Stellar activity analysis and correction strategy

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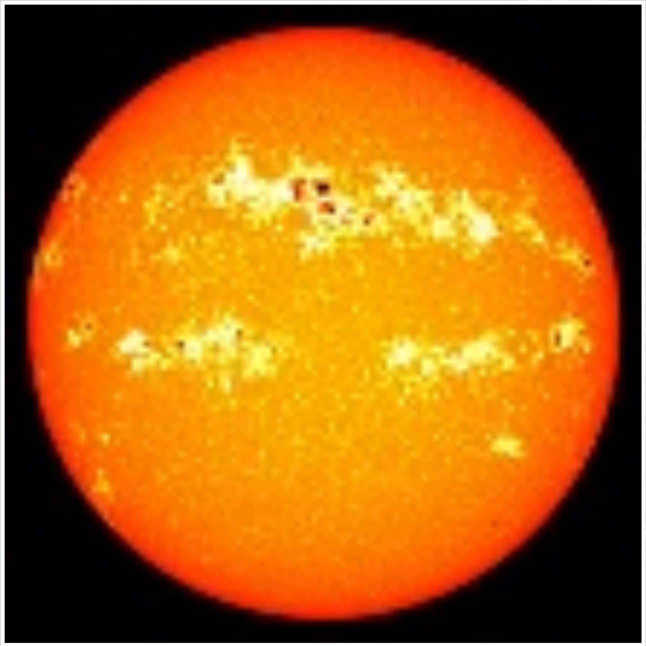
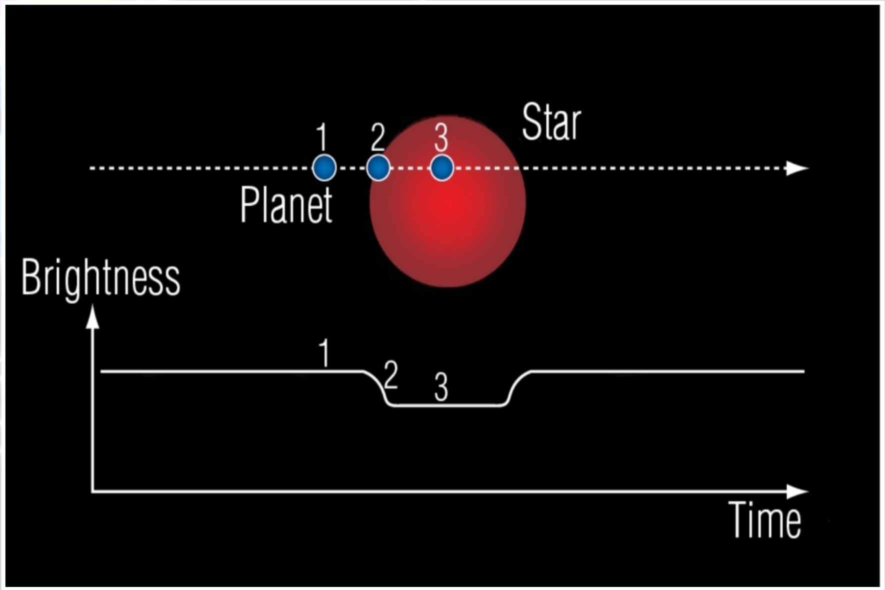
Why we have to care about stellar activity

- - spots: $\Delta m = 0.0035$ mag
  (Fröhlich & Lean, 2004);
- - faculae: $\Delta F \approx 10^{-4}$
  (Bonomo et al., 2008)

Planet transit
- eclipse: $\Delta F = 10^{-4}$ for Earth,
  $\Delta F = 10^{-2}$ for Jupiter.





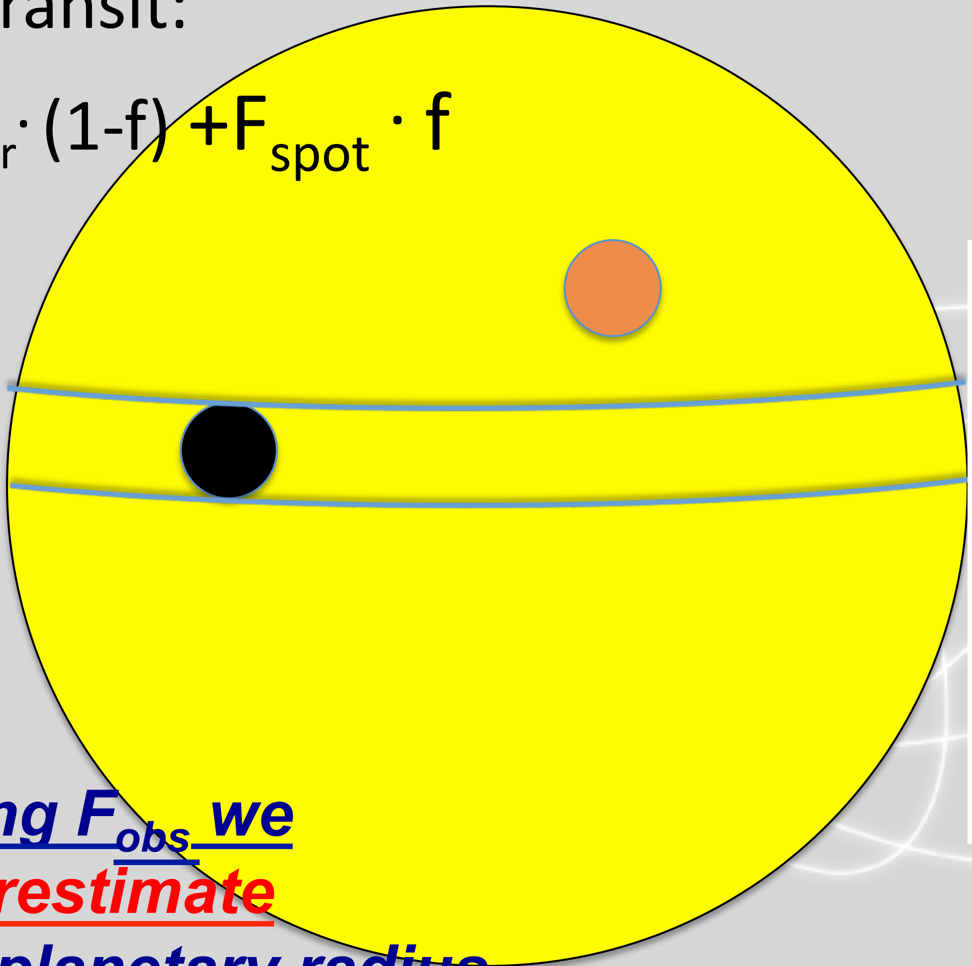
Activity properties relevant for planetary atmosphere observations

- Low mass stars – dF- dM types – typical EChO targets
- Variations on several time scales: flares, stellar rotation, active region evolution, cycles
- Coloured phenomenon – Wavelength dependence .
- Surface inhomogeneities → dependence on transit geometry

Case 1): Unocculted spot

Out of transit:

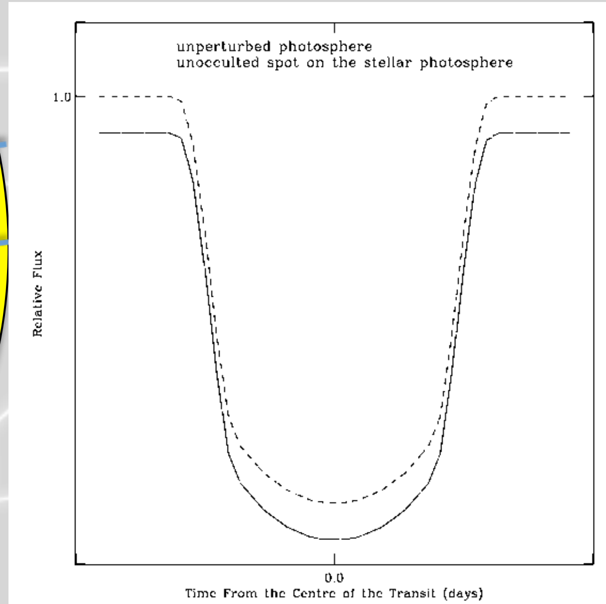
$F_{obs}=F_{star}\cdot(1\text{-}f)+F_{spot}\cdot f$



During the transit:

$F_{ecl} = F_{star}$

$F_{obs} < F_{ecl}$, $\Delta F_{obs}=\Delta F_{true}$



→ $\Delta F/F_{ecl} < \Delta F/F_{obs}$

Using F_{obs} we overestimate the planetary radius

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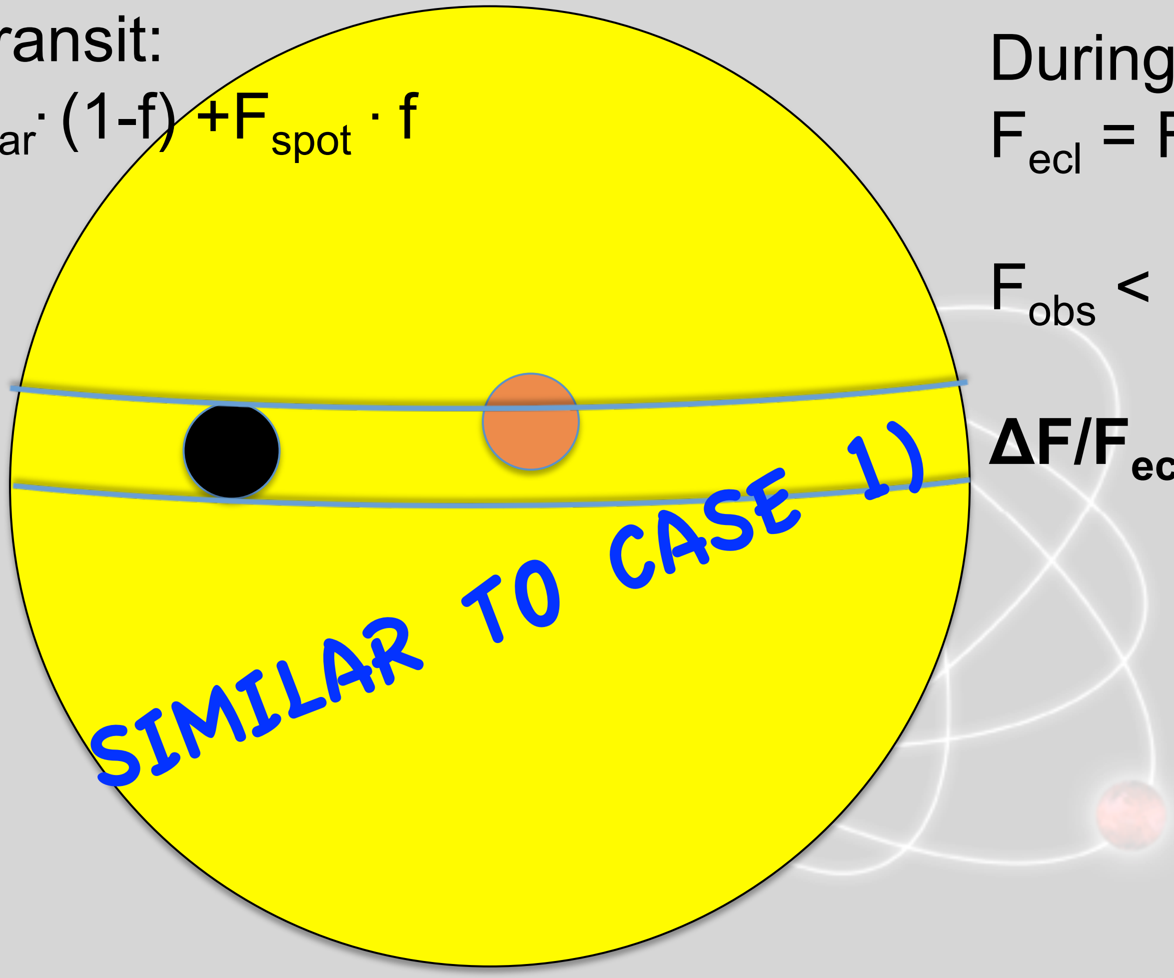
Case 2): Occulted spot

Out of transit:

$F_{obs}=F_{star}\cdot(1-f)+F_{spot}\cdot f$



During the transit :

$F_{ecl} = F_{star}$

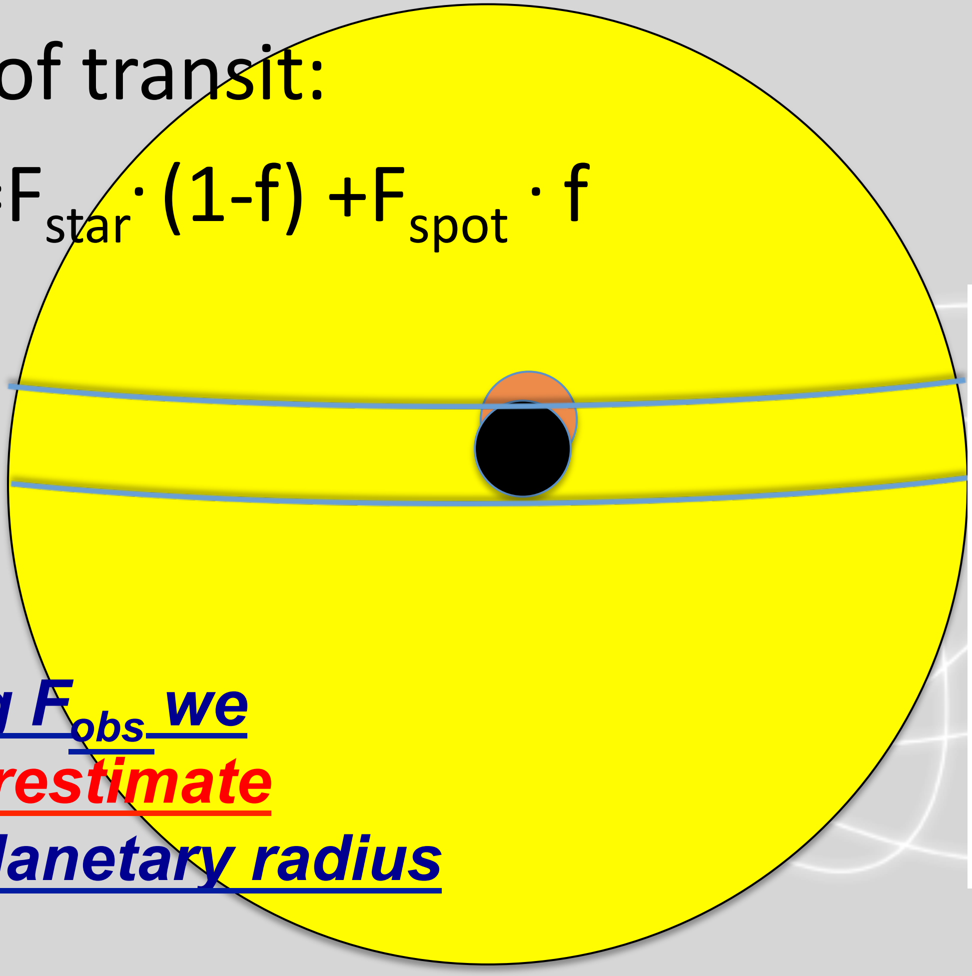
$F_{obs} < F_{ecl} \rightarrow$

$\mathbf{\Delta F/F_{ecl} < \Delta F/F_{obs}}$

Case 2): Occulted spot

Out of transit:

$F_{obs} = F_{star} \cdot (1-f) + F_{spot} \cdot f$

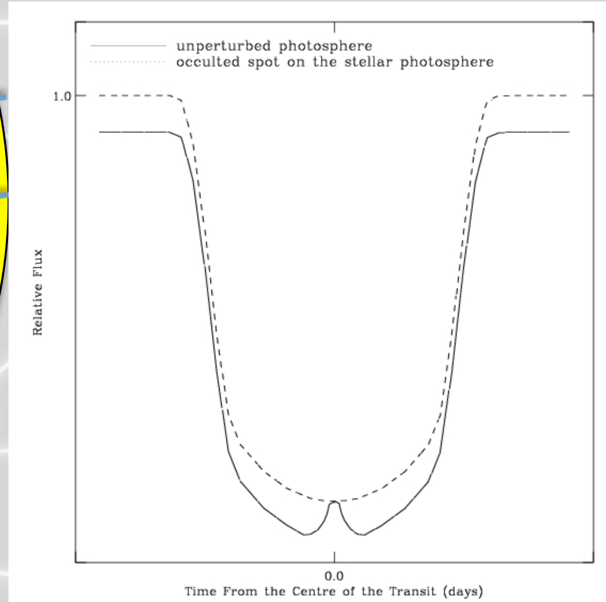


Using F_{obs} we underestimate the planetary radius

During the transit on the spot:

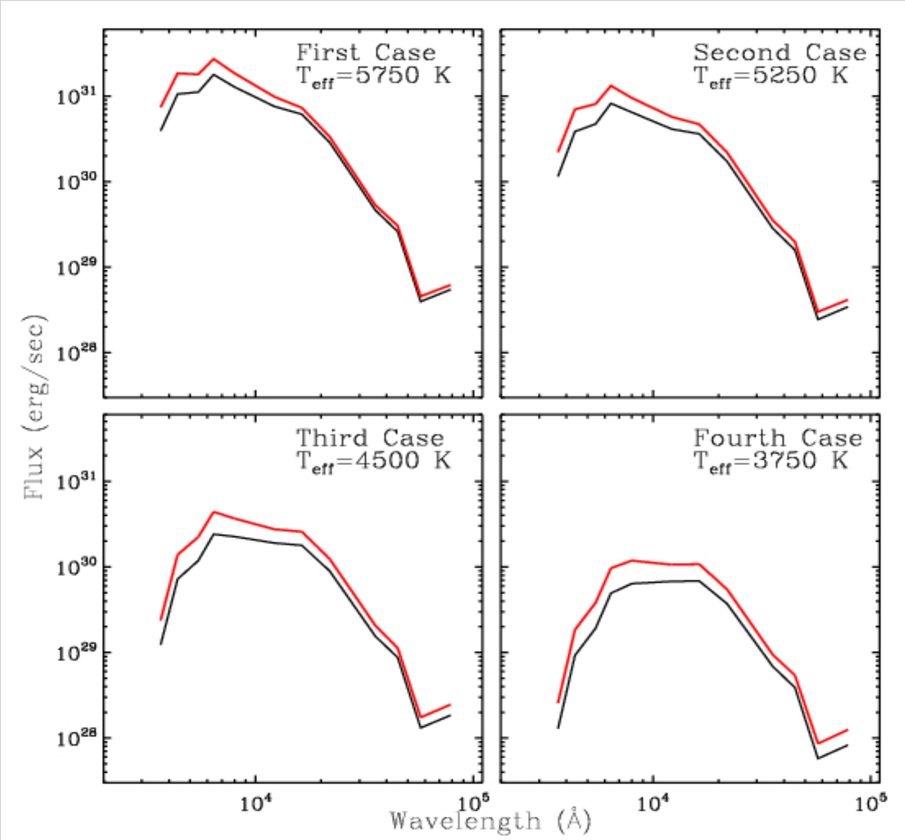
$F_{ecl} = F_{spot}$

$F_{obs} > F_{ecl}$, $\Delta F_{obs} < \Delta F_{true}$



$\rightarrow \Delta F_{true}/F_{ecl} > \Delta F_{obs}/F_{obs}$

Activity is a coloured phenomenon



- $T_{spot} < T_{star}$
- Spectrum distortion

Examples of four stars in a range of T_{eff} with a spot coverage f= 0.5, ΔT=1250 K *(Ballerini et al. 2012)*

We need to correct the spectrum for the activity if we want to recover the planetary signal

Methods:

- Time series analysis *(see Danielski talk)*
- Spectrum analysis *(see Scandariato poster)*

Spectrum analysis

Objective :

Using the visible spectrum as an instantaneous calibrator to correct the IR spectrum in order to recover the planetary signal → Large band, spectral Resolution, high SNR

– Simplified spotted star models

Spectrum analysis

Assumptions:

- Variations observed in visible band may be attributed completely to the activity and the planet contribution is negligible
- Stellar activity is due to the presence of a dominant spot at T=Tspot (with Tspot < Tstar) covering a fraction **f** (filling factor) of the stellar surface
- The stellar flux in presence of the spot can be expressed as

Flux(spotted) = Flux(star)*(1-**f**) + Flux(Tspot)***f**

Method:

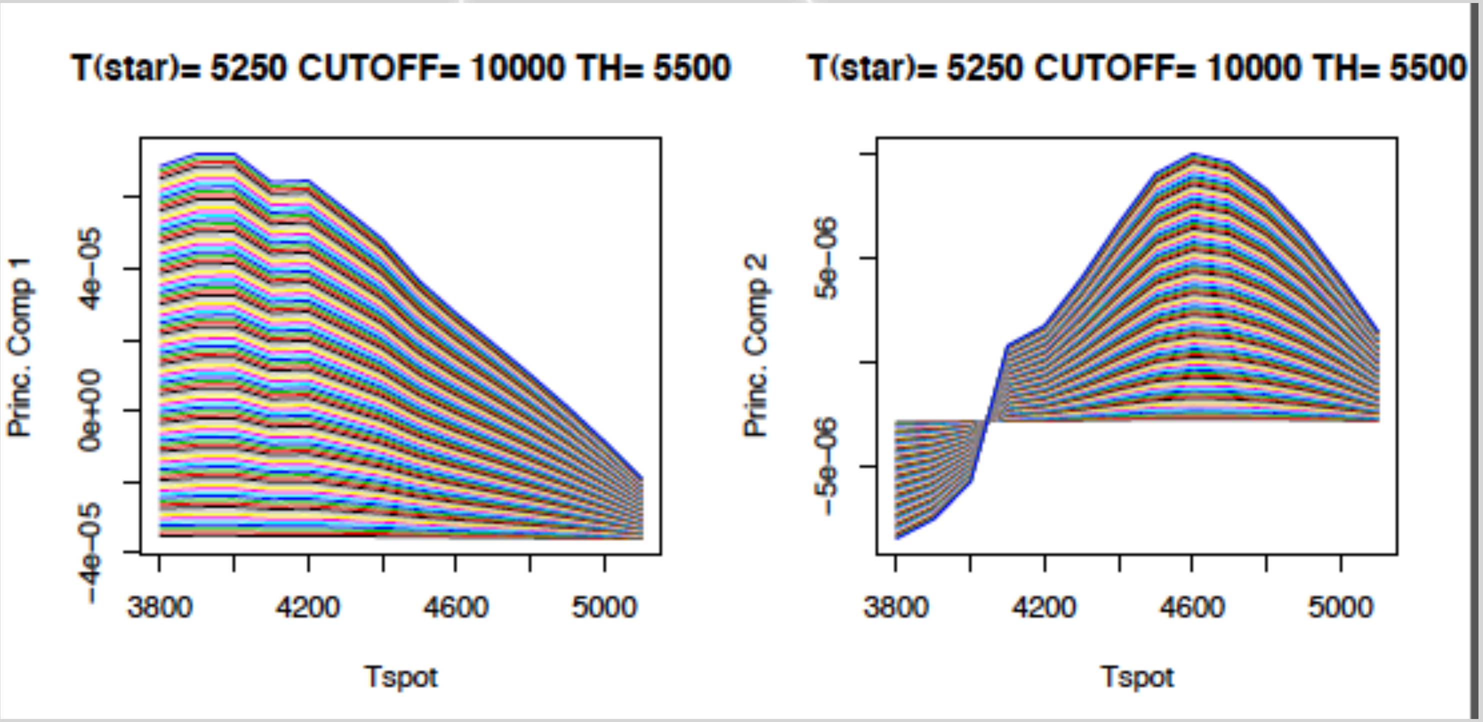
- For each spectral type, creation of a grid of reference spotted stars, varying **Tspot** and filling factor **(f)**.
- Computation of **Principal Components** and derivation of their dependence on Tspot and f.
  - Rotation of the spectra in a system of independent variables
  - The first ones explain most of the variance
  - We may describe the spectra with a small number of variables

Method:

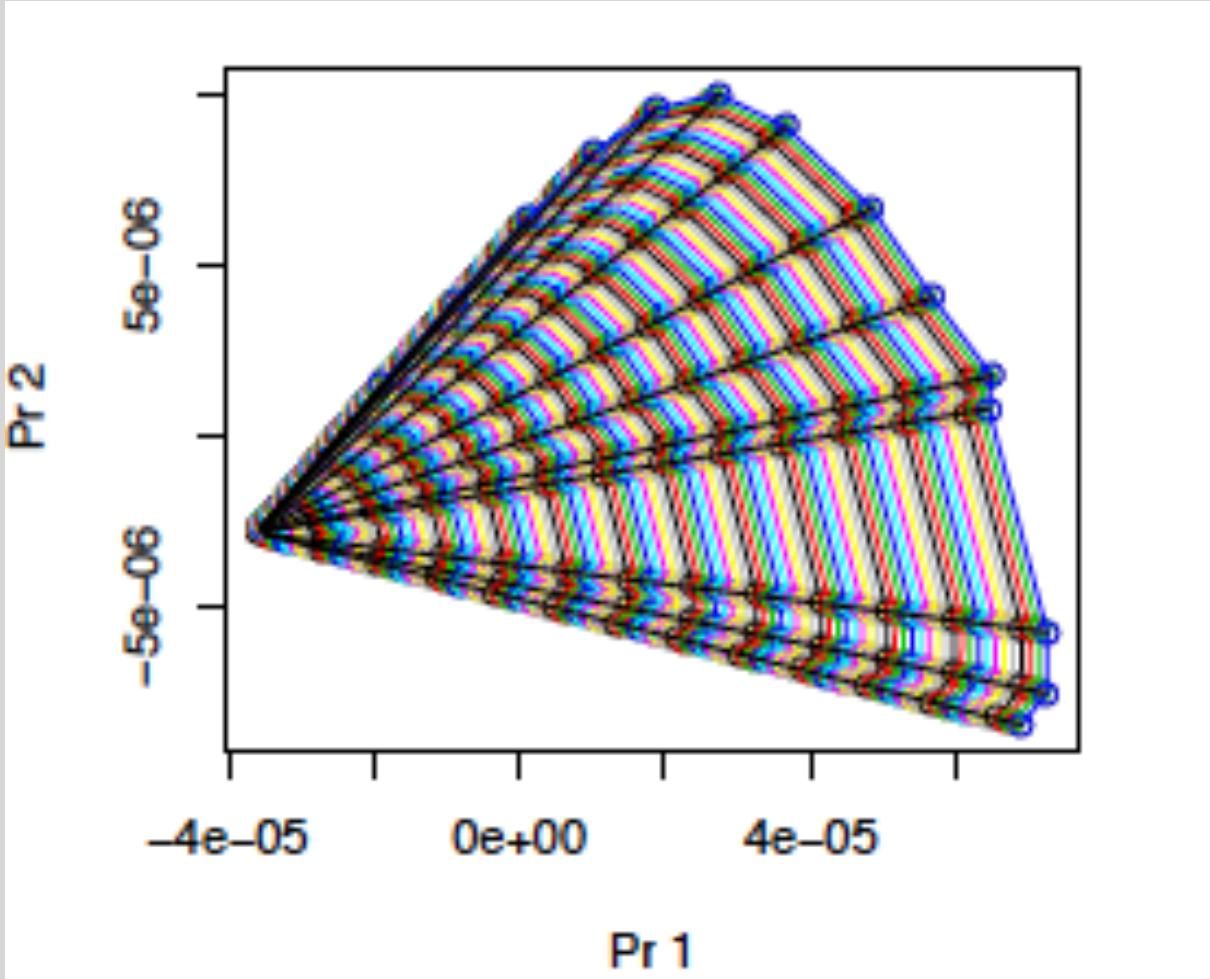
- Simulations of "real" stars
- Projection of "real" stars on the Principal Component space to recover **Tspot** and **f.**
- Correct the spectrum using the derived **Tspot** and **f**, and quantify the reduction of the activity induced effects in the infrared.

Results:

Two components explain more the 90% of the variance: dependence on *Tspot* and *f*



Results



Results

1000 simulations assuming min(S/N) =200 per resolution element → in most cases we recover the spot configuration within ΔTspot=100K and Δf= 0.001

T(star)=6000 K									
	T(spot)=5500			T(spot)=5200			T(spot)=5000		
f	0.005	0.01	0.02	0.005	0.01	0.02	0.005	0.01	0.02
Df <0.001	91.7%	67.3%	77.0%	100%	100%	100%	100%	100%	100
dT <100K	100%	100%	100%	94.7%	99.8%	100%	93.6%	96.6%	100%

Results

T(star)=5250 K									
	T(spot)=4800			T(spot)=4500			T(spot)=4200		
f	0.005	0.01	0.02	0.005	0.01	0.02	0.005	0.01	0.02
Df <0.001	64.7%	61.9%	61.0%	99.7%	100%	100%	100%	100%	100
dT <100K	61.2%	68.9%	73.6%	98.8%	100%	100%	99.8%	100%	100%

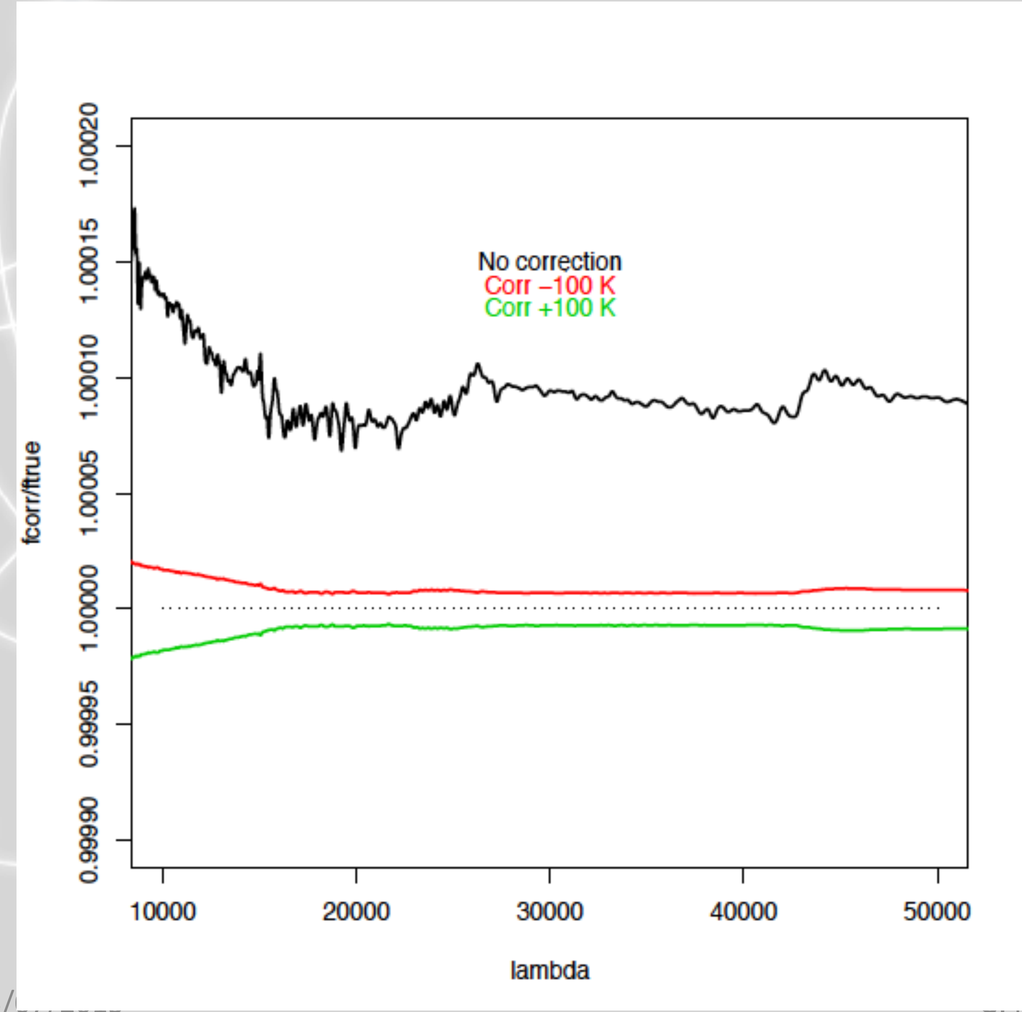
T(star)=4200 K									
	T(spot)=3800			T(spot)=3400			T(spot)=3100		
f	0.005	0.01	0.02	0.005	0.01	0.02	0.005	0.01	0.02
Df <0.001	63.7%	78.4%	96.3%	100%	100%	100%	100%	100%	100
dT <100K	62.3%	78.4%	96.3%	100%	100%	100%	100%	100%	100%

Results

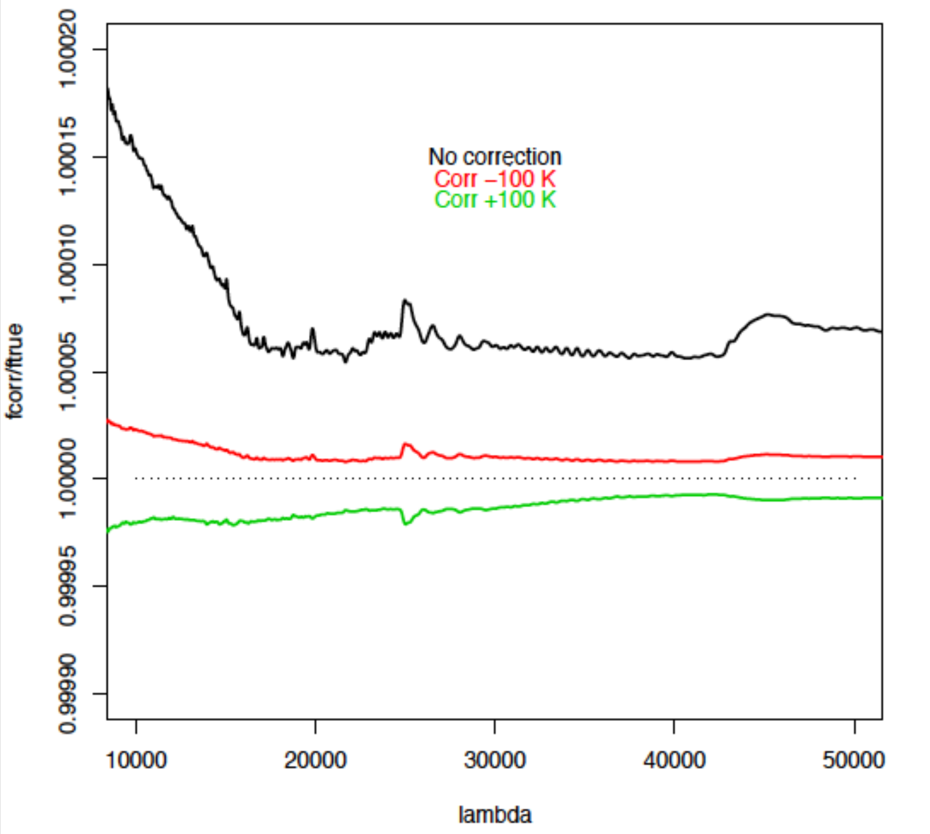
- A correction with dTspot < 100K reduces significantly the spectrum distortion.

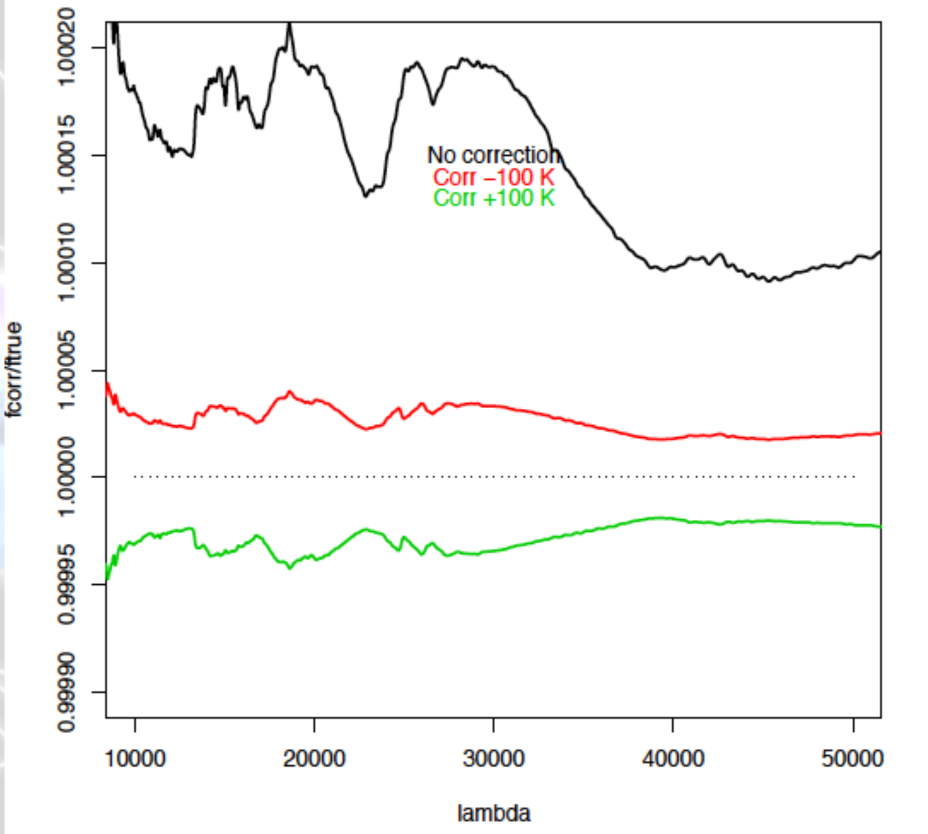
Some examples:

T(star)=6000K



Results


No correction
Corr −100 K
Corr +100 K
fcorr/ftrue
lambda
0.99990
0.99995
1.00000
1.00005
1.00010
1.00015
1.00020
10000
20000
30000
40000
50000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0.99990
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1.00000
1.00005
1.00010
1.00015
1.00020
10000
20000
30000
40000
50000

Results

- The presented method is able to reduce significantly the activity induced spectrum distortion within the adopted assumptions.
- It works well for solar type stars
- For dM stars a residual distortion is still present
- We are developing a method based on observed spectra instead than models

Work in progress: observed dM stars

- The Sloan Digital Sky Survey Data Release 7: Spectroscopic M Dwarf Catalog. I. Data, *(West et al., AJ, 2011)*: **50000 dM**
- spectra (from M0 to M9) with R **=2000,**

Band = **3800 - 9000 Ang**

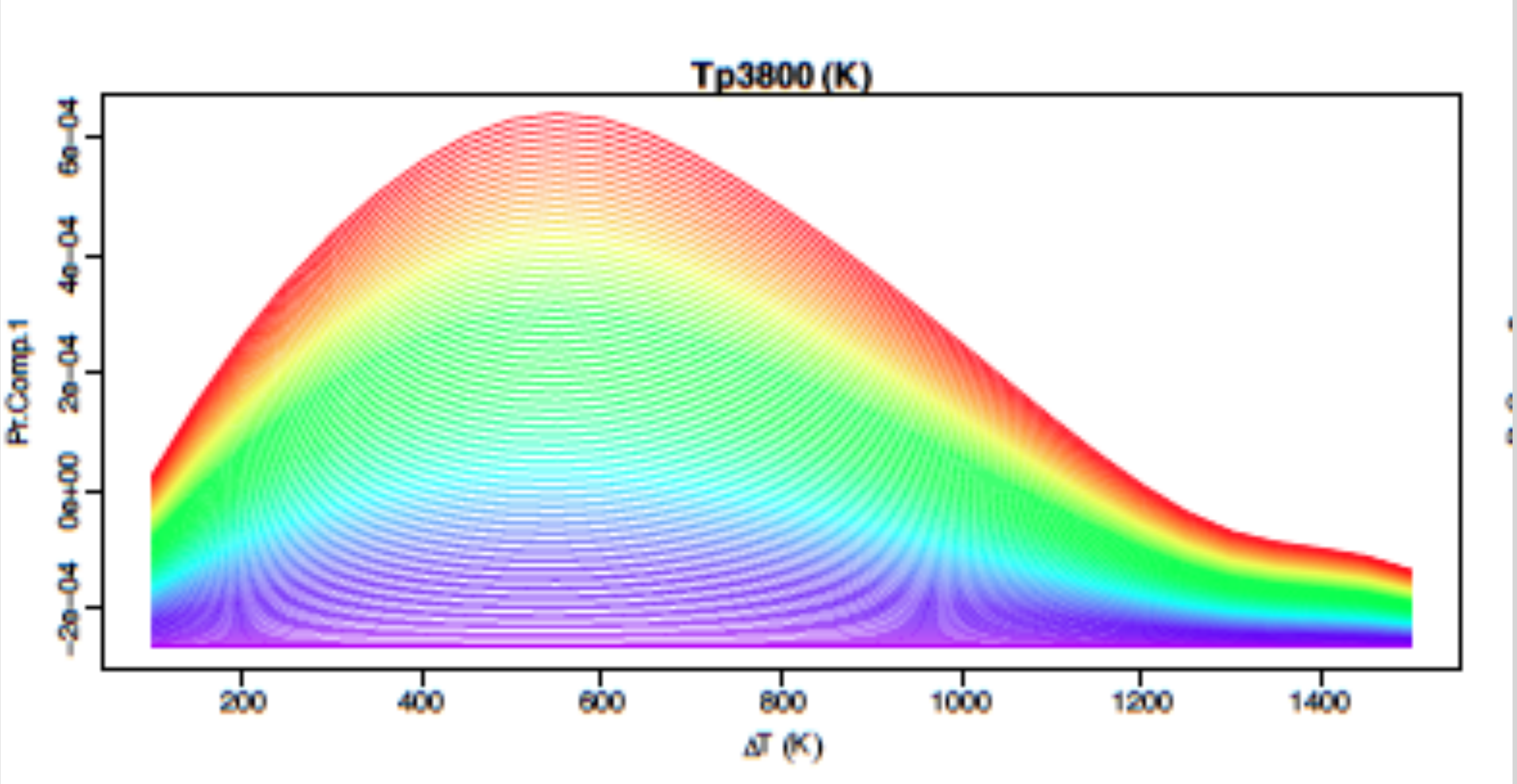
- **measurements** of AV , RV and EWHα.

Work in progress: observed dM stars

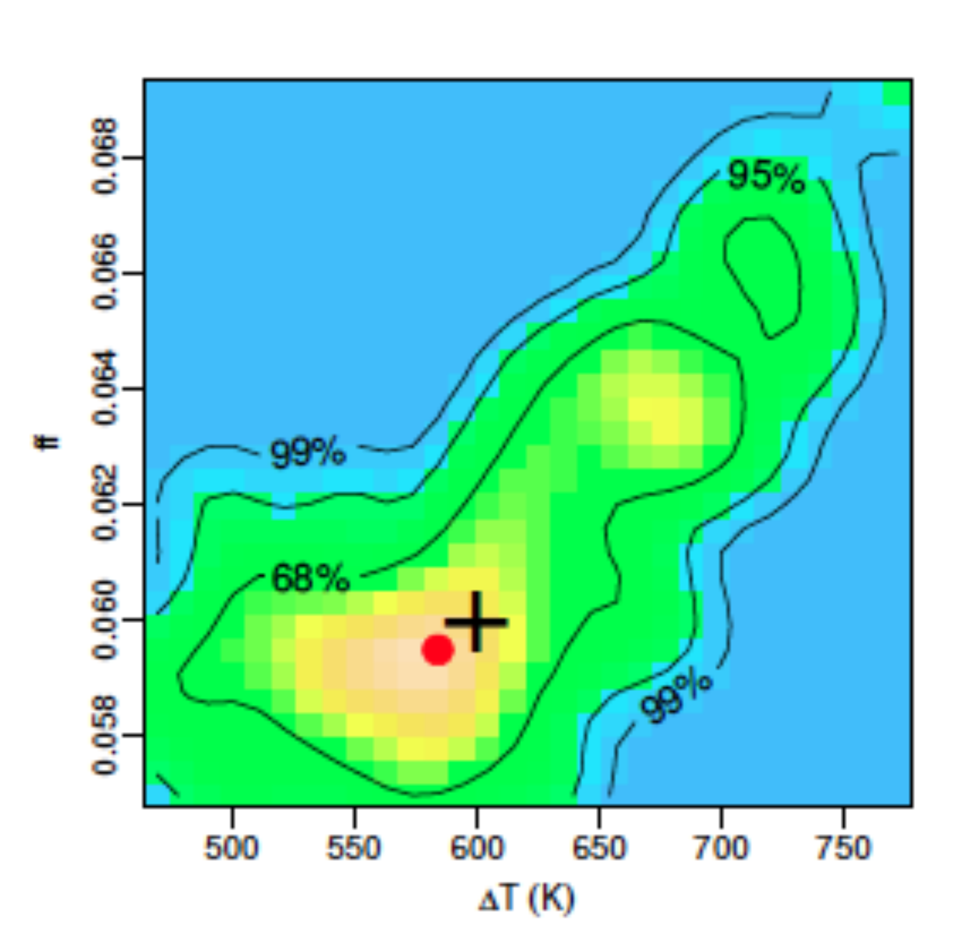
Templates of dM quiet stars *(see Scandariato poster)*

- we co-added the 100 spectra per subtype with the highest S/N and lowest values of Halpha
- we degrade the spectrum at R=300.
- Template spectra are used to build the grid to derive the principal components.
- Qualitatively we obtain results similar than with models

Initial results:



Initial results:



Also in this case we are able to recover pretty well the spot configuration

Next step: *test if active stars of SDSS can be modeled with this approach*

Still to do:

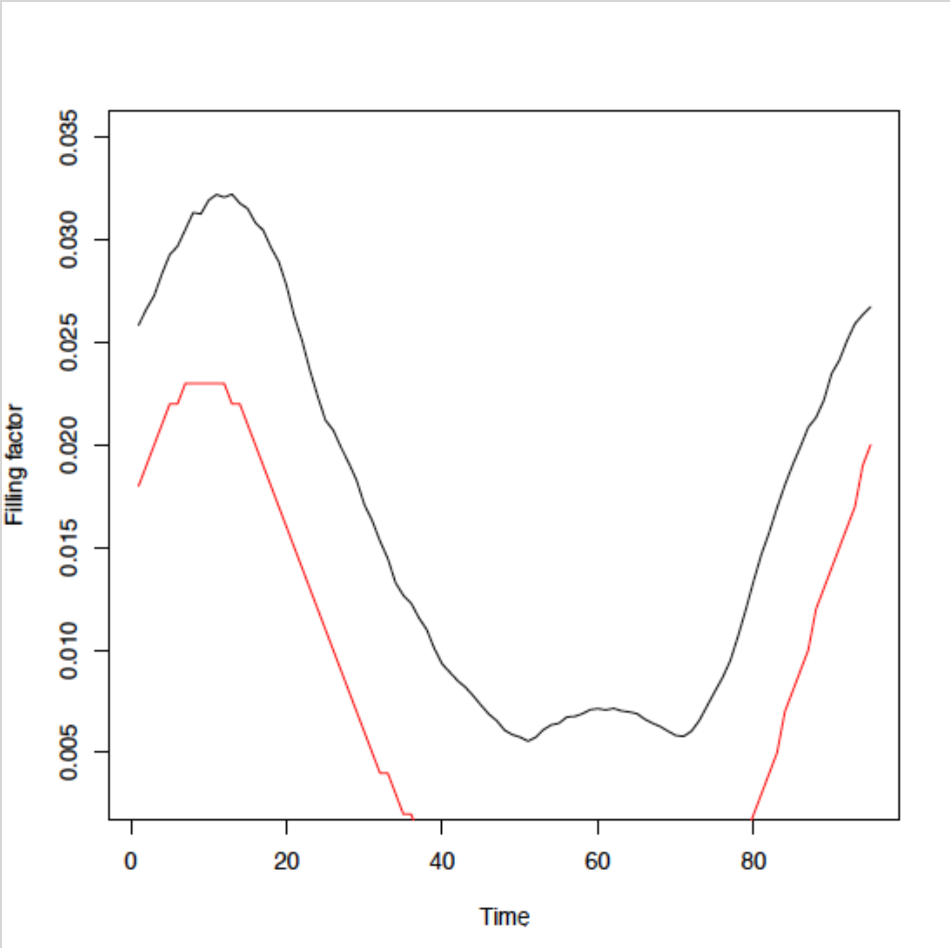
- We will apply the method to active SDSS stars
- If it works we will demonstrate that active dM stars may be modeled by a star+spot combination *(and derive spot properties statistics of an unbiased sample of dM active stars)*

Summary & next steps

- We have developed a method to recover the spot stellar configuration from the observed spectrum
- It is possible to significantly reduce activity induced spectrum distortion
- We will test the method also on a more complex modeled spectra and time series

Summary & next steps

- Tests already started on the Herrero & Ribas model→ A first test show that we may easily reproduce the Tspot and filling factor, except for a systematic offset due likely to the effect of the faculae (present in the H&R model)
- Fine tuning likely still necessary



Comparison with H&R Model:

•Tspot: well reproduced
•f : correct behavior, systematically lower