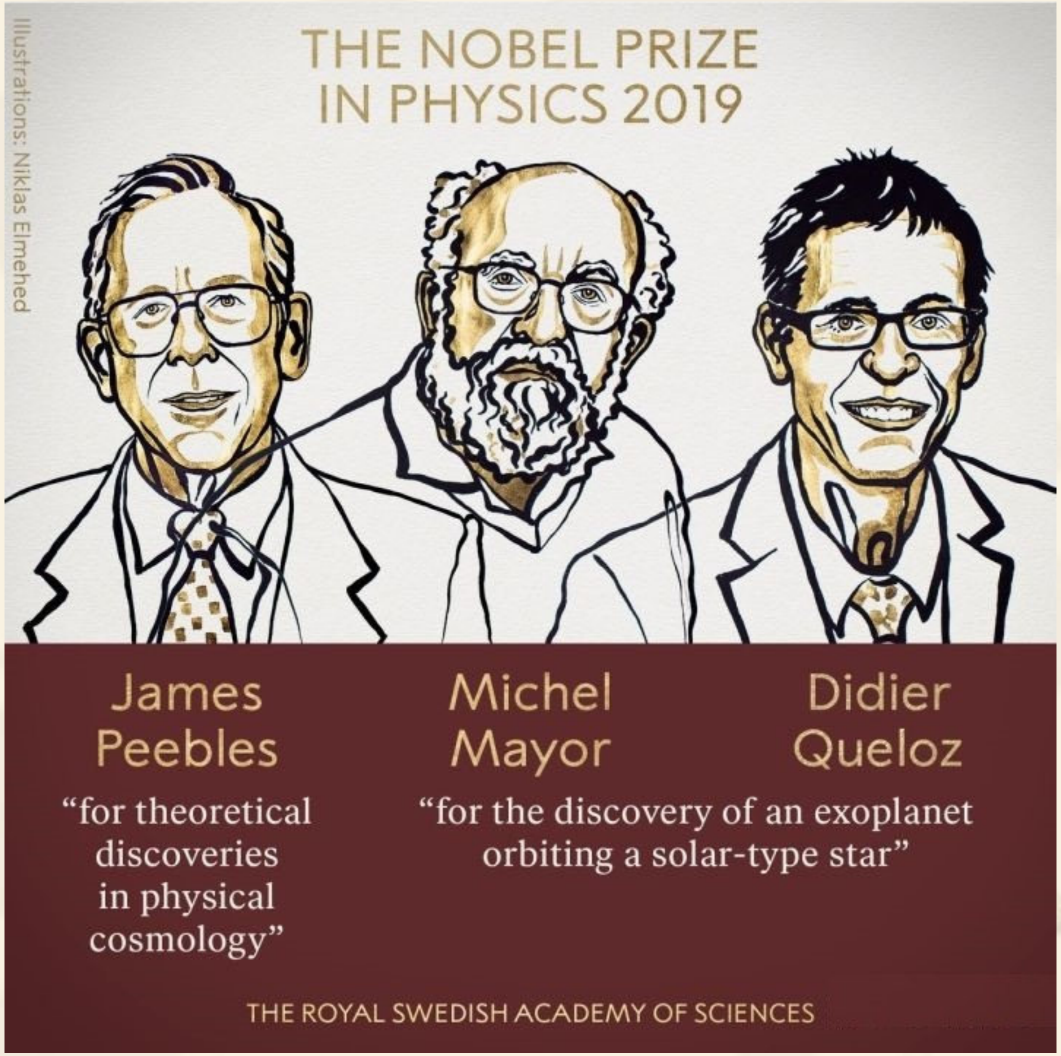
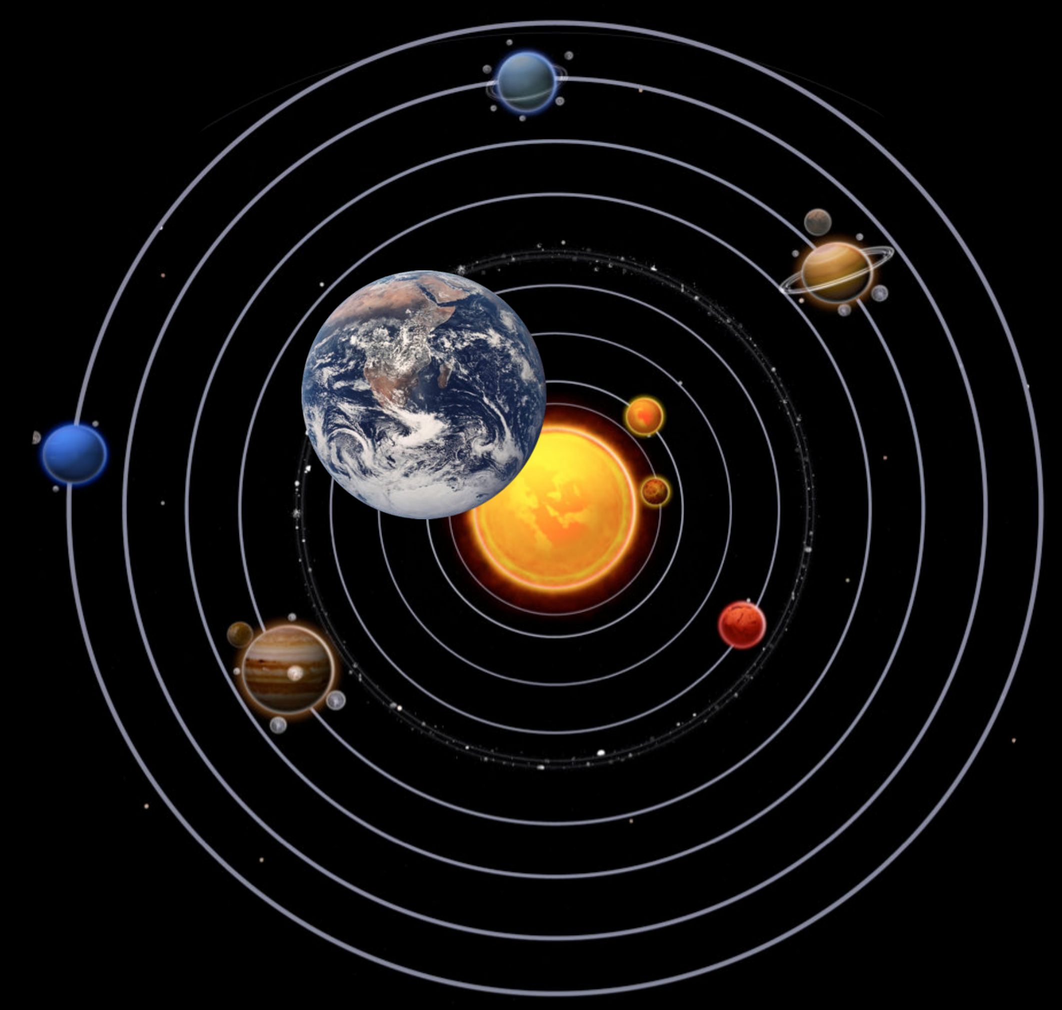
第四章：太阳系外行星



Illustrations: Niklas Elmehed
THE NOBEL PRIZE
IN PHYSICS 2019
James
Peebles
"for theoretical
discoveries
in physical
cosmology"
Michel
Mayor
Didier
Queloz
"for the discovery of an exoplanet
orbiting a solar-type star"
THE ROYAL SWEDISH ACADEMY OF SCIENCES

本章内容

- 行星如何形成？
- 系外行星的主要搜寻方法有哪些？
- 什么是宜居带？
- 系外行星的发现空间是怎样的？
- 发现系外行星的主要望远镜有哪些？
- 存在宜居系外行星甚至是地外文明吗？



R.B. Dong

Nearly Every Star in Our Galaxy Has Planets

How Do Planets Form?

D. Fabrycky

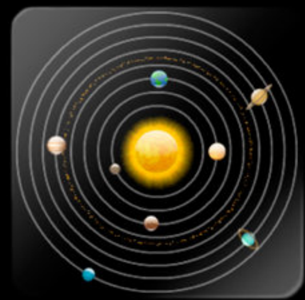
分子云→原恒星（吸积物质、角动量守恒）→原行星盘→行星与自己的盘→卫星

Protostar

Protoplanetary Disk

Debris Disk

Planetary System



Last for a few million years (Myr)

0.1% lifetime

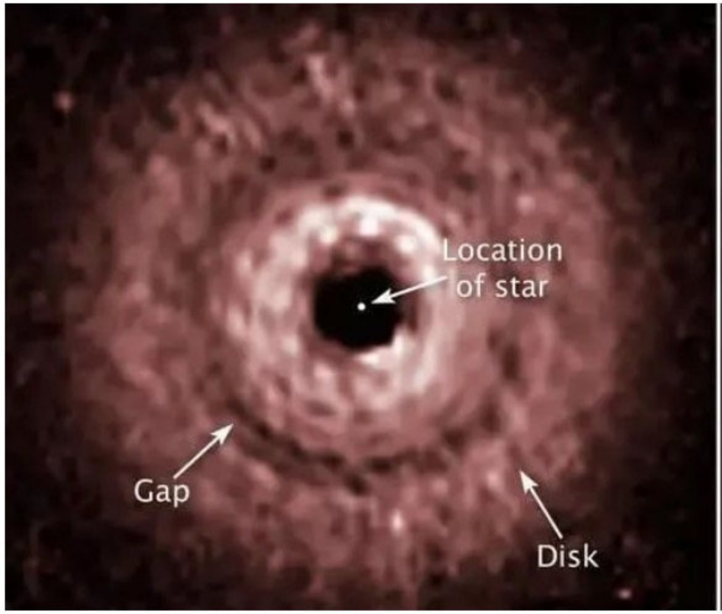
$t = 0$

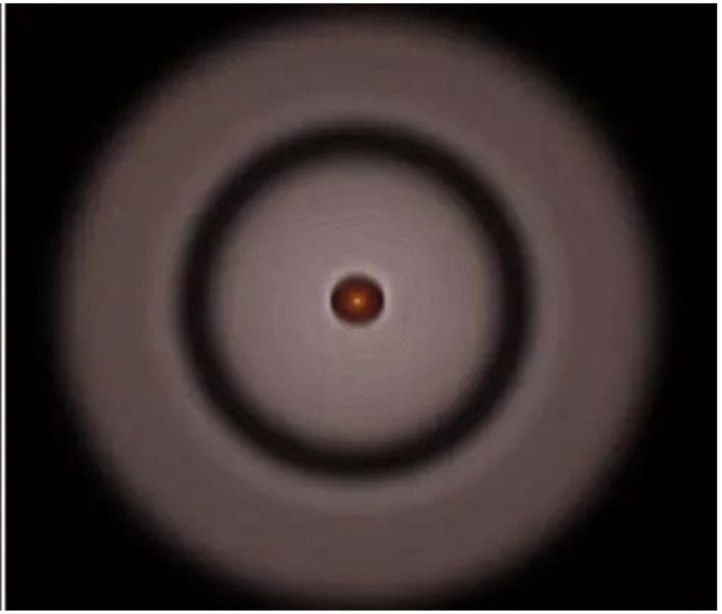
$t = 4.5$ Gyr

R.B. Dong

当恒星诞生后，在它的周围会形成**尘埃盘**，行星就是在盘中形成的，这已经被HST确认。HST首次解析了明亮的猎户座星云中近200颗恒星周围的原行星盘。通过观察附近天空中其他地方的恒星，HST完成了对恒星周围的岩屑盘规模最大、灵敏度最高的可见光波段的成像调查（岩屑盘由尘埃和岩屑组成，可能是行星形成时遗留下来的物体彼此碰撞造成的）。

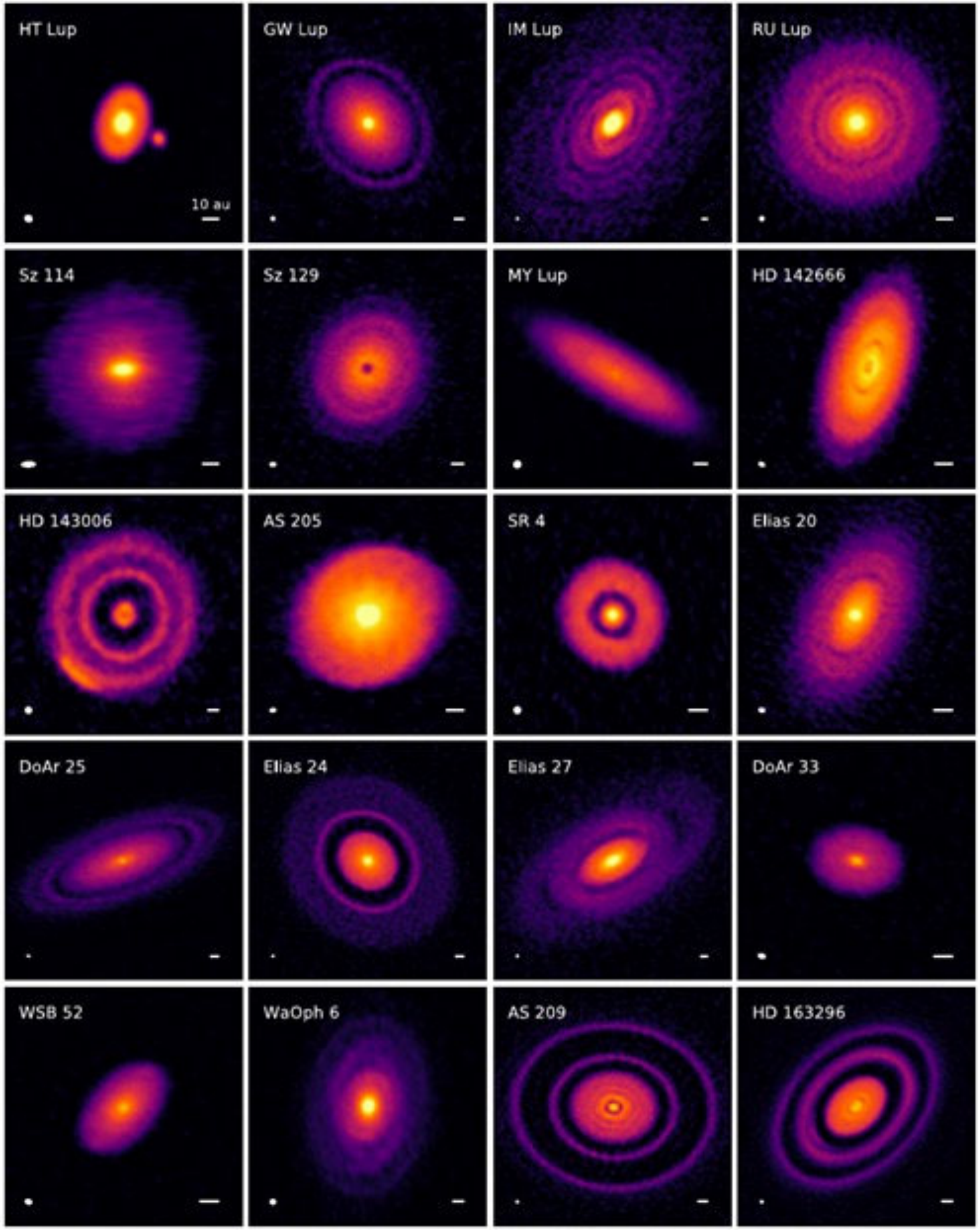
长蛇座TW和绘架座β这两颗特殊的恒星说明了这些发现。用一个遮罩阻挡住恒星的强光之后，在围绕长蛇座TW旋转的由气体和尘埃组成的巨大原行星盘中，科学家通过HST发现了一个神秘的缝隙。这个缝隙很可能是由一颗正在生长，却还不可见的行星造成的，行星在引力作用下扫除掉物质，像扫雪机一样在圆盘上划出一条窄道。





○ 这张哈勃图像(左)显示了一个由尘埃和气体组成的原行星盘的缝隙，它围绕着附近的红矮星长蛇座TW旋转。| 图片来源：NASA、ESA、J. Debes、H. Jang-Condell、A. Weinberger、A. Roberge、G. Schneider 和 A. Feild

行星形成观测



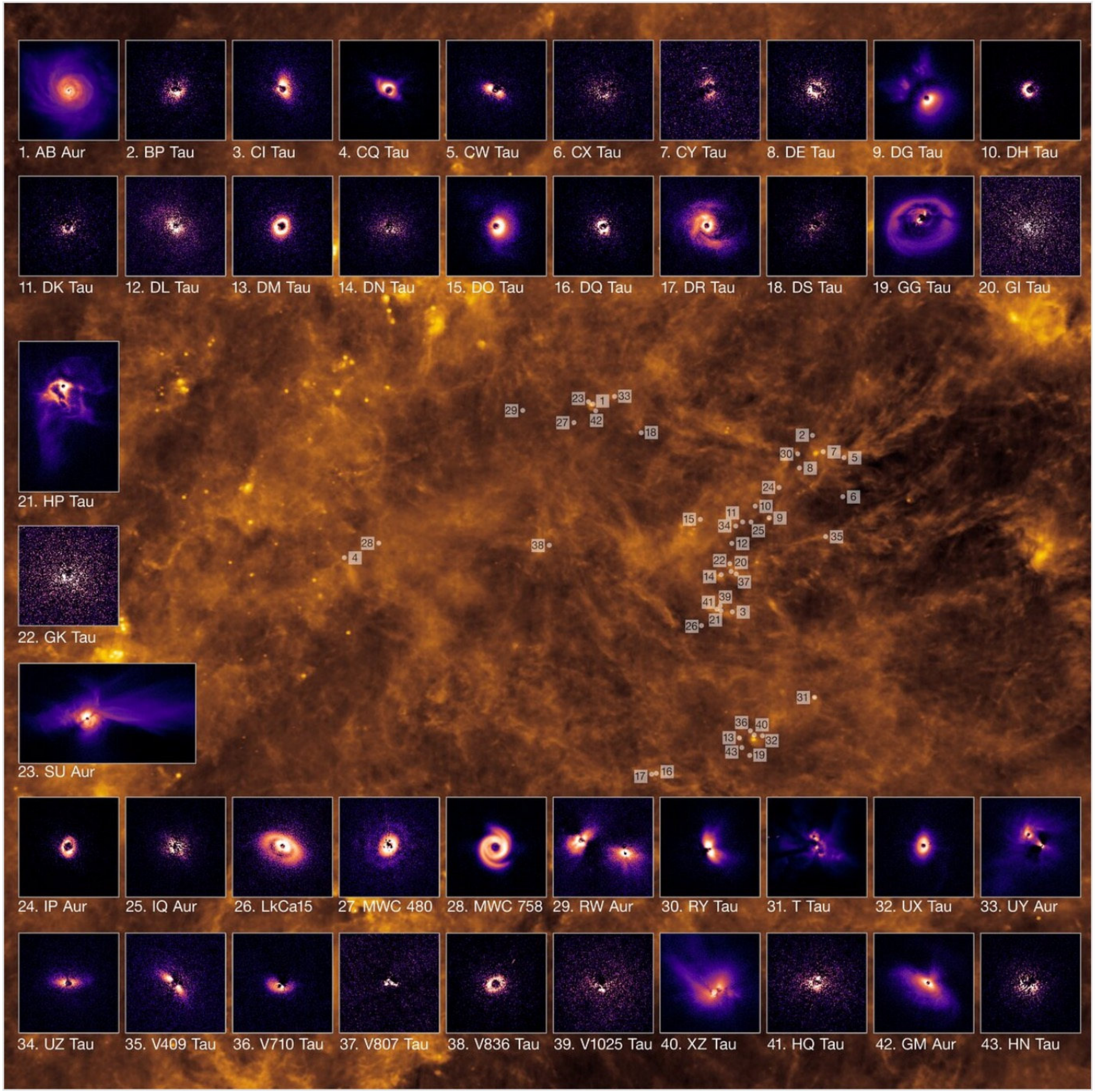
DSHARP 项目观测到的20个原行星盘的240GHz尘埃连续谱(Andrews et al. *ApJ*, 869, L41, 2018)

原行星盘的盘风
（房敏 紫金山天文台）

快速旋转扁椭球行星中的热对流

European Southern Observatory

Planet-forming discs in the Taurus cloud



Search...

About the Image

Id: eso2405c
Type: Collage
Release date: 5 March 2024, 14:00
Related releases: eso2405
Size: 7000 x 7000 px

About the Object

Type: Milky Way : Star : Circumstellar Material : Disk : Protoplanetary
Category: Exoplanets

Image Formats

Fullsize Original
240.5 MB checksum
Large JPEG
11.8 MB
Publication TIFF 4K
20.7 MB
Publication JPEG
4.9 MB
Screensize JPEG
382.3 KB

Zoomable

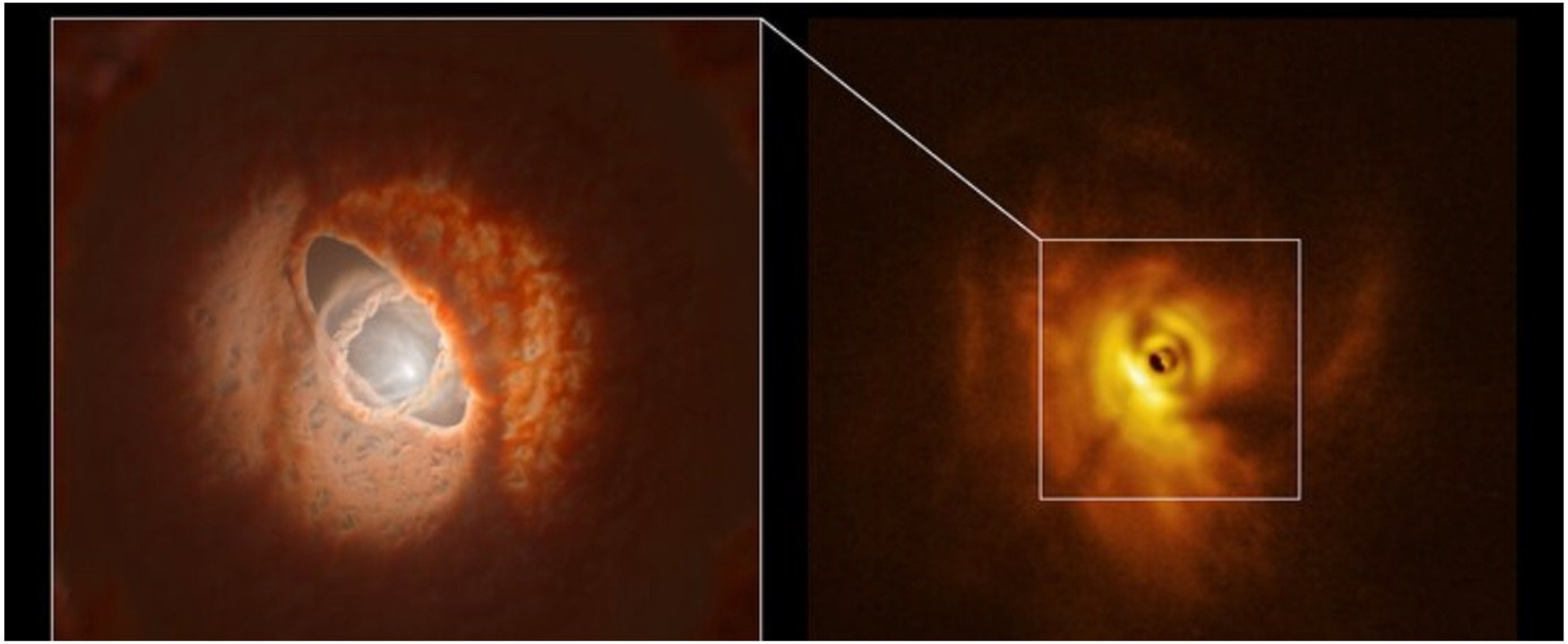
Zoomable

(ESO/A.Garufi et al.; IRAS)

eso2014 — Science Release

New Observations Show Planet-forming Disc Torn Apart by its Three Central Stars

3 September 2020

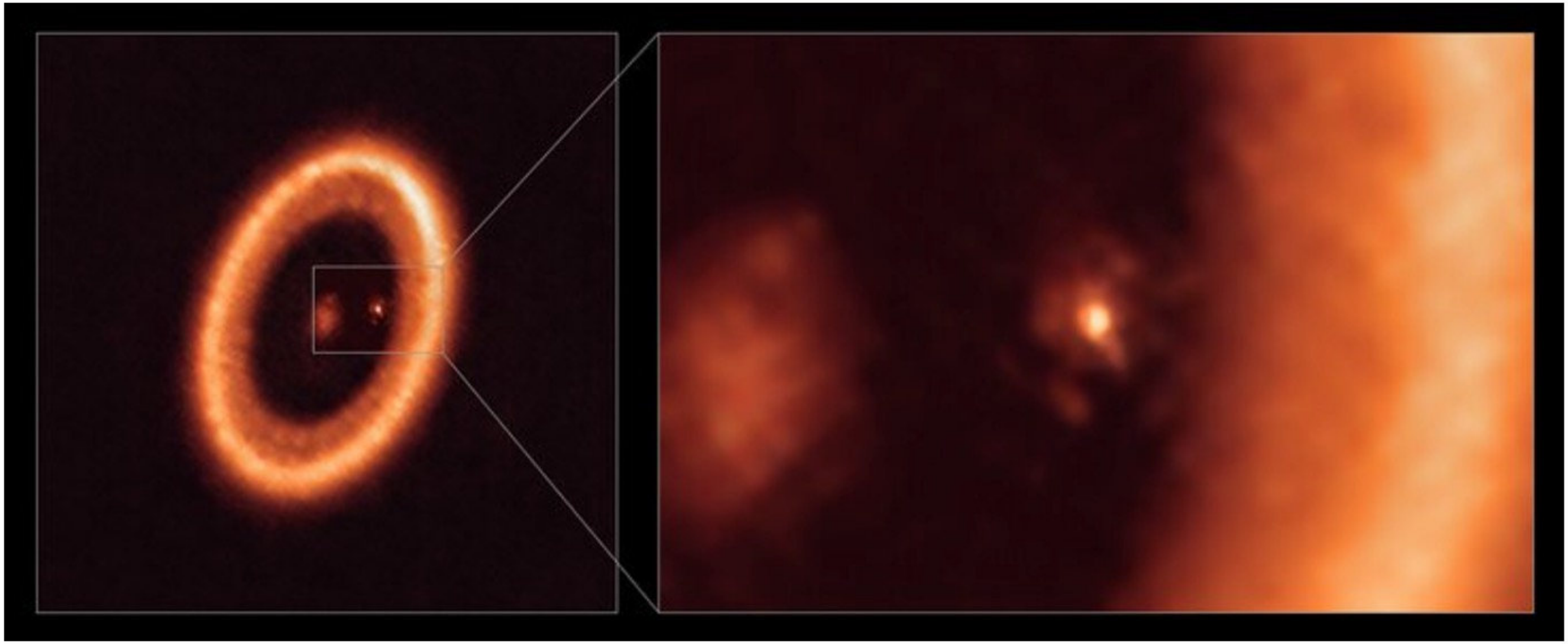


A team of astronomers have identified the first direct evidence that groups of stars can tear apart their planet-forming disc, leaving it warped and with tilted rings. This new research suggests exotic planets, not unlike Tatooine in Star Wars, may form in inclined rings in bent discs around multiple stars. The results were made possible thanks to observations with the European Southern Observatory's Very Large Telescope (ESO's VLT) and the Atacama Large Millimeter/submillimeter Array (ALMA).

eso2111 — Science Release

Astronomers make first clear detection of a moon-forming disc around an exoplanet

22 July 2021



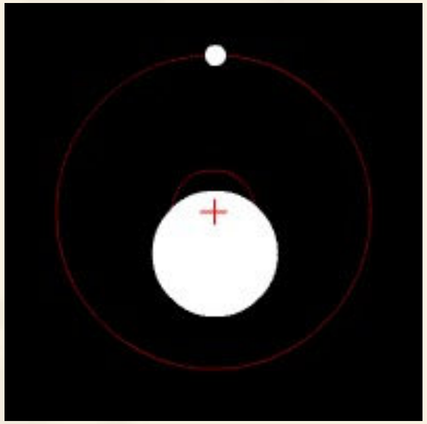
Using the Atacama Large Millimetre/submillimeter Array (ALMA), in which the European Southern Observatory (ESO) is a partner, astronomers have unambiguously detected the presence of a disc around a planet outside our Solar System for the first time. The observations will shed new light on how moons and planets form in young stellar systems.

主要探测方法

- 动力学方法
  - 视向速度法
  - 脉冲星计时法
  - 天体位置测量法
- 凌日法（掩食）
- 微引力透镜方法
- 直接成像法

动力学方法

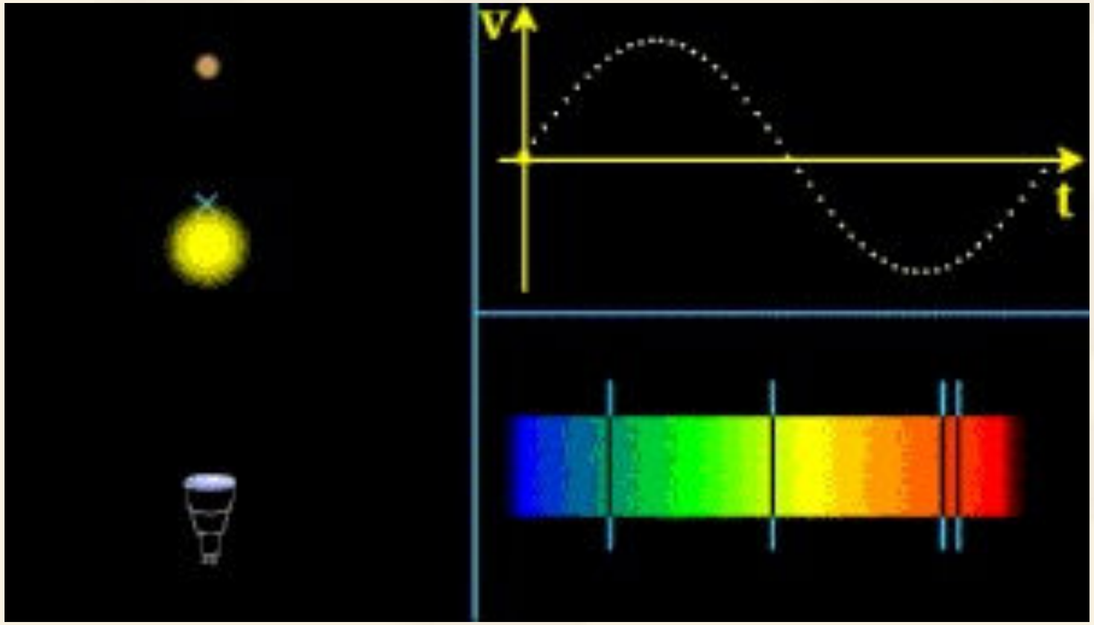
- 视向速度法
- 脉冲星计时法
- 天体位置测量法

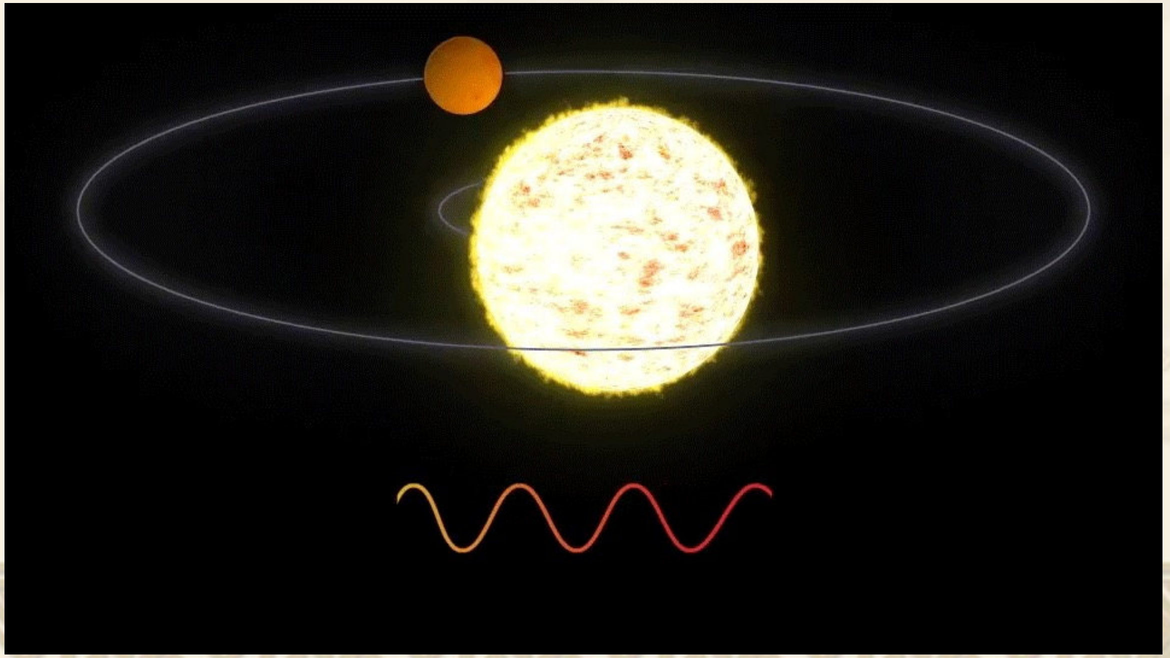


原理

- 行星围绕恒星运动
- 恒星也围绕质心运动（轨道半径小）
- 恒星的运动比行星的运动好测量

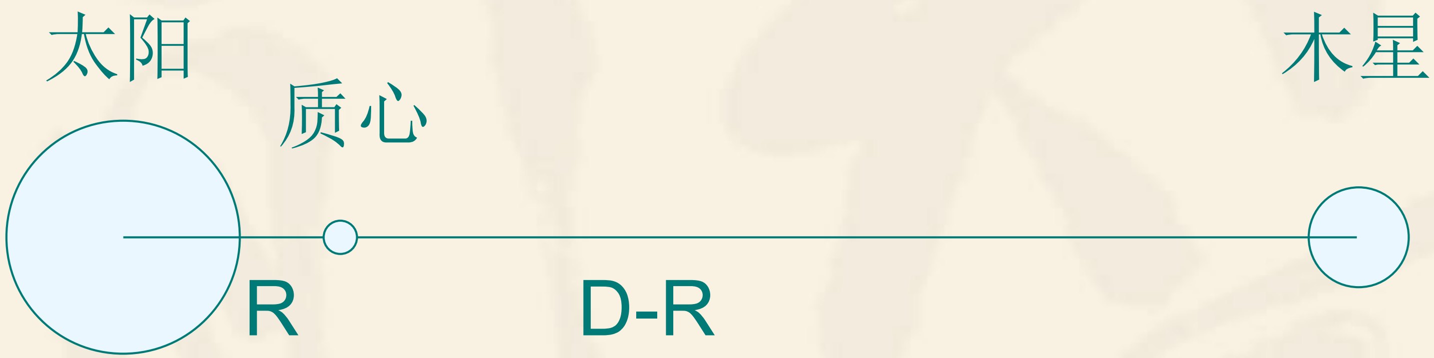
视向速度法/多普勒方法





基于高精度视向速度的系外行星研究（清华大学王雪凇）

视向速度法/多普勒方法



$M_{Sun}R = M_{Jupiter}\ (777\ 547\ 199 - R)$

$M_{Sun} / M_{Jupiter} \sim 1000$

$R = 776\ 770\ km > R_{sun} = 695\ 500\ km$

- 主要的行星在太阳的一侧（1980s）：质心离太阳中心更远
- 木星与其他行星位于太阳的两侧：质心靠近太阳中心
- 在 ~0.3 – 2 R_{sun} 之间，平均：~1.25R_{sun}

太阳绕质心的运动速度（太阳-木星系统）

太阳绕质心运动的轨道周长：

$$2\times\pi\times 7.77\times 10^5\,\mathrm{km} = 4.9\times 10^6\,\mathrm{km} = 4.9\times 10^9\,\mathrm{m}.$$

太阳绕质心运动的轨道周期：

~11.86年=$3.74\mathrm{x}10^8$ s

太阳绕质心运动的轨道速度：

$$4.9\times 10^9/3.74\times 10^8 = 13\,\mathrm{m\,s^{-1}}.$$

太阳绕质心运动的轨道速度差：~ 26m/s

目前的探测精度：~ 0.5-1 m/s, Doppler法，需要谱线

将来有望提高到：~0.1-0.5 m/s甚至更好

- 至少探测到半个或整个周期：大轨道行星难探测
- 如果轨道平面与视向垂直，无法探测
- 往往会低估行星质量：如果轨道倾角不知道
- 如果是圆轨道，Doppler曲线为sin函数，如果是椭圆轨道，稍复杂，但依然存在周期性
- 多行星系统：Doppler曲线复杂，理论分析仍可以证认每个行星的存在
- 地球-太阳系统：~ 0.1 m/s, 需要用其它方法发现，更长时间径向速度监测可能探测到

视向速度法/多普勒方法小结

原理

•恒星相对我们有径向运动
•产生红移和蓝移

缺点

•只对大质量行星敏感
•小的、快速的轨道
•看不到行星

优点

•目前最敏感的测量方法

第一个类太阳的系外行星系统发现

- 1988, 加拿大天文学家Bruce Campbell，G.A.H. Walker & S. Yang, 多普勒测量：Gamma Cephei恒星（仙王座伽玛星）可能存在一个行星，2003年得到确认
- 美国天文学家 Paul Bulter & Geoffrey Marcy 从1987年起最早开始认真搜寻类太阳的extra-solar planets：认为至少需要几年数据
- 1995年10月6日，Michael Mayor & Didier Queloz发现恒星51 Pegasi（飞马座）周围存在一个行星！G5型恒星，质量约为1.1太阳质量，温度比太阳略低

1988

Gamma Cephei Ab

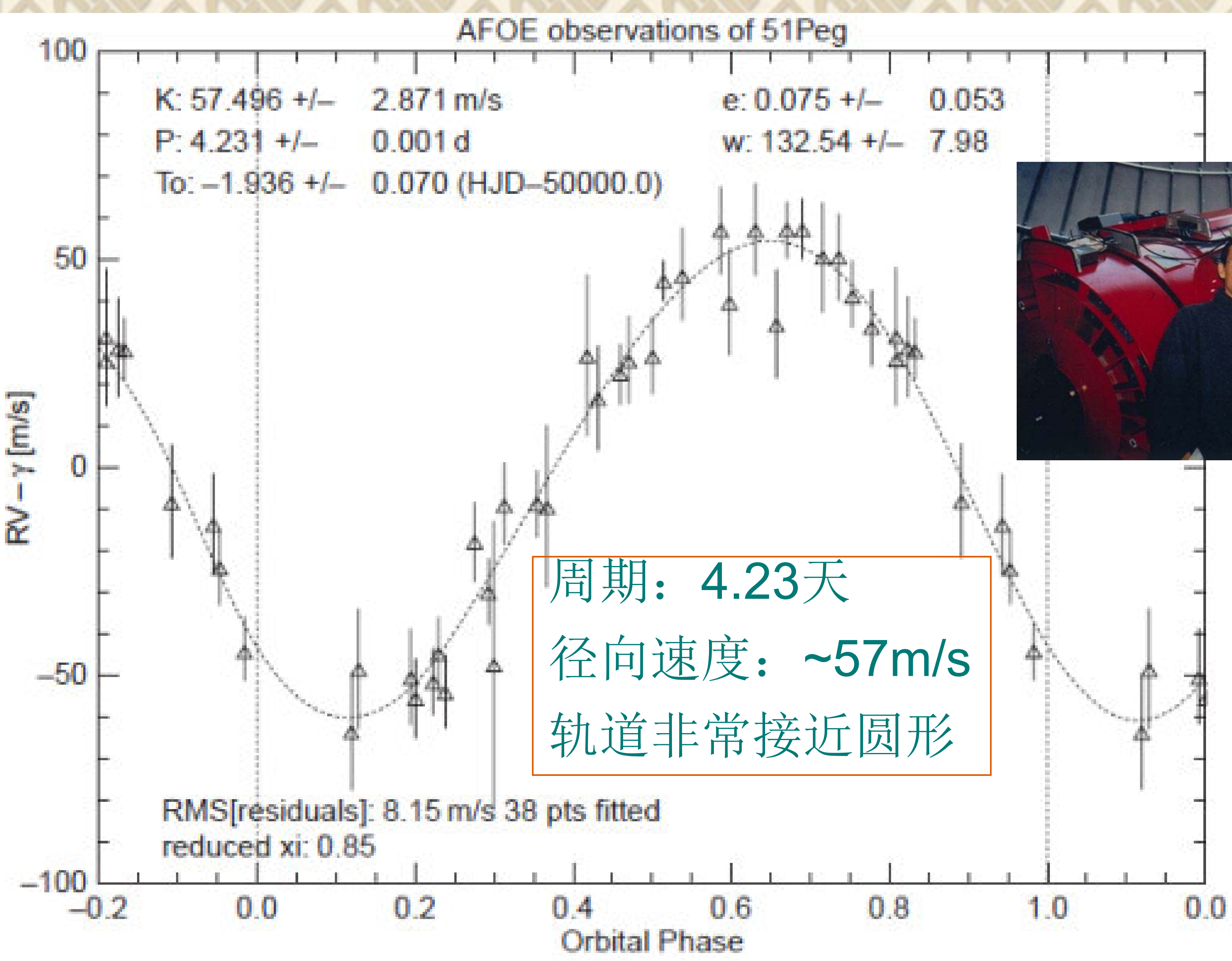
1.6 $M_{Jupiter}$ around a subgiant

but actually stellar signal? oops..

but actually not… oops..

Campbell et al. 1988
Walker et al. 1992
Hatzes et al. 2003

（credit：清华大学 王雪凇）

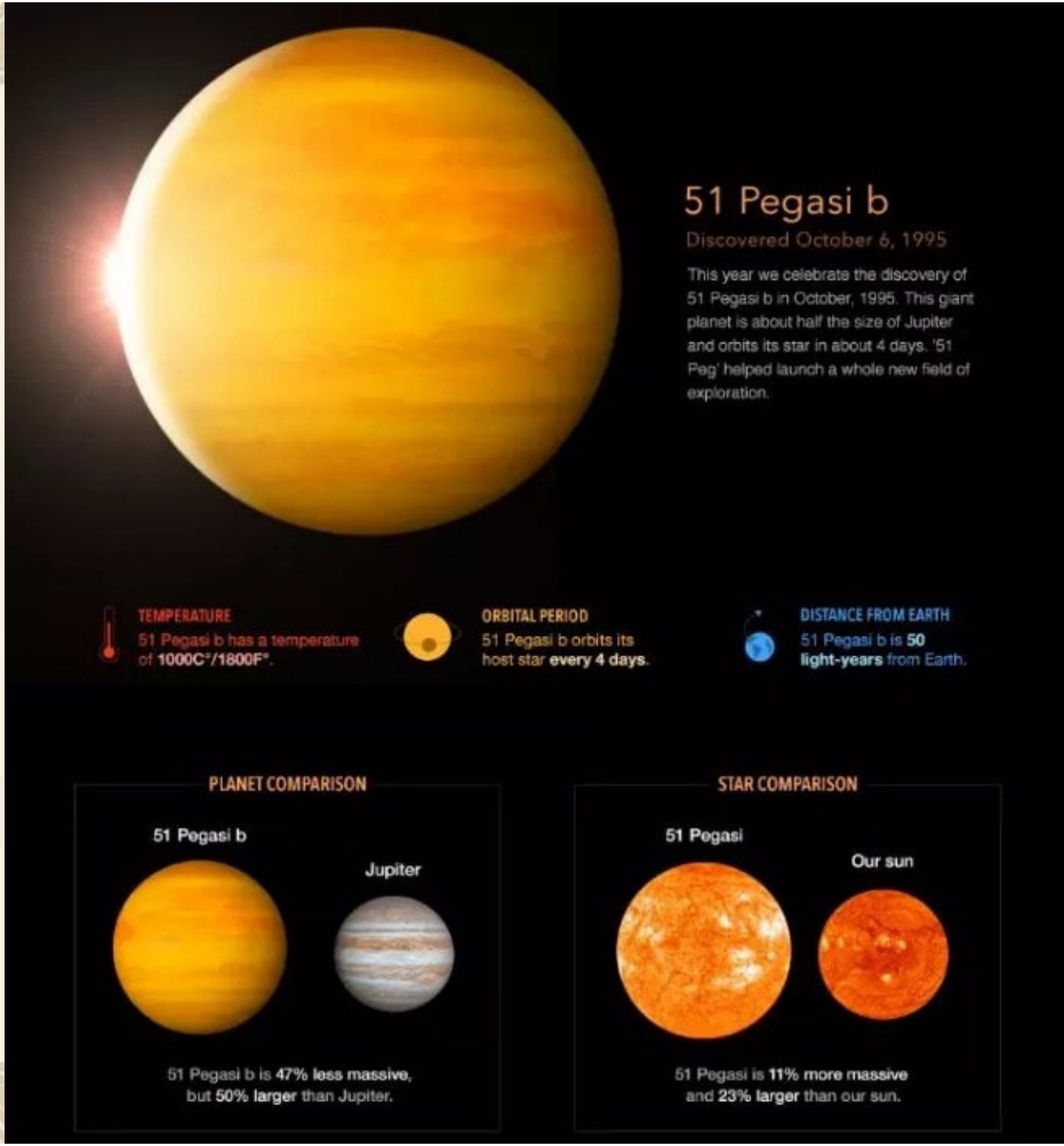


周期：4.23天

径向速度：~57m/s

轨道非常接近圆形

Figure 4.3 Radial velocity measurements of 51 Pegasi made by Korzennik and Contos using the advanced fibreoptic echelle spectrometer on the 1.5 m telescope at the Whipple Observatory near Tucson, Arizona.


51 Pegasi b
Discovered October 6, 1995
This year we celebrate the discovery of 51 Pegasi b in October, 1995. This giant planet is about half the size of Jupiter and orbits its star in about 4 days. '51 Peg' helped launch a whole new field of exploration.
TEMPERATURE
51 Pegasi b has a temperature of 1000C°/1800F°.
ORBITAL PERIOD
51 Pegasi b orbits its host star every 4 days.
DISTANCE FROM EARTH
51 Pegasi b is 50 light-years from Earth.
PLANET COMPARISON
51 Pegasi b
Jupiter
51 Pegasi b is 47% less massive, but 50% larger than Jupiter.
STAR COMPARISON
51 Pegasi
Our sun
51 Pegasi is 11% more massive and 23% larger than our sun.

行星51 Pegasi b的质量估算

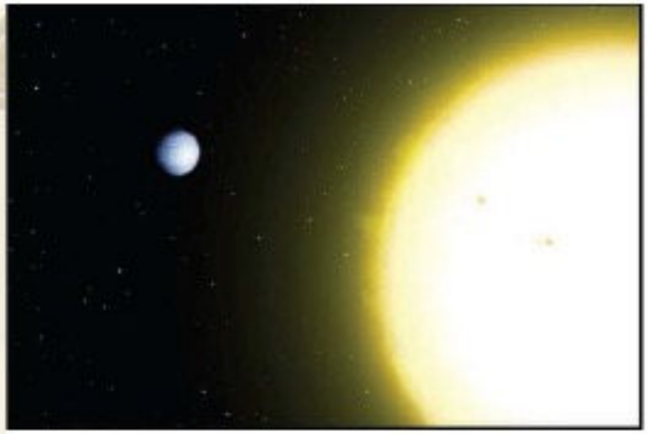


Figure 4.4 Artist's impression of 51 Pegasi b orbiting its sun. Image: Wikipedia Commons.

轨道周期：4.23天~365 472秒

轨道周长：57x365 472 = 20 831 904 m

轨道半径：3 315 500 m

行星的轨道半径：$a = (GM\,P^2/4\pi^2)^{1/3}$

$$= [6.67\times10^{-11}\times2.12\times10^{30}\times(365\,472)^2/4\pi^2]^{1/3}$$
$$= 7.82\times10^{9}\,\mathrm{m}$$

0.052AU

行星的质量：$M_{\mathrm{planet}}\times7.81\times10^{9} = M_{\mathrm{star}}\times3\,315500$

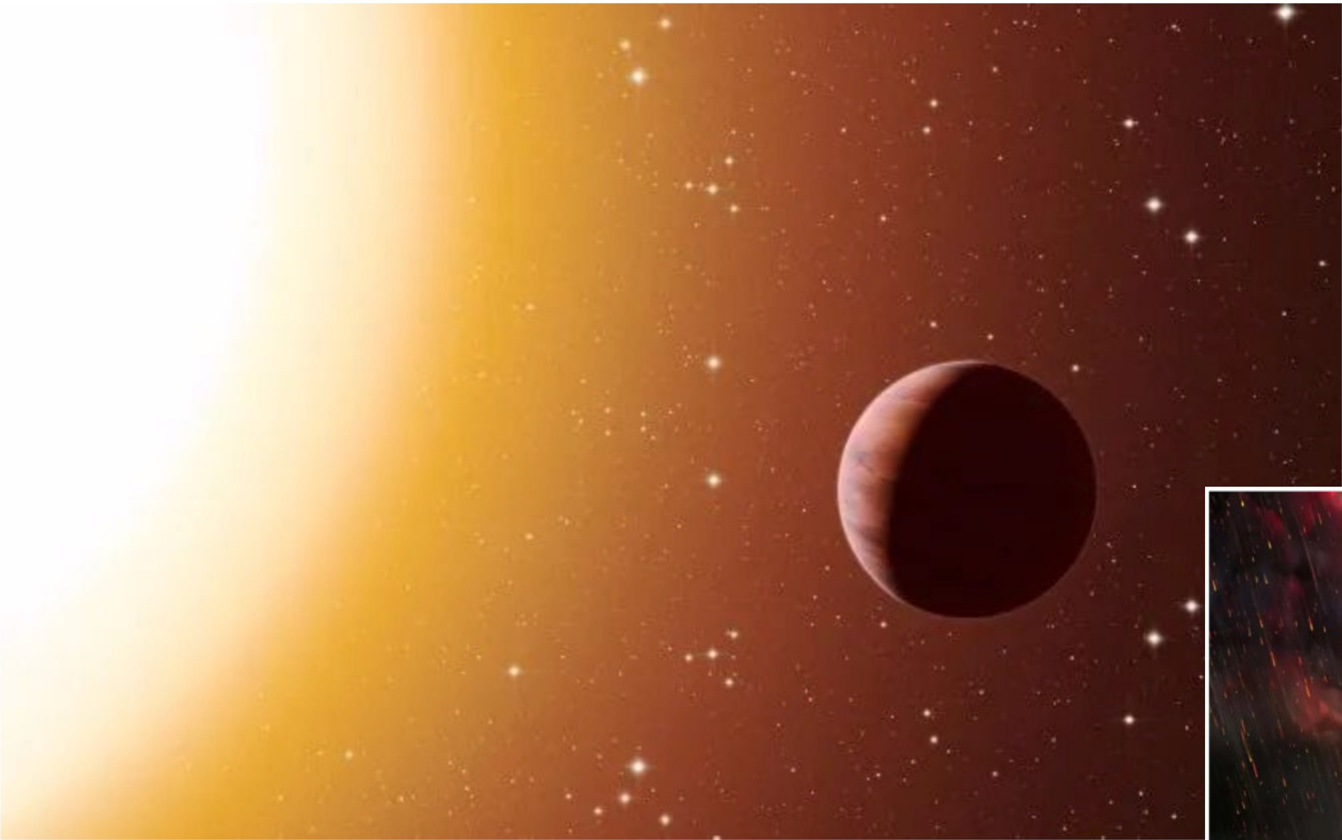
$$M_{\mathrm{planet}} = 2.12\times10^{30}\times(3\,315\,500/7.81\times10^{9})\,\mathrm{kg}$$
$$= 9\times10^{26}\,\mathrm{kg}$$

$0.47M_{木星}$

最小质量

- 大质量的气体行星（Gas Giant）没有预计在恒星附近被发现
- 在远处形成，向内迁移？
- 抛射恒星附近的小的行星？
- 这样的恒星系统不太可能存在生命

最近，欧洲南方天文台所属的甚大望远镜（VLT）在双鱼座内观测到一颗气态行星WASP-76b，距离地球640光年，它被它的伴侣——距其0.33个天文单位的WASP-76潮汐锁定，因此也只能以正面永远朝向自己的恒星。



这颗行星被称为"炽热的木星"，是一颗非常靠近其恒星运行的气态巨行星。/ NASA

WASP-76b上的永夜铁雨 / NASA

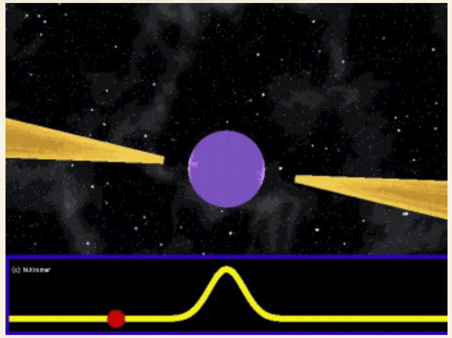
"你与我的距离，不过日地的三分之一，而你给我的光与热，却比太阳给地球的多了千倍。"

让WASP-76b痛苦的是，自己面朝恒星的**昼侧在恒星的光辉下，温度高达2700摄氏度**。即使是铁元素也无法在这样的高温下留存，尽数被蒸发至空气中。而与昼侧相对的**夜侧，则在1500摄氏度的永夜之中迎来被昼侧的吹至的铁蒸汽，超过1000度的温差使得铁蒸汽在夜侧冷凝为铁雨降下**。也正是因此。WASP-76b的一半只能在永恒的长夜里，湮没在滚滚铁雨恸哭之下，仿若阿鼻炼狱一般让人不堪设想。

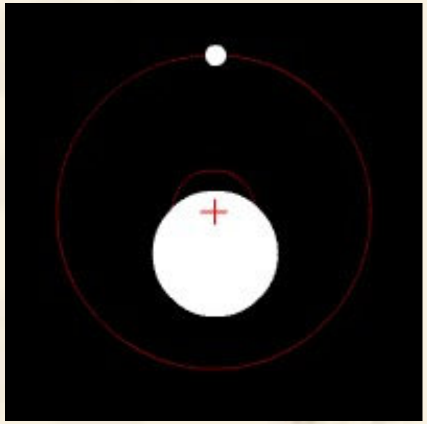
（《中国国家天文》）

脉冲星计时法

原理



- 脉冲星发射周期性非常好的信号
- 脉冲星相对地球的速度略有变化
- Doppler效应测量可到极高精度



优点：

- 非常灵敏
- 容易
- 可探测小质量的行星

缺点：

- 仅对脉冲星系统适用

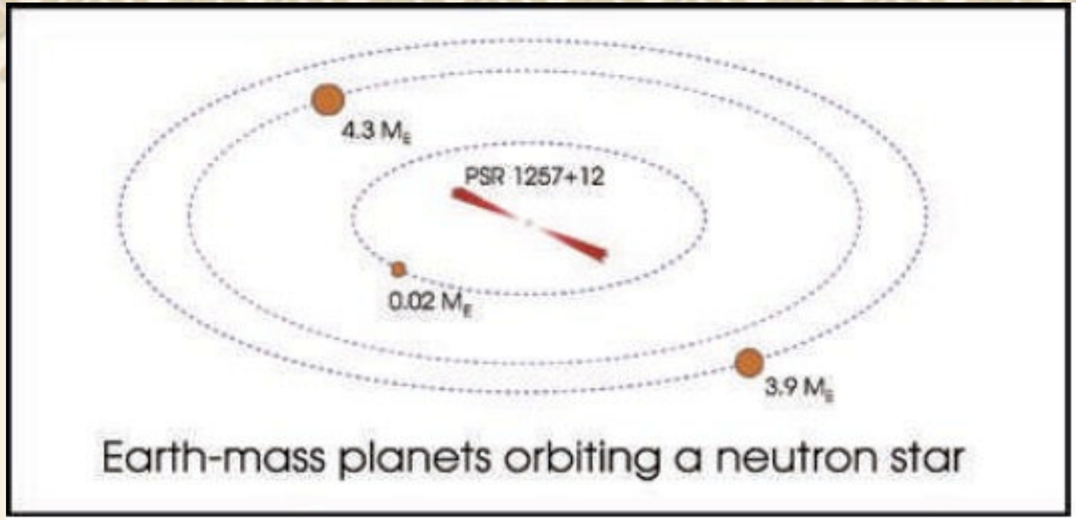


Figure 4.2 Planets orbiting the pulsar PSR 1257+12 at distances of 0.19, 0.36 and 0.46 AU.

- 脉冲星-行星系统很少：难于存活于超新星爆发？
- 脉冲星周围存在环绕的气体盘：2006年Spitzer， 4U 0142+61, 存在行星？
- 脉冲星的辐射强，不适合生命的存在（也没“太阳”光）
- PSR B1257+12, 1992年发现两个行星，质量：4.3，3.9地球质量，在水星轨道之内；随后又发现了两个小质量的行星（0.004，0.02地球质量）
- PSR B1620-26，发现一个2.7倍木星质量的行星
- 其它三个脉冲星系统存在一至三个行星，但还没有确认

天体位置测量法

原理

- 短期内绕银心运动近似直线；双星或行星系统中恒星会有额外微小圆形或椭圆运动

优点

- 对大的轨道更敏感

缺点

- 需要极高位置精度
- 大质量的行星
- 大的轨道需要长的观测时间

- 目前还没有通过天体位置测量法探测到新的系外行星
- 难观测：例如，太阳-木星系统位于30光年远
  - R ~ 776 770 km
  - D ~ 30光年~3×10^{14}km
  - 角径 ~ $7.77 \times 10^5 / 3 \times 10^{14}$~ 2.6×10^{-9} rad ~0.00054角秒
  - HST分辨率：~0.05角秒 → 0.0005角秒位置精度
- 幸运的例外：HST通过天体位置测量法证认了Gliese 876中行星（之前由视向速度法发现）
- Gliese 876：D~15.6光年，HST两年的位置监测（+视向速度观测），确定轨道平面，确定行星质量
- NASA空间干涉项目（SIM）：

  位置测量精度：~0.000001角秒！

Gaia (spacecraft)

From Wikipedia, the free encyclopedia

Gaia is a space observatory of the European Space Agency (ESA) designed for astrometry: measuring the positions and distances of stars with unprecedented precision.[7][8] The mission aims to construct by far the largest and most precise 3D space catalog ever made, totalling approximately 1 billion astronomical objects, mainly stars, but also planets, comets, asteroids and quasars among others.[9]

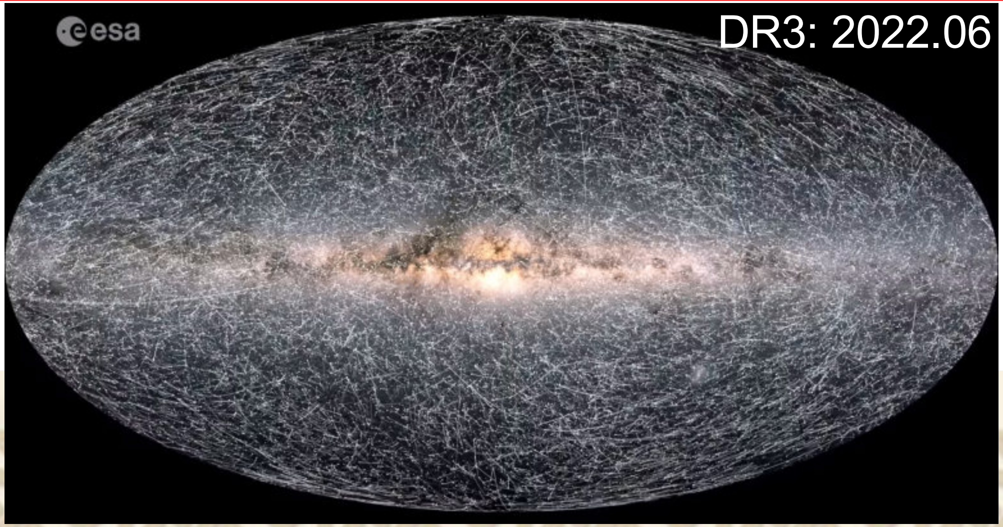
The spacecraft will monitor each of its target objects about 70 times[10] over a period of five years to study the precise position and motion of each target.[11][12] The spacecraft has enough consumables to operate for approximately nine years, if its detectors are not degrading as fast as initially expected. The mission could therefore be extended.[2] The *Gaia* targets represent approximately 1% of the Milky Way population[10] with all stars brighter than magnitude 20 in a broad photometric band that covers most of the visual range.[13] Additionally, *Gaia* is expected to detect thousands to tens of thousands of Jupiter-sized exoplanets beyond the Solar System,[14] 500,000 quasars outside our galaxy and tens of thousands of new asteroids and comets within the Solar System.[15][16][17]

Gaia will create a precise three-dimensional map of astronomical objects throughout the Milky Way and map their motions, which encode the origin and subsequent evolution of the Milky Way. The spectrophotometric measurements will provide the detailed physical properties of all stars observed, characterizing their luminosity, effective temperature, gravity and elemental composition. This massive stellar census will provide the basic observational data to analyze a wide range of important questions related to the origin, structure, and evolutionary history of our galaxy.

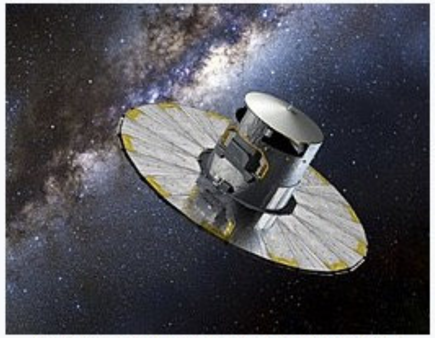
Successor to the *Hipparcos* mission, the telescope is part of ESA's Horizon 2000+ long-term scientific program. *Gaia* was launched on 19 December 2013 by Arianespace using a Soyuz ST-B/Fregat-MT rocket flying from Kourou in French Guiana.[18][19] The spacecraft currently operates in a Lissajous orbit around the Sun–Earth L_2 Lagrangian point.

Contents [hide]

Gaia is an ambitious mission to chart a three-dimensional map of our Galaxy, the Milky Way, in the process revealing the composition, formation and evolution of the Galaxy. Gaia will provide unprecedented positional and radial velocity measurements with the accuracies needed to produce a stereoscopic and kinematic census of about one billion stars in our Galaxy and throughout the Local Group. This amounts to about 1 per cent of the Galactic stellar population.



Gaia



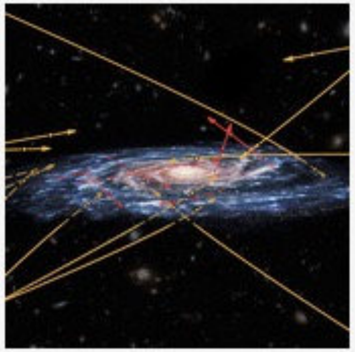
Artist's impression of the *Gaia* spacecraft

Mission type	Astrometric observatory
Operator	ESA
COSPAR ID	2013-074A
SATCAT no.	39479
Website	sci.esa.int/gaia/
Mission duration	planned: 5 years; possible extension by one to four years[1][2] elapsed: 4 years, 10 months and 25 days
Spacecraft properties	
Manufacturer	EADS Astrium e2v Technologies
Launch mass	2,029 kg (4,473 lb)[3]
Dry mass	1,392 kg (3,069 lb)
Payload mass	710 kg (1,570 lb)[4]
Dimensions	4.6 m × 2.3 m (15.1 ft × 7.5 ft)
Power	1910 watts
Start of mission	
Launch date	19 December 2013, 09:12:14 UTC[5]

NEWS

Galactic ghosts: Gaia uncovers major event in the formation of the Milky Way

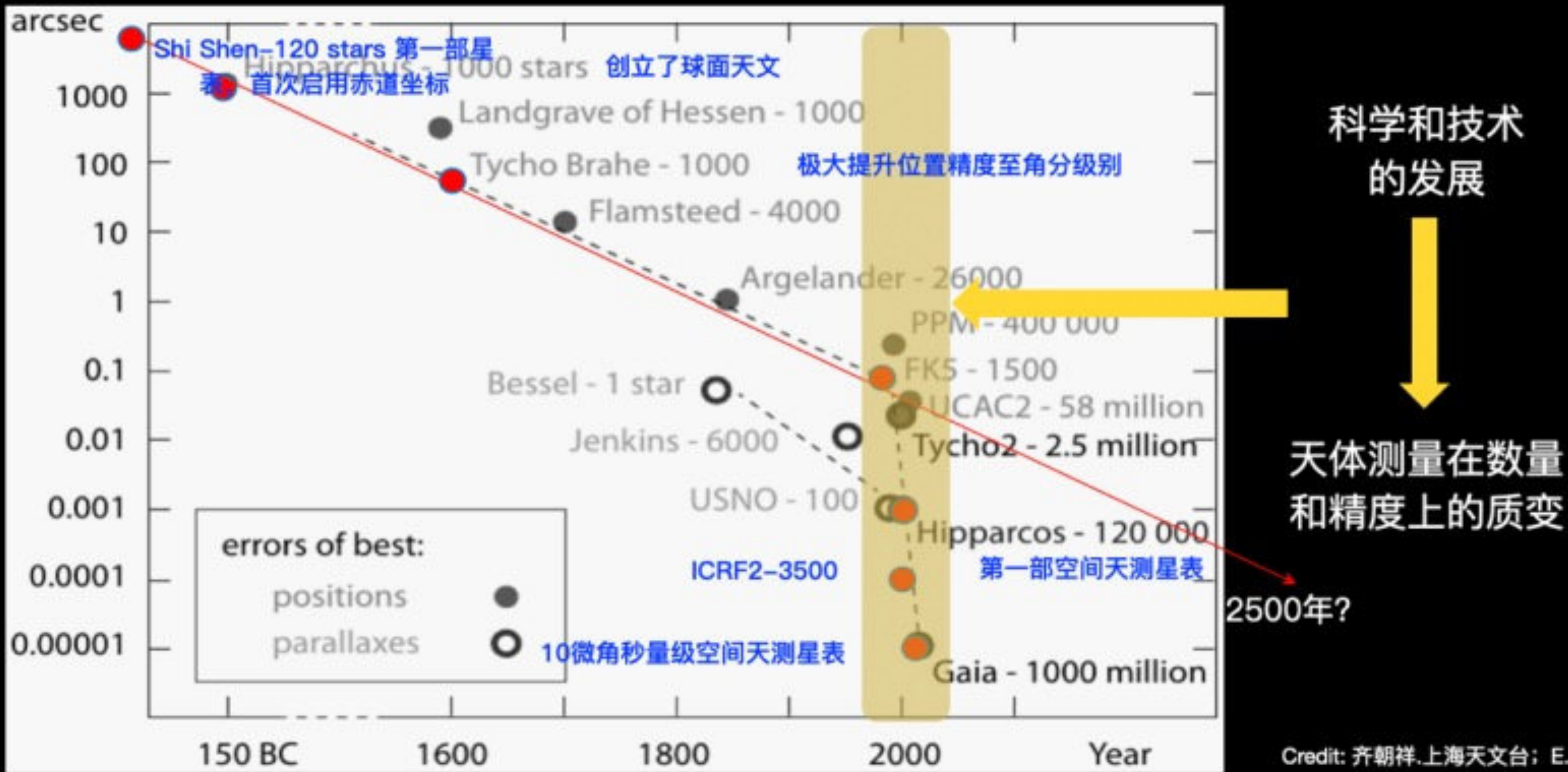
31 October 2018 ESA's Gaia mission has made a major breakthrough in unravelling the formation history of the Milky Way. Instead of forming alone, our Galaxy merged with another large galaxy early in its life, around 10 billion years ago. Read more



Gaia spots stars flying between galaxies

02 October 2018 A team of astronomers using the latest set of data from ESA's Gaia mission to look for high-velocity stars being kicked out of the Milky Way were surprised to find stars instead sprinting inwards – perhaps from another galaxy. Read more

近2400年来天体位置测量精度以及星数随时间的发展



Credit: 齐朝祥.上海天文台；E. Hog et al.

The Innovation | 太阳系邻居的“人口调查”：寻找另一颗“地球”

原创 Jianghui Ji TheInnovation创新 2022-06-23 00:01 发表于浙江

宜居行星探测是国际天文学的前沿课题， 研究将试图回答“地球是否独一无二？”、“行星如何成为生命的摇篮？”等科学问题。中科院紫金山天文台季江徽团队介绍了“近邻宜居行星巡天计划”的核心科学目标，拟**基于微角秒级空间天体测量方法搜寻太阳系近邻的100颗类太阳型恒星周围的宜居带类地行星，开展近邻行星系统的全面普查**，预期在宜居带类地行星的发现方面取得重大突破。文章以News & Buzz形式在线发表于The Innovation。

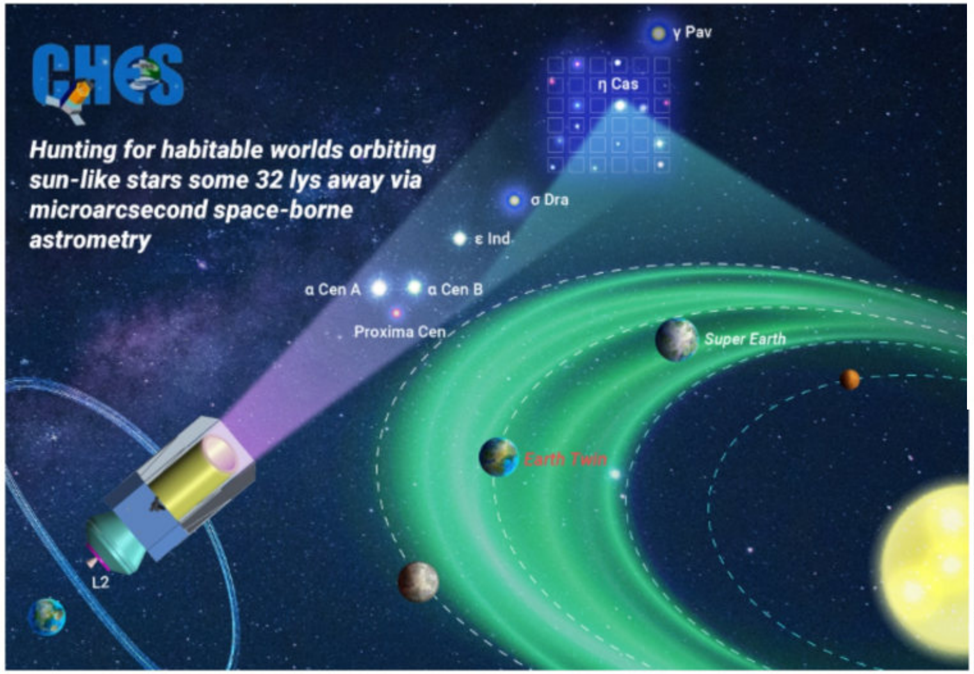


图1 近邻宜居行星巡天计划

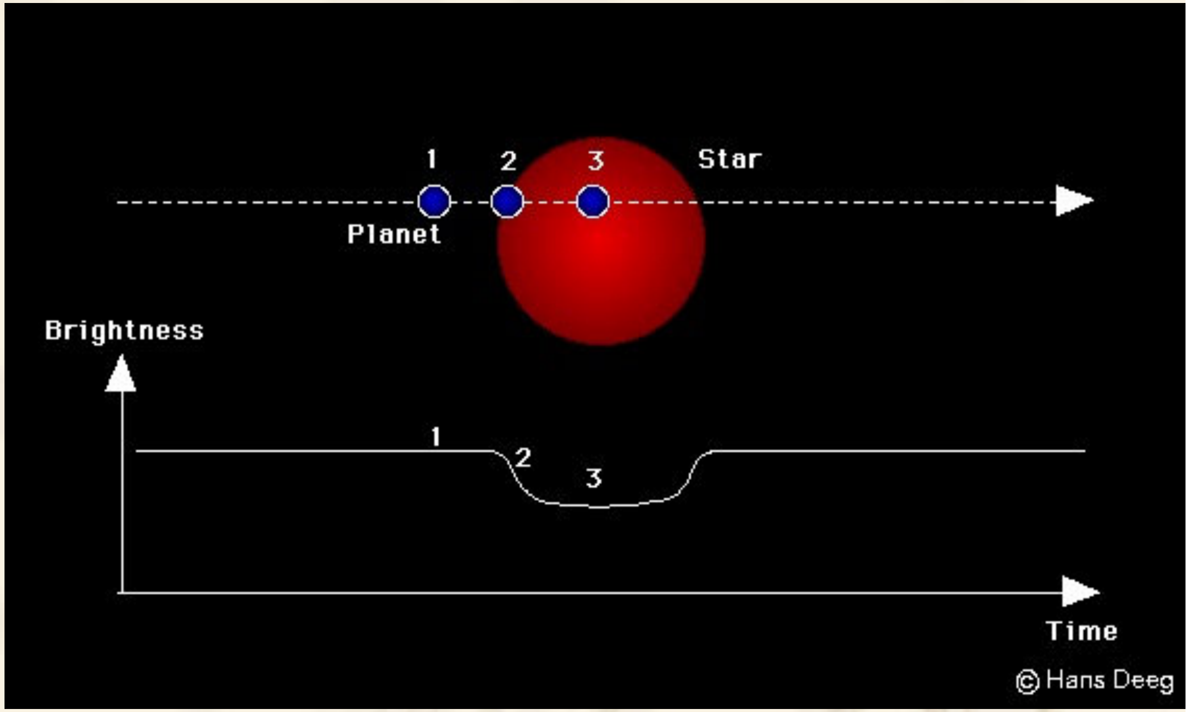
“近邻宜居行星巡天计划”(Closeby Habitable Exoplanet Survey, CHES)旨在通过微角秒级相对天体测量方法探测围绕100颗近邻类太阳型恒星(距太阳系约32光年)运行的宜居带类地行星，目前被中国科学院遴选为未来发射的候选空间任务(图1)。如果在近邻类太阳型恒星周围的宜居带发现具有与地球相似的轨道、质量和环境的类地行星(或地球2.0)将是又一次“人类的巨大飞跃”，并帮助我们回答诸如“我们在宇宙中是孤独的吗？”、“行星如何成为生命的摇篮？”等诸多科学问题。自从发现第一颗围绕主序星运行的行星以来，迄今天文学家共发现5000余颗系外行星，而**距太阳系32光年的行星发现总数占比仅仅约为2%**，我们仍然对太阳系近邻恒星周围的行星知之甚少。**CHES独特的探测方法将填补近邻行星的探测空白，寻找宜居行星甚至可使未来人类造访并确定新的栖息家园**。

CHES将基于空间高精度相对天体测量方法，预期在近邻类太阳型恒星的宜居带首次发现围绕其运行的地球2.0，测量它们的真实质量和三维轨道，完成近邻行星系统全面普查，填补近邻行星的发现空白。这项任务将回答近邻恒星宜居带中是否存在类地行星，揭示其分布，预估行星系统中宜居带行星出现的概率，了解太阳系行星的宜居性和演化。此外，CHES通过超高精度天体测量可以研究黑洞质量精确测量、银河系暗物质分布等科学问题，促进人类对宇宙的深入认知。

凌日（掩食）法

原理

- 行星阻挡了恒星光, 使恒星变暗

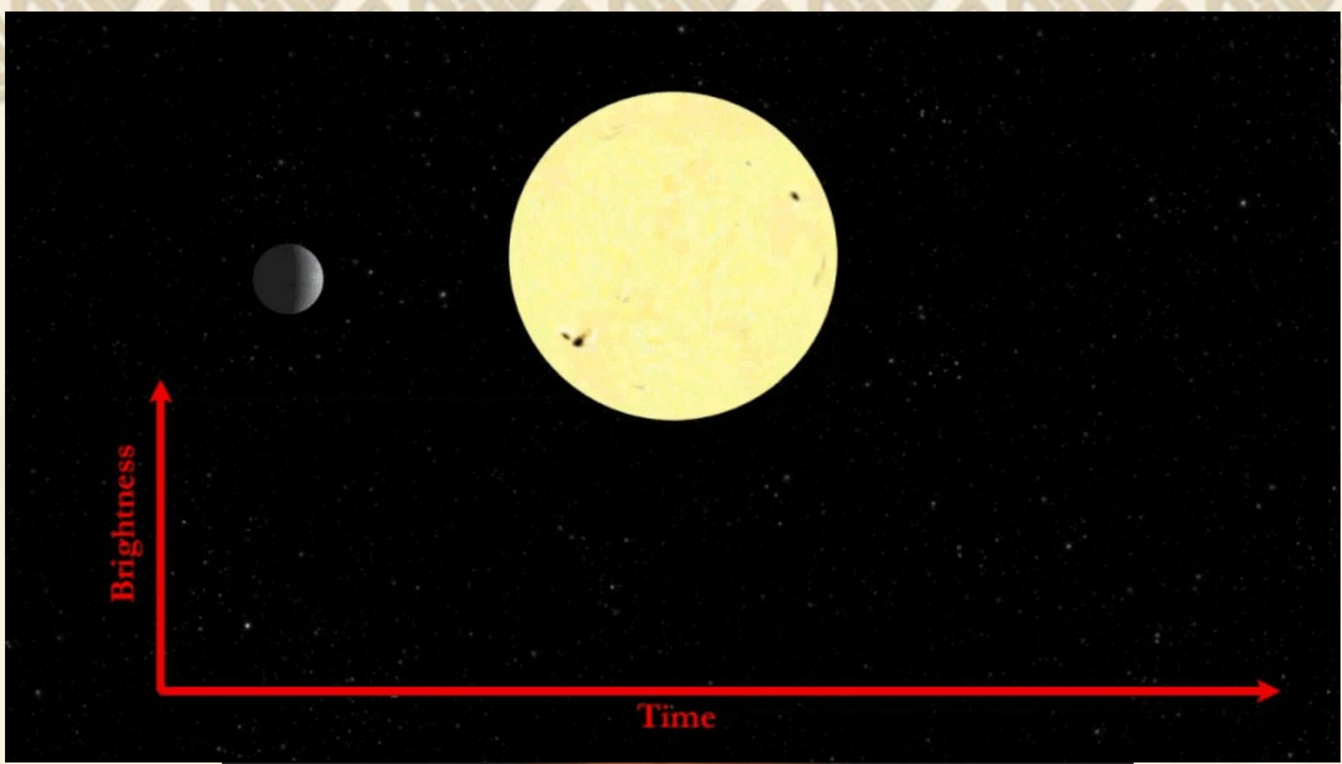


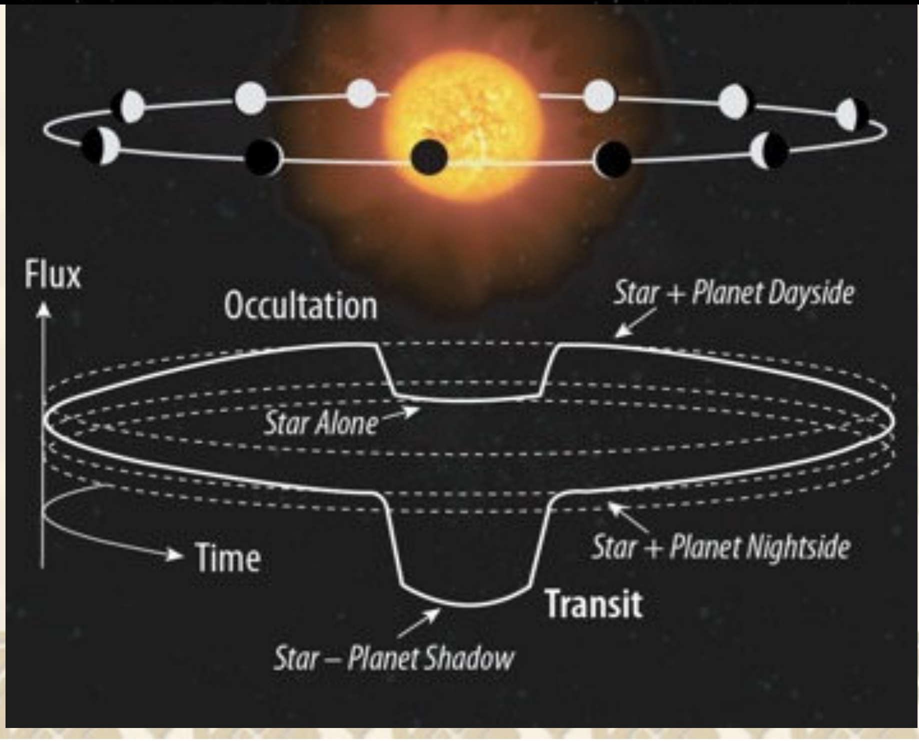
缺点

- 观测几率小

优点

- 空间观测容易进行
- 观测恒星（被行星大气）吸收光谱
- 测量行星大气


Brightness
Time


Flux
Occultation
Star + Planet Dayside
Star Alone
Time
Star + Planet Nightside
Transit
Star – Planet Shadow

掩食：太阳-木星系统

- 木星的半径约为太阳半径的1/10
- 掩食时，太阳的发光面积减少了1/100（设面亮度均匀）
- 太阳的光度变化：

$$\Delta m = 2.5 \log_{10}(0.99) \\ = -0.011 \text{ magnitudes.}$$

掩食法发现行星

- 1999 11.5：HD 209469（最早被径向速度法发现），亮度下降了1.7%
- 2002，OGLE-TR-56B发现，后被径向速度法确认
- 2006，HST搜寻了180000个恒星（在26 000光年范围），发现了16个候选者，3个被证认。若16个都被证认，银河系中可能存在~60亿个木星大小的行星！

- 类地球-太阳系统发生掩食的概率：~0.5%
- 空间项目：Kepler & COROT
- 掩食法可以测量行星的大小，加上质量，可以估算行星的密度，研究行星的结构
- 可以通过恒星的吸收光谱分析，得到行星的大气成份：HST观测

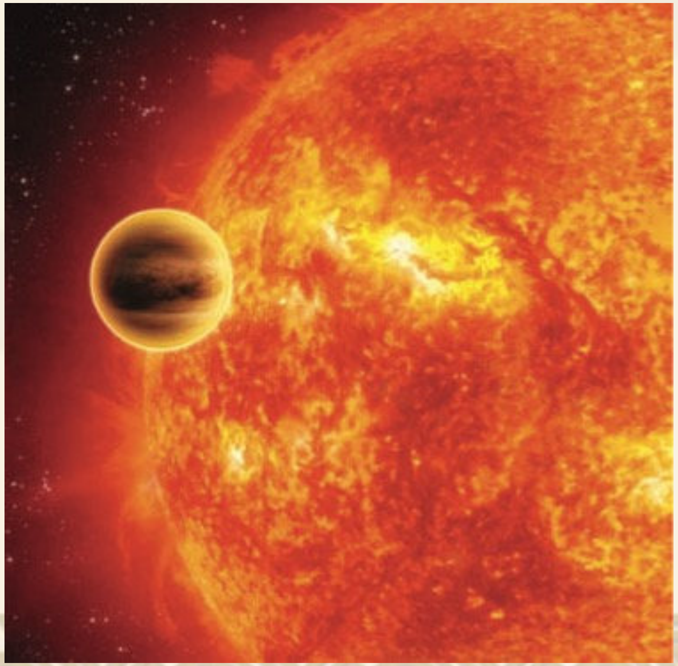


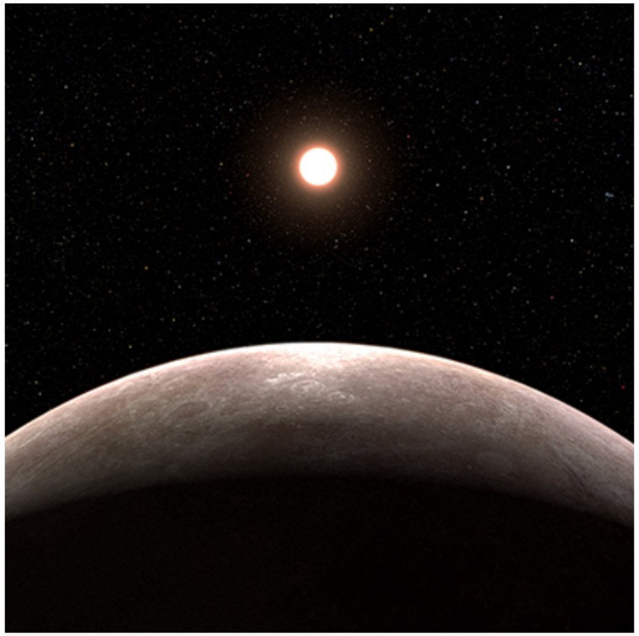
Figure 4.7 An artist's impression of the planet HD 209458b showing an extended envelope of carbon and oxygen and tail of evaporating hydrogen. Image: ESA and Alfred Vidal-Madjar (Institut d'Astrophysique de Paris, CNRS, France).

NASA's Webb Confirms Its First Exoplanet

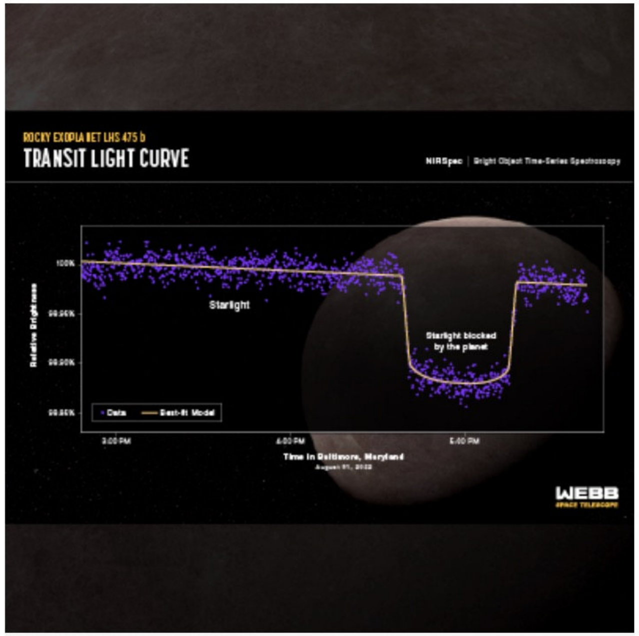
January 11, 2023 1:15PM (EST) | Release ID: 2023-102

The planet is rocky and almost precisely the same size as Earth, but whips around its star in only two days.

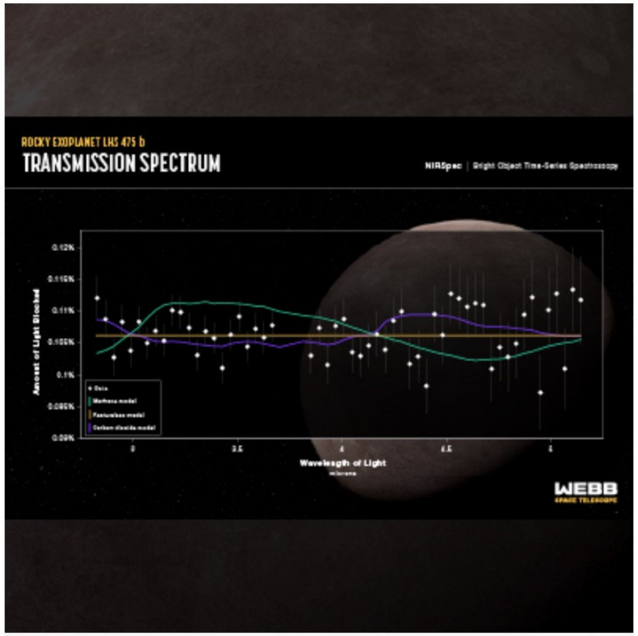
Researchers using NASA's James Webb Space Telescope have formally embarked on a new frontier: Identifying and analyzing rocky exoplanets that orbit red dwarf stars. A team led by Kevin Stevenson and Jacob Lustig-Yaeger, both of the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland, confirmed that LHS 475 b not only exists, it is a small, rocky planet that is almost exactly the same size as Earth. Before Webb, researchers typically targeted planets that are larger than Jupiter, which is 11 times wider than Earth. This will inevitably be the first of many discoveries Webb data will help researchers make as they continue exploring planets elsewhere in our Milky Way galaxy.



Exoplanet LHS 475 b and Its Star (Illustration)



Exoplanet LHS 475 b (NIRSpec Transit Light Curve)

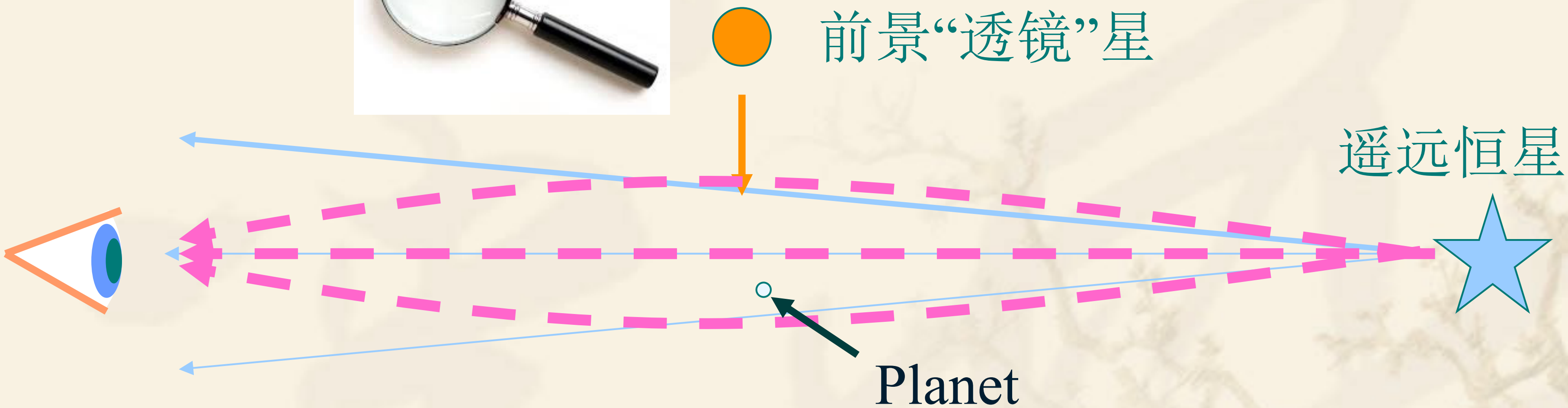


Exoplanet LHS 475 b (Transmission Spectrum)

微引力透镜

技术

- 广义相对论 – 光线在引力场中弯曲
- 微引力透镜效应：恒星的亮度增加



- 仔细观测遥远恒星的亮度，可以探测透镜恒星周围有没有行星

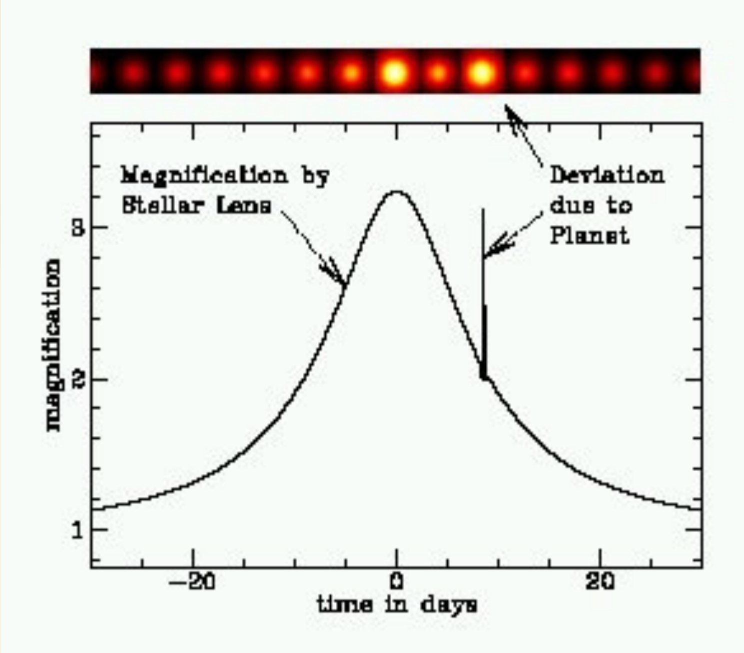
微引力透镜

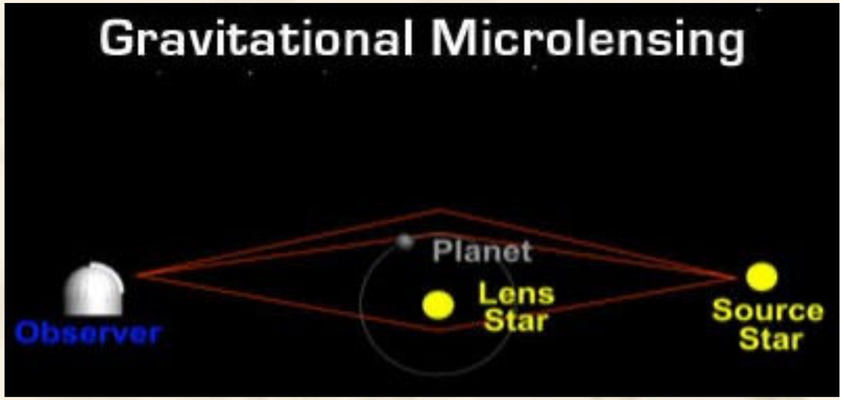
缺点

- 透镜事件很少
- 几乎无法重复、后续观测
- 得到的行星的信息很少

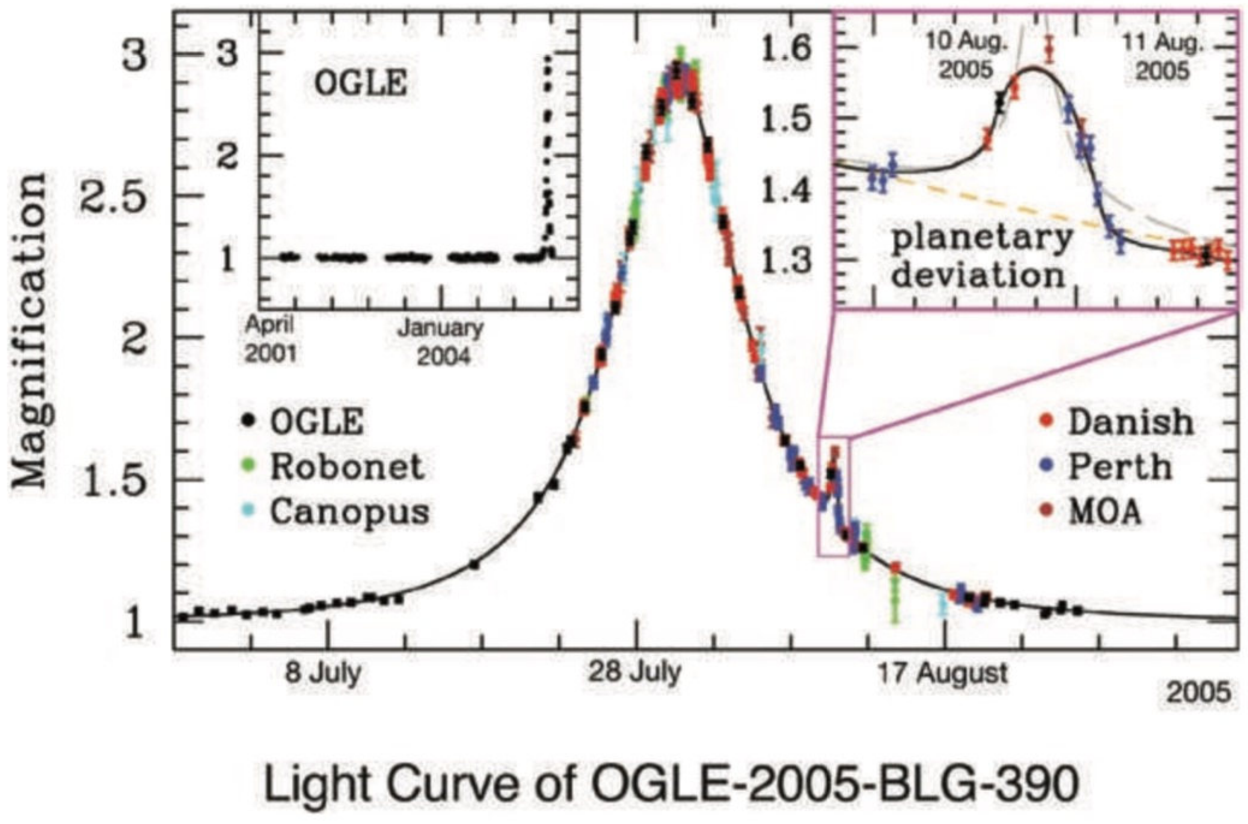
优点

- 可以很“便宜”监测很多恒星
- 对小质量的行星敏感





- 2007年底观测到微引力透镜事件：~1000（仅4例新的系外行星）
- 自动望远镜观测网，连续观测



Light Curve of OGLE-2005-BLG-390

Figure 4.8 Observations by the OGLE consortium showing the microlensing caused by a planet of 5.5 Earth masses. Image: ESO press release March 2006.

- 2006 1.25，OGLE-2005-BLG-390Lb被发现
  - ~ 5.5 地球质量， ~ 2.6AU
  - 恒星：红矮星， 2 1500光年，朝向银河系中心
  - 当时为最小质量的围绕主序星的行星（Gliese 581,2007.4,径向速度法，~5地球质量）

- 截止于2016/04，有46个太阳系外行星通过微引力透镜法被探测到
- 2008年，发现类木星-土星-太阳系统
  - 恒星：~5000 光年，0.5太阳质量
  - 近的行星：~0.71木星质量，~2.3AU
  - 远的行星：~0.27木星质量，距离两倍
  - 质量比（3：1）；距离比（1：2）；轨道周期比（2：5）非常类似木星-土星！

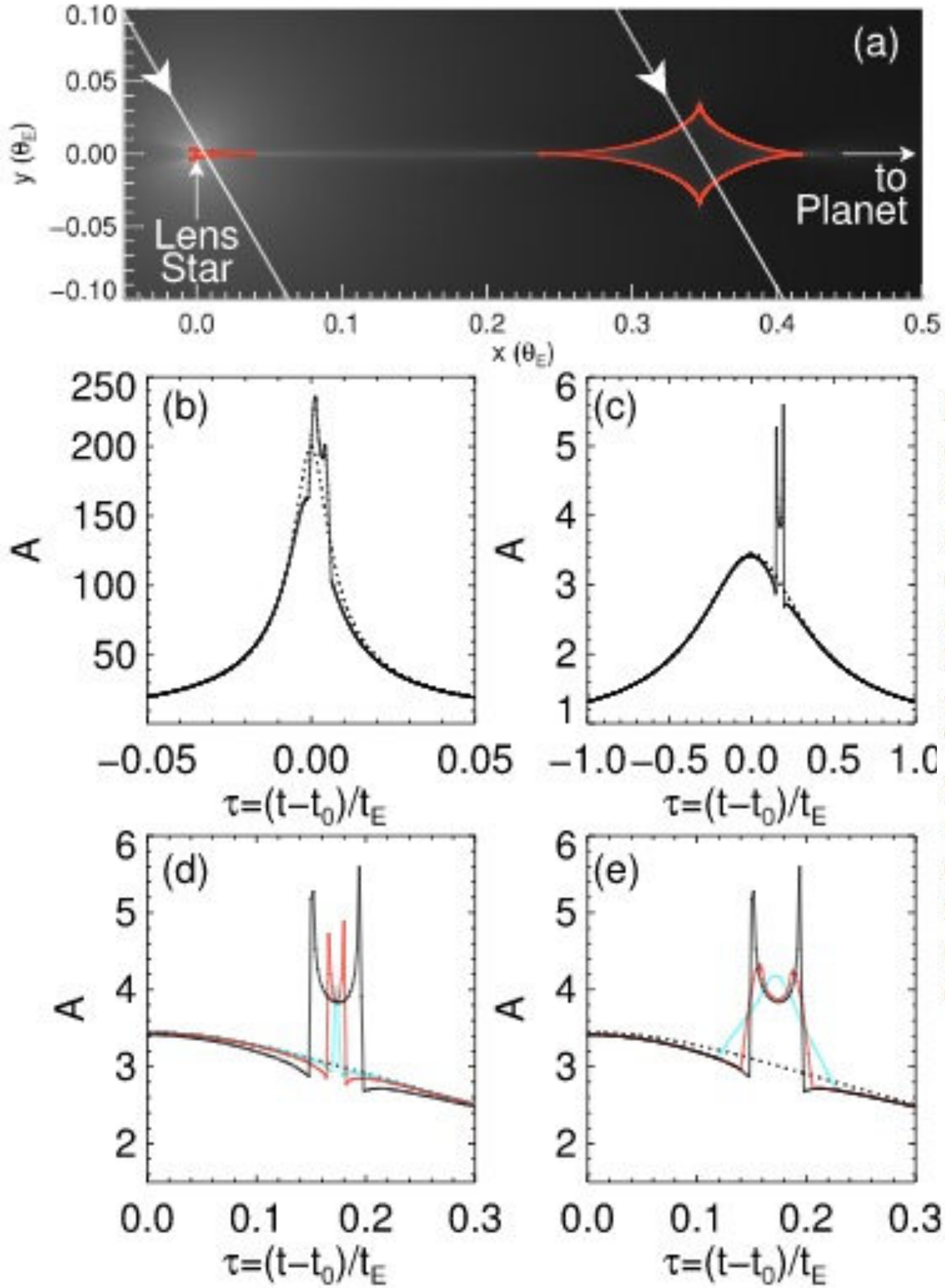


Fig. 10.— (a) Magnification map for a planet with $q = 0.001$ and $s = 1.188$ and a source size $\rho = 0.001$. The red lines indicate the caustics. Two example source trajectories are shown. The scale is such that the Einstein ring is a circle of radius 1.0 centered at (0,0). The planet is located at (1.188,0), just outside the Einstein ring (off the right-hand side of the plot). (b) Light curve corresponding to the left-hand source trajectory (a central caustic crossing). The dotted line shows the corresponding light curve for a point lens. (c) Light curve corresponding to the right-hand source trajectory (a planetary caustic crossing). (d) Detail of (c) showing the variation in the planetary signal for different values of $q = 10^{-3}, 10^{-4}, 10^{-5}$ (black, red, cyan). (e) The variation in the planetary signal for different values of $\rho = 0.001, 0.01, 0.03$ (black, red, cyan).

（D. A. Fischer et al.）

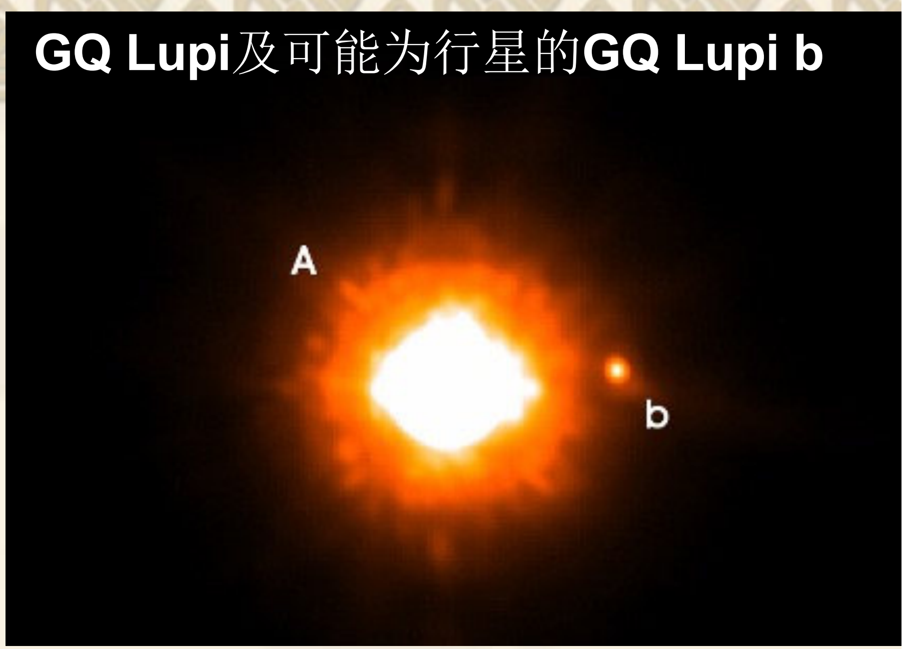
直接成像法

缺点：

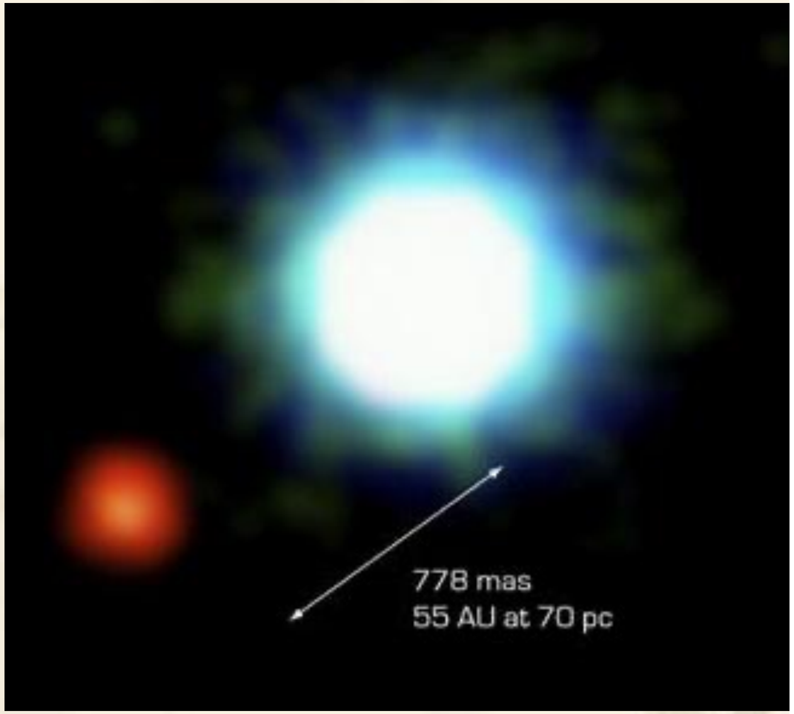
- 恒星与行星亮度对比度大
- 一般依赖空间观测

优点：

- 估计行星的大小（?）
- 可以研究行星的光谱



GQ Lupi及可能为行星的GQ Lupi b



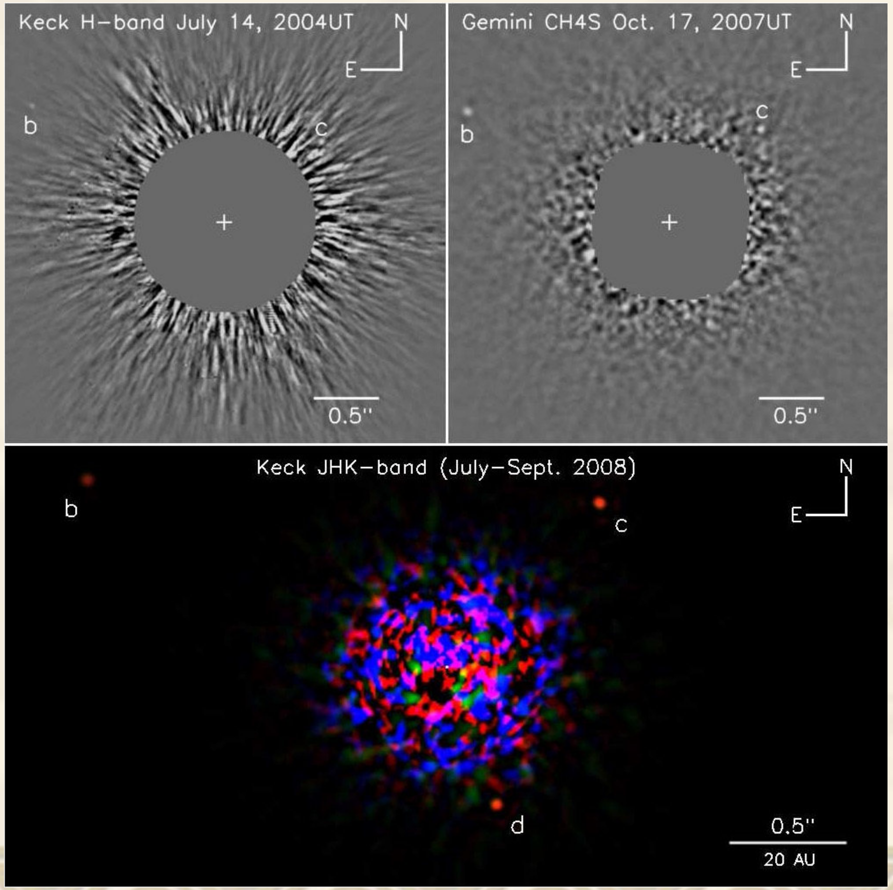
2M1207（蓝色）及其行星M1207b

明星“走光”图

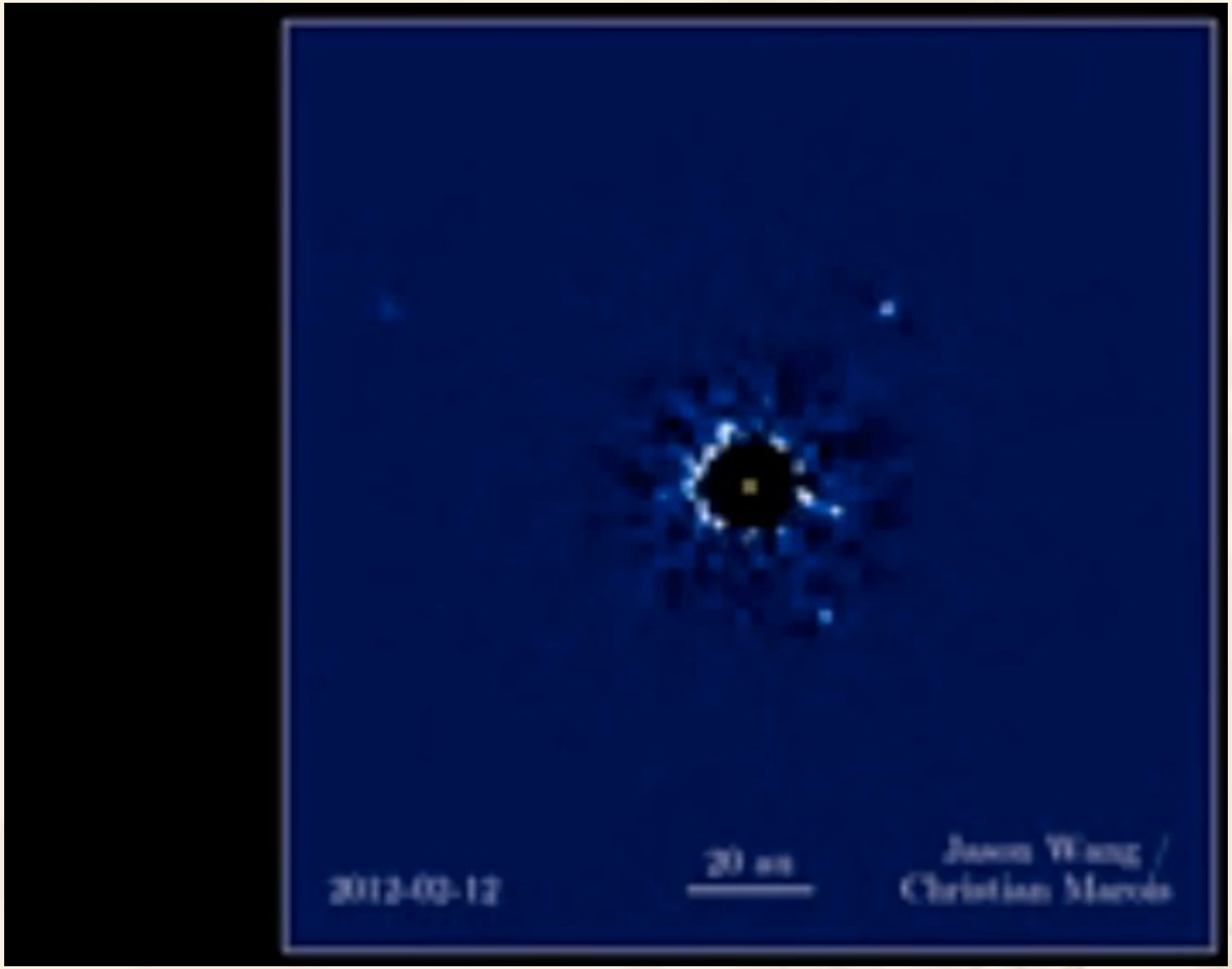

为什么直接成像法很难？

为什么直接成像法很难？

- 2004年7月：ESO VLT，棕矮星2M1207及其行星2M1207b
- 2008年11月13日，Keck（Gemini），HR 8799的三个行星直接成像



Four planets orbit a star



Four Planets Orbiting Star HR 8799
Video Credit & CC BY License: J. Wang (UC Berkeley) & C. Marois (Herzberg Astrophysics), NExSS (NASA), Keck Obs.

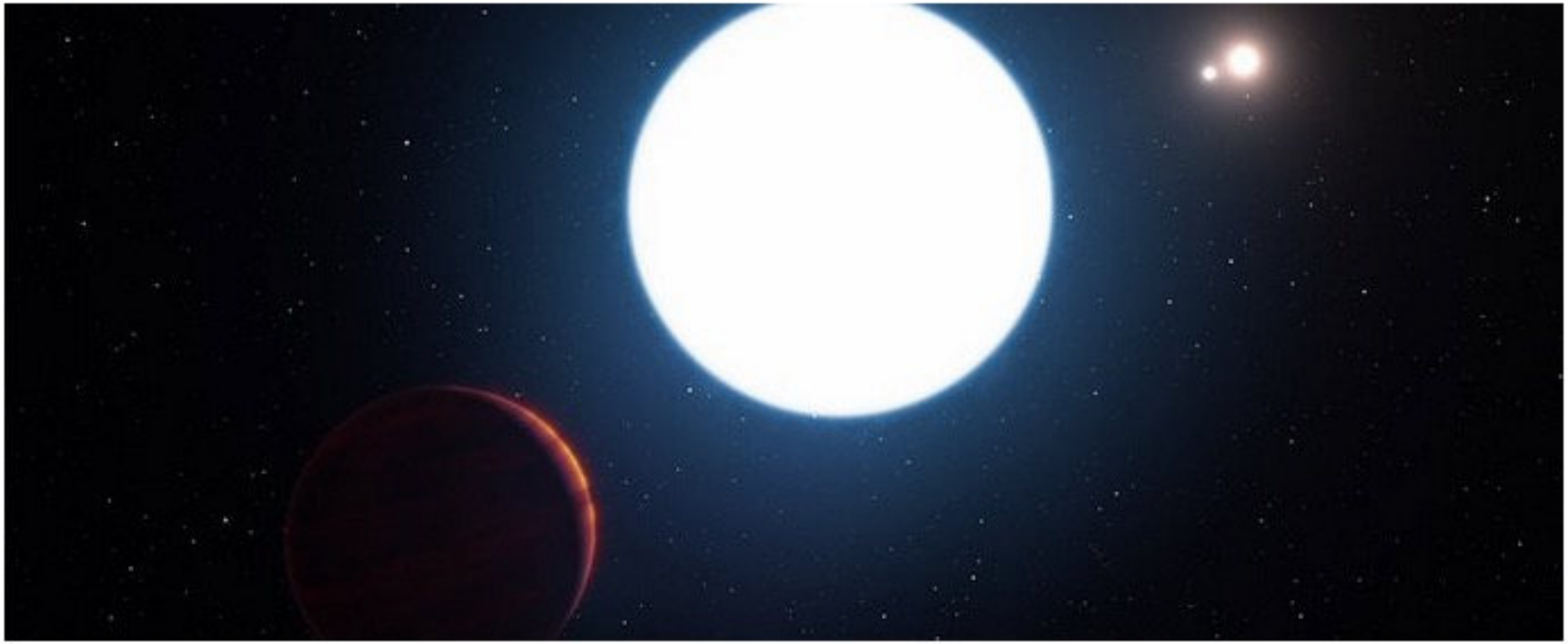
Explanation: Does life exist outside our Solar System? To help find out, NASA has created the Nexus for Exoplanet System Science (NExSS) to better locate and study distant star systems that hold hope of harboring living inhabitants. A new observational result from a NExSS collaboration is the featured time-lapse video of recently discovered planets orbiting the star HR 8799. The images for the video were taken over seven years from the Keck Observatory in Hawaii. Four exoplanets appear as white dots partially circling their parent star, purposefully occluded in the center. The central star HR 8799 is slightly larger and more massive than our Sun, while each of the planets is thought to be a few times the mass of Jupiter. The HR 8799 system lies about 130 light years away toward the constellation of the Flying Horse (Pegasus). Research will now continue on whether any known or potential planets -- or even moons of these planets -- in the HR 8799 star system could harbor life.

eso1624 — Science Release

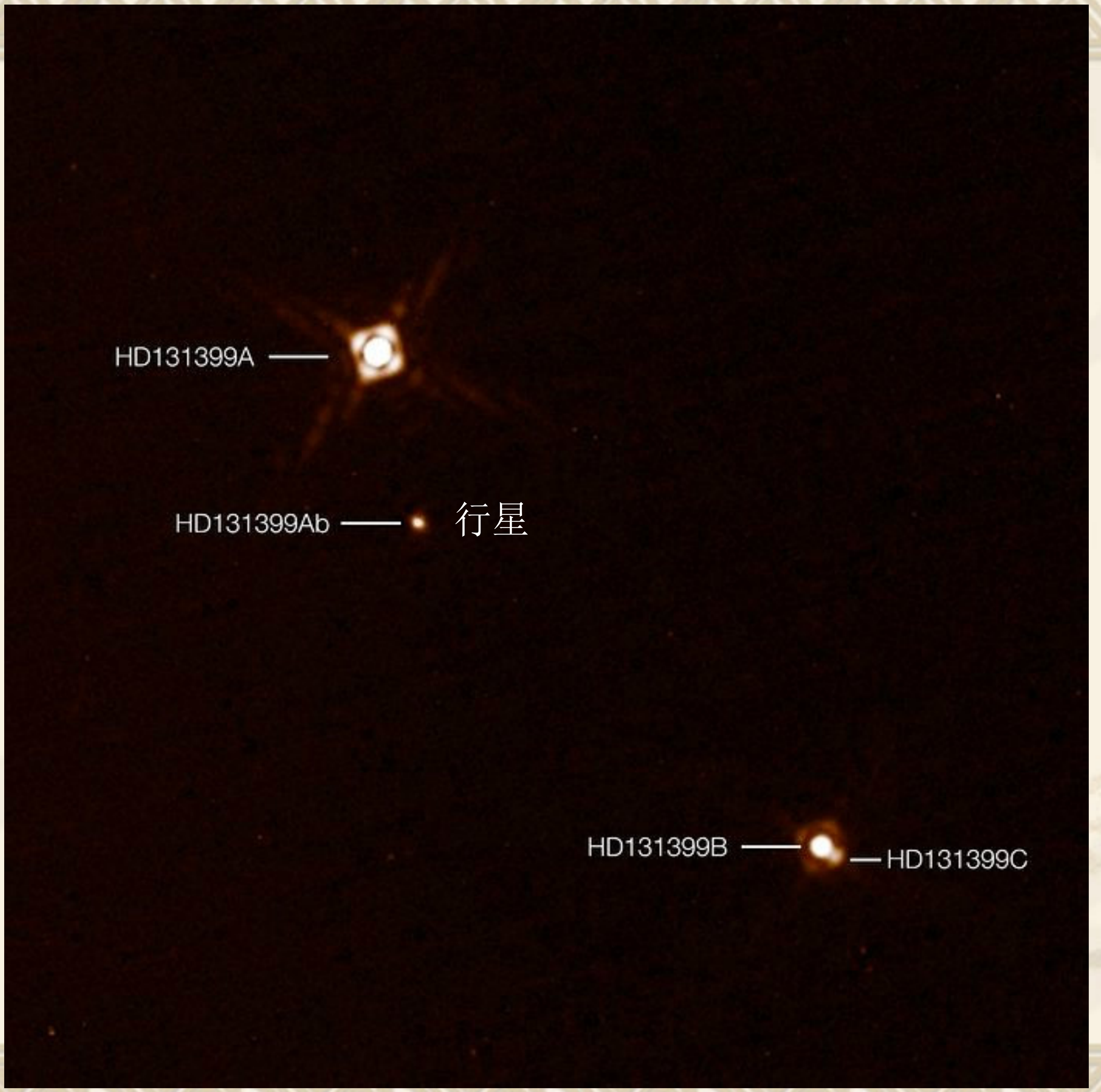
SPACE SCOOP

A Surprising Planet with Three Suns

7 July 2016



A team of astronomers have used the SPHERE instrument on ESO's Very Large Telescope to image the first planet ever found in a wide orbit inside a triple-star system. The orbit of such a planet had been expected to be unstable, probably resulting in the planet being quickly ejected from the system. But somehow this one survives. This unexpected observation suggests that such systems may actually be more common than previously thought. The results will be published online in the journal Science on 7 July 2016.


HD131399A
HD131399Ab
行星
HD131399B
HD131399C

First Giant Planet around White Dwarf Found

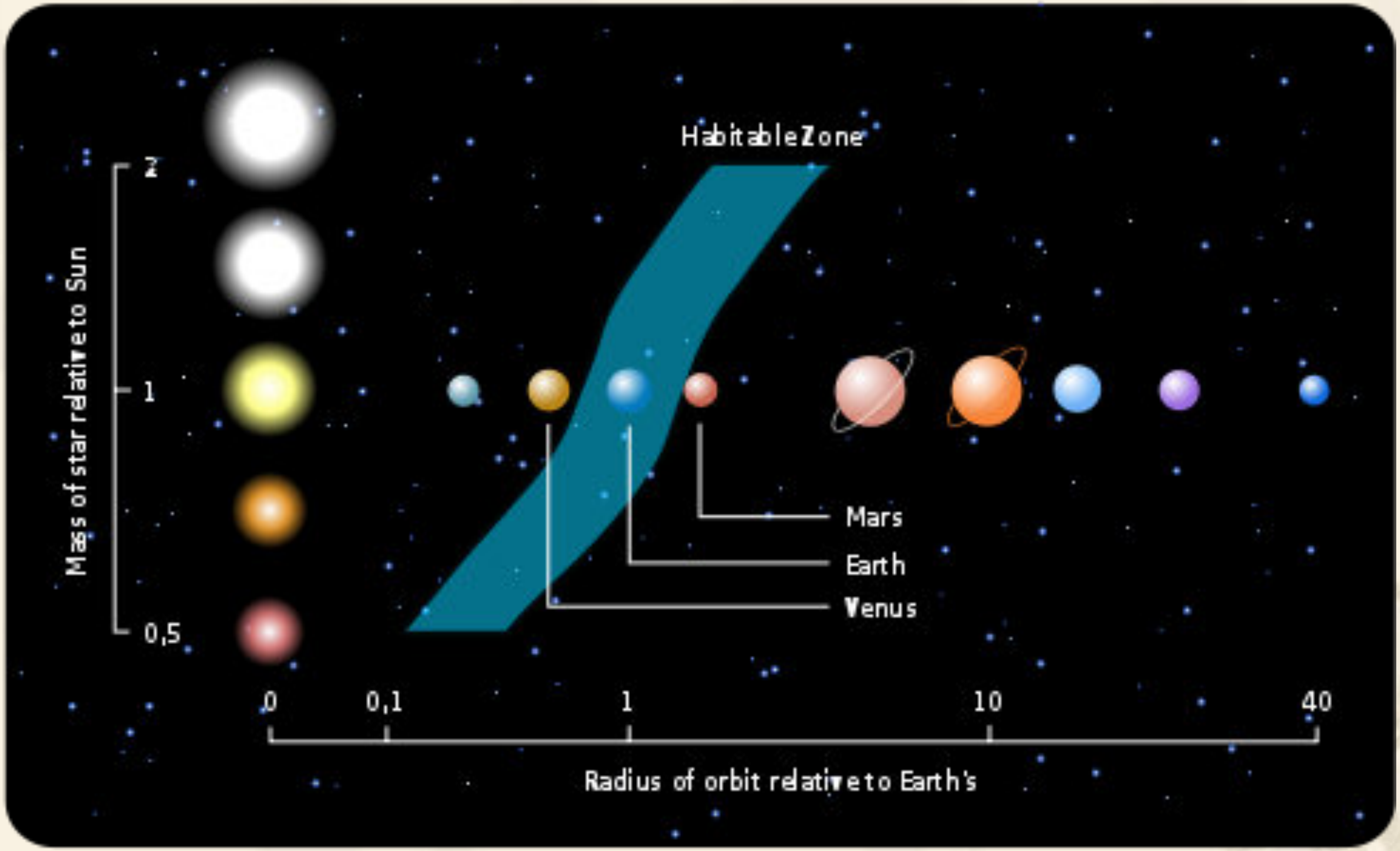
ESO observations indicate the Neptune-like exoplanet is evaporating

4 December 2019

Researchers using ESO's Very Large Telescope have, for the first time, found evidence of a giant planet associated with a white dwarf star. The planet orbits the hot white dwarf, the remnant of a Sun-like star, at close range, causing its atmosphere to be stripped away and form a disc of gas around the star. This unique system hints at what our own Solar System might look like in the distant future.

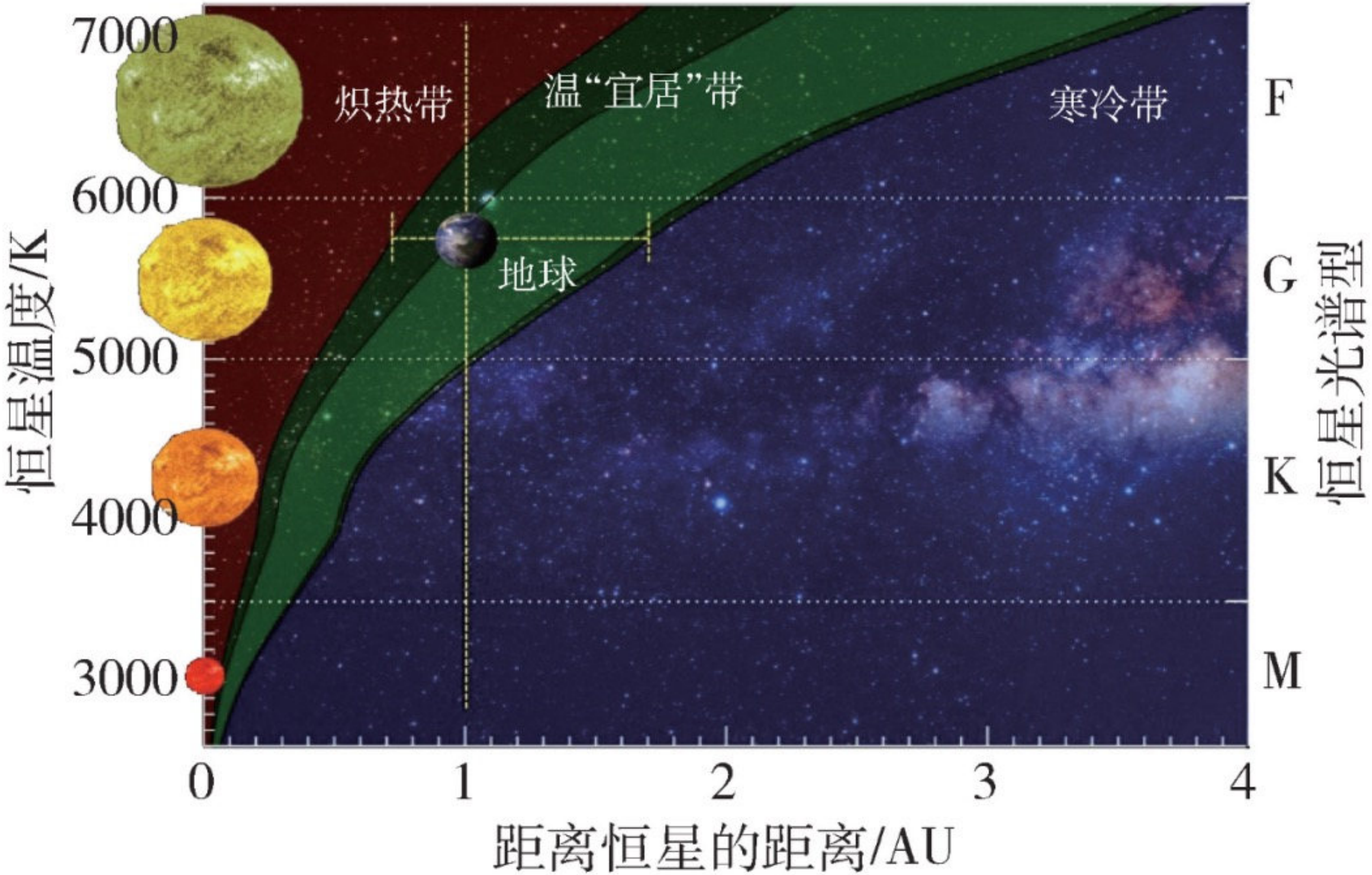
"*It was one of those chance discoveries,*" says researcher Boris Gänsicke, from the University of Warwick in the UK, who led the study, published today in *Nature*. The team had inspected around 7000 white dwarfs observed by the Sloan Digital Sky Survey and found one to be unlike any other. By analysing subtle variations in the light from the star, they found traces of chemical elements in amounts that scientists had never before observed at a white dwarf. "*We knew that there had to be something exceptional going on in this system, and speculated that it may be related to some type of planetary remnant.*"

可居住带



（假设和我们类似的生命形式）

主序星的宜居带

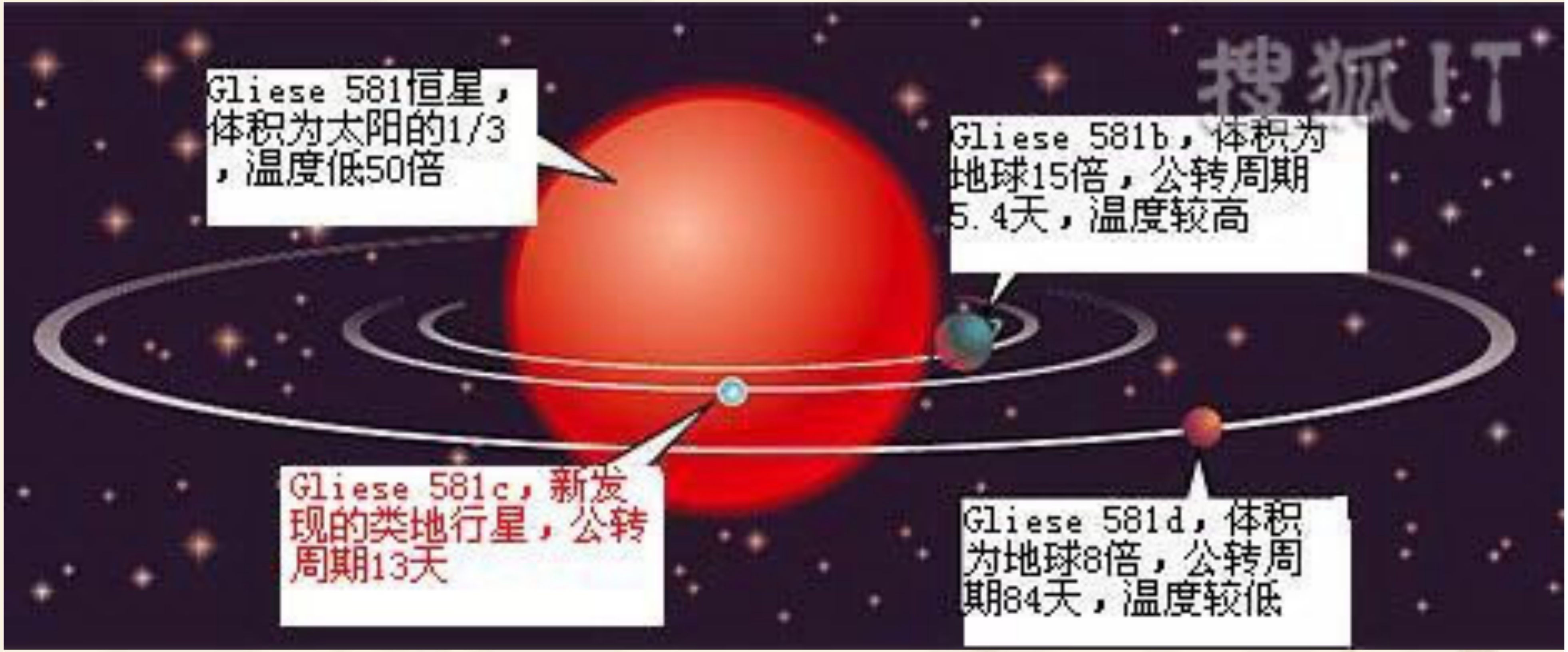


7000
6000
5000
4000
3000
恒星温度/K
炽热带
温“宜居”带
寒冷带
地球
F
G
K
M
恒星光谱型
0
1
2
3
4
距离恒星的距离/AU

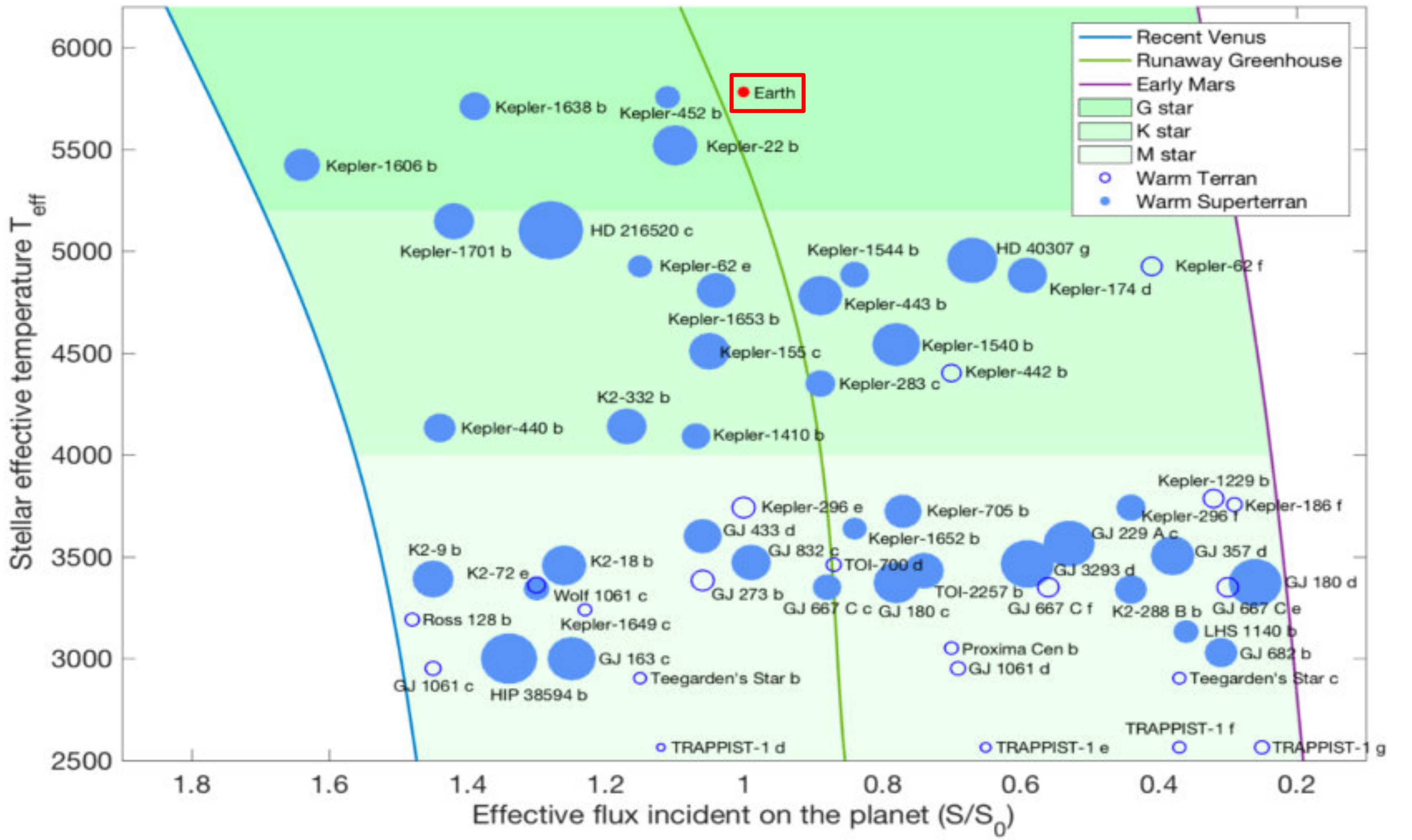
地球上为什么存在生命？

- 足够长的恒星和行星寿命
- 适宜的恒星光度（行星距离）
- 稳定的低偏心率行星轨道
- 适宜的自转倾斜度
- 具有合适成分的行星大气
- 具有磁场
- 月球稳定地球自转轴
- 附近存在一个大质量的木星

第一颗在宜居区发现的类地行星



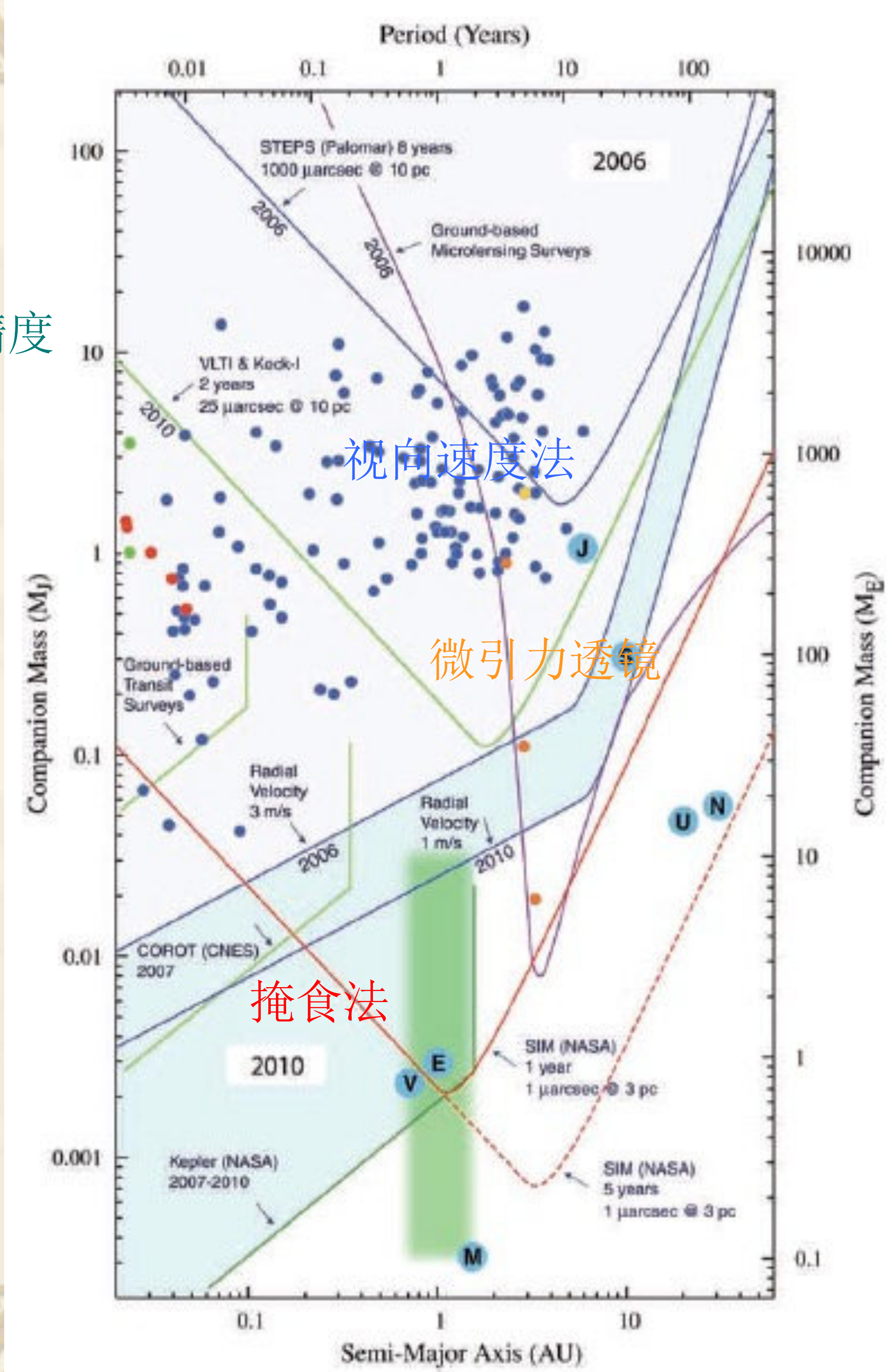
- 格利泽581c是由瑞士日内瓦天文台的Stephane Udry所领导的团队所发现，他们使用**欧洲南天文台**位于智利La Silla的3.6米的**望远镜**上的HARPS仪器
- 比地球大50%，重5倍，表面温度0-40度，可能存在液态水



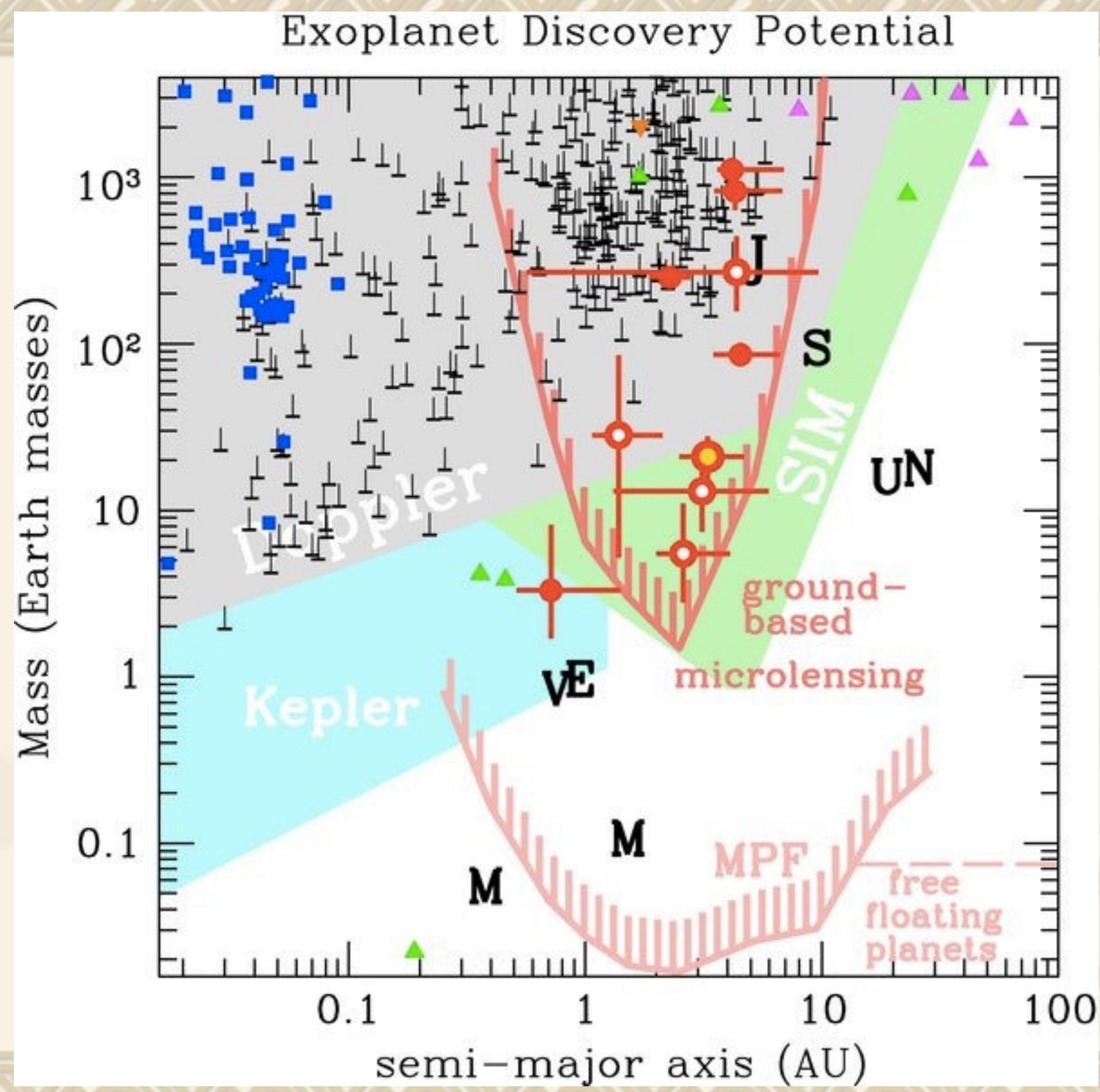
已发现的宜居带类地行星(Ji et al. 2022)

发现空间

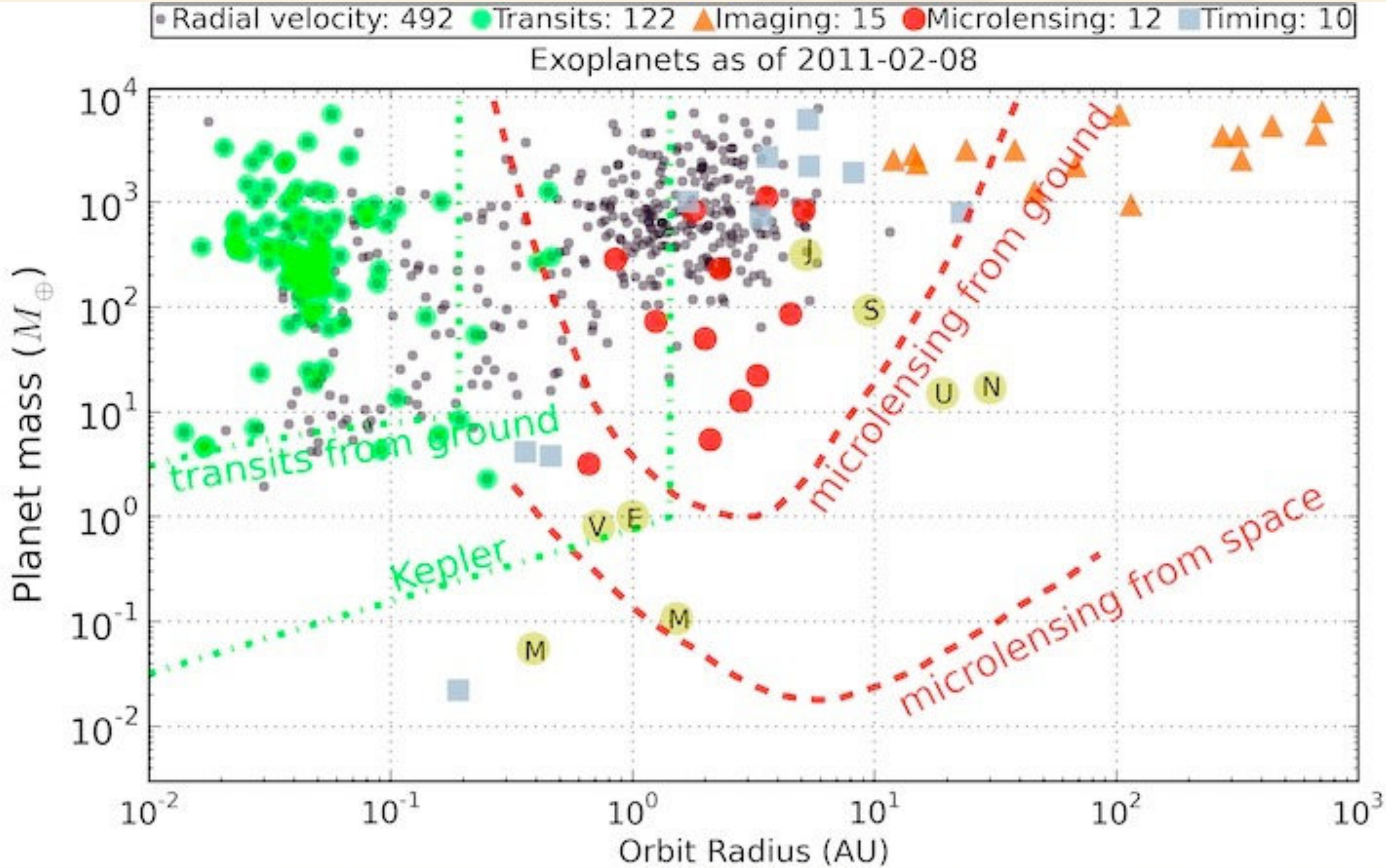
天体位置法精度



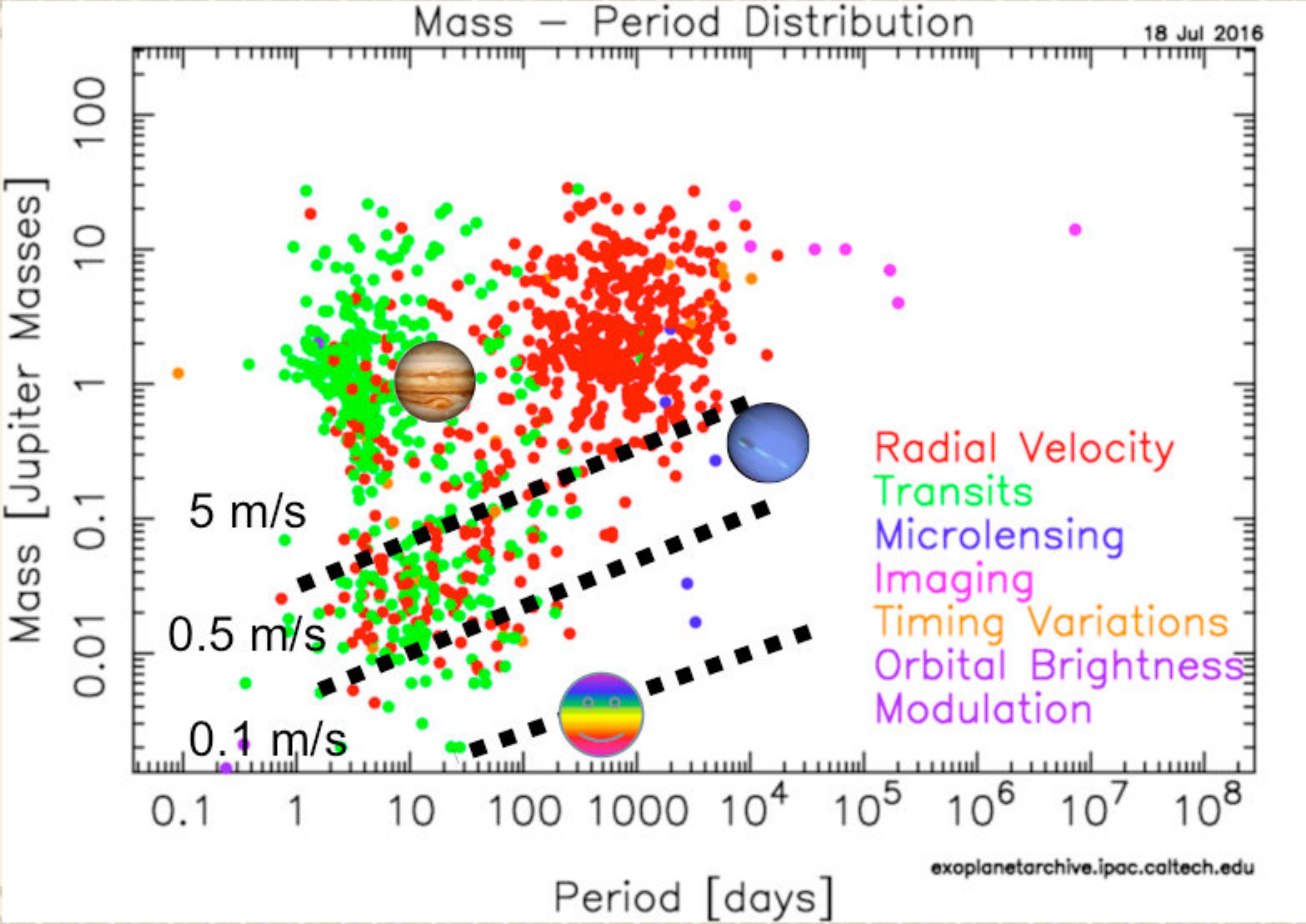
（2007年版本）



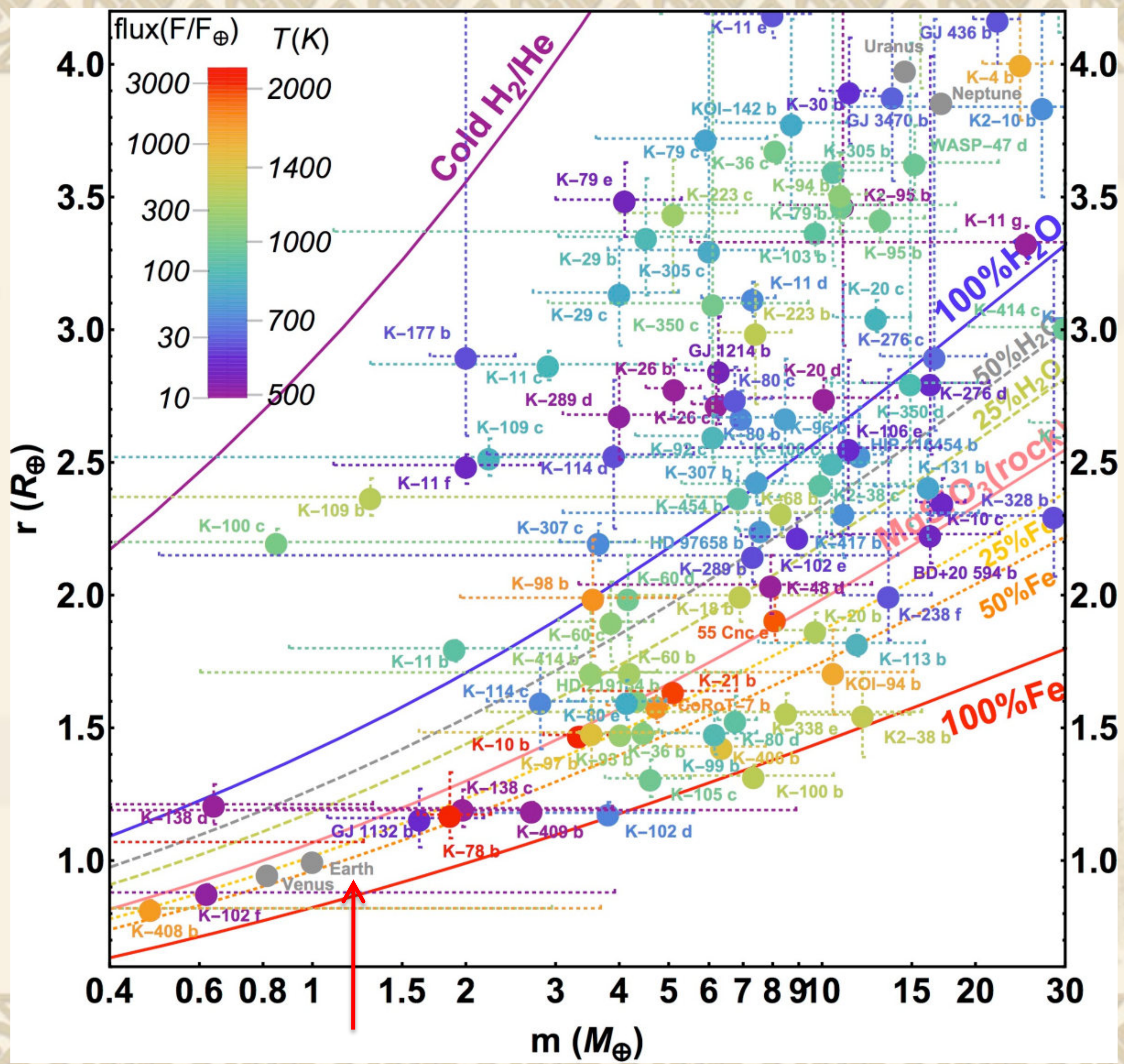
Exoplanet Discovery Potential
Mass (Earth masses)
semi-major axis (AU)
10³
10²
10
1
0.1
0.1
1
10
100
Doppler
Kepler
SIM
J
S
UN
VE
M
M
ground-based
microlensing
MPF
free floating planets

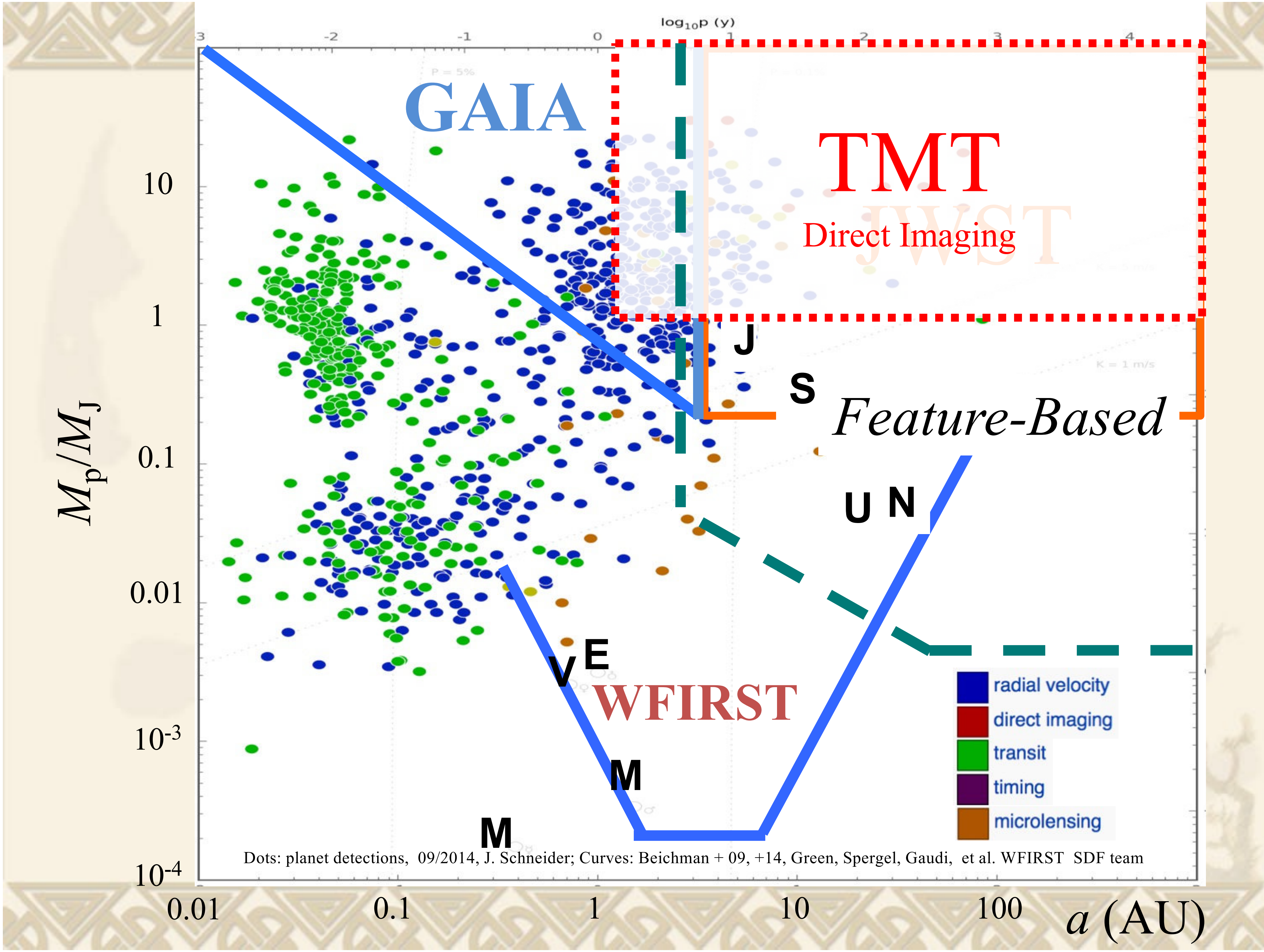


Radial velocity: 492
Transits: 122
Imaging: 15
Microlensing: 12
Timing: 10
Exoplanets as of 2011-02-08
Planet mass ($M_\oplus$)
Orbit Radius (AU)
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
transits from ground
Kepler
microlensing from ground
microlensing from space
J
S
U
N
V
E
M
M

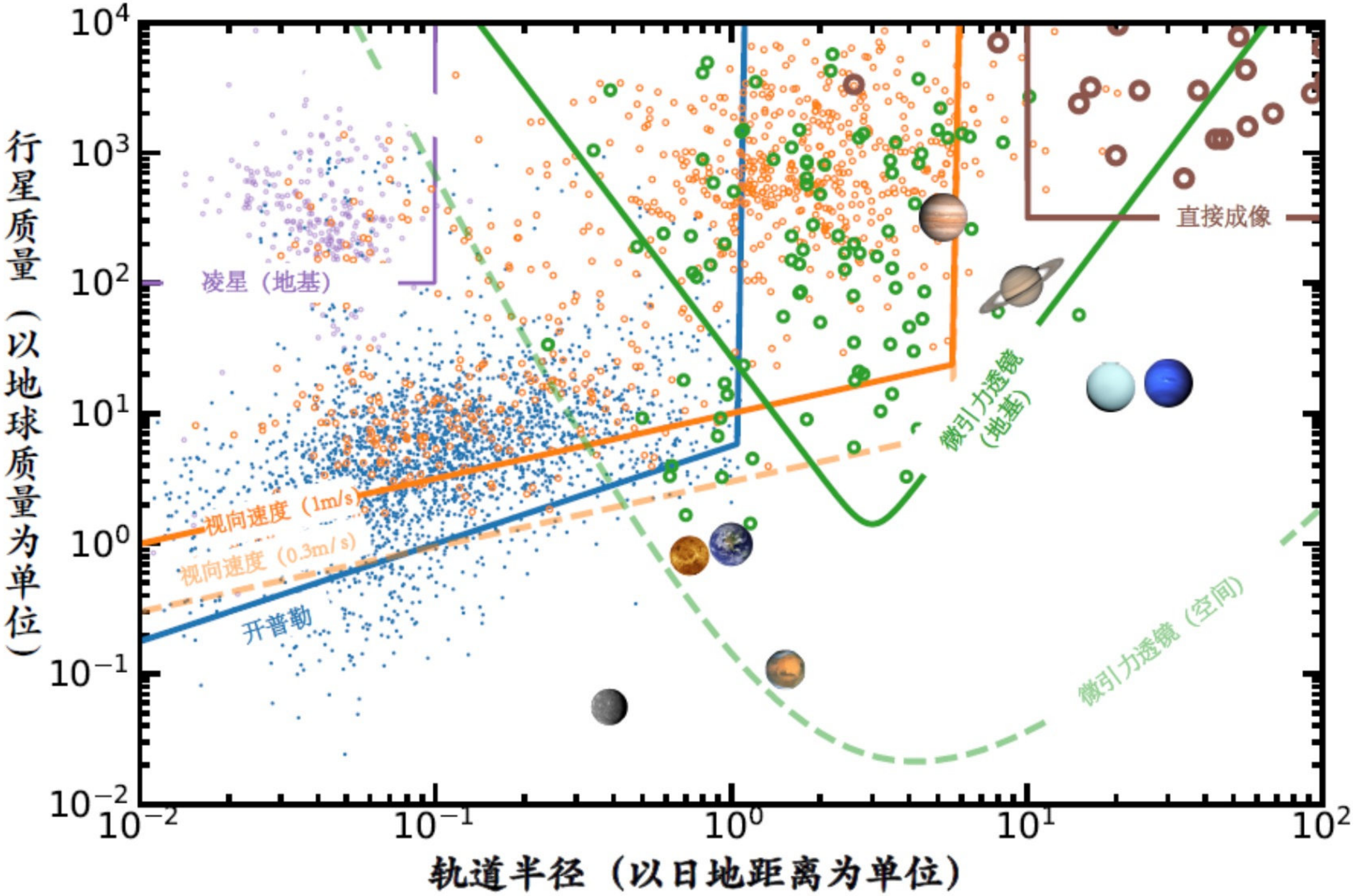


Mass – Period Distribution
18 Jul 2016
Mass [Jupiter Masses]
Period [days]
5 m/s
0.5 m/s
0.1 m/s
Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness
Modulation
exoplanetarchive.ipac.caltech.edu


flux(F/F⊕)
T(K)
3000
1000
300
100
30
10
2000
1400
1000
700
500
Cold H2/He
100%H2O
50%H2O
25%H2O
MgSiO3(rock)
25%Fe
50%Fe
100%Fe
r (R⊕)
m (M⊕)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.4
0.6
0.8
1
1.5
2
3
4
5
6
7
8
9
10
15
20
30
Uranus
Neptune
Earth
Venus
GJ 436 b
K-4 b
K2-10 b
K-11 e
K-30 b
GJ 3470 b
KOI-142 b
WASP-47 d
K-79 c
K-36 c
K-305 b
K-79 e
K-223 c
K-94 b
K2-95 b
K-79 b
K-11 g
K-29 b
K-305 c
K-103 b
K-95 b
K-11 d
K-20 c
K-29 c
K-350 c
K-223 b
K-414 c
K-276 c
K-177 b
GJ 1214 b
K-11 c
K-26 b
K-20 d
K-80 c
K-289 d
K-276 d
K-26 c
K-350 d
K-109 c
K-80 b
K-96 b
K-106 e
HIP 116454 b
K-114 d
K-131 b
K-11 f
K-307 b
K-454 b
K-68 b
K-328 b
K-109 b
K-100 c
K-307 c
HD 97658 b
K-417 b
K-289 b
K-102 e
BD+20 594 b
K-60 d
K-98 b
K-48 d
K-18 b
K-20 b
K-238 f
55 Cnc e
K-60 c
K-11 b
K-414 b
K-60 b
K-113 b
HD 219134 b
K-21 b
KOI-94 b
K-114 c
CoRoT-7 b
K-80 e
K-338 e
K2-38 b
K-10 b
K-80 d
K-97 b
K-93 b
K-36 b
K-406 b
K-99 b
K-100 b
K-105 c
K-138 c
K-138 d
GJ 1132 b
K-409 b
K-102 d
K-78 b
K-102 f
K-408 b



log10p (y)
-3
-2
-1
0
1
2
3
4
GAIA
TMT
Direct Imaging
JWST
Feature-Based
WFIRST
J
S
U
N
E
V
M
M
10
1
0.1
0.01
10-3
10-4
Mp/MJ
0.01
0.1
1
10
100
a (AU)
radial velocity
direct imaging
transit
timing
microlensing
Dots: planet detections, 09/2014, J. Schneider; Curves: Beichman + 09, +14, Green, Spergel, Gaudi, et al. WFIRST SDF team

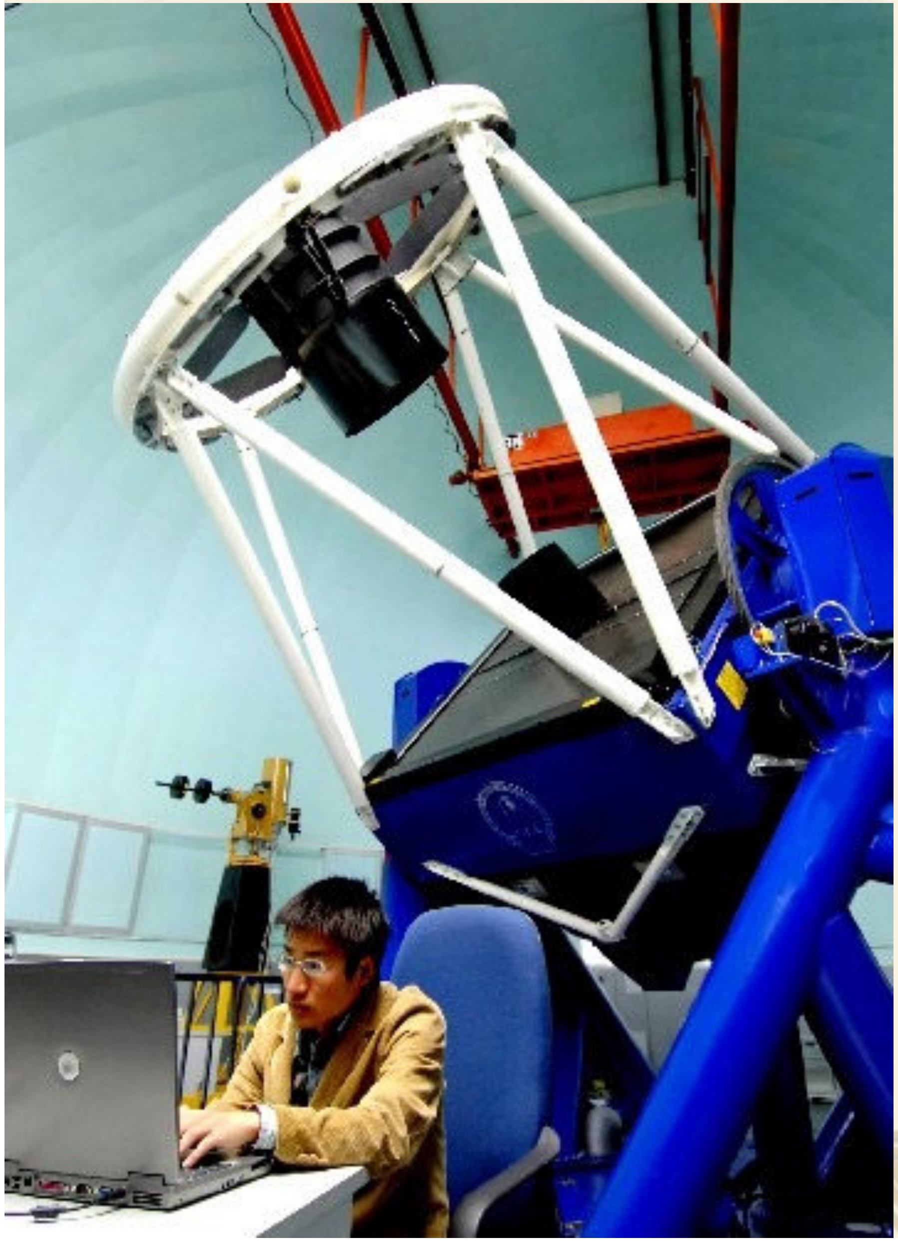


2021年9月8日在线发表

【图1】：已知的系外行星的质量-轨道半径分布。不同颜色的点代表不同方法发现的行星：地基望远镜凌星（紫色），开普勒卫星凌星（蓝色），视向速度法（橙色），地基望远镜微引力透镜法（绿色），直接成像法（褐色）。实线表示各方法探测的灵敏区间，绿色的虚线表示未来空间望远镜微引力透镜法的预计探测区间。小图标标识了太阳系八大行星。

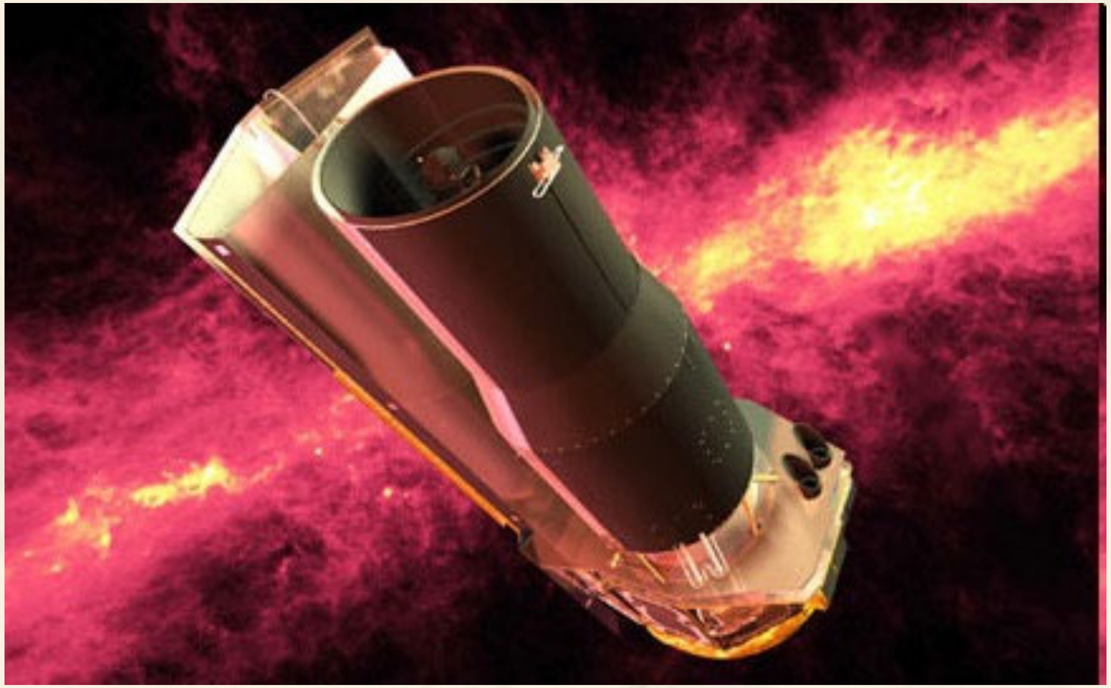
Figure 1. Distribution of known planets in the mass vs. semi-major axis plane. Dots of different colors represent planet detections from different detection techniques: ground-based transit (purple), transits by the Kepler spacecraft (blue), radial velocity (RV) surveys (orange), microlensing (green), and direct imaging (brown). The curves indicate the sensitivity limits of various present and future detection techniques/surveys. The positions of the Solar System planets are also marked. (Figure from Zhu & Dong, ARA&A)

LiJET（中国）



- 探测方法：
  视向速度法
- 正在进一步
  提高精度

Spitzer红外空间望远镜(NASA)

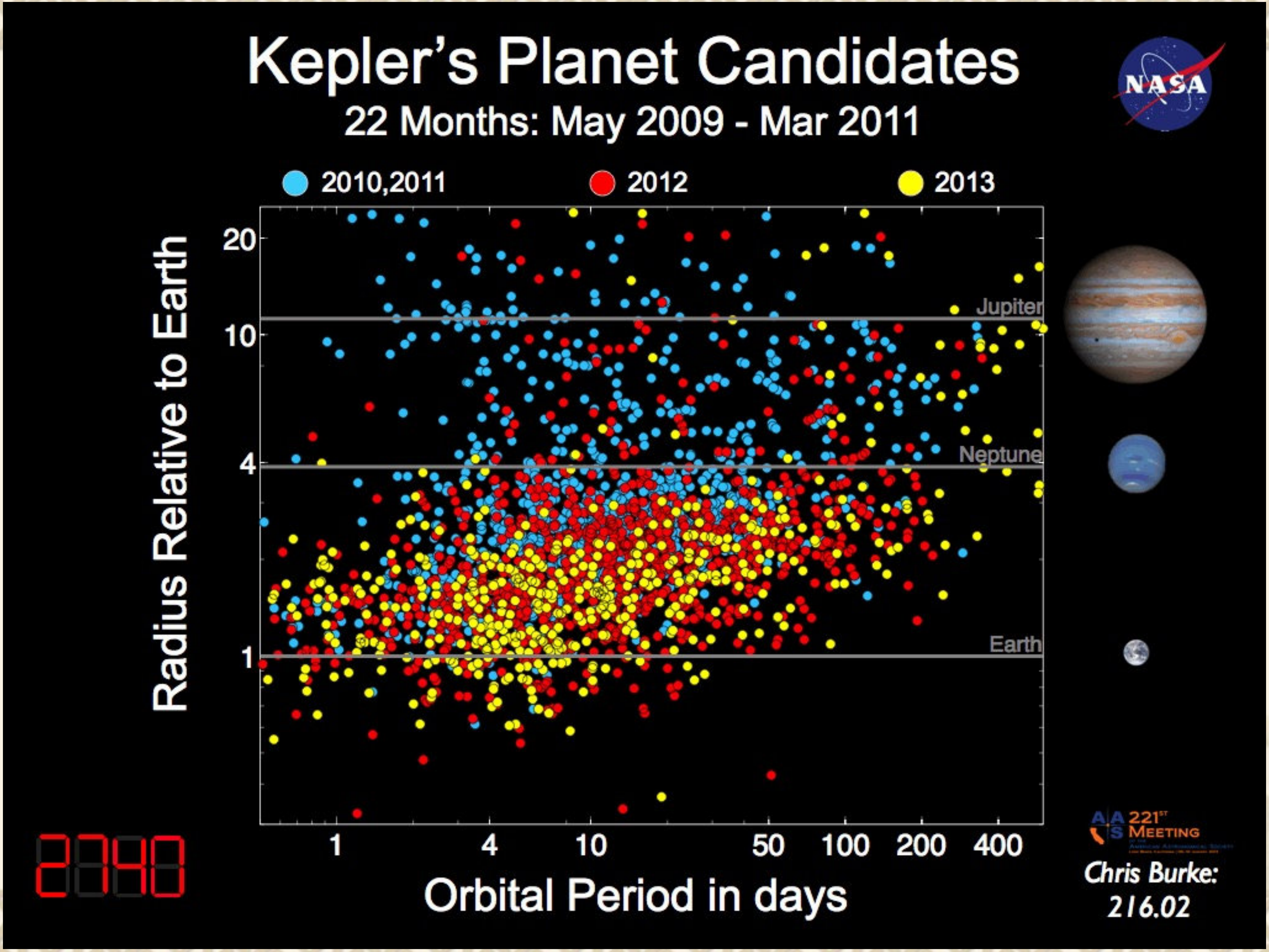


- 发射时间：2003
- 探测方法：来自行星远红外辐射

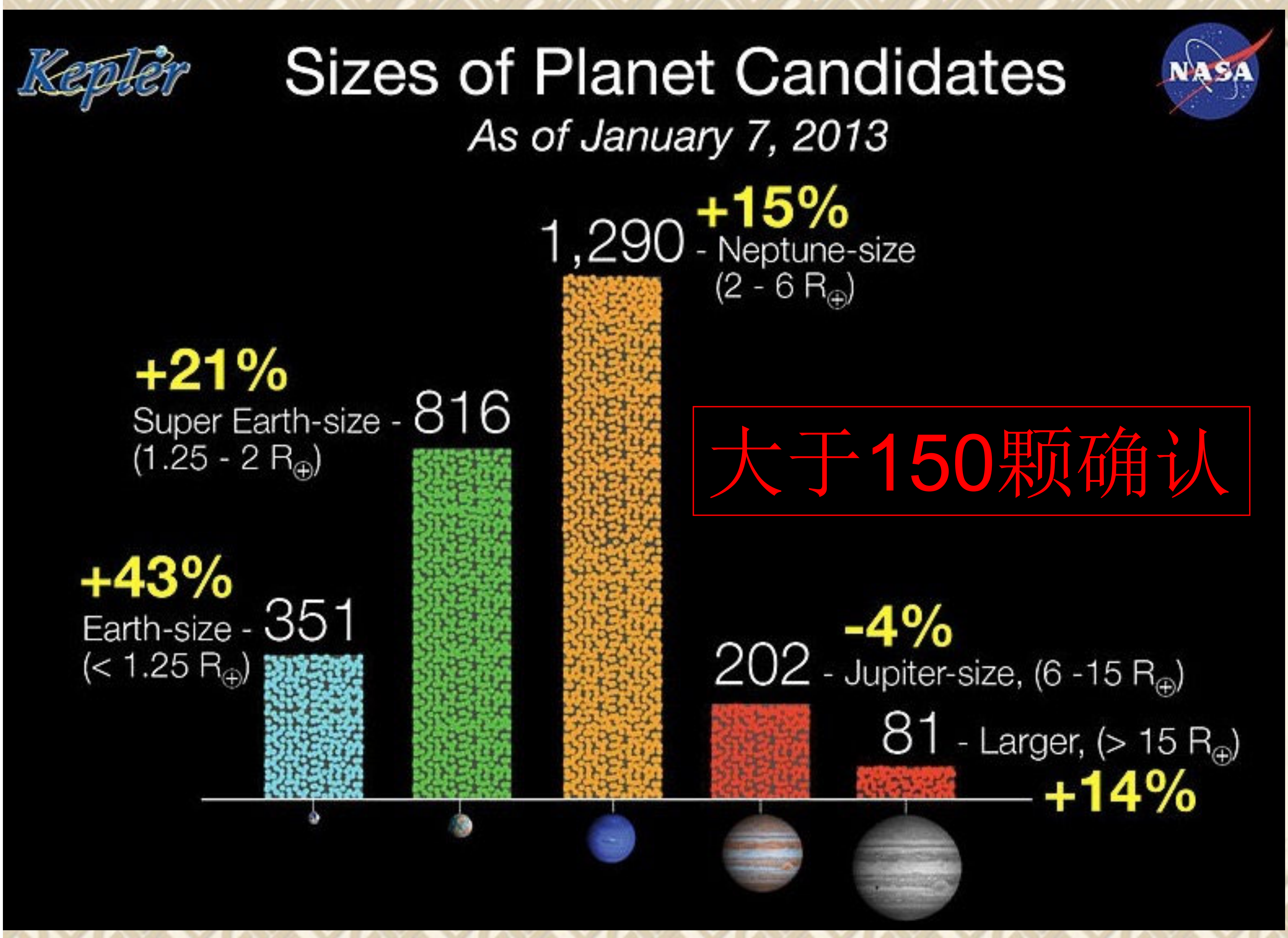
Kepler空间望远镜(NASA)

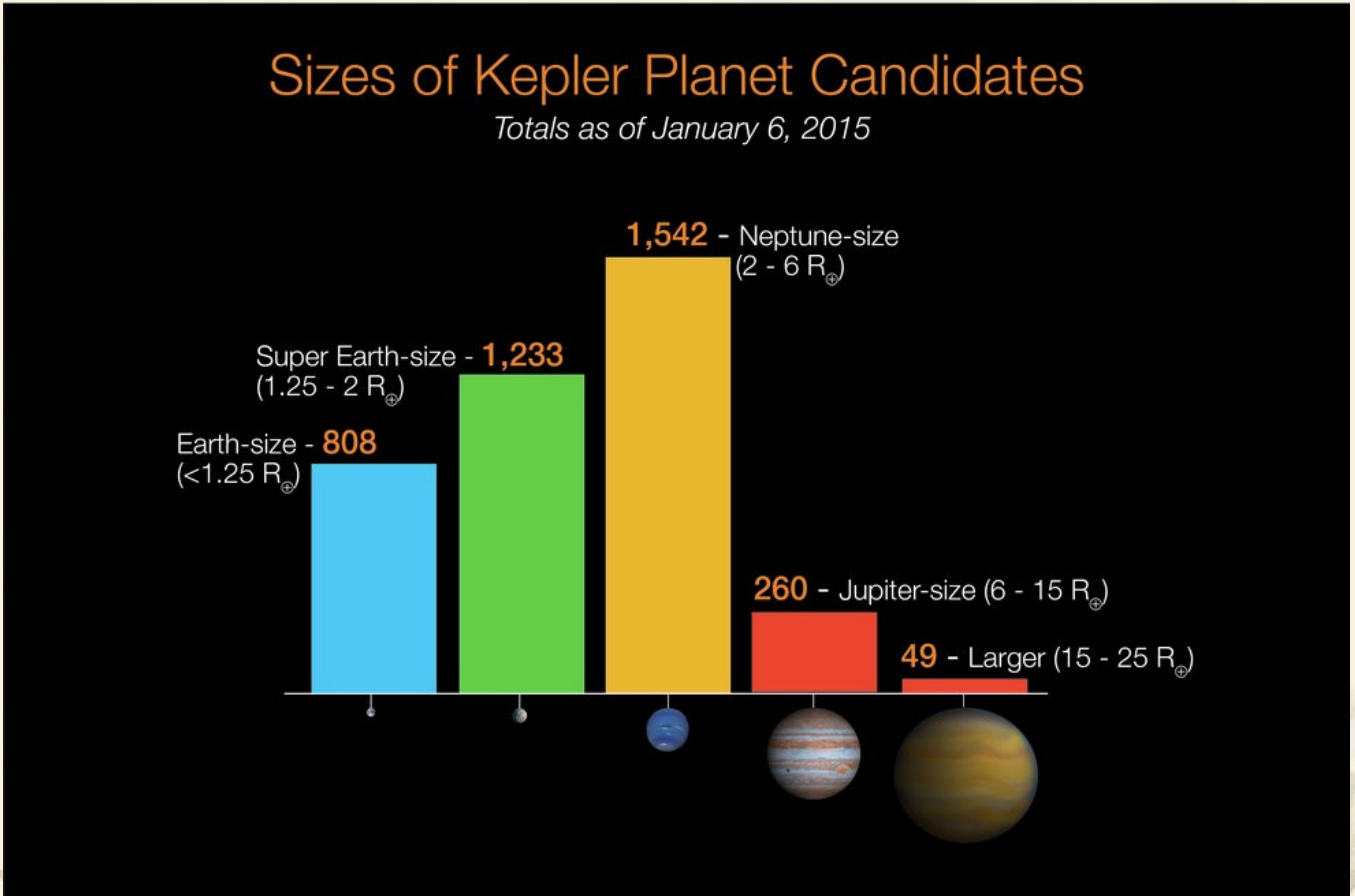
- 发射时间：2009.3.6
- 探测方法：掩食法
- 已发现系外行星候选者：>5000

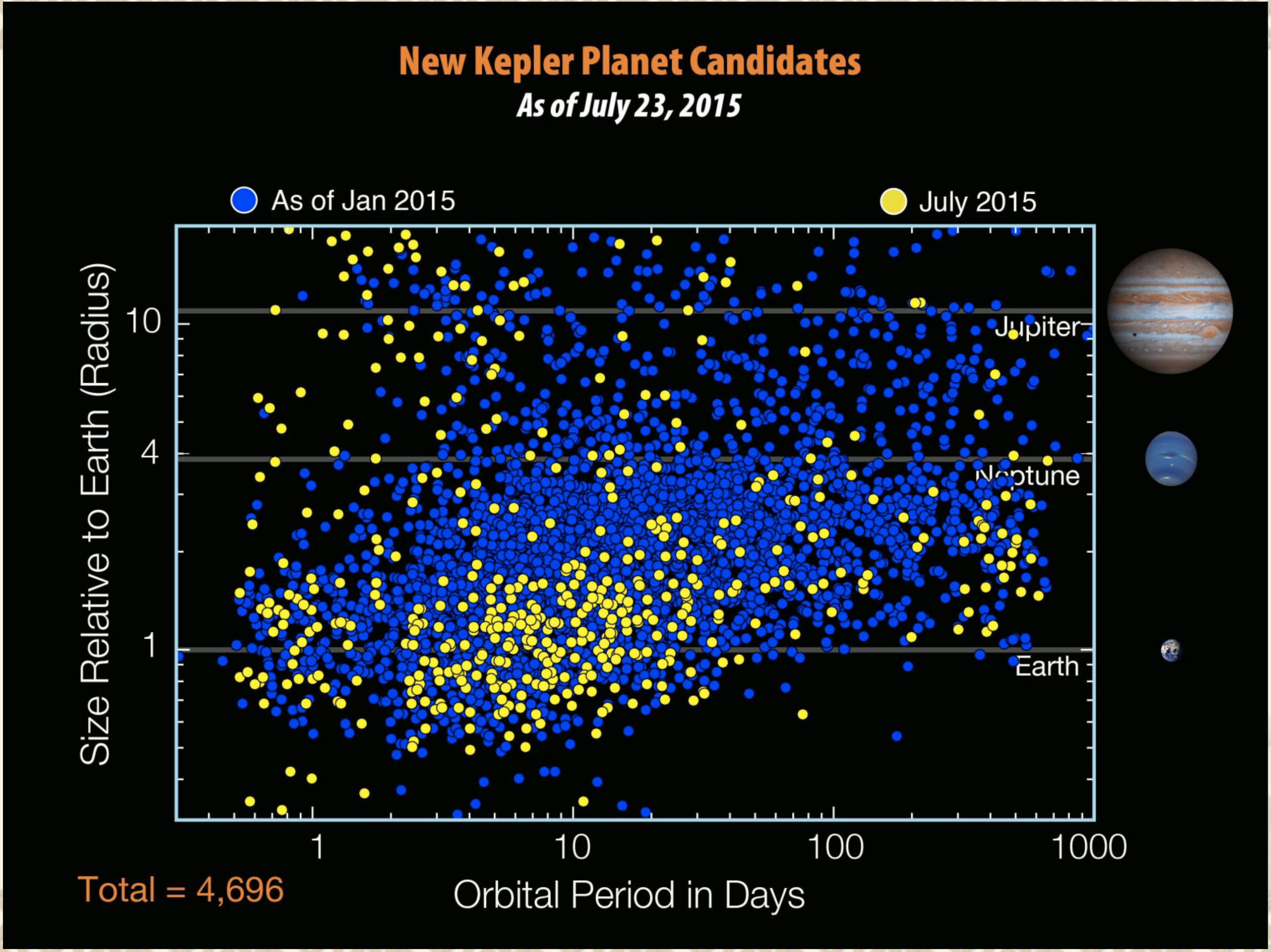
2018年底停止工作

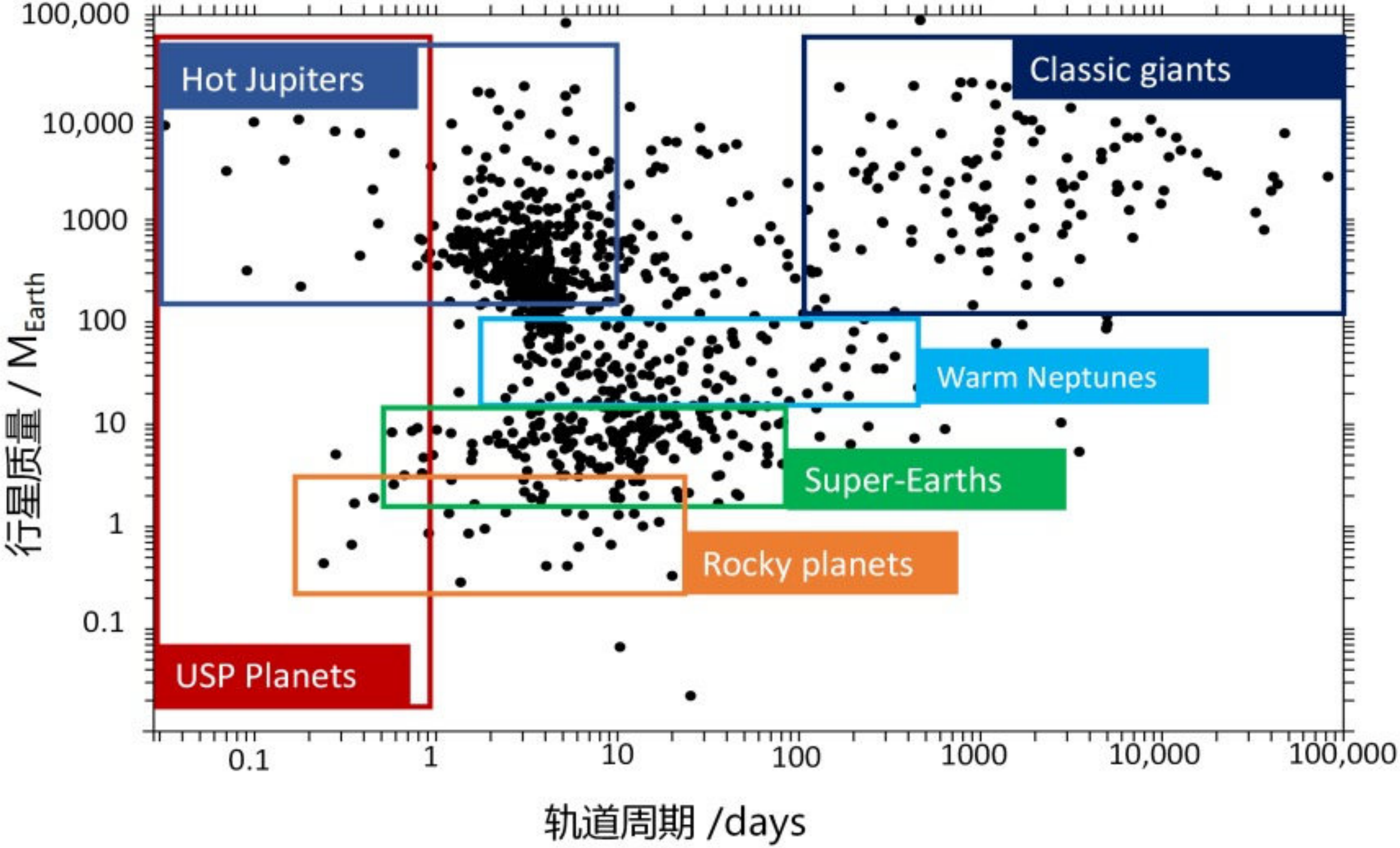


Kepler's Planet Candidates
22 Months: May 2009 - Mar 2011
2010,2011
2012
2013
Radius Relative to Earth
20
10
4
1
Jupiter
Neptune
Earth
1
4
10
50
100
200
400
Orbital Period in days
2740
NASA
AAS 221ST MEETING
Chris Burke:
216.02


Kepler
Sizes of Planet Candidates
As of January 7, 2013
NASA
+15%
1,290 - Neptune-size
(2 - 6 R⊕)
+21%
Super Earth-size - 816
(1.25 - 2 R⊕)
+43%
Earth-size - 351
(< 1.25 R⊕)
-4%
202 - Jupiter-size, (6 -15 R⊕)
81 - Larger, (> 15 R⊕)
+14%
大于150颗确认


Sizes of Kepler Planet Candidates
Totals as of January 6, 2015
1,542 - Neptune-size (2 - 6 $R_{\oplus}$)
Super Earth-size - 1,233 (1.25 - 2 $R_{\oplus}$)
Earth-size - 808 (<1.25 $R_{\oplus}$)
260 - Jupiter-size (6 - 15 $R_{\oplus}$)
49 - Larger (15 - 25 $R_{\oplus}$)


New Kepler Planet Candidates
As of July 23, 2015
As of Jan 2015
July 2015
Size Relative to Earth (Radius)
10
4
1
Jupiter
Neptune
Earth
1
10
100
1000
Orbital Period in Days
Total = 4,696



Hot Jupiters
Classic giants
Warm Neptunes
Super-Earths
Rocky planets
USP Planets
100,000
10,000
1000
100
10
1
0.1
行星质量 / M_{Earth}
0.1
1
10
100
1000
10,000
100,000
轨道周期 /days

科学家利用人工智能发现迄今为止距其主星最近的最小行星

来源：央视新闻 | 2024年10月14日 14:58:55

近日，由中国科学院上海天文台葛健教授带领的国际团队**创新了一种结合GPU相位折叠和卷积神经网络的深度学习算法，**并成功在开普勒（Kepler）2017年释放的恒星测光数据中**发现了五颗直径小于地球、轨道周期短于1天的超短周期行星，其中四颗是迄今为止发现的距其主星最近的最小行星，类似火星大小。**

这是天文学家**首次利用人工智能一次性完成搜寻疑似信号和识别真信号的任务**，相关研究成果发表在国际天文学期刊《皇家天文学会月报》（MNRAS）上。

（总台央视记者 帅俊全 褚尔嘉）

编辑：宿党辉　责任编辑：刘亮

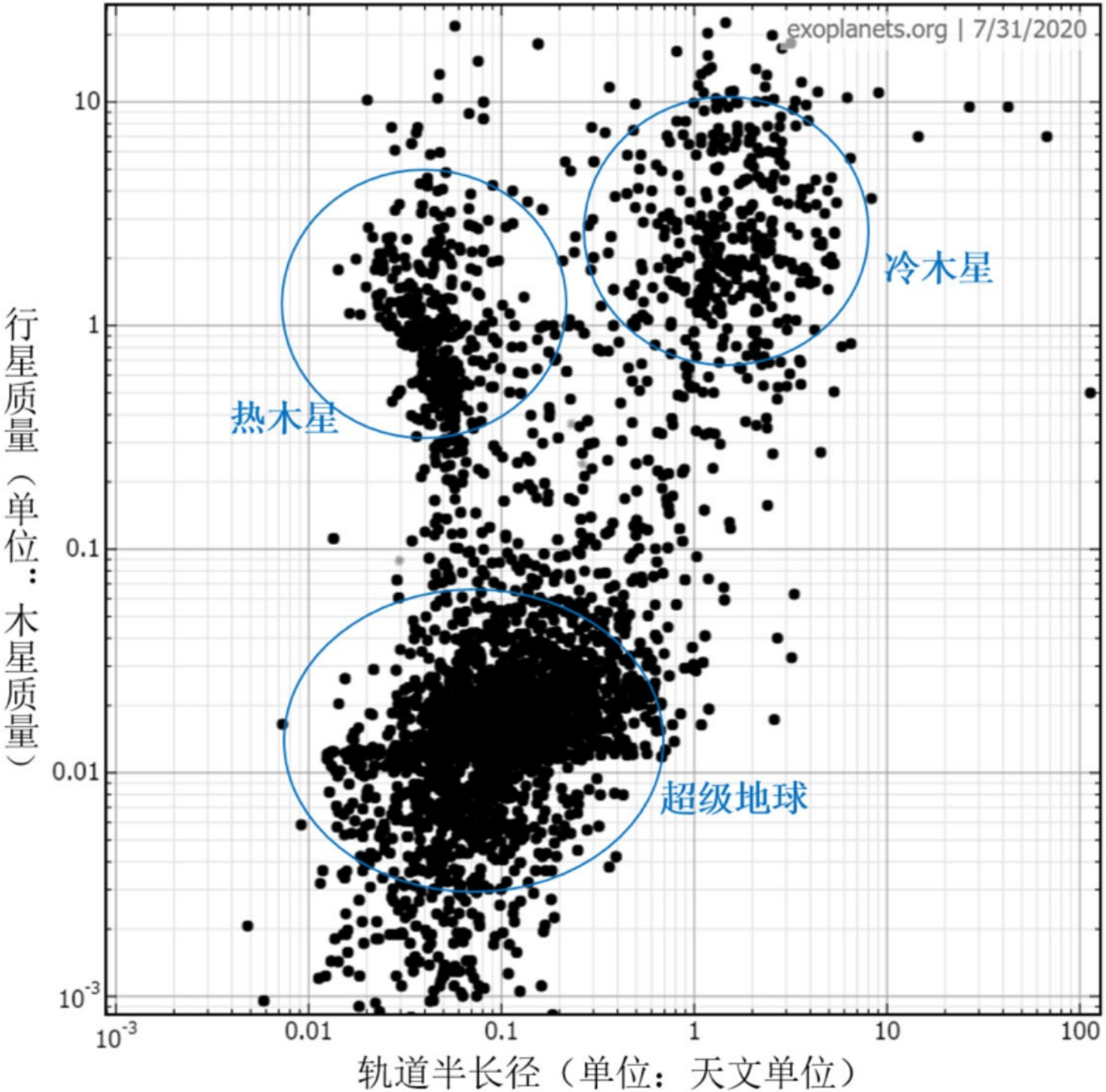
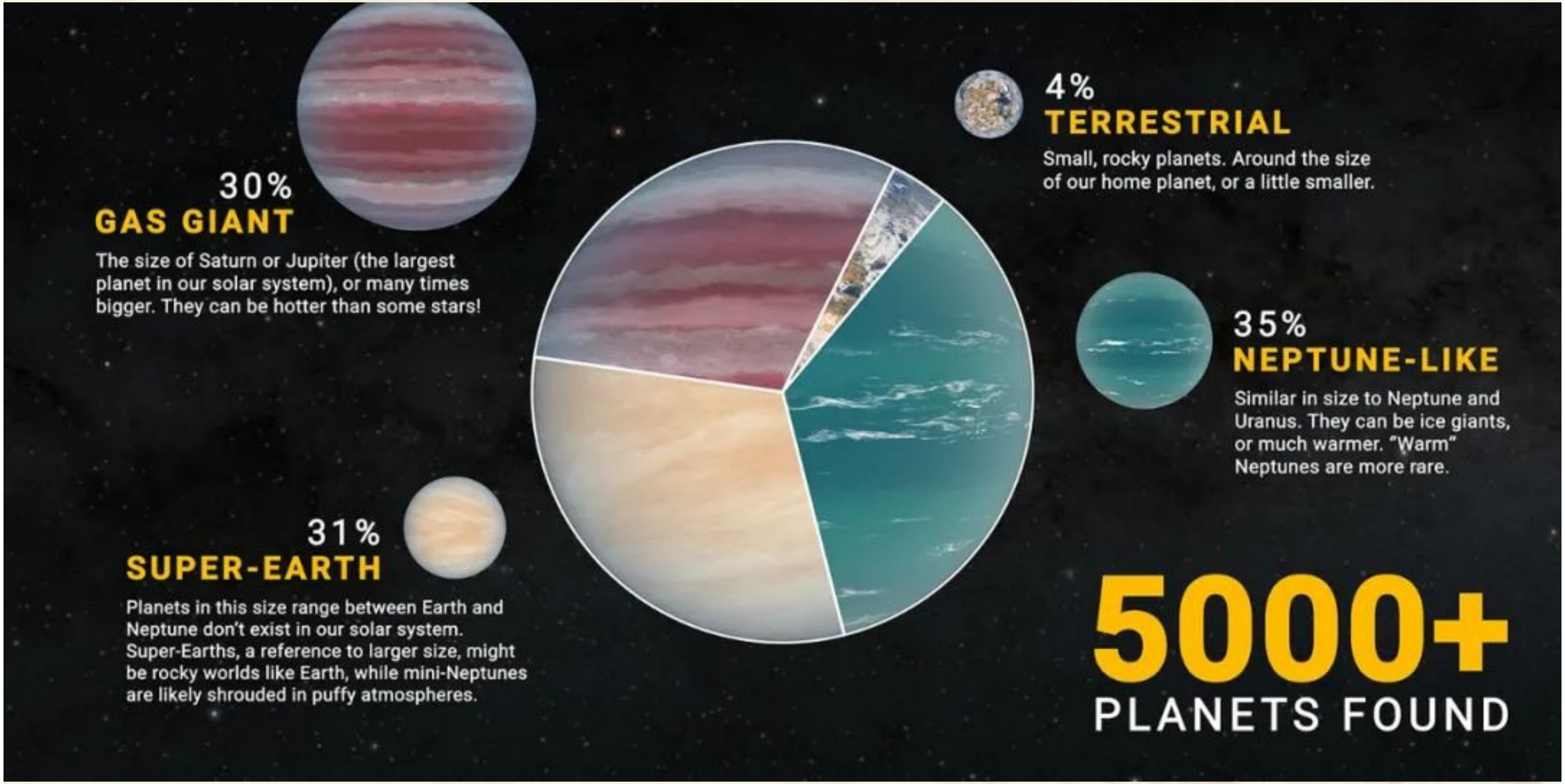


图3 已知系外行星的轨道半长径–行星质量分布图. 数据来源: http://exoplanets.org



NASA确认的5000多颗行星，其中4%是类地行星、30%是类木行星（或气态巨行星）、31%是超级地球、35%是类海行星，图片来源：NASA

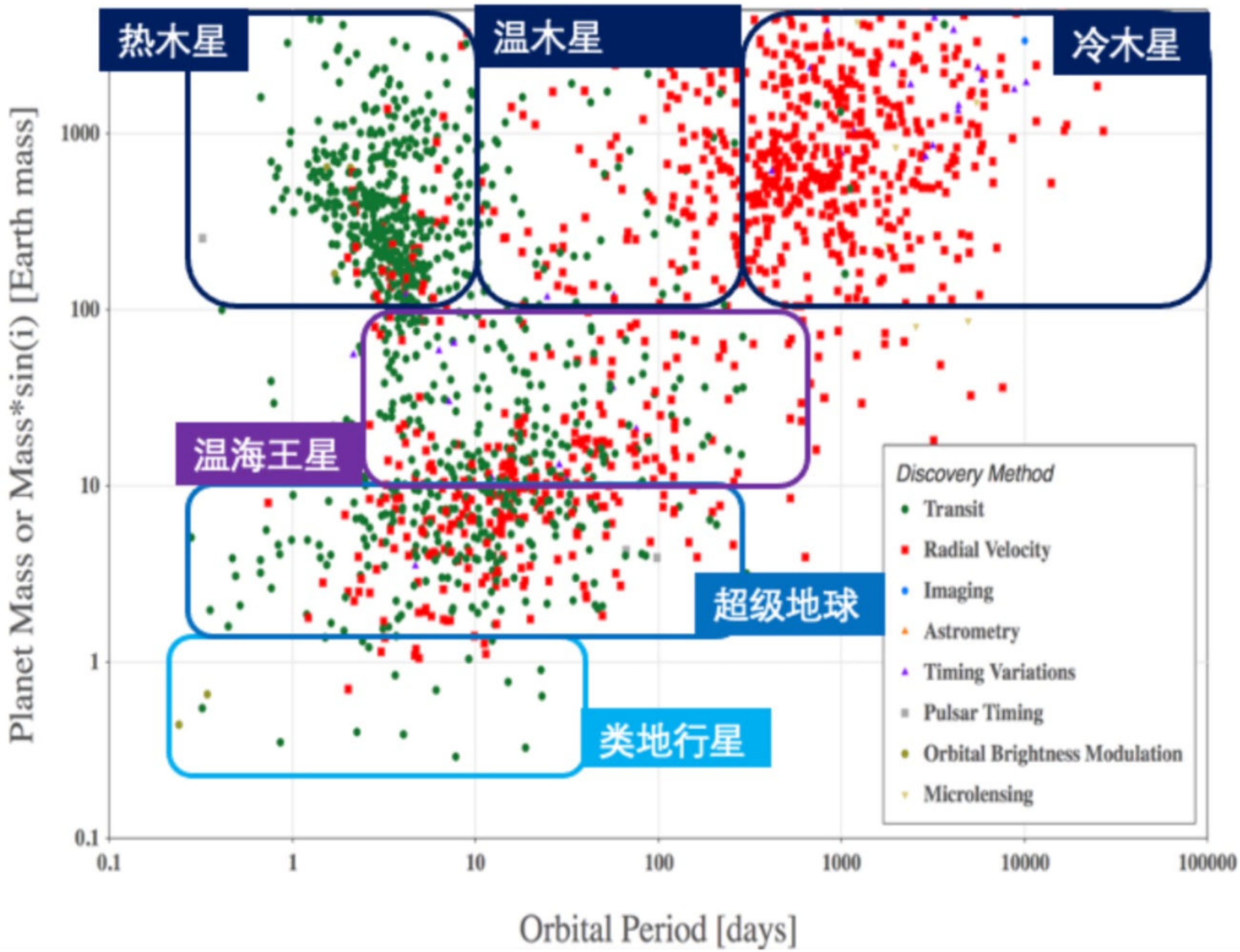
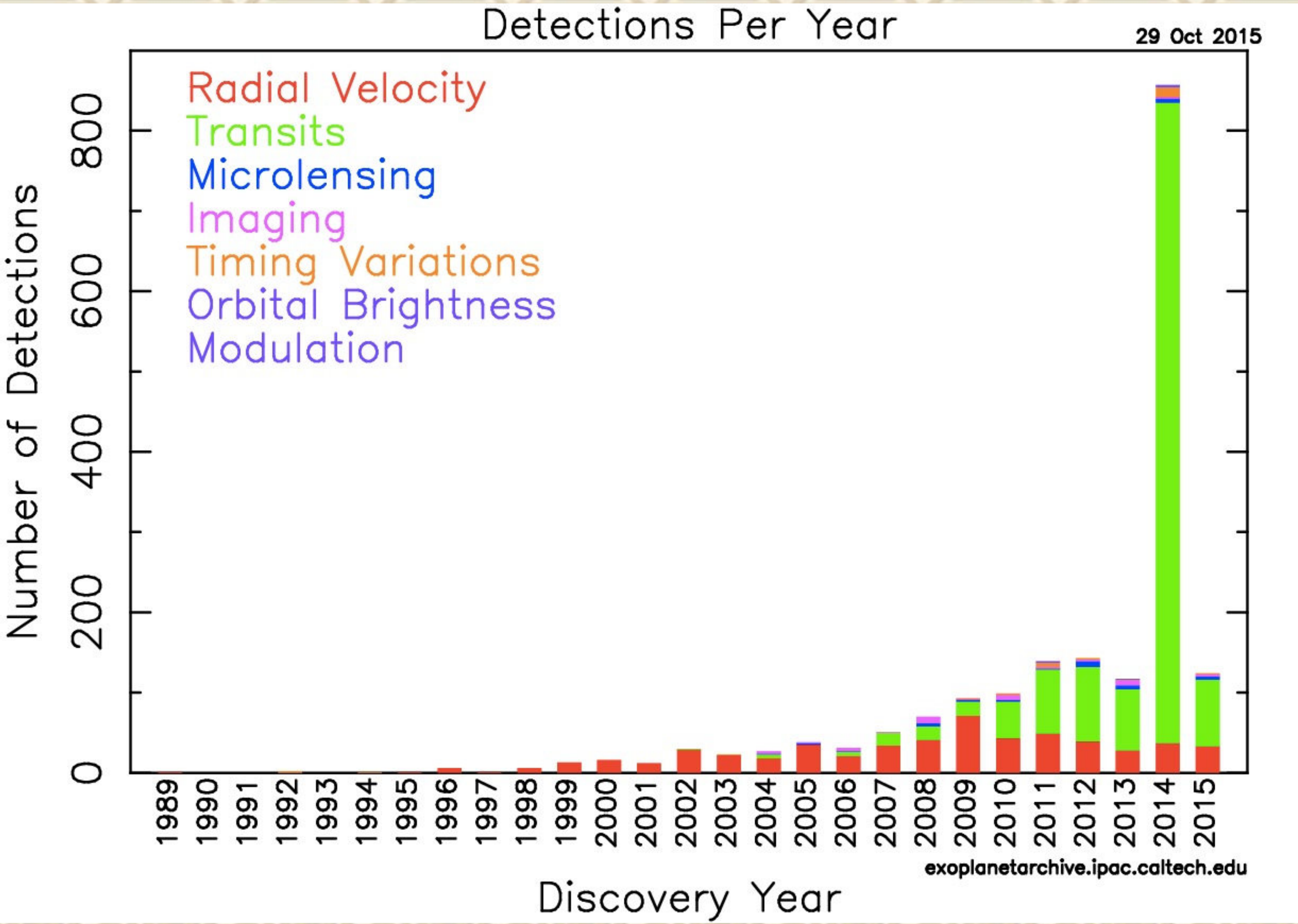
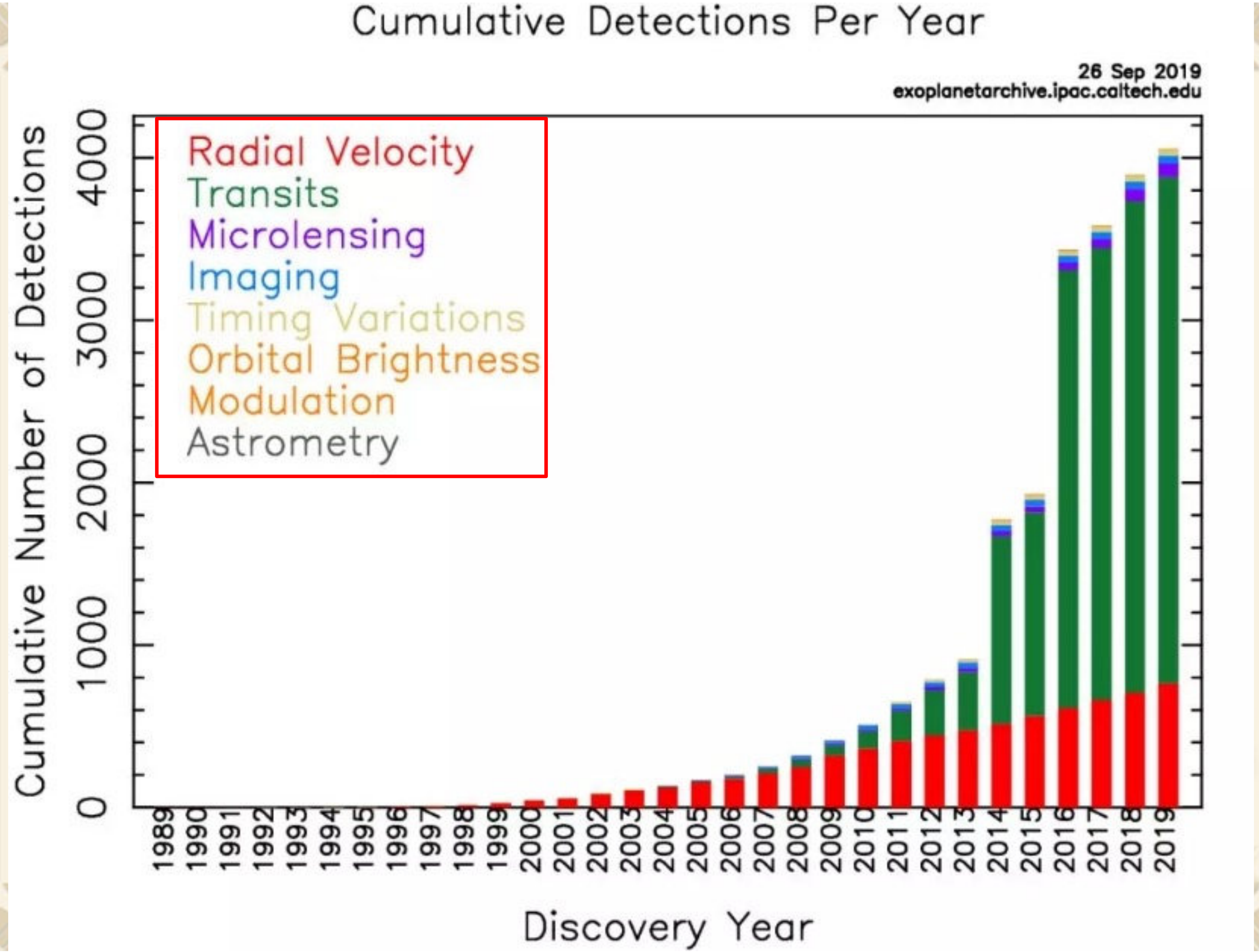


图2 系外行星的类型

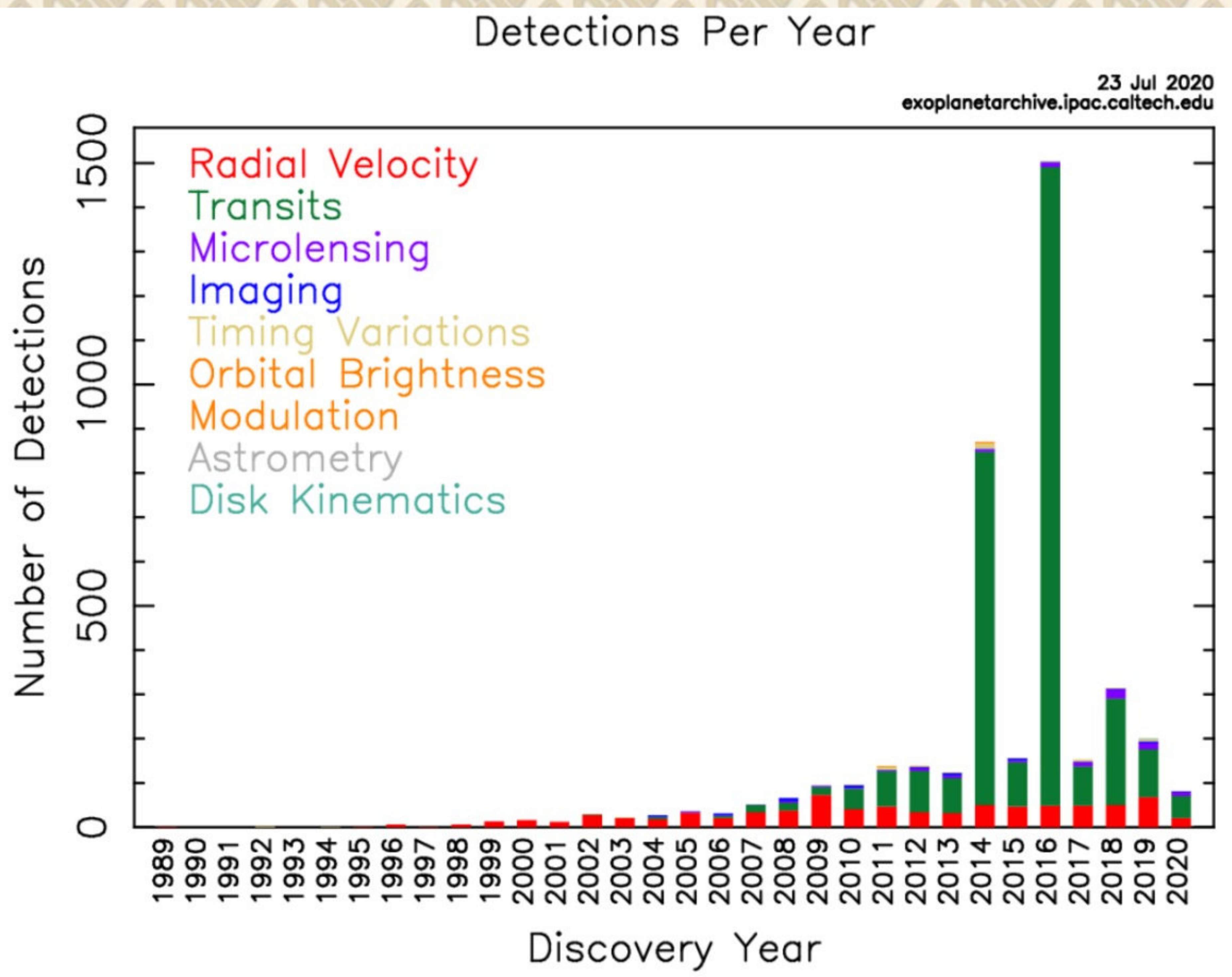
（季江徽）

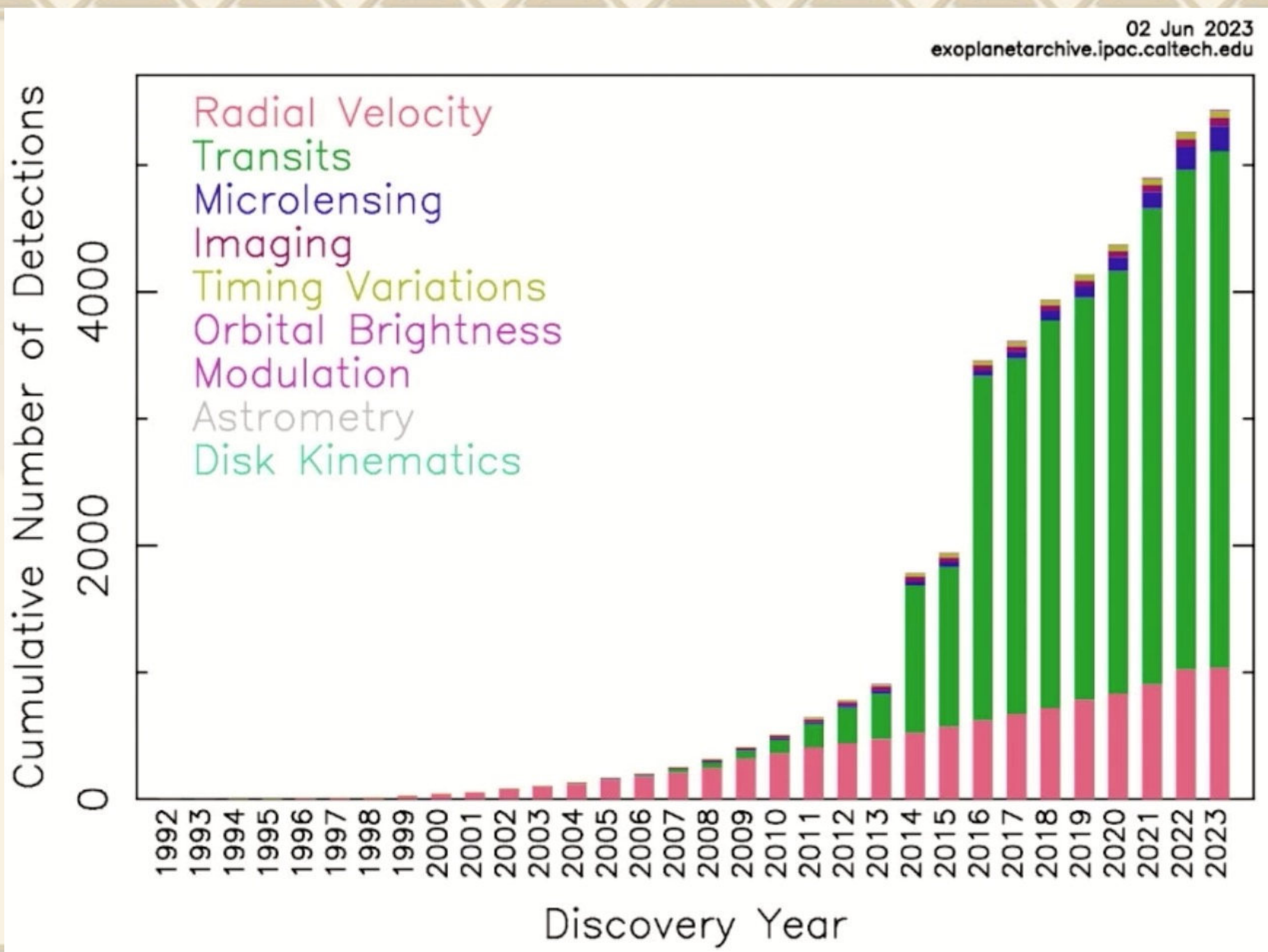


Detections Per Year
29 Oct 2015
Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness
Modulation
Number of Detections
0
200
400
600
800
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
exoplanetarchive.ipac.caltech.edu
Discovery Year



Cumulative Detections Per Year
26 Sep 2019
exoplanetarchive.ipac.caltech.edu
Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness
Modulation
Astrometry
Cumulative Number of Detections
0
1000
2000
3000
4000
1989
1990
1991
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
Discovery Year


Detections Per Year
23 Jul 2020
exoplanetarchive.ipac.caltech.edu
Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness
Modulation
Astrometry
Disk Kinematics
Number of Detections
0
500
1000
1500
1989
1990
1991
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
Discovery Year


02 Jun 2023
exoplanetarchive.ipac.caltech.edu
Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness
Modulation
Astrometry
Disk Kinematics
Cumulative Number of Detections
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
2023
Discovery Year

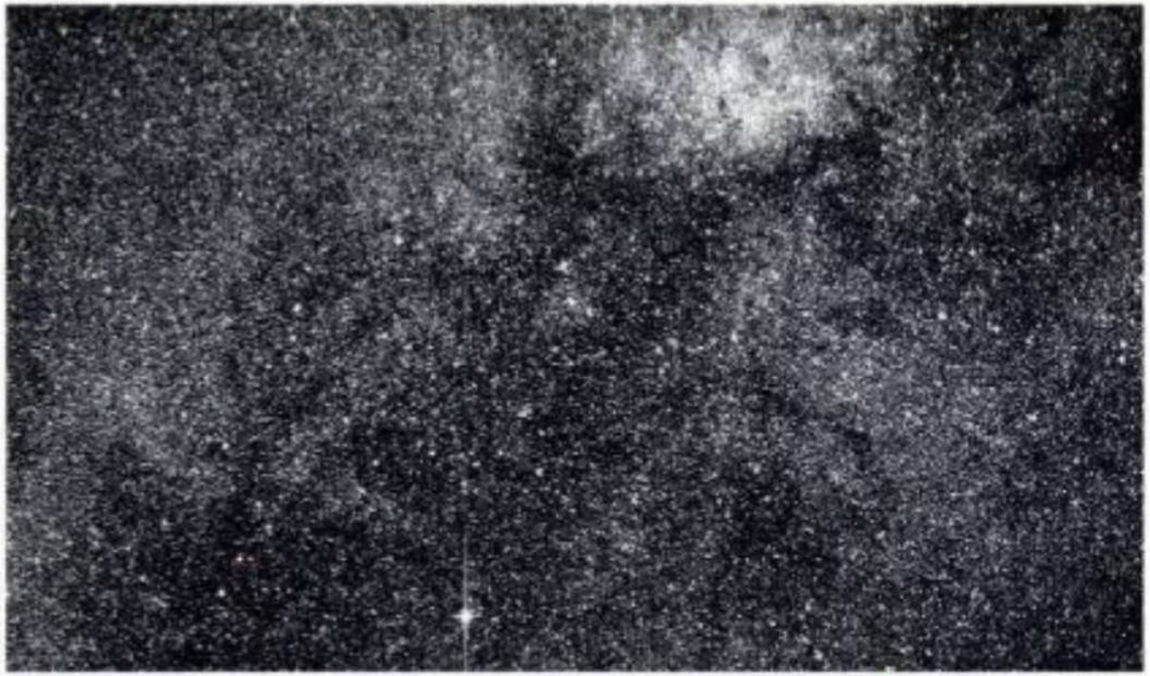
First shot from new NASA telescope

NASA's new planet-hunting satellite just sent back its first stunning image.

The Transiting Exoplanet Survey Satellite (TESS) launched in April and made a slingshot manoeuvre around the moon on 17 May. This sent it flying towards an orbit that will pass between Earth and the moon. It is expected to reach that orbit and start searching for planets in June.

The image below, taken on 26 April, is its first camera test. In the picture, the constellation Centaurus takes centre stage, and each bright point is one of more than 200,000 stars. The flash at the bottom is the star Beta Centauri, 391 light years away.

Over two years, TESS is expected to find about 20,000 exoplanets orbiting relatively nearby stars. TESS will replace the Kepler Space Telescope, which has found more than 5000 exoplanet candidates so far, and confirmed about half of them. Rather than looking at distant stars within a small area of sky, as Kepler did, TESS will look at closer stars over 85 per cent of the sky.



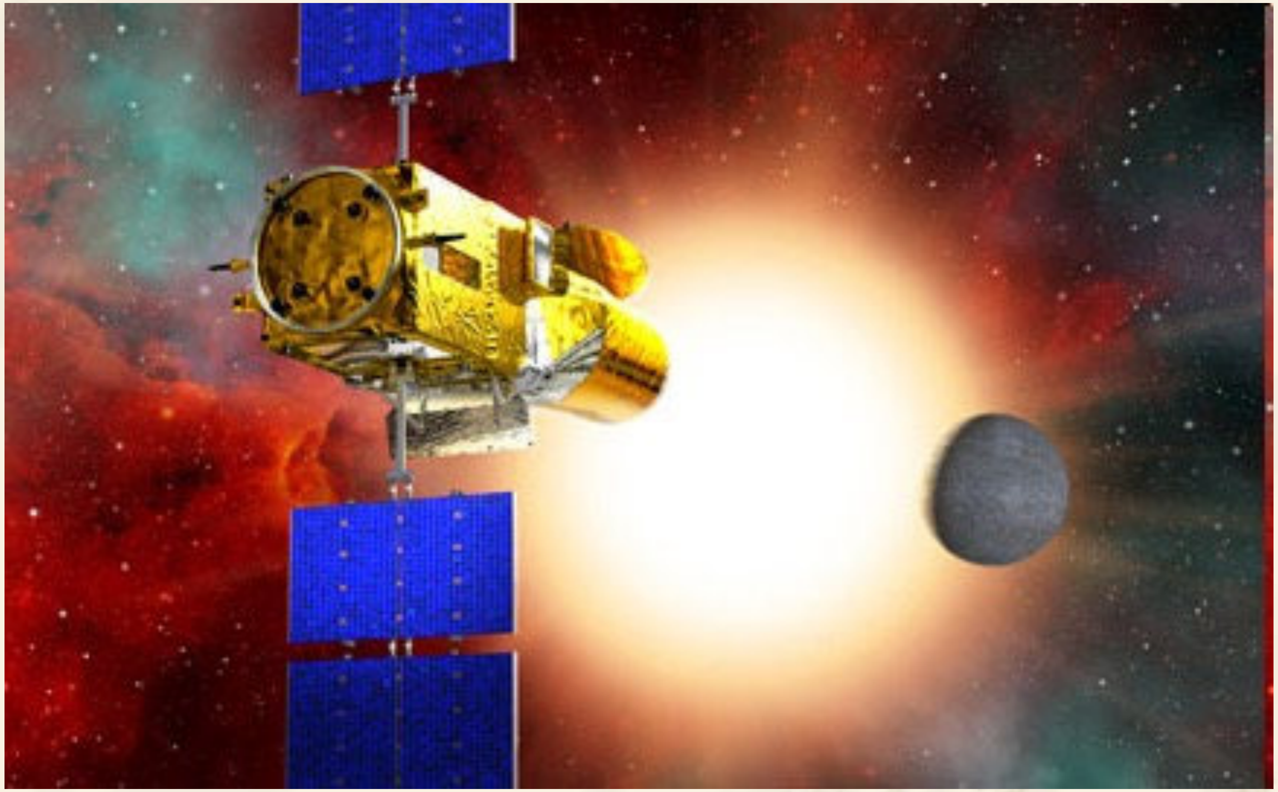
NASA/GSFC

Transiting Exoplanet Survey Satellite

Artist concept of TESS

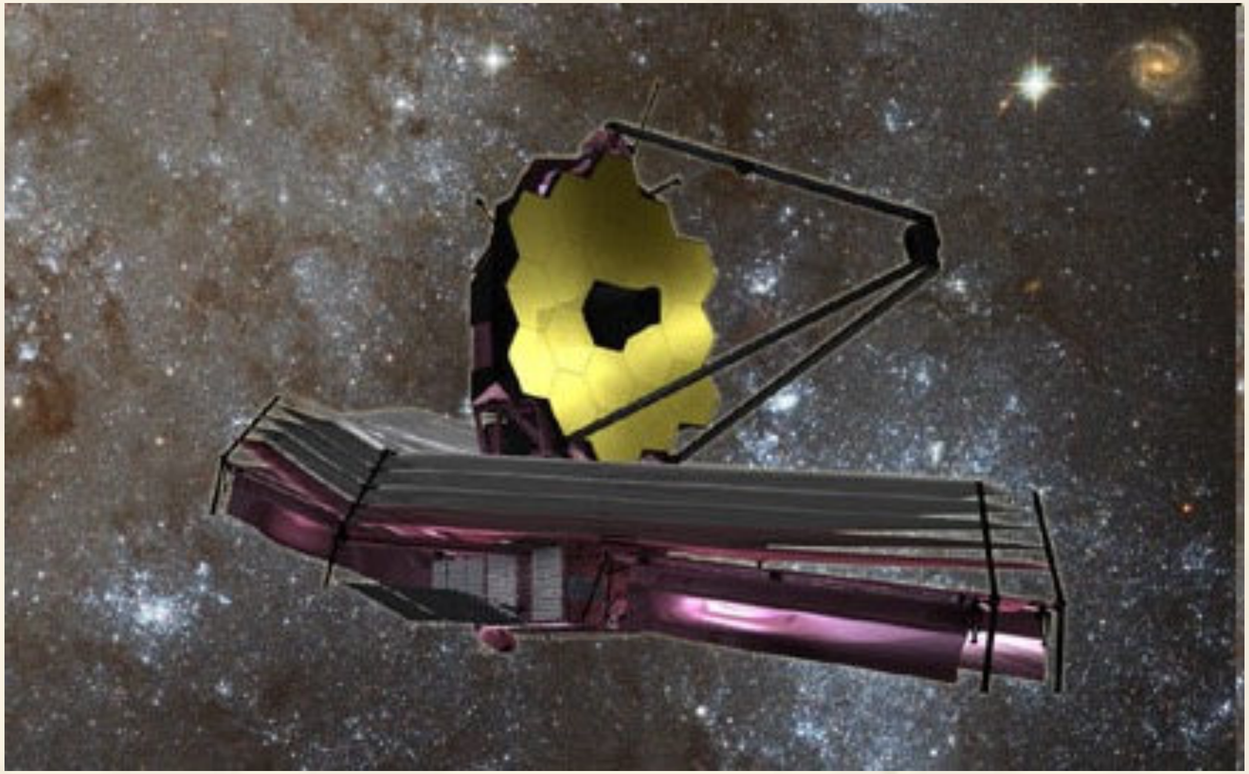
Mission type	Space observatory[1][2]
Operator	NASA / MIT
COSPAR ID	2018-038A
SATCAT no.	43435
Website	tess.gsfc.nasa.gov tess.mit.edu
Mission duration	Planned: 2 years Elapsed: 1 year, 5 months, 13 days
Spacecraft properties	
Bus	LEOStar-2/750[3]
Manufacturer	Orbital ATK
Launch mass	362 kg (798 lb)[4]
Dimensions	3.7 × 1.2 × 1.5 m (12 × 4 × 5 ft)
Power	530 watts[4]
Start of mission	
Launch date	April 18, 2018, 22:51:31 UTC[5]
Rocket	Falcon 9 Block 4 (B1045.1)
Launch site	Cape Canaveral SLC-40
Contractor	SpaceX

CoRoT（COnvection ROtation and planetary Transits）卫星(法国)



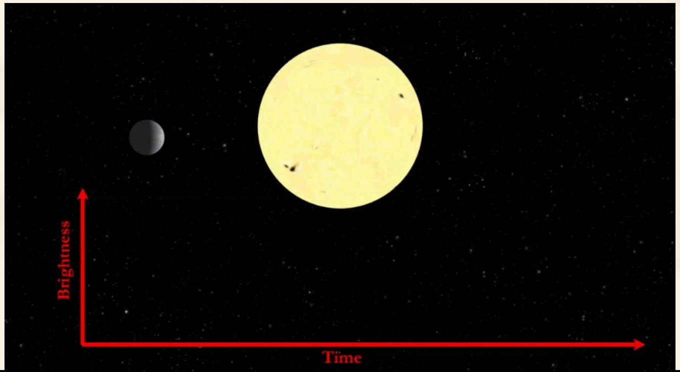
- 发射时间：2006.12 （2013报废）
- 探测方法：掩食法

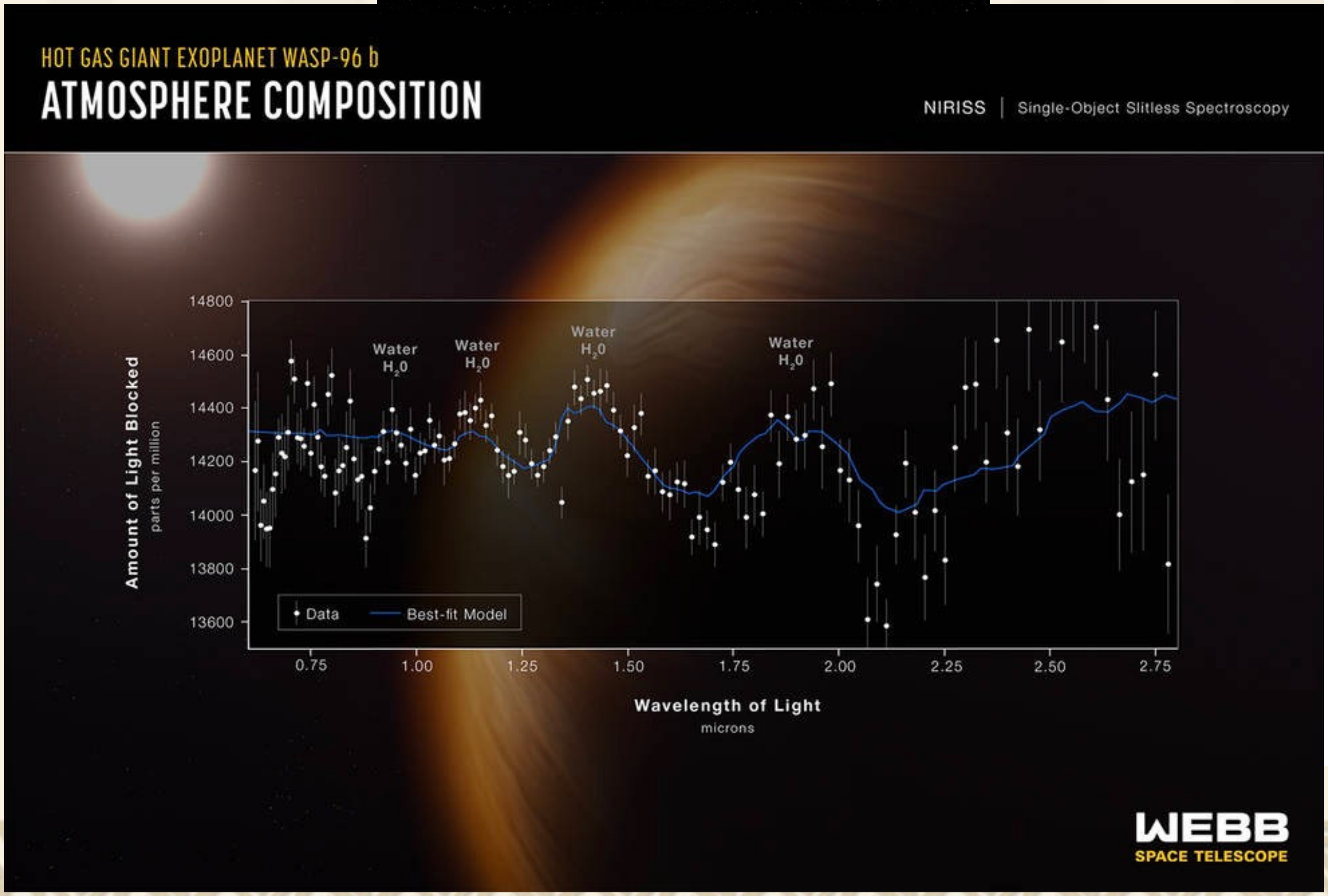
JWST空间望远镜(NASA)



- 发射时间：2021年底
- 探测方法：红外成像、掩食等

JWST：热气体巨行星WASP-96b的红外光谱

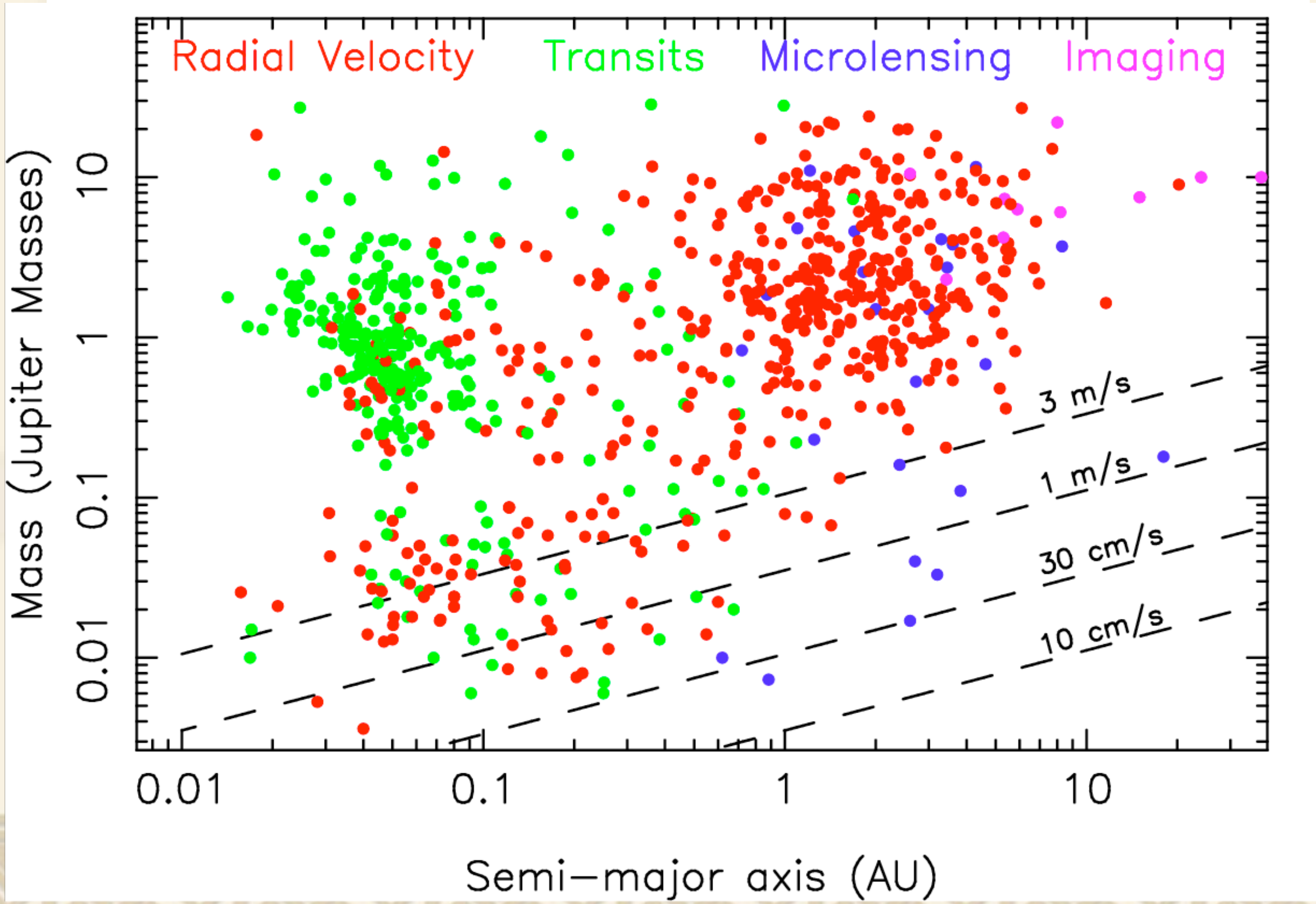




- 0.48倍木星质量，1.2倍木星半径
- 围绕类太阳恒星，1150光年处
- 轨道周期3.5天
- 凌星时大气分子在恒星谱留下吸收特征，与无遮挡时的恒星谱比对，得系外行星大气透射谱
- 水分子的清晰信号，表面700多度
- 云雾存在及变化的证据
- 前所未有的分析数百上千光年外系外行星大气的能力

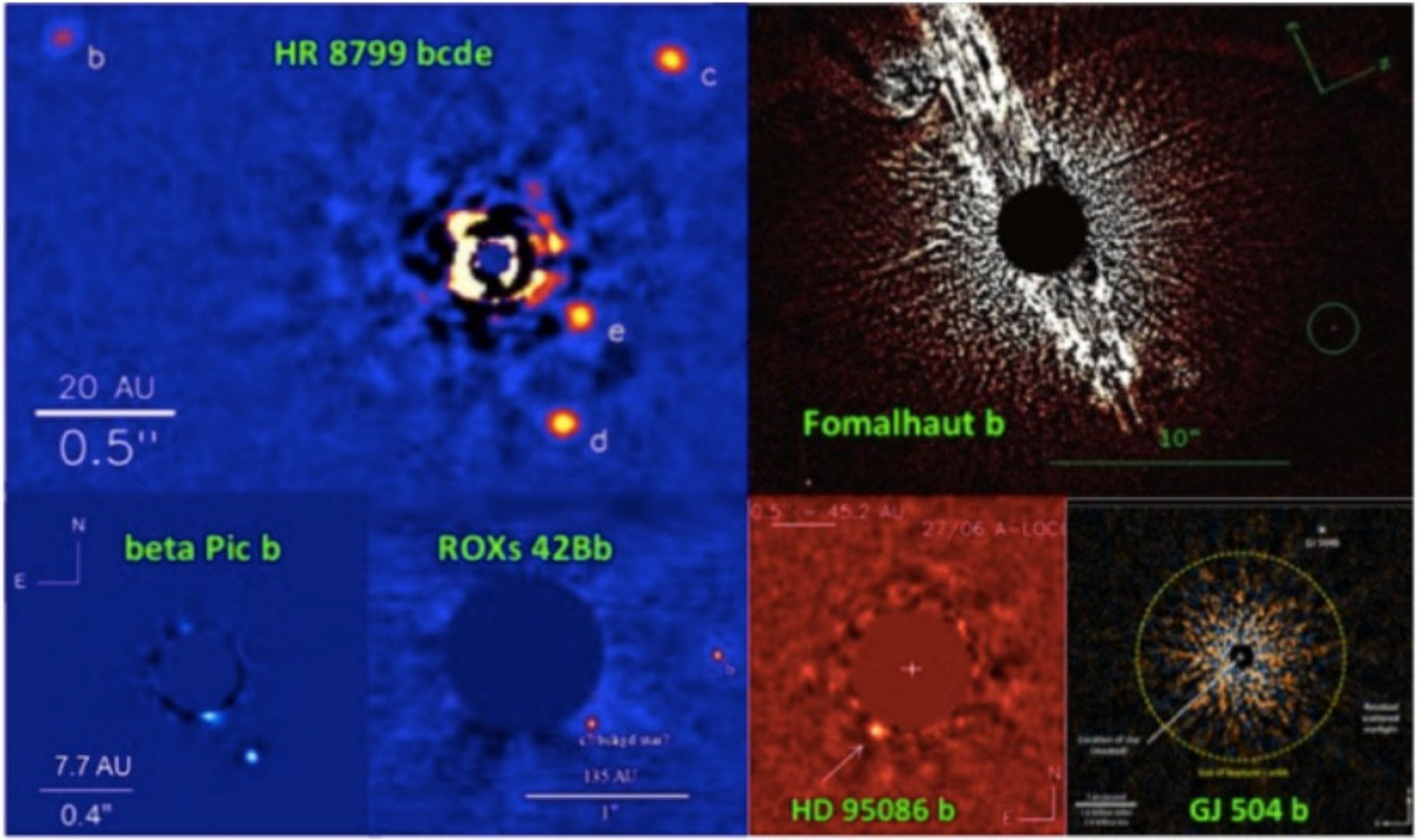
(NASA, ESA, CSA, STScI, internet)

Doppler Detection of Planetary Systems



Direct Detection and Characterization of Exoplanets

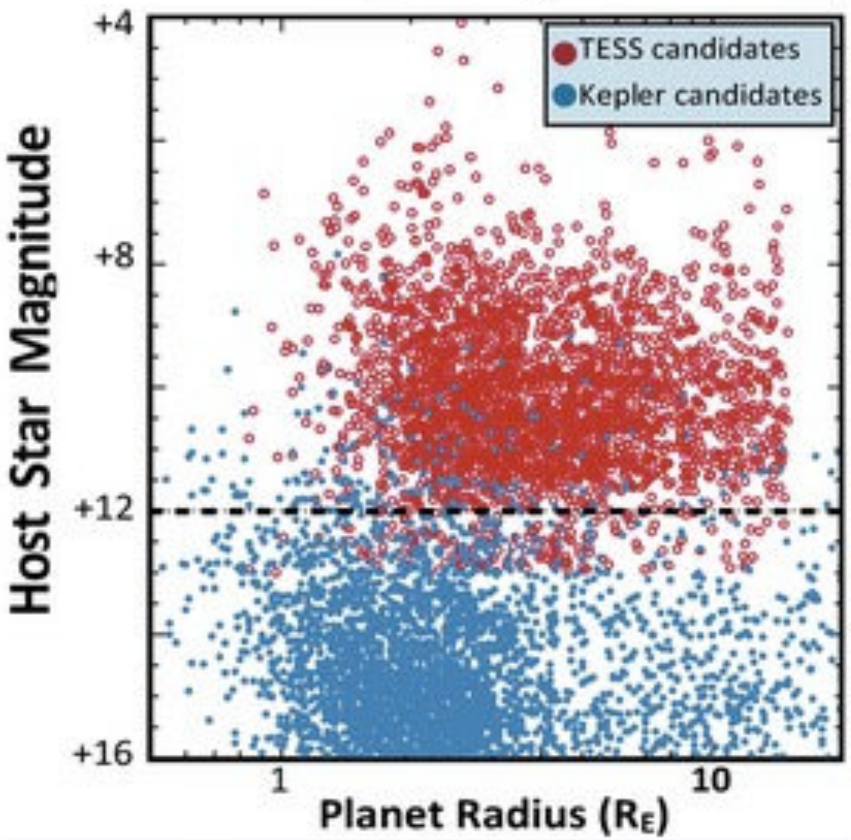
TMT



A gallery of directly-imaged planets: (clockwise from the top-left) HR 8799 bcde (Marois et al. 2008, 2010a), Fomalhaut b (Kalas et al. 2008), GJ 504 b (Kuzuhara et al. 2013), HD 95086 b (Rameau et al. 2013), ROXs 42Bb (Currie et al. 2014b), and β Pic b (Lagrange et al. 2010). Other companions with masses below/near the deuterium-burning limit (~13 MJup) have also been imaged, many of them at wider separations (e.g., Chauvin et al. 2005; Goldman et al. 2010; Ireland et al. 2011; Luhman et al. 2011; Bowler et al. 2013; Delorme et al. 2013; Kraus et al. 2014; Bailey et al. 2014; Naud et al. 2014).

TMT
can push further

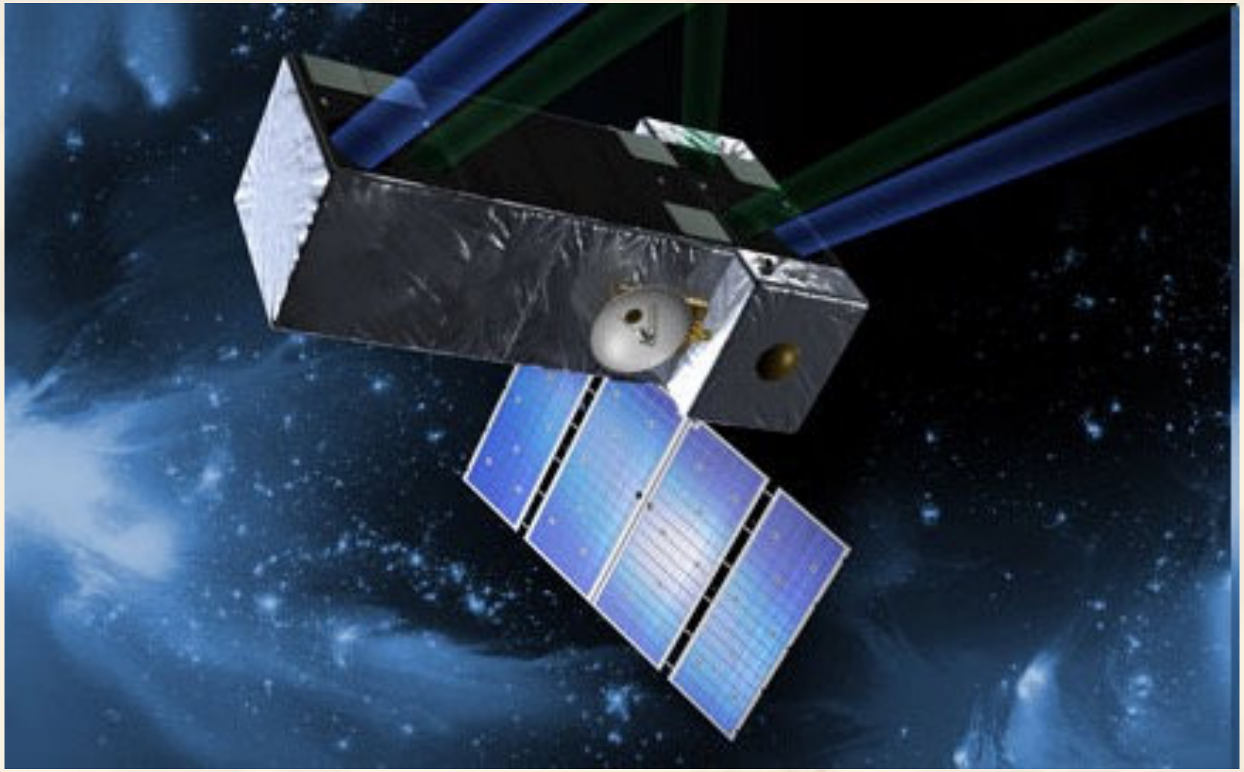
Transiting Exoplanets



Predicted planet yields from TESS (Ricker et al. 2014). Both these surveys will be complete when TMT operations begin. TESS will find many planets around bright stars, while K2 will find larger numbers of planets around cooler stars.

Gravitational Microlensing

空间光学干涉望远镜(SIM)



- 发射时间：？？？？
- 位置测量精度：~1微角秒
- 探测方法：天体位置测量法

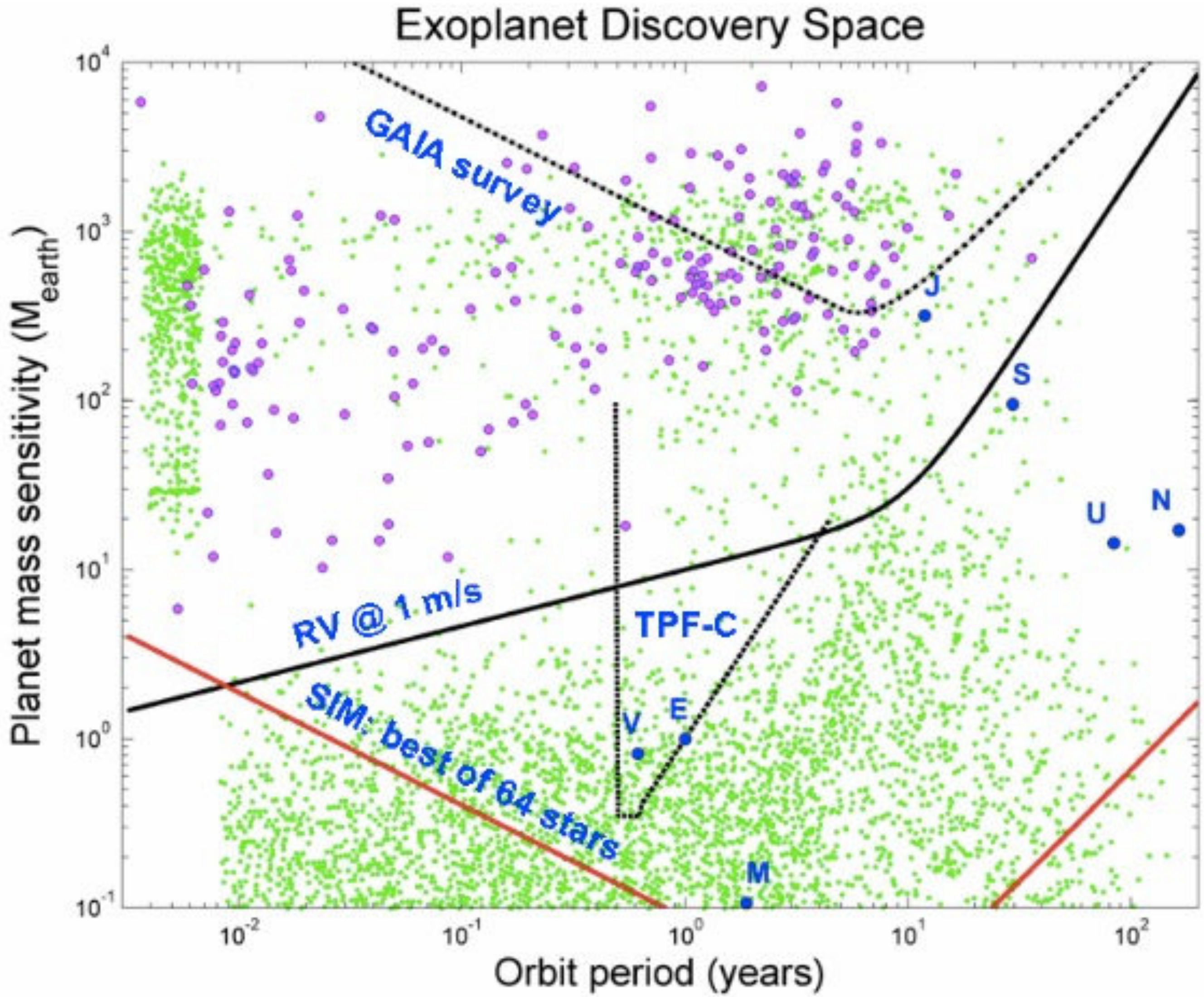
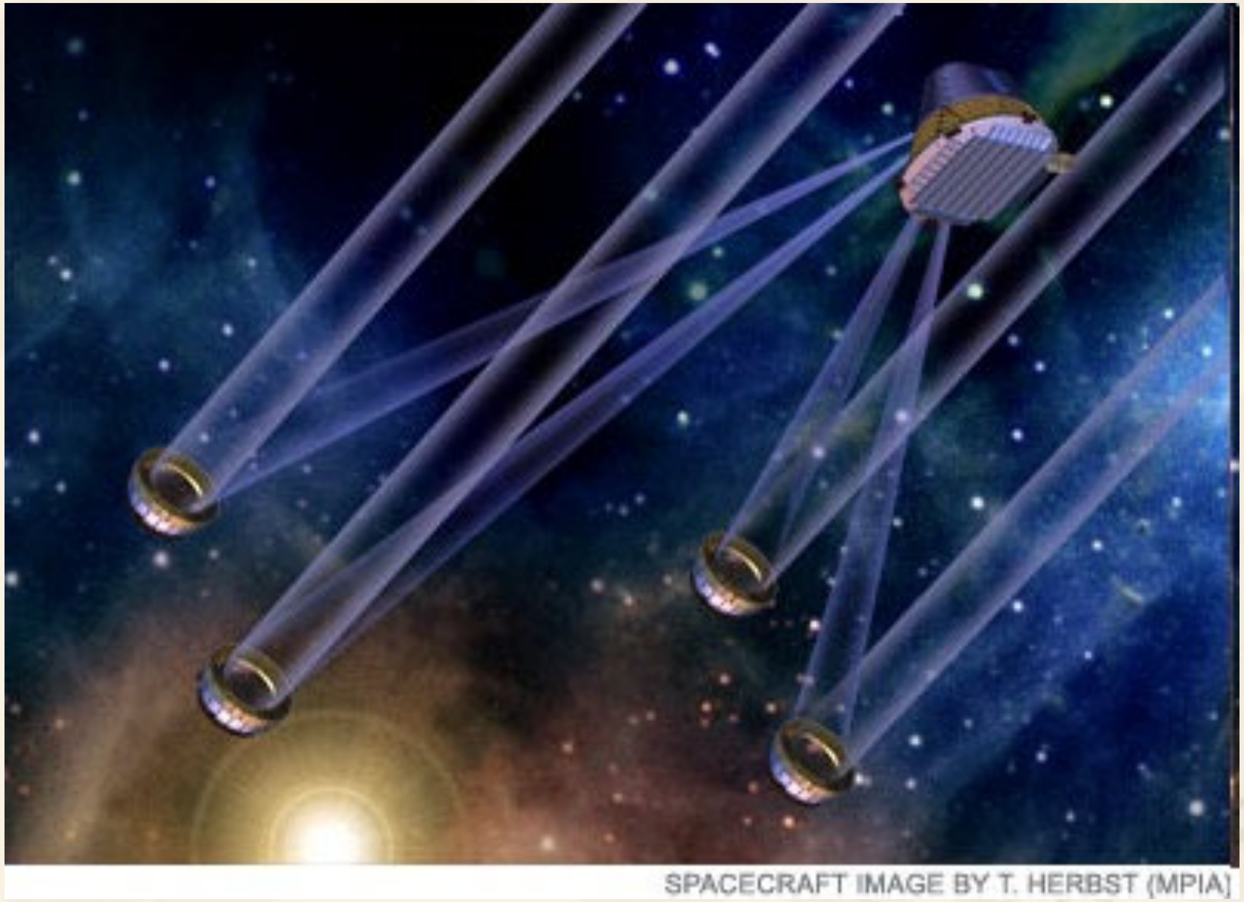


Figure 1: SIM is the only mission that explores almost the entire range of masses and orbit periods where terrestrial planets form and evolve. The red curve is for the most favorable of 64 candidate stars, while the least favorable star is about an order of magnitude above this line. (The discovery space lies above each line). Green dots represent planet distributions from the simulations of Ida & Lin (2004ab), and purple dots show the known RV detections.

Terrestrial Planet Finder Inteferometer（NASA）



- 发射时间：？？？？
- 探测方法：天体位置测量法


Exoplanet
Missions
WFIRST
JWST2
ARIEL
TESS
PLATO
Kepler
LUVOIR5
CHEOPS 4
Spitzer
Gaia
Hubble1
Starshade
Rendezvous5
HabEx5
CoRoT3
OST5
NASA
Missions
Non-NASA
Missions
W. M. Keck Observatory
Large Binocular
Telescope Interferometer
NN-EXPLORE
1 NASA/ESA Partnership
2 NASA/ESA/CSA Partnership

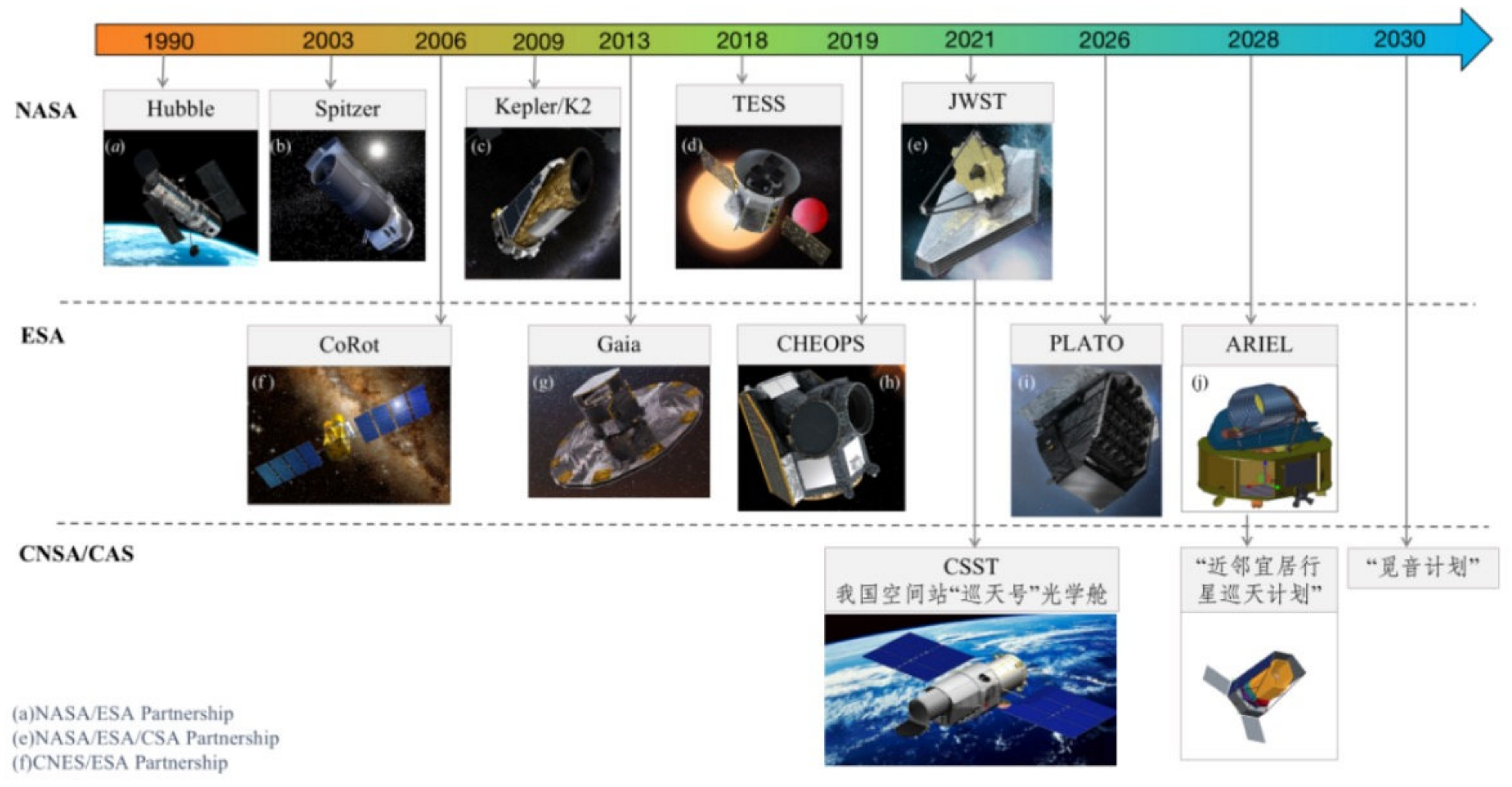
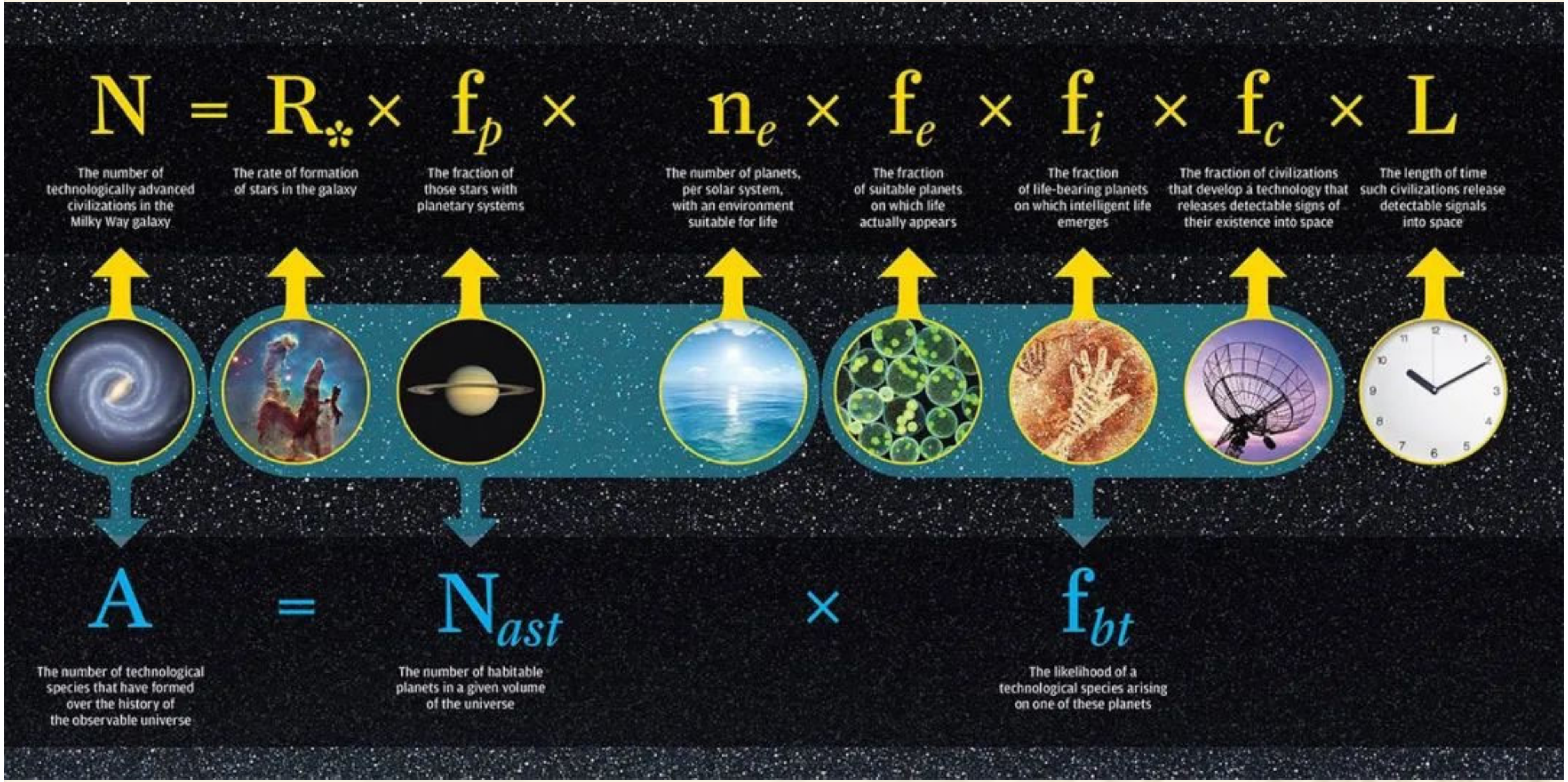


图6 系外行星探测任务. 图片来源: (b~d)NASA; (a), (e~j) ESA

(courtesy of J.H. Ji, PMO)

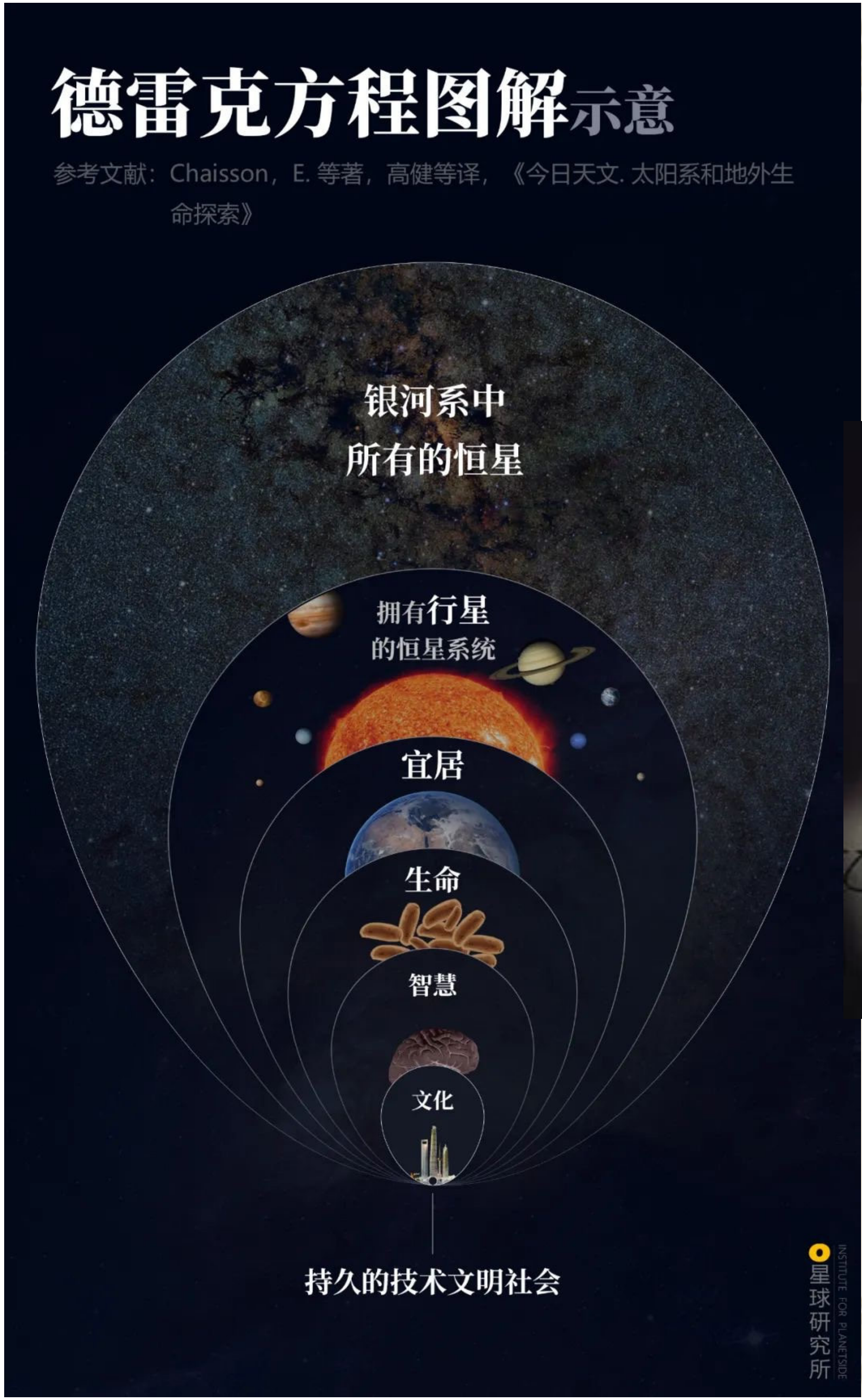


德雷克方程, 在银河系中发现生命或发达文明的概率的数学公式.可以简单的认为是银河系中宜居行星的数目乘以宜居行星上出现发展出发达文明的似然函数(图片来源: University of Rochester)

The Drake Equation.

$$N = R^{*} \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- **N** – The number of civilisations in our galaxy in which communication might be possible.
- **R*** – The average rate of star formation per year in our galaxy
- **f_p** – The fraction of stars with planets
- **n_e** – The average number of planets that can potentially support life (per star with planets.)
- **f_l** – The fraction that can go on to support life.
- **f_i** – The fraction that can go on to support intelligent life.
- **f_c** – The fraction of civilisations that develop a technology detectable from space.
- **L** – Length of time such civilisations release detectable signs into space.

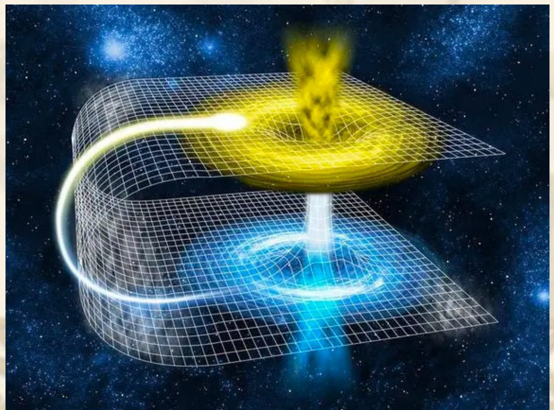


弗兰克·德雷克在白板上写下他著名的方程式.(图片来源: SETI.org)

$$N = N_s \times F_p \times F_l \times F_i \times L_c/L_s$$

- **N** is the number of civilizations in the Milky Way today. 银河系地外文明总数目
- **N_s** is the number of stars in the Milky Way. 银河系恒星总数目
- **F_p** is the fraction of stars with habitable planets. 具有宜居行星的恒星比率
- **F_l** is the fraction of habitable planets with life. 有生命存在的宜居行星比率
- **F_i** is the fraction of life-bearing planets where intelligent civilizations arise. 有生命的宜居行星上高等文明出现的比率
- **L_c** is the typical lifetime of a civilization in years. 高等文明存在的典型时间
- **L_s** is the typical lifetime of a star (10 billion years for Sun-like stars). 恒星的典型寿命

我们可以和高等外星文明有效交流吗？



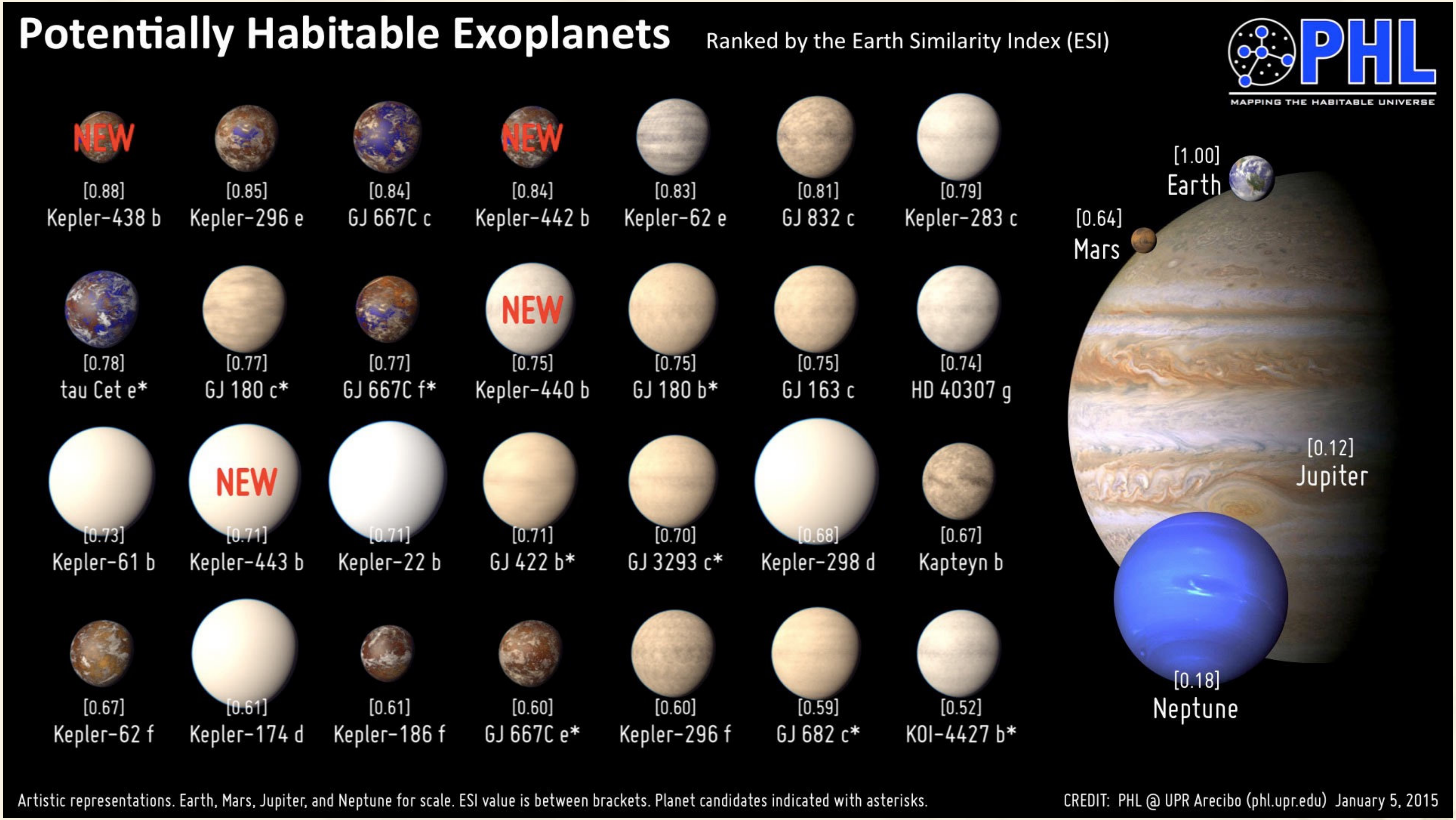
地外文明的规模

"**卡达谢夫文明尺度(Kardashev Scale)**"的名字来源于俄罗斯(前苏联)天体物理学家尼古拉·卡达谢夫(Nikolai Kardashev)，他提出ETI可以根据其所能利用的能量的多少进行分类。他在1964年的一篇《地外文明传递信息》(*Transmission of Information by Extraterrestrial Civilizations*)的论文中提出了一个分类方式——**"卡达谢夫文明尺度"**，包括以下内容：

- I型文明(行星文明)是指那些能够使用和储存其行星上所有可用能量的文明($\sim 4 \times 10^{12}\ W$)
- II型文明(恒星文明)是那些能够使用和控制其整个恒星系统的能量的文明($\sim 4 \times 10^{26}\ W$)
- III型文明(星系文明)是指那些能够控制整个星系能量的文明($\sim 4 \times 10^{37}\ W$)

在1973年出版的《宇宙联系：地外视角》(*The Cosmic Connection: An Extraterrestrial Perspective*)一书中，著名的天文学家兼科普大师的卡尔·萨根写到，由于人类还没有达到I型发展水平，因此应该有一个0型发展水平。正如萨根所说：

> "I型文明能够为通讯目的聚集相当于地球目前全部输出功率的能量，这些能量应被广泛应用于供暖、供电、交通等；除了与地外文明的通讯之外，还有许多其他使用目的。根据这个I型文明的定义，人类还达不到I型文明的标准……我们现在的文明应大约被归类在0.7型的文明。"



Potentially Habitable Exoplanets
Ranked by the Earth Similarity Index (ESI)
PHL
MAPPING THE HABITABLE UNIVERSE
NEW
[0.88] Kepler-438 b
[0.85] Kepler-296 e
[0.84] GJ 667C c
NEW
[0.84] Kepler-442 b
[0.83] Kepler-62 e
[0.81] GJ 832 c
[0.79] Kepler-283 c
[0.78] tau Cet e*
[0.77] GJ 180 c*
[0.77] GJ 667C f*
NEW
[0.75] Kepler-440 b
[0.75] GJ 180 b*
[0.75] GJ 163 c
[0.74] HD 40307 g
[0.73] Kepler-61 b
NEW
[0.71] Kepler-443 b
[0.71] Kepler-22 b
[0.71] GJ 422 b*
[0.70] GJ 3293 c*
[0.68] Kepler-298 d
[0.67] Kapteyn b
[0.67] Kepler-62 f
[0.61] Kepler-174 d
[0.61] Kepler-186 f
[0.60] GJ 667C e*
[0.60] Kepler-296 f
[0.59] GJ 682 c*
[0.52] KOI-4427 b*
[1.00] Earth
[0.64] Mars
[0.12] Jupiter
[0.18] Neptune
Artistic representations. Earth, Mars, Jupiter, and Neptune for scale. ESI value is between brackets. Planet candidates indicated with asterisks.
CREDIT: PHL @ UPR Arecibo (phl.upr.edu) January 5, 2015

NASA spies Earth-sized exoplanet orbiting Sun-like star

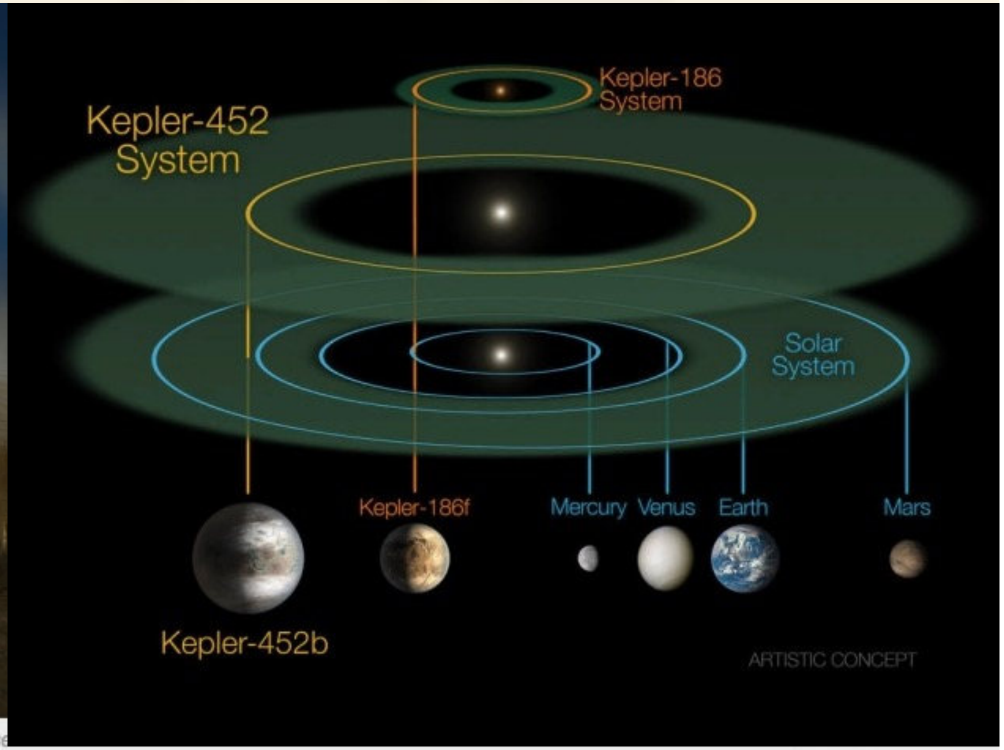
Potentially rocky world spotted by Kepler spacecraft offers glimpse at Earth's future.

Alexandra Witze

23 July 2015 | Updated: 23 July 2015

SETI Institute/Danielle Futse

An artist's impression of exoplanet Kepler-452b, which is likely to be rocky, just as Earth is.



NASA/JPL-CalTech/R. Hurt

Kepler-452b and its star compared to the Solar System and a previously discovered Earth-like exoplanet.

eso1629 — Science Release

SPACE SCOOP

Planet Found in Habitable Zone Around Nearest Star

Pale Red Dot campaign reveals Earth-mass world in orbit around Proxima Centauri

24 August 2016

Astronomers using ESO telescopes and other facilities have found clear evidence of a planet orbiting the closest star to Earth, Proxima Centauri. The long-sought world, designated Proxima b, orbits its cool red parent star every 11 days and has a temperature suitable for liquid water to exist on its surface. This rocky world is a little more massive than the Earth and is the closest exoplanet to us — and it may also be the closest possible abode for life outside the Solar System. A paper describing this milestone finding will be published in the journal Nature on 25 August 2016.

eso2202 — Science Release

New planet detected around star closest to the Sun

10 February 2022

A team of astronomers using the European Southern Observatory's Very Large Telescope (ESO's VLT) in Chile have found evidence of another planet orbiting Proxima Centauri, the closest star to our Solar System. This candidate planet is the third detected in the system and the lightest yet discovered orbiting this star. At just a quarter of Earth's mass, the planet is also one of the lightest exoplanets ever found.

eso1837 — Science Release

Super-Earth Orbiting Barnard's Star

Red Dots campaign uncovers compelling evidence of exoplanet around closest single star to Sun

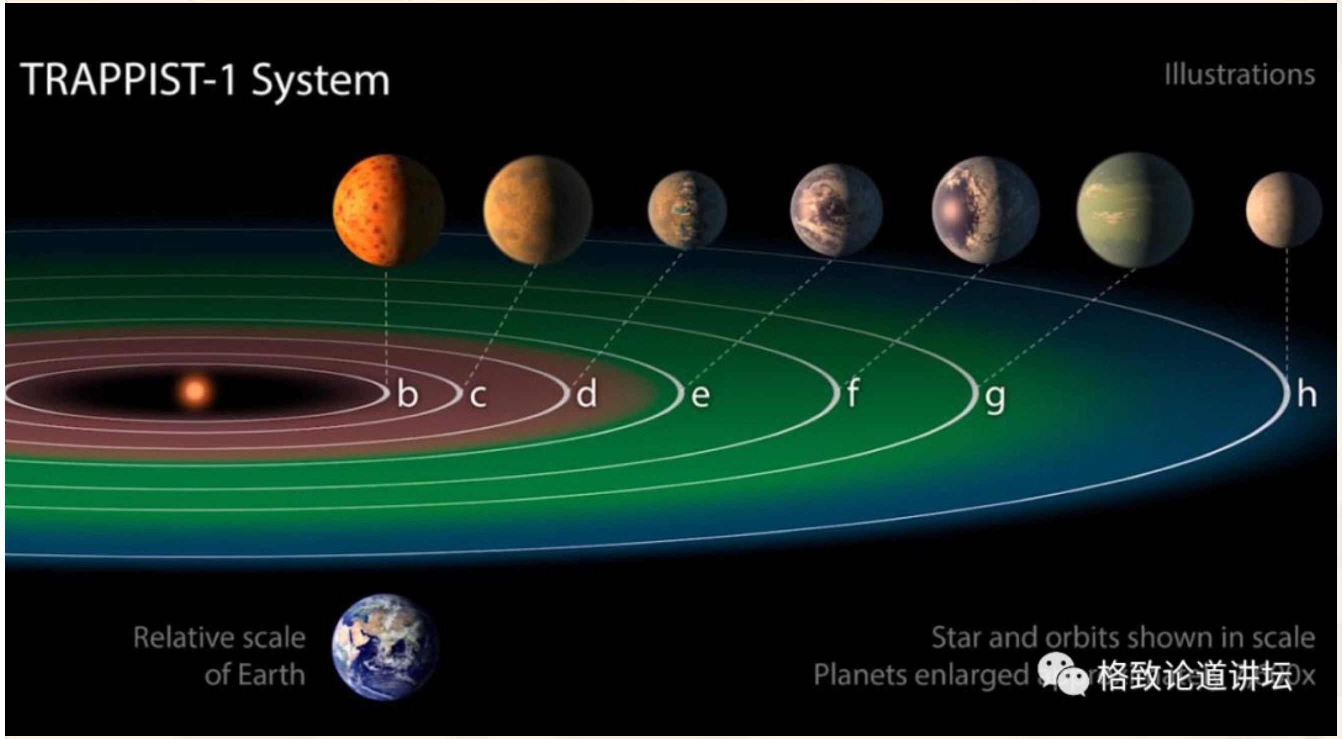
14 November 2018

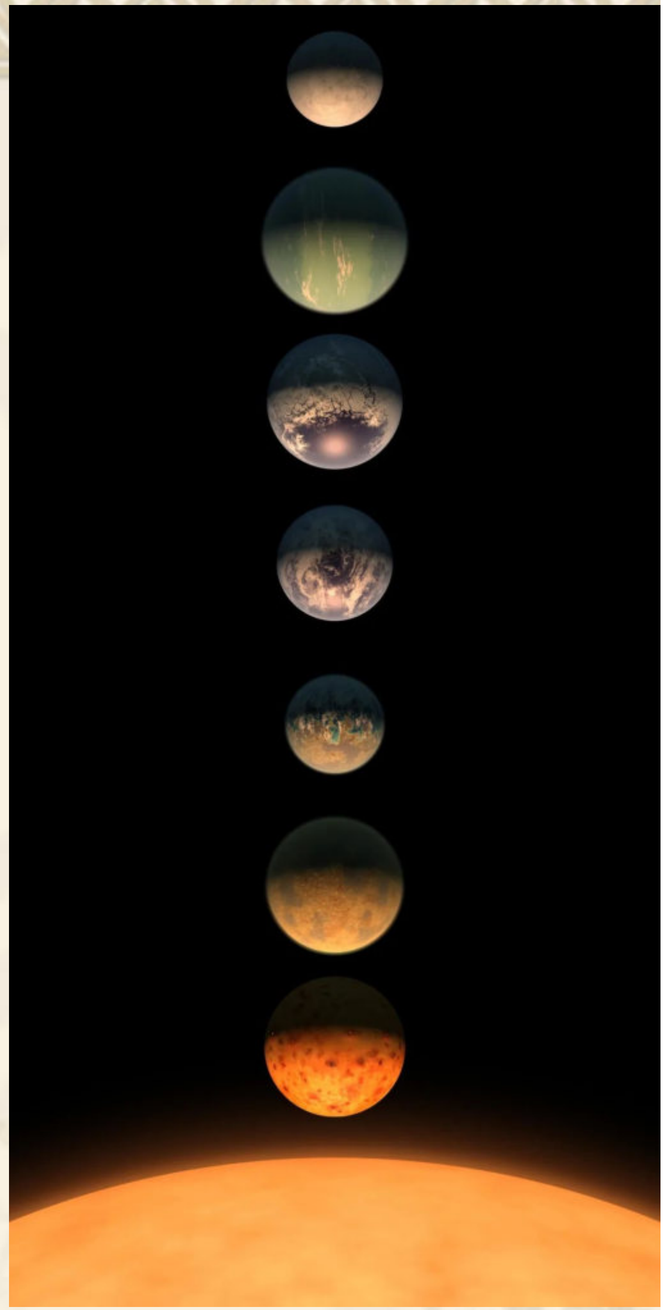
The nearest single star to the Sun hosts an exoplanet at least 3.2 times as massive as Earth — a so-called super-Earth. One of the largest observing campaigns to date using data from a world-wide array of telescopes, including ESO's planet-hunting HARPS instrument, have revealed this frozen, dimly lit world. The newly discovered planet is the second-closest known exoplanet to the Earth. Barnard's star is the fastest moving star in the night sky.

A planet has been detected orbiting Barnard's Star, a mere 6 light-years away. This breakthrough — announced in a paper published today in the journal *Nature* — is a result of the Red Dots and CARMENES projects, whose search for local rocky planets has already uncovered a new world orbiting our nearest neighbour, Proxima Centauri.

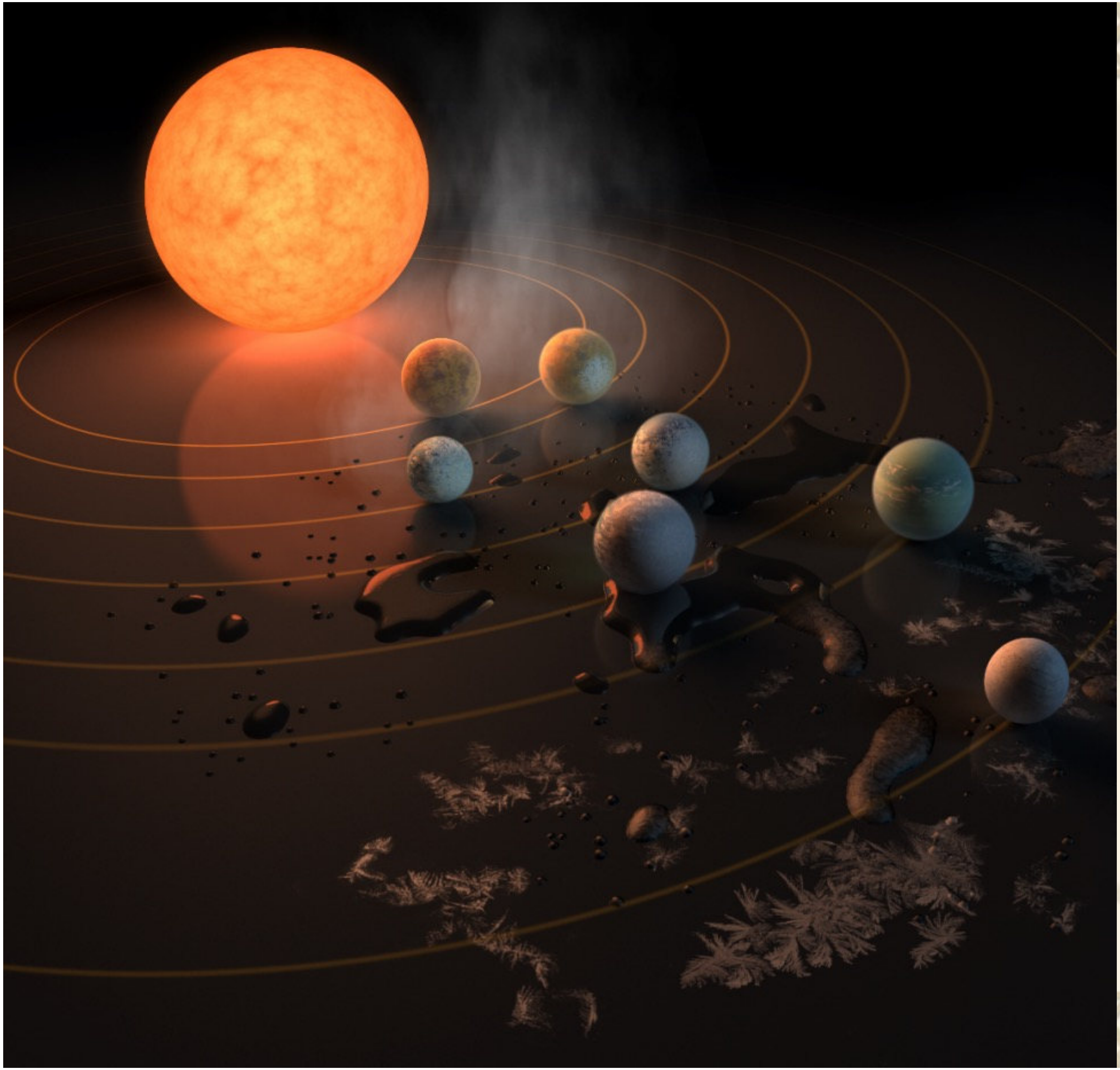
Seven Worlds for TRAPPIST-1
Illustration Credit: NASA, JPL-Caltech, Spitzer Space Telescope, Robert Hurt (Spitzer, Caltech)

Explanation: Seven worlds orbit the ultracool dwarf star TRAPPIST-1, a mere 40 light-years away. In May 2016 astronomers using the Transiting Planets and Planetesimals Small Telescope (TRAPPIST) announced the discovery of three planets in the TRAPPIST-1 system. Just announced, additional confirmations and discoveries by the Spitzer Space Telescope and supporting ESO ground-based telescopes have increased the number of known planets to seven. The TRAPPIST-1 planets are likely all rocky and similar in size to Earth, the largest treasure trove of terrestrial planets ever detected around a single star. Because they orbit very close to their faint, tiny star they could also have regions where surface temperatures allow for the presence of liquid water, a key ingredient for life. Their tantalizing proximity to Earth makes them prime candidates for future telescopic explorations of the atmospheres of potentially habitable planets. All seven worlds appear in this artist's illustration, an imagined view from a fictionally powerful telescope near planet Earth. Planet sizes and relative positions are drawn to scale for the Spitzer observations. The system's inner planets are transiting their dim, red, nearly Jupiter-sized parent star.





红矮星TRAPPIST-1和它的七颗类地行星想象图，
图片来源@NASA



由斯皮策望远镜发现的Trappist-1系统的艺术加工想像图，一颗距离地球约40光年的超冷红矮星Trappist-1，周围环绕着7颗地球大小的行星。随着离恒星距离的由近及远，水会因过热而蒸发殆尽（图上显示为水汽），或者因过冷而凝结为冰。在合适的中间距离，水能以液态形式存在，这一区间被认为适合生命存在，被称作“宜居带”。版权／NASA/JPL-Caltech/R.Hurt(IPAC)


NASA

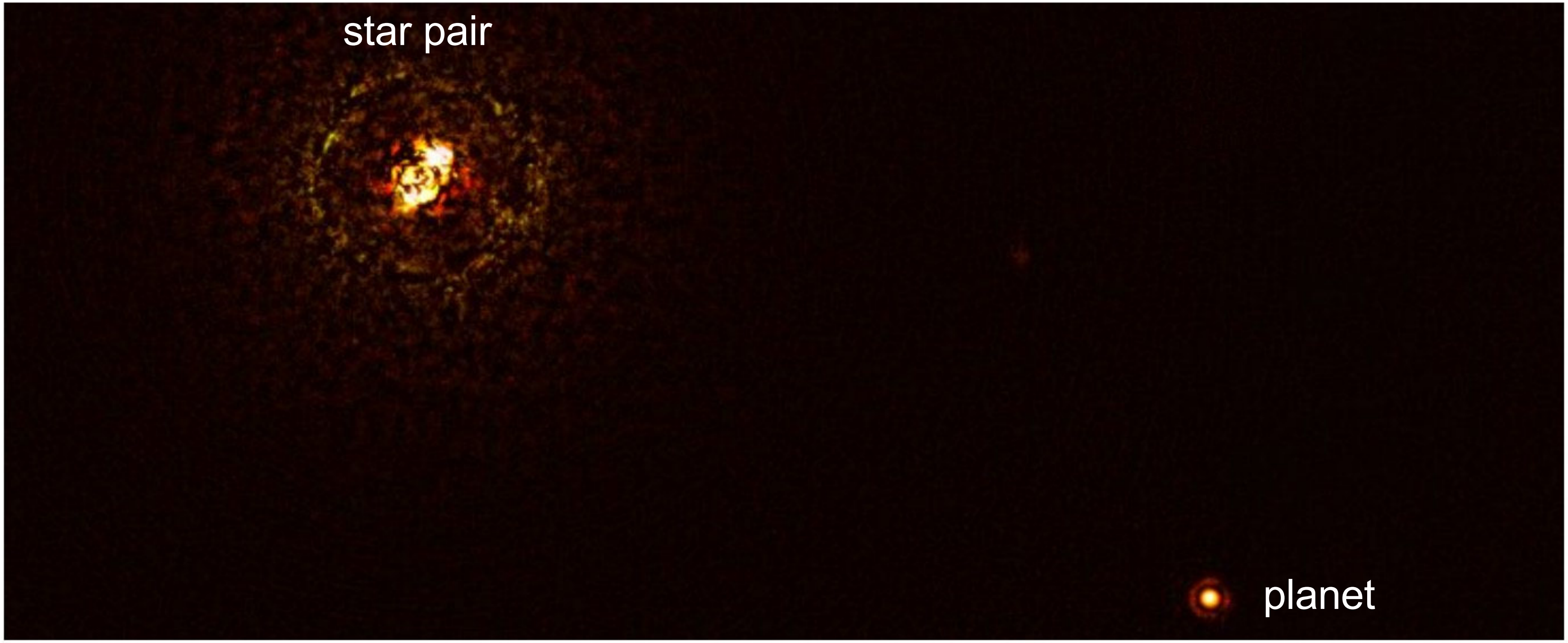

葫芦娃

eso2118 — Science Release

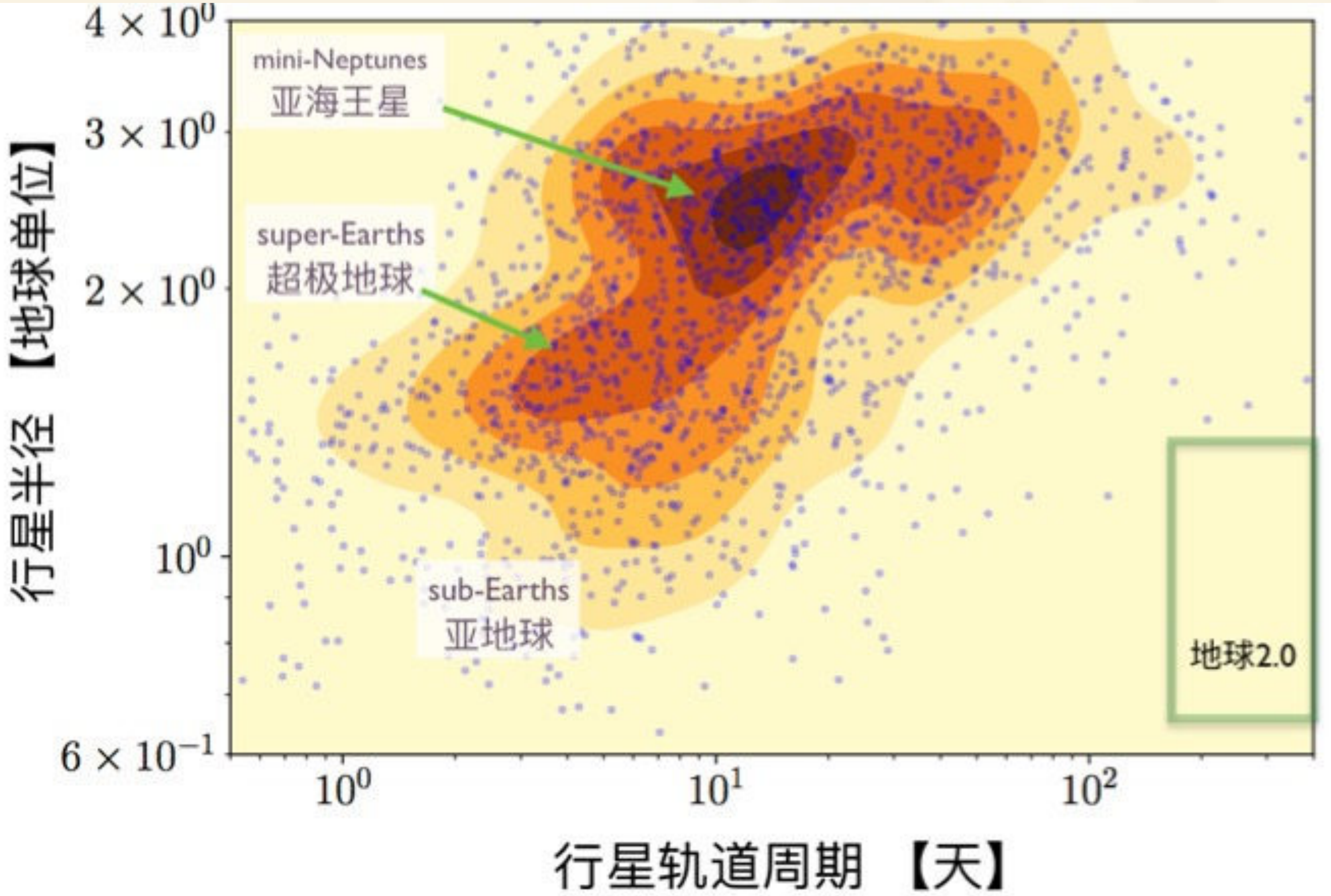
ESO telescope images planet around most massive star pair to date

8 December 2021

恒星对总质量大于6Msun



The European Southern Observatory's Very Large Telescope (ESO's VLT) has captured an image of a planet orbiting b Centauri, a two-star system that can be seen with the naked eye. This is the hottest and most massive planet-hosting star system found to date, and the planet was spotted orbiting it at 100 times the distance Jupiter orbits the Sun. Some astronomers believed planets could not exist around stars this massive and this hot — until now.



mini-Neptunes
亚海王星
super-Earths
超级地球
sub-Earths
亚地球
地球2.0
4 × 10^0
3 × 10^0
2 × 10^0
10^0
6 × 10^−1
10^0
10^1
10^2
行星半径 【地球单位】
行星轨道周期 【天】

“超级开普勒”

图6. 上海天文台提出的ET卫星计划。七个广角望远镜分别凝视着开普勒已观察过的天区及其邻居区域，通过仔细测量二十多万个恒星四年中每刻的光度，捕抓到小型行星凌星时的微弱信号。即使每十个太阳中只有一个有地球，ET也能在4年内找到十几个地球。除此之外，ET可以找到成千上万个不同种类的系外行星，包括地球的远亲近戚。

搜寻第二个地球和生命
（上海天文台 葛健）

Methods of detecting exoplanets

From Wikipedia, the free encyclopedia

Contents [hide]

Home Catalogue Plots Tools EXOplanet .eu News Bibliography Meetings Links

Encyclopaedia of exoplanetary systems

This encyclopaedia provides the latest detections and data announced by professional astronomers on exoplanetary systems. It contains objects lighter than 60 masses of Jupiter, which orbit stars or are free-floating. It also provides a database on exoplanets in binary systems, a database on circumstellar disks, an exhaustive bibliography, a list of exoplanet-related meetings, and links to other resources on the subject.

Established in February 1995 Developed and maintained by the exoplanet TEAM

Last update: Oct. 22, 2024 currently 7341 planets.

The catalog: Filter, sort, export

The plots: Online plotting tool

EXOplanet .eu

7344 exoplanets so far

For the use of this catalogue:

README first

Exoplanet.eu V2.20.1

1995 - 2024

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CNRS, l'Observatoire de Paris, PADC Paris Astronomical Data Centre, IVOA, europlanet, anr

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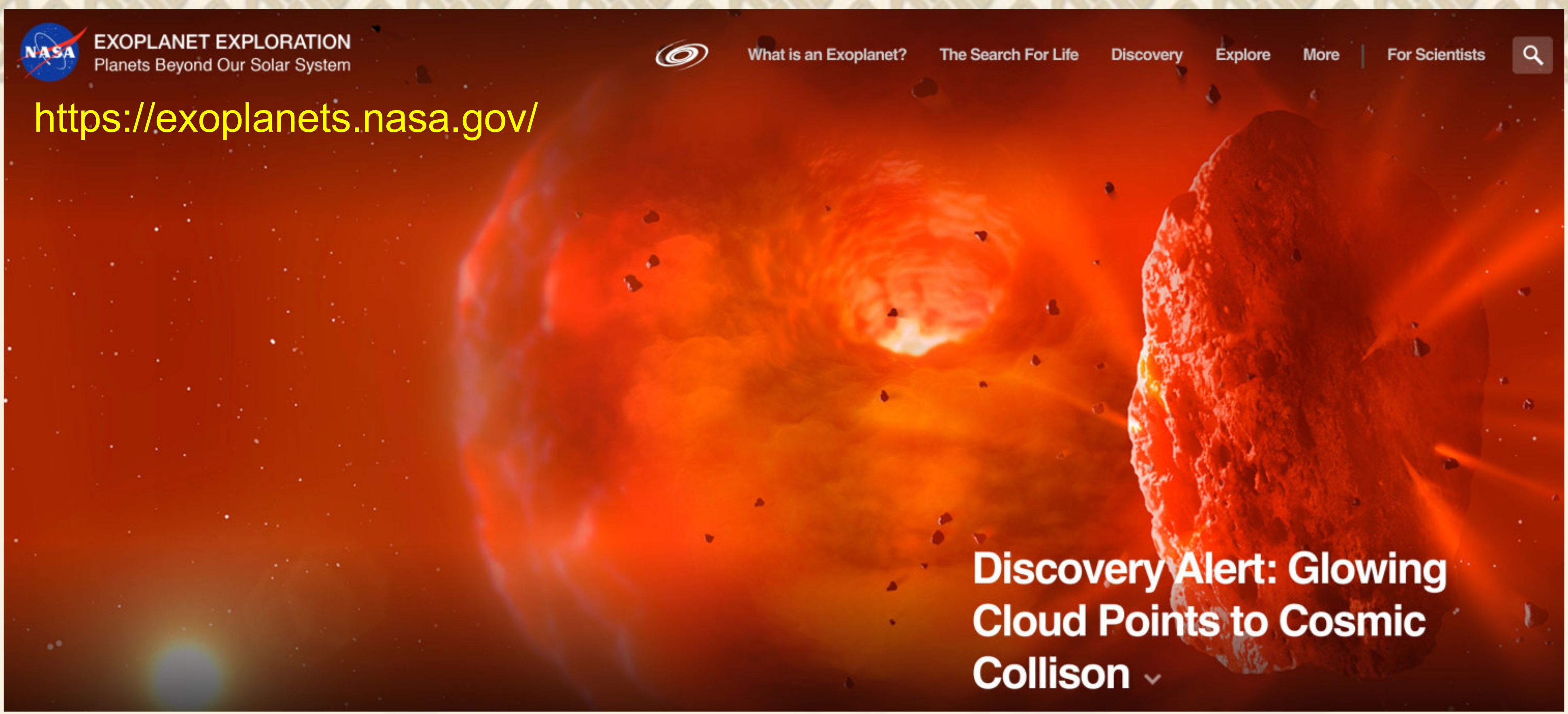
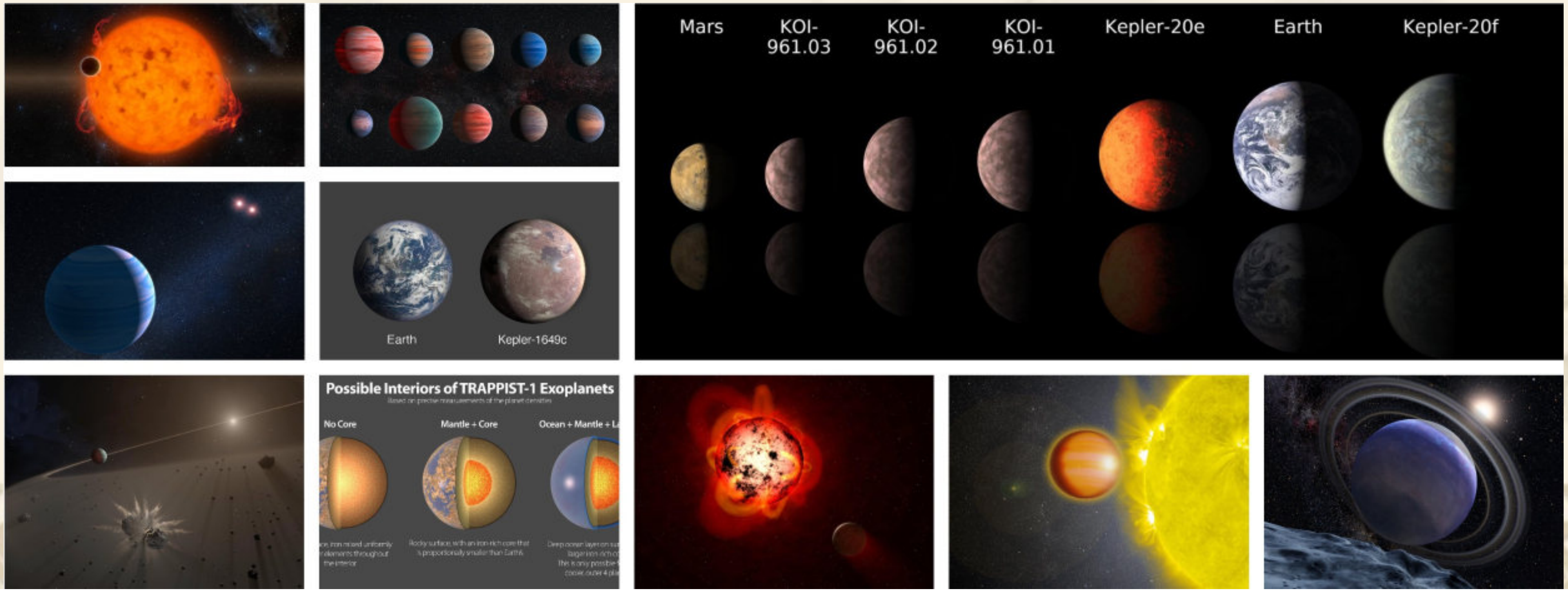

EXOPLANET EXPLORATION
Planets Beyond Our Solar System
What is an Exoplanet?
The Search For Life
Discovery
Explore
More
For Scientists
https://exoplanets.nasa.gov/
Discovery Alert: Glowing Cloud Points to Cosmic Collison


Mars
KOI-961.03
KOI-961.02
KOI-961.01
Kepler-20e
Earth
Kepler-20f
Earth
Kepler-1649c
Possible Interiors of TRAPPIST-1 Exoplanets
No Core
Mantle + Core

eso2120 — Science Release

ESO telescopes help uncover largest group of rogue planets yet

22 December 2021

Rogue planets are elusive cosmic objects that have masses comparable to those of the planets in our Solar System but do not orbit a star, instead roaming freely on their own. Not many were known until now, but a team of astronomers, using data from several European Southern Observatory (ESO) telescopes and other facilities, have just discovered at least 70 new rogue planets in our galaxy. This is the largest group of rogue planets ever discovered, an important step towards understanding the origins and features of these mysterious galactic nomads.

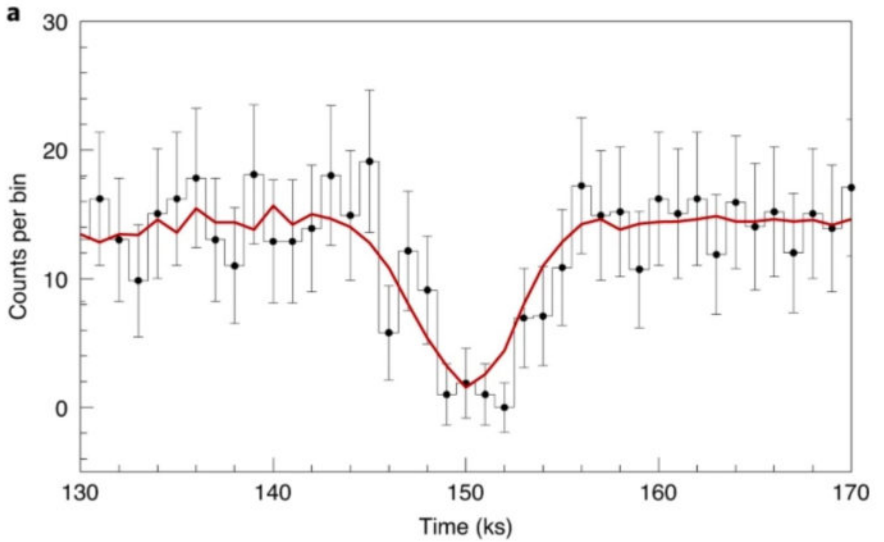
nature astronomy

Article | Published: 25 October 2021

A possible planet candidate in an external galaxy detected through X-ray transit

Rosanne Di Stefano, Julia Berndtsson, Ryan Urquhart, Roberto Soria, Vir
Carmichael & Nia Imara

Fig. 1: Background-subtracted X-ray light curves defined by data points for Chandra ObsID 13814.



Abstract

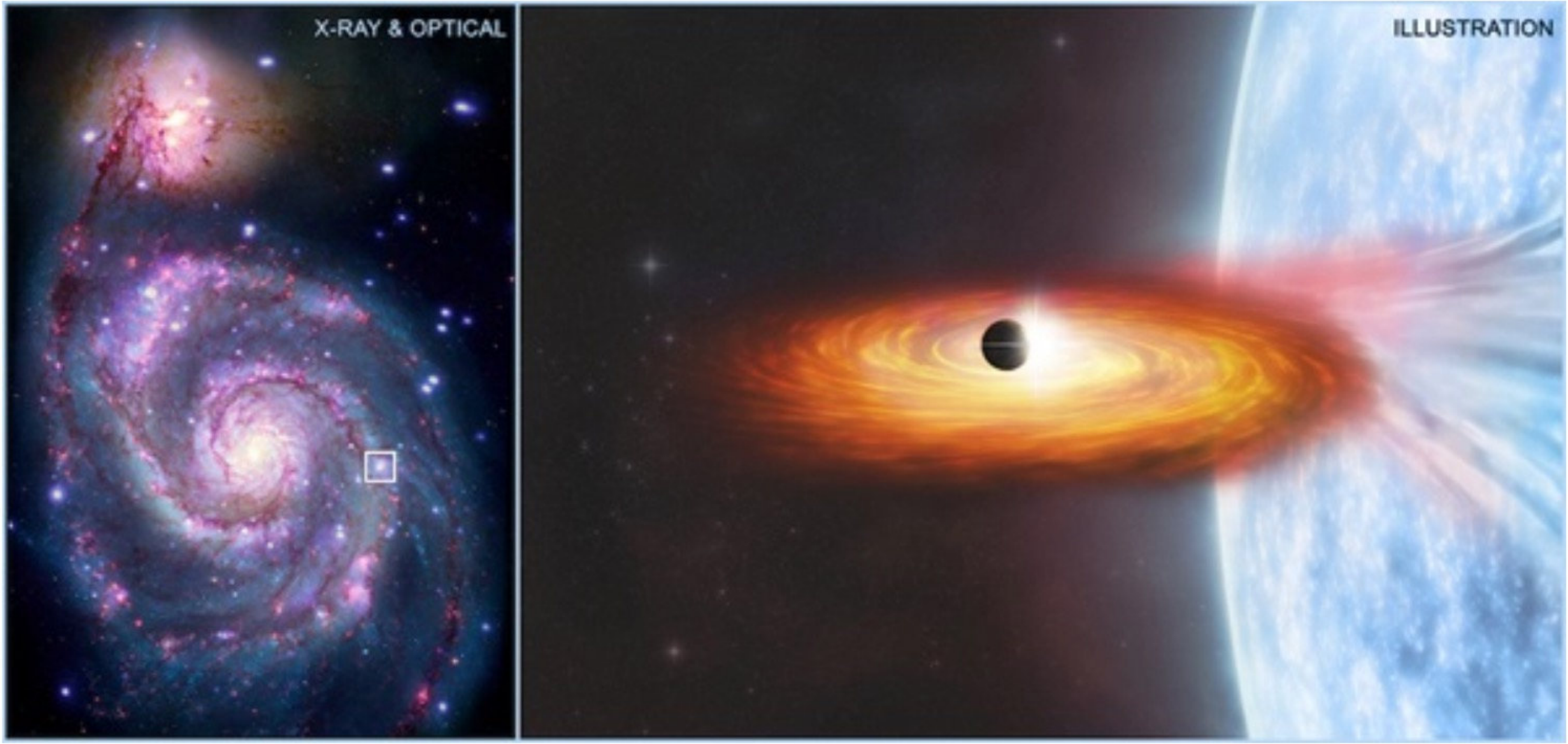
Many lines of reasoning suggest that external galaxies should host planetary systems, but detecting them by methods typically used in our own Galaxy is not possible. An alternative approach is to study the temporal behaviour of X-rays emitted by bright extragalactic X-ray sources, where an orbiting planet would temporarily block the X-rays and cause a brief eclipse. We report on such a potential event in the X-ray binary M51-ULS-1 in the galaxy M51. We examined a range of explanations for the observed X-ray dip, including a variety of transiting objects and enhancements in the density of gas and dust. The latter are ruled out by the absence of changes in X-ray colours, save any with sharp density gradients that cannot be probed with our data. Instead, the data are well fit by a planet transit model in which the eclipser is most likely to be the size of Saturn. We also find that the locations of possible orbits are consistent with the survival of a planet bound to a mass-transfer binary.

Found: The first exoplanet outside of our Milky Way

In a galaxy far, far away lies an exoplanet circling a binary system that contains a neutron star or black hole.

By Caitlyn Buongiorno | Published: Friday, October 29, 2021

RELATED TOPICS: EXOPLANET | GALAXIES



The Whirlpool Galaxy (left) in X-ray and optical light. On the right is an artist's concept of the M51-ULS-1 system with the neutron star or black hole syphoning material from its companion star. The planet is eclipsing the X-rays generated by the superheated material around the compact object.

X-ray: NASA/CXC/SAO/R. DiStefano, et al.; Optical: NASA/ESA/STScI/Grendler; Illustration: NASA/CXC/M.Weiss

序号	行星名称	距离（光年）	公转周期（天）	质量（木星）	主星（太阳）	轨道（AU）
1	GJ 849c	30	1924	0.77	0.49	2.39
2	Beta Umi b	131	522	6.1	1.4	1.4
3	Kepler 39b	3560	21.1	20	1.29	0.155
4	Kepler 167b	1115	4.4	0.012	0.8	0.048
5	水星	–	88.0	0.00017	1	0.39