Emergence of internetwork magnetic fields into the chromosphere and transition region

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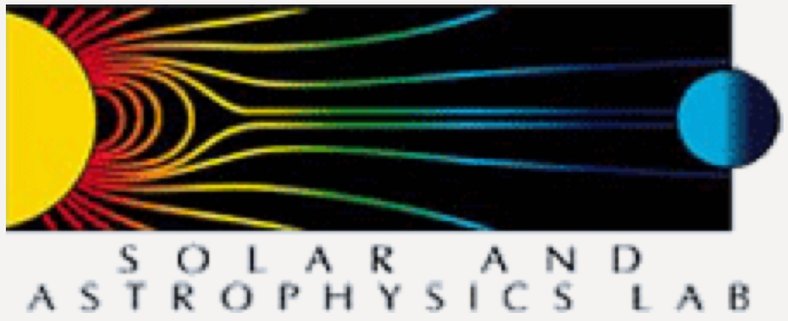
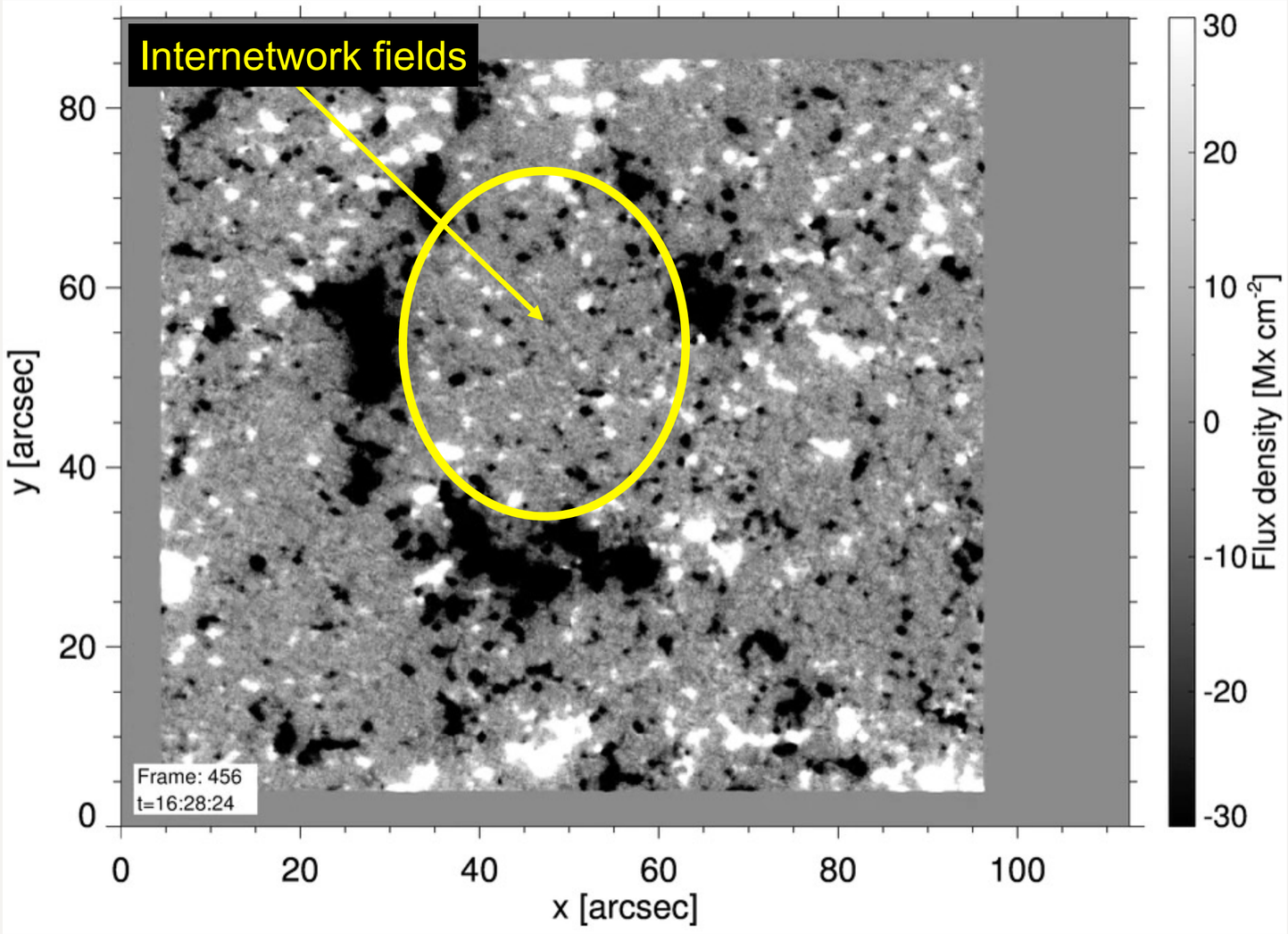


Internetwork fields

- Up to 50% of the QS flux is in the form of IN patches (Wang et al. 1995).
- IN elements appear at a rate of 120 Mx cm^{-2} day^{-1} (Gošić et al. 2016) (the rate in ARs is 1 Mx cm^{-2} day^{-2} Thornton & Parnell 2010).



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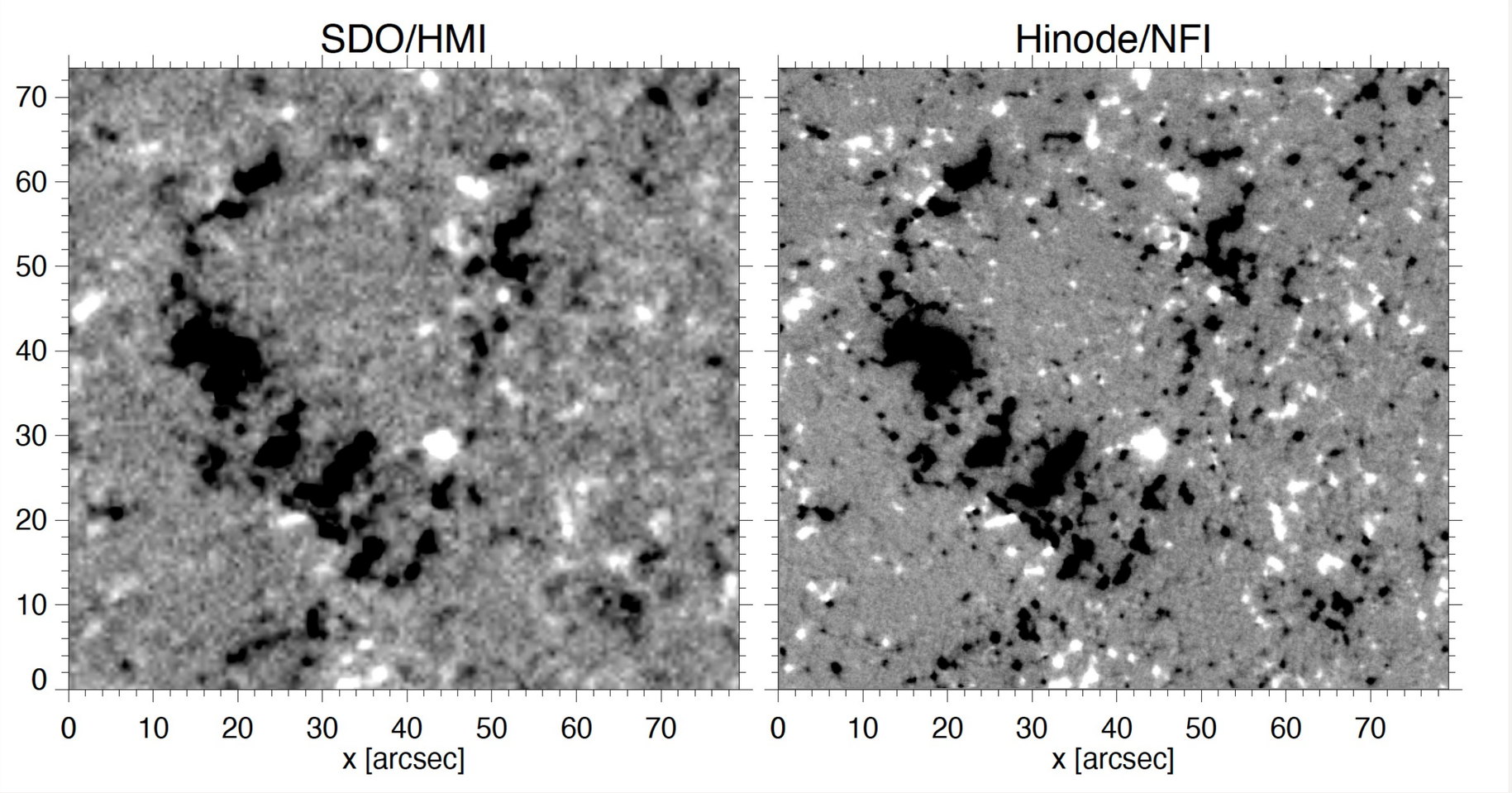
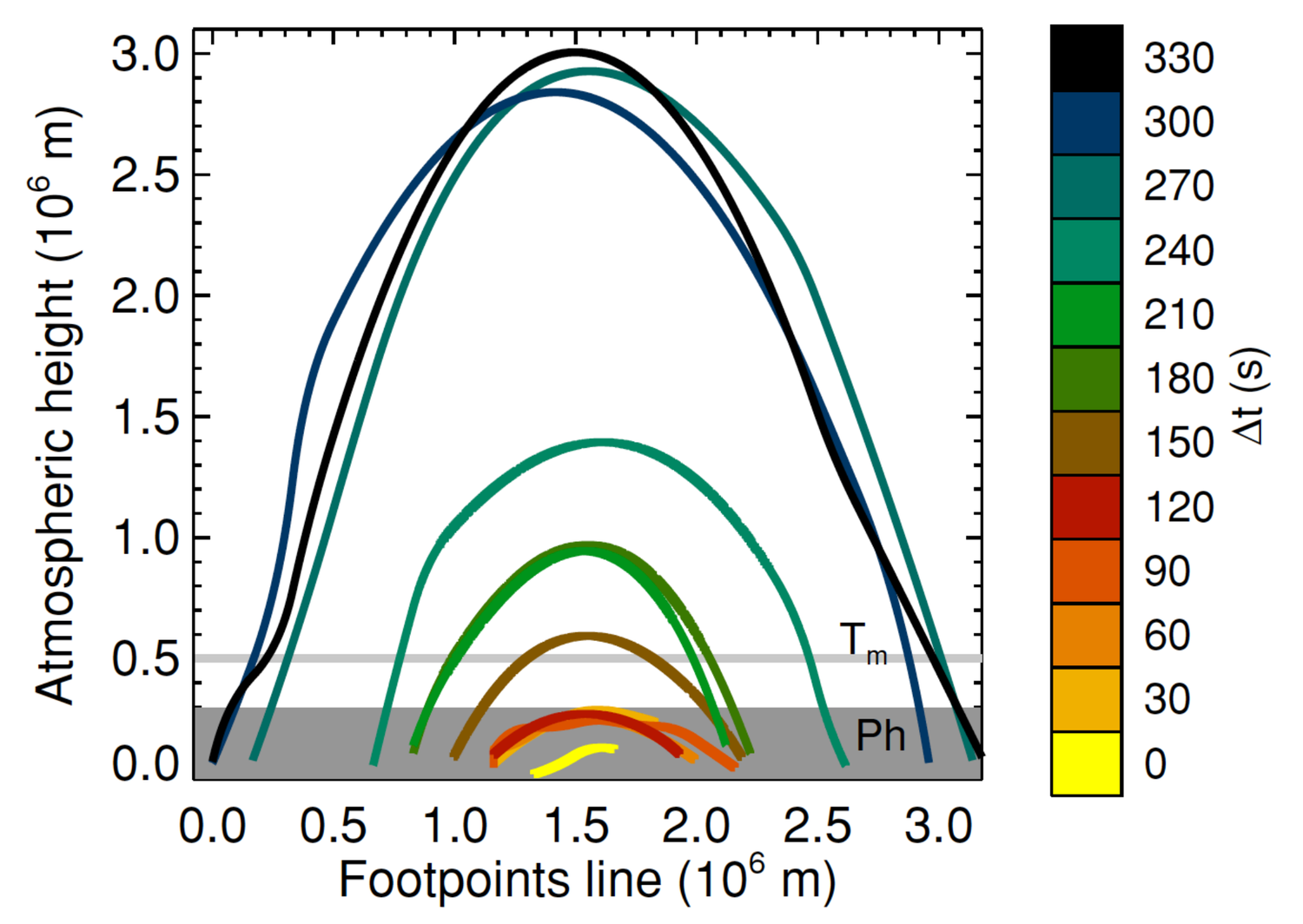


Motivation

IN fields have a large appearance rate and maintain the quiet Sun network
(Gošić et al. 2014, Gošić et al. 2016)

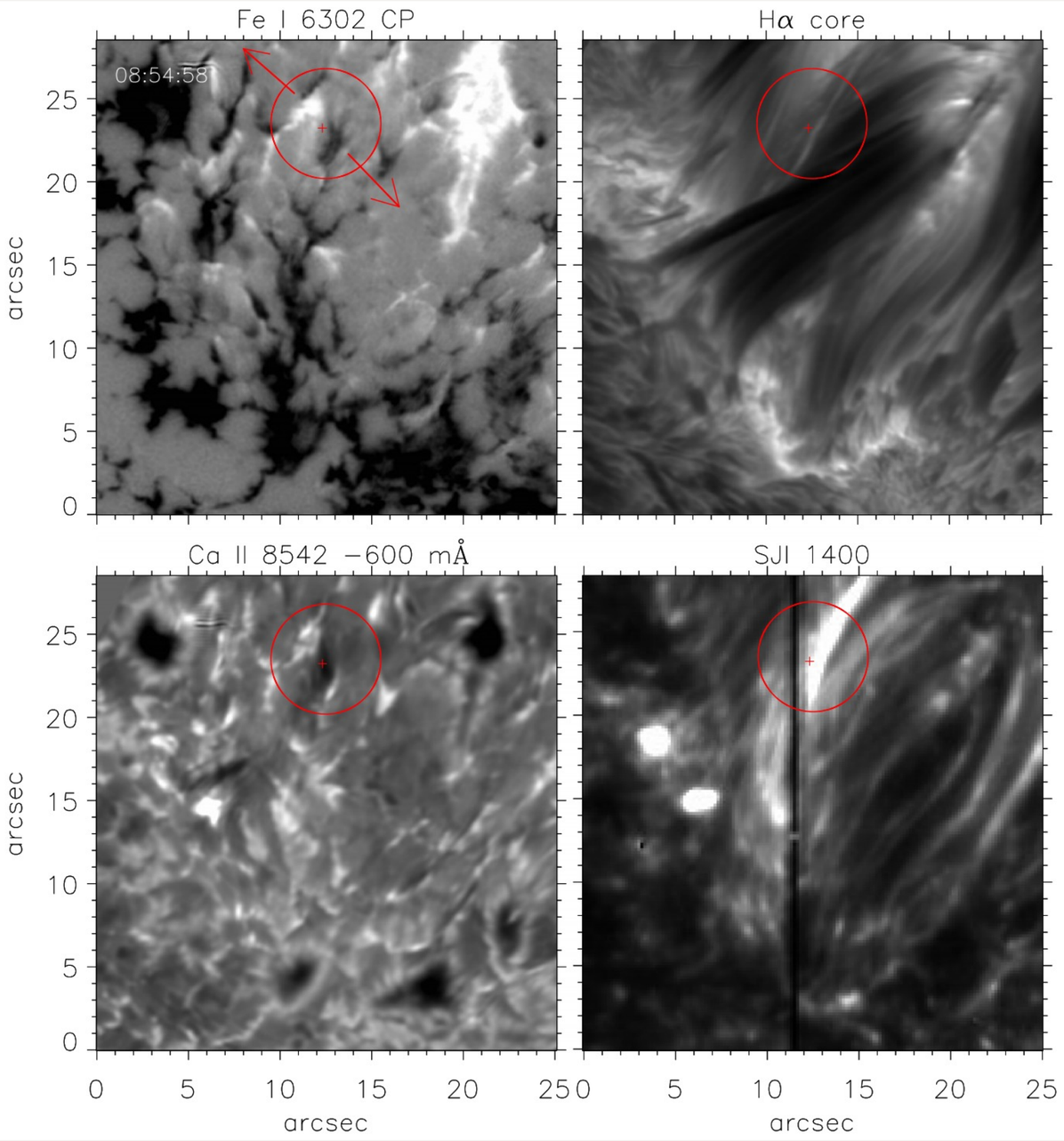
They occur all over the Sun and may carry a substantial amount of energy
(Trujillo Bueno et al. 2004)

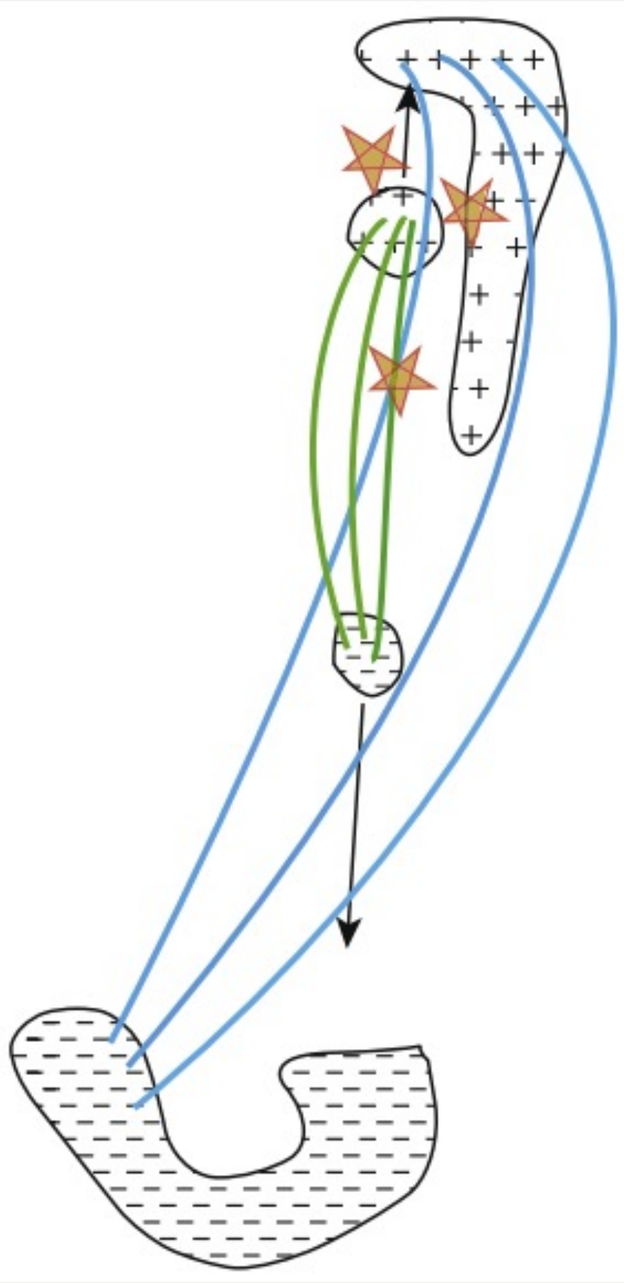
Emergence of bipolar internetwork magnetic fields



Martínez González et al. 2010

Emergence of bipolar internetwork magnetic fields





Ortiz et al. 2016

Previous studies

Extrapolations of the magnetic field lines suggest that small-scale IN loops can rise up to heights of 2–3 Mm above the continuum forming layer (Martínez González et al. 2010, Gošić et al., 2022, also Martínez González & Bellot Rubio 2009).

MHD simulations do not consistently show IN magnetic loops reaching the chromosphere, let alone the transition region or corona (Stein & Nordlund 2006, Isobe et al. 2008, Amari et al. 2015, Moreno-Insertis et al. 2018).

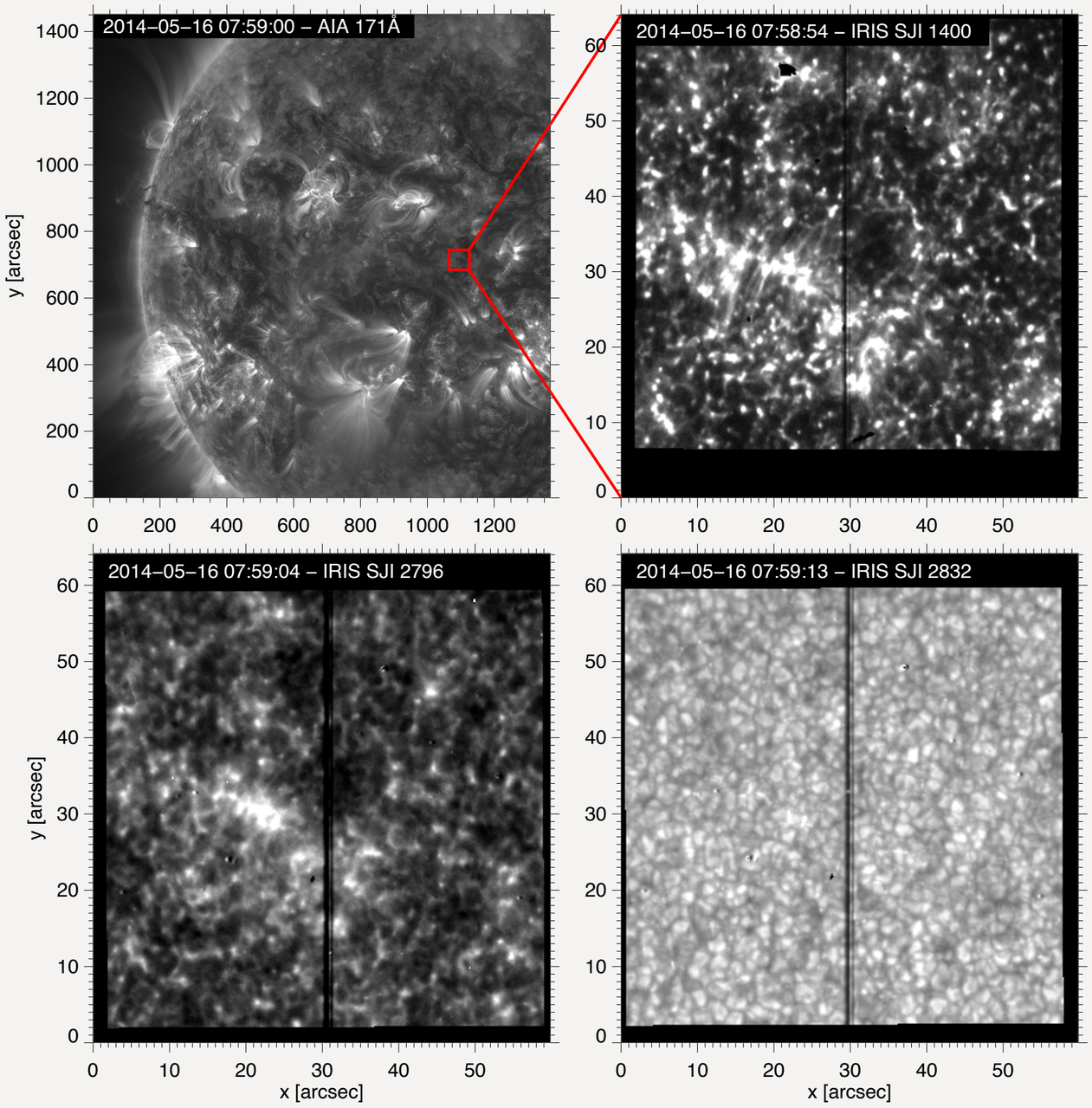
Goal

Are IN fields capable of reaching the chromosphere and the upper solar atmosphere?

Observations - IRIS

Medium sparse 2-step rasters:

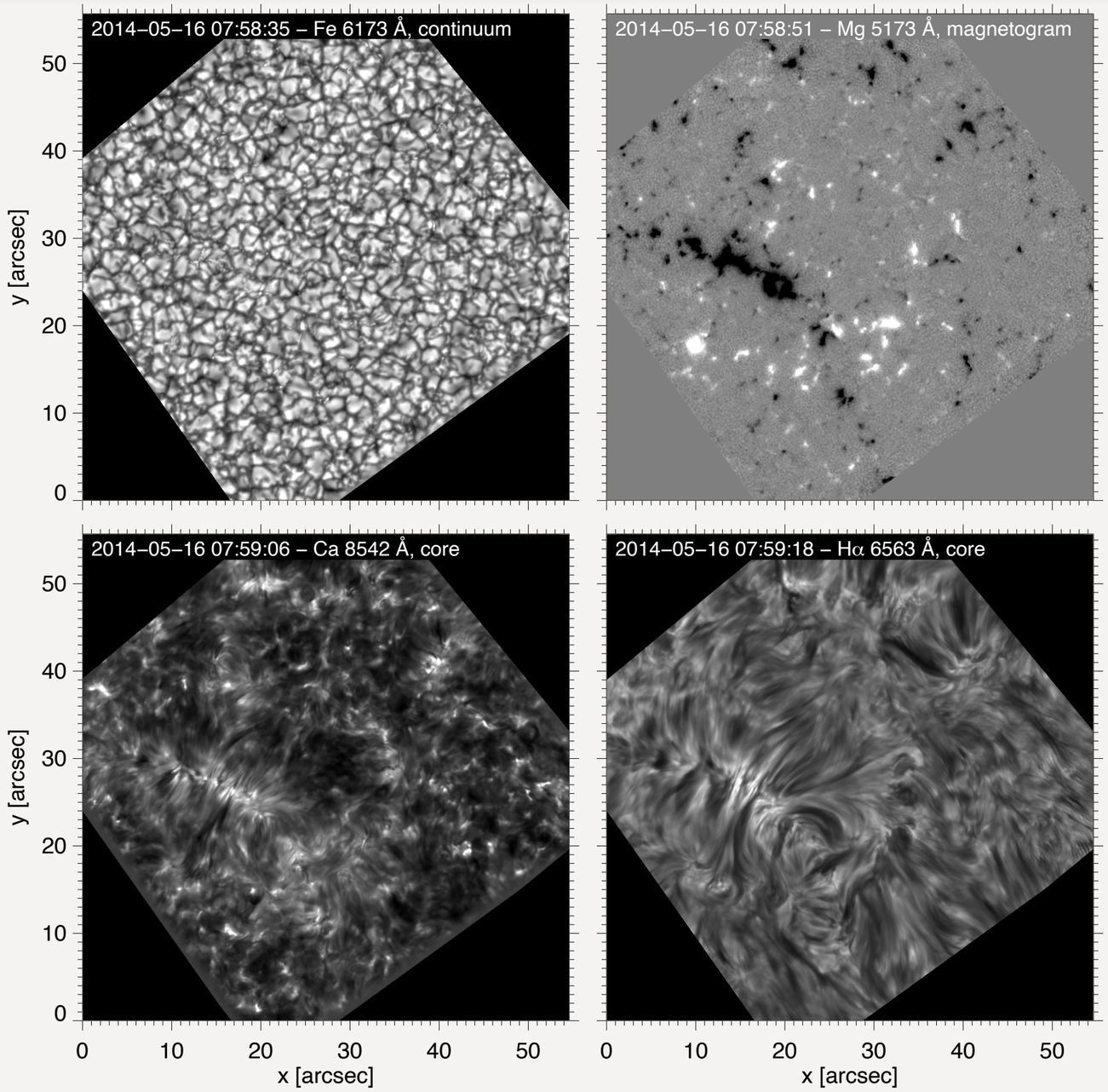
- SJI 1400, SJI 2796, SJI 2832
- quiet Sun at the disk center
- high raster cadence: 18.6 sec
- SJI cadence: 19 sec
- duration: 3 hr



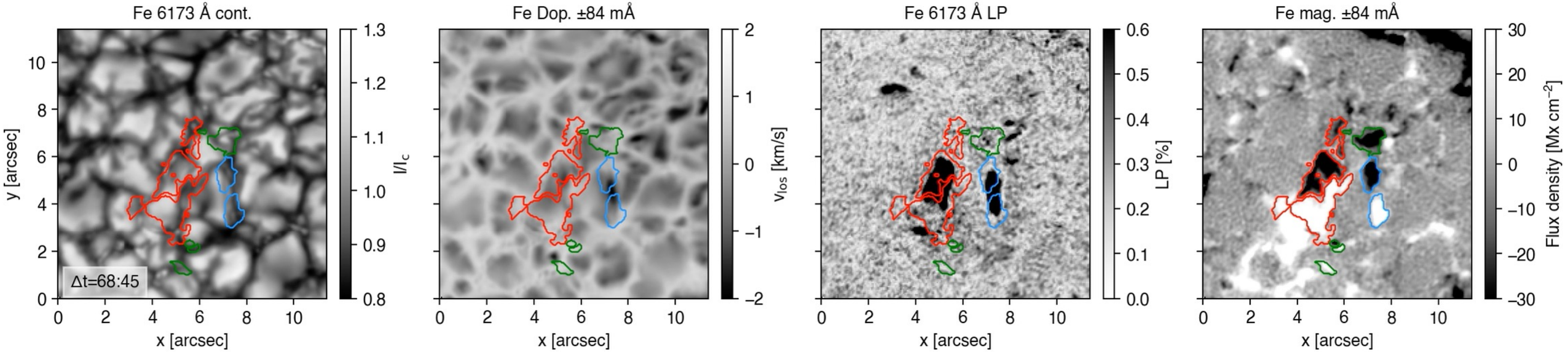
Observations - SST

SST time sequences:

- Lines: Fe I 6173 Å, Mg I b_2 5173 Å
  Ca II 8542 Å and Hα 6563 Å
- cadence: 55 sec
- duration: 3 hr

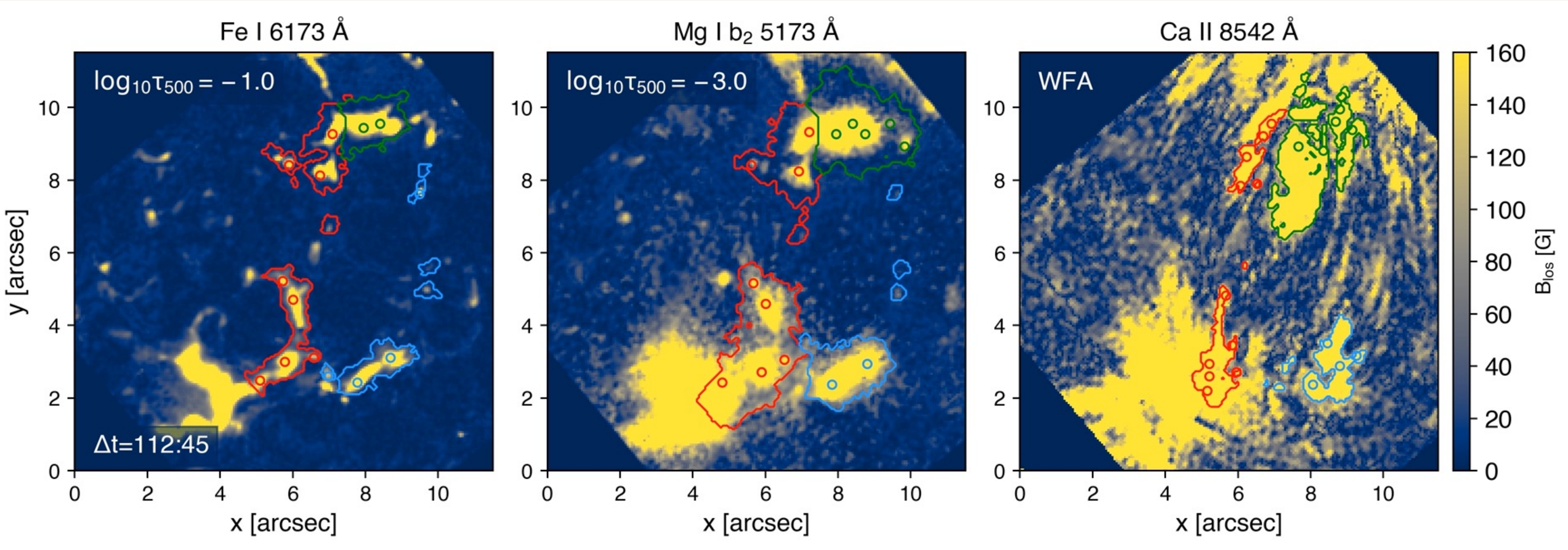


Emergence of IN fields in the photosphere



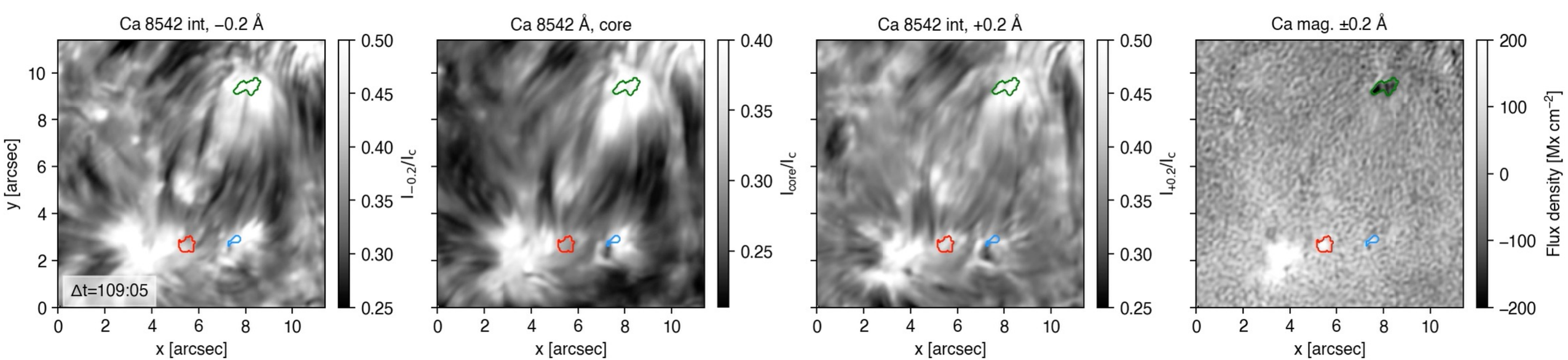
- Emerging IN clusters as seen in the photospheric Fe I line.

Emergence of IN fields in the photosphere and beyond



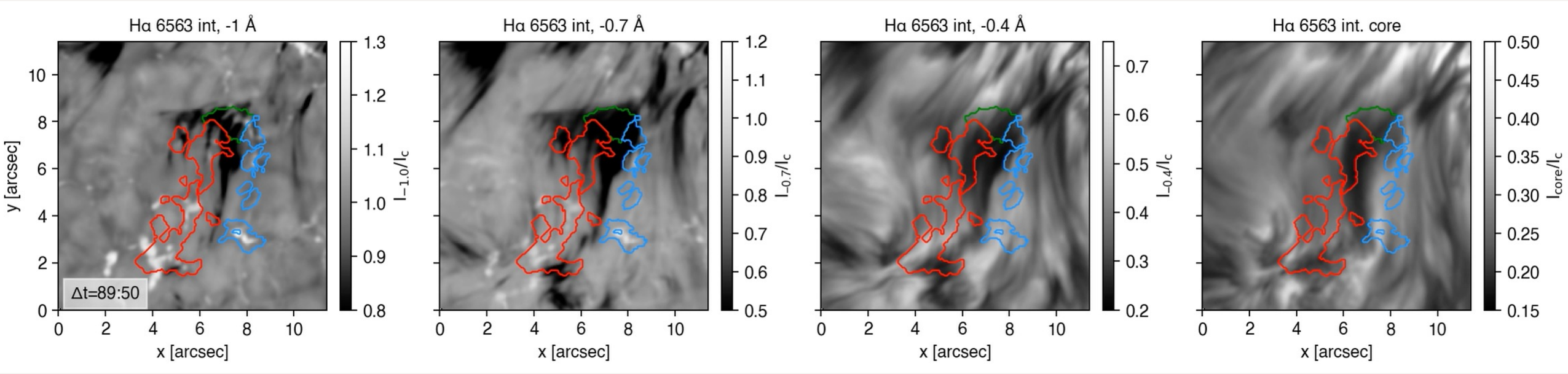
- Longitudinal magnetic fields derived from the SIR inversions of the Fe I and Mg I b_2 lines, and from the WFA applied to the Ca II measurements.
- The maximum longitudinal field strengths are between 450 and 800 G.

Emergence of IN fields in the photosphere and beyond



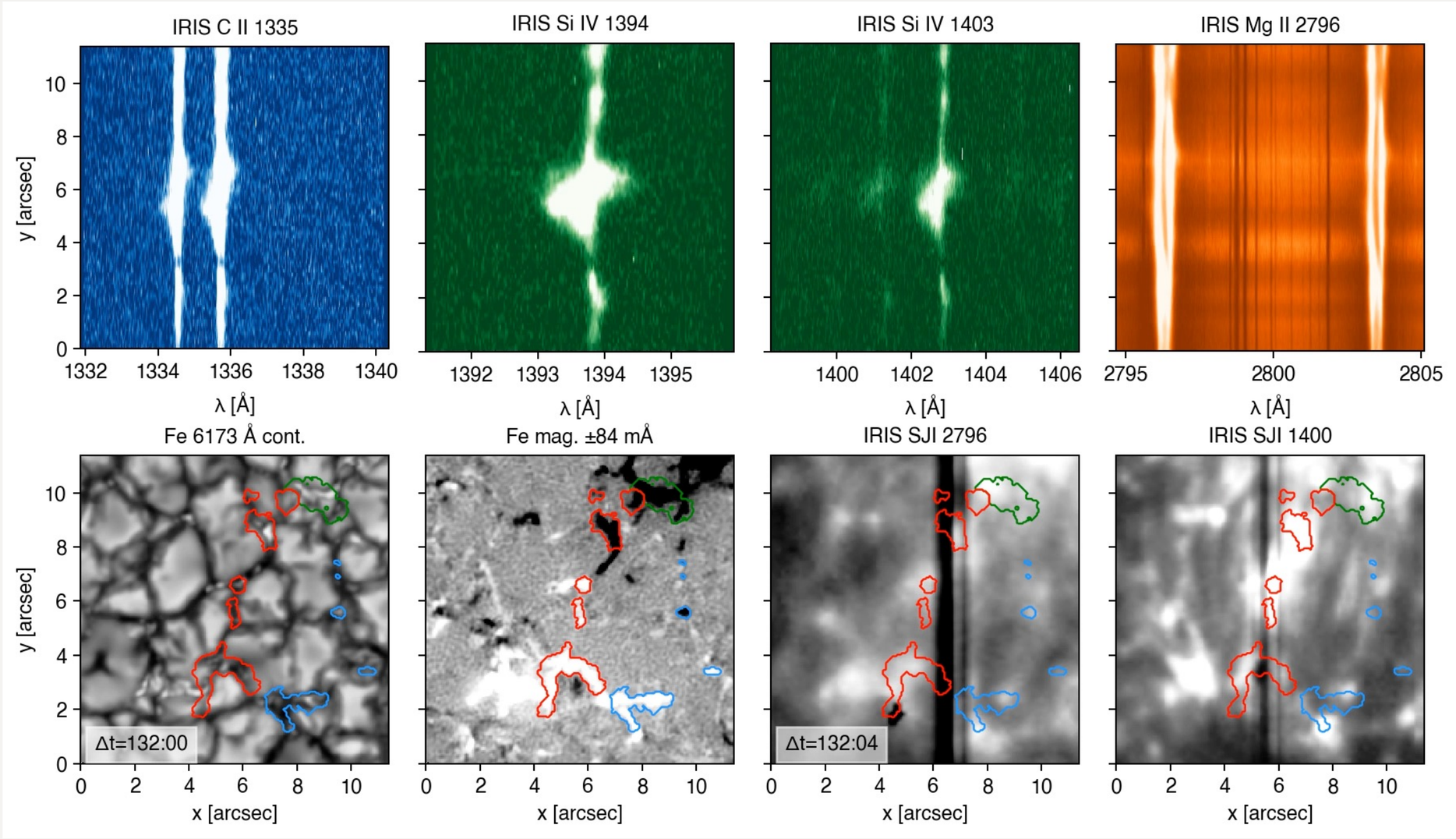
- Ca II filtergrams showing the temporal evolution of the chromospheric features above the emerging flux region.

Emergence of IN fields in the photosphere and beyond



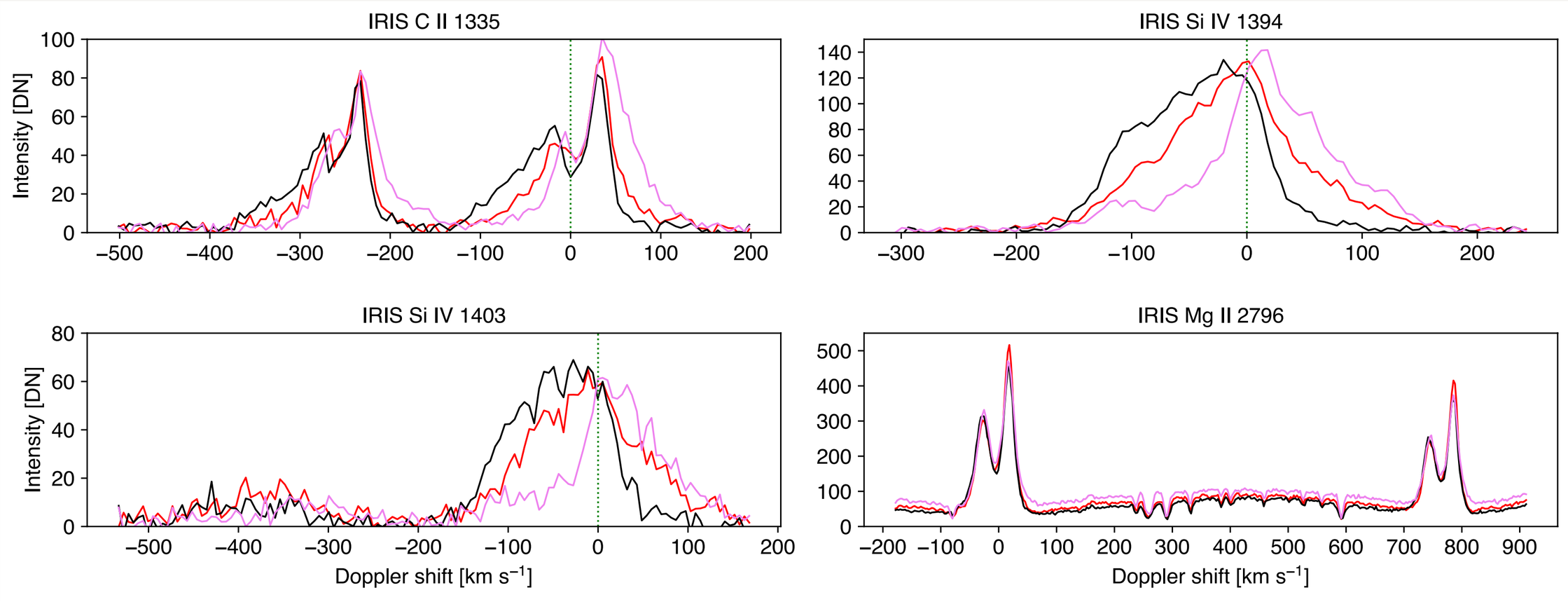
- Flux emerging region as seen in the chromospheric Hα line. Surge-like phenomenon is expected to be observed in the Ca II and Hα lines when new and preexisting fields reconnect (Guglielmino et al. 2010, 2018, 2019; Nóbrega-Siverio et al. 2017).

Emergence of IN fields through the upper solar atmopshere



- Temporal evolution of the signals in the IRIS FUV and NUV spectral regions above the emerging internetwork clusters.

Emergence of IN fields through the upper solar atmopshere



- Selected spectral profiles in the IRIS C II 1335 (upper left), Si IV 1394 (upper right), Si IV 1403 (lower left), and Mg II h&k (lower right) lines at different locations along the slit. The far-UV profiles show strong blue and red shifts during the maximum emission, indicating plasmoid-mediated magnetic reconnection between the upward moving internetwork magnetic fields and the ambient network fields, which is consistent with previously reported observations (Innes et al. 1997, 2015, Peter et al. 2014, Rouppe van der Voort et al. 2017, Guglielmino et al. 2018, Guo et al. 2020).

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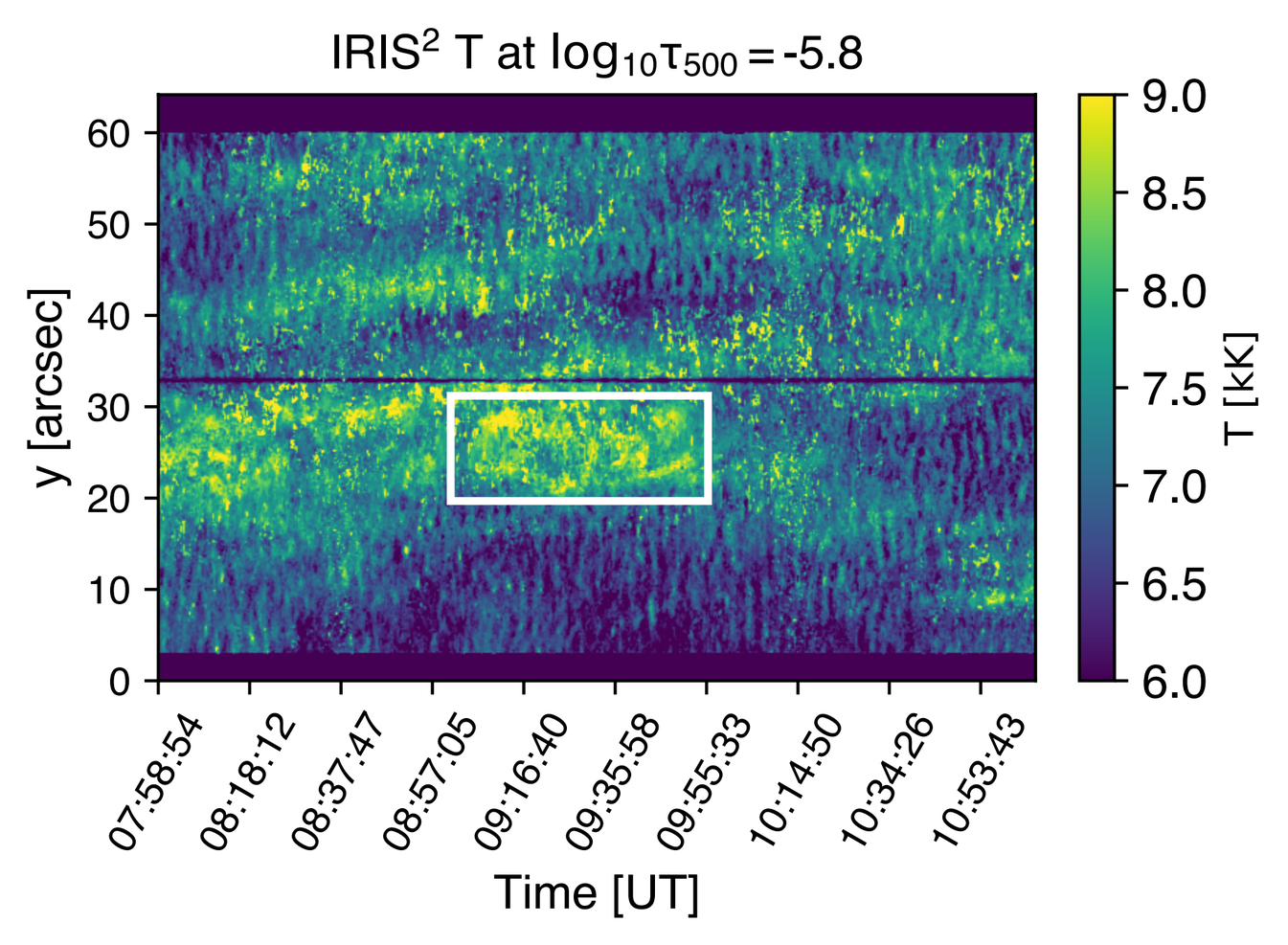

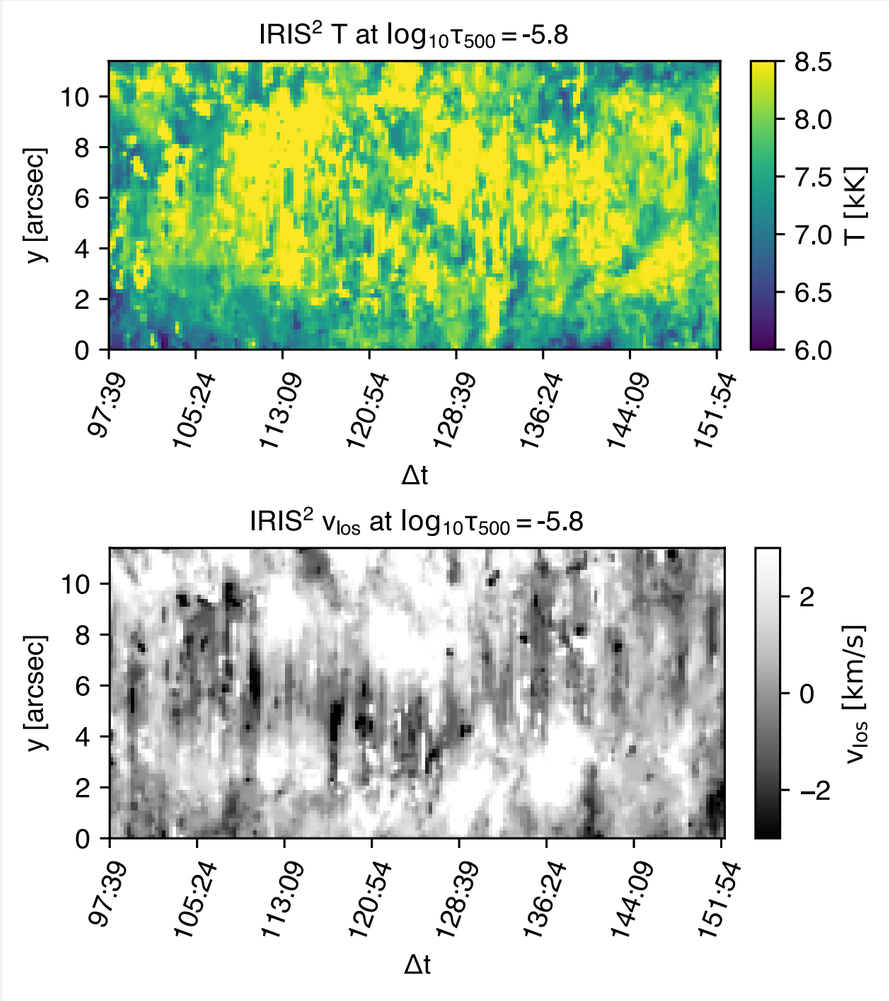

- Temperature maps obtained through IRIS^2 inversions (Sainz Dalda et al. 2019). The highest temperatures correspond to the internetwork emerging flux region (indicated by the white box), and network magnetic elements.

Summary and conclusions

- Internetwork magnetic fields with strengths between 450 and 800 G can reach the chromosphere, as demonstrated from full spectropolarimetric measurements in the Ca II 8542 Å line.
- According to our observations, it took about 1 hr for the IN fields to fully break through the ambient fields and emerge in the chromospheric layers.
- IRIS observations reveal that small-scale IN loops can even reach the transition region.

Internetwork loops can locally heat the upper solar atmosphere.