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Exoplanet Transit Database

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Planetární soustavy ve vesmíru

Hvězdárna Valašské Meziříčí

24. října 2009

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exoplanety...

- definice neexistuje ...

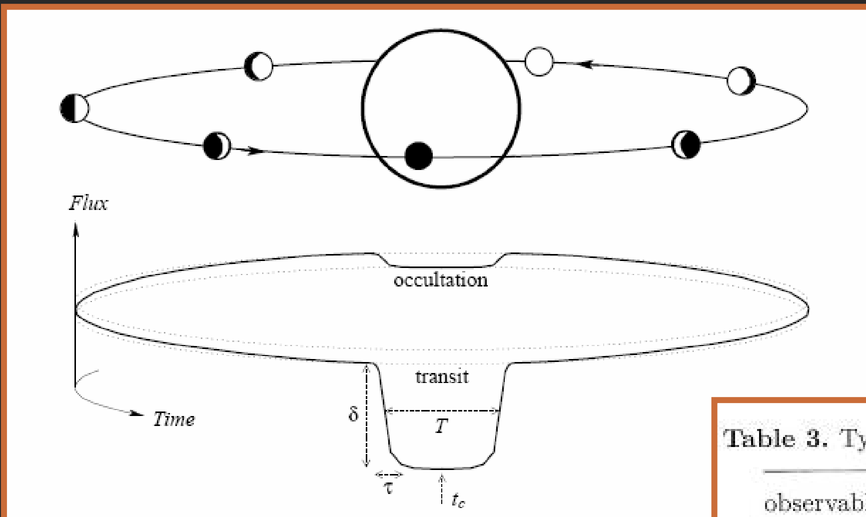
- **neoficiální definice**:
  - obíhá kolem hvězdy nebo vícenásobného hvězdného systému – eliminace free-floating planet-mass objektů
  - neobíhá kolem další planety
  - minimální hmotnost 10^{22} kg
  - maximální hmotnost 13 M_{Jup} ($m \textit{sin}\, i < 13\ M_{Jup}$)

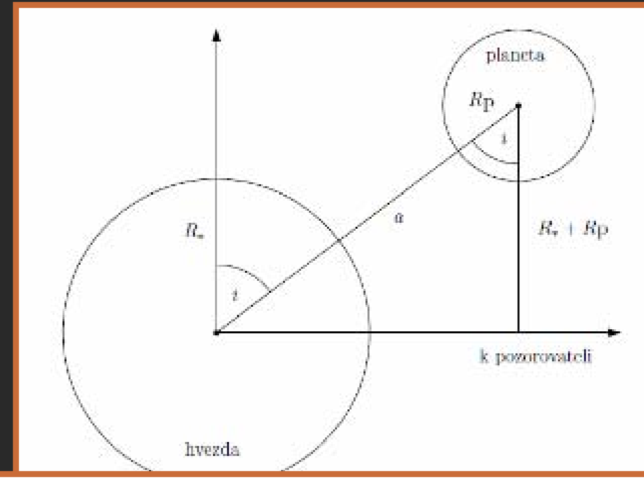
- 1992 Wolszczan a Frail – PSR B1257+12 (vznik planet v okolí pulzaru ??)
- 1995 Mayor & Quelez – 51 Peg b (cca 400 do dnešního dne)
- 2000 Charbonneau; Henry – první tranzit, HD 20945 b (62)
- ...
- 2008 velké množství pozorovatelů

tranzity ...

- 2000 Charbonneau; Henry – první tranzit, HD 20945 b (62)

... 2008 velké množství pozorovatelů





- pravděpod. a délka trvání tranzitu

$$p_{\rm trans} = \frac{R_* + R_p}{a} \approx \frac{R_*}{a}$$

$$t_Z = \frac{P}{\pi} \arcsin\left(\frac{\sqrt{(R_* + R_P)^2 - a^2\cos^2 i}}{a}\right)$$

$$i = \arccos\sqrt{\frac{(R_* + R_P)^2}{a^2} - \sin^2\frac{\pi t_Z}{P}}$$

Table 3. Typical values of observables for Jupiter-like and Earth-like planets

observable	Jupiter	Earth
angular separation	0″.5	0″.1
brightness contrast at visible λλ	6×10^{-7}	1.5×10^{-10}
brightness contrast at 10 µm	1.5×10^{-7}	1.2×10^{-7}
astrometric amplitude	500 µas	0.3 µas
radial-velocity amplitude	13 m s^{-1}	0.1 m s^{-1}
transit probability	10^{-3}	5×10^{-3}
transit depth	1%	10^{-4}
transit duration	30 h	13 h
timing residuals	2.5 s	1.5 ms

The host star is assumed to be a Sun twin at a distance of 10 pc

proč ETD ...

- velké množství pozorovatelů ... co dělat s daty ???
- *říjen 2008* – spuštěna pro veřejnost

inspirace ...

- NASA/IPAC/NExScI Star and Exoplanet Database (NStED)
  - http://nsted.ipac.caltech.edu/
- Amateur Exoplanet Archive (AXA)
  - http://brucegary.net/AXA/x.htm

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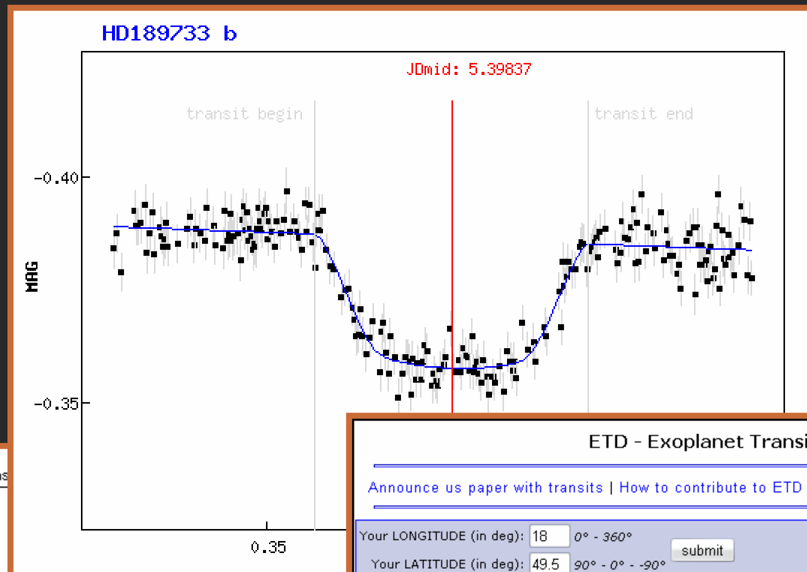
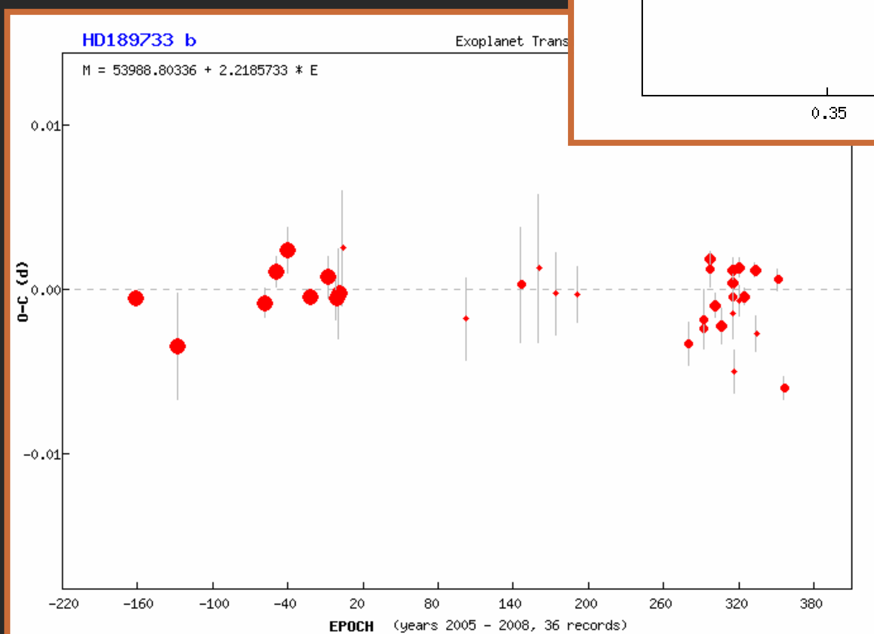
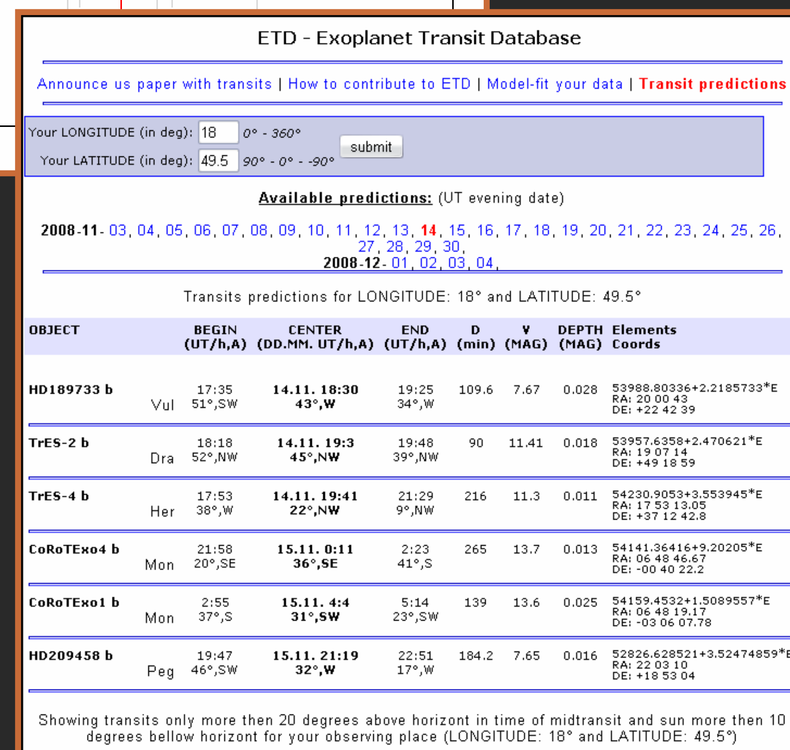
jak vypadá ETD ...

- *transit predictions*
- *model-fit your data*
- *O-C gates*







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Announce us paper with transits | How to contribute to ETD | Model-fit your data | **Transit predictions**

Your LONGITUDE (in deg): 18 *0° - 360°*
Your LATITUDE (in deg): 49.5 *90° - 0° - -90°*
submit

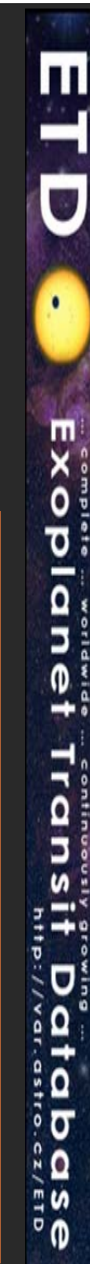
Available predictions: (UT evening date)

2008-11- 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30,
2008-12- 01, 02, 03, 04,

Transits predictions for LONGITUDE: 18° and LATITUDE: 49.5°

OBJECT		BEGIN (UT/h,A)	CENTER (DD.MM. UT/h,A)	END (UT/h,A)	D (min)	V (MAG)	DEPTH (MAG)	Elements Coords
HD189733 b	Vul	17:35 51°,SW	**14.11. 18:30 43°,W**	19:25 34°,W	109.6	7.67	0.028	53988.80336+2.2185733*E RA: 20 00 43 DE: +22 42 39
TrES-2 b	Dra	18:18 52°,NW	**14.11. 19:3 45°,NW**	19:48 39°,NW	90	11.41	0.018	53957.6358+2.470621*E RA: 19 07 14 DE: +49 18 59
TrES-4 b	Her	17:53 38°,W	**14.11. 19:41 22°,NW**	21:29 9°,NW	216	11.3	0.011	54230.9053+3.553945*E RA: 17 53 13.05 DE: +37 12 42.8
CoRoTExo4 b	Mon	21:58 20°,SE	**15.11. 0:11 36°,SE**	2:23 41°,S	265	13.7	0.013	54141.36416+9.20205*E RA: 06 48 46.67 DE: -00 40 22.2
CoRoTExo1 b	Mon	2:55 37°,S	**15.11. 4:4 31°,SW**	5:14 23°,SW	139	13.6	0.025	54159.4532+1.5089557*E RA: 06 48 19.17 DE: -03 06 07.78
HD209458 b	Peg	19:47 46°,SW	**15.11. 21:19 32°,W**	22:51 17°,W	184.2	7.65	0.016	52826.628521+3.52474859*E RA: 22 03 10 DE: +18 53 04

Showing transits only more then 20 degrees above horizont in time of midtransit and sun more then 10 degrees bellow horizont for your observing place (LONGITUDE: 18° and LATITUDE: 49.5°)



transit predictions ...

- cca měsíční předpověď pro libovolné místo na světě

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Your ELONGITUDE (in deg): 15 *0° - 360°*

Your LATITUDE (in deg): 50 *90° - 0° - -90°*

submit

Available predictions: (UT evening date)

2009-04 - 07, 08, 09, 10, 11, 12, 13, 14, **15**, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30,
2009-05 - 01, 02, 03, 04, 05, 06, 07, 08,

Transits predictions for ELONGITUDE: 15° and LATITUDE: 50°

OBJECT		BEGIN (UT/h,A)	CENTER (DD.MM. UT/h,A)	END (UT/h,A)	D (min)	V (MAG)	DEPTH (MAG)	Elements Coords
HAT-P-4 b	Boo	0:6 75°,SE	**15.04. 2:13 70°,SW**	4:19 50°,W	253	11.2	0.008	54245.8154+3.056536*E RA: 15 19 57.92 DE: +36 13 46.7
TrES-2 b	Dra	22:35 38°,NE	**16.04. 23:20 44°,NE**	0:5 50°,NE	90	11.41	0.018	53957.6358+2.470621*E RA: 19 07 14 DE: +49 18 59

Showing transits only more then 20 degrees above horizont in time of midtransit and sun more then 10 degrees bellow horizont for your observing place (ELONGITUDE: 15° and LATITUDE: 50°)

Credit & Contact

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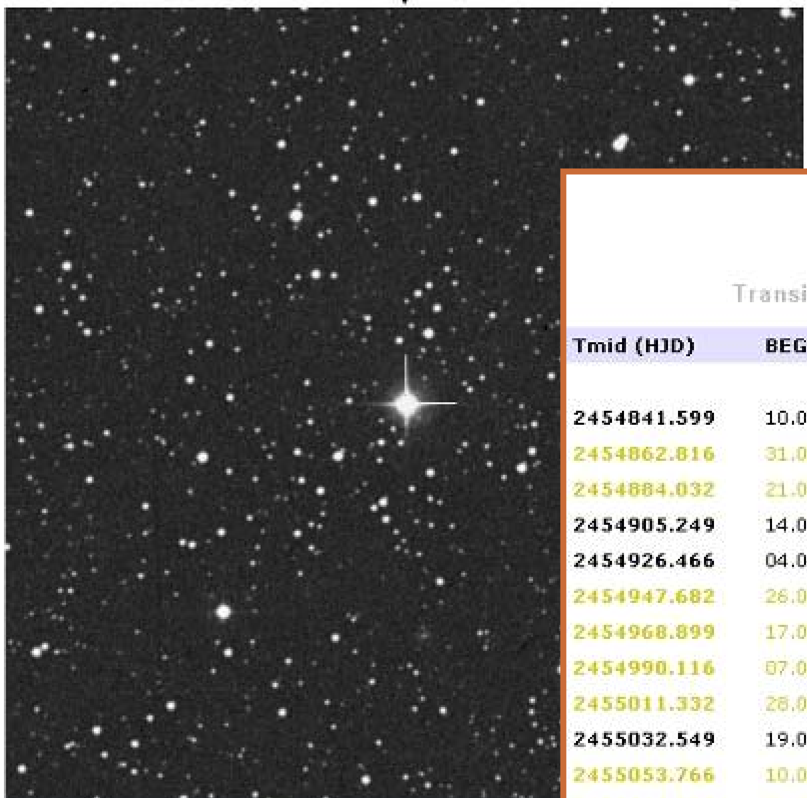
- roční předpověď

HD17156 b (Cas)

RA (J2000): **02 49 44**, DE (J2000): **+71 45 12**,
V = **8.17 mag**, dV = **0.008 mag**, duration = **192.6 minutes**
Per = **21.21663d**, T0(HJD) = **2454459.69987**



Transits predictions for NEXT 365 days.
LONGITUDE: 15° and LATITUDE: 50°

Transit occurs below 20° in the sky. | During the daylight. | **Observable.**

Tmid (HJD)	BEGIN (UT/h,A)	CENTER (DD.MM. UT/h,A)	END (UT/h,A)
2454841.599	10.01 0:46(46°,NW)	**10.01. 2:22(40°,N)**	10.01 3:59(35°,N)
2454862.816	31.01 5:58(33°,N)	**31.01. 7:34(35°,N)**	31.01 9:11(40°,N)
2454884.032	21.02 11:10(54°,NE)	**21.02. 12:46(61°,NE)**	21.02 14:23(67°,N)
2454905.249	14.03 16:22(65°,N)	**14.03. 17:58(58°,NW)**	14.03 19:35(50°,NW)
2454926.466	04.04 21:34(37°,N)	**04.04. 23:10(34°,N)**	05.04 0:46(32°,N)
2454947.682	26.04 2:46(37°,N)	**26.04. 4:22(42°,NE)**	26.04 5:58(49°,NE)
2454968.899	17.05 7:58(64°,NE)	**17.05. 9:34(68°,N)**	17.05 11:10(68°,N)
2454990.116	07.06 13:10(54°,NW)	**07.06. 14:46(47°,NW)**	07.06 16:22(40°,N)
2455011.332	28.06 18:22(33°,N)	**28.06. 19:58(32°,N)**	28.06 21:34(35°,N)
2455032.549	19.07 23:34(46°,NE)	**20.07. 1:10(53°,NE)**	20.07 2:46(60°,NE)
2455053.766	10.08 4:46(69°,N)	**10.08. 6:22(66°,N)**	10.08 7:58(59°,NW)
2455074.982	31.08 9:57(44°,NW)	**31.08. 11:34(38°,N)**	31.08 13:10(34°,N)
2455096.199	21.09 15:9(33°,N)	**21.09. 16:46(36°,N)**	21.09 18:22(42°,NE)
2455117.415	12.10 20:21(57°,NE)	**12.10. 21:58(64°,NE)**	12.10 23:34(68°,N)
2455138.632	03.11 1:33(63°,NW)	**03.11. 3:10(56°,NW)**	03.11 4:46(48°,NW)
2455159.849	24.11 6:45(36°,N)	**24.11. 8:22(33°,N)**	24.11 9:58(32°,N)
2455181.065	15.12 11:57(38°,N)	**15.12. 13:34(45°,NE)**	15.12 15:10(52°,NE)

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model-fit your data ...

(uploading and processing the light curves to the database)

Předpokládáme:

- *N* diff. magnitud m_i získaných v čase t_i a chyba σ_i (z Poisson stat. a read-out šumu)

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step 1 / 5

INSTRUCTION: In the first step, just select an exoplanet and load data file with observation. Also select if data are in geocentric or heliocentric JD and specify, if brightness is given in MAG or FLUX.

Choose exoplanet CoRoT-1 b Mon

Data file with observation: *Required 3 columns: JD, MAG, ERROR. Other columns are ignored. Columns must be separated by space or TAB.* [Procházet...]

JD format: (•) geocentric ( ) heliocentric

Brightness column: (•) in magnitudes ( ) in flux

[Continue >]

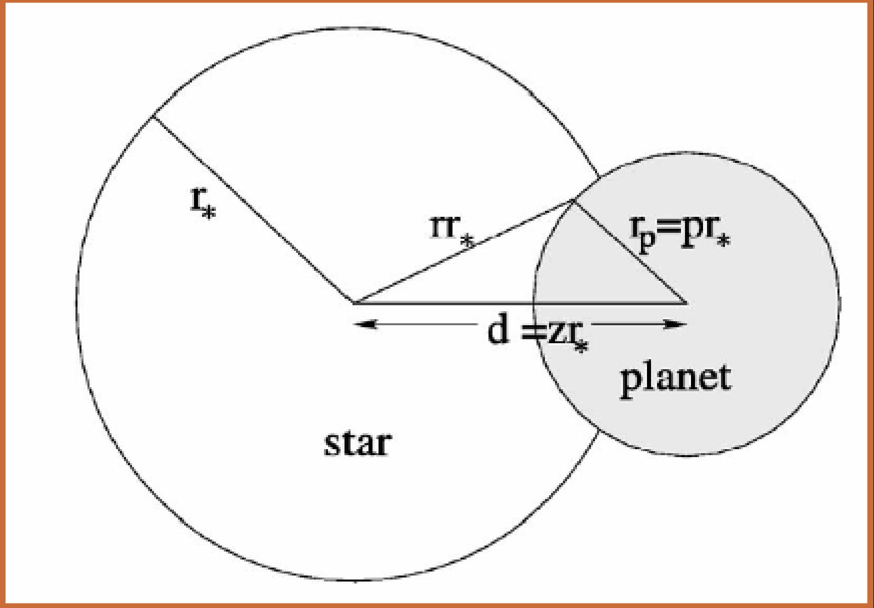
```
JD V-C s1 V-C1 s2 V-C2 s3 C-C1 s4 C-C2 s5 C1-C2 s6
Aperture: 4, Filter: Violet, JD: geocentric
2454765.24318 -1.2739 0.0023 -0.4039 0.0017 -2.0782 0.0034 0.8700
2454765.24411 -1.2699 0.0023 -0.3966 0.0017 -2.0756 0.0034 0.8733
2454765.24503 -1.2620 0.0023 -0.4031 0.0017 -2.0702 0.0034 0.8589
2454765.24601 -1.2842 0.0023 -0.4089 0.0017 -2.0875 0.0034 0.8753
2454765.24694 -1.2713 0.0023 -0.4025 0.0017 -2.0743 0.0034 0.8688
2454765.24786 -1.2772 0.0023 -0.4012 0.0017 -2.0854 0.0034 0.8760
```

our model

$$m(t_i) = A - 2.5 \log F(z[t_i, t_0, D, b], p, c_1) + B(t_i - t_{mean}) + C(t_i - t_{mean})^2$$

- $F(z, p, c_1)$ is a relative flux decrease from the star due to the transiting planet.
- star and planet are limb darkened and dark disks, radius ratio $p=R_P/R_S$ ($p \leq 0.2$)
- the projected relative separation of the planet from the star is z
- linear limb darkening law with coefficient c_1
- A, B and C describe systematic trends in the data and the zero-point shift of the magnitudes

- Mandel, K., Agol, E. 2002, ApJ, 580, 171 – Analytic light curves for planetary transit searches
    - occultsmall routine as our $F(z, p, c_1)$

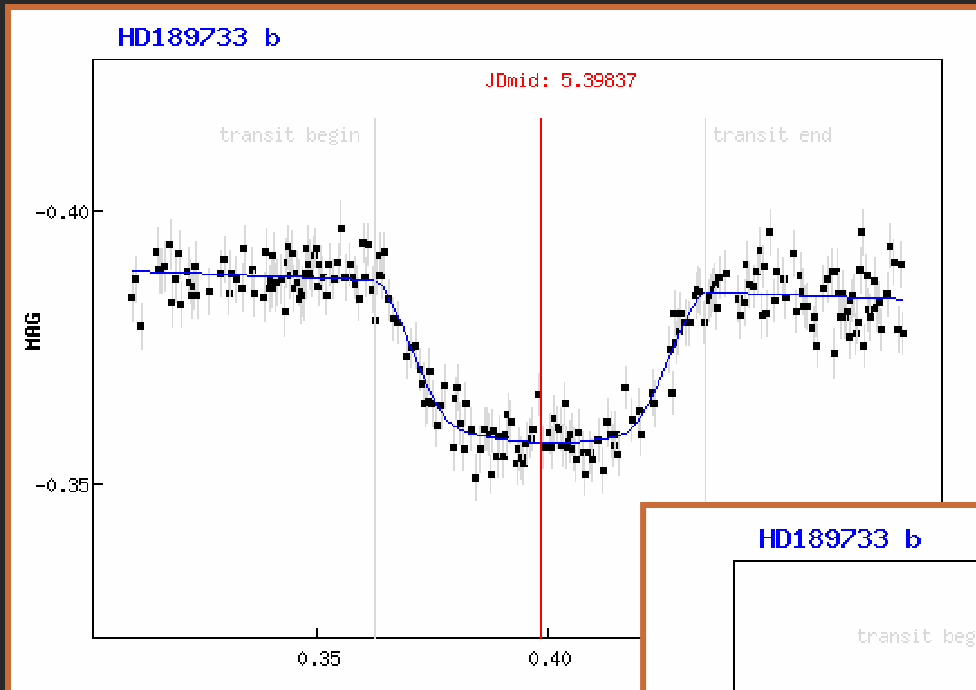


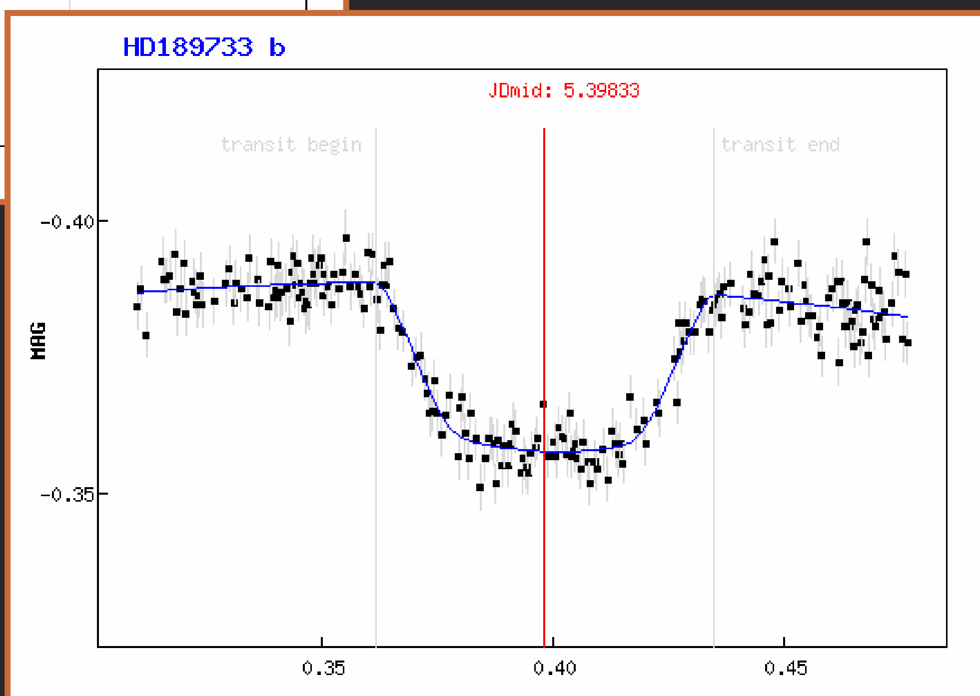
fitting algorithm

- Markov Chain Monte Carlo simulations
    - time-consuming method ☹

- Press, W. H., et al. 1992 - Numerical recipes in C. The art of scientific comp.
    - Levenberg-Marquardt non-linear least squares fitting algorithm

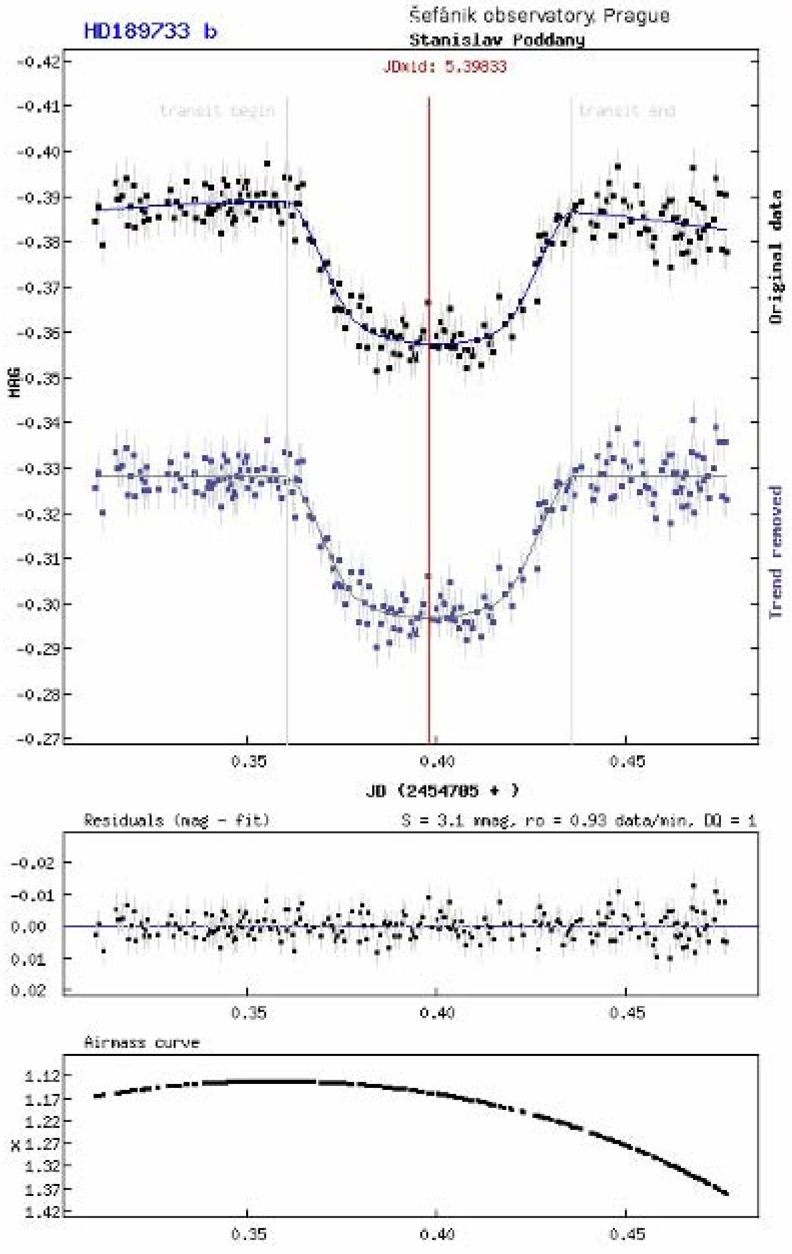
$$m(t_i) = A - 2.5 \log F(z[t_i, t_0, D, b], p, c_1) + B(t_i - t_{mean}) + C(t_i - t_{mean})^2$$





- odstranění systematických trendů

ETD záznam ...



Exoplanet: HD189733 b

Observer: Stanislav Poddaný

Post address: Štefánik observatory, Prague

E-mail: poddany@observatory.cz

Station: Štefánik observatory, Prague

Observing location: ELongitude: **15°** | Latitude: **50°**

Equipment: Meade LX 200 0.40 m + SBIG ST10XME

Used filter: U B V R I Clear

Notes: FHW 10 pixel exposure 20 - 25 s no autoguiding

Observation already published:

JD mid: 2454705.39833 +/- 0.0004

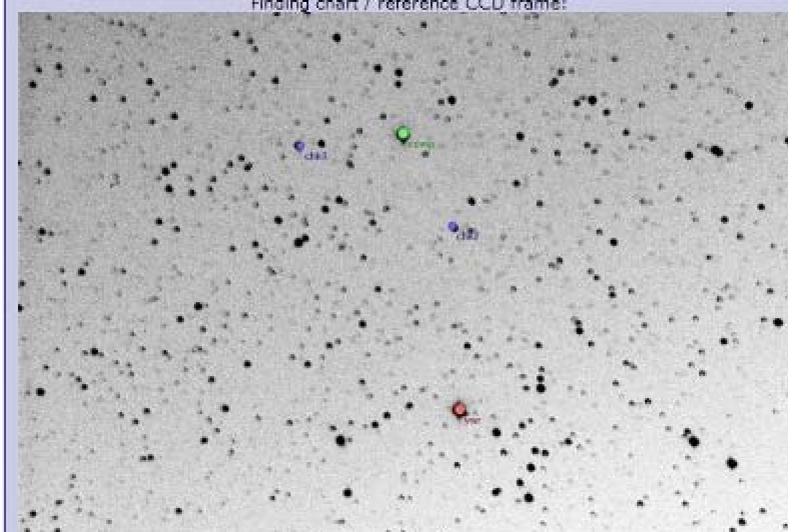
HJD mid: 2454705.40224 +/- 0.0004 (helcor = **0.00391**)

Mid transit - UT: 2008-08-26 21:33:35

Duration: 108.2 +/- 1.8 minut

Depth: 0.0312 +/- 0.001 mag

Finding chart / reference CCD frame:



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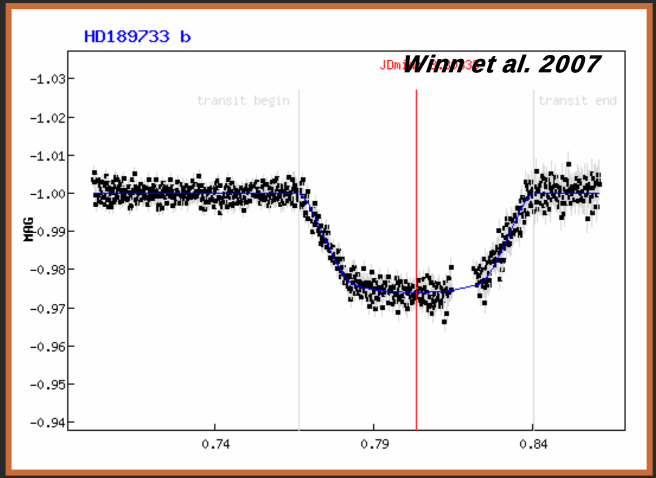
- **ETD versus Winn et al. 2007 and AXA fit**

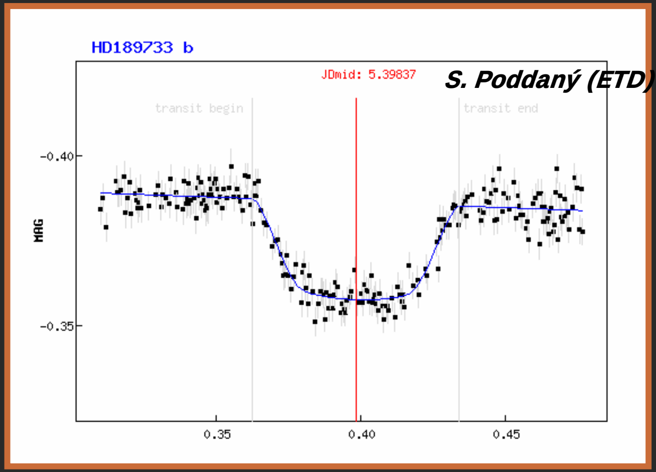
Table 1
The comparison of our results with Winn et al. (2007).

HD189733b	ETD	Winn et al. (2007)
Central time (HJD)	2453988.80333 (12)	24543988.80331 (27)
Duration (min)	106.01 ± 0.50	109.62 ± 1.74

Table 2
The comparison of our results with the AXA database.

HD189733b	ETD	AXA
Central time (HJD)	2454705.40228 (41)	2454705.4023 (5)
Duration (min)	102.09 ± 1.60	98.4 ± 1.8
Depth (mag.)	0.0287 ± 0.0006	0.02895 ± 0.00080



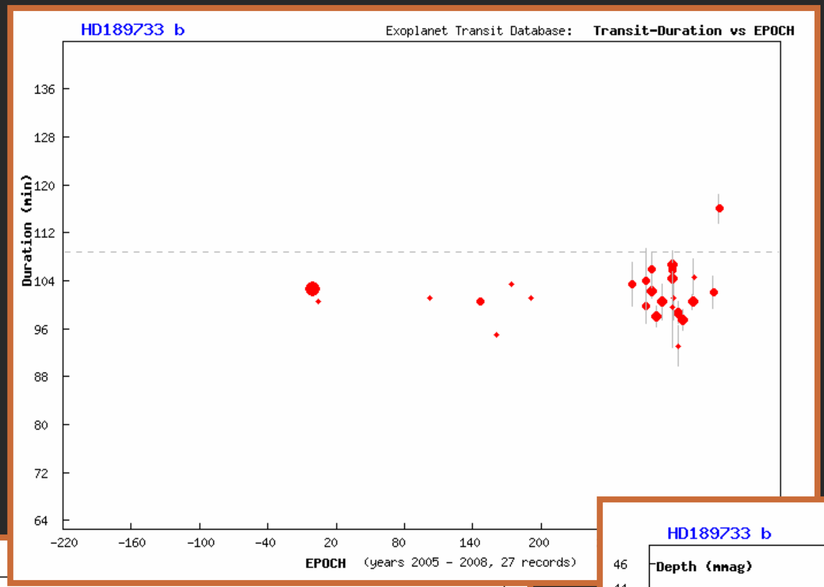


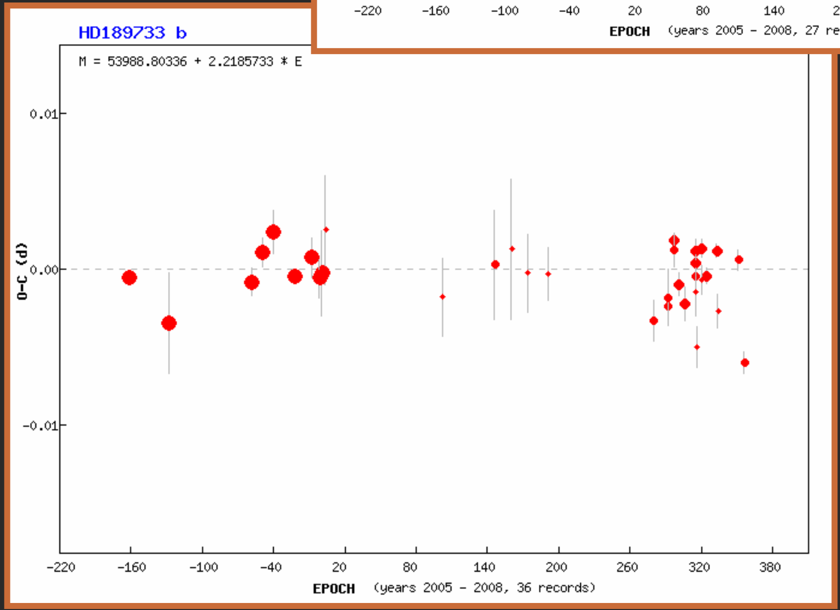
O-C gates ...

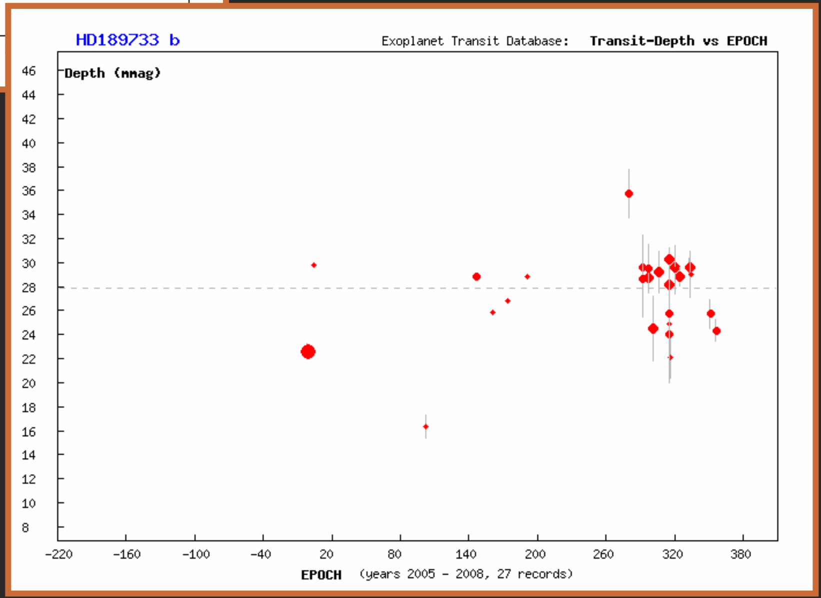
Current statistics:
(22. 10. 2009)

\# of objects: **58**
\# of transits: **1078**

DQ	# of transits
1	258
2	122
3	292
4	181
5	222







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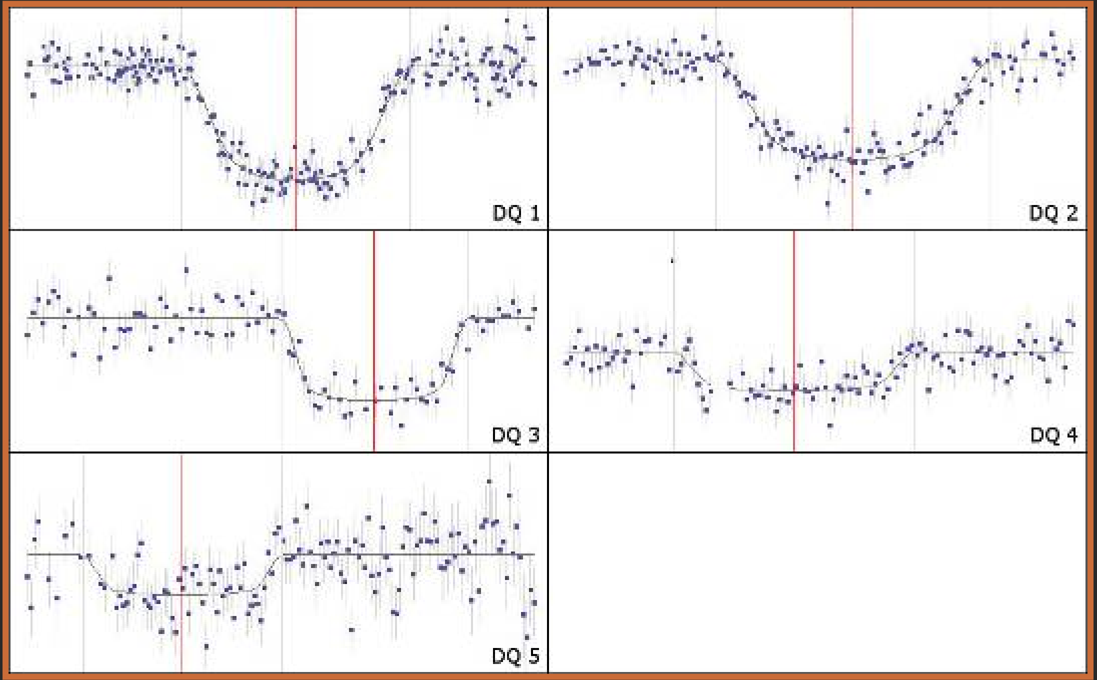
DQ index ...

$$\alpha = \frac{\delta}{S}\sqrt{\rho} \qquad (3)$$

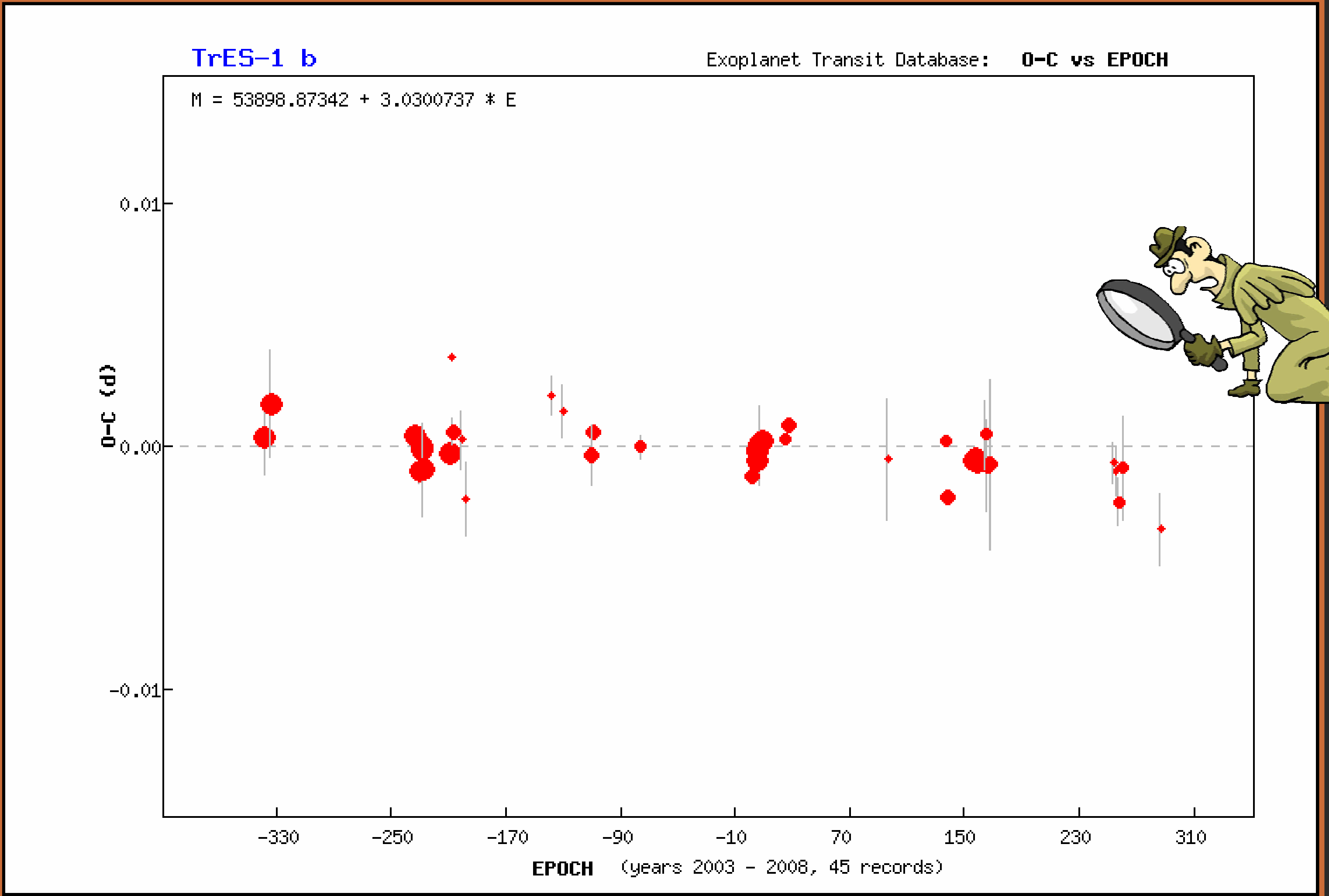
where α is a temporary data quality index, S is the mean absolute deviation of the data from our fit and $\rho = N/l$ means the data sampling, where l is the length of observing run in minutes.

Table 3
The distribution of the quality of the light curves according to their *DQ* index (example of the light curves see Fig. 3).

DQ index	1	2	3	4	5
Threshold	$\alpha \geqslant 9.5$	$9.5 > \alpha \geqslant 6.0$	$6.0 > \alpha \geqslant 2.5$	$2.5 > \alpha \geqslant 1.3$	$1.3 > \alpha$



TrES-1 b ...



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• **Holman M. J., & Murray N. W., 2005, Science, 307, 1288**

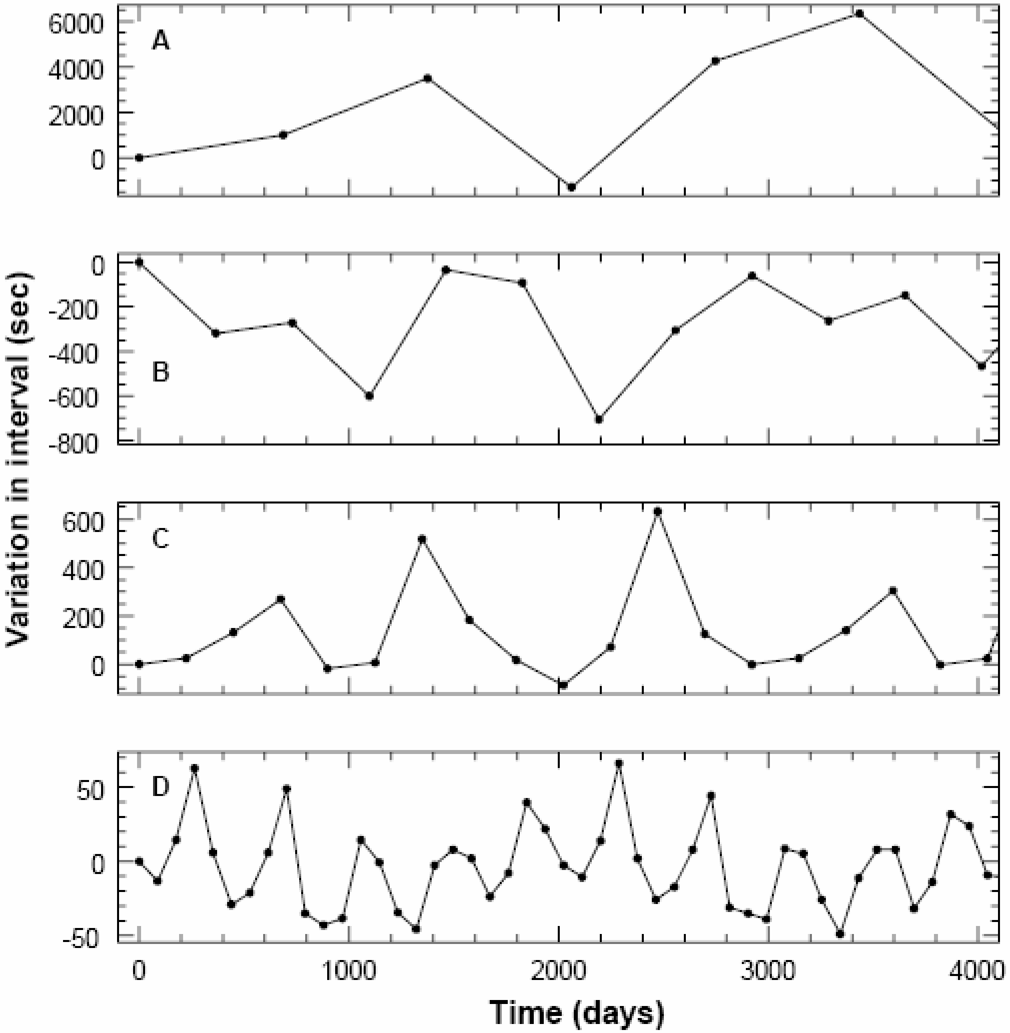
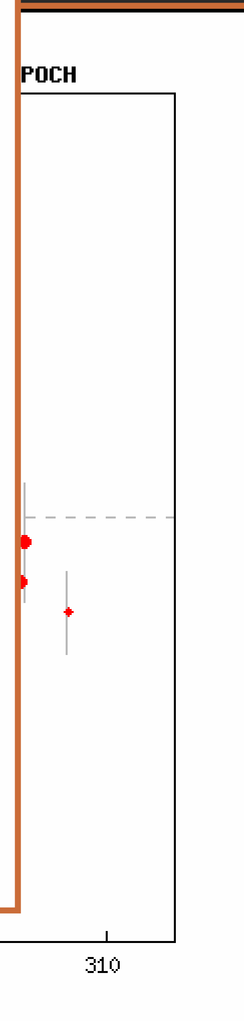


Fig. 1. The variations of the interval between successive transits of terrestrial planets, induced by the other planets in the solar system. (**A** to **D**) The variations for Mars, Earth, Venus, and Mercury, respectively. To guide the eye, the solid line connects the times of each transit. The transit intervals result from numerically integrating the equations of motion of the planets in our solar system and calculating the transit times as seen by distant observers located in the present-day orbital planes of the various planets.



ETD Exoplanet Transit Database

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• **Holman M. J., & Murray N. W., 2005, Science, 307, 1288**

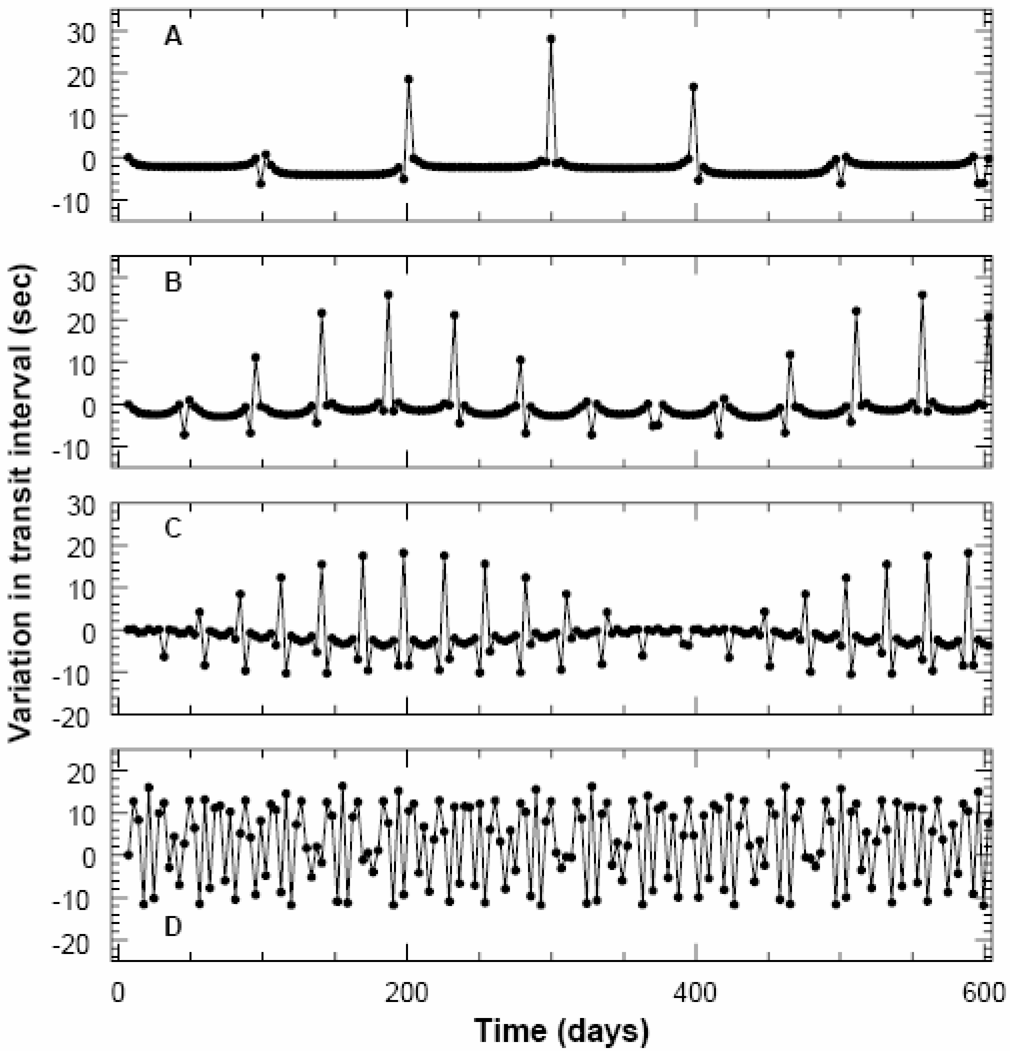
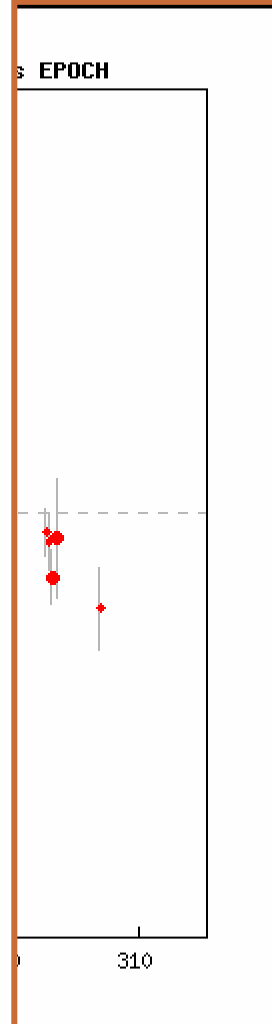


Fig. 2. Transit times of HD 209458b. The numerically determined variation of the interval between successive transit centers of HD 209458b as a function of time, with each panel showing the results for a different set of orbital parameters for a hypothetical second planet with a mass of $M_2 = 10^{-3} M_{\odot}$. In the simulations, HD 209458b has an initial orbital period $P_1 = 3.5248$ days and eccentricity $e_1 = 0.025$. The planets are assumed to be coplanar, with the system viewed edge-on. (**A**) The results for a perturbing planet with orbital period $P_2 = 99.8$ days and eccentricity $e_2 = 0.7$. (**B** to **D**) The results for perturbing planets with orbital periods P_2 of 46.4, 28.0, and 19.2 days and eccentricities e_2 of 0.5, 0.3, and 0.1, respectively. Radial-velocity measurements have ruled out the presence of such planets in the actual HD 209458b system (*20*).



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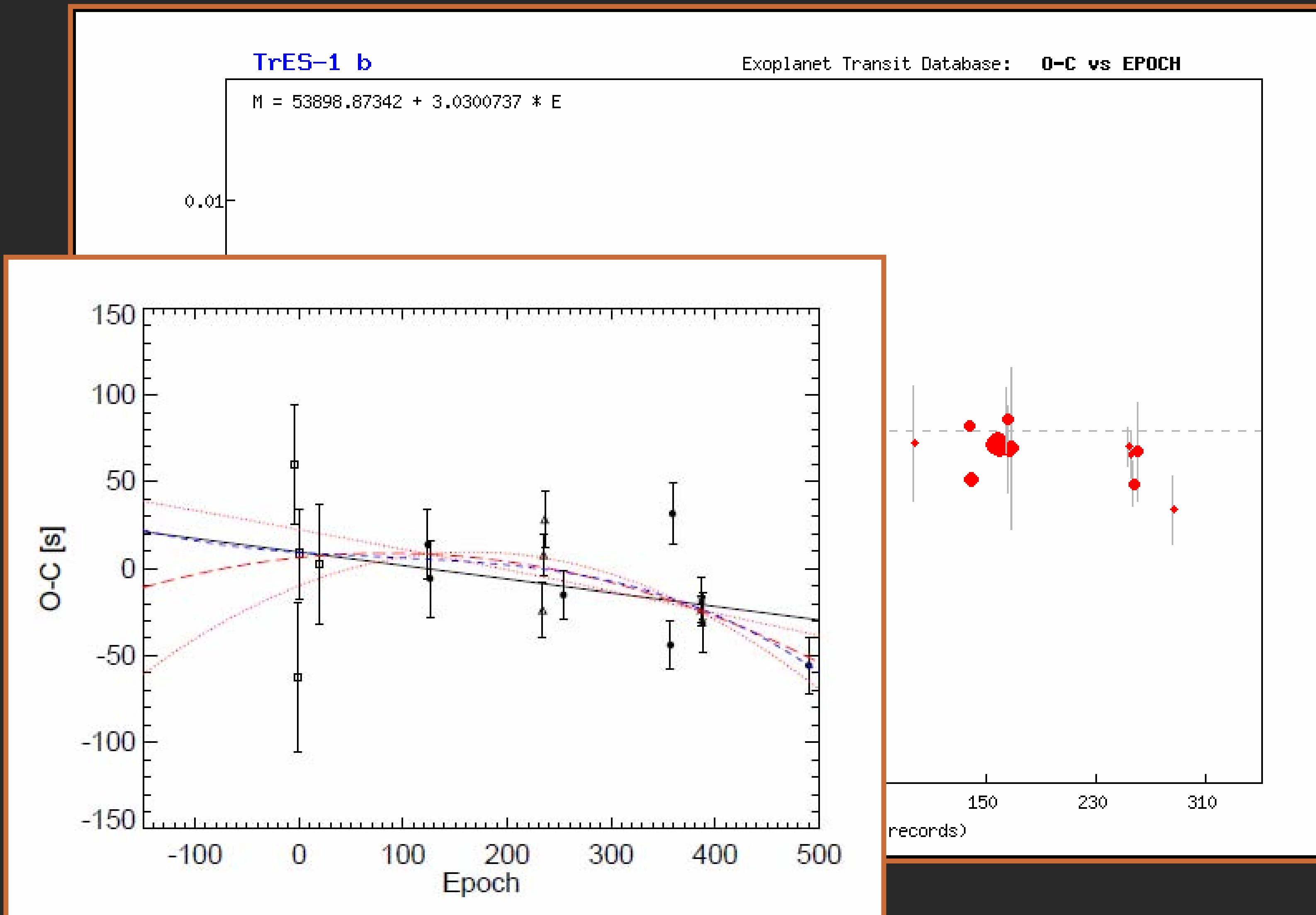
TrES-1 b ...



• **Rabus et al. A&A 2009**

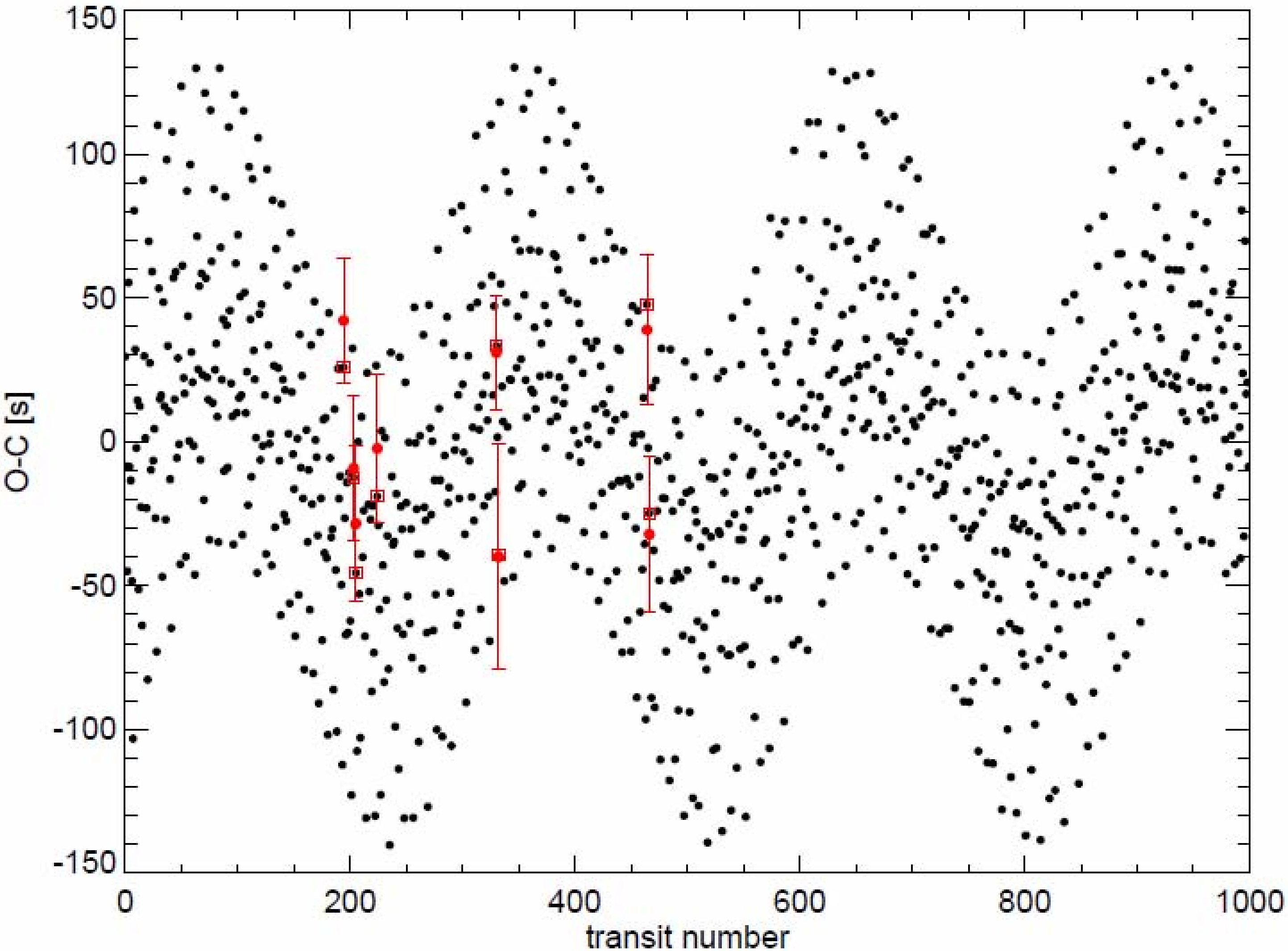


Fig. 8. Simulated O-C diagram of TrES-2 and the best fit perturber with a mass of 18 $M_{\oplus}$ and an orbit of 0.051 AU. The red dots correspond to the observations and the squares to the corresponding simulated O-C values.

• Rabus et al. A&A 2009

GJ 436b ... TTV

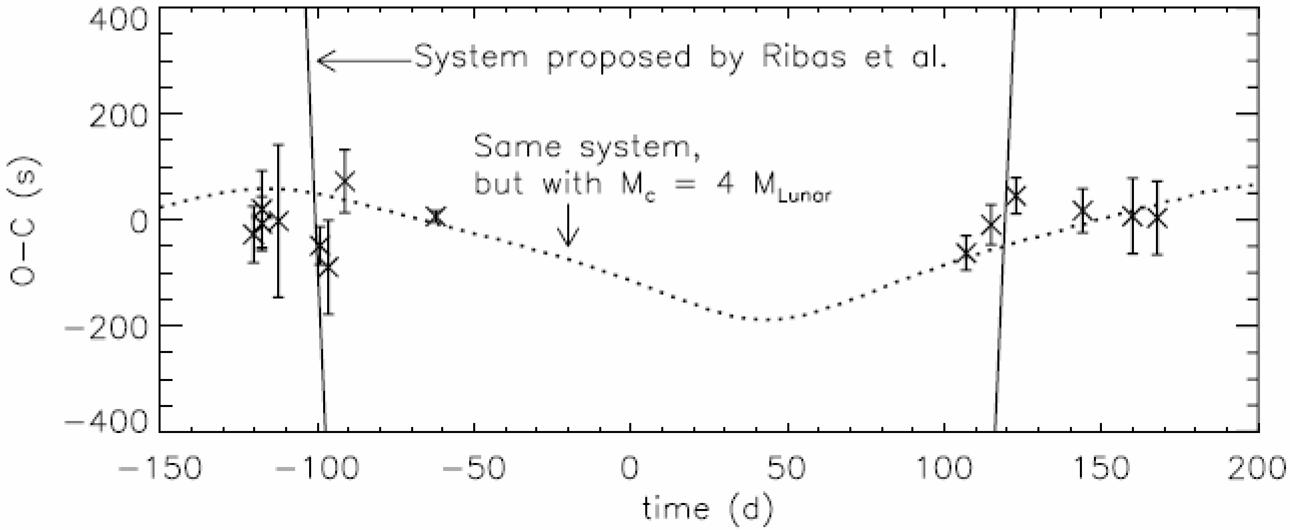
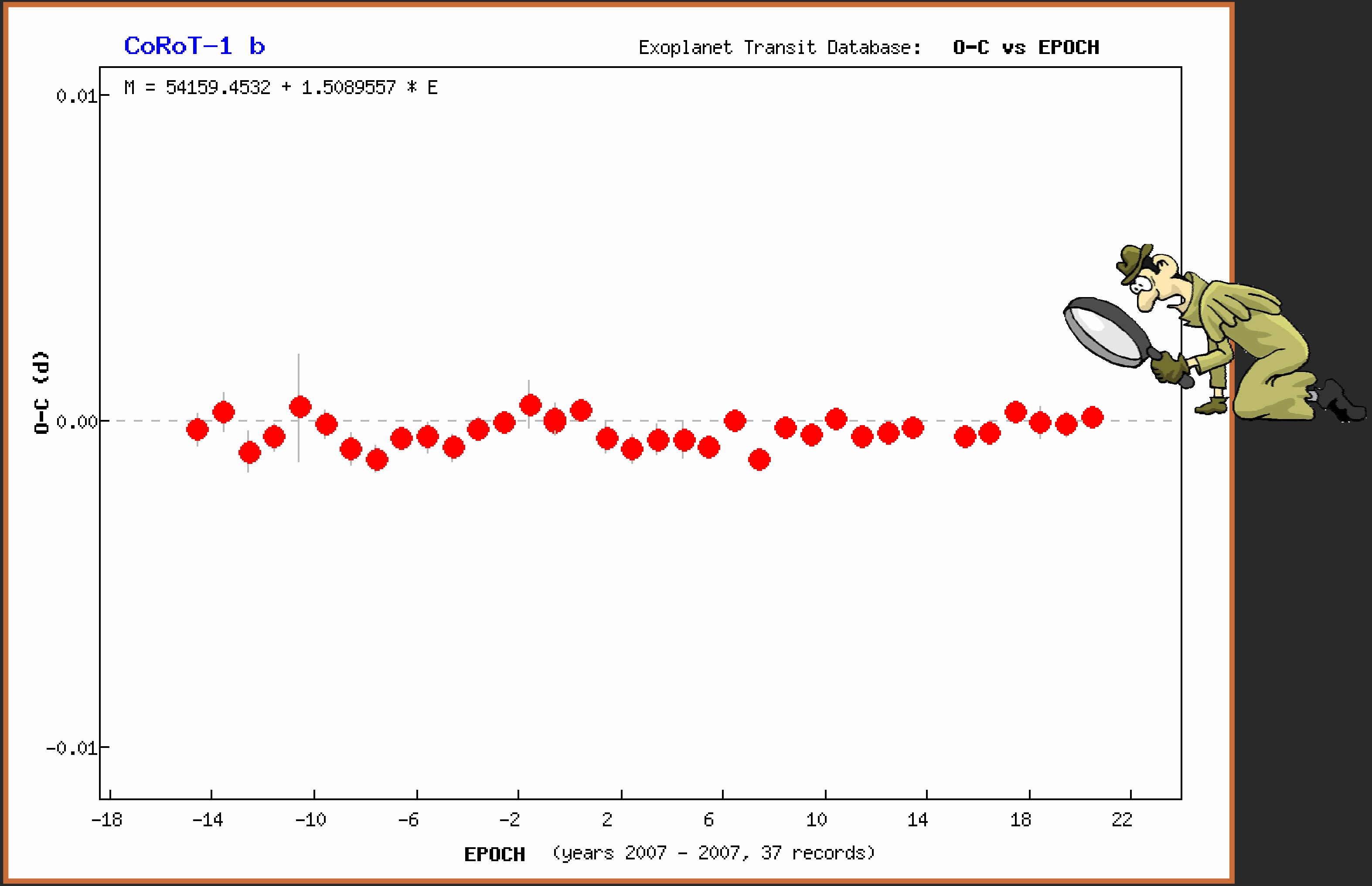


Figure 6. Transit timing residuals (observed − calculated) for GJ 436, along with theoretical variations that would be expected due to a second planet in a 2:1 resonance, with a mass of 5 $M_\oplus$ (solid line) and 0.05 $M_\oplus$ (dotted line). Calculations and figure by D. Fabrycky.

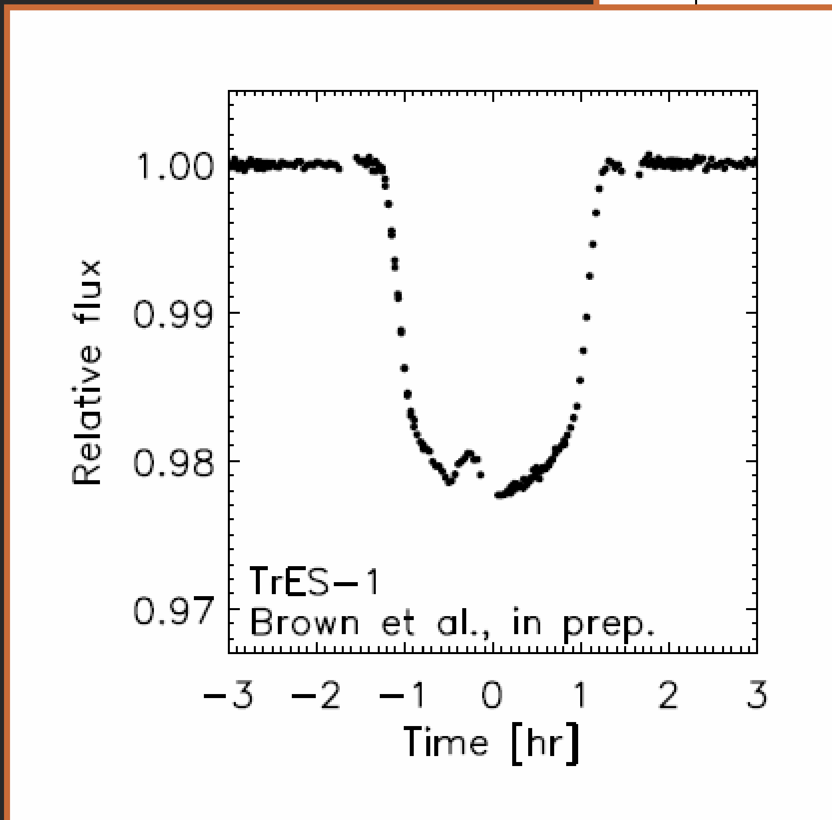
Exoplanet Transit Database
... complete ... worldwide ... continuously growing ...
http://var.astro.cz/ETD

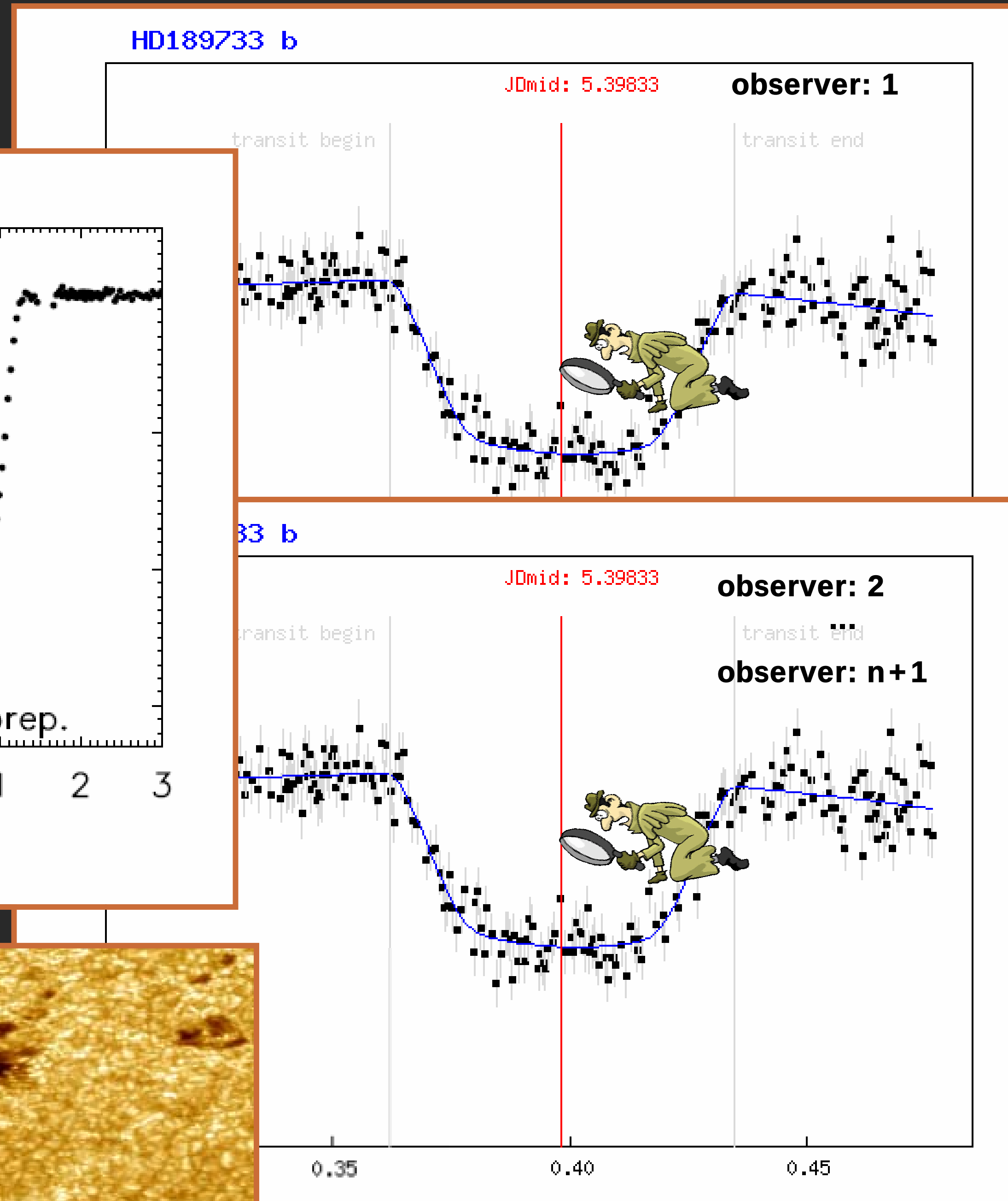
CoRoT-1 b ... TTV

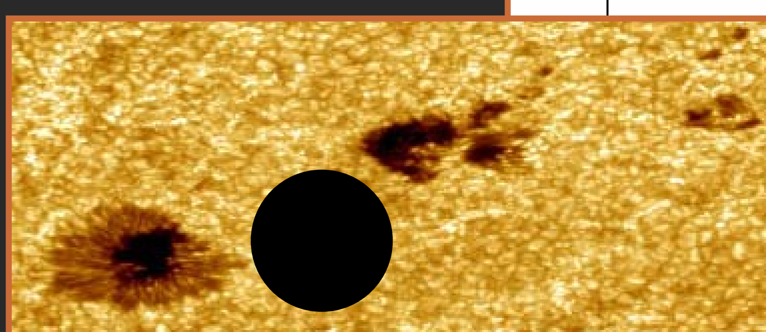


Jacob L. Bean A&A 2009

- **pozorování skvrny**







ETD Exoplanet Transit Database

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Exoplanet Transit Database. Reduction and processing of the photometric data of exoplanet transits

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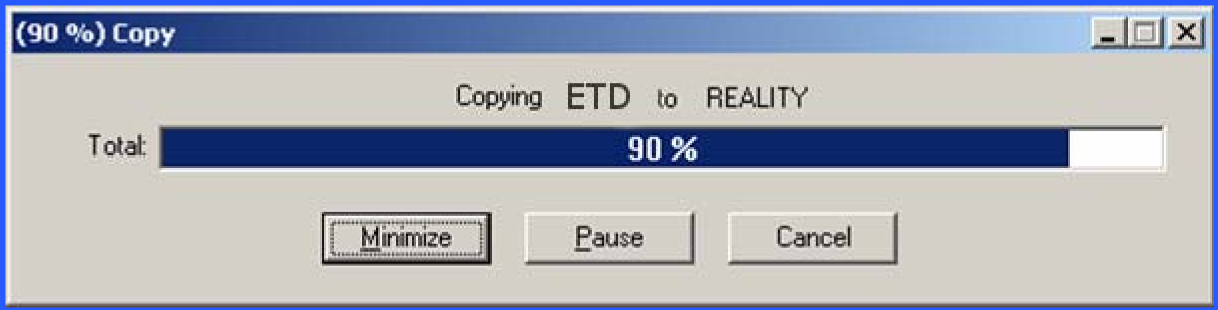
ABSTRACT

We demonstrate the newly developed resource for exoplanet researchers – The Exoplanet Transit Database. This database is designed to be a web application and it is open for any exoplanet observer. It came on-line in September 2008. The ETD consists of three individual sections. One serves for predictions of the transits, the second one for processing and uploading new data from the observers. We use a simple analytical model of the transit to calculate the central time of transit, its duration and the depth of the transit. These values are then plotted into the observed–computed diagrams (O–C), that represent the last part of the application.



více jak 90 % práce hotovo *...*

===> *90% na nás stále ještě čeká ... ☹*

Děkuji za pozornost.