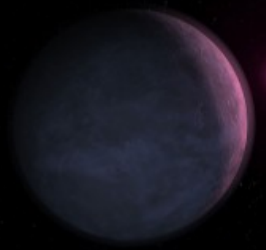
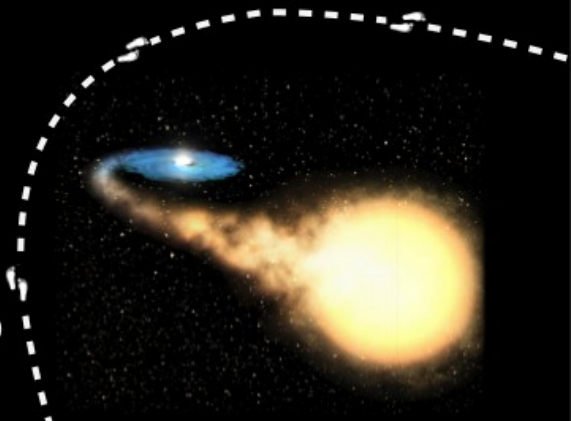
Sprehod skozi vesolje

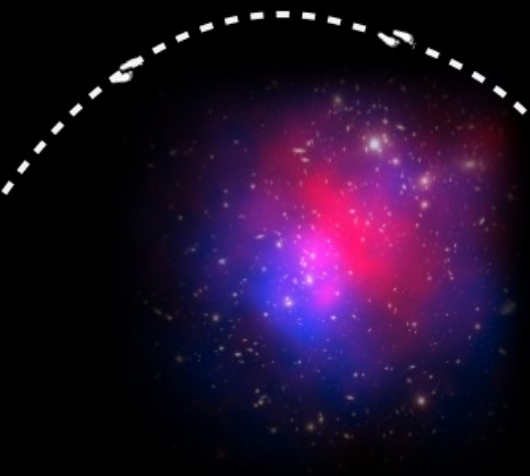
poljudna astronomska predavanja





vsak prvi četrtek v mesecu* ob 19h
na Fakulteti za Matematiko in Fiziko
Jadranska 19, Ljubljana

*od oktobra do junija



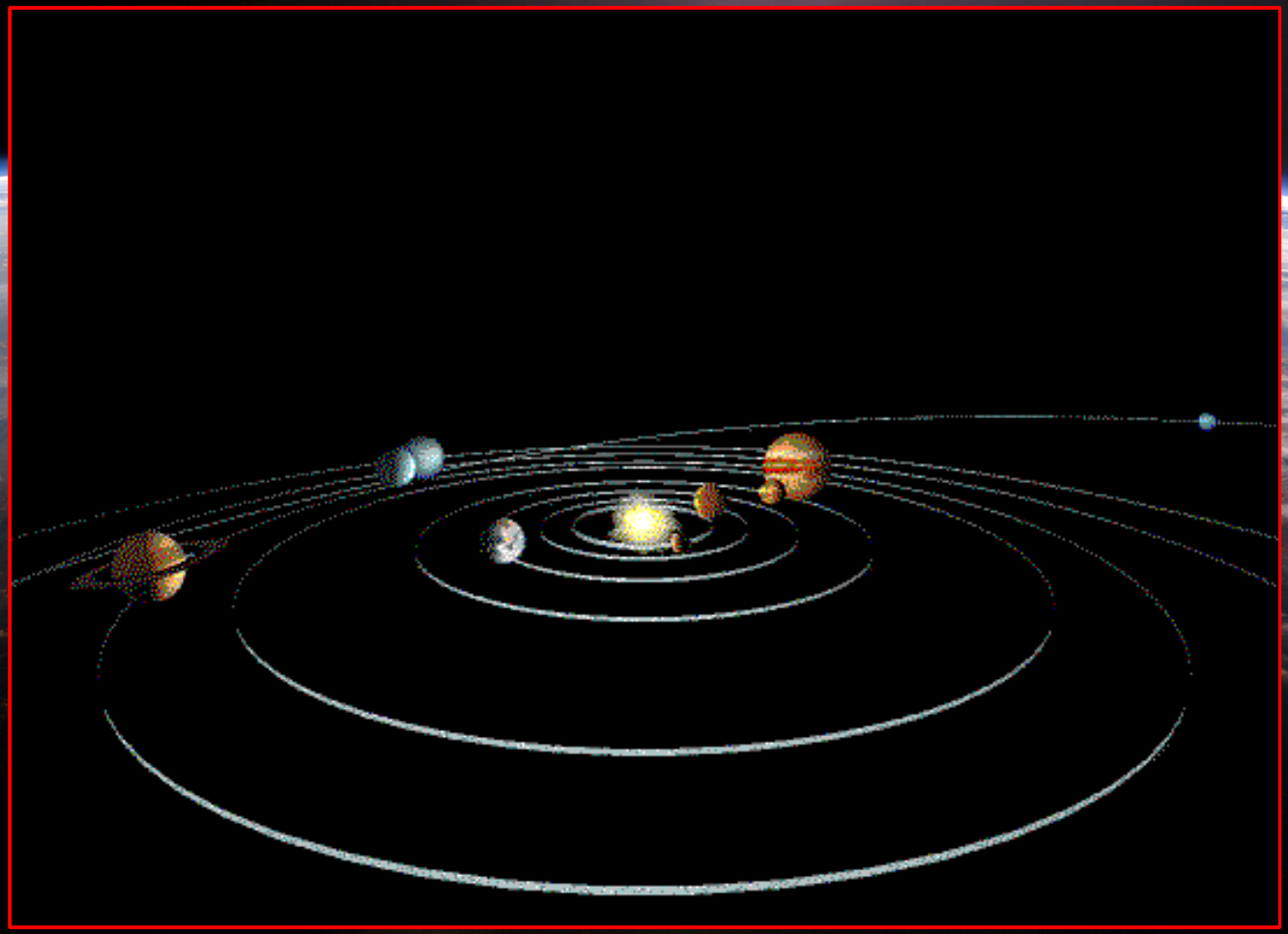
več informacij na
PORTAL VESOLJE
www.portalvvesolje.si

Letošnje teme: planeti okoli drugih sonc, astrobiologija, Sonce, razvoj zvezd, dinamika galaksij, rentgenska astronomija, črne luknje, jate galaksij, kozmologija.

Planeti okoli drugih sonc

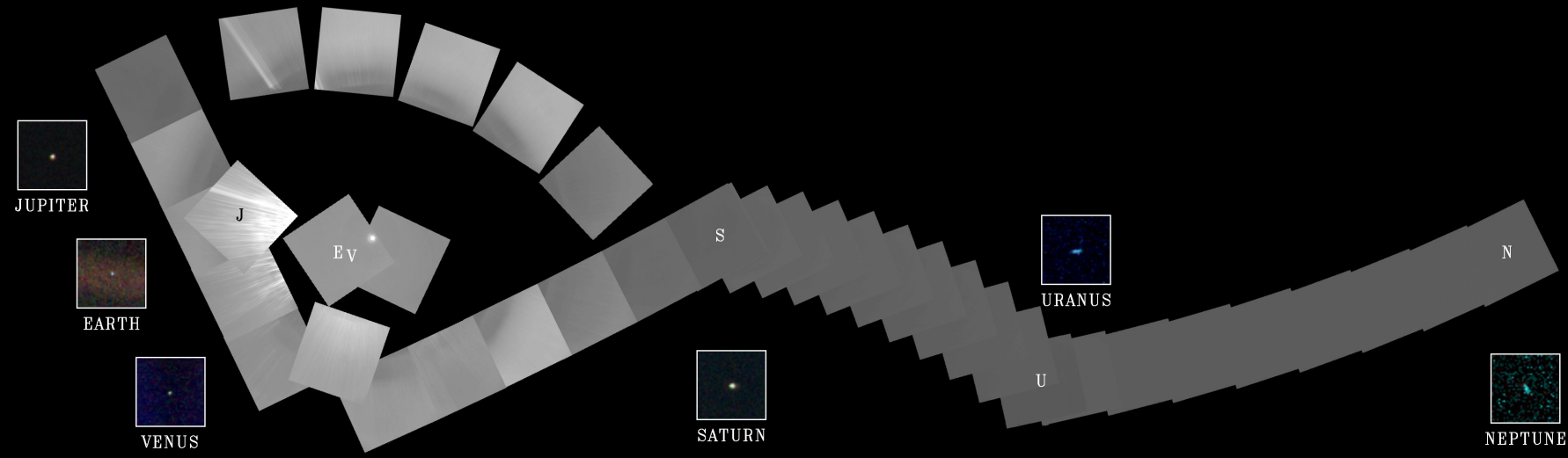
Tomaž Zwitter

Naše Osončje

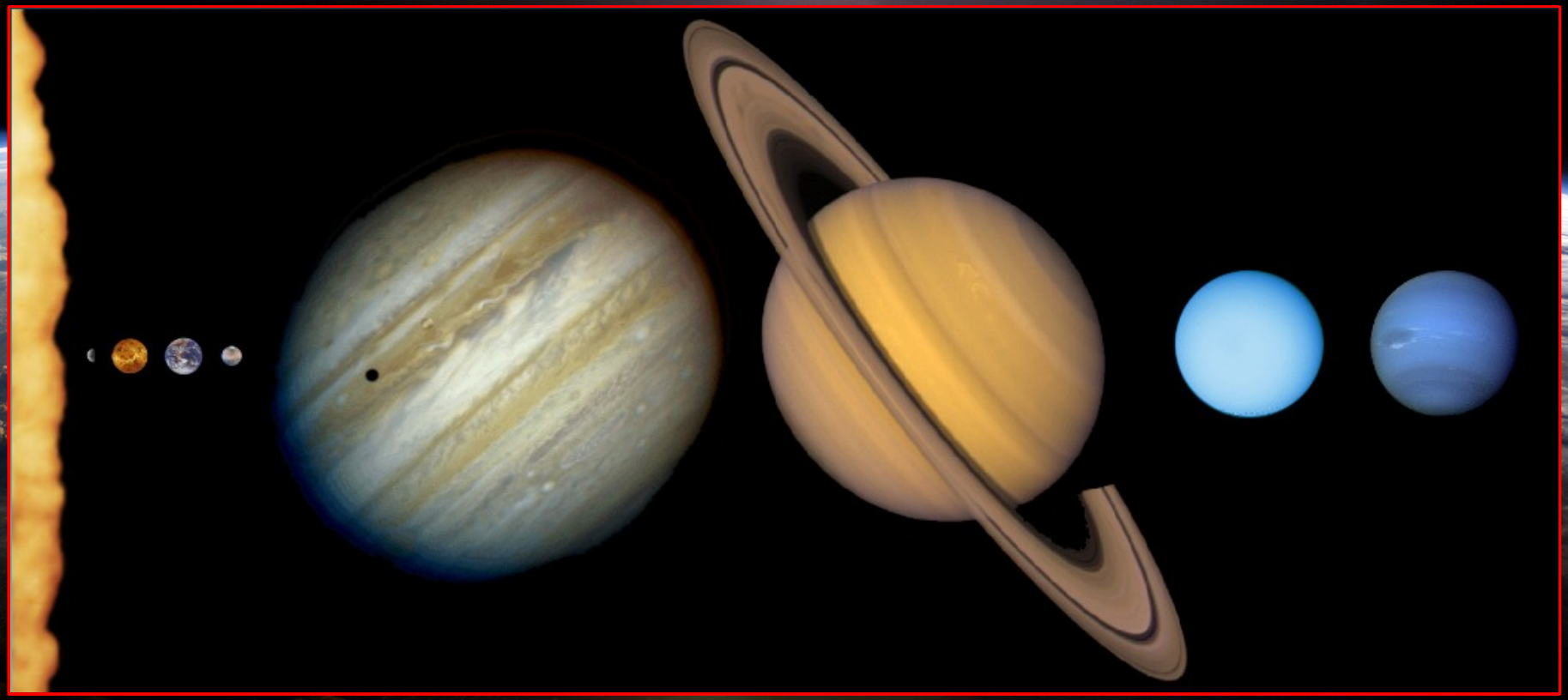


Naše Osončje:

portret s sonde Voyager



Naše Osončje

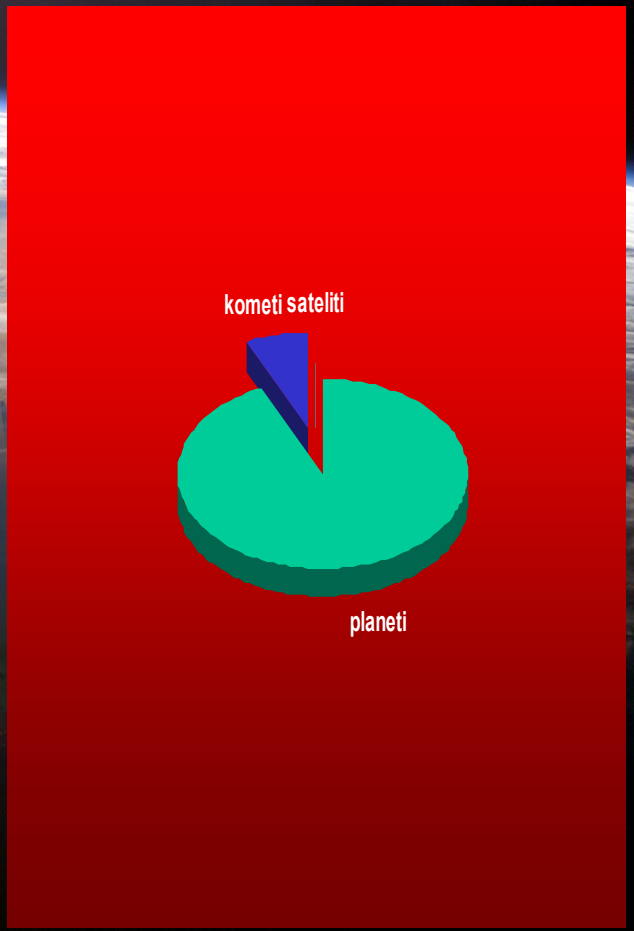


Zgodovina odkrivanja našega Osončja

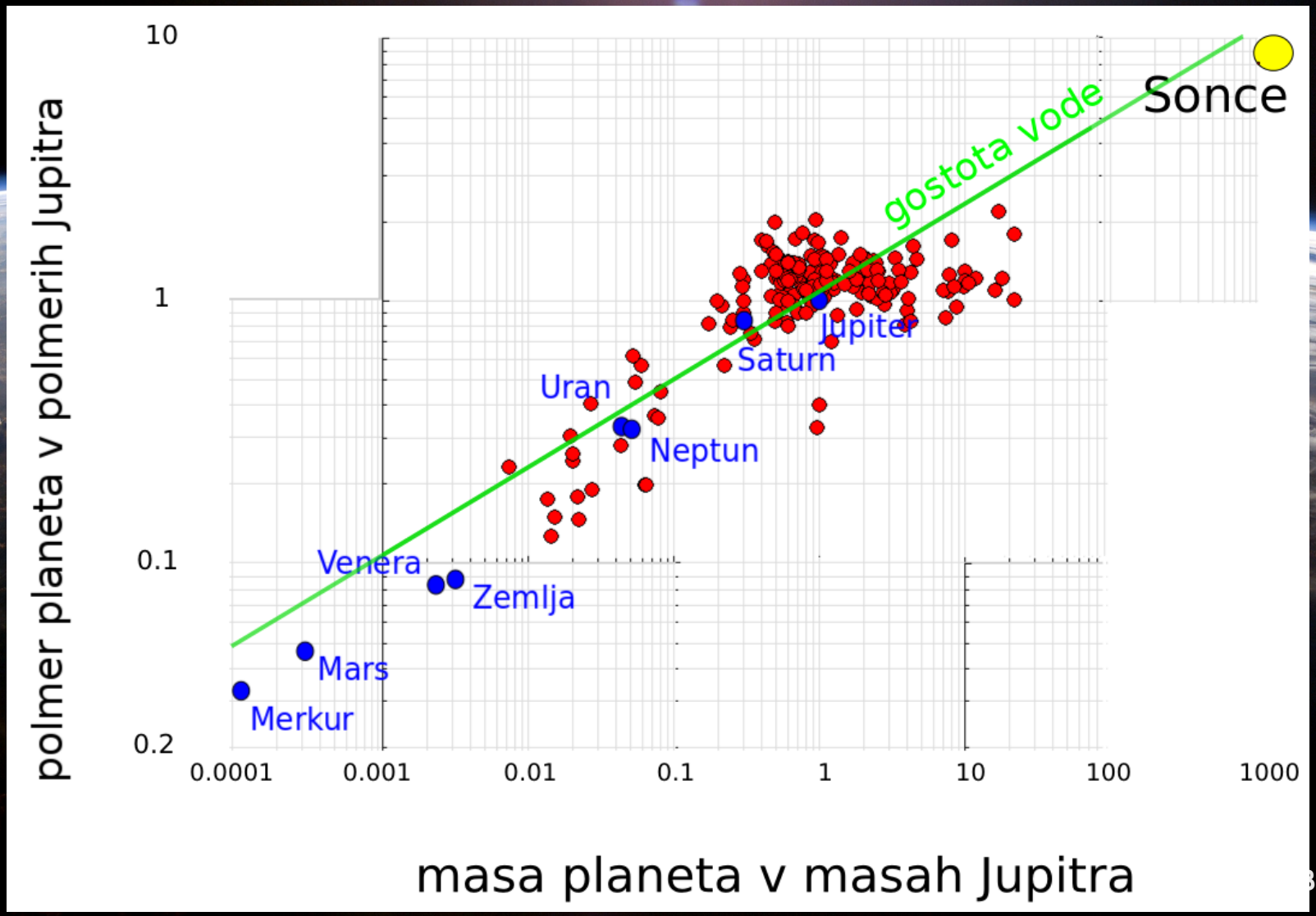
- do 1600: Zemlja, Sonce, Luna, Merkur, Venera, Mars, Jupiter, Saturn
- 17. stoletje: 9 Jupitrovih in Saturnovih lun
- 18. stoletje: Uran in 2 njegovi luni, 2 Saturnovi luni
- 19. stoletje: Neptun, še 8 večjih lun, asteroidi (464)
- 20. stoletje: Pluton, z vesoljskimi sondami in uporabo CCD kamer število odkritij malih objektov "eksplodira"
- 21. stoletje: Plutona ni več med planeti

Naše Osončje

- Porazdelitev mase:
  - Sonce: 99.85%
  - planeti: 0.135%
  - kometi: 0.01% ?
  - sateliti: 0.00005%
  - medplanetna snov (prah in plin): 0.0000001% ?



Masa in polmer planetov



Planeti okoli drugih zvezd: zgodovina

- Prvi planet odkrit zunaj Osončja odkrit leta 1991 (pulzar s planeti), prvi planeti okoli normalne zvezde (51 Peg) pa leta 1995.
- Kasneje se je potrdilo še eno zgodnejše odkritje:

letters to nature

Nature **339**, 38 - 40 (04 May 1989); doi:10.1038/339038a0

The unseen companion of HD114762: a probable brown dwarf

DAVID W. LATHAM*, TSEVI MAZEH†, ROBERT P. STEFANIK*, MICHEL MAYOR‡ & GILBERT BURKI

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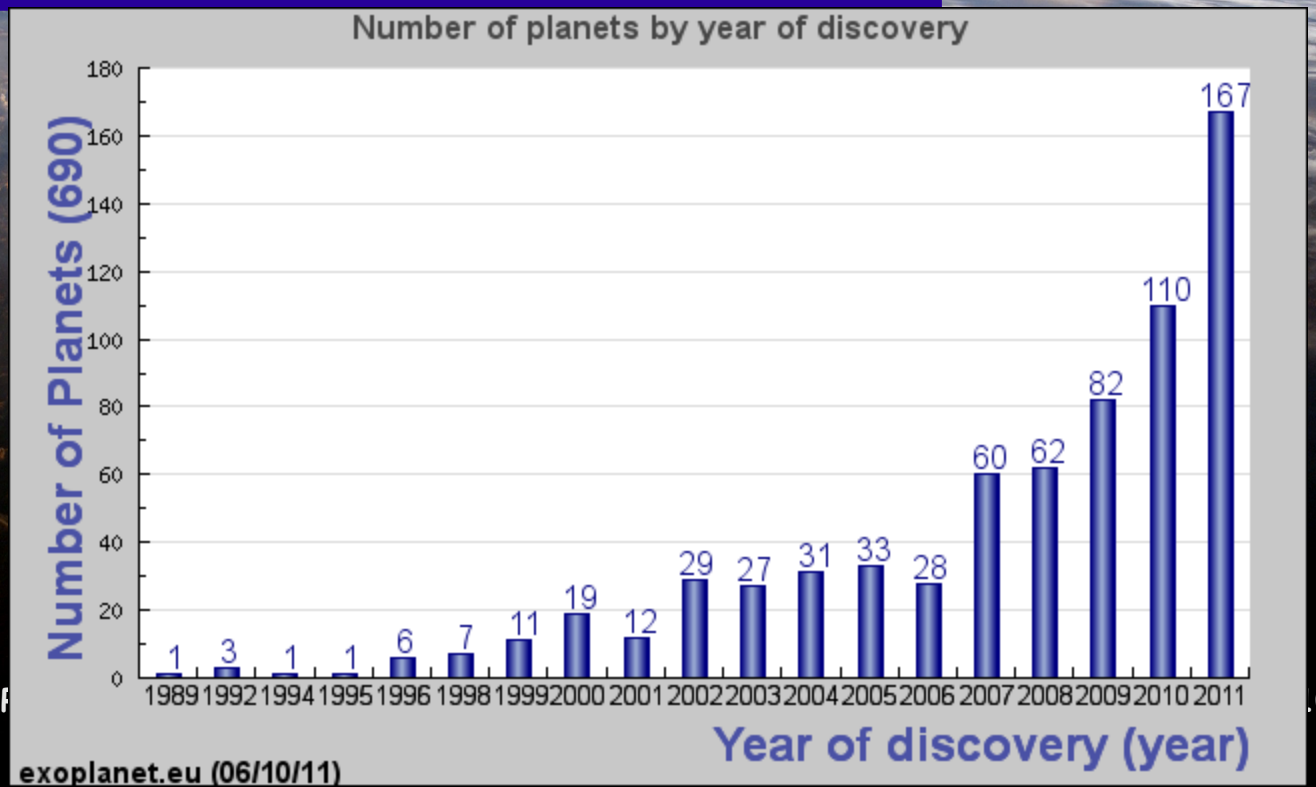
‡Observatoire de Geneve, Chemin des Maillettes 51, Ch-1290 Sauverny, Switzerland

BROWN dwarfs are substellar objects with too little mass to ignite hydrogen in their cores. Despite considerable effort to detect brown dwarfs astrometrically[1–4], photometrically[4–9], and spectroscopi-cally[10–12], only a few good candidates have been discovered. Here we present spectroscopic evidence for a probable brown-dwarf companion to the solar-type star HD114762. This star undergoes periodic variations in radial velocity which we attribute to orbital motion resulting from the presence of an unseen companion. The rather short period of 84 days places the companion in an orbit similar to that of Mercury around the Sun, whereas the rather low velocity amplitude of about 0.6 km s^{-1} implies that the mass of the companion may be as low as 0.011 solar masses, or 11 Jupiter masses. This leads to the suggestion that the companion is probably a brown dwarf, and may even be a giant planet. However, because the inclination of the orbit to the line of sight is unknown, the mass of the companion may be considerably larger than this lower limit.

Trenutno stanje

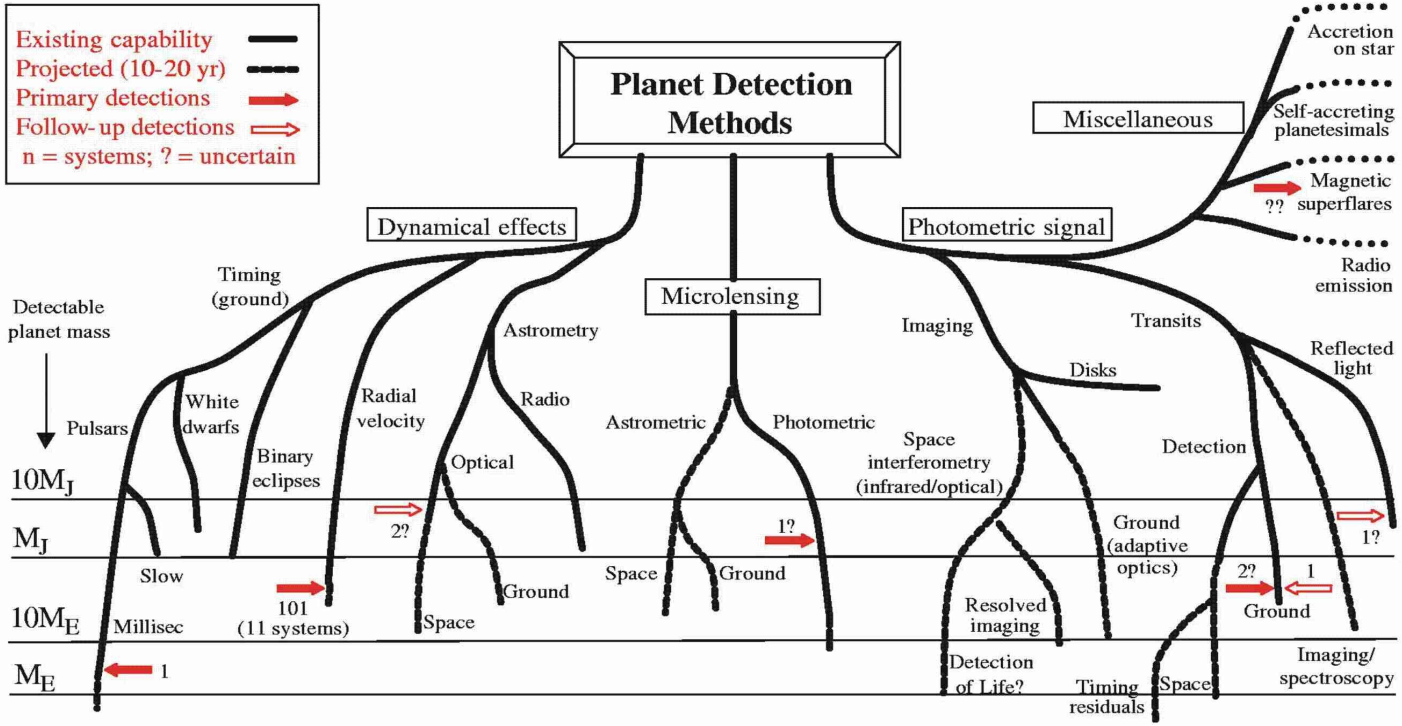
6. oktobra 2011 poznanih 565 zvezd s planeti

- 690 planetov
- 82 večplanetnih sistemov



Planet Detection Methods

Michael Perryman: Rep. Prog. Phys, 2000, 63, 1209 (updated Aug 2002)



Načini odkrivanja

Pri poskusu direktnega opazovanja planeta nas močno slepi svetloba z zvezde.

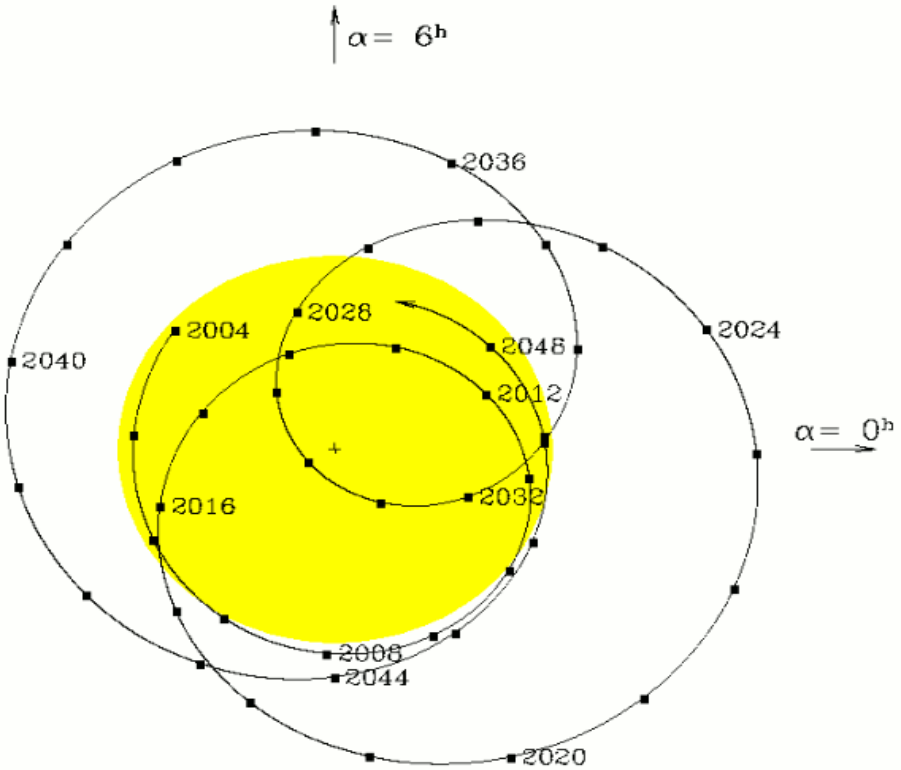
Zvezde se gibljejo skozi prostor. Sonce z 220 km/s obkroži središče Galaksije v 200 milijonih let. Torej v nekaj letih zelo majhen del obhoda. Let zvezde skozi prostor je v ravni črti.

Izjema: dvojna zvezda ali zvezda s planeti. V obeh primerih zvezda kroži okoli skupnega težišča.

Načini odkrivanja: astrometrija

$$r_{\odot} = r_{\text{planet}}\left(m_{\text{planet}}/M_{\odot}\right)$$

Pentljasta krivulja označuje položaj težišča Osončja glede na položaj središča Sonca (znak +). Rumeni krog je velikost Sonca. Pike na krivulji označujejo položaj težišča ob začetku vsakega koledarskega leta.



Načini odkrivanja: astrometrija

$$r_{\odot} = r_{planet} \left(m_{planet} / M_{\odot} \right)$$

$$v_{planet} = 2 \pi r_{planet} / P$$

$$v_{planet}^{2} / r_{planet} = G M_{\odot} / r_{planet}^{2}$$

$$r_{\odot} = (2\pi)^{-2/3} G^{1/3} m_{planet} (M_{\odot})^{-2/3} P^{2/3}$$

Če je za planet z maso Jupitra, ki kroži okoli zvezde z maso Sonca, perioda 2 leti, je $r_{\odot}$ enak 0.32 polmera Sonca.

Načini odkrivanja: astrometrija

$$r_{\odot} = (2\pi)^{-2/3} G^{1/3} m_{planet} (M_{\odot})^{-2/3} P^{2/3}$$

0,32 polmera Sonca vidimo na razdalji
1,3 pc pod kotom 1,2 mas = 5,7 mm na razdalji 1000 km;
100 pc pod kotom 15 μas = 0,07 mm na razdalji 1000 km.

Načini odkrivanja: spektroskopija

$$r_{\odot} = r_{\text{planet}}\,(m_{\text{planet}}/M_{\odot})$$

$$v_{\odot} = 2\,\pi\, r_{\odot}/P \qquad v_{\text{planet}} = 2\,\pi\, r_{\text{planet}}/P$$

$v_{\text{planet}} = (GM_{\odot}/r_{\text{planet}})^{1/2}$, kjer je $M_{\odot}$ masa zvezde.

$$v_{\odot} = (GM_{\odot}/r_{\text{planet}})^{1/2}\,(m_{\text{planet}}/M_{\odot})$$

3. Keplerjev zakon mi da r_{planet}, iz zadnje enačbe tako dobim m_{planet}.

Spektroskopija: ocena temperature na planetu

$$(1-a_P)\,[L_\odot / (4\pi\, r_P^2)]\,(\pi R_p^2) = (4\pi\, R_P^2)\,\sigma\, T_P^4$$

$$T_P = [(1-a_P)\, L_\odot / (16\pi\, \sigma\, r_P^2)]^{1/4}$$

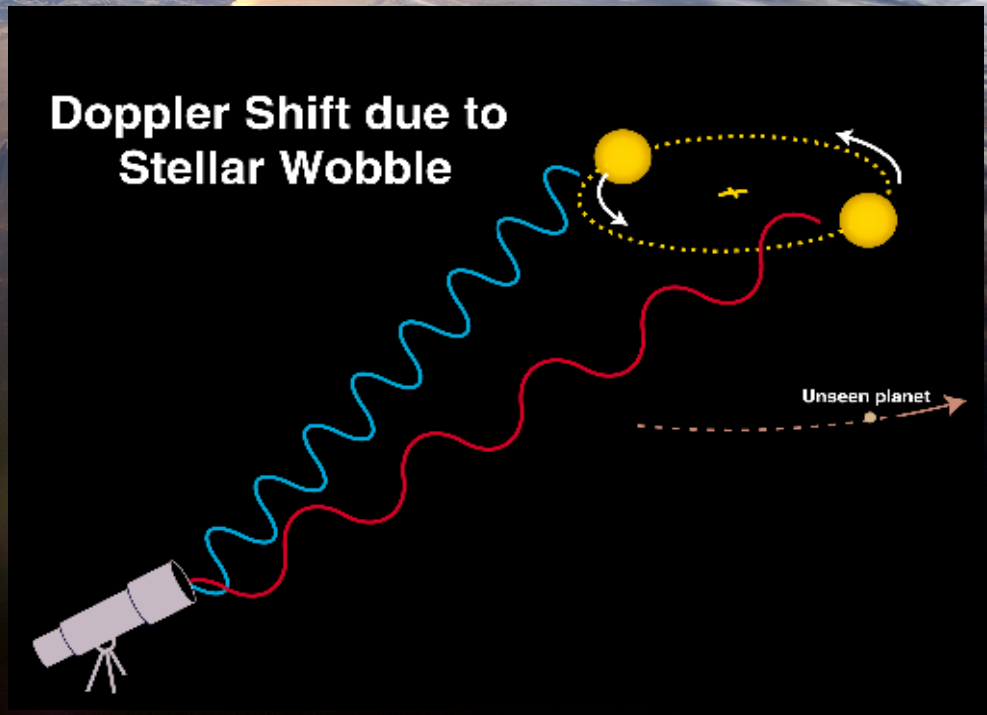
Približevanje/oddaljevanje zvezde: spektroskopija

- Spektroskopska meritev hitrosti preko Dopplerjevega pojava
- gravitacijski vpliv planeta na gibanje zvezde

V dvozvezdju je hitrost lahko >10 km/s

Planeti imajo manjšo maso, zato hitrosti le ~10 m/s.

Potrebujemo izjemno natančen instrument.



Približevanje/oddaljevanje zvezde: spektroskopija

Spektrograf HARPS na 3.6-m teleskopu Evropskega južnega observatorija na La Silli.

Spektrograf HARPS na ESOvem 3,6-m teleskopu na La Silli

- echellov spektrograf hranjen z optičnimi vlakni
- valovne dolžine 378-691 nm
- 72 redov x 4000 točk/sled = 288000 točk
- $\lambda / d\lambda$ = 115.000, vsaka točka po ~1,3 km/s
- V 10 minutah S/N=110 na točko za zvezdo z Mv = 8,5 in tipom G2V.
- Dosegljiva točnost radialne hitrosti: 0,9 m/s.

Najtočnejši spektrograf na svetu.

Zemlji podoben planet

Astronomy & Astrophysics manuscript no.
(DOI: will be inserted by hand later)

April 29, 2007

The HARPS search for southern extra-solar planets⋆

XI. Super-Earths (5 & 8 $M_\oplus$) in a 3-planet system

S. Udry[1], X. Bonfils[2], X. Delfosse[3], T. Forveille[3], M. Mayor[1], C. Perrier[3], F. Bouchy[4], C. Lovis[1], F. Pepe[1], D. Queloz[1], and J.-L. Bertaux[5]

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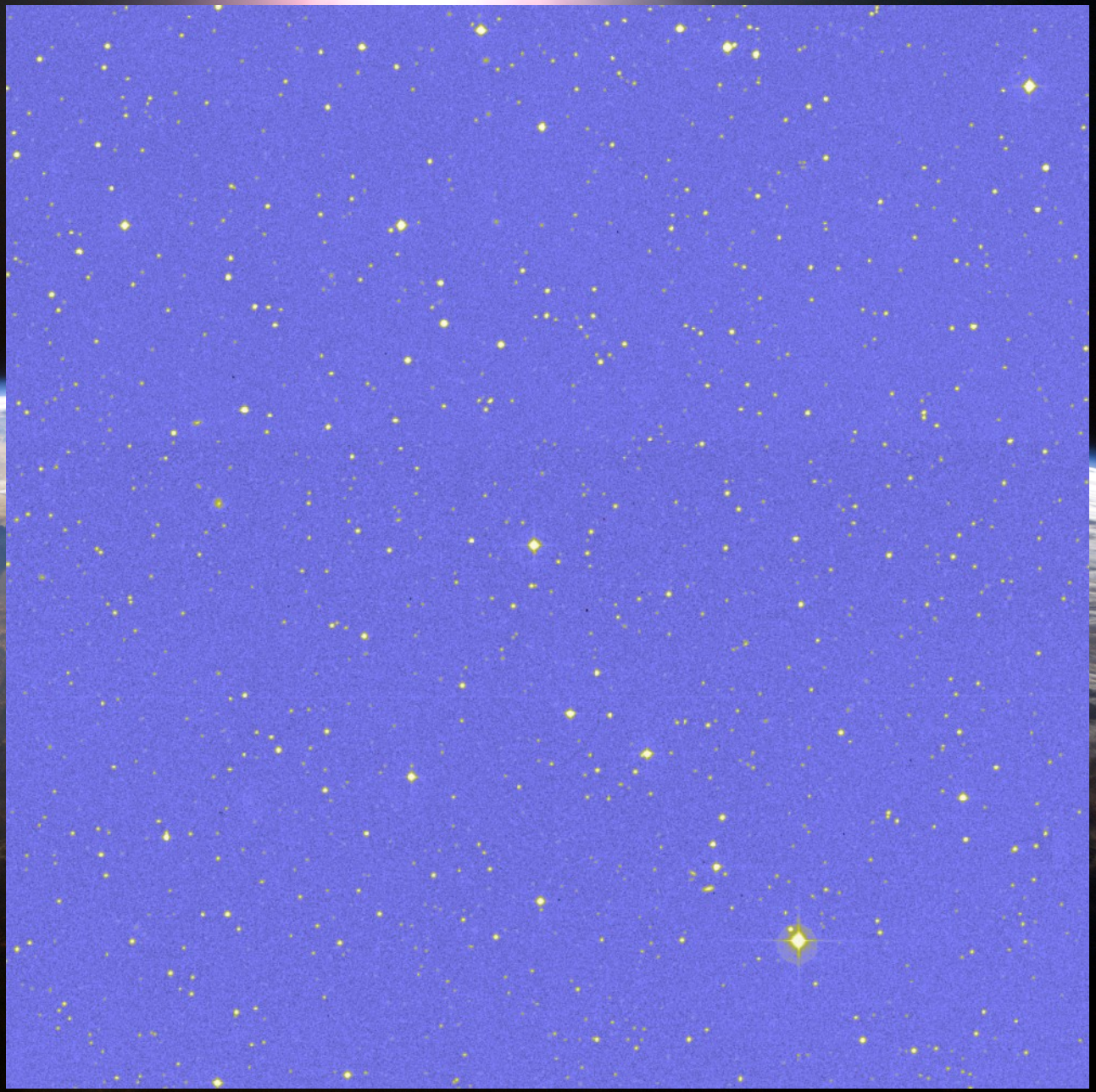
e-mail: stephane.udry@obs.unige.ch
[2] Centro de Astronomia e Astrofisica da Universidade de Lisboa, Tapada da Ajuda, 1349-018 Lisboa, Portugal
[3] Laboratoire d'Astrophysique, Observatoire de Grenoble, Université J. Fourier, BP 53, F-38041 Grenoble, Cedex 9, France
[4] Institut d'Astrophysique de Paris, CNRS, Université Pierre et Marie Curie, 98bis Bd Arago, 75014 Paris, France
[5] Service d'Aéronomie du CNRS/IPSL, Université de Versailles Saint-Quentin, BP3, 91371 Verrières-le-Buisson, France

Received ; accepted To be inserted later

Abstract. This Letter reports on the detection of two super-Earth planets in the Gl 581 system, already known to harbour a hot Neptune. One of the planets has a mass of 5 $M_\oplus$ and resides at the "warm" edge of the habitable zone of the star. It is thus the known exoplanet which most resembles our own Earth. The other planet has a 7.7 $M_\oplus$ mass and orbits at 0.25 AU from the star, close to the "cold" edge of the habitable zone. These two new light planets around an M3 dwarf further confirm the formerly tentative statistical trend for i) many more very low-mass planets being found around M dwarfs than around solar-type stars and ii) low-mass planets outnumbering Jovian planets around M dwarfs.

Key words. stars: individual: Gl 581, stars: planetary systems – techniques: radial velocities – techniques: spectroscopy

Zvezda HO Tehtnice = Gliese 581

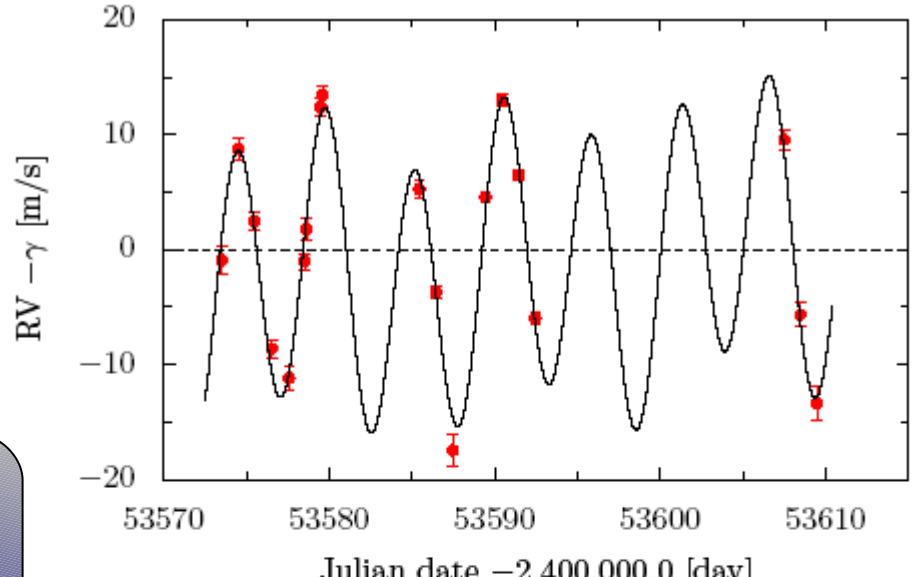


Zvezda HO Tehtnice

- hitrost glede na Sonce: 38 km/s (zvezda debelega diska)
- starost vsaj 2 milijardi let (majhna kromosferska aktivnost)
- v atmosferi 2-krat manjši delež kovin kot v Soncu
- masa 0,3 mase Sonca, podobno polmer
- rdeča pritlikava zvezda (površinska temperatura 3600 K)
- izsev 80-krat manjši od Sončevega

Zvezda HD Tehtnice

50 opazovanj, točnost 0,9 m/s



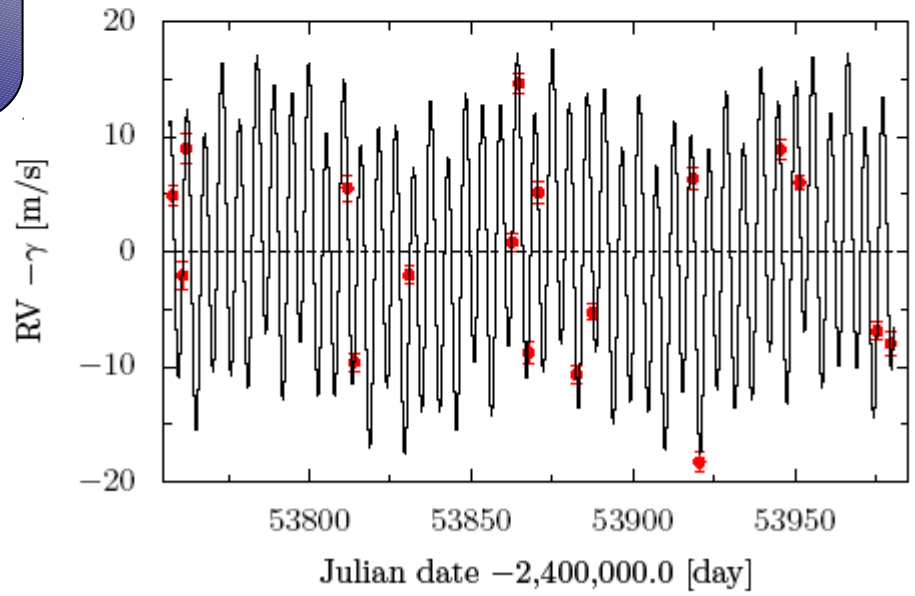


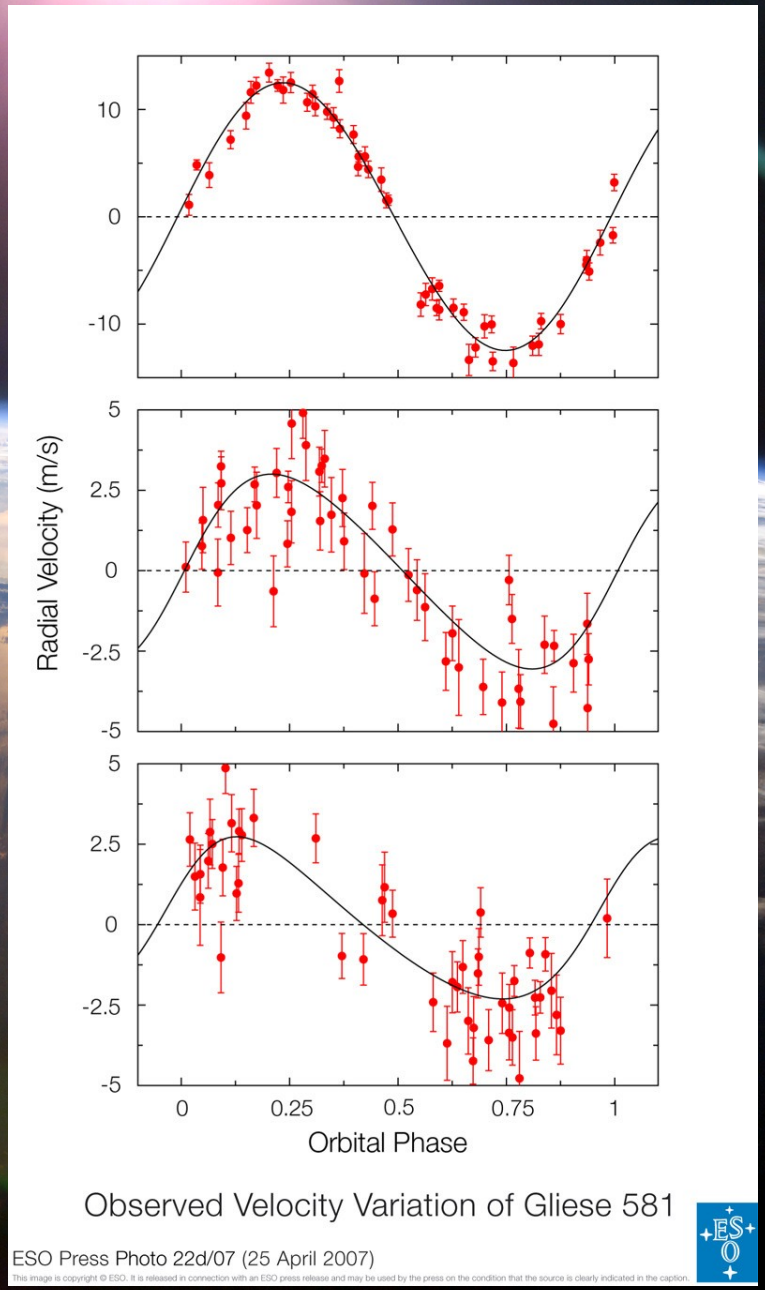
Fig. 4. Temporal display of the 3-planet Keplerian model of Gl 581, on time intervals with dense observational sampling.

Zvezda HO Tehtnice

prvi planet

drugi planet

tretji planet



Zvezda HO Tehtnice

Table 1. Orbital and physical parameters derived from 3-planet Keplerian models of Gl 581 for the free-eccentricity and circular cases. Uncertainties are directly derived from the covariance matrix.

Parameter		Circular case			Free eccentricity case		
		Gl 581 b	**Gl 581 c**	**Gl 581 d**	**Gl 581 b**	**Gl 581 c**	**Gl 581 d**
P	[days]	5.3687±0.0003	12.931±0.007	83.4±0.4	5.3683±0.0003	12.932±0.007	83.6±0.7
T	[JD-2400000]	52999.99±0.05	52996.74±0.45	52954.1±3.7	52998.76±0.62	52993.38±0.96	52936.9±9.2
e		0.0 (fixed)	0.0 (fixed)	0.0 (fixed)	0.02±0.01	0.16±0.07	0.20±0.10
V	[km s^{-1}]		-9.2115 ± 0.0001			-9.2116 ± 0.0002	
ω	[deg]	0.0 (fixed)	0.0 (fixed)	0.0 (fixed)	273±42	267±24	295±28
K	[m s^{-1}]	12.42 ± 0.19	3.01±0.16	2.67±0.16	12.48 ± 0.21	3.03±0.17	2.52±0.17
$a_1 \sin i$	[10^{-6} AU]	6.129	3.575	20.47	6.156	3.557	18.98
$f(m)$	[$10^{-13} M_\odot$]	10.66	0.365	1.644	10.80	0.359	1.305
$m_2 \sin i$	[M_{Jup}]	0.0490	0.0159	0.0263	0.0492	0.0158	0.0243
$m_2 \sin i$	[$M_\oplus$]	15.6	5.06	8.3	15.7	5.03	7.7
a	[AU]	0.041	0.073	0.25	0.041	0.073	0.25
N_{meas}			50			50	
Span	[days]		1050			1050	
σ (O-C)	[ms^{-1}]		1.28			1.23	
χ^2_{red}			3.17			3.45	

Sedaj odkrili še četrti planet.

Zvezda HO Tehtnice

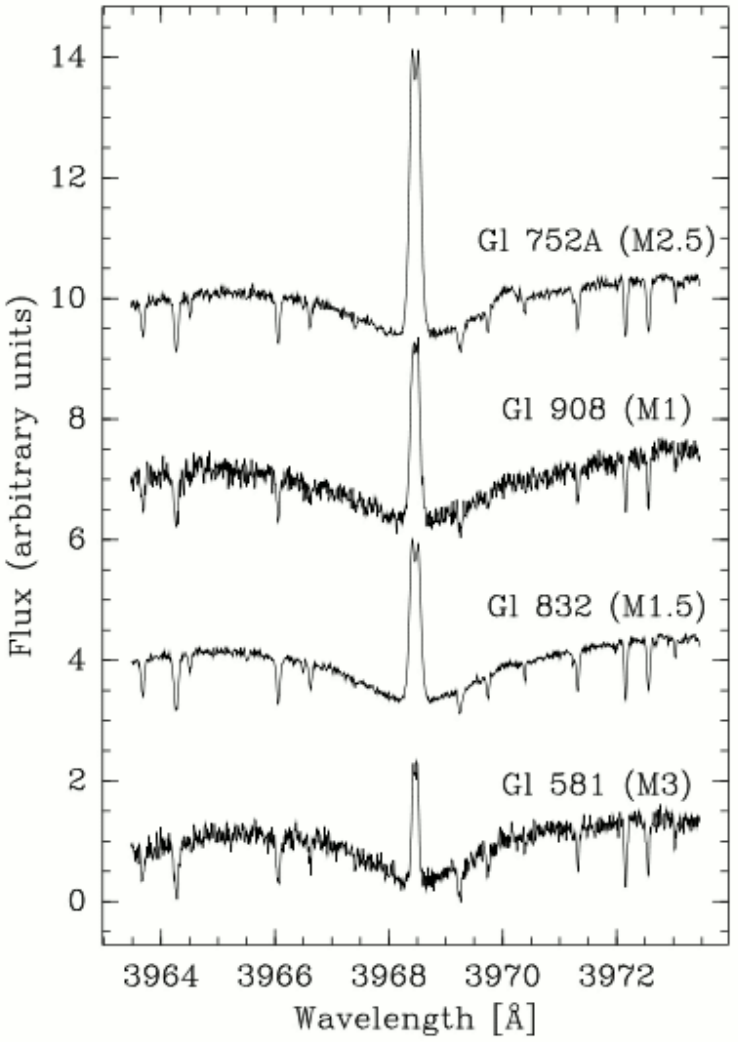


Fig. 1. HARPS spectra of the Ca II H (λ = 3968.47 Å) line region for Gl 581 and three comparison stars with similar spectral type and apparent magnitude. The stars are displayed in order of ascending chromospheric activity, and from top to bottom are Gl 752A, Gl 908, Gl 832 and Gl 581. The chromospheric emission peaks look prominent against the weak blue continuum of these M dwarfs, but they actually denote very weak chromospheric emission relative to the bolometric luminosity. Amongst those 4 stars, Gl 581 has the weakest chromospheric activity.

Zemlji podoben planet

- obhodna doba 12,9 dneva
- masa ≥ 5 Zemljinih mas
- polmer ~1,5 Zemljinih polmerov
- površinska temperatura 0 – 40 stopinj Celzija

Internal Structure of Massive Terrestrial Planets

Diana Valencia[a,1], Richard J O'Connell[a] and Dimitar Sasselov[b]

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[b] Harvard-Smithsonian Center for Astrophysics, Department of Astronomy, Harvard University, Cambridge, Massachussets, 02138

[1]Corresponding Author E-mail address: valencia@mail.geophysics.harvard.edu

ABSTRACT

Planetary formation models predict the existence of massive terrestrial planets and experiments are now being designed that should succeed in discovering them and measuring their masses and radii. We calculate internal structures of planets with one to ten times the mass of the Earth (Super-Earths) in order to obtain scaling laws for total radius, mantle thickness, core size and average density as a function of mass. We explore different compositions and obtain a scaling law of $R \propto M^{0.267-0.272}$ for Super-Earths. We also study a second family of planets, Super-Mercuries with masses ranging from one mercury-mass to ten mercury-masses with similar composition to the Earth's but larger core mass fraction. We explore the effect of surface temperature and core mass fraction on the scaling laws for these planets. The scaling law obtained for the Super-Mercuries is $R \propto M^{\sim 0.3}$.

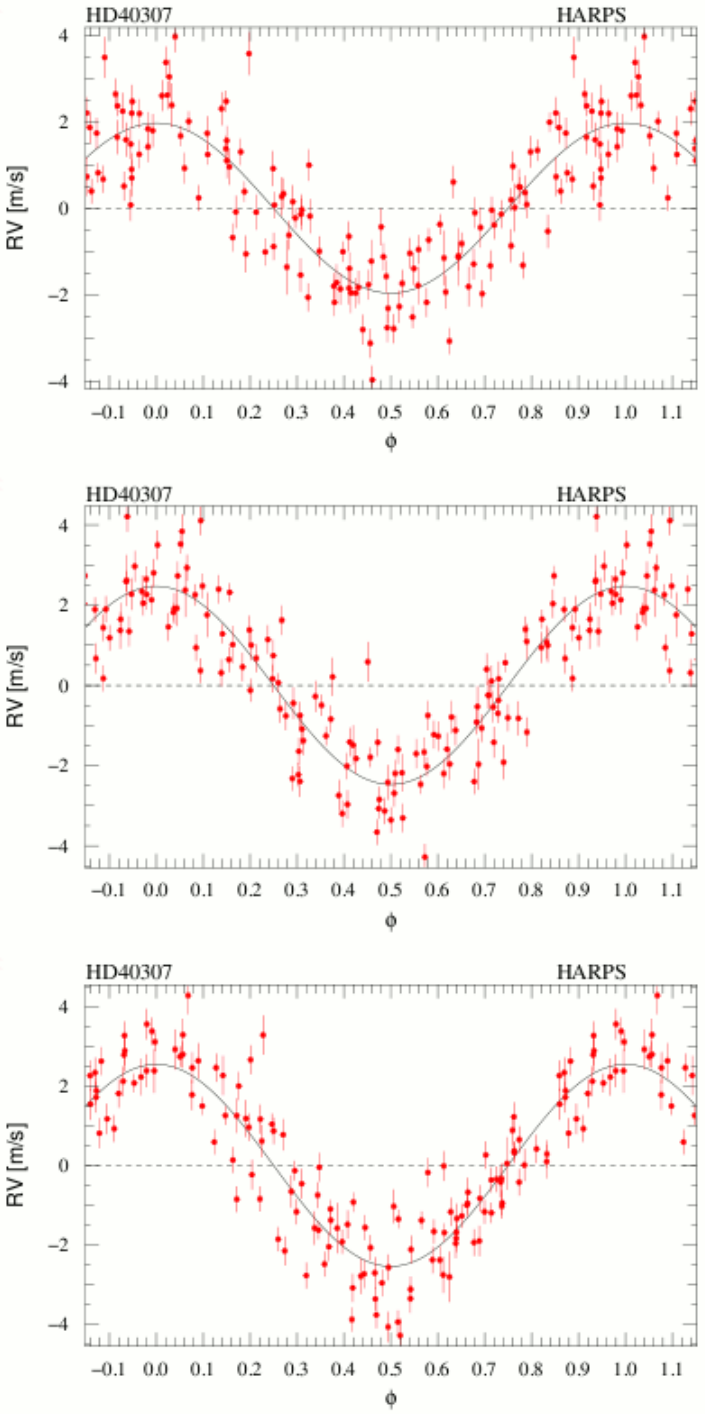
Velikosti Zemlji podobnih planetov

Več Zemlji podobnih planetov

Mayor idr. 2008

Zvezda HD40307 ima tri:

- mase
  4,2, 6,9 in 9,2 M_{Zemlje}
- obhodne dobe
  4,3, 9,6 in 20,5 dneva
- površinske temperature
  540, 340, 210 °C



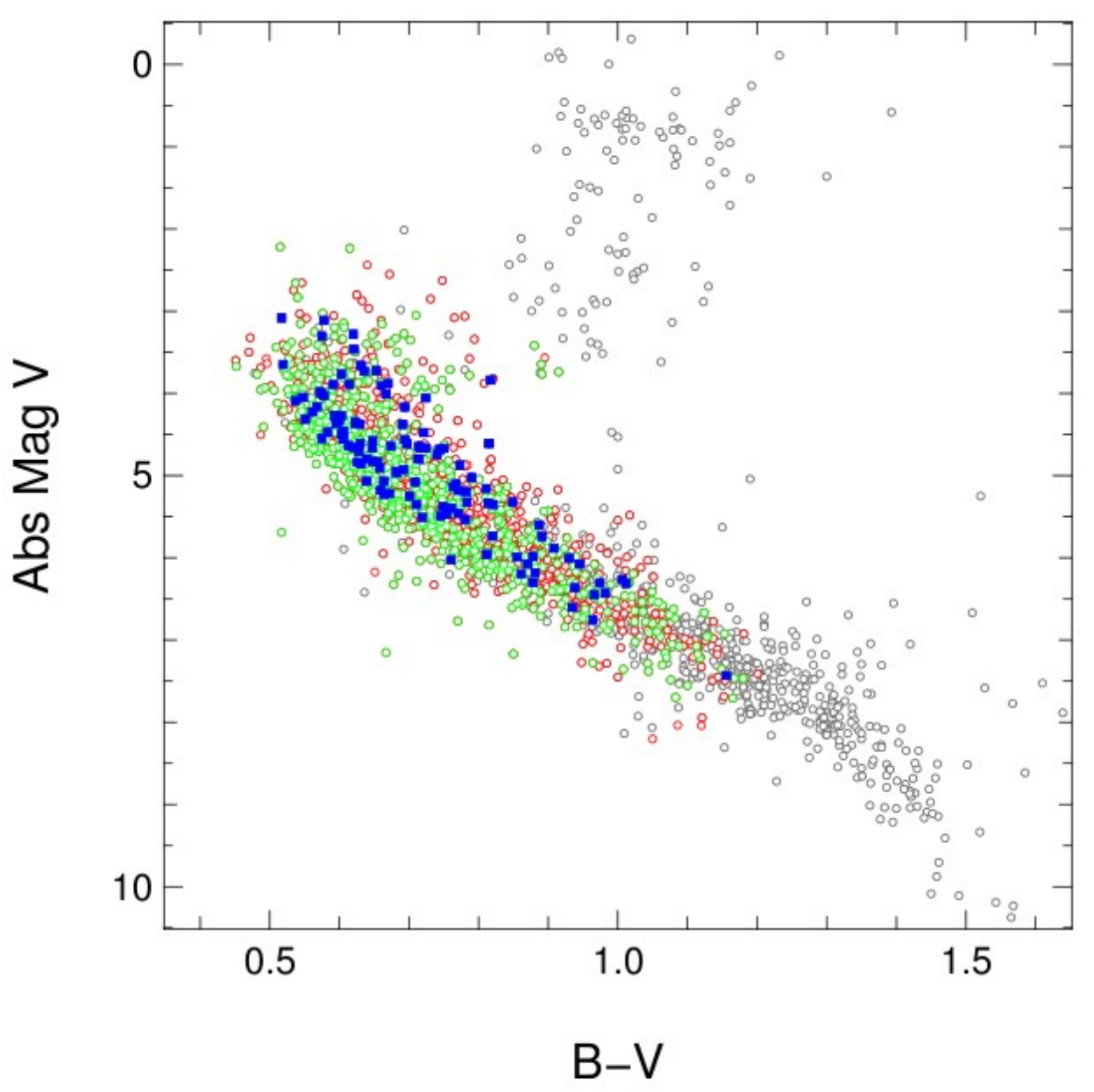


Fig. 1. HR-diagram of Hipparcos 2008 catalogue (black) , CORALIE volume limited sample (red), HARPS sample of low activity stars (green) and stars with planetary systems (blue)

HARPS: zadnji rezultati

Mayor idr. 2011

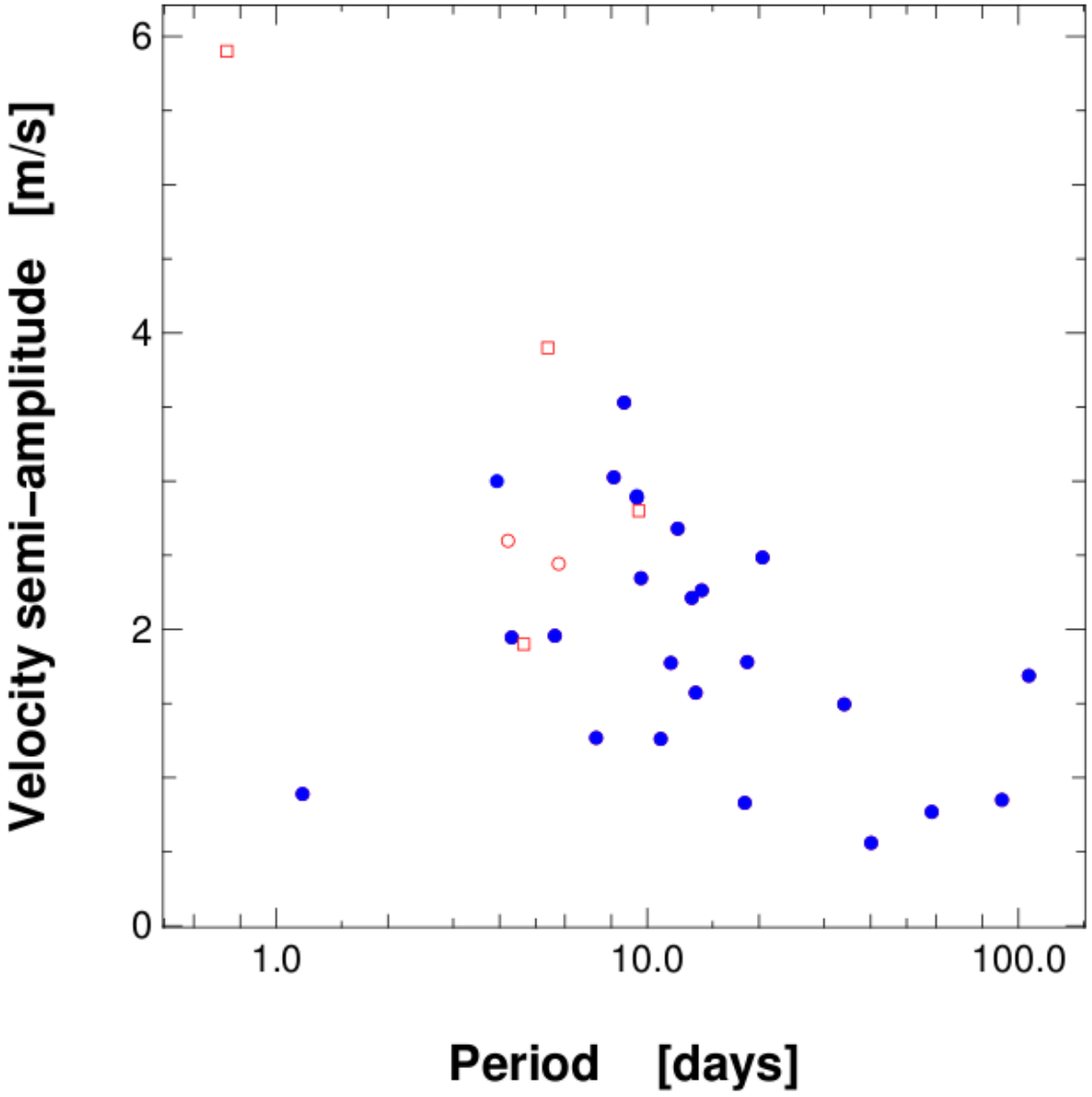


Fig. 2. Radial-velocity semi-amplitude K as a function of orbital period for super-Earths ($M < 10\,M_{\oplus}$) hosted by solar-type stars. HARPS detection are plotted as blue dots and objects from the literature in red symbols (circles for the southern sky and square for the northern sky).

HARPS: zadnji rezultati

Mayor idr. 2011

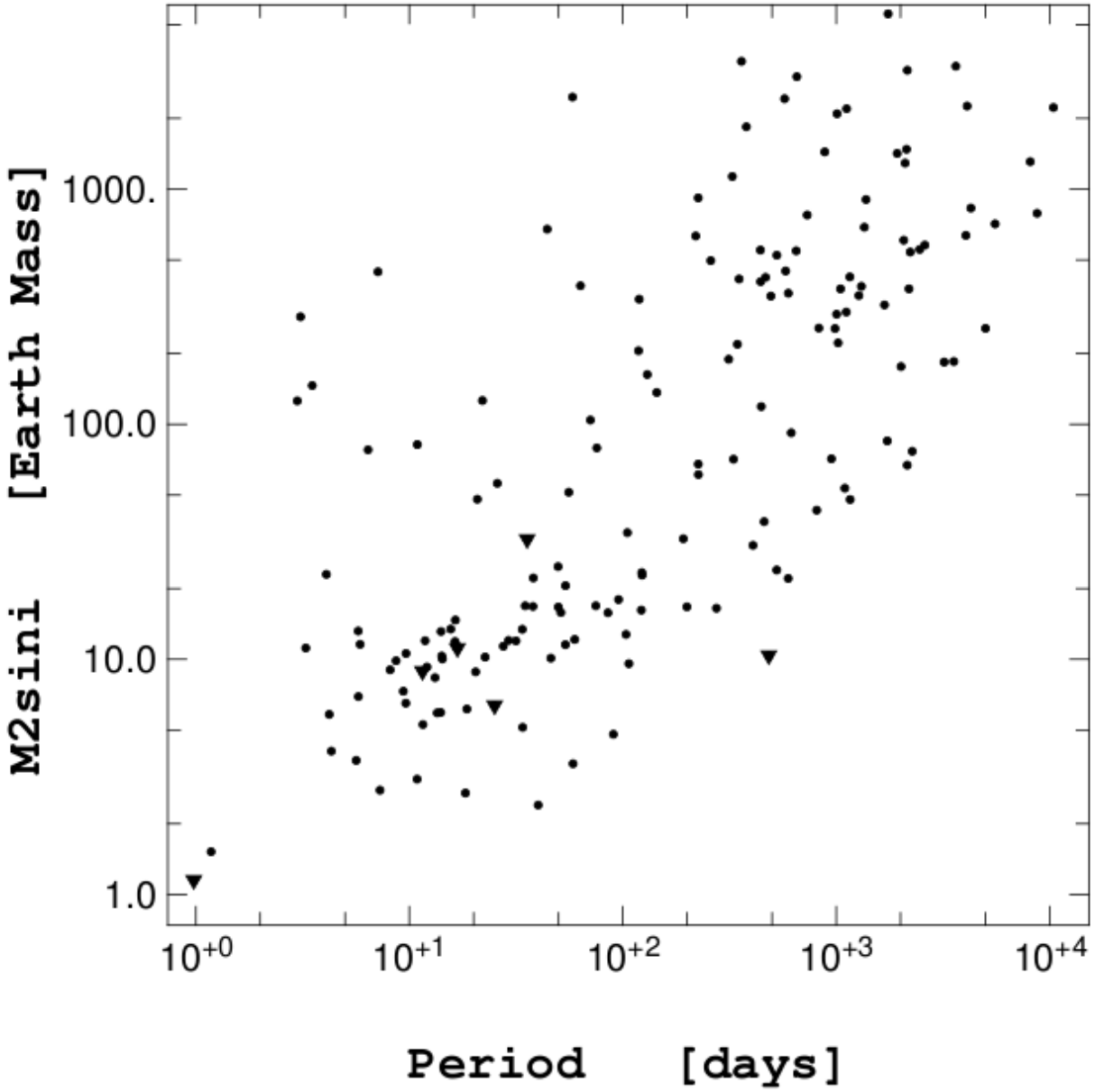


Fig. 5. Plot of the 155 planets (dots) and 6 candidates (triangles) of the considered HARPS+CORALIE sample in the $m_2 \sin i$ – $\log P$ plane .

HARPS: zadnji rezultati

Mayor idr. 2011

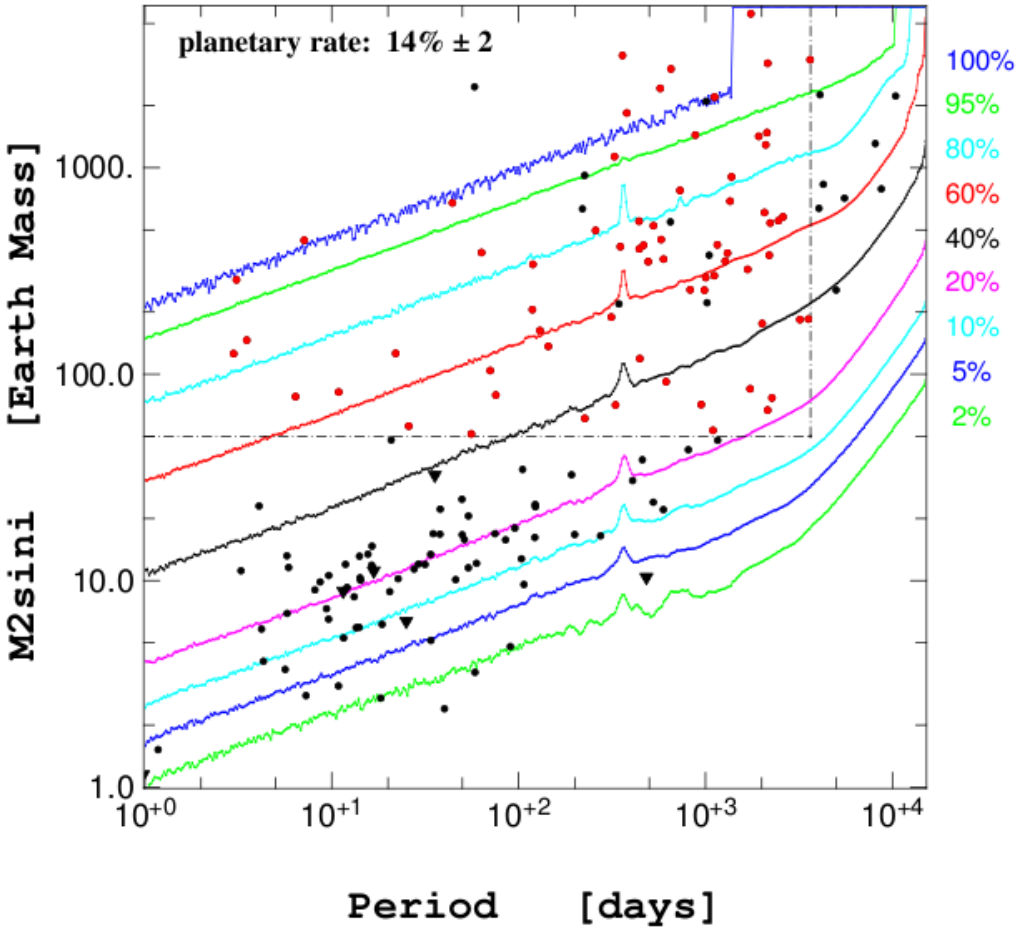


Fig. 6. Same as Fig. 5 with detection probability curves superimposed. These detection probabilities are valid for the whole sample of 822 stars. After correcting for the detection bias, the fraction of stars with at least one planet more massive than 50 $M_\oplus$ and with a period smaller than 10 years is estimated to be 14 ± 2 %. The red points represent the planets which have been used to compute the corrected occurrence rate in the box indicated by the dashed line. The planets lying outside the box or being part of a system already taken into account are excluded; they are shown in black.

HARPS: zadnji rezultati

Mayor idr. 2011

HARPS: zadnji rezultati

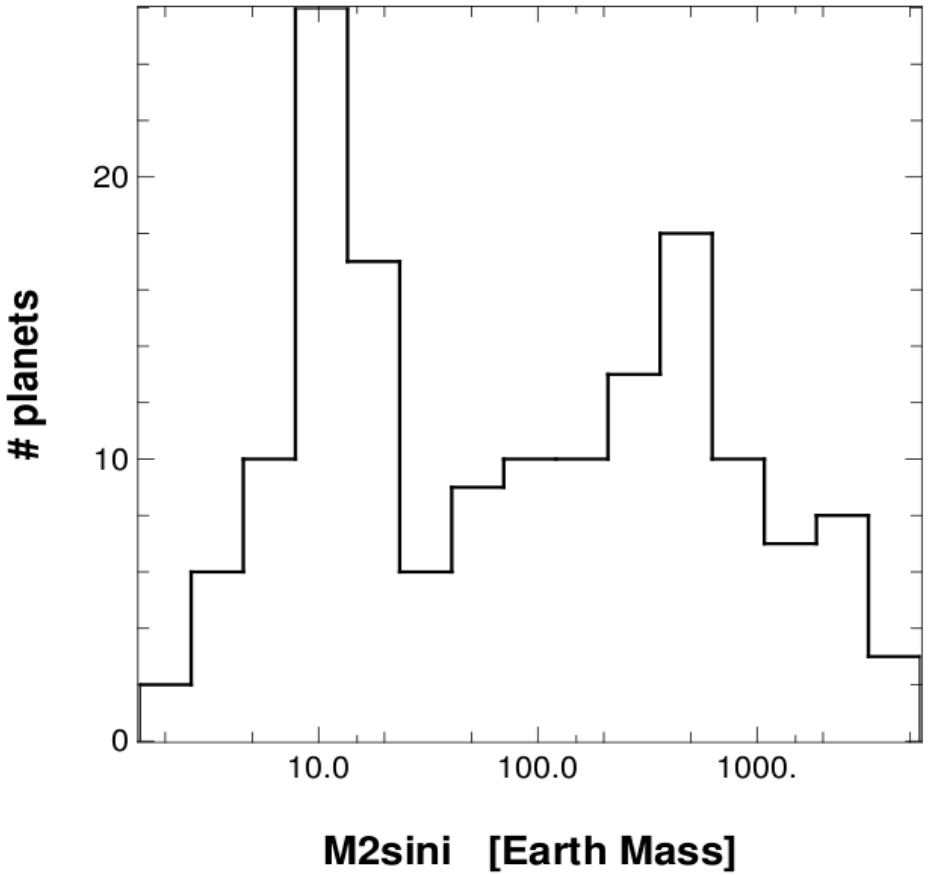


Fig. 10. Observed mass histogram for the planets in the combined sample. Before any bias correction, we can already notice the importance of the sub-population of low-mass planets. We also remark a gap in the histogram between planets with masses above and below ~30 $M_{\oplus}$.

Mayor idr. 2011

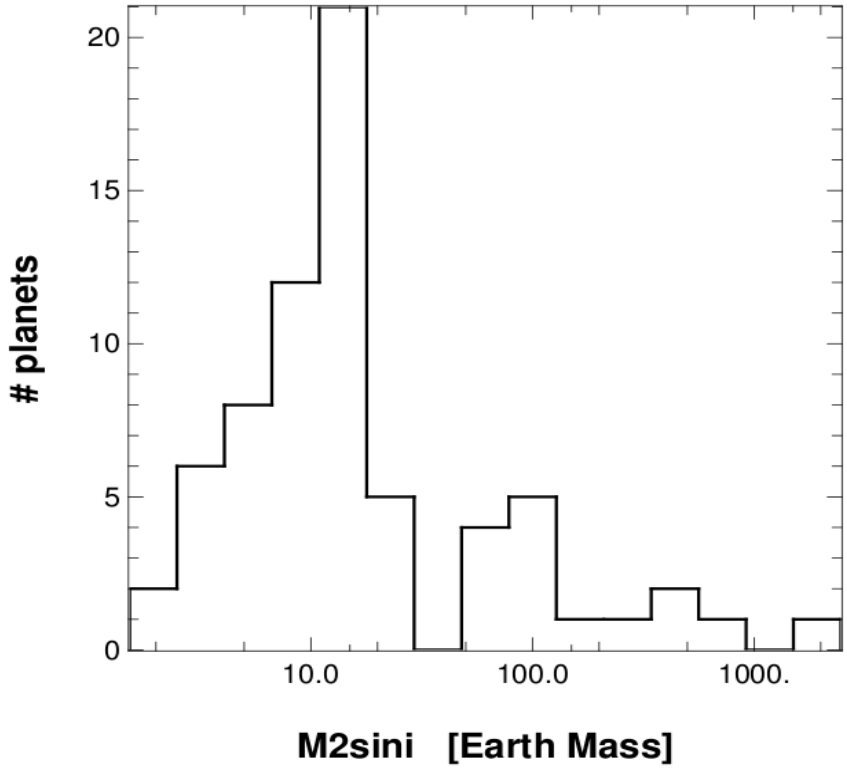


Fig. 11. Same as Fig. 10 but for planets with periods smaller than 100 days. We see the dominance of low-mass planet with short orbital periods.

HARPS: zadnji rezultati

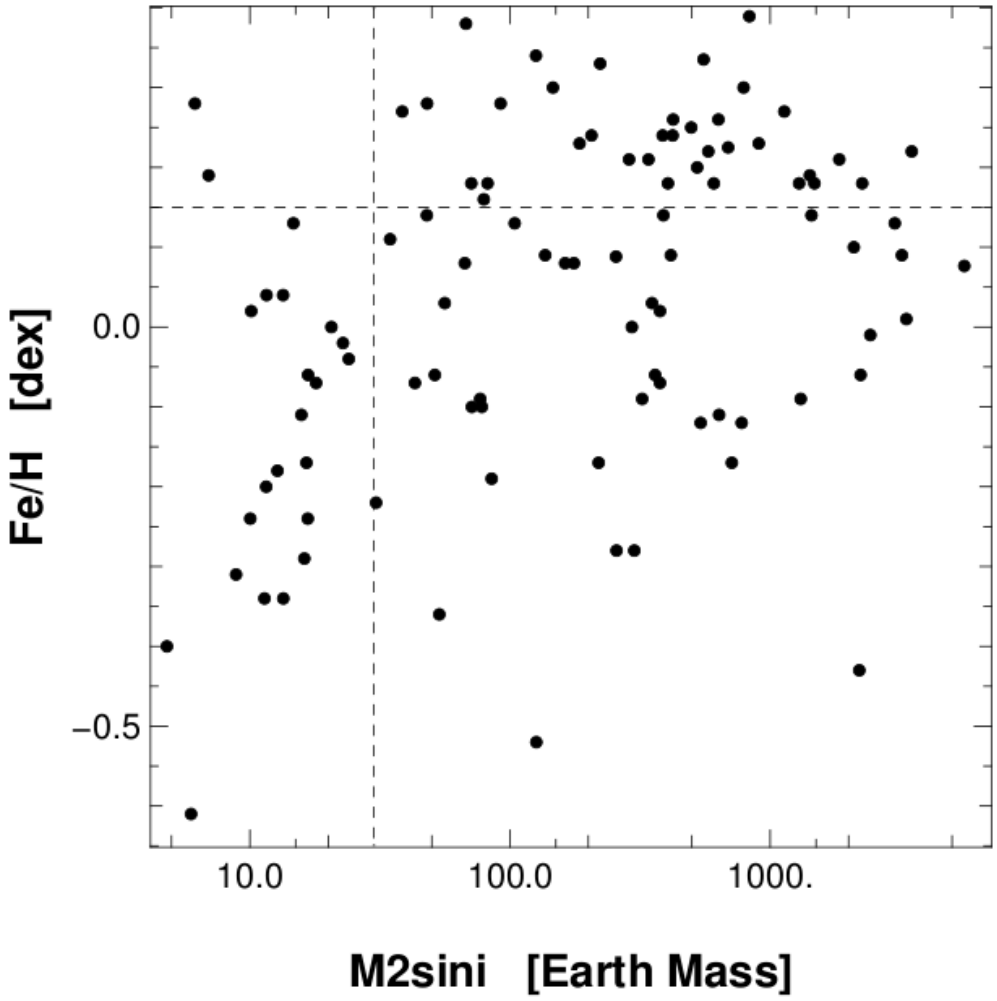


Fig. 17. Estimation of the planetary-mass limit between the two regimes for the metallicity dependance of host stars. A vertical line at 30 $M_{\oplus}$ distinguishes the two populations. We should note that such a limit also corresponds to the gap in the mass distribution (see Fig. 10 and 12). On the right side of the vertical line we do not observe significant changes of the metallicity distribution above 30 M⊕. We remark that stars with metallicity exceeding 0.15 are for their huge majority associated with planets more massive than 30 $M_{\oplus}$.

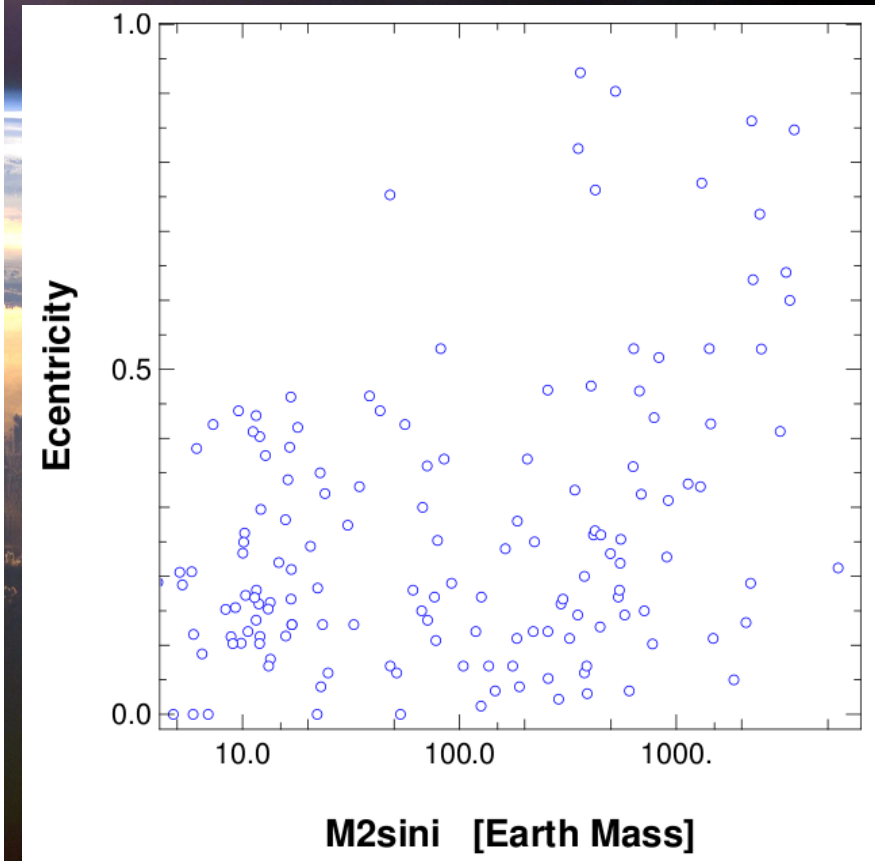
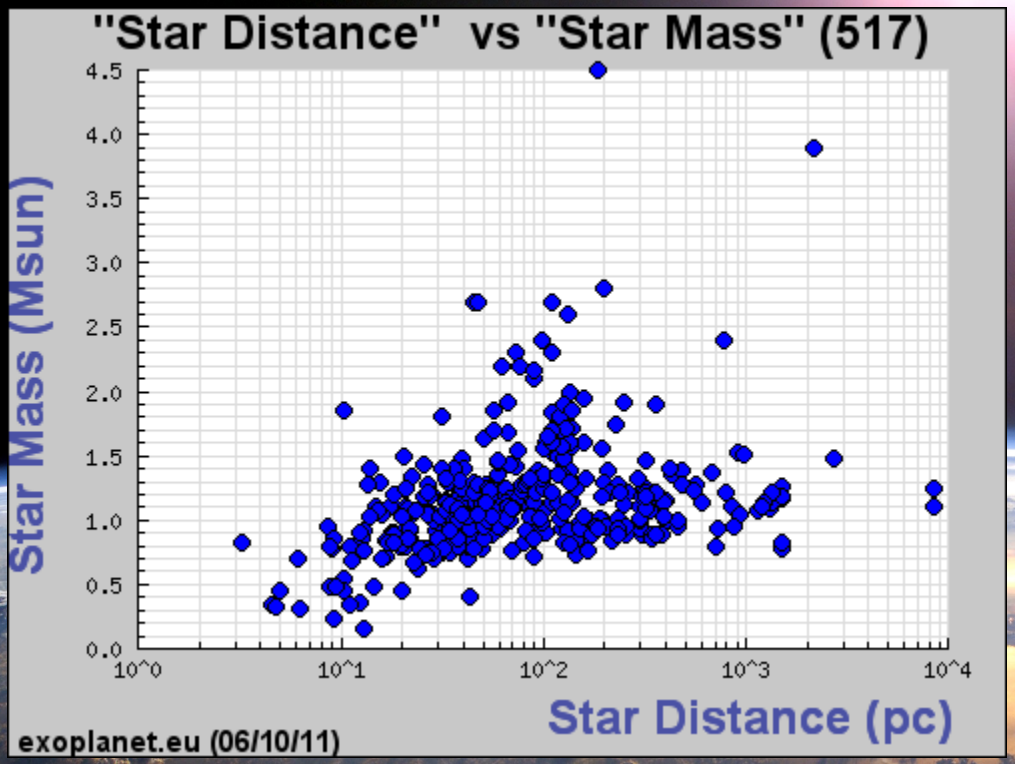


Fig. 15. Mass-eccentricity diagram for the planets in the combined sample.

Mayor idr. 2011

HARPS: zadnji rezultati



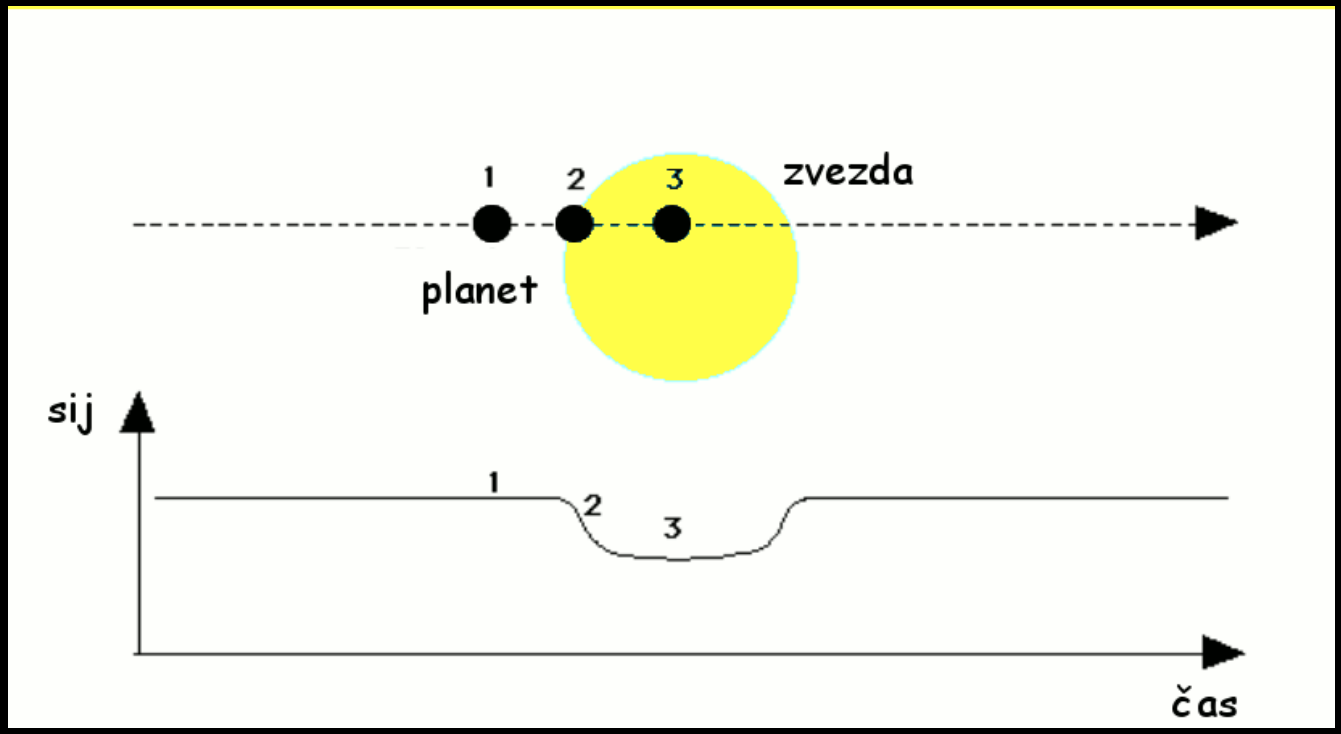
Orjaški planeti (masa nad 50 Zemljinih, orbitalna perioda pod 10 let) so prisotni ob 14% zvezd.

Nad-Zemlje in Neptuni (masa pod 30-40 Zemljinih) s periodami 40..80 dni so prisotni ob 50% zvezd.

Mayor idr. 2011

Opazovanje potemnitve zvezde

Planet prekrije del ploskve zvezde.

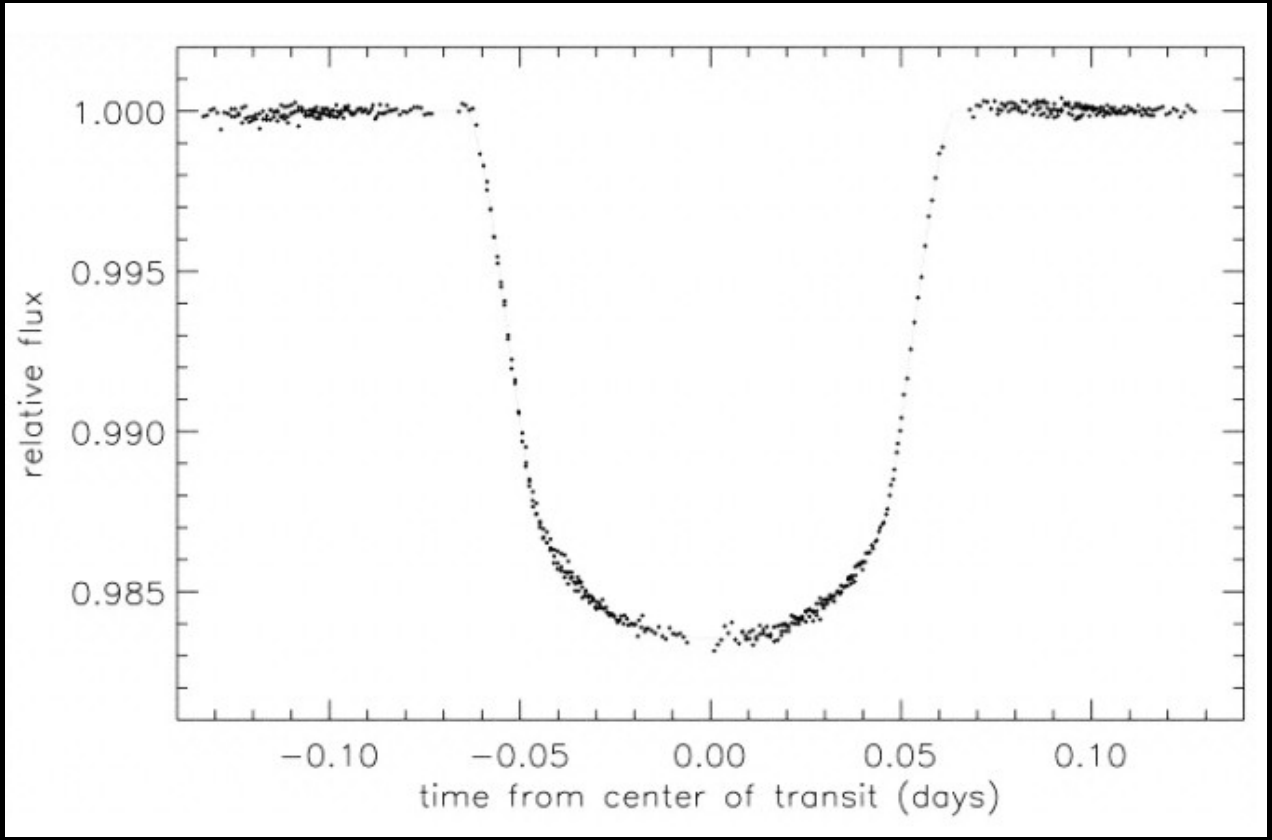


$(j_{\text{zunaj prehoda}} - j_{\text{med prehodom}})/j_{\text{zunaj prehoda}} = (\pi R_{\text{planet}}^2) / (\pi R_{\odot}^2) = (R_{\text{planet}} / R_{\odot})^2$

Delež potemnitve zvezde ob prehodu planeta.

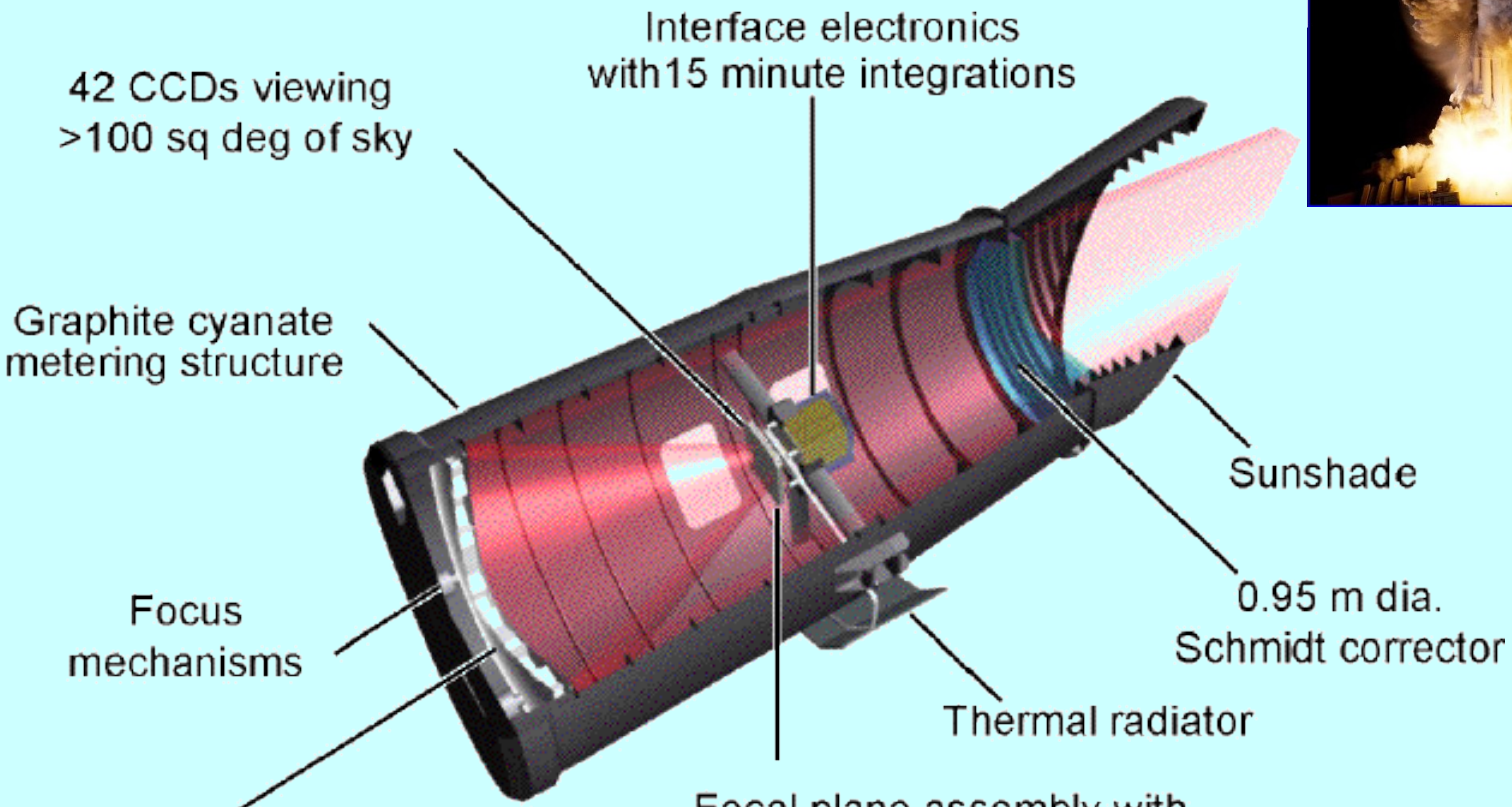
Opazovanje potemnitve zvezde

Planet prekrije del ploskve zvezde.

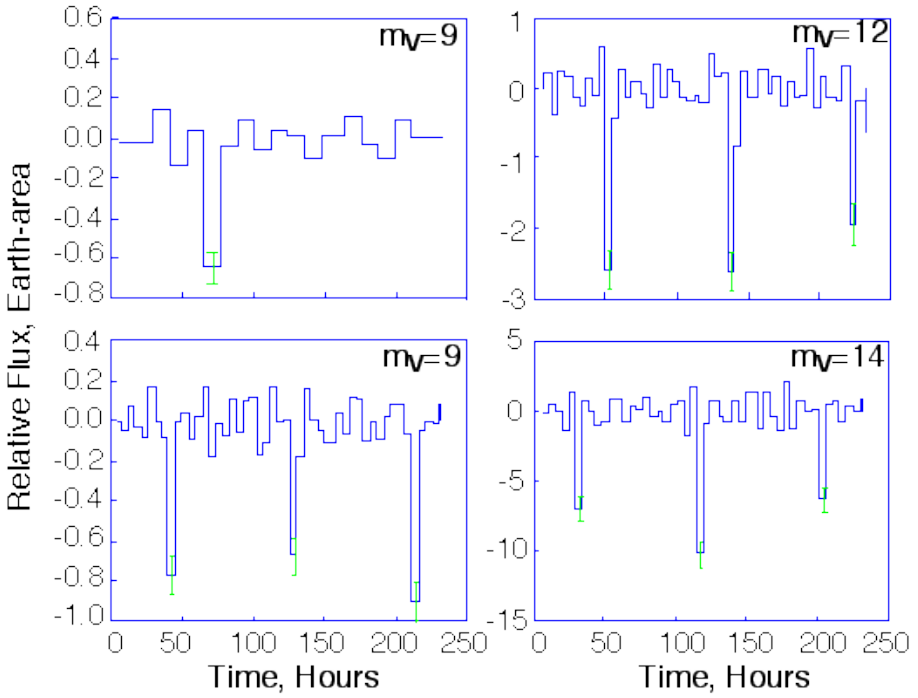


6. marec 2009

Kepler



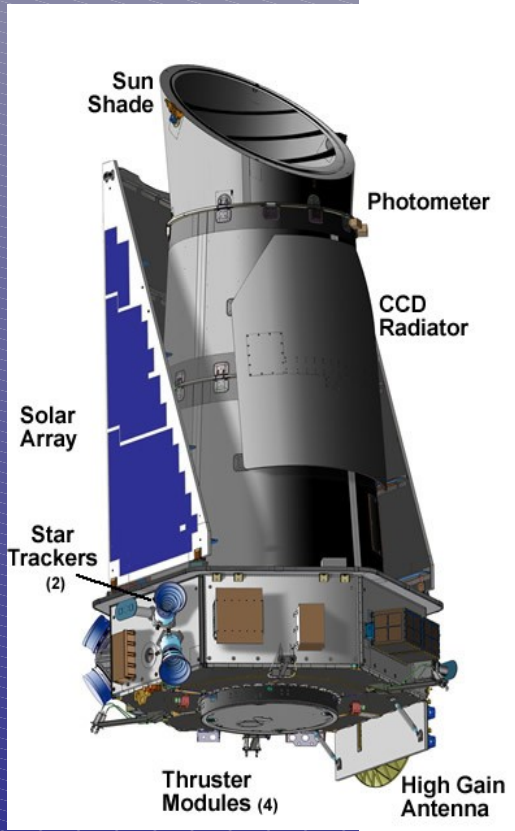
- direktno opazovanje:
  - prehod planeta preko zvezdine ploskvice
  - periodično je zvezda je videti nekoliko temnejša



6,5h integracija, 20E-6 točnost
Za zvezdo 12. magnitude.

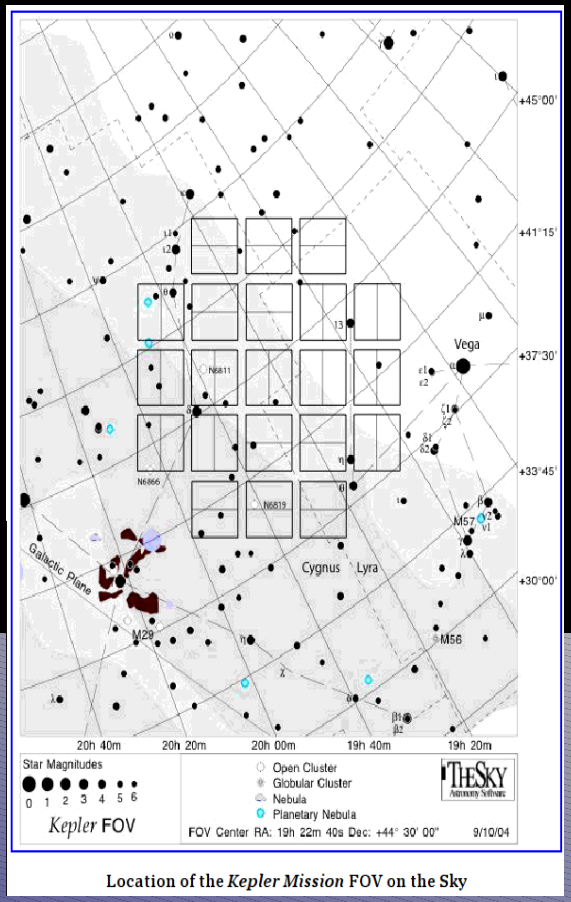
System Characteristics:

- Spacebased Photometer: 0.95-m aperture
- Primary mirror: 1.4 meter diameter, 85% light weighted
- Detectors: 95 mega pixels (42 CCDs with 2200x1024 pixels)
- Bandpass: 430-890 nm FWHM
- Dynamic range: 9th to 16th magnitude stars
- Fine guidance sensors: 4 CCDs located on science focal plane
- Attitude stability: <9 milli-arcsec, 3 sigma over 15 minutes.
- Science data storage: >60 days
- Uplink X-band: 7.8125 bps to 2 kbps
- Downlink X-band: 10 bps to 16 kbps
- Downlink Ka-band: Up to 4.33125 Mbps
- Photometric One-Sigma Noise Performance:
- Total noise with solar-like stellar variability and photon
- shot noise for an mv=12 star: < 2x10-5
- Flight segment and instrument mass: 1071 kg, maximum expected (10/06)
- Flight segment and instrument power: 771 W, maximum expected (10/06)

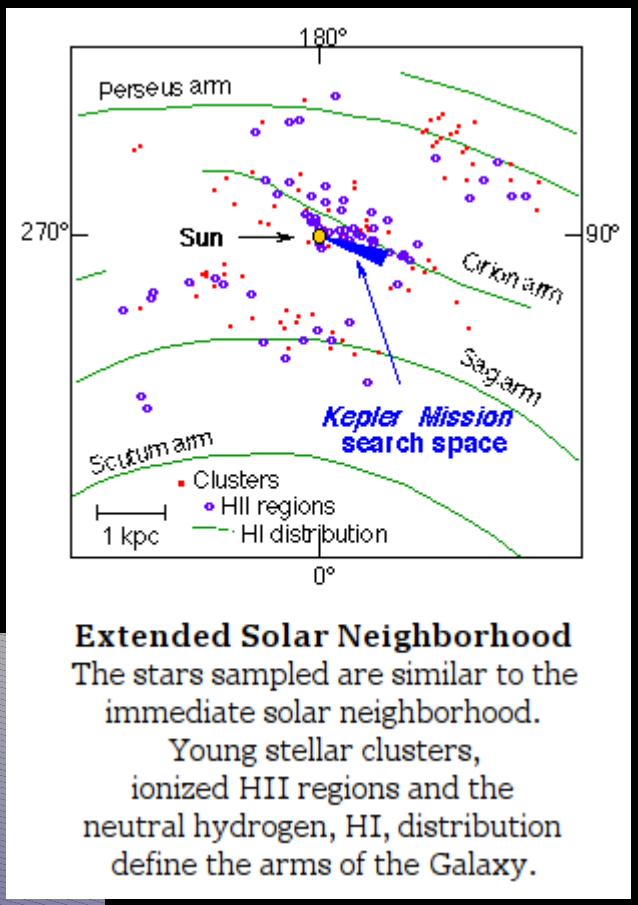


Kepler

Kepler



Location of the *Kepler Mission* FOV on the Sky



Extended Solar Neighborhood
The stars sampled are similar to the immediate solar neighborhood. Young stellar clusters, ionized HII regions and the neutral hydrogen, HI, distribution define the arms of the Galaxy.

pričakovani rezultati

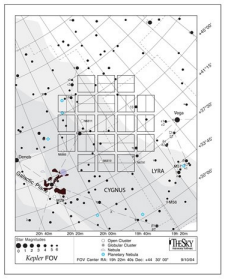
v 4 letih misije:

- 50 planetov z R~R_z
- 185 planetov z R~1.3 R_z
- 640 planetov z R~2.2 R_z
- 12% sistemov z dvema ali več planeti

National Aeronautics
and Space Administration

Kepler
First Light Image

April 08, 2009



Kepler

JPL

LASP LHS SAO SETI Institute STScI

Characteristics of planetary candidates observed by *Kepler*, II: Analysis of the first four months of data

Borucki idr. (tudi Andrej Prša) 2011

Abstract. On 1 February 2011 the *Kepler* Mission released data for 156,453 stars observed from the beginning of the science observations on 2 May through 16 September 2009. There are 1235 planetary candidates with transit like signatures detected in this period. These are associated with 997 host stars. Distributions of the characteristics of the planetary candidates are separated into five class-sizes; 68 candidates of approximately Earth-size ($R_p < 1.25\ R_\oplus$), 288 super-Earth size ($1.25\ R_\oplus < R_p < 2\ R_\oplus$), 662 Neptune-size ($2\ R_\oplus, < R_p < 6\ R_\oplus$), 165 Jupiter-size ($6\ R_\oplus < R_p < 15\ R_\oplus$), and 19 up to twice the size of Jupiter ($15\ R_\oplus < R_p < 22\ R_\oplus$). In the temperature range appropriate for the habitable zone, 54 candidates are found with sizes ranging from Earth-size to larger than that of Jupiter. Six are less than twice the size of the Earth. Over 74% of the planetary candidates are smaller than Neptune. The observed number versus size distribution of planetary candidates increases to a peak at two to three times Earth-size and then declines inversely proportional to area of the candidate. Our current best estimates of the intrinsic frequencies of planetary candidates, after correcting for geometric and sensitivity biases, are 5.4% for Earth-size candidates, 6.8% for super-Earth size candidates, 19.3% for Neptune-size candidates, 2.4% for Jupiter-size candidates, and 0.15% for very-large candidates; a total of 0.341 candidates per star. Multi-candidate, transiting systems are frequent; 17% of the host stars have multi-candidate systems, and 33.9% of all the candidates are part of multi-candidate systems.

Characteristics of planetary candidates observed by *Kepler*, II: Analysis of the first four months of data

Borucki idr. (tudi Andrej Prša) 2011

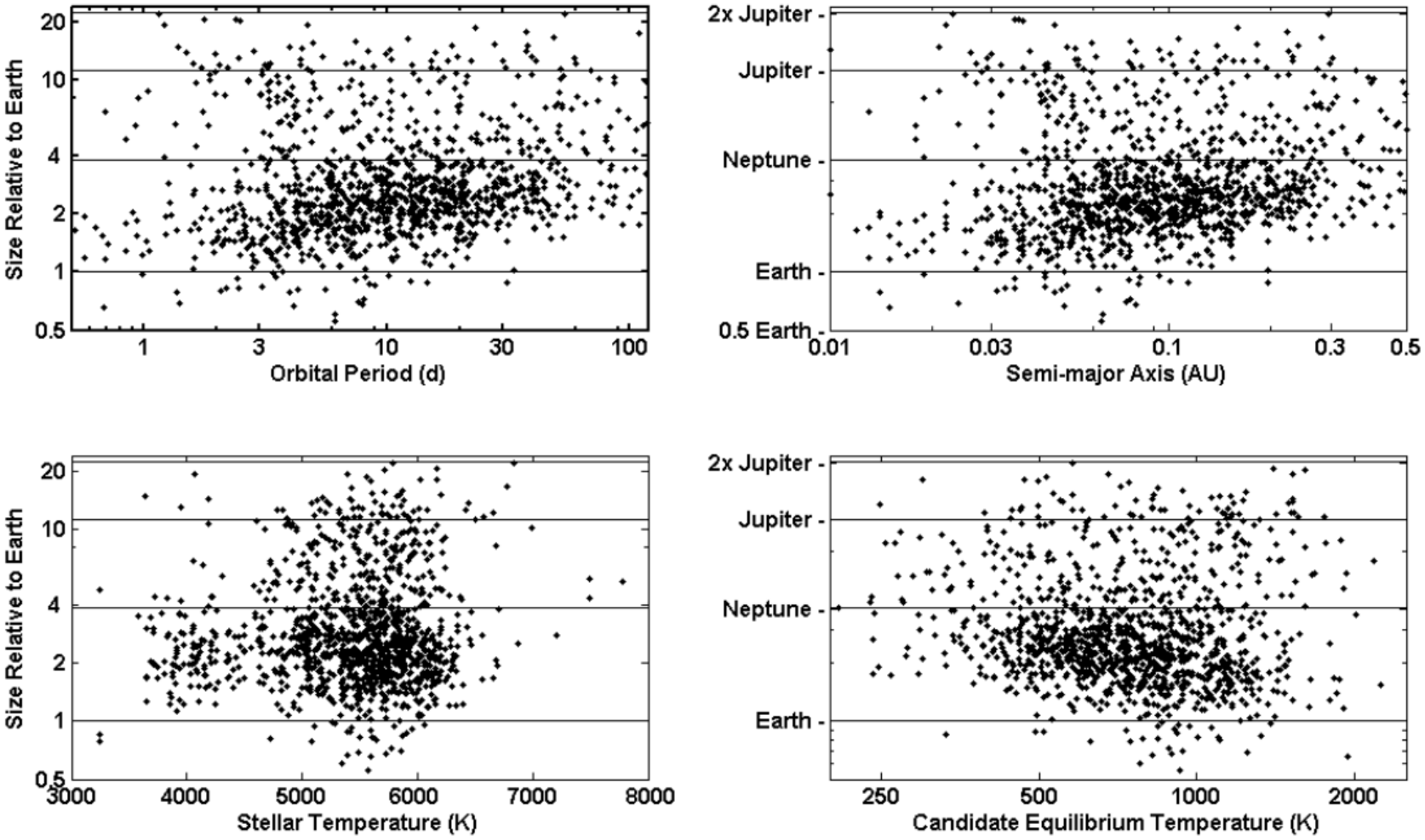
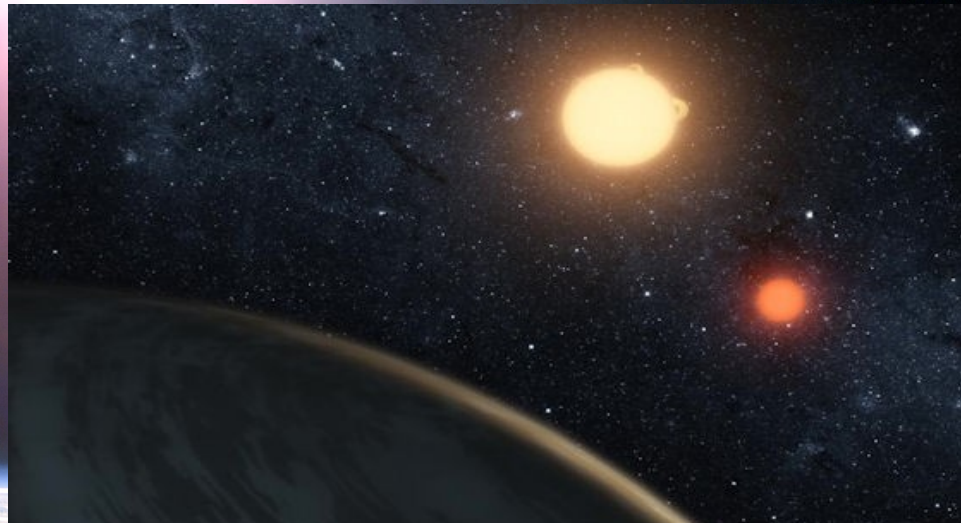
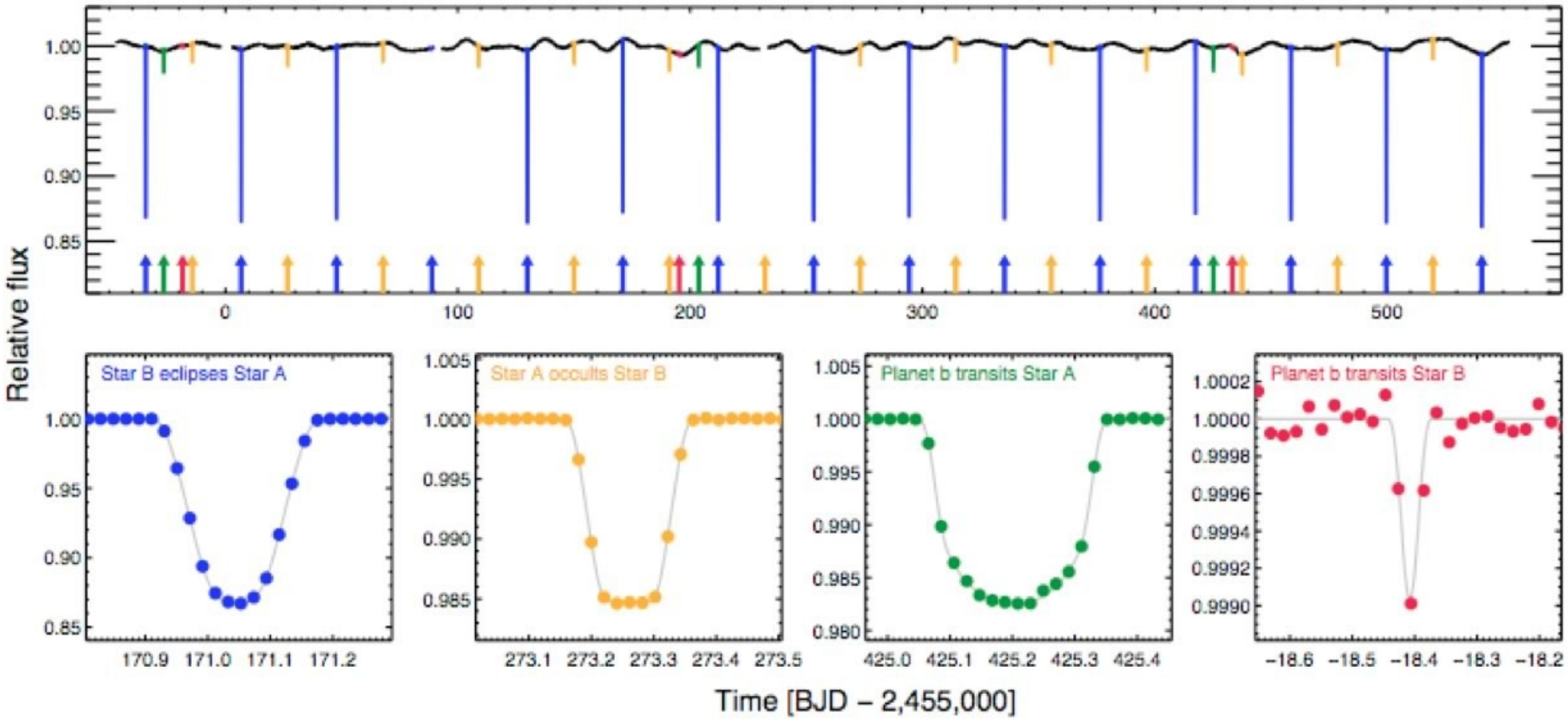


Figure 3. Candidate size versus orbital period, semi-major axis, stellar temperature, and candidate equilibrium temperature[3]. Uncertainties in candidate size are mostly due to the uncertainty in stellar sizes, i.e., approximately 25%. Horizontal lines mark ratios of candidate sizes for Earth-size, Neptune-size , and Jupiter-size relative to Earth-size.

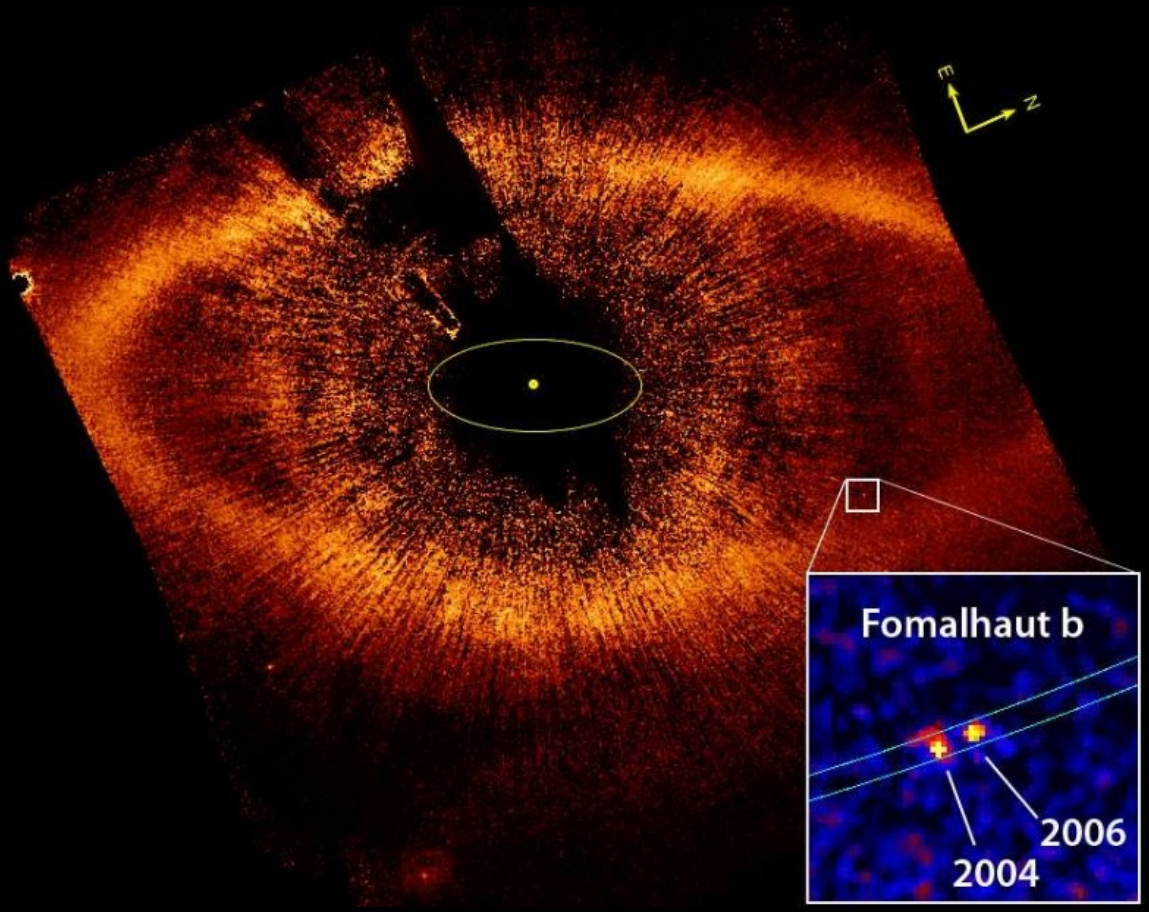
Doyle idr. (tudi Andrej Prša) 2011

Dvojna zvezda s planetom Kepler 16b





Opazovanje odbite svetlobe planeta (z zastrto svetlobo zvezde)



ZVEZDA FORMALHAUT

izsev planeta: 0,34 10^{-6} L_{SONCE}

polmer planeta: 1,2 $R_{JUPITER}$

temperatura planeta: 130 °C

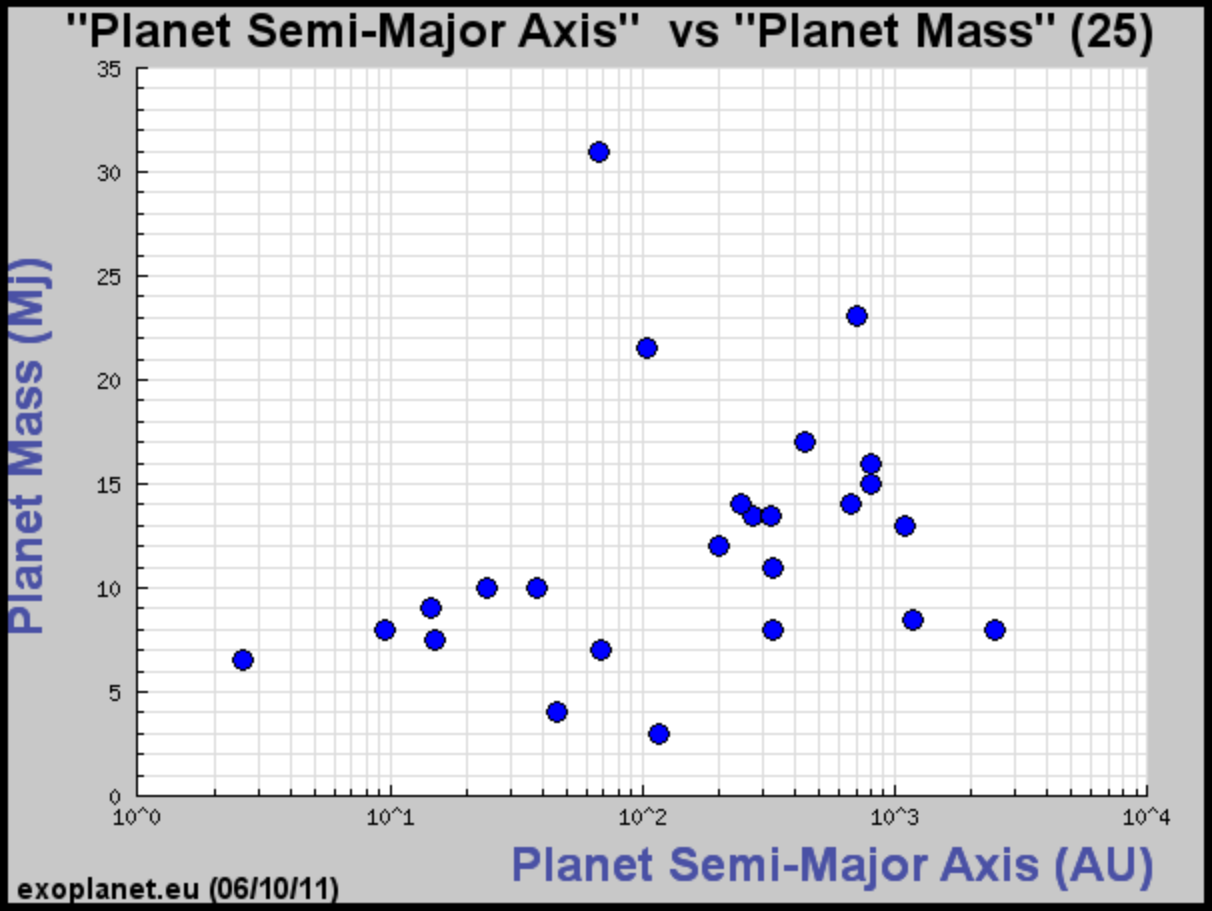
razdalja od zvezde: 115 a.e.

orbitalna perioda: 872 let

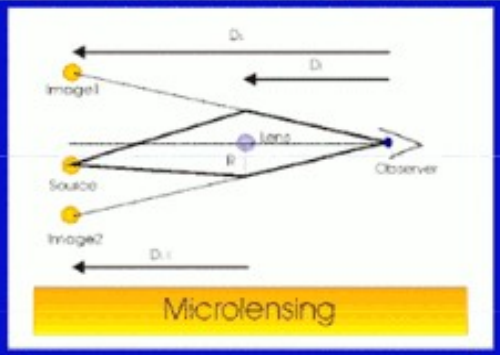
Kalas idr. 2008

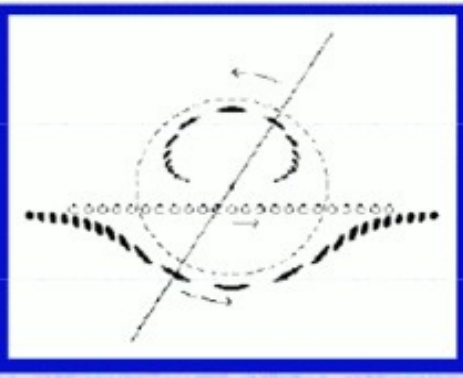
Opazovanje odbite svetlobe planeta (z zastrto svetlobo zvezde)

Planeti odkriti z direktnim slikanjem: 25 planetov okoli 22 zvezd.



Gravitational Microlensing

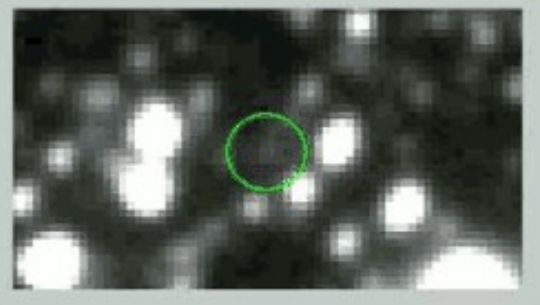


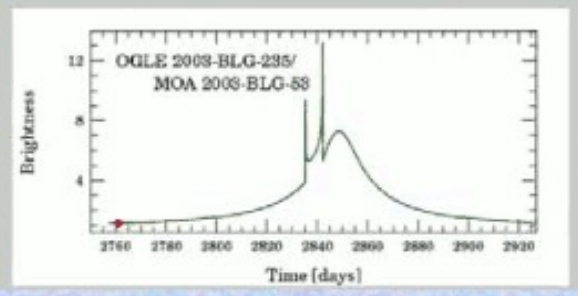


A gravitational lens creates two Images of a background star. Geometry of a lensing event is defined by location of trajectory of the lensed star with respect to the Einstein ring of the lens:

$$R_E^2 = \frac{4GM_L D}{c^2} \qquad D = \frac{D_{LS} D_L}{D_S}$$

Shapes and locations of source images change according to position changes of the lensed star with respect to the lens and its Einstein ring

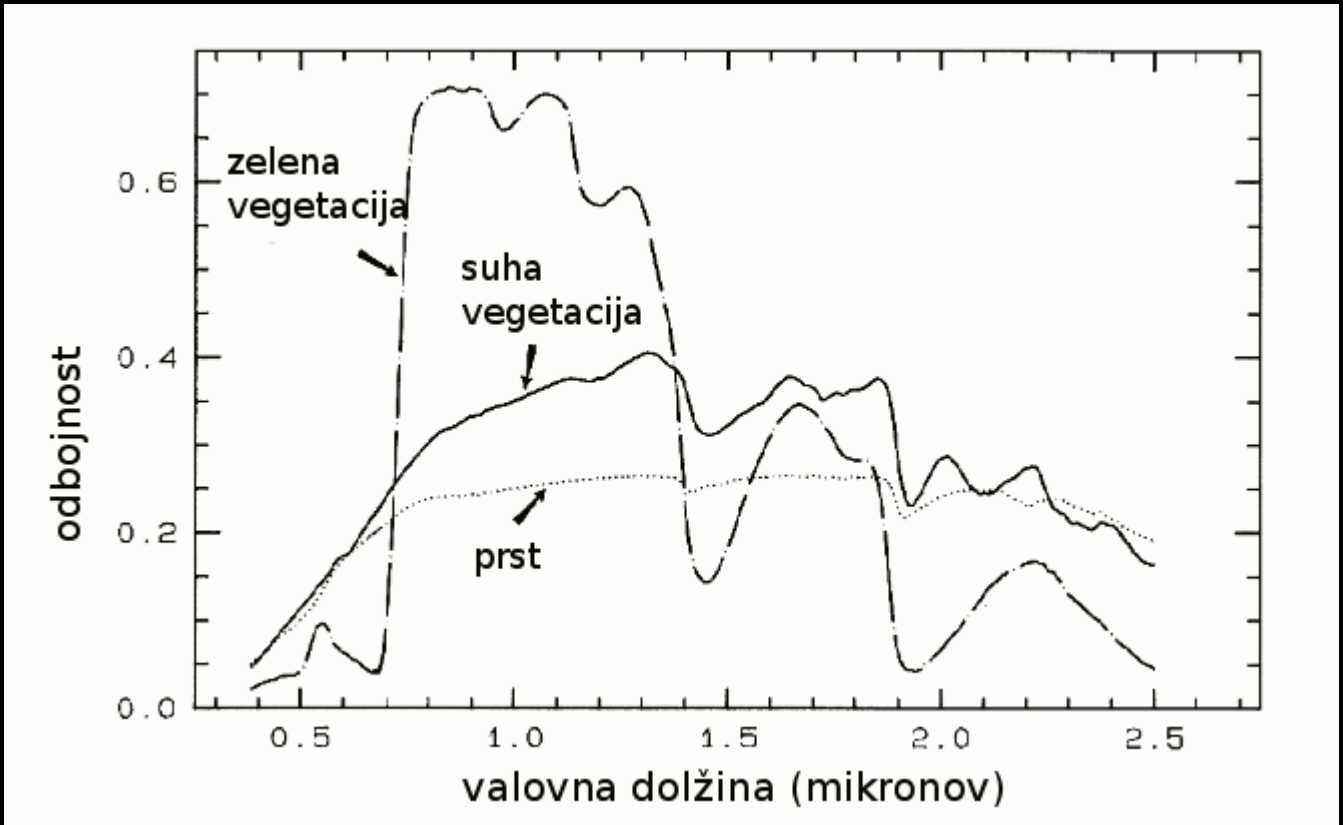




The presence of a planet around the lensing star further modifies the light curve of the background star

- An appropriate geometry occurs very infrequently (need to observe millions of stars) and the phenomenon is not repeatable
- The method is sensitive to Earth-mass planets

Odbita svetloba s planeta: odkrivanje vegetacije



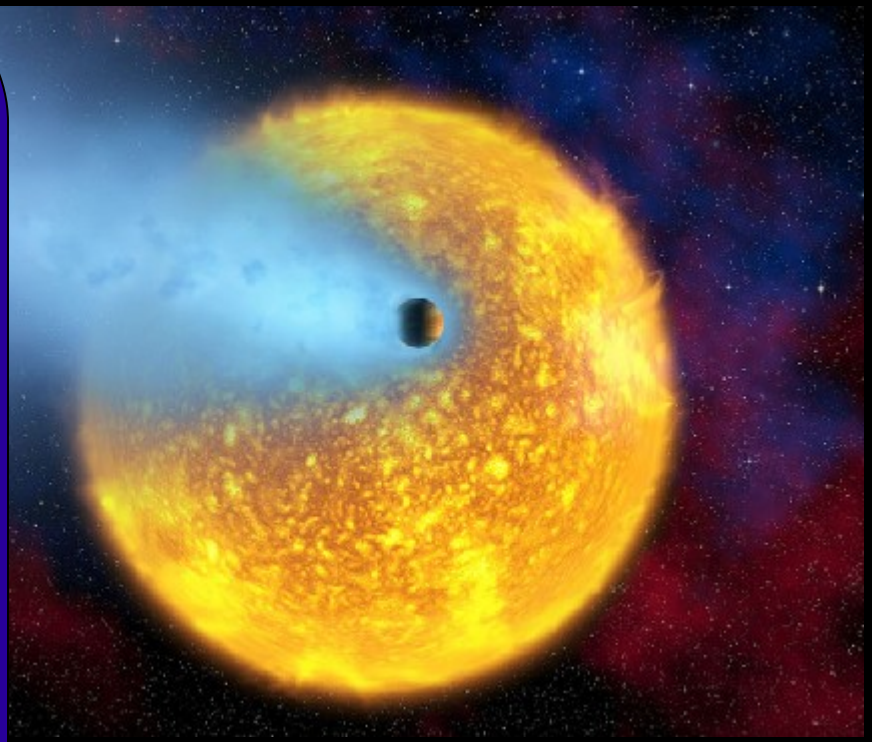
POTREBOVALI BI POLJE 150 3-metrskih TELESKOPOV

Arnold idr. 2009

Planet ob zvezdi HD 209458 ima atmosfero

Ob prehodu planeta preko zvezdine ploskvice opazimo poleg geometrijskega pokritja dela zvezde še dodatno absorpcijo zaradi natrija, vodika in ogljika v planetovi atmosferi.

Oddaljenost od Zemlje: 160 sv.l.
masa planeta: 0.7 $M_{Jupiter}$
polmer planeta: 1.5 $R_{Jupiter}$
planet izgublja: ~10^7 kg/s



Niso (še) odkrili O_2!

Velika vprašanja

- Izvor Osončja?
- Pogostost planetnih sistemov?
- Pogostost zemeljskih planetov?
- Življenje še kje v Osončju? Zakaj je Zemlja izjema?
- Je življenje še kje v vesolju? Izjema ali pravilo? Inteligentno življenje?

Hvala za pozornost!