A new BD from the CoRoT sample and the frequency of close-in brown dwarfs

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Transiting exoplanets from the CoRoT space mission⋆,⋆⋆

XXIX. An object in the brown dwarf desert with 2:3 commensurability with its host star

This talk is based on a paper submitted to A&A on 16 June 2015, under revision now.

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What are brown dwarfs?

Giant planets	Brown dwarfs	Stars (MS)
No fusion at all	Short-live (10^5 yrs)	Long-live ($10^{6..10}$ yrs)
	D- or Li-burning	H-burning and others
	D+H→He3	4H → 1 He4
	Li+H→He4	

65 M_{Jup}
(Chabrier et al. 1996)

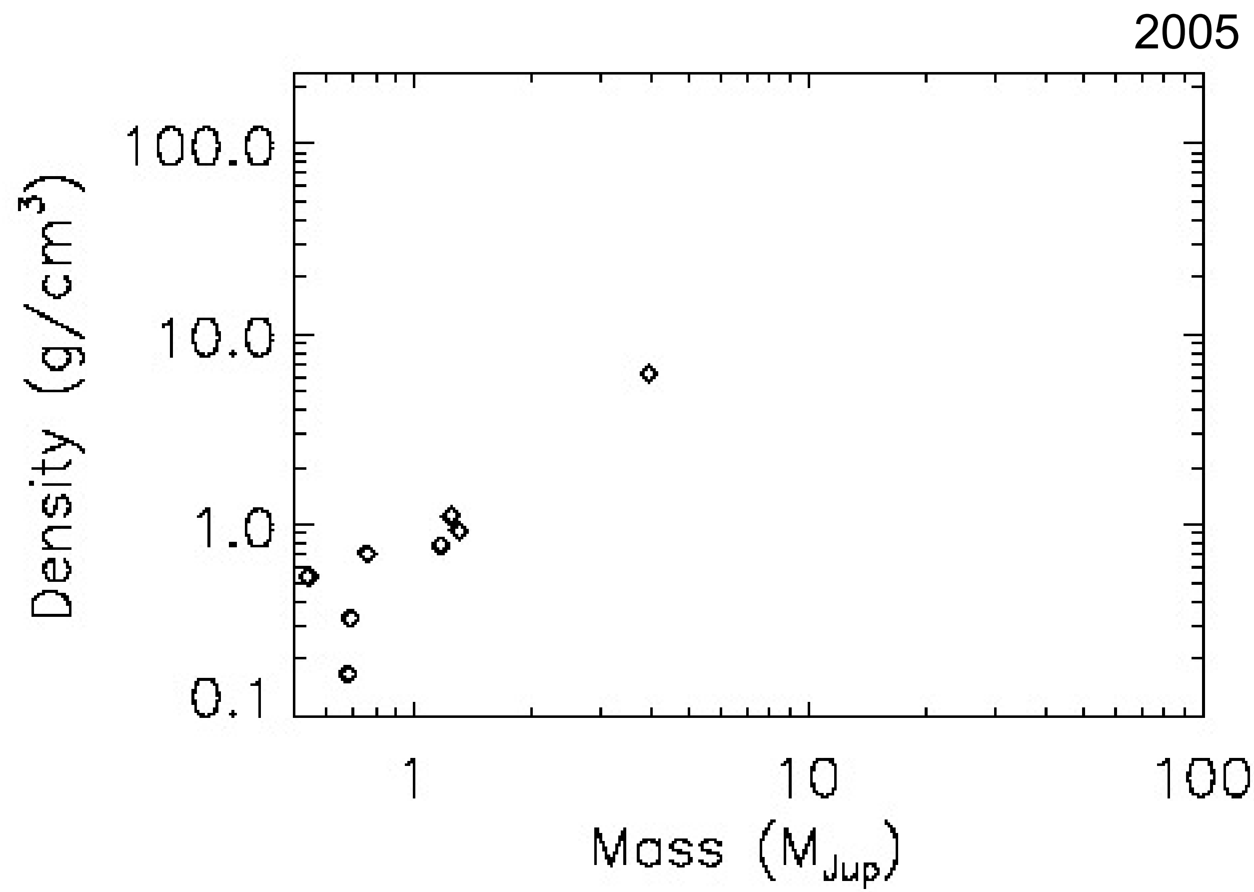
11-16 M_{Jup}

(Spiegel et al. 2011)

75-80 M_{Jup}

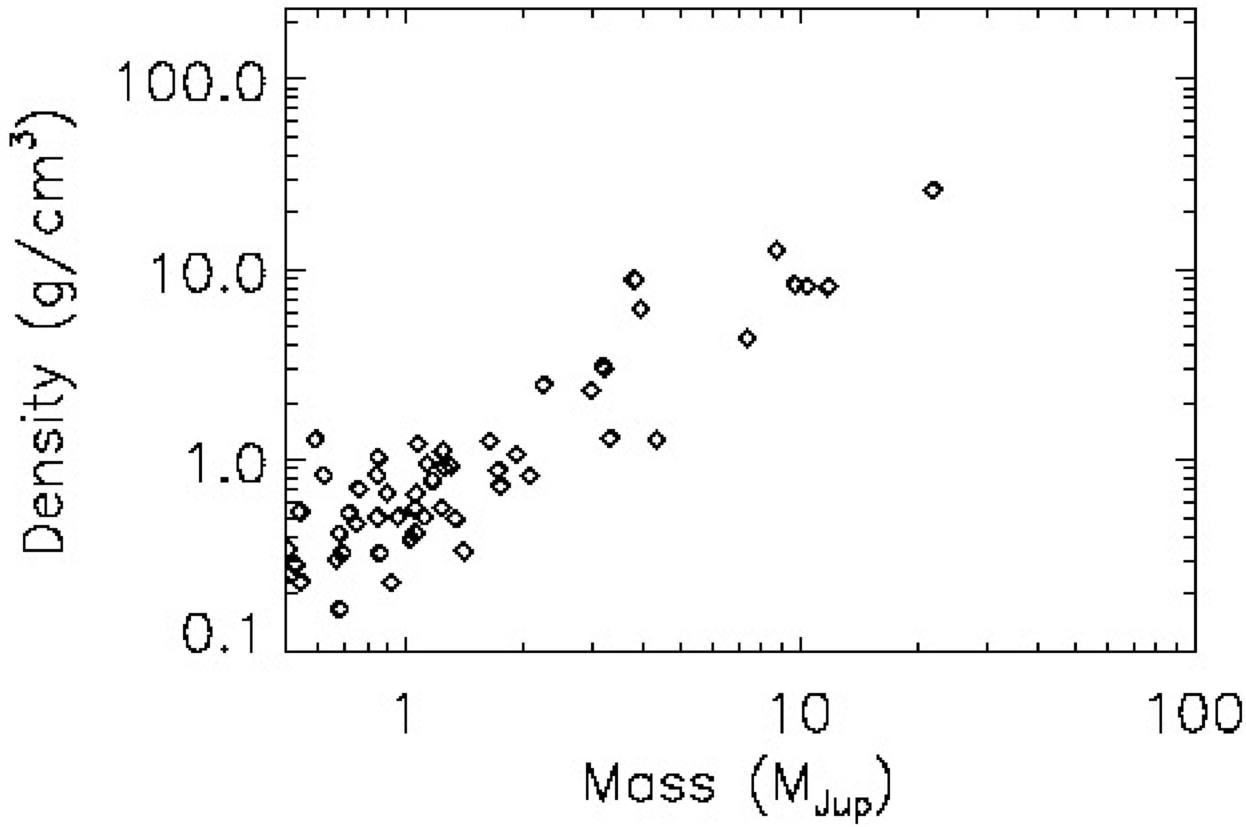
Baraffe et al.
(2003)

Mass-density diagram for giant planets and brown dwarfs

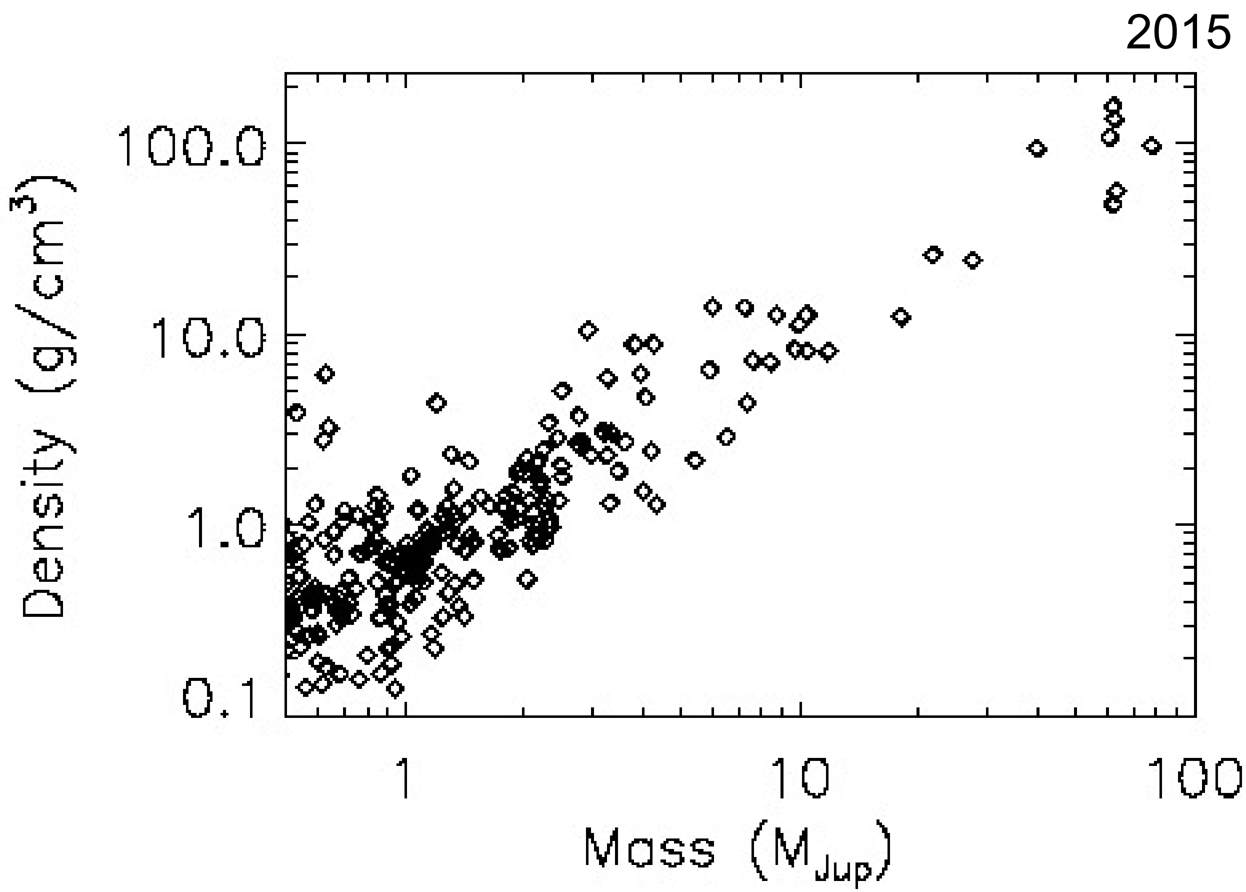


Mass-density diagram for giant planets and brown dwarfs

2010



Mass-density diagram for giant planets and brown dwarfs



Hatzes & Rauer 2015, submitted

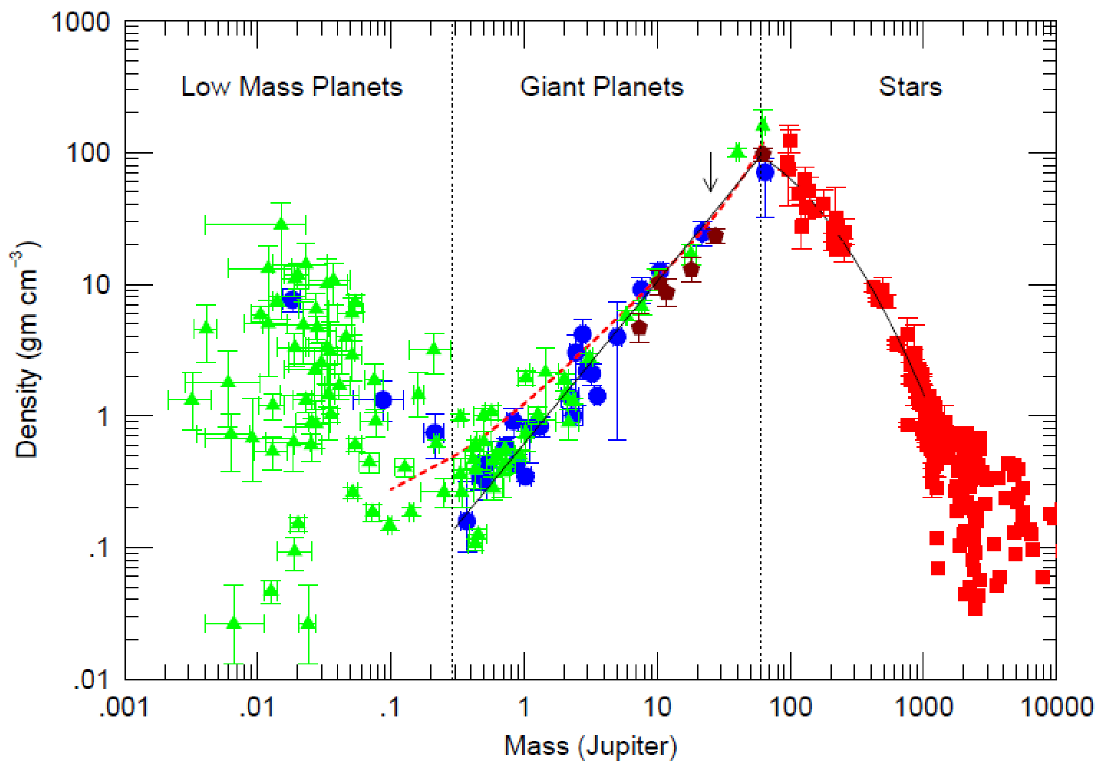


Fig. 1.— The density and mass of stars (red squares), giant planets and brown dwarfs, and low mass planets. Triangles represent Kepler discoveries and dots are CoRoT exoplanets. Ground-based discoveries for high mass giant planets are shown by pentagons. The line represents a linear fit to the giant planets and brown dwarfs in the mass range M = 0.35 - 60 M_{Jup}. A second order polynomial fit (curved line) was made to the lower end of the stellar main sequence. The boundary between the low mass planets and giant planet occurs at M = 0.3 M_{Jup}. The boundary between the giant planets and stars is at M = 60 M_{Jup} (0.060 $M_{\odot}$). The dashed red line shows the mass-density relationship for H/He dominated giant planets taken from Fortney et al. (2007).

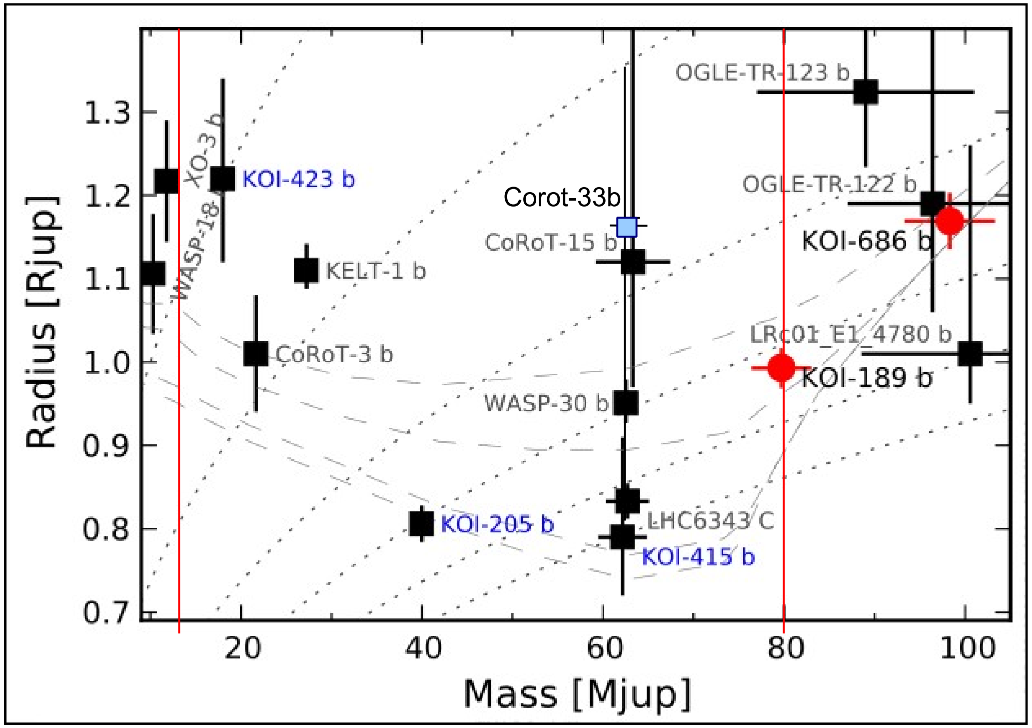
How many brown dwarfs are known in total,
in binary systems,
as transiting one?

W. R. Johnston (2015 June 14):
http://www.johnstonsarchive.net/astro/browndwarflist.html

2179 brown dwarfs are known.
427+ are in binary systems.

Ma & Ge (2014, MNRAS 439, 2781):

65 brown dwarfs are closer than
2 AU to FGK dwarfs.



9 or 10 brown dwarfs are <u>transiting</u>,
including this new one.

Figure: M. Deleuil. *Data sources:*
Deleuil et al., 2008; Bouchy et al., 2011a, 2011b,
Johnson et al., 2011, Siverd et al. 2012,
Moutou et al., 2013, Diaz et al., 2013, 2014;
Anderson et al. 2011, Csizmadia et al., (submitted)

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CoRoT-33b, a new, rare transiting brown dwarf

Star: R=14.71 magnitude

5225 ± 80K, G9V

logg = 4.4 ± 0.1 cgs

vsini = 5.7 ± 0.4 km/s

[Fe/H] = 0.44 ± 0.1

$M=0.93^{+0.05}_{-0.02}\ M_{\odot}$, $R=1.01^{+0.17}_{-0.09}\ R_{\odot}$

Age > 4.6 Gyr

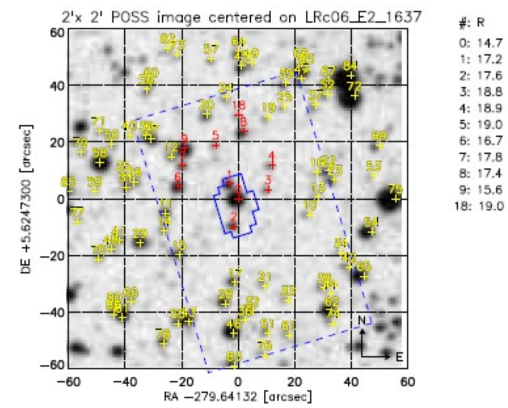
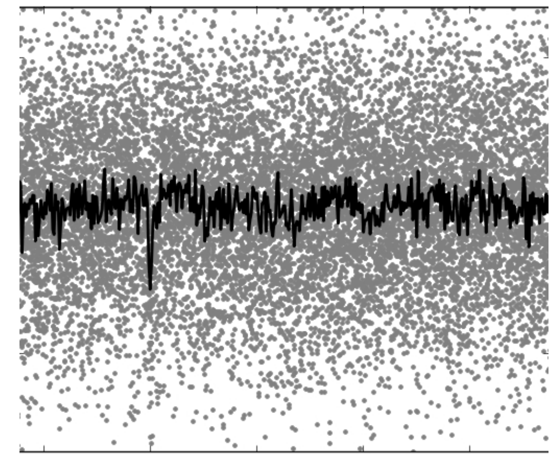


Fig. 2. Finding chart and contamination source map for CoRoT-33. Red numbers denote stars whose contribution to the observed flux was taken into account; yellow numbers denote stars whose contamination was checked but was found negligible. Star with number 0 corresponds to CoRoT-33.



Brown dwarf:

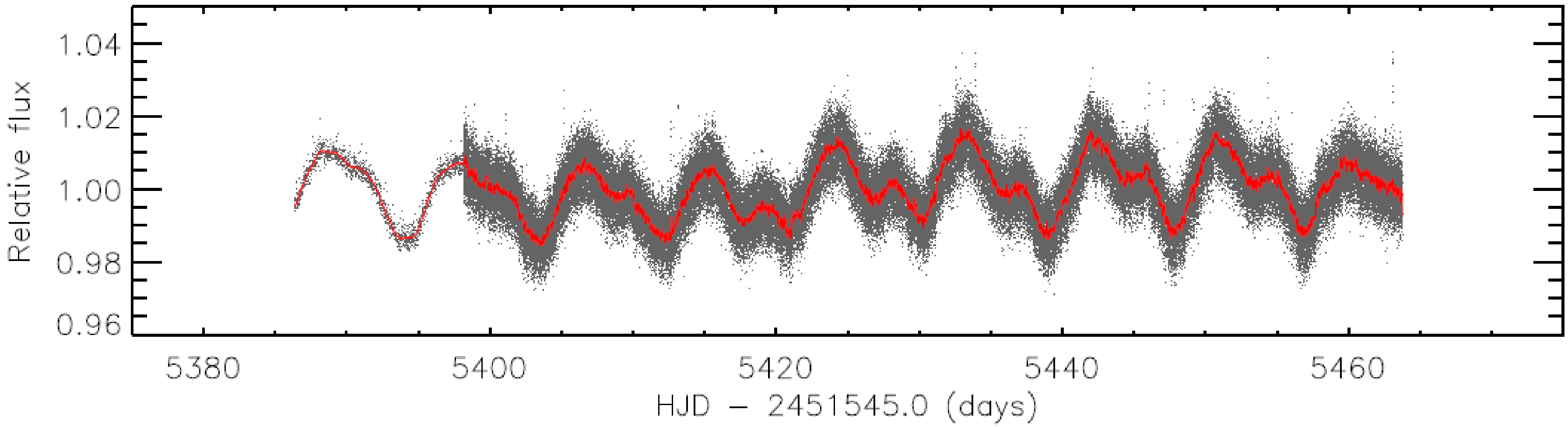
P = 5.819143 days

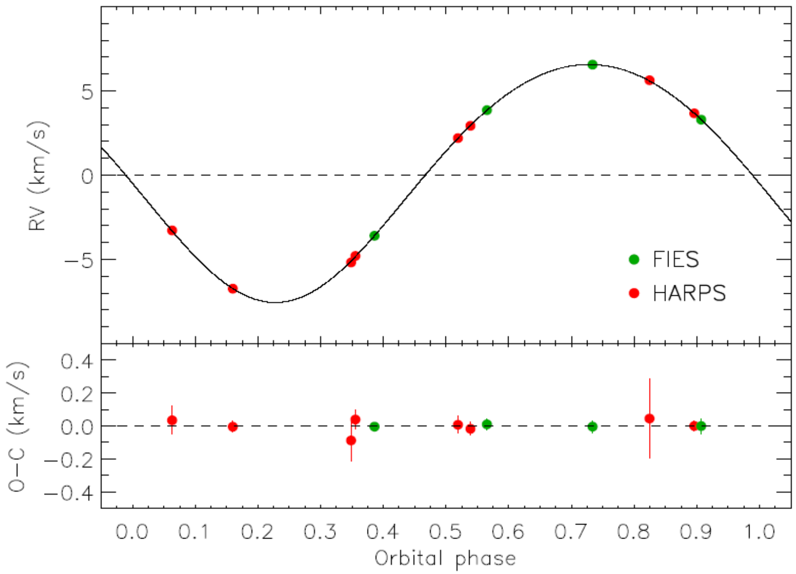
$M = 62.1^{+2.1}_{-0.9}\ M_{Jup}$, $R=1.2 \pm 0.6\ R_{Jup}$

e=0.0700 ± 0.0016

Courtesy of S. Aigrain

1.4 hours long transit, 0.28% transit depth





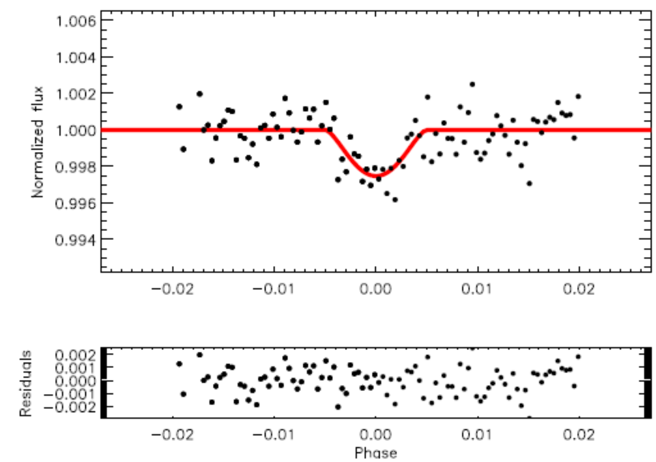


Fig. 3. Upper panel: Phase-folded RV measurements of CoRoT-33. Red circles represent the HARPS-measurements while green circles do the data points obtained by FIES-instrument. Black solid line represents the eccentric orbit fit. The RV points and the fit is shifted by the γ-velocity of the system. Lower panel: it shows the residuals of the fit. Vertical lines on the data points indicate their error bars.

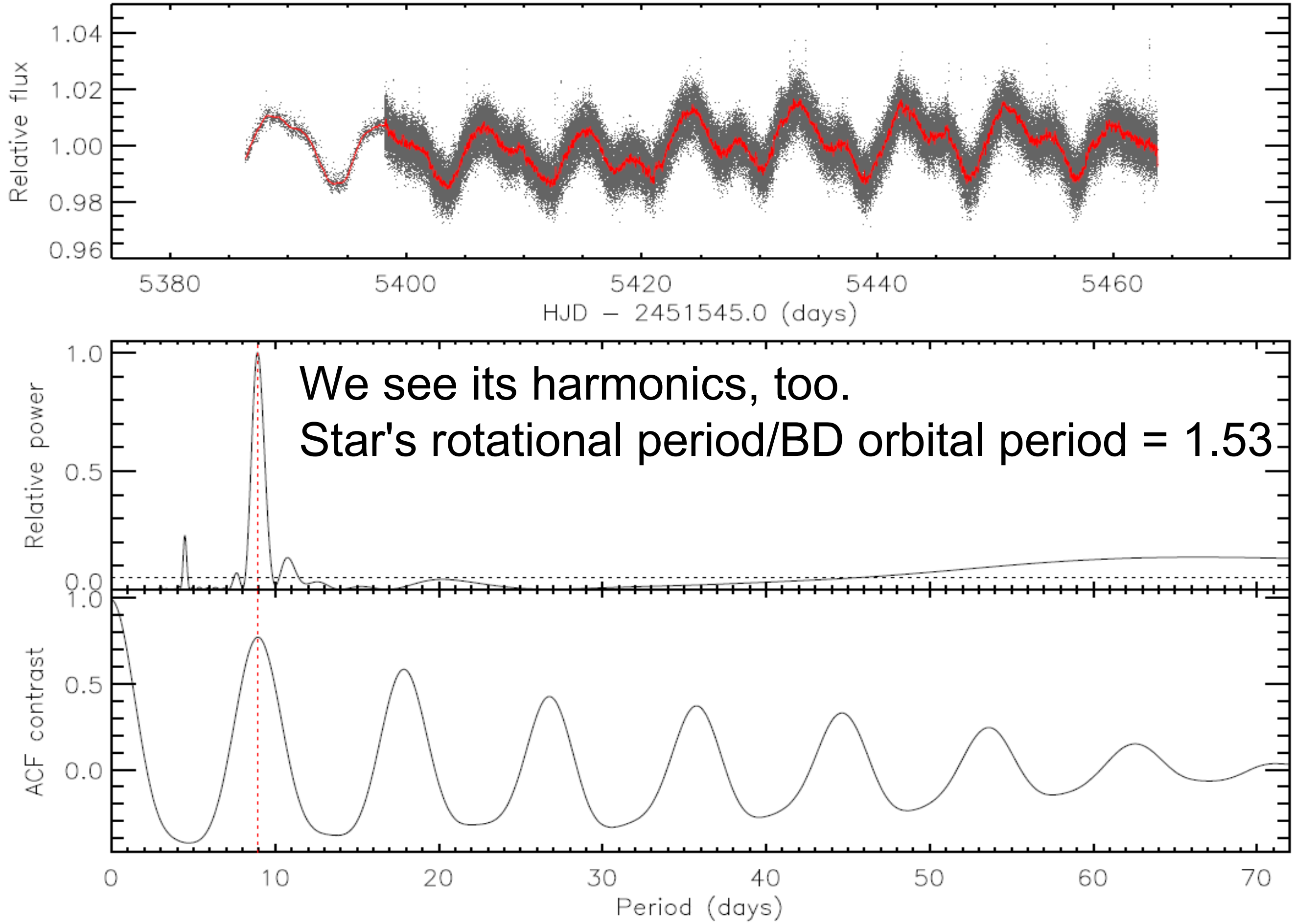


Fig. 1. *Upper panel*. Full CoRoT light curve of CoRoT-33. The grey points represent the median-normalized raw data points after a 5-point width median filtering. Only data points with flag "0" have been used for this curve. The red line is a convolution of the raw light curve with a Savitzky-Golay filter that enhances the light curve variations. Flux is normalized to the median of all flux values. *Middle panel*. Lomb-Scargle periodogram of the light curve of CoRoT-33. The horizontal dashed line denotes the 0.01 % false-alarm probability. The vertical red line marks the rotation period of the star. *Lower panel*. Autocorrelation function (ACF) of light curve, following the subtraction of the best fitting transit model. The red dashed line marks the peak corresponding to the rotation period of CoRoT-33 (see Section 3.4)

Béky et al. (2014, ApJ and references thereof), hot Jupiters:

HAT-P-11	1:6
Kepler-17b:	1:12
CoRoT-2b:	5:13
CoRoT-4b:	1:1
Kepler-13b:	3:5
Tau Boo:	1:1

Csizmadia et al. (2015, subm.), brown dwarf:

CoRoT-33b	2:3

Eigmüller et al. (2015, subm.), F+dM binary:

BEST-C2	1:2

Many binary stars: 1:1

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S. Ferraz-Mello, M. Tadeu dos Santos, H. Folonier, Sz. Csizmadia, J.-D. do Nascimento Jr, M.Pätzold:

Interplay between tidal forces and magnetic braking

(ApJ, 2015, in press):

Rotational period = tidal braking + magnetic braking

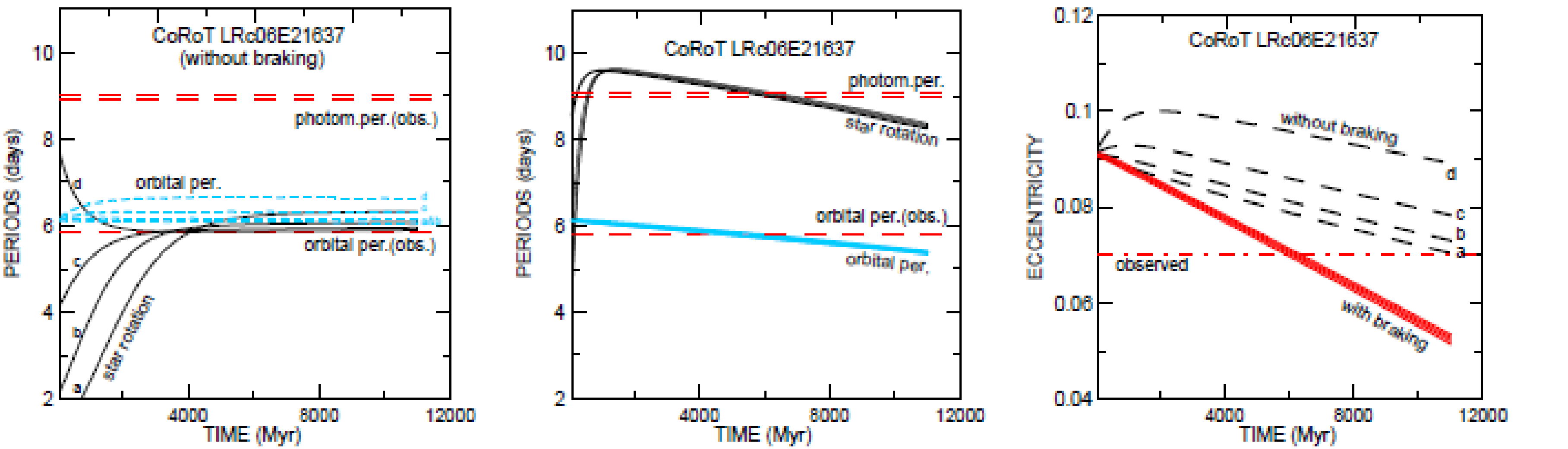

Fig. 4.— *Left:* Evolution of the star's rotation and of the orbital period of the companion in the classical approach when the stellar rotation is only affected by tides. *Middle:* Evolution resulting from the joint action of the tidal torque on the star and the stellar wind braking. The horizontal dashed lines show the observed values of the orbital period of the companion and the photometric period of the star; *Right:* Eccentricity evolution in the two cases. Four different values of the initial period of rotation of the star were considered: 1, 2, 4 and 8 days, labelled, resp. a, b, c, d.

Brown dwarf frequency from CoRoT for P < 10 days

Kepler: 4 transiting brown dwarfs, no final result

KELT, WASP: 1 transiting BD, HAT: 1 non-transiting brown dwarf

CoRoT: homogeneous, no big changes expected, same observtional bias for hot Jupiters and brown dwarfs

3 transiting brown dwarfs / 22 hot Jupiters (P<10days) = ~14%

True hot Jupiter frequency (P<10 days) = 1.2 % (Wright et al. 2012)

True brown dwarf frequency (P<10 days) = 0.14 x 0.012 = 0.2%, but...

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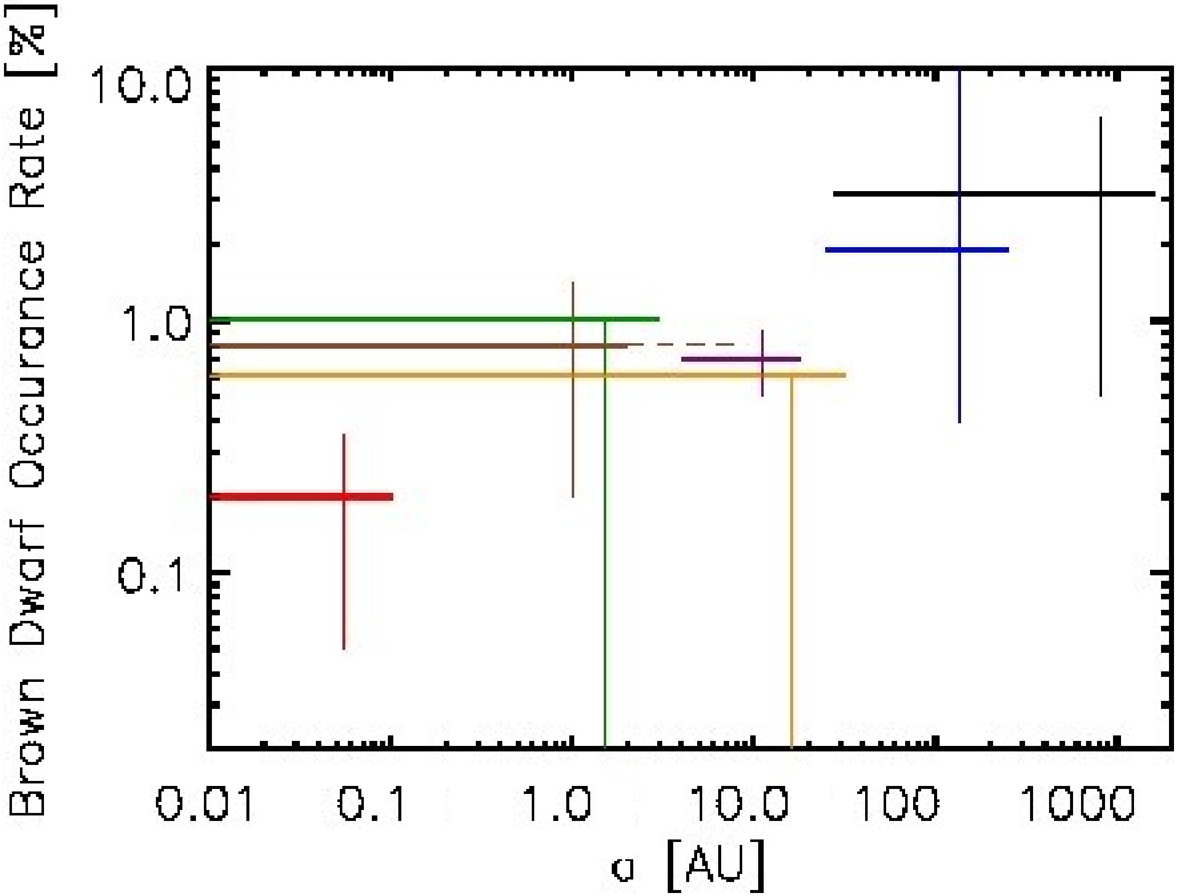
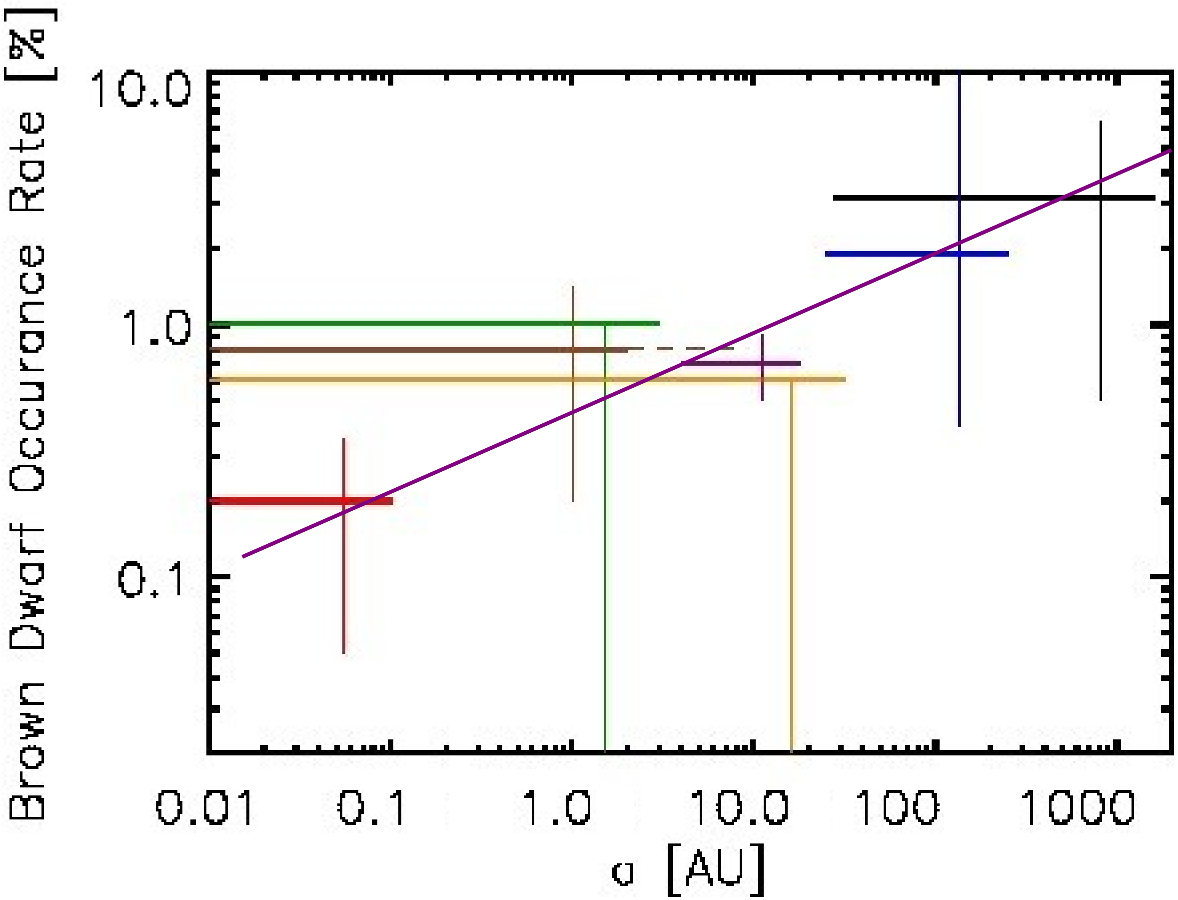
The brown dwarf desert: 1./ Started to be populated
2./ Distance – frequency
3./ Very poor statistics, but some patterns...



Black: Metcher & Hillenbarnd 2009
Blue: Lafrenière et al. 2007
Green: Grether & Lineweaver 2006
Orange: Sahlmann et al. 2011
Brown: Wittenmeyer et al. 2008
Violet: Patel et al. 2007
Red: This study, Csizmadia et al. 2015

The brown dwarf desert:

1./ Started to be populated
2./ Distance – frequency relationship
3./ Very poor statistics, but some patterns...



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$$f \approx 0.55^{+0.8}_{-0.55} \left(\frac{a}{1\,AU} \right)^{0.23 \pm 0.06}$$

But:
- small number statistic
  arge error bars of input
- pe cautious
- do not extrapolate to
  larger distance than 1000 AU

Conclusions

- ~10th transiting brown dwarf was found, validated and characterized
- metal-rich recorder: implications on brown dwarf formation?
- slightly, but significantly eccentric: $e=0.0700 \pm 0.0016$
- older than 4.6 Gyrs
- 2:3 commensurability between stellar rotation and orbital period, supported by:
    - Transit periods
    - Light curve modulations
    - Rstar + vsini
- only tides does not explain this rotational period
- tides + magnetic braking + high mass companion explains P_{rot}
- important test case for tidal theory calibrations
- brown dwarf frequency is ~0.2% / star / P<10 days (??)
- occurance rate – distance relationship for MS star + BD binaries (?)

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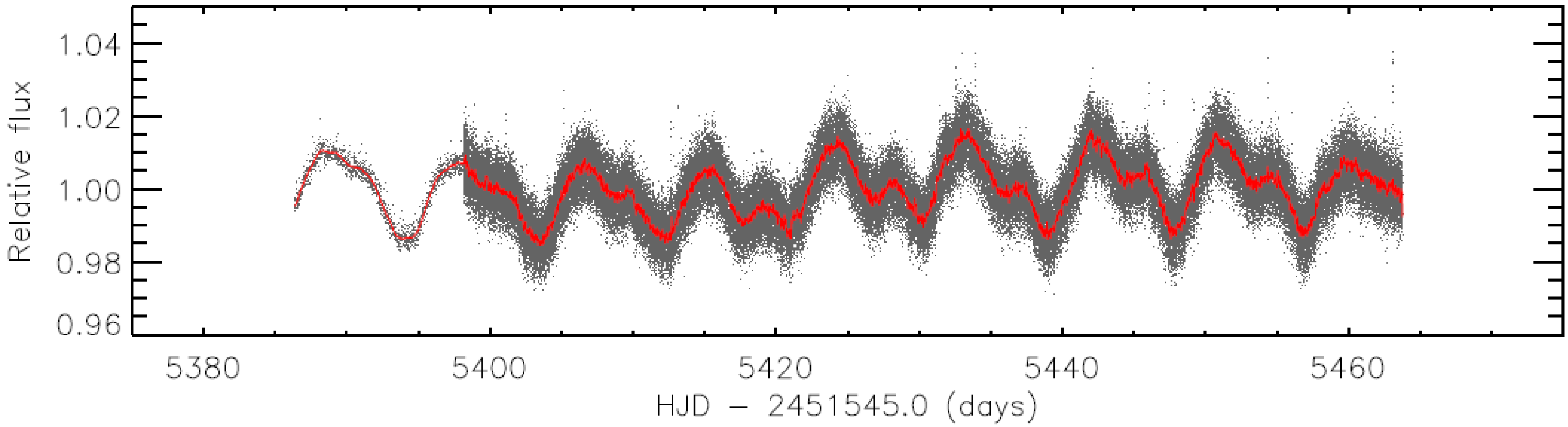
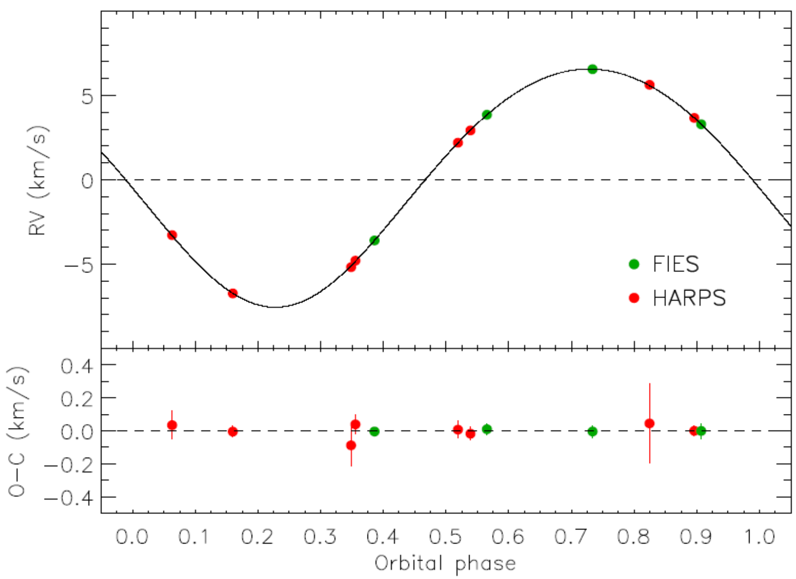
Backup slide





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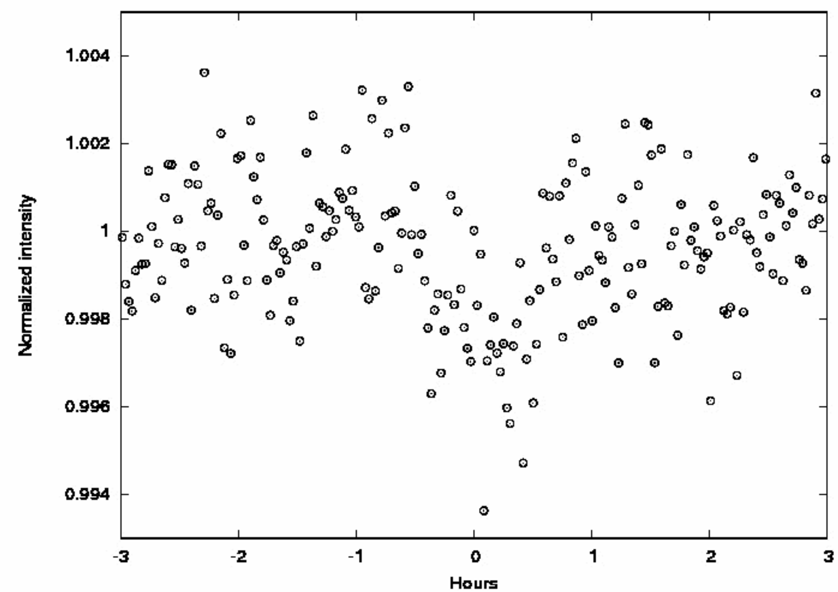

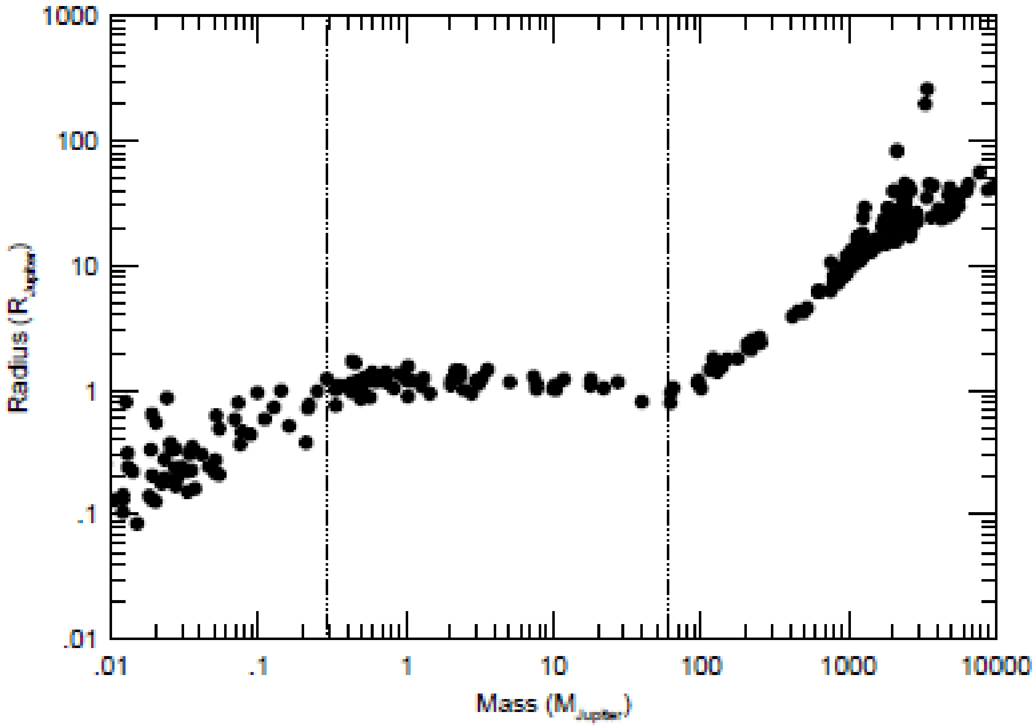

Fig. 2.— The points from Figure 1 shown in the mass-radius plane.

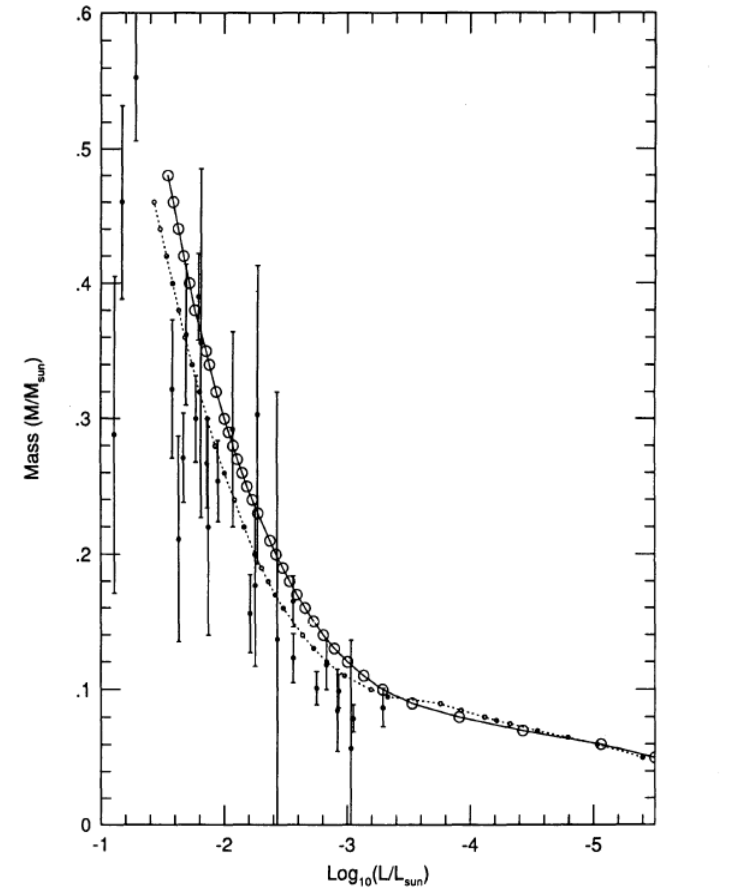

FIG. 3.—Mass-luminosity relations for case A (*dotted line connecting small open circles*) and case B (*solid line connecting large open circles*). The observed points with error bars are from Henry (1991).

/Hatzes & Rauer, 2015, submitted/

/Laughlin & Bodenheimer, 1993, ApJ/