An RV Error Budget & Performance Simulations for the HISPEC Spectrograph

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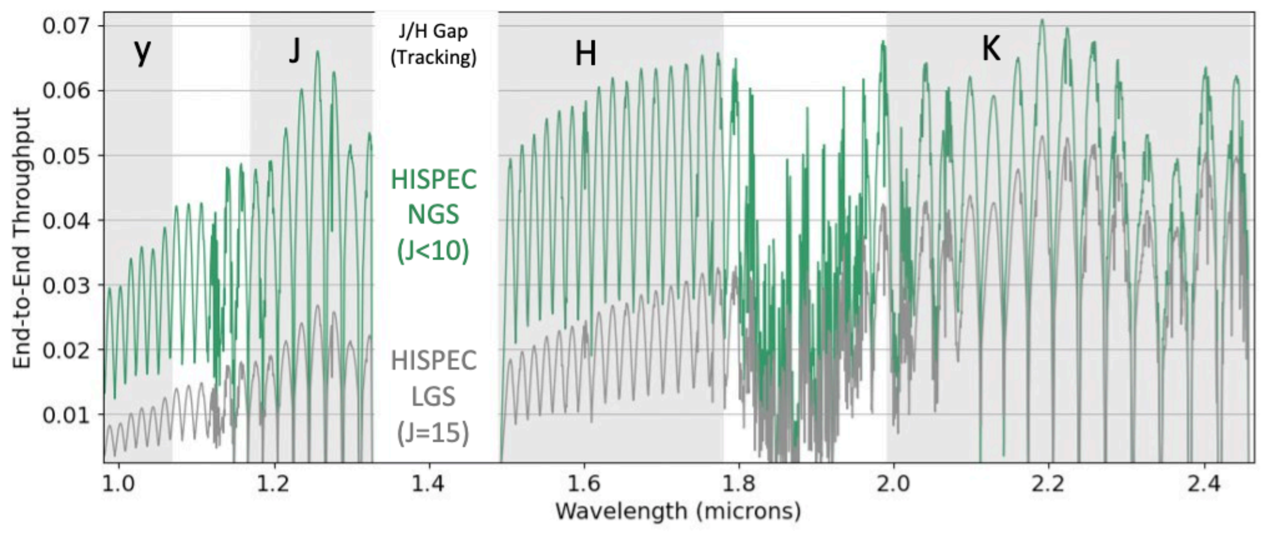
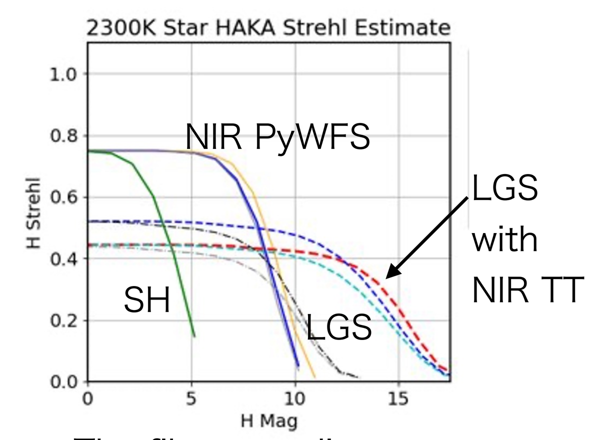
Instrument Specifications

HISPEC Key Properties
Coverage: 0.98 - 2.5um
Resolution: 150k (yJ) 100k (HK)
Fiber: 9um SMF (40 mas on sky)
Sampling: 3 pixel, diffraction-limited
Calibration: LFC, etalon, ThAr/Gas Cell
Simultaneous Cal? Yes
Telescope: Keck II (10 m)
Detectors: H4RG 10 (yJ), H4RG 15 (HK)
Throughput: 3-7% (max NGS AO mode)
Design: All reflective TMAs, 3 fiber traces

HISPEC is a NIR single mode fiber-fed stabilized spectrograph for the Keck II telescope with the sub m s^{-1} RV precision goal. See Dimitri Mawet's poster or Nem Jovanovic's Talk for more details.

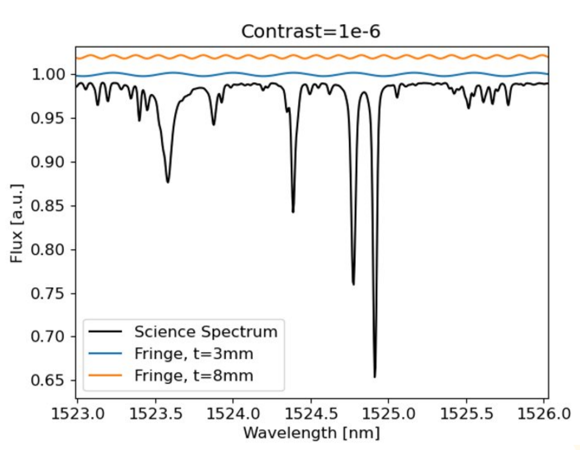


Throughput of HISPEC for natural guide star mode (NGS, using a Shack Hartmann) and laser guide star (LGS) at the faint limit of J=15. .

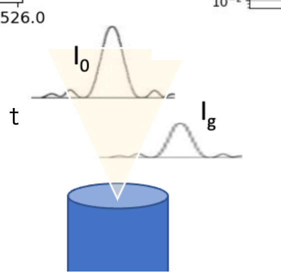


The fiber coupling was determined with simulations and rely on the HAKA AO upgrade for Keck.

Fringing

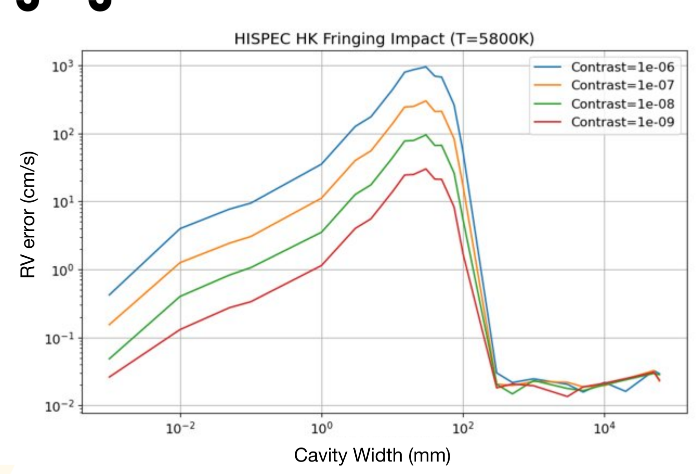


Fringe impact was simulated at the 1D level assuming variable etalon thickness, t



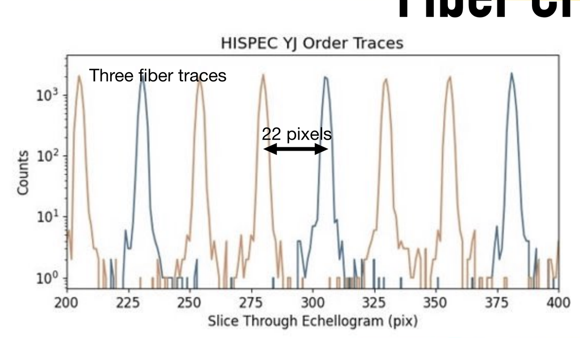
$$\phi = \frac{4\pi}{\lambda} nt$$

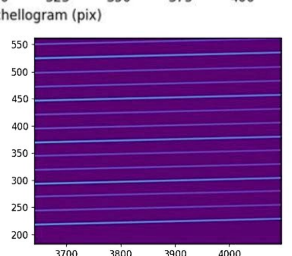
$$I = I_0 + I_g + 2\sqrt{I_0 I_g}\cos\phi$$



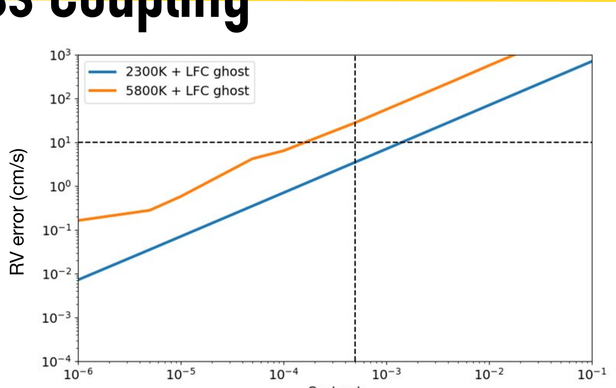
The fiber injection transmissive optics will be wedged to reduce the coupling of the coherent fraction of the ghosts. The goal is for the ghost to science contrast to be <3e-9 for each optic.

Fiber Cross Coupling





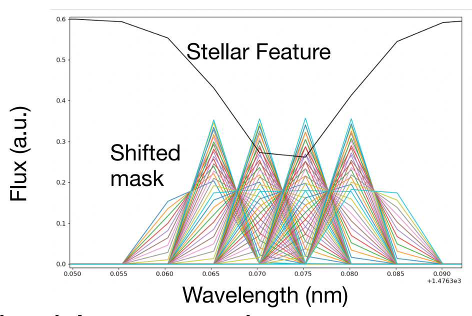
Cross coupling was estimated for using PyEchelle to be ~0.05% before alignment errors, which at most could double the value.



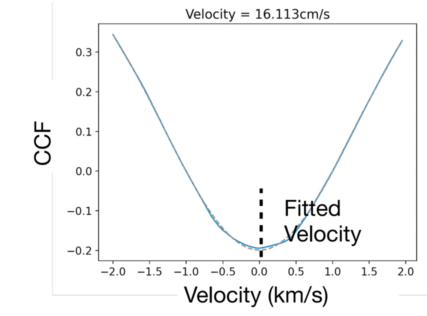
RV error versus the contrast of LFC cross talk relative to the extracted science light. We plan to reduce cross talk further in post processing.

Simulation Techniques

Some terms were evaluated using CCFs starting at data at the 1D level. The CCF code was inherited from Roy & Halverson.

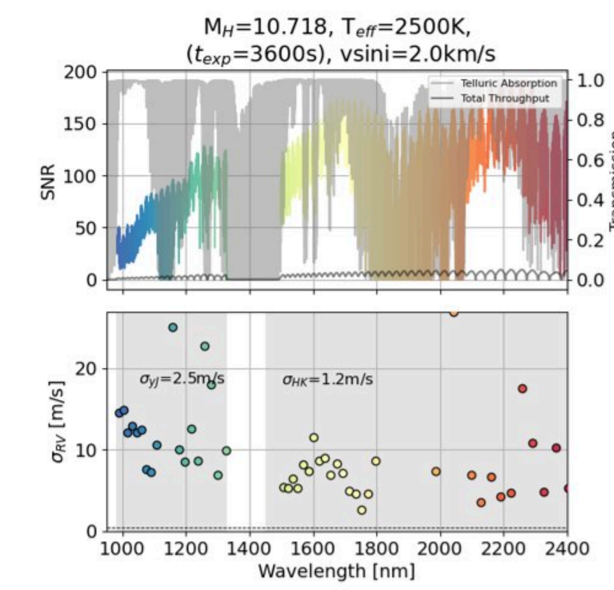


Stellar binary masks were generated from the Phoenix spectra themselves - these were cross correlated against the model spectrum before/after inducing spectral noise sources.

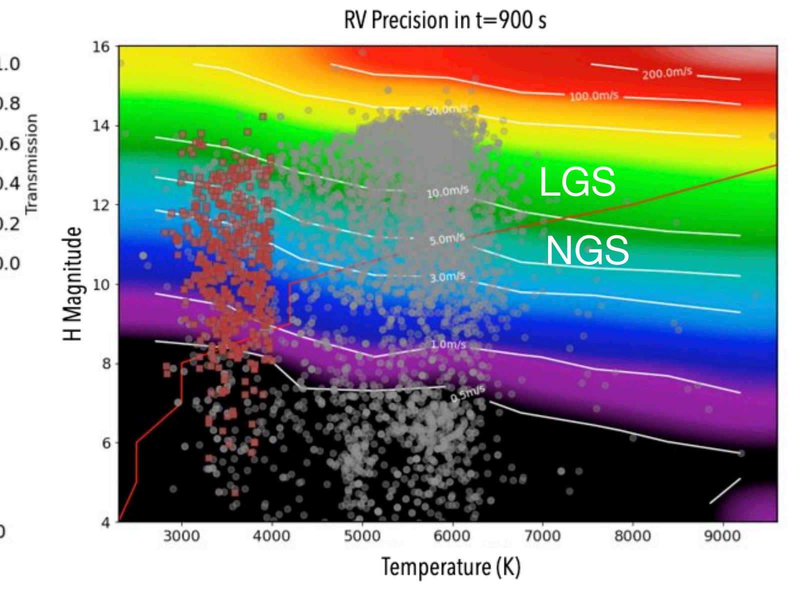


The resulting CCFs are fit with a Gaussian to determine the central RV.

Photon Limited Performance

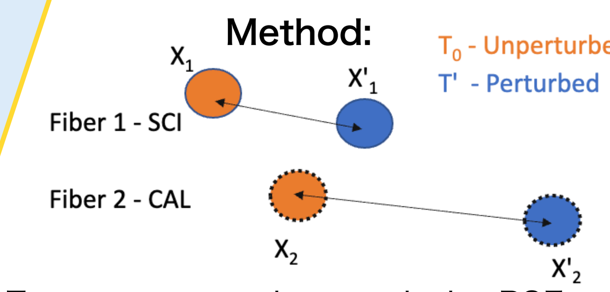


Simulated RV performance of TRAPPIST-1 assuming a 50 cm/s noise floor. The photon-noise limited RV precision follows the methods of Bouchy et al. 2001 masking tellurics >1% deep.



The expected RV precision for a 900 sec exposure with HISPEC on stars of a range of magnitudes and temperatures. Gray points show confirmed planets and brown squares are TOIs with T<4000K.

Thermo-mechanical



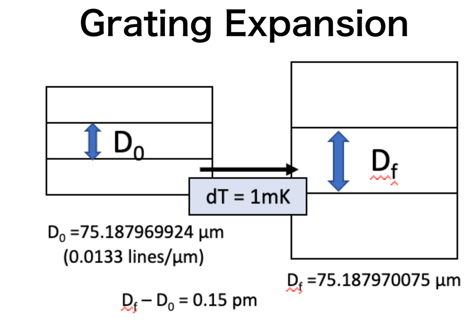
Zemax was used to track the PSF centers across multiple orders - the absolute shift and the shift relative to the calibration trace was recorded after thermal movements.

Global Optics Movements from dT=1mK change.

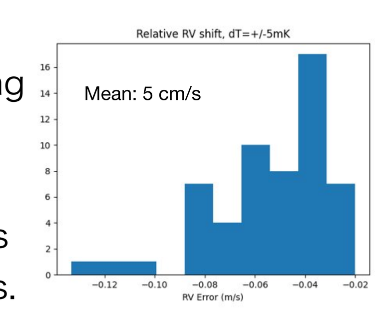
(dT = 1mK)	Fiber	Coll. TMA-1	Coll. TMA-2	Coll. TMA-3	Pupil	Cross DIsp.	Cam. TMA-1	Cam. TMA-2	Cam. TMA-3	Detector
dX (nm)	0.30	0.39	0.41	0.26	0.43	0.22	0.20	0.30	0.152	0.40
dY (nm)	0.12	-0.25	0.049	-0.04	0	0.22	-1.0	1.16	-1.25	1.23
dZ (nm)	0.02	-0.24	0.07	-0.20	0	0.47	-2.85	2.52	-3.28	2.5

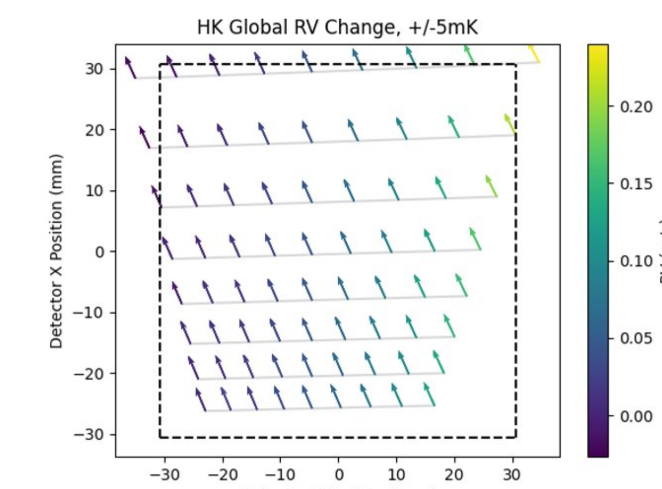
Optics offsets for a 1mK temperature change as determined in a SolidWorks analysis. Rotations are negligible in this model framework that does not consider gradients.

Grating Expansion

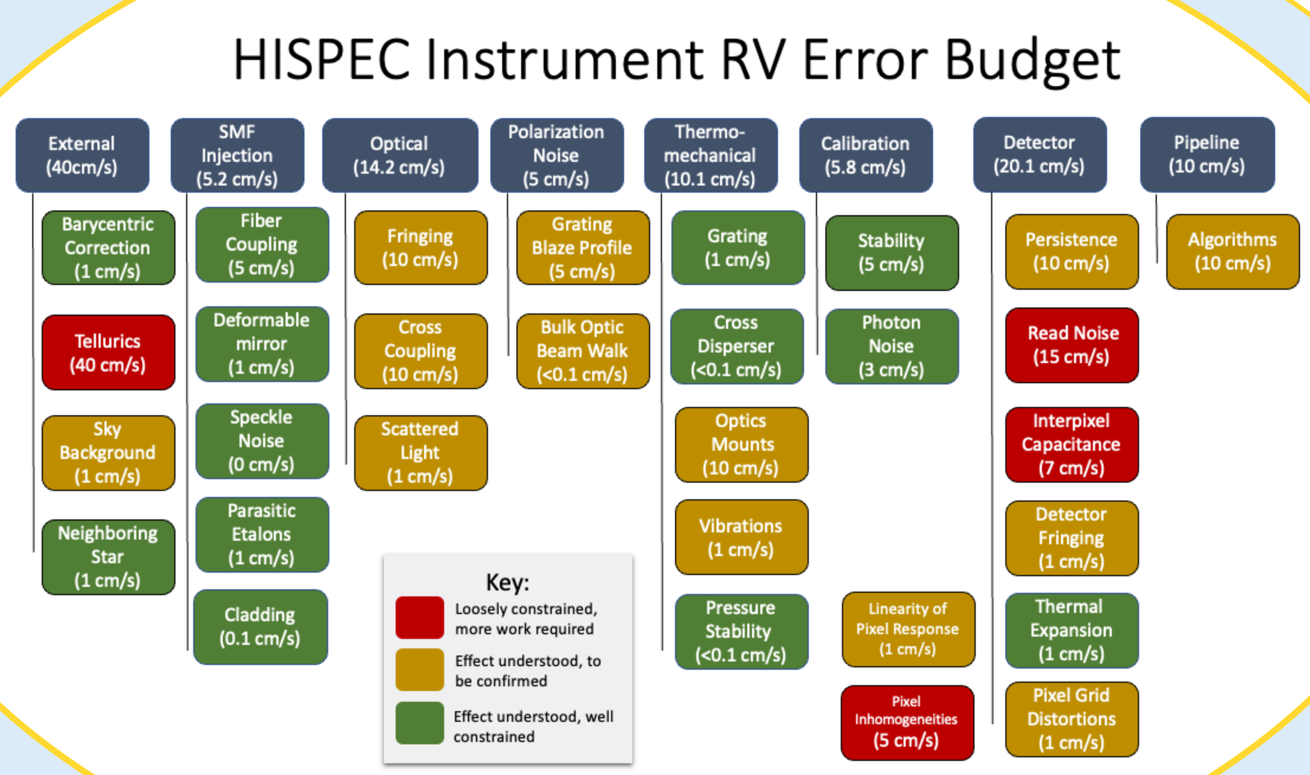


HISPEC's echelle grating is germanium (CTE=2e-6/C). Expansion causes cm/s RV changes.





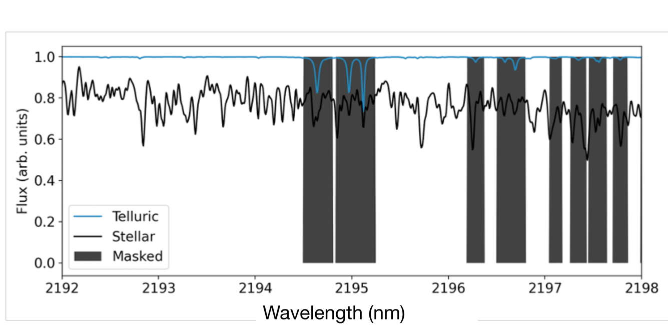
Thermal stability relative to calibration trace is **6 cm/s on average for 10mK peak-to-peak**. HISPEC's goal is 1mK RMS stability, and more thermal analyses are planned.



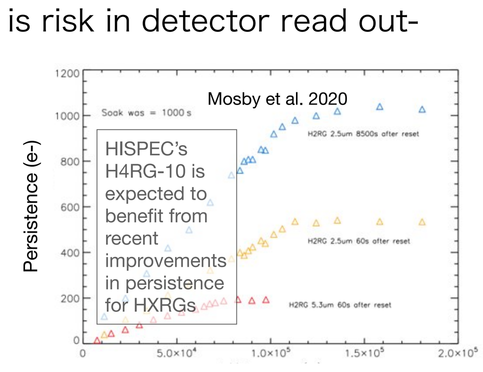
High Risk Terms

HISPEC holds RV error terms relevant to all NIR spectrographs: tellurics and NIR detector effects.

Tellurics Sub m/s on-sky RV performance has not yet been demonstrated in the NIR, largely due to Earth's atmosphere. For photon-noise limited RV estimates we mask 10km/s around tellurics deeper than 1% and hold 40 cm/s for the systematic error due to micro-tellurics. This is ambitious but our goal for HISPEC's DRP and will build on work done for PARVI, SPIRou, and other NIR PRV instruments.



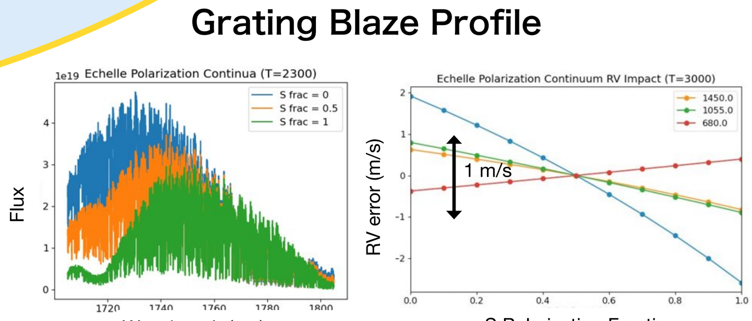
Detector Effects HISPEC's detectors are an H4RG-10 for BSPEC (yJ) and an H4RG-15 for RSPEC (HK). HISPEC will characterize the detectors before integrating them into the spectrograph. There is risk in detector read out-related noise (e.g. 1/f noise, alternating column noise), inter pixel capacitance, and the persistence of the detector. Detector noise terms were referenced from Bechter et al. 2020.



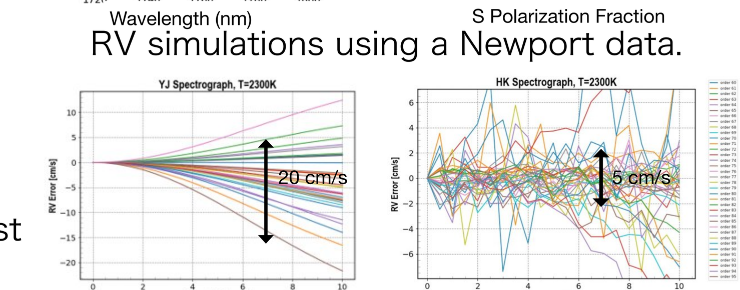
Polarization

Grating Blaze Profile

It is known uncorrected blaze changes leave m/s errors. HISPEC will blaze correct as the baseline correction, but is investigating polarization scrambling options. Other continuum changes (e.g. fiber coupling) show 5 cm/s post correction is possible, but more validation is needed.

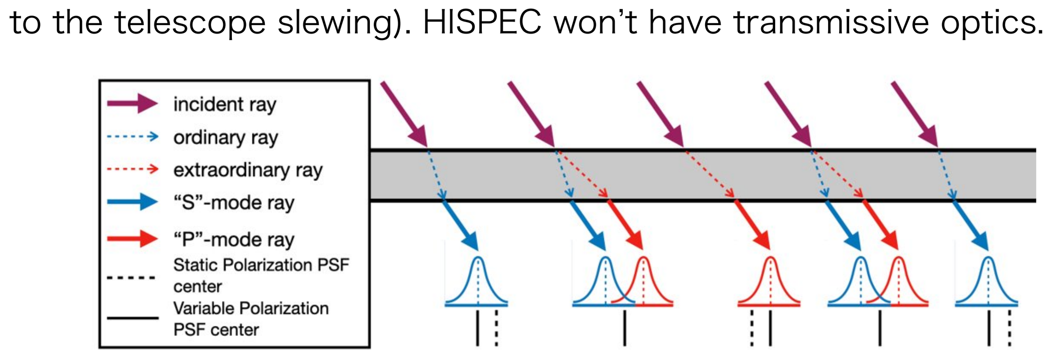


RV simulations using a Newport data.



RV before and after continuum correction.

Bulk optic beam walk can be due to birefringence in transmissive optics. Any optic deflecting the optical path angle differently between two polarization modes (e.g. a prism) would cause a shift of the spots on the detector as the polarization fraction of light changes (e.g. due to the telescope slewing). HISPEC won't have transmissive optics.



See talk by Rose Gibson for more details.

Acknowledgements

We thank Gautam Vasisht and Bryson Cale for providing useful information about PARVI, Andrew Bechter for his communications about I-Locater RV simulations, Julian Stürmer for help with PyEchelle, and Roger Smith for conversations on NIR detectors.

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