Exoplanets

Petr Kabáth

Lecture 1 Fall 2025/2026

03 October 2025

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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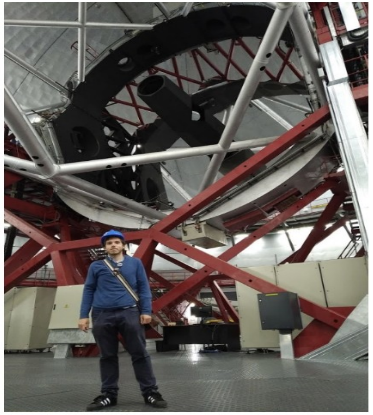
OUR BLOG

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

18 SEP, 2019

Hasta mañana!



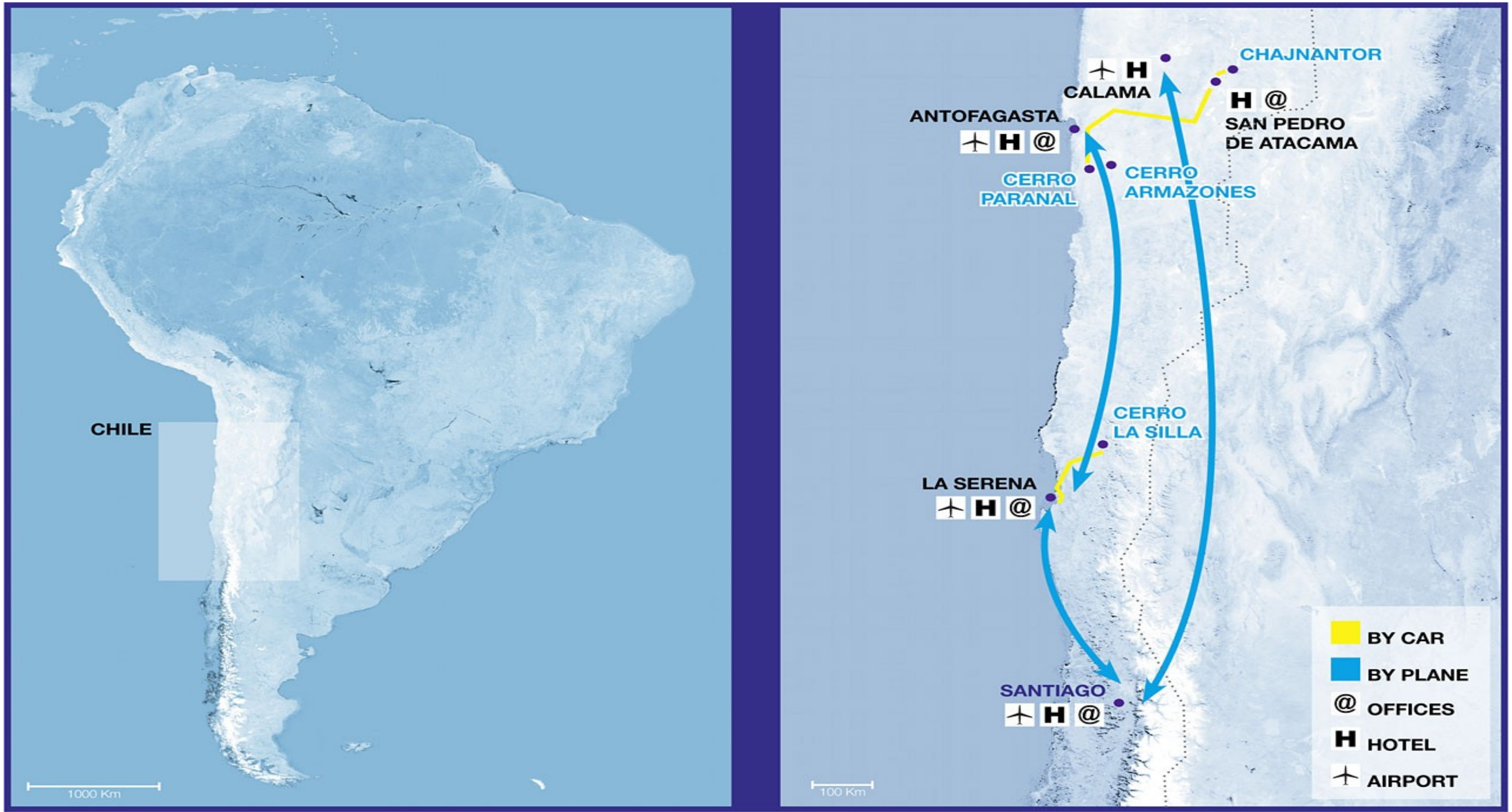
27 AUG, 2019

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

Webpage of Exoplanet research group at ASU

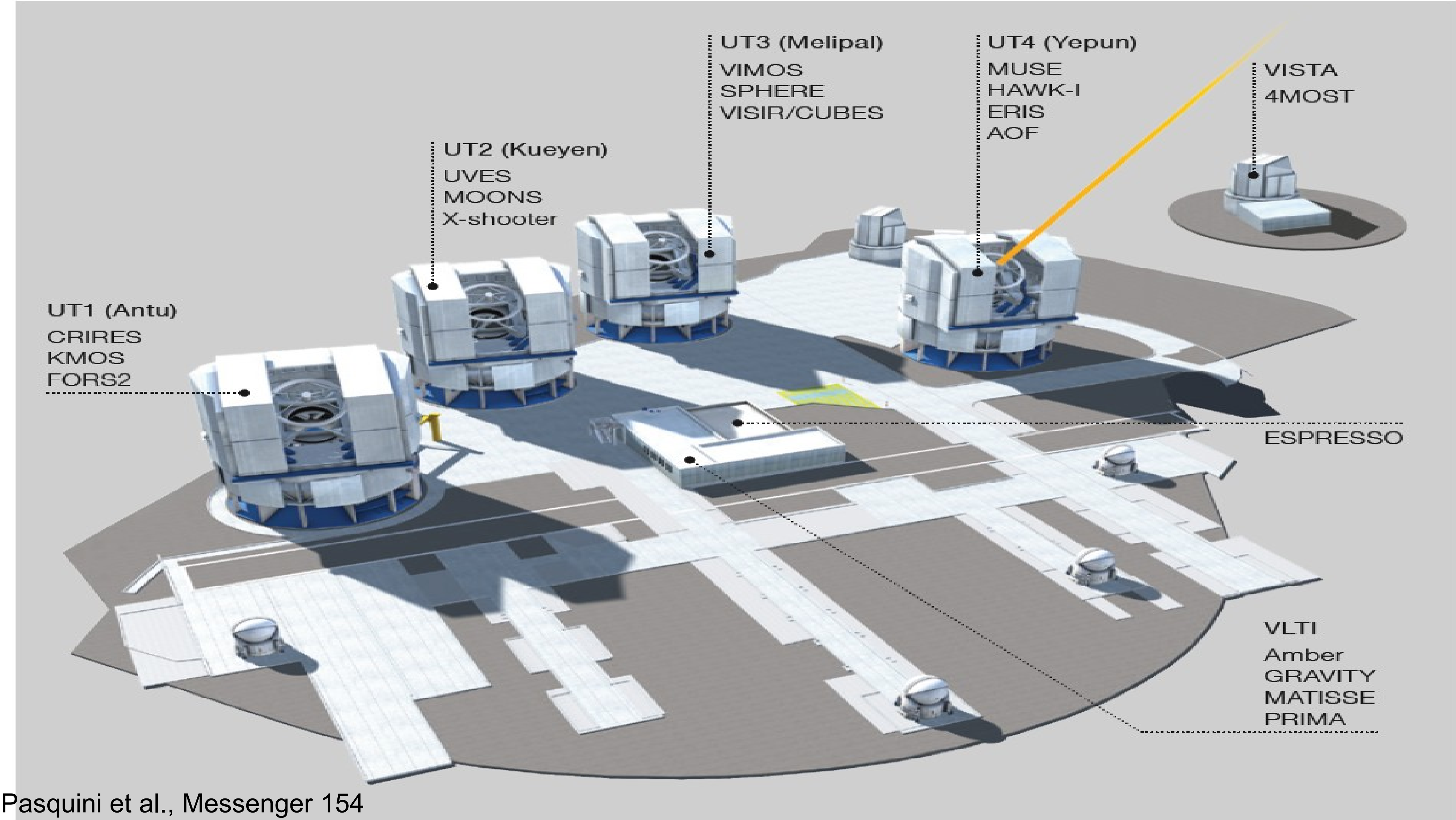
http://stelweb.asu.cas.cz/exogroup/

ESO observatories



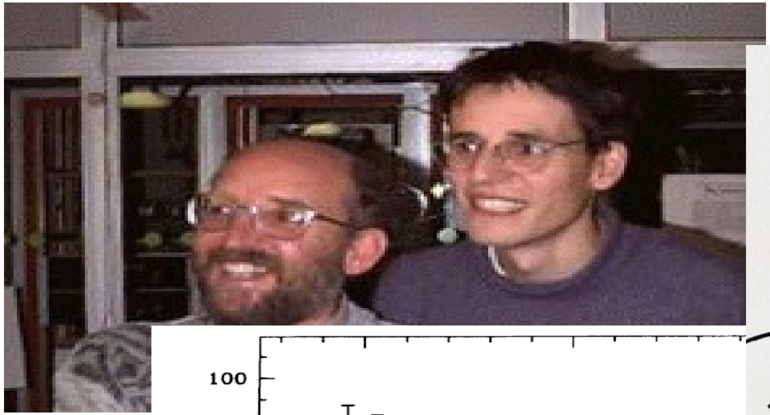
La Silla

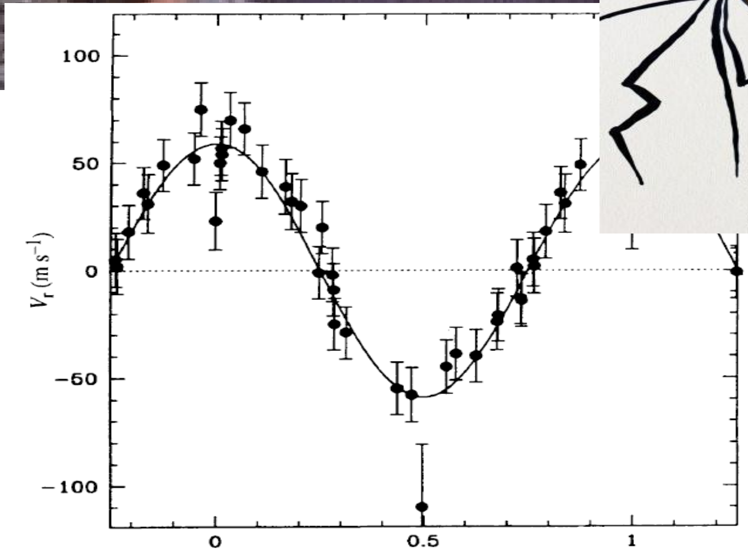

PARE



Pasquini et al., Messenger 154

What will be the lecture about?





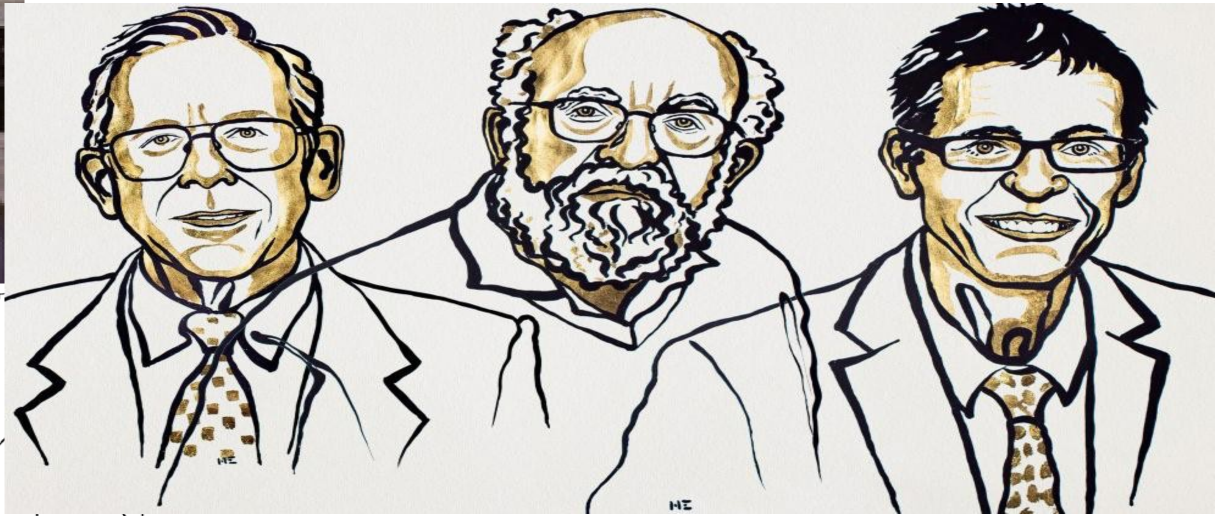


Image from Mayor and Queloz, 1995, Nature

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

PLATO Community

Exoplanets lecture 2025/2026

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

Exoplanets II 2025/2026 (summer)
J. Žák, O. Chrenko

tmosféry exoplanet

) Metody detekce a charakterizace exoplanet - Představení metod detekce (radiální rychlosti, tranzity, přímé zobrazení, mikročočky, astrometrie, časování tranzitů - TTVs). Určování parametrů: hmotnost, poloměr, hustota. Vztah hmotnost-poloměr (Mass-Radius elationship). Stavové rovnice (EoS - Equation of State). Otevřené otázky a výzvy v detekci a charakterizaci exoplanet.

) Demografie exoplanet a interakce hvězda-planeta - Statistika a distribuce exoplanet, typy exoplanet (horcí Jupiteři, super-Země, mini-Neptuni atd.). "Radius valley" a jeho interpretace. Princip "Know thy star, know thy planet" - vliv vlastností hostitelské hvězdy. nterakce hvězda-planeta: Vliv stáří hvězdy a metalicity prostředí, Slapové síly a jejich důsledky (např. vázaná rotace, vývoj oběžné dráhy), Urychlování rotace hvězd (spin-up) vlivem planet, Hvězdná aktivita a její dopad na planety a jejich atmosféry. Nástroje pro tudium dynamiky a stability (např. SPOCK, MEGNO, NAMD).

) Stelární a planetární inklinace - Rossiterův-McLaughlinův efekt (RMe). Princip Rossiterova-McLaughlinova efektu. Měření RMe a interpretace (progradní, retrográdní, polární dráhy). Dopplerovská tomografie. Degenerace a nejednoznačnosti v měření RMe. tudium planetárních systémů s dvojhvězdami. Vliv diferenciální rotace hvězd a hvězdné konvekce. Planetární sklon rotační osy (planetary obliquity).

) Exoplanetární atmosféry - Základní teorie atmosfér, vertikální struktura. Teplotně-tlakový profil (T-P profil). Opacita. Chemické složení: rovnovážná a nerovnovážná chemie. Globální cirkulační modely (GCM - General Circulation Models). Typy pozorování tmosfér: Tranzitní spektroskopie, Spektroskopie sekundárních zákrytů (eclipse spectroscopy), Fázové křivky. Charakterizace atmosfér pomocí dat s nízkým spektrálním rozlišením (low-resolution spectroscopy).

) Exoplanetární atmosféry - Aerosoly: formace, složení, vliv na pozorování. Charakterizace atmosfér pomocí dat s vysokým spektrálním rozlišením (high-resolution spectroscopy): Detekce jednotlivých molekulárních a atomárních druhů, Měření rychlostí větru, otace planety. Efekty asymetrie v atmosféře (denní/noční strana, terminátor). Odstranění telurické kontaminace z pozorování. Význam izotopů a izotopologů pro pochopení formování a evoluce atmosfér. Atmosférický únik a jeho mechanismy.

) Planetární evoluce a migrační mechanismy - Spojitost mezi současnými vlastnostmi planet a jejich evoluční historií. Mechanismy migrace planet: Migrace v protoplanetárním disku, Gravitační rozptyl (planet-planet scattering), Kozai-Lidovův mechanismus a ekulární evoluce. Planety v rezonanci a jejich význam pro dynamickou historii systémů. Degenerace v modelech planetární evoluce. Hnědí trpaslíci.

) Obyvatelnost, biosignatury a budoucnost výzkumu - Koncept obyvatelné zóny a faktory ovlivňující obyvatelnost. Biosignatury: hledání známek života v atmosférách exoplanet. Fermiho paradox a jeho možná řešení. Připravované a budoucí mise pro výzkum xoplanet (ARIEL, PLATO, HWO). Přínos výzkumu planet Sluneční soustavy pro studium exoplanet.

ormování exoplanet

) Od prachu k planetesimálám - role prachu v protoplanetárních discích, dynamika prachu v plynu, usazování v rovině disku, radiální drift, koagulace, materiálové a dynamické bariéry pro růst zrn, modelování rozdělení velikostí, nestability směsi prach-plyn.

-10) Akreční procesy - akrece planetesimál, akrece balvanů, obří impakty, vznik jader obřích planet, akrece plynu, gravitační nestabilita.

1-12) Migrace planet v protoplanetárním disku - základy lineární poruchové analýzy hydrodynamických rovnic, principy studia migračních momentů sil, pojem termální hmotnosti, hlavní momenty síly (Lindbladův a korotační), typy migrace (I, II, III), role struktury a astností protoplanetárního disku (turbulentní viskozita, termofyzikální procesy, přenos tepla), vývoj excentricity a sklonu, pokroky v modelování migrace planet.

3) Projevy protoplanet vnořených v disku - vytvoření mezery v prachu a v plynu, kinematické poruchy v proudění plynu, cirkumplanetární obálka a disk, vztah k pozorováním (sub-mm tepelné kontinuum, emise CO molekul, světlo rozptýlené na prachu).

4) Možné scénáře původu hlavních exoplanetárních populací - scénář formování “zevnitř ven”, scénář “roztržení rezonančních řetězců”, role vnitřního okraje disku (sublimační fronta prachových zrn, magnetosferická dutina), role tlakových maxim, rozplynutí rotoplanetárního disku, migrace vyvolaná vysokou excentricitou dráhy.

Lecture description

- Student should acquire basic knowledge on exoplanetary science and on the various aspects of detection, characterisation and description of exoplanetary environments
- The lecture serves as an introduction into various topics from exoplanet research but it also touches the planetary evolution and astrobiology and precise astronomical instrumentation (space- ground-based)
- Students should learn where to find the data from space missions and ground-based projects and how to work with them – tools, methods introduction
- The lecture should serve as an introduction for subsequent lecture Exoplanets II which follows in summer semester and which exoplers in more depth exoatmospheres and planetary evolution
- Students should also acquire presenting skills of scientific paper

Exam

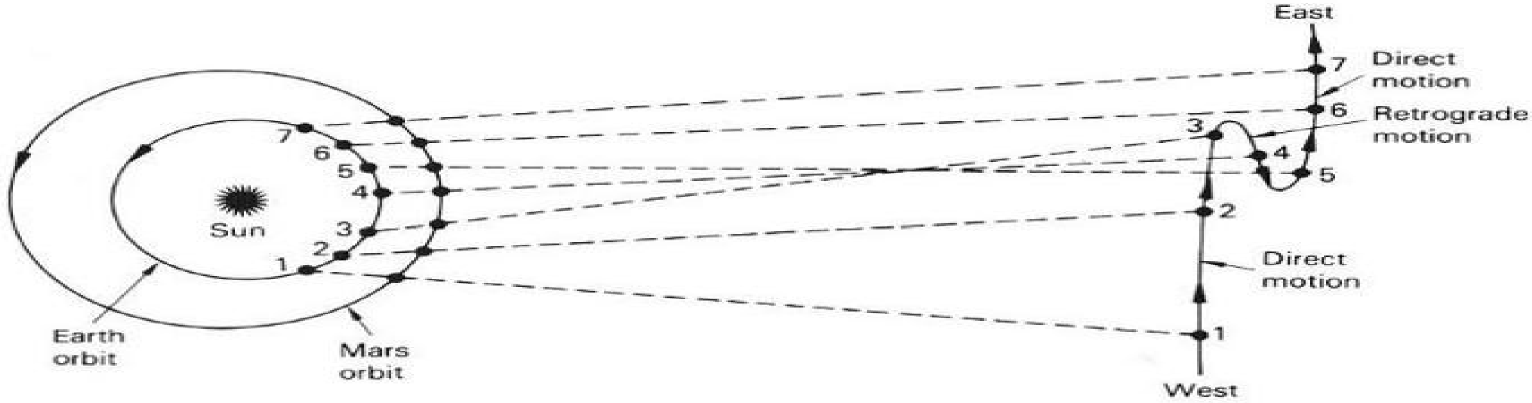
- Typically, a project work on a given topic selected from lecture topics needs to be prepared and defended
- The project defense has a purpose to discuss with students about the acquired knowledge on exoplanets
- During the lecture time, one block is allocated for students to present a paper in journal club style with exoplanet research results of their choice

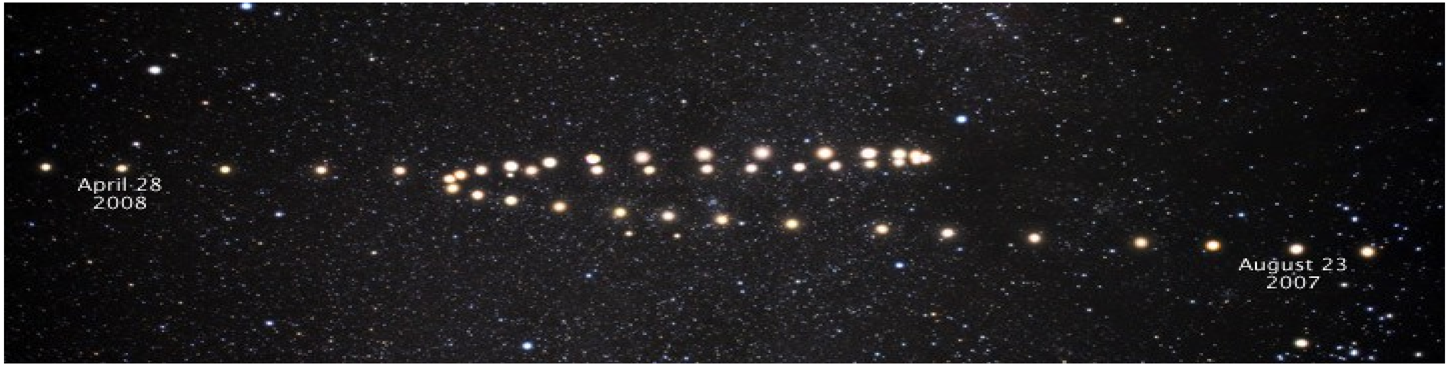
Literature

- **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**

A planet

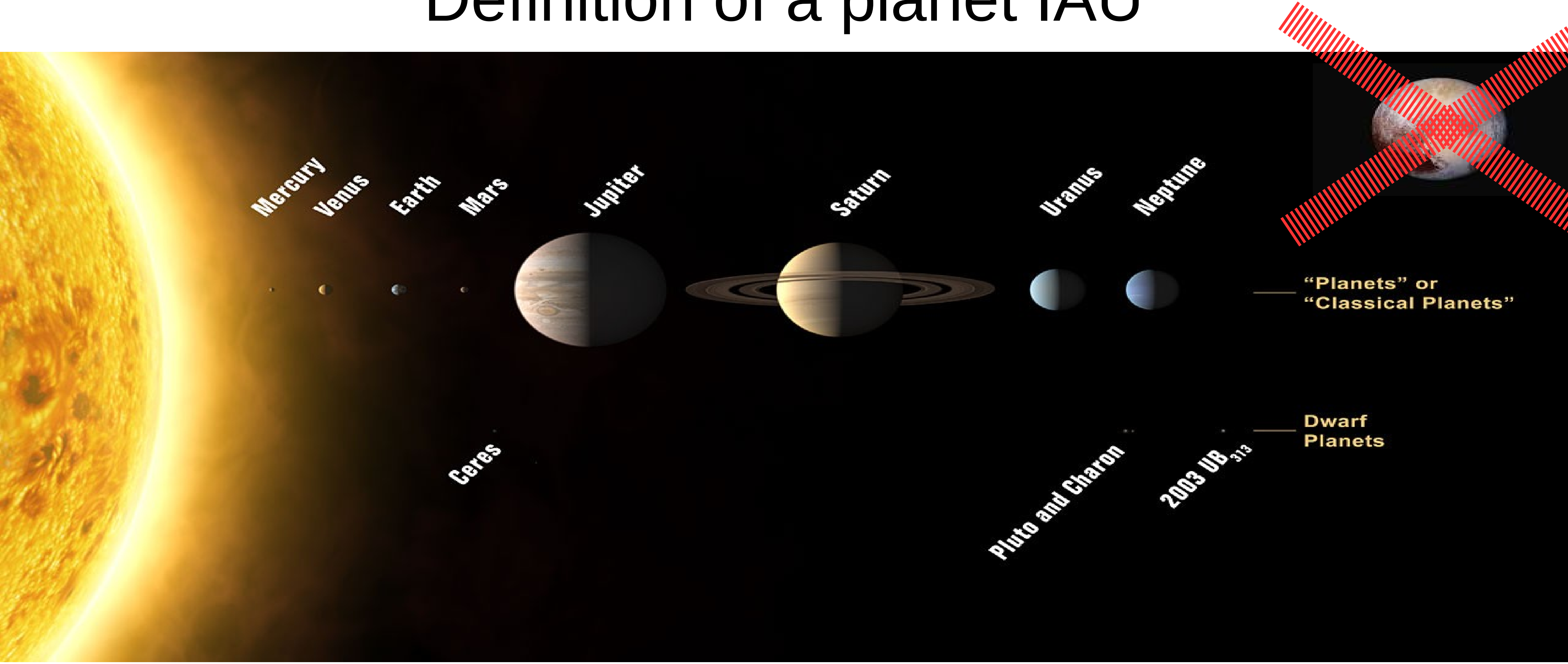
Πλανήτης - planétés – „tulák“





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

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

Observations of Venus

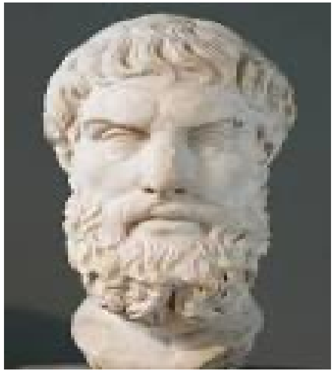
- Babylonian observations of Venus
  span of more than 20 years
  in approx. 17th century BC
- This copy from 7 BC in cuneiform
- Recognition of periodicity (Venus cycles)
- First recorded astronomical observations
- Ammisaduqa 4th after Hammurabi

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

Ancient times



Wikipedia

- Epicurius (341-270 BC)

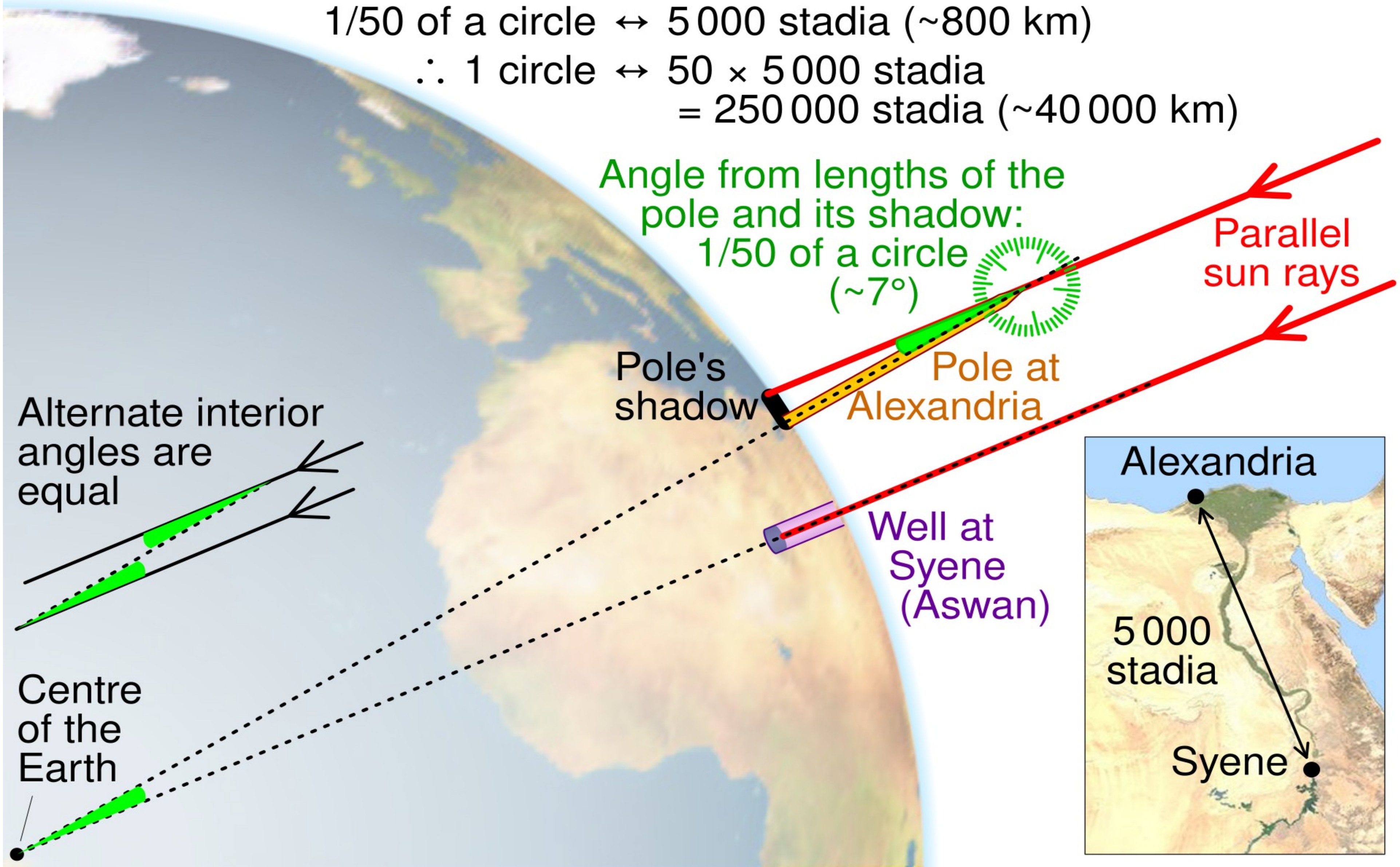
  “There are infinite worlds both like and

  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

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


1/50 of a circle ↔ 5 000 stadia (~800 km)
∴ 1 circle ↔ 50 × 5 000 stadia
= 250 000 stadia (~40 000 km)
Angle from lengths of the pole and its shadow: 1/50 of a circle (~7°)
Parallel sun rays
Pole's shadow
Pole at Alexandria
Alternate interior angles are equal
Well at Syene (Aswan)
Alexandria
5 000 stadia
Syene
Centre of the Earth

Importance of stars

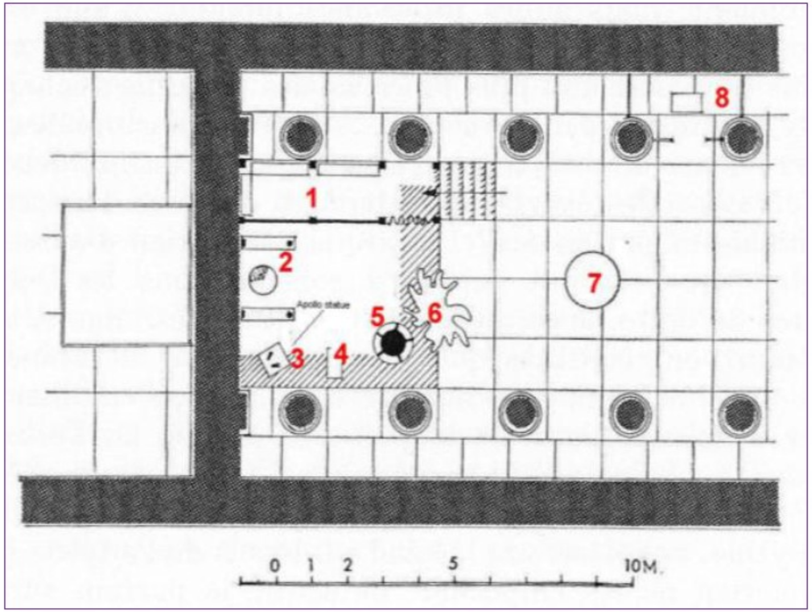


Figure 3: A reconstructed ground plan of the Temple of Apollo, the *adyton* and the positions of statues etc. based on ancient texts. Key: 1 = *oikos*, the waiting room for the opropoi. 2 = the beehive-shaped stone *omphalos*. 3 = the statue of Apollo. 4 = the tomb of Dionysos, the son of Semeli. 5 = the *adyton* where vapor ascend while Pythia is sitting at the tripod. 6 = the secret laurel tree. 7 = Estia's room. 8 = the sanctuary of Poseidon (after Roux, 1976: 134).

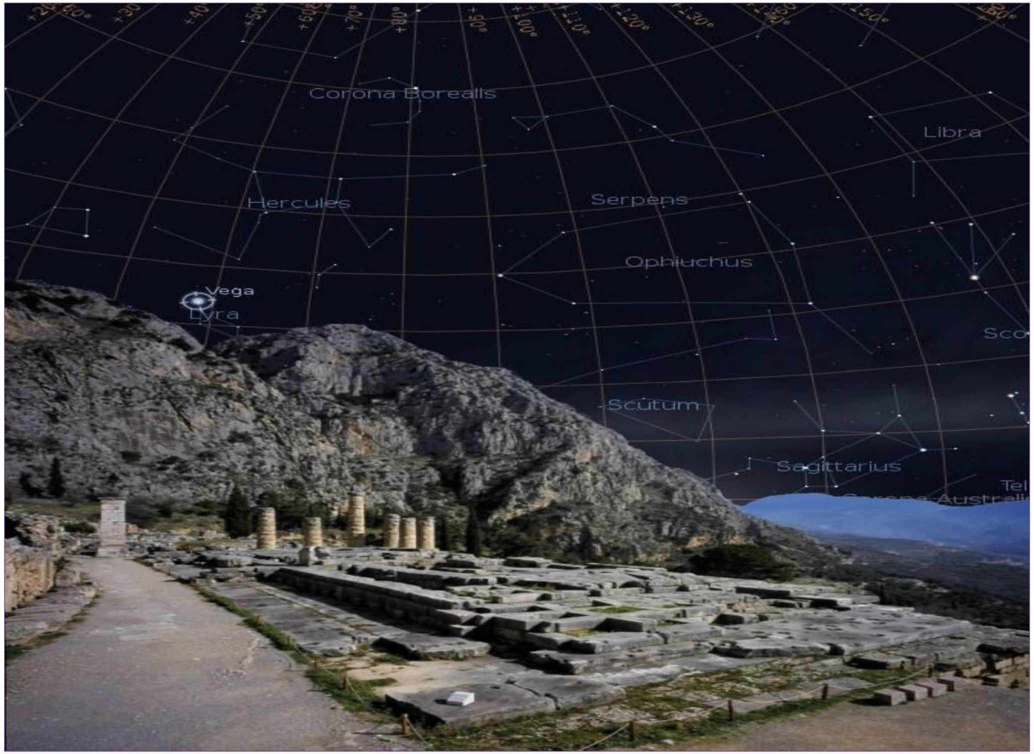


Figure 5: The heliacal rising of Vega above the Faidriades in the northeastern Delphi sky at dawn on 21 December 480 BC.

https://ui.adsabs.harvard.edu/abs/2013JAHH...16..184L/abstract

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)

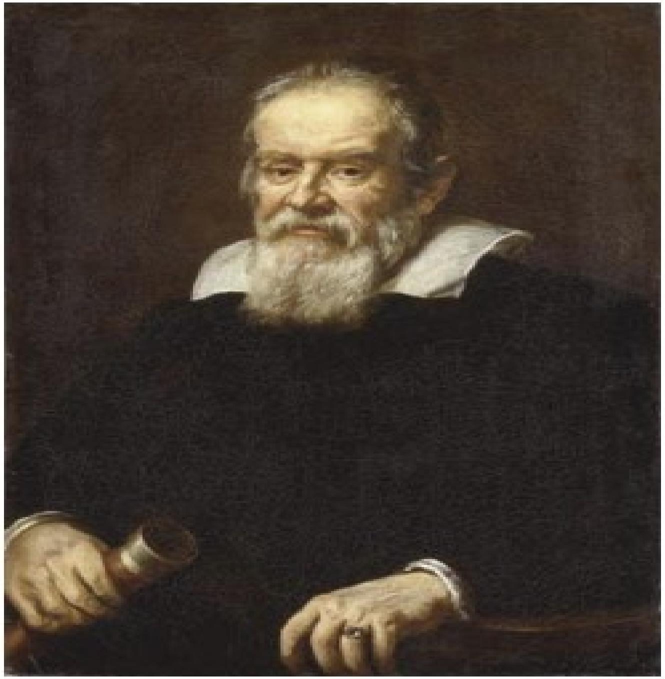
Copernicus (1473-1543)

- 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

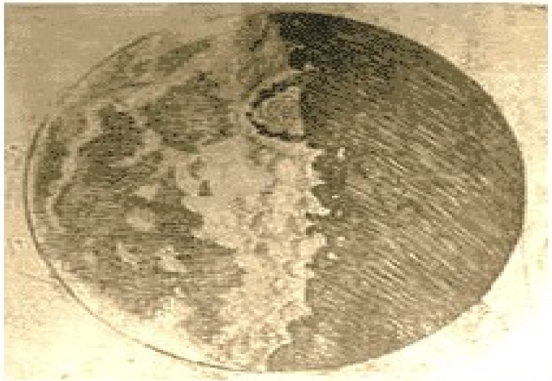
Galileo (1564-1642)

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



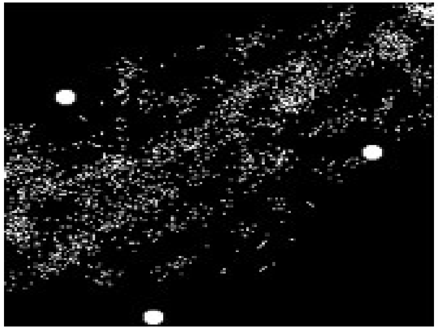
Wikipedia

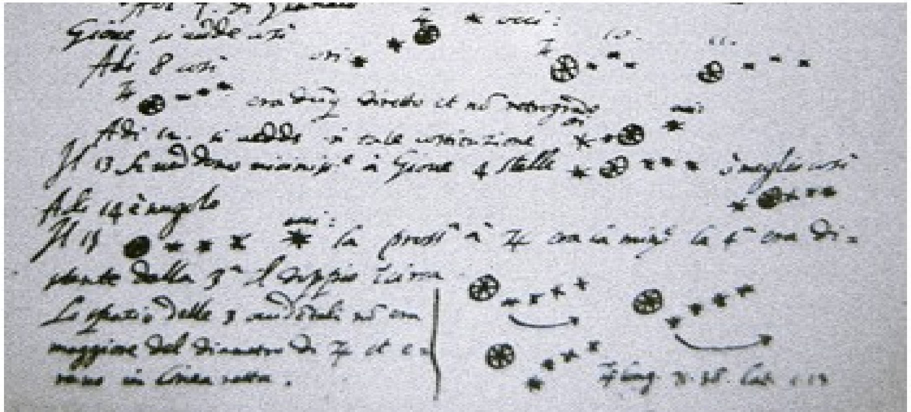
First discoveries with the telescope

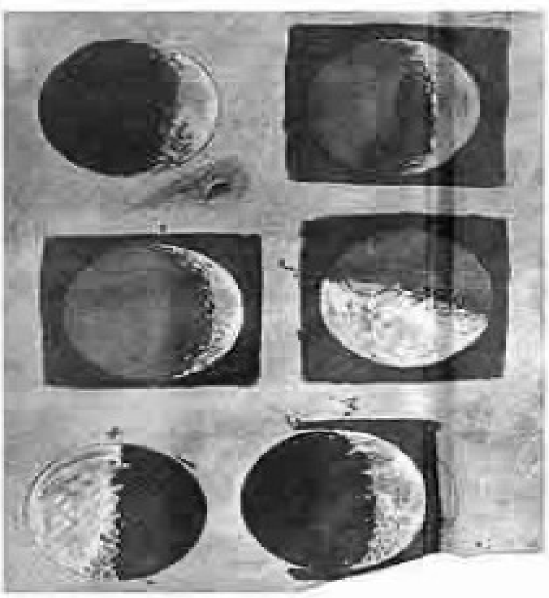


One of Galileo's drawings of the moon. 1610 A. D.

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







Christian Huygens

- Work The Cosmotheoros (1698)

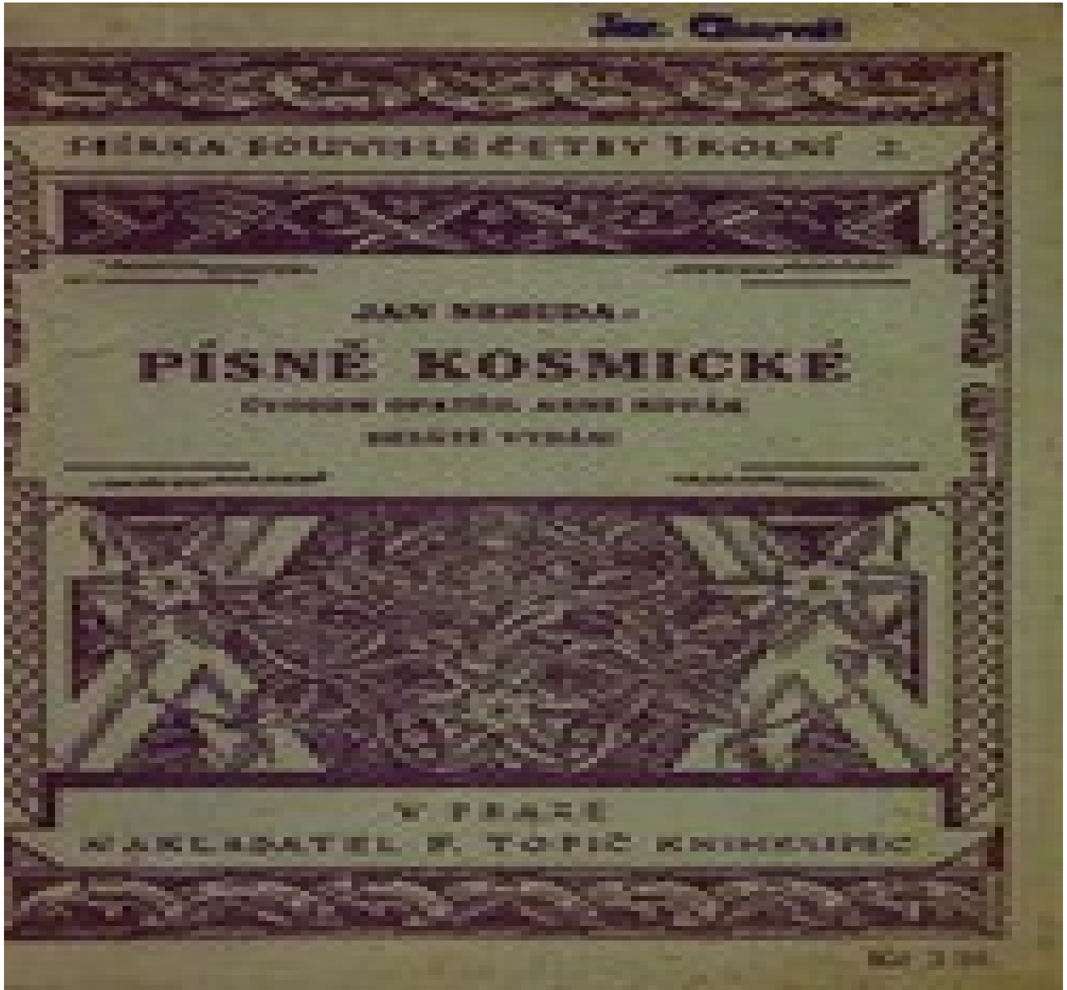
  - how would life on other planets be?

  - 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 týž,
z nichž se i Země spletla.

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

„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 $V^3 \sim \frac{1}{P}$. 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 ± 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.

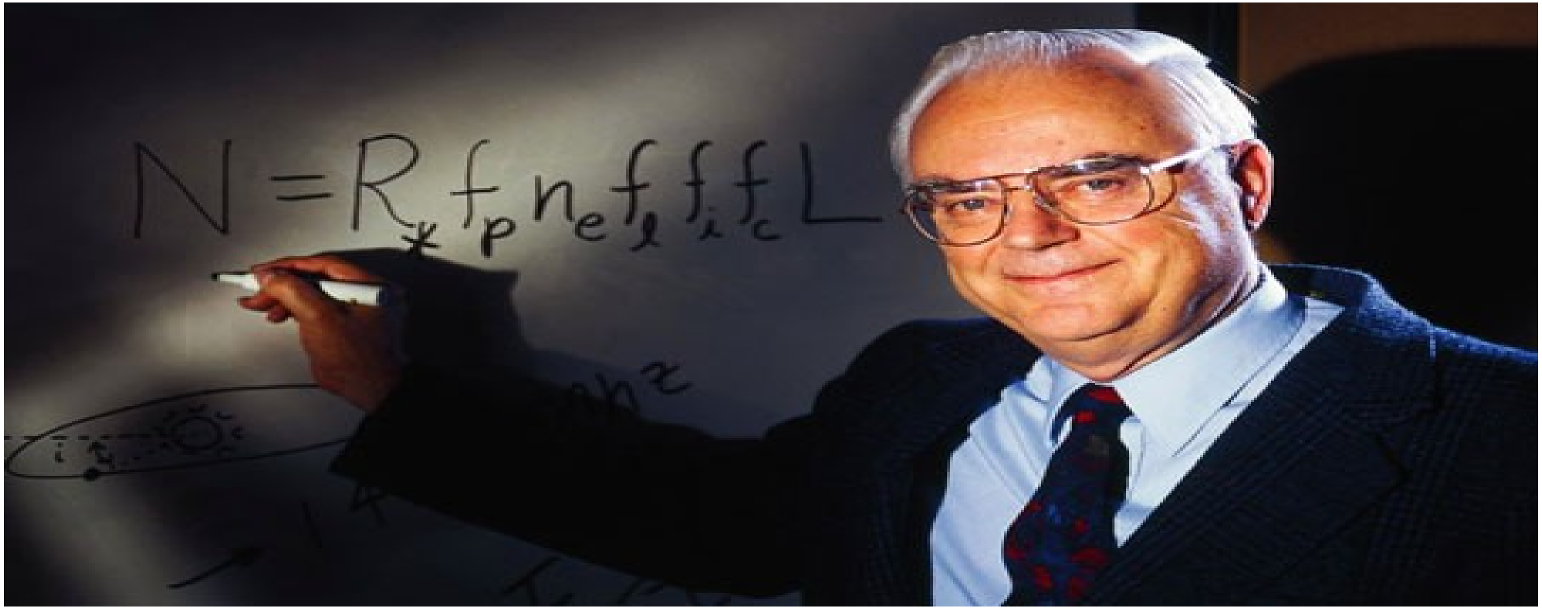
Berkeley Astronomical Department,
University of California.
1952 July 24.

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
- fp = the fraction of those stars that have planets
- ne = the average number of planets that can potentially support life per star that has planets
- fl = the fraction of planets that could support life that actually develop life at some point
- fi = the fraction of planets with life that actually go on to develop intelligent life (civilizations)
- fc = 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

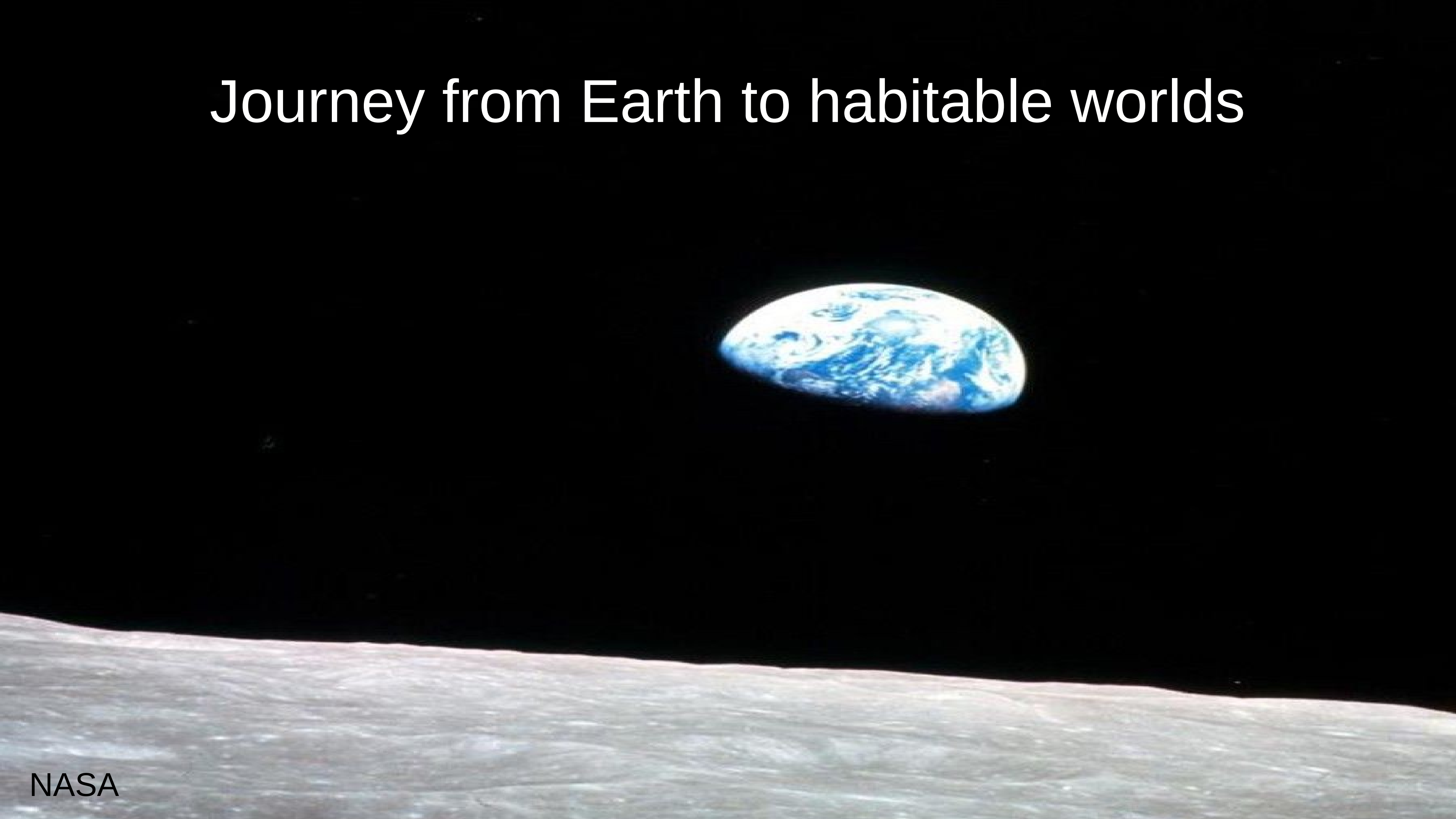
  - no planets detected, yet

- There was instrumentation to detect planets in 1950s, so where are all the planets?

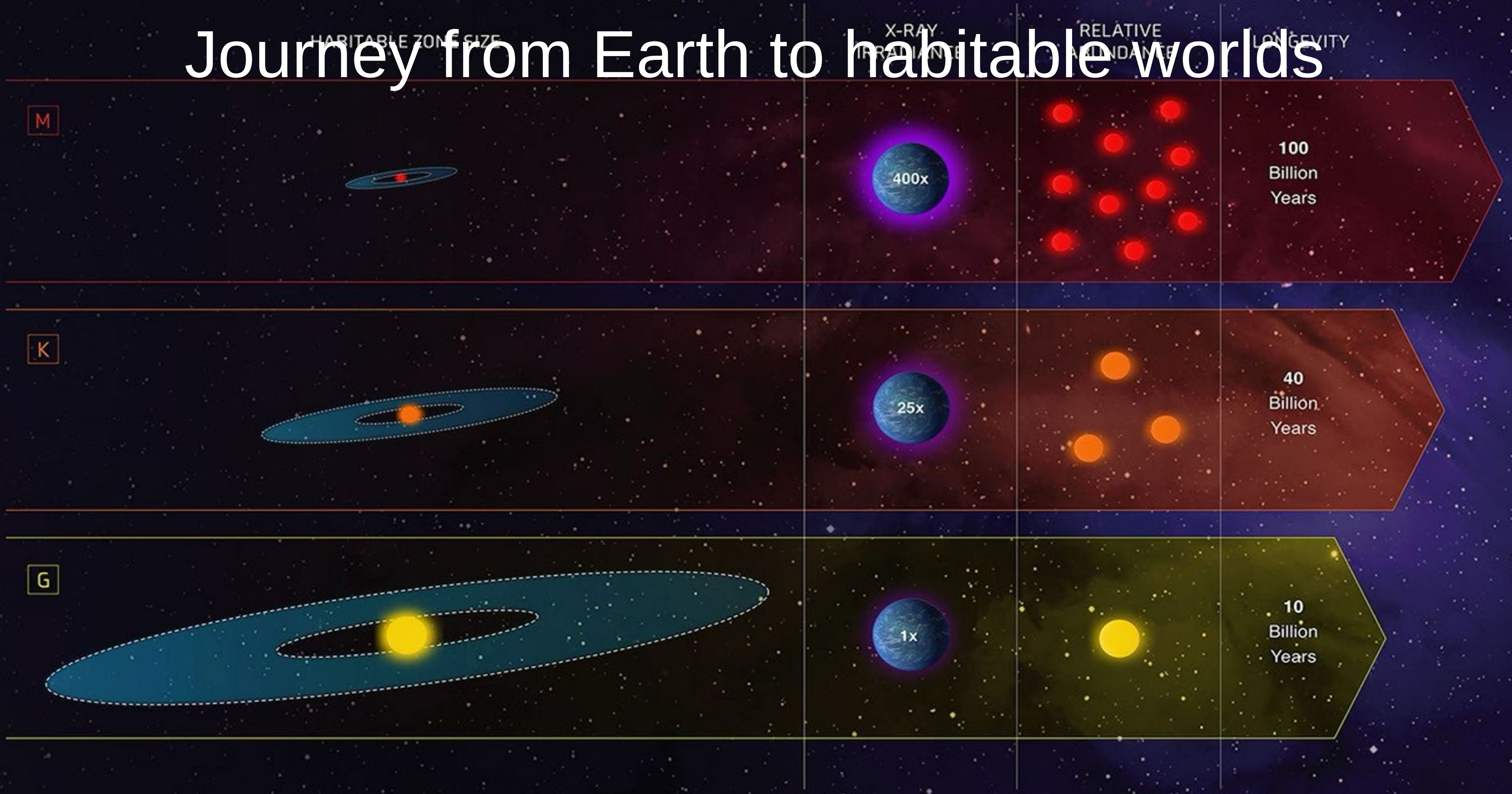
  - a transit can be detected by 20cm telescope

- First Radial Velocity surveys targeting specific stars

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

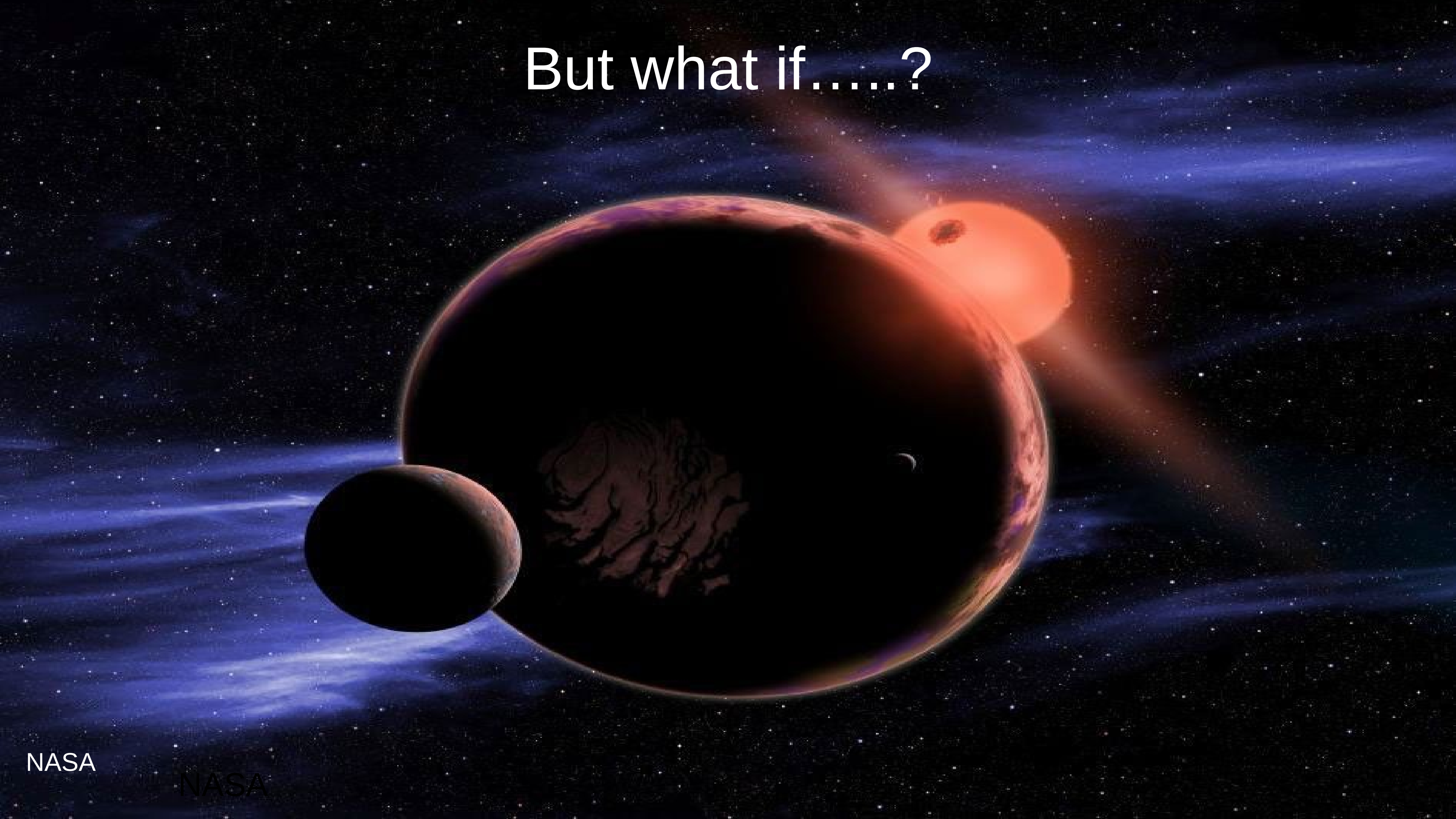

Journey from Earth to habitable worlds
NASA

Journey from Earth to habitable worlds



NASA

But what if…..?



NASA

NASA

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

Gordon Walker & Bruce Campbell

- Started around 1971, calibration with HF lamp
- First real planet detected but retracted
- Precisions in RVs down to 3 m/s
- Gamma Cephei story to be discussed next time

And finally, first exoplanets detected

Detection of extreme planets

A planetary system around the millisecond pulsar PSR1257 + 12

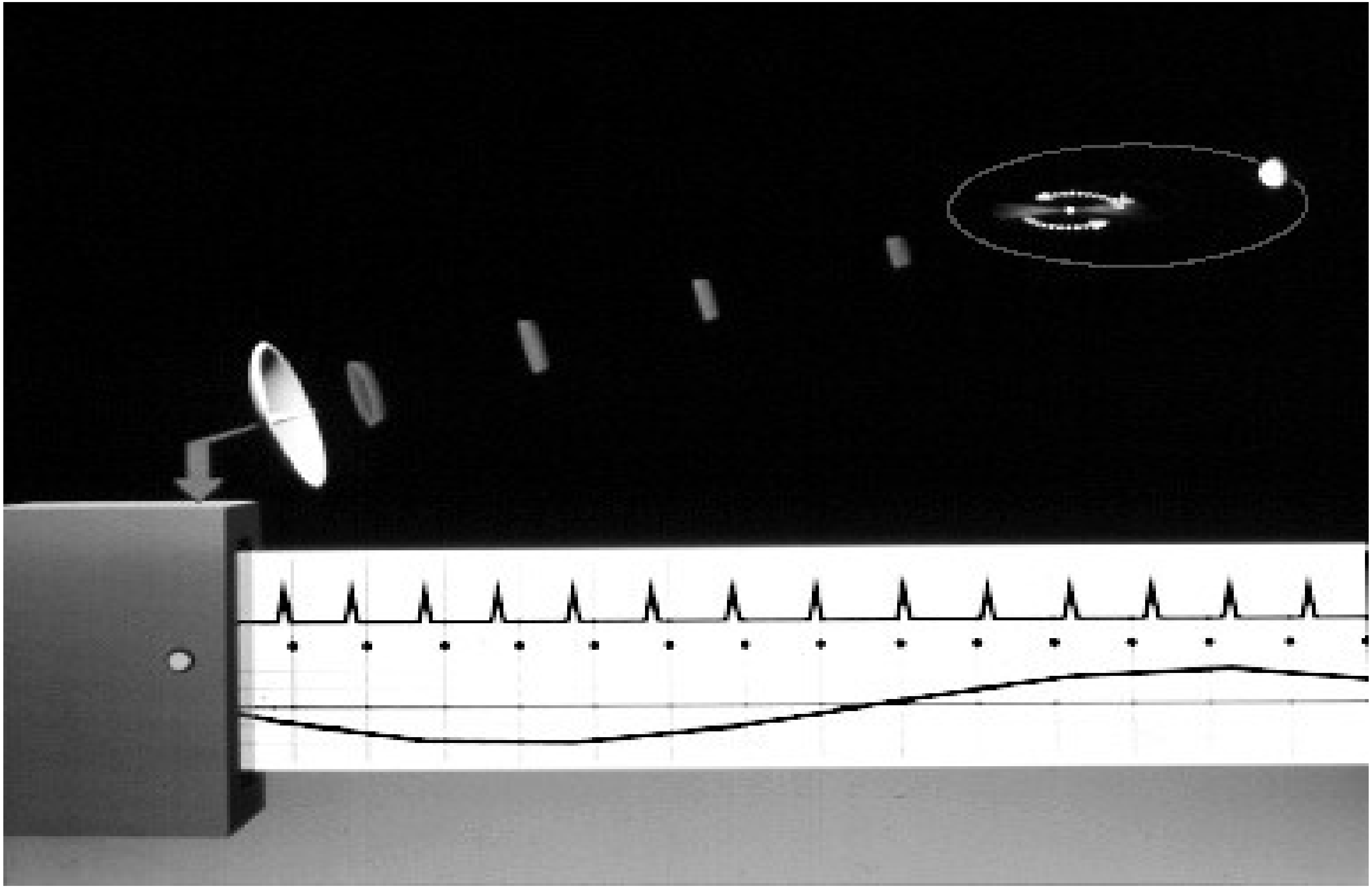
A. Wolszczan & D. A. Frail

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

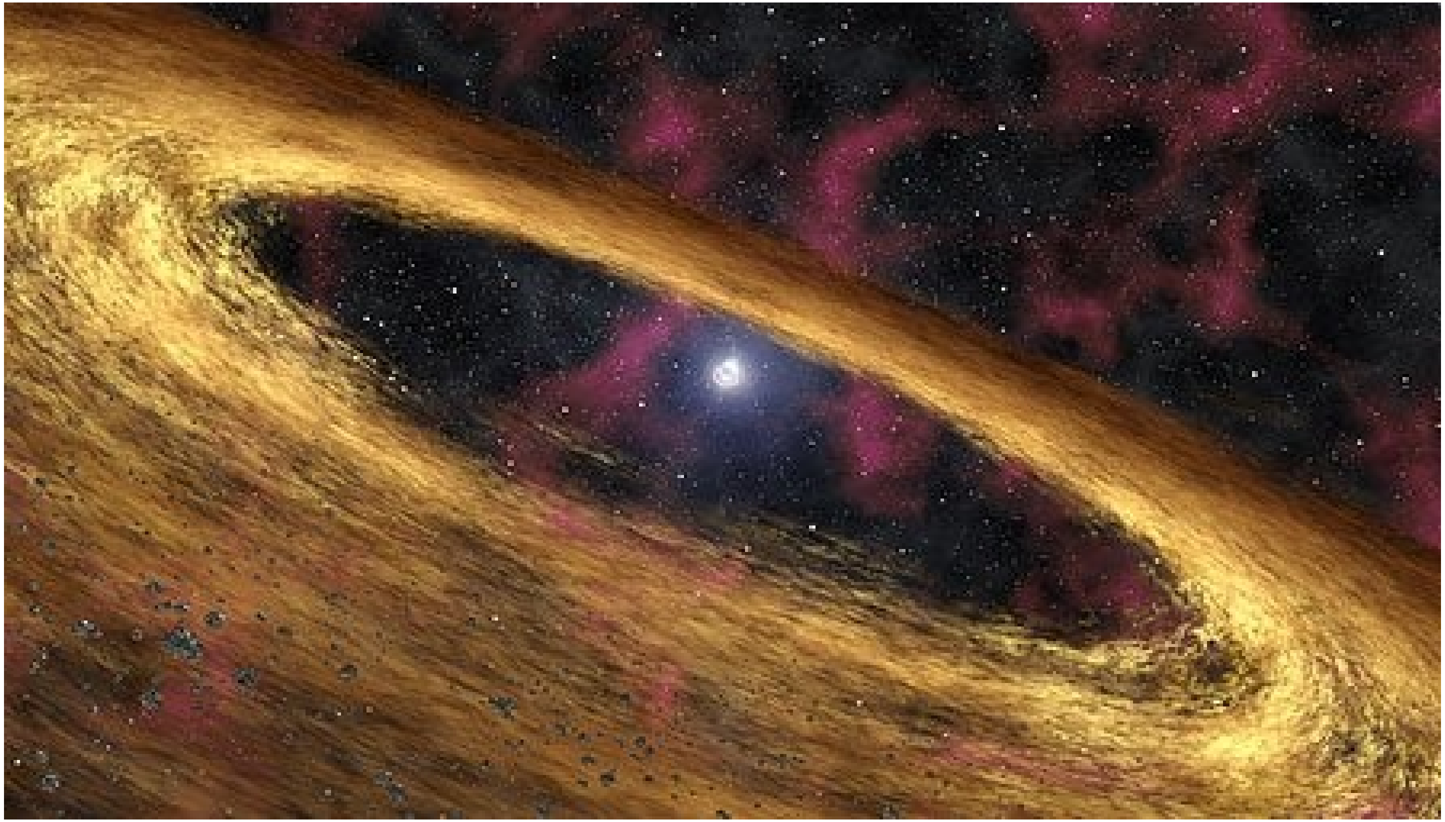
Zhongxiang Wang1, Deepto Chakrabarty1 & David L. Kaplan1

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

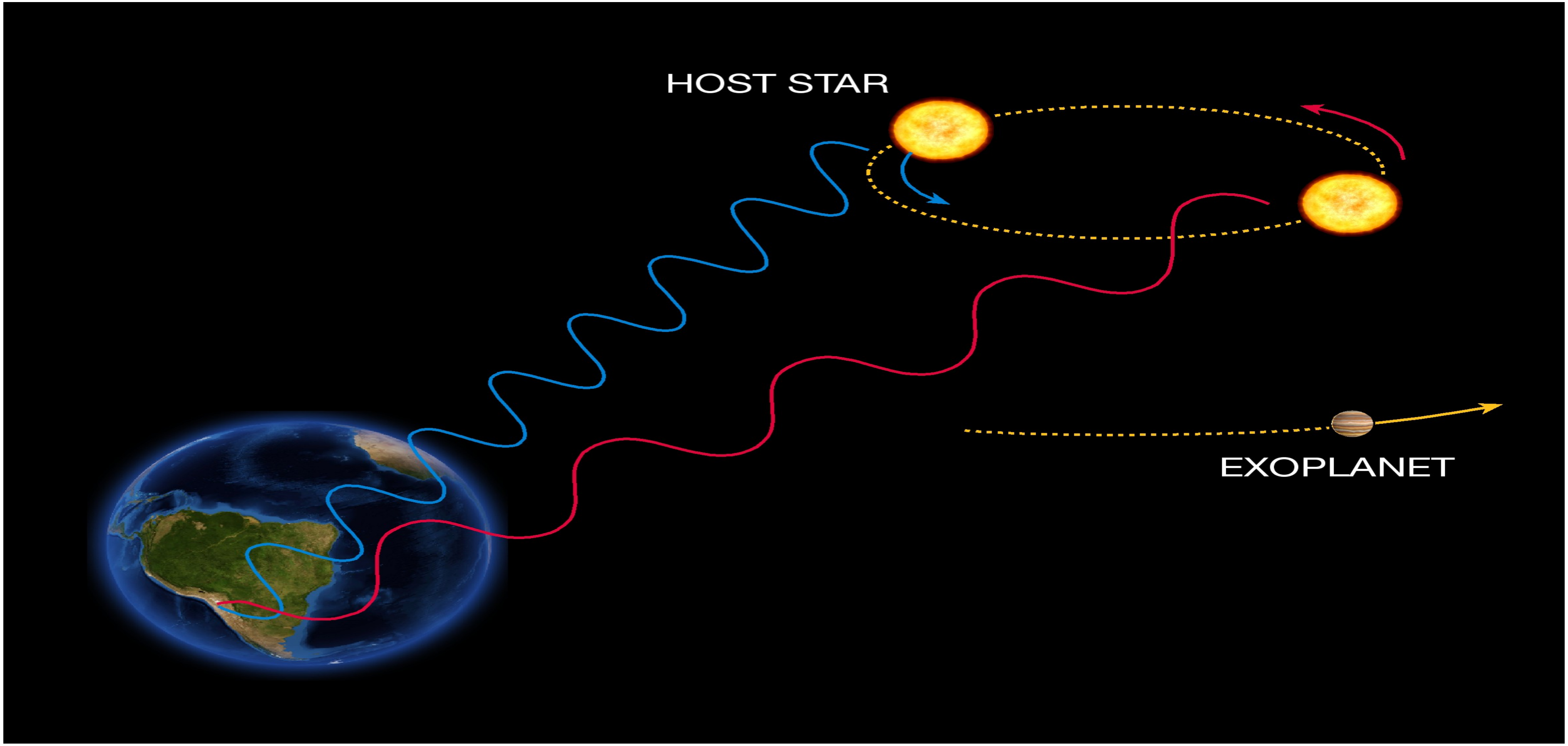
- Mesurements of Radial Velocities with high accuracies (m/s regimes)
- Spectral type catalogs
- Serching among bright stars in the solar neighbourhood
- First planet around solar type star detected by radial velocity survey in 1995
- So how does radial velocity measurement work?

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

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

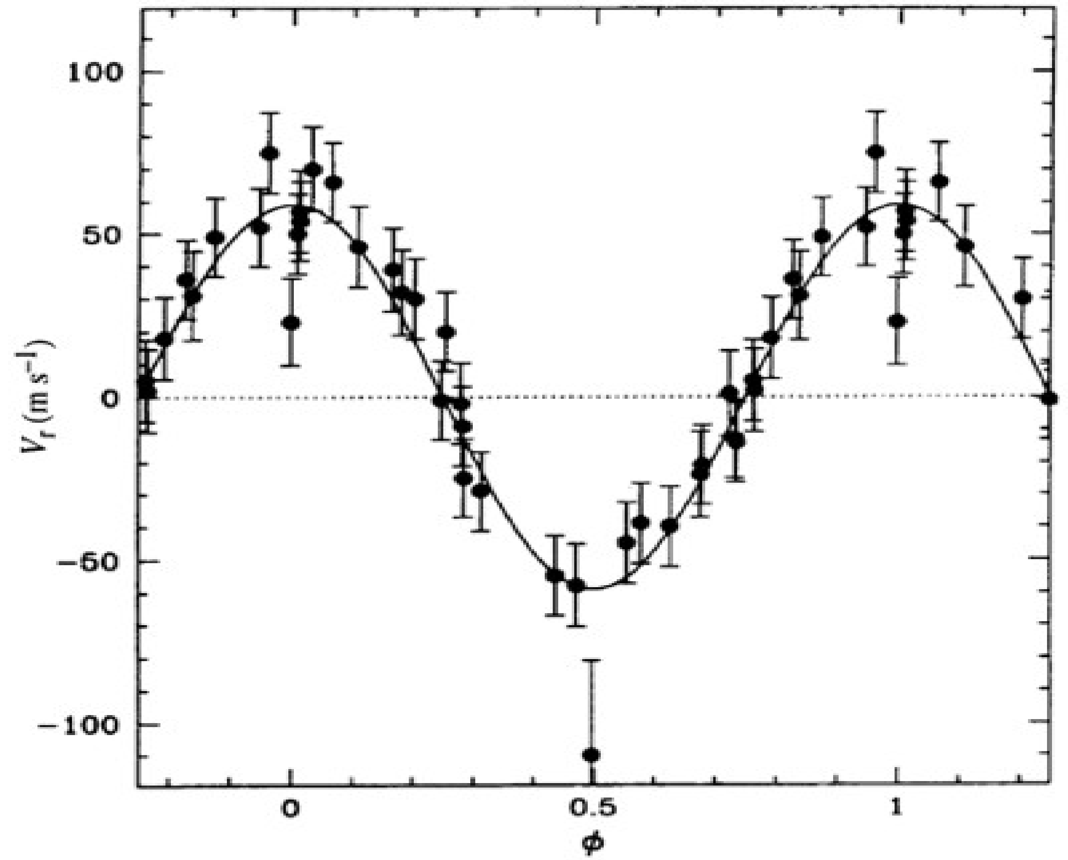
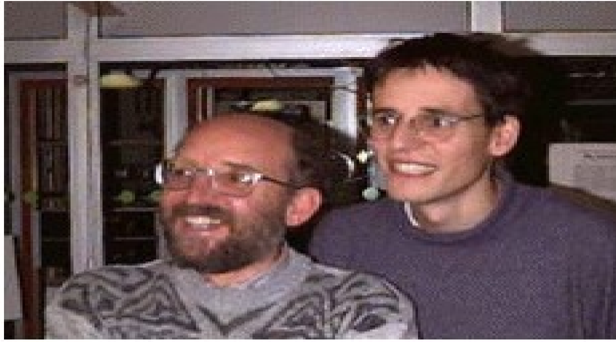


FIG. 4 Orbital motion of 51 Peg corrected from the long-term variation of the γ-velocity. The solid line represents the orbital motion computed from the parameters of Table 1.



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)

51 Peg compared

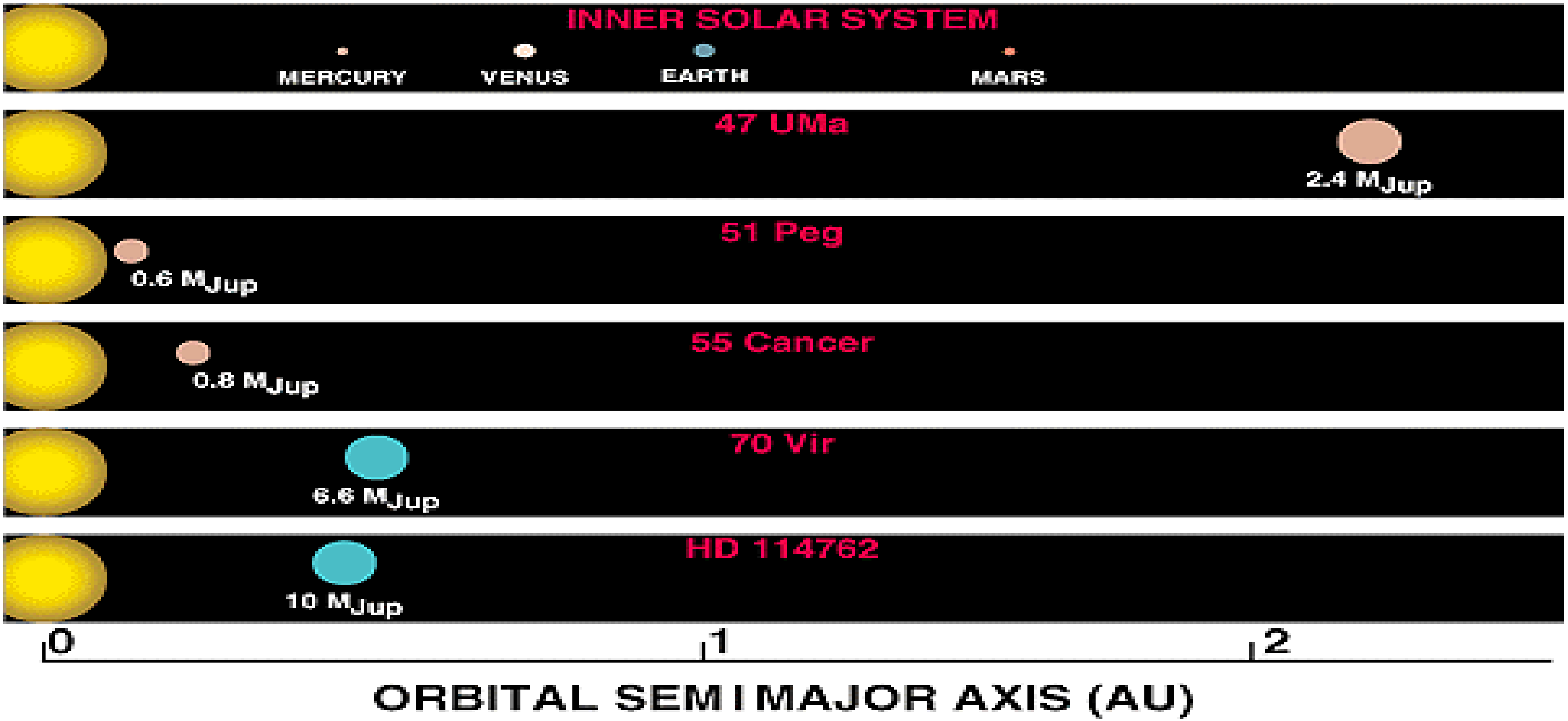
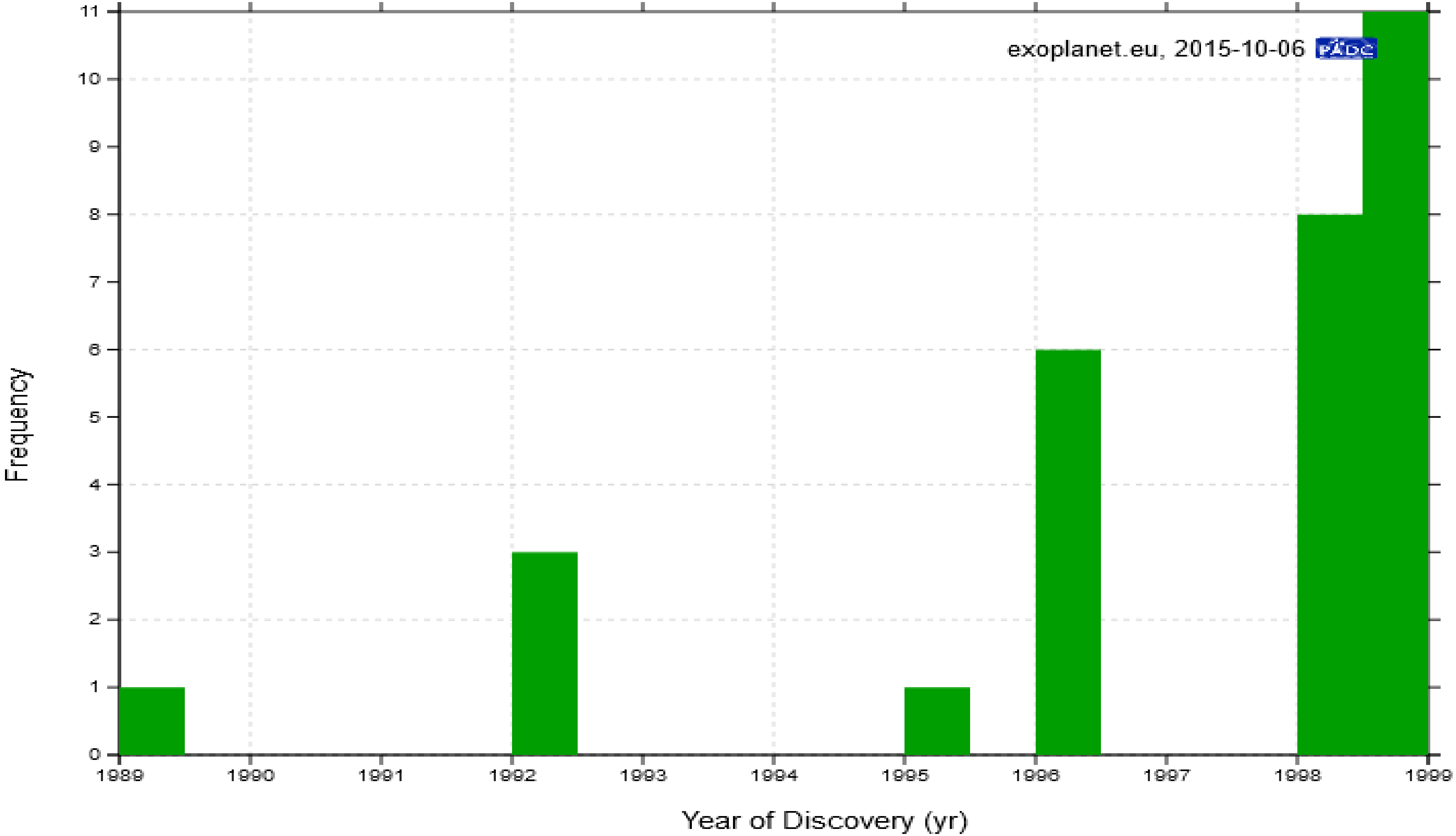


Image from Keele University

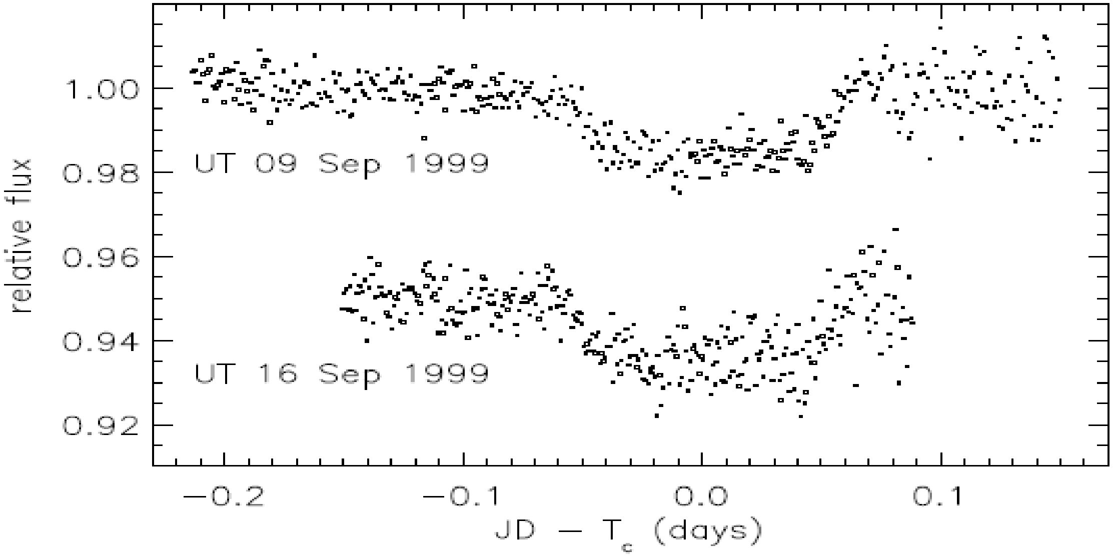
RV surveys and planet types

- 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

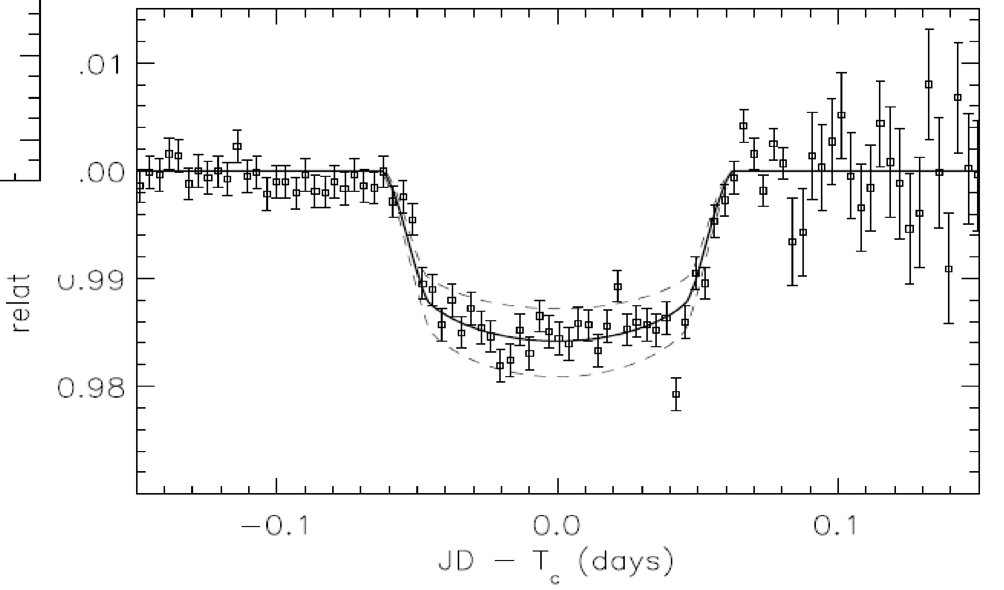


When the planet eclipses its star

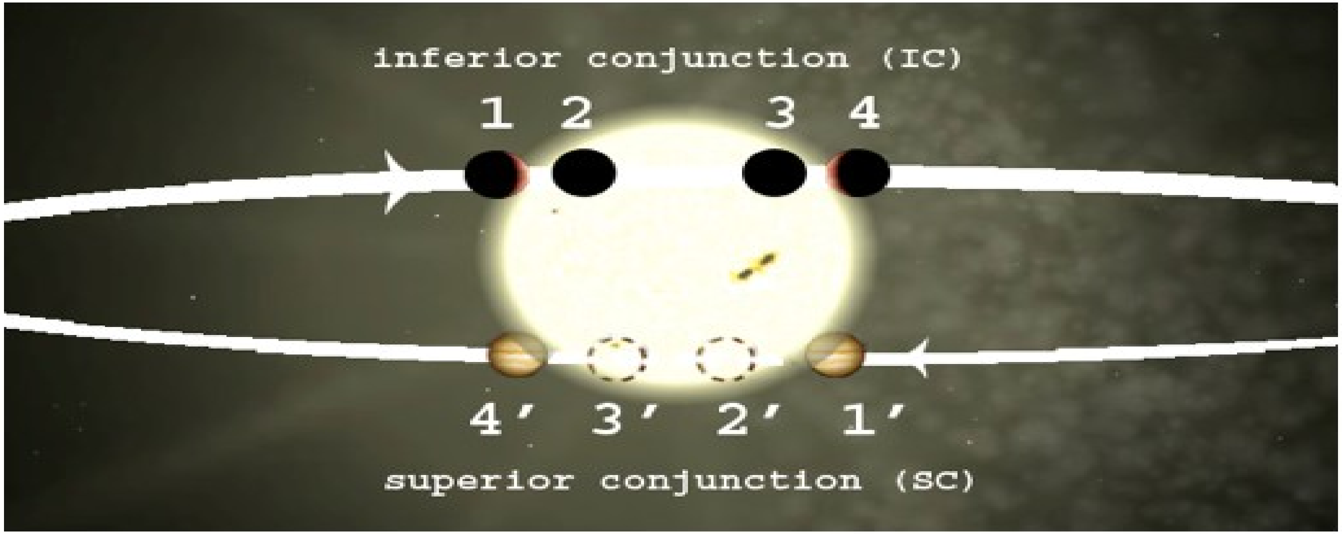


HD209458b

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

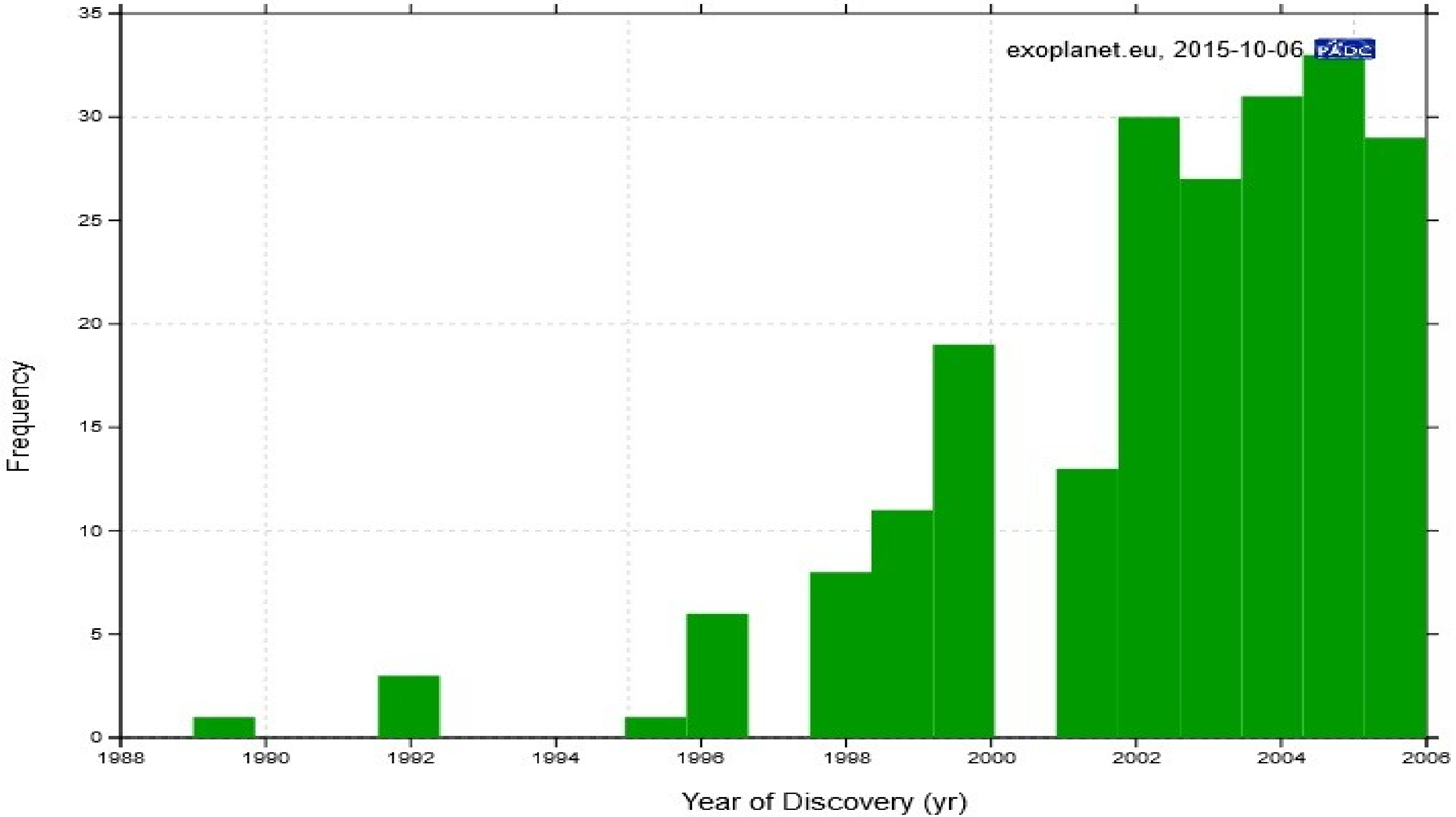
Each site consists of 8 telescopes with wide angle CCDs

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

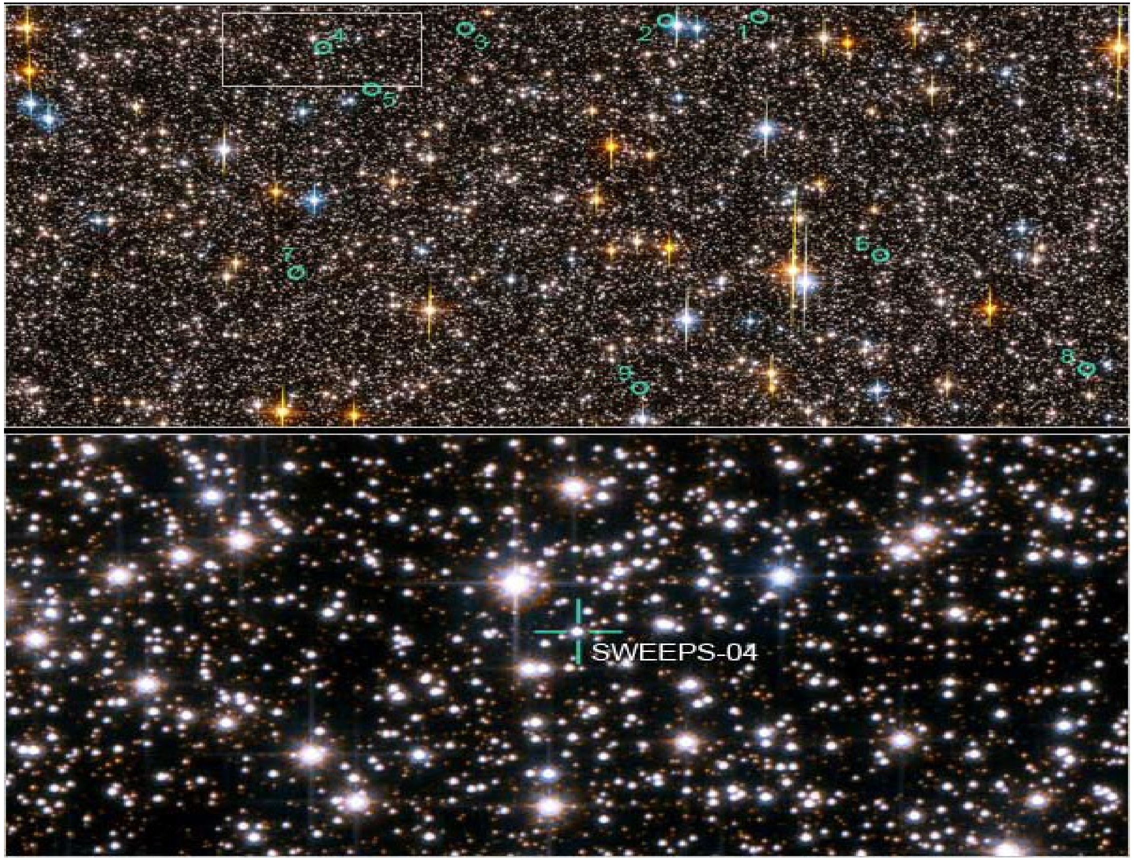
Received 3 March 2008 / Accepted 30 April 2008

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

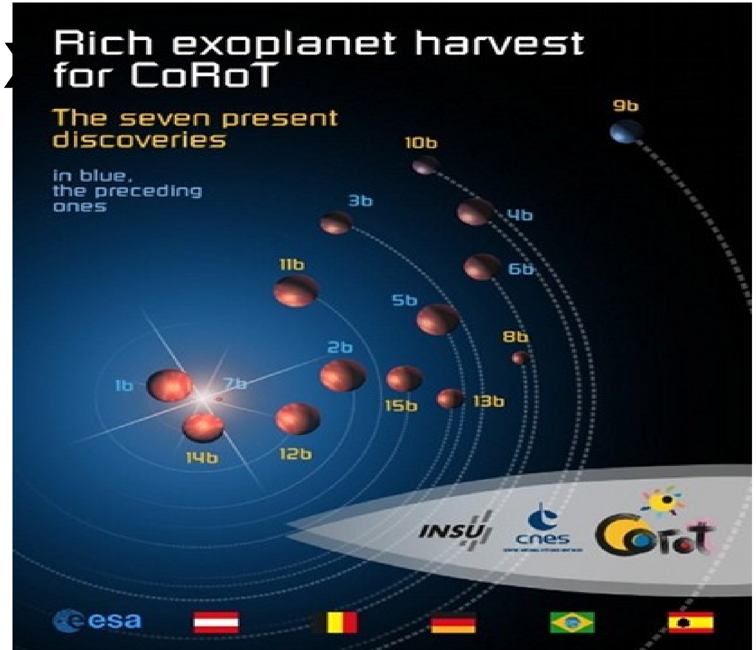
CoRoT

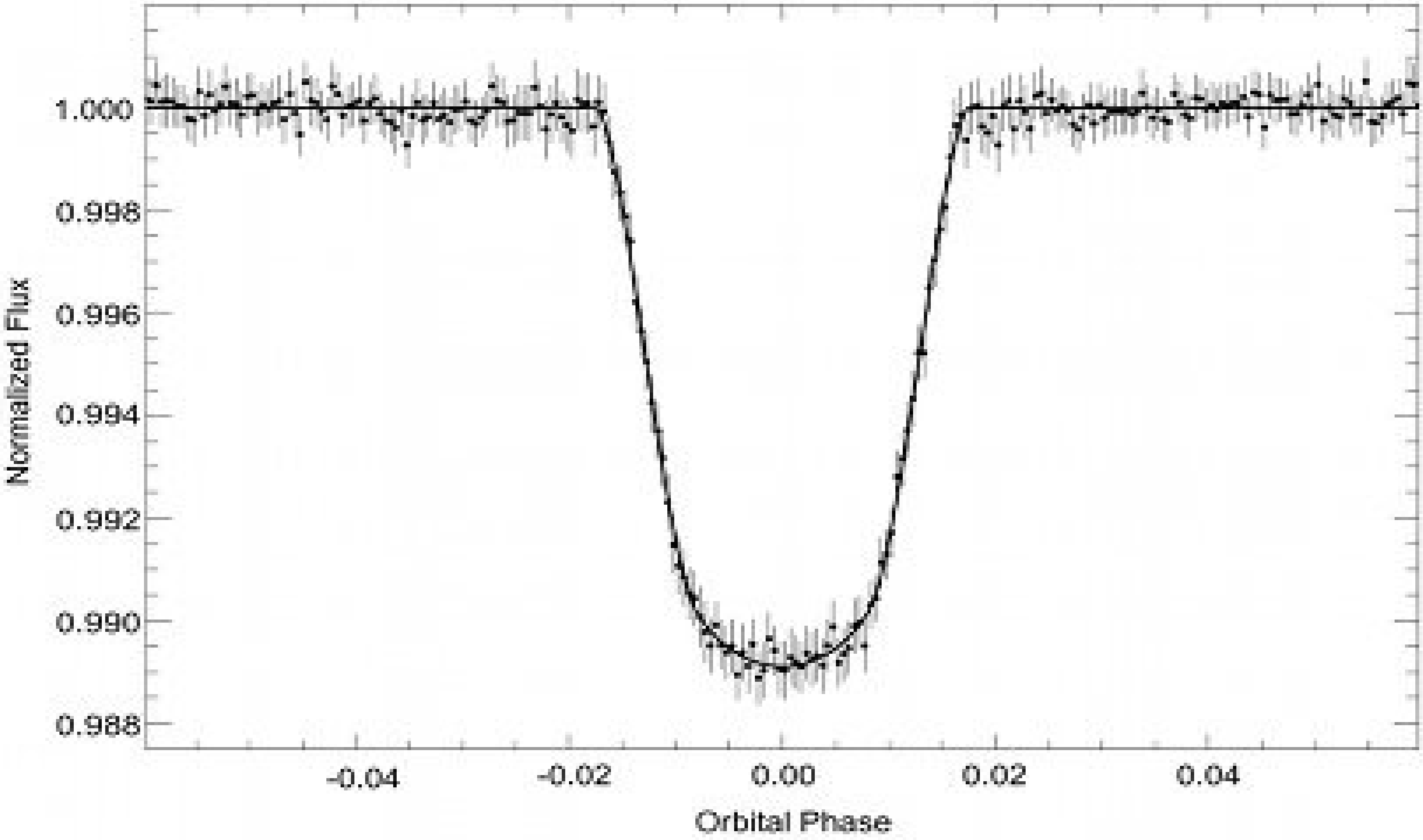
Convection, Rotation and planetary Transits

Launched 2006 – mission end 2013

,5

ESA webpages



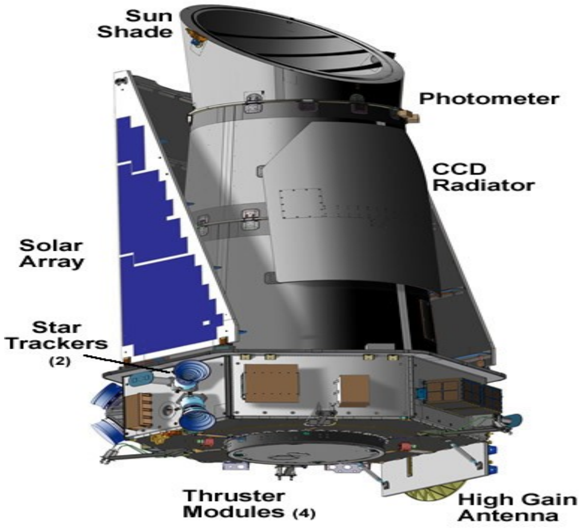


ESA webpages

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



etected 1030 confirmed planets

ore to come from K2

ler 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;

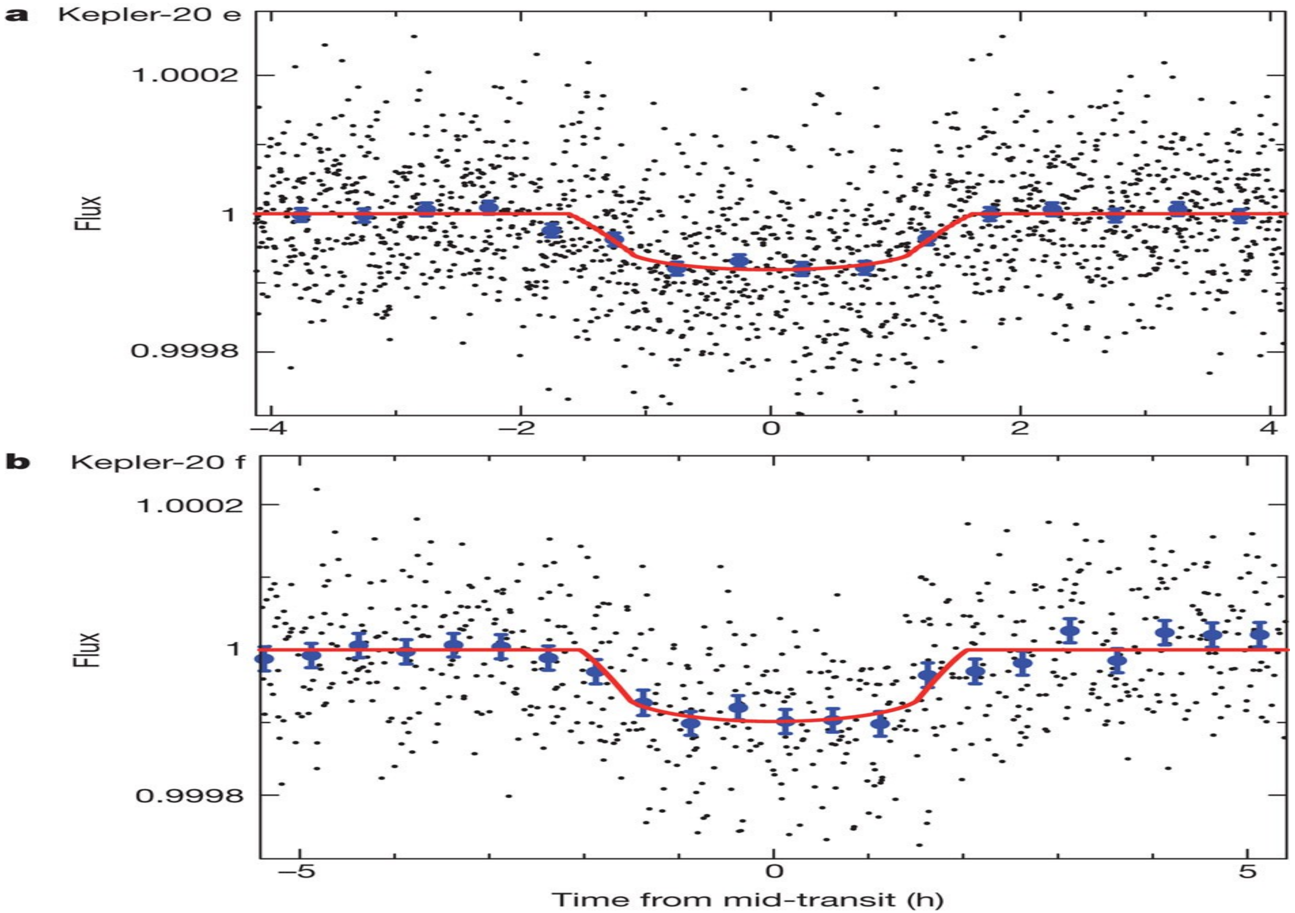
Determine the distribution of sizes and shapes of the orbits of these planets;

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

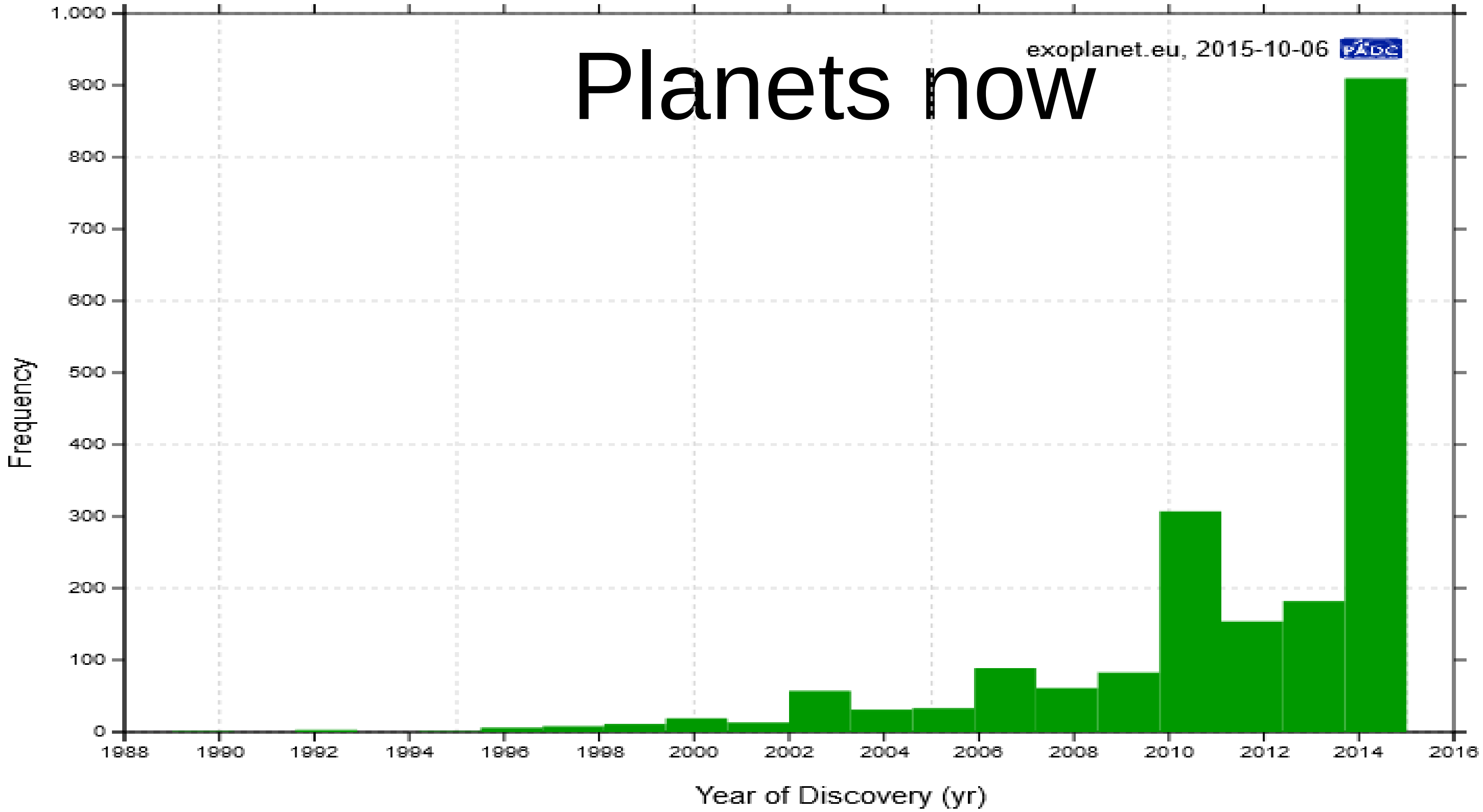
nature

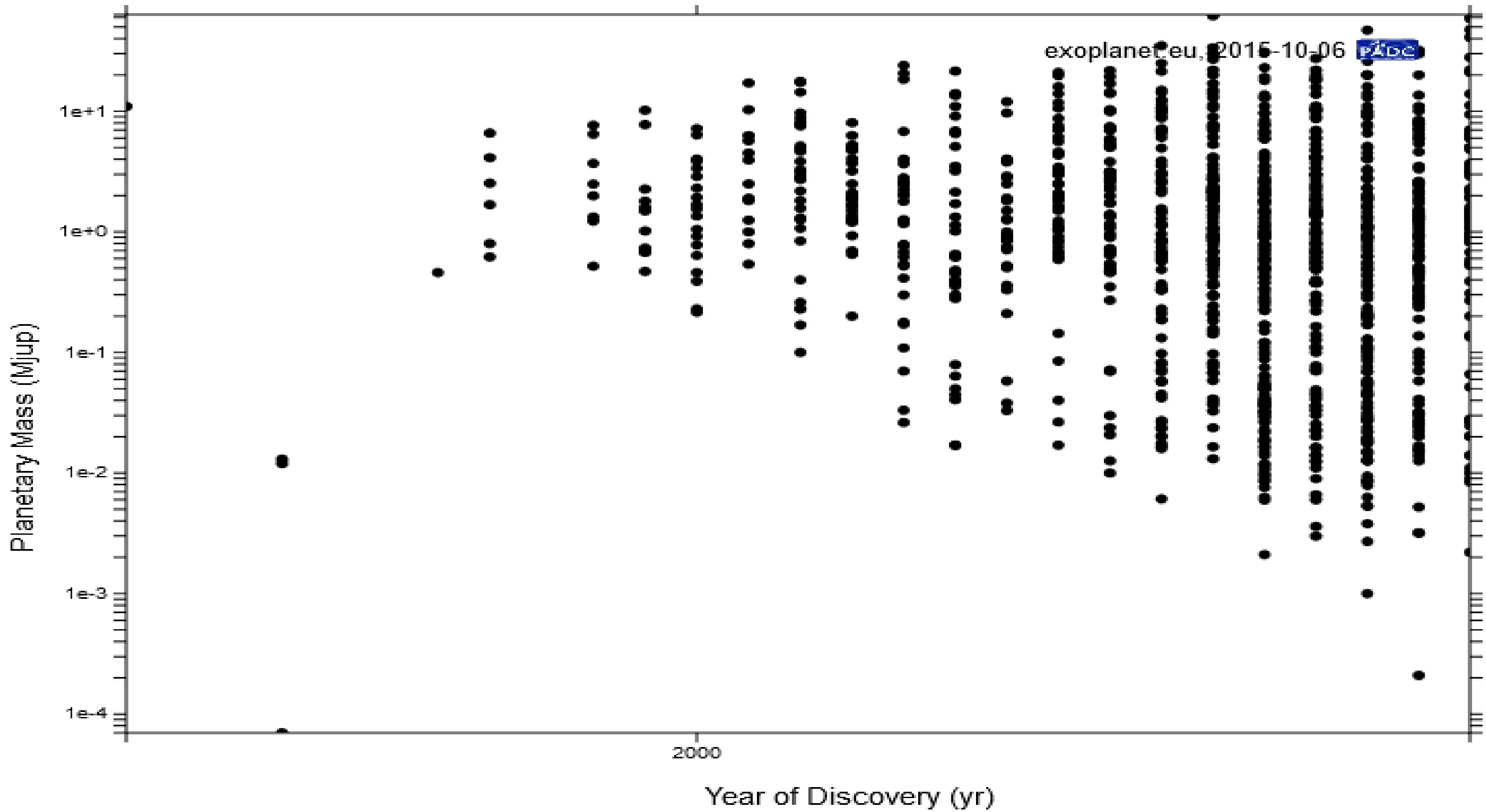
2 Earth like planets – Kepler 20 e and f

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

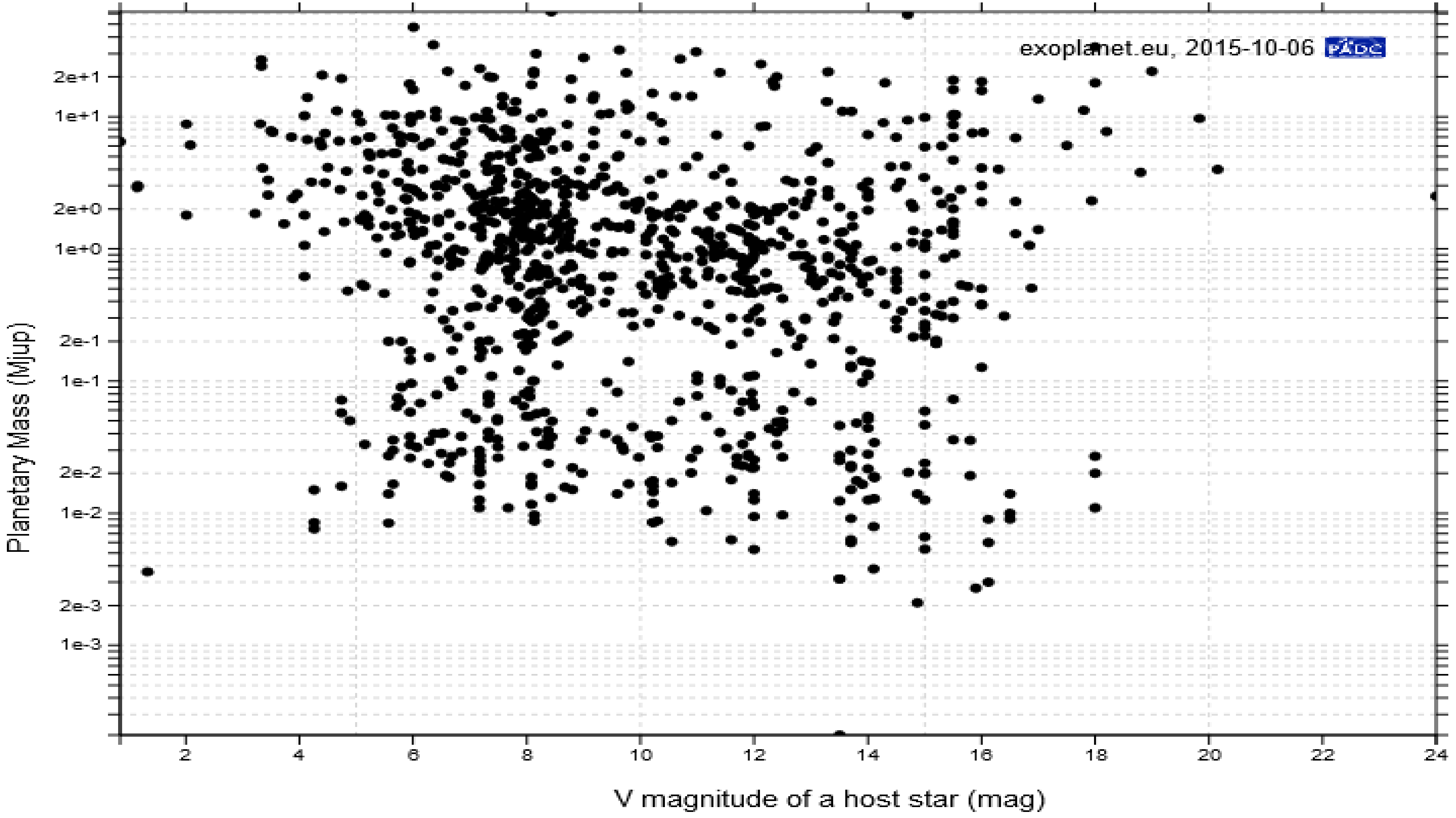
How many planets do we know today? State of the art

Planets now

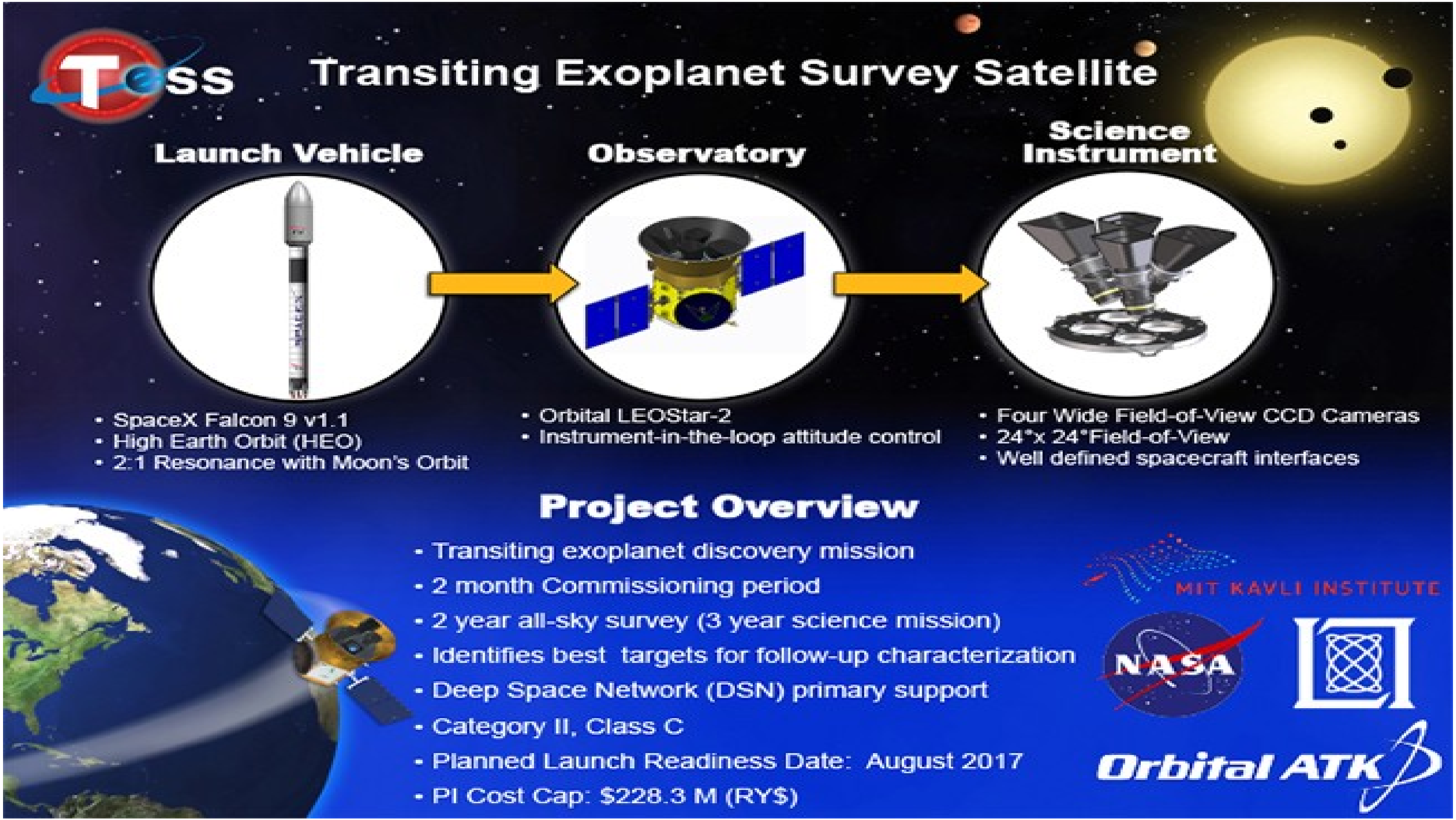

exoplanet.eu, 2015-10-06
PADC
Frequency
1,000
900
800
700
600
500
400
300
200
100
0
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year of Discovery (yr)



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

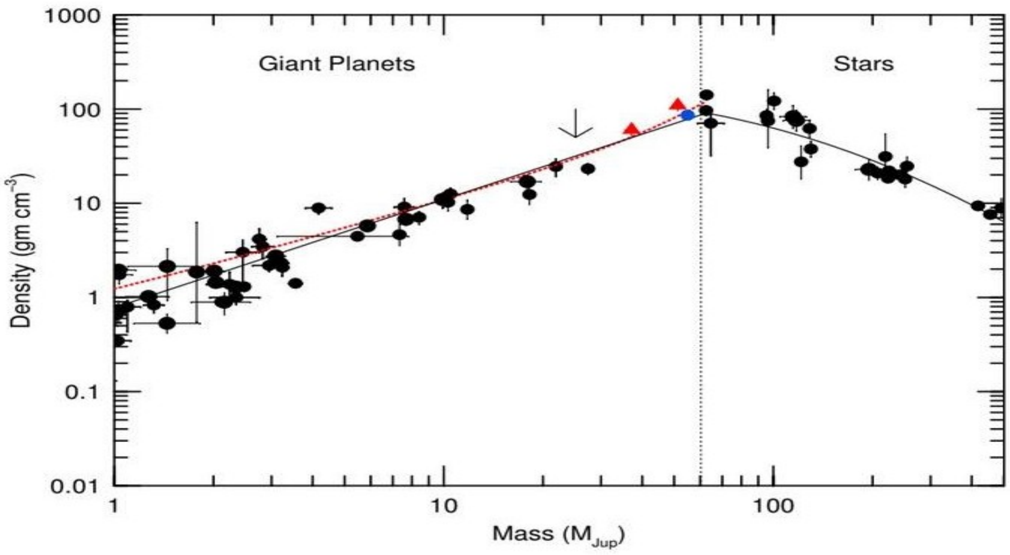

exoplanet.eu, 2015-10-06
PADC
Planetary Mass (Mjup)
2e+1
1e+1
2e+0
1e+0
2e-1
1e-1
2e-2
1e-2
2e-3
1e-3
2
4
6
8
10
12
14
16
18
20
22
24
V magnitude of a host star (mag)

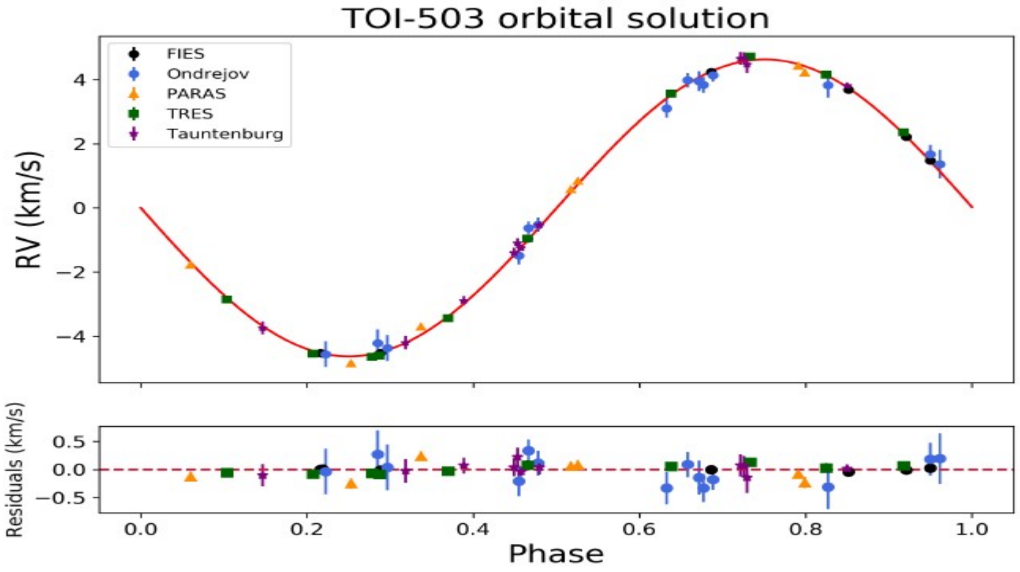
TESS


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

Plato Space mission

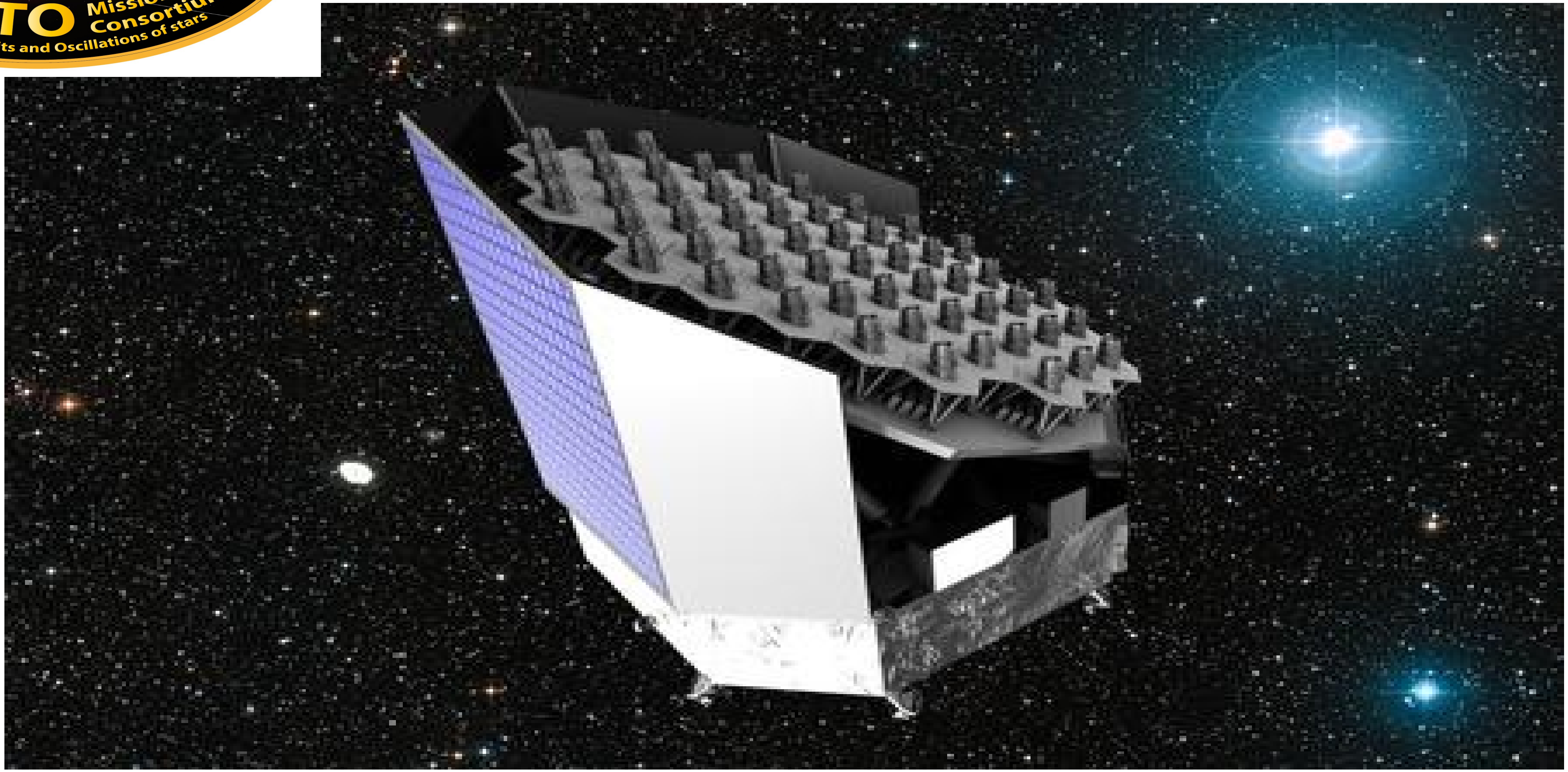
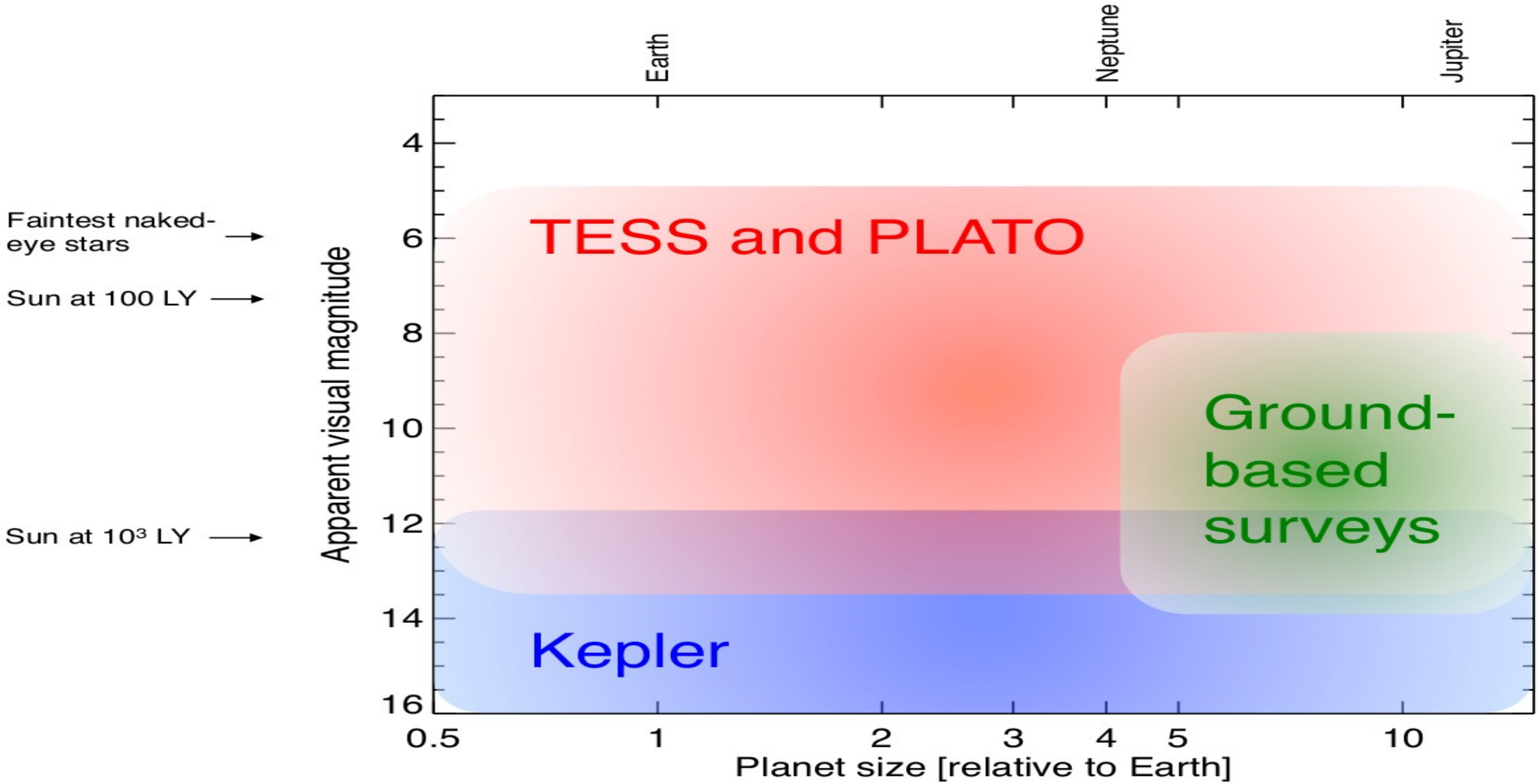


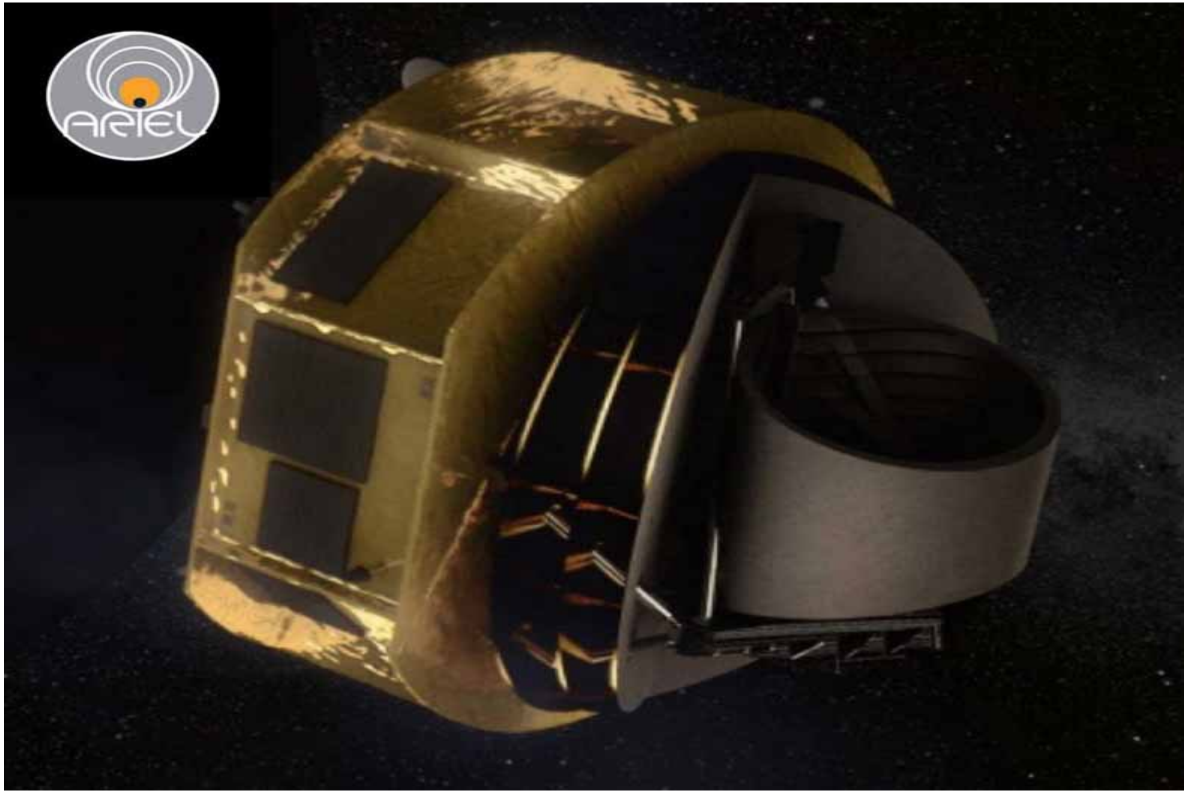
Fig.1: *PLATO Space mission is the motivation for PLATOSpec. PLATO will need large amount of ground based support. Credit: Thales Alenia Space*

Space missions compared



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