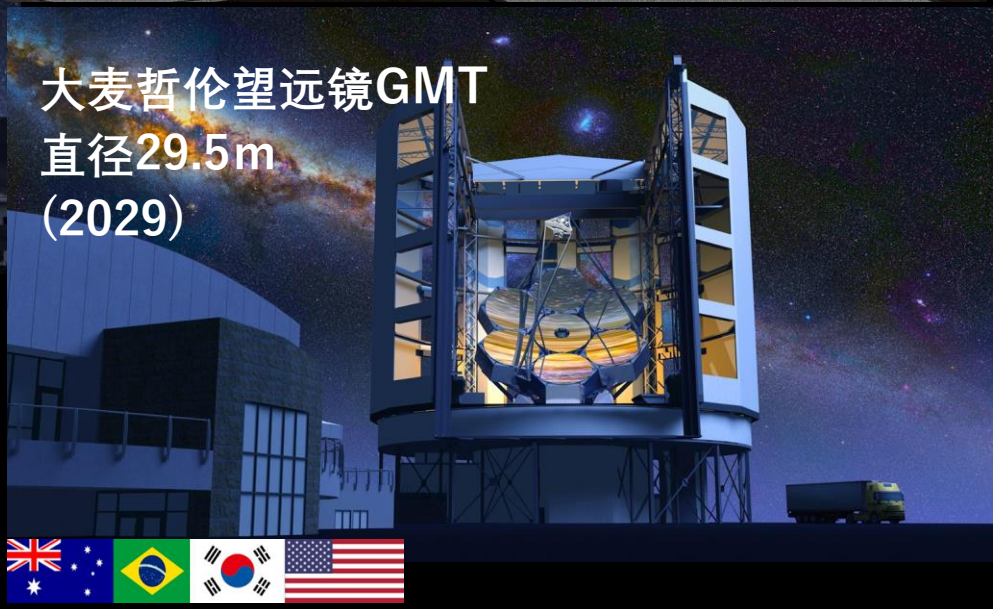
系外行星大气成分探测

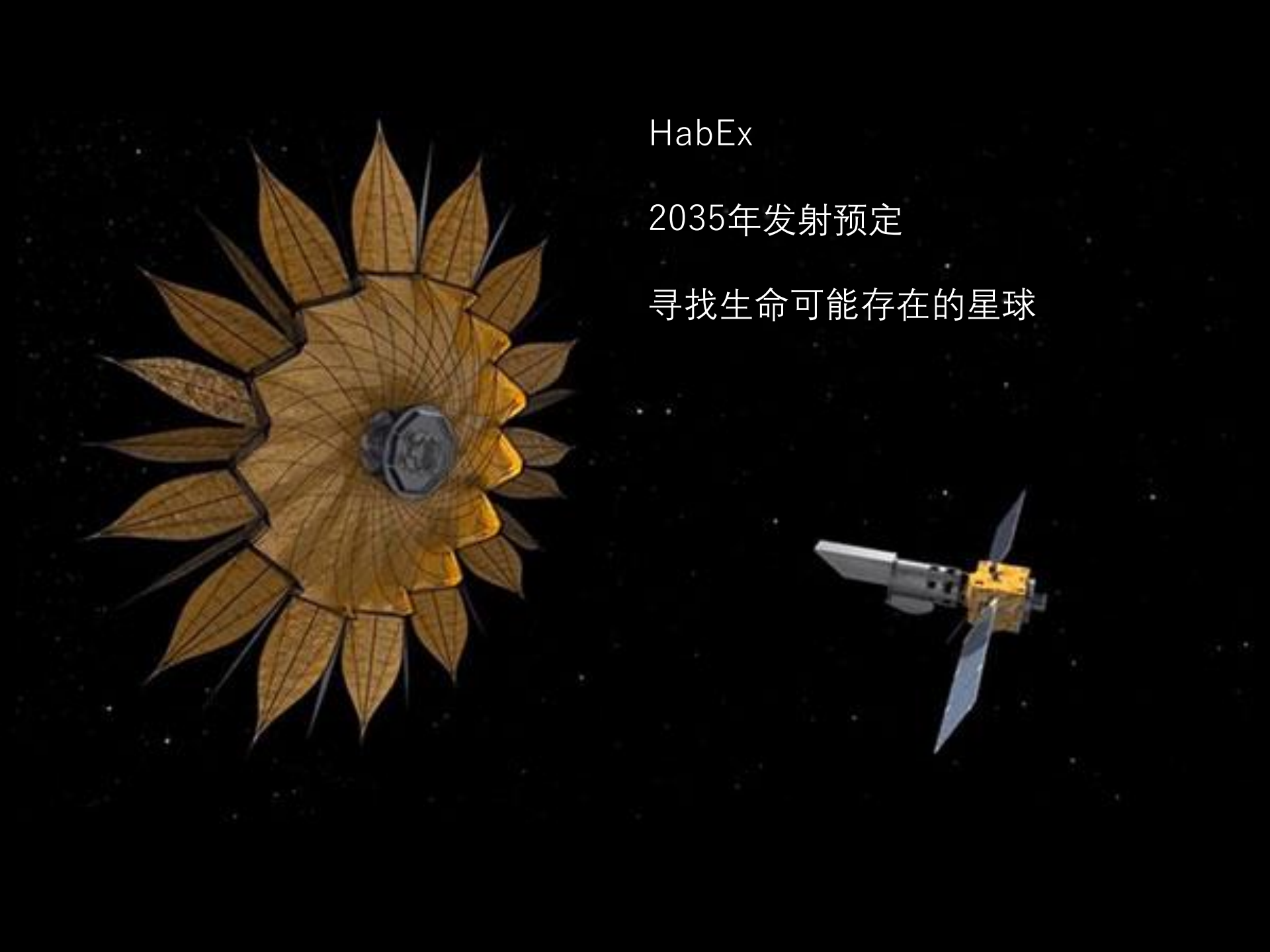

HOT GAS GIANT EXOPLANET WASP-39 b
ATMOSPHERE COMPOSITION
NIRSpec | Bright Object Time-Series Spectroscopy
Carbon Dioxide
CO_2
Amount of Light Blocked
2.35%
2.30%
2.25%
2.20%
2.15%
2.10%
2.05%
2.00%
Data
Best-fit Model
3.00
3.50
4.00
4.50
5.00
5.50
Wavelength of Light
microns
WEBB
SPACE TELESCOPE

未来的望远镜计划


欧洲极大望远镜E-ELT
直径40m
(2027)


30米望远镜TMT
直径30m
(202X?)


大麦哲伦望远镜GMT
直径29.5m
(2029)



HabEx

2035年发射预定

寻找生命可能存在的星球

????年：与外星智慧生命第一次接触

小结

天体生物学是研究生命在宇宙中起源、进化和分布的学科

随着系外行星的发现，天体生物学的研究将变得越来越重要

天体生物学研究要取得进展需要天文学、生物学、地球科学等领域的专家通力合作


Space: the final frontier. These are the voyages of the starship *Enterprise*. Its continuing mission: to explore strange new worlds. To seek out new life and new civilizations. To boldly go where no one has gone before!
Star Trek: The Next Generation