

Line-profile variations in radial-velocity measurements by fitting a Skew Normal distribution



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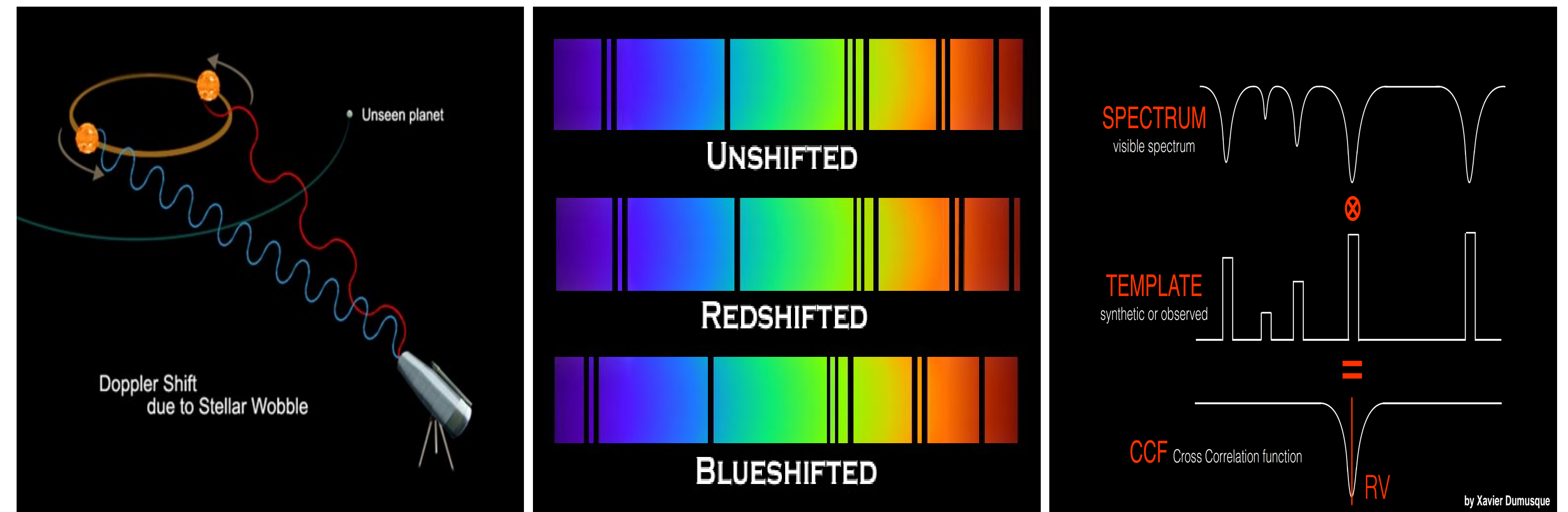
SUMMARY

- For detecting Exoplanets, the **cross-correlation function (CCF)** is derived for calculating the **radial velocity (RV)** of the star
- The CCF is an average of all the absorption lines in a stellar spectrum
- **Stellar activity** induces RV variations by a modification of the spectral line asymmetry, while an orbiting companion only induces a pure Doppler shift on spectral lines without modifying their shape
- **Disentangling the stellar activity** from the Doppler shift caused by an “Earth-like” planet is challenging. **Both active regions and Doppler shift induce variation in RV of few m/s**

METHODOLOGY

- In the common analysis the measurement of the RV and the evaluation of the line asymmetry are retrieved separately
- We propose a **1 step procedure** by fitting a **Skew Normal distribution** to the CCF, which allows us to focus on variations in RV caused by active regions
- We correct the RV from stellar activity, in order to retrieve the pure RV of the star due to the Doppler effect
- We implement a **bootstrap analysis** to retrieve accurate standard errors by using the measurement errors of each CCF

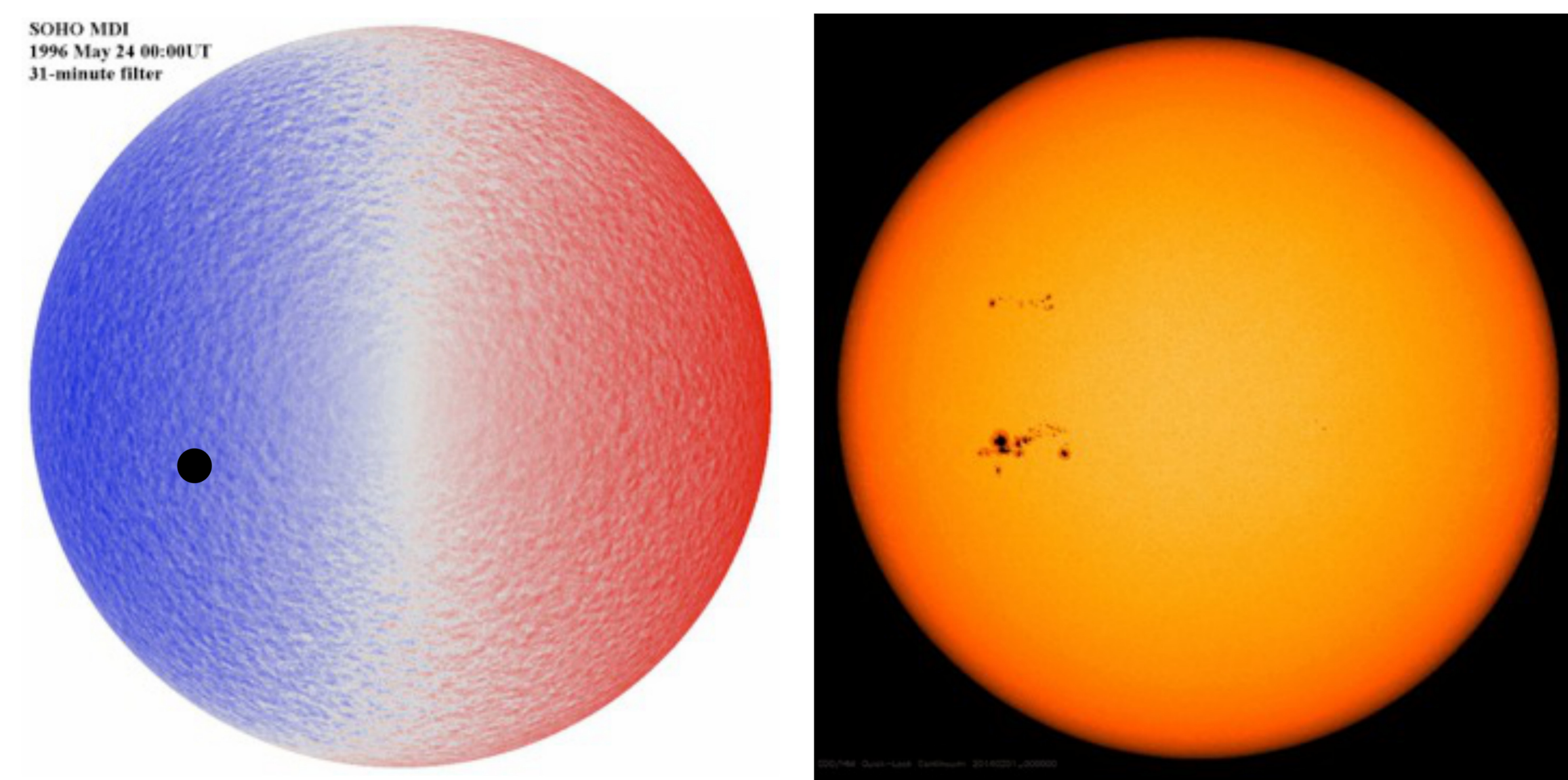
RADIAL VELOCITY METHOD AND IMPACT OF ACTIVE REGIONS



Exoplanets will only produce a RV variation induced by a **pure Doppler shift** on stellar spectra. **Stellar activity** does not produce a blueshift or a redshift on the spectra, but creates a **spurious RV signal** by modifying the shape of spectral lines.

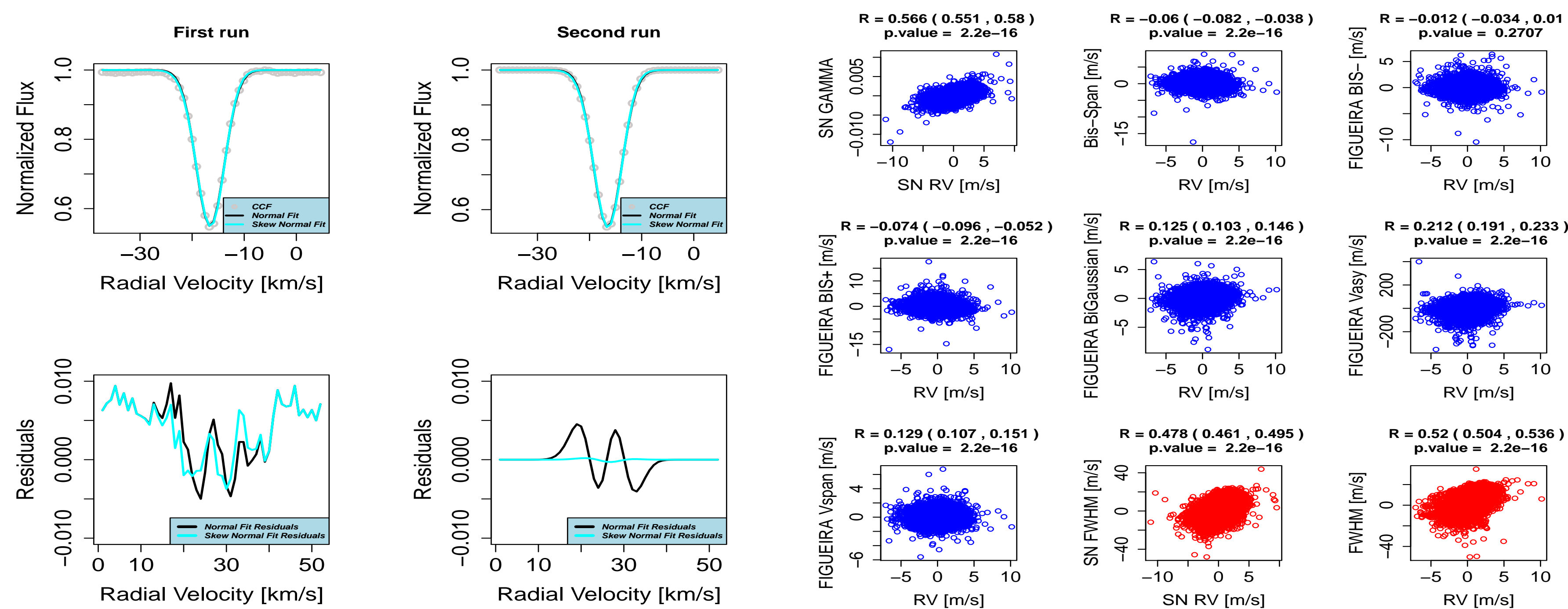
In this work we focus on the impact of **Active Regions** (i.e. **Spots and Faculae**) on the photosphere of the star.

- Flux
- Convective blue-shift



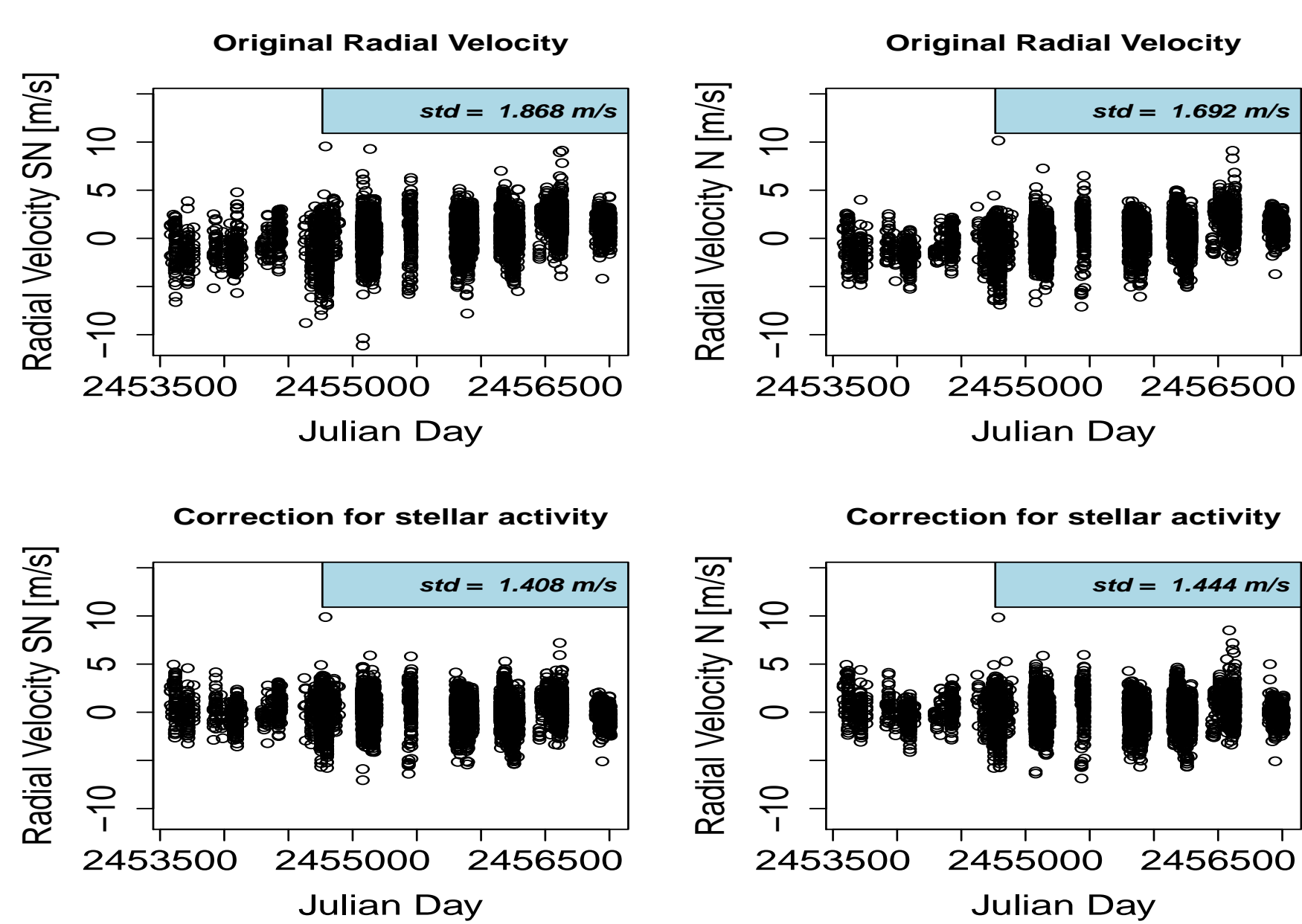
RESULTS ON TAU CETI

As the CCF is the result of a cross correlation, the residuals of a Normal or a SN fit show some **red noise**. Then, we subtracted the median of the residuals obtained for all CCFs before performing a **second fitting round**



To correct from stellar activity signals, it is common to consider a **linear combination** of the RVs with the **BIS SPAN** and the **FWHM** (or γ and SN FWHM in the SN case):

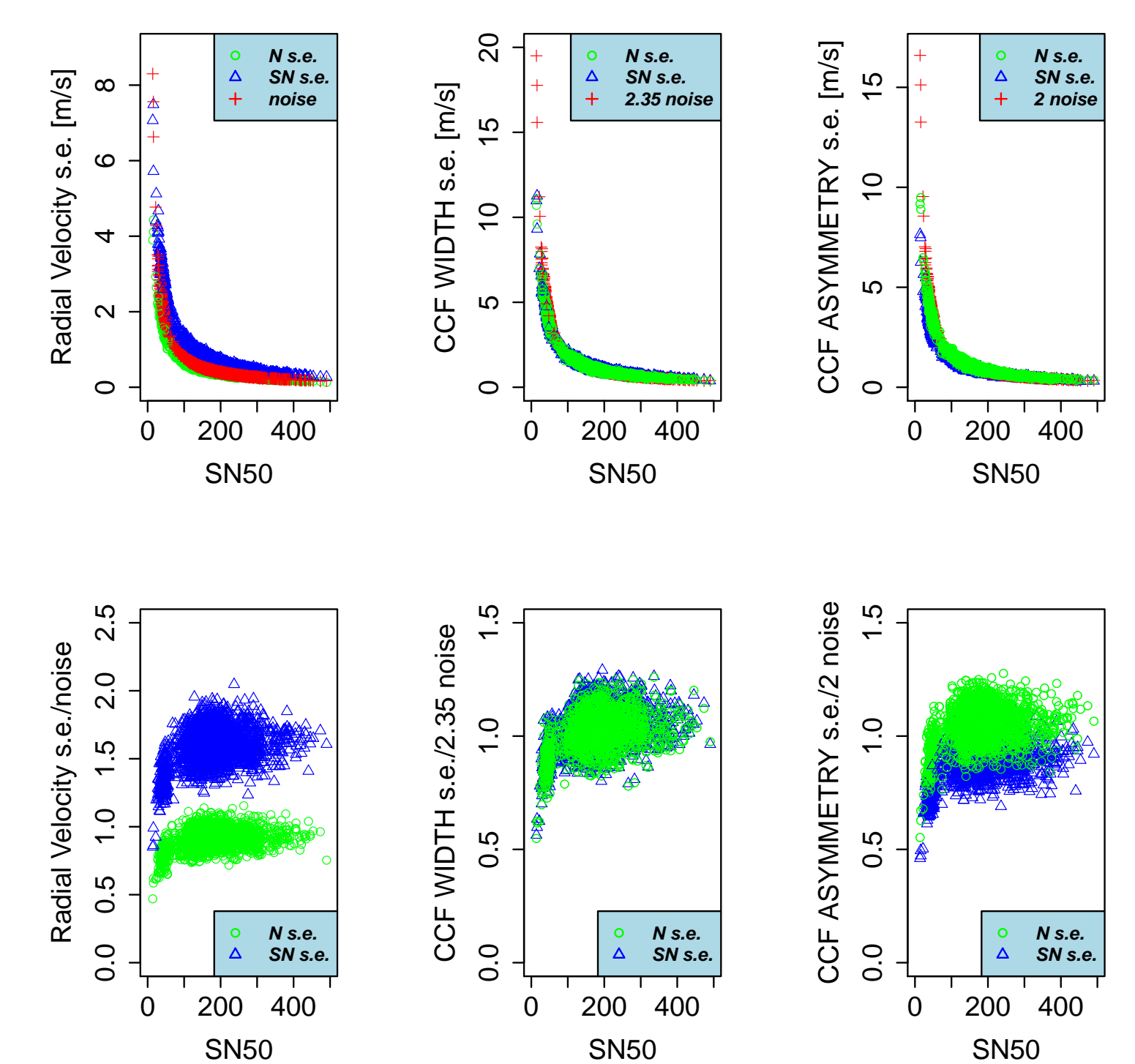
$$RV = \beta_0 + \beta_1\gamma + \beta_2FWHM + \epsilon, \epsilon \sim N(0, \sigma^2I)$$



Parameter	Normal Fitting	Skew Normal Fitting
β_0	0.00013	$2.22e - 16$
β_1	$4.83e - 6$	$2.22e - 16$
β_2	$2.22e - 16$	$2.22e - 16$
R^2	0.27	0.43

EVALUATION OF UNCERTAINTIES

Using a **bootstrap** we measured the **standard errors** for the parameter of interests of the analysis.



When fitting the SN to the CCF, the **asymmetry errors** are **15% smaller** than when using the pure photon-noise error estimate on the RVs provided by the HARPS reduction pipeline.

ESSENTIAL REFERENCES

- [1] Azzalini A. *A class of distributions which includes the normal ones*. Scand. J. Statist., 1985.
- [2] Simola U., Dumusque, X. and Cisewski, J. *Cross correlation function line-profile variations in radial-velocity measurements by fitting a Skew Normal distribution*. Astronomy & Astrophysics, 2017.

ONGOINGS

- **New missions** are starting, such as **EXtreme PREcision Spectrograph (EXPRES)** by the Yale Exoplanet group
- With **more precise data** we can test our novel procedure for **disentangling stellar activity** from pure Doppler signal
- Evaluate different statistics beyond the mean of the SN for retrieving the RV of the star and improve the function to correct the RVs from stellar activity

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