The Alfvénic Motions Of The Sun's Outer Atmosphere

Scott W. McIntosh
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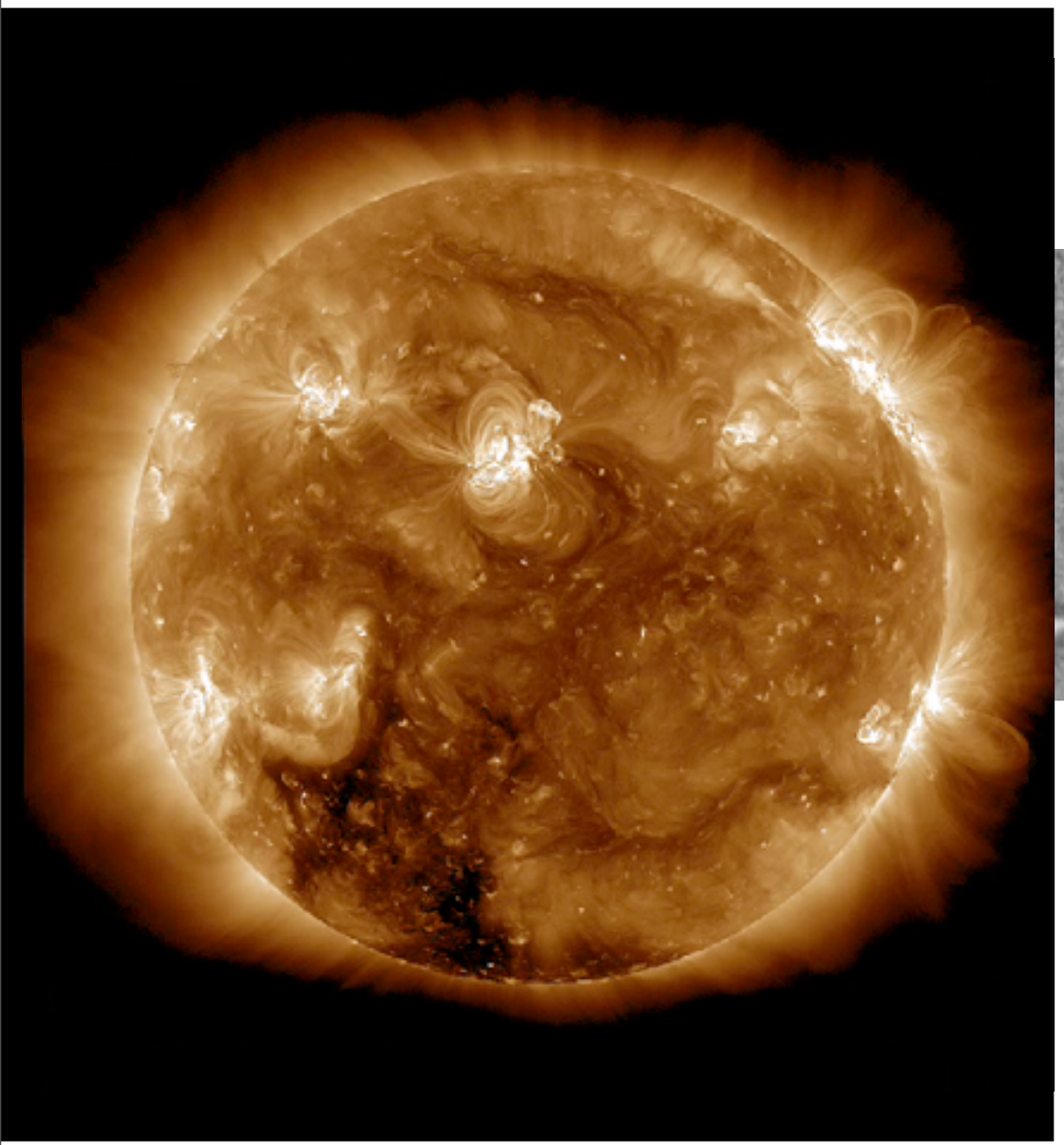

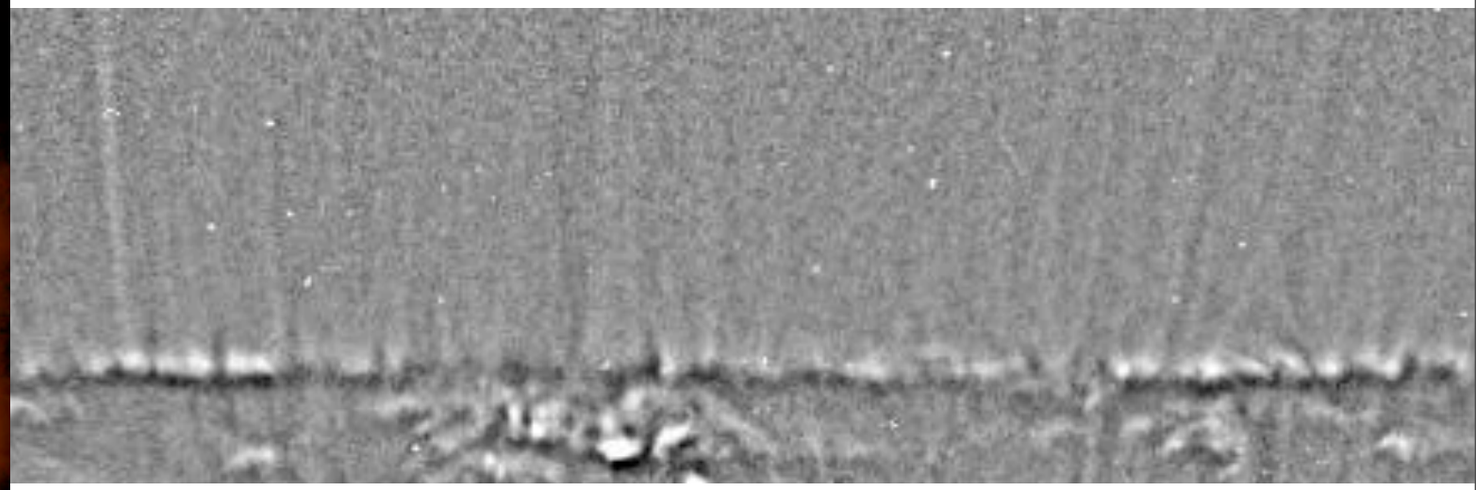

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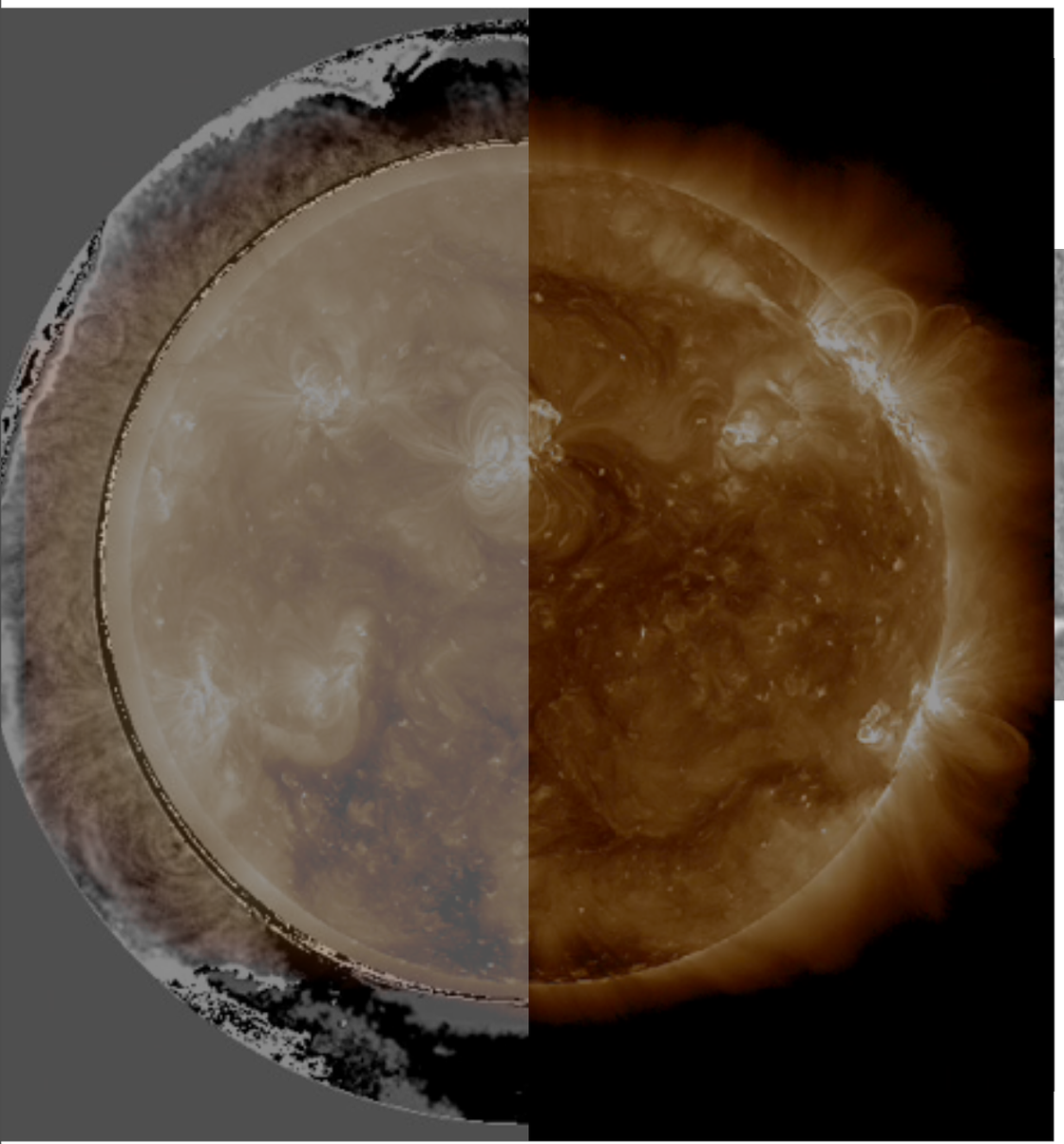

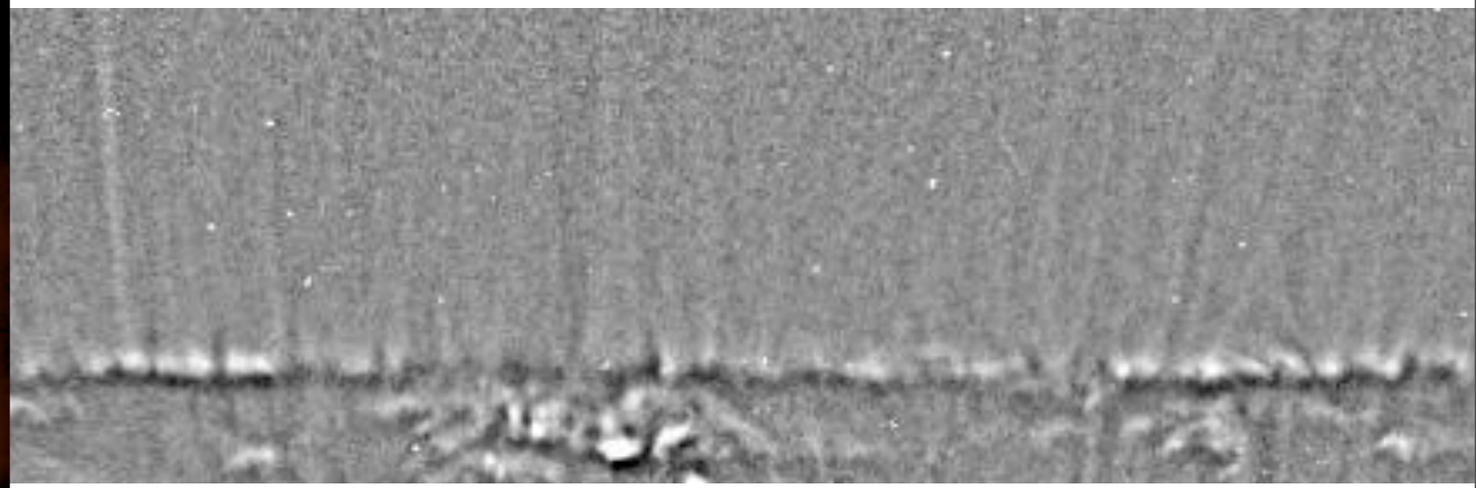

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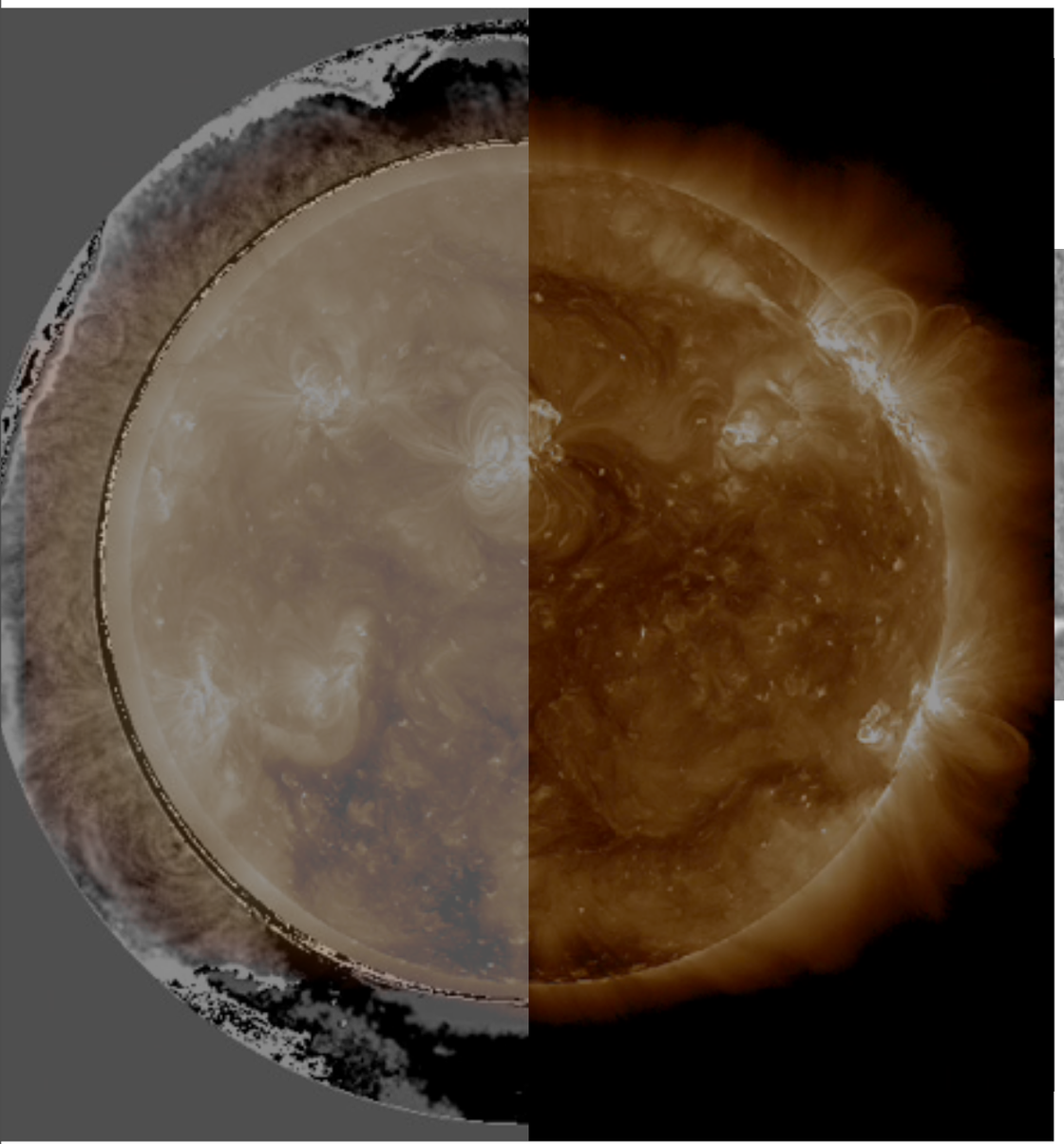

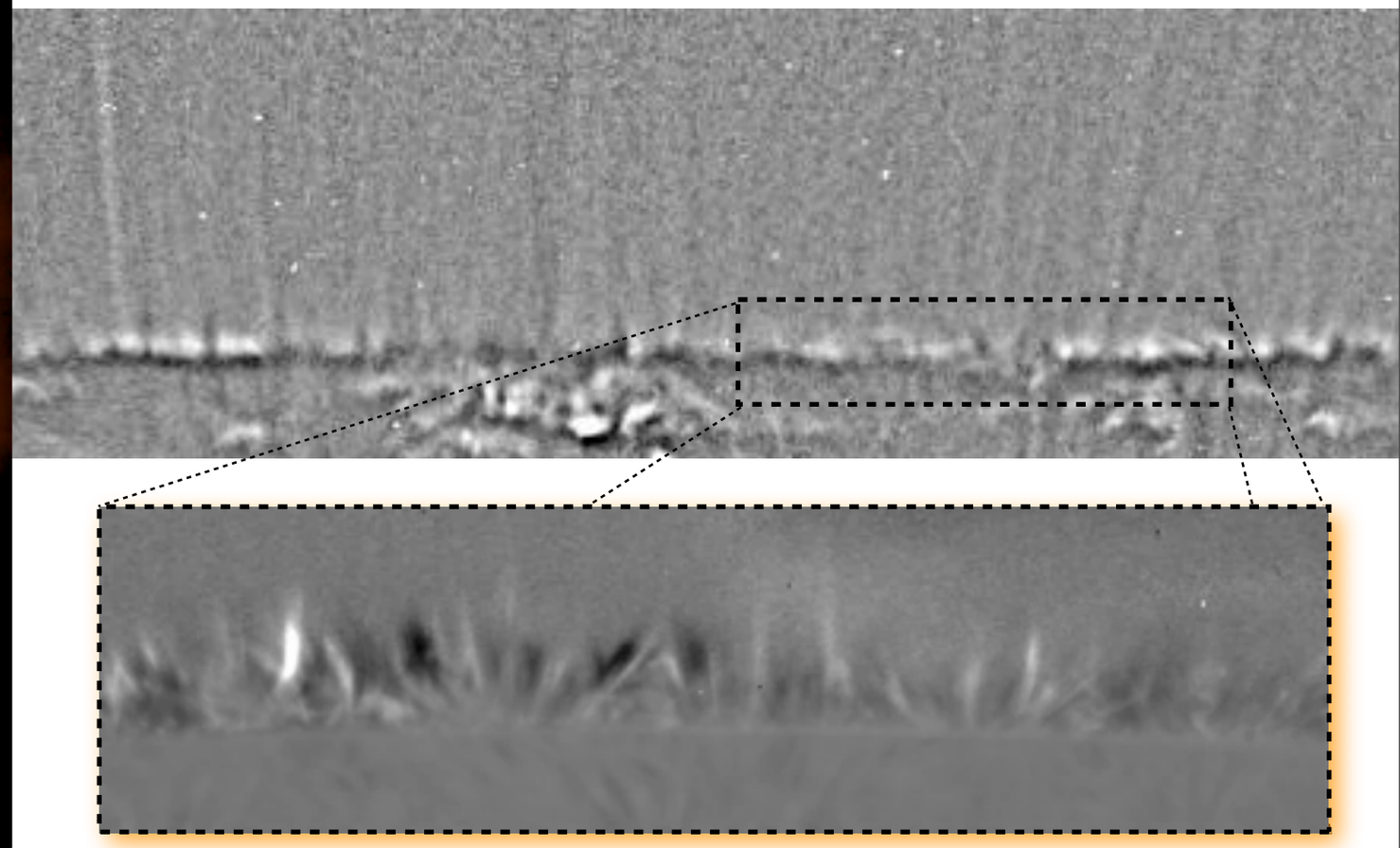

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Overview

- ➡CoMP's "Discovery"
  - ➡Coronal Seismology
- ➡Abundant ("Dark") Energy?
  - ➡Hinode/SOT and the Chromosphere
  - ➡SDO/AIA and the Corona
- ➡Reconciling Wave Energies
- ➡Time-Distance Seismology
- ➡Complex Wave Scenarios
  - ➡Wave-Wave Interaction in Trans-Equatorial Loops
  - ➡Material-Wave Interaction in Polar Coronal Holes
  - ➡Abundant Torsion
- ➡What Next?
  - ➡IRIS and the Transition Region
  - ➡The COronal and Solar Magnetism Observatory (COSMO)
- ➡SWx Impact
  - ➡CMEs and Non-thermal Energy

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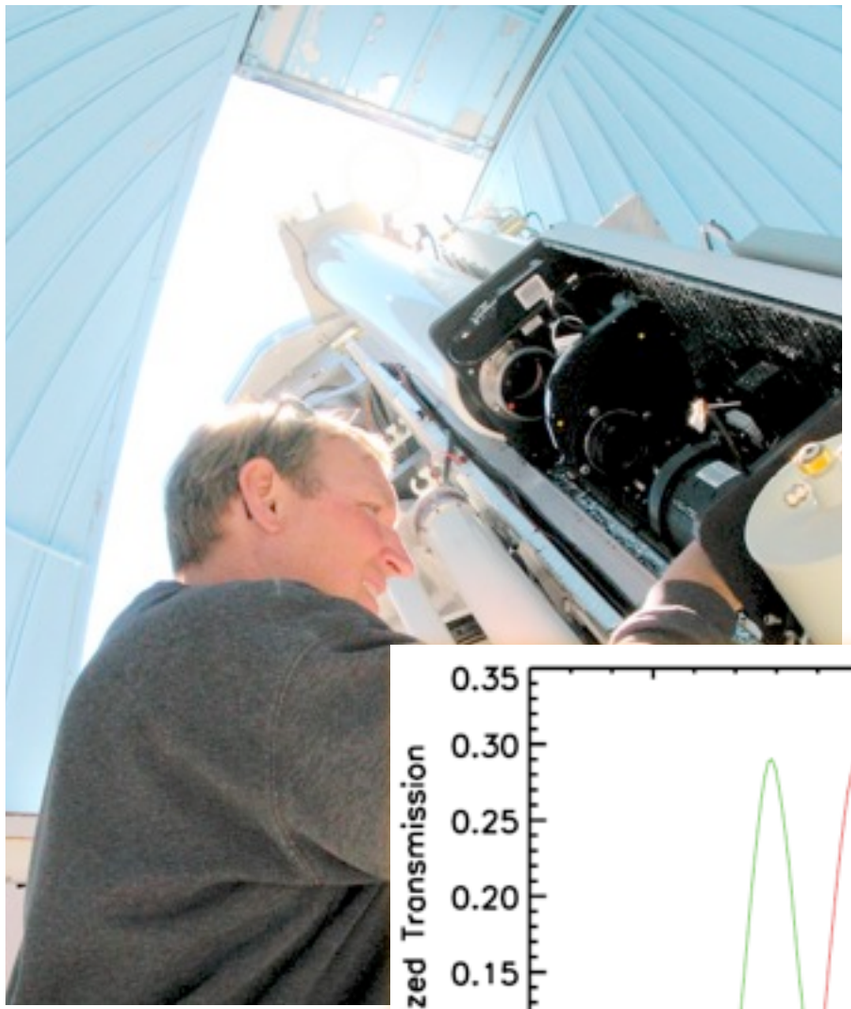
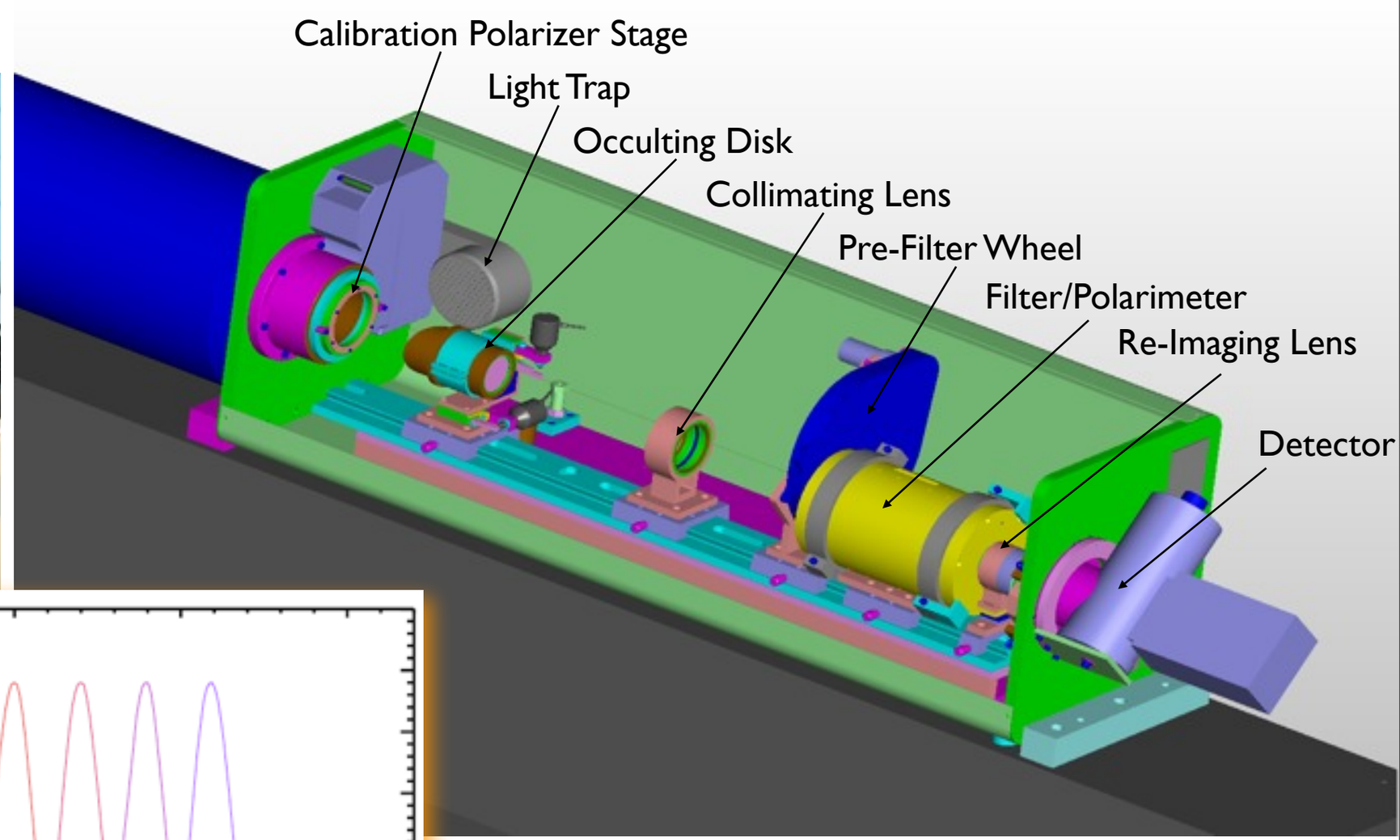
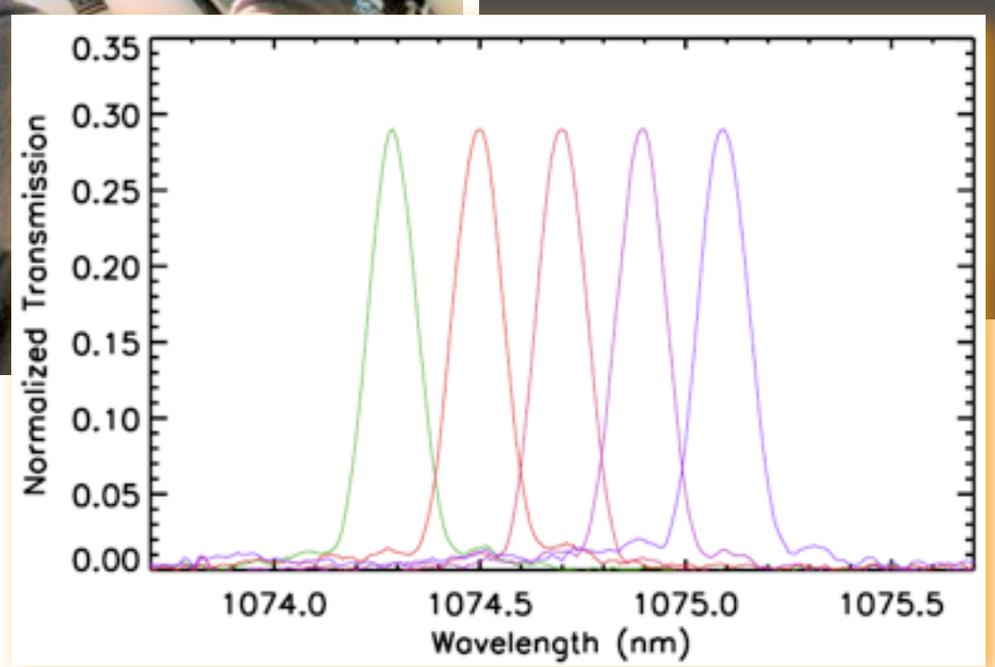
CoMP's Discovery

Imaging Spectro-Polarimeter







CoMP Measurements

Linear → POS B Direction

Circular → LOS B Strength

Doppler Shift → Velocity

Non-Thermal Broadening → Hidden "Dark" Energy?

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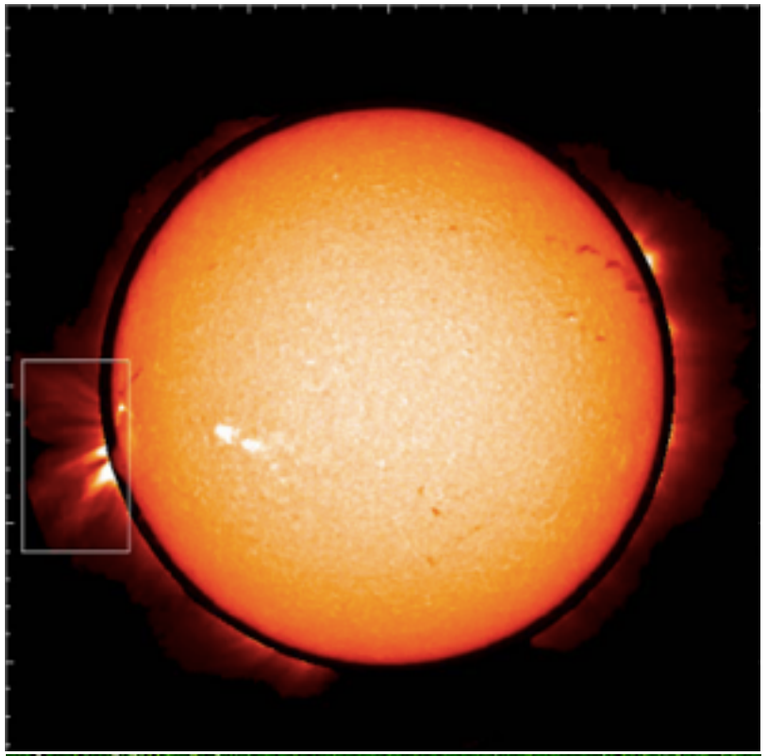
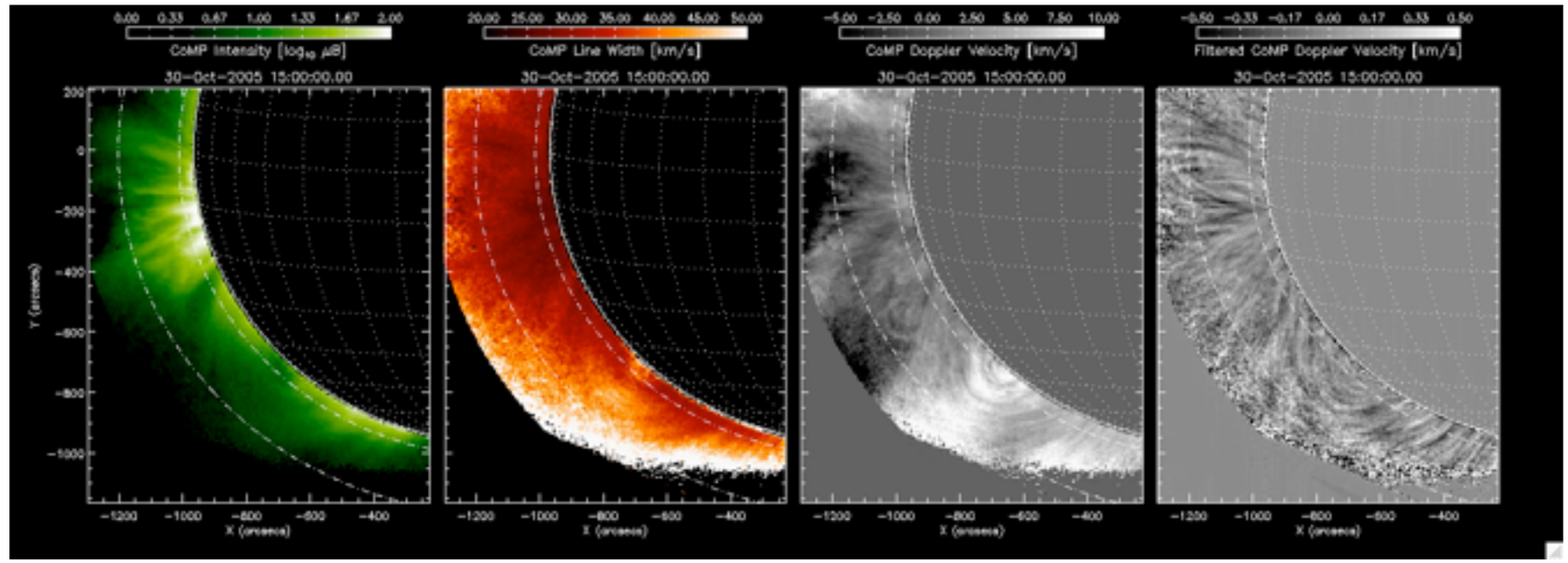
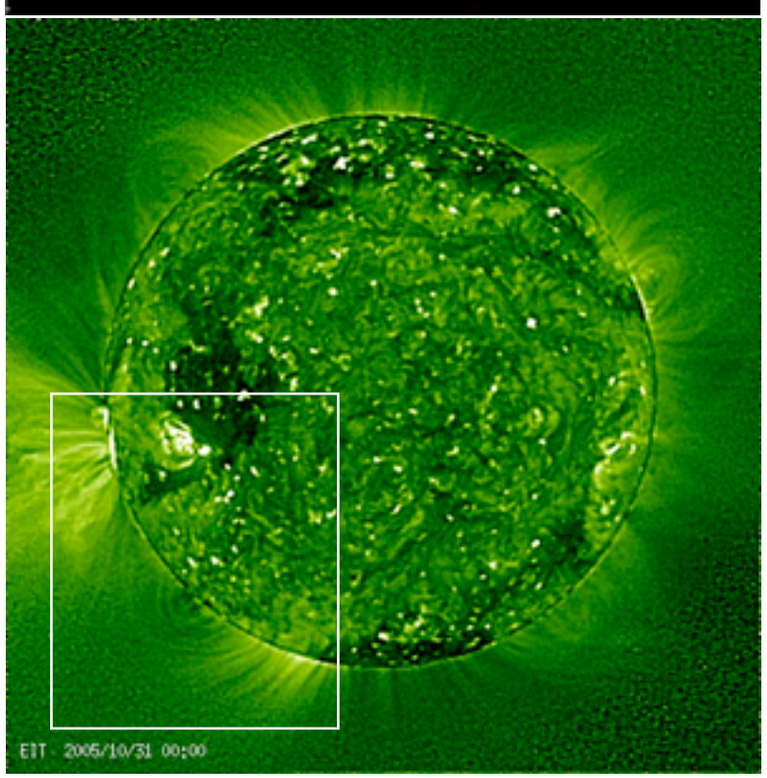
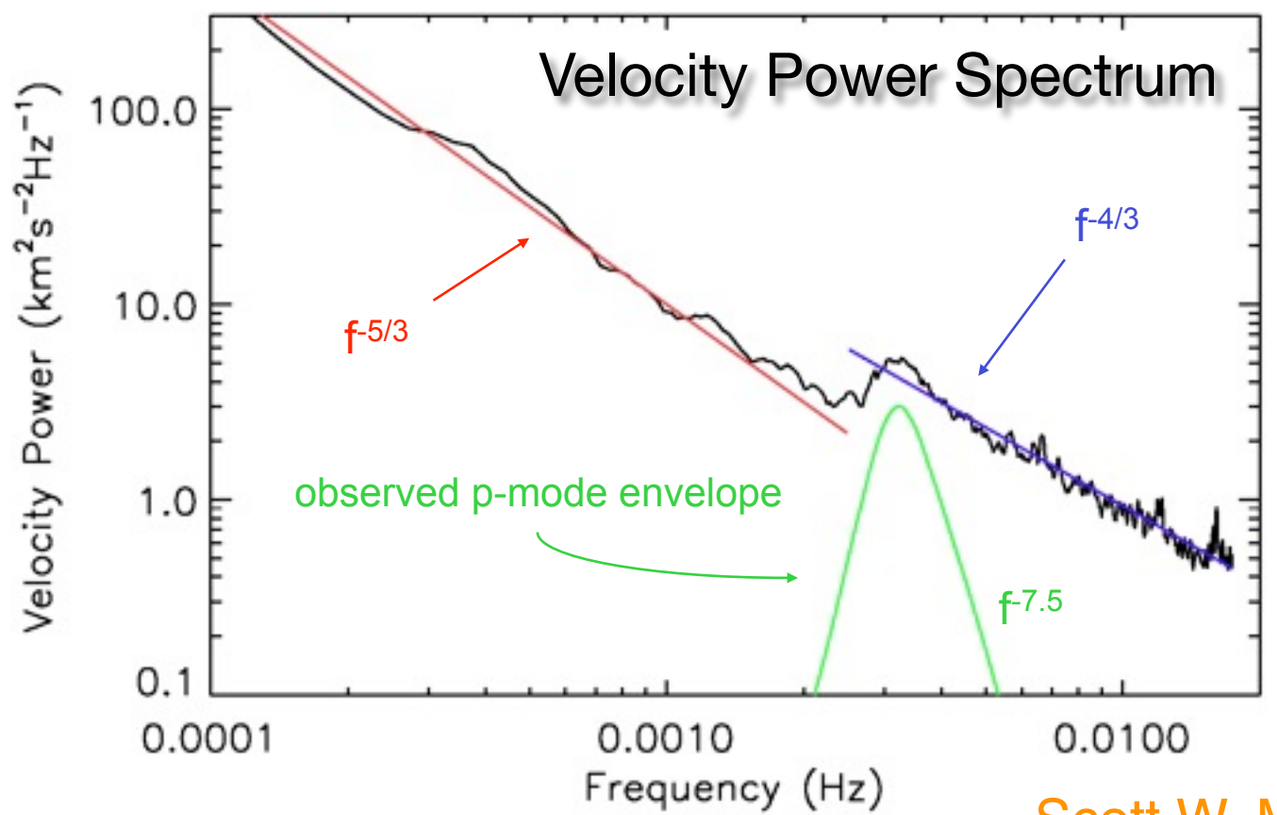
CoMP's Discovery









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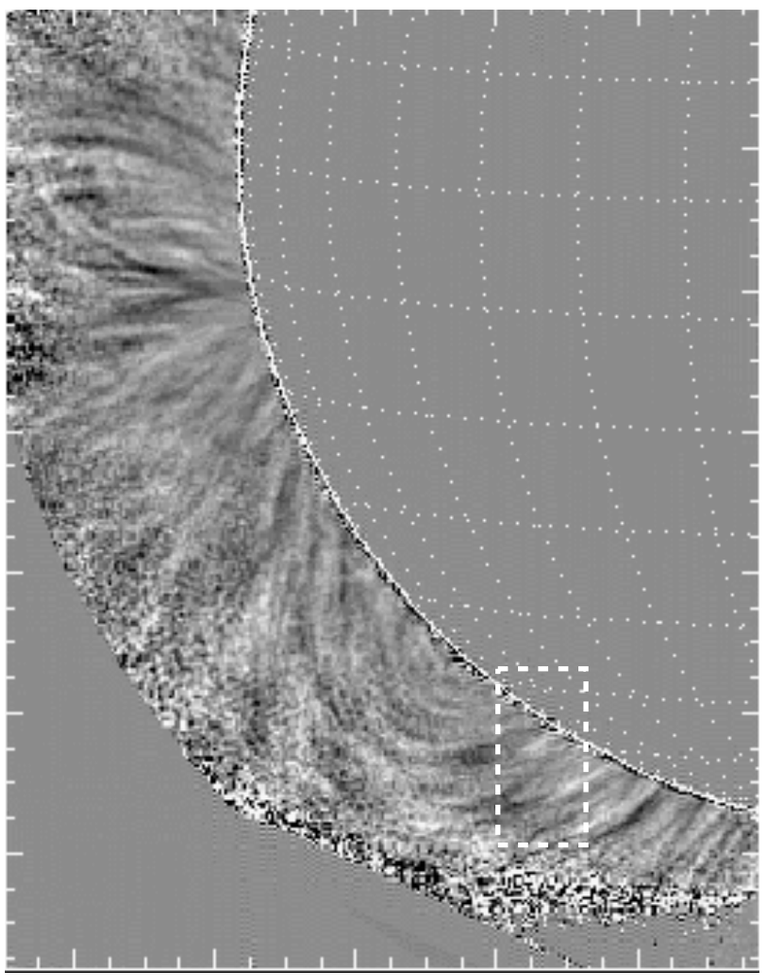
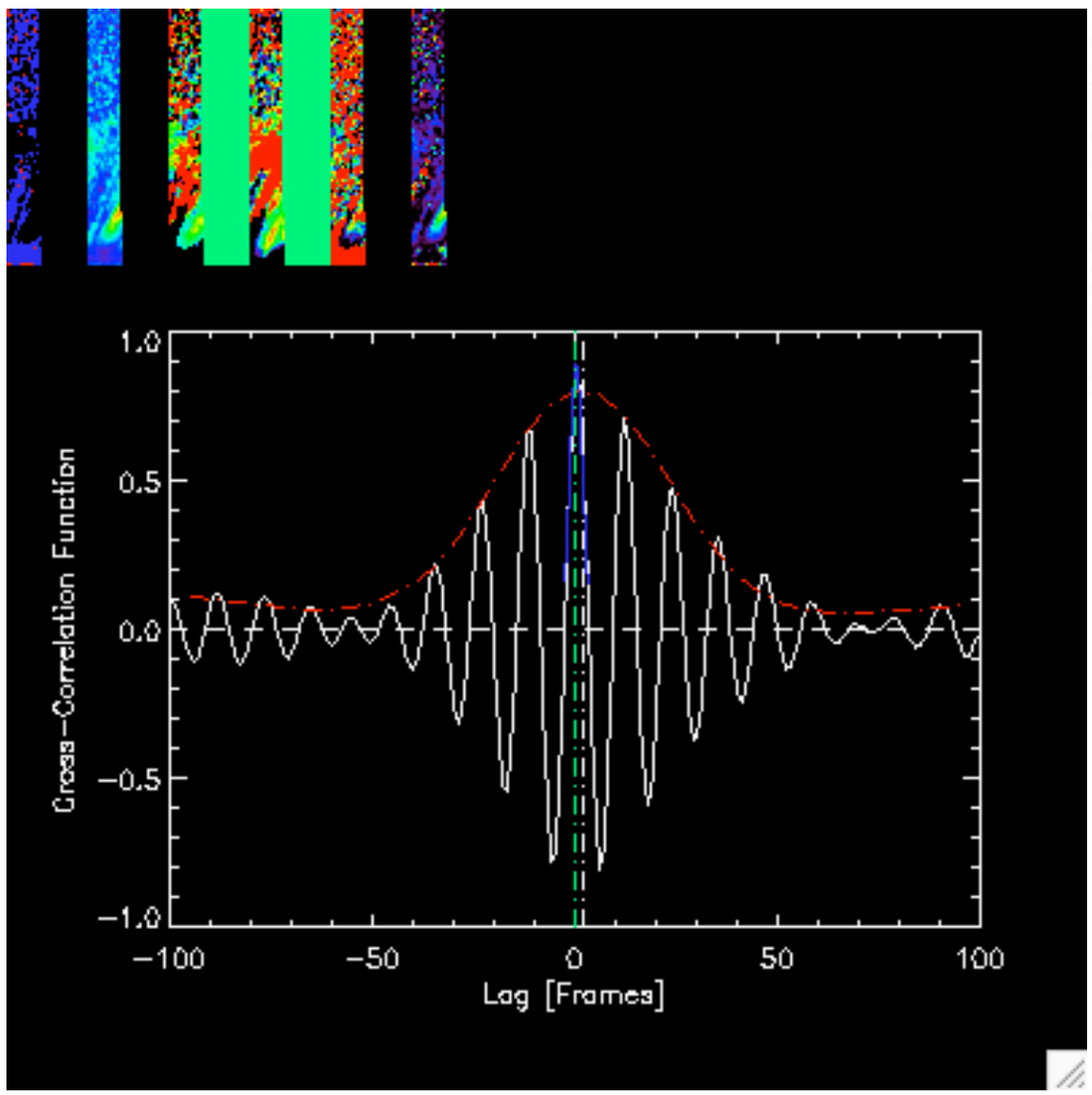
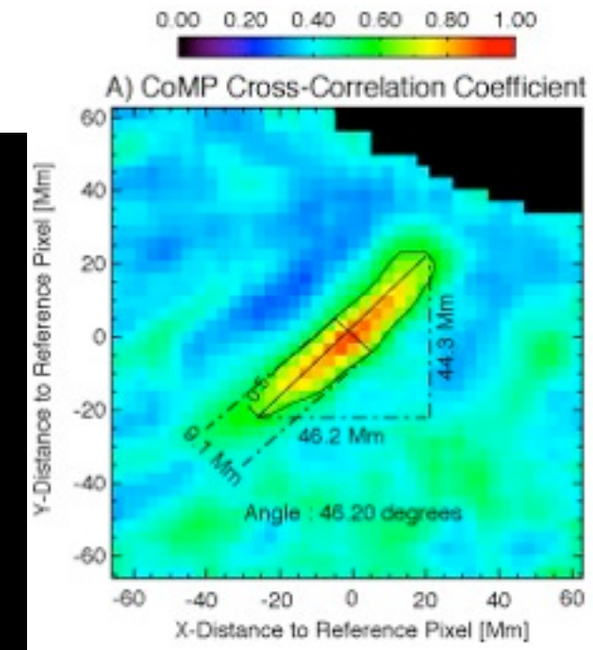
CoMP's Discovery

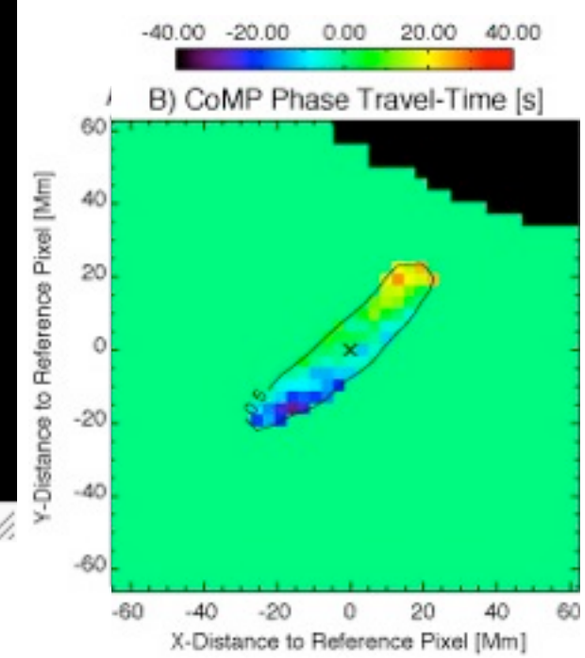
"Coronal Seismology"

"Track" the apparent motion of the Doppler Signal









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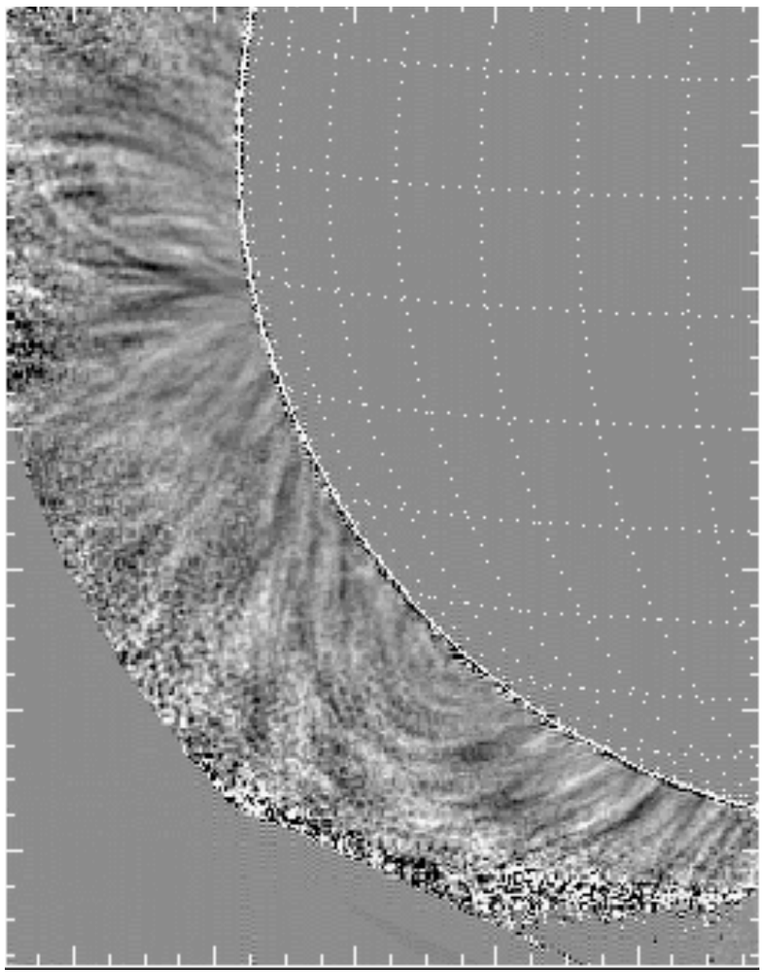

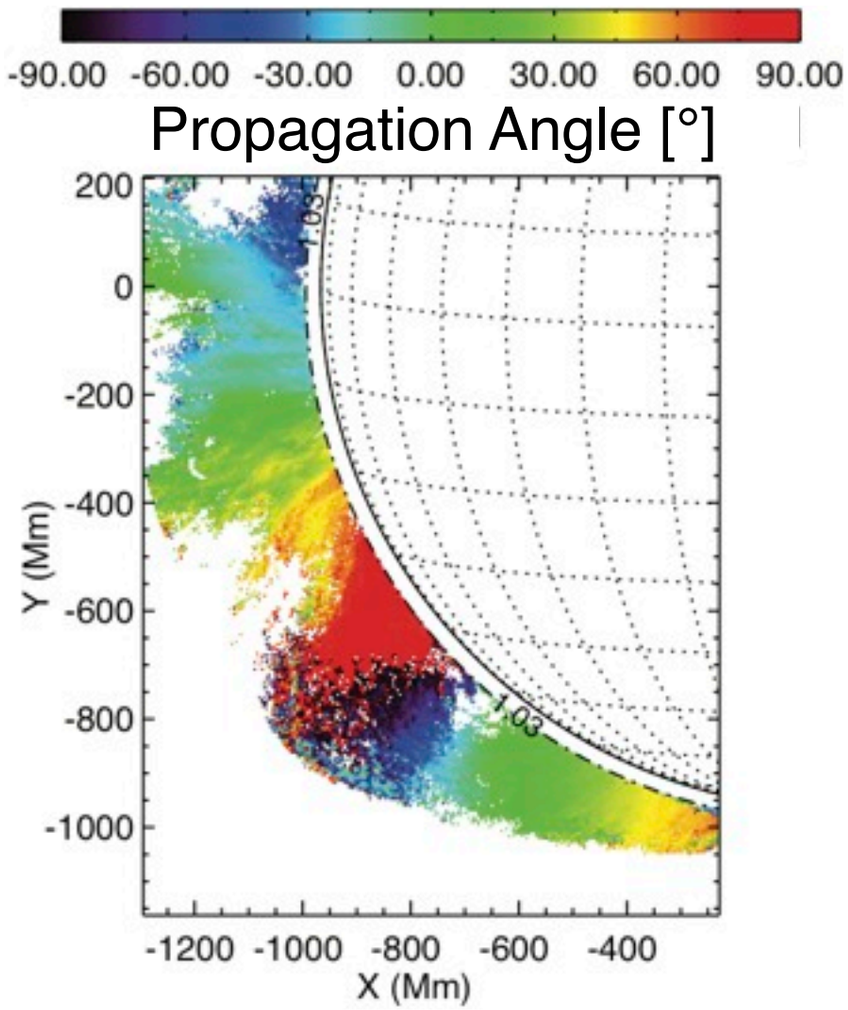

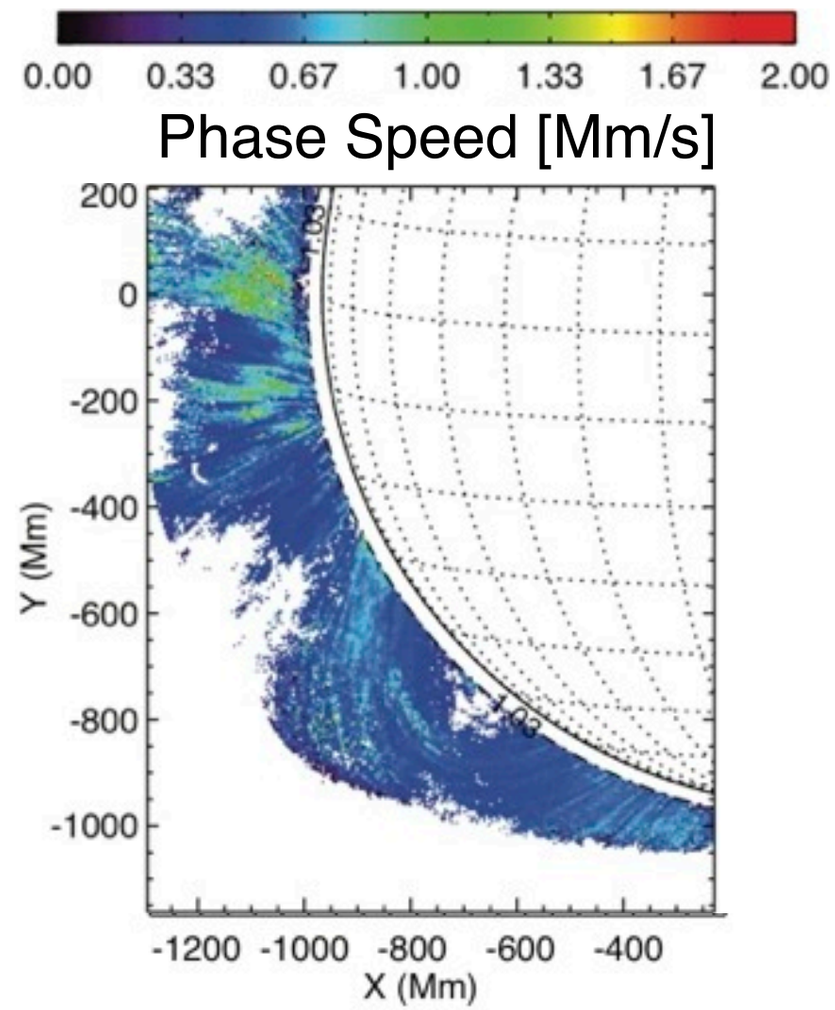

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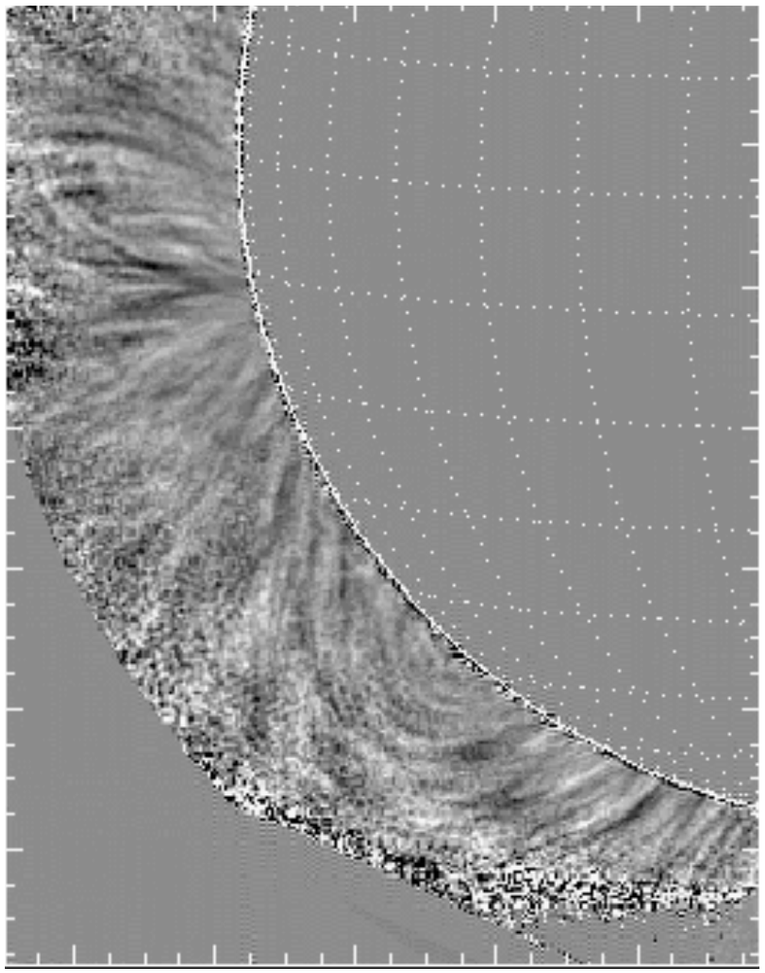

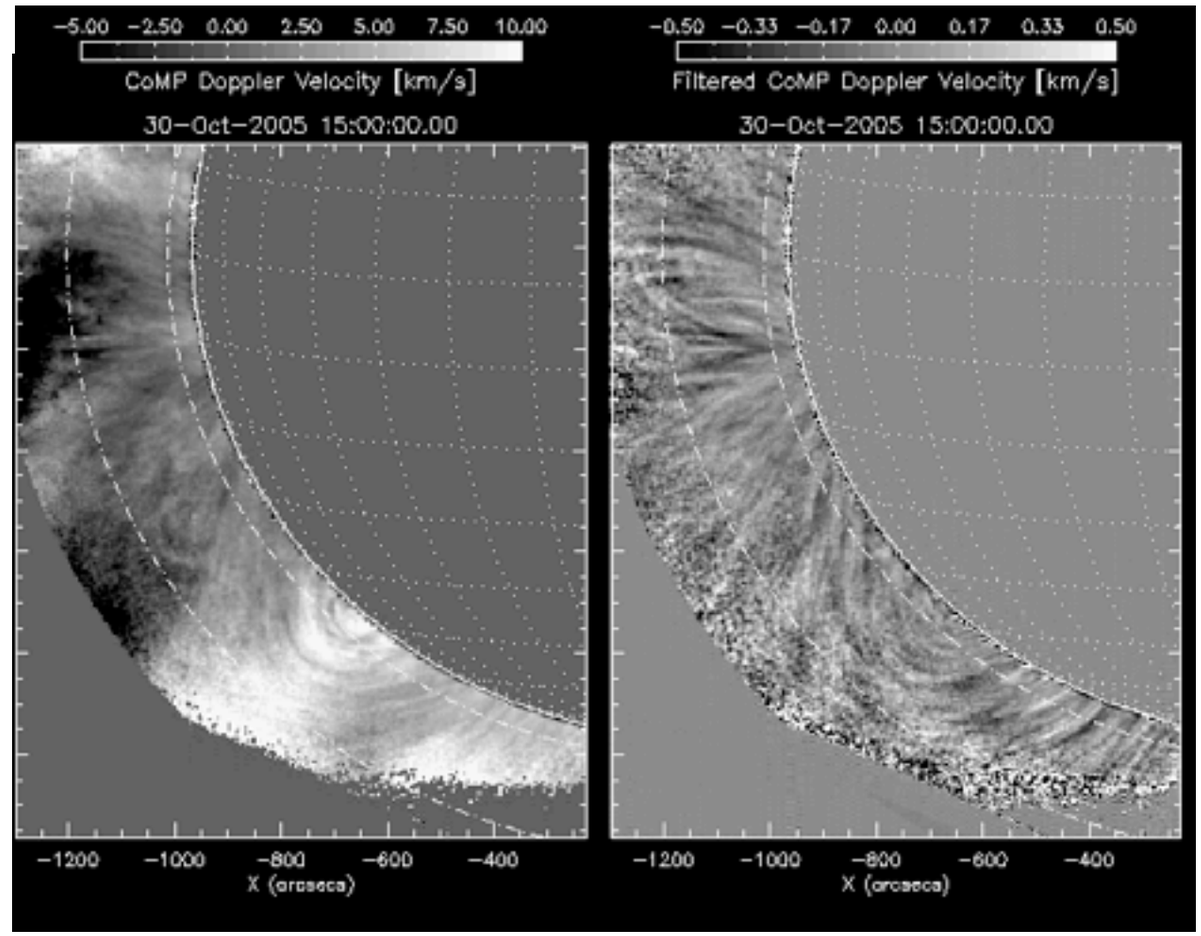

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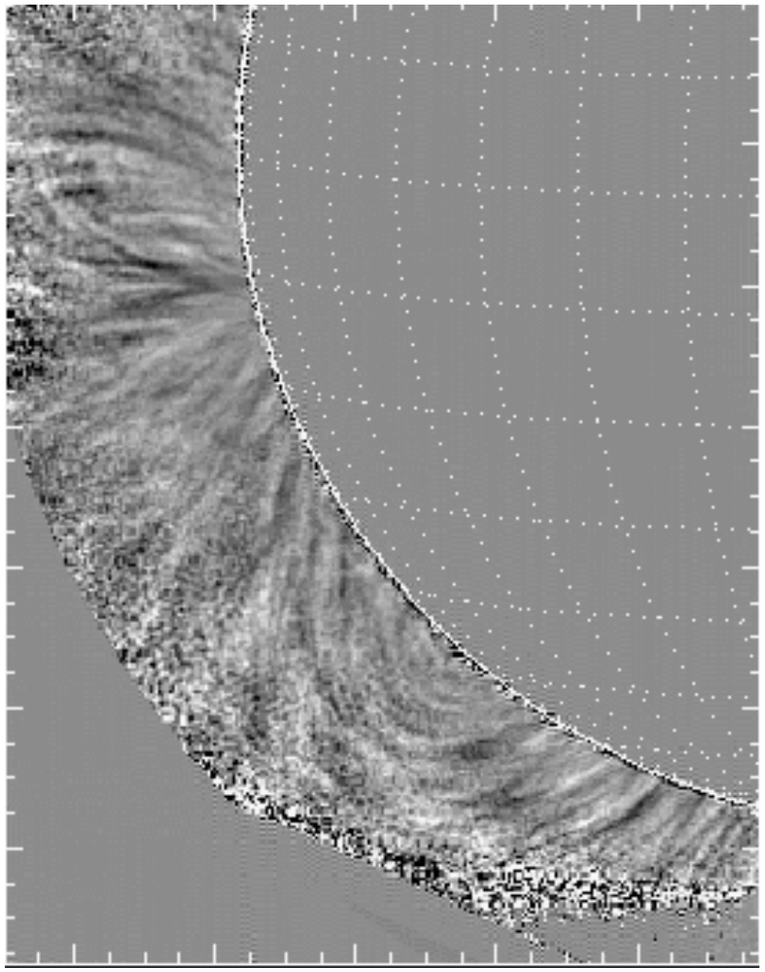

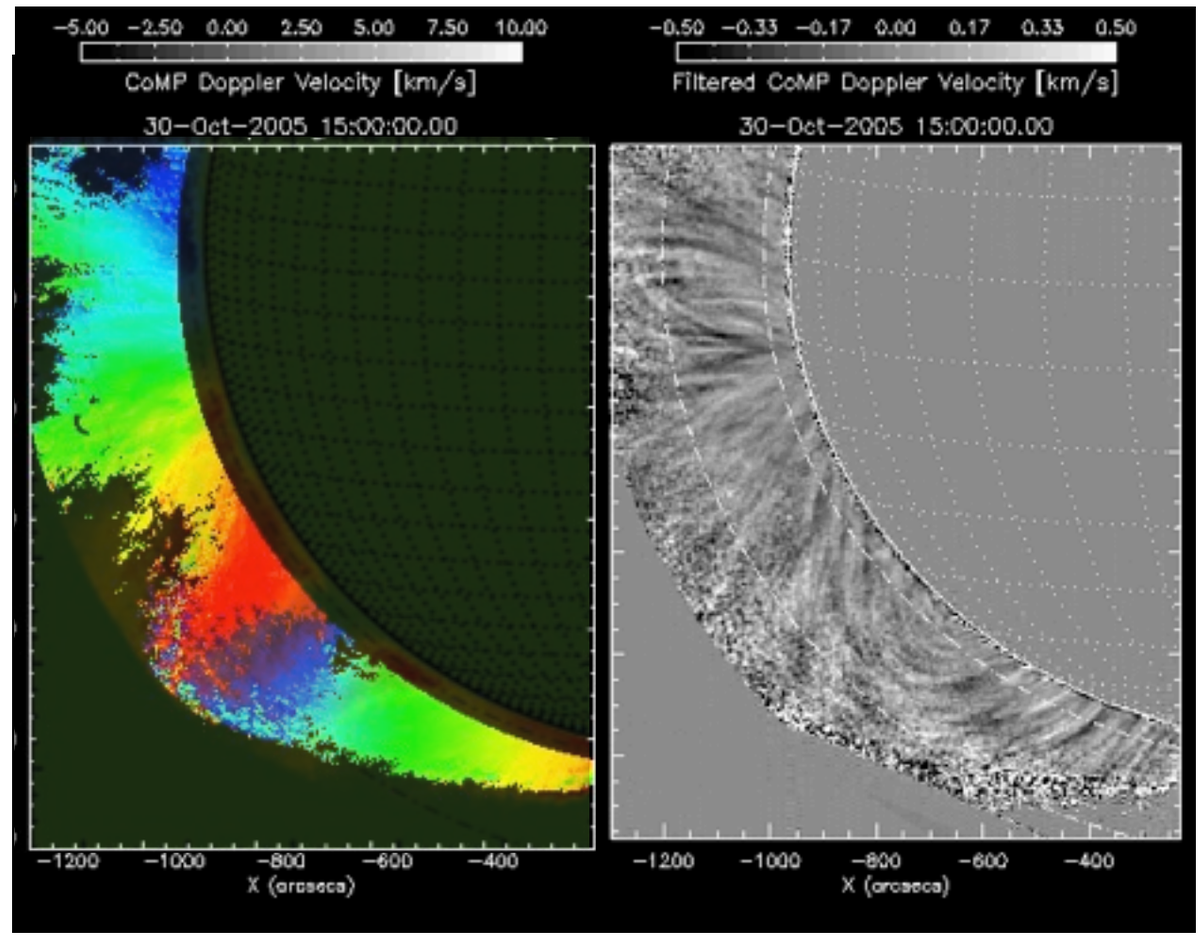

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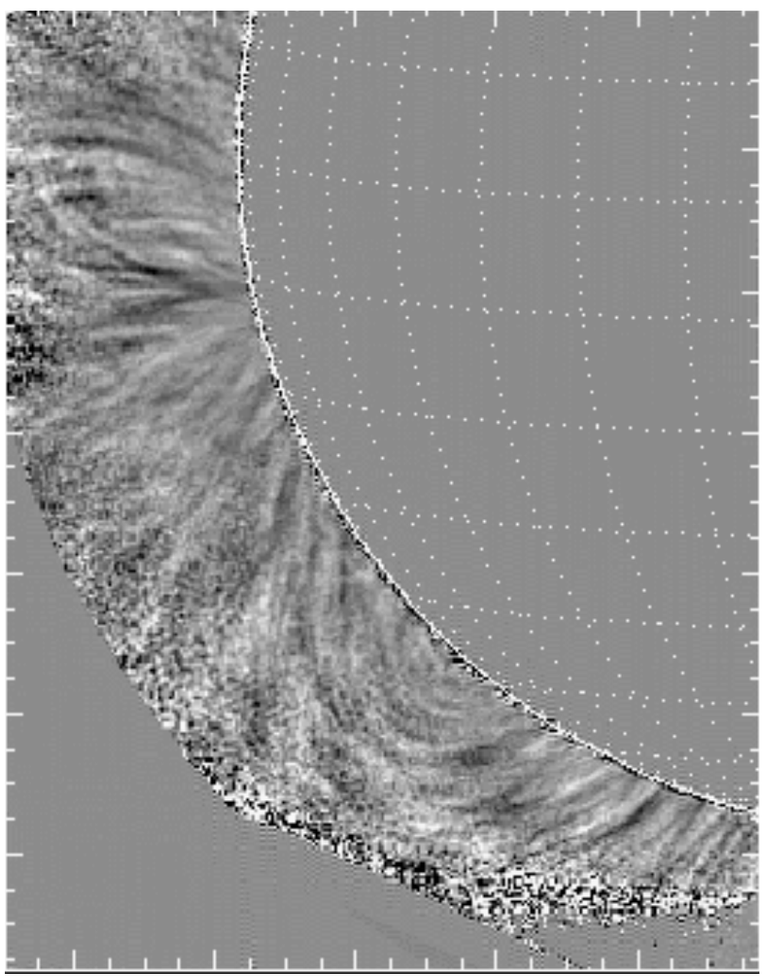

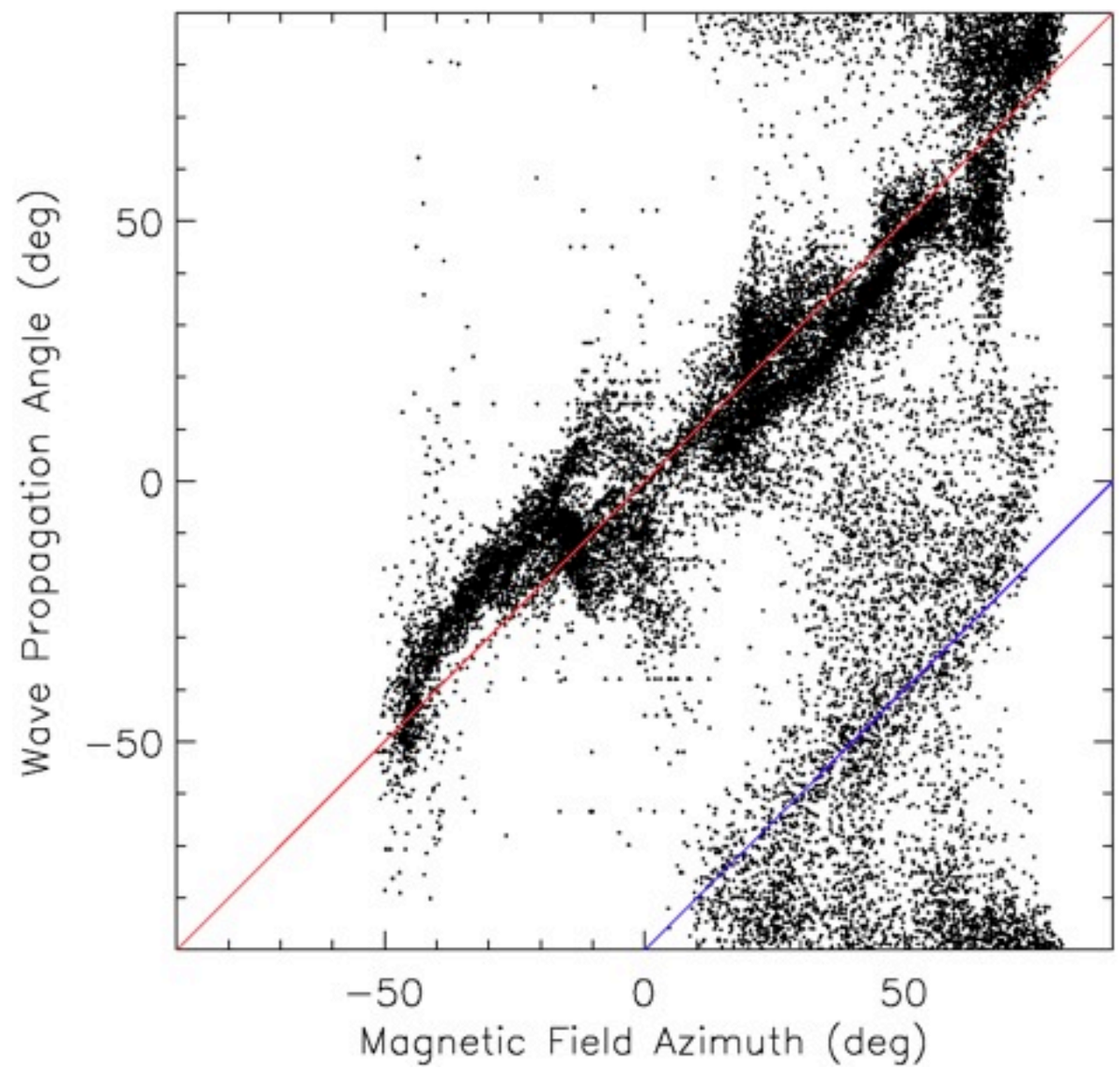

One-to-One* Match of Inferred and Observed Azimuth

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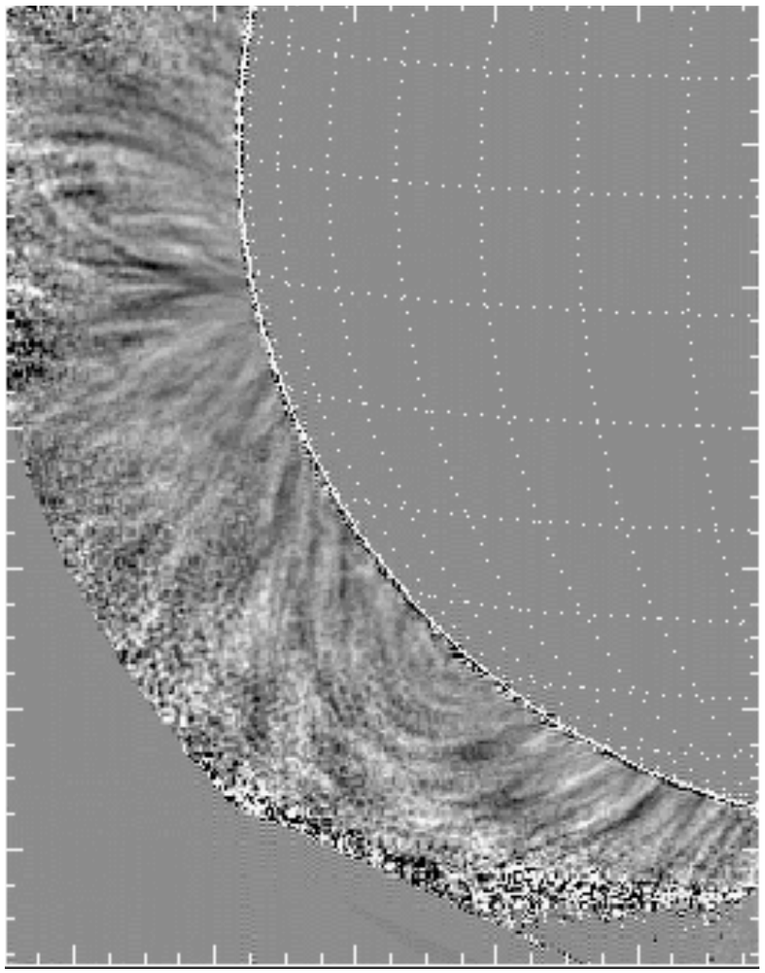

Results

Wave motions throughout the corona
Propagate at speeds of ~1Mm/s
"Follow" the field

Alfvén(ic) Waves!

What is the Resolved Energy Flux?

$$E_A = f \rho v^2 V_A$$

Energy Flux Estimate: ~0.1W/m²

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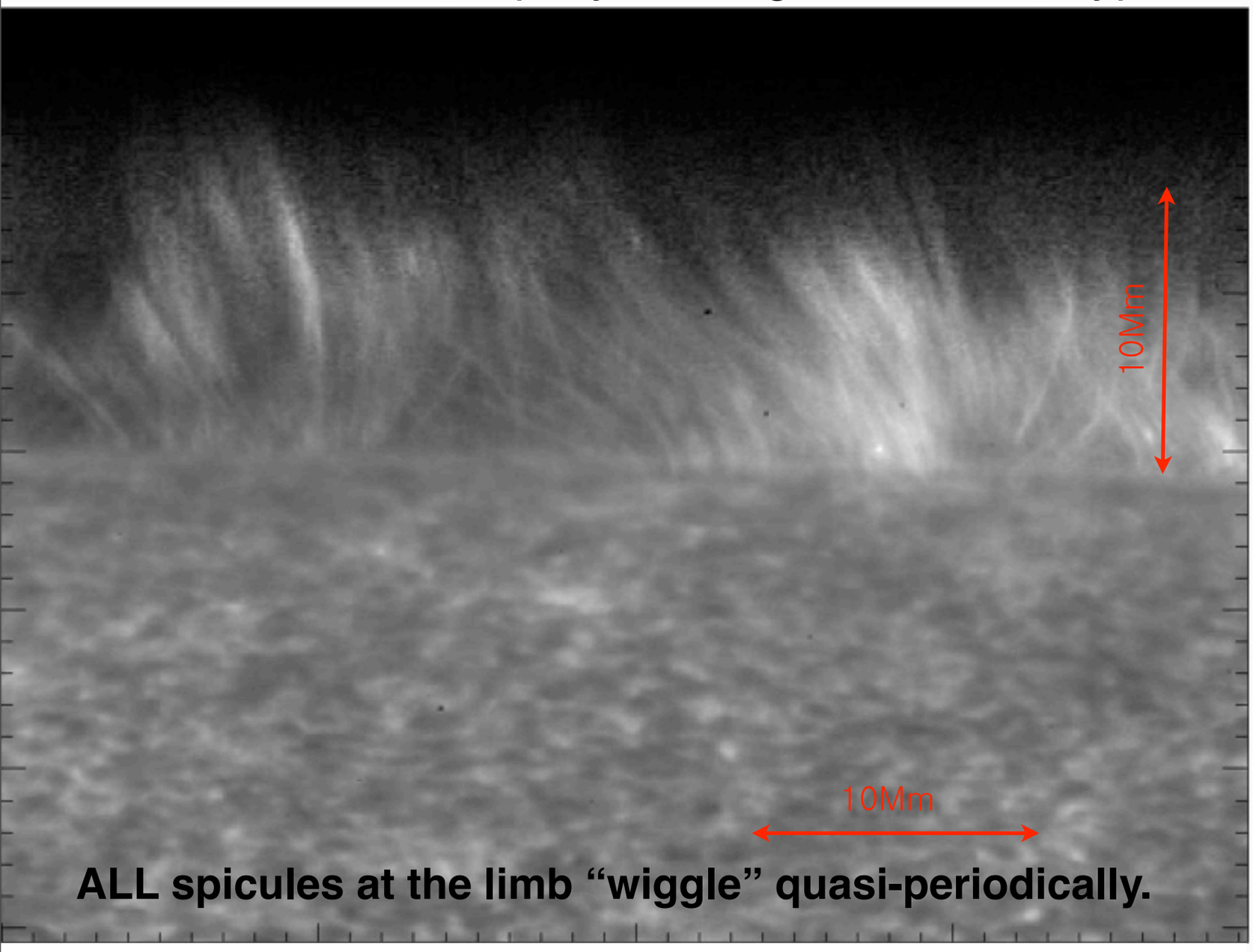
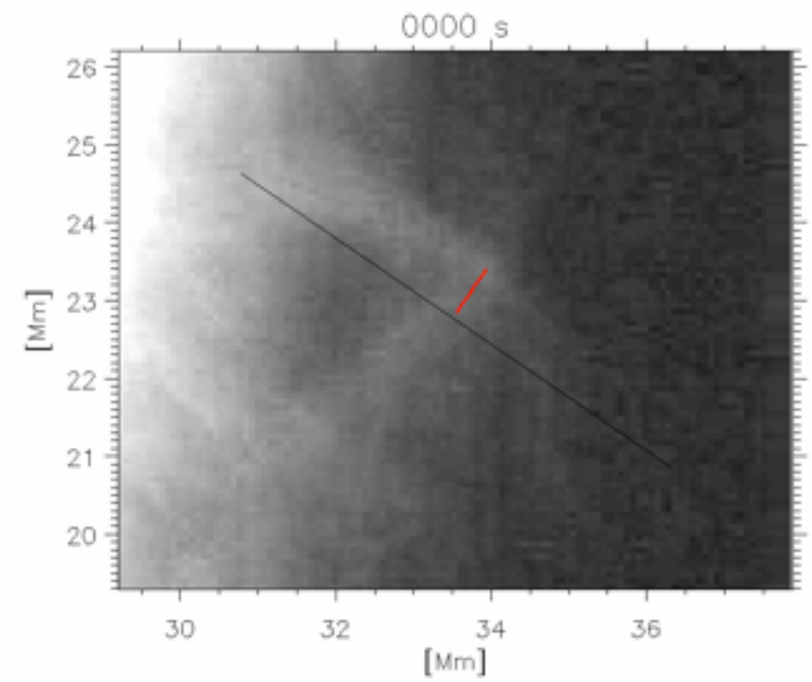
Abundant ("Dark") Energy?

Hinode/SOT

The limb chromosphere is dominated by fine [≤70km], tall [~5-10Mm], short-lived [~10-100s] rapidly forming structures ["Type-II spicules"].



ALL spicules at the limb "wiggle" quasi-periodically.



Period:

150-400s

Transverse Displacement:

0.3±0.15Mm

Apparent Speed:

~50km/s

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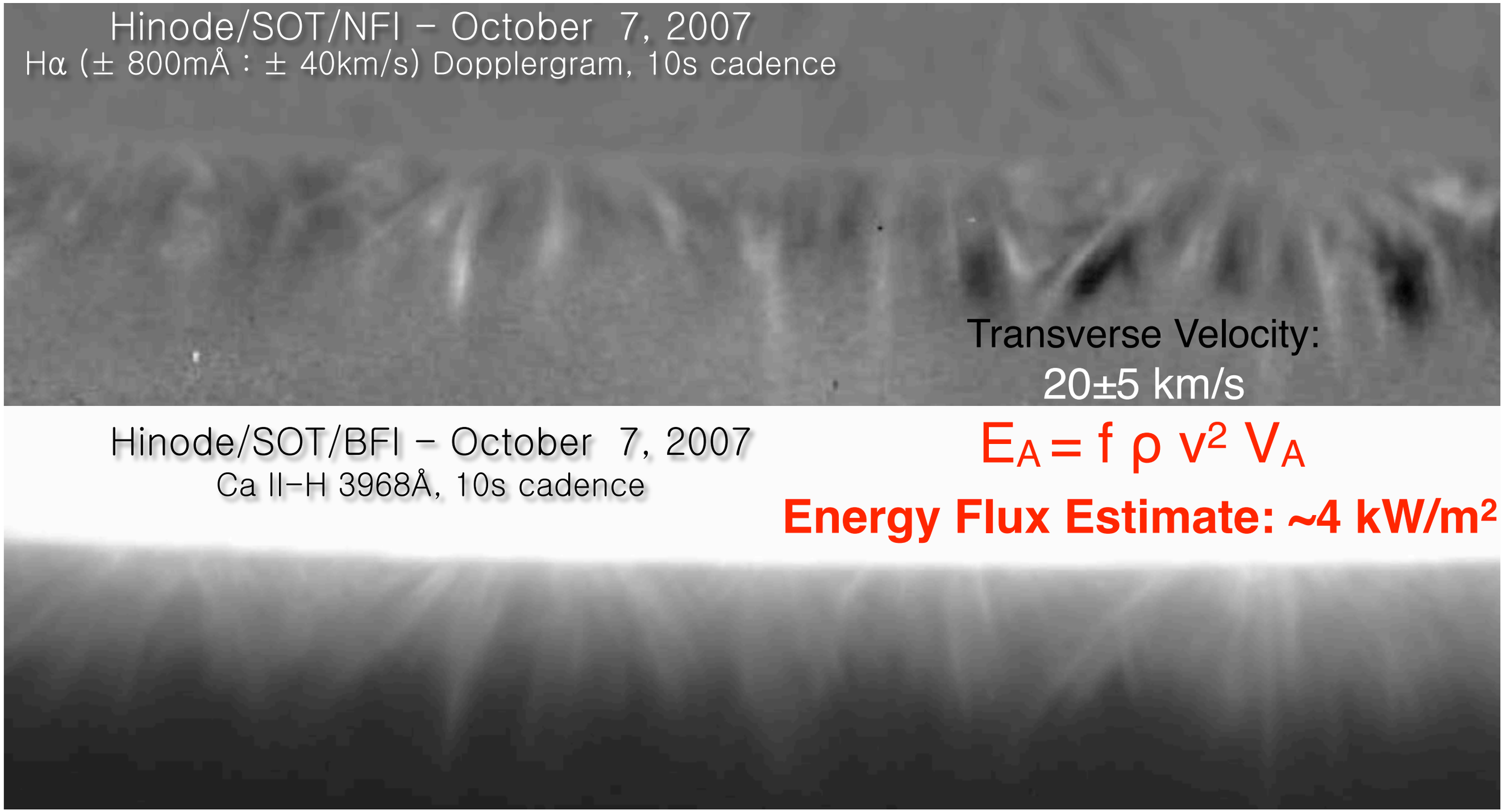
Abundant ("Dark") Energy?

Hinode/SOT



$$E_A = f\,\rho\,v^2\,V_A$$

Energy Flux Estimate: ~4 kW/m²

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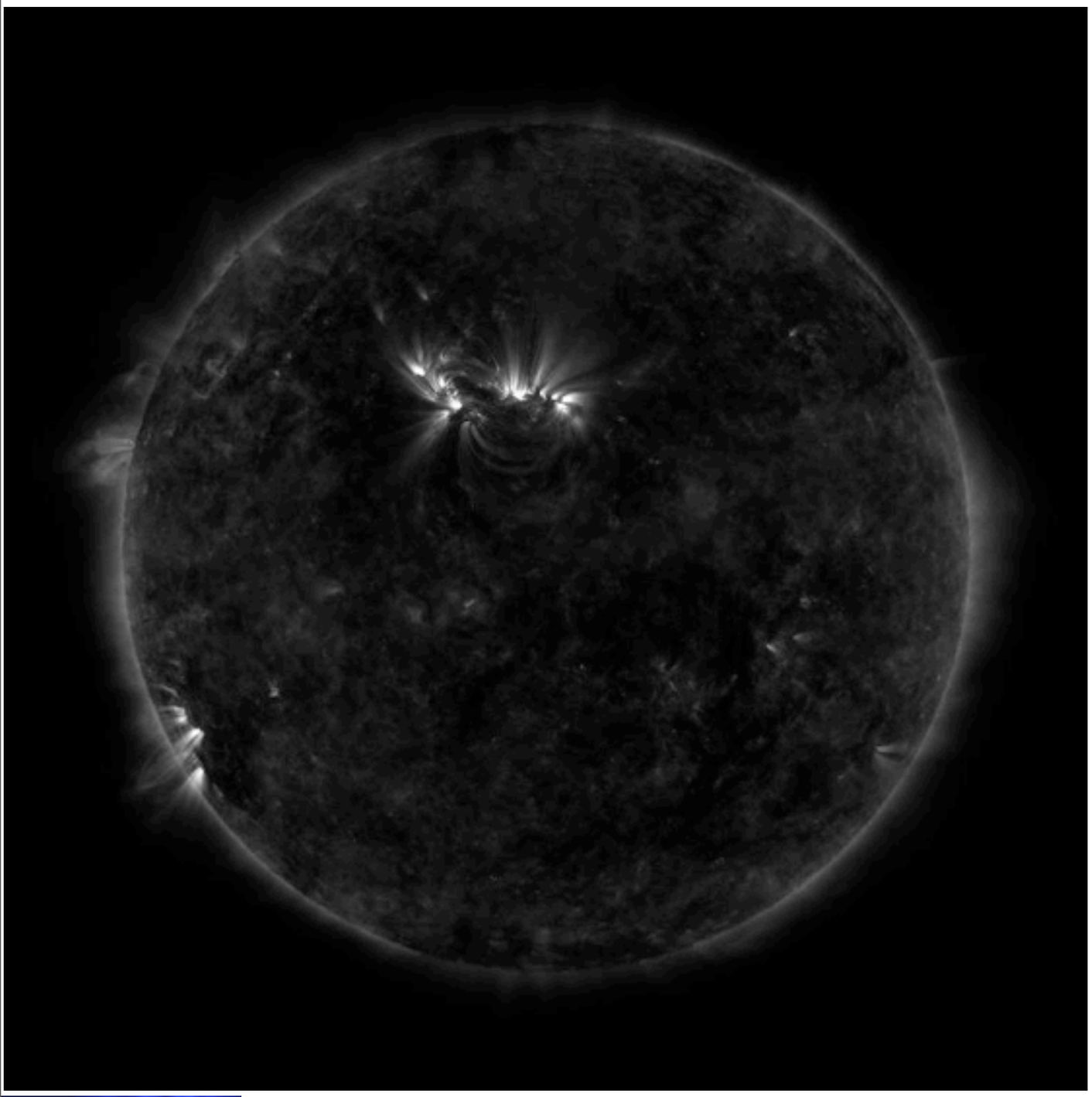
Abundant (“Dark”) Energy?

SDO/AIA



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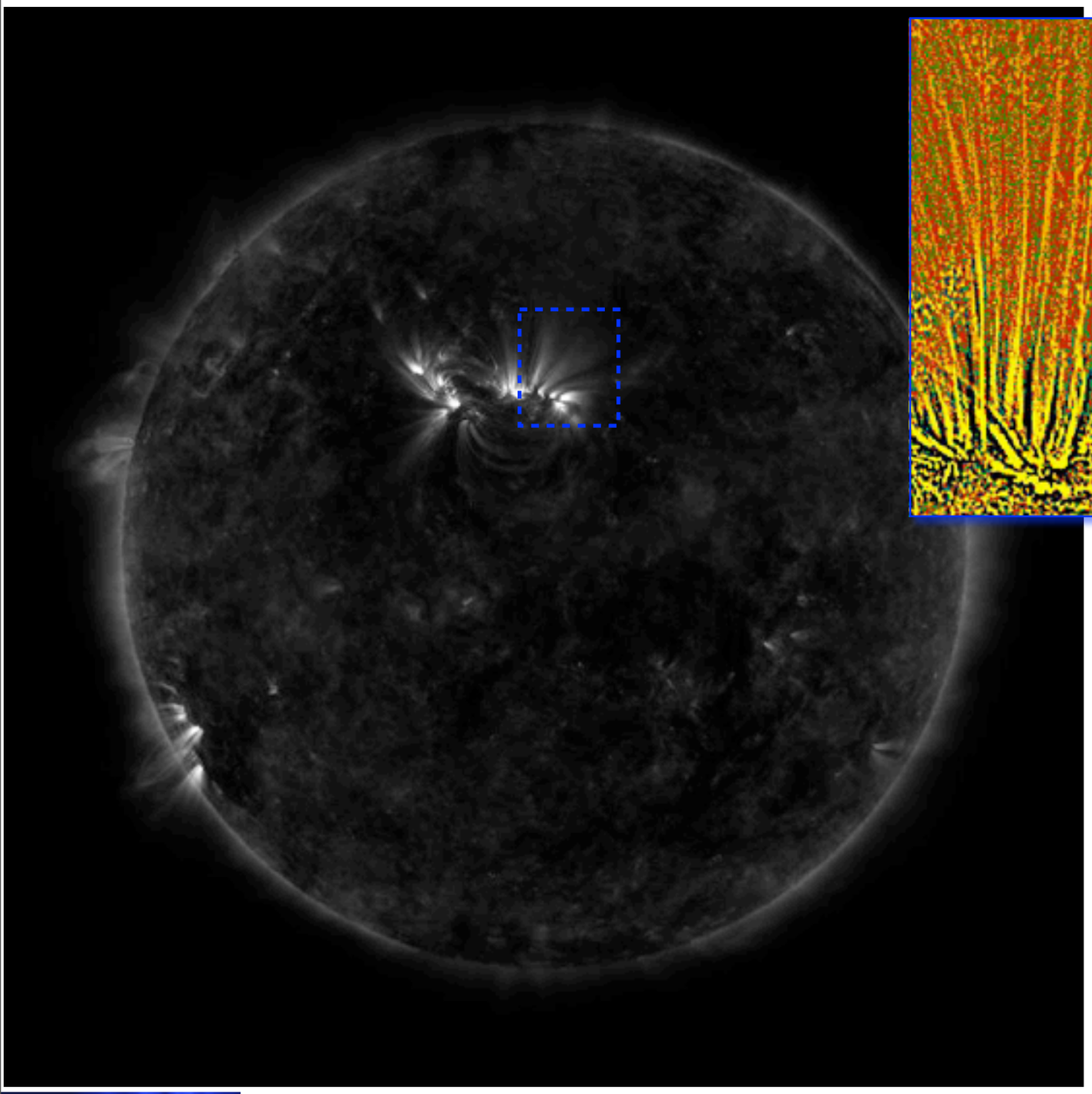
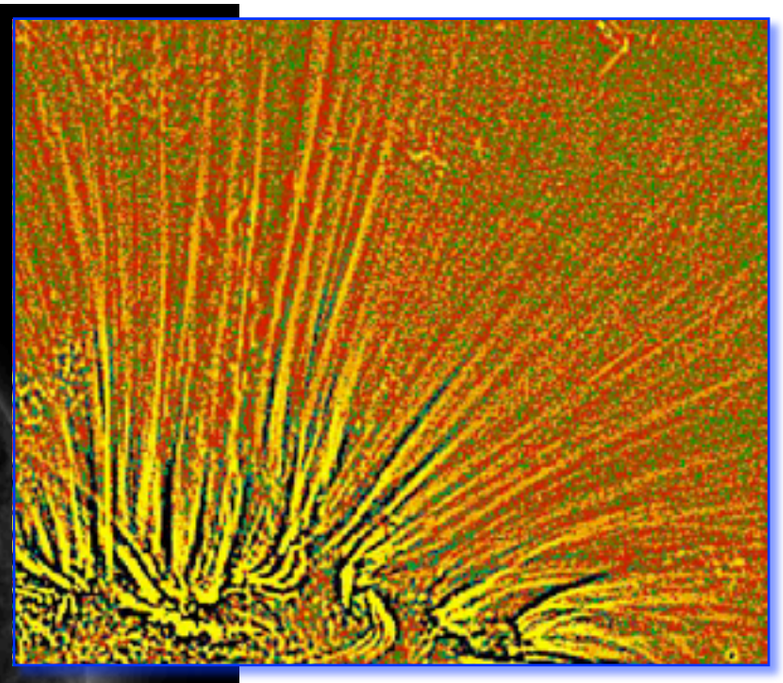
SDO/AIA





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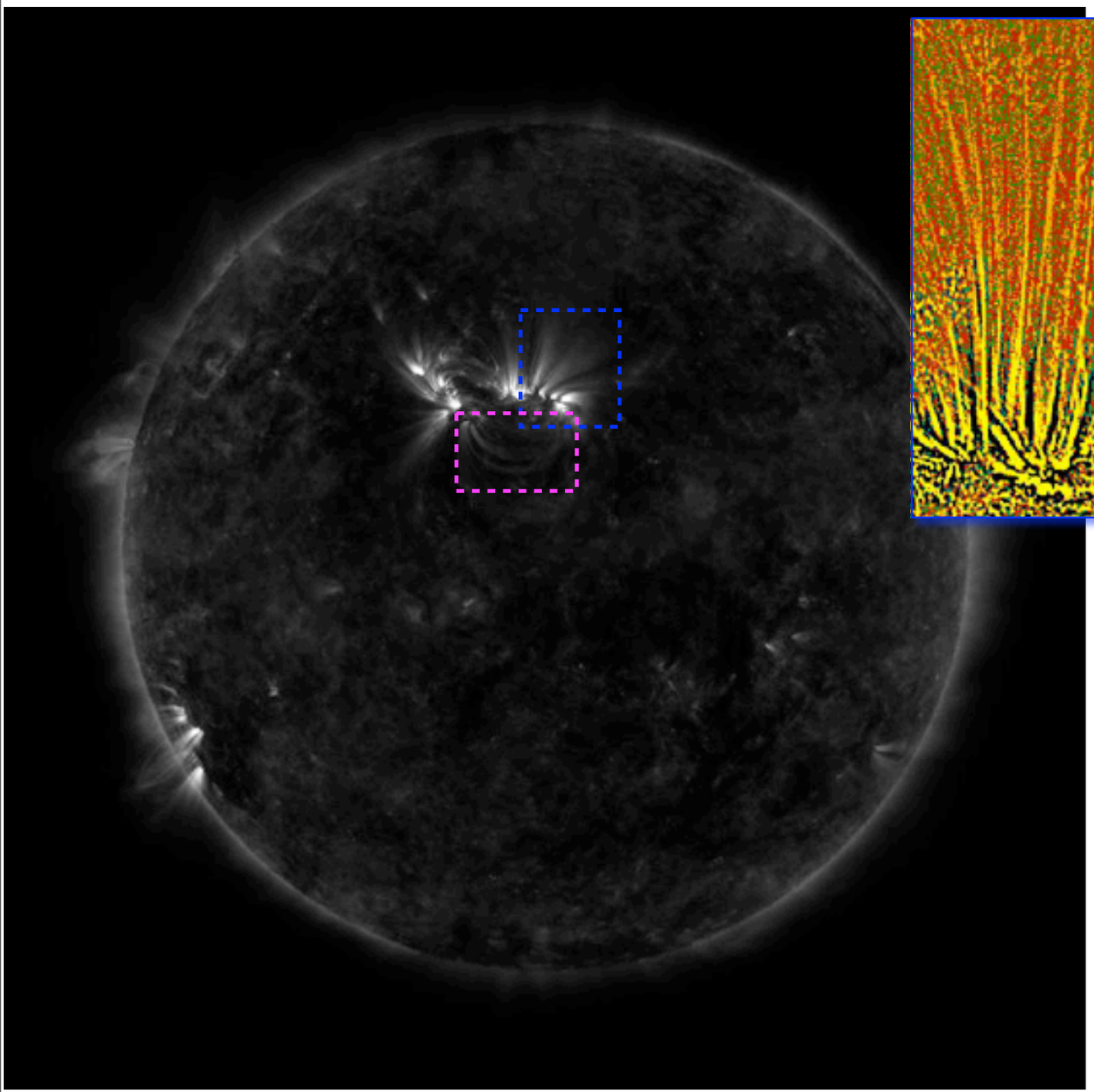

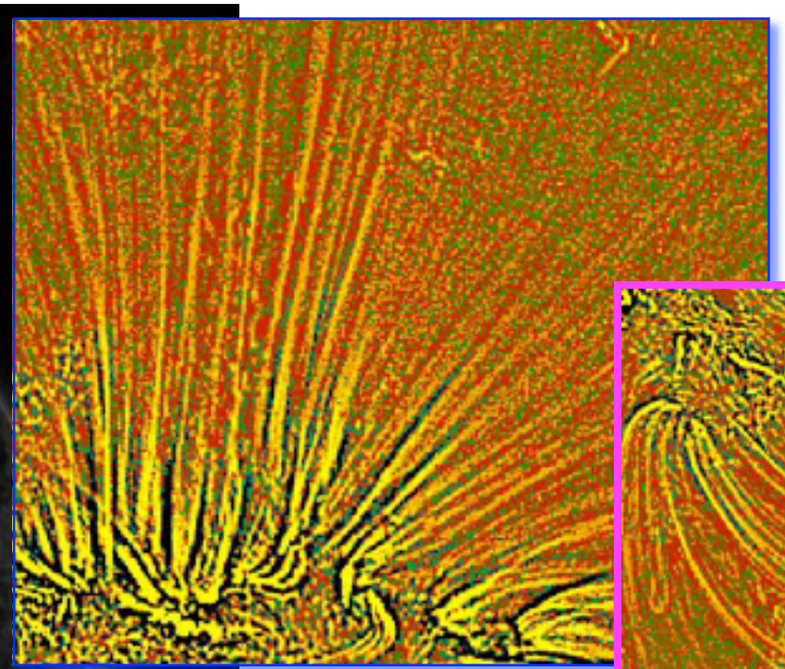

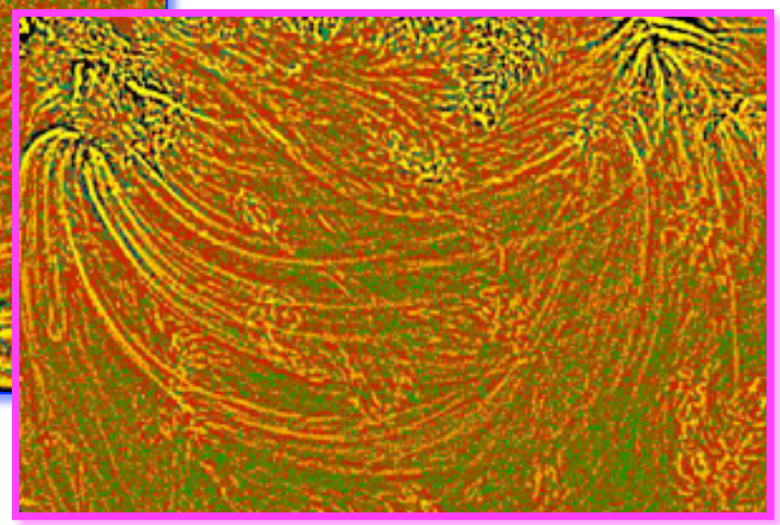

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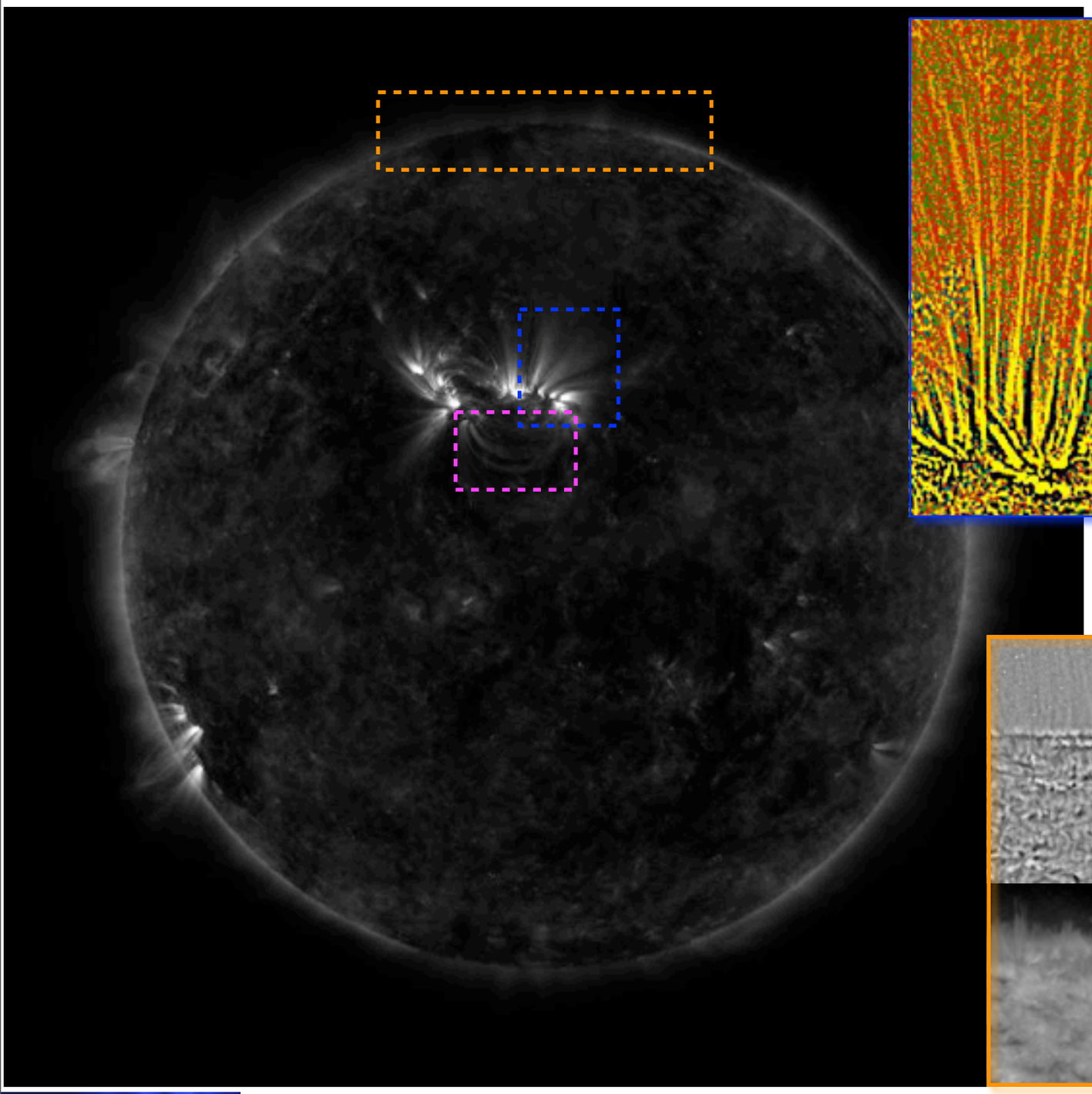

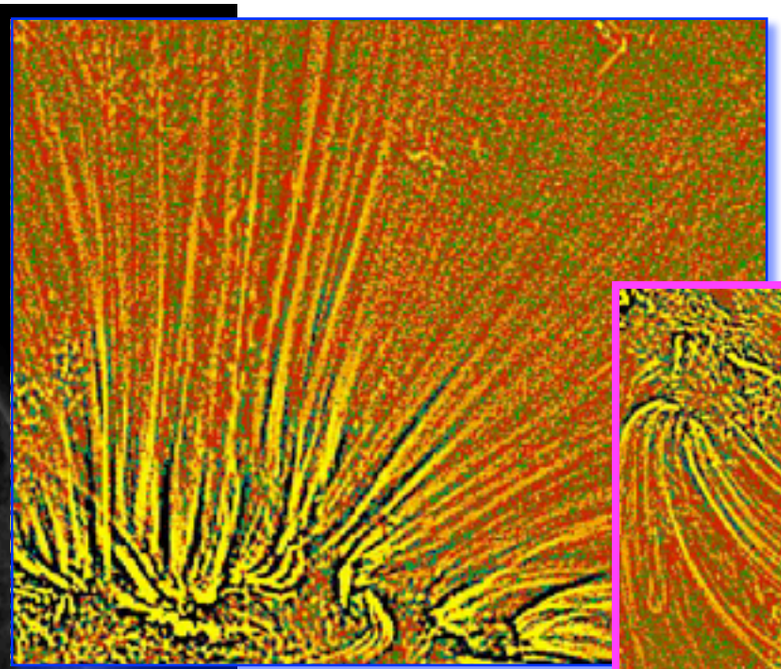

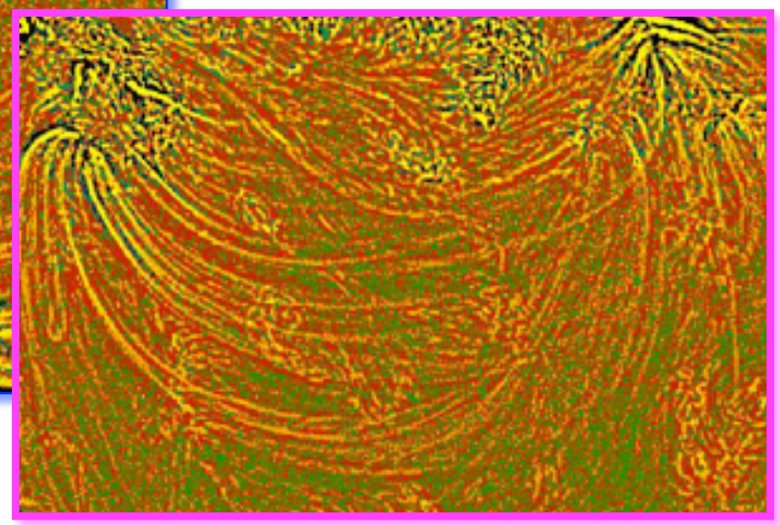

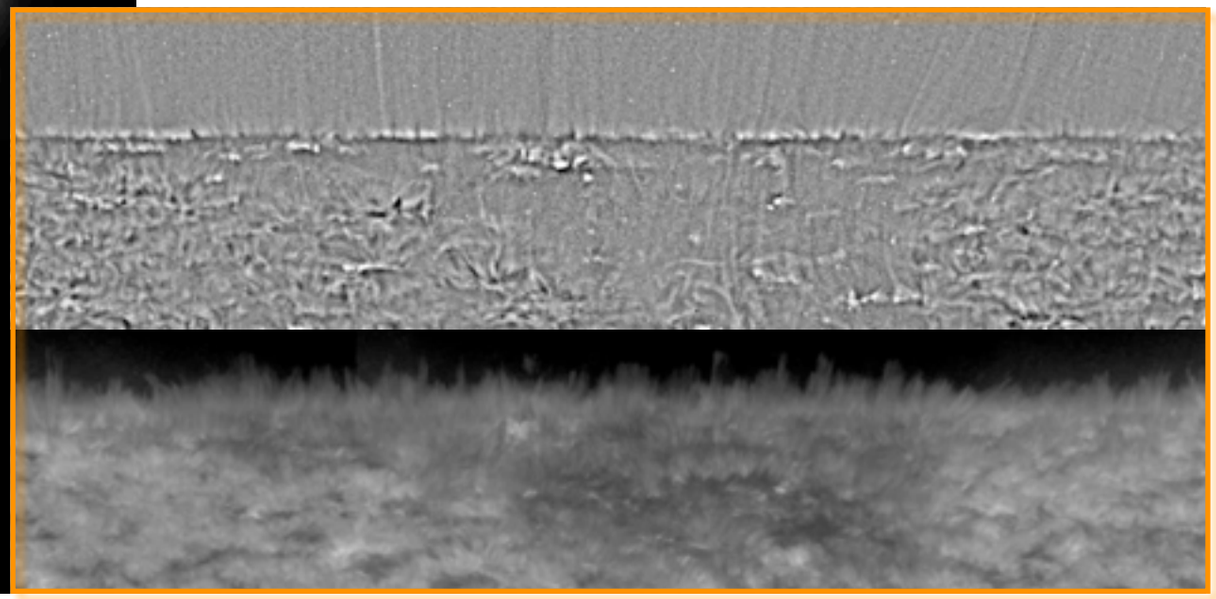

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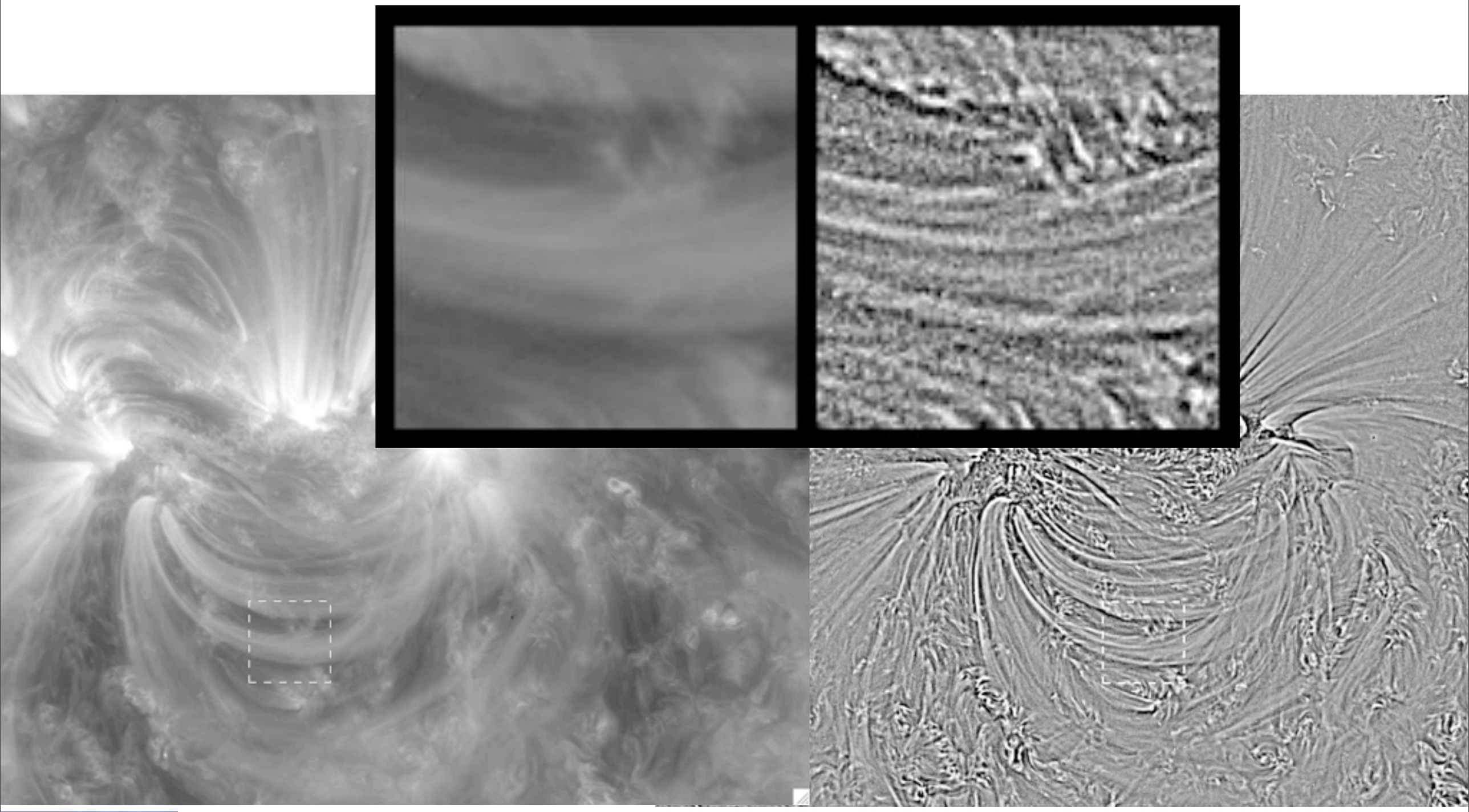

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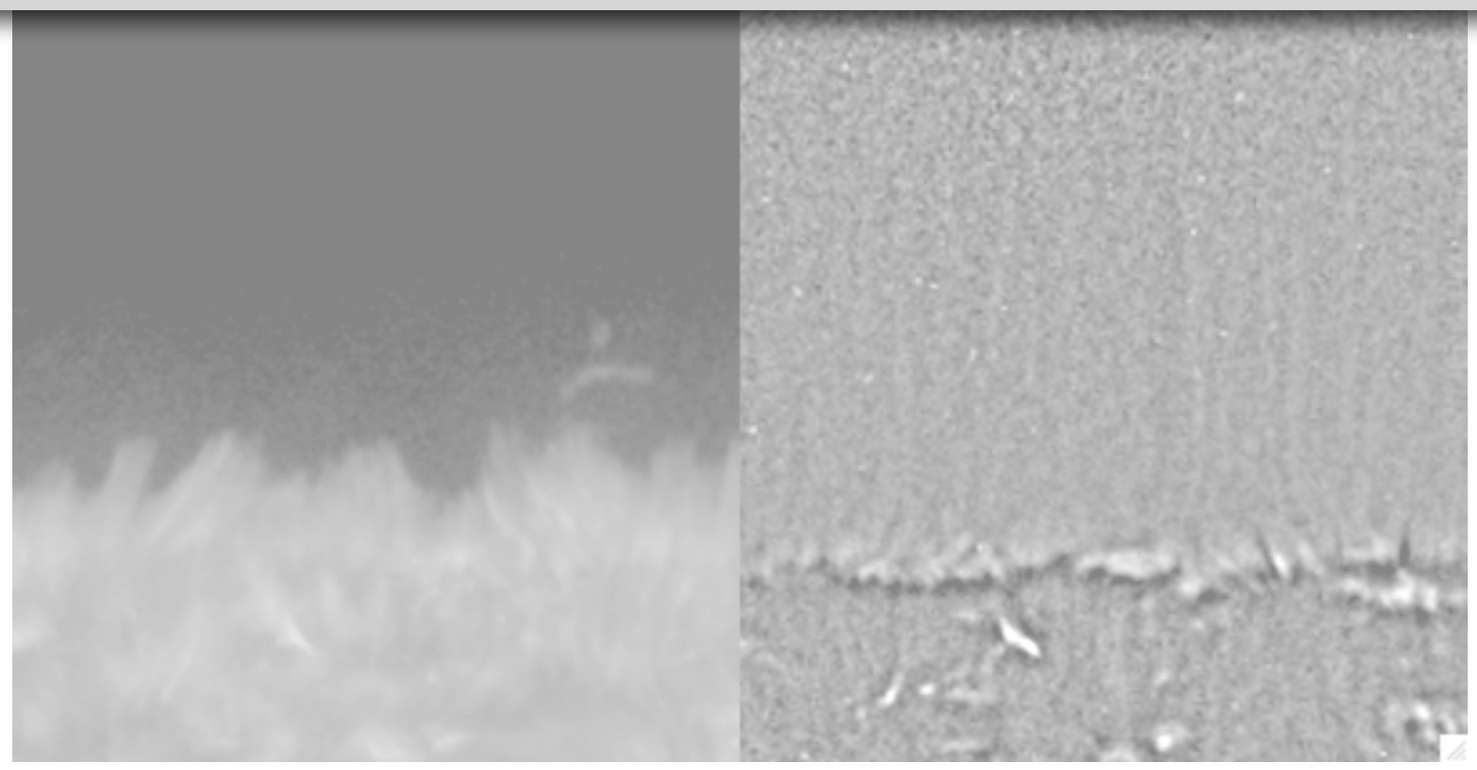
X-T vs Height 304Å X-T vs Height 171Å

Optically thin coronal emission makes for massive line of sight superposition, but “wiggles” are still visible in the corona.



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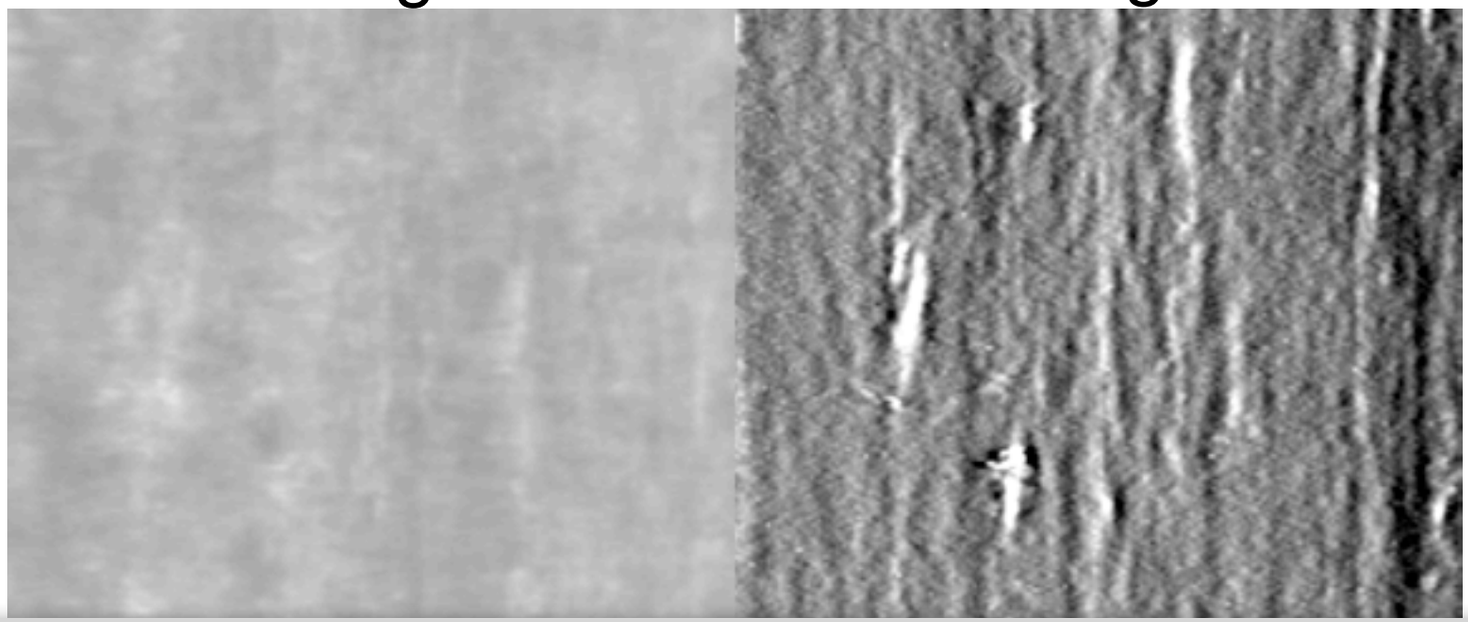

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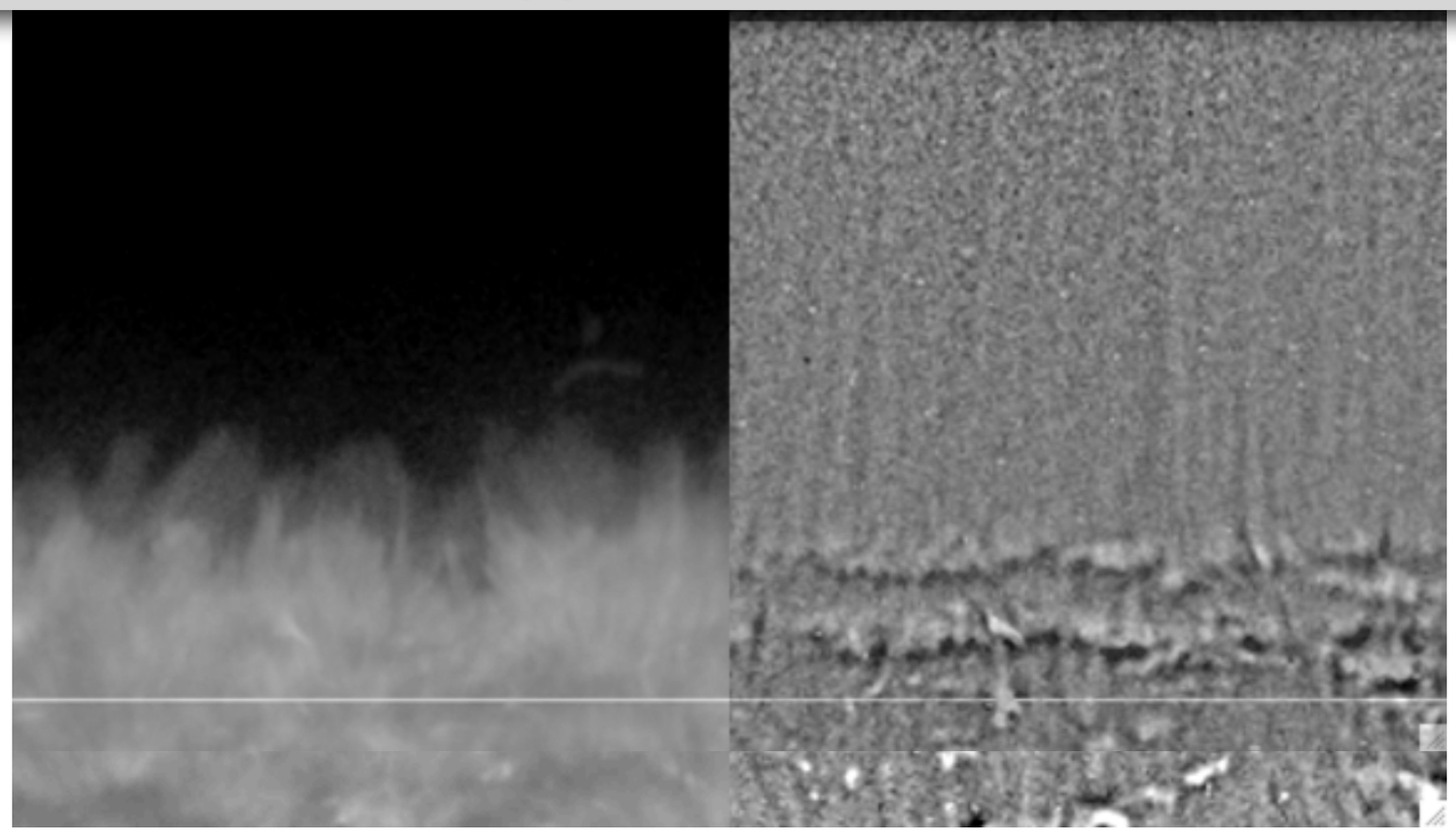

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Abundant ("Dark") Energy?

SDO/AIA

Quantifying Observed Transverse Wave Properties Using Monte-Carlo Simulations

Goal: Investigate lifetimes, periods and wave amplitudes that can reproduce the observed wiggles.

Monte Carlo Recipe

1. Sprinkle "spicules" randomly (uniformly) in time/space
2. Random (uniform) dist^n of spicule lifetimes **[300±100 s]**
3. Equal intensity of all spicules
4. Apply random Alfvénic properties:
   - ★Uniform dist^n of Periods **[e.g., 50-350 s]**
   - ★Gaussian dist^n of Amplitudes **[e.g., 25 (±10) km/s]**
   - ★Uniform dist^n of Phases **[0 - 2π]**
   - ★Uniform dist^n of Polarization Angles **[0 - 2π]**

5. Adjust to spatio/temporal resolution of observation

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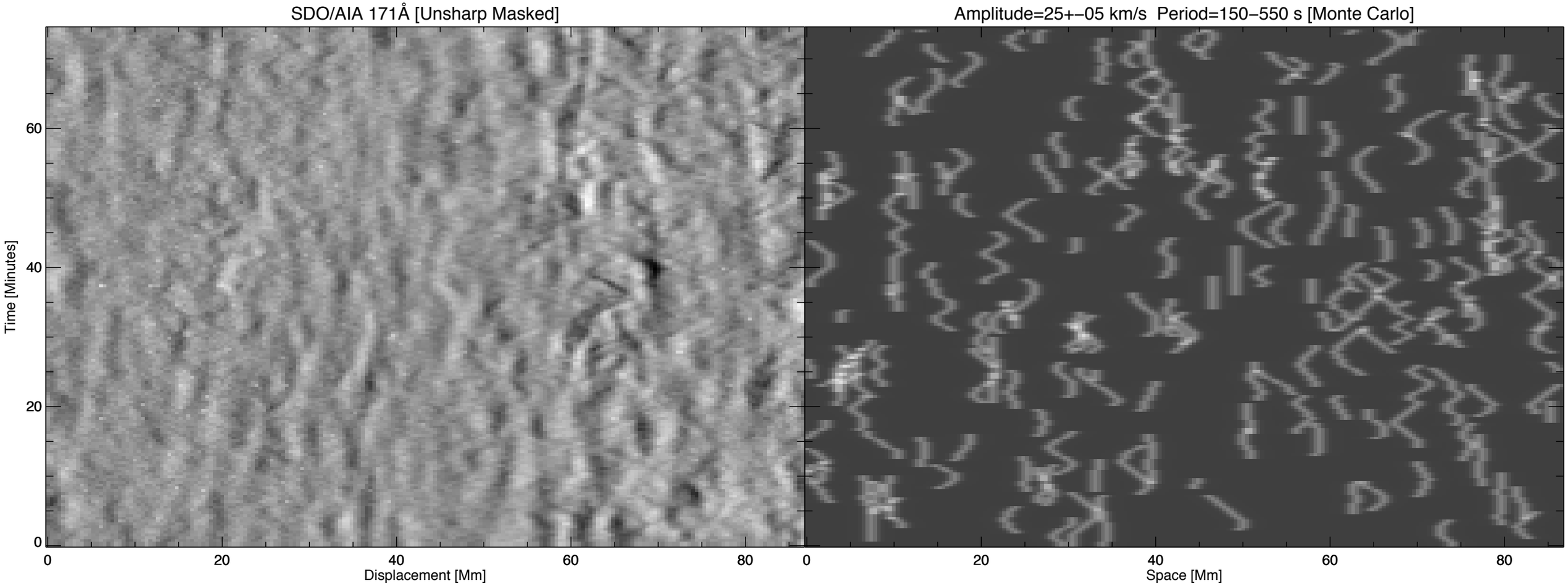
Monte Carlo Simulation

The “Goldilocks” Test



Transverse oscillation amplitudes of order 25 km/s appear to match well

Oscillation periods more difficult to determine, but MC sims fit data well for 150-550 s periods.

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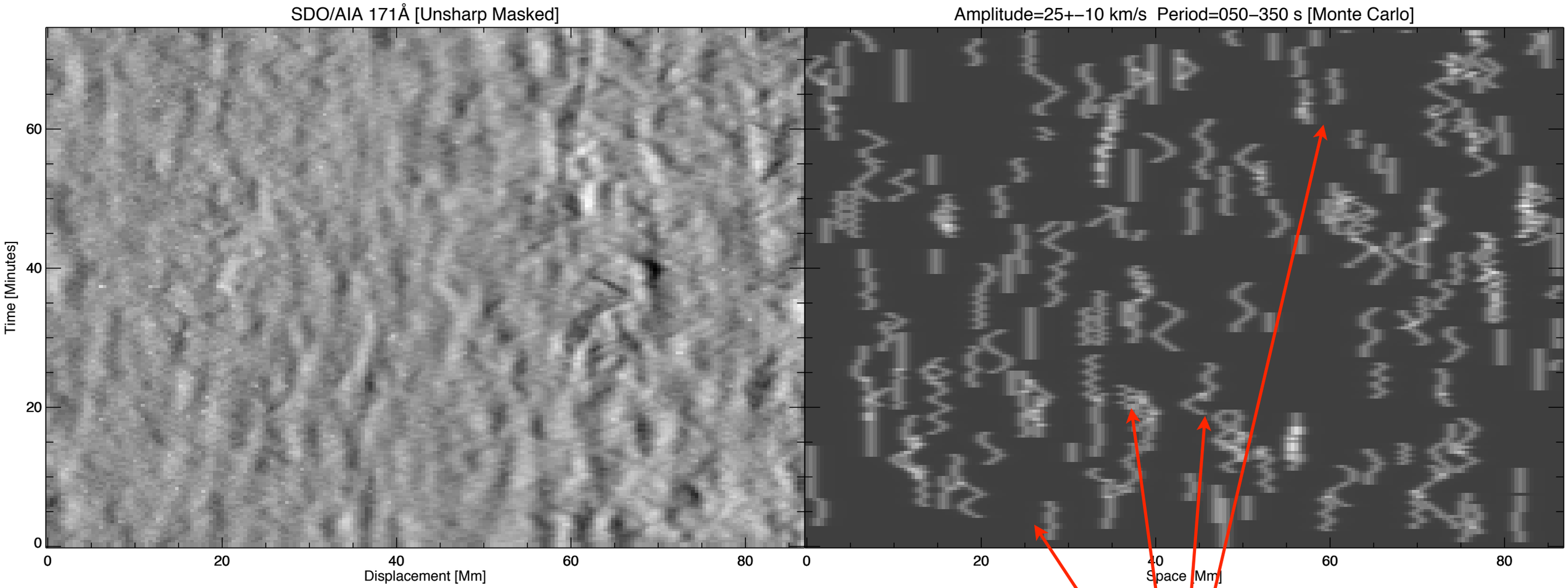

Monte Carlo Simulation

The “Goldilocks” Test

Short periods (50-150 s) would show more “swings” than observed

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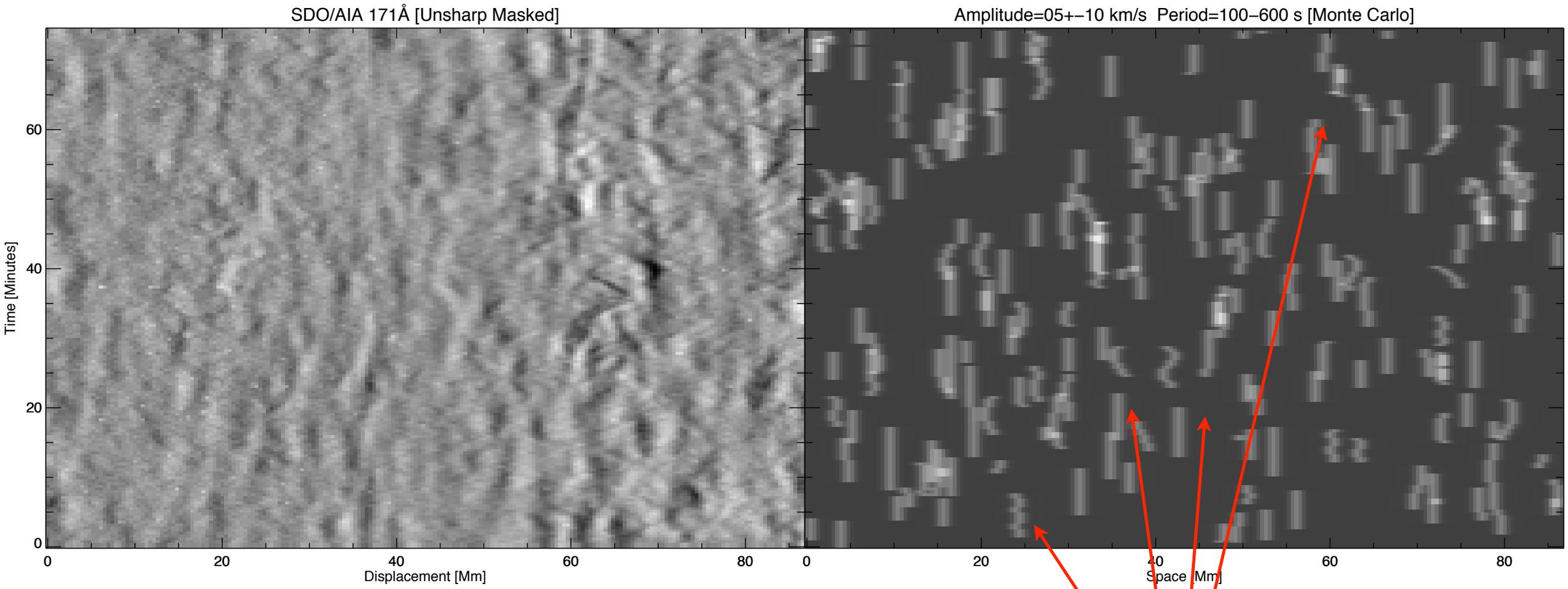

Monte Carlo Simulation

The “Goldilocks” Test

lower amplitudes (<10km/s) would show few wiggles!

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Abundant ("Dark") Energy?

SDO/AIA

For Coronal Densities $\begin{cases} \rho^{QS/CH} = 5\text{-}10\times10^{-13}\ kg/m^3 \\ \rho^{AR} = 5\text{-}10\times10^{-12}\ kg/m^3 \end{cases}$

Wave Filling Factor "f" ~ 1

Estimated Wave Phase Speed V_A

Estimated Wave Amplitude v

$$E_A = f\ \rho\ v^2\ V_A$$

Region	Amplitude (km/s)	Period (s)	Phase Speed (km/s)	Power (Wm^{-2})	Required (Wm^{-2})
Coronal Hole	25 ± 5	150 - 600	~300 (@15Mm)	~100 - 200	**100 - 200**
Quiet Sun	20 ± 5	150 - 600	~250 (@15Mm)	~100 - 200	**100 - 200**
Active Region	5 ± 5	100 - 400	~600	~100	**~2,000**

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Reconciling Wave Energies

Recalling:

Hinode [Chromosphere]	**~4kW/m²**
CoMP [Corona]	**~0.1W/m²**
SDO [TR/Corona]	**~100W/m²**

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Why is the CoMP wave energy flux SO low?

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Reconciling Wave Energies

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Hinode [Chromosphere] **~4kW/m²** ✓

CoMP [Corona] **~0.1W/m²** ✗

SDO [TR/Corona] **~100W/m²** ✓

Why is the CoMP wave energy flux SO low?

Advance our M-C scheme to understand the impact of poor spatial resolution on CoMP energy flux:

Period [50-350 s]
Lifetime [300±100 s]
Phase/Polarization [0 - 2π]

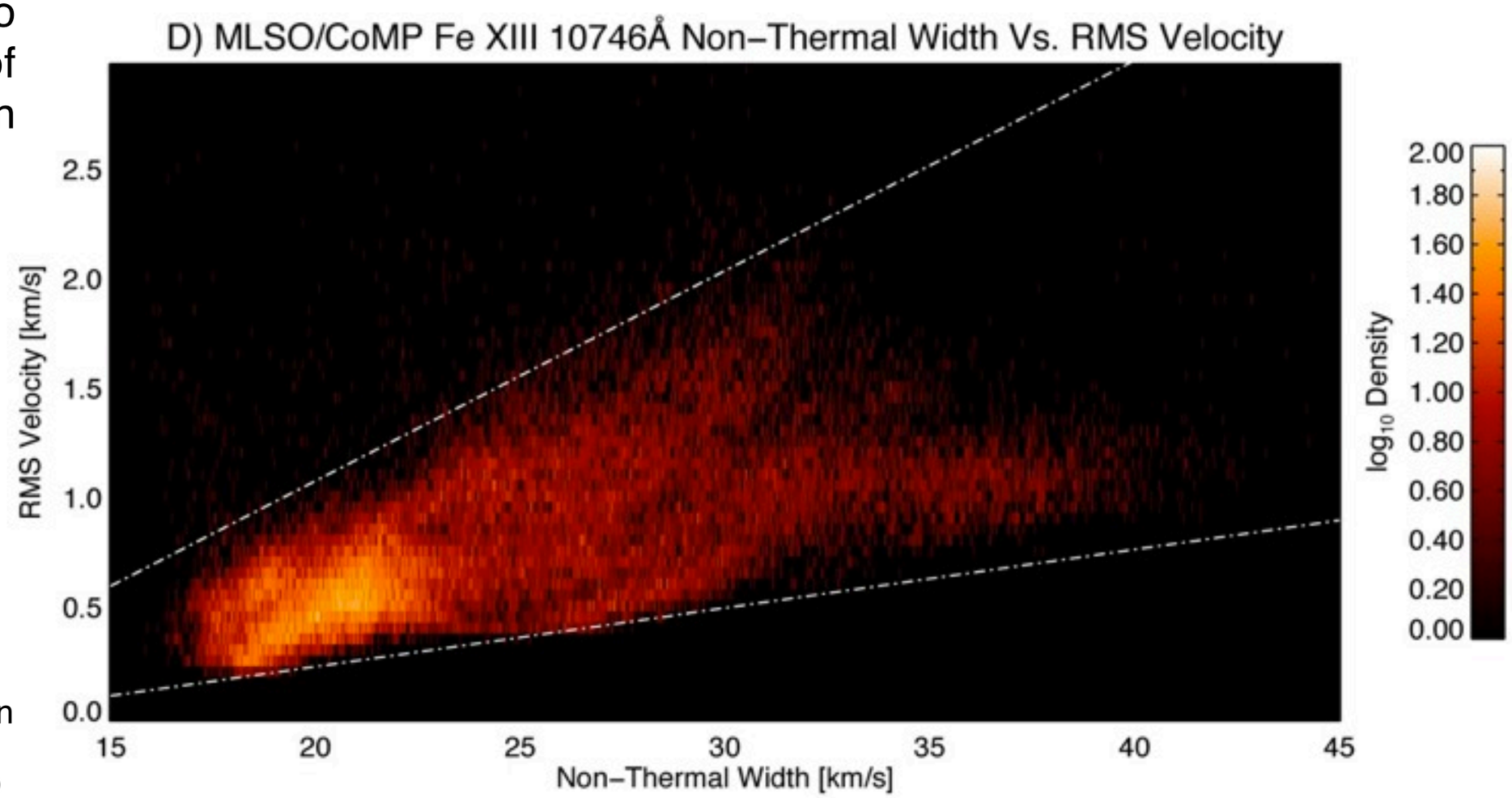
Wave Amplitude [X±5km/s]

ONLY new variable:

of "threads" in LOS

VARY X & #

Where every thread emits a gaussian of Thermal Width (Fe XIII) 21km/s
(total is convolved with Inst. Width of CoMP 21km/s)



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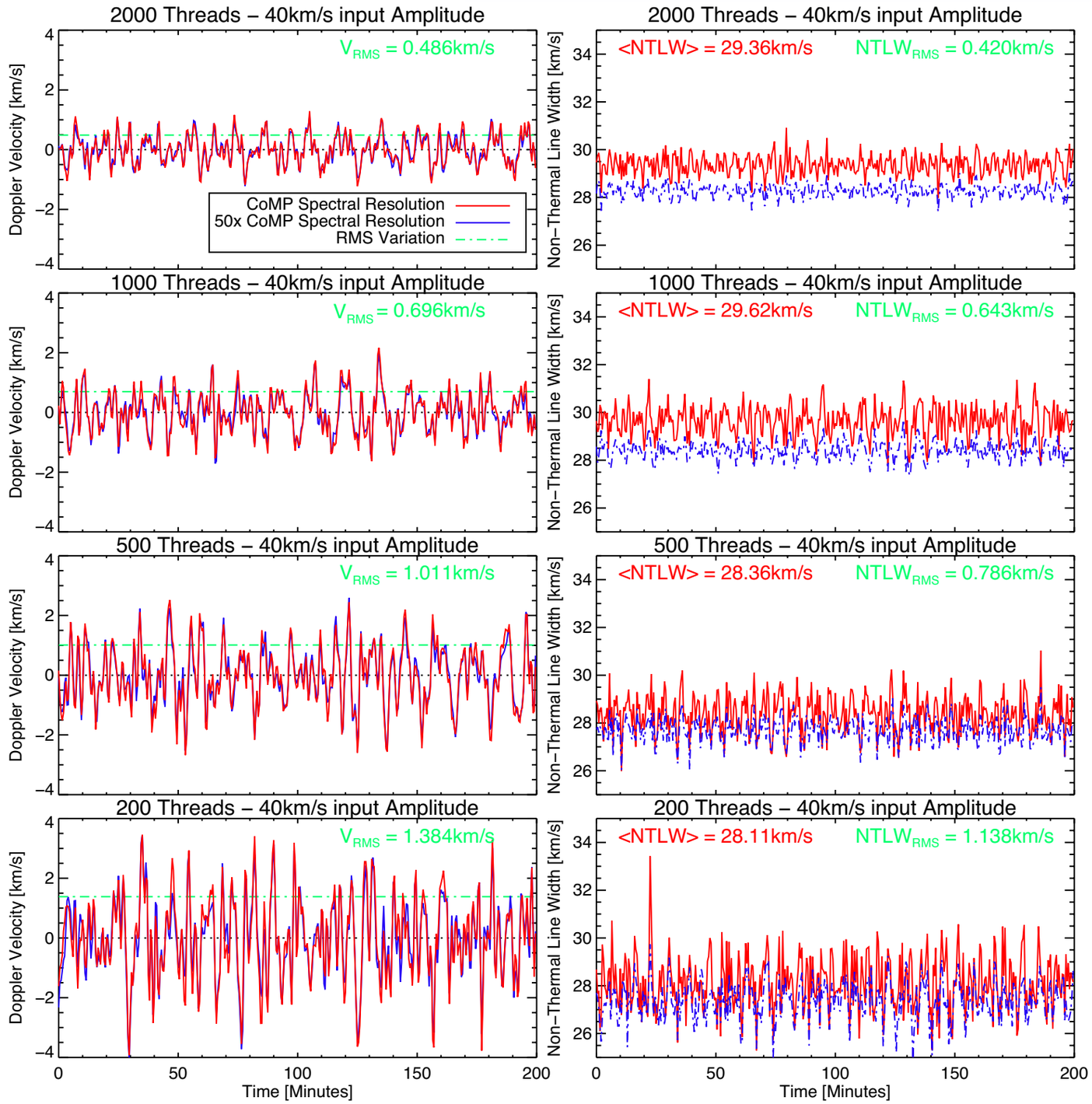
Reconciling Wave Energies

Increasing Threads

Increasing RMS



Increasing RMS

Increasing Width

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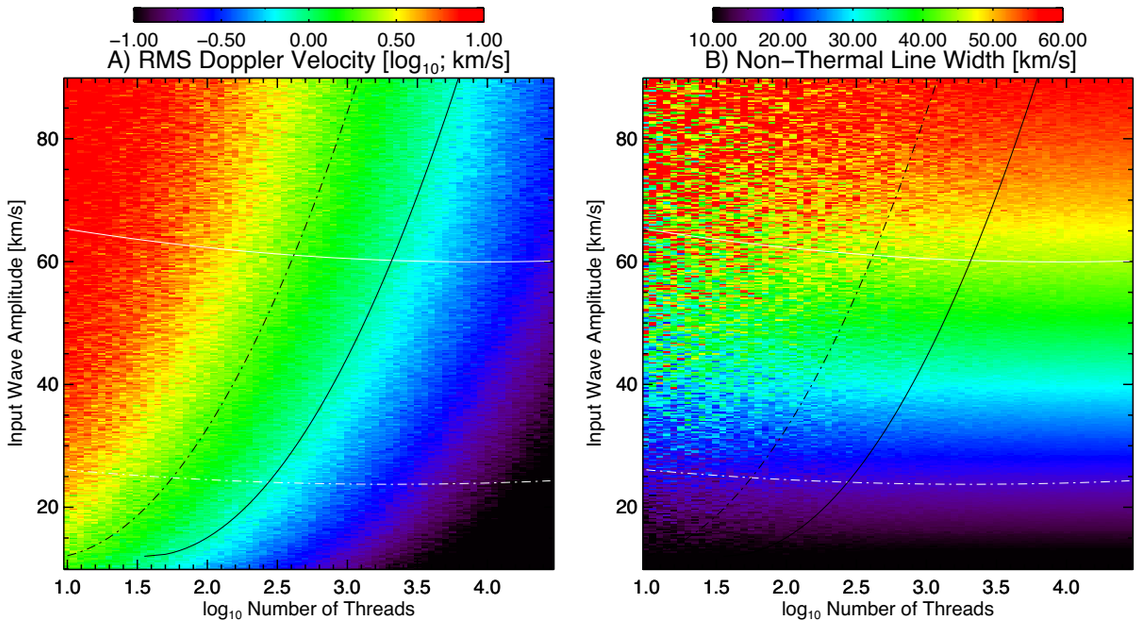
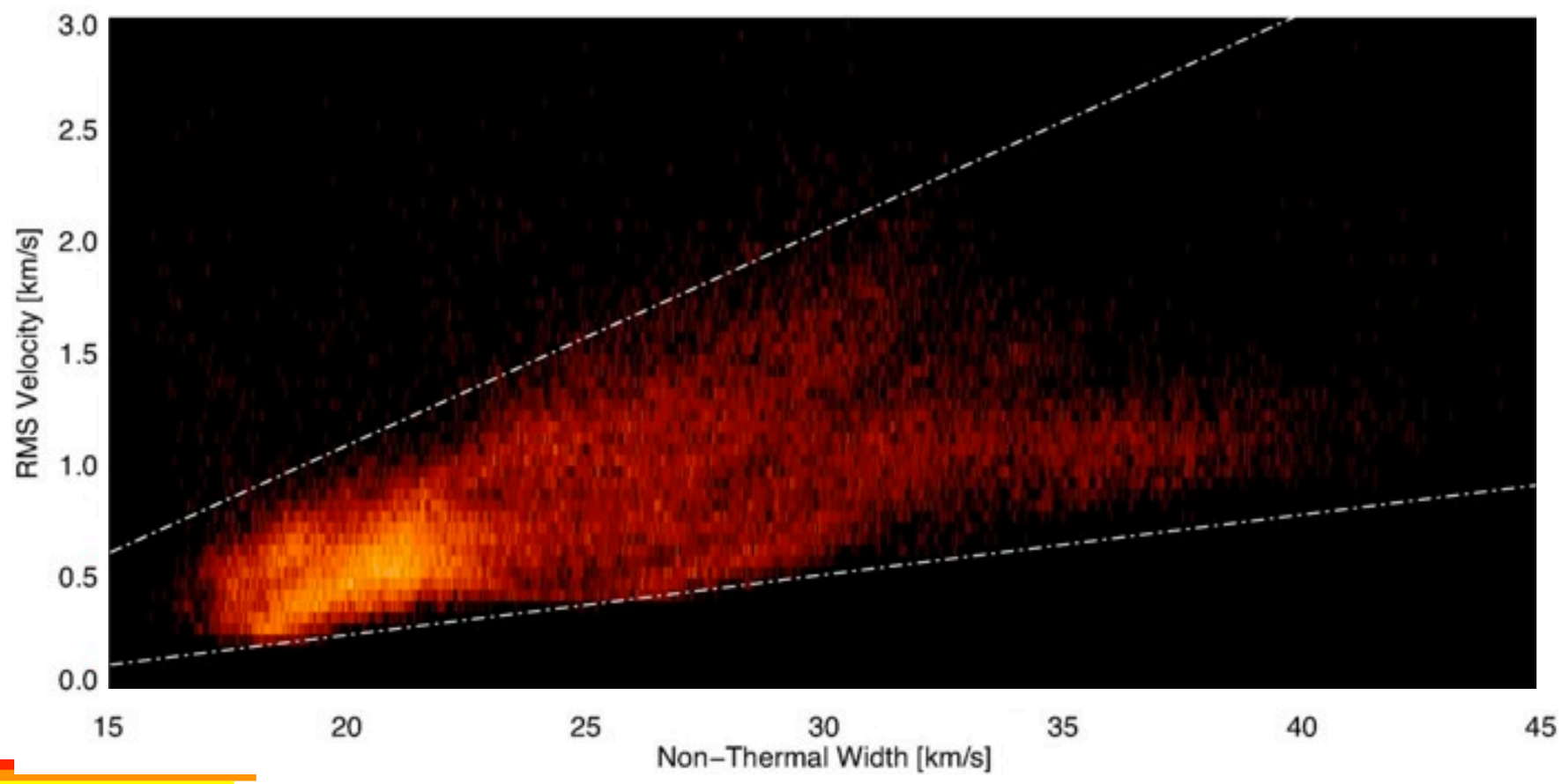
Reconciling Wave Energies



non-thermal velocity expressed in terms of unresolved velocity components:

$$V_{nt} = \sqrt{(V_{\perp}^2 + V_{+}^2)}$$



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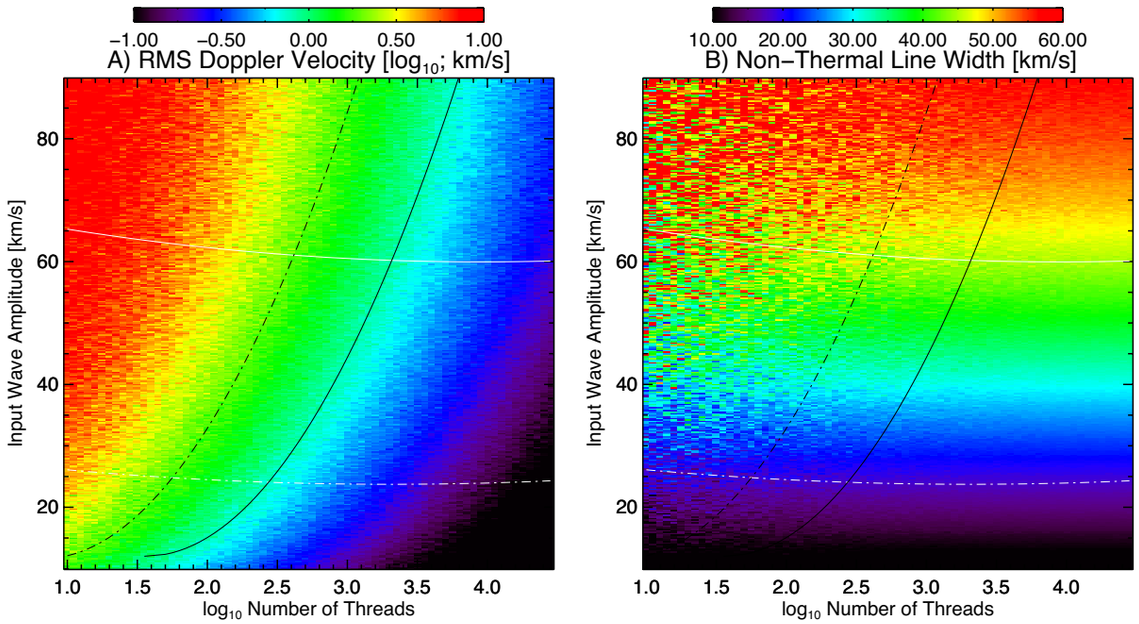

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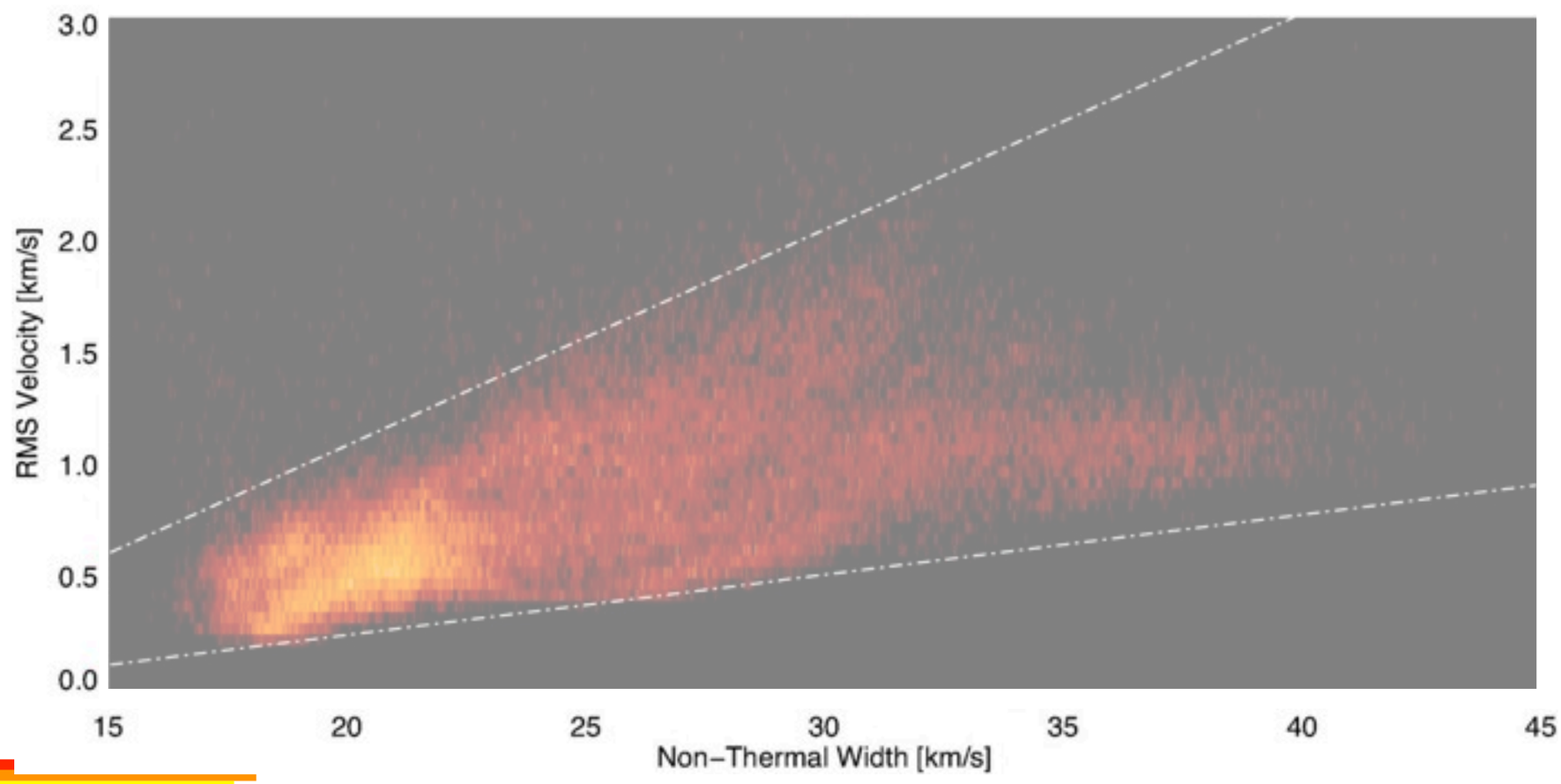

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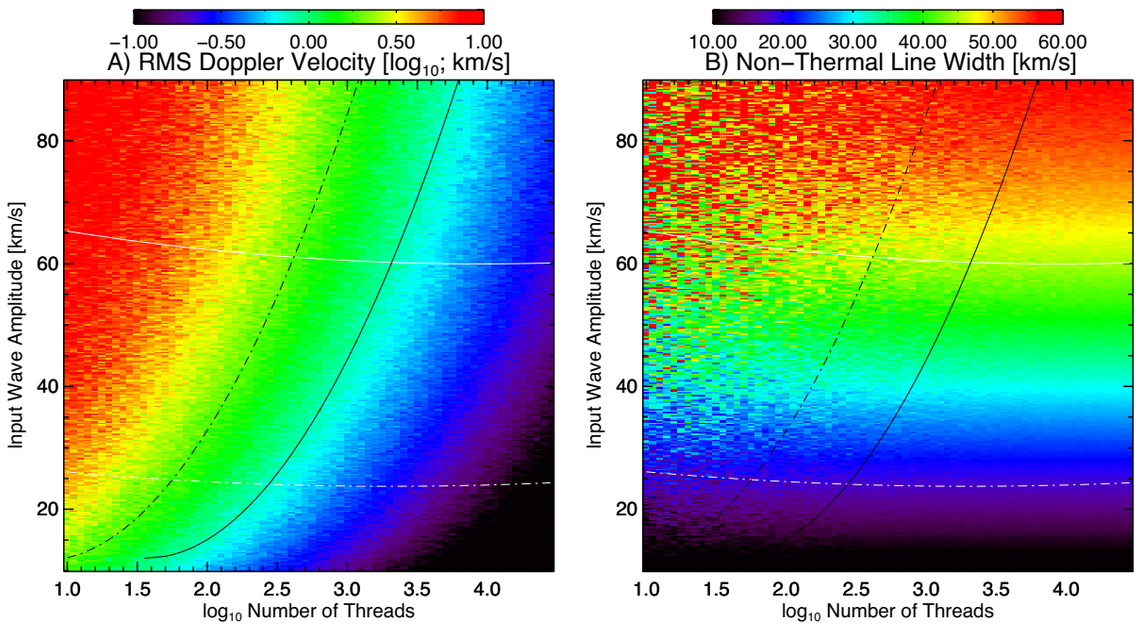

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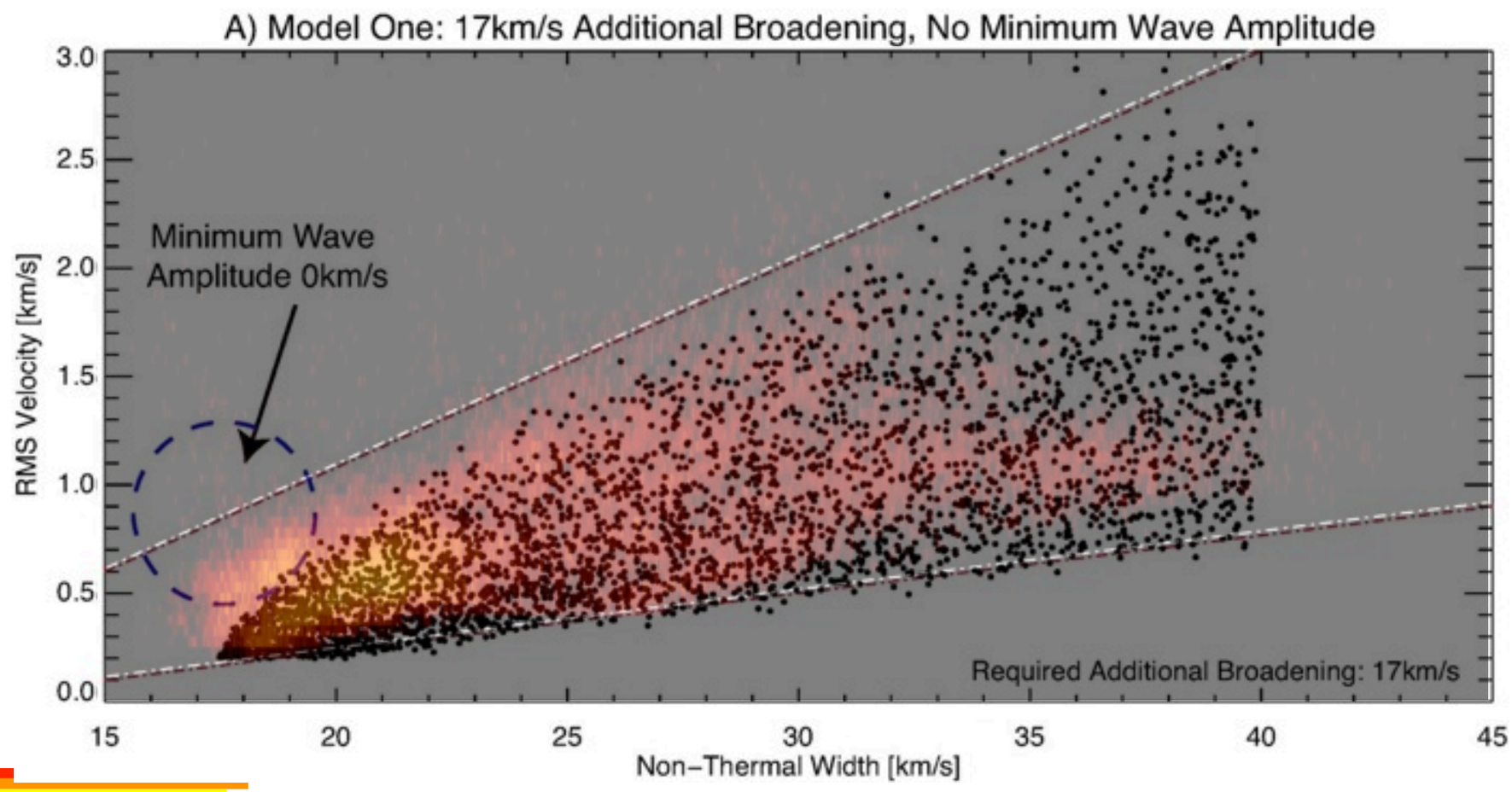

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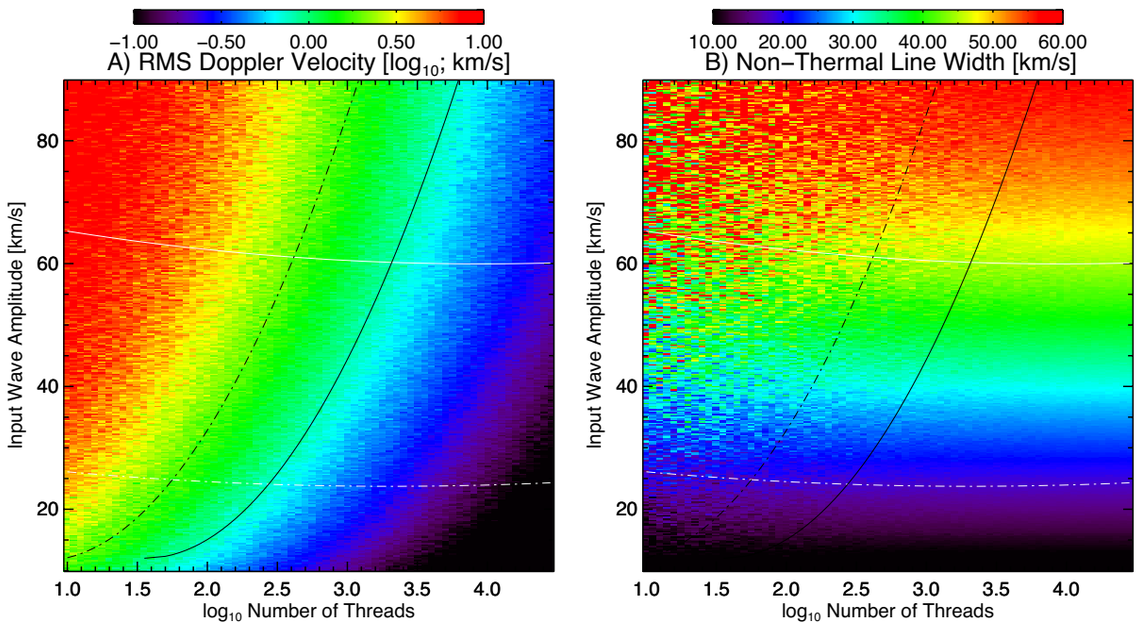
Reconciling Wave Energies



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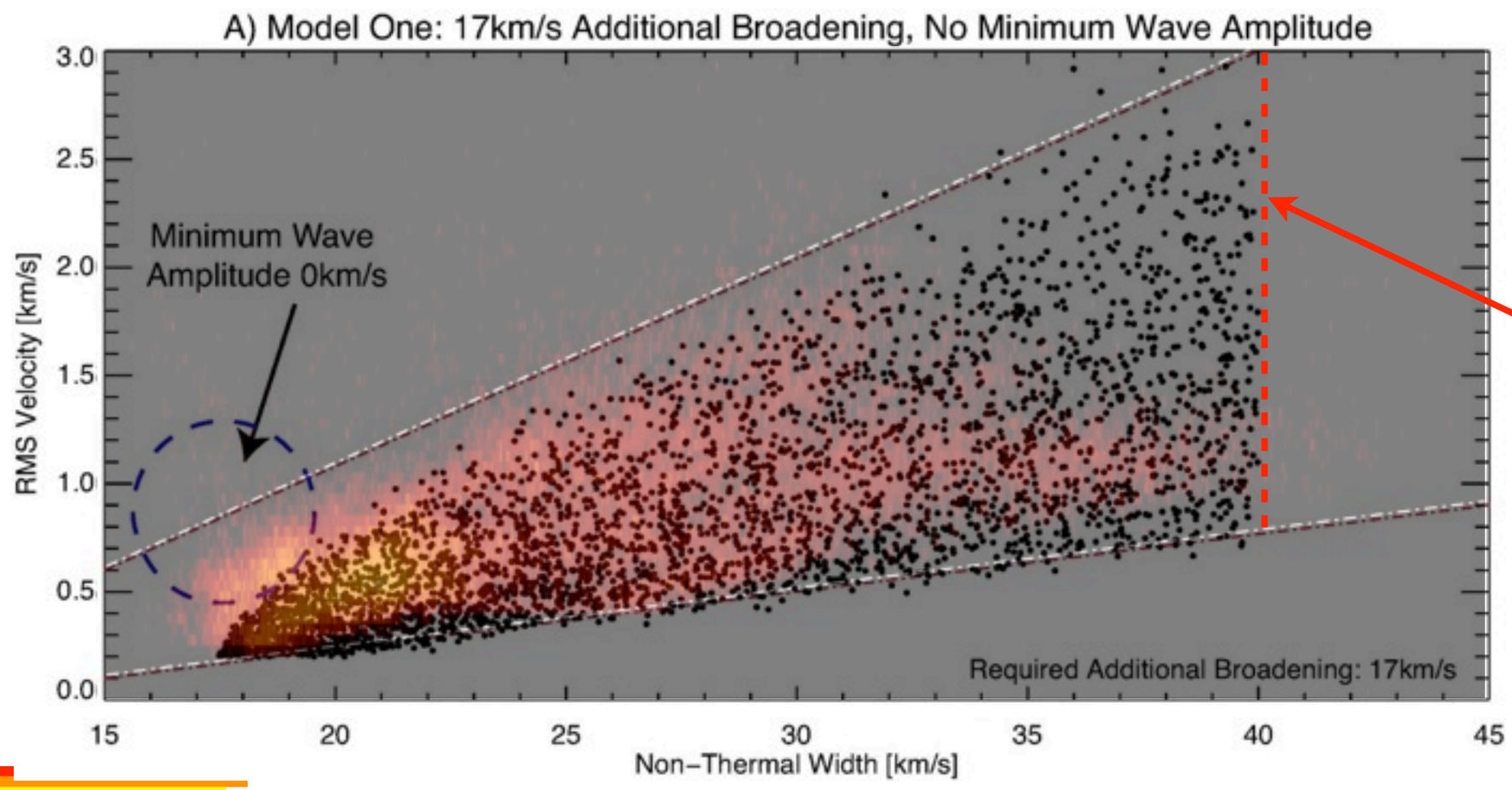

Max. Amp 45km/s

HAO/STSW

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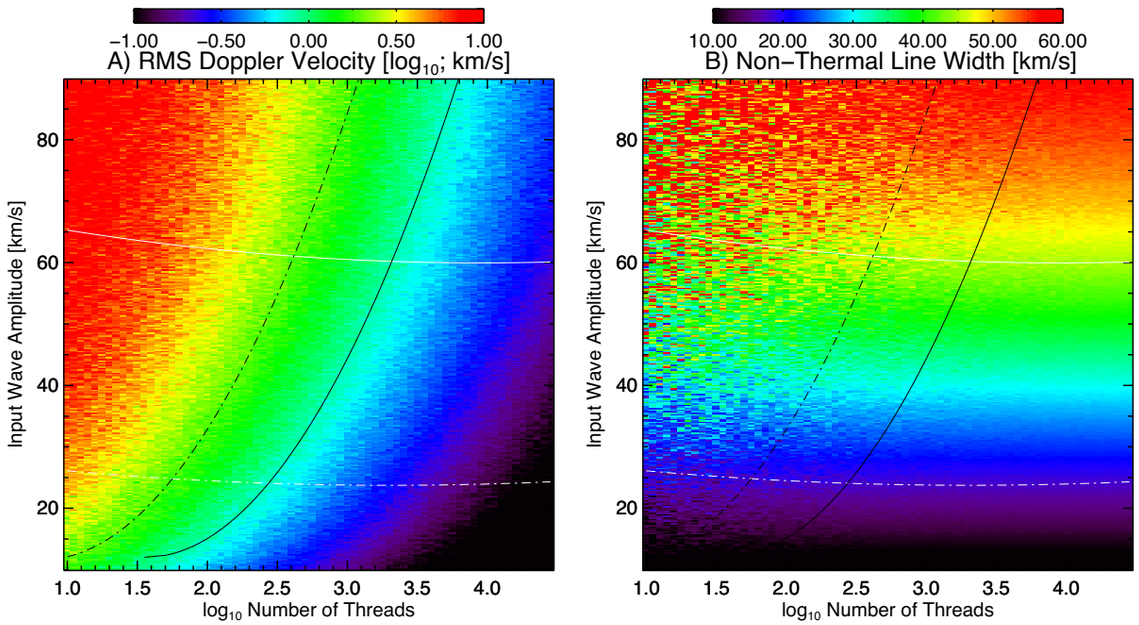
Reconciling Wave Energies



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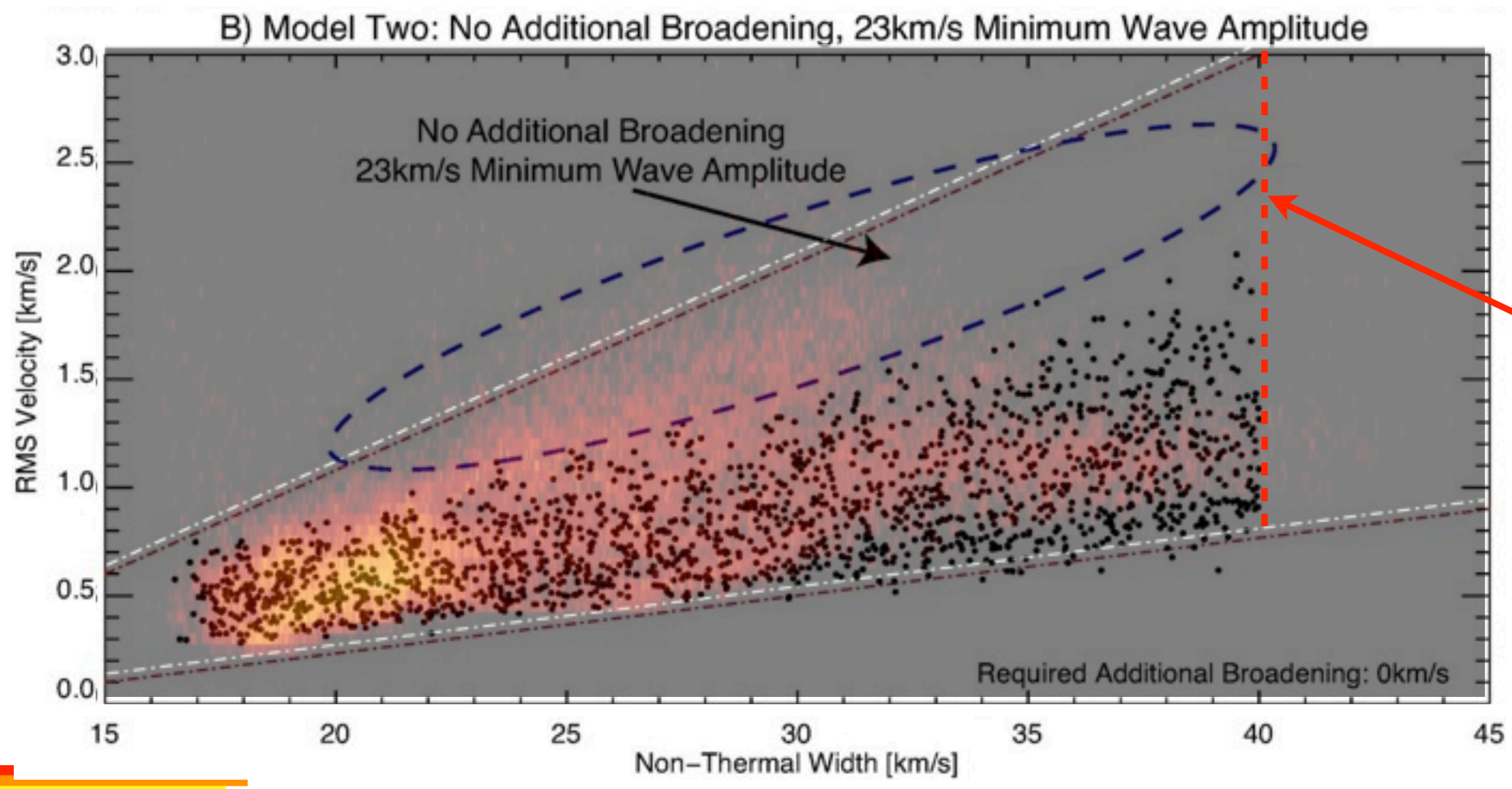

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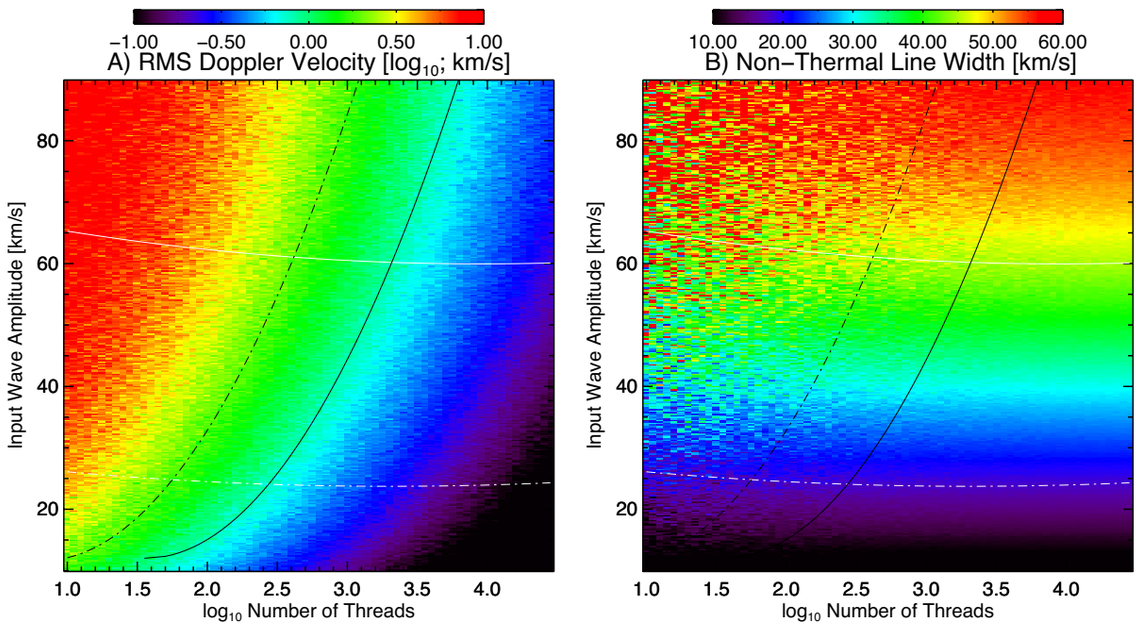
Reconciling Wave Energies



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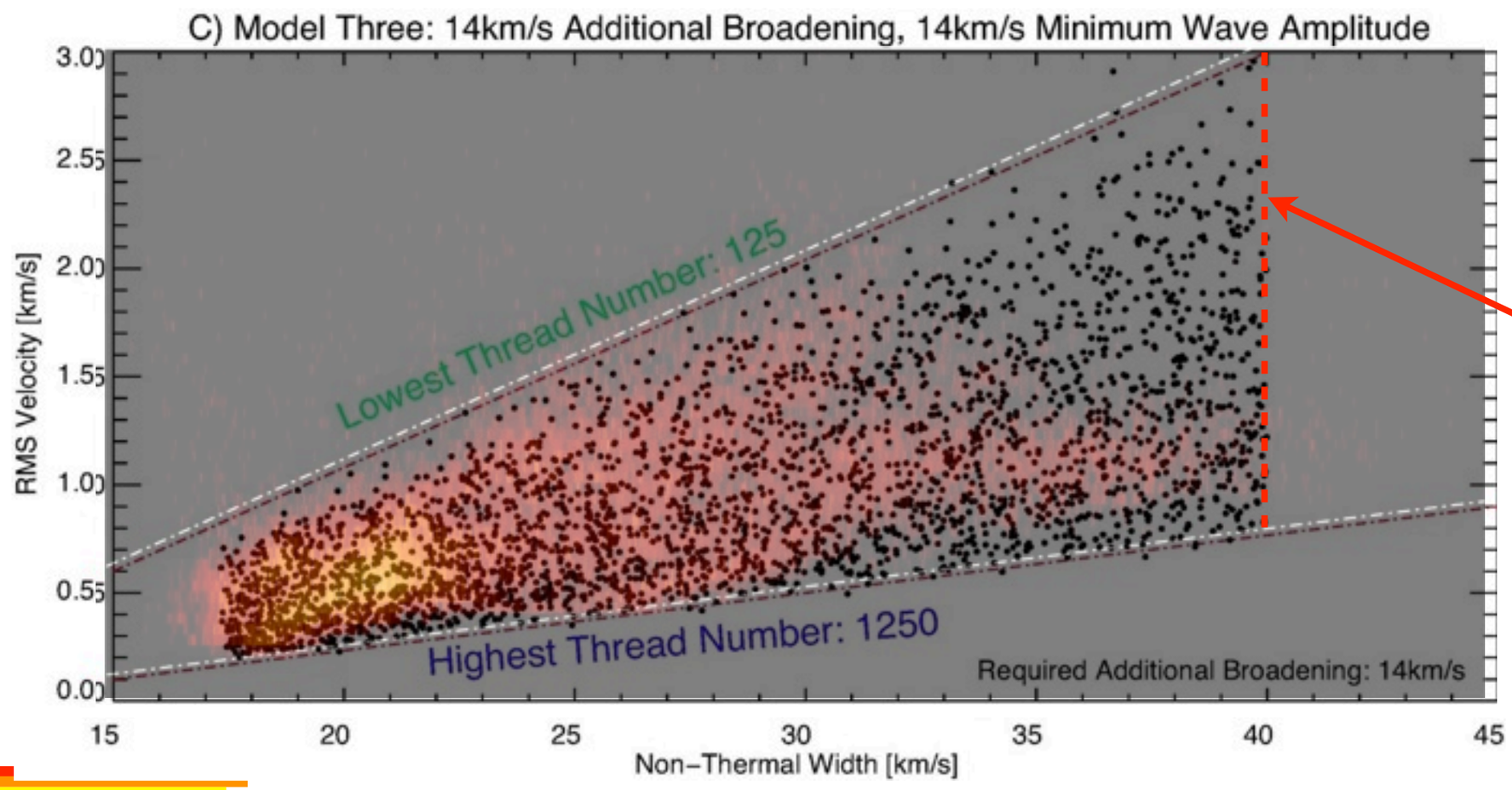

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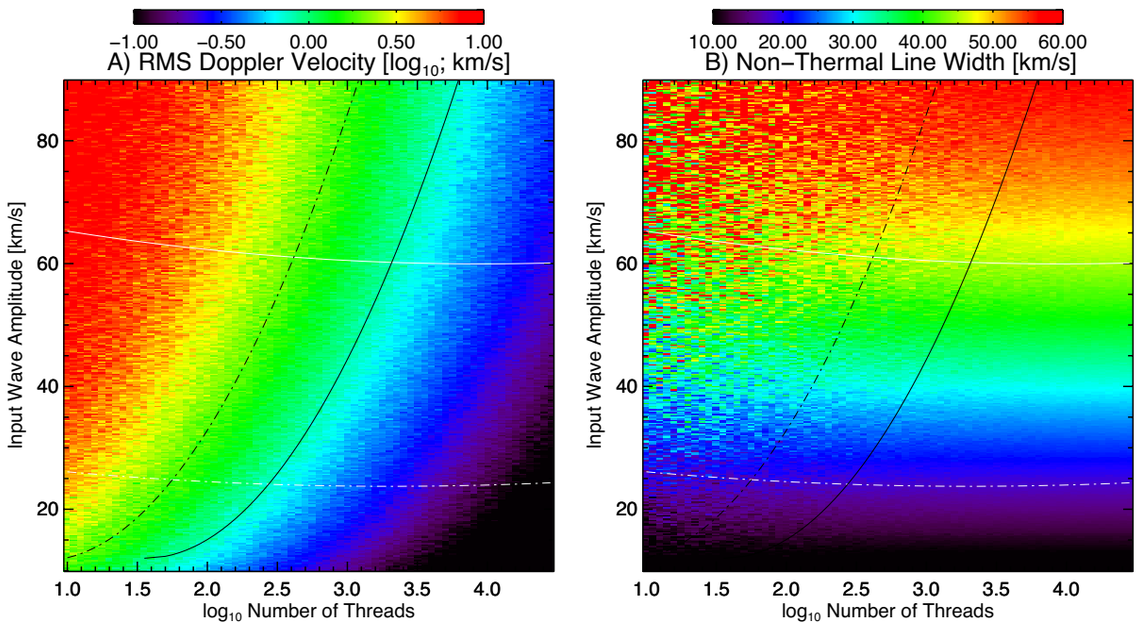

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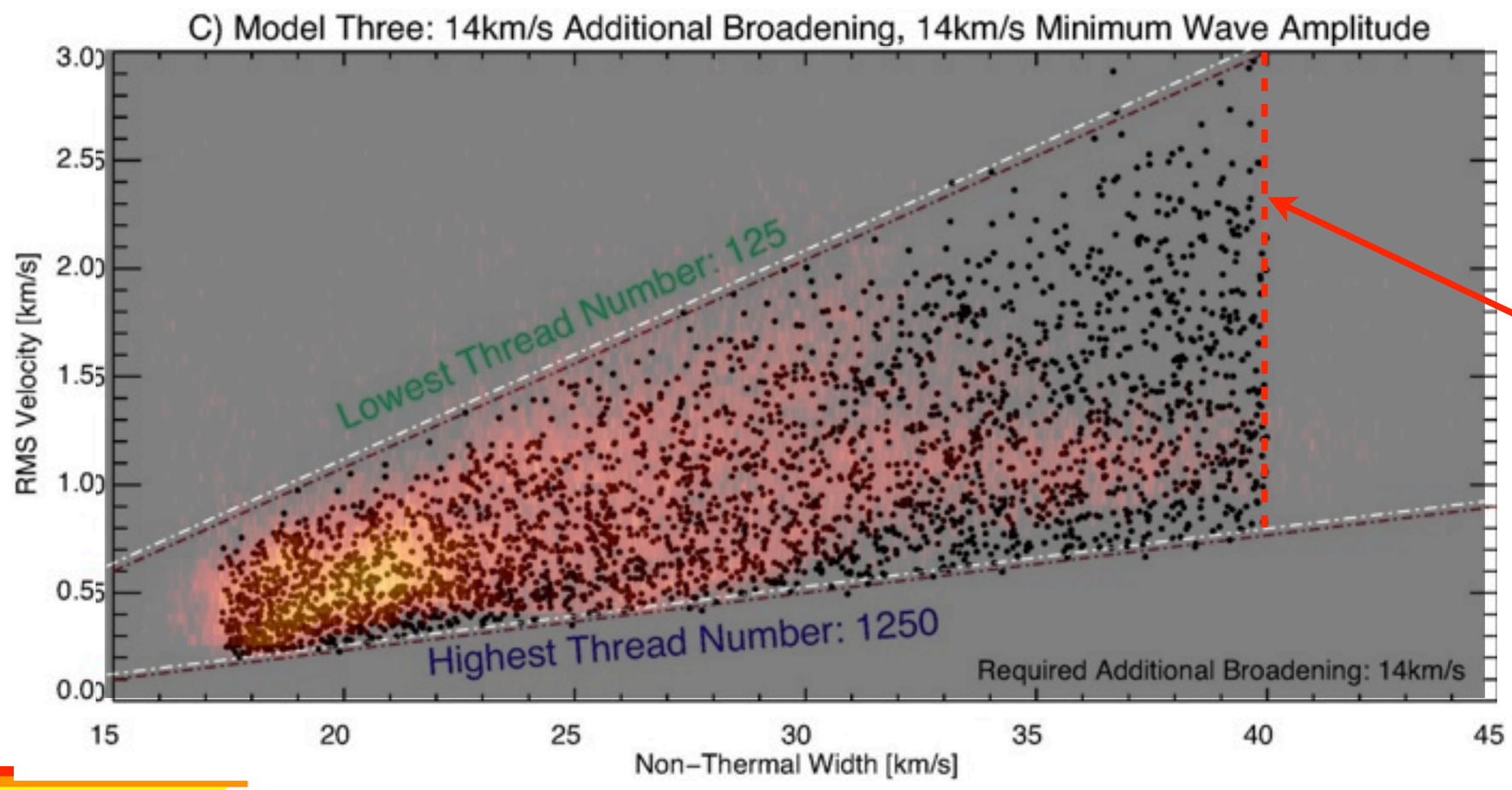

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V_{+} ?

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Recalling:

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SDO [TR/Corona]	**~100W/m²**

Hinode [Chromosphere]	**~4kW/m²**	
CoMP [Corona]	**50-100W/m²**	**
SDO [TR/Corona]	**~100W/m²**	

CoMP sees an Energetic Corona!

** Have to take into account the energy in the unresolved (non-thermal) velocities.

The energy is hidden by the resolution of the instrument.

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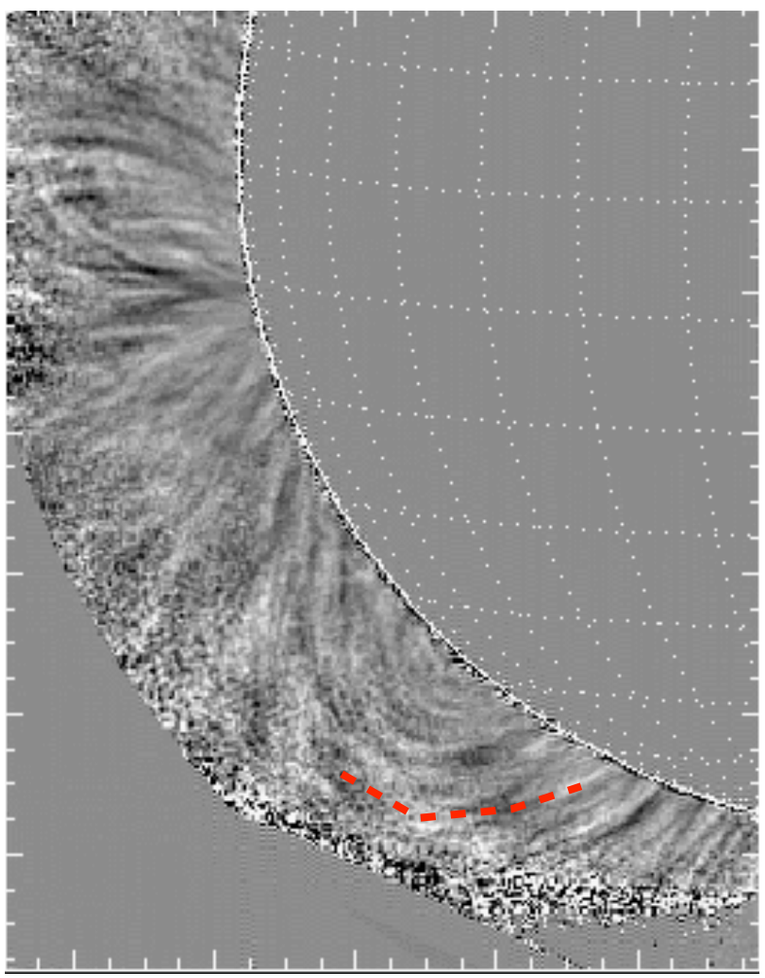
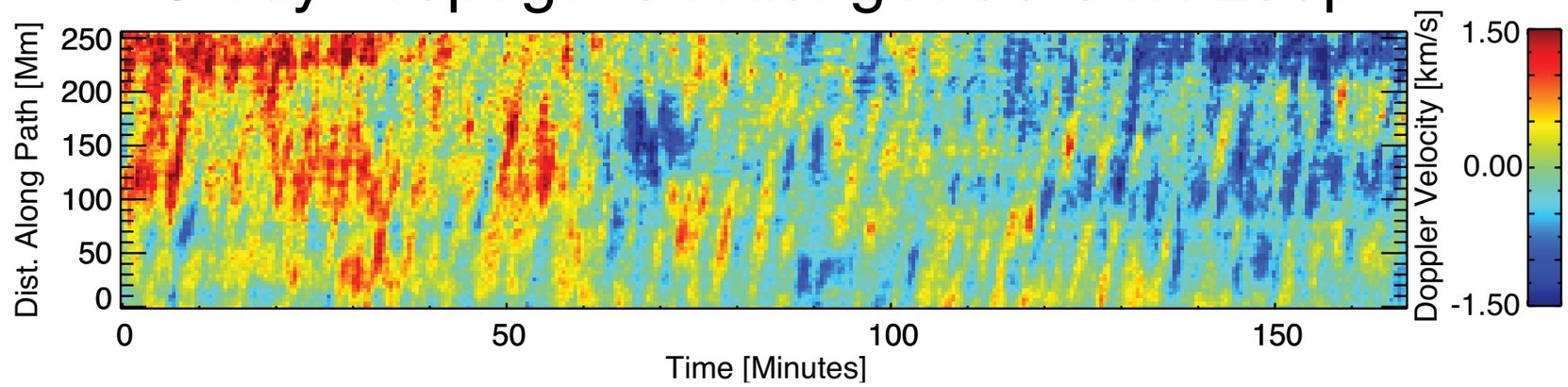
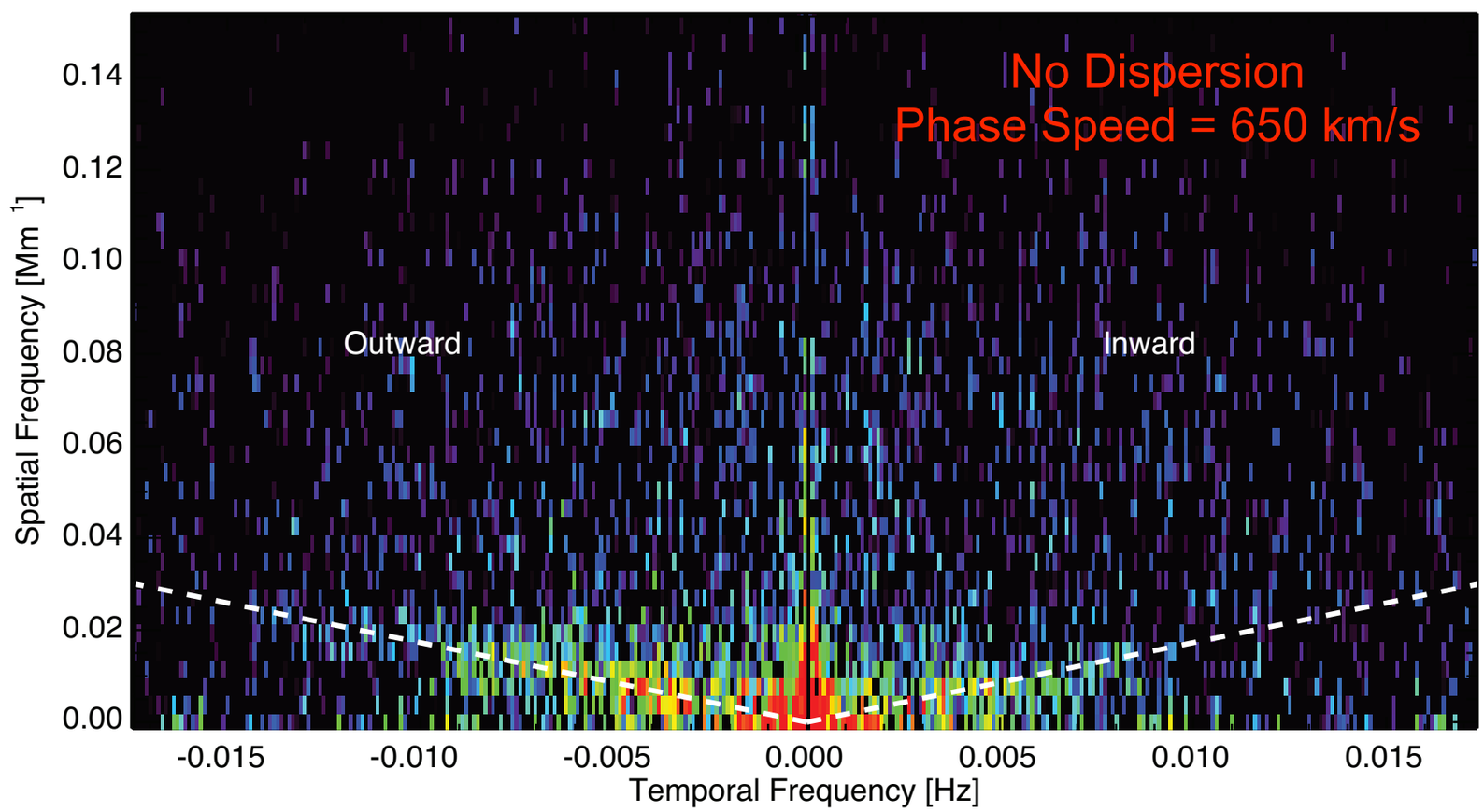
Time-Distance Seismology

Can We See What Happens to That Wave Energy?

Study Propagation Along A Coronal Loop







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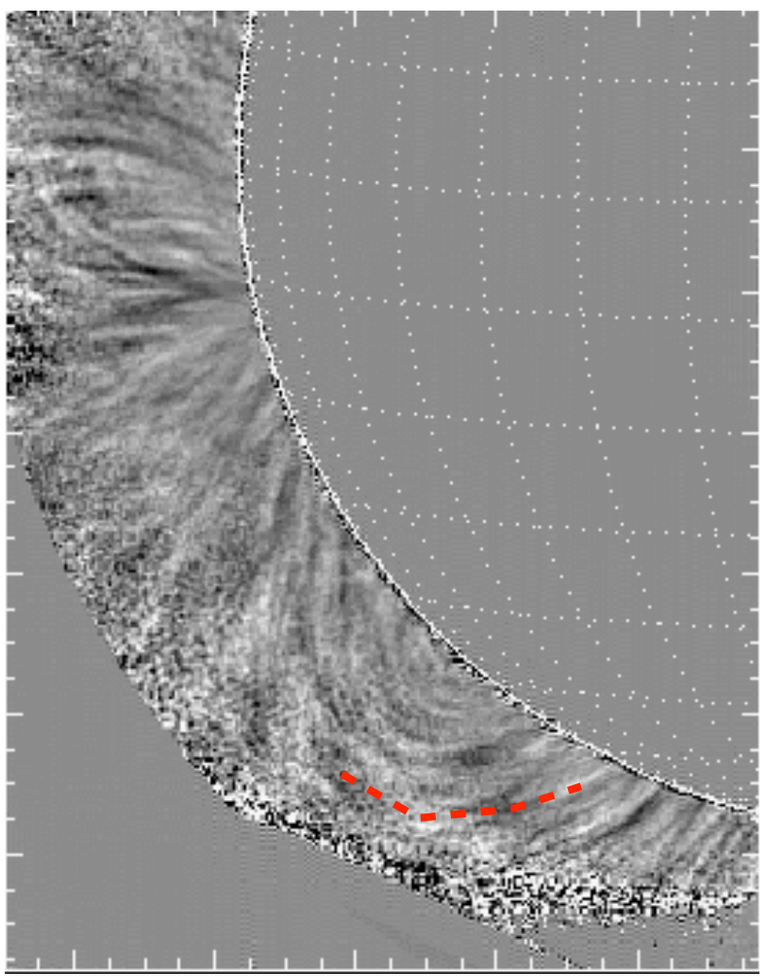

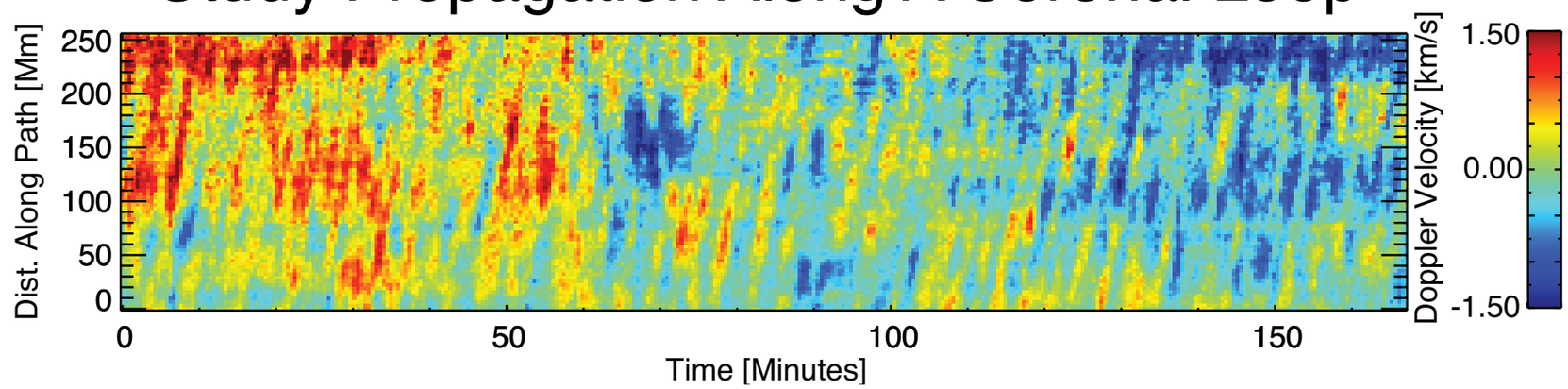

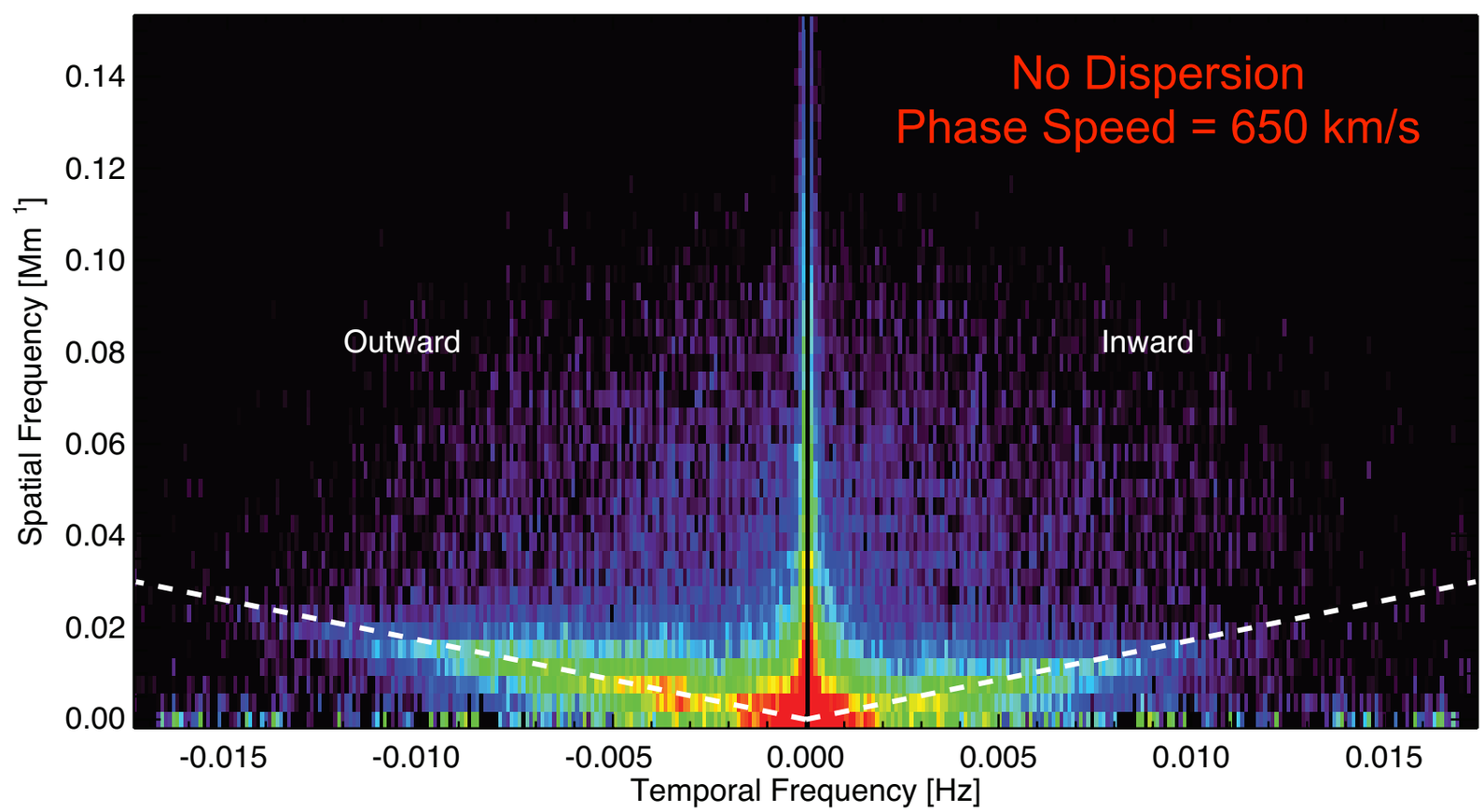

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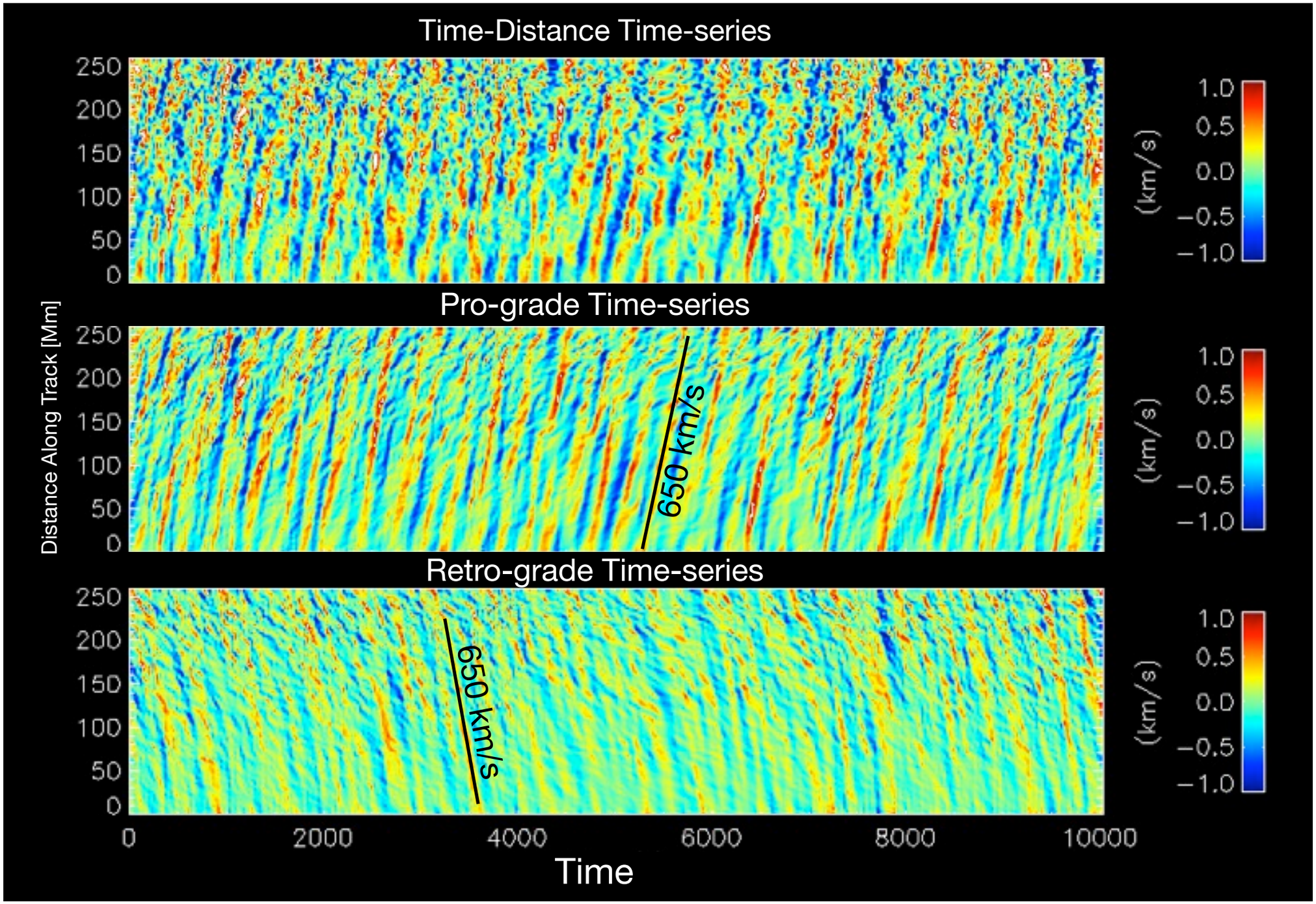

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Time-Distance Seismology

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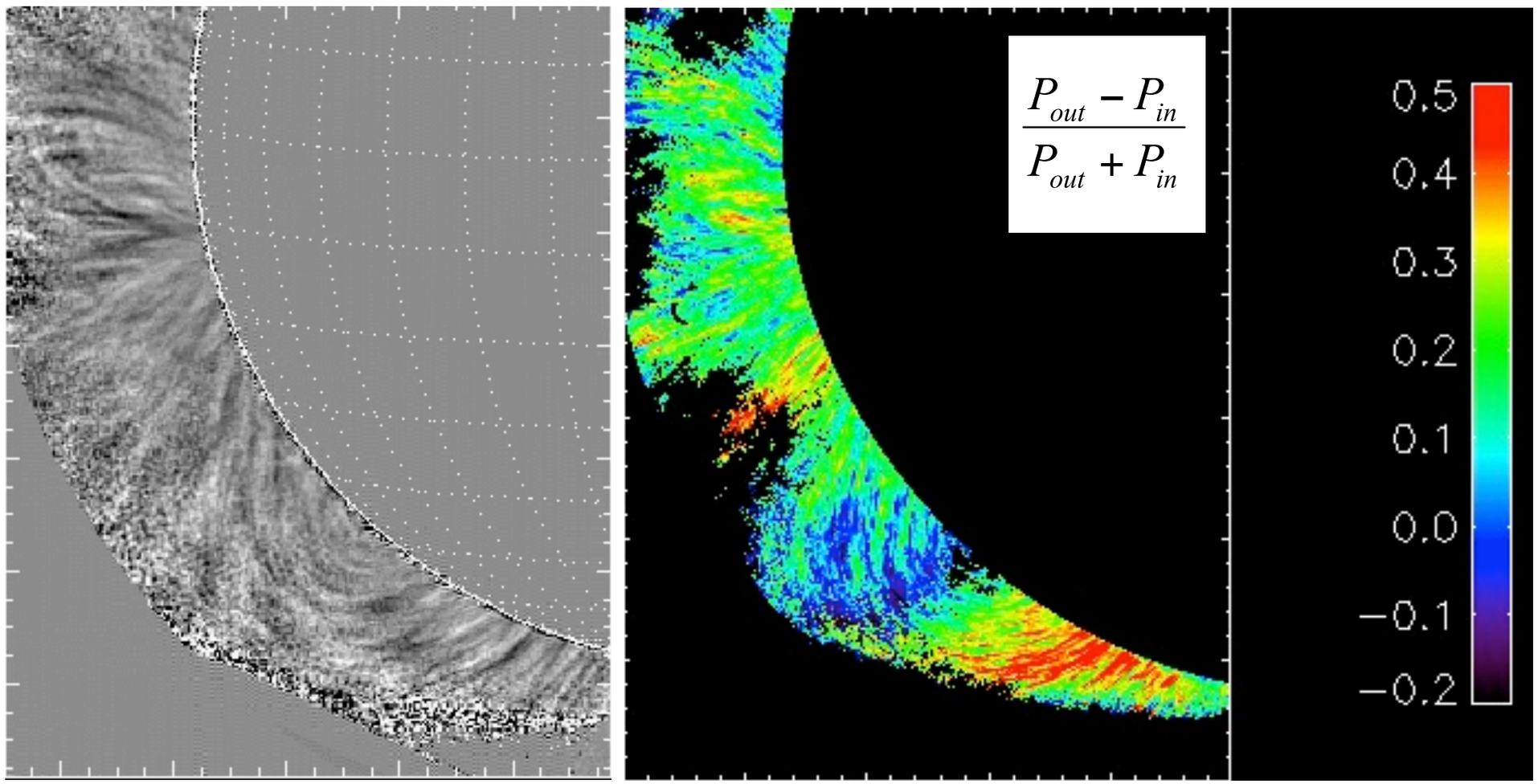
Time-Distance Seismology

Decomposing the time-series on each “loop” structure into its pro- and retro-grade parts we can study the ratio of outward to inward wave power in the corona.



The wave energy rarely crosses the loop apex!

Often $P_{out} > 3P_{in}$

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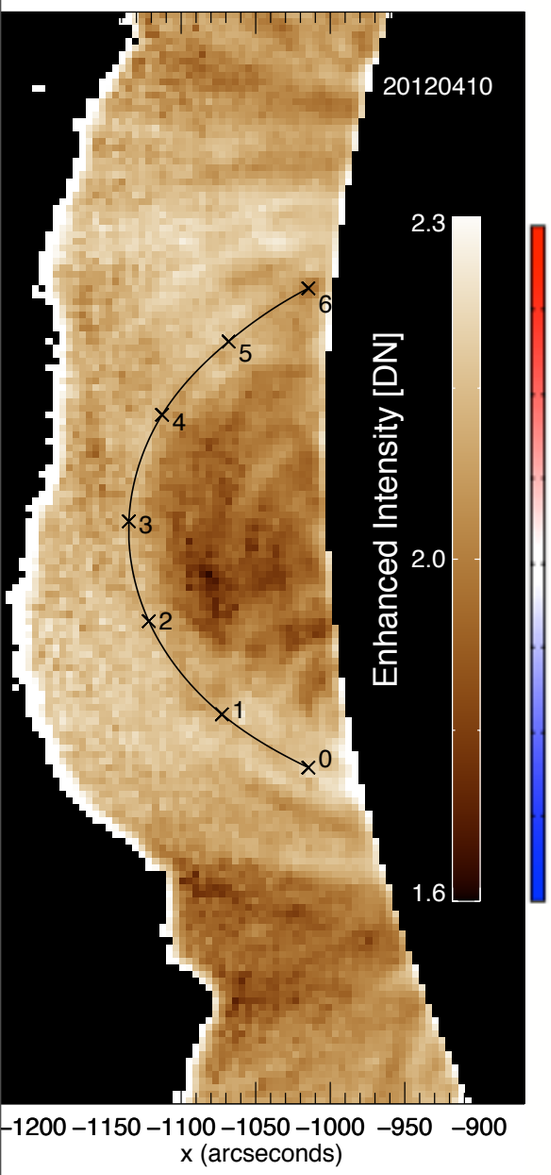
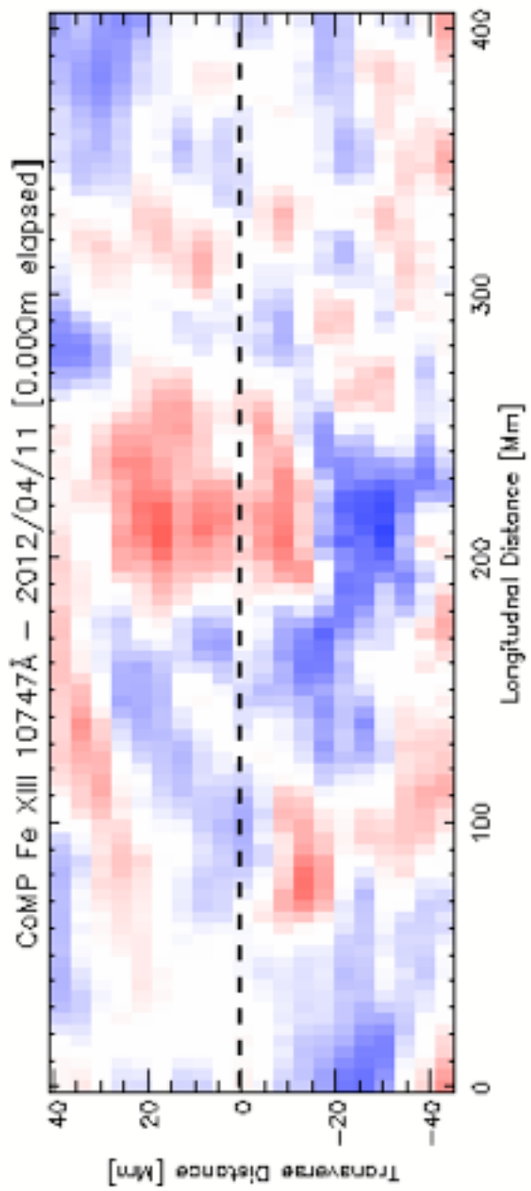
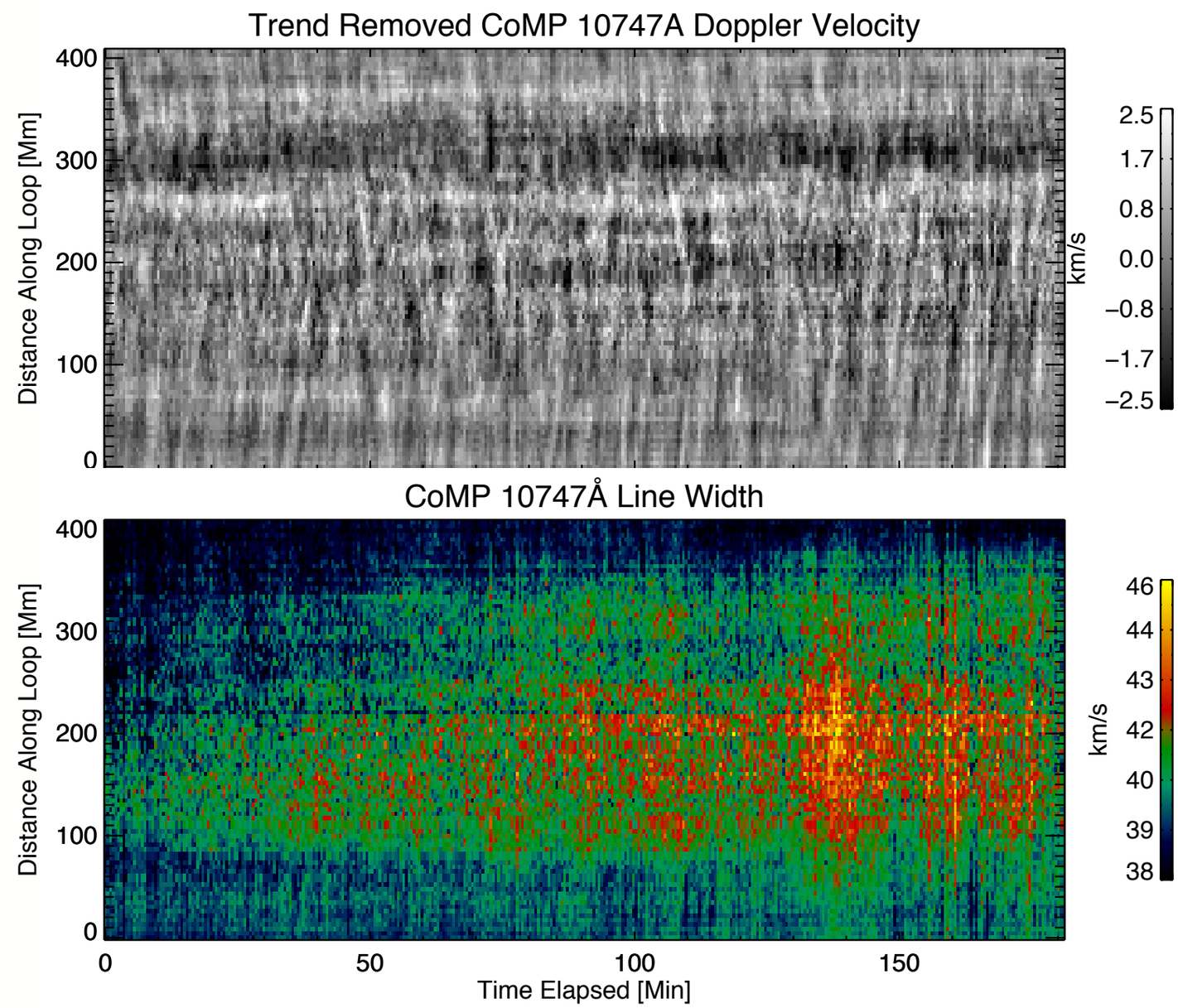
Complex Wave Scenarios

Trans-equatorial loops offer further insight.....







....the upper portions of the loop show some interesting behavior...

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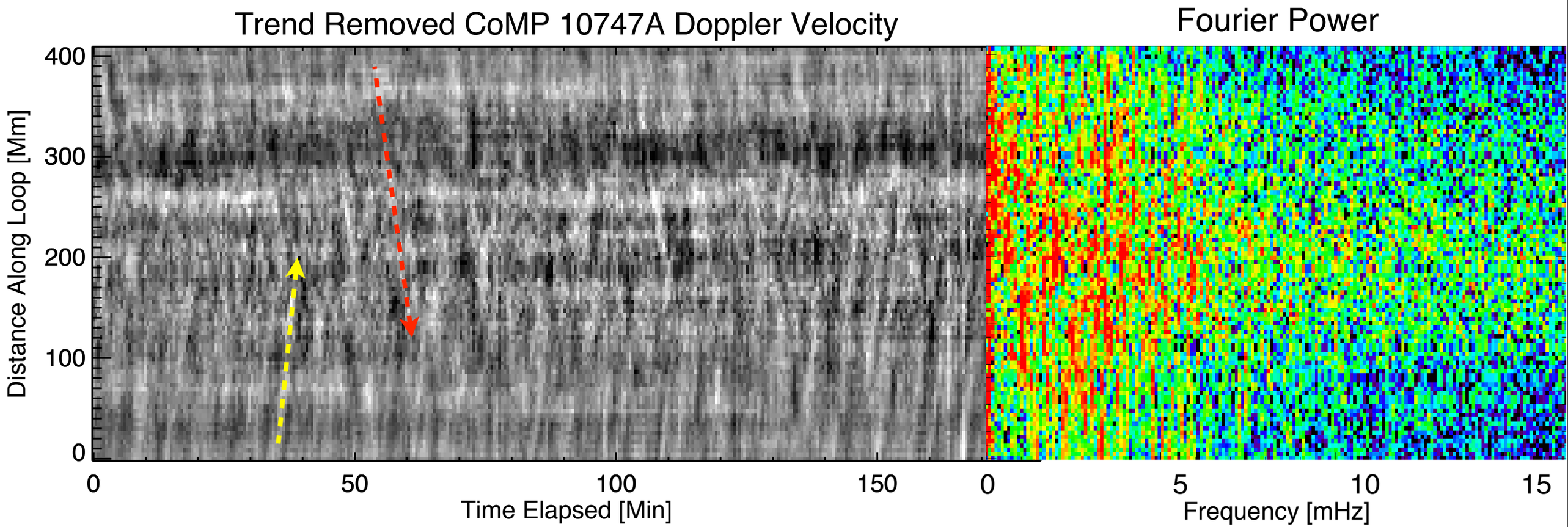
Complex Wave Scenarios

HF Wave Generation in the corona?



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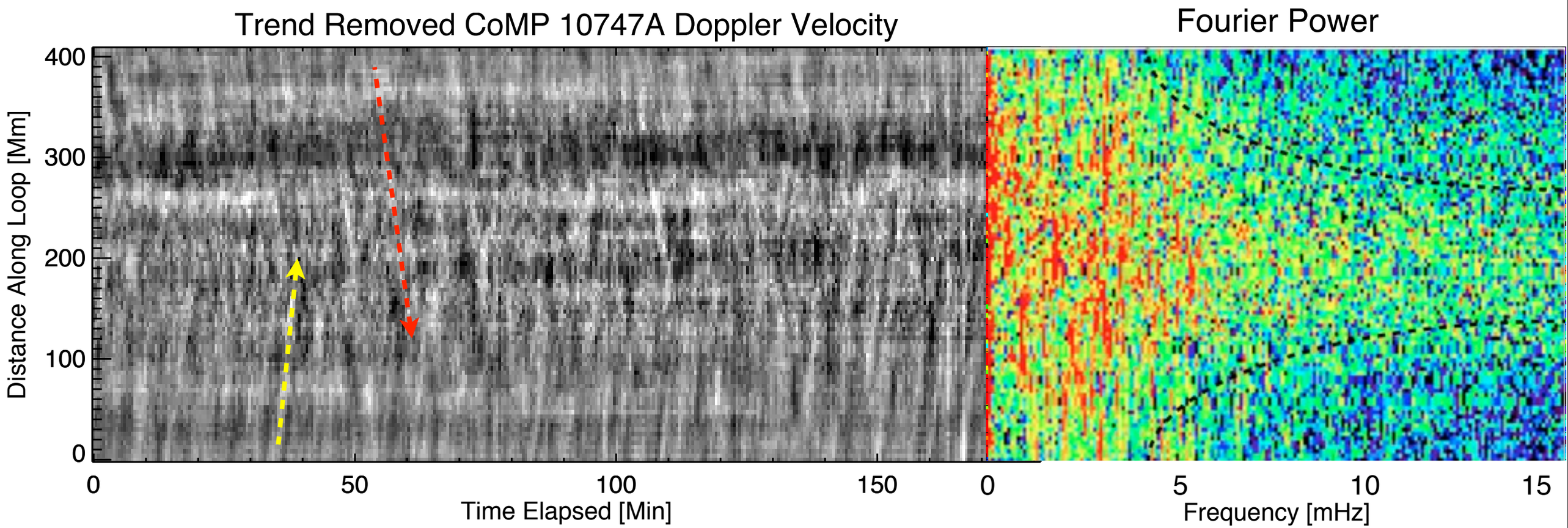

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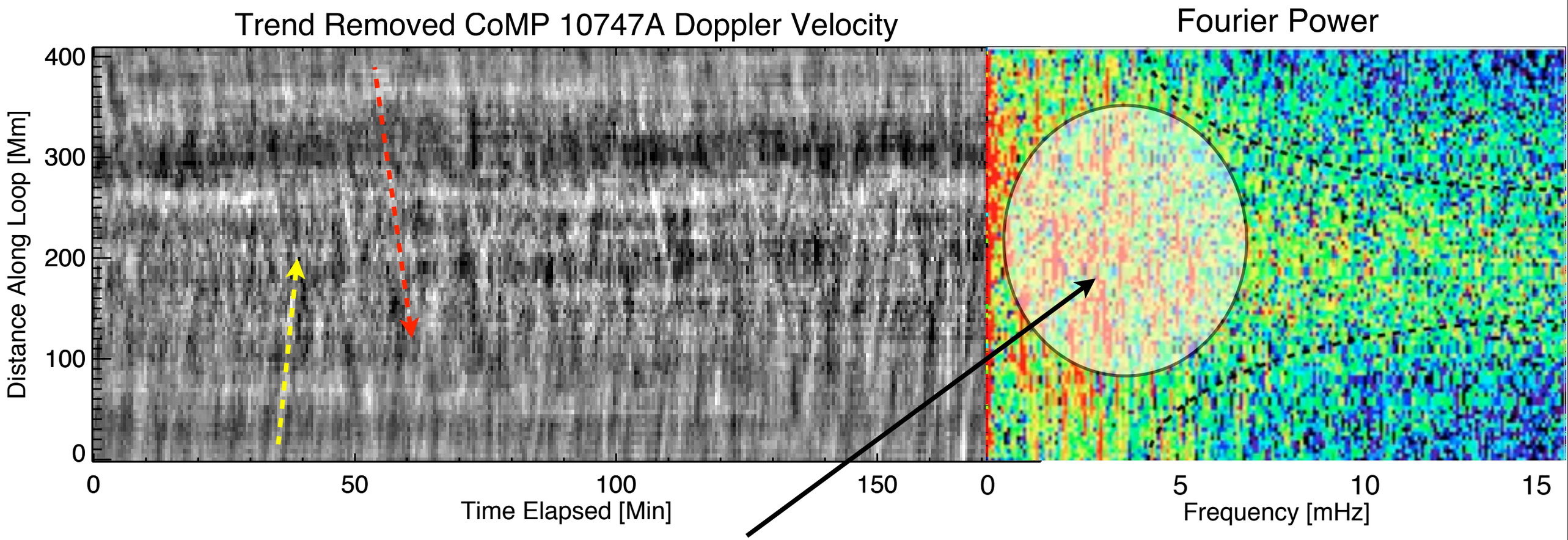

Low-frequency
Amplitude Growth
(superposition)

HAO/STSW

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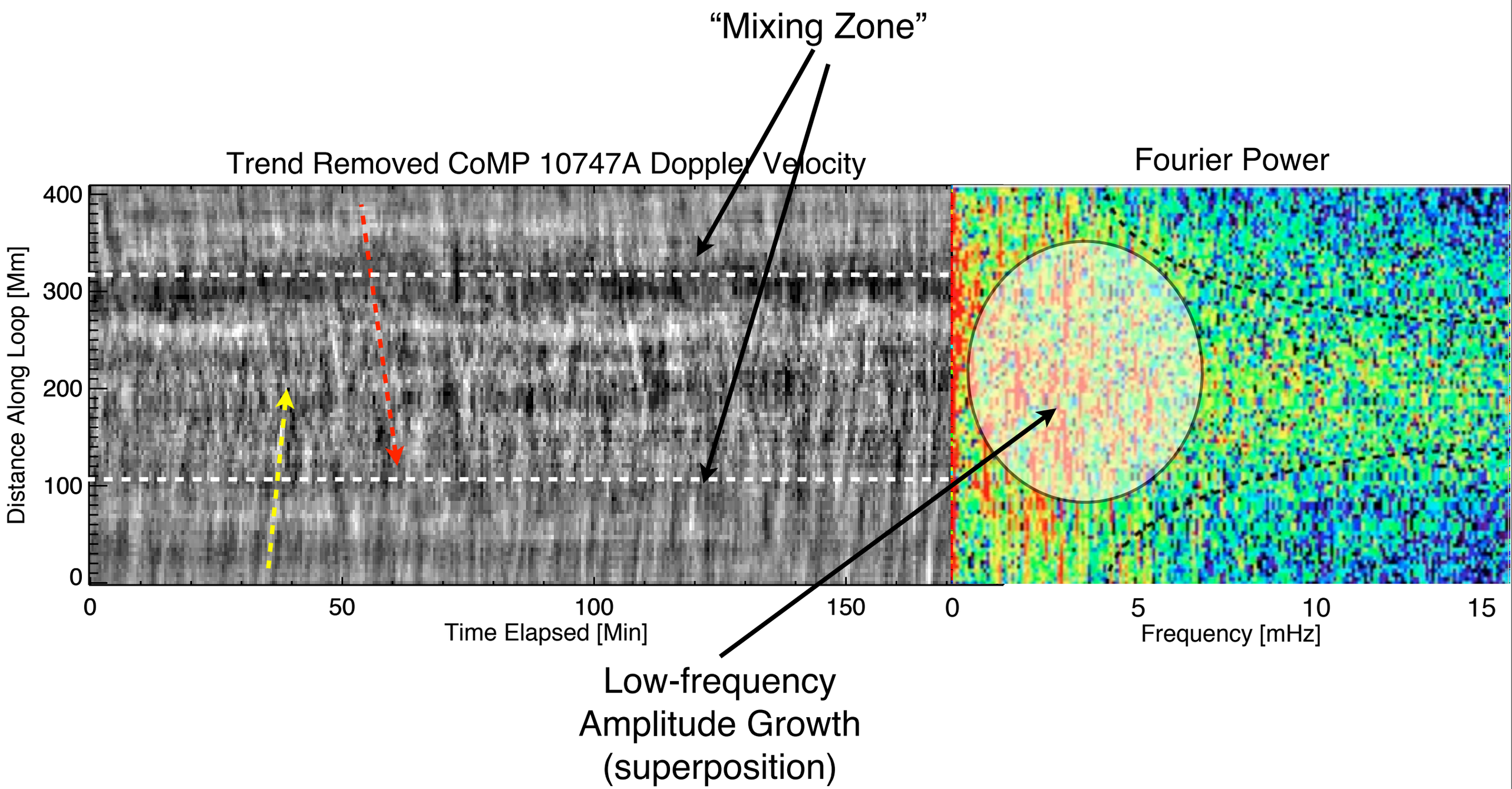

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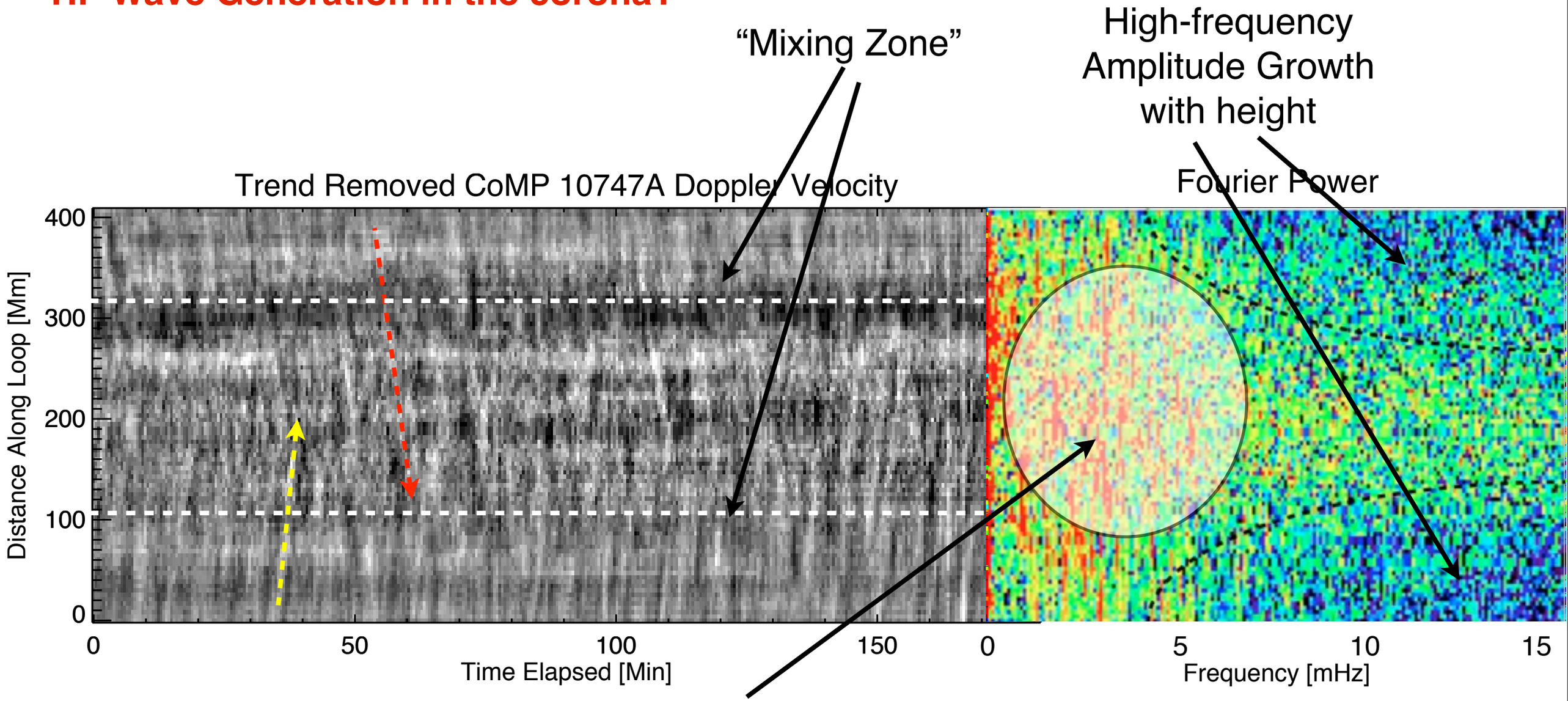

Low-frequency Amplitude Growth (superposition)

Are we seeing the "generation" of high frequency waves in the corona as a result of low-frequency wave interaction?

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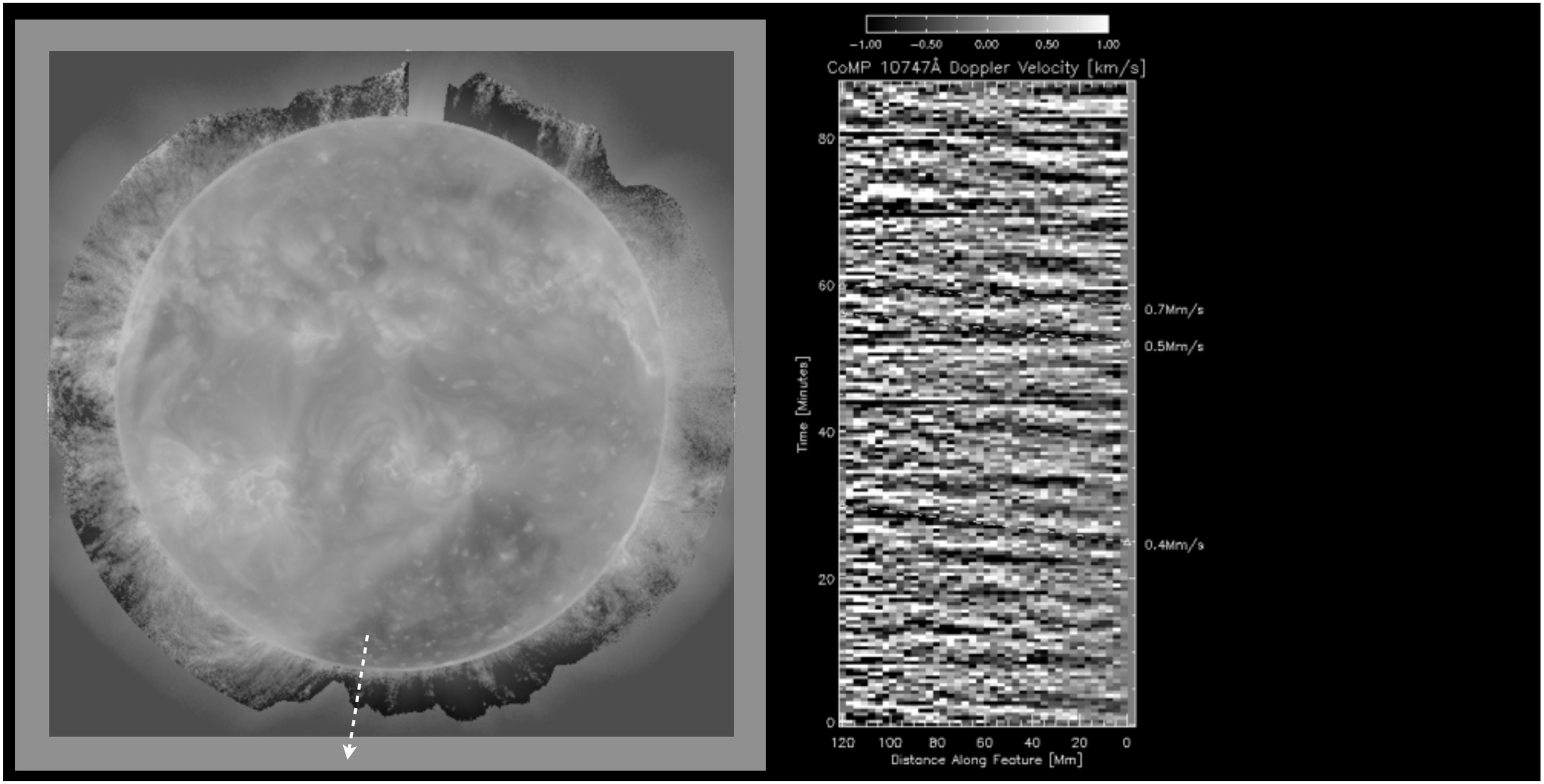
Complex Wave Scenarios

Spicules & Waves

The fast solar wind input is “clumpy” - a recipe for turbulent acceleration?



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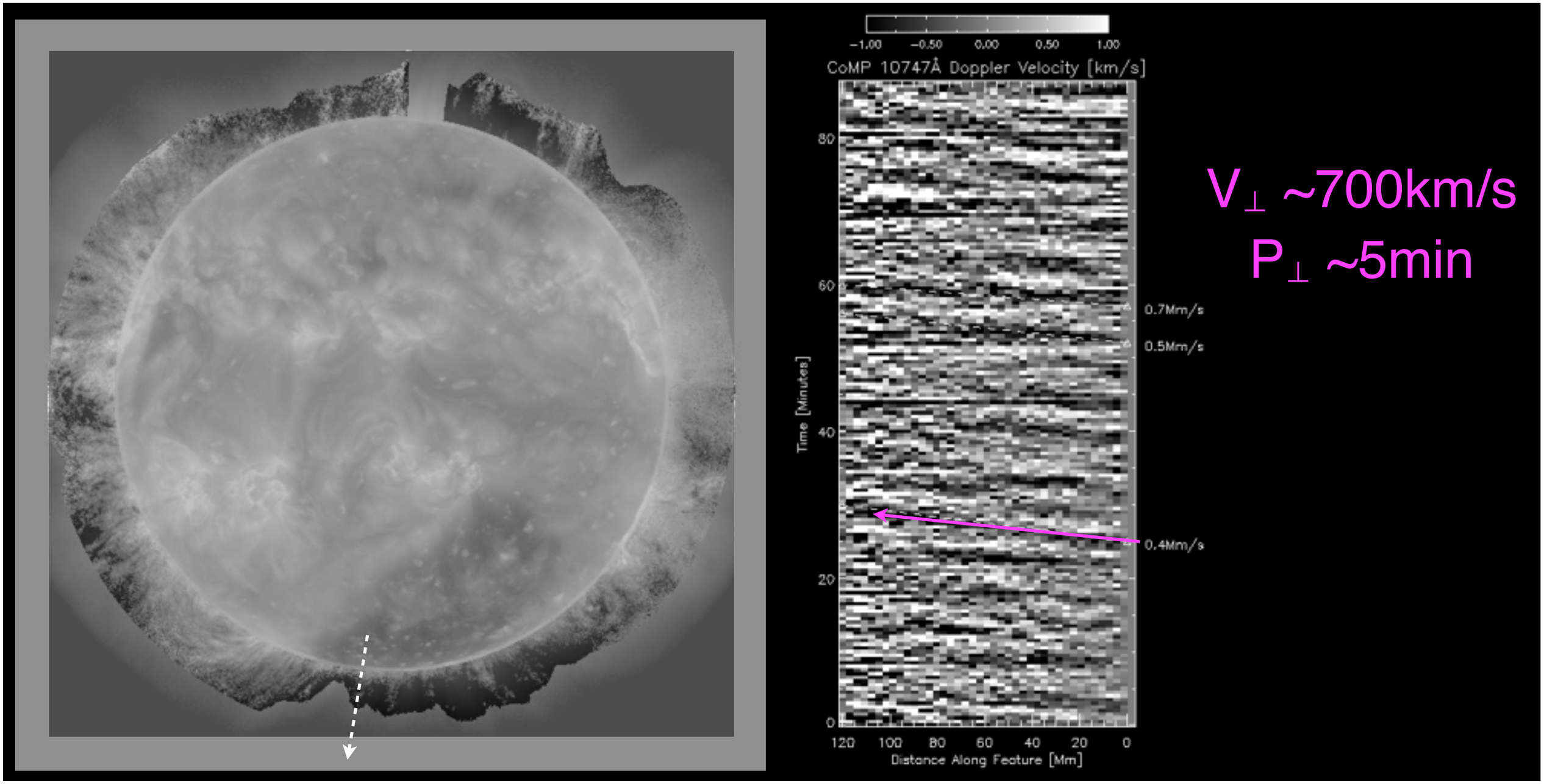

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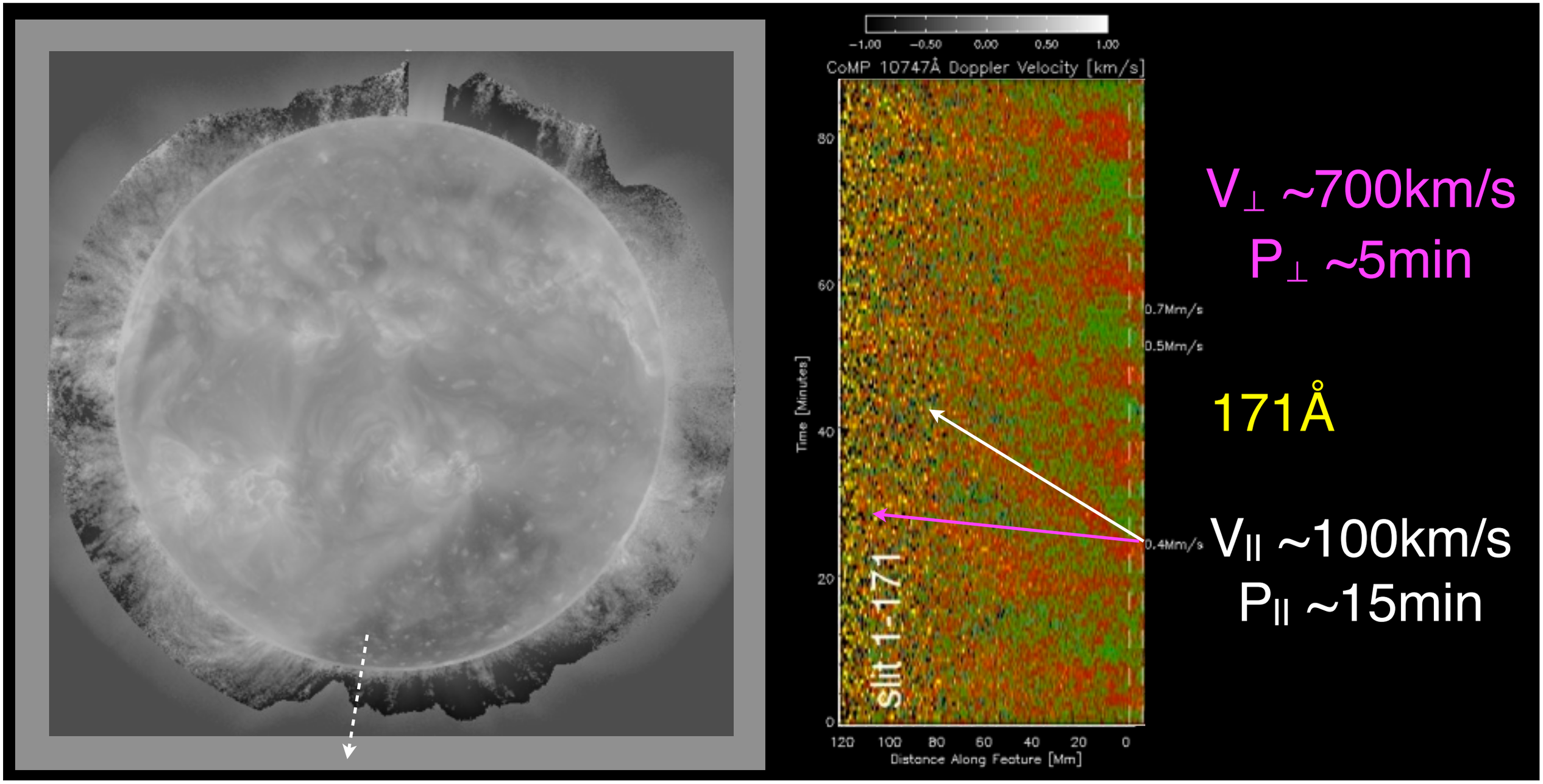

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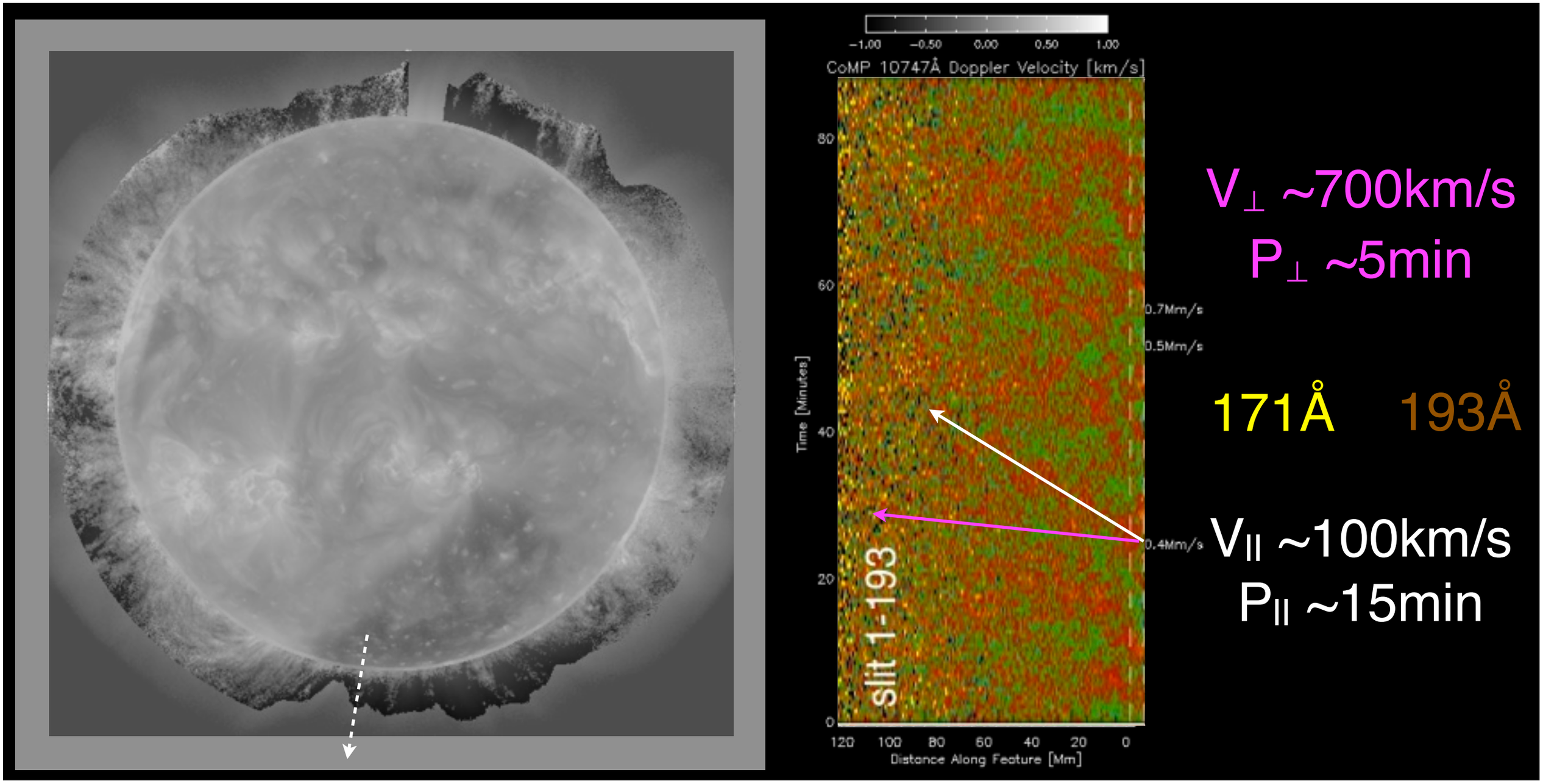

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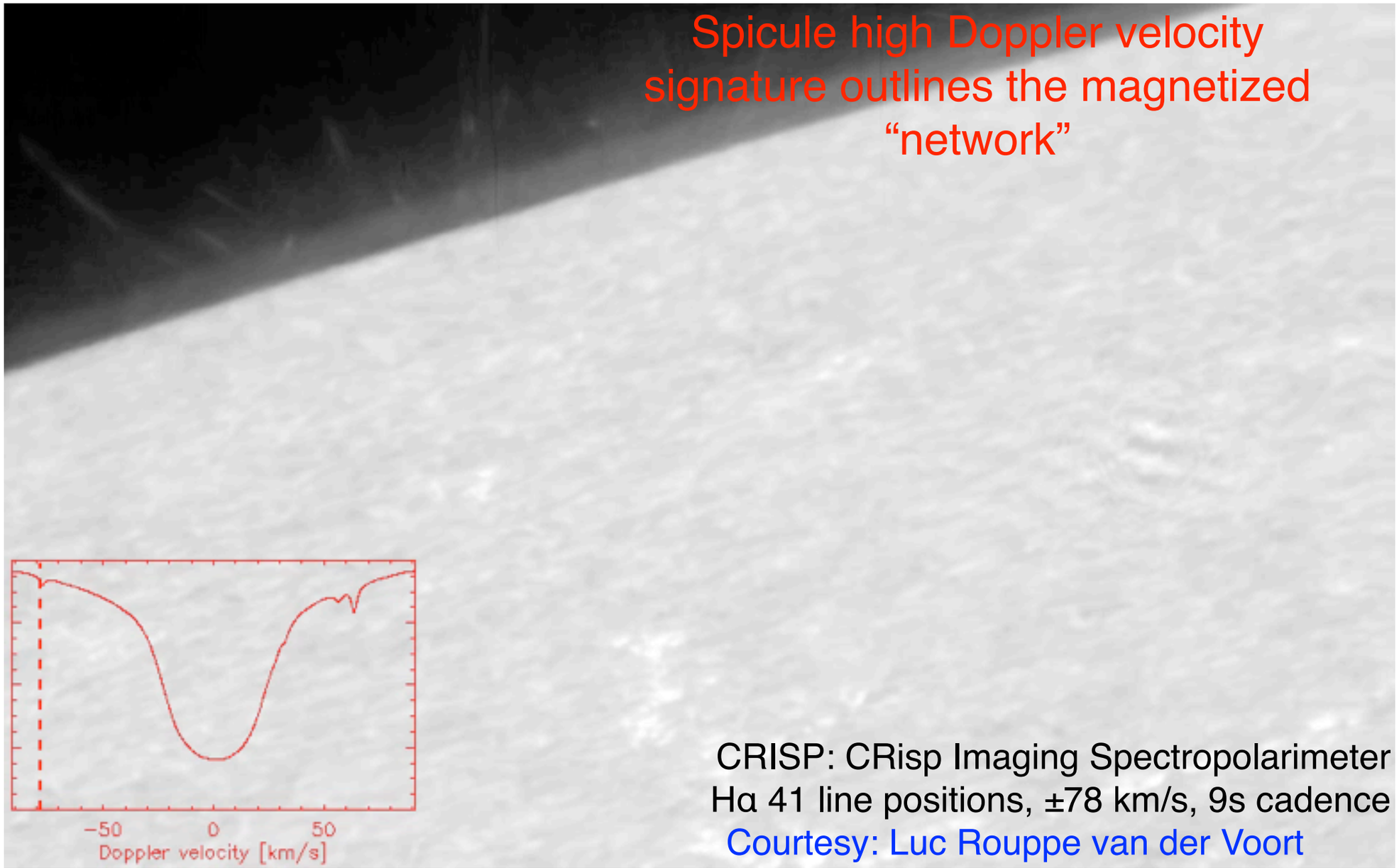
Complex Wave Scenarios

SST/CRISP Hα limb observations



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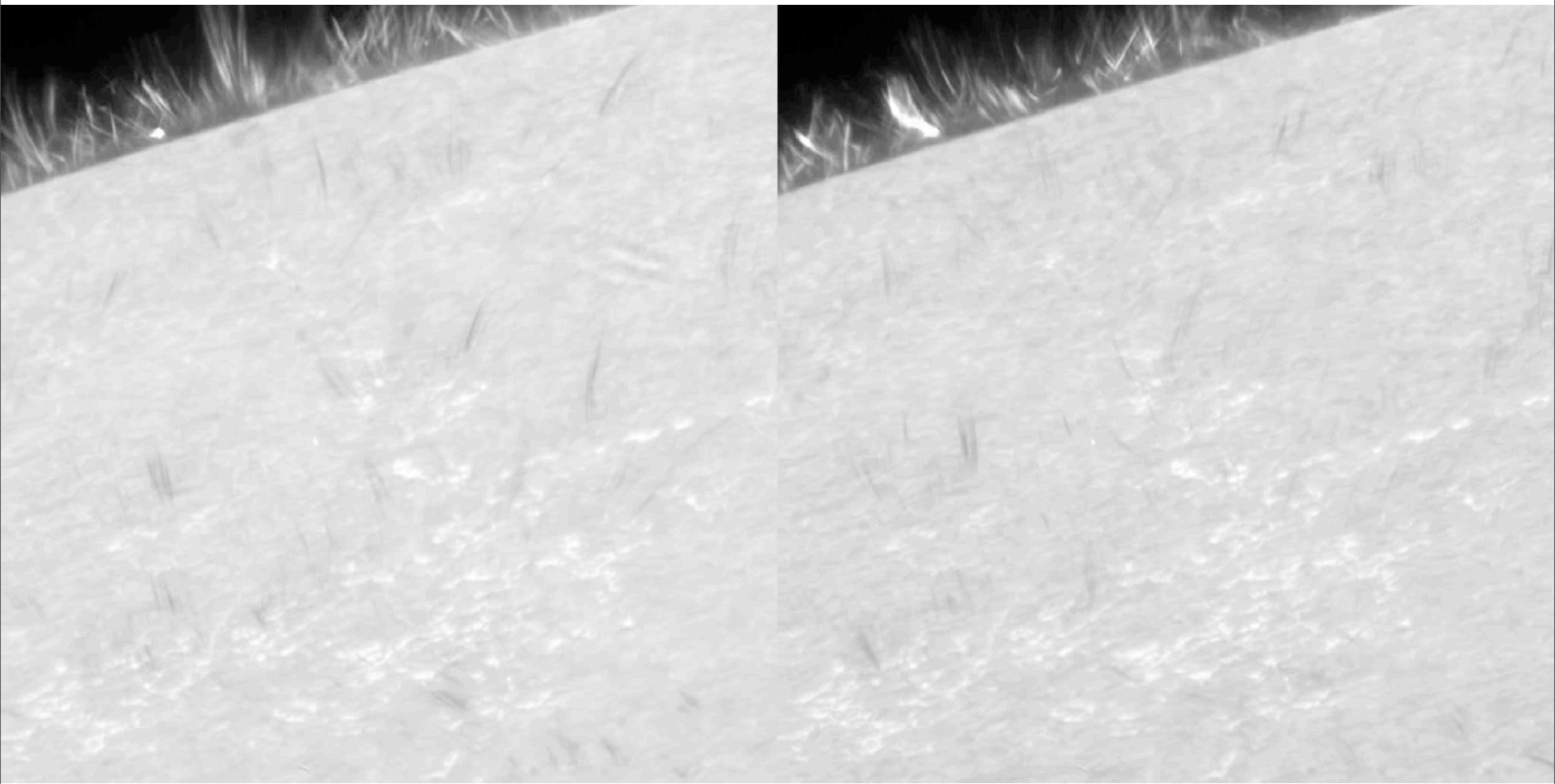
Complex Wave Scenarios

Hα blue wing: -51 km/s

Hα red wing: +51 km/s



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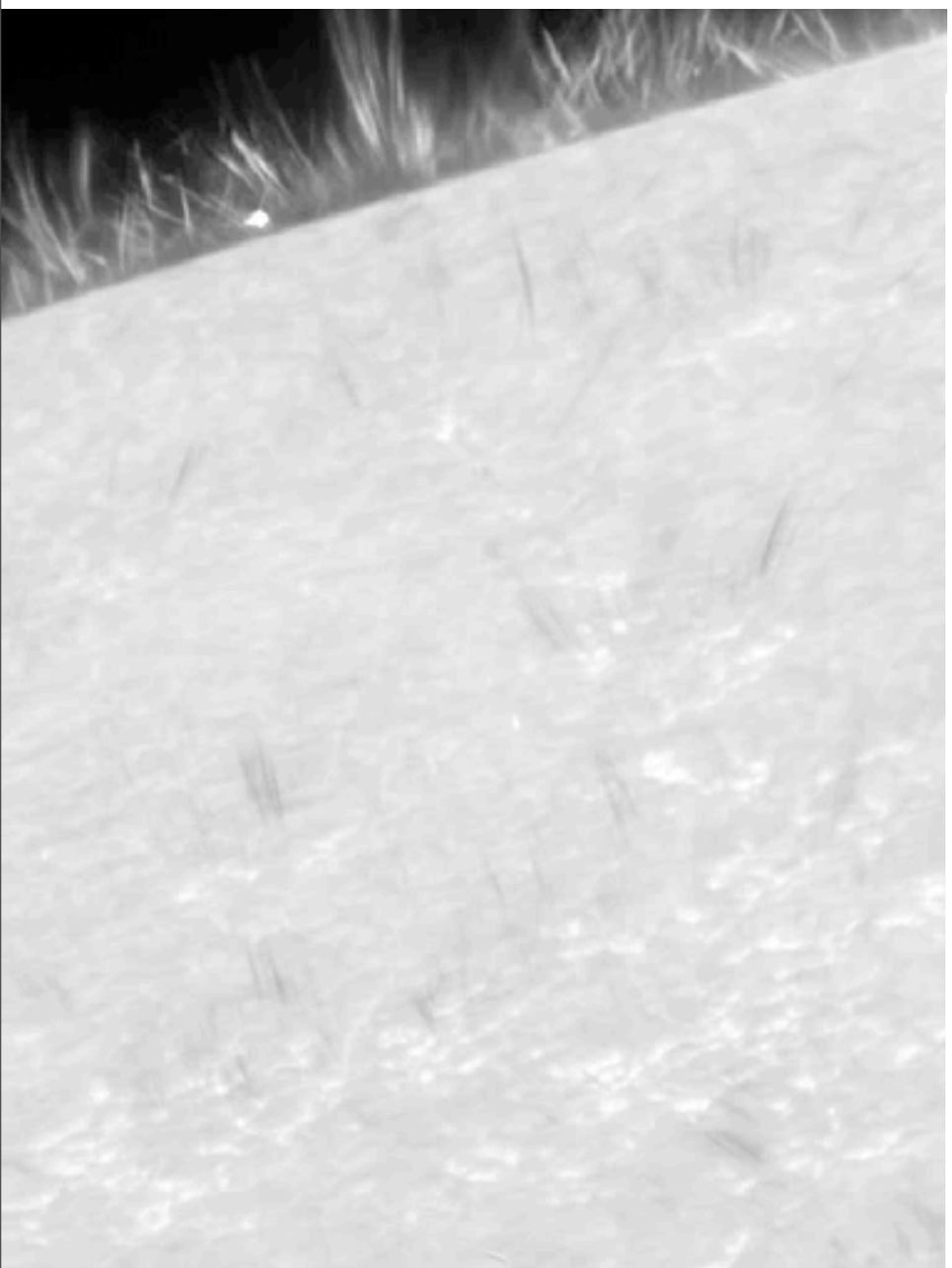
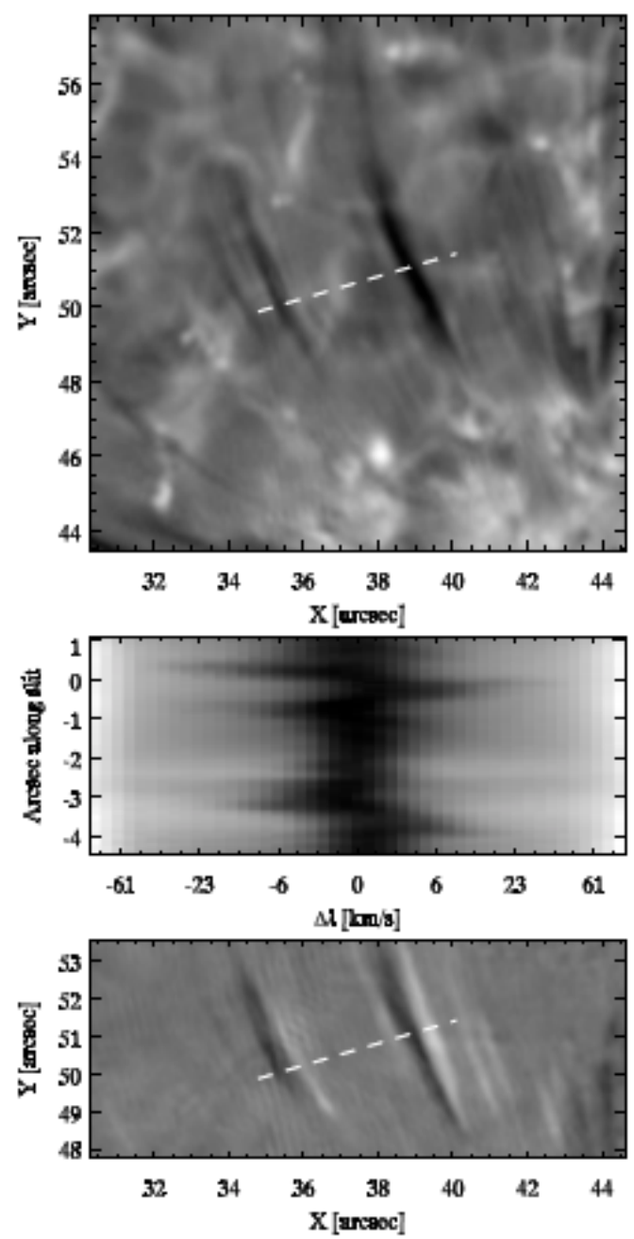
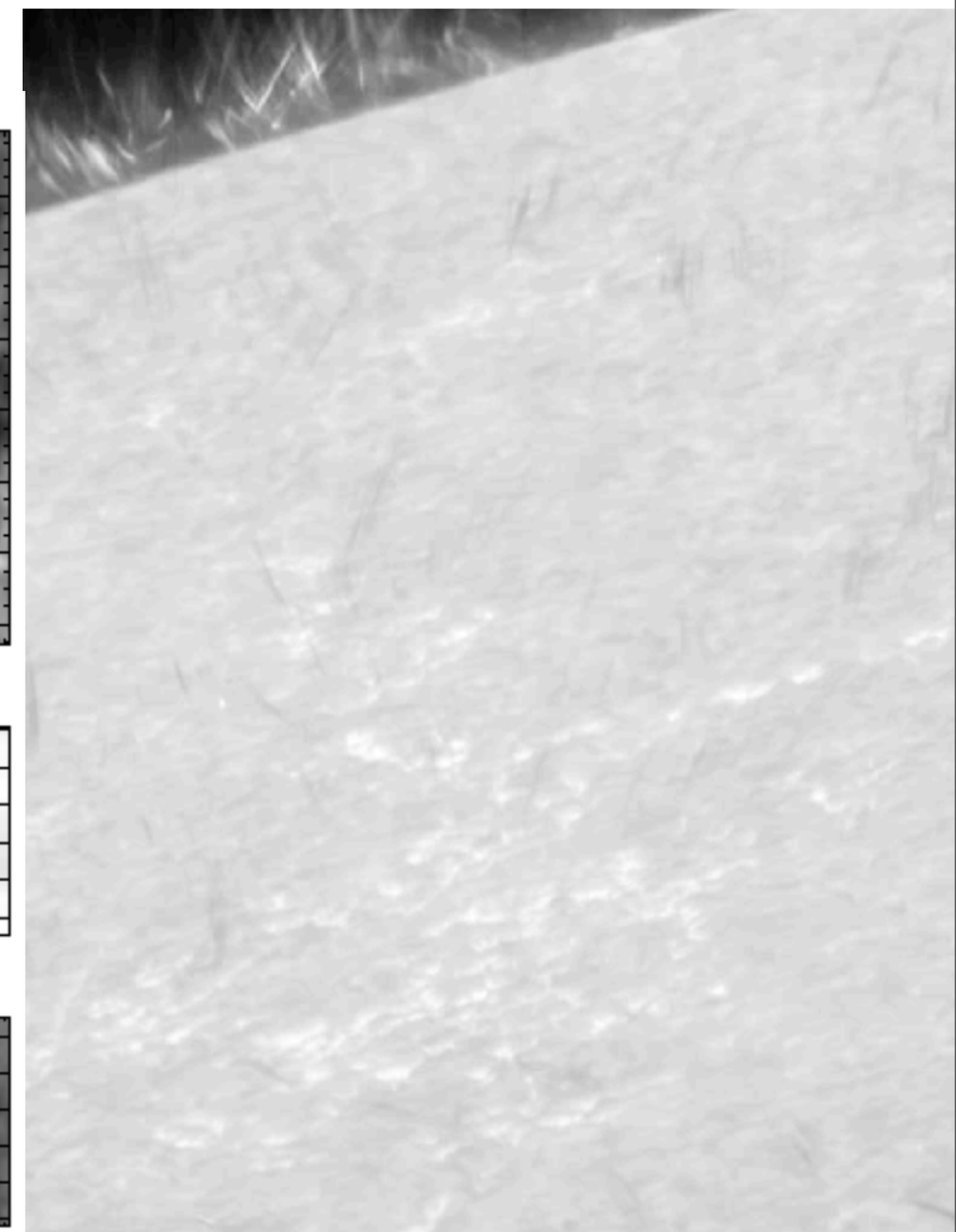


Twist/Torsion



Hα red wing: +51 km/s



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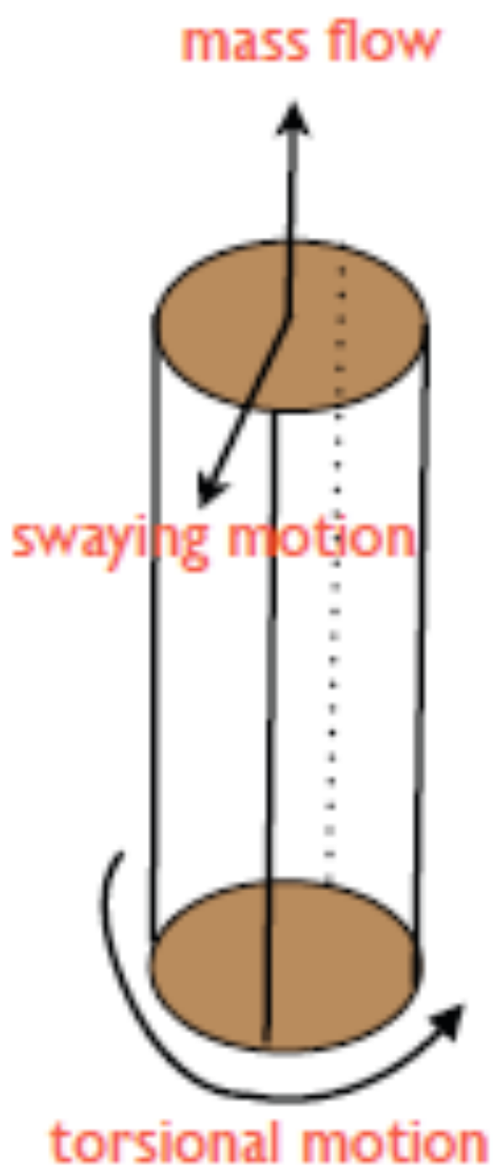

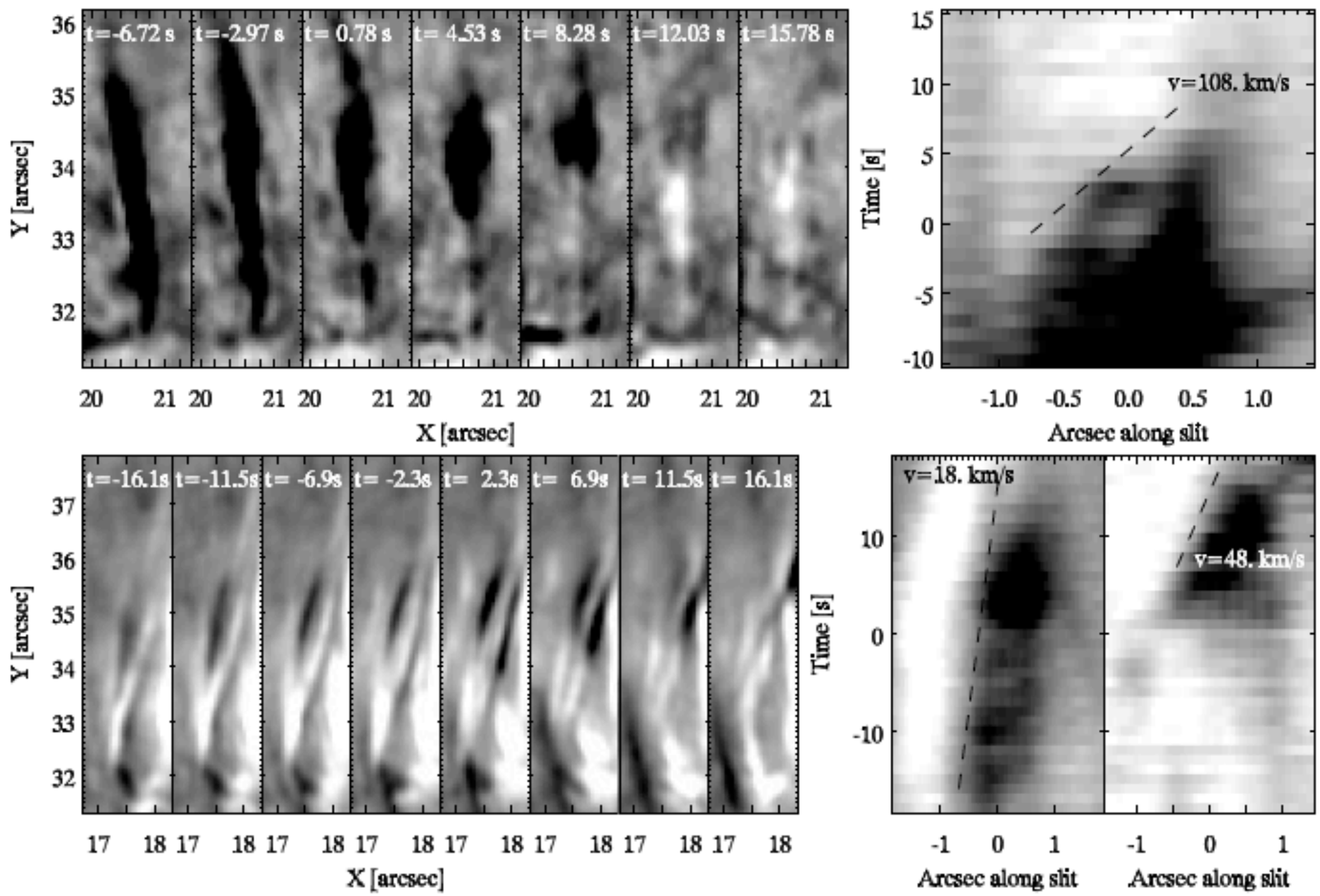

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What's Next?

The IRIS Mission is designed to study the mass and energy flow through the chromosphere and into the heliosphere.

Suite to study the onset and initial phases of geo-effective solar storms.

Launch June 28, 2013

- White-light K-Coronagraph (1.01 - 5.00 R_{sun})
- Imaging Spectro-polarimetry
  - 1.5m Versatile CoMP (1.01 - 5.00 R_{sun})
  - Chromospheric Vector Magnetograph

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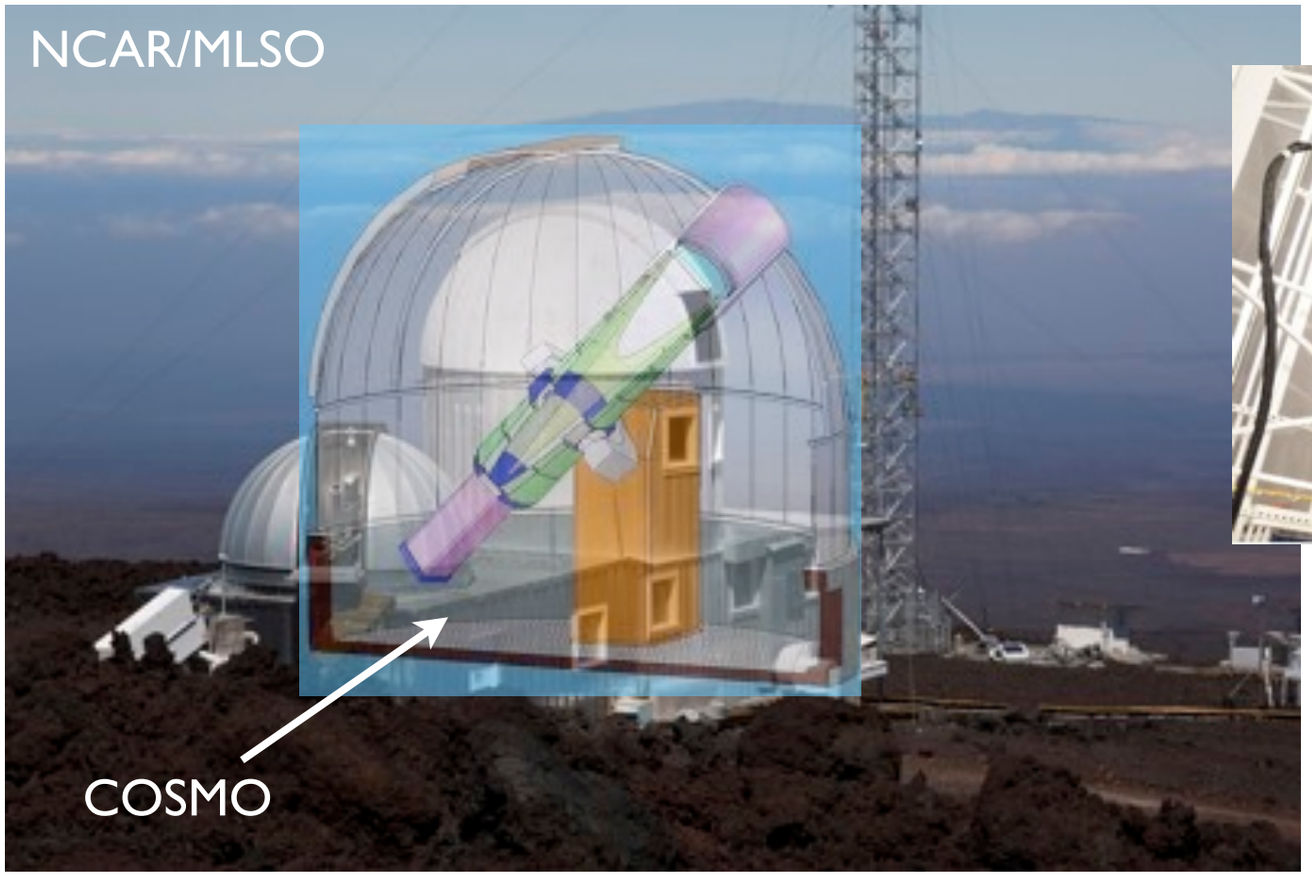
What's Next?



The IRIS Mission is designed to study the mass and energy flow through the chromosphere and into the heliosphere.

Launch June 28, 2013

Suite to study the onset and initial phases of geo-effective solar storms.

- White-light K-Coronagraph (1.01 - 5.00 R_{sun})
- Imaging Spectro-polarimetry
  - 1.5m Versatile CoMP (1.01 - 5.00 R_{sun})
  - Chromospheric Vector Magnetograph

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Conclusions

- ★The outer atmosphere is replete with transverse [Alfvénic] wave motions.
- ★Significant wave energy is present throughout, possibly with strong reflection back into the lower atmosphere.
- ★The waves provide valuable insight into coronal geometry and magnetic field strengths.
- ★IRIS will be able to “lay to rest” the correspondence of Alfvénic motion and line widths and allow us to study the wave properties in considerable detail.
- ★We haven’t even go to the “torsional” aspects of waves....
- ★Modeling the complex wave scenarios may lead to breakthroughs in understanding the energy transport into the heliosphere.

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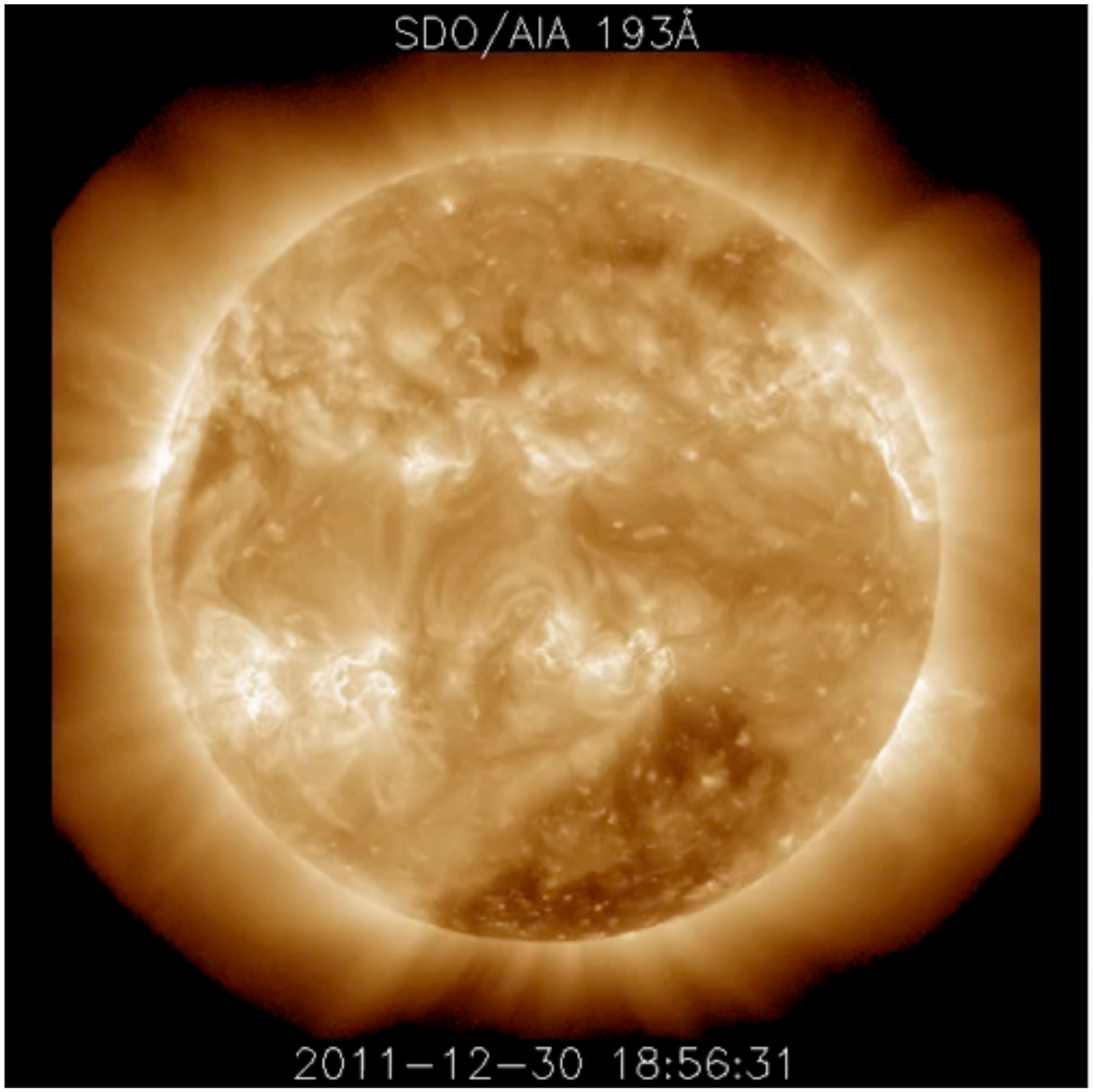
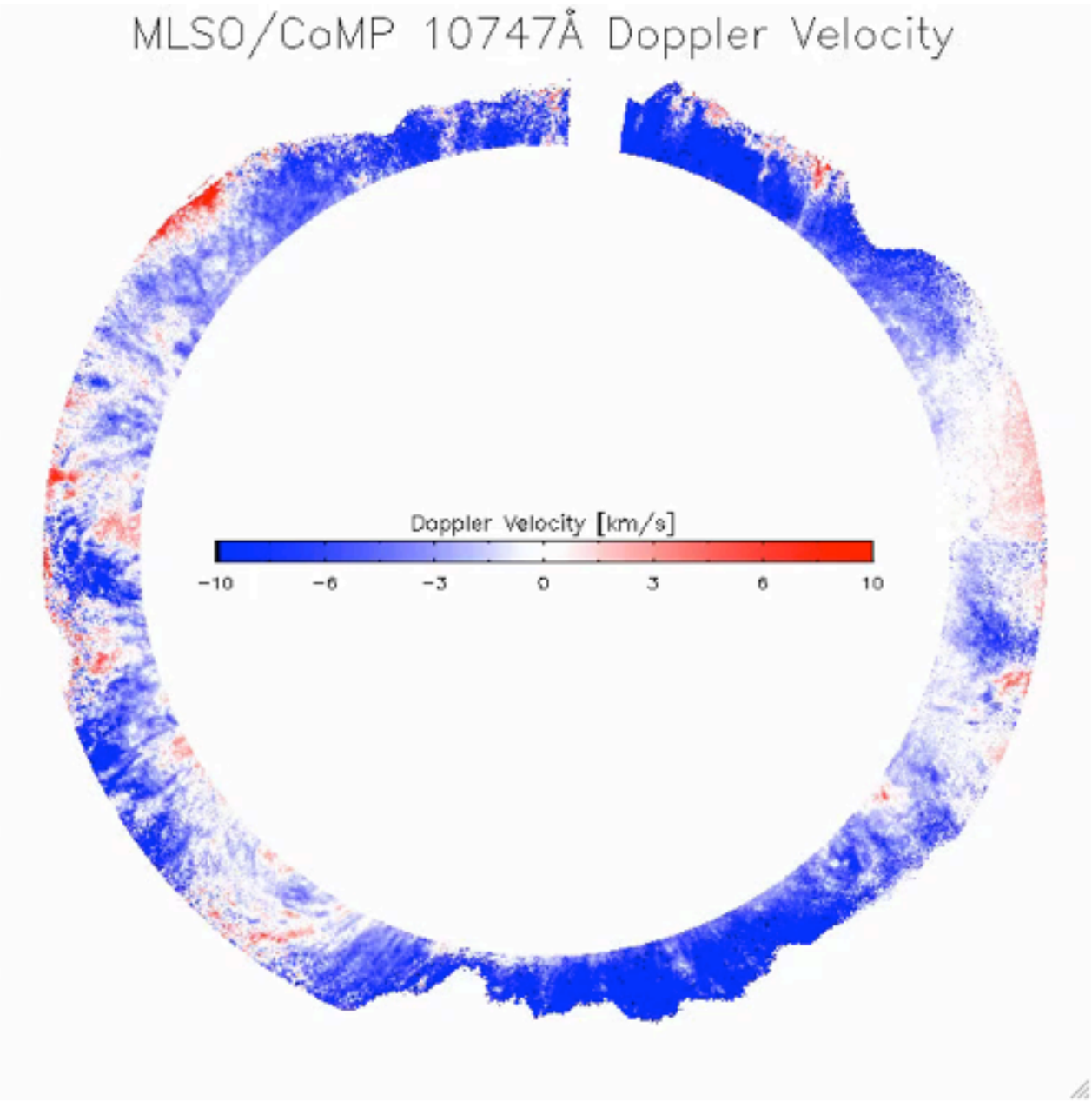
SWx Impact

The power of spectral imaging....





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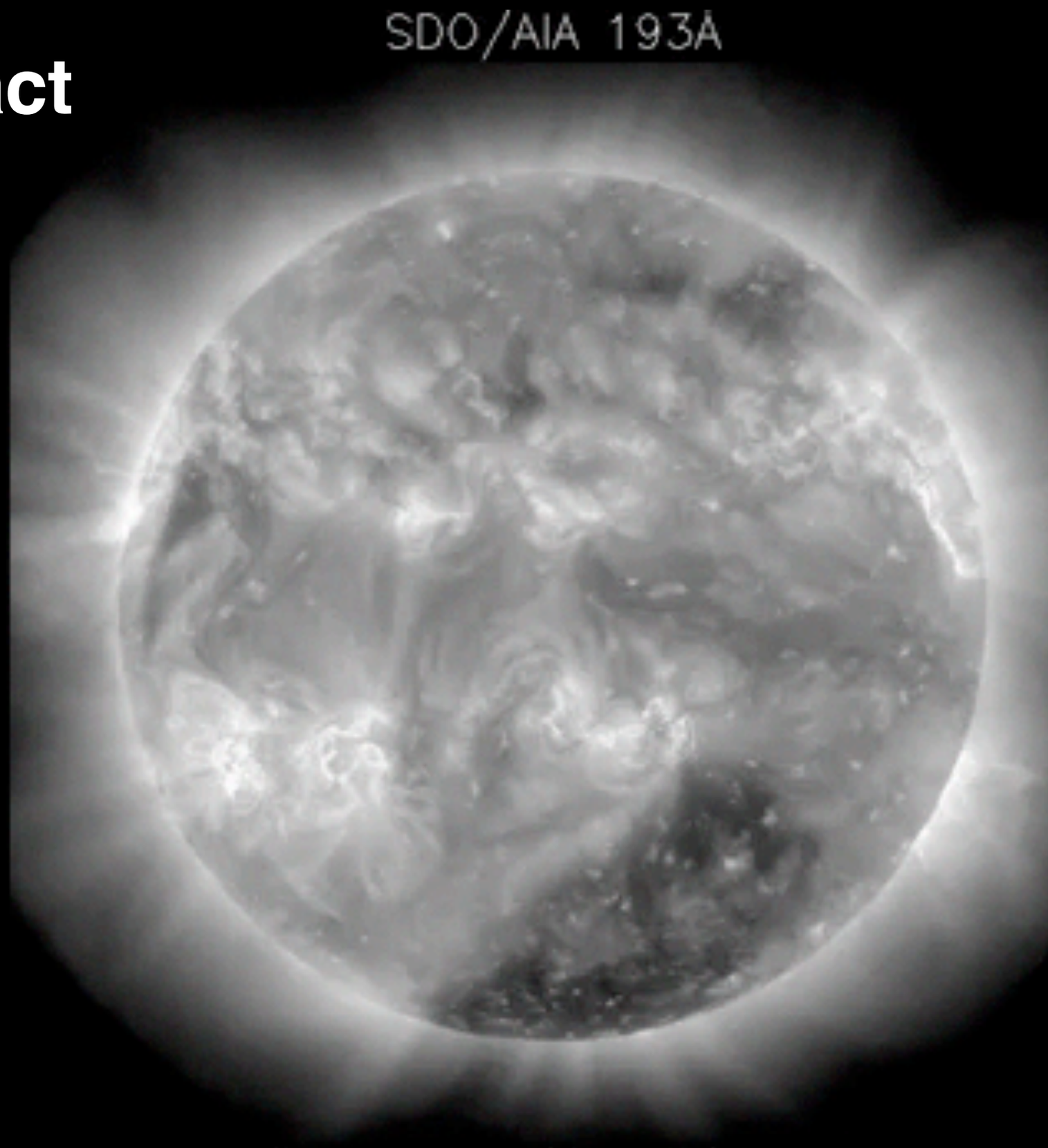
SWx Impact



HAO/STSW

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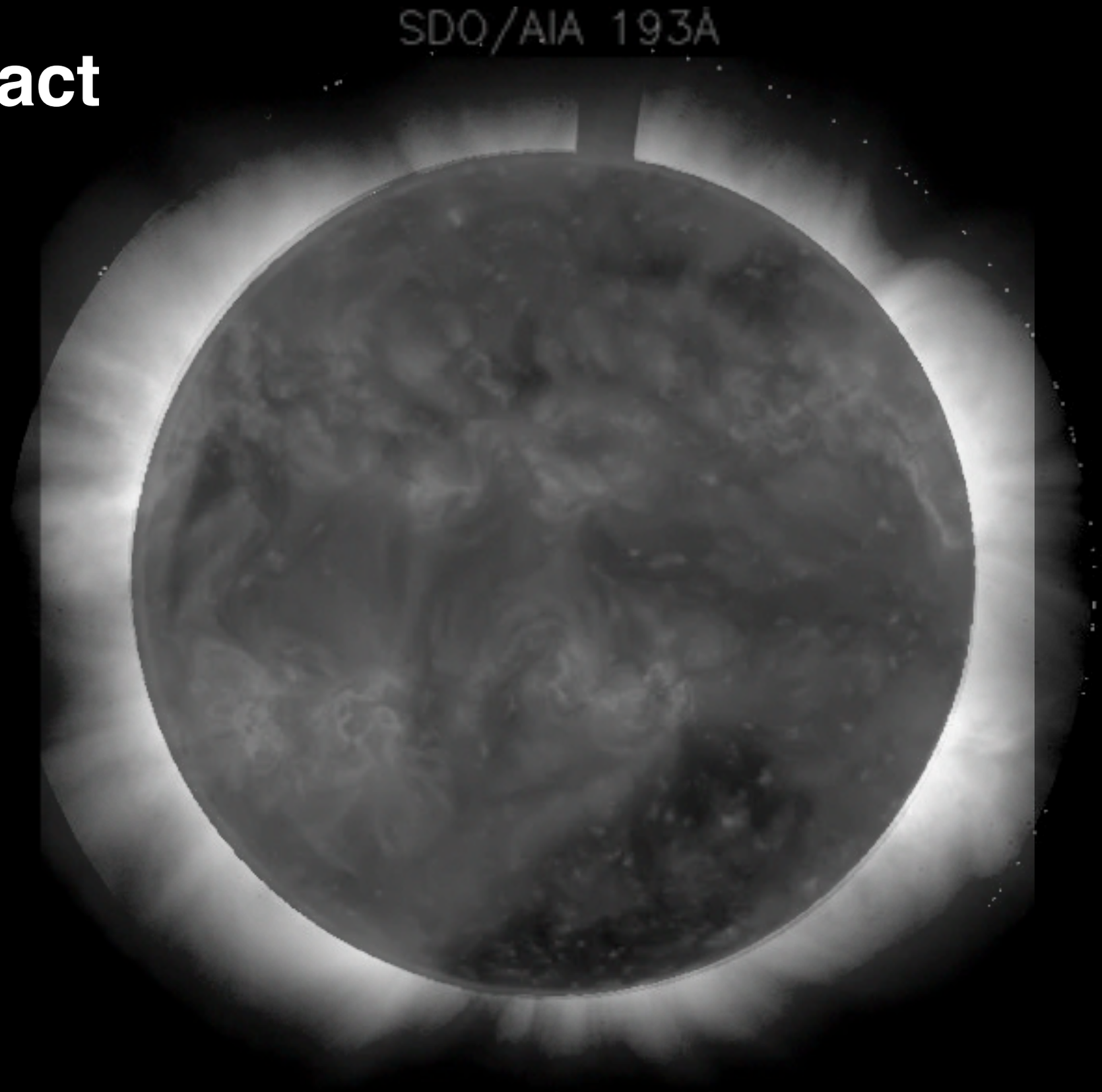
SWx Impact

MLSO/CoMP
Fe XIII
10747Å

Intensity



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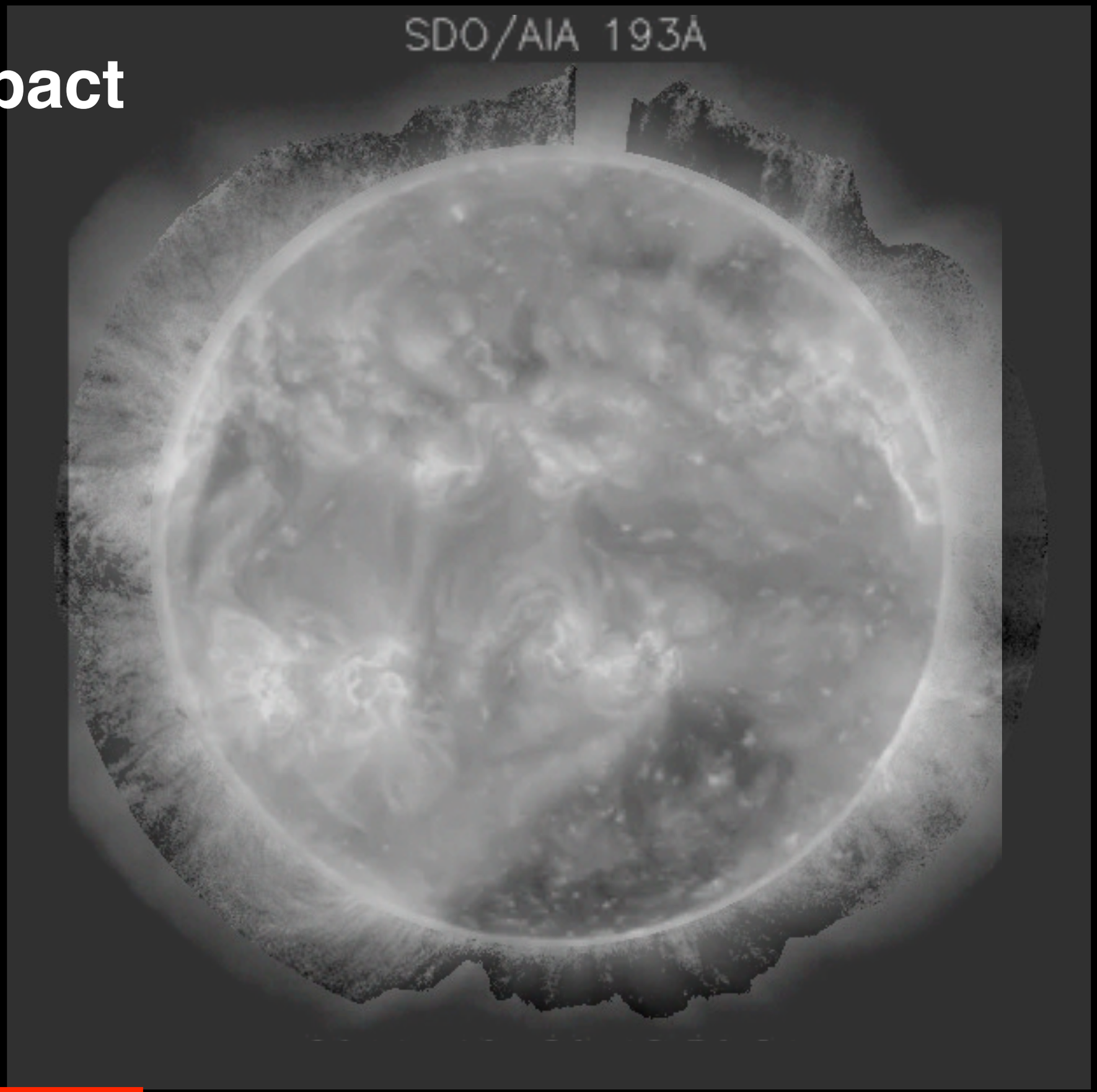

Velocity

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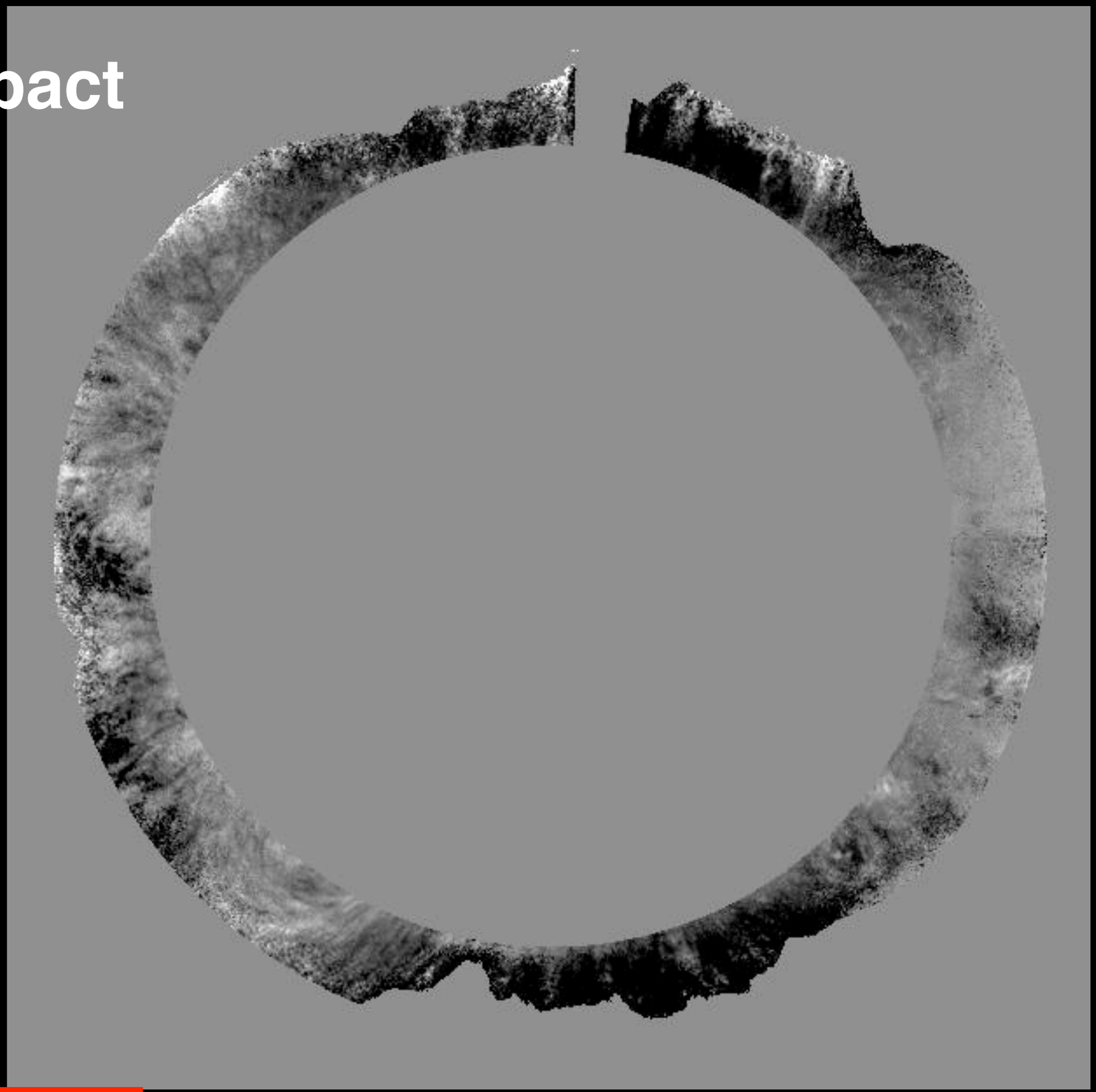
Fe XIII
10747Å



Velocity

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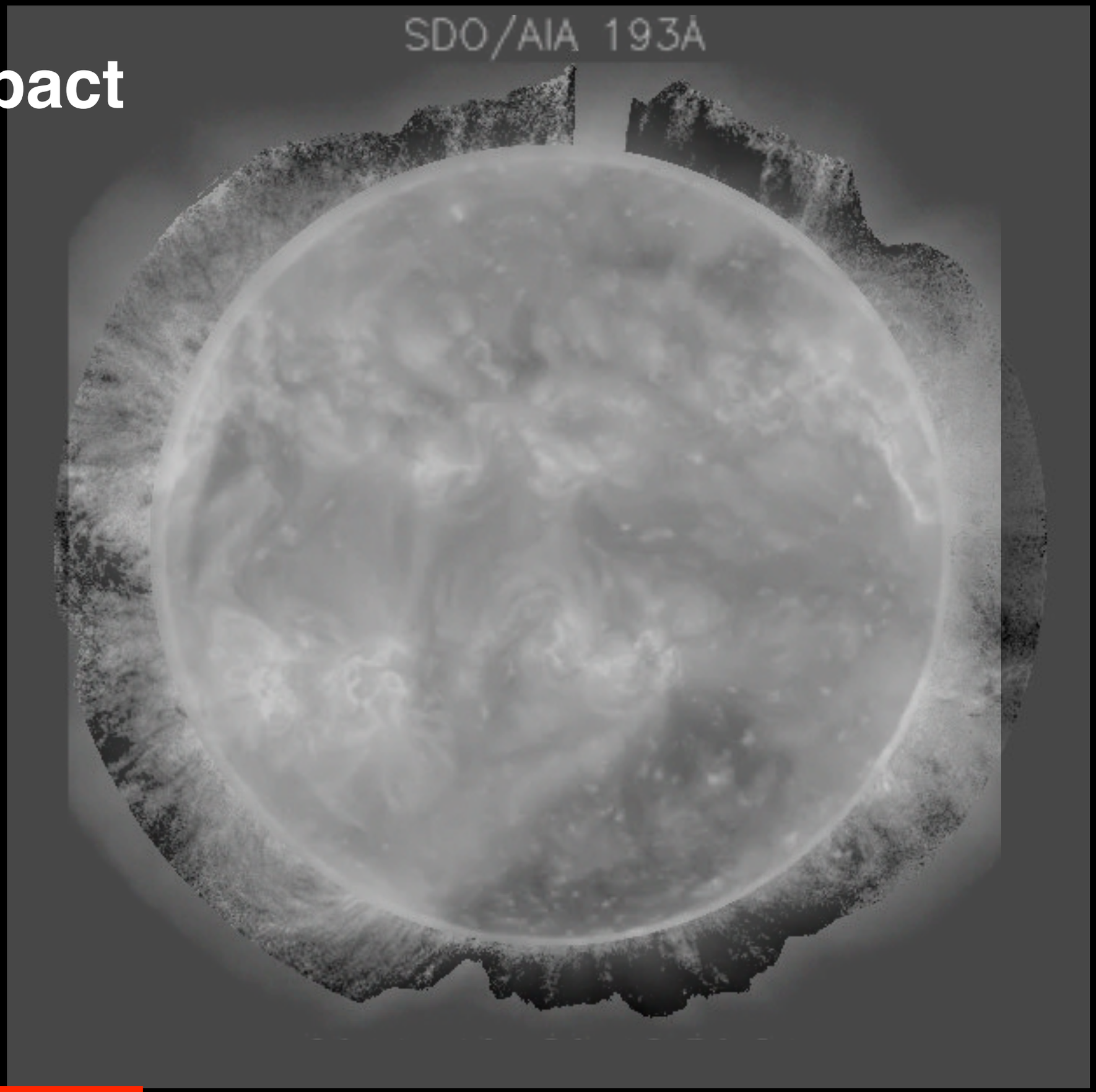

Velocity

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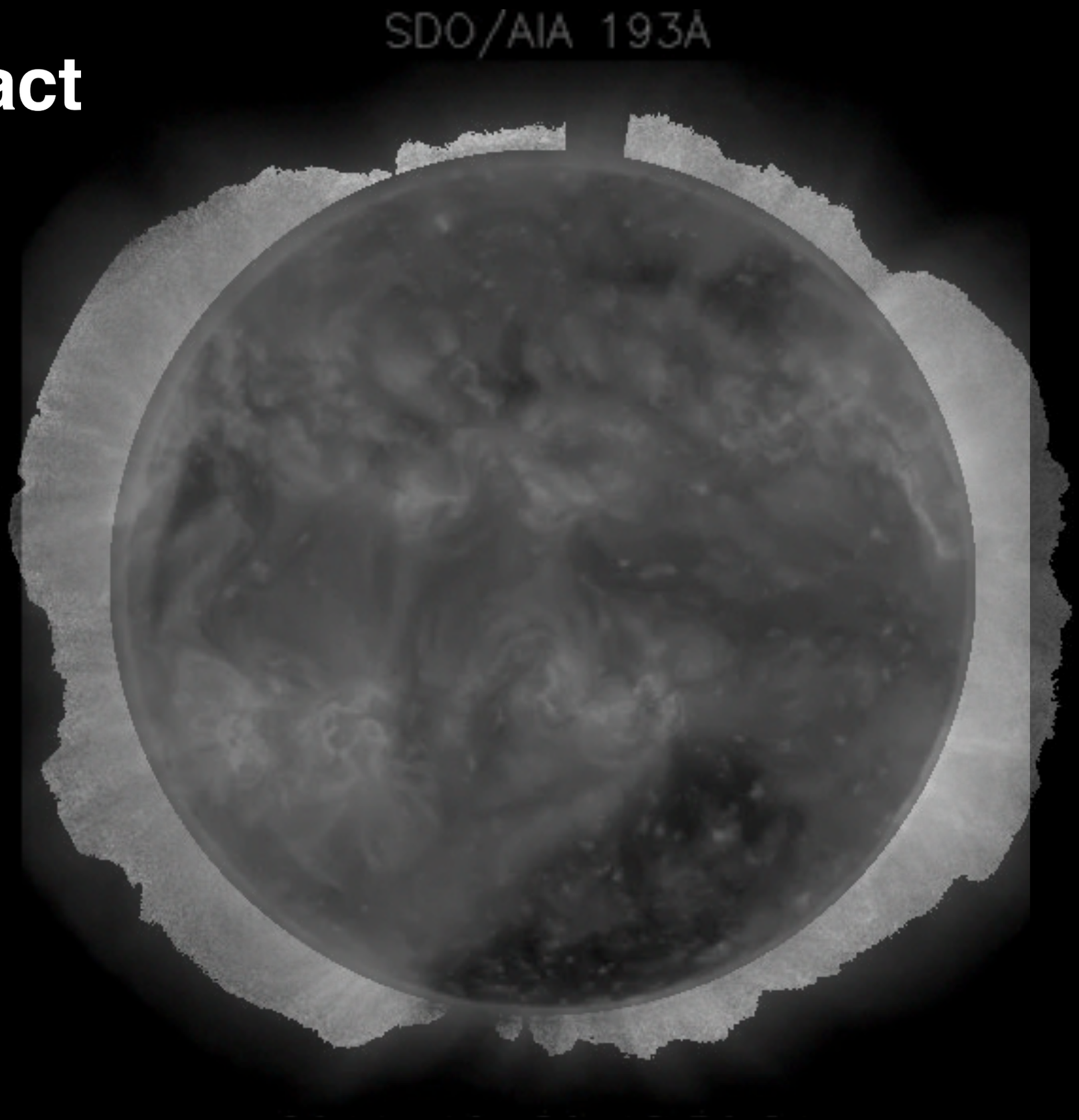

Width
[apparently
invariant with time]

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Width
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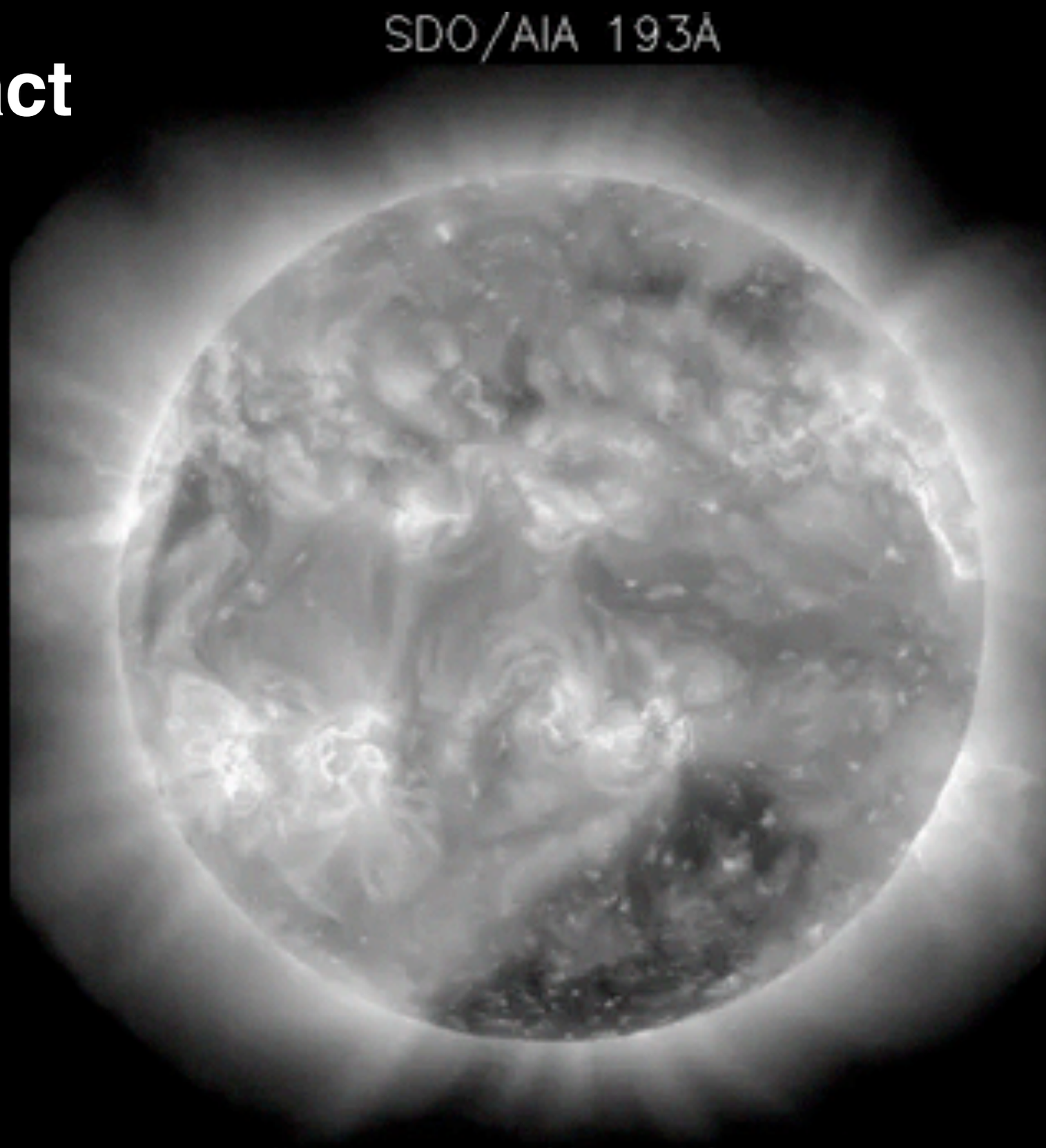

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