QUANTIFYING THE LIKELIHOOD OF SUBSTRUCTURE IN CORONAL LOOPS

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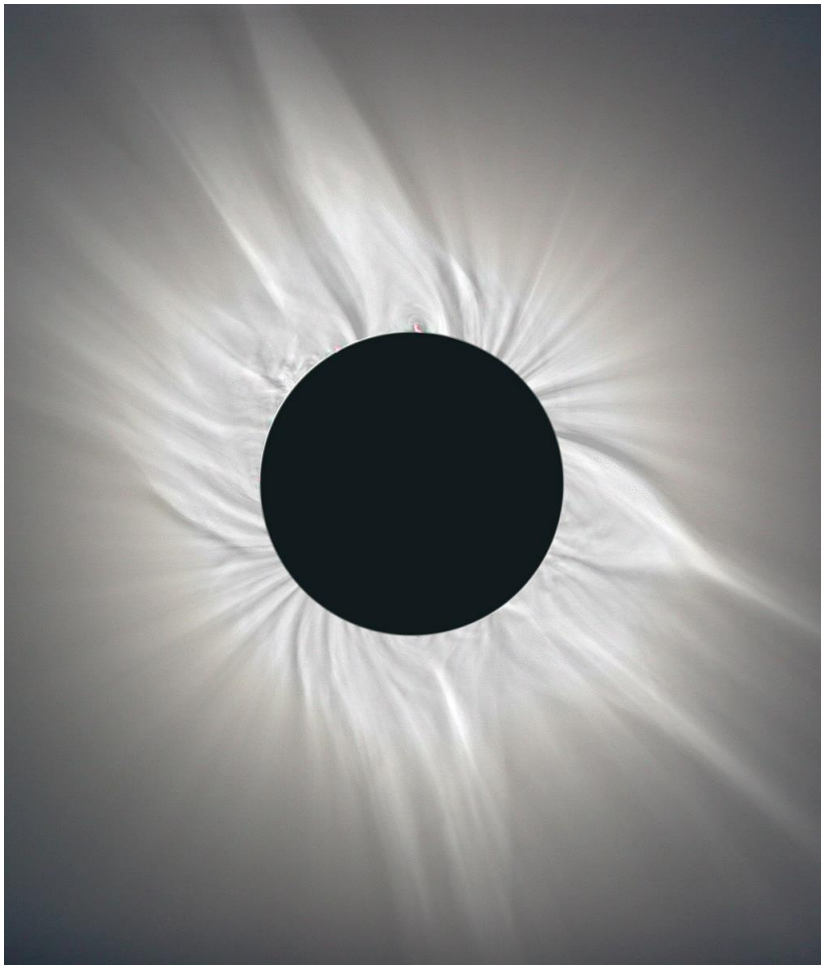
Coronal Heating

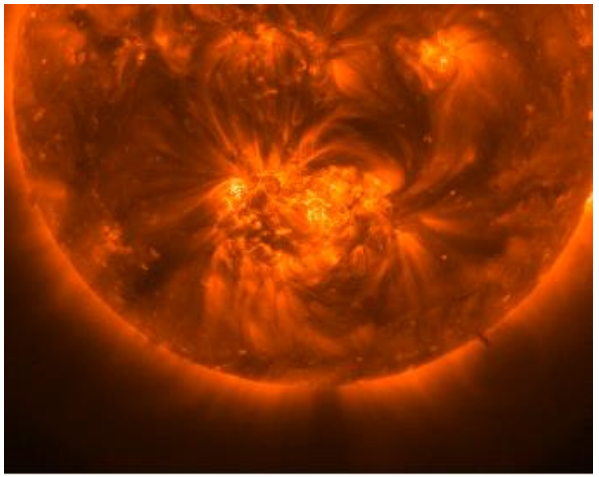
- 500,000 - 3 million K
- 1000 times hotter than surface of sun
- Power required = ~ 1kilowatt/ m^2

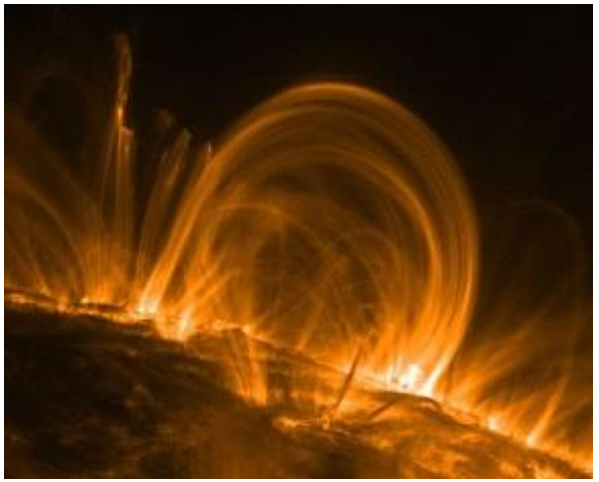


http://apod.nasa.gov/apod/ap090726.html

Coronal Loops

- Magnetic flux tube filled with hot plasma
- Connects regions of opposite polarity
- Potential location of coronal heating mechanisms





AIA 193 A 2012/07/11 18:53:44 (top)
http://www.daviddarling.info (bottom)

Coronal Heating -Solutions

Nanoflares

- *Small scale*
- Small consecutive bursts of energy that contributes to heating
- Magnetic reconnection induced by stresses from footpoint motions causing braids in flux tubes

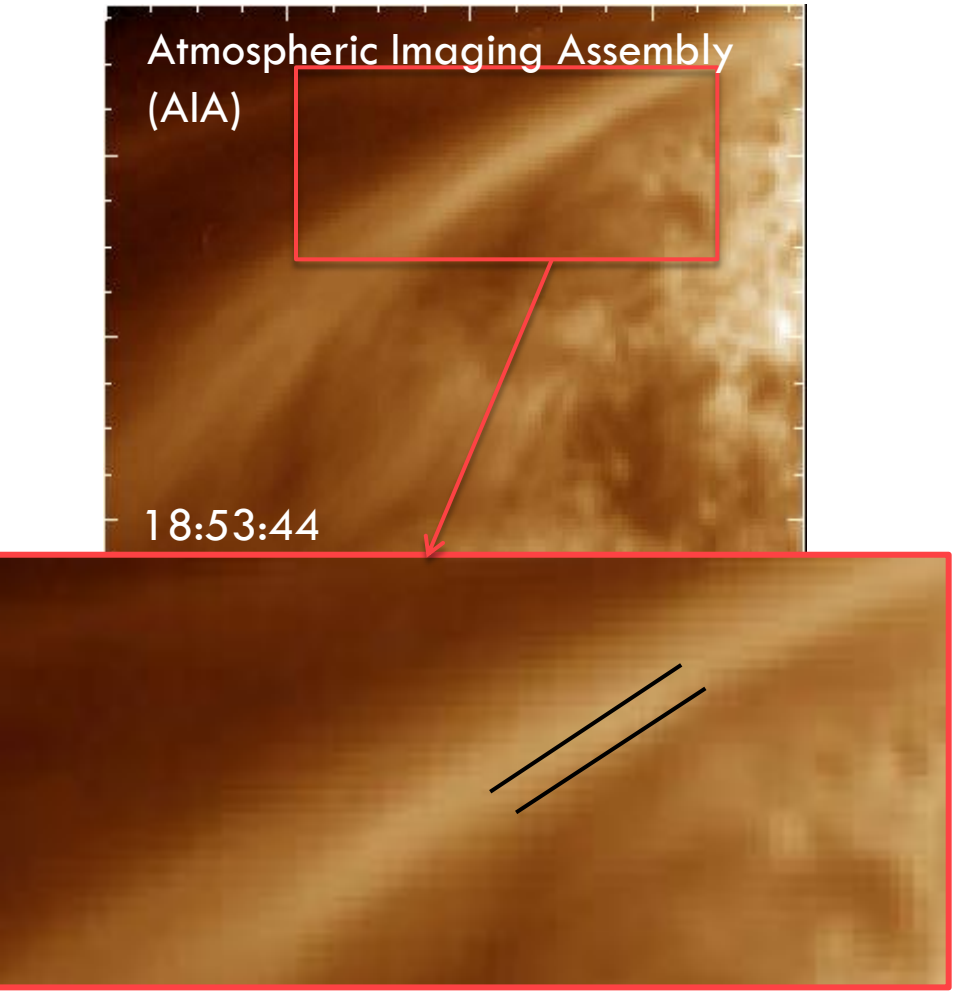
Alfven Waves

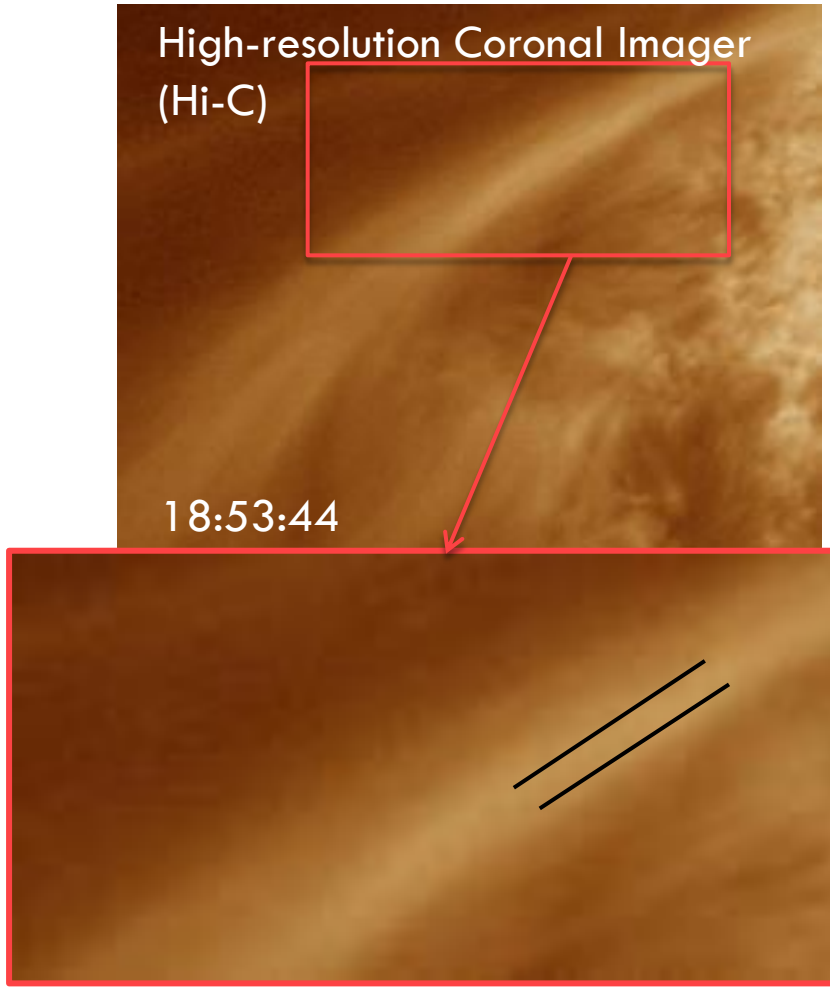
- *Large scale*
- Alfven waves dissipate energy into plasma through turbulence
- Waves propagate along flux tubes

Goal

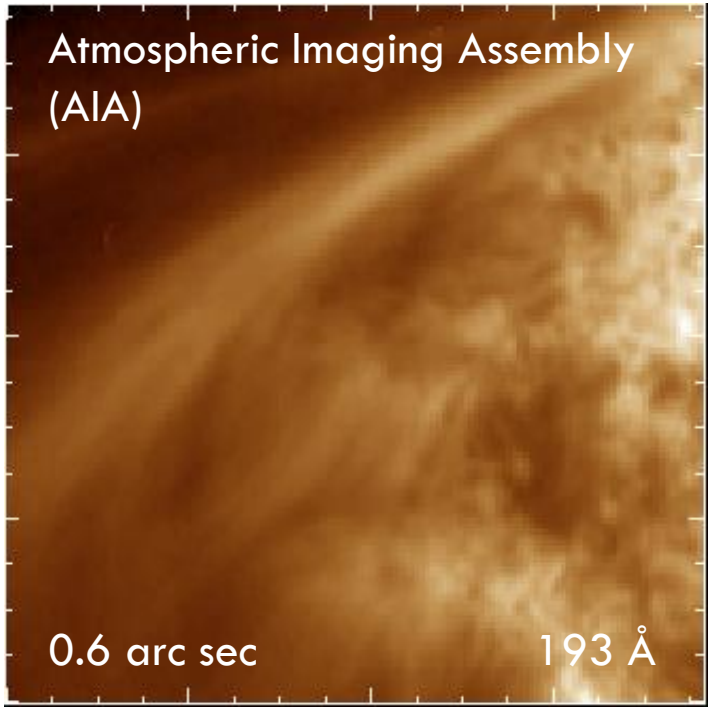
By identifying the substructure of coronal loops, we determine dominant spatial scales and constrain theories of coronal heating.

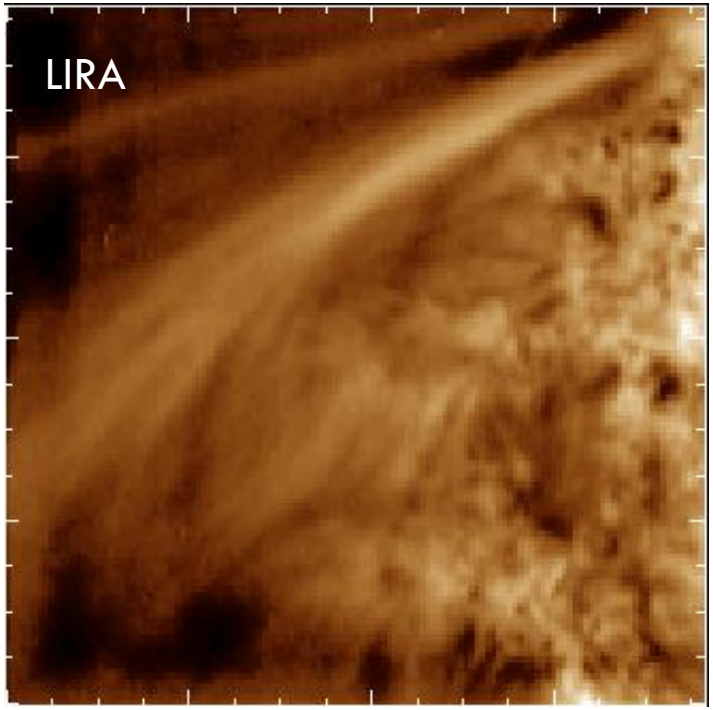
Increased Spatial Resolution





Increased Spatial Resolution





Low-Count Image Reconstruction and Analysis (LIRA)

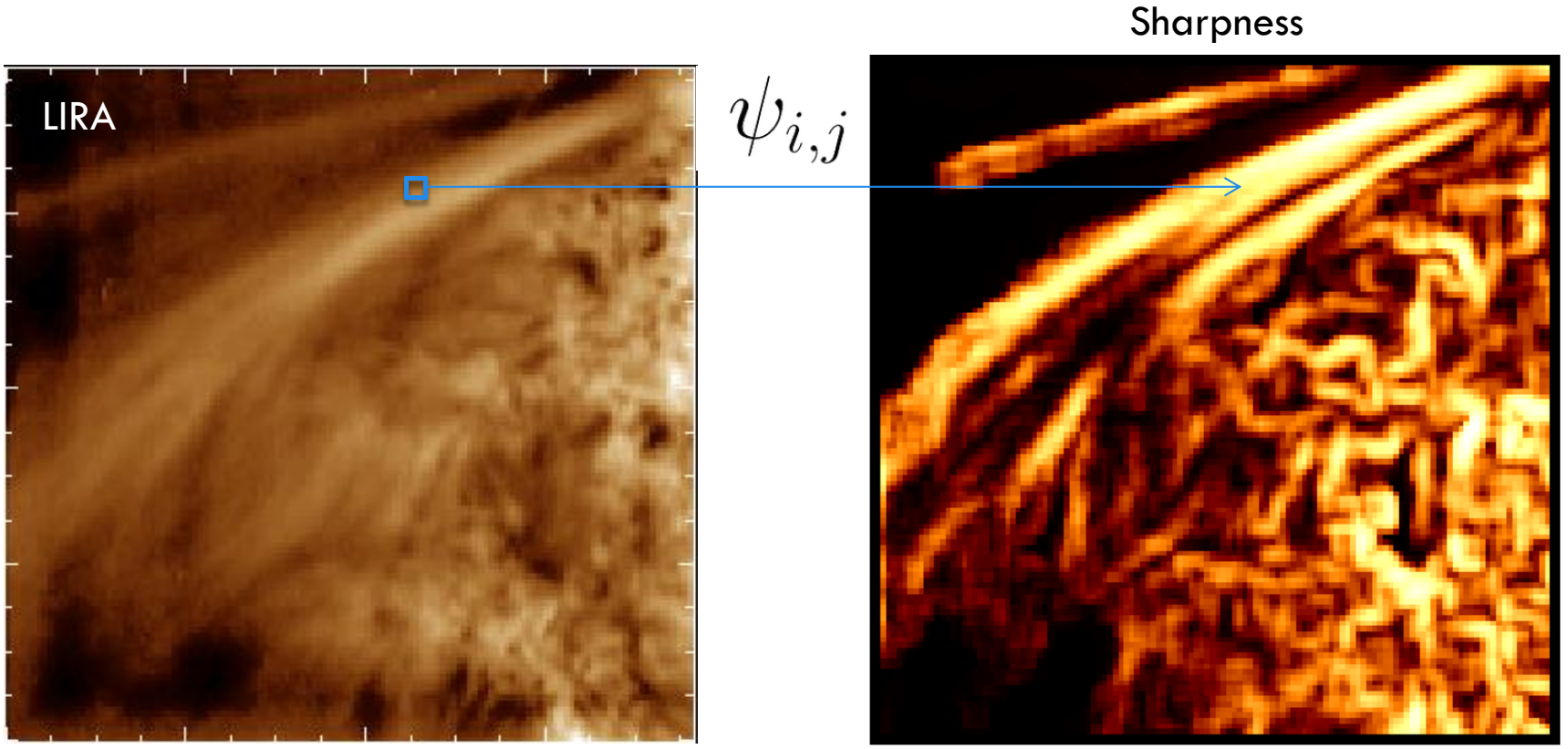
- Bayes / Markov Chain Monte Carlo
- Two components
  - 1 smooth underlying baseline
  - Inferred multi-scale component

Esch et al. 2004
Connors & van Dyk 2007

‘Sharpness’ Value

Wee & Paramesran 2008

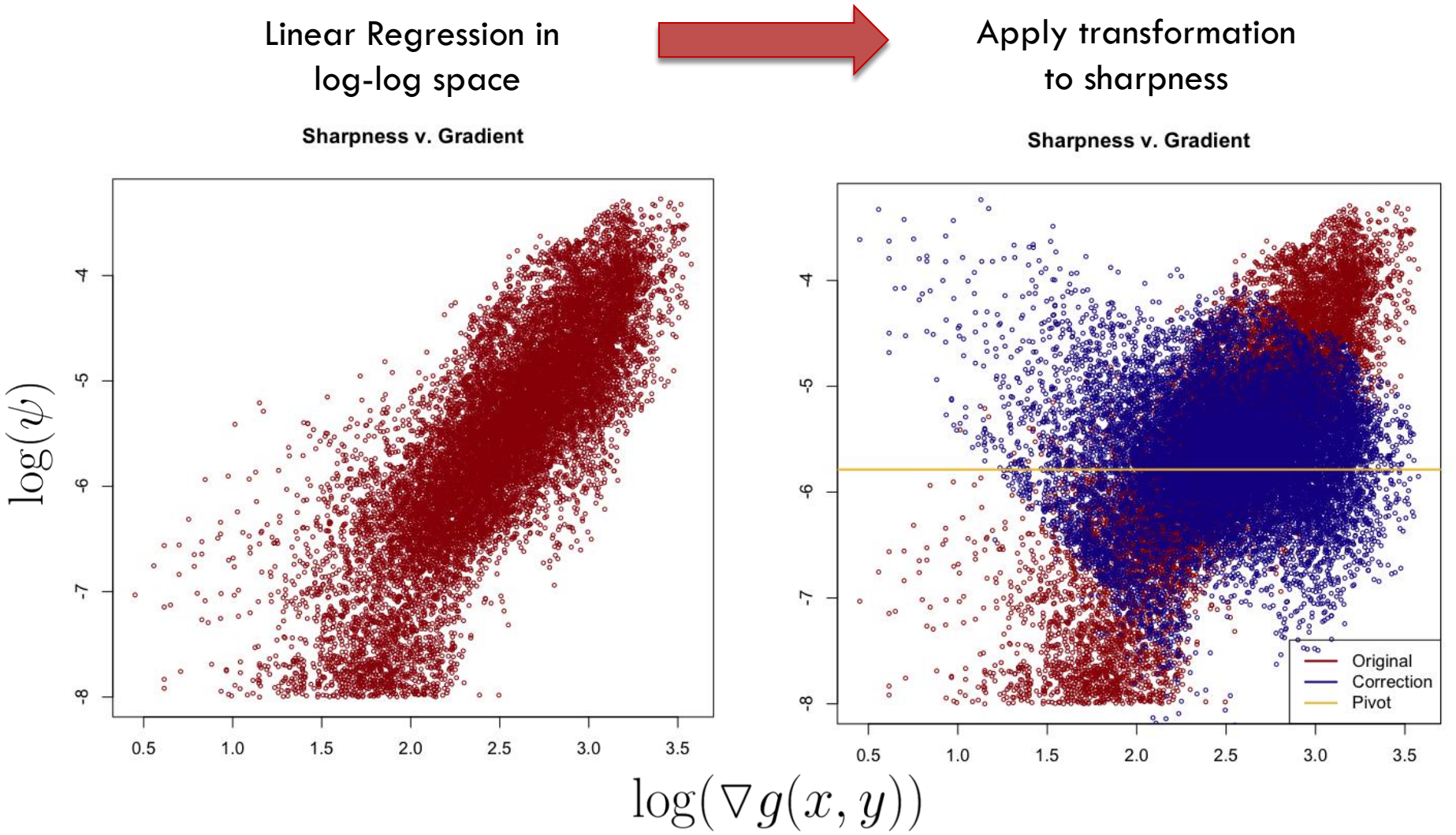
- Quantify the prominence of the substructure



Gradient Correction

Linear Regression in log-log space

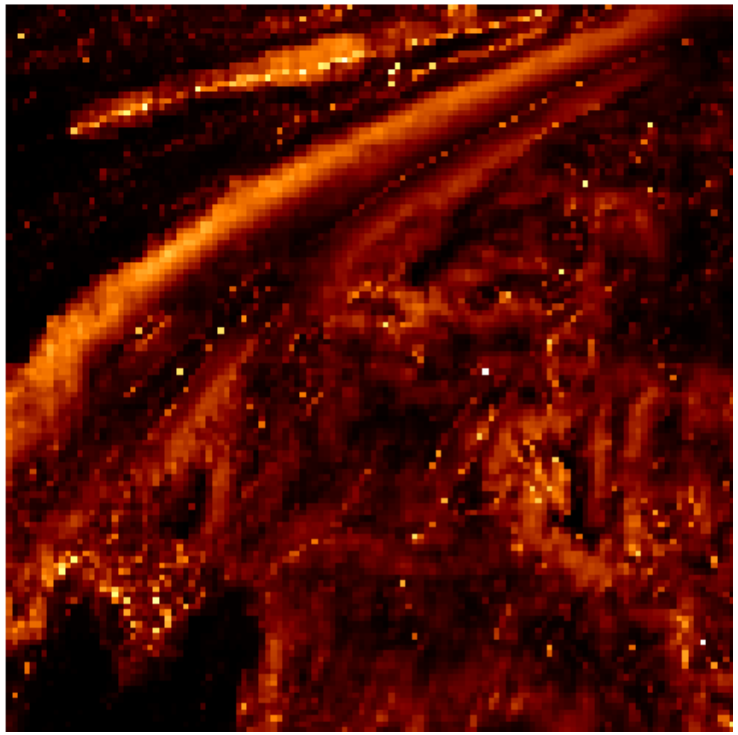
Apply transformation to sharpness



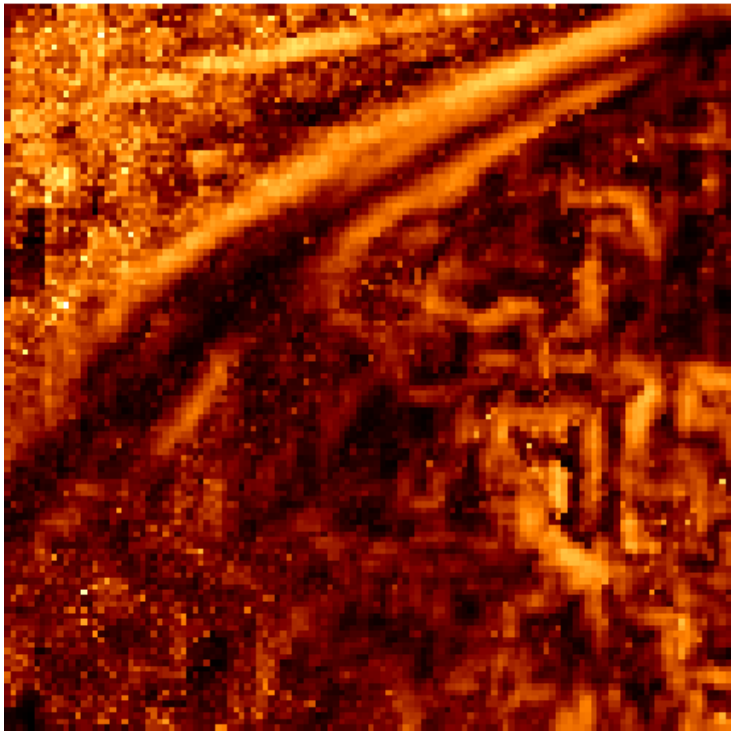
Significance of Substructure

- Null hypothesis = no substructure in coronal loop
- Null image = convolve observed image with PSF

LIRA on Observed
Corrected Sharpness



LIRA on Null Image
Corrected Sharpness

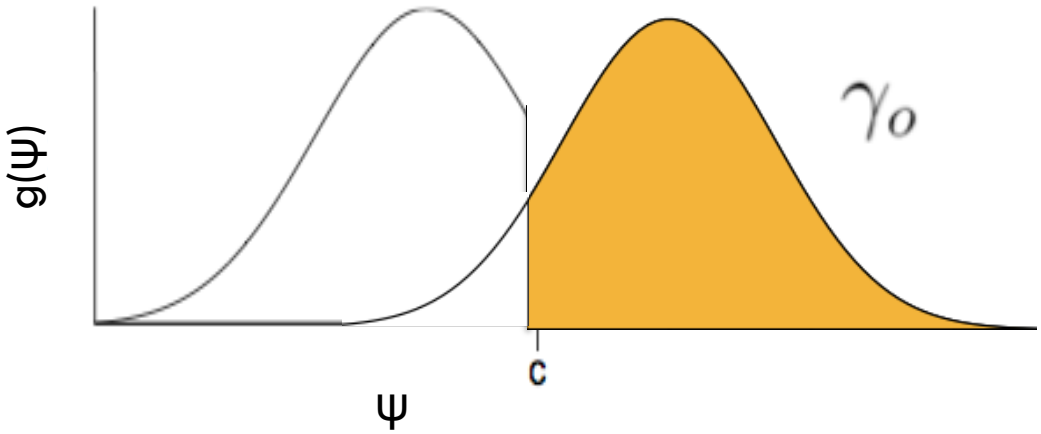


p-Value Upper Bound

Stein et al. 2014 (draft)

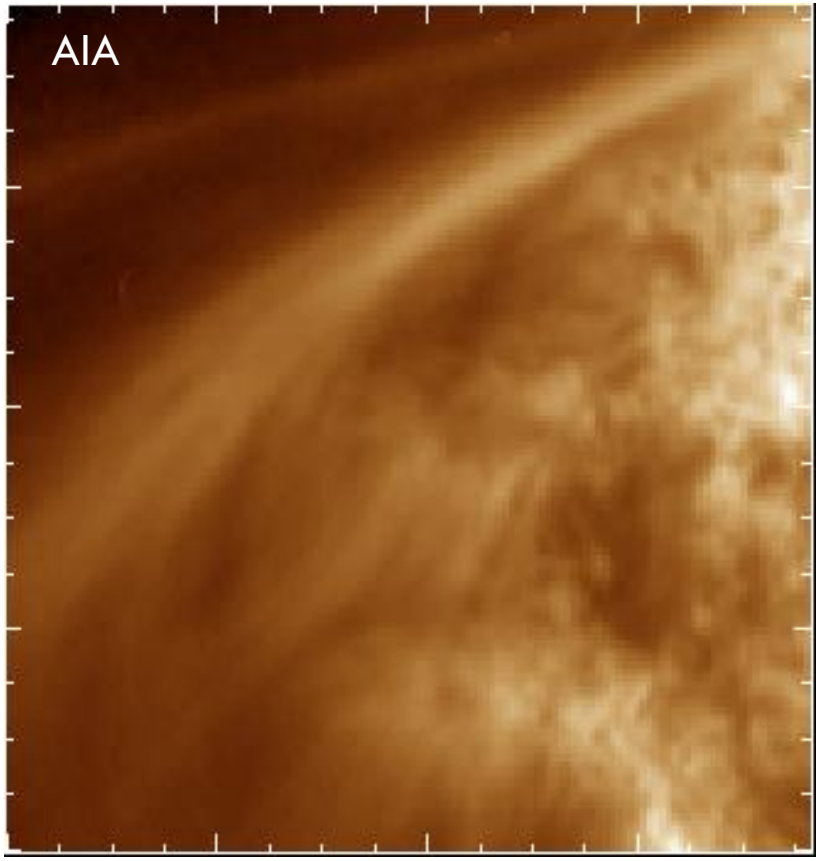
- 5 Poisson realizations of double convolved image
- Compare sharpness for the observed image (Ψ_o) and the simulated images (Ψ_n)

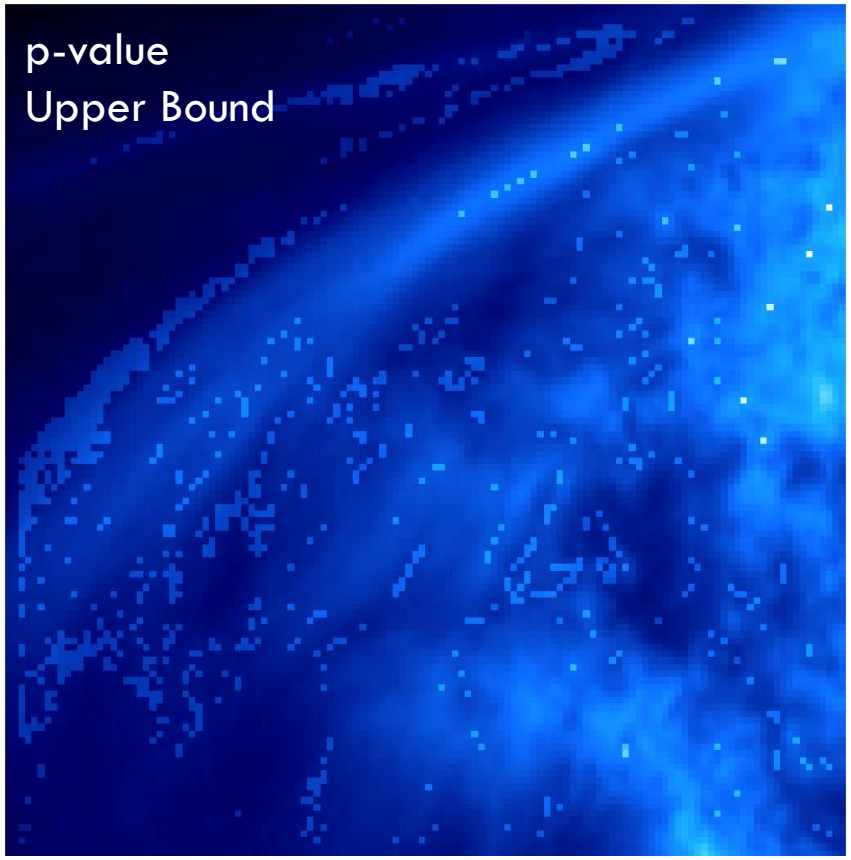
p-value upper bound $\hat{u} = \frac{\gamma_n}{\gamma_o}$



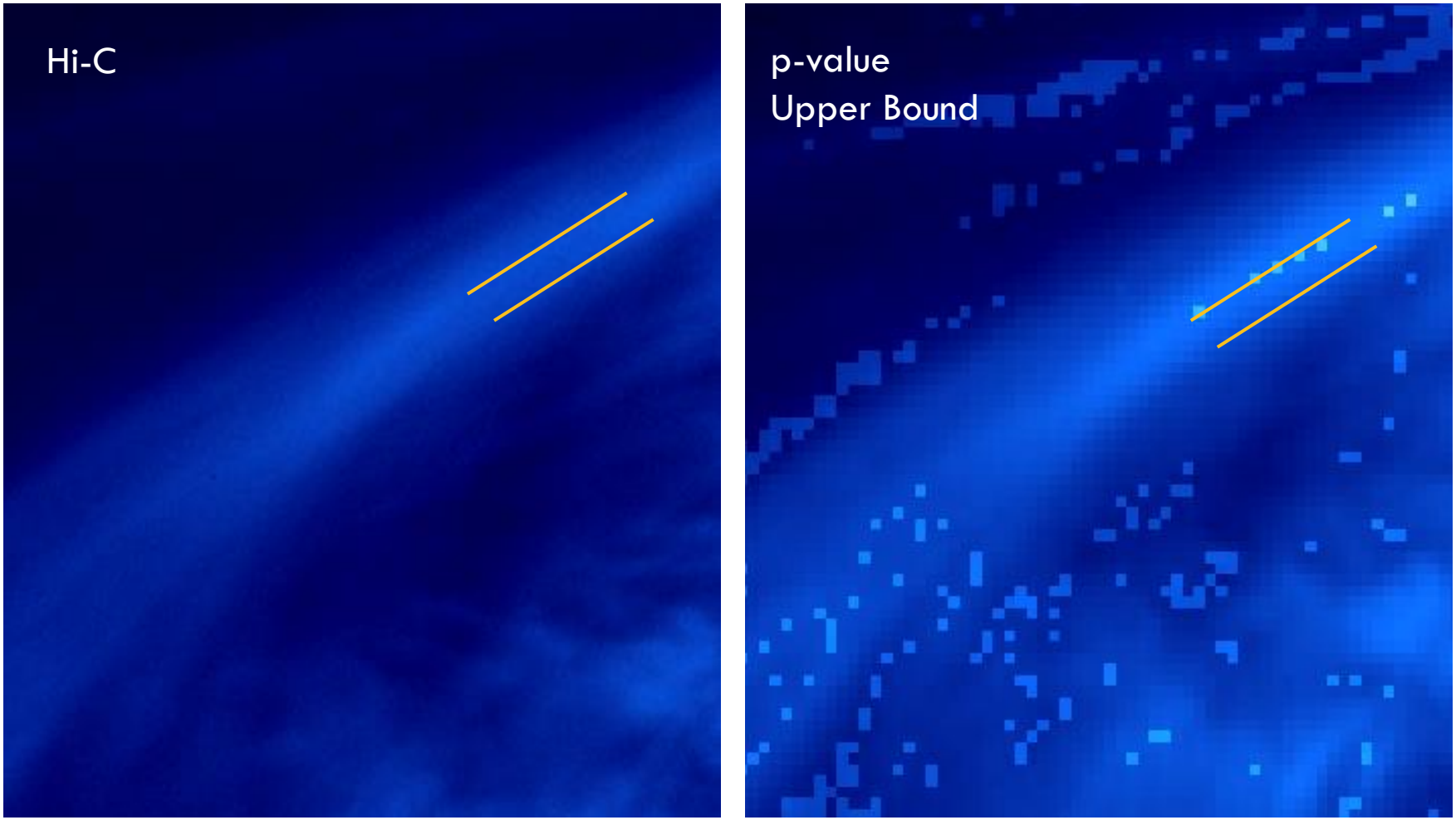
p-Value Upper Bound

- Significant sharpness: $\hat{u} < 0.06$



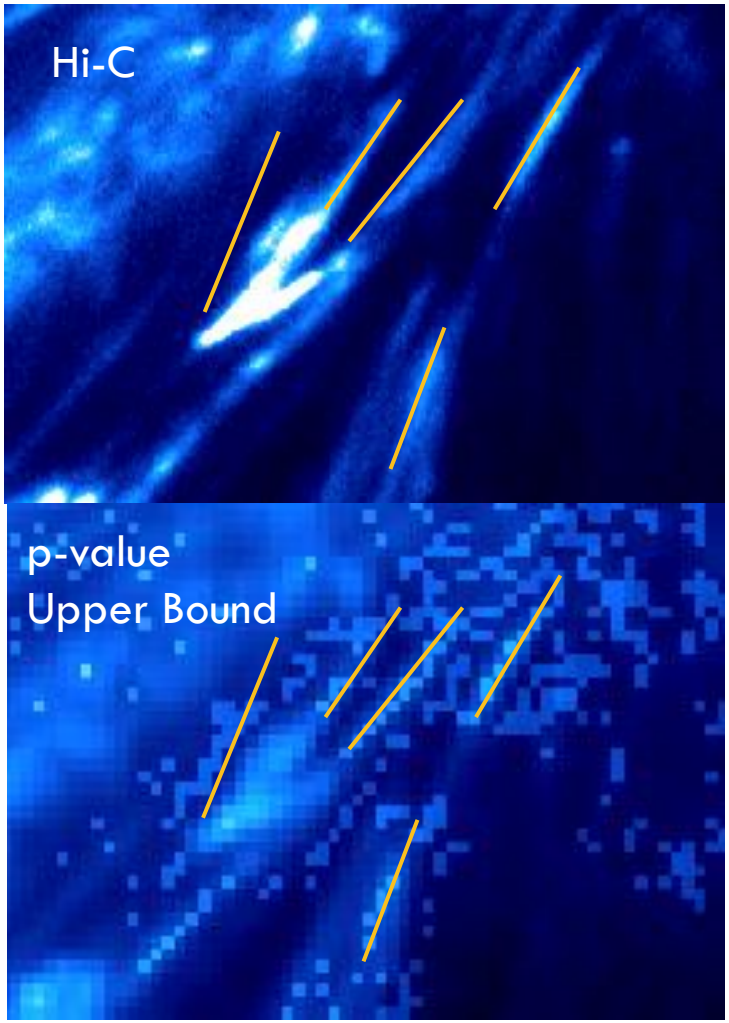


Hi-C Comparison

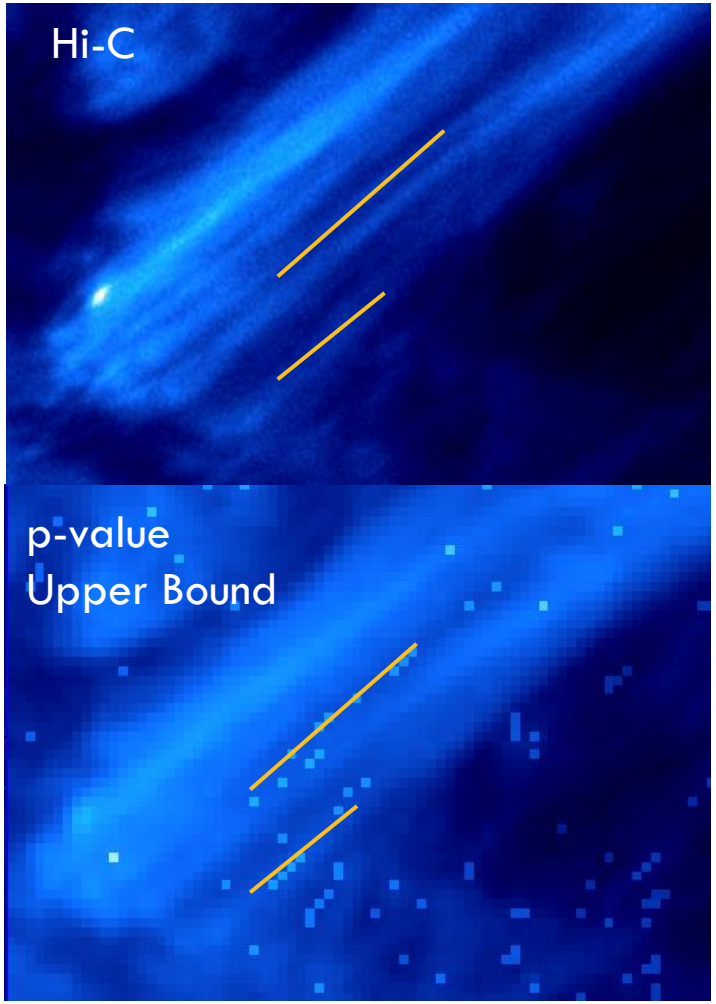


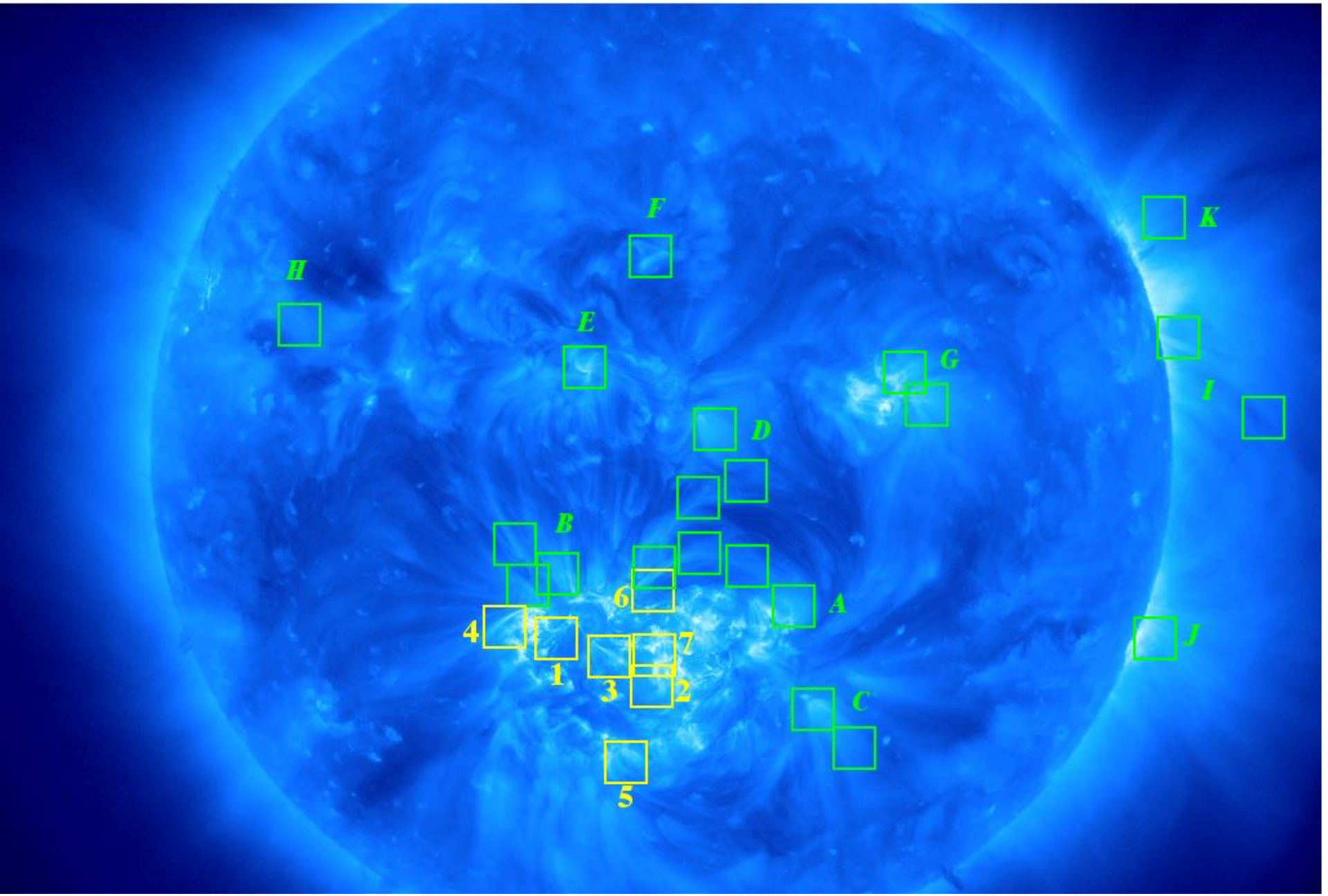
Hi-C Comparison

Trial 1



Trial 6




F
K
H
E
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I
D
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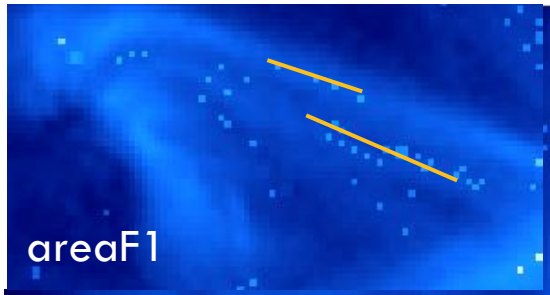
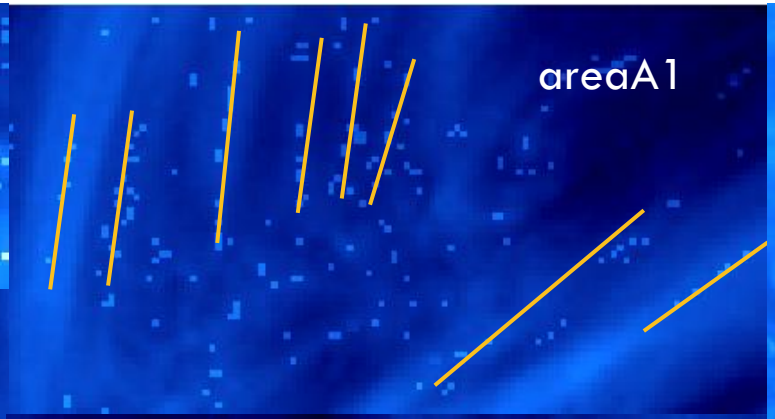
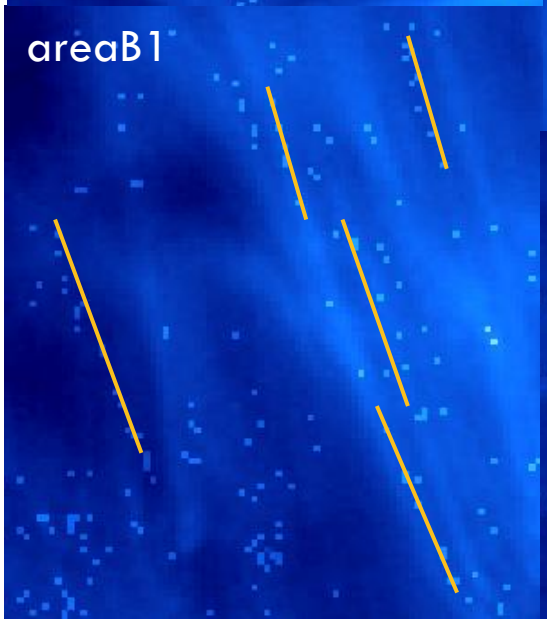
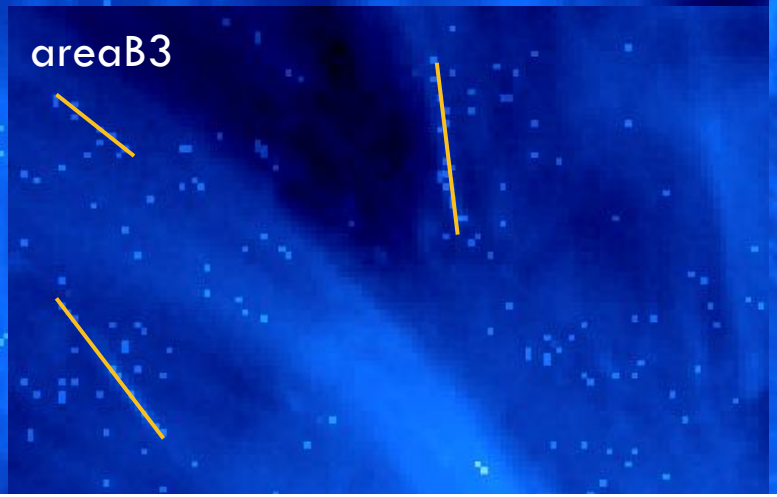
A
6
4
7
1
3
2
J
C
5

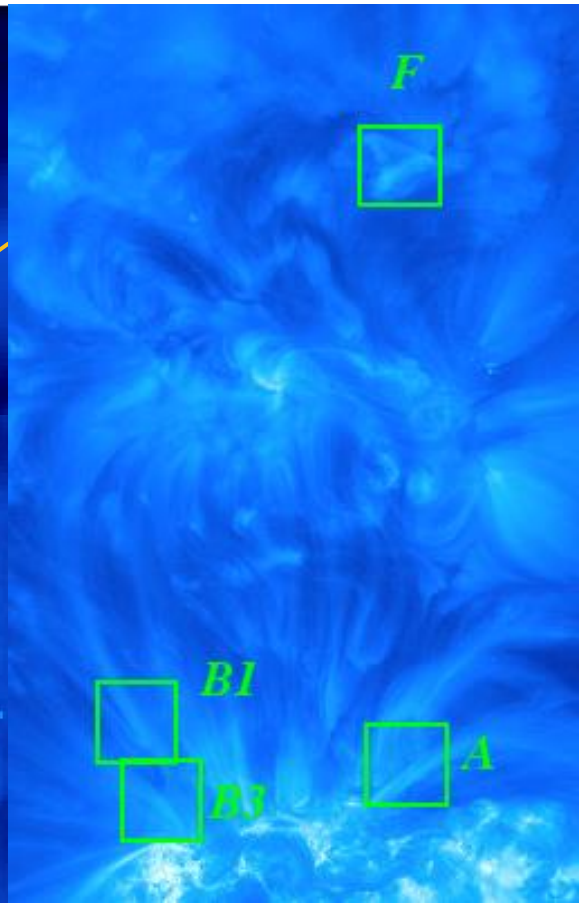
Detected Loops











Summary

- Developed method to search for substructure in solar images
- Found evidence for substructure in AIA images that we observe in Hi-C
- Similar evidence of substructure in AIA loops outside of Hi-C region:
  - Loops with strands appear to be ubiquitous
  - Supports nanoflare model
- Not all loops found to have substructure – unclear if statistical or physical explanation
- Isolated points possibly result of Poisson artifacts

Future Work

- Results are preliminary
  - Quantify false positives and non-detections
  - Increasing power could expand detection regions
- Understand implications of results
  - Relation between bright points and detections – compare significant pixel light curves
  - Why some loop complexes show no detections

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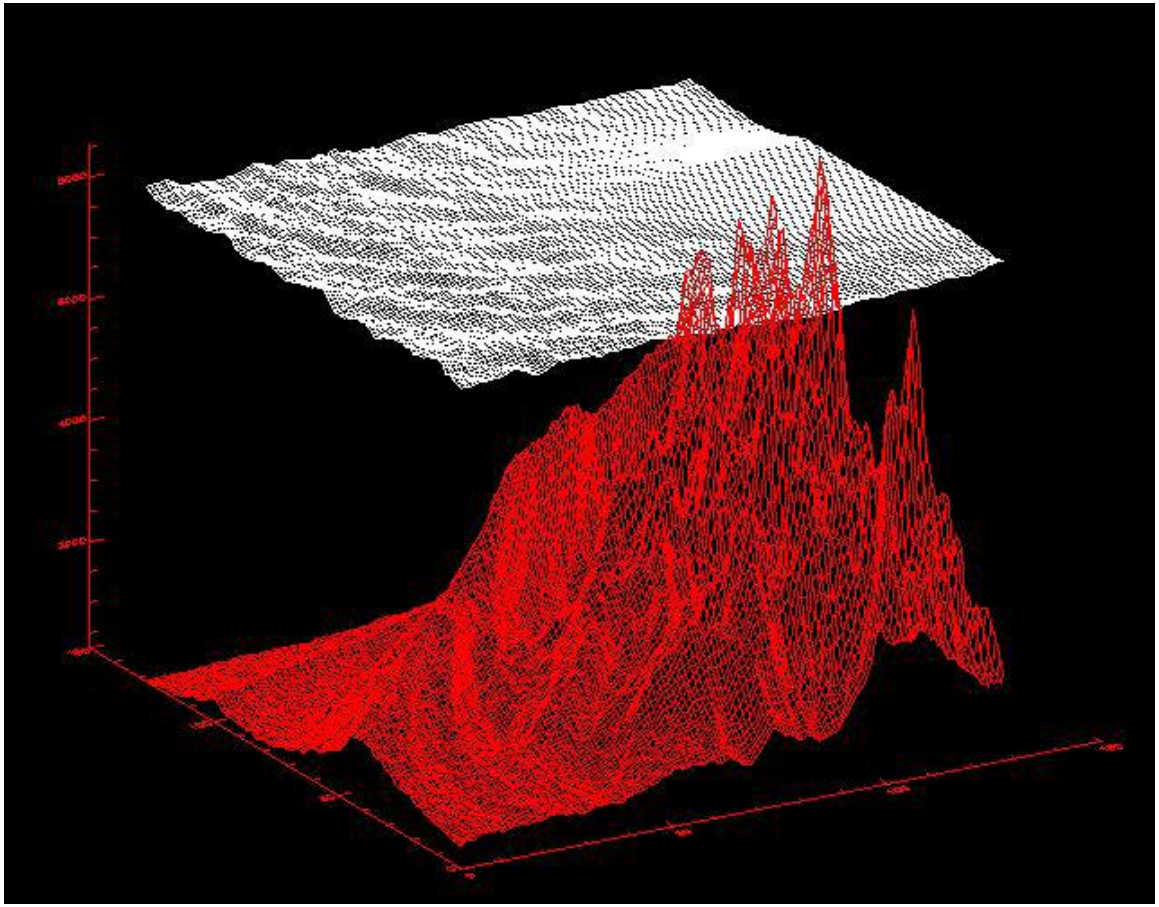
Extra Slides

Baseline Model

1. Begin with max
2. Correct using min curvature surface through convex hull
3. Iterate until surface lies below data



LIRA Operations

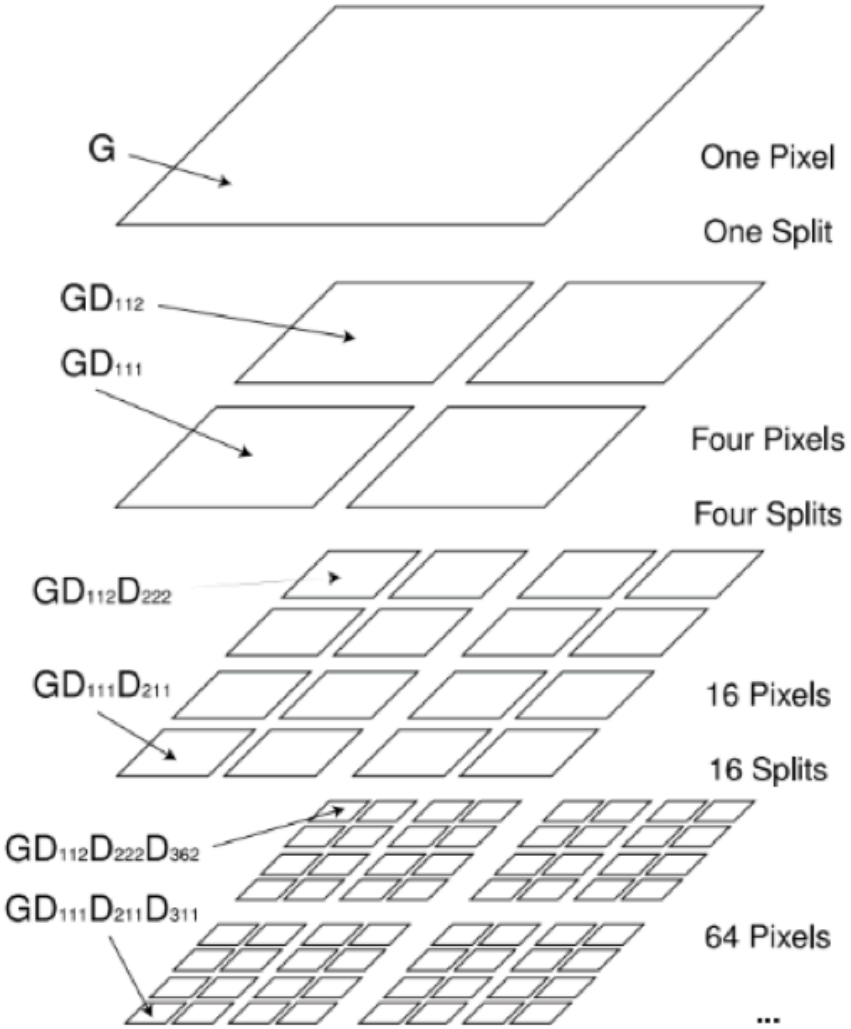
INPUT

- Point Spread Function (PSF)
- Observed Image (2^nx2^n)
- Baseline Model
- Prior & Starting Image

OUTPUT

- MCMC iterations of Multi-scale Counts
  - Posterior distribution of departures from baseline
  - De-convolution

Multi-scale Representation



‘Sharpness’ Value

$$g(x,y)$$ → Image matrix

$$\tilde{g}(x,y) = \frac{g(x,y)}{\sqrt{\sum_{x=0}^{N-1}\sum_{0}^{N-1}[g(x,y)]^2}}$$ → Normalization

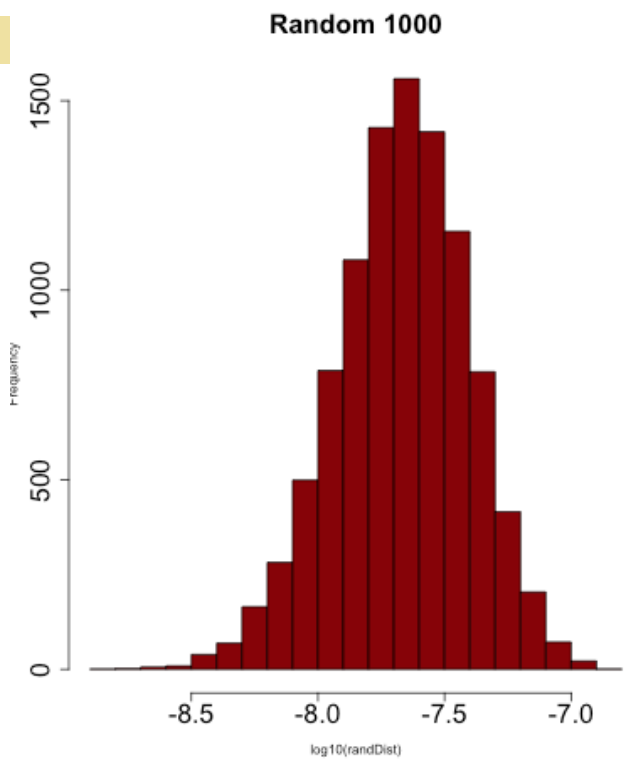
$$G = \tilde{g}(x,y) - \mu$$ → Subtract mean

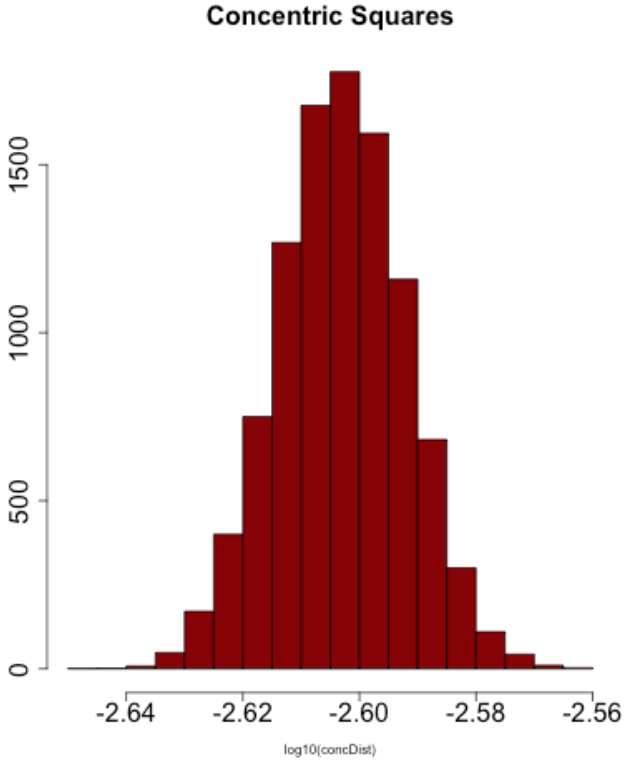
$$S_{\tilde{g}} = \frac{1}{(N-1)} GG^T$$ → Covariance matrix

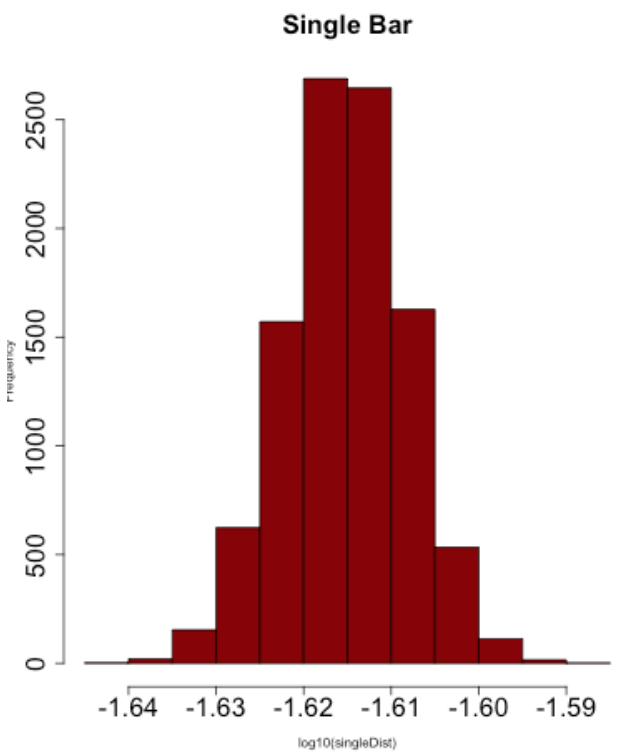
$$S_{\tilde{g}} = UDV$$ → Singular Value Decomposition

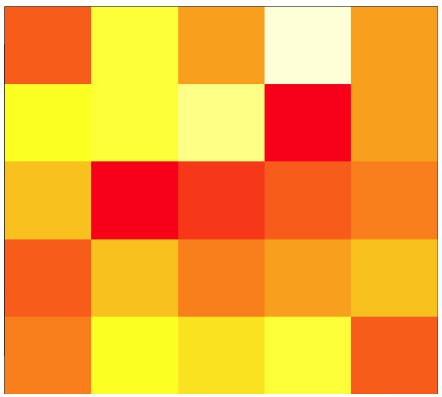
$$\sum^{N} \lambda^2 = \psi$$ → Sum of squared eigenvalues (diagonal of *D*)

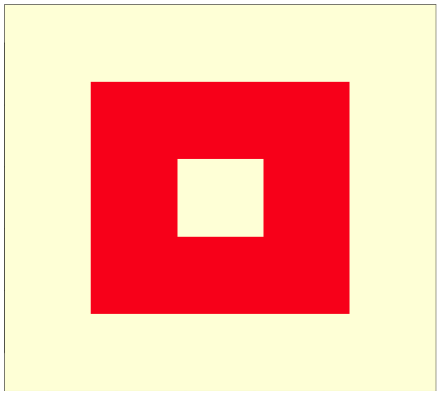
Sharpness & Structure Dependence

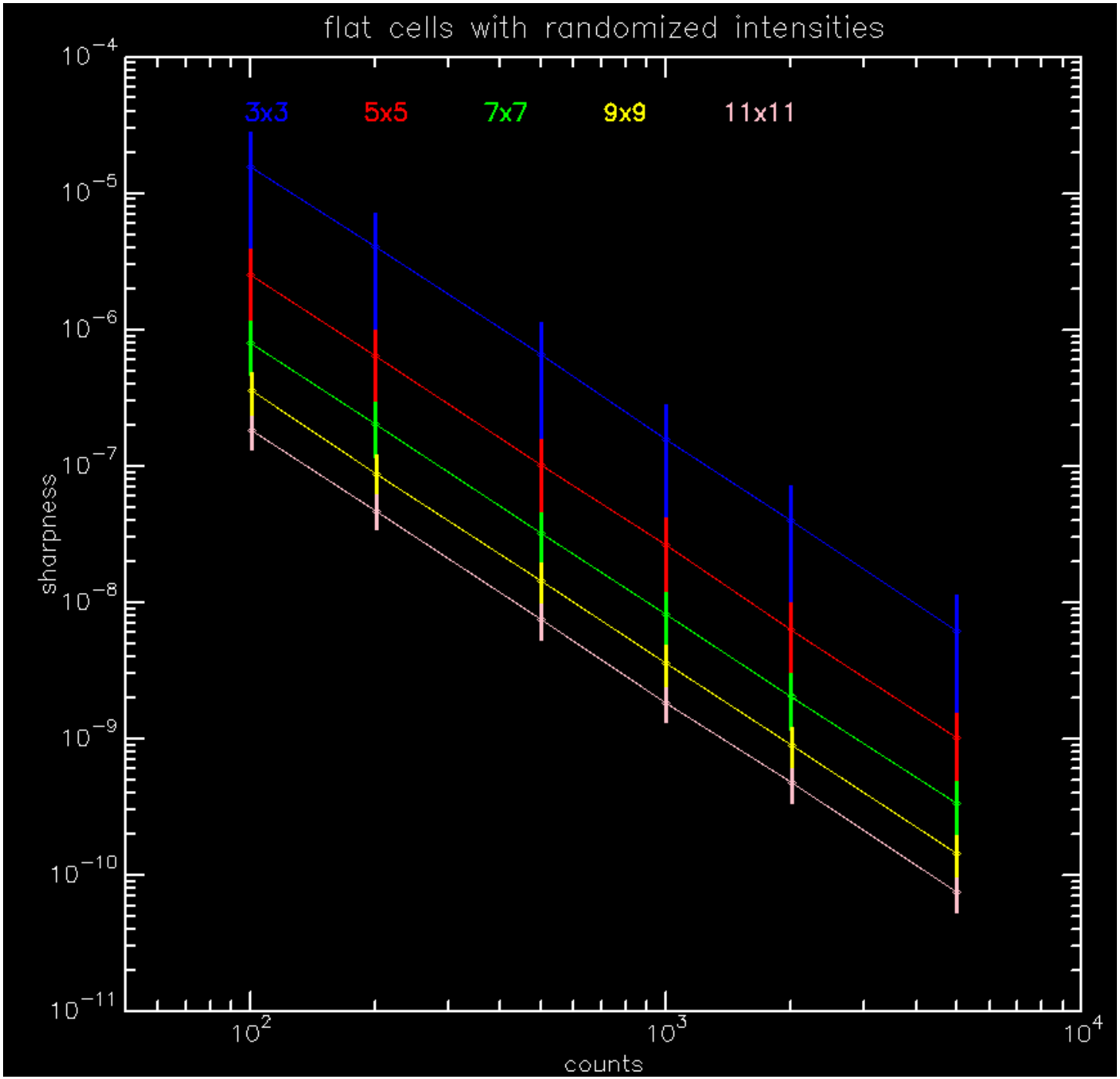






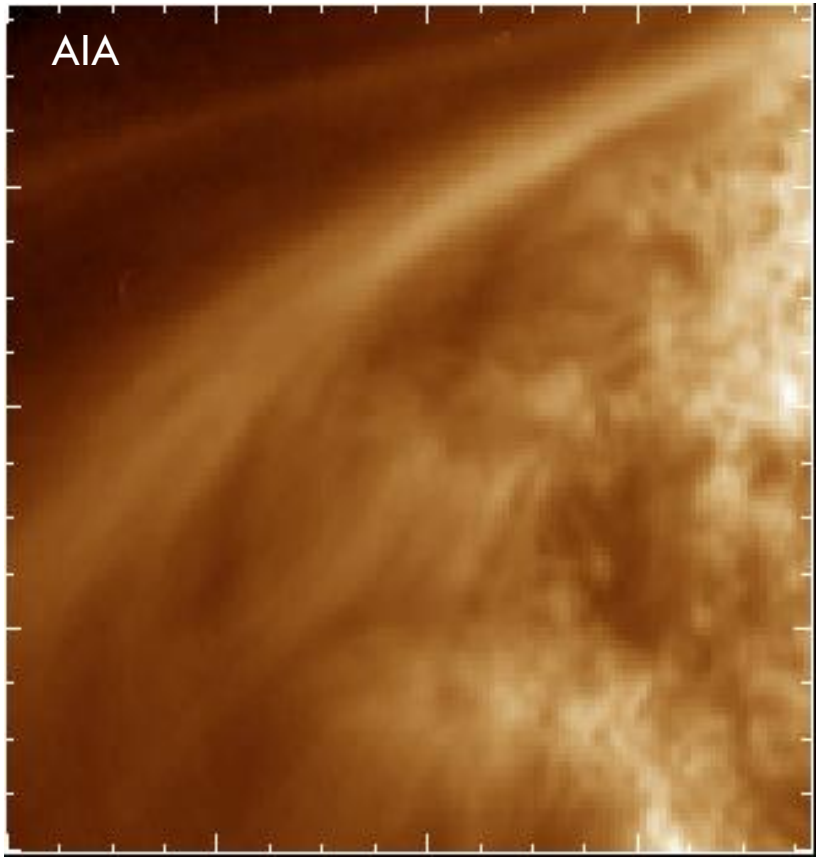


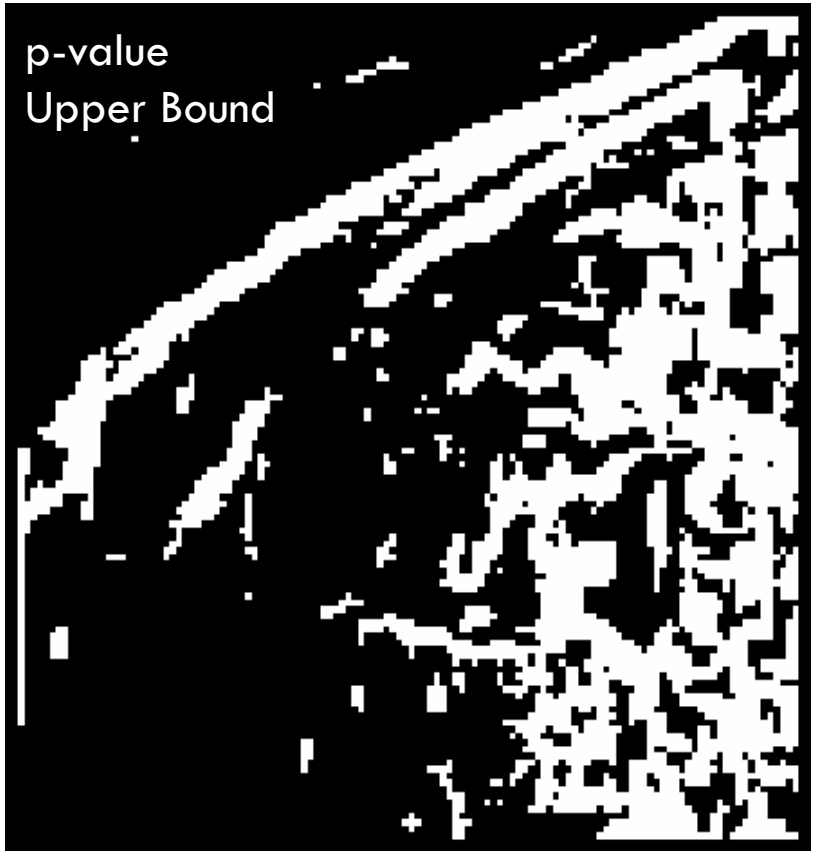



flat cells with randomized intensities
3x3
5x5
7x7
9x9
11x11
sharpness
counts
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{2}
10^{3}
10^{4}

Edge Detection

- Gradient steepest along edges → edge detection





Gradient Correction

$$\psi' = 10^{\log(\psi) - (a \times \log(\nabla g) - \bar{\nabla} g)}$$

$$\log(\psi) = a \times \log(\nabla g) + b$$