LECTURE – 1

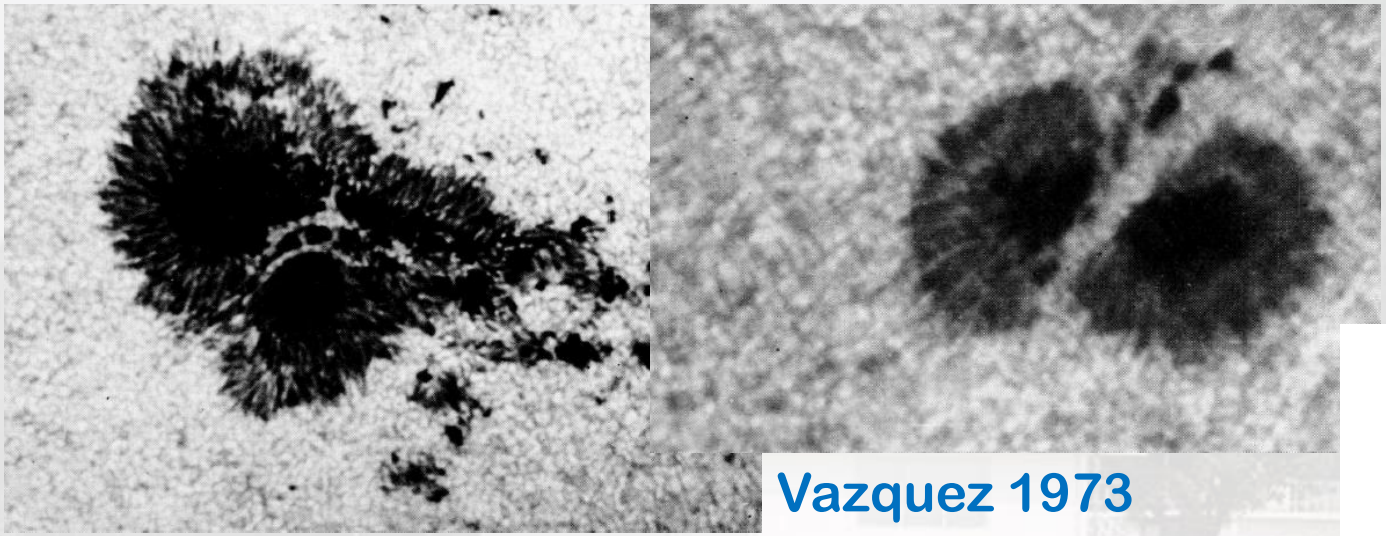
SUNSPOT LIGHT BRIDGES – Morphology & Magnetic Properties

Rohan Eugene Louis

OVERVIEW

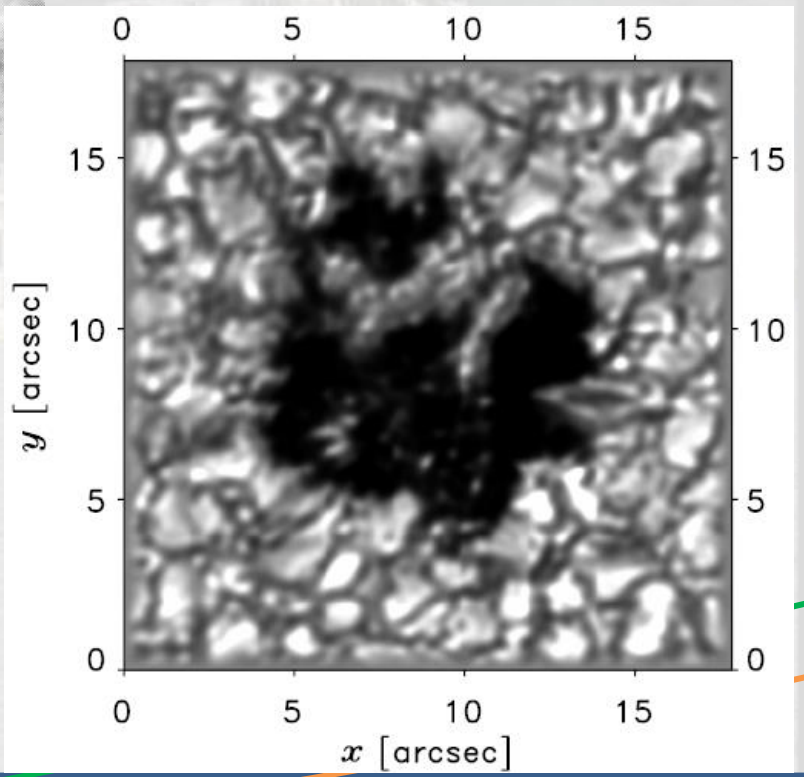
- Photospheric Morphology
- Fine Structure
- Evolution
- Plasma Motions
- Magnetic Field Properties

MORPHOLOGY OF LBs



Vazquez 1973

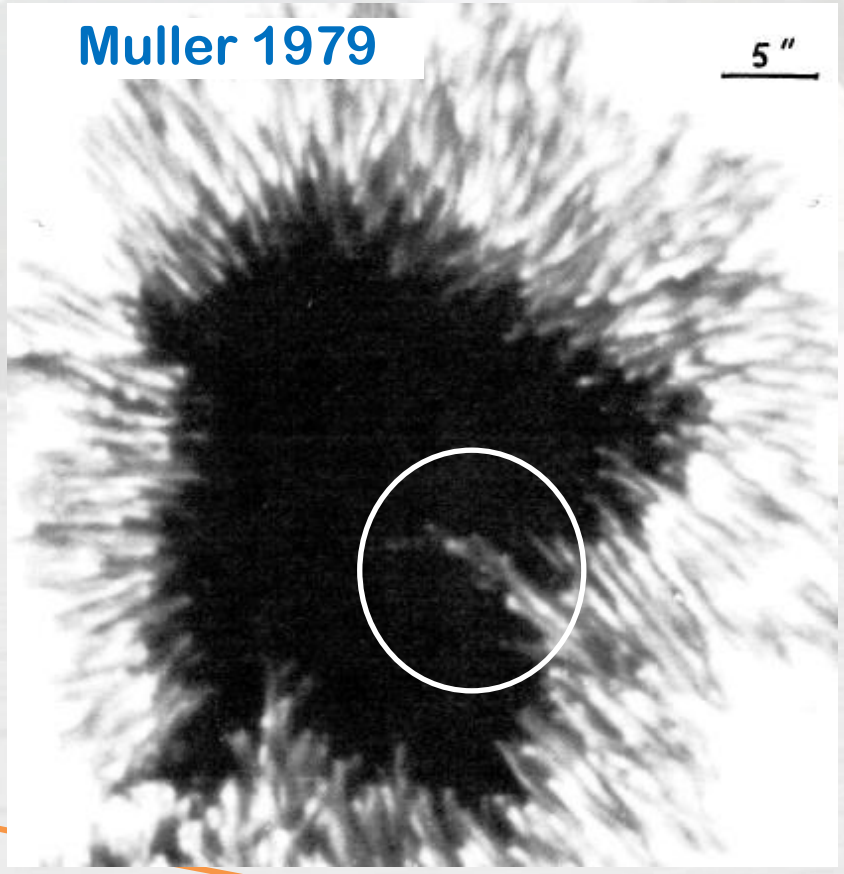
Sobotka et al. 1999

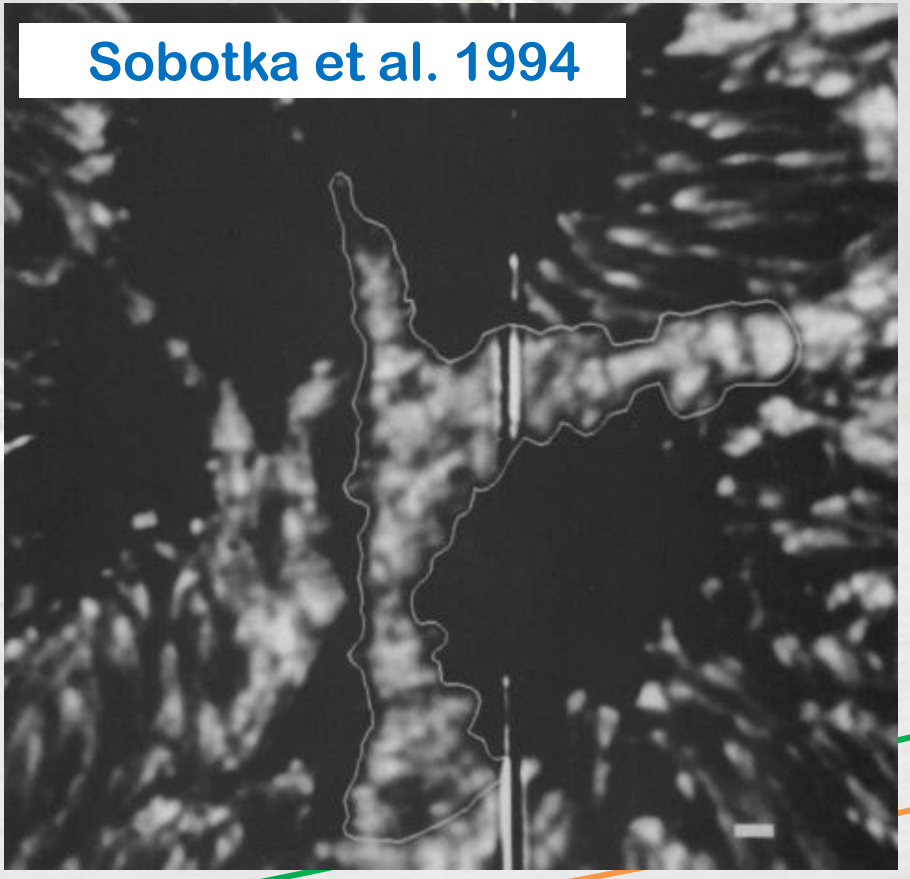


- Bright elongated structures appear in umbra of pores & sunspots
- Earliest obs. of LBs by Bray & Loughhead (1964)
- Tend to be seen during formation/fragmentation of sunspots

MORPHOLOGY OF LBs

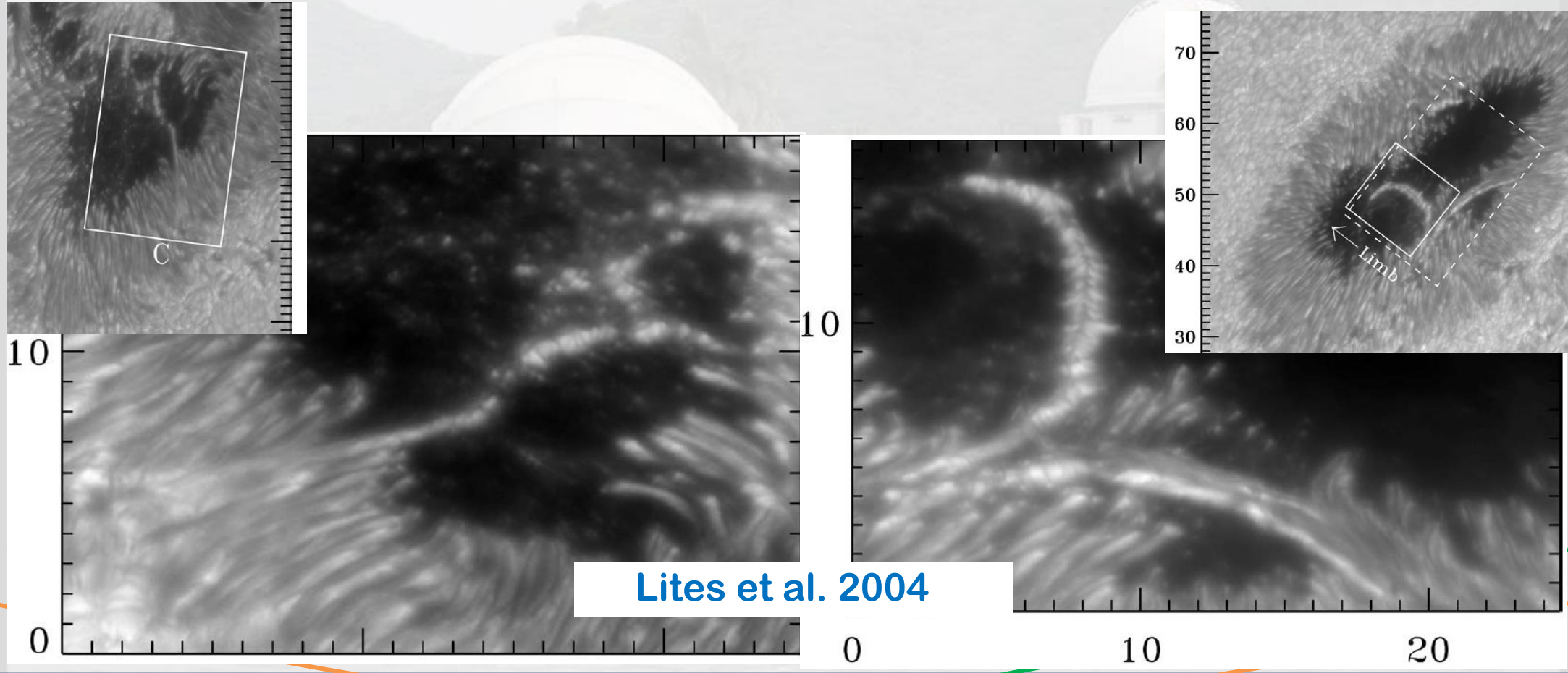
- Can appear as extension of penumbra filament
- Fine structure in broad/strong LBs (granular) show bright cells with dark lanes





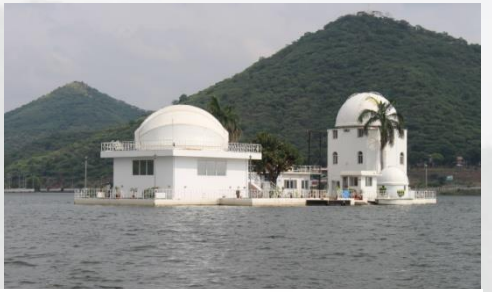
FINE STRUCTURE OF LBs

- Introduction of Adaptive Optics revealed plethora of small-scale features

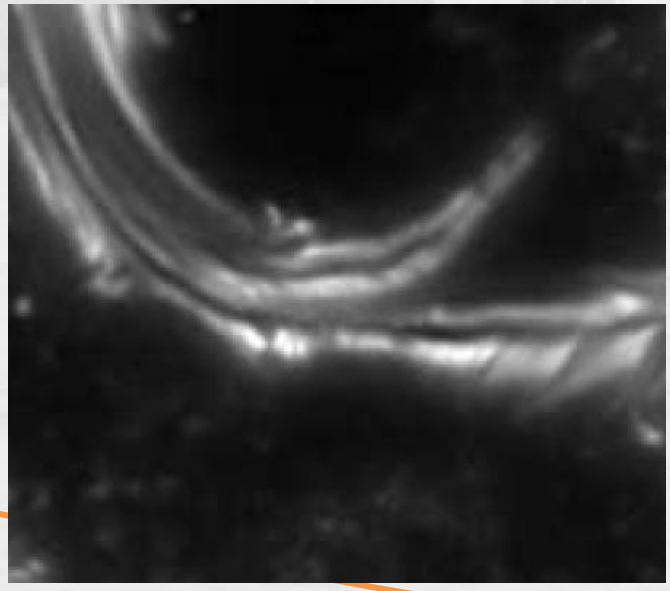


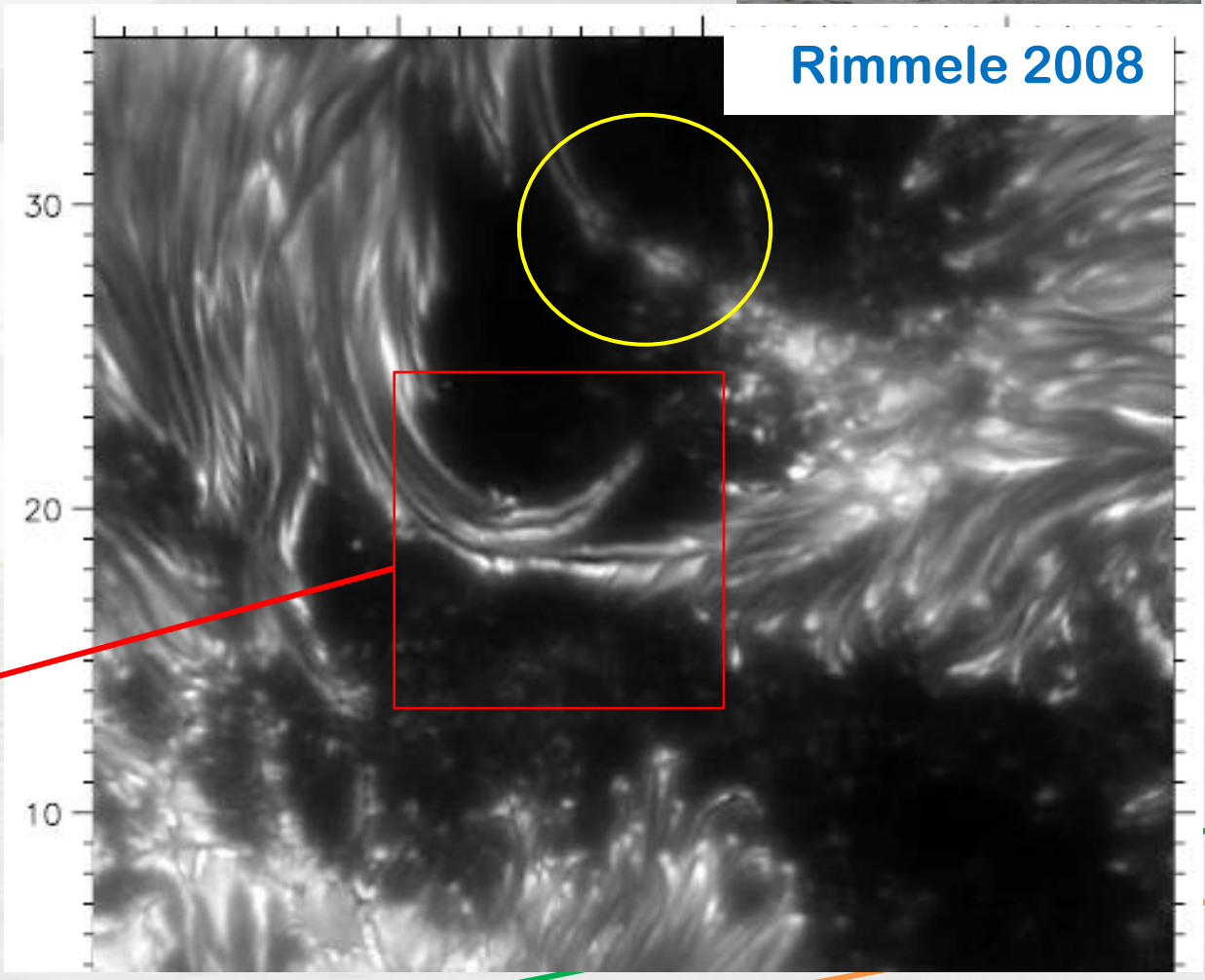
Lites et al. 2004

FINE STRUCTURE OF LBs

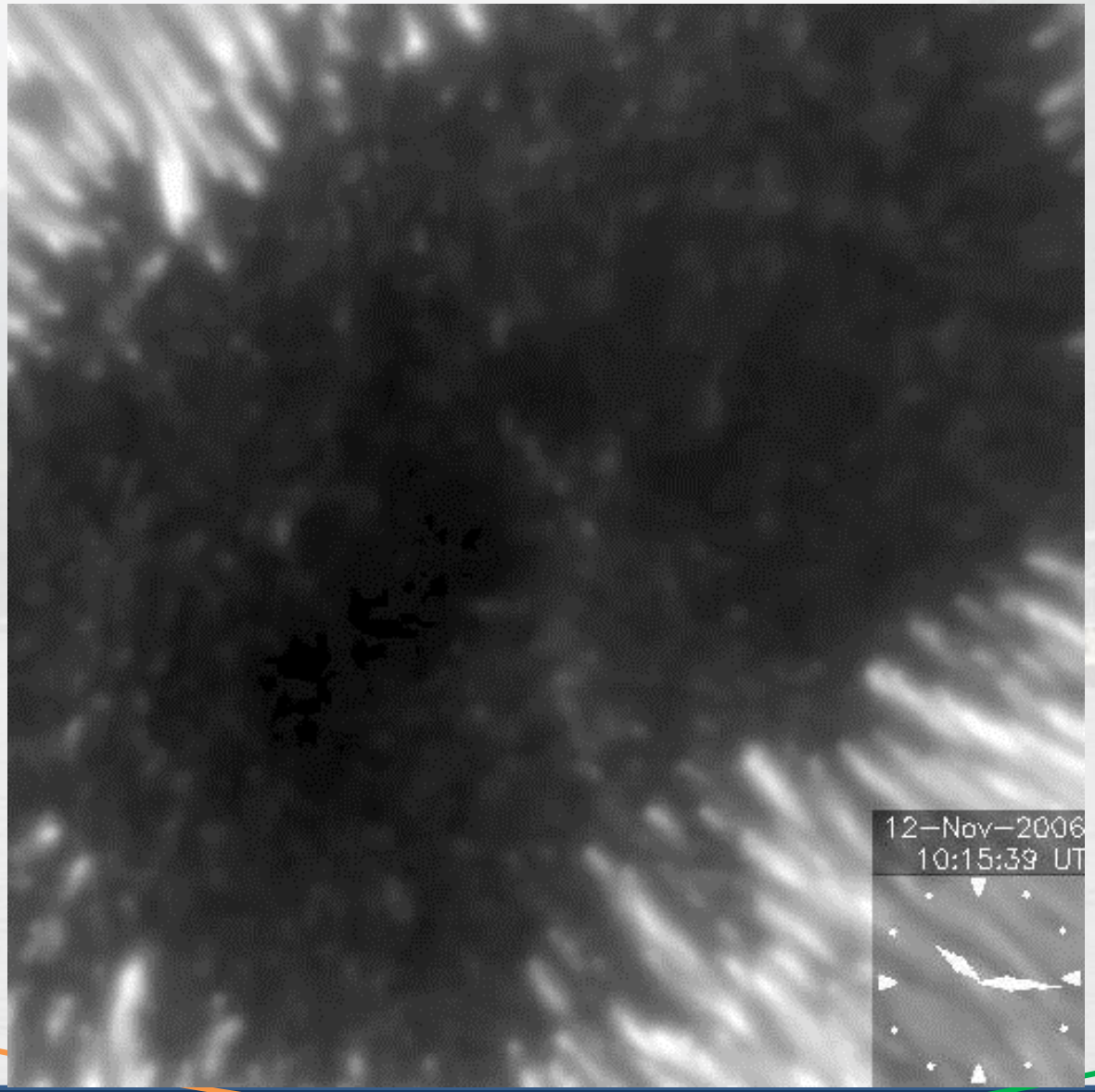


- Morphology of LBs closely associated to UDs & dark-cored penumbral filaments
- Existence of barb-like features in penumbral LBs





FORMATION OF LBs



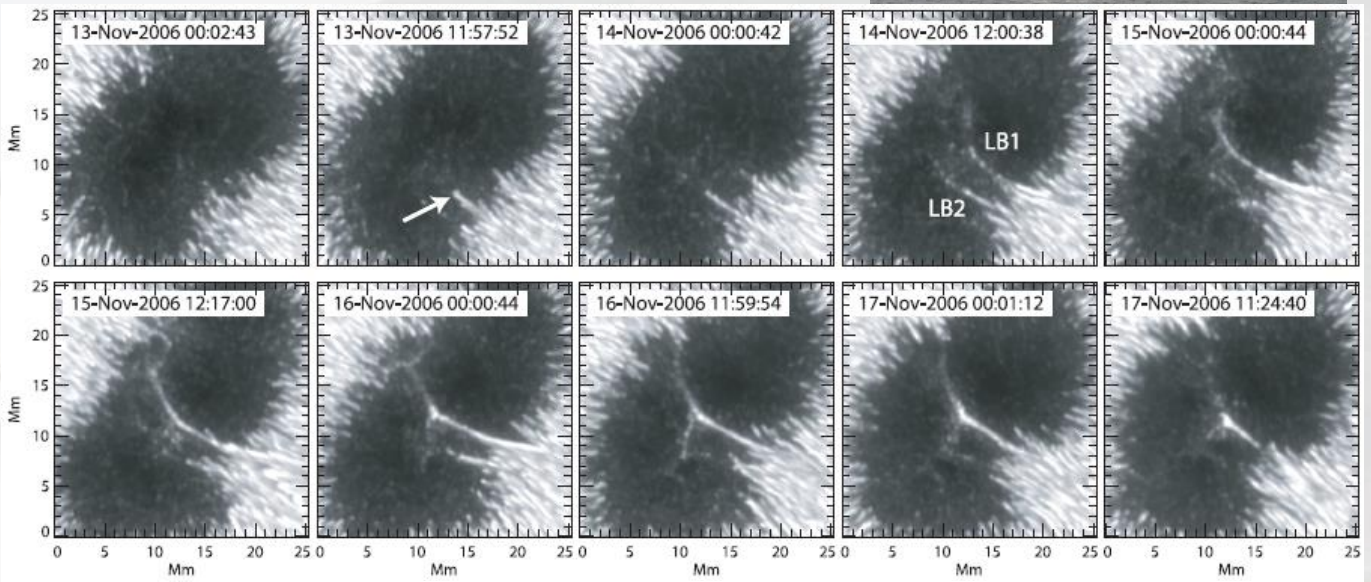
- Obs. from Hinode
- 50 cm space telescope
- Stable, seeing-free
- 5 days of obs.

Katsukawa et al. 2007

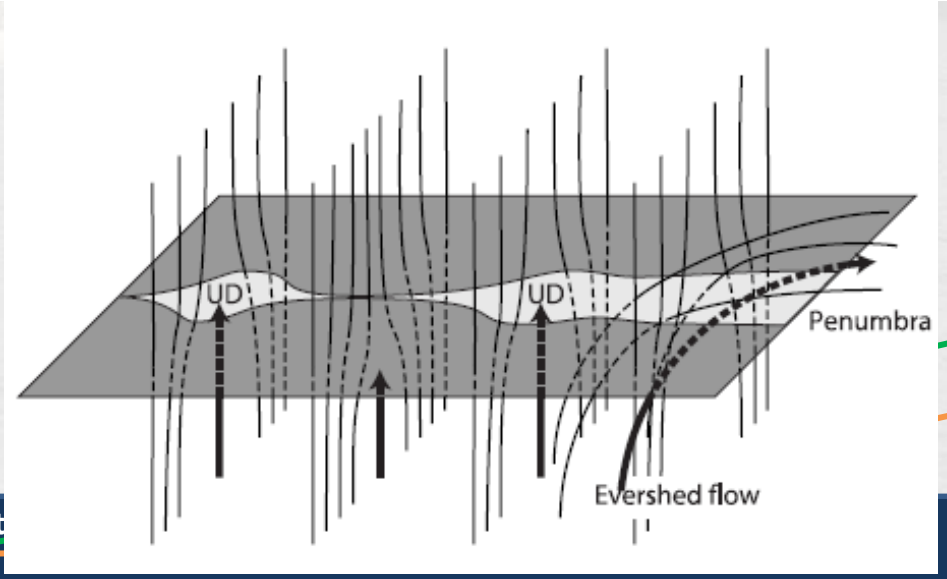
FORMATION OF LBs

Katsukawa et al. 2007

- Relatively slow inward motion of UDs well inside umbra
- Formation accompanied by motion of UDs from leading edges of penumbra filaments



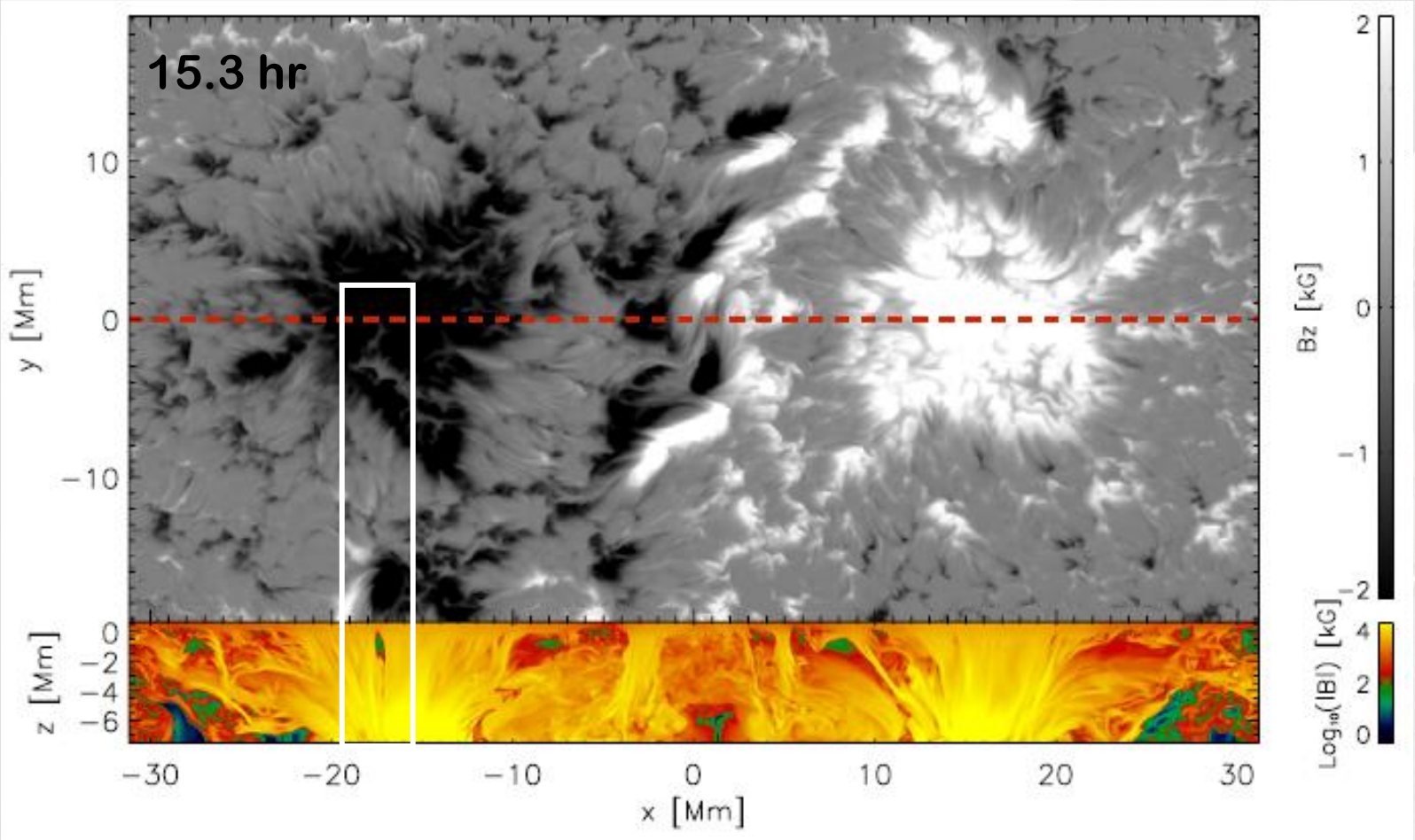
- Presence of UDs deep in umbral core signifies convective penetration & weakening of umbral magnetic field
- Once the field is sufficiently reduced, LB formation occurs by incursion of penumbral filaments



FORMATION OF LBs

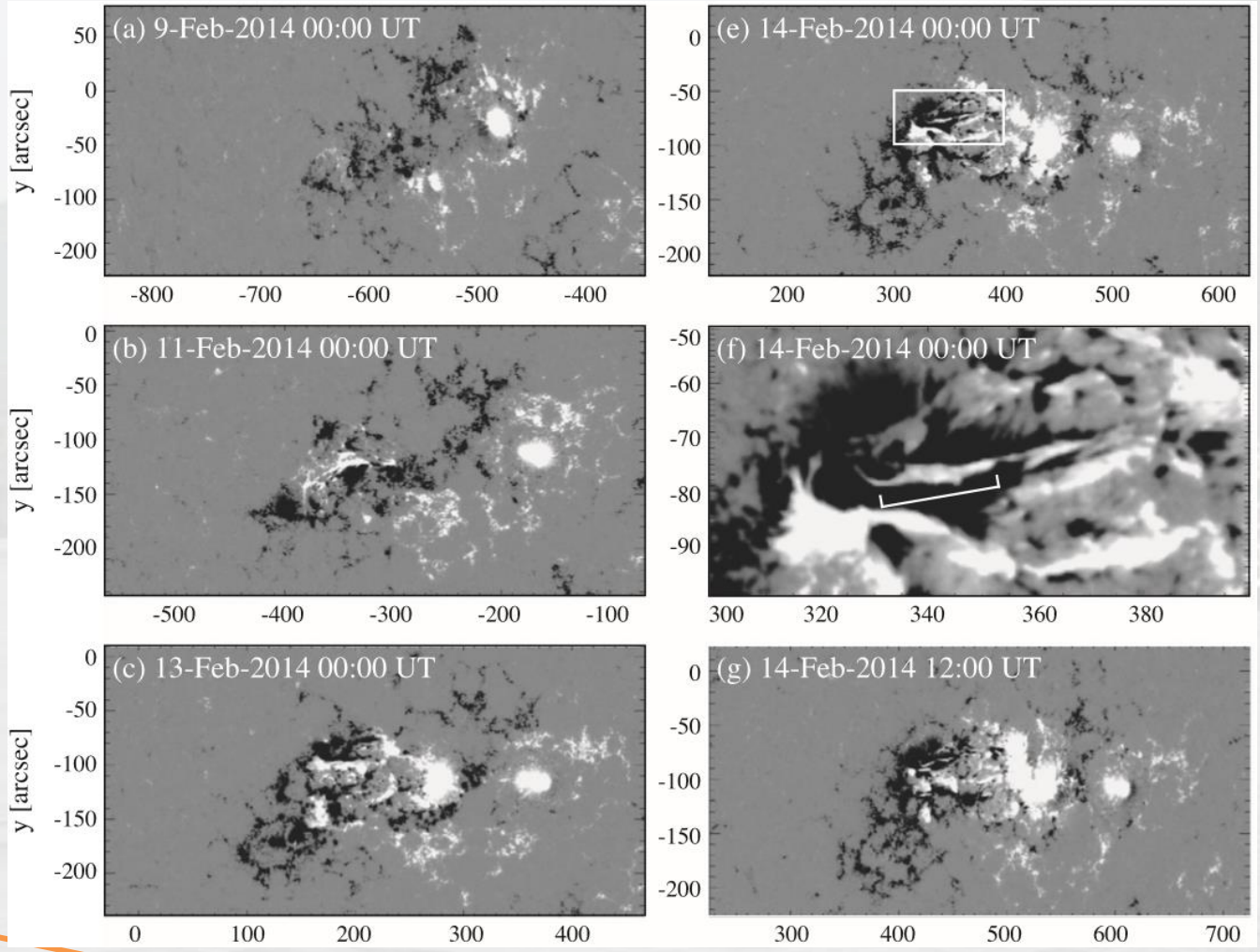
Cheung et al. 2010

MHD simulations of AR formation using MURaM



- LB develops with weakly magnetised plasma getting squeezed by coalescence of magnetic fragments to form bipolar magnetic structure/spot

FORMATION OF LBs

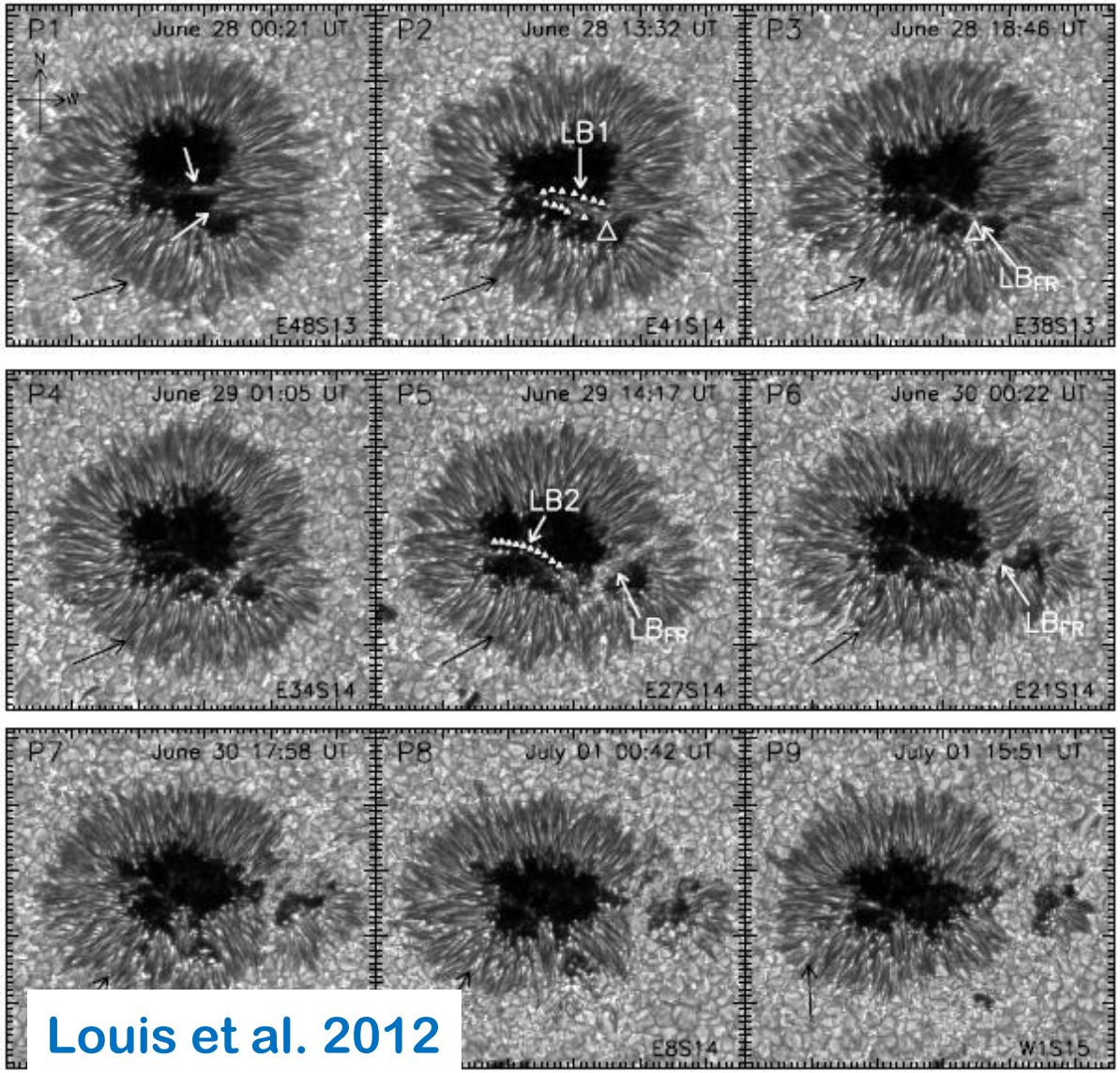


- LB formation in complex AR as shown in MHD simulations
- LB is large area comprising upflows sandwiched by emerging magnetic polarities

Toriumi et al. 2015

EVOLUTION OF LBs

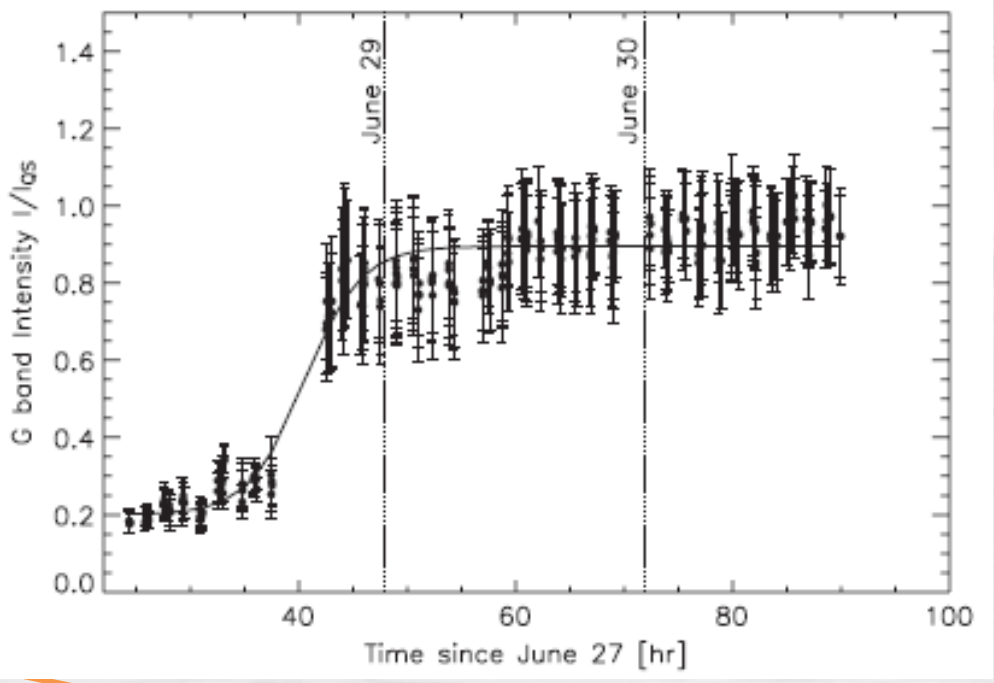
- Evolution of LB from coalescence of UDs → penumbral incursion to granular structure → fragmentation of parent spot
- Several transient LBs form but do not lead to fragmentation
- Area of fragment ~15% of parent
- Umbral area ~6 % of parent
- Fragmentation after 48 hr of LB formation

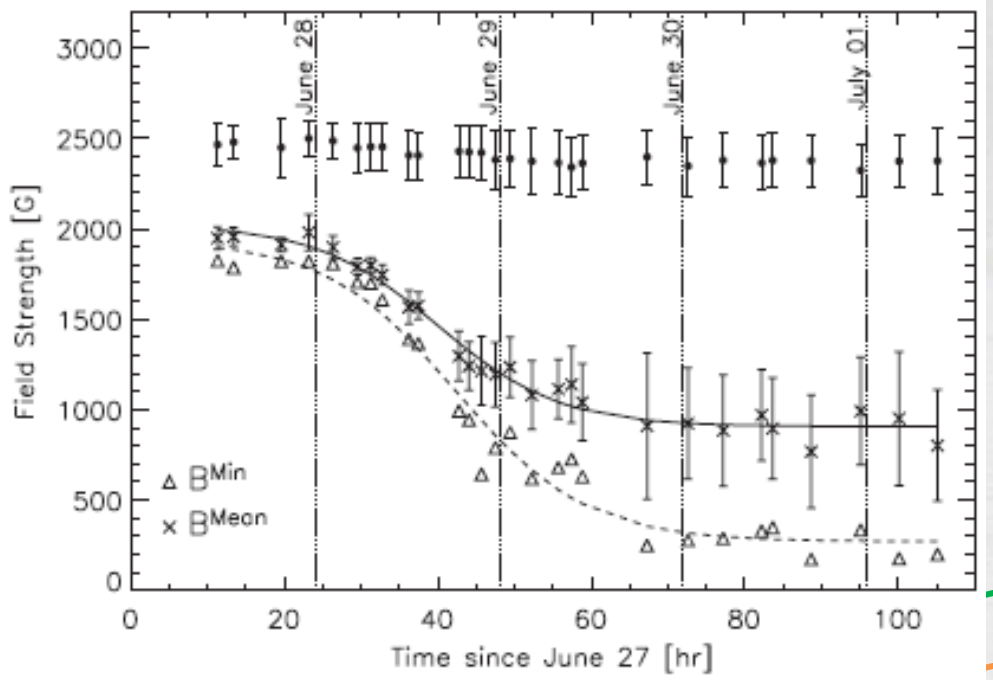


Louis et al. 2012

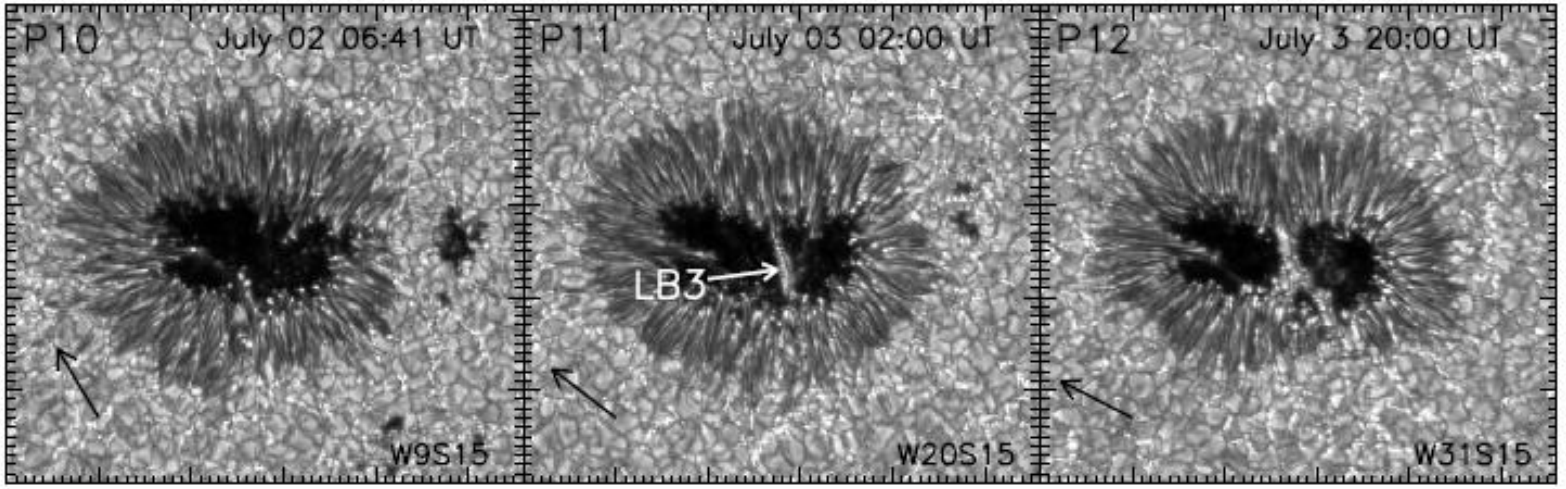
EVOLUTION OF LBs

- Transition from penumbral to granular intensity in about 12 hr
- Associated with reduction in field strength in similar manner

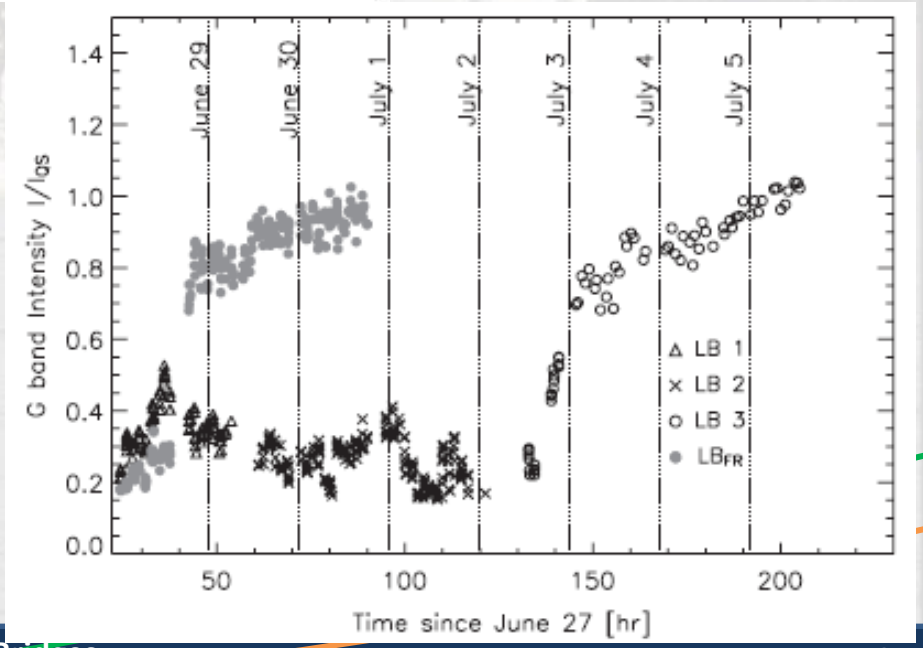




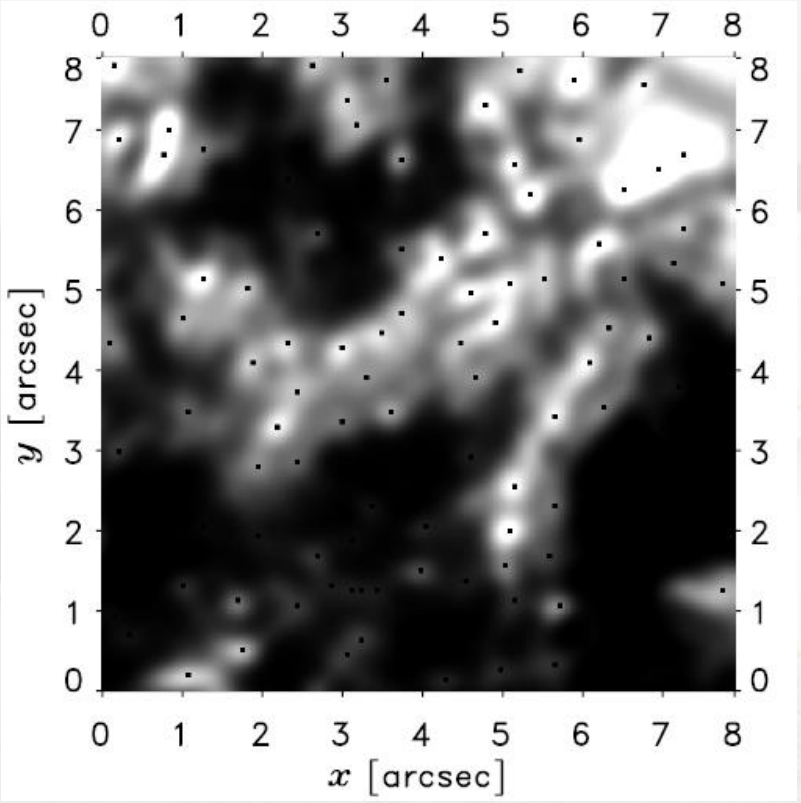
EVOLUTION OF LBs

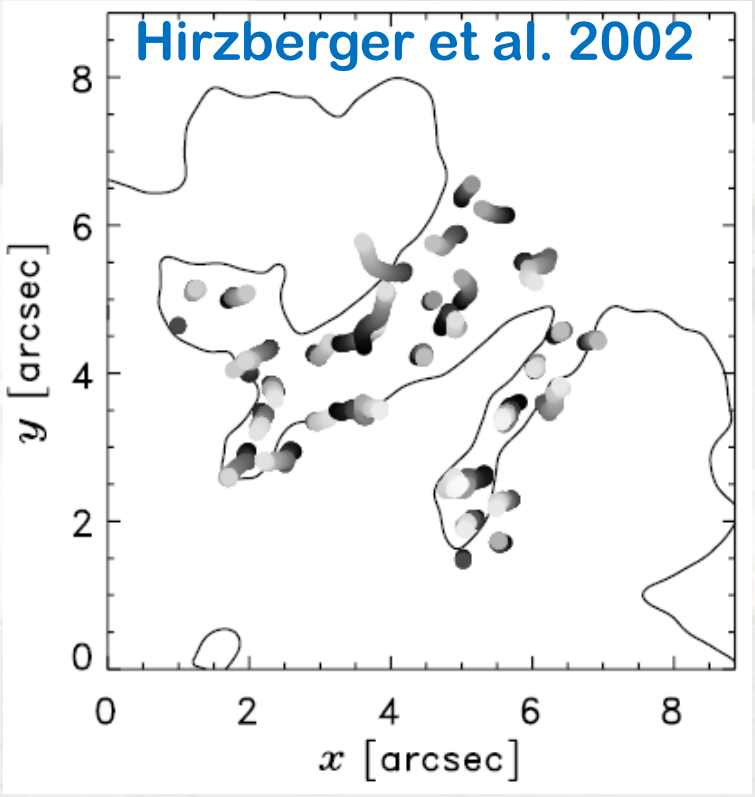


- LBs that develop into granular structures have similar light curves
- However, this is not sufficient condition for spot fragmentation



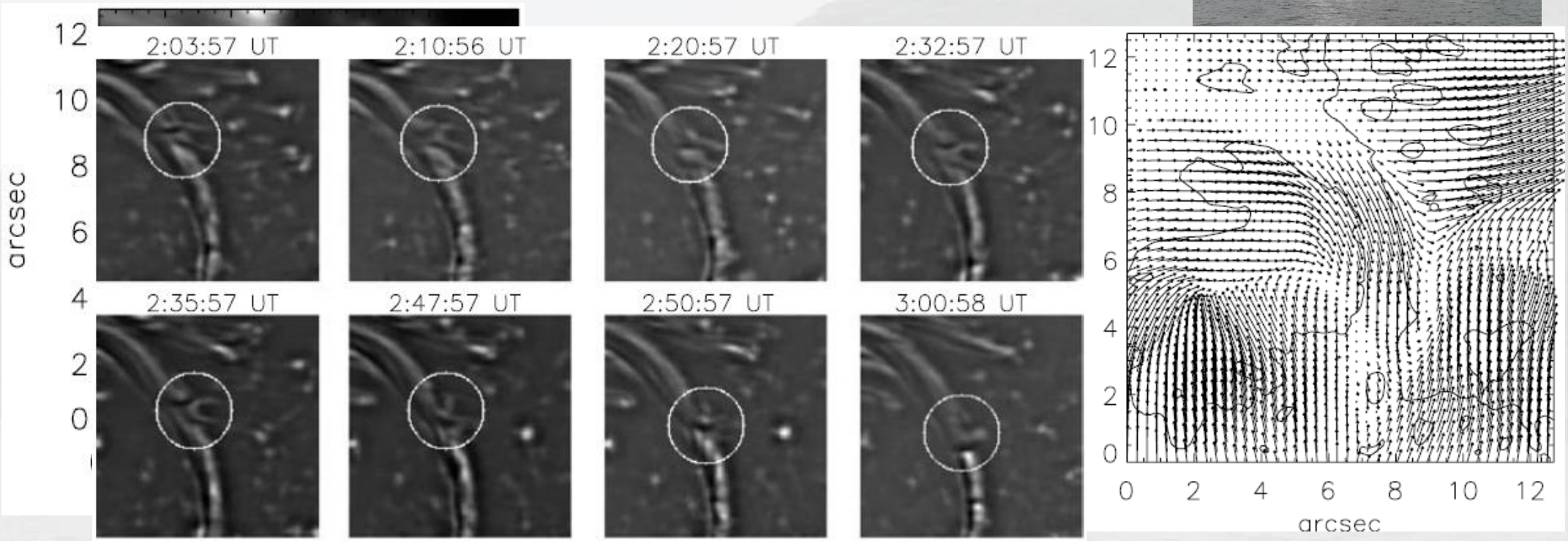
PLASMA MOTIONS IN LBs





- Bright grains with irregular motion of about 0.25 km/s reaching max. of 1km/s
- Lifetime of about 5 min lasting upto 20 min
- Merging, splitting, some moving into umbra becoming indistinguishable from UDs

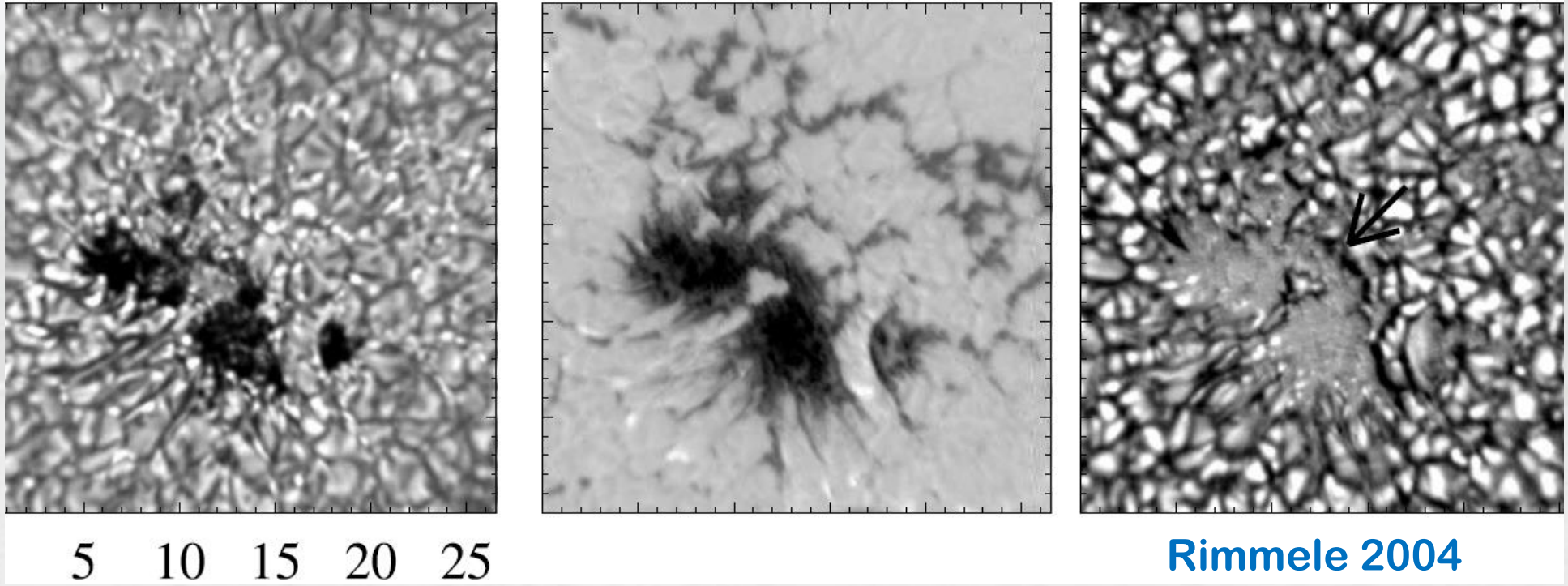
PLASMA MOTIONS IN LBs



Louis et al. 2008

- Small-scale features in penumbral LB exhibit unidirectional motion with significant evolution over 30 min
- Persistent horizontal motion is also unidirectional motion with speeds of about 0.25 km/s

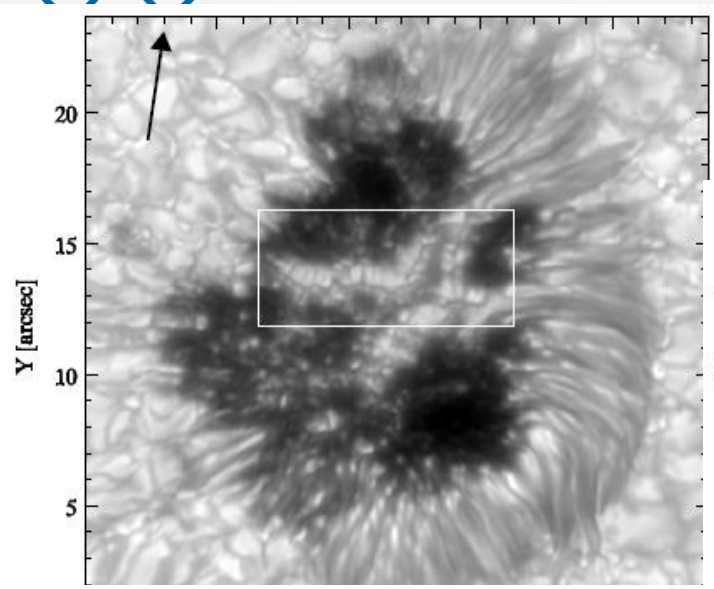
PLASMA MOTIONS IN LBs



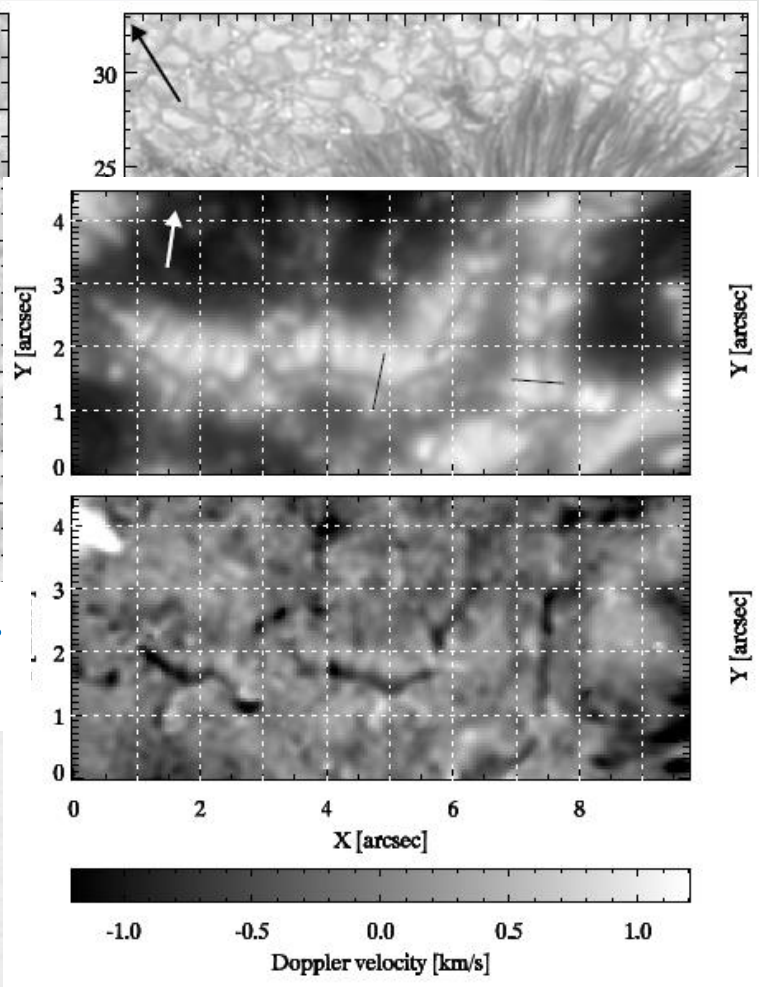
Rimmele 2004

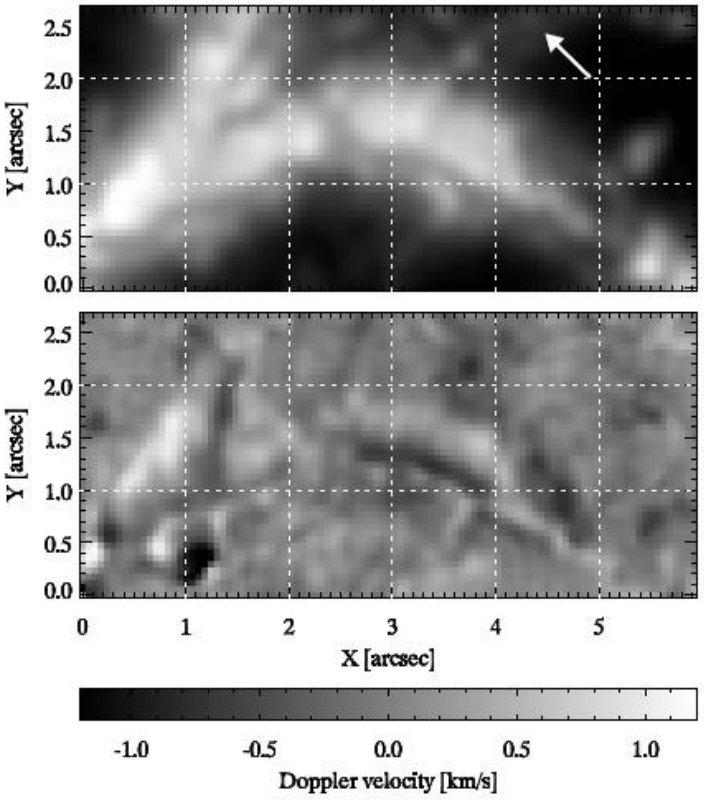
- Bright central structure associated with blueshifts/upflows, edges exhibit downflows along narrow channels
- Reduced line-of-sight magnetic field in LB

PLASMA MOTIONS IN LBs



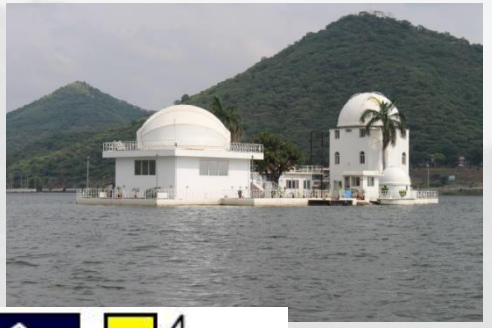
Rouppe van der Voort et al. 2010

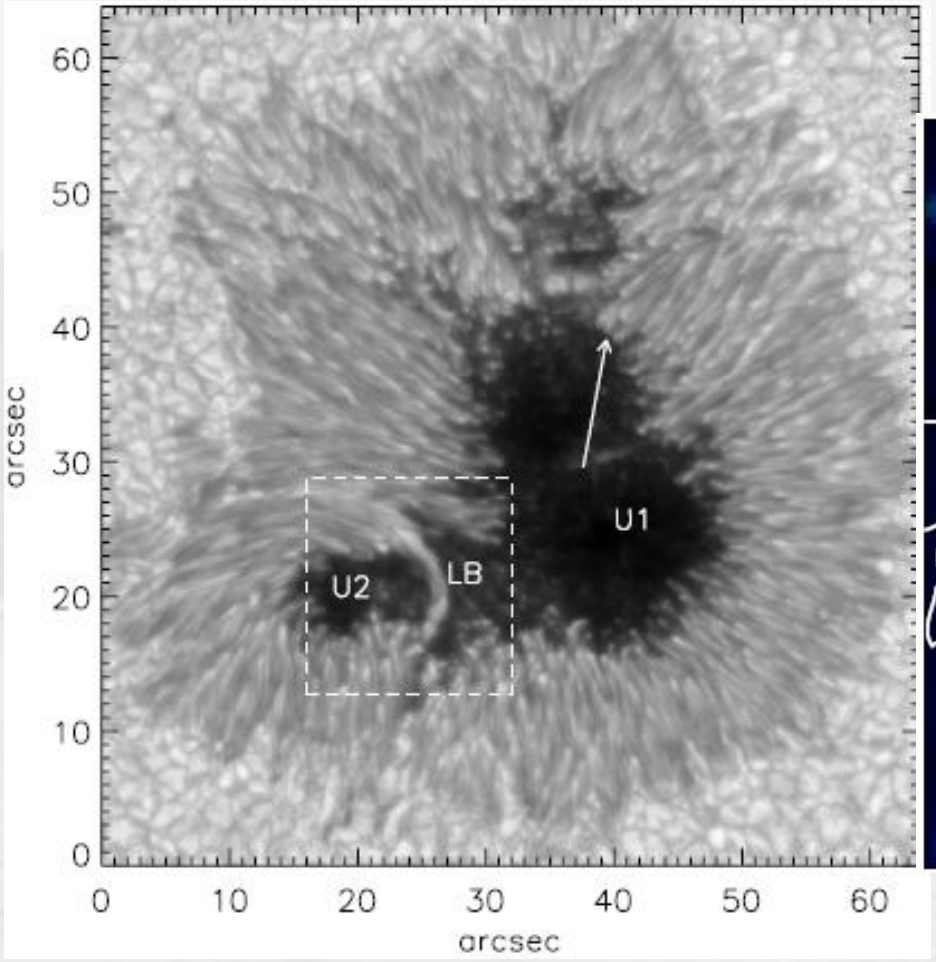


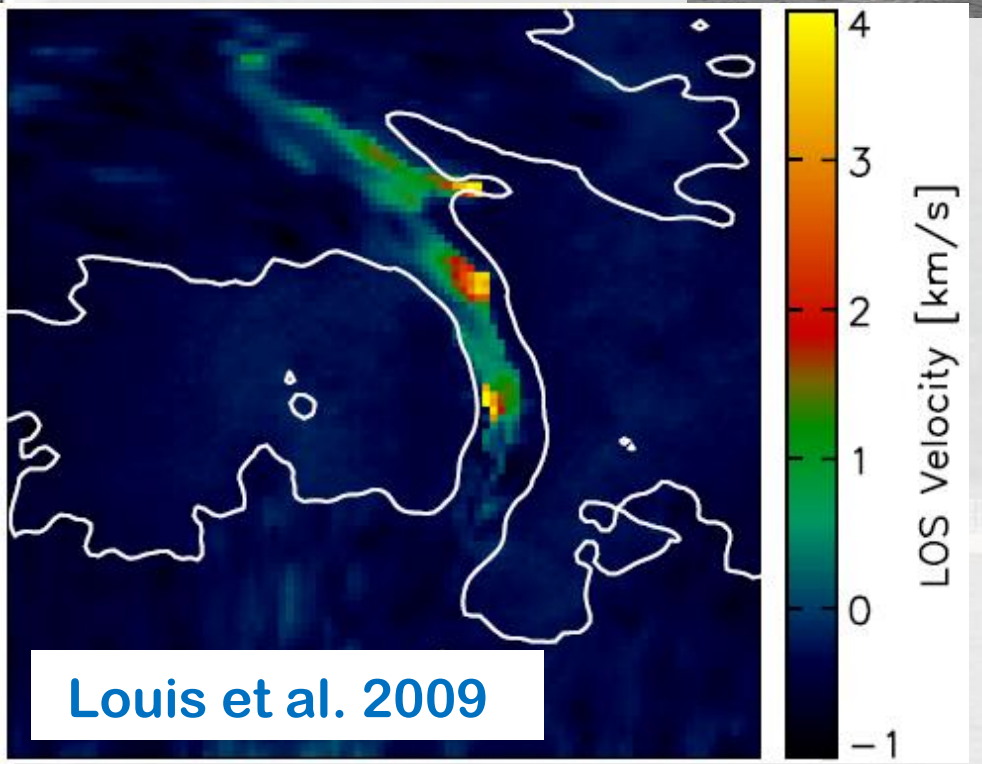


- Upflows of 0.5-1.0 km/s along dark lanes flanked by weaker downflows that are patchy, max. downflows of 1 km/s

PLASMA MOTION IN LBs

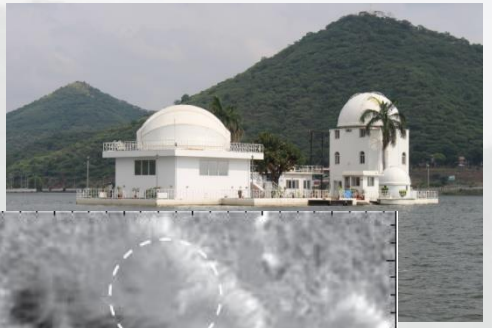


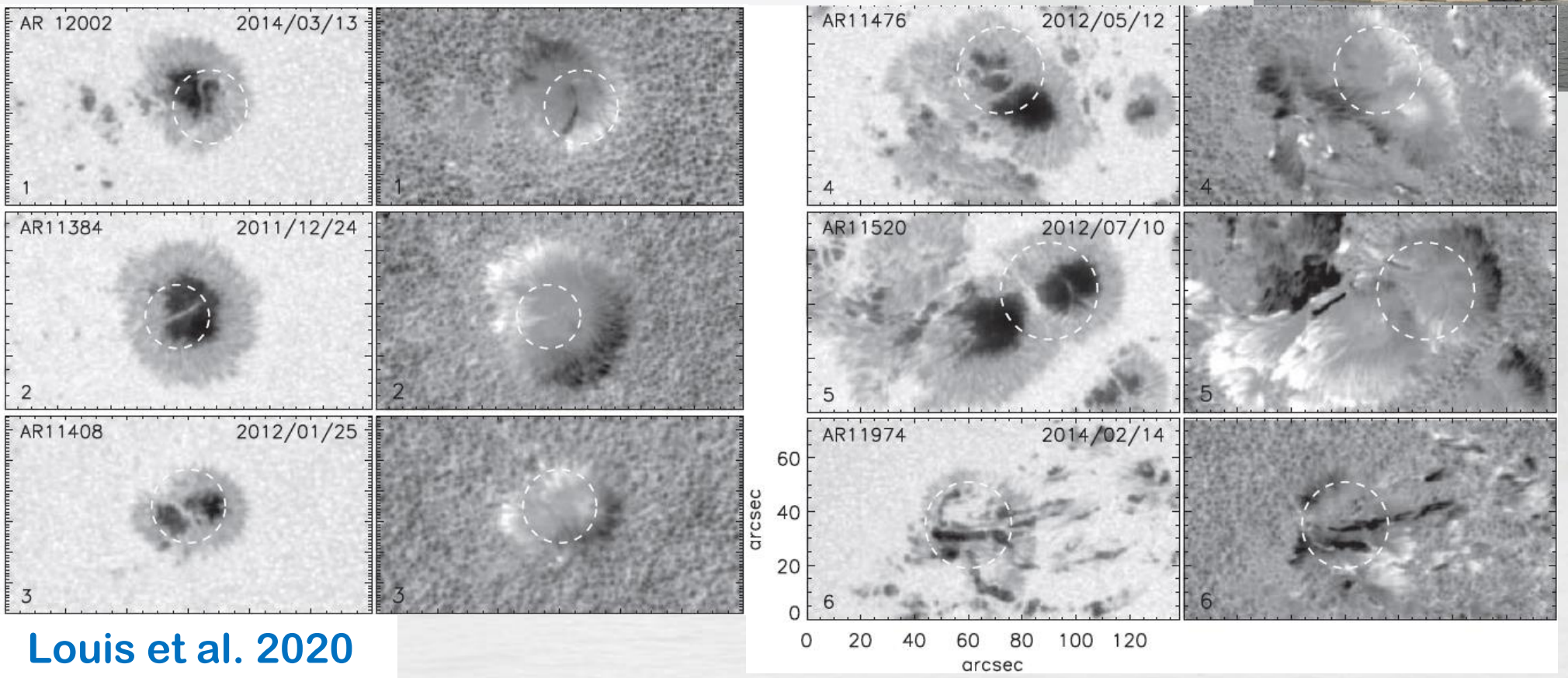




- Localized patches of supersonic downflows in penumbral LB
- Polarity same as the sunspot

PLASMA MOTION IN LBs

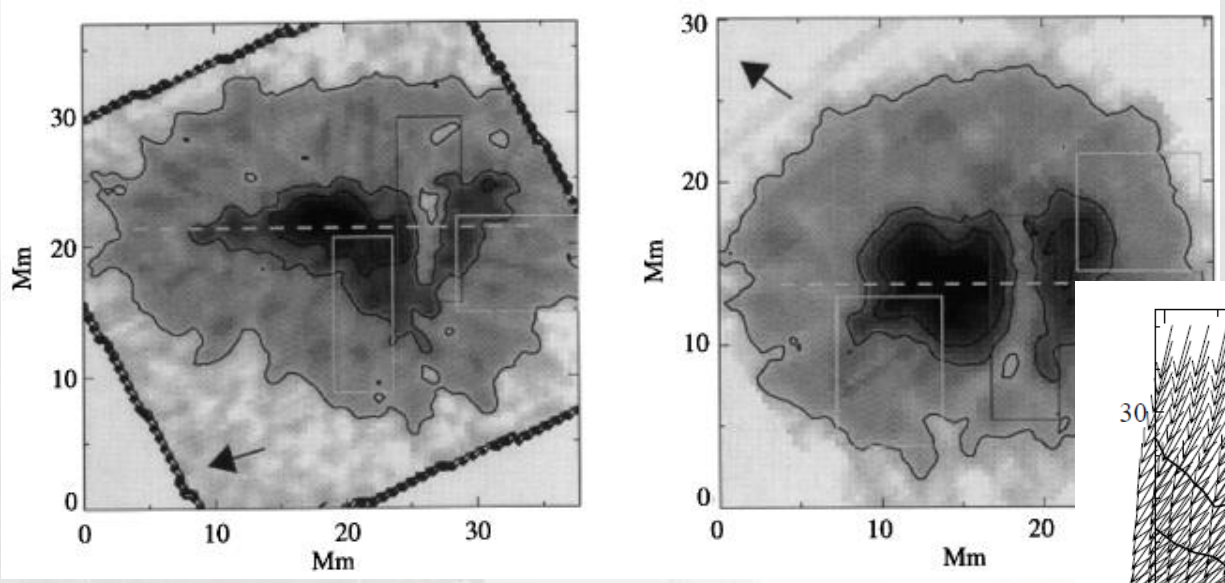




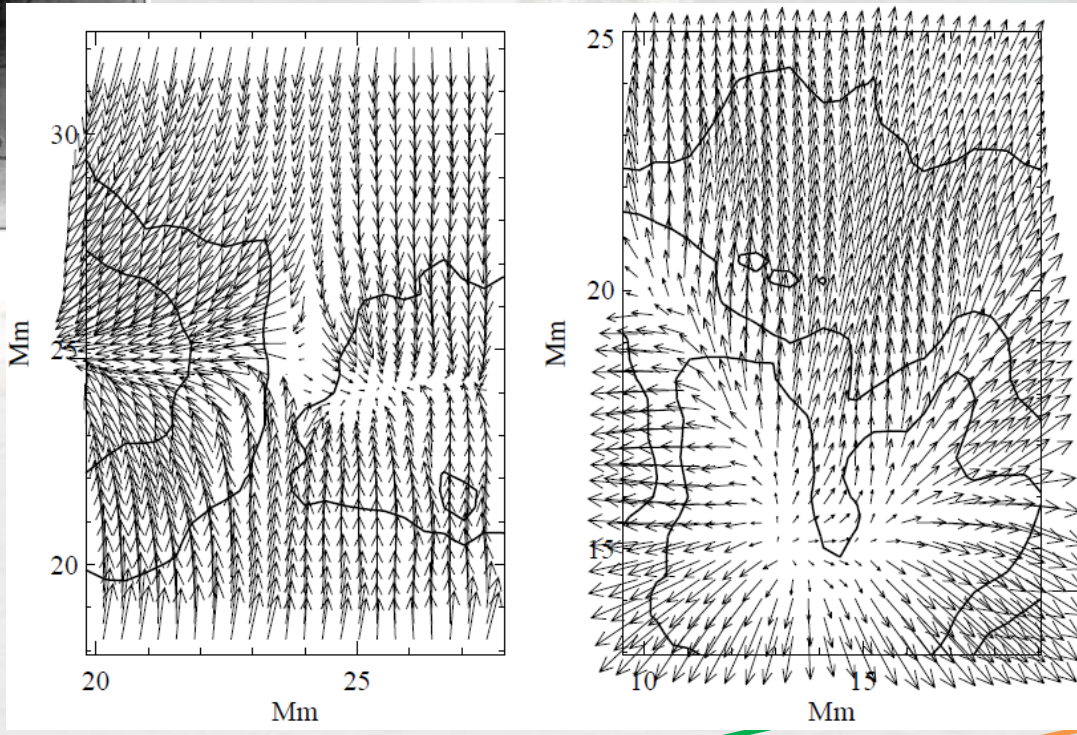
Louis et al. 2020

- Morphologically similar LBs can have diverse plasma flows
- Granular LBs with weak, upflows and downflows, difficult to ascribe general behaviour for penumbral/filamentary LBs

MAGNETIC PROPERTIES OF LBs

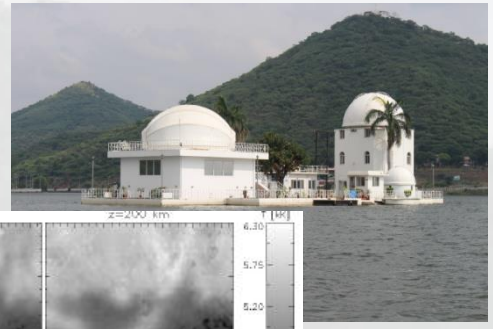


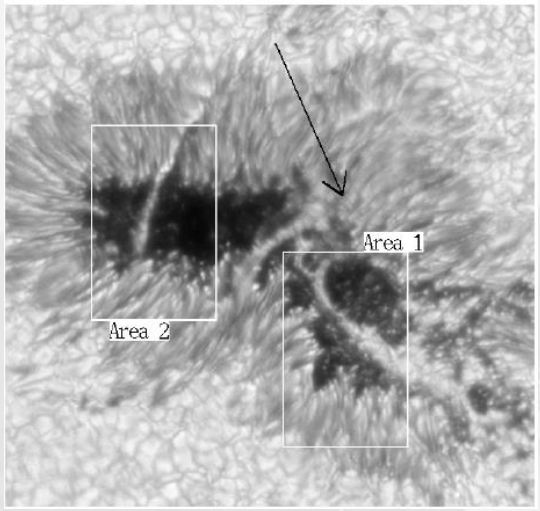
Leka 1997



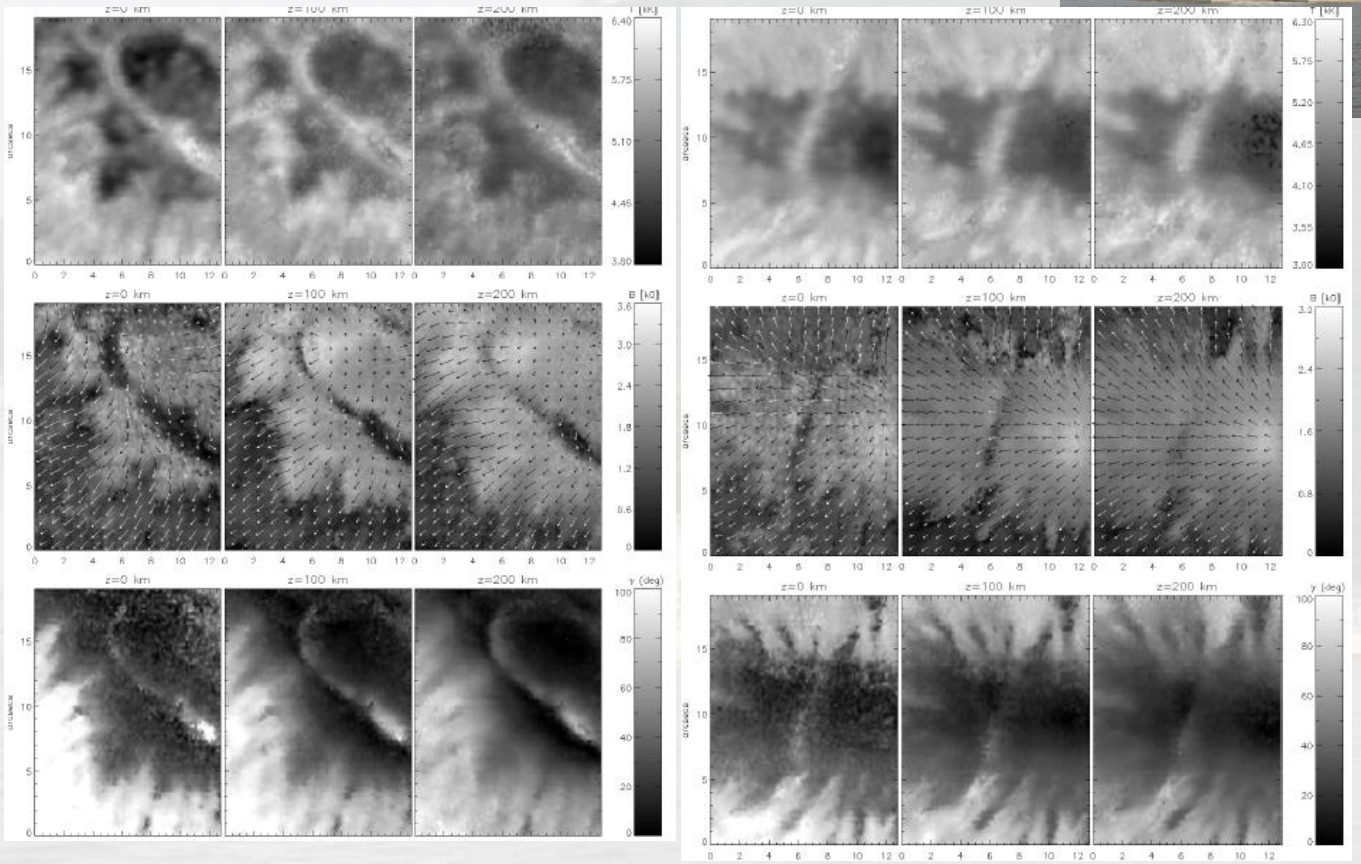
- Full-Stokes polarimetry of 11 sunspot LBs
- ME inversion to derive physical parameters
- LBs have weaker, inclined magnetic fields rel. umbra

MAGNETIC PROPERTIES OF LBs





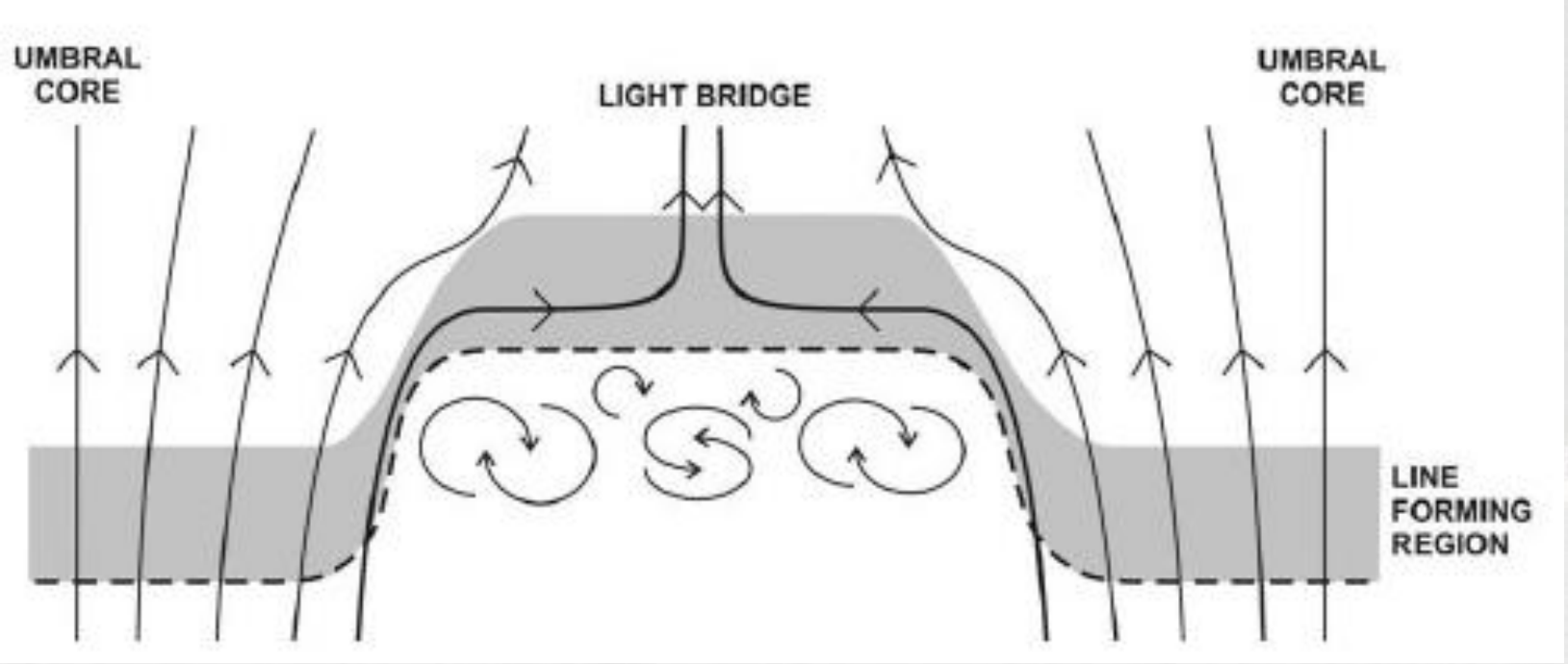
Jurčák et al. 2006



- Inversion of Stokes profiles with SIR for depth-dependent parameters
- Field strength increase with height, inclination becoming rel. vertical
- Temp. enhancements around 100-200 km

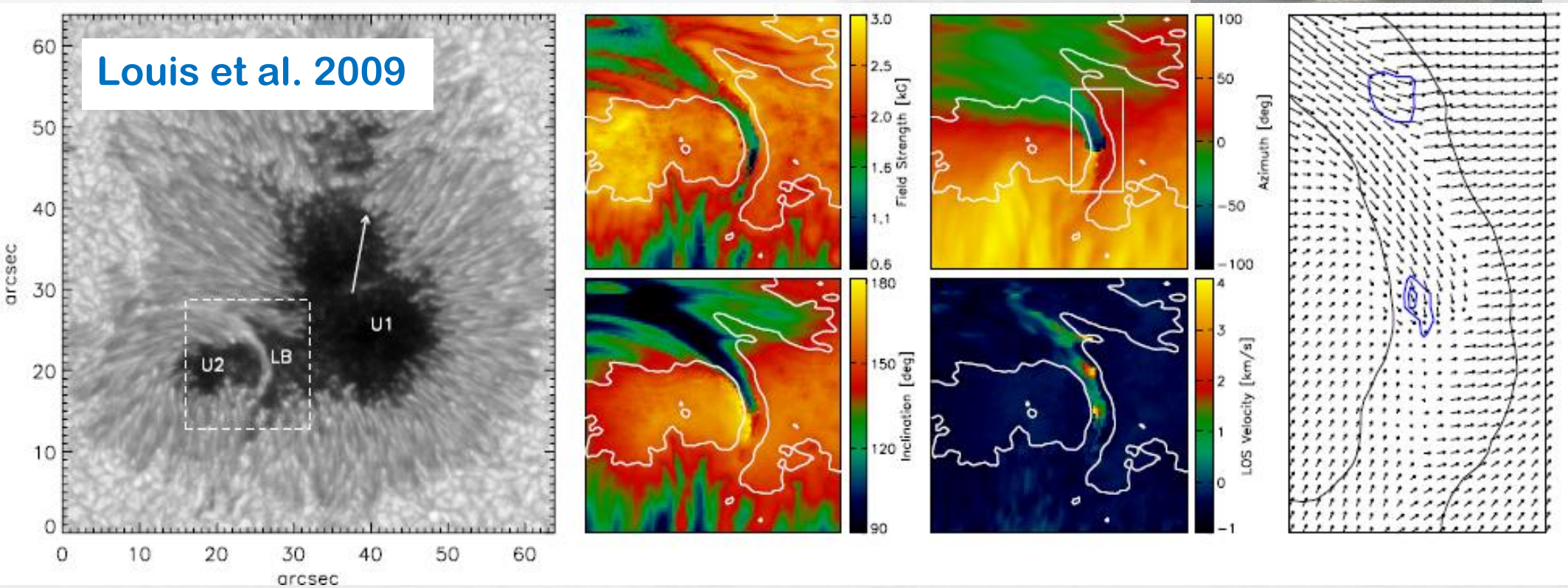
MAGNETIC PROPERTIES OF LBs

Jurčák et al. 2006



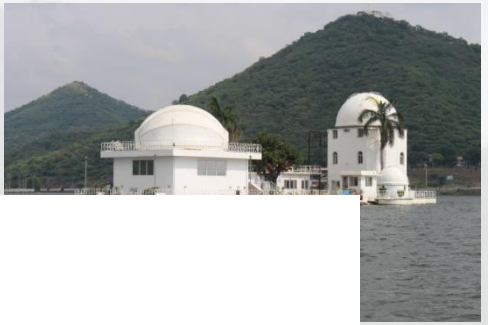
- Magnetic canopy over LB as a result of convective intrusion in sunspot umbra
- Likely to be associated with currents, could drive transients from stressed config.

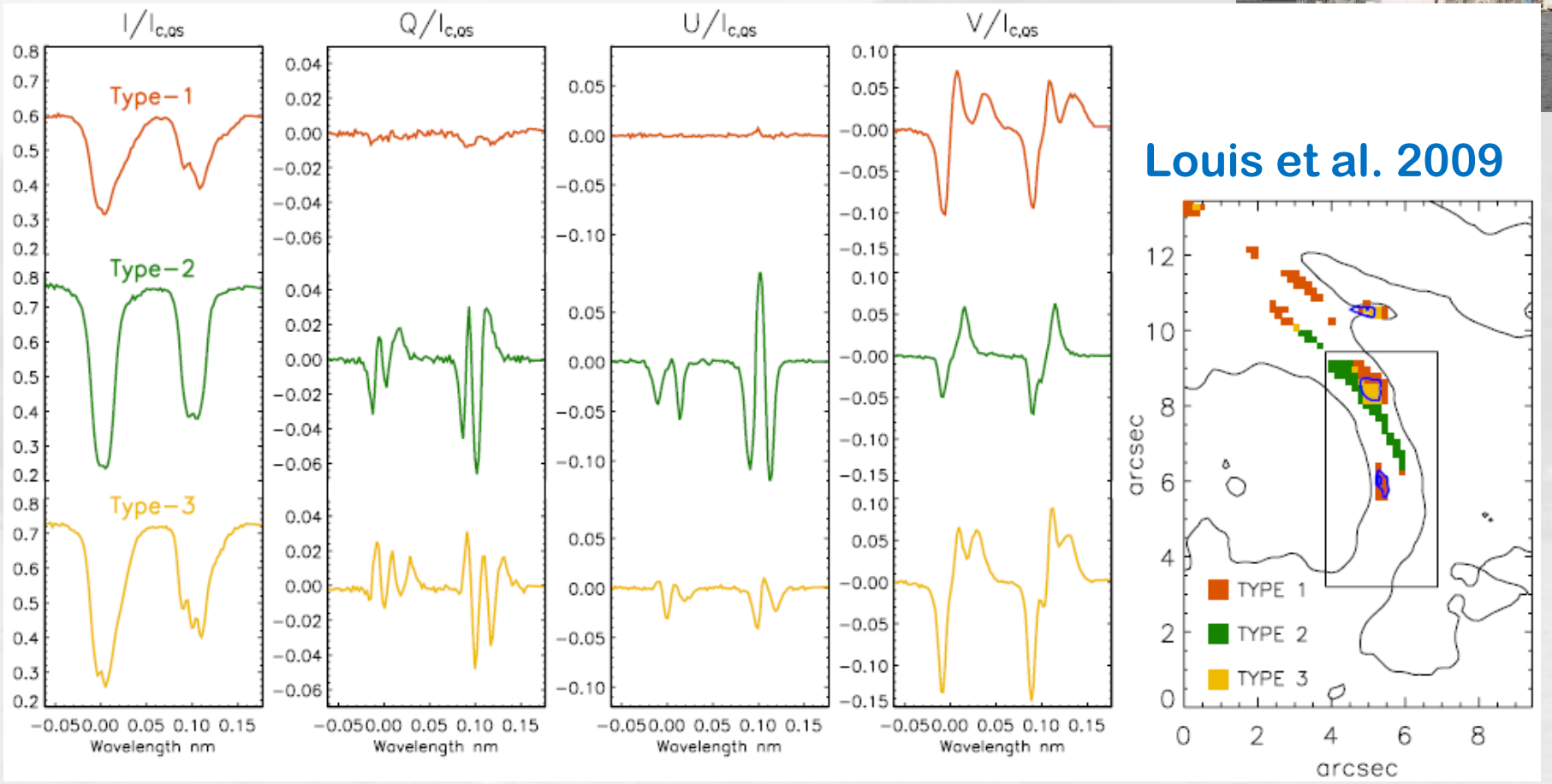
MAGNETIC PROPERTIES OF LBs



- LB appears as extension of penumbra with highly inclined fields with patch of weak fields near southern end, one supersonic downflowing patch close-by
- Horizontal magnetic field aligned with LB axis for most part except for edge closest to umbra where field diverges

MAGNETIC PROPERTIES OF LBs



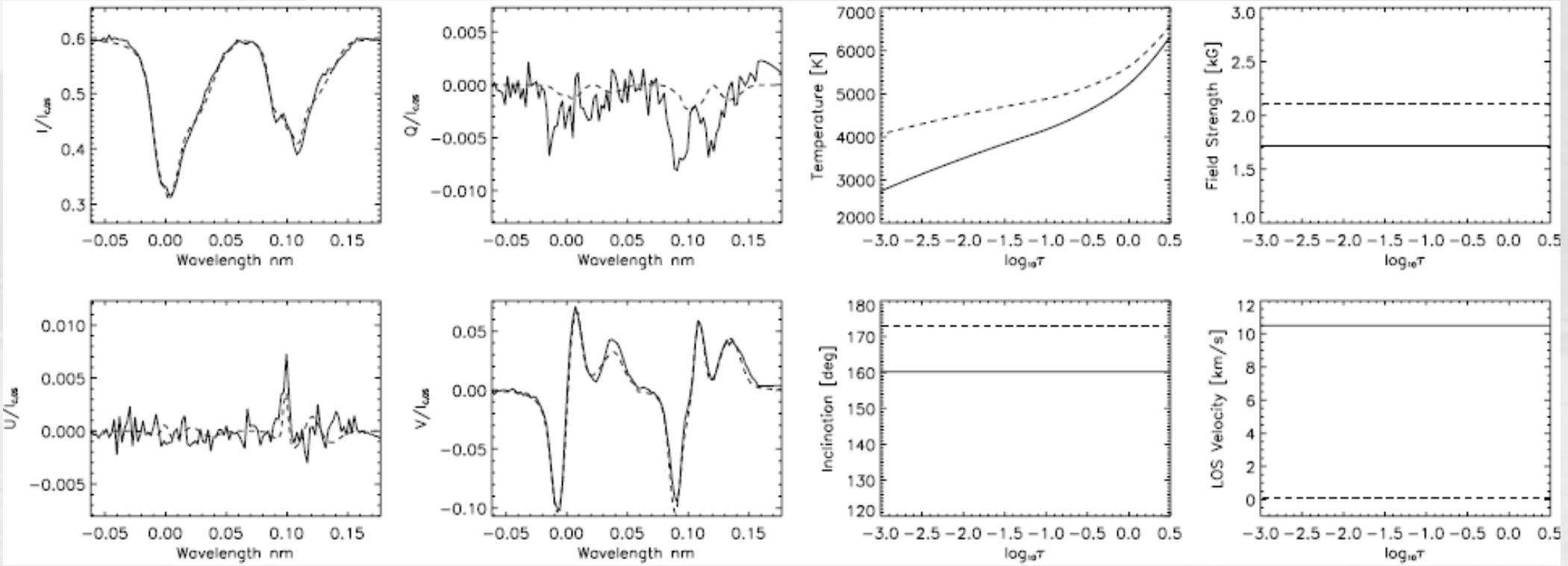


Louis et al. 2009

- Presence of anomalous Stokes profiles in LB
- Different spectral characteristics in LB point to varying physical conditions

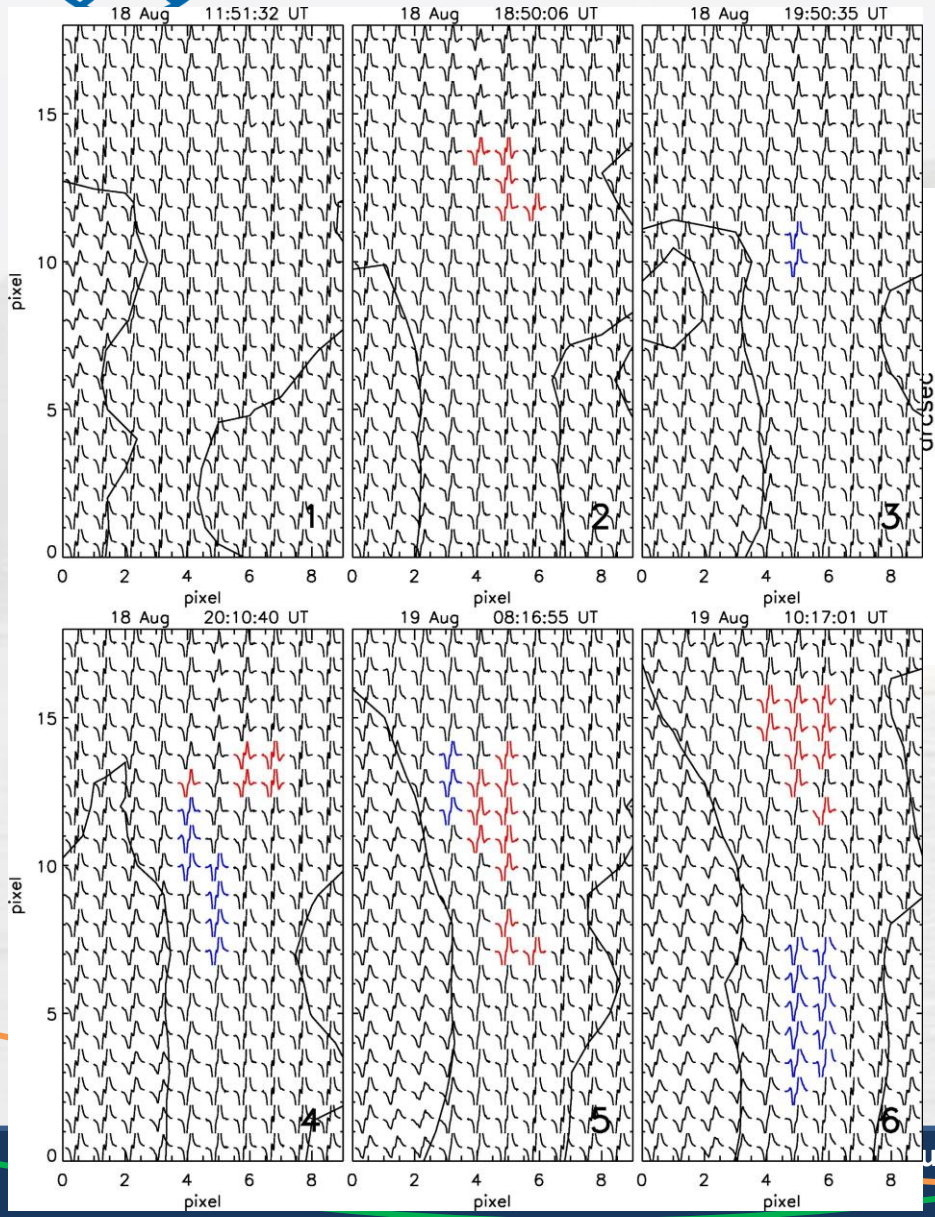
MAGNETIC PROPERTIES OF LBs

Louis et al. 2009

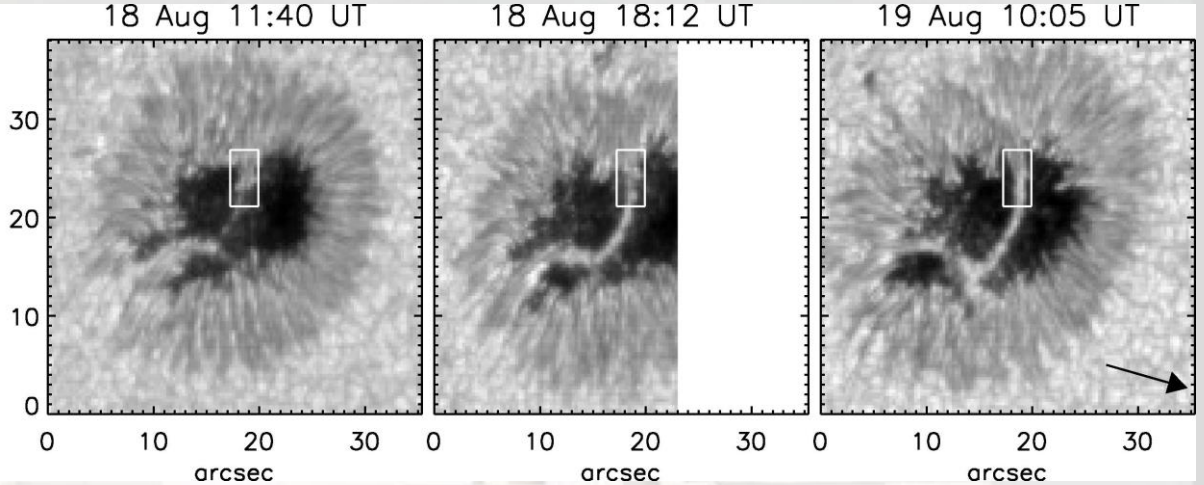


- **Supersonic downflows reproduced from SIR inversions with multiple height independent components as well as discontinuities along LOS**

MAGNETIC PROPERTIES OF LBs



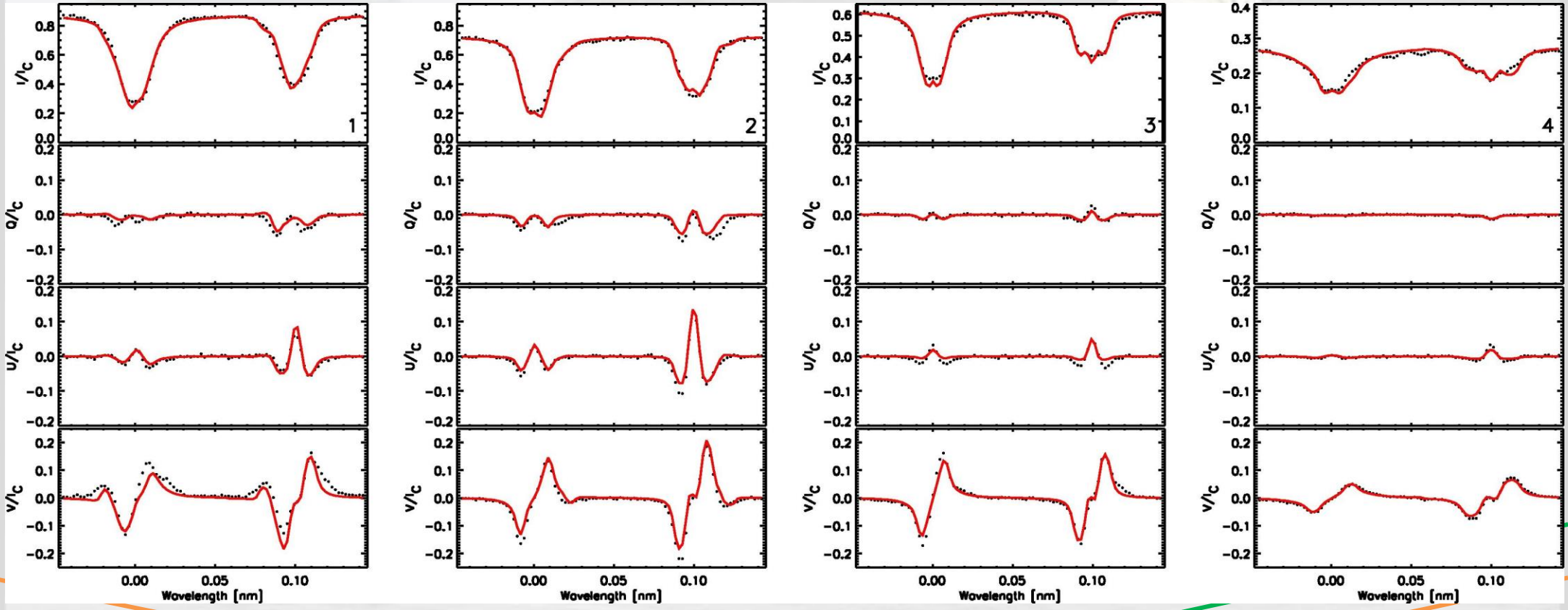
Louis 2015



- Anomalous profiles obs. once LB structure has matured
- Nature spatially and time-dependent
- Strong (>5 km/s) red and blue-shifted comp. with opp. polarity as sunspot
- Fill fraction less than 10%

MAGNETIC PROPERTIES OF LBs

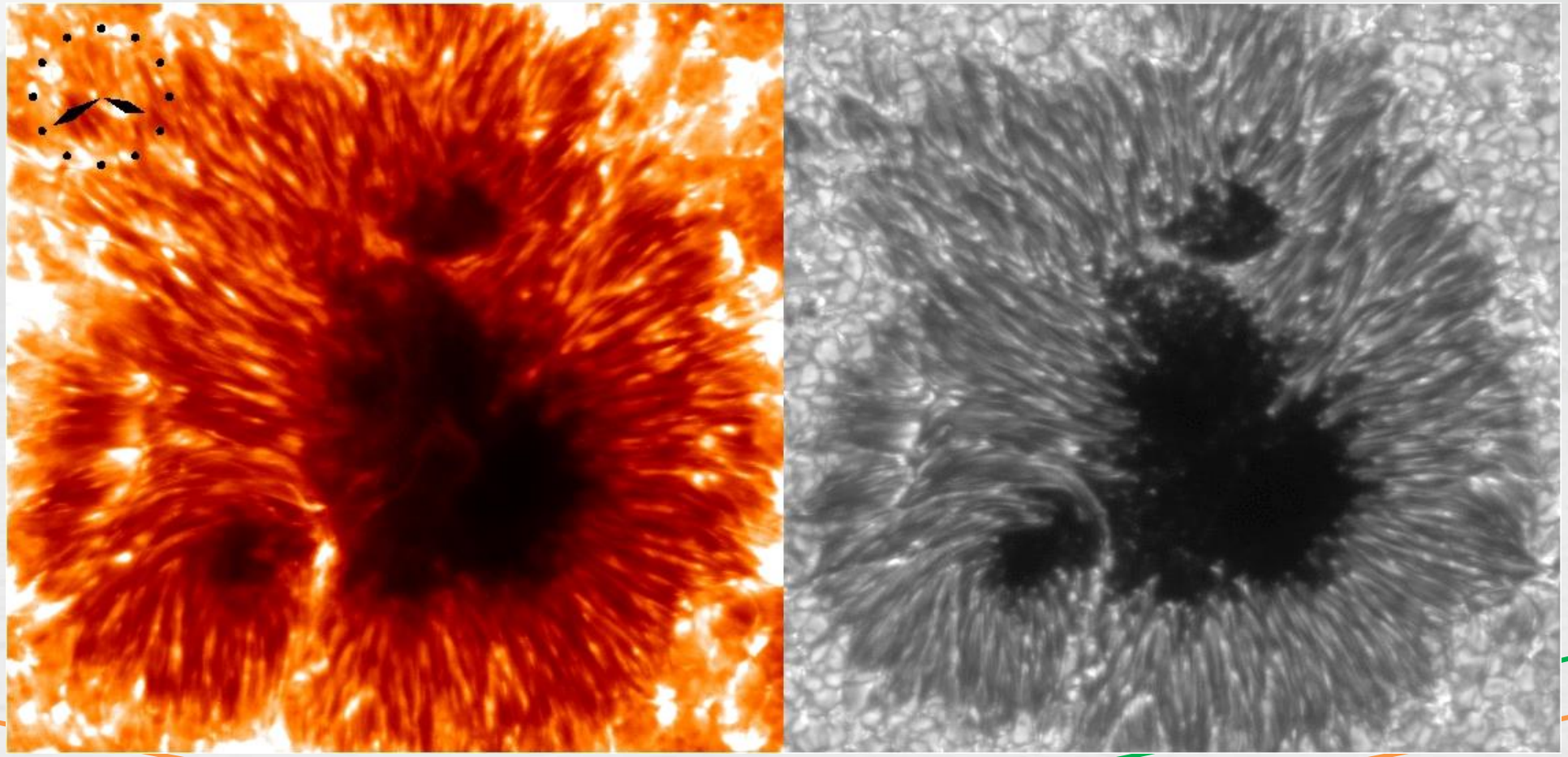
Blue-shifted | Red-shifted | Penumbra | Umbra



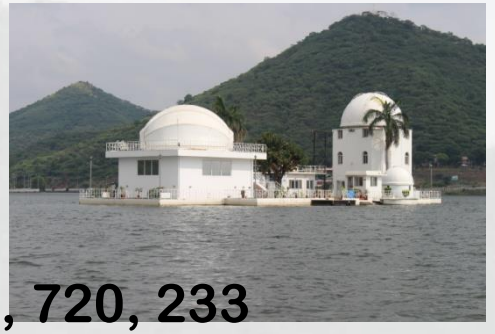
SUMMARY

- LBs are convective intrusions in the sunspot/pore umbrae
- Morphology can be umbra, penumbra, granular depending on evolutionary phase, and influenced by intrinsic thermodynamic conditions & magnetic properties of adjacent umbra
- Development of LB to granular stage can lead to spot fragmentation under specific conditions
- Plasma motions in granular LBs support convective origin
- Those associated with anomalous Stokes profiles are still not understood
- Convective intrusions often associated with weaker magnetic fields
- Force adjacent umbral magnetic field to form canopy
- LBs are sites where number of dynamic phenomena are obs. upper atmosphere
- Cause & effect of underlying photospheric inhomogeneities with dynamics in chromosphere/TR are topic of interest

RELATION TO UPPER ATM. PHENOMENA……



REFERENCES



- Cheung, M., Rempel, M., Title, A. M., Schussler, M. 2010, ApJ, 720, 233
- Hirzberger, J., Bonet, J. A., Sobotka, M., Vazquez, M., Hanslmeier, A. 2002, A&A, 383, 275
- Jurcak, J., Martinez Pillet, V., Sobotka, M. 2006, A&A, 453, 1079
- Katsukawa, Y. et al. 2007, PASJ, 59, 577
- Leka, K. D. 1997, ApJ, 484, 900
- Lites, B. W., Scharmer, G. B., Berger, T. E., Title, A. M. 2004, Sol. Phys., 61, 297
- Louis, R. E., Bayanna, A. R., Mathew, S. K., Venkatakrishnan, P. 2008, Sol. Phys. 252, 43
- Louis, R. E., Luis Bellot, L., Mathew, S. K., Venkatakrishnan, P. 2009, ApJL, 704, 29
- Louis, R. E., Ravindra, B., Mathew, S. K., Bellot Rubio, L., Raja Bayanna, A., Venkatakrishnan, P. 2012, ApJ, 755, 16
- Louis, R. E. 2015, Adv. Sp. Res. 56, 2305
- Louis, R. E., Beck, C., Choudhary, D. B. 2020, ApJ, 905, 153
- Muller, R. 1979, Sol. Phys., 61, 297

REFERENCES

- Rimmele, T. 2004, ApJ, 604, 906
- Rimmele, T. 2008, ApJ, 672, 684
- Rouppe van der Voort, L. H. C., Bellot Rubio, L. R., Ortiz, A. 2010, ApJL, 718, 78
- Sobotka, M., Bonet, J. A., Vazquez, M. 1994, ApJ, 426, 404
- Sobotka, M., Bonet, J. A., Vazquez, M. et al. 1999, ApJ, 511, 436
- Toriumi, S., Katsukawa, Y., Cheung, M. 2015, ApJ, 811, 137
- Vazquez, M. 1973, Sol. Phys., 31, 377