Exoplanets

Petr Kabáth
Lecture 1 Fall 2023/2024
06 October 2023

Career in astronomy

- High School Slovanské náměstí 6 (Brno)
- Masaryk university Brno (physics)
- AsÚ Ondřejov
- Freie Universitaet Berlin (physics)
- Technische Uni. Berlin/DLR Berlin
- European Southern Observatory Chile
- AsÚ Ondřejov
- Leader exoplanet group
- PI of PLATOSPec and CZ PLATO participation


PlatoSpec
Ground-based support
for exoplanetary
space missions.

Blog ERASMUS+ - erasmus.asu.cas.cz

Astronomický ústav AV ČR

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OUR BLOG

The largest optical telescope in the world, within the ERASMUS+ program - part 1

18 SEP, 2019

Hasta mañana!

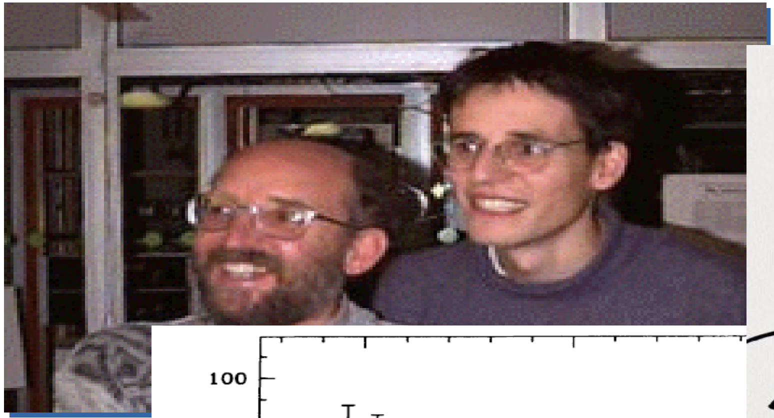
27 AUG, 2019

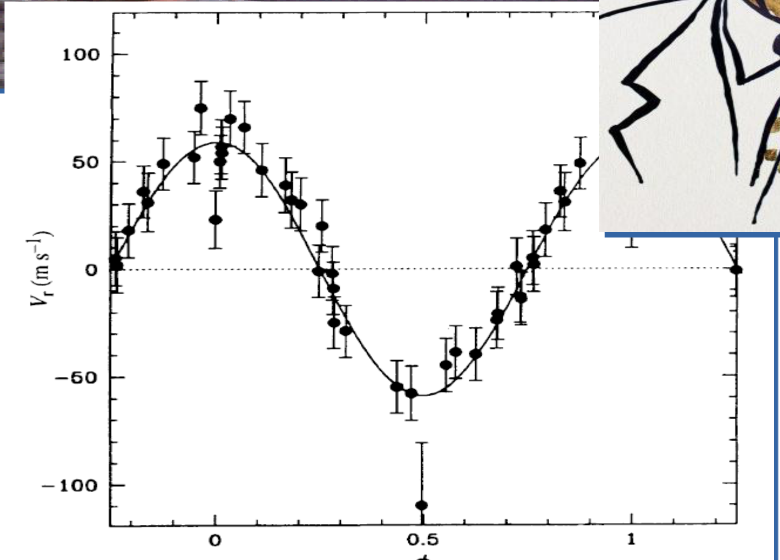
Hello. My name is Patrik Čechvala. I would like to tell you a story about one lost

Webpage of Exoplanet research group at ASU

http://stelweb.asu.cas.cz/exogroup/

What will be the lecture about?





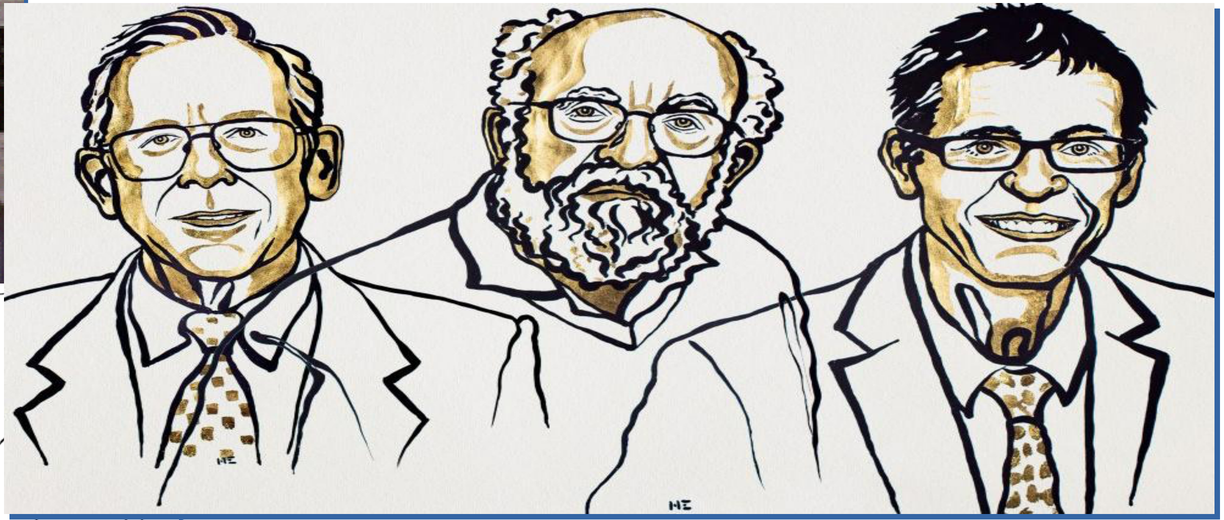


Image from Mayor and Queloz, 1995, Nature

Astronomický ústav AV ČR

Hot topic?

- Physics Nobel Prize winning theme (½)
- Detection of the first exoplanet around a Sun like star
- Seeking for our place in the Universe
- In the Czech Republic there was no working group on the new topic
- However, it is not only about the NP!!

PLATO Community

Exoplanets lecture 2020/2021

1. History of search for exoplanets. Precise radial velocity measurements and what preceded the discovery of the 51 Peg b.

- 2. Methods of detection of exoplanets – spectroscopy and radial velocities, photoemtry, eclipses and direct imaging, the role of adaptive optics
- 3. Which detection methods are most successful? How to combine them the most efficient way?
- 4. The role of space missions
- 5. Instrumentation used for detection of exoplanets
- 6. Exoplanets and statistics
- 7. Mass and radius diagram of exoplanets
- 8. Exoplanetary systems and their evolution (and brown dwarfs)
- 9. Characterisation of exoplanetary atmospheres
- 10. Exoplanets and habitability
- 11. Influence of host stars on exoplanets
- 12. What can we expect on the field of exoplanetary research – discussion
- One lecture will be held in Ondrejov and an observing session can be arranged for interested students

Exam

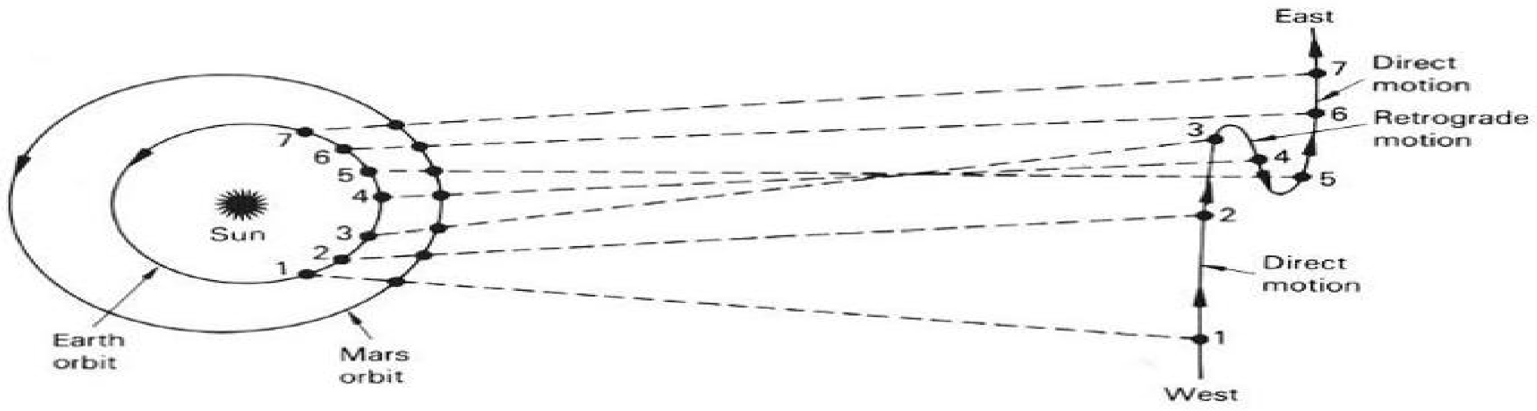
- Topics from the lectures will be divided among students
- Each student will be asked to prepare a presentation introducing the given topic
- Each student will also present paper/s relevant to the topic
- The presentation and the paper introduction will be performed as a discussion round discussing the topics introduced during the course

Literature

- **Peryman - Exoplanet Handbook, Cambridge Univ. Press (2018), ISBN: 9781108419772**
- **Sagan - Cosmos : The Story of Cosmic Evolution, Science and Civilisation, ISBN: 0349107033**
- **Winn - Transits and Occultations, https://arxiv.org/abs/1001.2010**
- **Handbook on Exoplanets: https://link.springer.com/referencework/10.1007/978-3-319-55333-7**

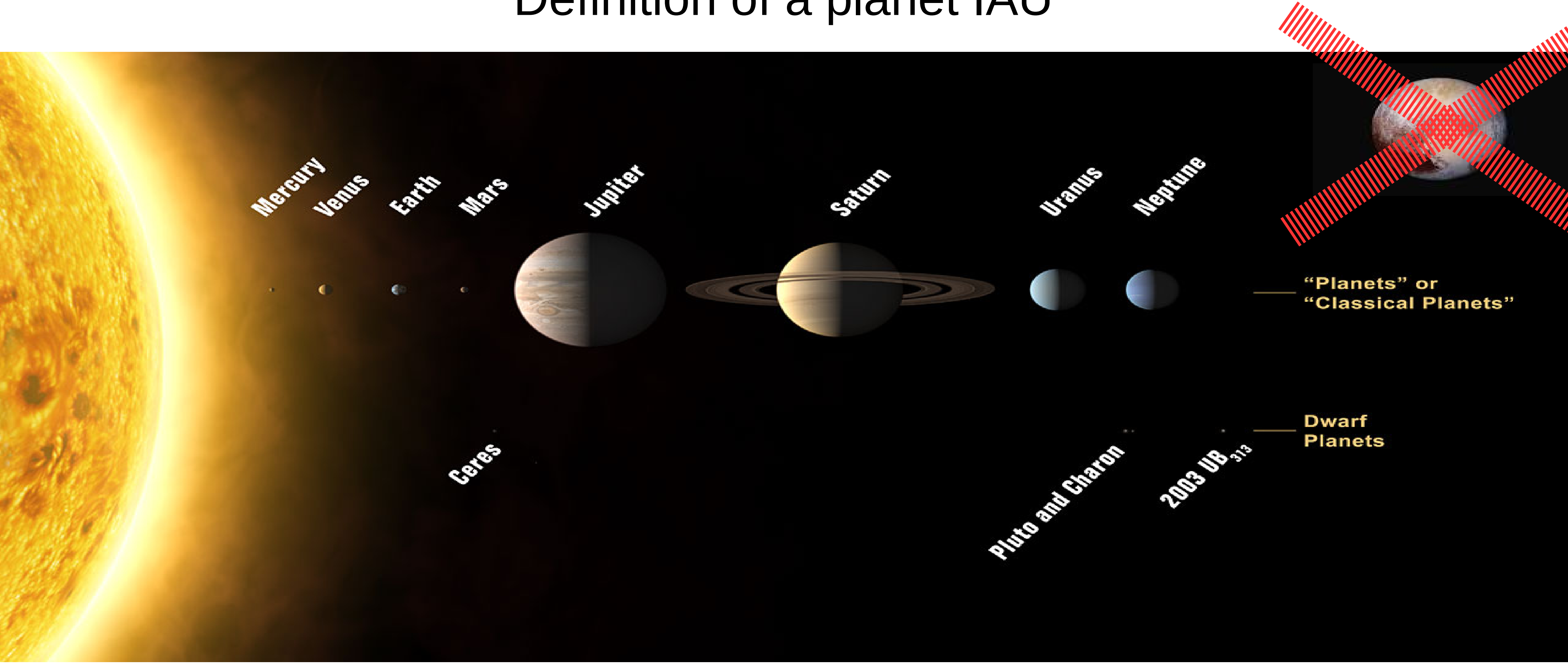
A planet

Πλανήτης - planétés – „tulák“



Credit: NASA

Definition of a planet IAU



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

An Exoplanet

A planet orbiting a star other than Sun

What are open questions in exoplanetary research?

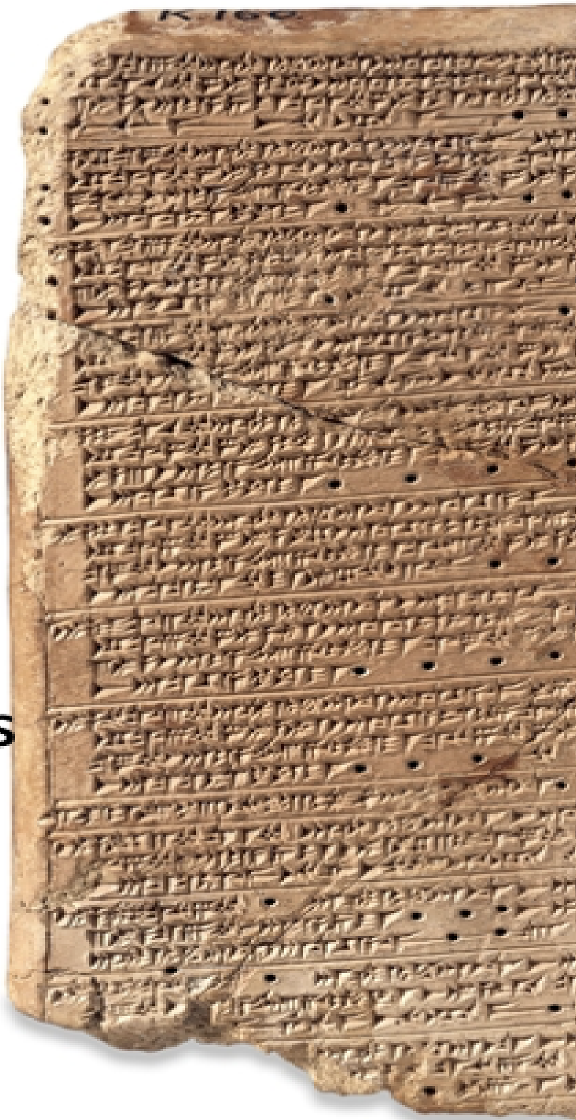
Exoplanetary Science Questions

- We are eager to understand statistical distribution of exoplanets in the Universe
- How do exoplanetary systems evolve?
- How do exoplanets compare to the Solar system?
- Are we unique?
- Life in the Universe

History

Observations of Venus

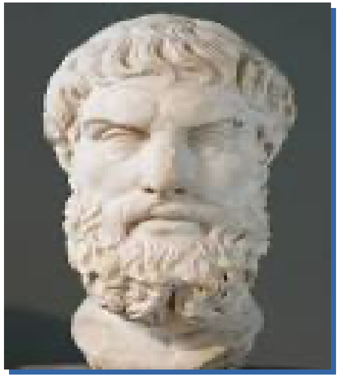
- Babylonian observations of Venus
  span of more than 20 years
  in approx. 17th century BC
- This copy from 7 BC in cuneiform
- Recognition of periodicity (Venus cycles)
- First recorded astronomical observations
- Ammisaduqa 4th after Hammurabi



British M

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

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


Wikipedia

Ancient times

- Epicurius (341-270 BC)

  “There 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

[9] Furthermore, there are infinite worlds both like and unlike this world of ours. For the atoms being infinite in number, as was proved already, are borne on far out into space. For those atoms, which are of such nature that a world could be created out of them or made by them, have not been used up either on one world or on a limited number of worlds, nor again on all the worlds which are alike, or on those which are different from these. So that there nowhere exists an obstacle to the infinite number of the worlds.

[10] Moreover, there are images like in shape to the solid bodies, far surpassing perceptible things in their subtlety of texture. For it is not impossible that such emanations should be formed in that which surrounds the objects, nor that there should be opportunities for the formation of such hollow and thin frames, nor that there should be effluences which preserve the respective position and order which they had before in the solid bodies: these images we call idols.

Ancient times

- 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

Democritus according to Hippolytus, *Refutation of the Heresies* I 13 2, in Diels and Kranz, *Die Fragmente der Vorsokratiker*, vol. 2, section 68 A 40, p. 94. Translation from Guthrie, *A History of Greek Philosophy*, vol. 2, p. 405

Giordano Bruno

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

De l'infinito universo et mondi

(On the Infinite Universe and Worlds, 1584)

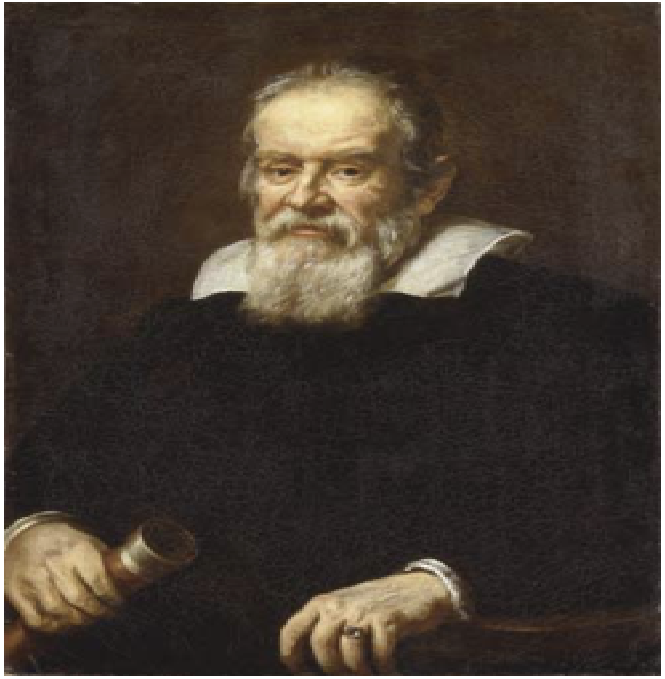
Copernicus (1473-1543)

- 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

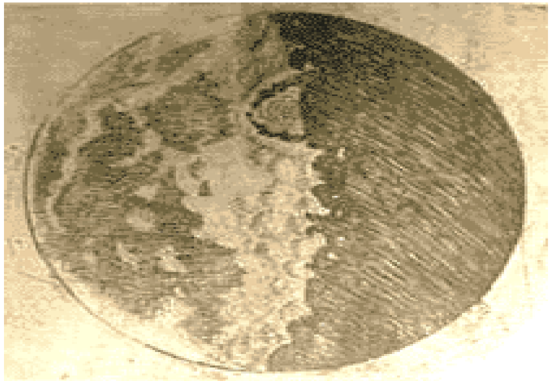
Galileo (1564-1642)

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



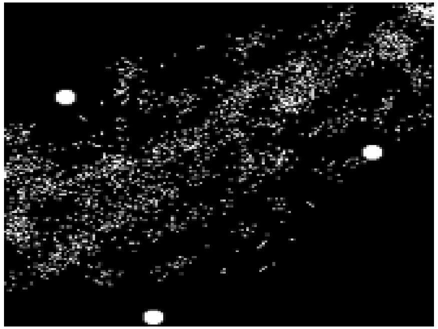
Wikipedia

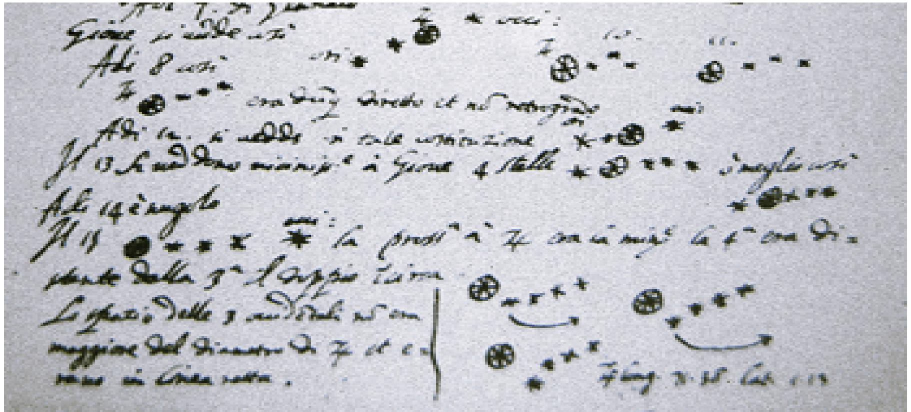
First discoveries with the telescope

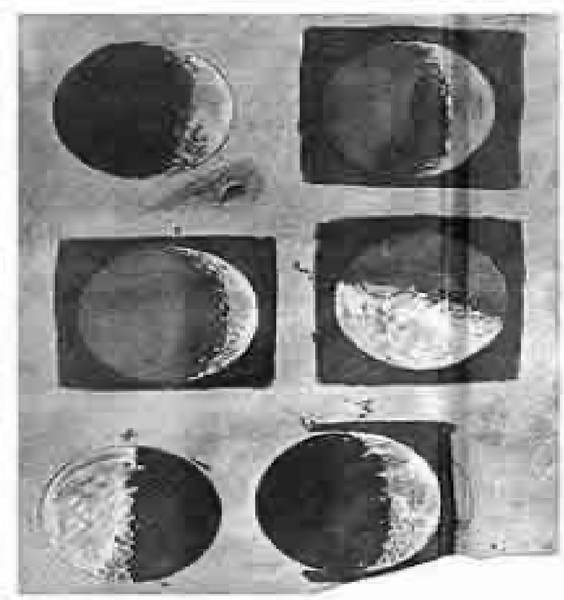


One of Galileo's drawings of the moon. 1610 A. D.

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





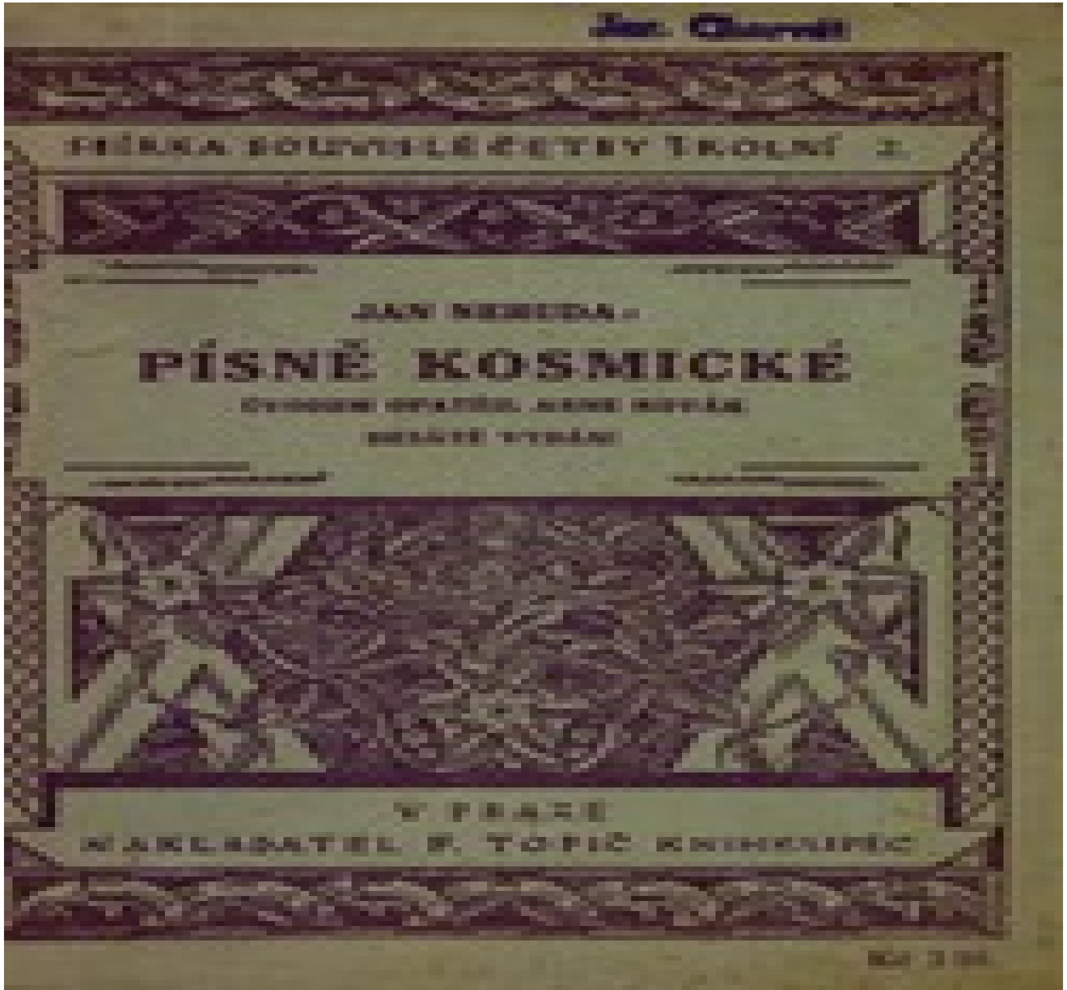


Christian Huygens

- 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_type=PDF_HIGH&whole_paper=YES&type=PRINTER&filetype=.pdf

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 $V^2 \sim \frac{1}{r}$. 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 ± 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 ± 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.

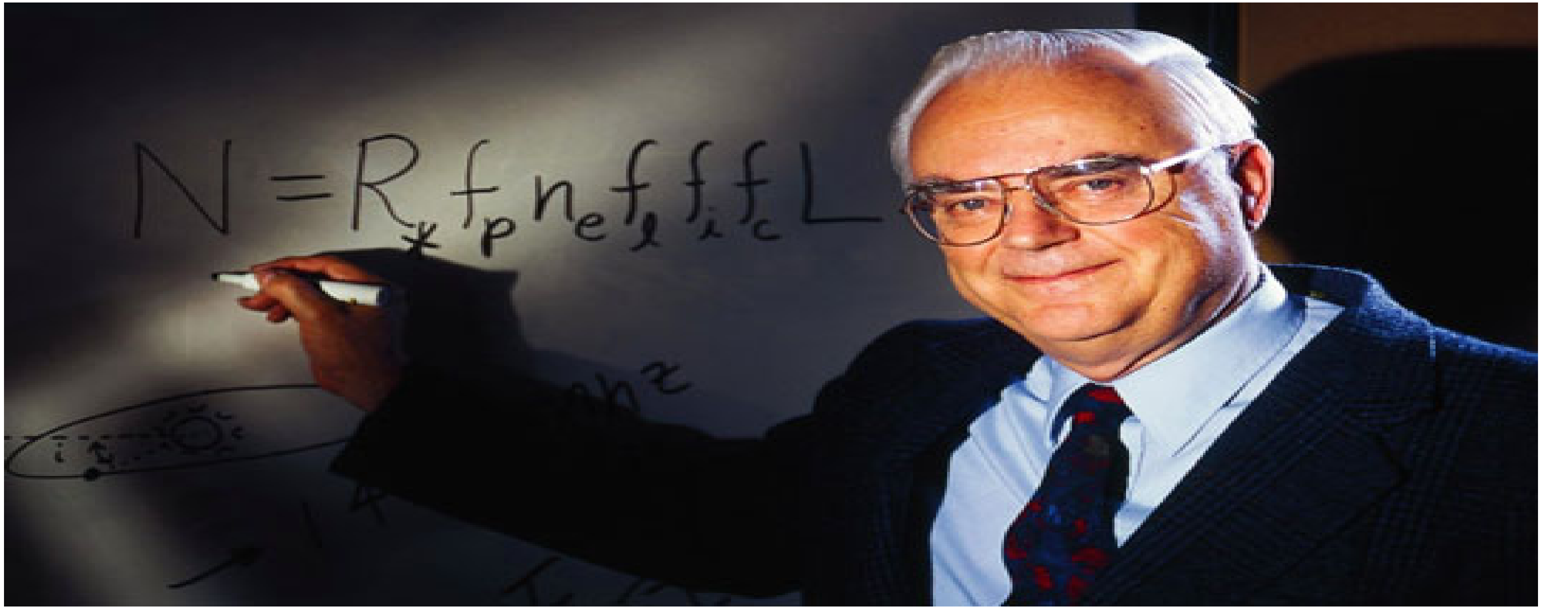
Berkeley Astronomical Department,
University of California.
1952 July 24.

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

So the answer was (in 1960)?

10-20

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

First attempts

- Griffin R.
- https://articles.adsabs.harvard.edu//full/1967ApJ...148..465G/0000465.000.html

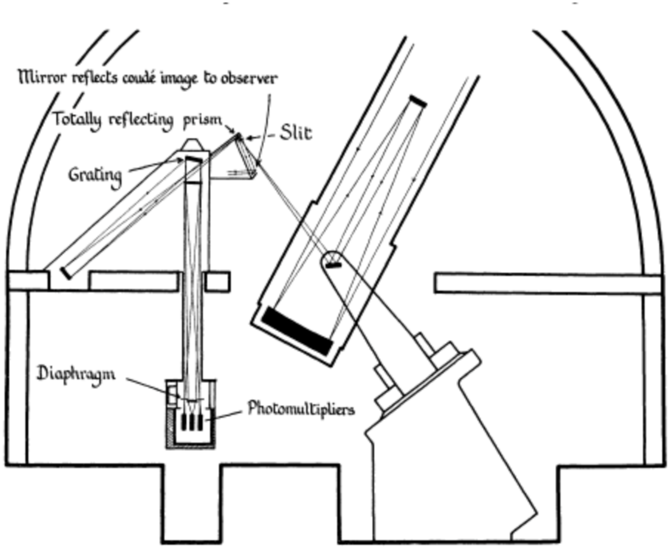


FIG. 1.—Sectional diagram of the Cambridge 36-inch coudé reflector and radial-velocity spectrometer

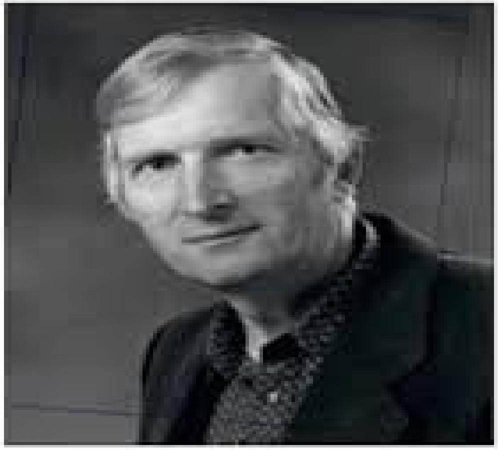
CORAVEL

- Spectrograph at Danish 1.54 at ESO Chile
- Project started 1971 Marseilles and Geneva teams
- RV accuracies 250 m/s
- Decomissioned 1998

Credit: ESO

Cells filled with gas

- First spectroscopic exoplanet survey 1971
- Hydrogen Fluoride cell for calibration
- The goal is to convert pixel scale (detector) into wavelength as accurately as possible
- http://articles.adsabs.harvard.edu/pdf/1979PASP...91..540C

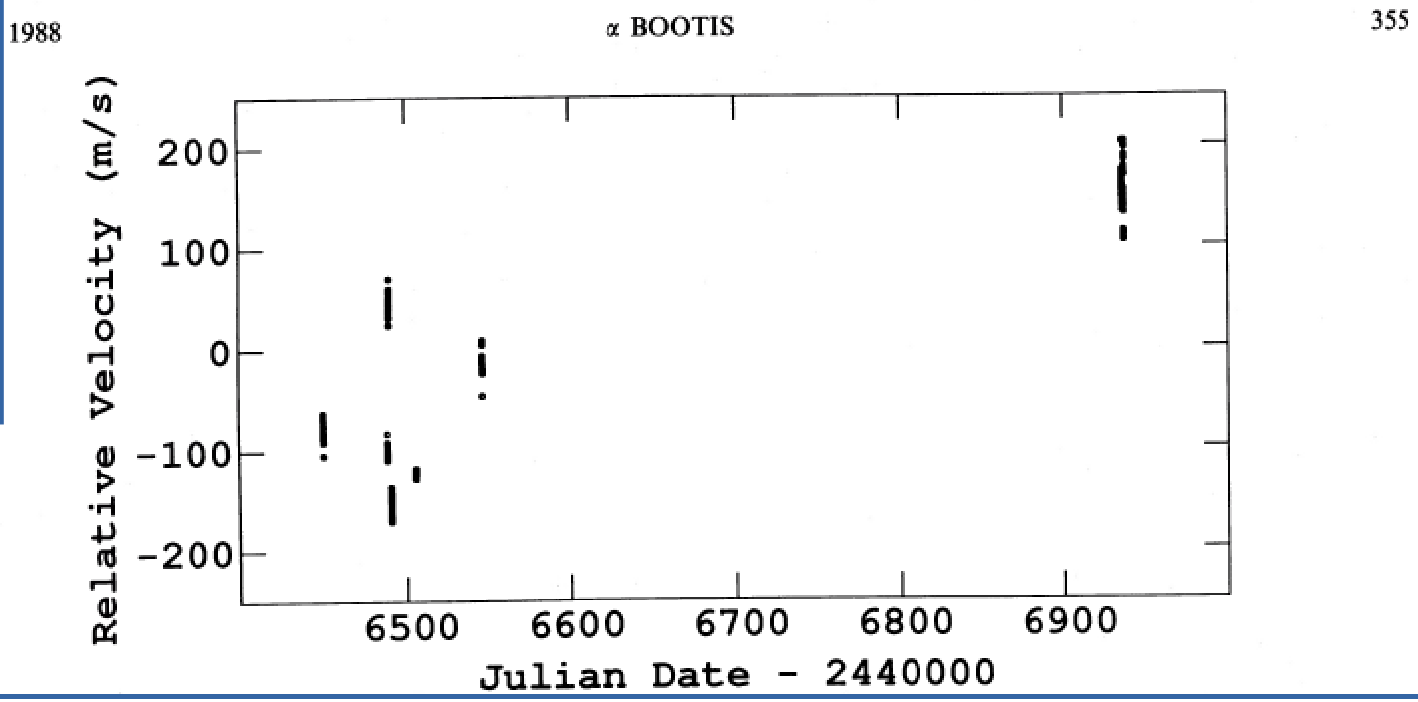



https://dtm.carnegiescience.edu/news/brief-personal-history-exoplanets

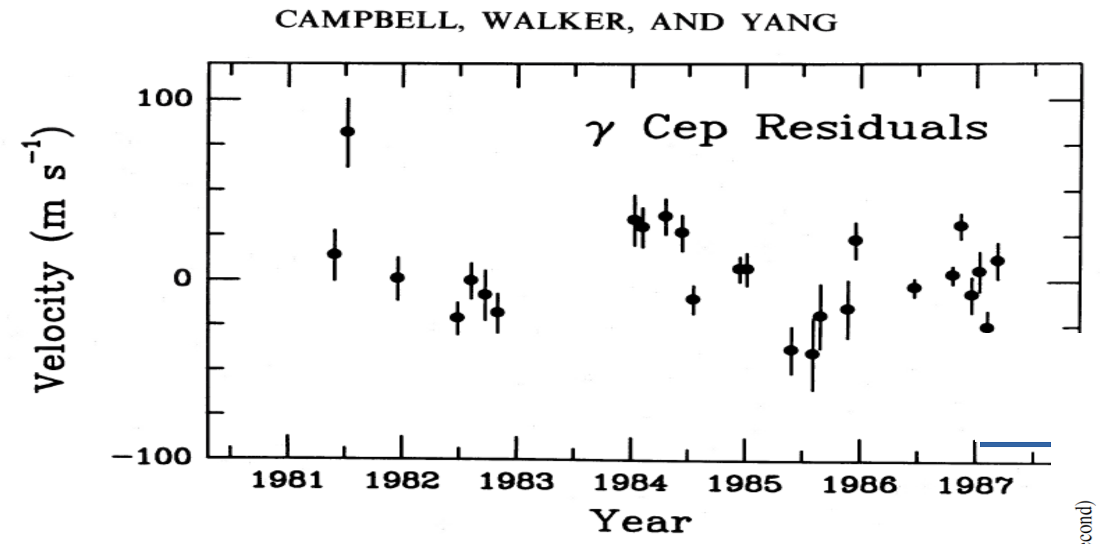
Telluric lines and other methods

- Cochran W. D., 1988, ApJ, 334, 349 (based on Griffin and Griffin)

W. Cochran
U. Texas



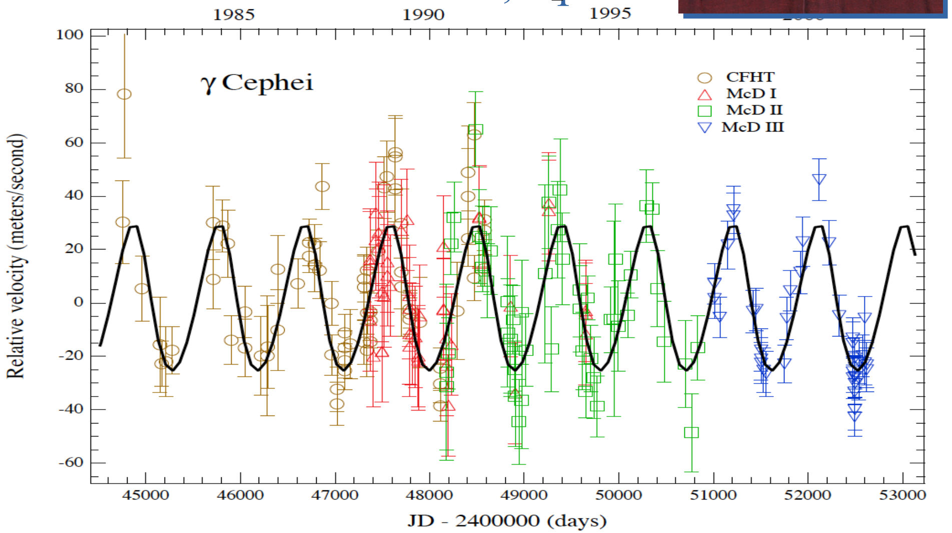
The Case of gamma Cep



Campbell, Walker and Yang, 1988, ApJ

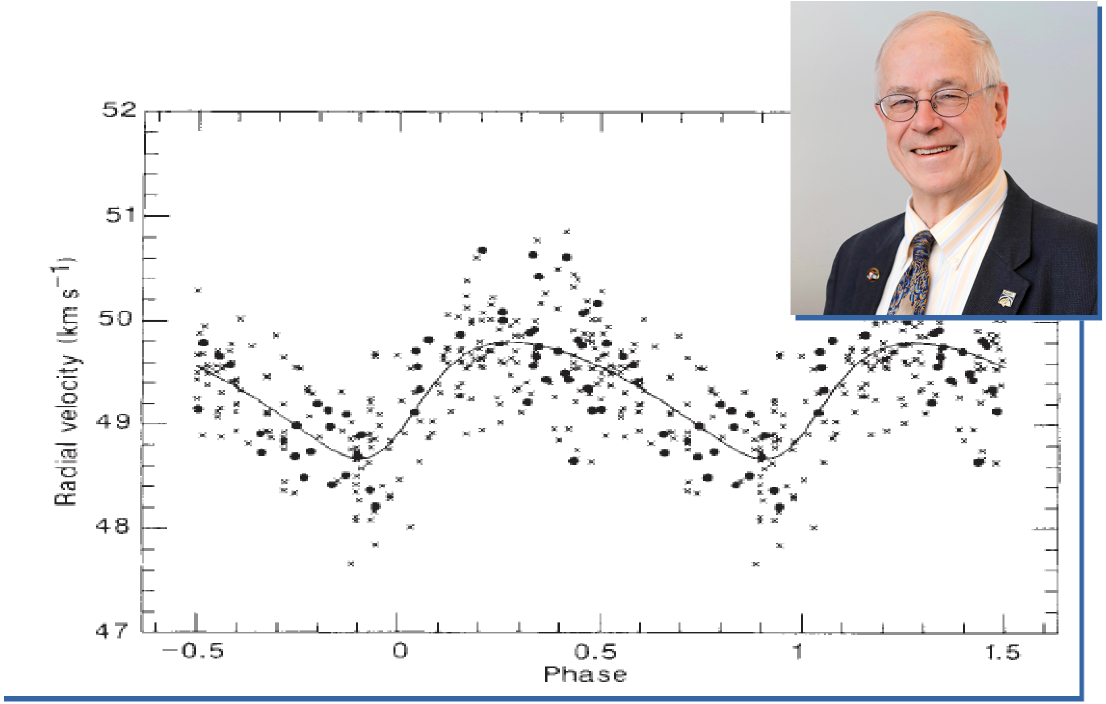
P = 903 days
Mass = 1.85 Mjupiter

Hatzes et al. 2003, ApJ



The Case of Dave Lathams planet

- HD114762
- A BD? A planet?
- 11- 65 Jupiter Masses?
- Or more or less?
- Mass of 107 Jup. confirmed
- very low inclination
- Flavien, A&A
- https://arxiv.org/abs/1910.07835



From Latham et al. 1989, Nature

And finally, first exoplanets detected

Detection of extreme planets

A planetary system around the millisecond pulsar PSR1257 + 12

A. Wolszczan &

D. A. Frail

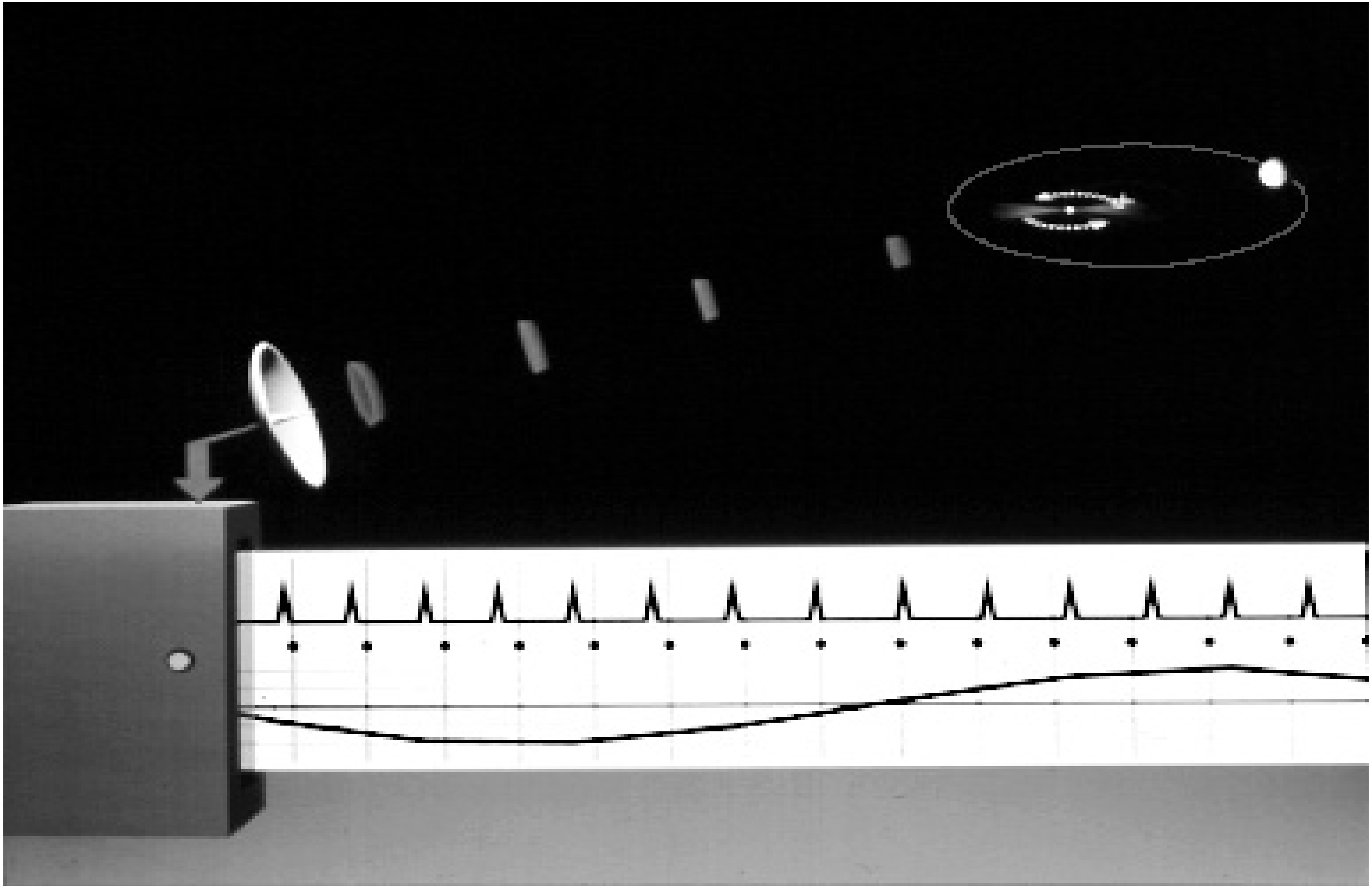
Letters to Nature

Nature 355, 145 - 147

(09 January 1992);

Wikipedia

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



http://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

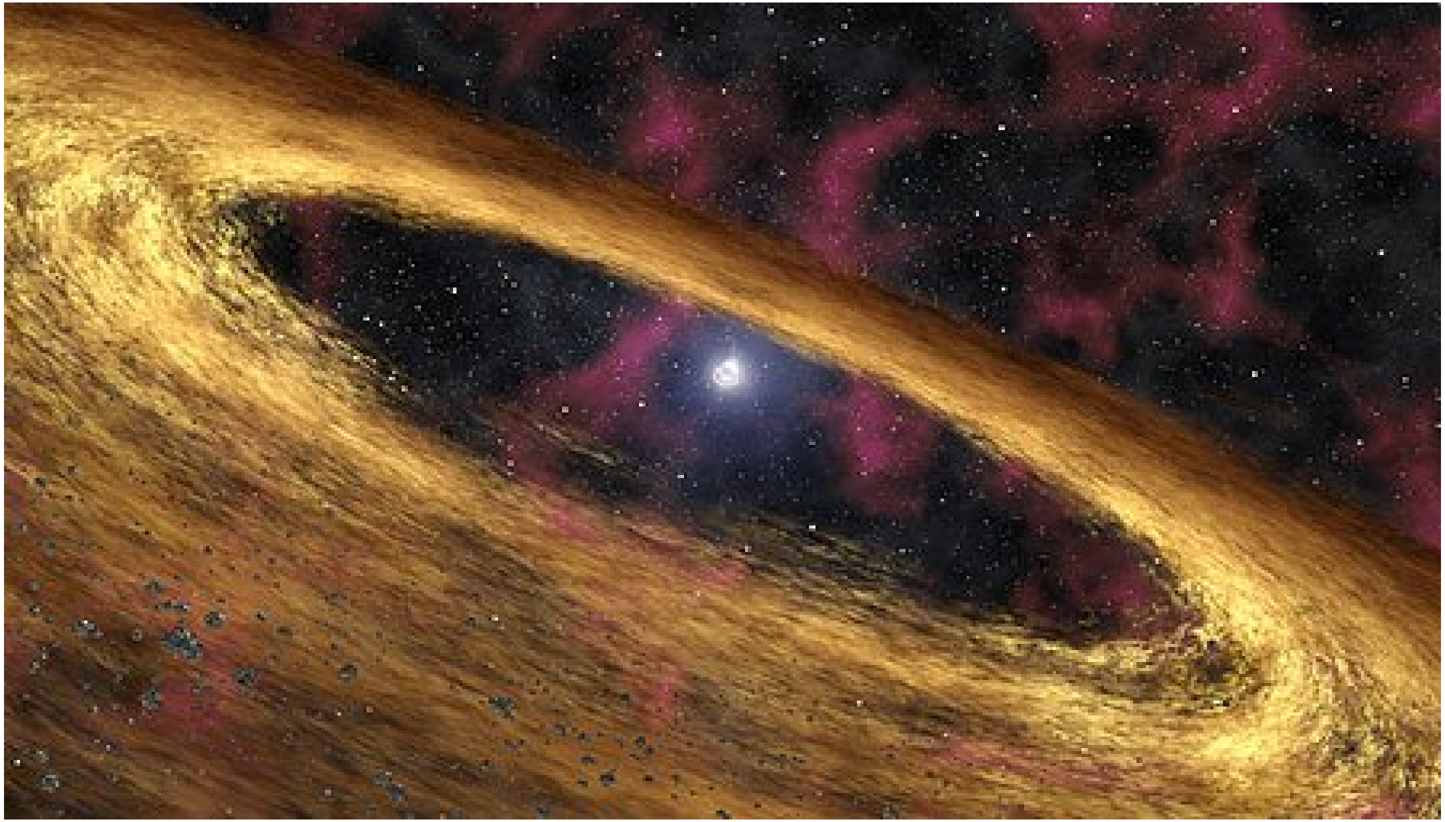
Zhongxiang Wang1, Deepto Chakrabarty1 & David L. Kaplan1

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

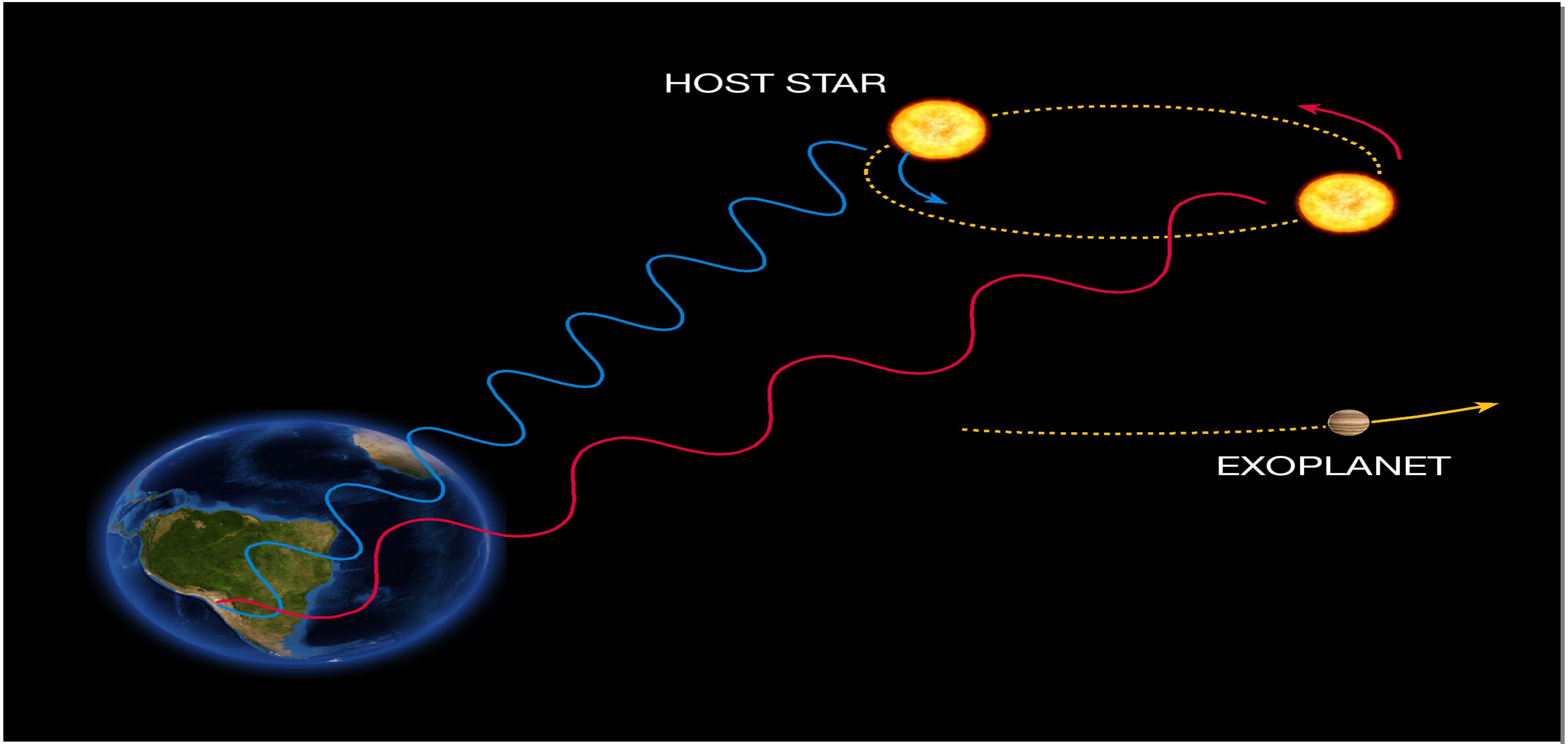
- Mesurements of Radial Velocities with high accuracies (m/s regimes)
- Spectral type catalogs
- Serching among bright stars in the solar neighbourhood
- First planet around solar type star detected by radial velocity survey in 1995
- So how does radial velocity measurement work?

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

Radial velocity method



The Radial Velocity Method

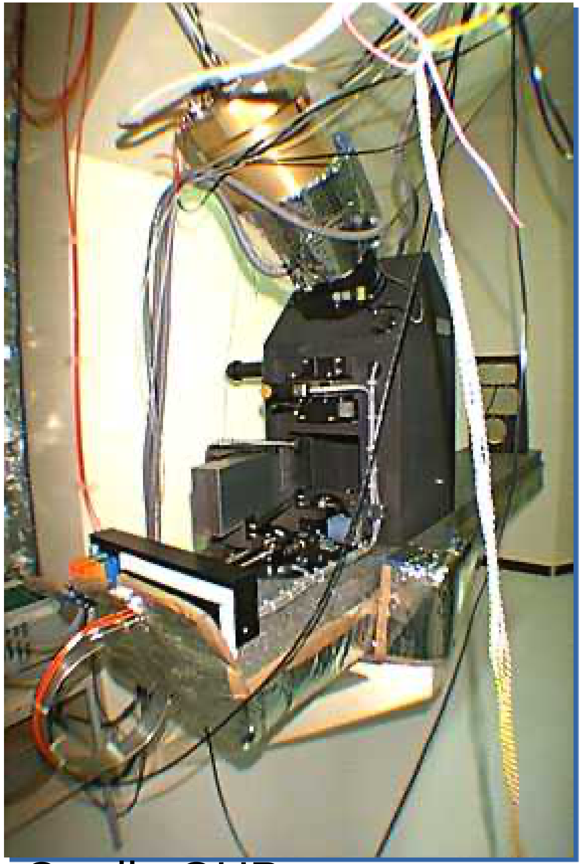
ESO Press Photo 22e/07 (25 April 2007)

The Case of 51 Peg

ELODIE at OHP

Credit OHP

1.93-m at OHP - ELODIE



Credit: OHP

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

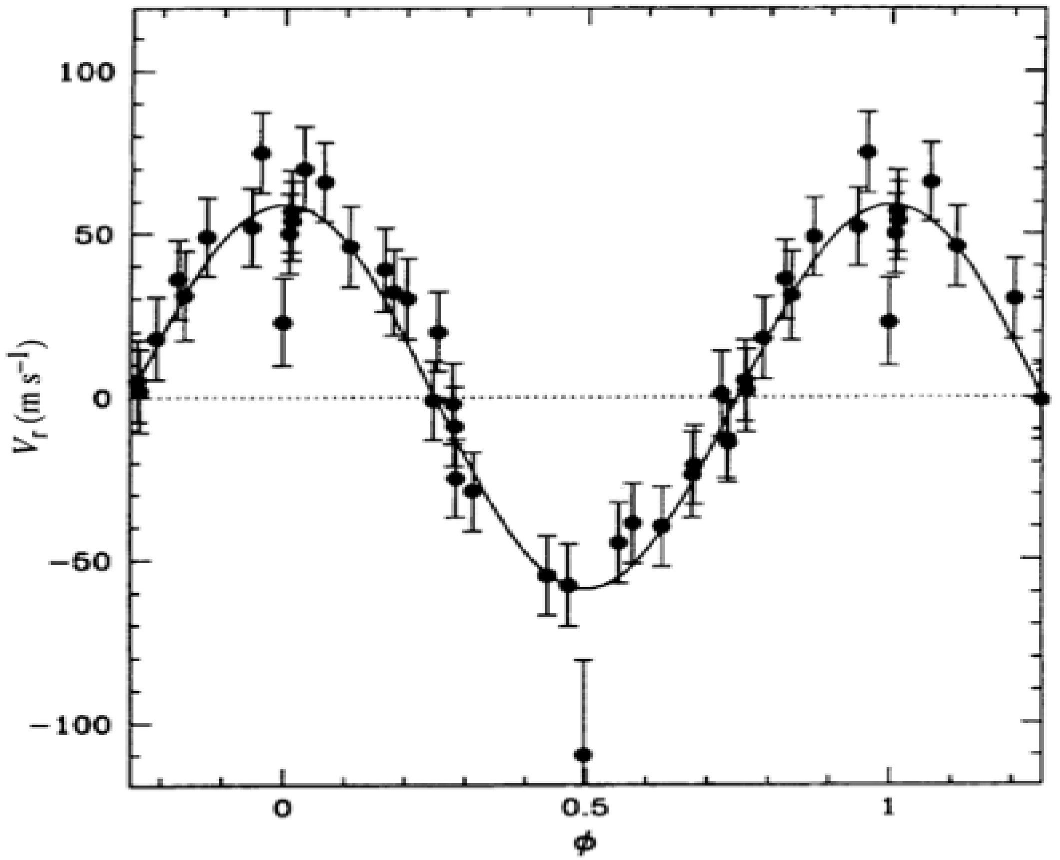
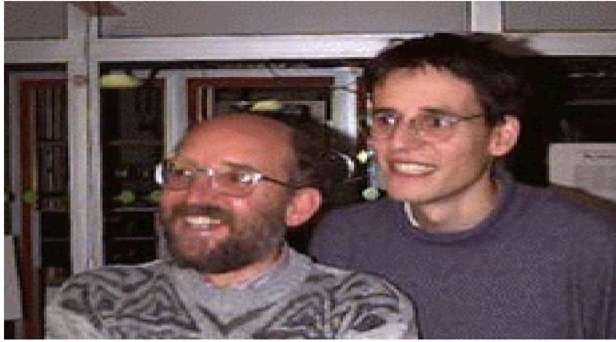


FIG. 4 Orbital motion of 51 Peg corrected from the long-term variation of the γ-velocity. The solid line represents the orbital motion computed from the parameters of Table 1.



Mayor and Queloz, 1995, Nature

51 Peg b

- 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)

51 Peg compared

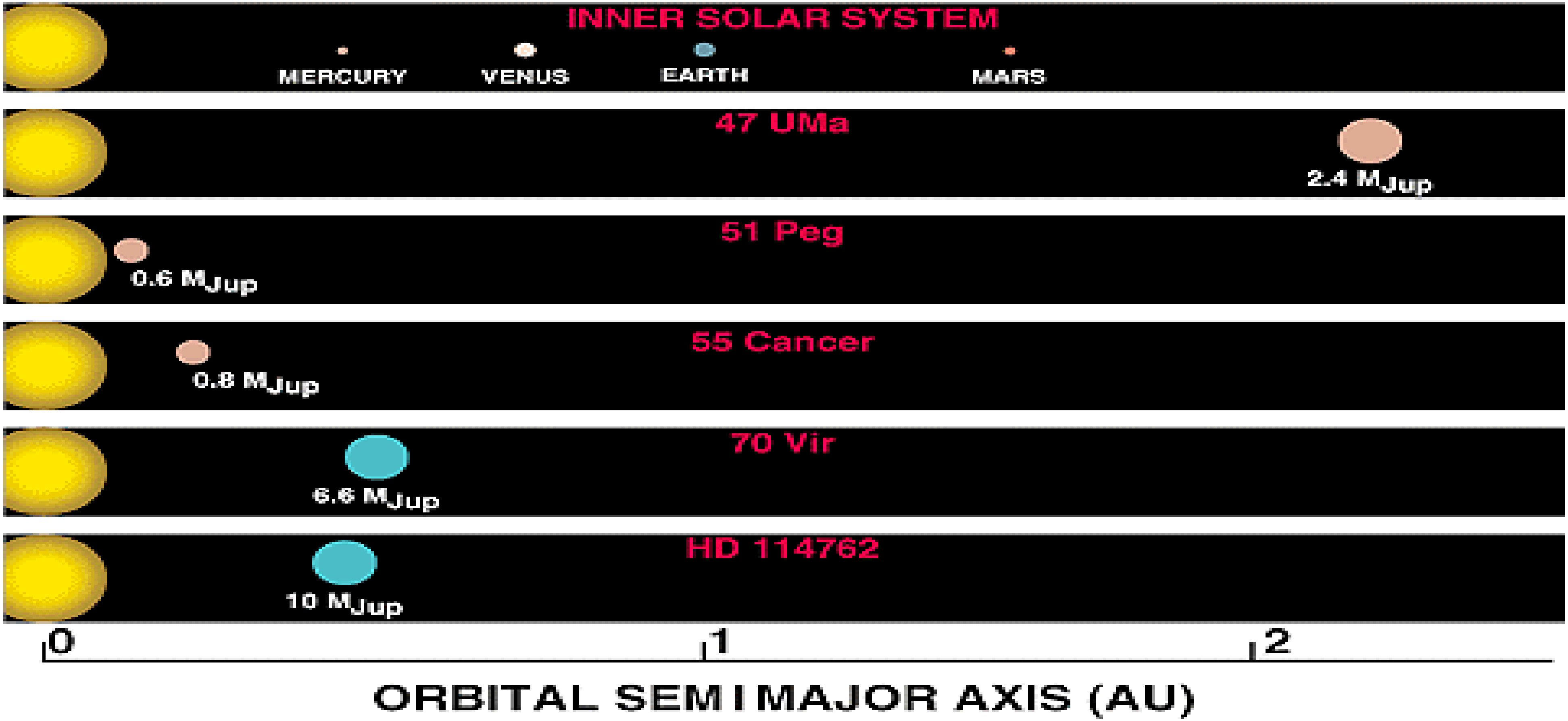
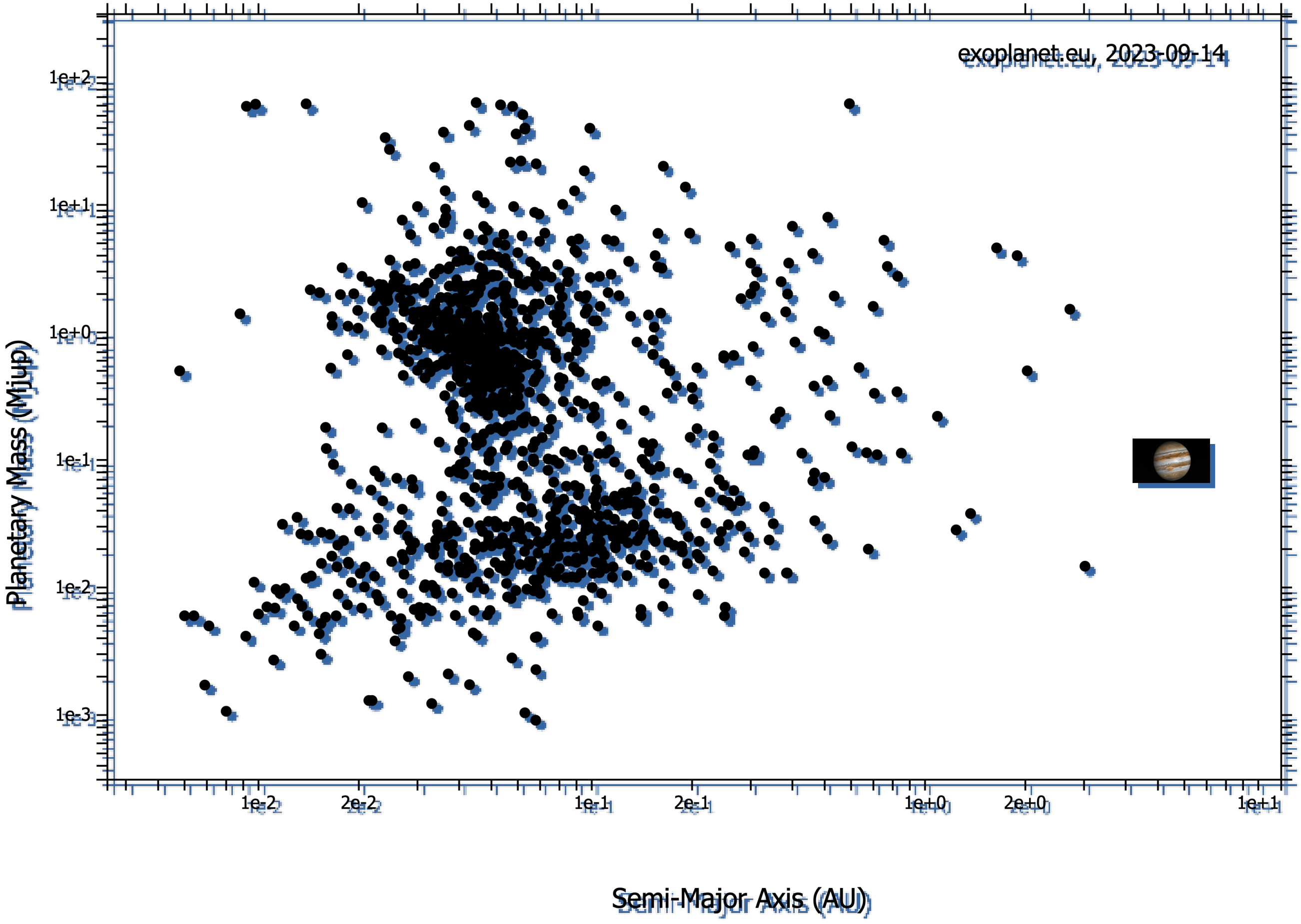


Image from Keele University

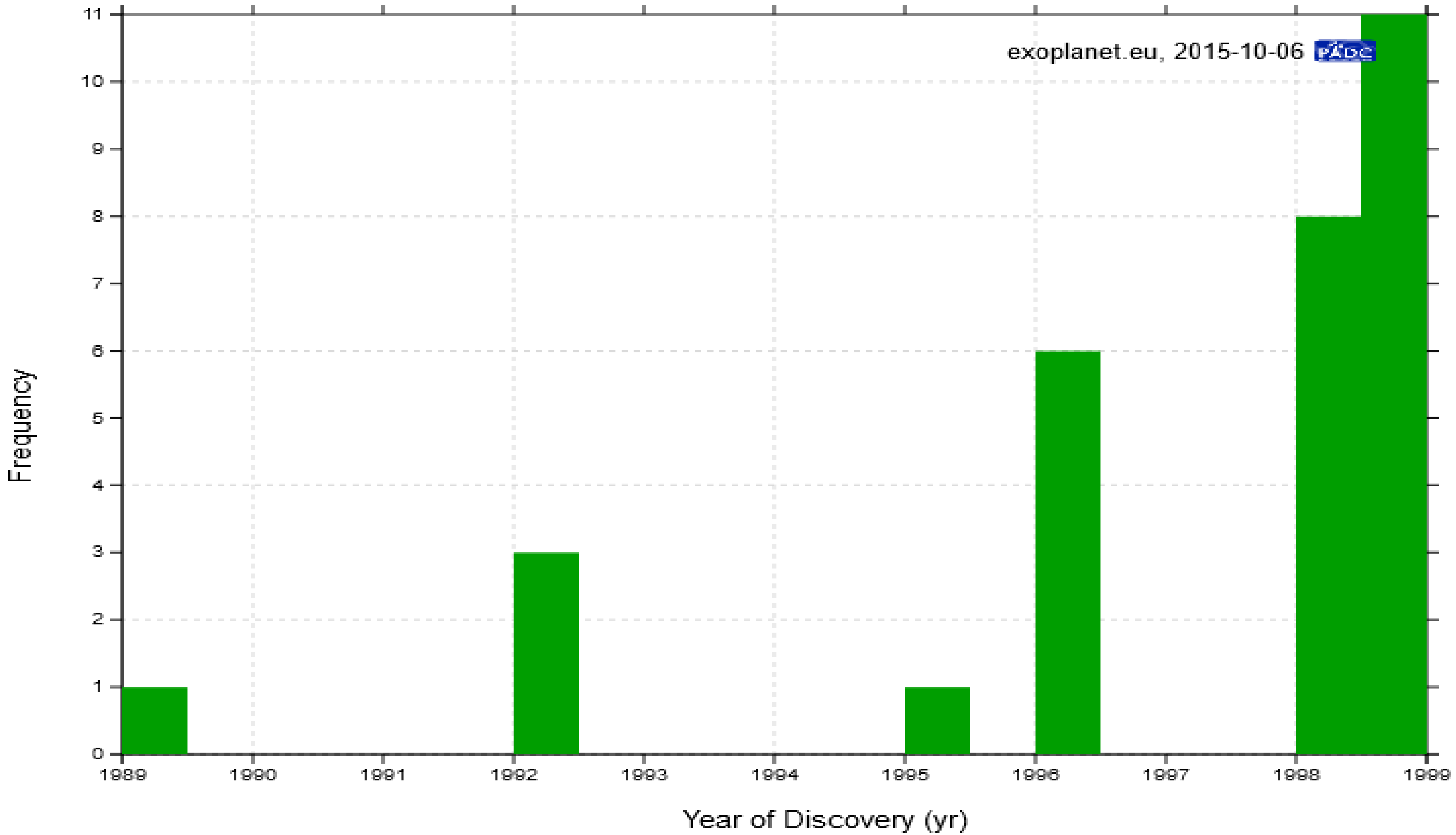
Long periodic planets



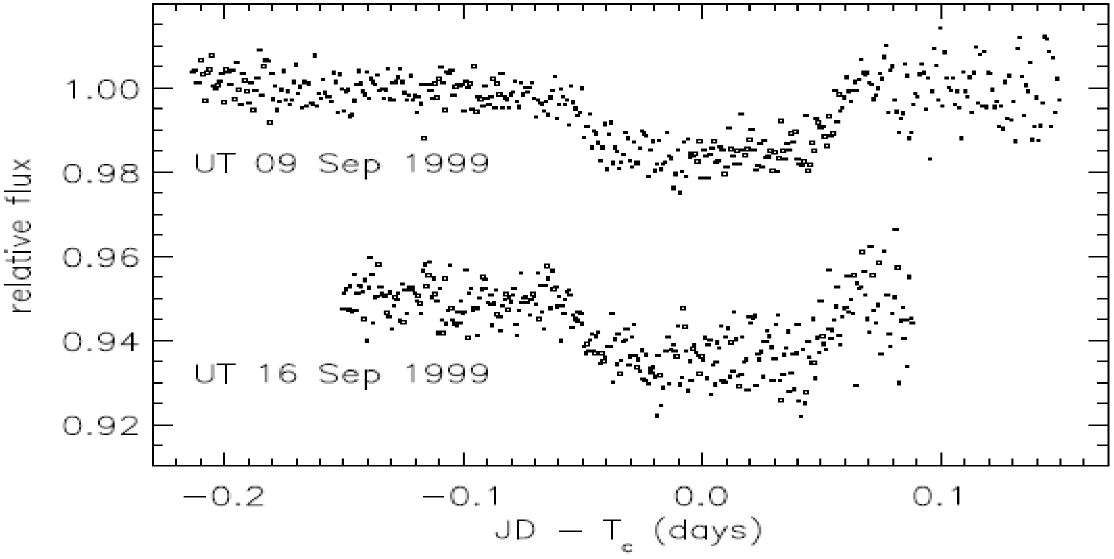
RV surveys and planet types

- 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?

Exoplanets in 2000

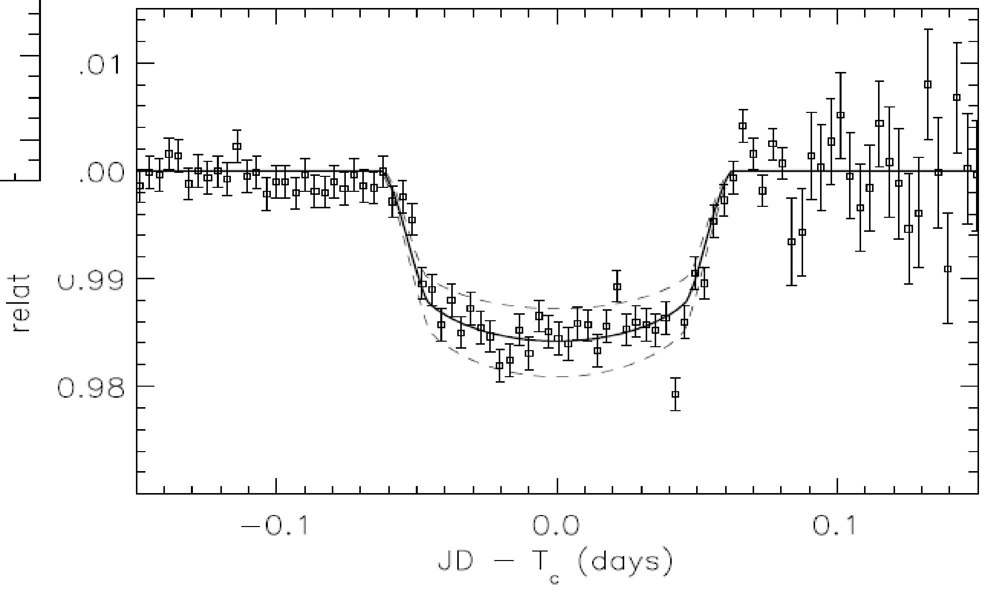


When the planet eclipses its star

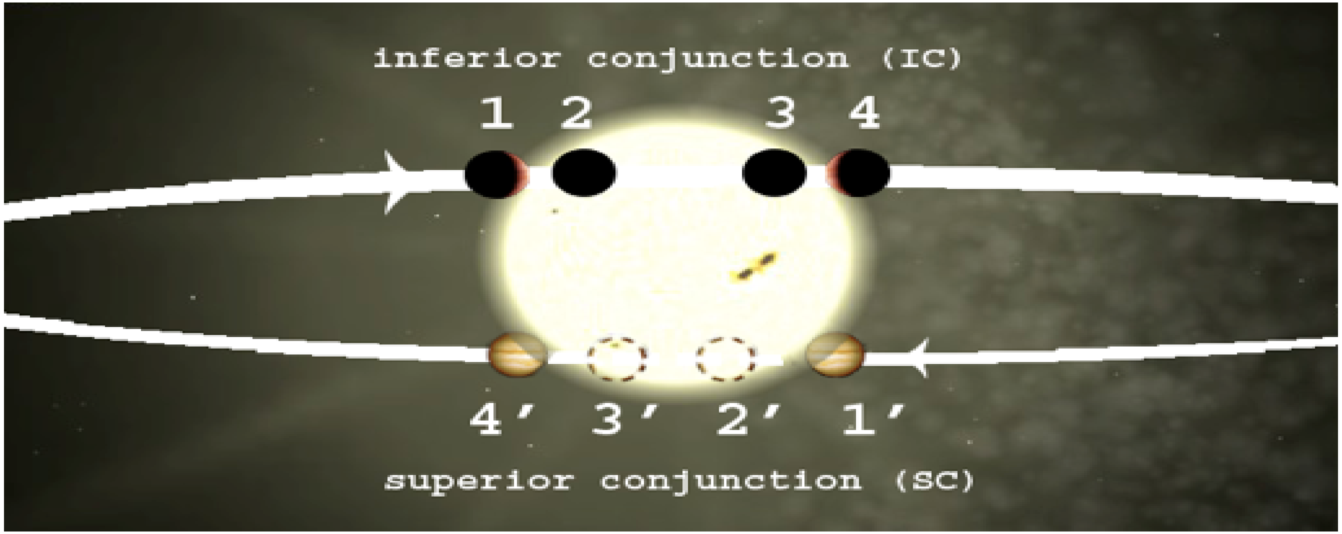


HD209458b

Charbonneau et al. 2000



Eclipses/transits



From Angerhausen et al. 2008

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

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/

And are hot-Jupiters common?

- What is the occurance rate for hot-Jupiters?

  - Fischer claim around 1 percent

  - Jupiter sized planets 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

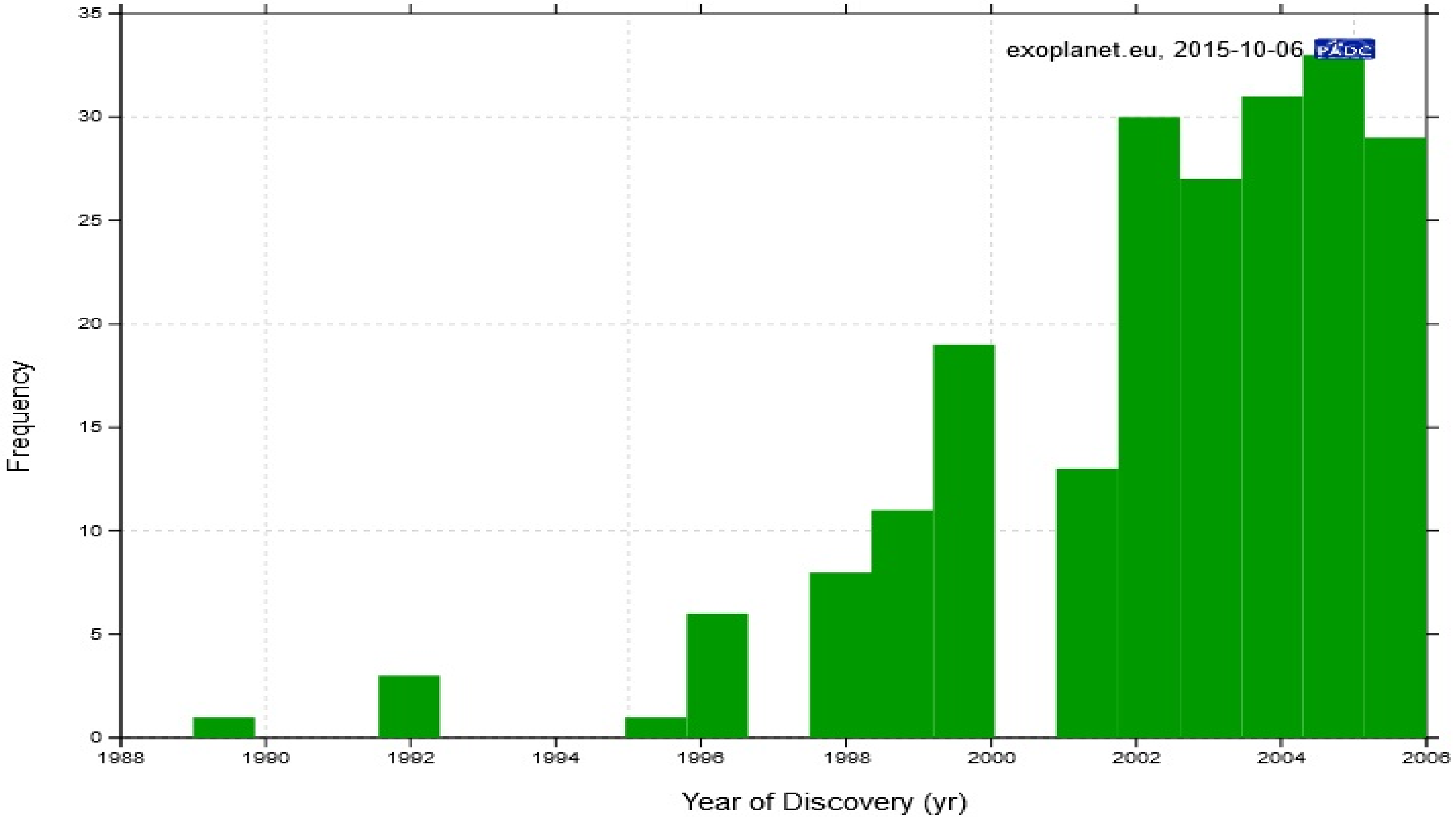
Each site consists of 8 telescopes with wide angle CCDs

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

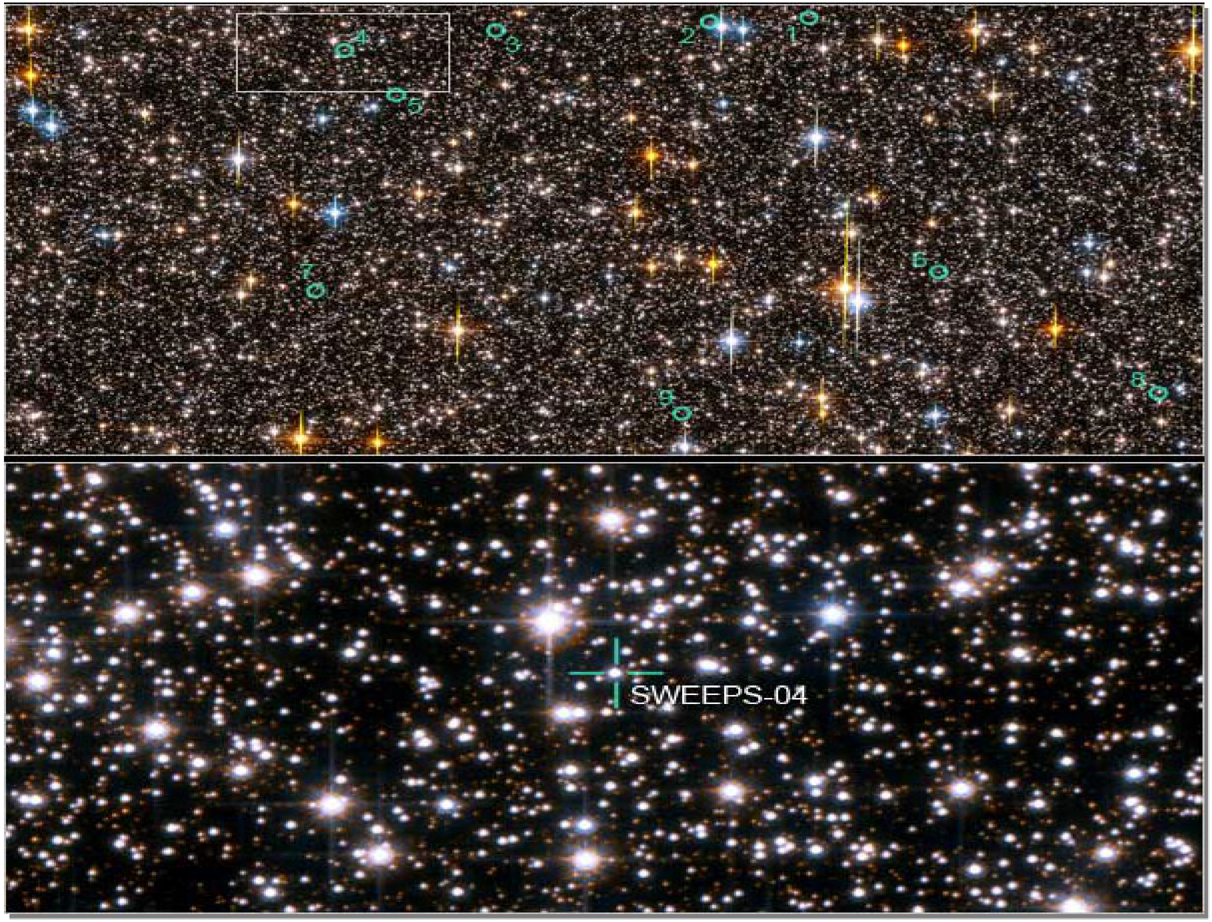
Received 3 March 2008 / Accepted 30 April 2008

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

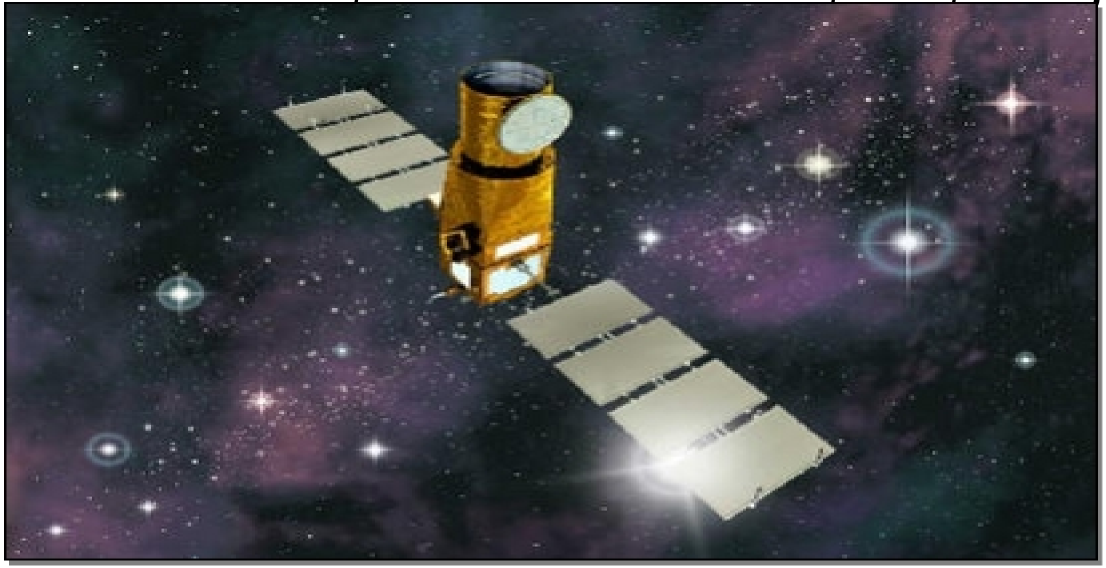
Space missions

CoRoT

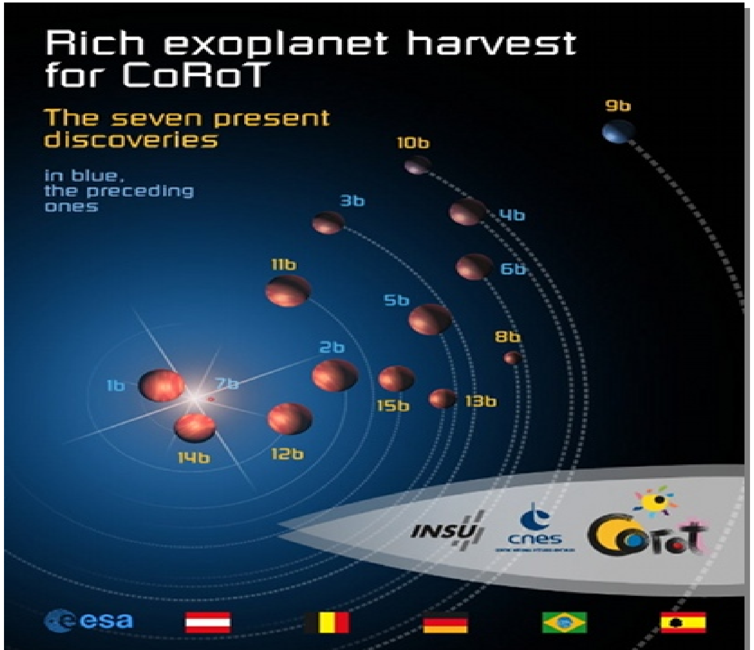
Convection, Rotation and planetary Transits

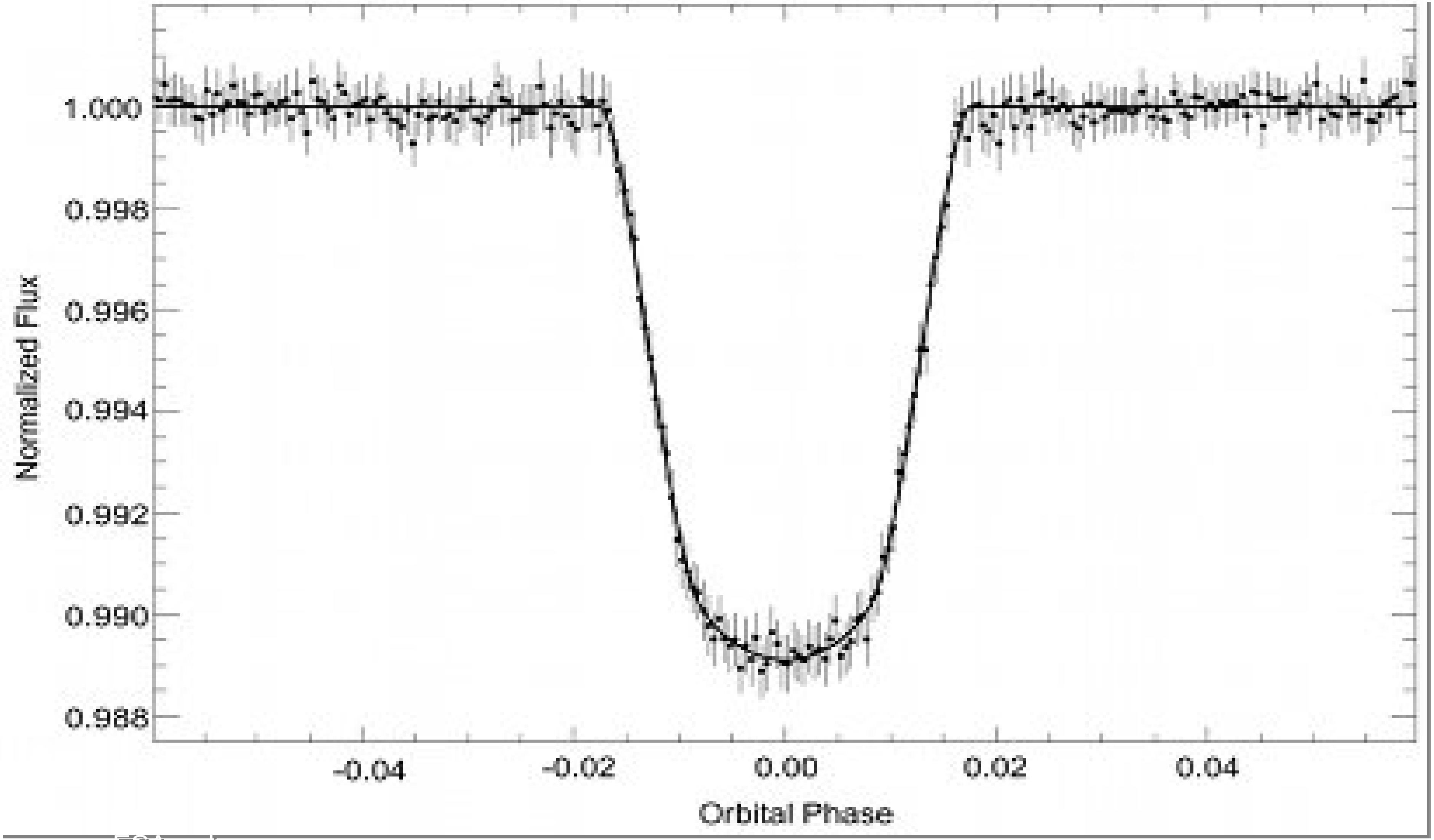
Launched 2006 – mission end 2013

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



ESA webpages

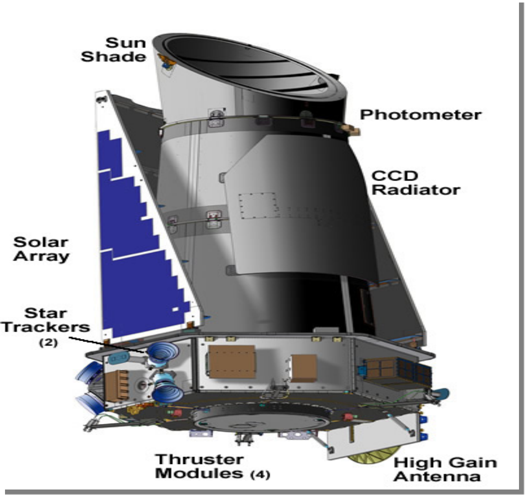




ESA webpages

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

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;

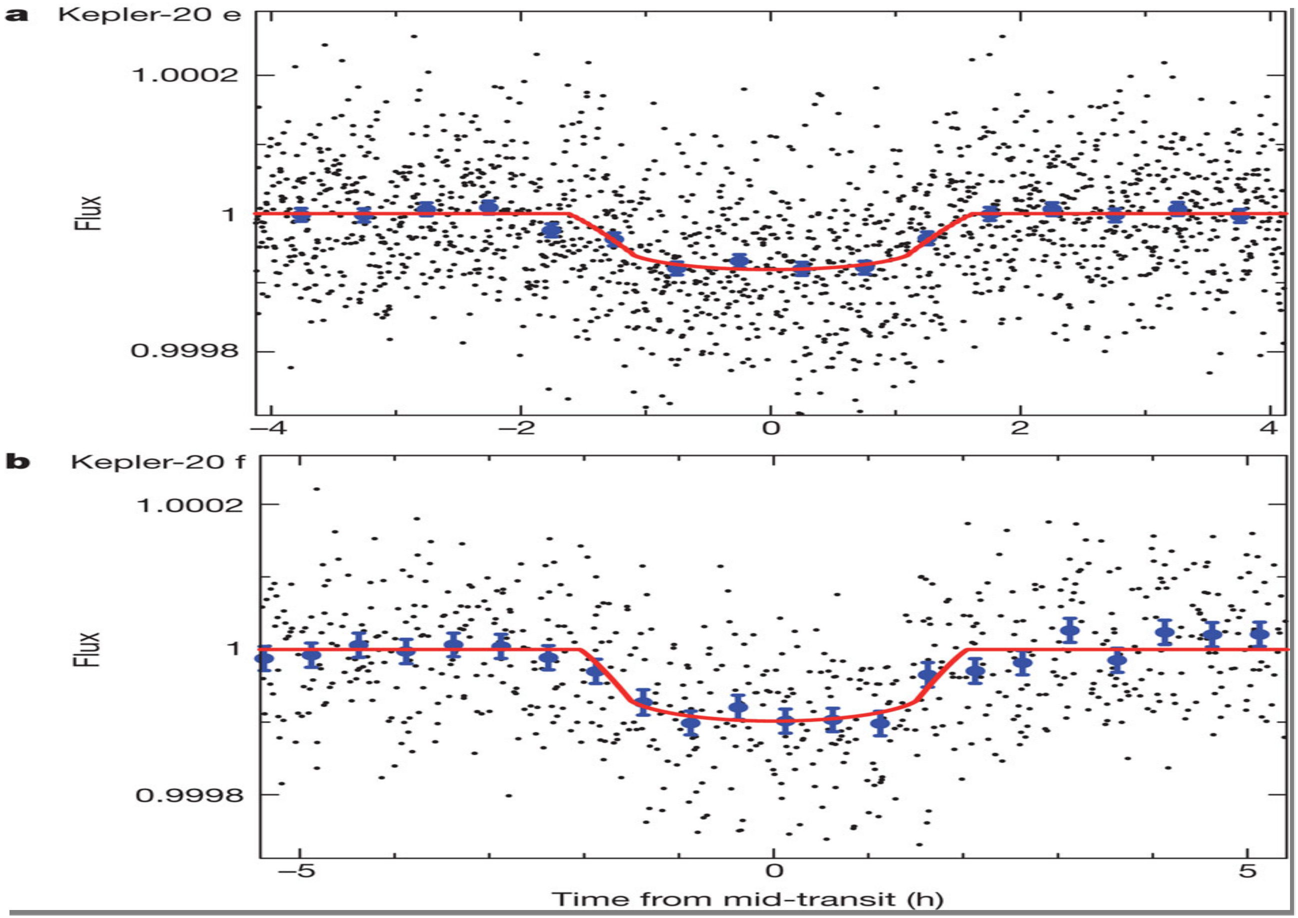
Determine the distribution of sizes and shapes of the orbits of these planets;

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.



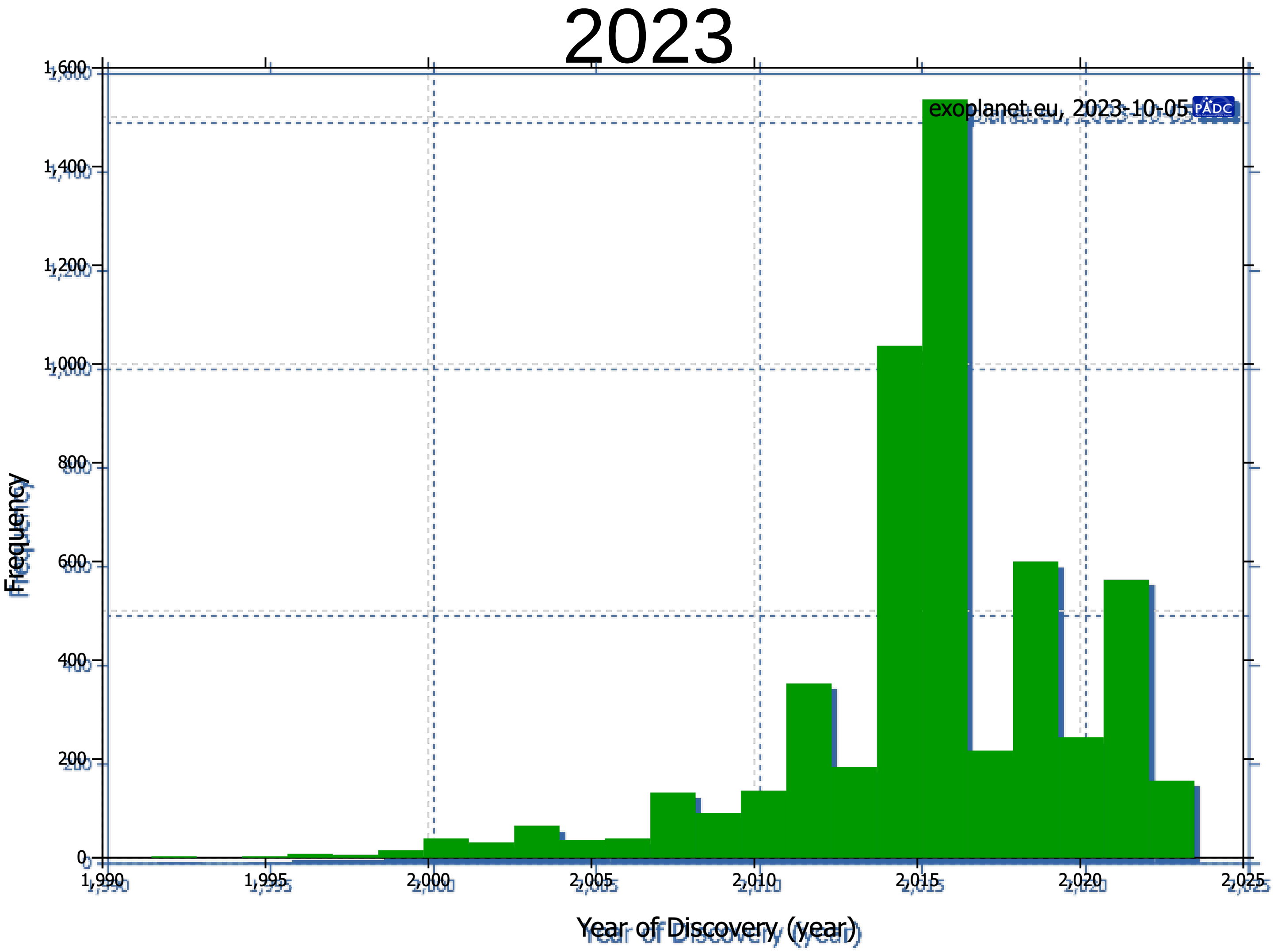
F Fressin *et al. Nature* **000**, 1-5 (2011) doi:10.1038/nature10780

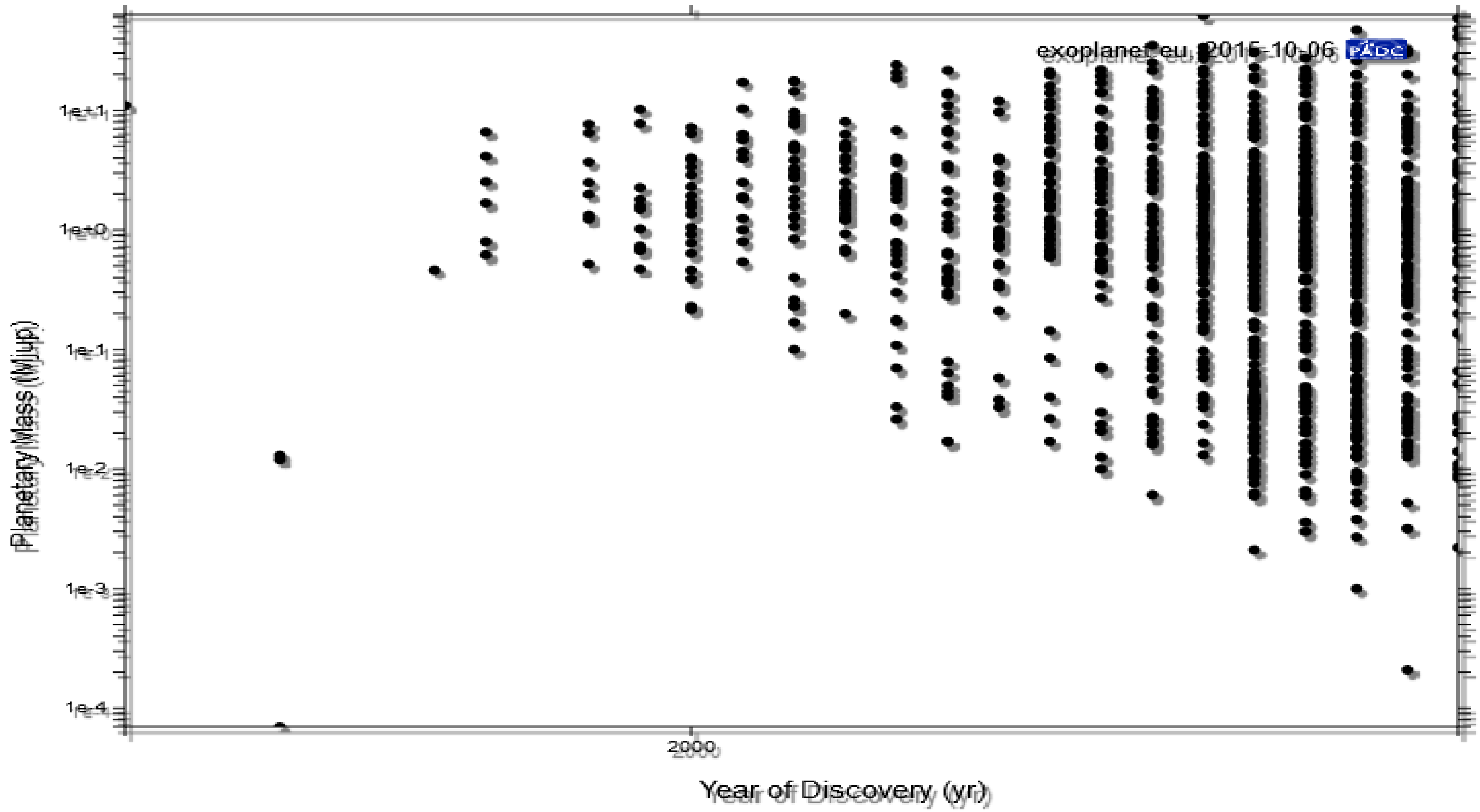
Note: This figure is from a near-final version AOP and may change prior to final publication in print/online

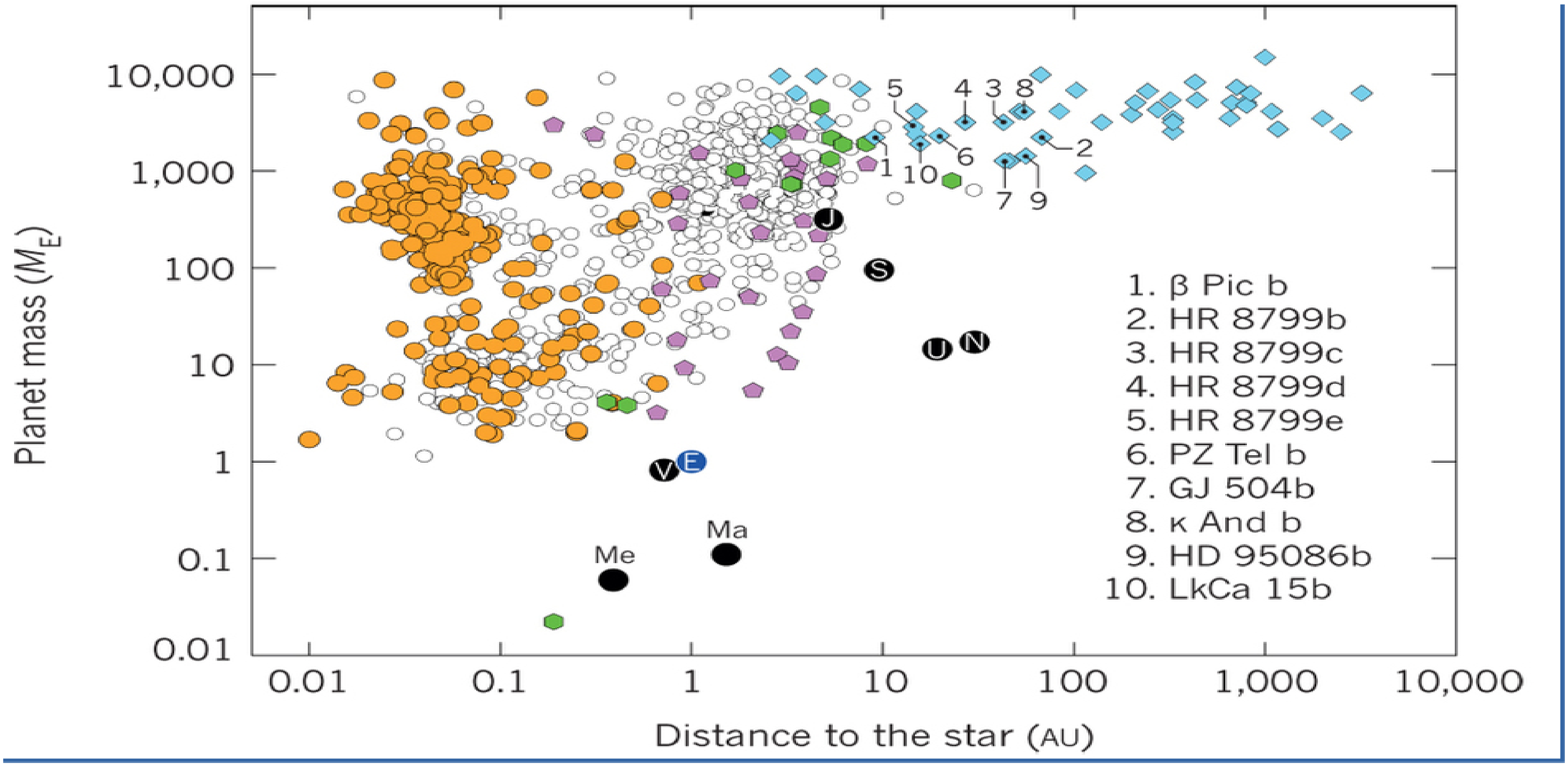
2 Earth like planets – Kepler 20 e and f

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

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

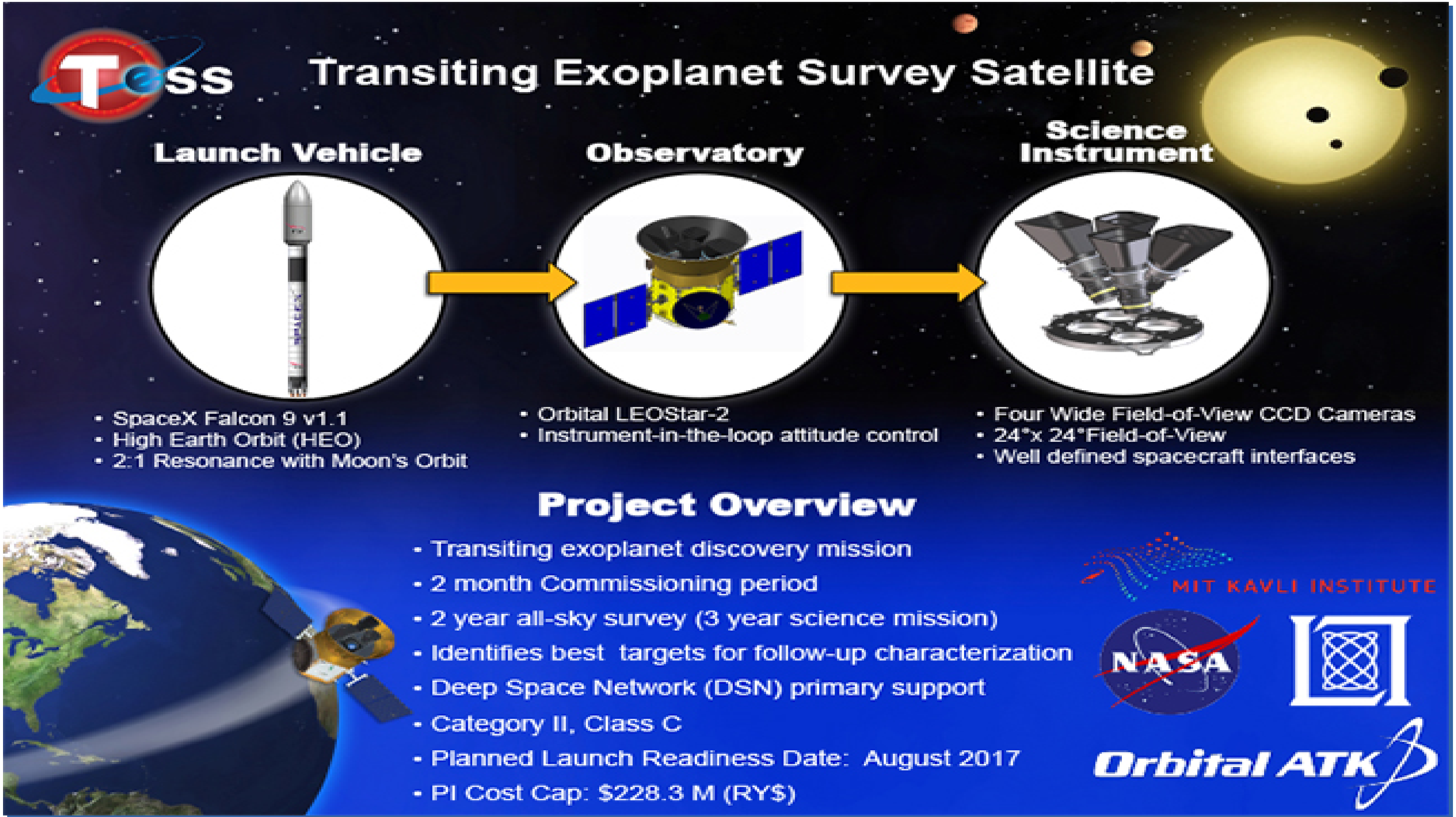

2023
exoplanet.eu, 2023-10-05
PADC
Frequency
Year of Discovery (year)
1,600
1,400
1,200
1,000
800
600
400
200
0
1,990
1,995
2,000
2,005
2,010
2,015
2,020
2,025


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



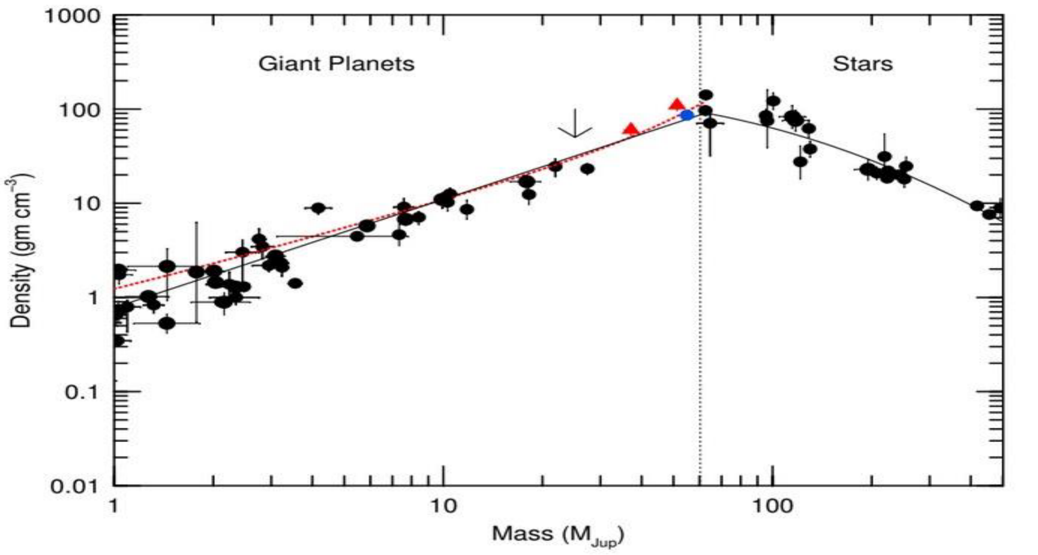
Pepe, et al. 2014 http://arxiv.org/ftp/arxiv/papers/1409/1409.5266.pdf

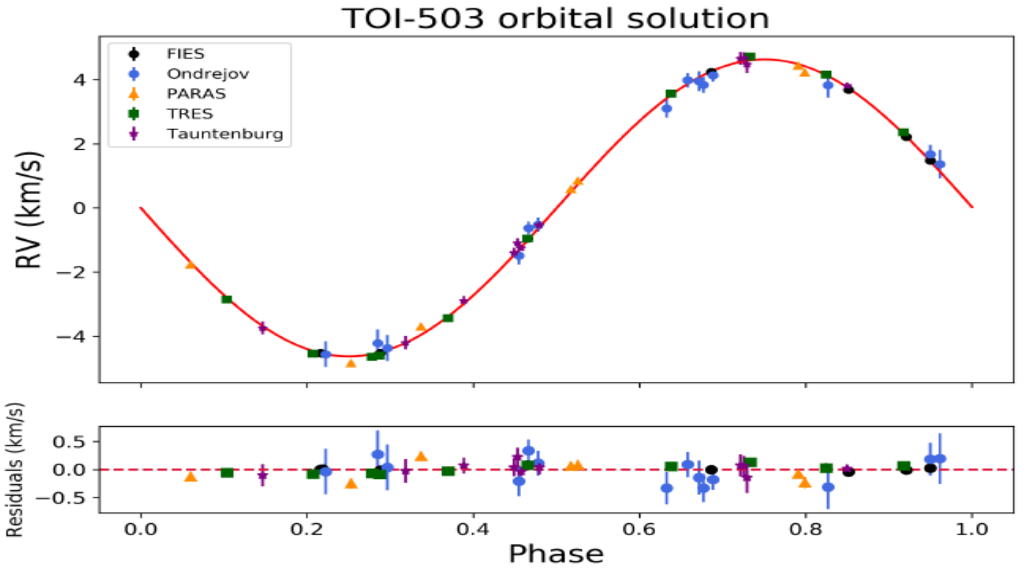
TESS


TESS
Transiting Exoplanet Survey Satellite
Launch Vehicle
Observatory
Science Instrument
• SpaceX Falcon 9 v1.1
• High Earth Orbit (HEO)
• 2:1 Resonance with Moon's Orbit
• Orbital LEOStar-2
• Instrument-in-the-loop attitude control
• Four Wide Field-of-View CCD Cameras
• 24°x 24°Field-of-View
• Well defined spacecraft interfaces
Project Overview
• Transiting exoplanet discovery mission
• 2 month Commissioning period
• 2 year all-sky survey (3 year science mission)
• Identifies best targets for follow-up characterization
• Deep Space Network (DSN) primary support
• Category II, Class C
• Planned Launch Readiness Date: August 2017
• PI Cost Cap: $228.3 M (RY$)
MIT KAVLI INSTITUTE
NASA
Orbital ATK

First Brown Dwarf from Ondřejov

- Mass – 53 Jupiter masses
- Radial velocities between -5 a +5 km/s





Parsson et al. 2019 and Subjak et al. 2019

Paper about three new hot Jupiters

ACCEPTED MANUSCRIPT

TOI-2046b, TOI-1181b and TOI-1516b, three new hot Jupiters from *TESS*: planets orbiting a young star, a subgiant and a normal star

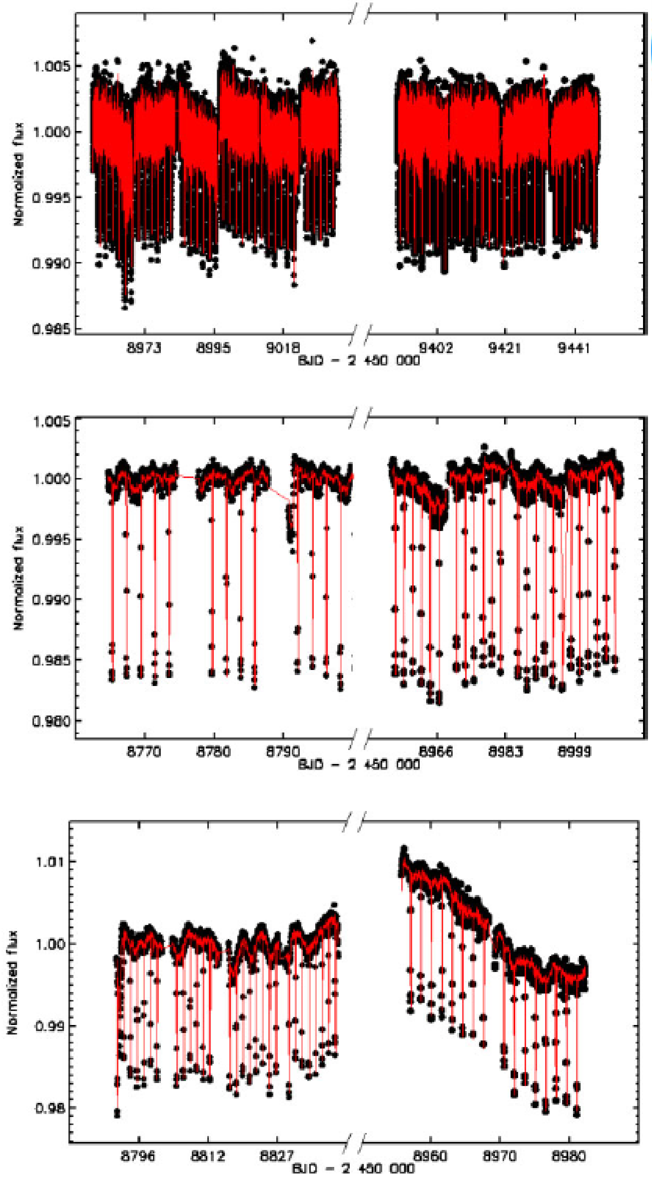
Petr Kabáth ✉, Priyanka Chaturvedi, Phillip J MacQueen, Marek Skarka, Ján Šubjak, Massimilliano Esposito, William D Cochran, Salvatore E Bellomo, Raine Karjalainen, Eike W Guenther ... Show more

Monthly Notices of the Royal Astronomical Society, stac1254,
https://doi.org/10.1093/mnras/stac1254
Published: 26 May 2022

The KESPRINT and the TESS teams collaboration

Our TESS targets

- TOI-1181
  sectors 14-26 and 40
- TOI-1516
  sectors: 17,18,24,25
- TOI29046
  sectors: 18, 19, 24, 25



Observatories involved

Astronomický ústav AV ČR

- Photometry:

  Muscat2 (Spain), The Carlson R Chambliss obs. (USA)

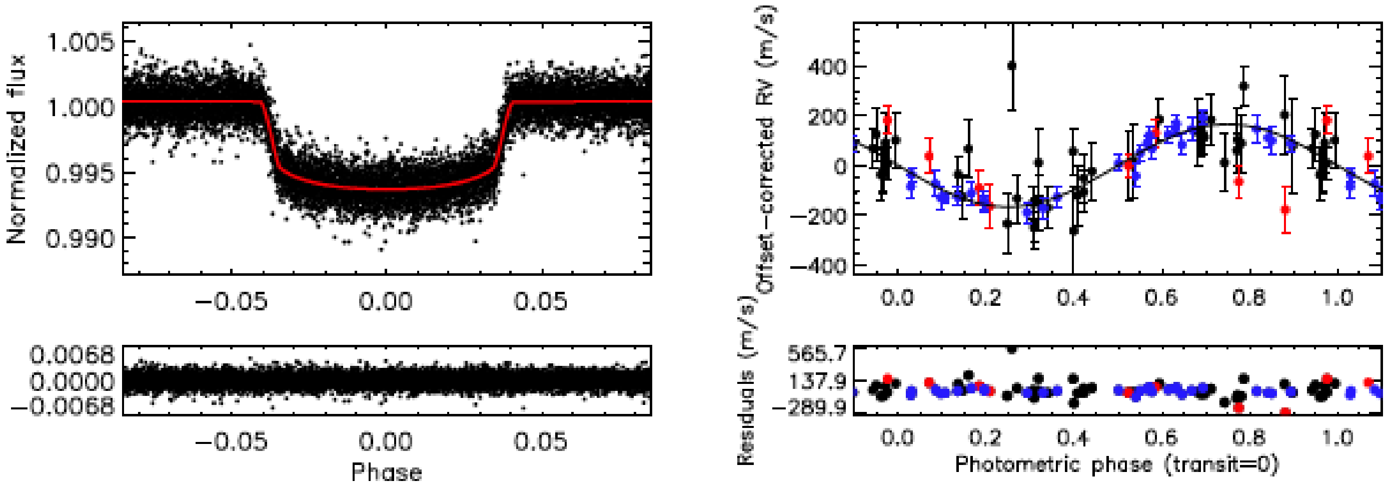
  Gemini North (USA)

- Spectroscopy:

  TCES (Tautenburg, Germany), Tull (Texas, USA), OES (Czechia), TRES (USA)

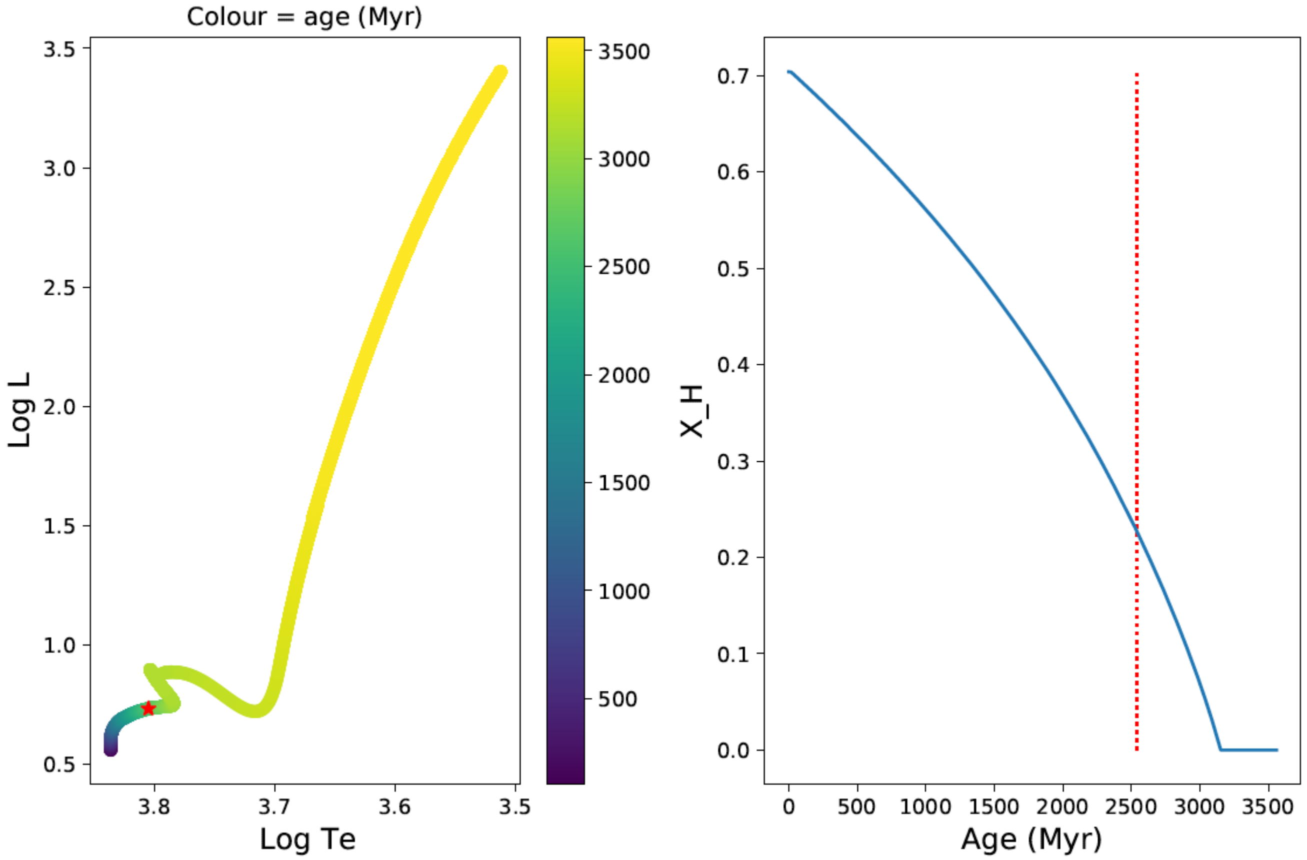
TOI-1181b

- A hot Jupiter around a F subgiant star
- Period 2.1 days
- Radius 1.3 $R_{Jupiter}$ and Mass 1.18 $M_{Jupiter}$



From Kabath et al. 2022 MNRAS,

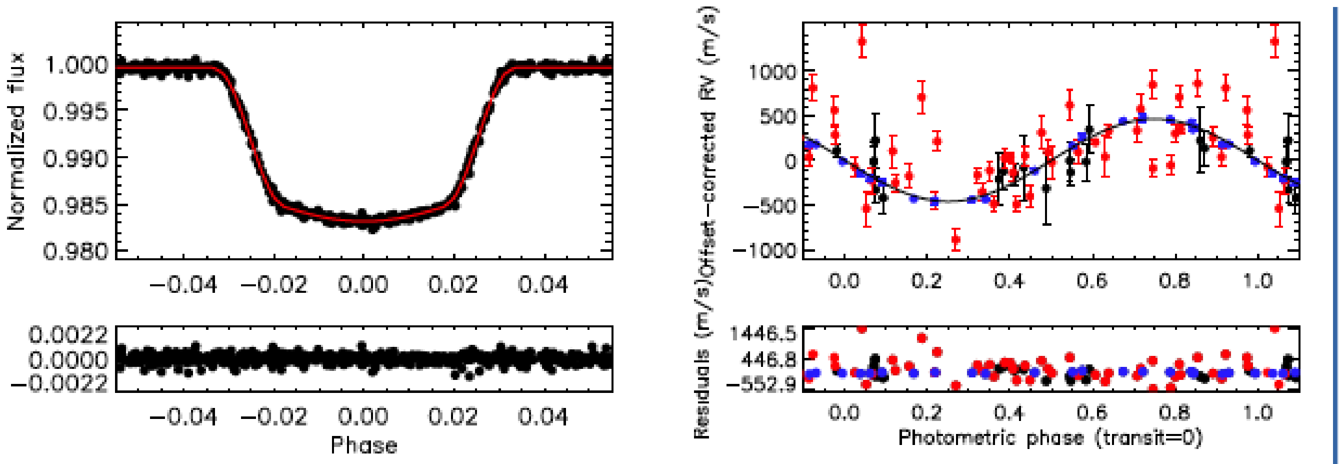
TOI-1181b



From Kabath et al. 2022 MNRAS, Volume 513, Issue 4, pp.5955-5972

TOI-1516b

- A regular hot Jupiter
- Period 2.06 days
- Radius 1.36 $R_{Jupiter}$ and Mass 3.16 $M_{Jupiter}$

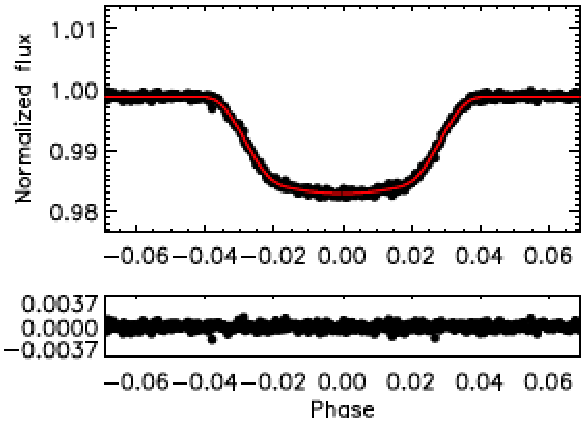


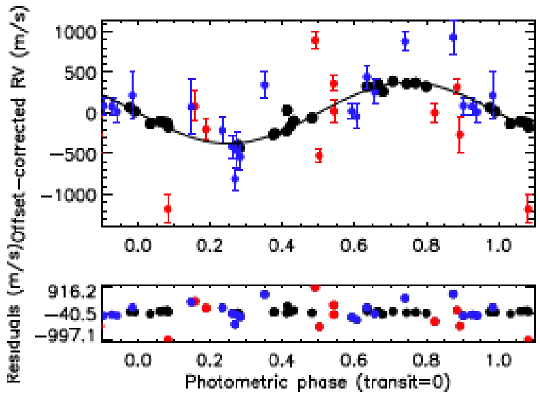
From Kabath et al. 2022 MNRAS, Volume 513, Issue 4, pp.5955-5972

Astronomický ústav AV ČR

Hot Jupiter around young star TOI-2046b

- Young system perhaps 100-400 Myr (Li line)
- Period 1.5 days
- Radius 1.44 $R_{jupiter}$ and Mass 2.3 $M_{Jupiter}$

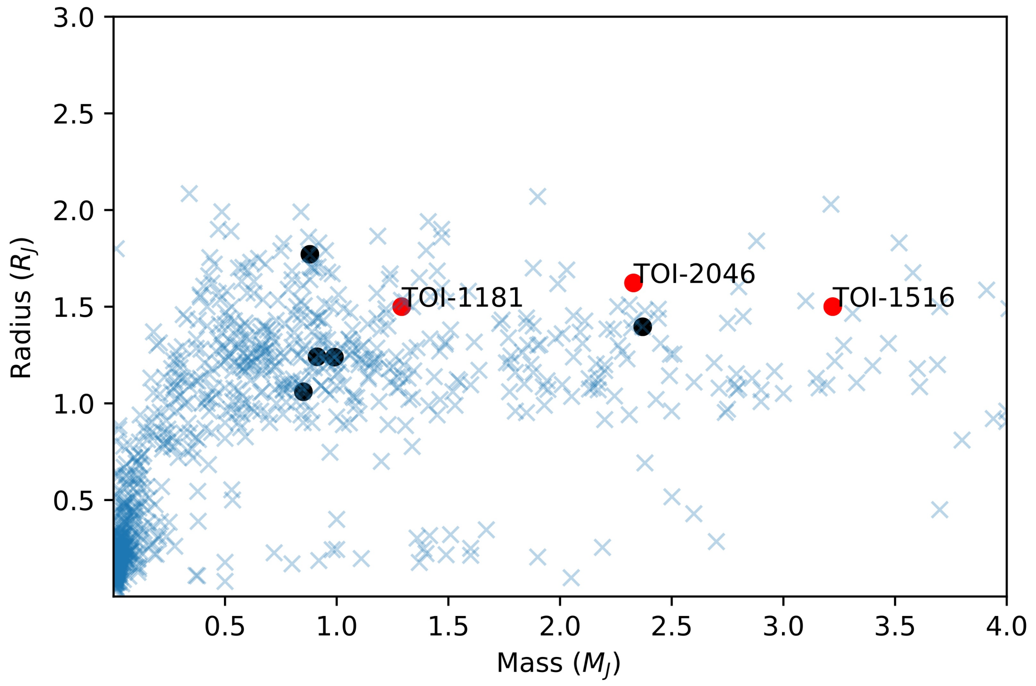




From Kabath et al. 2022 MNRAS, Volume 513, Issue 4, pp.5955-5972

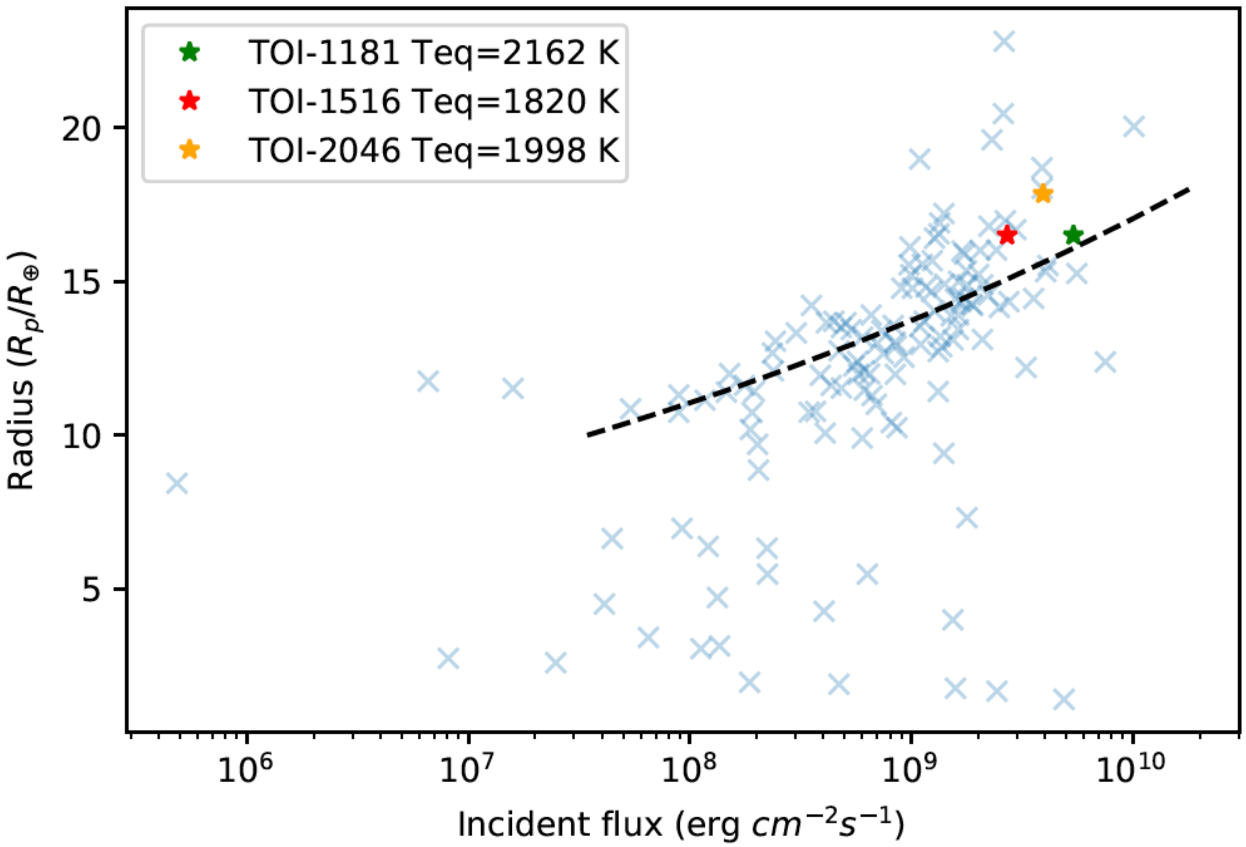
General characteristics

- Mass-Radius diagram



From Kabath et al. 2022 MNRAS, Volume 513, Issue 4, pp.5955-5972

Radius vs. insolation



From Kabath et al. 2022 MNRAS, Volume 513, Issue 4, pp.5955-5972

Plato Space mission

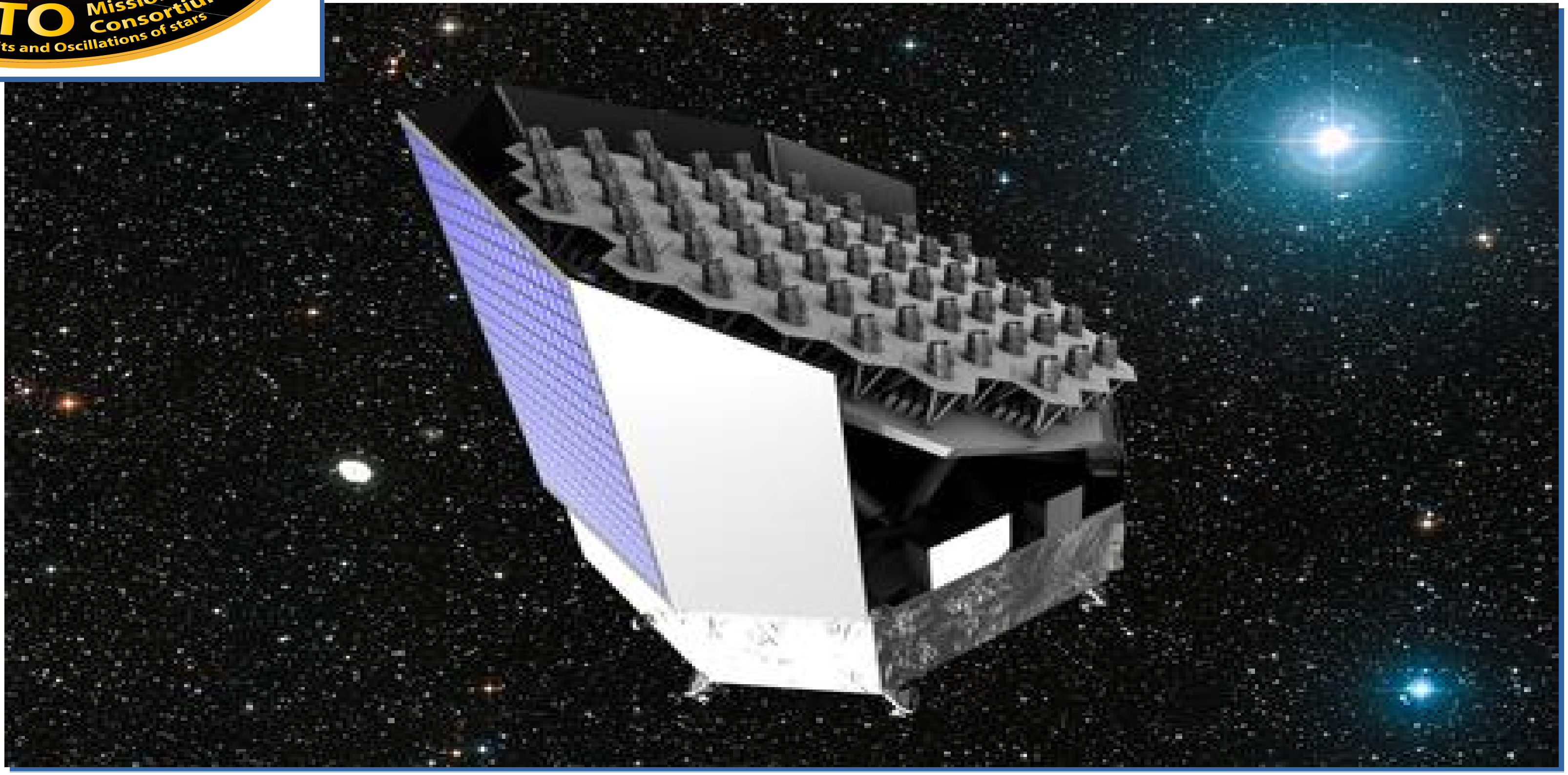
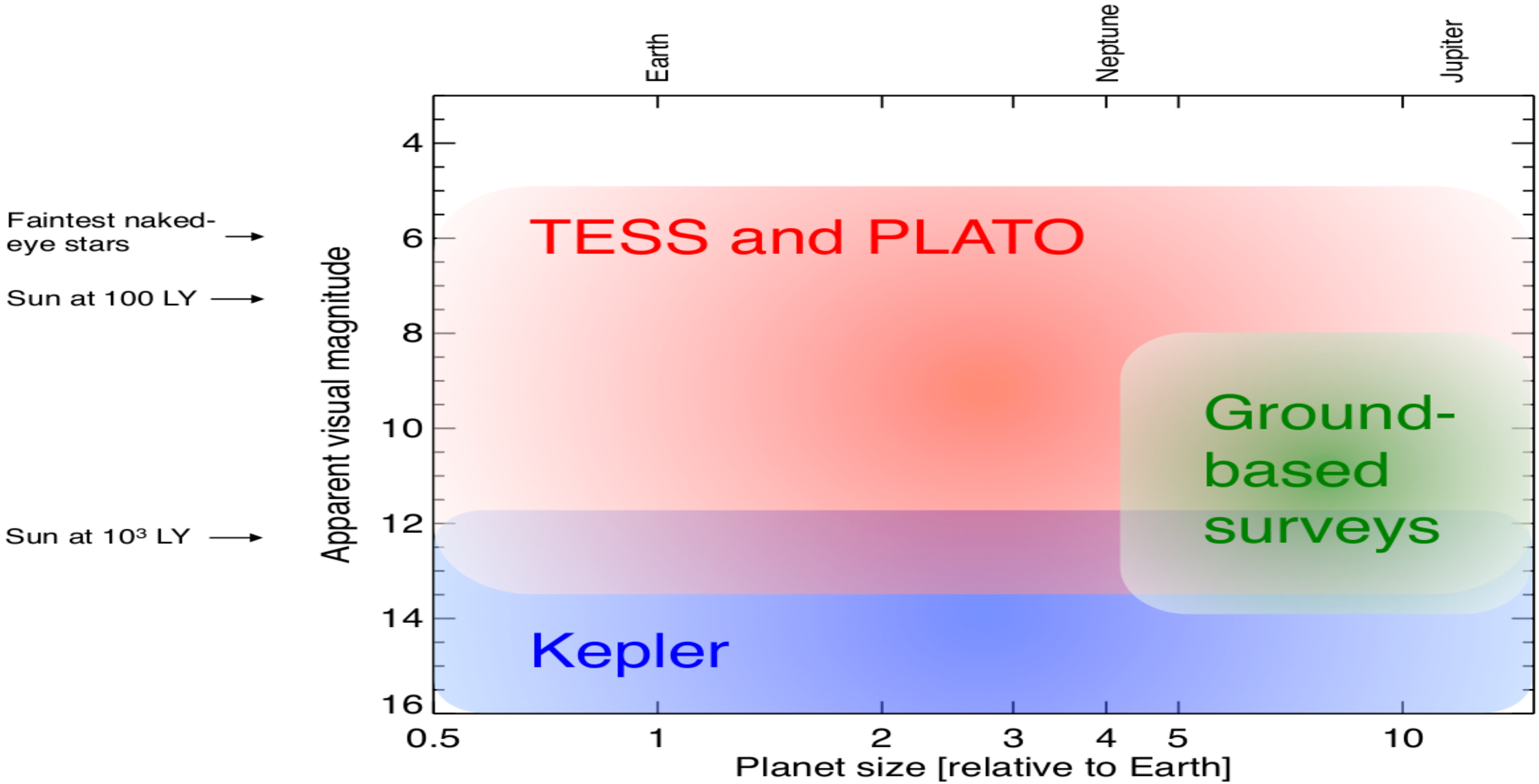
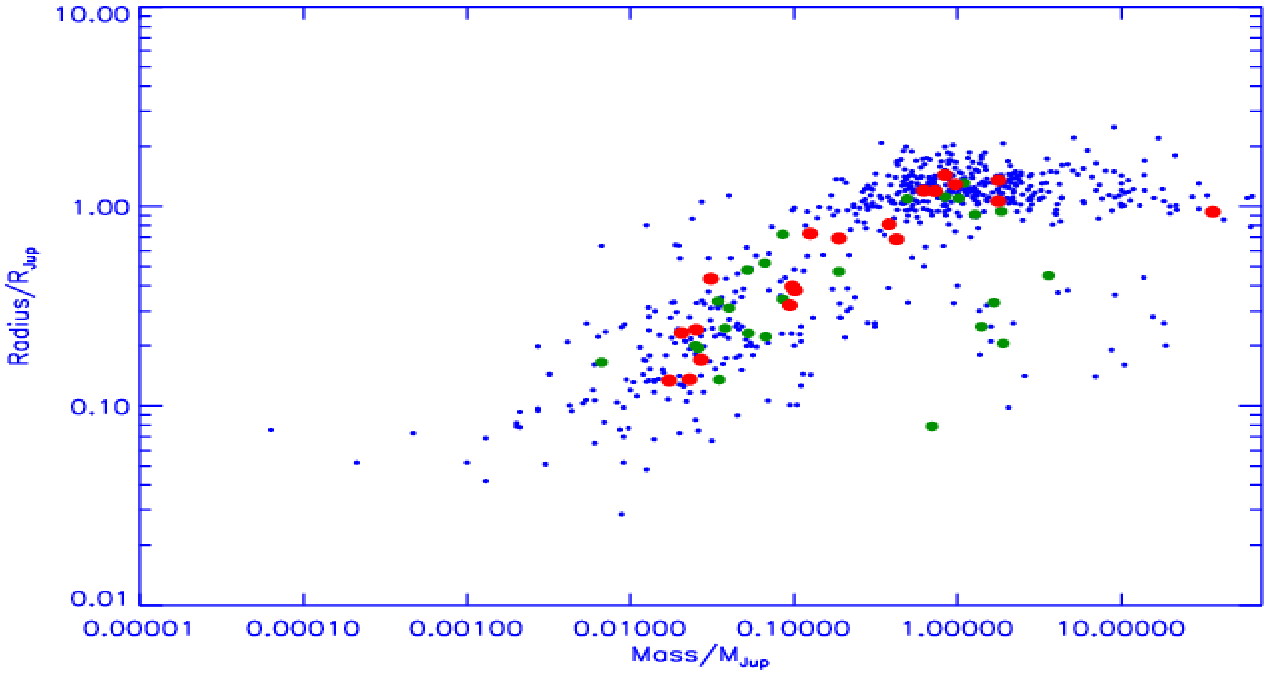


Fig.1: PLATO Space mission is the motivation for PLATOSpec. PLATO will need large amount of ground based support. Credit: Thales Alenia Space

Space missions compared



Importance of a follow-up from ground (with small telescopes)



Sep. 2017 – approx. 120 K2 planets

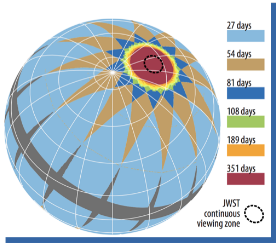
Blue – all planets 4000
Green – K2 planets (40)
Red – KESPRINT (21)

Csizmadia et al. 2017

Csizmadia et al. Plato mission conference 2017

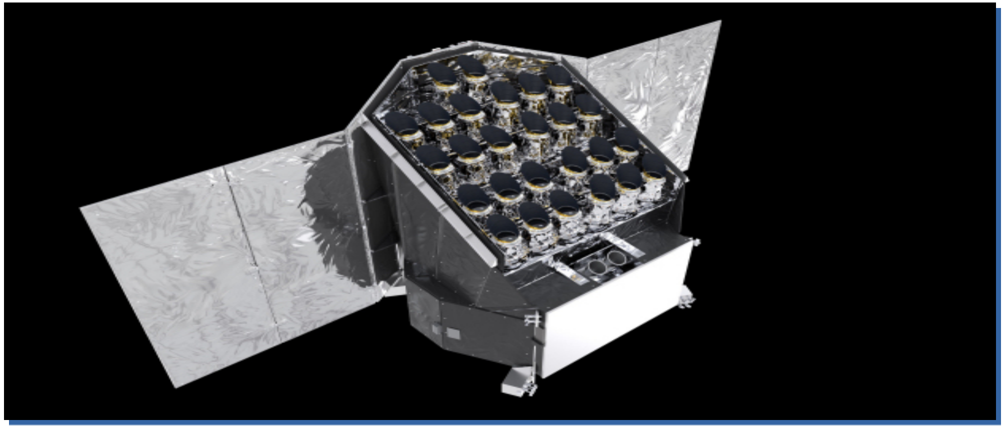
Space missions and detection of exoplanets

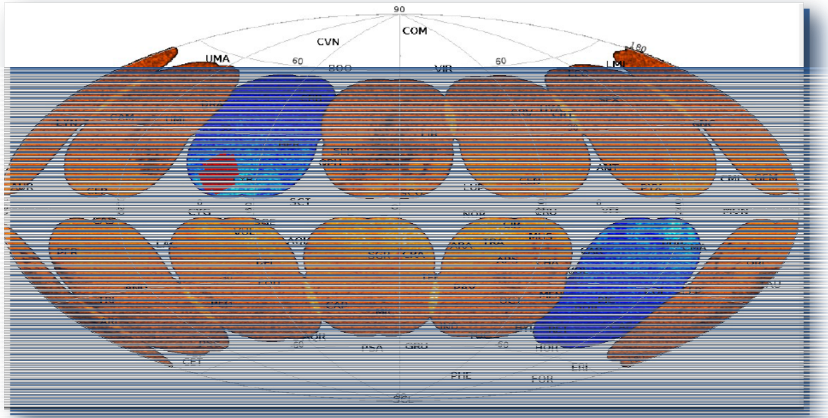
- TESS – 85% of sky, expected thousands of planets (many thousands of candidates)



From https://heasarc.gsfc.nasa.gov

- PLATO – monitoring of 1milion stars sample

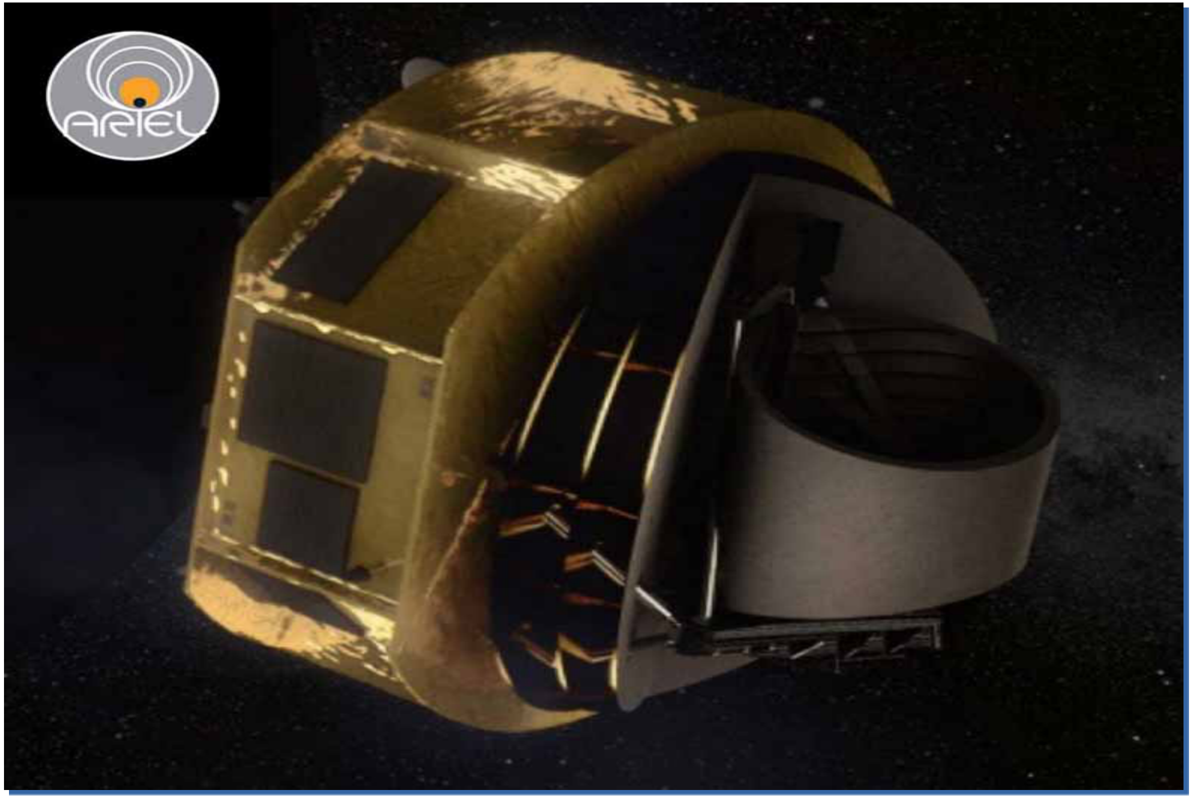




From https://platomission.com

Participation in Ariel

- CZ contribution is being defined
- Leaders: ÚFCHJH S. Civis and M. Ferus
- P. Kabath is in WG Stellar charac.



Elliptical primary mirror:Â 1.1 x 0.7 metres

Reading

- Mayor and Queloz 1995, http://www.nature.com/nature/journal/v378/n6555/abs/378355a0.html
- http://mintaka.sdsu.edu/faculty/wfw/CLASSES/ASTR510/PAPERS/Mayor-Queloz_51Peg.pdf
- ELODIE: 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
- http://lasp.colorado.edu/education/outerplanets/exoplanets.php#detection
- HUYGENS http://www.staff.science.uu.nl/~gent0113/huygens/huygens_ct_en.htm
- Epicurus Letter to Herodotus http://users.manchester.edu/Facstaff/SSNaragon/Online/texts/316/Epicurus,%20LetterHerodotus.pdf

Next lecture

- Methods of detection of exoplanets

HAVE A GREAT WEEK