SOAP-GPU: Efficient Spectral Modelling of Stellar Activity Using Graphical Processing Units

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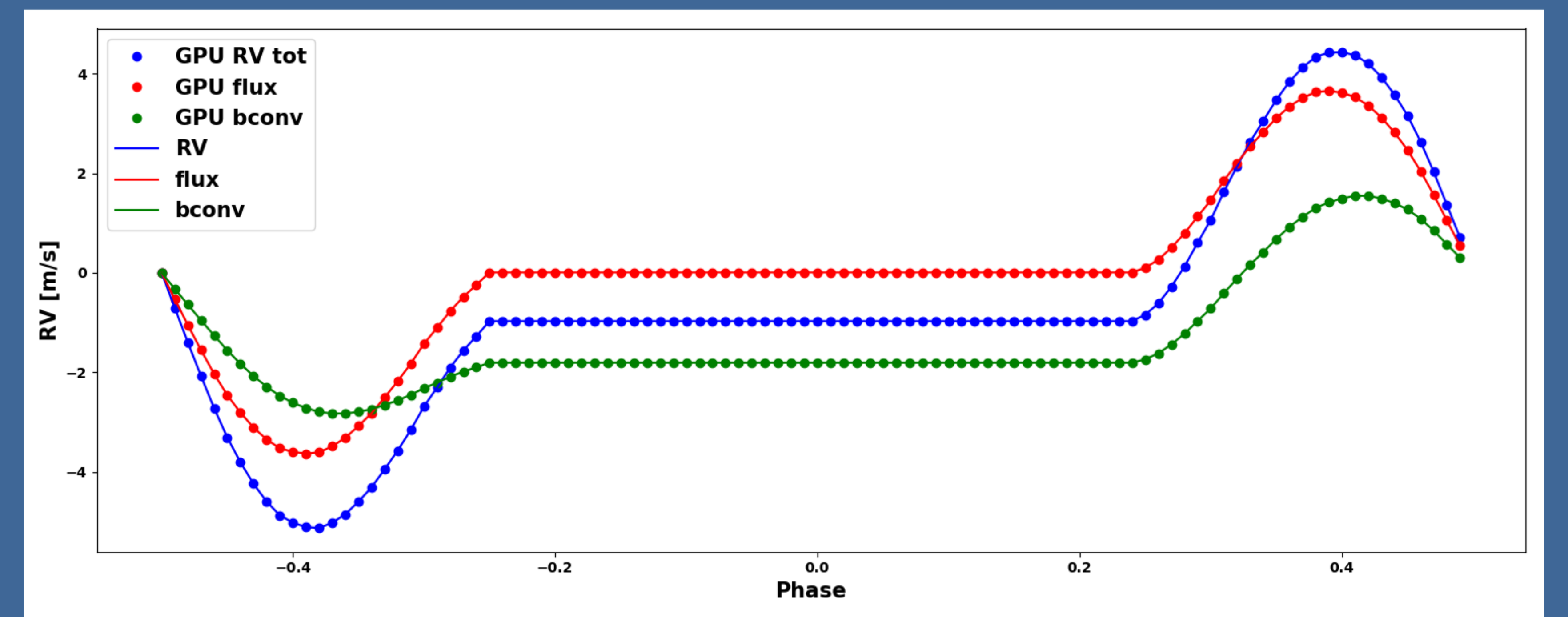
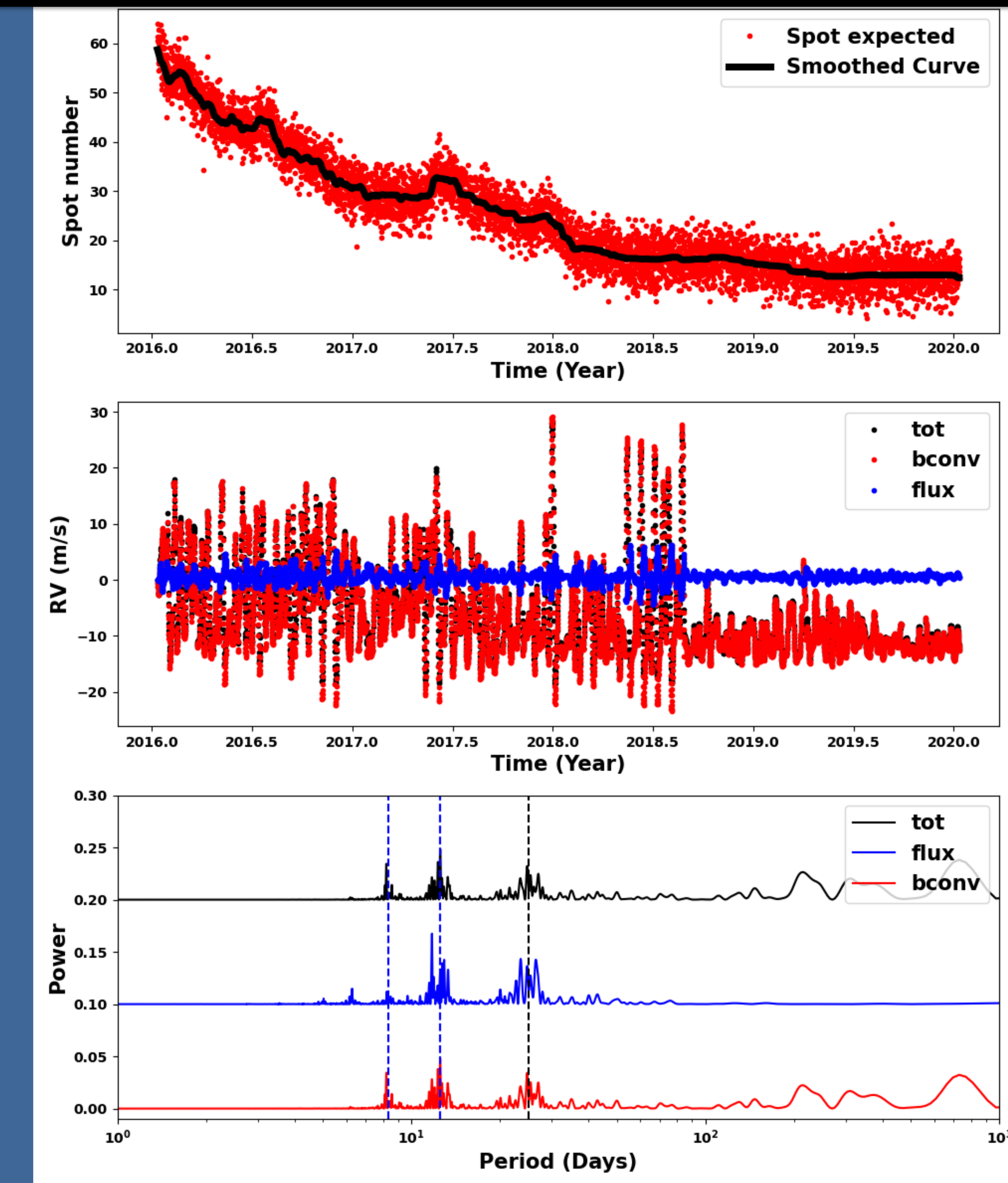
Abstract

Stellar activity mitigation is one of the major challenges for the detection of earth-like exoplanets in radial velocity measurements. Several promising techniques are now investigating the use of spectral time-series, to differentiate between stellar and planetary perturbations. In this context, developing a software that can efficiently explore the parameter space of stellar activity at the spectral level is of great importance. We developed a new version of the Spot Oscillation And Planet (SOAP) 2.0 code that can model stellar activity at the spectral level using graphical processing units (GPUs). Benchmarking calculations show that this new code improves the computational speed by a factor of 60 while having the same accuracy. On top of that, we implemented a realistic simulation of activity on solar-type stars (number of active regions, evolution), therefore allowing to generate realistic spectral time-series affected by activity perturbations within seconds. The outcome of this code is essential to test any algorithm that tries improving planetary signal detection by mitigating stellar activity at the spectral level.

Results



The figure above is the spot simulation comparison between SOAP-GPU and SOAP 2.0. A single spot with 1% area of the entire disk surface is simulated. At each phase, three spectra are simulated to represent the flux effect, the effect of convective blue shift inhibition (bconv) and the combination of these two (tot). In this case we simulated 100 phase steps. It took ~40 mins to simulate those spectra with SOAP 2.0 while SOAP-GPU only used 35 seconds on a Nvidia RTX-3090 card. The computation speed is improved by a factor of ~60.



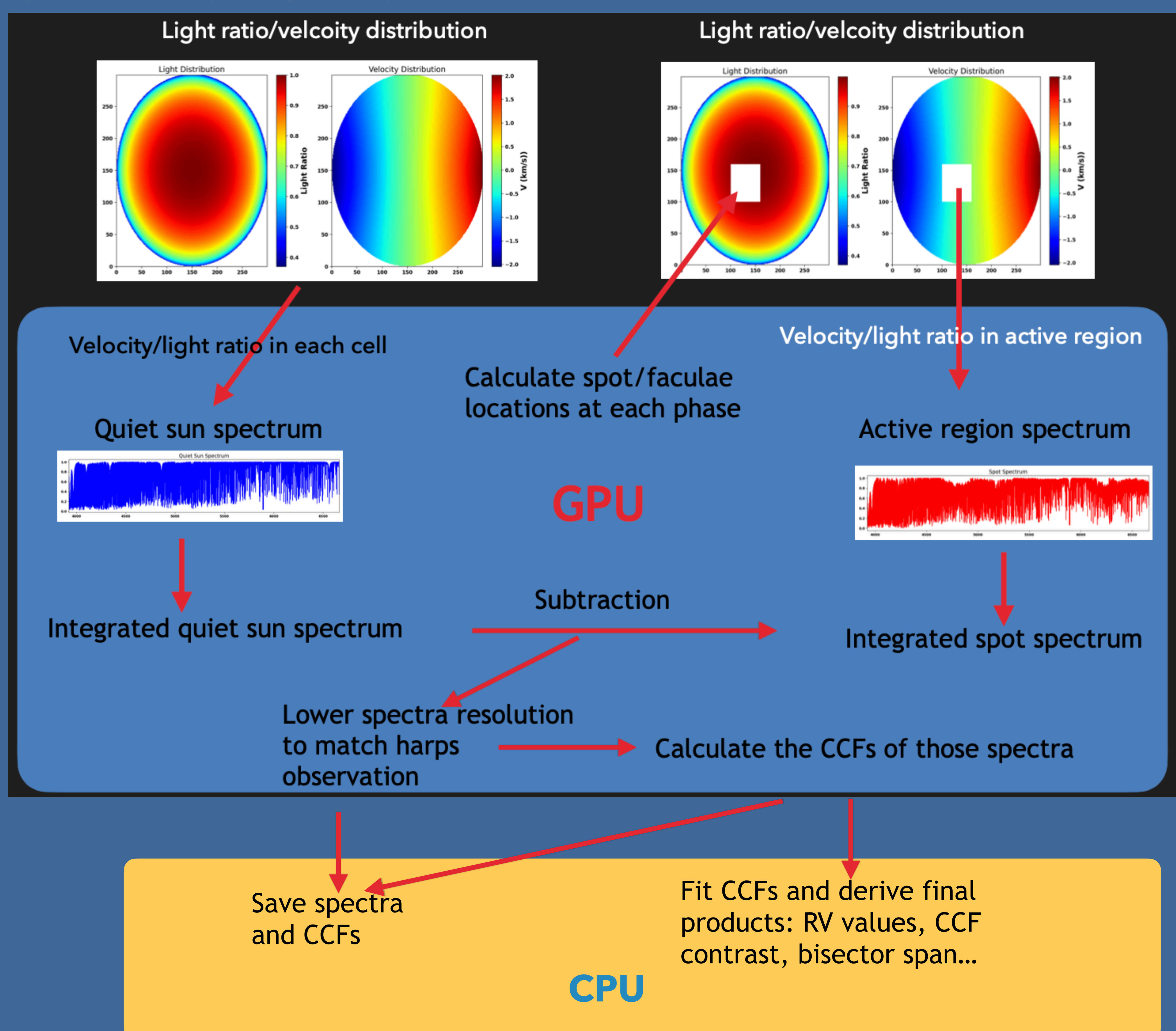
The figure above is the simulation of realistic solar activities with SOAP-GPU. We simulated 4 years of solar activities with real spot number evolution. We simulated 4 observations on each day. Each observation has three spectra to cover the flux effect, the convective blueshift effet and the total effect. We run the simulation on a Nvidia RTX-3090 card. It took only 30 mins to finish the entire simulation.

Top: The injected daily spot number. The smoothed curve was derived with real observation from Solar Influences Analysis Data Center (SIDC).

Middle: The radial velocity data derived from simulated spectra. There are 5840*3 spectra simulated in total. We implemented an activity configuration with small spots surrounded with large faculae. Since the faculae is dominated in solar activities, the inhibition of convective blue shift is dominated effect in the radial velocity data.

Bottom: Lomb-Scargle periodograms of the radial velocity time series.The solar rotation period is labelled with black dashed line and the first and second harmonics are labelled with blue dashed lines.

Overview of SOAP-GPU



Step 1.The observed spectra of the quiet solar photosphere and of a solar active region with the dimension of 547840 are copied to the GPU. The sun disk containing 300x300 cells is initialised with the light and velocity distribution depending on the differential rotation and linear limbing darkening law (Dumusque et al. 2014).

Step 2.The projected velocity and light ratio in each cell is applied to the quiet sun spectrum. In order to inject the projected velocity in each cell into the spectrum, we implement GPU to perform fast interpolation: A GPU grid with 1070 blocks, each block having 512 threads is used to perform fast interpolation for each cell. Compared with SOAP 2.0 which uses ~8 mins to compute the integrated quiet sun spectrum, the SOAP-GPU only takes 7 seconds to compute, which is ~60 times faster than SOAP 2.0.

Step 3. Spots/faculae are initialised with number (N) of activate regions, geometry coordinates and evolution parameters (Borgniet et al. 2015). The rotation matrices are computed at each phase to localise the active regions in the disk surface. A GPU grid with N blocks, each block with 3 threads is launched to calculate the rotation matrices.

Step 4 . The projected velocity and light ratio in each cell of active regions is injected into the active region spectrum with a 1070x512 GPU grid.

Step 5. The integrated active region spectrum at each phase is subtracted from the integrated quiet sun spectrum, which generates the final spectra. A 1070x512 GPU grid is launched to lower the resolutions of those spectra to match the harps observations and to derive the corresponding CCFs. The final products such as radial velocity data, CCF contrast and bisector span are derived using a C code running on a single CPU

Reference

1. Dumusque, X., Boisse, I., & Santos, N. C. 2014, ApJ, 796, 132
2. Borgniet, S., Meunier, N., & Lagrange, A. M. 2015, A&A, 581, A133

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