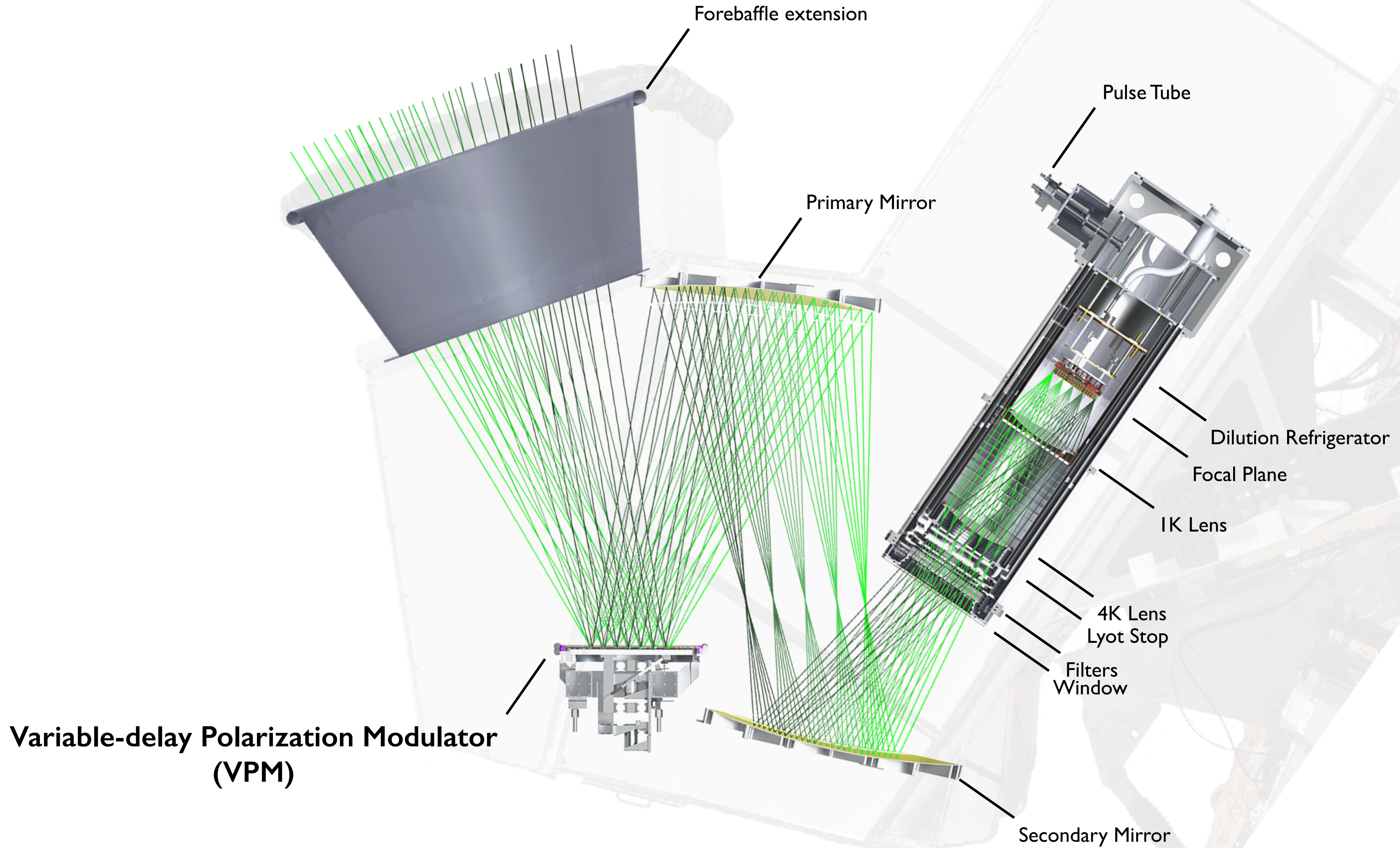


Efficacy of the Variable-delay Polarization Modulator

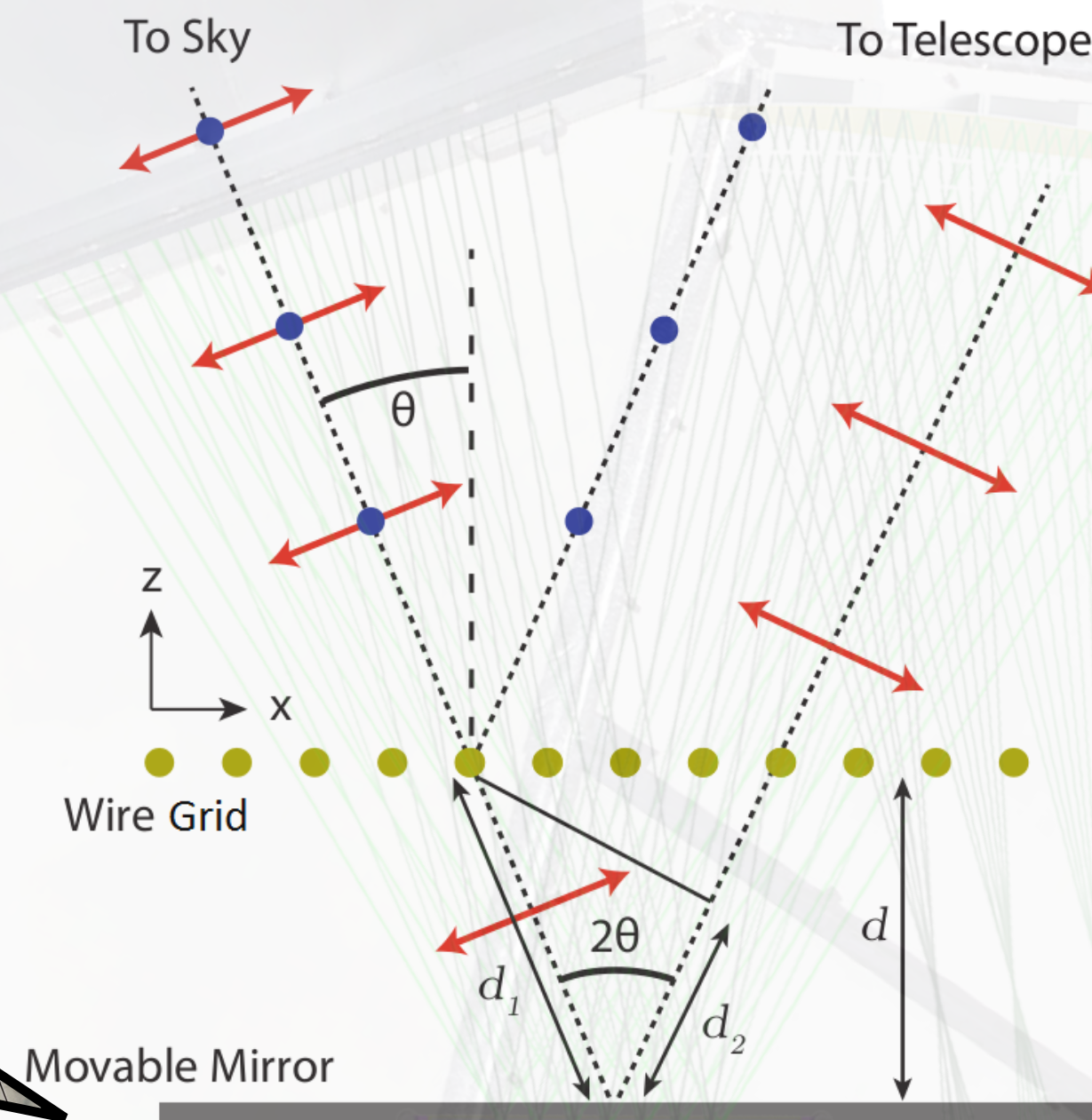
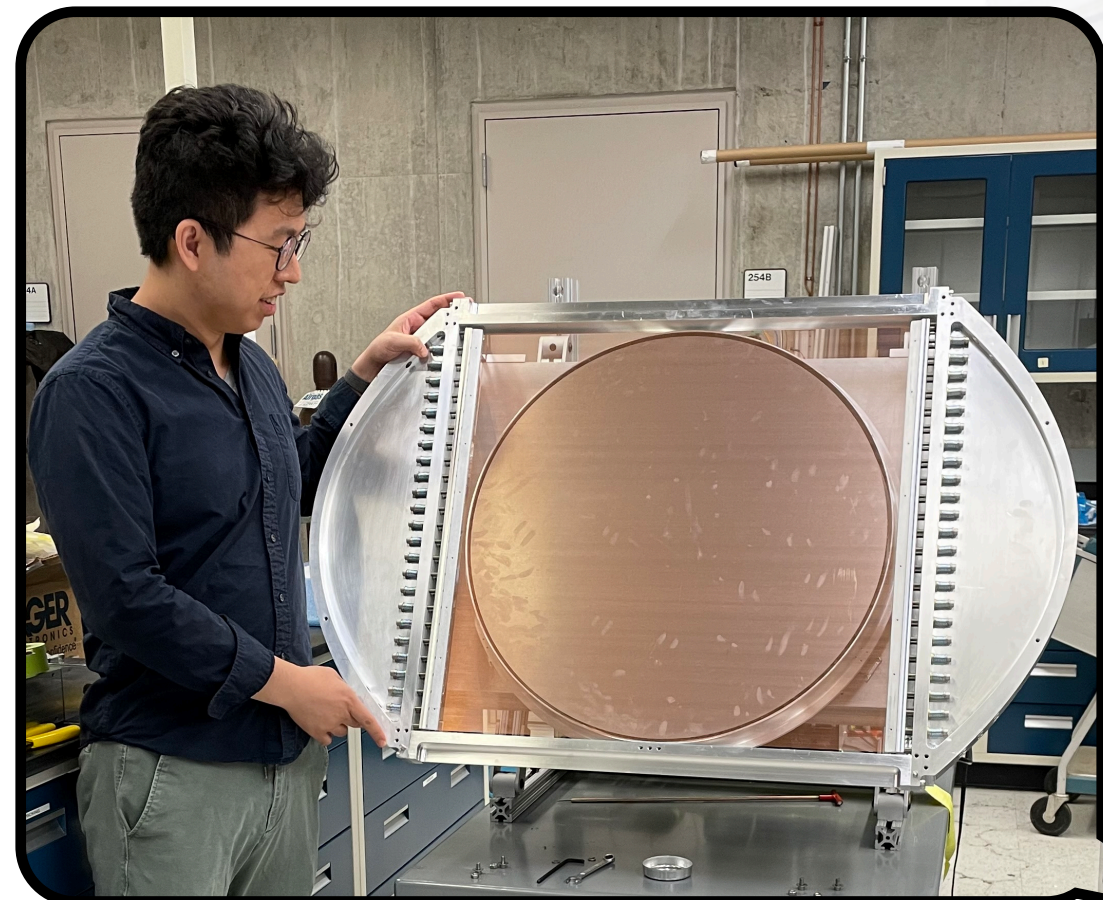
Lessons Learned from CLASS

Yunyang Li on behalf of the CLASS Collaboration



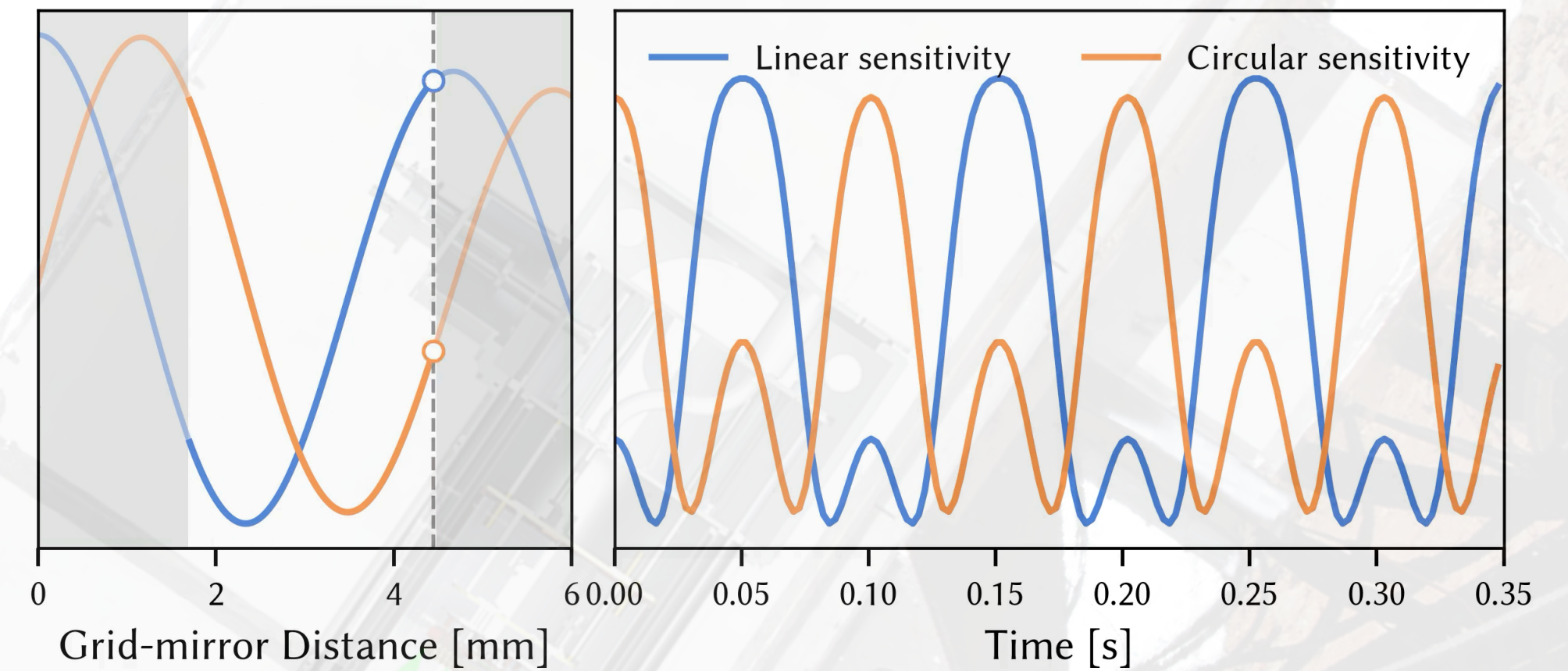


Variable-delay Polarization Modulation

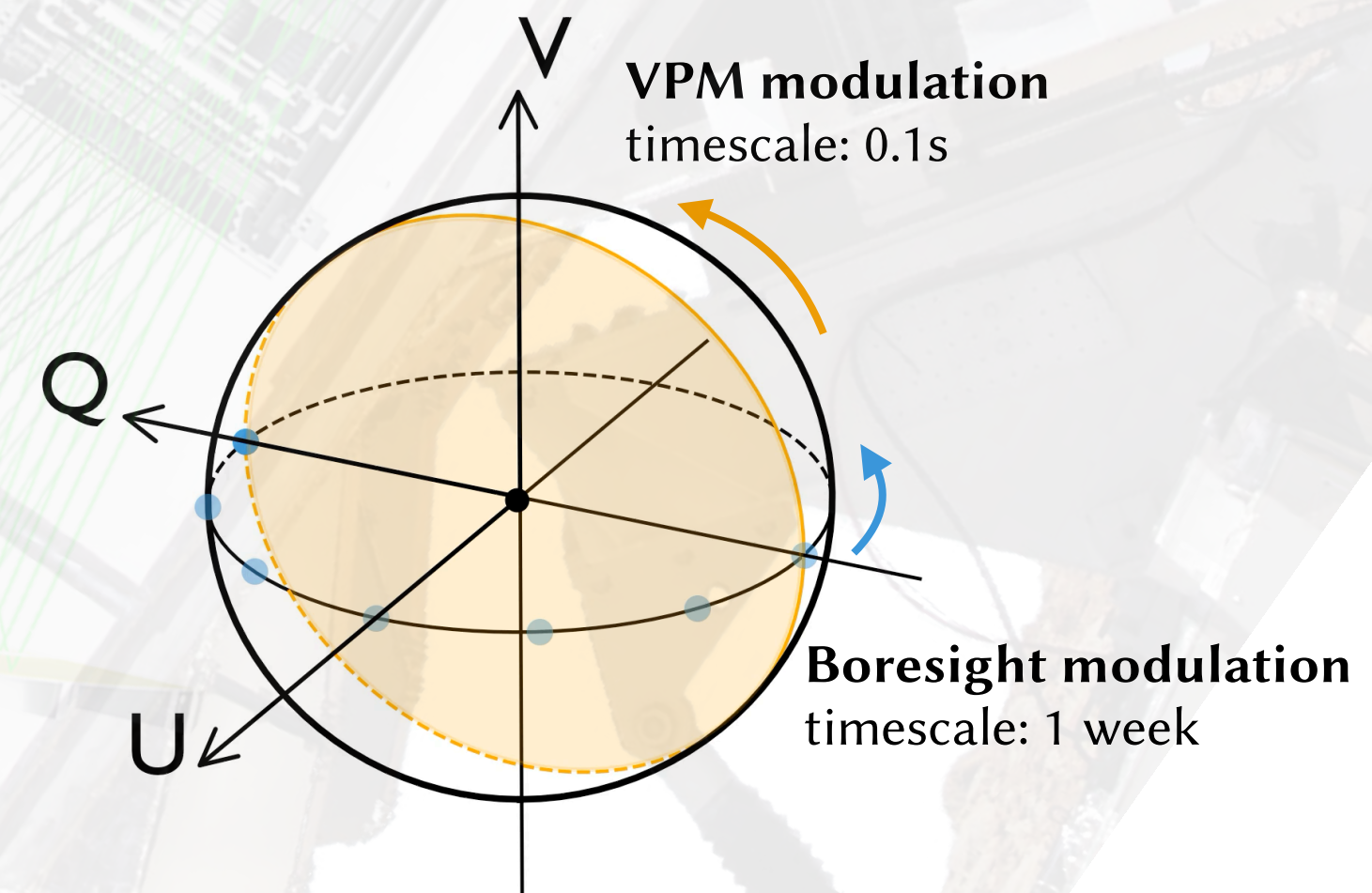


J. Eimer

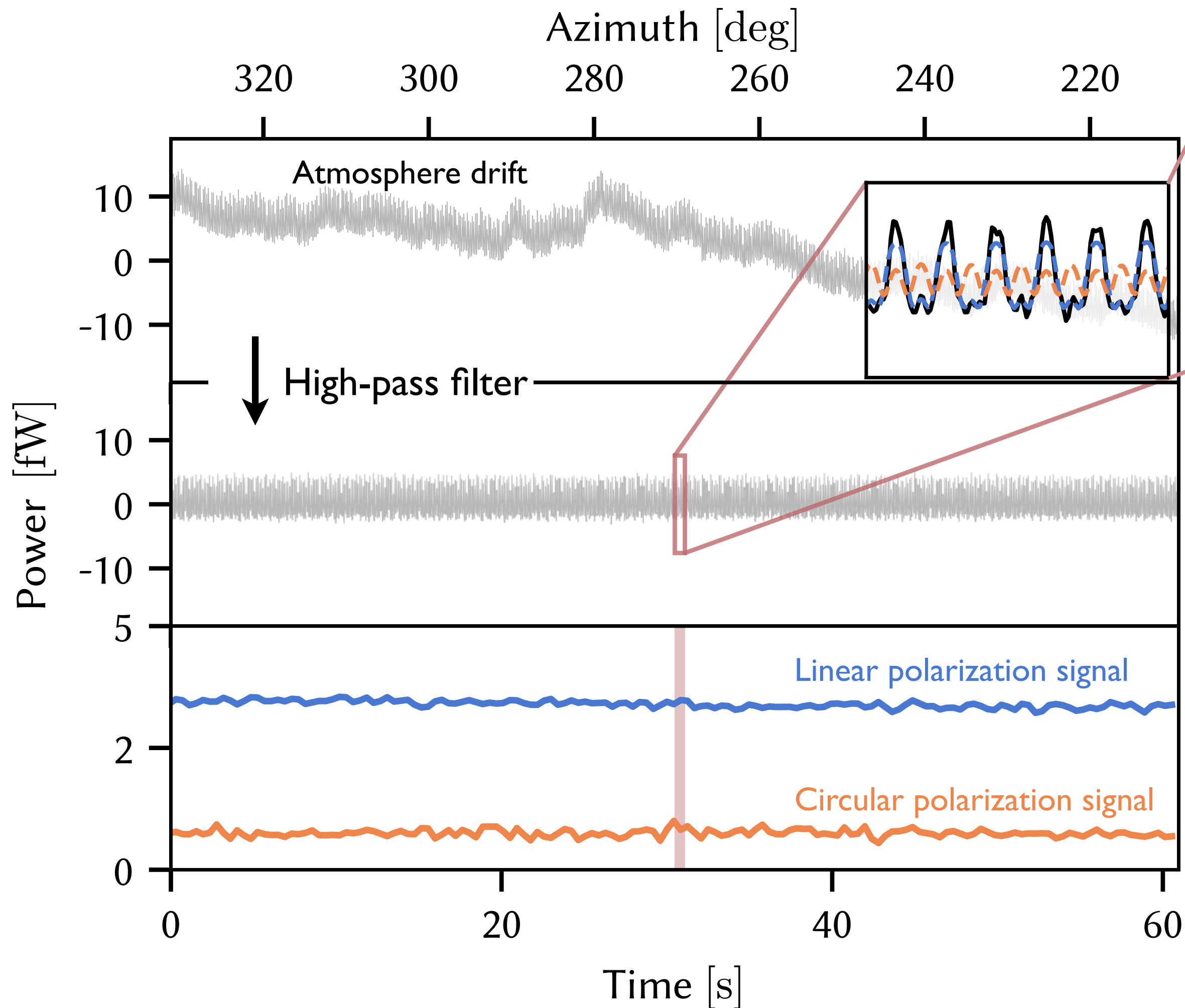
$$\text{Linear pol. phase delay: } \phi = \frac{4\pi d \cos \theta}{\lambda}$$



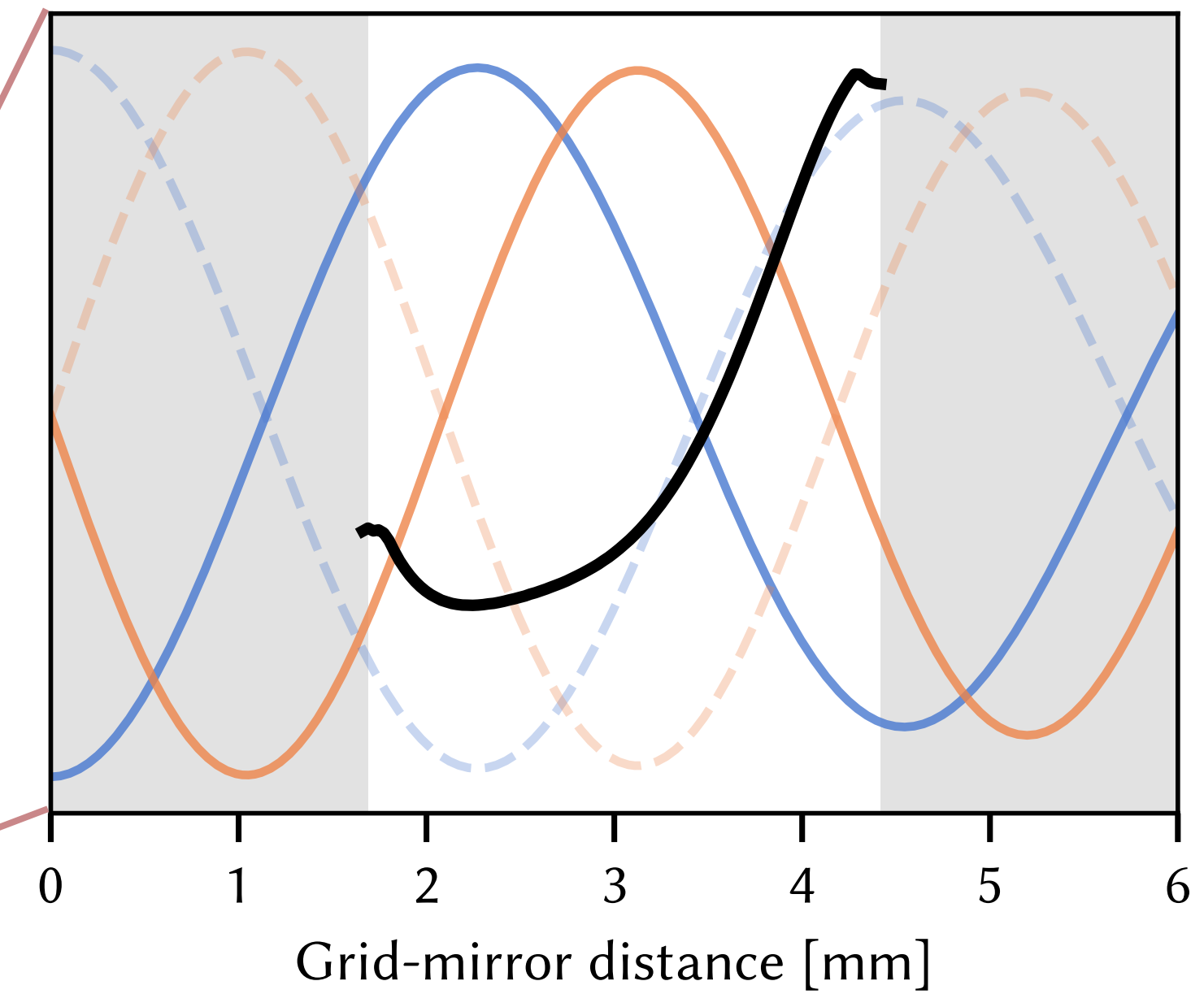
- Front-end modulation with $\gtrsim 70\%$ linear polarization efficiency.
- Sensitive to circular polarization as well!
- Boresight rotation needed for polarization angle sampling.



VPM: Demodulation and Emission



VPM Synchronous Signal (VSS)



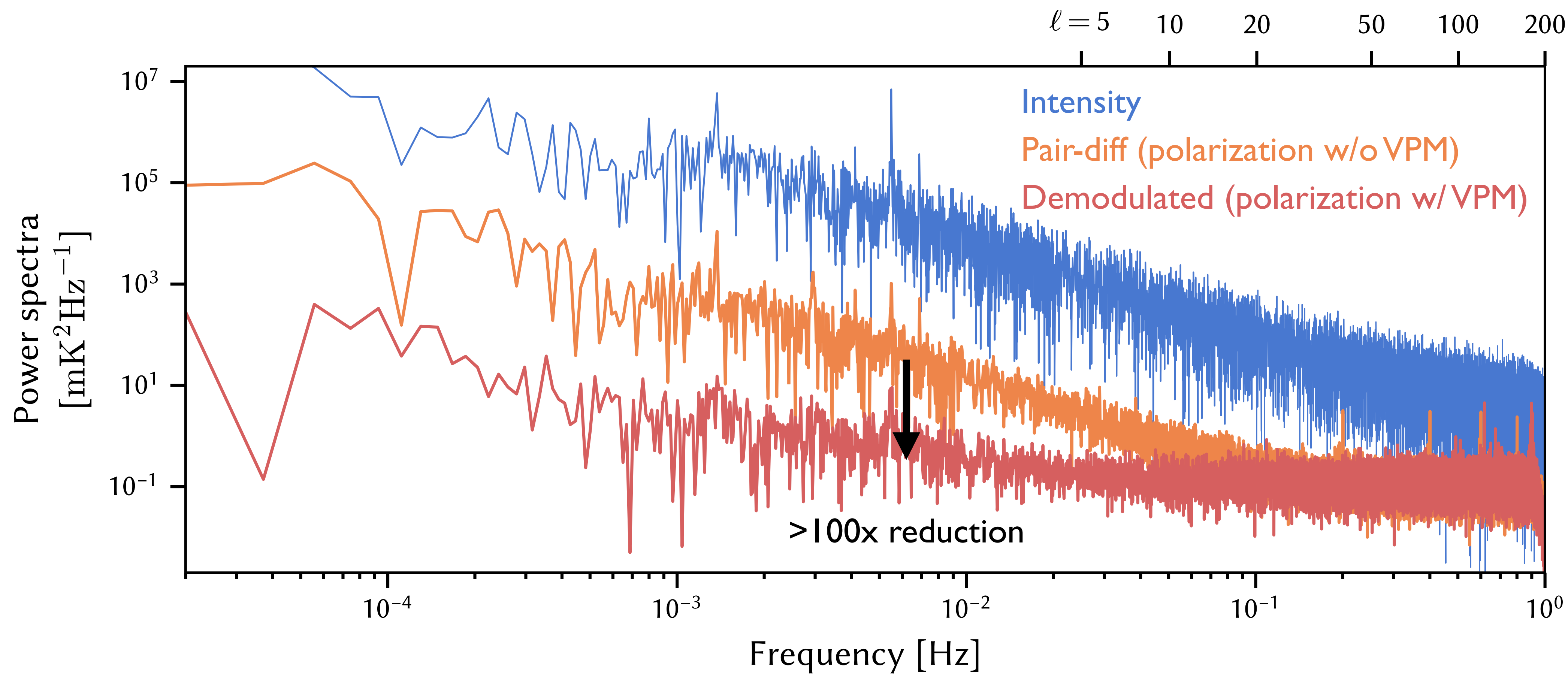
VPM emits *at same frequency* as polarization modulation.

Demodulation *does not account* for the VSS, therefore, VSS \rightarrow DC levels in demodulated polarization data.

- *Stable*: does not significantly impact I/f.
- **Contribute** to the *scan synchronous noise*.
- **Intensity-like**: *cancels upon pair-diff.*

VPM: Results

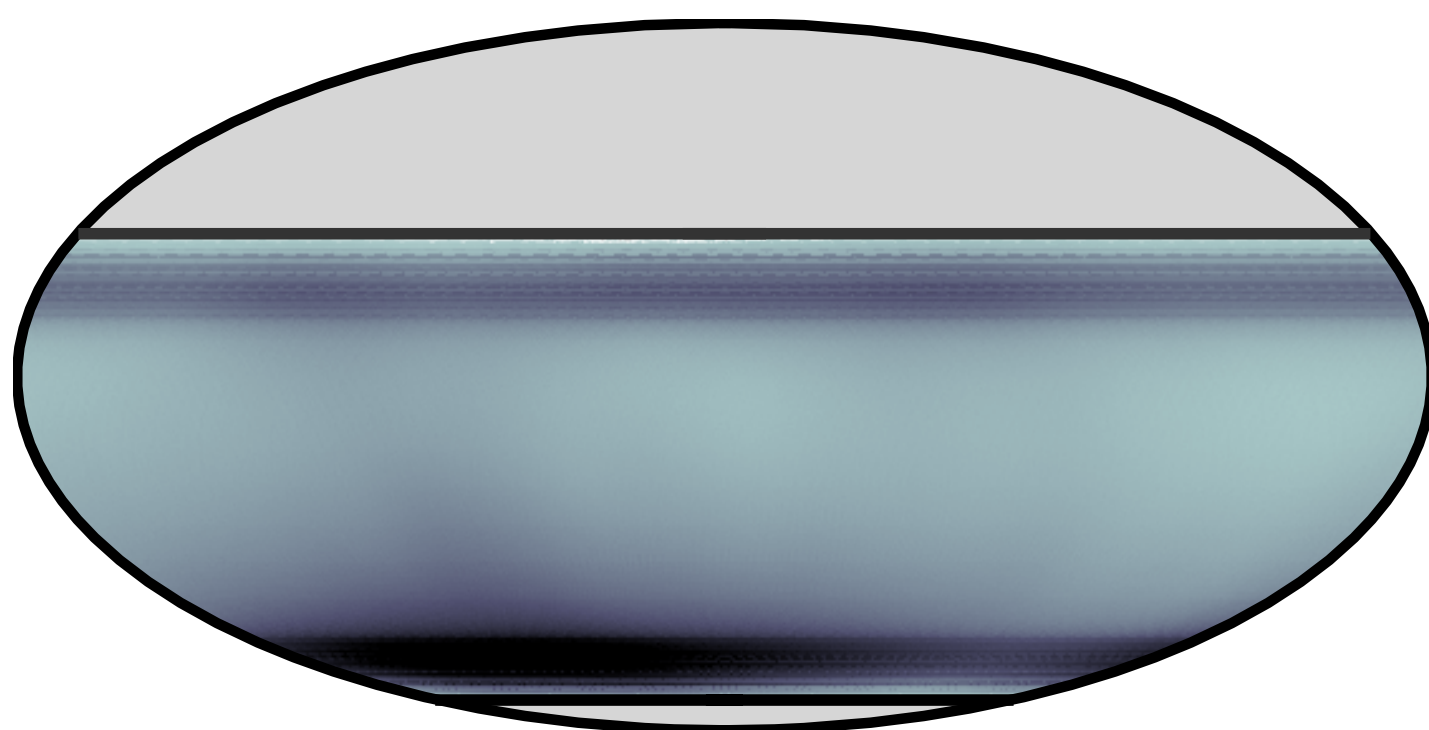
Modulation reduces noise power at <10 mHz by over *two orders of magnitude* compared to pair-differencing unmodulated detectors.



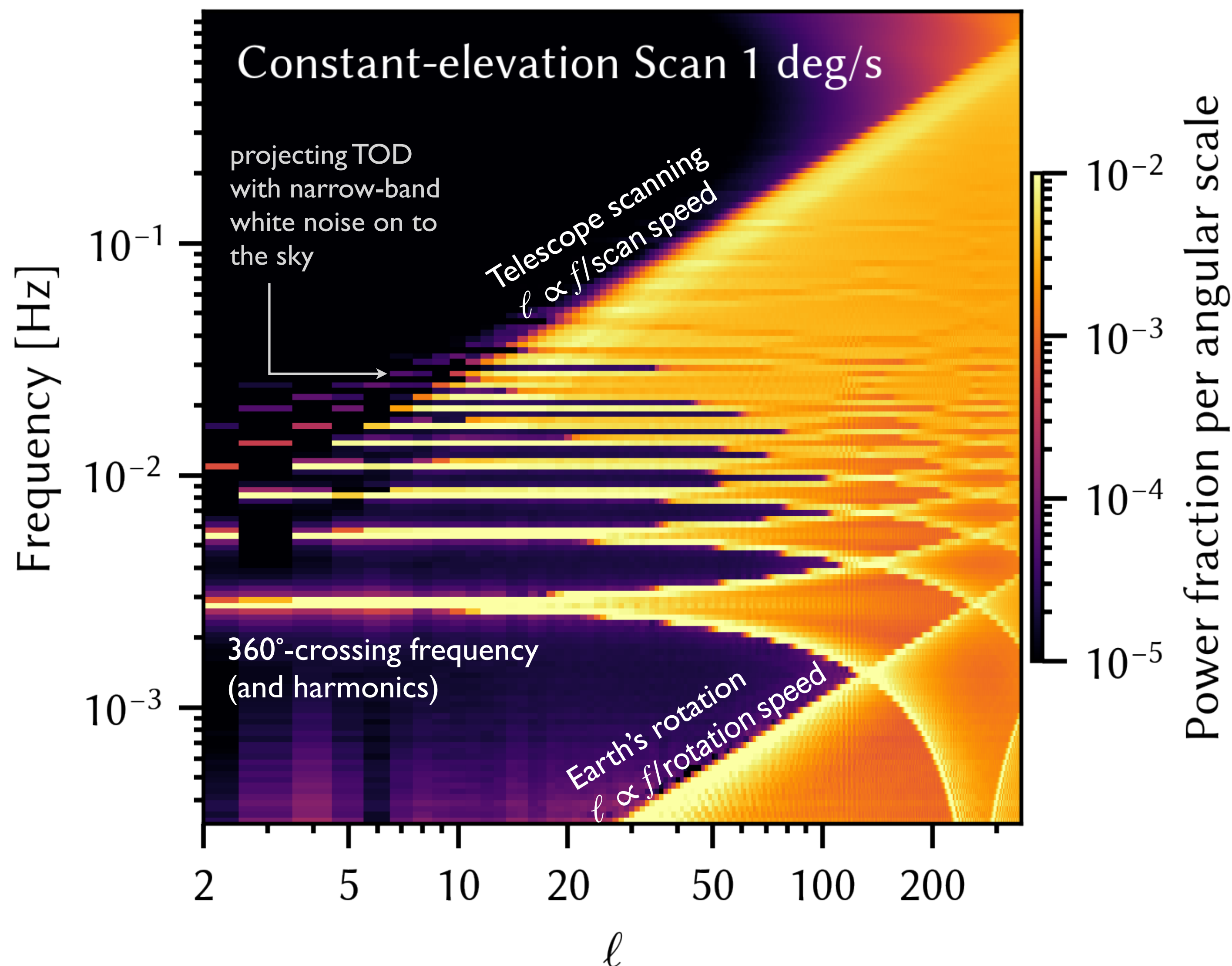
Harrington+(2021) Adapted

Mappings between Fourier & Harmonic modes

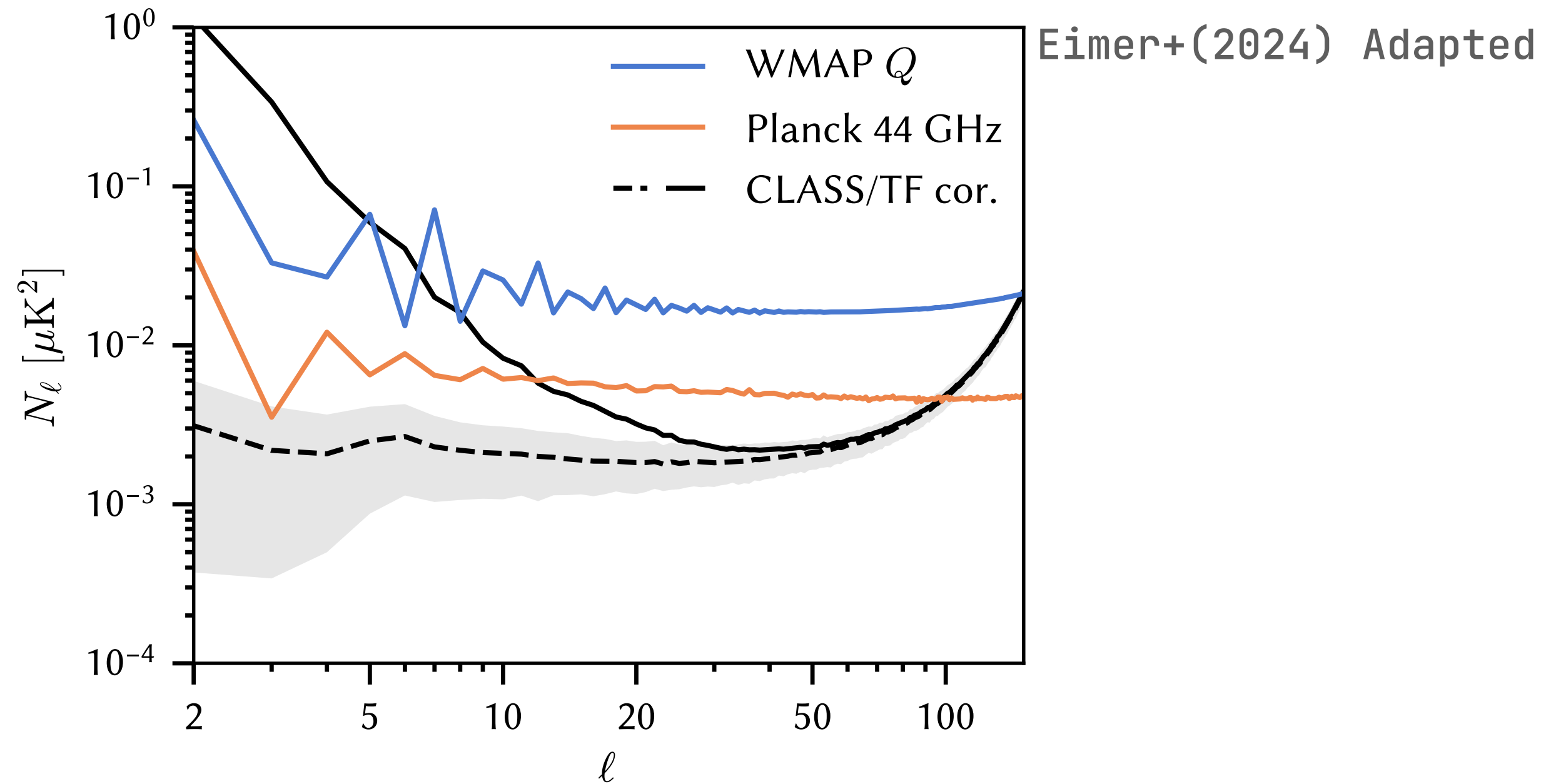
Continuous constant-elevation scans



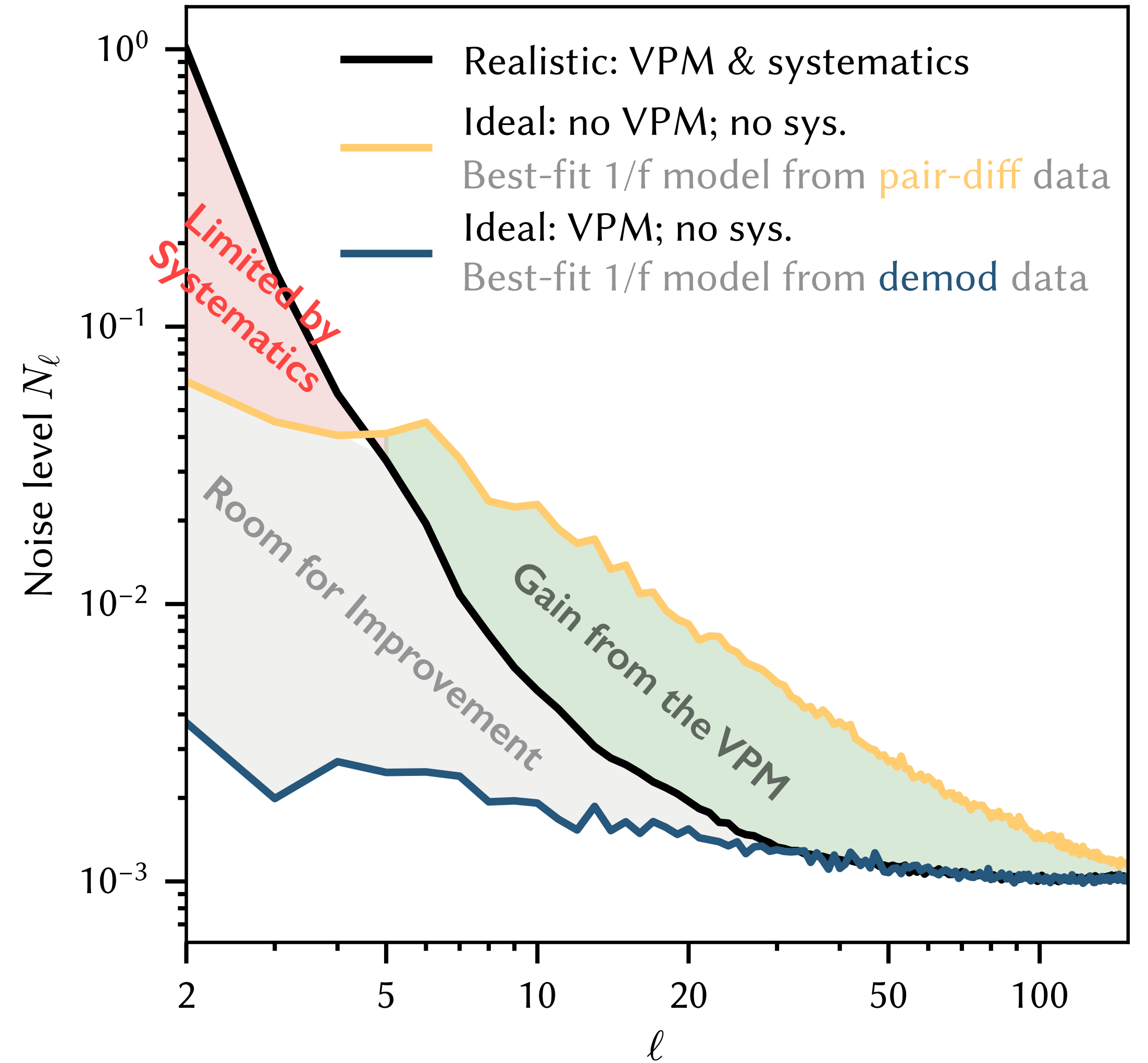
- Both the *Earth's rotation* and *telescope scanning* contribute to large angular scales ($\ell > 20$)
- Most of the *largest angular scales* ($\ell > 2$) comes from the scanning frequency and its harmonics.
- Systematics at these frequencies are more concerning than just $1/f$.



Breakdown of the 40 GHz sensitivity



- VPM significantly improves the map level $1/\ell$ noise up to $\ell < 150$.
- The largest angular scales ($\ell < 10$) are limited by systematics (filtering corrections primarily associated with scan-synchronous noise).



Cleary+(2024) Adapted

Summary

- VPM modulates *linear* (70% efficiency) and *circular* polarization.
- VPM increases low frequency mapping speed by *over two orders of magnitude*.
- VPM emission leaks into demodulated polarization signal
 - Does not significantly contribute to 1/f noise.
 - Contributes part of scan synchronous noise (mostly canceled with pairs).
- After 1/f noise is mitigated, residual *scan synchronous noise* is the primary challenge to largest angular scale measurement.
 - Paper in preparation on 2016-2023 data on characterization of possible sources.
 - 2023-2024 higher elevation scans to probe ground pickup.
 - New RHWP modulator just installed to investigate modulator systematics.
 - Further study of atmospheric polarization.