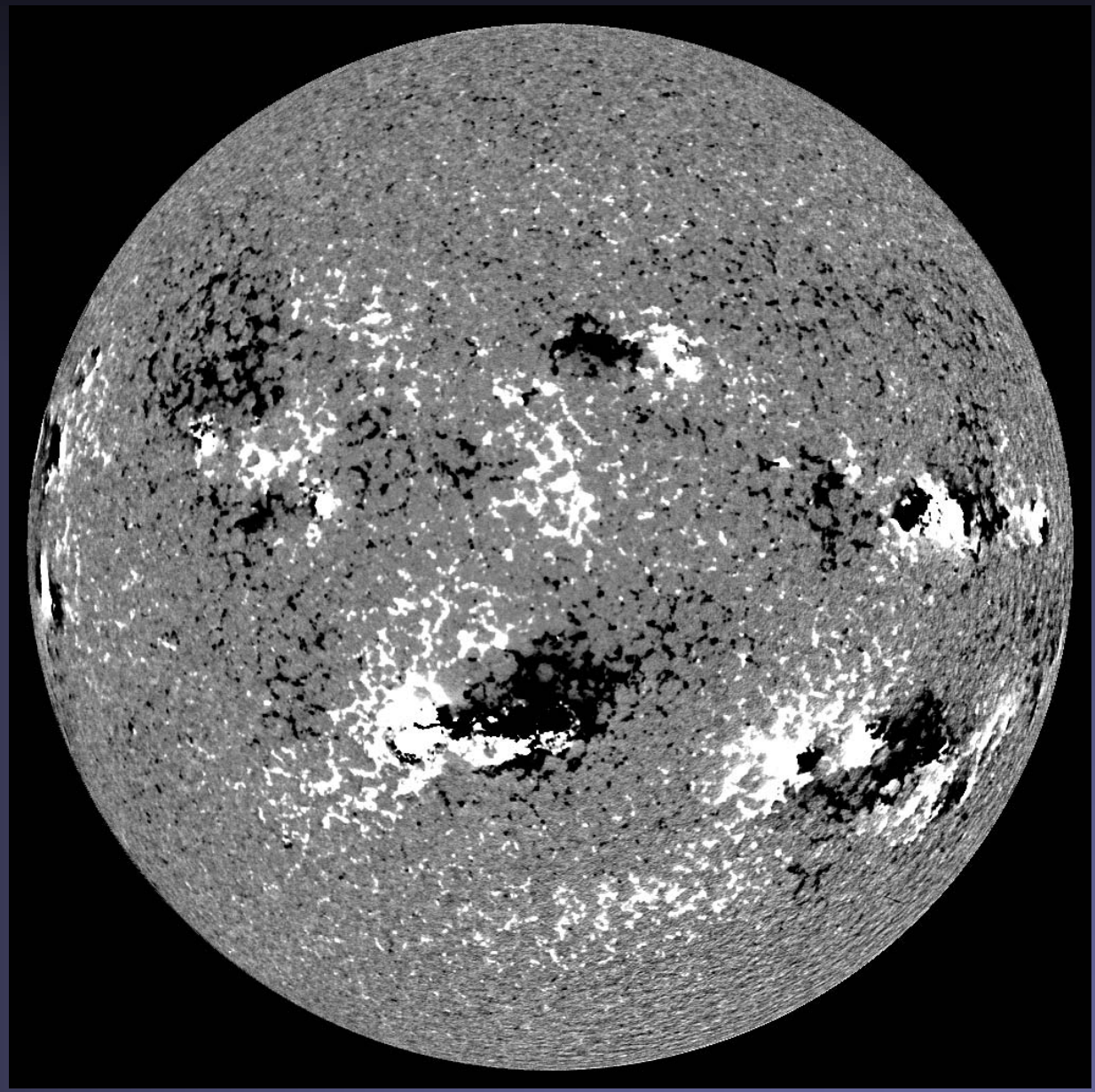
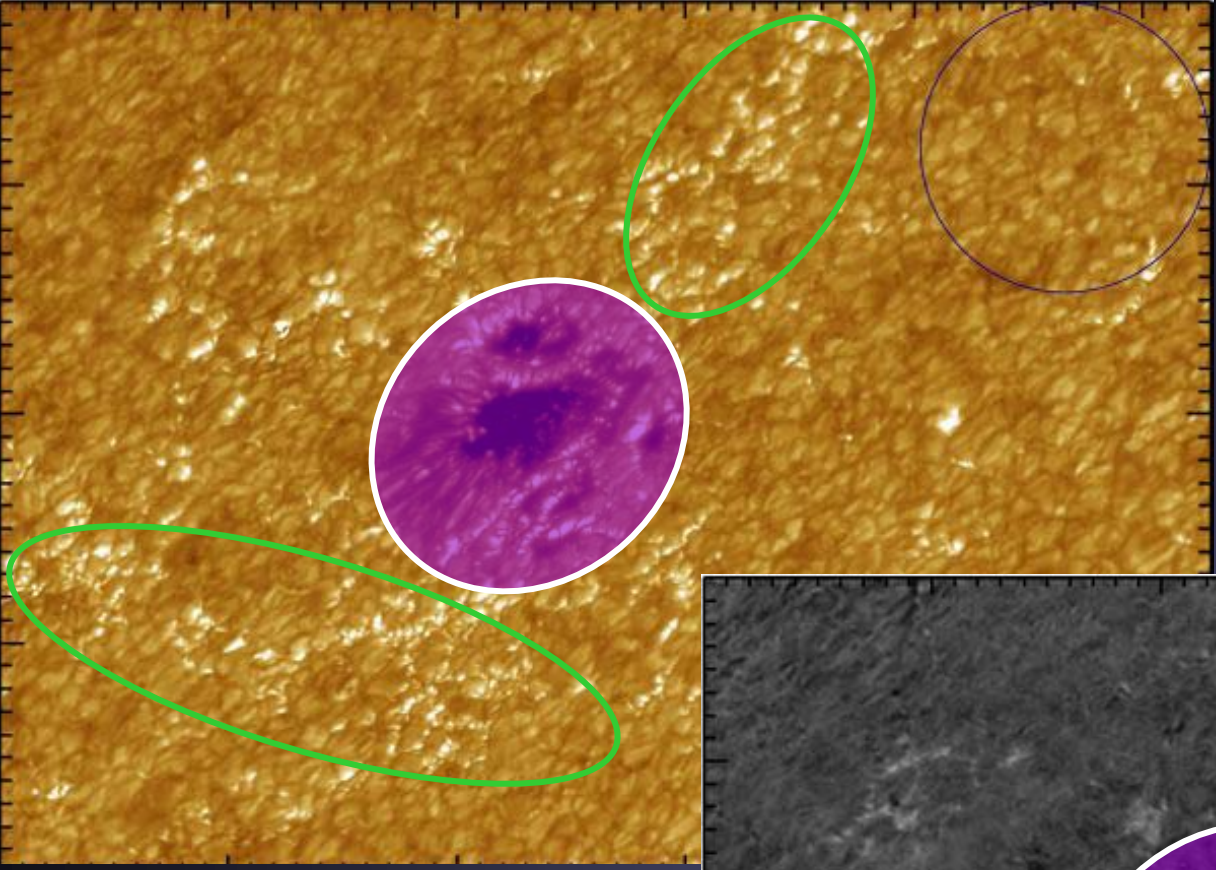
Non-spot magnetic fields

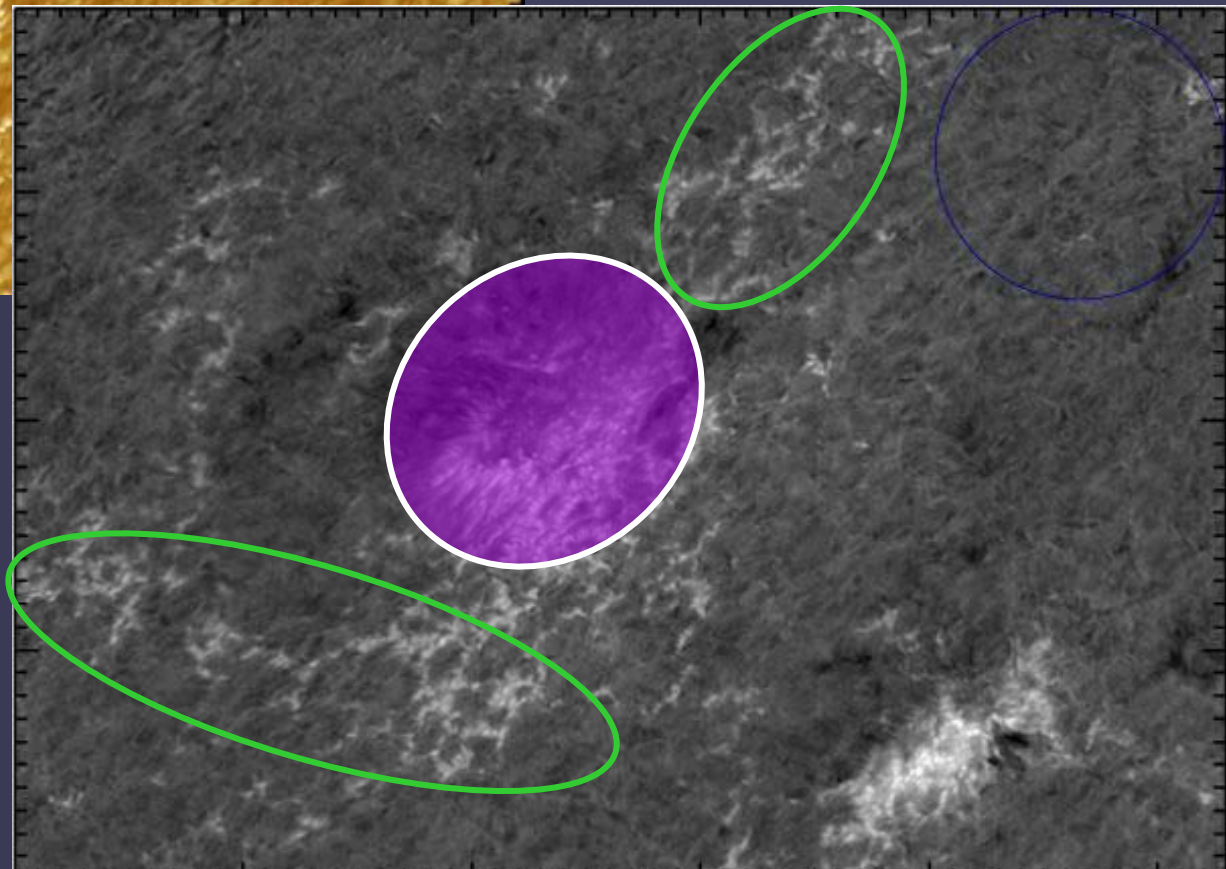
Non-spot fields

- Sunspots cover in general <0.2% of solar surface
- What about the remaining 99.8%?
- What are plage or facular regions & network composed of?



Facular fields



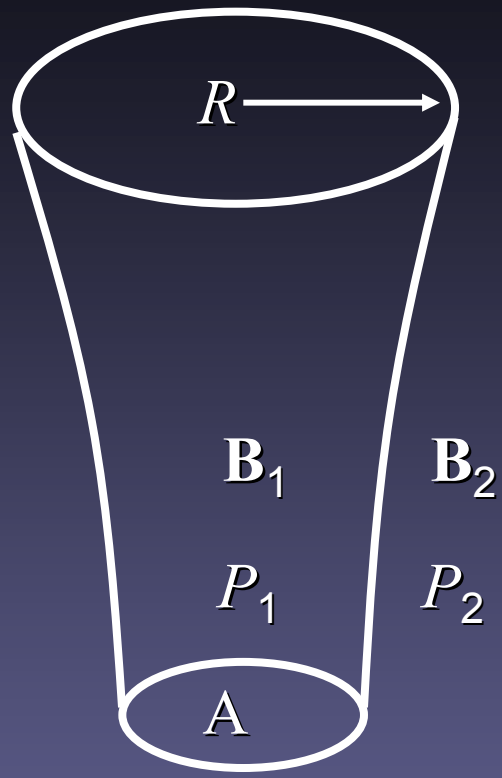


Facular fields are composed of magnetic elements, small (<300 km diameter) flux tubes.

Magnetic flux tubes

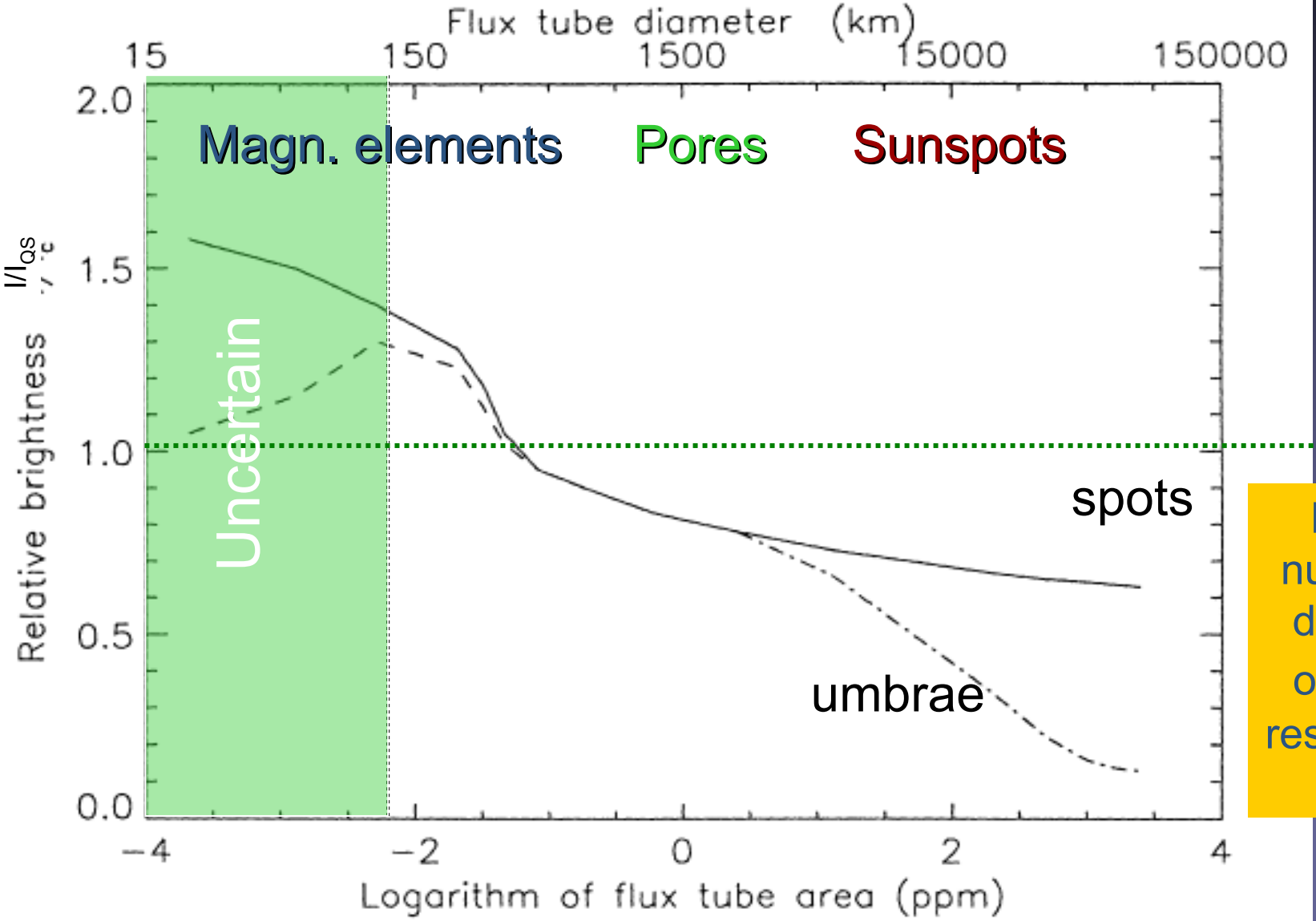
- Magnetic elements are intersections of solar surface & small magnetic flux tubes
- Thin flux tubes, $R<H_P$, where H_P is the pressure scale height, display no variation across their cross-section
- Pressure balance: $\frac{B_1^2}{8\pi} + P_1 = P_2 + \frac{B_2^2}{8\pi}$
- In hydrostatic equilibrium with $T = \text{const}$, $P_1 \sim \exp(-z/H_p)$ ➔ $B_1 \sim \exp(-z/2H_p)$
- Magnetic flux is conserved ➔ $\iint B(x,y,z)dxdy = \text{const}$

➔ For thin tube: $BR^2 = \text{const}$ ➔ $R \sim \exp(+z/2H_p)$



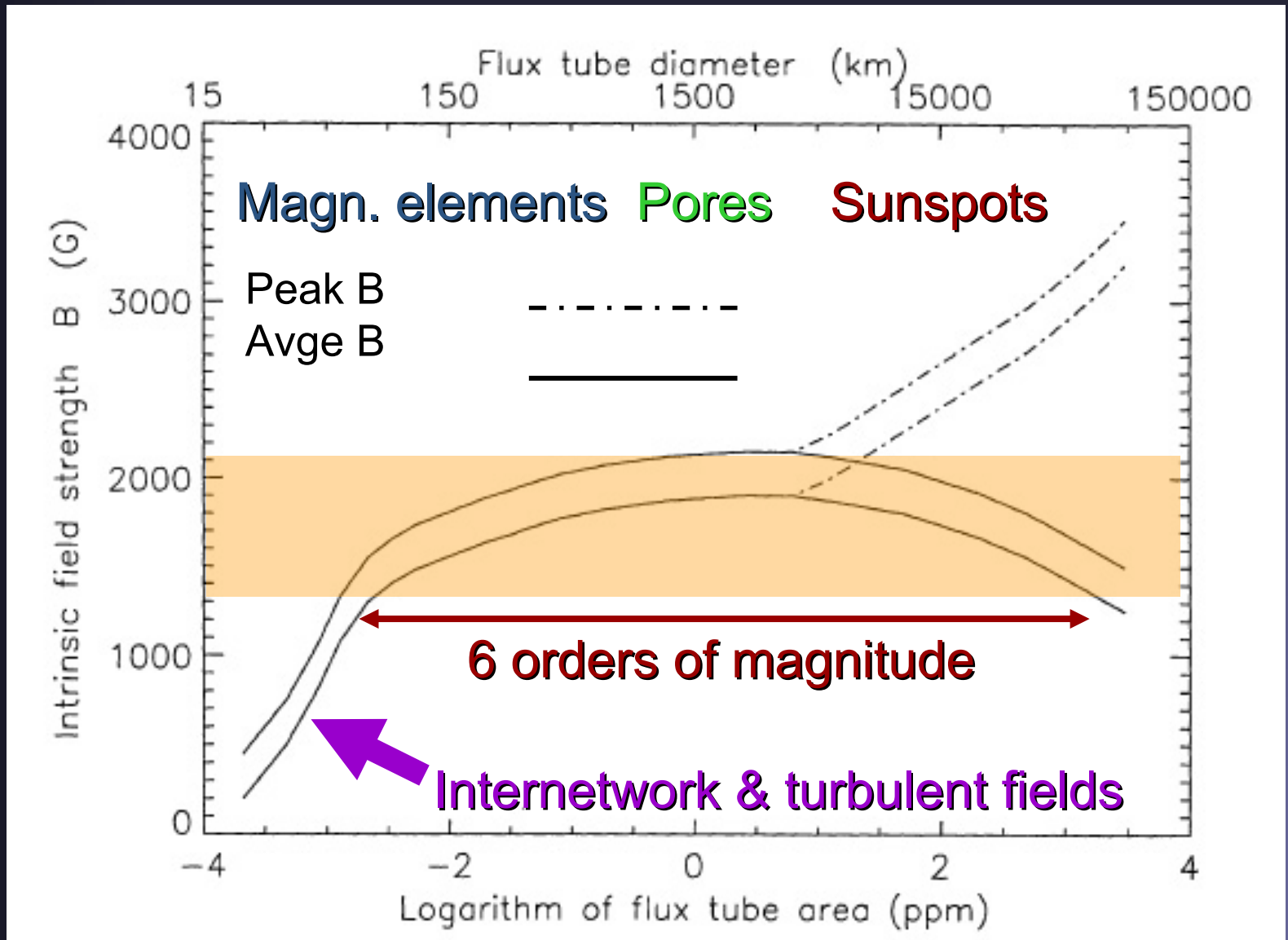
Rump of a flux tube

Temperature contrast vs. size

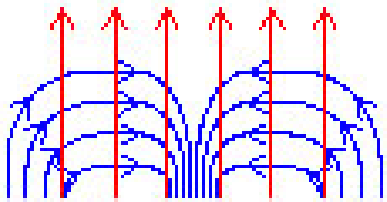


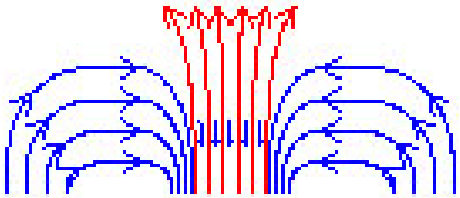
Exact numbers depend on λ, μ, resolution, etc.

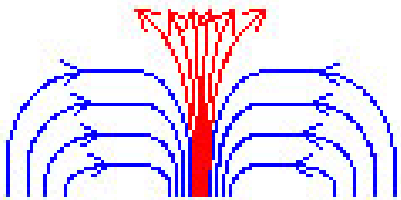
Surprisingly constant field strength



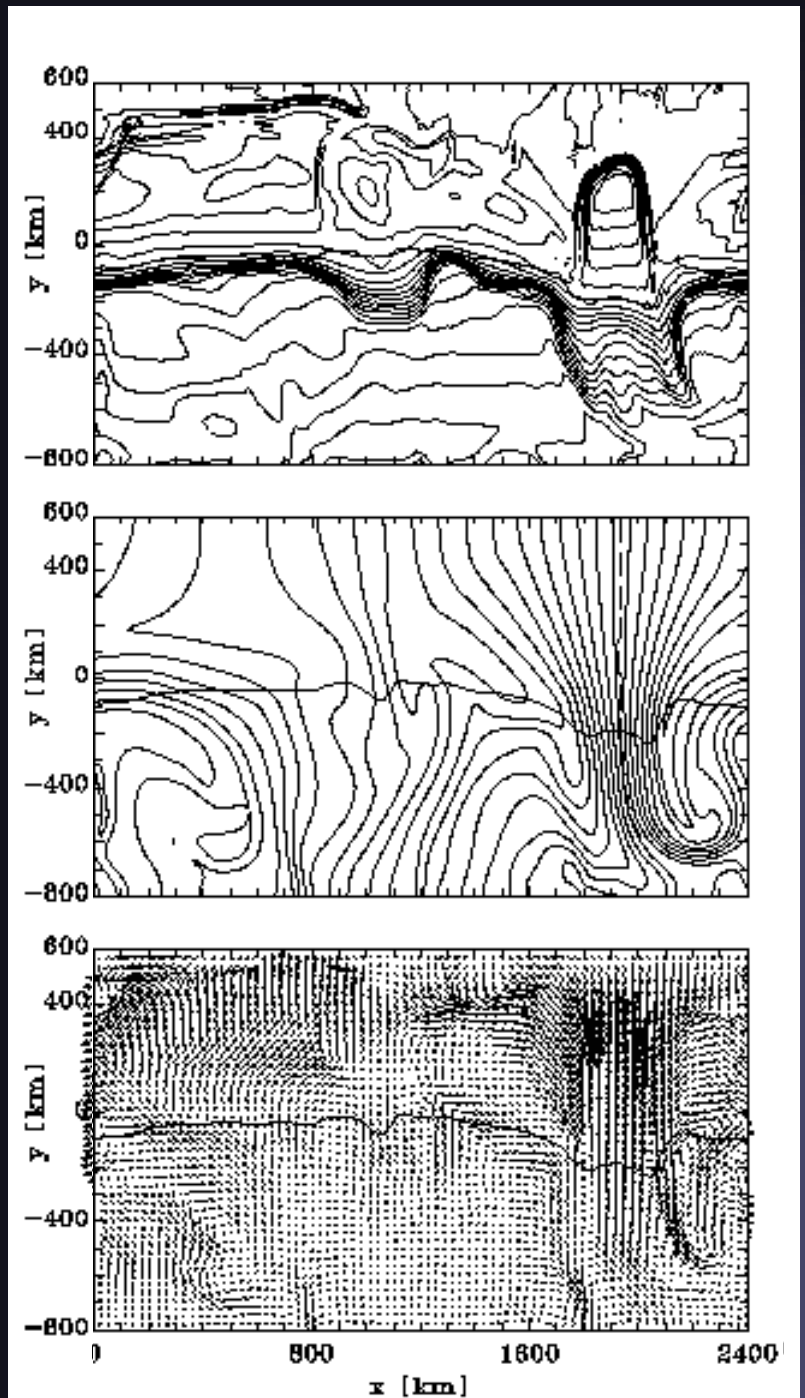
Convective intensification







- Flux advection by horizontal flow (flux expulsion)
- Suppression of convection, cooling and downflow
- Evacuation, field intensification



Convective intensification

- 2D, compressible
- radiation, ionization
- 2400 x 1400 km^2
- 240 x 140 points (10 km hor. resol.)
- <B> = 100, 200, 400 G
- collapse + rebound

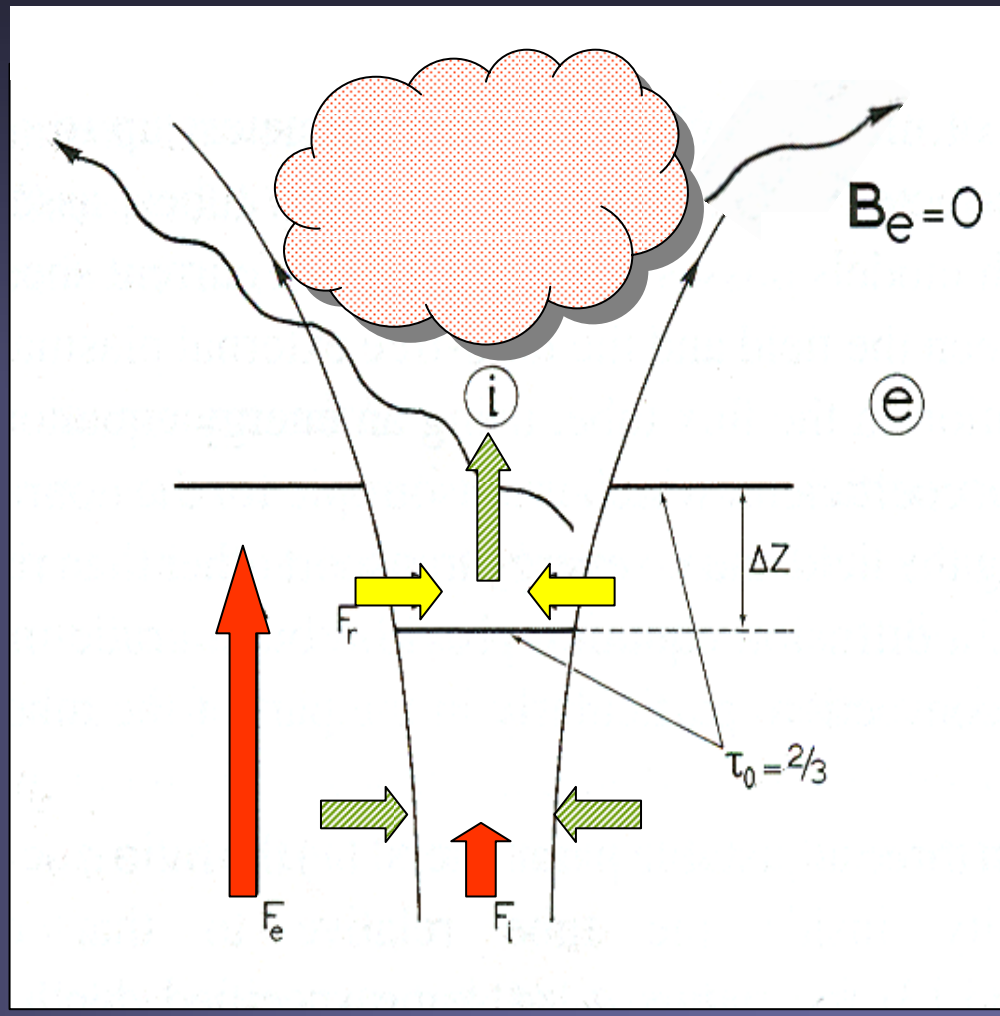
(Grossmann-Doerth, Schüssler & Steiner, 1998)

Magnetic elements: brightness

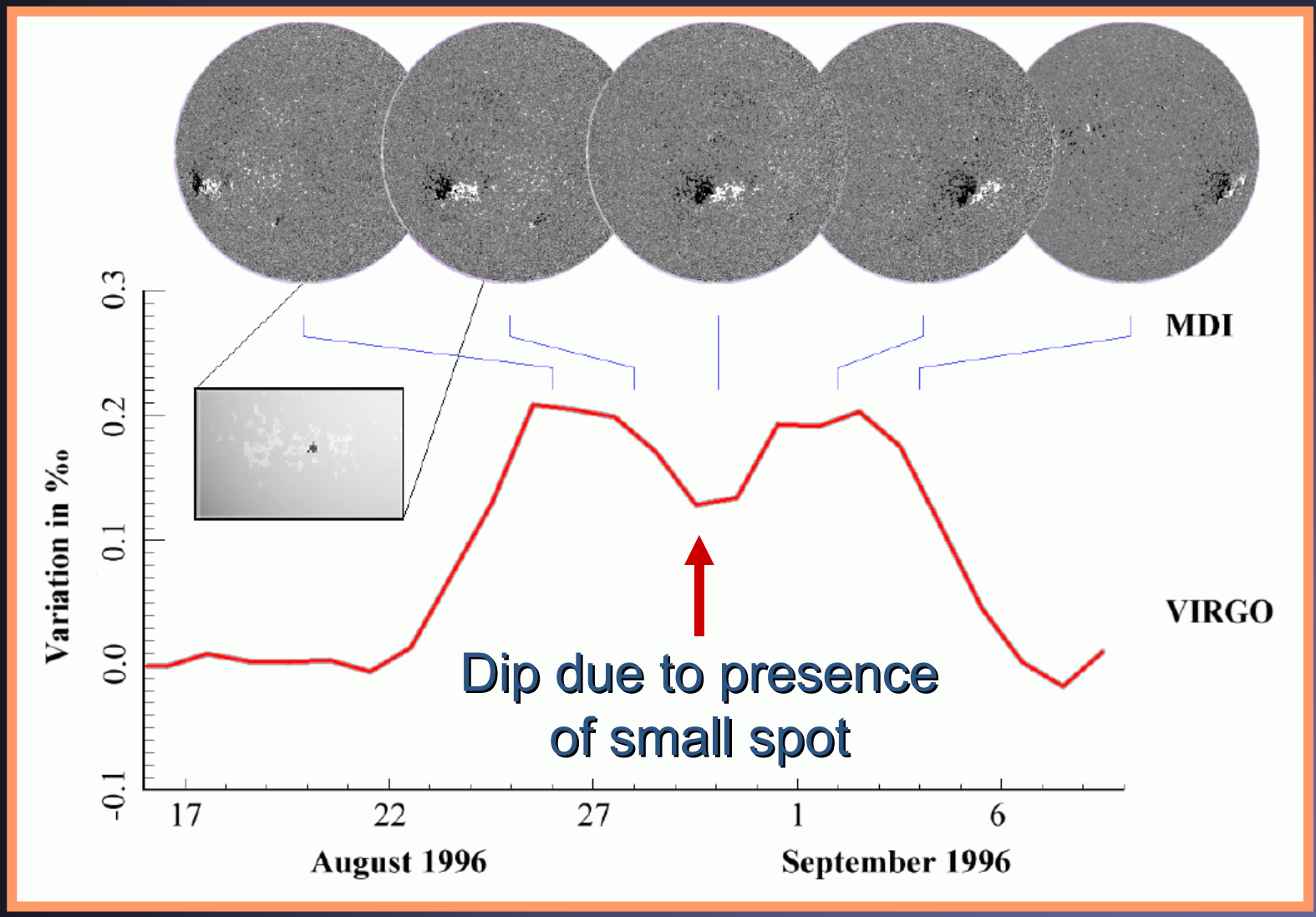
- Convection quenched by magnetic field (red arrows) ➔ heat blocked
- Inflow of radiation into evacuated flux tube through hot walls (yellow arrows). Excess heat flux

➔Enhanced emission. Inflow wins since FTs are narrow: diameter ~ Wilson depress.

- Excess energy comes partly from deep CZ (over Kelvin-Helmholtz timescale

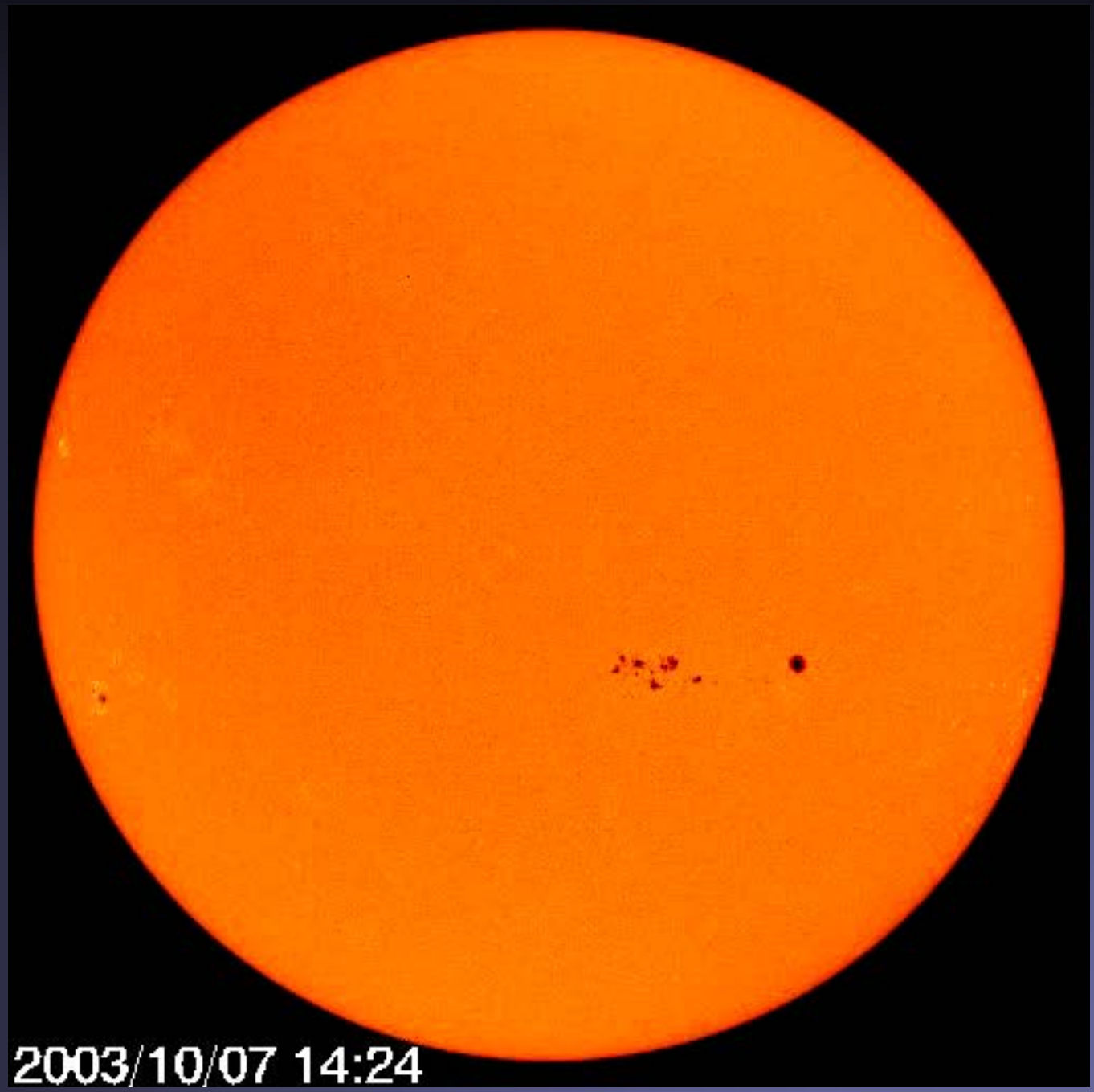


Faculae lead to brightening of the whole Sun



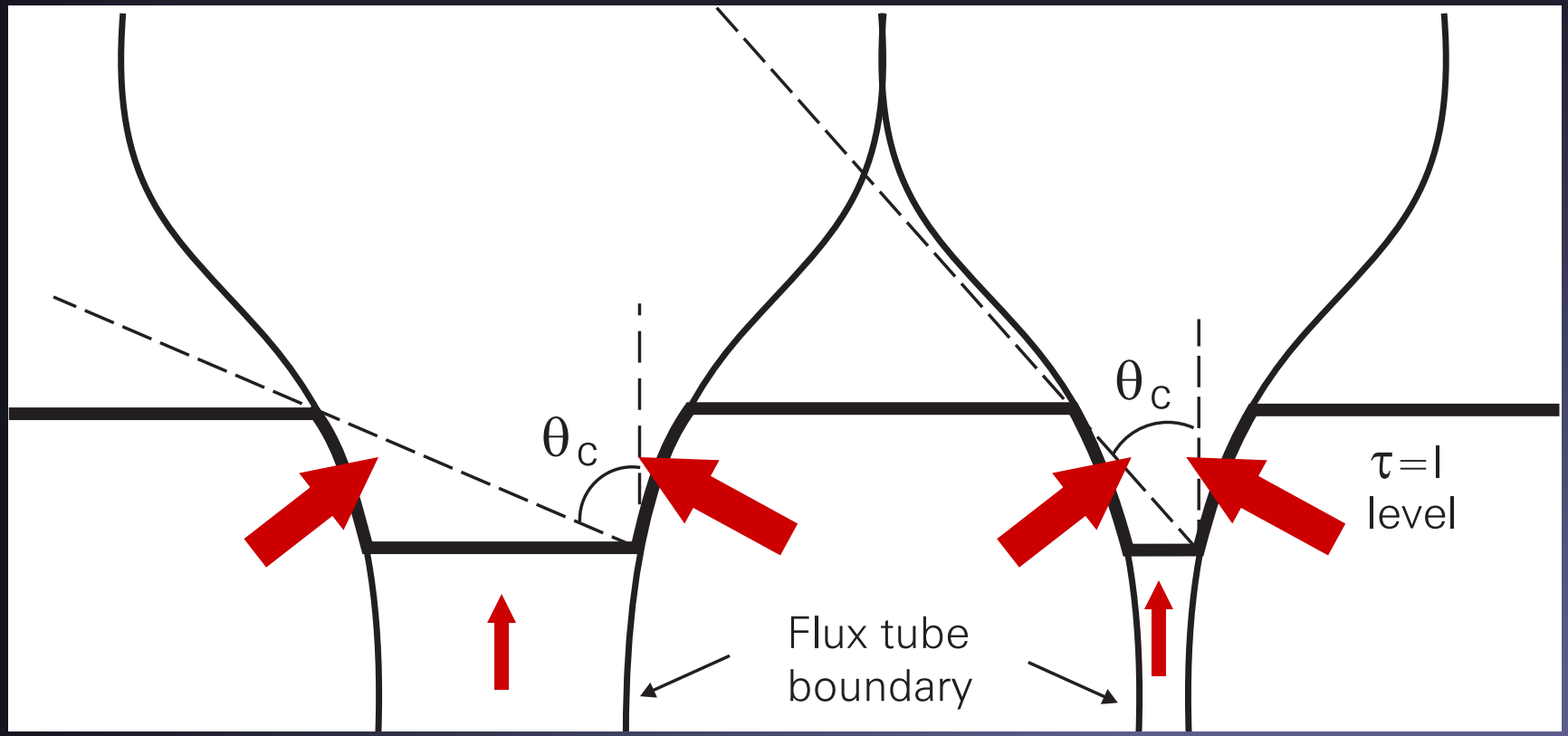
Why are faculae best seen near limb?

The Sun in White Light, with limb darkening removed



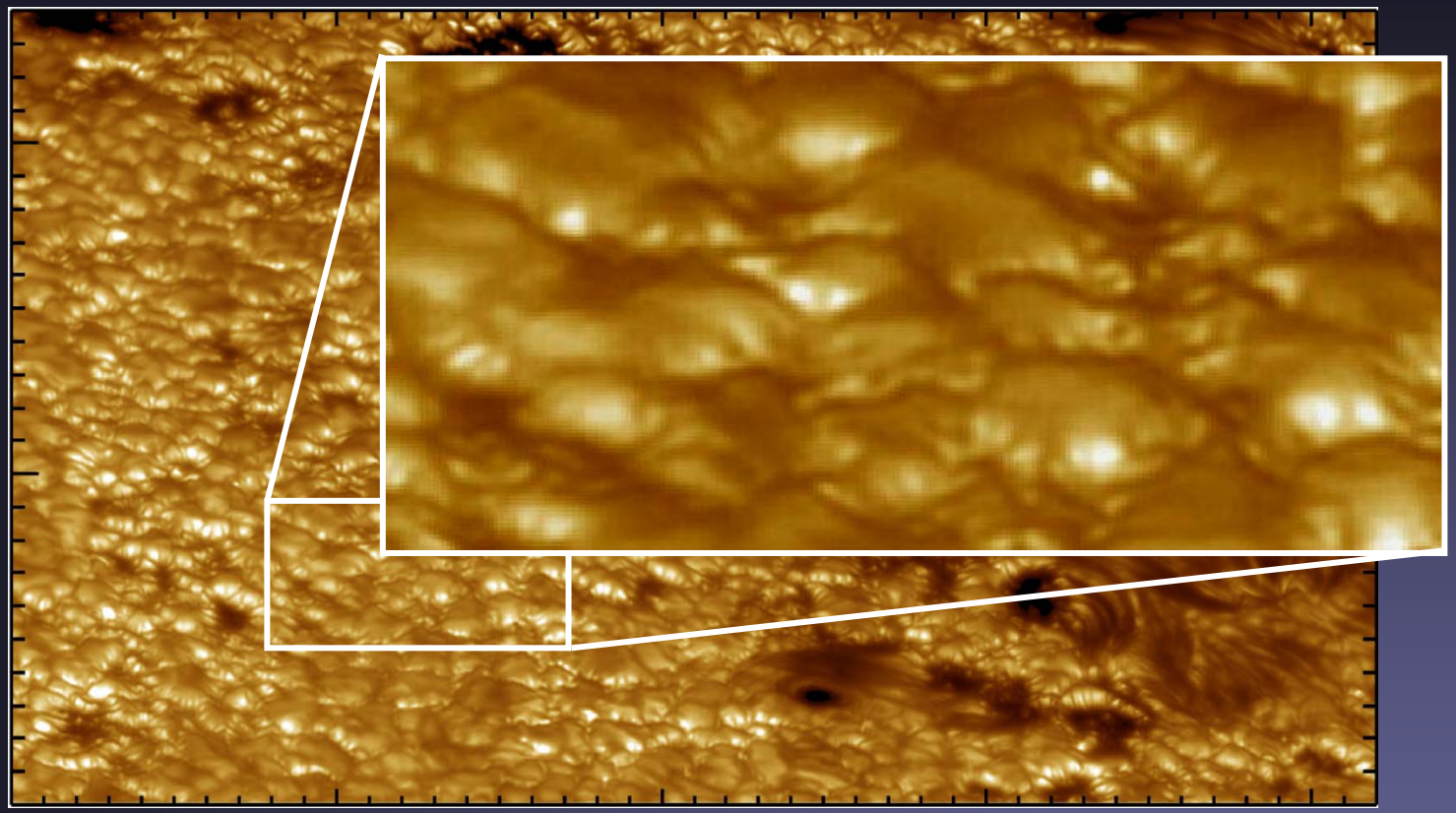
MDI on SOHO

Flux-tube brightening near limb



- The flux tubes expand with height (pressure balance
- Most energy radiates into them through walls, which are hot.
- They appear brightest when hot walls are well seen, i.e. near limb (closer to limb for larger tubes)

Facular brightening

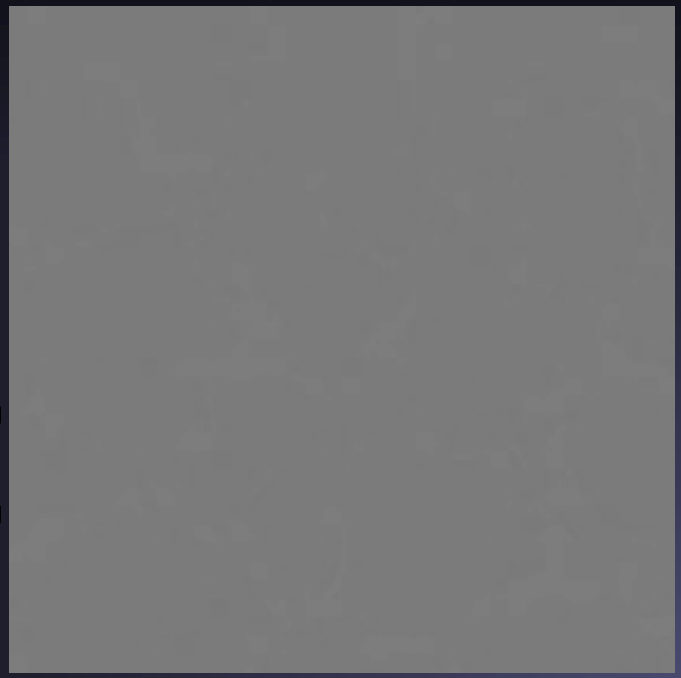


(continuum image: SST, La Palma θ=60° λ=488nm)

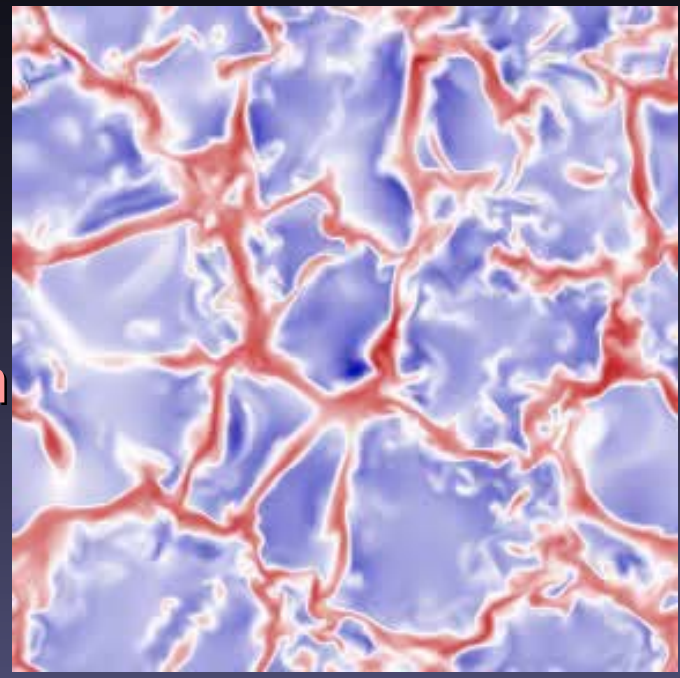
Recent observations reveal:
(Lites et al. 2004)

- 3D appearance of faculae
- extension up to 0.5”
- narrow dark lanes centerward of faculae

B_z
(Z=0)
>500G
>1000G
>1500G



6 Mm



v_z
(Z=0)

3-D compressible radiation-MHD simulations

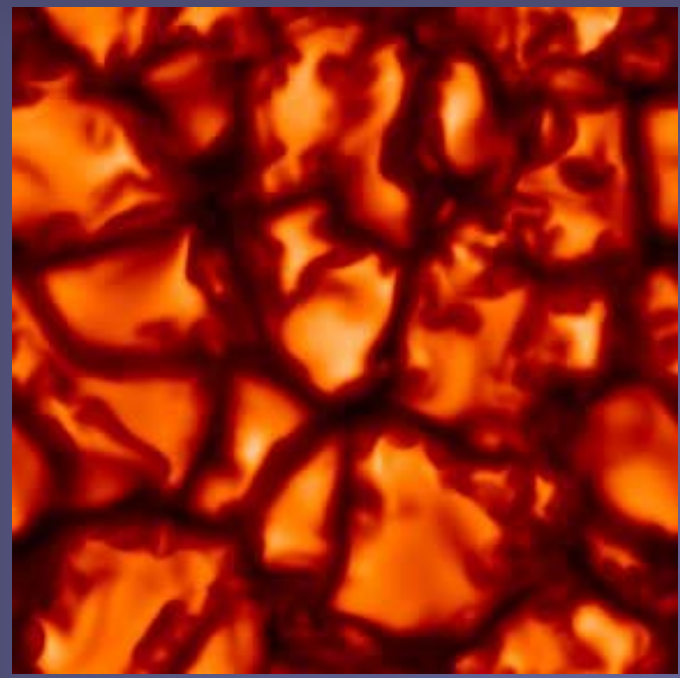
Plage: $B_Z(t=0) = 200$ G

Grid Size: 288 x 288 x 100

Vertical extent: 1.4 Mm

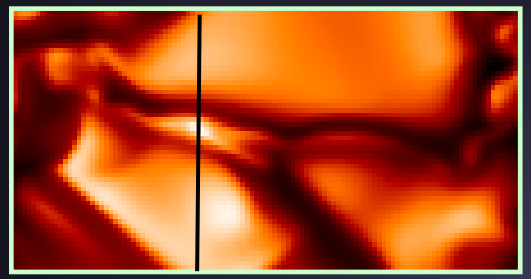
Horizontal extent: 6 Mm

Vögler et al. 2005



I_c
(Z=0)

Vertical cut through sheet-like structure



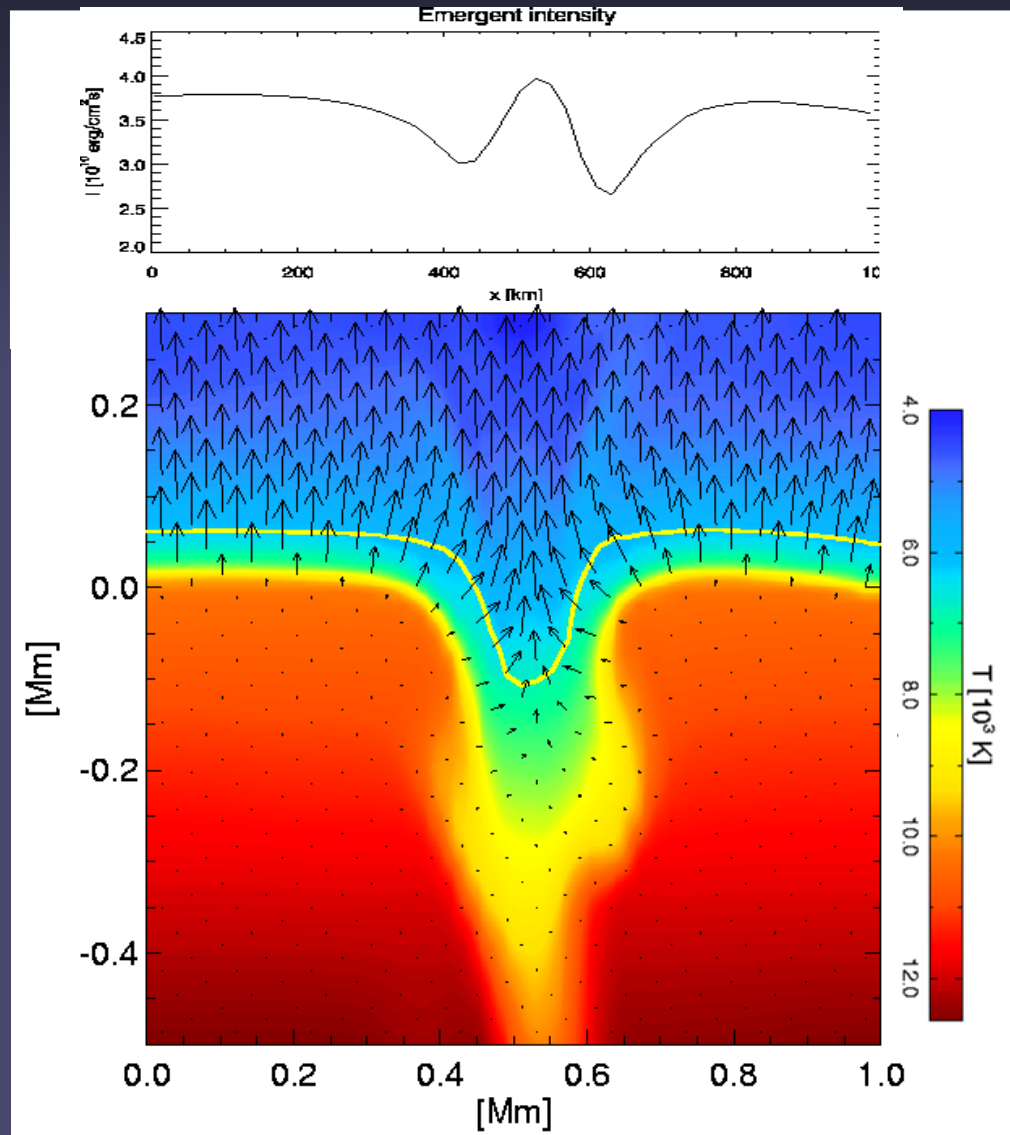
I

B_z

- partial evacuation leads to a depression of the τ=1 level
- lateral heating from hot walls (Spruit 1976)

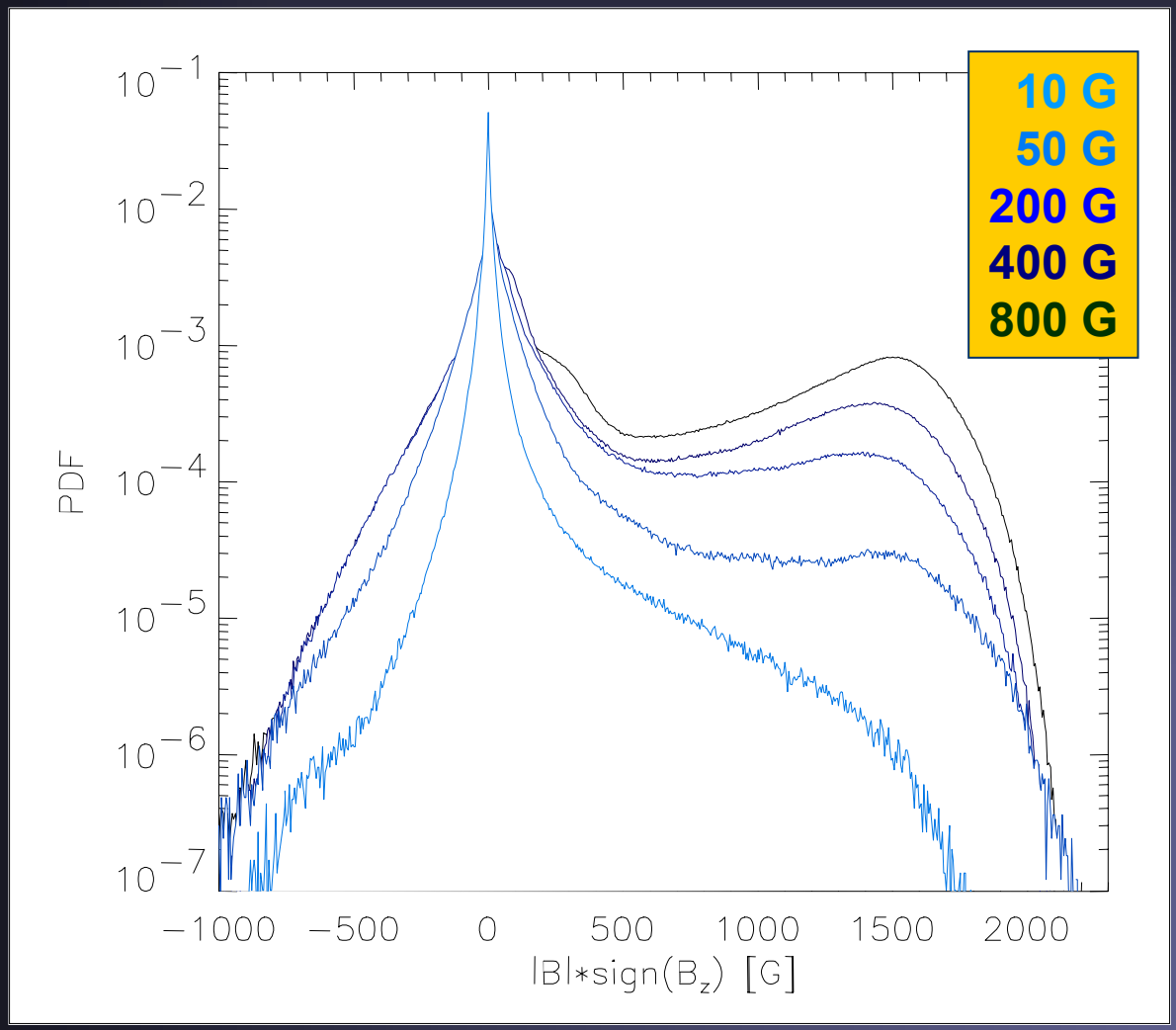
➔Brightness enhancement of small structures

Radiation flux vectors &



From quiet Sun to strong plage

Probability density function of field strength around τ=1



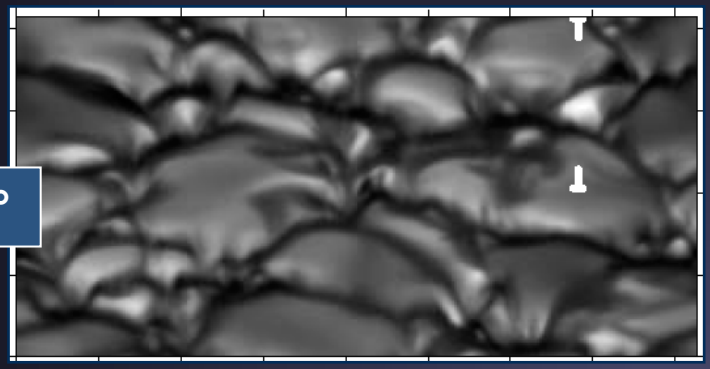
- Weak fields: exponential or lognormal
- Strong fields: Gaussian
- Efficiency of convective field intensification decreases for small B_0

Facular brightening

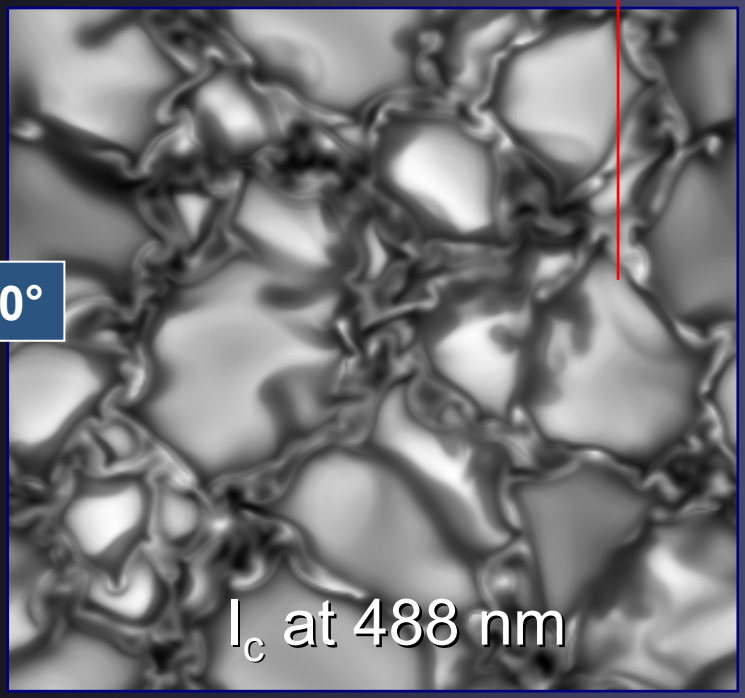
Simulation: B_0=400 G

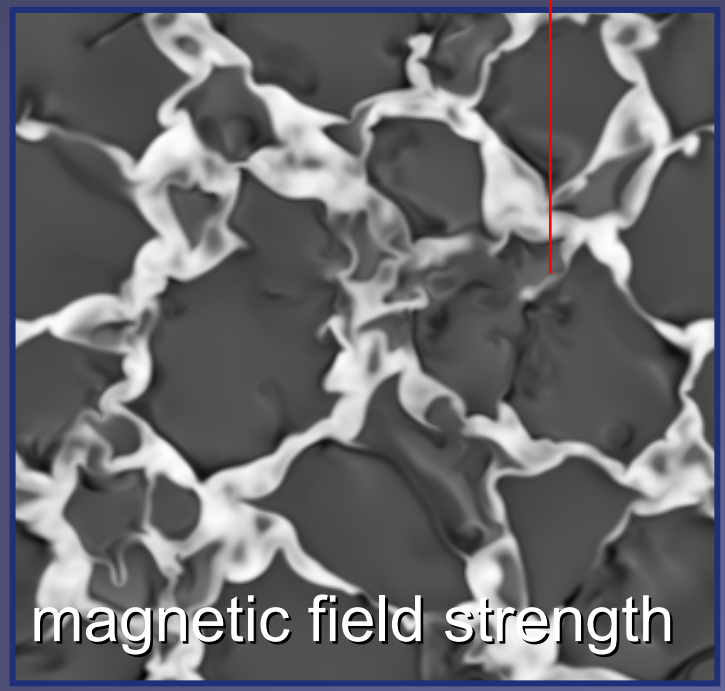
Observation

θ=60°



θ=0°



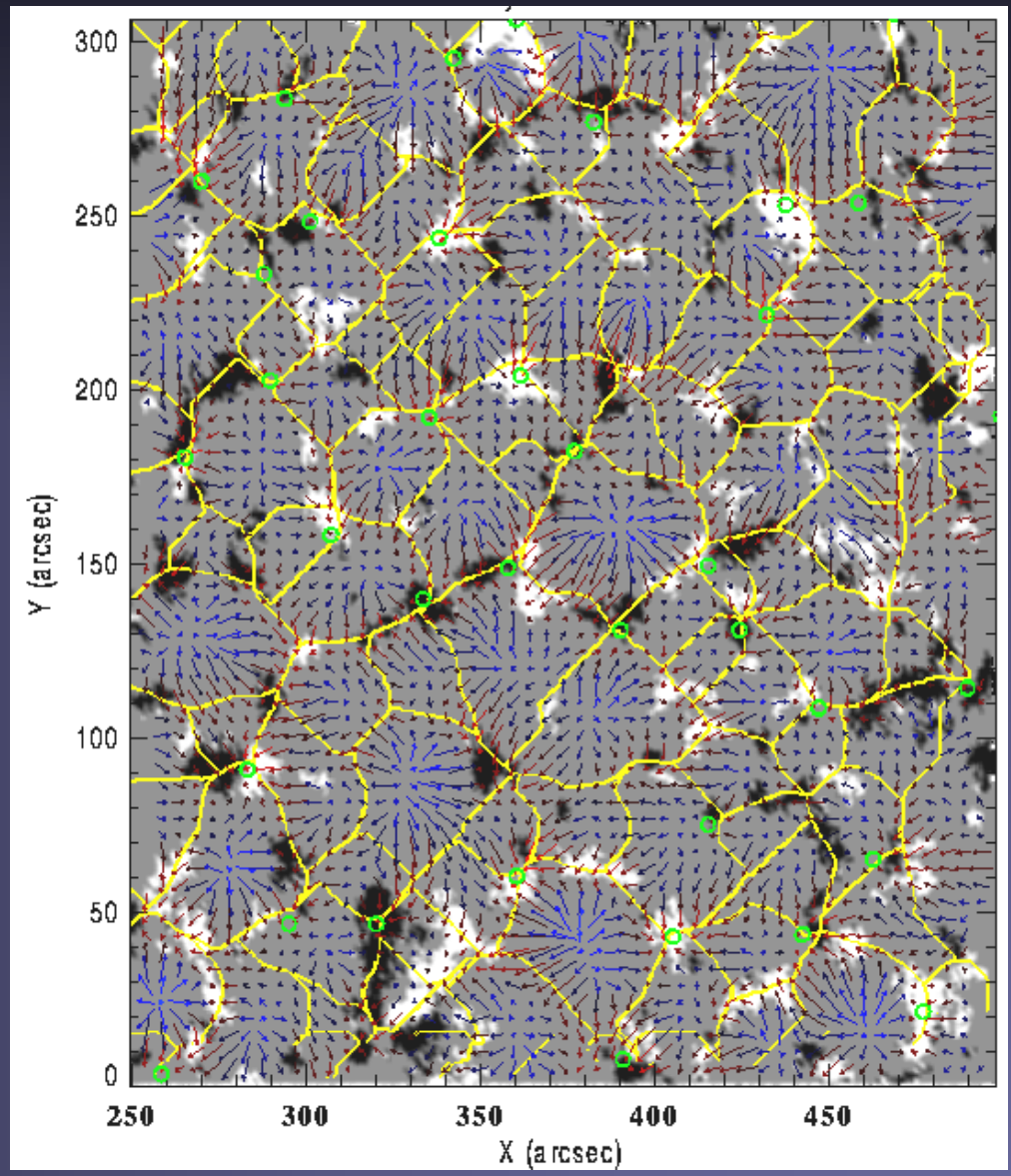


(Keller et al. 2004)

Supergranules and magnetic field

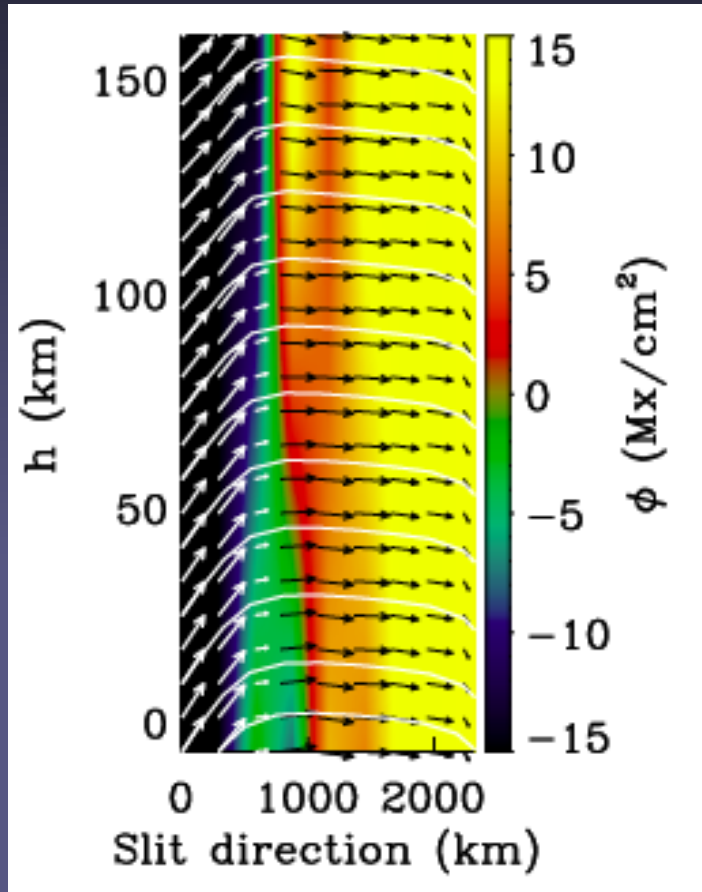
- Magnetogram: black and white (oppos. polarities)
- Horizontal velocity: arrows
- Divergence: blue arrows > 0; red arrows: < 0
- Supergranule boundaries: yellow
- Magnetic field at edges of supergranules, as in simulations for granules

➔ B swept out by flow of supergranules



What is between the flux tubes?

- **Internetwork:** Zeeman effect → mainly horizontal hG fields, forming small, low-lying loops. Fed by emergence of small (10^{17} Mx) dipoles in granules
- **Turbulent field:** Hanle effect → "Zeeman invisible" field mixed on small scales. Same as internetwork field, or separate? Trujillo Bueno et al. (2004) propose that turbulent field dominates magnetic energy density in photosphere



Martinez et al. 2007

Which dynamo feeds QS flux?

- Active and ephemeral regions: main dynamo (orientation of bipolar regions & solar cycle variation of their number and location)
- IN & turbulent fields: not yet decided
  - local turbulent dynamo (Cattaneo 1999; Vögler & Schüssler 2007; 2008)
  - main dynamo, with fluctuations due to flux recycling (e.g. Ploner et al. 2002; de Wijn et al. 2005)

Surface dynamo

Vögler and Schüssler 2007

$B_{vertical}$

Continuum intensity