



C ● R ● T-exo-7b

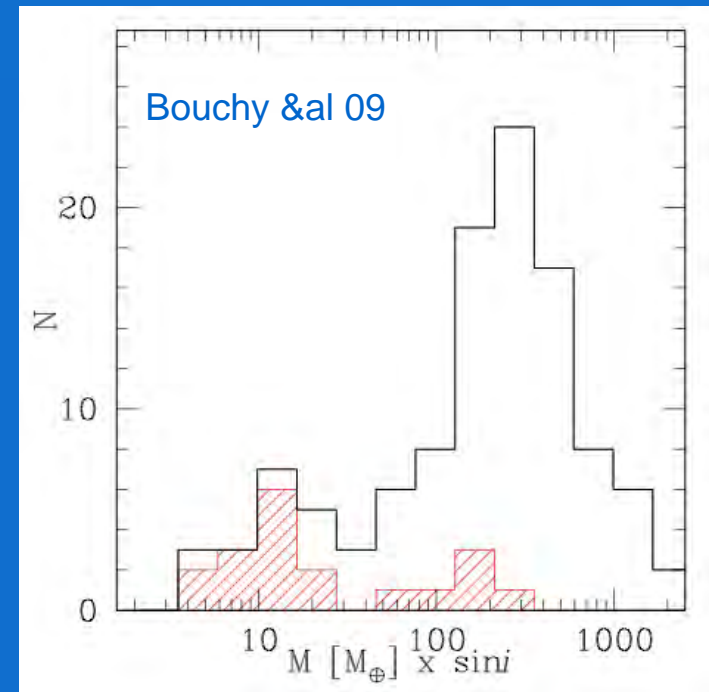
Has CoRoT discovered the  
first transiting Super-Earth  
around a main sequence star ?

D. Rouan, A. Léger, J. Schneider, R. Alonso, B. Samuel, H. Deeg, M. Deleuil, M. Fridlund,  
and all the **CoRoT Exoplanet Science Team**



## Short period planets: the *small* component

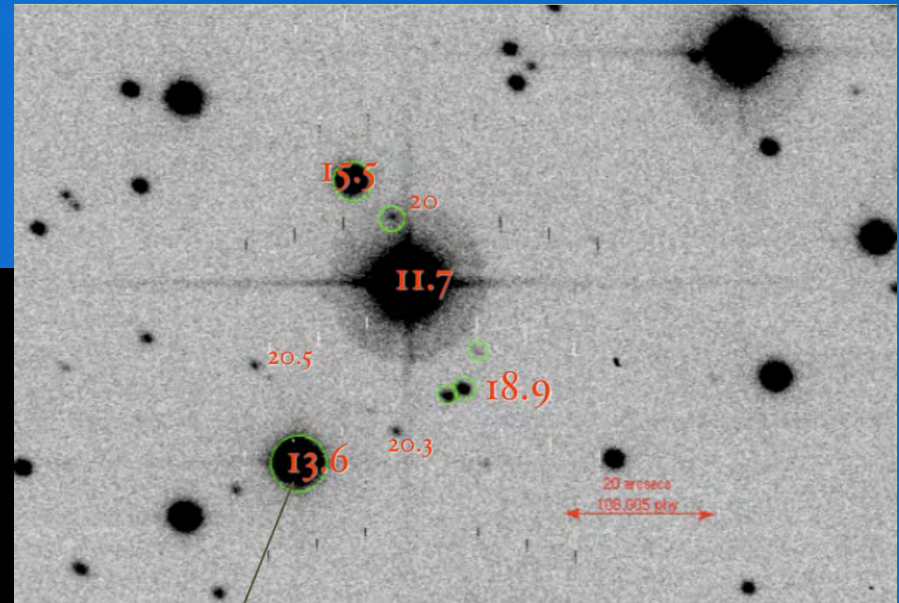
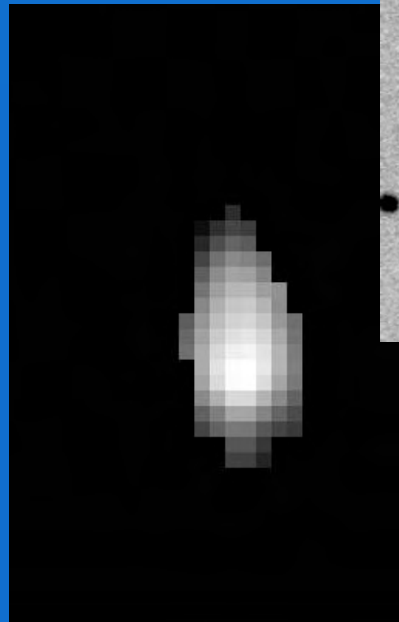
- 2006: first Super Earth detected with gravitational lensing
  - ⇒ Beaulieu et al. Nature 06
- Recent results from radial velocity point to a very significant population of Super-Earth: most recent
  - ⇒ 9.3  $M_{\oplus}$  Howard et al. ApJ accepted
  - ⇒ 7.5  $M_{\oplus}$  Bouchy et al. A&A accepted
- Today 20 planet w  $M < 0.1 M_{\text{Jup}}$
- Not yet a size measured
  - ⇒ needed for deriving the structure
- One of important goal of CoRoT
  - ⇒ detect transits of Super-Earth
  - ⇒ performances allow it
  - ⇒ A first case ?





## The star and the data taking

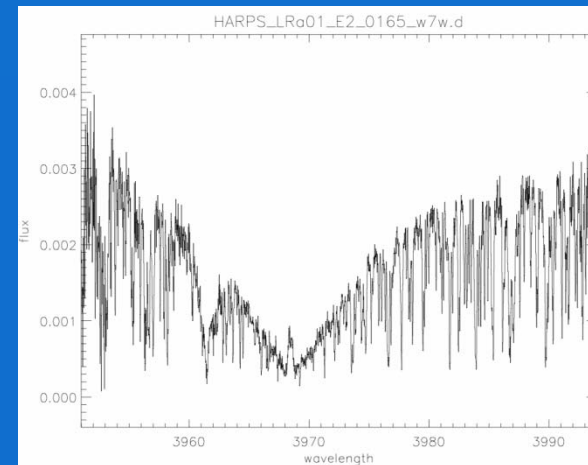
- Field: LRa01 anti-center direction - 135 days long
- The star: LRa01\_E2\_165  
⇒  $m_V = 11.7$
- The mask on CoRoT CCD:
- 3 colors
- Sampling: 32s





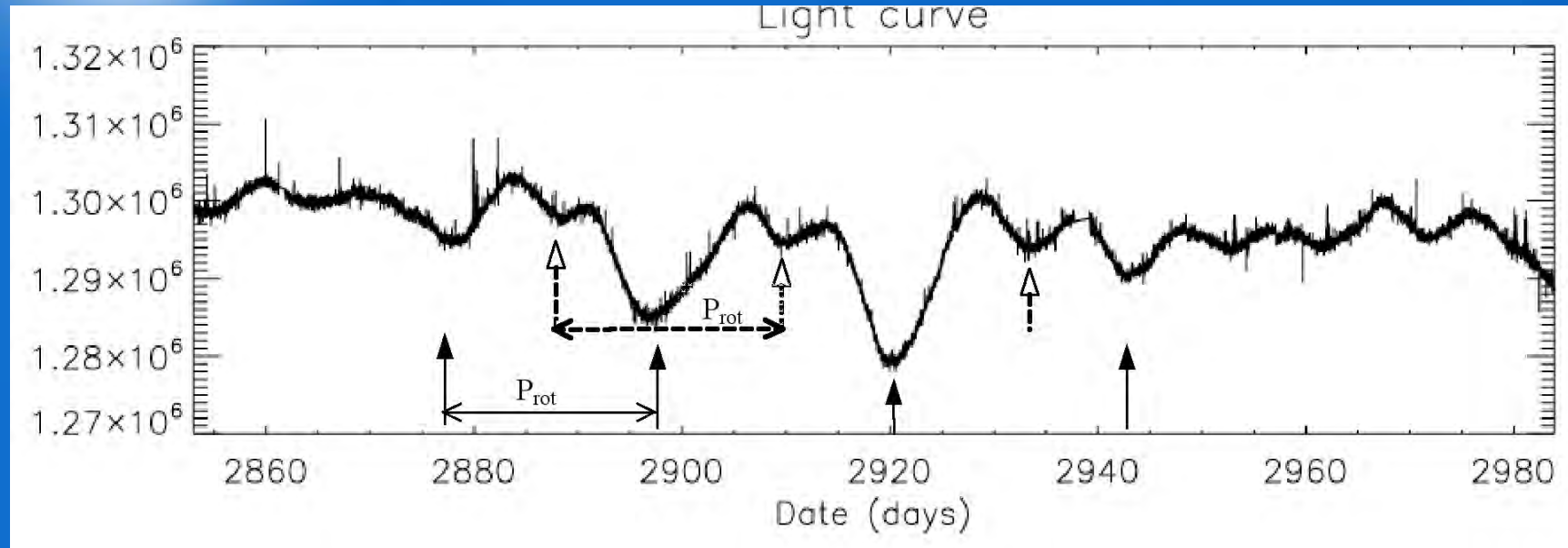
## The star and its fundamental parameters

- Spectra taken with UVES, HARPS
- Analyzed by several groups
  - ⇒ See Magali Deleuil presentation for the details
- Parameters :
  - ⇒ K0V star
  - ⇒  $T_{\text{eff}} = 5250 \text{ K}$
  - ⇒  $R_{\star} = 0.87 \pm 0.04$
  - ⇒  $M_{\star} = 0.93 \pm 0.03$
  - ⇒  $M/H = 0.05 \pm 0.05$
  - ⇒ Distance =  $130 \text{ pc} \pm 30$
  - ⇒  $.5 < \text{age} < 8 \text{ Gyr}$  (1.2 preferred ?)
  - ⇒ **active** : emission feature in core of H and K Ca lines





## The overall light curve

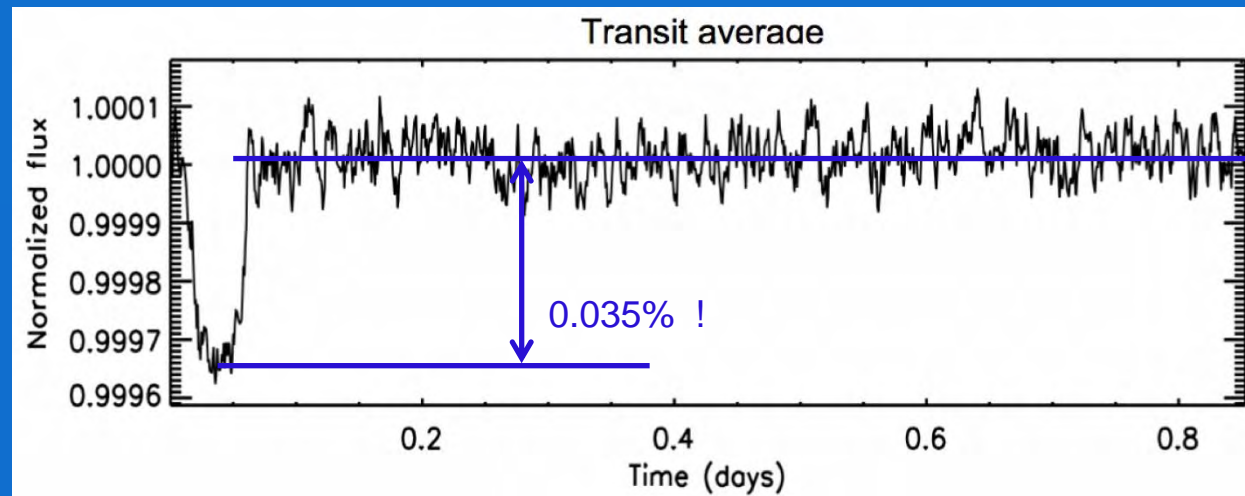
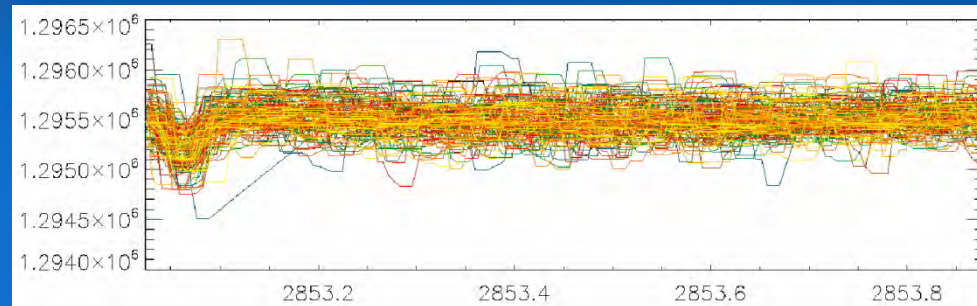


- Very active star with 2% modulation
- Spots crossing the disk because of rotation are clearly seen  
⇒ rotation period = 23 days





## The folded light curve



- First detected by alarm mode
- 153 transits, all ~ seen when superimposed
- short period :  $P = 0.8536$  days  
⇒ transit depth :  $\Delta F/F = 0.035\%$



Is this actually a small transiting planet ?

**FOLLOW-UP IS MANDATORY !**

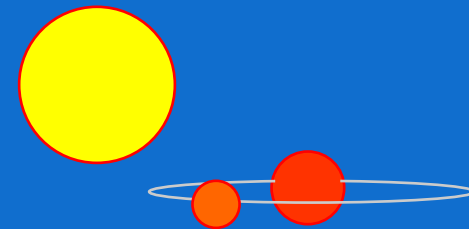
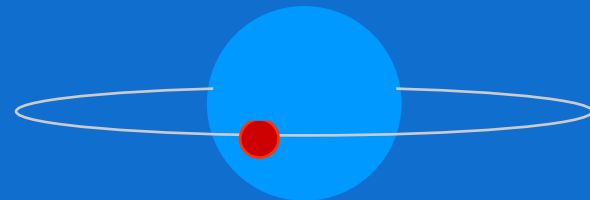
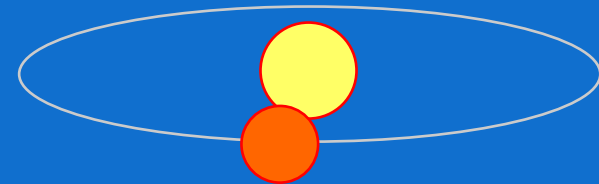
A big effort of the whole team



# The ennemy : the false positive !

which produces a signal analogous to a transiting planet

- Eclipsing Grazing Binary
- Eclipsing Binary in a dwarf/giant system
- Eclipsing Binary in a triple system

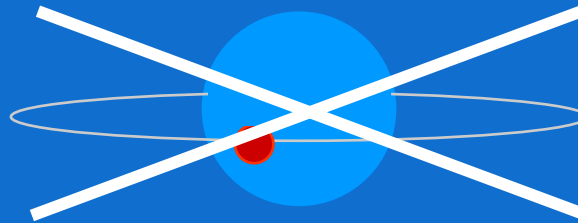






## Follow-up 1: spectroscopy

- UVES and HARPS spectra
  - ⇒ no blend
  - ⇒ K0V star
- Corot-Exo7 cannot be a giant star
- Exclude a binary system dwarf/giant

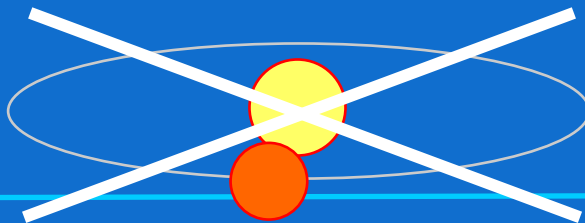
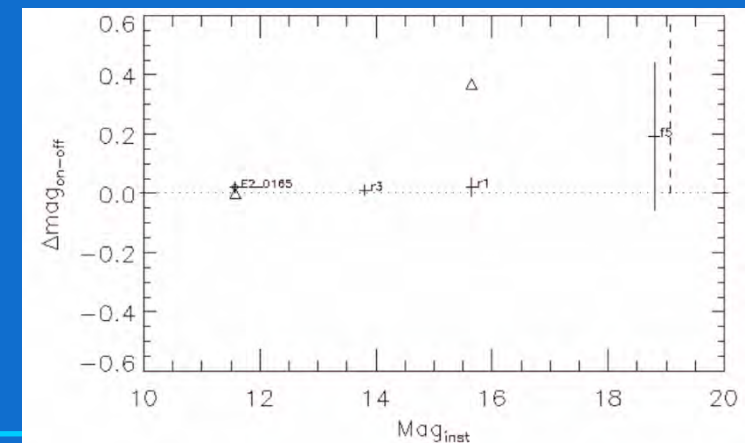
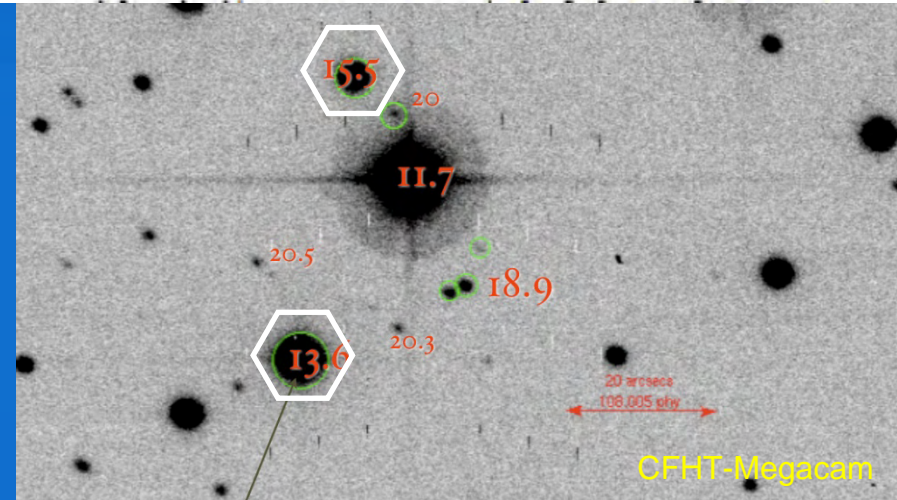




## Follow-up

- ON/OFF photometry with CFHT and 80cm IAC
- PSF + mask  
light in corot-aperture :
  - 99.63 % from E2\_0165
  - 0.24 % V=15.5 17" NE
  - <0.1% V=13.6 30"SE
- Only those 2 stars could produce false alarm
- ON/OFF photometry :
  - ⇒ NO  $\Delta\text{mag} > \text{alarm}$
- BEB (not within PSF) are excluded**

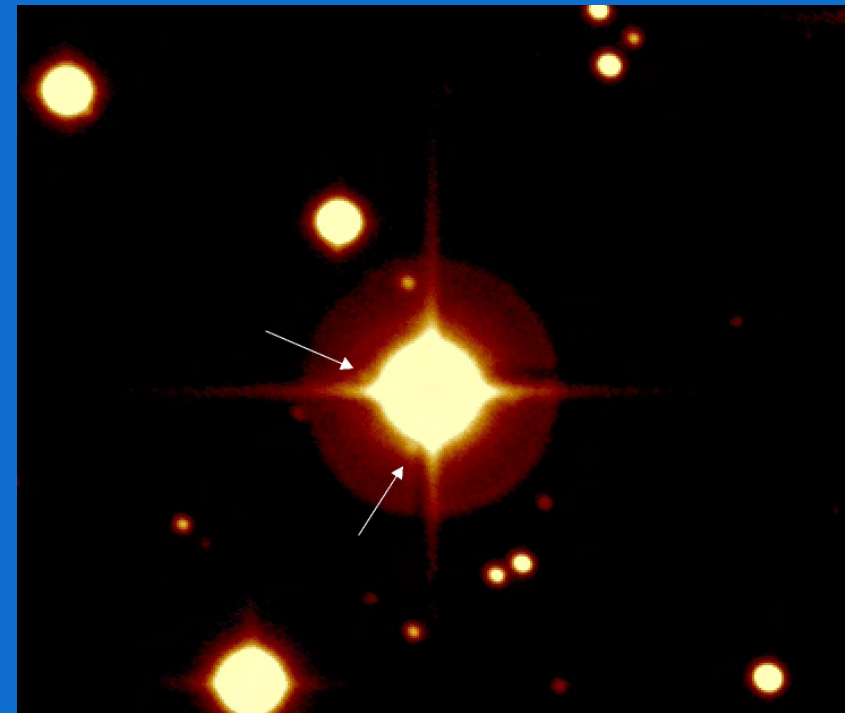
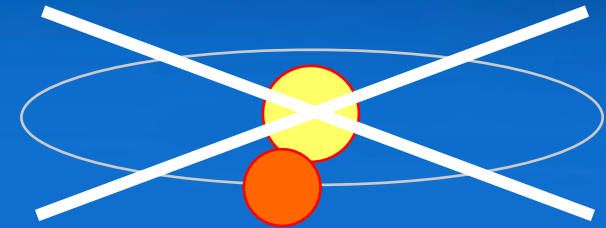
| name  | del-RA<br>arcs | del-DEC<br>arcs | mag    | conf<br>fact | rel<br>flux | alarm<br>delmag |
|-------|----------------|-----------------|--------|--------------|-------------|-----------------|
| 0165  | 0.0            | 0.0             | 11.570 | 1.000        | 0.99633     | 0.00046         |
| 15.5m | 8.3            | 15.3            | 15.640 | 0.103        | 0.00241     | 0.2068 *        |
| 15.4m | 32.8           | 27.2            | 15.420 | 0.000        | 0.00000     | Inf             |
| 13.6m | 16.3           | -26.3           | 13.810 | 0.005        | 0.00069     | 1.0149 *        |
| 18.9m | -7.5           | -16.1           | 18.800 | 0.063        | 0.00008     | Inf             |
| 20m   | 2.4            | 10.5            | 19.700 | 0.867        | 0.00048     | 2.1744          |





## Follow-up 3 : Good seeing Imaging

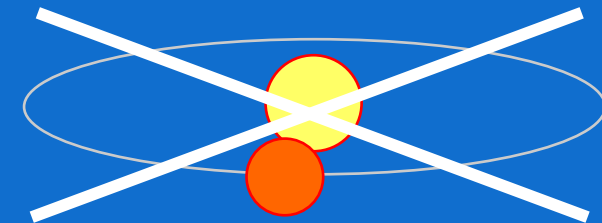
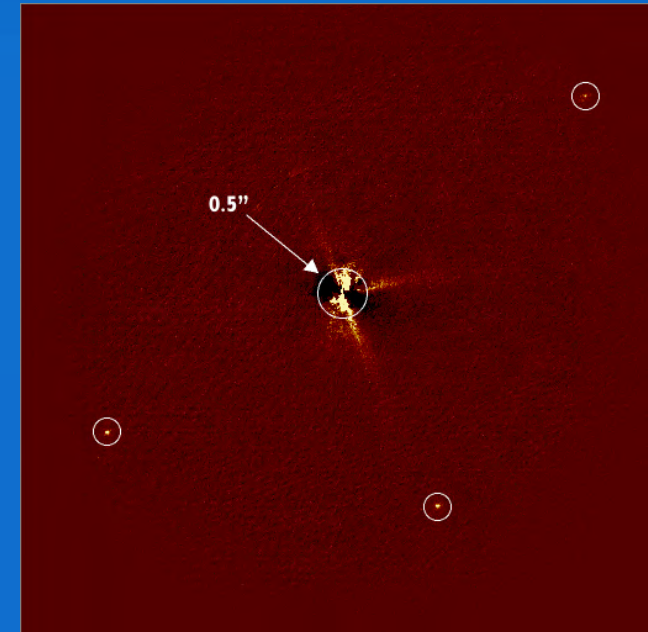
- Good angular resolution images using CFHT-MEGACAM in g-band
  - ⇒ sub-pixel recentering
  - ⇒ median of the cube
- Two faint stars detected @ 4.5 & 5.5''
- Magnitude estimate (fake stars added) :  $\Delta m = 10$ 
  - ⇒ too faint to cause a  $3.5 \cdot 10^{-4} \Delta F/F$
- **Close BEB excluded**





## Follow-up 4: Adaptive Optics Imaging

- High angular resolution image in J-band with NACO-VLT
  - ⇒ rotation on the sky: 5 positions
  - ⇒ median subtraction (E2\_165 vanishes)
  - ⇒ derotation
  - ⇒ median stacking
- Three new stars (2 on CFH)
  - ⇒ all at angular distance  $> 4''$
  - ⇒  $J = 18.4 - 18.7$
  - ⇒ redenning  $\Delta m(g) \approx 10 = \text{CFHT}$
  - ⇒ too faint to be BEB false positive
- **BEB between  $0.5''$  to  $4''$  excluded**

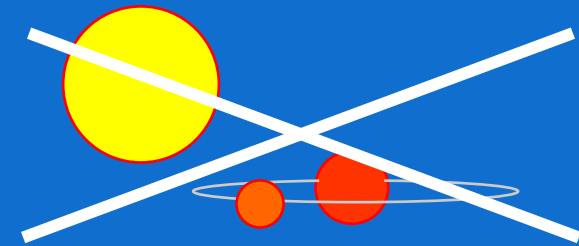
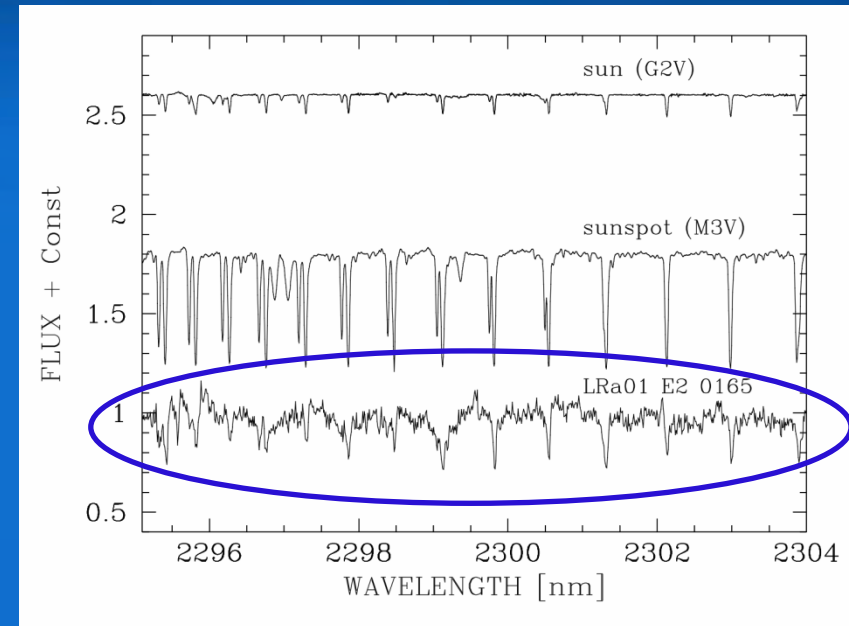






## Follow-up 5: IR spectra w CRILES

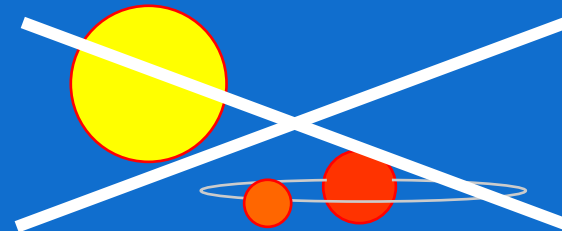
- Triple system with BEB ?
- IR spectra with CRILES-VLT:
  - ⇒ AO + 0.3" slit  $R=6 \cdot 10^4$
  - ⇒ K-band : CO overtone lines
- Very sensitive method since
  - ⇒  $\Delta m_K$  is small between M and K
  - ⇒ CO lines are strong in M stars
- Result:
  - ⇒ No late K or M earlier than M6 and brighter than  $K=12.3$  at the distance of Corot-Exo7 within 0.3"
- Eclipsing binary of M stars earlier than M6 orbiting Corot-Exo7b excluded





## Follow-up 6: X-ray activity

- If binary with  $P=0.85$  days Strong X-ray emitter
  - ⇒ e.g. : YY Gem = M1V  $P = 0.81$  days
- ROSAT all sky survey
  - ⇒ 0.1 - 2 keV
  - ⇒ region of Corot-Exo7b
- Results:
  - ⇒ NO binary similar to YY Gem out to  $250 \pm 100$  pc
- Late M binary system orbiting Corot-Exo7b excluded

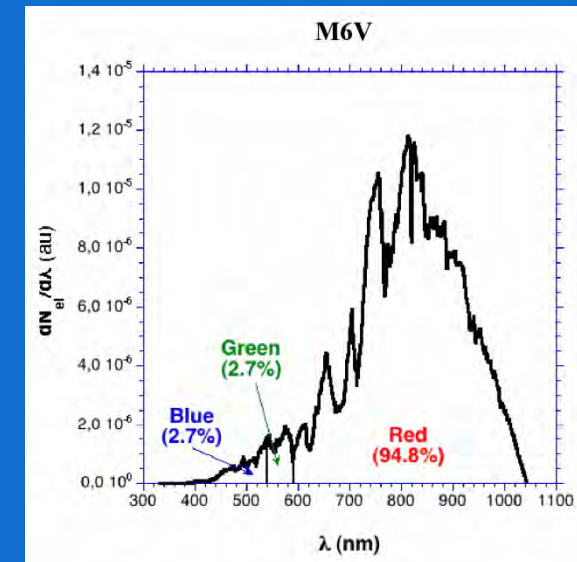
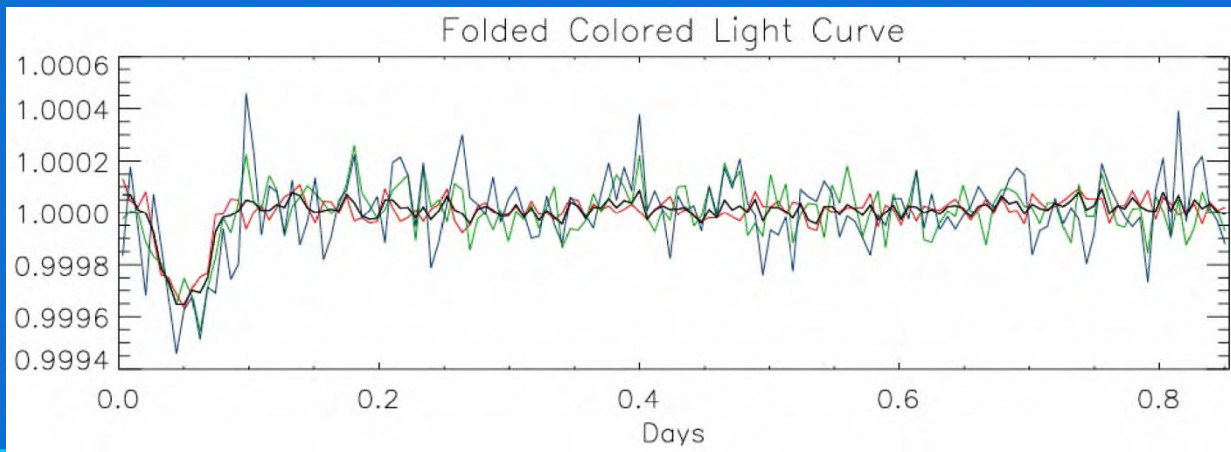
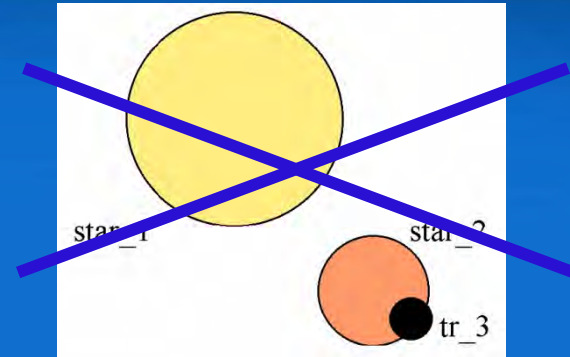






## Follow-up 7: CoRoT colors

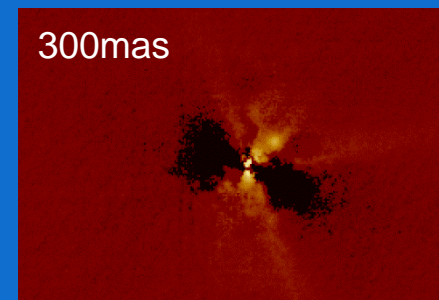
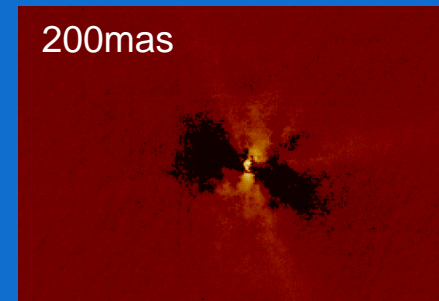
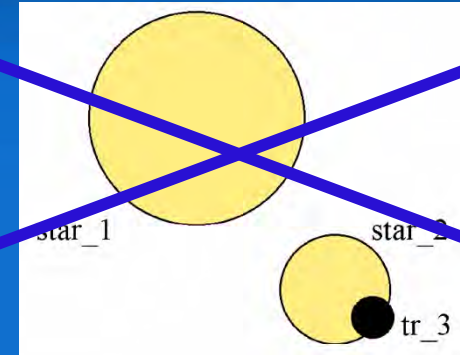
- Triple system with a Jupiter transiting a second star ?
- CoRoT Colors : 3 Light Curves
  - ⇒ *Blue, Green, Red*
  - ⇒ transit is achromatic !
- Eliminate a triple system because star\_2, and thus the transit signal, would be red





## Follow-up 8: Adaptive Optics Imaging

- Jupiter transiting a background star of same color as Corot-Exo7 ?
  - ⇒ Would not be detected in Corot colors
  - ⇒ the star must be  $3.5 \cdot 10^{-2}$  fainter
- High angular resolution image with NACO-VLT
  - ⇒ add a fake  $m_V=16.7$  star at  $0.2''$  and  $0.3''$
  - ⇒ do the same processing as before
  - ⇒ a star with  $\Delta m = 5$  would be detected at 300 mas and likely at 200 mas
- Probability to have a star of mag 16.5 and same color, w a transiting Jupiter within  $0.25'' < 2 \cdot 10^{-4}$ 
  - ⇒ independant evaluation by F. Fressin





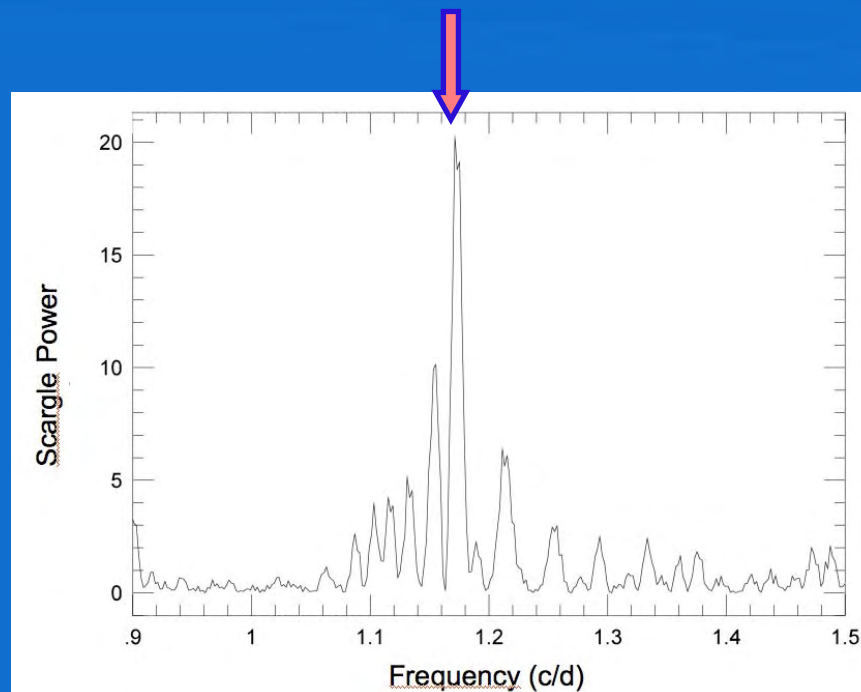
## Follow-up 9: Radial Velocity with HARPS

Radial Velocity with HARPS :

- see talk by F. Bouchy
- Many nights of observation
- Preliminary results
- NO stellar, substellar or Jupiter mass
- compatible with a transiting planet  $M < 11 M_{\oplus}$
- data reduction still continuing

Most recent :

- Scargle diagram peak at .851 days !





All *known* cases of false positives practically eliminated with a high level of confidence

The transit should be due to a  
**Super Earth planet**  
with a fairly high probability



## Planet characteristics

period:  $P = 0.8536$  d (one year = 20.5 h)

$a = 0.017$  AU =  $2.8 R_{\star}$

Other parameters: depend on LC analysis.

Two groups used independent methods

variability is also a player: it makes the g

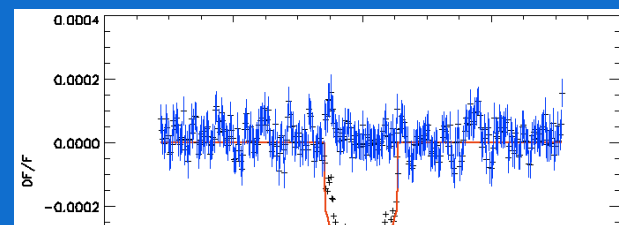
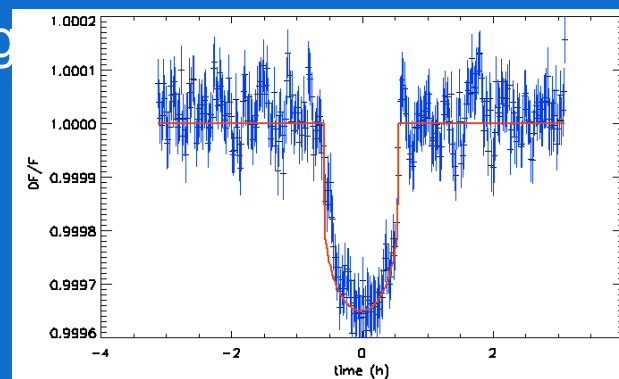
Group 1 :

transit with rather sharp edges  
medium impact parameter

straightforward analysis (Kepler +  
Eddington limb-darkening)

impact param =  $0.67 \pm .03$

$R_{pl} = 1.74 R_{\oplus} \pm .13$

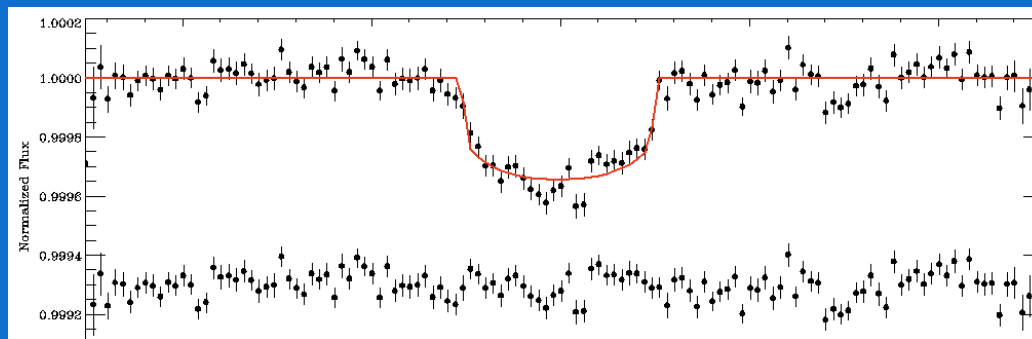




## Planet characteristics

Group 2 :

- ▶ transit with rather long ingress/egress  
high impact parameter
- ▶ More sophisticated analysis (Gimenez 03)
- ▶ Correction for suspected Time Transit Delays  
Stellar parameters do not conflict w spectroscopy
- ▶ Uses then spectroscopy parameters
- ▶ impact param =  $0.86 \pm .09$
- ▶  $R_{pl} / R = 0.020$
- ▶  $R_{pl} = 1.76 R_{\oplus}$
- ▶ Good agreement







# Nature of CorotExo7b ?

lot of exciting physics ! for example :

elongation under tidal forces: 1%

temperature

between 1100 et 2000 K depending on albedo : pretty hot !



structure ?

rocky : if  $M > 6 M_{\oplus}$

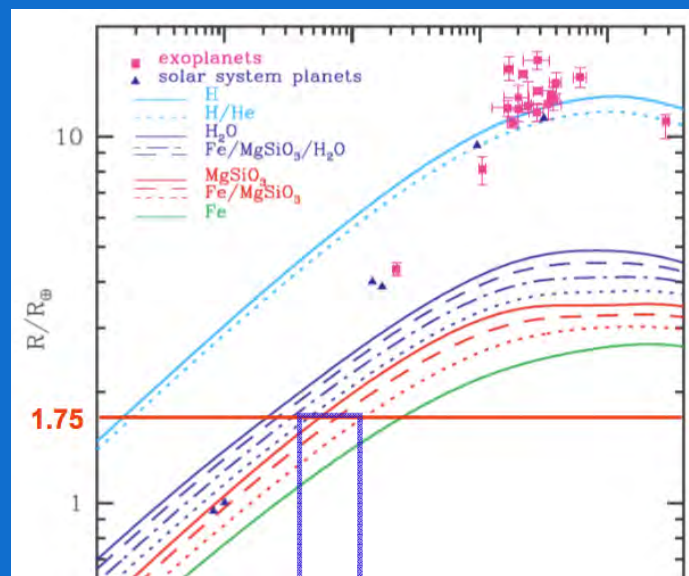
- solid or liquid lava ?

*ocean-planet* if  $M < 5 M_{\oplus}$

- then super-critical water

atmosphere ?

escape of volatiles requires  
0.1 to 1 Gyr





SO...

C  R  T-exo-7b

the

first transiting Super-Earth  
around a main sequence star ?

we gave good reasons to believe it !

Still a lot of work to characterize it fully and  
determine its structure

And a great thank to the technical team



The End  
of this talk

... the continuation of

an intensive work for the team !

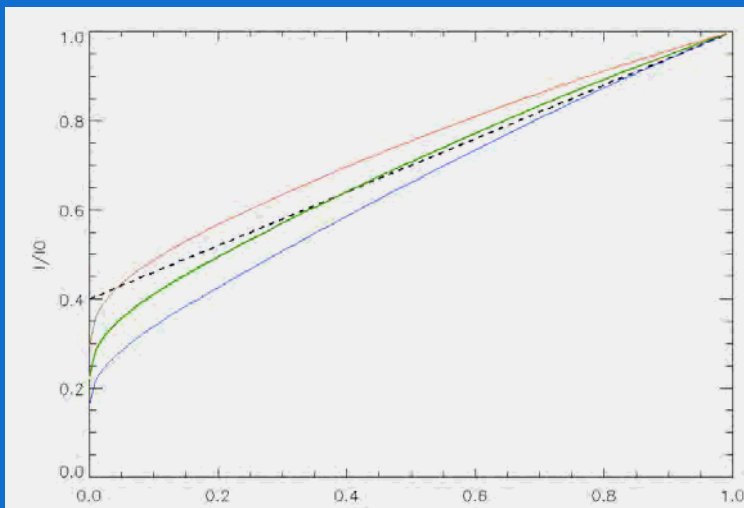


## Eddington limb-darkening ?

limb-darkening effect in K0V star

→ Claret 2003 in V, R and I band ( $\approx$  CoRoT spectrum): solid

→ Eddington (dash line):  $I/I_0 = .4 (1 + 3/2 \mu)$





## Time Transit Variations ?

could be due to satellite perturbations

→ excluded for the time being

gravitational perturbations by another closein planet ?

→ more likely

→ debate on the amplitude of the effect : 10 minutes or hours ?

can be taken into account



# Structure of Corot-Exo-7b

