On the detection of reflected light from exoplanets

ENAA 2013

J. H. C. Martins[1,2] P. Figueira[1] N. Santos[1,2] F. Pepe[3]

July 18, 2013

[1] Centro de Astrofísica, Universidade do Porto

[2] Departamento de Física e Astronomia, Faculdade de Ciências, Universidade do Porto

[3] Observatoire de Genéve, Université de Genève

Outline

1. Motivation
2. Cross Correlation Function
3. The Data
4. The Method
5. Results
6. Conclusions

Motivation

- At optical wavelengths, an exoplanet's signature is essentially reflected light from the host star

Motivation

- At optical wavelengths, an exoplanet's signature is essentially reflected light from the host star
- The planet's optical spectrum is almost a copy of the star's spectrum

Motivation

- At optical wavelengths, an exoplanet's signature is essentially reflected light from the host star
- The planet's optical spectrum is almost a copy of the star's spectrum
- The analysis of the planet's reflected light might give us an estimate of the planet's atmospheric composition, albedo, orbital velocity (and therefore mass)

The problem

- Albedo is low, with typical values 0.05-0.4 (Cowan & Agol 2011; Rowe et al. 2008; Evans et al. 2013)

The problem

- Albedo is low, with typical values 0.05-0.4 (Cowan & Agol 2011; Rowe et al. 2008; Evans et al. 2013)
- Planets are small and have a low cross section

The problem

- Albedo is low, with typical values 0.05-0.4 (Cowan & Agol 2011; Rowe et al. 2008; Evans et al. 2013)
- Planets are small and have a low cross section
- Jupiter mass planet, 2 days orbit and albedo = 0.3:

$$\frac{Flux_{reflected}}{Flux_{incident}} \approx 6.8 \times 10^{-5}$$

The problem

- Albedo is low, with typical values 0.05-0.4 (Cowan & Agol 2011; Rowe et al. 2008; Evans et al. 2013)
- Planets are small and have a low cross section
- Jupiter mass planet, 2 days orbit and albedo $= 0.3$:

$$\frac{Flux_{reflected}}{Flux_{incident}} \approx 6.8 \times 10^{-5}$$

- we require spectra with S/N over 10^5!!!

The problem

- Albedo is low, with typical values 0.05-0.4 (Cowan & Agol 2011; Rowe et al. 2008; Evans et al. 2013)
- Planets are small and have a low cross section
- Jupiter mass planet, 2 days orbit and albedo = 0.3:

$$\frac{Flux_{reflected}}{Flux_{incident}} \approx 6.8 \times 10^{-5}$$

- we require spectra with S/N over 10^5!!!
- In the case of the Earth, with an albedo of 0.29:

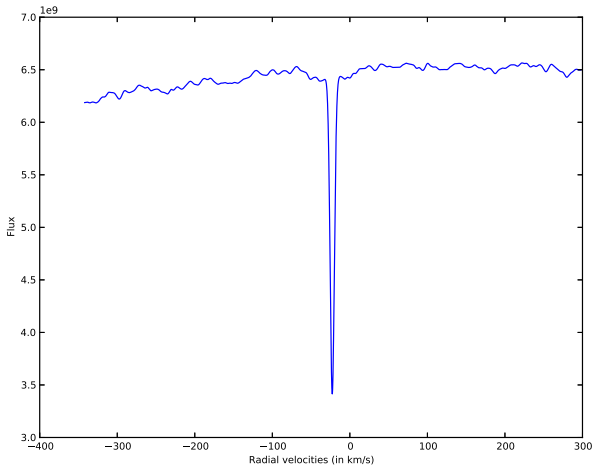
$$\frac{Flux_{reflected}}{Flux_{incident}} \approx 5.3 \times 10^{-10}$$

Cross Correlation Function

to the rescue!!!

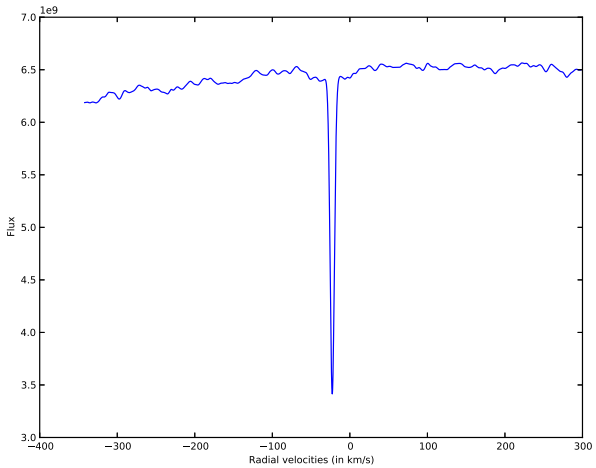
The Cross Correlation Function

- The CCF of a spectrum with a binary mask has been used extensively for the determination of precise radial velocities (e.g. with the HARPS spectrograph) (Baranne et al. 1996)



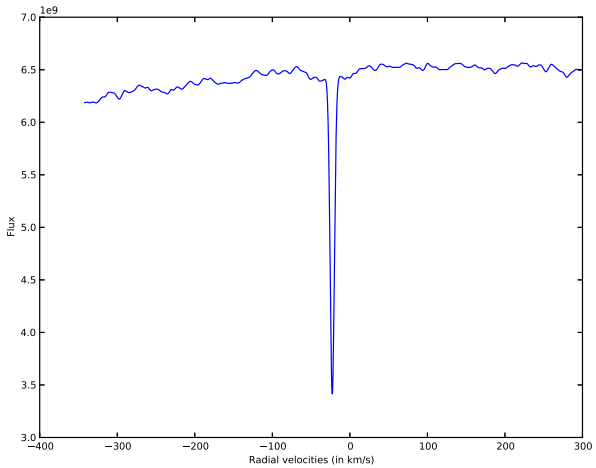
The Cross Correlation Function

- The CCF of a spectrum with a binary mask has been used extensively for the determination of precise radial velocities (e.g. with the HARPS spectrograph) (Baranne et al. 1996)
- It can be seen as an average spectral line of the original spectrum



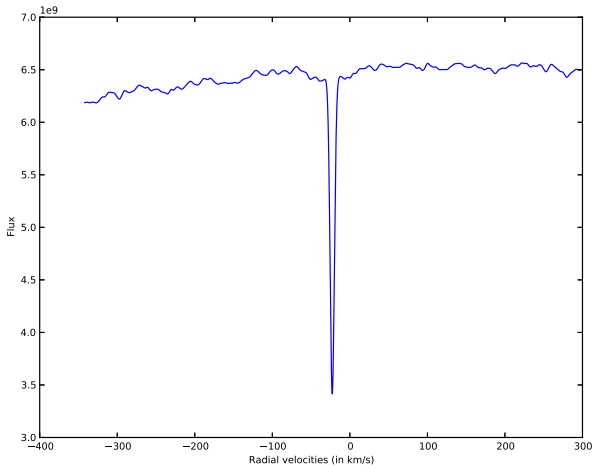
The Cross Correlation Function

- The CCF of a spectrum with a binary mask has been used extensively for the determination of precise radial velocities (e.g. with the HARPS spectrograph) (Baranne et al. 1996)
- It can be seen as an average spectral line of the original spectrum
- $S/N_{CCF} = \sqrt{n}\, S/N_{spectrum}$



The Cross Correlation Function

- The CCF of a spectrum with a binary mask has been used extensively for the determination of precise radial velocities (e.g. with the HARPS spectrograph) (Baranne et al. 1996)
- It can be seen as an average spectral line of the original spectrum
- $S/N_{CCF} = \sqrt{n}\, S/N_{spectrum}$
- for a binary mask with 3600, the S/N increases 60 times!!!



The Data

- We combined the CCFs of real HARPS spectra to simulate 10 h of observations of multiple prototypical planetary systems with short period orbits

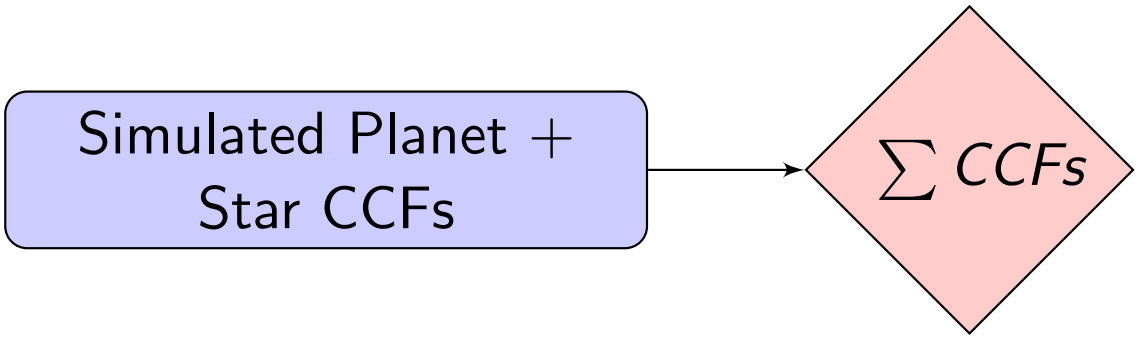
The Data

- We combined the CCFs of real HARPS spectra to simulate 10 h of observations of multiple prototypical planetary systems with short period orbits
- We wanted to test the possibility of detecting the planet's reflected light with next generation instruments and observing facilities (ESPRESSO@VLT and HIRES@E-ELT)

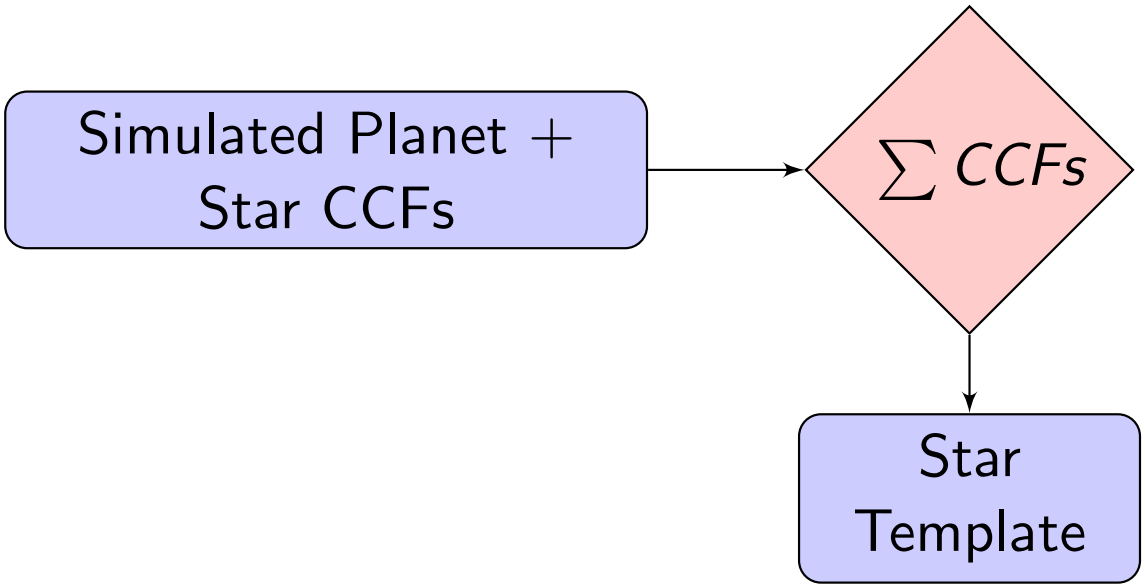
The Detection Method

Simulated Planet + Star CCFs

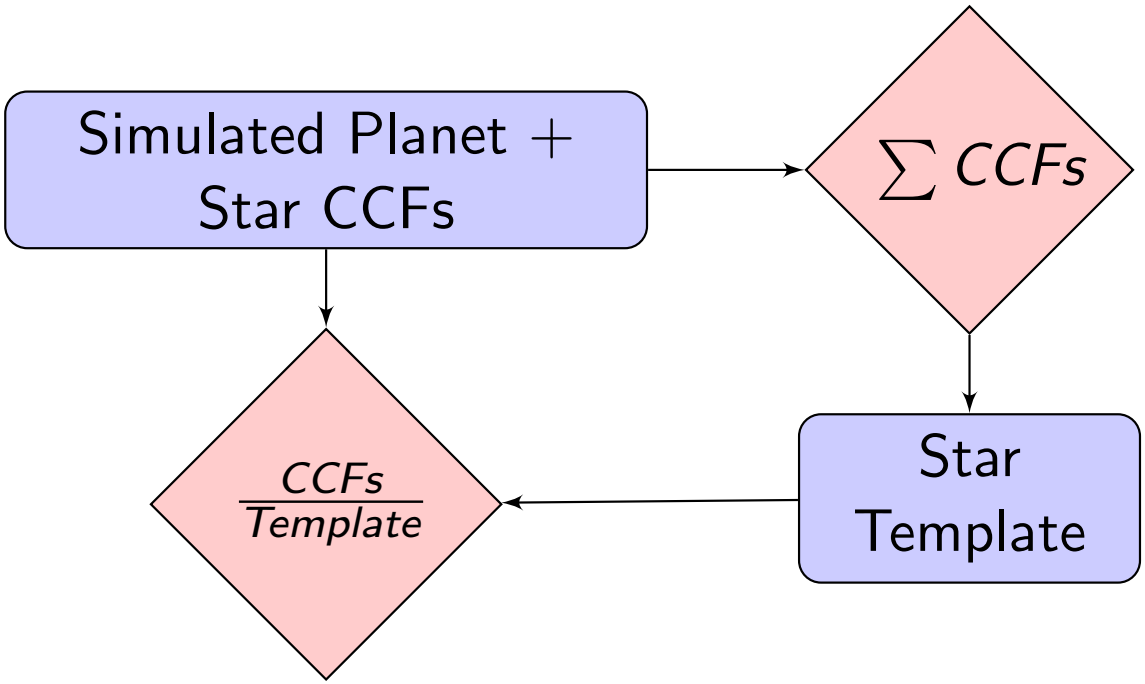
The Detection Method



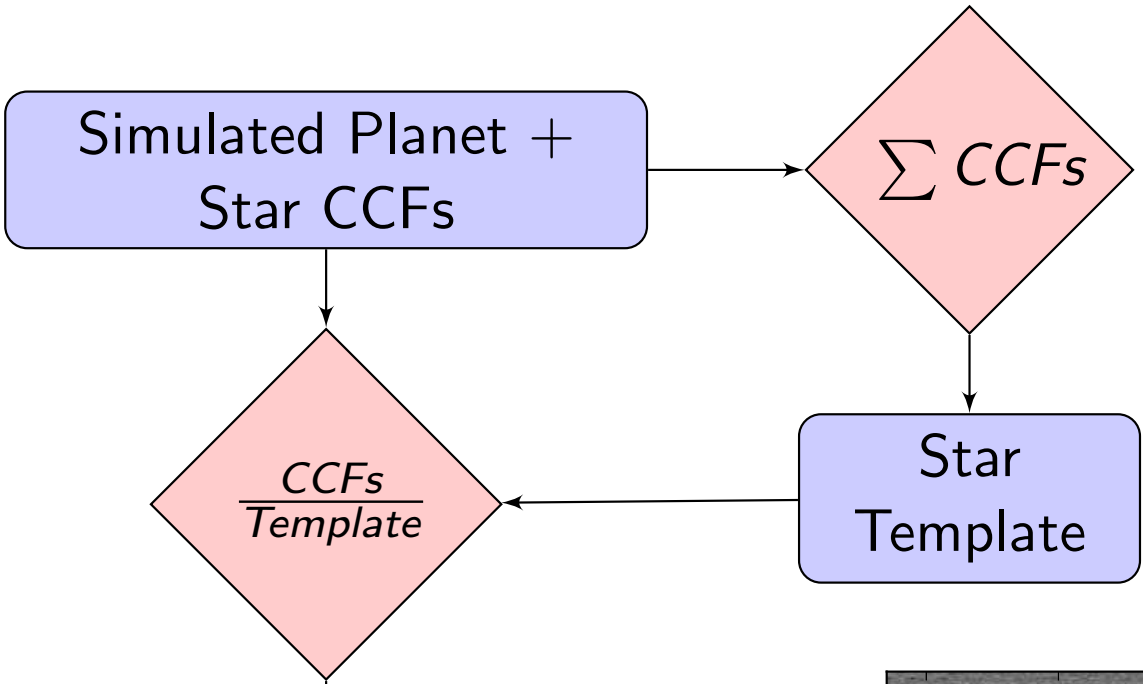
The Detection Method

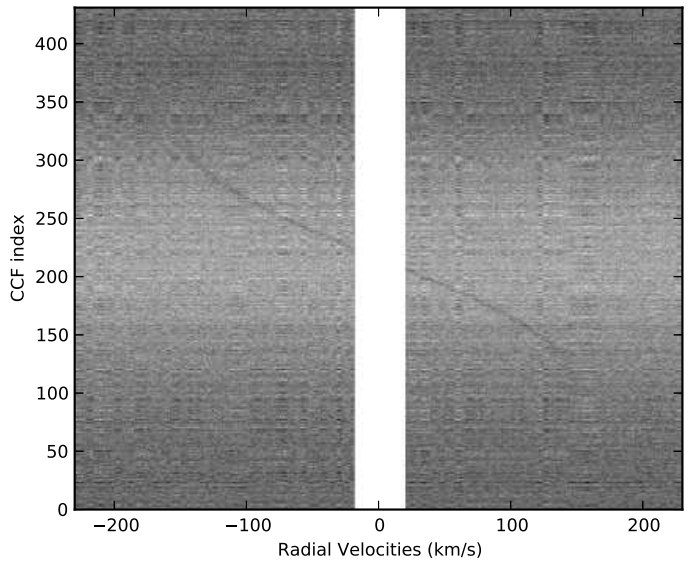


The Detection Method

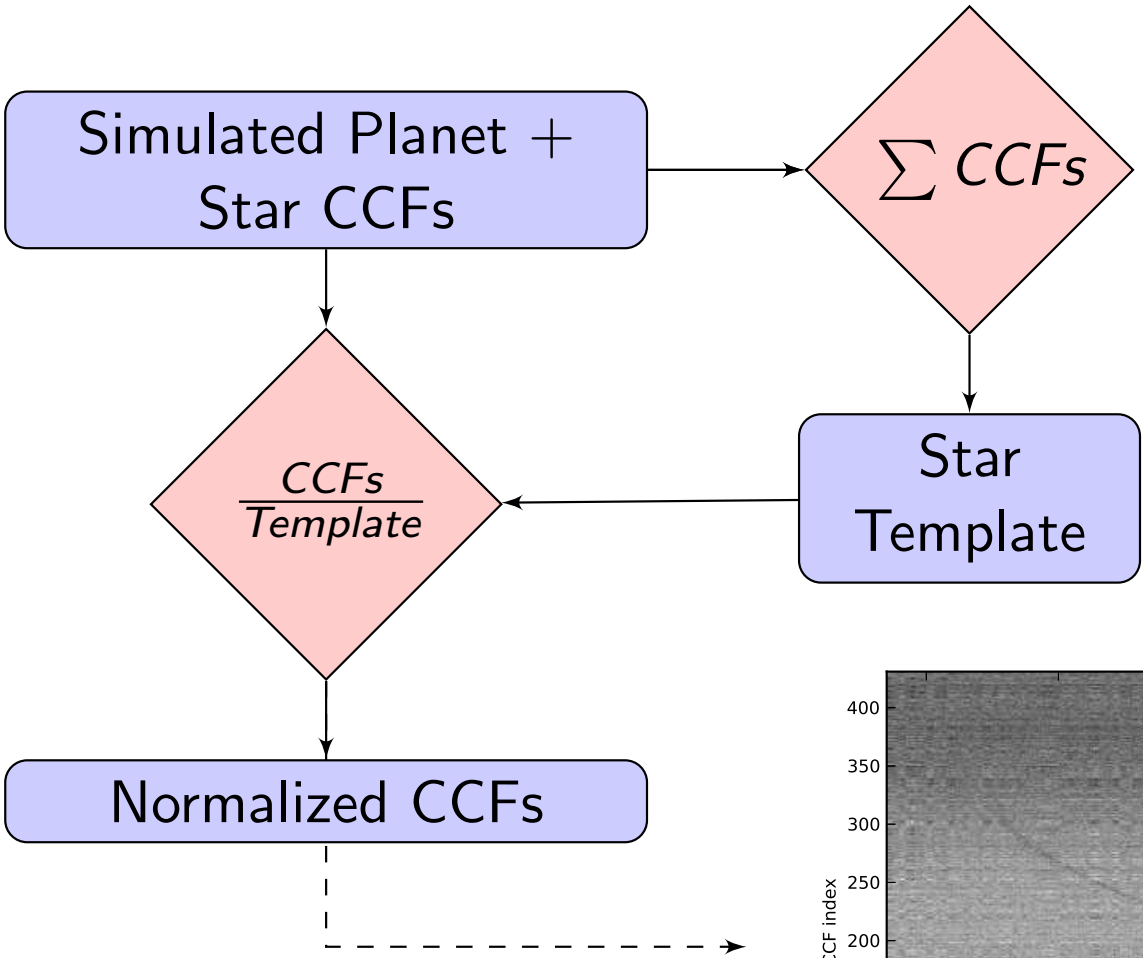


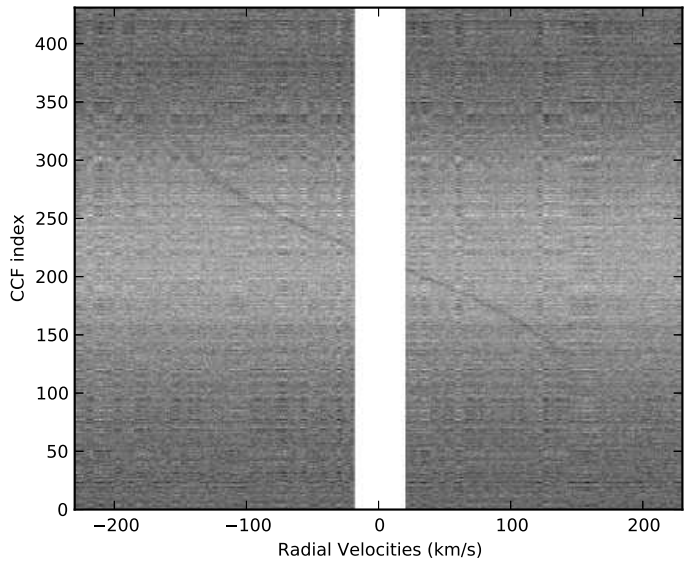
The Detection Method



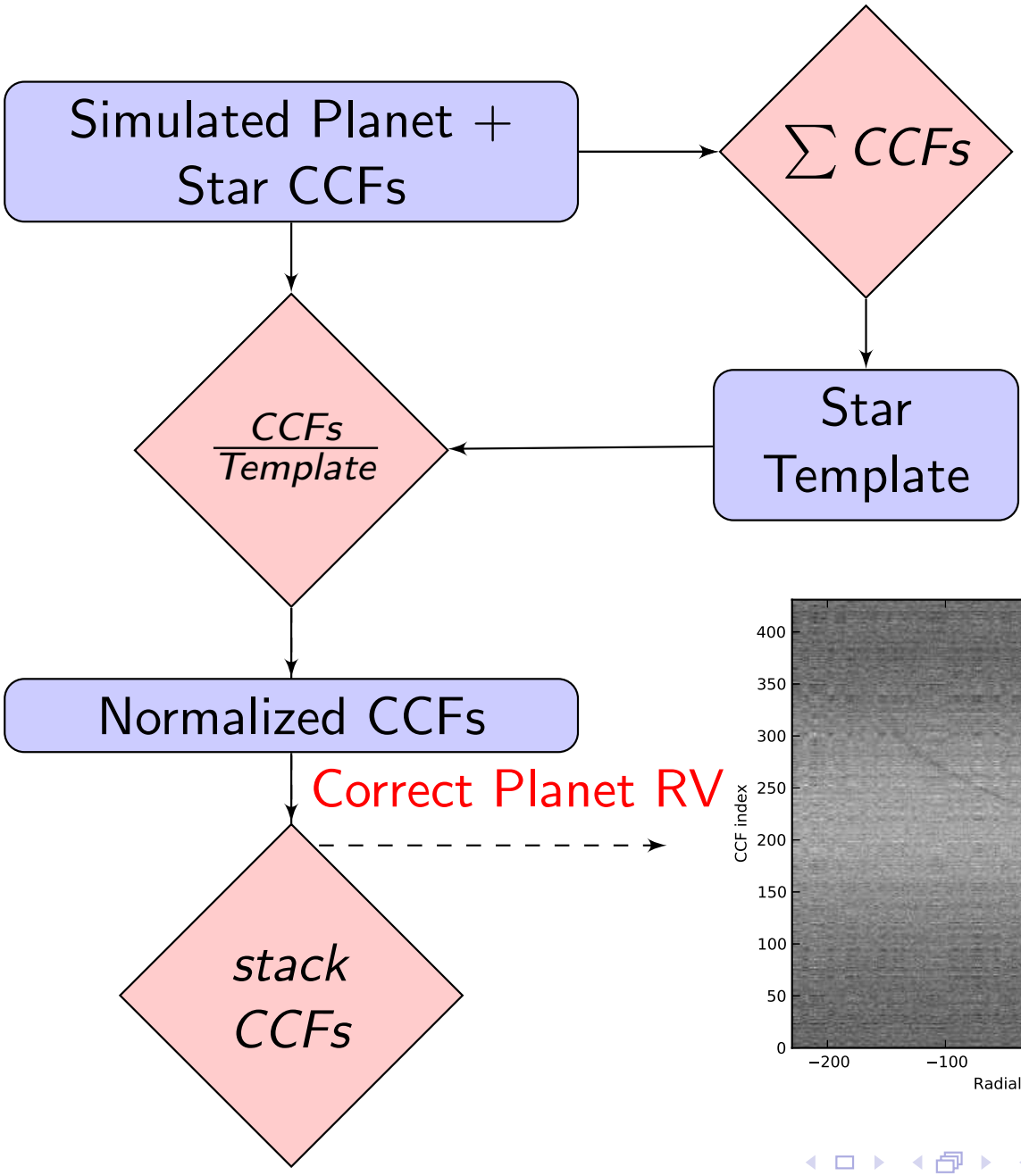


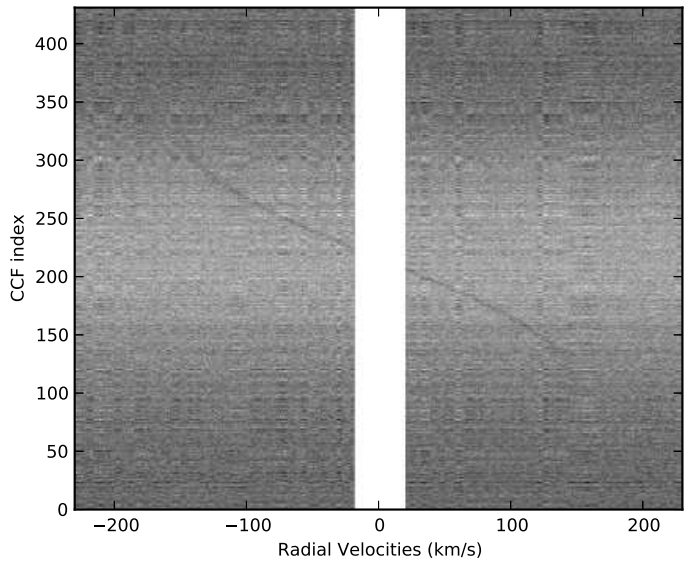
The Detection Method



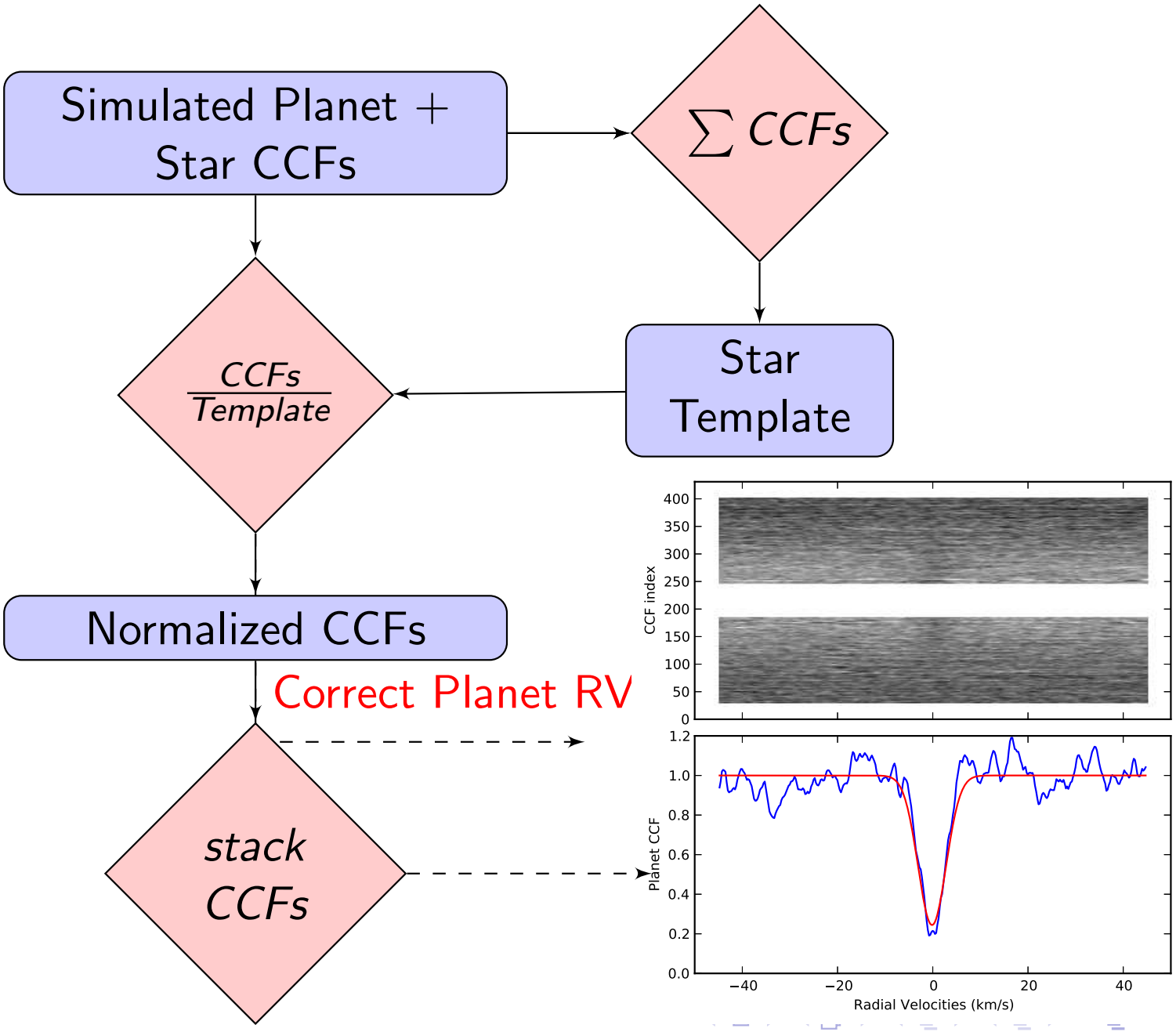


The Detection Method

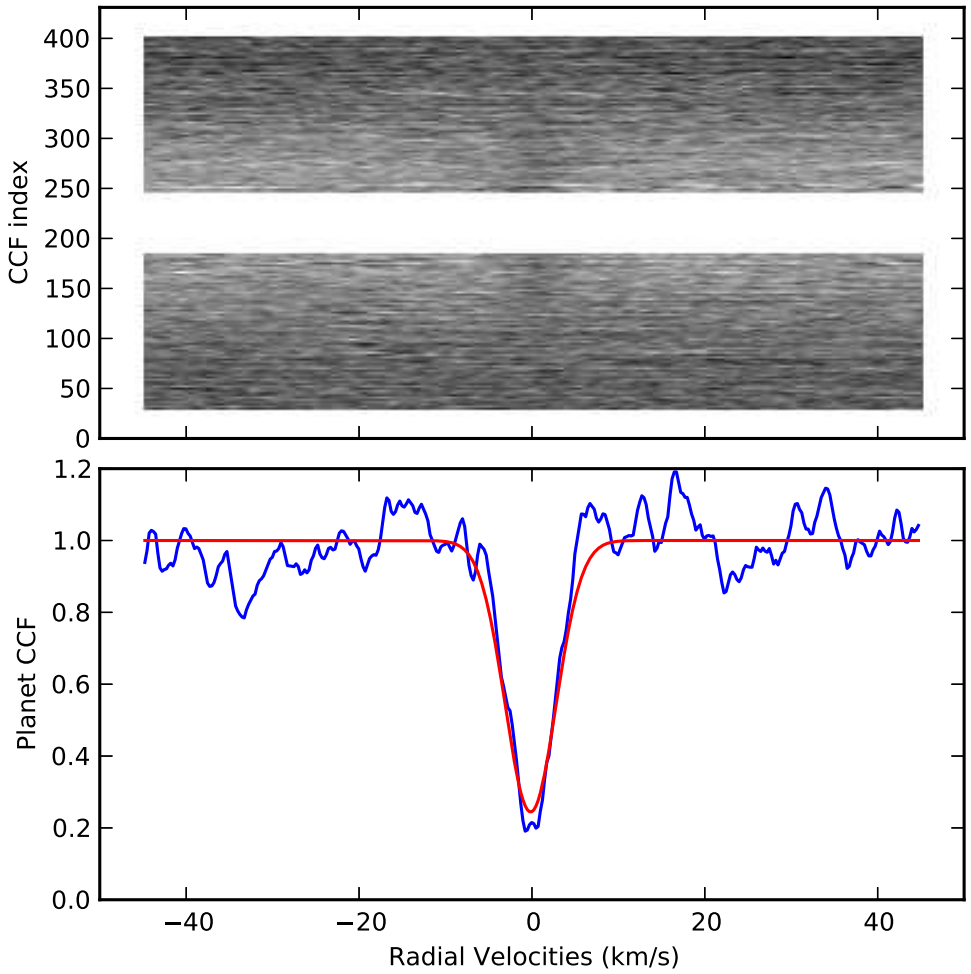




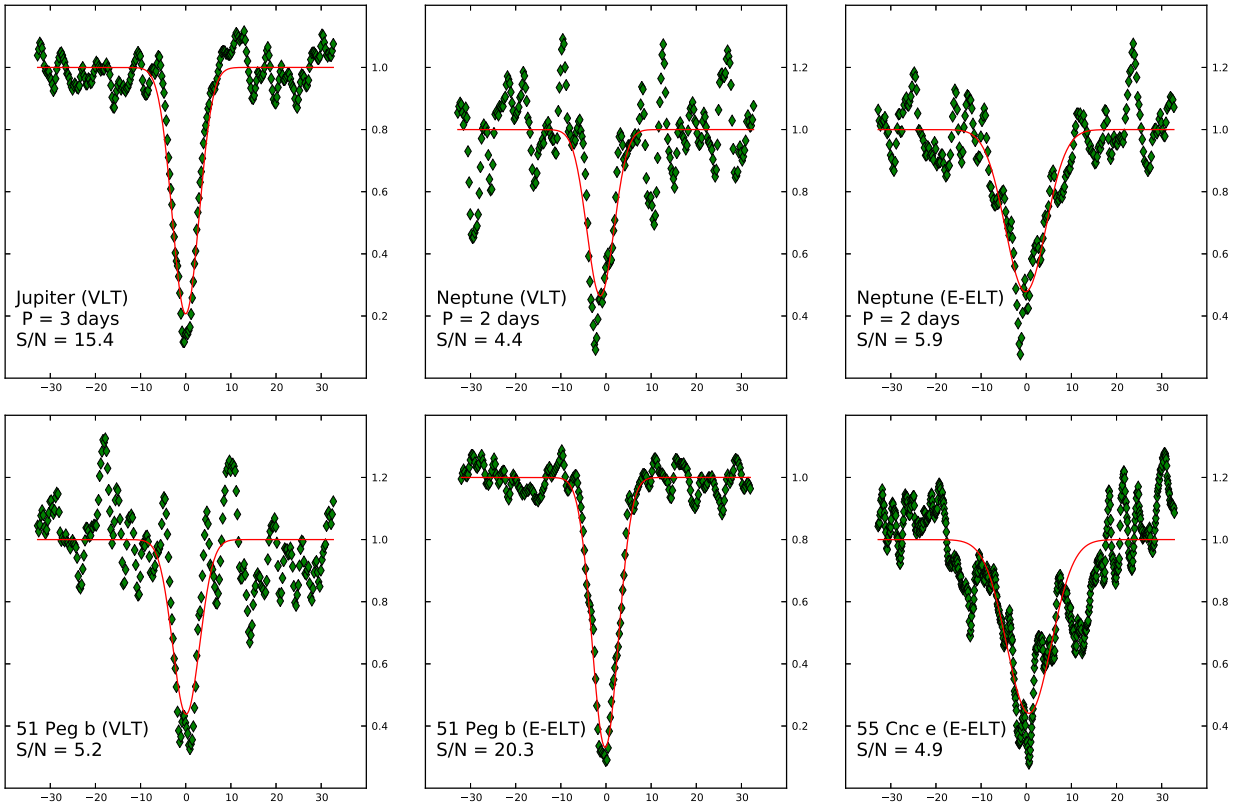
The Detection Method



Results


CCF index
400
350
300
250
200
150
100
50
0
Planet CCF
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−40
−20
0
20
40
Radial Velocities (km/s)

Results



Each case corresponds to 10h of observations.

Conclusions

- It is possible to detect a planets's reflected light by using the Cross Correlation Function

Conclusions

- It is possible to detect a planets's reflected light by using the Cross Correlation Function
- The detection of 51 Peg b with VLT shows that it is possible to detect the reflected light of a real object with a current telescope

Conclusions

- It is possible to detect a planets's reflected light by using the Cross Correlation Function
- The detection of 51 Peg b with VLT shows that it is possible to detect the reflected light of a real object with a current telescope
- Next generation observing facilities will permit the collection of spectra with the required S/N, which should allow for the detection the reflected light of smaller planets at longer period orbits

THANK YOU!