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# Magnetic Structure of Umbral Dots with SOT SP

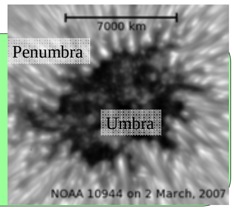

H.Watanabe, R.Kitai, K.Ichimoto (Kyoto University) and Y.Katsukawa (NAOJ)

contact e-mail: watanabe@kwasan.kyoto-u.ac.jp


## INTRODUCTION AND SCIENCE OBJECTIVE

The sunspot is one the most prominent structures in the solar photosphere, although there are many unresolved problems remaining. One of them is the source of energy transport in sunspots. Radiative energy alone is insufficient for accounting for the observed brightness of a sunspot, so any form of convective energy transport, i.e., umbral dot (UD) is essential for understanding.

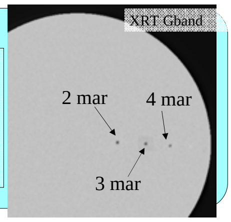
In Kitai et al. (2007), we performed statistical analyses of temperature (4600-5500K), size (~300km), lifetime (~15min), proper motion (peripheral only, ~1.0km/s), using Hinode SOT FG data, which has been difficult for ground-based observations.




## OBSERVATION

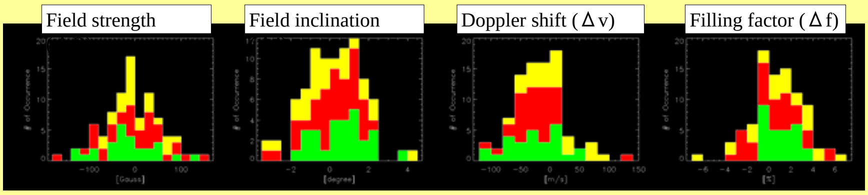
Instrument : Solar Optical Telescope Spectro-Polarimeter (SP)
Target : NOAA 10944 which was a decaying sunspot, from 2 March 2007 to 4 March 2007.
Heliocentric coordinate was (S6, W17) on 2 March, (S5, W30) on 3 March, (S6, W43) on 4 March.
Observation : Normal map mode, 0.147"x0.147"/pixel, 80"x80" field of view
＊We inverted full Stokes parameters into magnetic and Doppler field using Milne-Eddington model atmosphere.
＊All data are transformed as if they are seen from the top. * Doppler velocity is calculated by Stokes V zero cross.

<Spatial random error>
Field strength: 13Gauss
Field inclination: 0.7°
Doppler shift: 10m/s
Filling factor: 0.2%




## RESULTS FROM SPECTRO-POLARIMETRIC DATA

We measure the local difference of four physical parameters (ΔB:field strength, Δi: field inclination, Δv: Doppler shift, Δf: magnetic filling factor) using the inverted SP maps. For example, ΔB=B(UD)-B(UD's surrounding). Histograms of the local differences are shown below. Green color indicates UDs observed on 2 March, red color for UDs on 3 March, yellow color for UDs on 4 March.



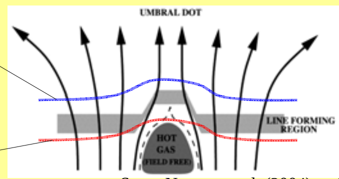

↓Table 1: Center-to-limb variation of UD magnetic field

| average | 2 Mar (S6,W17) | 3 Mar (S5,W30) | 4 Mar (S6,W43) | Total average |
|---|---|---|---|---|
| Field strength (ΔB) | -17 Gauss | -6 Gauss | 1 Gauss | -7 Gauss |
| Field inclination (Δi) | 0.6° | 0.1° | -0.1° | 0.3° |
| Doppler shift (Δv) | -28 m/s | -24 m/s | -3 m/s | -18 m/s |
| Filling factor (Δf) | 0.9% | 0.4% | 0.9% | 0.7% |

The average values on each observing days are listed in Table 1. ***When we observe UDs near disk center (2 Mar), they show smaller field strength, more inclined field inclination, and relative blue shift, while they show almost no difference near the limb (4 Mar).***
We try to explain these variations in terms of formation height differences based on center-to-limb variation. When the sunspot was observed at the disk center, we can see the deepest layer. *This may be evidence for the cusp-shaped magnetic field configuration of small convective cells.*

Observed at limb
Field strength: same or stronger
Field inclination: same or vertical
Doppler shift: slow upflow

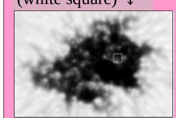
Observed at disk center
Field strength: weaker
Field inclination: more inclined
Doppler shift: fast upflow



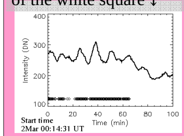
Socas Navarro et al. (2004)

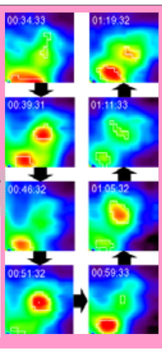
## OSCILLATORY LIGHT CURVE

Position of the UD (white square) ↓



Light curve at the center of the white square ↓

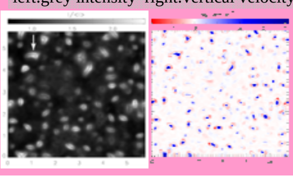


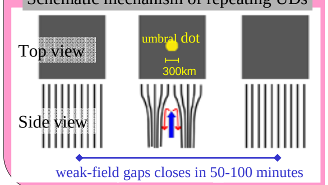

Thanks to Hinode's seeing-free observation, *we found some cases of repeating UDs.* In left figures, 6 UDs occurred in sequence, whose average lifetime is ~12 minutes. While UD occurred in sequence, the brightness did not decrease to its background level, but kept higher brightness. This kind of oscillatory light curve was found only in the center of the umbra in a mature sunspot.

Recent 3D MHD numerical simulation was done by Schüssler & Vögler (2006). In their simulation, an UD is a natural result of overstable oscillatory convection which is a preferred mode below the photosphere in the sunspot. UD's oscillatory light curve may be evidence of this overstable convection.

3D numerical simulation by Schüssler & Vögler (2006) ↓
left:grey intensity right:vertical velocity



Schematic mechanism of repeating UDs




Our interpretation of this repeating UDs with oscillatory light curve is as follows: *On account of the dynamic motion beneath the sunspot, weak-field gaps are created and UDs are excited by the overstable magnetoconvection. The weak-field gap may close in 50-100 min.*

## SUMMARY & DISCUSSION

Our analysis revealed the magnetic field around UDs using Hinode SP. As a result, we found

**(1)Observed at disk center, UDs show smaller filed strength, more inclined field inclination, and relative blue shift compared to their surroundings.**

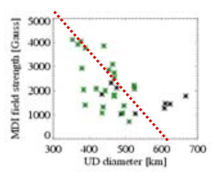
**(2)Observed near the limb, UDs show almost no difference in their magnetic and Doppler field.**

**(3)This center-to-limb variation can be understood by a formation height difference of Fe I 6302 line.**

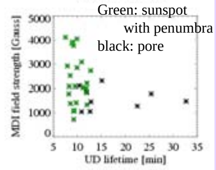
**(4)Part of UDs show oscillatory light curve with period of ~12 min and duration of 50-100min. This may be evidence of magneto-convection.**

Preliminary Study

We are now interested in UD's lifetime and size dependence on the average field strength or the sunspot configuration. UD's are the manifestation of the convection, so the study of UD leads to the convection zone, where we can not look into. If you are interested in our latest research, please talk to me!




Scatter diagram between UD diameter and average field strength of the sunspot. The UDs in weaker field sunspots have larger diameter.




Scatter diagram between UD lifetime and average field strength.
The UDs in pores (smaller field strength) have longer lifetimes.