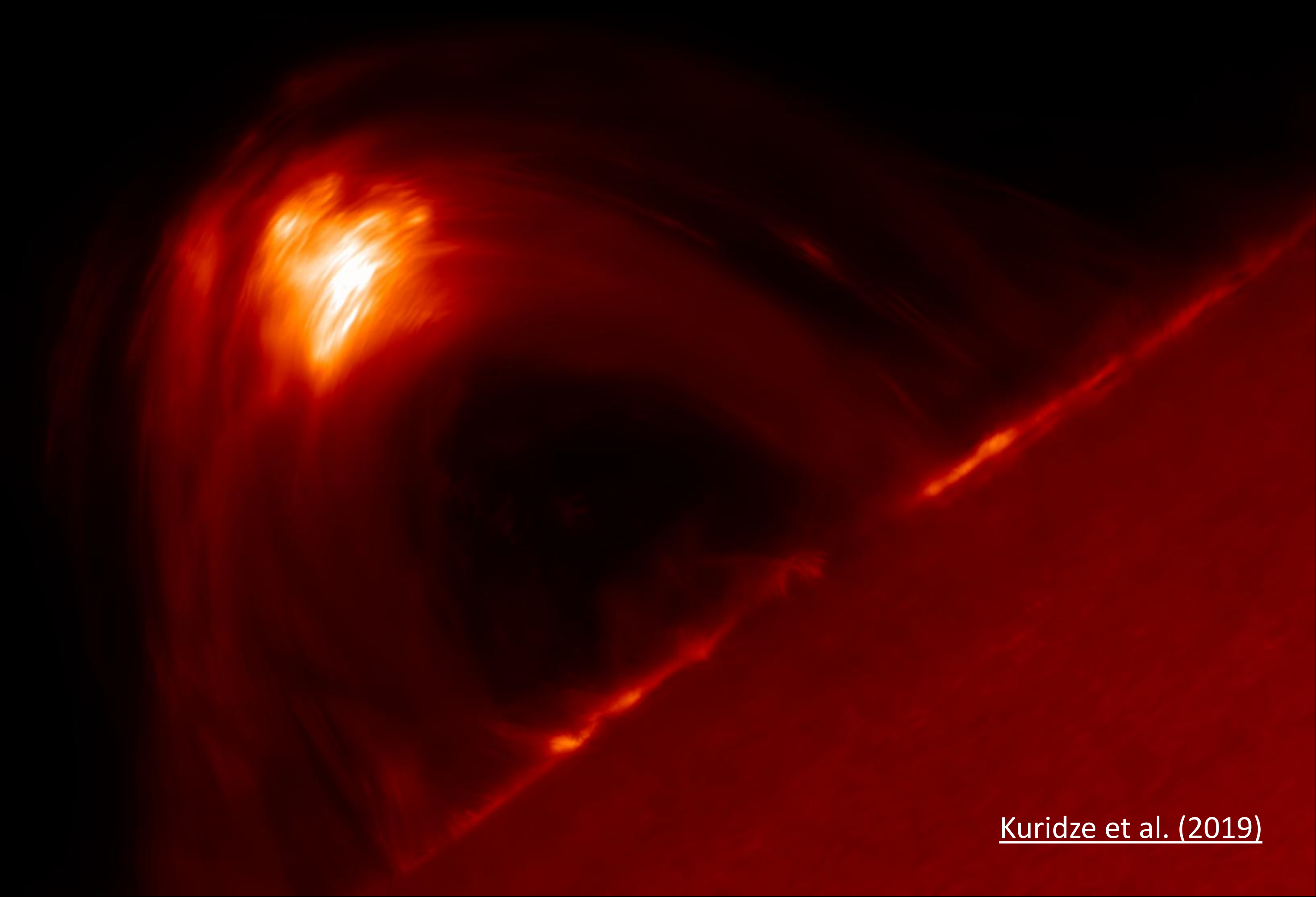
Exploring Solar Flares
The Magnetism of Flare Loops



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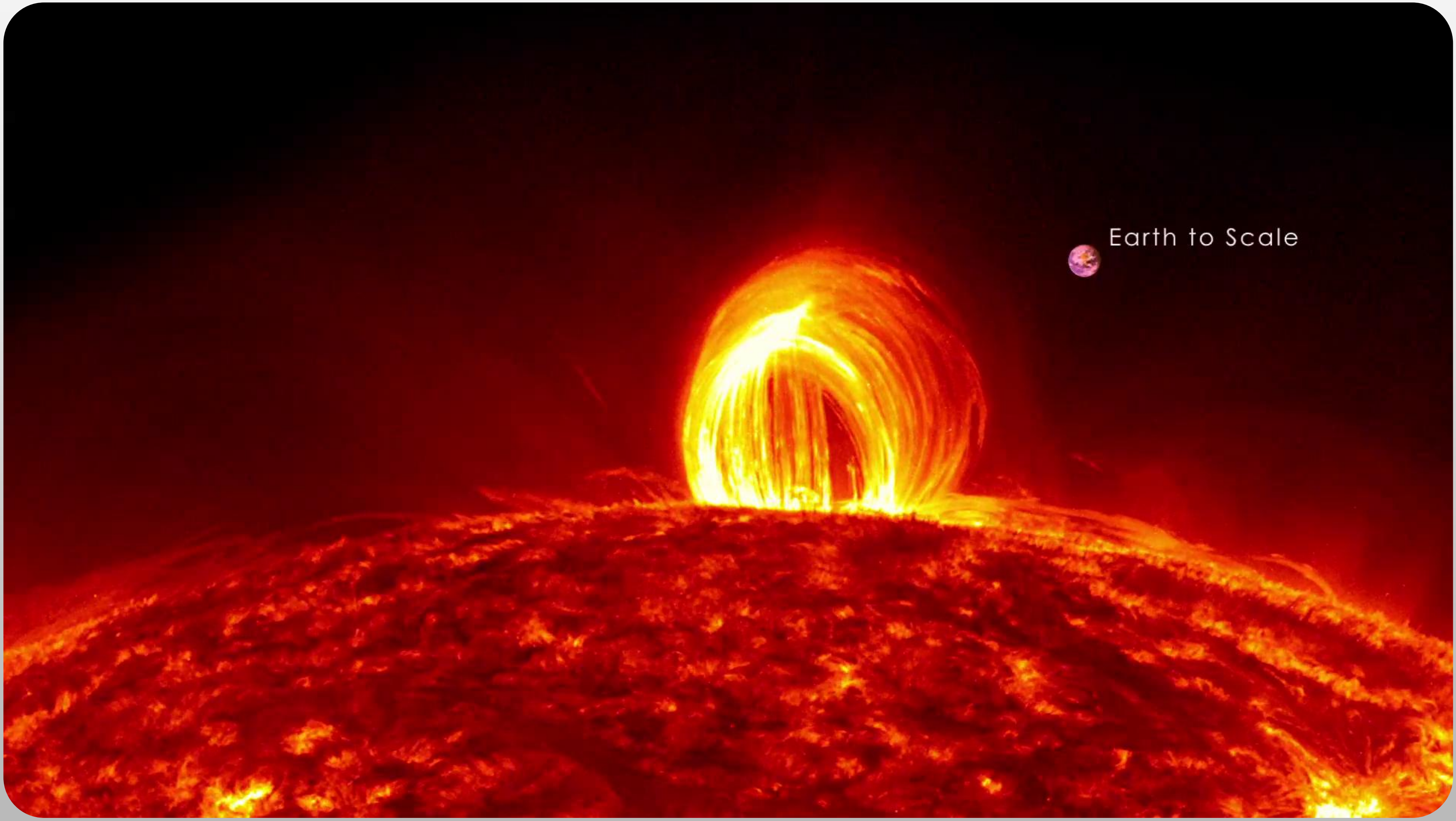
Kuridze et al. (2019)

"If the Sun did not have a magnetic field,
it would be as uninteresting a star
as most astronomers believe it to be."

the most probable author of the quotation: R.B. Leighton

Fiery Looping Rain on the Sun

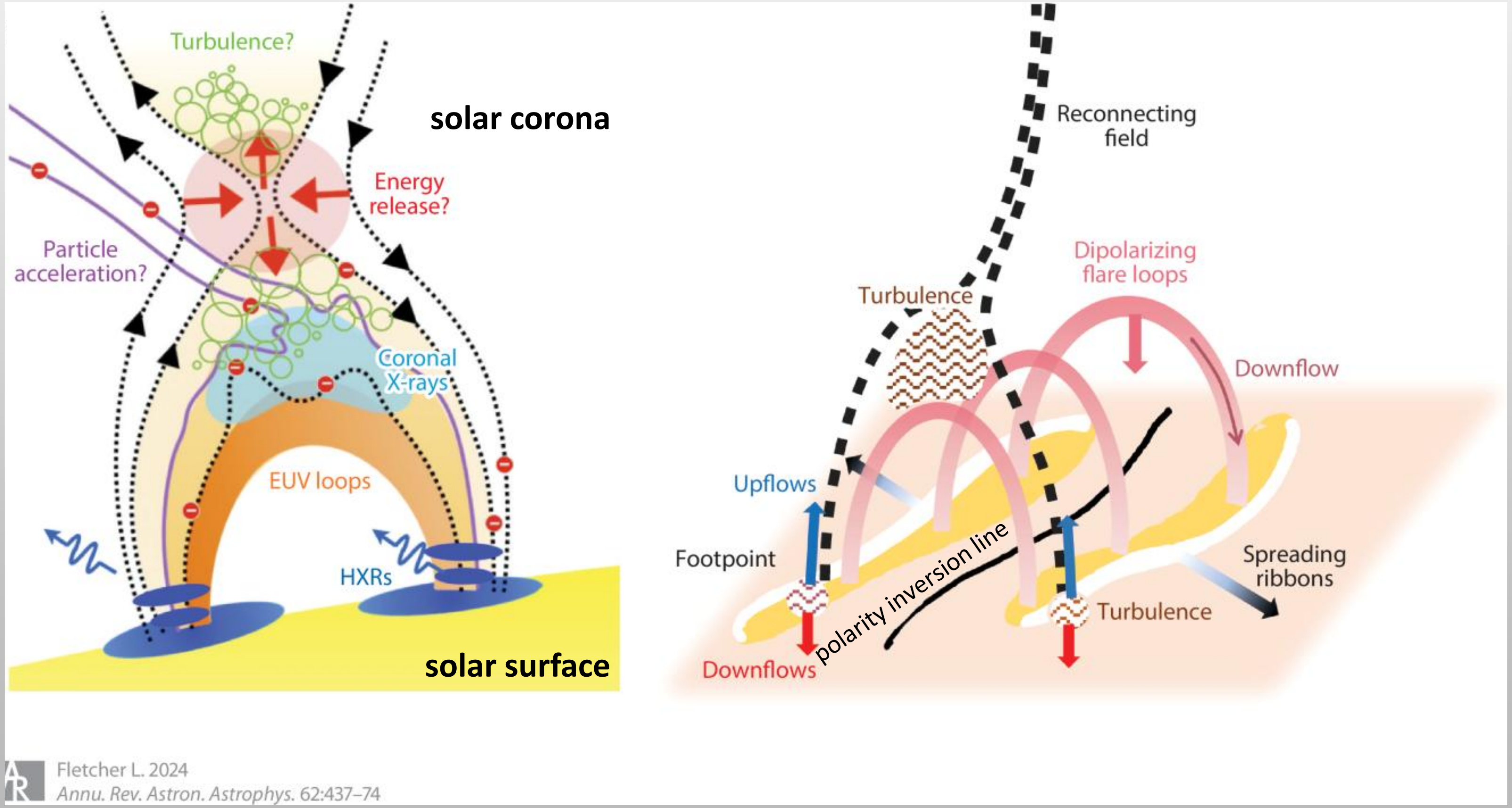


Solar Flare – More Than Just a Fiery Spectacle

Nature: Essentially a magnetic phenomenon, closely linked to the rapid reconfiguration of coronal magnetic fields (a flare occurs when the solar corona relaxes).

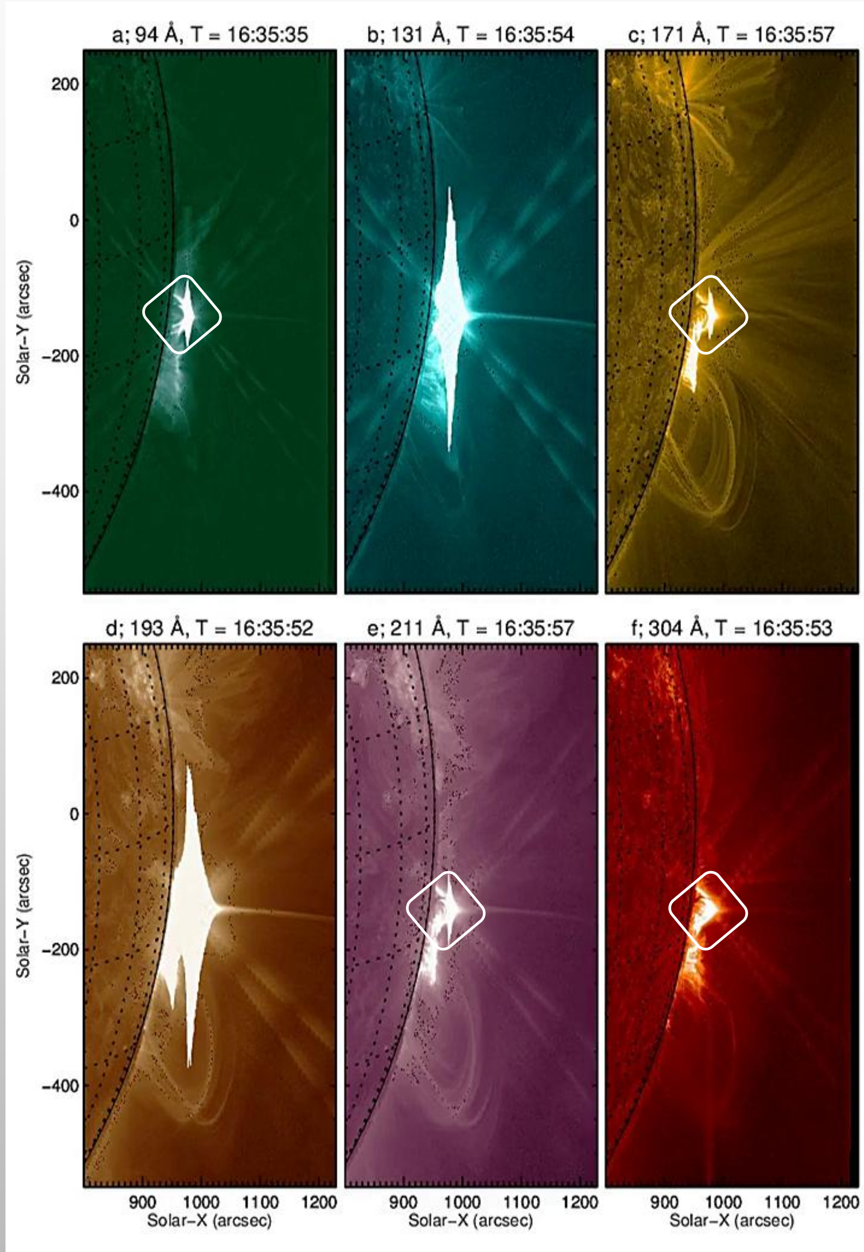
Consequences: Intense plasma heating (up to ~10 million K) within a relatively small volume, accompanied by its expansion, flows, and particle acceleration (acting as a powerful particle accelerator à la super-LHC at CERN).

Observability: Flare plasma emits across the entire accessible electromagnetic spectrum, from radio waves to γ rays.

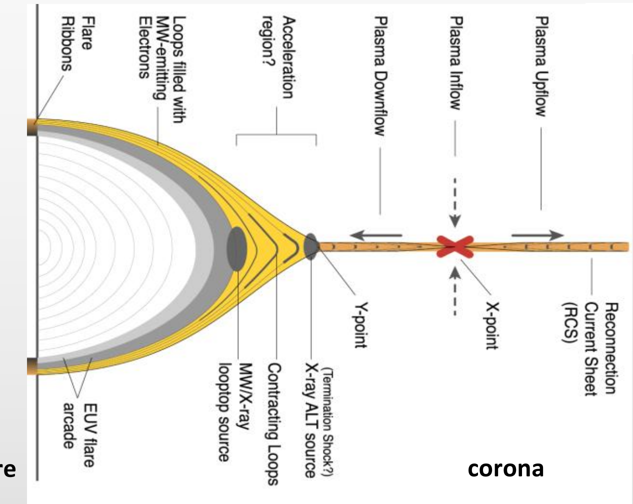


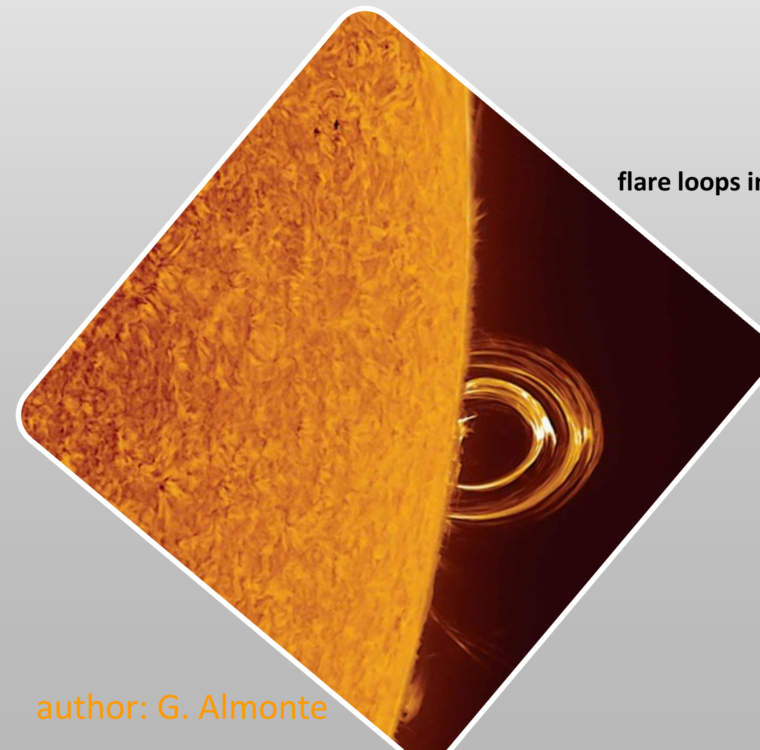
Fletcher (2024)

Second-Strongest X8.2-Class Flare of Solar Cycle 24 (10 Sep 2017)



limb in Extreme UV (Veronig et al. 2018)

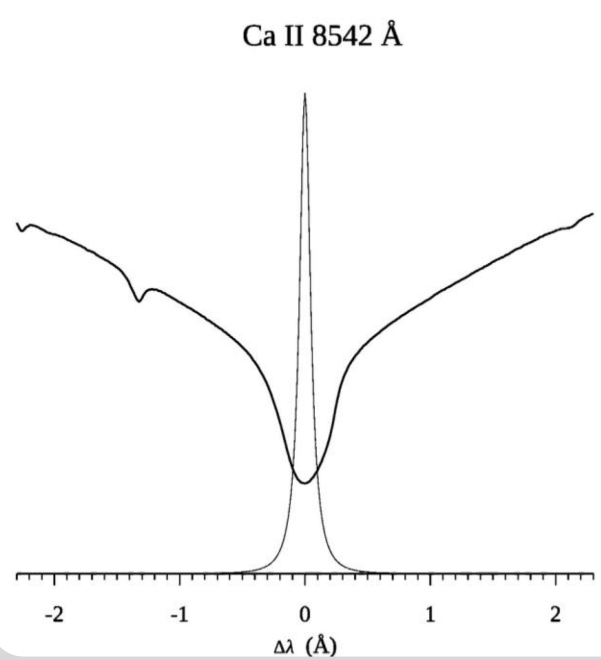


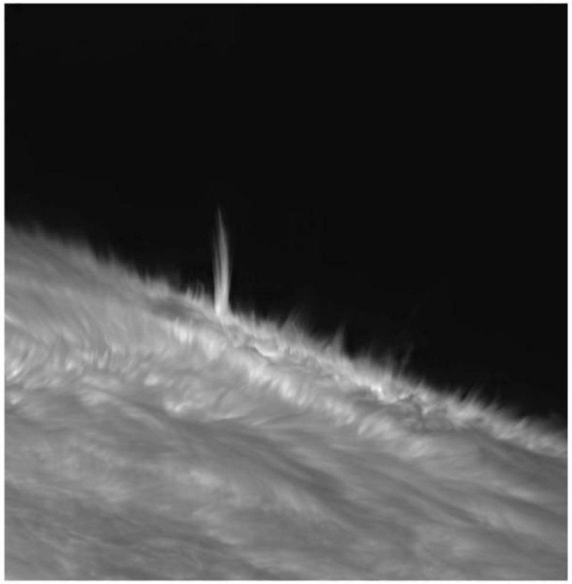


flare loops in Hα

author: G. Almonte

Example: Narrow-band Imaging Spectroscopy at the Limb



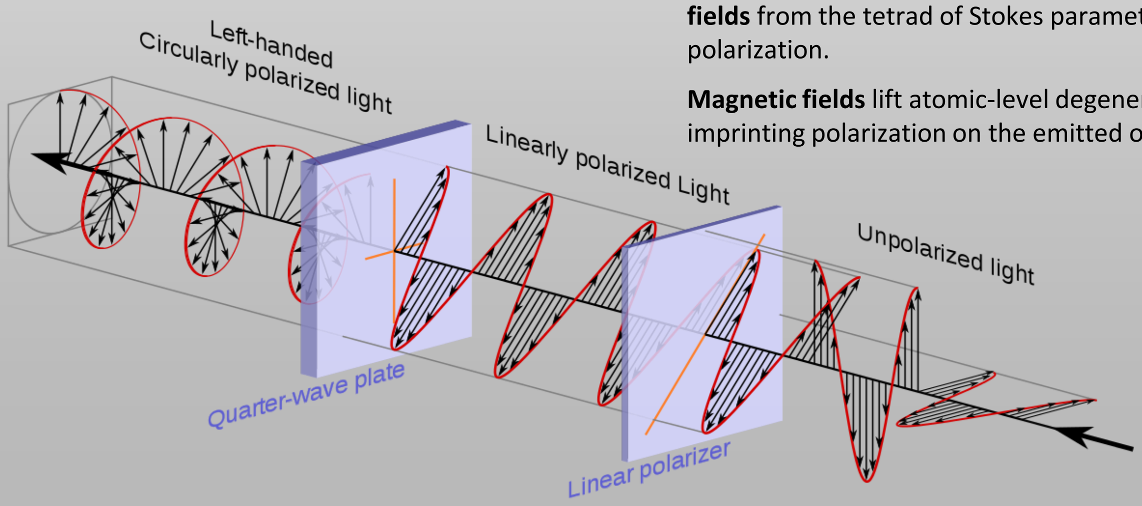


Kuridze et al. (2021)

Spectropolarimetry

Spectropolarimetry is essentially precise differential photometry, enabling the inference of **magnetic fields** from the tetrad of Stokes parameters *I*, *Q*, *U*, and *V*, with *Q* and *U* encoding **linear** and *V* **circular** polarization.

Magnetic fields lift atomic-level degeneracies by introducing spatial anisotropy (**Zeeman effect**), imprinting polarization on the emitted or absorbed radiation.



light source

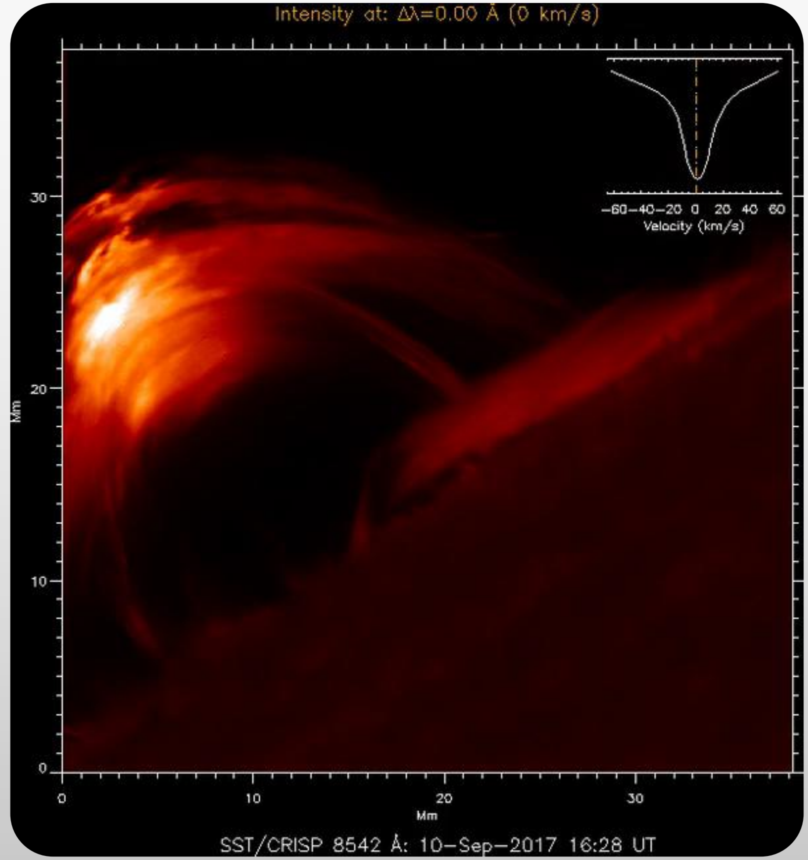
Wave Polarization = "Wave Directionality" (didactically)

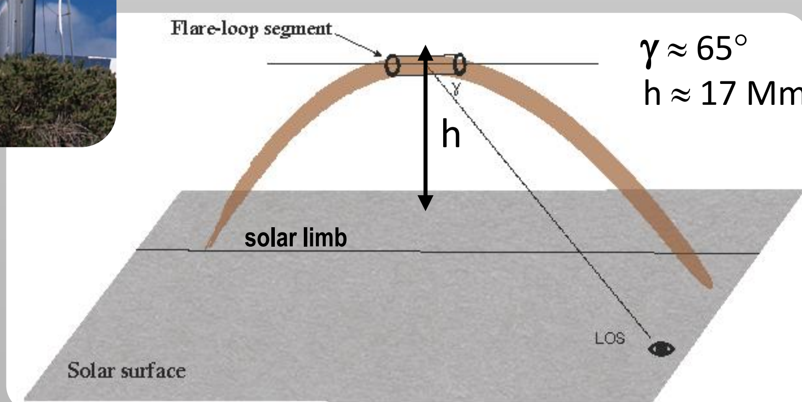
Describes the direction in which a wave oscillates.

Appears when optical processes are **anisotropic**, i.e., when the medium has direction-dependent properties.

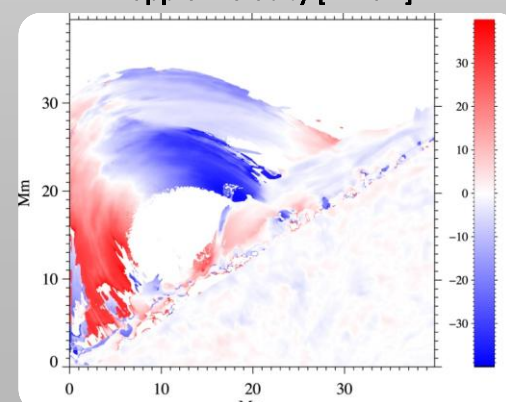
Imaging spectroscopy and spectropolarimetry of flare loops

Swedish 1-m Solar Telescope (SST)



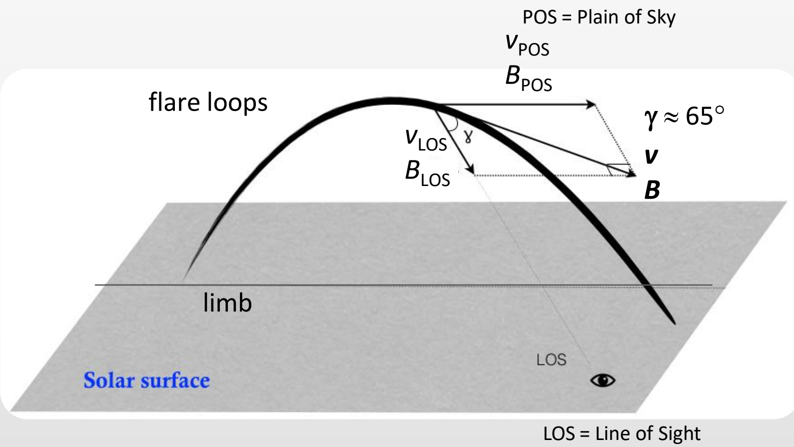


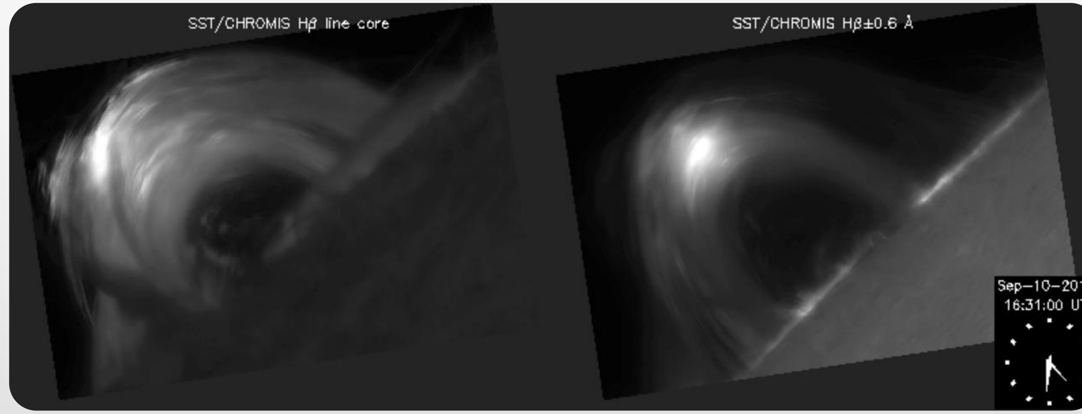
Doppler velocity [km s^{-1}]



Kuridze et al. (2019)

Towards the Velocity and Magnetic Field Structure of Flare Loops





$$\tan\gamma = \frac{v_{\mathrm{POS}}}{v_{\mathrm{LOS}}} = \frac{B_{\mathrm{POS}}}{B_{\mathrm{LOS}}}$$

$$\boldsymbol{B} \approx \frac{B_{\mathrm{LOS}}}{\cos\gamma}$$

Idea: The plasma in flare loops is magnetically confined, and its motion is guided by the loop's magnetic field.

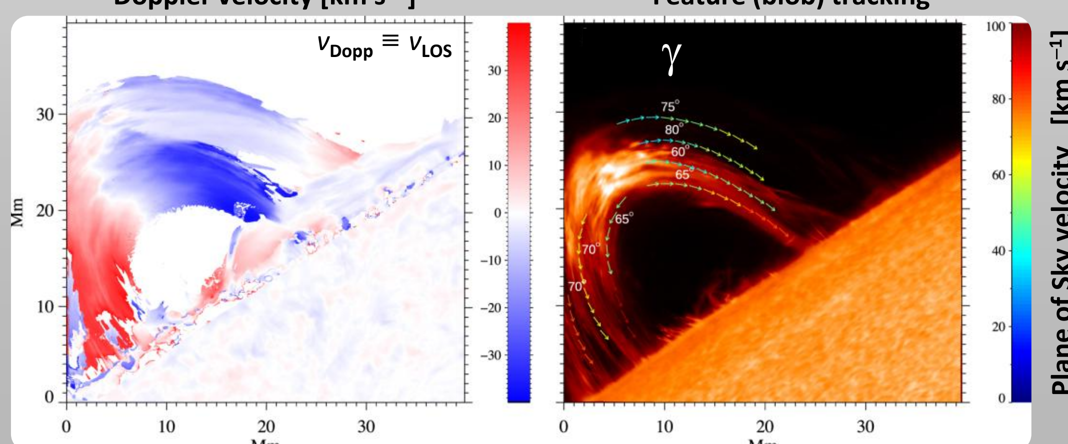
v_{LOS}, v_{POS} - imaging spectroscopy

B_{LOS} - spectropolarimetry

$\boldsymbol{B}$, B_{POS} - geometry (γ)

Kuridze et al. (2019)

Doppler velocity [km s^{-1}] **Feature (blob) tracking**



v_{POS}

POS = Plain of Sky

Weak Field Approximation

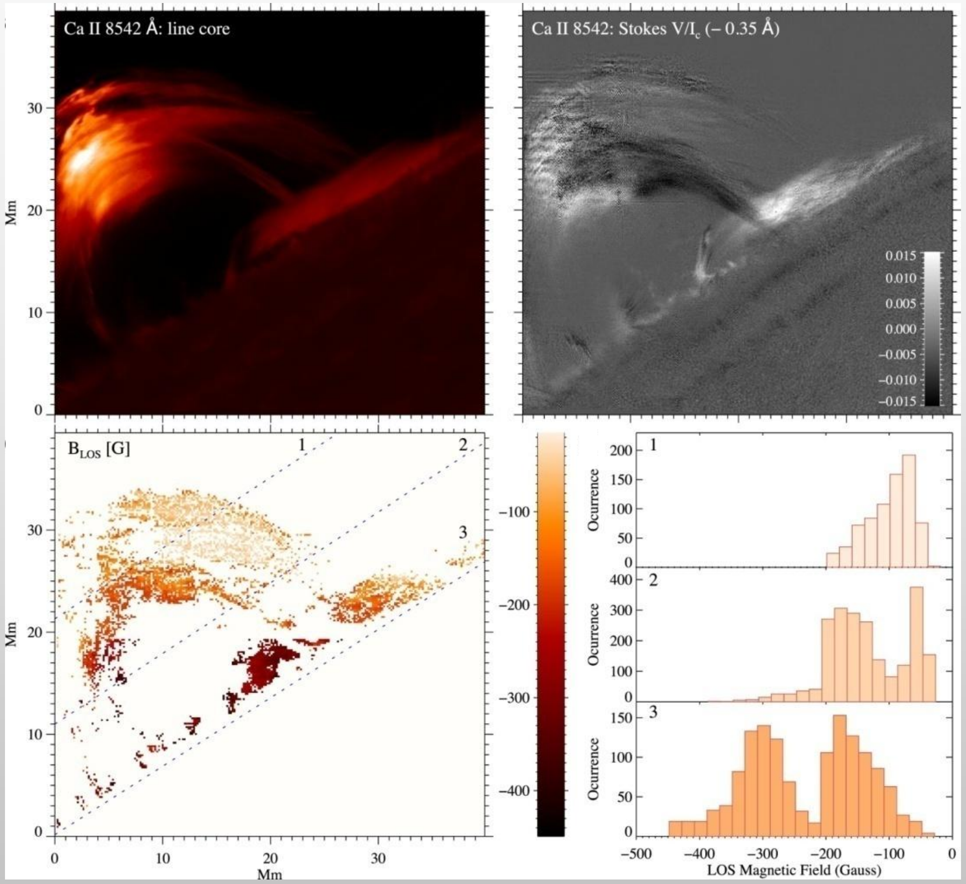
- simplest method to estimate the line-of-sight magnetic field component B_{LOS} from the intensity – Stokes $I(\lambda)$ – and circular polarization – Stokes $V(\lambda)$,

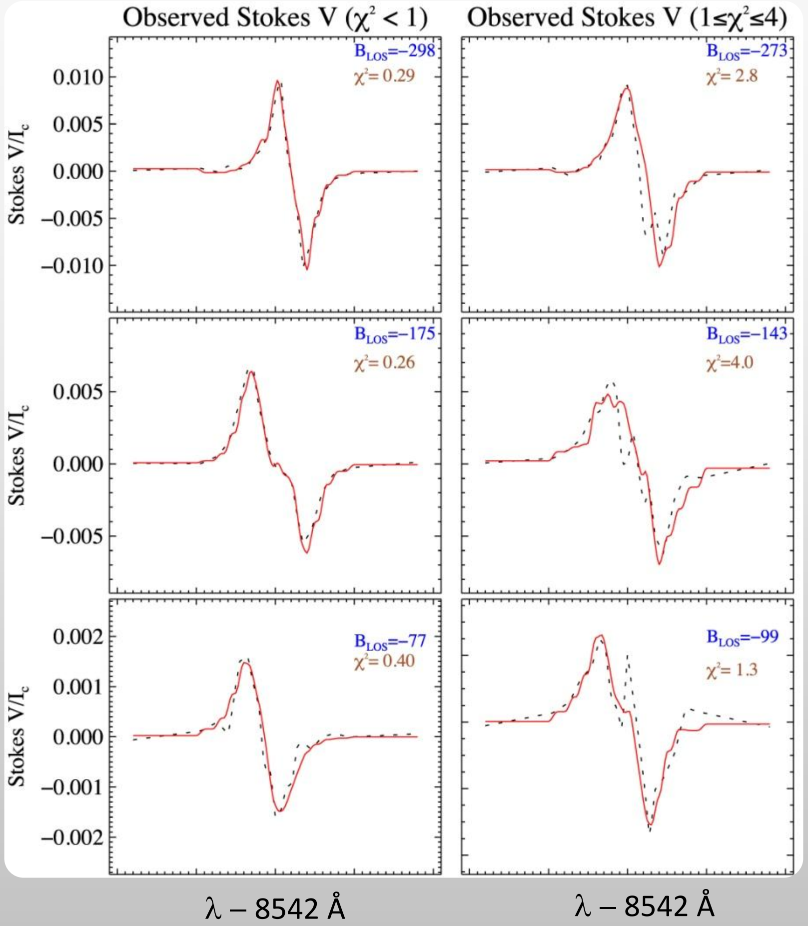
$$V(\lambda) = -4.67 \times 10^{-13} g_{\mathrm{eff}} \lambda_0^2 B_{\mathrm{LOS}} \frac{\partial I(\lambda)}{\partial \lambda},$$

- valid under the condition:

Zeeman splitting ($\Delta\lambda_{\mathrm{H}}$) << Doppler width ($\Delta\lambda_{\mathrm{Dopp}}$).

Inferring B_{LOS}: Stokes *V* profiles & Weak Field Approximation





- Weak Field Approximation $$V(\lambda) = -4.67 \times 10^{-13} g_{\rm eff}\, \lambda_0^2 B_{\rm LOS} \frac{\partial I(\lambda)}{\partial \lambda},$$

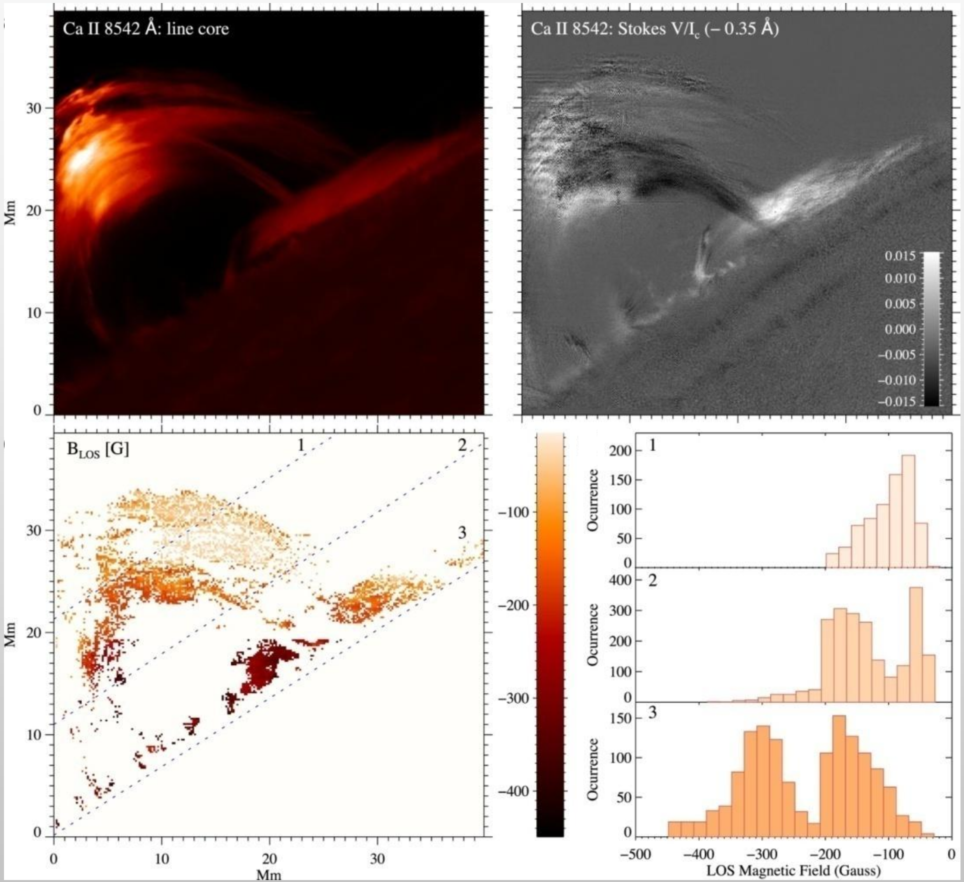
--------- observed Stokes *V*

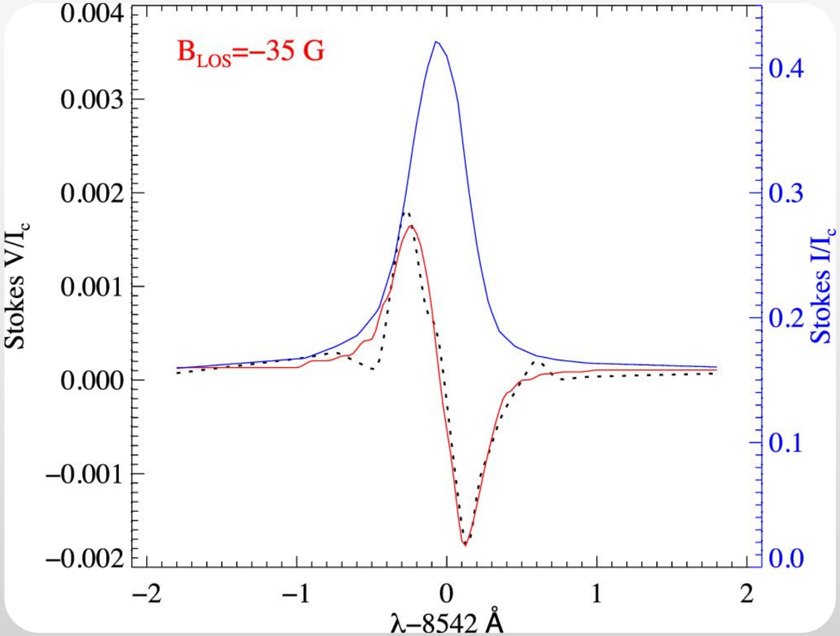
——— the WFA fits obtained from the derivative of Stokes *I*

- typical magnetic field strength ***B*** ≈ 350 gauss (0.035 T) inferred at the loop apex and 420 gauss (0.042 T) at mid-altitudes

Kuridze et al. (2019)

Inferring B_{LOS}: Stokes *V* profiles & Weak Field Approximation





Weak Field Approximation

$$V(\lambda) = -4.67 \times 10^{-13} g_{\rm eff}\, \lambda_0^2 B_{\rm LOS} \frac{\partial I(\lambda)}{\partial \lambda},$$

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observed Stokes *V*

observed Stokes *I*

the WFA fits obtained from the derivative of Stokes *I*

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Summary: Magnetic Fields of Coronal Flare Loops

Major flare loops: B ≈ 350 G (0.035 T) at ~25,000 km above the solar surface
and 420 G (0.042 T) at mid-altitudes

Independent confirmation: Microwave spectra from the Expanded Owens Valley Solar Array (EOVSA)

Context: Nature of stellar superflares

Puzzle: The Missing Linear Polarization — Undetected or Truly Absent?

Measuring such fields requires:

- Excellent site and telescope
- Advanced instrumentation & proper setup
- Suitable spectral diagnostics (preferentially at near IR)
- Favorable flare event and orientation

Takeaway:

Achieving these measurements needs a **favorable combination of many factors**—and some luck

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Typical magnetic field strengths for comparison:

Corona:	~0.1 – 1 G
Prominences / spicules:	~10 G
Sunspots / magnetic bright points:	~1000 G
Earth:	~0.25 – 0.65 G