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Characteristic Dependence of Umbral Dots on thier Magnetic Structure

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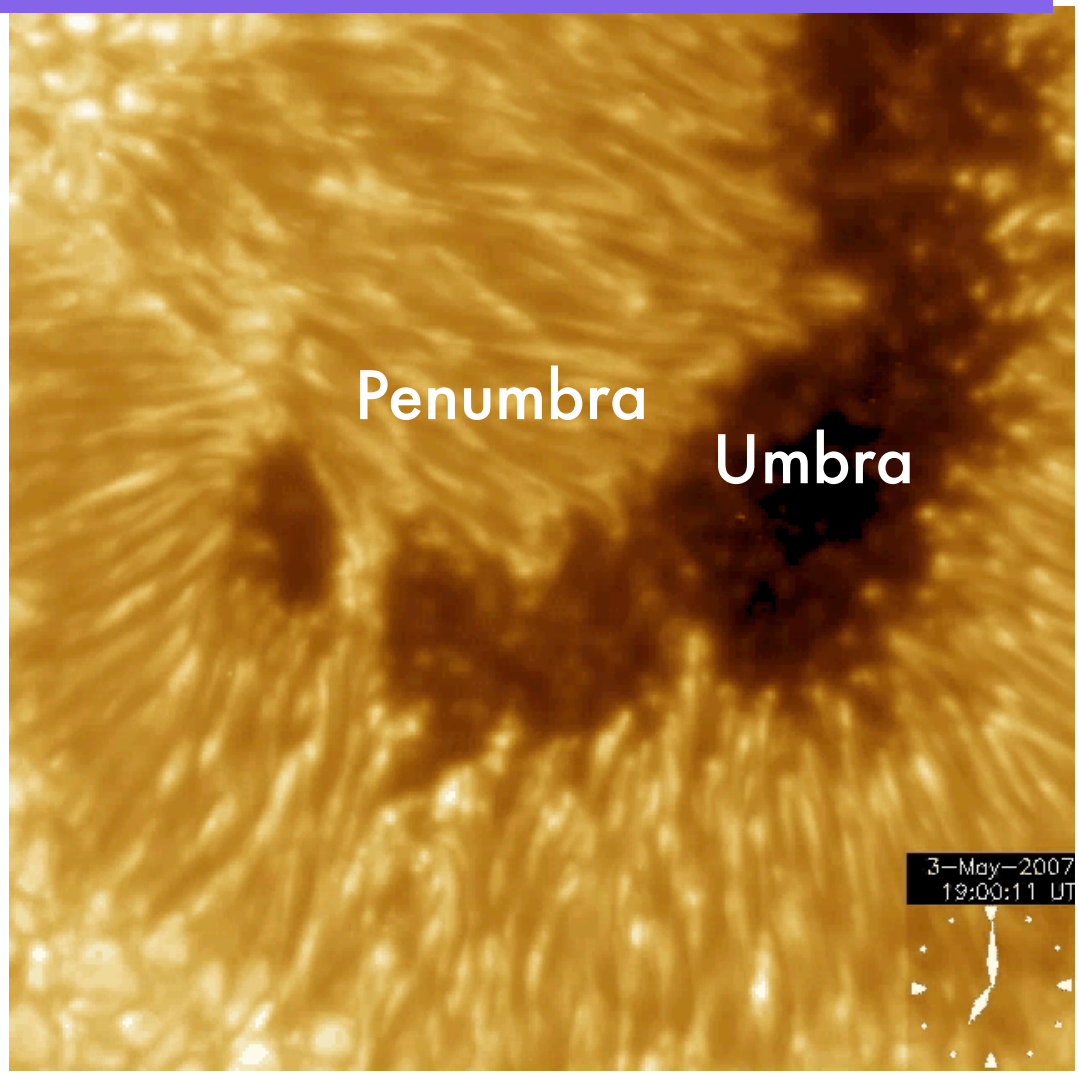
Introduction

- Umbral dot (UD)

Size	200 - 400 km
Lifetime	5-40 min typically 10 min
Proper motion	peripheral:0.5-1km/s umbra inward central: static
Field strength	2000-2500 Gauss ~40 Gauss weaker
Doppler velocity	upflow 30 - 100 m/s

ex. Watanabe et al. (2008)



Hinode SOT G-band Courtesy to T.J.Okamoto

Background 1/2

- Observation
- Theory

Observation		Theory
The umbra is dark and cool	⇔	The convection is suppressed by magnetic field
Field strength of umbra is at most 3500Gauss	⇔	If the convection is suppressed entirely, the umbra should have > 5000Gauss
umbral dot ~500K hotter than umbra	⇔	Magnetoconvection should take place

Danielson (1964), ApJ, 139, 45

Deinzer (1965), ApJ, 141, 548

Motivation

- **High-resolution data obtained by the *Hinode* satellite**
- **Magnetoconvection origin**
  - size, lifetime, proper motion, ...
  - magnetic field, field inclination
  - correlation between magnetic field and UD
- **Comparison with 3D MHD simulations**
  - structure of sunspot
  - classification of UDs

applicable to the physics in accretion disk, low T starts, ...

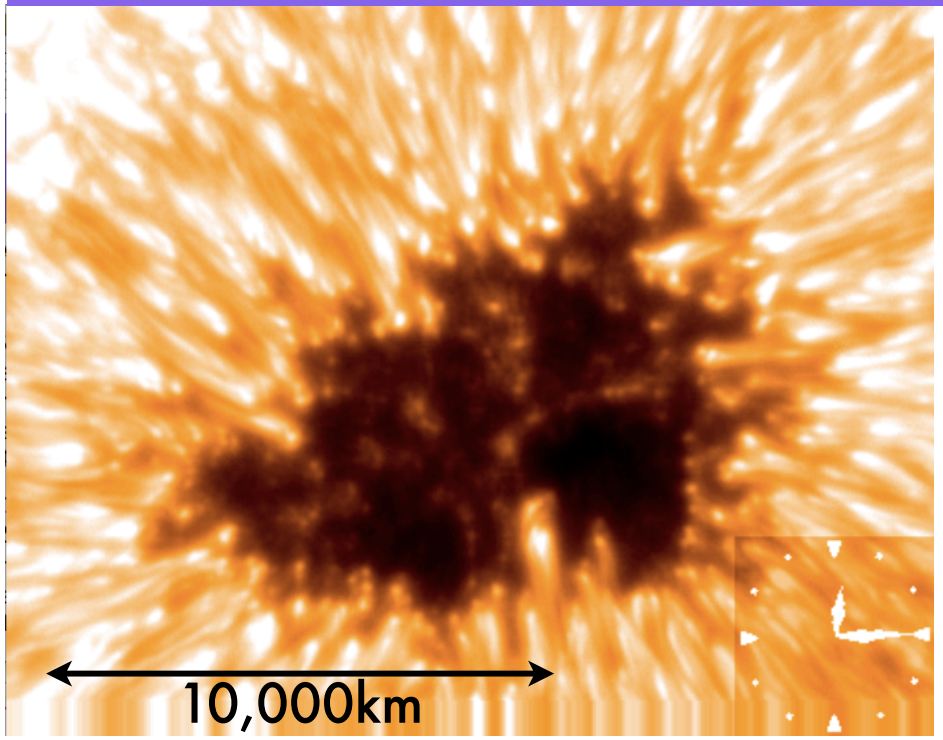
Outline

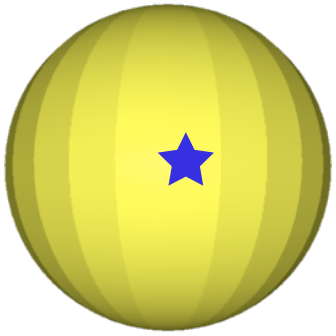
- Detect the UD's lifetime and size without bias
  - automatic detection
- Magnetic field information derived from Hinode/SP

Correlations
Parameter survey of magnetoconvection

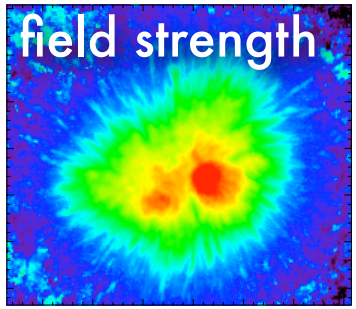
"Characteristic Dependence of Umbral Dots on their Magnetic Structure"
Hiroko Watanabe, Reizaburo Kitai, Kiyoshi Ichimoto
ApJ 702, 1048-1057 (2009)

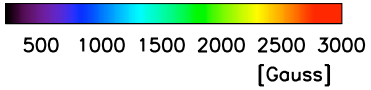
Data





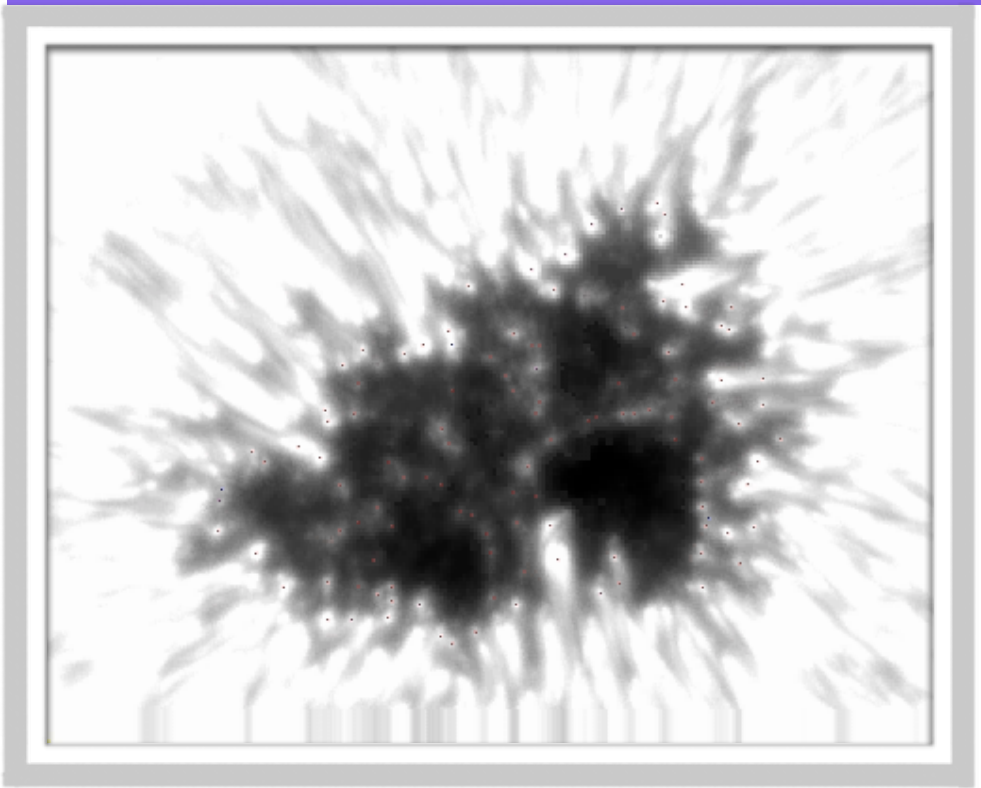
Position of the target





- *Hinode* SOT
- Mar 1, 2007
- imaging: blue continuum (4505Å)
  - 25sec cadence, 2 hours duration
  - spatial resolution 0.054arcsec (40km)
- spectropolarimeter: Fe I 6302.5Å
  - 8 min to scan 10,000km area
  - spatial resolution 0.16arcsec (100km)

Analysis 1/2

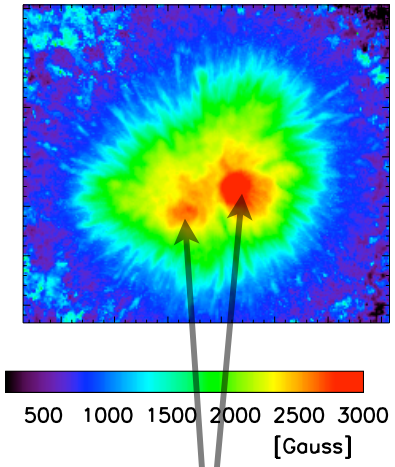


- Automatic detection
  - peak position with $I_{peak}>1.3\times I_{bg}$
  - The continuation between successive frames

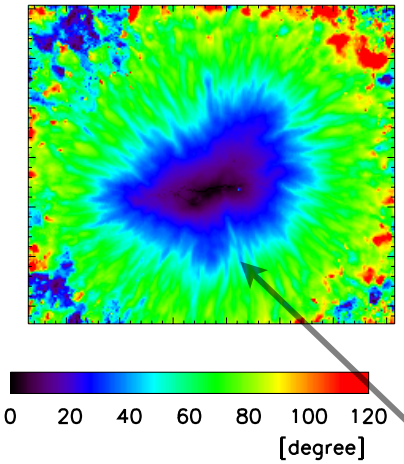
- Total amount of UDs is 2268
  (average 124 per frame)
- UD parameters
  - lifetime
  - size
  - brightness ratio
    (I_{peak} / $I_{background}$)
  - average speed
  - velocity orientation

Analysis 2/2

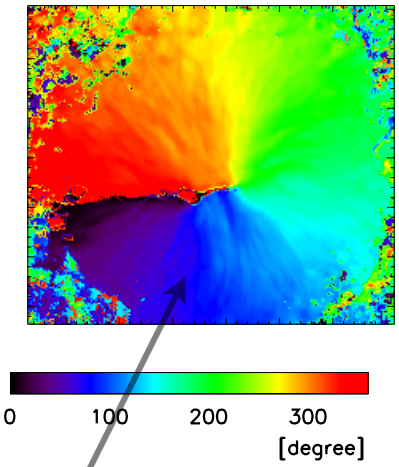
field strength *B*

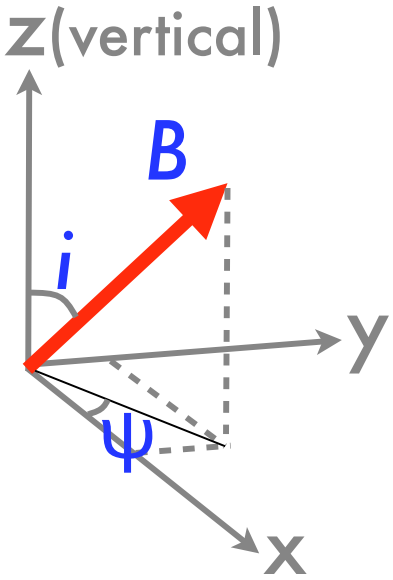


field inclination *i*



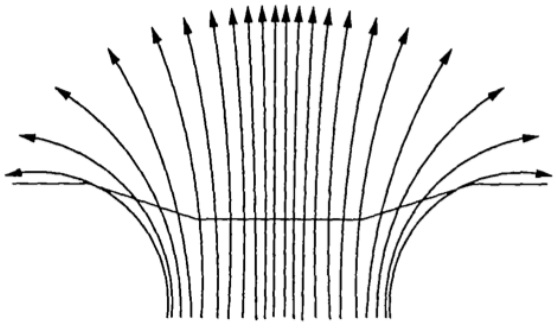
field azimuth *ψ*





especially strong field region dark core

isotropic distribution



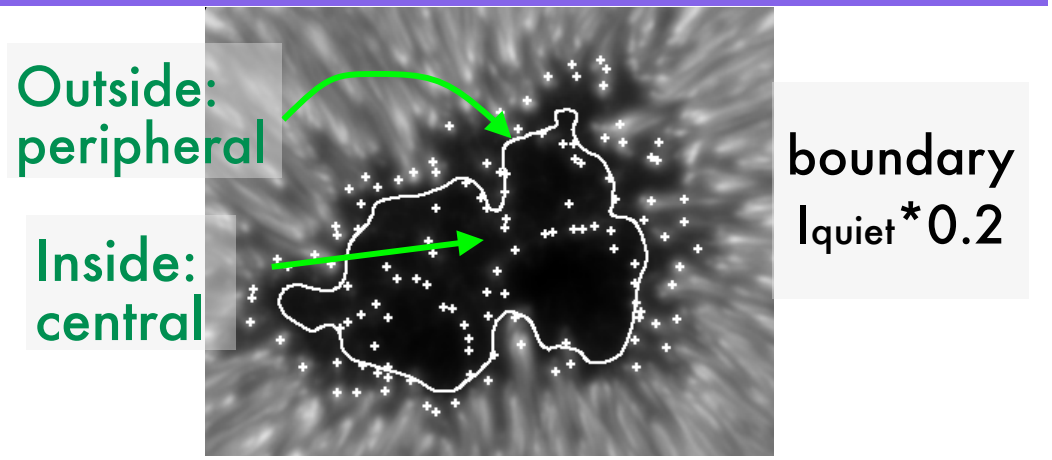
- Magnetic field at UD's occurrence site
  - field strength, field inclination, field azimuth

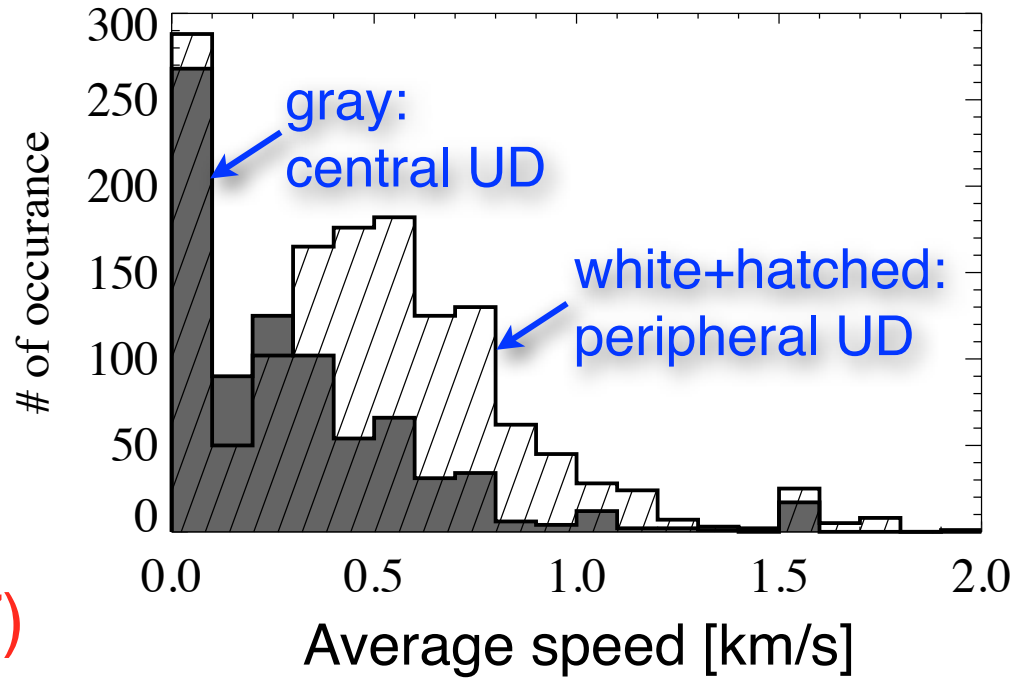
Result 1/4

- Histogram

	average	central	peripheral
lifetime	7.4min	6.5min <	7.8min
Radius	184km	178km <	187km
Ipeak / Ibg	1.73	1.51 <	1.85
average speed	0.44 km/s	0.33 km/s <	0.50 km/s

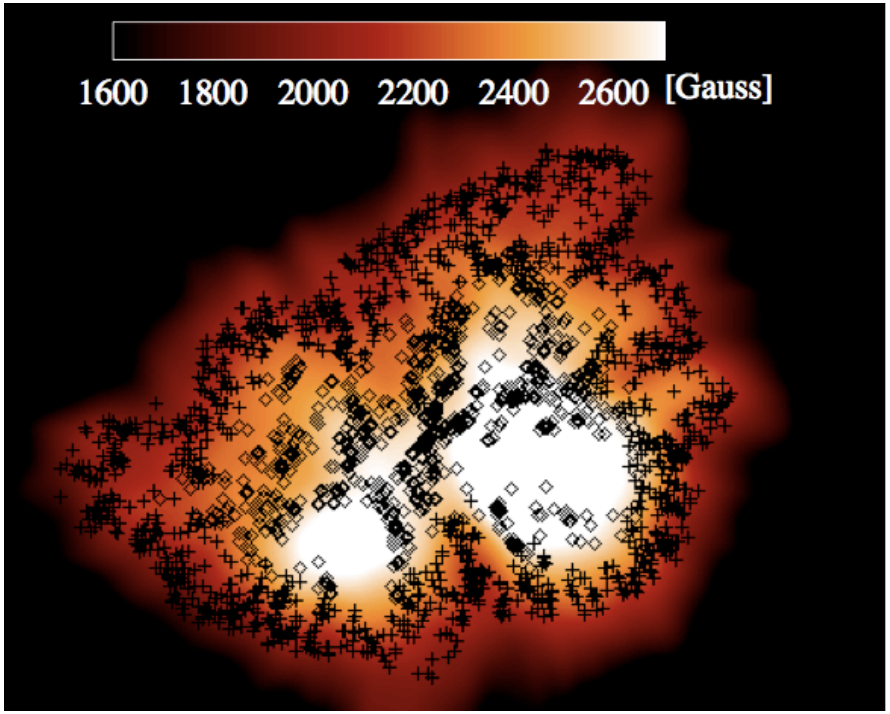
The same as the previous studies (Sobotka et al. 1997)

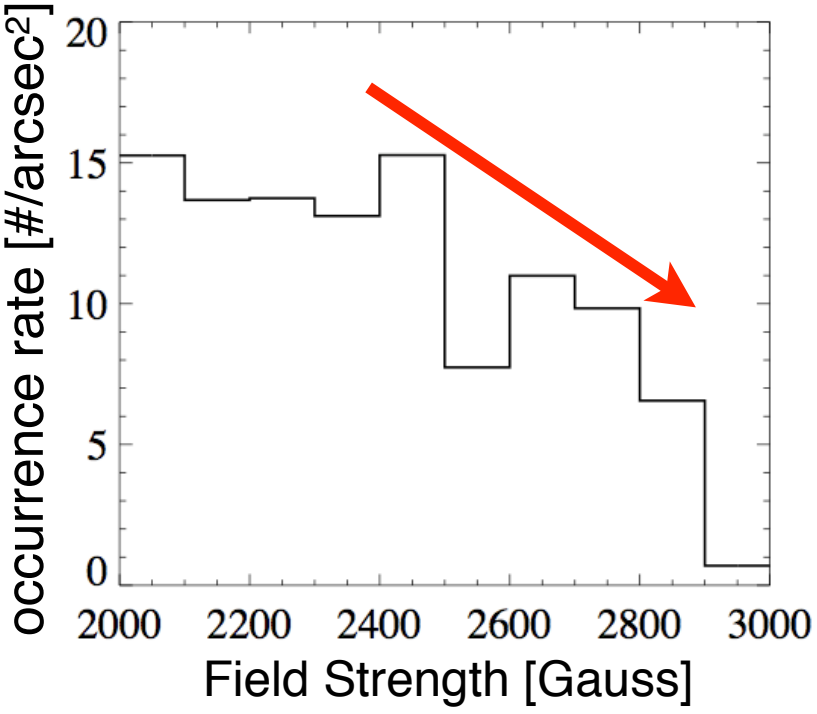




Result 2/4

- Spatial distribution
  - Fewer UDs in stronger fields⇒ Suppression of convection
  - Cellular patterns⇒ Reflect the global substructure?





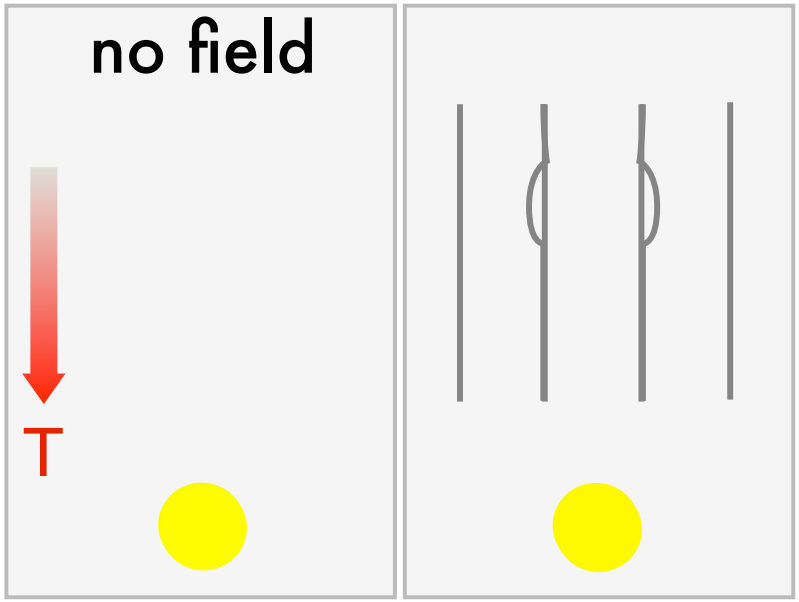
Result 3/4

- Correlations
  - lifetime

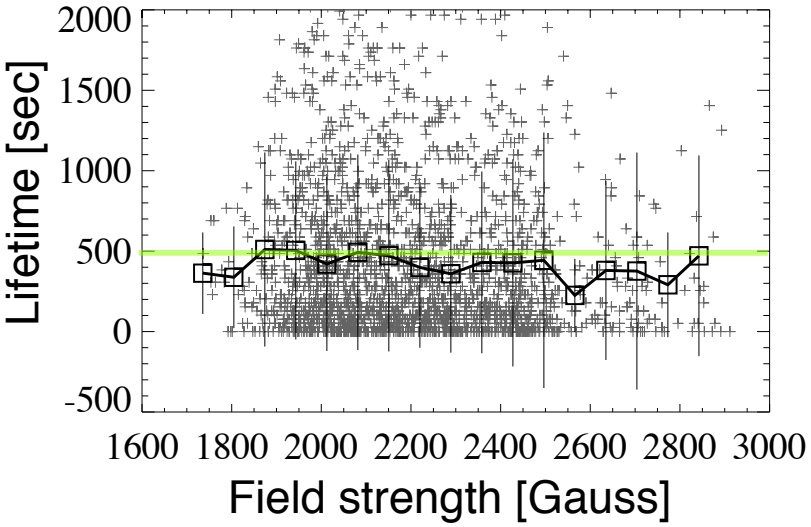
    almost constant
  - size

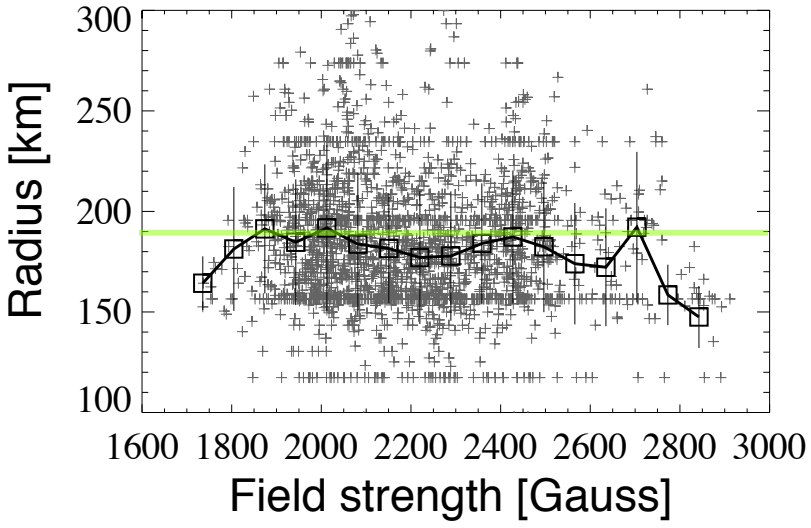
    almost constant

    a bit smaller in strong fields?



buoyancy and size are inversely correlated to ***B***





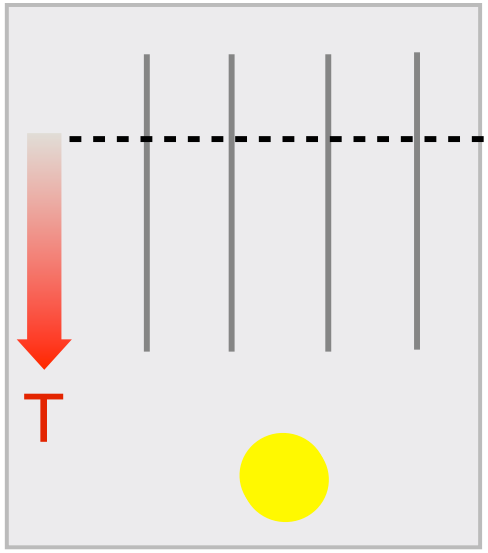
Lifetime

- What determines the lifetime of UDs?

cooling time
radiative cooling time

No!

about 10sec ≪ 600sec



cooled at the surface

duration of the supply
size / rise velocity

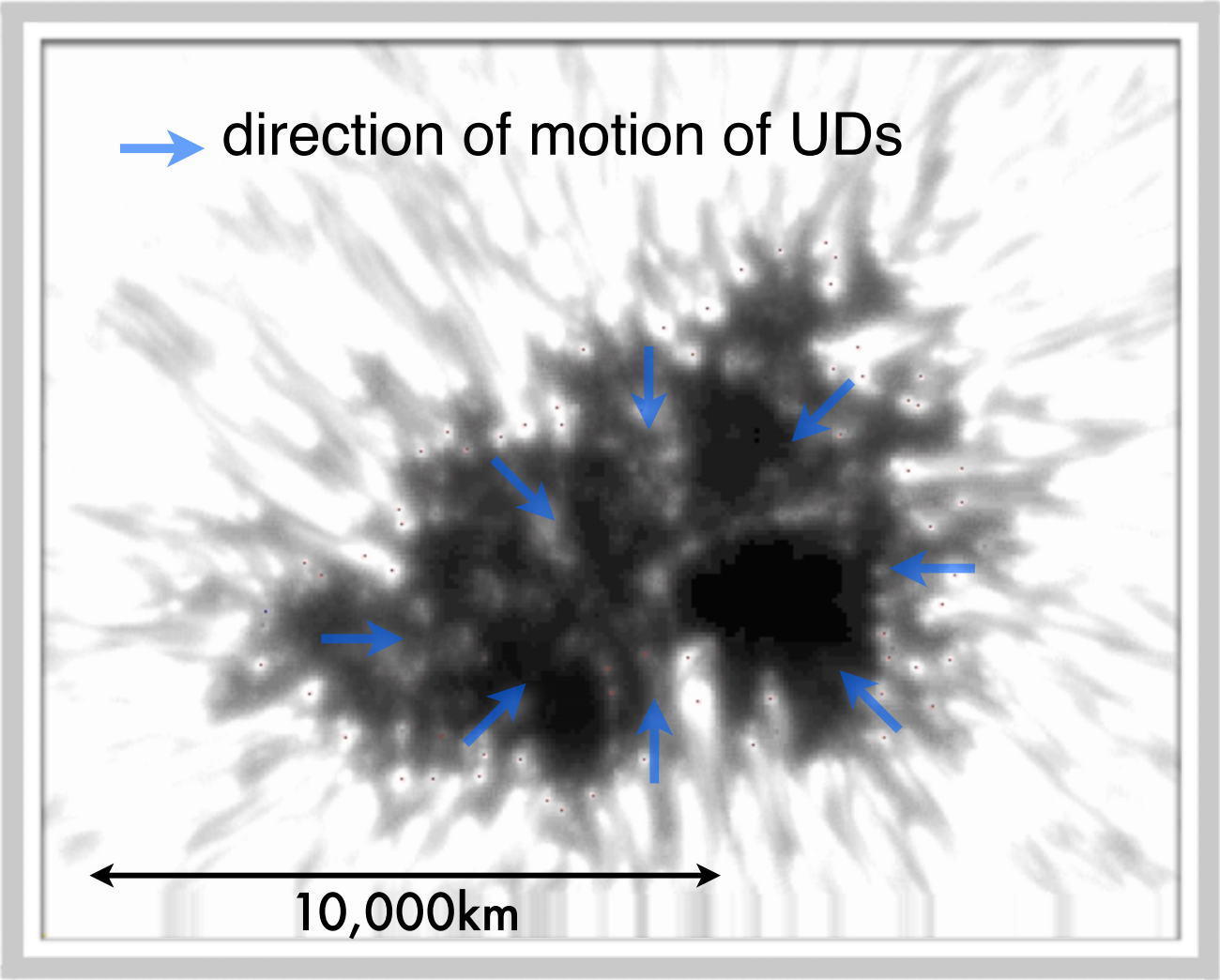
Maybe Yes!

size~300km、
lifetime~600sec、
∴ rise velocity~0.5km/s

If ***B*** is strong, both size and rise velocity is smaller.
Then lifetime is constant.

Proper motion

- Velocity analysis

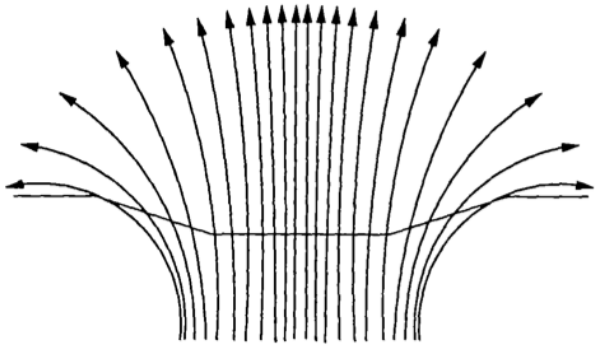


Central (vertical ***B***)

- almost no motion

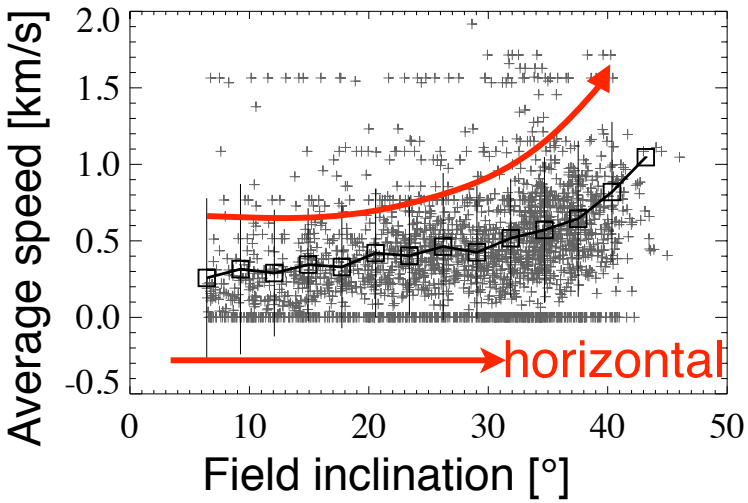
Peripheral (oblique ***B***)

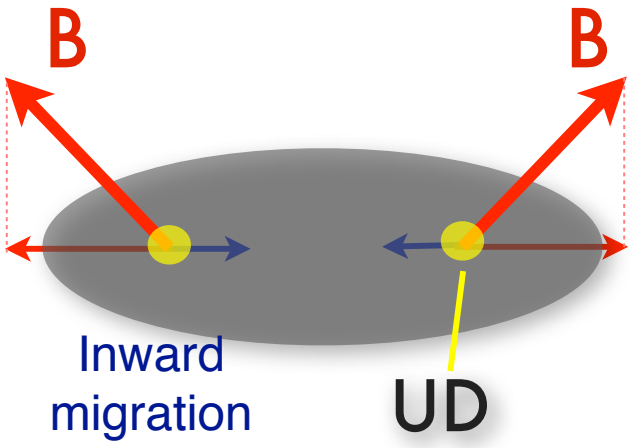
- inward migration

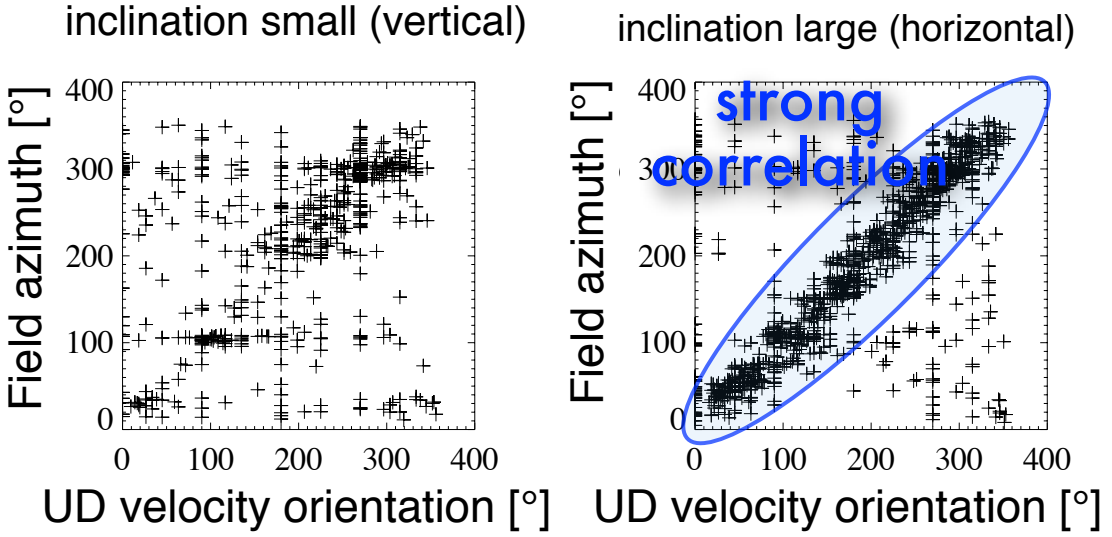


Result 4/4

- Velocity analysis
  - speed…faster in more inclined field regions
  - orientation
    - horizontal ***B*** toward center
    - vertical ***B*** weak correlation

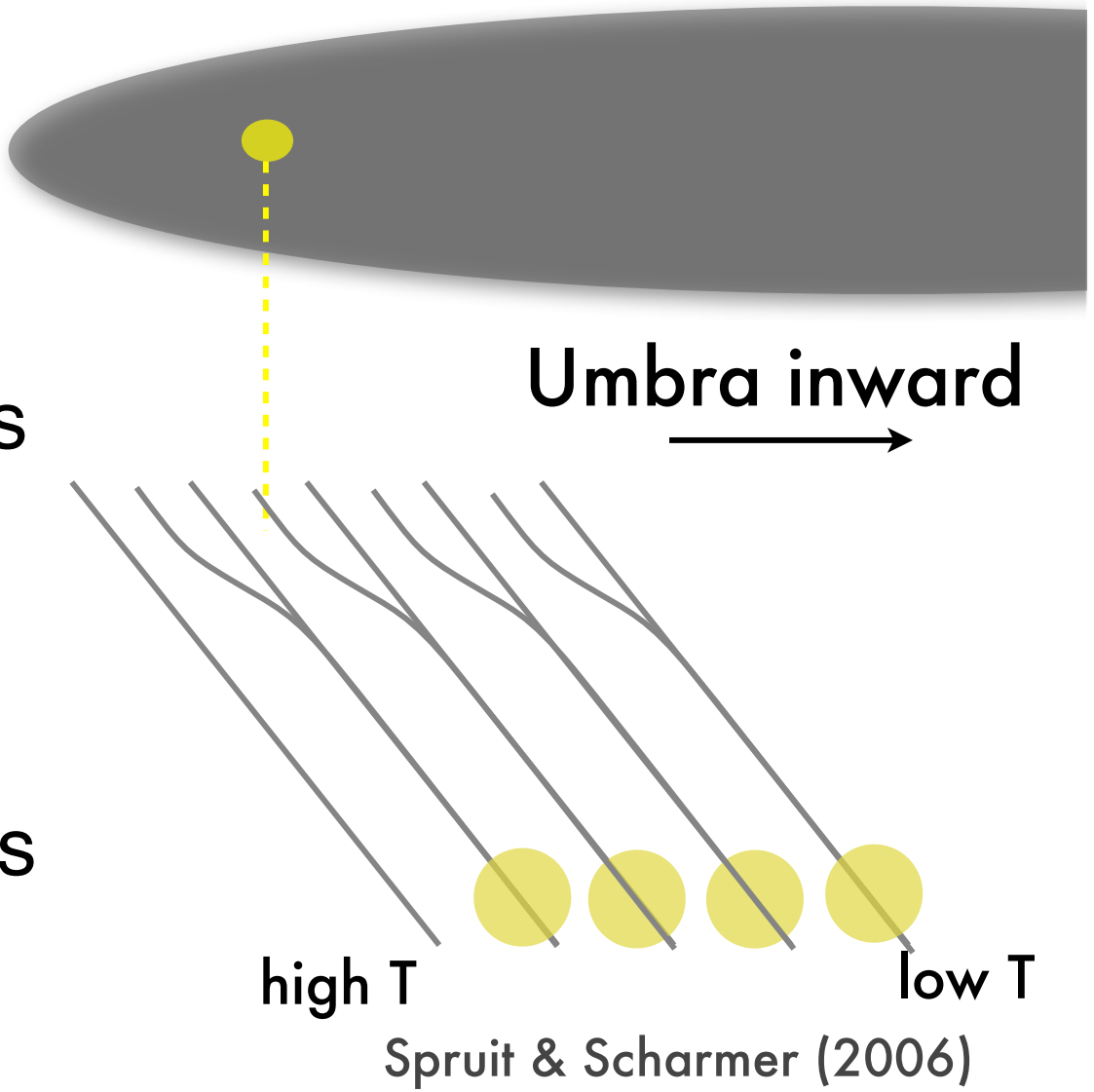






Inward migration

1. ascending, cooling
2. bending of field lines
3. a reduction of ***B***
4. ascending of hot gas



Spruit & Scharmer (2006)

Summary

umbral dot is the target which can directly measure the interaction between magnetic field and convection

- In strong magnetic field regions...
  - low occurrence rate ⇒ **Suppression of convection**
  - constant lifetime⇒ **lifetime~size / rise velocity, both size and velocity are smaller**
- In the inclined field regions...
  - move faster towards the center of the umbra

⇒ **Bending of field lines by cooled gas**