Evolution of sunspot small-scale features

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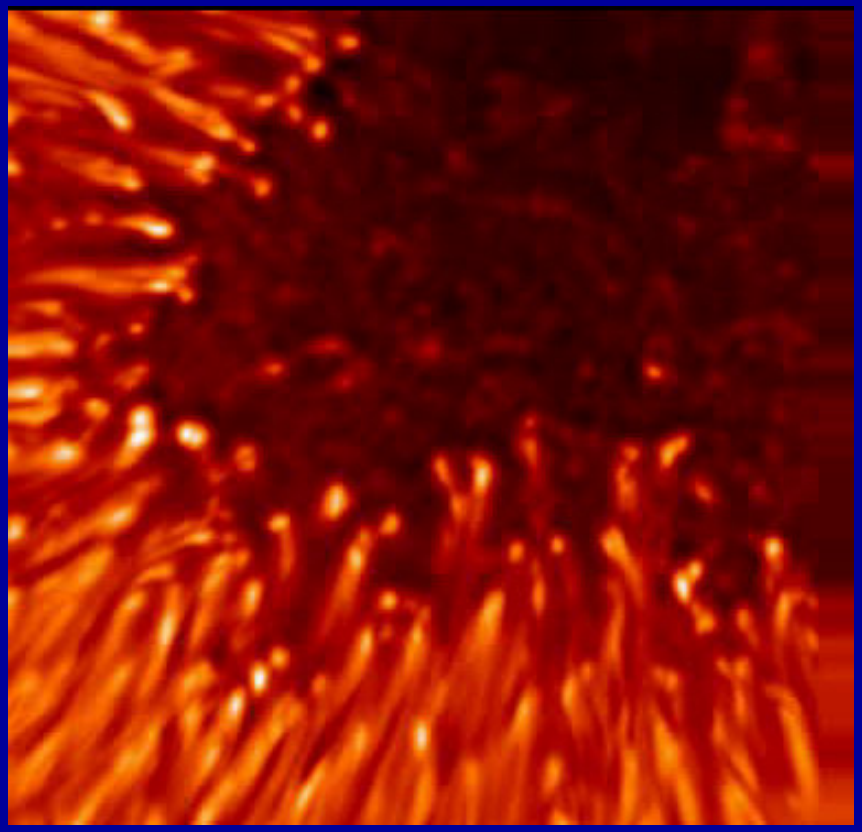
Introduction

Umbral dots
- central (CUDs)
- peripheral (PUDs)

Penumbral grains (PGs), often at ends of bright penumbral filaments



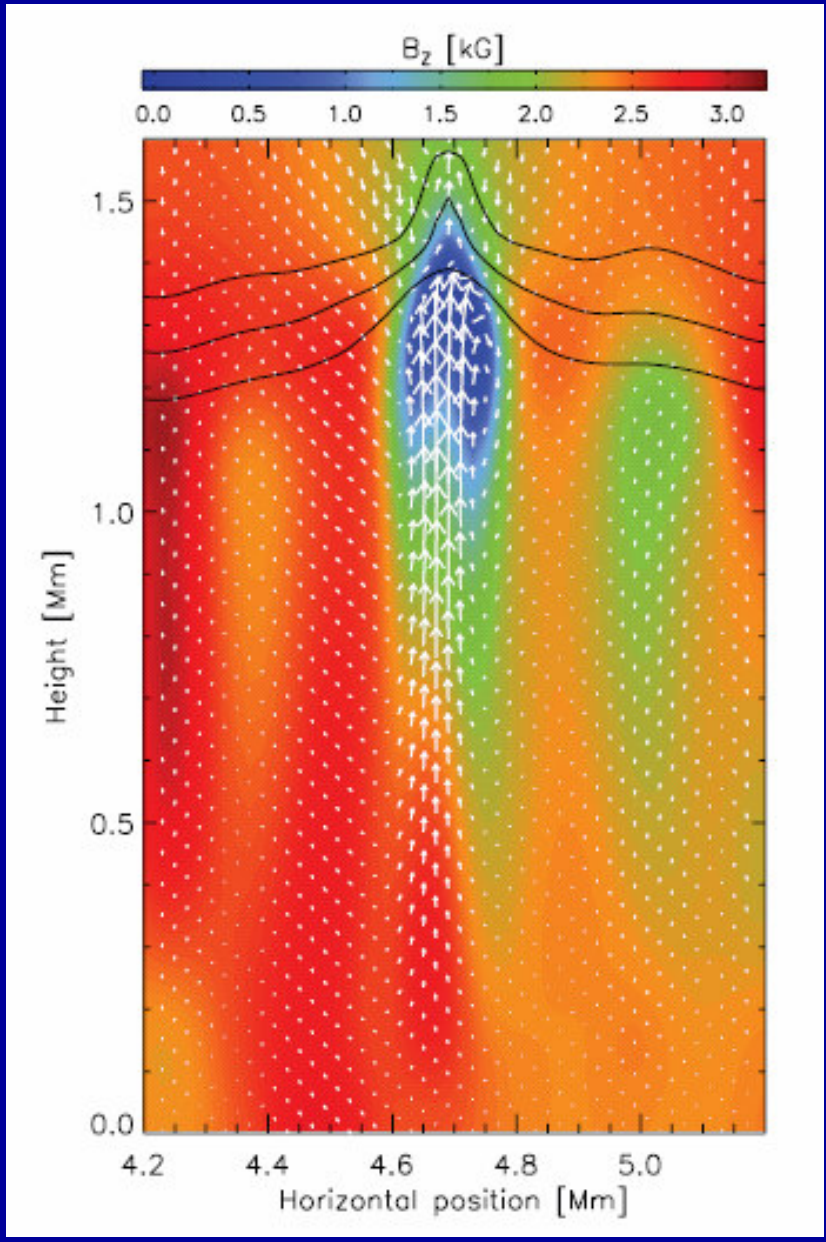
SST, 2004, obs. Sobotka, Puschmann, Möstl

Upflows and more inclined magnetic field are observed in PUDs, no such signatures in CUDs (Riethmüller et al. 2008). Enhanced LOS velocity and inclination in bright penumbral filaments (Jurčák et al. 2007)

Recent MHD simulations:

UDs are nonstationary narrow plumes of rising hot plasma with strongly reduced magnetic field (Schüssler & Vögler 2006).

Similarly, elongated plumes may be formed in inclined magnetic field of the inner penumbra, giving rise to PGs (Rempel et al. 2008).



Schüssler & Vögler 2006

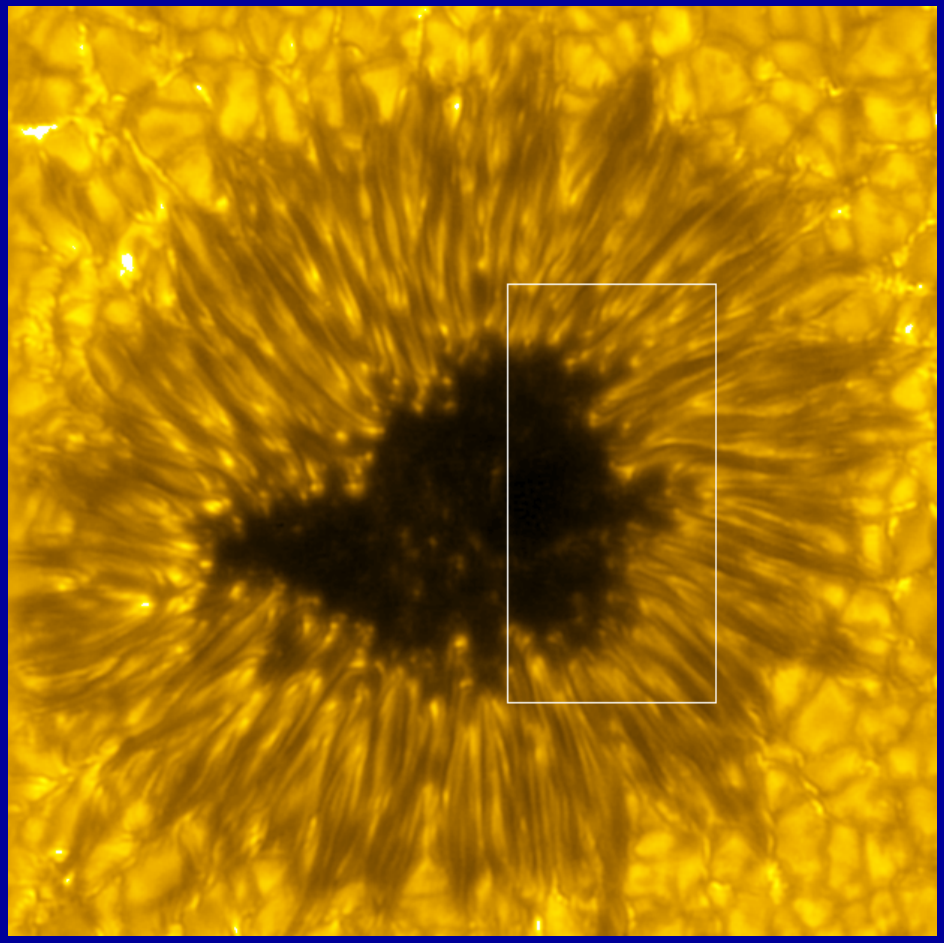
Observations

HINODE / SOT, 27 Feb 2008, NOAA 10944, μ = 0.97

SP: 34 repeated scans in
Fe I 6302 Å lines,
full Stokes, 3 hours,
resolutions: 333 s, 0".32

BFI: 185 frames in
G-band (4305 Å), 3 hours,
resolutions: 60 s, 0".22

After the co-alignment,
FOV of SP is 8' x 16'.

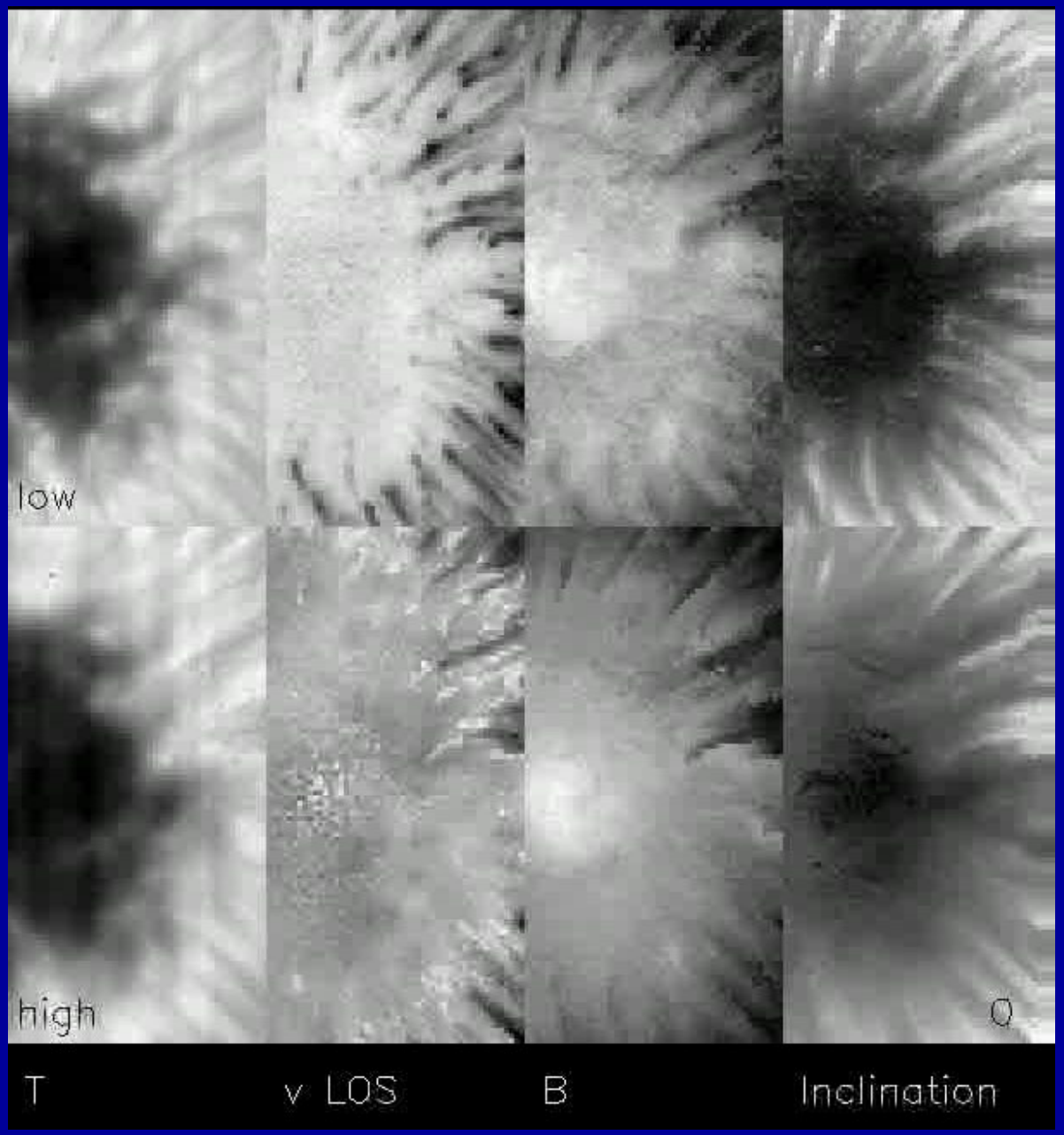


Data inversion and analysis

Inversion code SIR (Ruiz Cobo & del Toro Iniesta 1999)

34 3D maps of
T, v_{LOS}, B, γ
Averaged in height:
low photosphere:
$-0.5 < \log \tau < -0.2$
high photosphere:
$-2.0 < \log \tau < -1.4$

G-band frames:
v_{HOR} , d_{eff}



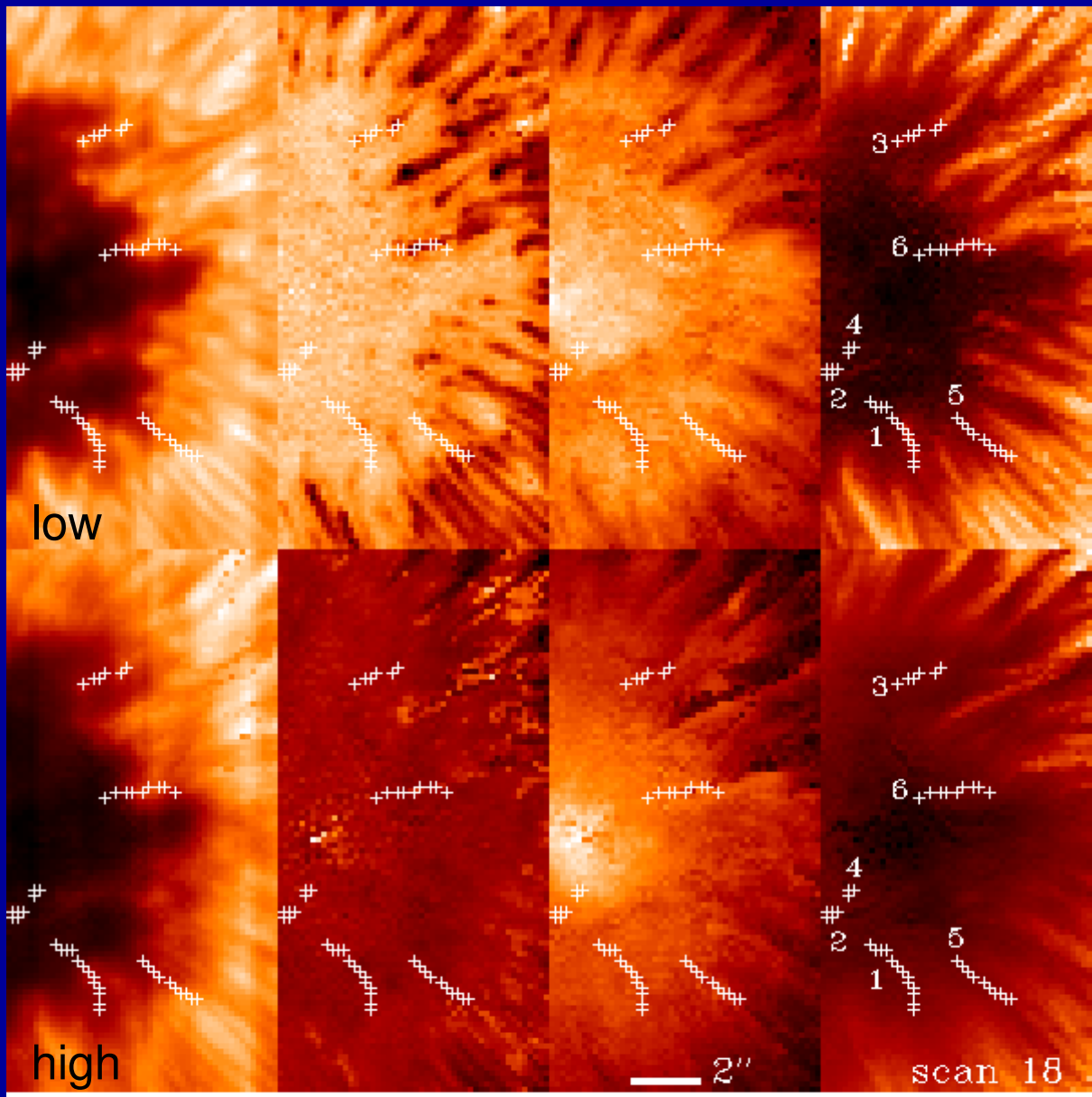
Results

Evolution of
***T*, v_{LOS}, *B*, γ**
in 7 long-lived features and in their surroundings

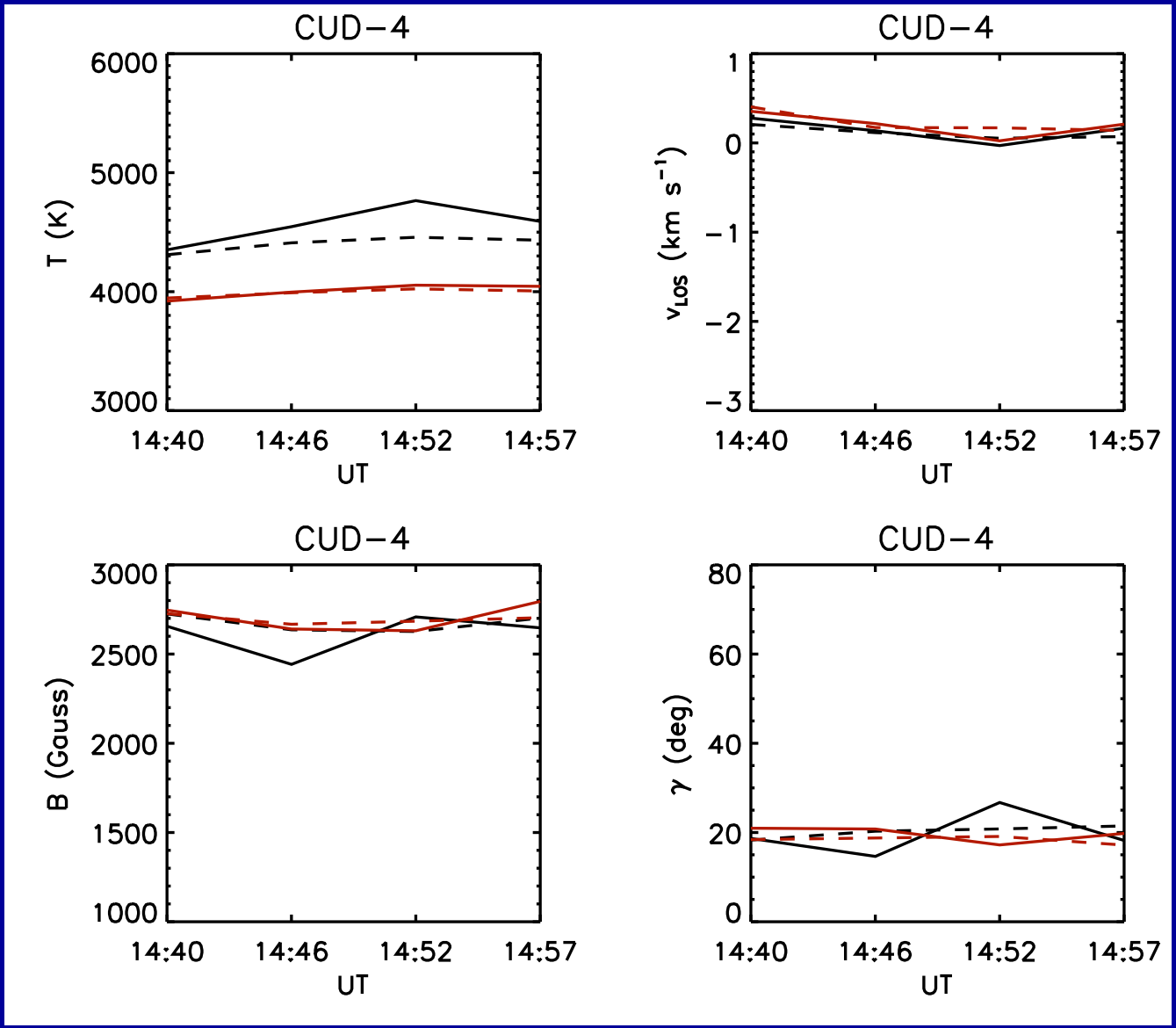
Features:

2a, 2b, 4 … CUDs
1 … PUD
3, 6 … PGs → PUDs
5 … PG

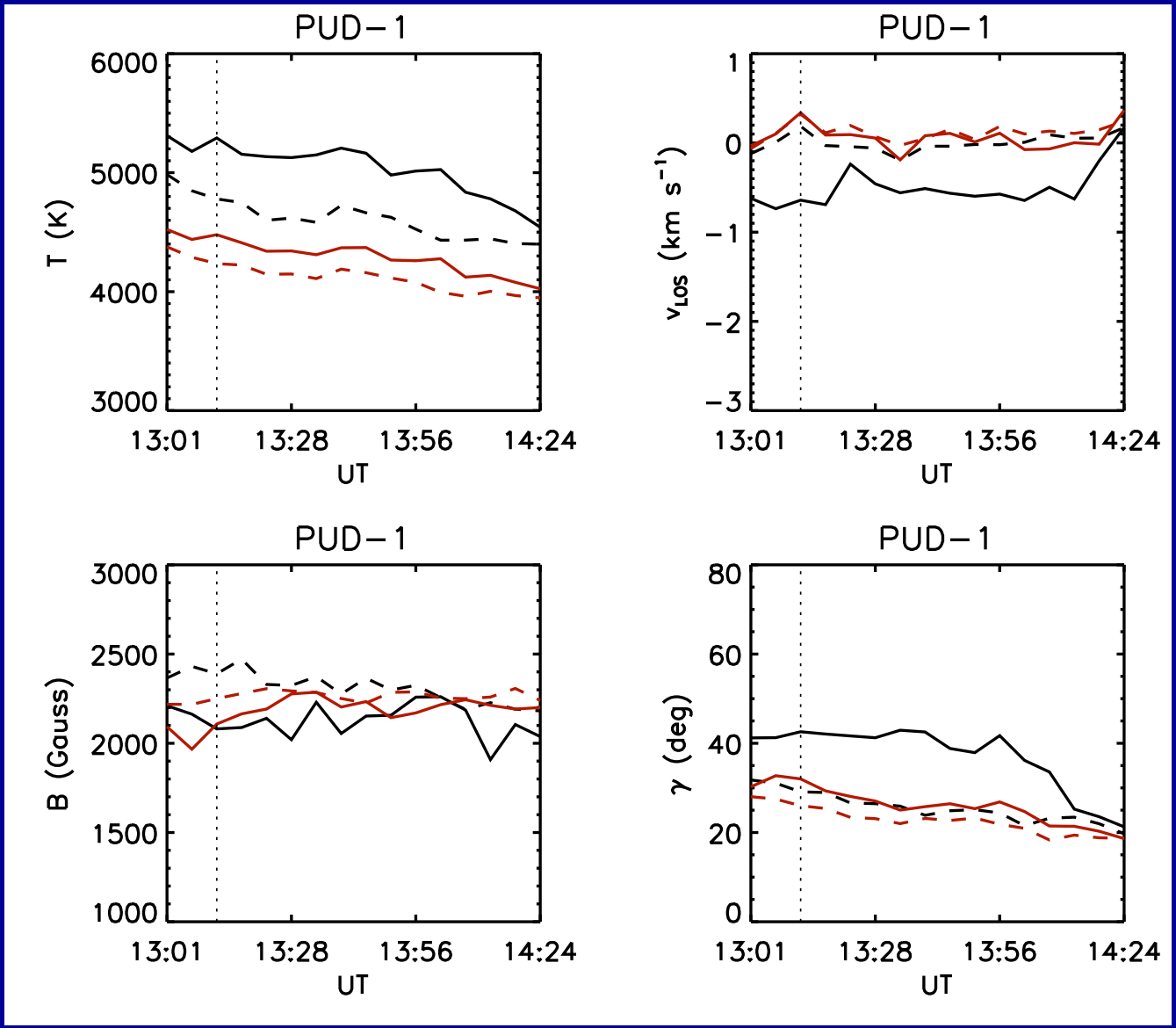
crosses depict the trajectories of features



Temporal evolution of T, v_{LOS}, B and inclination
central umbral dot

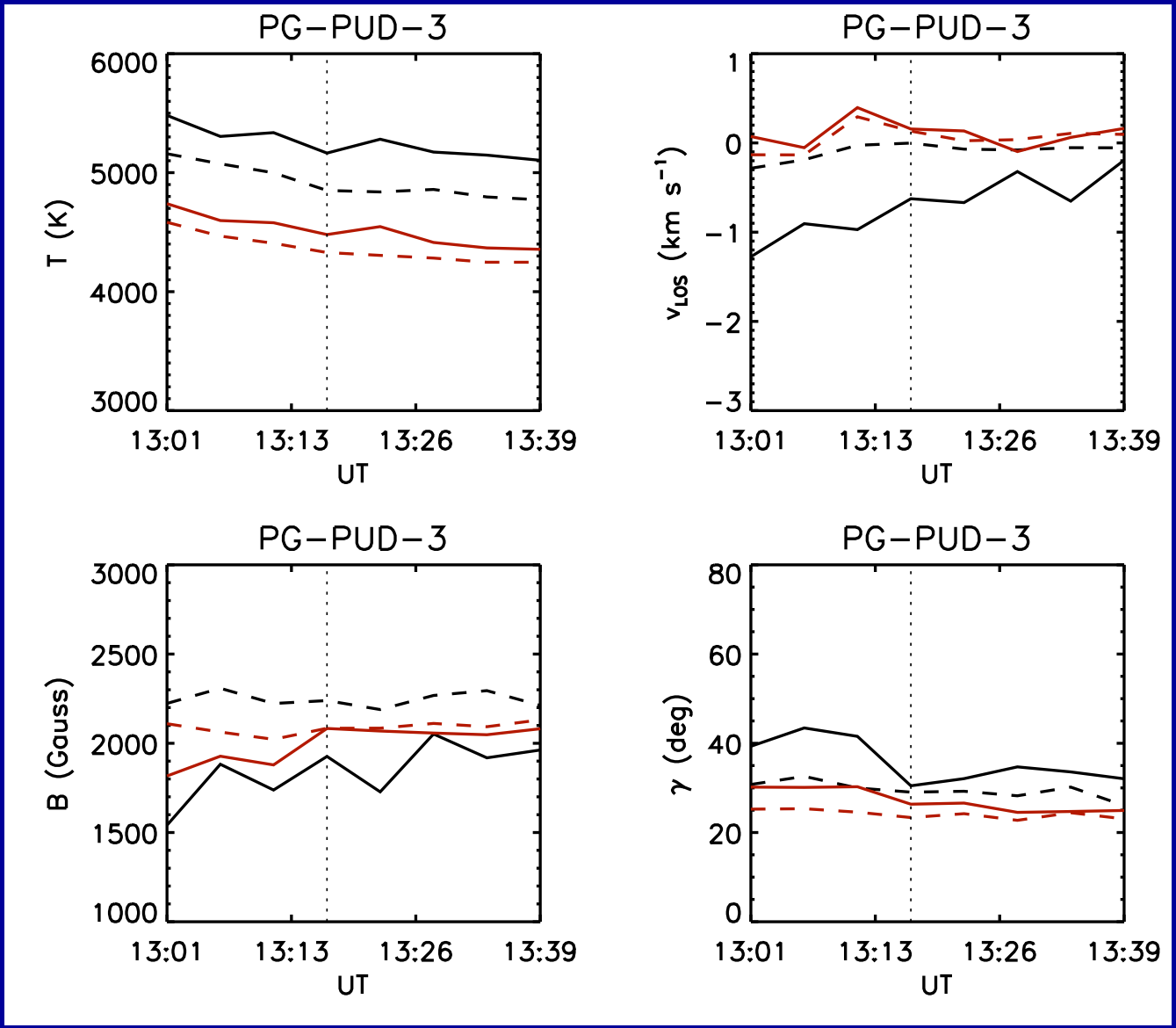


Temporal evolution of T, v_{LOS}, B and inclination peripheral umbral dot

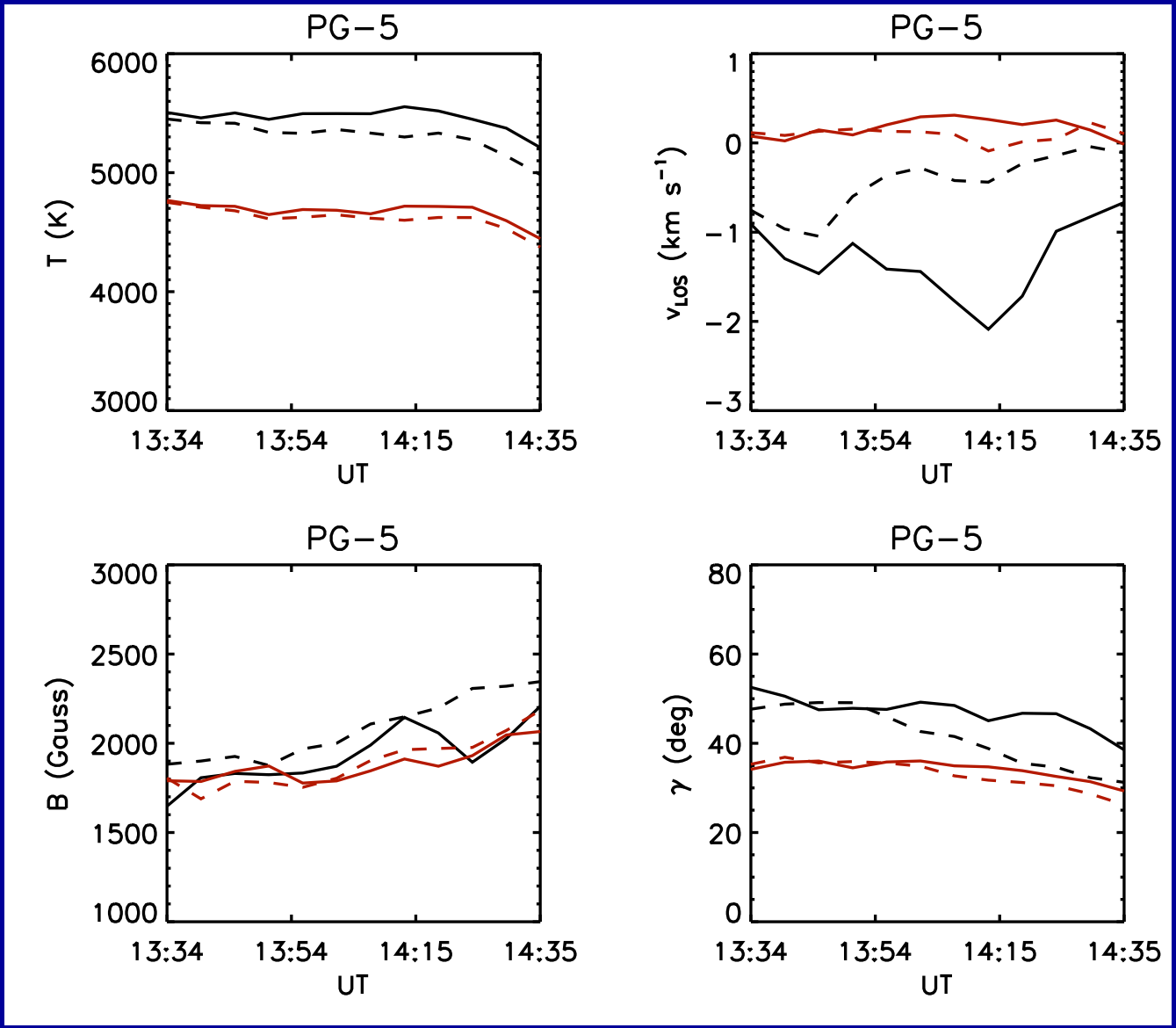


Temporal evolution of T, v_{LOS}, B and inclination

penumbral grain → peripheral umbral dot



Temporal evolution of T, v_{LOS}, B and inclination
penumbral grain



Average values of physical parameters in the low (high) photosphere for all observed CUDs, PUDs and PGs

negative values of Δv_{LOS} correspond to upflows

	size	v_{HOR} (km/s)	ΔT (K)	Δv_{LOS} (km/s)	ΔB (G)	$\Delta\gamma$ (deg)
CUDs	0".30	< 0.10	240 (60)	+0.05 (-0.04)	-100 (-50)	1 (2)
PUDs	0".35	0.39	400 (180)	-0.42 (-0.05)	-200 (-60)	6 (3)
PGs	0".42	0.38	390 (200)	-1.23 (+0.20)	-400 (-60)	10 (3)

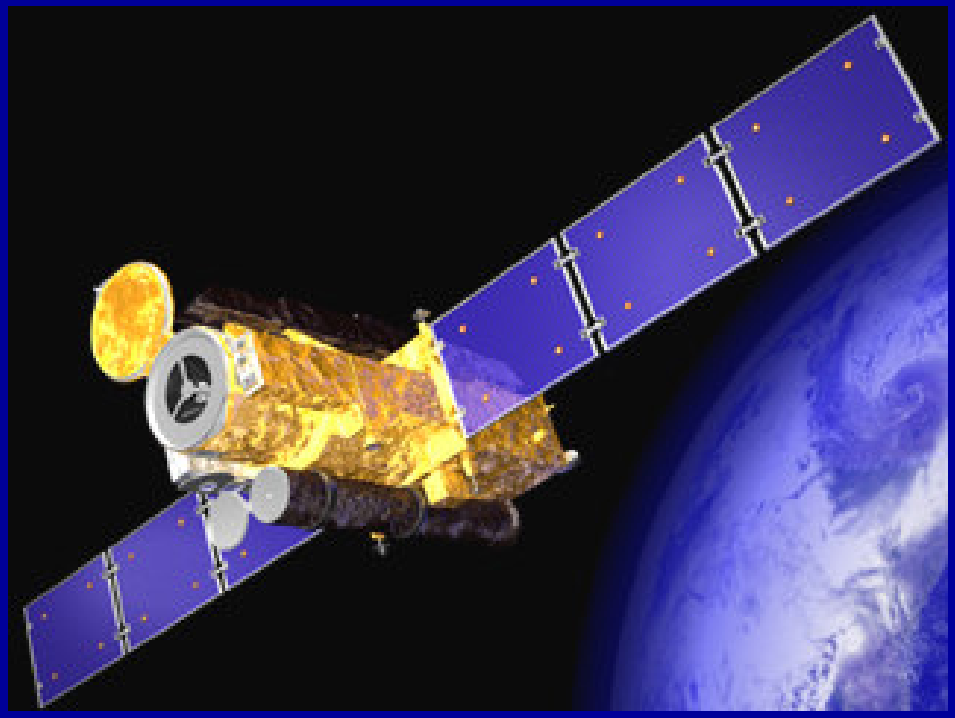
Summary

1. **All features:** enhanced T and reduced B, mainly in low photosphere (CUDs – minimum differences).
2. **CUDs:** no LOS motions and mag. field inclination enhancement compared to their surroundings.
3. **PUDs:** significant upflows and more horizontal mag. field than in the surrounding umbra – in low photosphere; horizontal speed similar to PGs.
4. **PGs:** stronger upflows and more inclined mag. field (compared to the surroundings) than in PUDs – – in low photosphere.
5. **During the evolution of PGs into PUDs**, upflows and inclination decrease gradually or with a jump at the time of detachment from a penumbral filament.

Discussion

1. Concerning the LOS velocities and field inclination, **PUDs are more similar to PGs than to CUDs**.
2. CUDs are formed in a stronger and more vertical mag. field than PUDs and they are located deeper – at the continuum formation level and below, so that upflows cannot be detected (Riethmüller et al. 2008).
3. PUDs are formed near the penumbra in a weaker and more inclined mag. field; they are located higher than CUDs and the upflowing plasma reaches low photospheric layers. Their horizontal motions are probably connected with the inclined mag. field, what is predicted by the simulations (Rempel et al. 2008).

Thank you for attention



HINODE is a Japanese mission developed and launched by ISAS/Jaxa, with NAOJ as domestic partner and NASA and STFC (UK) as international partners. It is operated by these agencies in co-operation with ESA and NSC (Norway).