

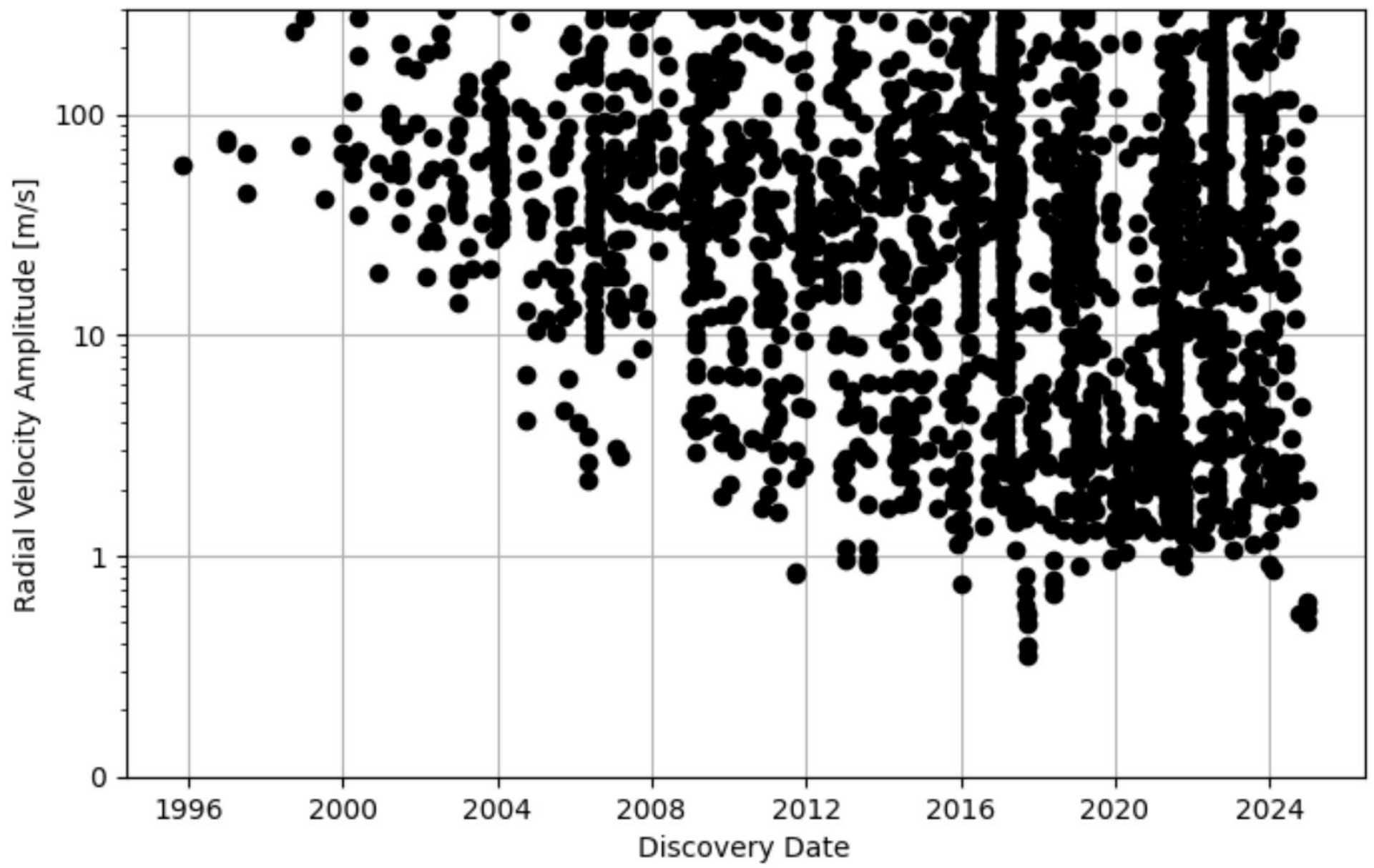
PLANETARY MASSES IN MOTION:
NAVIGATING THE IMPACT OF
STELLAR VARIABILITY ON
EXOPLANET MASS AND ORBIT
DETERMINATIONS

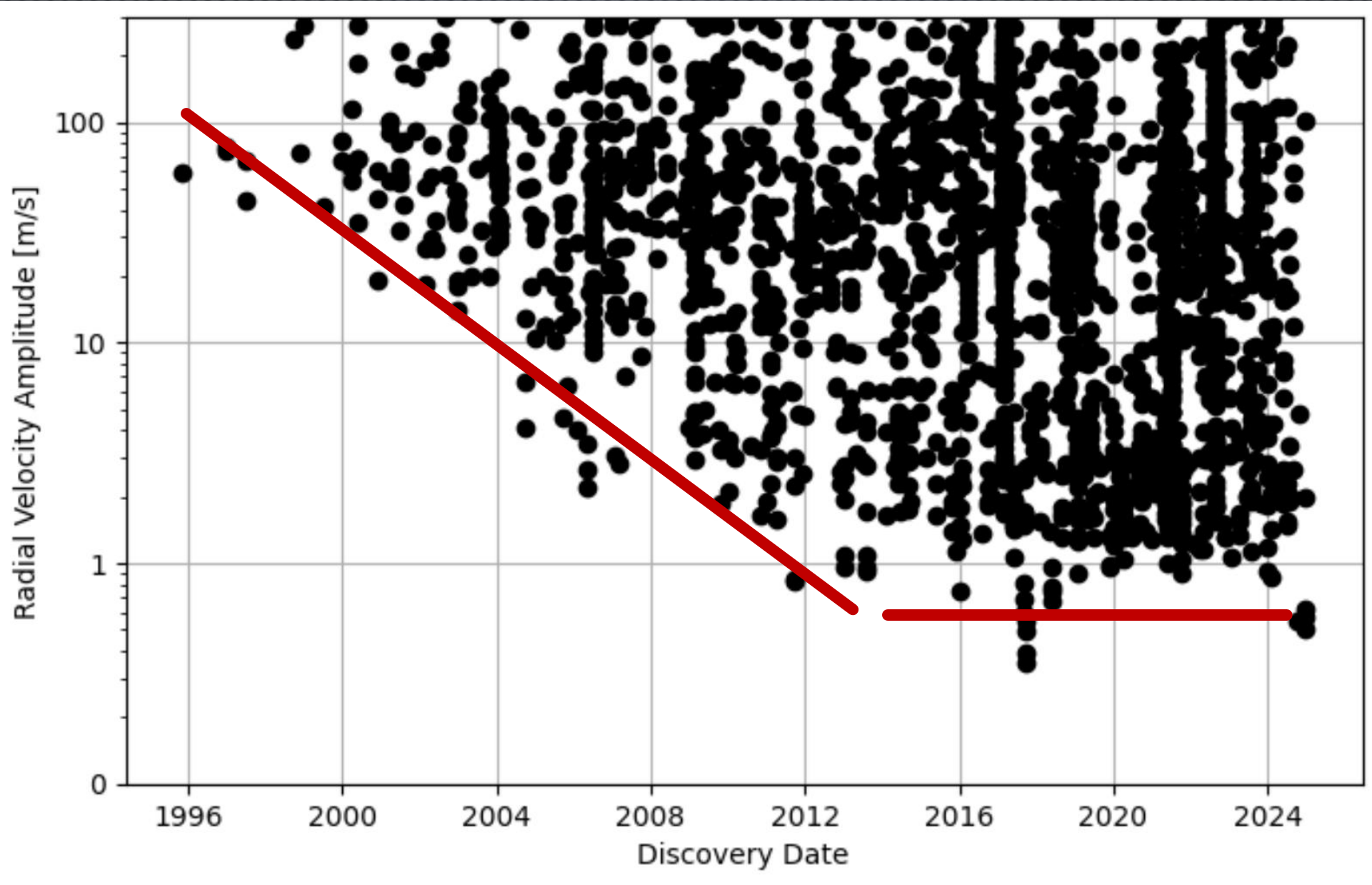
BJ FULTON

THE PROBLEM

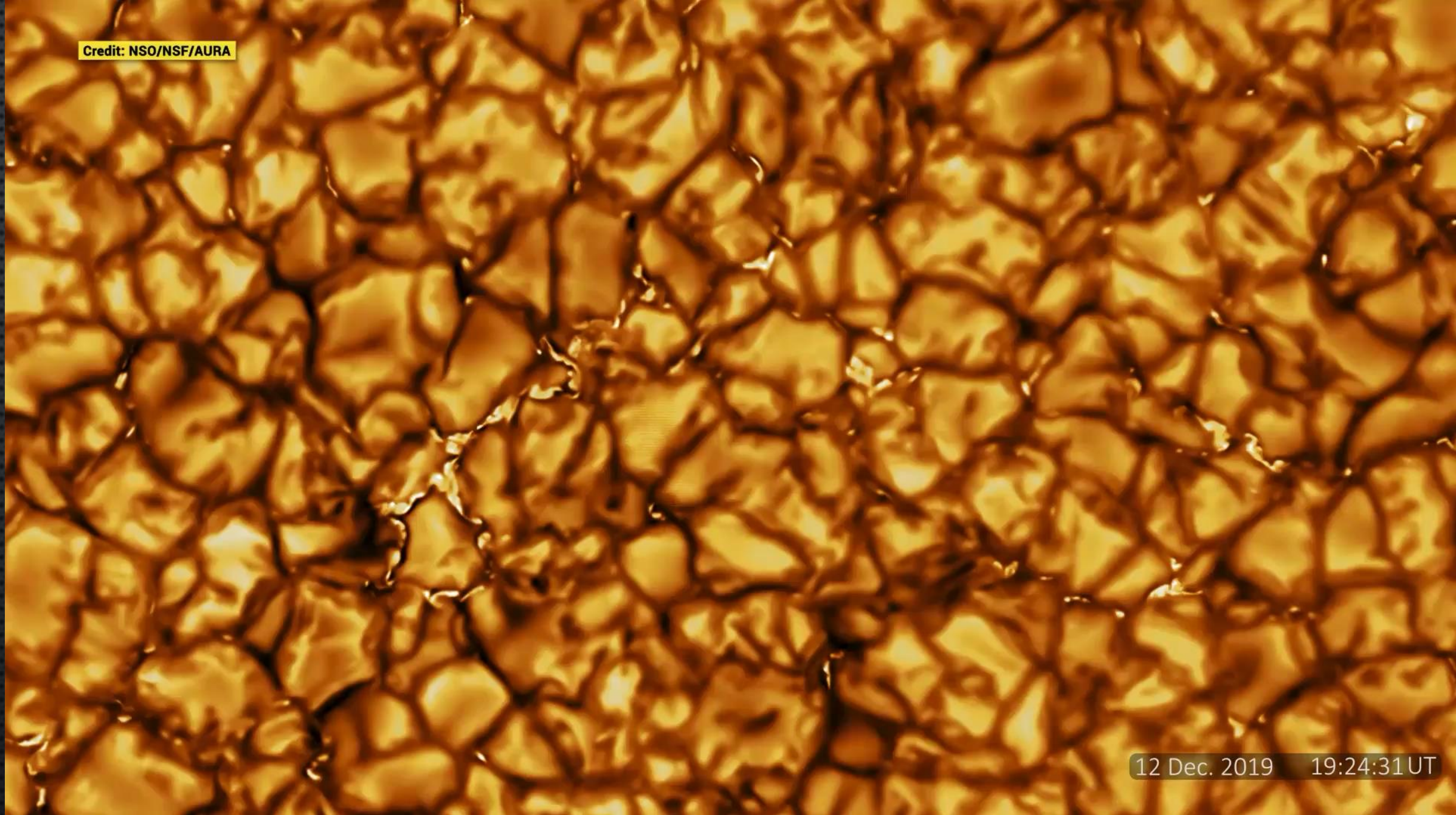
- EPRV SPECTROGRAPHS ARE NOW REACHING INCREDIBLE PRECISIONS
- CM/S ON STARS HUNDREDS OF PARSECS AWAY
- SEVERAL ATOMS IN THE SILICON LATTICE STRUCTURE IN THE CCD







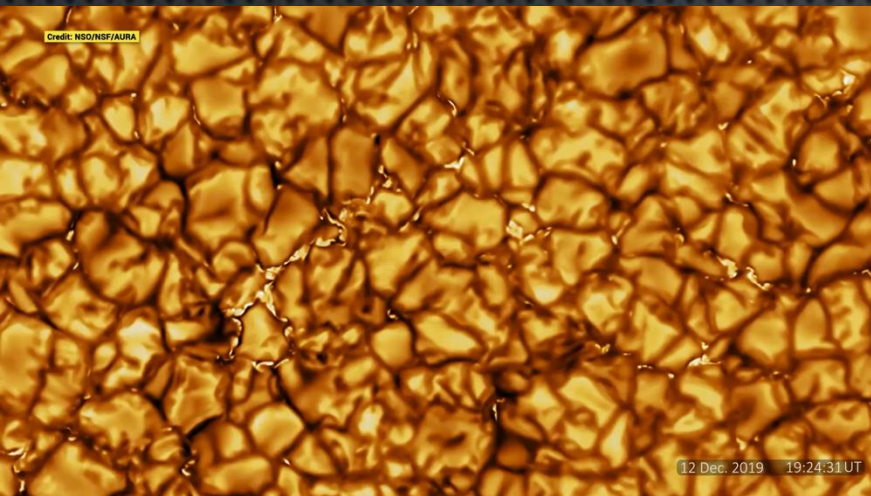
Credit: NSO/NSF/AURA



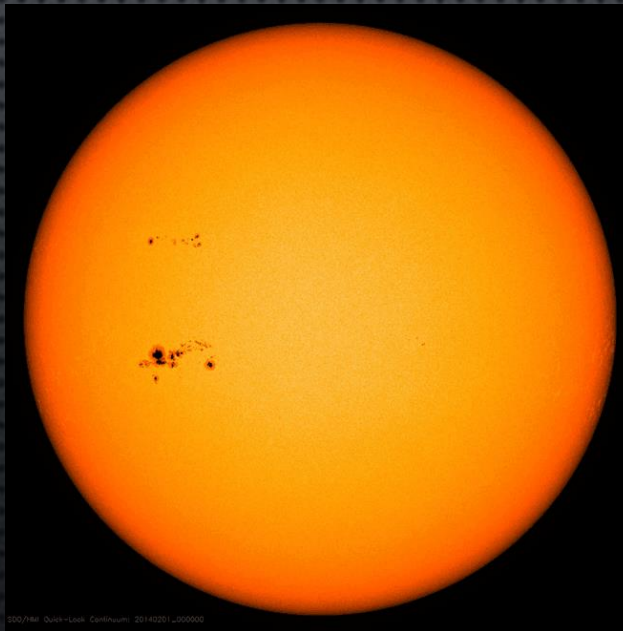
12 Dec. 2019 19:24:31 UT

THREE CLASSES OF ACTIVITY

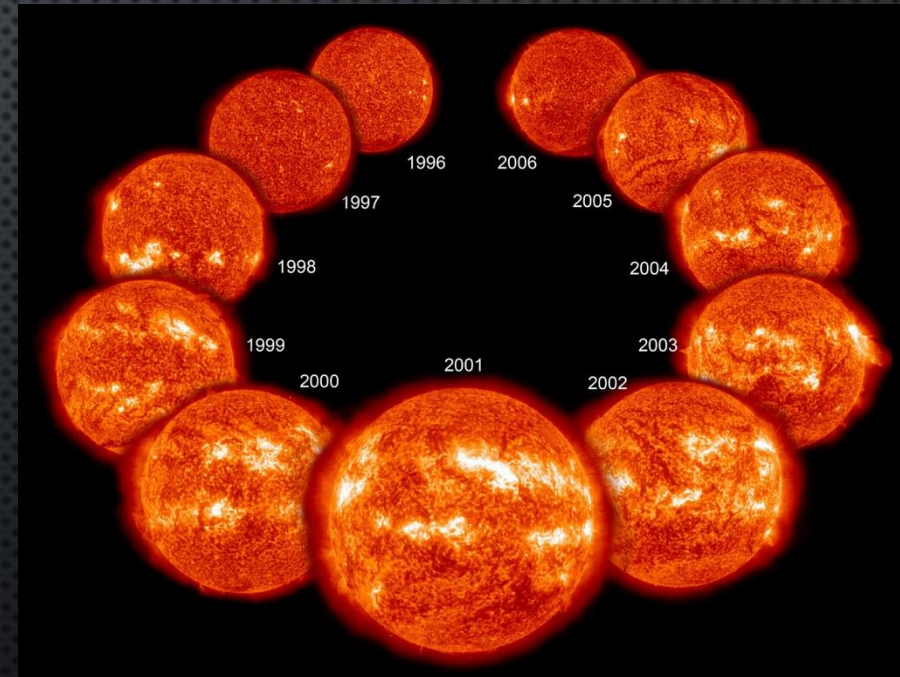
granulation



rotation

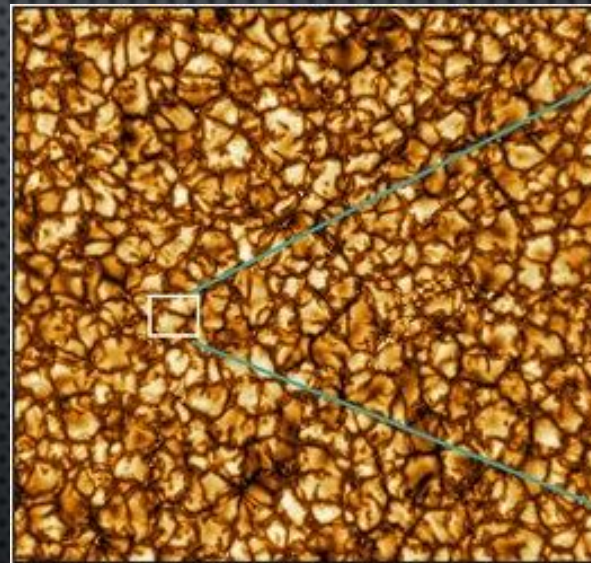


magnetic cycles

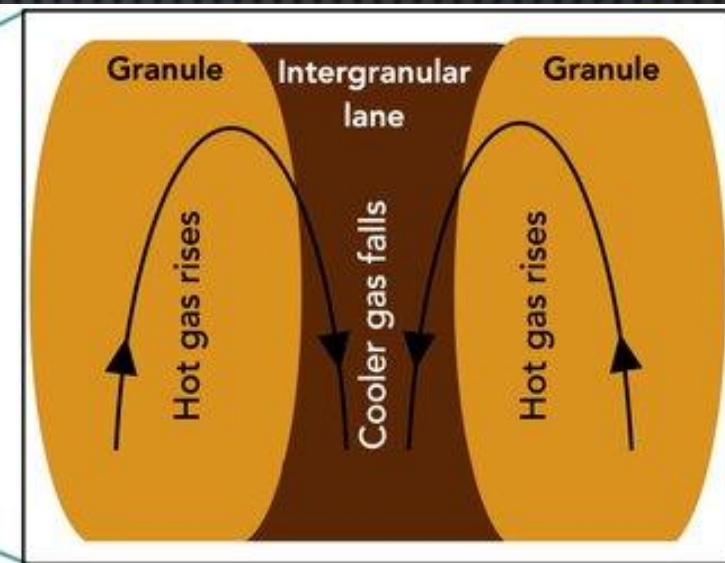


GRANULATION

- CONVECTIVE CELLS
- BRIGHT “GRANULES” ARE HOTTER MATERIAL MOVING TOWARD THE SURFACE
 - ~ 1 KM/S VERTICAL VELOCITY
- DARK INTERGRANULAR LANES ARE WHERE COOLER GAS SINKS AWAY FROM THE SURFACE
 - SMALLER AREA BUT SINK FASTER THAN GRANULES RISE
- HOURS TIMESCALE FOR SUN-LIKE STARS
- MORE UPWELLING AREA THAN DOWNWELLING LEADS TO CONVECTIVE BLUESHIFT



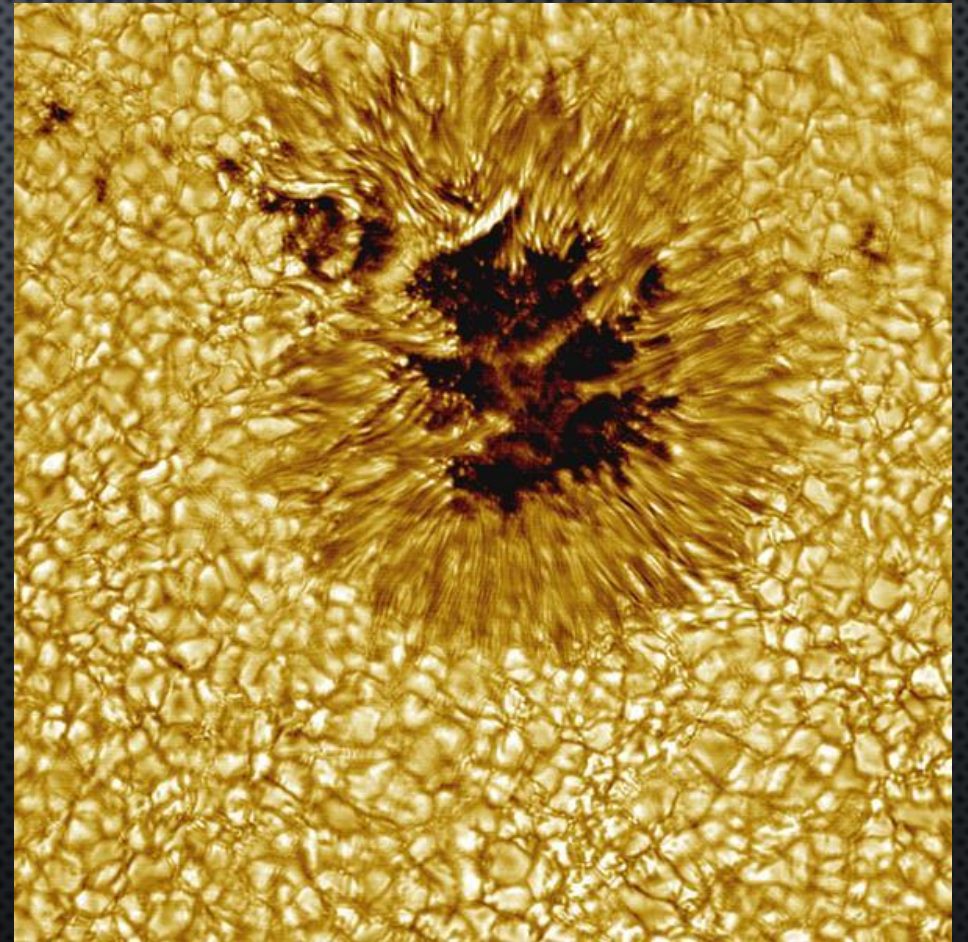
Granulation at the Sun's surface



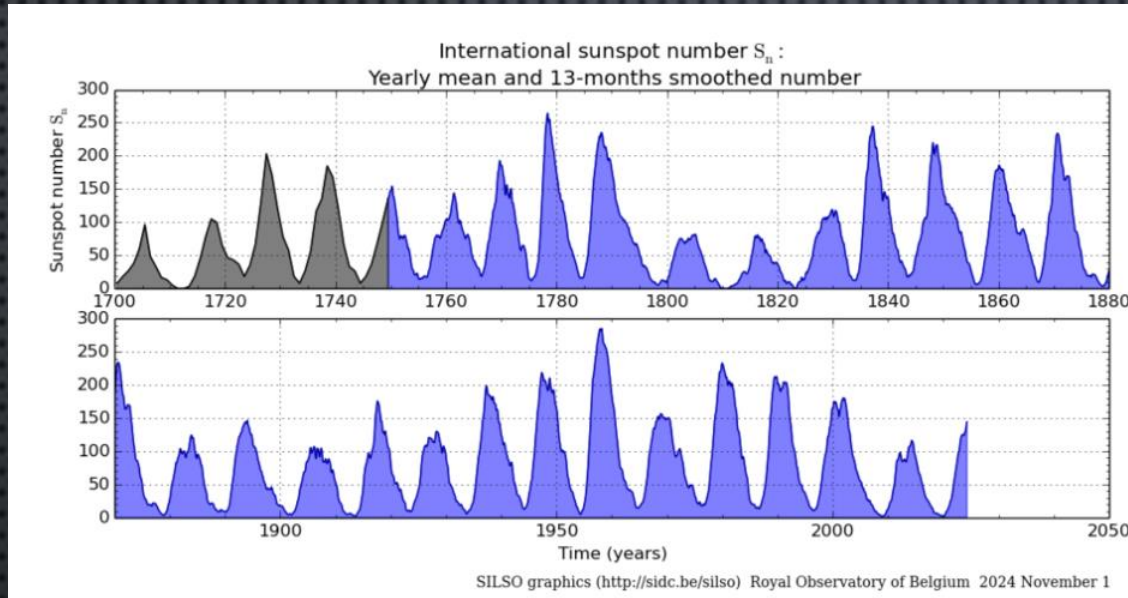
Convection cell in the star's photosphere.

ROTATION

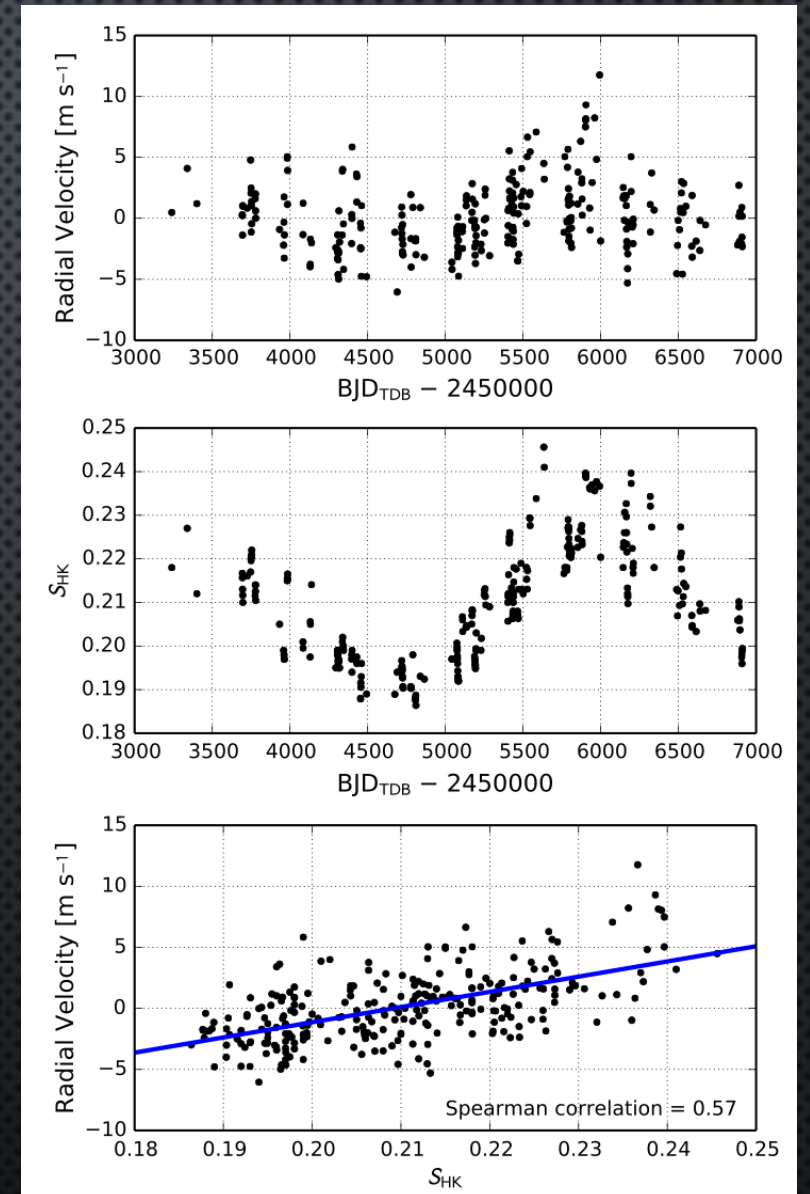
- STAR SPOTS AND FACULAE INTERFERE WITH GRANULATION
- BLOCKS A PORTION OF THE CONVECTIVE BLUESHIFT
- AS THE STAR ROTATES THE RADIAL COMPONENT OF THE OVERALL CONVECTIVE BLUESHIFT CHANGES
- HUGE VARIABILITY IN AMPLITUDE FOR DIFFERENT STELLAR TYPES
- SIGNIFICANTLY WORSE FOR YOUNG STARS



MAGNETIC ACTIVITY CYCLES

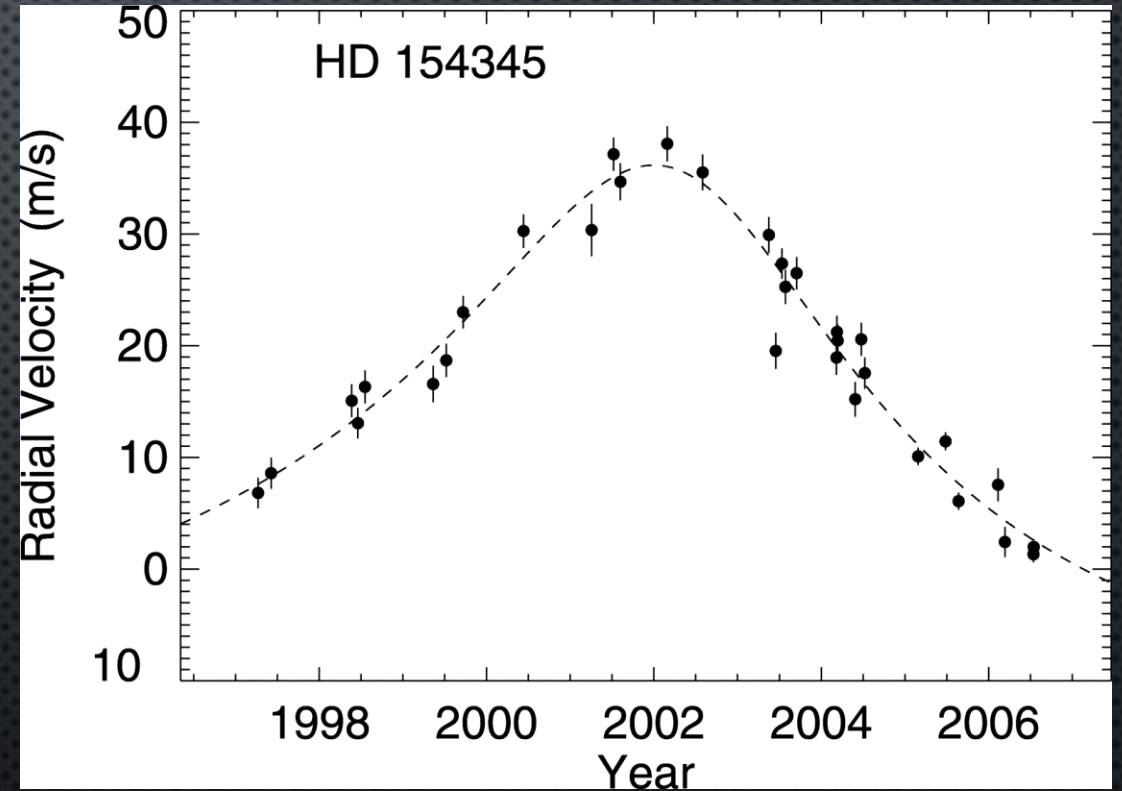


- MEAN NUMBER OF SPOTS CHANGES SIGNIFICANTLY
- MORE SPOTS = LESS CONVECTIVE BLUESHIFT
- MORE SPOTS = MORE ROTATIONAL MODULATION
- TRACKED NICELY BY CAHK



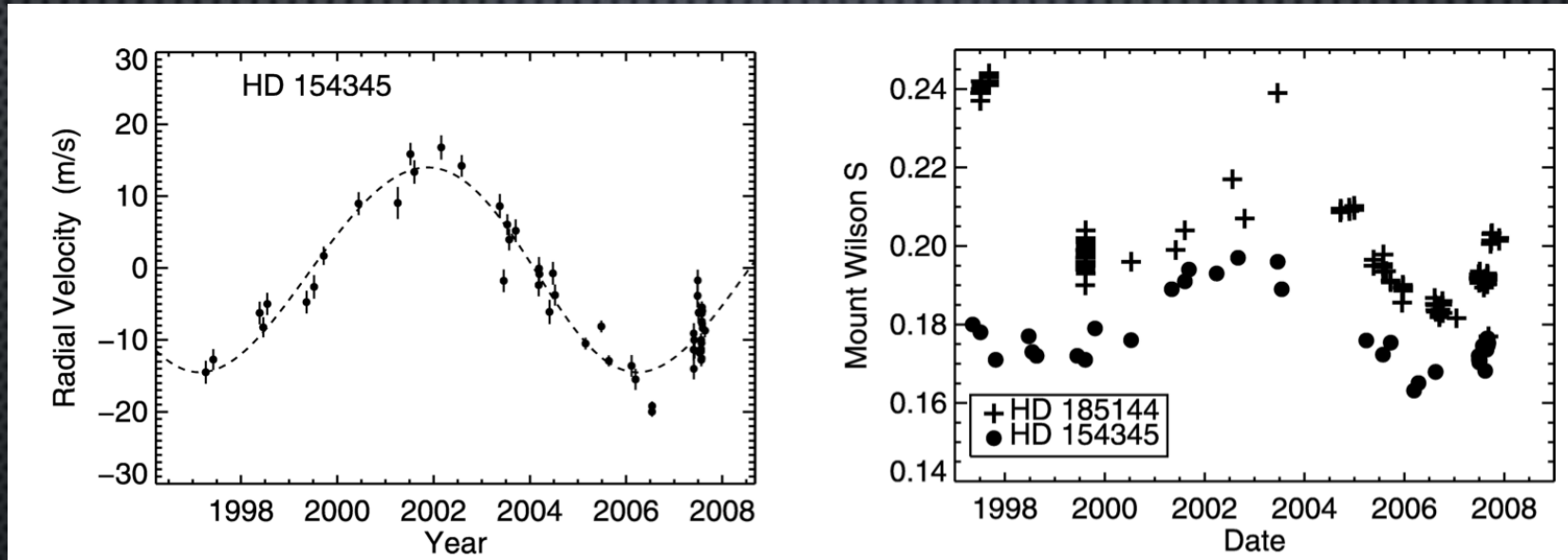
THE STORY OF HD 154345

- PUBLISHED AS A PLANET CANDIDATE IN 2007 WITH A PARTIAL ORBIT



Wright et al. (2007)

THE STORY OF HD 154345

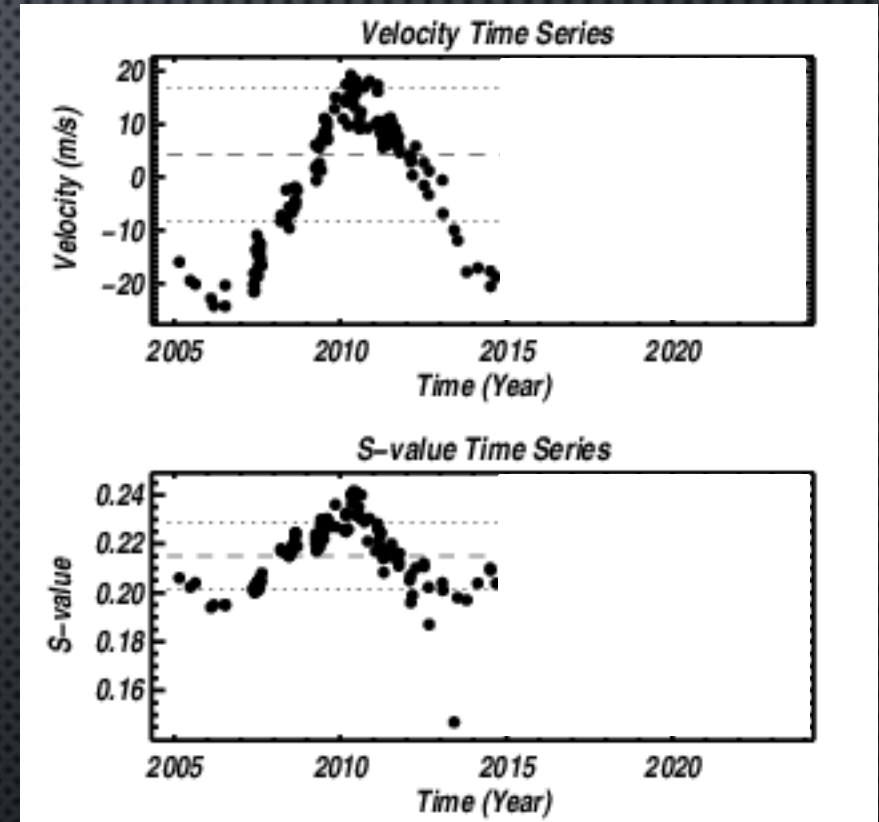


Wright et al. (2009)

- PUBLISHED AS A CONFIRMED “JUPITER-TWIN” IN 2009 WITH ONE FULL ORBIT
- S-VALUES DERIVED FROM CAHK SHOWED SAME PATTERN AS VELOCITIES BUT INTERPRETED AS SIMPLY A COINCIDENCE BECAUSE THE RV SIGNAL WAS TOO LARGE TO BE CAUSED BY ACTIVITY

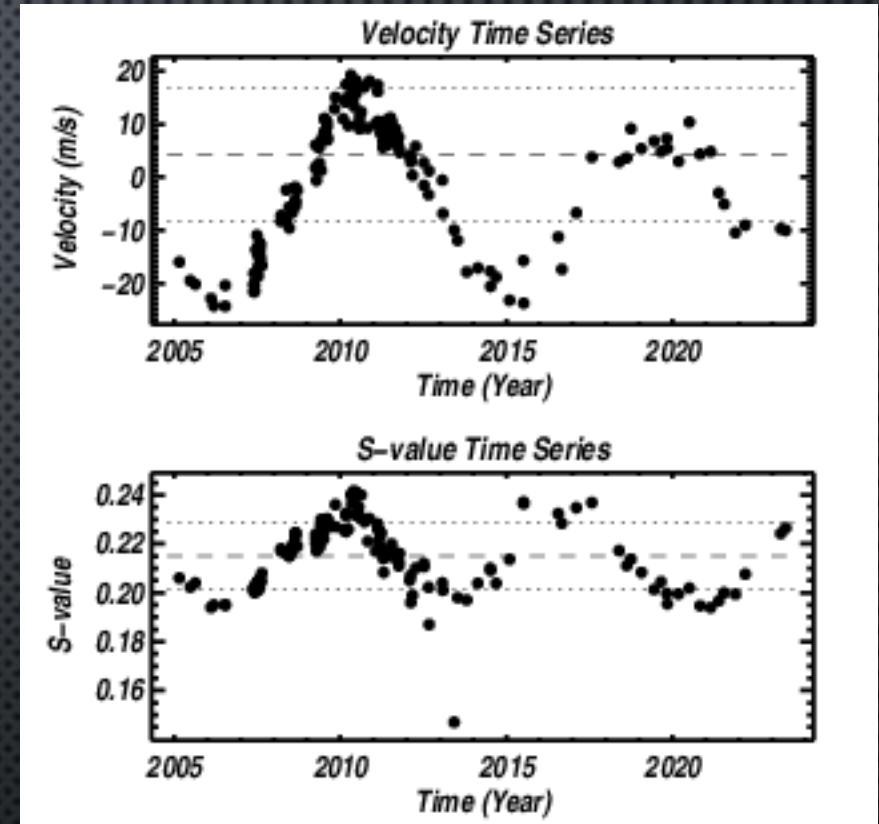
THE STORY OF HD 154345

- IN THE NEXT DECADE WE STARTED TO SEE OTHER STARS WITH SIMILAR HIGH AMPLITUDE CORRELATIONS BETWEEN S-VALUE AND RV
- “CONTINUED MONITORING OF HD 154345 SINCE 2008 HAS SHOWN THAT THE ACTIVITY CYCLE CONTINUES TO BE WELL CORRELATED WITH THE RVs, AMPLIFYING THE COINCIDENCE. SIMILAR CORRELATIONS AMONG A SMALL NUMBER OF OTHER STARS OF SIMILAR SPECTRAL TYPE HAVE BEGUN TO CAST DOUBT ON THE PLANETARY HYPOTHESIS FOR HD 154345”



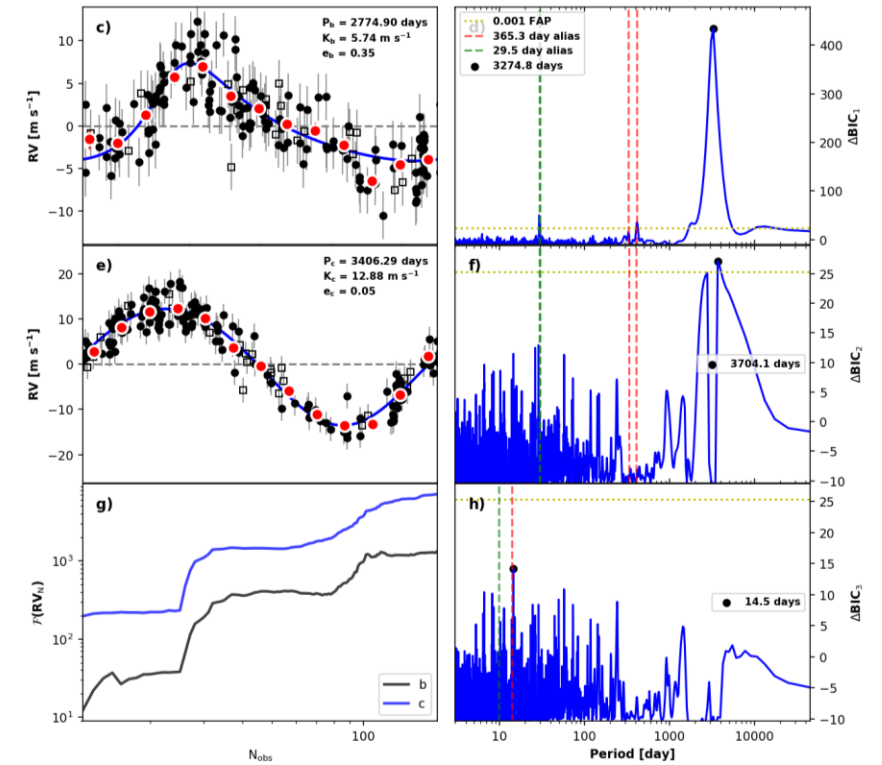
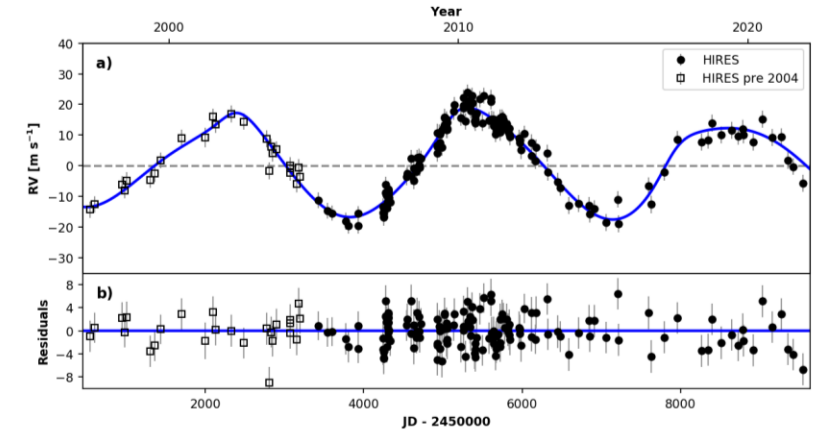
THE STORY OF HD 154345

- AFTER 2015 WE STARTED TO NOTICE THAT THE S-VALUES WERE COMPLETELY OUT OF PHASE WITH THE RV SIGNAL



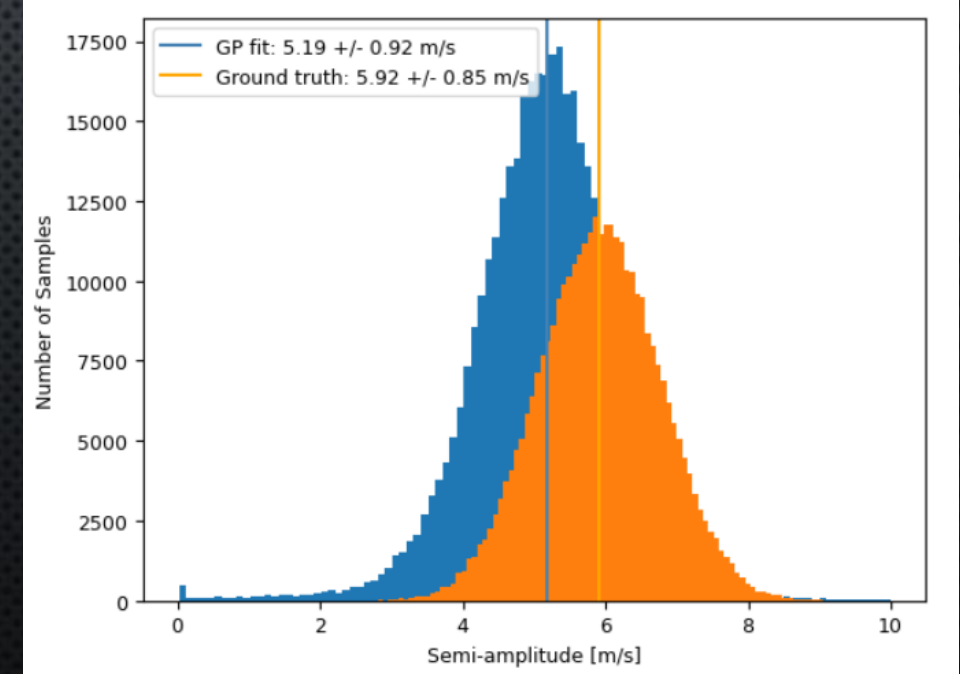
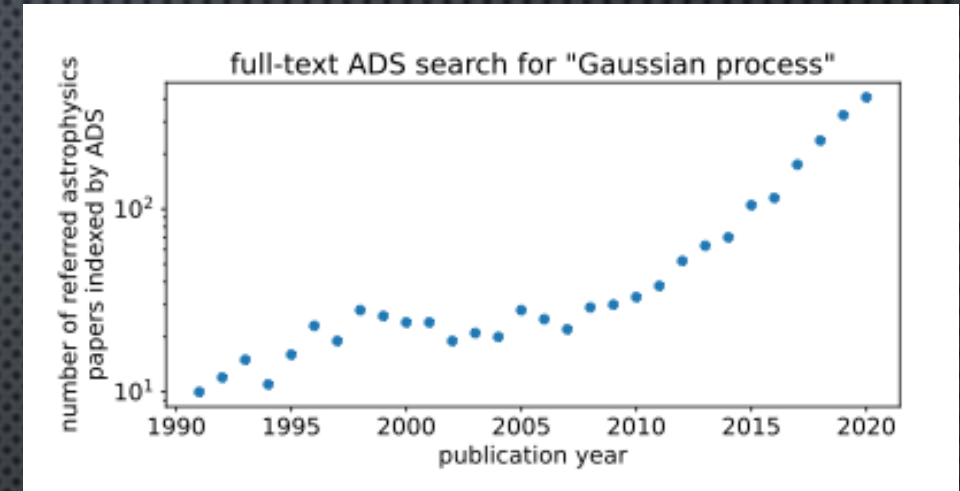
THE STORY OF HD 154345

- BY 2021 WE WERE ABLE TO SEPARATE THE TWO SIGNALS USING THE RVs ALONE
- QUASI-PERIODIC ACTIVITY SIGNAL WITH A PERIOD OF 7.6 YEARS
- PLANET ON CIRCULAR ORBIT WITH PERIOD OF 9.3 YEARS

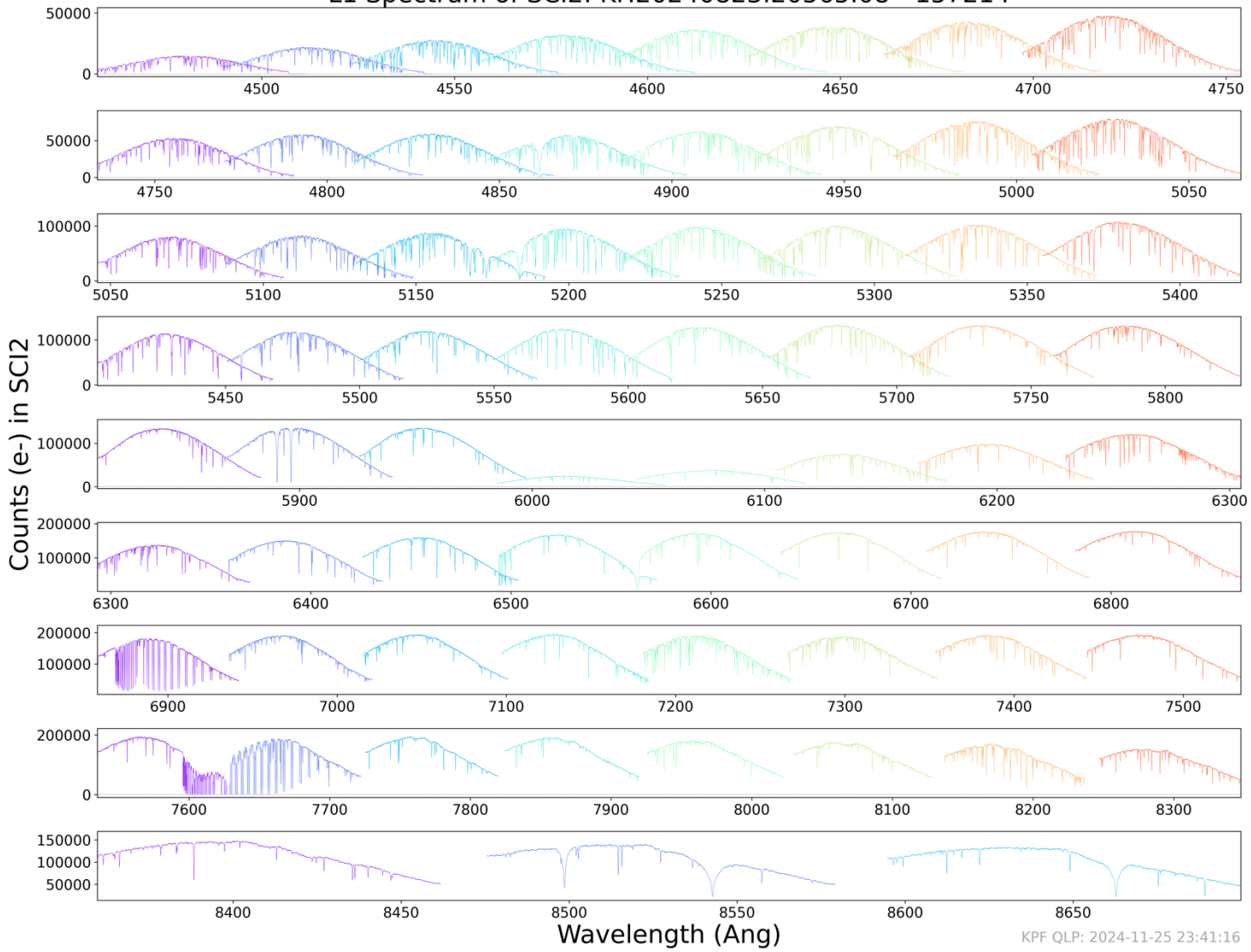


COMPENSATING FOR STELLAR ACTIVITY

- GAUSSIAN PROCESS REGRESSION
- QUICKLY GAINED POPULARITY IN THE LATE 2010'S AS A WAY TO SIMULTANEOUSLY FIT FOR STELLAR ACTIVITY IN THE TIMESERIES DATASETS THEMSELVES
- ESPECIALLY USEFUL IN CASES WHERE WE KNOW BOTH THE PLANET'S PERIOD AND THE ROTATION PERIOD OF THE STAR
- CAN CONSTRAIN THE GP HYPERPARAMETERS FROM MANY DIFFERENT DATASETS AT ONCE (E.G. CAHK, PHOTOMETRY, CCF CHARACTERISTICS, ETC.)
- QUASI-PERIODIC KERNEL MOST COMMON
- PROBLEMS FOR RVs:
 - DIFFICULT TO DISENTANGLE QUASI-PERIODIC AND PERIODIC SIGNALS FROM RV DATA ALONE, ESPECIALLY FOR LOW-AMPLITUDE SIGNALS
 - THE GP CAN INTERFERE WITH THE KEPLERIAN FIT AND BIAS THE AMPLITUDE



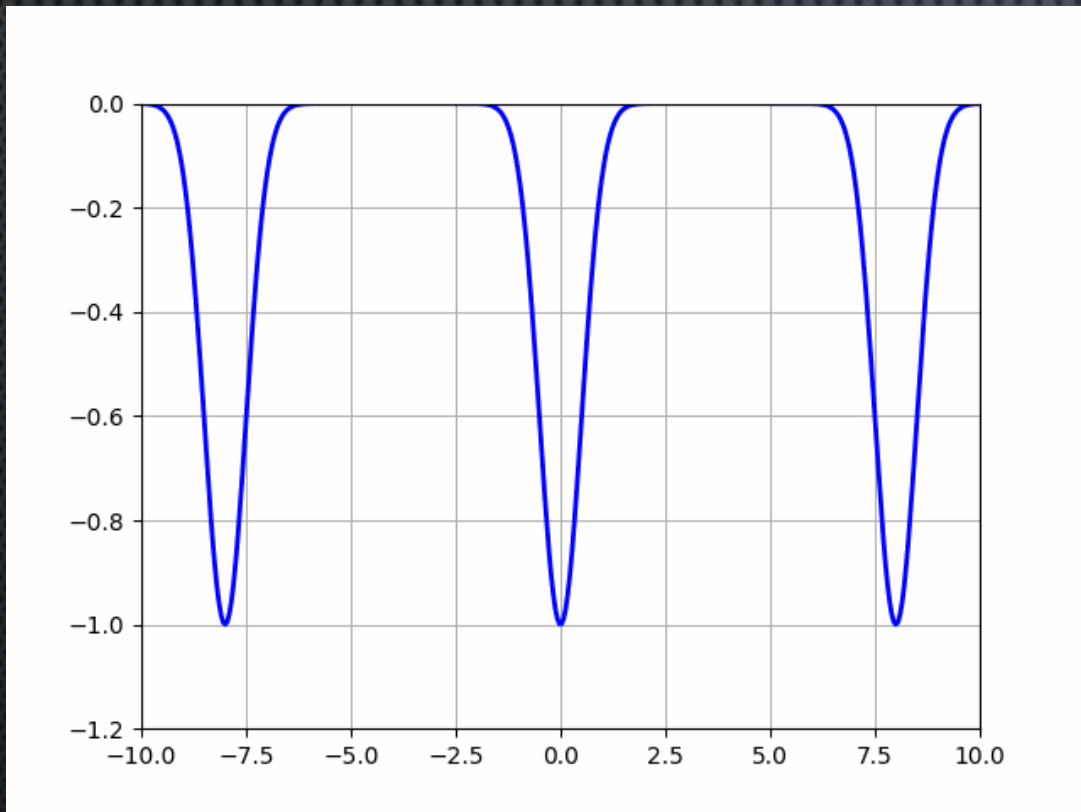
L1 Spectrum of SCI2: KP.20240823.20565.08 - 157214



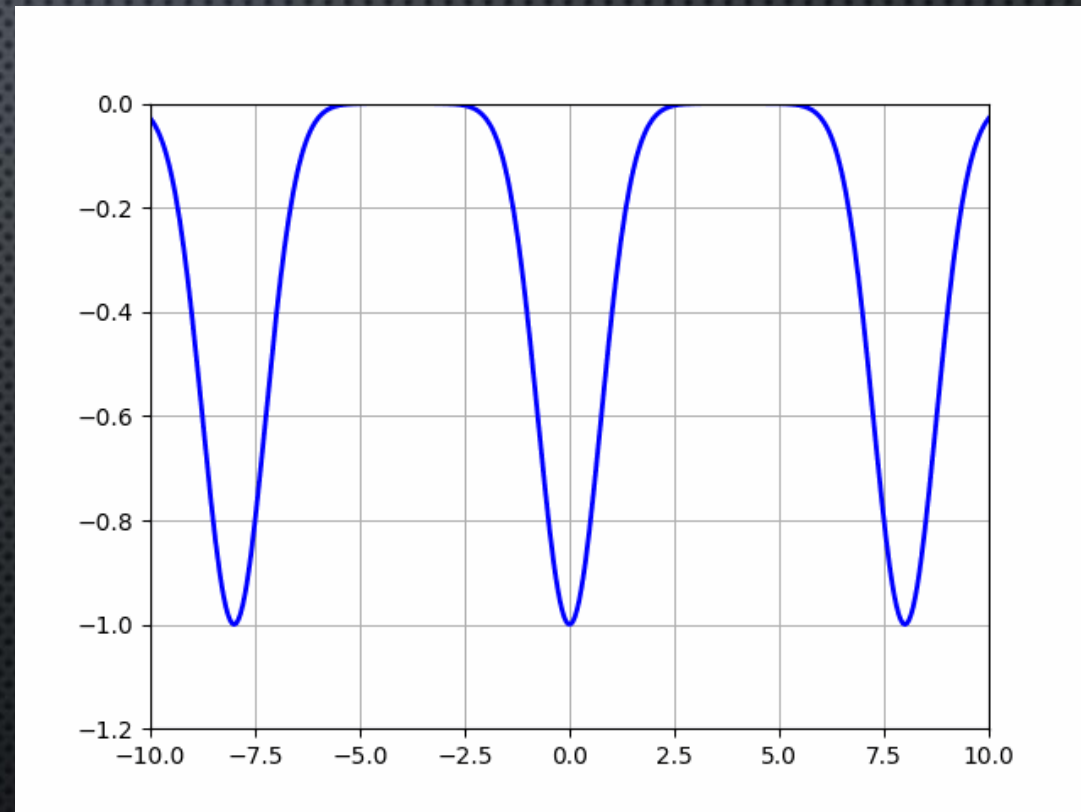
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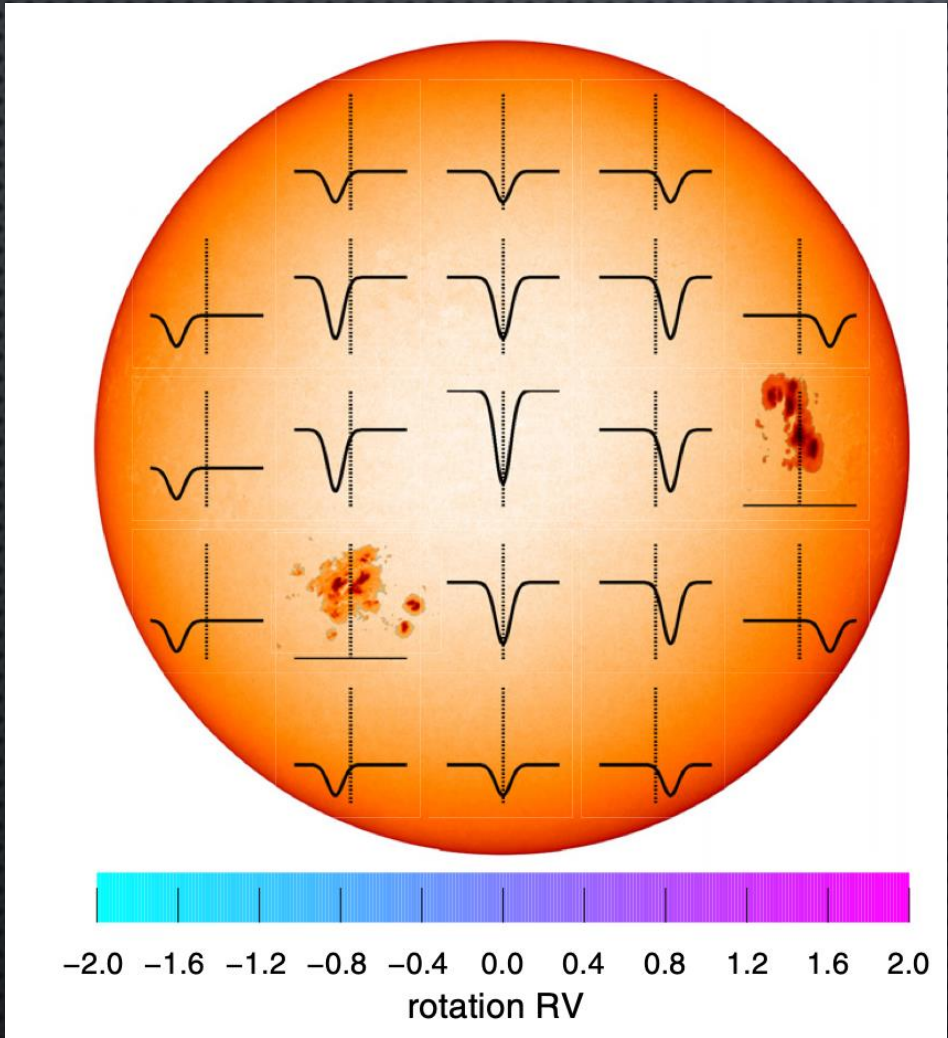


DOPPLER SHIFT

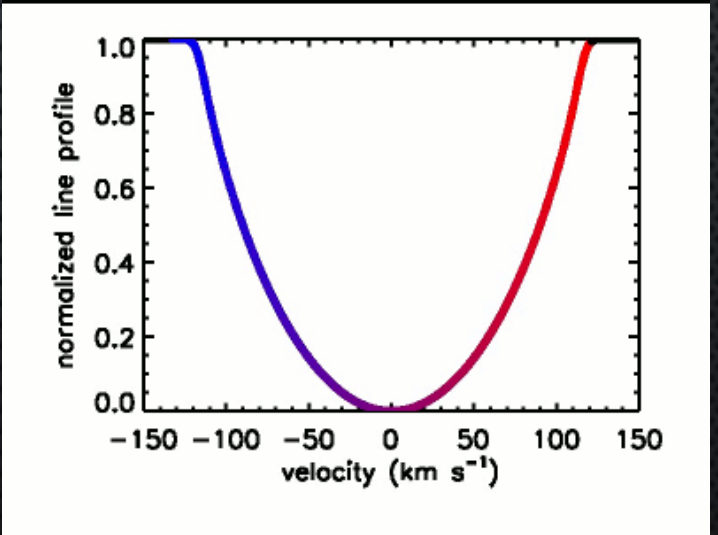
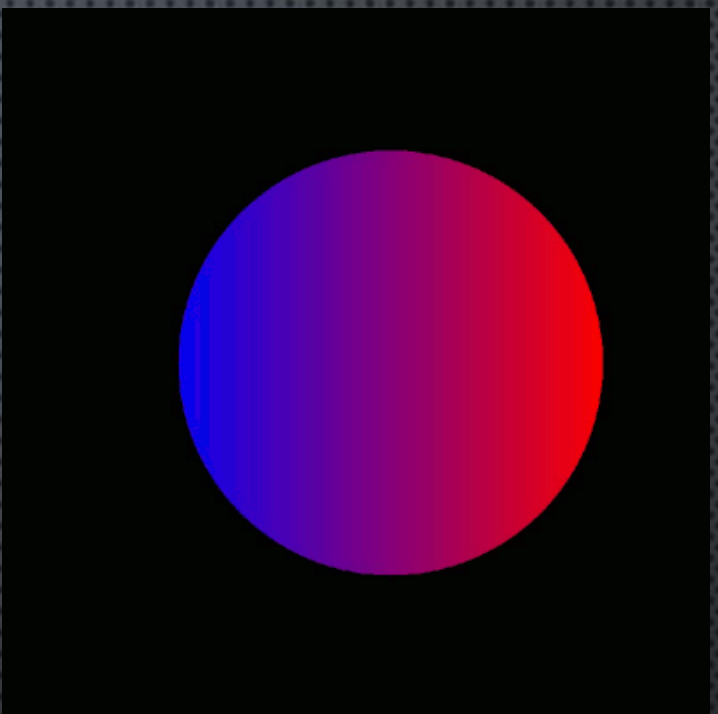


LINE DISTORTIONS

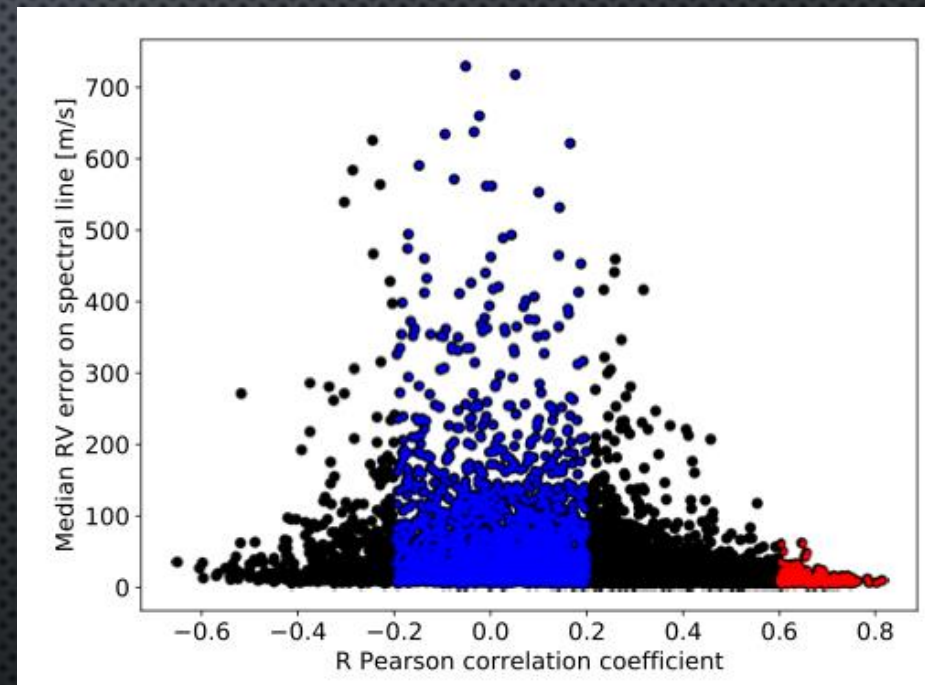
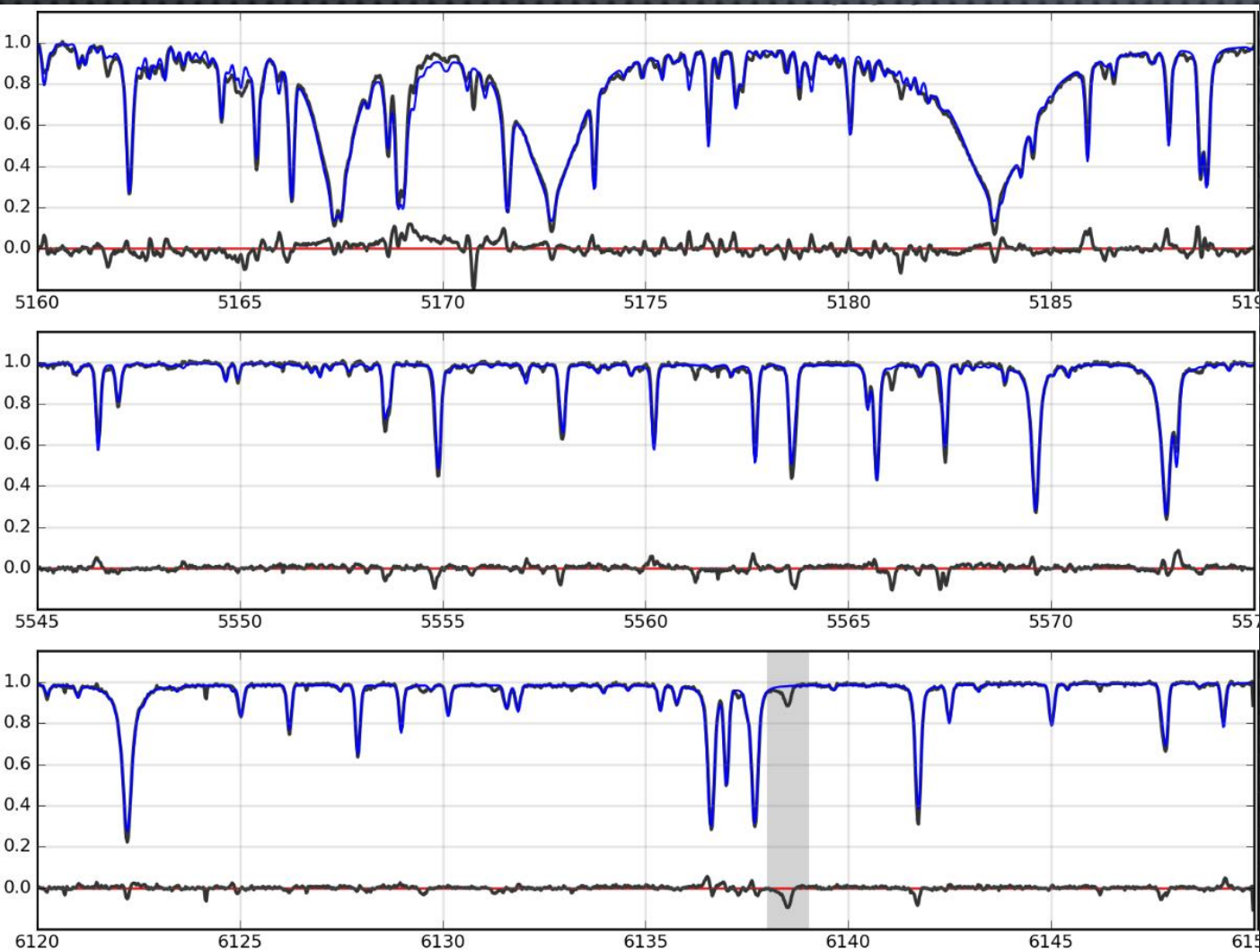




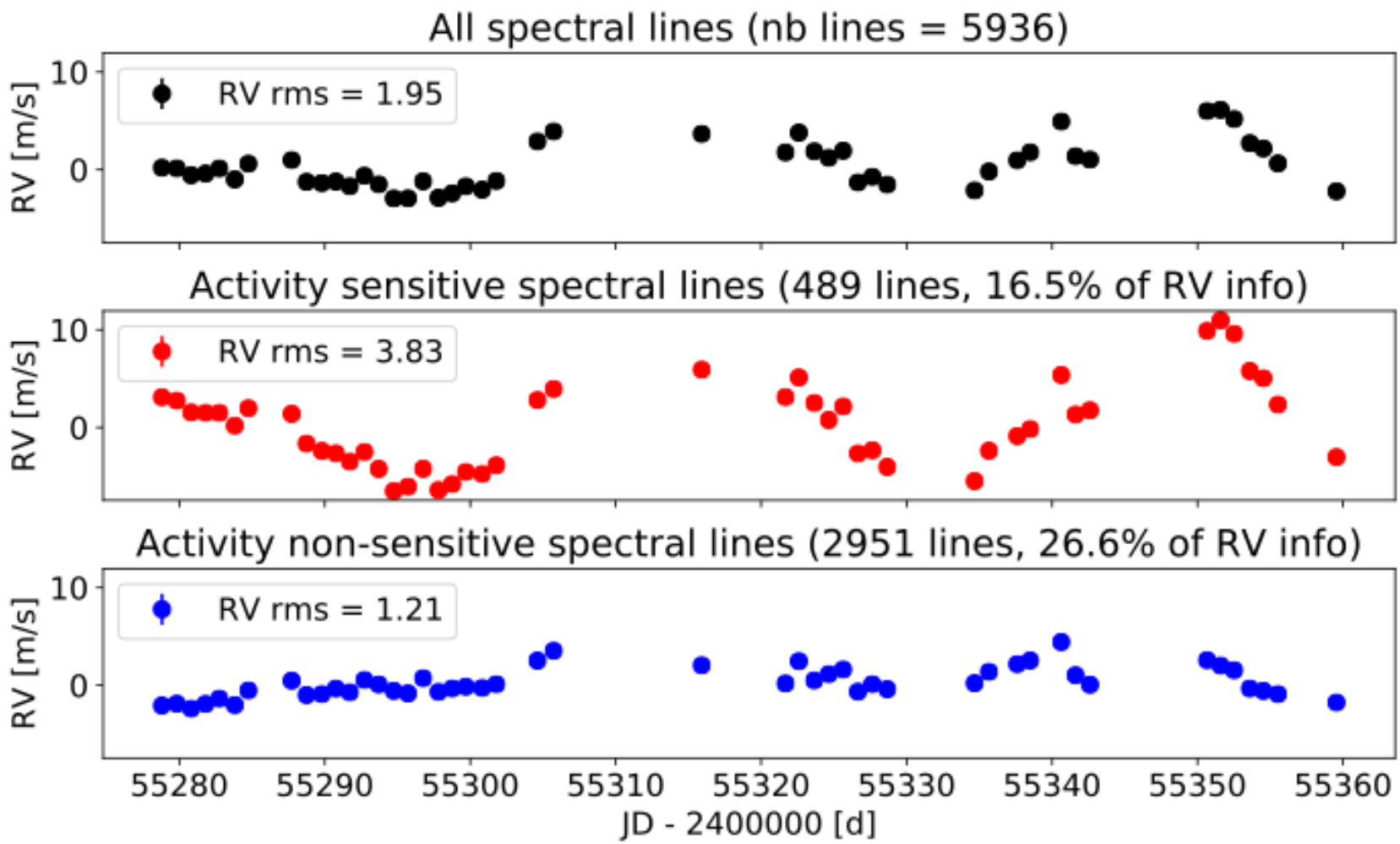
Dumusque et al. (2014)

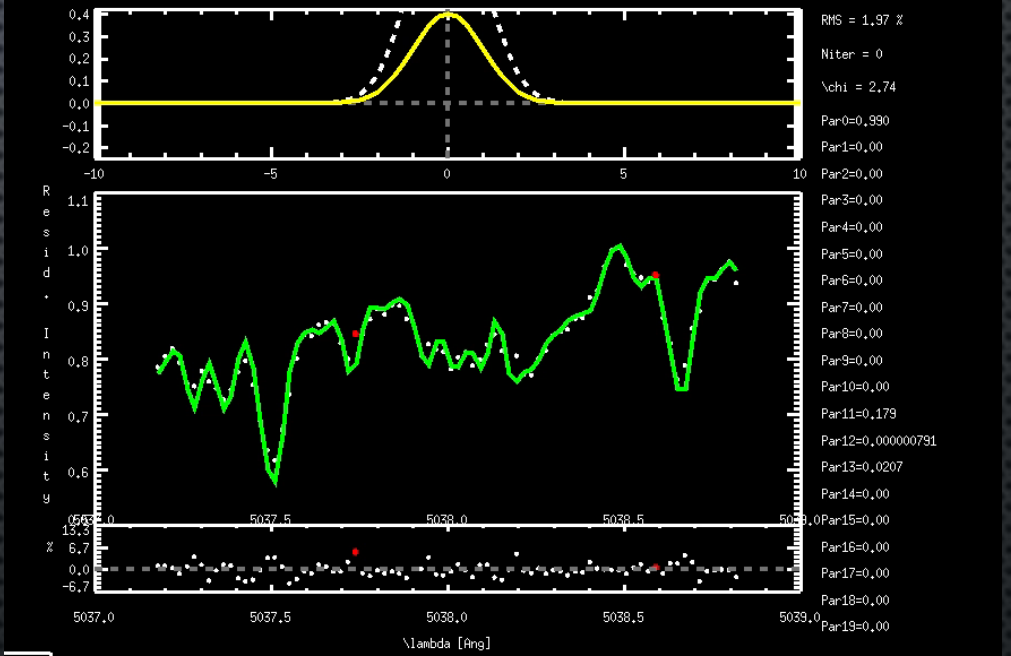
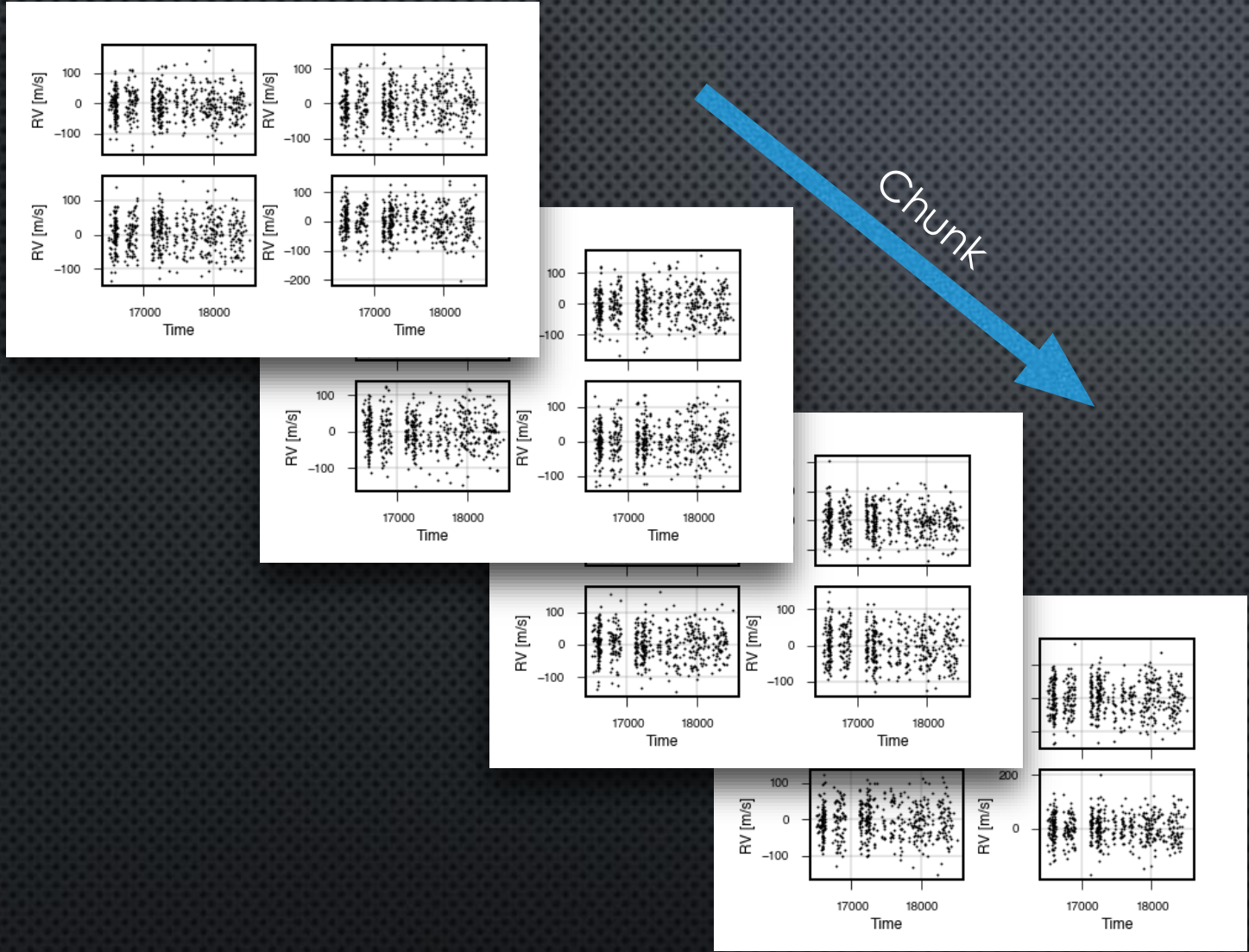


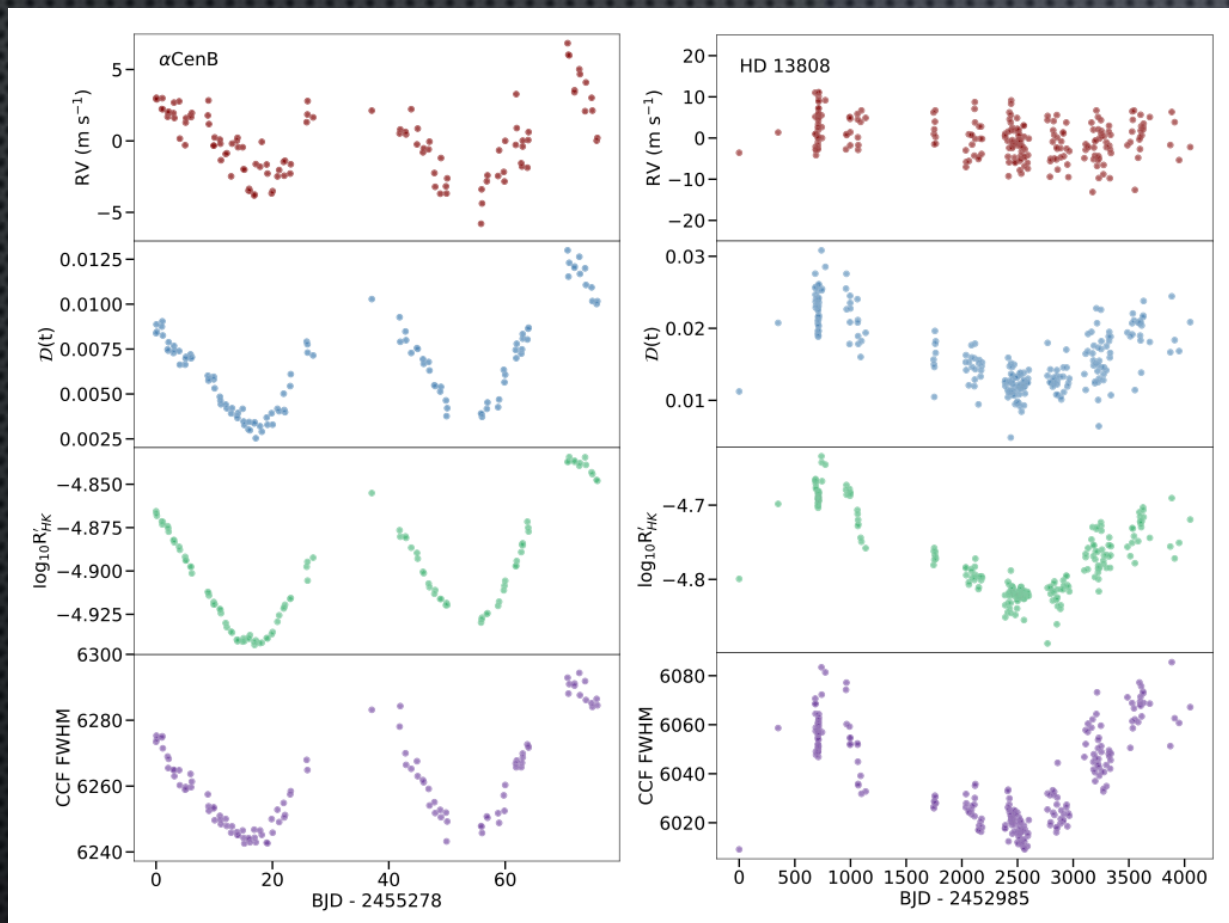
Marshall Johnson



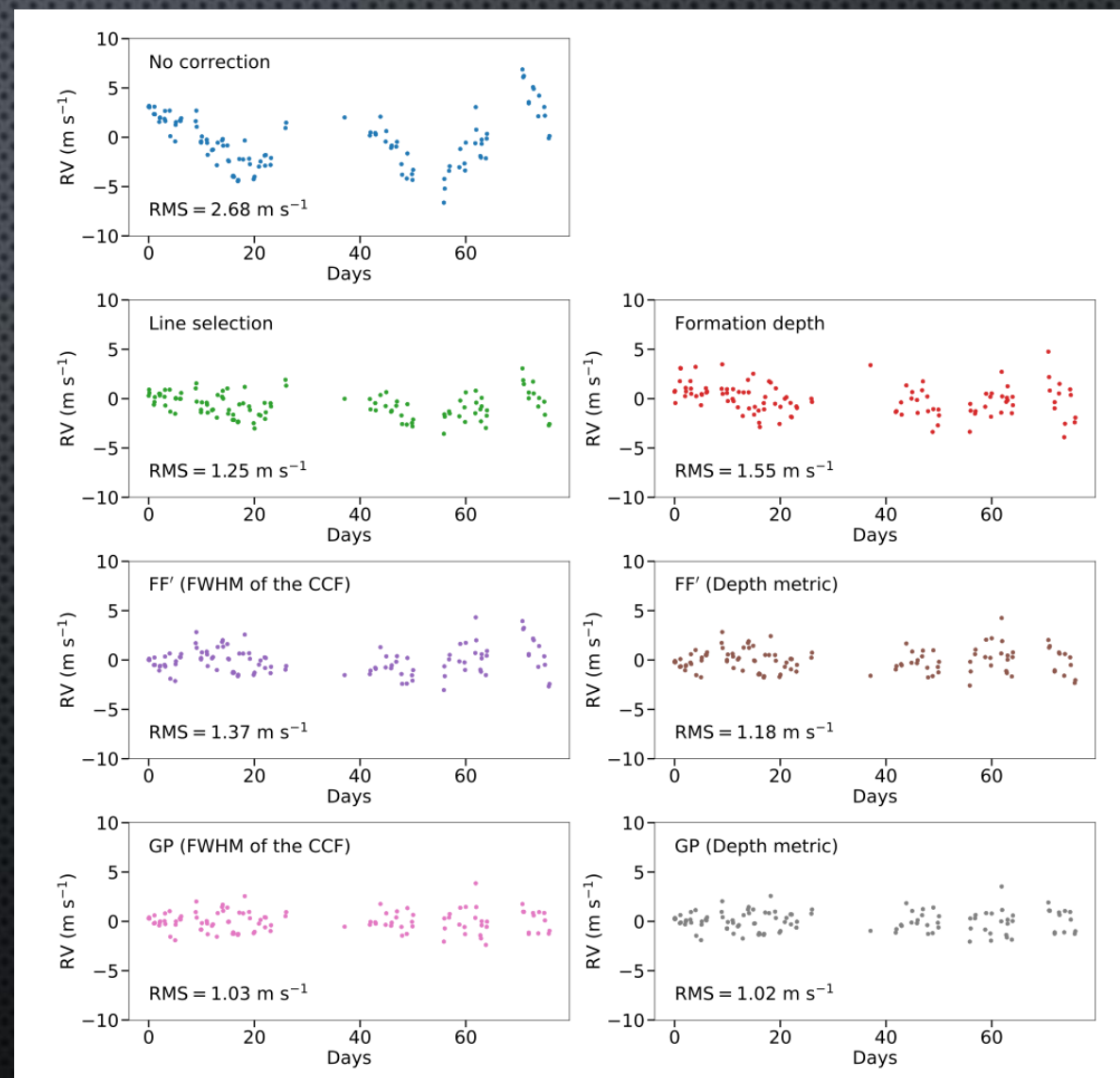
Dumusque et al. (2018)





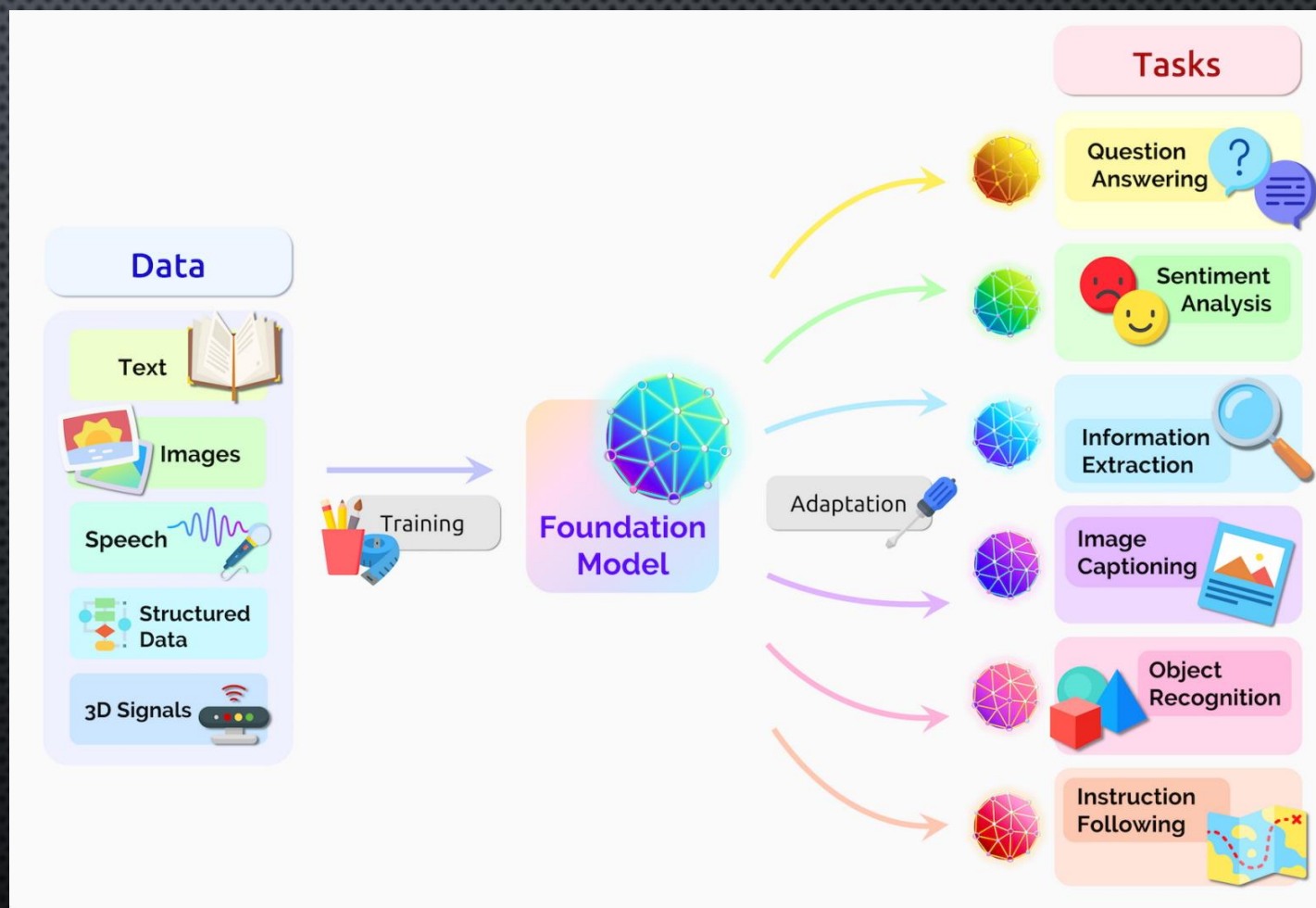


Siegel et al. (2024)



ARE TRANSFORMERS IN OUR FUTURE?

- TRANSFORMERS HAVE REVOLUTIONIZED THE CAPABILITIES OF AI/ML
- PREVIOUS GENERATIONS OF NEURAL NETWORKS RELIED ON MASSIVE PRE-LABELED DATASETS
- TRANSFORMERS CAN DISCOVER RELATIONSHIPS WITHIN THE DATA ON THEIR OWN
- ASTRONOMY DATASETS AND BUDGETS ARE GENERALLY TOO SMALL TO TRAIN FOUNDATIONAL MODELS
- FINE-TUNING EXISTING MODELS MAY SUFFICE



SUMMARY

- WE'RE GOOD AT BUILDING SPECTROGRAPHS
- STELLAR PHOTOSPHERES ARE MOVING TARGETS
- STARS ARE ALWAYS TRYING TO TRICK US
- RV DATASETS ARE NOW LARGE ENOUGH TO EXPLORE NEW COMPUTING TECHNIQUES