Strategic Opportunities (Sweet Promises) For Space Weather from Synoptic Full-Disk Vector Magnetogram Data

(and some Sour Realities)

KD Leka

NorthWest Research Associates, USA

previously or currently licensed to run and/or publish with:

Haleakala Stokes Polarimeter (Stokes II)
Huairou Video SpectroMagnetograph
Advanced Stokes Polarimeter
Imaging Vector Magnetograph*
Mitaka Solar Flare Telescope
SoHO/Michelson Doppler Imager
Hinode/SpectroPolarimeter
SOLIS VectorSpectroMagnetograph
SDO/Helioseismic and Magnetic Imager*

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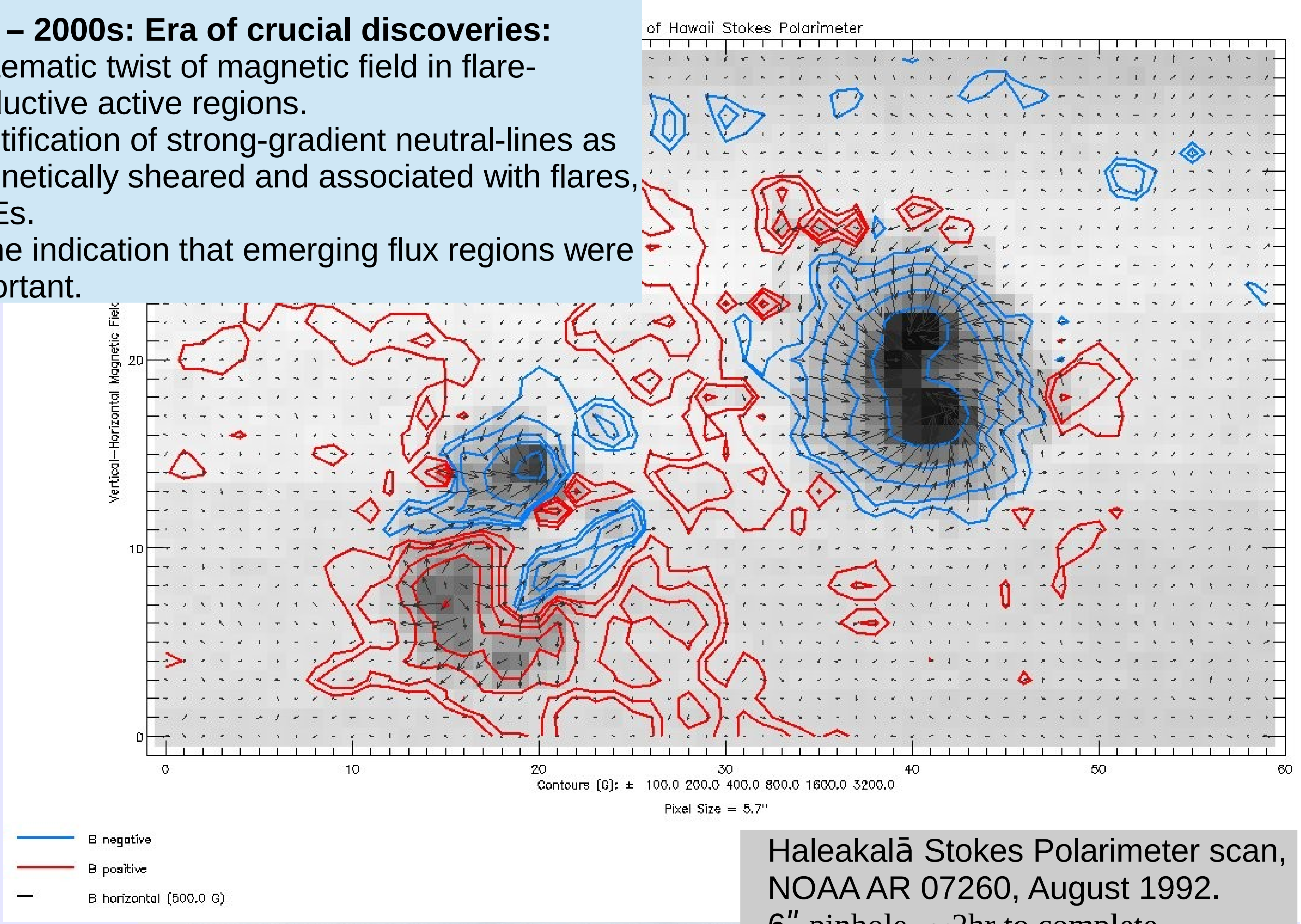
First, how far we've come!

- **1980s – 2000s: Era of crucial discoveries:**
  - Systematic twist of magnetic field in flare-productive active regions.
  - Identification of strong-gradient neutral-lines as magnetically sheared and associated with flares, CMEs.
  - Some indication that emerging flux regions were important.



Haleakalā Stokes Polarimeter scan, NOAA AR 07260, August 1992.
6″ pinhole, ∼2hr to complete.

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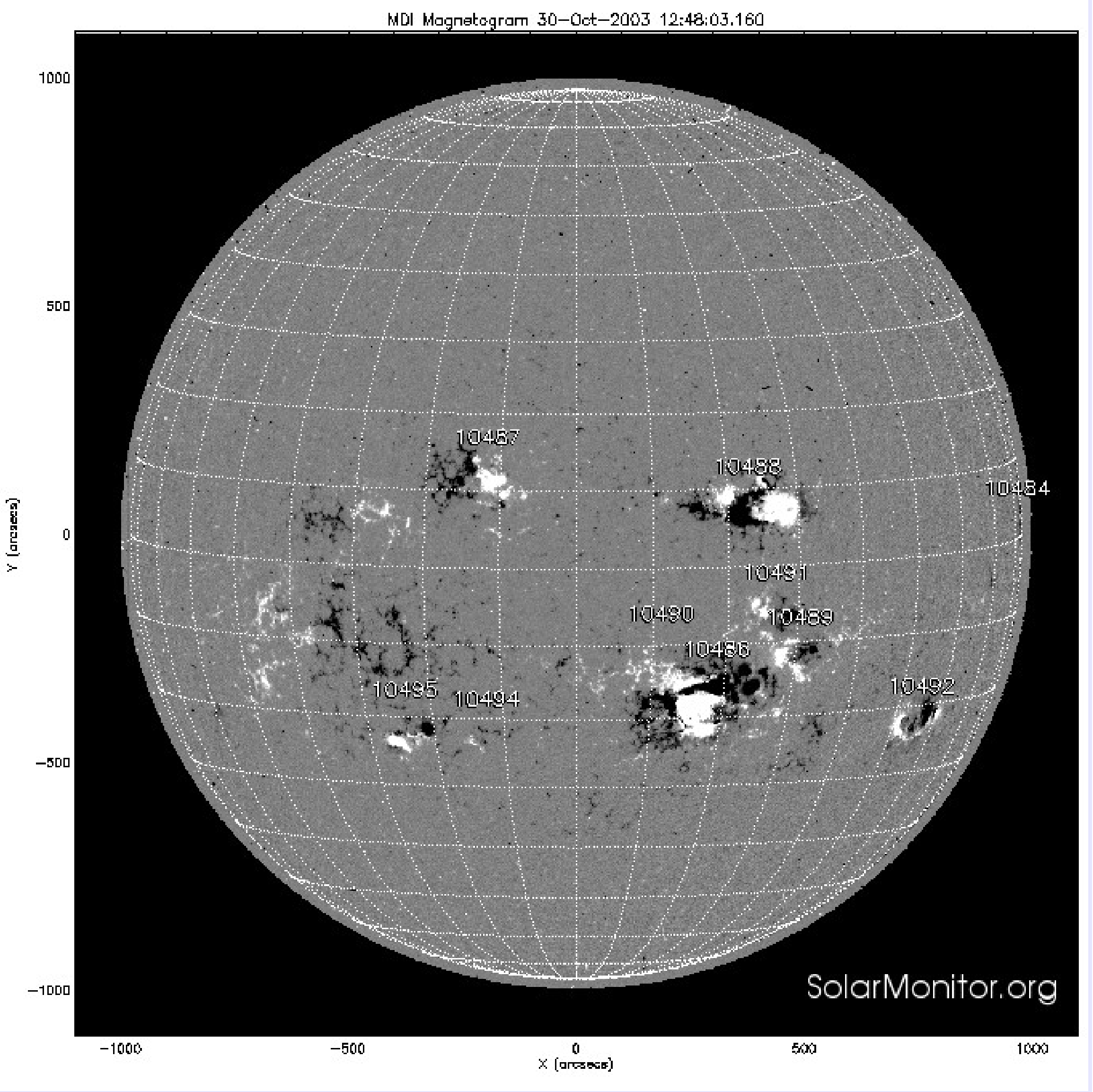
Next came:
Synoptic full-disk line-of-sight data.

- Fair (1/day) to high (1/few min) cadence.
- Poor (5º) to good (1") spatial resolution

Time of: statistics, full-disk (and, with synoptic estimates, whole-sun) models.

Statistics. And "not missing anything" (*huge* advantage of MDI, GONG, now HMI, over single-site observing such as Mt. Wilson, SOLIS).



- Mt Wilson Observatory (1974-2010)
- Wilcox (1976 – present)
- NSO/KP Solar Magnetograph (1974 – 1992)
- NSO/KP SpectroMagnetograph (1992-2003)
- SoHO/MDI (1996-2010)
- NSO/SOLIS VectorSpectroMagnetograph (?? – present)*
- GONG+ network (2001 – present)
- SDO/HMI (2010 – present)*

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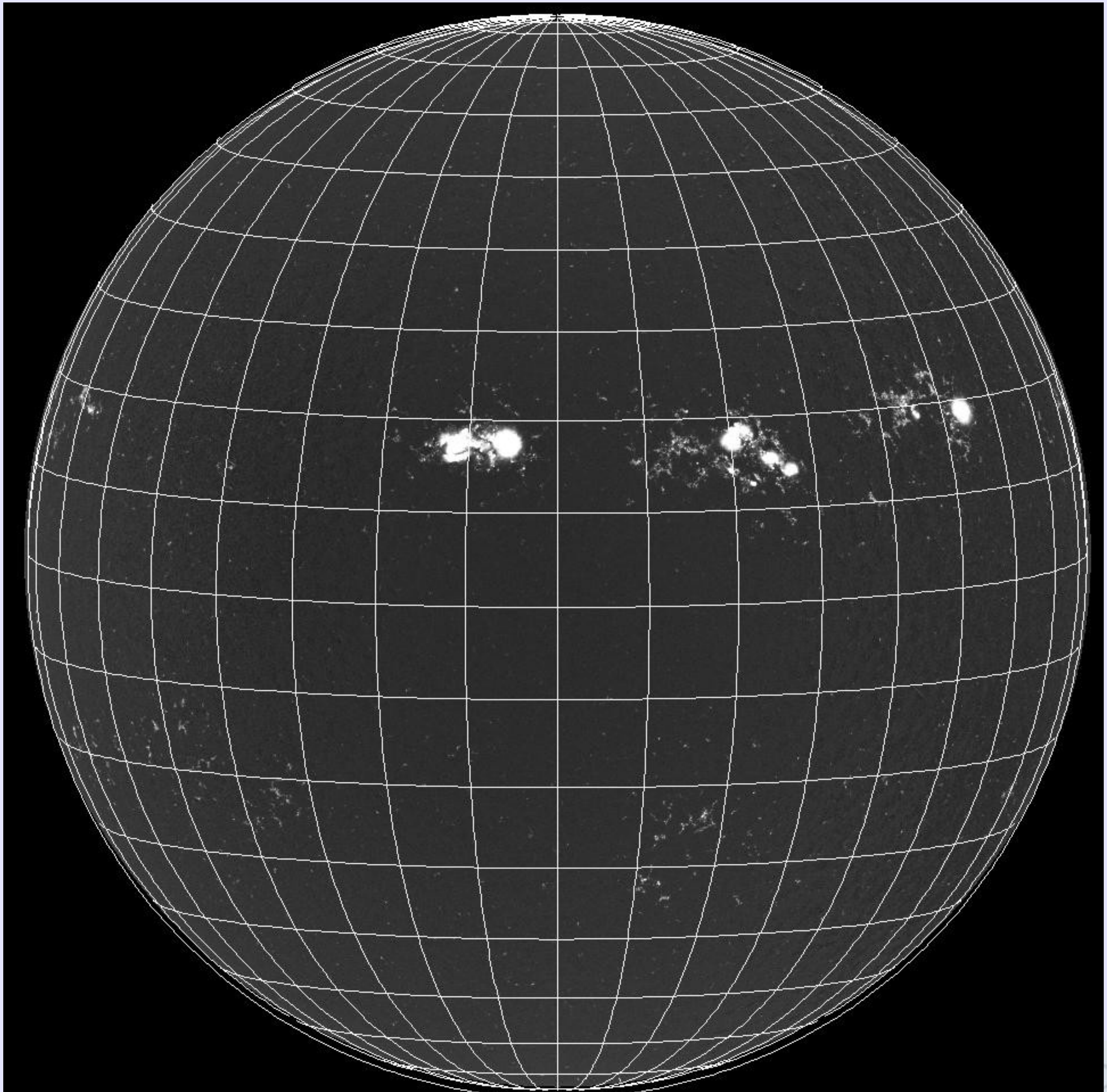
Now: Full-Disk Synoptic Vector Field

Data example: HMI.



Some vector field programs:

- run routinely, but
- limited FOV, observing time, lifetime (Hinode/SP, various ground-based.)

Some are full-disk, but

- limited cadence/coverage). (e.g. SOLIS/VSM, Huairou),

SDO/HMI: respectable

- Cadence,
- Resolution,
- Coverage.
- *But*: limited lifetime.

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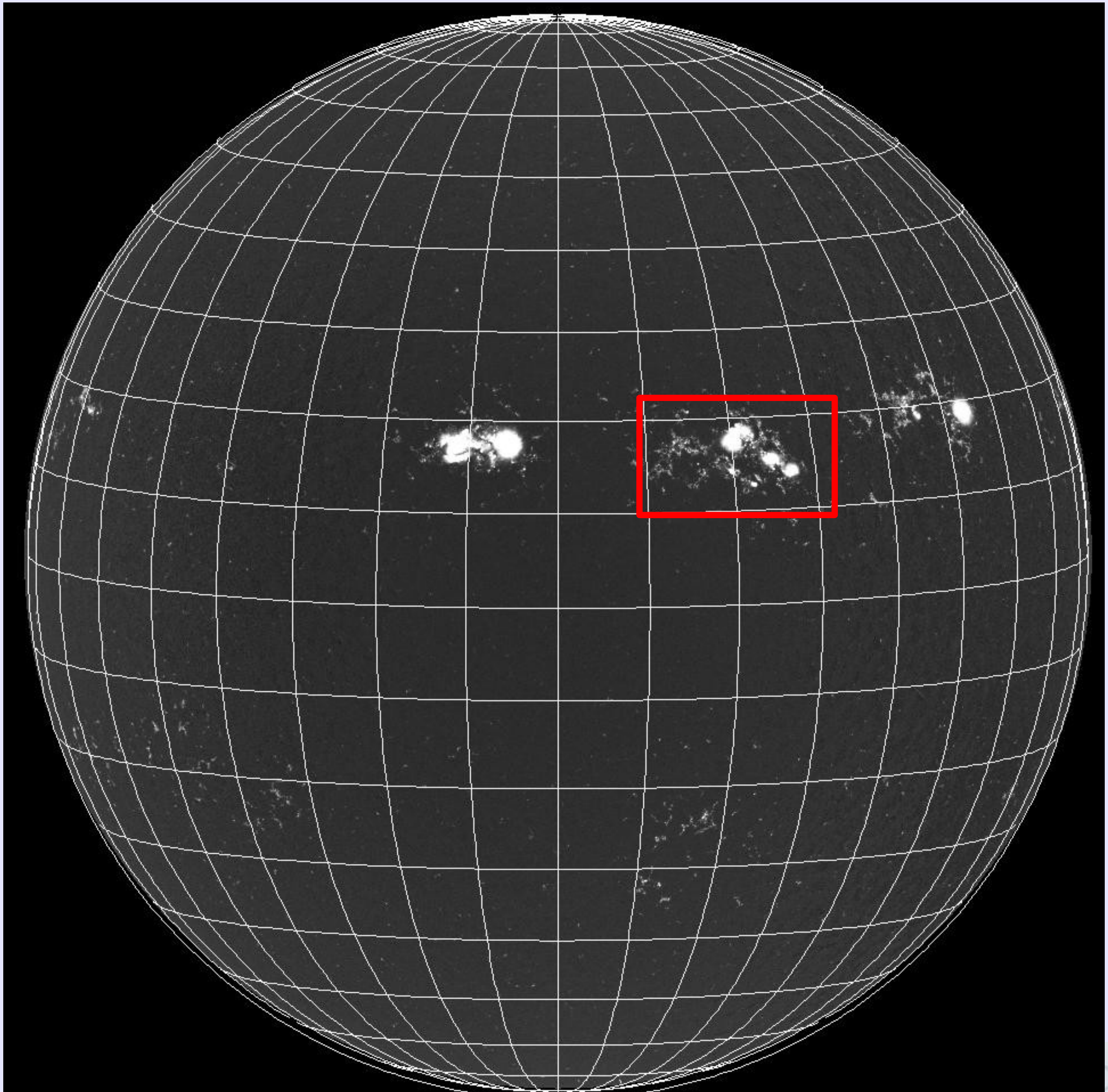

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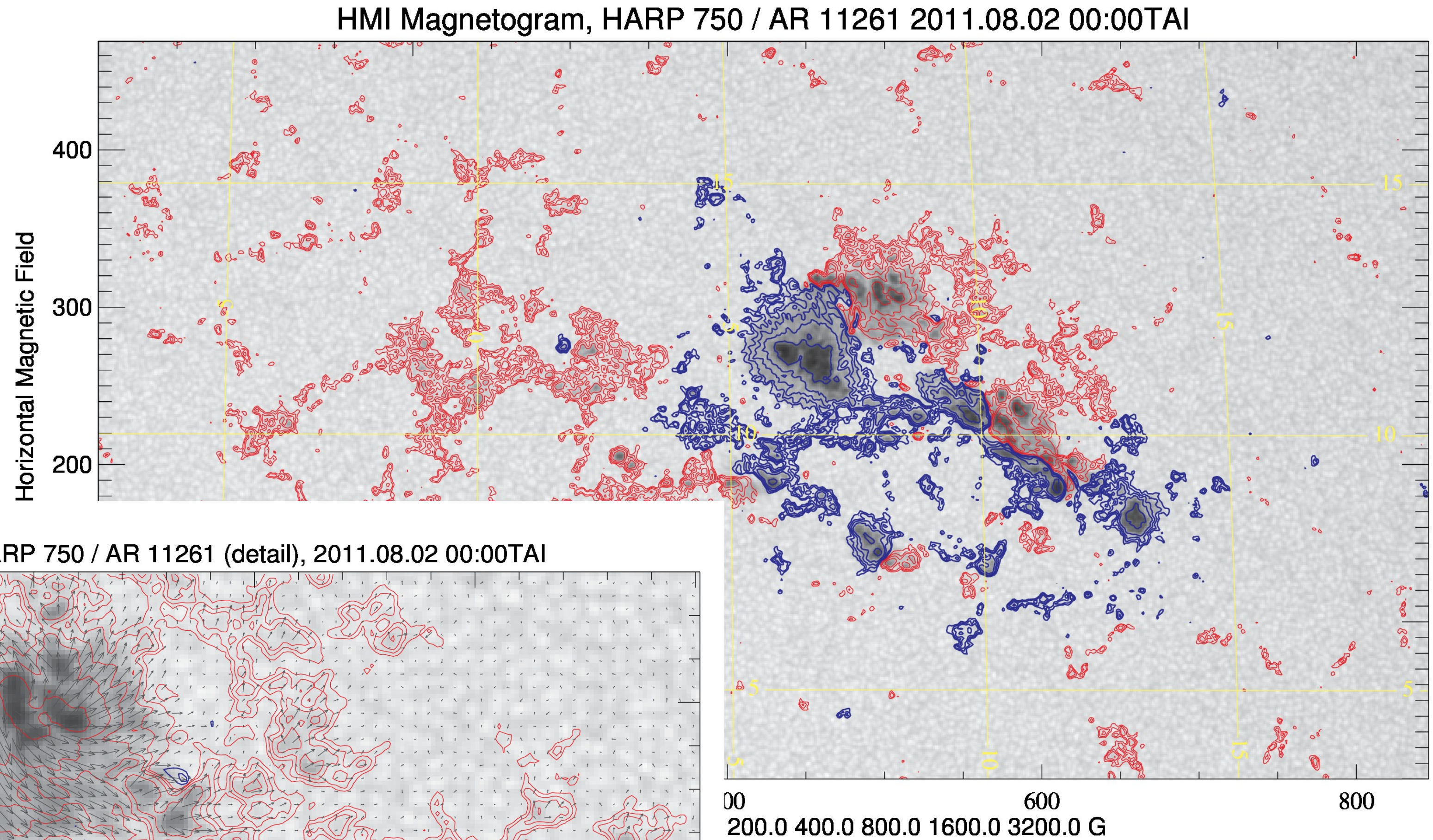
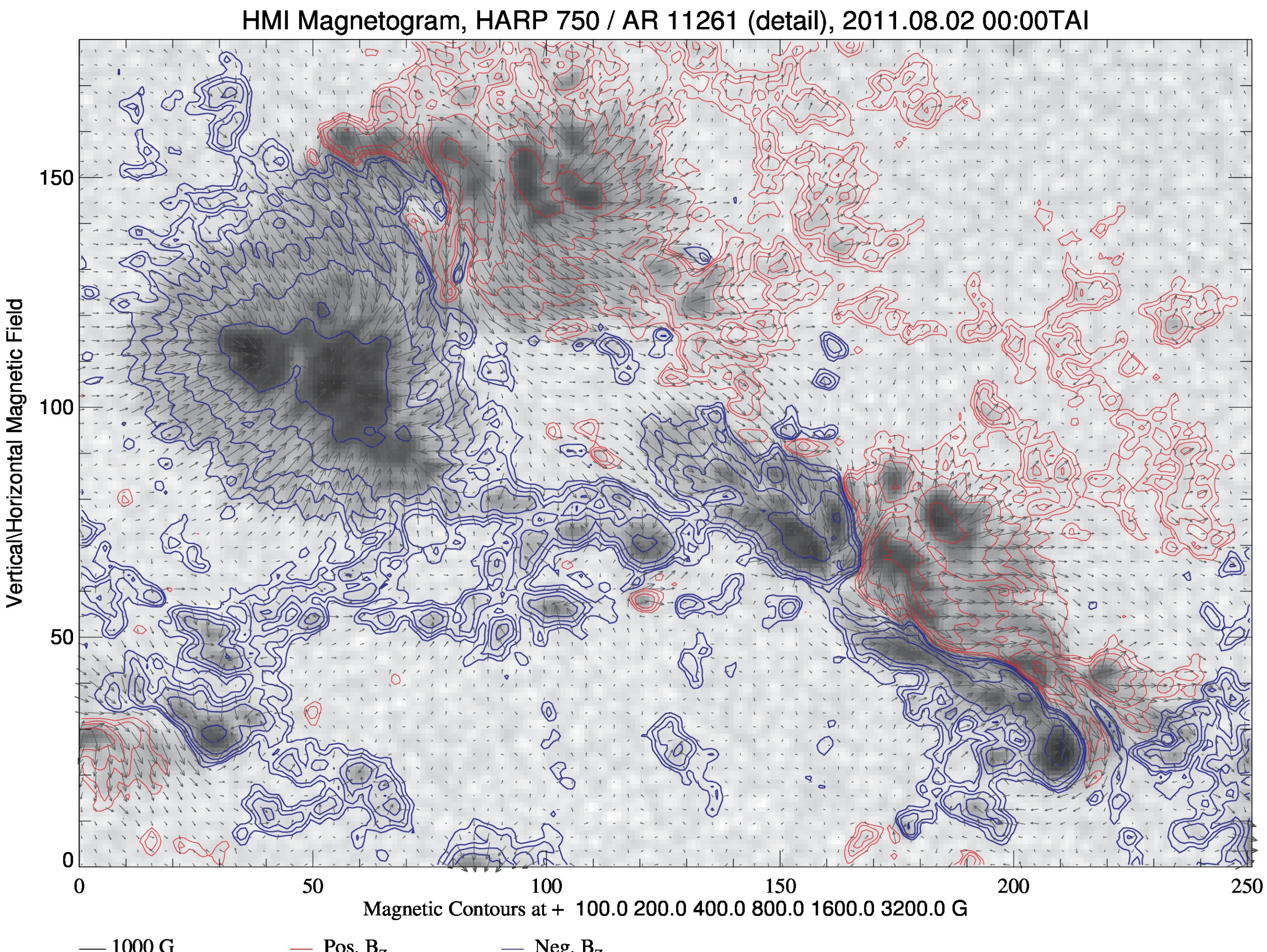
Data example: HMI.

Radial Field,
positive, **negative**





(Horizontal component plotted every 3rd pixel for clarity)

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Sweet Promises, I: *Physical* Quantities.

With Full-Disk Photospheric Vector:

- Remove projection effects
  - *no limits as f(μ) (μ = observing angle).*
  - *Fewer assumptions and approximations required*
- Global B_r, B_θ, B_φ
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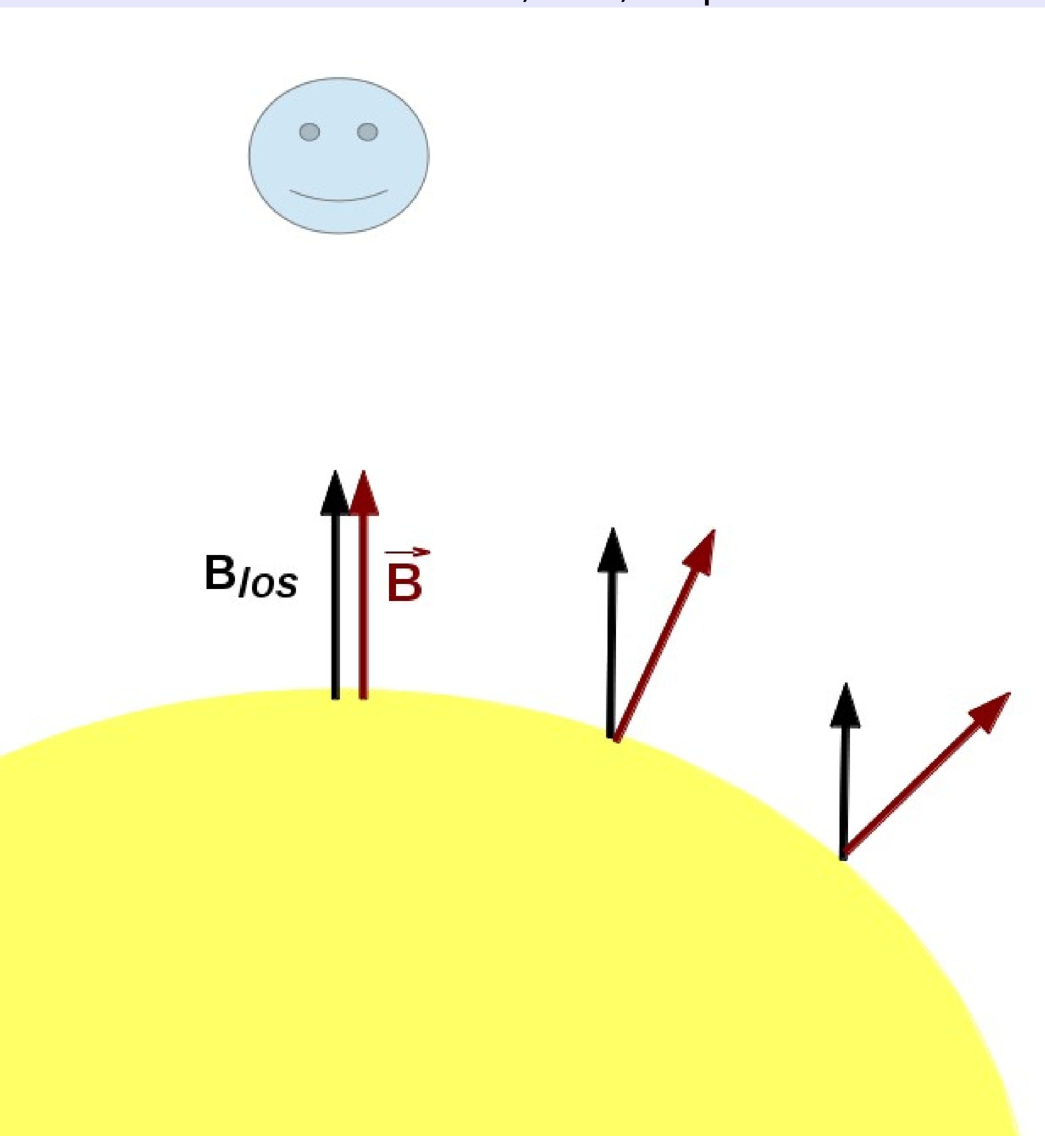

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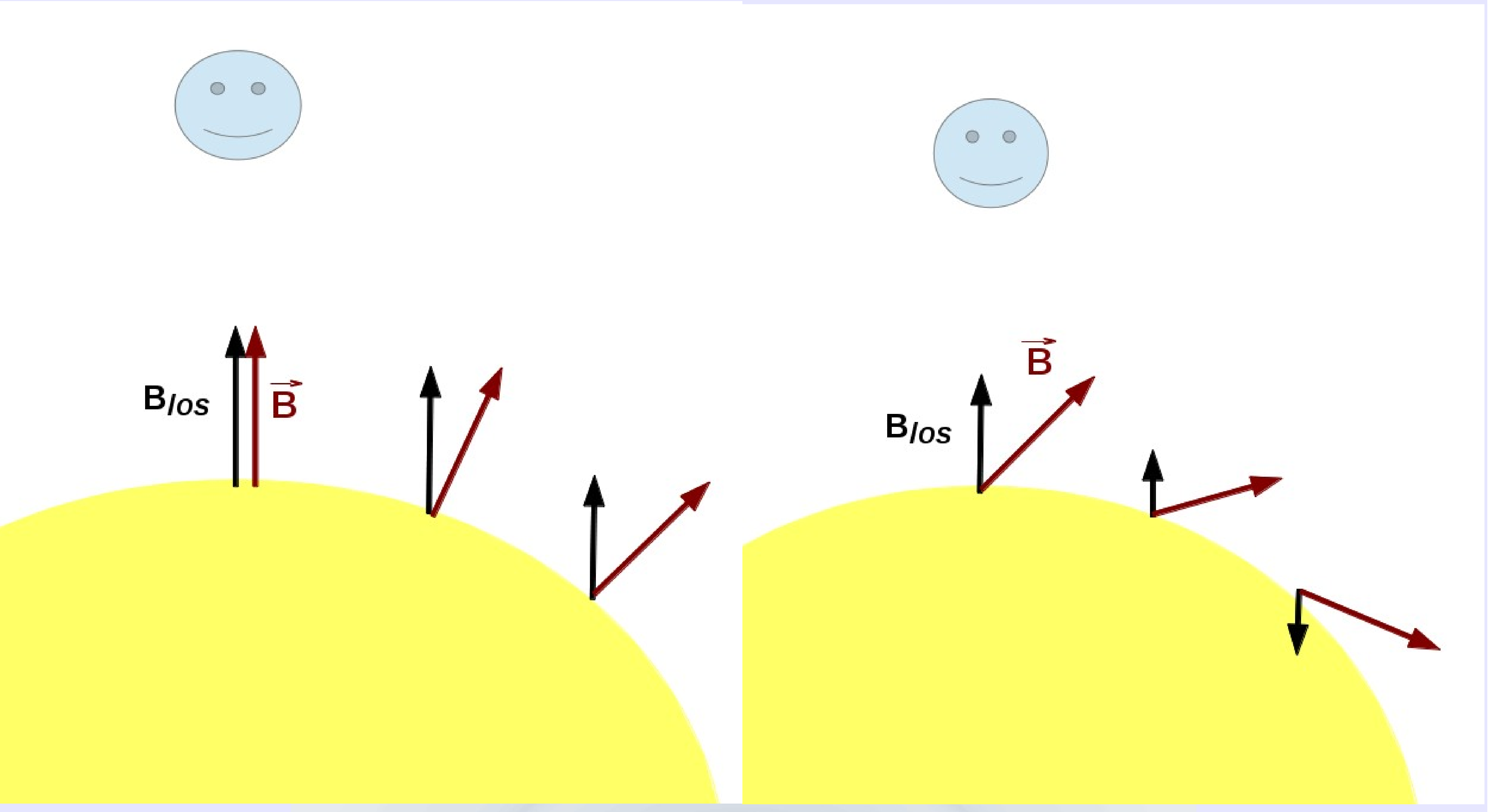

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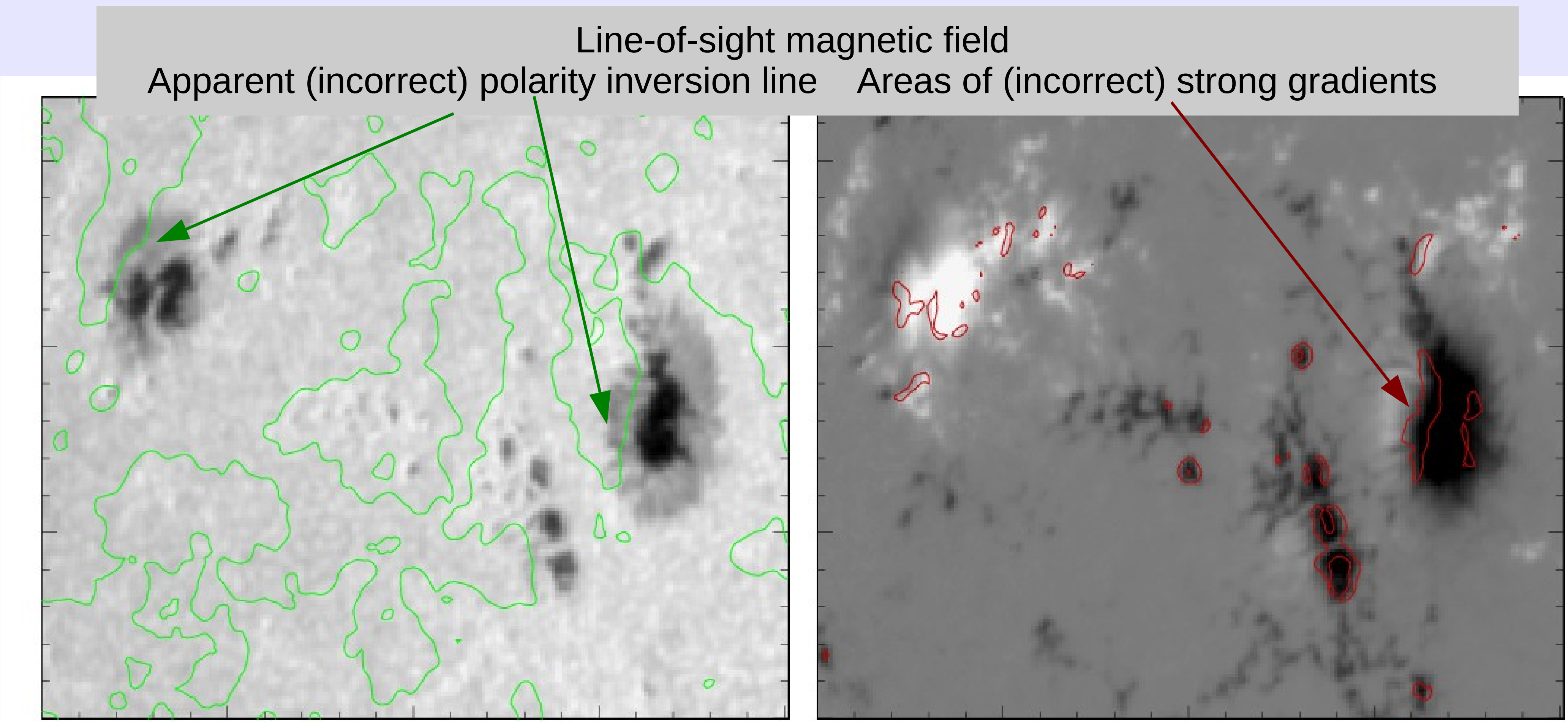

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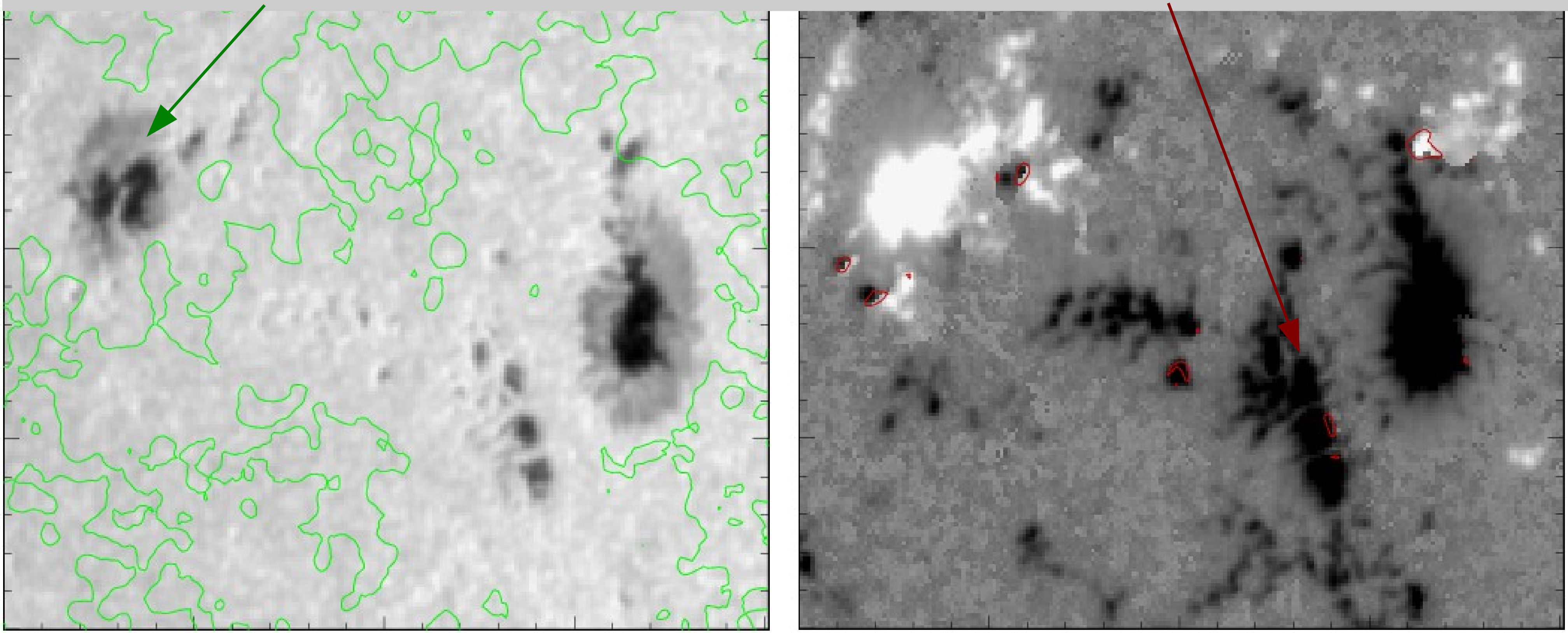
Radial magnetic field (from vector-field observations)

Correct polarity inversion lines (each spot is unipolar) Correct (fewer) strong gradients



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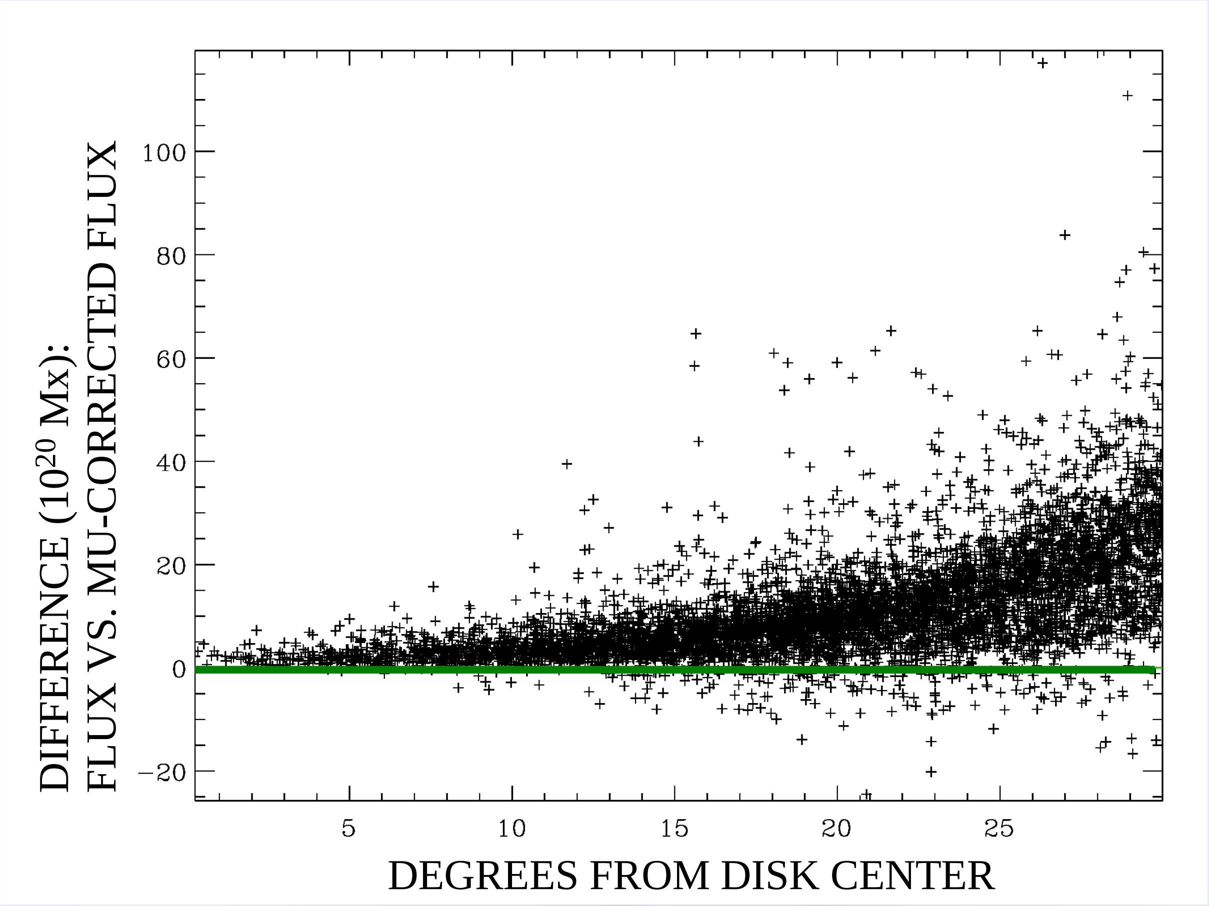

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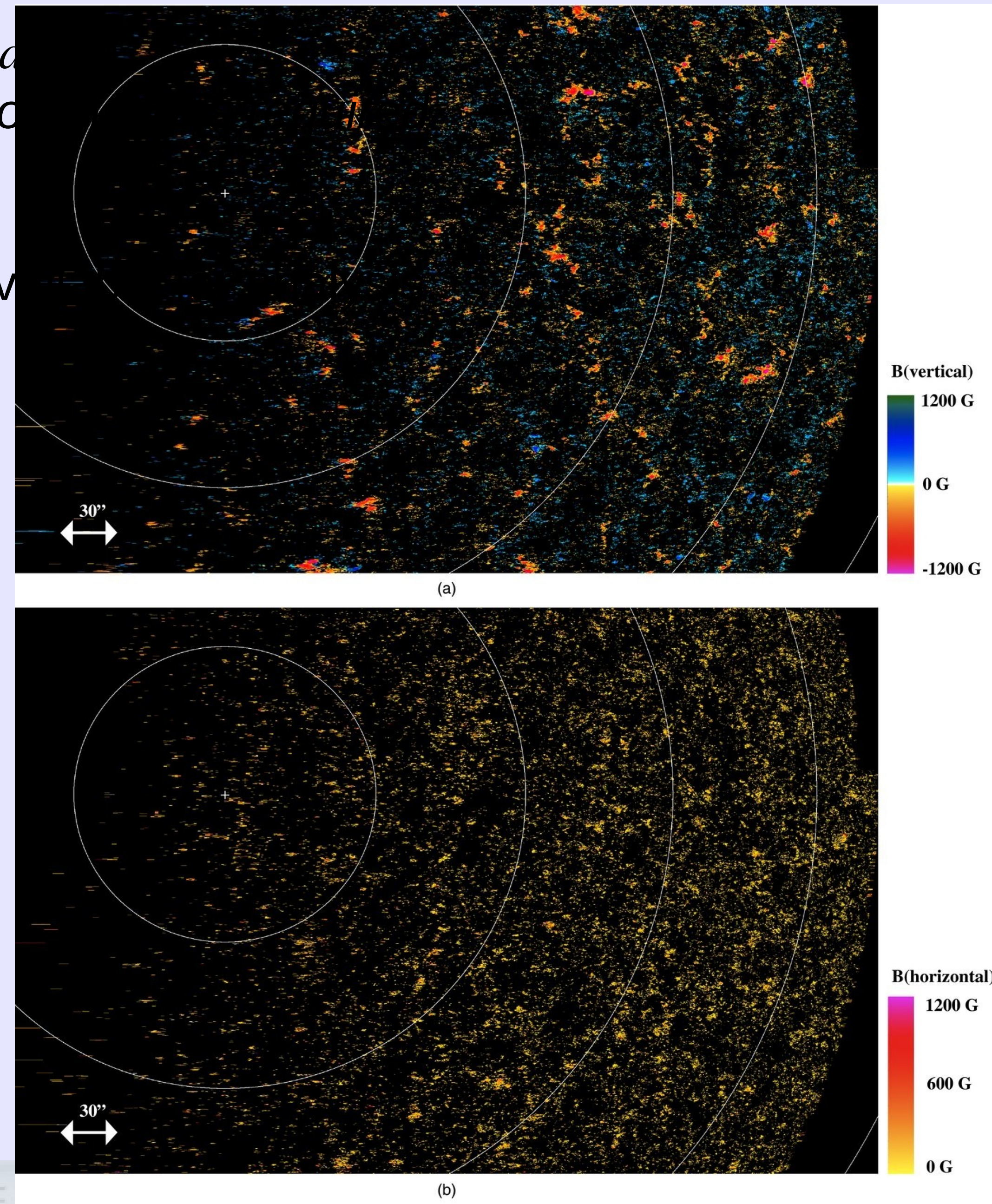

Figure 4 from Is the Polar Region Different from the Quiet Region of the Sun?
Hiroaki Ito et al. 2010 ApJ 719 131
doi:10.1088/0004-637X/719/1/131

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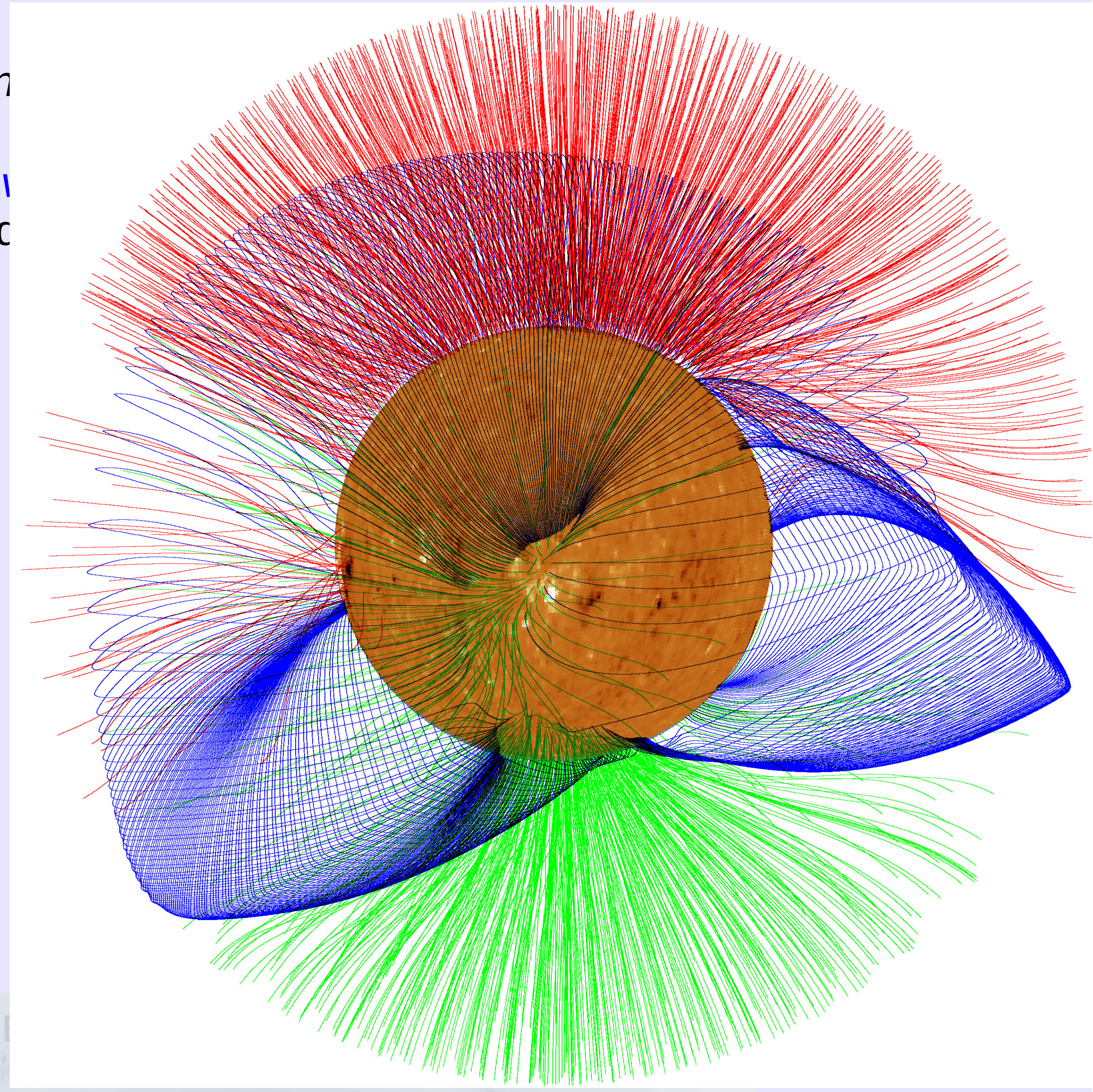

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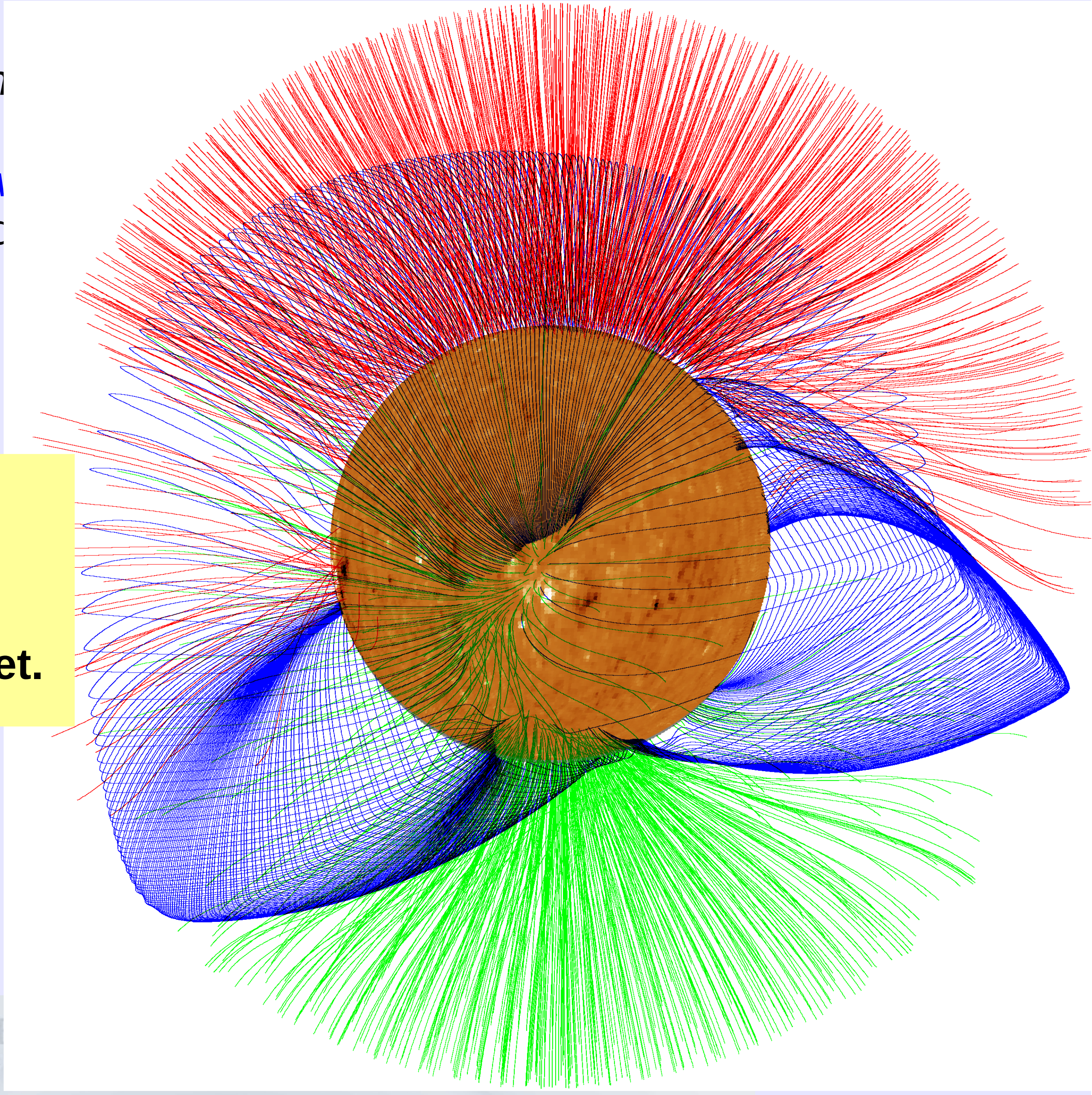

Why this matters:

- **Global Field Models,**
- **open flux,**
- **heliospheric current sheet.**

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From ***B****(x,y)* → **the distribution, morphology, and complexity of the photospheric magnetic field:**

- **Magnetic field vector** .... $|B|, \varphi, \gamma$
- **Horizontal gradients of the magnetic fields** .... $|\nabla_h \vec{B}|$
- **Vertical current density** .... $J_z = \nabla_h \times B_h$
- **Magnetic twist (related: force-free parameters)**.................... $\alpha = J_z / B_z$
- **Current helicity density**.. $h_c = B_z J_z$
- **Shear angle (deviation from potential)**............... $\Psi = \cos^{-1}(\vec{B}^p \cdot \vec{B}^o / B^p B^p)$
- **Magnetic free energy proxy** .... $\rho_e = (\vec{B}^p - \vec{B}^o)^2 / 8\pi$

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Results from 2nd Flare Forecasting Comparison Workshop
NWRA Discriminant Analysis, M1.0+ flares, Ranked by Heidke Skill Scores

0	M10min_Z00max_lat0hr_val24hr_EFREE_TOT.nwra_mag_da	0.506734
1	M10min_Z00max_lat0hr_val24hr_HORIZ_SHEAR_SIZE45.nwra_mag_da	0.441125
2	M10min_Z00max_lat0hr_val24hr_SHEAR_SIZE45.nwra_mag_da	0.435163
3	M10min_Z00max_lat0hr_val24hr_HC_TOT.nwra_mag_da	0.429926
4	M10min_Z00max_lat0hr_val24hr_NJZ_TOT.nwra_mag_da	0.412456
5	M10min_Z00max_lat0hr_val24hr_JZ_PBZ_TOT.nwra_mag_da	0.412456
6	M10min_Z00max_lat0hr_val24hr_JZCHIRAL_TOT.nwra_mag_da	0.412456
7	M10min_Z00max_lat0hr_val24hr_JZ_TOT.nwra_mag_da	0.408101
8	M10min_Z00max_lat0hr_val24hr_PJZ_TOT.nwra_mag_da	0.395504
9	M10min_Z00max_lat0hr_val24hr_JZ_NBZ_TOT.nwra_mag_da	0.395504
10	M10min_Z00max_lat0hr_val24hr_JZ_NBZ_ABS_NET.nwra_mag_da	0.392557
11	M10min_Z00max_lat0hr_val24hr_JZ_PBZ_ABS_NET.nwra_mag_da	0.389317
12	M10min_Z00max_lat0hr_val24hr_HC_ABS_NET.nwra_mag_da	0.377373
13	M10min_Z00max_lat0hr_val24hr_NL_SHEAR_SIZE45.nwra_mag_da	0.374586
14	M10min_Z00max_lat0hr_val24hr_JZ_BZ_NET_ABS_DIFF.nwra_mag_da	0.373817
15	M10min_Z00max_lat0hr_val24hr_NLHORIZ_SHEAR_SIZE45.nwra_mag_da	0.369808
16	M10min_Z00max_lat0hr_val24hr_PFLUX_TOT.nwra_mag_da	0.368685
17	M10min_Z00max_lat0hr_val24hr_JZ_BZ_NET_ABS_SUM.nwra_mag_da	0.356307
18	M10min_Z00max_lat0hr_val24hr_JZHETER_TOT.nwra_mag_da	0.353208
19	M10min_Z00max_lat0hr_val24hr_FLUX_TOT.nwra_mag_da	0.350686

etc….

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These all require vector ***B***.

etc....

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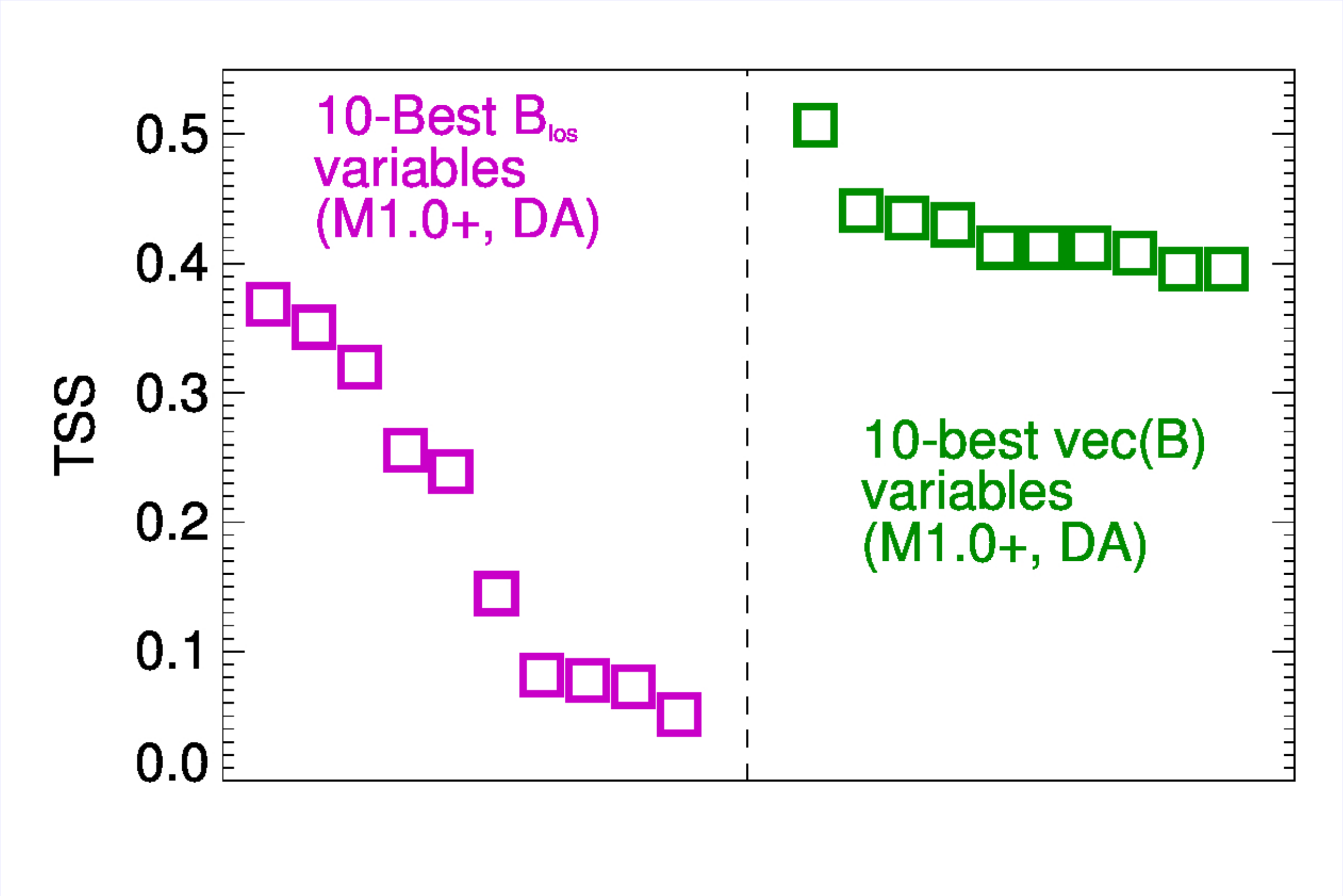

See also
Yang, et al 2013.

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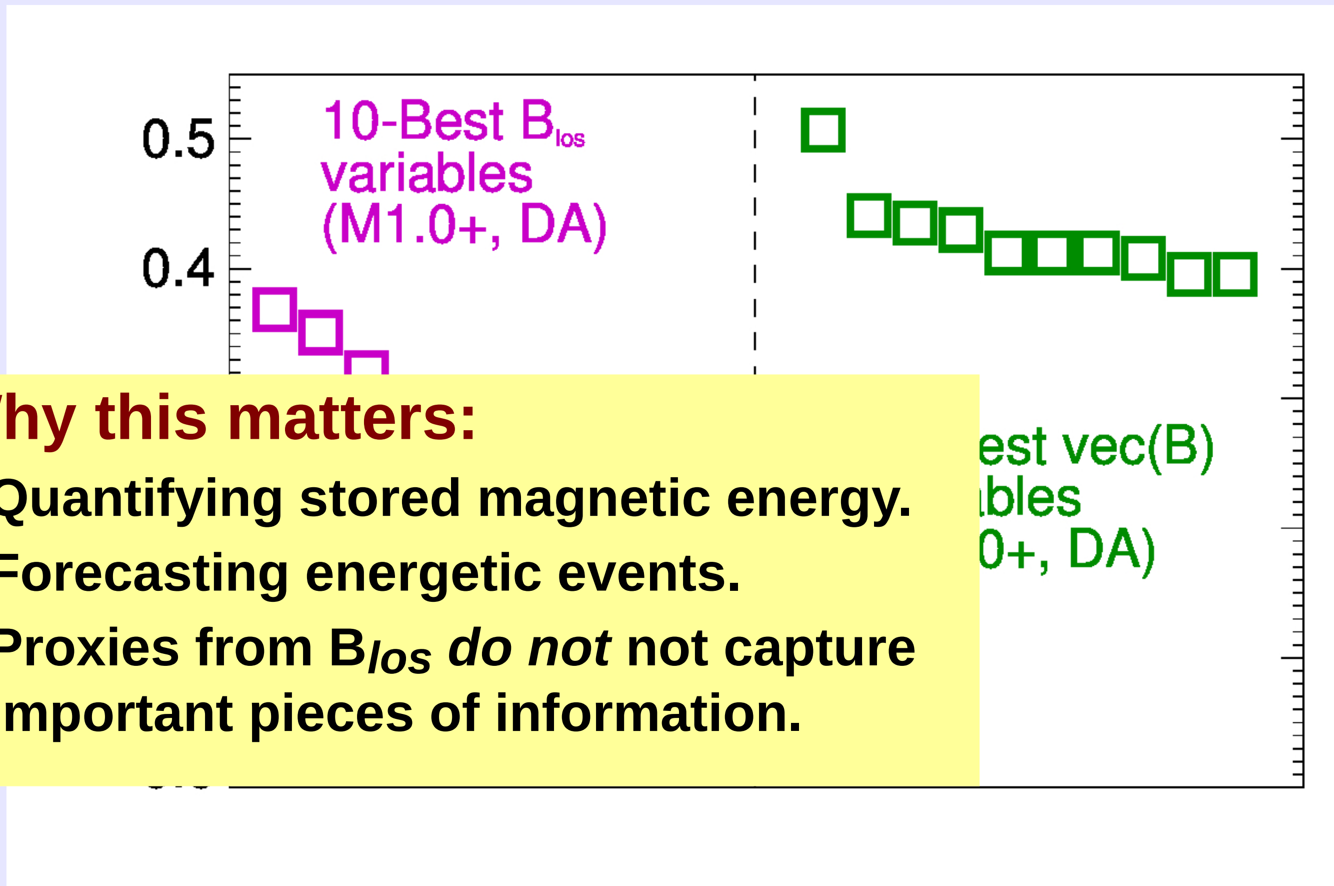

Why this matters:

- **Quantifying stored magnetic energy.**
- **Forecasting energetic events.**
- **Proxies from B_{los} *do not* not capture important pieces of information.**

See also Yang, et al 2013.

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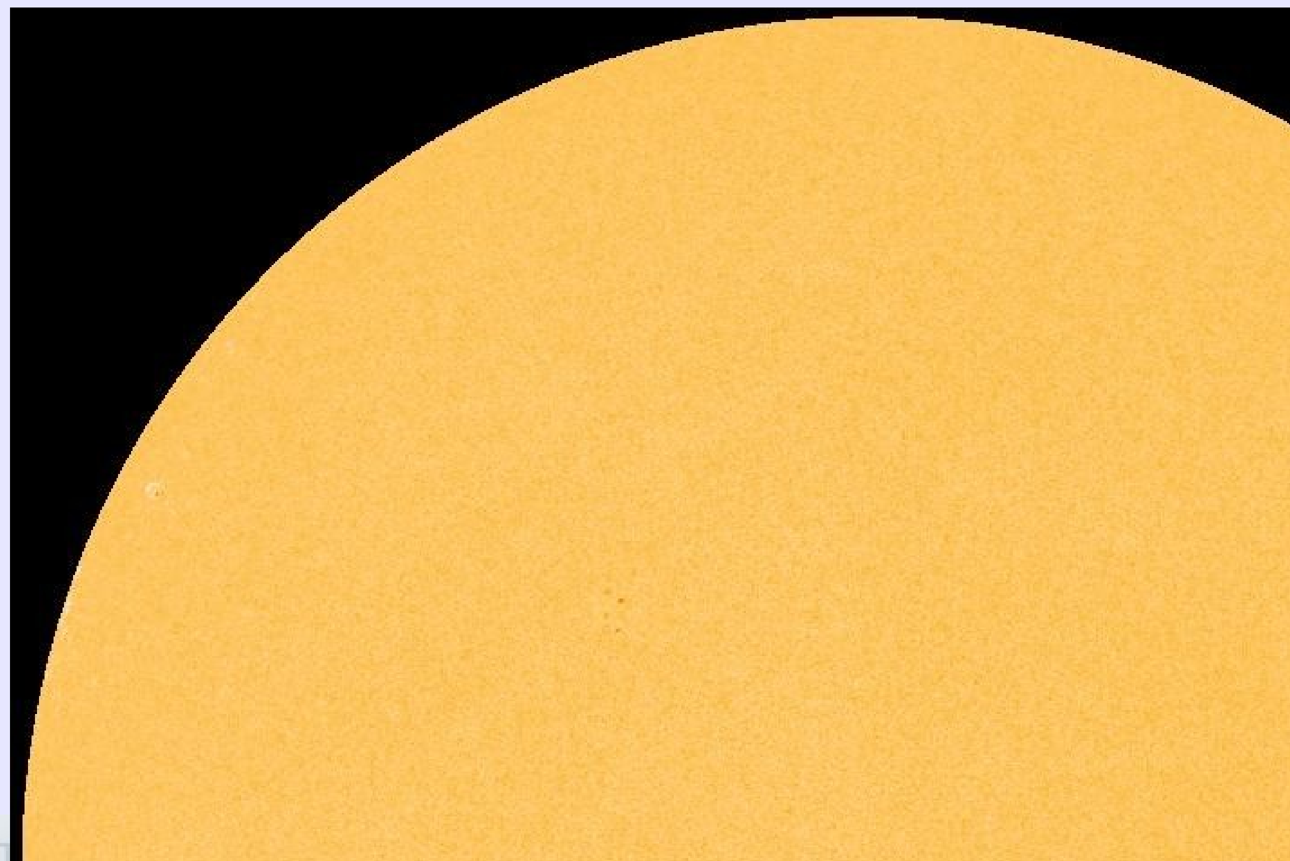
Sweet Promises, II: *No missed "events".*

Observer's wisdom: "The... *[flare, emergence, eruption, feature-formation of interest]* always happen when it is ...*[cloudy, bad seeing, dark, raining, instruments are broken]*."

- Fundamental questions still linger. Example: Magnetic Emergence and Sunspot Formation
  - How do sunspots form?
  - What are the *first* indications of a new region?
  - How/when does the corona react, locally and over distance?



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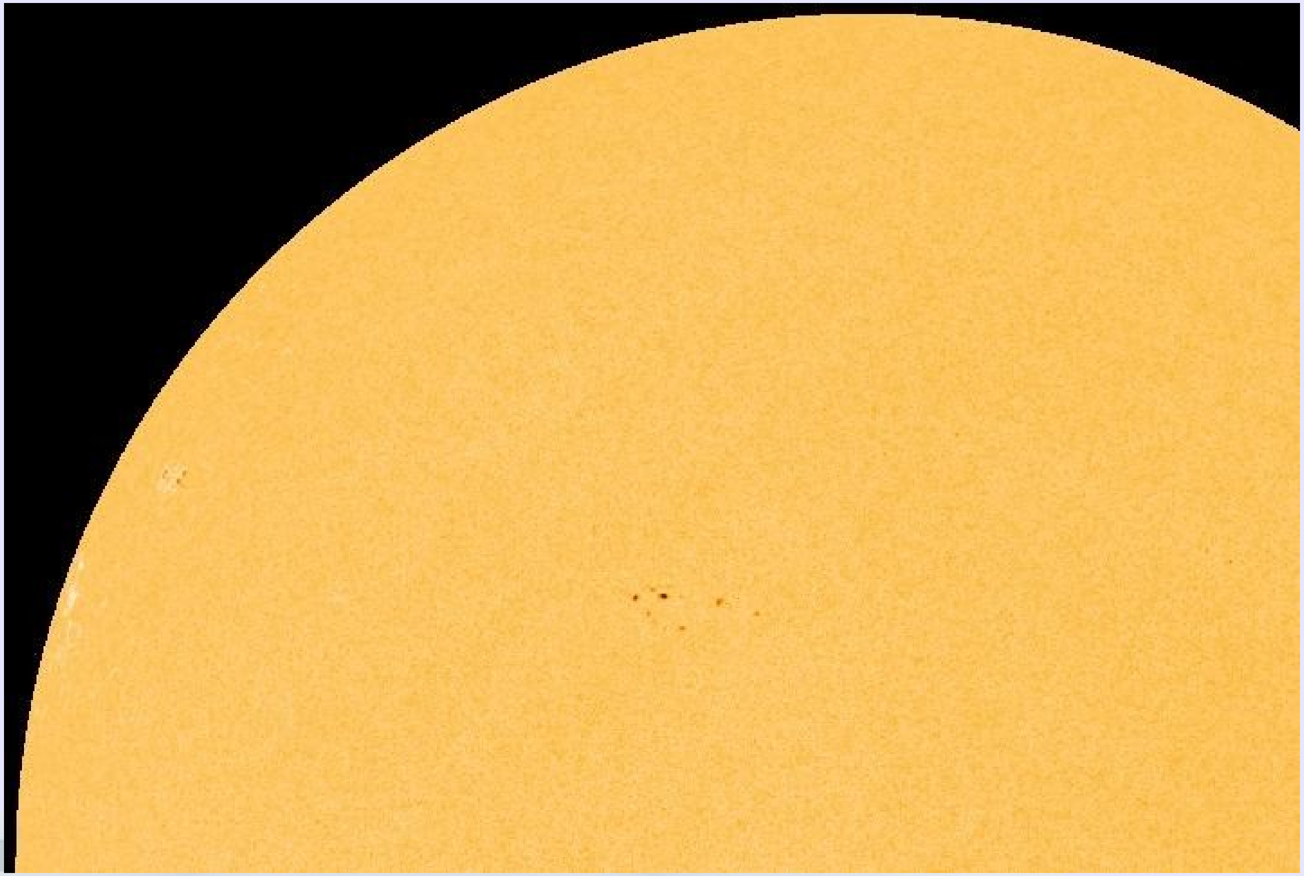

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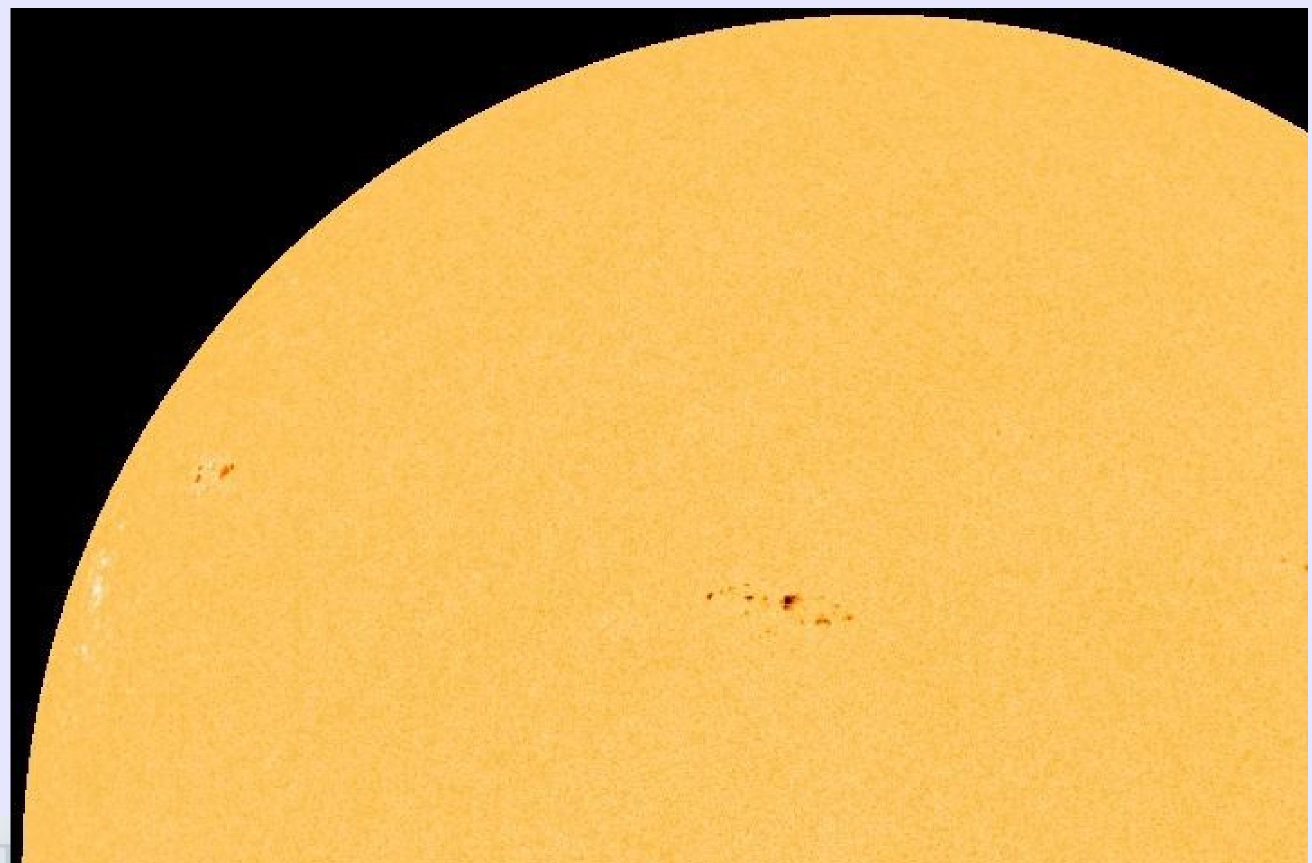

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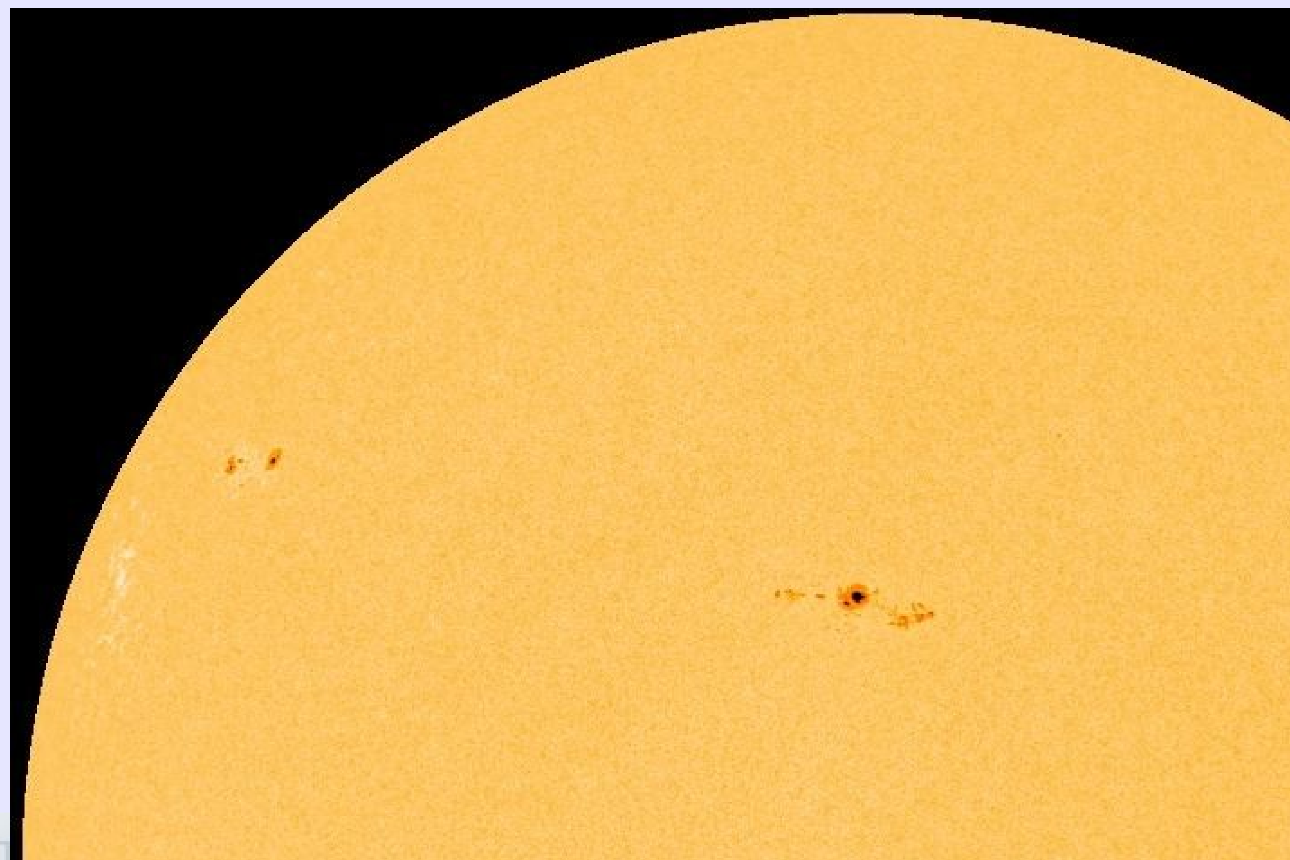

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Sweet Promises, III: *Statistics*

“Only with gobs of data can reliable statistical analysis be performed.”

Distributions:

- With insufficient data, *distributions are not characterizable*.
- If (e.g.) assume a Gaussian Distribution, 2 parameters (3 data points) are required.
  - Many distributions are not Gaussian.
  - We don't know what the distributions *are*.
  - *eo ipso,* “gobs of data” are required
    - This is especially true to characterize the tails of distributions.

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> “gobs” (adj):
> lots and lots and lots
> and lots and lots...
> and then more.

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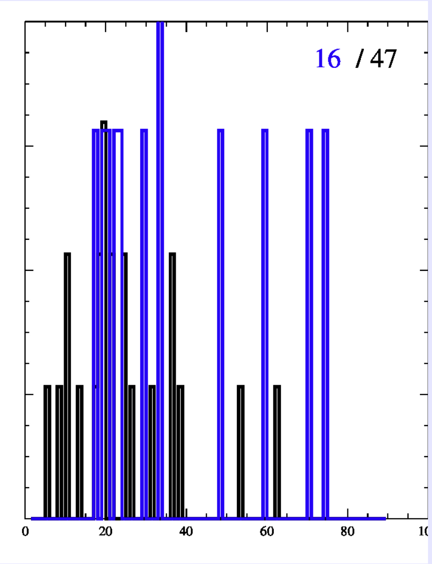

Distribution of the length of magnetic neutral line for Flaring (color) and non-flaring (black) active regions.

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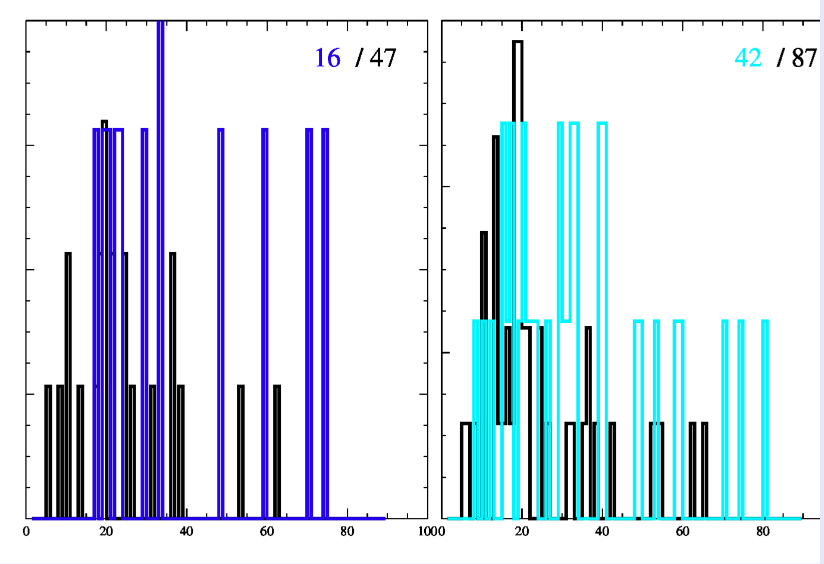

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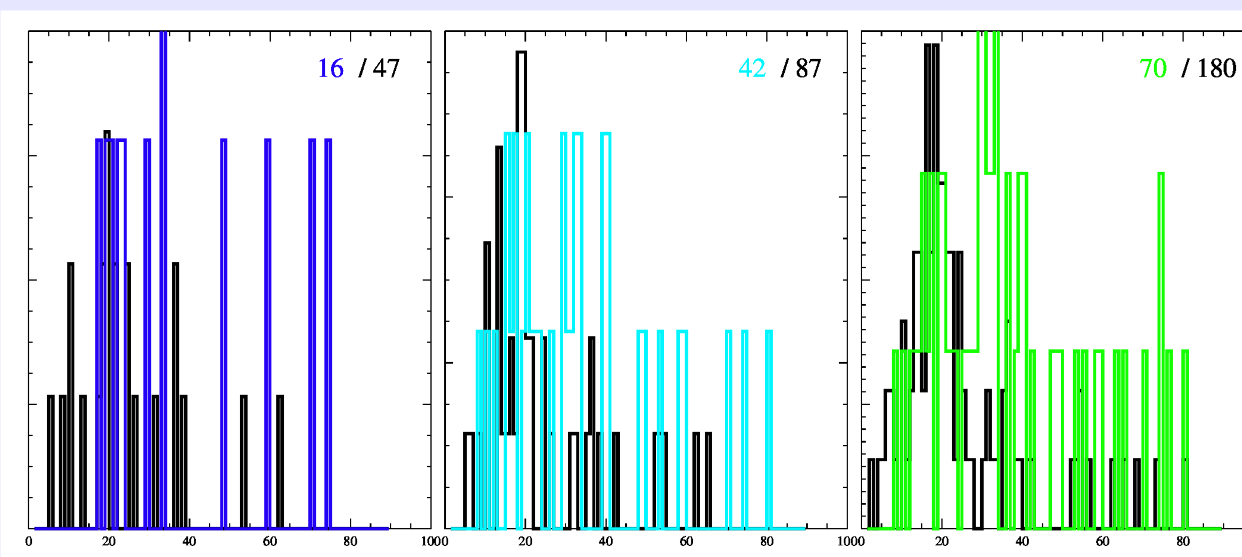
  - *eo ipso,* “gobs of data” are required
    - This is especially true to characterize the tails of distributions.



f the length of magnetic neutral line for
) and non-flaring (black) active regions.

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Sweet Promises, III: *Statistics*

“Only with gobs of data can reliable statistical analysis be performed.”

Distributions:

- With insufficient data, *distributions are not characterizable*.
- If (e.g.) assume a Gaussian Distribution, 2 parameters (3 data points) are required.
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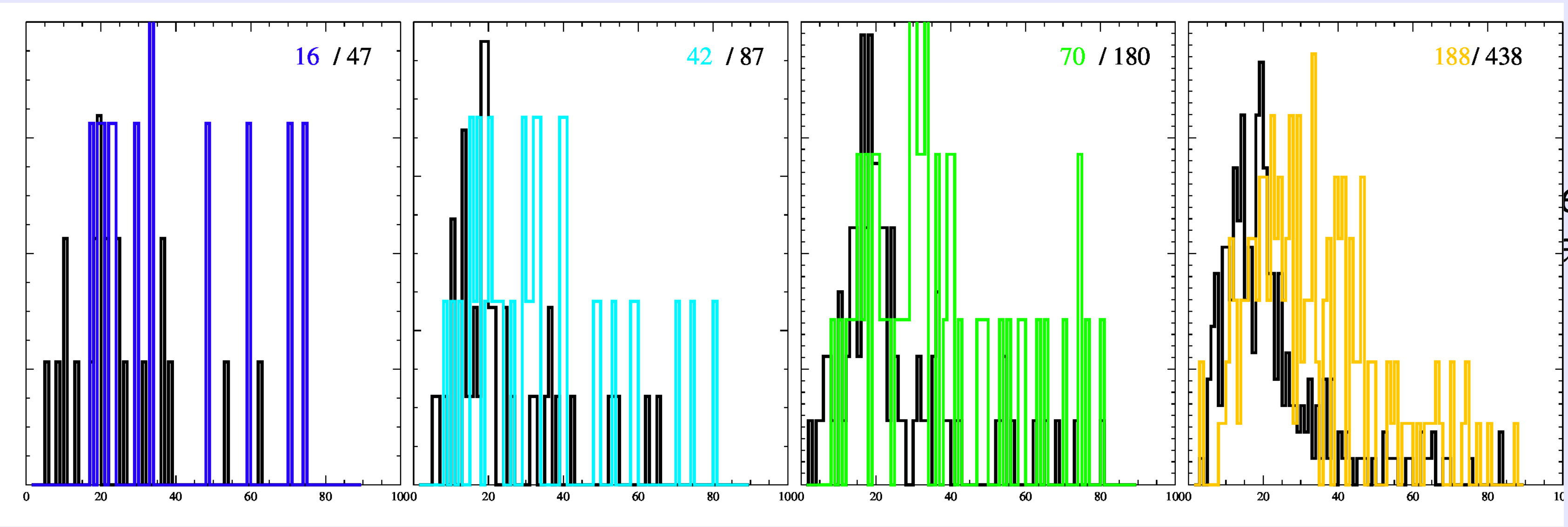

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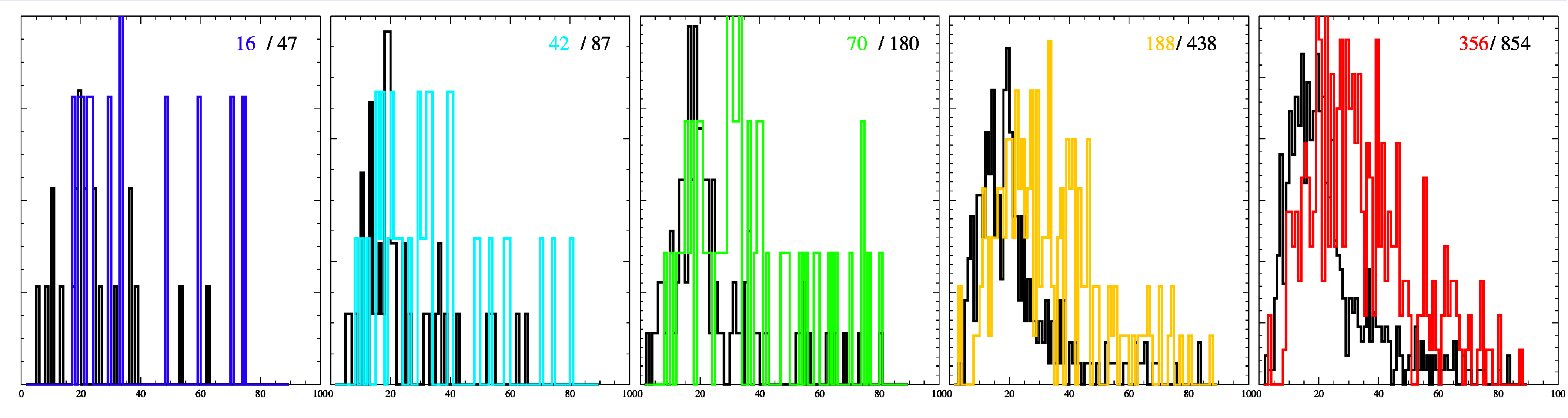

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Sour Realities, I: Data volume.

- Spectral, temporal, spatial sampling vs. data volume.
- Distribution issues.
- Real-time vs. archive.
  - *Space Weather research: operational data should be identical to research data.*

Sour Realities, II: Data reduction.

- *Much more complex than for B_{los}*
  - Calibration, Inversion, Disambiguation, *more*...
  - Longer processing time
  - Algorithms *will* fail somewhere (assumptions, statistics).
  - *Stability is crucial.*

Sour Realities, III: Limitations in the photosphere.

- A single, forced boundary.
  - *Inconsistent with popular assumptions.*
  - Cannot perform height-derivatives.

Sour Realities, IV: Limitations of unresolved data.

- *Data are discrete and generally unresolved.*
- Finite-differences and gradients: caution!
  - But hold information anyway?

Both of these are topics for entire separate talks...

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Future Strategic Synoptic Solar Vector Field Facilities:

Progress *can* be made in Space Weather research and operations with synoptic solar vector field facilities.

No limit on $$ or time (“Fairy Godmother....”):

- *Multiple* space-based HMI-like facilities
- at Earth-, Far- and Polar vantage points.
- *Hot-spares ready & waiting.*

To have Operational Space Weather products from Vector magnetic field data ready for the *next* solar cycle, we can, and really must, do *now*:

- *International ground*-based *network* of imaging-based vector magnetographs (with image-stabilization and deblurring/AO).
- Similar temporal and spatial sampling to HMI, better spectral sampling.
- Match/complement existing facilities so that present samples can be extended, not “start all over again” statistically.

A “must”: Research Support.

- Fundamental questions regarding solar activity and space weather are *ready for investigation* using large samples of Synoptic Photospheric Vector Magnetic Field data.

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