Magnetic field measurements at the photosphere and coronal base

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MOTIVATIONS

- Magnetic free energy in the Sun's corona remains essentially unknown
- This energy drives flares, CMEs, probably coronal heating
- Significant investment has been made by NASA and others to
  - study space weather observationally, yet no instrument flown in space can measure the free energy: flight instruments mostly observe only *effects*, not *causes*
  - compute the free energy using extrapolations of fields measured at the photosphere, yet such work is physically inconsistent, at best
- We wish to place Space Weather Prediction on a firmer foundation
  - Measure **B** under force-free conditions
  - Apply Chandrasekhar's virial theorem
- We wish to study the physical transition from photosphere to corona

METHODS

We use the IBIS and FIRS spectropolarimeters to observe active regions in :

- Photospheric Fe I 630 nm
- Chromospheric Ca II 854.2 nm
- Chromospheric He I 1083 nm

We attempt to derive vector fields at the coronal base from the He I lines. These lines form in a narrow layer near the coronal base and contain measurable Stokes I(QU)V signals.

Inversion of He I IQUV data is tractable, constrained also by

- Photospheric magnetic field measurements
- Chromospheric field-aligned motion of plasma along fibrils seen in Ca II

Unlike photospheric images, the fibril-morphology of Ca II and He I line core images indicate that the magnetic fields sampled at these wavelengths are close to force-free. Observed active region structures are long-lived compared with Alfven crossing times: the magnetic fields are close to magnetostatic equilibrium.

At this stage **we cannot yet derive vector B over an active region: we need higher s/n data for 1083, to invert 854.2nm data, and a more robust scheme to track fibril motions.**

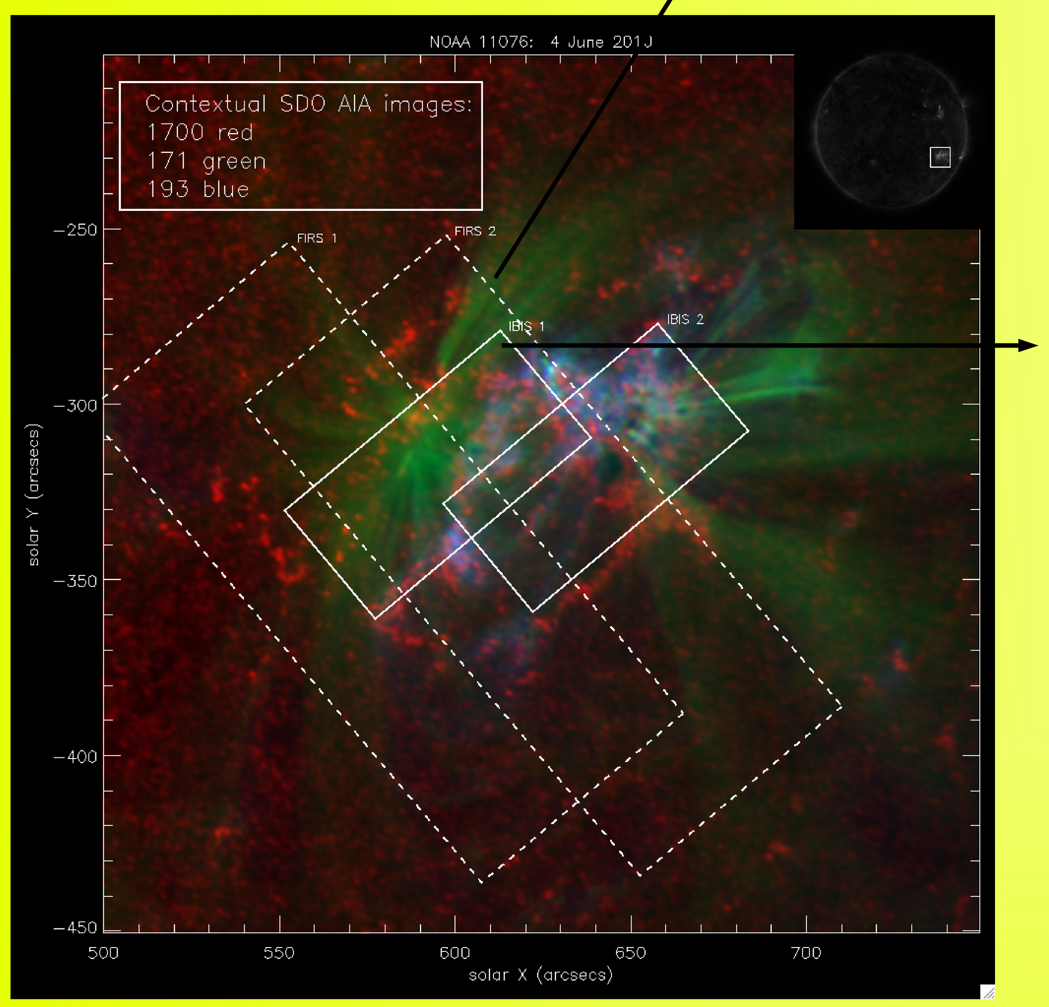
In this work we compare extrapolated fields with recent data.

OBSERVATIONS

From June 3-12 2010 we obtained FIRS and IBIS data from ~13:30 to ~17:00 UT, of

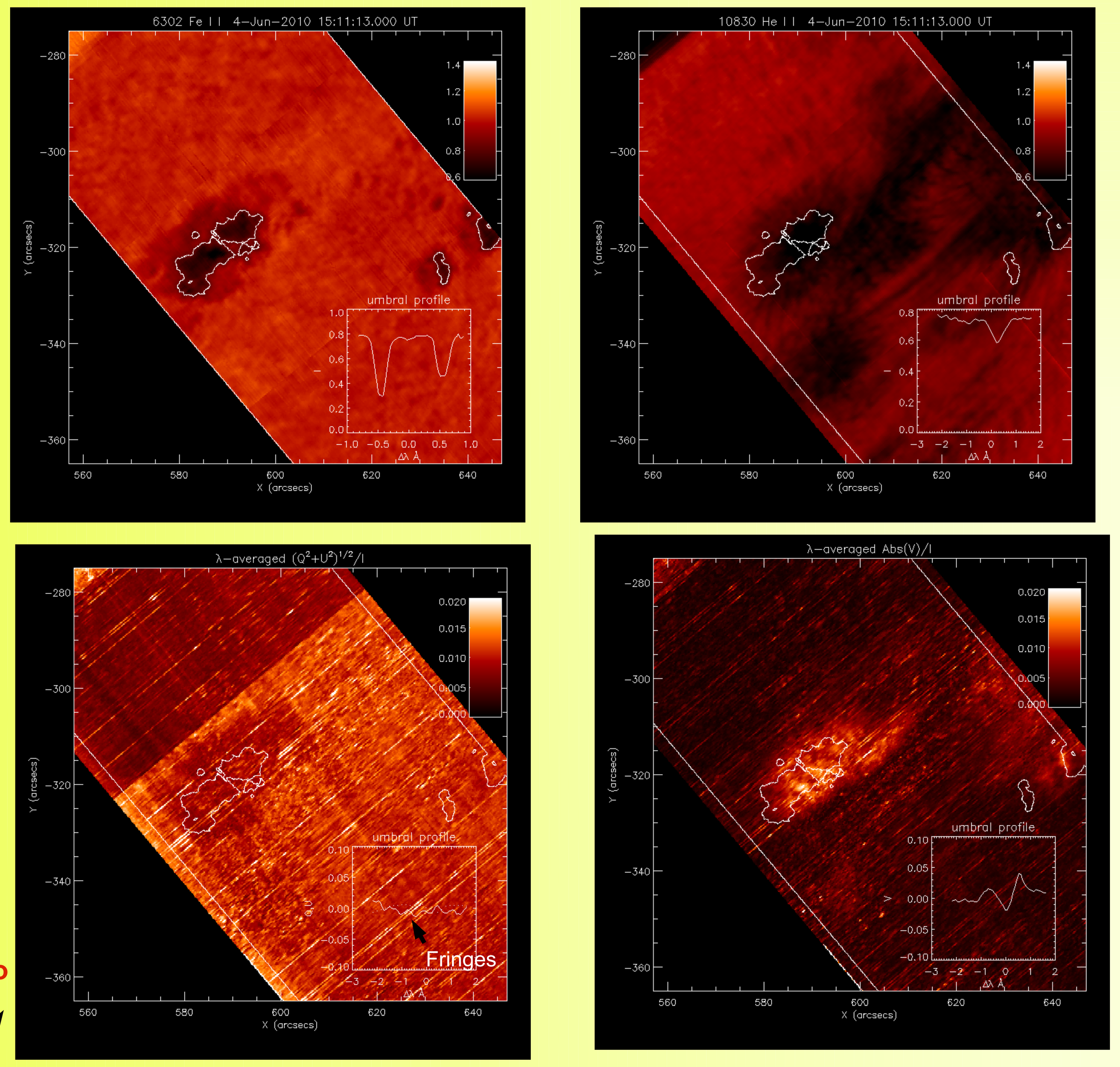
- NOAA 11076 from W28 S19 (3 June) to the limb (11 June)
- NOAA 11077 from W40 N10 (5 June) to the limb
- NOAA 11078 from W42 S19 (8 June)

-These are compact active regions



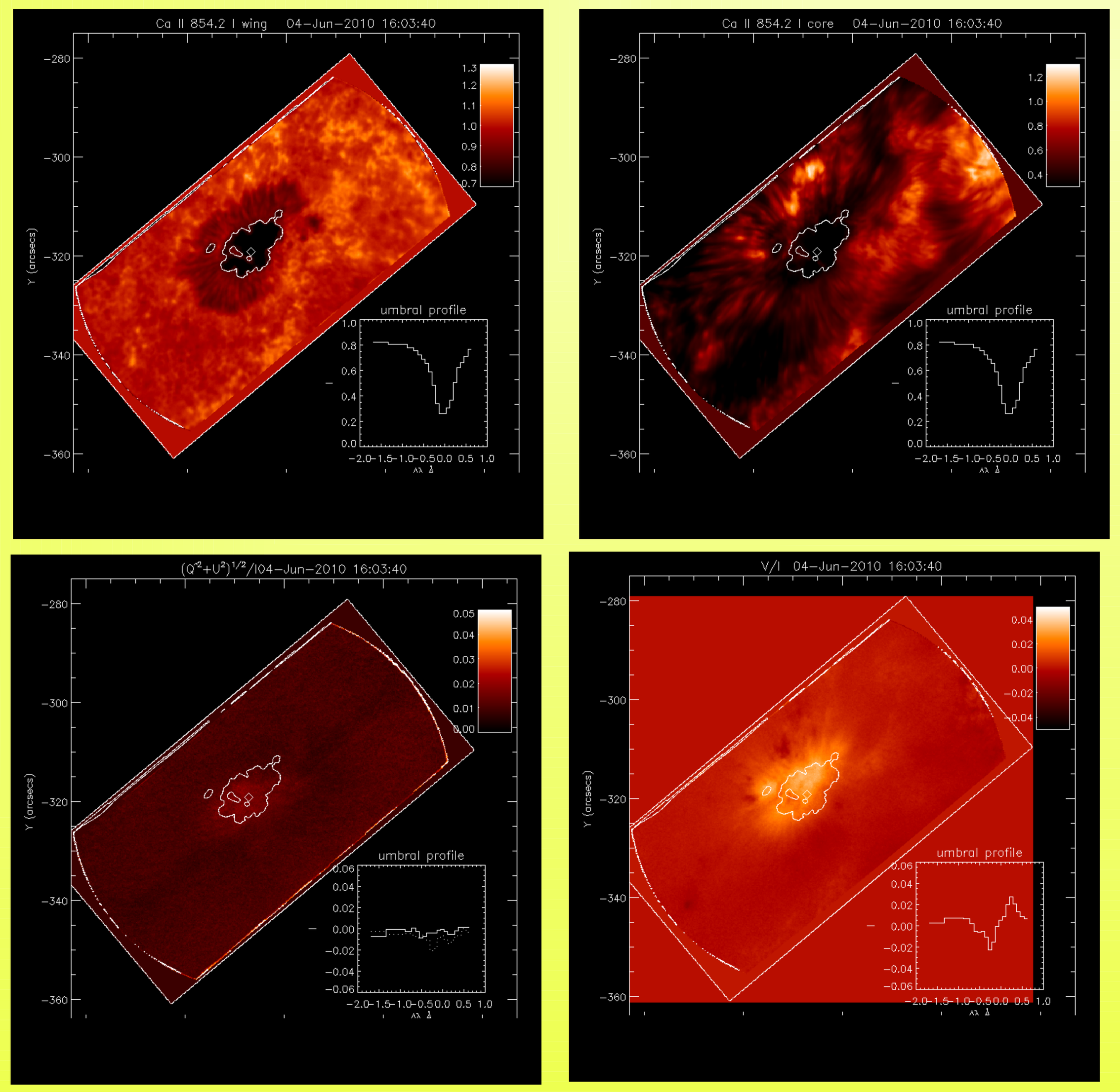
FIRS a 4-slit scanning slit spectropolarimeter

- Jaeggli, Lin, Kuhn, Mickey (IfA Hawaii), Hegwer, Rimmele, Penn (NSO)
- Newly commissioned at the Dunn Solar Telescope, Sunspot NM
- Fe I 630.15 and 630.25 lines (photospheric vector **B**): R ~600,000
- He I 1083 lines (chromospheric/coronal base vector **B**): R ~300,000
- Maps of 145 steps of 10s duration, spanning 175" x 75"
- 4 state polarization modulation
- 1083 QUV, B sensitivities per 0.33x0.33" pixel, Σ 25 wavelengths/profile
  - σ(QUV)=0.0009 I_c (random, high frequency noise)
  - σ(QUV)=0.0014 I_c (measured rms fringes/systematic errors)
  - $\sigma(B_{LOS})$~ 5-10 G (formal)
  - Fringes+noise dominate QU => no vector field (but see below)



IBIS Fabry-Pérot spectropolarimeter

- Ca II 854.2 nm, photospheric/chromospheric vector **B**: R >200,000
- Images 40"x80", scans 20 wavelengths 6 polarization states, dual beam, 34 s cadence
- 854.2 Sensitivity per 0.17"x0.17" pixel
  - σ(QUV)=0.006 I_c (photon noise limited)
  - $\sigma(B_{LOS})$~38 G (for one 34s scan), but small crosstalk
  - Similar to FIRS 1083, but acquired *every 34 s with superior image quality*



MEASURING CHROMOSPHERIC VECTOR FIELDS: B(strength), θ (inclination), φ (azimuth)

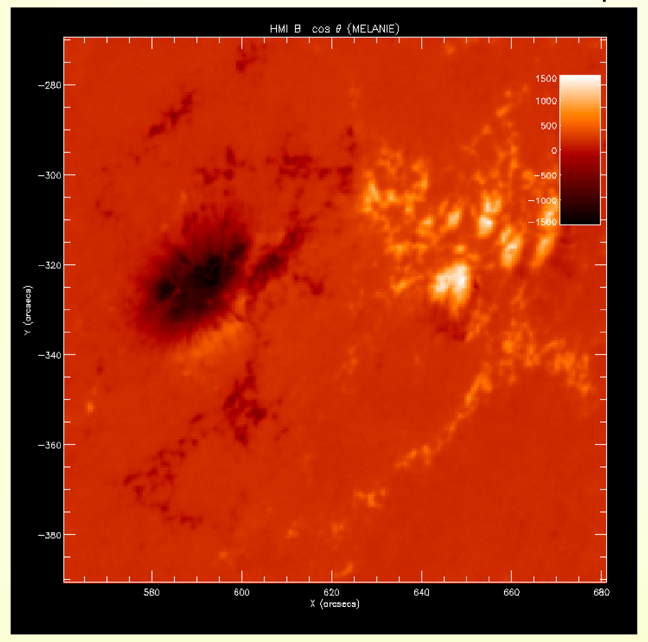
Line	region	Product (technique)	instrument
Fe I 6302	photosphere	Vector **B** (Milne-Eddington inversions + NLFFF extrapolations)	HMI/SDO
Ca II 8542	chromosphere	Vector **V** (**fibril kinematics**) Vector **B** (not done - requires NLTE inversions)	IBIS
He I 10830	Chromosphere/ Coronal base	B_{LOS} (HAZEL inversions)	FIRS

Critical Assumptions

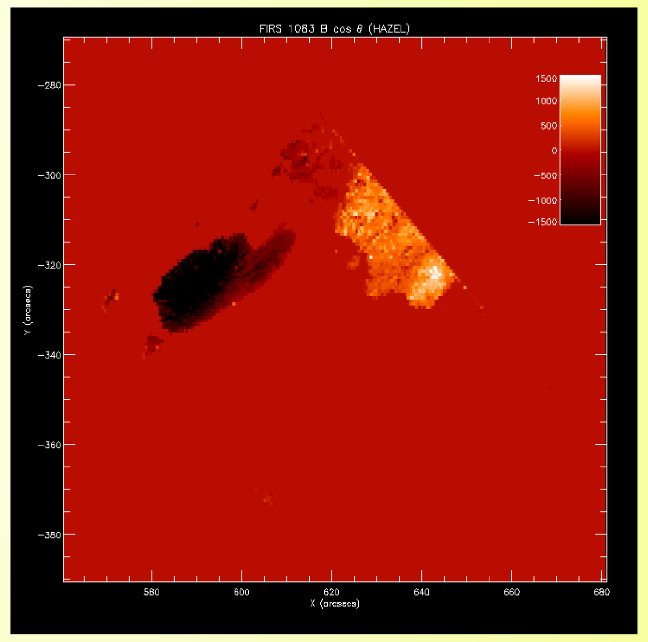
- *vectors V and B are parallel (or anti-parallel)*
- *Ca II and He I lines form in the same overall hydromagnetic structure.*

- FIRS I(QU)V → B cos θ, HAZEL inversions of 1083, z ~ 2Mm ?
- IBIS (QU) fibrils→ φ; kinematics → θ,φ; V,I → B cos θ

B cos θ VERY crude, inversions required

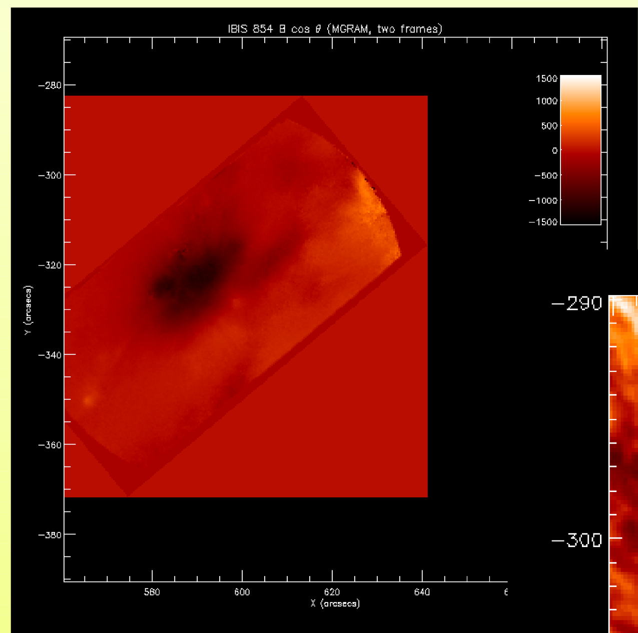


Photosphere inversion



Coronal base Inversion for B cos θ only

Strong fields



chromosphere
Ca II magnetogram

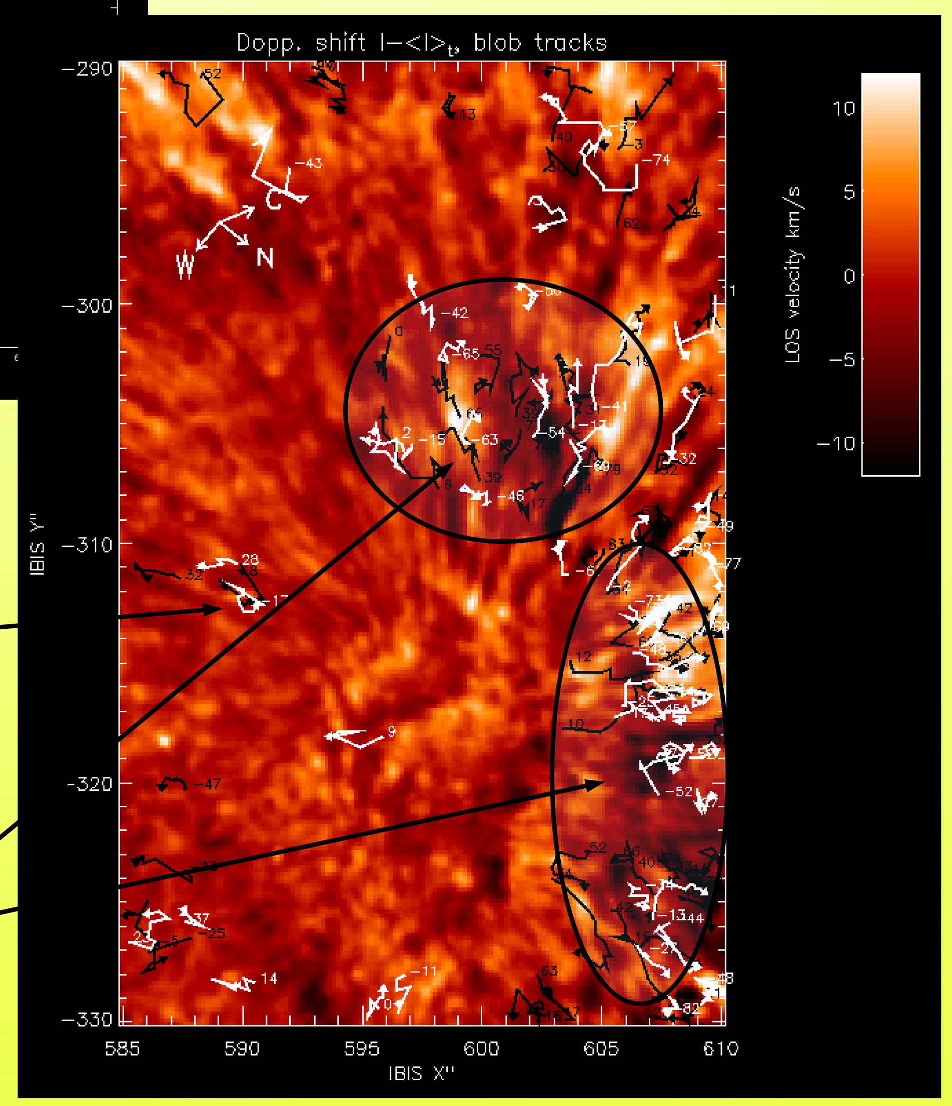
Chromospheric Vector velocity fields → θ,φ

Feature tracking (YAFTA) → φ
+Doppler shifts → θ

White=bright features tracked
Black=dark

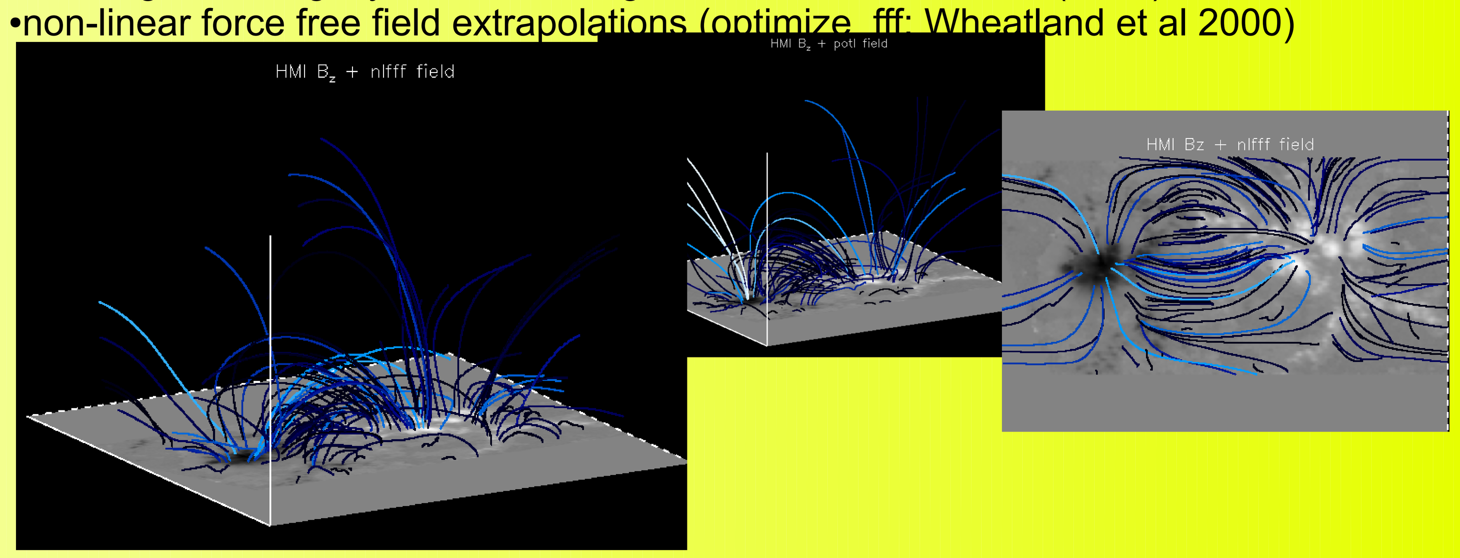
Refined algorithms are needed

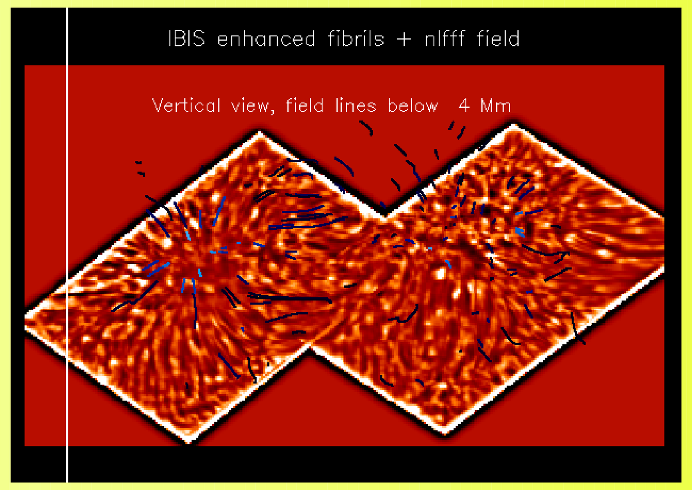
Somewhat coherent velocity patterns aligned with fibril morphology



FORCE FREE FIELDS FROM HMI/SDO vs DATA

- MELANIE inversions of projected data (normal=z direction)
- 180 degree ambiguity resolved using Leka, Barnes & Crouch (2009)
- non-linear force free field extrapolations (optimize, fff; Wheatland et al 2000)





These NLFF solutions are similar to potential

Only field lines below 4Mm height are shown

NLFF fields:
- shorter than fibrils: lie too high in general θ too large
- frequently have incorrect φ

CONCLUSIONS

In this first analysis of successful joint FIRS/IBIS chromospheric observations from June 2010:

- Fibril structure confirms both 854 and 1083 lines form mostly in low β conditions (at least Stokes I, if not QUV)
- Full chromospheric inversions are not yet possible, requiring higher S/N data
- Thus we are presently unable to measure directly vector fields in low β conditions
- Nevertheless, at the coronal base, we have found
  - Morphological constraints (magnetic azimuth φ from fibrils)
  - Kinematic constrains (velocity vector elevation θ and azimuth φ from fibril motions)
  - B cos θ from 1083nm
  - Consistency between the above
  - Sunspot fields at coronal base differ measurably from NLFFF/potential states

We conclude that, while challenging, this observational approach to determining hydromagnetic conditions at the coronal base is promising.

We are learning how to optimize the new FIRS instrument to increase s/n ratios

We intend to refine and aggressively pursue this mode of attack during the SDO and future IRIS missions.

A near-IR Fabry-Pérot system for 1083nm is highly desirable (Judge 2010 Decadal Survey White Paper)

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