Exoplanety

Vybrané kapitoly z astrofyziky
Podzim 2015
AI MFF UK

Observations of Venus

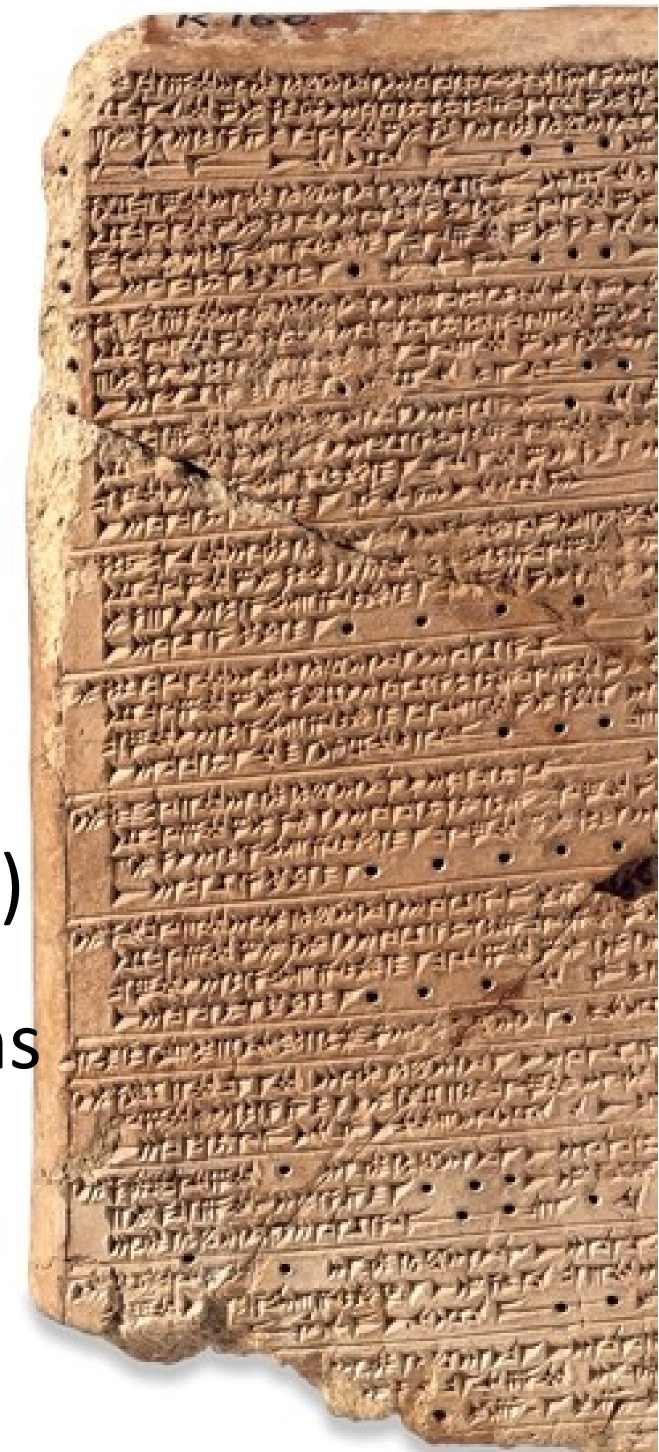
- Babylonian observations of Venus

  span of more than 20 years

  in approx. 17th century BC
- This copy from 7 BC in cuneiform
- Recognition of periodicity (Venus cycles)
- First recorded astronomical observations
- Ammisaduqa 4th after Hammurabi

V. G. Gurzadyan - http://arxiv.org/pdf/physics/0311035v1.pdf

http://www.britishmuseum.org/explore/highlights/highlight_objects/me/c/cuneiform_venus.aspx



British Mus

IAU Resolution: Definition of a "Planet" in the Solar System

Contemporary observations are changing our understanding of planetary systems, and it is important that our nomenclature for objects reflect our current understanding. This applies, in particular, to the designation "planets". The word "planet" originally described "wanderers" that were known only as moving lights in the sky. Recent discoveries lead us to create a new definition, which we can make using currently available scientific information.

RESOLUTION 5A

The IAU therefore resolves that planets and other bodies in our Solar System, except satellites, be defined into three distinct categories in the following way:

(1) A "planet" [1] is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (c) has cleared the neighbourhood around its orbit.

(2) A "dwarf planet" is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape [2], (c) has not cleared the neighbourhood around its orbit, and

(d) is not a satellite.

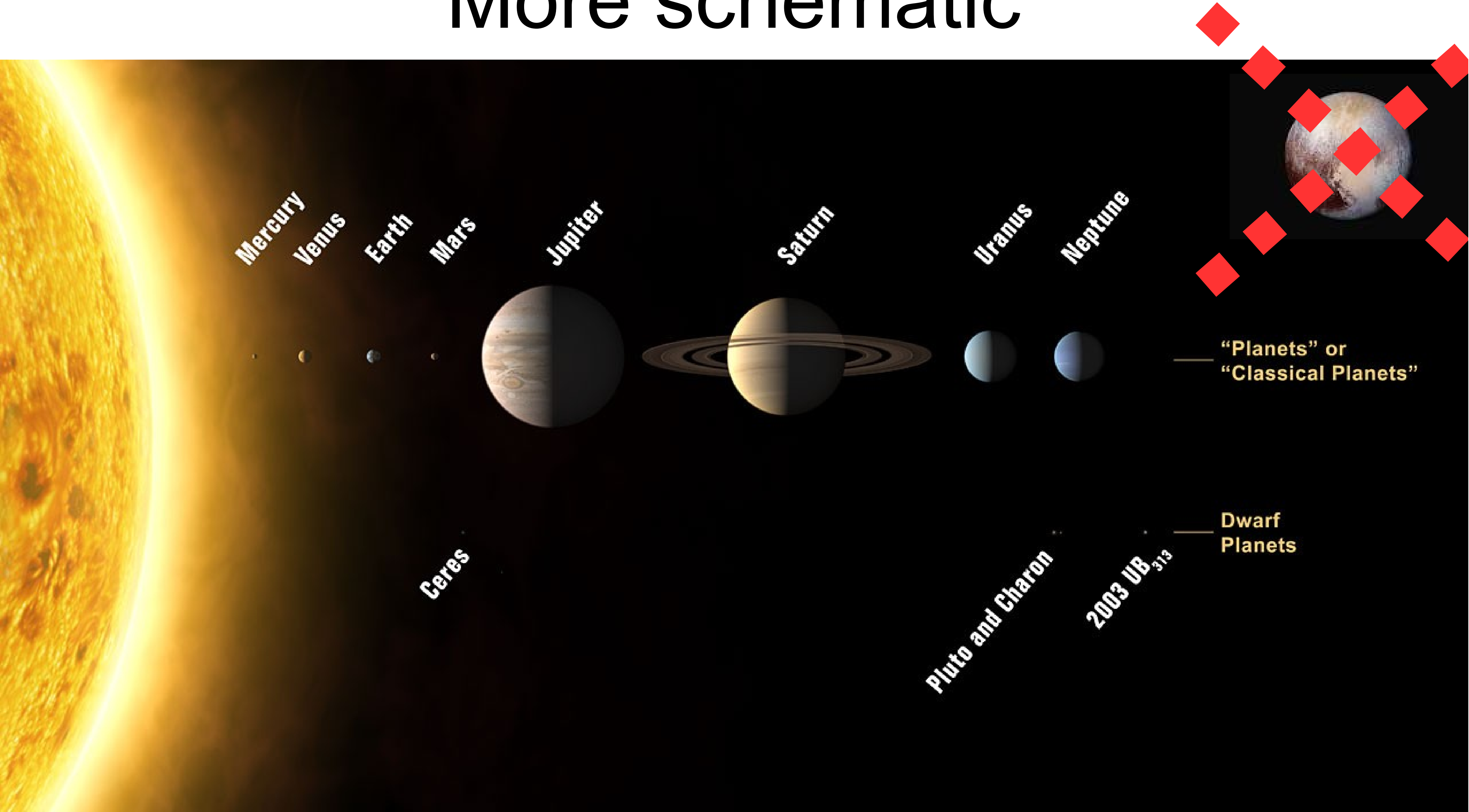
(3) All other objects [3], except satellites, orbiting the Sun shall be referred to collectively as "Small Solar-System Bodies".

RESOLUTION 6A

The IAU further resolves:

Pluto is a "dwarf planet" by the above definition and is recognized as the prototype of a new category of trans-Neptunian objects.

More schematic



http://www.iau.org/news/pressreleases/detail/iau0603/

An Exoplanet

A planet orbiting a star other than Sun

Motivation

- Are we alone in the Universe
- Search for extraterrestrial life – Earth-like planets
- Statistical distribution of exoplanets
- How do planetary systems evolve?

Image NASA

Lectures fall 2015

- Lecture 1: Overview and summary on planets

(07 October 2015)

- Lecture 2: Methods to detect exoplanets

(14 October 2015)

- Lecture 3 : Characterization of exoplanets

(21 October 2015)

- Lecture 4 : Future of exoplanetary research

(04 November 2015)

Outline: Lecture 1

- History of planet hunting over centuries
- Modern days
- First planets detected
- How many planets do we know today? State of the art?

Ancient times to nowadays

- There are innumerable worlds of different sizes. In some there is neither sun not moon, in others they are larger than in ours and others have more than one. These worlds are at irregular distances, more in one direction and less in another, and some are flourishing, others declining. Here they come into being, there they die, and they are distroyed by collision with one another. Some of the worlds have no animal or vegetable life nor any water.

Democritus 460-370 BC, A History of Greek Philosophy: Volume 2, The Presocratic Tradition from Parmenides to Democritus

By W. K. C. Guthrie, William Keith Chambers Guthrie

Ancient times

- Epicurius (341-270 BC)

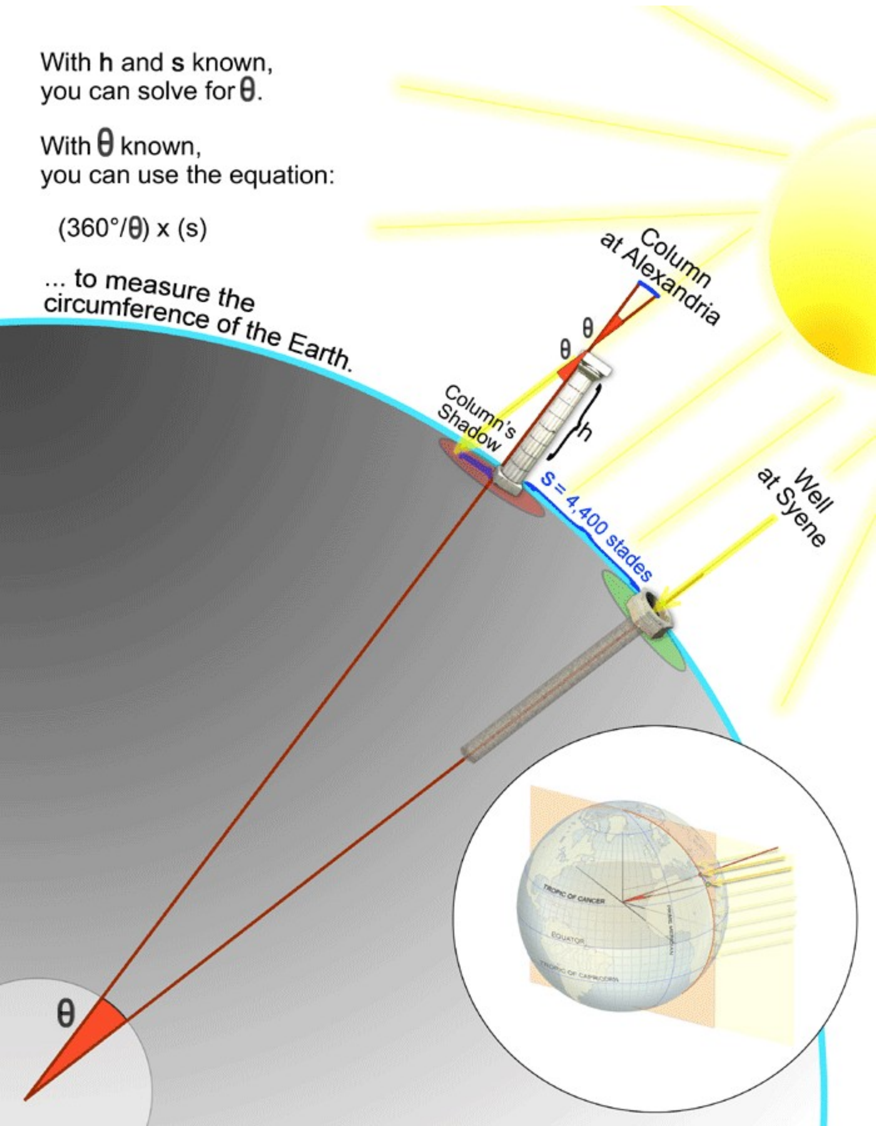
"Th ere are infinite worlds both like and

unlike this world of ours" inhabited by "living creatures and plants and other things we see in this world.

- Letter to Herodotus about 300 BC
  http://users.manchester.edu/Facstaff/SSNaragon/Online/texts/316/Epicurus,%20LetterHerodotus.pdf

Circumference of the Earth

- Eratosthenes



Eratosthenes of Cyrene (c. 276 BC – c. 195/194 BC) was a Greek mathematician, geographer, poet, astronomer, and music theorist.

Measured the Earth size to be about 250.000 stadii -> anything between 39.000 – 46.000 km depedndent on the stadium length

Today's value for Earth circumference is: 40.075 km

Therefore, Eratosthenes measured the size of Earth only with an error less than 20%!

Image from:
http://oceanservice.noaa.gov/education/kits/geodesy/media/supp_geo02a.html

http://www.windows2universe.org/the_universe/uts/eratosthenes_calc_earth_size.html

Copernicus (1473-1543)

- Copernicus proposes that Earth orbits the Sun with other planets
- Solar system with a Sun as a central body
- HELIOCENTRIC MODEL (publ. 1543)

Jan Matejko's 1872 painting, Wikipedia

Giordano Bruno

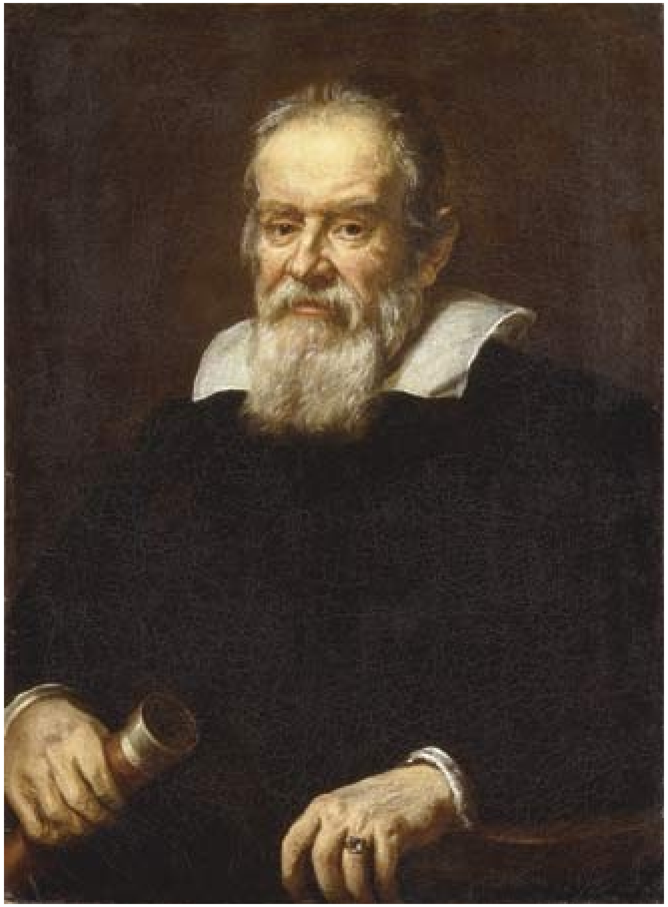
- Disputed the uniquenes of the Earth
- Supports Copernicu's model of the Solar system
- Proposes that there are other planets in the Universe

De l'infinito universo et mondi

(On the Infinite Universe and Worlds, 1584)

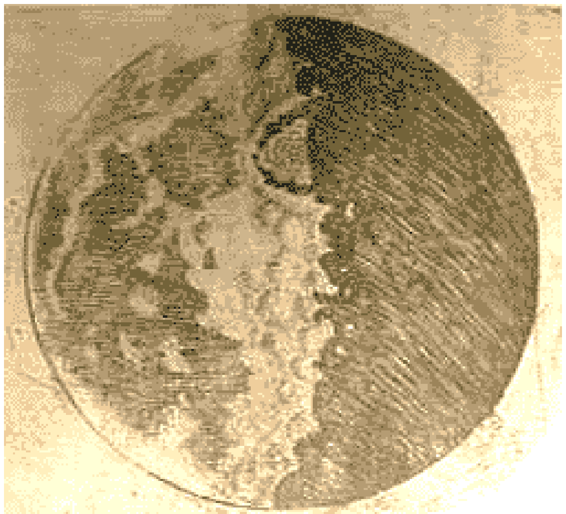
Galileo (1564-1642)

- Telescope
- First observations:
  - planets in the Solar system
  - Gallielan moons
  - Moon details



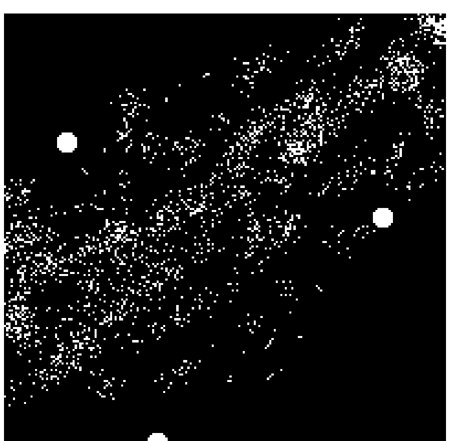
Wikipedia

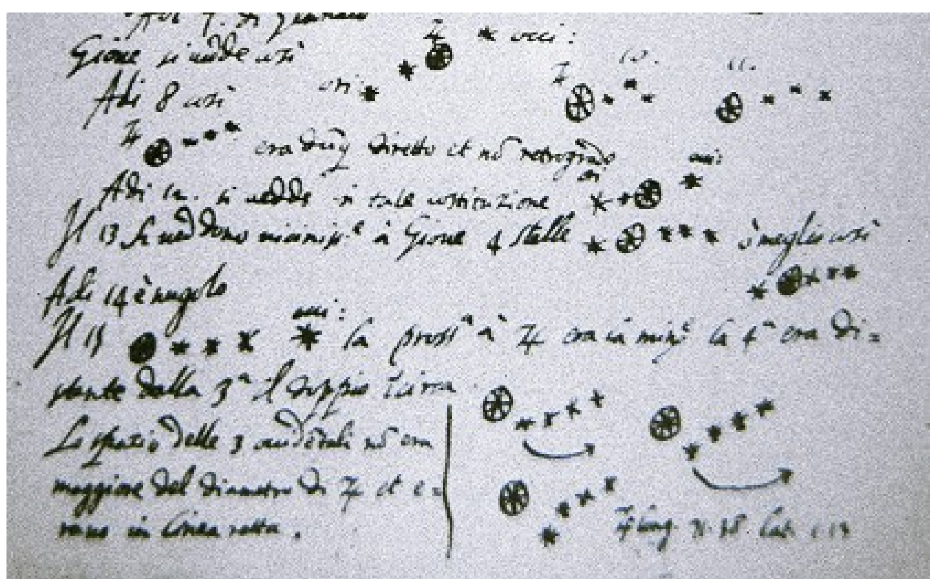
First discoveries with the telescope

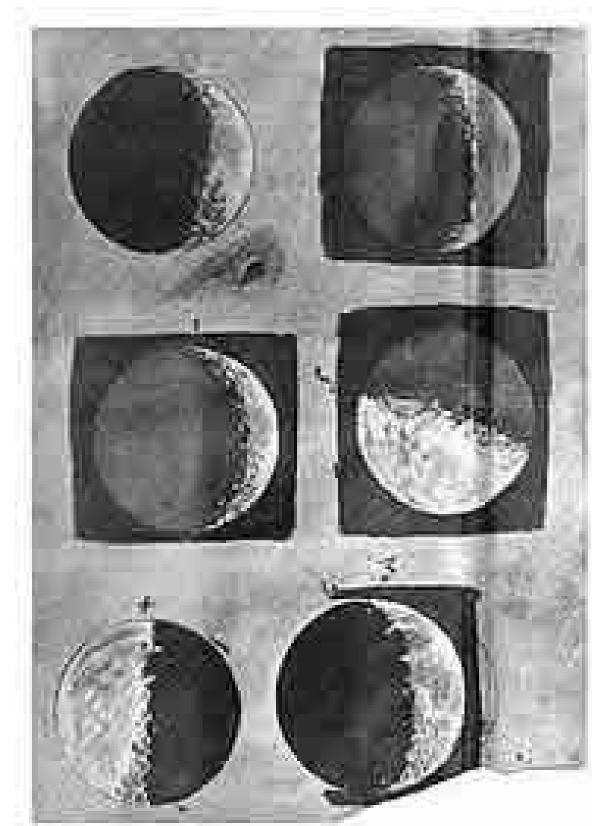


One of Galileo's drawings of the moon. 1610 A. D.

- The Moon
- Galilean moons (Shephard moons)
- Sun spots
- Planets drawings
- The Milky way





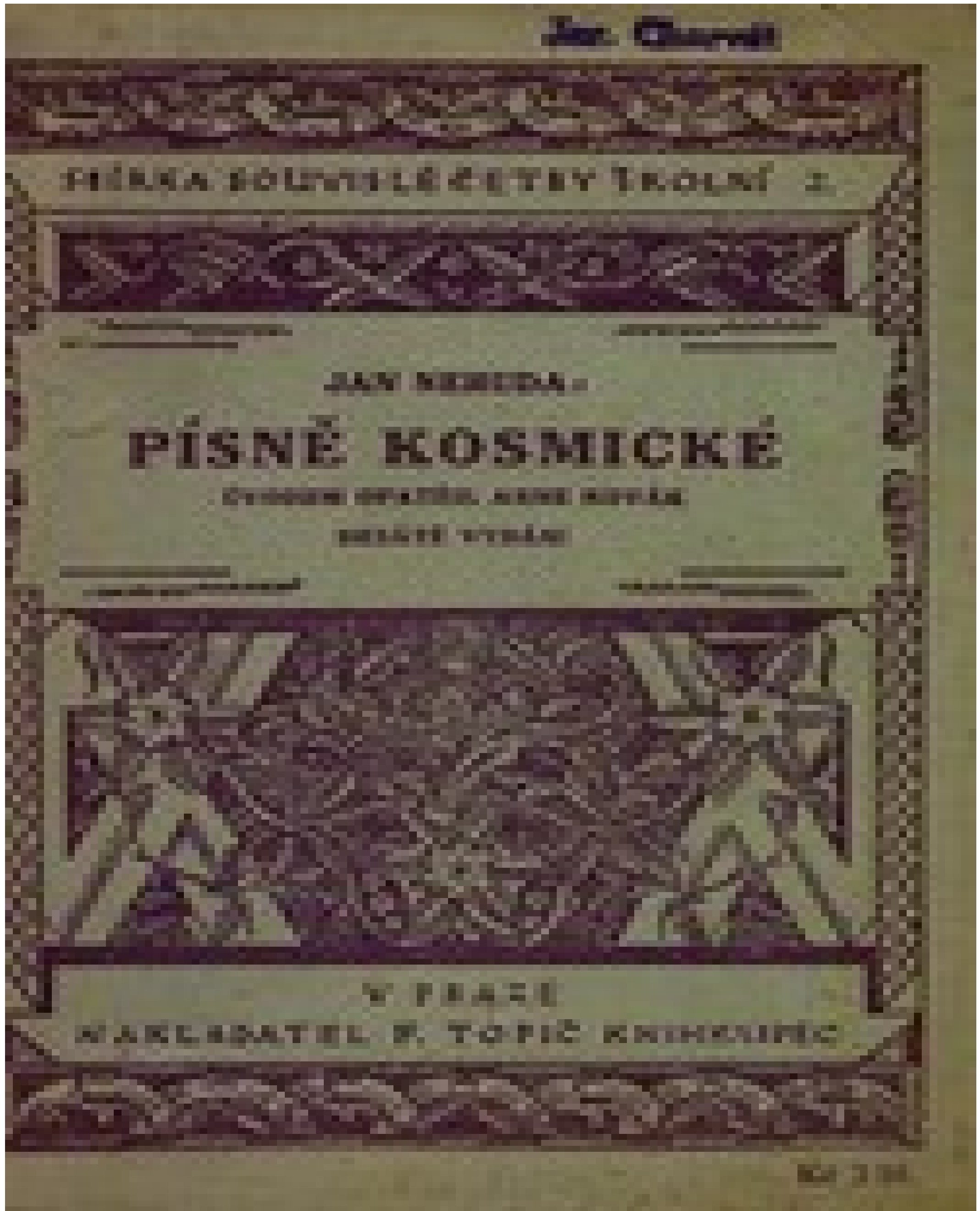


Christian Huygens

- Work The Cosmotheoros (1698)
  - how would life on other planets be?
  - planets similar to Earth
  - water and life as we know it from the Earth

http://www.staff.science.uu.nl/~gent0113/huygens/huygens_ct_en.htm

Jan Neruda


JAN NERUDA
PÍSNĚ KOSMICKÉ
V PRAZE
NAKLADATEL F. TOPIČ KNIHKUPEC

O hvězdách potom podotknul,
po nebi co jich všude,
skoro že samá slunce jsou,
zelené, modré, rudé.

Vezmem-li pak pod spektroskop
paprslek jejich světla,
že v něm nálezném kovy tyž,
z nichž se i Země spletla.

Umlknul. Kolem horlivě
šuškají posluchači.
Žabák se ptá, zdaž o světech
ještě cos zvědít ráči.

„Jen bychom rády věděly,“
vrch hlavy poulí zraky,
„jsou-li tam tvoři jako my,
jsou-li tam žáby taky!“

http://web2.mlp.cz/koweb/00/03/37/00/56/pisne_kosmicke.pdf

Modern days

Otto Struve (1897-1963)

- First thoughts how to detect the alien worlds
  - spectroscopy
  - photometry

- Paper from 1952 – On high precision radial velocities
- measurements

McDonald Observatory archives

http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?1952Obs....72..199S&data

there is a good chance that by using somewhat larger equipment at the next eclipse, definite and accurate measurements of line width will become available.

I should like to say here how indebted we are to Professor Redman who at very short notice acquired a site for us at Khartoum and without whose assistance we should hardly have been able to set up our instruments in the short time available to us.

Mr. Sadler. I ask you to return your thanks to Prof. Brück and to all those who have taken part in this Colloquium. It is my task to predict eclipses, not to observe them but we have all found these preliminary accounts of the results expected, with varying degrees of optimism, most interesting. The meeting is now adjourned at $12^h\ 40^m$.

PROPOSAL FOR A PROJECT OF HIGH-PRECISION STELLAR RADIAL VELOCITY WORK

By Otto Struve

With the completion of the great radial-velocity programmes of the major observatories, the impression seems to have gained ground that the measurement of Doppler displacements in stellar spectra is less important at the present time than it was prior to the completion of R. E. Wilson's new radial-velocity catalogue.

I believe that this impression is incorrect, and I should like to support my contention by presenting a proposal for the solution of a characteristic astrophysical problem.

One of the burning questions of astronomy deals with the frequency of planet-like bodies in the galaxy which belong to stars other than the Sun. K. A. Strand's[1] discovery of a planet-like companion in the system of 61 Cygni, which was recently confirmed by A. N. Deitch[2] at Poulkovo, and similar results announced for other stars by P. Van de Kamp[3] and D. Reuyl and E. Holmberg[4] have stimulated interest in this problem. I have suggested elsewhere that the absence of rapid axial rotation in all normal solar-type stars (the only rapidly-rotating G and K stars are either W Ursae Majoris binaries or T Tauri nebular variables,[5] or they possess peculiar spectra[6]) suggests that these stars have somehow converted their angular momentum of axial rotation into angular momentum of orbital motions of planets. Hence, there may be many objects of planet-like character in the galaxy.

But how should we proceed to detect them? The method of direct photography used by Strand is, of course, excellent for nearby binary systems, but it is quite limited in scope. There seems to be at present no way to discover objects of the mass and size of Jupiter; nor is there much hope that we could discover objects ten times as large in mass as Jupiter, if they are at distances of one or more astronomical units from their parent stars.

But there seems to be no compelling reason why the hypothetical stellar planets should not, in some instances, be much closer to their parent stars than is the case in the solar system. It would be of interest to test whether there are any such objects.

We know that *stellar* companions can exist at very small distances. It is not unreasonable that a planet might exist at a distance of 1/50 astronomical unit, or about 3,000,000 km. Its period around a star of solar mass would then be about 1 day.

We can write Kepler's third law in the form $V^3 \sim \frac{1}{P}$. Since the orbital velocity of the Earth is 30 km/sec, our hypothetical planet would have a velocity of roughly 200 km/sec. If the mass of this planet were equal to that of Jupiter, it would cause the observed radial velocity of the parent star to oscillate with a range of $\pm$ 0·2 km/sec—a quantity that might be just detectable with the most powerful Coudé spectrographs in existence. A planet ten times the mass of Jupiter would be very easy to detect, since it would cause the observed radial velocity of the star to oscillate with $\pm$ 2 km/sec. This is correct only for those orbits whose inclinations are 90°. But even for more moderate inclinations it should be possible, without much difficulty, to discover planets of 10 times the mass of Jupiter by the Doppler effect.

There would, of course, also be eclipses. Assuming that the mean density of the planet is five times that of the star (which may be optimistic for such a large planet) the projected eclipsed area is about 1/50th of that of the star, and the loss of light in stellar magnitudes is about 0·02. This, too, should be ascertainable by modern photoelectric methods, though the spectrographic test would probably be more accurate. The advantage of the photometric procedure would be its fainter limiting magnitude compared to that of the high-dispersion spectrographic technique.

Perhaps one way to attack the problem would be to start the spectrographic search among members of relatively wide visual binary systems, where the radial velocity of the companion can be used as a convenient and reliable standard of velocity, and should help in establishing at once whether one (or both) members are spectroscopic binaries of the type here considered.

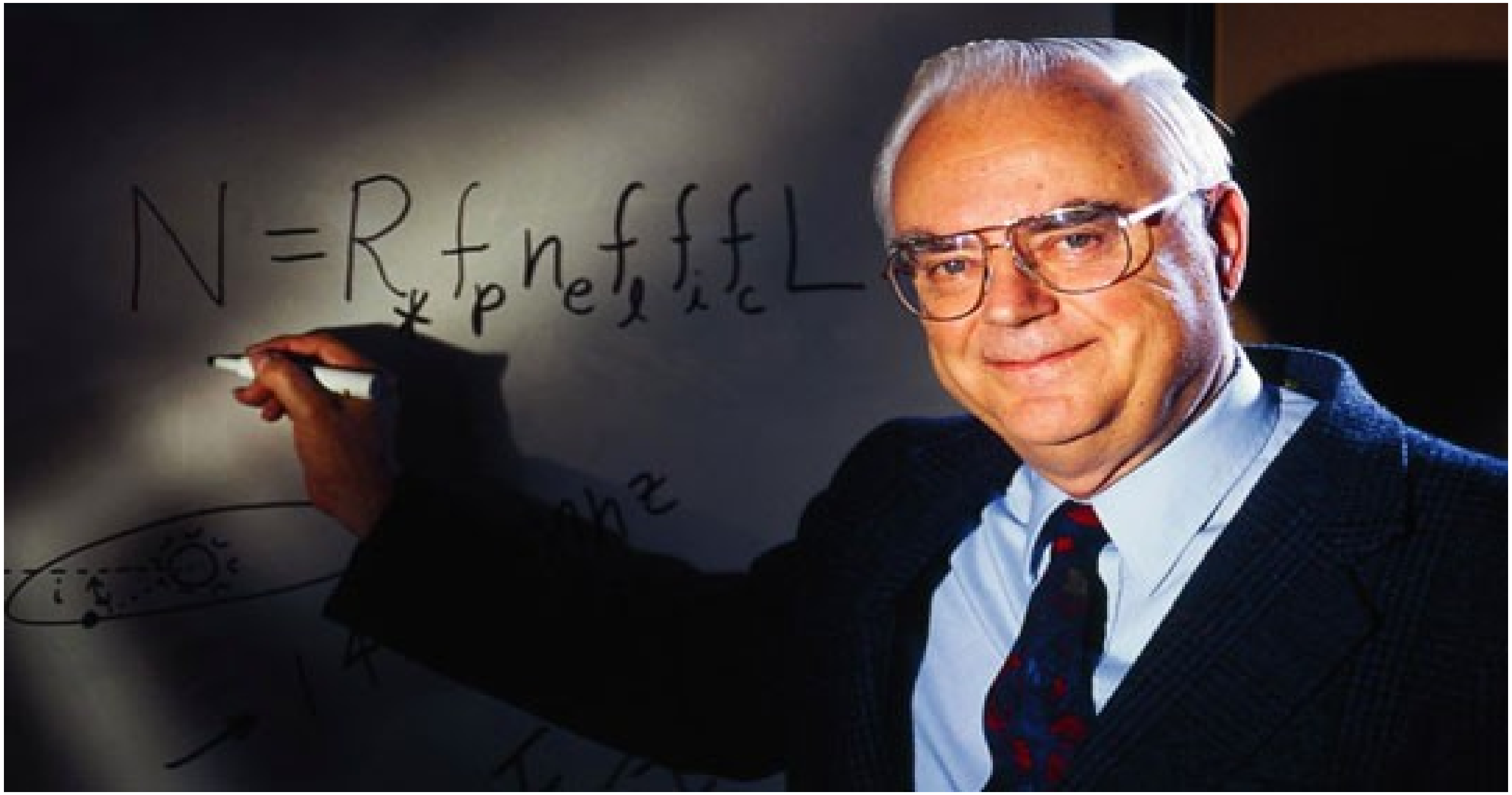
Berkeley Astronomical Department,
University of California.
1952 July 24.

References

1. *A.J.*, **51**, 12, 1944; *Pub. A.S.P.*, **55**, 29, 1952.
2. *Izvestia Gl. Astr. Obs., Poulkovo*, **18**, No. 146, 1951.
3. *A.J.*, **51**, 7, 1944.
4. *Ap. J.*, **97**, 41, 1943.
5. See G. Herbig's paper presented at the Victoria 1952 meeting of the *A.A.S.* and *A.S.P.*
6. See P. W. Merrill's note on HD 117555 in *Pub. A.S.P.*, **60**, 382, 1948.

Life in the Galaxy

- Are we alone?
- Frank Drake - 1960



www.space.com

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

N – number of civilizations able of radio comm.

- R^* = the average rate of star formation in our galaxy
- f_p = the fraction of those stars that have planets
- n_e = the average number of planets that can potentially support life per star that has planets
- f_l = the fraction of planets that could support life that actually develop life at some point
- f_i = the fraction of planets with life that actually go on to develop intelligent life (civilizations)
- f_c = the fraction of civilizations that develop a technology that releases detectable signs of their existence into space
- L = the length of time for which such civilizations release detectable signals into space

So the answer was (in 1960)?

10-20

Carl Sagan - Cosmos

But where all the planets are?

- Since Struve's proposal of RV measurements

  - no planets detected, yet
- There was instrumentation to detect planets in 1950s, so where are all the planets?

  - a transit can be detected by 20cm telescope
- First Radial Velocity surveys targeting specific stars

  - solar type stars – because of assumption of possible life friendly environment

And finally, first exoplanets detected

Detection of extreme planets

A planetary system around the millisecond pulsar PSR1257 + 12

A. Wolszczan &

D. A. Frail

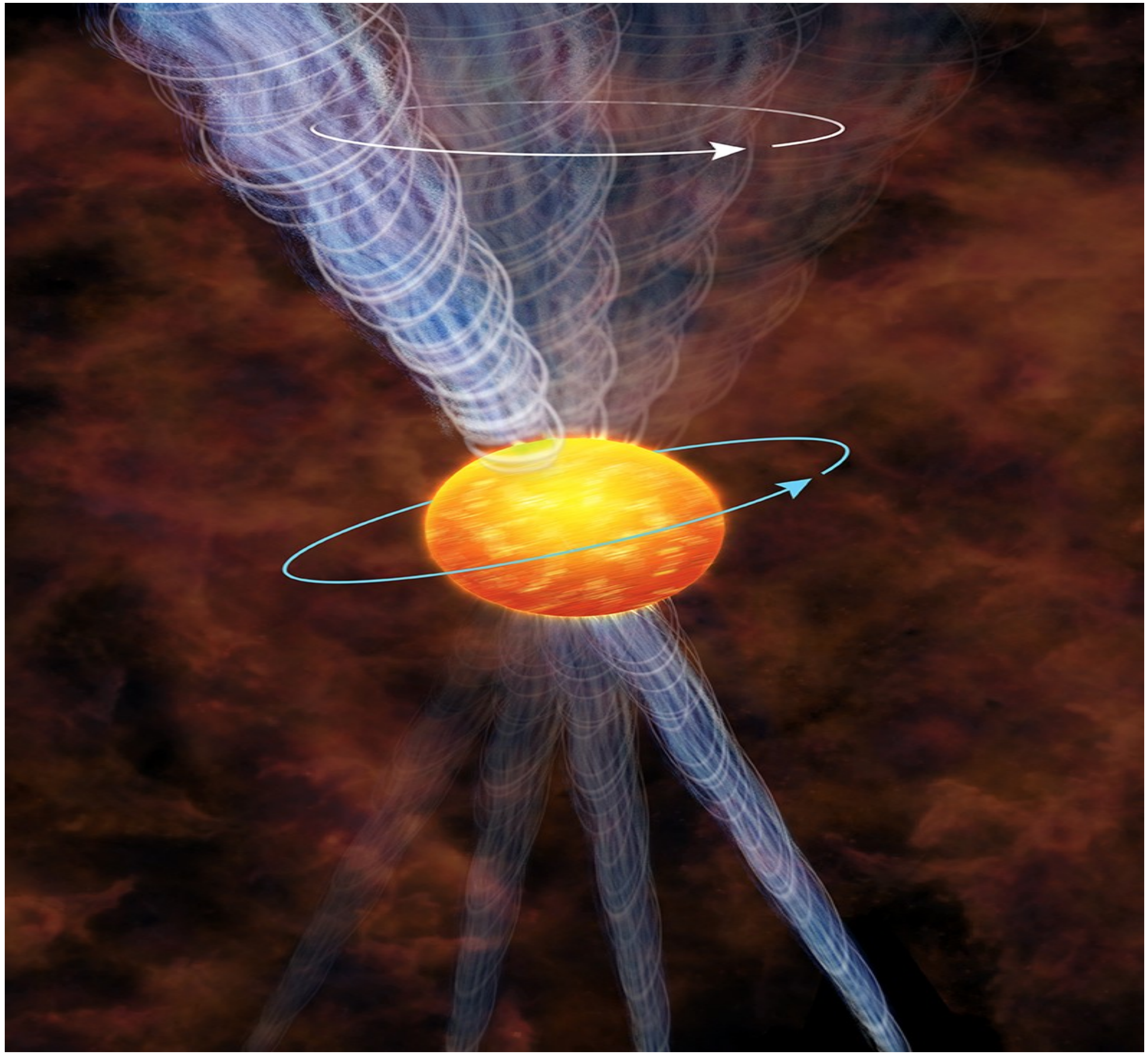
Letters to Nature

Nature 355, 145 - 147

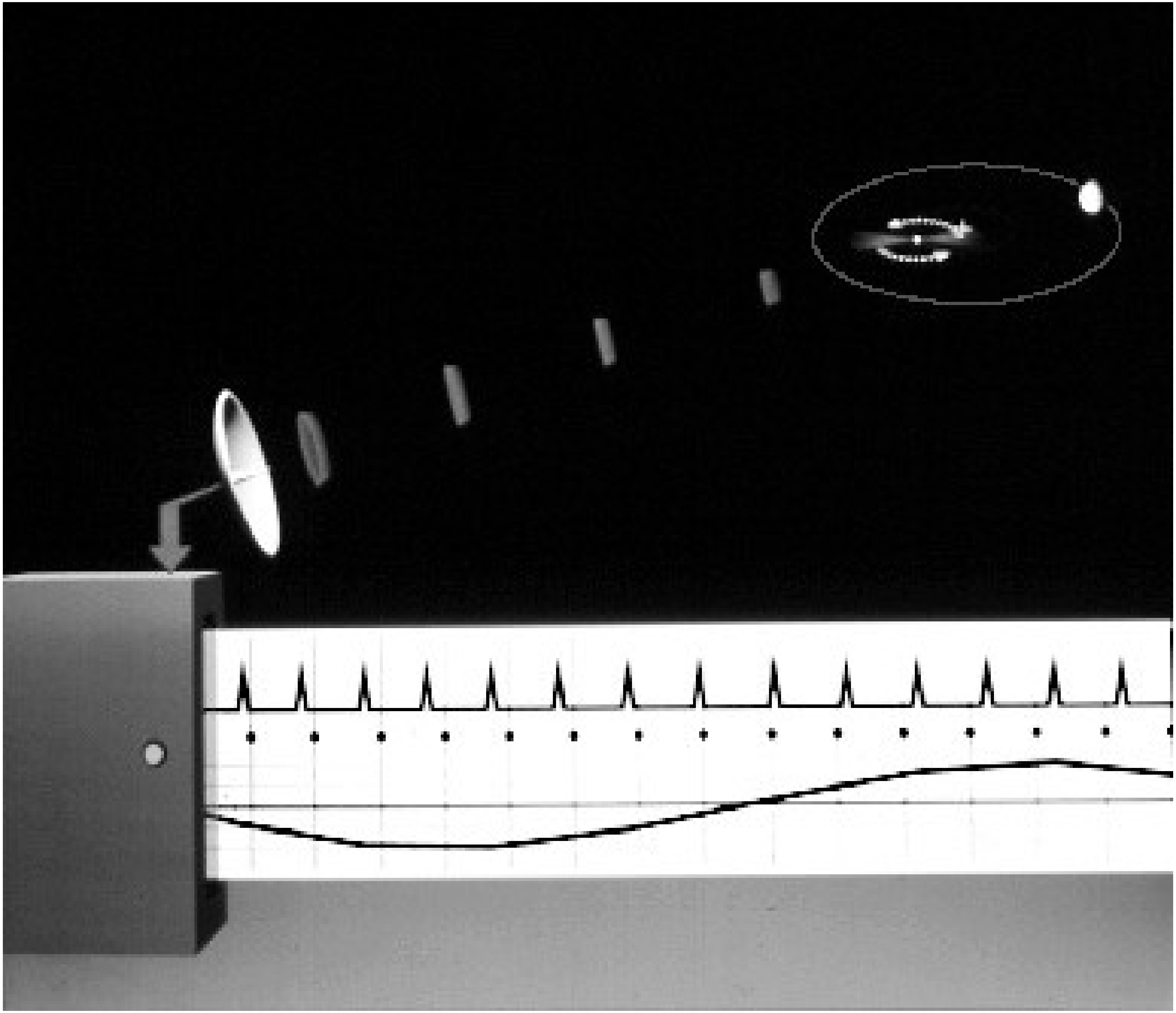
(09 January 1992);

Wikipedia

http://www.nature.com/nature/journal/v355/n6356/abs/355145a0.html



http://chandra.harvard.edu/photo/2013/vela/



http://www2.astro.psu.edu/users/alex/pulsar_planets_text.html

How did they form?

- Evidence of the disk around pulsars (2006 Spitzer)
- Forming after the death of the star?

A debris disk around an isolated young neutron star

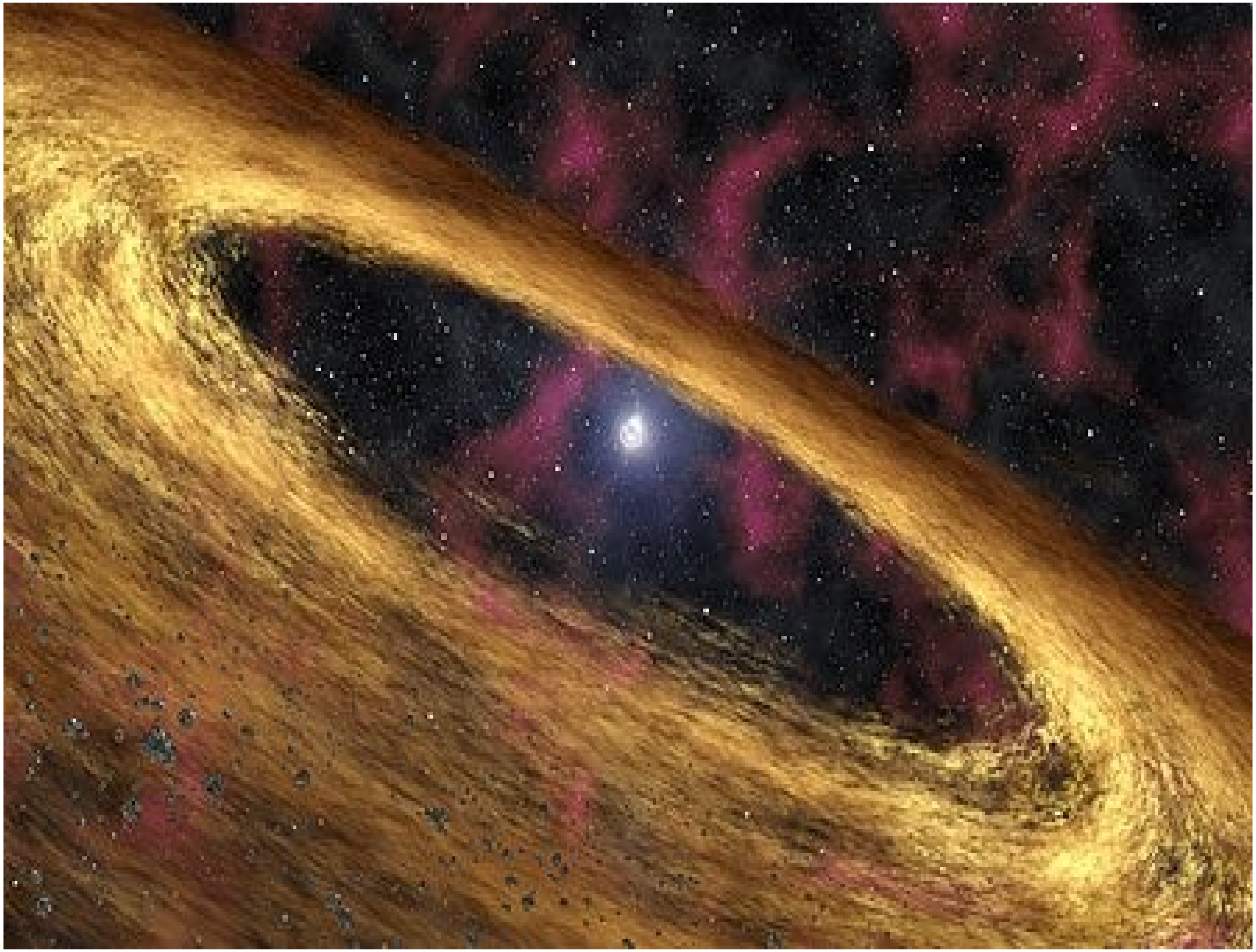
Zhongxiang Wang1, Deepto Chakrabarty1 & David L. Kaplan1

Nature 440, 772-775 (6 April 2006) | doi:10.1038/nature04669; Received 5 August 2005; Accepted 21 February 2006

Reading:

http://science.nasa.gov/science-news/science-at-nasa/2006/05apr_pulsarplanets/

http://www.nature.com/nature/journal/v440/n7085/full/nature04669.html



http://science.nasa.gov/science-news/science-at-nasa/2006/05apr_pulsarplanets/

But well, ….

- Pulsars environments are the most hostile places for life
- One of the main motivation is to find the extraterrestrial life, defined as we know it from the Earth (water, organic molcules, etc.)
- Therefore, planets around solar type stars are more suitable targets for surveys
- Solar type (spectral type similar F-K), Solar analogs (similar Teff), solar twins (same Teff, same metallicity)

Radial Velocity surveys

- Mesurements of Radial Velocities with high accuracies (m/s regimes)
- Spectral type catalogs
- Serching among bright stars in the solar neighbourhood
- First planet around solar type star detected by radial velocity survey in 1995
- So how does radial velocity measurement work?

Like for binaries just,

- the mass of the object causing the radial velocity variation is much smaller

(planets are defined as less massive than 13 Jupiter Masses)

- So, the accuracies needed are m/s instead of km/s as for bianaries
- targeting suitable stars

A&A 418, 989–1019 (2004)
DOI: 10.1051/0004-6361:20035959

Astronomy & Astrophysics

The Geneva-Copenhagen survey of the Solar neighbourhood⋆,⋆⋆

Ages, metallicities, and kinematic properties of ∼14 000 F and G dwarfs

B. Nordström[1,4], M. Mayor[3], J. Andersen[2,5], J. Holmberg[2,5], F. Pont[3], B. R. Jørgensen[4], E. H. Olsen[2], S. Udry[3], and N. Mowlavi[3]

[1] Niels Bohr Institute for Astronomy, Physics & Geophysics, Blegdamsvej 17, 2100 Copenhagen, Denmark
[2] Astronomical Observatory, NBIfAFG, Juliane Maries Vej 30, 2100 Copenhagen, Denmark
[3] Observatoire de Genève, 51 Ch. des Maillettes, 1290 Sauverny, Switzerland
[4] Lund Observatory, Box 43, 22100 Lund, Sweden
[5] Nordic Optical Telescope Scientific Association, Apartado 474, 38700 Santa Cruz de La Palma, Spain

Received 31 December 2003 / Accepted 23 January 2004

Table A.1. Sample left-hand page of the catalogue (Fields 1-25 for the first 100 stars).

HIP	Name	Comp	f_b	f_s	RA J2000 h m s	Dec J2000 ° ′ ″	l °	b °	V mag	b-y mag	β	E(b-y) mag	$logT_e$	[Fe/H]	d pc	M_v mag	δM_v mag	f_r	f_g	age Gy	σ_{age}^{low} Gy	σ_{age}^{high} Gy	mass $M_\odot$	σ_{mass}^{low} $M_\odot$	σ_{mas}^{high} $M_{(}$
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	2
437	HD 15		*		00 05 17.8	+48 28 37	115	-14	8.304	0.592								G	*						
431	HD 16				00 05 12.4	+36 18 13	113	-26	8.092	0.311			3.810	0.10											
420	HD 23				00 05 07.4	-52 09 06	319	-64	7.552	0.366	2.626	0.015	3.770	-0.19	42	4.44	0.49	H		7.6	3.6	10.9	0.99	0.94	1.0
425	HD 24		*		00 05 09.7	-62 50 42	312	-53	8.146	0.377	2.607	0.013	3.763	-0.31	70	3.91	1.29	H		9.3	7.8	11.0	1.01	0.97	1.0
	HD 25				00 05 22.3	+49 46 11	115	-12	7.590	0.256	2.675	-0.005	3.828	-0.38	87	2.89	0.91	F		2.0	1.6	2.4	1.31	1.24	1.3
447	HD 26		*		00 05 22.2	+08 47 16	104	-52	8.238	0.645	2.546							G	*						
461	HD 39	AB	*		00 05 29.0	+34 06 20	112	-28	7.852	0.337	2.628	0.014	3.784	-0.55	91	3.06	1.85	H		4.7	4.0	5.6	1.14	1.09	1.2
	HD 59				00 05 33.5	+46 39 46	115	-15	8.595	0.363	2.613	0.007	3.772	-0.24	87	3.90	1.03	F		7.4	5.3	9.8	1.02	0.97	1.0
462	HD 63		*		00 05 31.1	-09 37 02	89	-69	7.132	0.298	2.663	0.008	3.806	-0.20	51	3.62	0.50	H		2.9	1.7	3.8	1.21	1.15	1.2
459	HD 67			*	00 05 28.4	-61 13 33	313	-55	8.822	0.424			3.743	-0.14	54	5.17	0.33	H					0.87	0.83	0.9
475	HD 70				00 05 41.6	+58 18 47	117	-4	8.221	0.395	2.582	0.010	3.752	-0.49	48	4.83	0.74	H		14.9	7.4		0.84	0.81	0.9
482	HD 85	AB	*		00 05 44.4	+17 50 25	108	-44	7.754	0.275	2.661	-0.014	3.820	-0.08	87	3.06	0.64	F		1.9	1.3	2.3	1.35	1.28	1.4
493	HD 101				00 05 54.7	+18 14 06	108	-43	7.456	0.373	2.598	0.001	3.765	-0.32	38	4.55	0.61	H		9.4	5.4	14.2	0.94	0.87	1.0
490	HD 105				00 05 52.5	-41 45 11	333	-73	7.509	0.373	2.627	0.019	3.766	-0.21	40	4.49	0.55	H		8.6	4.8	12.6	0.97	0.92	1.0
	HD 117	ABC	*		00 05 57.0	-30 19 41	12	-80	9.047	0.385	2.644	0.077	3.800	-0.26	98	3.76	0.55	F		3.3	2.0	4.7	1.14	1.07	1.2
518	HD 123	AB	*		00 06 15.8	+58 26 12	117	-4	5.978	0.421			3.746	0.04	20	4.44	0.85	H		12.8	8.5	15.1	0.98	0.92	1.0
510	HD 126		*		00 06 08.0	+09 42 53	105	-52	7.803	0.312	2.647	0.002	3.798	-0.21	90	3.03	1.28	H		2.7	2.3	3.1	1.31	1.23	1.3
522	HD 142	AB	*		00 06 19.1	-49 04 30	322	-66	5.710	0.330	2.640	0.006	3.791	-0.09	26	3.67	0.68	H		3.6	2.8	4.3	1.20	1.12	1.2
530	HD 153				00 06 26.0	+42 45 09	114	-19	8.357	0.388	2.601	0.010	3.763	-0.16	123	2.90	2.16	H		3.8	3.1	4.9	1.30	1.18	1.3
529	HD 156				00 06 24.9	-18 02 17	72	-76	7.311	0.248	2.699	0.007	3.844	0.23	131	1.72	1.27	F		1.1	0.9	1.3	1.87	1.75	2.0
519	HD 160	AB	*		00 06 16.8	-64 14 25	311	-52	7.801	0.291	2.689	0.036	3.840	0.25	160	1.63	1.41	F		1.1	0.8	1.3	1.92	1.79	2.0

The Case of 51 Peg

ELODIE at OHP

http://www.obs-hp.fr/www/guide/elodie/elodie-sans.html

http://www.obs-hp.fr/www/guide/elodie/elodie-sans.html

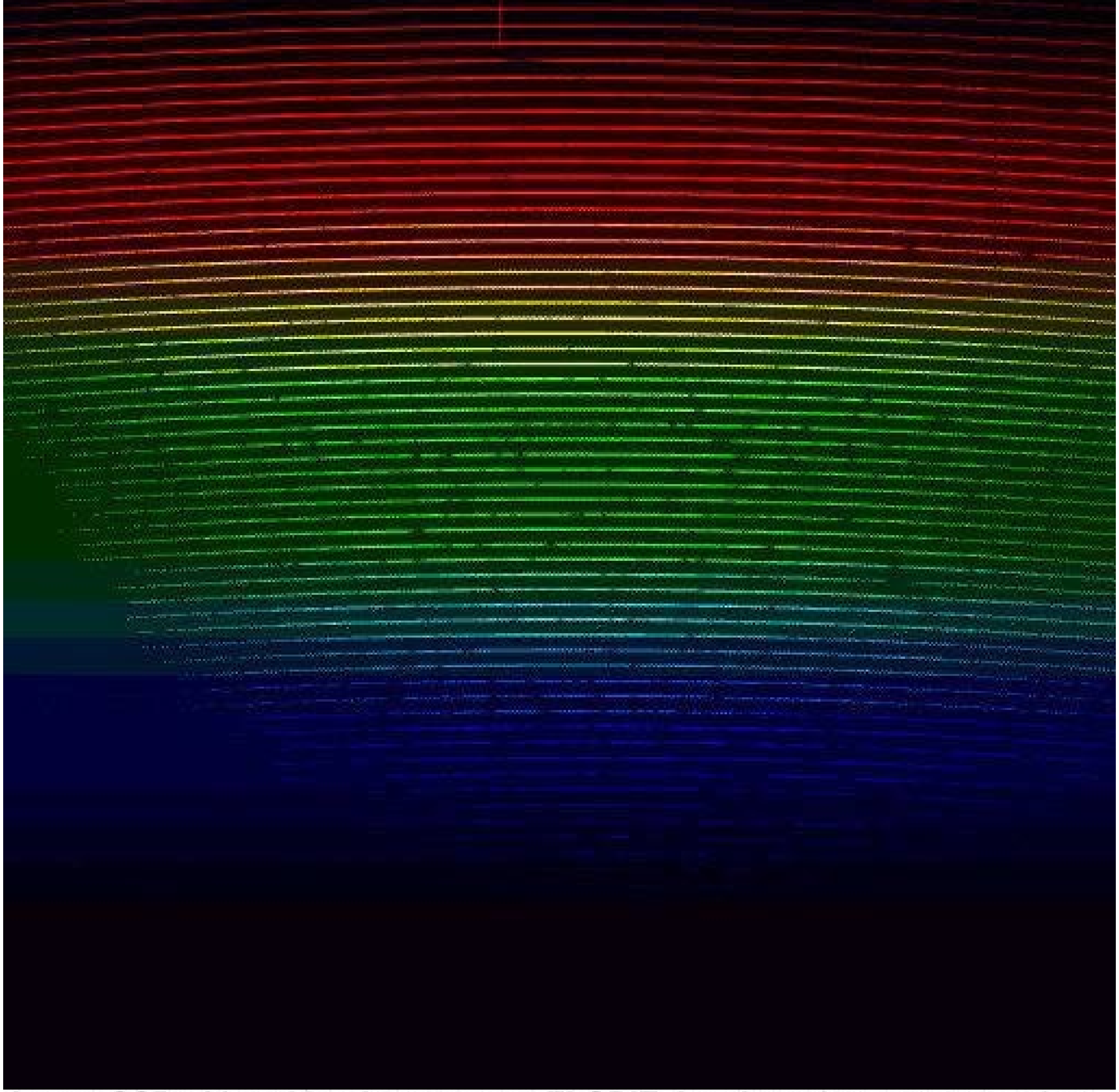


Image CCD 1024x1024 obtenue avec ELODIE. Les 67 ordres correspondant à la fibre étoile sont visibles. Les couleurs affichés correspondent approximativement au domaine spectral couvert (3850 - 6850 Å).

http://www.obs-hp.fr/www/guide/elodie/elodie-sans.html

ELODIE

- Echelle-spectrograph was located at Observatoire de Haute Provence at 1.93m telescope (now replaced by SOPHIE)
- Permitted measurements with accuracy down to 15m/s for 9 mag stars
- JUST A NOTE – WEATHER ABOUT 15 percent better than Ondrejov (ONLY)

http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?1996A%26AS..119..373B&data_type=PDF_HIGH&whole_paper=YES&type=PRINTER&filetype=.pdf

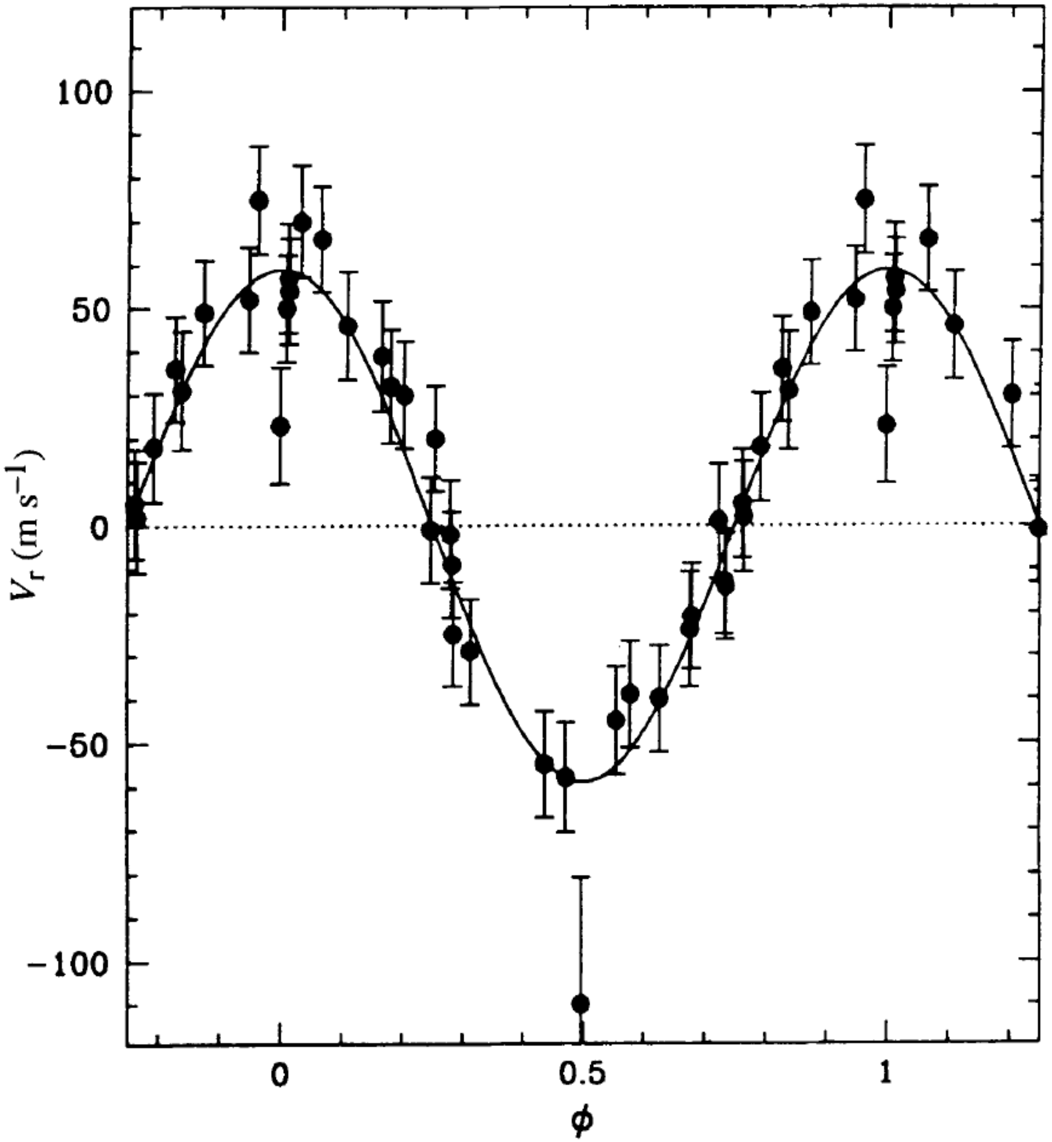
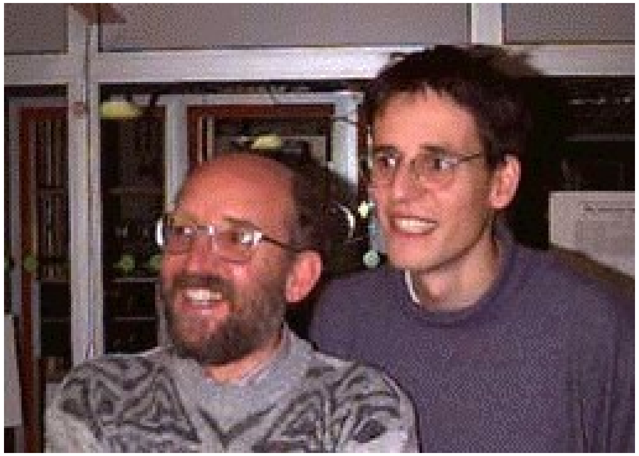


FIG. 4 Orbital motion of 51 Peg corrected from the long-term variation of the γ-velocity. The solid line represents the orbital motion computed from the parameters of Table 1.



Mayor and Queloz, 1995, Nature

51 Peg

- Characteristics:
  - detected 1995, Mayor and Queloz, Nature
  - Mass: 0,45 M Jupiter
  - Radius : 1,9 R Jupiter
  - Period : 4.23 days
  - Semi.-m.axis: 0.052 AU
  - Star: G2 IV
- Mayor and Queloz, 1995, Nature, 378, 355

(http://www.nature.com/nature/journal/v378/n6555/abs/378355a0.html)

RV surveys and planet types

- After 51 Peg Radial velocity surveys begin to report new planets
- Mostly they are so-called hot-Jupiters a new class of planets – close to the host, hot, Jupiter-sized, short orbital period
- How did they get so close to the host star?
- What is the composition of their atmosphere?
- How common are they?
- And are there smaller planets too?

51 Peg compared

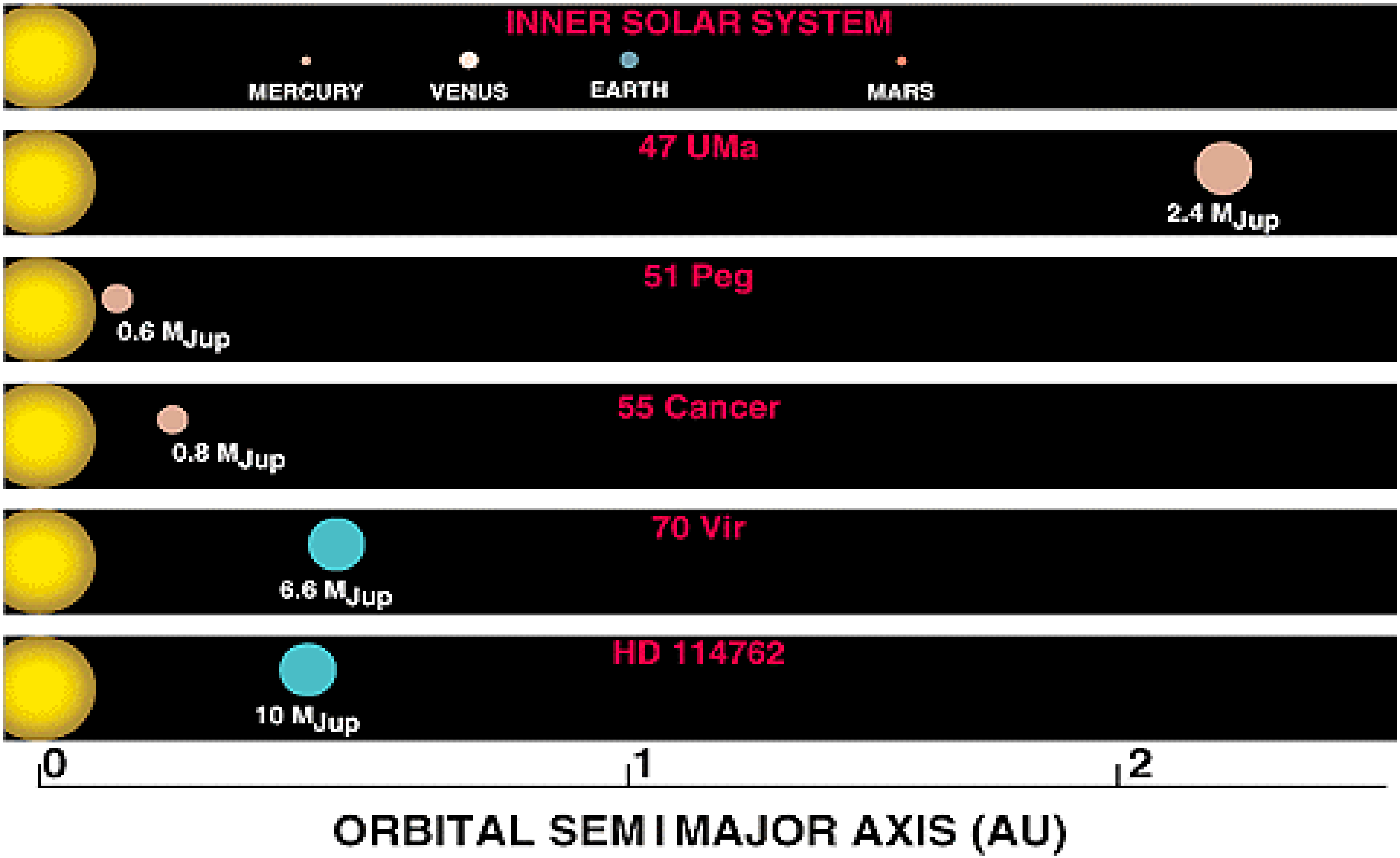
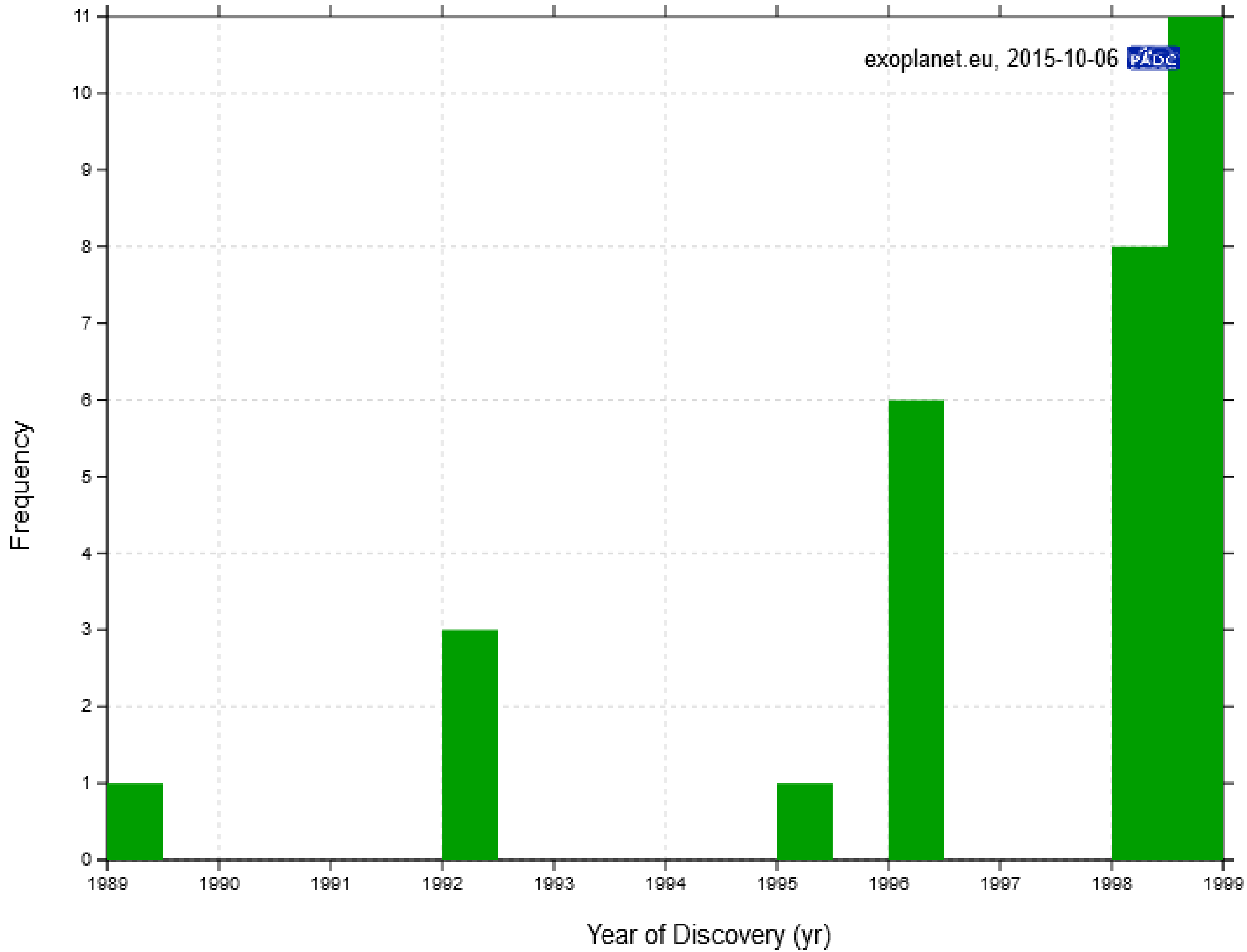


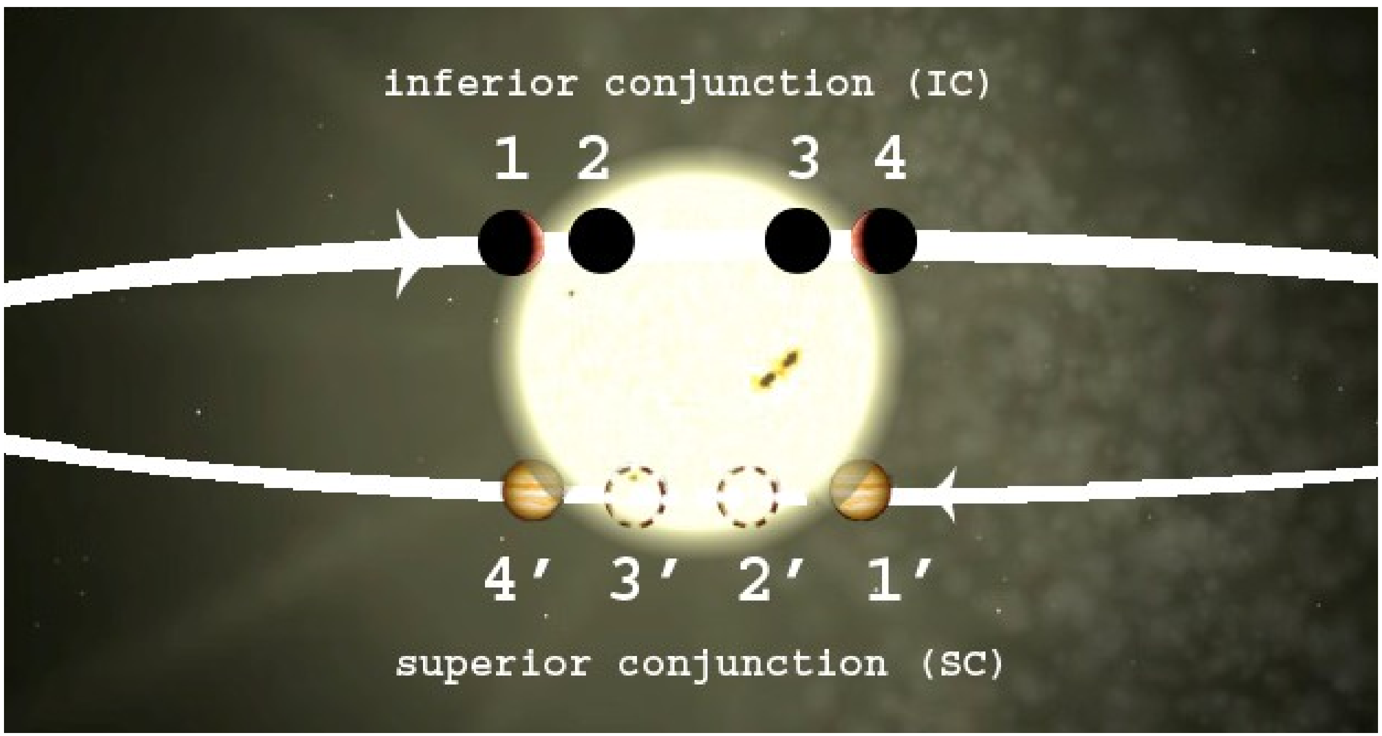
Image from Keele University

Exoplanets in 2000



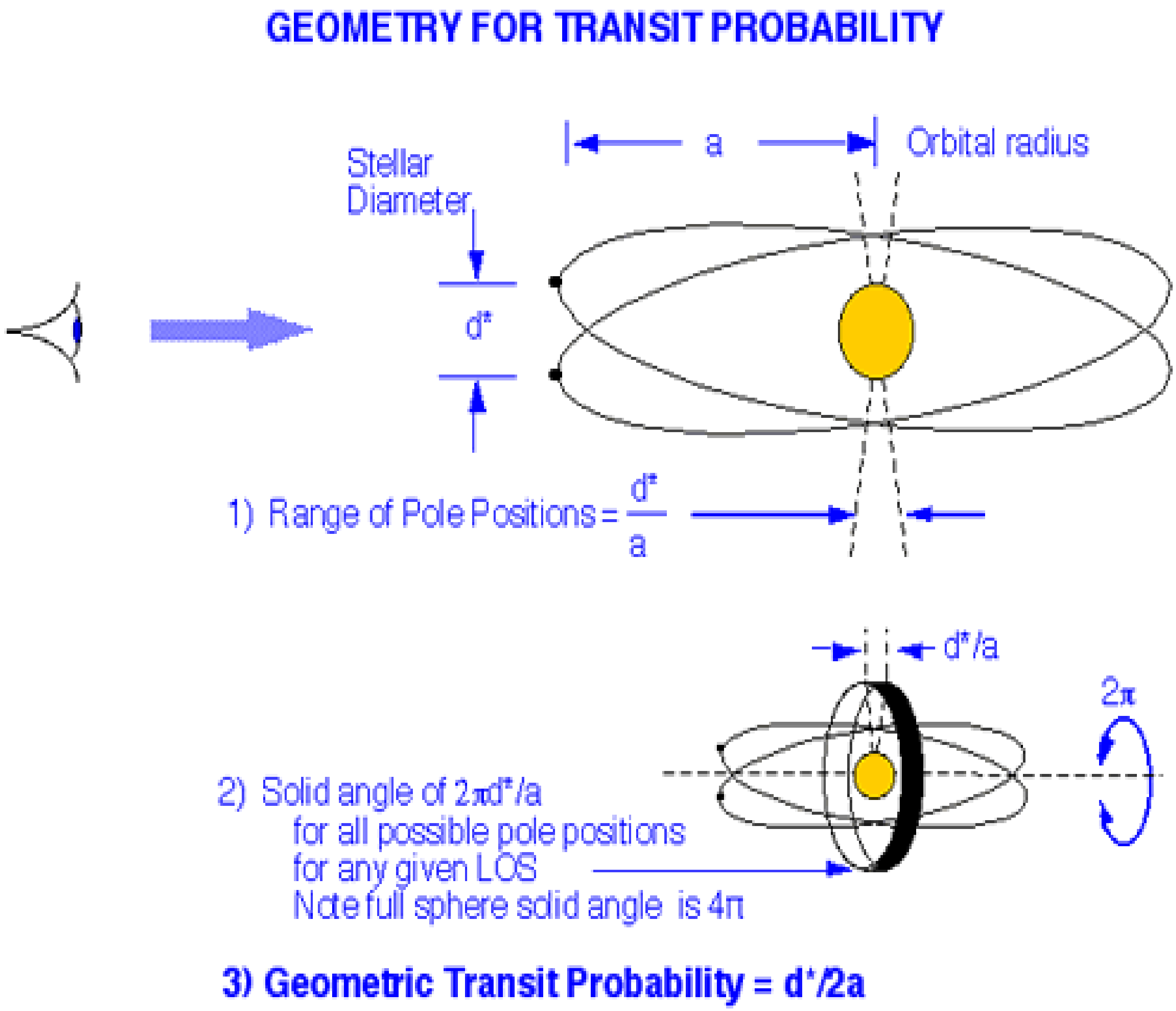
Can we detect a transit?

Eclipses/transits



From Angerhausen et al. 2008

Well, if we are lucky



NASA Kepler Space mission webpages

Motivation to detect a transit?

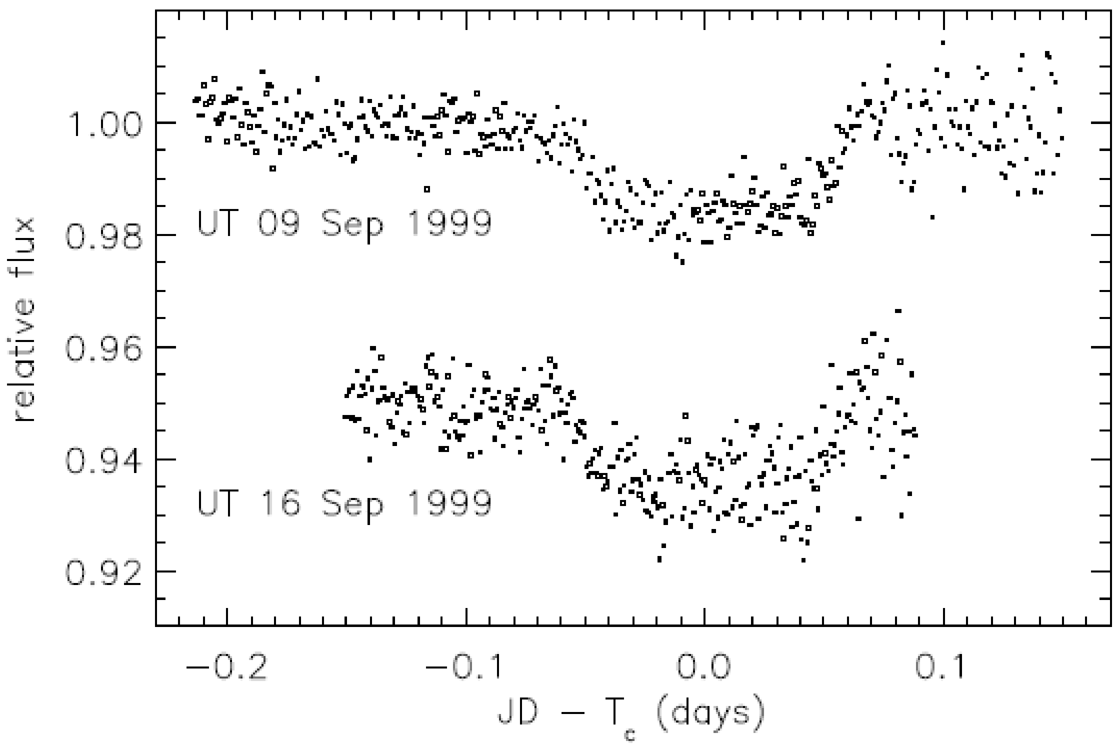
- Some planets should transit stellar discs (in line of sight towards the observer) especially the close-to-star ones
- Geometrical probability of a transit of a hot-Jupiter is about 10 percent
- Assuming every system with planet hosts a hot-Jupiter, then 1 in 10 should present a transit

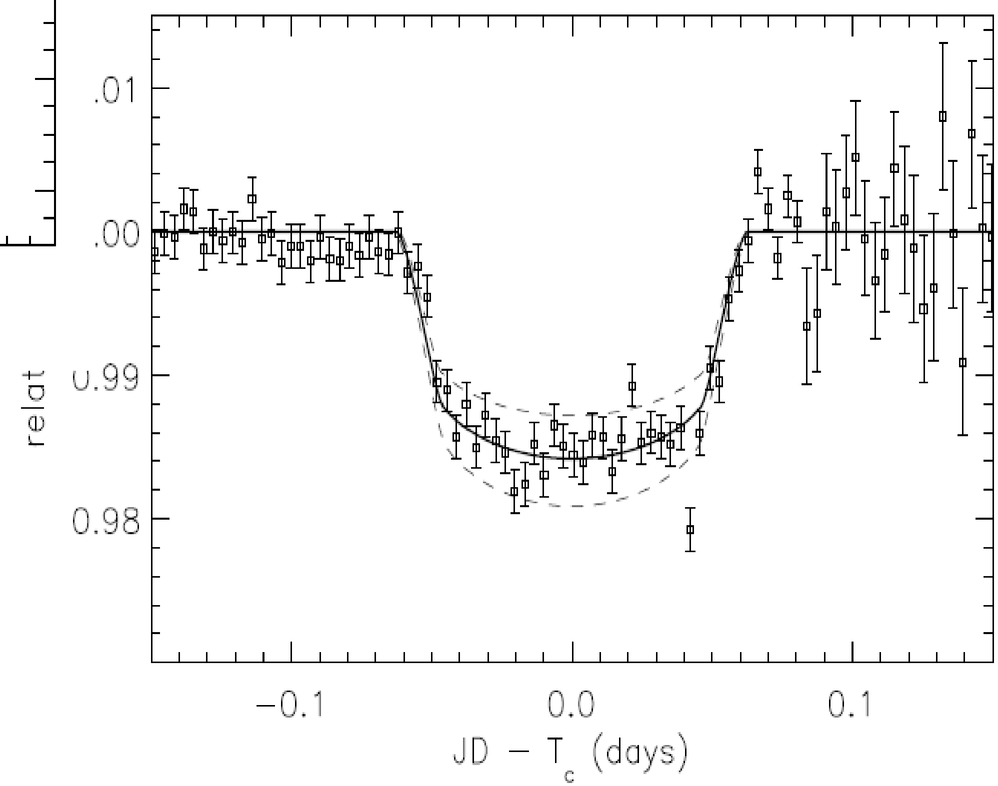
Transit Properties of Solar System Objects

Planet	Orbital Period P (years)	Semi-Major Axis a (A.U.)	Transit Duration (hours)	Transit Depth (%)	Geometric Probability (%)	Inclination Invariant Plane (deg)
Mercury	0.241	0.39	8.1	0.0012	1.19	6.33
Venus	0.615	0.72	11.0	0.0076	0.65	2.16
Earth	1.000	1.00	13.0	0.0084	0.47	1.65
Mars	1.880	1.52	16.0	0.0024	0.31	1.71
Jupiter	11.86	5.20	29.6	1.0100	0.089	0.39
Saturn	29.5	9.5	40.1	0.75	0.049	0.87
Uranus	84.0	19.2	57.0	0.135	0.024	1.09
Neptune	164.8	30.1	71.3	0.127	0.015	0.72
	$P^2M^* = a^3$		13sqrt(a)	$\% = (d_p/d^*)^2$	d*/D	phi

https://web.njit.edu/~gary/320/Lecture10.html

When the planet eclipses its star





HD209458b

Charbonneau et al. 2000

HD209458b

- Parameters

  - Mass : 0.69Mj
  - Radius : 1.38 Rj
  - O. period : 3.5 days

- Star: G0V

  brightness: 7 mag (V)

  Teff: 6092 K

  Metallicity: 0.02

http://mnras.oxfordjournals.org/content/418/3/1822

Some statistics

And are hot-Jupiters common?

- What is the occurance rate for hot-Jupiters?

  - Fischer claims around 1 percent

  - Jupiter sized planets at greater distances probably more common but difficult to detect (long orbital period)

- Where are the small planets (Neptune - Earth)?

  - undetected, high accuracy of cm/s needed but they seem to be very common

As of 2006

Ground based transit survey projects

SuperWasp – the most successful ground based survey operated by UK universities

2 robotic observatories – La Palma, Spain and South Africa

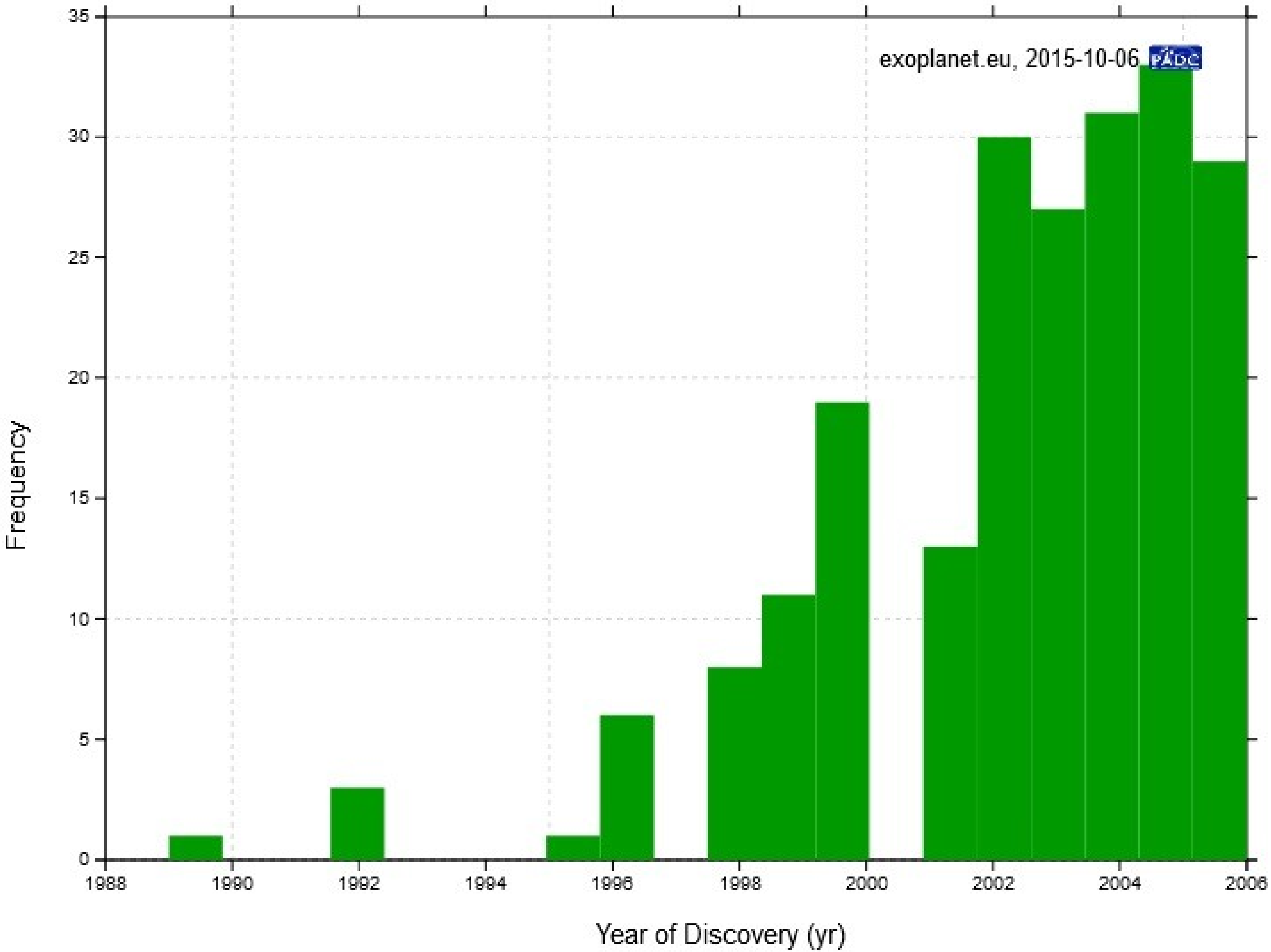
Each site consists of 8 telescopes with wide angle CCDs

More than 100 planets discovered

since 2002

http://www.superwasp.org/index.html

How many stars do have planets? (2006)



New planets detected – small planets

- GJ436b – Neptune-sized planet detected, first of its kind
- Warm Neptune
- Mass: 0.07Mj
- Radius: 0.38 Rj
- Star: M2.5
- SMALL PLANETS DO EXIST

BUTLER P., VOGT S., MARCY G., FISCHER D., WRIGHT J., HENRY G., LAUGHLIN G. & LISSAUER J.

ApJ. Letters, 617, 580

A&A 487, 373–381 (2008)
DOI: 10.1051/0004-6361:200809698

Astronomy & Astrophysics

Spectroscopic parameters for 451 stars in the HARPS GTO planet search program⋆,⋆⋆

Stellar [Fe/H] and the frequency of exo-Neptunes

S. G. Sousa[1,2], N. C. Santos[1,3], M. Mayor[3], S. Udry[3], L. Casagrande[4], G. Israelian[5], F. Pepe[3], D. Queloz[3], and M. J. P. F. G. Monteiro[1,2]

[1] Centro de Astrofísica, Universidade do Porto, Rua das Estrelas, 4150-762 Porto, Portugal
e-mail: sousasag@astro.up.pt
[2] Departamento de Matemática Aplicada, Faculdade de Ciências da Universidade do Porto, Portugal
[3] Observatoire de Genève, 51 Ch. des Mailletes, 1290 Sauverny, Switzerland
[4] University of Turku – Tuorla Astronomical Observatory, Väisäläntie 20, 21500 Piikkiö, Finland
[5] Instituto de Astrofísica de Canarias, 38200 La Laguna, Tenerife, Spain

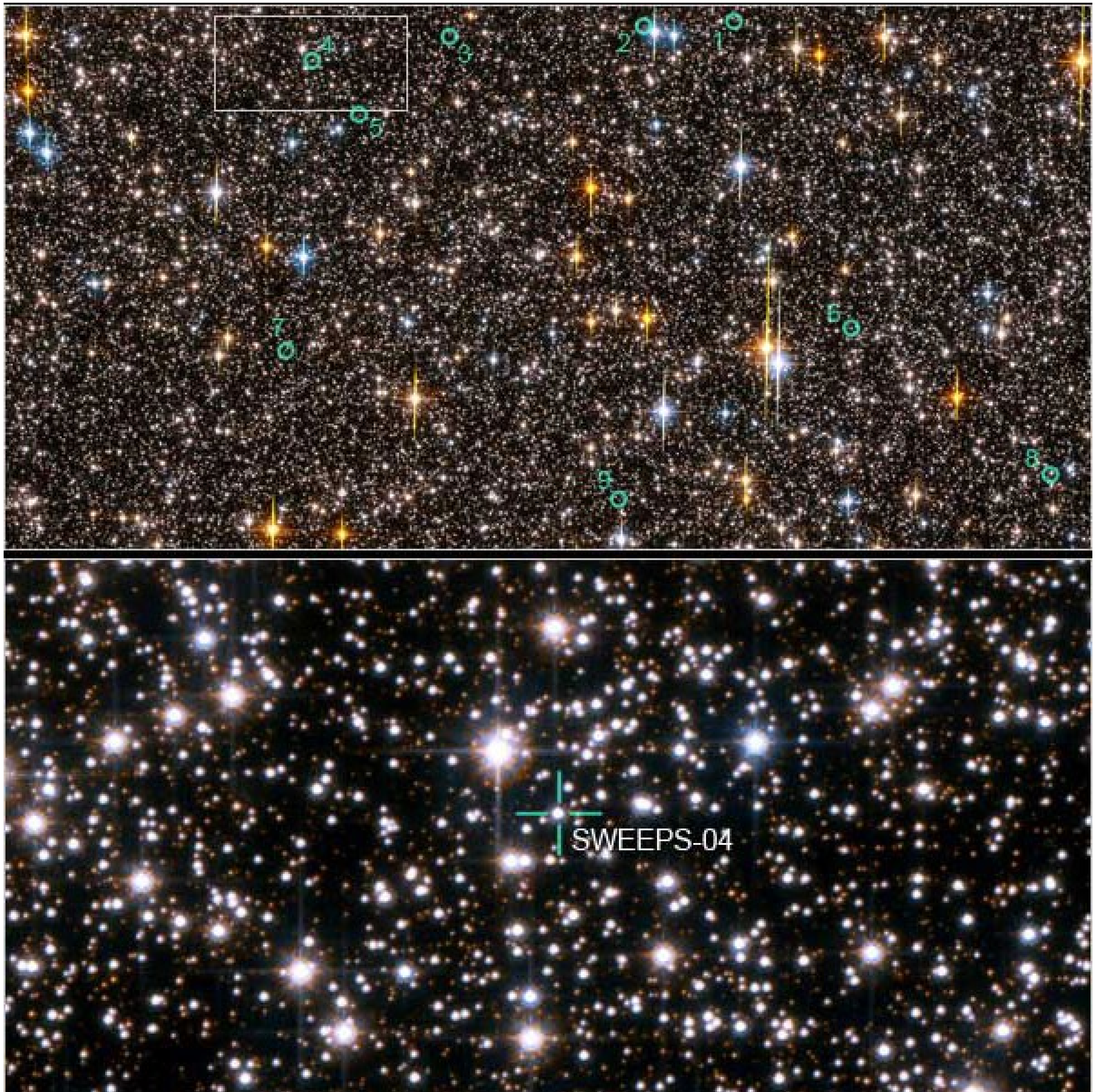
Received 3 March 2008 / Accepted 30 April 2008

ABSTRACT

To understand the formation and evolution of solar-type stars in the solar neighborhood, we need to measure their stellar parameters to high accuracy. We present a catalogue of accurate stellar parameters for 451 stars that represent the HARPS Guaranteed Time Observations (GTO) "high precision" sample. Spectroscopic stellar parameters were measured using high signal-to-noise (S/N) spectra acquired with the HARPS spectrograph. The spectroscopic analysis was completed assuming LTE with a grid of Kurucz atmosphere models and the recent ARES code for measuring line equivalent widths. We show that our results agree well with those ones presented in the literature (for stars in common). We present a useful calibration for the effective temperature as a function of the index color $B-V$ and [Fe/H]. We use our results to study the metallicity-planet correlation, namely for very low mass planets. The results presented here suggest that in contrast to their jovian couterparts, neptune-like planets do not form preferentially around metal-rich stars. The ratio of jupiter-to-neptunes is also an increasing function of stellar metallicity. These results are discussed in the context of the core-accretion model for planet formation.

Key words. methods: data analysis – techniques: spectroscopic – stars: fundamental parameters – stars: planetary systems – stars: planetary systems: formation – Galaxy: solar neighborhood

OBSERVE AS MANY STAR AS POSSIBLE TO FIND TRANSITS



NASA web

Space missions

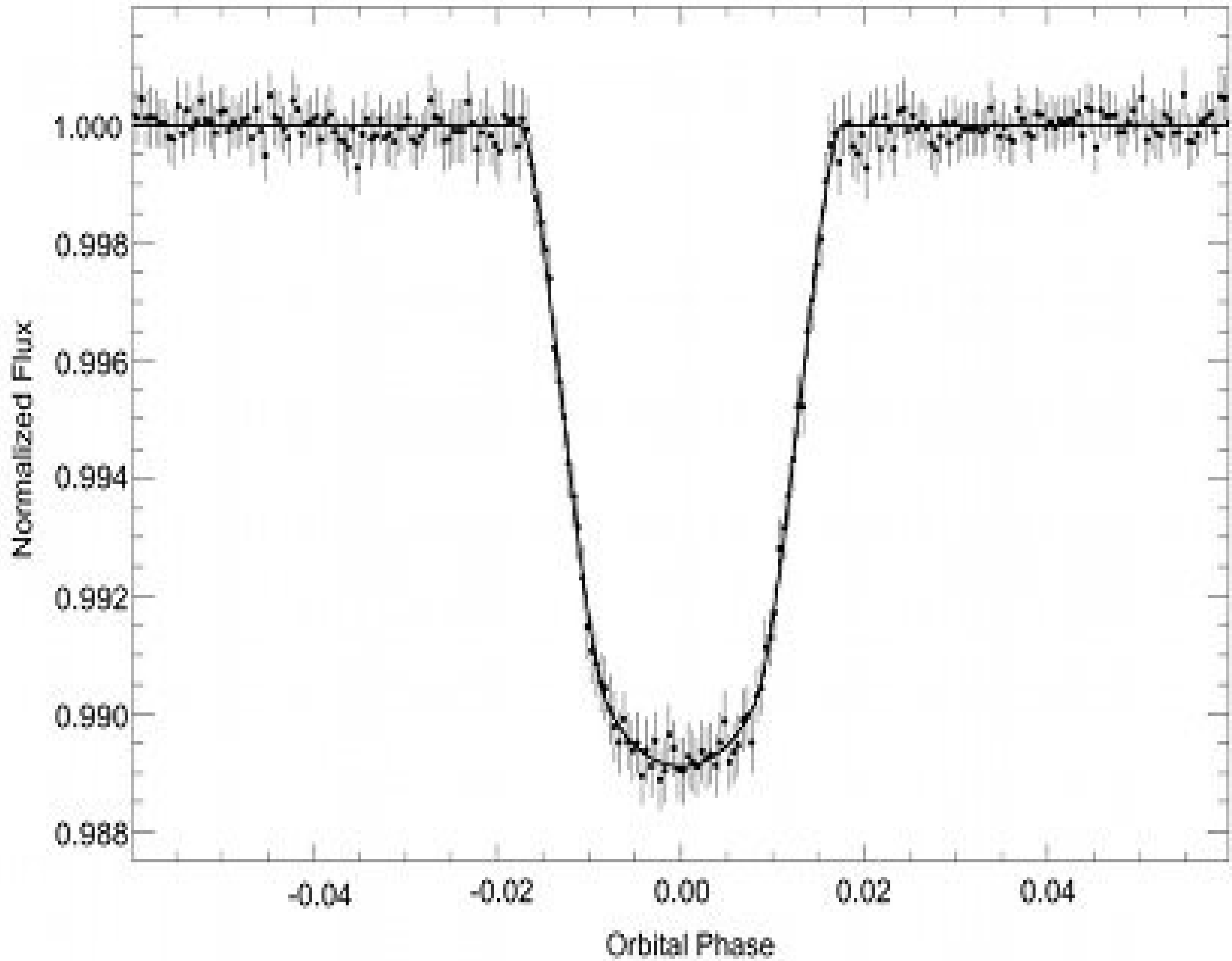
CoRoT

Convection, Rotation and planetary Transits

Launched 2006 – mission end 2013

28cm mirror, 4 detectors of 1,5x1,5deg

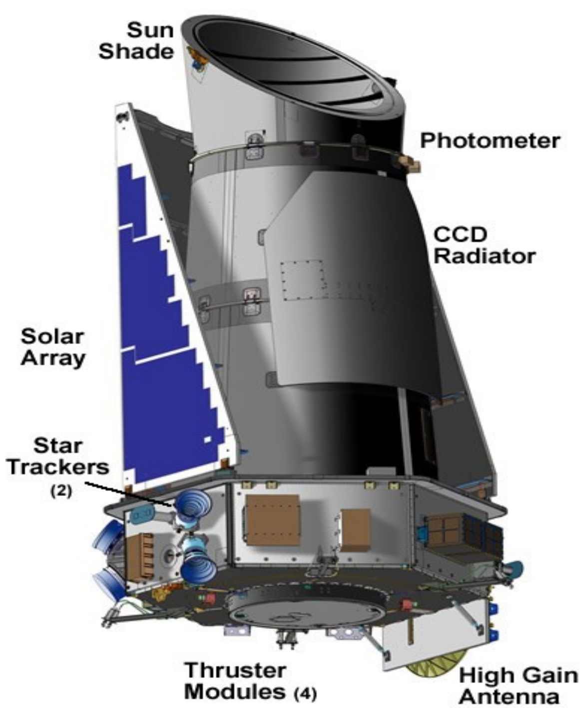
ESA webpages



ESA webpages

Kepler

- 1.4-m mirror, telescope equipped with an array of 42 CCDs, each of 50x25 mm CCD has 2200x1024 pixels.
- launch March 2009, now continuing as K2



Monitored 100k stars in Cygnus constellation

Detected 1030 confirmed planets

More to come from K2

Kepler webpage - http://kepler.nasa.gov/

Kepler

Determine the abundance of terrestrial and larger planets in or near the habitable zone of a wide variety of stars;

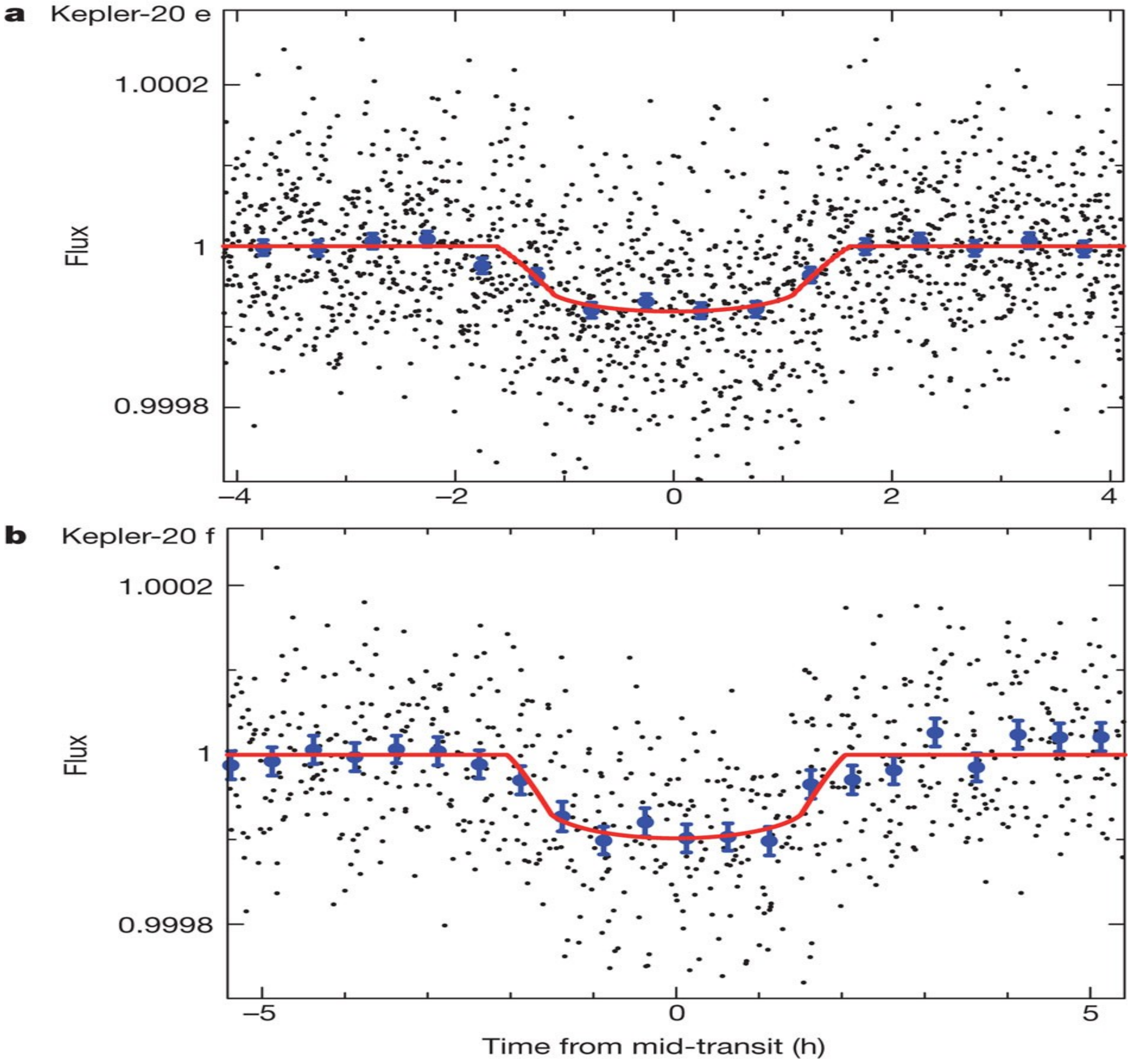
Determine the distribution of sizes and shapes of the orbits of these planets;

Estimate how many planets there are in multiple-star systems;

Determine the variety of orbit sizes and planet reflectivities, sizes, masses and densities of short-period giant planets;

Identify additional members of each discovered planetary system using other techniques; and

Determine the properties of those stars that harbor planetary systems.



F Fressin *et al.* *Nature* **000**, 1-5 (2011) doi:10.1038/nature10780

Note: This figure is from a near-final version AOP and may change prior to final publication in print/online

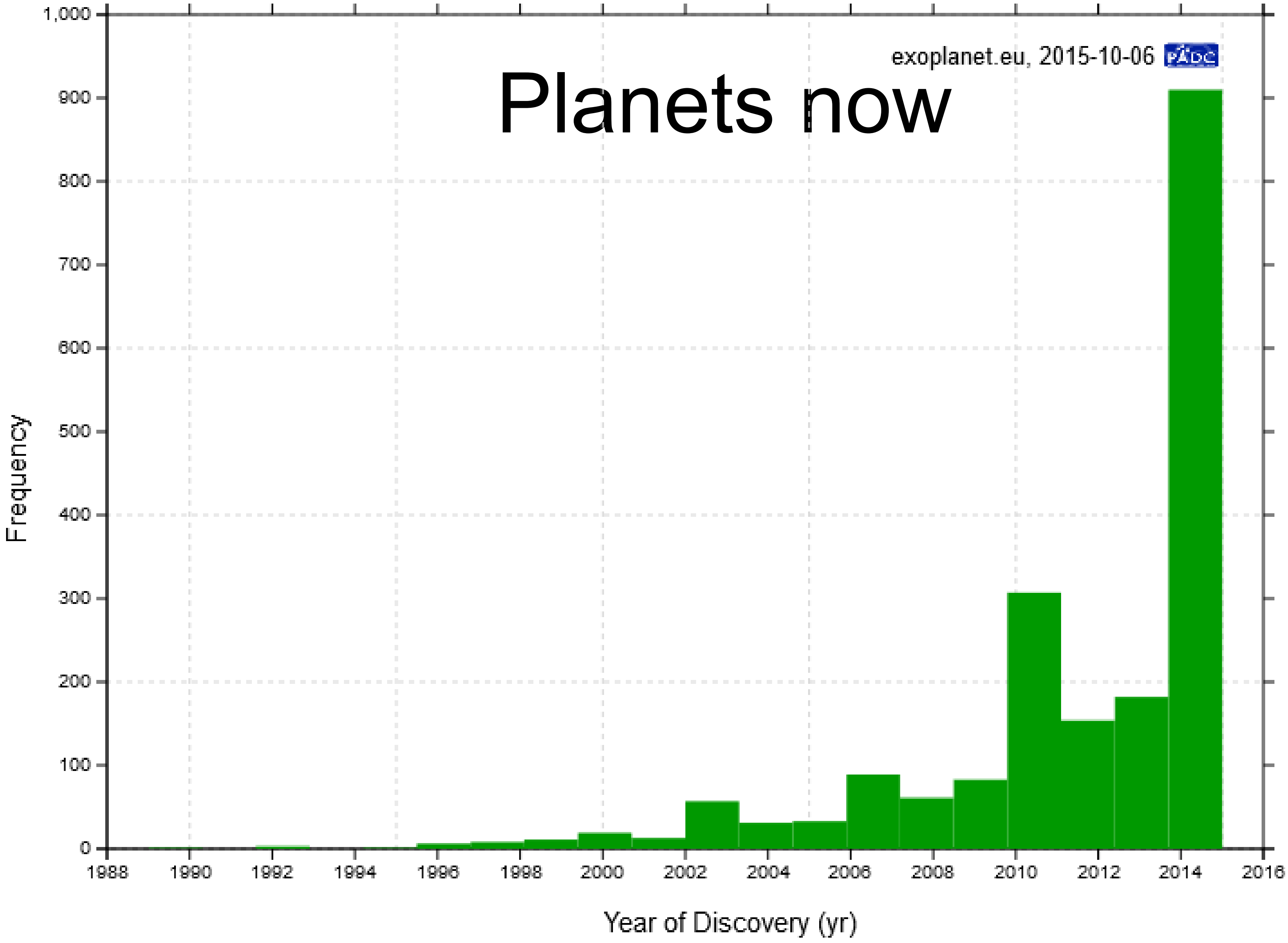
nature

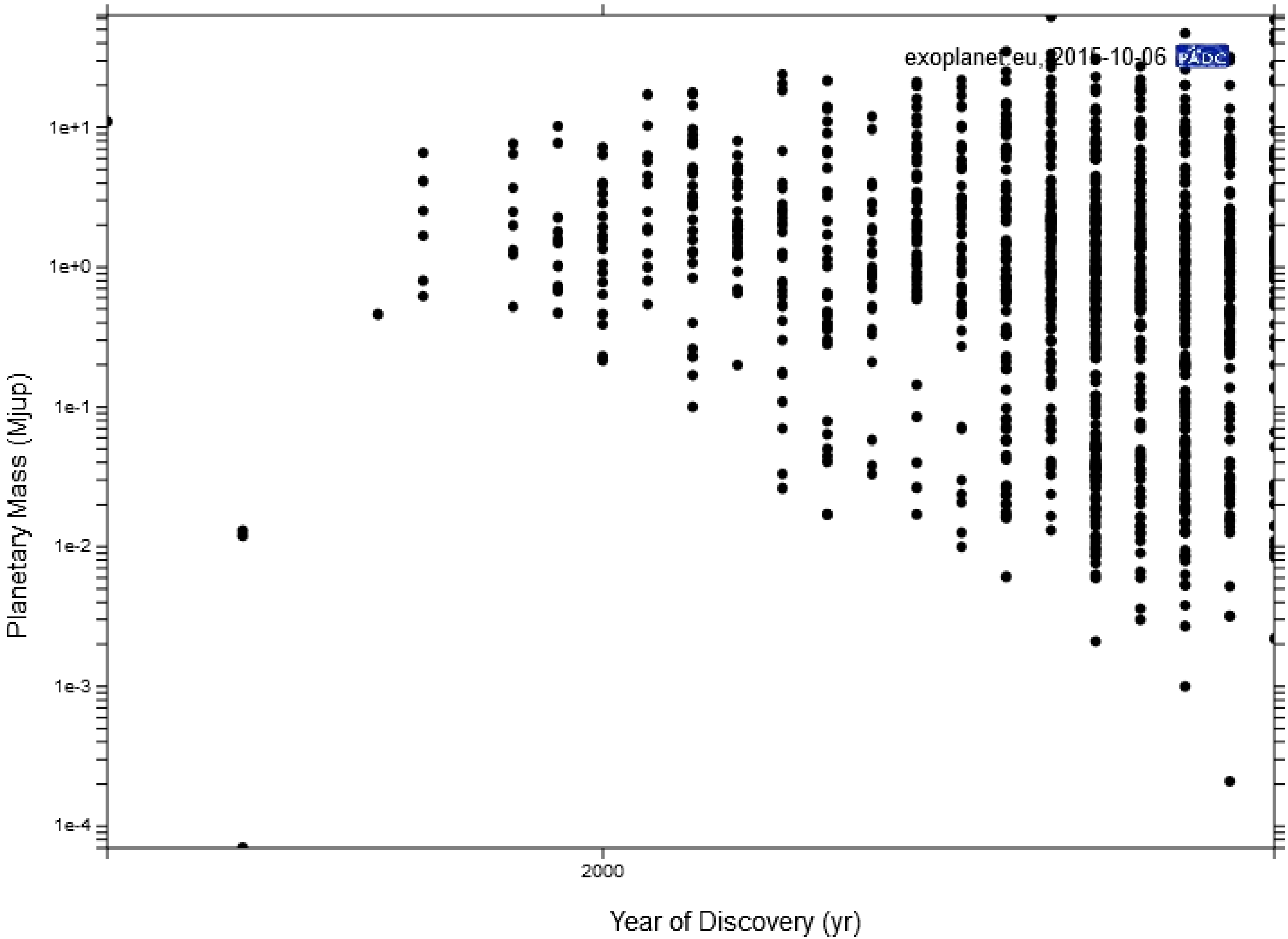
2 Earth like planets – Kepler 20 e and f

http://kepler.nasa.gov/Mission/discoveries/

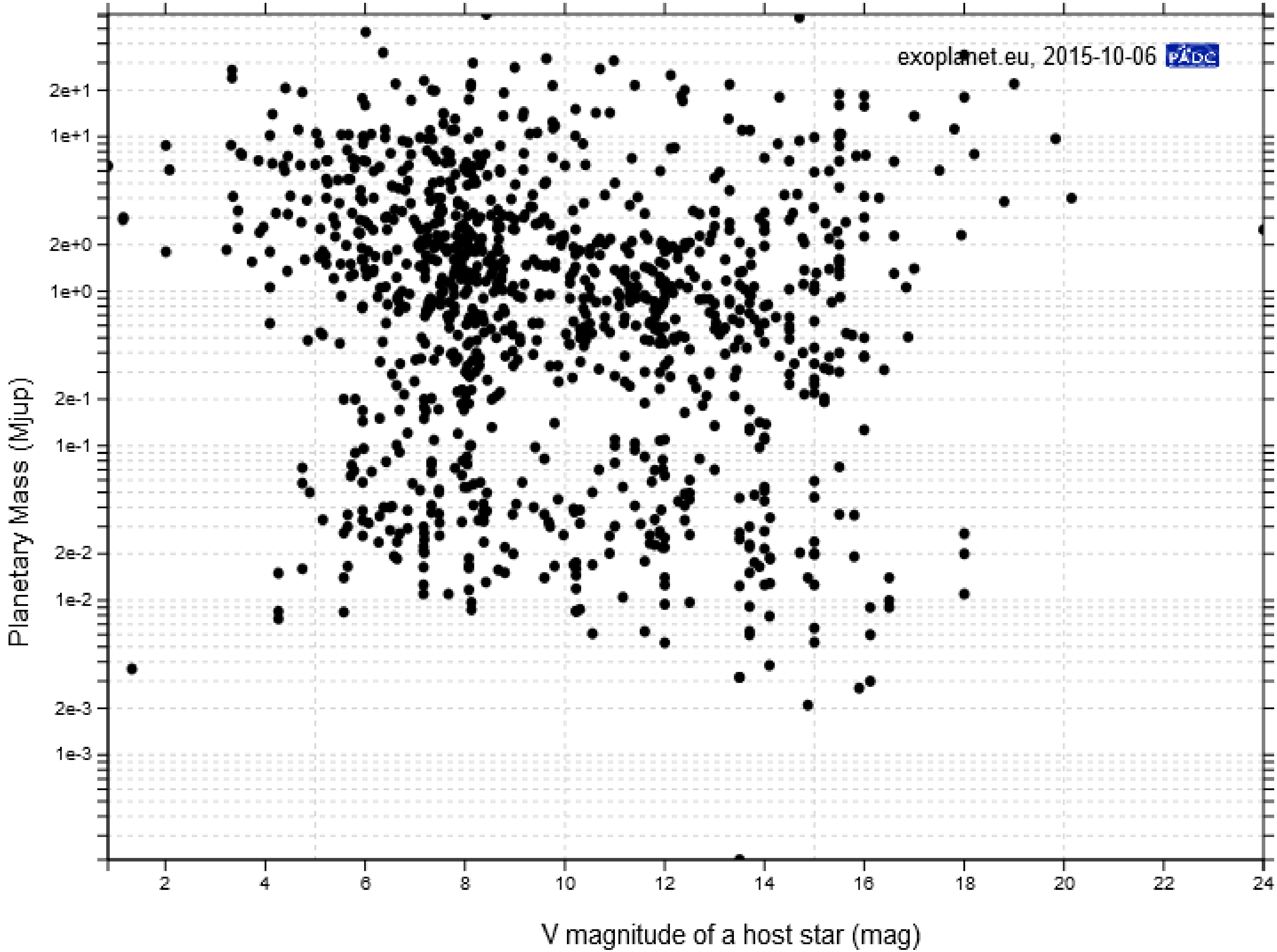
How many planets do we know today? State of the art

Planets now


exoplanet.eu, 2015-10-06
PADC
Frequency
Year of Discovery (yr)
1,000
900
800
700
600
500
400
300
200
100
0
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016

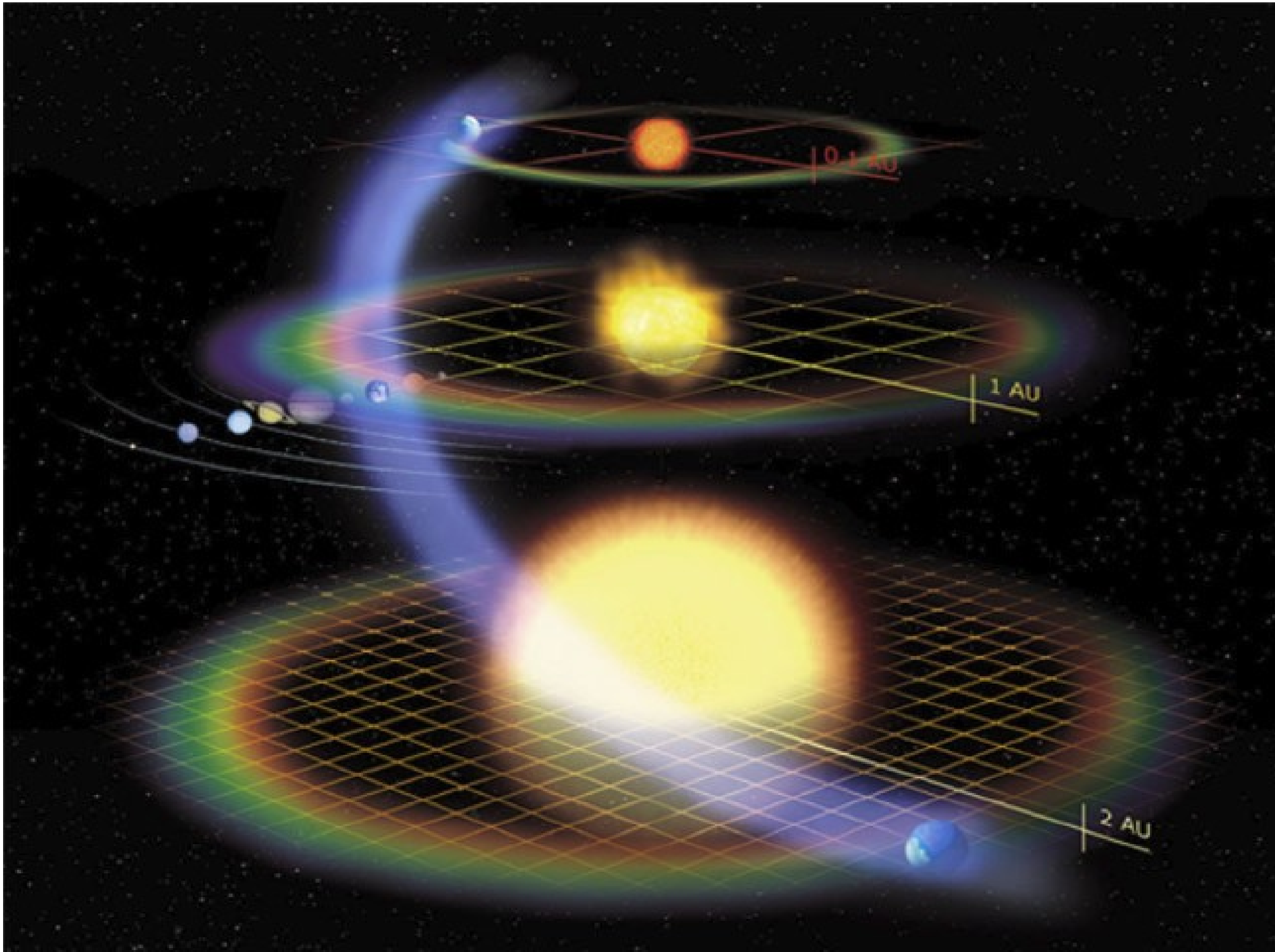


exoplanet.eu, 2015-10-06
PADC
1e+1
1e+0
1e-1
1e-2
1e-3
1e-4
Planetary Mass (Mjup)
2000
Year of Discovery (yr)

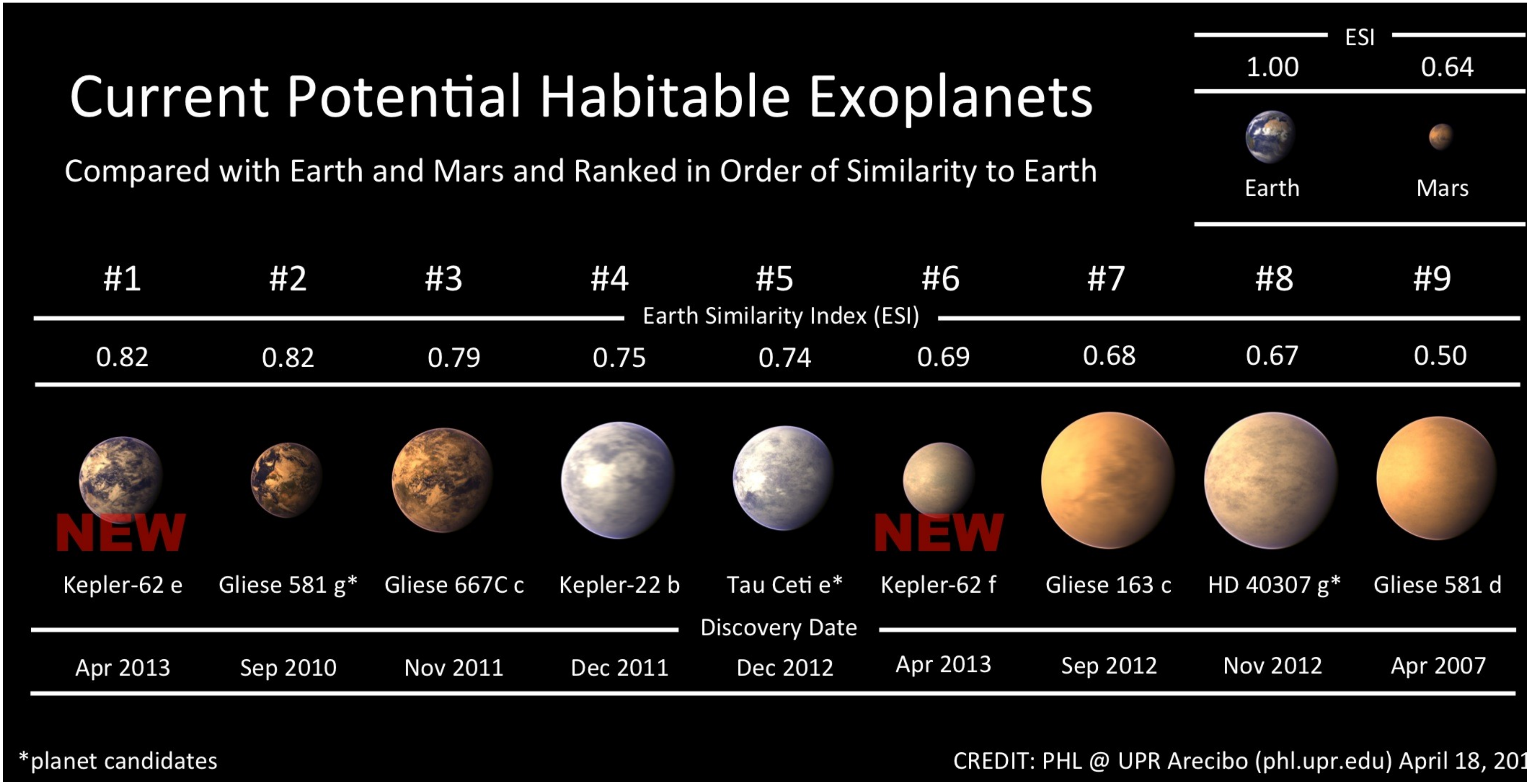


exoplanet.eu, 2015-10-06
PADC
Planetary Mass (Mjup)
2e+1
1e+1
2e+0
1e+0
2e-1
1e-1
2e-2
1e-2
2e-3
1e-3
2
4
6
8
10
12
14
16
18
20
22
24
V magnitude of a host star (mag)

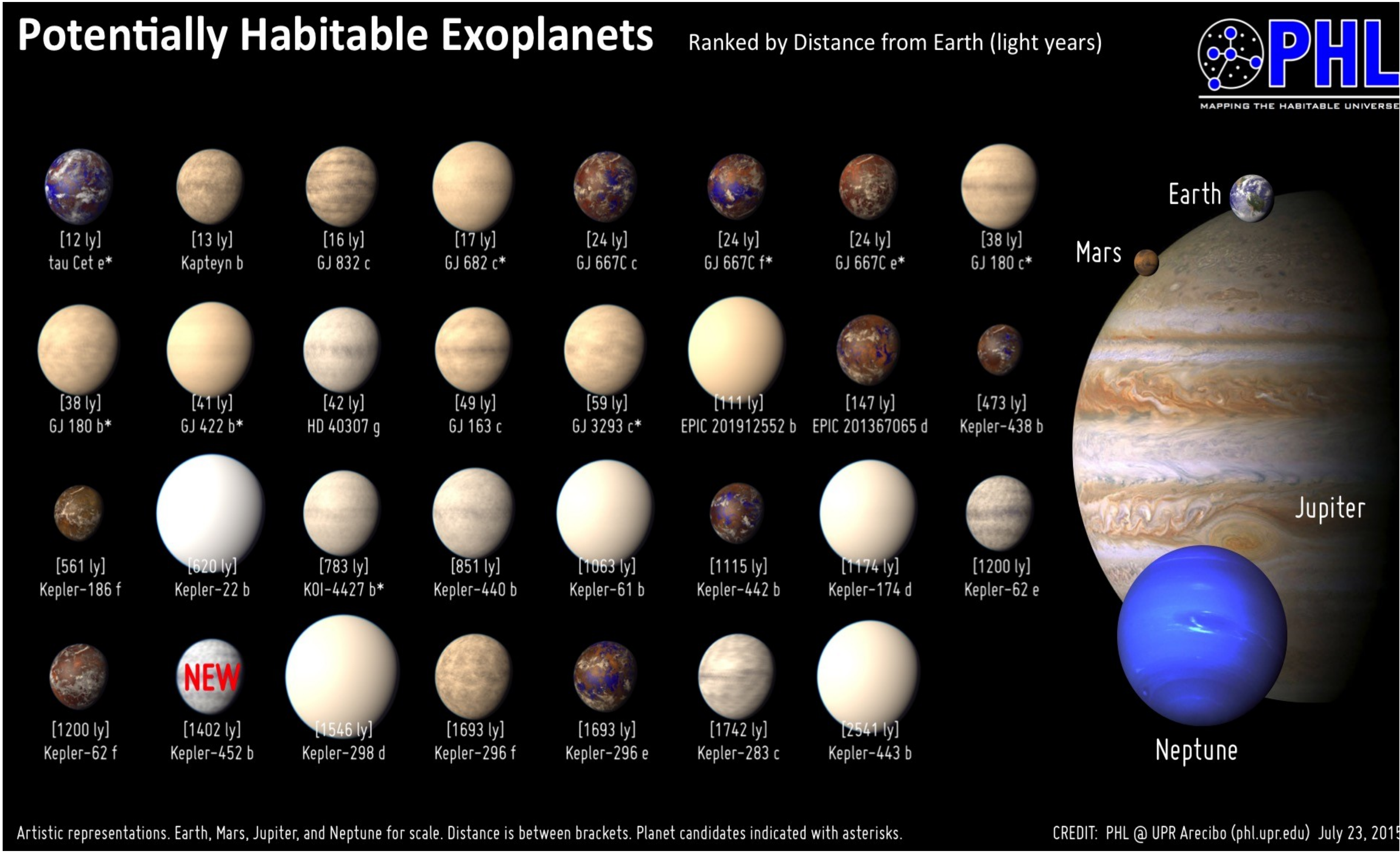
Habitable zones (liquid water)



http://news.discovery.com/space/planetary-habitable-zones-defined-by-alien-biochemistry-111118.htm

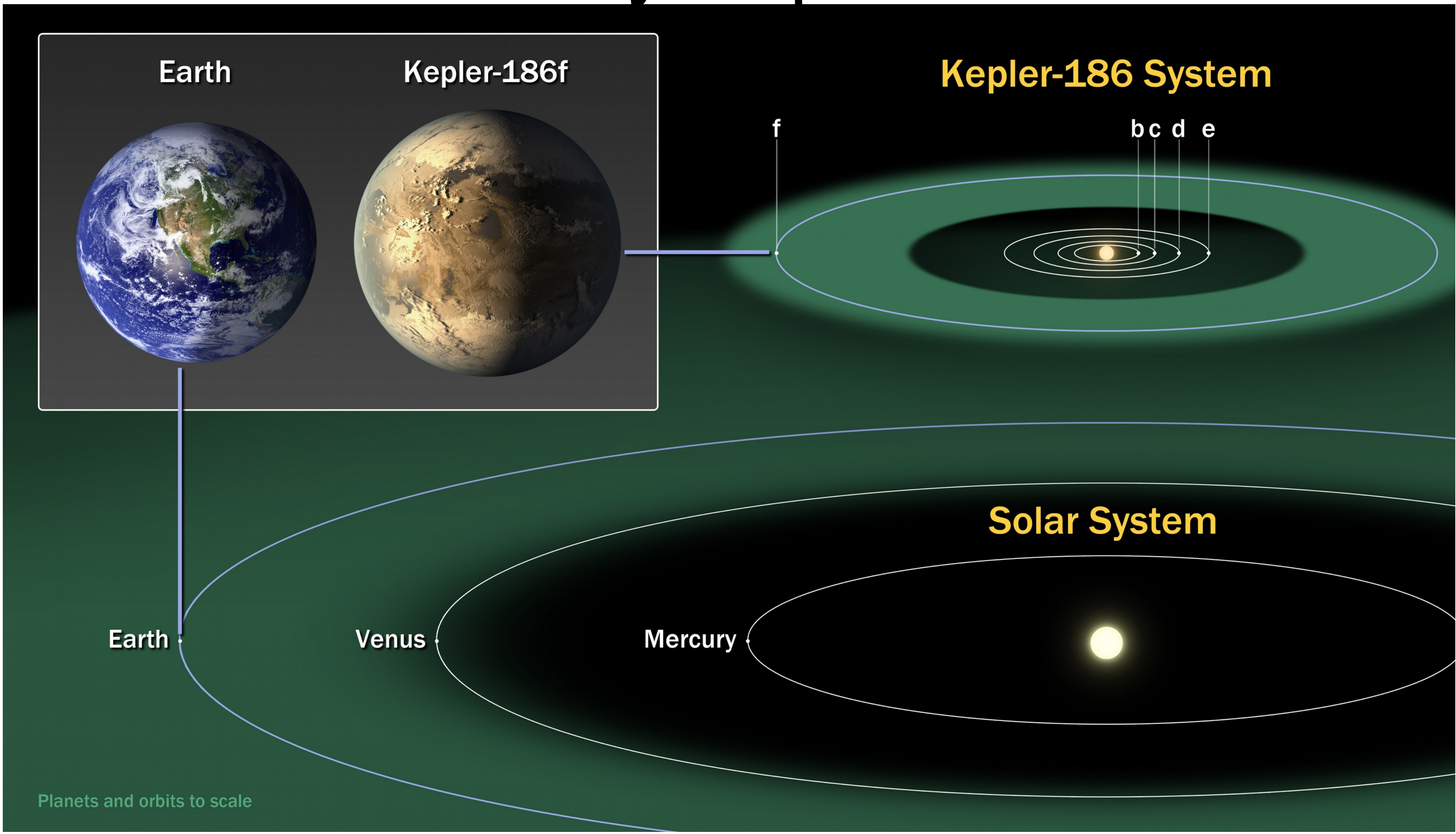


http://phl.upr.edu/press-releases/nasakeplerdiscoversnewpotentiallyhabitableexoplanets



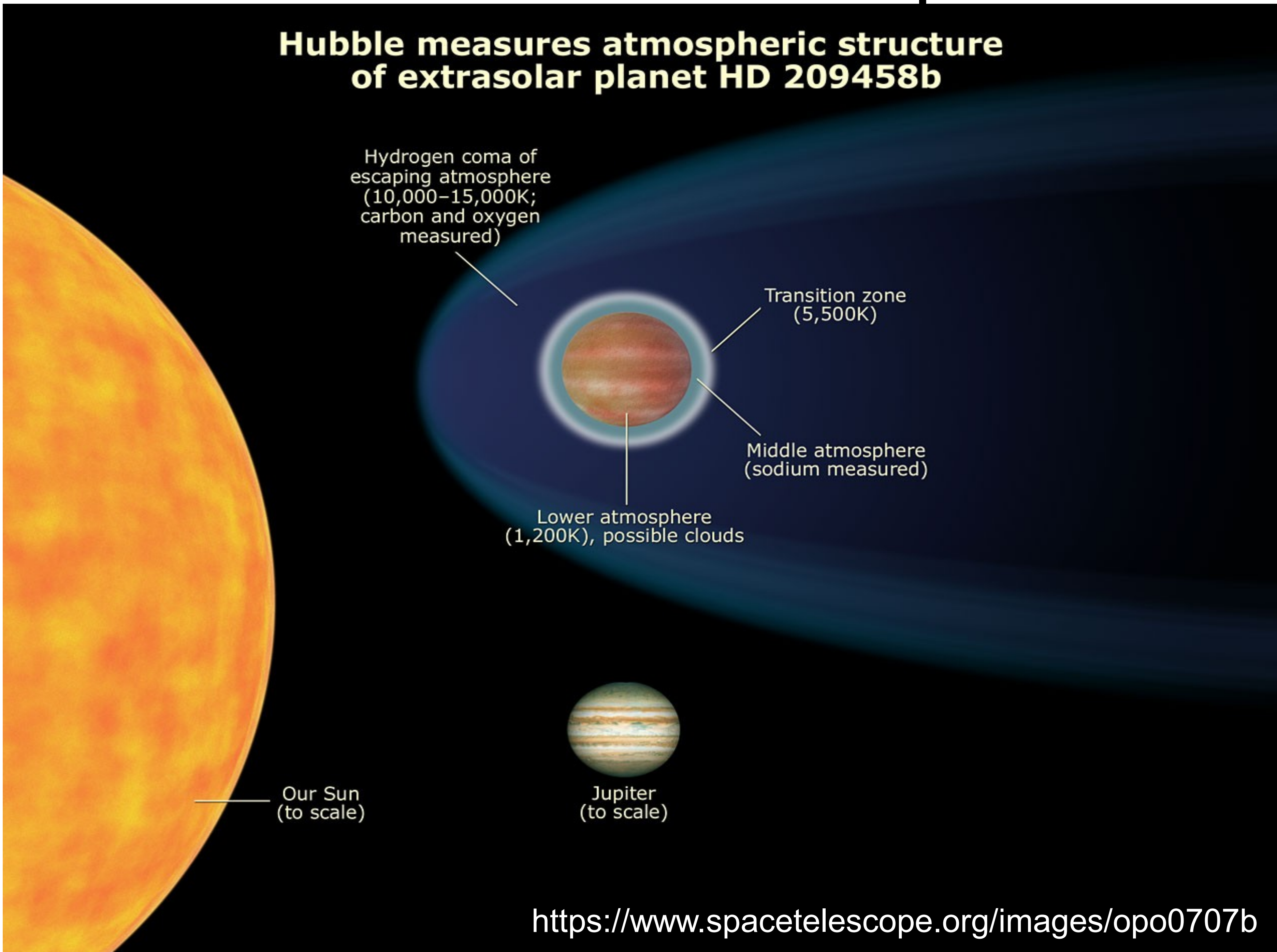
http://phl.upr.edu/projects/habitable-exoplanets-catalog

And finally Kepler 186f



https://www.nasa.gov/ames/kepler/nasas-kepler-discovers-first-earth-size-planet-in-the-habitable-zone-of-another-star

Characterization of exoplanets



https://www.spacetelescope.org/images/opo0707b

Weather on exoplanets

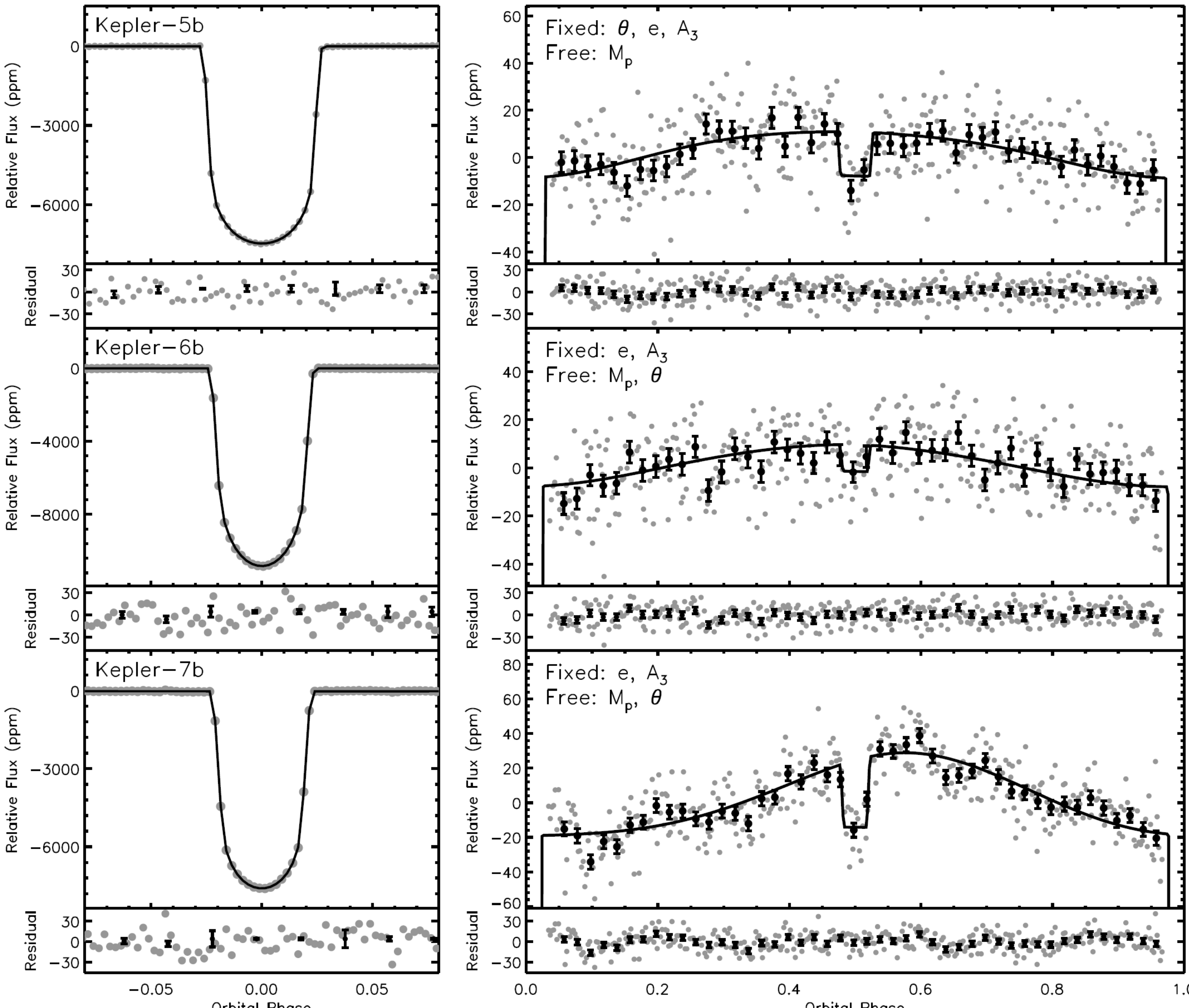
CHANGING PHASES OF ALIEN WORLDS: PROBING ATMOSPHERES OF KEPLER PLANETS WITH HIGH-PRECISION PHOTOMETRY

Lisa J. Esteves, Ernst J. W. De Mooij, and Ray Jayawardhana

The Astrophysical Journal, Volume 804, Number 2

Weather on exoplanets (cont.)

4



Finding life

Next lecture

- How do the detection methods work?
- Which planets can we detect now?
- Description of some latest results of surveys
- What are the limitiations of searches?

HAVE A GREAT WEEK