Observations of Fine Scale Structures and Dynamics in Sunspots

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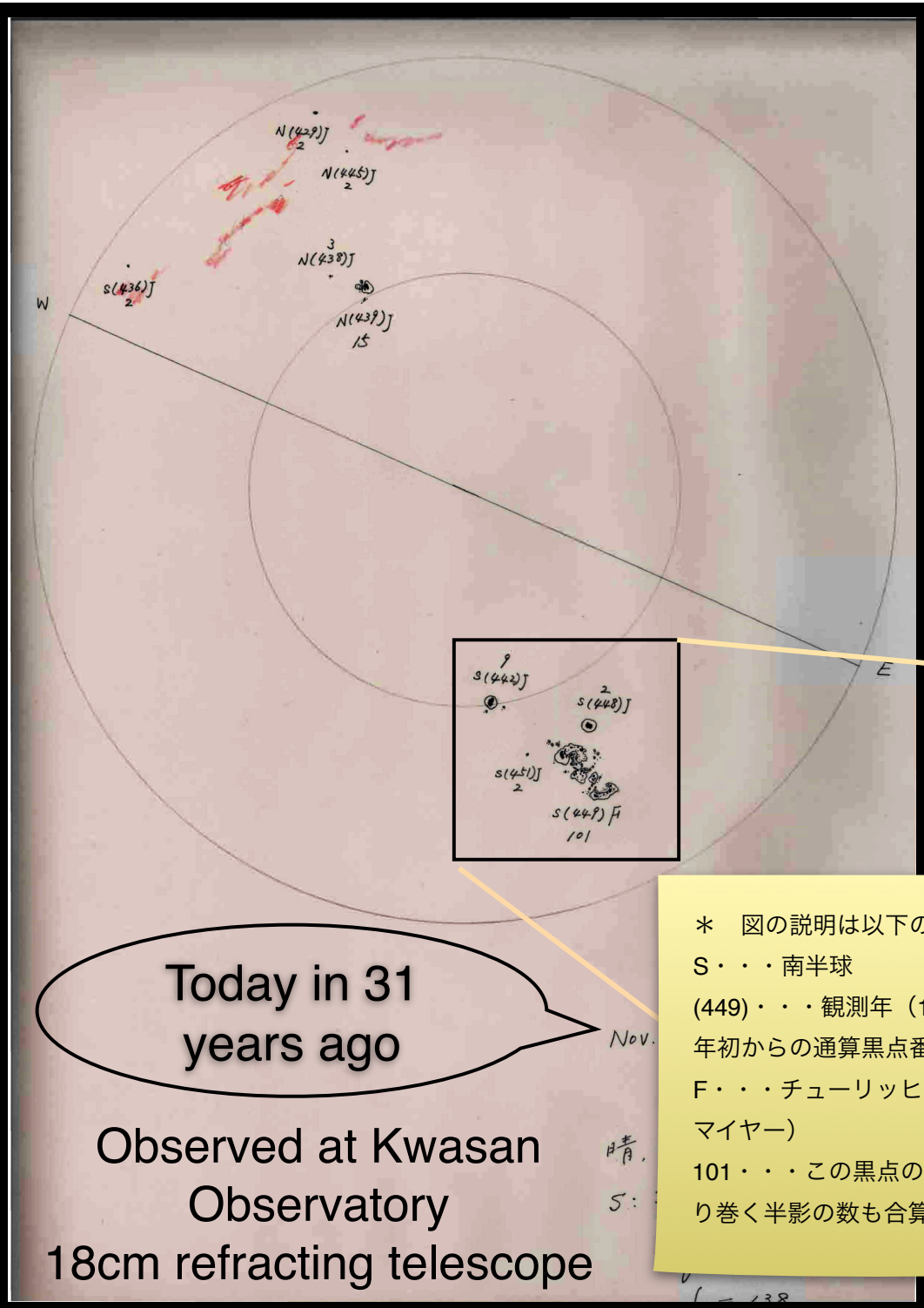
(Kyoto U.)

Sunspot sketch by “Kyoto’s Galileo”

Mr. Suzuki

He draws a sketch of sunspot everyday for more than 50 years!

How attractive sunspots are!!

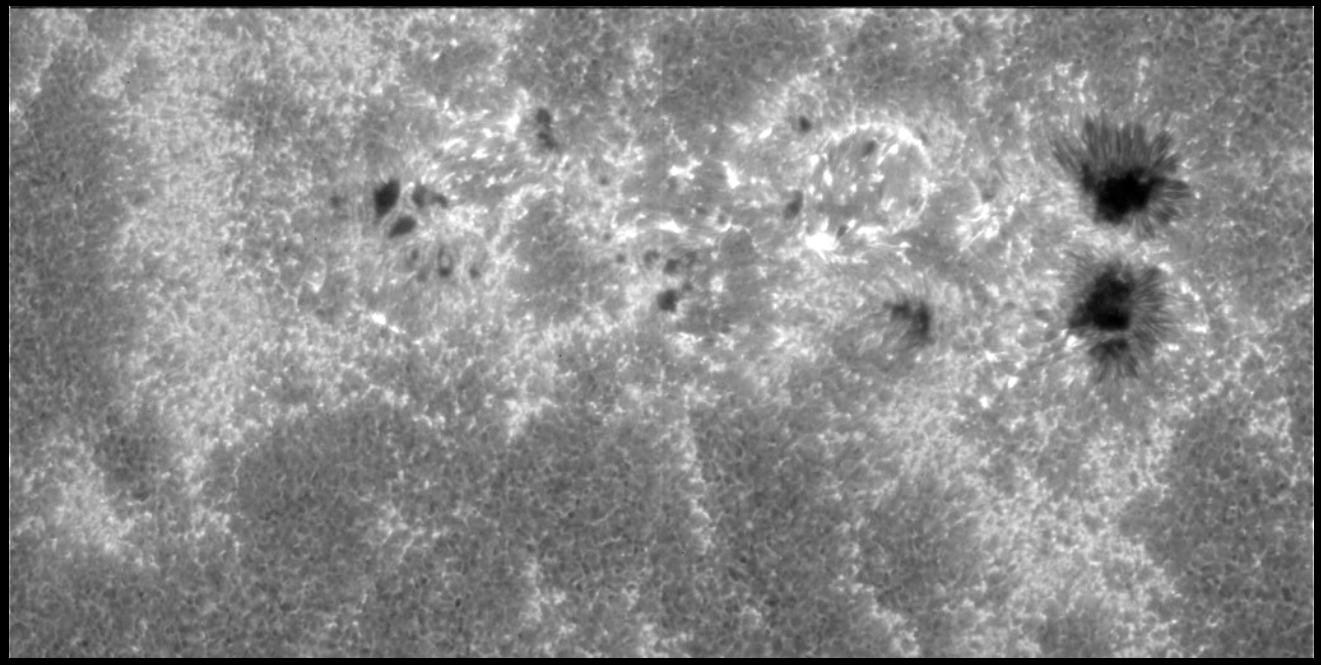


Today in 31 years ago

Observed at Kwasan Observatory
18cm refracting telescope

＊　図の説明は以下のようになります。
S・・・南半球
(449)・・・観測年（1982年）における年初からの通算黒点番号）
F・・・チューリッヒ黒点型（ワールドマイヤー）
101・・・この黒点の黒点数（本影を取り巻く半影の数も合算されています）

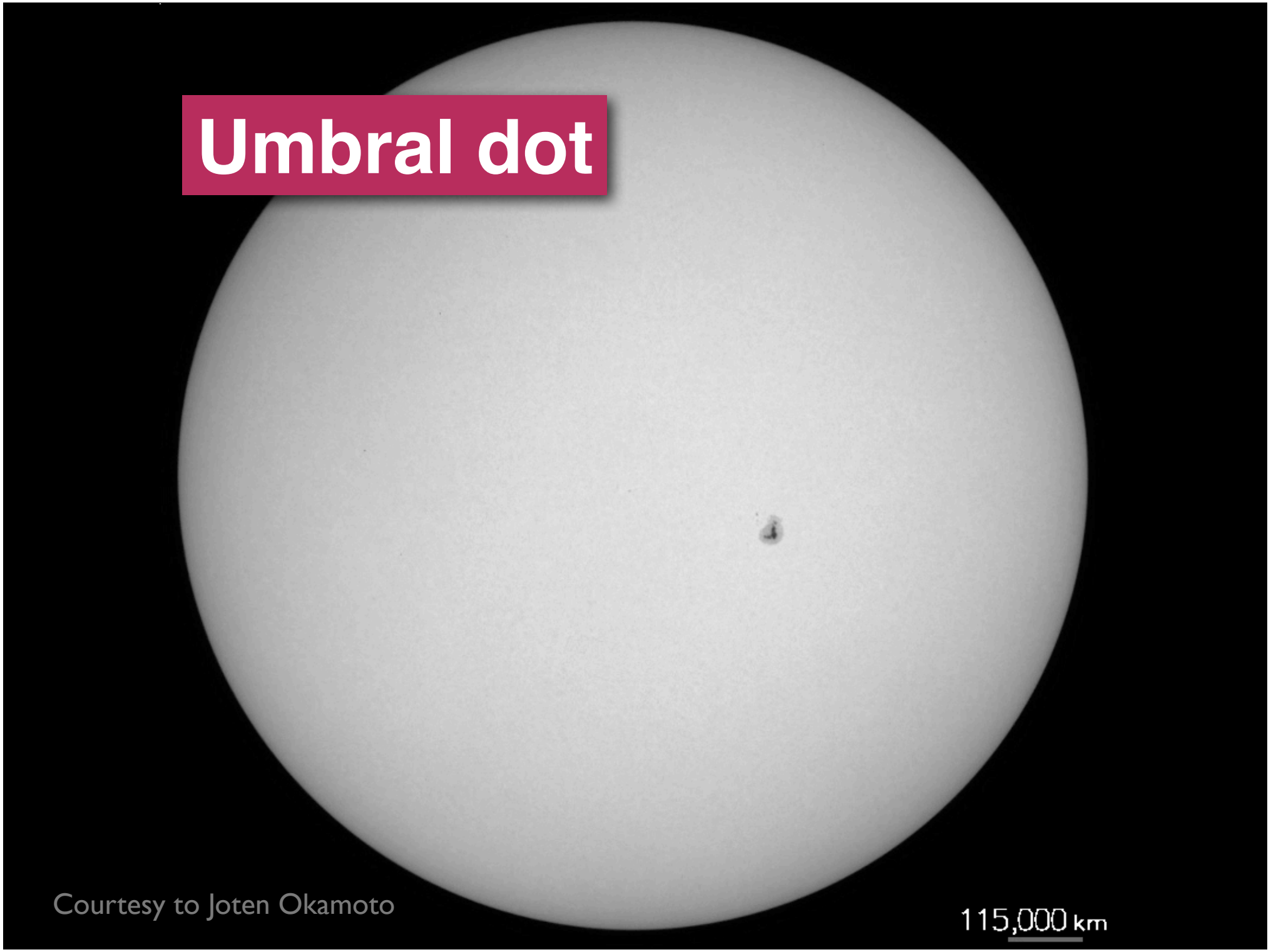
Advantage in the satellite is **SEEING-FREE!**

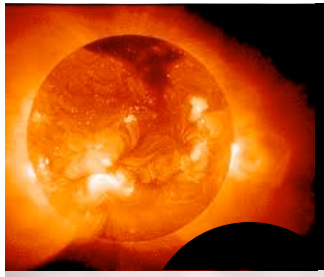


Top:
Hida Observatory
SMART/FISCH
Continuum (left)
and Hα (right)

2013-10-22
NOAA 11875

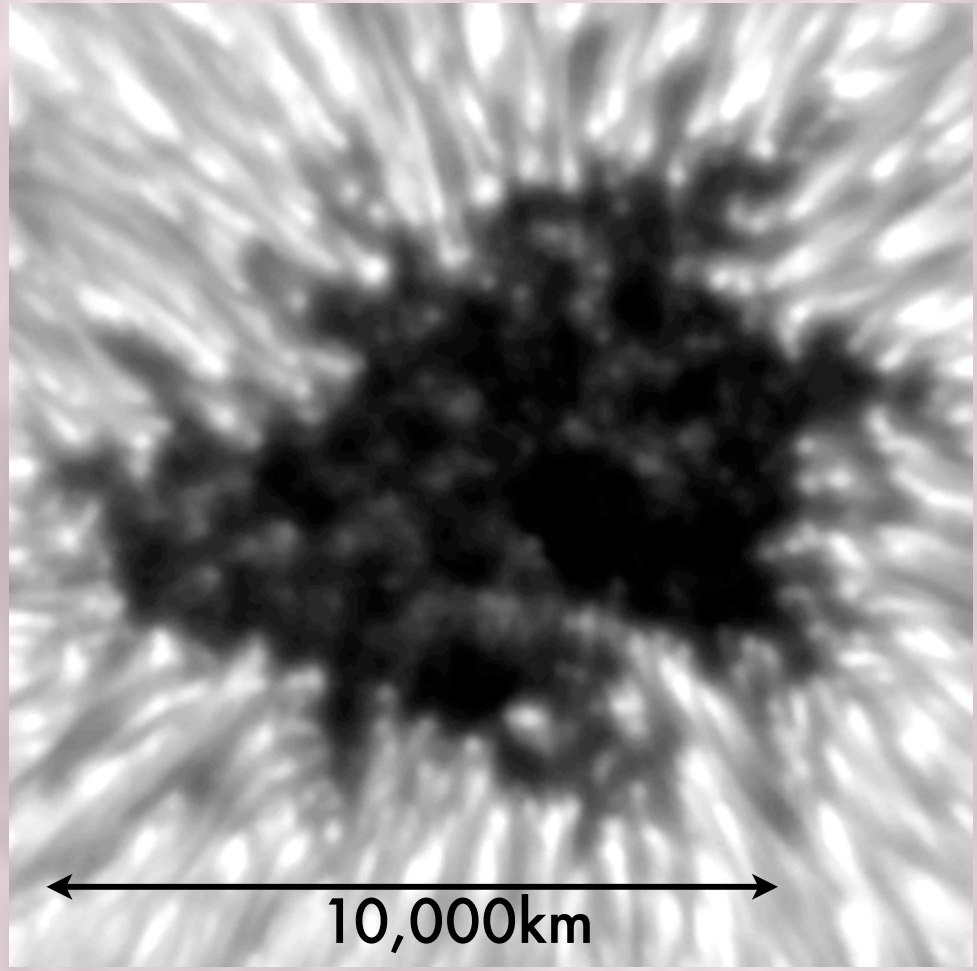
Bottom:
Hinode SOT
Ca II H line
20s cadence

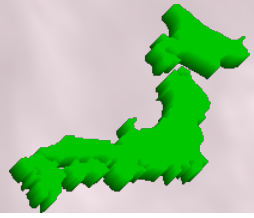

Umbral dot
Courtesy to Joten Okamoto
115,000 km



Umbral dot

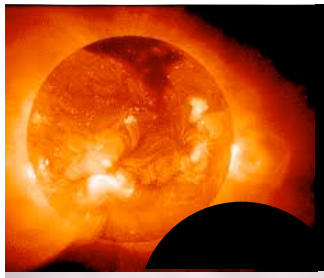
Size	200 - 400 km
Lifetime	typically 10 min (More UDs with shorter lifetime)
Apparent proper Motion	Periphery: 0.5-1km/s umbra inward Central: Static
Field strength perturbation	a few hundreds Gauss weaker than the surroundings
Velocity perturbation	Central strong upflow and surrounding diffuse downflow



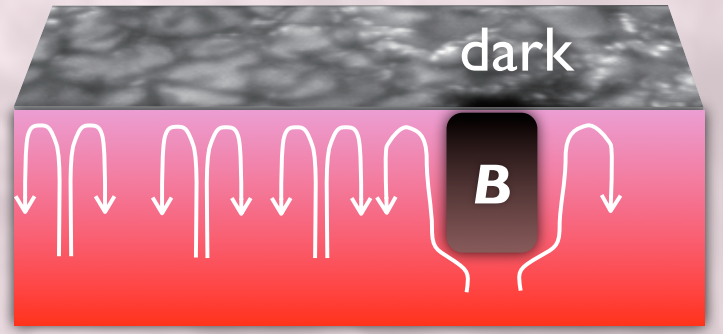


Size of one umbral dot
≈ Hokkaido

Sobotka et al. 1997a,b, Watanabe et al. 2009, Ortiz et al. 2010, ★Riethmüller et al. 2013

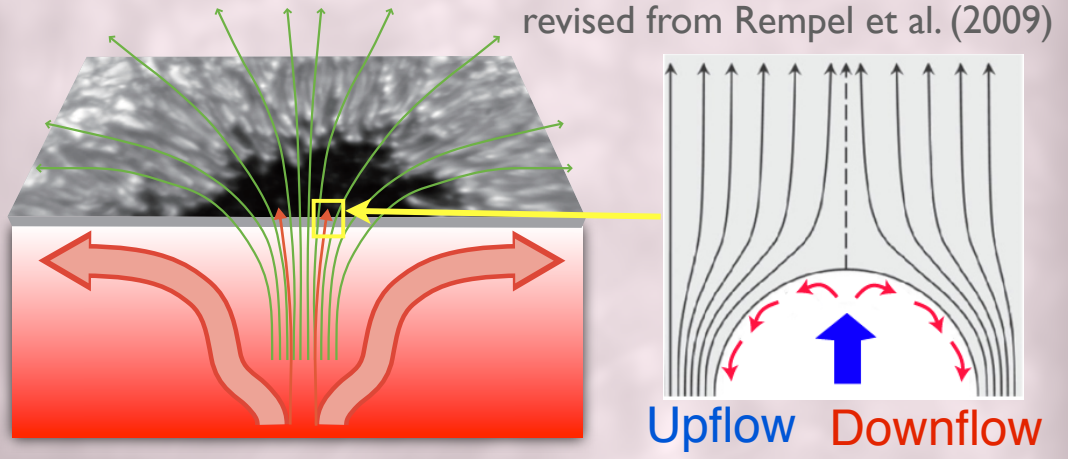


Convection



The strong magnetic field inhibit the convective heat transport →dark sunspot

revised from Rempel et al. (2009)



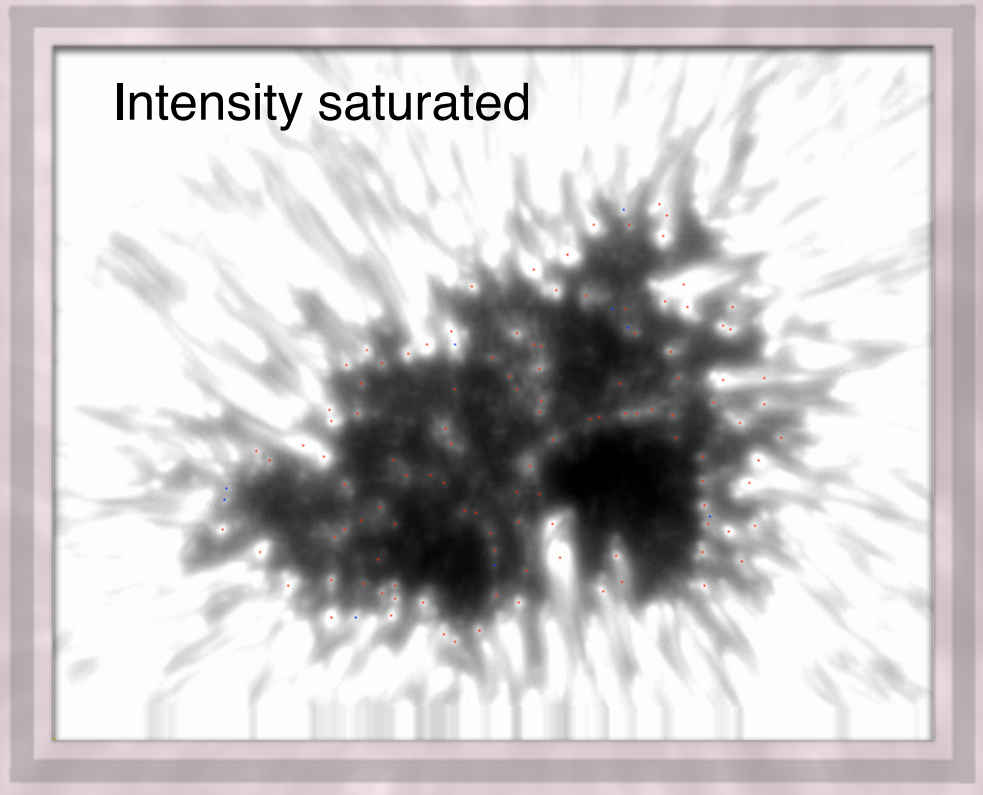
Umbral dot is a manifestation of magneto-convection

Umbral dot is a unique observational target for studying magneto-convection in situ !!

Also useful for subsurface diagnoses !

Umbral Dot Analysis

- Watanabe et al. (2009) performed umbral dot analysis in the framework of magneto-convection



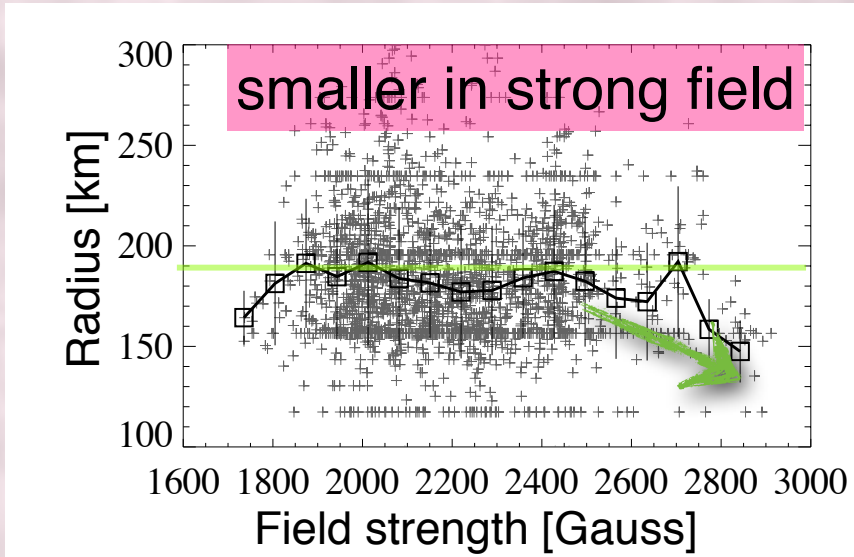
Total amount of 2268 UDs

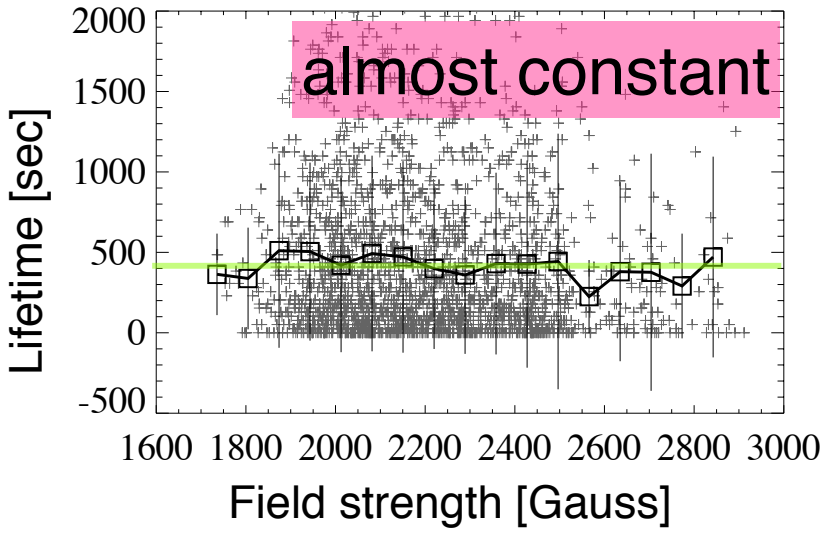
+ SP map

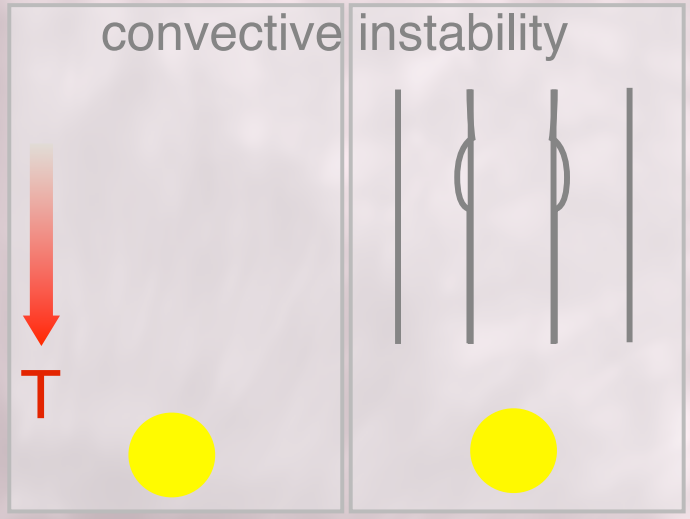
We can see how the lifetime and size of magneto-convective manifestation depends on its environmental magnetic field

It's like "Parameter Survey"

Umbral Dot Analysis







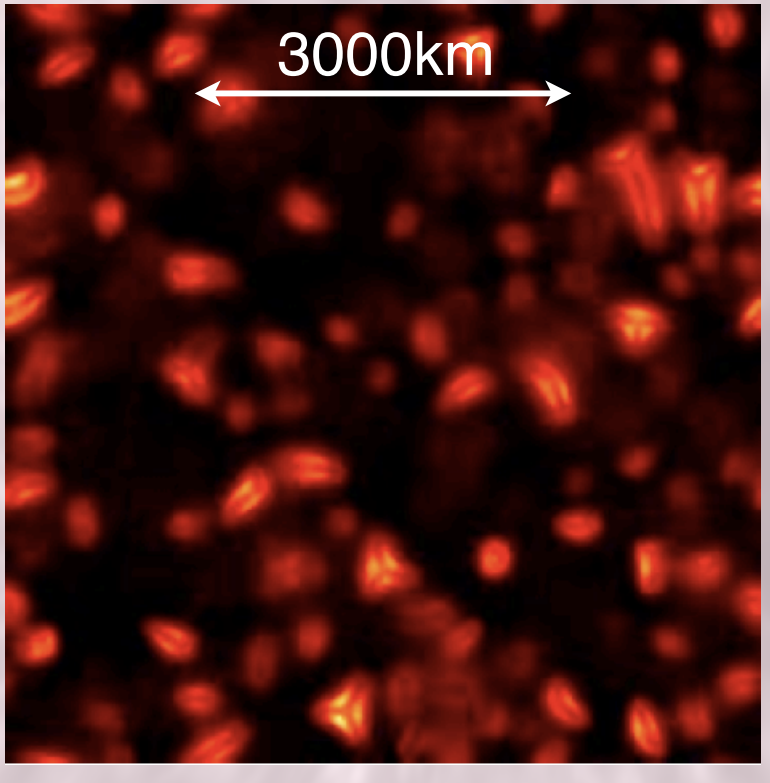
rise speed and size are inversely correlated to ***B***

- 3D simulation (private comm. with Dr. Schüssler) produces shorter lifetime in stronger fields.

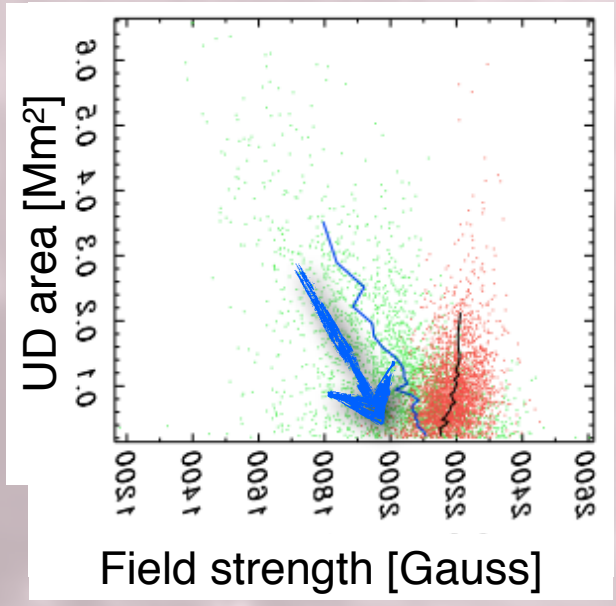
May be able to give some solid constraints to the simulation settings

Simulation + Analysis

- Bharti et al. (2010) performed “(observational) analysis” on the simulated umbral dots



Bolometric intensity map
of 3D radiative simulation
(Schüssler & Vögler 2006)



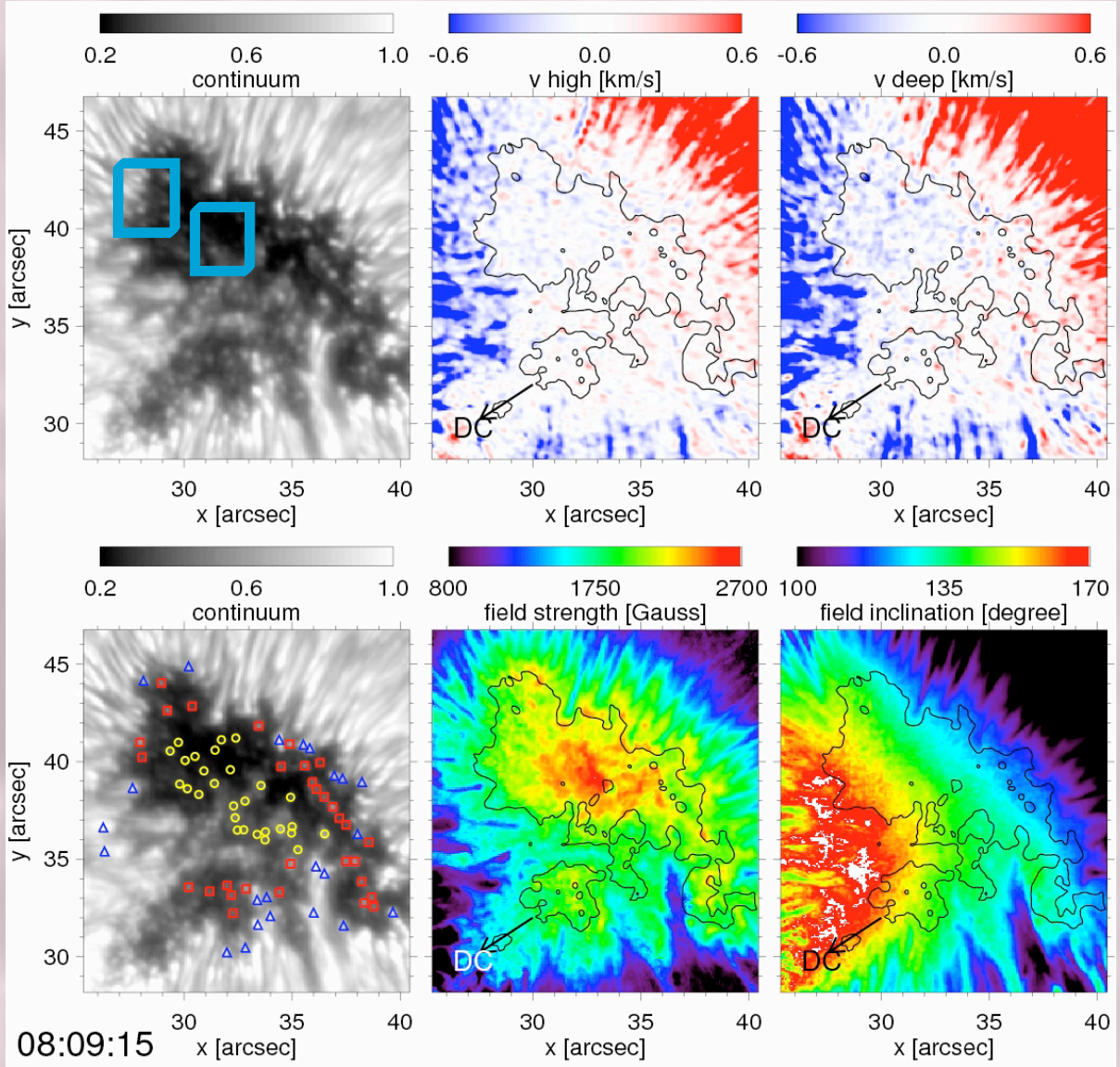
※ Please see green points because red points represent different phase from usual umbral dot

- Lifetime also decreases as the field strength gets stronger ⇄

  incompatible with observation

Evolution tracking in-situ

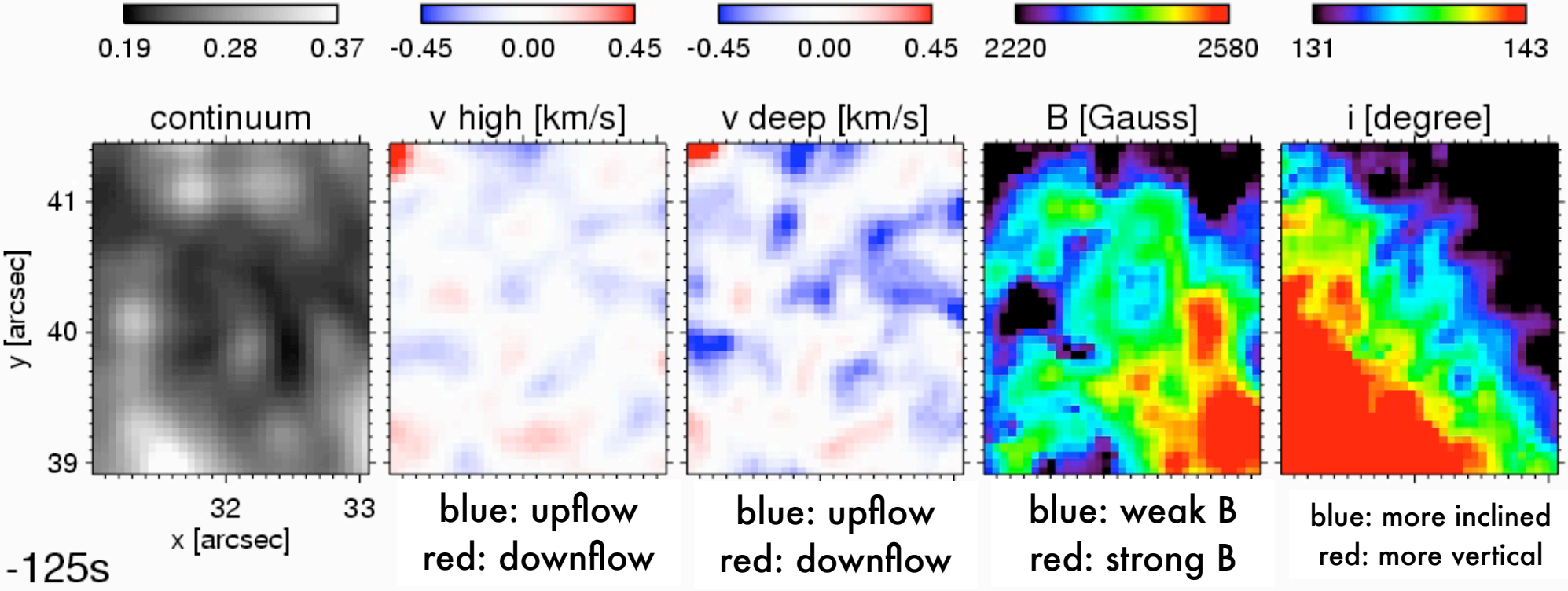
- 1min cadence observation of full Stokes 2D imaging was performed by CRISP/Swedish Solar Telescope
- *We could track the evolution of umbral dot in magnetic and velocity fields!*



Watanabe et al. (2012)

SST/CRISP Fe 6301&6302

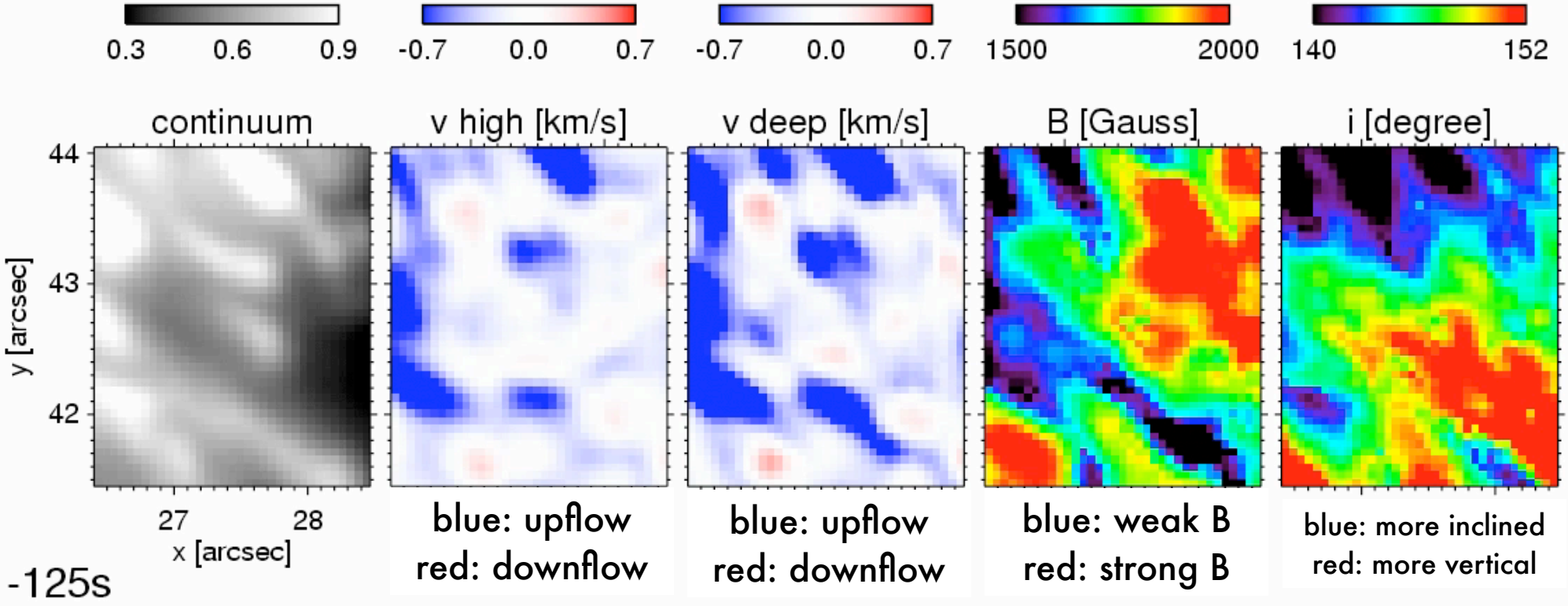
Evolution in-situ 1



Upflow synchronized with the peak of continuum
(0.3 km/s for $v_{\_high}$, 0.5 km/s for $v_{\_deep}$)

Field reduction in the first half (about 50 Gauss),
and disappear by colliding into the strong field region

Evolution in-situ 2



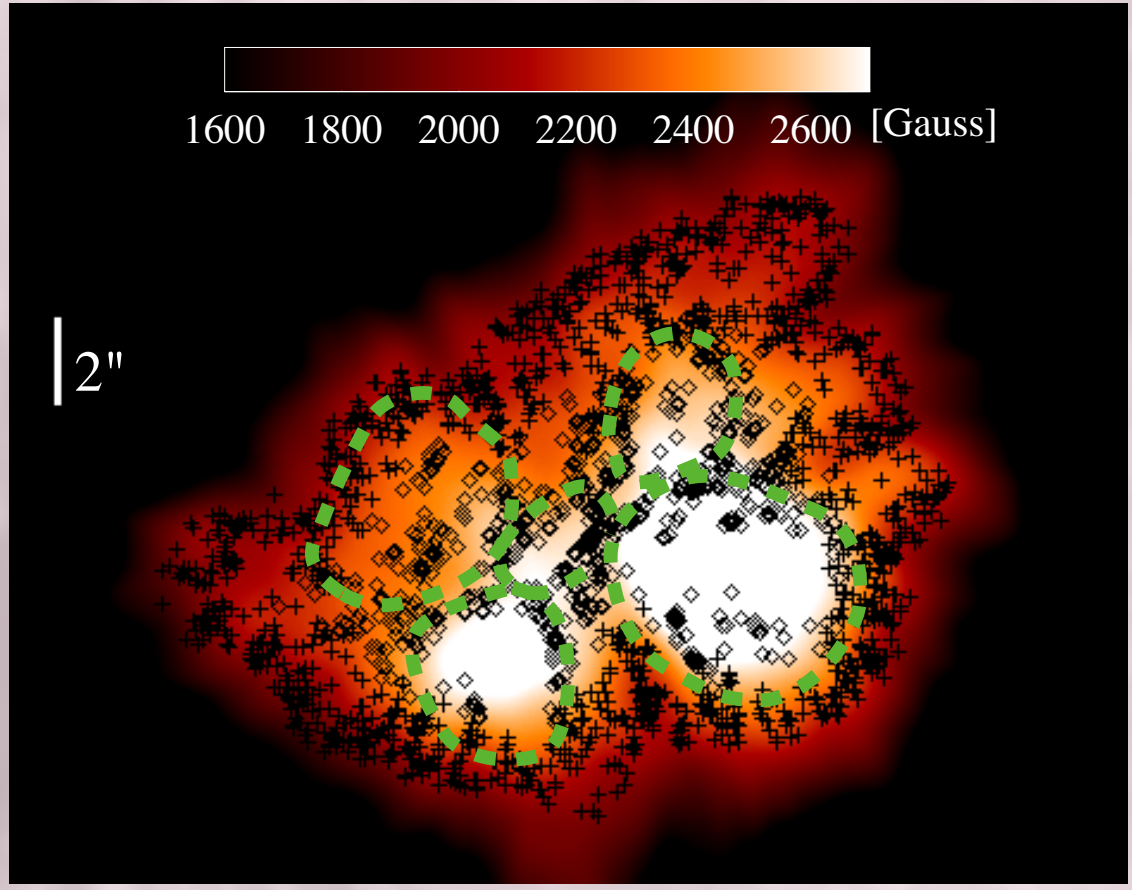
Strong upflow at the leading tip of the penumbral grain → evolve into an isolated UD

The leading edge of the UD seems to be **blocked by the strong field "walls"**

Distribution → Subsurface

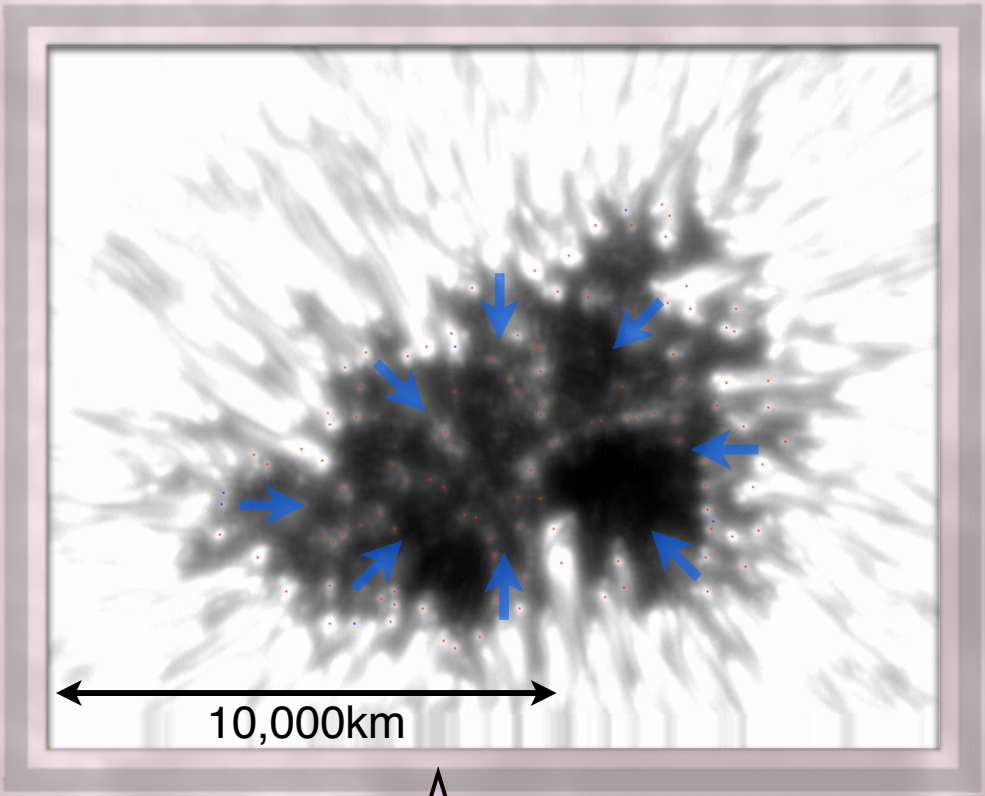
- The distribution of umbral dot location in Watanabe et al. (2009) reminds us of “cluster-type sunspot”

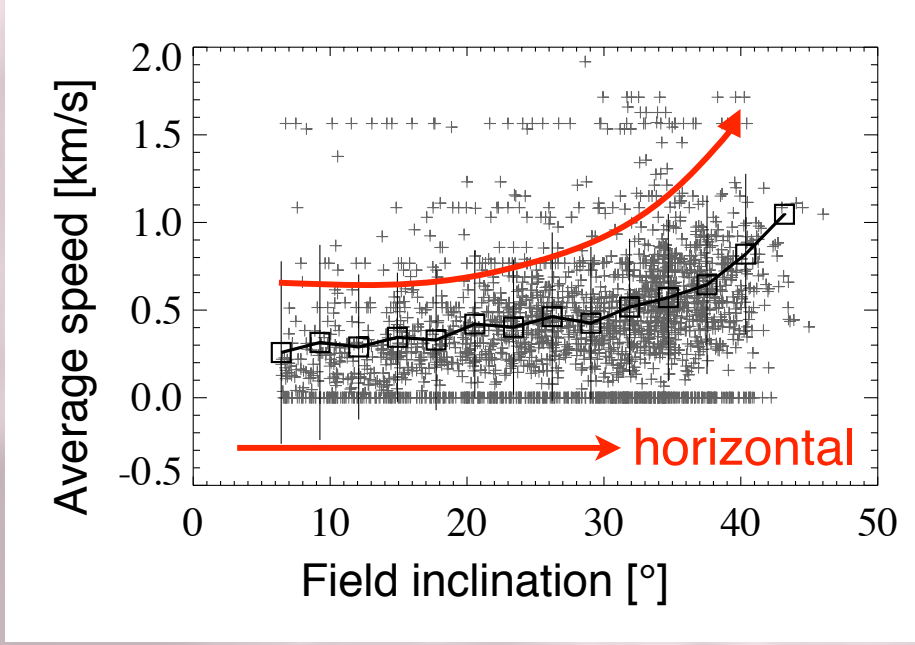
Looking into UD distribution may work much more efficiently for subsurface diagnosis than the helioseismology.
(c.f.,Schunker et al. 2013)



Background: magnetic field strength
Black symbols: umbral dot location for 2268 samples
Watanabe et al. (2009)

Inward migration





※ Note that this “speed” is not upflow or downflow, but the apparent motion speed

Important!!

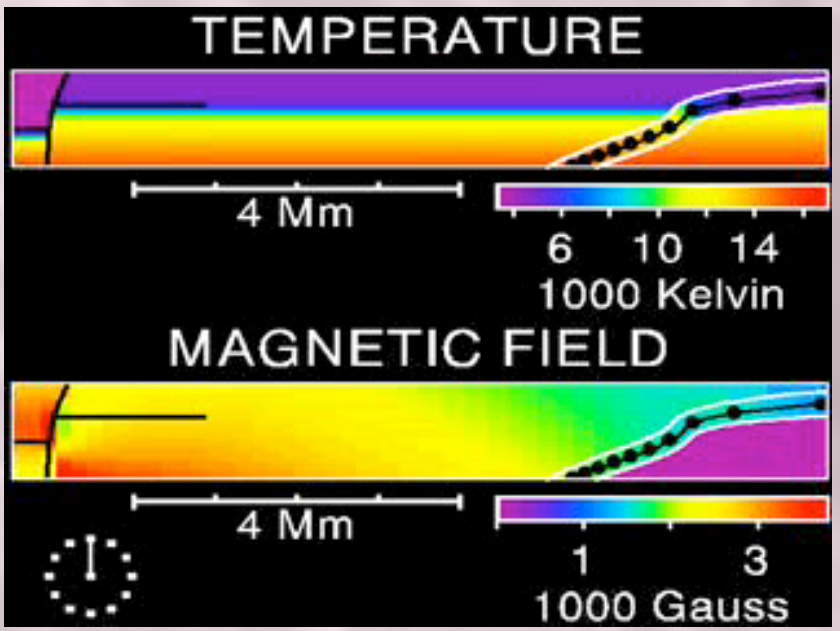
Why the migration is always toward umbra center, better seen in periphery?

- We found positive correlation between field inclination and apparent motion speed

Two Models

[Single flux tube model]
e.g., Schlichenmaier et al. 1998

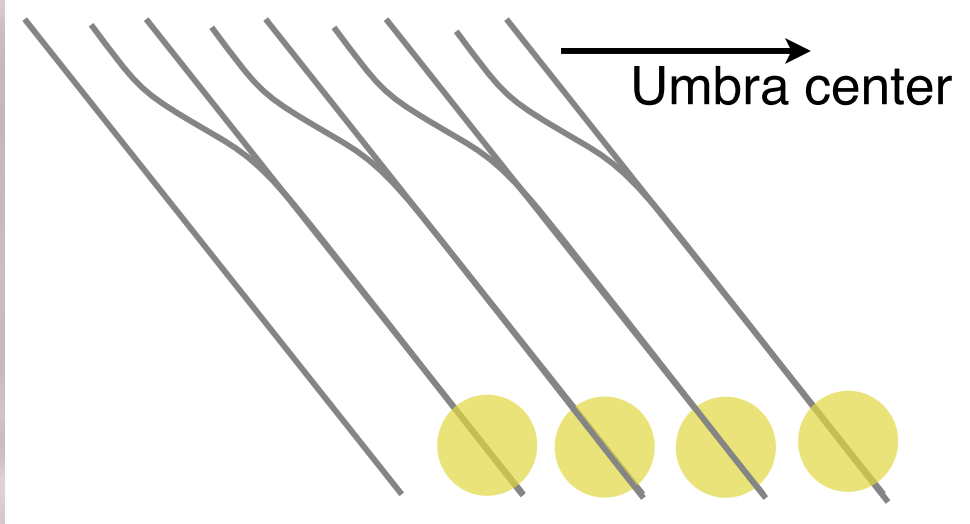
- Push their way through the vertical field “forest”



※ This simulation is for Evershed flow, but can continues to penumbral grain

[Convection model]
e.g., Scharmer et al. 2008

- Inward migration is the successive appearance of convective plasma



Gas ascends and cools radiatively → lose buoyancy and bends the field line → reduce the magnetic pressure in the umbra side → triggers a new upflow

Consistency with Models

- Note: This is MY interpretation...

[Single flux tube model] e.g., Schlichenmaier et al. 1998	[Convection model] e.g., Scharmer et al. 2008
Can not understand UDs in the same framework	***Unified model*** for UDs, penumbral grain, penumbral filament ★
I'm not sure how this model can reproduce peripheral umbral dot and the relation with the field inclination	***Positive correlation*** between the field inclination and apparent motion speed can be understood ★
The strong field "wall" at the leading edge of migration UD can be understood ★	How can the convection model explain the strong field "wall" that is pushed by UD migration?

Future work

Umbral dot is a unique observational target for studying magneto-convection in situ !!

- Time evolution of UDs in magnetic and velocity field from seeing-free satellite observation

Also useful for subsurface diagnoses !

- Statistical analysis of distribution map (in other words, dark umbral core evolution) may give some hints to the subsurface structure and how it evolves