IMaX Observing Strategies

Optimizing the 2nd Flight

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Sunrise Co-I Meeting @ MPS

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Observing modes during 2009 flight

2009 Observing Modes

- Fe I 5250.208 Å line
- V5-6: $(-80, -40, +40, +80, +227)$ mÅ
- L12-2: 12 equidistant WL points from 5250.015 to 5250.400 Å
- L3-2, V3-6 $(60, +60, +227)$ mÅ

This Analysis

... will only deal with vector modes (full magnetic field information)
V5-6, V7-6 modes

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Analysis Methods 2009

Milne-Eddington

Height independent values for

- B, γ, χ
- v_{LOS}
- fit parameters: λ_{DOPP}, S_0, S_{GRAD}, η_0, a_{damp}.

$\Rightarrow$ 9 free parameters

SPINOR / SIR

- T-stratification (HSRA): T_0, T_{GRAD}
- B, γ, χ
- v_{LOS}, v_{mic}

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Number of measured data points in V5-6 mode:
4 (λ) $\times$ 4 (Stokes) + 1 continuum = 17

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Solar Conditions

2009 flight

- ”only” quiet Sun data sets
  - high photon flux
  - low polarization signal

Re-flight

- observations at all activity levels
- quiet Sun: known performance
- plage / penumbra / umbra:
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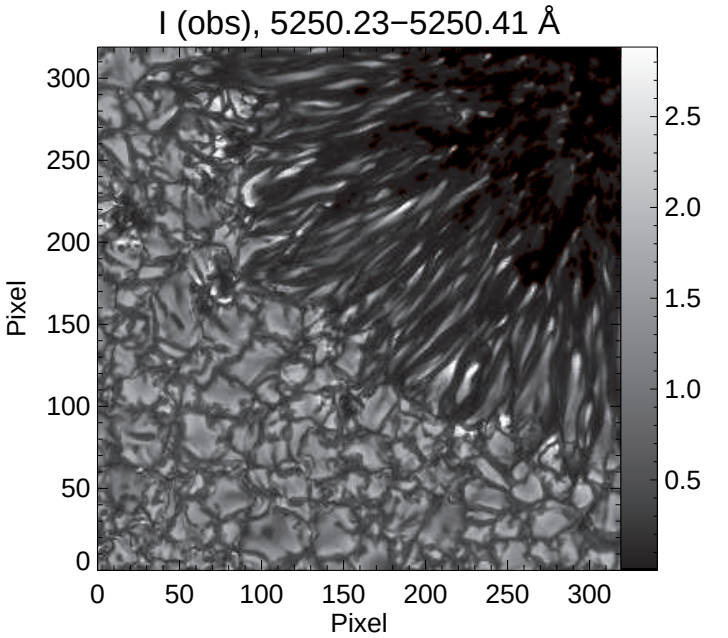
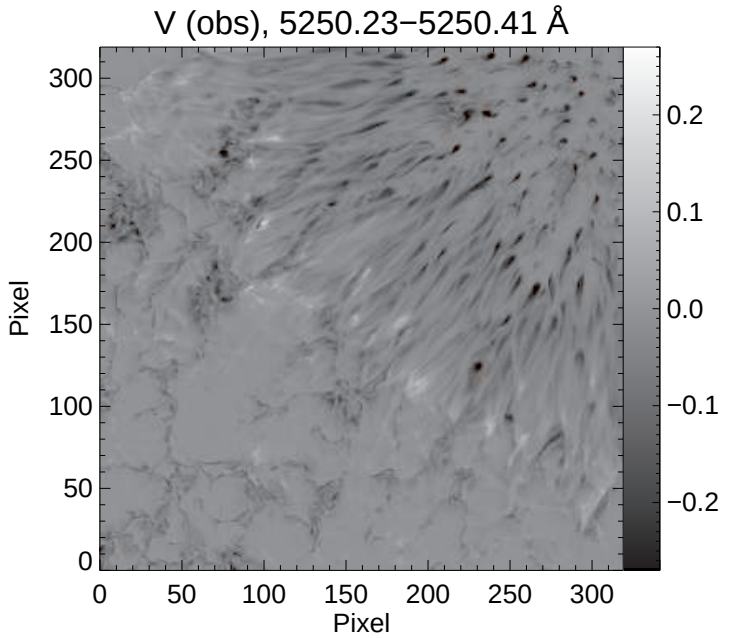
Motivation

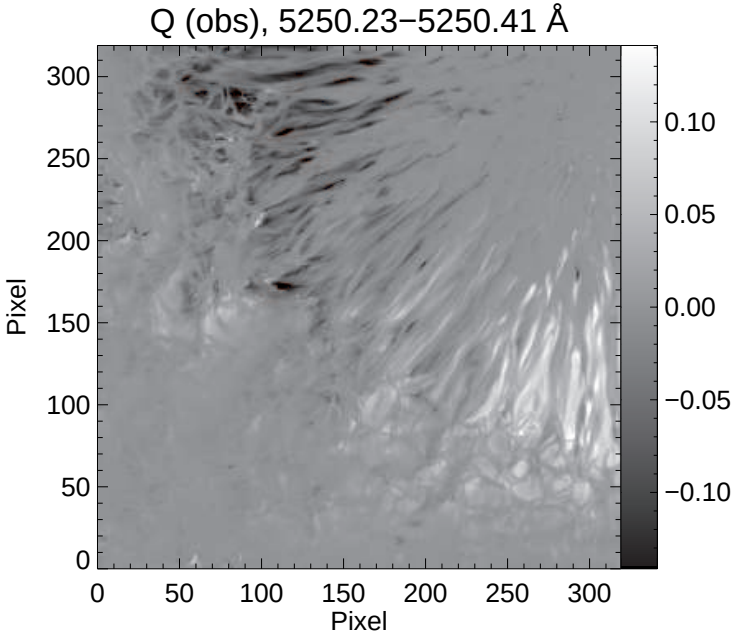
Is it possible to optimize IMaX observations?

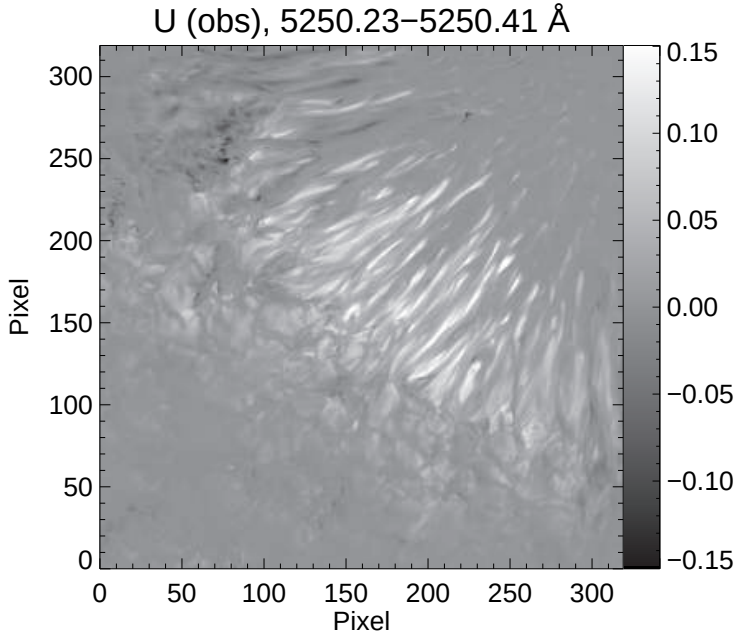
- Adapt observing modes to solar conditions
- Which spectral line (5250.2, 5250.6, both)?
- How many wavelength points?
- Beyond Milne-Eddington: reliable gradients?

MuRAM cube: 1/4 sunspot (M. Rempel / M. Schüssler)









MHD degradation

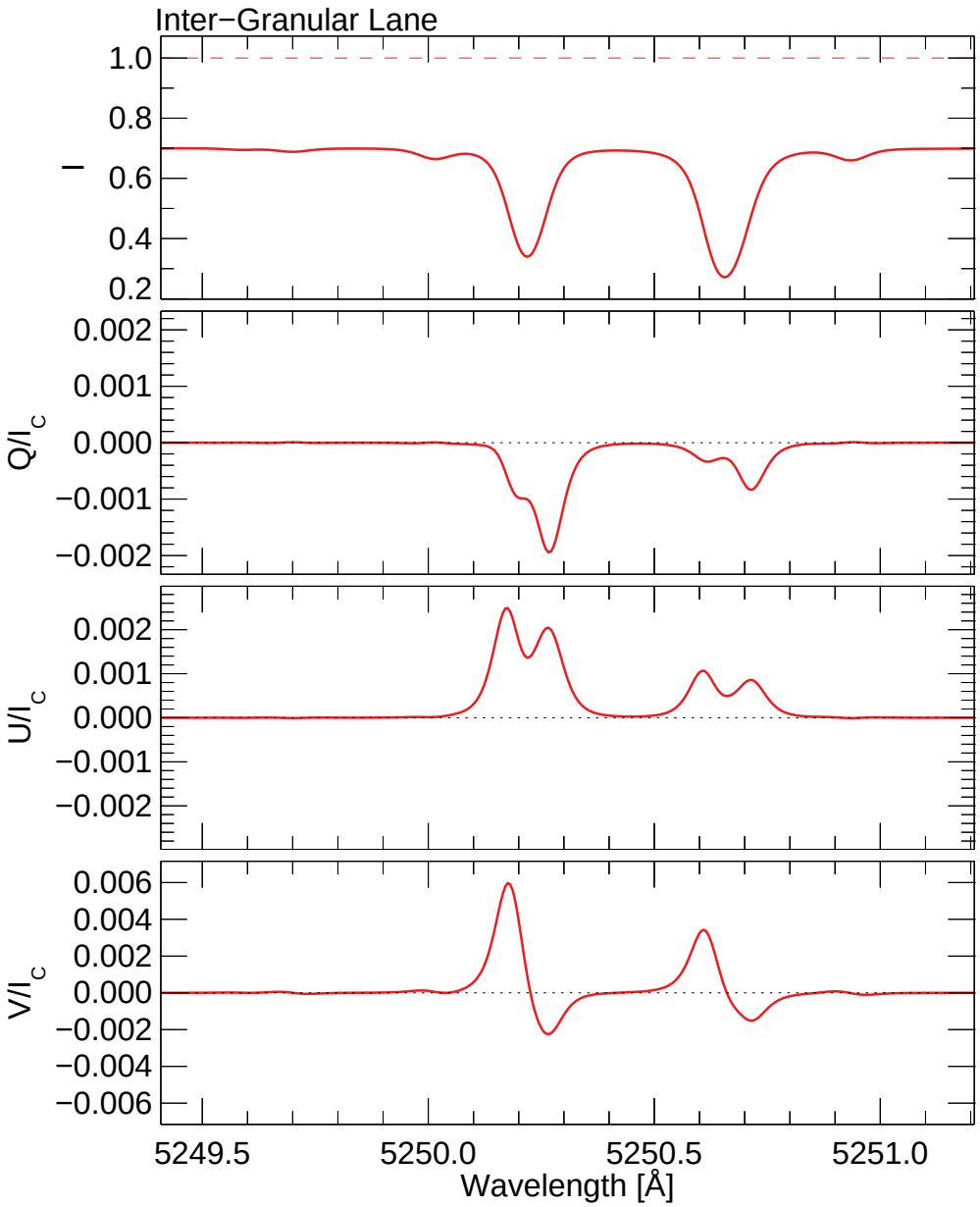
MHD original resolution: $32 \times 32 \times 16$ km^3

- binned to 64×64 km^2
- IMaX spectral PSF applied
- wavelength sampling:
  - continuous (100 WL points over V5-6 range)
  - simulating observing modes V5-6, V7-6
    V5-6: $(-80, -40, +40, +80, +227)$ mÅ
    V7-6: $(-140, -90, -40, +40, +90, +140, +227)$ mÅ
- noise added (normal distribution):
  levels $1 \cdot 10^{-4}$ (= noise-free) and $3 \cdot 10^{-3}$ of I_c
  $\Rightarrow$ increase of noise level in umbra
- disk center

The Spectra - Quiet Sun

Intergranular Lane

- degraded with IMaX spectral PSF
- 6 strongest lines around Fe I5250.2 Å
- good continuum
- weak Q,U,V signals



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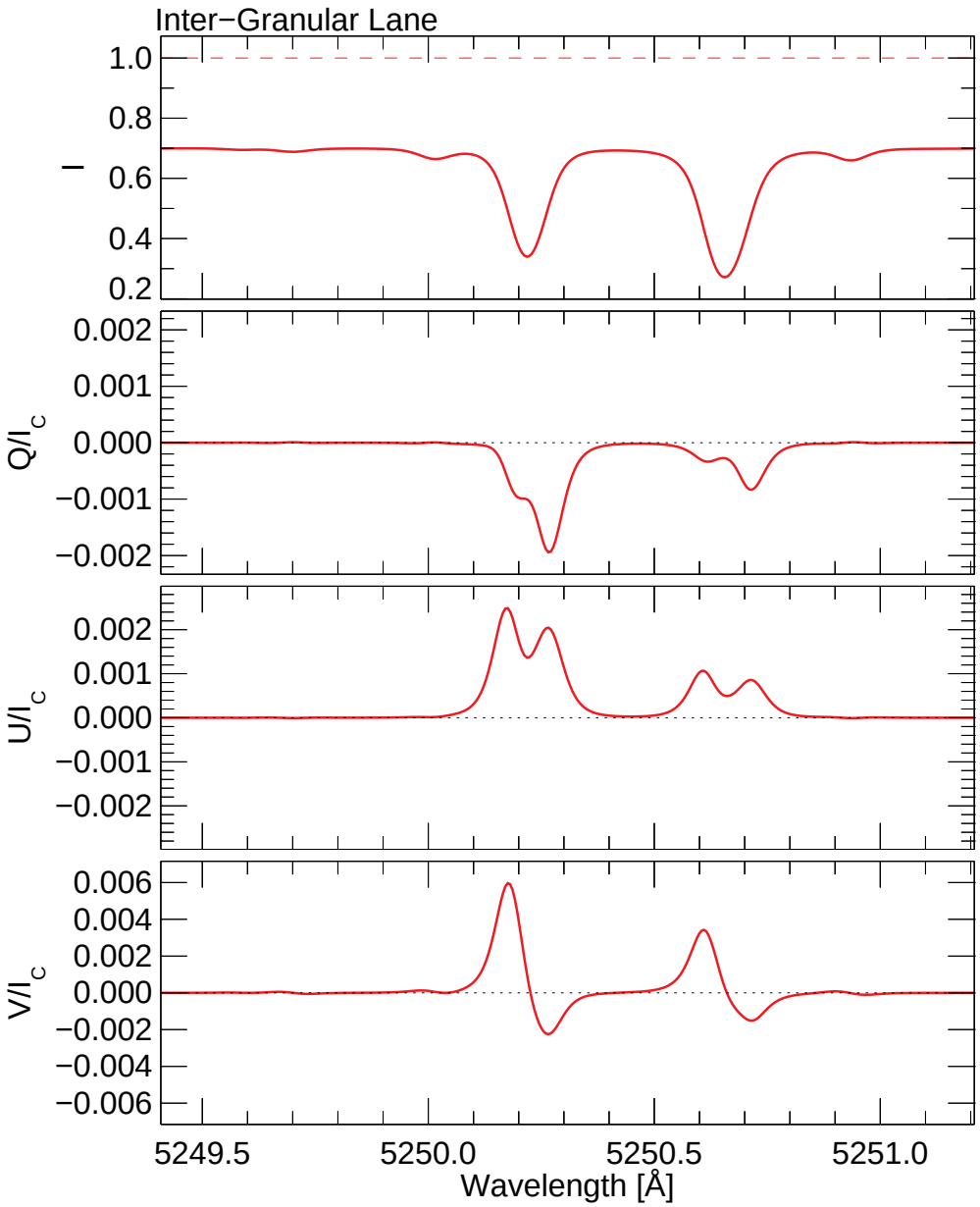

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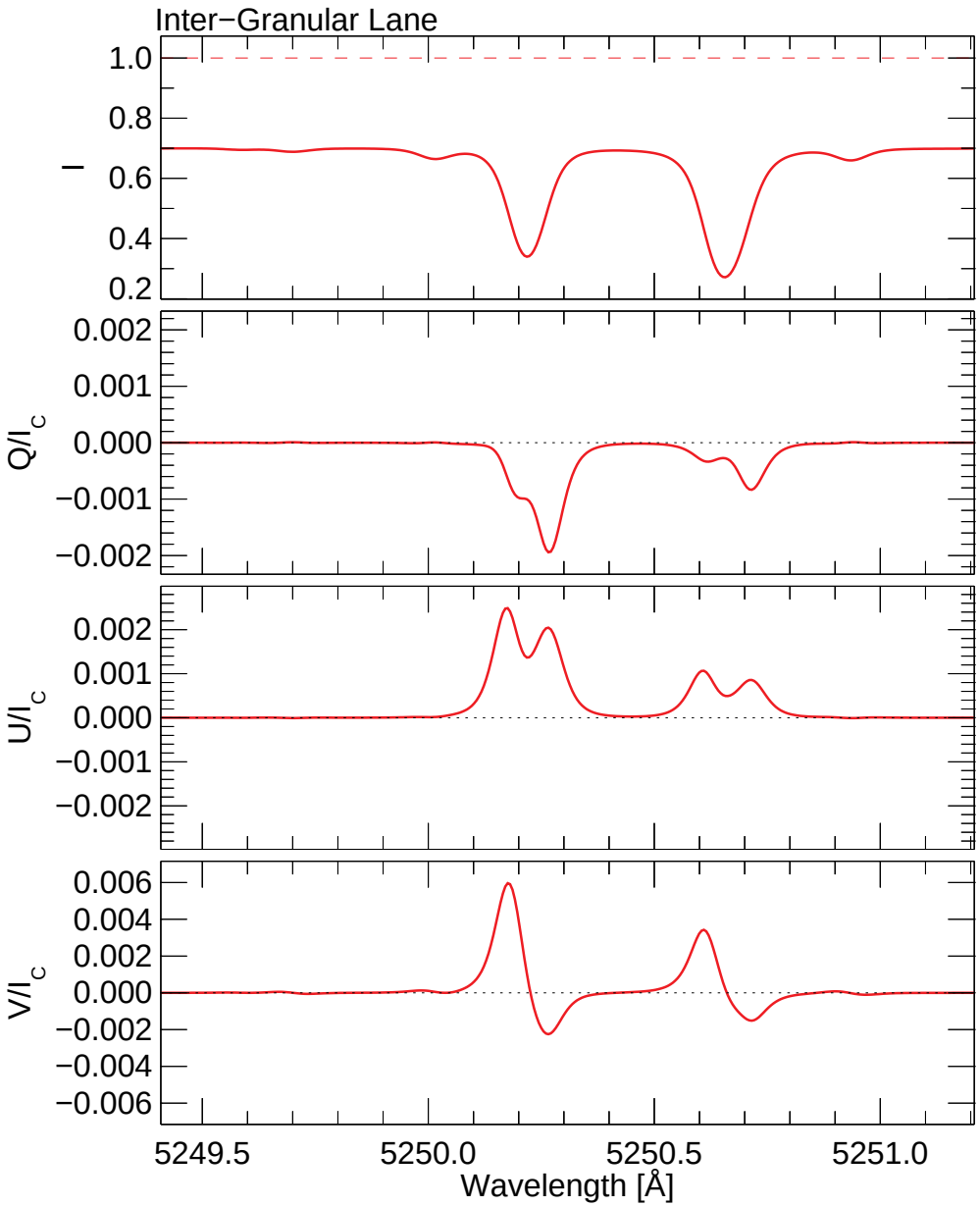

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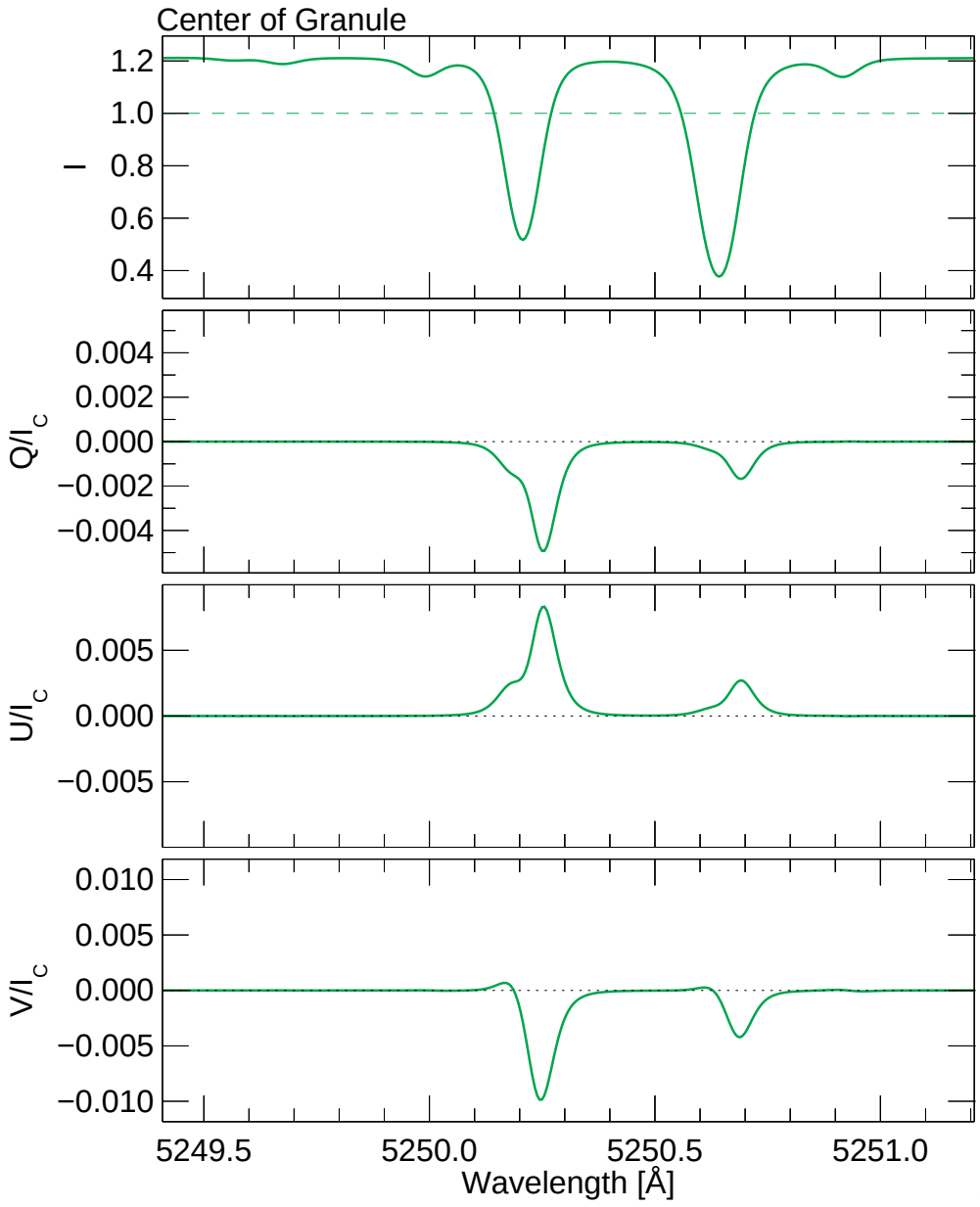

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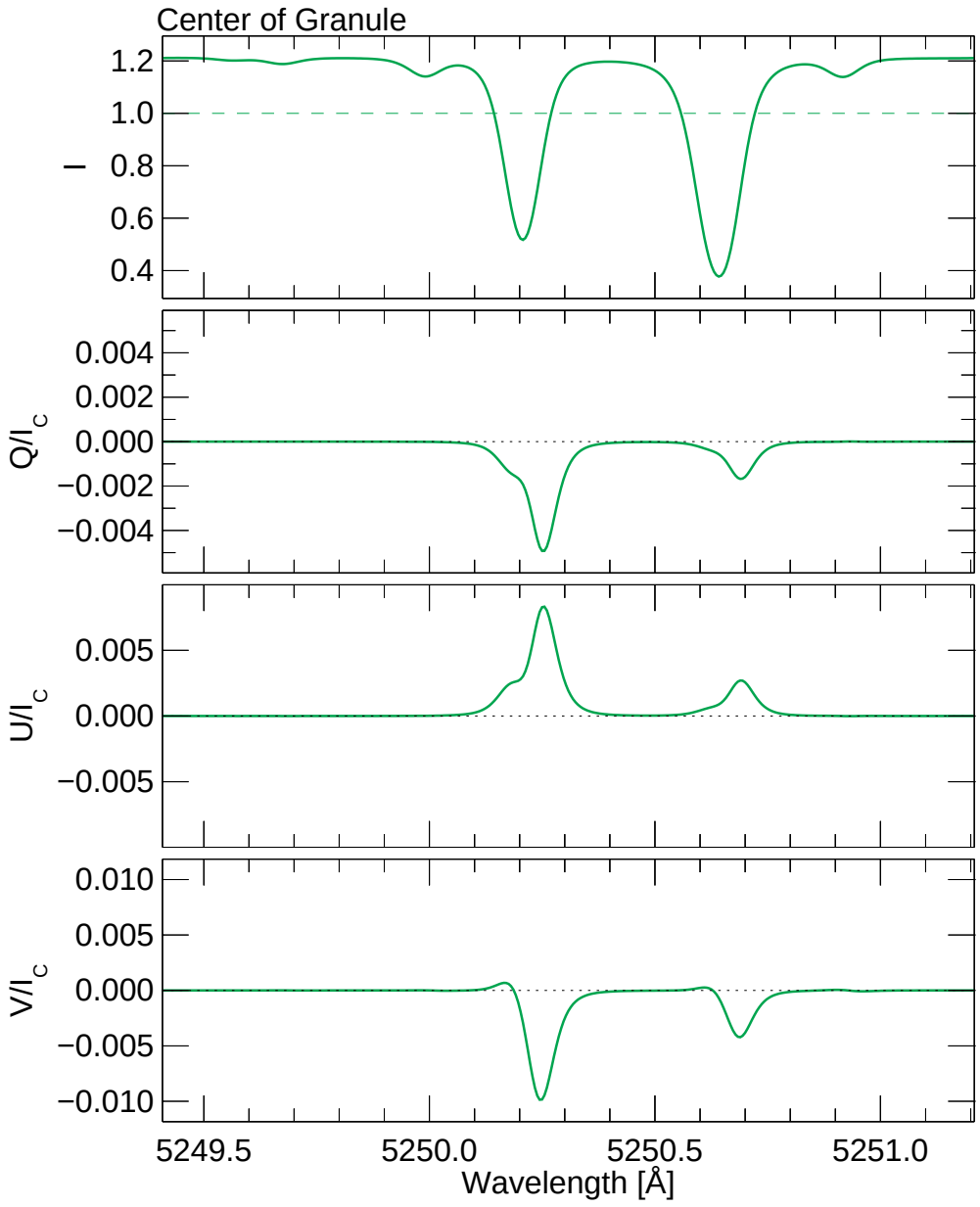

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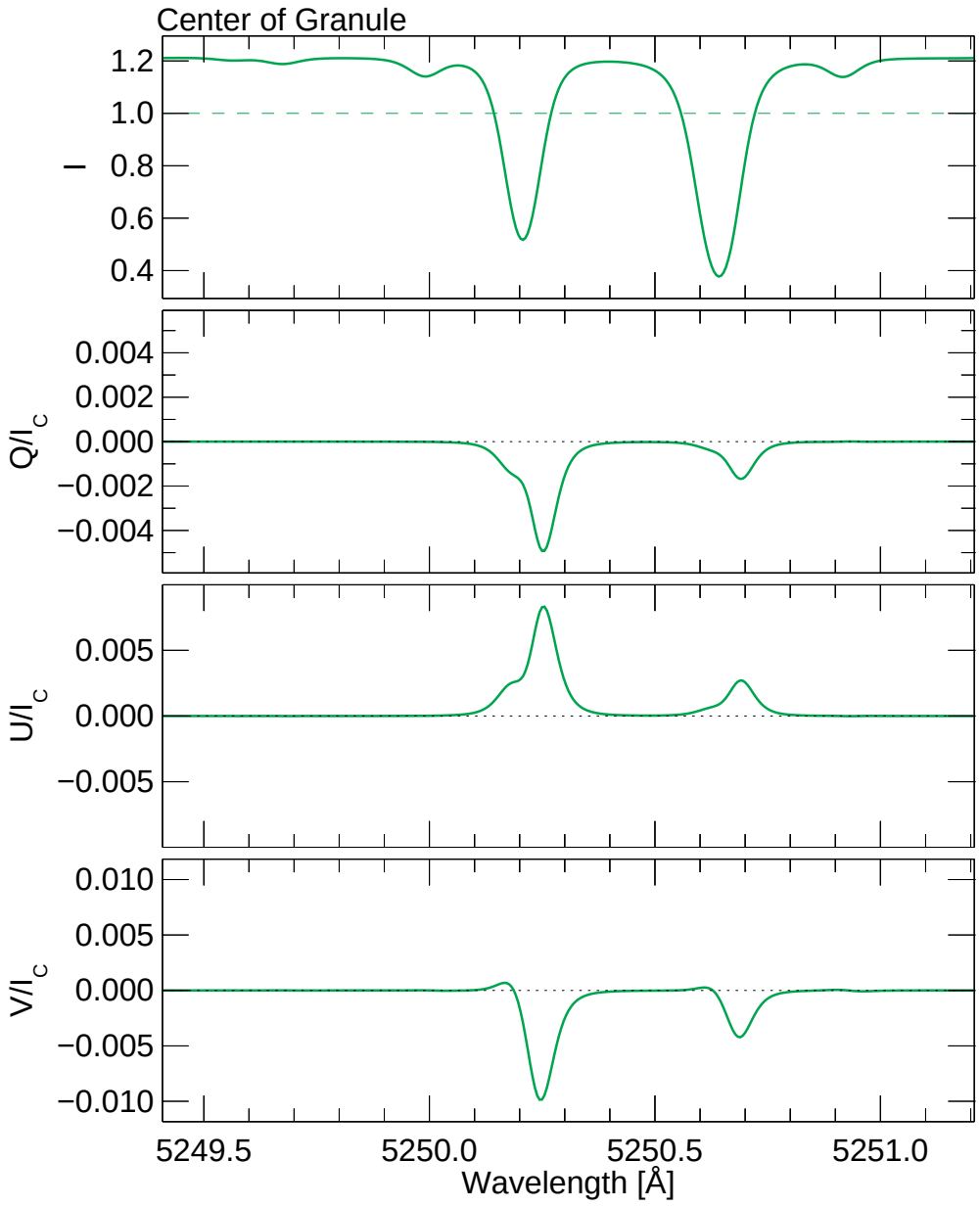

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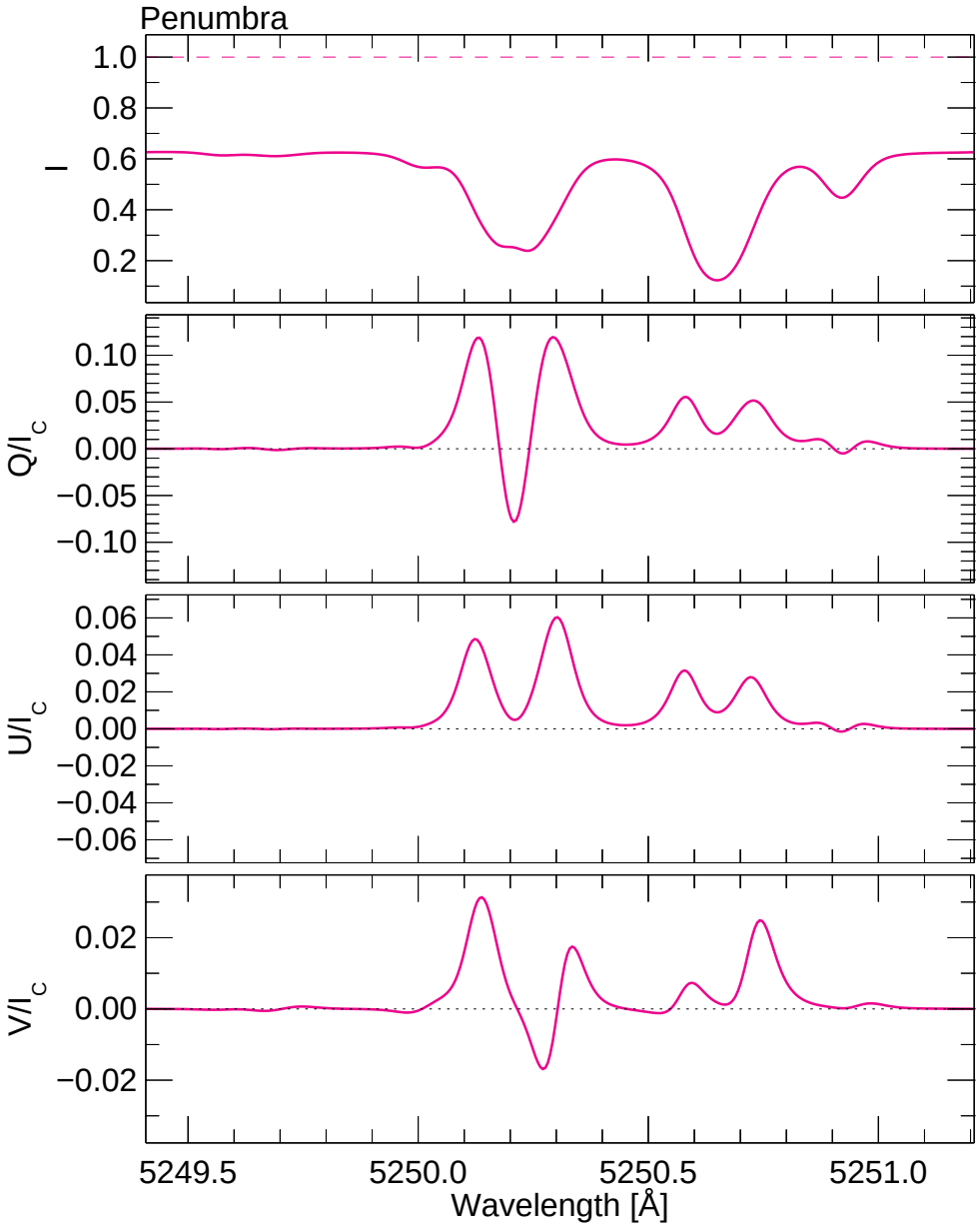
- fair continuum
- Q,U,V high
- asymmetries



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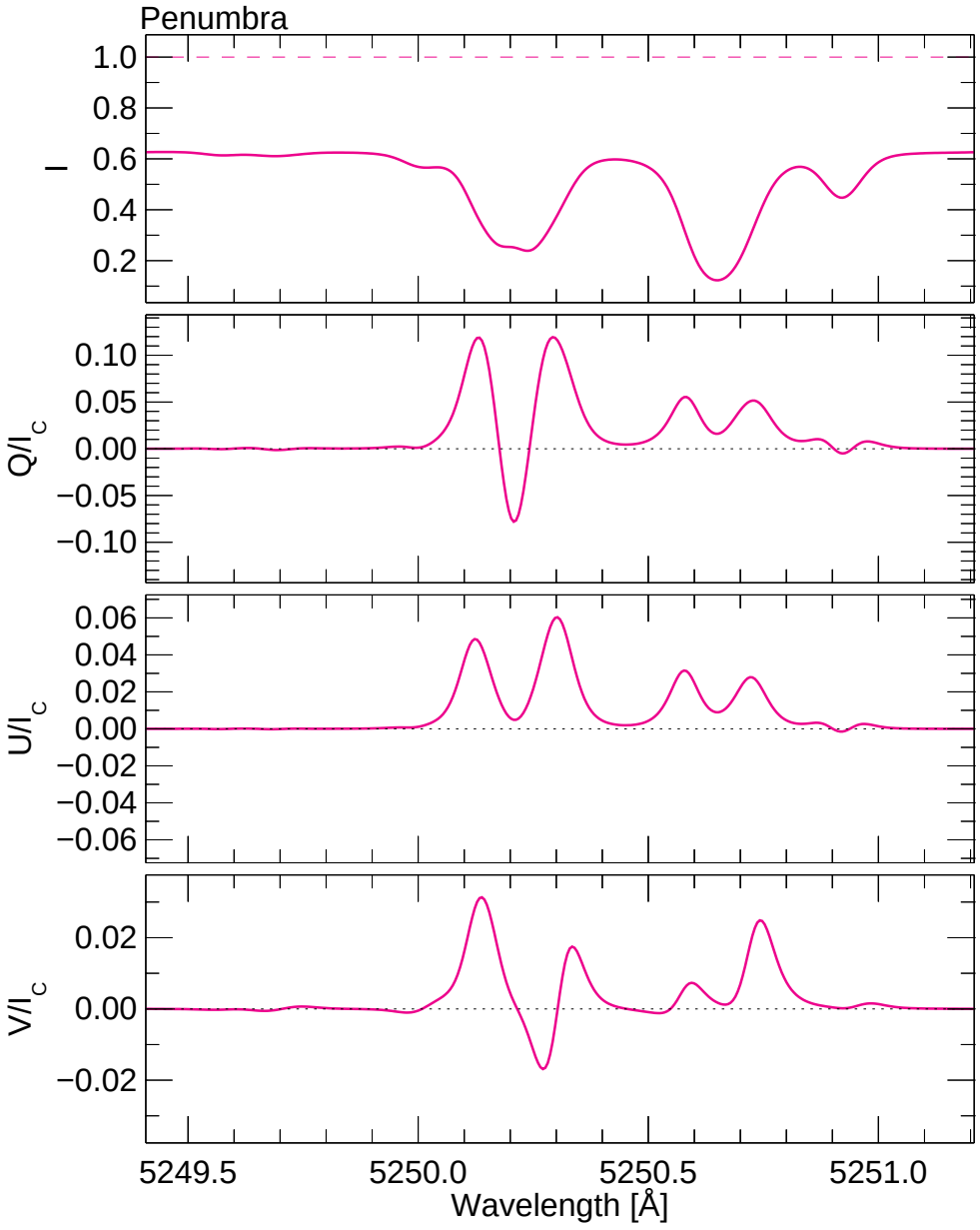

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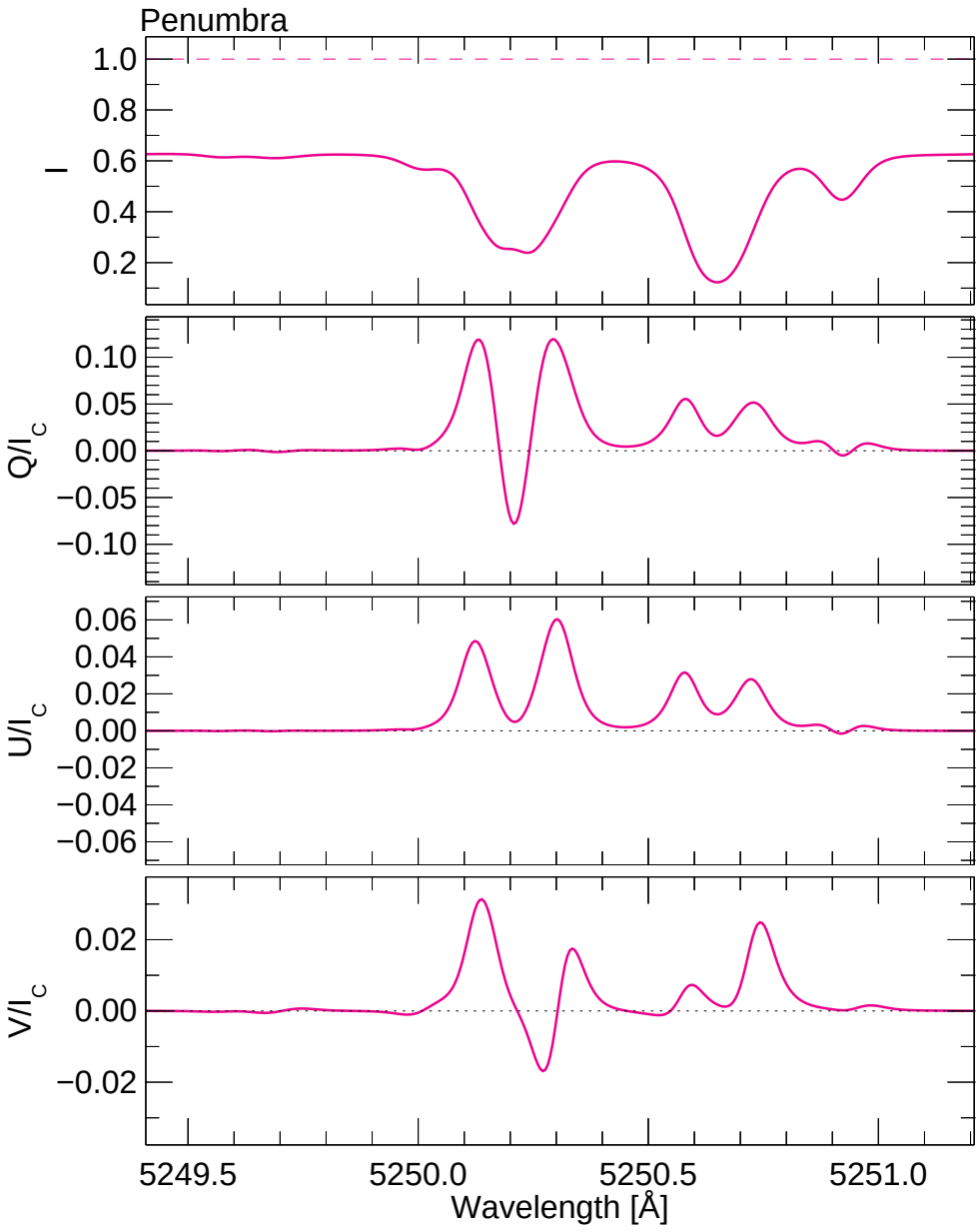

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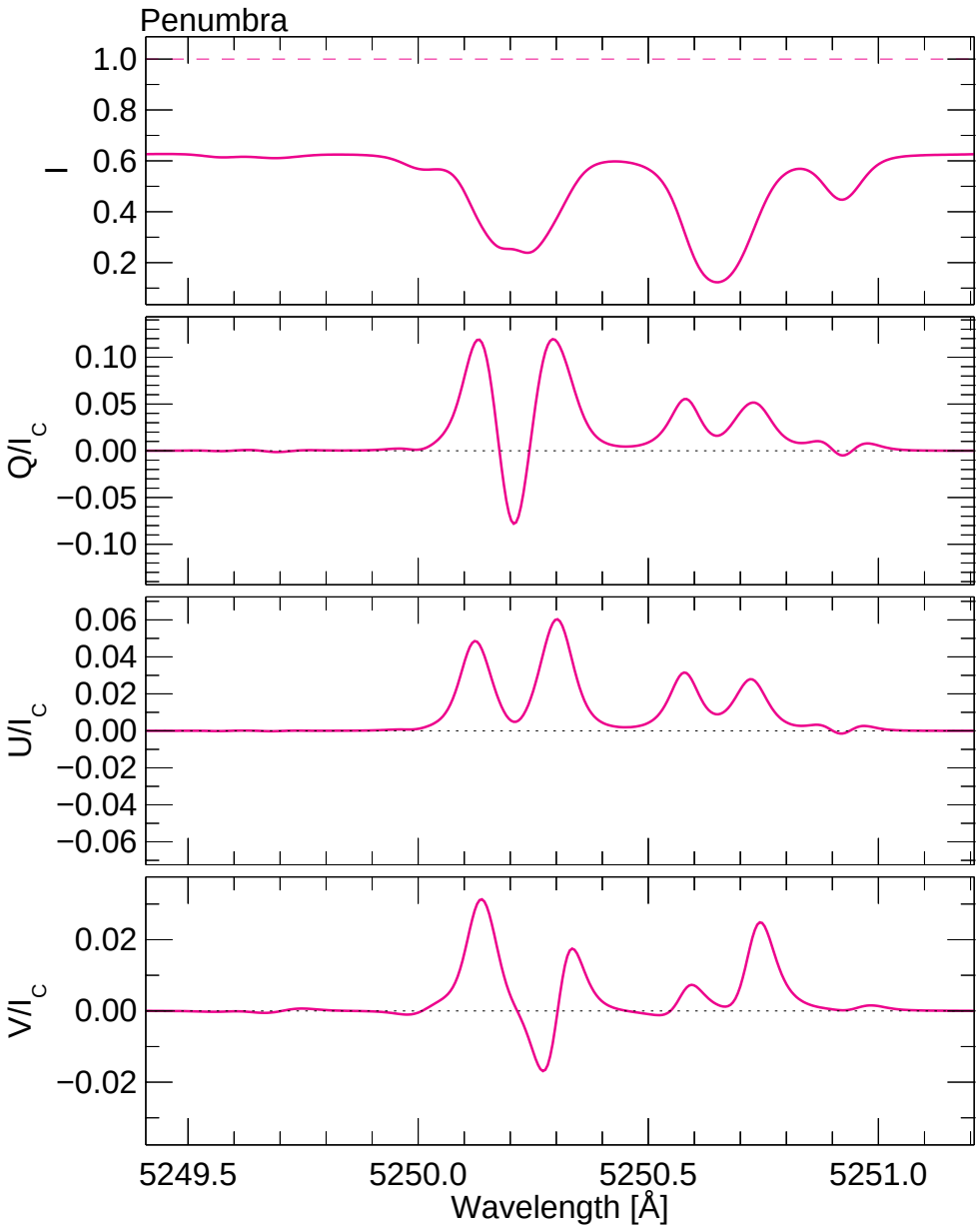

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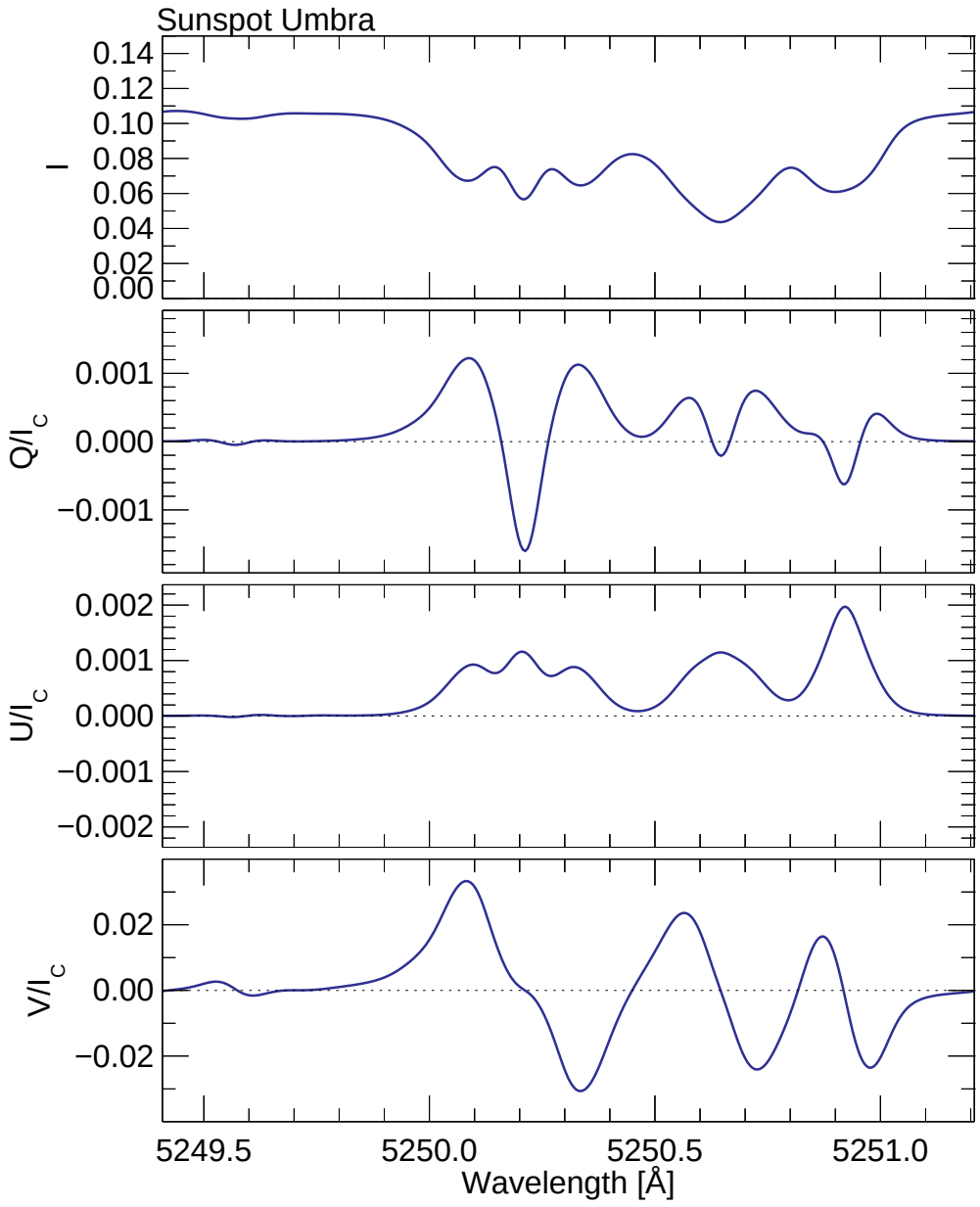
  $\Rightarrow$ noise level $\times 3$!!



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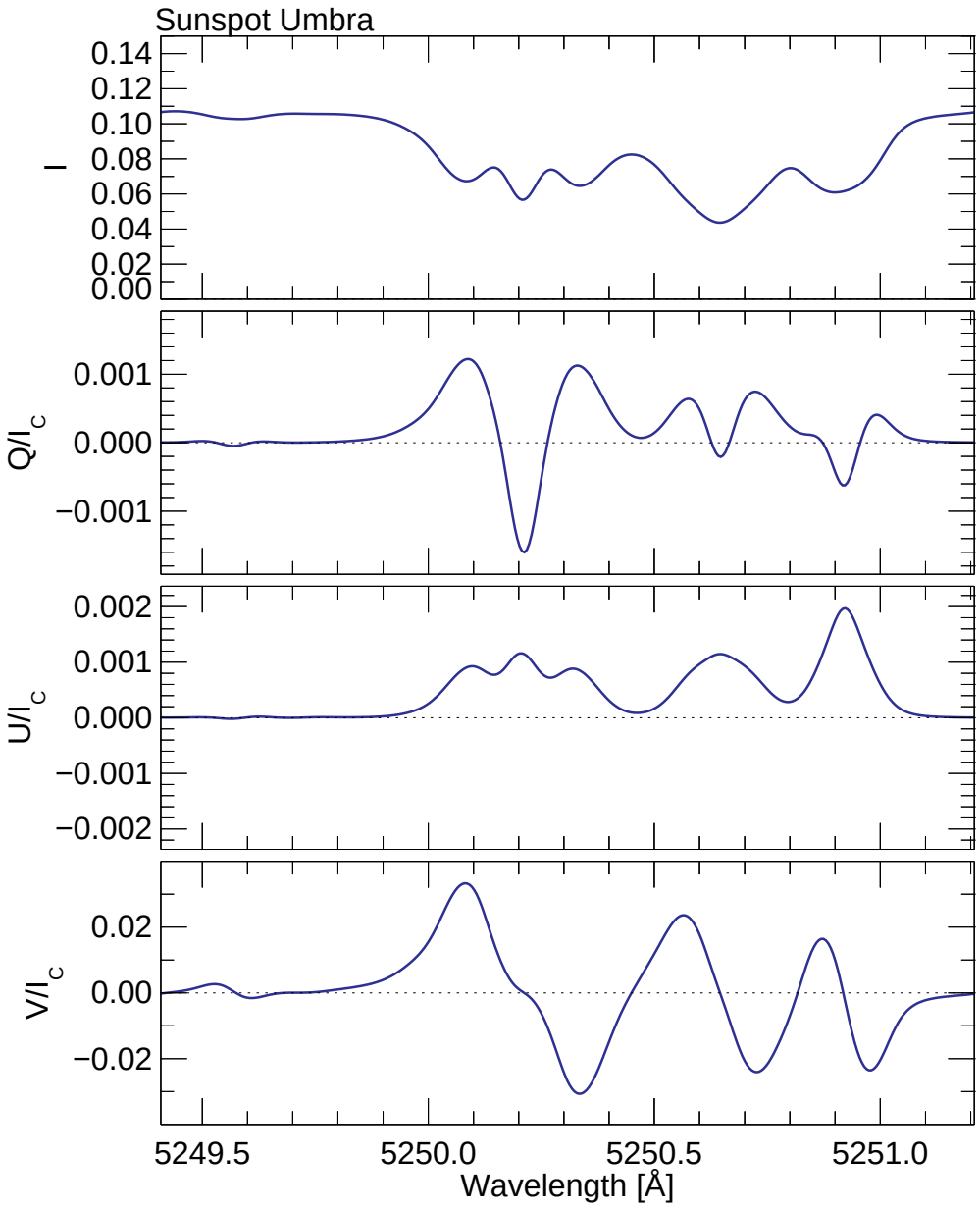

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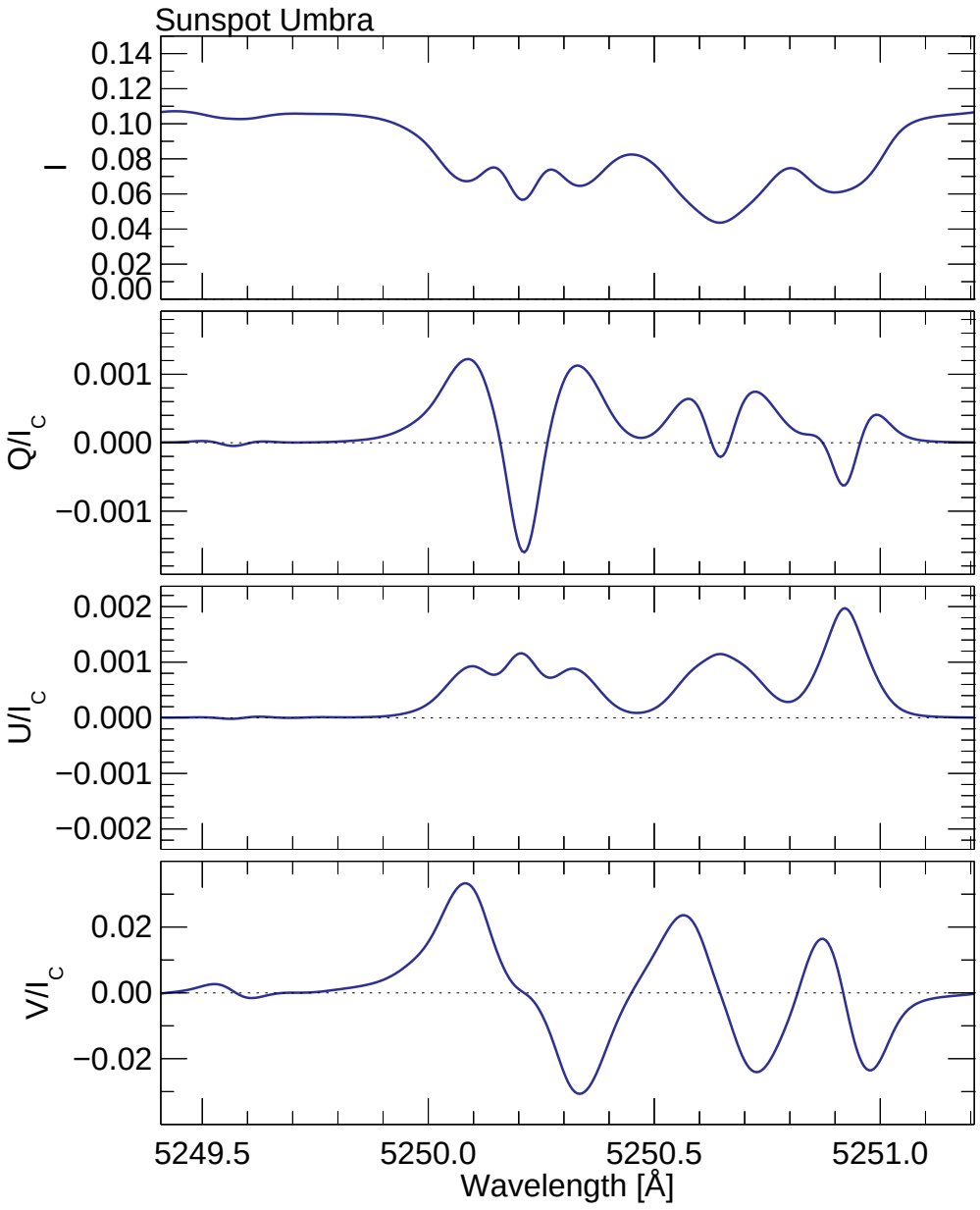

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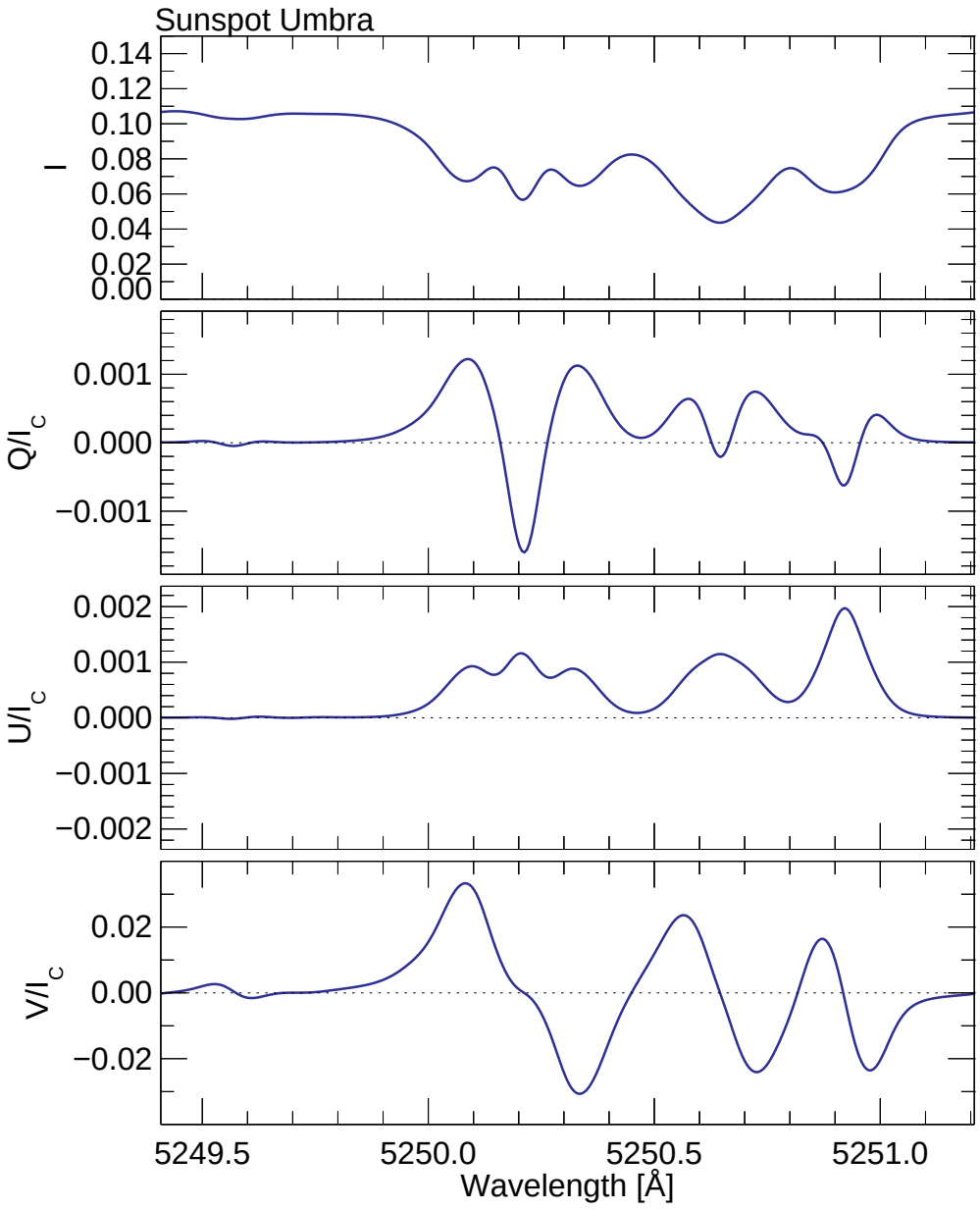
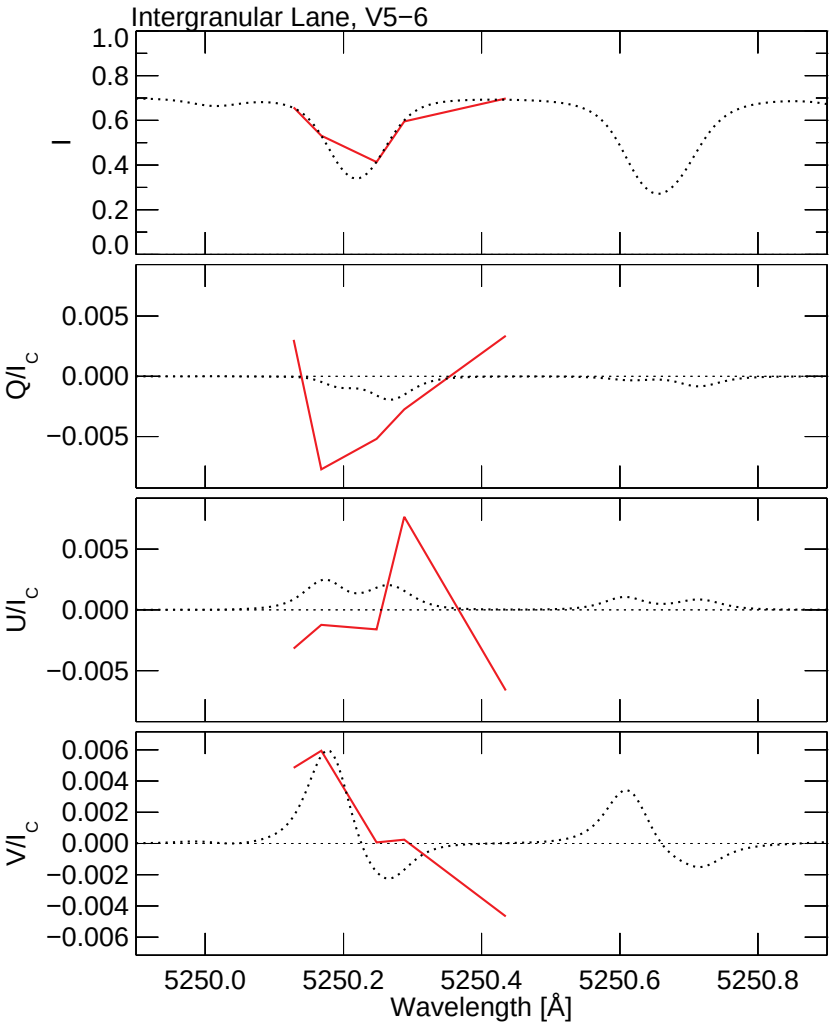
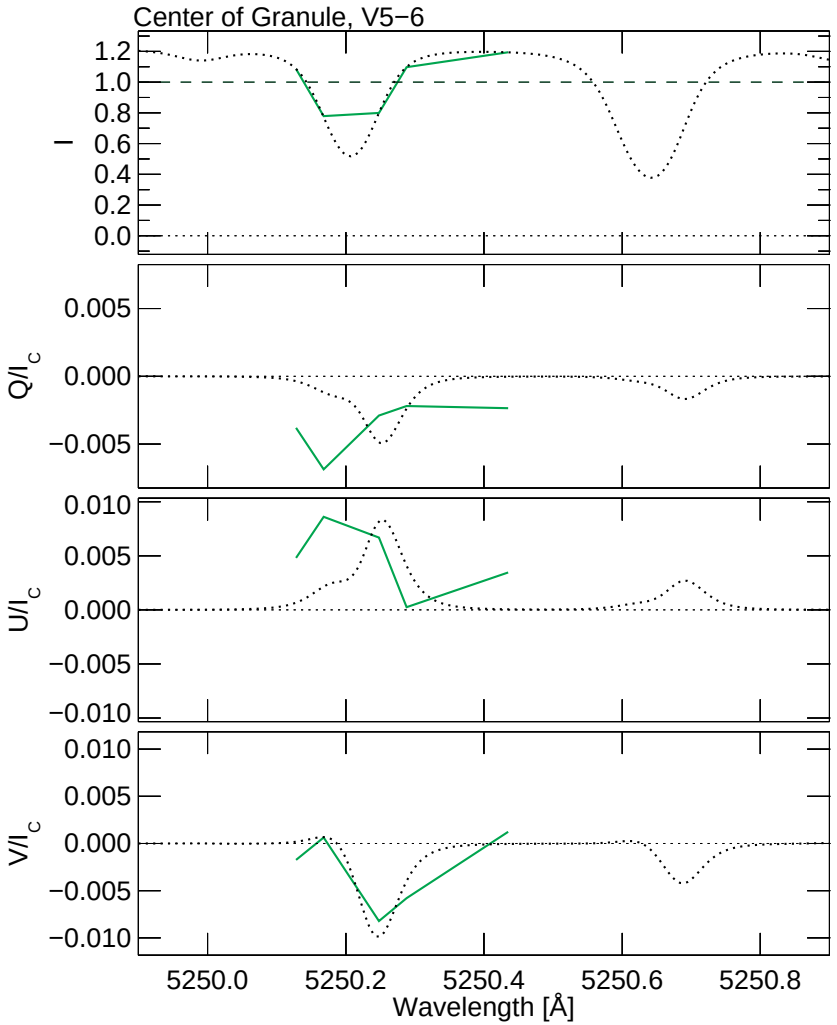


The Spectra - Quiet Sun, V5-6, noise $3 \cdot 10^{-3}$





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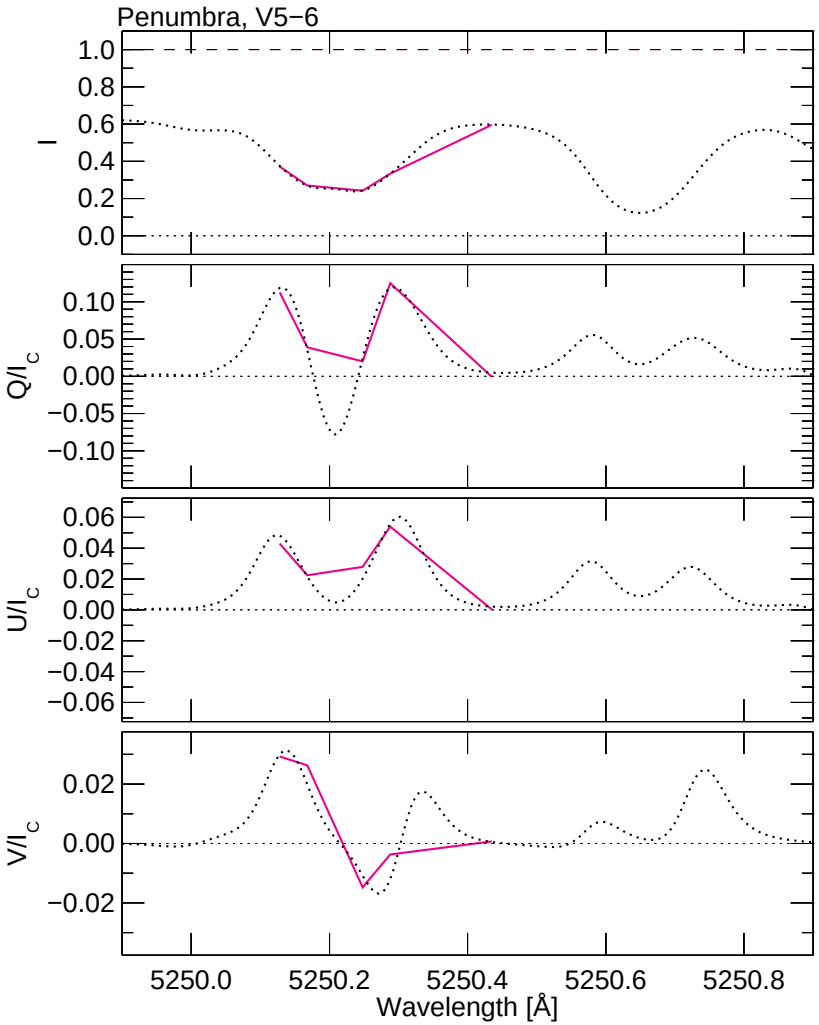
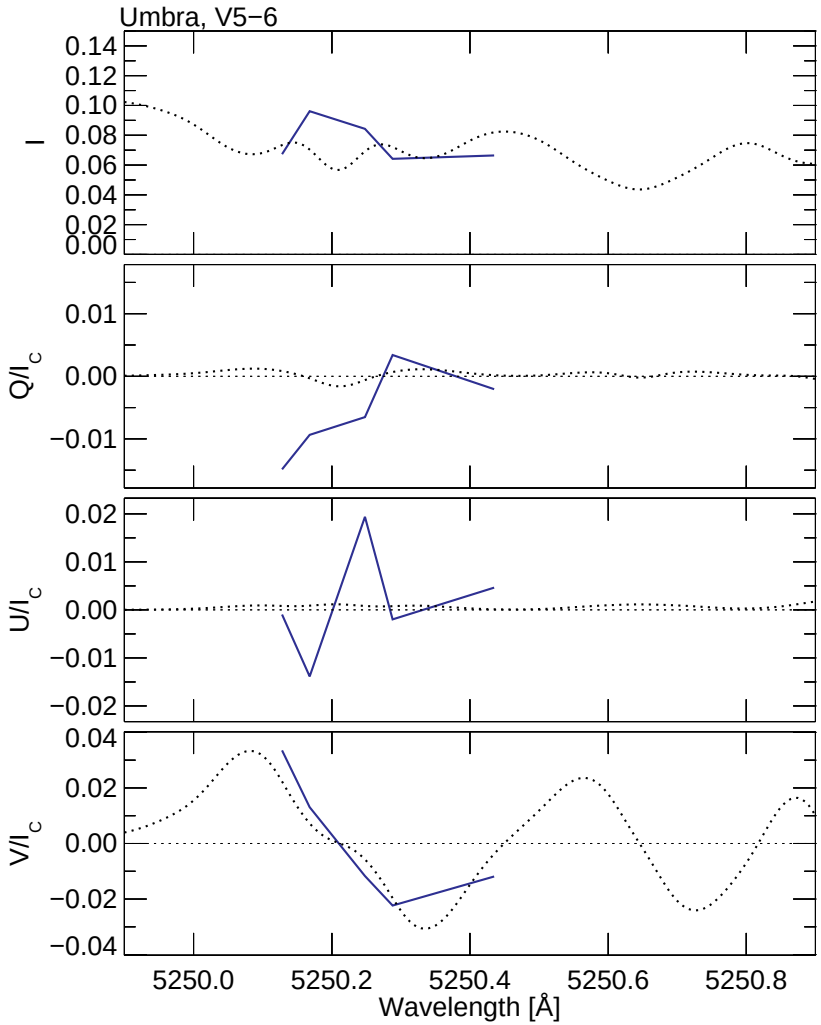
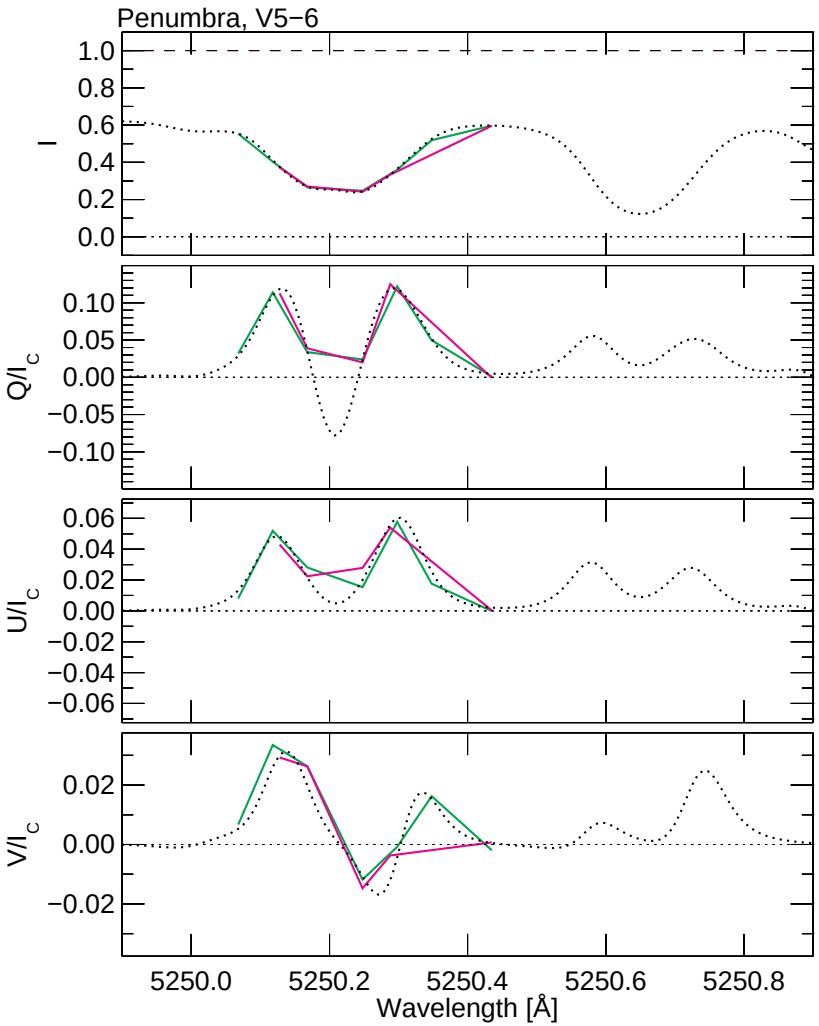
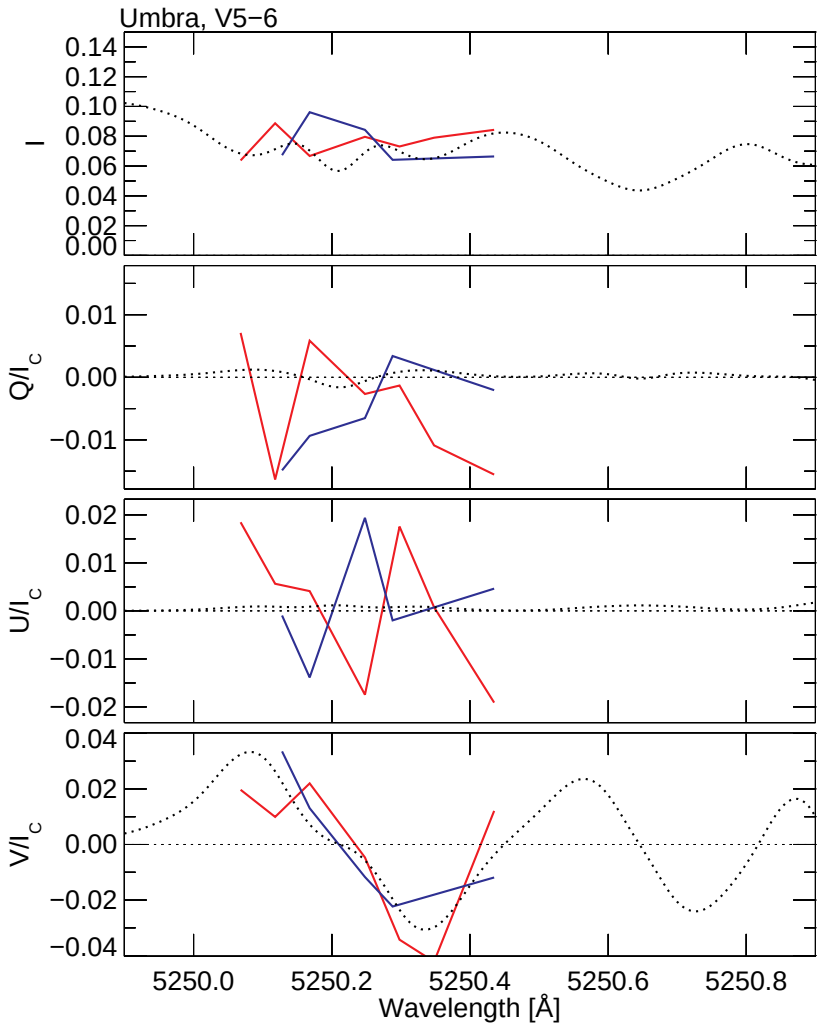




The Spectra - Sunspot, V7-6, noise $3 \cdot 10^{-3}$





The Spectra

Problems with spectra

- continuum level:
  in umbra no continuum between 5250.2 Å and 5250.6 Å
- significant contribution of 5250.6 Å line
- noise level:
  intensity in umbra reduced to $< 10\%$
  $\Rightarrow$ noise level 1% or larger!
- complex (*pathological*) profiles:
  difficult to interpret with noise and only 5 WL-points

Inversion Setup

1. Milne-Eddington
   Problem: Fe I 5250.6 Å line — OK - not shown
2. SPINOR/SIR with HSRA (and T_0, T_{GRAD}), 1 node — OK - not shown
3. SPINOR with 3 nodes in T, B, γ, χ, v_{LOS}, and 1 v_{mic} — this analysis

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How to compare MHD and Inversions?

Determine height layer for comparison

1. Compute RFs
   - for every pixel and every parameter
   - use RF to compute height average of MHD cube for every pixel

   $\Rightarrow$ not (yet) implemented.
2. Use temperature stratification
   - perform 3-node inversion of noise-free data
   - Find location where $T_{\mathrm{MHD}}(z) = T_{\mathrm{inv}}(\tau)$
   - Take $\pm$50 km around this location

   $\Rightarrow$ simple, fast

   (!) same height layer for all atmospheric parameters

   (!) temperature comparison MHD - inversion not useful

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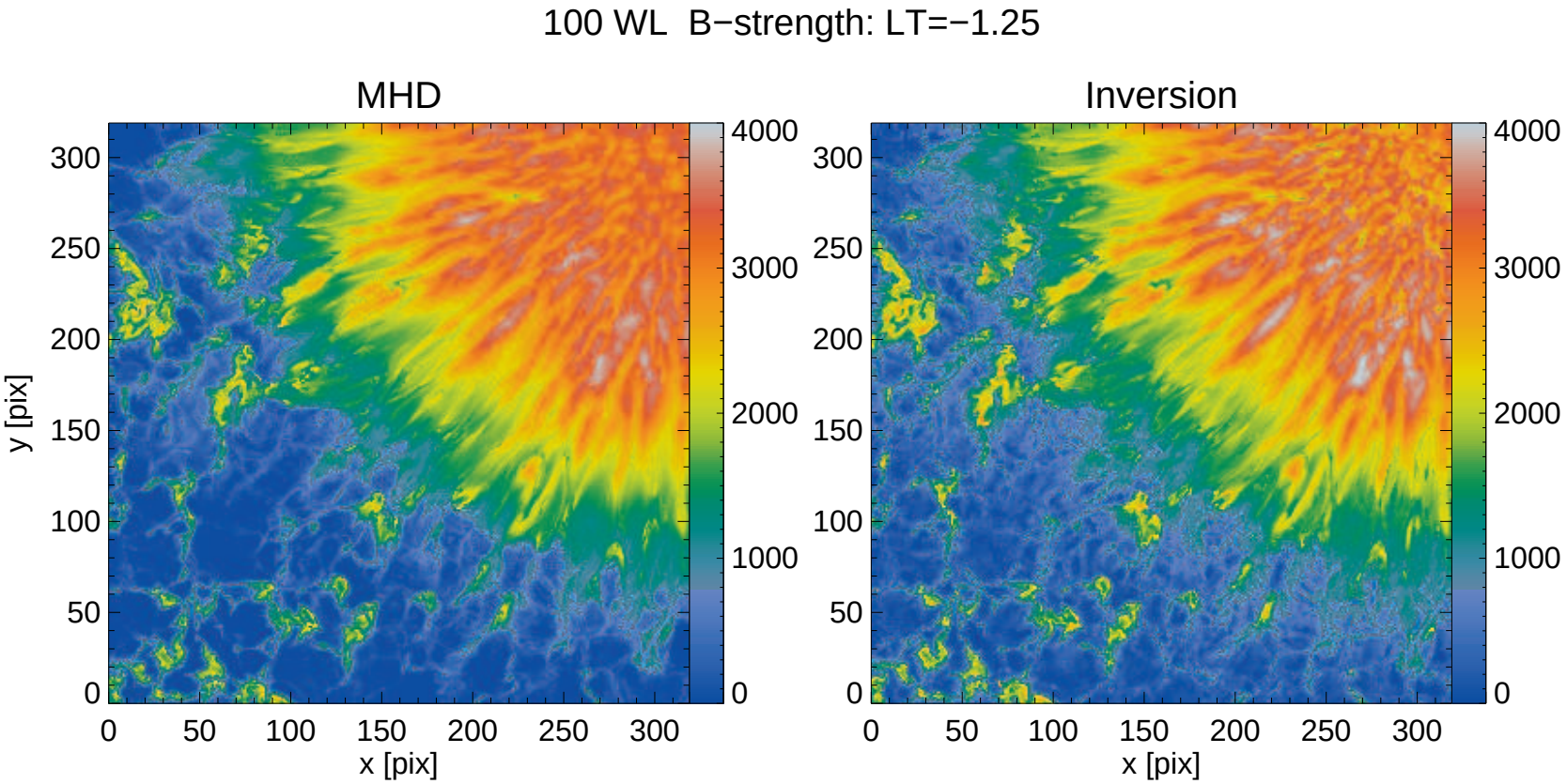
Qualitative Comparison

Next Slides:

- magnetic field strength
- height layer: $\log \tau = -1.25$

$\Rightarrow$ *best* layer

B-Field: $\log \tau = -1.25$ 100 WL points

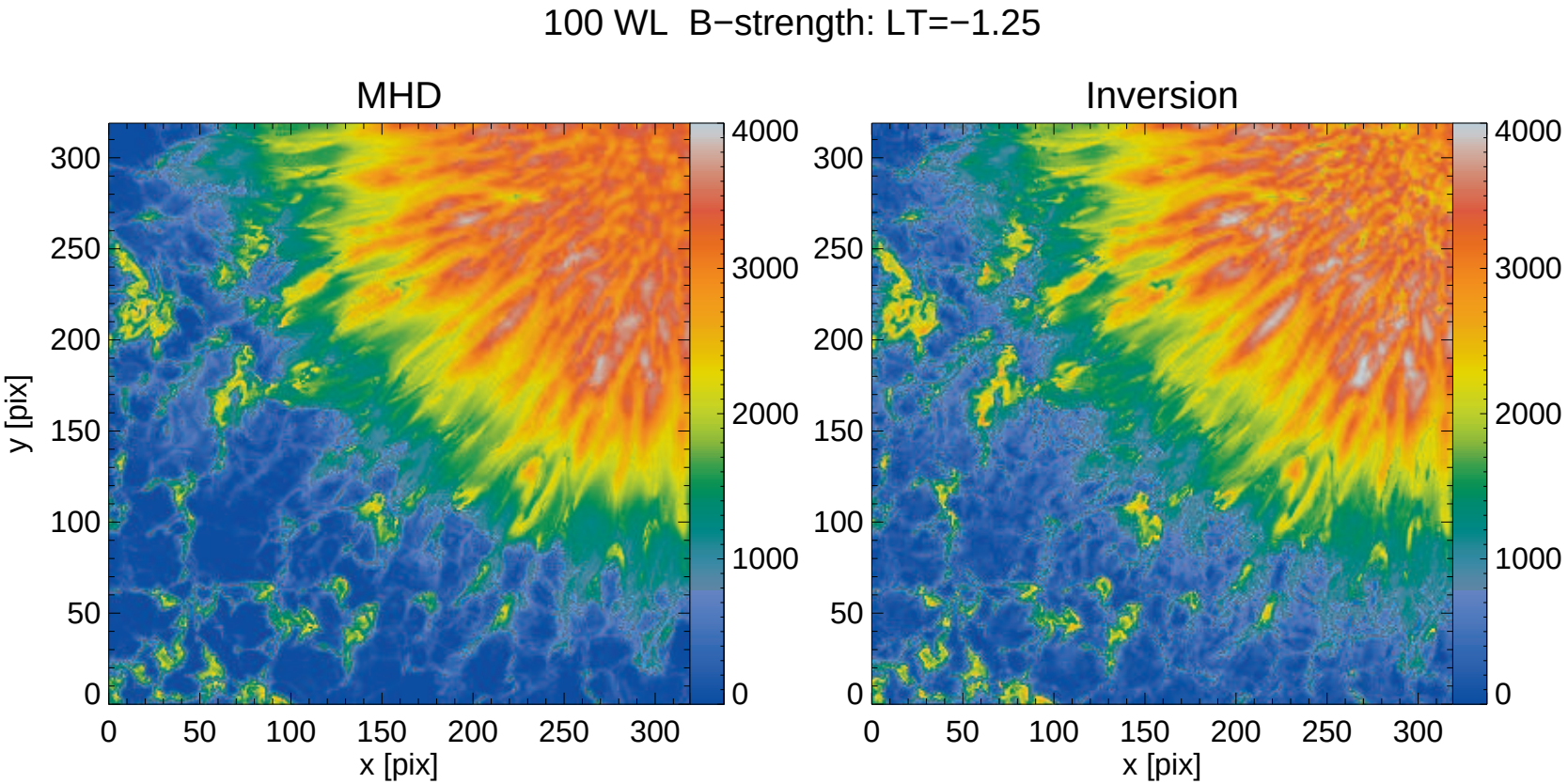


Inversion Setup

no noise, 100 WL points from -80 mÅ to +227 mÅ

slightly too weak in umbra, slightly too strong in QS

B-Field: $\log \tau = -1.25$ 100 WL points



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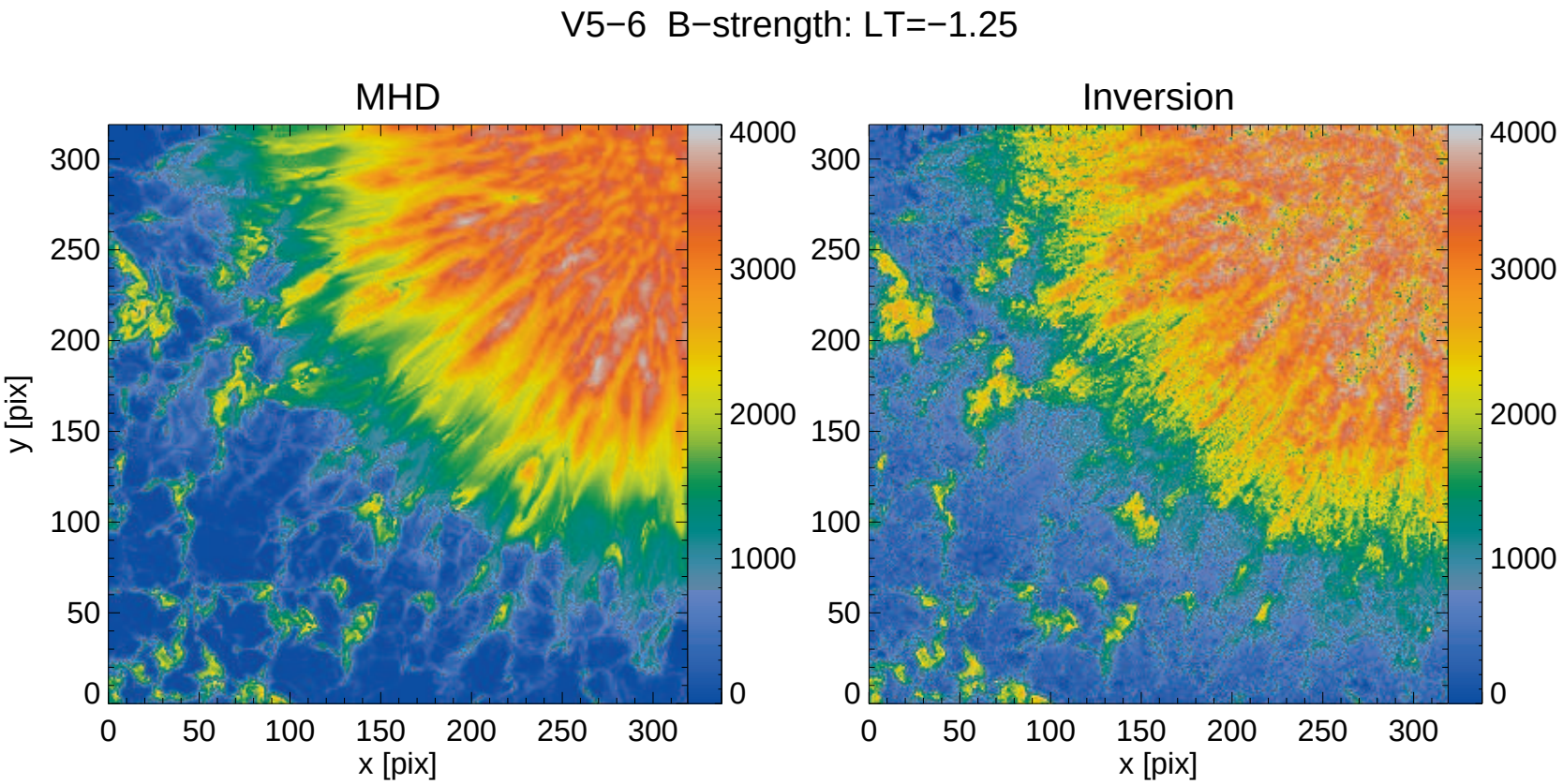
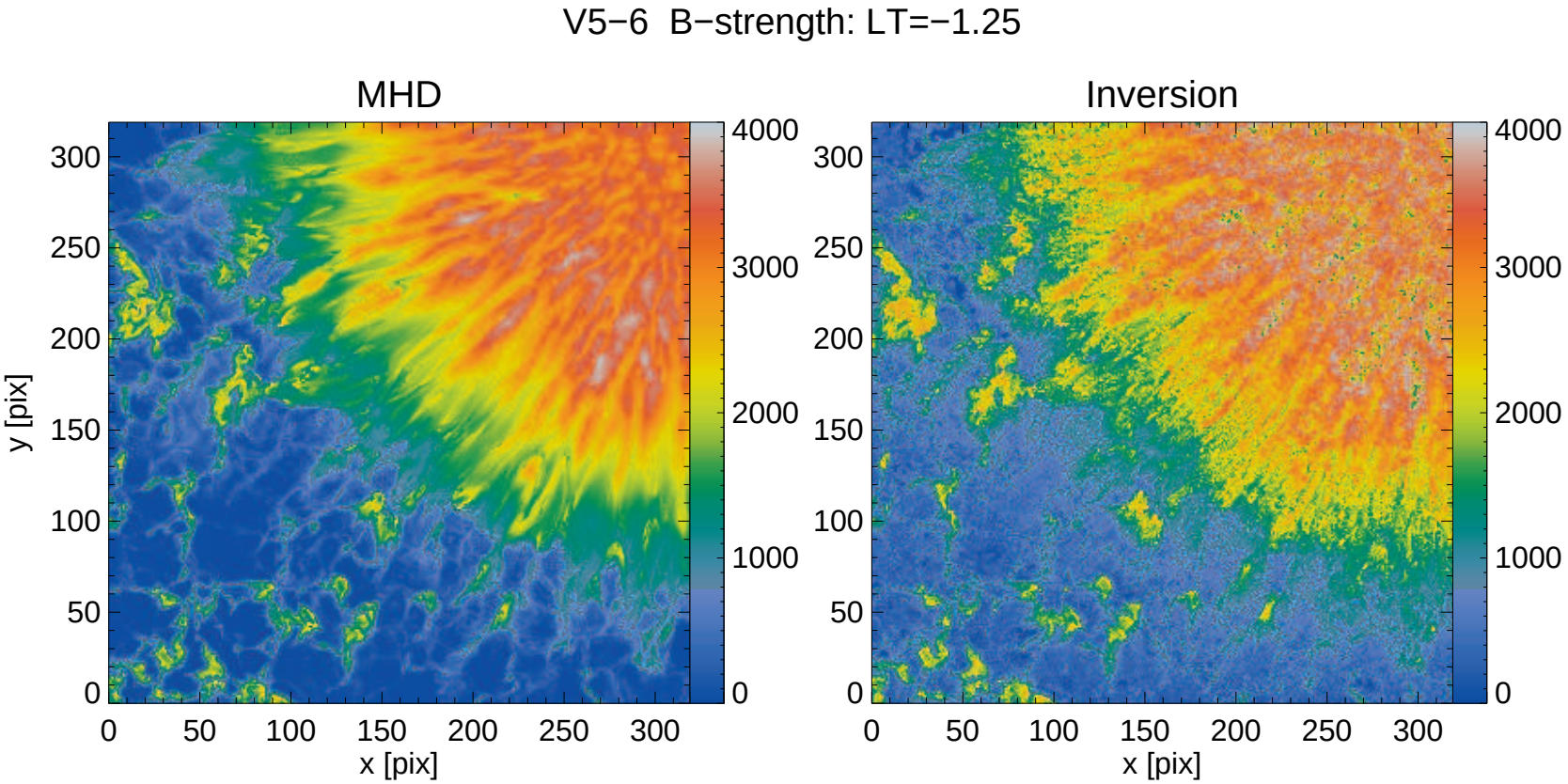


Inversion Setup

V5-6 mode, noise level $3{\cdot}10^{-3}$

noise in umbra, too strong granular fields

B-Field: $\log \tau = -1.25$ V5-6



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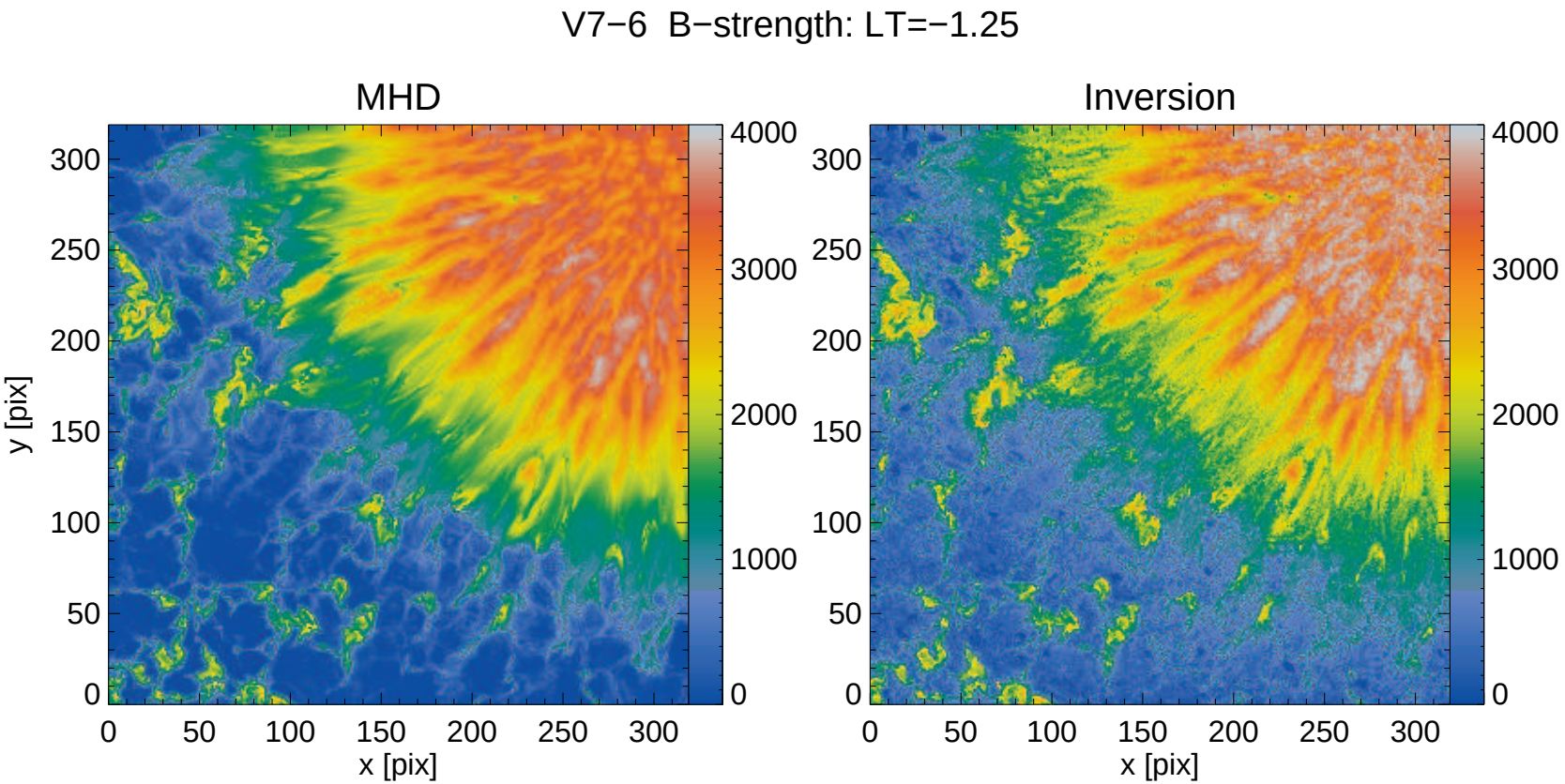
B-Field: $\log \tau = -1.25$ V7-6



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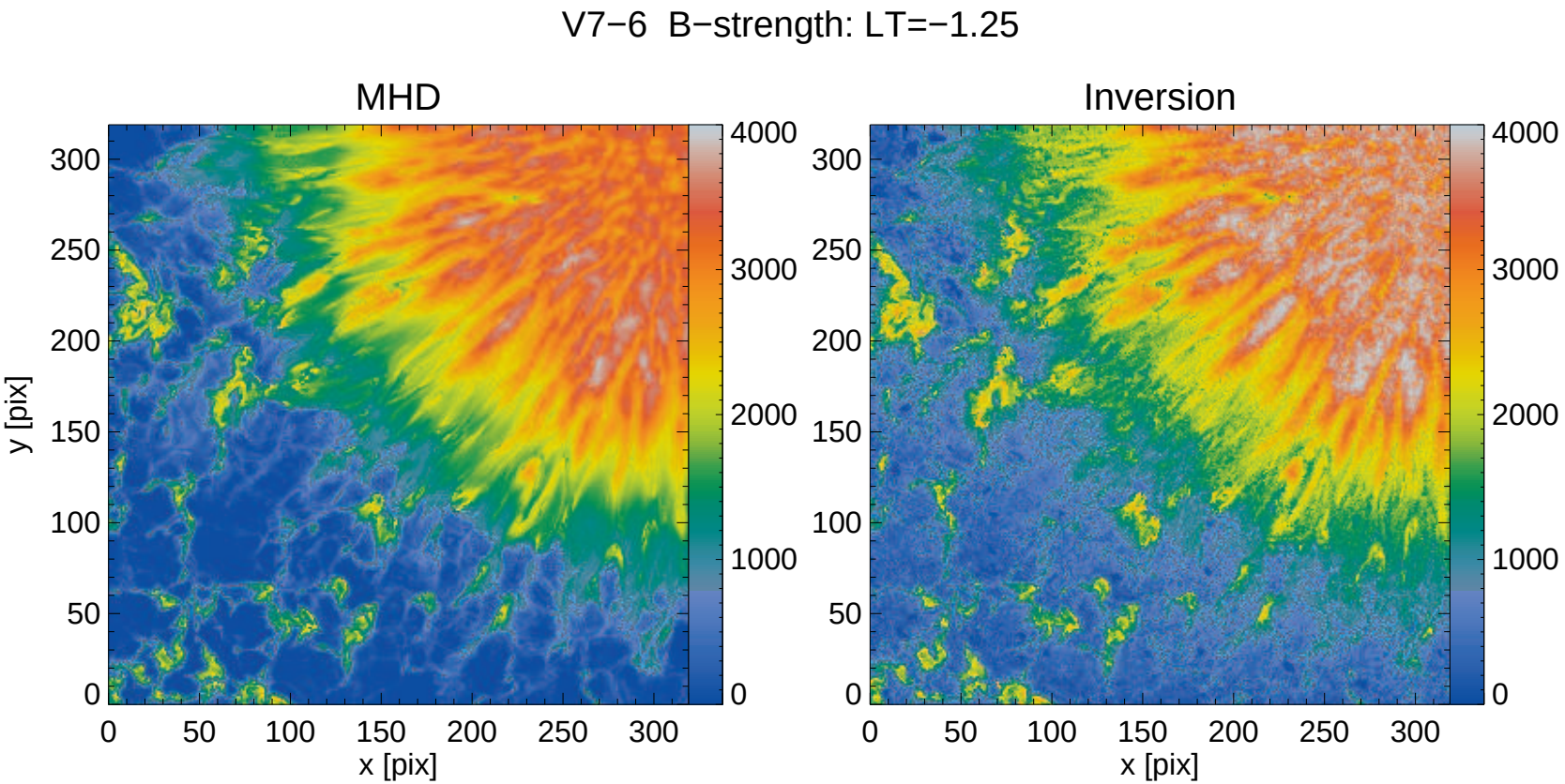

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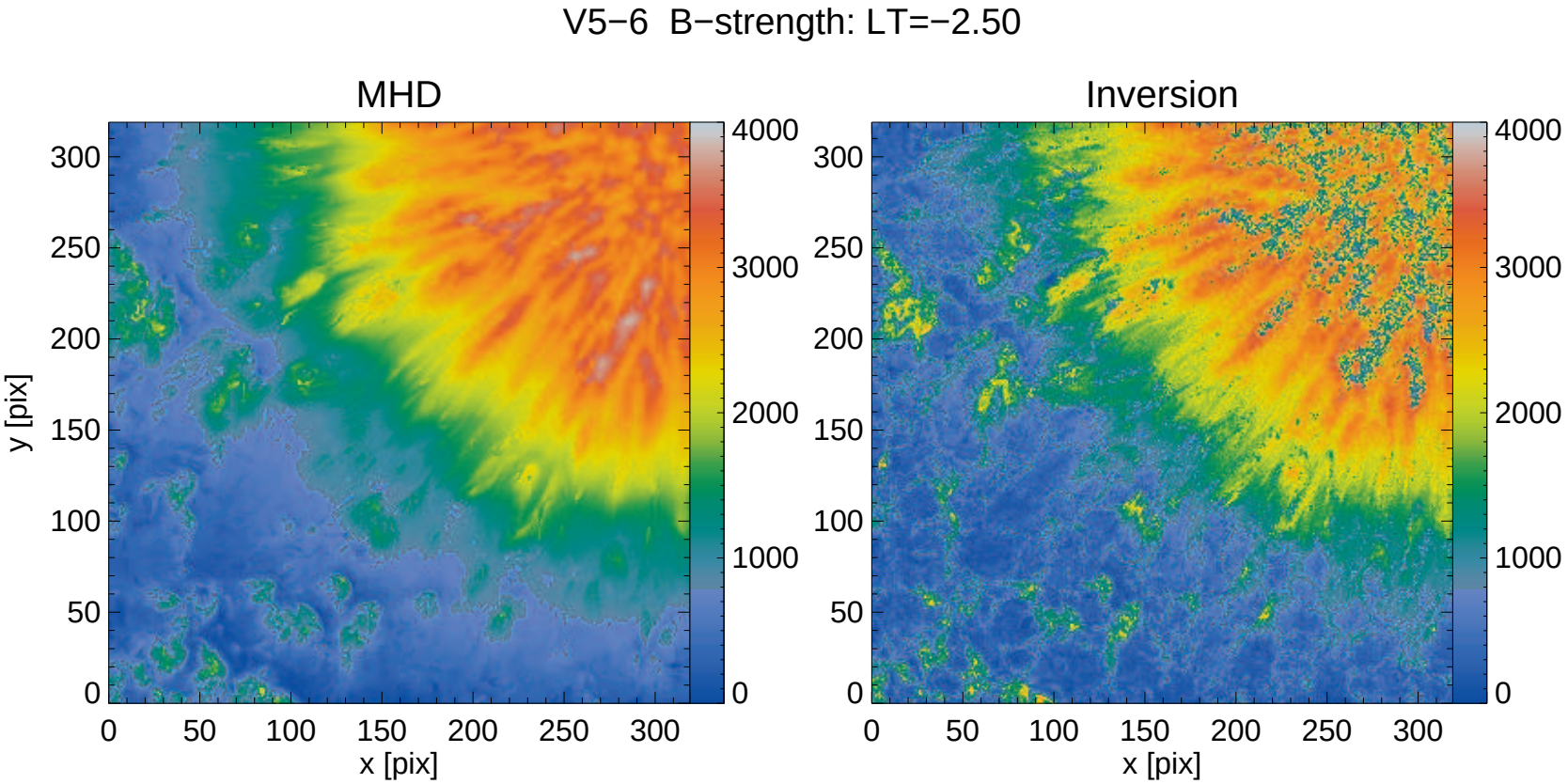
How about gradients? - High layers

Next slides:

- magnetic field strength
- height layer: $\log \tau = -2.5$

$\Rightarrow$ upper photosphere

B-Field: $\log\tau = -2.50$ V5-6

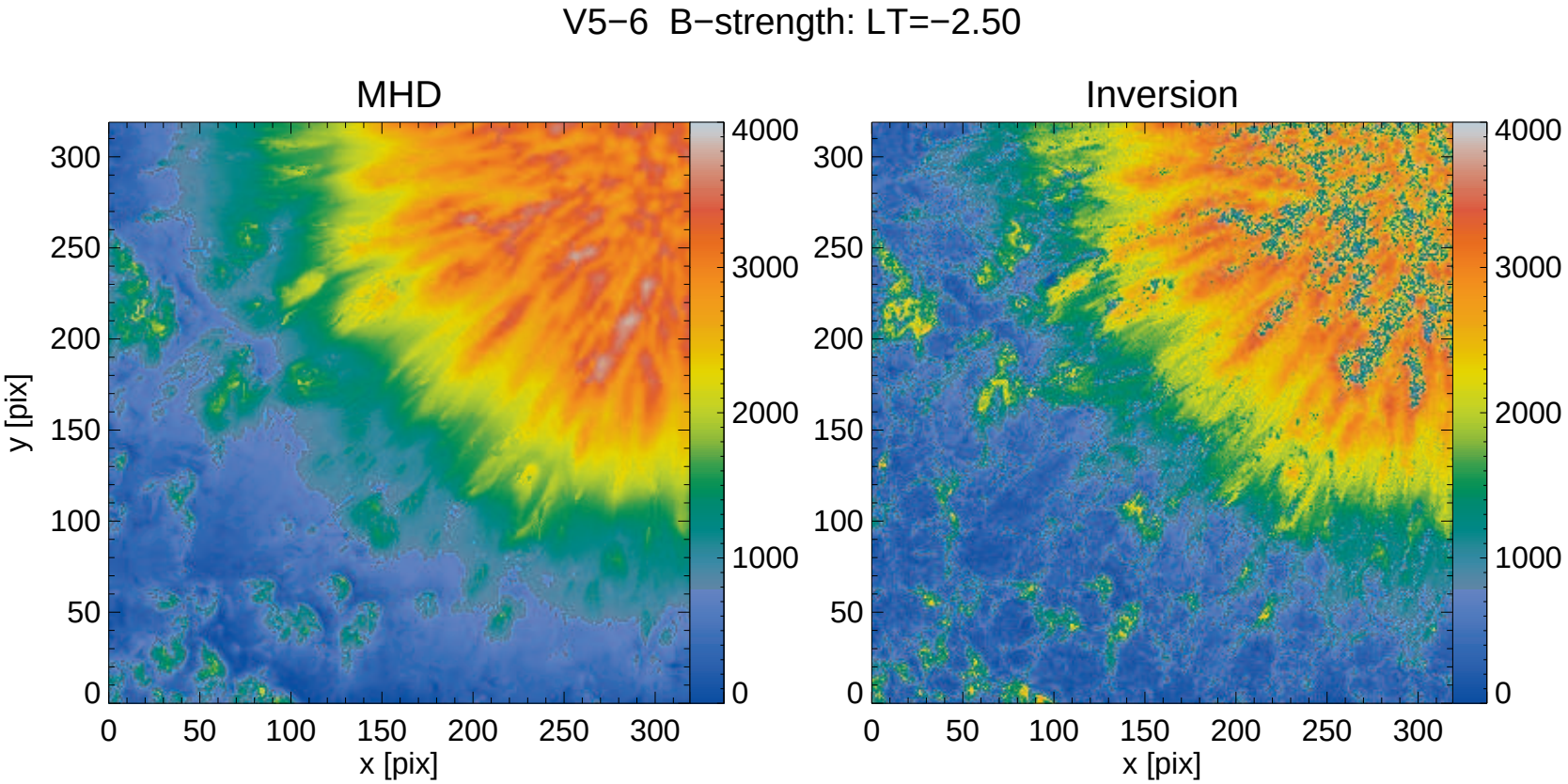


Inversion Setup

V5-6 mode, noise level $3{\cdot}10^{-3}$

noise in umbra, no expansion & too strong network patches

B-Field: $\log \tau = -2.50$ V5-6



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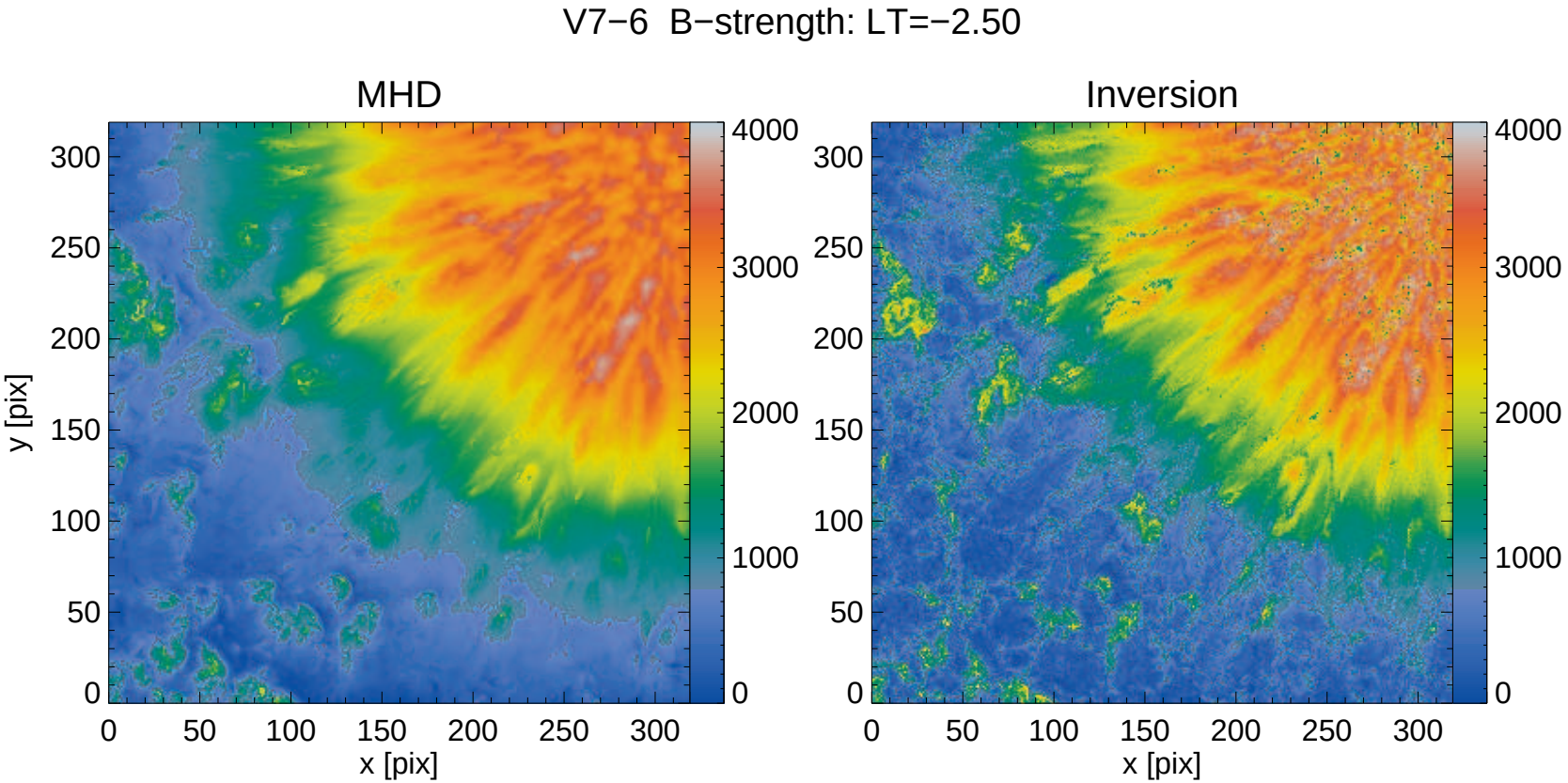
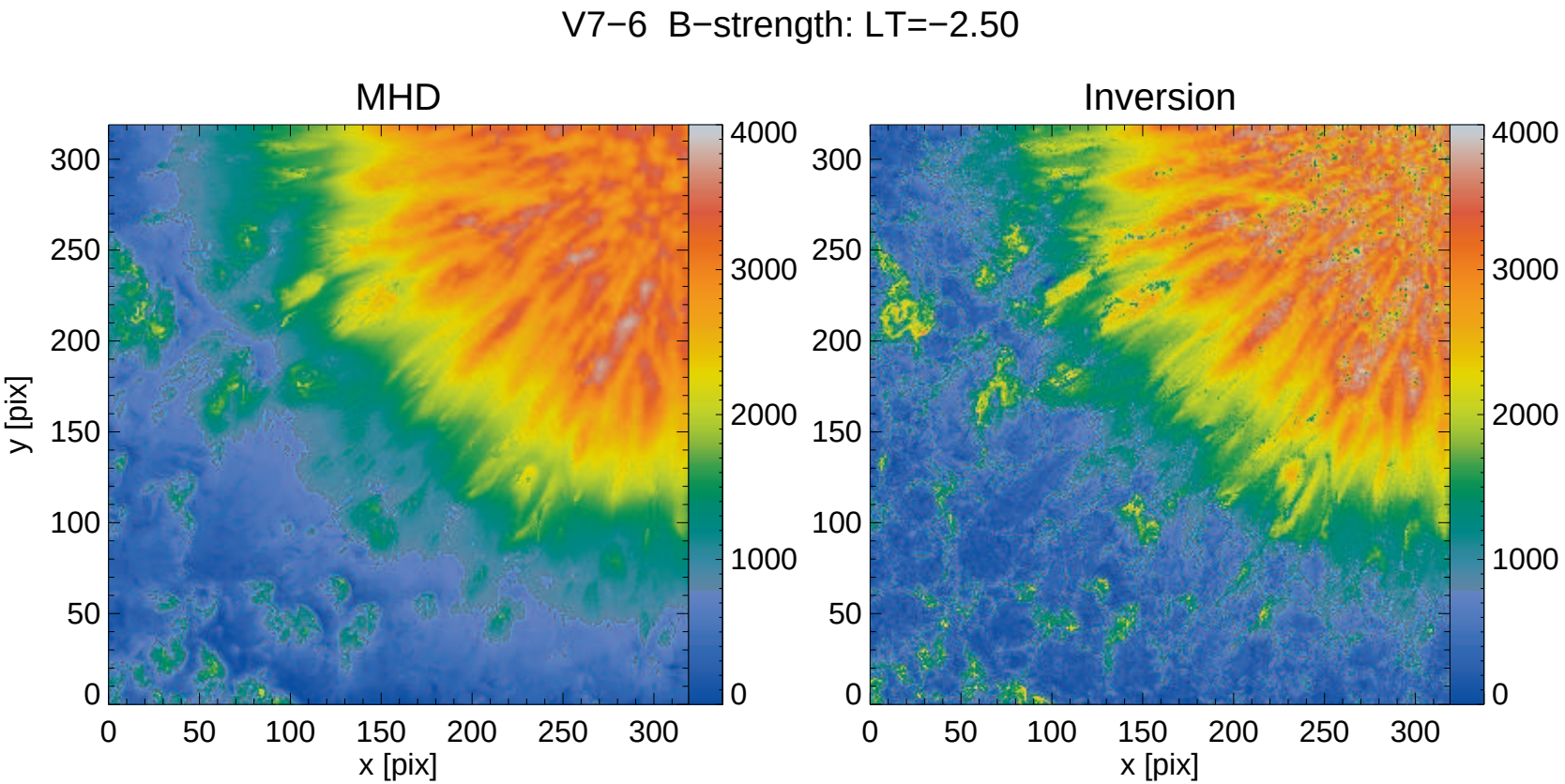


Inversion Setup

V7-6 mode, noise level $3{\cdot}10^{-3}$

noise in umbra (reduced), no expansion & too strong network

B-Field: $\log \tau = -2.50$ V7-6



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How about gradients? - Deep layers

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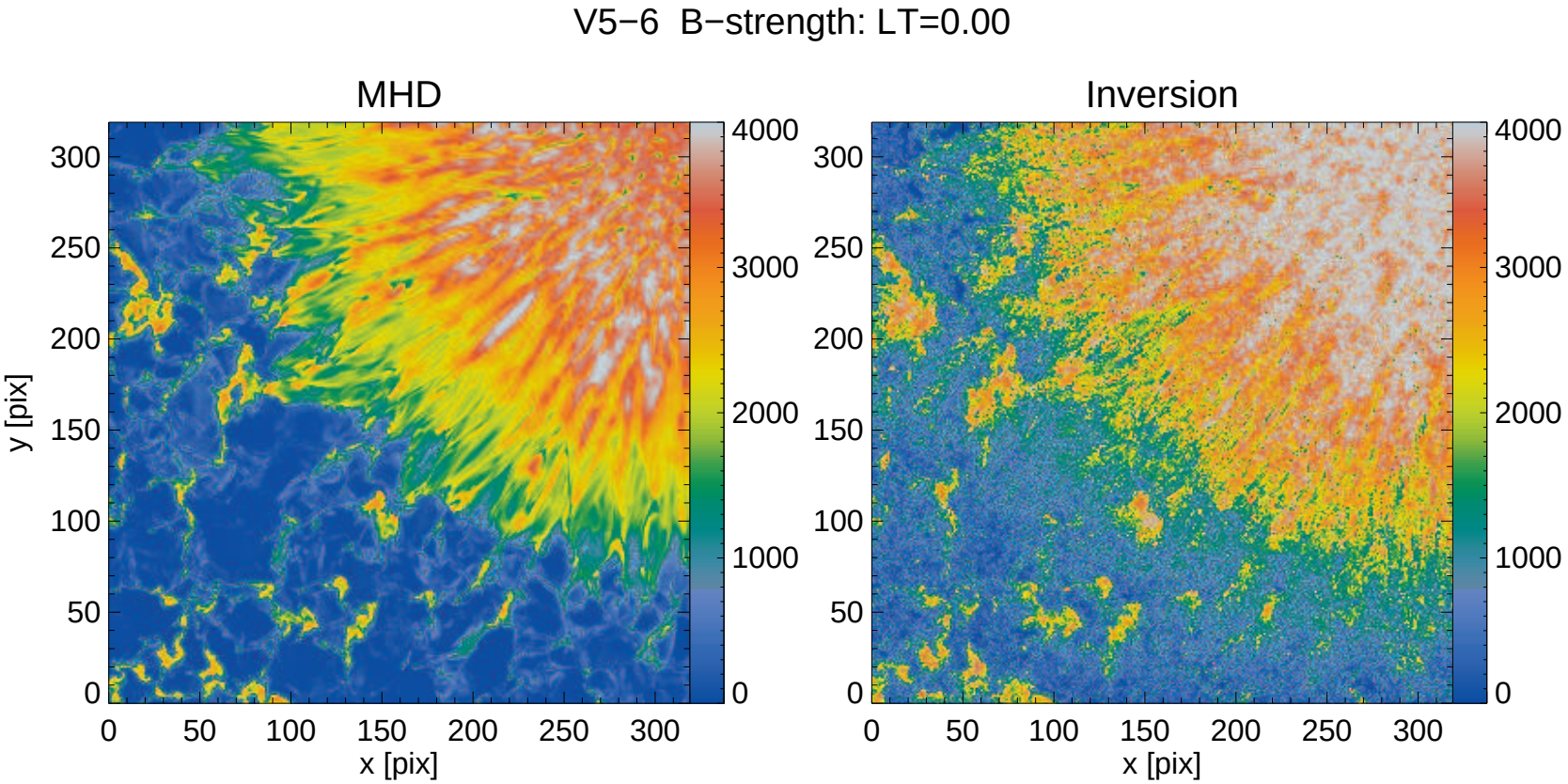
- magnetic field strength
- height layer: $\log \tau = 0.0$

$\Rightarrow$ deep photosphere

B-Field: $\log \tau = 0.0$ V5-6



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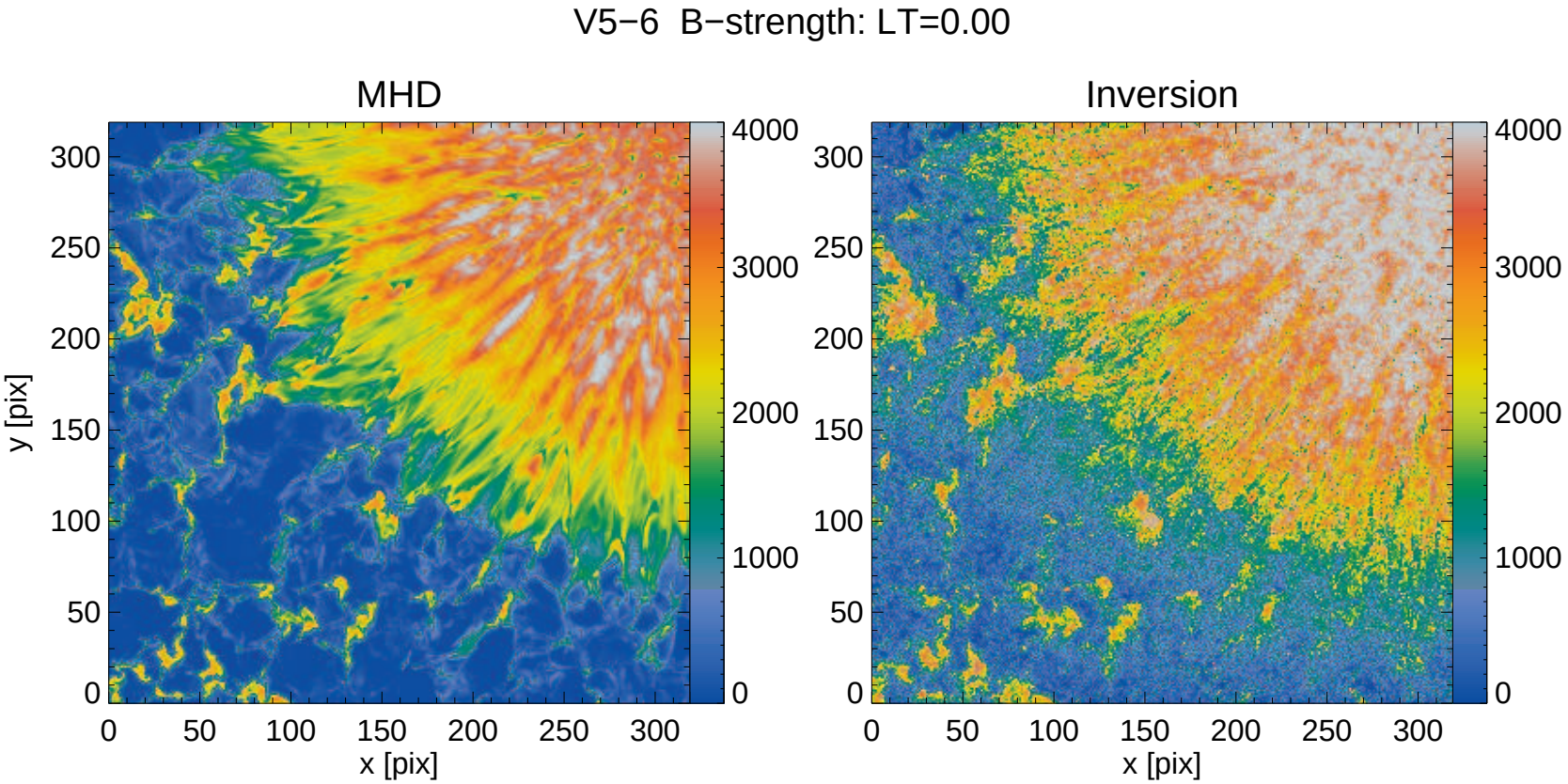
too strong, especially penumbra

B-Field: $\log \tau = 0.0$ V5-6

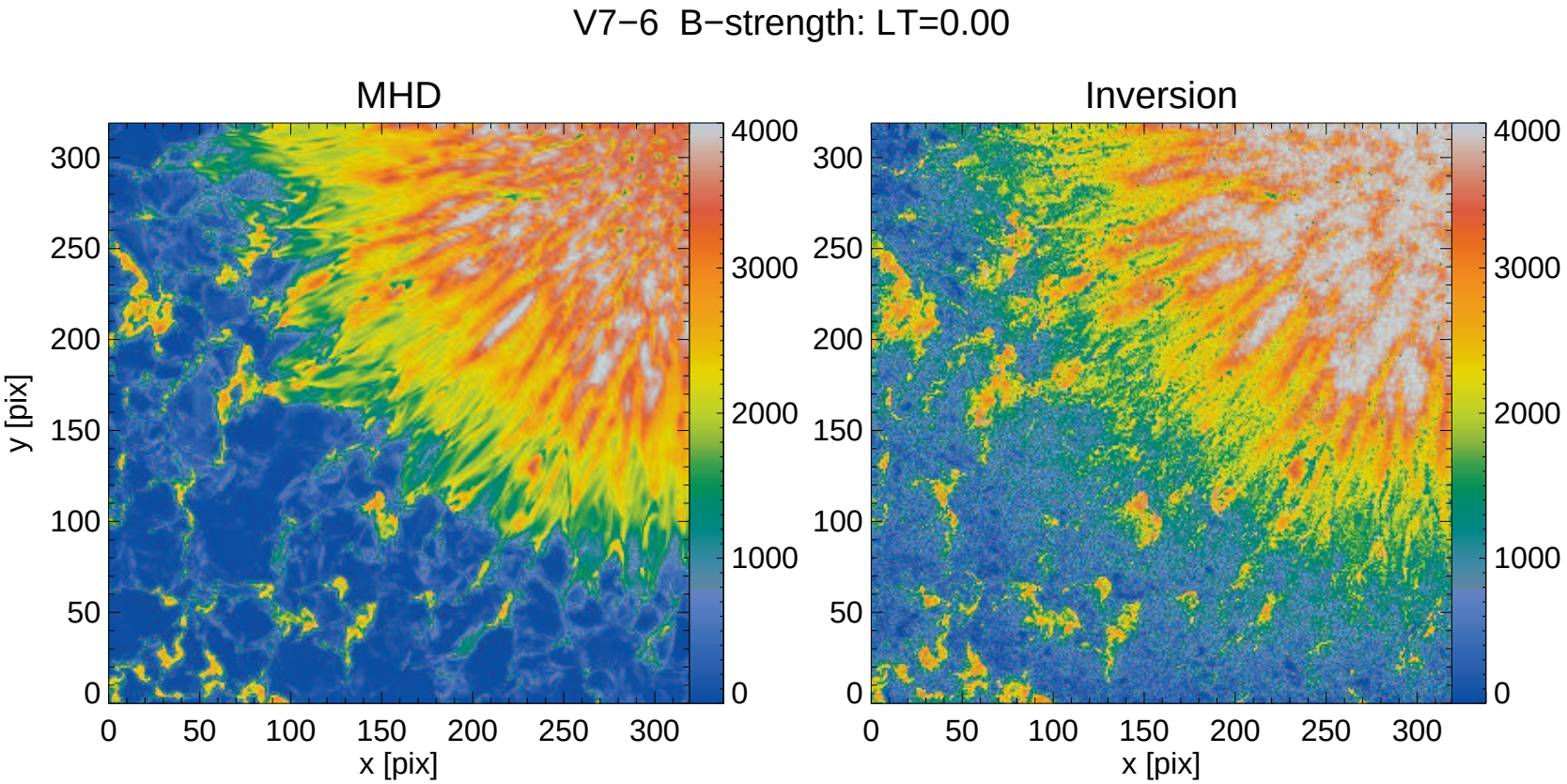


Inversion Setup

V5-6 mode, noise level $3{\cdot}10^{-3}$

too strong, especially penumbra

B-Field: $\log \tau = 0.0$ V7-4

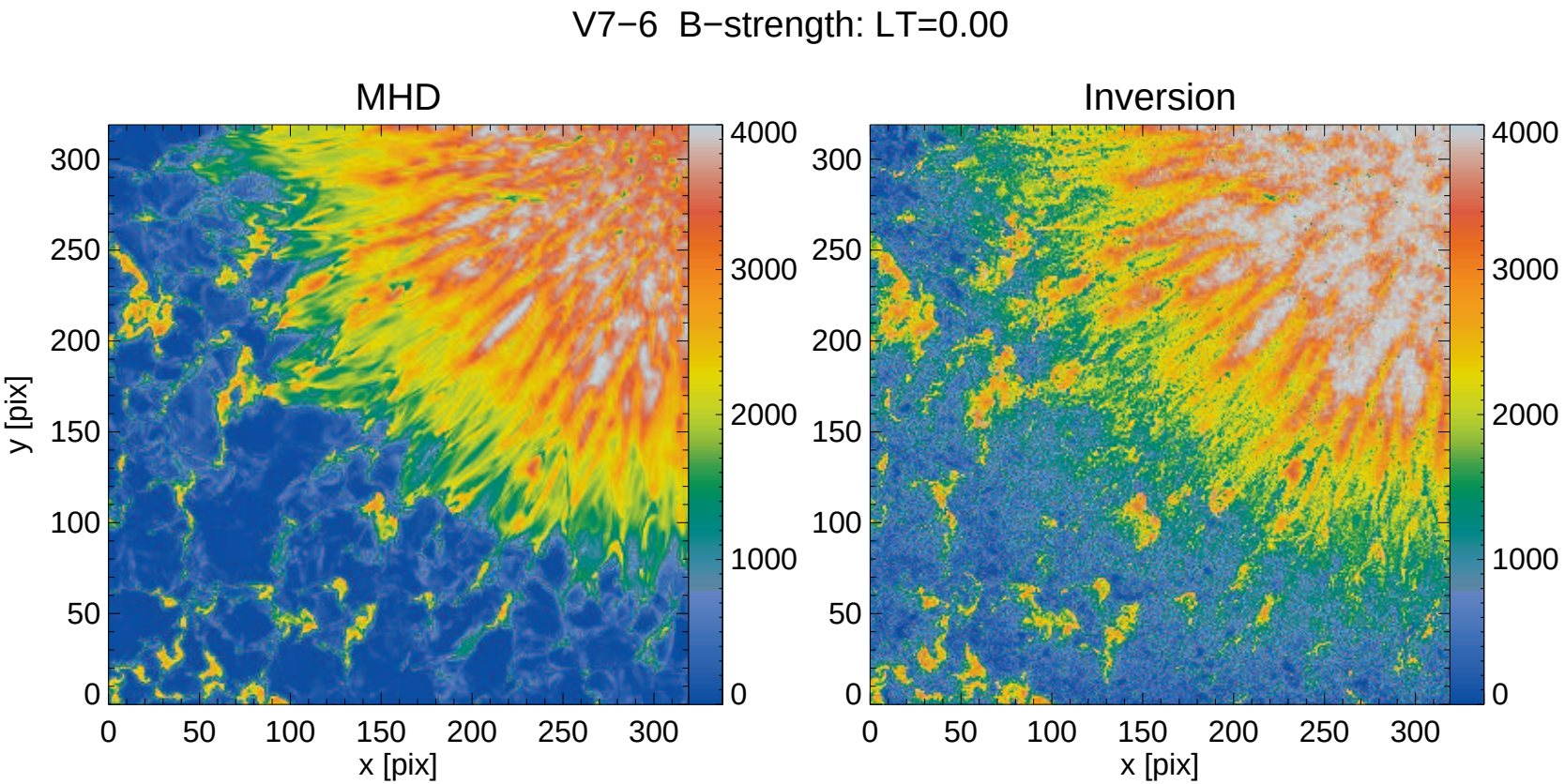


Inversion Setup

V7-4 mode, noise level $3{\cdot}10^{-3}$

slightly too strong in QS and umbra

B-Field: $\log \tau = 0.0$ V7-4



Inversion Setup

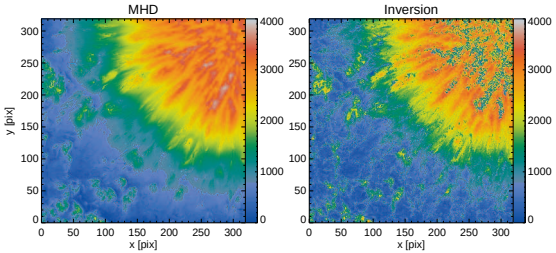
V7-4 mode, noise level $3{\cdot}10^{-3}$

slightly too strong in QS and umbra

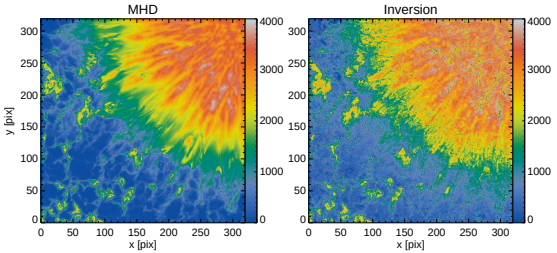
All Parameters & Heights

V5-6

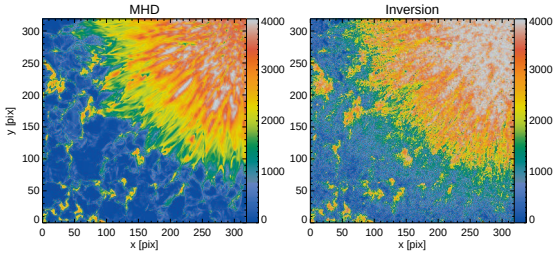
V5−6 B−strength: LT=−2.50



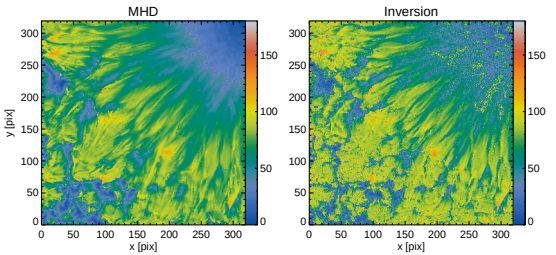
V5−6 B−strength: LT=−1.25



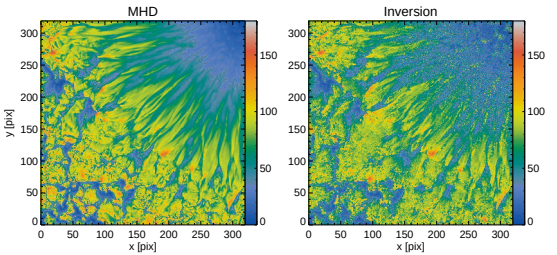
V5−6 B−strength: LT=0.00



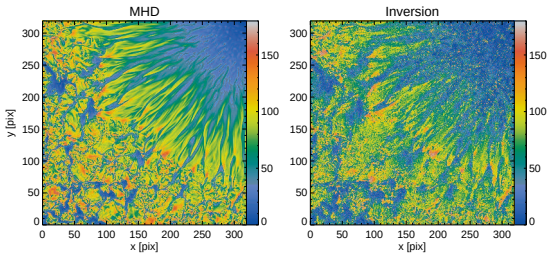
V5−6 Inclination: LT=−2.50



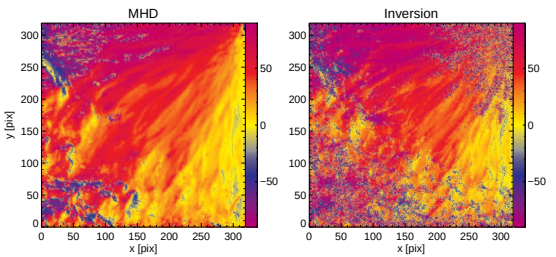
V5−6 Inclination: LT=−1.25



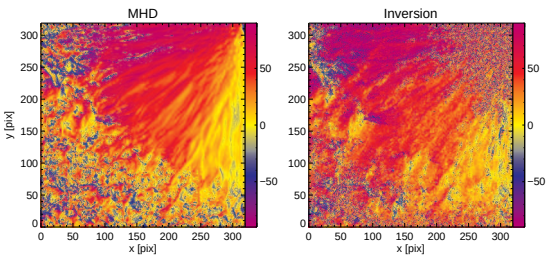
V5−6 Inclination: LT=0.00



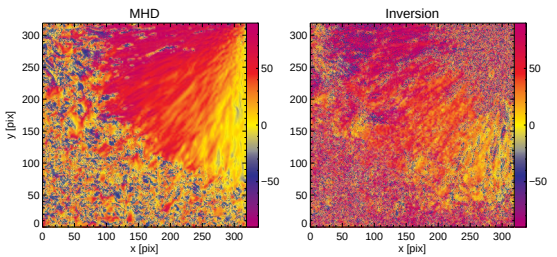
V5−6 Azimuth: LT=−2.50



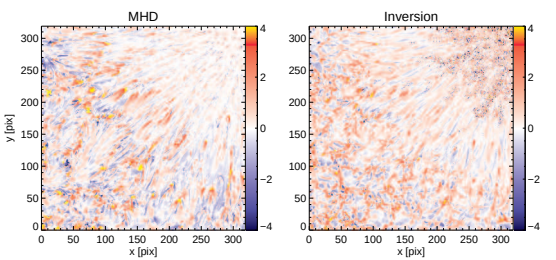
V5−6 Azimuth: LT=−1.25



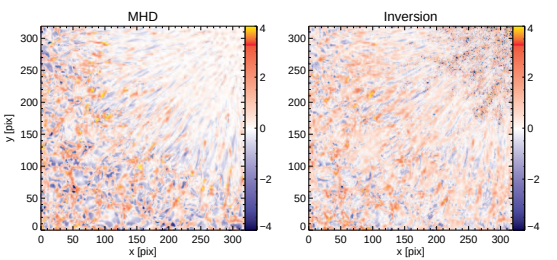
V5−6 Azimuth: LT=0.00



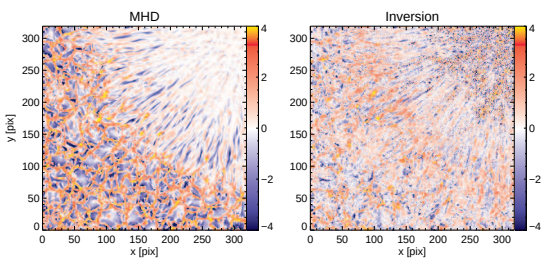
V5−6 LOS−velocity: LT=−2.50



V5−6 LOS−velocity: LT=−1.25



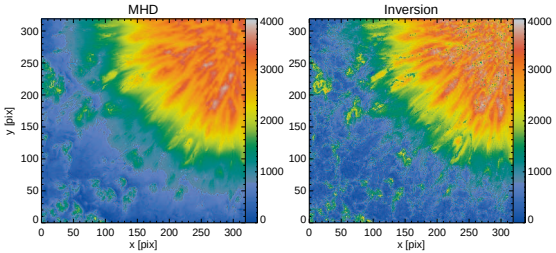
V5−6 LOS−velocity: LT=0.00



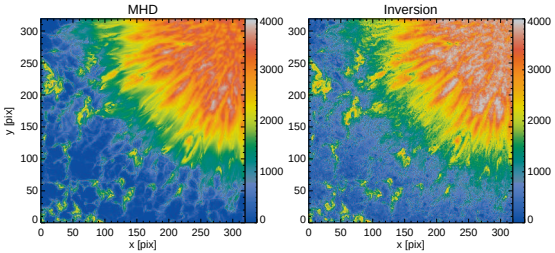
All Parameters & Heights

V7-6

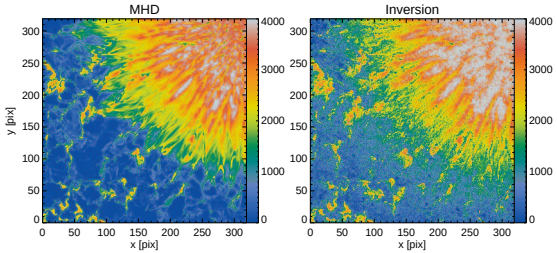
V7−6 B−strength: LT=−2.50



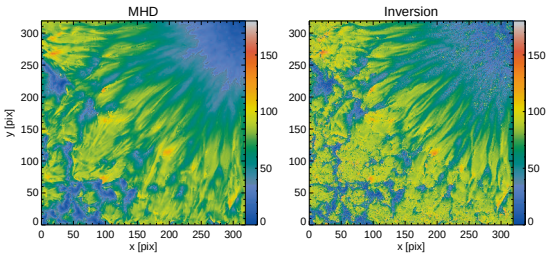
V7−6 B−strength: LT=−1.25



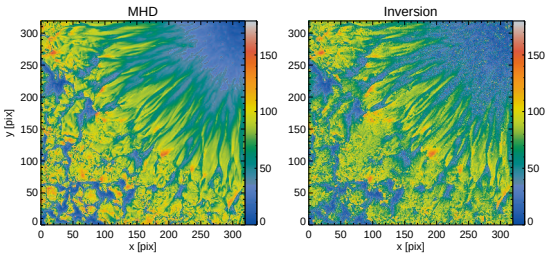
V7−6 B−strength: LT=0.00



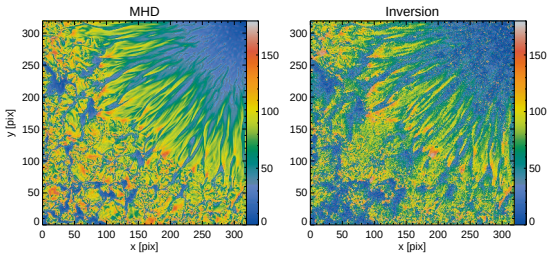
V7−6 Inclination: LT=−2.50



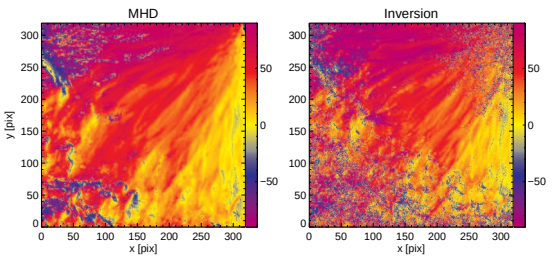
V7−6 Inclination: LT=−1.25



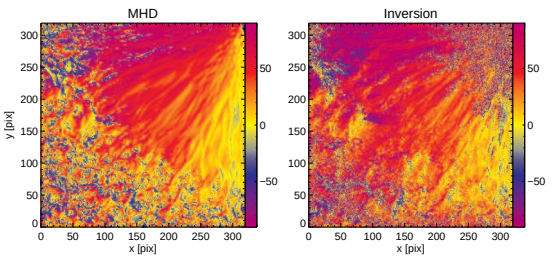
V7−6 Inclination: LT=0.00



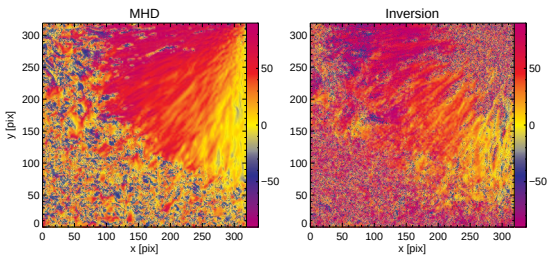
V7−6 Azimuth: LT=−2.50



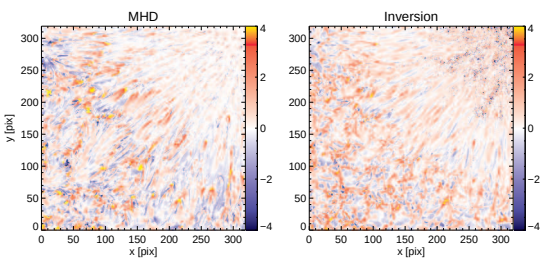
V7−6 Azimuth: LT=−1.25



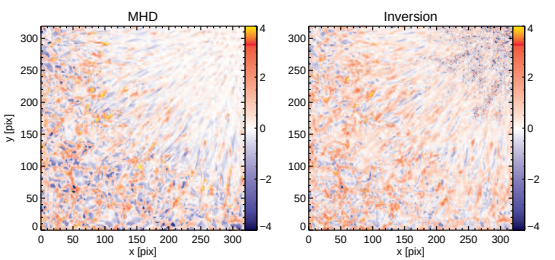
V7−6 Azimuth: LT=0.00



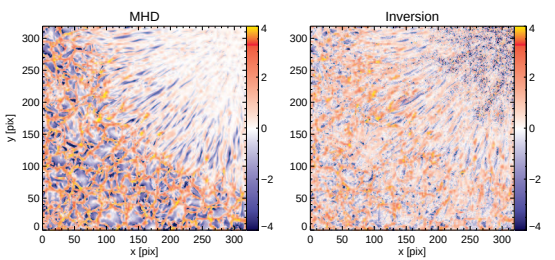
V7−6 LOS−velocity: LT=−2.50



V7−6 LOS−velocity: LT=−1.25

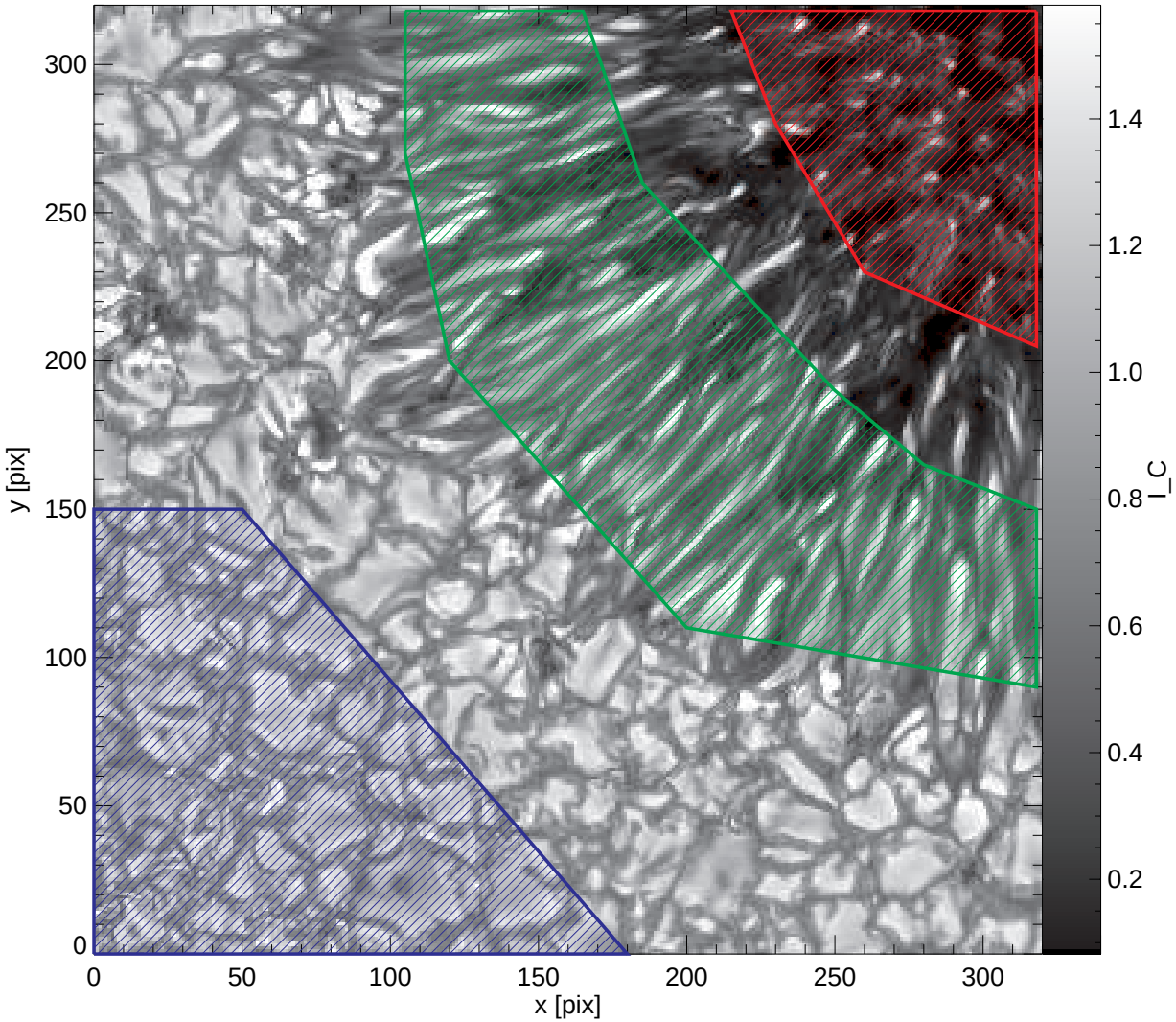


V7−6 LOS−velocity: LT=0.00



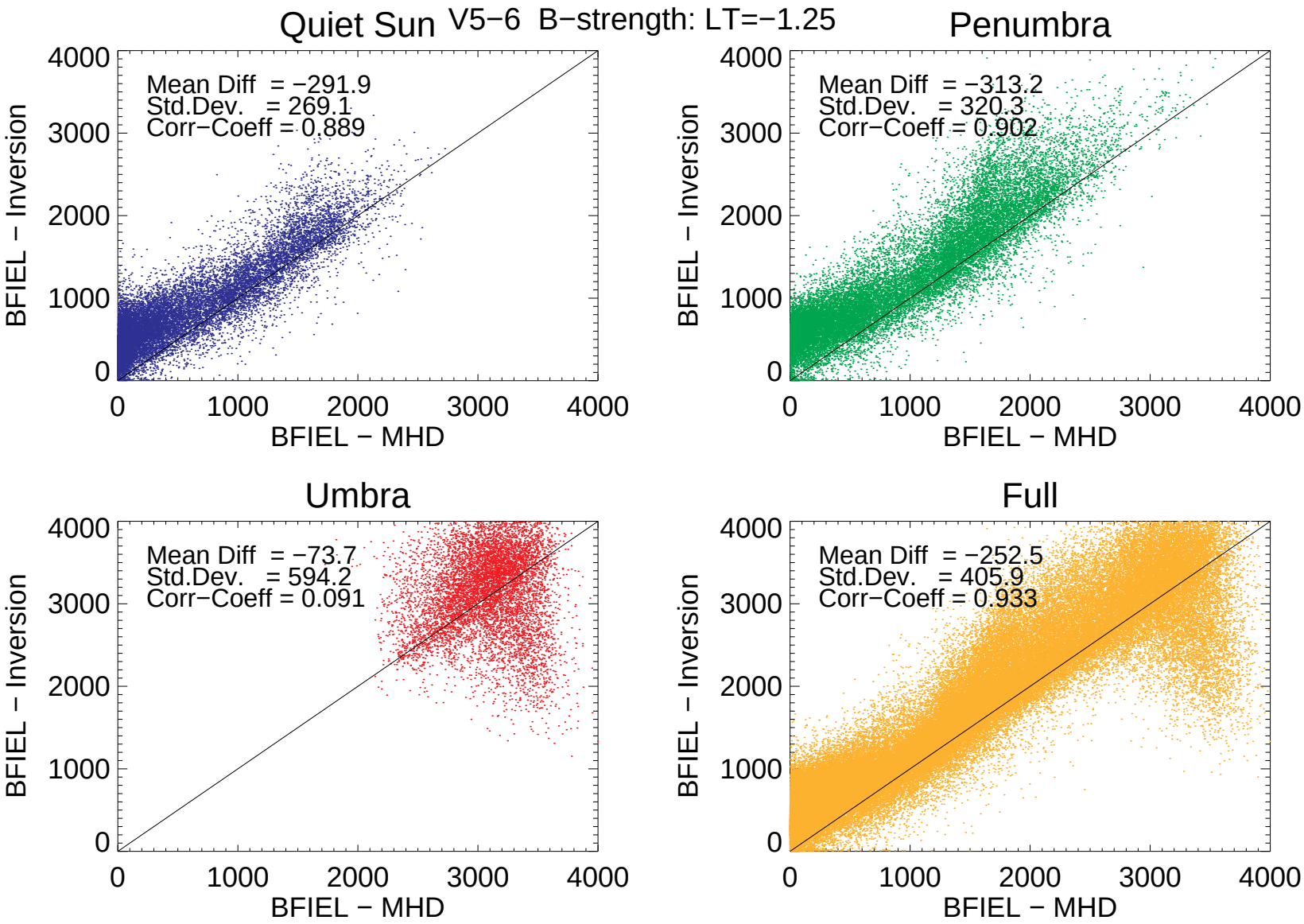
Quantitative Comparison

Umbra
Penumbra
Quiet Sun
Full



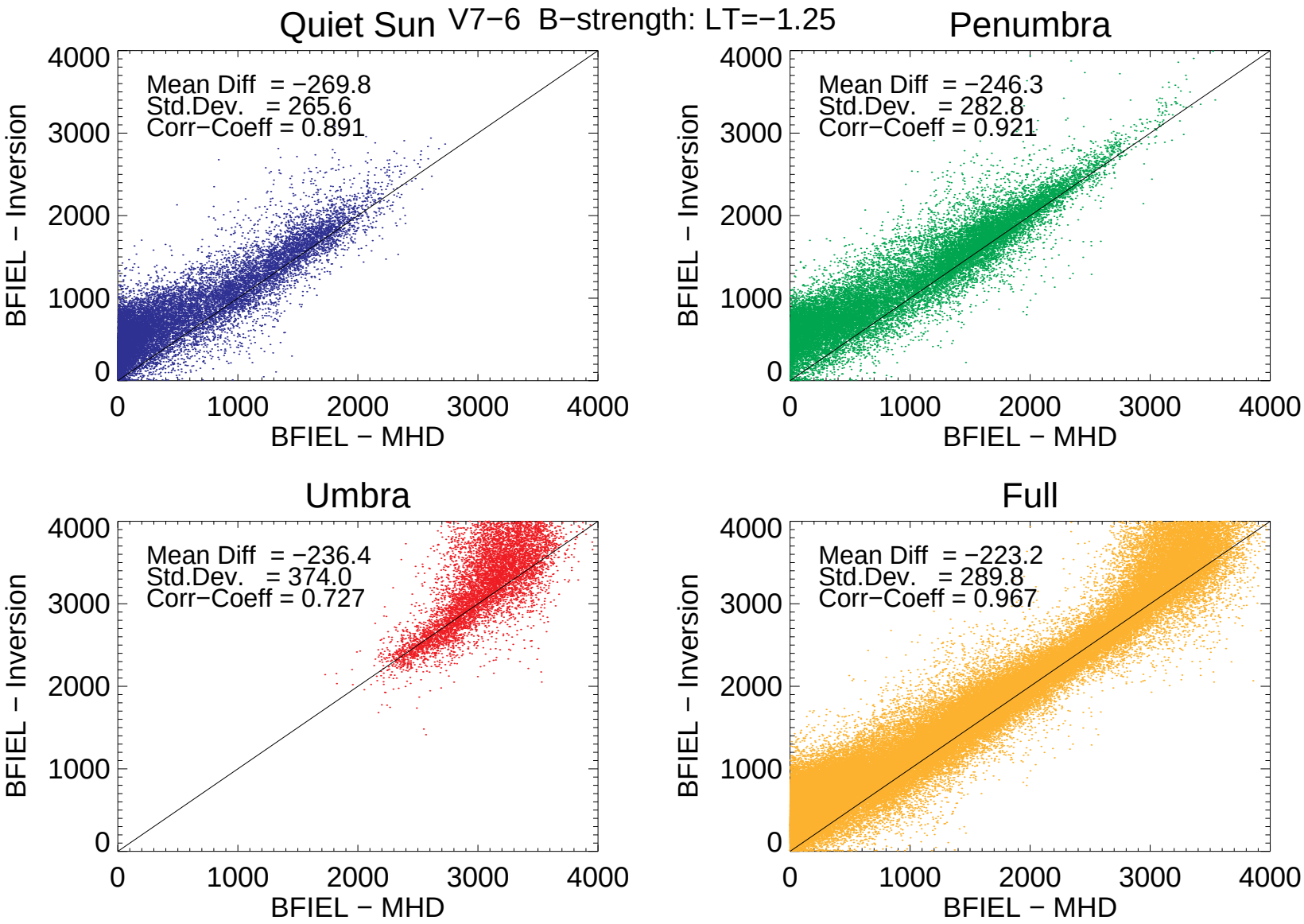
B-field

$\log \tau = -1.25$, V5-6



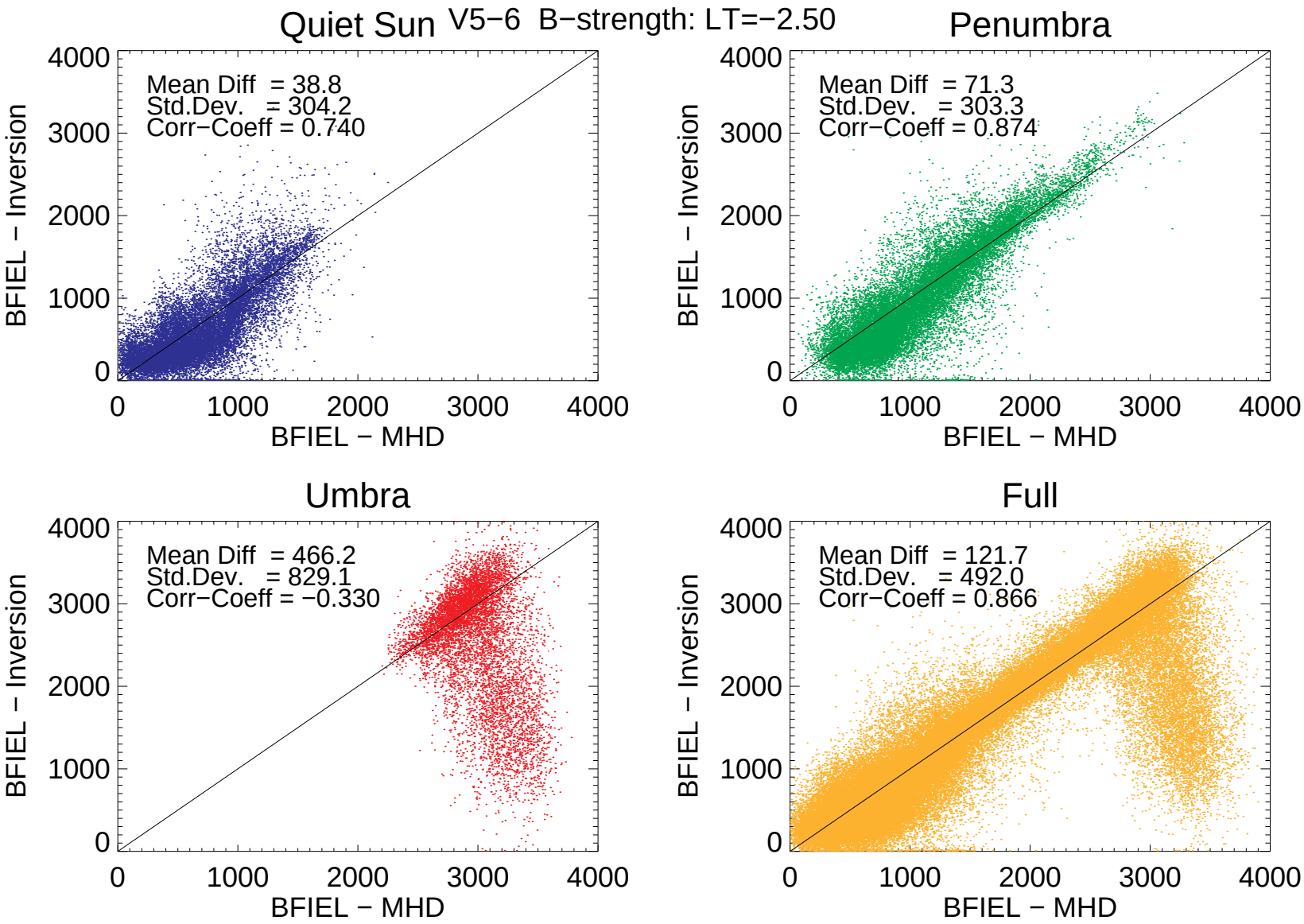
B-field

$\log \tau = -1.25$, V7-6



B-field

$\log \tau = -2.50$, V5-6



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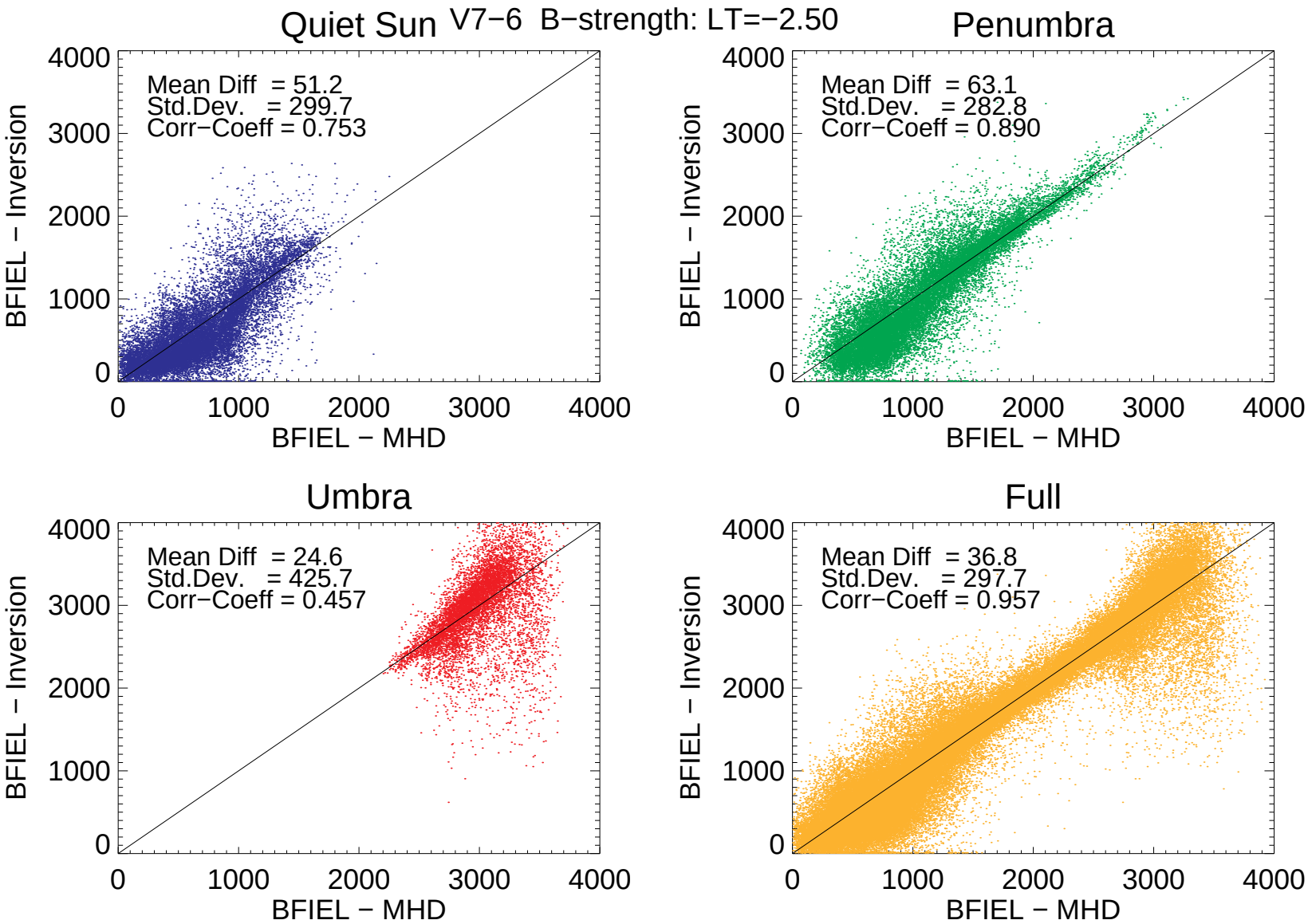
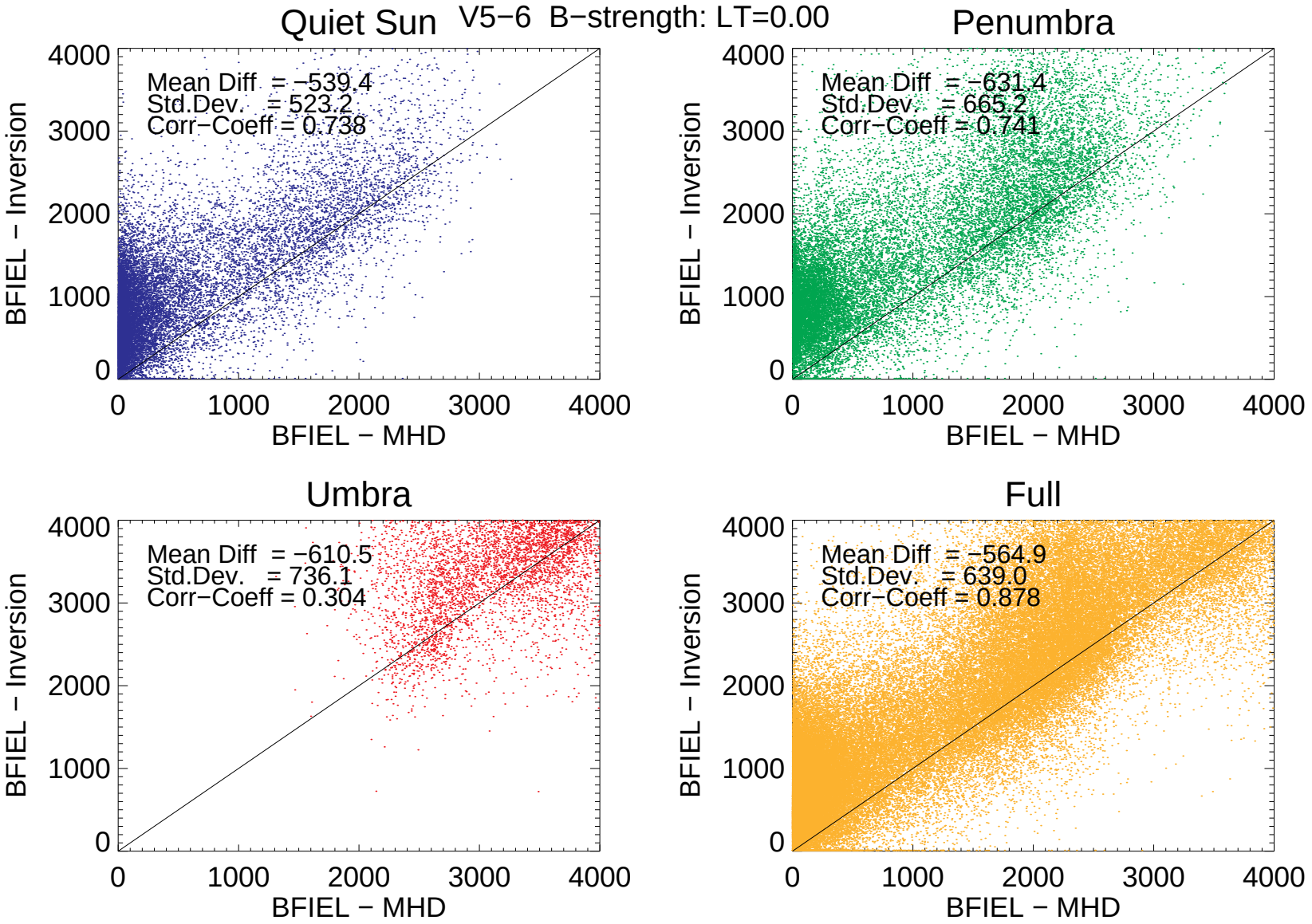


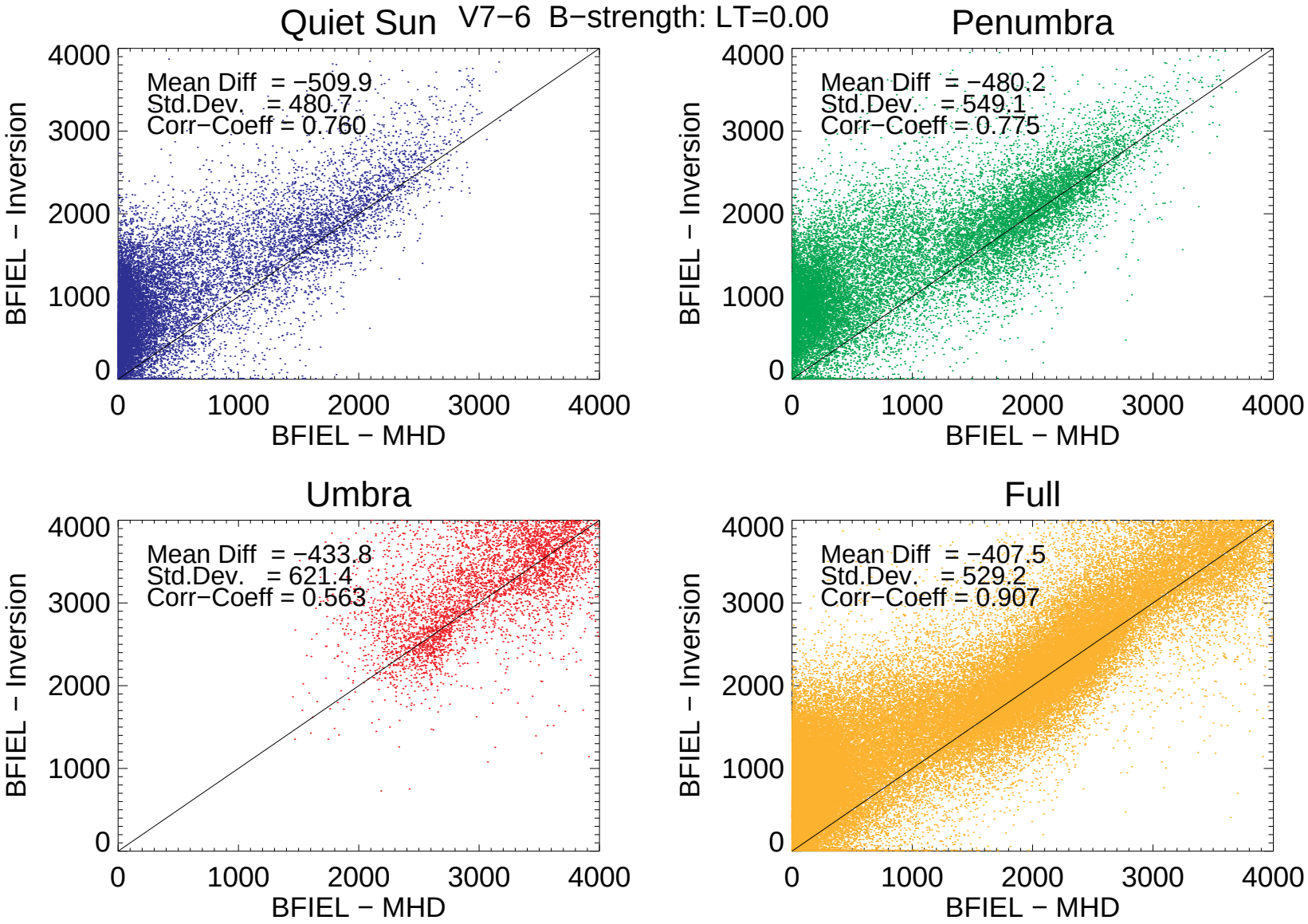
B-field

$\log \tau = 0.00$, V5-6

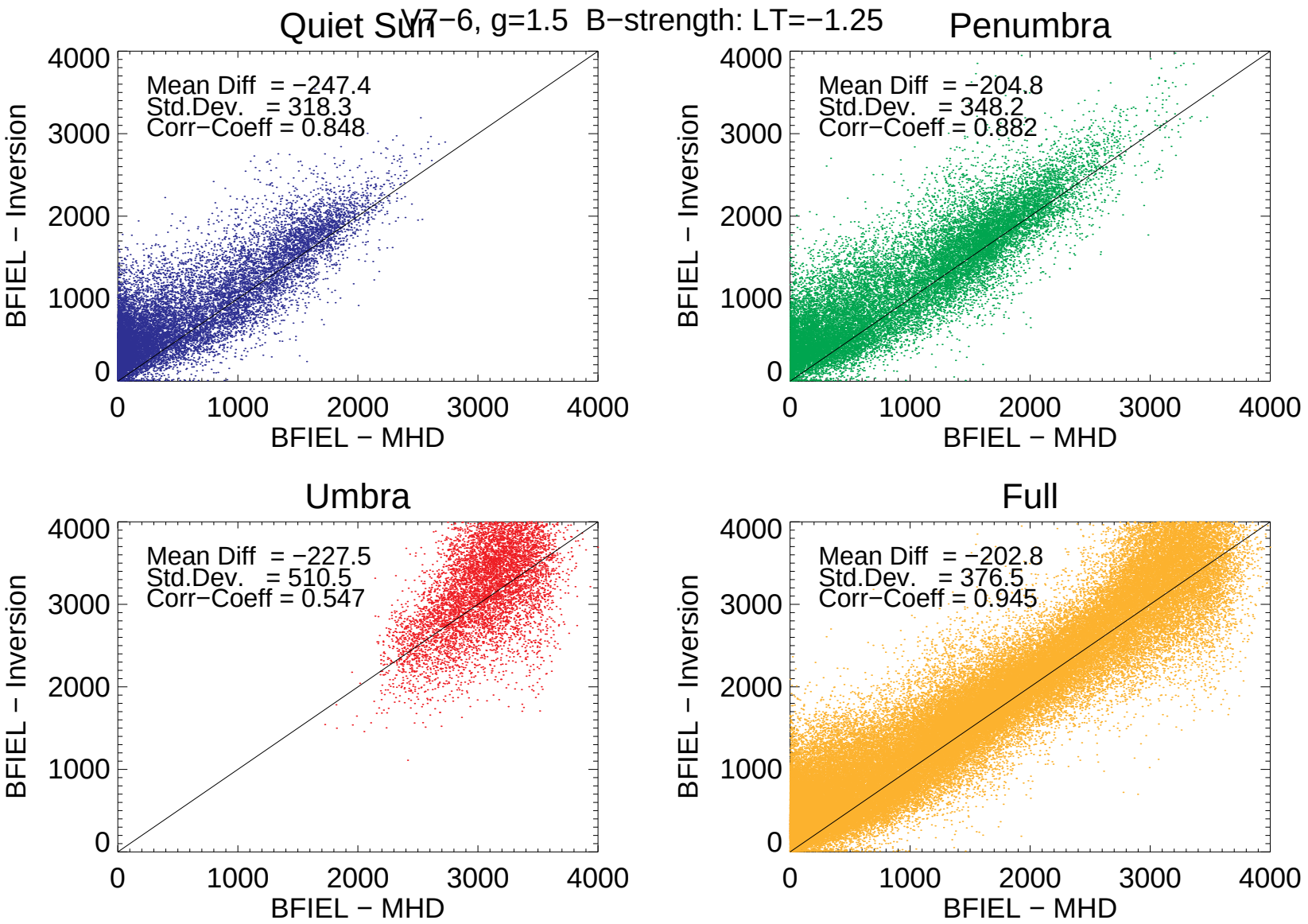


B-field

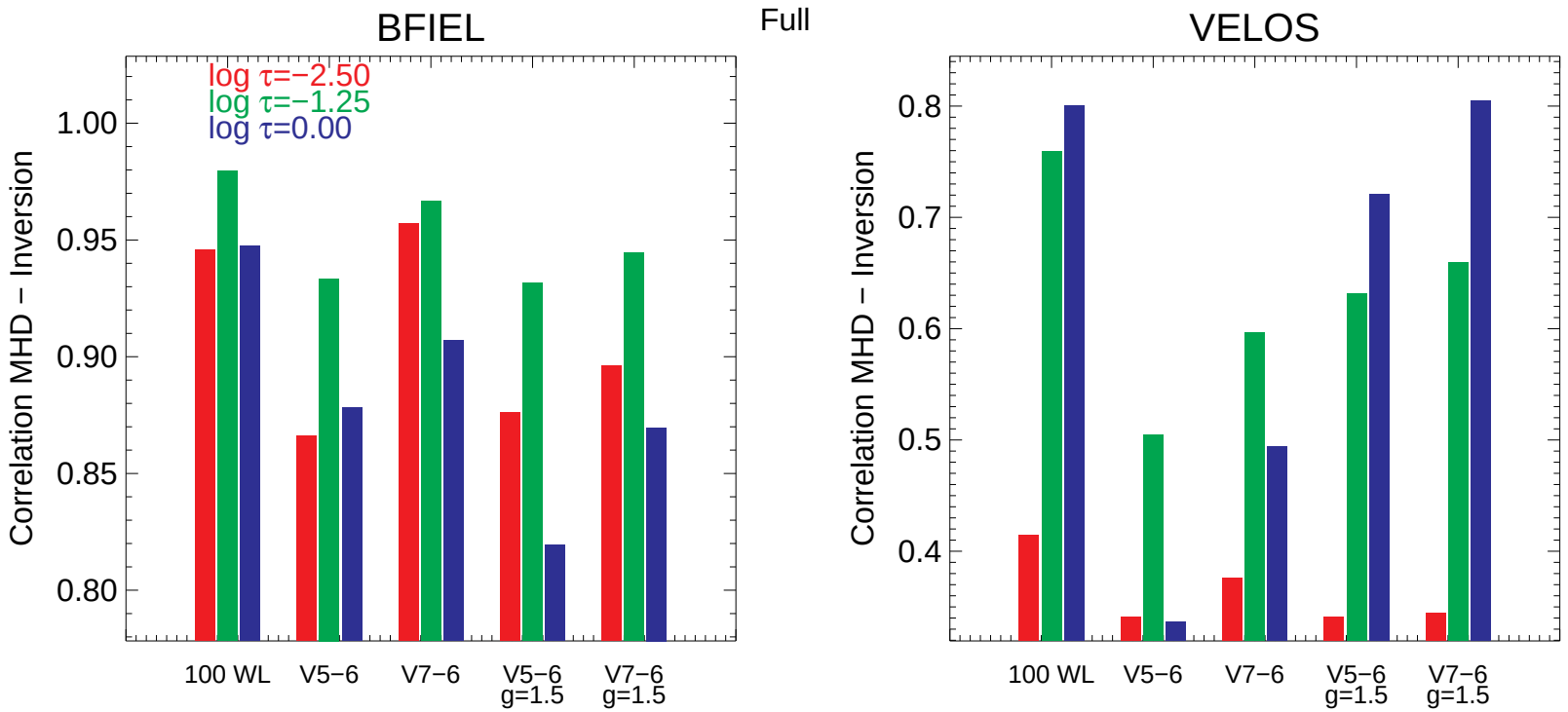
$\log \tau = 0.00$, V7-6



B-field Fe I 5250.6 Å, $\log\tau = -1.25$, V7-6



Comparison: Correlation Coefficient



- between MHD solution and inversion
- average over whole region (QS, penumbra, umbra)
- 2 right bars: $g = 1.5$ Fe I 5250.6 Å line

Conclusions

- V5-6 mode good for 1-node inversions
  (SPINOR/SIR or ME, not shown)
  BUT: ME inversions difficult in sunspot (Fe I 5250.6 Å)
- V7-6 mode required for height dependent inversions
  (V5-6 wrong in some regions)
- Fe I 5250.6 Å line worse for B, slightly better for v_{LOS}

Reflight

- continuum point: to the blue?
- umbra: longer integration?
- even more WL points to cover both Fe I lines?
  (number of photons is constant for same t_{acq})
- more simulations? (browse my PC ...)

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