
The future of precise radial velocities in exoplanet discovery and characterization

Dr. Jennifer Burt
Exoplanet Exploration Program Office
Jet Propulsion Laboratory, California Institute of Technology

CL#26-2020

Roles of Radial Velocities

Pure RV Discovery

- Long term surveys of bright, nearby stars, pushing to lower masses and wider orbits (almost) regardless of inclination and period
- Improved understanding / modeling of stellar variability as it manifests in spectral lines
- Vetting provisional HWO targets / building base lines to determine masses of future detections

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Synergies with Transiting Planets

- Confirmation of planetary nature
- Measurements of mass, ecc, obliquity
 - Determination of bulk density and atmospheric scale height
- Insights into stellar variability for transmission spectroscopy (TLS)
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Synergies with Other Fields

- HRCC atmospheric abundances, orbital obliquities,
- Solar/Stellar astrophysics : characterization of active regions & magnetic cycles, asteroseismology,
- Fundamental constants : Determining α , H_0

EPRV x Solar Physics Workshop – Day 1

Time Pacific US / UTC	Talk Title	Speaker
8:00a / 3:00p	Welcome & Workshop Goals	Jennifer Burt (JPL) & Heather Cogle (University of Warwick)
8:45a / 3:45p	The headache of solar/stellar variability for planet hunters	Annelies Morlier (University of Birmingham)
9:30a / 3:30p	Overview: Solar Data for EPRV Studies	BE Chaplin (University of Birmingham)
9:00a / 4:00p	Looking at the Sun through ESPRESSO - the PaT solar telescope	André M. Silva (University of Porto)
9:15a / 4:15p	Polarimetric Sun-as-a-star observations with ARIEL in the search for Earth-sized exoplanets around Solar-type stars	Kiran Chouh (University of Birmingham)
9:30a / 4:30p	Estimation and statistics of Solar Flare mass based on CHASE Sun-as-a-star spectroscopic data	Tiangyi Xie (Nanjing University)
9:45a / 4:45p	DKIST Overview	Serena Crivell (National Solar Observatory)
10:05a / 5:05p	Radial velocities from a spatially resolved sunspot library	Amy Goodrich (University of Göttingen)
10:20a / 5:20p	Group Discussion / Additional Q&A	All

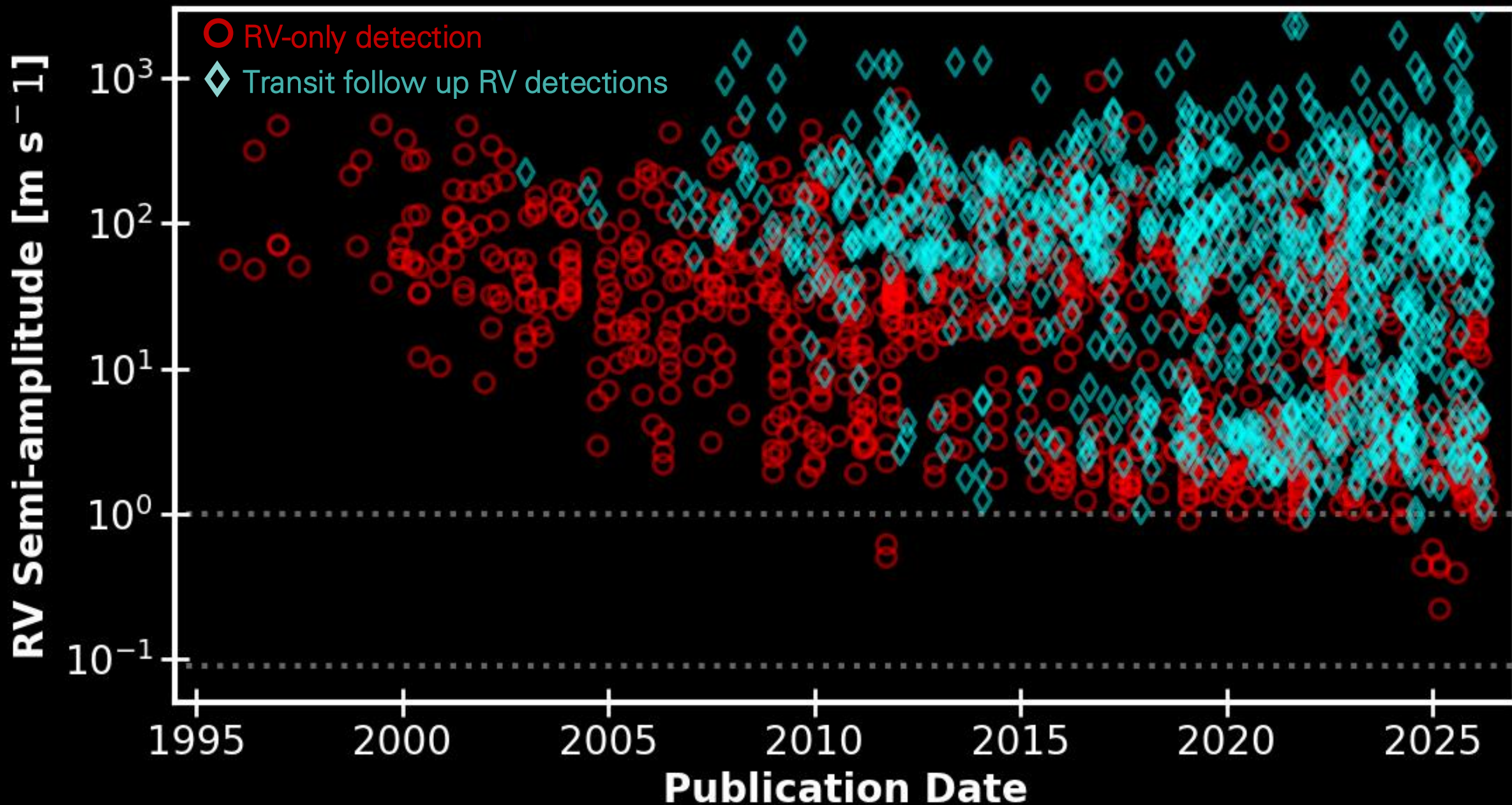
EPRV x Solar Physics Workshop – Day 2

Time Pacific US / UTC	Talk Title	Speaker
8:00a / 3:00p	Welcome Back	Jennifer Burt (JPL) & Heather Cogle (University of Warwick)
8:05a / 3:05p	Next generation Ground based solar Observing Network (ngGONG)	Alexander Payne (National Solar Observatory)
8:25a / 3:25p	HARPS and HARPS-N: Sun-as-a-star data release, a HARPS-N quiet Sun Benchmark, and future solar minimum opportunities	Matteo Di Mauro (University of Sheffield)
8:45a / 3:45p	Sun-as-a-star Studies: Magnetic Variability and Spectral Signatures Using a Decade of HARPS-N Dispersed Spectra	Parvathi Menon (Indian Institute of Astrophysics)
9:00a / 4:00p	Decoding the Radial Velocity Signatures of Solar Flares with 3D MHD Simulations	Florian Bell (University of Graz)
9:15a / 4:15p	Solar Dynamics Observatory Overview	Dean Pascoe (Normal Research)
9:35a / 4:35p	Center-to-Ring variations of solar active regions, observations of spots, faculae, and network in the 6173 Å continuum	Alex Payne (Leeds Institute for Astrophysics)
9:50a / 4:50p	EVE Sun as a star rMie continuum	Hugh Hudson (University of Glasgow)
10:05a / 5:05p	Reversed C Solar Line Bisectors, and Implications for EPRV	Diana Deming (University of Maryland)
10:20a / 5:20p	Group Discussion / Follow On Plans	All

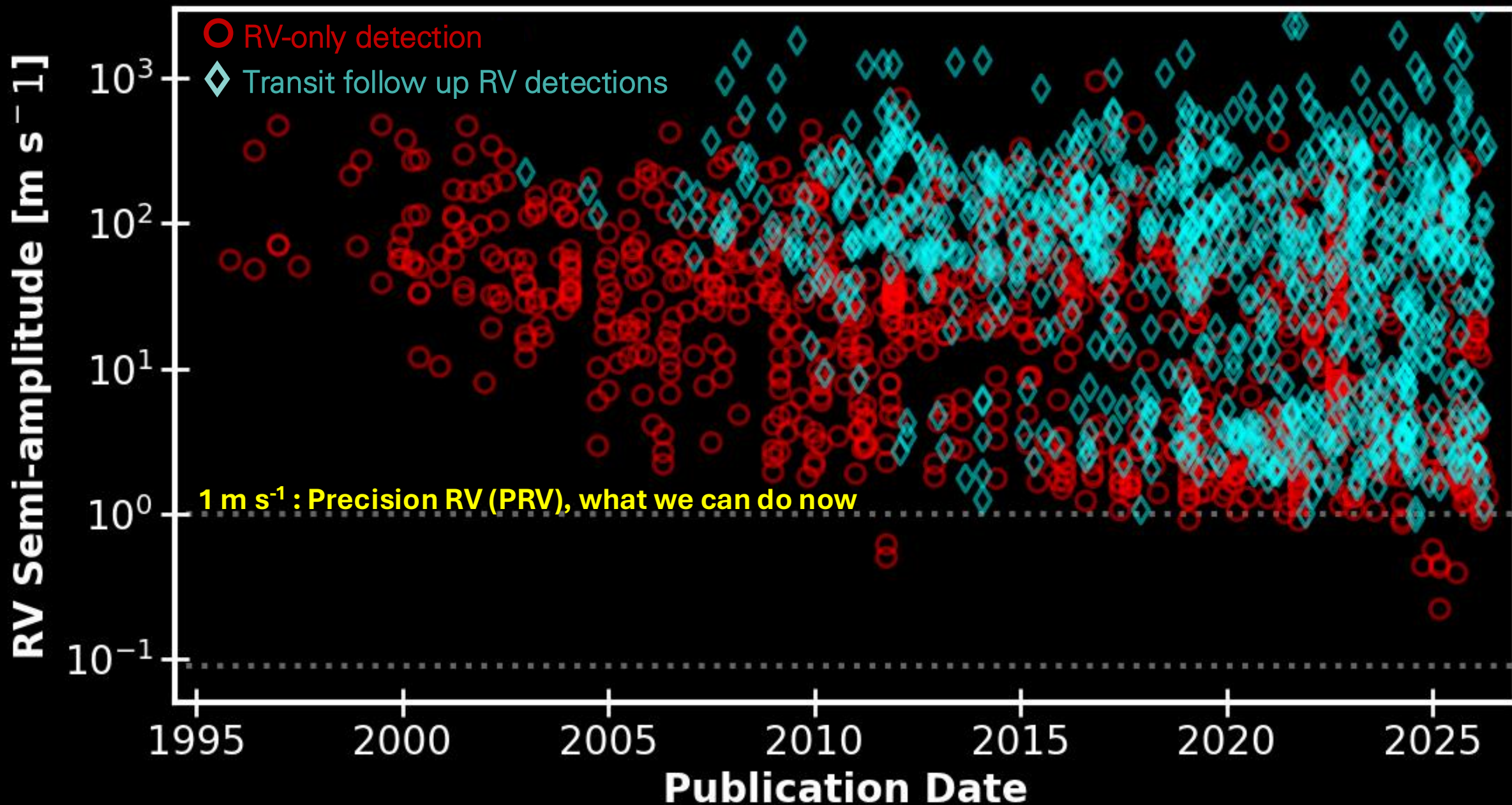
Thursday, June 11th, 2026
 8:00 – 10:30a US Pacific
 3:00 – 5:30p UTC
 Zoom Link:
bit.ly/EPRV_SolarPhysics

Presented by the
 EPRV Research Coordination Network

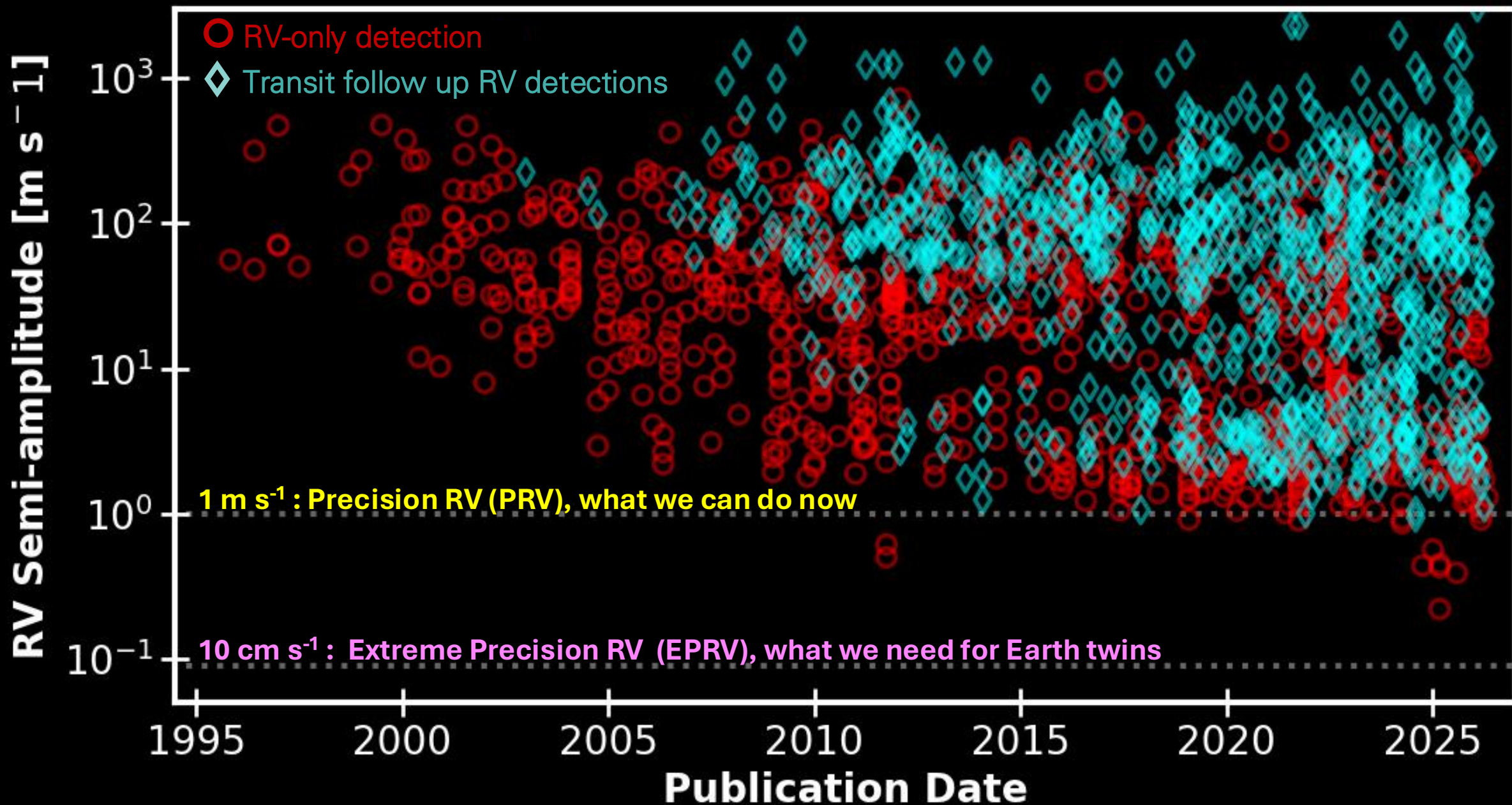
What can we currently detect? [20% RV precision or better]



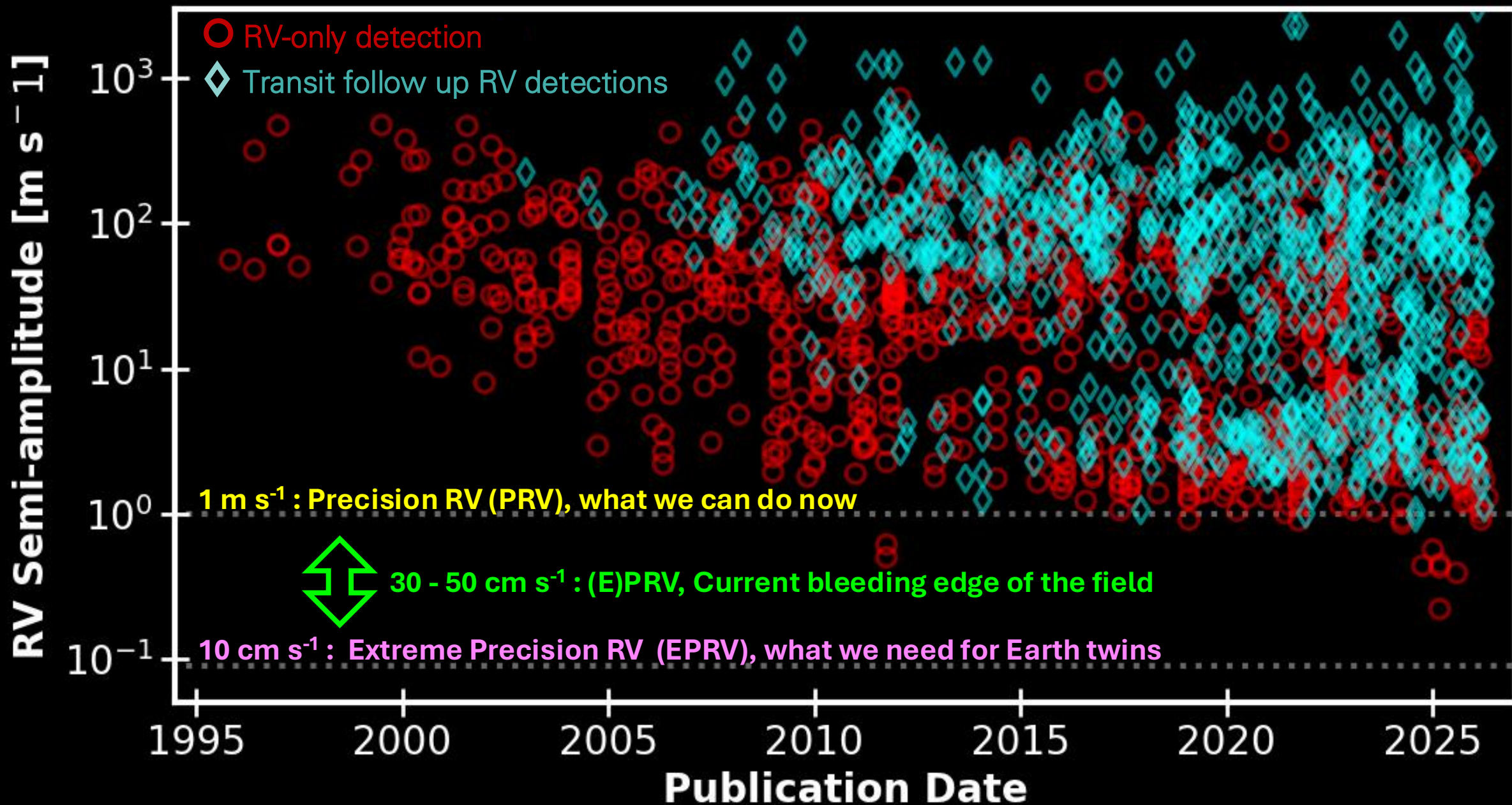
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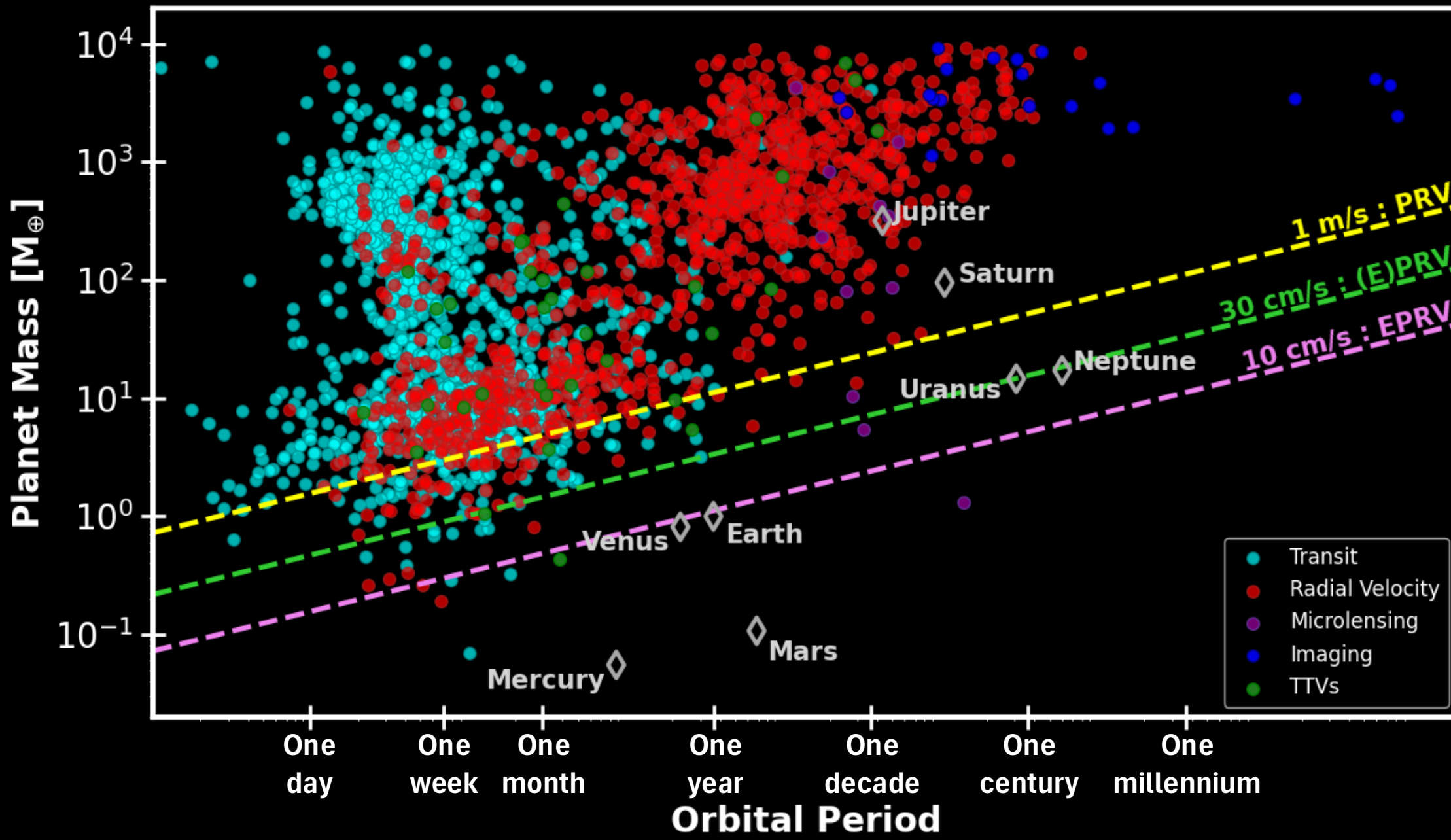


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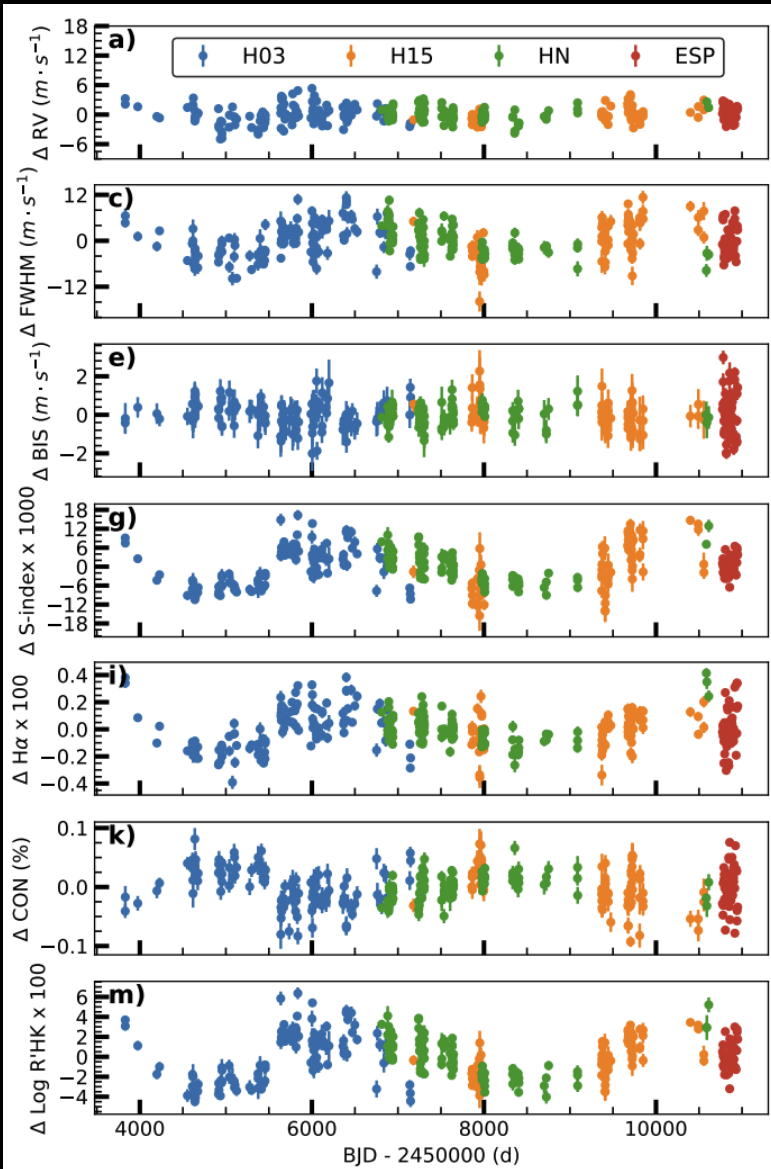
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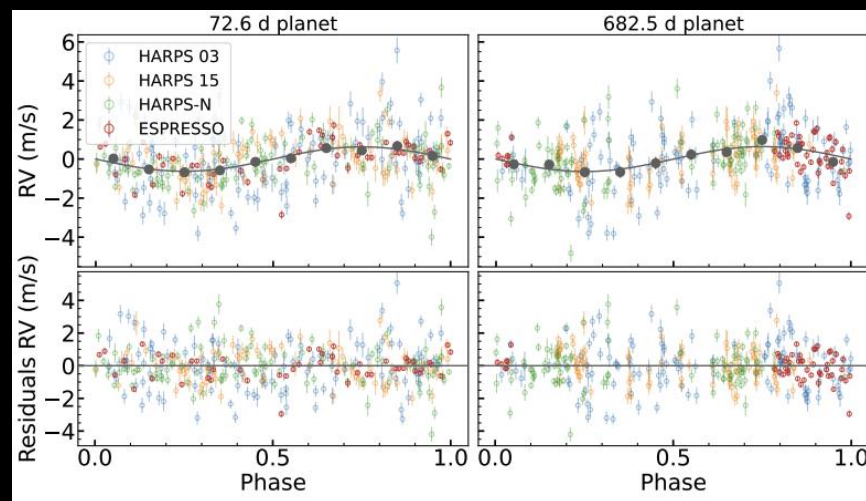
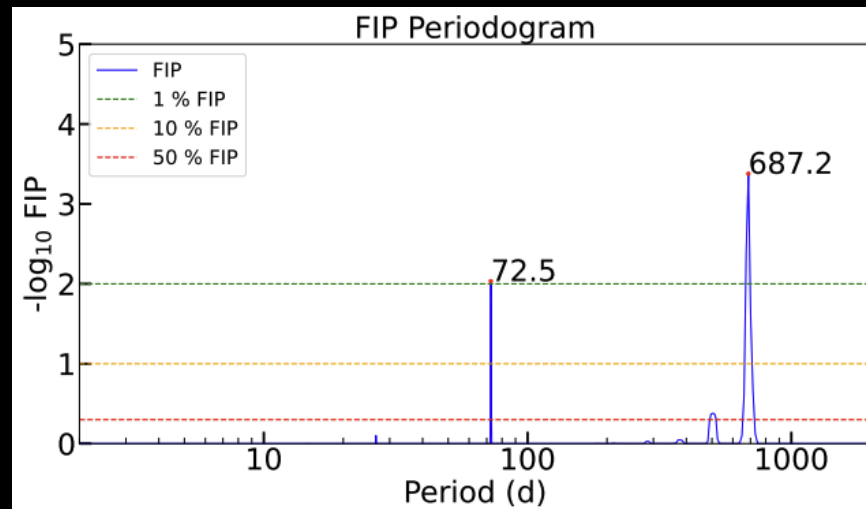
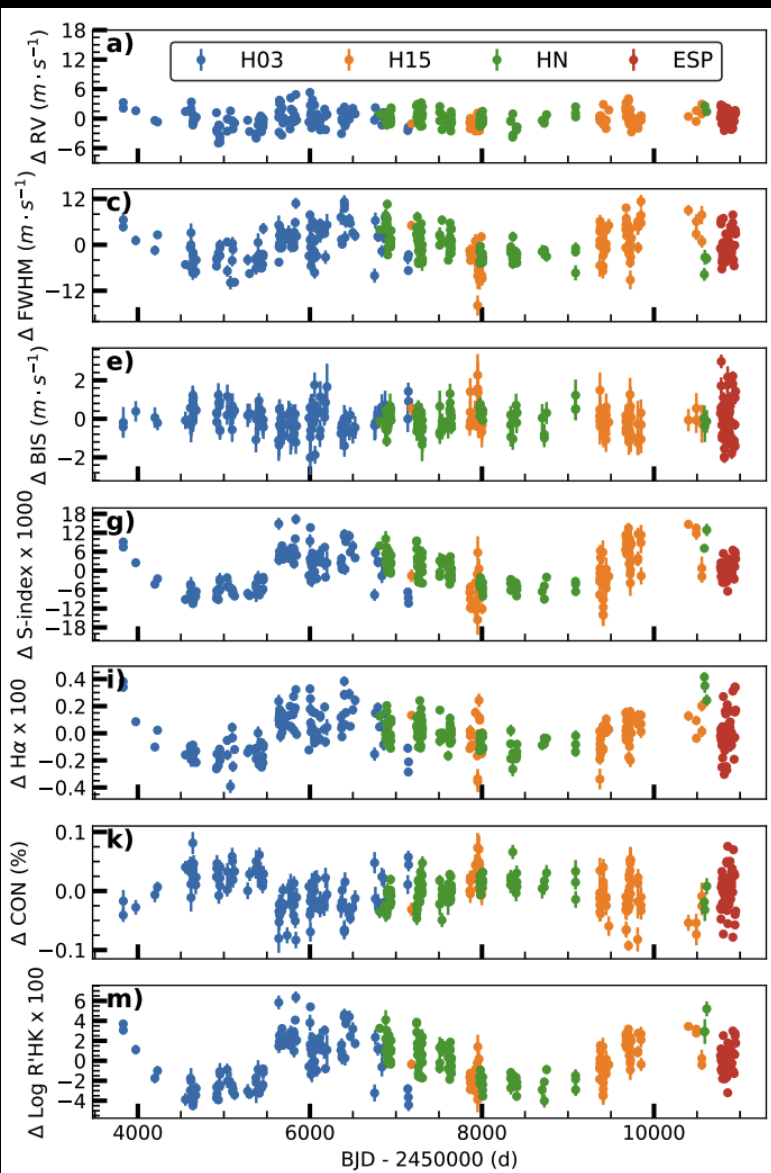
State of the Field – Pure RV Detections

HD 161098 (G8V, $V = 7.68$ mag, $d = 29.75$ pc)



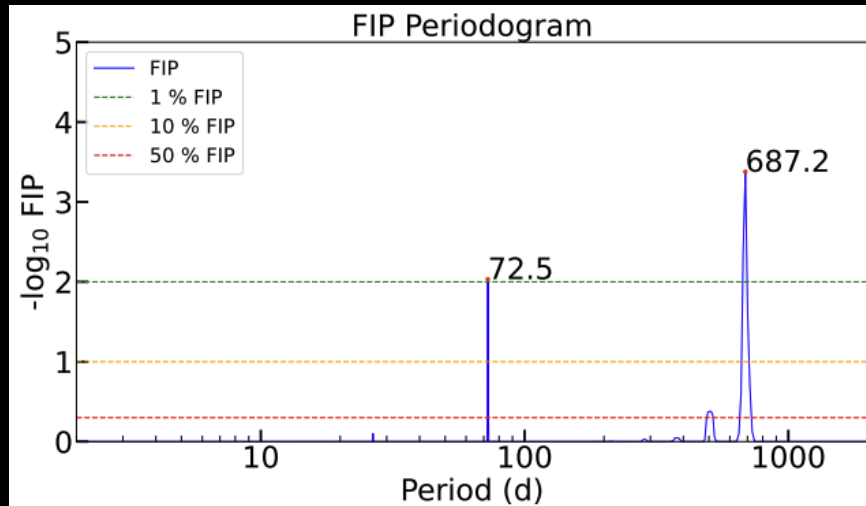
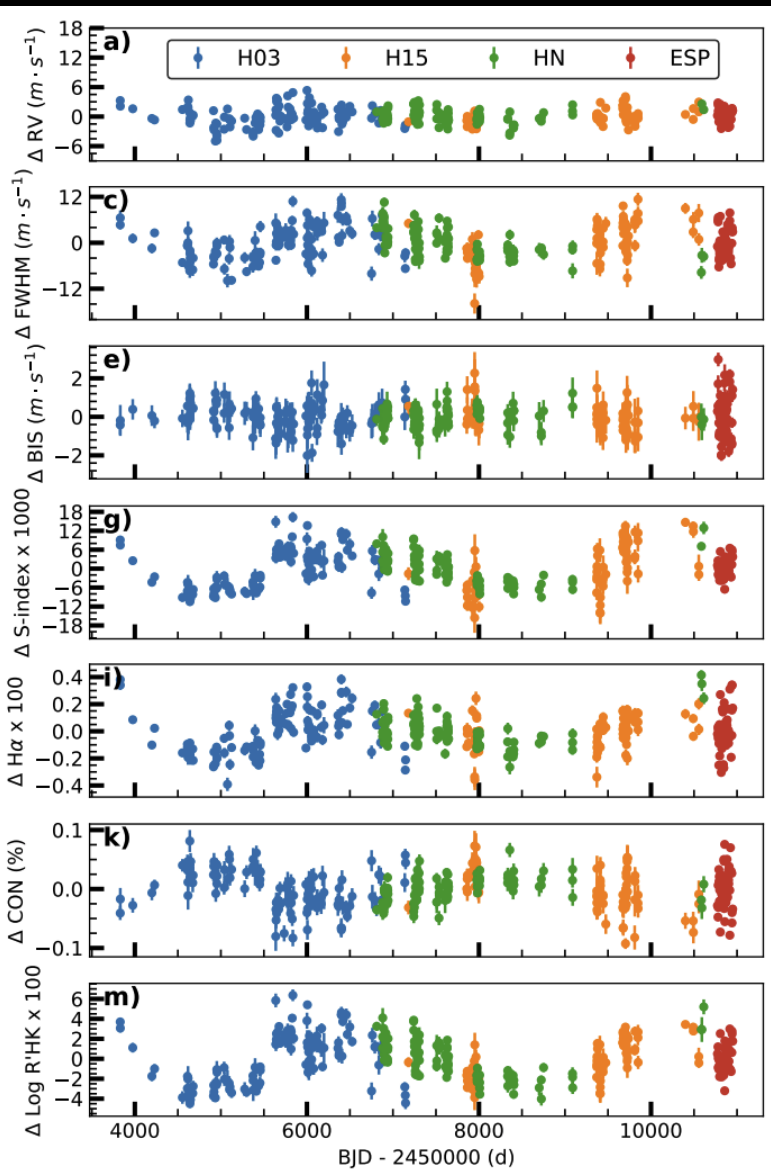
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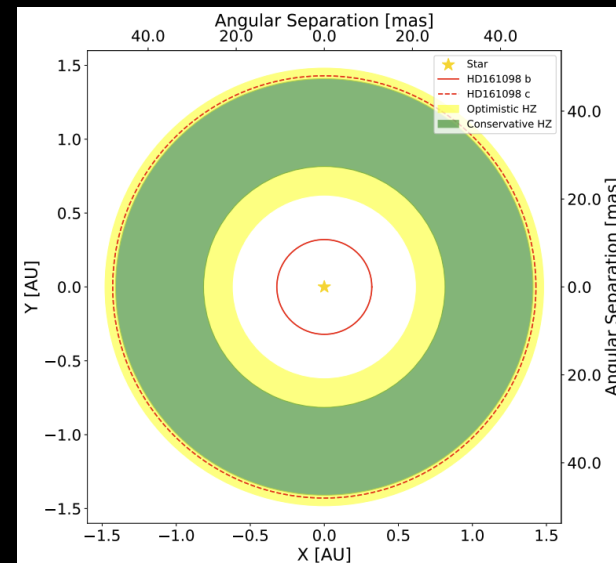
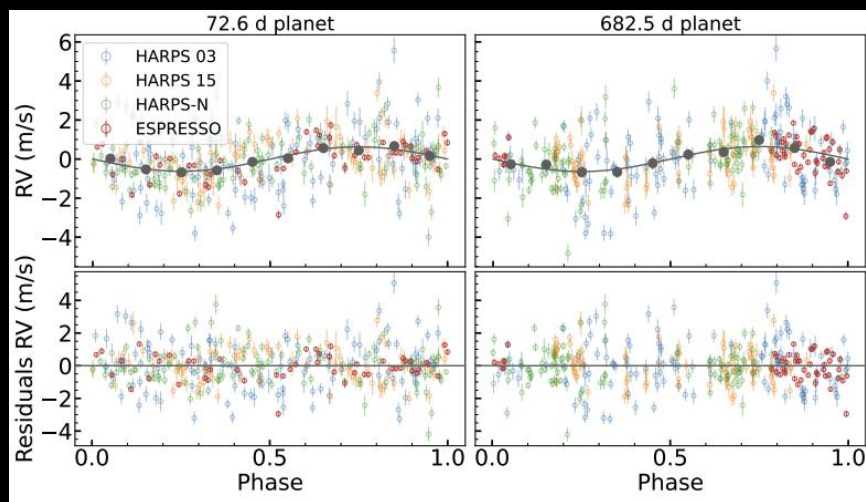


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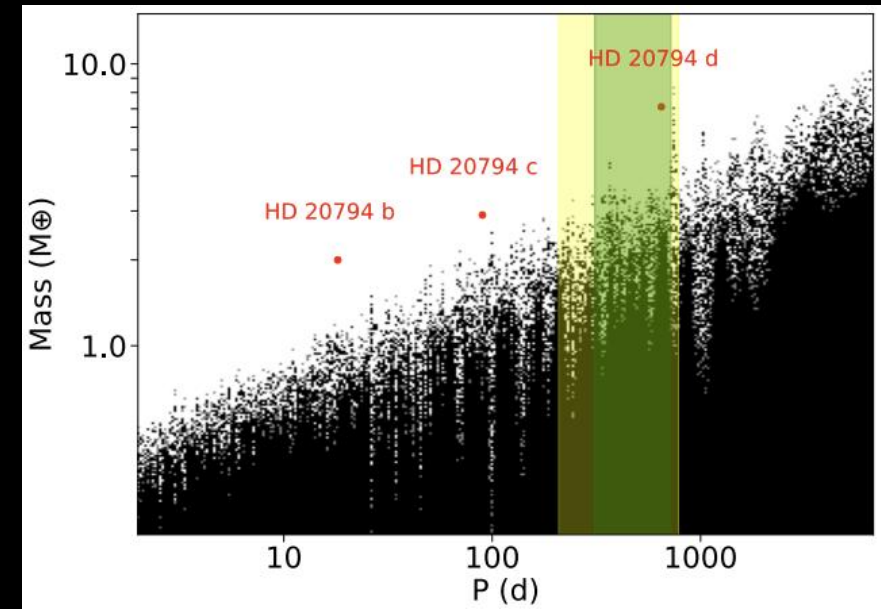
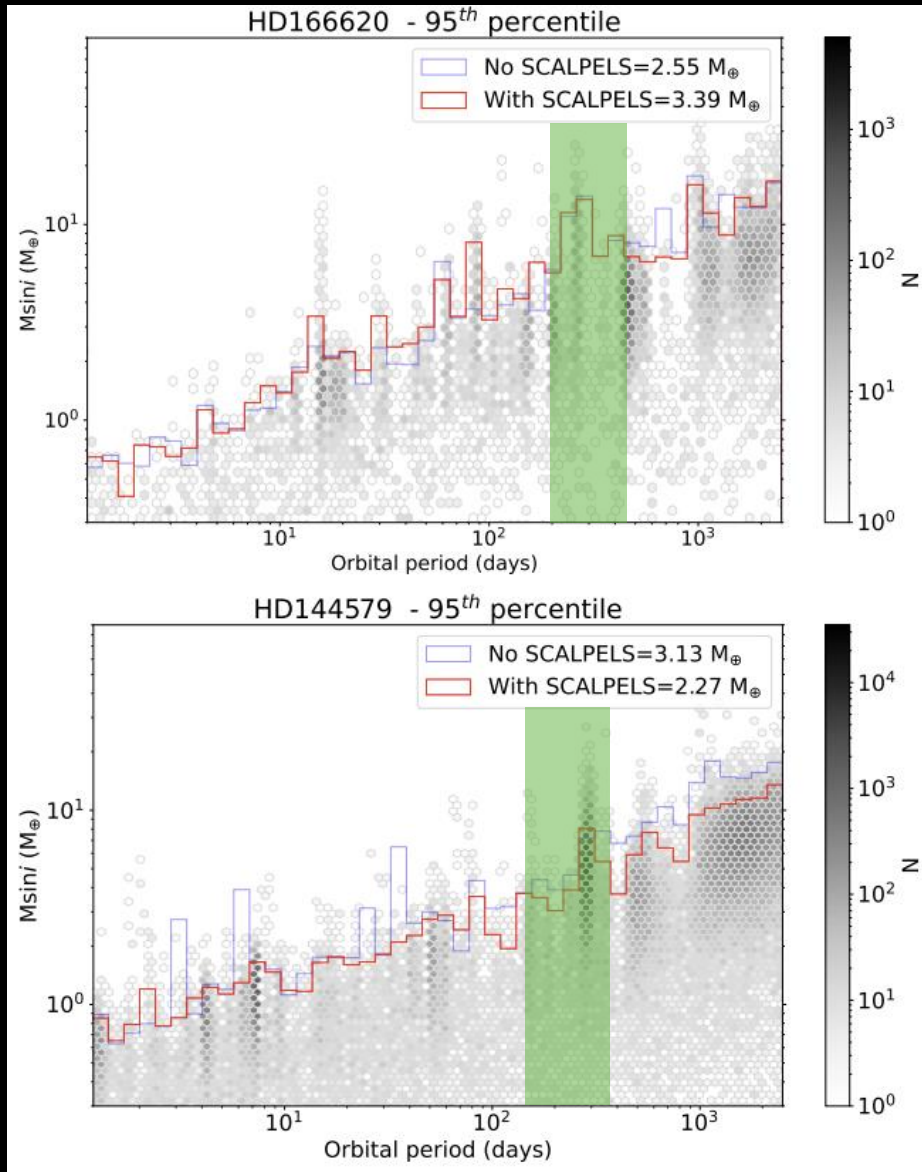
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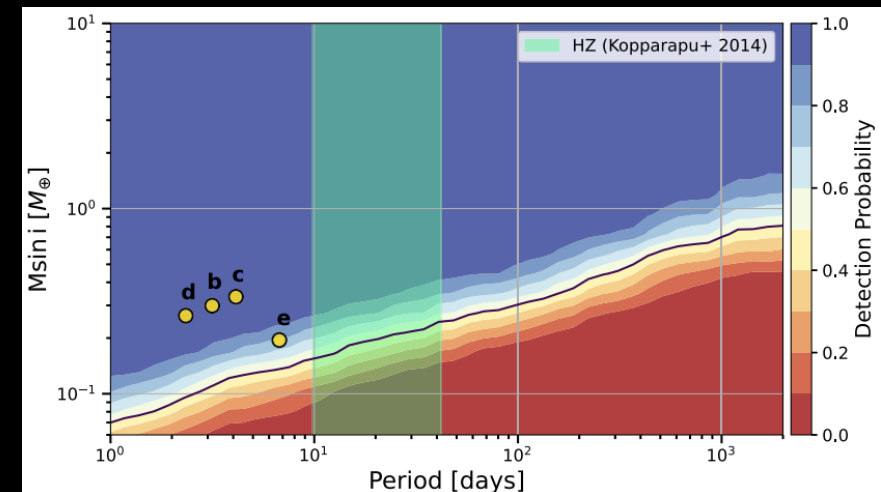
Parameter	HD 161098 b	HD 161098 c
T_0 (BJD)	$2460877.7^{+2.8}_{-2.9}$	2460236^{+57}_{-62}
P (d)	$72.578^{+0.059}_{-0.060}$	$682.5^{+9.5}_{-9.9}$
K (m s^{-1})	0.63 ± 0.10	0.64 ± 0.12
$M_p \sin i$ (M_\oplus)	3.63 ± 0.59	$7.8^{+1.5}_{-1.4}$
a (au)	0.3207 ± 0.0037	1.429 ± 0.021
S (S_\oplus)	$6.48^{+0.42}_{-0.40}$	$0.326^{+0.022}_{-0.021}$
T_{eq} (K)	406.8 ± 6.5	192.7 ± 3.2



State of the Field – Stellar RV Sensitivity



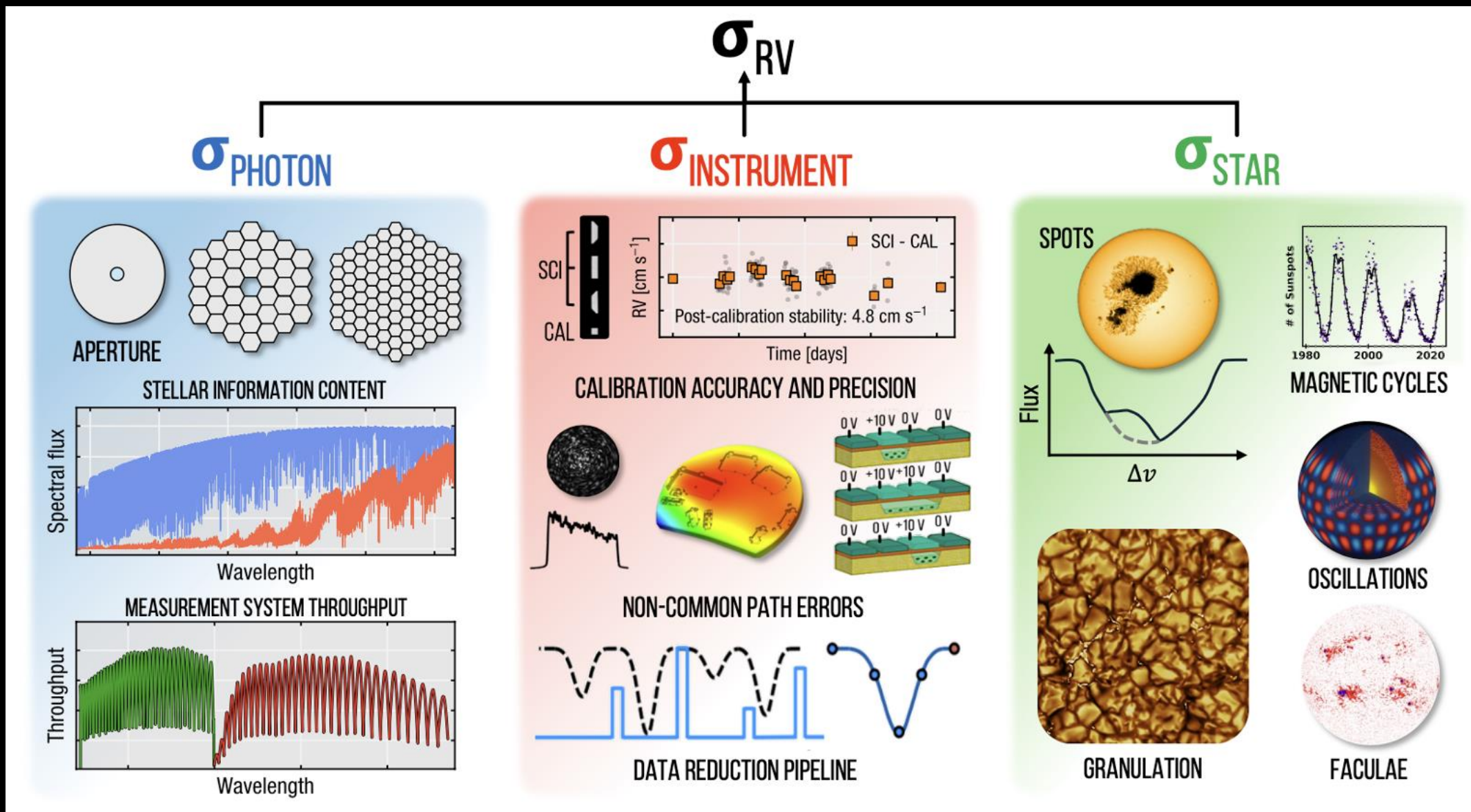
Nari et al. 2025



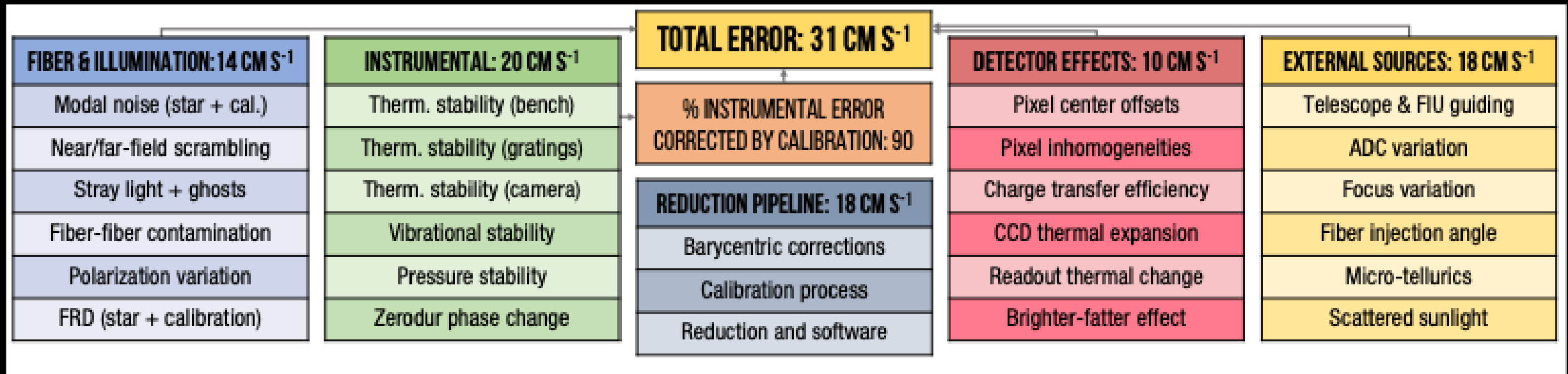
Basant et al. 2025

adapted from John et al. 2024

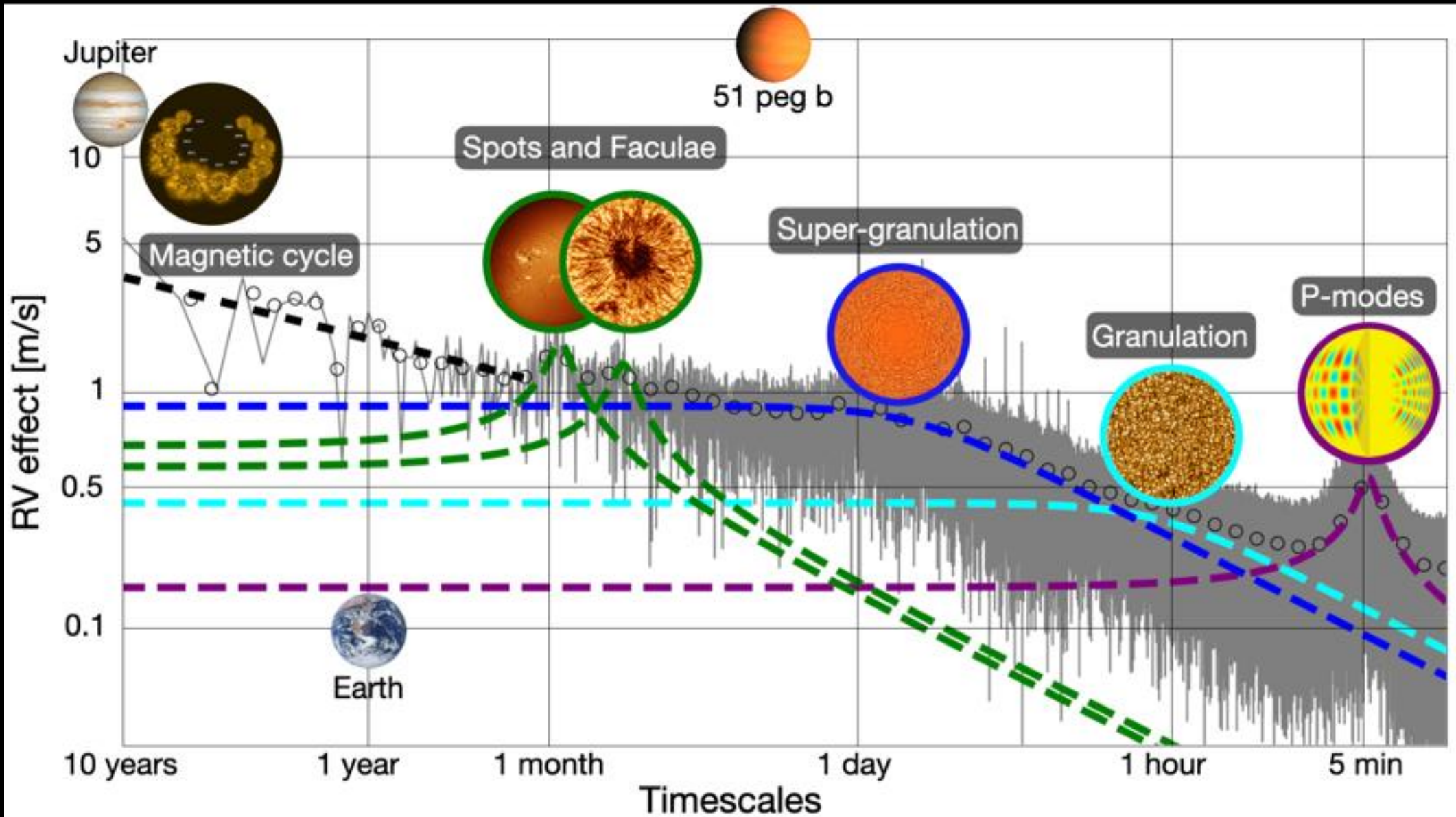
RV Uncertainty Contributions



RV Uncertainty Contributions -- facility

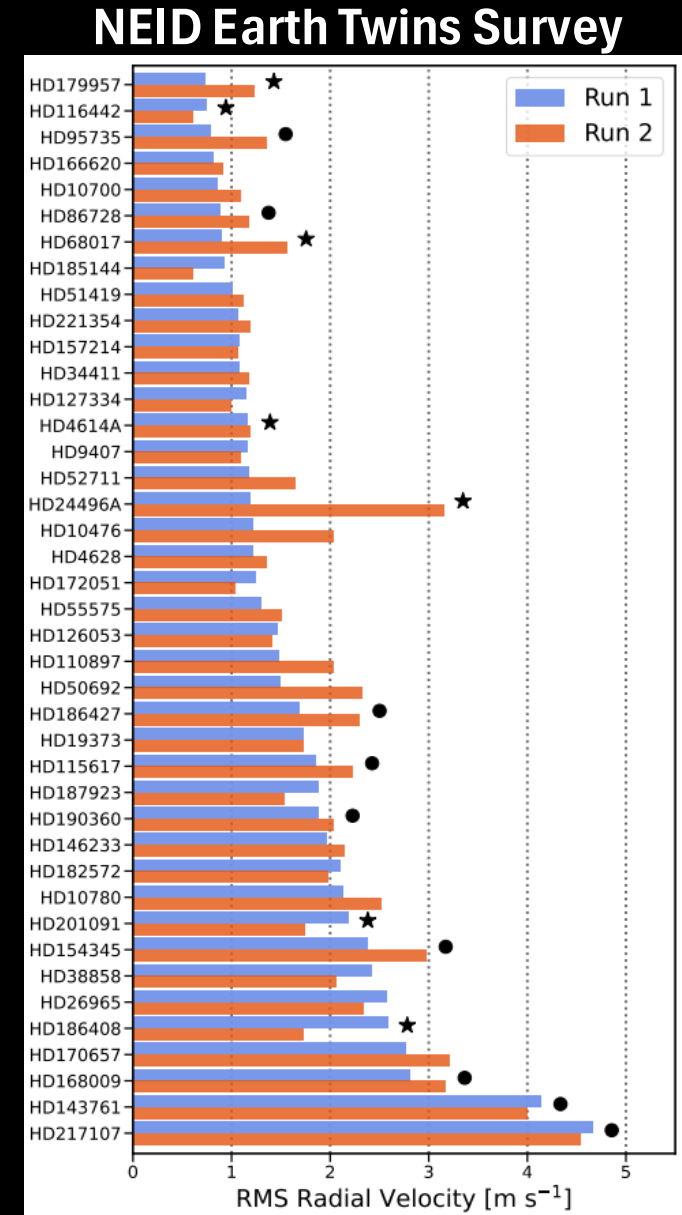


RV Uncertainty Contributions -- stellar variability



State of the Field – Recent / Ongoing Surveys

- EXPRES 100 Earths Survey
- NEID Earth Twins Survey
- HARPS-N Rocky Planet Search
- ESPRESSO GTO
- HUNting for M Dwarf Rocky planets Using MAROON-X (HUMDRUM)
- *Terra Hunting Experiment (HARPS3)
- *2nd Earth Spectrograph (2ES)
- ... many additional, PI-level efforts



State of the Field – Recent / Ongoing Surveys

NN-EXPLORE Key Program at the WIYN Telescope

Call for Proposals

The [NASA-NSF Exoplanet Observational Research program \(NN-EXPLORE\)](#) seeks to advance the understanding of exoplanets and exoplanetary systems in areas of mutual interest to both agencies.

With this call, the NN-EXPLORE program invites proposals for a single Key Program at the WIYN 3.5m telescope. The program will make use of up to 12 nights per semester for 4 years. Subject to funding availability, up to \$300,000 per year will be provided to the selected team.

The deadline for proposals submitted to this call is September 30th, 2026, 11:59 MST. Notices of Intent (NOIs) are required on or before July 31, 2026.

This program does not replace the NN-EXPLORE GO program. General NN-EXPLORE GO proposals, both single-semester and long-term, will be available for 2027A.

1. Scope

NN-EXPLORE solicits observing proposals targeted to exoplanet-related research, with emphasis on enhancing the scientific return of past NASA missions, and supporting ongoing and planned ones. These include Kepler, K2, TESS, HST, JWST, Roman, HWO, etc.

The scope of this Key Program includes observations to:

- Characterize known exoplanets and exoplanetary systems
- Characterize the physical or observational properties of target stars and their stellar environments
- Confirm or validate exoplanet candidates
- Search for exoplanets relevant to HWO including planets that may impact the habitable zones of likely target stars for the Habitable Worlds Observatory (HWO)

Of particular interest for this Call are precursor science observations for the [Habitable Worlds Observatory \(HWO\)](#). HWO was recommended by the Astro2020 Decadal Survey as the next NASA Flagship mission after Roman, and it is currently under study as a preformulation mission concept.

EPRV in Space?

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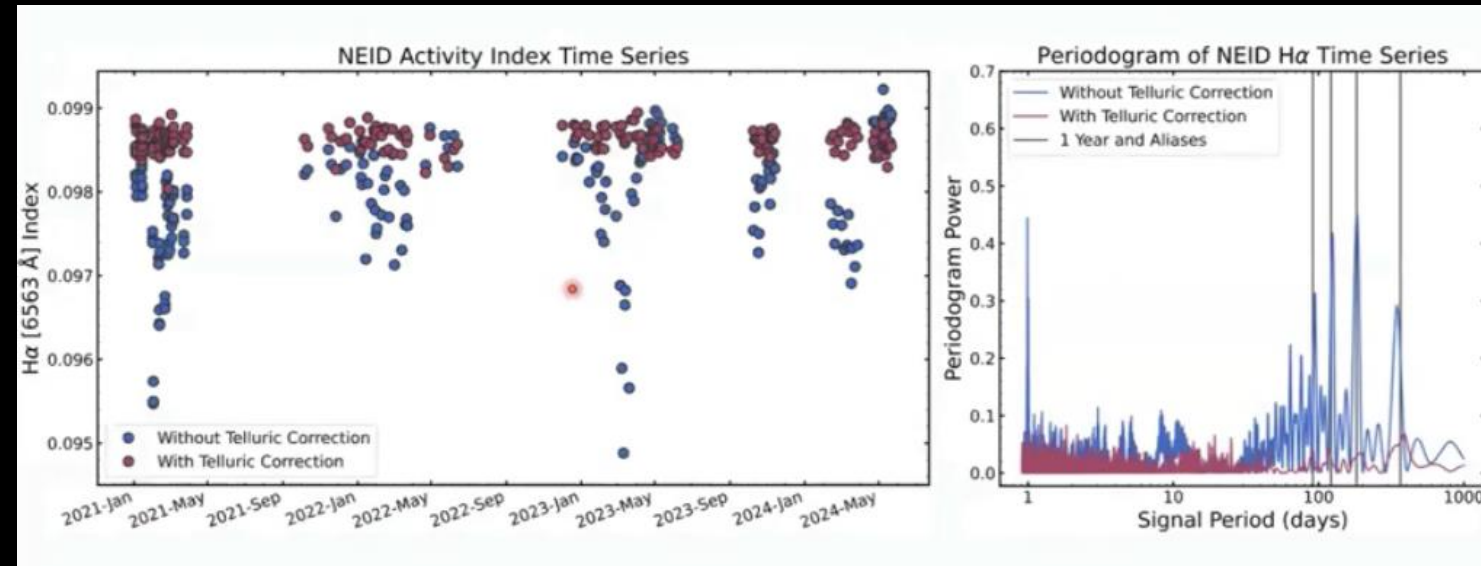
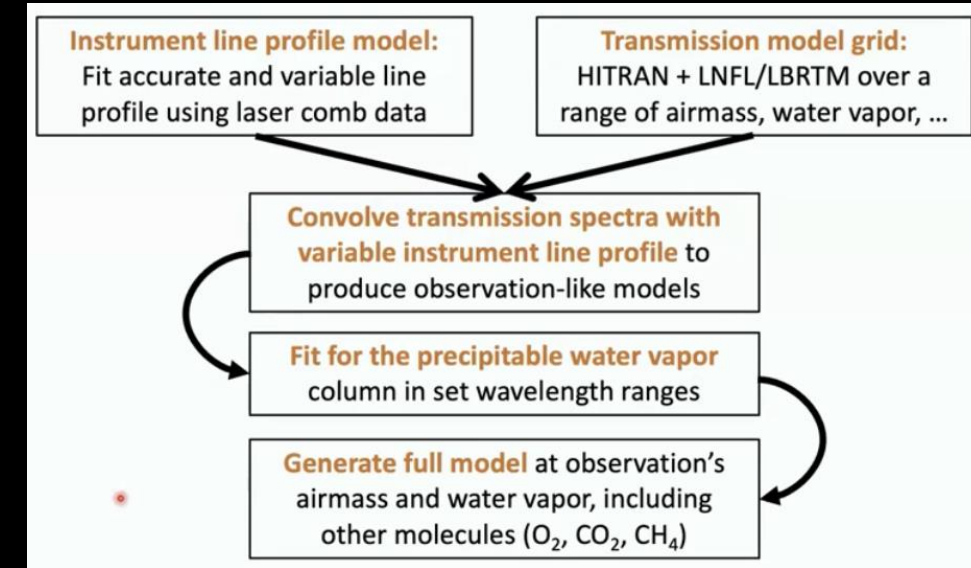
Benefits of Space-based Observations

- **Lack of telluric contamination**
- **Additional blue/NUV wavelength coverage**
- **Lack of weather losses and day/night cycle**

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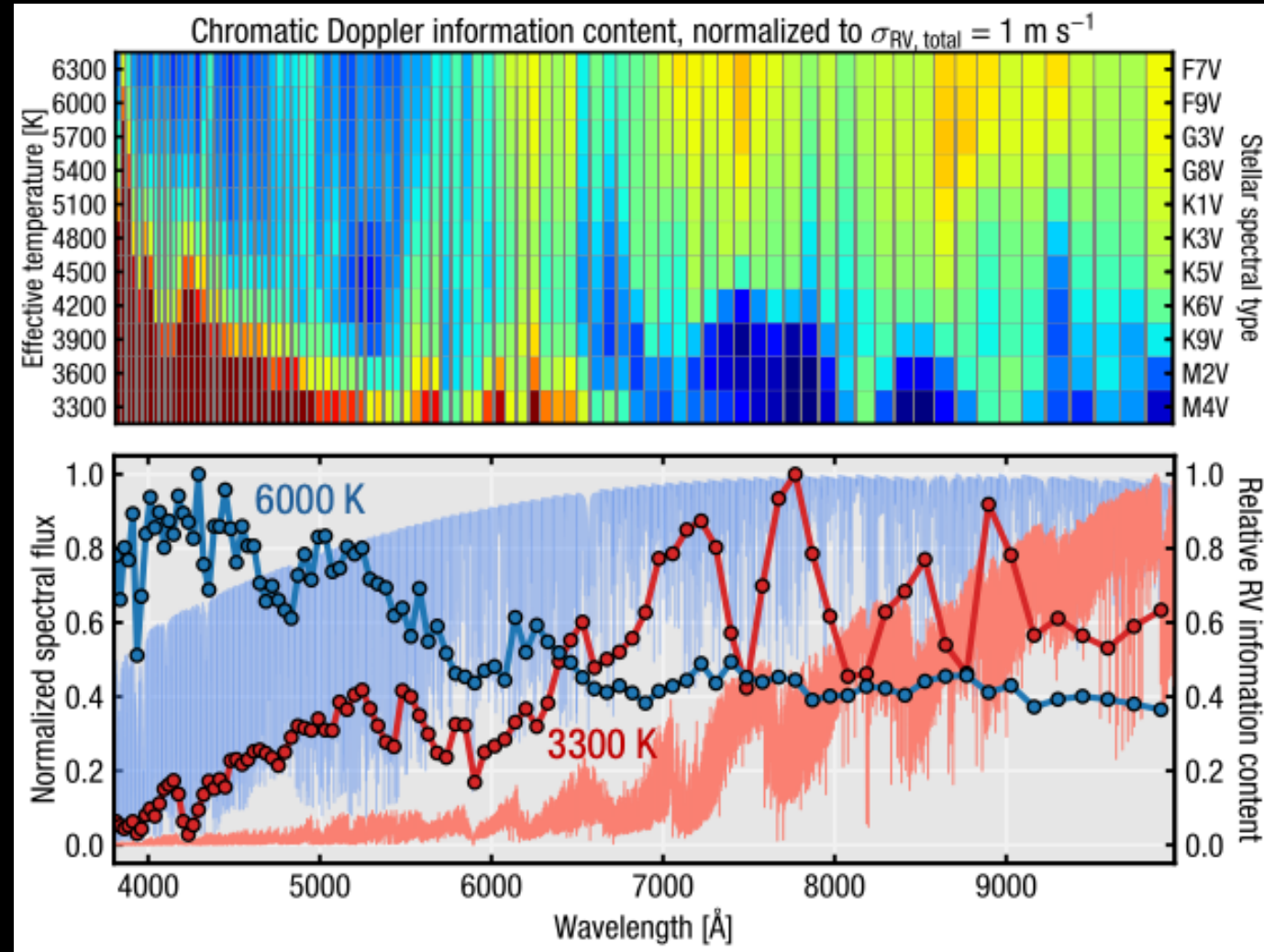
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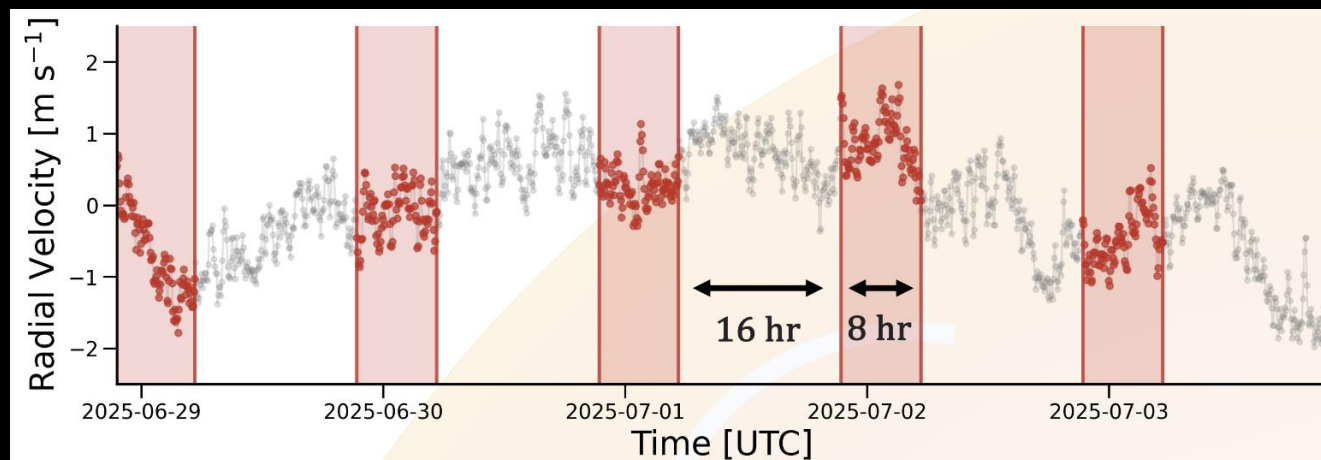
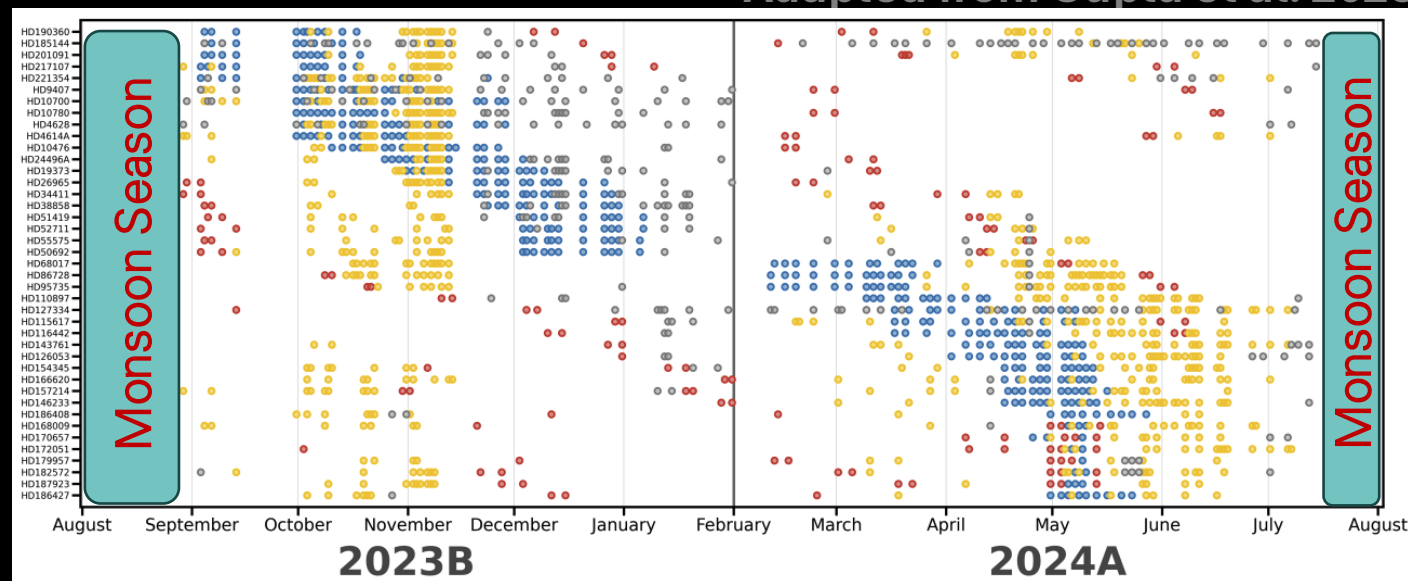


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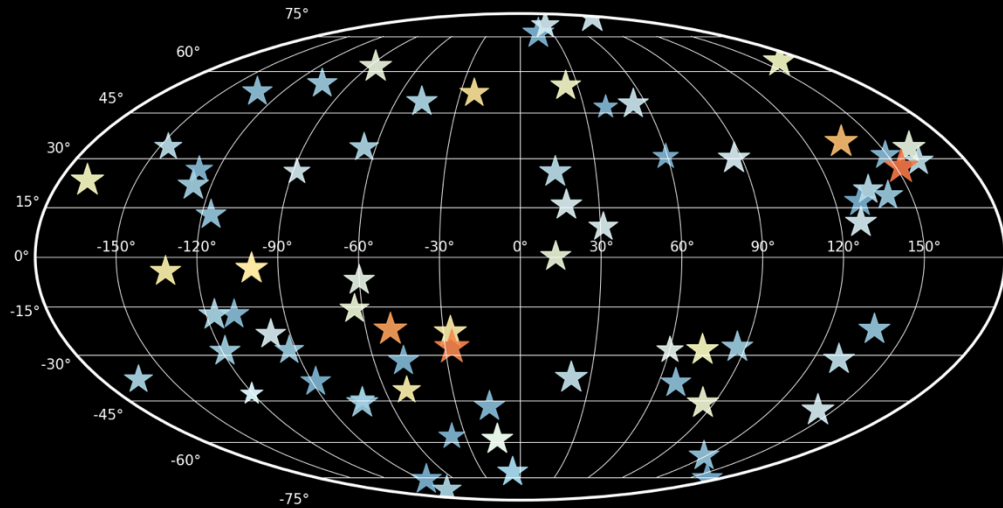
Adapted from Gupta et al. 2025



Courtesy Arvind Gupta & RCN Standard Stars Group

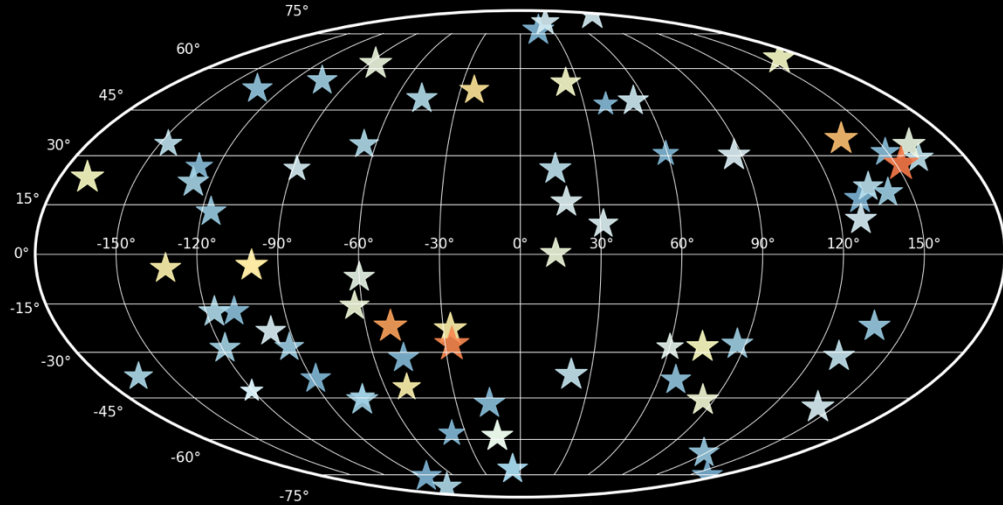
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($V_{\text{ sini}} \leq 5.0 \text{ km/s}$ & $T_{\text{eff}} \leq 6000\text{K}$)**



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Photon Noise Limitations

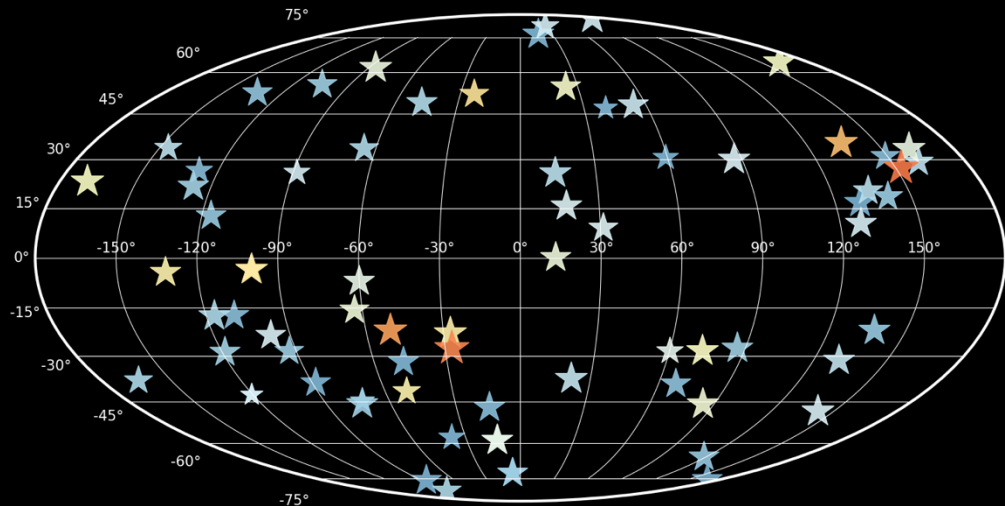
- **Assuming NEID* + Roman primary mirror, observing each target once to 10 cm s^{-1} photon noise & binning over stellar pulsations requires **~17.5 hours****

*NEID ETC with 20% throughput bump and 0.3" seeing to account for lack of atmosphere

**No slew/acquisition time included

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Other high-level concerns

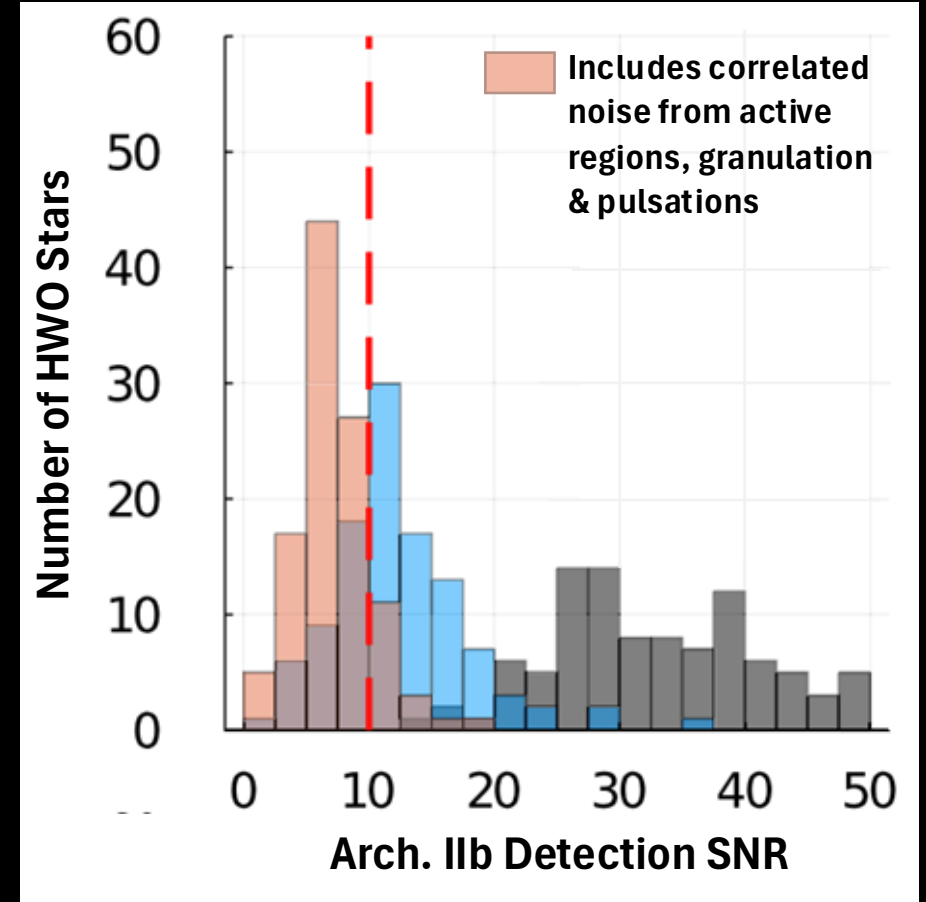
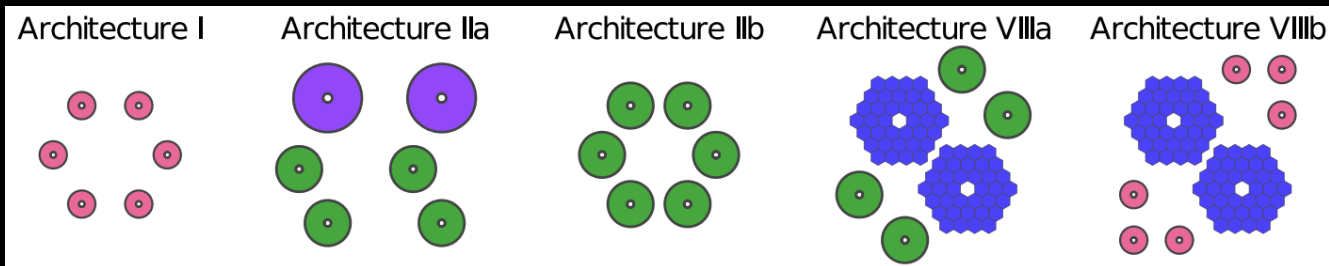
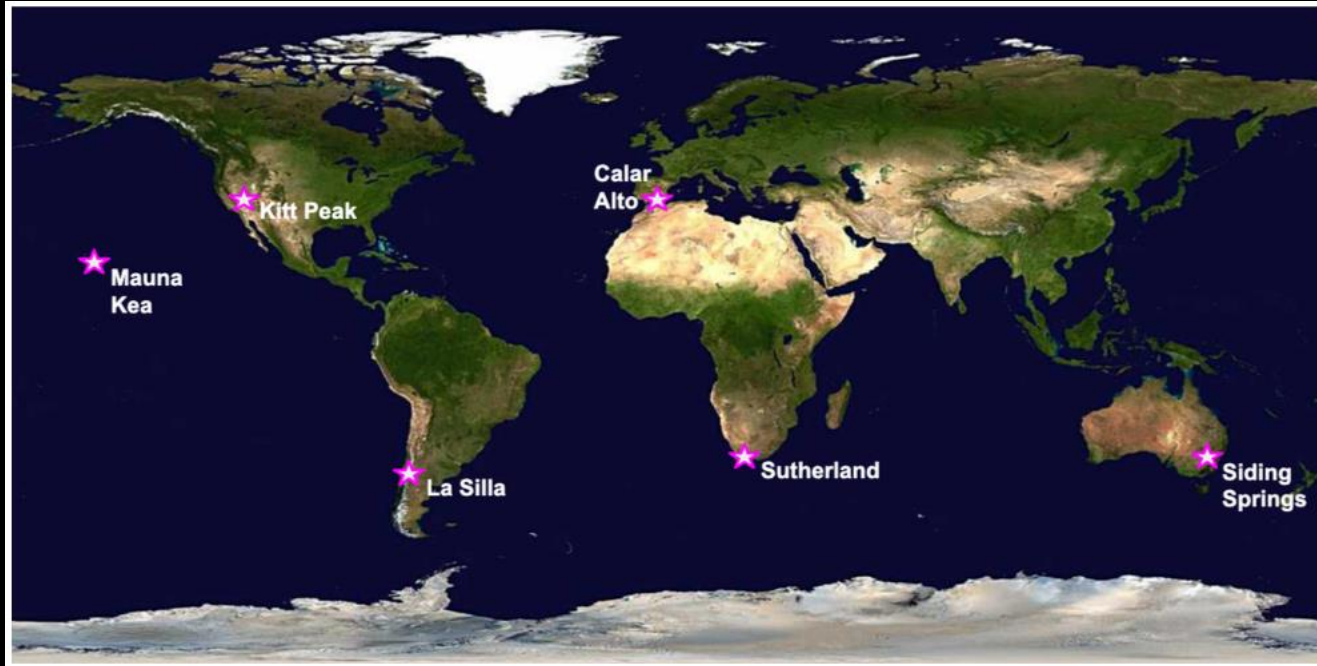
- No currently available wavelength calibration subsystem is reliable enough
- Cosmic ray contamination / detector degradation given how much of the detector we use
- Thermal cycling concerns based on mission orbit

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Instead of Space : Coordinated Ground-Based Efforts

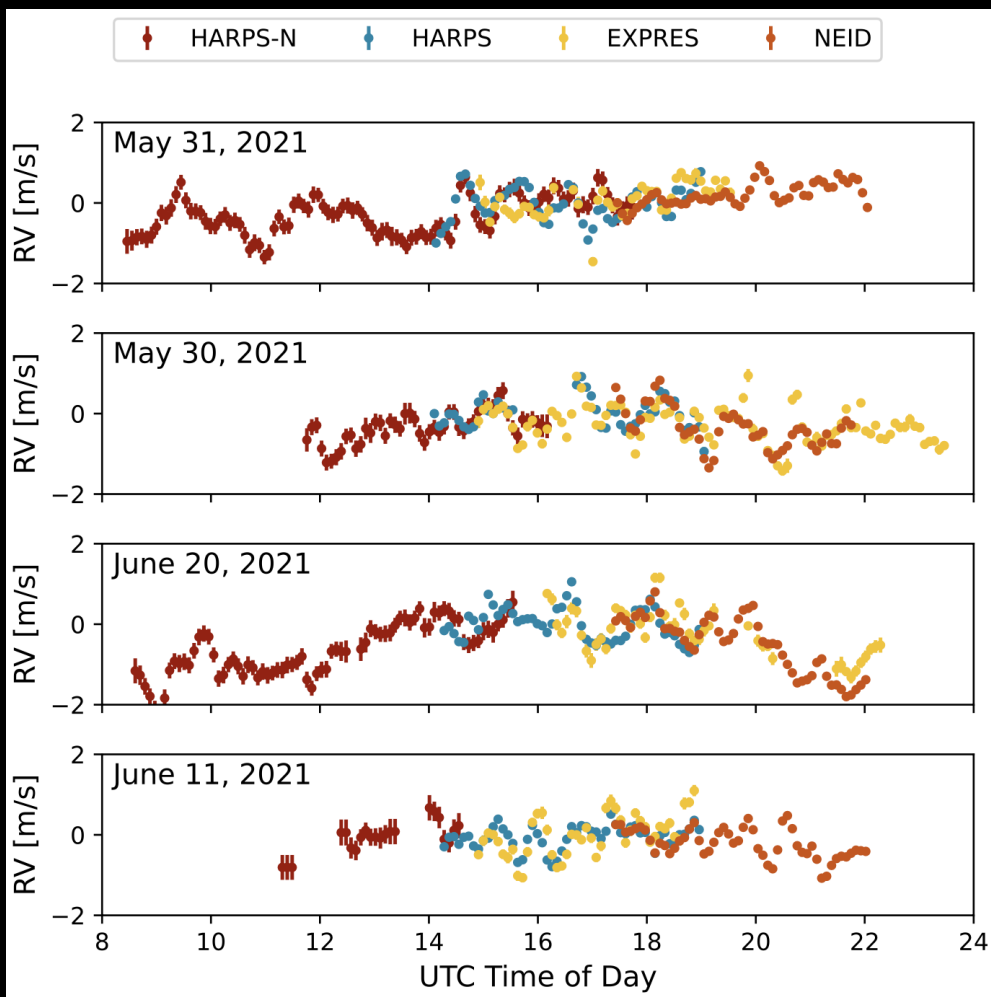
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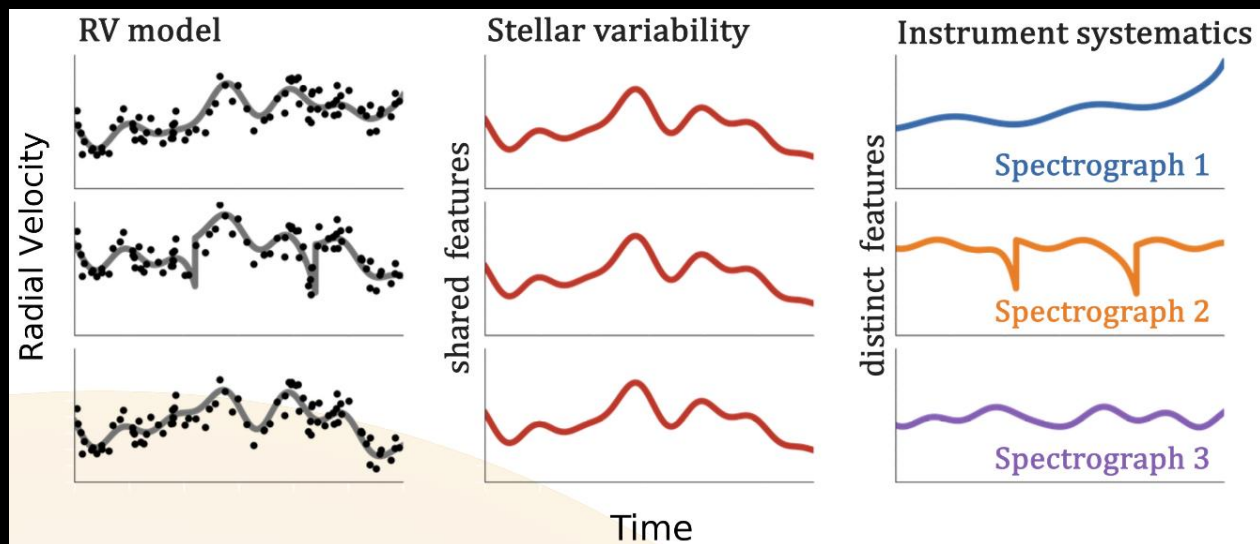
Simulations from Luhn et al. 2023 showing results of a 10-year, 100% allocation EPRV survey carried out on six 10 cm s^{-1} spectrographs paired with 3.5m telescopes (Architecture IIb). Even in the face of correlated noise (red histogram) 80% of HWO stars considered detect an Earth analog at 20% RV precision or better.

Instead of Space : Coordinated Ground-Based Efforts

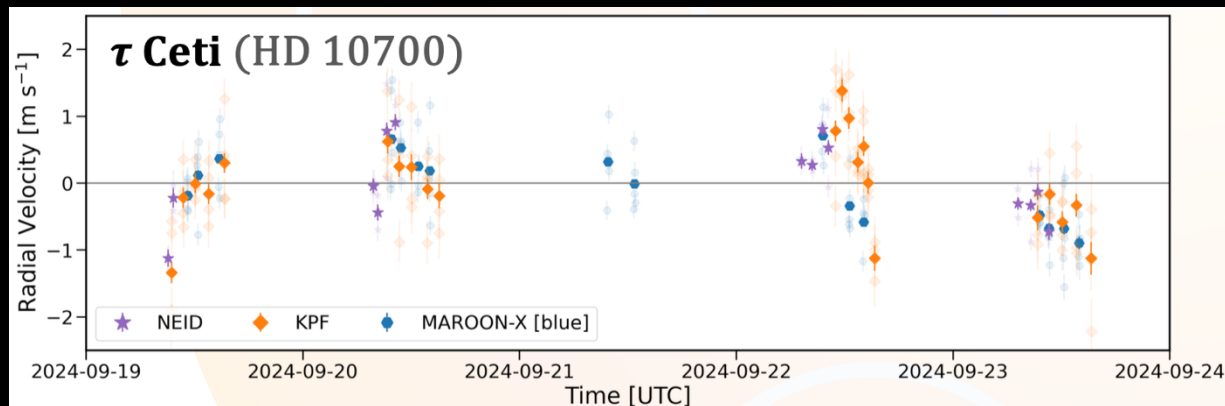
Courtesy Arvind Gupta & RCN Standard Stars Group



Zhao et al. 2023 – Solar data



Observing the same targets across multiple instruments on similar timescales / precisions allows the disentanglement of stellar signals from instrument systematics

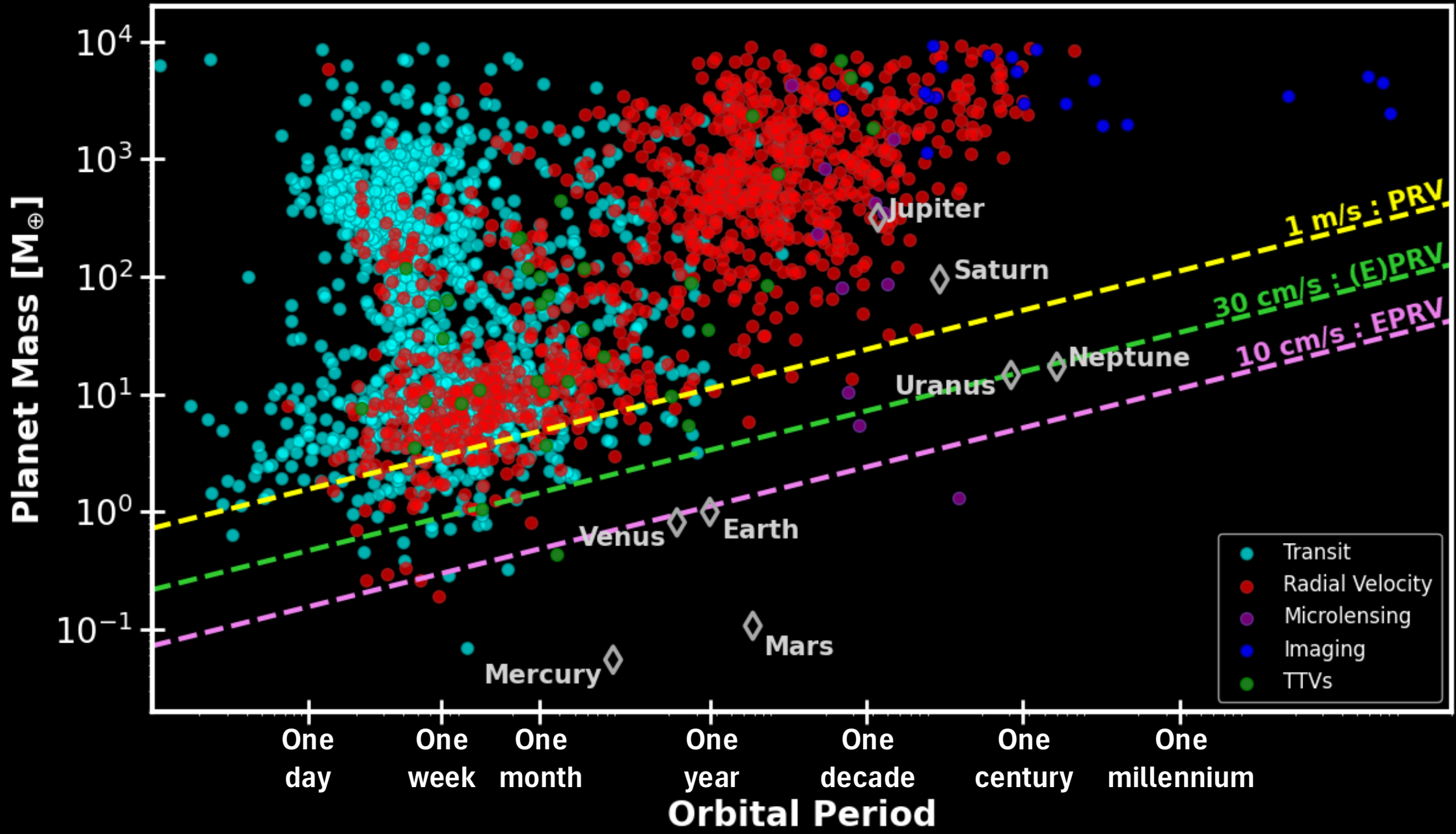


Instead of Space : Coordinated Ground-Based Efforts

UK Research Initiative

Every bit of improvement counts!

$$K = \left(\frac{2\pi G}{P}\right)^{1/3} \cdot \frac{m_{pl} \sin(i)}{(M_* + m_{pl})^{2/3}} \cdot \frac{1}{\sqrt{1 - e^2}}$$

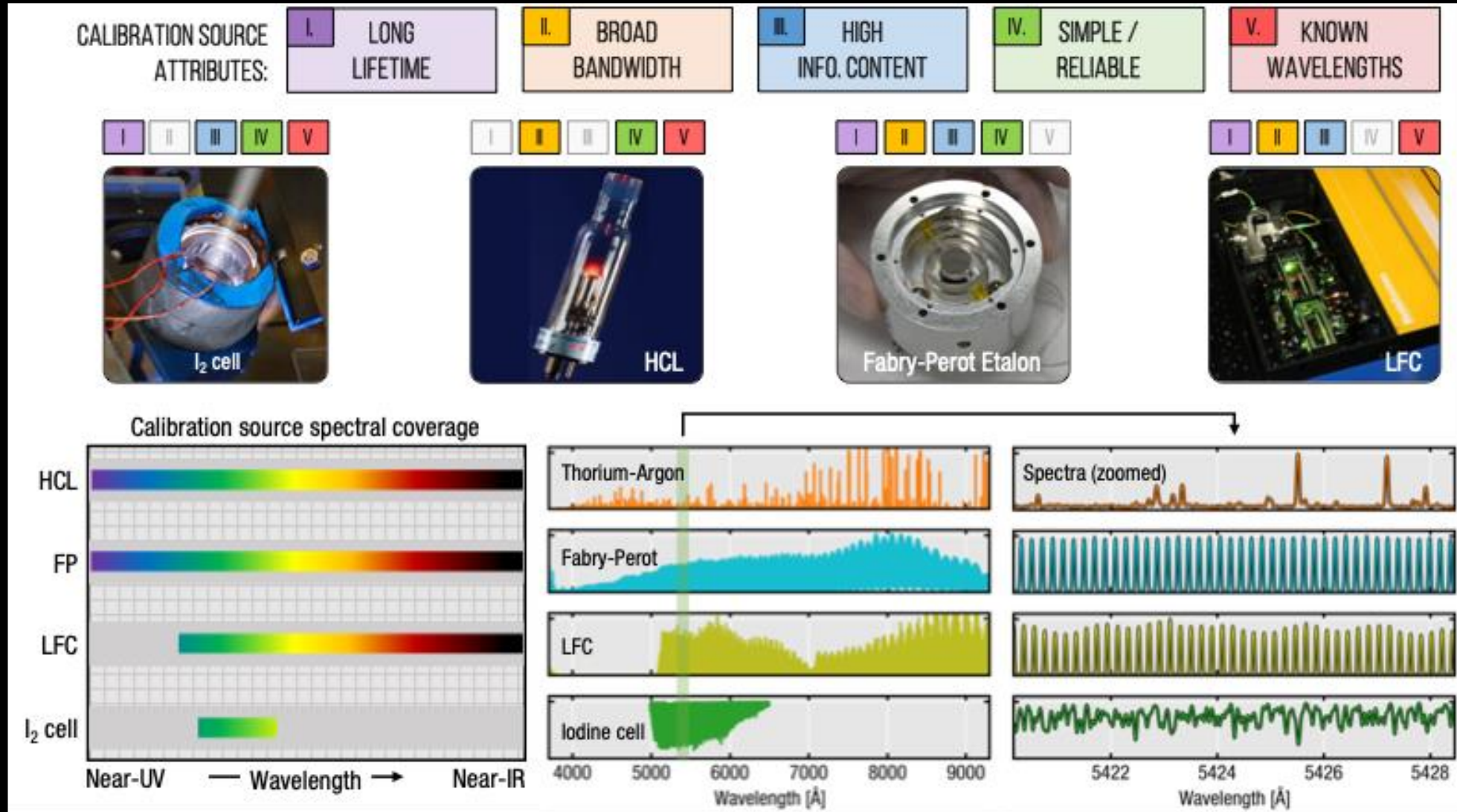


The future of precise radial velocities in exoplanet discovery and characterization

Dr. Jennifer Burt
Exoplanet Exploration Program Office
Jet Propulsion Laboratory, California Institute of Technology

Back Up Slides

What to do instead? - Blue Wavelength Calibration



Major Challenges

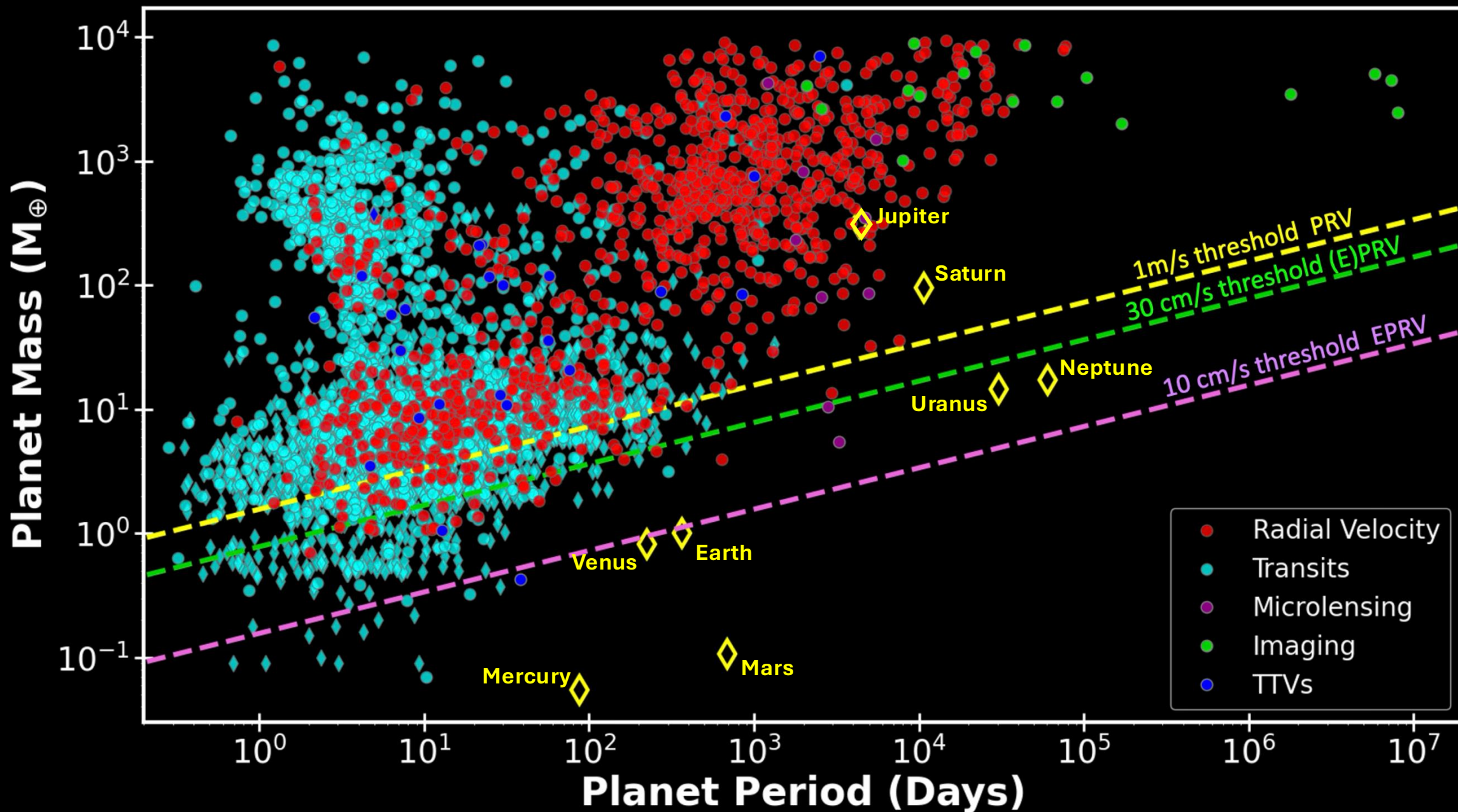
Useful overview on what's needed to move the field forward to Earth-detecting capabilities presented in the EPRV Working Group's Final Report

(Crass et al. 2021)

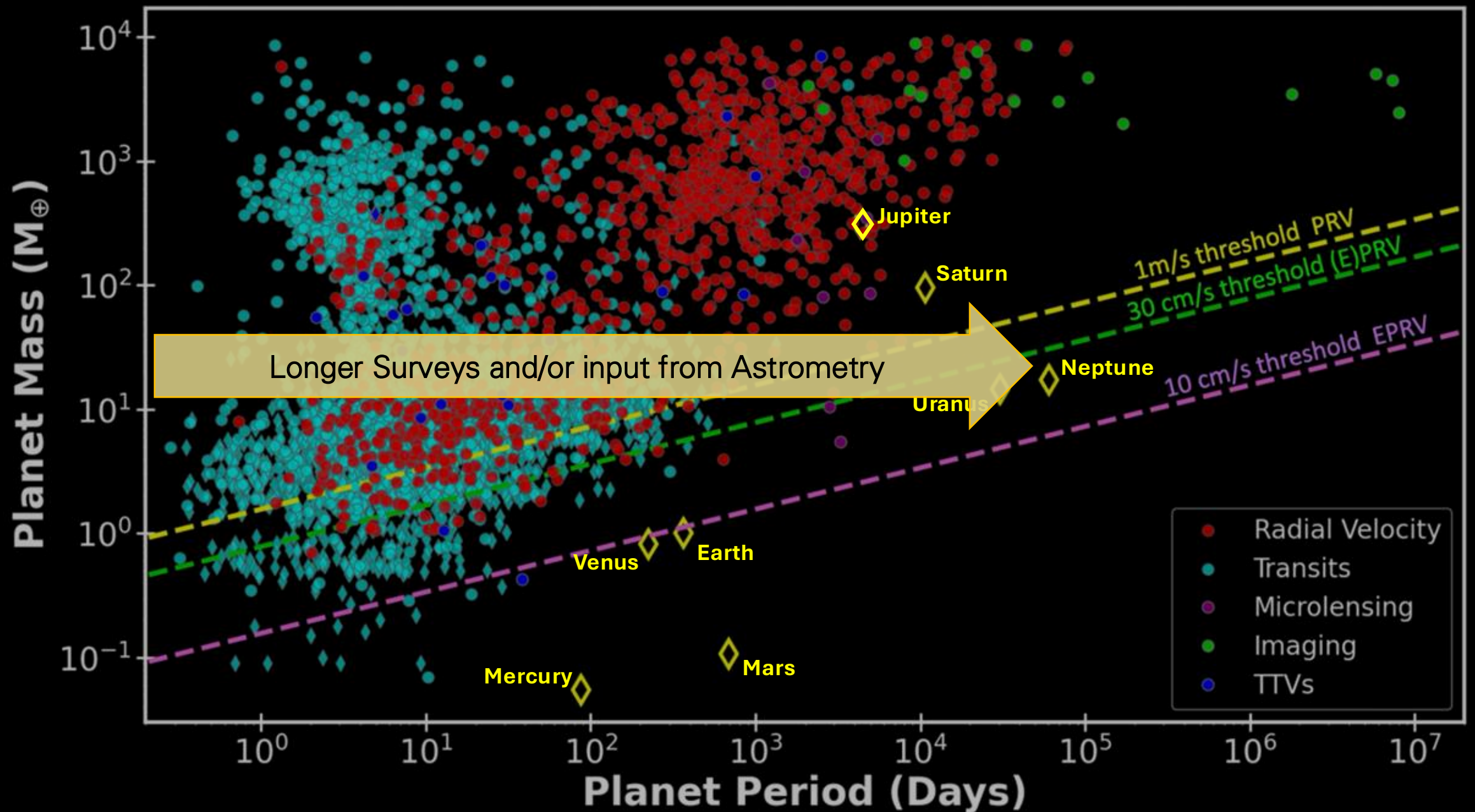
TABLE 6-1. Near-term Roadmap (1–5 years) to determine the feasibility and likelihood of a successful EPRV survey.

Stellar Variability:
Support the adoption of solar feeds for spectrographs that demonstrate >100k spectral resolution, SNR > 300 and <50 cm/s stability over a day.
Determine how well variability mitigation strategies built from Sun-as-a-star knowledge translate to other spectral types present in the proposed list of target stars.
Determine the level of RV precision and accuracy enabled by stellar variability mitigation strategies and modeling and the corresponding implications for the planet mass determinations.
Instrumentation:
Maximize knowledge gained from current instruments still under development, construction, commissioning, and that have recently begun operations.
Establish or use existing testbeds for full instrument system development and component testing and characterization, and verification of software-based instrument simulators and select pipeline modules.
Determine whether it will be possible to secure a sufficient number of CCDs for a full EPRV survey in a timely manner.
Determine whether CMOS (complementary metal-oxide semiconductor) detectors are an acceptable replacement for CCD detectors.
Investigate the continued availability of gratings required for high-resolution spectrographs.
Determine if there are alternative, cheaper, and more robust methods of fabricating gratings.
Investigate the feasibility of securing robust, long-lived, high-stability calibration sources.
Architecture:
Determine whether extreme AO in the visible combined with fiber injection of single-mode fiber-fed diffraction limited spectrographs presents a viable and more desirable option than traditional seeing-limited RV instruments.
Determine whether it would be practical to retrofit existing telescopes for dedicated, robotic operation for EPRV observations, or whether new telescopes are required. Determine which of these options presents the least risk and requires the fewest resources.
Identify suppliers for multiple, large-aperture telescope systems and conduct site selection surveys, should the building of new telescopes be required for the full EPRV survey.
Telluric Line Contamination:
Determine whether telluric contamination lines in spectra can be adequately mitigated, over a sufficiently broad wavelength range.
Extensive and Detailed Theoretical Analysis:
Determine what combination of spectral bandwidth, resolution, SNR and cadence is sufficient for the detection of Earth-analog systems.
Explore the advantages of spectropolarimetry in EPRV observations (e.g., as implemented in SPIRou).
Specify, based on lessons learned from observational data, the required quality of the spectra (including resolution and SNR) to detect Earth analogs, which then constrains the required effective apertures, observing time, and cadence.
Software:
Support the development of a well-designed, well-engineered, and actively maintained open-source pipeline with demonstrated ability to retrieve state of the art results on EPRV data from multiple instruments.
Programmatic:
Ensure the needed staffing of personnel with expertise in PRV, heliophysics, and stellar variability to conduct the necessary analysis as well as conduct an EPRV survey. This necessarily involves establishing formal collaborations with non-U.S. entities, and creating attractive employment paths for early career (graduate students, postdoctoral fellows, and non-tenure track researchers) experts in PRV science and technology.
Establish a Research Coordination Network and Standing Advisory Committee.

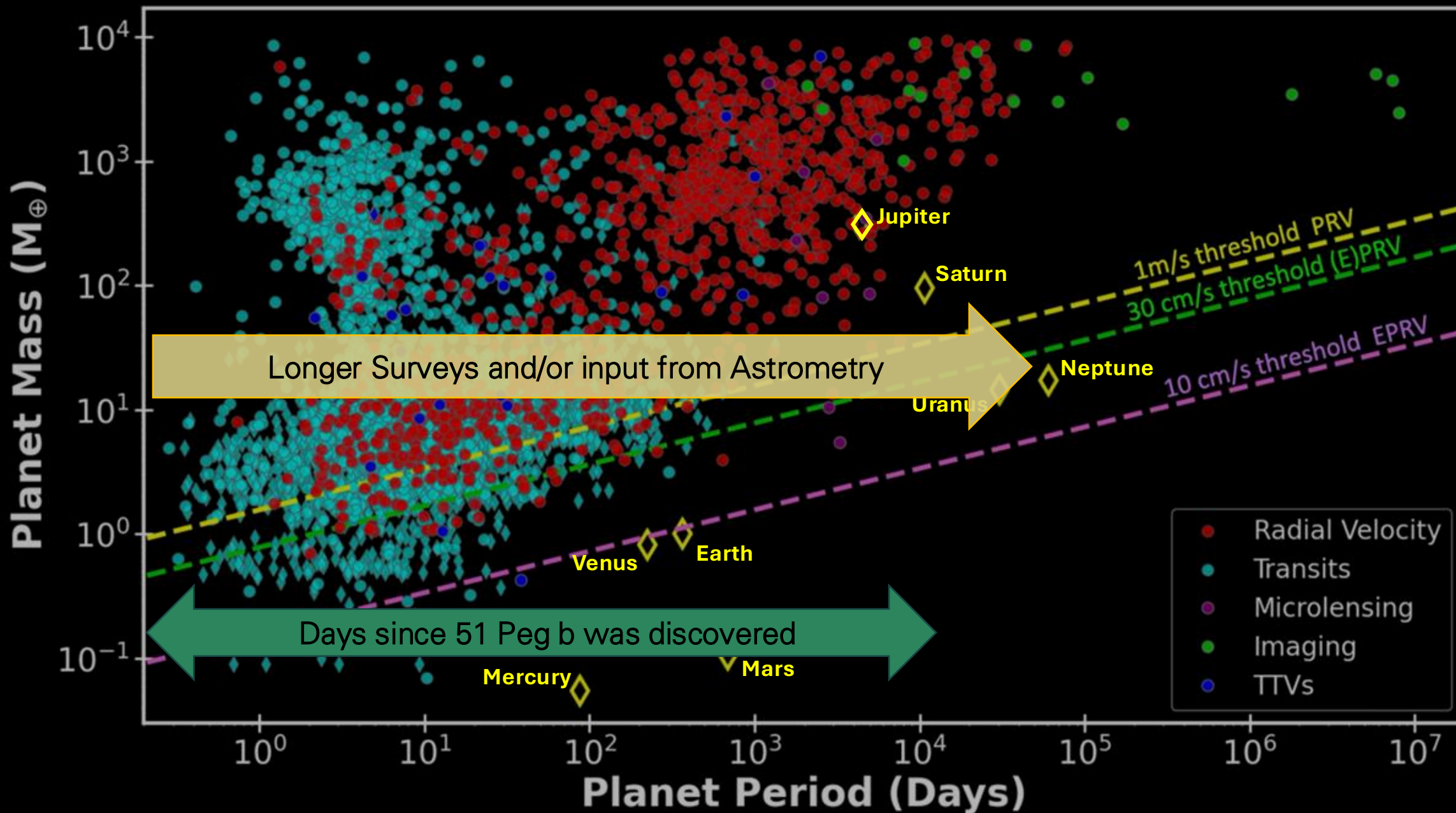
Major Challenges



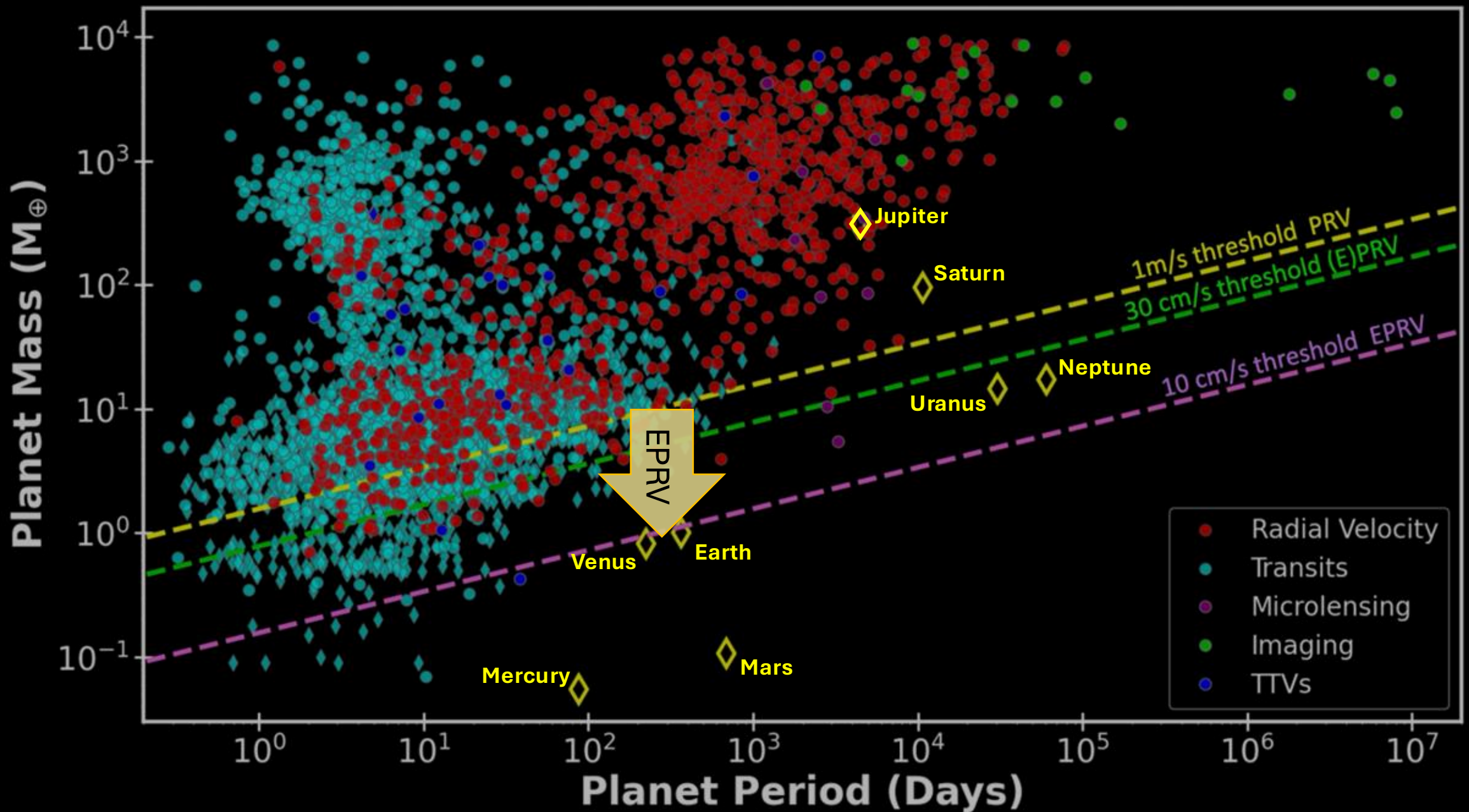
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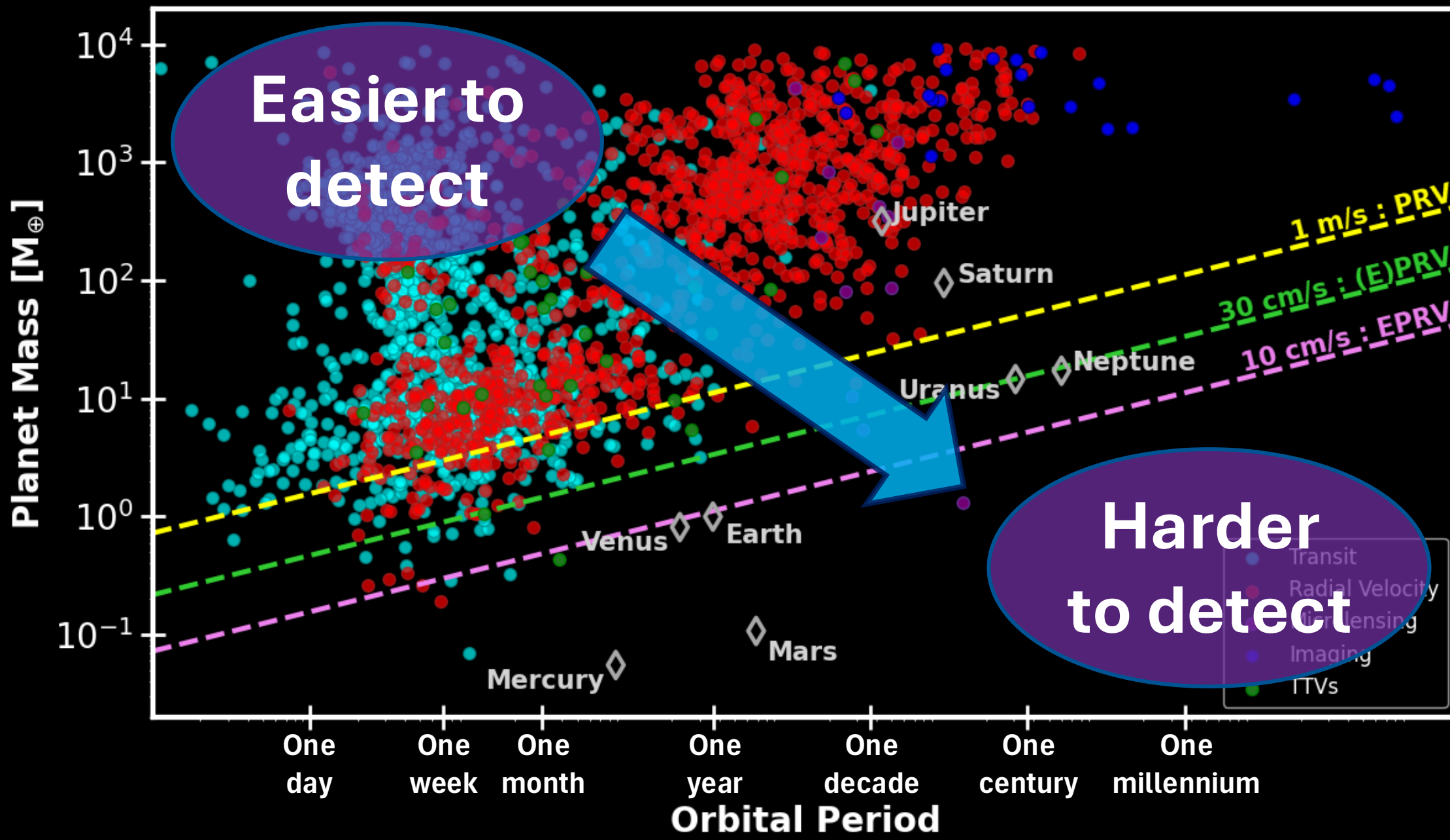


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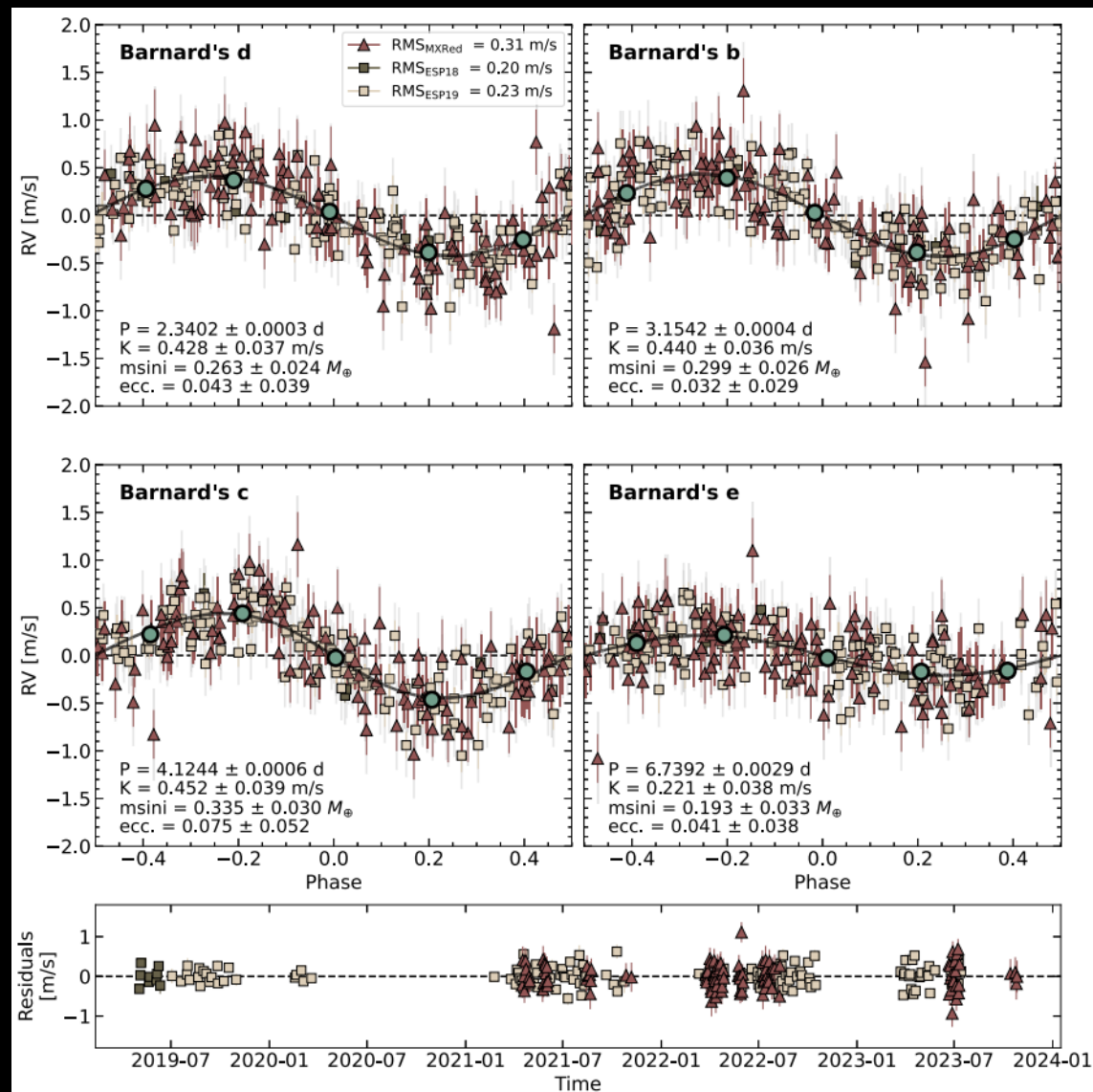
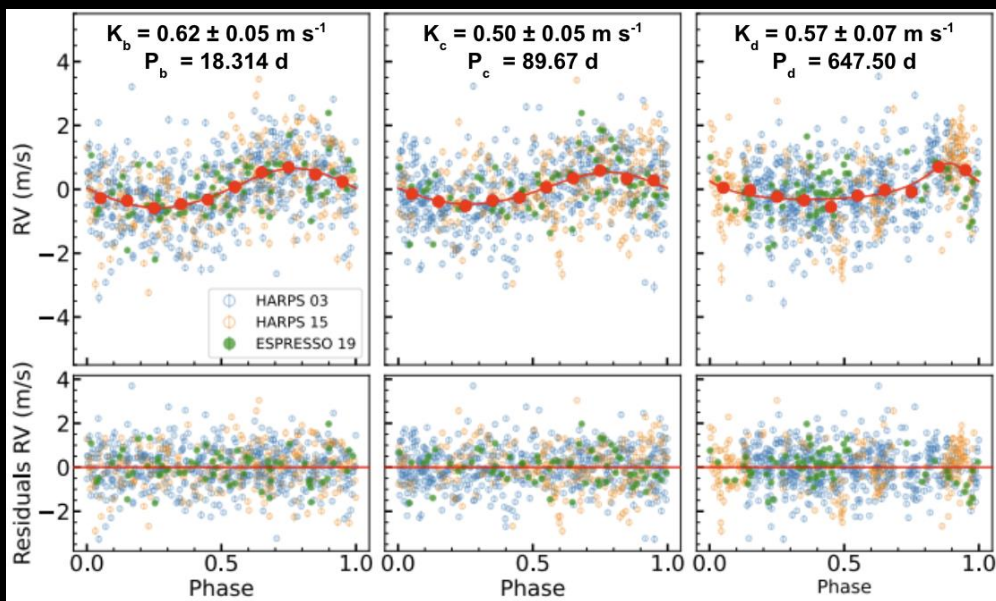
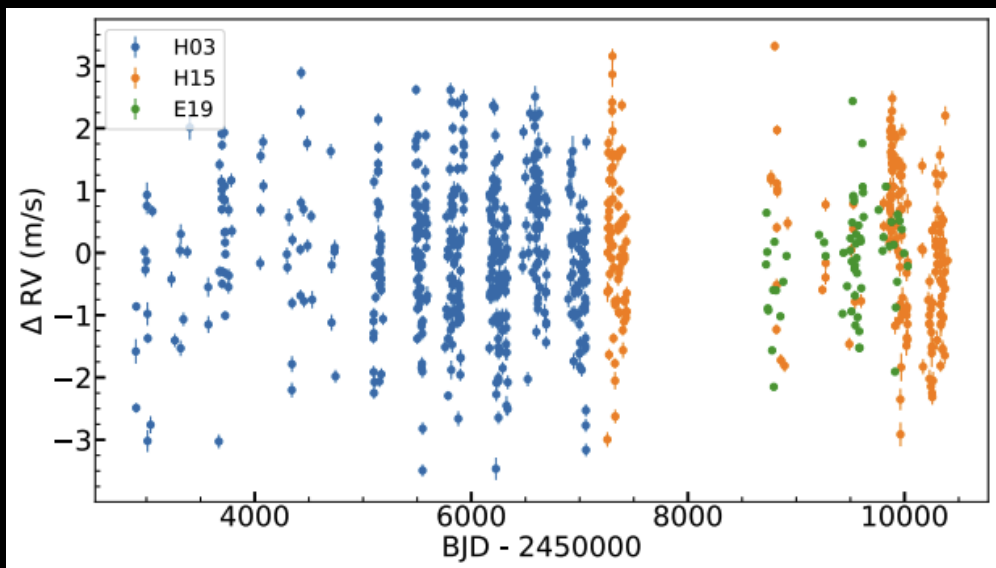


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State of the Field – Pure RV Detections



Basant et al. 2025

RV Uncertainty Contributions

**Current and upcoming
RV instruments capable
of delivering single
measurement precision
 $\leq 1 \text{ m s}^{-1}$ in the visible
or $\leq 3 \text{ m s}^{-1}$ in the NIR**

Instrument	First Light	Bandpass [nm]	Resolution [$\lambda / \Delta\lambda$]	Telescope & Aperture [m]	Reference
HARPS*	2003	380-690	115,000	La Silla 3.6m	Mayor et al. 2003
HARPS-N*	2012	380-690	115,000	TNG [3.6m]	Cosentino et al. 2014
SOPHIE+	2012	380-690	75,000	OHP 1.93m	Bouchy et al. 2013
APF	2014	500-620	110,000	APF [2.4m]	Vogt et al. 2014
CARMENES	2016	520-1710	82,000	Calar Alto 3.5m	Quirrenbach et al. 2014
iSHELL	2016	2180-2470	80,000	IRTF [3.2m]	Cale et al. 2019
IRD	2017	970-1750	70,000	Subaru [8.2m]	Kotani et al. 2018
EXPRES*	2018	390-780	137,500	LDT [4.3m]	Blackman et al. 2020
HPF	2018	800-1270	50,000	HET [10m]	Mahadevan et al. 2014b
PFS	2018	500-620	120,000	Magellan Clay [6m]	Crane et al. 2008
ESPRESSO*	2018	380-790	140,000	VLT [8m]	Pepe et al. 2021
PARVI*	2019	1145-1766	60,000	Hale [5m]	Cale et al. 2023
SPIRou	2019	980-2350	64,000	CFHT [3.6m]	Donati et al. 2020
MAROON-X*	2020	500-920	85,000	Gemini-N [8m]	Seifahrt et al. 2020
NEID*	2021	380-930	115,000	WIYN [3.4m]	Schwab et al. 2016
KPF*	2022	445-870	97,000	Keck I [10m]	Gibson et al. 2024
PARAS-2	2022	380-690	107,000	PRL [2.5m]	Chakraborty et al. 2024
NIRPS*	2023	970-1800	84,000	La Silla 3.6m	Artigau et al. 2024a
HARPS3*	2026	380-690	115,000	INT [2.5]	Thompson et al. 2016
iLocater	2026	970-1310	190,000	LBT [8.4m]	Crass et al. 2022
MARVEL	2026	380-950	135,000	Mercator Obs. [0.8m]	Pember et al. 2022
HISPEC	2026	980-2500	100,000	Keck II [10m]	Konopacky et al. 2023
2ES	2027	370-890	120,000	ESO/MPG 2.2m	Stürmer et al. 2024
G-CLEF	2029	350-950	105,000	GMT [25m]	Szentgyorgyi et al. 2018

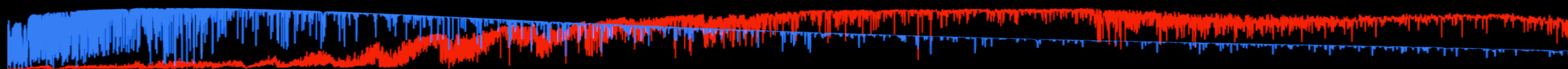
*Spectrographs that have, or are soon adding, a solar feed to allow day time observations of the Sun.

RV Uncertainty Contributions – photon noise

Landscape of high precision Doppler spectrometers

5800 K

2800 K



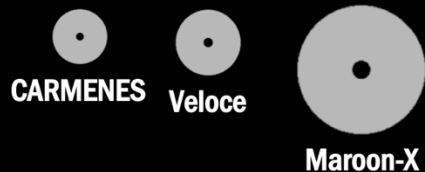
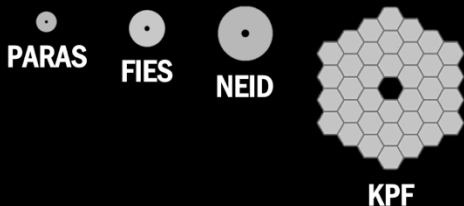
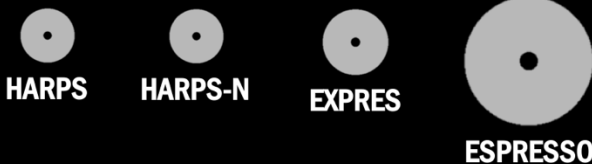
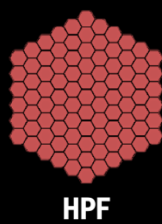
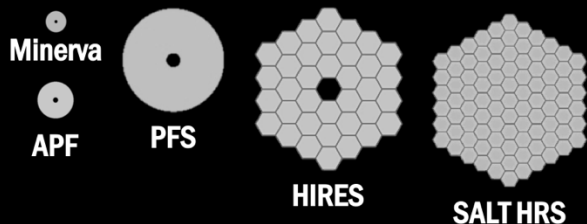
Telluric contamination

Z

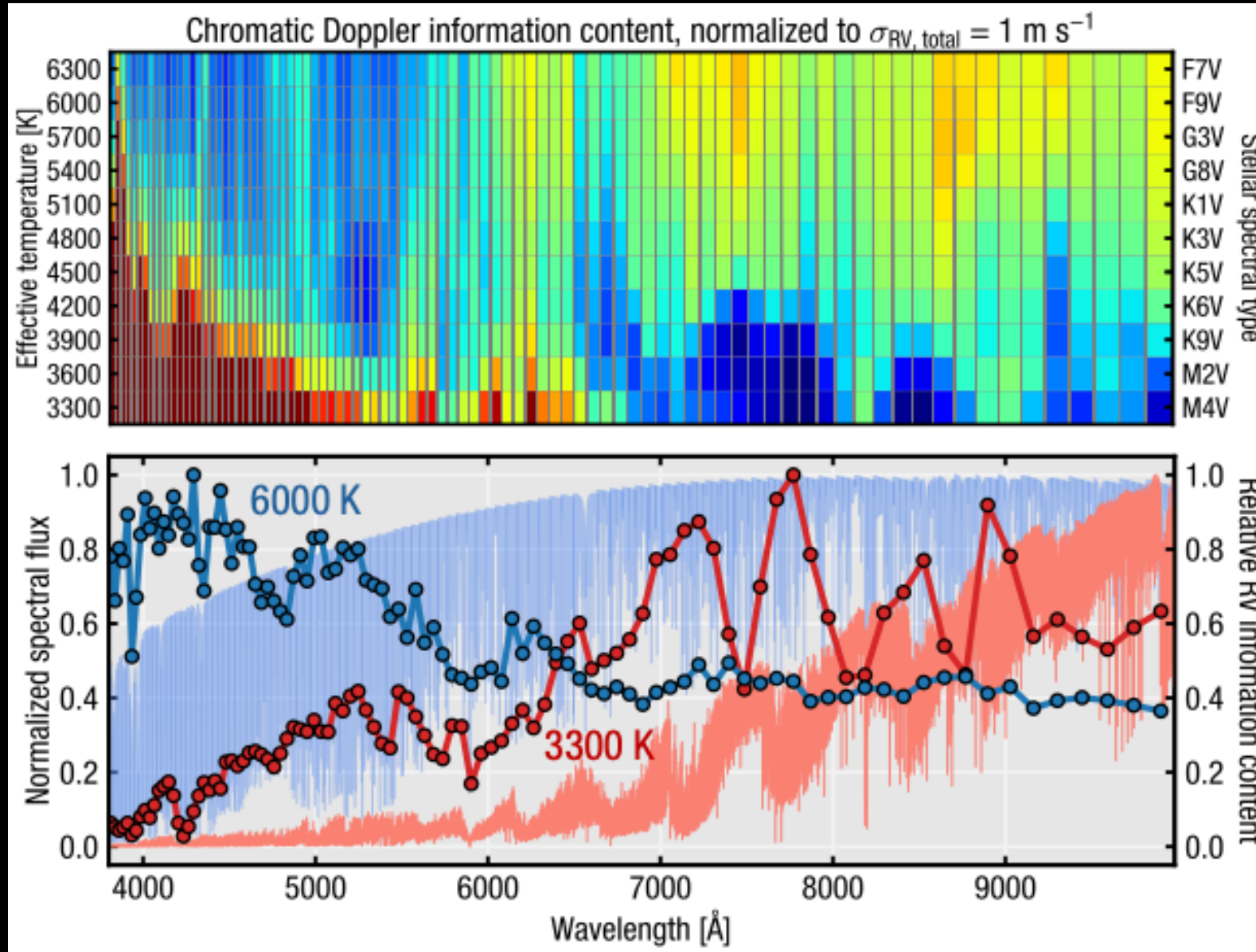
Y

J

H



RV Uncertainty Contributions – stellar information content



State of the Field

