Un-spot-able Signals:
Searching for Null Space Radial Velocity

A.J. deVaux[1], Emily Rauscher[1], Rachael Roettenbacher[1]
[1]University of Michigan | Contact: ajdv@umich.edu

There can be patterns on every star that contribute zero signal to photometric light curves. By creating a mathematical framework that identifies these patterns, we have found they can contribute radial velocity (RV) signals of order 10 meters per second, adding another potential complicating factor to the detection and characterization of exoplanets with RV.
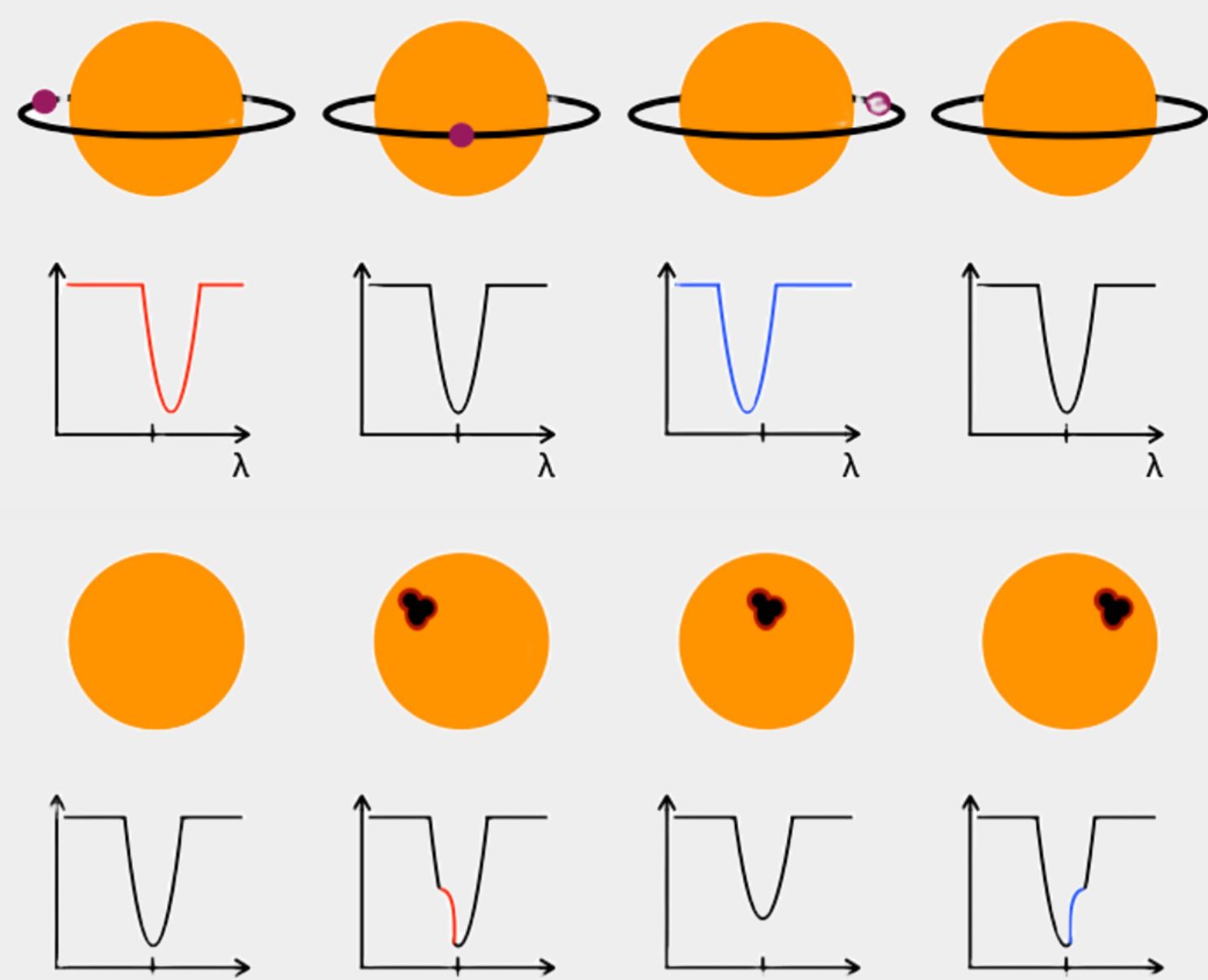
Background: Why RV?

Importance of RV accuracy

To measure the mass of exoplanets, especially terrestrial ones, precise radial velocity (RV) measurements are required. To do this, any additional sources of RV must be corrected for.

Spottiness in Measuring RV

Starspots generate RV signals due to the spectral distortions they create, mimicking exoplanet RV signals. This means it is crucial to understand the impact of stellar surface features on RV.

Comparison between RV due to an exoplanet (top) and RV due to a starspot (bottom). Figure provided by R. Roettenbacher (adapted from Haywood 2015).
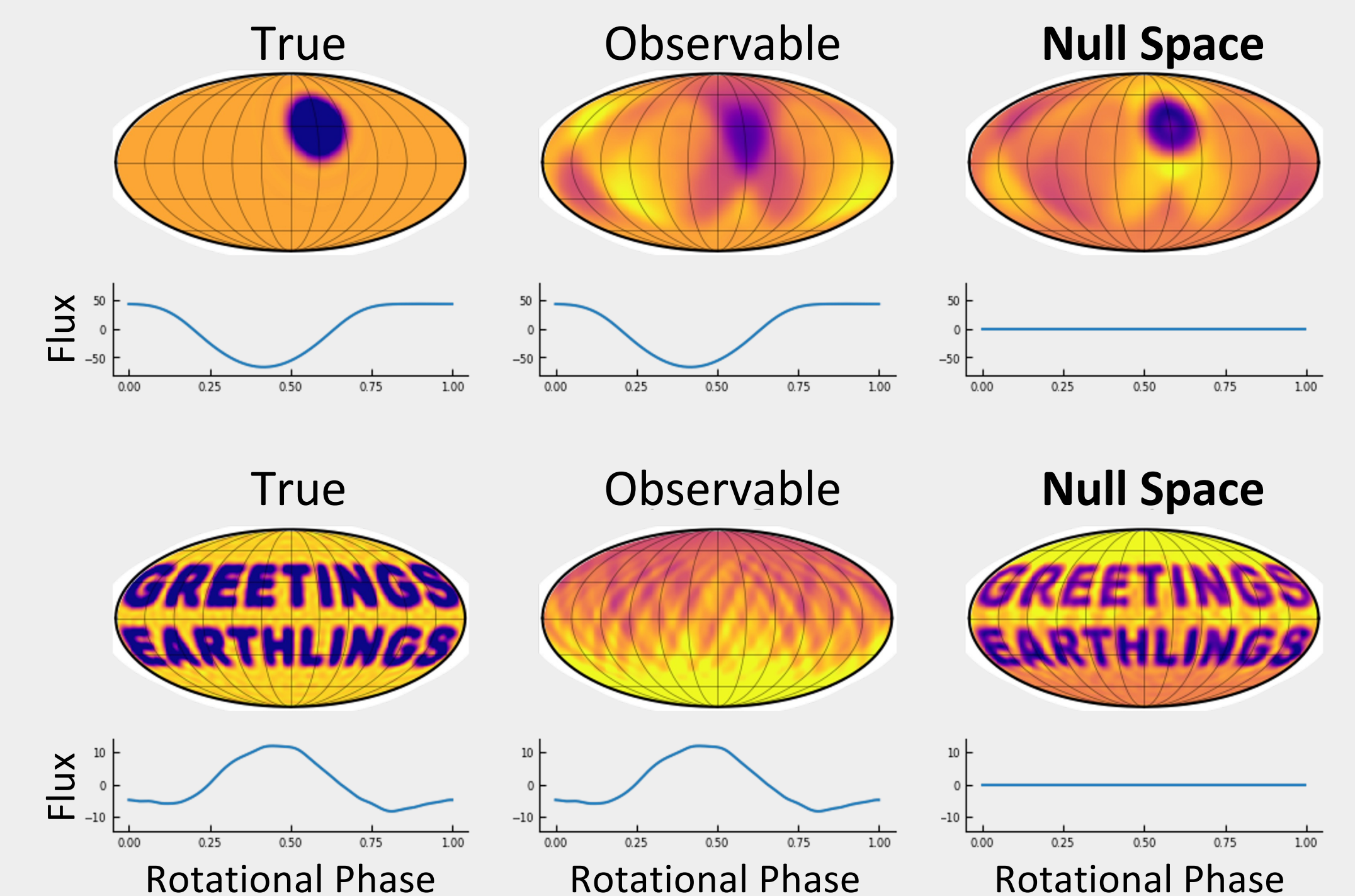
Starspot Maps to the Rescue

Fortunately, we can map star spots through photometric monitoring, measuring the variation in flux as they rotate in and out of view. We can then calculate the RV signals these spots should induce.
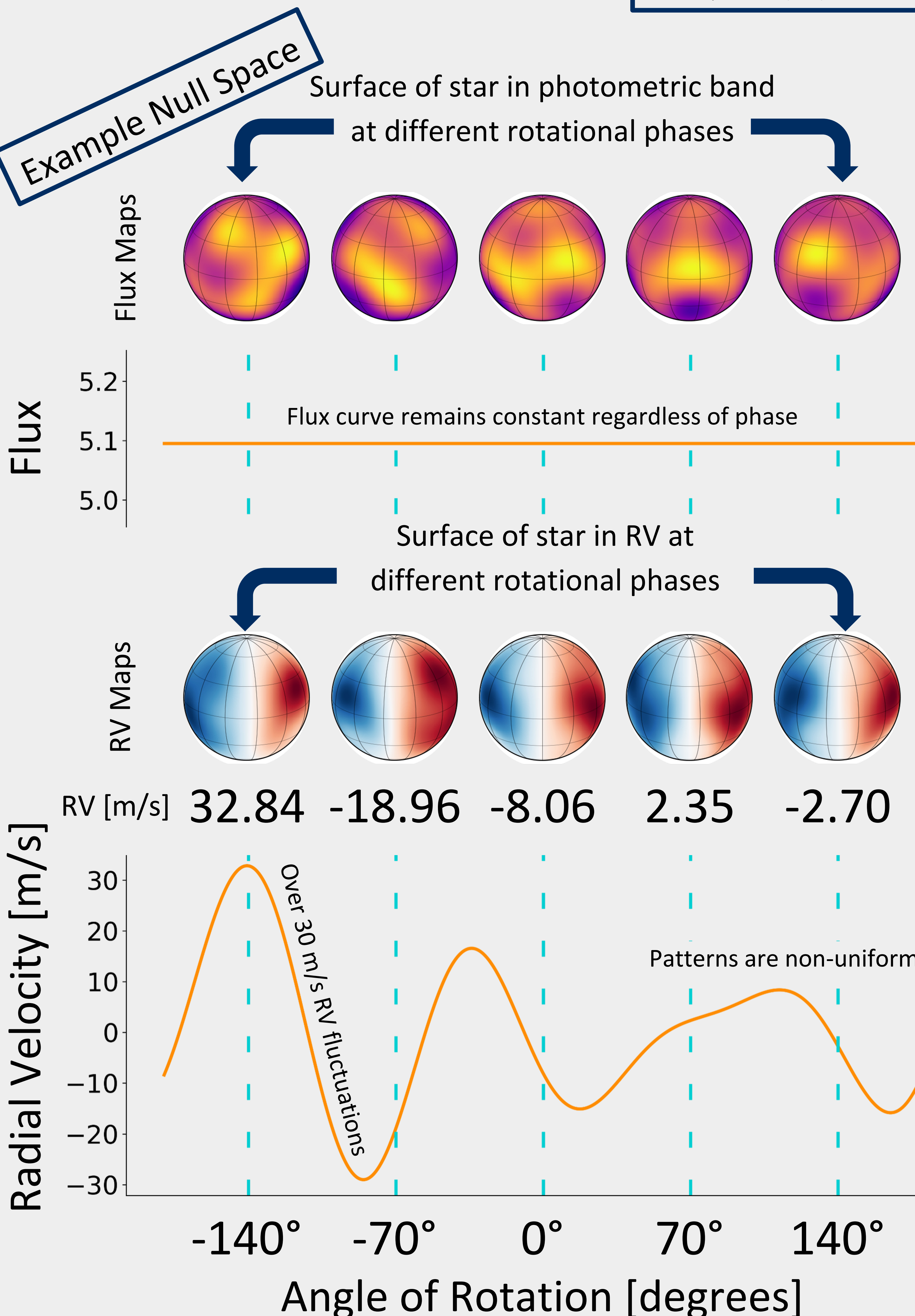
But, what if there are invisible spots?

Identifying Patterns

(Eigen)Mapping the Unknown

To generate null space maps, we used "eigenmapping" to create a new basis set that isolated null space patterns. This was done through the starry and ThERESA python libraries following a similar process used for exoplanet eclipse mapping (2). Using the properties of Epsilon Eridani (inc = 70° and v_{rot} = 2.4 km/s) with quadratic limb darkening, we identified 24 null space maps.

Scaling to Reality

We took each map and set its intensity range to be a realistic representation of a star like Epsilon Eridani (within 0.42 to 1.35 times the uniform component). For these realistic maps, we calculated the RV signals they produced. Am example null space pattern and its corresponding flux and RV curves can be seen to the right.

Null Space: An Invisible Problem

The null space is defined as any pattern on a star that contributes zero photometric signal regardless of phase (see diagram to the right), and more null space patterns exist at higher spatial resolution. Even with inclination and limb darkening, both of which reduce the size of the null space by breaking up symmetries, a majority of surface modes will be "un-spot-able." While these patterns contribute no observable signals in light curves, we have found that they can generate RV signals.

Example true (left), observable (middle) and null space (right) surfaces (3).

Example Null Space

Surface of star in photometric band at different rotational phases

Flux curve remains constant regardless of phase

Because null space maps add zero signal to light curves, any linear combination of them will also be in the null space.

Surface of star in RV at different rotational phases

| RV [m/s] | 32.84 | -18.96 | -8.06 | 2.35 | -2.70 |

Null space patterns can induce a radial velocity signal

Over 30 m/s RV fluctuations

Patterns are non-uniform

Any observed stellar flux curve could have "un-spot-able" patterns contributing to the stellar RV curve

Impacts & Future Work

Because a majority of the maps have a RV signal of order 10 meters per second, there can be significant RV contributions from the null space. While these impacts repeat with each rotation of the star, they are not uniform throughout which will increase the challenge of identifying and correcting for them.
- I will be presenting this research again at the 247th AAS meeting
- We also plan to publish these results and make the code publicly available

I will be applying to graduate school this winter, so be on the lookout for my application!

References

1. Challener and Rauscher 2022
2. Challener and Rauscher 2023
3. Luger *et al.* 2021
4. Rauscher *et al.* 2018
5. Roettenbacher *et al.* 2022