Magnetic heating of the active chromosphere

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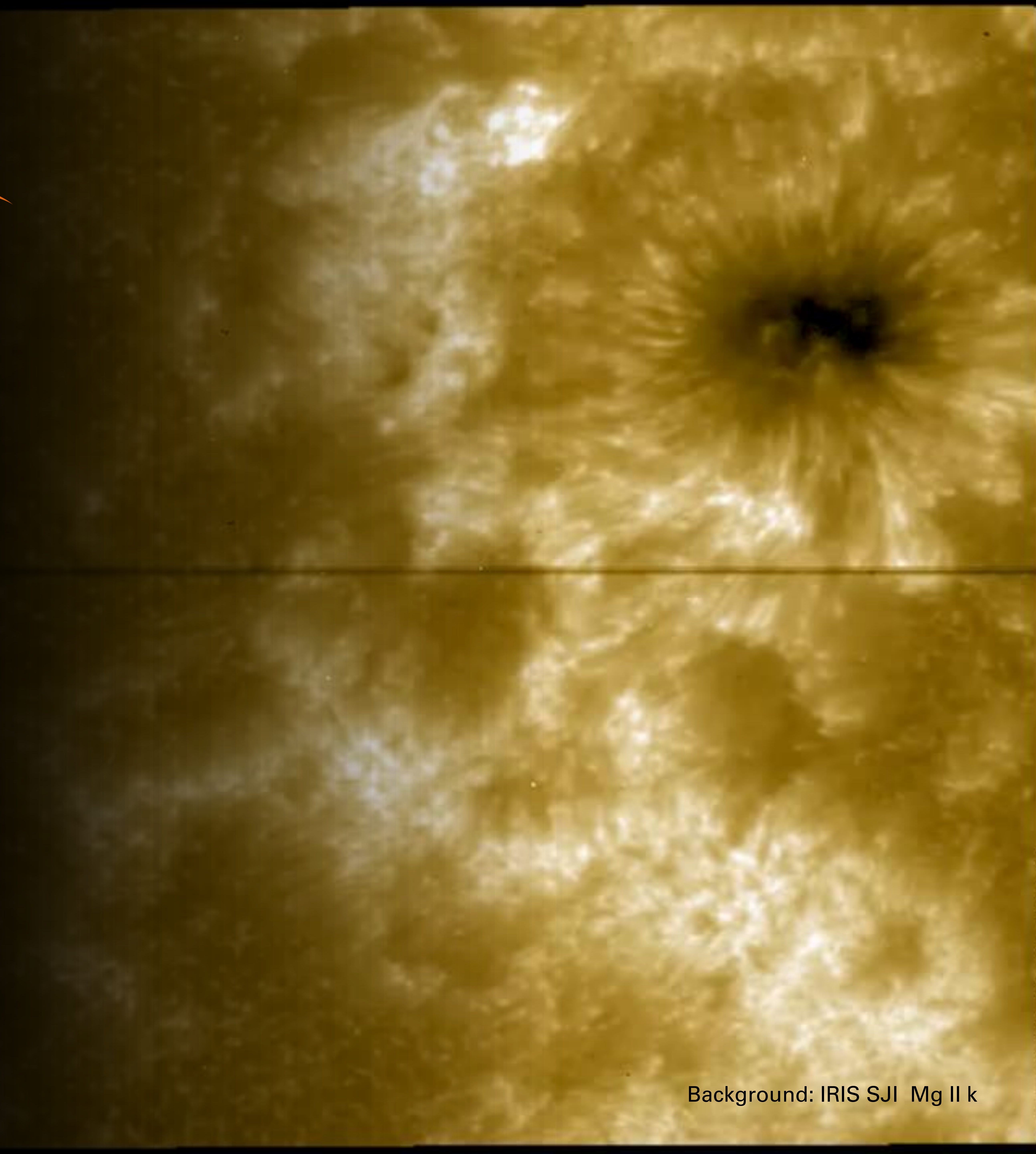
ISSI team meeting, October 2022



Background: IRIS SJI Mg II k

Radiative energy losses [kW m^{-2}]

compiled by Withbroe & Noyes (**1977**)

	Lower chromosphere	Upper chromosphere	Total
QS	2	0.3	4
AR	≥10	2	20

Heating mechanisms

compiled by Withbroe and Noyes (**1977**)

QS	**acoustic shocks**, reconnection, Joule heating
AR	**MHD waves**, reconnection, Joule heating

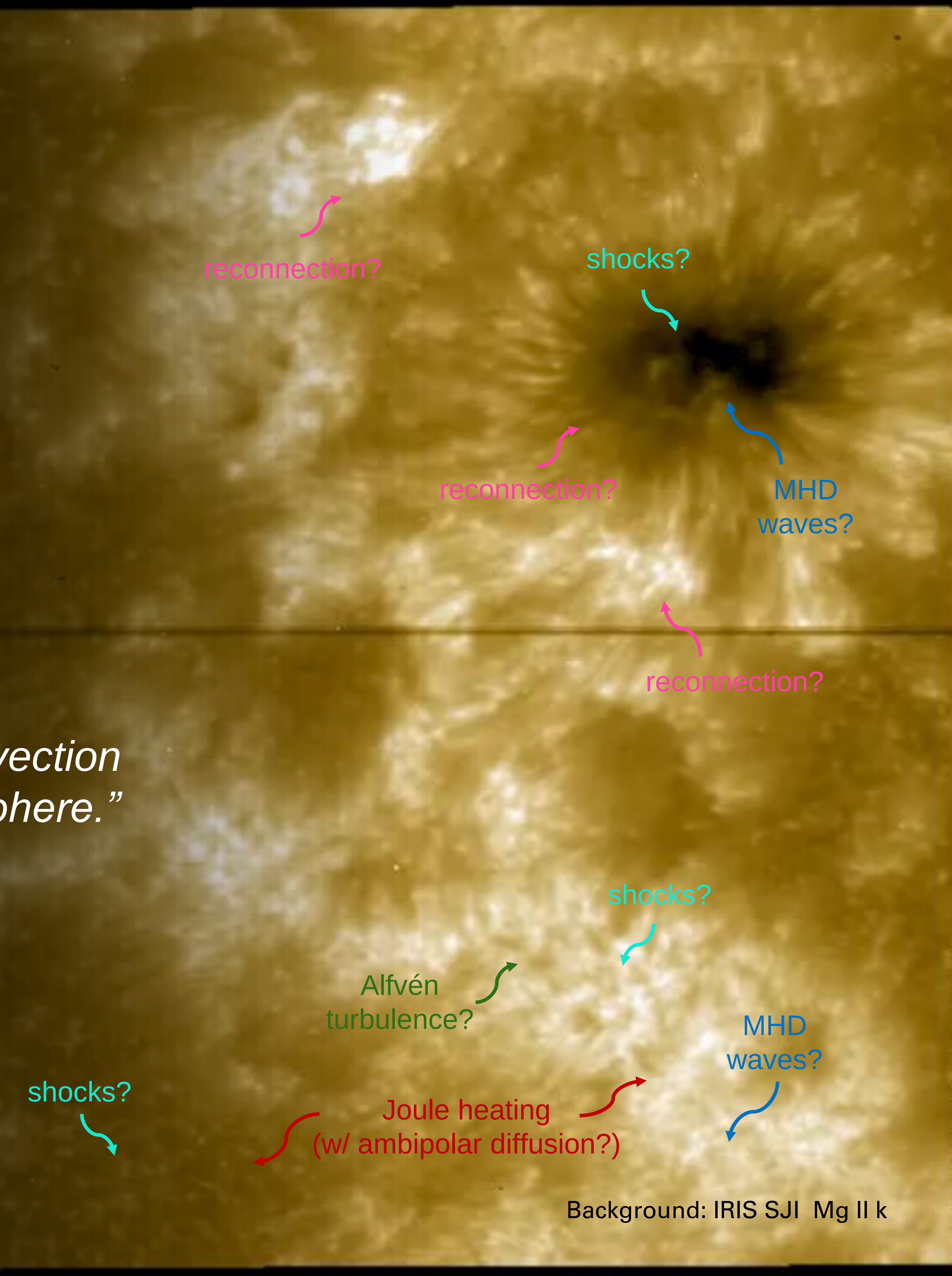
other: mass flows and thermal conduction from above

“(…) dissipation of energy carried by waves generated in the convection zone is the most likely source of the energy heating the chromosphere.”

Heating mechanisms

compiled by Carlsson, De Pontieu & Hansteen (**2019**)

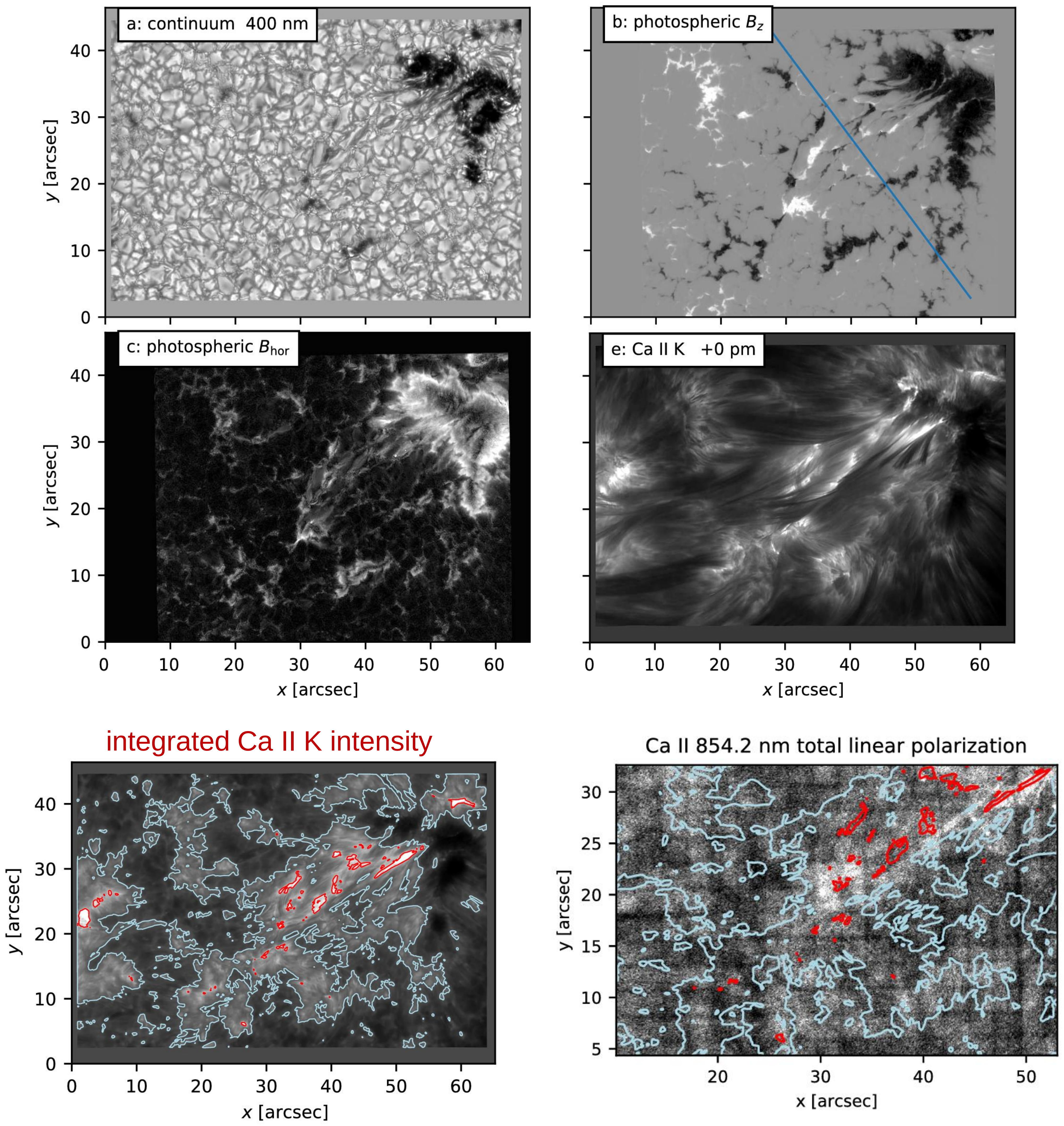
QS	acoustic shocks, reconnection, Joule heating, ion-neutral effects
AR	magnetoacoustic shocks, reconnection, Joule heating, Alfvén turbulence, MHD waves, ion-neutral effects



Background: IRIS SJI Mg II k

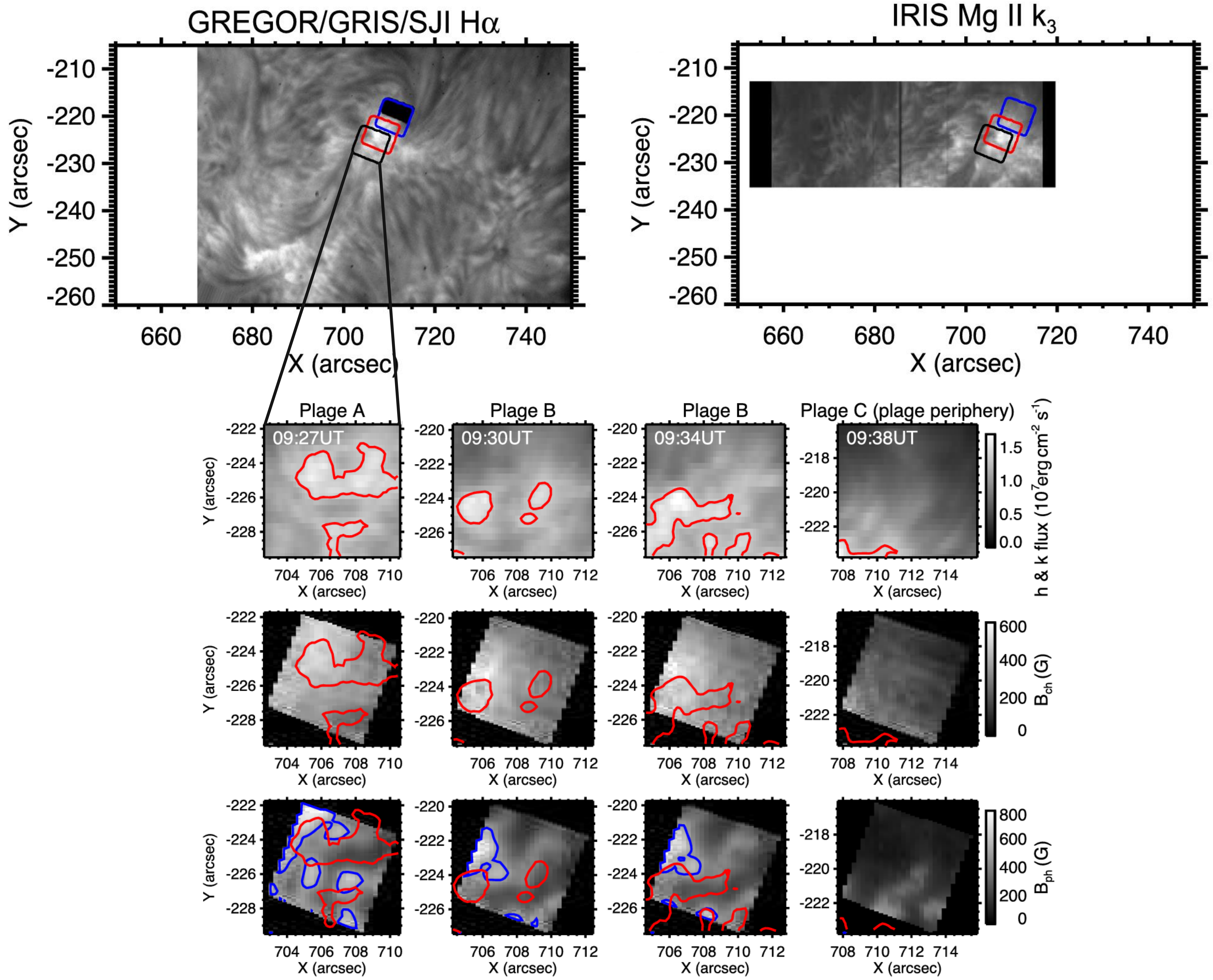
High-resolution proxies for chromospheric heating

SST/CRISP and CHROMIS observations



Leenaarts+ (2018)

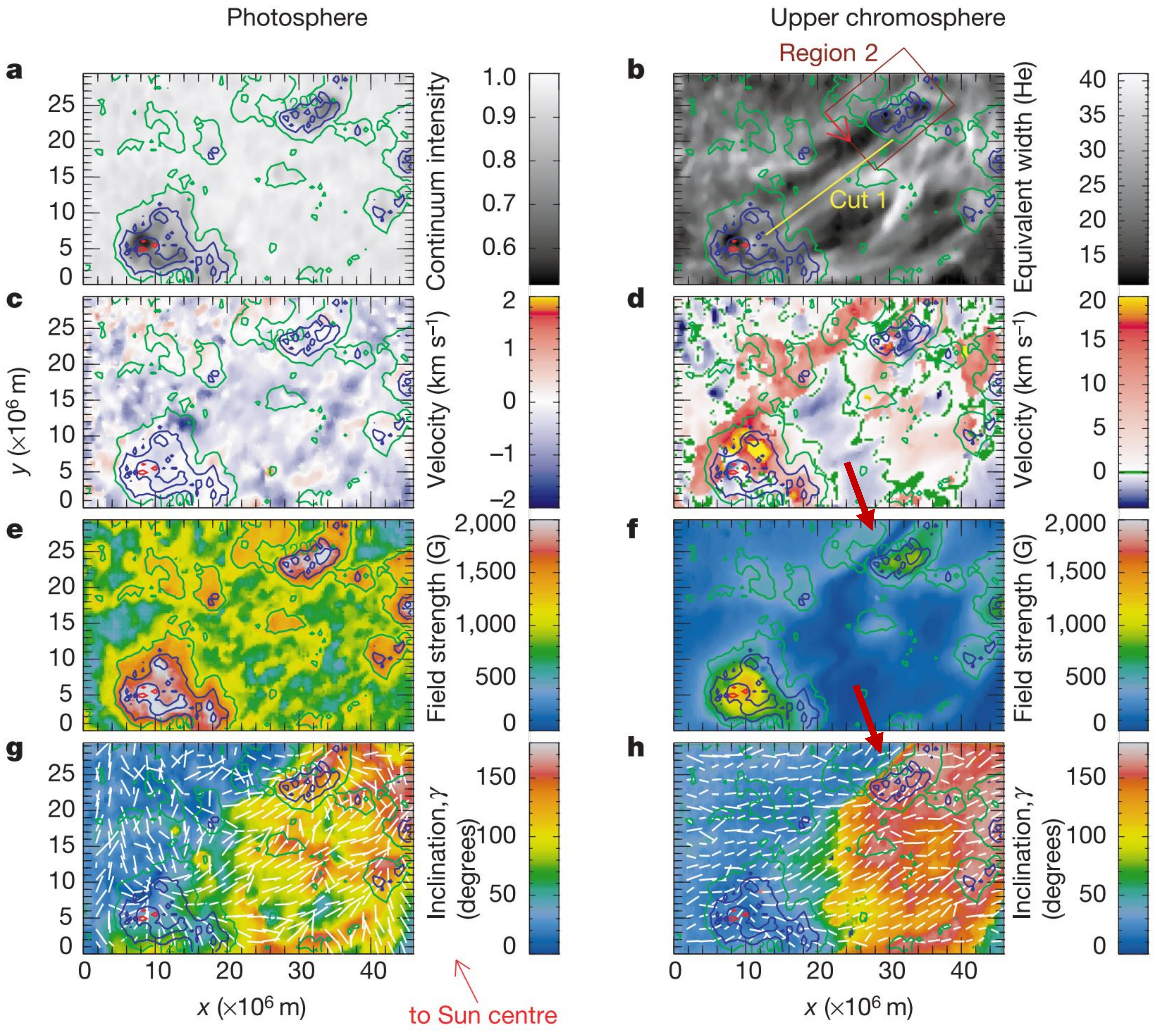
GREGOR/GRIS and IRIS observations



Anan+ (2021)

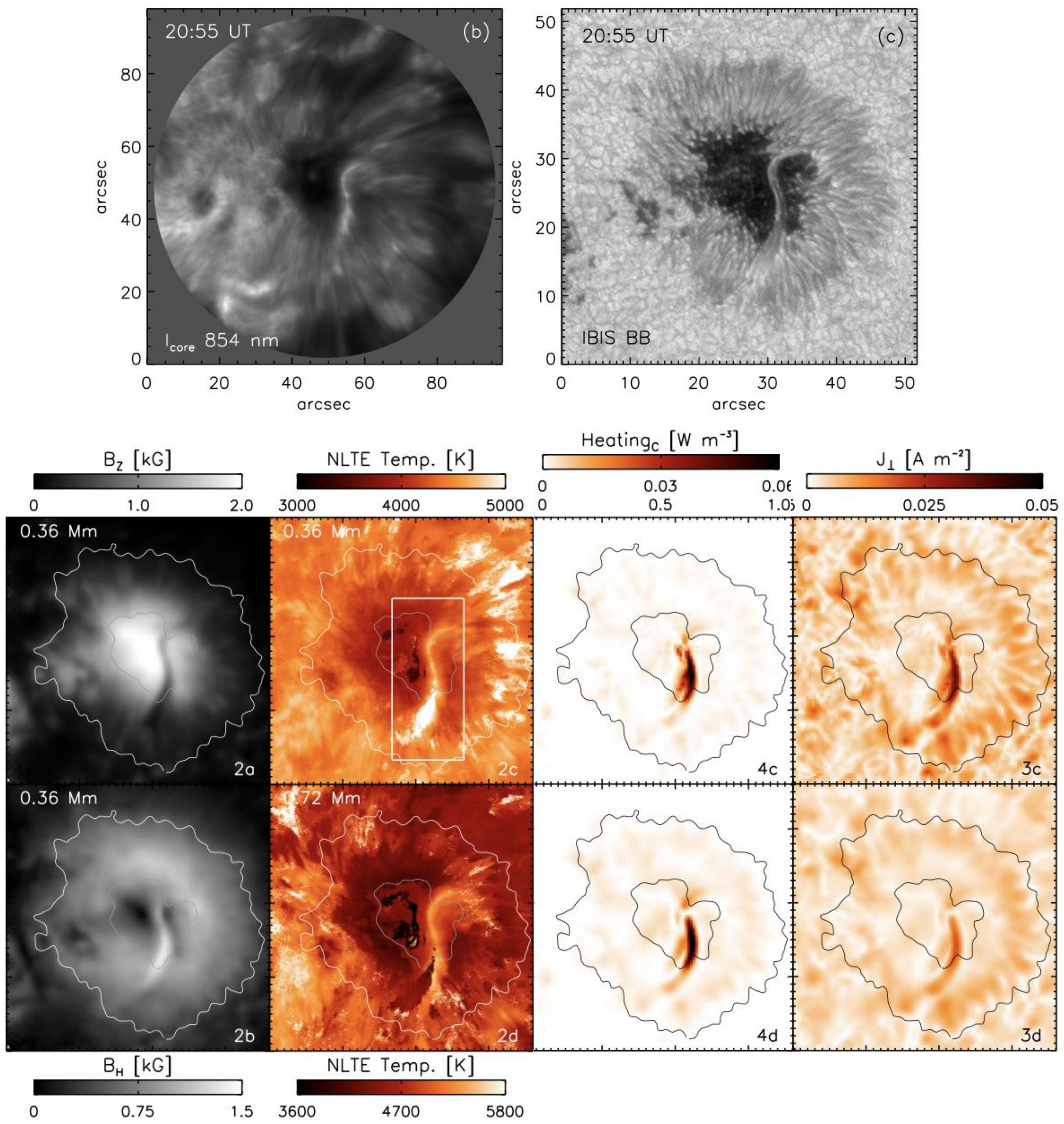
Electric currents in the chromosphere are poorly understood

He I 10830, VTT observations



Solanki+ (2003)

Ca II 8542, Dunn/IBIS observations

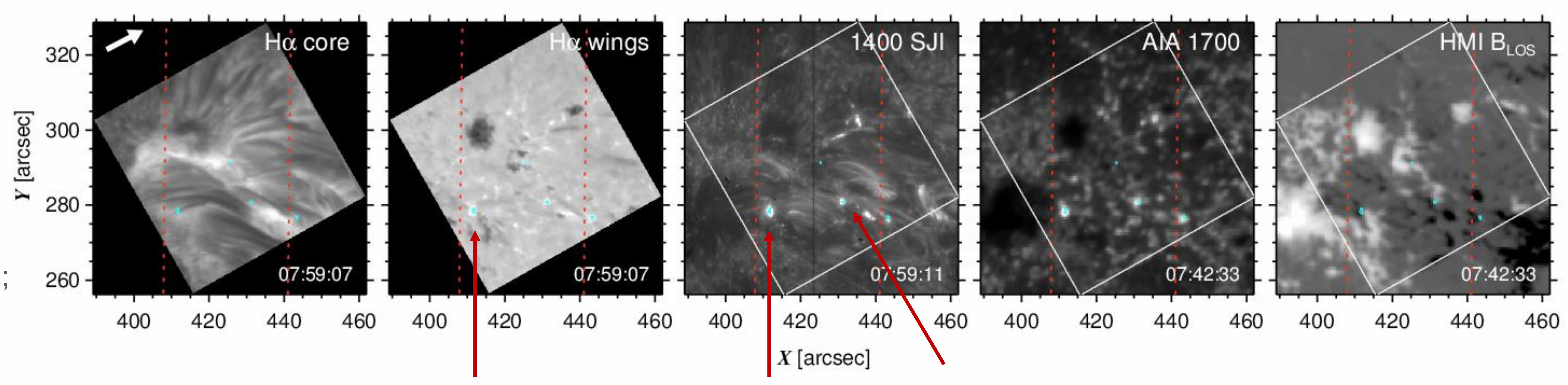


Louis+ (2021)

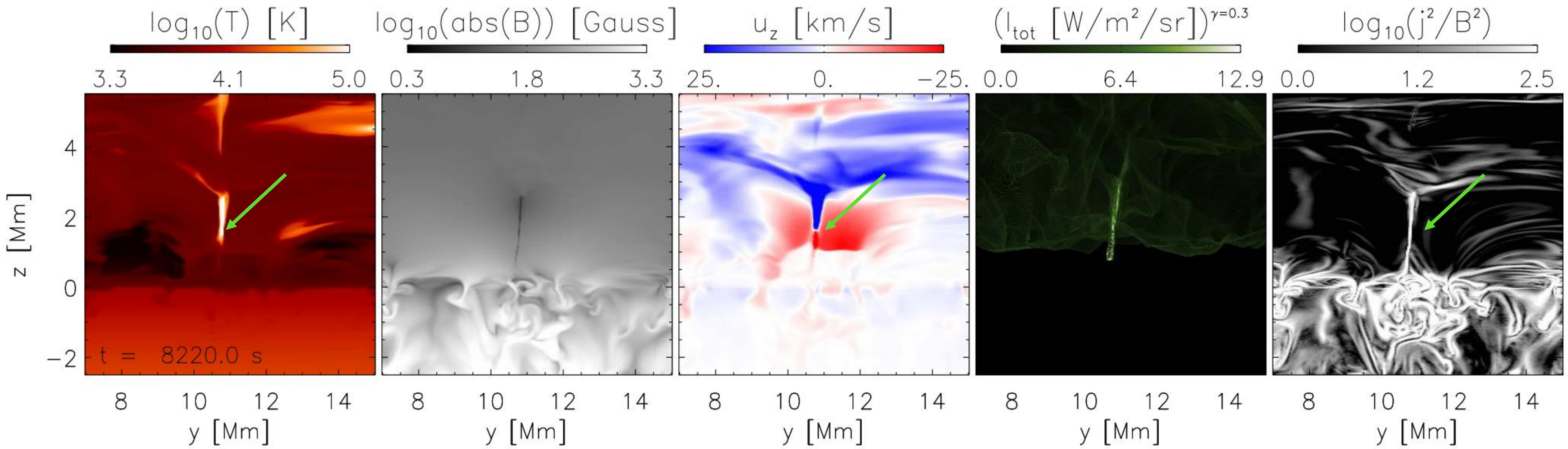
Heating in chromospheric current sheets: UV-bursts

IRIS, AIA, SST
observations
Vissers+ (2015)

see also, e.g., Peter+(2014);
Guglielmino+(2018)
Tian+(2018)



2D cut of a 3D Bifrost simulation



Hansteen+ (2019)

see also, e.g., Nobrega-Siverio+ (2017);
Priest+ (2018); Peter+ (2019)

Joint observations with ALMA and the 1-m SST in 2019

da Silva Santos+ (2020, 2022a, 2022b)

Cycle 6
April 13, 2019

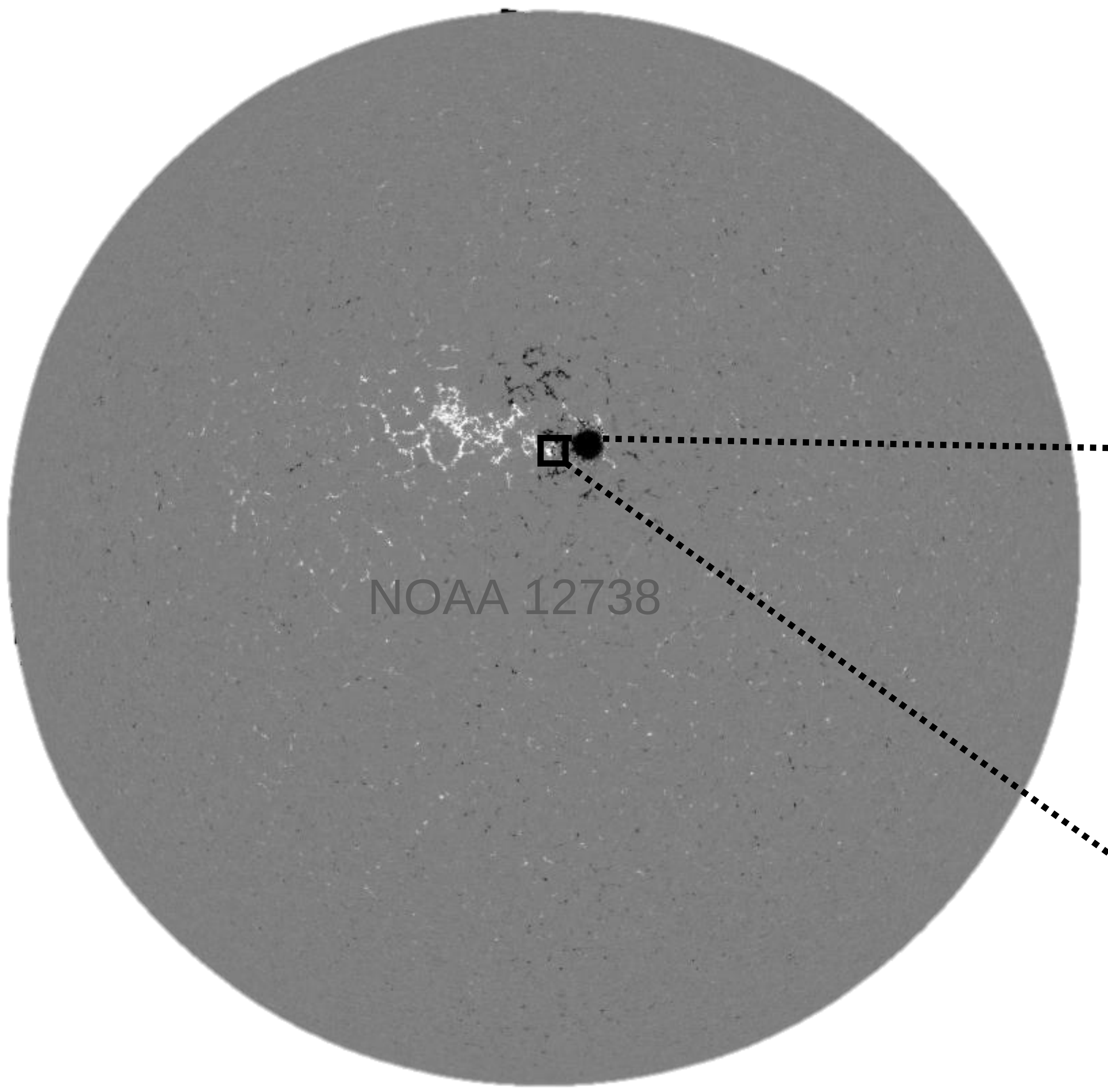
14:15 … 17:50 UT

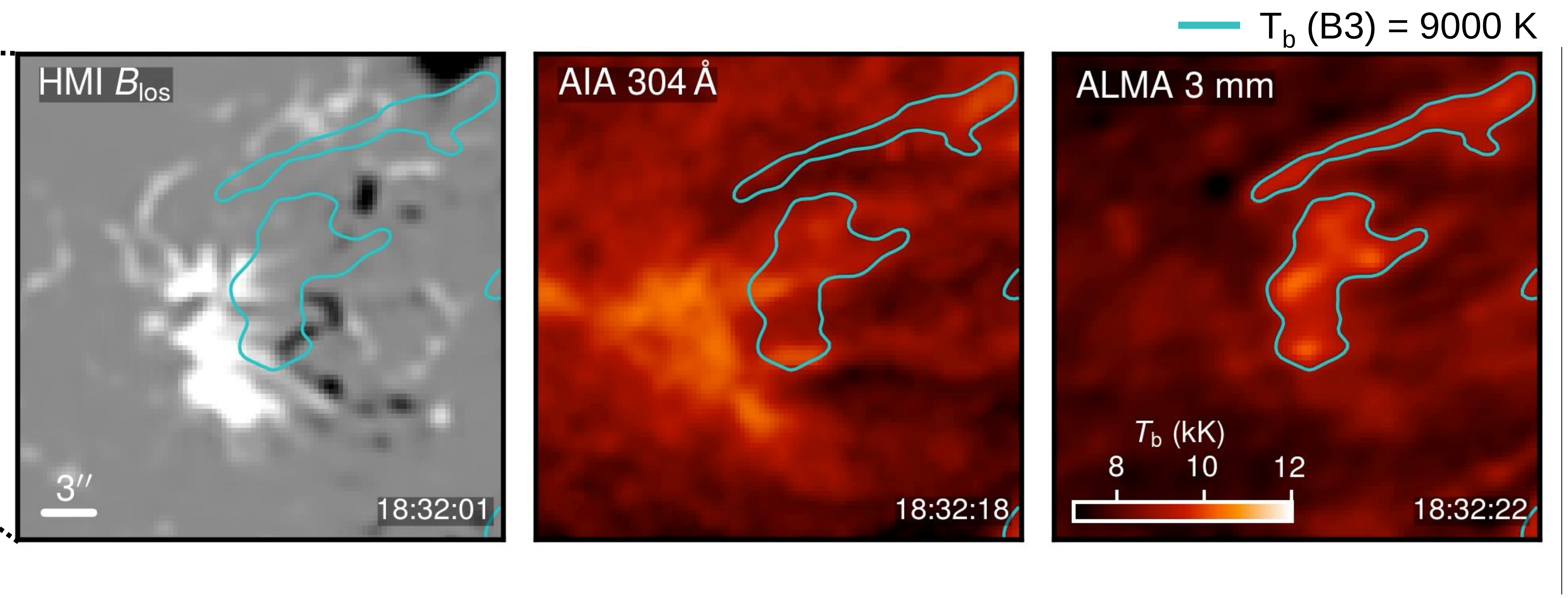
IRIS: NUV (e.g. Mg II h and k), FUV (e.g. Si IV, C II) passbands, dense raster
Hinode/SOT/SP and EIS: Fe I 6301 magnetograms and EUV lines
ALMA: Band 6 (1.25 mm continuum), baselines up to 700 m – 0.6 arcsec, mosaic

18:50 UT

1m- SST/CRISP: Ca II 8542 and Fe I 6173 (polarimetry), single scan
ALMA: Band 3 (3 mm continuum), baselines up to 700 m – 1.2 arcsec, 2sec cadence

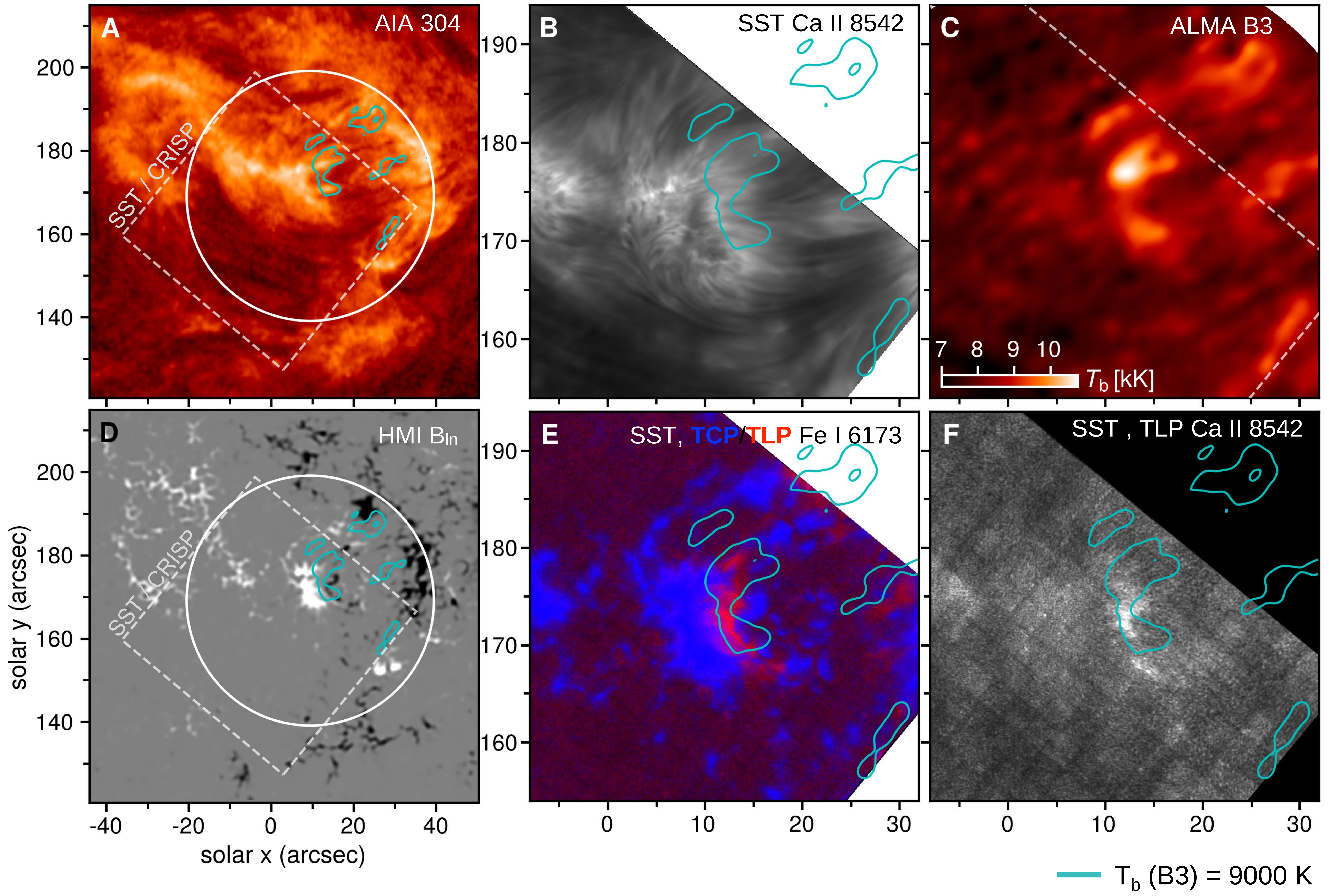
All data are available upon request

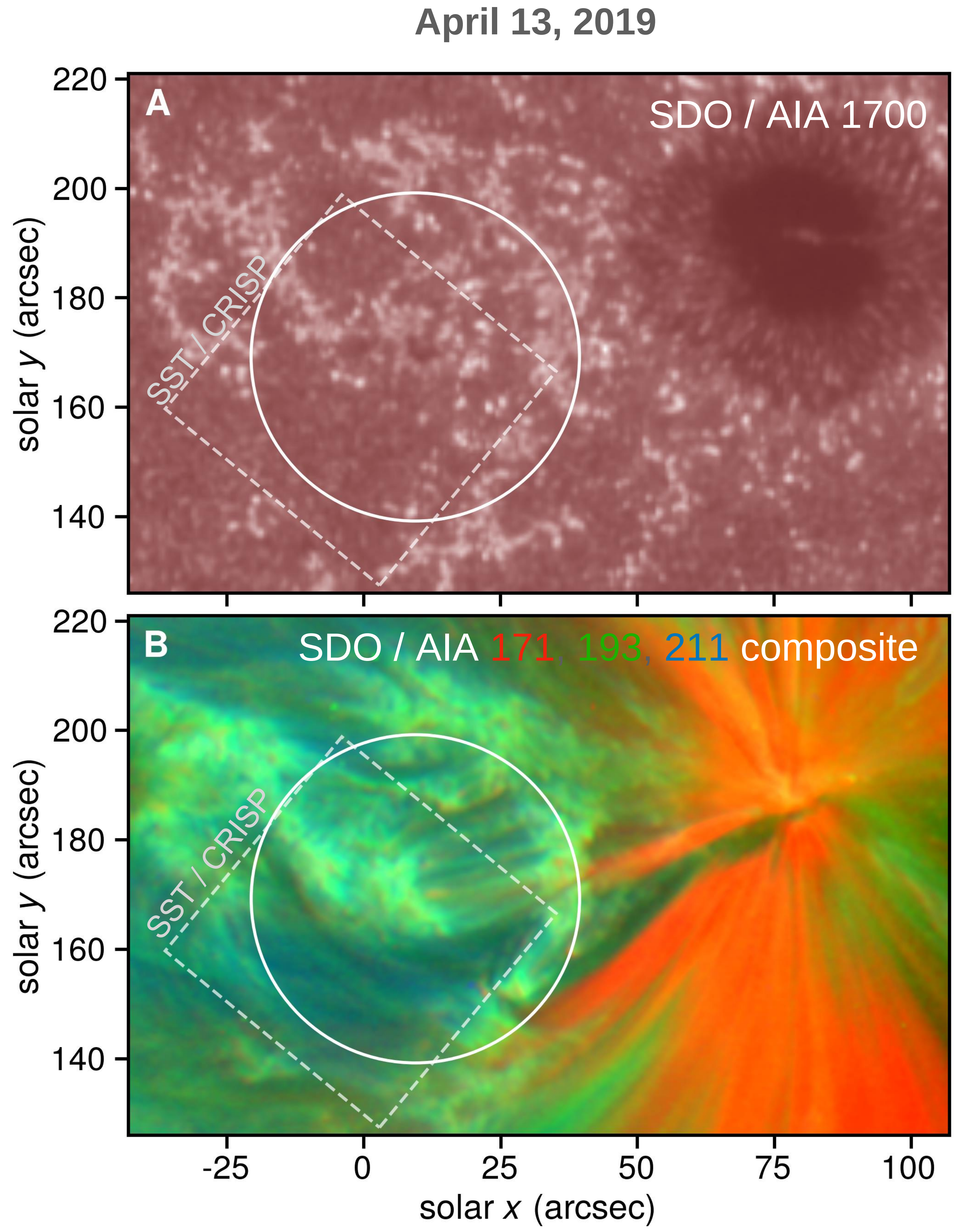


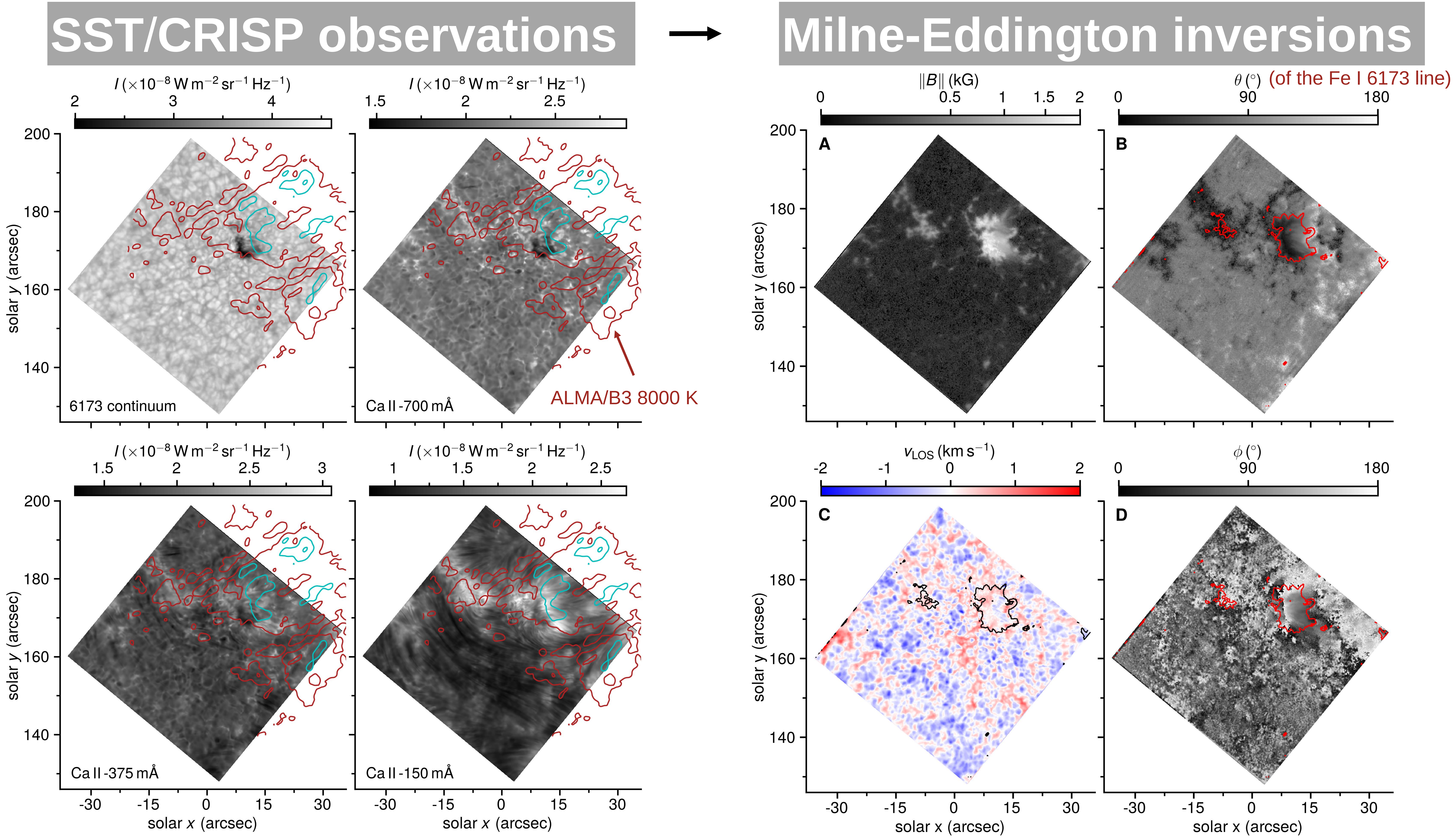


Flux emergence and chromospheric heating

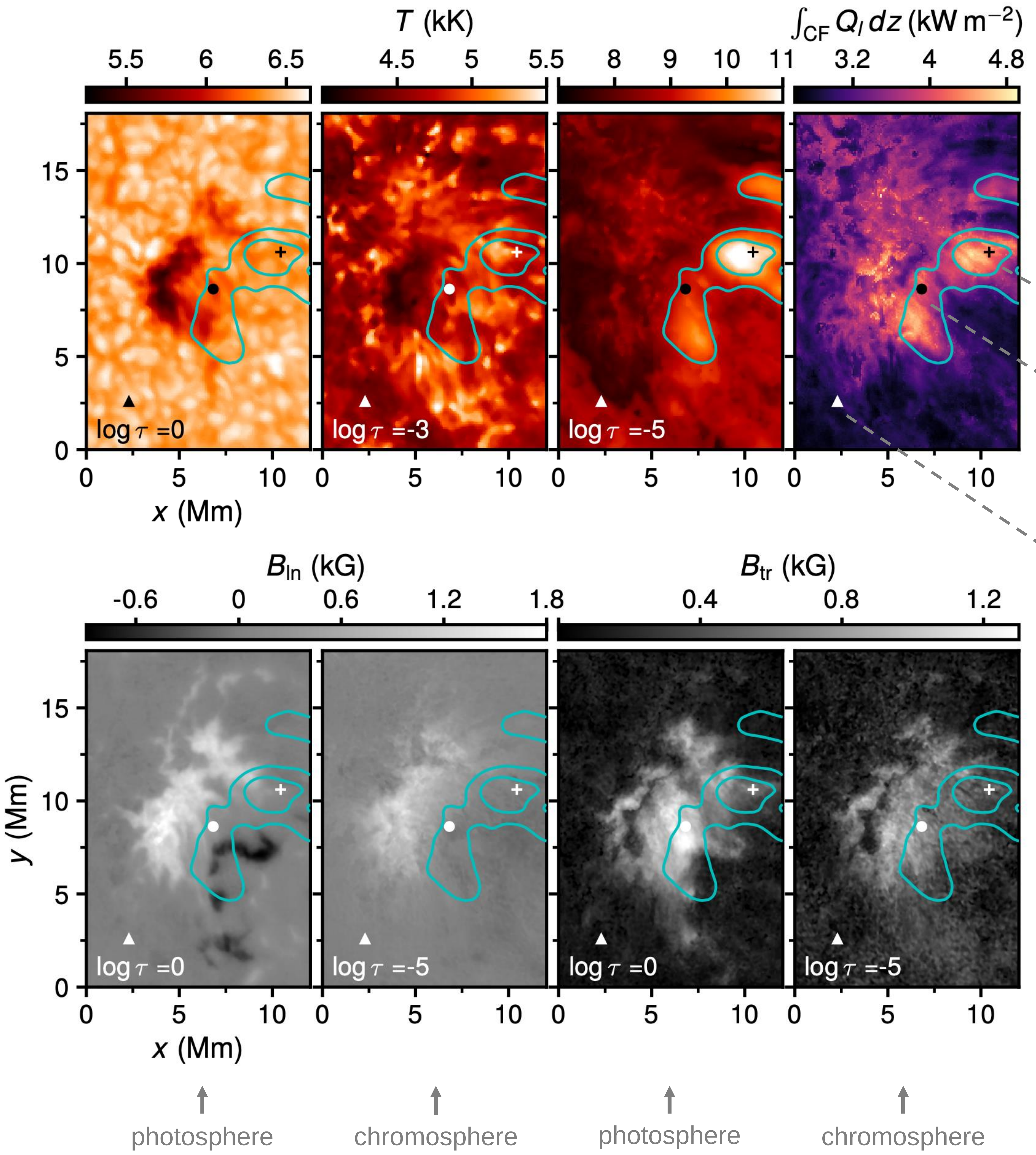
J. M. da Silva Santos, S. Danilovic, J. Leenaarts, J. de la Cruz Rodríguez, X. Zhu, S. White, G. Vissers & M. Rempel **(2022, *A&A, 661, A59*)**





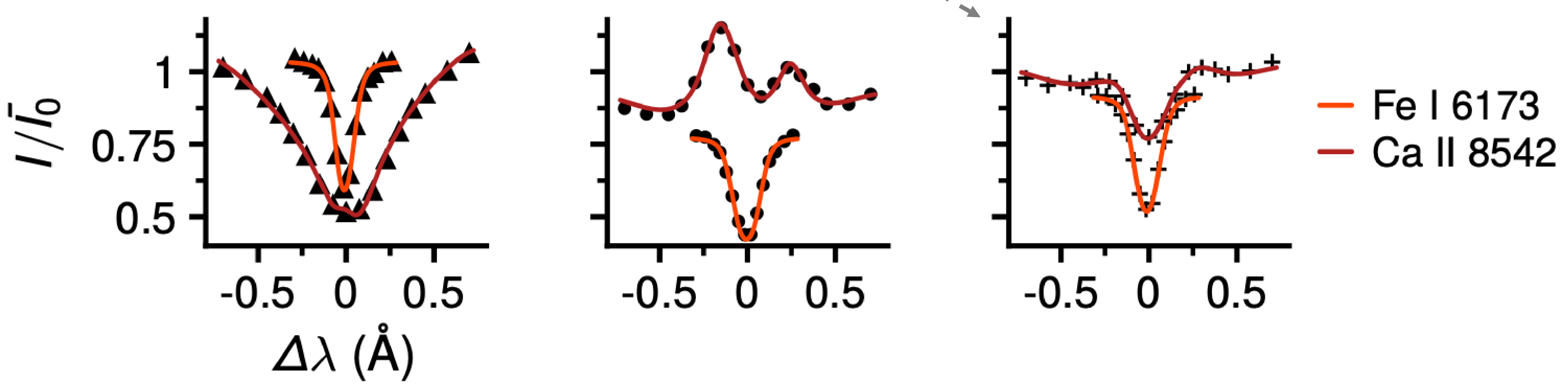

SST/CRISP observations
Milne-Eddington inversions
I (×10⁻⁸ W m⁻² sr⁻¹ Hz⁻¹)
6173 continuum
Ca II -700 mÅ
Ca II -375 mÅ
Ca II -150 mÅ
ALMA/B3 8000 K
solar y (arcsec)
solar x (arcsec)
‖B‖ (kG)
θ (°) (of the Fe I 6173 line)
v_LOS (km s⁻¹)
φ (°)
A
B
C
D

Non-LTE inversions of SST/CRISP+ALMA 3 mm data



Radiative losses (Ca II, Mg II, HI) within the contribution function of the 3 mm continuum (upper chromosphere T ~ 10,000 K)

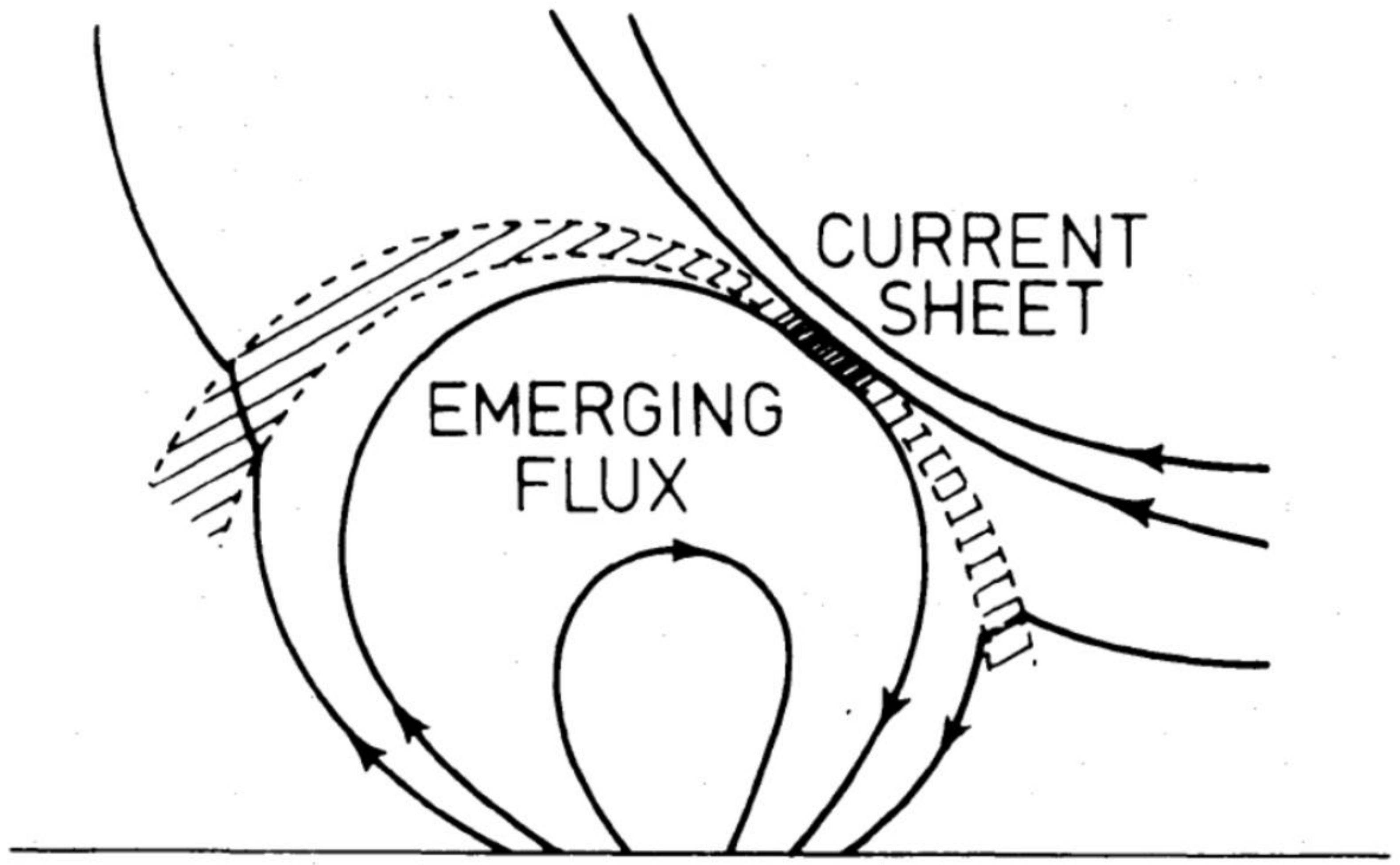
$$Q_l \sim \mathrm{h}\nu_0(n_i R_{ij} - n_j R_{ji})$$



example fits at different locations

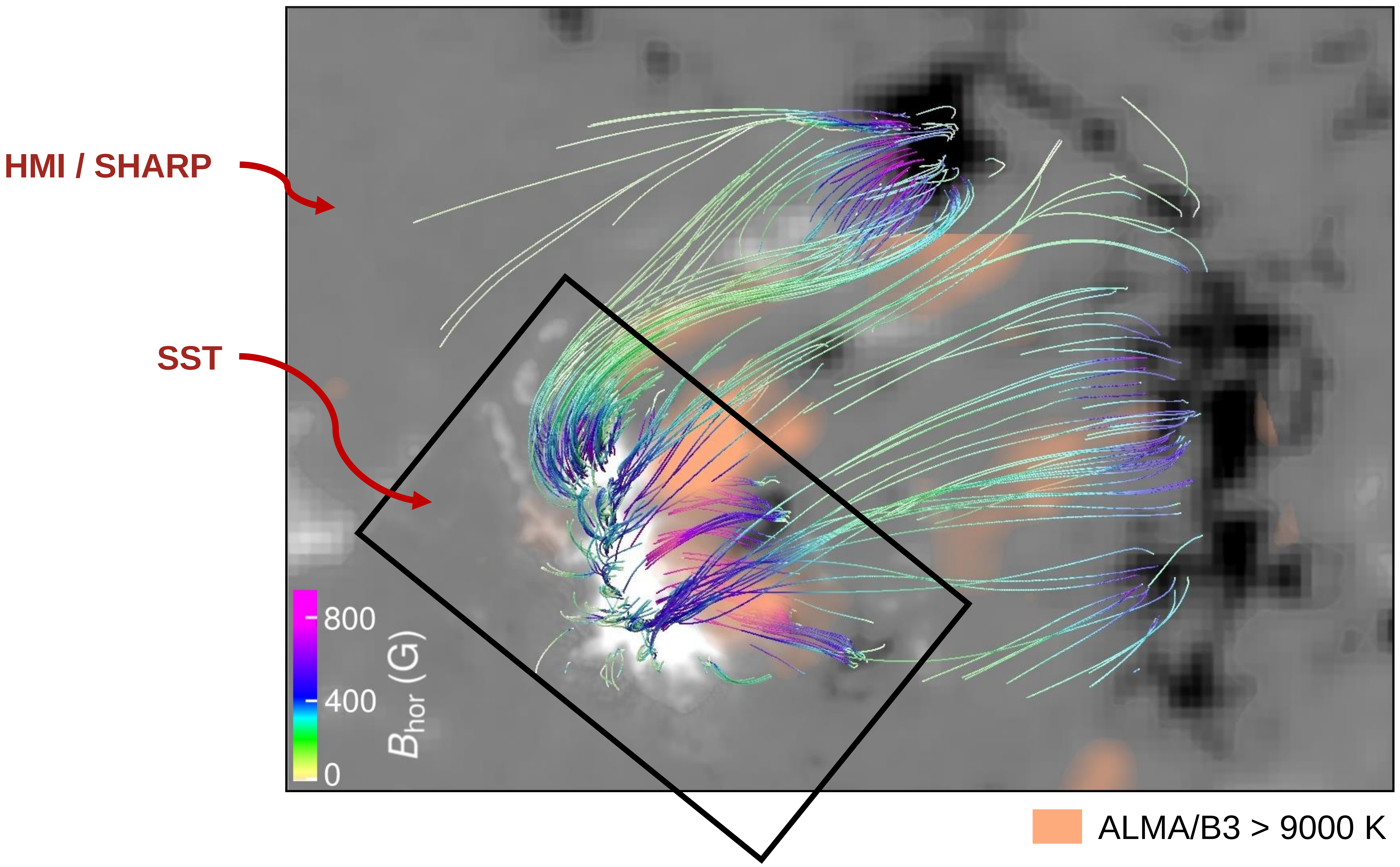
STiC code

Magnetohydrostatic extrapolation based on the SST+HMI (composite) vector magnetogram



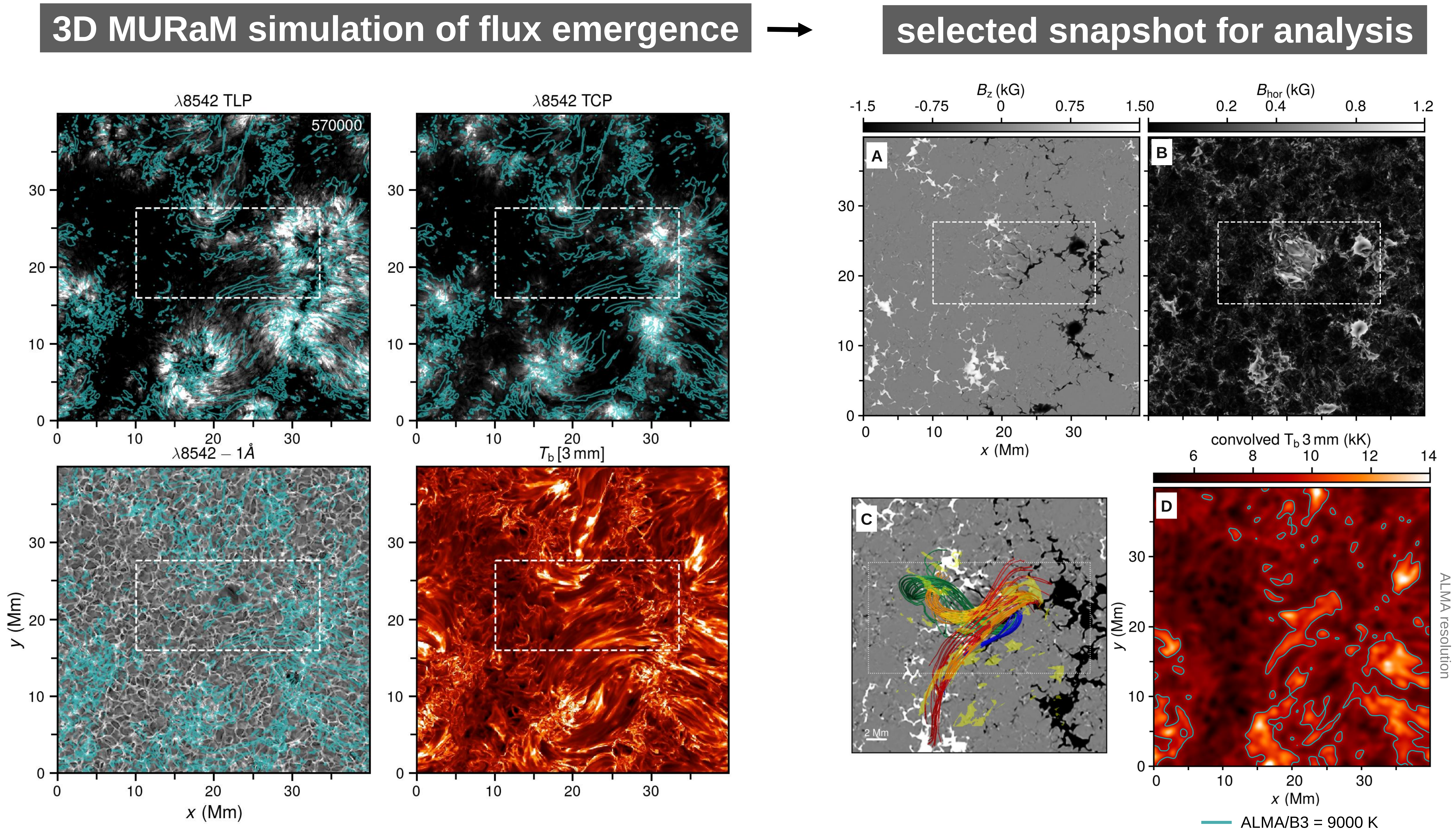
Heyvaerts+ (1977)

see also, e.g., Galsgaard+ (2007)
Cheung & Isobe (2014)
Archontis & Hansteen (2014)
Ortiz+ (2016)

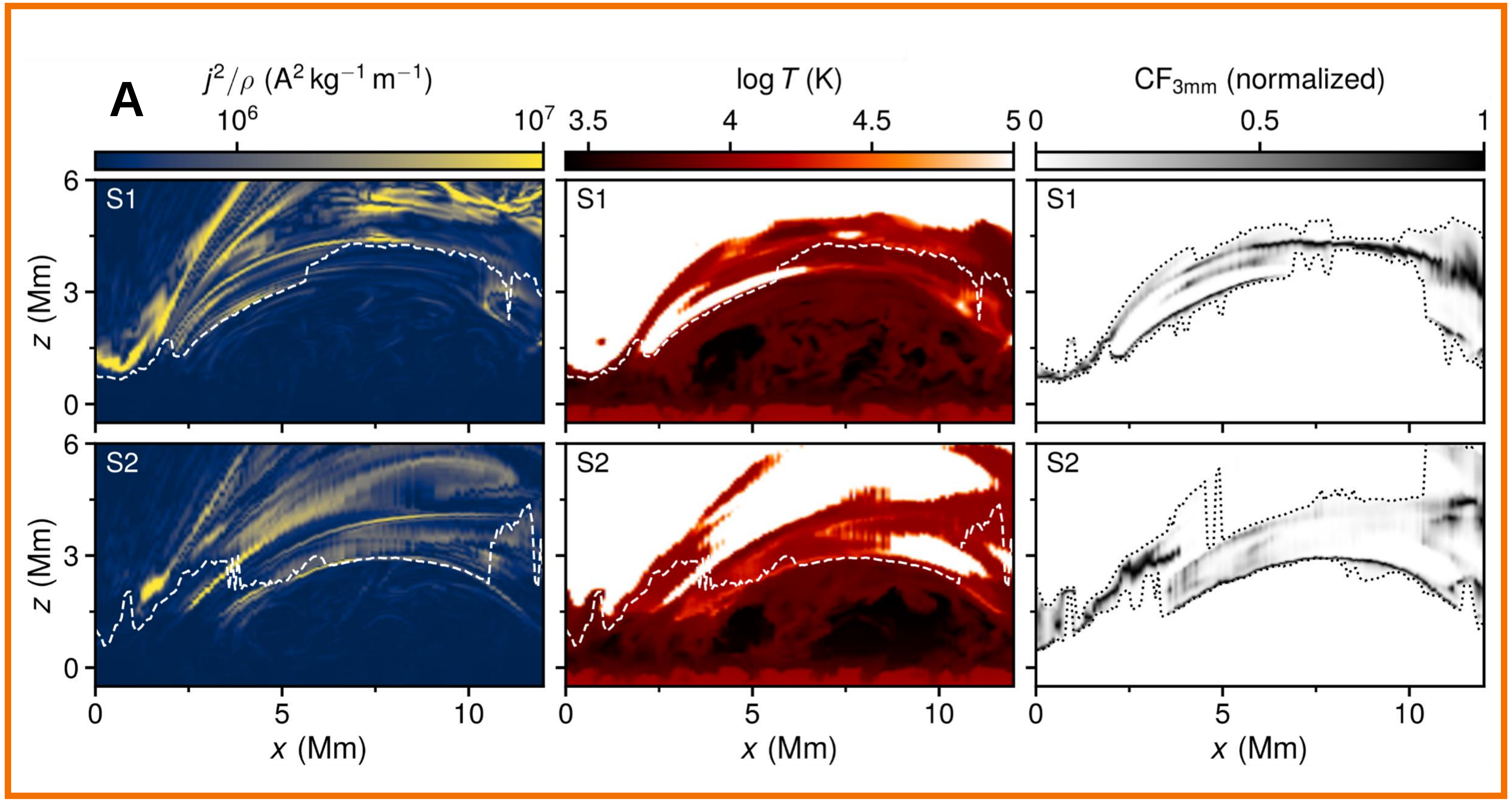


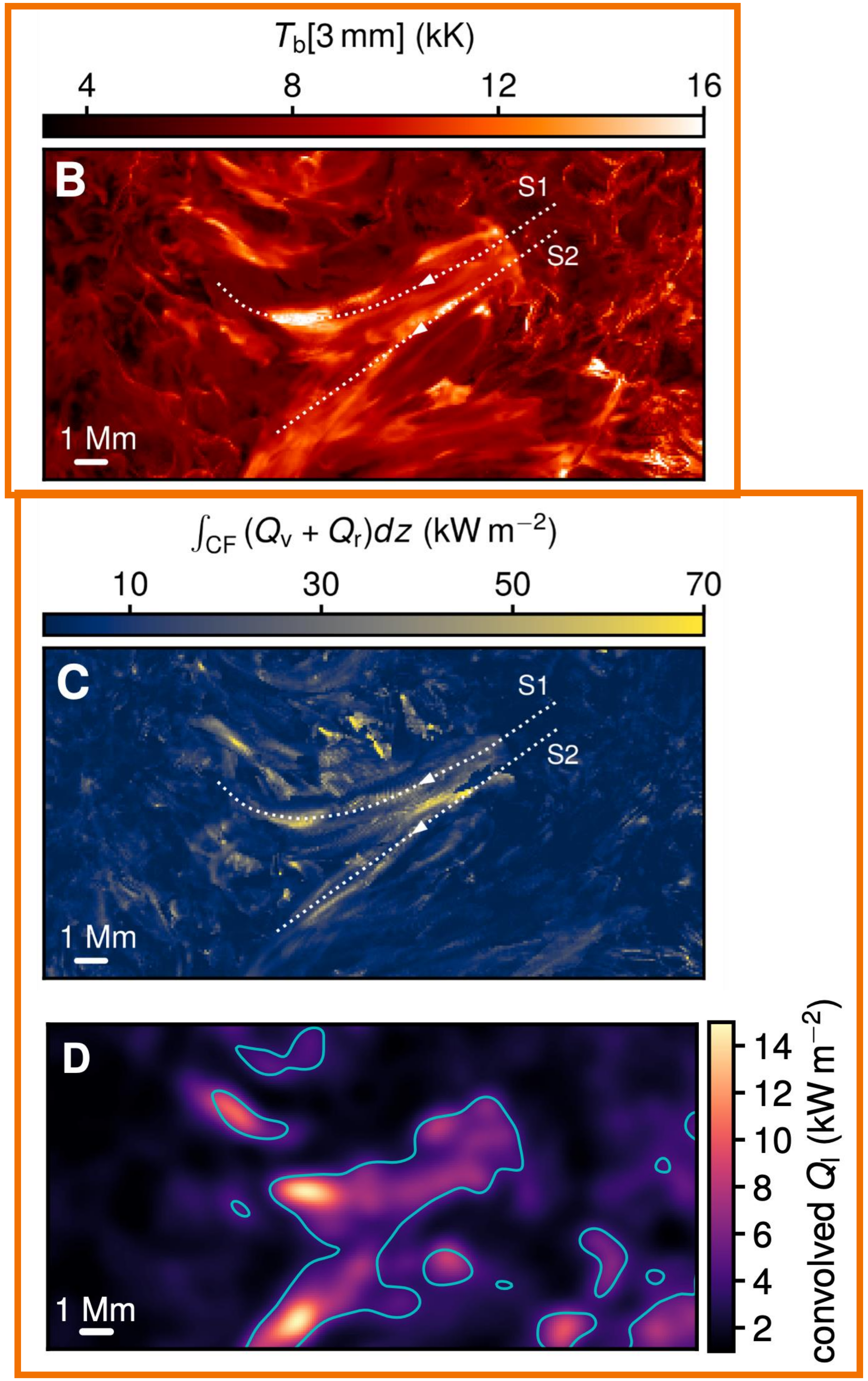
da Silva Santos+ (2022)

see e.g., Zhu & Wiegelmann (2018); Zhu+ (2020) on the extrapolation algorithm



3D MURaM simulation of flux emergence
selected snapshot for analysis
λ8542 TLP
570000
λ8542 TCP
λ8542 − 1Å
T_b [3 mm]
y (Mm)
x (Mm)
B_z (kG)
-1.5
-0.75
0
0.75
1.50
B_{hor} (kG)
0.2
0.4
0.8
1.2
A
B
C
2 Mm
D
convolved T_b 3 mm (kK)
6
8
10
12
14
ALMA resolution
ALMA/B3 = 9000 K





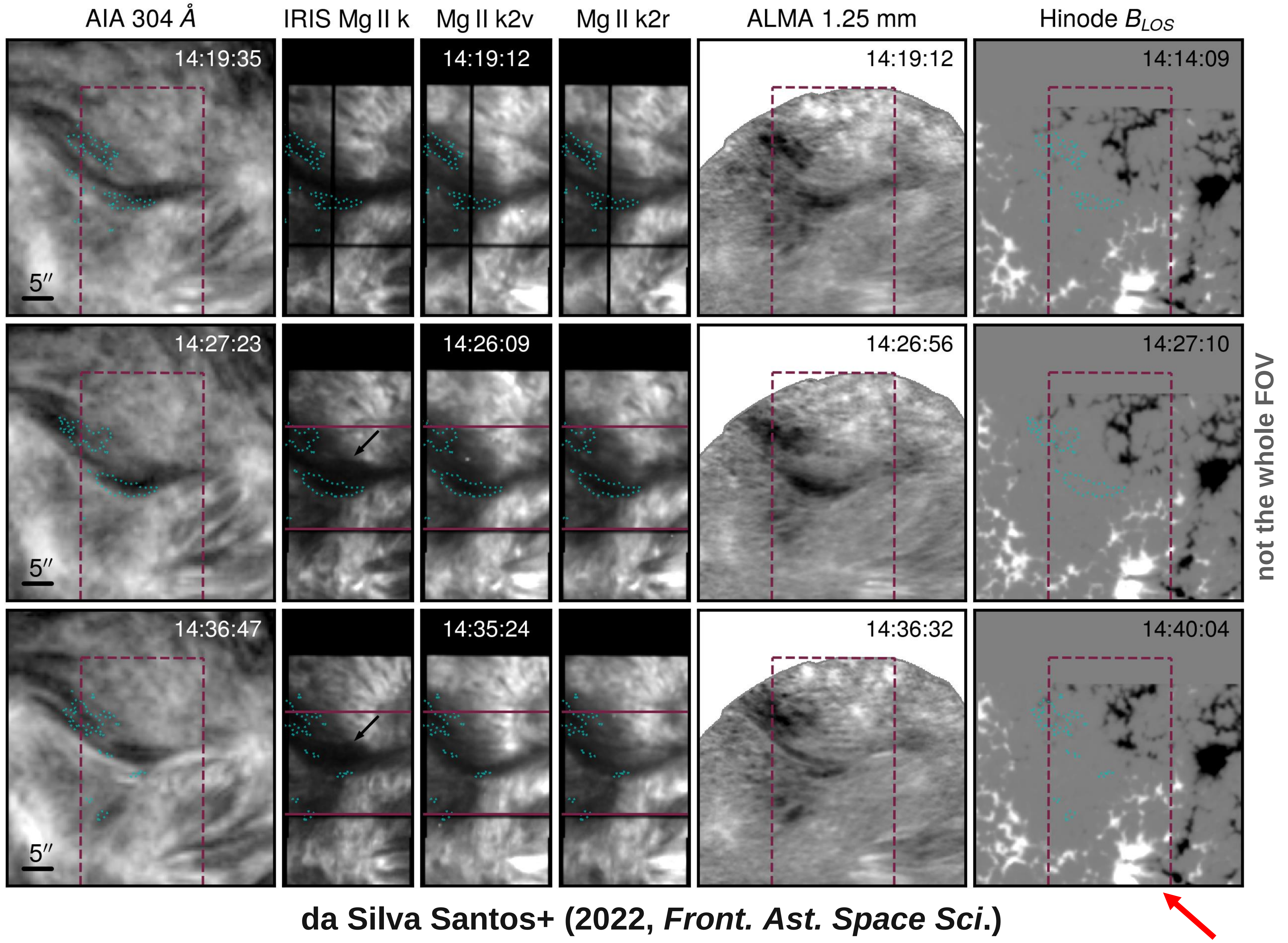
A Vertical slices of the MURaM atmosphere

B 3 mm brightness temperature

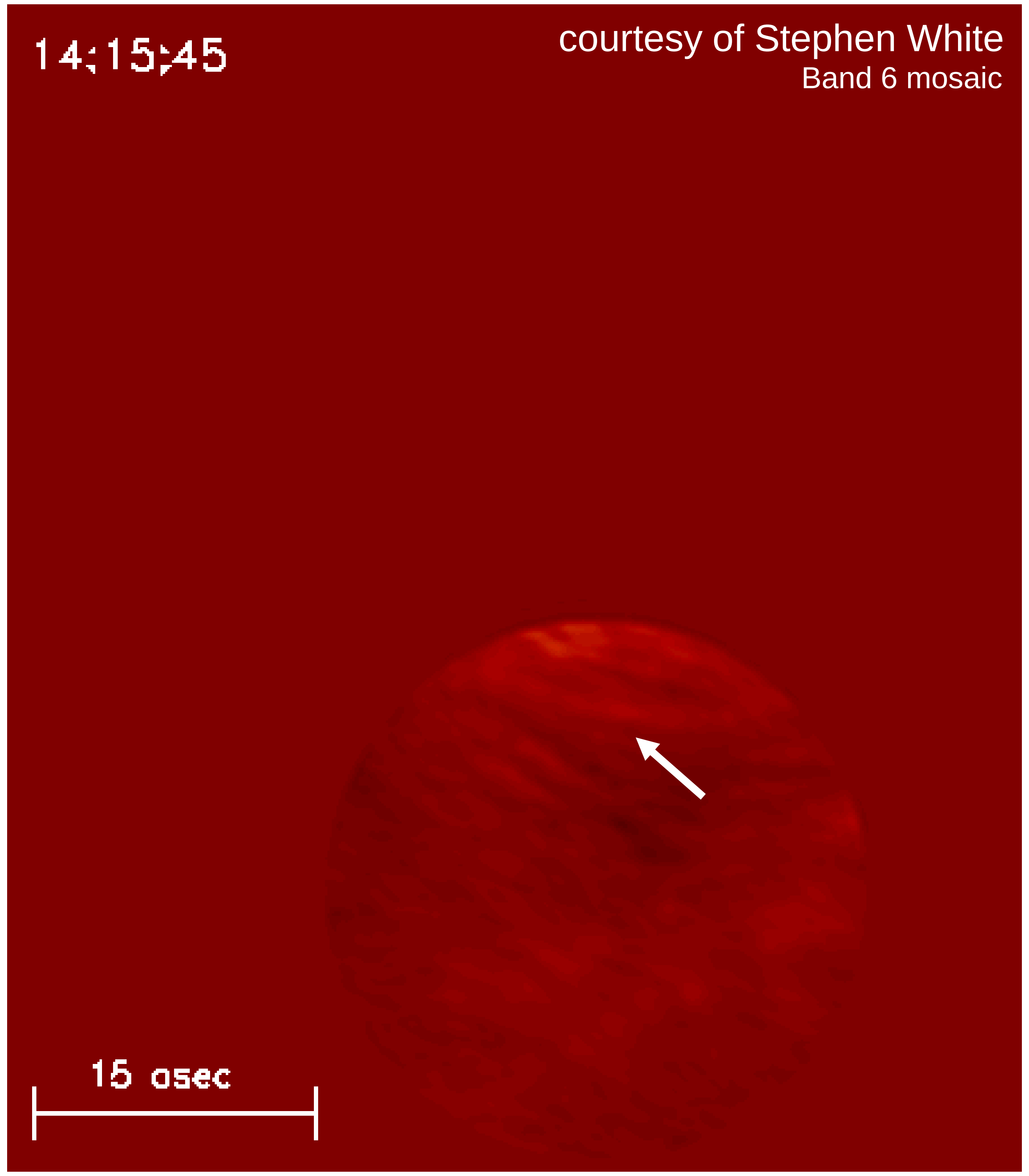
C Total heating rates within the 3 mm formation range (**capped**)

D Chromospheric radiative losses within the 3 mm formation range

IRIS / Hinode / ALMA observations of the AR hours earlier



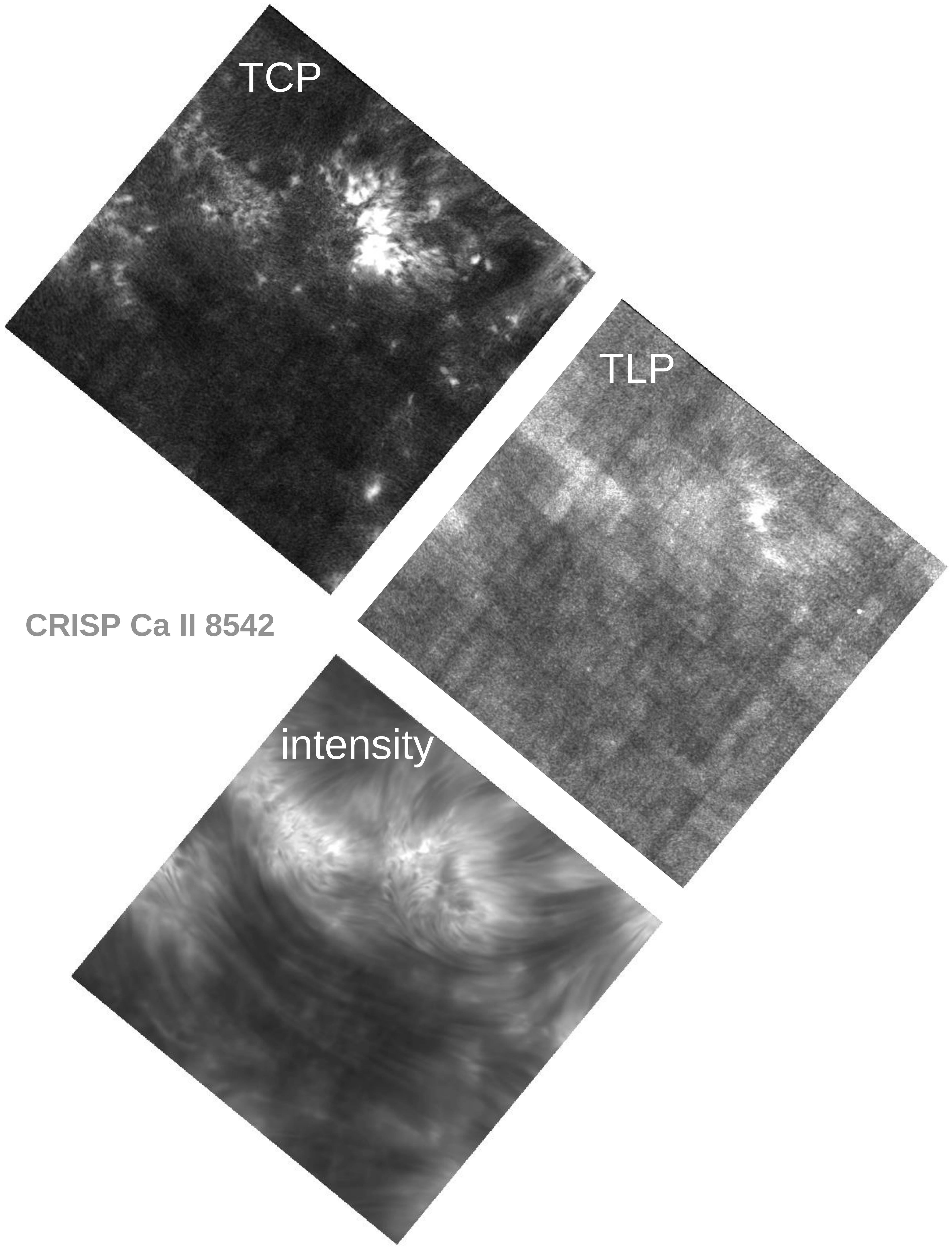
da Silva Santos+ (2022, *Front. Ast. Space Sci.*)



April 13, 2019

Band 6 (1.25 mm continuum)
~ 1.5 min cadence
~ 2h total time
0.6 arcsec resolution **(px size 0.3)**

with coobservations from IRIS
and Hinode/SP /EIS + EOVSA(?)
(but not SST or other)



Conclusions

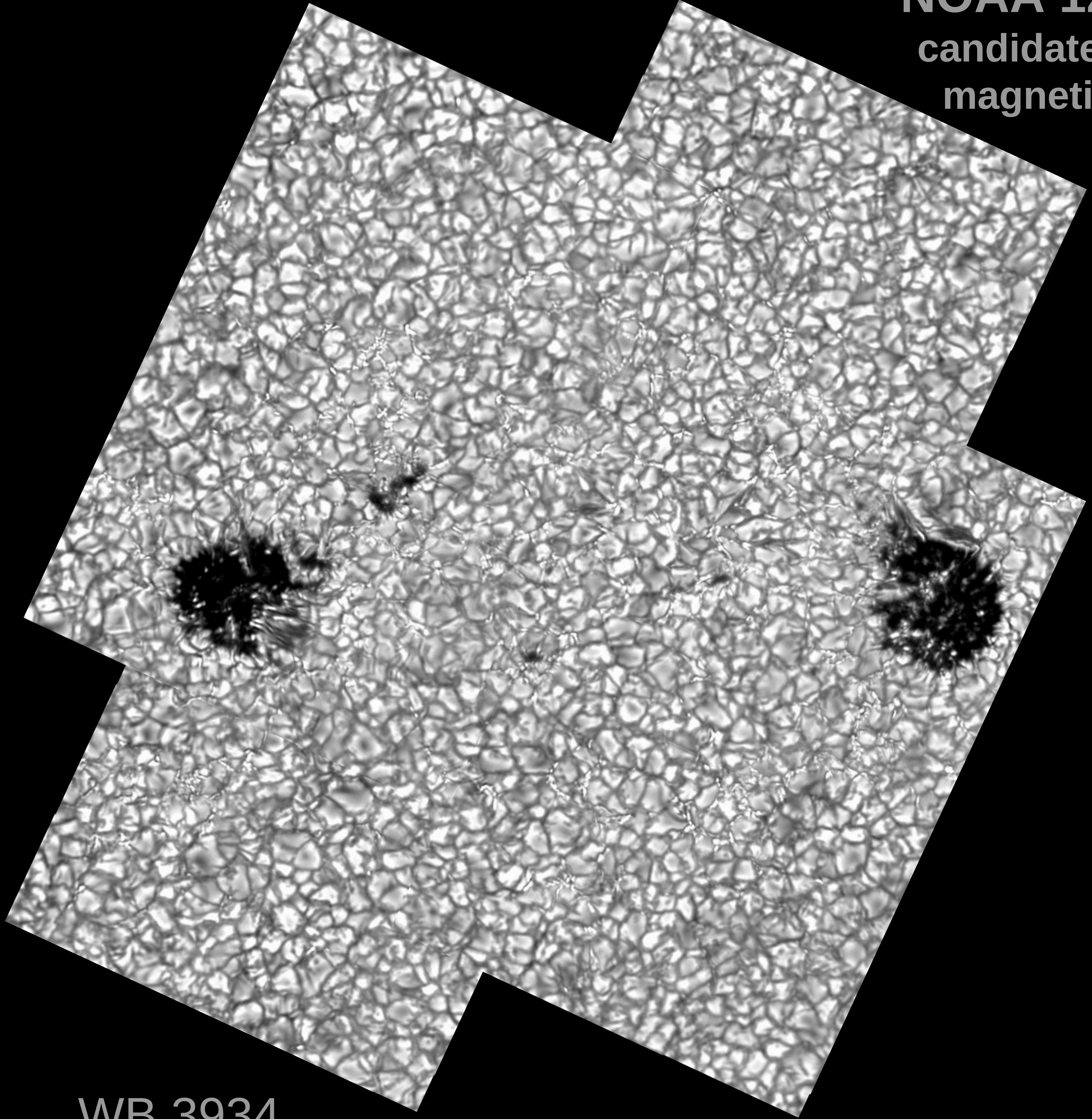
- Persistent, enhanced chromospheric temperatures are associated with the interaction of **low-lying magnetic loops** and the **canopy in an AR**.
- **Radiative cooling rates** (upper chromosphere ~10,000 K) up to ~5 kW m^{-2} — a factor >2 higher than in the surroundings.
- The main observables are reproduced by **MURaM simulation**.

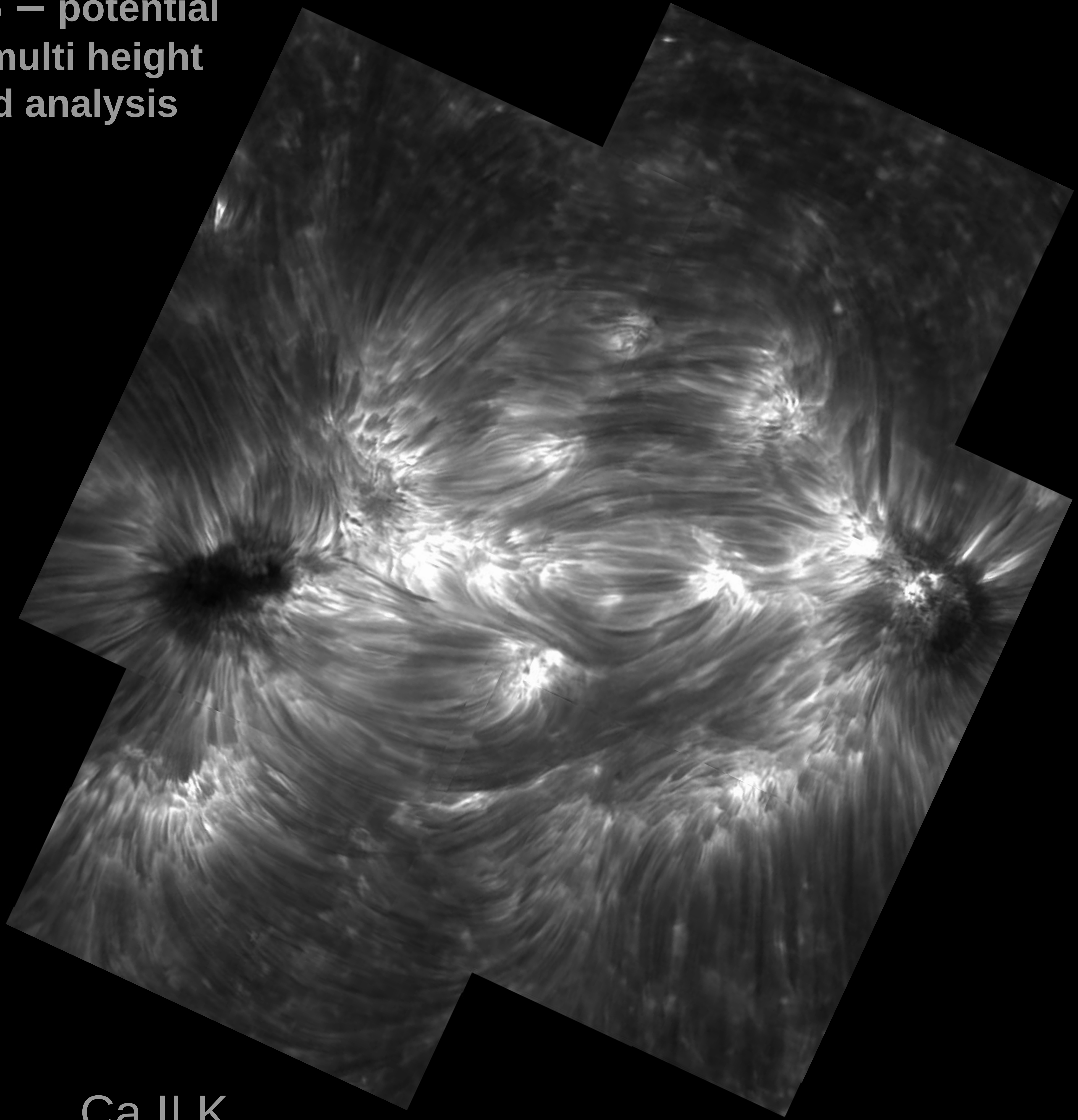
(freely available) inversion codes

https://github.com/jaimedelacruz/stic
https://github.com/jaimedelacruz/pyMilne

SST / CHROMIS

NOAA 12723 – potential candidate for multi height magnetic field analysis


WB 3934


Ca II K

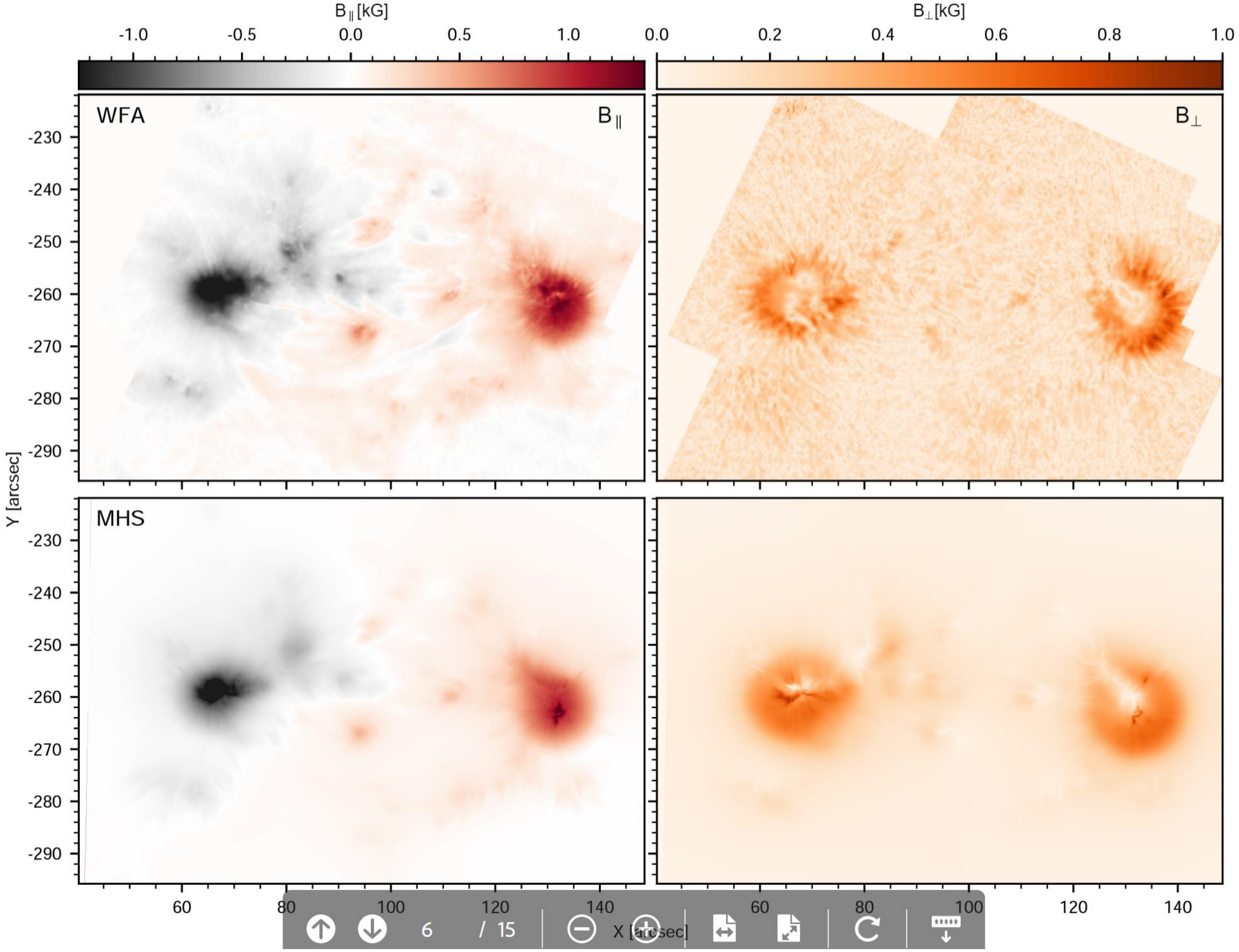
da Silva Santos, J. M. 2020, PhD Thesis

Gregal Vissers, S. Danilovic, X. Zhu, J. Leenaarts J., de la Cruz Rodríguez, C. J. Díaz Baso, J. M. da Silva Santos, and T. Wiegelmann
A&A, 662, A88 (2022)

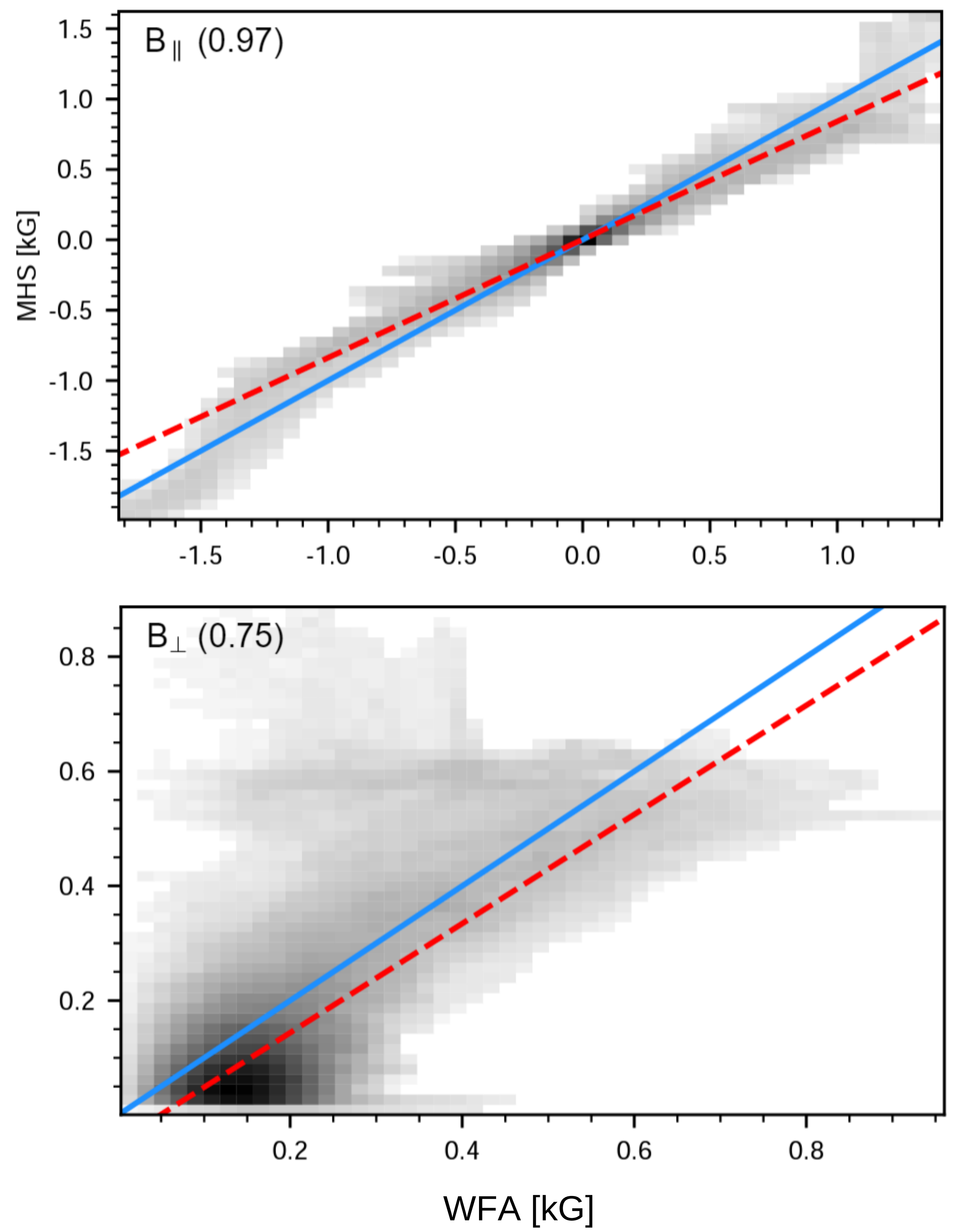
Comparing the **chromospheric magnetic field** inferred (1) directly from the SST/CRISP Ca II spectra and (2) from extrapolations of a photospheric magnetogram (Fe I 6173)

(1)

(2)



The Na I 5896 line was not used in this paper



What does this imply for the corona? Can we improve the extrapolation using multiple line constraints? What can we learn about chrom. heating?