Distinguishing Planets from Granulation: A Synthetic Spectra Generator

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1. Granulation and Planet Detection

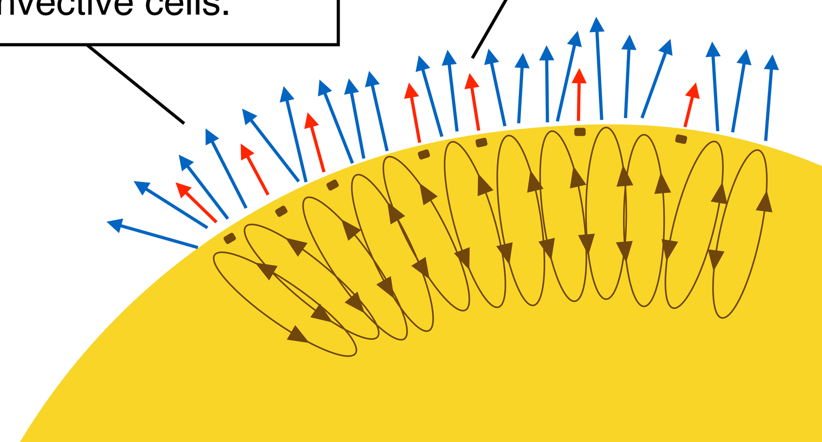
Background: Doppler spectroscopy (the radial velocity method) is one of the most widely-used methods to detect exoplanets.

Problem: Convective motion (granulation) in stellar atmospheres perturbs the shape of spectral lines and introduces radial velocity "noise," obscuring signals from low-mass planets.

Implication: Stellar spectra encode signals from granulation, but we do not yet understand how to use this information to mitigate the impact of granulation noise on searches for low-mass, Earth-like planets.

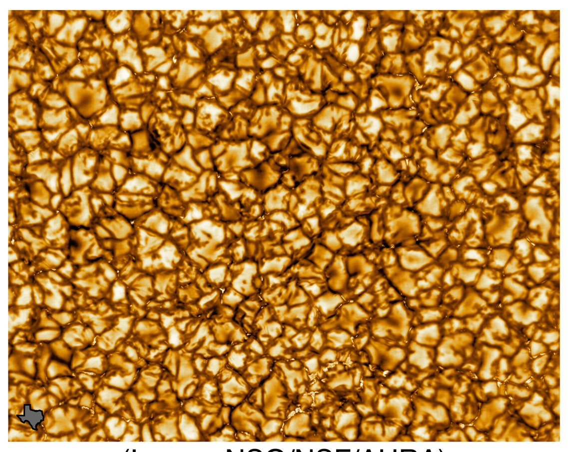
Goal: Create a tool to generate synthetic time-series spectra with an observationally-informed model for line-shape variability from granular motions.

Importance: Use this synthetic spectra generator as a testing bed for analysis techniques and machine learning models for stellar activity mitigation.



Most light from the star is blueshifted by the upward motion of convective cells.

Some light is redshifted by downward motion in smaller intergranular lanes.

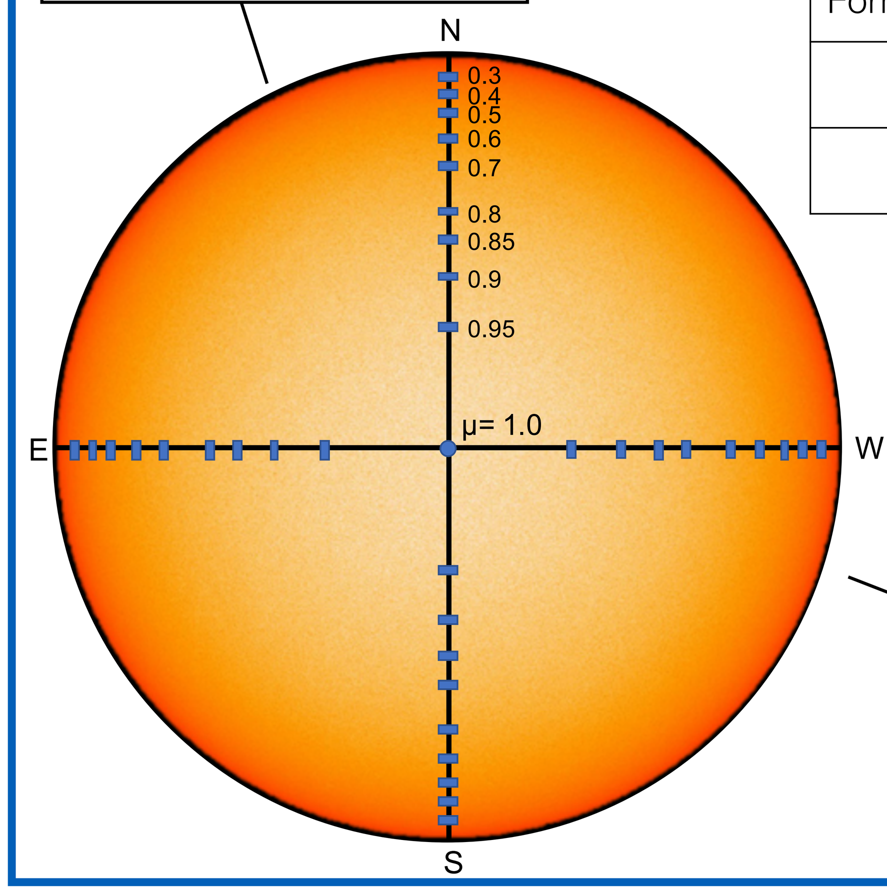


(Image: NSO/NSF/AURA)

The solar hemisphere has millions of granules which evolve on ~15 minute timescales.

2. Input Solar Spectra

Löhner-Böttcher et al.[1,2] have measured solar spectroscopic time-series at 41 spatially-resolved limb positions.



Summary of the **FeI 5434.5 Å** line observations.

Rest Wavelength [Å]	5434.5232
Formation Height [km]	550
g_{eff}	0
Sampling [s]	1.5

Deep lines (like FeI 5434.5 Å) sample larger physical height ranges in the stellar atmosphere.

Magnetic-insensitivity makes this line a good template for other insensitive lines.

High-cadence sampling densely probes the typical lifetime of granules (~10-15 minutes).

The observations were conducted with the Laser Absolute Reference Spectrograph (LARS) on the Vacuum Tower Telescope (VTT). The spectral resolution of ~700,000 ensures that minute variations in the line shapes are resolved.

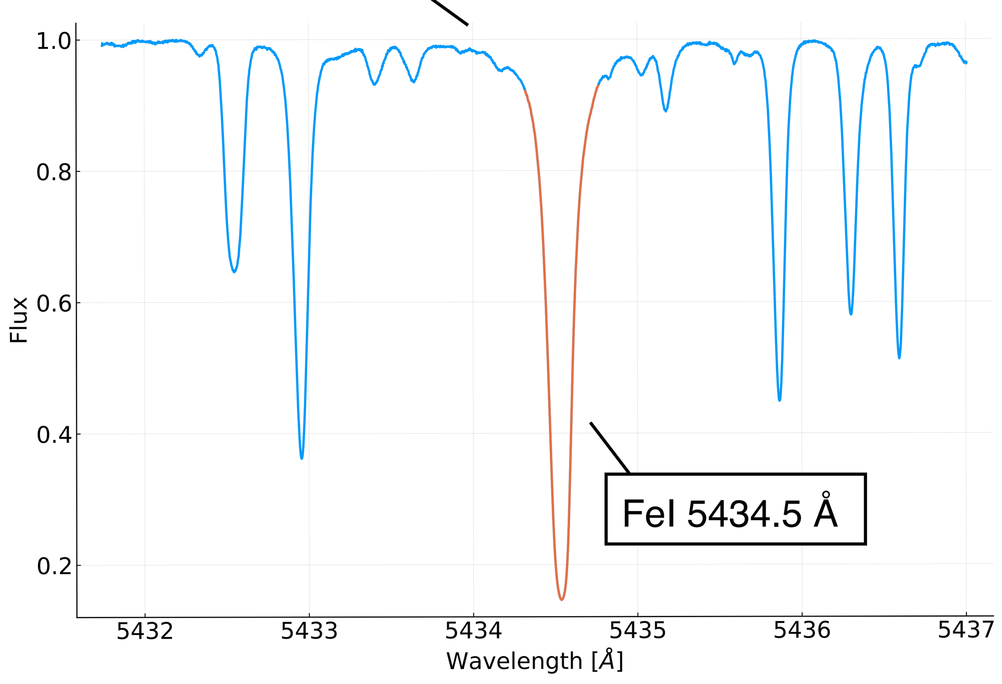
3. Synthesizing Observationally-Informed Spectra

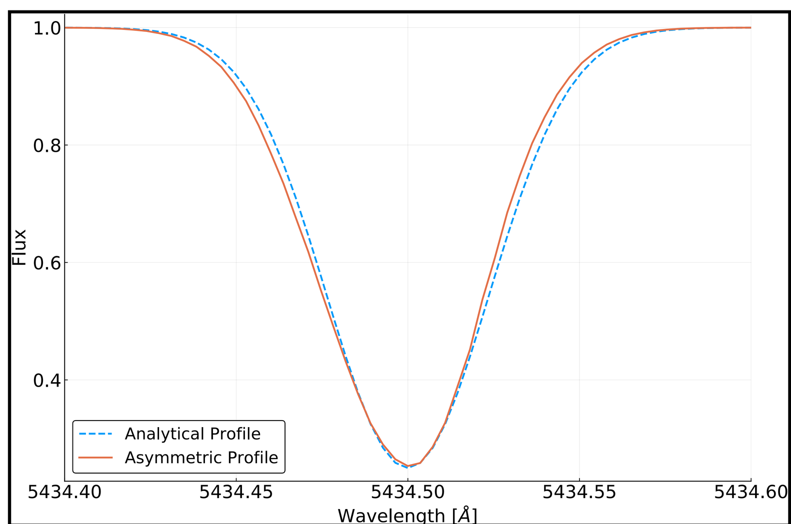
Input:
- Observed spatially-resolved spectra

Calculate:
- Compute perturbed line profiles
- Apply some physics (e.g., differential rotation)
- Integrate the spectrum across the disk

Output:
- Synthetic time-series spectra

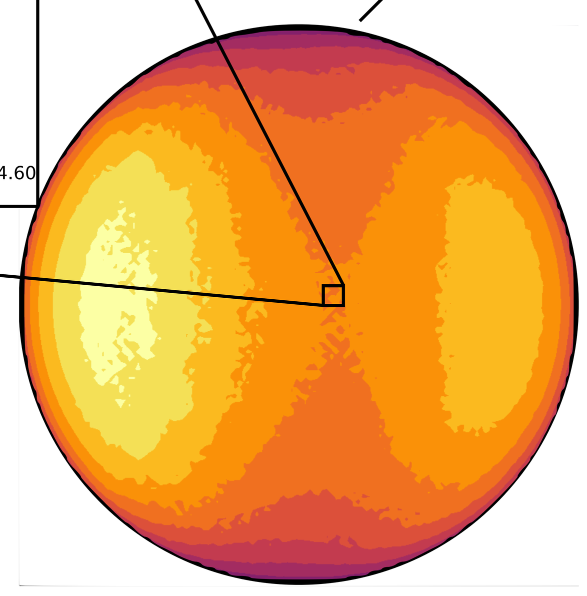
The observed solar spectra encode temporal variability from granulation. We use these line shape variations to synthesize lines.





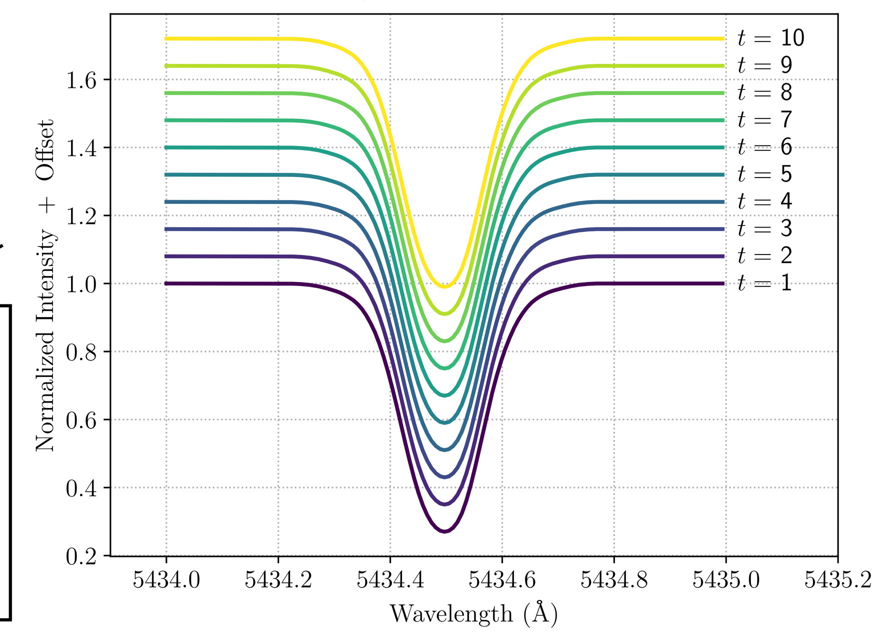
We synthesize a line profile at each spatial grid cell for every time step of the simulation.

A simulated map of the Sun at a single wavelength. At full resolution, each spatial cell contains about ~15 solar granules.

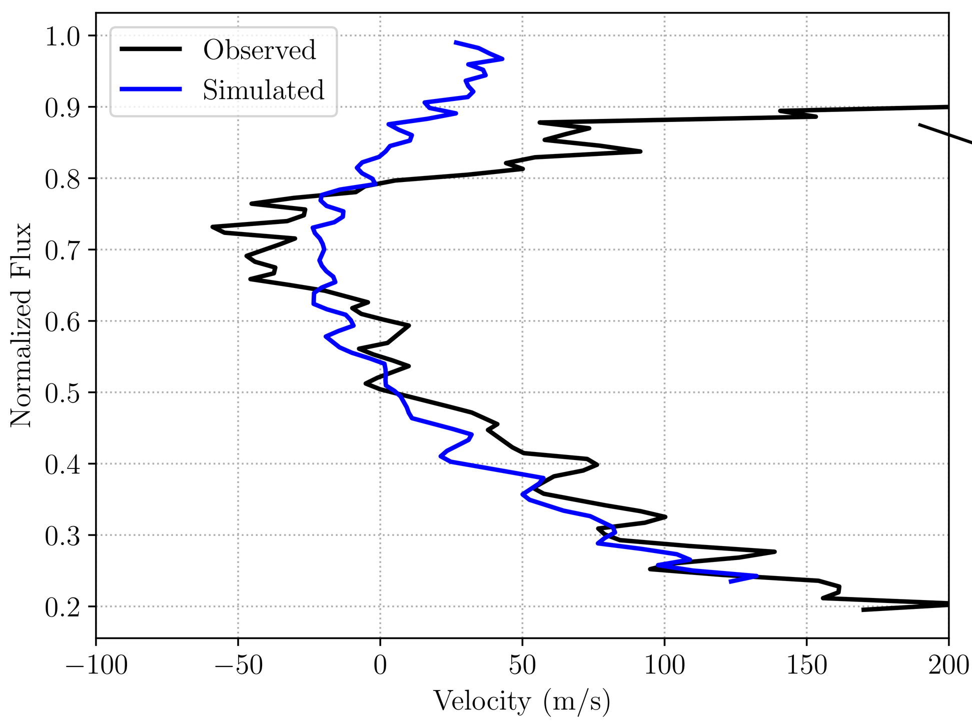


The final spectrum for each time step is computed by summing resolved spectra across the stellar disk.

Each curve shows the disk-integrated spectrum at a given time step (small vertical offsets have been added for clarity).



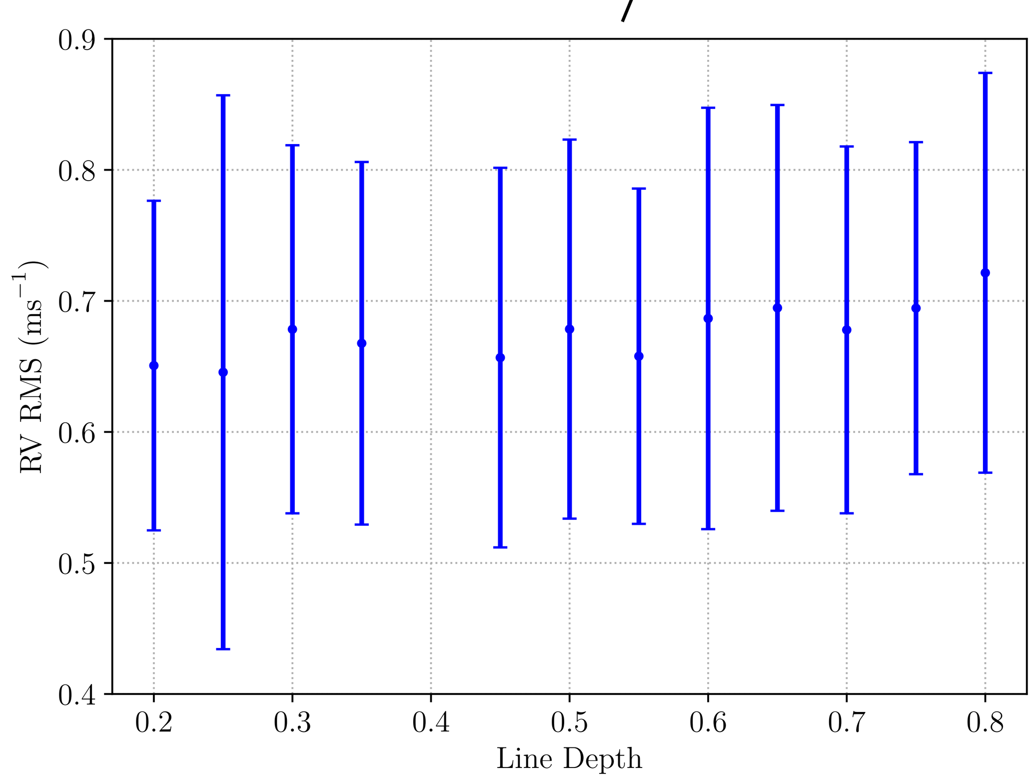
4. "Analyzing" the Synthetic Spectra



The observed bisector was measured with the NEID solar telescope. NEID is a new EPRV spectrograph currently in commissioning at Kitt Peak on WIYN[3,4].

Bisector curves (which measure absorption line midpoint as a function of depth) measured from synthetic (blue) and observed (black) absorption lines generally agree, except in the top-most regions of the line where micro-tellurics and blends in the line wings become prominent.

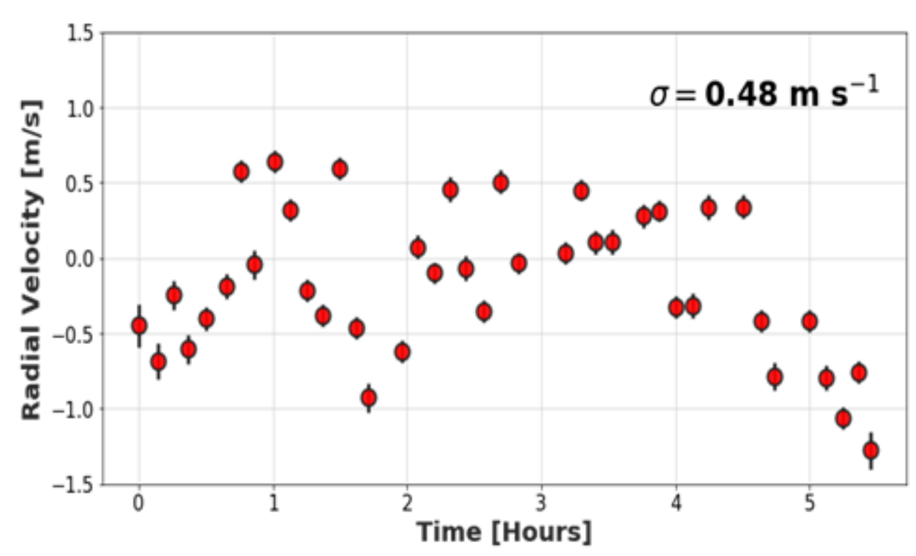
The RMS of apparent velocities measured from synthetic lines do not show any strong trend with line depth.



5. Future Work and Prospects

- Is there an optimal observing strategy for mitigating granulation noise?
- What algorithms can distinguish the spectroscopic signatures of active regions and granulation?
- What algorithms can identify lines that are similarly affected by granulation?
- Compare the temporal evolution of our synthetic spectra to that of observations taken with the newly-commissioned NEID spectrograph.

(Image: Andy Monson)



The NEID spectrograph will observe daytime disk-integrated solar spectra to an instrumental precision of ~0.3 cm/s. These spectra will present new opportunities for studying stellar variability. Velocities measured from preliminary observations taken at State College, PA are shown above.

Download

References

1. Löhner-Böttcher et al. (2018), A&A, 611, 4
2. Löhner-Böttcher et al. (2019), A&A, 624, 57
3. Schwab et al. (2016), Proceedings of the SPIE, 9908
4. Lin et al., in prep.

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