Modeling the photosphere of active stars

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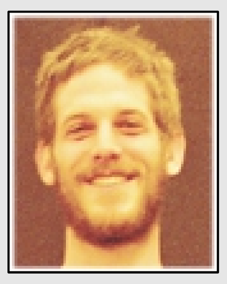


Stellar activity in the form of dark spots and bright faculae induces photometric modulations and apparent radial velocity (RV) variations in stellar data. Those may hamper the detection of Earth-like planets. It will be crucial to understand the influence of such activity effects to make the most out of present and future planet search instruments like **HARPS**, **CARMENES** and **ESPRESSO** and space missions like **EChO**. We present a methodology to simulate the time-series spectra and photometry of the spotted photosphere of a rotating star.

Methodology

We use **BT-Settl** and **Pollux** database models (*0.1* to *10 μm*, *R=150.000*, Allard et al. 2013) to generate synthetic spectra of the photospheres of stars of types *F, G, K*, and *M* (*3000<T<7000 K*). The spectrum of the entire visible face of the star is obtained by summing up the spectral contributions of a grid of small surface elements. We try to include in each such element **all available effects** and use as many **free parameters** as possible:

a) differential rotation (period ***P***) of the star and individual Doppler shifts (Wöhl et al. 2010):

$$P(\phi) = P_0 - P_{sun}\cdot sin^2\phi \qquad P_{sun} = 3.1913°/day$$

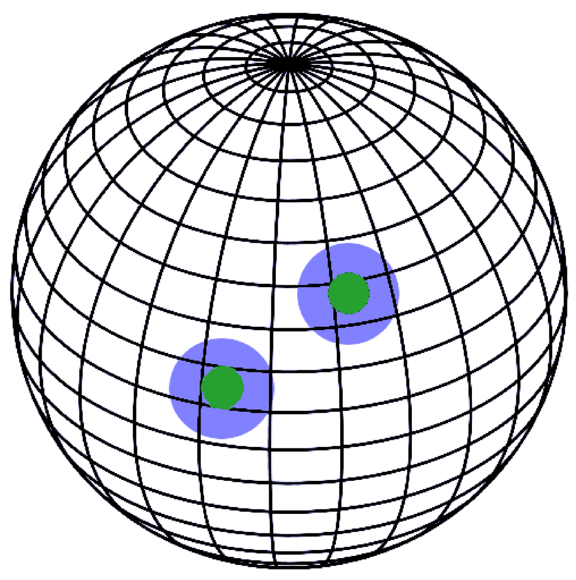
b) stellar inclination i_s
c) dark sunspots (radius R_s, temperature contrast dT_1) rotating with the period of the star ***P*** at longitudes ***θ*** and latitudes ***ϕ***
d) limb darkening function **LD** obtained from Kurucz models (Kurucz et al. 2005) considering particular RVs:

$$F(\lambda,\mu) = f(\lambda)\otimes LD(\lambda,\mu)$$

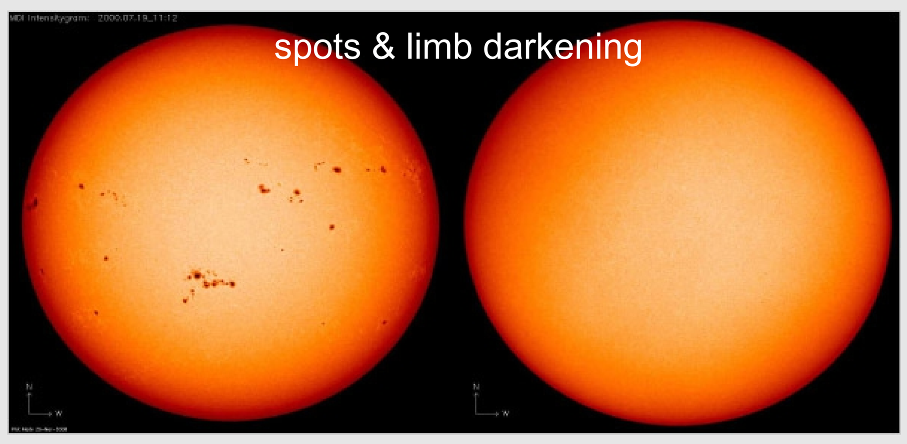
e) bright faculae (temperature contrast dT_2) connected with the size of the sunspots by factor ***Q*** and with limb brightening (Ortiz et al. 2002):

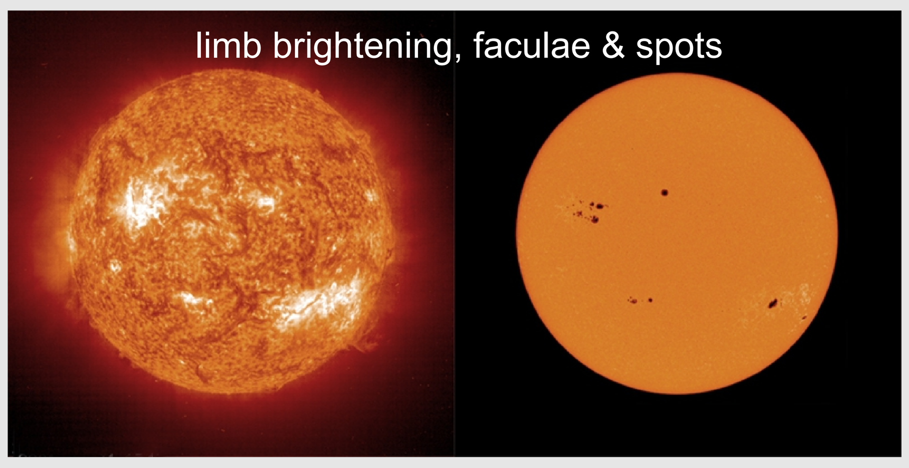
$$\Delta F = \chi_f(1-\mu) \qquad \chi_f = 1.2F_{cen}$$

f) planetary signal using the inclination i_p, spin-orbit angle, the semi-major axis ***a***, the radius R_p, and the period P_p
g) wavelength dependent photon noise



grid of surface elements
connection of spots & faculae





Different input model spectra

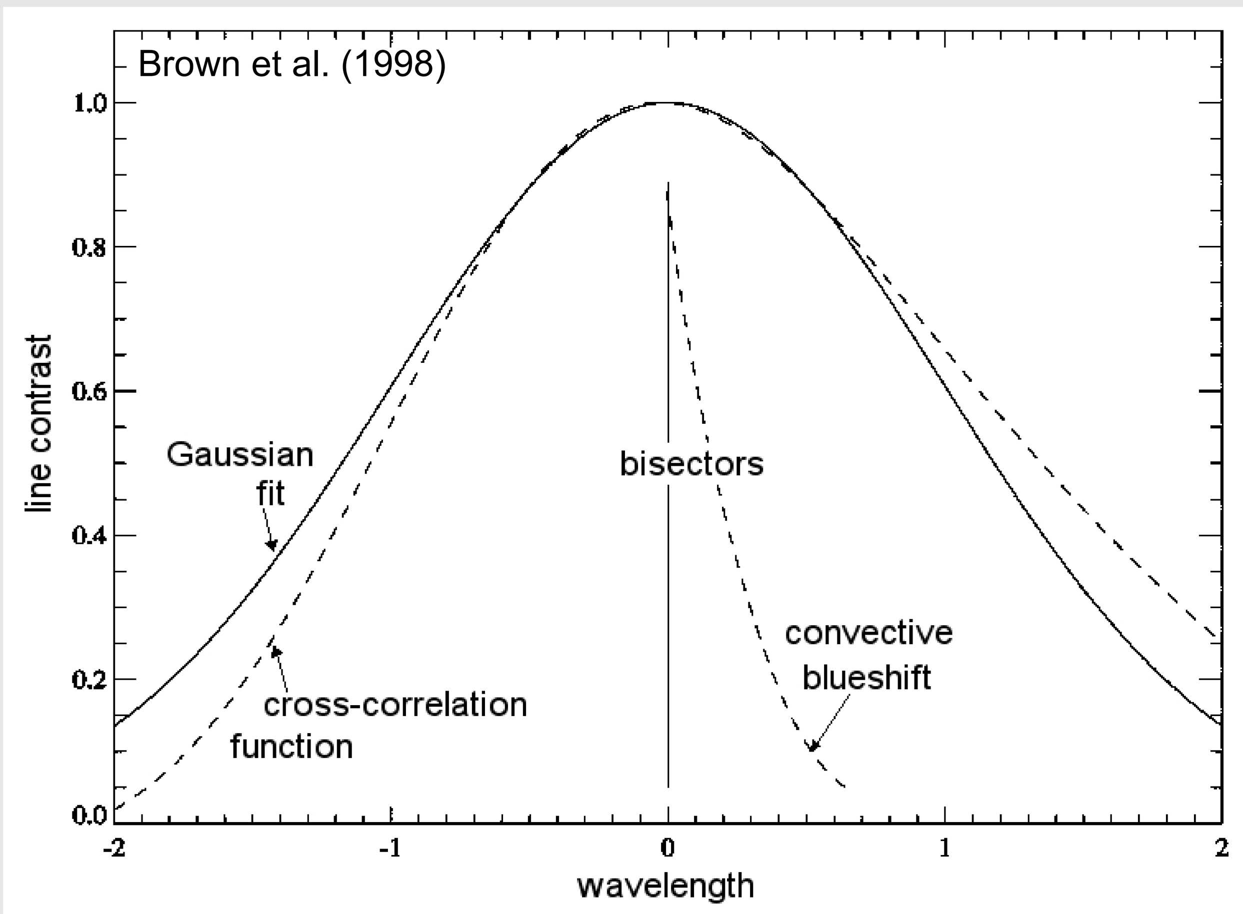
We manipulate differently the input spectra (defined by gravity & metallicity) for a surface element of the photosphere, a spot or a facula:

photosphere
- model spectra of temperature ***T***
- contrast dependent function reproducing the convective blueshift of the CCF

dark spot
- model spectra of $T\text{-}dT_1$
- different ***LD(λ,μ)*** and Doppler shift

bright faculae
- model spectra of $T\text{-}dT_2$
- different ***ΔF(λ,μ)*** and Doppler shifts (no knowledge of the spectral peculiarities)

The spectrum of the whole photosphere is then the sum of all visible surface elements.



The Cross-Correlation Function (CCF)

$$CCF_i = \frac{\sum(S-\overline{S})\cdot(M_i-\overline{M}_i)}{\sqrt{\sum(S-\overline{S})^2\cdot\sum(M_i-\overline{M}_i)^2}}$$

To form the CCF, we construct a **mask *M*** of delta functions from a normalized model spectrum ***S*** including:

1) removal of lines affected by activity. To find them, we process data with and without spots depending on temperature ***T***.

2) removal of line blends (broadness limit)

3) selection of lines of a certain contrast level

4) correction of sampling problem: usage of two delta functions around the fitted peak of each line

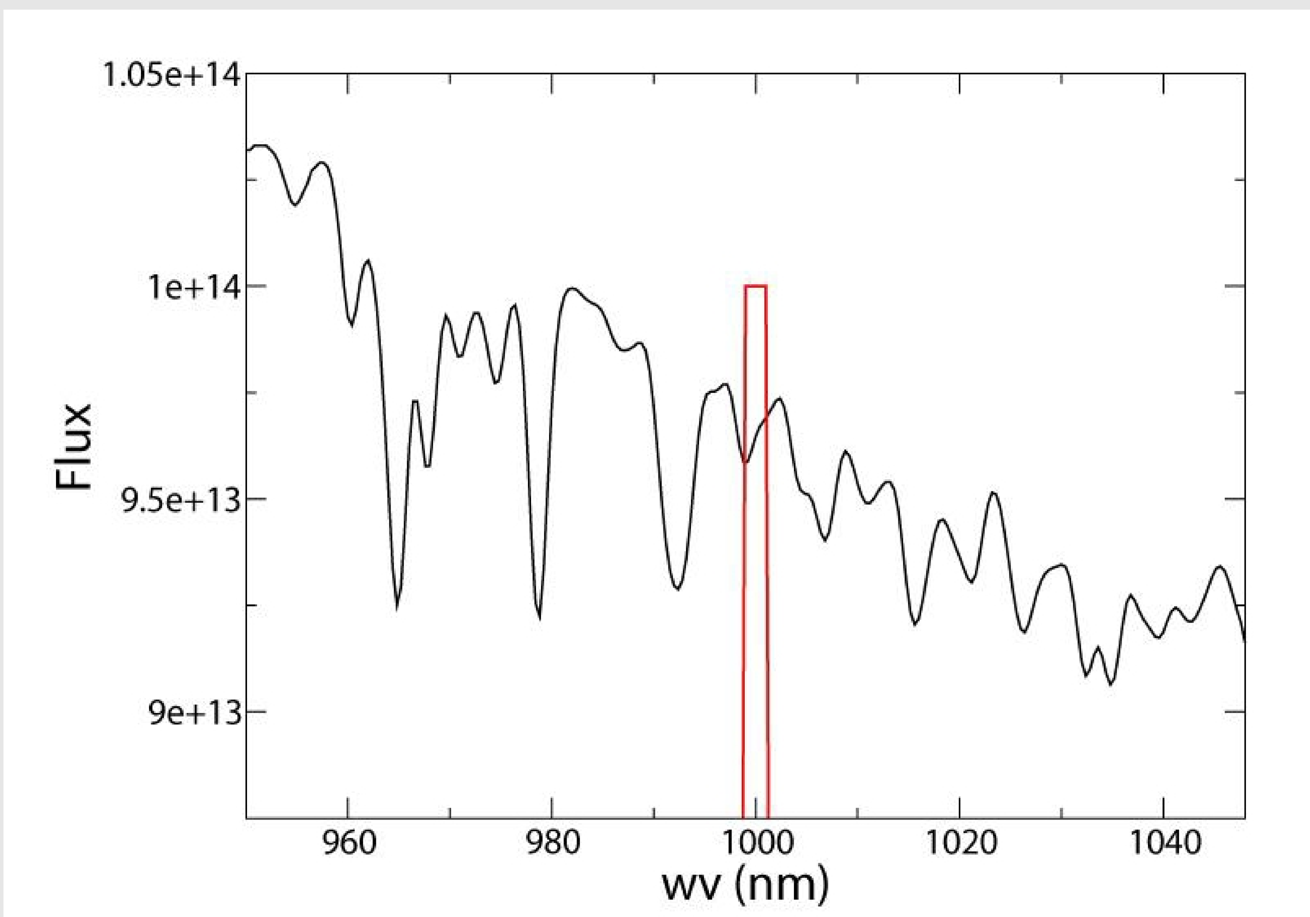
Results

We generate **time series spectra** from a simulated spotted rotating photosphere covering the whole rotation period of a star. We are able study and compare the RV signals of planets and different activity effects.

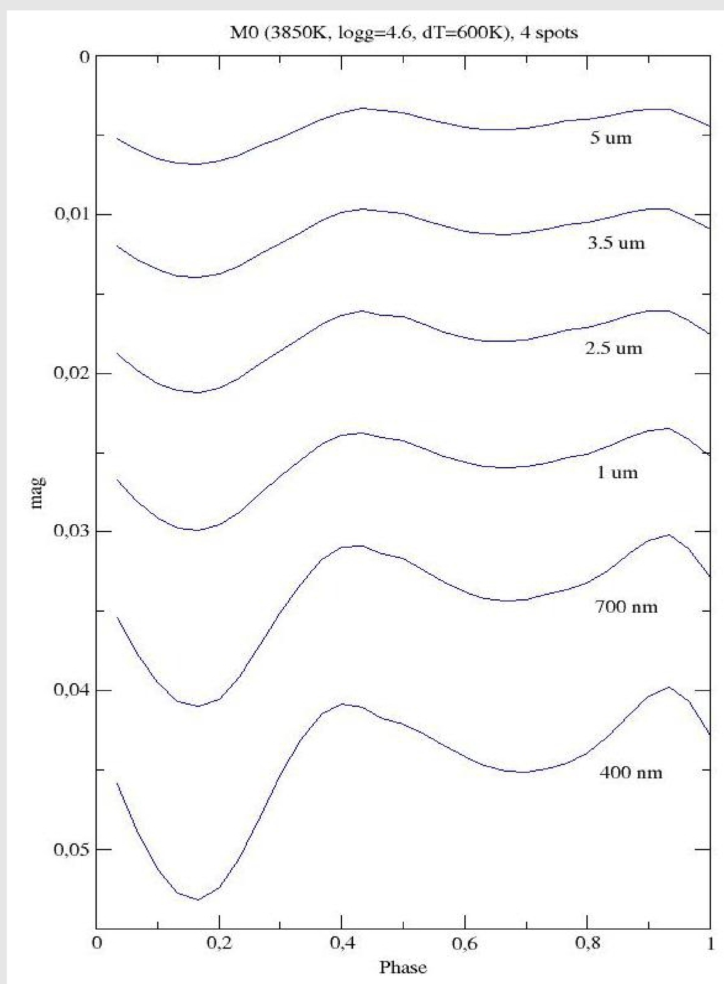
We produce **light curves** by convolving the spectra with filters of specific instruments and study the influence of stellar activity and planetary signals.

We compare the impact of photometric modulations and radial velocity jitter on the **different wavelength ranges** and select the best ones for RV measurements. We investigate the spot modulation at different spectral ranges.

Our results allow us to investigate the **effects of activity** patterns on the measurable stellar flux and hence define the best strategies to optimize exoplanet search and measurement experiments.



convolution of spectra with filter function (red)



photometric time series dependent on λ

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