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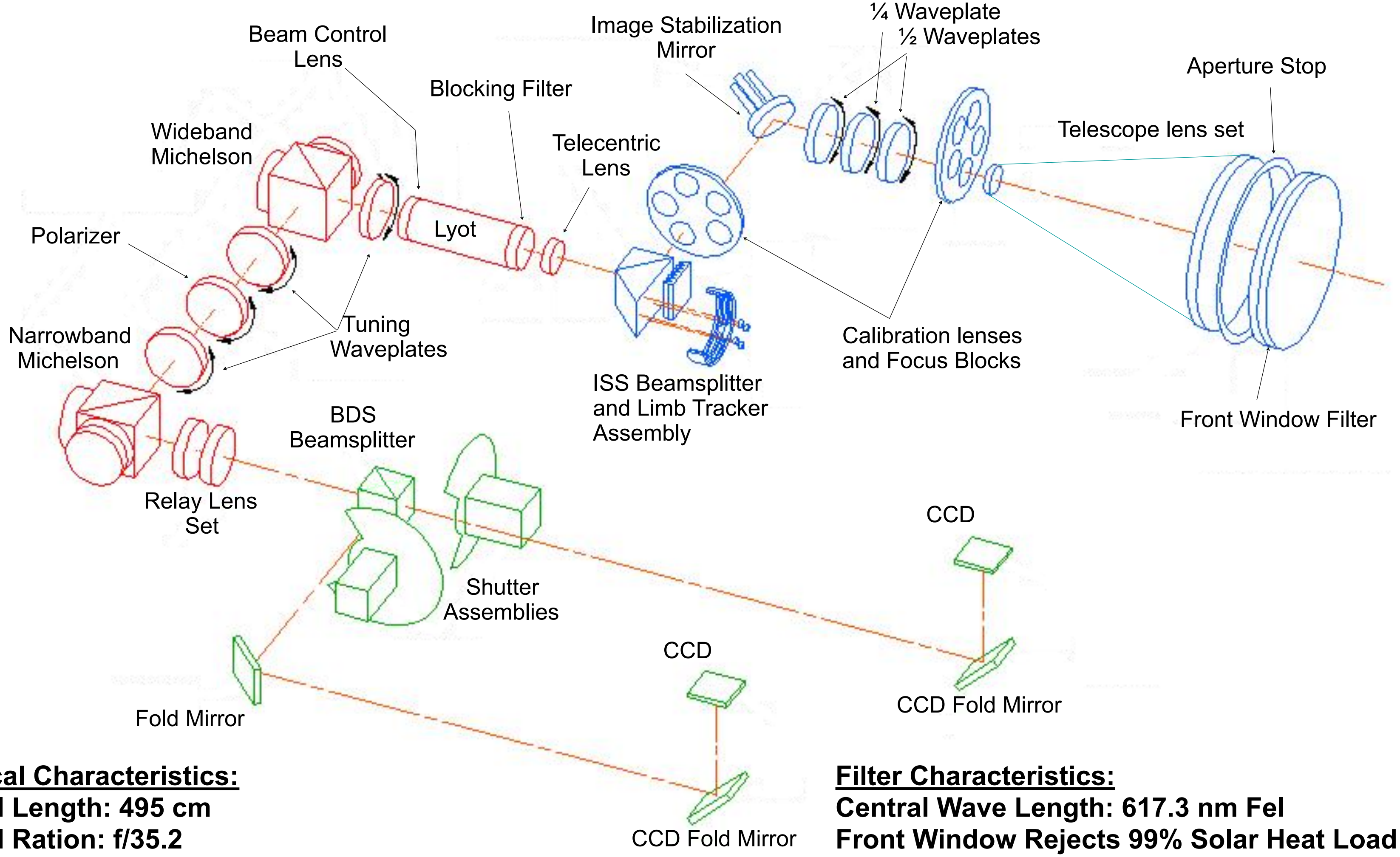
Solar Storms & Terrestrial Impacts Center

HMI Instrument, Pipeline Data Products, and Space Weather Relevance

Yang Liu and HMI team
Stanford University and other places

Instrument Overview – Optical Path

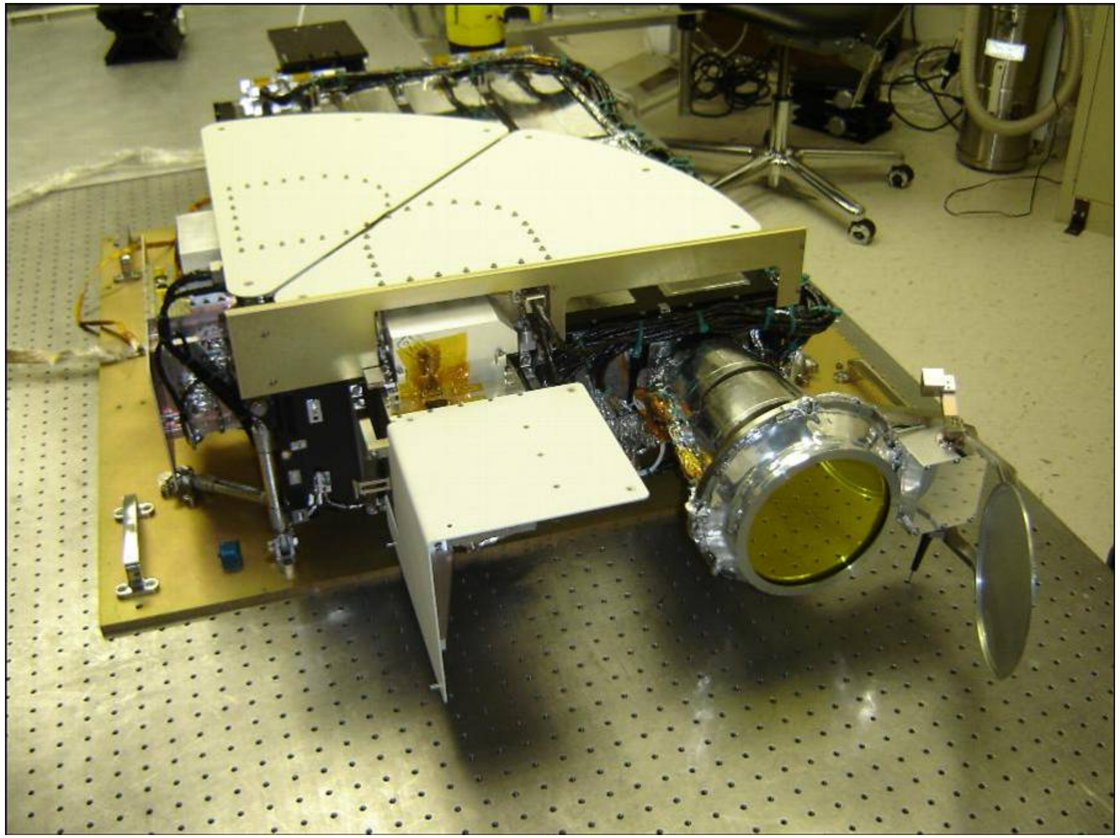


<u>Optical Characteristics:</u>
Focal Length: 495 cm
Focal Ration: f/35.2
Resolution: 1”
Re-imaging Lens Magnification: 2
Focus Adjustment Range: 16 steps

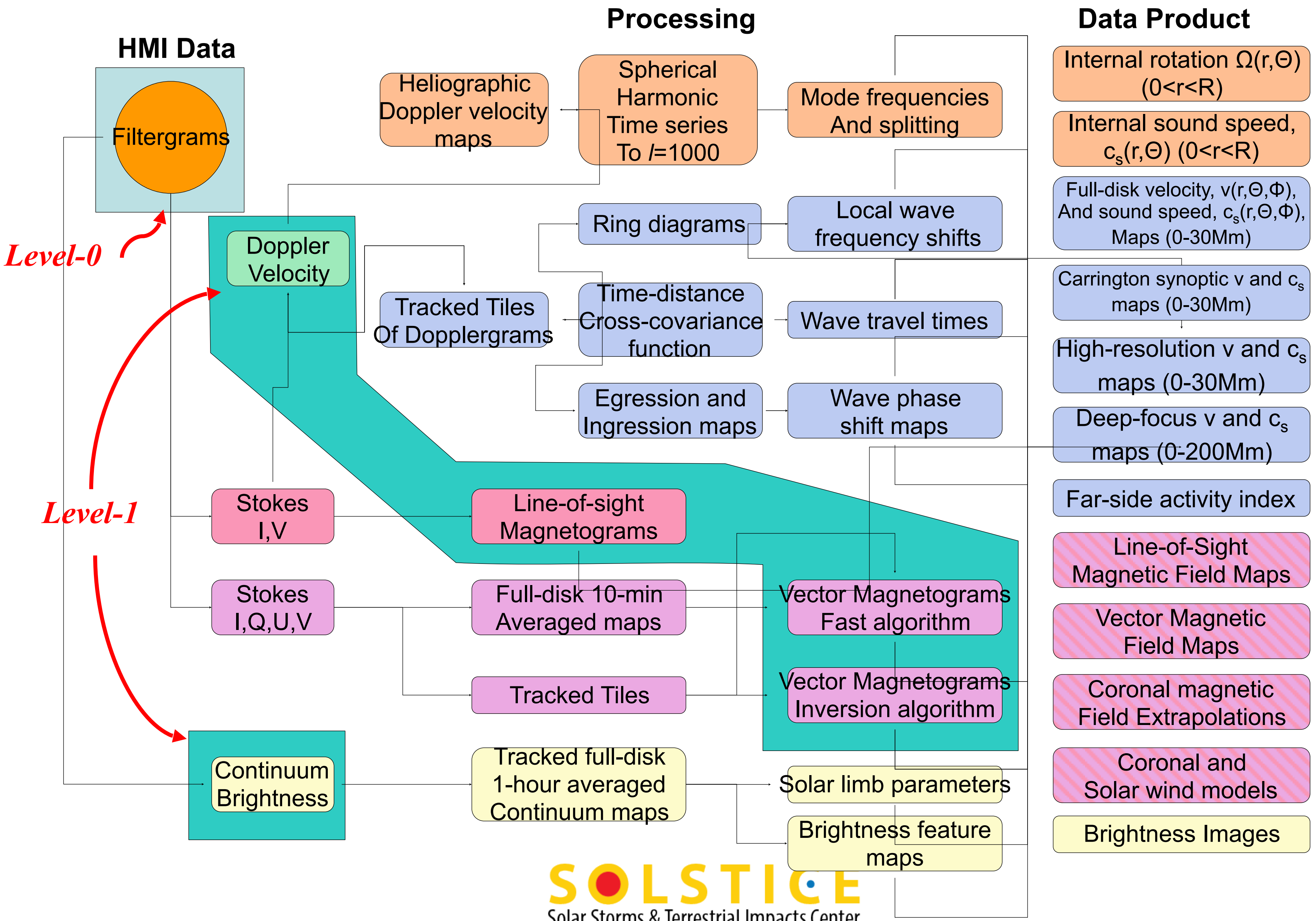
<u>Filter Characteristics:</u>
Central Wave Length: 617.3 nm FeI
Front Window Rejects 99% Solar Heat Load
Bandwidth: 0.0076 nm
Tunable Range: 0.05 nm
Free Spectral Range: 0.0688 nm

Summary of instrument properties

- **Filtergraph**
- **4096x4096 full disk coverage**
- **6173 FeI line**
- **0.5” pixels, 1” optical resolution**
- **76mA filter profiles**
  - Generally spaced at 69mA
- **Continuous coverage (>95%)**
- **Doppler and LOS at 45s cadence**
- **Full Stokes at 90s-135s cadence**
  - About 2e-3 on (Q,U,V) in 135s
  - About 1e-3 in 12 minutes
- **Uniform quality**
- **95% temporal coverage**
  - Eclipses are main problem



HMI – JSOC-SDP Pipeline



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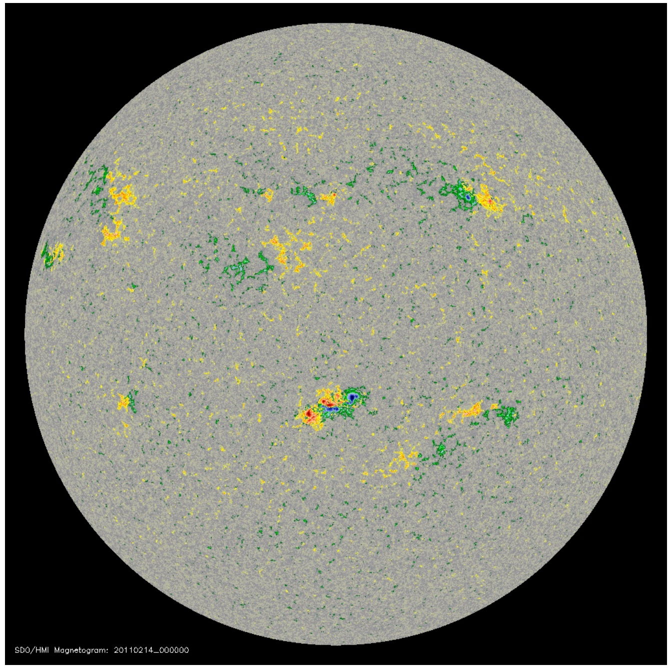
HMI Observables

- Continuum: Full disk with a cadence of 45-second or 720-second.
- Line depth: Full disk with a cadence of 45-second or 720-second.
- Line width: Full disk with a cadence of 45-second or 720-second.
- Dopplergram: Full disk with a cadence of 45-s or 720-s.
- LOS Magnetogram: Full disk with a cadence of 45-s or 720-s.
- **Vector magnetic field: Full disk with a cadence of 135-s/90-s or 720-s.**



Full Disk Vector Magnetogram Processing: Inversion

- Data information (basic)
  - Filtergram type instrument;
  - Fe I 6173 A spectral line (g = 2.5);
  - 6 wavelength positions; 6 polarization states;
  - 135/90 secs per set of [I, Q, U, V] (720-sec average currently);
- Inversion (Very Fast Inversion of the Stokes Vector, VFISV, Borrero+ 2011)
  - In forward problem:
    - Milne-Eddington approximation;
    - Among the 10 physical parameters, two are set to constant (damping and magnetic filling factor);
  - The inversion scheme:
    - Based on the Levenberg-Marquardt minimization algorithm.

INVERSION: Very Fast Inversion of the Stokes Vector (VFISV; Borrero+ 2011)

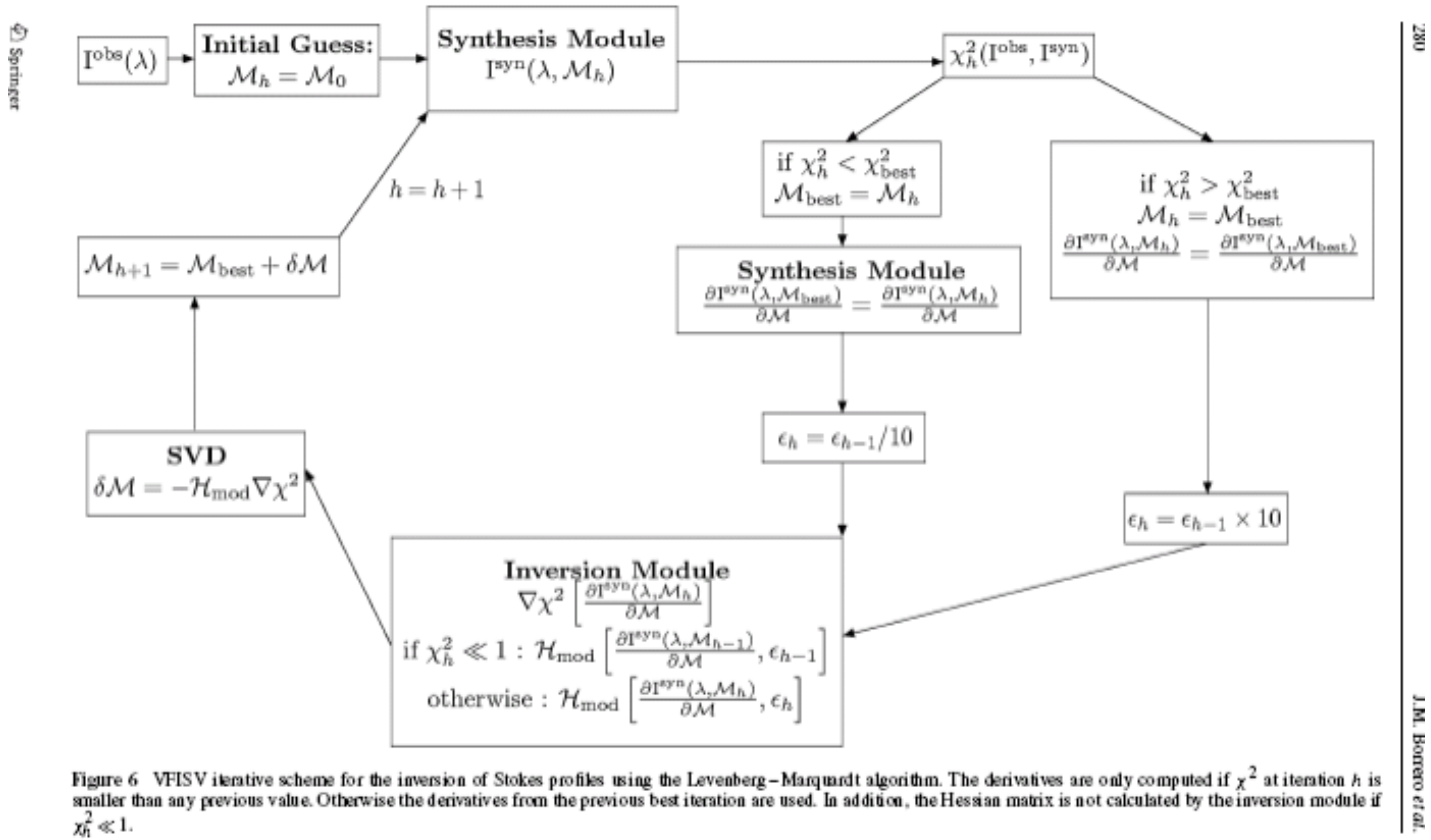


Figure 6 VFISV iterative scheme for the inversion of Stokes profiles using the Levenberg–Marquardt algorithm. The derivatives are only computed if χ^2 at iteration h is smaller than any previous value. Otherwise the derivatives from the previous best iteration are used. In addition, the Hessian matrix is not calculated by the inversion module if $\chi^2_h \ll 1$.

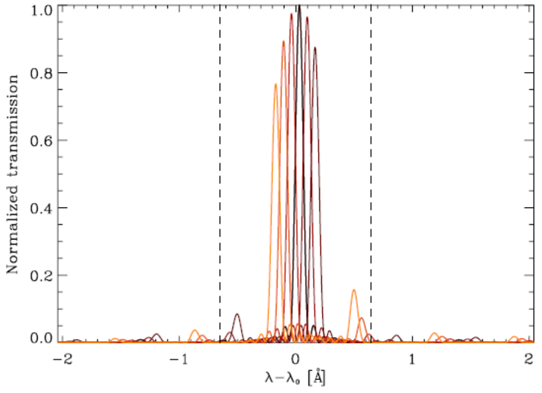
VFISV iterative scheme using the LM algorithm (Borrero et al. 2011)

Updated-VFISV: VFISV-FD10 (Centeno+ 2014)

- Weights selected: [1, 3 ,3, 2] for [I, Q, U, V];
- Regularization of x^2 to minimize double-minima problem;

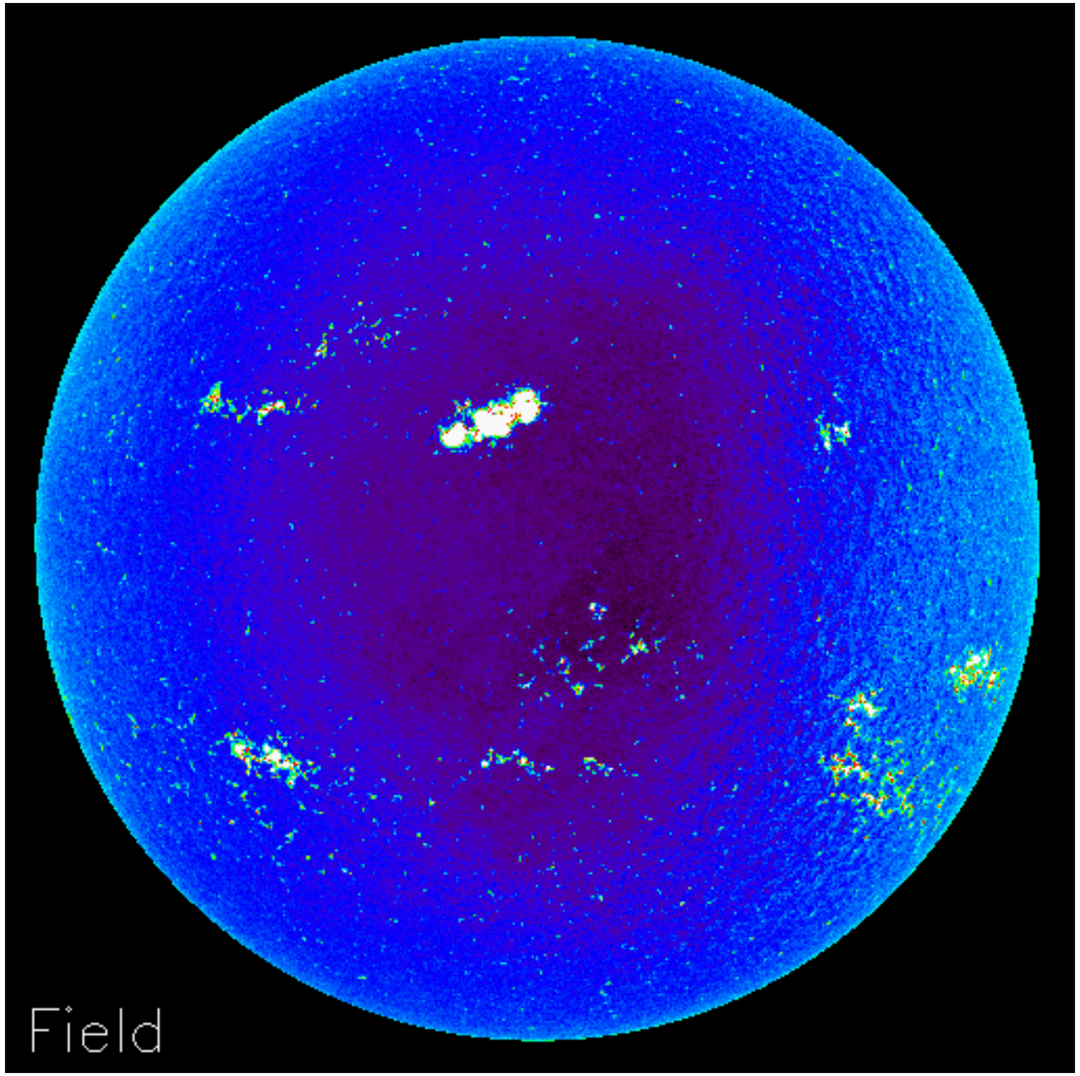
$$\chi^2_{new} = \chi^2_{old} + \varepsilon(\eta_0 C)^2, \text{ where } \varepsilon = 0.002, \text{ C} = 5.$$

- Hybrid approach for calculation of the line profile;
  - Inner (±0.65 mÅ) done using forward modelling;
  - Outer up to ± 2 mÅ done only for Stokes I.
- Variable change to improve code's efficiency;
  - S and S_0 change to $(S + S_0)$ and S_0;
  - η_0 and $\Delta\lambda_D$ change to $(\Delta\lambda_D \cdot \sqrt{\lambda_0})$ and $\sqrt{\lambda_0}$;



Full-disk vector magnetic field

- Field strength
- Inclination
- Azimuth
- Vlos
- Doppler width
- Etq0
- Dampling
- Src-continuum
- Src-gradient
- Chi-sqaure
- Their variances and covariances
- ......



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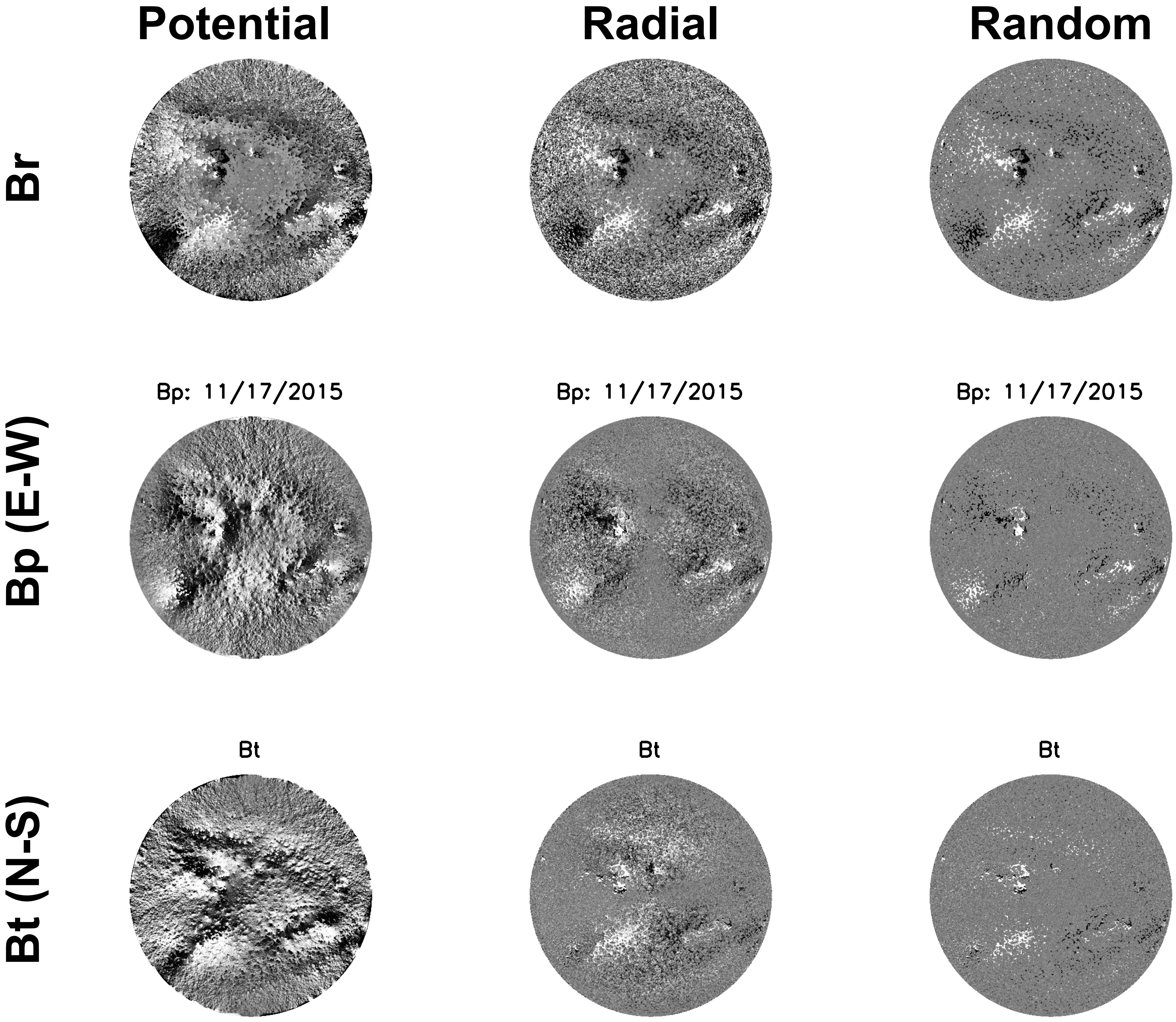
Full Disk Vector Magnetogram Processing: Disambiguation

- HMI uses ``minimum energy' method to disambiguate data for active regions and magnetic features with strong field (Metcalf et al. 1994, 2006, Leka et al. 2009); This method is expensive.

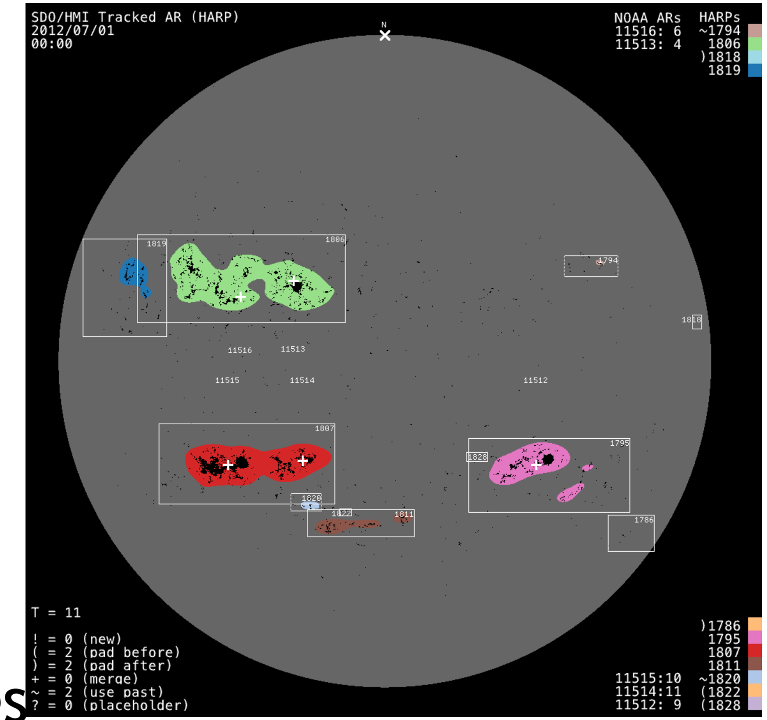
- For rest of the solar disk, we have three choices to disambiguate the transverse field data:
  - Potential field method;
  - Radial acute method; and
  - Random method.



Potential
Radial
Random
Br
Bp (E-W)
Bt (N-S)
Bp: 11/17/2015
Bp: 11/17/2015
Bp: 11/17/2015
Bt
Bt
Bt

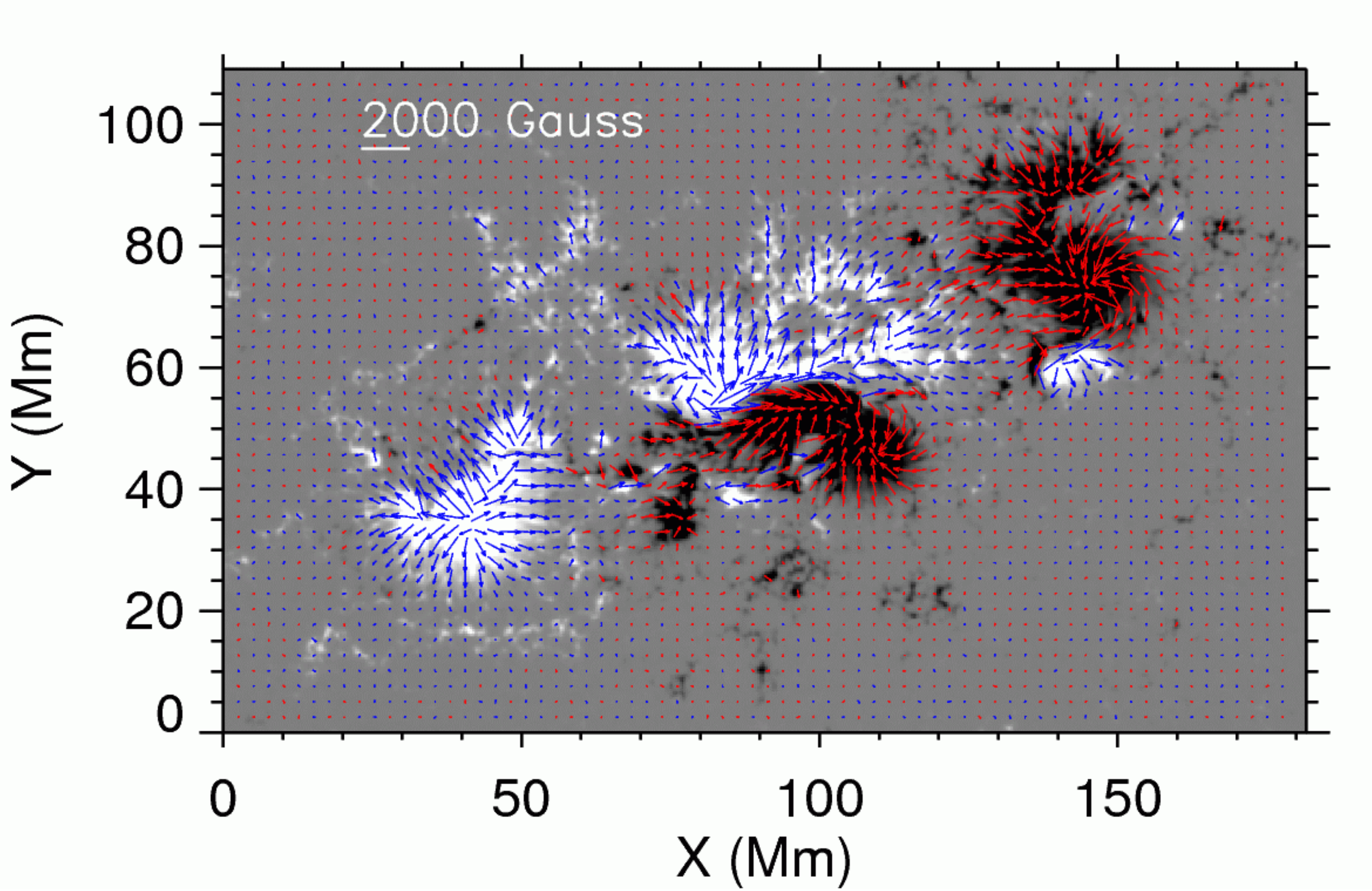
SHARP: Spaceweather HMI Active Region Patch

- Identify HMI Active Region Patch (HARP);
- Retrieve data from HARP geometric information;
- SHARP includes retrieved data and spaceweather parameters;
- Vector data in SHARP includes vector field on CCD coordiantes and mapped to heliographic coordinates with the Lambert Cylindrical Equal-Area projection (CEA).



[CEA example here]

Vector data for AR 11158



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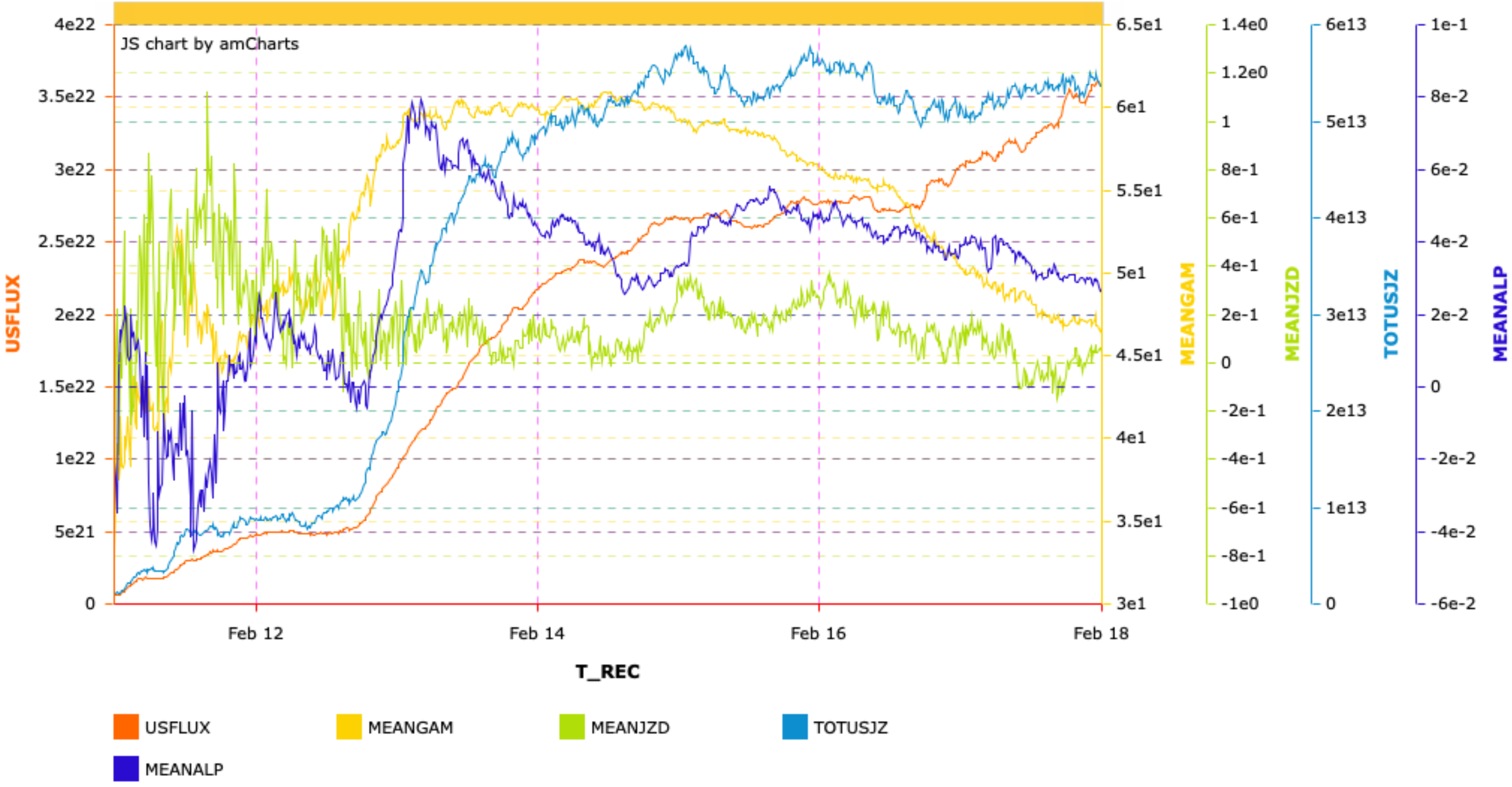
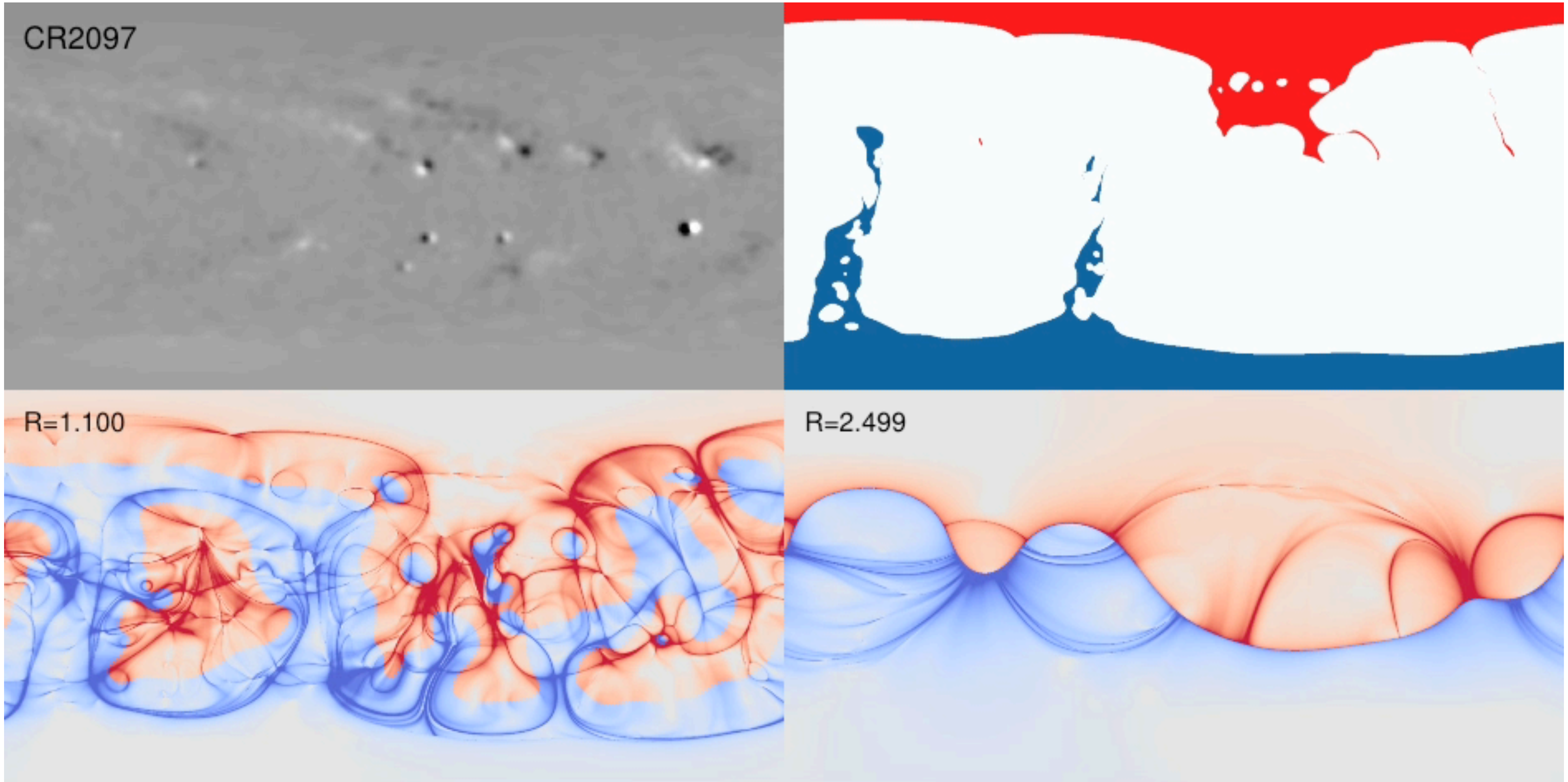
Space Weather Keywords in Sharp Headers

USFLUX Total unsigned flux in Maxwells
MEANGAM Mean inclination angle, gamma, in degrees
MEANGBT Mean value of the total field gradient, in Gauss/Mm
MEANGBZ Mean value of the vertical field gradient, in Gauss/Mm
MEANGBH Mean value of the horizontal field gradient, in Gauss/Mm
MEANJZD Mean vertical current density, in mA/m^2
TOTUSJZ Total unsigned vertical current, in Amperes
MEANALP Total twist parameter, alpha, in 1/Mm
MEANJZH Mean current helicity in G^2/m
TOTUSJH Total unsigned current helicity in G^2/m
ABSNJZH Absolute value of the net current helicity in G^2/m
SAVNCPP Sum of the Absolute Value of the Net Currents Per Polarity in Amperes
MEANPOT Mean photospheric excess magnetic energy density in ergs per cubic centimeter
TOTPOT Total photospheric magnetic energy density in ergs per cubic centimeter
MEANSHR Mean shear angle (measured using B_{total}) in degrees
SHRGT45 Percentage of pixels with a mean shear angle greater than 45 degrees in percent

Space weather keywords for AR 11158



Pipeline Products: Synoptic maps, Coronal holes, Q-maps



courtesy: X. Sun

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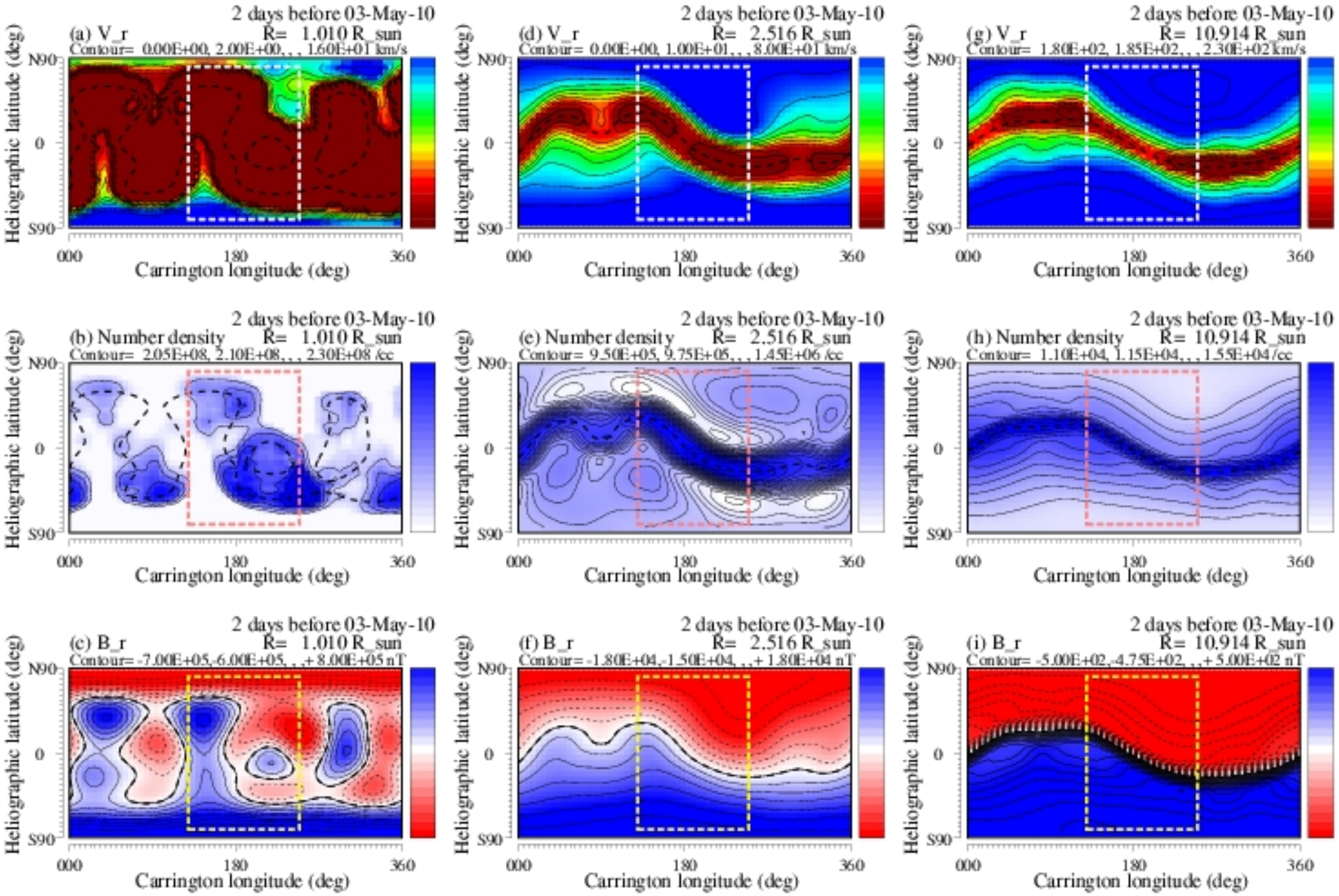
Pipeline Data Products : MHD Solution



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Issues in HMI Data

- Periodicity seen in HMI observables;
- East-west hemisphere asymmetry in vector magnetograms.

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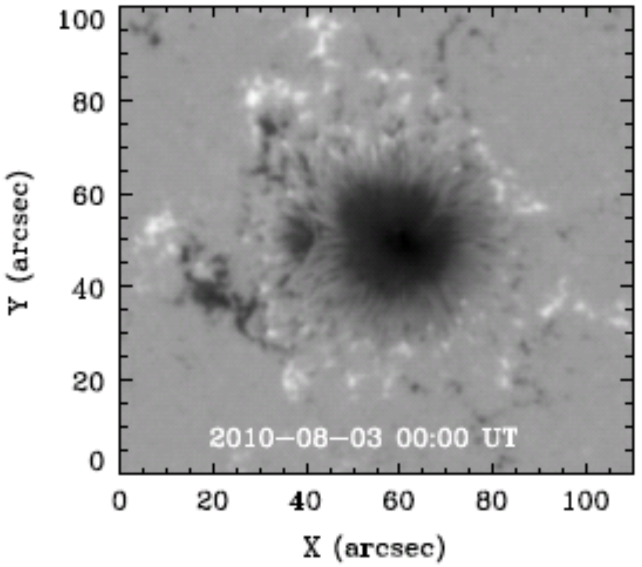
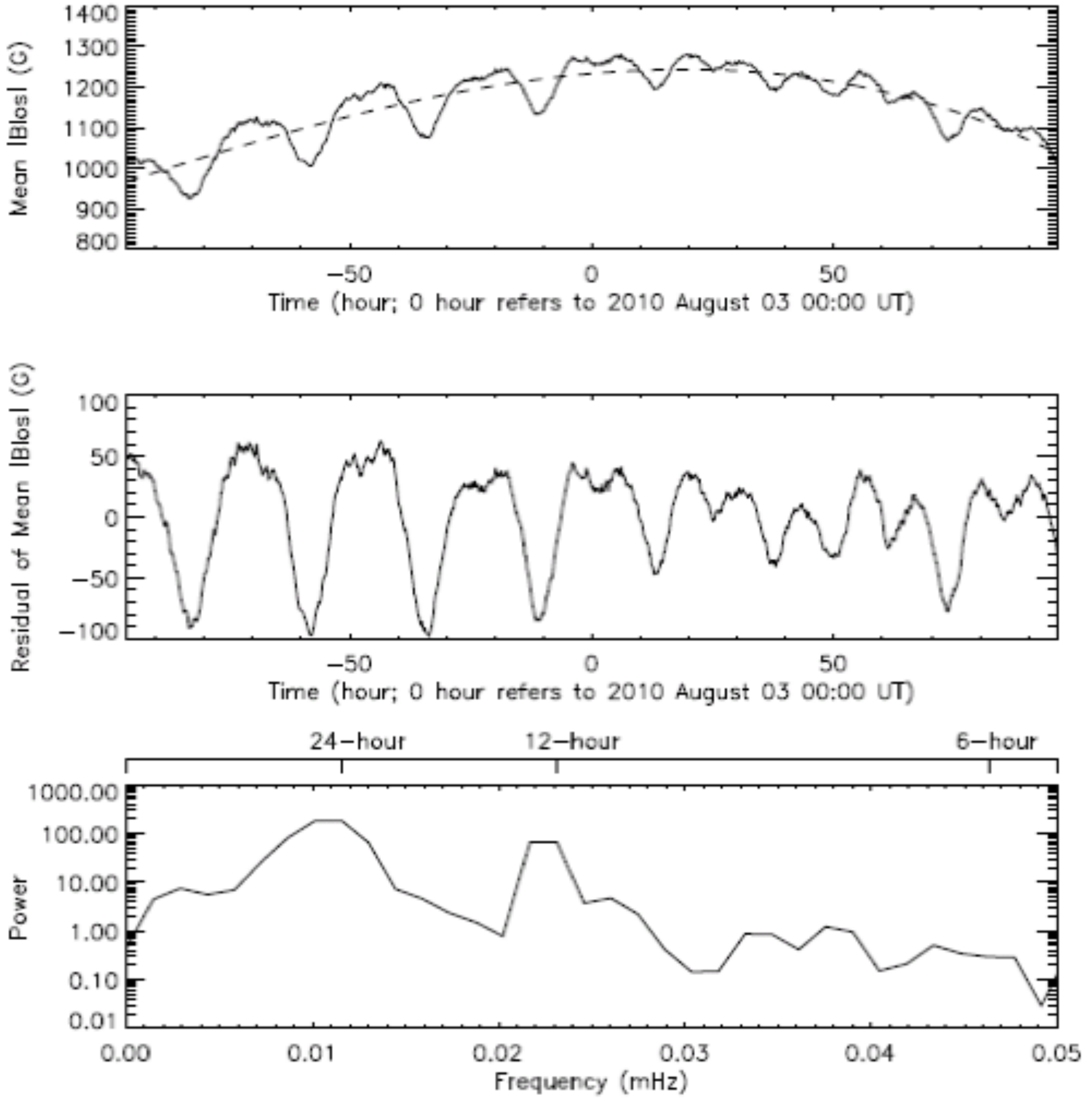
Periodicity in HMI observables



AR 11092 Aug 03 2010



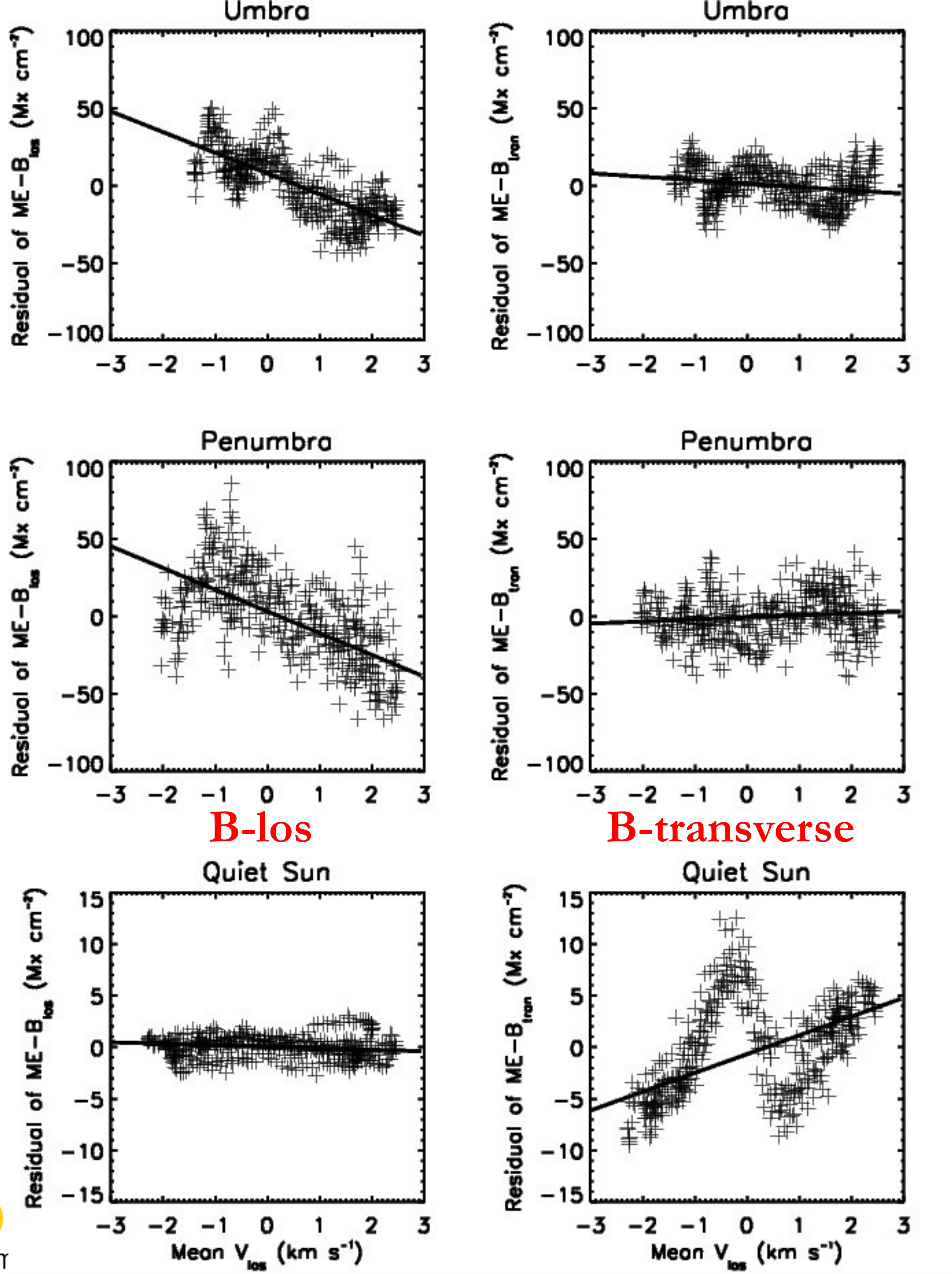
Data used are B-los from 30 July to Aug 06. Periodicity is seen at 24-h and 12-h.

Vector magnetic field measurement:

•B-los determined by Stokes V (LCP & RCP; Magnetic field shifts line profiles, pretty much like Doppler velocity does);

•B-transverse determined by Stokes Q & U (linear polarization; magnetic field only broadens line profiles.)

•Thus B-los and B-transverse might have different response to the oscillation.

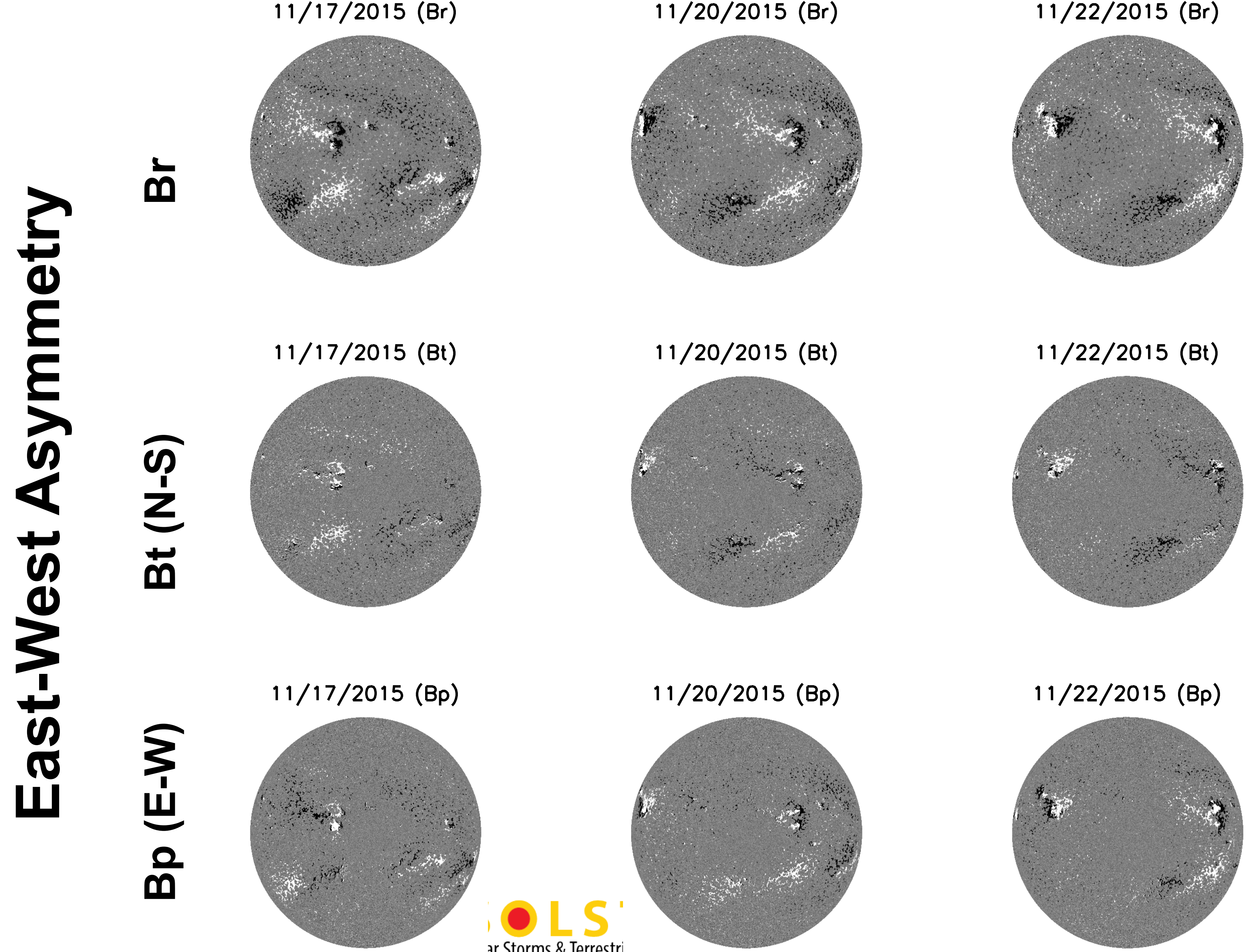


The periodicity depend on velocity, and much more significant in LOS field.

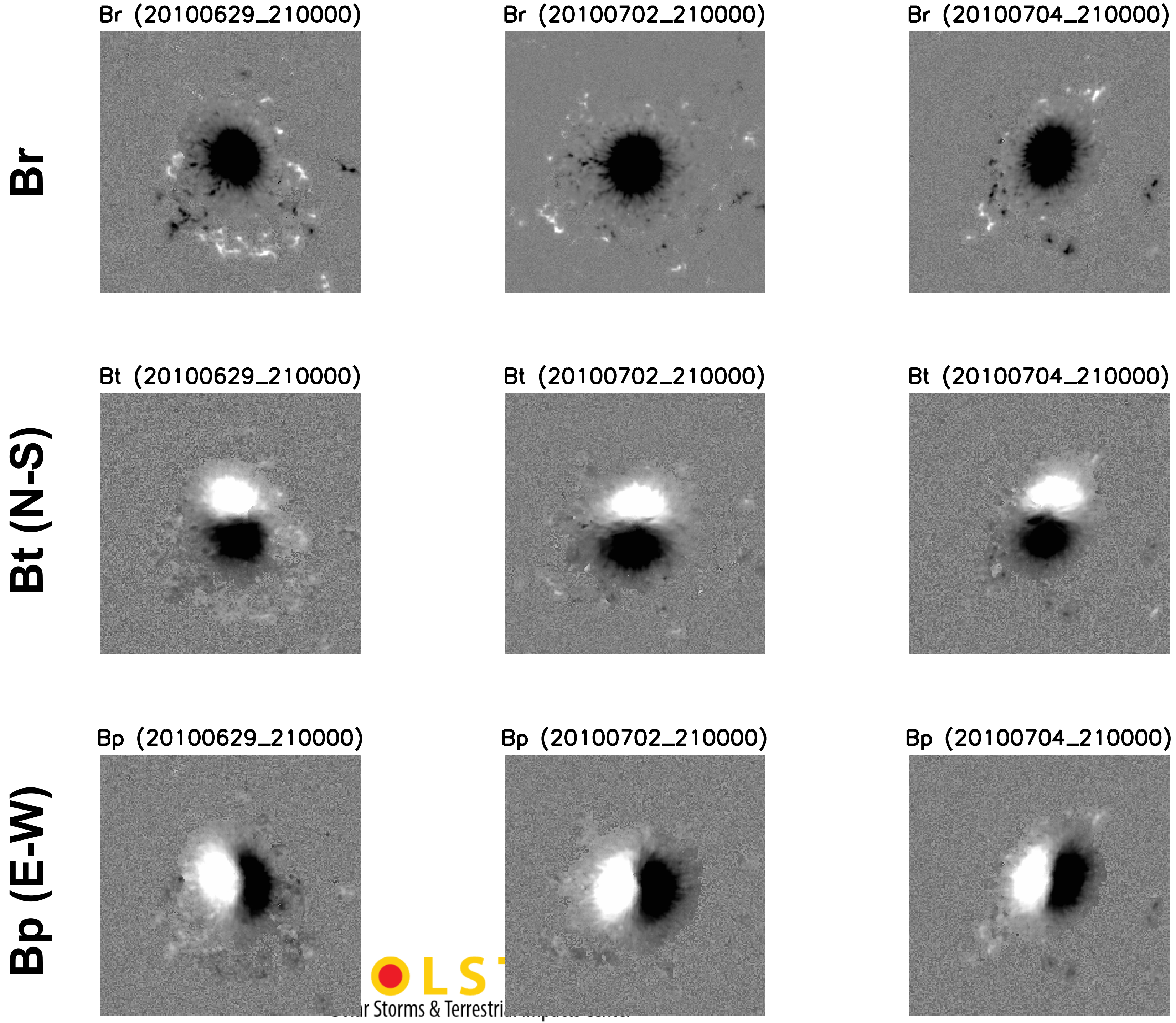
Issues in HMI Data

- Periodicity seen in HMI observables;

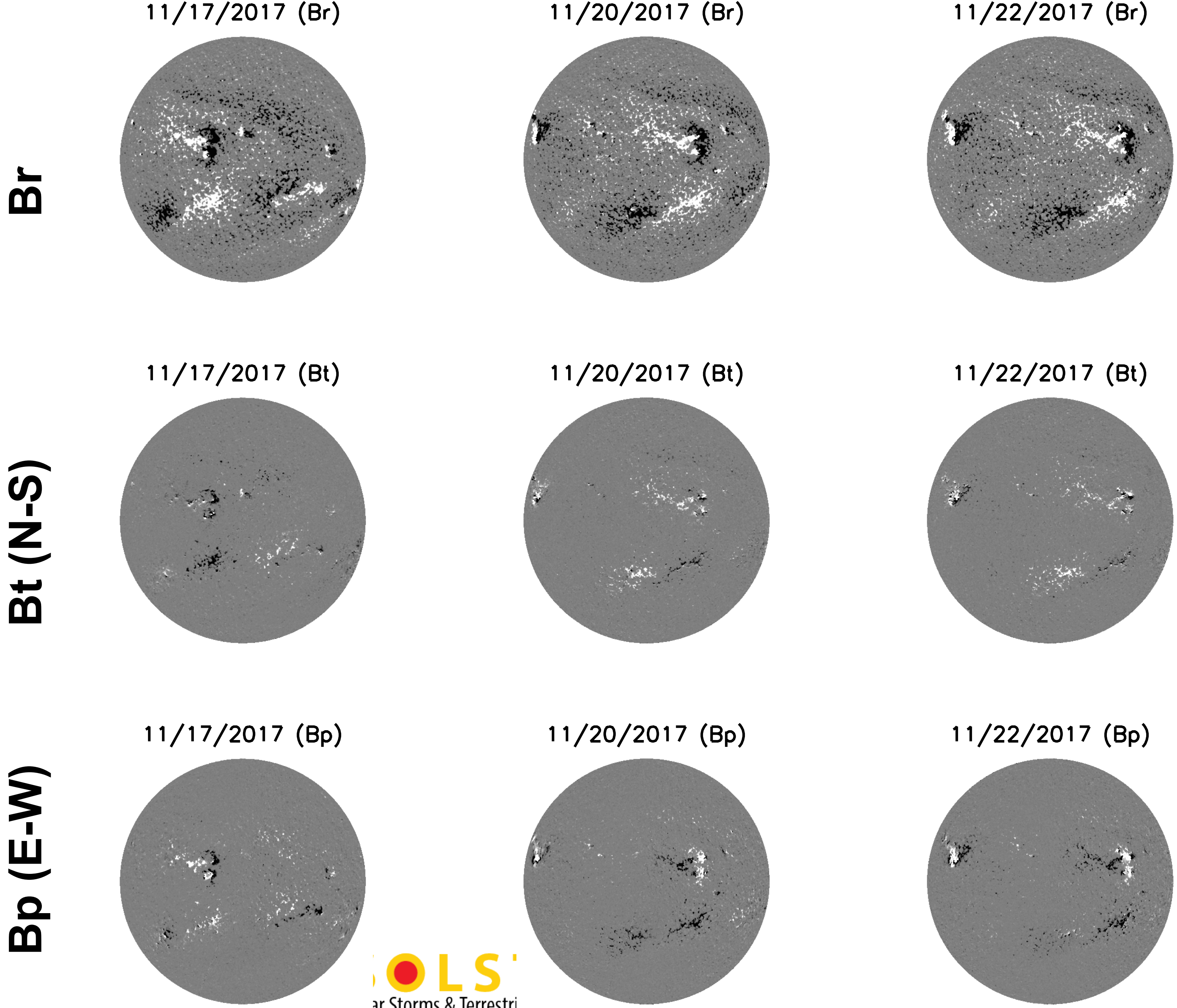
- East-west hemisphere asymmetry in vector magnetograms.


East-West Asymmetry
Br
Bt (N-S)
Bp (E-W)
11/17/2015 (Br)
11/20/2015 (Br)
11/22/2015 (Br)
11/17/2015 (Bt)
11/20/2015 (Bt)
11/22/2015 (Bt)
11/17/2015 (Bp)
11/20/2015 (Bp)
11/22/2015 (Bp)

Not for strong field: AR 11084 from 06/29 to 07/04



Not only in HMI data: SOLIS/VSM



Addressing the issues

- Periodicity:
  - using orbital velocity to minimize the oscillation in LOS observables (Couvidat+ 2012);
  - using empirical relationship to correct oscillation (Hoeksema+ 2014);
  - improving filter profiles to remove the oscillation (Scherrer + 2016).

- East-west hemisphere asymmetry:
  - improve VFISV to include filling factor as a variable to remove the asymmetry.

SOLSTICE will take a new approach to attack these issues!