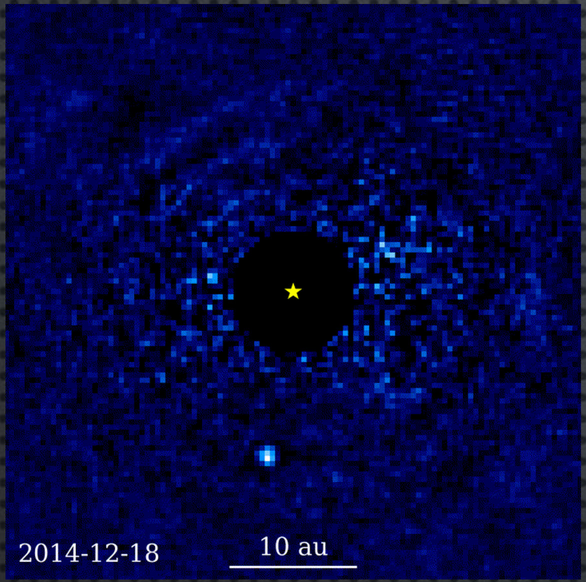
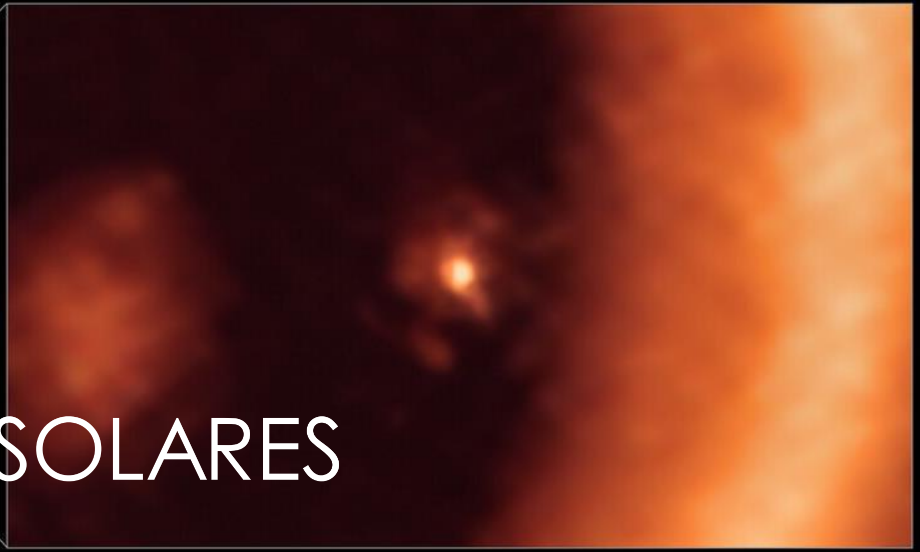
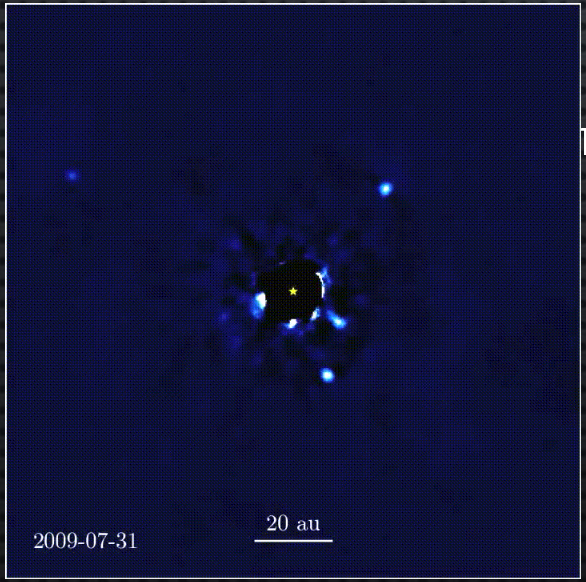




SISTEMAS EXTRASOLARES

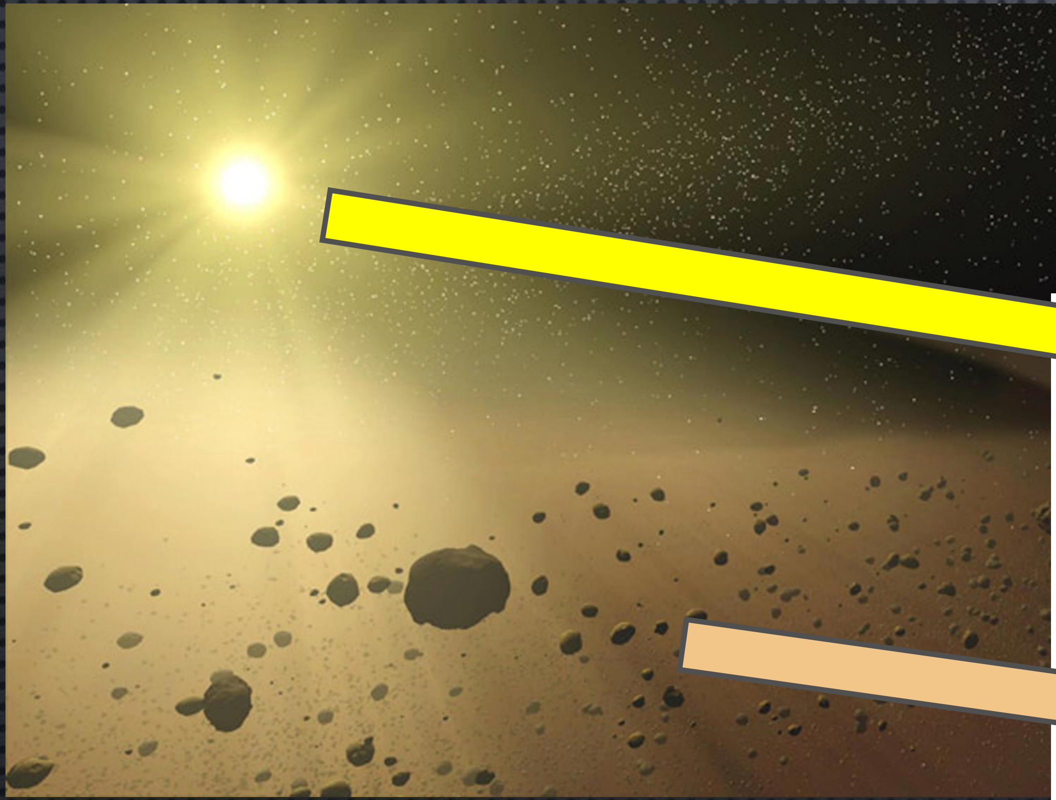
DR. JUAN SEBASTIÁN BRUZZONE[1]

[1]DEPARTAMENTO DE ASTRONOMÍA, FCIEN, UDELAR.

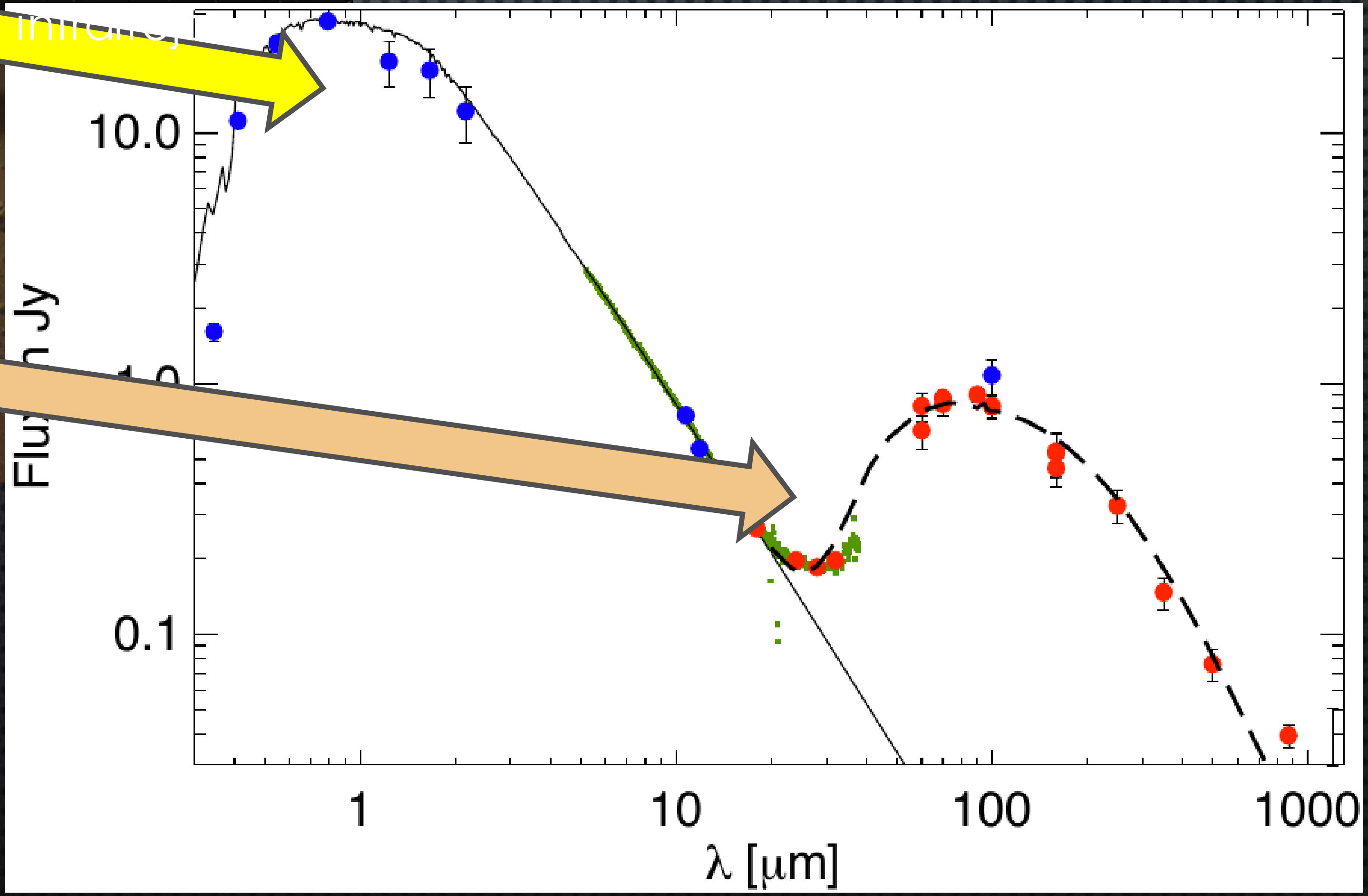


¿Cómo sabemos que existen sistemas planetarios en otras estrellas?
¿Cómo son los sistemas planetarios en otras estrellas y cómo se comparan con el Sistema Solar?
¿Podemos ver sistemas planetarios en formación?
¿Qué sabemos sobre los exoplanetas?
¿Podemos ver planetas en otras estrellas?
¿Sabemos de lunas en exoplanetas?

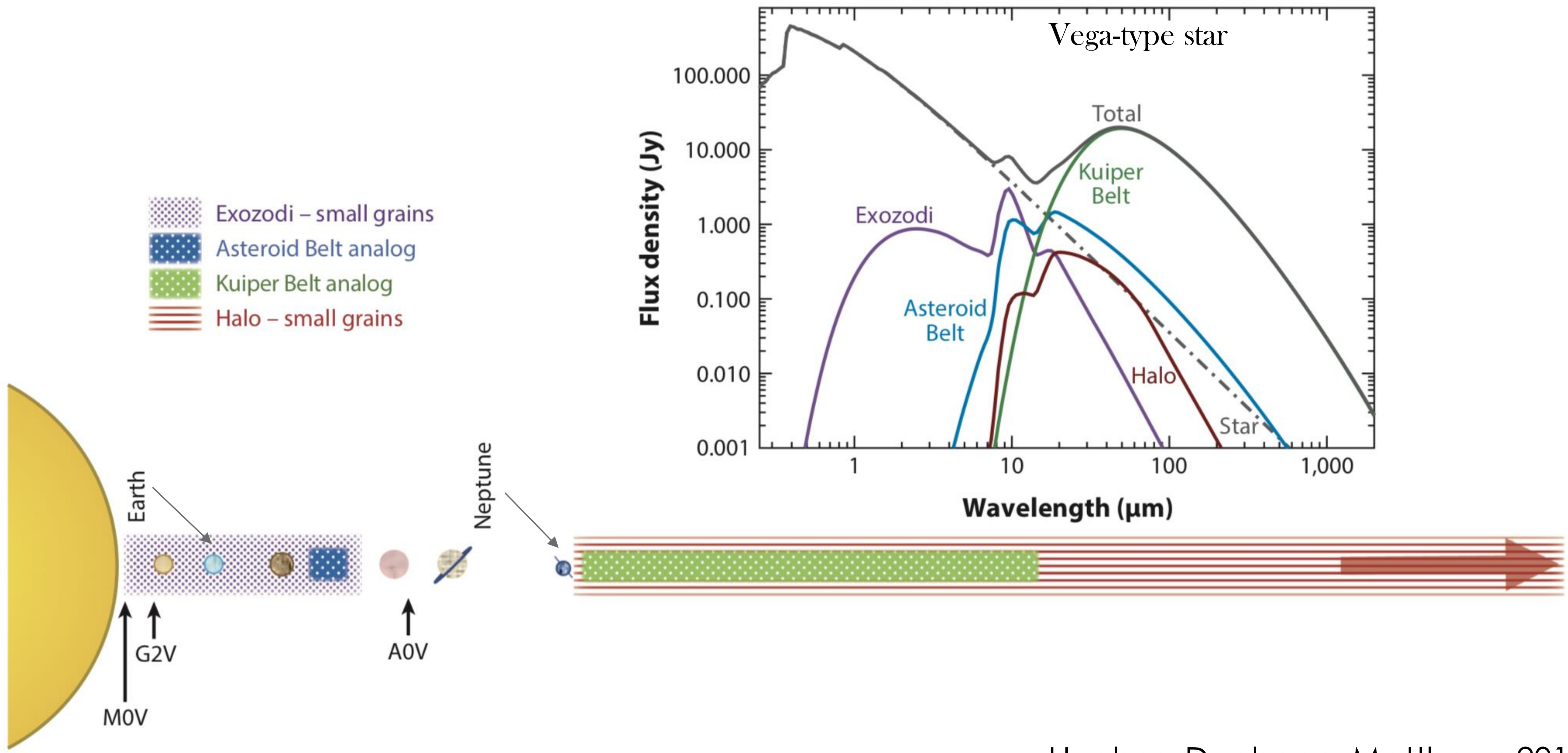
¿Cómo sabemos que existen sistemas planetarios en otras estrellas?



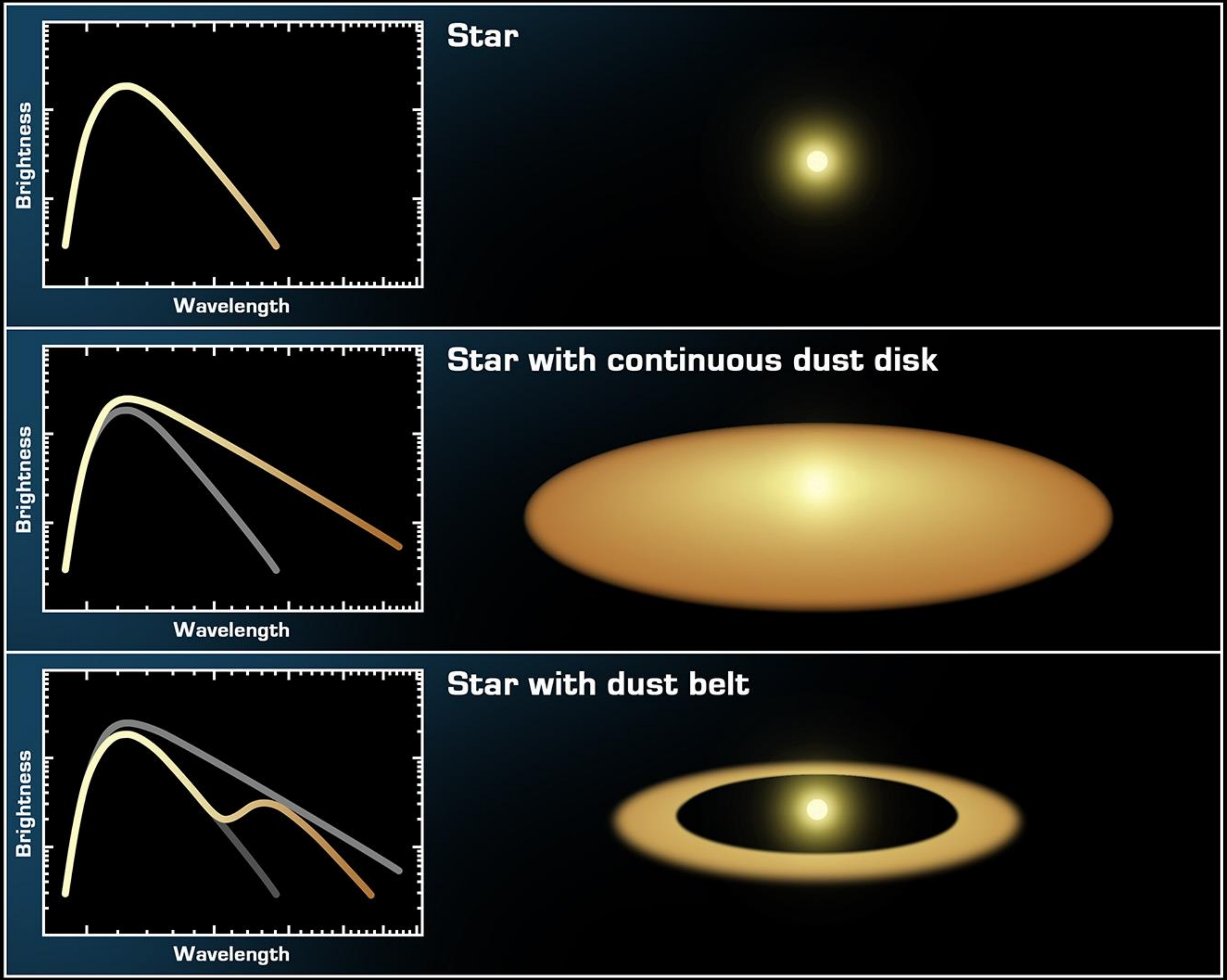
Más de 30 años atrás, astrónomos observaban que ciertas estrellas parecían emitir más luz en el infrarrojo que otras. Esperaban que existiera grandes cantidades de polvo que calentado por la estrella emitía ese exceso de luz infrarrojo



Era difícil poder obtener imágenes de otros sistemas planetarios. A principios de los años 80s se tenían imágenes de muy pocos sistemas. De todos modos con el tiempo crecían las observaciones como la de la derecha.

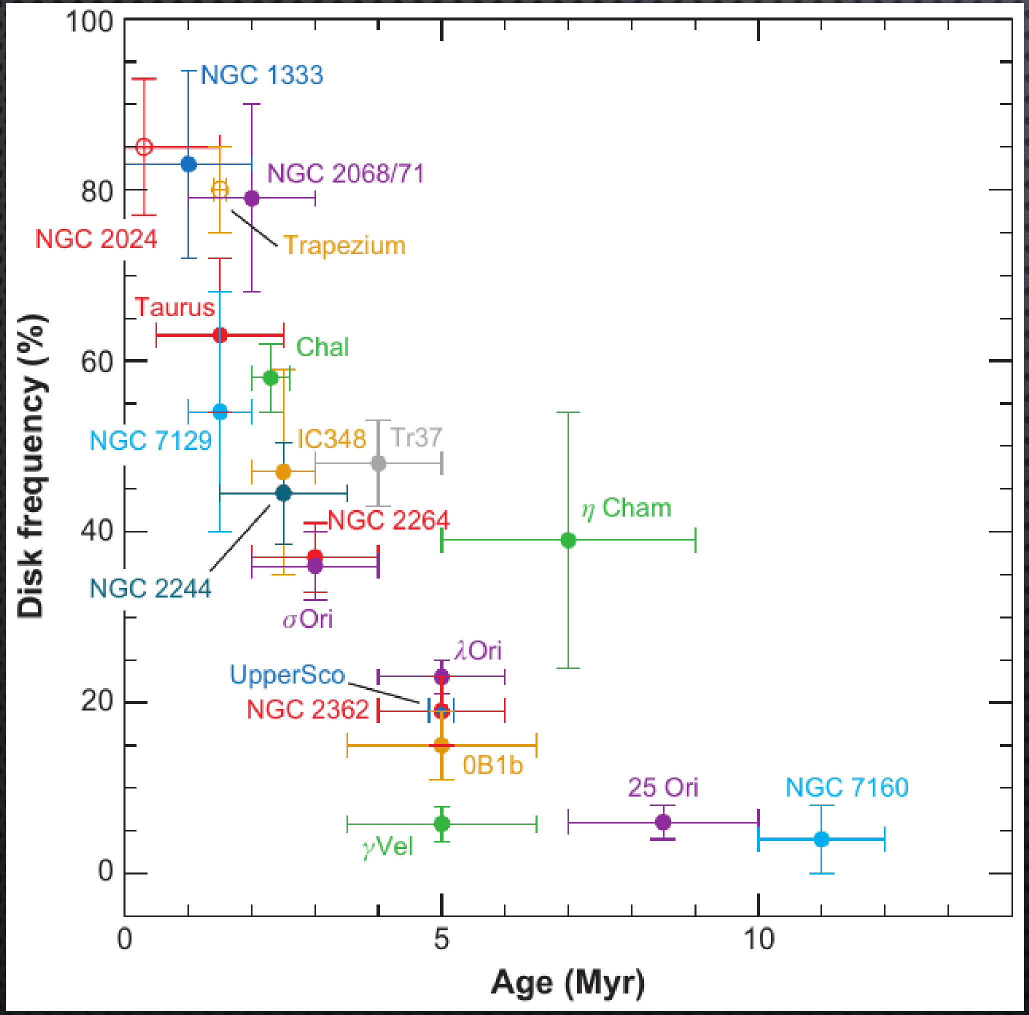


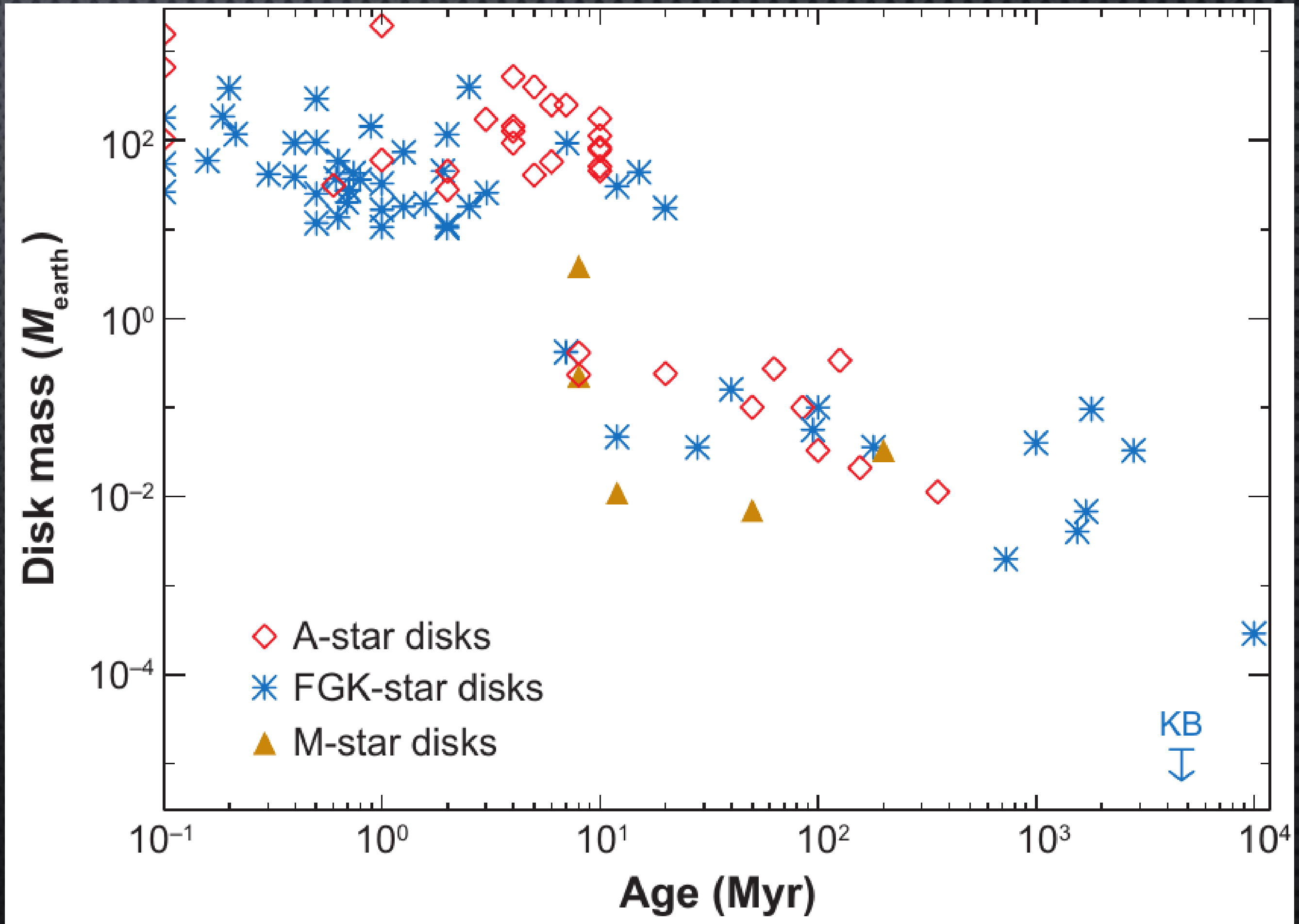
Hughes, Duchene, Matthews 2018.



NASA/JPL Caltech

SE DETECTAN MÁS DISCOS EN ESTRELLAS JÓVENES (EDAD < A 5 MILLONES DE AÑOS) LOS DISCOS DE MÁS DE 10 MILLONES DE AÑOS TIENEN 1% DE LA MASA.

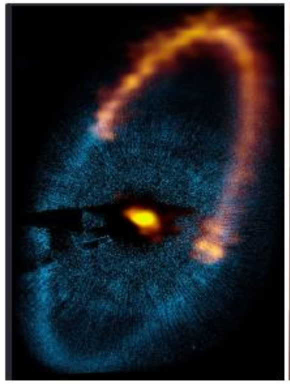


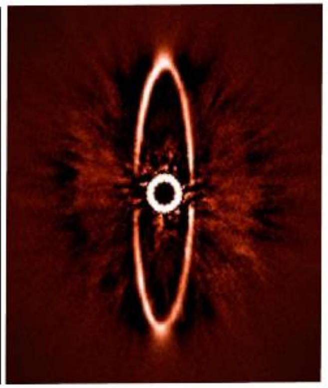


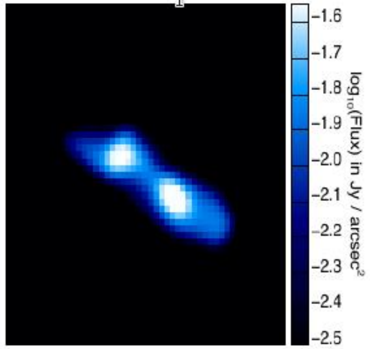
Los sistemas planetarios jóvenes que vemos directamente tienen tamaños similares, de ~100 UA.

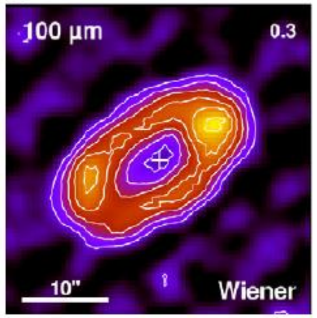
Table 1: Estimated blackbody disk radius r_{bb} versus observed radius r for a list of debris disks.

Star	Spectral Type	$L(L_\odot)$	T (K)	r_{bb} AU	Obs. r (AU)
Fomalhaut	A3	16.6	65	75	$\sim$ 140
HR 4796	A0	21	110	30	$\sim$ 70
HD 181327	F6	3.3	75	25	$\sim$ 90
q1 Eri	F8	1.6	60	27	$\sim$ 75
HD 15115	F2	3.1	65	32	$\sim$ 90
HD 207129	G2	1.3	50	35	$\sim$ 160





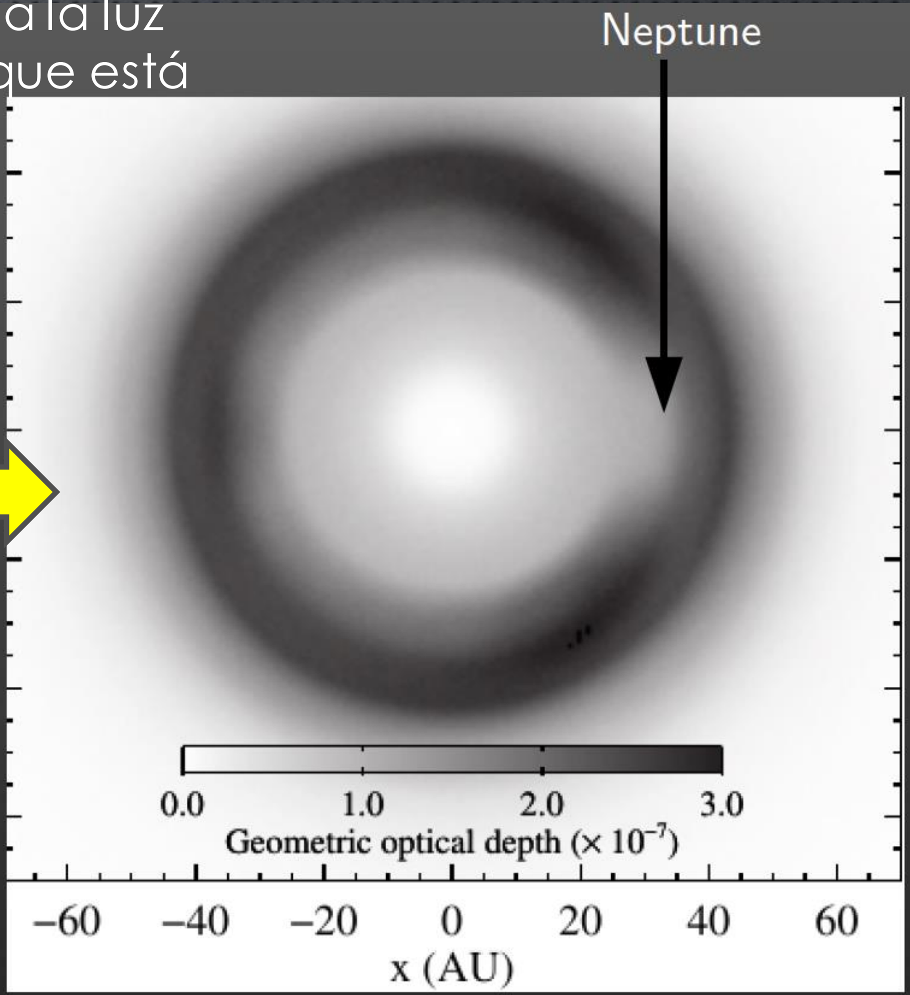




El polvo liberado por cometas y asteroides en el sistema solar está ppalmente cerca del plano común de los planetas. Ese polvo refleja la luz solar produciendo la Luz Zodiacal y también emite luz infrarroja ya que está siendo calentado por el Sol.

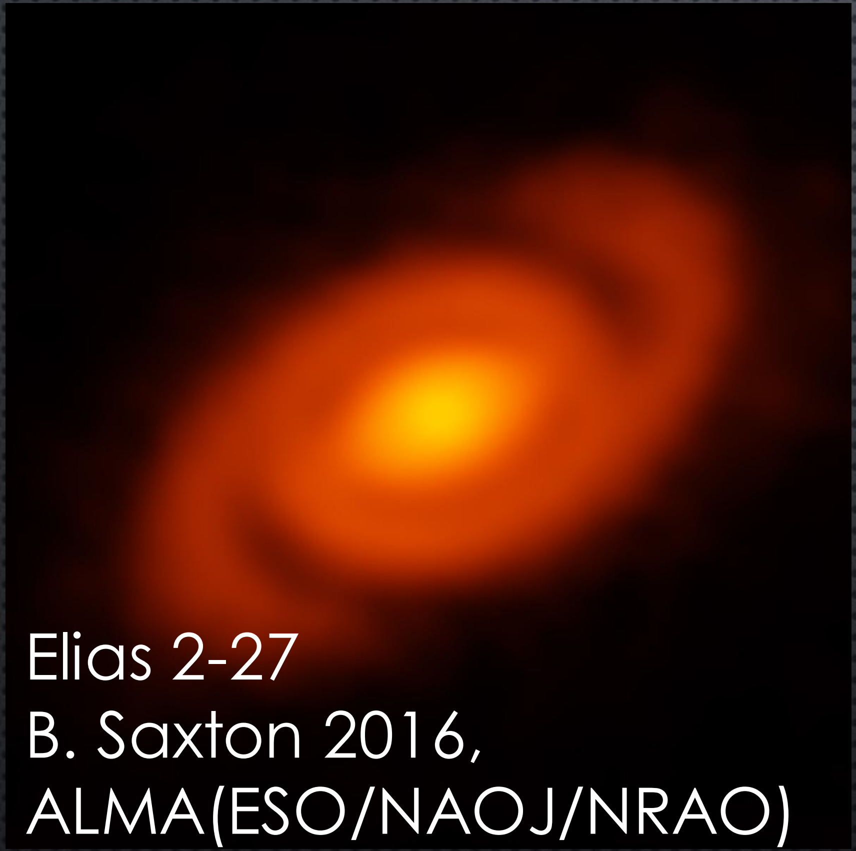
Civilizaciones lejanas que mirasen al Sol podrían detecta un exceso de luz emitido por el polvo tibio y sabrían que hay un sistema planetario.

Zodiacal light over Paranal, Chile. ESO/Beletsky

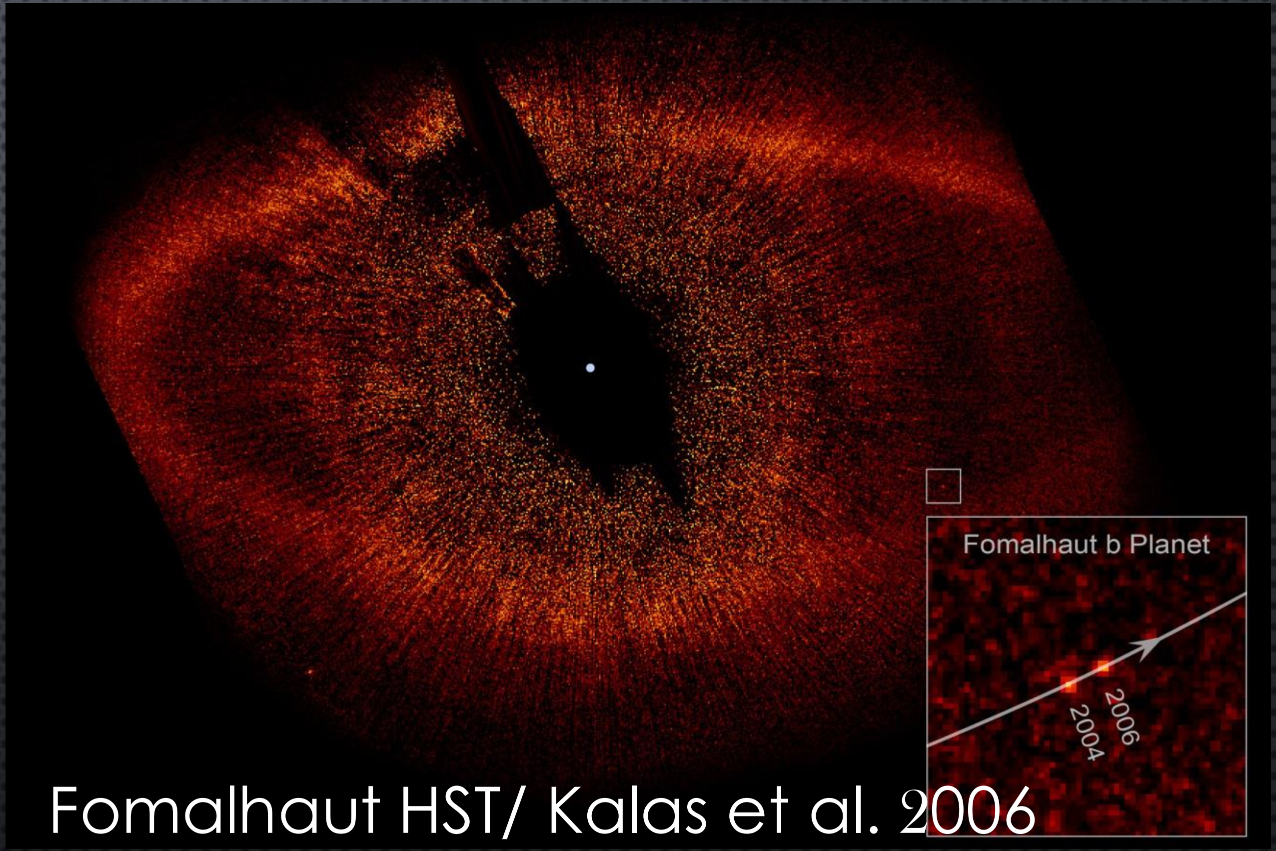


Solar System dust models at 60 microns.
Kuchner & Stark 2010.

PODEMOS VER IMÁGENES DE OTROS SISTEMAS PLANETARIOS!

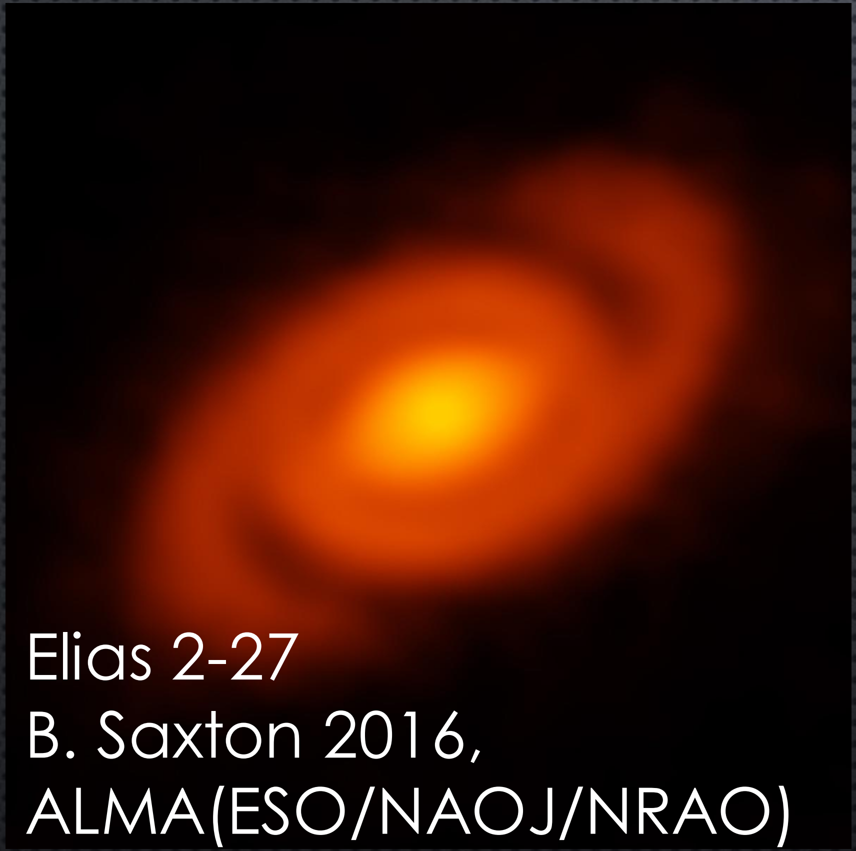


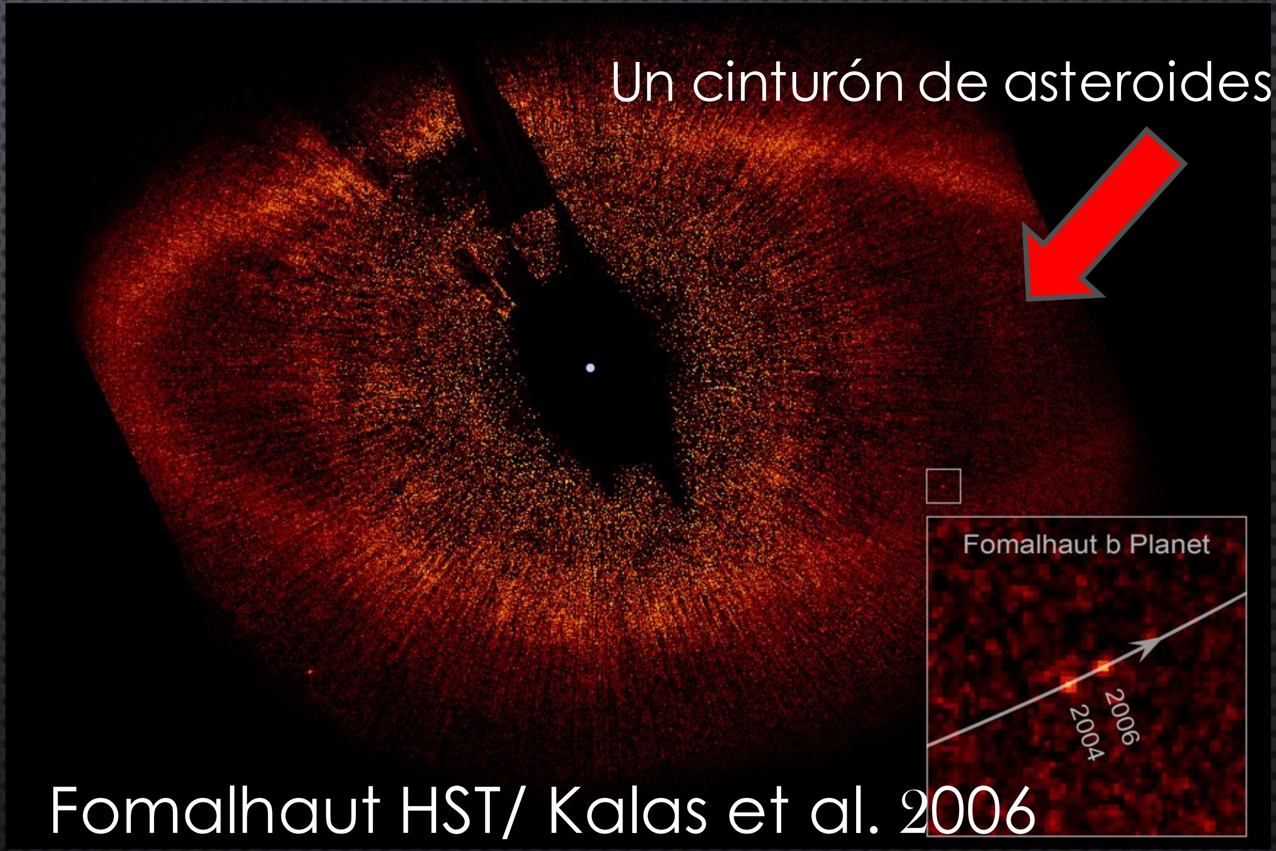
Disco protoplanetario
(<~10 Maños)



Disco escombros
(>~10M años-1G años)

PODEMOS VER IMÁGENES DE OTROS SISTEMAS PLANETARIOS!



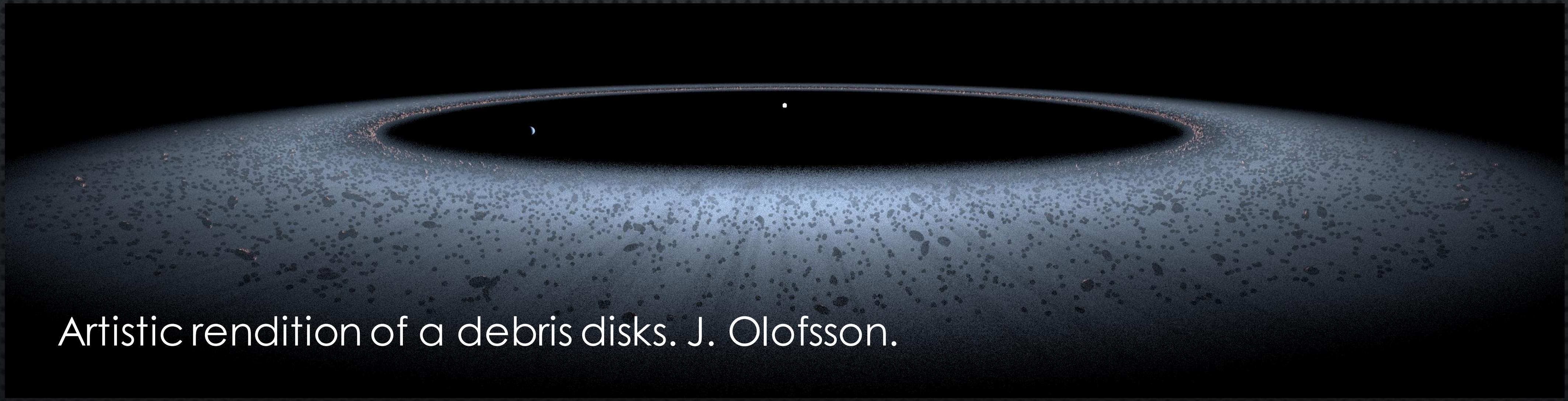


Disco protoplanetario
(<~10 Maños)

Disco escombros
(>~10M años-1G años)

¿Cinturones de asteroides en otras estrellas? Discos ricos en polvo, con muy poco gas

Fomalhaut disk in scattered light.
NASA/HST. Kalas et al 2008.



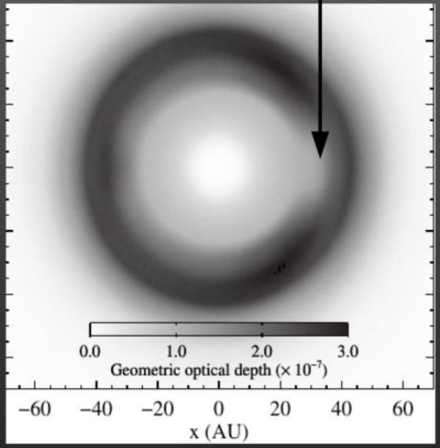
Artistic rendition of a debris disks. J. Olofsson.

¿Cinturones de asteroides en otras estrellas? Discos ricos en polvo, con muy poco gas

Fomalhaut disk in scattered light.
NASA/HST. Kalas et al 2008.

Recuerden el polvo en el sistema solar

Zodiacal light over Paranal, Chile. ESO/Beletsky



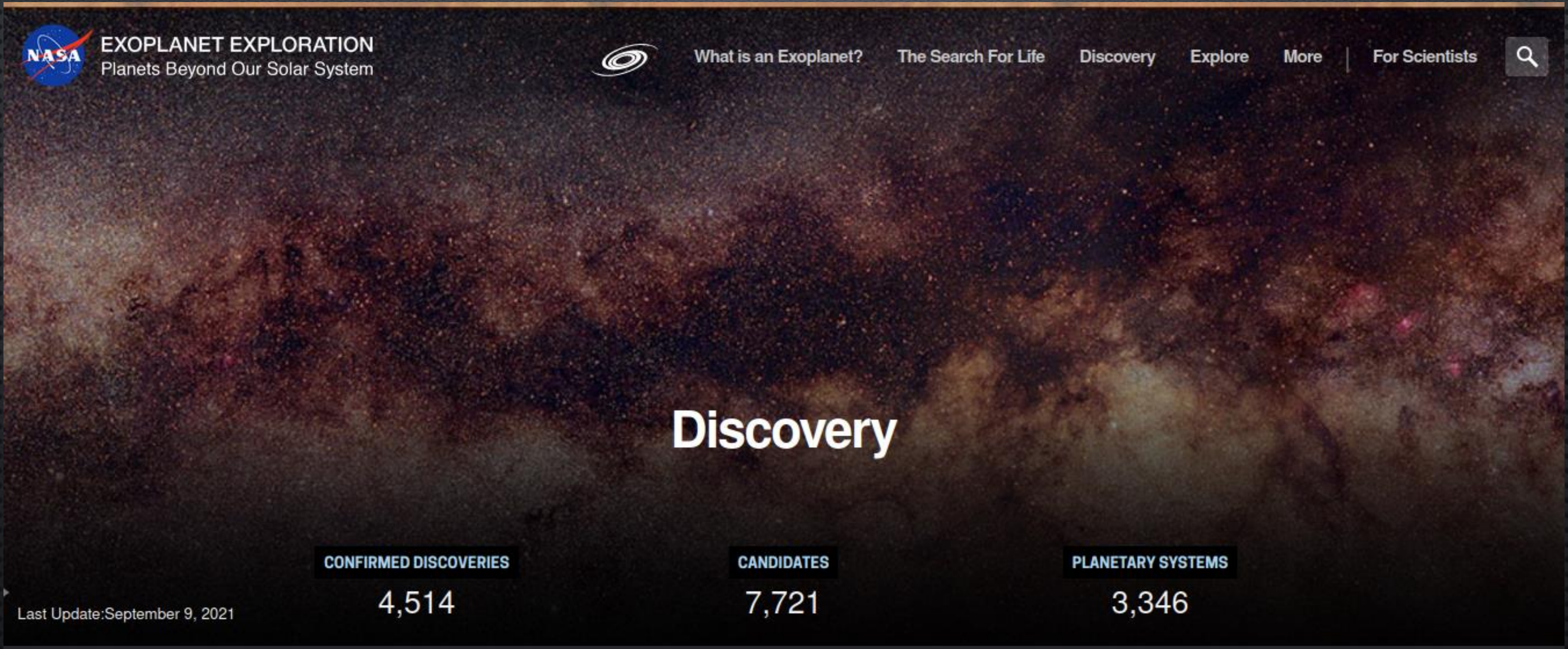
Solar System dust models at 60 microns. Kuchner & Stark 2010.

Artistic rendition of a debris disks. J. Olofsson.

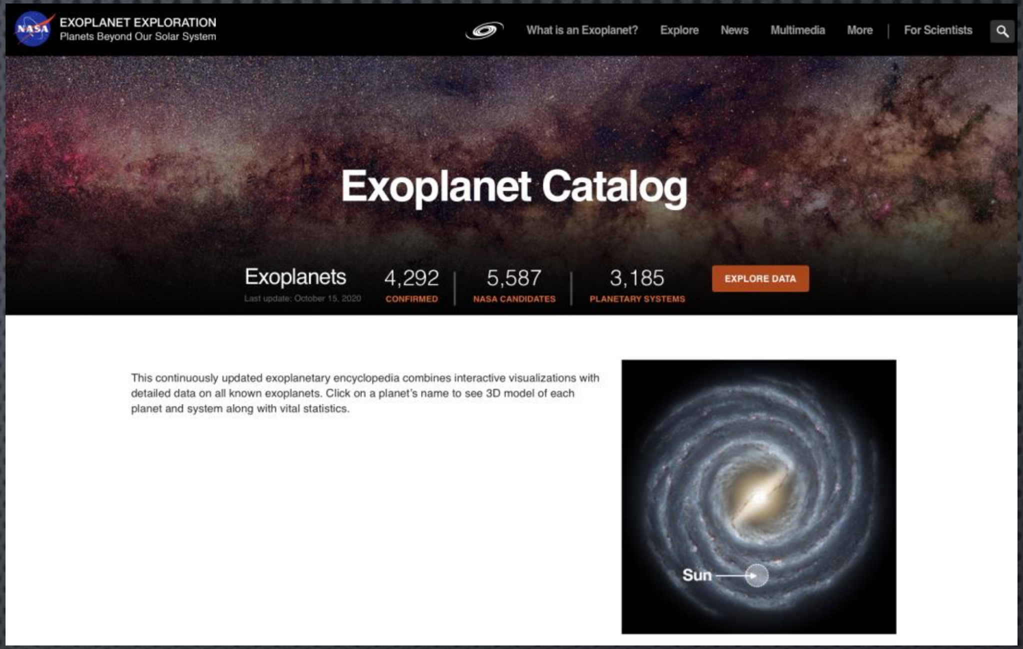
OBTENER IMÁGENES DE EXOPLANETAS Y CINTURONES DE ASTEROIDES Y COMETAS EN OTRAS ESTRELLAS ES MUY DIFÍCIL

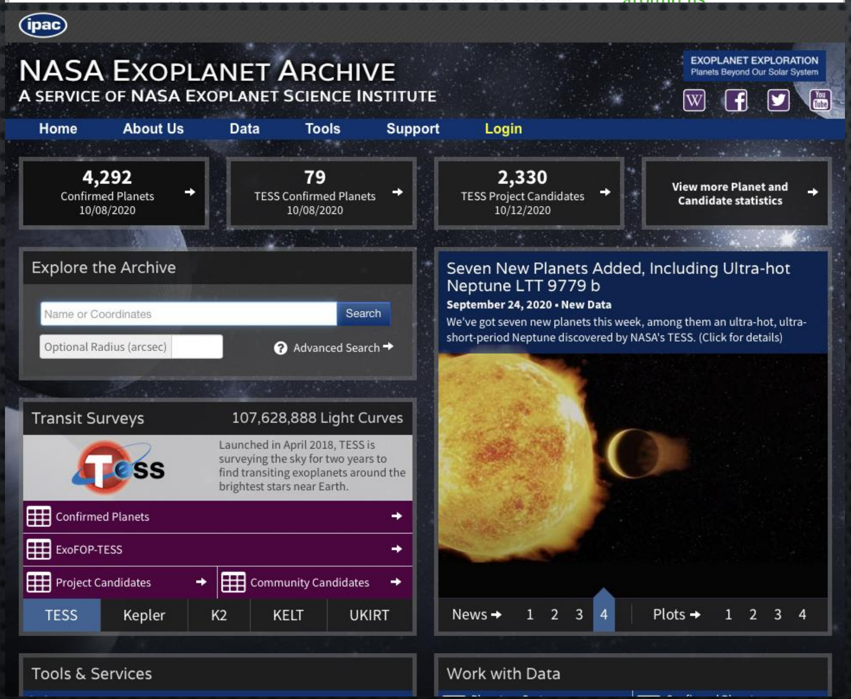
El desafío: detectar planetas y discos entorno a estrellas cercanas. Planetas y cinturones muy ténues comparados con sus estrellas. Más sobre esto pronto.

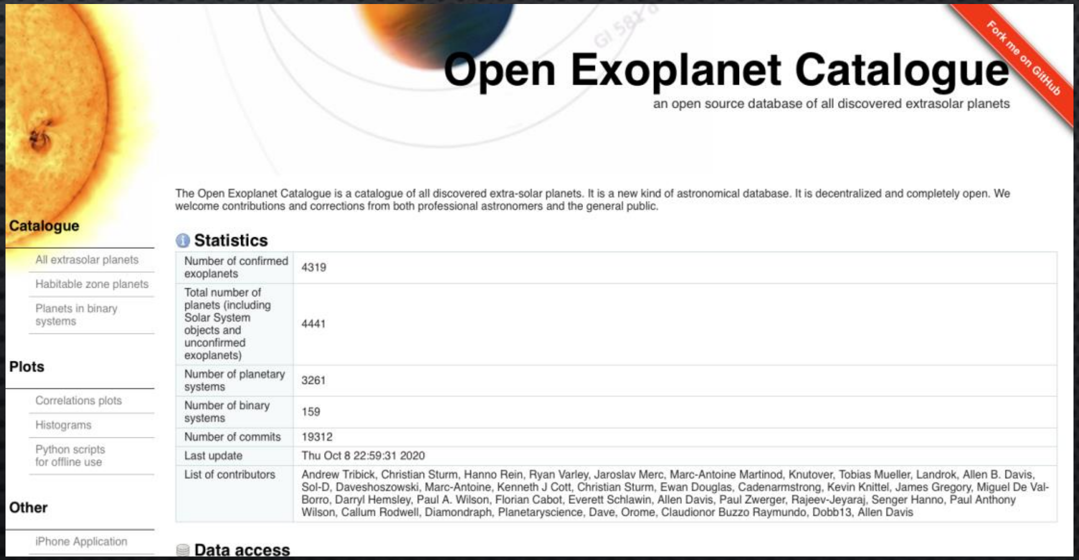
3346 Sistemas Planetarios y 4514 planetas confirmados. Hay 7721 candidatos para confirmar.



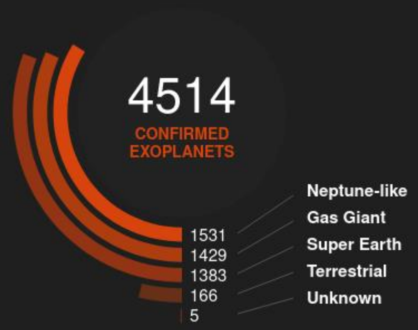
CATÁLOGOS DE LIBRE ACCESO EN LA WEB:







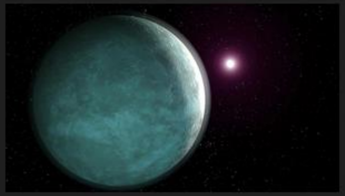
Planet Types



This chart tracks the current number of known planet discoveries beyond our solar system, sorted by type. Confirmed exoplanets have been validated by multiple ob
discoveries

Un planeta por cada estrella en la galaxia!

New Discovery

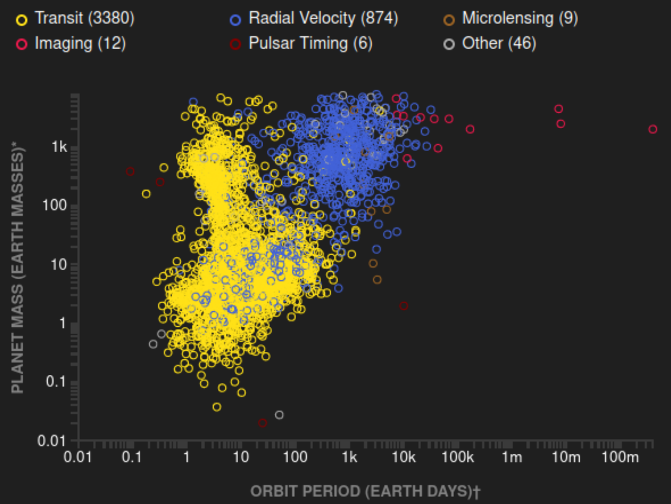


PLANET NAME	PLANET TYPE
KMT-2018-BLG-1025L b	Neptune-like
DISCOVERY DATE	DETECTION METHOD
2021	Microlensing

› More about this planet

Exoplanet Census

For planets with both measured or estimated orbital period and mass



YEAR **2021** | DISCOVERIES‡ **4514**

1989 — 2021

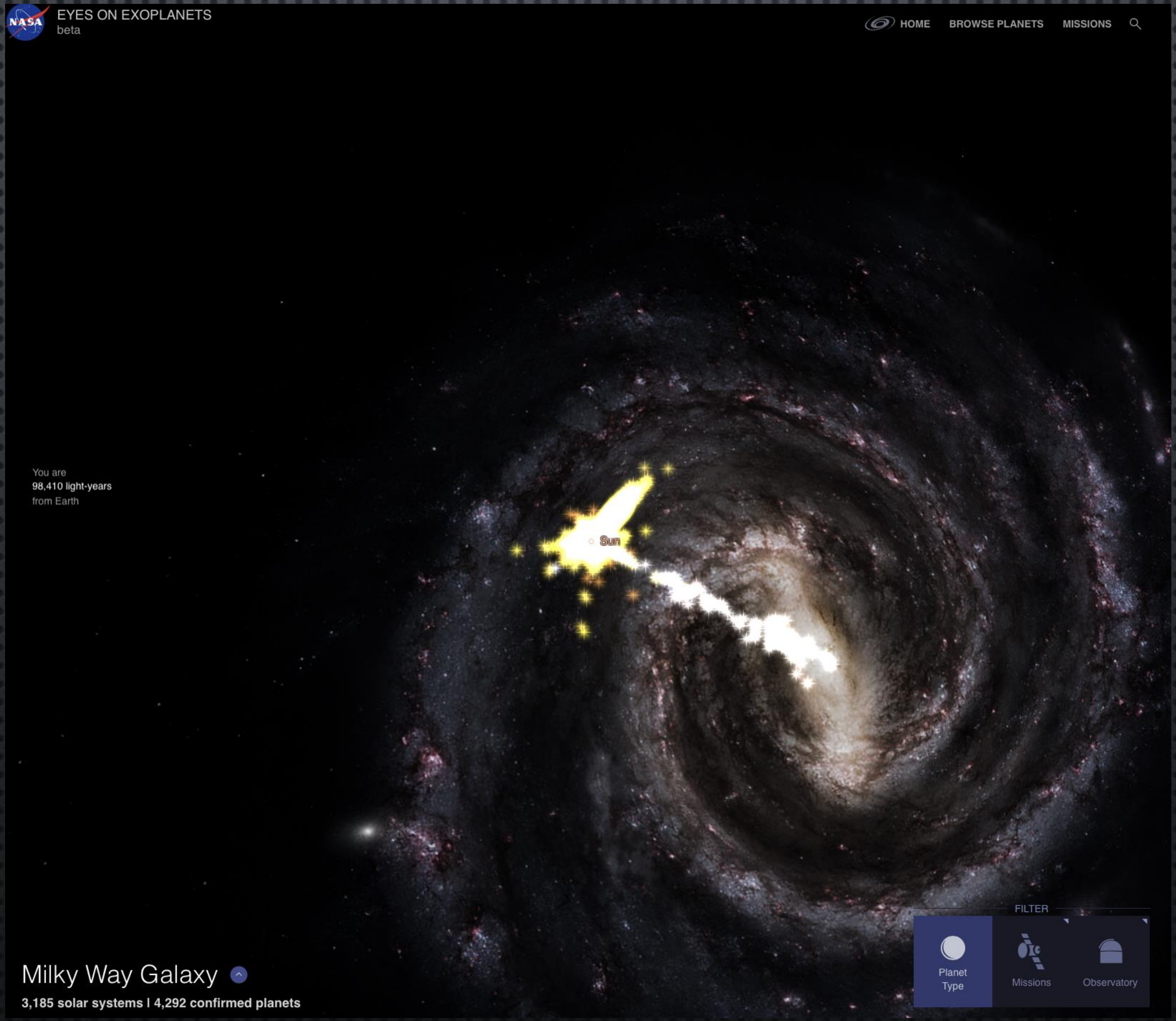
By Method

75.5%	Transit	⌄
19.4%	Radial Velocity	⌄
2.5%	Microlensing	⌄
1.2%	Imaging	⌄

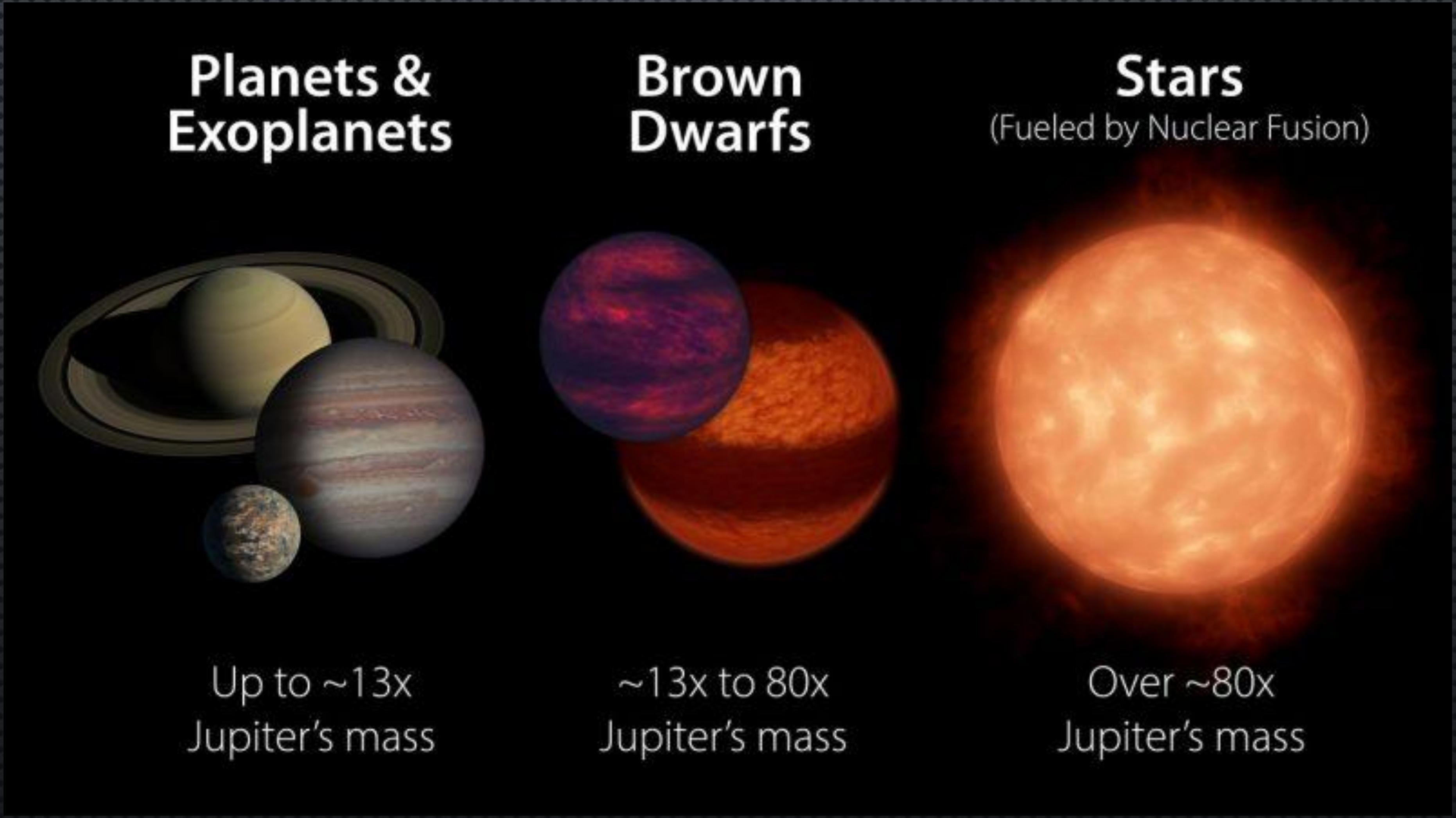
0.49% Transit Timing Variations, 0.35% Eclipse Timing Variations, 0.2% Orbital Brightness Modulation, 0.16% Pulsar Timing, 0.04% Pulsation Timing Variations, 0.02% Disk Kinematics, 0.02% Astrometry

› More about planet-hunting methods

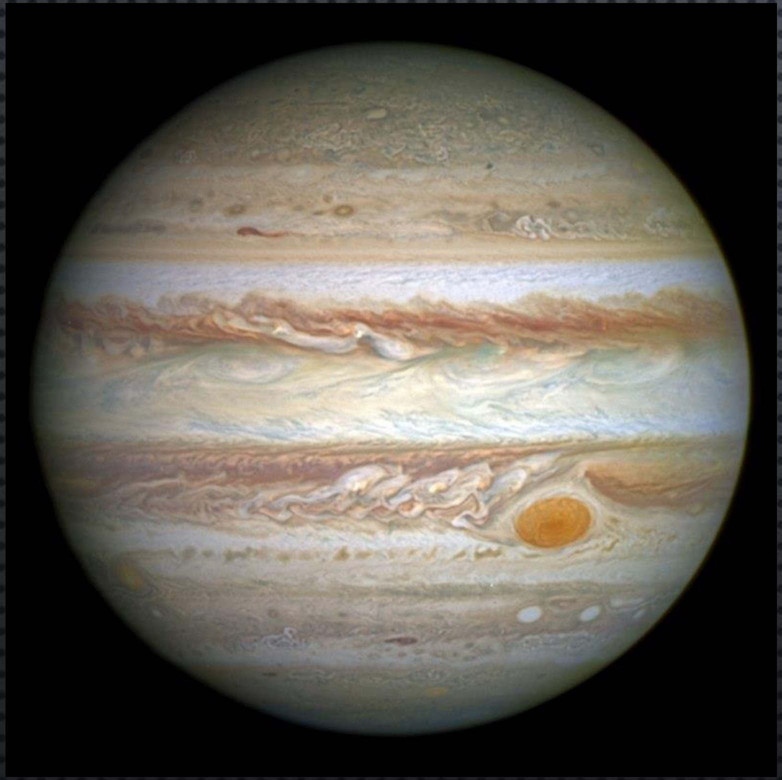
https://exoplanets.nasa.gov/eyes-on-exoplanets/#/



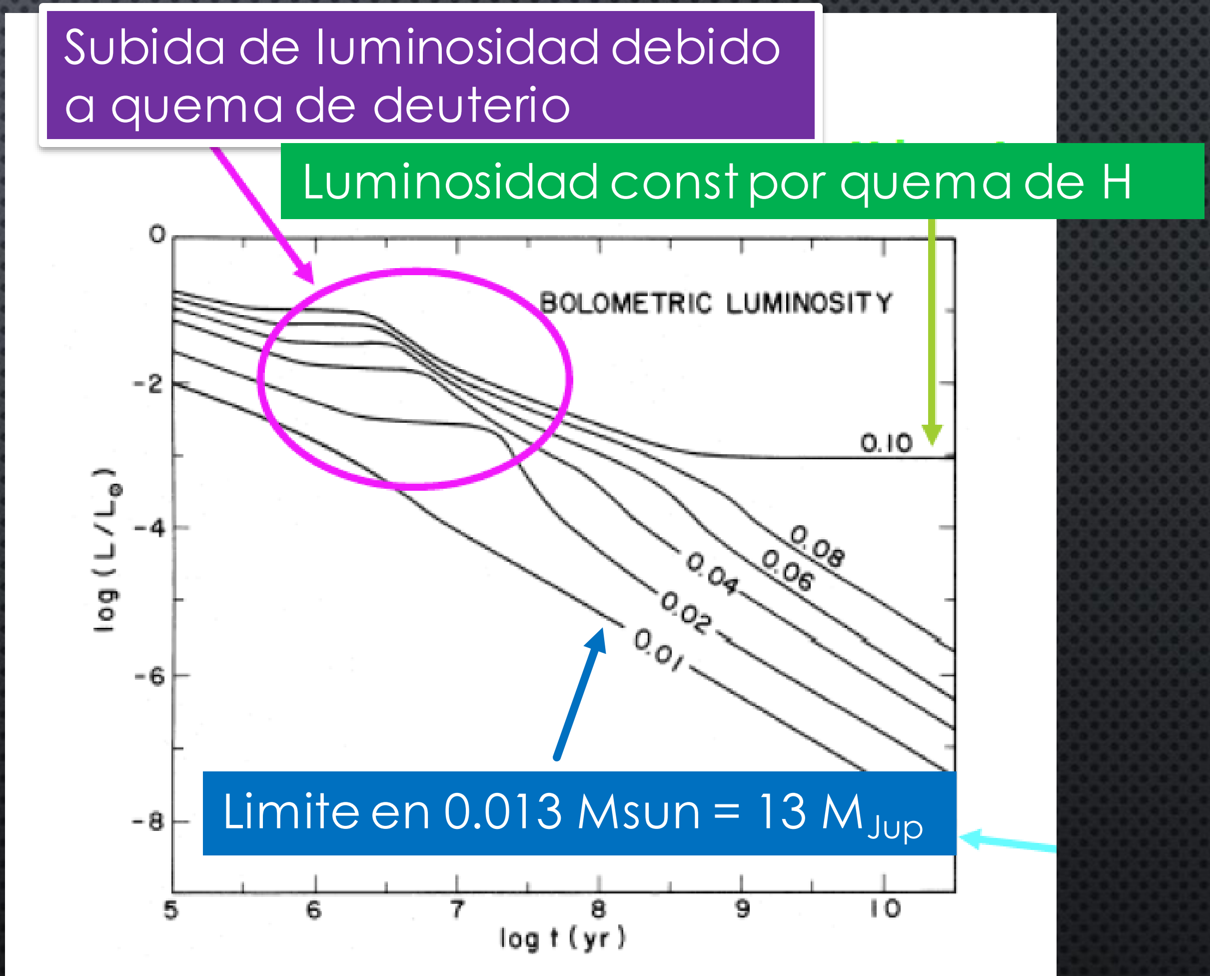
MASAS DE PLANETAS HASTA 13x MASA DE JÚPITER



PLANETA: NUNCA LLEGA A QUEMAR DEUTERIO

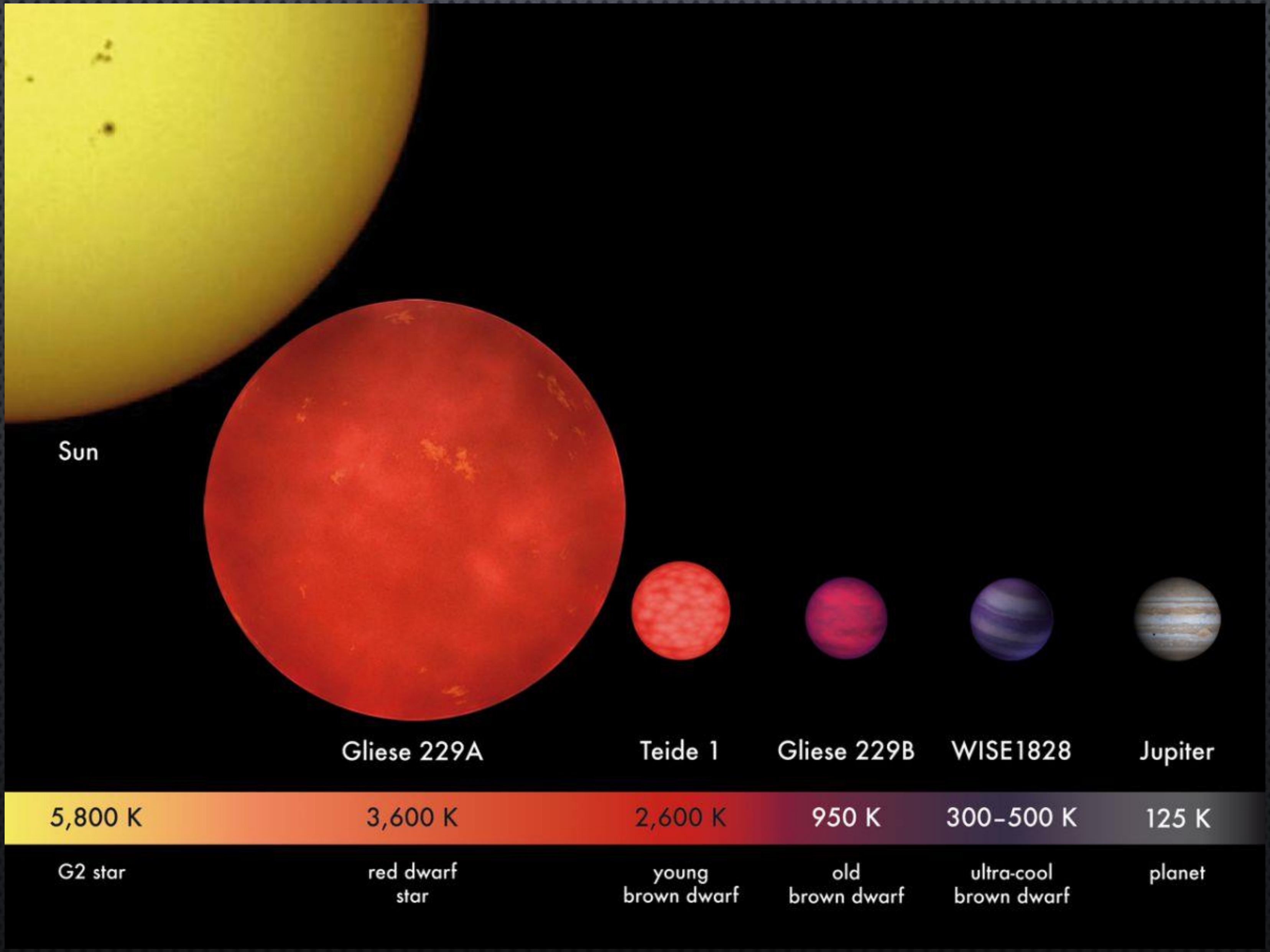


$M_{Jup} = 0.001\ M_{Sun}$

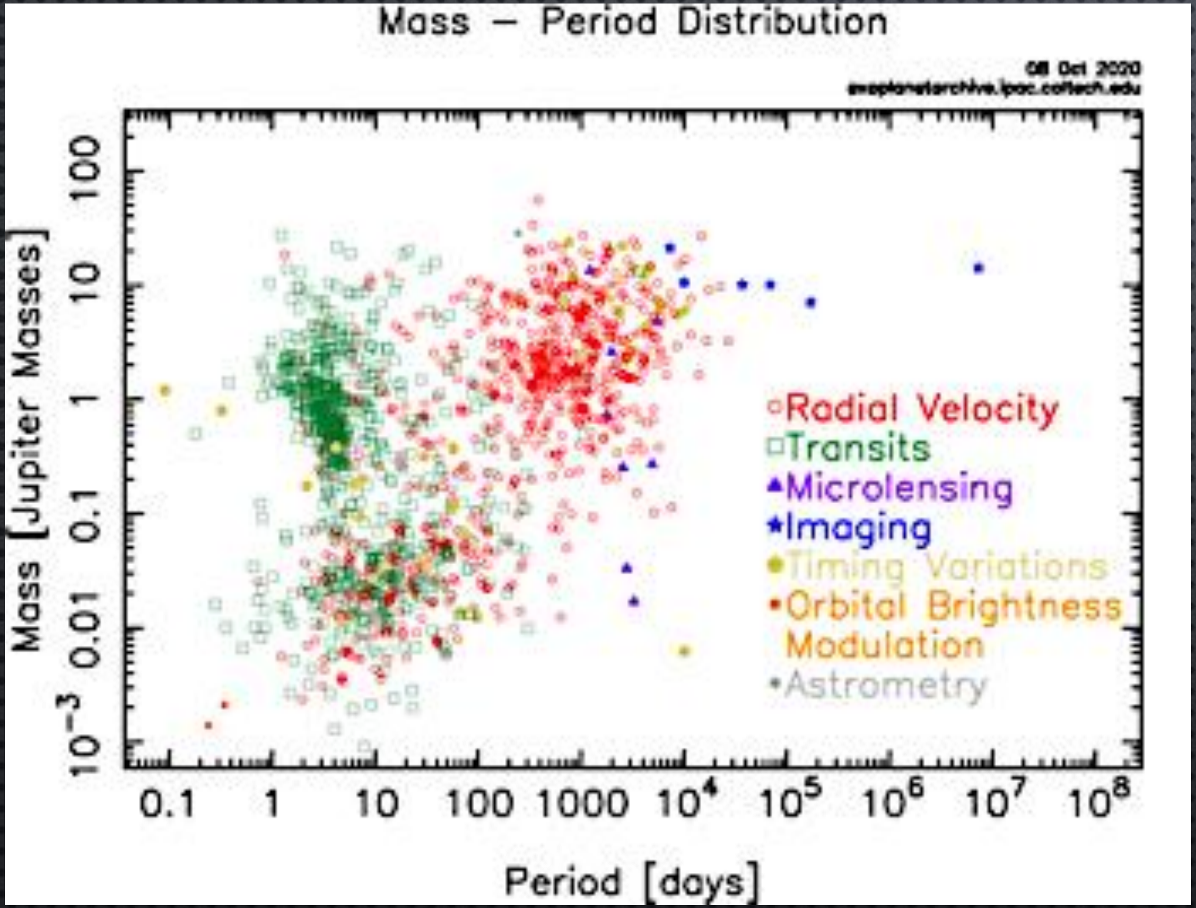


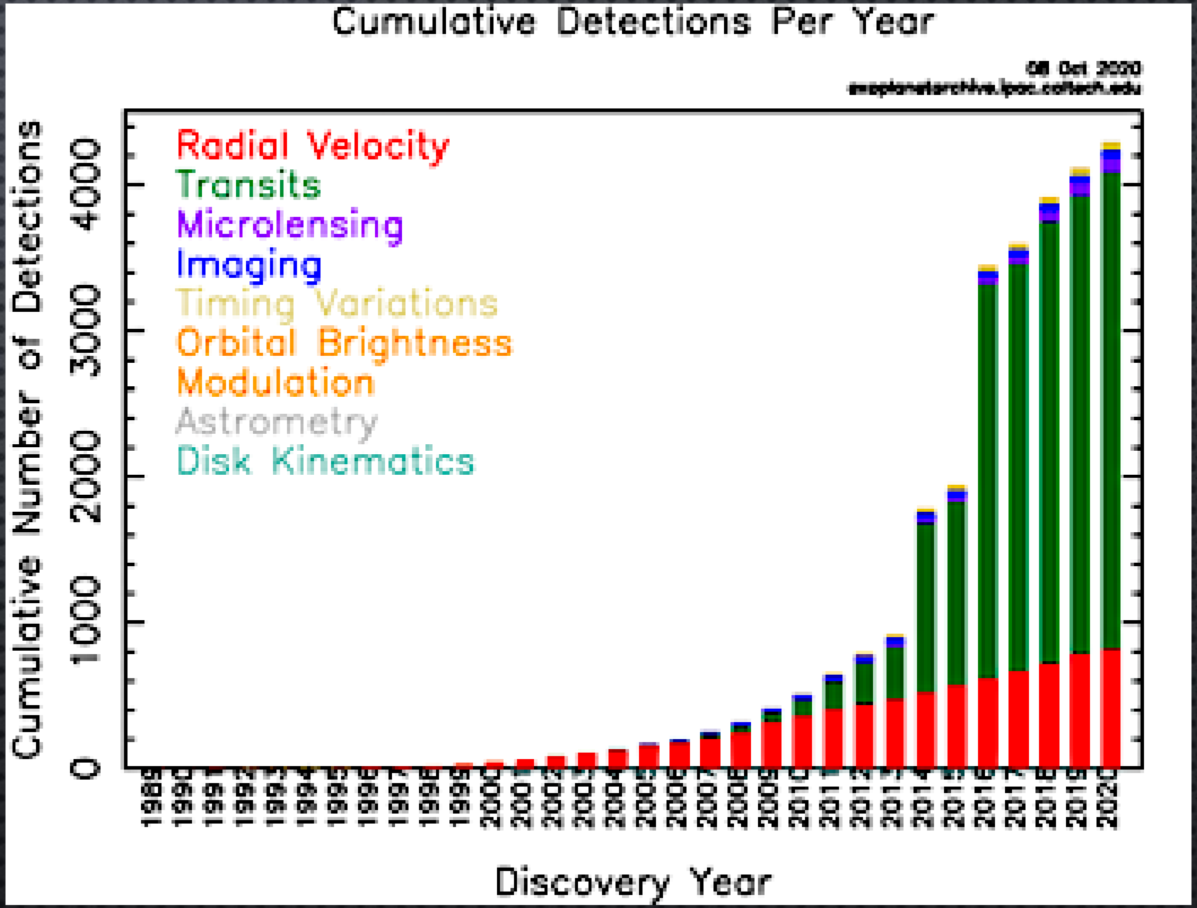
Nelson et al., 1986, AJ, 311, 226

ENANAS MARRONES CON TAMAÑOS COMO JÚPITER



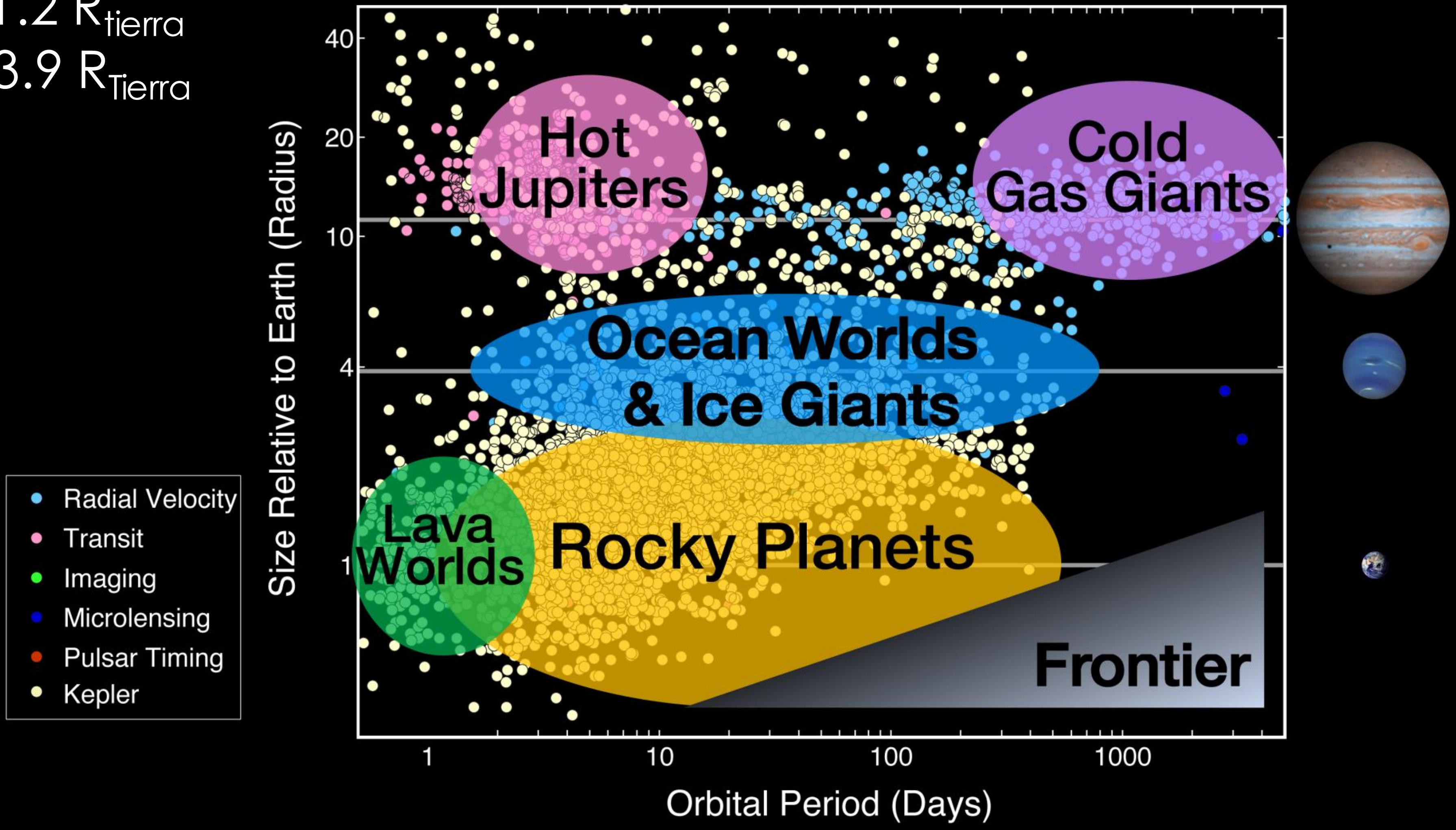
DISTRIBUCIÓN DE EXOPLANETAS DETECTADOS Y NÚMERO DE DESCUBRIMIENTOS POR TÉCNICA





Exoplanet Populations

$R_{jup} = 11.2\ R_{tierra}$
$R_{Nep} = 3.9\ R_{Tierra}$



CONTEO AL 07-04-2021

Summary Counts

All Exoplanets	4375
Confirmed Planets Discovered by Kepler	2394
Kepler Project Candidates Yet To Be Confirmed	2366
Confirmed Planets Discovered by K2	426
K2 Candidates Yet To Be Confirmed	889
Confirmed Planets Discovered by TESS [1]	122
TESS Project Candidates Integrated into Archive (2021-04-03 13:00:01) [2]	2601
Current date TESS Project Candidates at ExoFOP	2614
TESS Project Candidates Yet To Be Confirmed [3]	1436

[1] *Confirmed Planets Discovered by TESS* refers to the number planets that have been published in the refereed astronomical literature.

[2] *TESS Project Candidates* refers to the total number of transit-like events that appear to be astrophysical in origin, including false positives as identified by the TESS Project.

[3] *TESS Project Candidates Yet To Be Confirmed* refers to the number of TESS Project Candidates that have not yet been dispositioned as a Confirmed Planet or False Positive.

Confirmed Exoplanet Statistics

Discovery Method	Number of Planets
Astrometry	1
Imaging	51
Radial Velocity	837
Transit	3325
Transit timing variations	21
Eclipse timing variations	16
Microlensing	108
Pulsar timing variations	7
Pulsation timing variations	2
Orbital brightness modulations	6
Disk Kinematics	1

Transiting Exoplanets	**3354**
All Exoplanets	**4375**

Exoplanet Mass and Radius

Confirmed Planets with mass	1042
Confirmed Planets with m sin i	854
Confirmed Planets with radius	3352

Kepler Mission Counts

Confirmed Planets Discovered by Kepler [2]	2394
Candidates and Confirmed in Habitable Zone [1, 3] (180 K < Equilibrium (T) < 310 K) or (0.25 < Insolation (Earth flux) < 2.2)	361
Kepler Project Candidates [3]	4717
Kepler Project Candidates Yet To Be Confirmed	2366
Total Candidates and Confirmed Planets [4]	**4780**

[1] This is the number of planets in the Kepler Field where the stellar host was observed by the Kepler Spacecraft. Not all of these planets were detected or discovered by Kepler.

[2] This is the number of planets that were discovered utilizing Kepler observations.

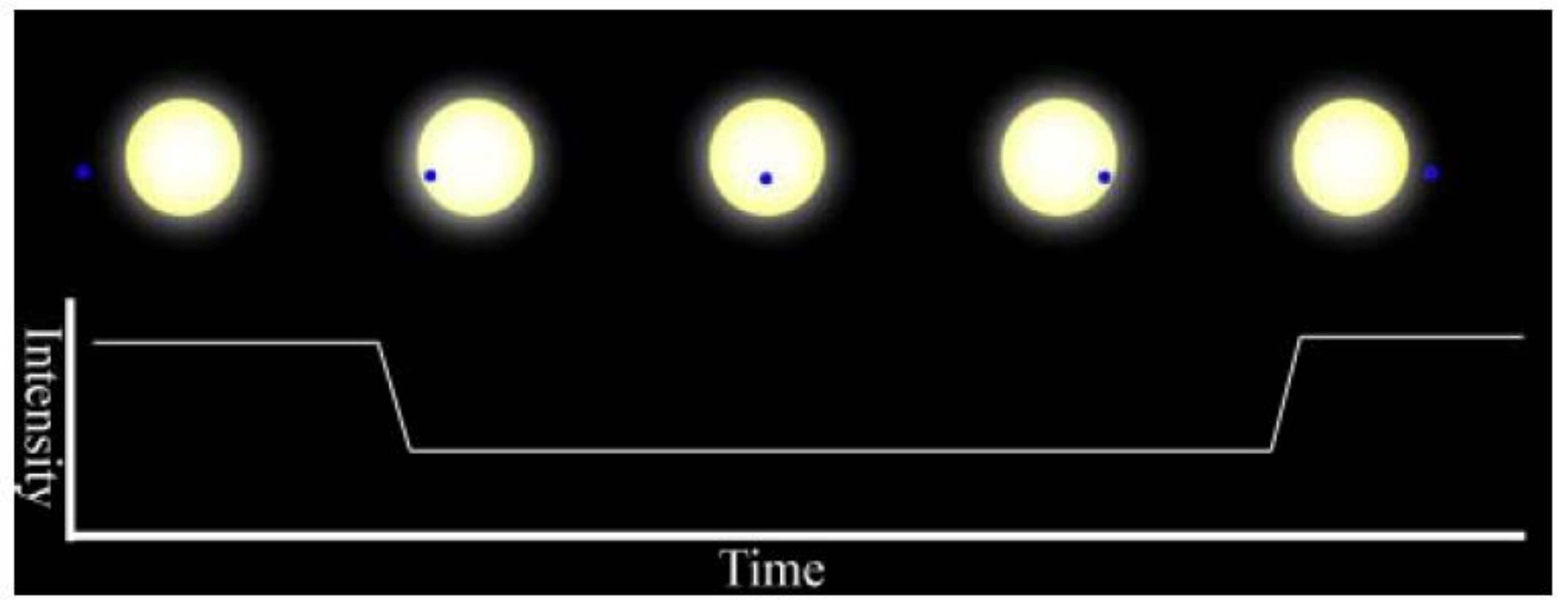
[3] Kepler Project Candidates are all KOIs marked by the Kepler Project as a CANDIDATE in the KOI Cumulative table. This includes planets that have been confirmed or validated.

[4] Total Candidates and Confirmed Planets is the union of the Confirmed Planets and KOI Cumulative data sets. Note that some confirmed planets were never designated as candidates.

Exoplanets:
Cumulative Detections by Discovery Year

1989-2018

TRÁNSITOS(TR)

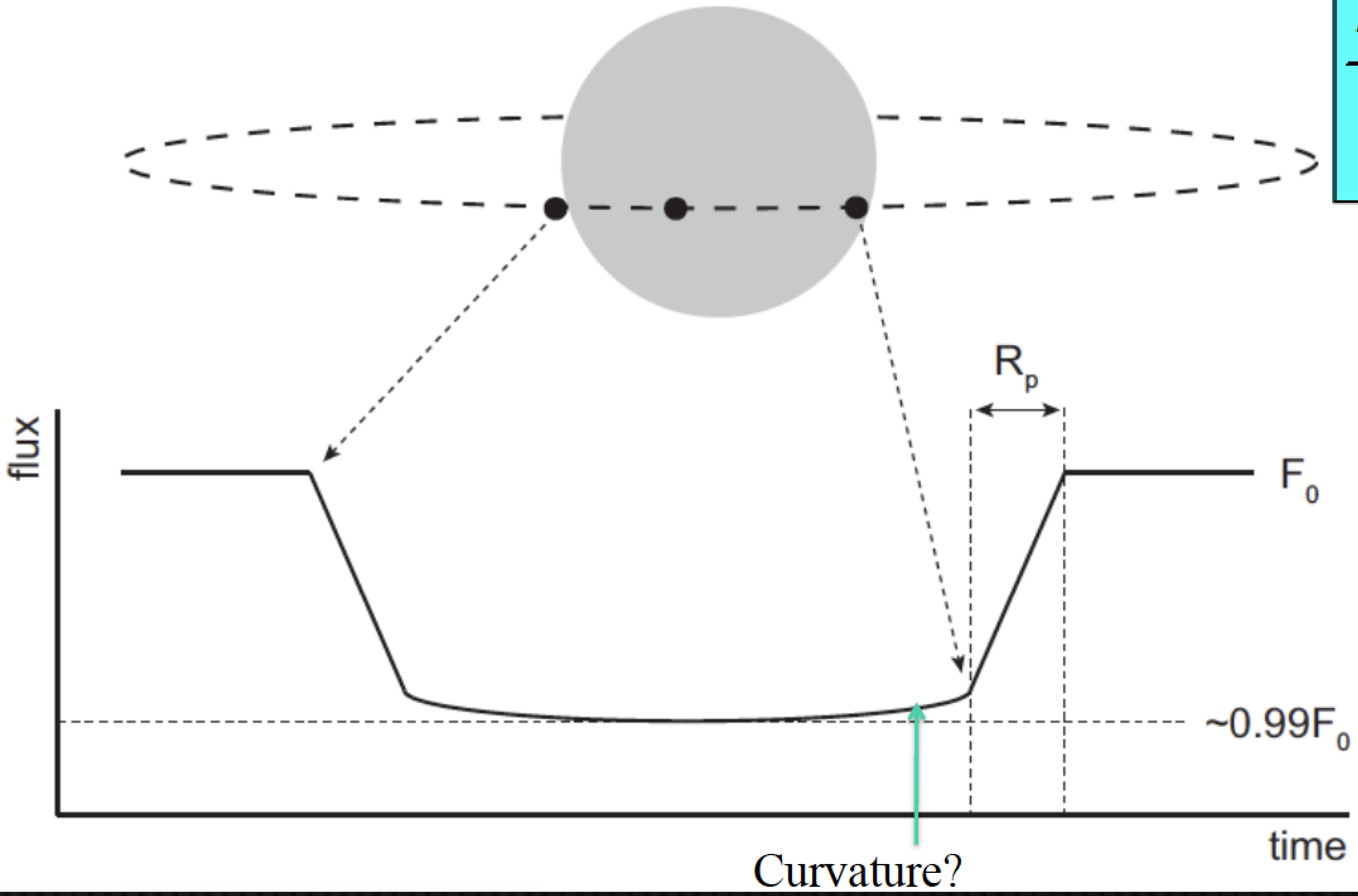


Planeta(s) transita disminuyendo el brillo de la estrella. Notar que el planeta no es visible, solo se mide el cambio del brillo de la estrella.

Instrumentos notables: KEPLER, TESS, KELT, SuperWASP

TRÁNSITOS(TR)

A Jupiter transit across the Sun is ~1%:

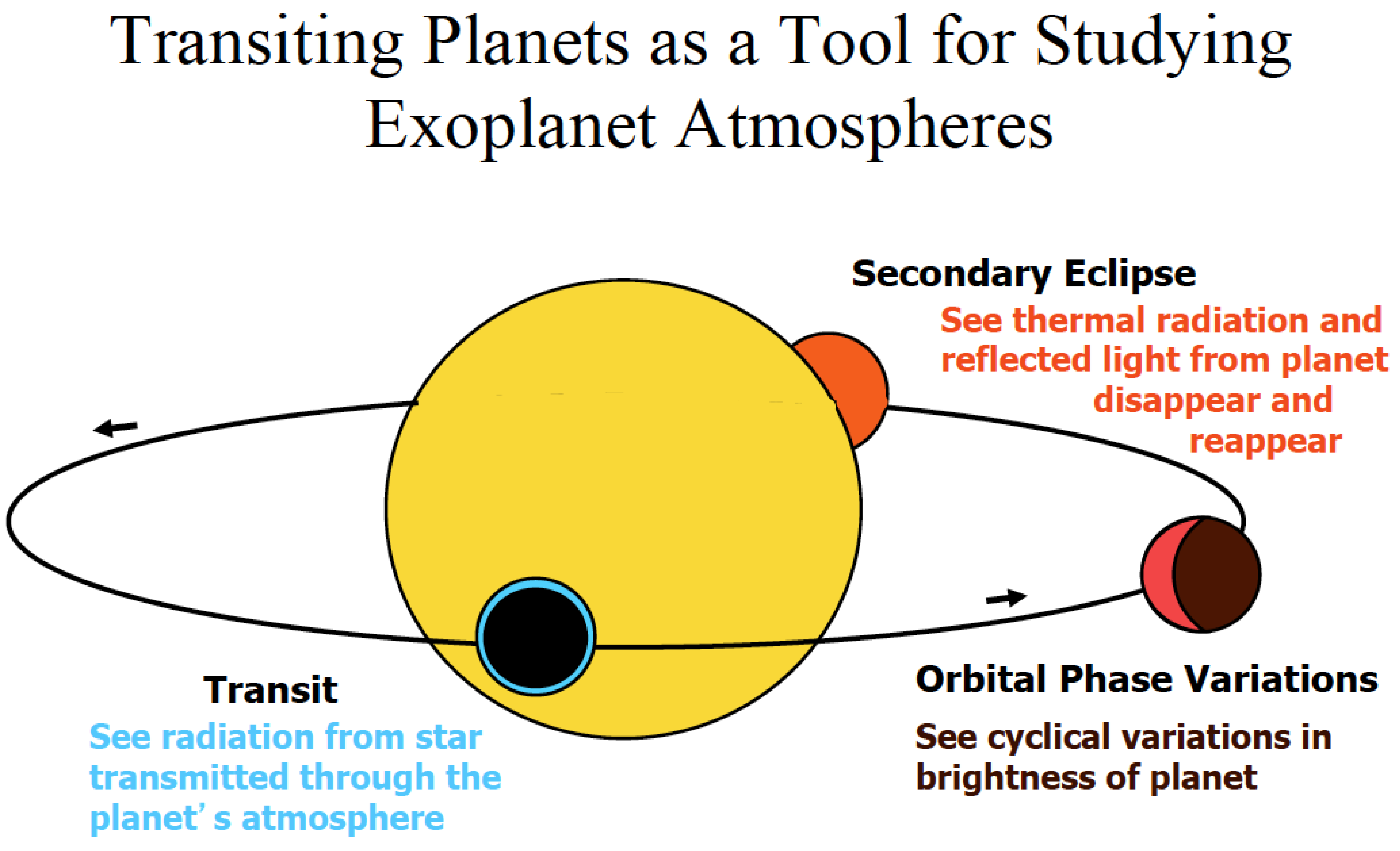


$$\frac{\Delta f}{f_*} = \frac{\pi R_p^{\,2}}{\pi R_*^{\,2}} = \left(\frac{R_p}{R_*}\right)^2$$

Se puede demostrar que la probabilidad de observar un tránsito es proporcional a: $d/2a$

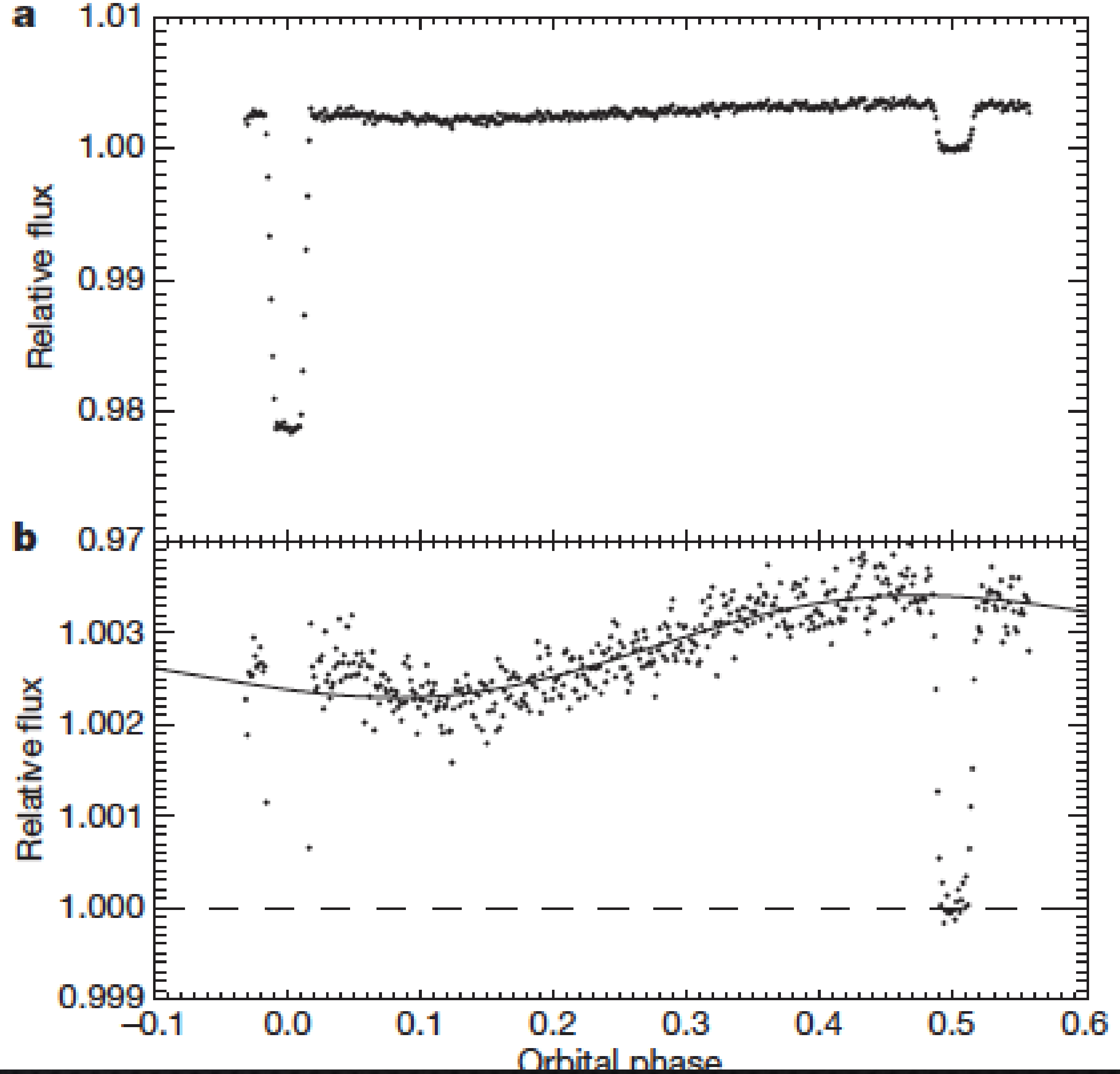
Dada la baja probabilidad se obsevan muchas estrellas simultaneamente

ESPECTROSCOPÍA DE TRÁNSITOS(TRSP)

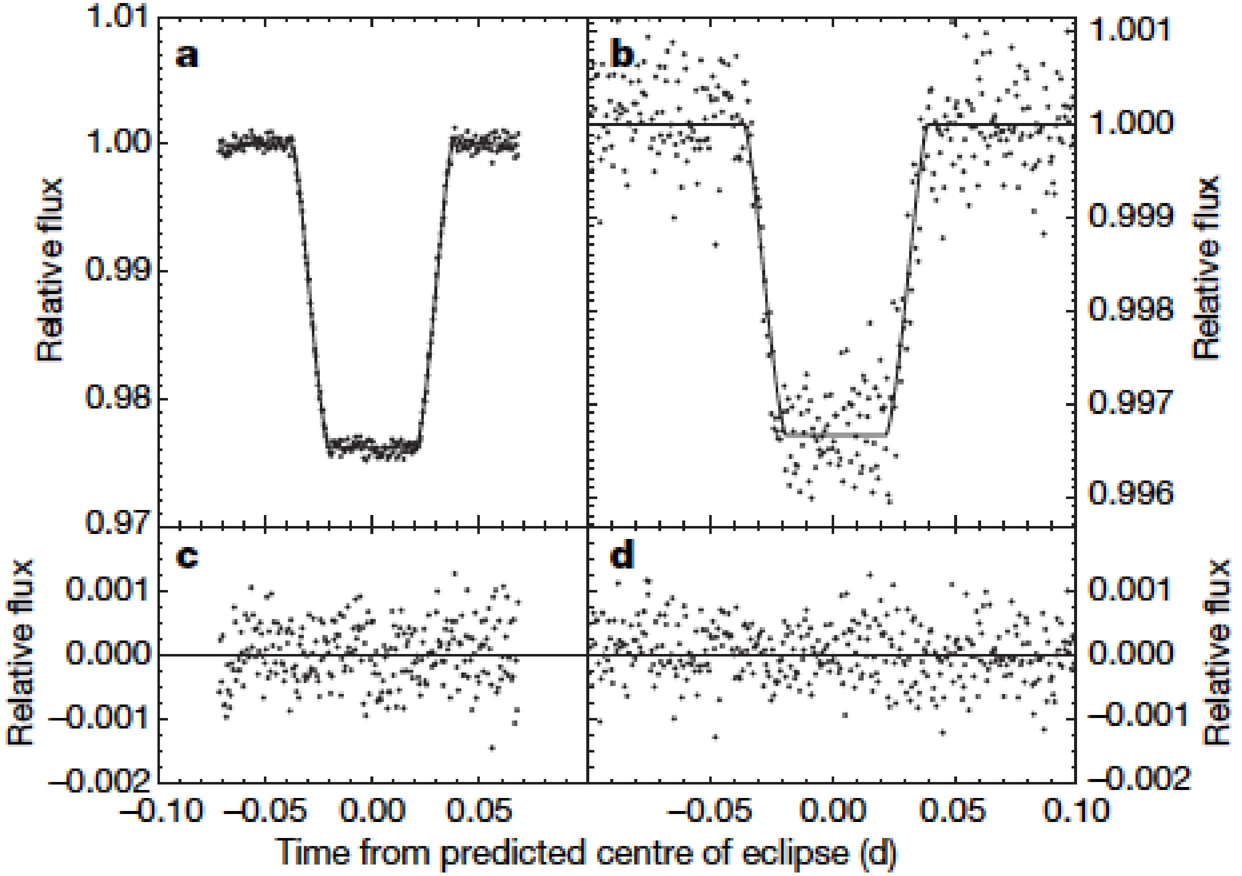


The Wild Tempera
Swings of an Exop

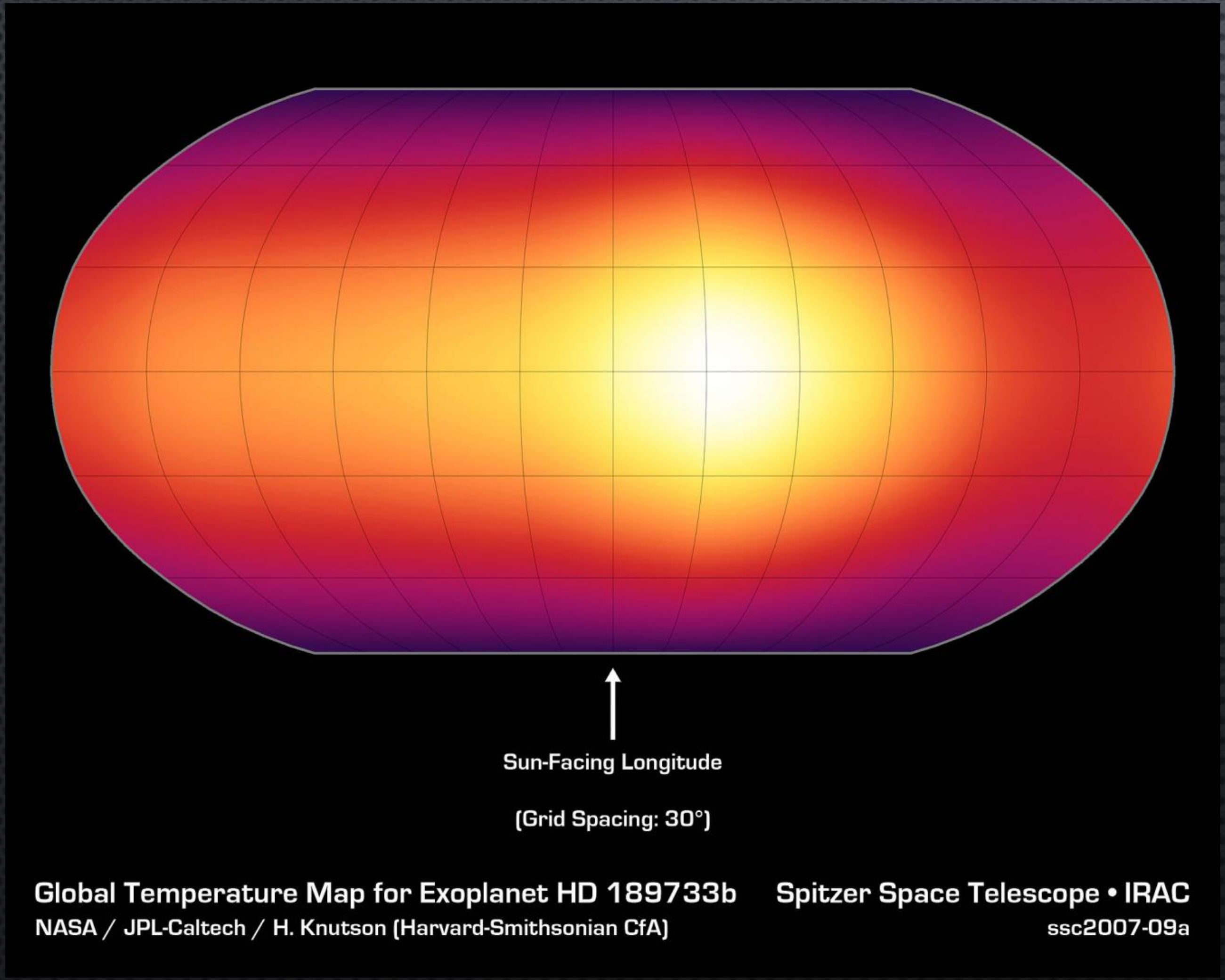
Primer mapa del contraste dia-noche del planeta HD 189733b Knutson et al., 2007

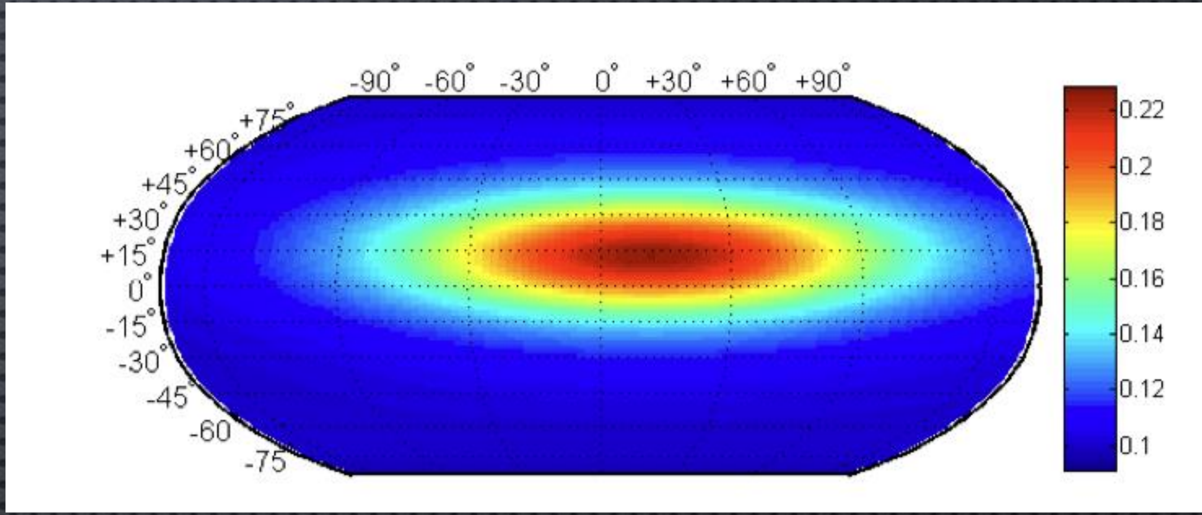


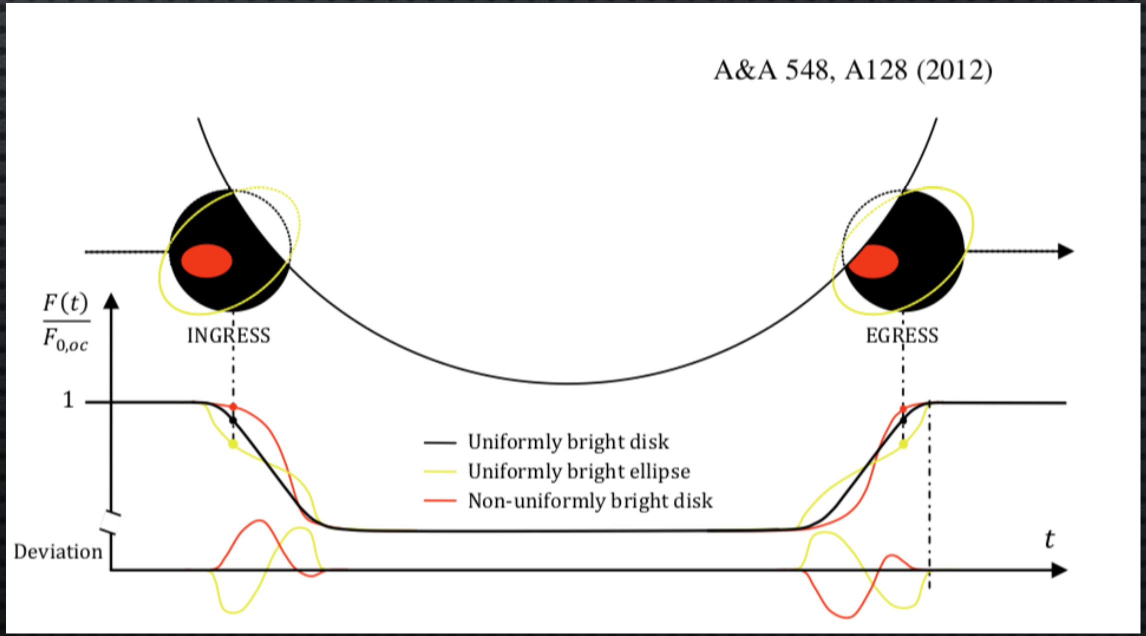
likely explanation. If the time delay is attributed to eccentricity e, then $e\cos\varpi = 0.0010 \pm 0.0002$, where ϖ is the longitude of pericentre, indicating that the eccentricity is extremely small, but non-zero.



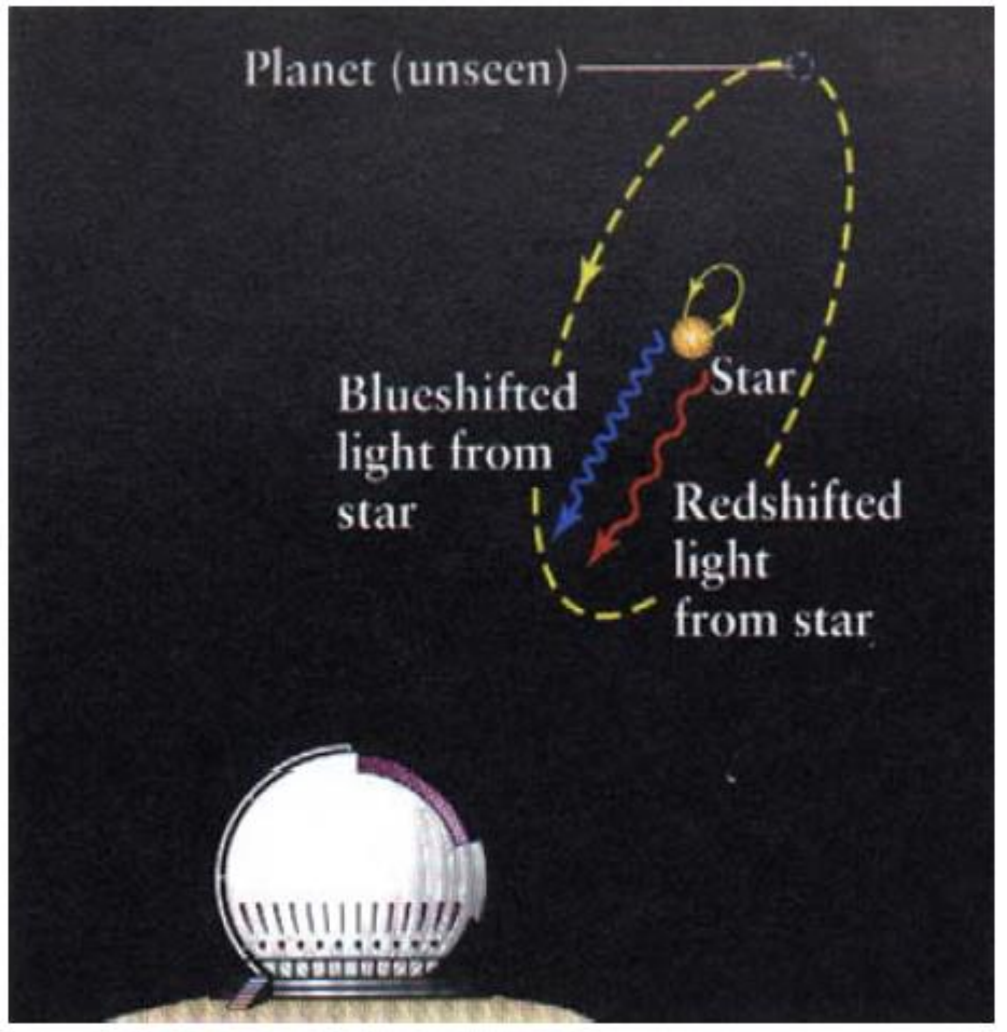
Mapas de 189733b Knutson et al., 2007, de Wit et al. 2012







VELOCIDAD RADIAL (RV)



La estrella y planeta(s) orbitan entorno al centro de masa (CM) del sistema.
La componente radial de la velocidad de la estrella (respecto al observador) genera un desplazamiento de las lÍneas espectrales de la estrella por efecto Doppler.
Midiendo el desplazamiento de las lÍneas espectrales se puede conocer la velocidad radial de la estrella y con suficiente tiempo medir el periodo de rotación entorno al CM.

El CM va a tener un movimiento que debe sustraerse para la correcta medicion del efecto Doppler.

Determinar el periodo P

$$r^3 = \frac{GM_*}{4\pi^2} P^2$$

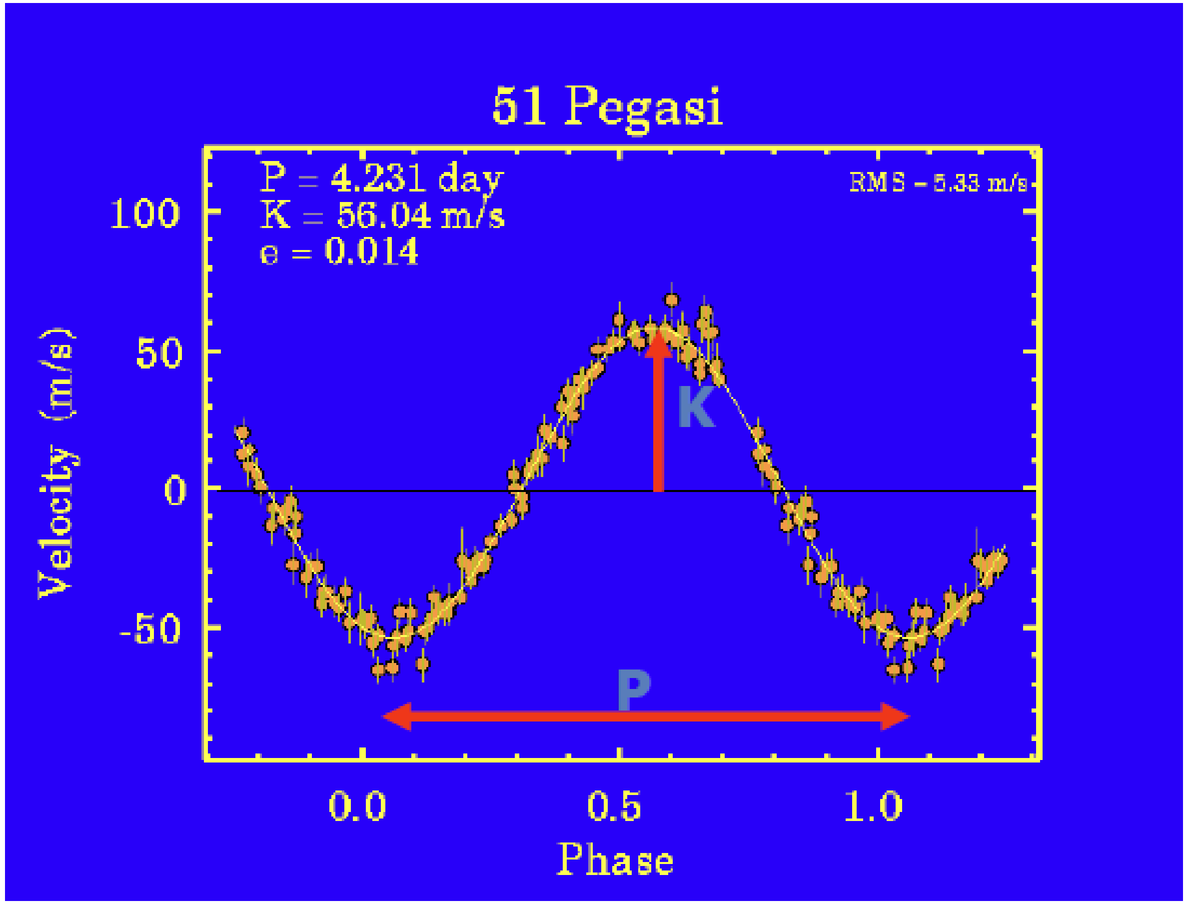
Asumir una orbita circular (inicialmente) para determinar la velocidad del planeta

$$V_p = \sqrt{GM_* / r}$$

Conservacion del momento angular:

$$M_p = M_* V_* / V_p$$

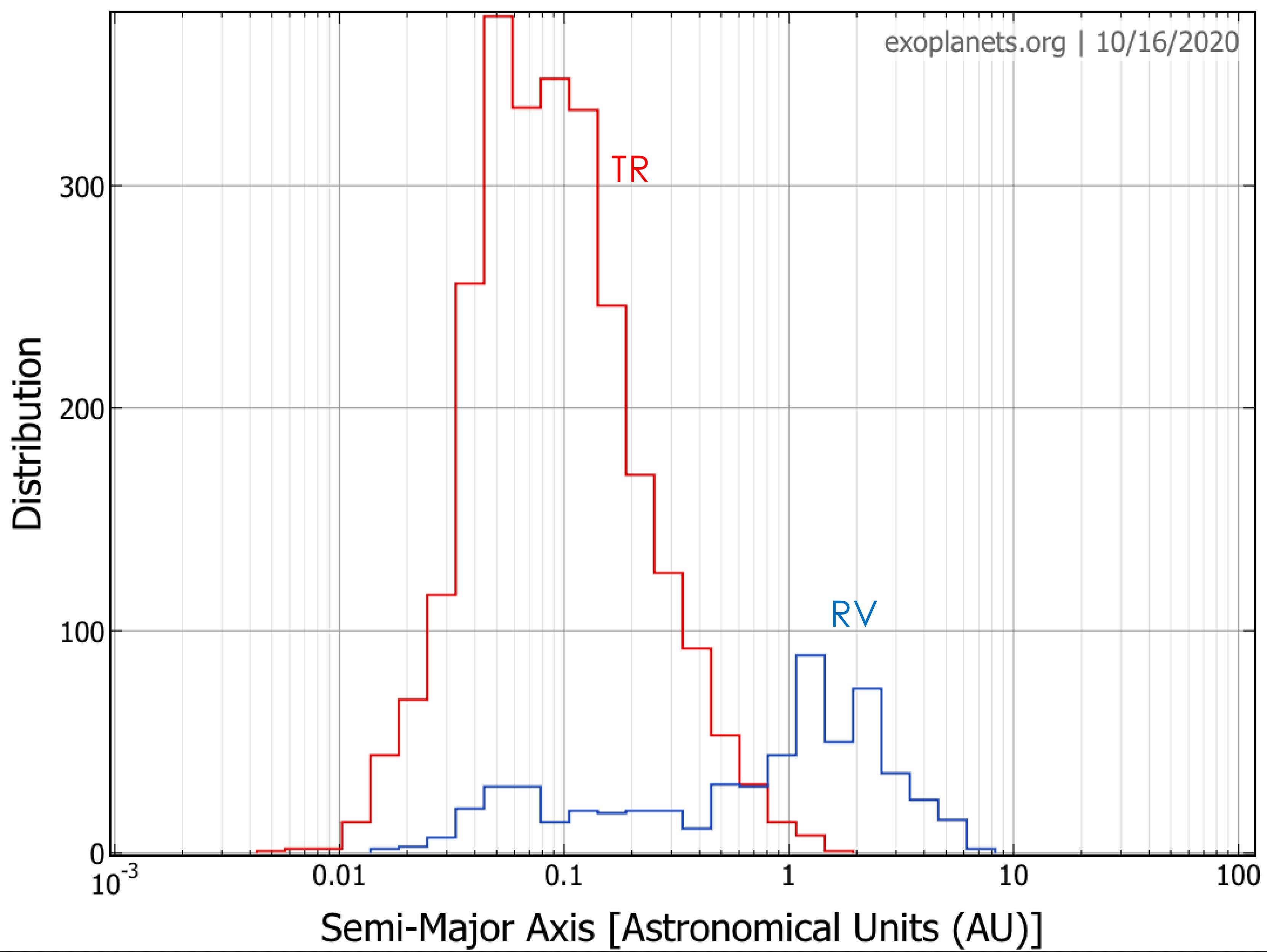
(i = inclination of orbital plane to line of sight)



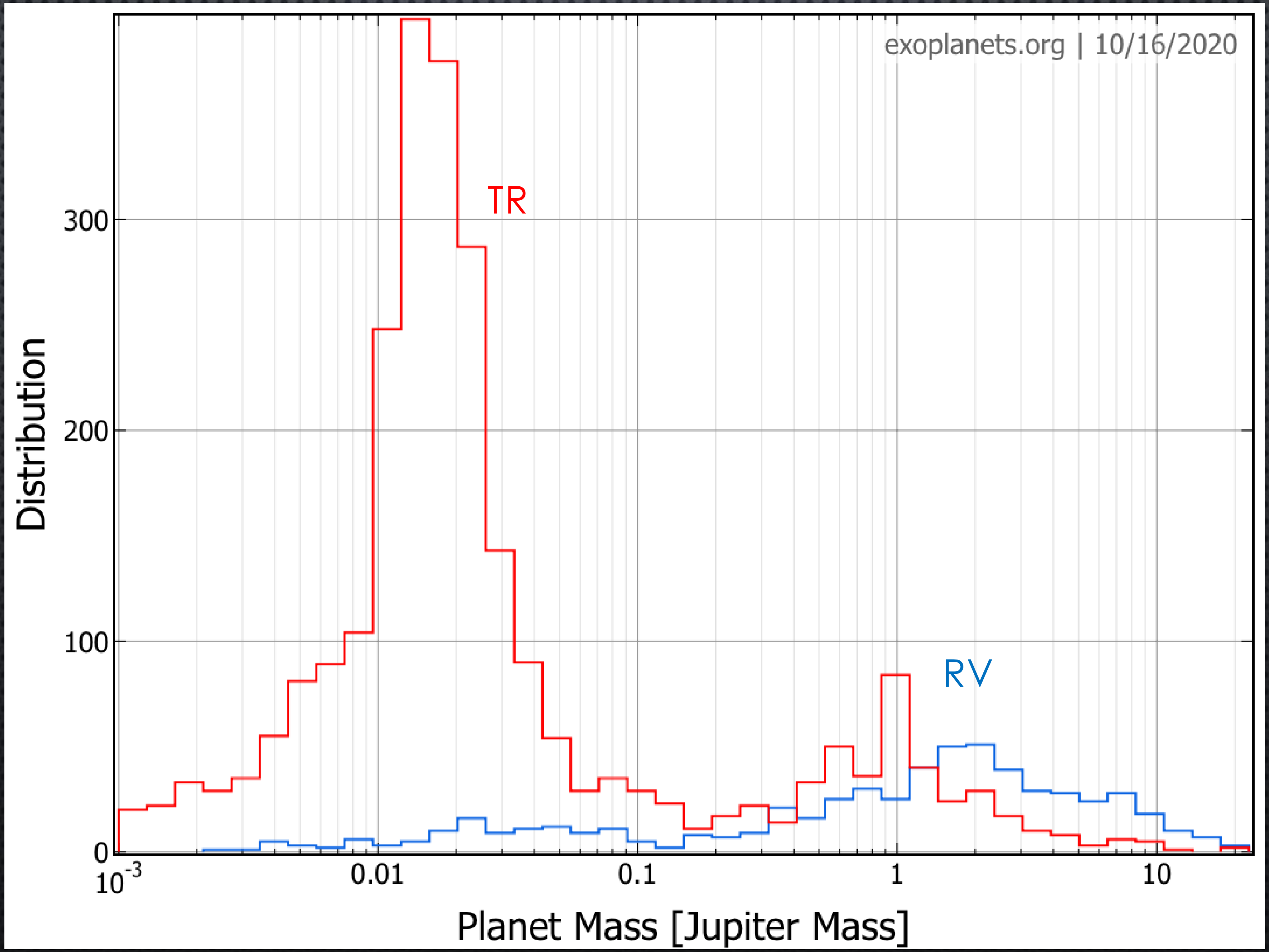
Asumir masa para la estrella (por tipo espectral) para estimar M sin(i)

$$M_p \sin i = M_* K / V_p$$

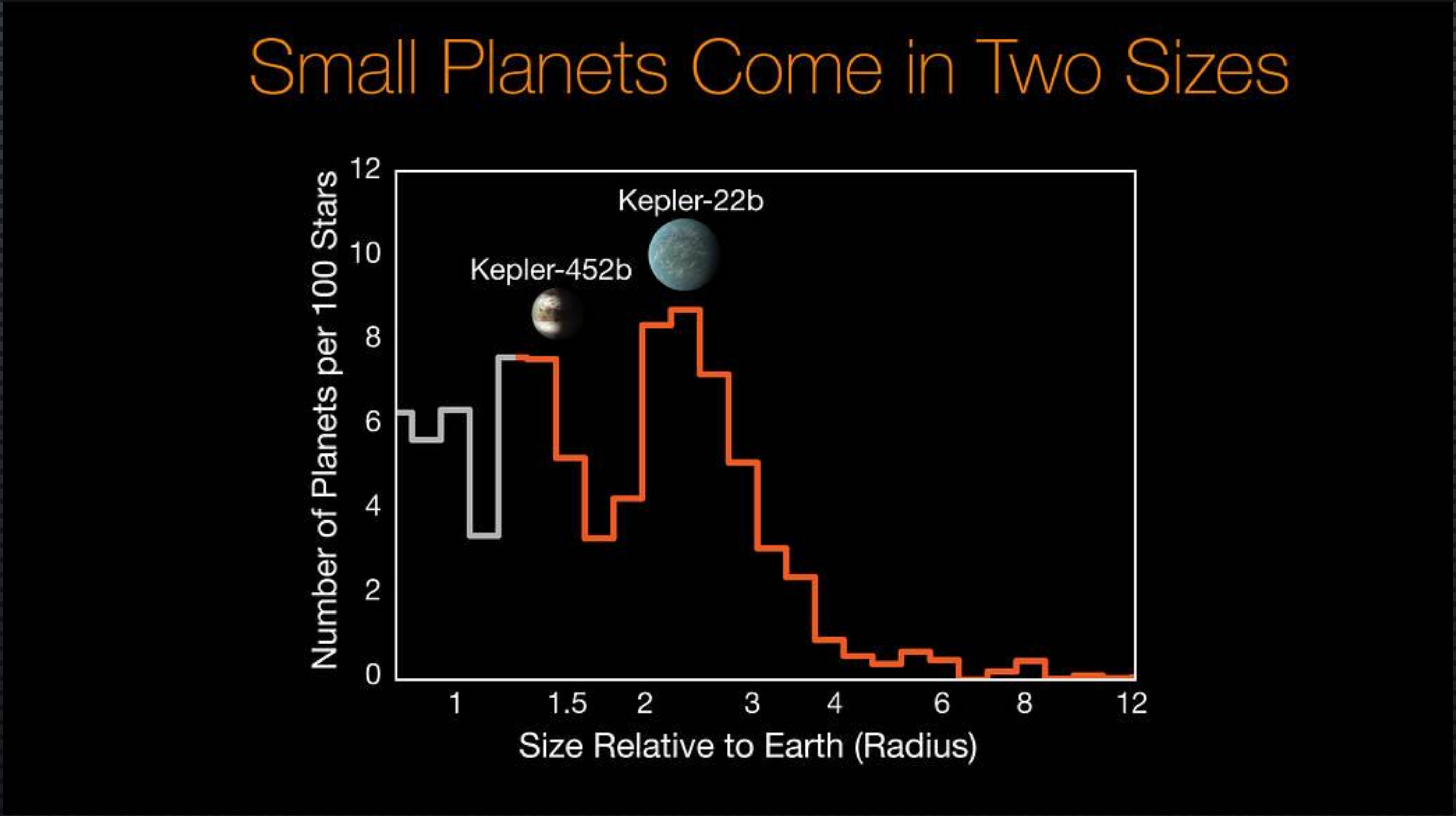
95.2% DE PLANETAS DETECTADOS POR TR+RV



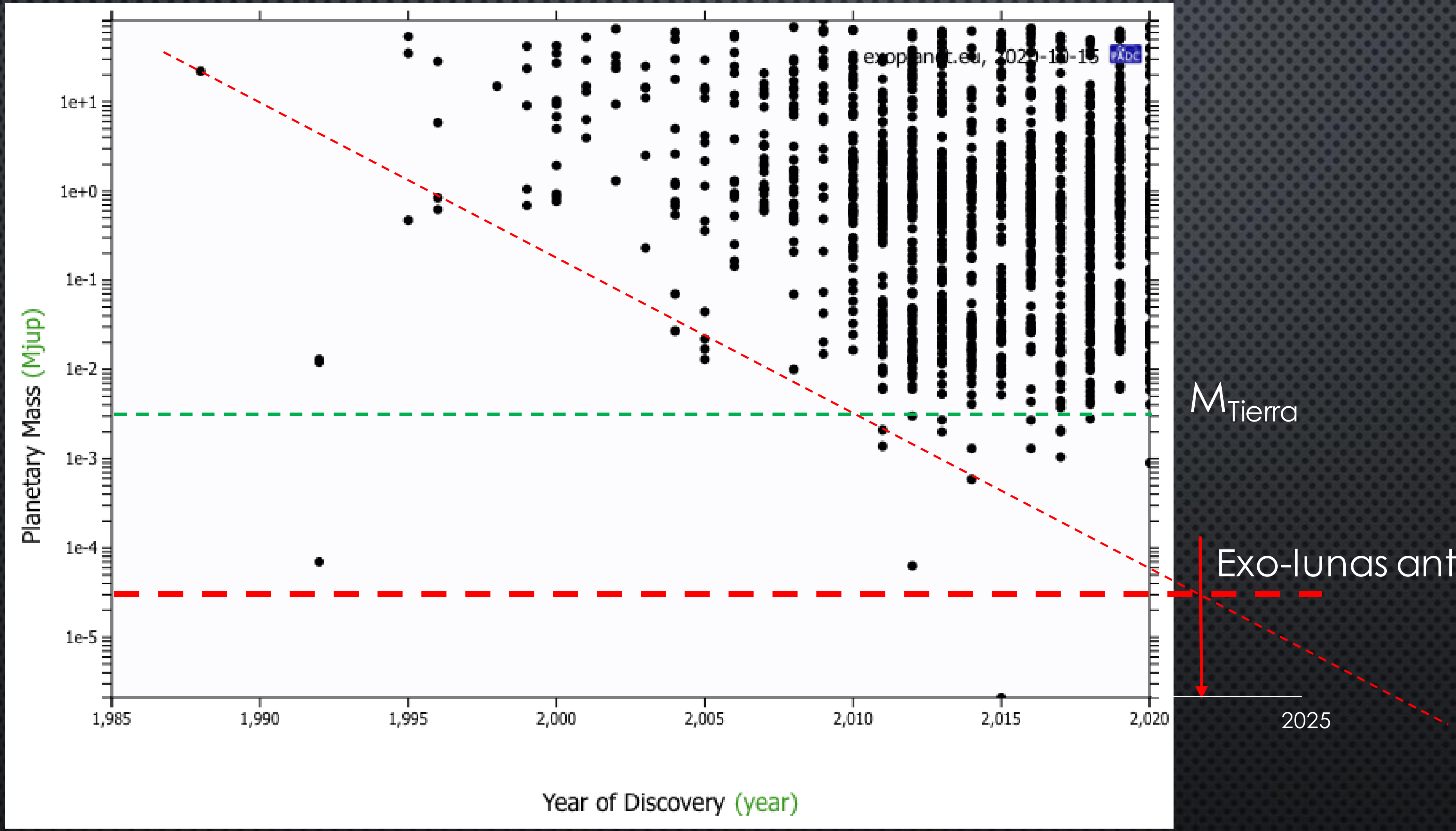
MASA DE PLANETAS SEGUN TR Y RV



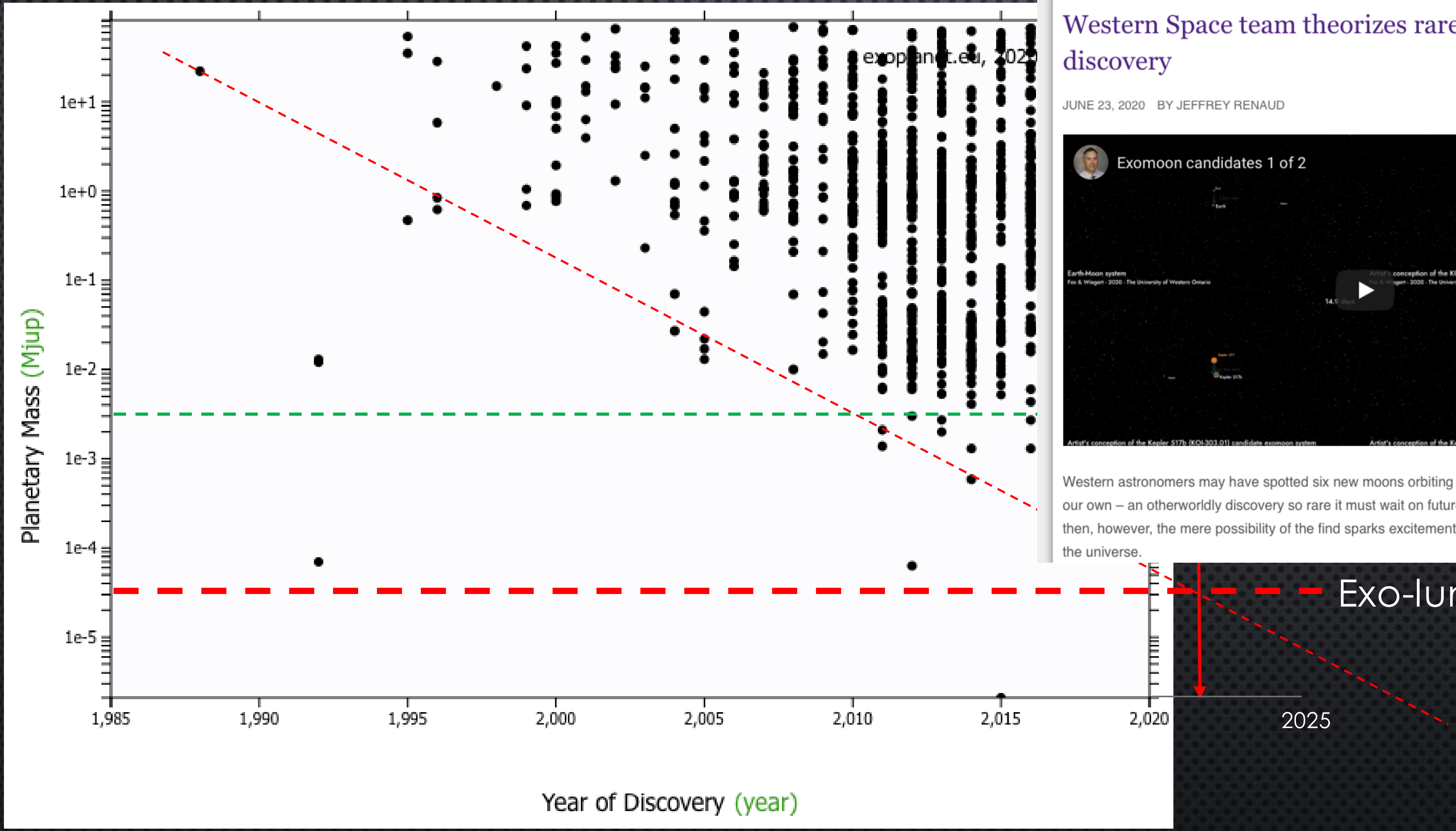
OBSERVACIONES CON KEPLER INDICAN UNA DISTRIBUCIÓN INTERESANTE DE PLANETAS CHICOS.

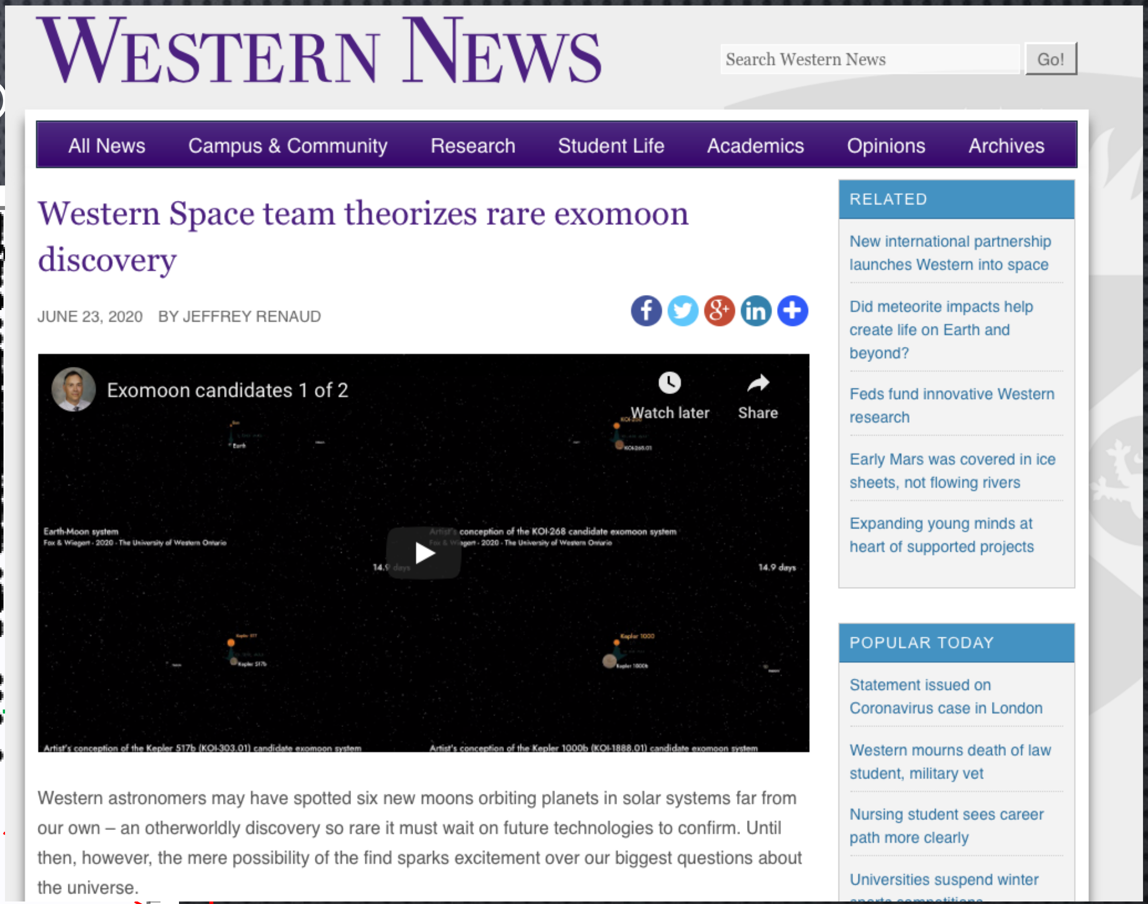


SE LOGRARÁ DETECTAR EXO-LUNAS PRONTO?



SE LOGRARÁ DETECTAR EXO-LUNAS PRO





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Western Space team theorizes rare exomoon discovery

JUNE 23, 2020 BY JEFFREY RENAUD

Exomoon candidates 1 of 2

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Earth-Moon system

Artist's conception of the KOI-268 candidate exomoon system

Artist's conception of the Kepler 517b (KOI-303.01) candidate exomoon system

Artist's conception of the Kepler 1000b (KOI-1888.01) candidate exomoon system

Western astronomers may have spotted six new moons orbiting planets in solar systems far from our own – an otherworldly discovery so rare it must wait on future technologies to confirm. Until then, however, the mere possibility of the find sparks excitement over our biggest questions about the universe.

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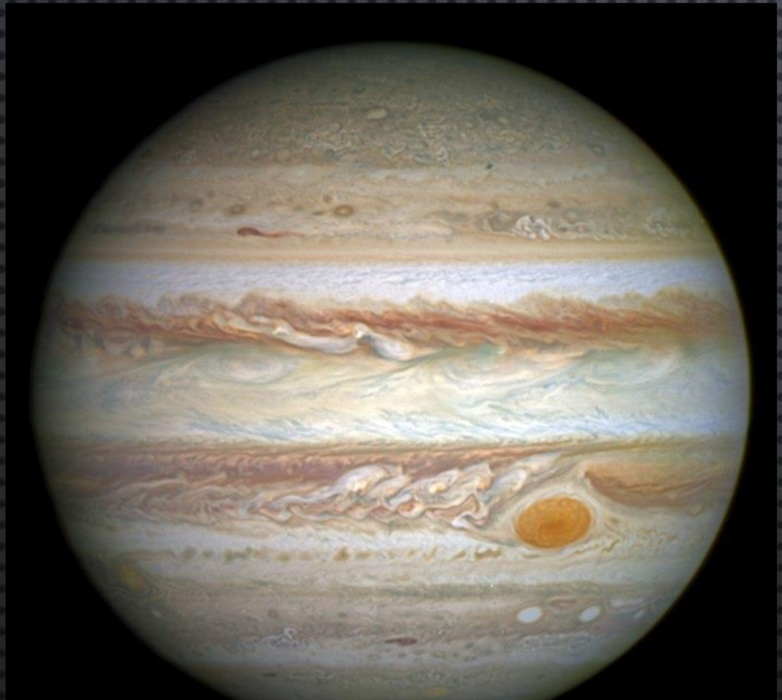
HOT-JUPITERS: REPRESENTACIÓN ARTÍSTICA. ES REALISTA?

HOT-JUPITERS: REPRESENTACIÓN ARTÍSTICA. ES REALISTA?

$$N \sim (2\Omega a / u)^{1/2}$$



$N_{jup} = 26$

$\Omega \sim 2e^{-4}$ rad/s

$a = 71e^{3}$ km

$u = 40$ m/s

$N_{Tierra} = 6$

$\Omega \sim 7e^{-5}$ rad/s

$a = 6.4e^{3}$ km

$u = 20$ m/s

$N_{HD80606b} = 2$

$\Omega \sim 2e^{-5}$ rad/s

$a = 94e^{3}$ km

$u = 1\text{-}2$ km/s

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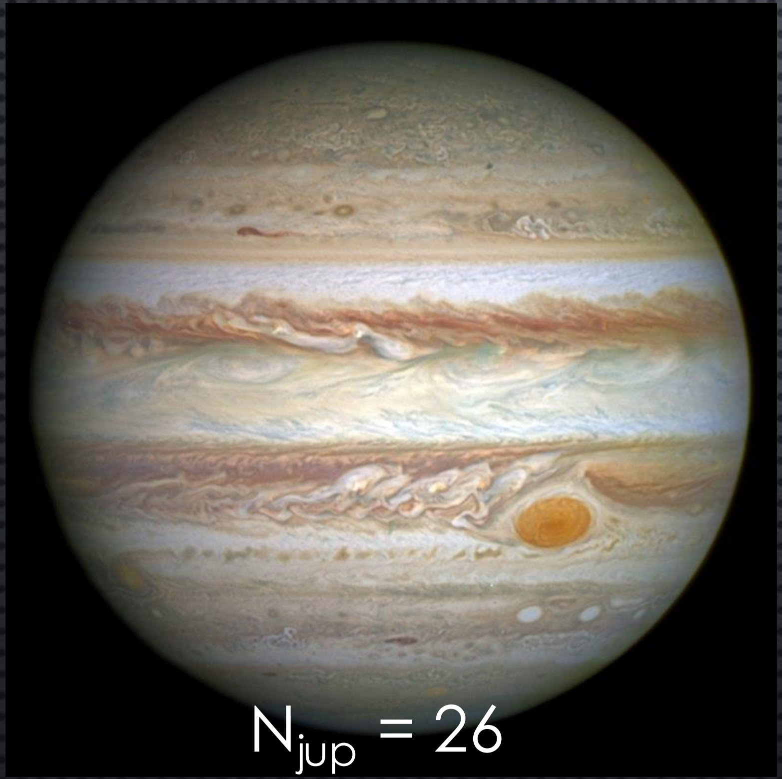

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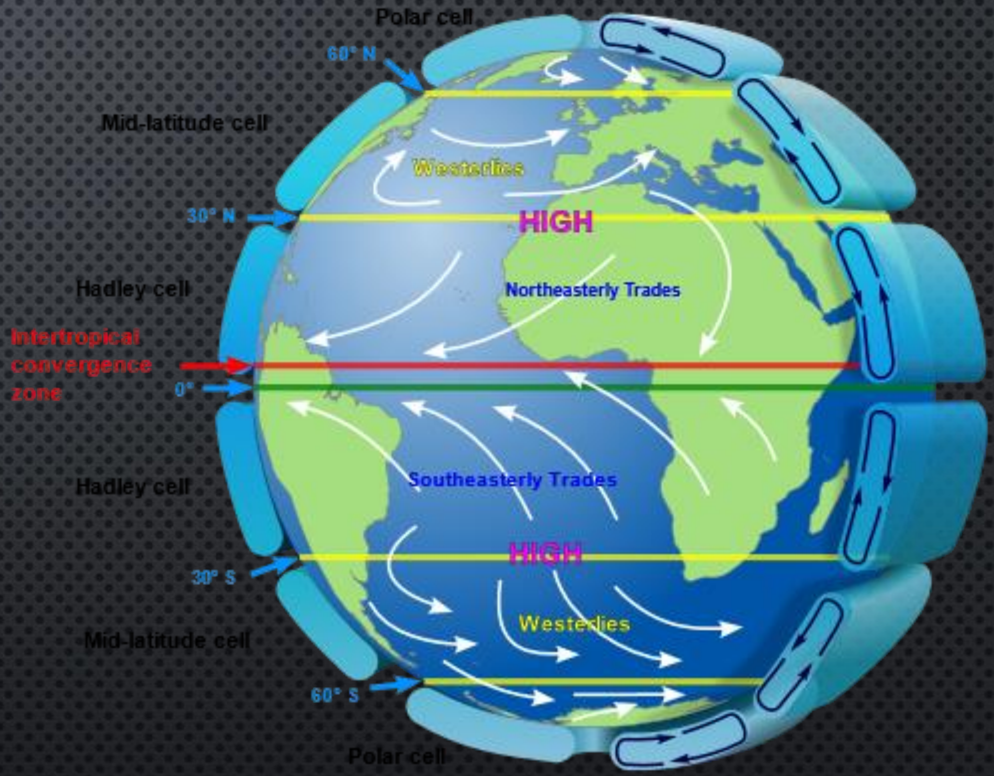

PRIMER EXOPLANETA, BAILES, LYNE & SCHEMAR, 1991.

$10\ M_{tierra}$ $P = 6$ meses

LETTERS TO NATURE

A planet orbiting the neutron star PSR1829−10

M. Bailes, A. G. Lyne & S. L. Shemar

University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank, Macclesfield, Cheshire SK11 9DL, UK

CONVENTIONAL optical techniques for detecting companions to stars have been unable to confirm the existence of other planetary systems. This is because of the small angular separation (less than an arcsecond) and relative luminosity (~10^{-10}) of any planet with respect to its parent star. As the velocity of the star due to the motion of a planet is likely to be only about one metre per second, detection through the Doppler shift of spectral lines in the stellar atmosphere is also impractical. Here we report observations which imply the existence of a planet-sized companion orbiting a neutron star, the pulsar PSR1829−10, whose motion can be seen by Doppler effects on the observed arrival times of the pulses from the rotating neutron star. The planet is about 10 times the mass of the Earth, and is in an almost circular six-month orbit. It is not clear whether it formed in the aftermath of the supernova that created the neutron star, or was pre-existing and somehow survived through the late phases of stellar evolution and neutron-star formation. In either case, the existence of the planet challenges conventional theories of the formation of neutron stars from supernovae and has important implications for the existence of planetary systems around other stars.

The radio pulsar PSR1829−10 was discovered in 1985 in a survey of the northern galactic plane at Jodrell Bank[1], and is estimated to be ~10 kpc from the Sun. Since then, timing observations have been made regularly on the 40 new pulsars detected in the survey in order to determine their positions and spin-down parameters. For 39 of these, solutions have been obtained, and the results have been published elsewhere[2-4]. The fortieth, PSR1829−10, showed period fluctuations whose nature has only just been established.

Observations were carried out with the 76-m Lovell telescope at Jodrell Bank at frequencies between 1,400 and 1,660 MHz. Arrival times were obtained by convolution of the pulses with an appropriate template and then corrected for the Earth's motion in the usual way, using the JPL DE200 barycentric ephemeris[5]. After fitting a standard slow-down model to the data[6], it is clear that the residuals shown in Fig. 1*a* are oscillatory, with a period of ~6 months. The most straightforward interpretation is in terms of binary motion. We have considered other possible causes of the sinusoidal variation such as the free precession of a neutron star[7,8] or Tkachenko oscillations in the superfluid interior of the neutron star[9,10]. Neither of these effec[…] has previously been identified, although the Crab pulsar sho[…] timing noise which occasionally has a quasi-periodic behavi[…] for two or three cycles[11]. However, there is no stable frequ[…]

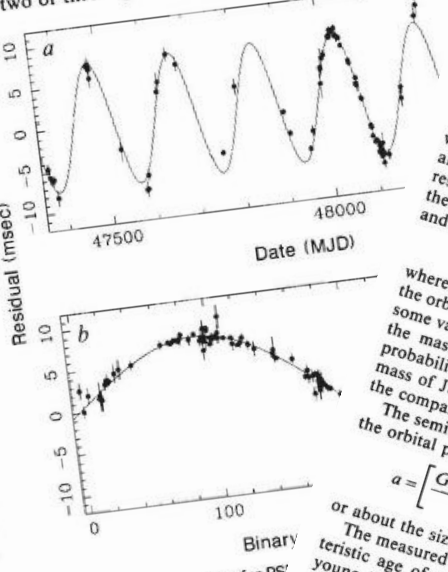

FIG. 1 The timing residuals for PS[…] model of the slow down. The smoo[…] binary system with the parameters give[…] against orbital phase.

or amplitude. Although we cannot discount the possibility that PSR1829−10 shows a more pure form of this phenomenon it seems unlikely that it would be confined to this one, much older and otherwise ordinary pulsar.

Fitting for a binary motion resulted in the smooth curve shown in Fig. 1*a* and the parameters that are given in Table 1. As can be seen from Fig. 1, the binary model provides an excellent fit to the data. Figure 1*b* shows the residuals plotted as a function of binary phase. The orbit is surprisingly circular, with an eccentricity of less than 0.1. The orbital period of the planet is close to 6 months, and we were of course concerned that the modulation of the pulsar period that we are observing is not some artefact of our data acquisition or reduction techniques. Fortunately we have observations of several hundred other pulsars that have been observed and reduced with exactly the same software as PSR1829−10, and none shows a similar periodicity. In particular, the sinusoid is absent in the residuals of the pulsar PSR1829−08, which is only 2 degrees away.

The mass function, which is a property of only two observables, the projected semimajor axis $a_p \sin i$ and the orbital period P_b, gives some information about the masses of the two objects:

$$f(m_p, m_c) = \frac{4\pi^2}{G}\frac{(a_p \sin i)^3}{P_b^2} = \frac{(m_c \sin i)^3}{(m_p + m_c)^2} = 1.4 \times 10^{-14}\ M_\odot \qquad (1)$$

where i is the inclination of the orbit to the plane of the sky, and m_p and m_c are the masses of the pulsar and companion respectively. Assuming that the mass of the pulsar is $1.4\ M_\odot$, then the mass of the companion body is clearly very much less, and in this approximation

$$m_c \sin i = 3.0 \times 10^{-5}\ M_\odot = 10.2\ M_E \qquad (2)$$

where M_E is the mass of the Earth. For random orientation of the orbital plane, the probability that the inclination is less than some value i_0 is $1 - \cos i_0$. There is therefore a 50% chance that the mass of the companion is less than $12\ M_E$ and only a probability of 0.0005 that the companion is greater than the mass of Jupiter, $300\ M_E$. For any reasonable inclination then, the companion is of planetary mass.

The semimajor axis of the orbit a is readily determined from the orbital period and the mass of the neutron star:

$$a = \left[\frac{G(m_p + m_c)P_b^2}{4\pi^2}\right]^{1/3} = 1.06 \times 10^8\ \text{km} = 0.710\ \text{AU} \qquad (3)$$

or about the size of the orbit of Venus around the Sun.

The measured period derivative of the pulsar gives a characteristic age of ~1.25 Myr, indicating that the pulsar is quite young. This is generally accepted as being an upper limit to the age of the pulsar[6]. The pulsar is losing rotational energy at a

TABLE 1 Measured parameters of the PSR1829−10 system

Epoch (MJD)*	48000.3
Pulsar period	330353.559543 ± 0.000008 μs
Pulsar period derivative	4.2056 ± 0.0002(10^{-15})
Pulsar period second derivative	(0.28 ± 0.03) × 10^{-24} s^{-1}
Dispersion measure	475 ± 1 cm^{-3} pc
Right ascension (1950.0)	18 h 29 min 55.01 s ± 0.01 s
Declination (1950.0)	−10° 23′ 50.6″ ± 0.5″
Projected semimajor axis, $a_p \sin i$	7.6 ± 0.3 light ms
Orbital period, P_b	184.4 ± 0.9 days
Eccentricity, e	≤0.1
Assumed longitude of periastron, ω	0.0°
Time of periastron (MJD)*, T_0	48168.0 ± 1.2 days
NS projected orbital velocity	0.90 ± 0.04 m s^{-1}
Planet projected orbital velocity	42 ± 2 km s^{-1}
Mass function, $f(m_p, m_c)$	(1.4 ± 0.2) × 10^{-14} $M_\odot$

* Mean Julian day.

two or more planets that may be influencing the observed value of $\dot{P}$ and $\ddot{P}$; it should be possible to establish which one of these is correct within a few years.

The existence of such a small mass in an almost circular orbit around a pulsar has implications for our understanding of the birth of pulsars, and their connection with supernovae, not to mention the presence of other planets outside the Solar System. The crucial question is whether the companion we have detected was a planet before the formation of the neutron star.

If so, then the standard theory[14] of neutron-star formation poses several problems. It is widely believed that neutron stars are formed in the collapse of the cores of massive stars with an accompanying supernova explosion in which the envelope of the pre-supernova star is ejected with a large velocity of ~5,000 km s^{-1}. The planet could therefore be destroyed or its orbit disrupted during either the pre-supernova giant phase of the star, the supernova explosion itself or afterwards. To obtain the PSR1829−10 system, the planet has had to survive all of the above and remain intact, bound and in a remarkably circular orbit.

An initial stellar mass of between ~6 and 60 $M_\odot$ is thought to be required to create a neutron star[14]. Such stars are much more luminous than the Sun, but incapable of driving all but the lighter elements from the planet's surface. During the giant phase, the planet would spiral into the centre of the star if the density of the stellar atmosphere at the distance of the planet were to become too large[15]. As we cannot uniquely determine the mass of the pulsar progenitor, and hence the radius of the giant, it is possible that the planet would survive this phase.

The supernova explosion, however, poses a serious threat to the survival of a bound and intact planet. Even if the explosion were symmetric, then the system would only remain bound if the amount of matter ejected from the system were less than

PRIMER EXOPLANETA, BAILES, LYNE & SCHEMAR, 1991.

10 M_{tierra} P = 6 meses

Retractado

A planet orbiting the neutron star PSR1829–10

M. Bailes, A. G. Lyne & S. L. Shemar

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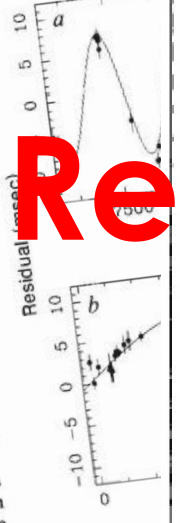

FIG. 1 The timir... model of the s... binary system ... against orbital...

No planet orbiting PSR1829–10

SIR — In an earlier paper[1], we reported a cyclic variation in the arrival times of the pulses from the neutron star PSR1829–10 with a period close to 6 months, and presented this as evidence for a 10-Earth-mass planet. As we noted in that paper, we were concerned that the 6-month periodicity might be an artefact concerned with the Earth's orbit around the Sun, but were encouraged by the fact that no such periodicity appeared in observational data for the 300 other pulsars currently under observation. We have nevertheless re-examined the algorithm used in computing for the Earth's orbital motion and now find that we can account for the observed radiation without the presence of a planet.

The standard analysis (p. 105 of ref. 2) involves correcting the observed arrival times to the barycentre of the Solar System using a precise ephemeris for the position of the Earth. An analytical model for the pulsar rotation and position is then adjusted to minimize a set of residuals, the differences between the observed barycentric arrival times and model times. Because this is a differential process, the approximation is made that the orbit of the Earth is circular. Provided that the difference between the

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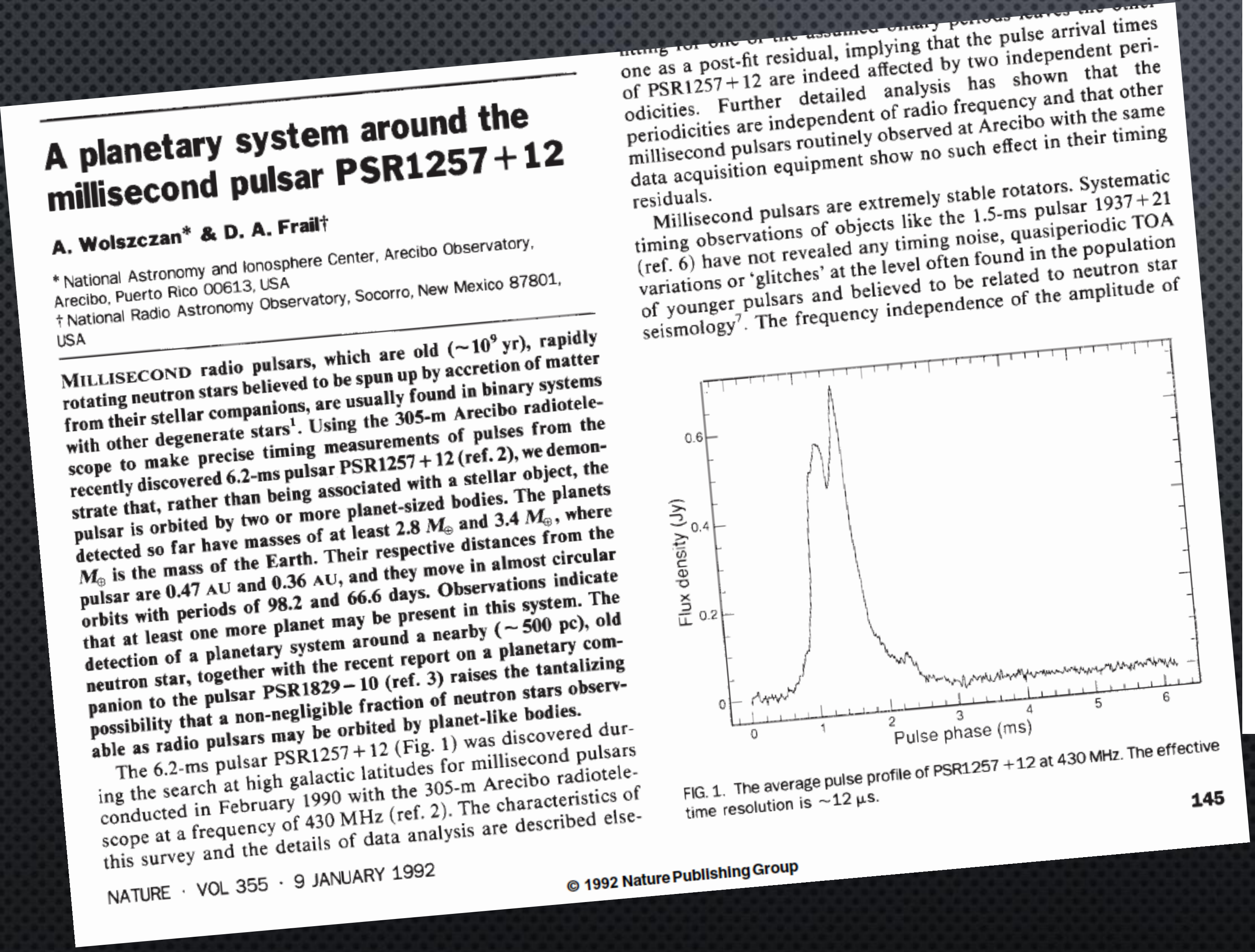
PRIMEROS EXOPLANETAS, WOLSZCZAN & FRAIL, 1992



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 (~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.

The 6.2-ms pulsar PSR1257+12 (Fig. 1) was discovered during the search at high galactic latitudes for millisecond pulsars conducted in February 1990 with the 305-m Arecibo radiotelescope at a frequency of 430 MHz (ref. 2). The characteristics of this survey and the details of data analysis are described else-

one as a post-fit residual, implying that the pulse arrival times of PSR1257+12 are indeed affected by two independent periodicities. Further detailed analysis has shown that the periodicities are independent of radio frequency and that other millisecond pulsars routinely observed at Arecibo with the same data acquisition equipment show no such effect in their timing residuals.

Millisecond pulsars are extremely stable rotators. Systematic timing observations of objects like the 1.5-ms pulsar 1937+21 (ref. 6) have not revealed any timing noise, quasiperiodic TOA variations or 'glitches' at the level often found in the population of younger pulsars and believed to be related to neutron star seismology[7]. The frequency independence of the amplitude of

FIG. 1. The average pulse profile of PSR1257+12 at 430 MHz. The effective time resolution is ~12 μs.

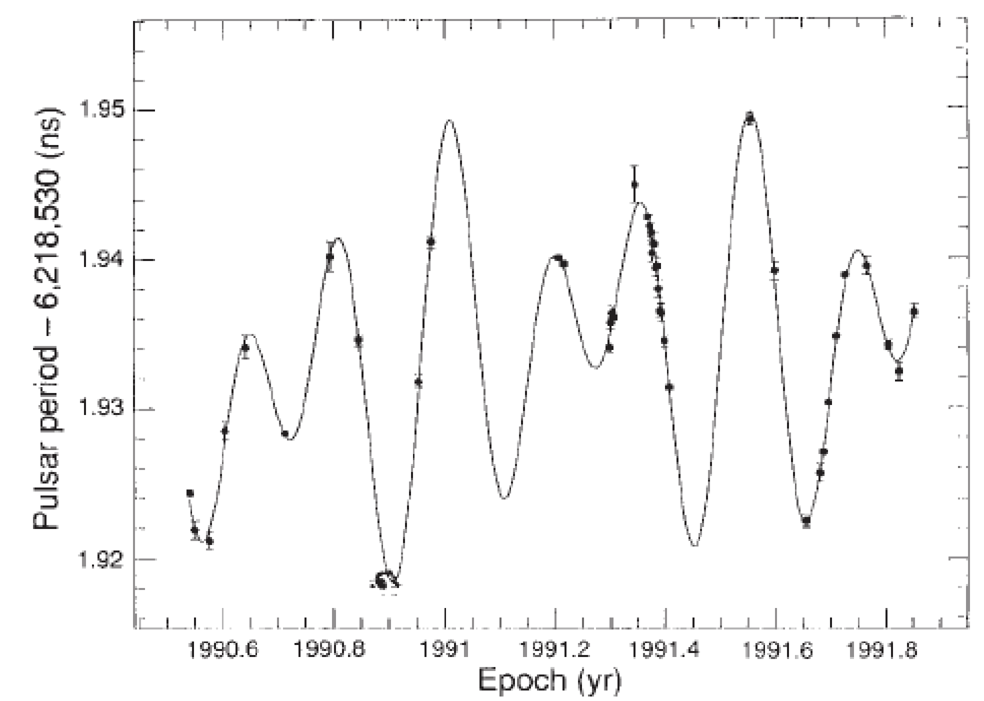


FIG. 3 Period variations of PSR1257+12. Each period measurement is based on observations made on at least two consecutive days. The solid line denotes changes in period predicted by a two-planet model of the 1257+12 system.

1ER EXOPLANETA POR VELOCIDAD RADIAL: MAYOR & QUELOZ, 1995

2019

A Jupiter-mass companion to a solar-type star

Michel Mayor & Didier Queloz

Geneva Observatory, 51 Chemin des Maillettes, CH-1290 Sauverny, Switzerland

The presence of a Jupiter-mass companion to the star 51 Pegasi is inferred from observations of periodic variations in the star's radial velocity. The companion lies only about eight million kilometres from the star, which would be well inside the orbit of Mercury in our Solar System. This object might be a gas-giant planet that has migrated to this location through orbital evolution, or from the radiative stripping of a brown dwarf.

For more than ten years, several groups have been examining the radial velocities of dozens of stars, in an attempt to identify orbital motions induced by the presence of heavy planetary companions[1–5]. The precision of spectrographs optimized for Doppler studies and currently in use is limited to about 15 m s^{-1}. As the reflex motion of the Sun due to Jupiter is 13 m s^{-1}, all current searches are limited to the detection of objects with at least the mass of Jupiter (M_J). So far, all precise Doppler surveys have failed to detect any jovian planets or brown dwarfs.

Since April 1994 we have monitored the radial velocity of 142 G and K dwarf stars with a precision of 13 m s^{-1}. The stars in our survey are selected for their apparent constant radial velocity (at lower precision) from a larger sample of stars monitored for 15 years[6,7]. After 18 months of measurements, a small number of stars show significant velocity variations. Although most candidates require additional measurements, we report here the discovery of a companion with a minimum mass of 0.5 M_J, orbiting at 0.05 AU around the solar-type star 51 Peg. Constraints originating from the observed rotational velocity of 51 Peg and from its low chromospheric emission give an upper limit of 2 M_J for the mass of the companion. Alternative explanations to the observed radial velocity variation (pulsation or spot rotation) are unlikely.

The very small distance between the companion and 51 Peg is certainly not predicted by current models of giant planet formation[8]. As the temperature of the companion is above 1,300 K, this object seems to be dangerously close to the Jeans thermal evaporation limit. Moreover, non-thermal evaporation effects are known to be dominant[9] over thermal ones. This jovian-mass companion may therefore be the result of the stripping of a very-low-mass brown dwarf.

The short-period orbital motion of 51 Peg also displays a long-period perturbation, which may be the signature of a second low-mass companion orbiting at larger distance.

Discovery of Jupiter-mass companion(s)

Our measurements are made with the new fibre-fed echelle spectrograph ELODIE of the Haute-Provence Observatory, France[10]. This instrument permits measurements of radial velocity with an accuracy of about 13 m s^{-1} of stars up to 9 mag in an exposure time of <30 min. The radial velocity is computed

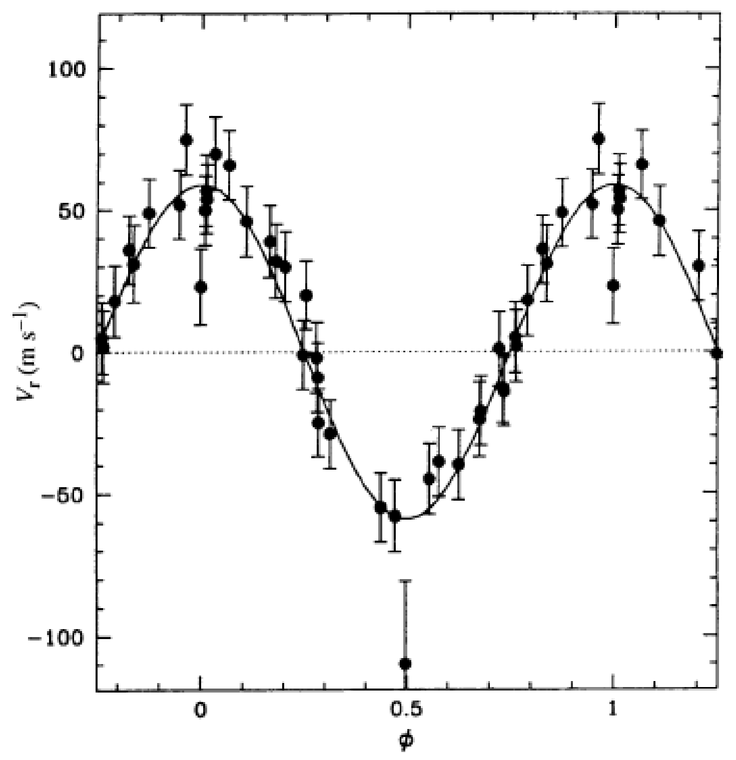
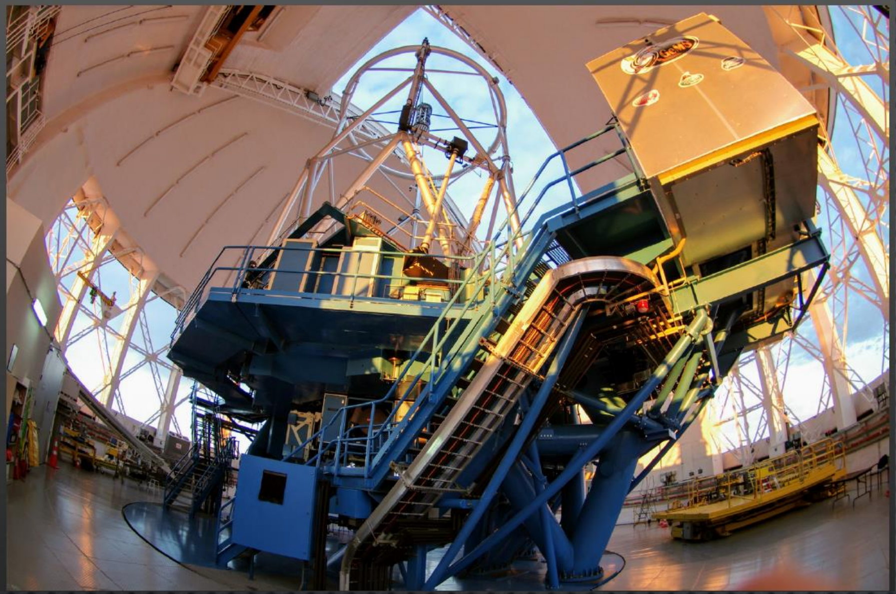
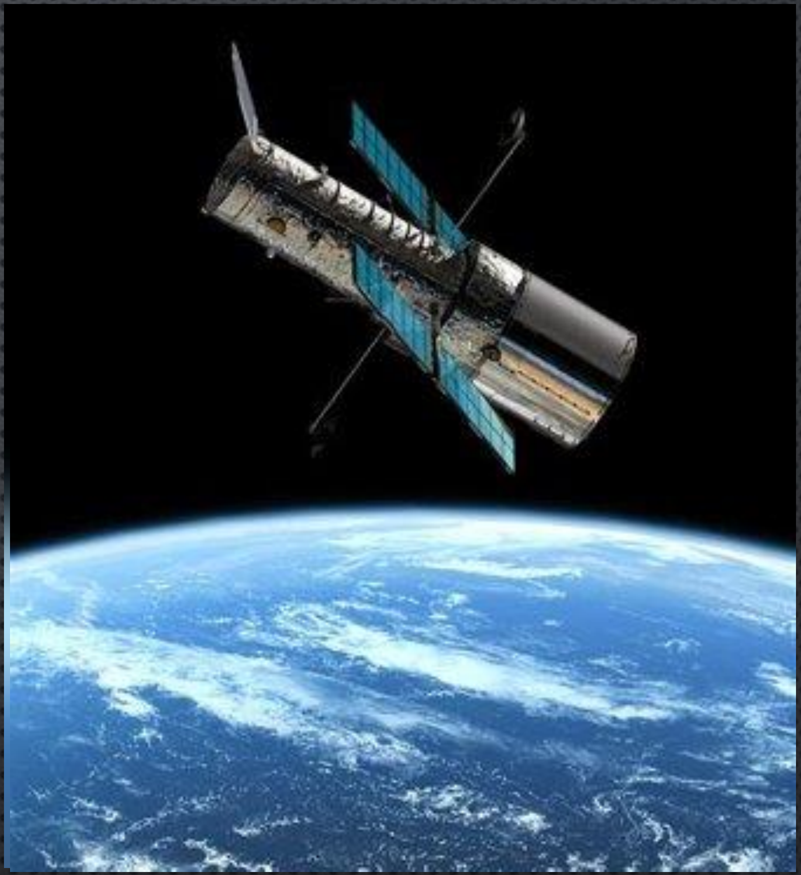


FIG. 4 Orbital motion of 51 Peg corrected from the long-term variation of the γ-velocity. The solid line represents the orbital motion computed from the parameters of Table 1.



Gemini/GPI

VLT/Sphere



Hubble/NASA

Magelan AO (Las Campanas)

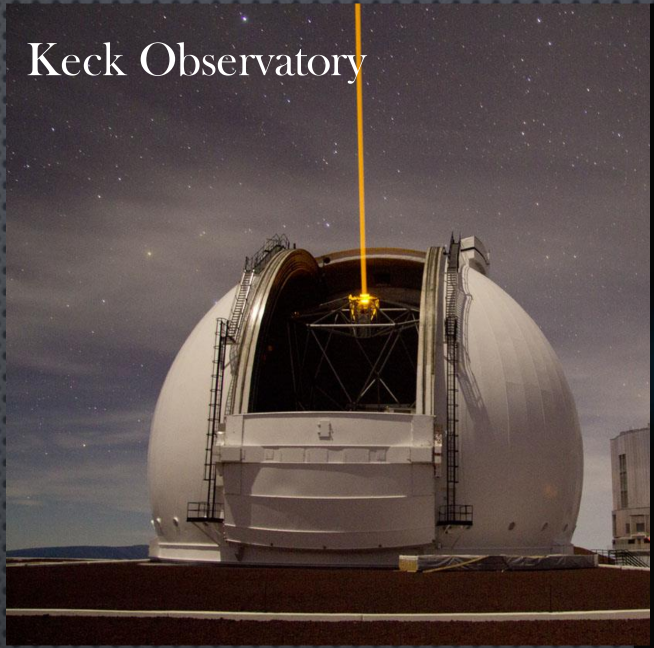
Subaru/HiCIAO

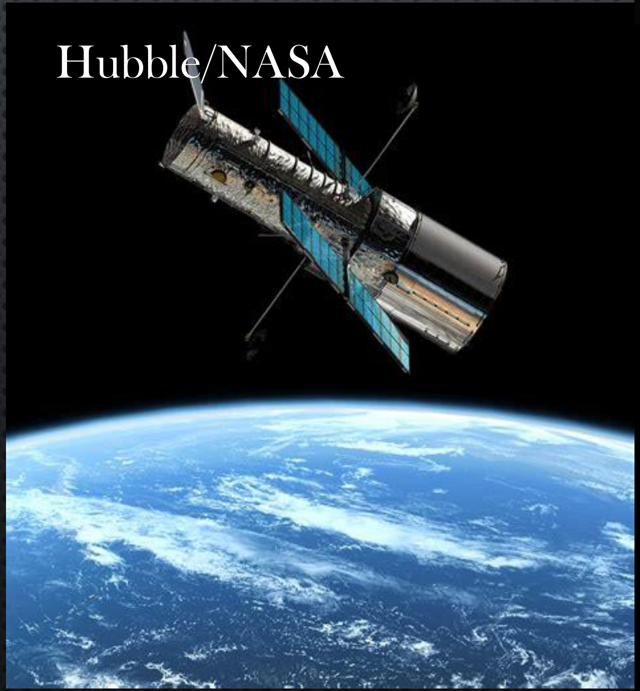
Optica Adaptativa reconstruye el frente de onda plano en tiempo ¨real¨.

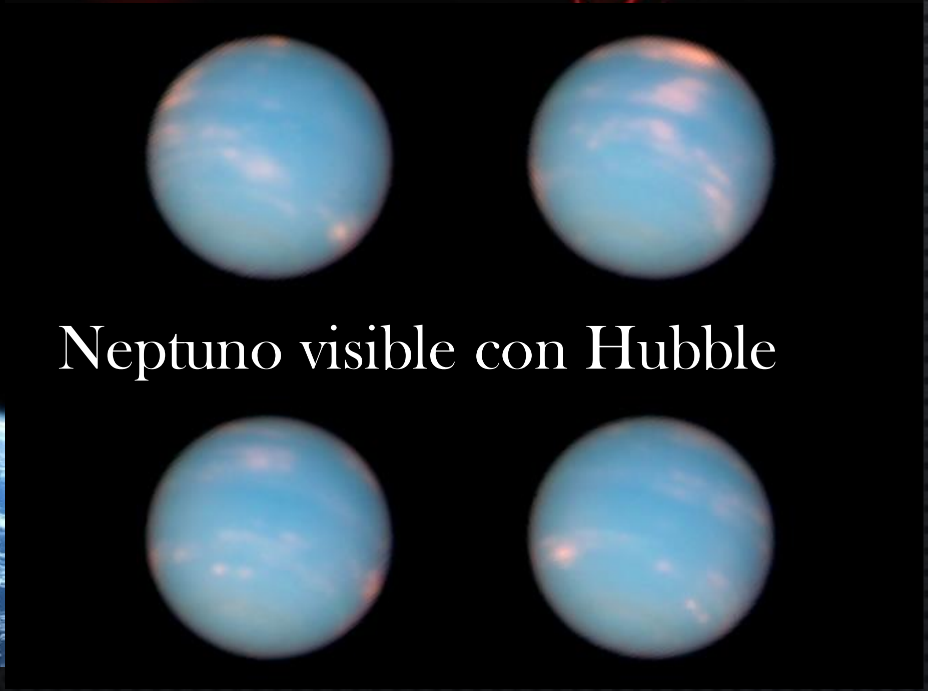
Permite alcanzar limite teorico de difracción del sistema óptico.

Implementaciones en Astronomía en near-IR

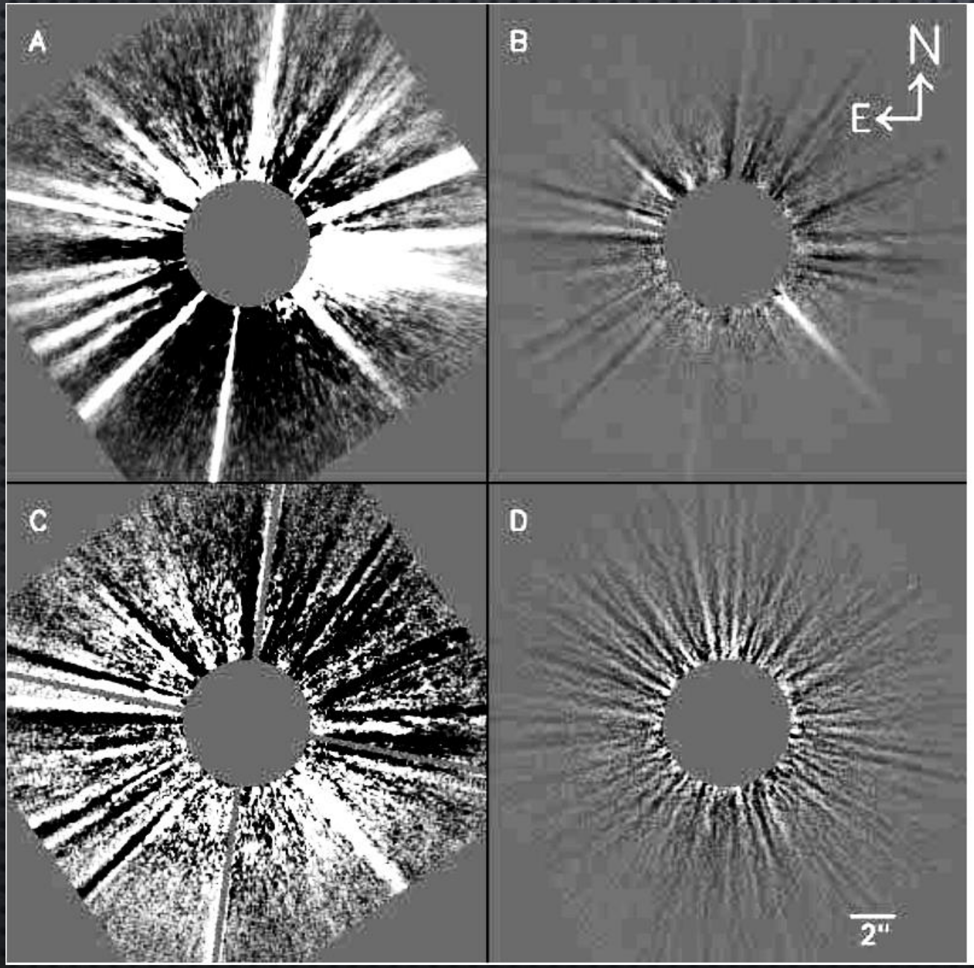
Aplicaciones en medicina, defensa e industria.



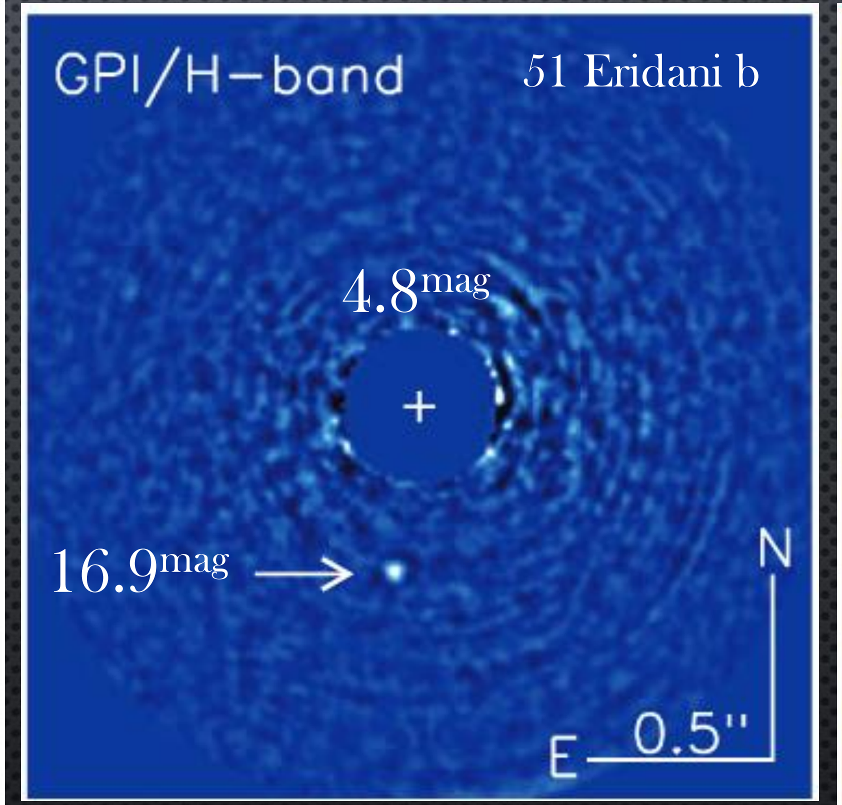




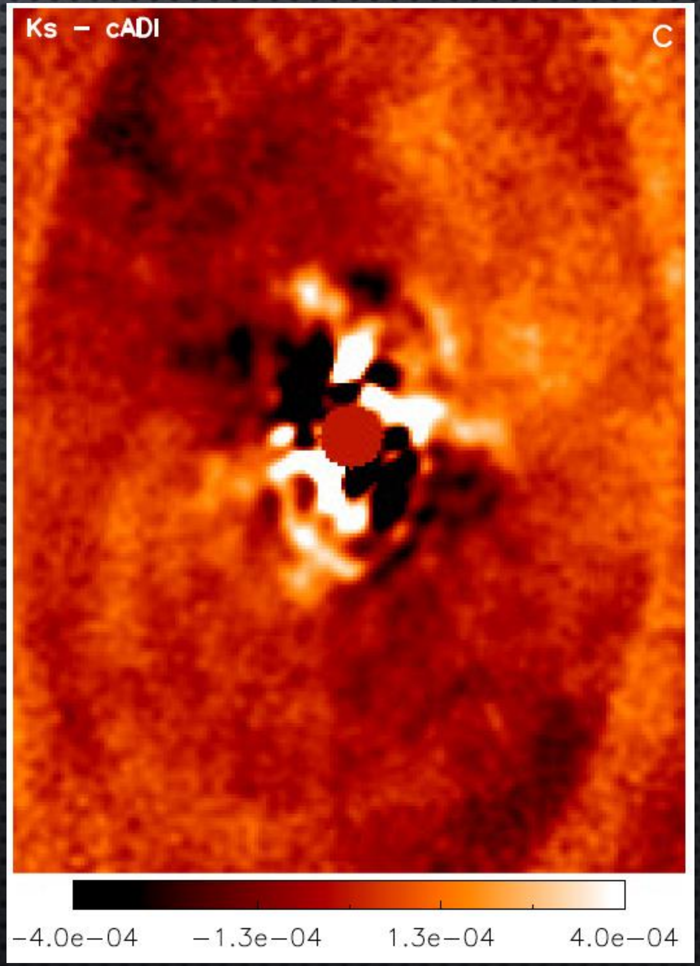
PODEMOS VER EXOPLANETAS Y CINTURONES DE ASTEROIDES Y COMETAS EN OTRAS ESTRELLAS!



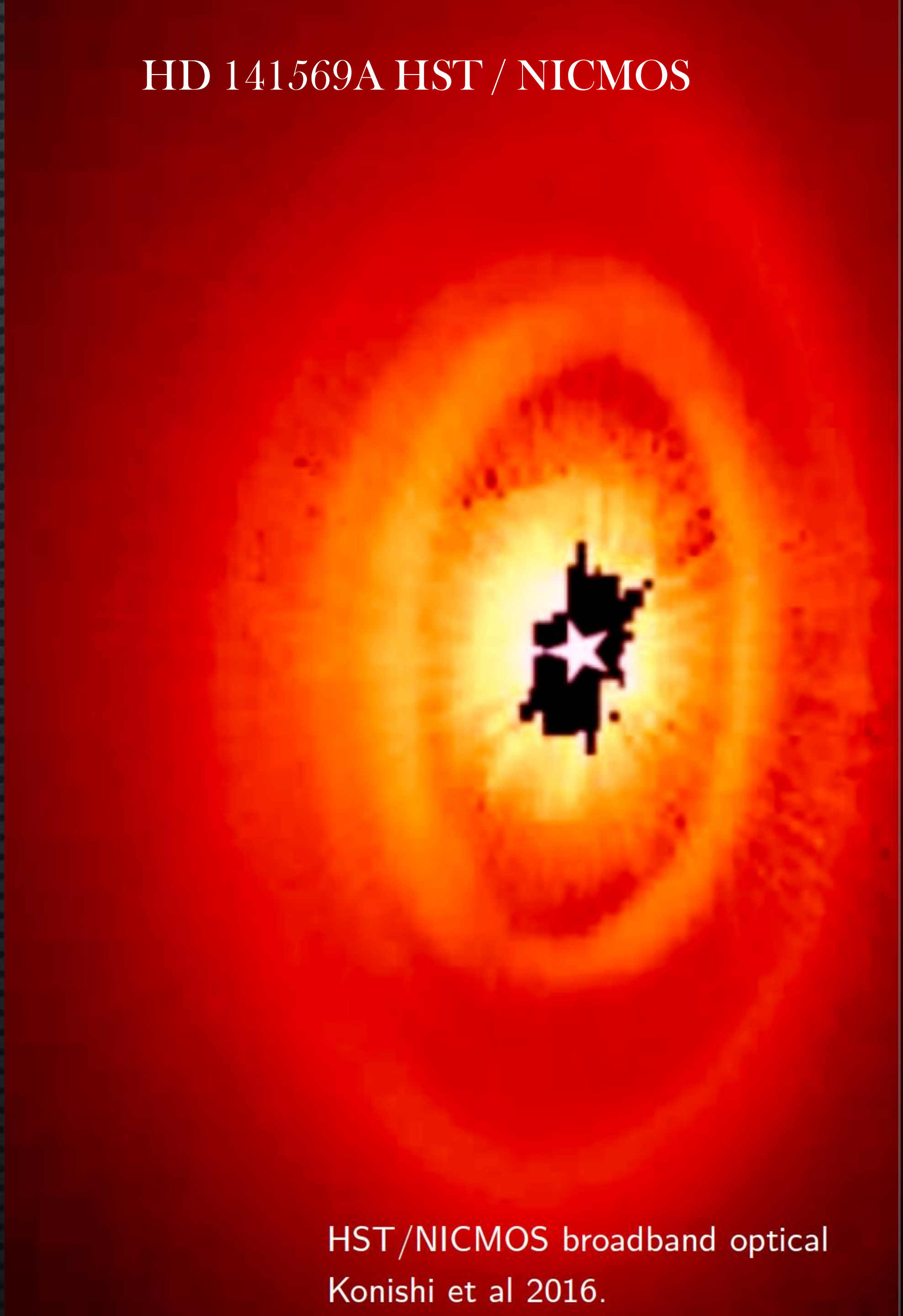
Marois et al., 2006

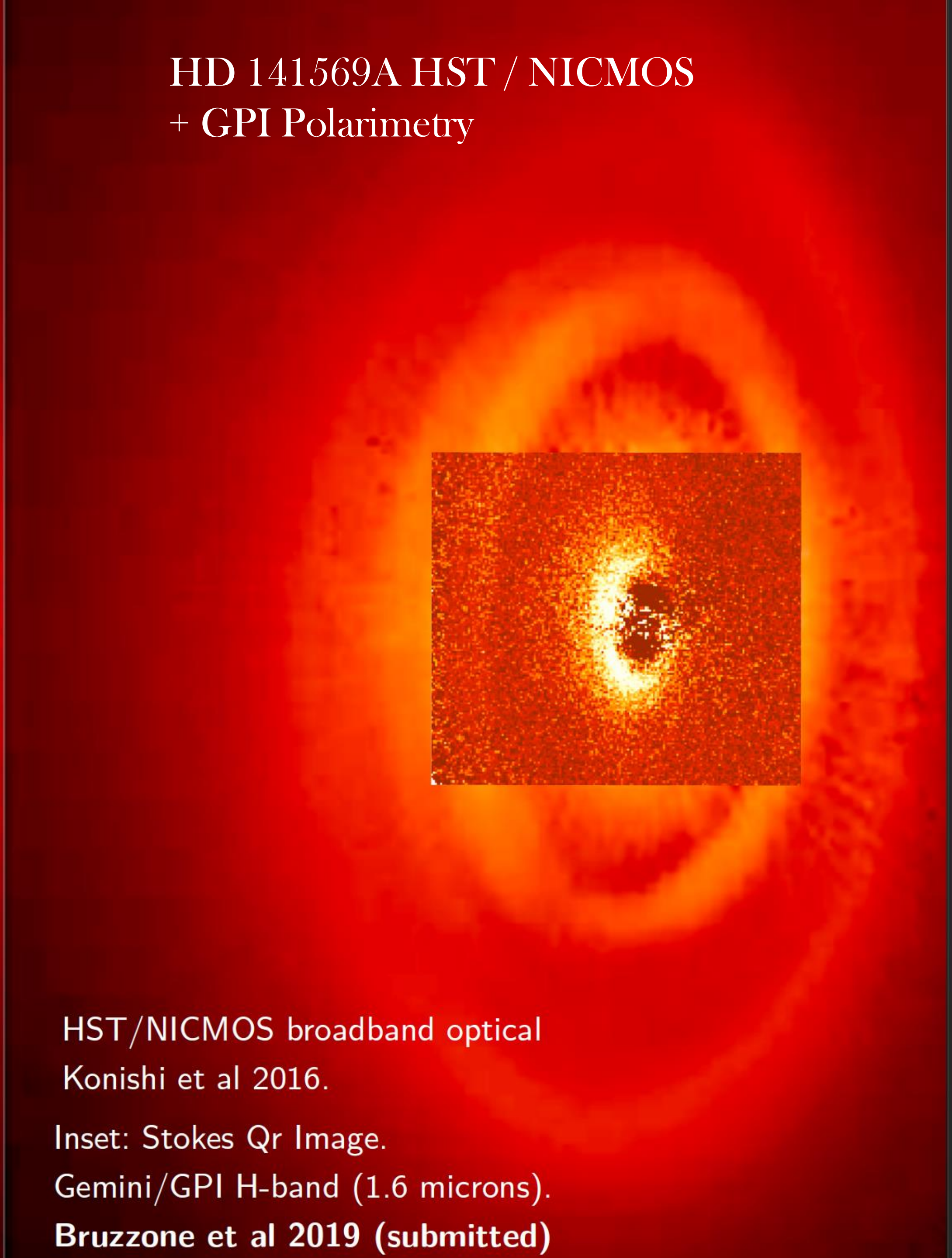


Macintosh et al., 2015

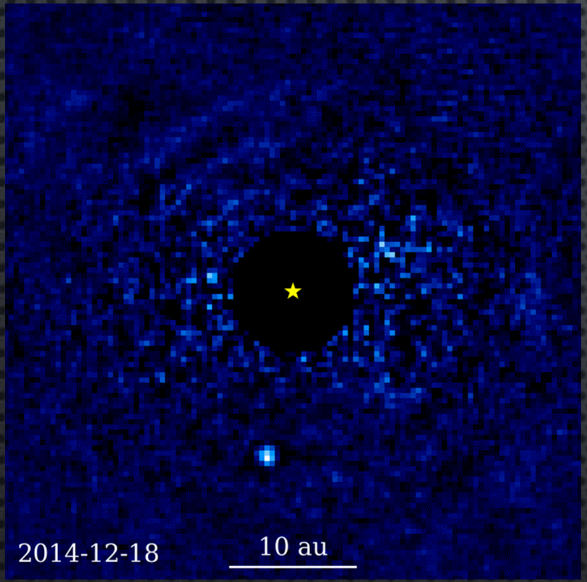


Perrot et al., 2016

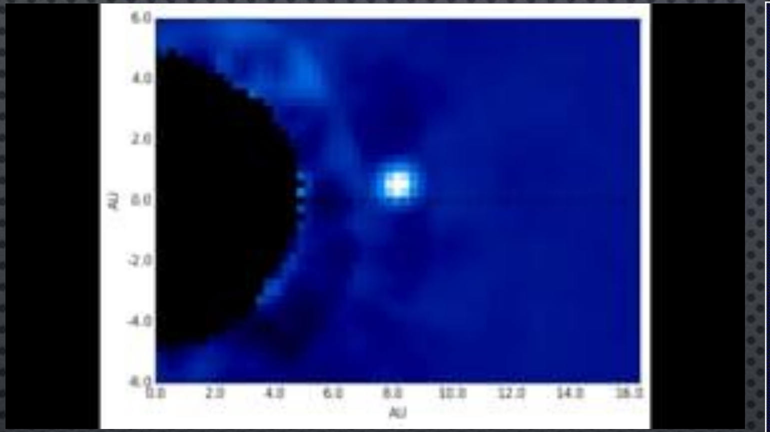

HD 141569A HST / NICMOS
HST/NICMOS broadband optical
Konishi et al 2016.


HD 141569A HST / NICMOS
+ GPI Polarimetry
HST/NICMOS broadband optical
Konishi et al 2016.
Inset: Stokes Qr Image.
Gemini/GPI H-band (1.6 microns).
Bruzzone et al 2019 (submitted)

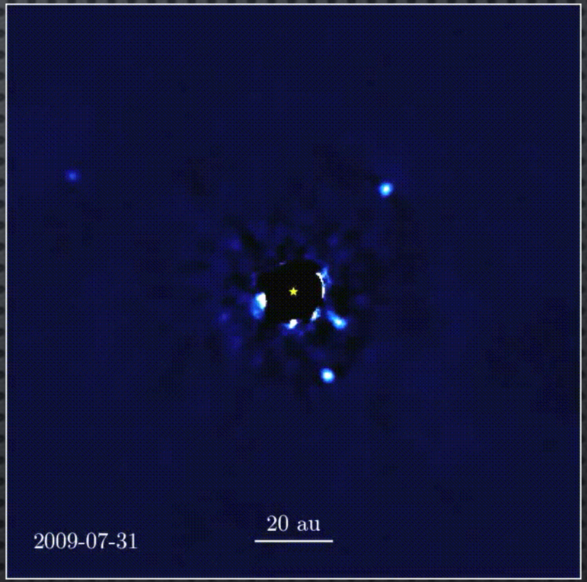
¿HABÍAS VISTO EXOPLANETAS ORBITAR SUS ESTRELLAS?



51 Eri b.
GPI Team

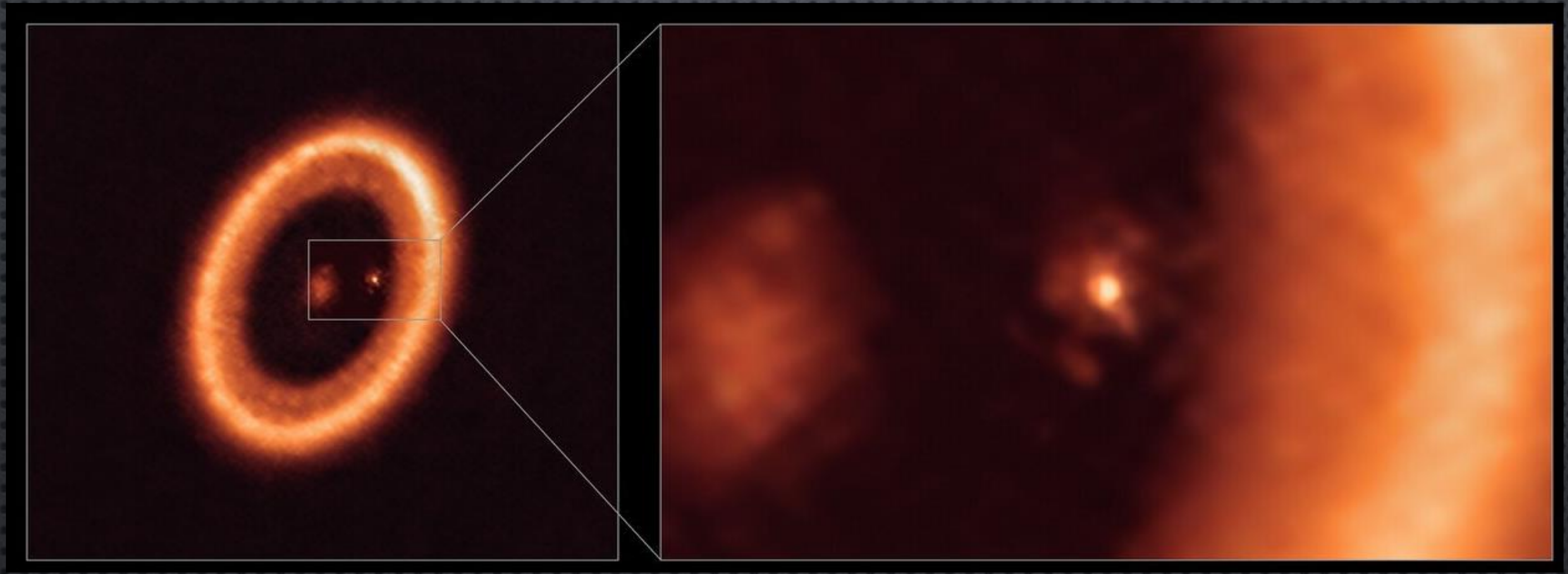


Beta Pictoris b. GPI Team



HR 8799
GPI Team

¿HABÍAS VISTO UNA LUNA EN FORMACIÓN?



PDS 70c y su disco circumplanetario formando posiblemente una luna. ALMA

Recursos

https://exoplanetarchive.ipac.caltech.edu/index.html
http://exoplanets.org
http://exoplanet.eu
http://exoplanets.nasa.gov

TESS: https://heasarc.gsfc.nasa.gov/docs/tess/
KELT: https://keltsurvey.org/about
KEPLER https://www.nasa.gov/mission_pages/kepler/main/index.html

Gemini Planet Imager: http://planetimager.org
SPHERE en VLT: https://www.eso.org/sci/facilities/paranal/instruments/sphere.html

NASA Eyes on Exoplanets: https://eyes.nasa.gov/eyes-on-exoplanets.html