Infer solar wind evolution from remote observations

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Difference between in situ and remote

$$S(k) = \int d\ell\, e^{-ik\ell} R(\ell)$$

$$R(\ell) = \langle f(x) f(x+\ell) \rangle$$

The power spectral density is defined as the Fourier transform of the autocorrelation function

BUT

When integrating along LOS, the field is no longer *f*, it is

$$\bar{f} = \int d\gamma\, w(\gamma) f(\gamma)$$

weights

integration path

$$R'(\ell) = \langle \bar{f}(x) \bar{f}(x+\ell) \rangle \implies S'(k) \neq S(k)$$

Numerical investigation

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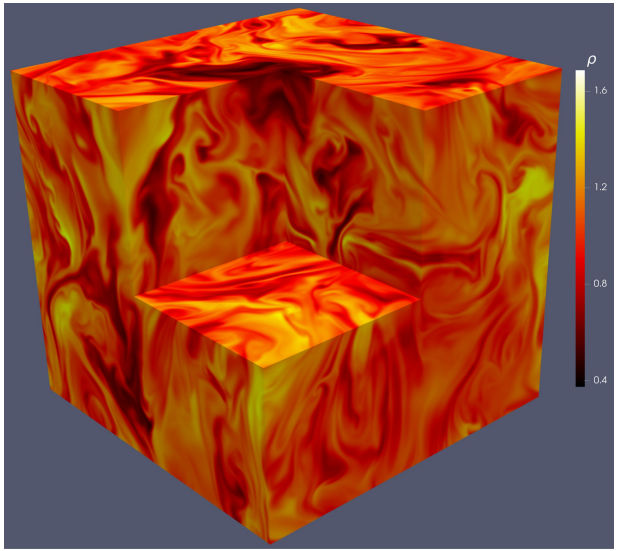
Simulation campaign

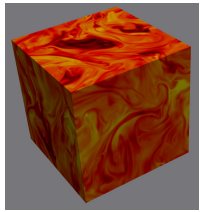


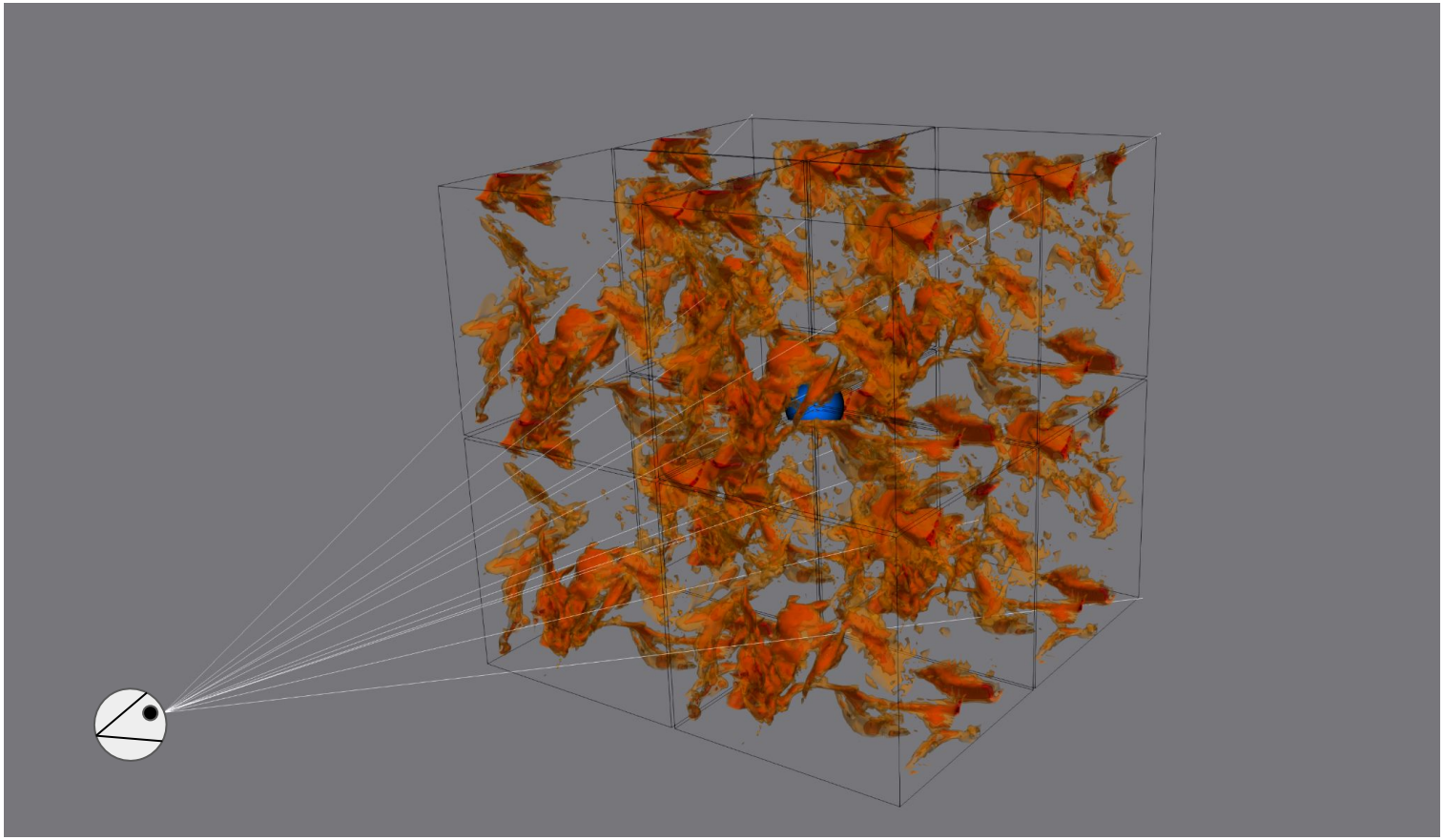
MHD simulation

isotropic

512^3

Rubik's heliosphere





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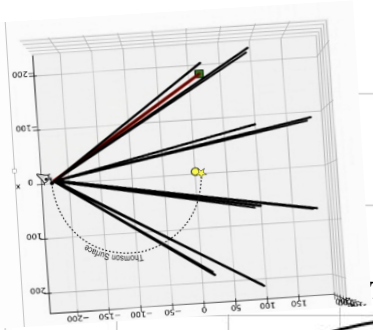
Forward modeling

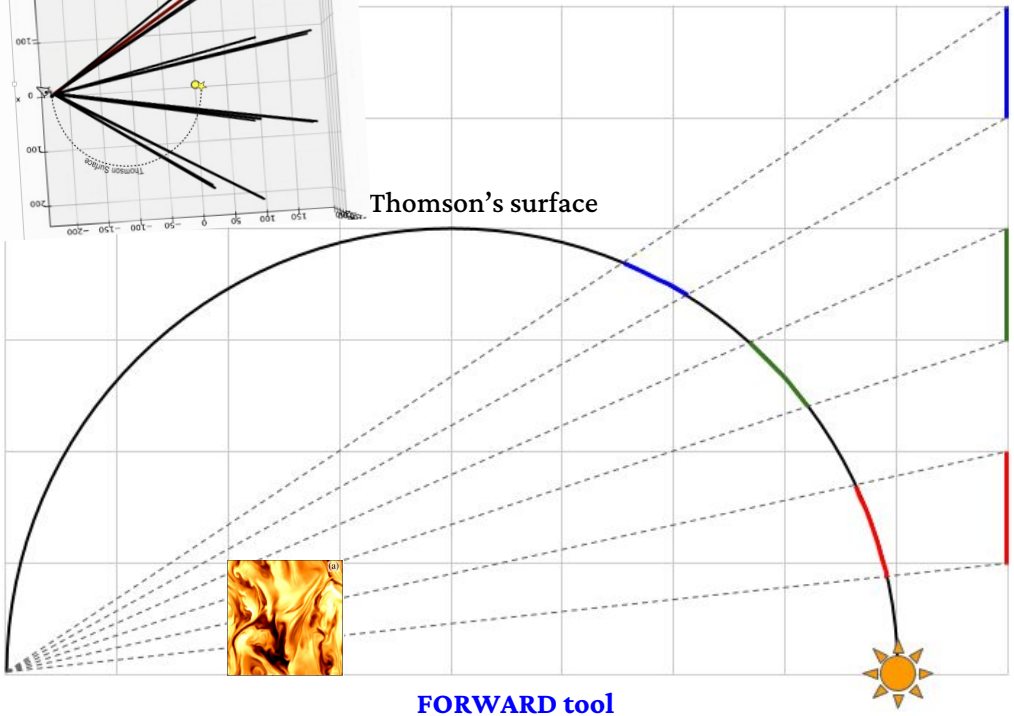


Thomson's surface

Far FOV

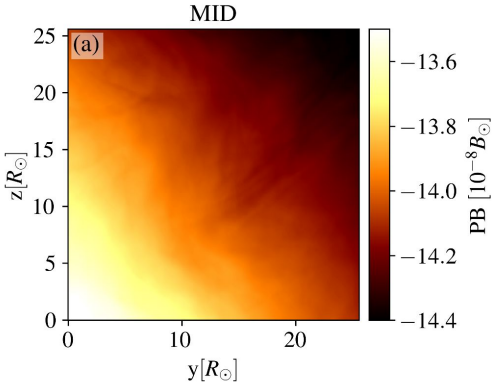
Mid FOV

Near FOV



FORWARD tool

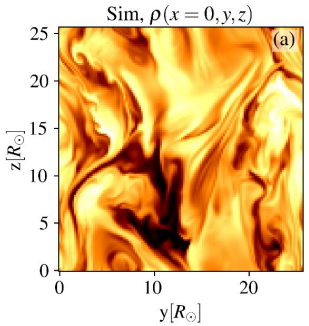
3d sampling Gibson+2016

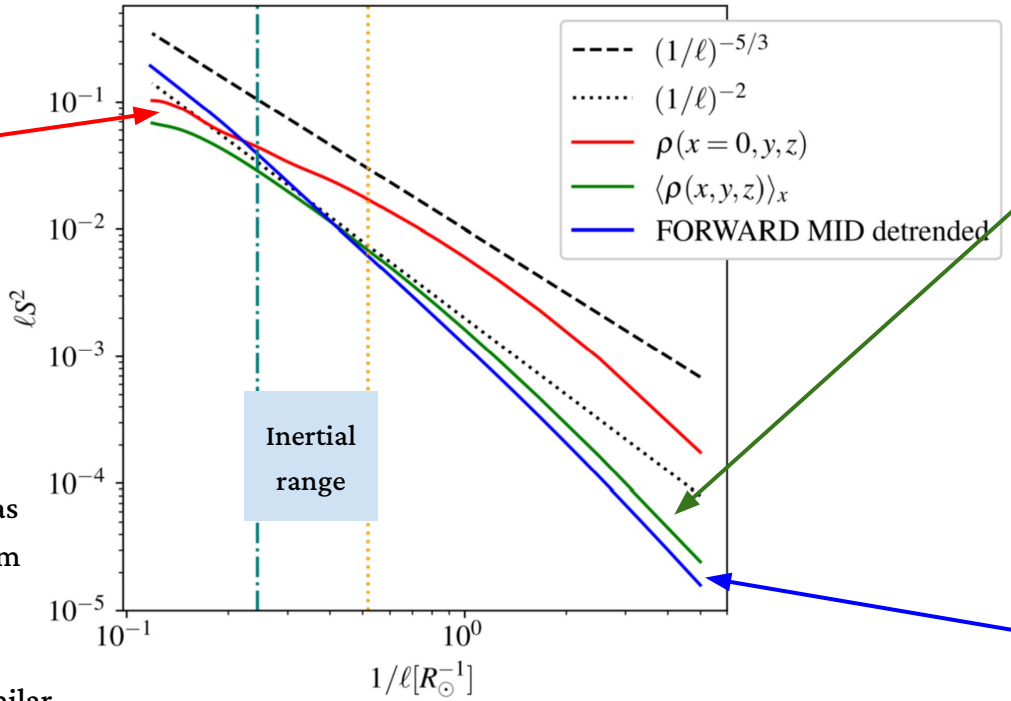


PUNCH-like image from "Rubik's heliosphere" through Forward modeling

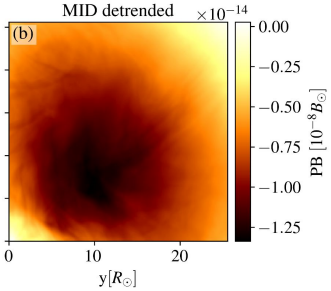
Equivalent power spectra

Simulation 2D plane

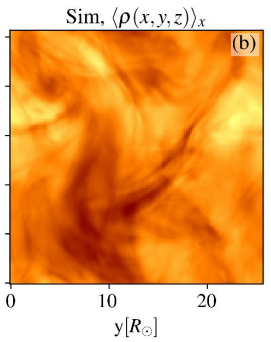




PUNCH-like



Integrated sim



- **Simulation 2D plane** has the expected scaling from turbulence theory
- **PUNCH-like** and **integrated sim** have similar scaling

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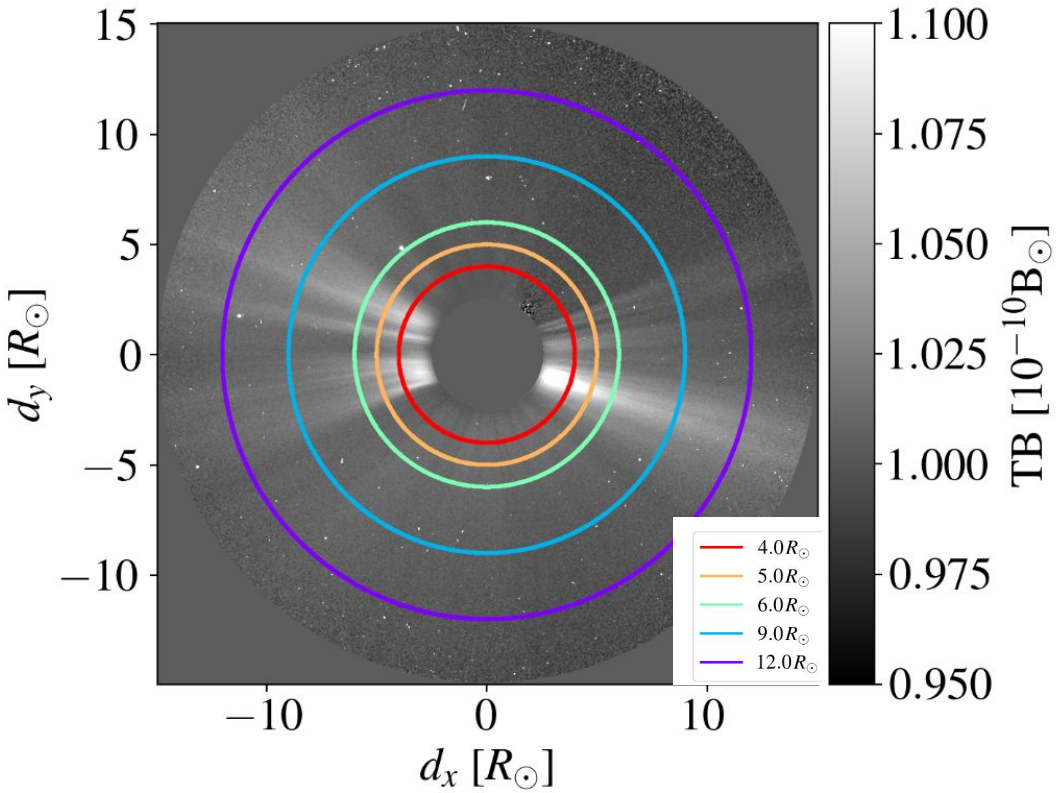
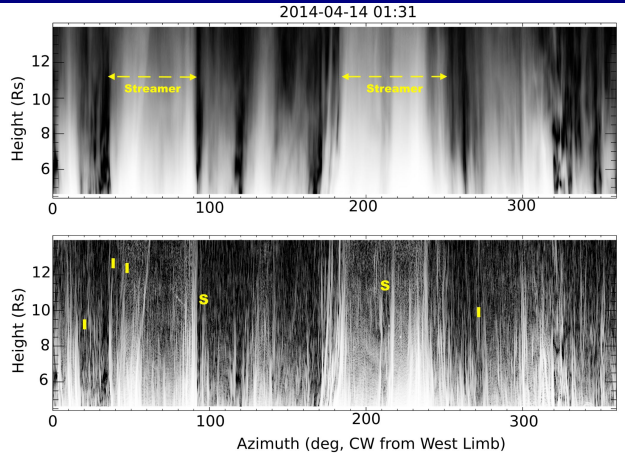
STEREO observations

Pecora+ in prep.

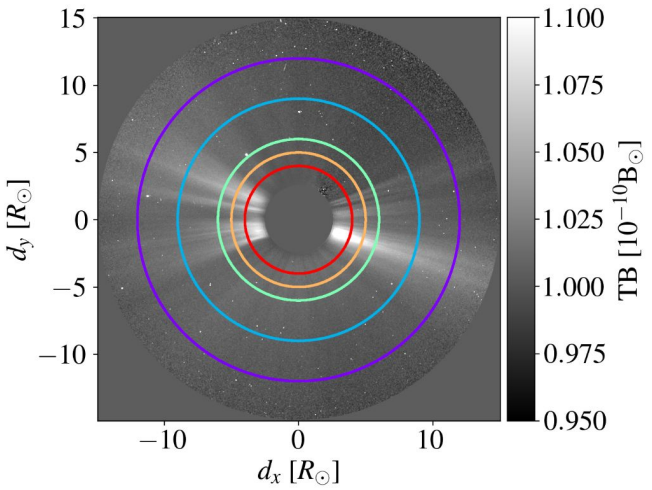
STEREO/COR2

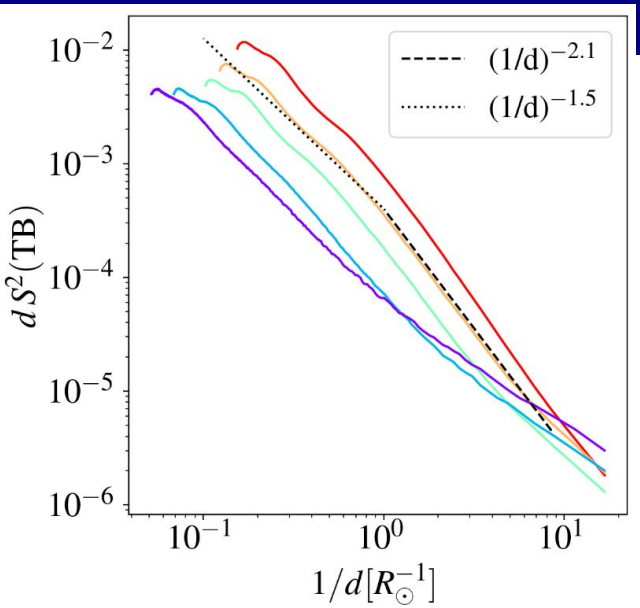




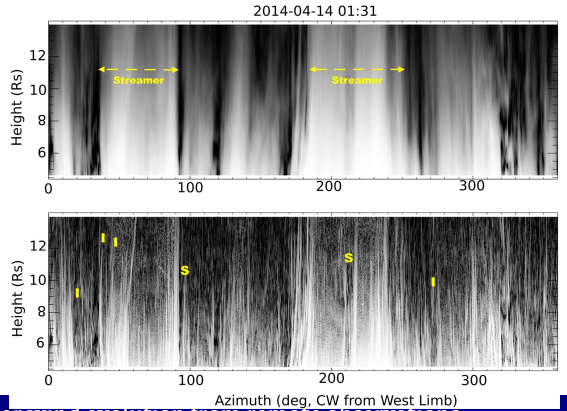
DeForest+ 2018

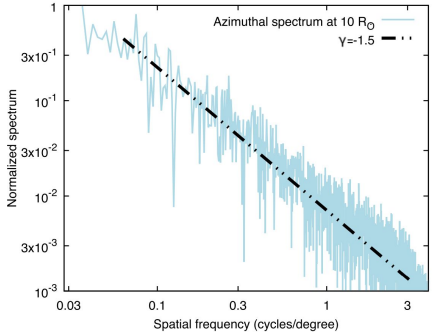
STEREO/COR2



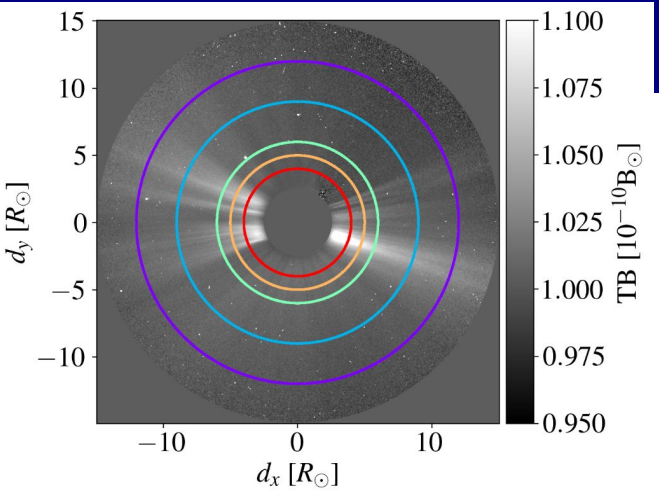


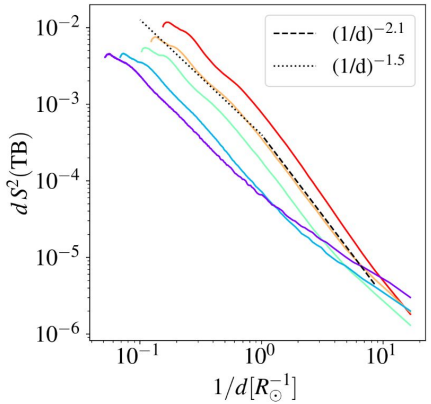
Pecora+ in prep

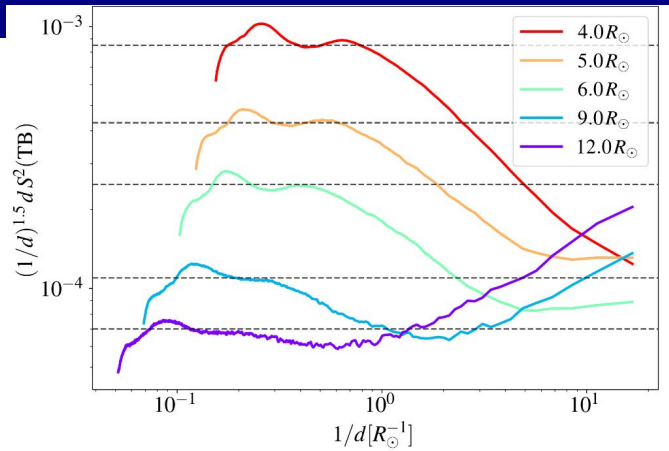




DeForest+ 2018

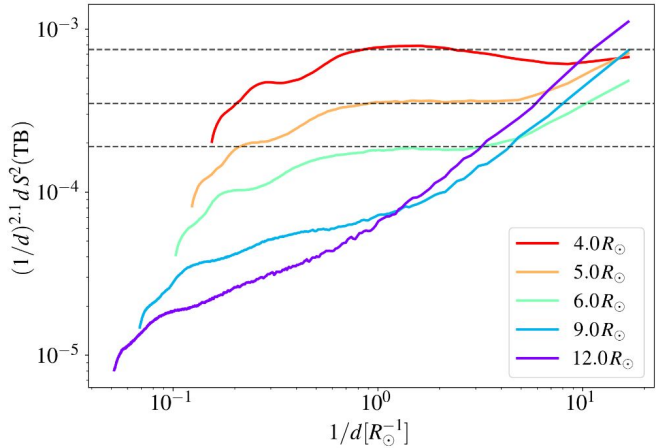






Compensated by -1.5

Emergence of 1/k range. Shift to large k's with larger distances



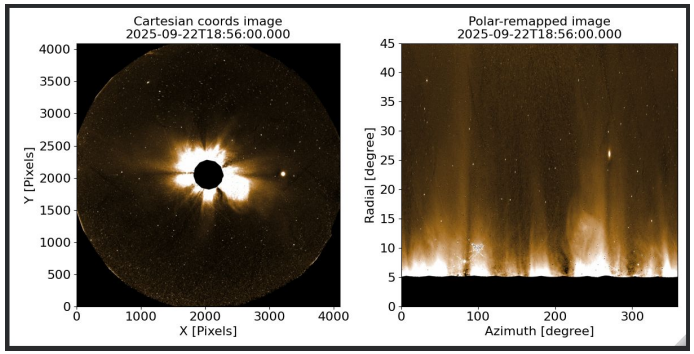
Compensated by -2.1

Emergence of inertial range. Washed out with larger distances. Lower resolution?

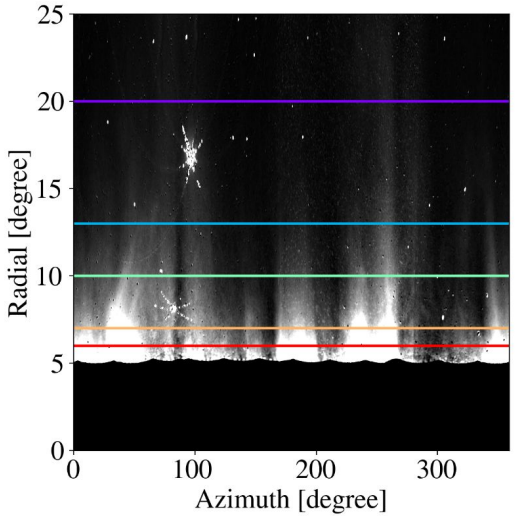
PUNCH observations

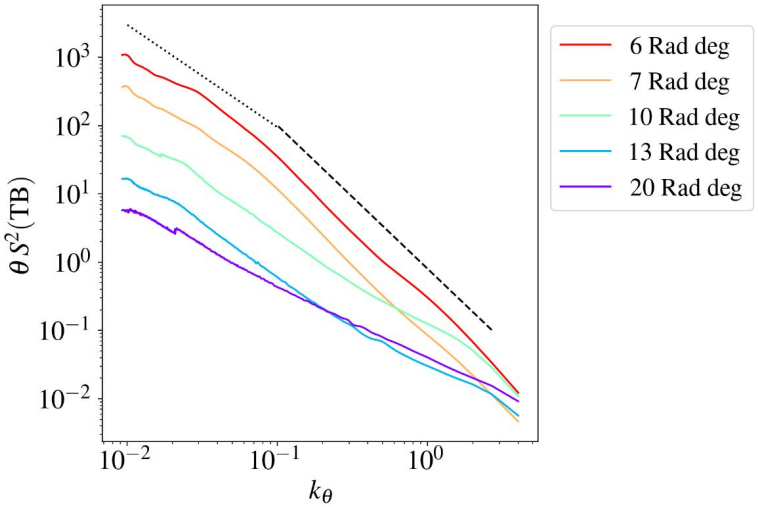
Pecora+ in prep.

PUNCH v0k

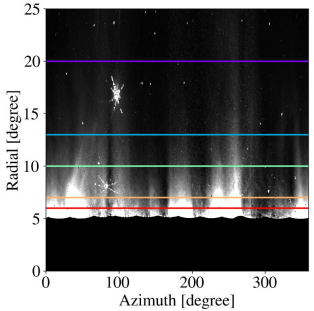


Thanks Ritesh Patel for the notebook!

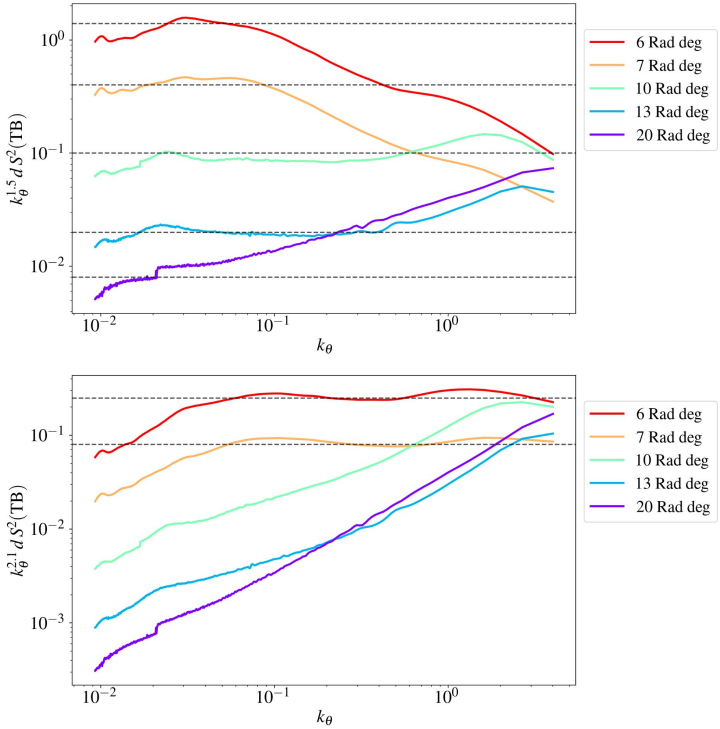




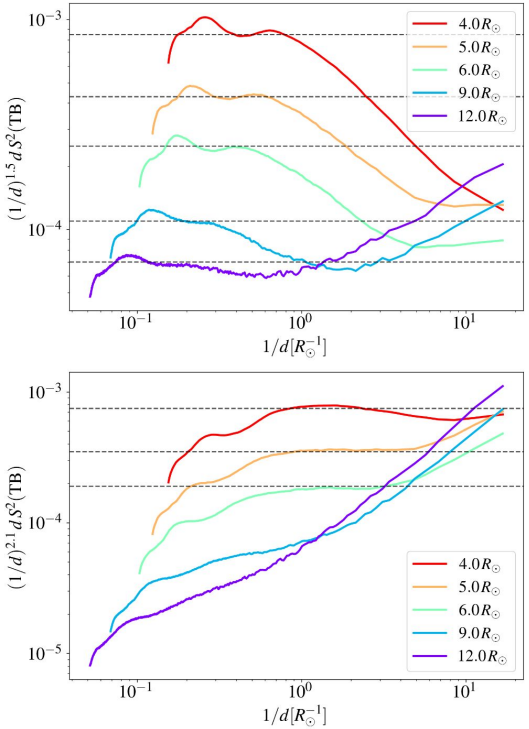
PUNCH v0k



PUNCH

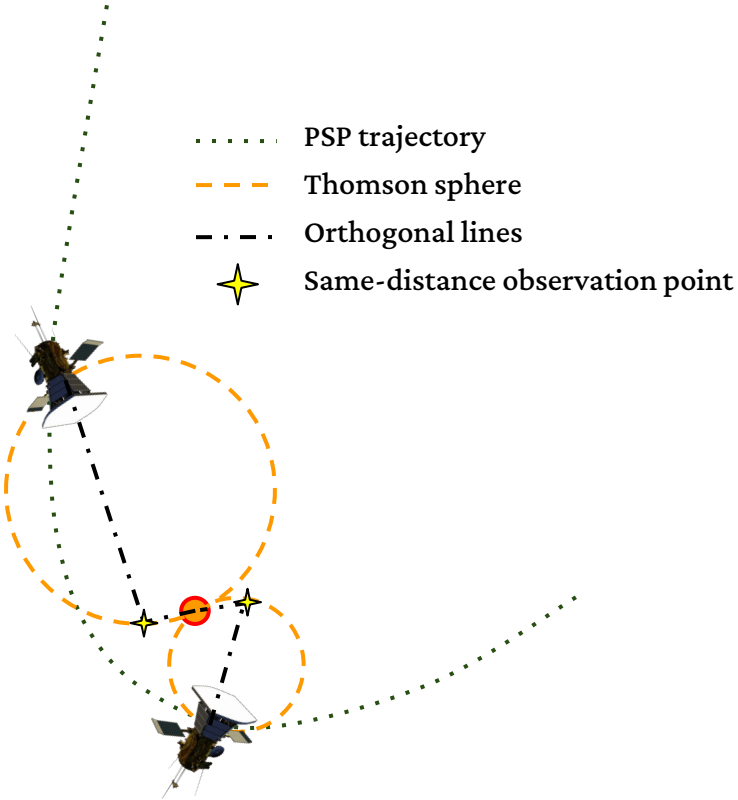


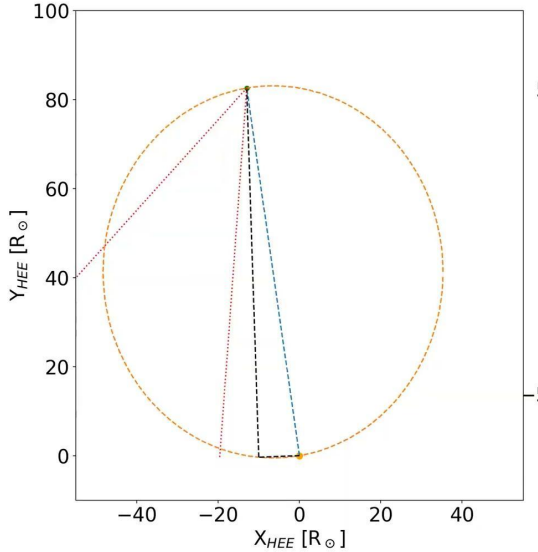
STEREO

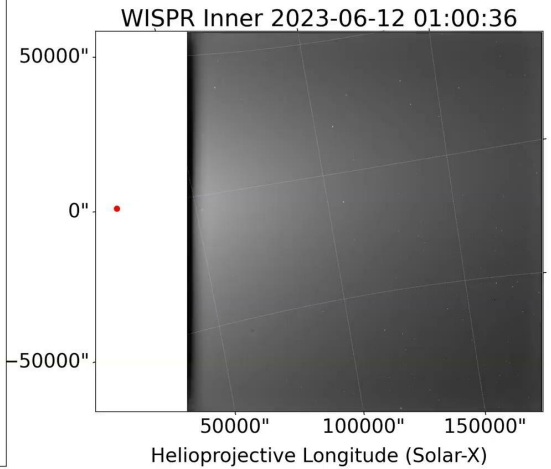


WISPR observations

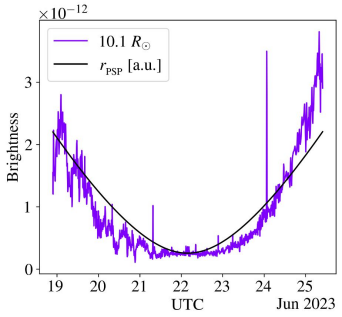
Pecora+ in prep.



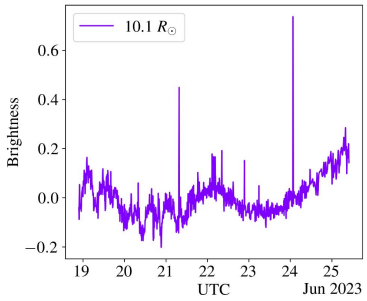


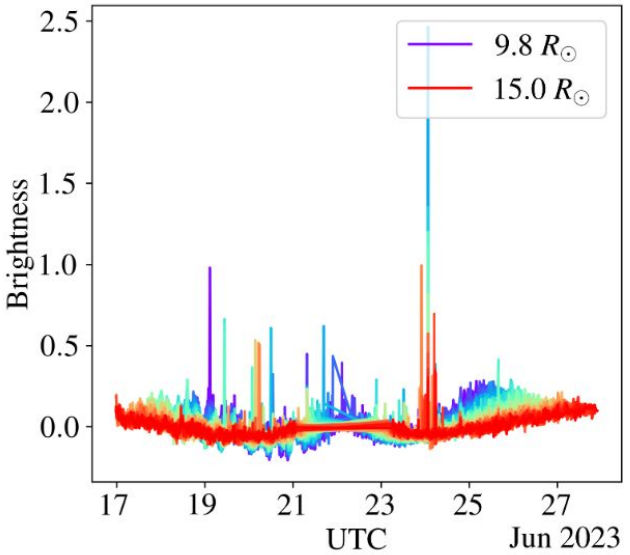


Pecora+ in prep.

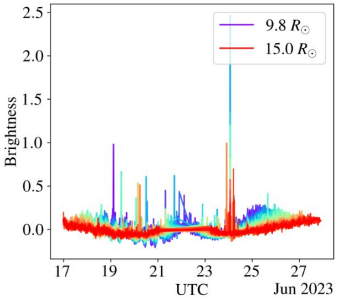


Rescaling by PSP distance



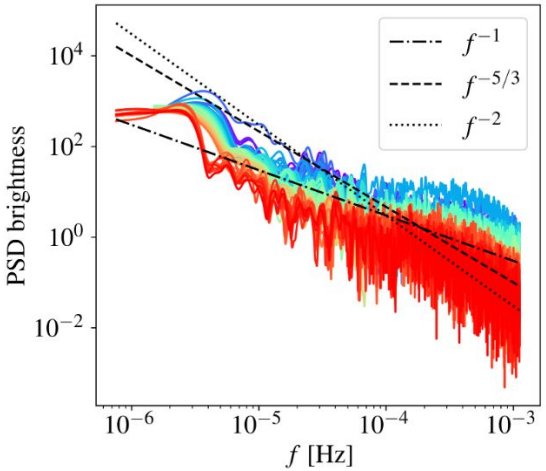


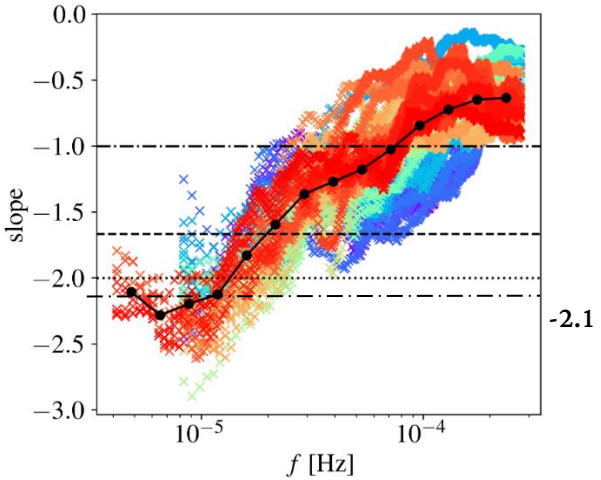
Pecora+ in prep.



Compute power spectra

(FT of autocorrelation function)



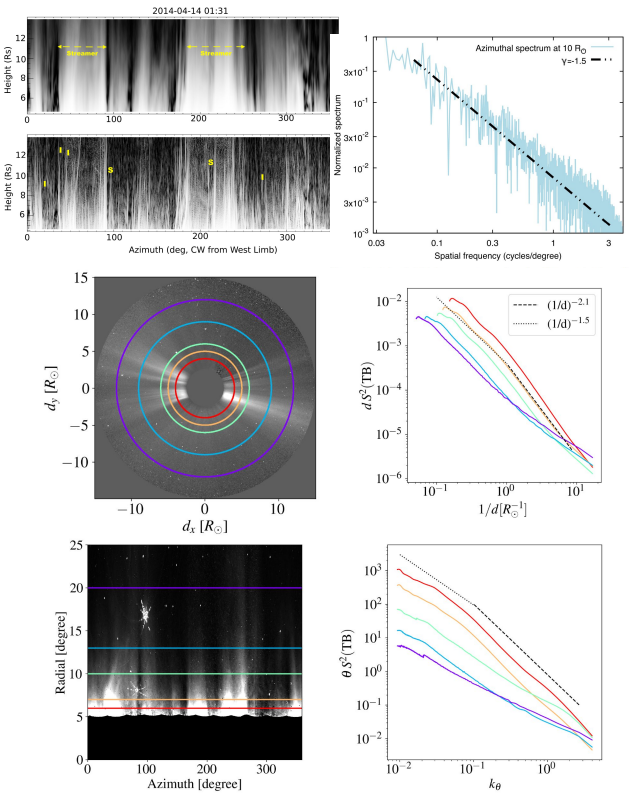


Local spectral slope

Pecora+ in prep.

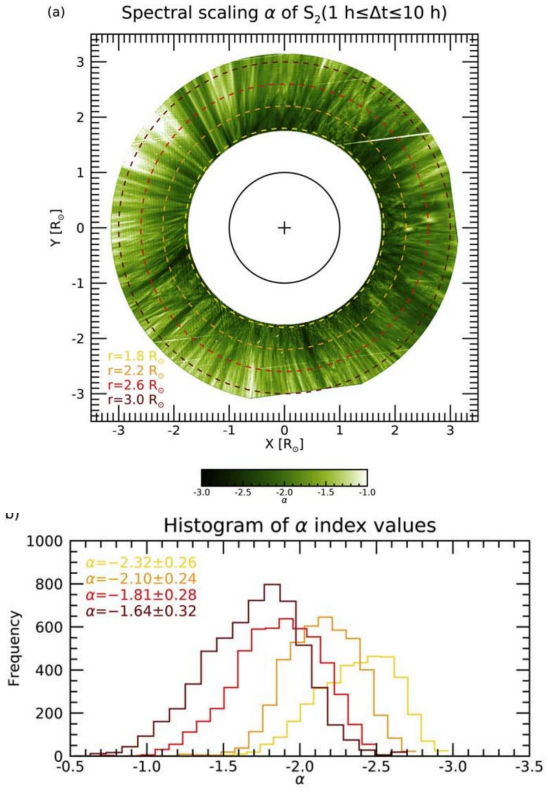
Conclusion & Discussion

3 different methods



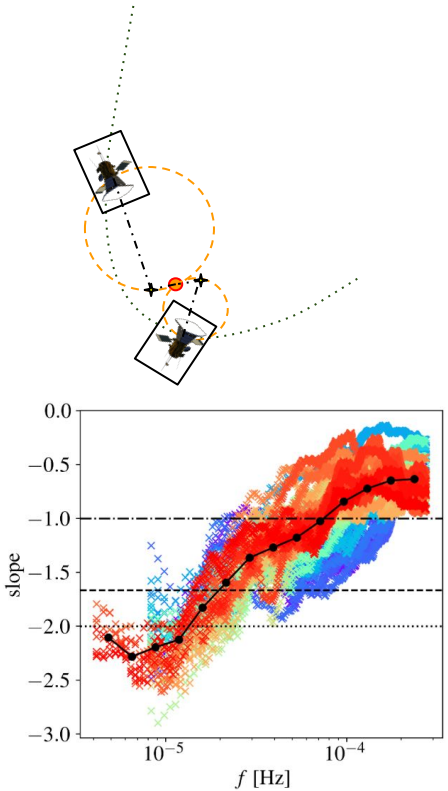
Azimuthal spectra

STEREO DeForest+ 2018, PUNCH Pecora+ in prep



Spectral slopes of slab fluctuations

SolO METIS, Telloni+ 2024



Admixture of slab & 2D?

PSP WISPR, Pecora+ in prep

Conclusions

- PSP, SolO and PUNCH observations: perfect synergy between in situ and remote
- LOS integration modifies “usual” turbulence scalings
- In simulations, $k^{-5/3}$ modifies into $k^{-2.1}$
- STEREO and PUNCH can observe (modified, azimuthal) 1/k and inertial range radial evolution
- PUNCH at v0k already comparable to STEREO!

- Can we build a library of simulations to match spectral properties of remote observations?
- Can we use sub-grid modeling + forward?
- Can we disentangle slab and 2D?

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