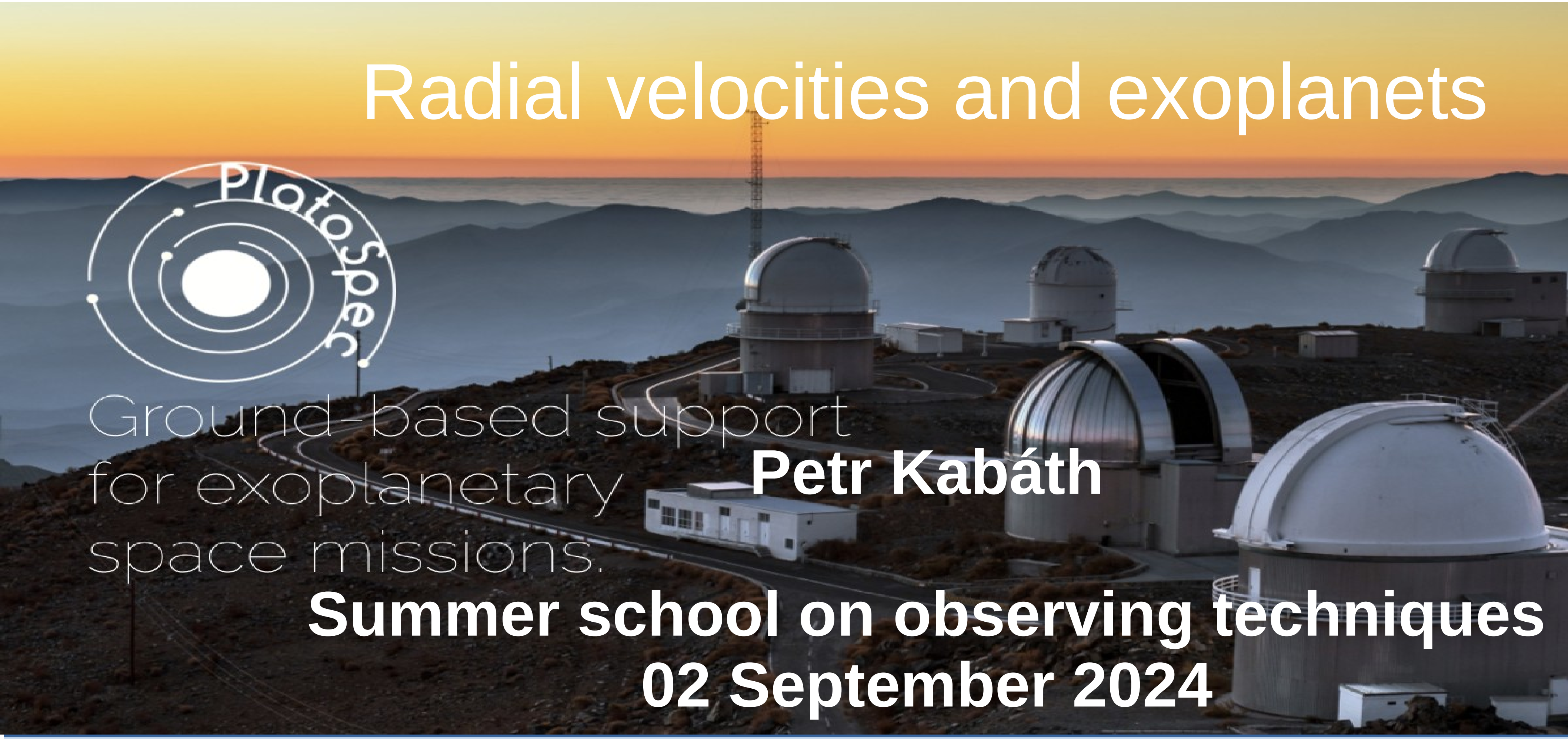
Radial velocities and exoplanets



PlatoSpec

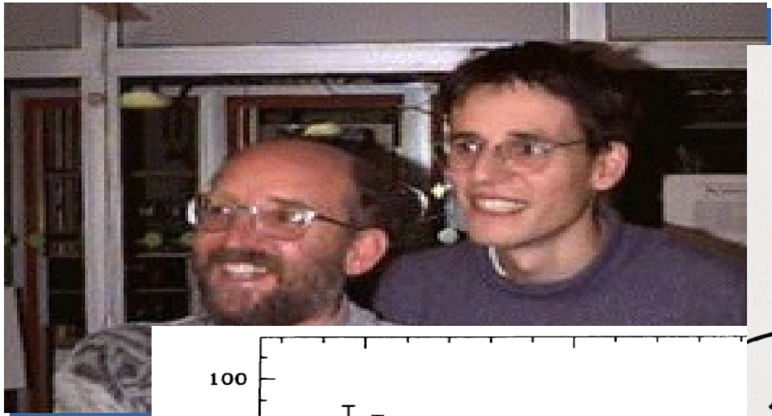
Ground-based support for exoplanetary space missions.

Petr Kabáth

Summer school on observing techniques

02 September 2024

What will be the lecture about?



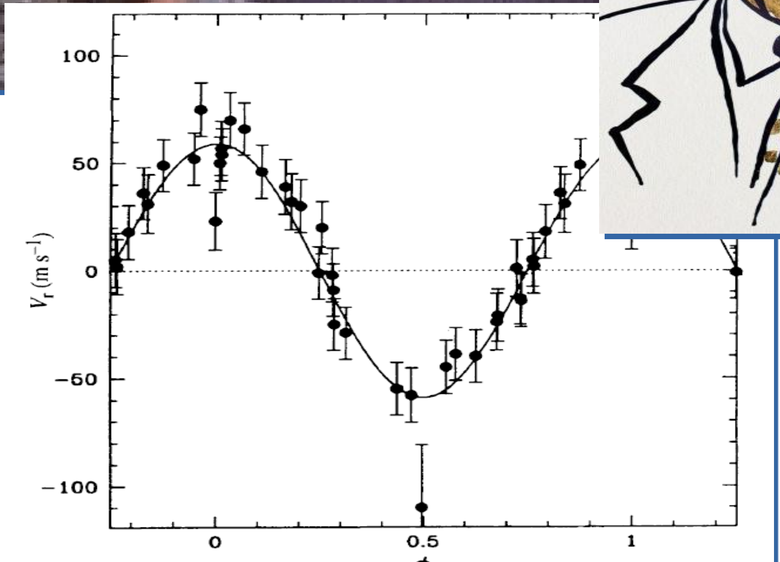
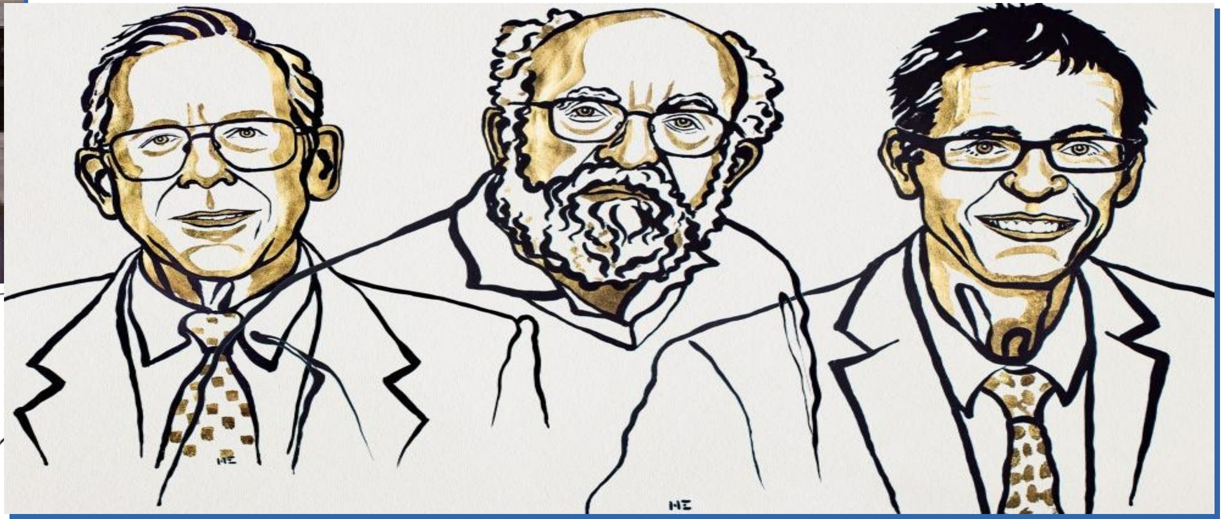
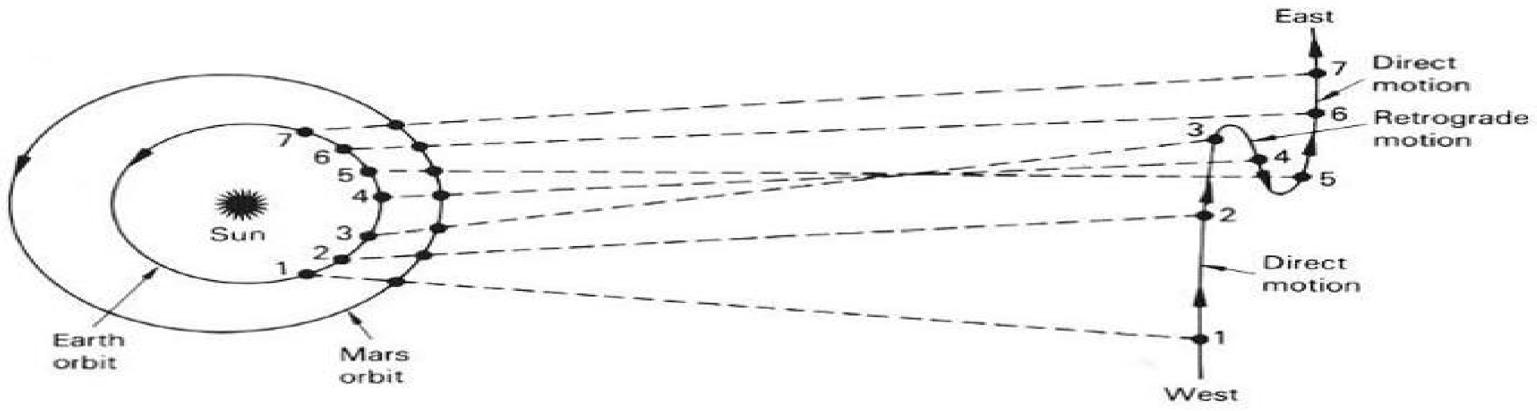


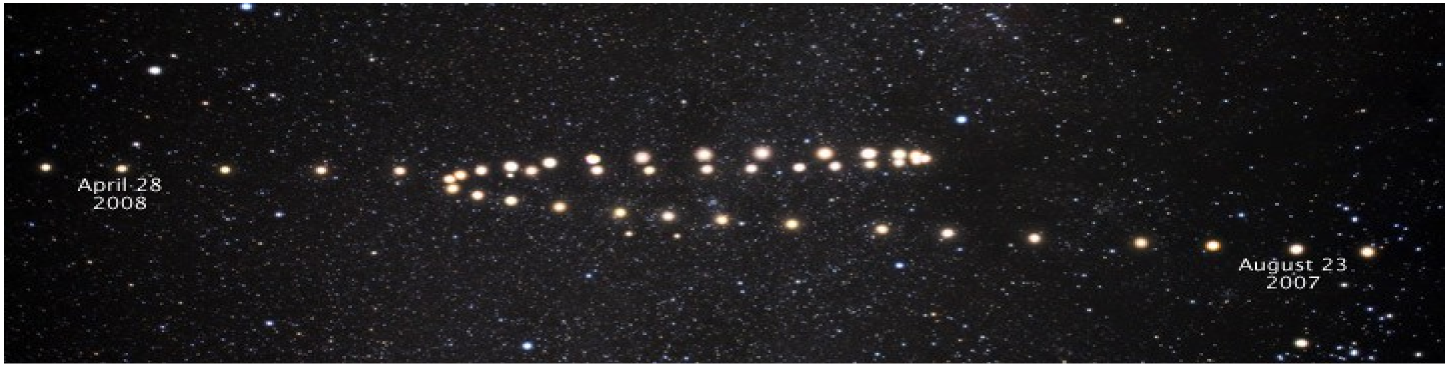
Image from Mayor and Queloz, 1995, Nature



A planet

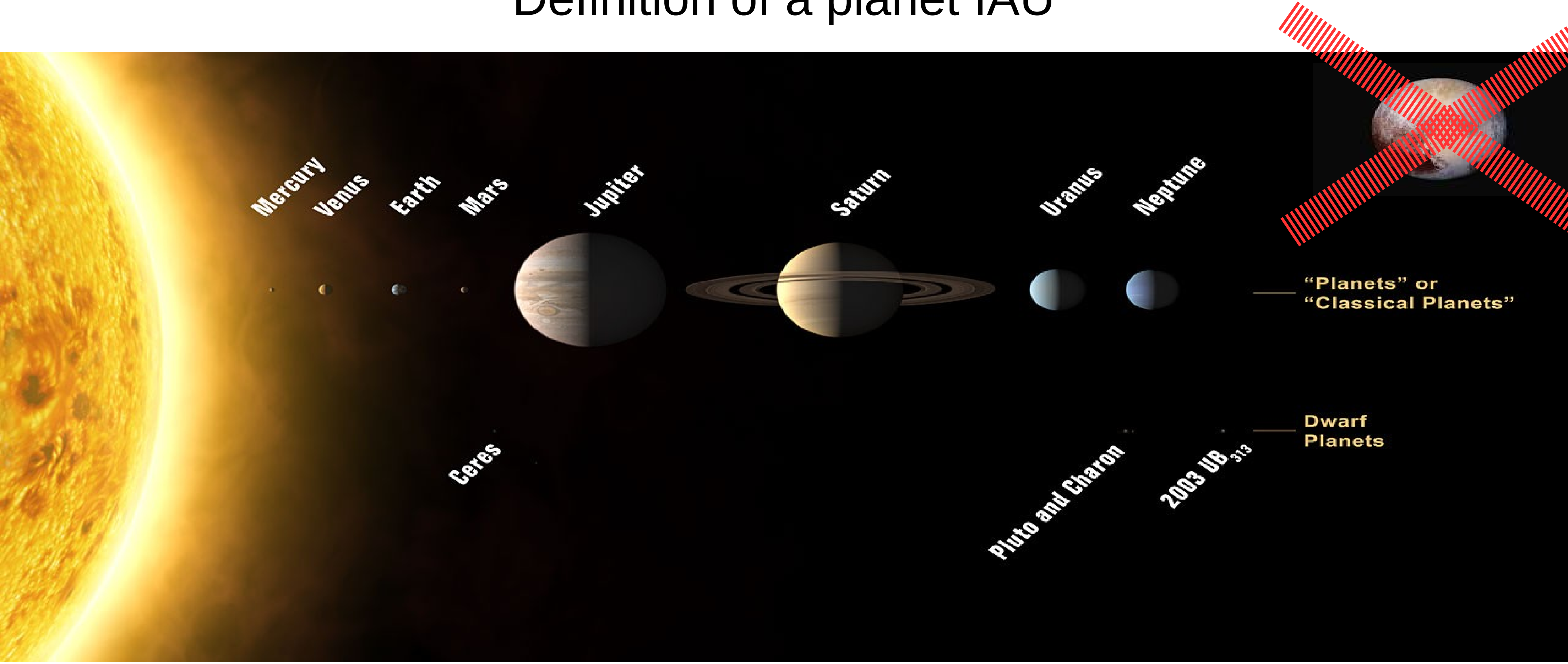
Πλανήτης - planétés – „tulák“





Credit: NASA

Definition of a planet IAU



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

An Exoplanet

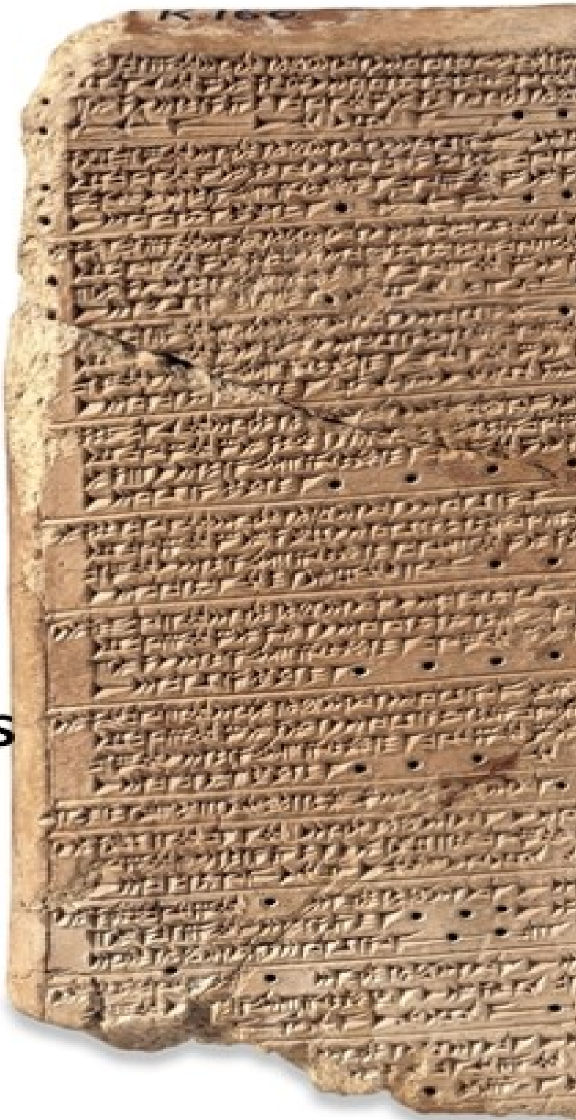
A planet orbiting a star other than Sun

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
- Star – planet interactions (relatively new topic but extremely important)

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

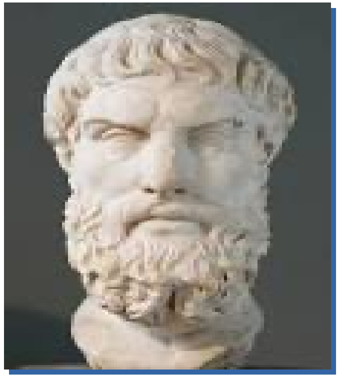


British M

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



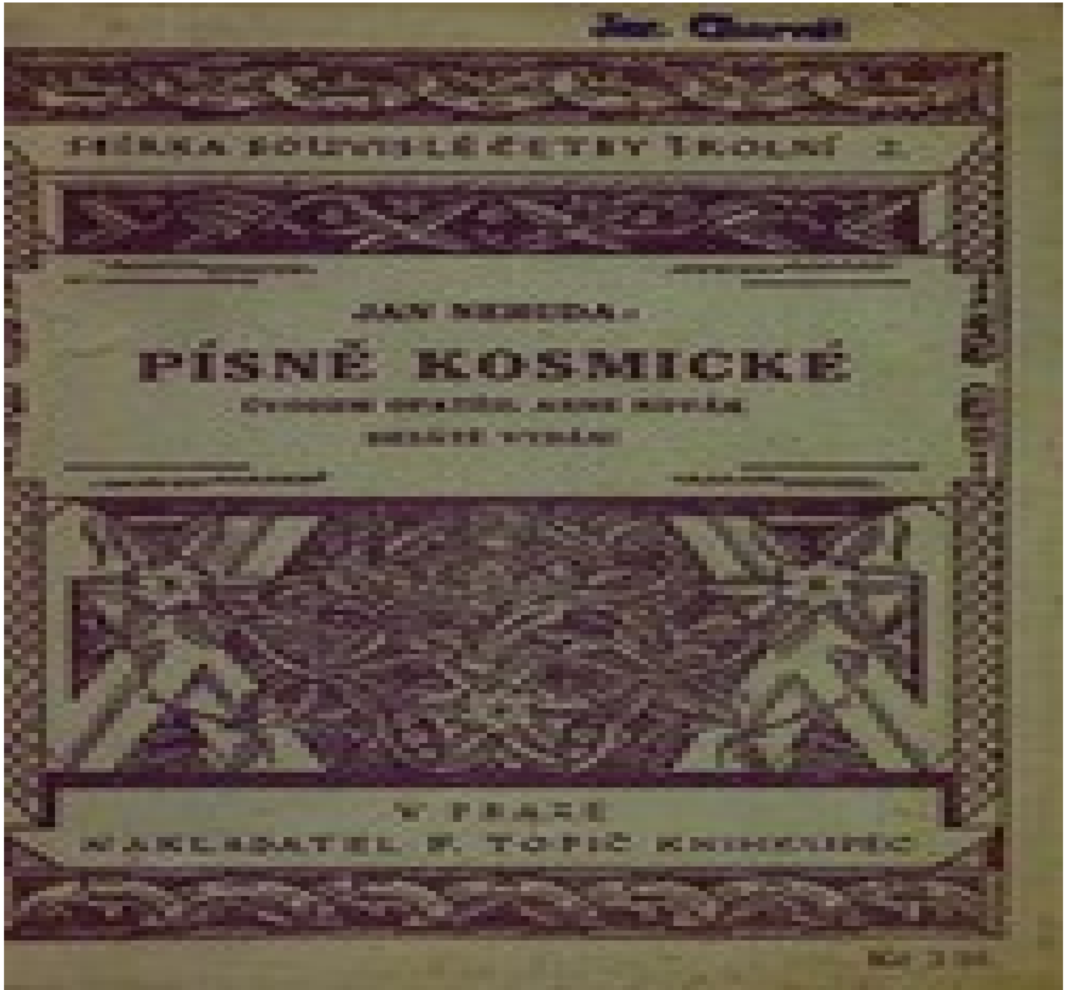
Wikipedia

- 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

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 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

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

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 $\pm$ 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.

But where are all the planets?

- 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

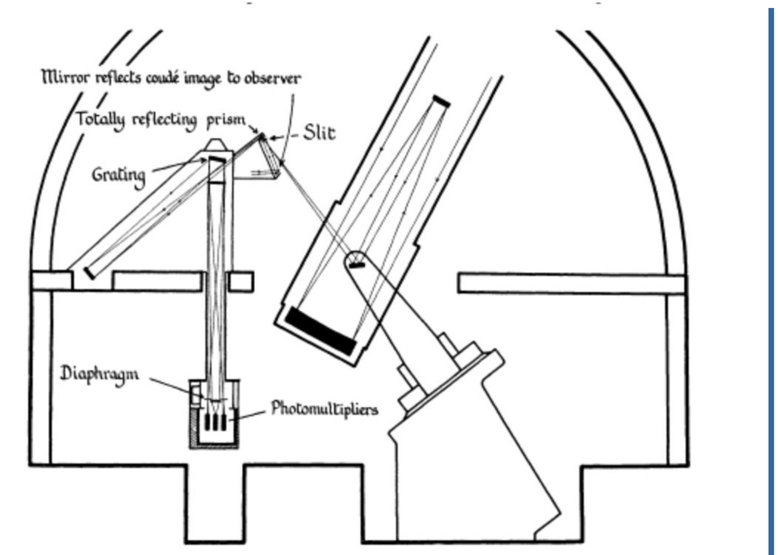


FIG. 1.—Sectional diagram of the Cambridge 36-inch coudé reflector and radial-velocity spectrometer

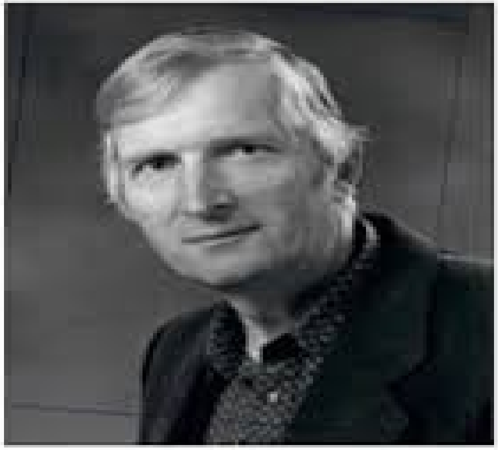
CORAVEL

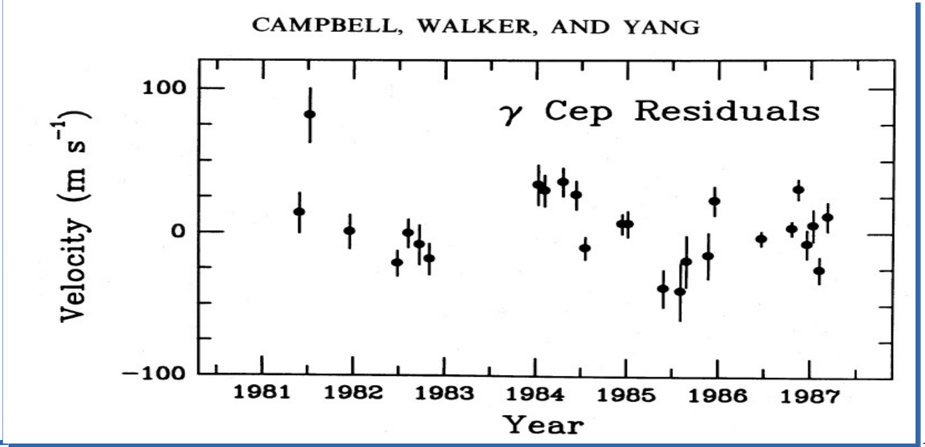
- Spectrograph at Danish 1.54 at ESO Chile
- Project started 1971 Marseilles and Geneva teams
- RV accuracies 250 m/s
- Decomissioned 1998

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



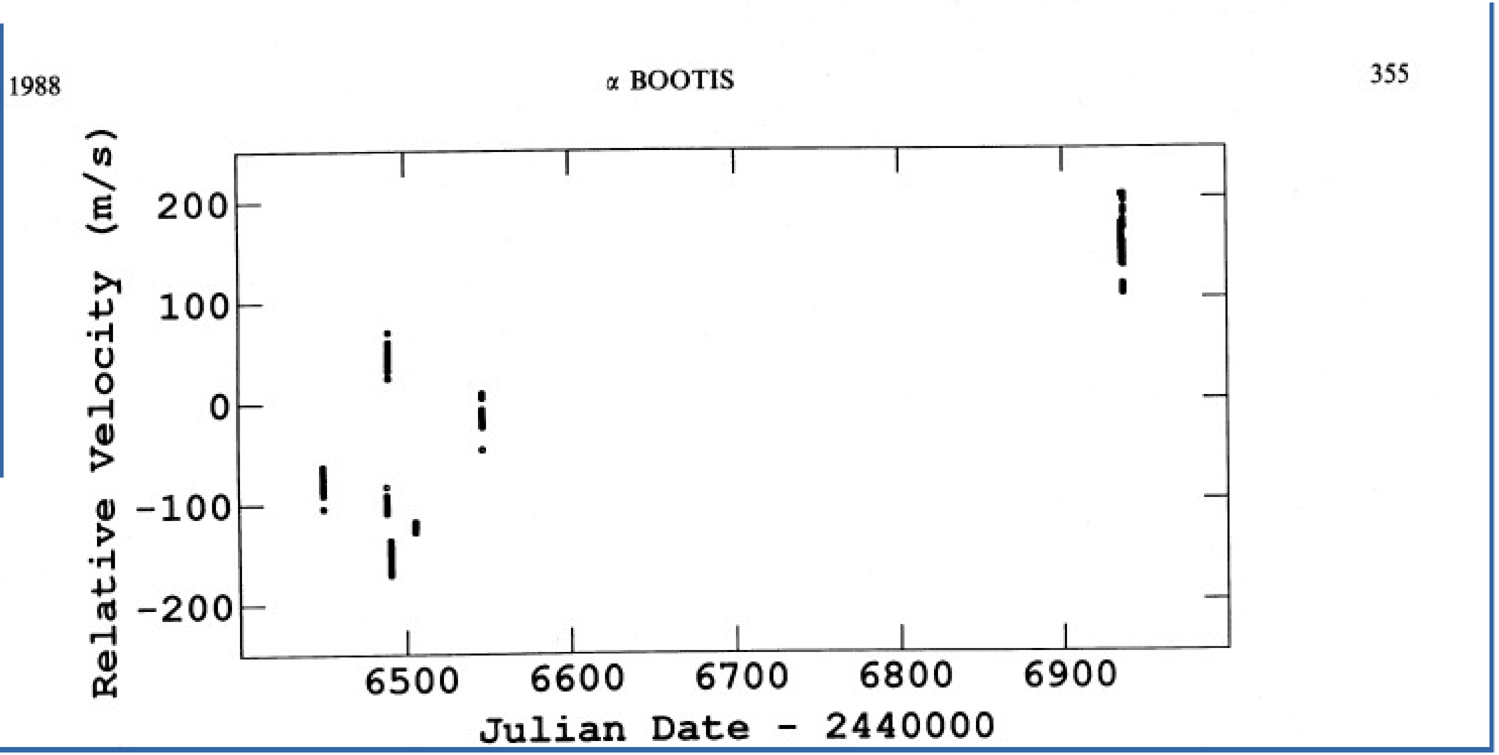


https://dtm.carnegiescience.edu/news/brief-personal-history-exoplanets

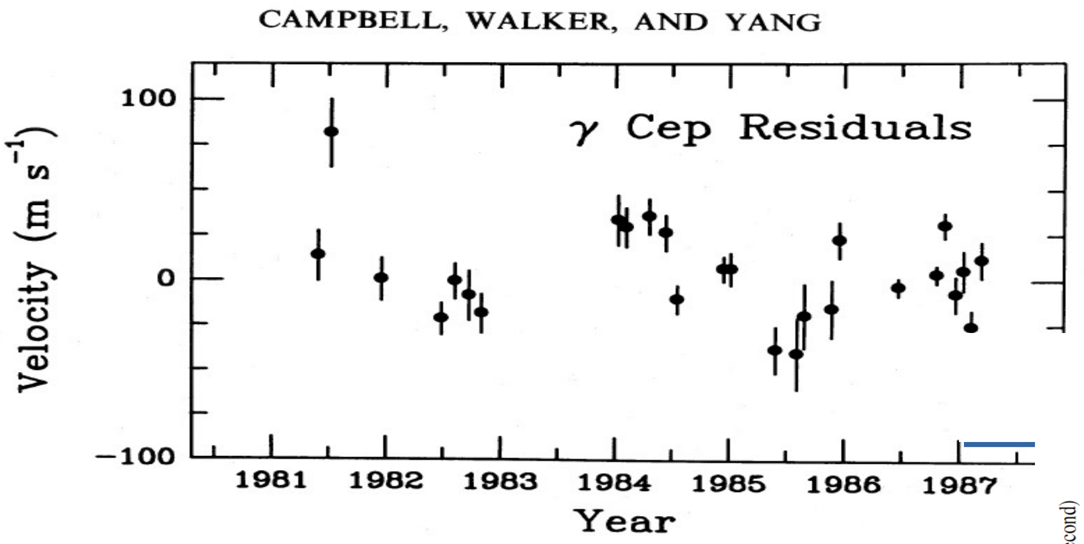
Telluric lines and other methods

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

W. Cochran
U. Texas



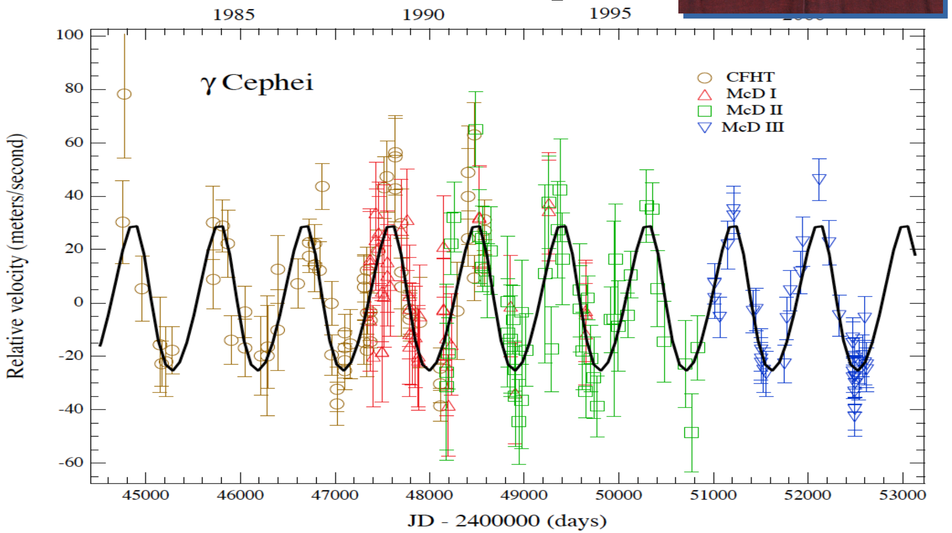
The Case of gamma Cep



Campbell, Walker and Yang, 1988, ApJ
RETRACTED

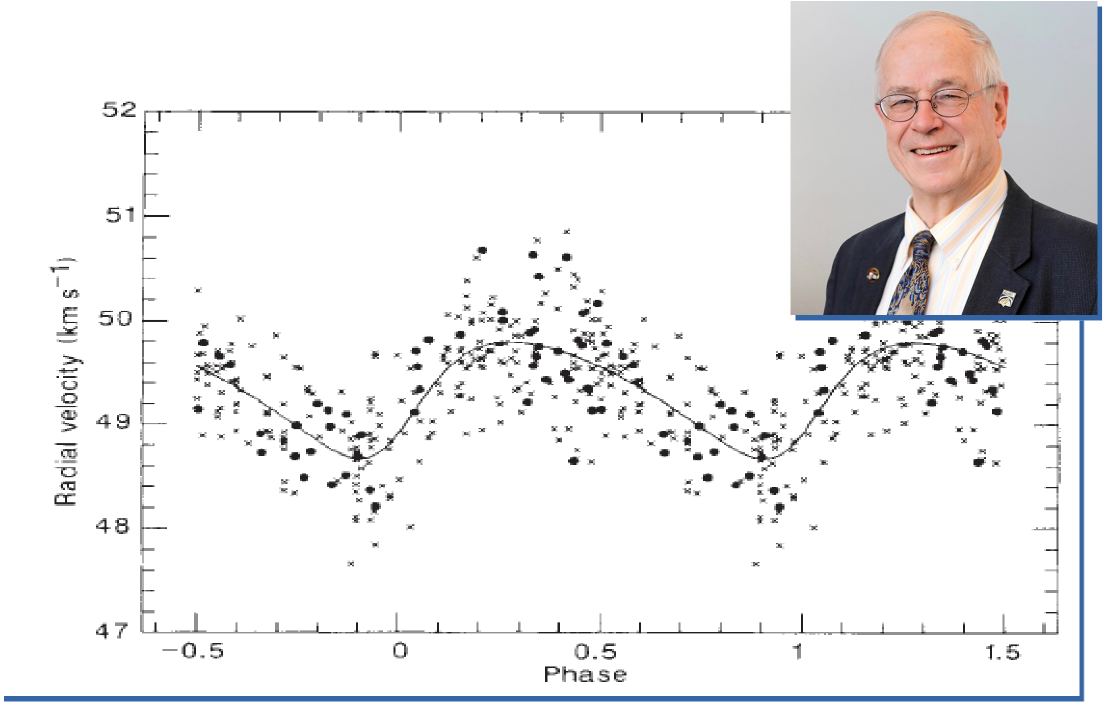
P = 903 days
Mass = 1.85 Mjupiter

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

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

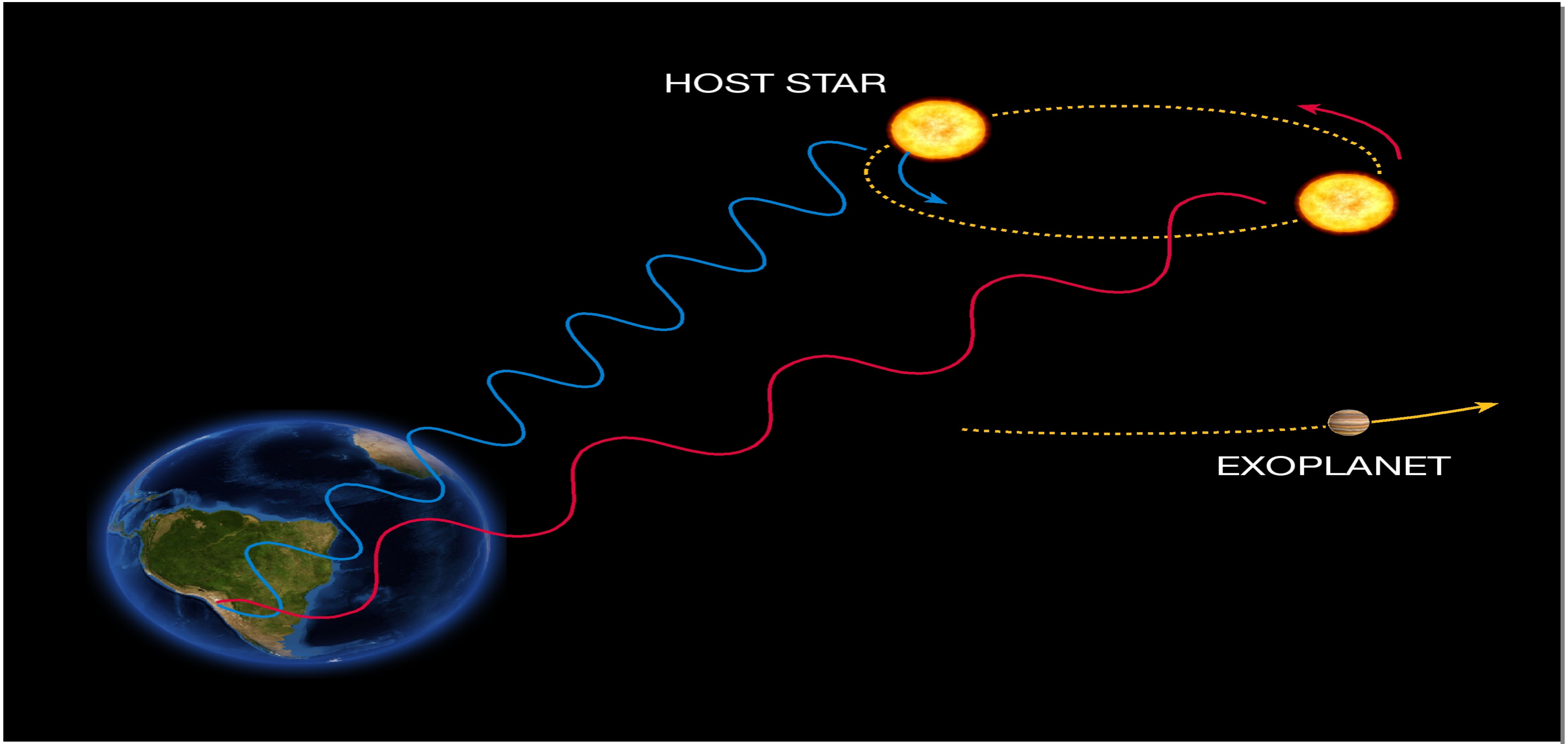
- Measurements of Radial Velocities with high accuracies (m/s regimes)
- Spectral type catalogs
- Searching among bright stars in the solar neighbourhood
- First planet around solar type star detected by radial velocity survey in 1995
- So how does radial velocity measurement work?

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 binaries
- targeting suitable stars

Radial velocity method



The Radial Velocity Method

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

Some equations

- Observable semi-amplitude of RV curve K:

$$K_1 = \sqrt{\frac{G}{(1-e^2)}}\, m_2 \sin i\, (m_1+m_2)^{-1/2}\, a^{-1/2} \quad K_1 = \frac{28.4329\,\mathrm{m\,s^{-1}}}{\sqrt{1-e^2}} \frac{m_2 \sin i}{M_{\mathrm{Jup}}} \left(\frac{m_1+m_2}{M_\odot}\right)^{-2/3} \left(\frac{P}{1\,\mathrm{yr}}\right)^{-1/3}$$

Using Kepler law and Newton's law, angular momentum conservation.

For details see:

http://adsabs.harvard.edu/full/1913PASP...25..208P

http://exoplanets.astro.yale.edu/workshop/EPRV/Bibliography_files/Radial_Velocity.pdf

$$\frac{M_p}{(M_p+M_\star)^{2/3}} = \frac{K_\star\sqrt{1-e^2}}{\sin i}\left(\frac{P}{2\pi G}\right)^{1/3}$$

Semi amplitude K

Table 1: Radial velocity signals for different kinds of planets orbiting a solar-mass star.

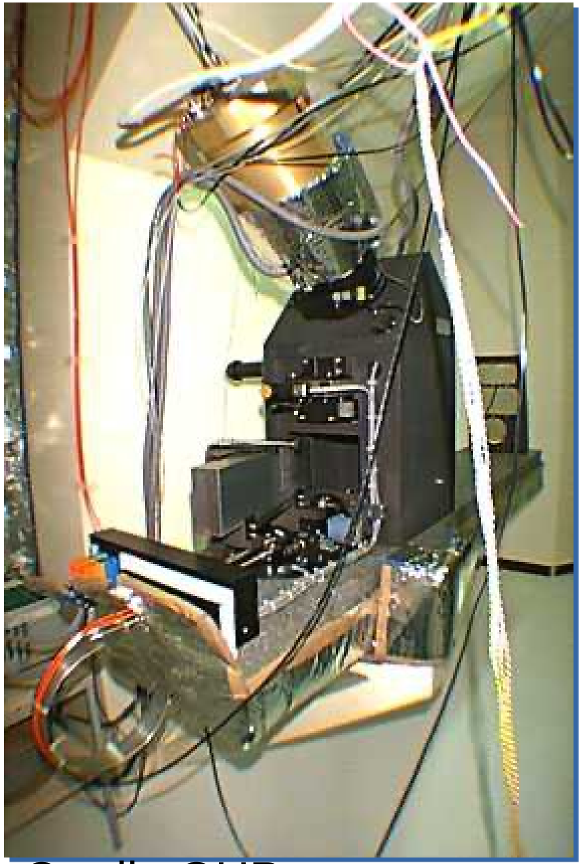
Planet	a (AU)	K_1 (m s^{-1})
Jupiter	0.1	89.8
Jupiter	1.0	28.4
Jupiter	5.0	12.7
Neptune	0.1	4.8
Neptune	1.0	1.5
Super-Earth (5 $M_\oplus$)	0.1	1.4
Super-Earth (5 $M_\oplus$)	1.0	0.45
Earth	0.1	0.28
Earth	1.0	0.09

2

FROM: http://exoplanets.astro.yale.edu/workshop/EPRV/Bibliography_files/Radial_Velocity.pdf

The Case of 51 Peg

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

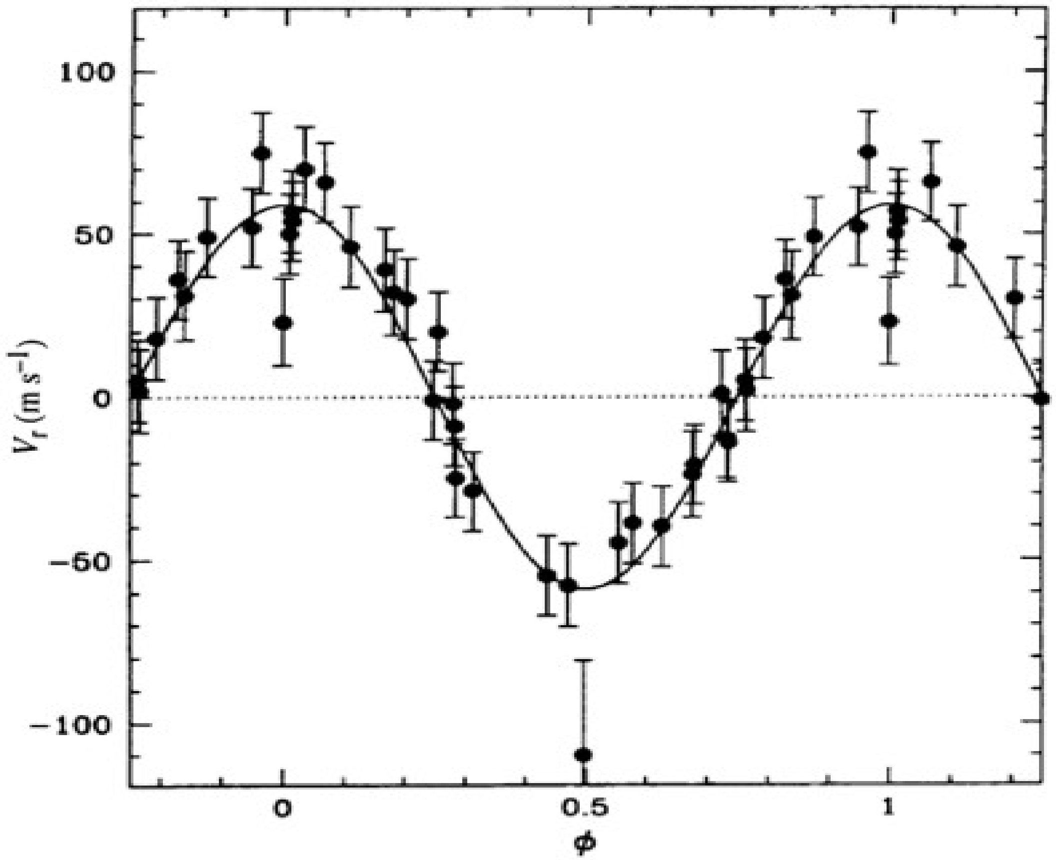
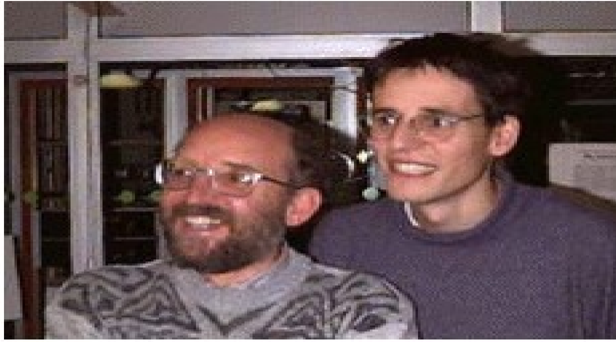


FIG. 4 Orbital motion of 51 Peg corrected from the long-term variation of the γ-velocity. The solid line represents the orbital motion computed from the parameters of Table 1.



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

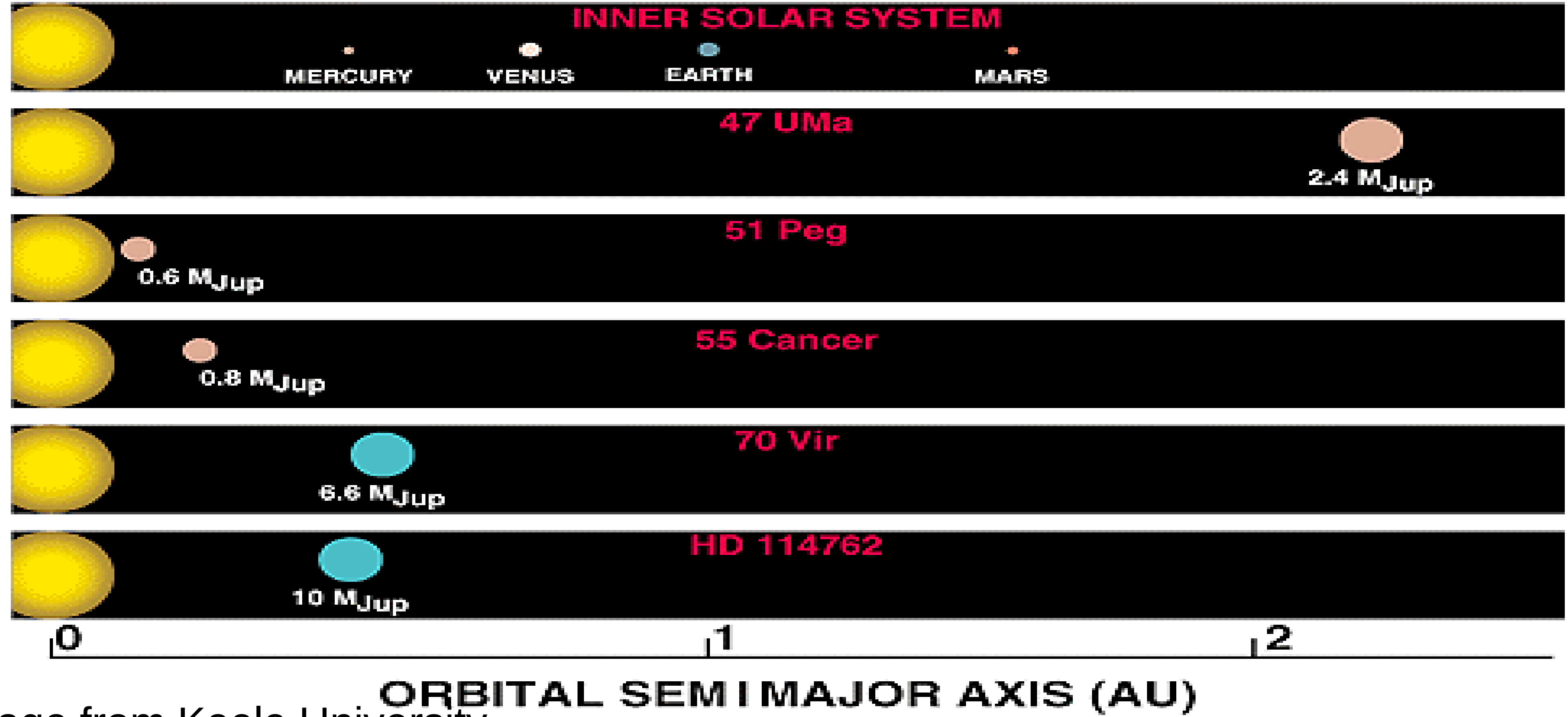
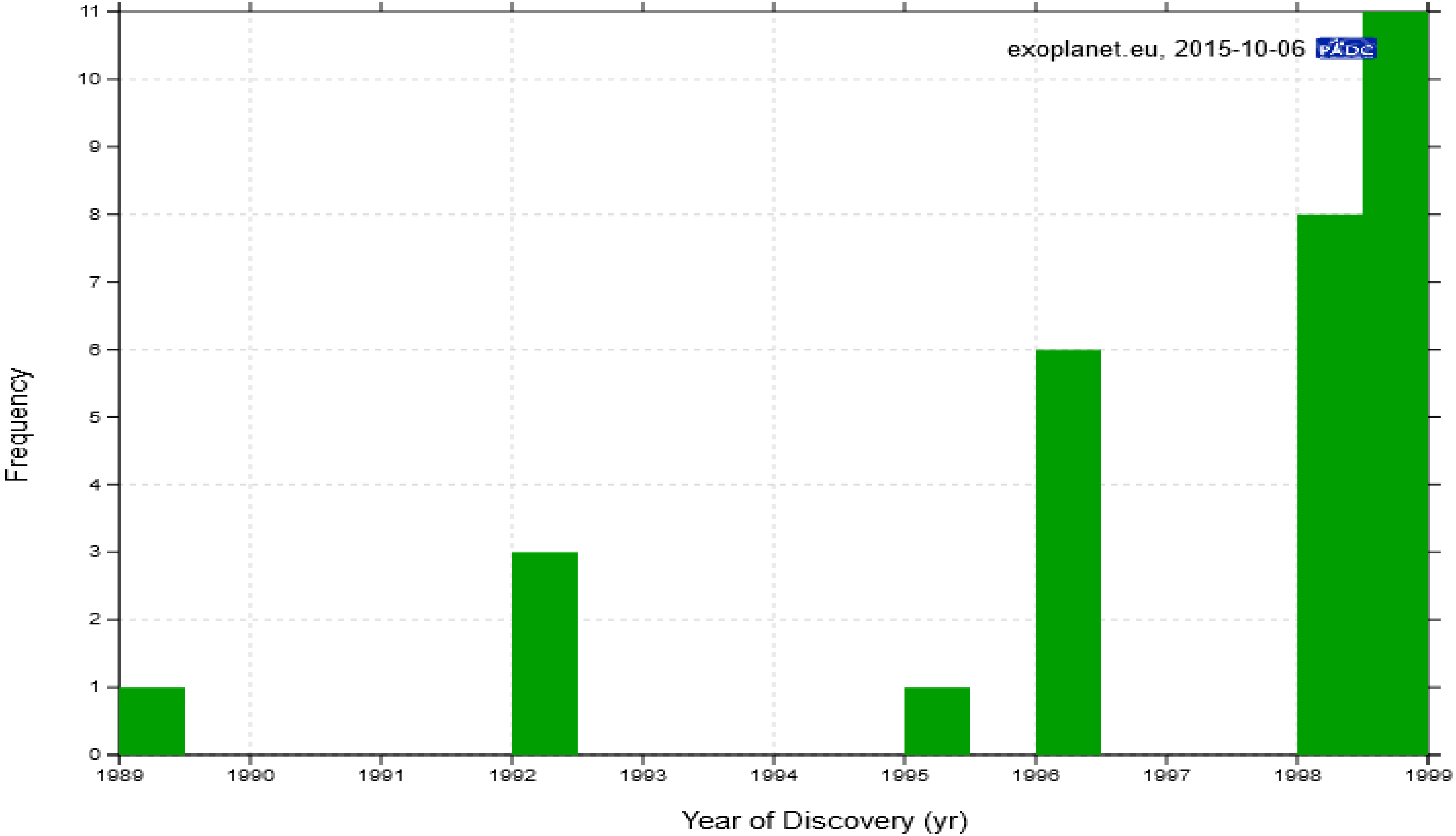


Image from Keele University

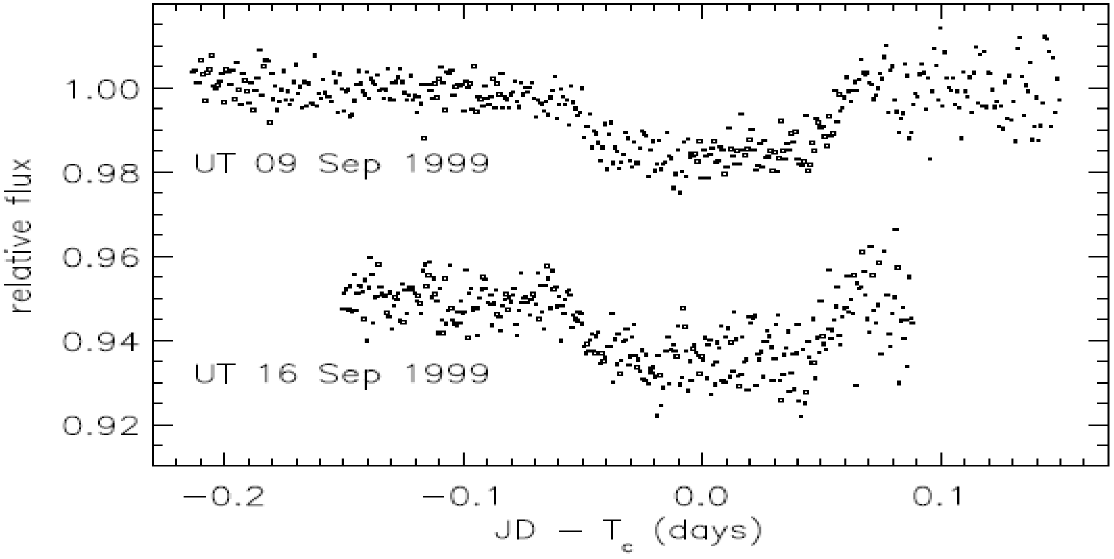
RV surveys and planet types

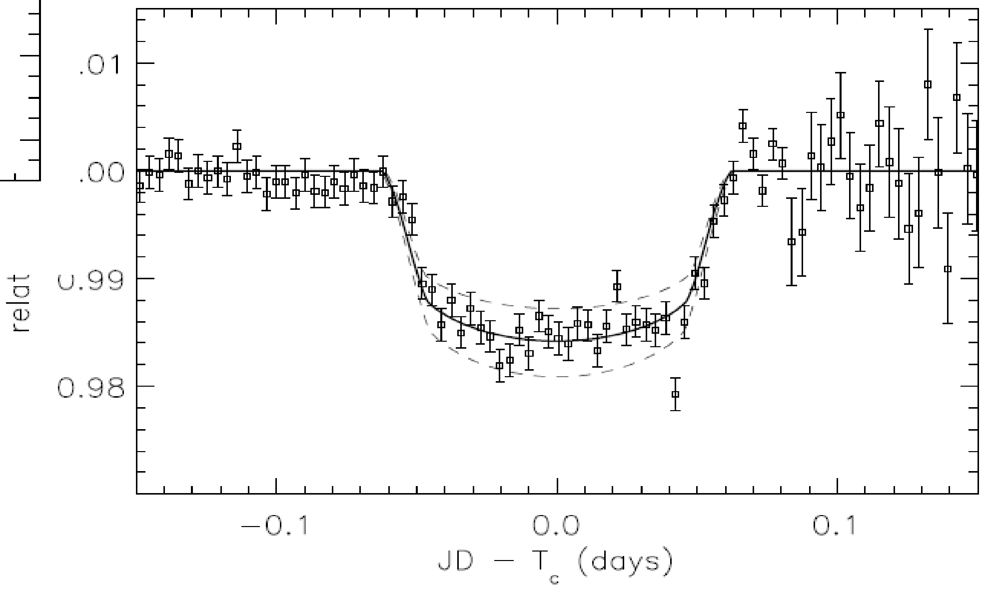
- After 51 Peg Radial velocity surveys begin to report new planets
- Mostly they are so-called hot-Jupiters a new class of planets – close to the host, hot, Jupiter-sized, short orbital period
- How did they get so close to the host star?
- What is the composition of their atmosphere?
- How common are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

Exoplanets in 2000



When the planet eclipses its star

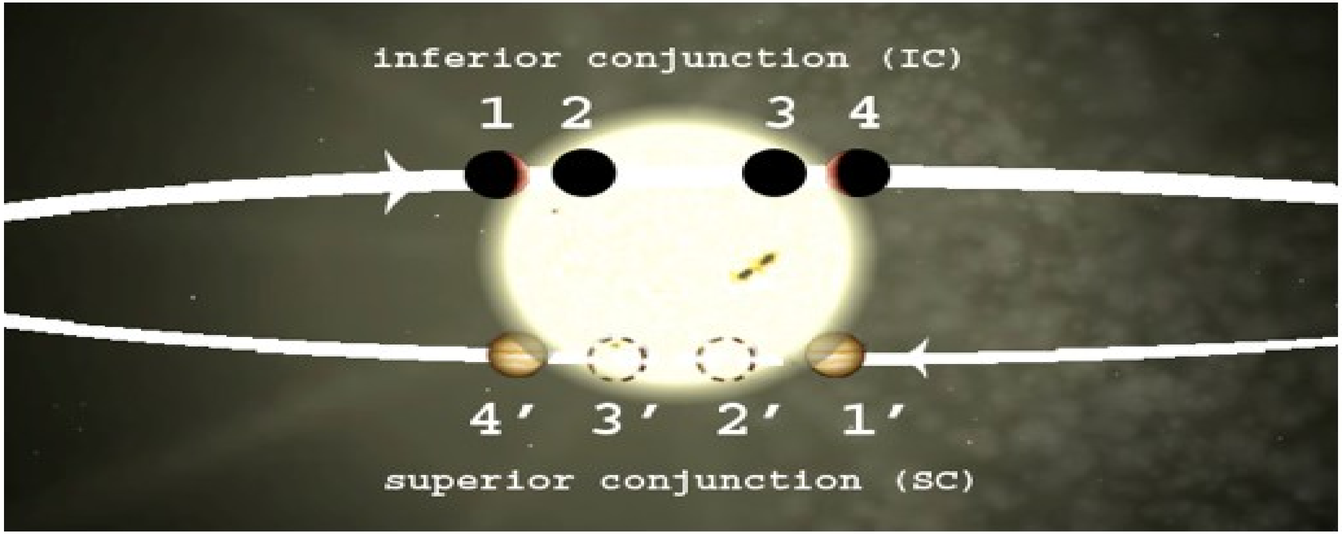




HD209458b

Charbonneau et al. 2000

Eclipses/transits



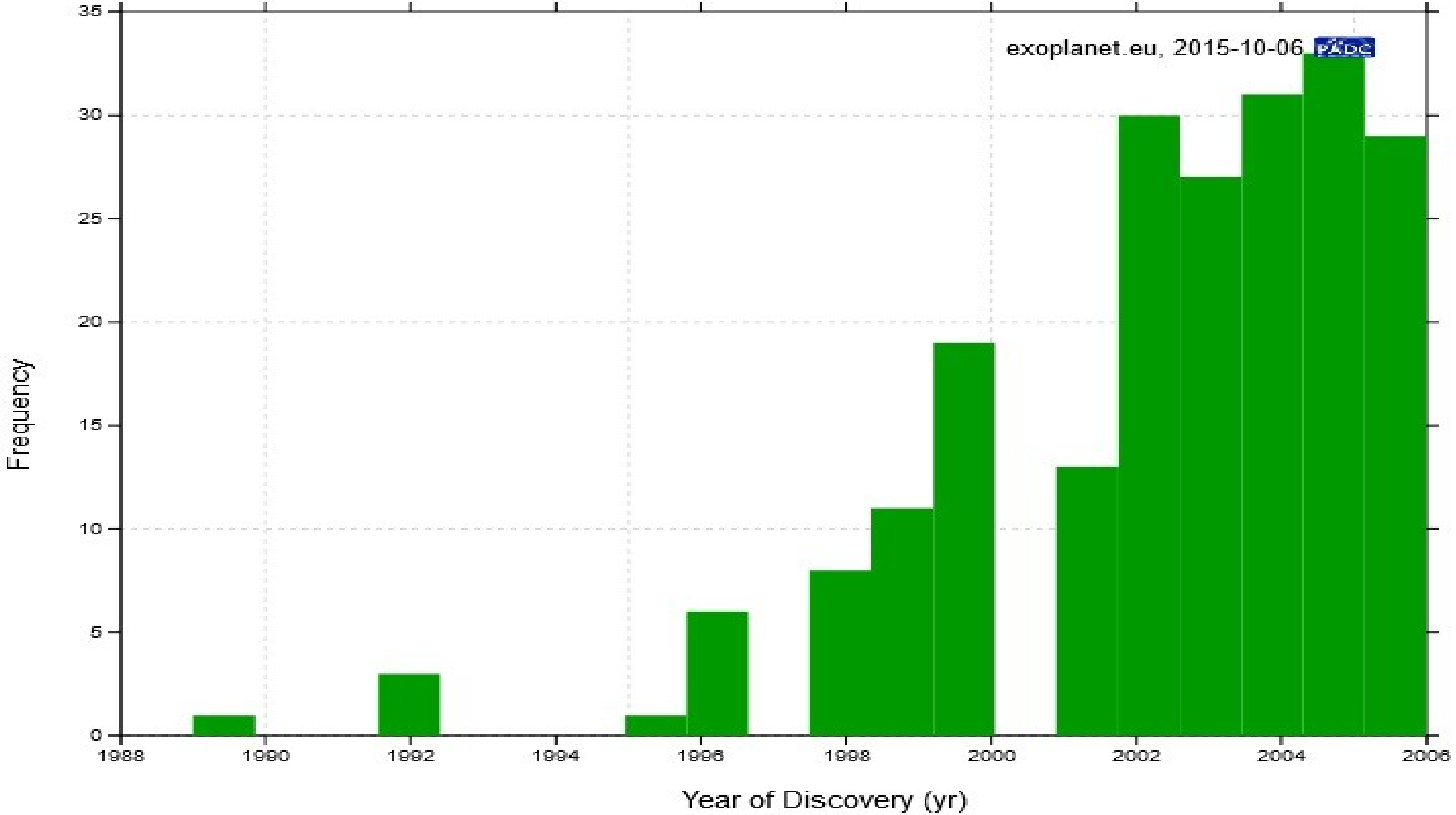
From Angerhausen et al. 2008

Transit Properties of Solar System Objects

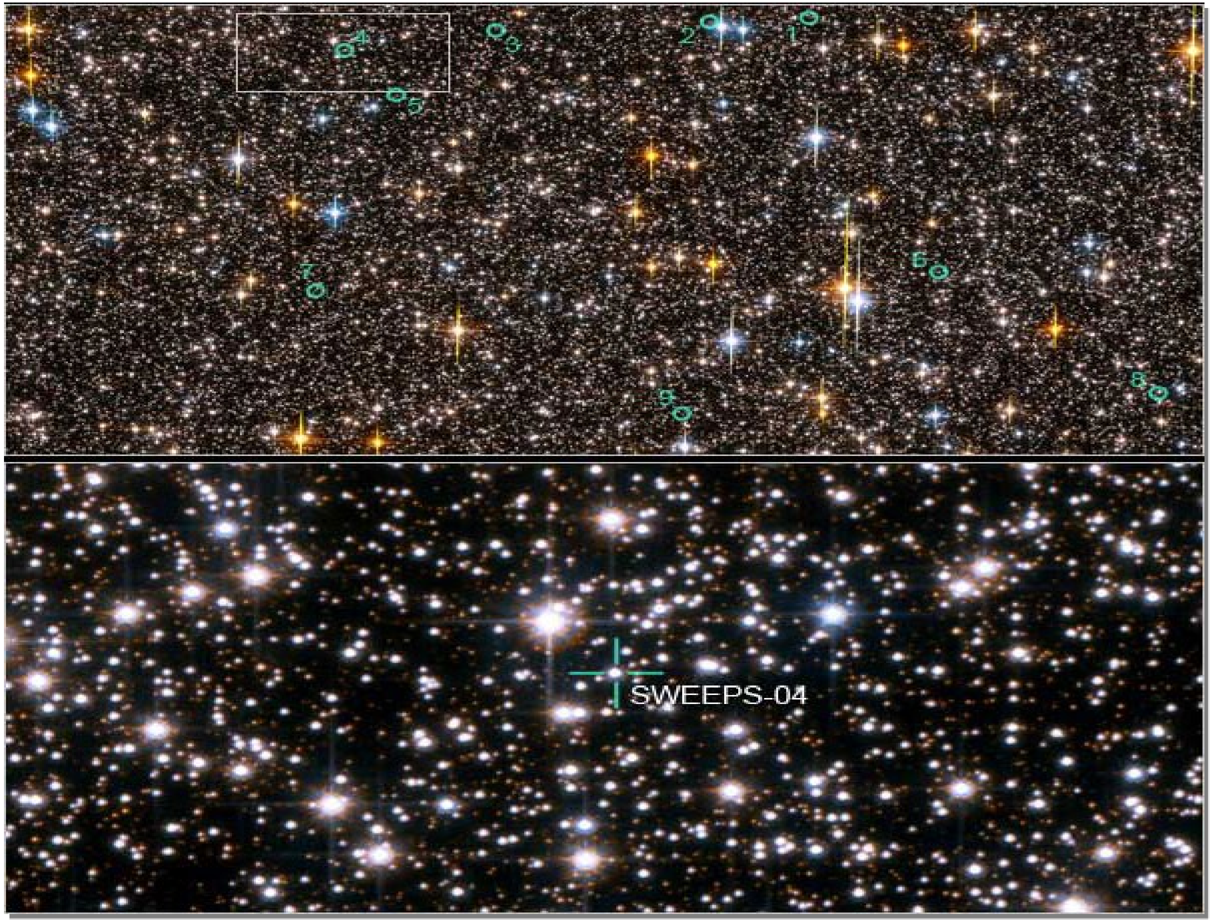
Planet	Orbital Period P (years)	Semi-Major Axis a (A.U.)	Transit Duration (hours)	Transit Depth (%)	Geometric Probability (%)	Inclination Invariant Plane (deg)
Mercury	0.241	0.39	8.1	0.0012	1.19	6.33
Venus	0.615	0.72	11.0	0.0076	0.65	2.16
Earth	1.000	1.00	13.0	0.0084	0.47	1.65
Mars	1.880	1.52	16.0	0.0024	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

How many stars do have planets? (2006)



OBSERVE AS MANY STAR AS POSSIBLE TO FIND TRANSITS



NASA web

Space missions

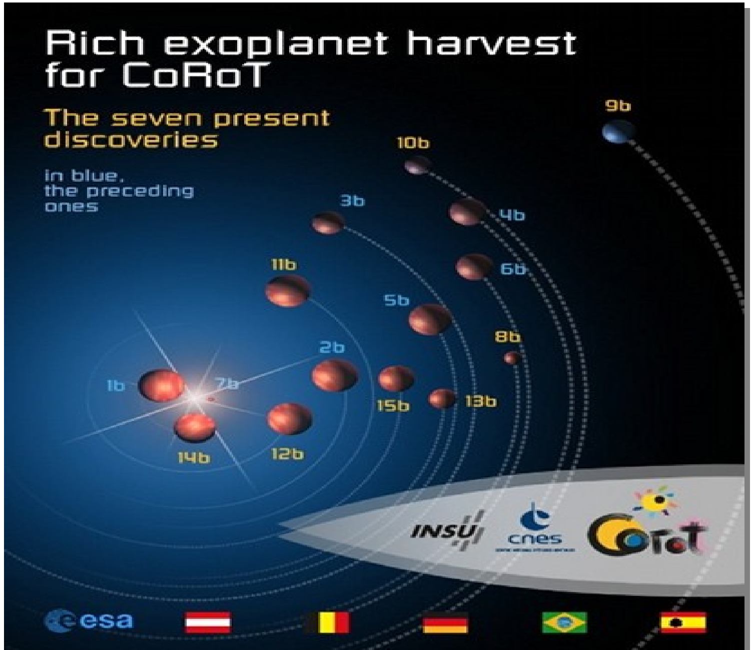
CoRoT

Convection, Rotation and planetary Transits

Launched 2006 – mission end 2013

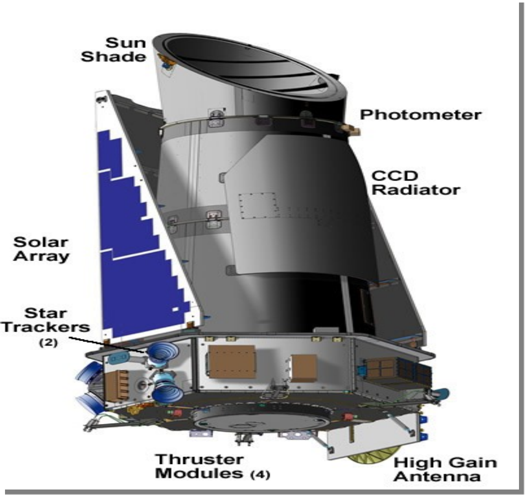
28cm mirror, 4 detectors of 1,5x1,5deg

ESA webpages



Kepler

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



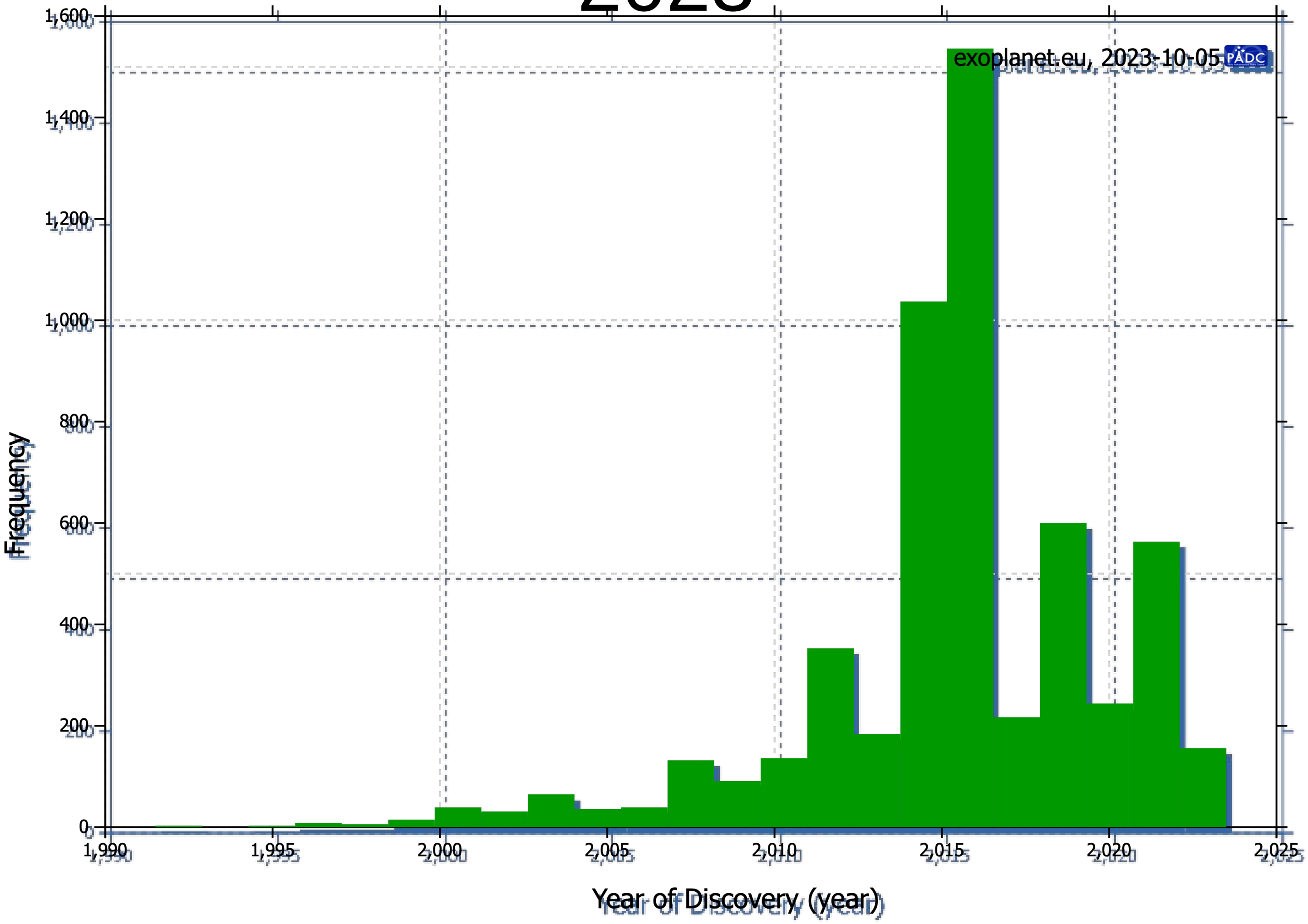
Monitored 100k stars in Cygnus

Detected more than 3000 confirmed planets

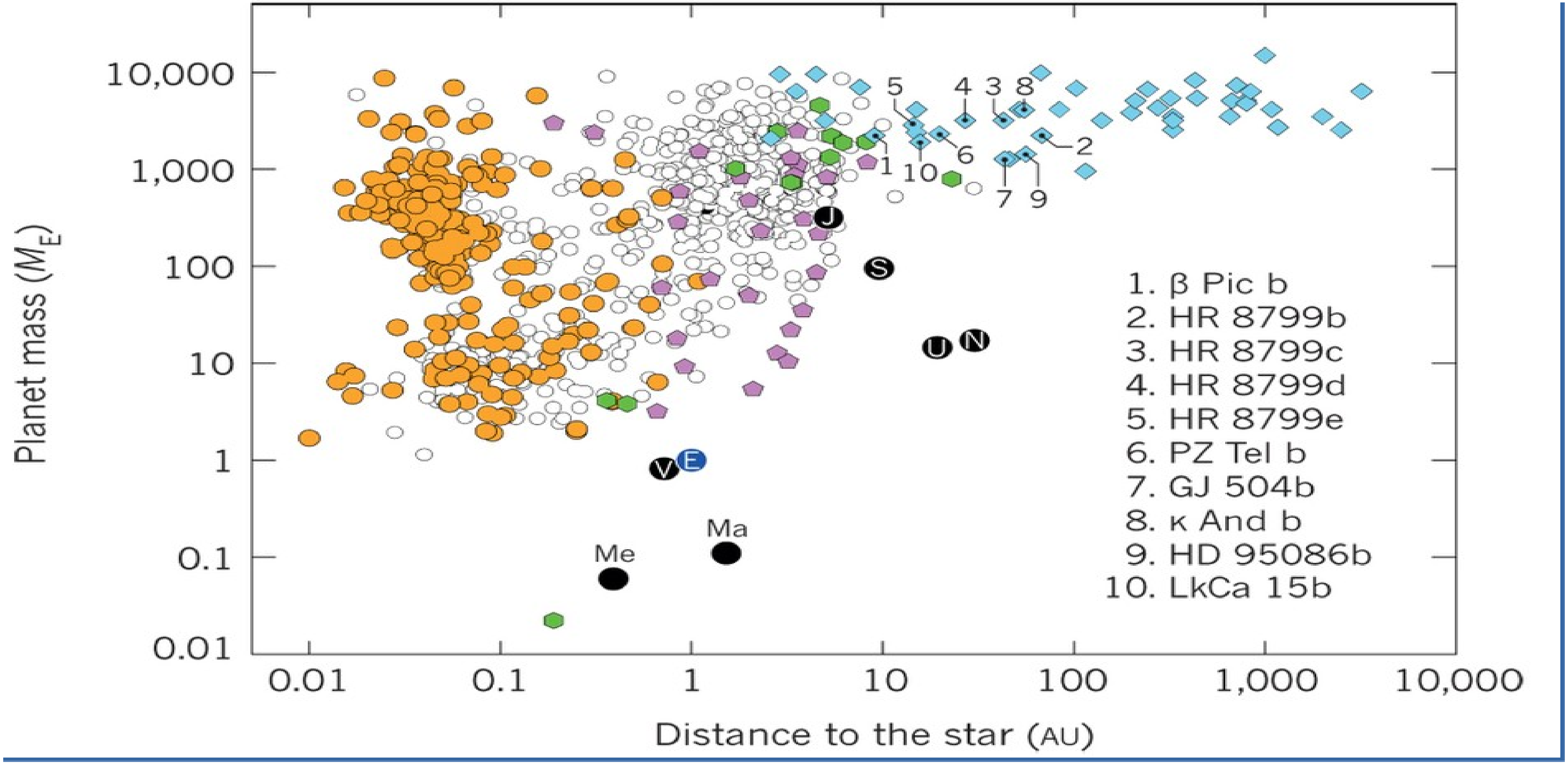
Kepler webpage - http://kepler.nasa.gov/

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

2023

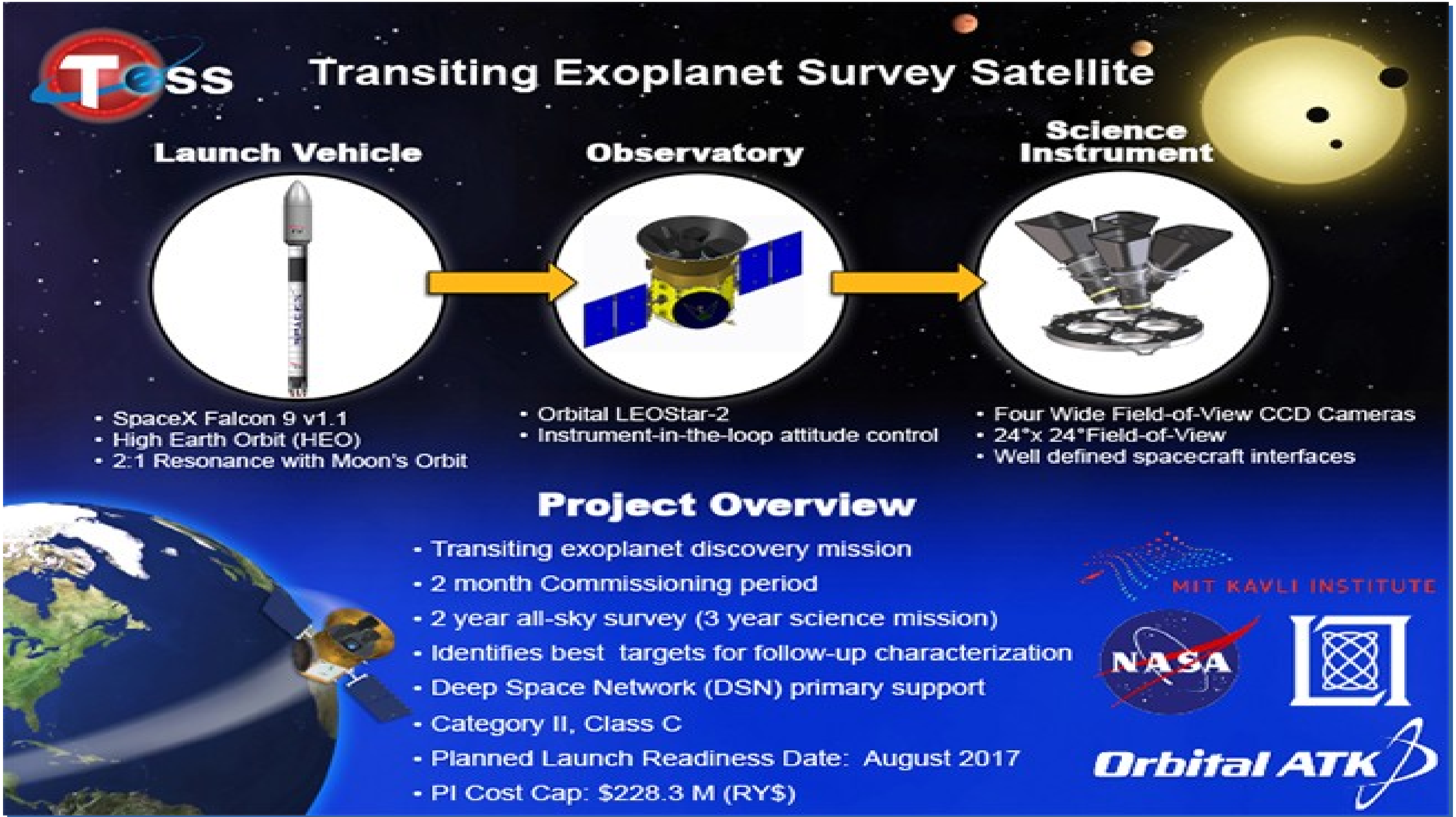


exoplanet.eu, 2023-10-05
PADC
Frequency
1,600
1,400
1,200
1,000
800
600
400
200
0
1,990
1,995
2,000
2,005
2,010
2,015
2,020
2,025
Year of Discovery (year)



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

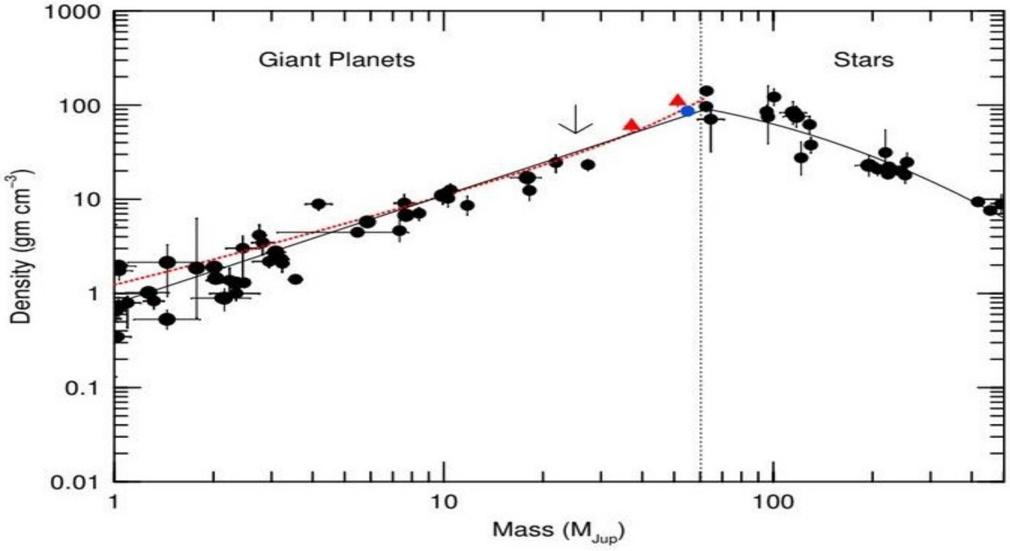
TESS

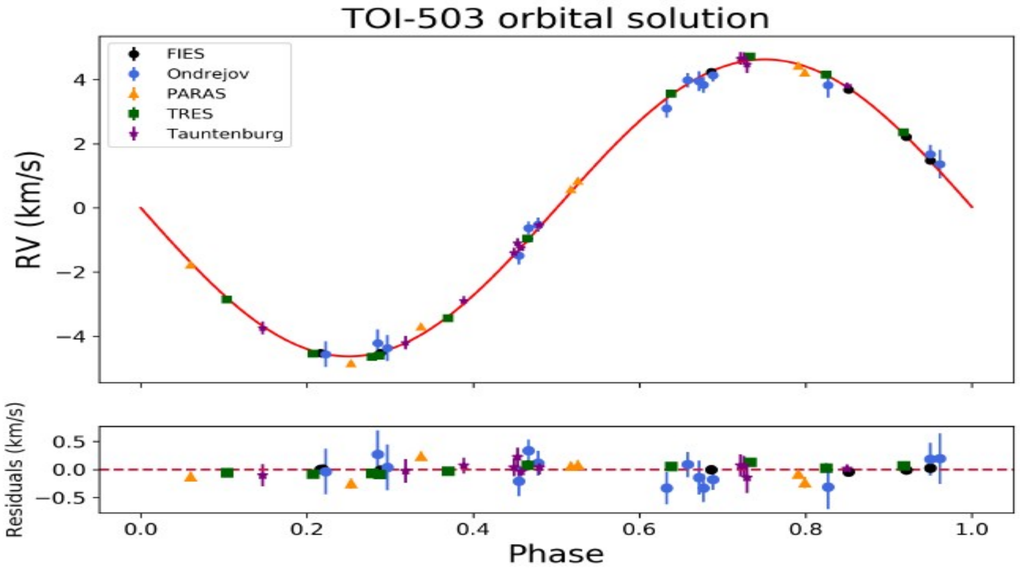


TESS
Transiting Exoplanet Survey Satellite
Launch Vehicle
Observatory
Science Instrument
• SpaceX Falcon 9 v1.1
• High Earth Orbit (HEO)
• 2:1 Resonance with Moon's Orbit
• Orbital LEOStar-2
• Instrument-in-the-loop attitude control
• Four Wide Field-of-View CCD Cameras
• 24°x 24°Field-of-View
• Well 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

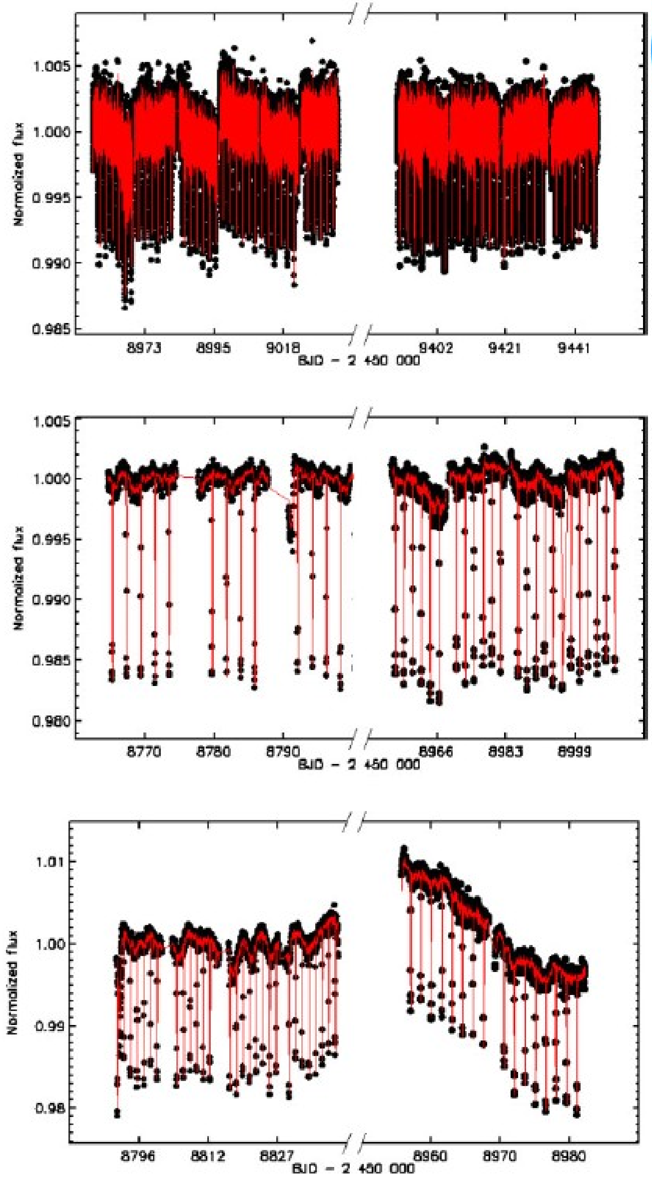
Our TESS targets

- TOI-1181

  sectors 14-26 and 40
- TOI-1516

  sectors: 17,18,24,25
- TOI29046

  sectors: 18, 19, 24, 25



Observatories involved

- Photometry:

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

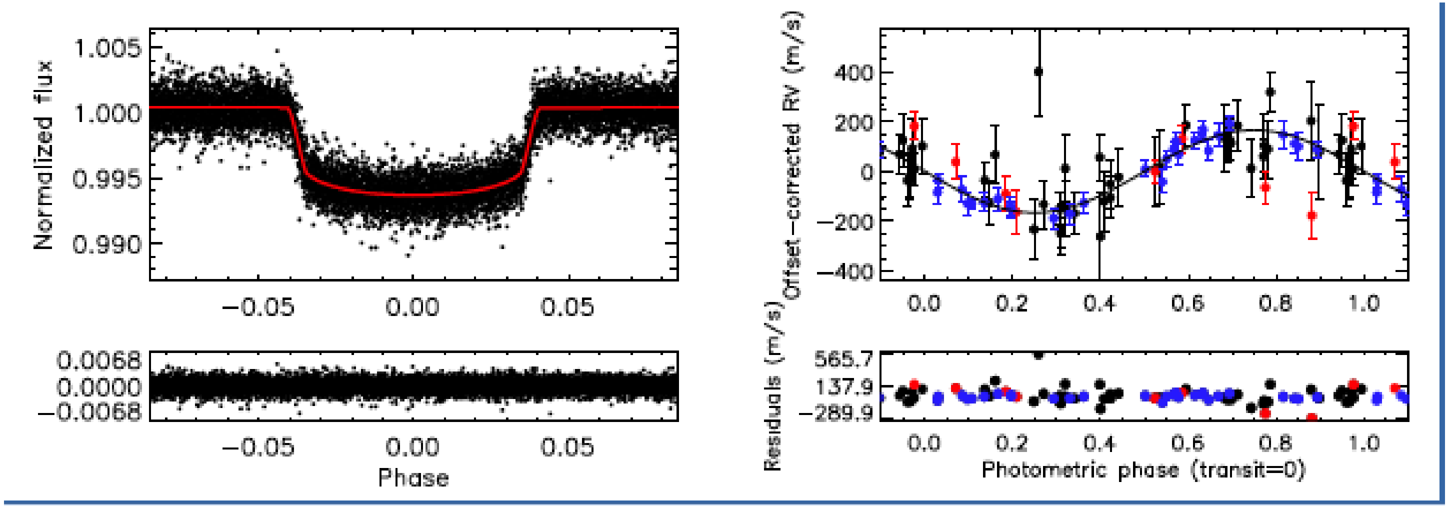
  Gemini North (USA)

- Spectroscopy:

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

TOI-1181b

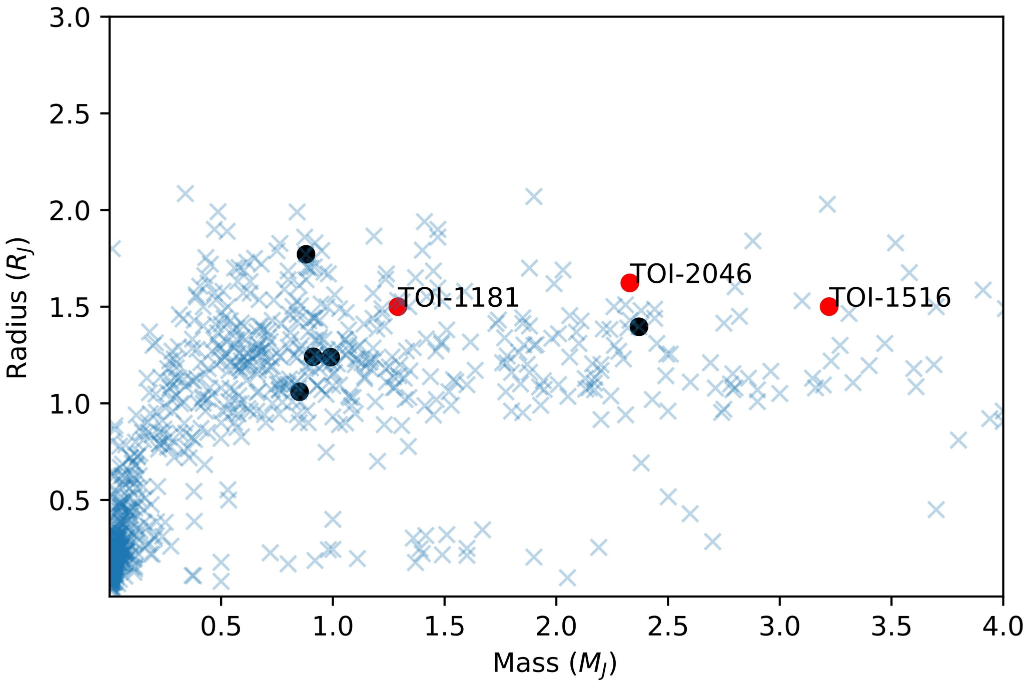
- A hot Jupiter around a F subgiant star
- Period 2.1 days
- Radius 1.3 $R_{Jupiter}$ and Mass 1.18 $M_{Jupiter}$



From Kabath et al. 2022 MNRAS,

General characteristics

- Mass-Radius diagram



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

Plato Space mission

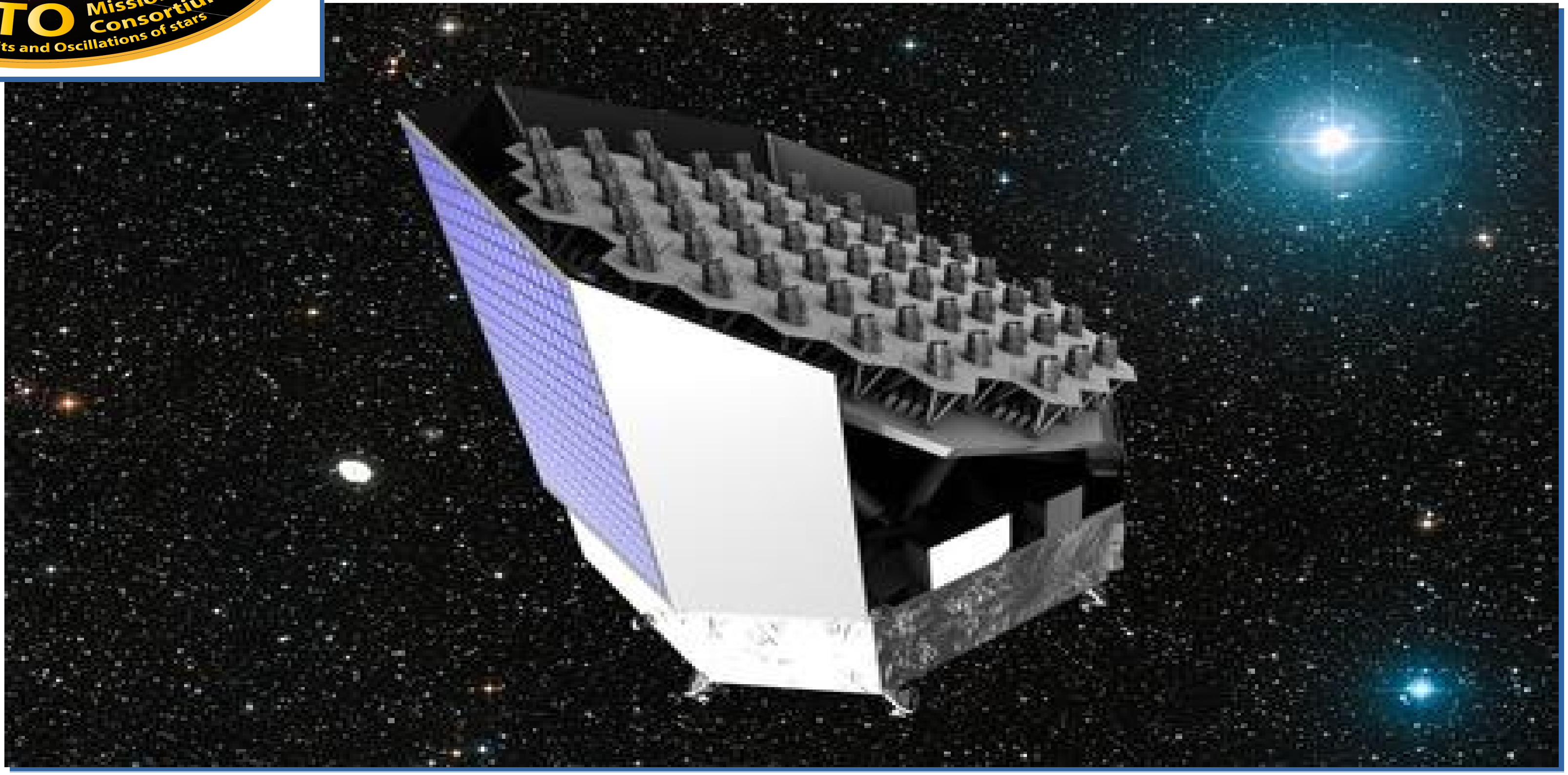
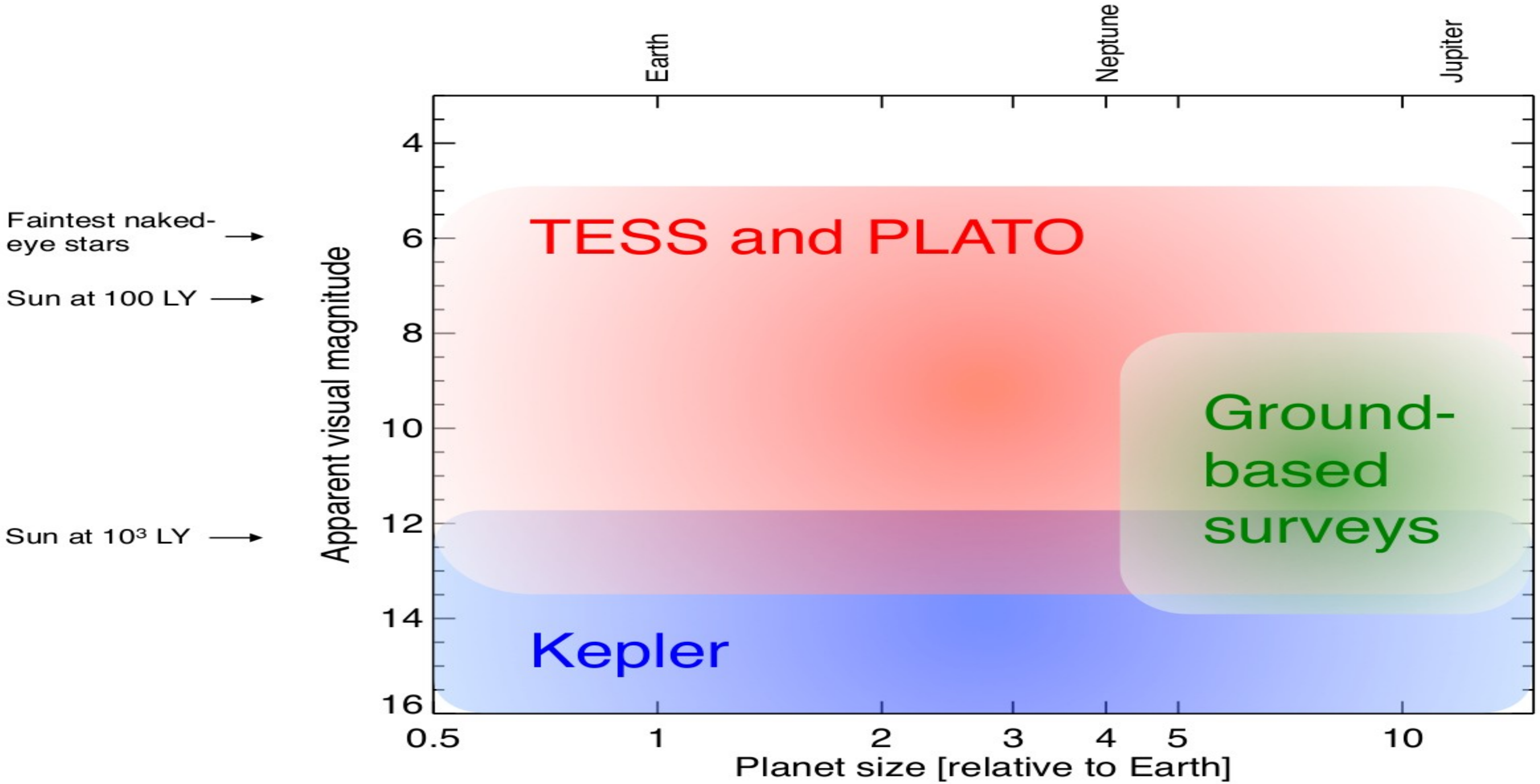
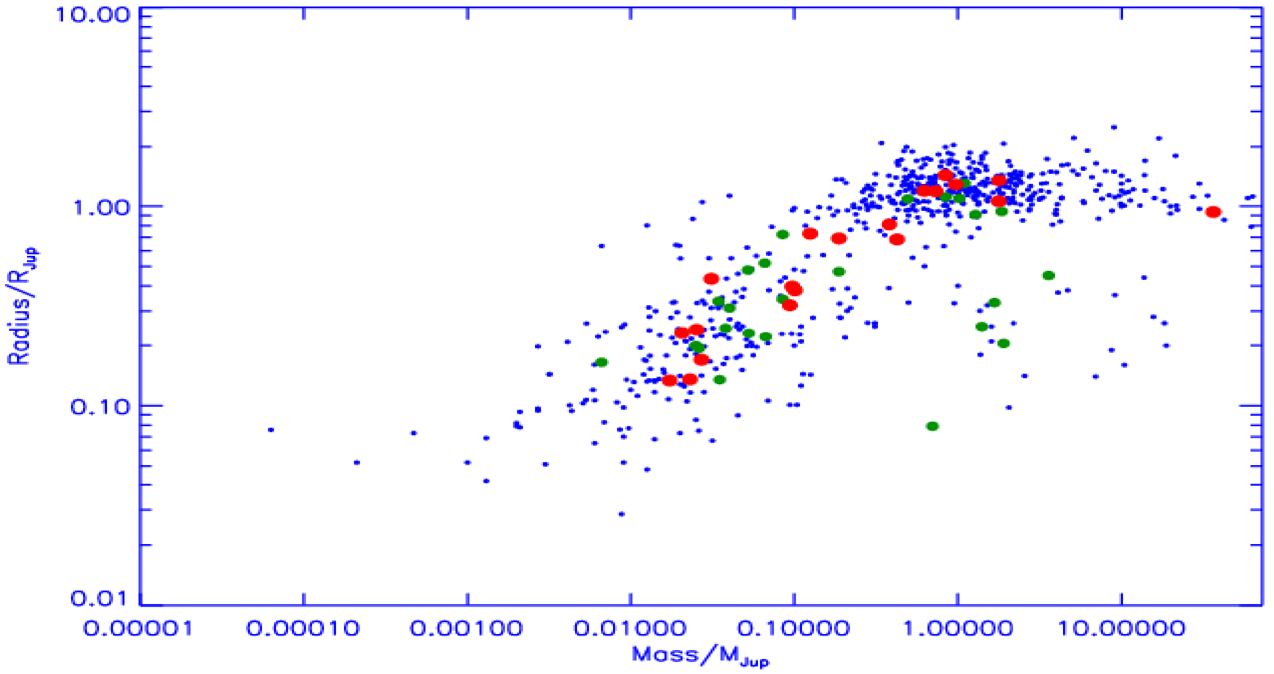


Fig.1: *PLATO Space mission is the motivation for PLATOSpec. PLATO will need large amount of ground based support. Credit: Thales Alenia Space*

Space missions compared



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



Sep. 2017 – approx. 120 K2 planets

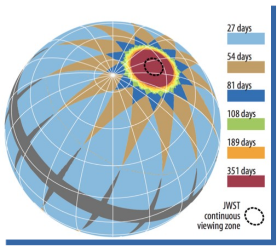
Blue – all planets 4000
Green – K2 planets (40)
Red – KESPRINT (21)

Csizmadia et al. 2017

Csizmadia et al. Plato mission conference 2017

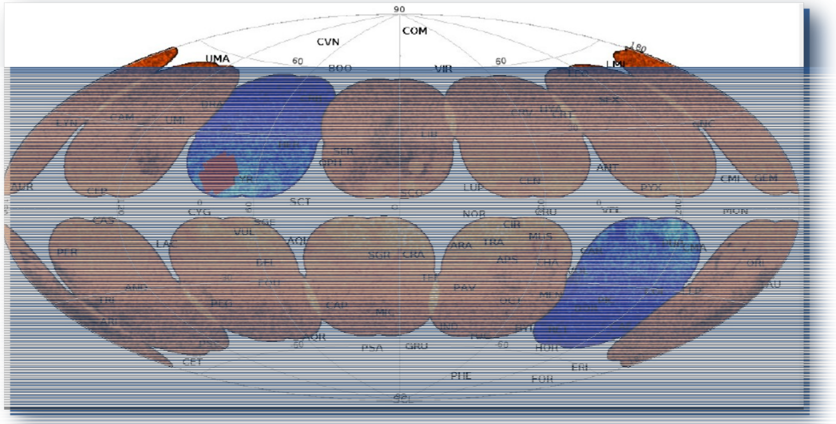
Space missions and detection of exoplanets

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



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

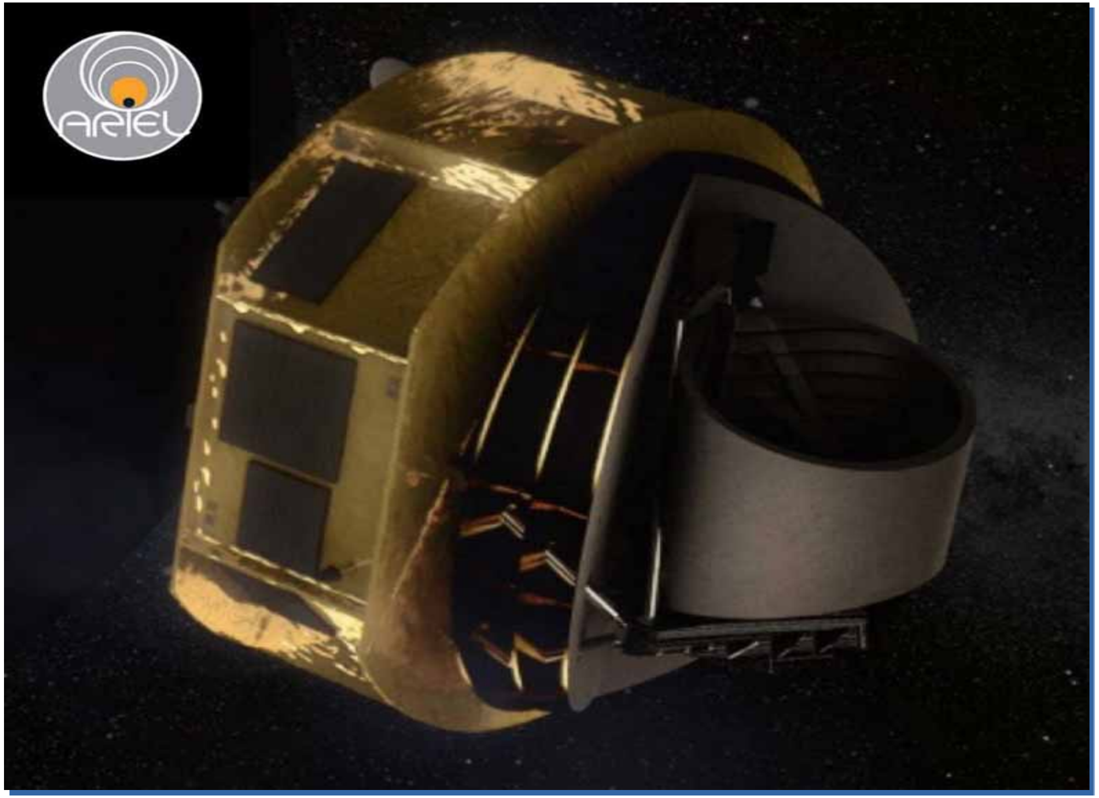
- PLATO – monitoring of 1milion stars sample



From https://platomission.com

Ariel – detection of exo-atmospheres

- Spectrograph to detect and characterise exoplanetary atmospheres
- Mainly giant planets and mini-Neptunes but perhaps also SuperEarths
- Launch after 2029



Elliptical primary mirror:Â 1.1 x 0.7 metres

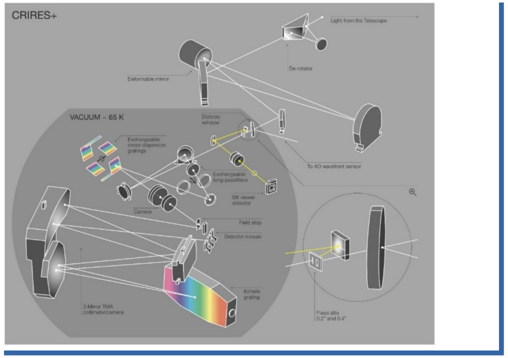
So do we need new spectrographs (on ground and in space)?

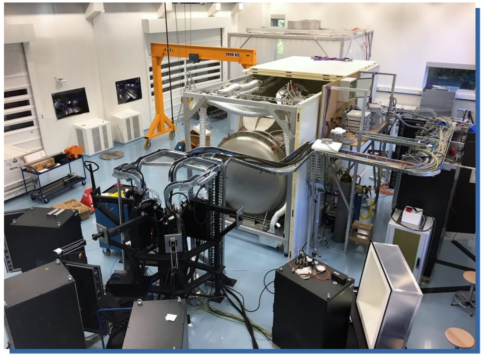
State of the art (just a few examples)

- Many new instruments start operations

  - ESPRESSO

  - CRIRES+

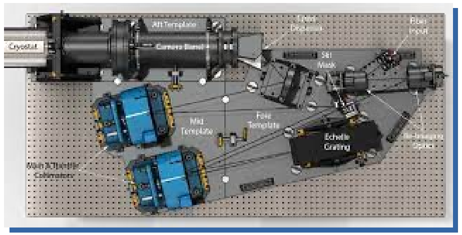




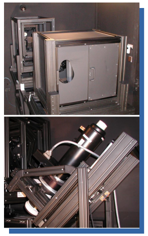
Images from www.eso.org

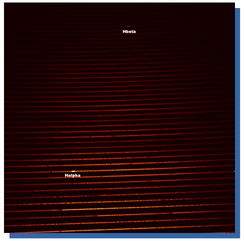
- But not so many coordinated on the 1-2m aperture telescopes

Sophie at OHP
Imag web OHP



Vilnius echelle -
https://arxiv.org/pdf/1601.06024.pdf





OES/TCES -
Ondrejov/Tautenburg

Stellar parameters

- We need to obtain stellar parameters:

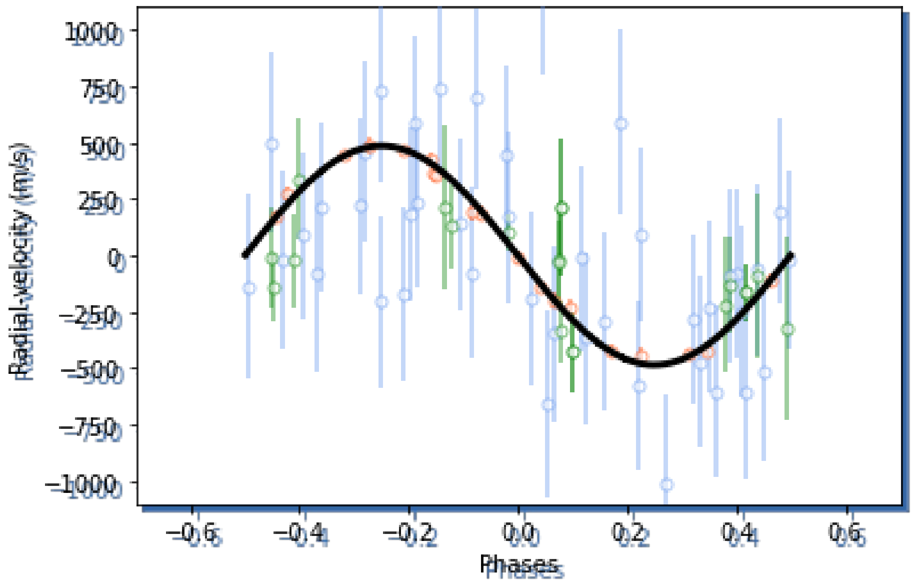
  Temperature, surface gravity, metallicity
- Each star needs about two spectra (might take up to 15 minutes each)

Stellar parameters				
$T_{\rm eff}$ [K]	Tull	6260 ± 100	6420 ± 100	6160 ± 100
$T_{\rm eff}$ [K]	iSpec OES/TCES	5990 ± 95	6520 ± 90	6250 ± 140
$T_{\rm eff}$ [K]	TRES	6177 ± 50	6170 ± 52	6143 ± 97
log g [cgs]	Tull	4.31 ± 0.18	4.25 ± 0.18	4.38 ± 0.18
log g [cgs]	iSpec OES/TCES	3.9 ± 0.15	4.25 ± 0.15	4.3 ± 0.15
log g [cgs]	TRES	4.27 ± 0.08	4.18 ± 0.22	4.35 ± 0.08
Fe/H [dex]	Tull	0.30 ± 0.12	−0.14 ± 0.12	0.04 ± 0.12
Fe/H [dex]	iSpec OES/TCES	0.05 ± 0.1	-0.05 ± 0.1	-0.06 ± 0.15
Fe/H [dex]	TRES	0.44 ± 0.08	-0.05 ± 0.1	0.29 ± 0.08
$v_{\rm sini}$ [km/s]	Tull	10.77 ± 0.30	11 ± 0.4	8.15 ± 0.15
$v_{\rm sini}$ [km/s]	iSpec OES/TCES	10.2 ± 1.5	11.8 ± 1.5	9.8 ± 1.6
$v_{\rm sini}$ [km/s]	TRES	11.8 ± 2.0	13.8 ± 2.0	8.8 ± 2.0

Precise radial velocities

- Characterization of gas giants
- About a minimum of 10-15 RV points needed
- This translates in about

  30 mins x objects x 15
- 1 object about 1 night!!
- Long periodic warm and cold gas planets, even more challenging!



The role of 1-2-m class telescopes

- Precise determination of stellar parameters
- False positives elimination
- Characterization of gas giants (mass, radius)
- For some limited target group, perhaps atmospheric characterization possible
- Proprietary telescope time = lots of observing time!

The PLATOSpec Consortium

- Astronomical Institute of Cz. Academy of Sciences - Petr Kabath (PI)
- Thüringer Landessternwarte Tautenburg - Artie Hatzes
- Universidad Católica de Chile - Leo Vanzi
- Universidad Adolfo Ibanez (Chile) – Rafael Brahm
- Masarykova univerzita (CZ) – Jan Janík

PLATOSPec specs

- Sensitive in blue Ca HK
- 365 nights available
- RV measurements
  - accuracy 3-5 m/s
  - for stars 4-11 mag
  - SNR 30-40 in max.
    1 hrs (est.)
- Physics of gas giants
- Ground-based follow-up
- Long-term programs

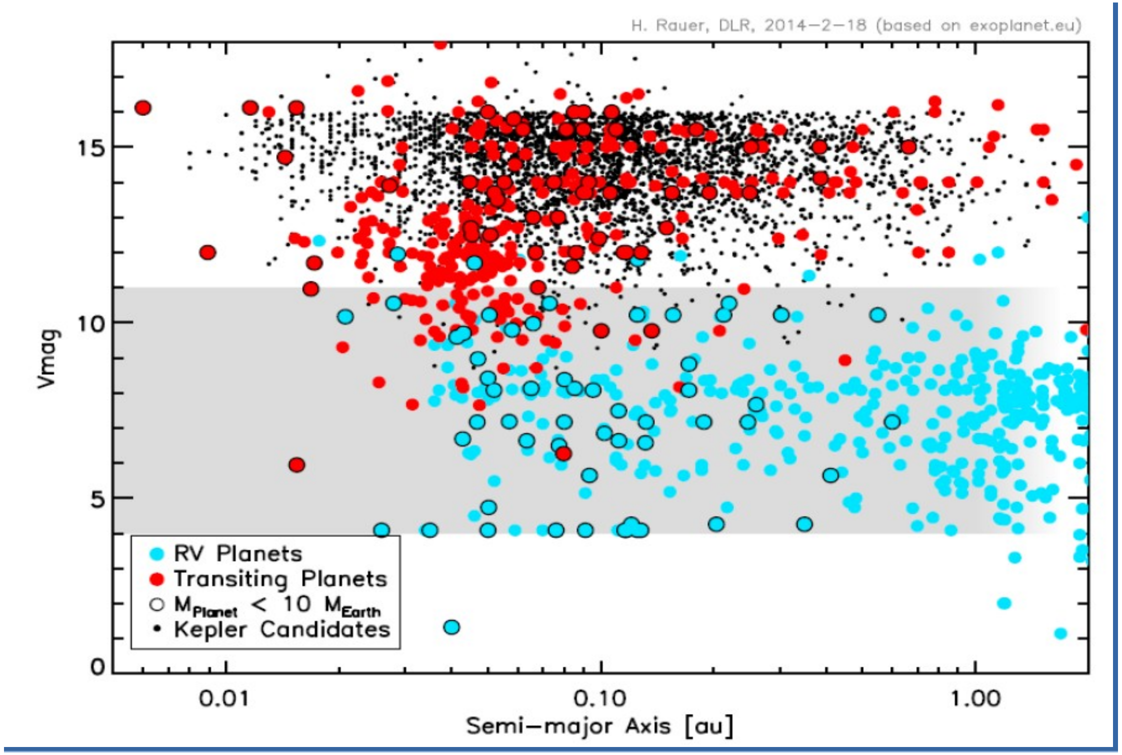
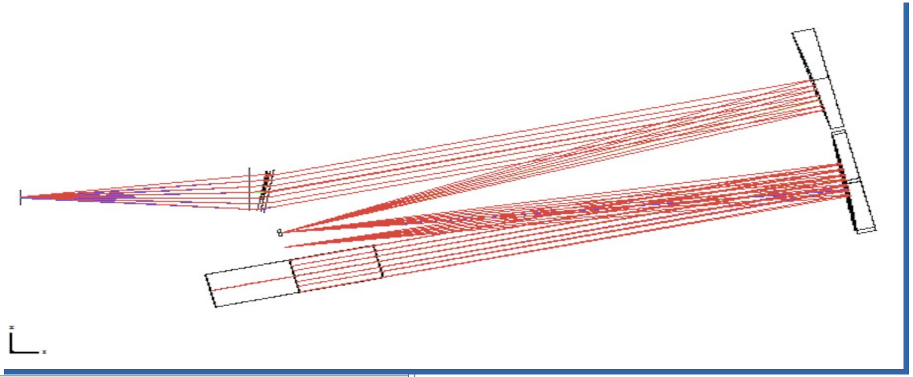


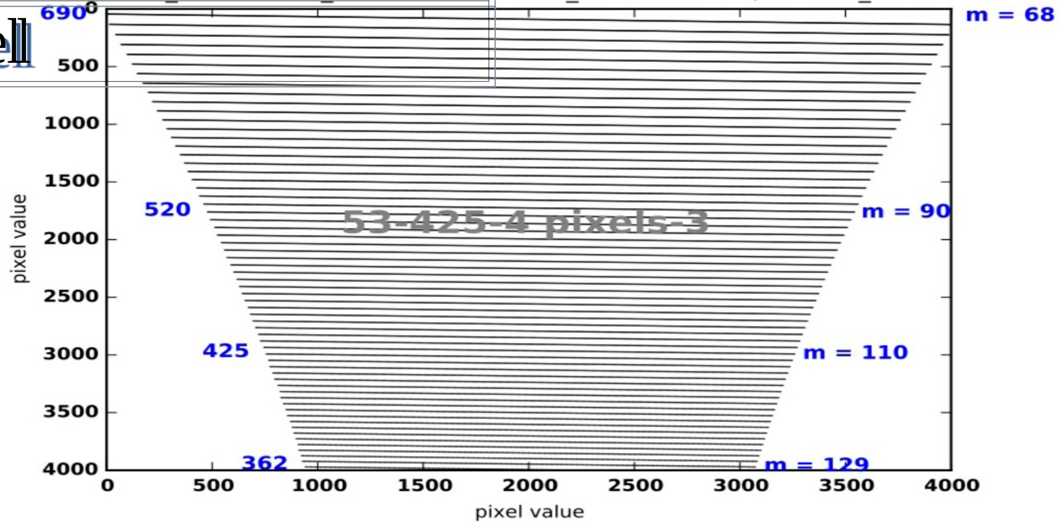
Fig. 2: *PLATO space mission will provide photometric measurements for about 1 million Stars in the grey area of the Figure. From Rauer et al. 2013*

Astronomický ústav AV ČR

The instrument

Table 1: Main paramateres of the spectrograph	
Echelle spectrograph	Parameter value
Wavelength coverage	360-680 nm
Spectral resolution	70k
Thermal stability	0.1deg
RV accuracy	3m/s
Calibration	ThAr+Iodine cell





Figures and Table from:

PLATO science justification report - ESO STC

The instrument

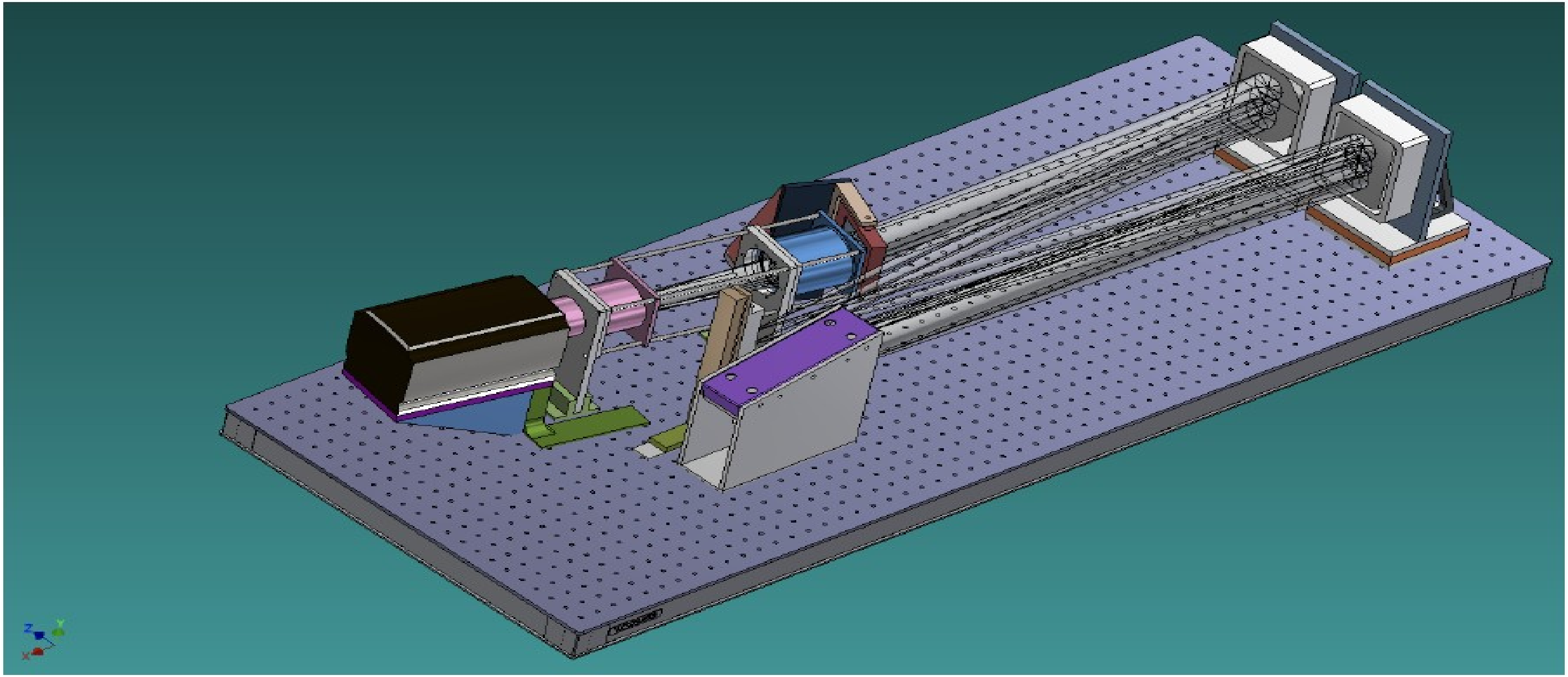


Figure from:
PLATO DR document 1.4

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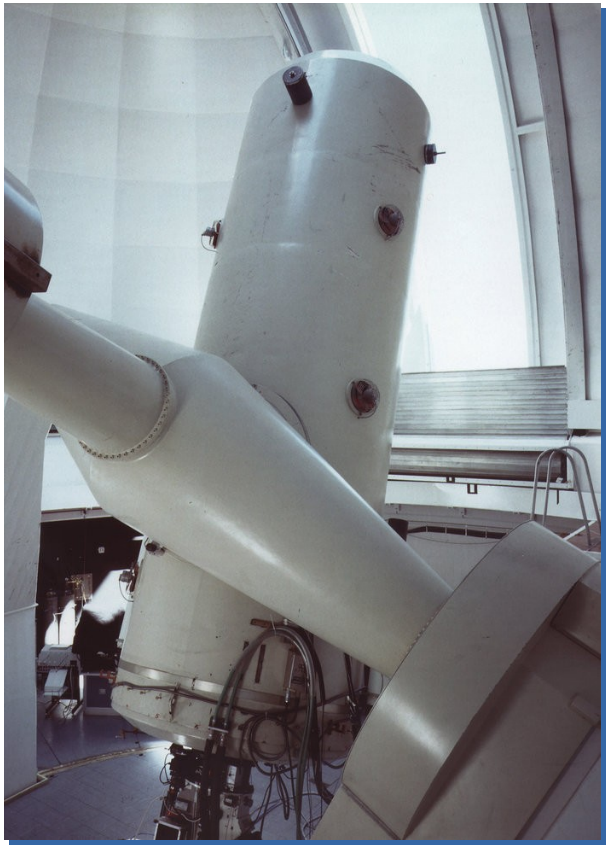
Where the lamas say good night

Foto Z. Bardon

E152 telescope

- Former ESO telescope
- Inaugurated at La Silla in 1966
- Hosted FEROS
- Telescope decommissioned in 2002
- However, the telescope was and now is in a very good shape!
- Telescope refurbished and online since 2022

E152 telescope



1.52-m former ESO telescope at La Silla

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E152 telescope

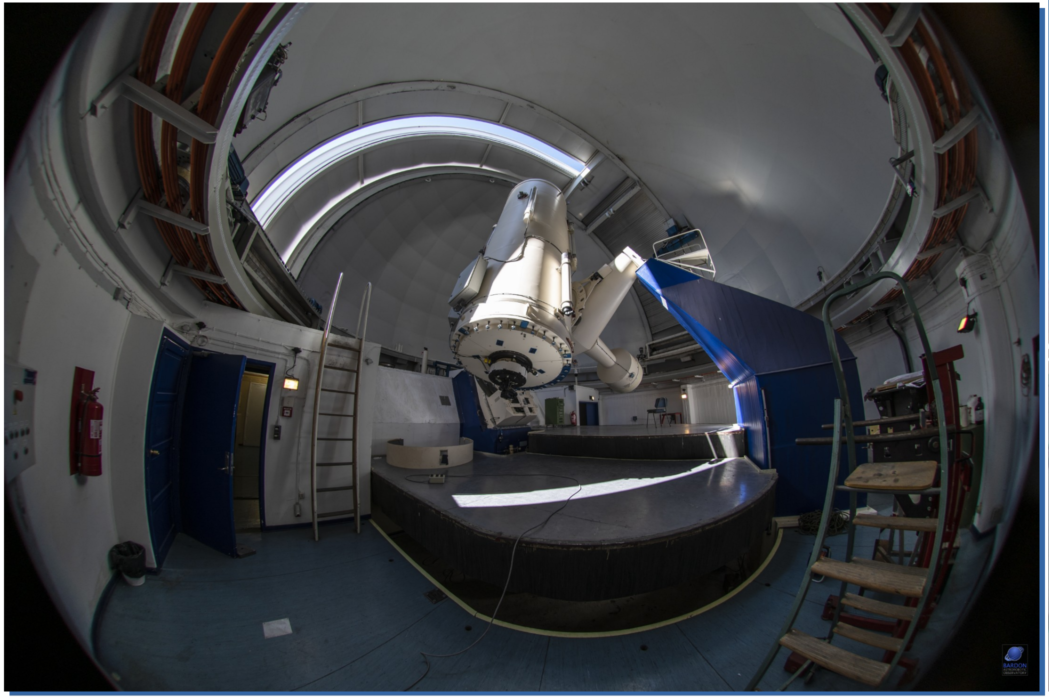
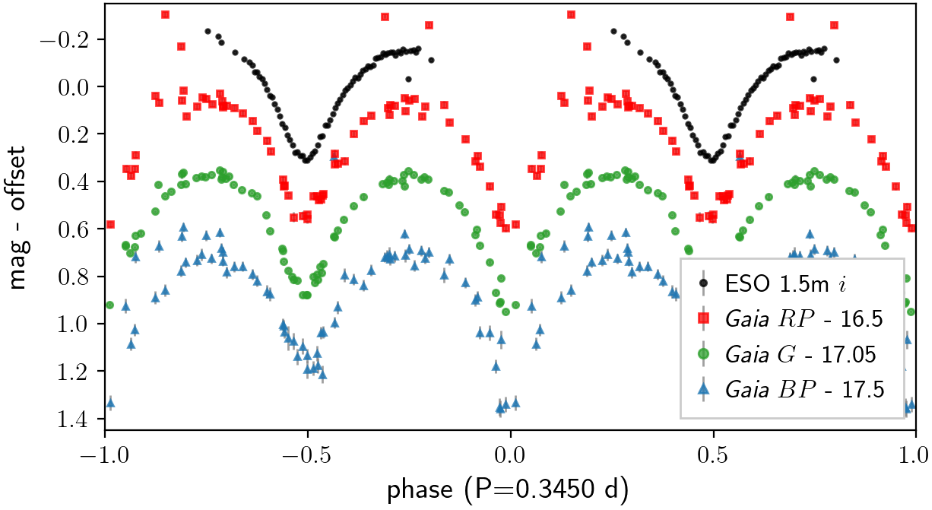


Foto Z. Bardon

1.52-m former ESO telescope at La Silla

E152 observing!!!

- Robotization finished April 2022 (ProjectSoft company)
- Since then an imager mounted and took several tens of nights
- Later simultaneous spectra and photometry will be available



Archive of D. Jones (IAC)

September 2022: PUCHEROS+

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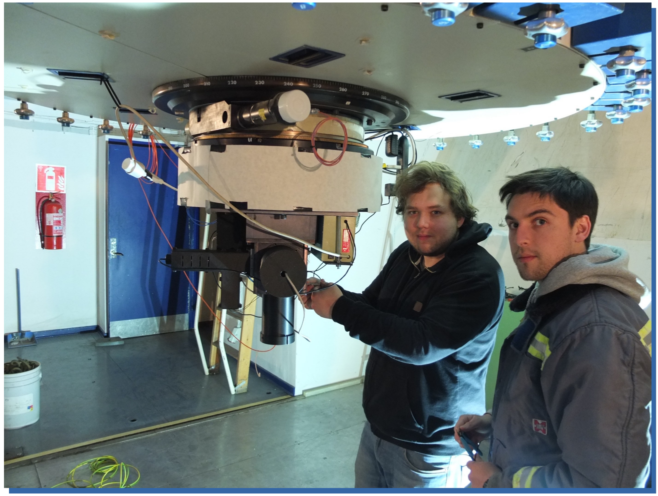
- Gap year (interim) spectrograph PUCHEROS+
- PUCHEROS is a fiber fed spectrograph with R approx. 20000
- ON SKY NOW

See Vanzi et al.

https://doi.org/10.1111/j.1365-2966.2012.21382.x



PUCHEROS+ modes offered

- **Spectroscopy (E152)**

  - echelle spectroscopy, fiber fed, ThAr non-simultaneous

  - R= approx 18000

  - wavelength range 400-700 nm

  - FOV of the autguider 1.6x1.6 arcmin approx

- **Photometry (old guider 15 cm x 2) – simultaneous w. spectroscopy**

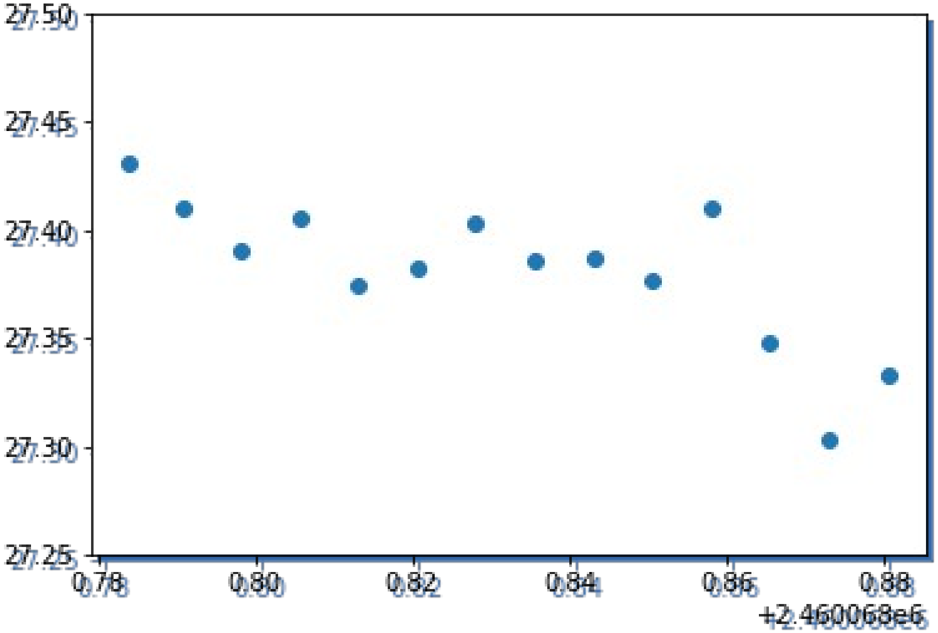
  - coaxial with E152, FOV about 1.2 deg

  - GrazCam: ugriz, prism filter (low res), focusser and rotator, GUIs under development

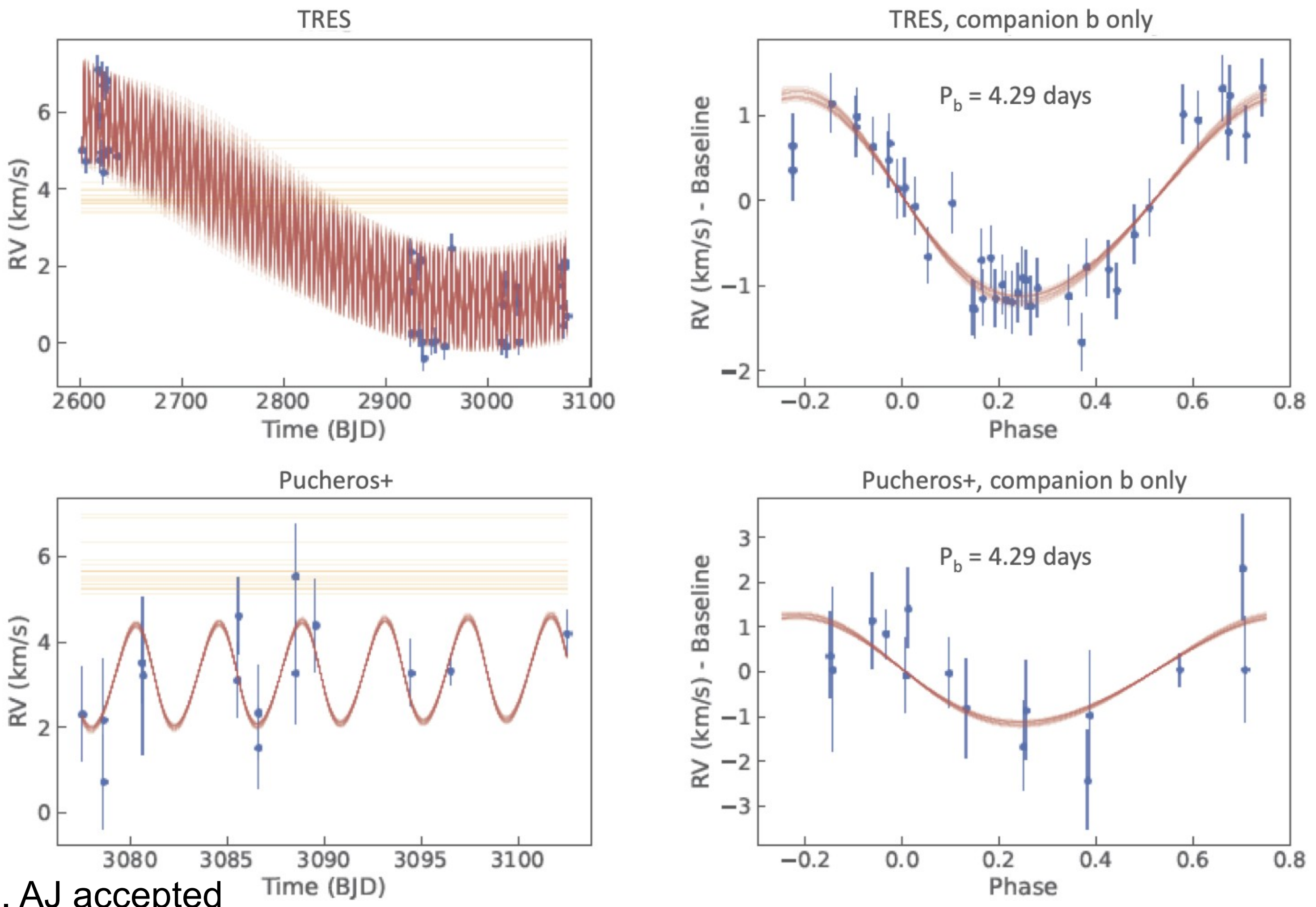
  - OnCam: ugriz, Halpha, clear, focussing unit, C4 (moravian instruments) CMOS, rapid readout, 4k by 4k, OPERATIONAL

PUCHEROS+

- HD13197 5.7 Vmag (BY Dra)
- Exp time 600 sec
- Scatter – about 30 m/s

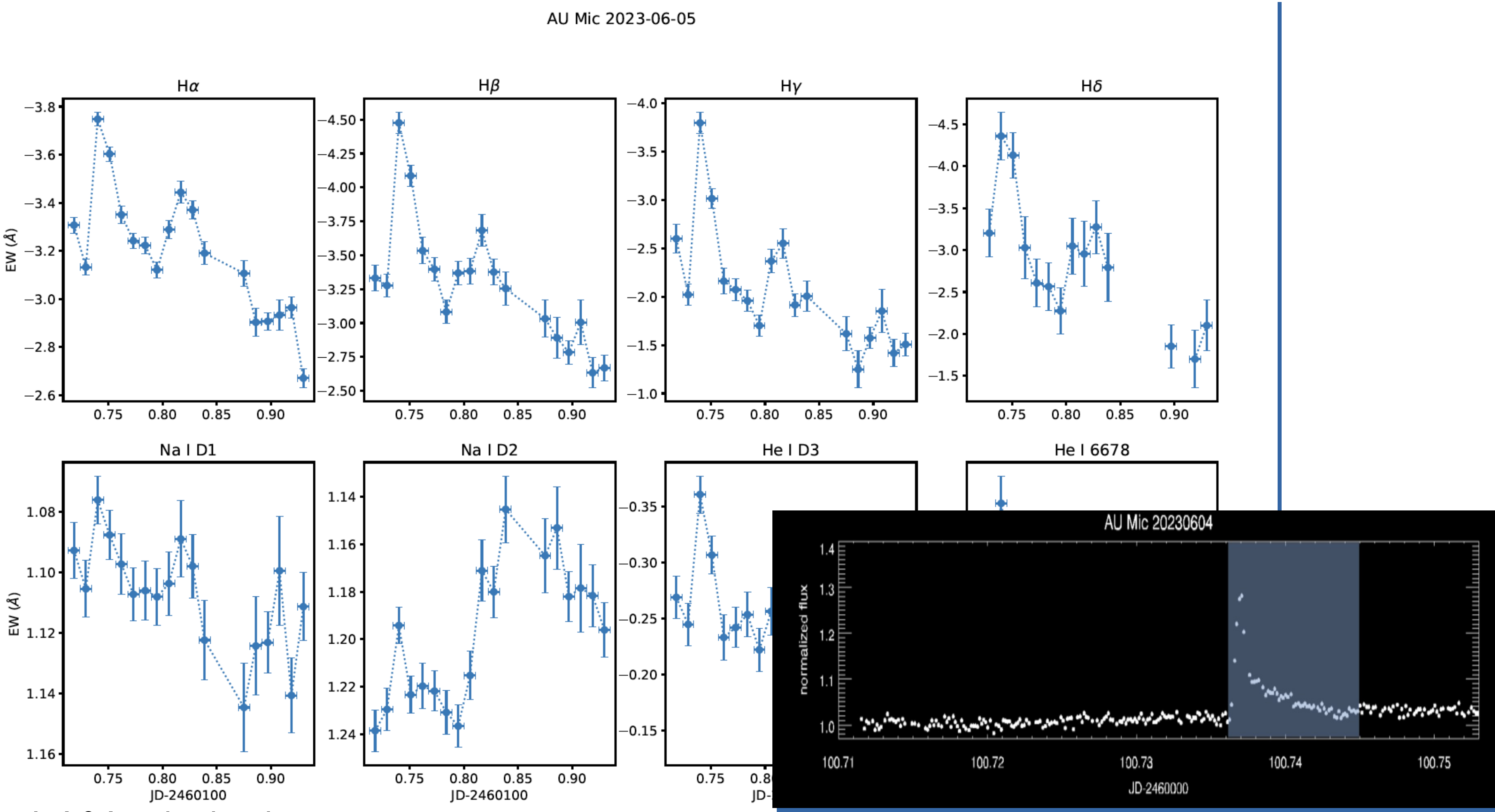


PUCHEROS+ first science

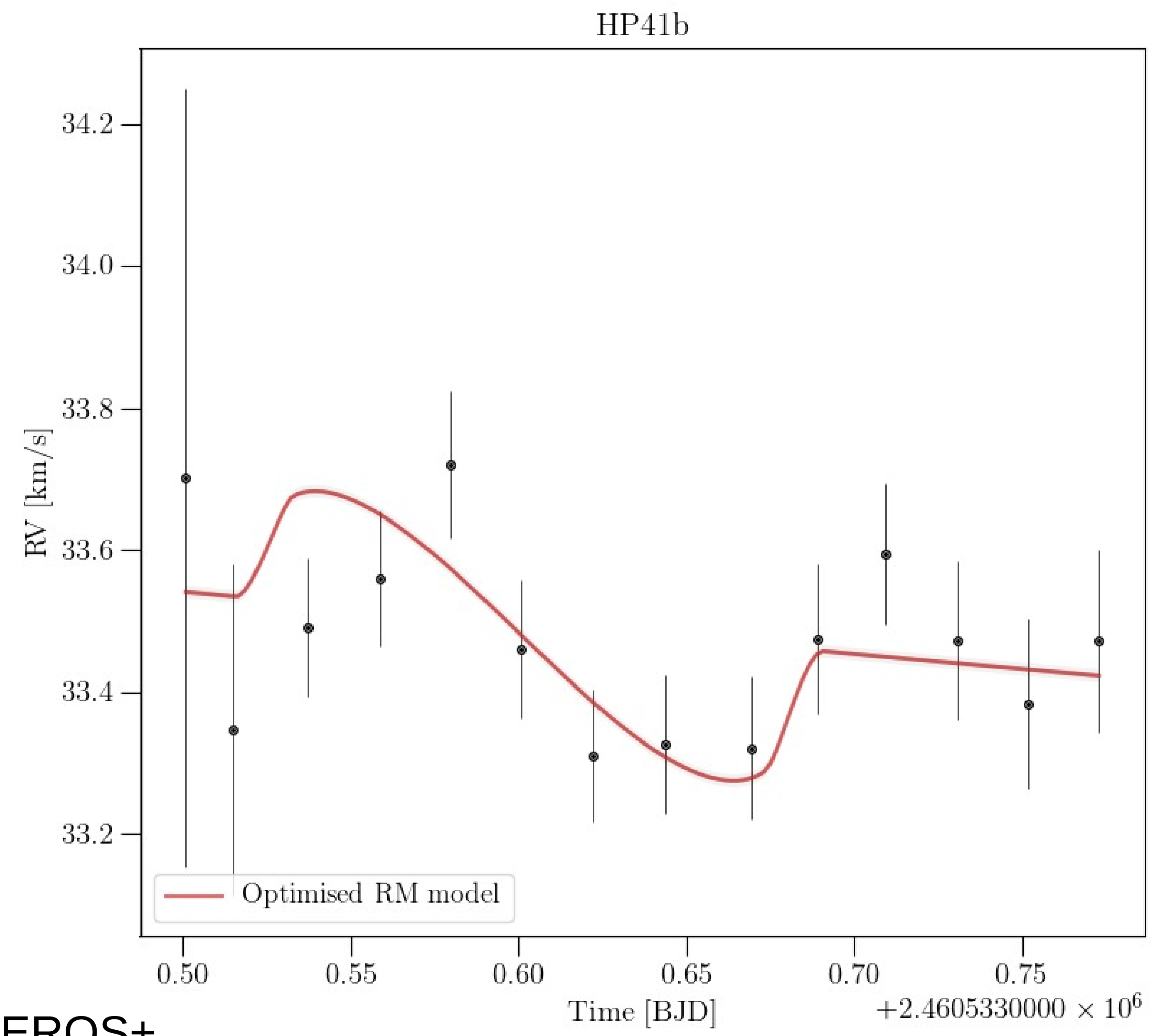


Subjak et al. AJ accepted

PUCHEROS+ first science



Odert et al. A&A submitted



Zak et al with PUCHEROS+

(Expected) performance

- PLATOSpec RV performance expected down to 3 m/s (1 m/s)
- PUCHEROS+ RV performance 20 m/s (night), 100 m/s (3 months)
- FIDEOS (see below) – long term over 3 months about 9 m/s
- OES over 3 months – about 300 m/s
- OES during one night – down to 12 m/s (IC bright) or typically about 80 m/s (see Kabath et al. 2020)

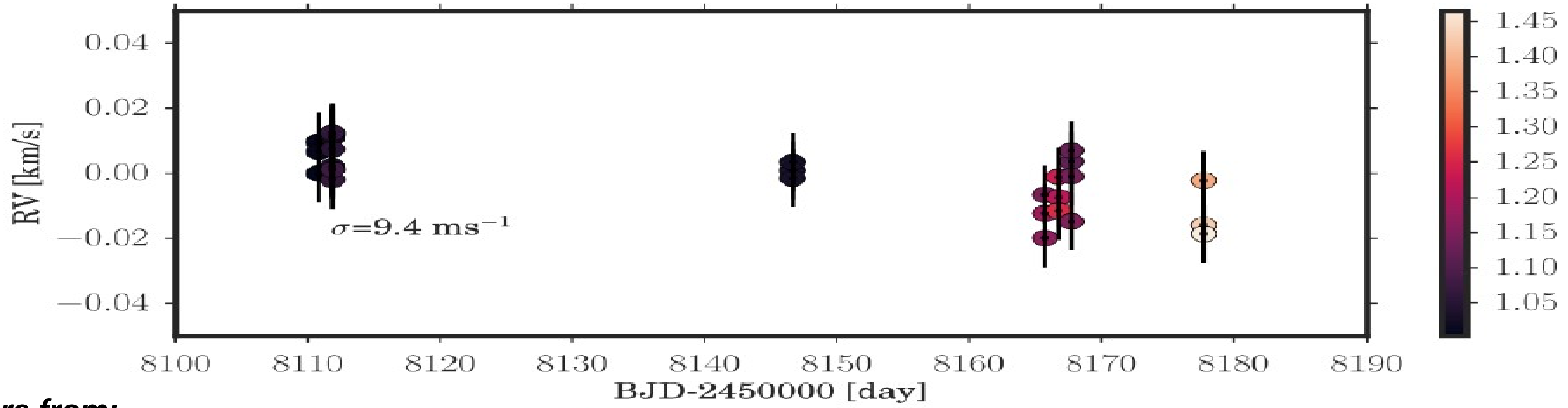


Figure from: Vanzi et al 2018

RV of HD72673(standard RV) measured with FIDEOS during 80 nights (Vanzi, L. et al. 2018).

PLATOSpec arrival

- Commissioning phase at La Silla 2nd half of 2024
- Science verification and test phase end 2024
- Test and verification of fully remote operations early end 2024, beginning 2025
- Normal operations early 2025 onwards

PLATOSpec operations

- Time distributed as follows:

  - 10% Chilean time

  - 80% Consortium time

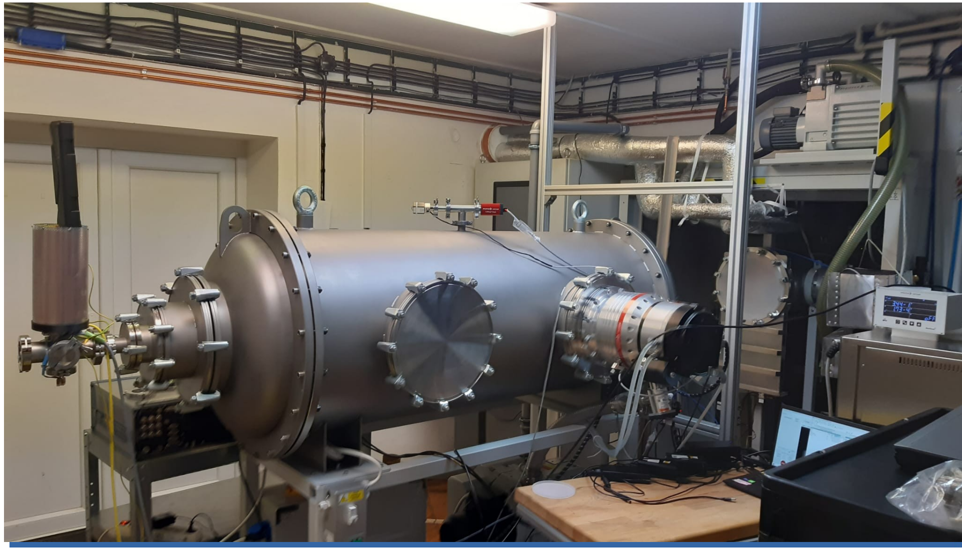
  - 10% Minor partners
- Each consortium member has its own 10% of nights from own share for discretionary use

PLATOSpec data flow

- Own data pipeline ceres+ based on FIDEOS pipeline ceres Brahm et al.
- Data products will be stored in ESO archive
- We will offer reduced spectra
- Consortium expects 1 year proprietary period or longer for special long term targets

What could happen next?

- Vacuum – stability and RVs below 1 m/s?
- Fabry Perot etalon – better RVs stability
- Tip-tilt correction
- Adaptive Optics facility
- Improving the telescope light path

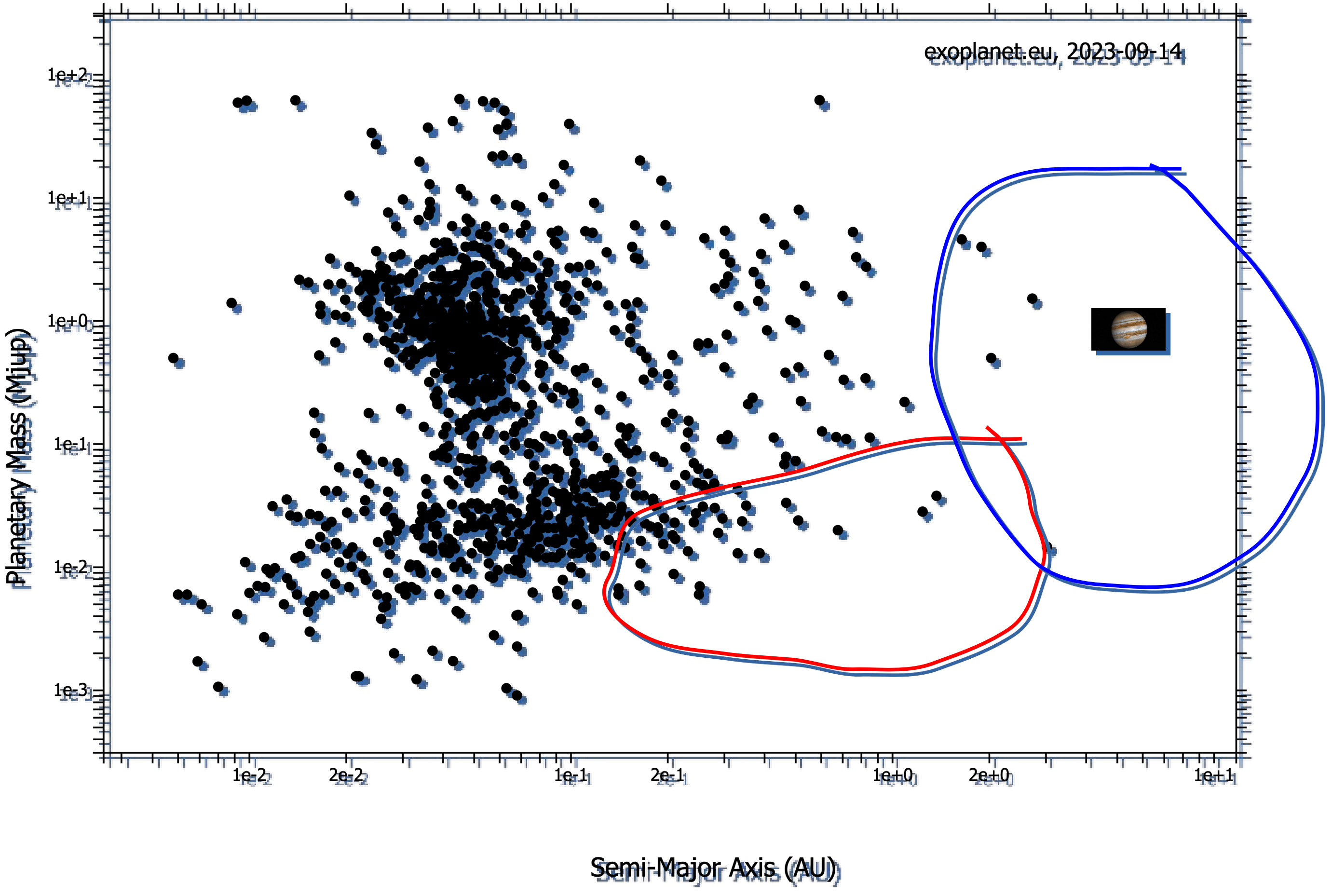


Conclusions

- **Improved duty cycle coverage in case of a network**
- **Long term projects (long period planets, monitoring) possible**
- **Proprietary time – no competing proposals!**
- **Ideal for gas giants physics**
- **Saving time of large(r) telescopes**

  - orbital solution of TOI503b (Subjak et al 2020) needed 13 points that would need perhaps about 4 hrs. on a larger telescope
- **Stellar parameters determination, initial screening, stellar variability**
- **Opportunity for external programs. if interested please contact us!**

Long periodic planets



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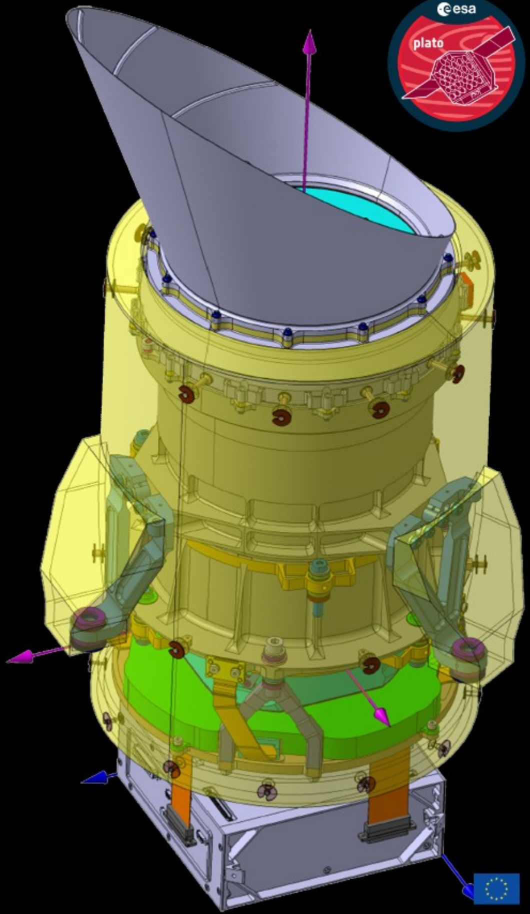
Thank you!

PlatoSpec



Space observatory
PLATO telescope
(2026)

E152 telescope
ESO, La Silla observatory
Chile (2021)

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2-meter Perek Telescope
Astronomical Institute ASCR
Czech Republic

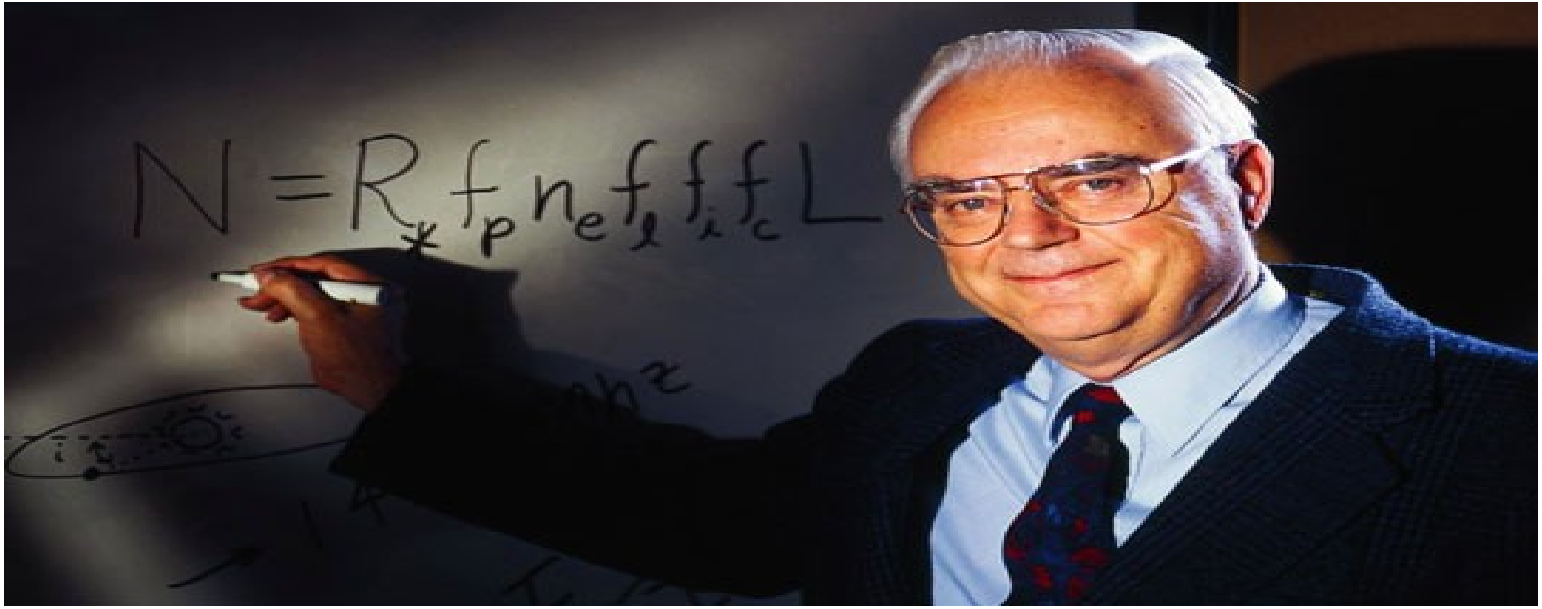
TLS

2-meter Alfred Jensch Telescope
The Karl Schwarzschild Observatory
Germany

Images credit: Zdenek Bardon/ESO

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

So the answer was (in 1960)?

10-20

Carl Sagan - Cosmos

Kepler

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

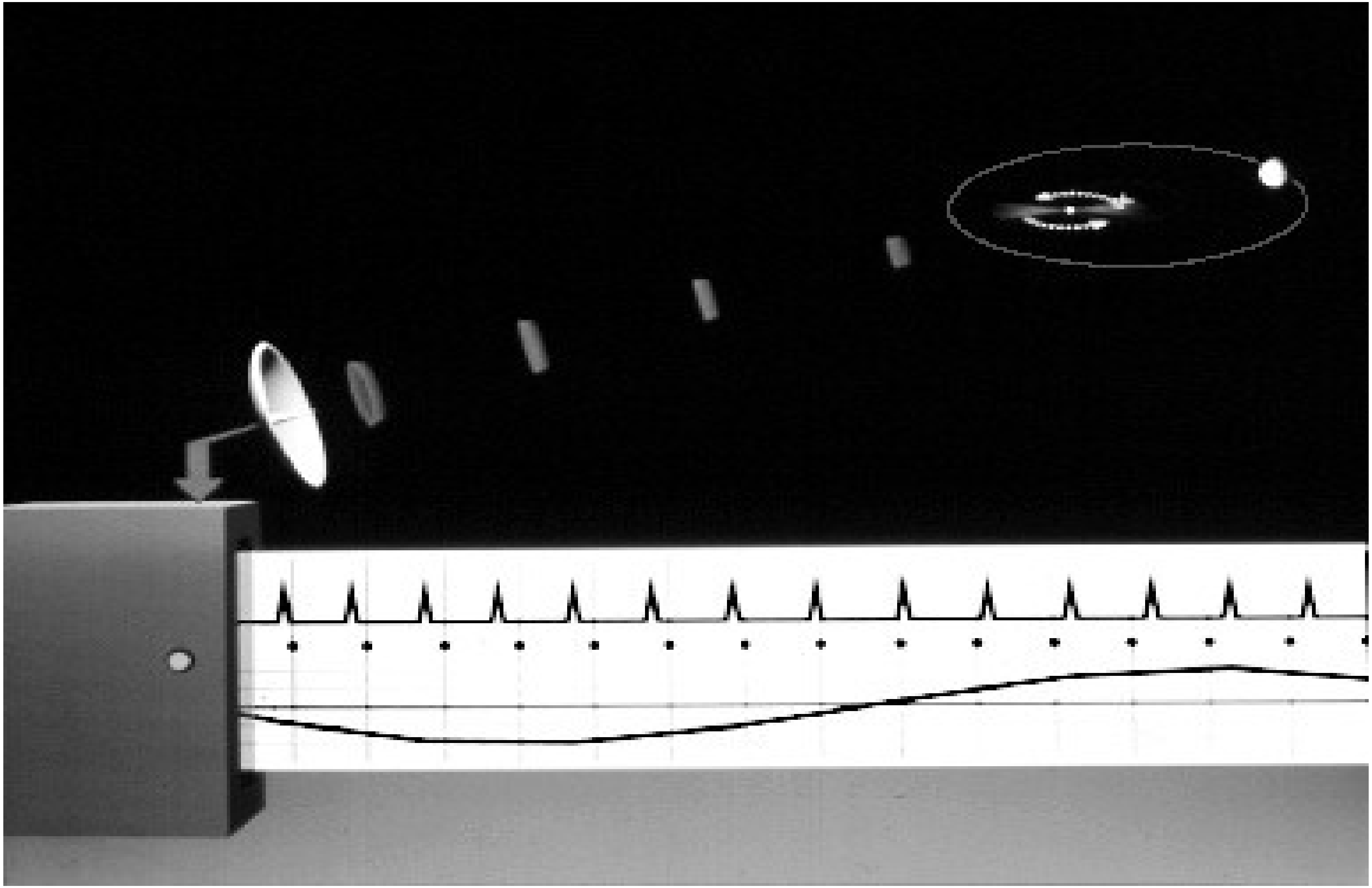
Determine the distribution of sizes and shapes of the orbits of these planets;

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.



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