On the decay of sunspots

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Structure and evolution of the magnetic flux tube of a simulated sunspot

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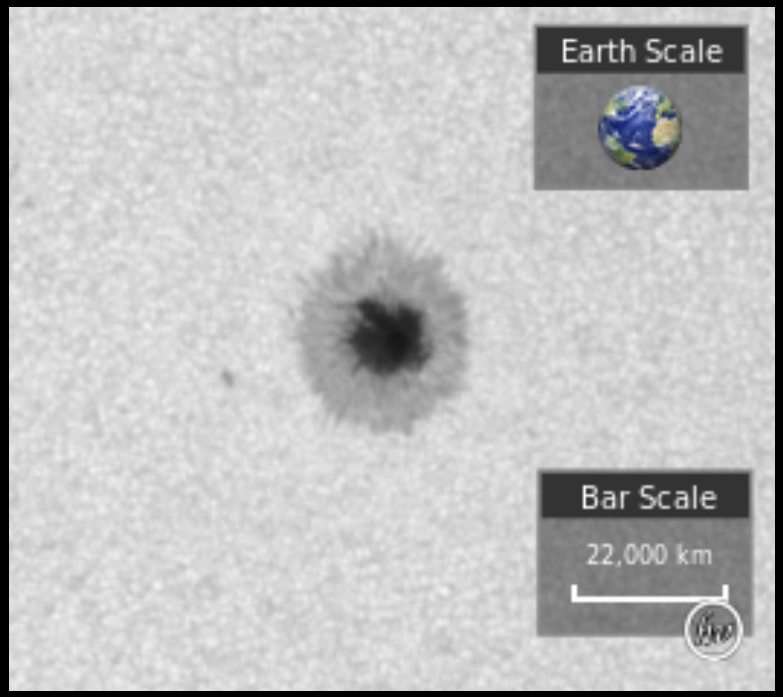
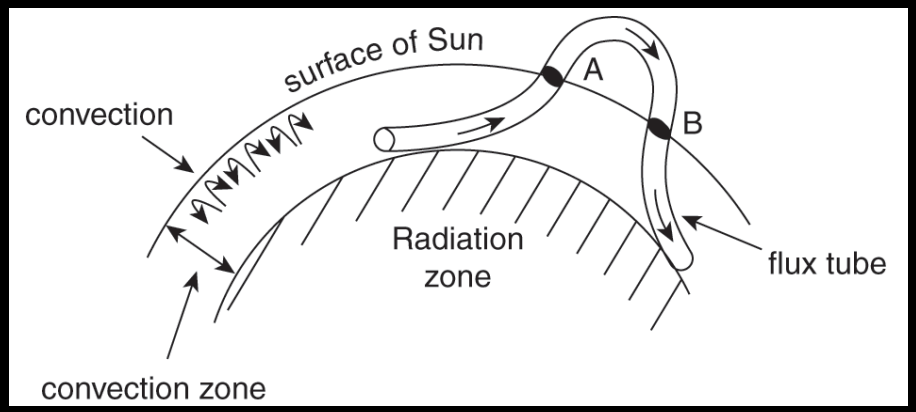
Sunspots

Observed lifetimes: Several days up to several weeks

Structure and evolution of the flux tube below the surface is unknown





Adapted from Davidson, 2016

Sunspot simulation

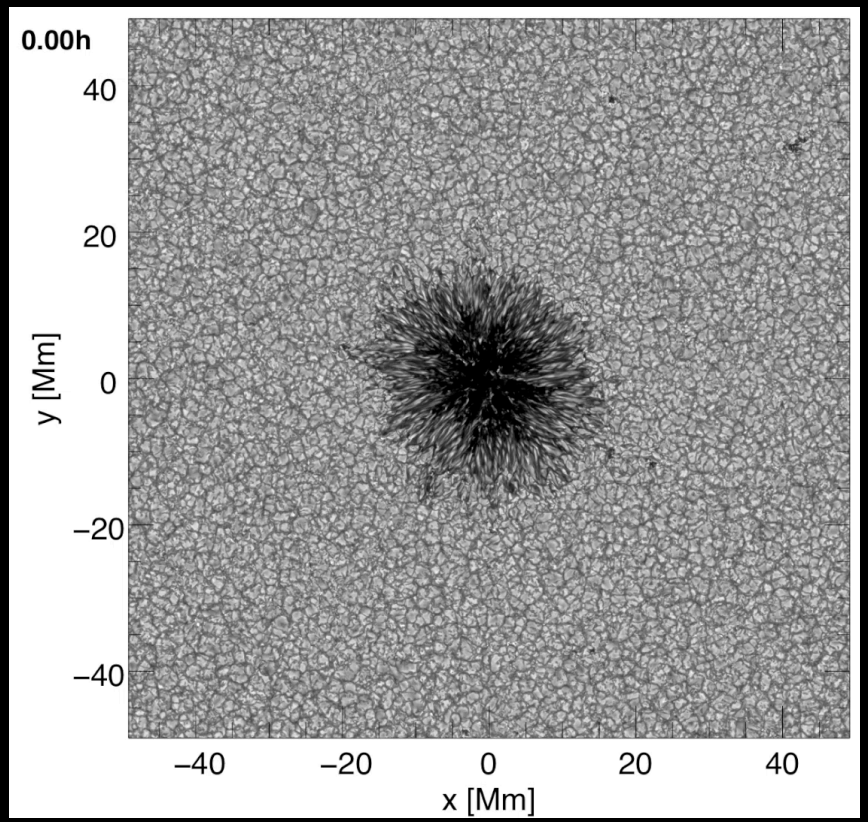
3D MHD simulation calculated by M. Rempel (2015)

Size of simulation domain: 98 x 98 x 18 Mm^3
(1024 x 1024 x 384 grid cells)

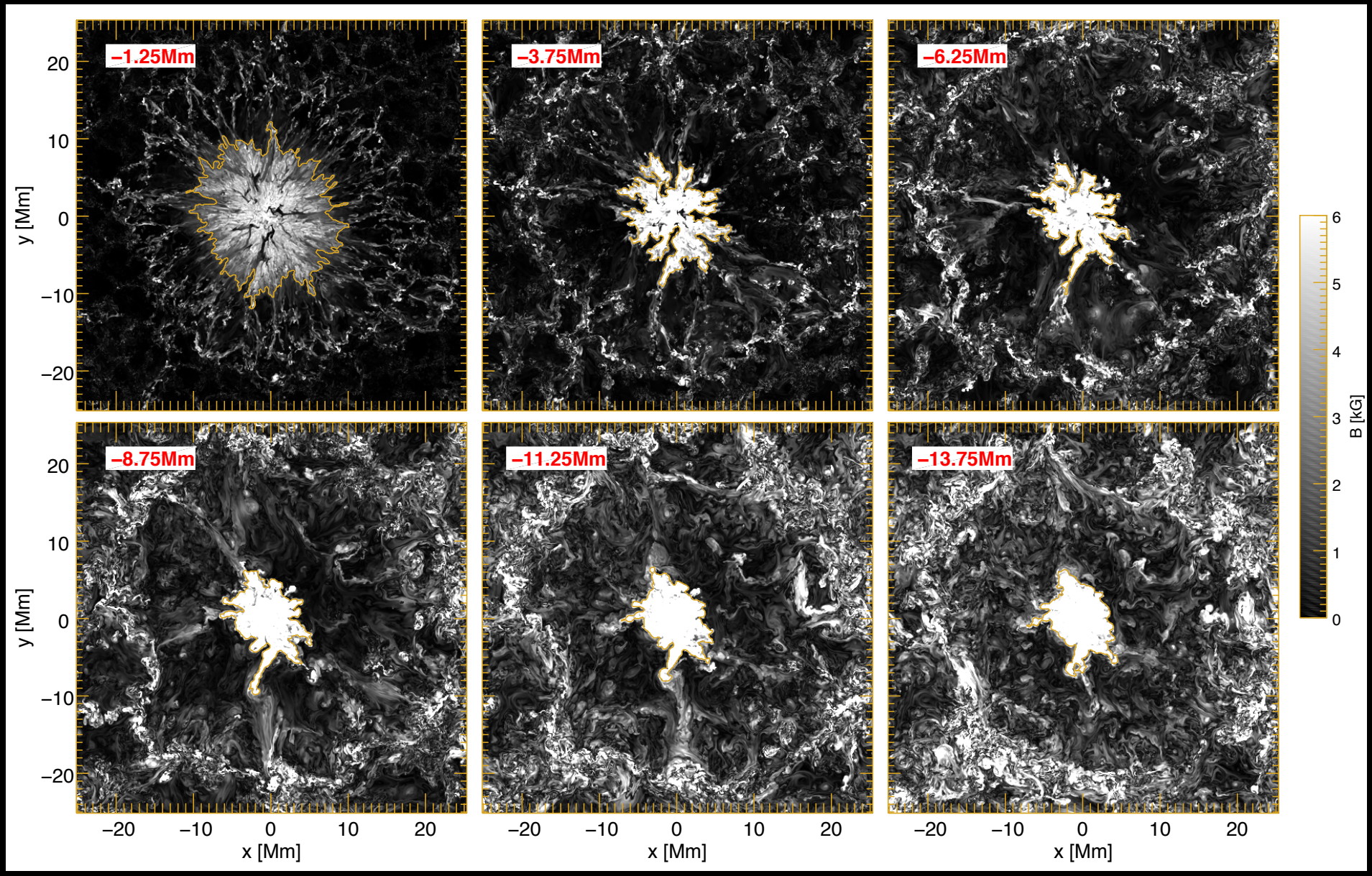
700 km (vertical) of
solar atmosphere

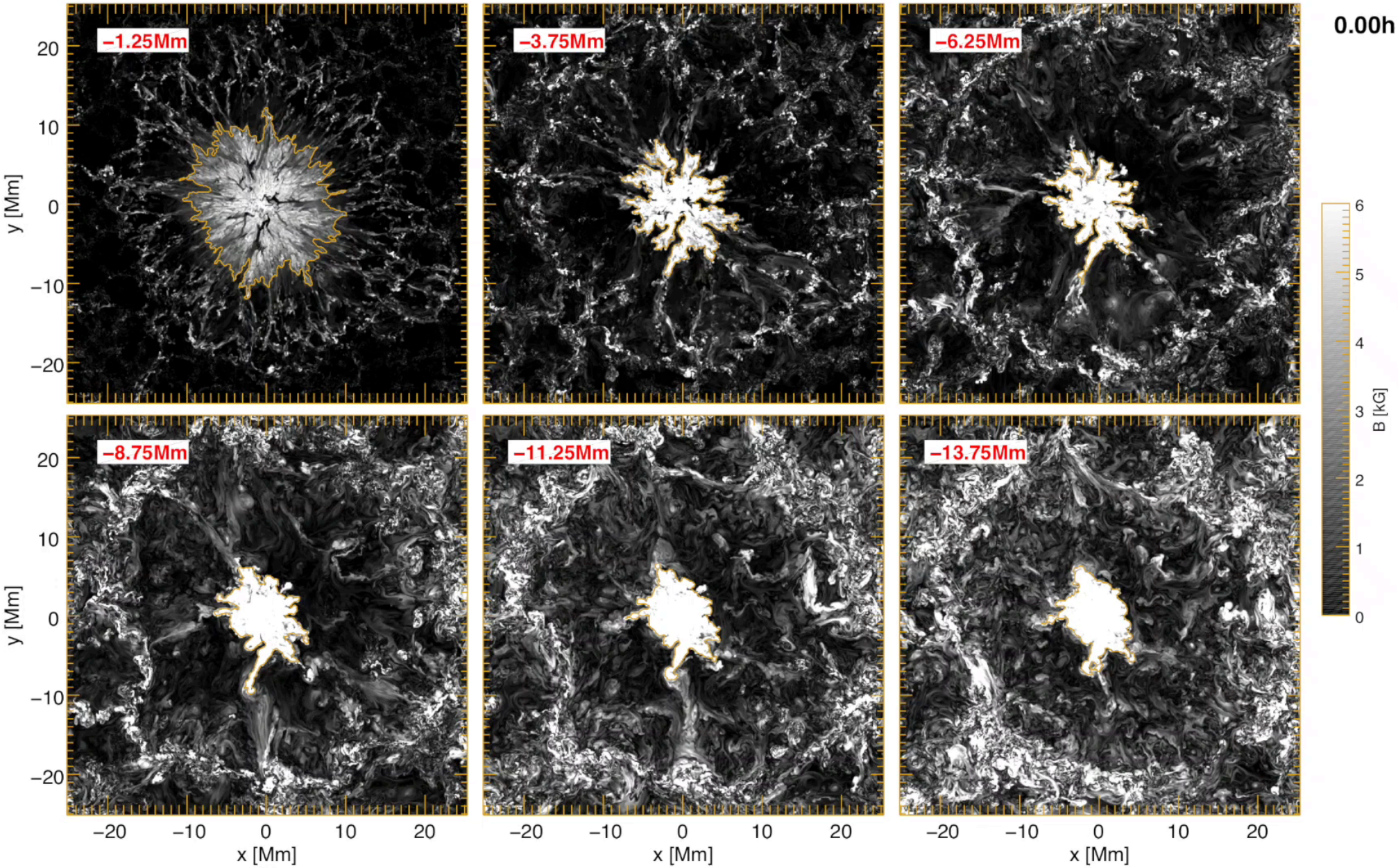
30 h of data for analysis

Sunspot and surroundings
reproduce characteristics
known from observations



Geometric structure of the magnetic flux tube



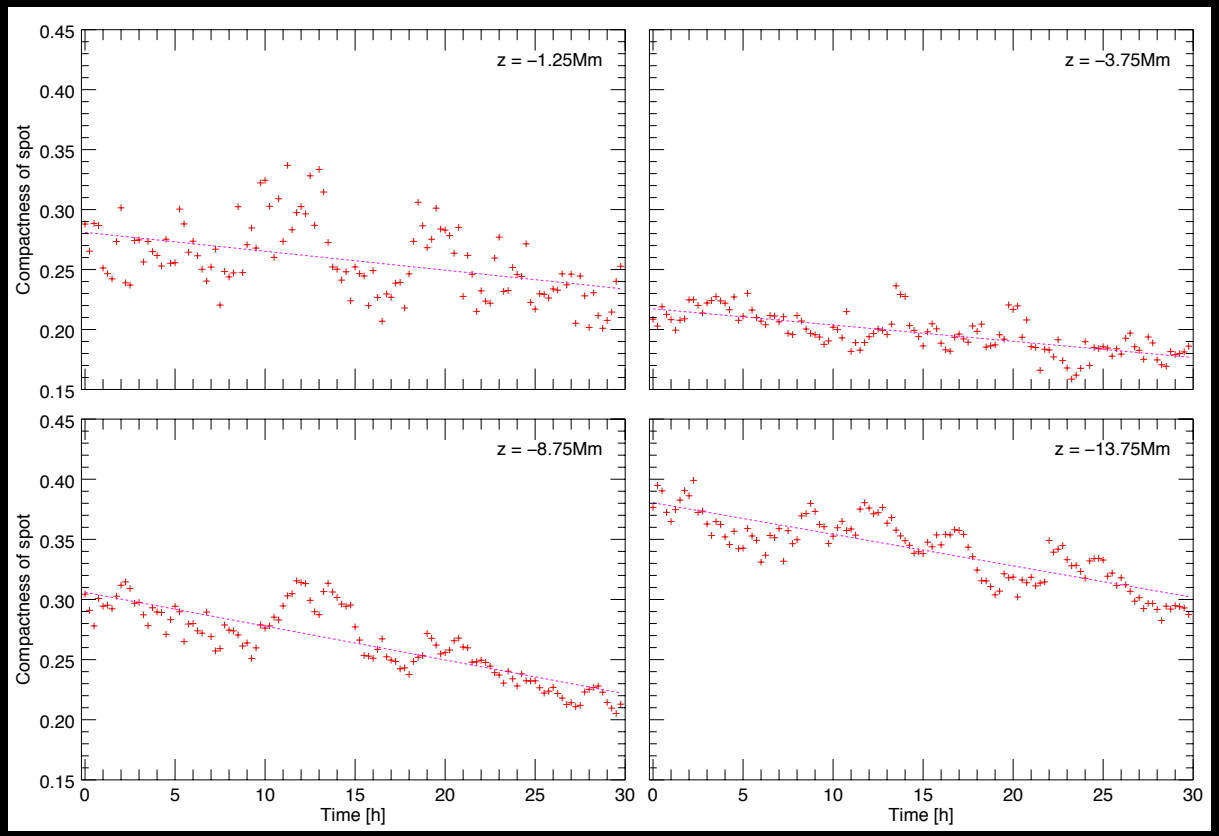

0.00h
−1.25Mm
−3.75Mm
−6.25Mm
−8.75Mm
−11.25Mm
−13.75Mm
y [Mm]
x [Mm]
B [kG]
20
10
0
−10
−20
6
5
4
3
2
1
0

Sunspot compactness

Compactness:

$$K = \frac{2}{r} \cdot \frac{A}{C} = 2\sqrt{\pi} \cdot \frac{\sqrt{A}}{C}$$

$K = 1$ for circular flux tube



Almost constant structure for z>-1 Mm

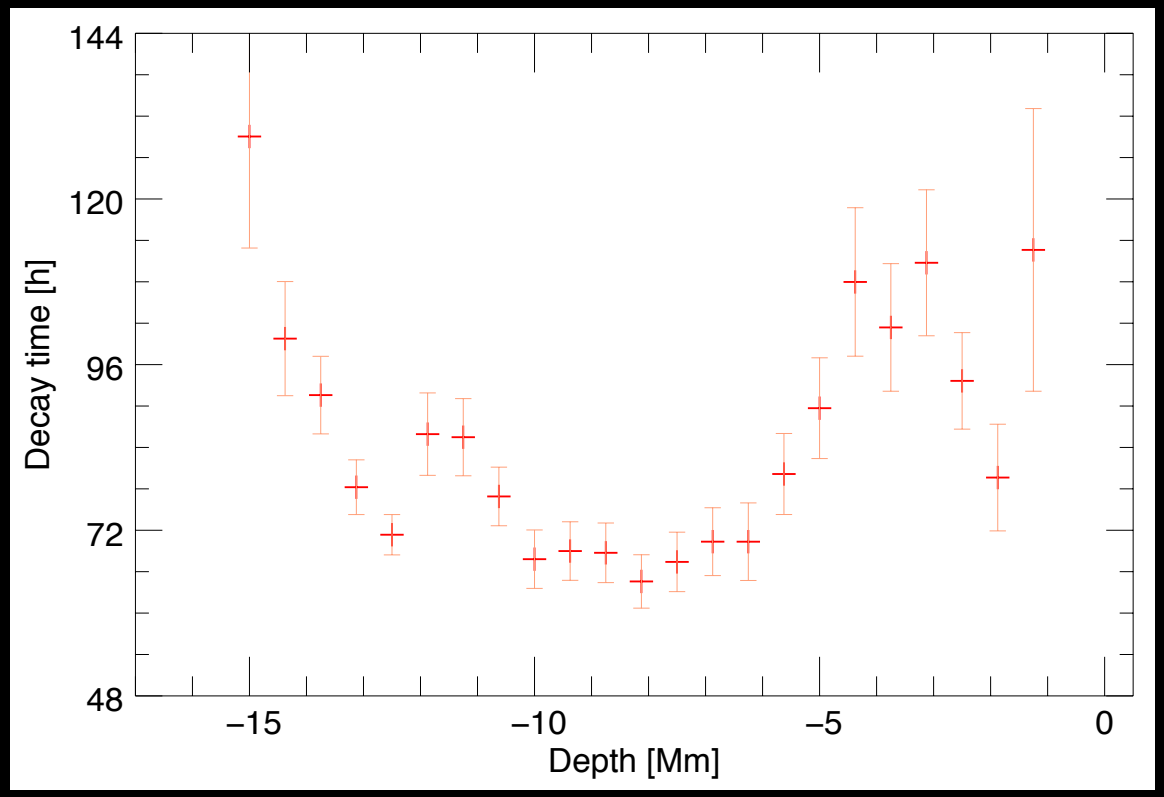
Area is almost constant in time – for all depths

Compactness decreases in time for z<-1 Mm

Evolution of the sunspot flux tube

Decay time: $t\left({}^{K_0(z)}/_{e}\right)$

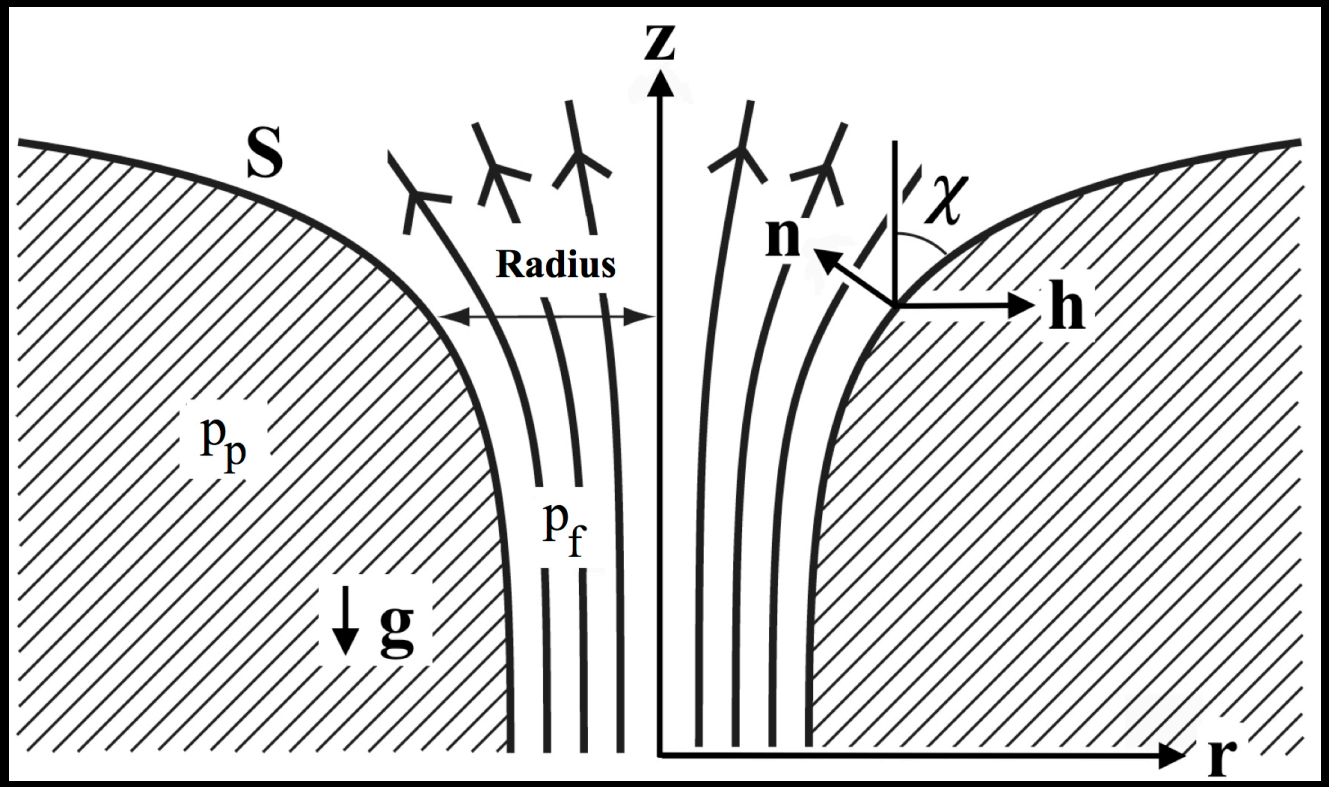
Longer decay times at z<-10 Mm can be ascribed to longer convective time scale



Sunspot stability - Analysis

Stability criterion: $(\rho_p - \rho_f) \cdot g \cdot \sin\chi - \frac{B^2}{4\pi R_c} > 0$

(Meyer et al. 1977)



Sunspot stability - Analysis

Stability criterion: $(\rho_p - \rho_f) \cdot g \cdot \sin\chi - \frac{B^2}{4\pi R_c} > 0$

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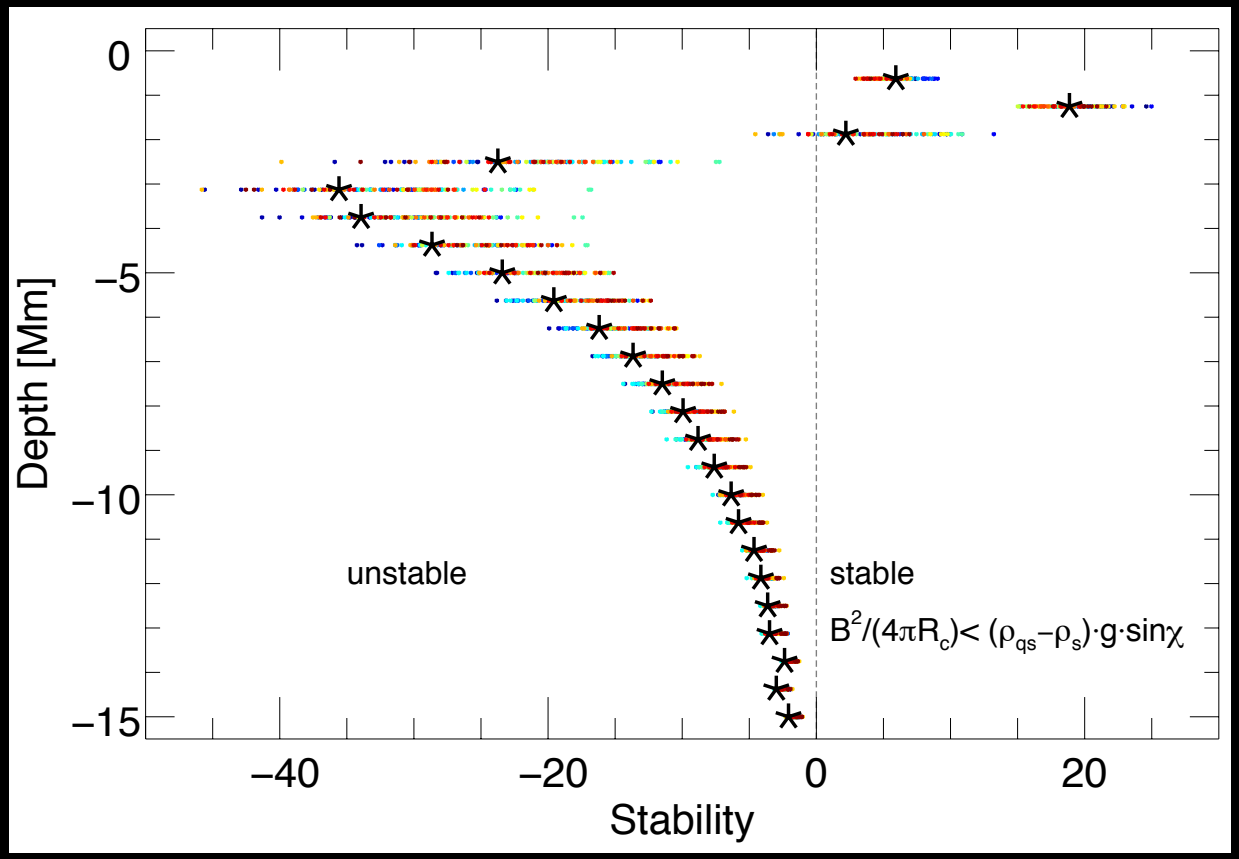
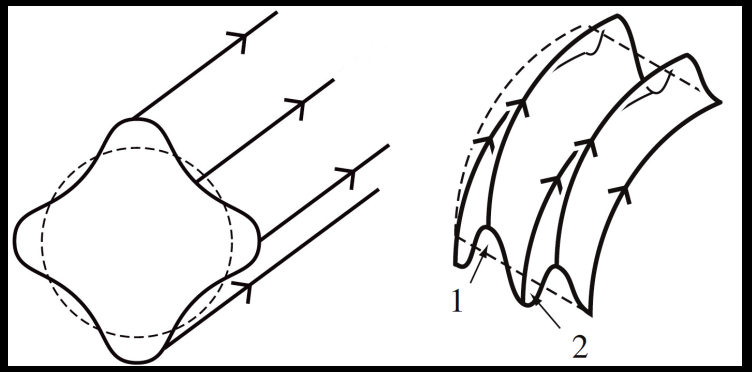
Stable condition for z>-1.5 Mm

Most unstable at z=-3.125 Mm



Interchange instability of a sunspot

Interchange instability transforms the boundary of the magnetic flux tube of the sunspot
– fluting instability



Adapted from Parker, 2013

Compactness is a measure of interchange instability

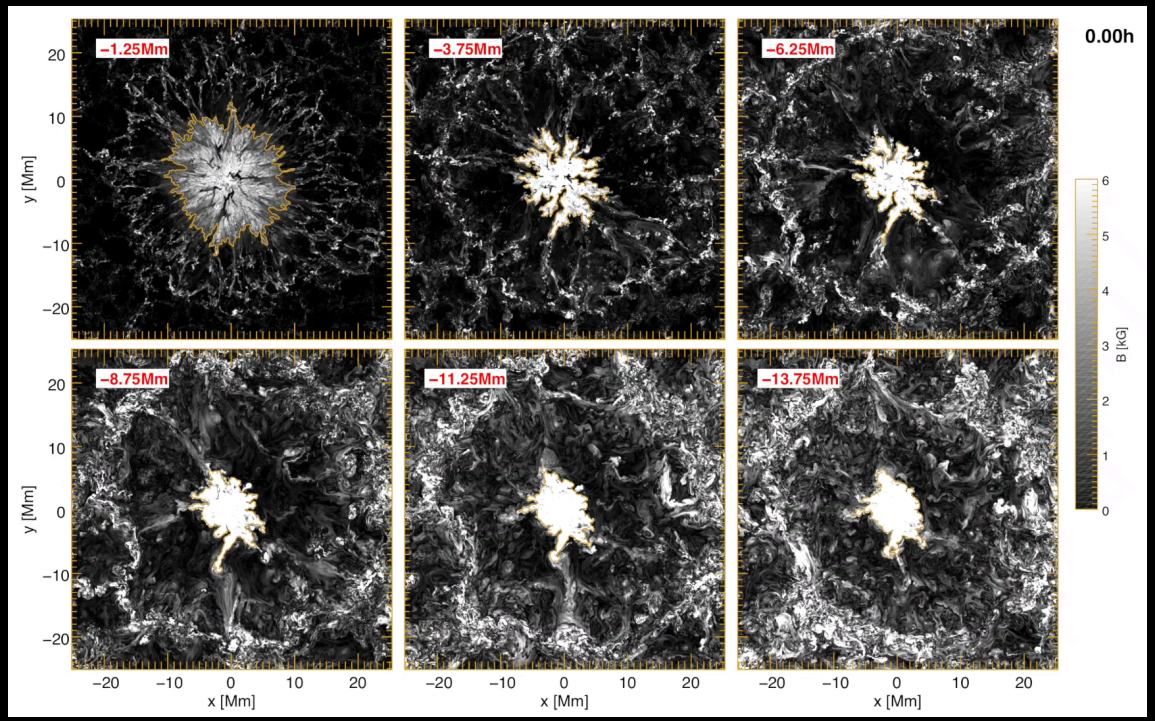
Buoyancy stabilises the magnetic flux tube towards the surface

Strongest instability and smallest compactness are localised between 3 Mm and 4 Mm below the surface

Evolution is strongest between 6 Mm and 10 Mm below the surface

Result: The onset of sunspot decay

Onset of sunspot decay happens below the solar surface due to degradation of the magnetic flux tube at its boundary through interchange instability

Magnetic flux at the surface is almost constant (no visible decay at the surface)

Sunspot is destroyed bottom up, i.e., no destruction mechanism at the surface is needed