Statistical Methods for Characterizing Variability in Stellar Spectra

Jessi Cisewski
Yale University

229th Meeting of the American Astronomical Society
January 7, 2017

Allen Davis (Yale), Xavier Dumusque (U. of Geneva), Debra Fischer (Yale), Eric Ford (Penn State)

⋆Special thanks to **SAMSI** for supporting this session⋆

SAMSI ASTRO Working Group IV
Astrophysical Populations

WG leaders: Jessi Cisewski, Eric Ford

David Stenning (SAMSI/Duke): **dstenning@samsi.info***

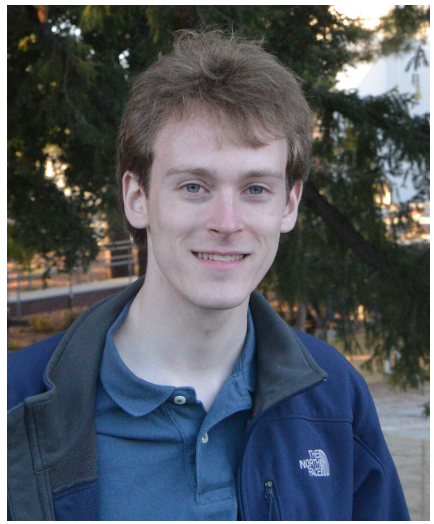
*Contact David if interested in joining group

Some of the group's goals:

- improve the statistical methodology for interpreting detections of exoplanets, gravitational waves (GW), as well as using those to infer the underlying population of planetary systems and GW sources
- developing techniques to robustly detect and characterize planets in the presence of stellar activity from Doppler Surveys for which we do not have a first-principles model
- detecting gravitational wave sources for which the details of the primary GW signal and/or backgrounds are unknown

Allen B. Davis Poster **425.04** TODAY

Insights on the spectral signatures of RV jitter from PCA



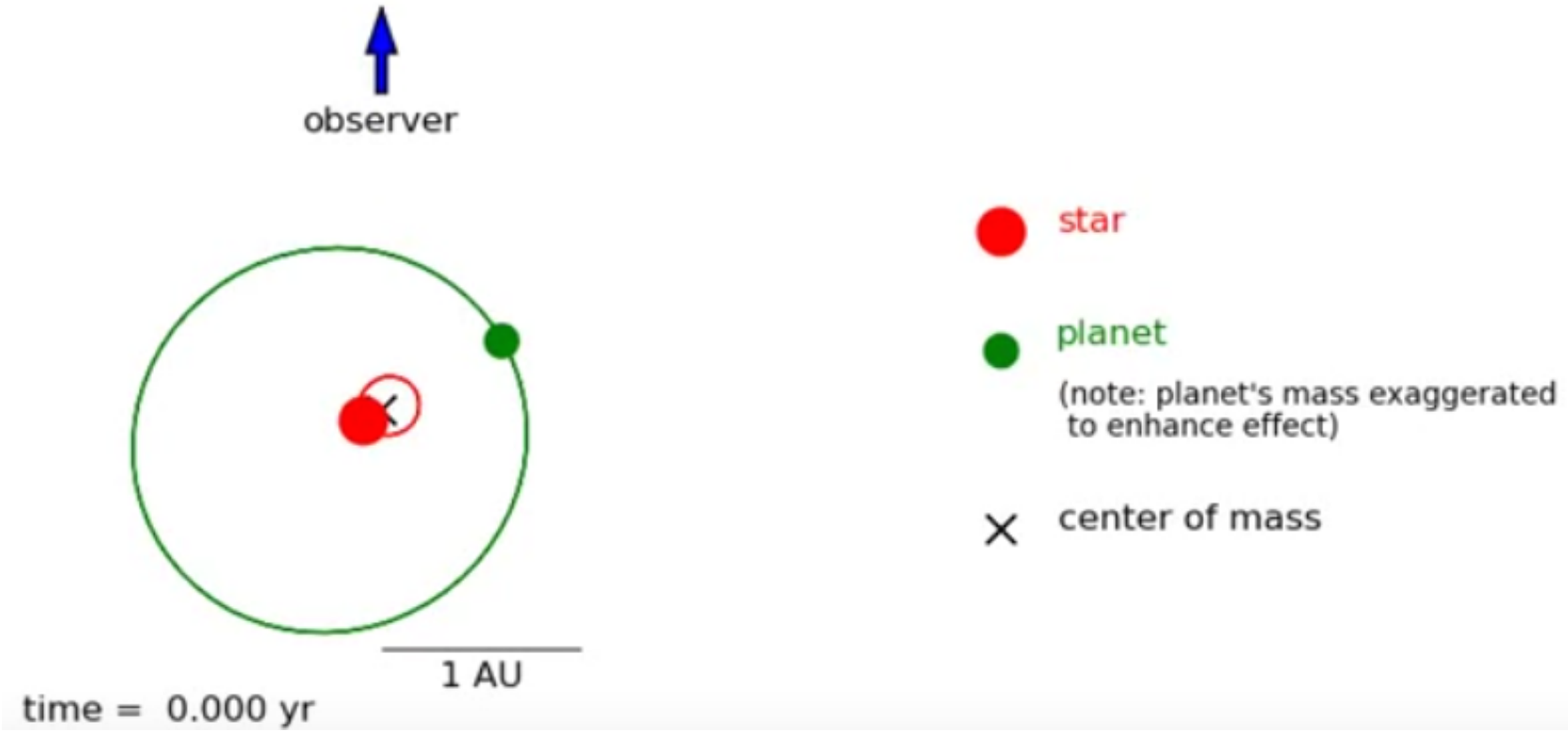
425. Extrasolar Planets Late Poster Session

1:00 PM - 2:00 PM

Longhorn D (Gaylord Texan Resort & Convention Center)

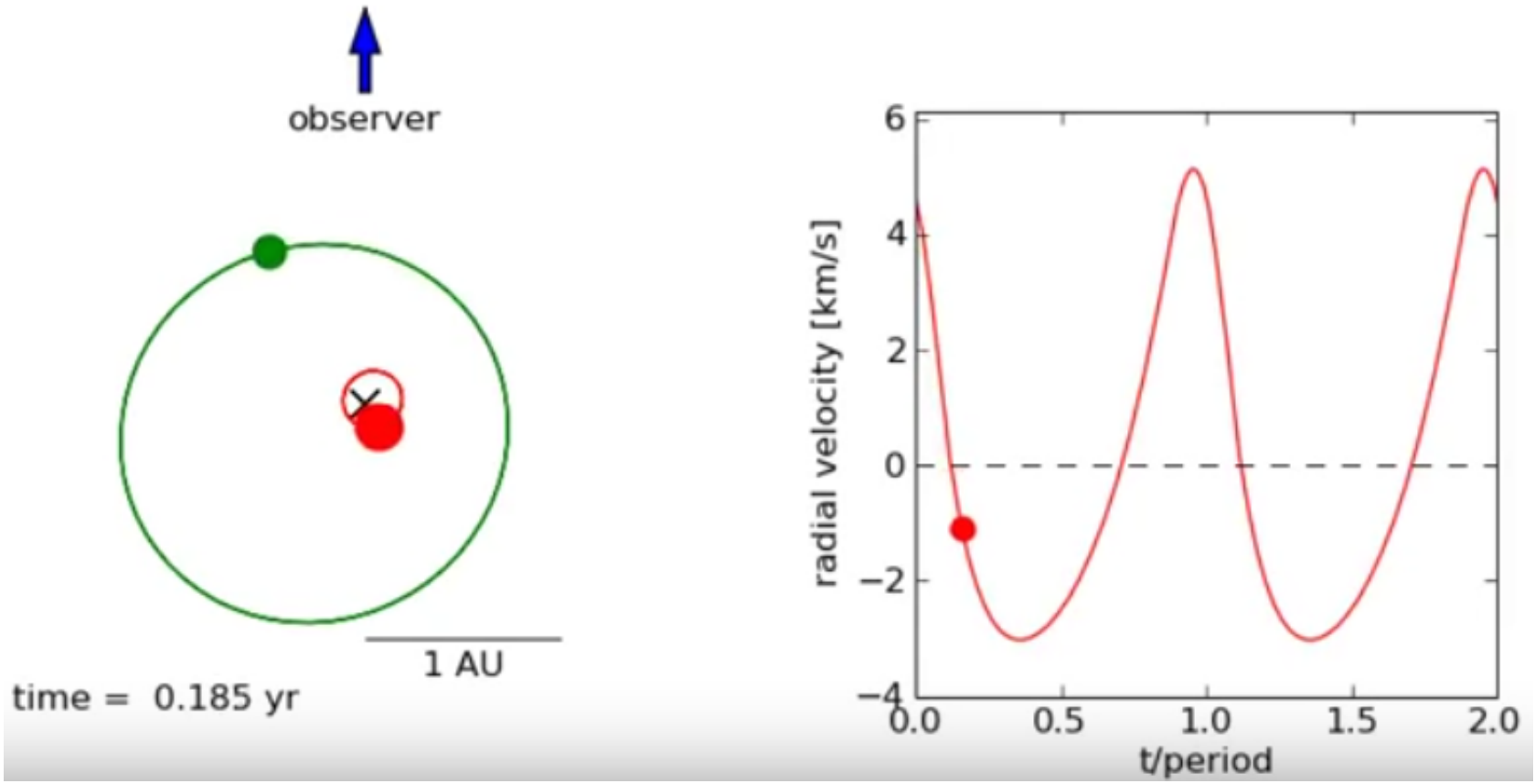
Jessi Cisewski

Radial Velocity Method



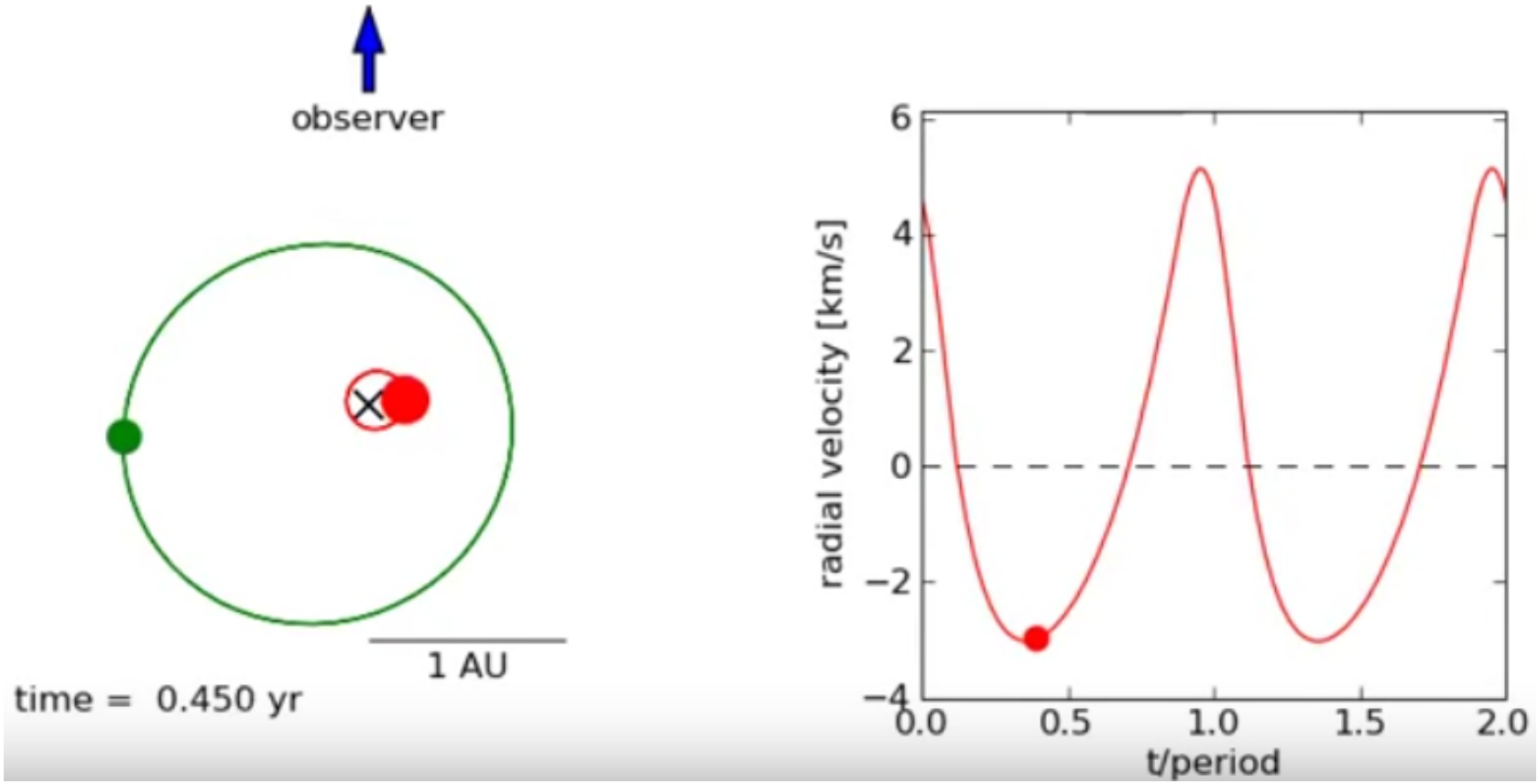
Plots: `https://www.youtube.com/watch?v=tUzDKlaTHFM`

Radial Velocity Method



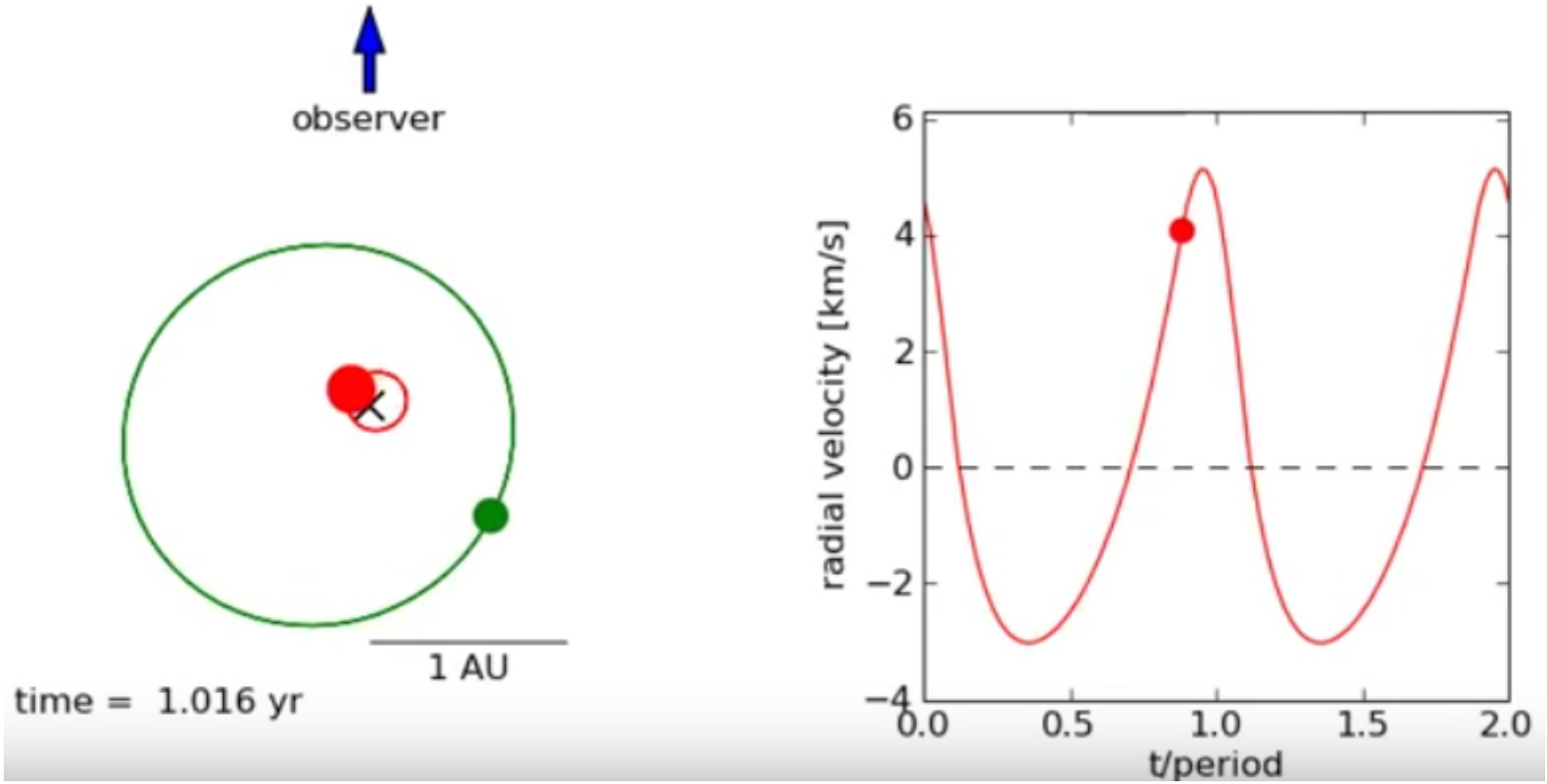
Plots: `https://www.youtube.com/watch?v=tUzDKlaTHFM`

Radial Velocity Method



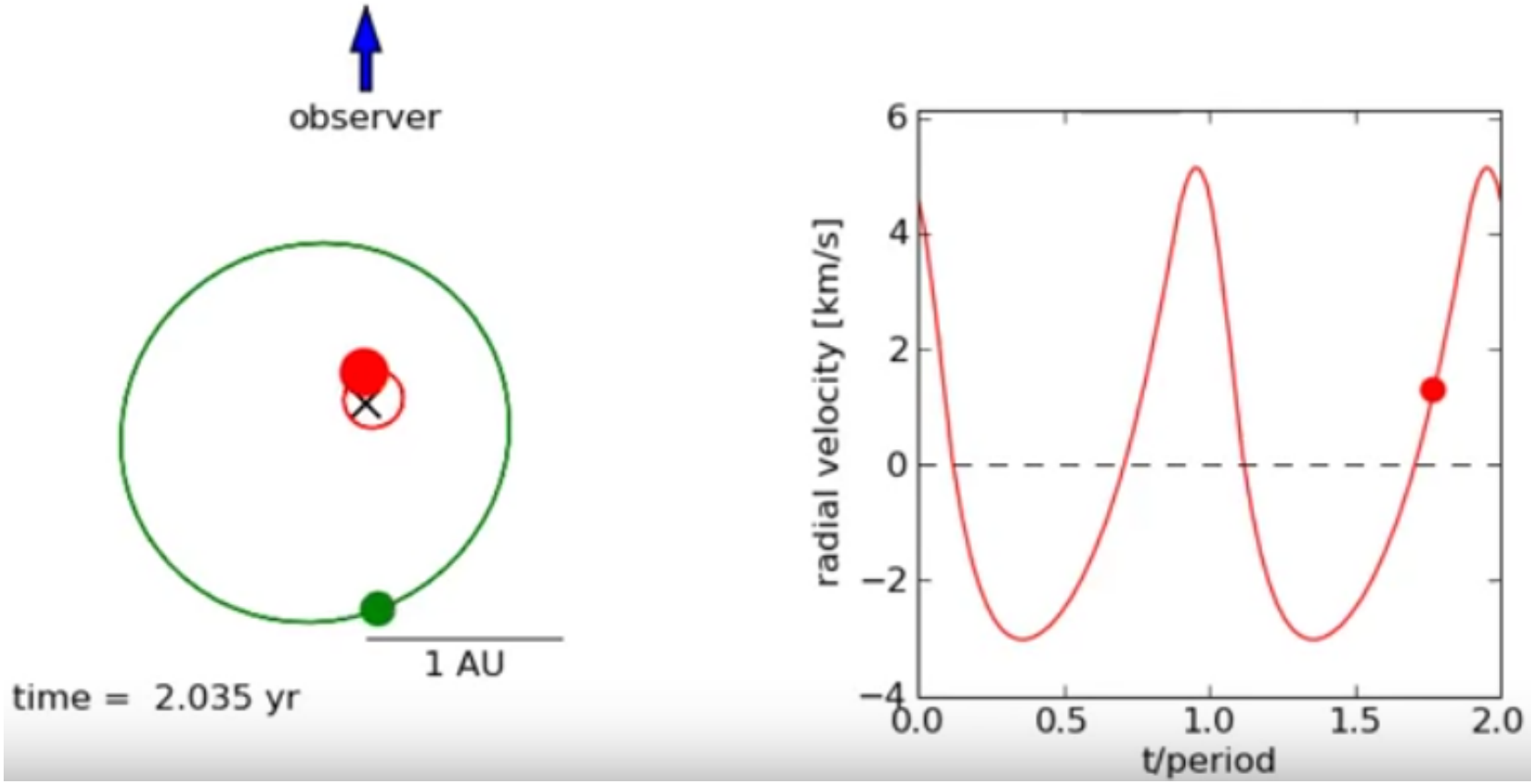
Plots: `https://www.youtube.com/watch?v=tUzDKlaTHFM`

Radial Velocity Method

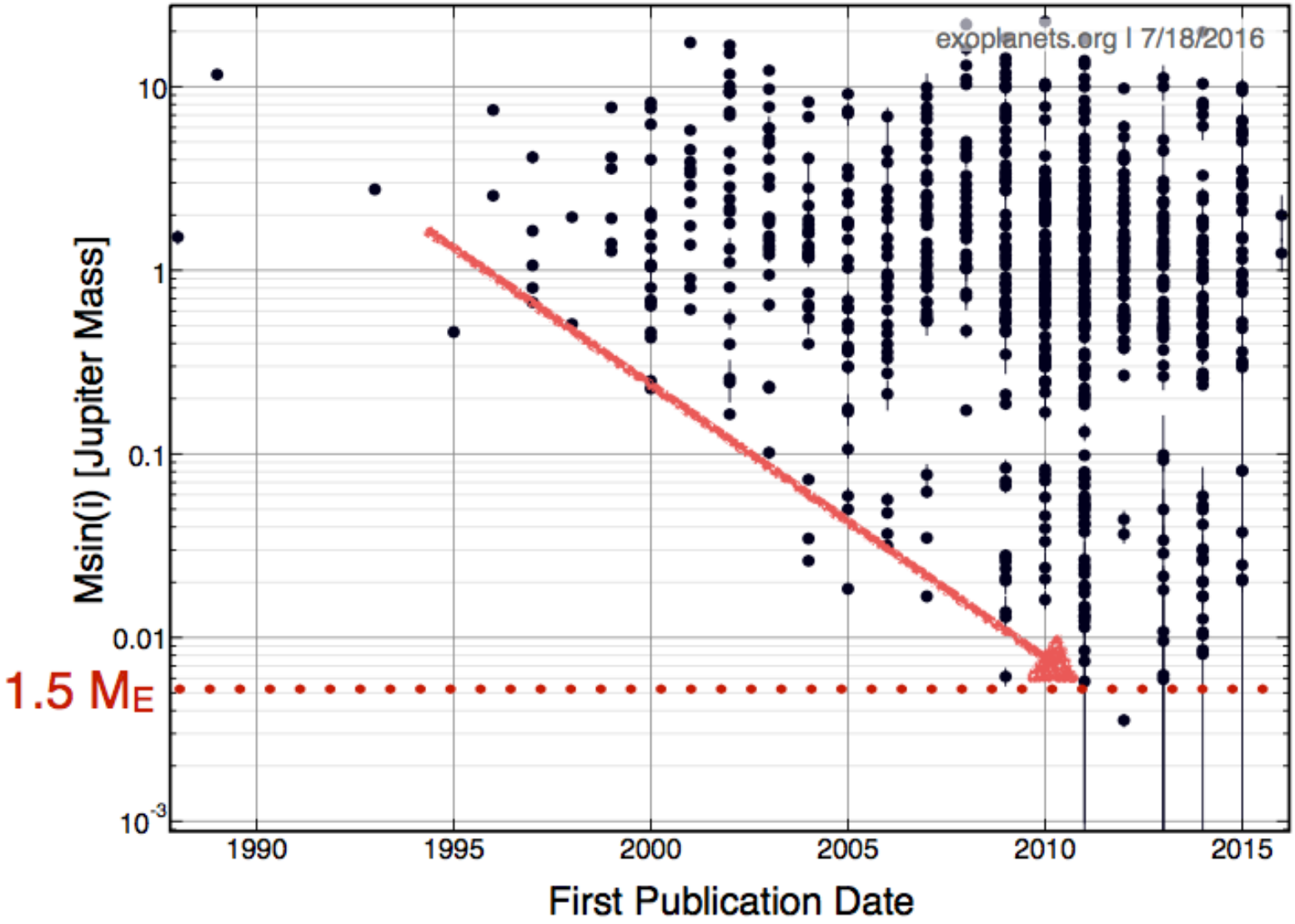


Plots: `https://www.youtube.com/watch?v=tUzDKlaTHFM`

Radial Velocity Method



Plots: `https://www.youtube.com/watch?v=tUzDKlaTHFM`



Plot: Debra Fischer and `http://exoplanets.org`

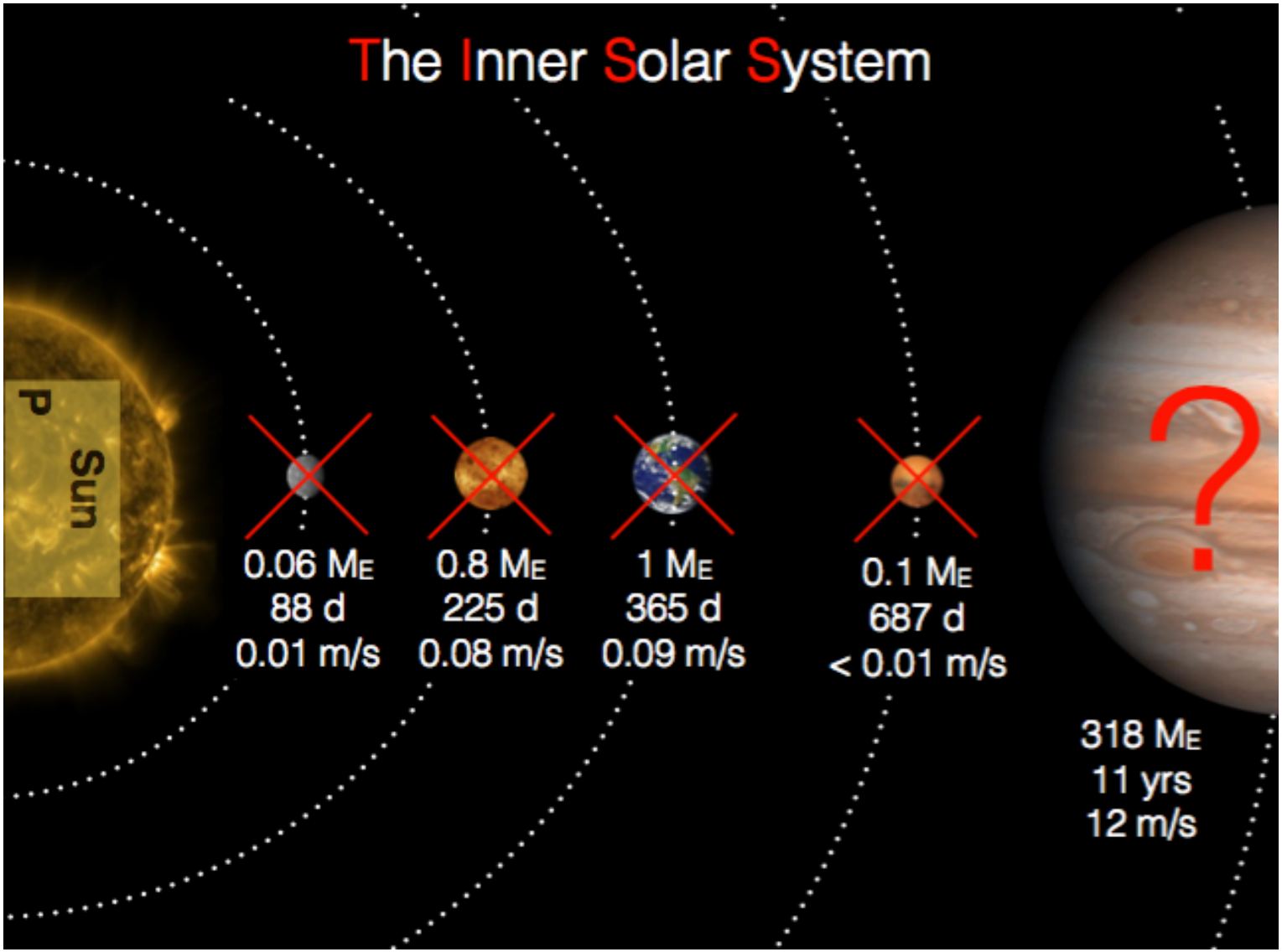


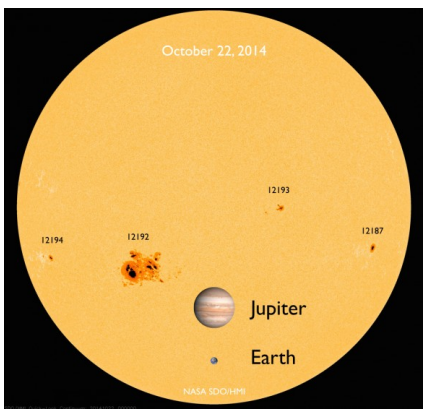
Figure: Xavier Dumusque (Geneva)

What's the problem?

What's the problem?

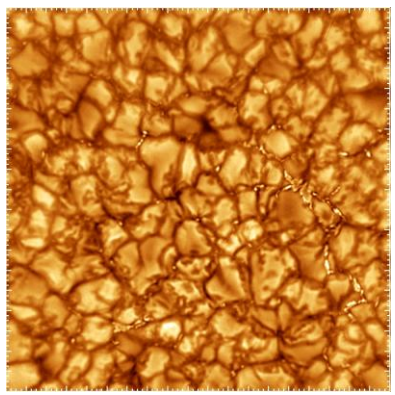
Stellar activity

Spots, plages, faculae, limb darkening, convective blue shift, stellar oscillation and magnetic cycles, ...



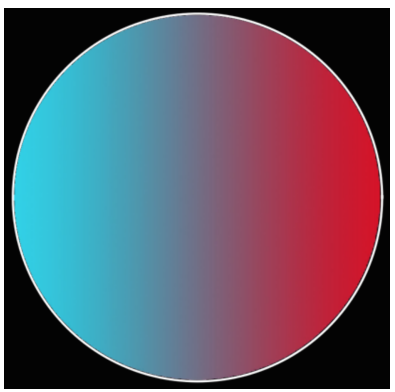
Spots

Credit: SDO/HMI/Alex Young, `universetoday.com`



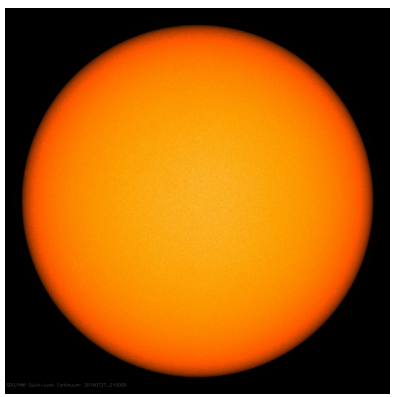
Granulation

Credit: BBSO/NJIT, `http://phys.org`



Rotation

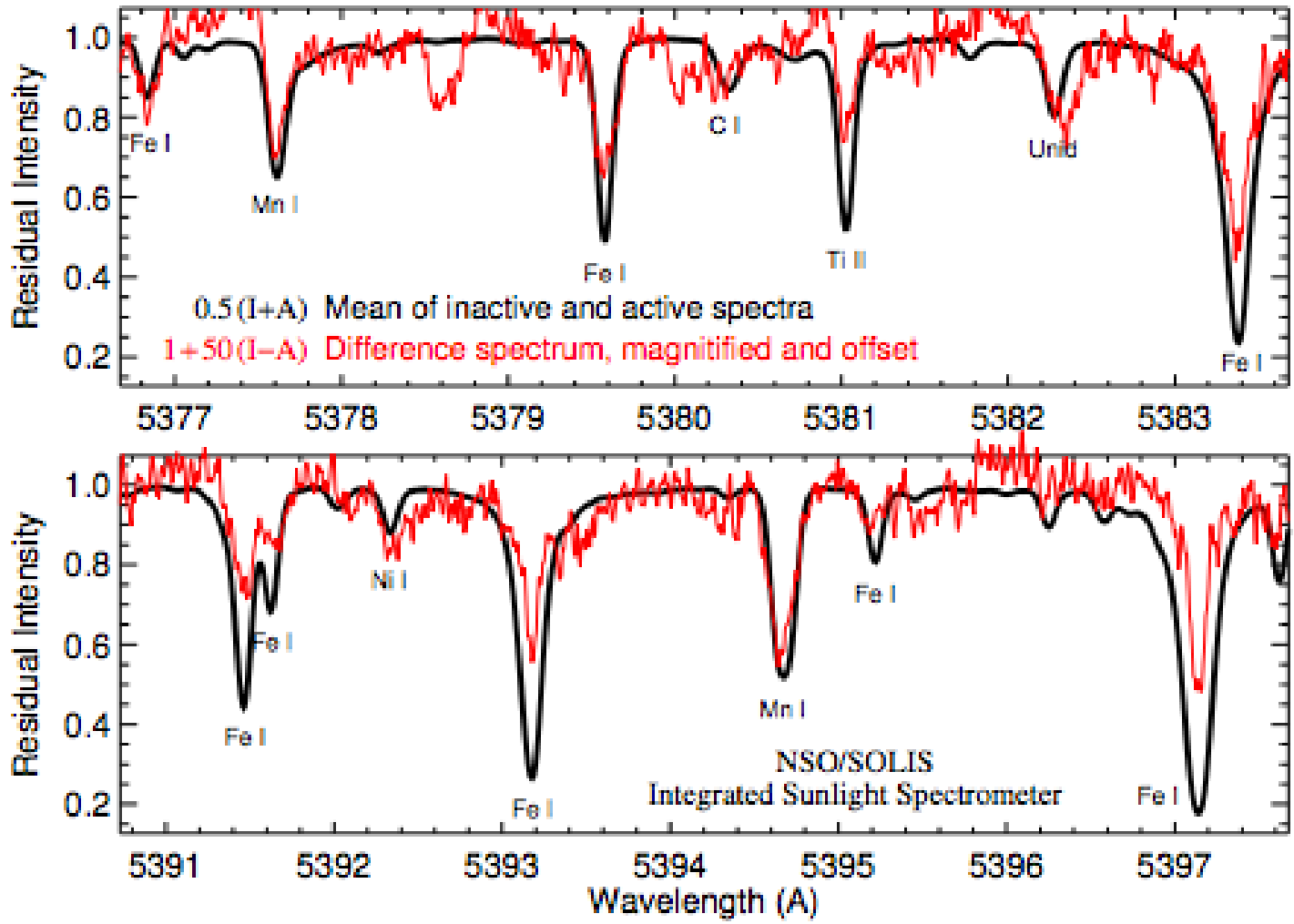
Credit: Xavier Dumusque (Geneva)



Limb Darkening

Credit: SDO/HMI

Stellar activity



- Figure 1 from Davis et al. (2017) (courtesy of J. Valenti)

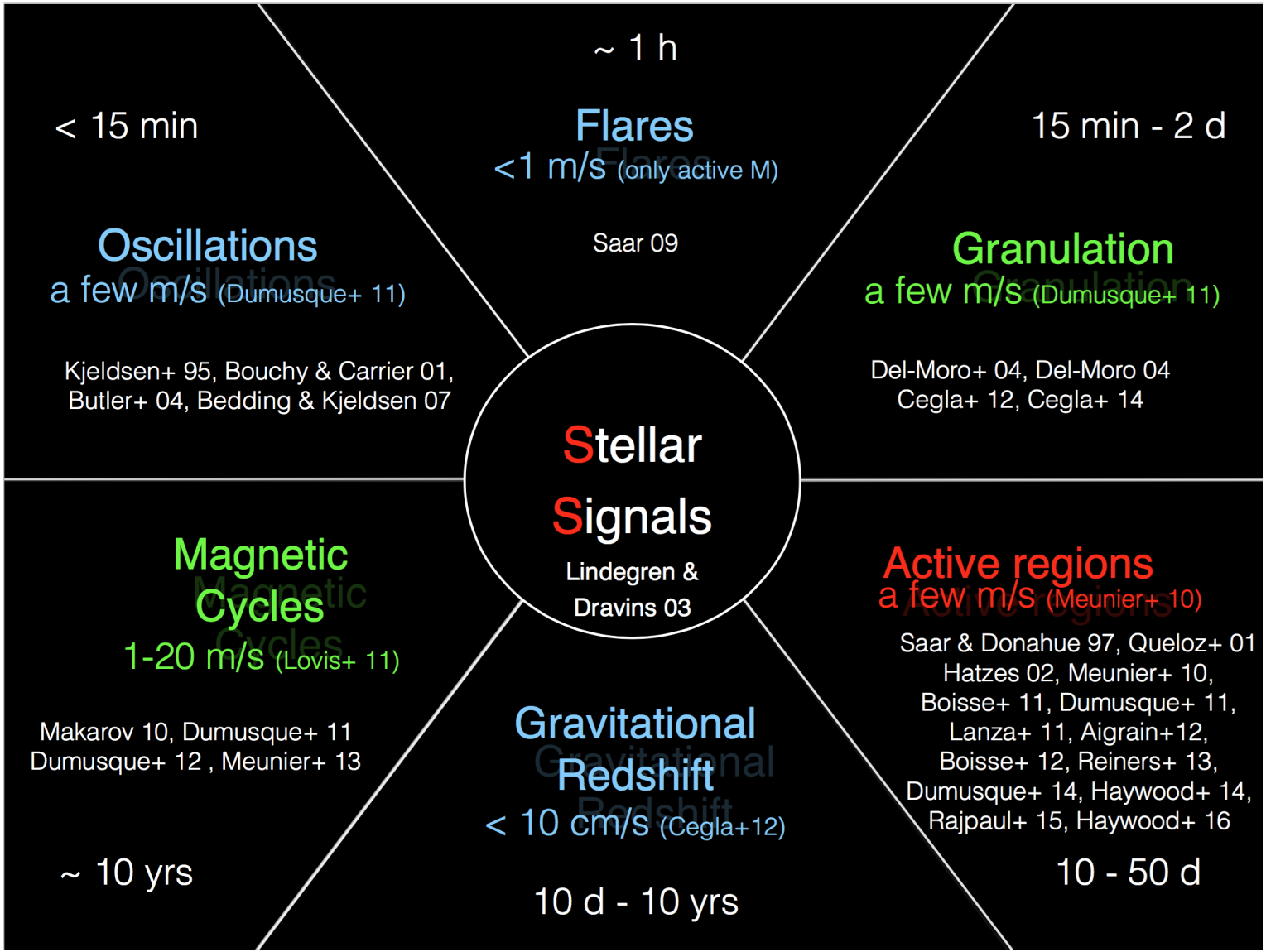
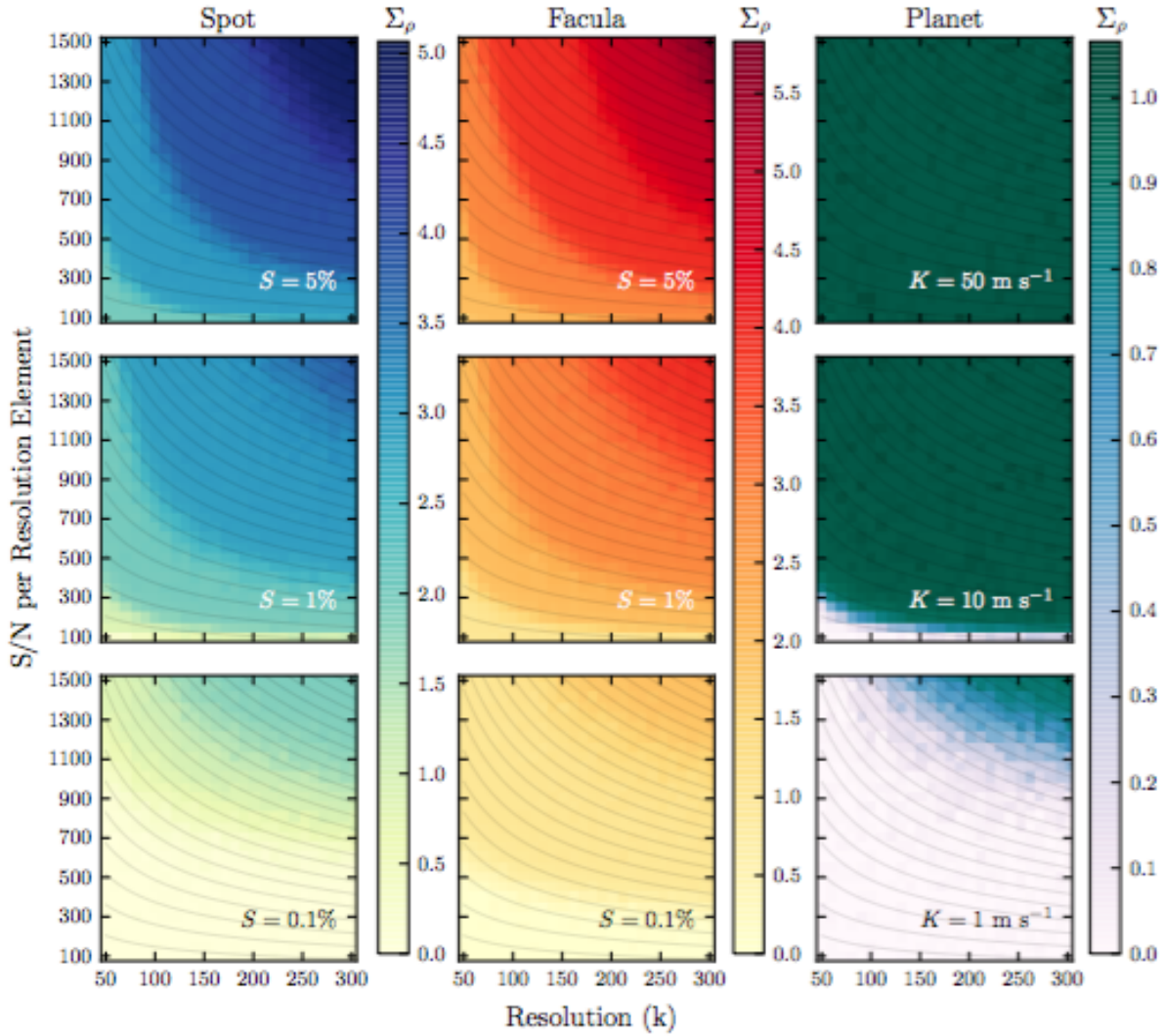
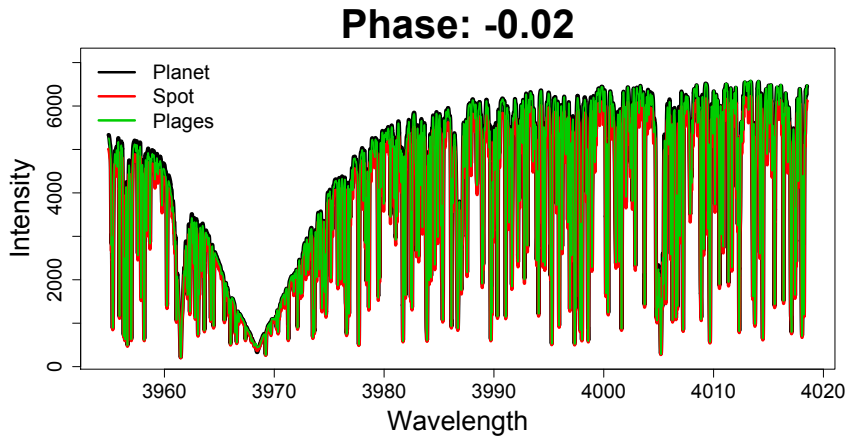


Figure: Xavier Dumusque (Geneva)

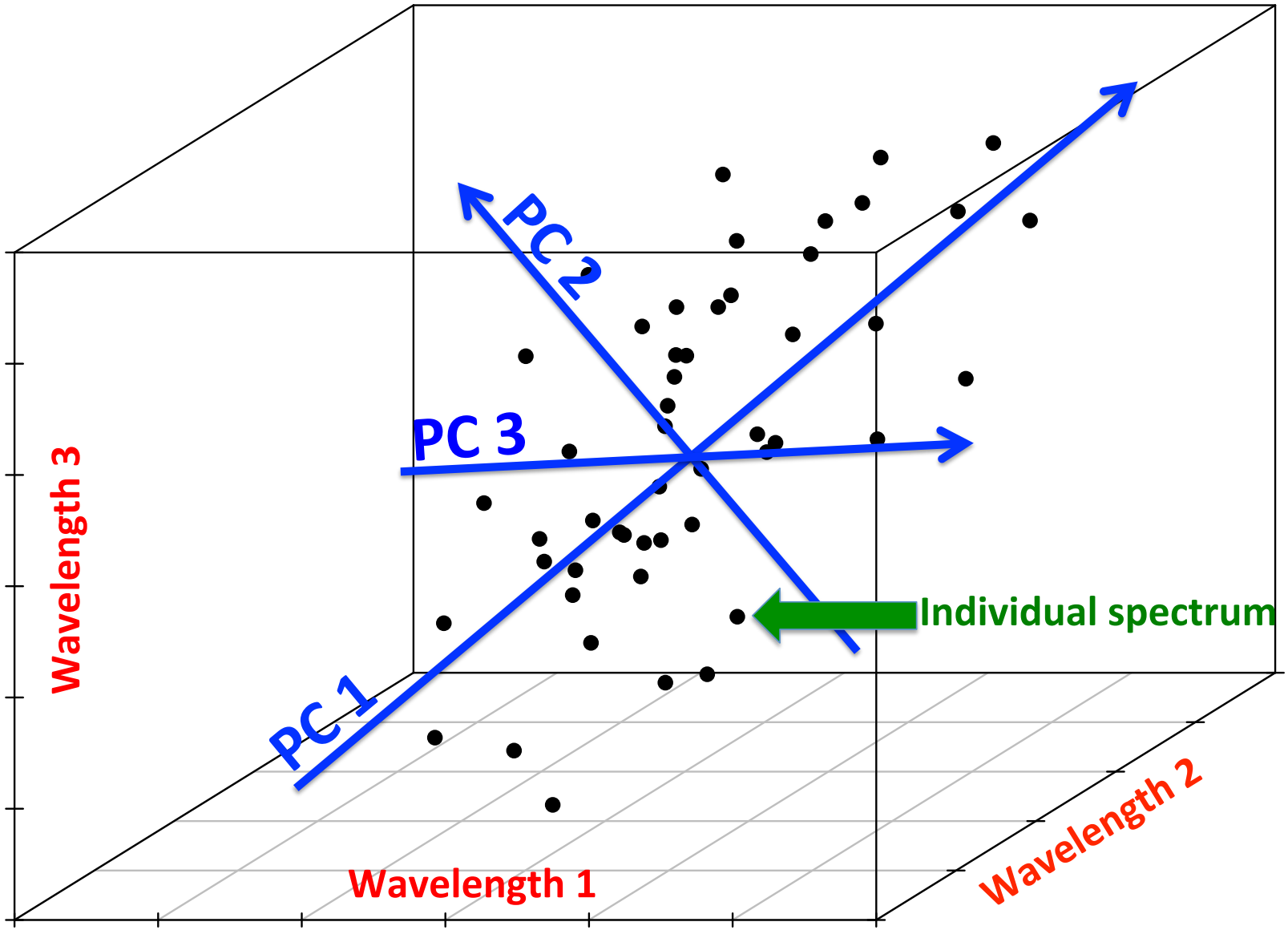


- Figure 7 from Davis et al. (2017)

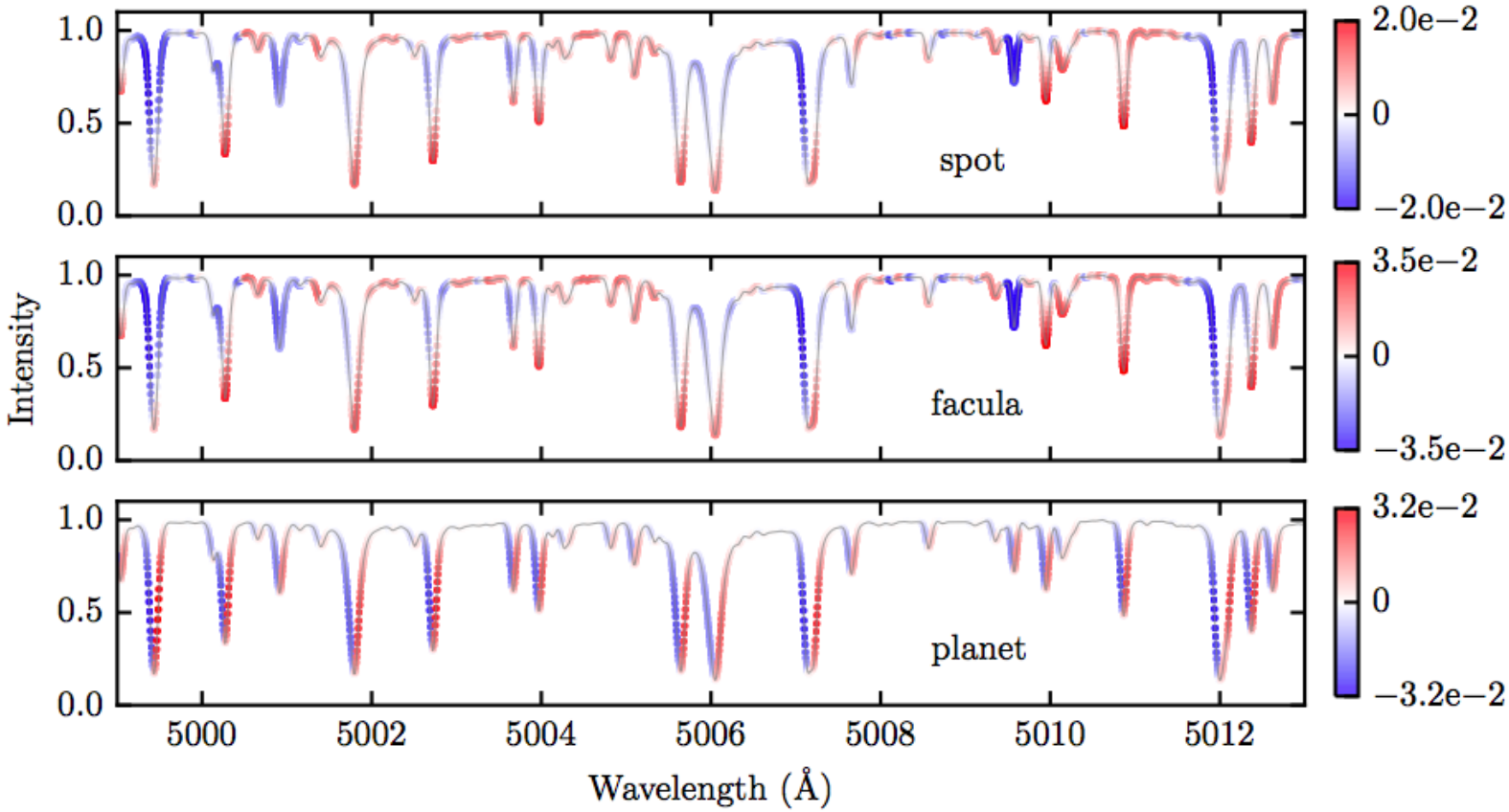
- SOAP 2.0 spectra (Dumusque et al., 2014)
- Wavelengths: 3925.87 A to 6661.54 A (∼500,000 measurements)
- An equatorial **spot**/**facula** with coverage area of 0.1%, 1%, 5%
- A **planet** in circular orbit with RV semi-amplitude of 1, 10, 50 m/s
- Stellar rotation period of 25 days, 1 spectra/day



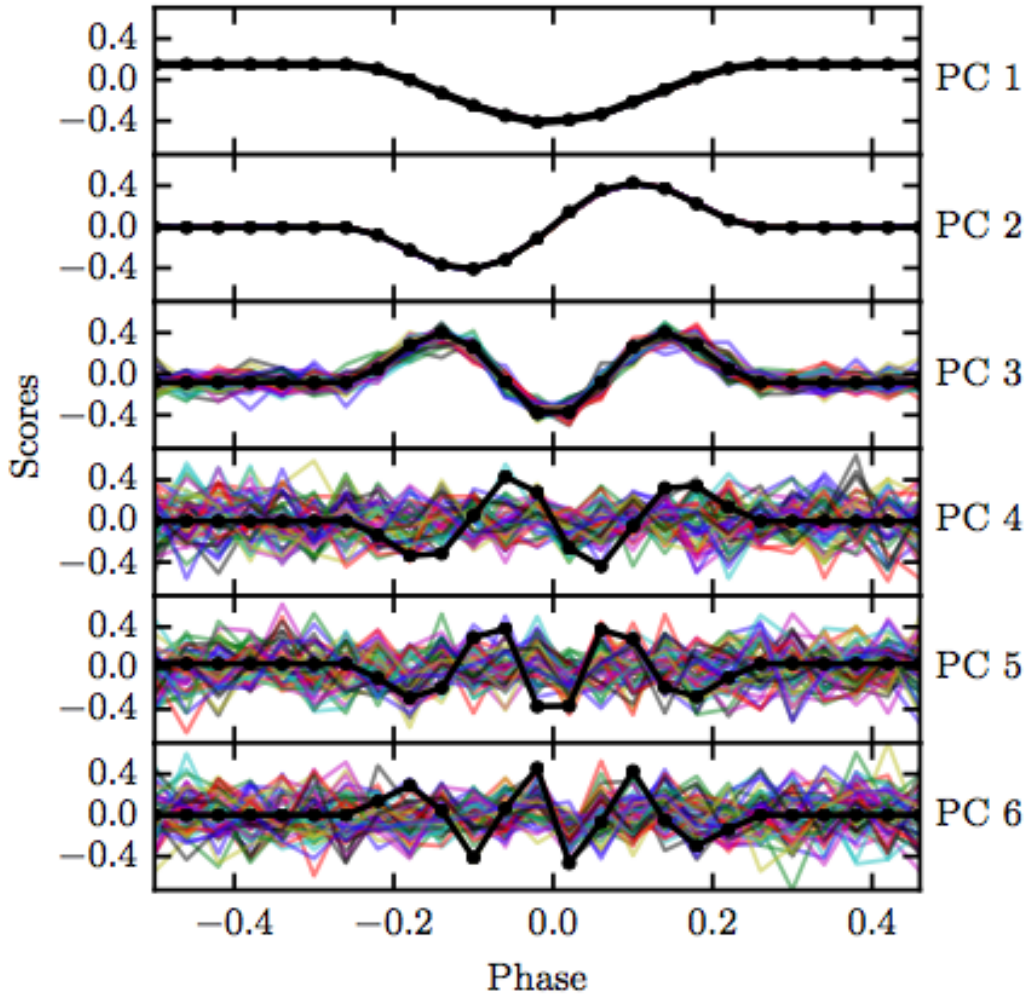
Principal Components Analysis



Jessi Cisewski



- Figure 3 from Davis et al. (2017)



- Figure 5 from Davis et al. (2017)
- 50 realizations of noise for the 1% spot
- Resolution = 150,000, S/N = 800

- 1% spot, Res = 150,000, S/N = 800, 50 sets of spectra

$$\Sigma_\rho = \sum_{i=1}^{10} \sum_{j=1}^{50} g(\rho_{ij}) \frac{\rho_{ij}}{50}$$

ρ_{ij}=correlation of PC i scores for realization j with PC i scores of high-res, noise-free PC scores

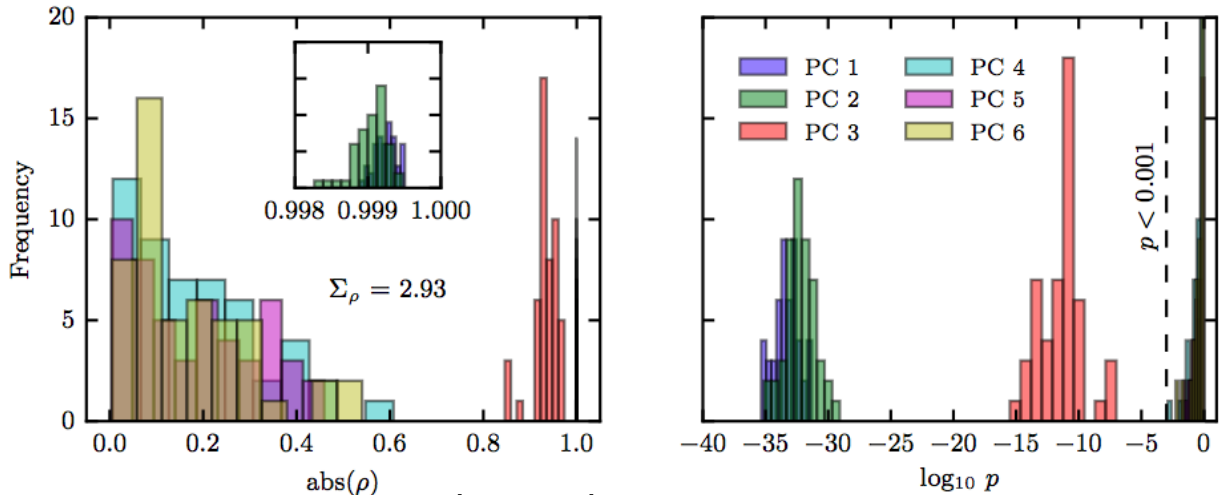
i=PC, j=independent realization of noise, $g(\rho_{ij}) = 1$ for small p-value (otherwise = 0)

- 1% spot, Res = 150,000, S/N = 800, 50 sets of spectra

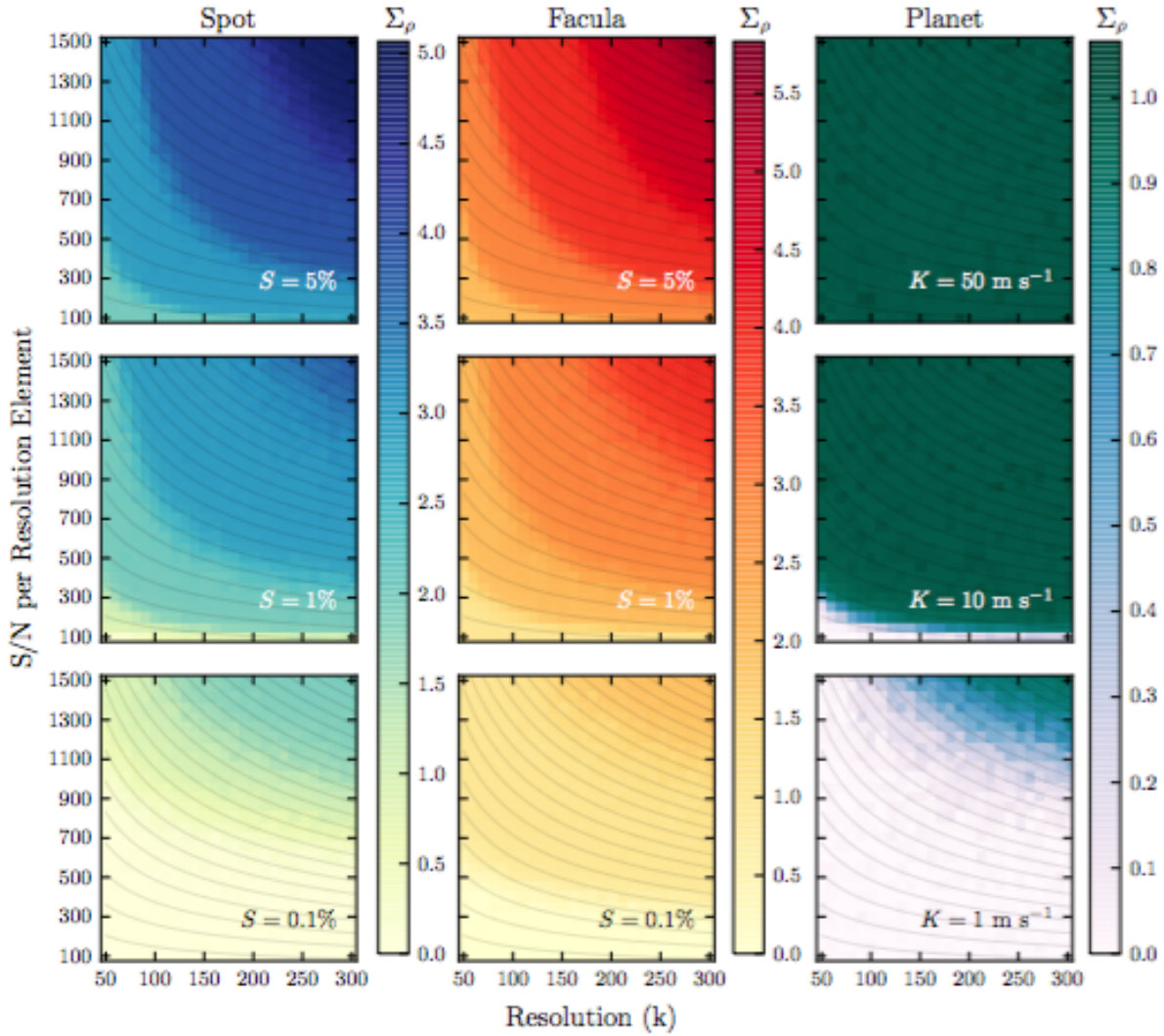
$$\Sigma_\rho = \sum_{i=1}^{10} \sum_{j=1}^{50} g(\rho_{ij}) \frac{\rho_{ij}}{50}$$

ρ_{ij}=correlation of PC i scores for realization j with PC i scores of high-res, noise-free PC scores

i=PC, j=independent realization of noise, $g(\rho_{ij}) = 1$ for small p-value (otherwise = 0)



- Figure 6 from Davis et al. (2017)



- Figure 7 from Davis et al. (2017)

Summary

- Radial velocity method is an effective technique for detecting exoplanets
- Signals for less massive planets require accounting for stellar activity
- Stellar activity can mimic planetary signals
- Statistical methods are needed to distinguish Doppler shifts from other variability in the spectra
- The sources of variability appear to have different effects on the spectra

- Allen B. Davis Poster **425.04** TODAY, 1:00 PM - 2:00 PM, Longhorn D

Summary

- Radial velocity method is an effective technique for detecting exoplanets
- Signals for less massive planets require accounting for stellar activity
- Stellar activity can mimic planetary signals
- Statistical methods are needed to distinguish Doppler shifts from other variability in the spectra
- The sources of variability appear to have different effects on the spectra

- Allen B. Davis Poster **425.04** TODAY, 1:00 PM - 2:00 PM, Longhorn D

THANK YOU!!!

Bibliography

Davis, A. B., Cisewski, J., Dumusque, X., Fischer, D. A., and Ford, E. B. (2017), "INSIGHTS ON THE SPECTRAL SIGNATURES OF RV JITTER FROM PCA," Submitted.

Dumusque, X., Boisse, I., and Santos, N. (2014), "SOAP 2.0: A TOOL TO ESTIMATE THE PHOTOMETRIC AND RADIAL VELOCITY VARIATIONS INDUCED BY STELLAR SPOTS AND PLAGESThe tool is available at http://www. astro. up. pt/soap. The work in this paper is based on observations made with the MOST satellite, the HARPS instrument on the ESO 3.6 m telescope at La Silla Observatory (Chile), and the SOPHIE instrument at the Observatoire de Haute Provence (France)." *The Astrophysical Journal*, 796, 132.