Photospheric magnetism

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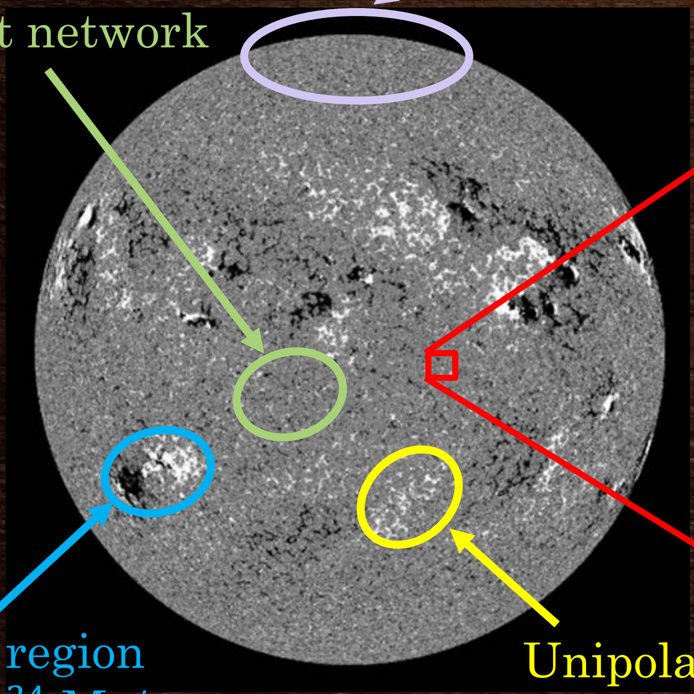
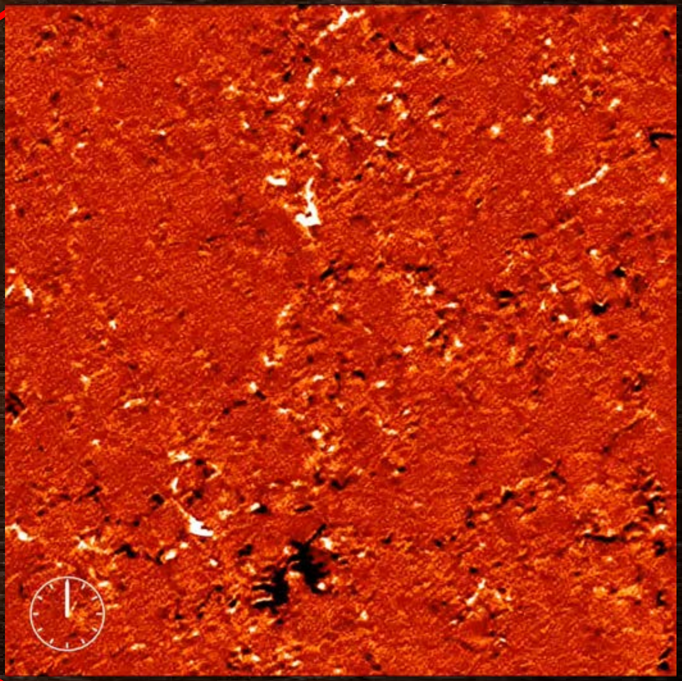
Large and small magnetic features



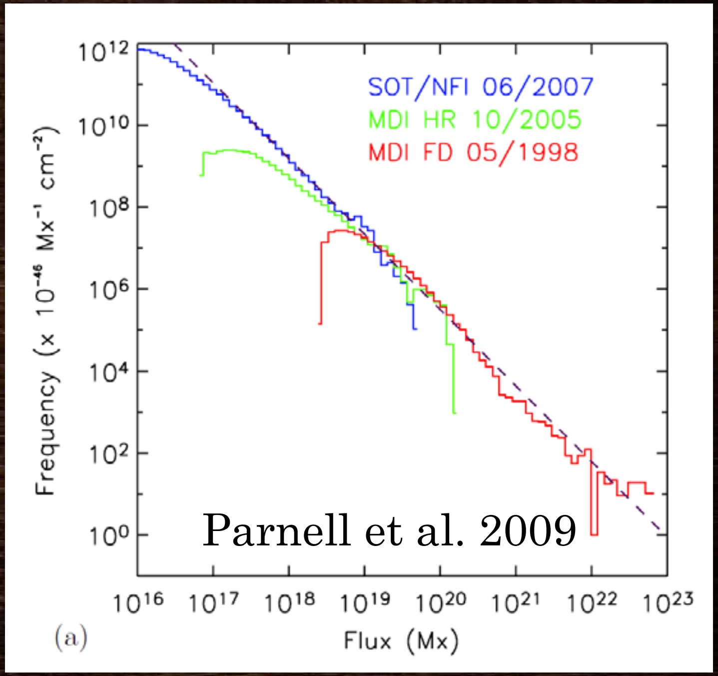
SDO/HMI



Sunrise / IMaX

How much magnetic flux in different types of features?

- PDFs of QS magnetic fluxes have been derived by Stenflo & Holtzreuter 2002, Khomenko+ 2003, Dominguez Cerdena+ 2006, Martinez Gonzalez+ 2008, Bühler+ 2013, etc.
- Parnell+ 2009: single power law of -1.85 covers frequency of features with fluxes from 10^{17} to 10^{22}
- Does a single power law mean that all magnetic features have same source?
- Also: Sun had different activity in 1998, 2005 and 2007). Should power laws be different at the top end?

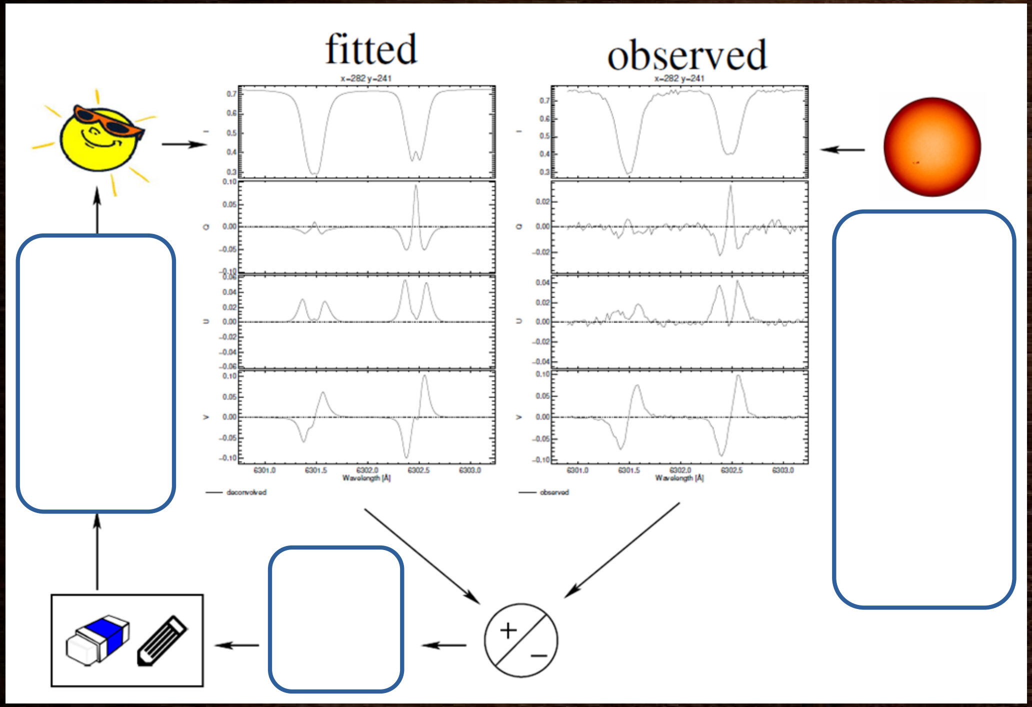


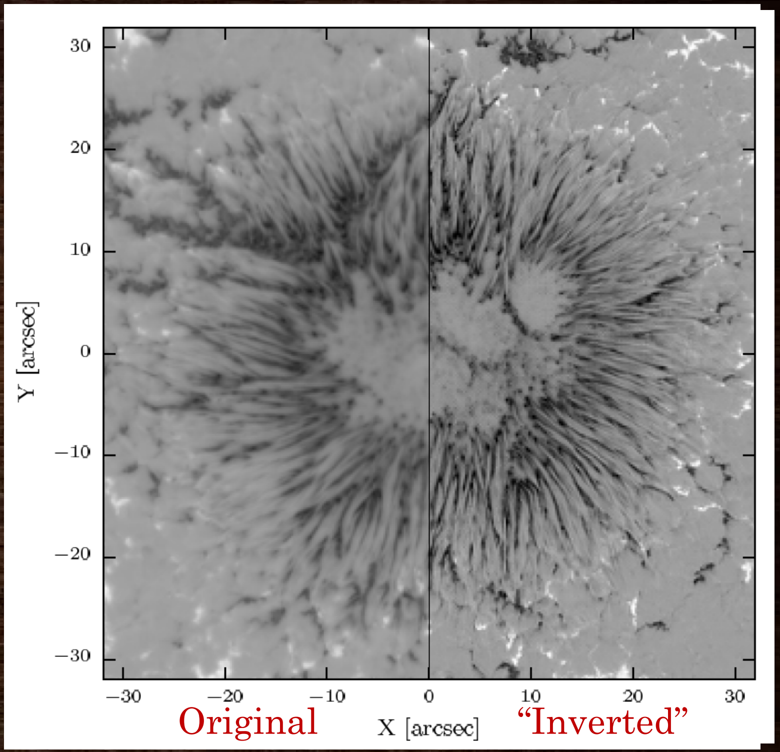
Magnetic flux per feature

2D coupled inversions

To deduce magnetic fields we need to measure Stokes profiles

Inversions are the main tool to extract the information in the Stokes profiles

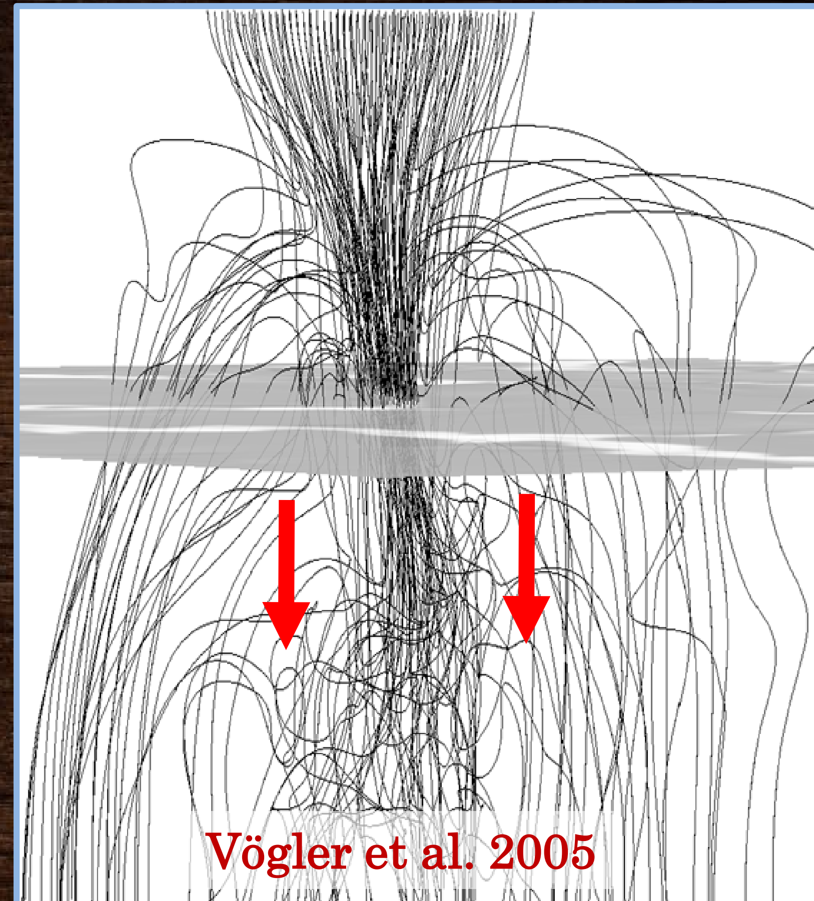


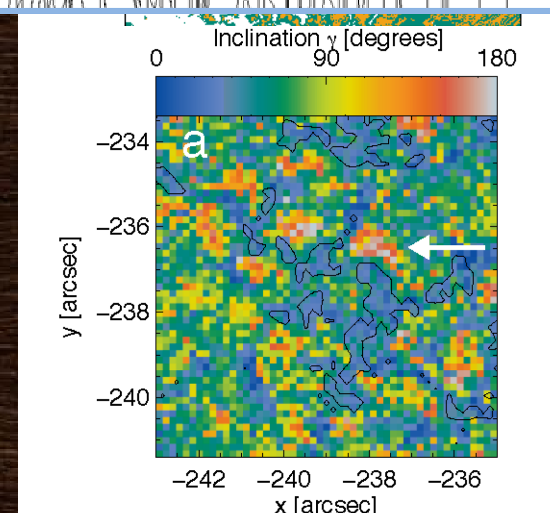


van Noort (2012); van Noort et al. (2012): remove effects of PSF → SPINOR 2D.
Followed by: Ruiz Cobo & Asensio Ramos (2013), Scharmer et al. (2013), Asensio Ramos & de la Cruz Rodriguez (2015), etc.

Active regions: plage

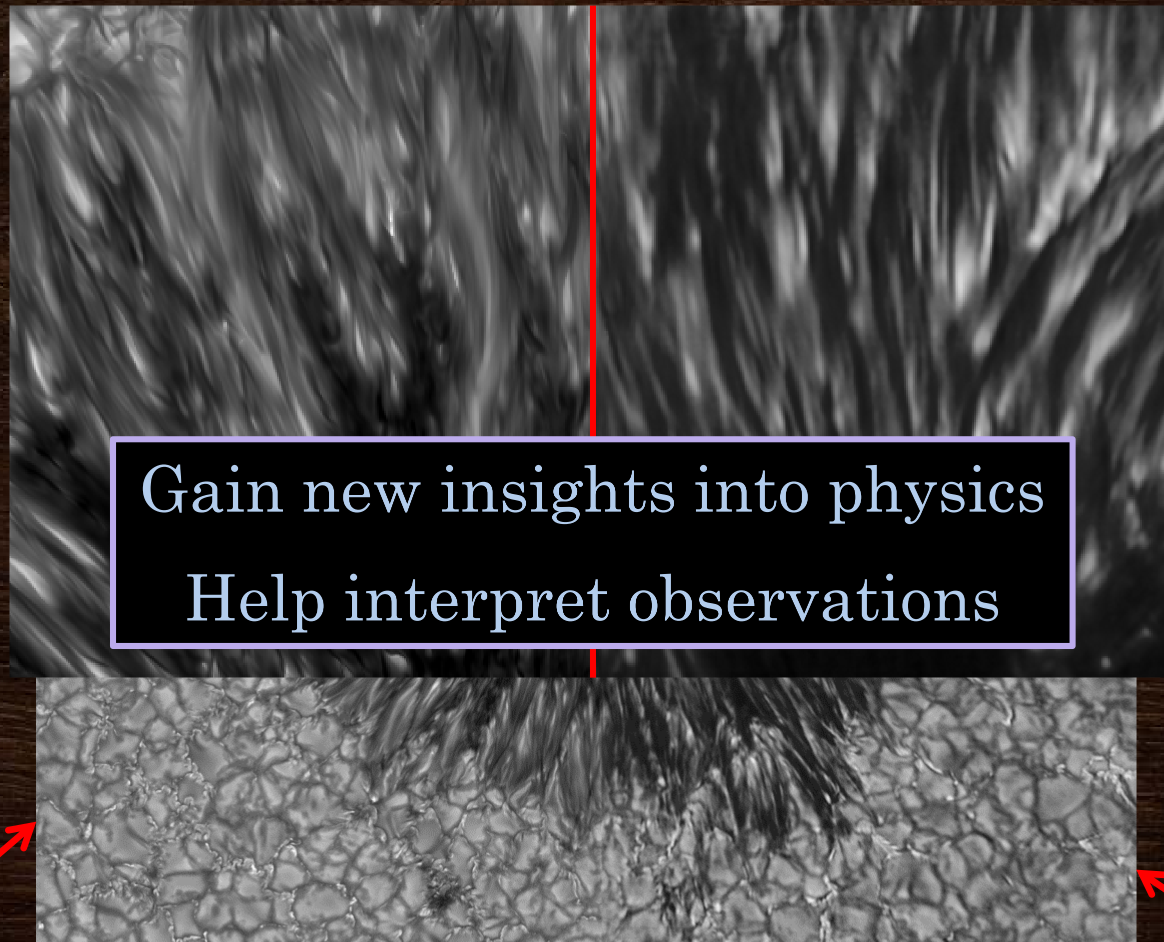
- Apply coupled inversion to plage observed by Hinode → structure of photosphere in 3D
- Photospheric canopies everywhere
- Magnetic elements expand just like thin tubes
- Strong, often supersonic down-flows (in deep layers of surroundings)
- Weak opposite polarity fields surrounding kG magnetic elements in lowest layers





Bühler et al. 2015

Simulation or observation?



Gain new insights into physics

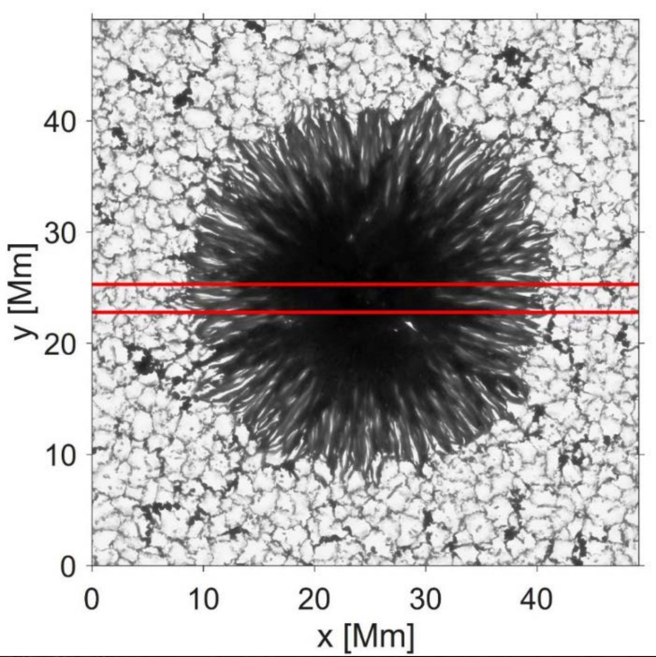
Help interpret observations

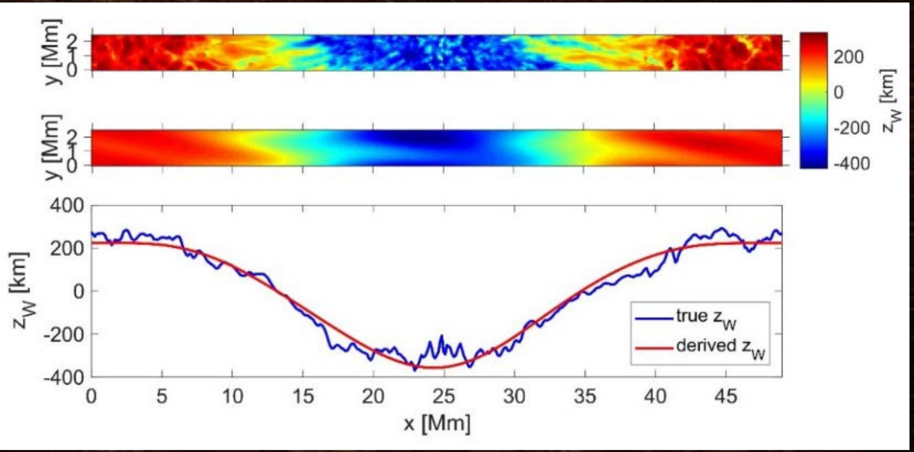
Simulation
(M. Rempel/HAO)

G-band observation
(F. Wöger/NSO)

Sunspots: Wilson depression

- Idea: Impose $\nabla \boldsymbol{B} = \frac{\partial B_x}{\partial x} + \frac{\partial B_y}{\partial y} + \frac{\partial B_z}{\partial z} = 0$
- Inversions provide $\boldsymbol{B}(x, y, \tau)$, not $\boldsymbol{B}(x, y, z)$. In general $\nabla \boldsymbol{B}(x, y, \tau) \neq 0$
- Take $\boldsymbol{B}$ from inversions, shift τ-scale up or down in z → changes $B_z(z)$. Compute $\nabla \boldsymbol{B}$ (Puschmann+ 2010)
- The $\tau(z) = 1$ surface which results in $\nabla \boldsymbol{B} = 0$ corresponds to the Wilson depression
- To remove small-scale disturbances keep just the lowest 4 Fourier components
- Test using Rempel's simulations

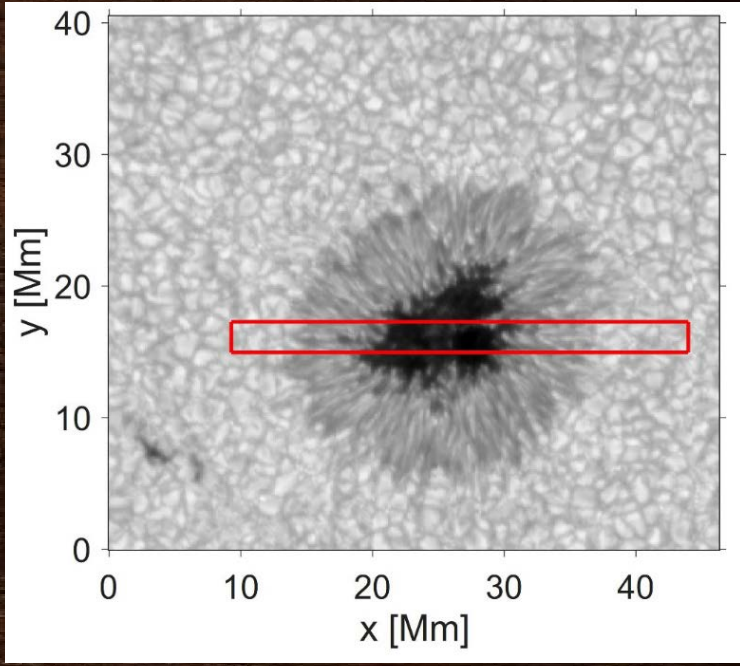


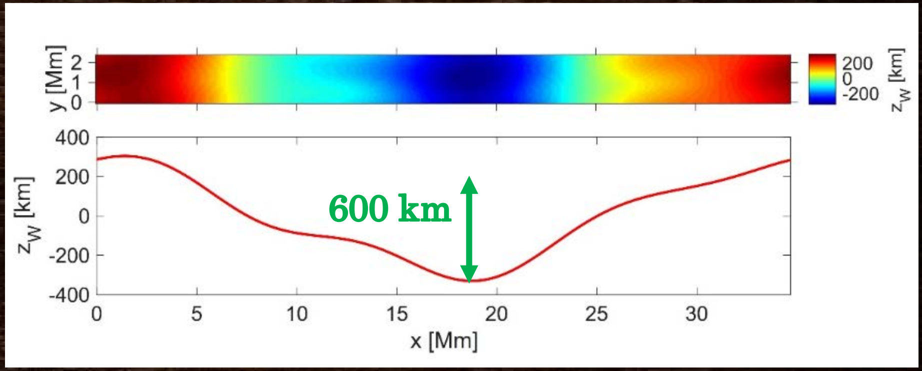


Löptien et al. 2018

Sunspots: Wilson depression

- Apply to Hinode observations of sunspots, inverted with 2D technique
- Result: maximum Wilson depression ≈ 600 km. Larger than Wilson dep. obtained from force balance (Martinez Pillet+ 90; Solanki+ 94; Mathew+ 04)
- → Umbral field is quite non-potential
- Next step: apply to many spots, estimate curvature forces in spot magnetic field

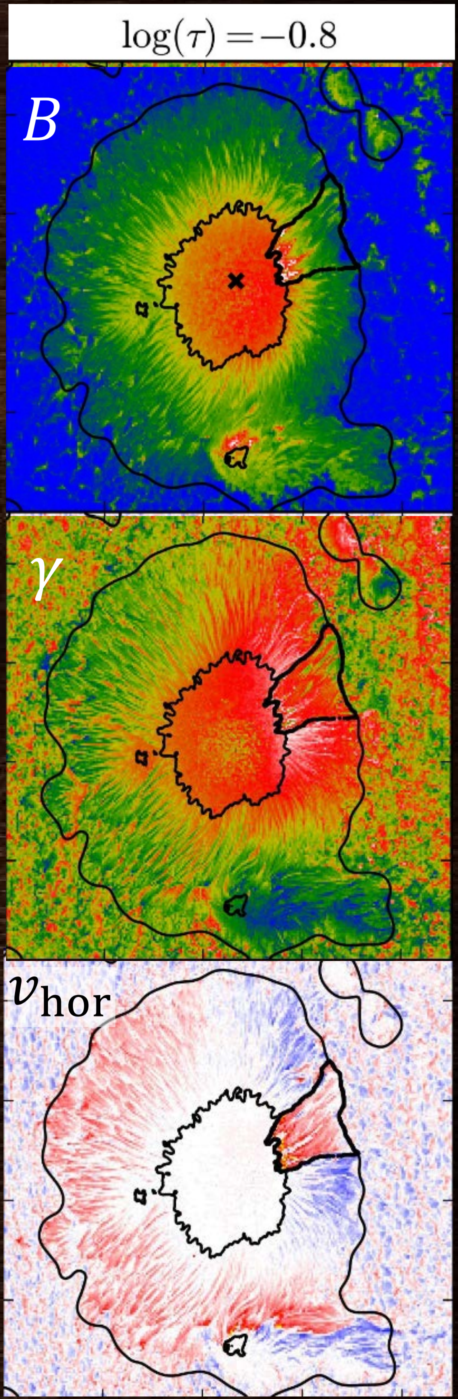




Löptien et al. 2018

Evershed & Counter-Evershed flows

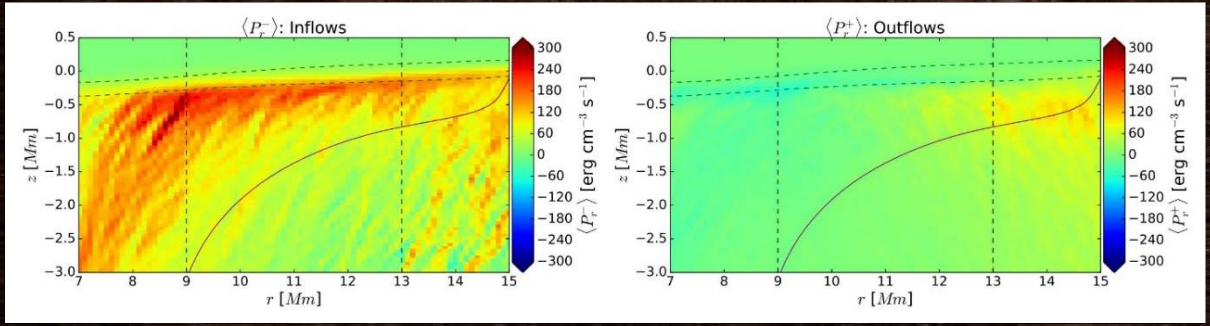
- Mature spots sometimes (rarely) display a counter Evershed flow, i.e., material in penumbra flowing towards the umbra
- What drives this counter-Evershed flow? And what drives the normal Evershed flow?
- Observations don't give a clear answer. Either magnetoconvection (i.e. buoyancy driven) or siphon flow (driven by gradients in magnetic field)
- Problem: information is obtained only on optical depth τ surfaces, which are strongly corrugated, but forces act at constant z



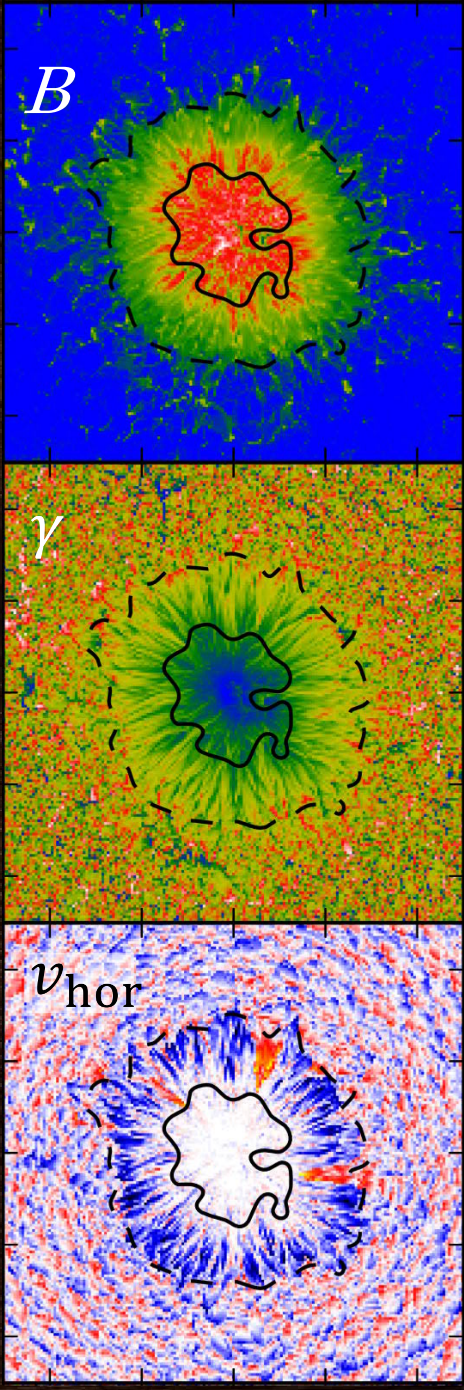
Siu Tapia et al. 2017

Evershed & Counter-Evershed flows

- Study MHD simulation of spot with counter flow
- Deduce forces driving normal & counter Evershed flows
- Results:
  - Normal Evershed flow is of magneto-convective origin
  - Counter Evershed flow is mainly a siphon flow

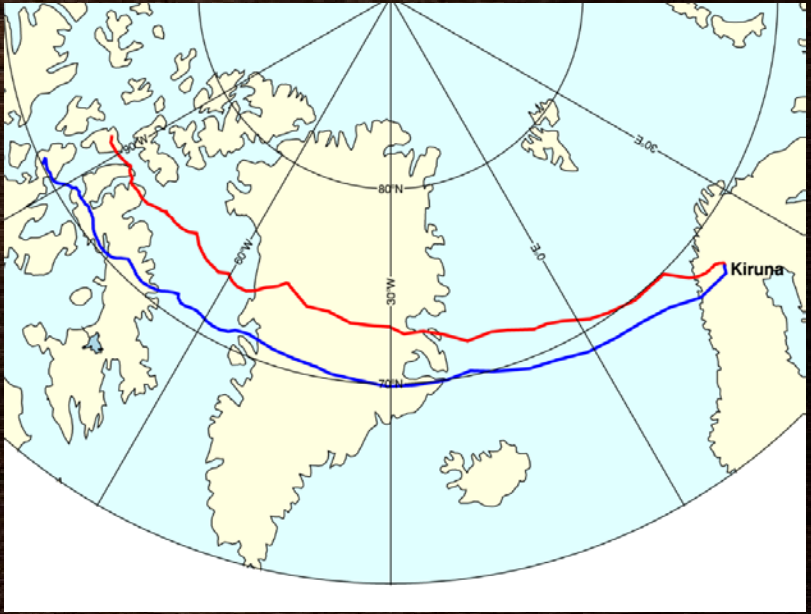


Siu Tapia et al. 2018

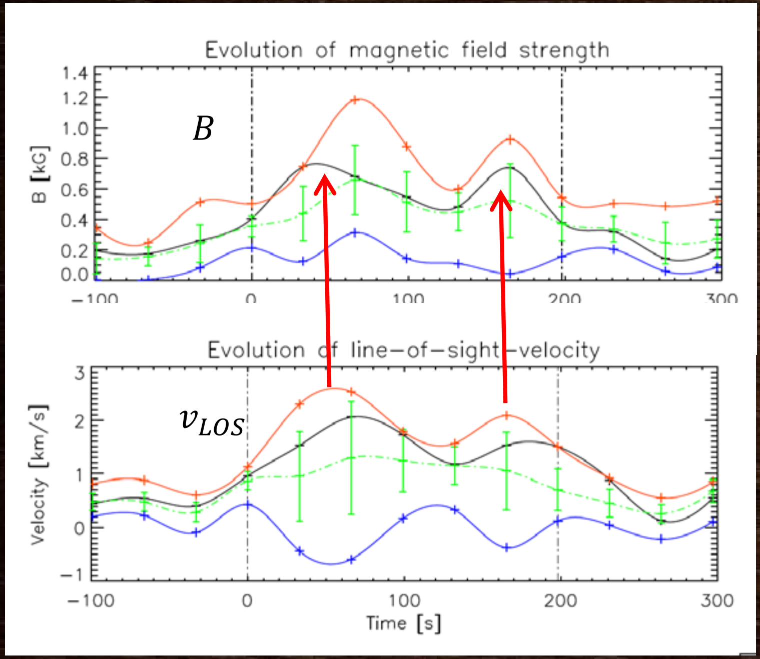


Sunrise balloon-borne solar observatory

- Aim: High resolution studies of photosphere (Solanki+ 2010; 2017)
- 1-m aperture Gregory telescope (Barthol+ 2011)
- 2 simultaneously working instruments:
  - SUFI, UV filter imager: between 214nm & Ca II H (Gandorfer+ 2011)
  - IMAX: vector magnetograph in Fe I 525.02 nm (Martínez Pillet+ 2011)
- Science flights in 2009 & 2013
- 85 journal papers so far
- Next flight in 2020-2021, with 4 (new) instruments: cover photosphere + chromosphere



Evolution: Magnetic intensification



—— Max. B & v_{LOS} in magn. Elem.
—— Surroundings

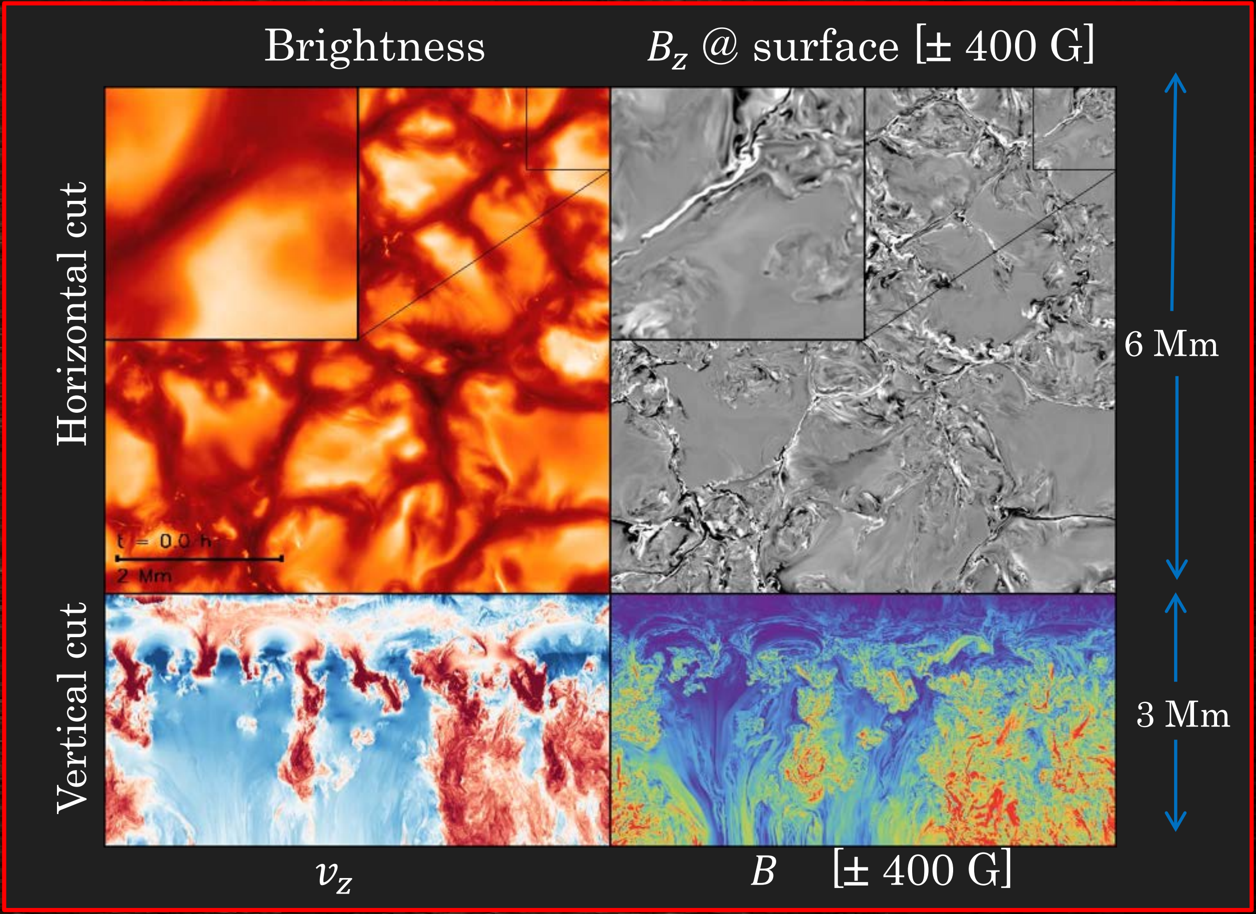
Lagg+ 2010; Martinez Gonzalez+ 2011; Narayan 2011; Utz+ 2014; Requerey+ 2014

- Quiet Sun FTs don't have a quiet life!
- Field strength fluctuates between weak (equipartition) & strong (kG) fields
- Often multiple convective collapses for same feature
- No clear upflows detected prior to weakening, unlike Grossmann-Doerth+ 1998
- Drivers: concentration by surrounding granules, vortices, downflows evolution (Requerey+ 2015, 2017)

Origin of internetwork field?

Rempel 2014

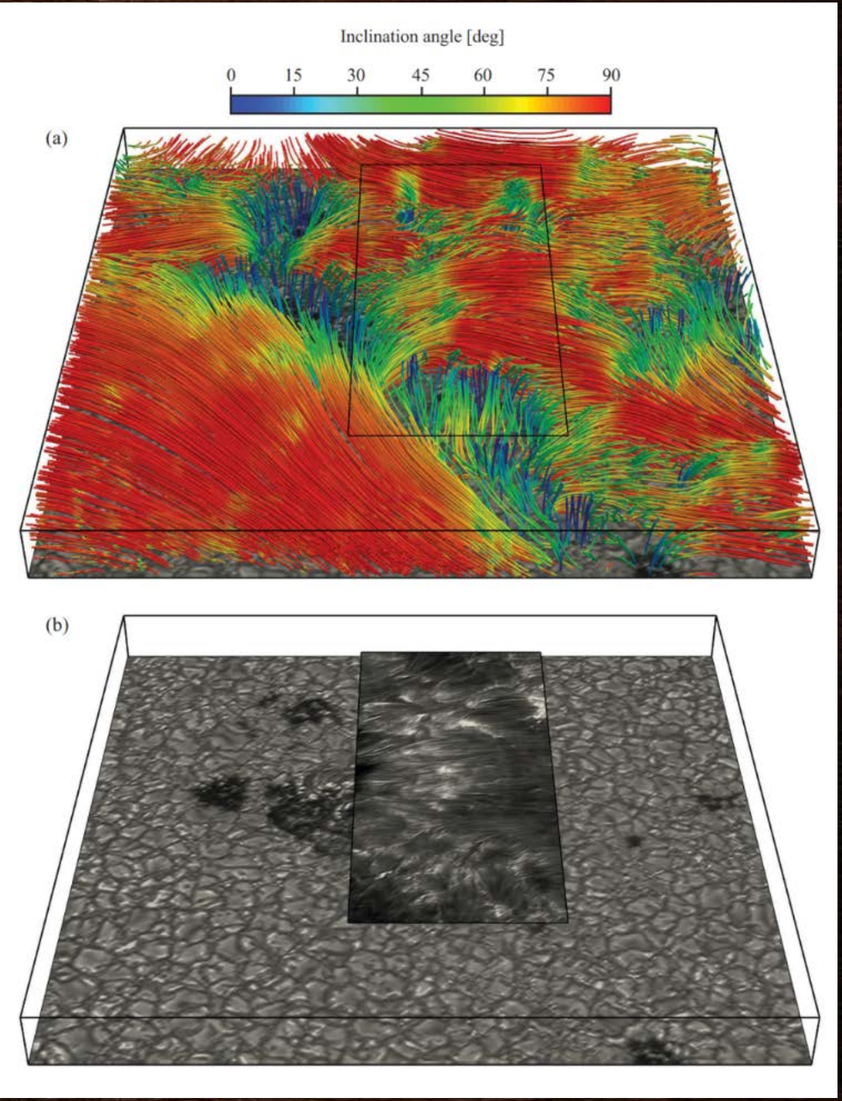
- Idea: source is small-scale dynamo → simul. (Schüssler & Vögler 07, 08)
- Support: Power spectra of B & v_z (Danilovic+ 2010, 2016); no cycle dependence (Bühler+ 2013; Lites+ 2015); field orientation (Lites+ 2017)



- To get consistency with obs. (Danilovic+ 2010, 2016), part of field is advected from deeper layers of CZ

Connection with upper atmosphere

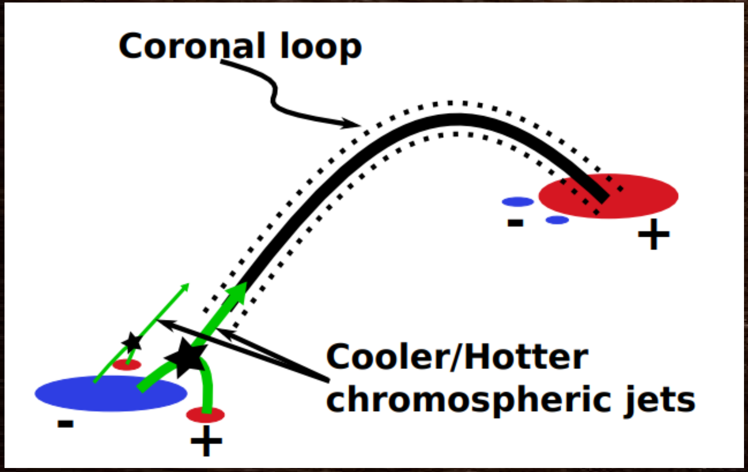
- Magnetostatic equilibrium starting from Spinor inversions of Sunrise/IMaX data
- Nearly horizontal field lines in low chromosphere follow long Ca II H fibrils seen in Sunrise/SuFI
- Where field lines are more vertical, fibrils are shorter and more chaotic

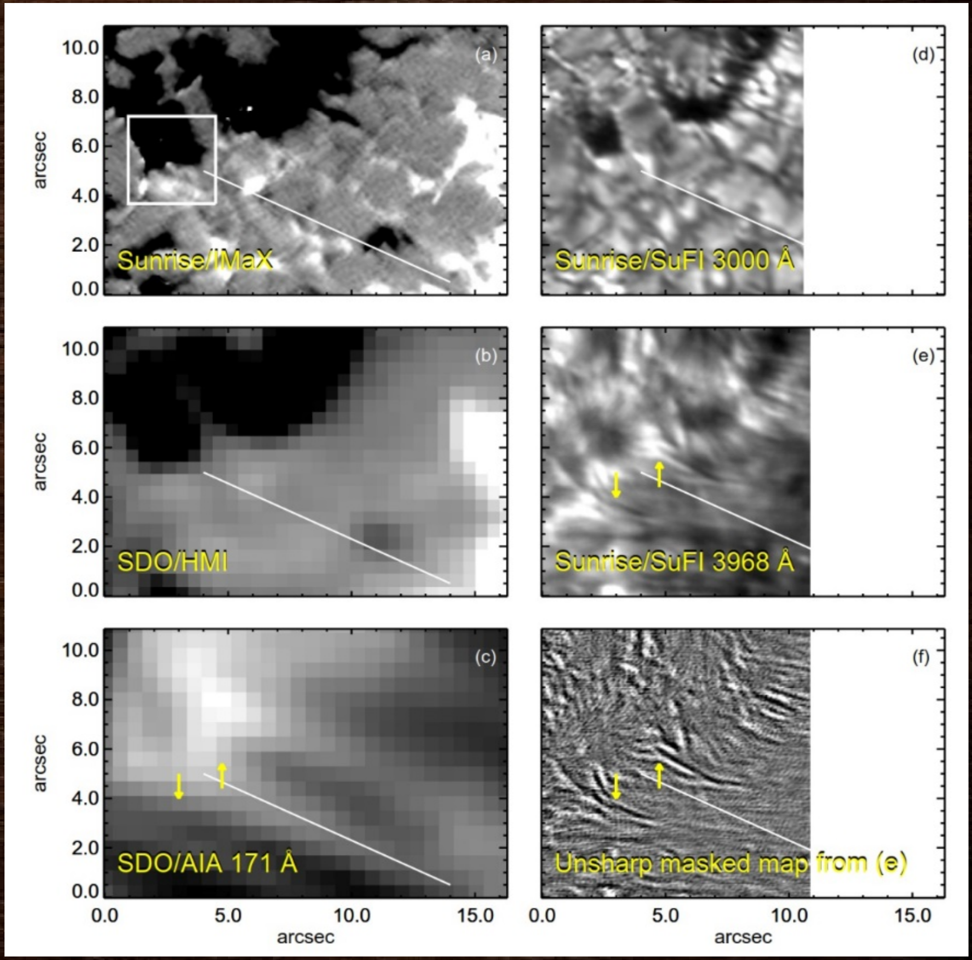


Wiegelmann+ 2016;
Jafarzadeh+ 2016

Magnetic flux cancellation & coronal loops

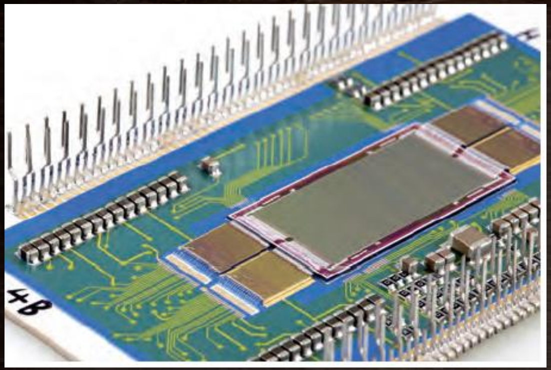
- Sunrise/IMaX: cancelling mixed polarity fields near footpoint of coronal loops
- Sunrise/SuFI: λ-shaped chromo-spheric jets
- Is magnetic cancellation / reconnection filling the loops with hot gas?





Chitta et al. 2016

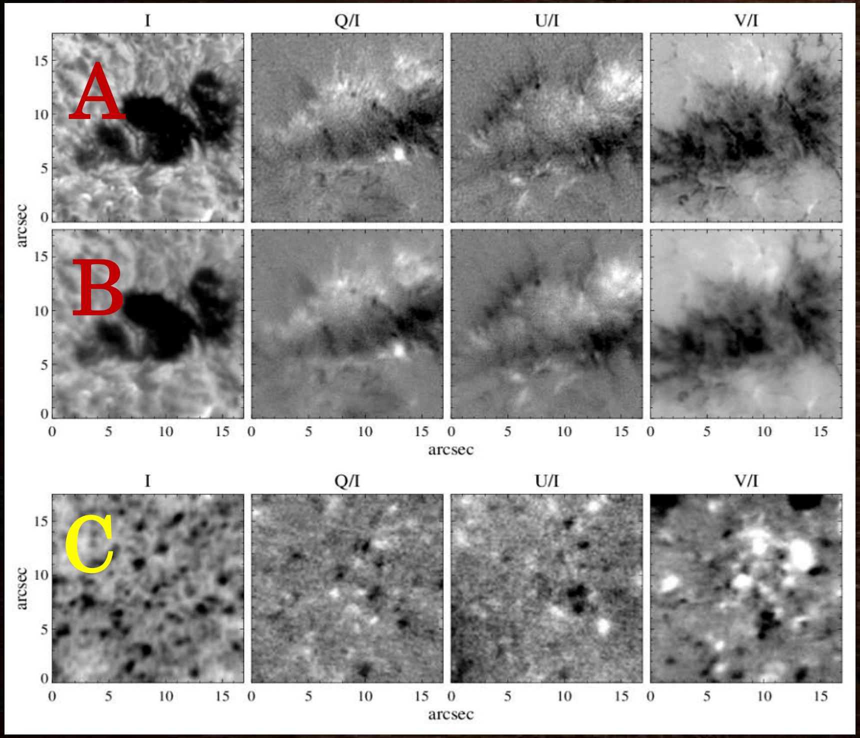
Fast Solar Polarimeter: FSP



pnCCD evaluation model

0.6 m telescope, Tenerife

- Fast and low-noise pnCCD or CMOS detector for high-precision polarimetry
- Successful performance tests with small evaluation model
- Full-scale instrument with 1k x 1k CMOS now running
- Iglesias+ 2015; 2016



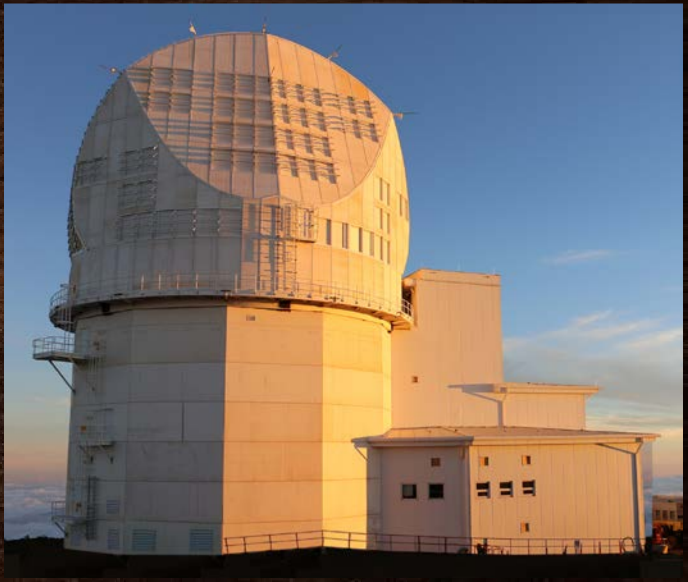
A. Small active region in Fe I 630.2 nm. MOMFBD restored

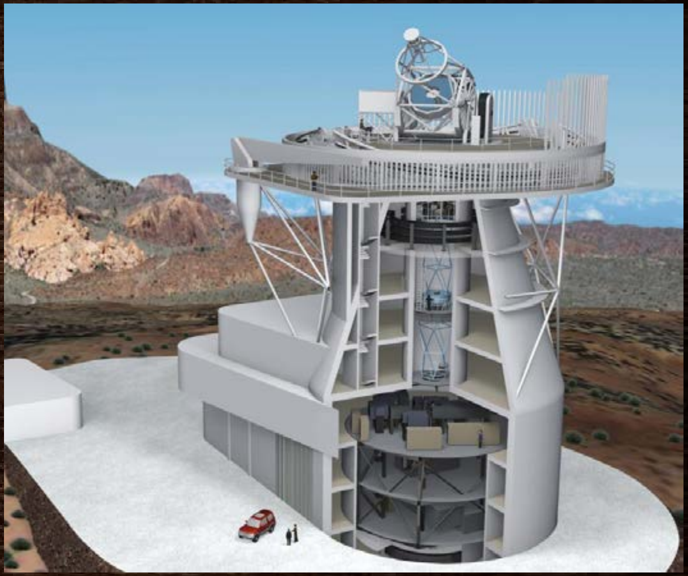
B. Same as A except simple averaging

C. Quiet Sun: polarimetric sensitivity of 0.02% and resolution like Hinode

Future: DKIST and EST

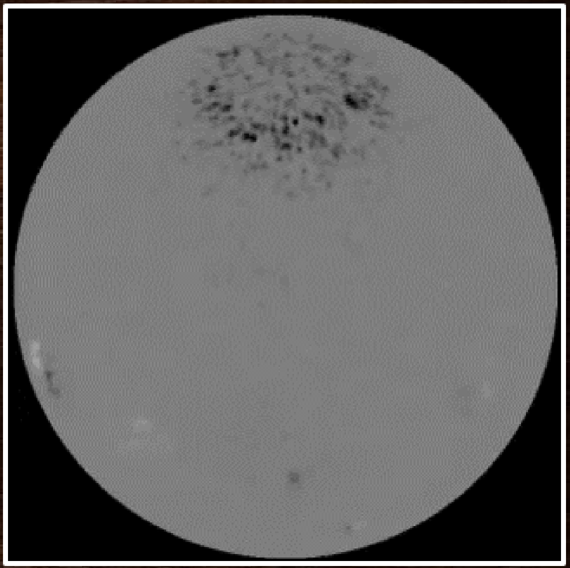
- DKIST being built on Maui; operational from 2019+ onwards
- EST being designed for Canary Islands; operational from 2026+
- ≈ 4m primary mirror diameter
- Aim at resolving 20-30 km on the solar surface
- Will each have a powerful suite of instruments (DKIST concentrating mainly on red and IR; EST more on full visible spectral range)
- Talk by Manolo Collados





Solar Orbiter Polarimetric & Helioseismic Imager = SO/PHI

- Photospheric science (for rest see talk by Holly Gilbert):
  - Magnetic & velocity field distributions at solar pole over solar cycle
  - Stereoscopy of magnetic & convective features
  - Removal of 180° ambiguity
  - Follow magnetic field evolution of ARs during near-co-rotation phase
  - Connection of solar surface with solar interior, corona and heliosphere



Thank you for your attention