On the common appearance of superstrong magnetic fields in bipolar light bridges

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ABSTRACT

Bipolar light bridges (BLBs) are bright features in sunspots located between two umbrae with opposite magnetic polarity. Recent observations revealed intriguing cases of BLBs with very strong magnetic fields of the order of 8.2 kG [1]. Since these observations were only a handful, it is a question of whether BLBs with extraordinarily strong fields are very rare.

We used the most extensive set of spectropolarimetric observations of sunspots with BLBs compiled so far, consisting of data acquired with Hinode/SOT-SP [2, 5]. We analyzed these data using a state-of-the-art inversion technique, which accounts for the data degradation caused by the intrinsic PSF of the telescope [7].

We identified 98 individual BLBs within 51 distinct sunspot groups. Since 66% of the identified BLBs were observed multiple times, our sample contained a total of 630 spectropolarimetric scans. Our analysis showed that 89% of the (individual) BLBs contain magnetic fields stronger than 4.0 kG, at the height of maximum magnetic sensitivity with even higher field strengths in deeper layers. We also found that BLBs display a unique continuum intensity and field strength combination, forming a population well-separated from the umbrae and the penumbrae.

SUBMITTED DRAFT

OBSERVATIONS AND DATA PROCESSING

Spectropolarimetric inversions of ARs with sunspots are taken from the MODEST catalogue [2]. When we started working on BLBs, the catalogue comprised 869 inverted spectropolarimetric scans of 78 ARs taken by Hinode/SOT-SP. Data were recorded between 2006 December 8 and 2019 July 27.

The MODEST inversions were performed using the spatially-coupled version of the SPINOR code [3, 6–8]. SPINOR assumes LTE and accounts for spatial smearing due to the telescope PSF. Atmospheric parameters vary with height.

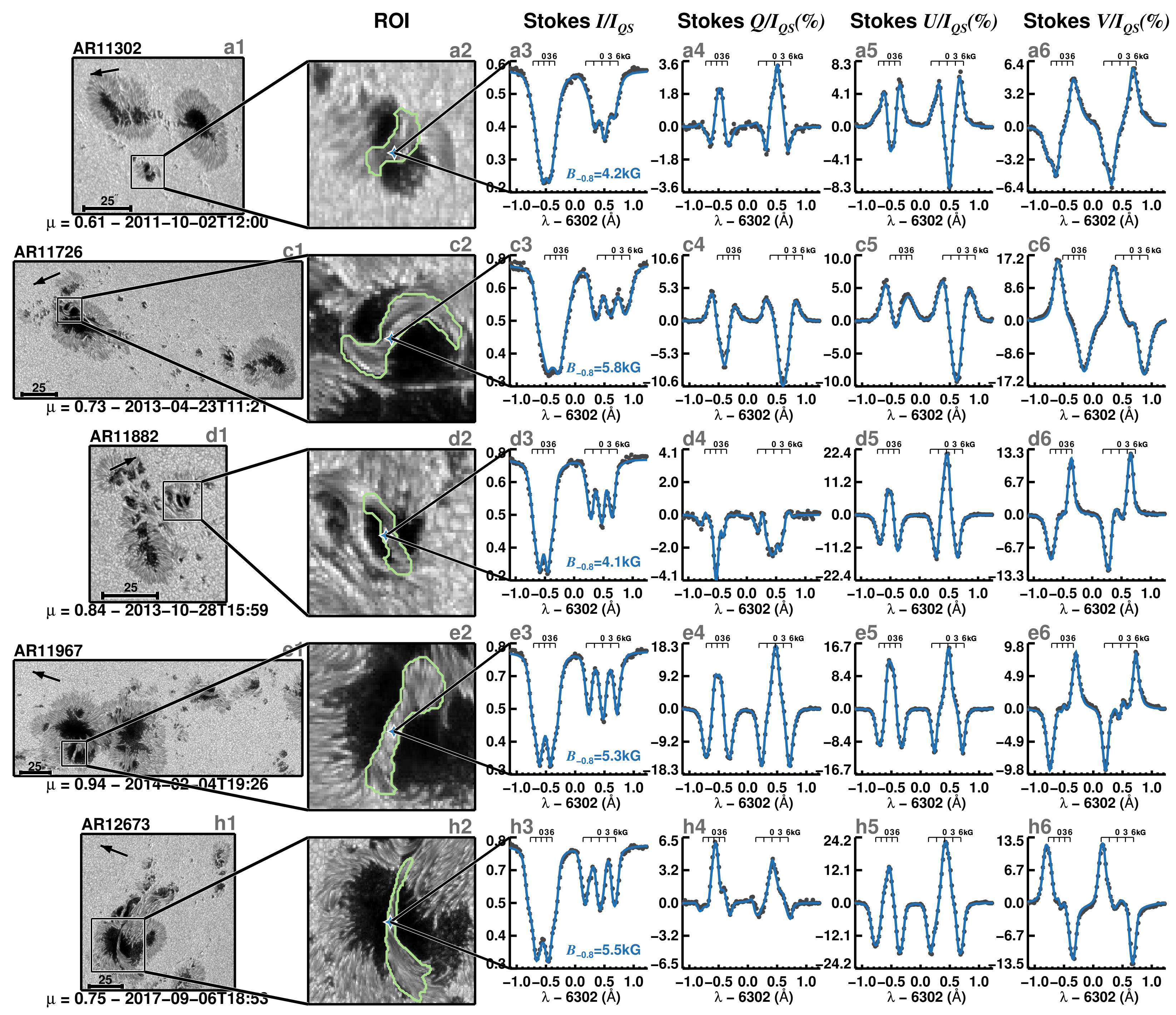

Figure: Observed Stokes profiles at selected positions within the BLBs and their MODEST fits. (Left) continuum images of the AR and a zoom-in into the BLBs (green contours). (Right) Observed Stokes profiles I, Q, U, and V (gray dots). The blue lines show the best-fit obtained with the spatially-coupled inversion.

SAMPLE OF BIPOLAR LIGHT BRIDGES

We identified 98 separate BLBs as part of 51 individual sunspot groups. A total of 448 Hinode/SOT-SP scans that contained BLBs were analysed. 66.3% (65/98) of BLBs were observed on more than one scan. In addition, in some cases multiple BLBs could be traced in a single Hinode/SOT-SP scan, depending on the complexity and size of the AR and the solar area covered by the scan. This led to 630 BLB scans.

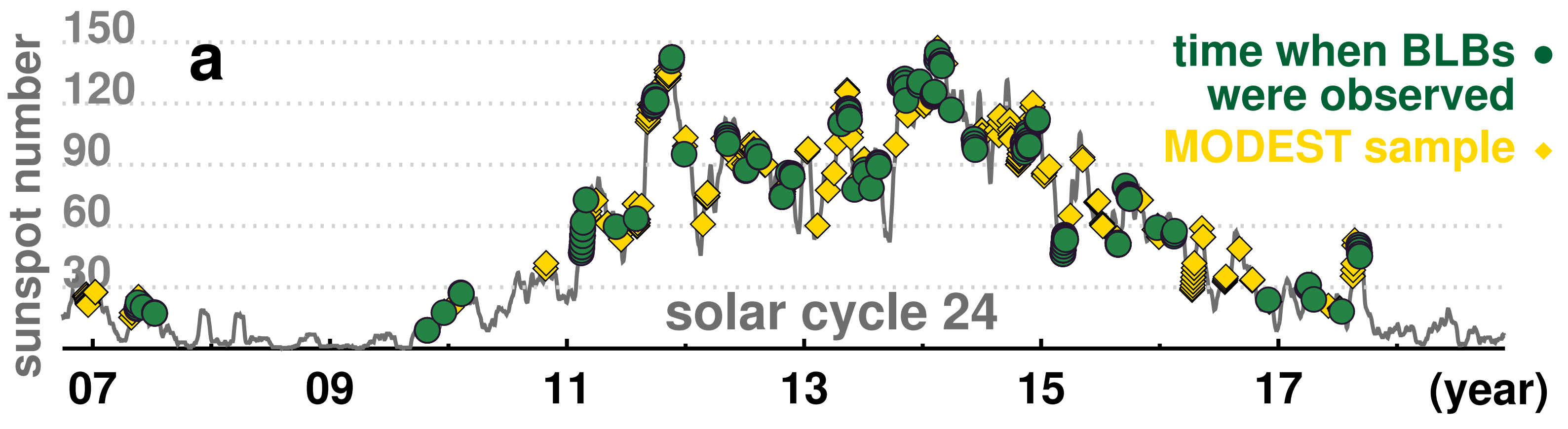

Figure: Characteristics of Hinode/SOT-SP scans harbouring BLBs. Panel (a) shows the smoothed daily sunspot number (grey line). Yellow diamonds mark all scans as part of the MODEST sample.

ISOLATED BLBs

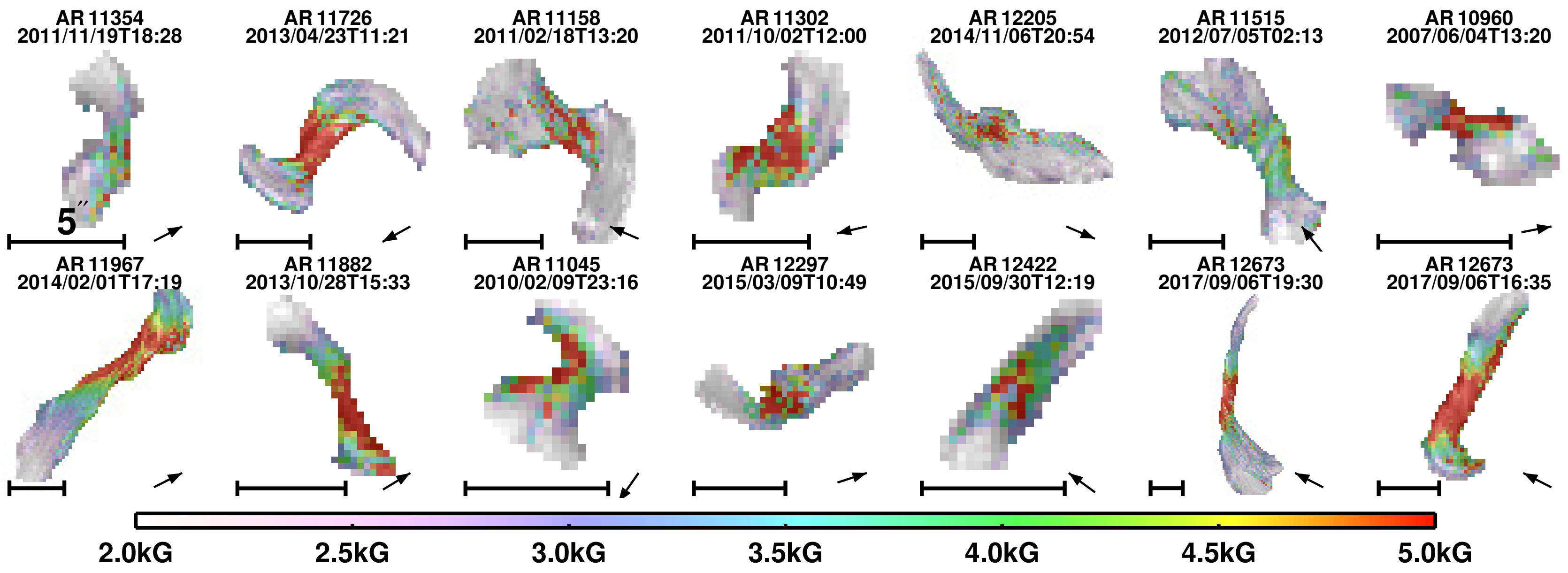

Figure: Continuum images of isolated BLBs. The locations of strong B within the BLB are colour-shaded.

All 98 BLBs contain, in at least one Hinode/SOT-SP scan, magnetic fields stronger than 4.5 kG at $\tau = 1$. For the middle and top nodes the percentage of fields stronger than 4.5 kG decreases to 51% (50/98) and 18.4% (18/98).

THREE DISTINCTIVE POPULATIONS IN THE I_c VS. B DIAGRAM

Penumbrae, umbrae, and BLBs form three separated populations with almost no overlap in the I_c vs. B diagram. The mean magnetic field inside BLBs is systematically higher than in umbrae, with their continuum intensities being similar to those in penumbral regions. The magnetic field strength in the BLBs decreases significantly more rapidly with height than the umbral and penumbral magnetic field strengths.

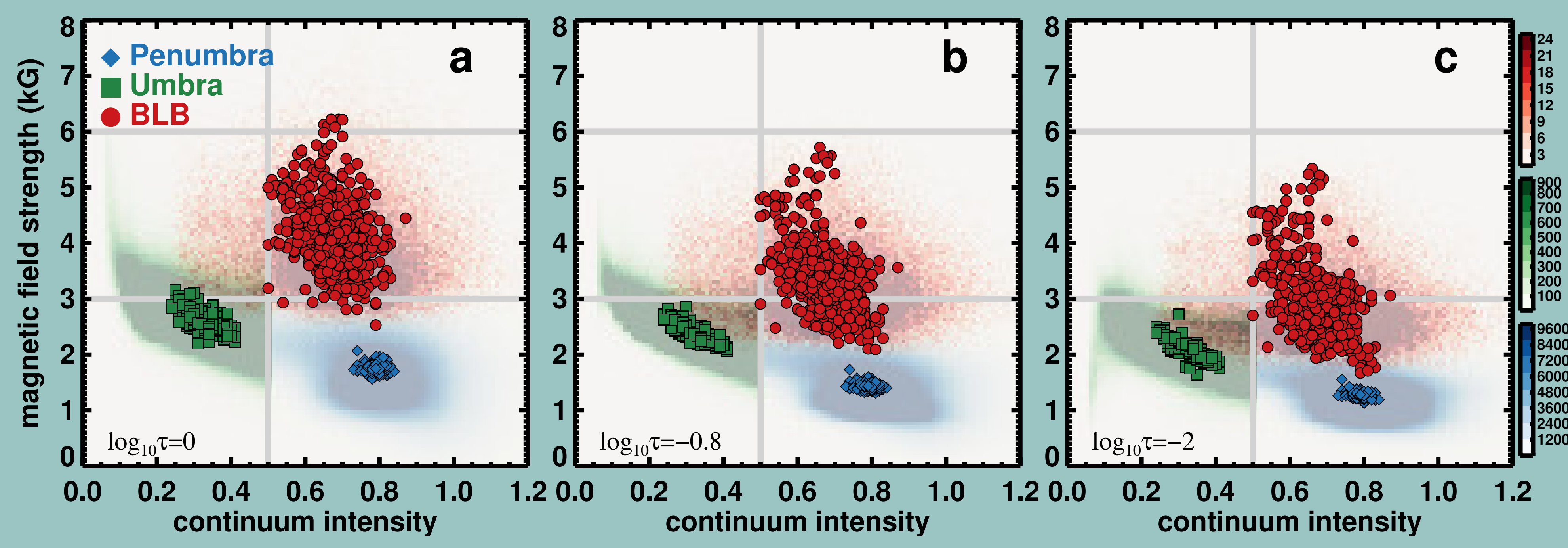

Figure: Magnetic field strength at three optical depths as a function of continuum intensity. Colours refer to penumbrae (blue), umbrae (green), and BLBs (red). The shaded regions are composed of all the pixels in a given region for all Hinode/SOT-SP scans with BLBs. Each scan of a sunspot group with a BLB is represented by a symbol displaying the mean value of the 25% strongest pixels within each of the three regions.

SUMMARY

We show here that the presence of extremely strong magnetic fields is rather common in bipolar light bridges.

The detailed atmospheric conditions within BLBs were obtained by applying spatially-coupled inversions assuming LTE conditions to the spectropolarimetric data, yielding excellent fits to the observed spectra.

The superstrong magnetic fields in BLBs form a very distinct population in the magnetic field strength vs. continuum intensity diagram. The average magnetic field strengths in this population at the deepest observable layer is between 3 and 6 kG, with individual pixels clearly exceeding this value.

OUTLOOK

The high continuum intensities indicate that convection persists even in the presence of superstrong magnetic fields, indicating the presence of magnetoconvection processes in a new regime. BLBs thus appear to be the best pathway to probing this largely unexplored magnetoconvection regime [cf. 4].

The frequent occurrence of superstrong fields in complex active regions may have implications for our understanding of solar active regions, possibly able to store larger amounts of magnetic energy than previously assumed. This can lead to enhanced and/or stronger eruptive activity, possibly of high relevance for the production of large solar flares.

REFERENCES

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