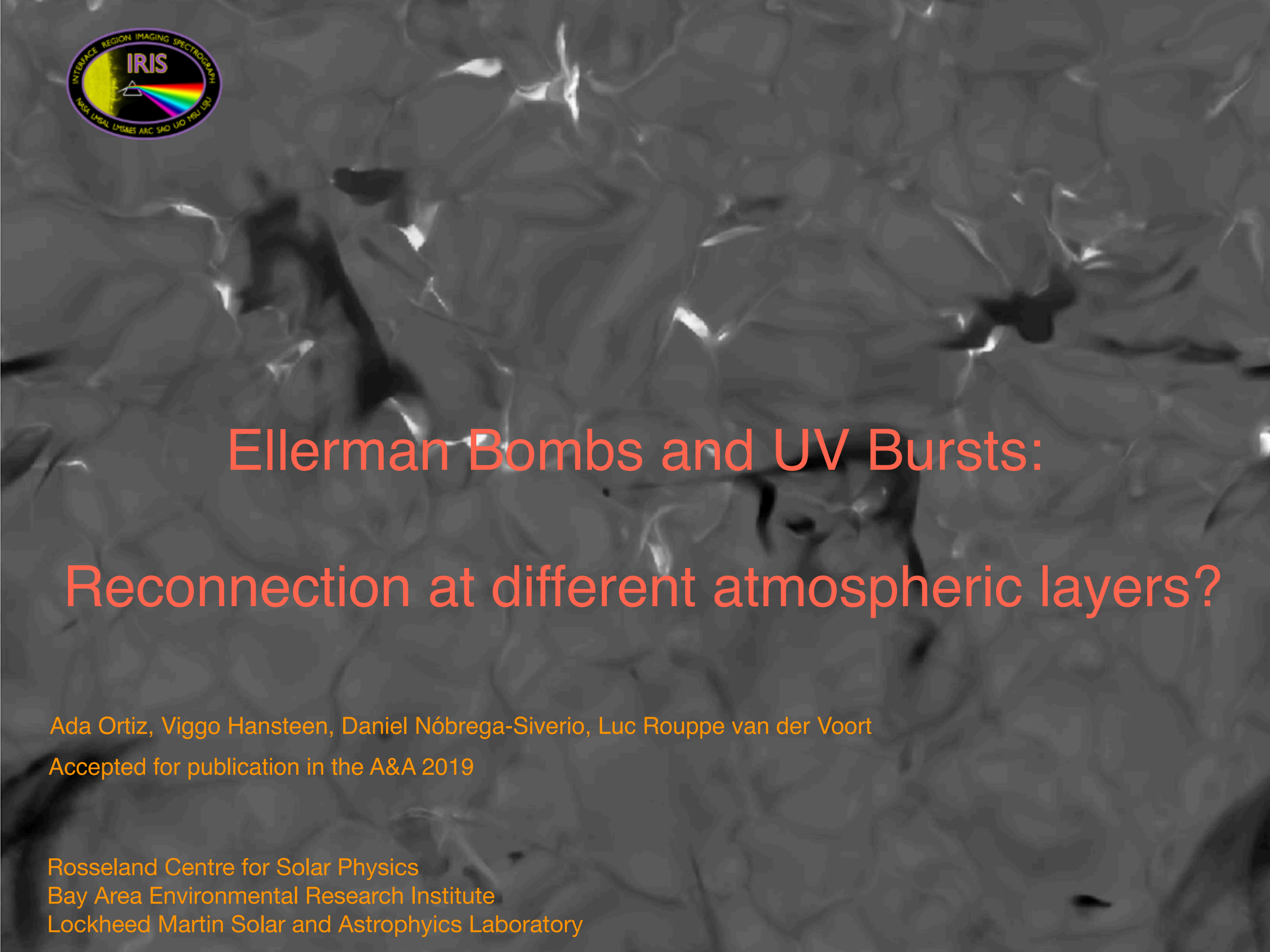

Ellerman Bombs and UV Bursts:

Reconnection at different atmospheric layers?

Ada Ortiz, Viggo Hansteen, Daniel Nóbrega-Siverio, Luc Rouppe van der Voort

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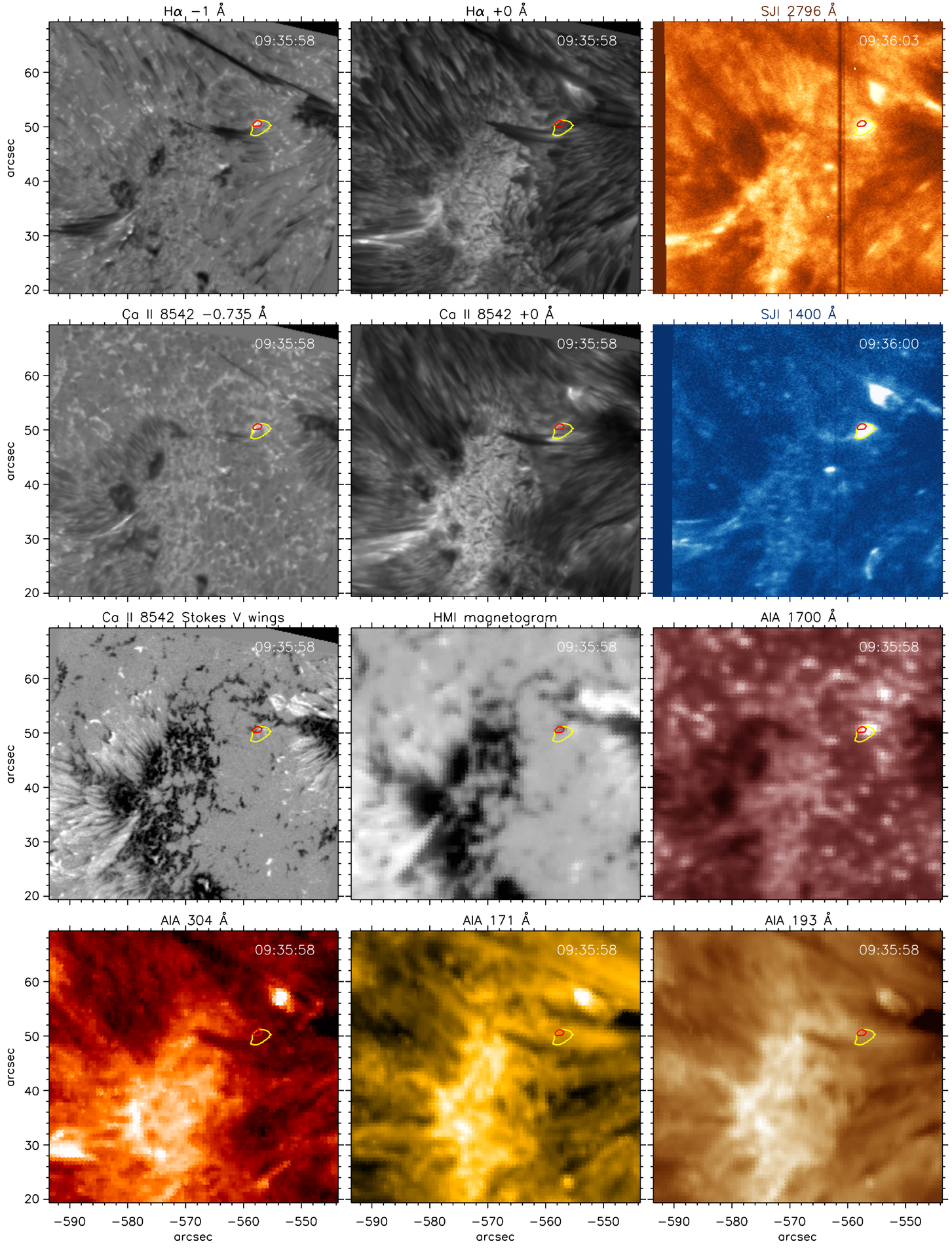
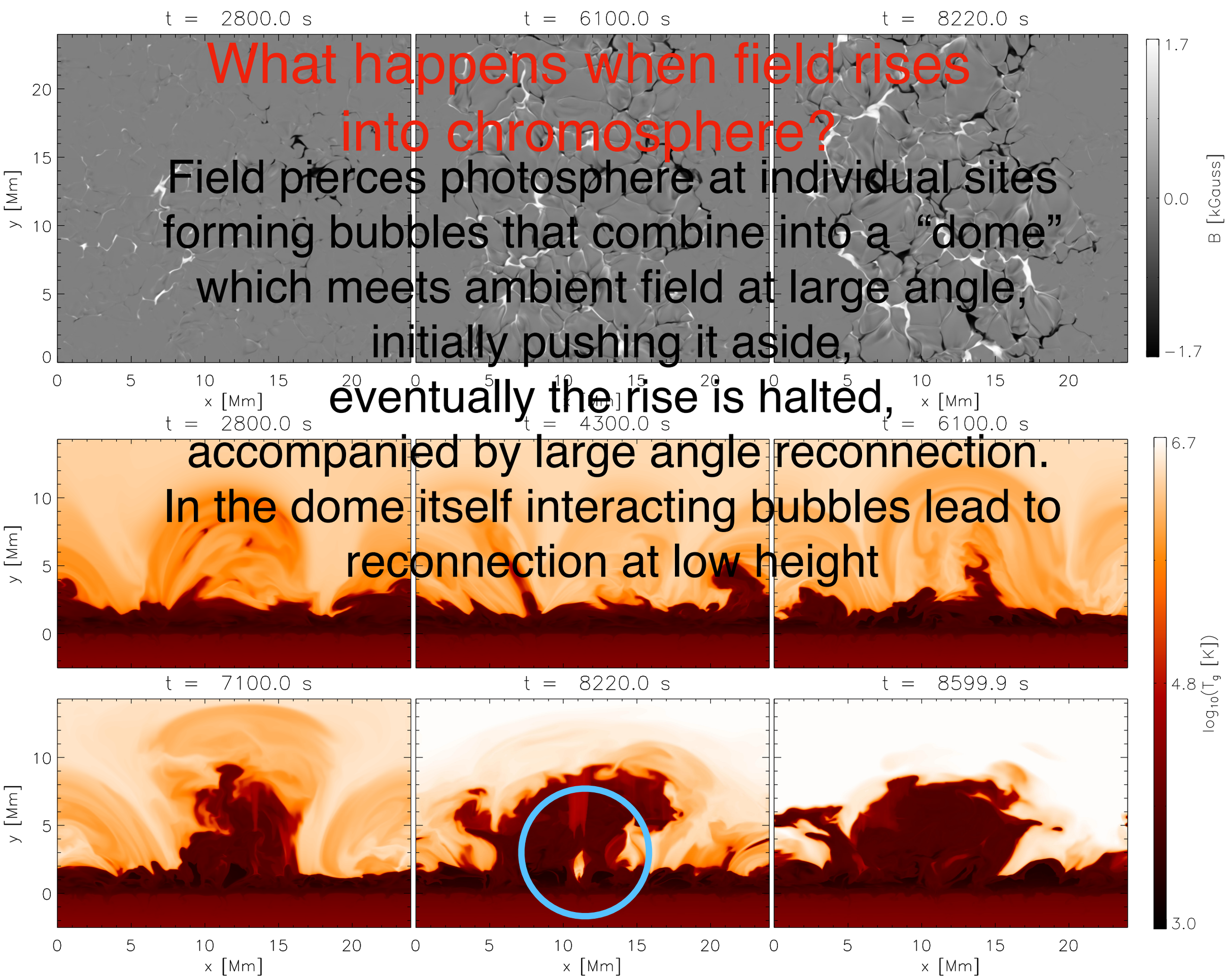
- site of opposite polarities
- EBs in Hα wing
- bright in Si IV, Ca II triplet wing, Mg II (k2), and AIA 1700
- (usually) dark in Hα and Ca II cores (as well as Mg II core)
- also dark in He II 304, Fe IX 171 and Fe XII 193
- surge (of cold material) visible in many channels



What happens when field rises into chromosphere?

Field pierces photosphere at individual sites forming bubbles that combine into a “dome” which meets ambient field at large angle, initially pushing it aside, eventually the rise is halted, accompanied by large angle reconnection. In the dome itself interacting bubbles lead to reconnection at low height



Observations: September 2016 coordinated SST - IRIS campaign

SST

- **CRISP** @ 1-m SST: 2-6 September 2016, AR 12585: flux emergence
- Scans of **6563 Å** and **Ca II 8542 Å**:
  - Hα: 15 wavelengths
  - Ca II 8542: 21 wavelengths w/spectropolarimetry
  - cadence: 20.2 s
  - sampling: 200 m Å for Halpha and 70 m Å for Ca IR
  - diffraction limited observations at high resolution: **0.14”** at 6300 Å

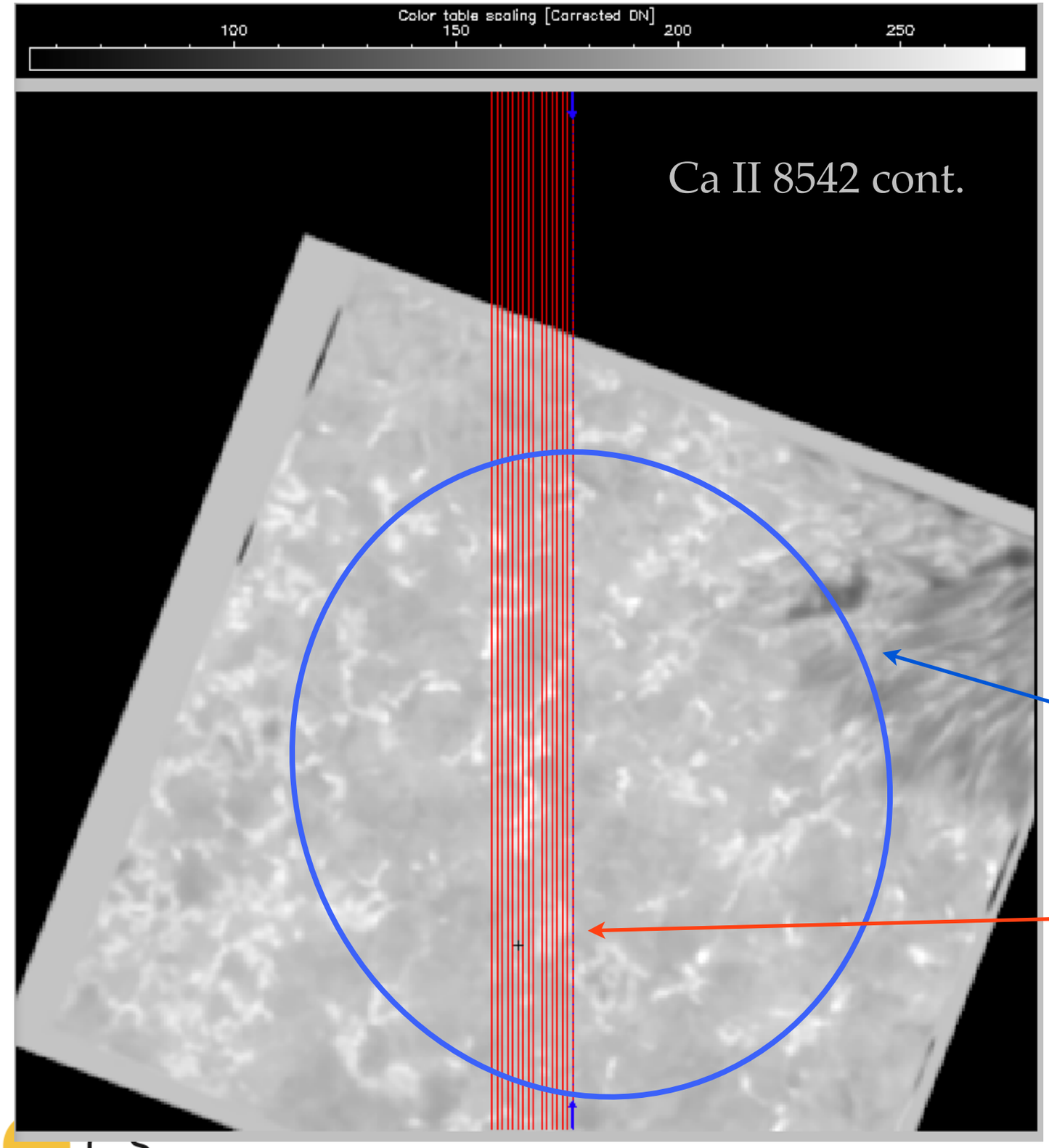
IRIS

- **IRIS**: 2-6 September 2016, AR 12585: medium dense 16-step raster
- Slit jaw images: **C II 1330** (TR), **Si IV 1400** (TR), **Mg II h/k 2796** (upper chrom.)
- FOV: 60” x 60” (SJI) & 5”x 60” (raster)
- cadence: 10 s (SJI) & 21 s (raster)
- Rasters in 3 spectral windows:
  - FUV 1: 1331.6 - 1358.4 Å (C II)
  - FUV 2: 1380.6 - 1406.6 Å (Si IV)
  - NUV: 2782.6 - 2833.9 Å (Mg II K & h)

3rd, 4th, 5th and 6th September 2016

R C S

FOV for 6th September 2016



8 cases of reconnection:

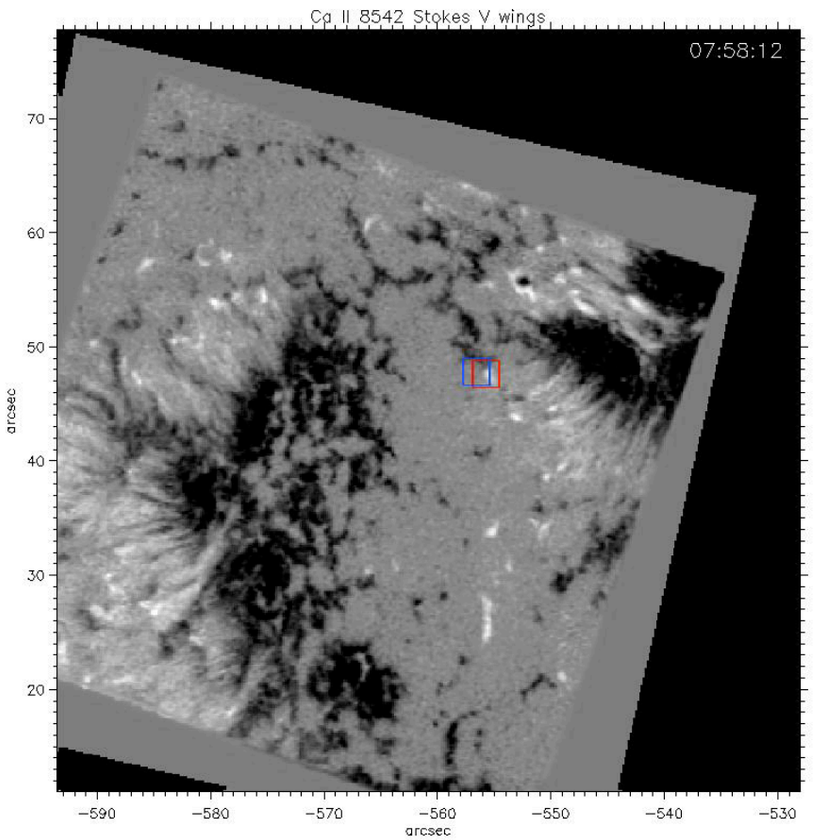
- 4 EB + UV burst
- 1 only EB
- 3 only UV burst

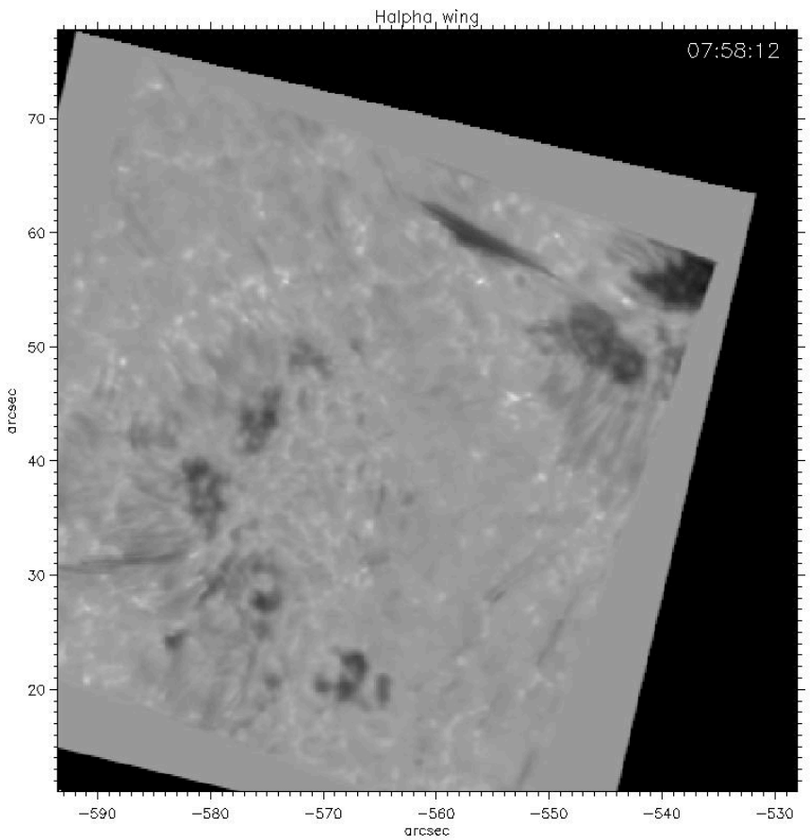
Flux emergence region: in all FOV

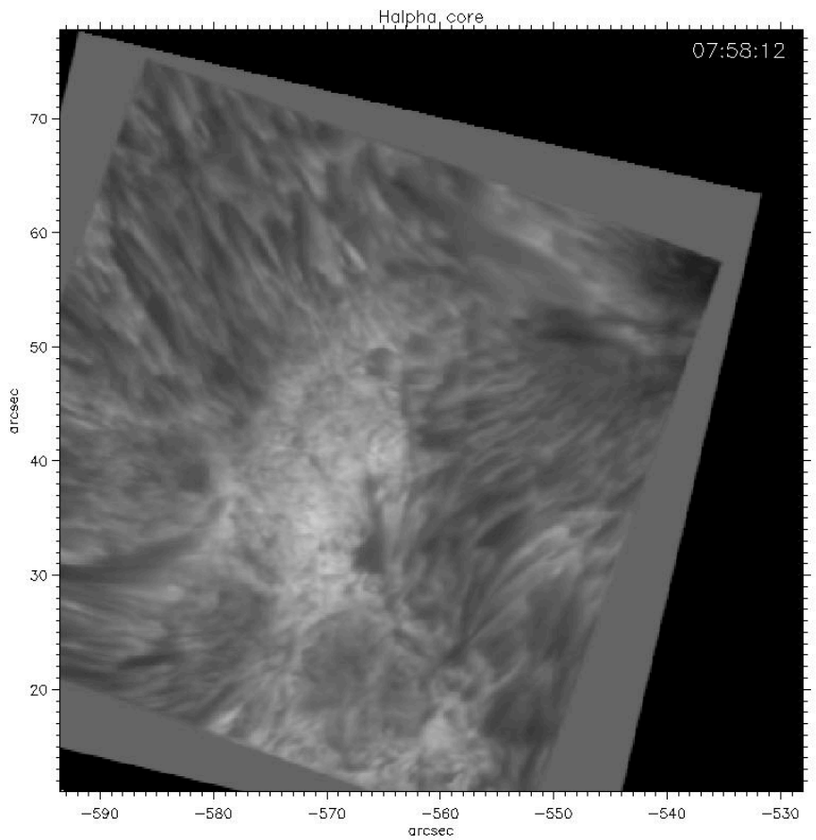
IRIS slit positions

3rd September 2016:
roughly 2 hours from 7:58 UT

Small spatial displacement between EB and UV burst







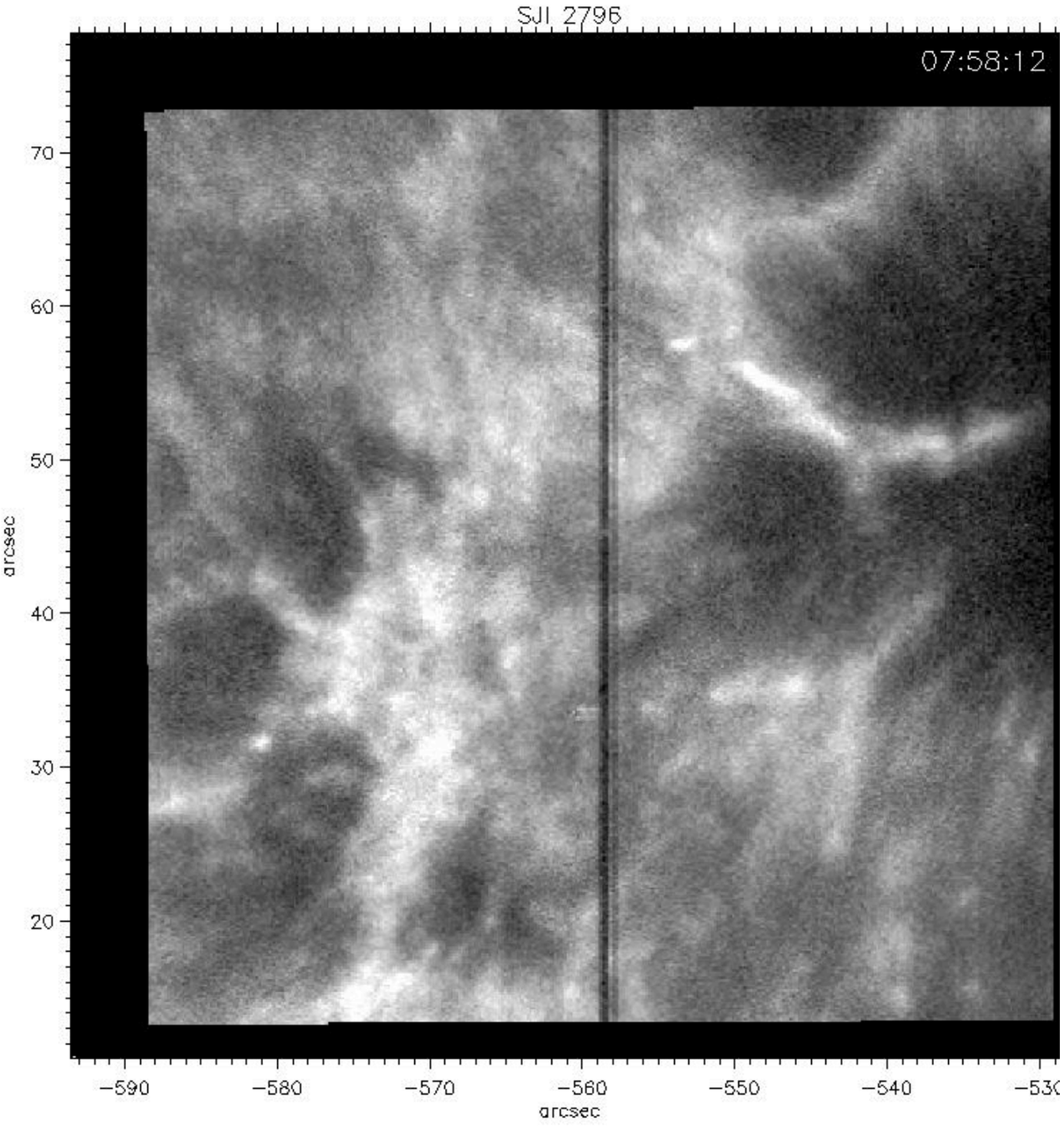
EB boundary

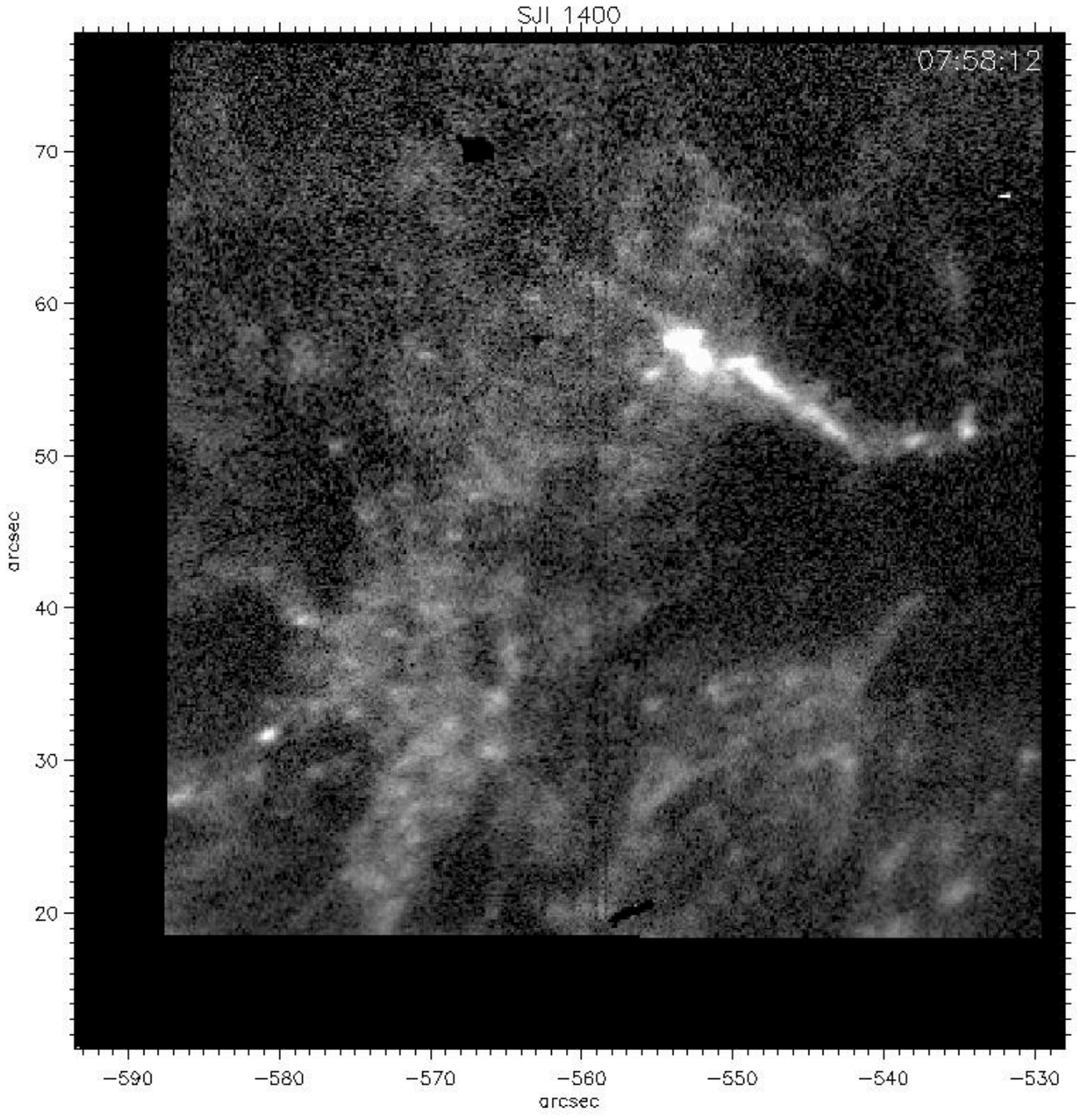
UV burst boundary

R C S

3rd September 2016

Small spatial displacement between EB and UV burst





EB boundary

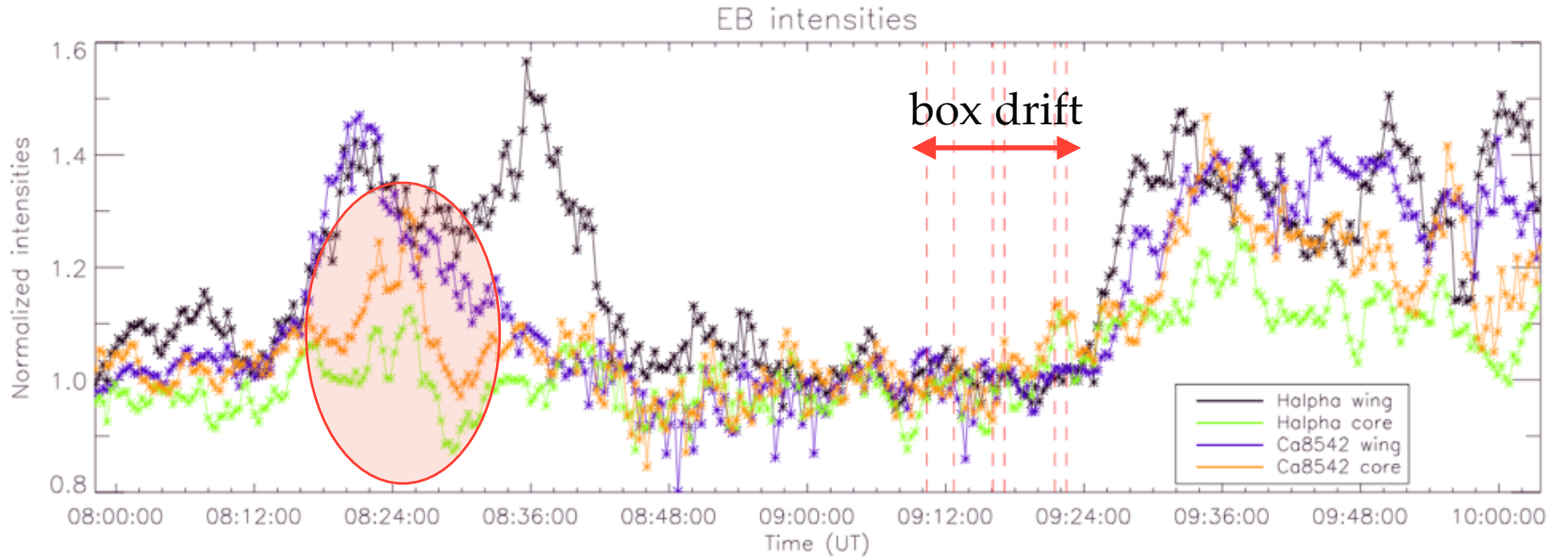
UV burst boundary

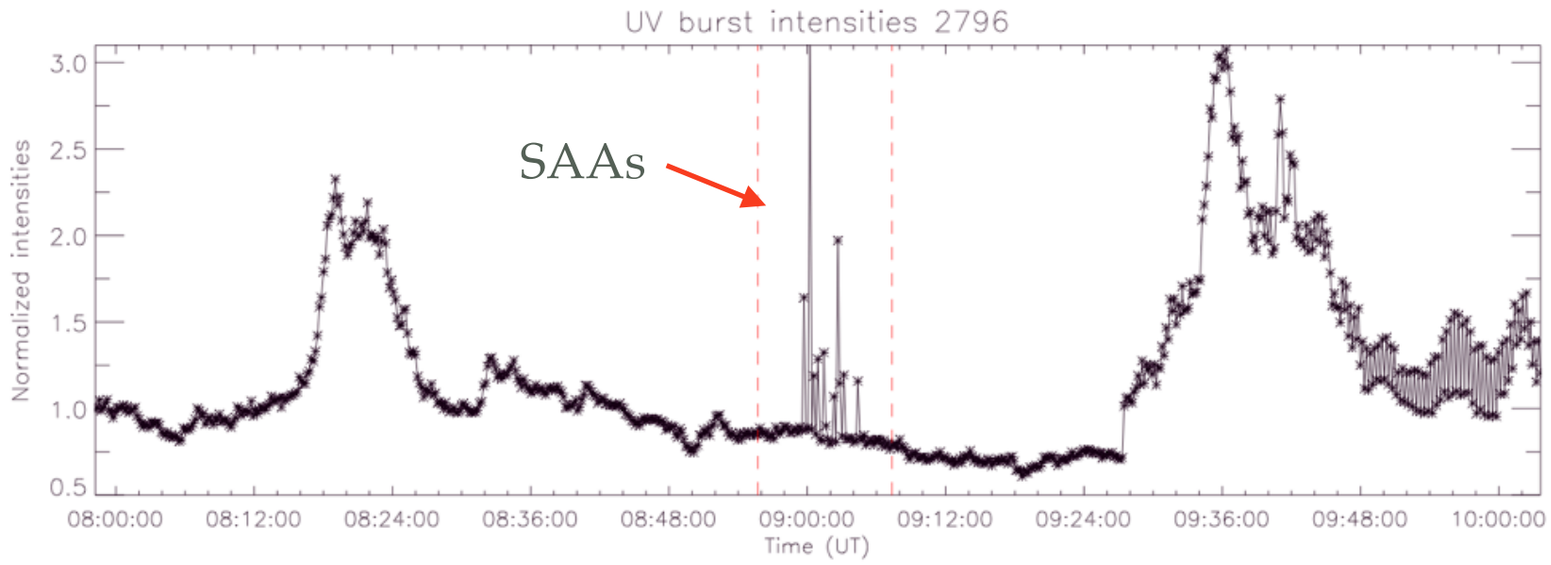
R C S

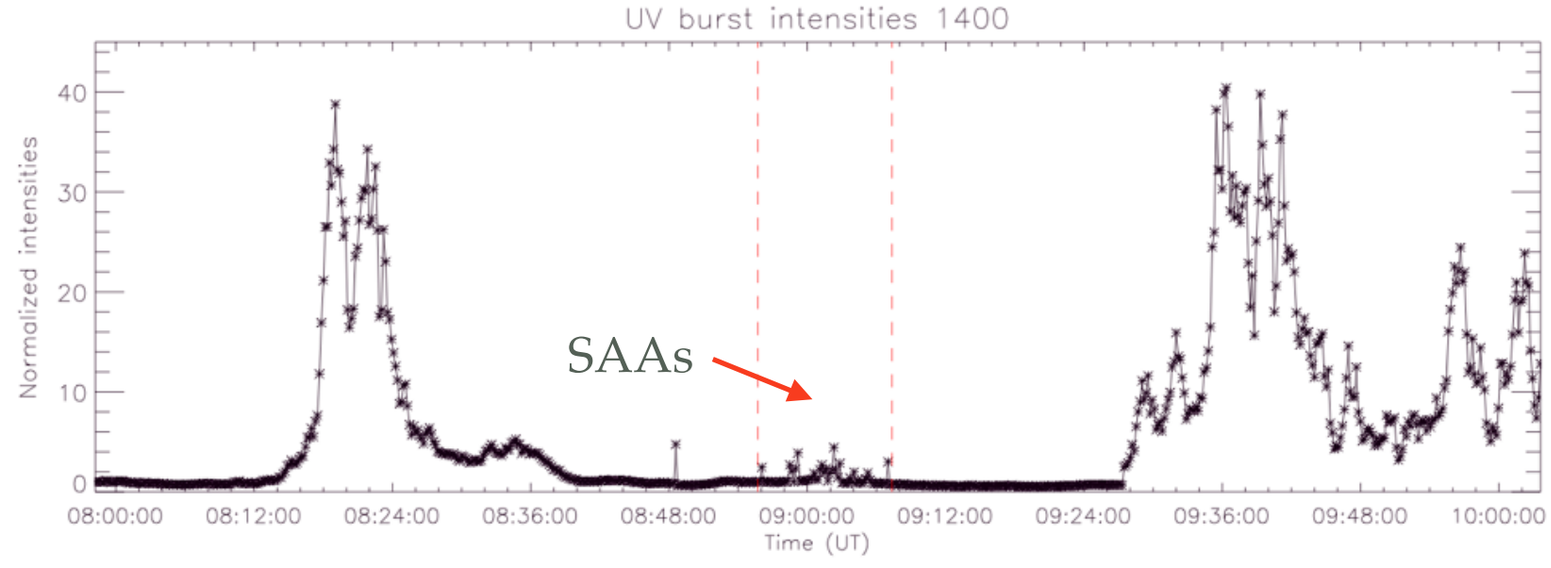
3rd September 2016

- 2 brightenings during observing sequence
- Hα wing and Ca wing have very similar behaviour
- Hα core and Ca core show some **brightenings** that coincide with bright feet of UV burst at 08:25 and 09:34-09:40 UT.
- EB lits up more **gradually**, UV burst has a **very steep** increase
- UV lits up **slightly later** than the EB:
  - almost **simultaneously** in 1st brightening
  - **2 min** later in 2nd brightening

Clear relationship between EB and UV burst as they happen almost simultaneously







R C S

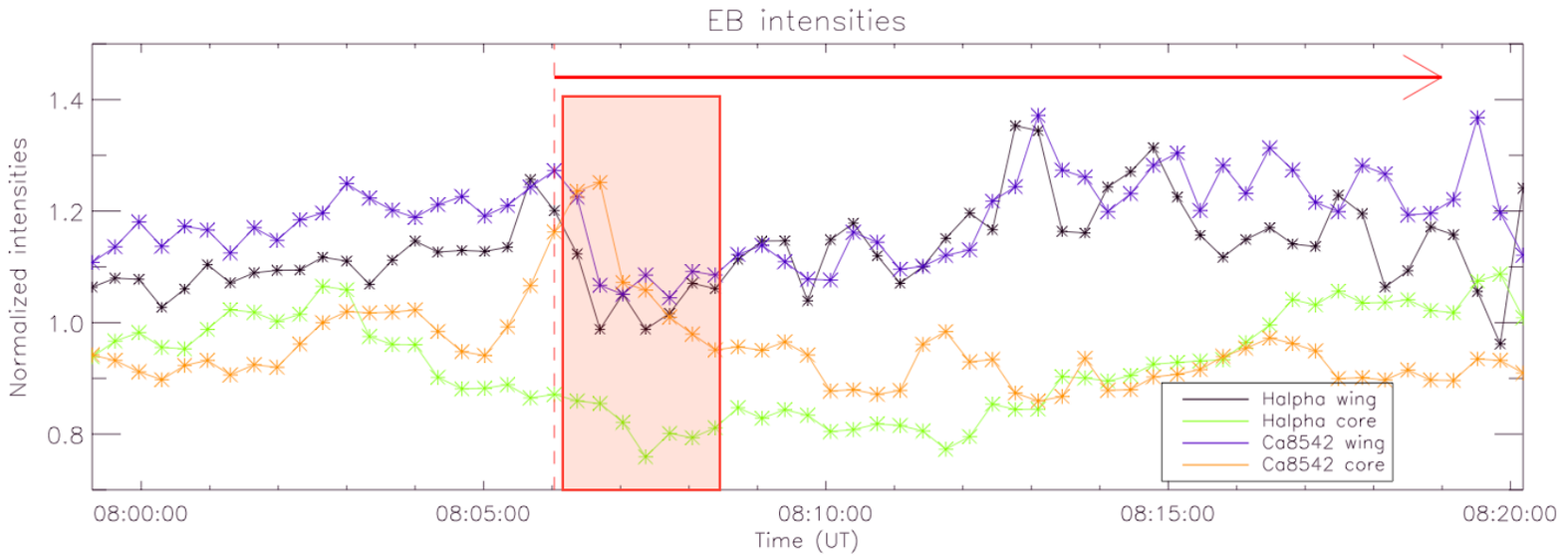
6th September 2016

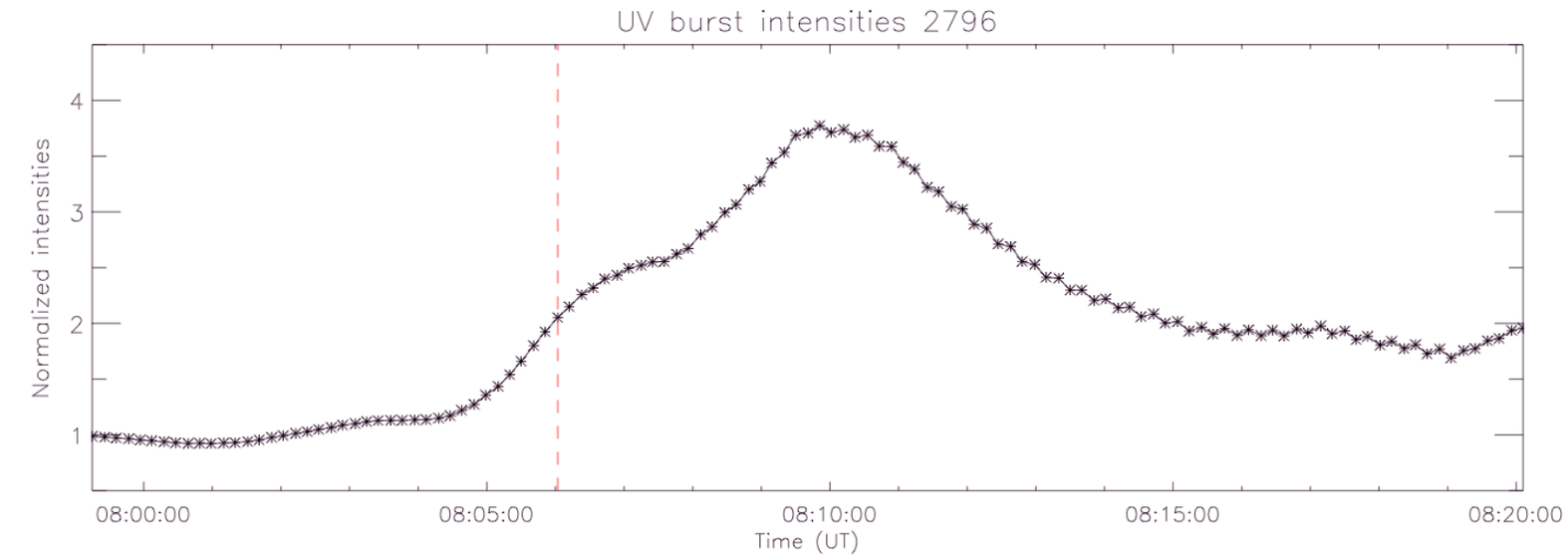
- Hα surge starts at 08:06:02 UT, lasting until the end of the observing sequence. Totally hides the EB for ~ 1 min.

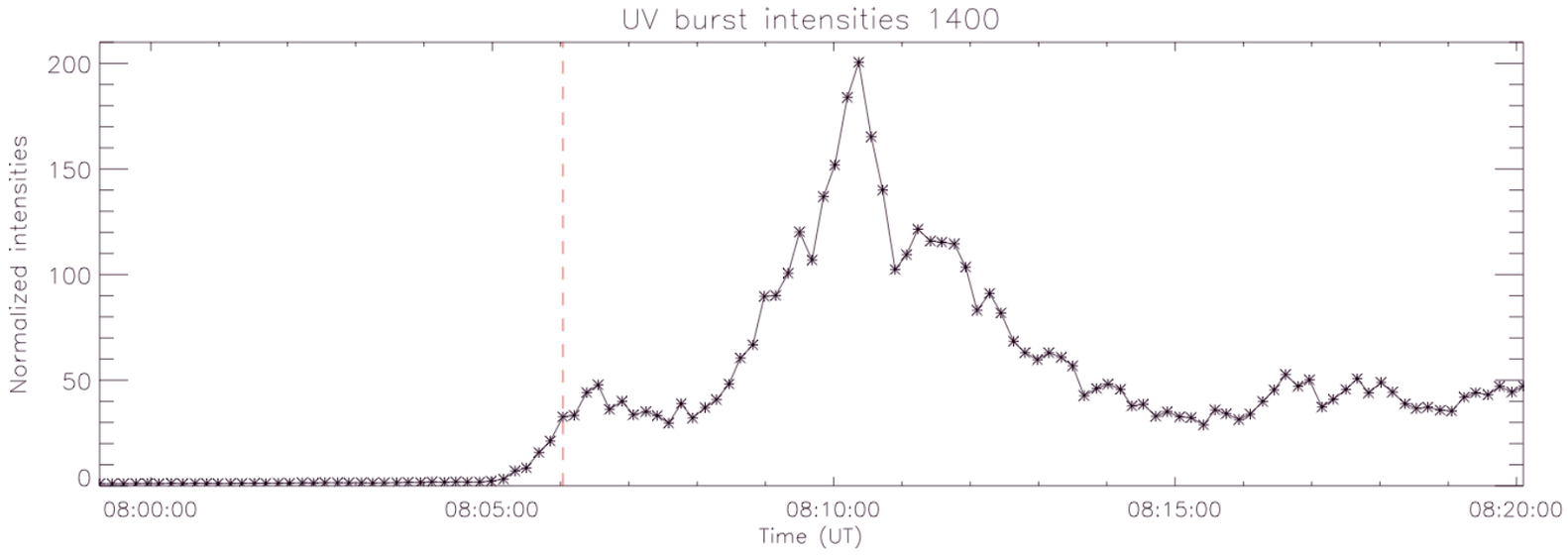
Unclear relationship between EB and UV burst: spatial coincidence but temporal?

- Again UV burst shows **steep** increase of intensity. EB shows almost flat temporal variation.

- UV burst lags 6-7 min after the EB appearance







6th September 2016

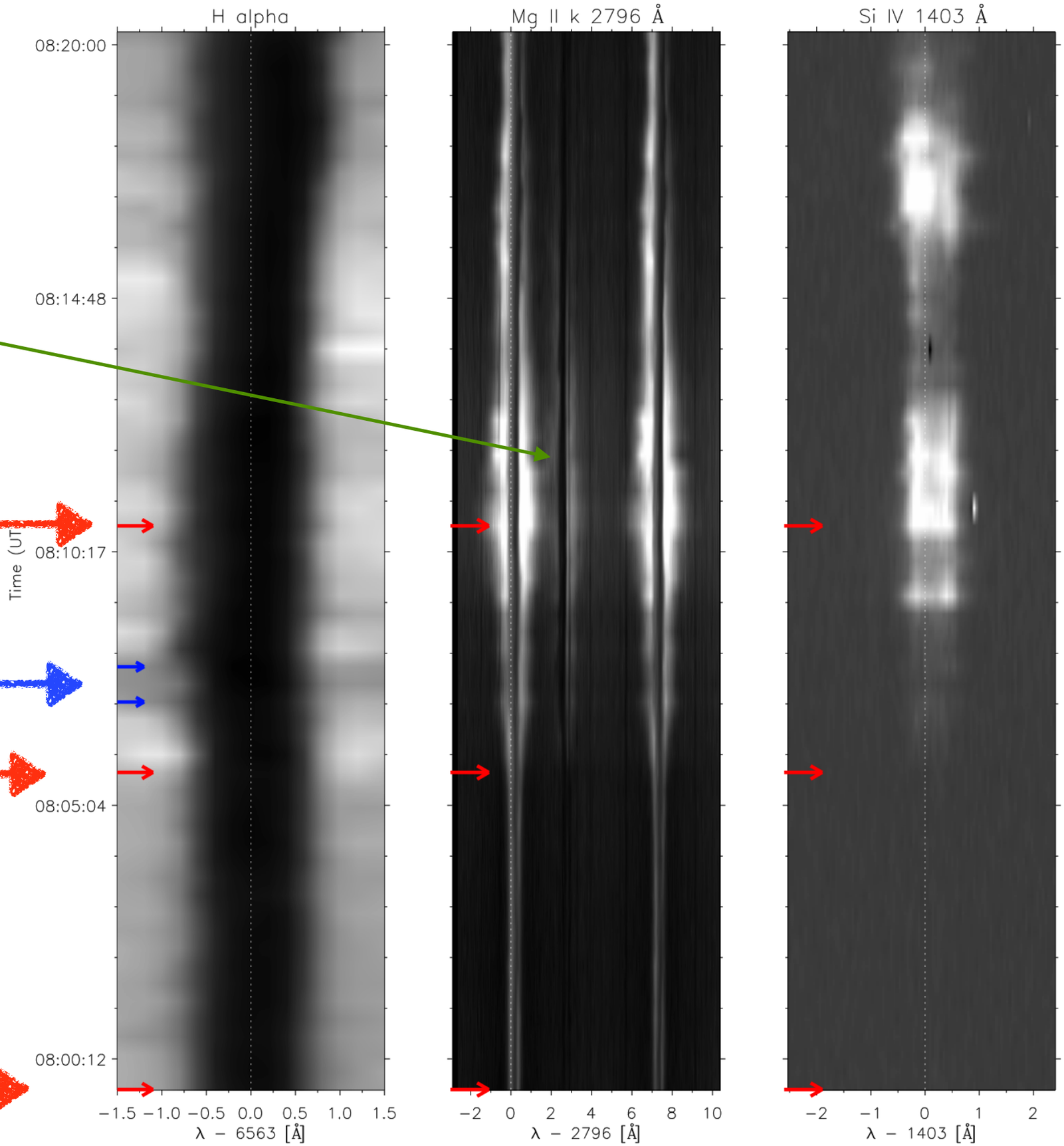
Mg triplet

maximum diameter of UV burst

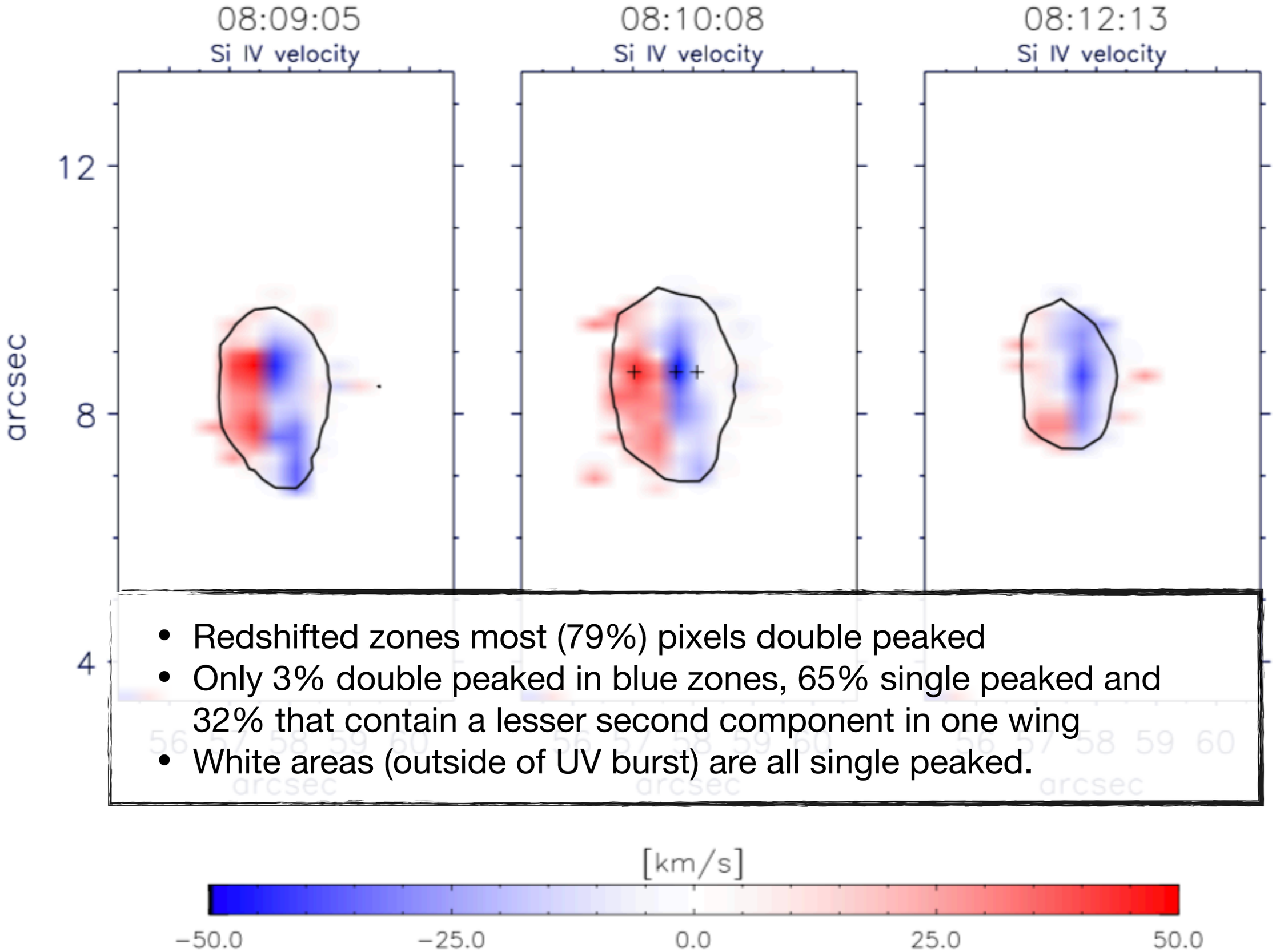
EB totally covered by Hα surge

UV burst starts

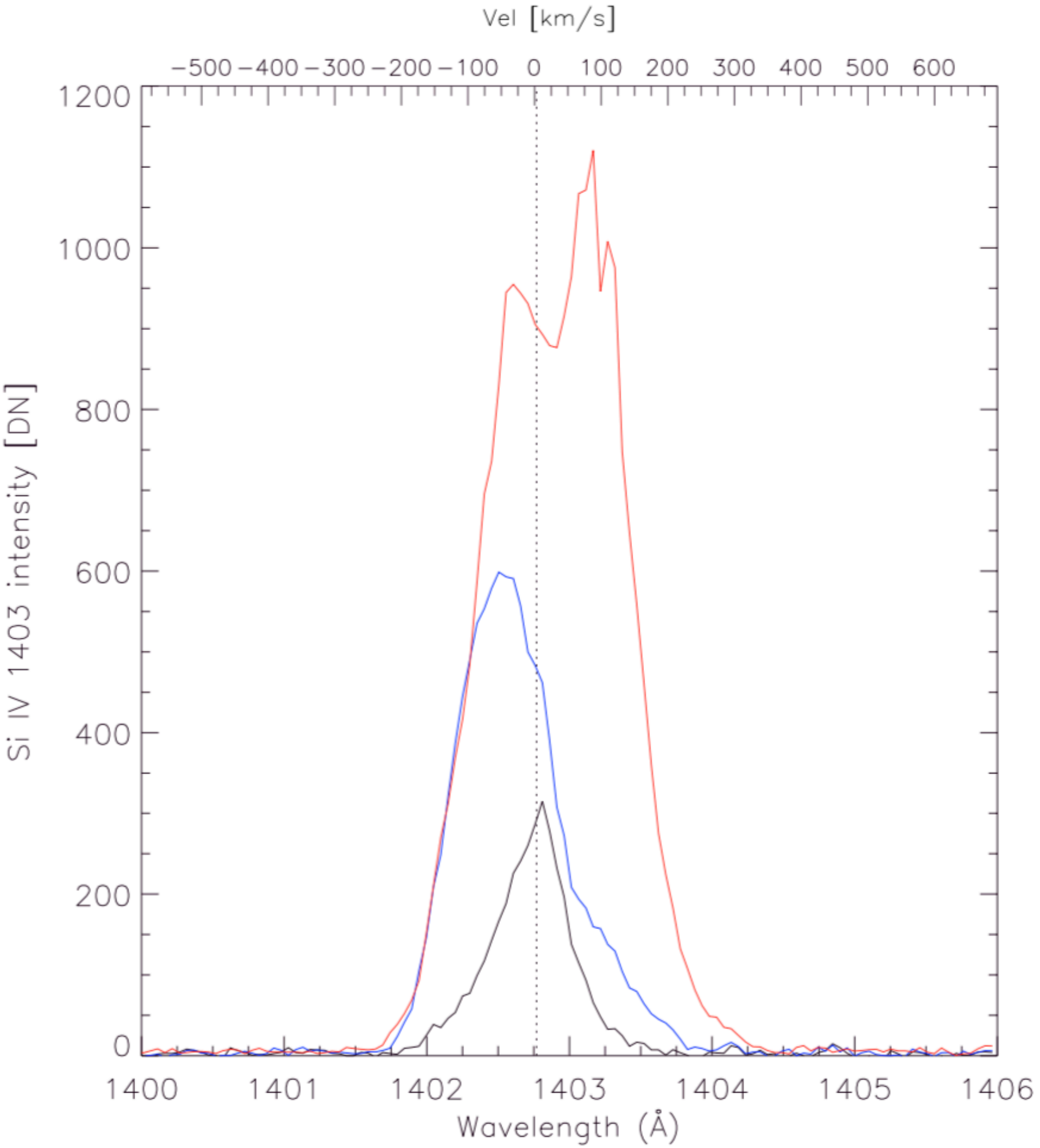
EB starts



R C S



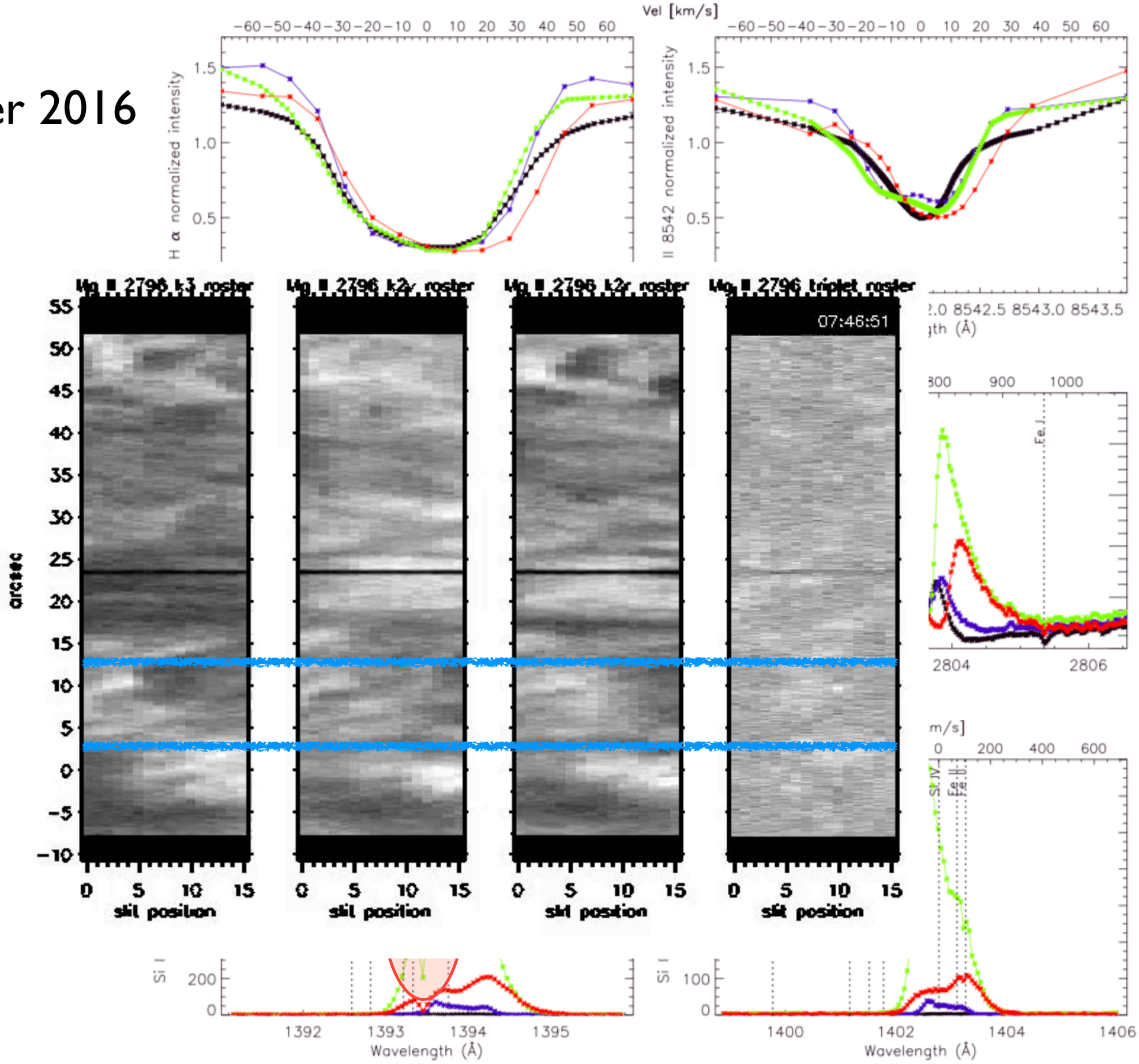
- Redshifted zones most (79%) pixels double peaked
- Only 3% double peaked in blue zones, 65% single peaked and 32% that contain a lesser second component in one wing
- White areas (outside of UV burst) are all single peaked.

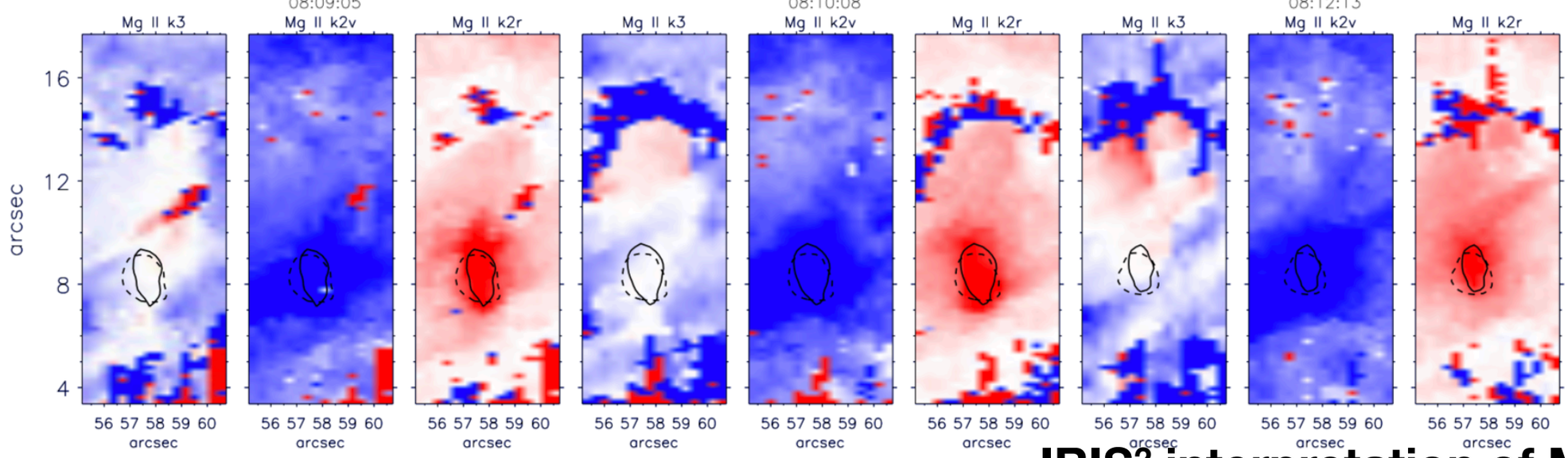

Vel [km/s]
−500 −400 −300 −200 −100 0 100 200 300 400 500 600
1200
1000
800
600
400
200
0
Si IV 1403 intensity [DN]
1400 1401 1402 1403 1404 1405 1406
Wavelength (Å)

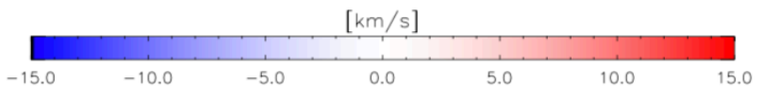
6th September 2016

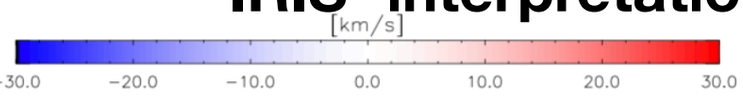
- **Mg triplet** appea
  the lower chromos
  heated: coincides v
  brightness of UV

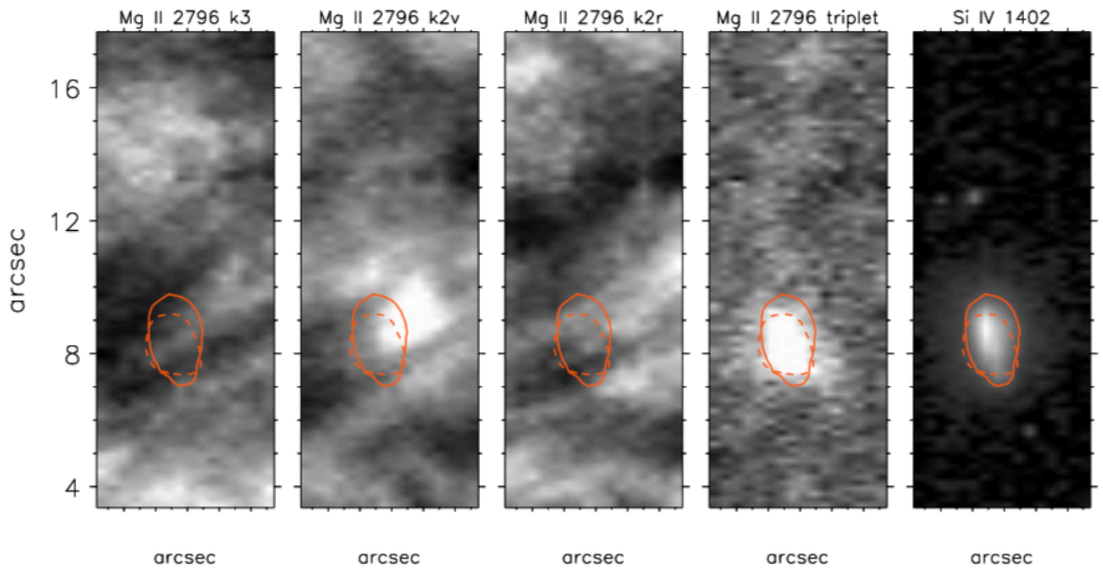
- **Absorption** in b
  Si IV 1394 Å shows
  presence of **cold** r
  along the LOS of th
  burst

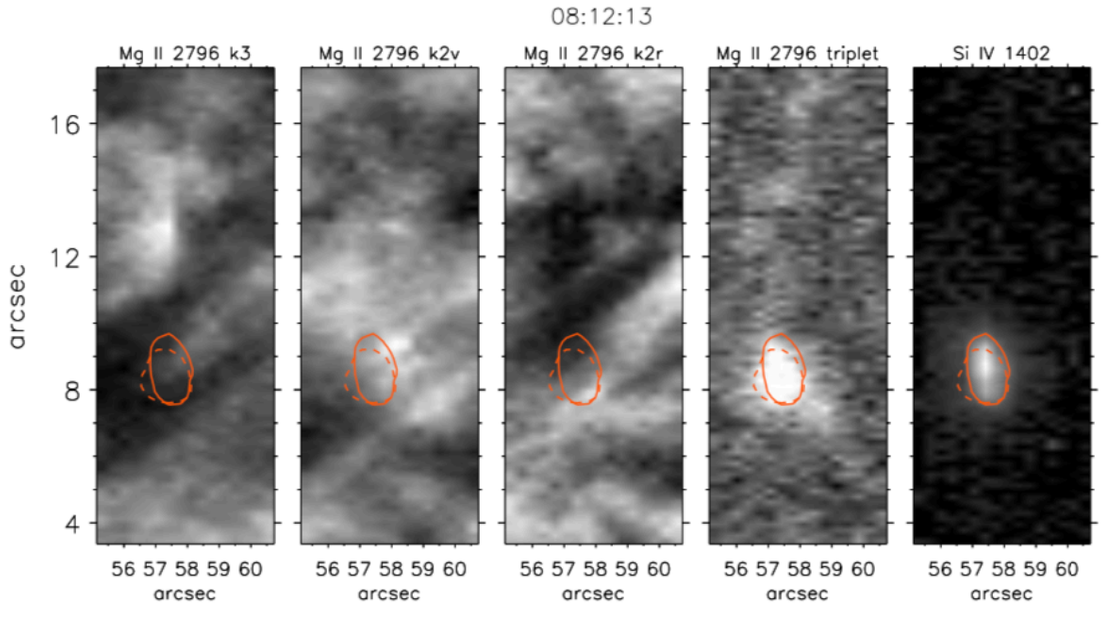






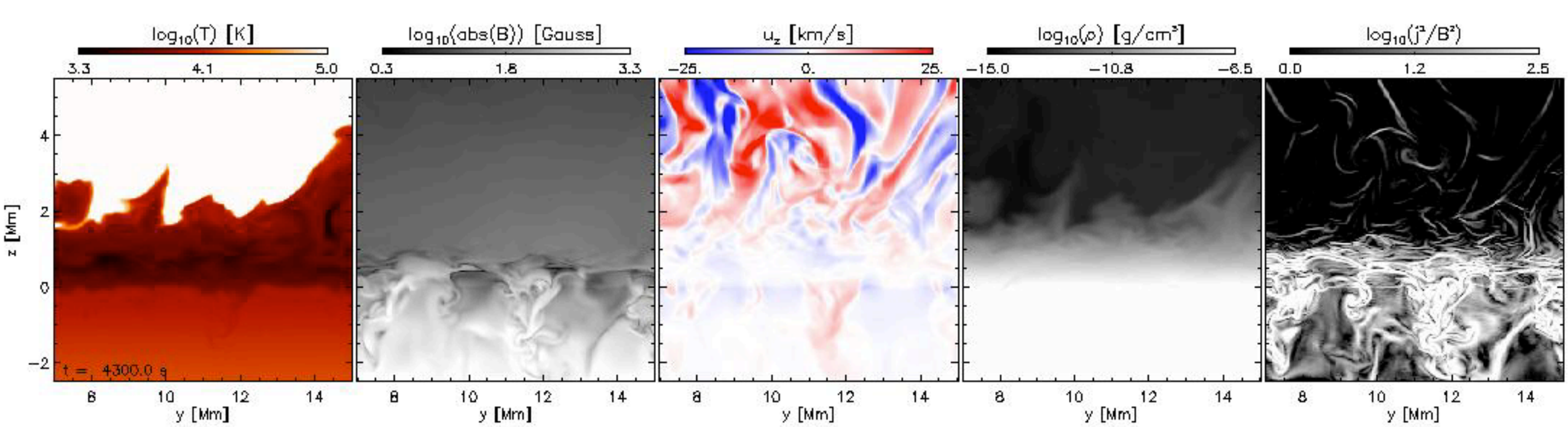




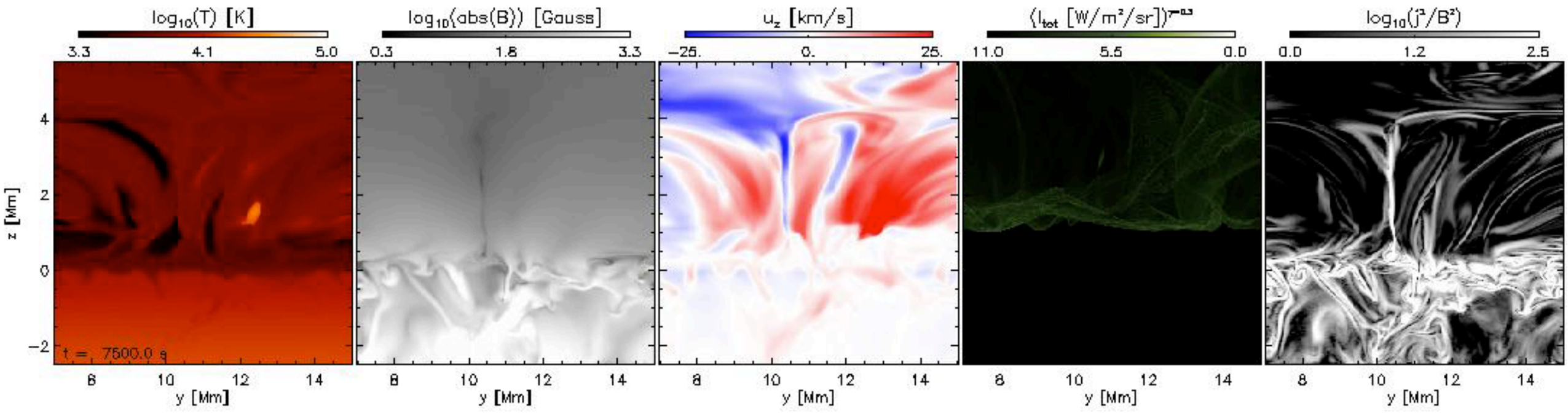


IRIS² interpretation of Mg II spectra

- Highly turbulent plasma, v_{turb} of 10-15 km/s covers area larger than the UV burst seen in other variables such as T_e, n_e, u_{los}
- Maximum of vturb in the lower chromosphere $\log(\tau) \approx -3$
- A region of smaller extent shows high electron densities of $n_e \simeq 10^{13}\ cm^{-3}$ which is order of magnitude more than ambient
- Filling same extent inverted temperature of $T_e = 7\,000$ K at $\log(\tau) \approx -3$, 2000 K hotter than ambient, and remaining constant up to $\log(\tau) \simeq -6$
- Velocities up-flowing -10 - -20 km/s.
- Upper chromosphere velocities down-flowing 10 km/s.



Flux emergence, from the photosphere to the corona…



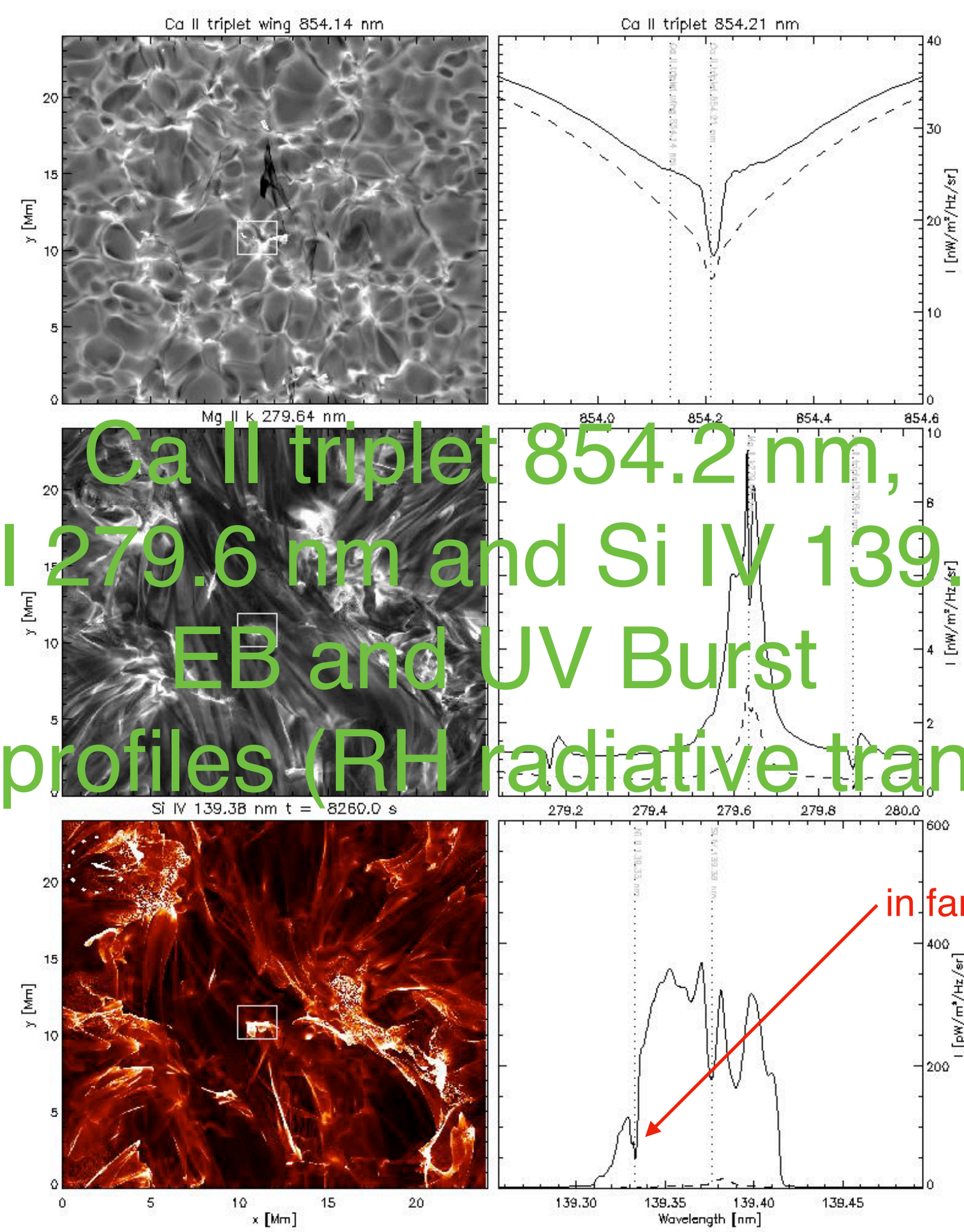
Discussion

- 3/9/16: 48% EB-only, 43% UV-burst only, 9% EB+UV
- 6/9/16: 48% EB-only, 36% UV-burst only, 16% EB+UV
- Possible to produce Hα wing EB emission if photosphere or TR > 20,000-80,000 K?

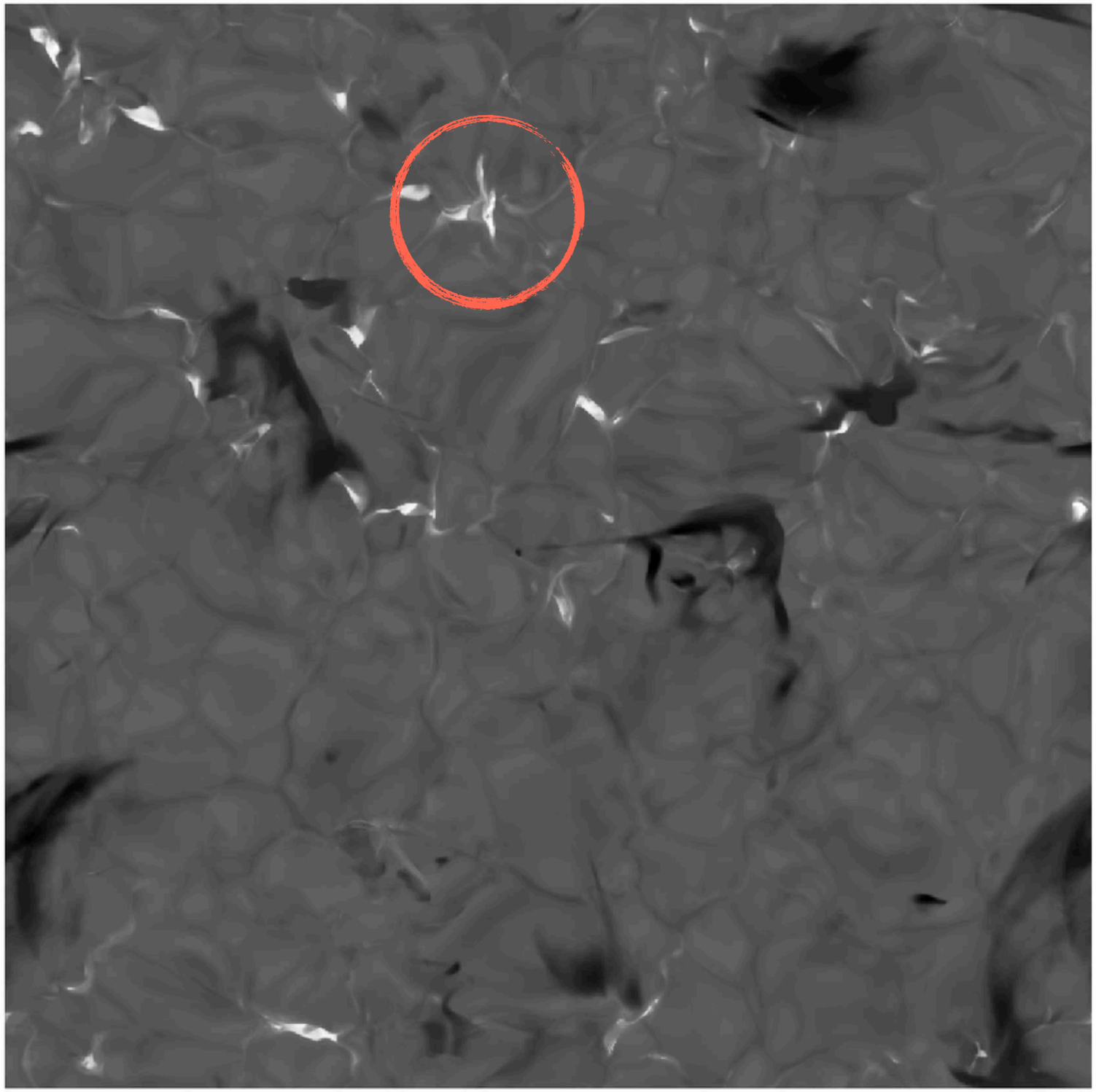
- Almost all EBs have accompanying cold surges
- Velocities in Si IV (line width) is very high ~200 km/s
- Temperature in UV bursts could be much higher than 80000 K.
- UV bursts formed several scale heights above Hα as part of same structure (nearly vertical current sheet)

Simulated Hα line wing

Ca II triplet 854.2 nm, Mg II 279.6 nm and Si IV 139.3 nm EB and UV Burst line profiles (RH radiative transfer)

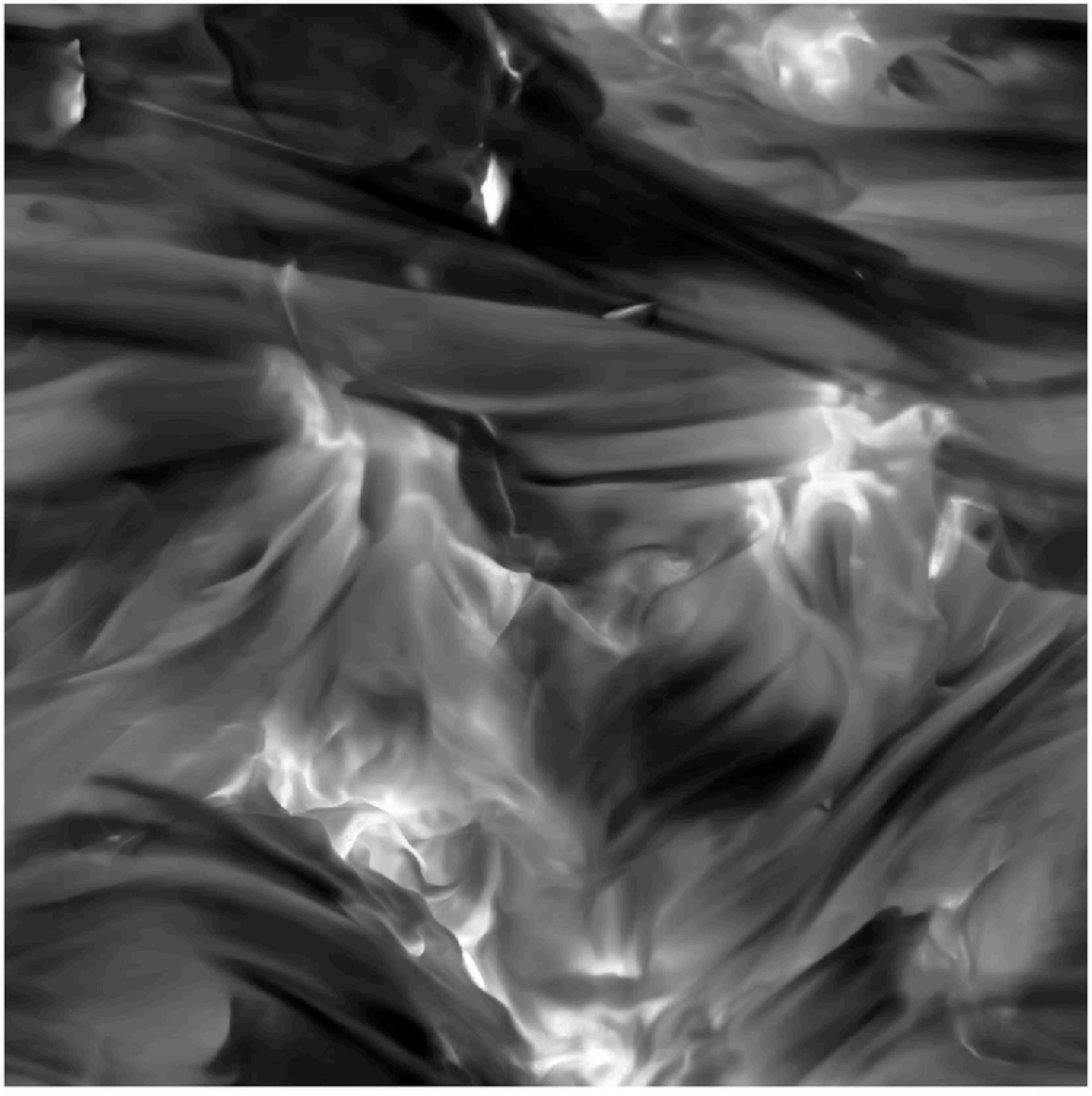


Hα line wing, during height of UV burst

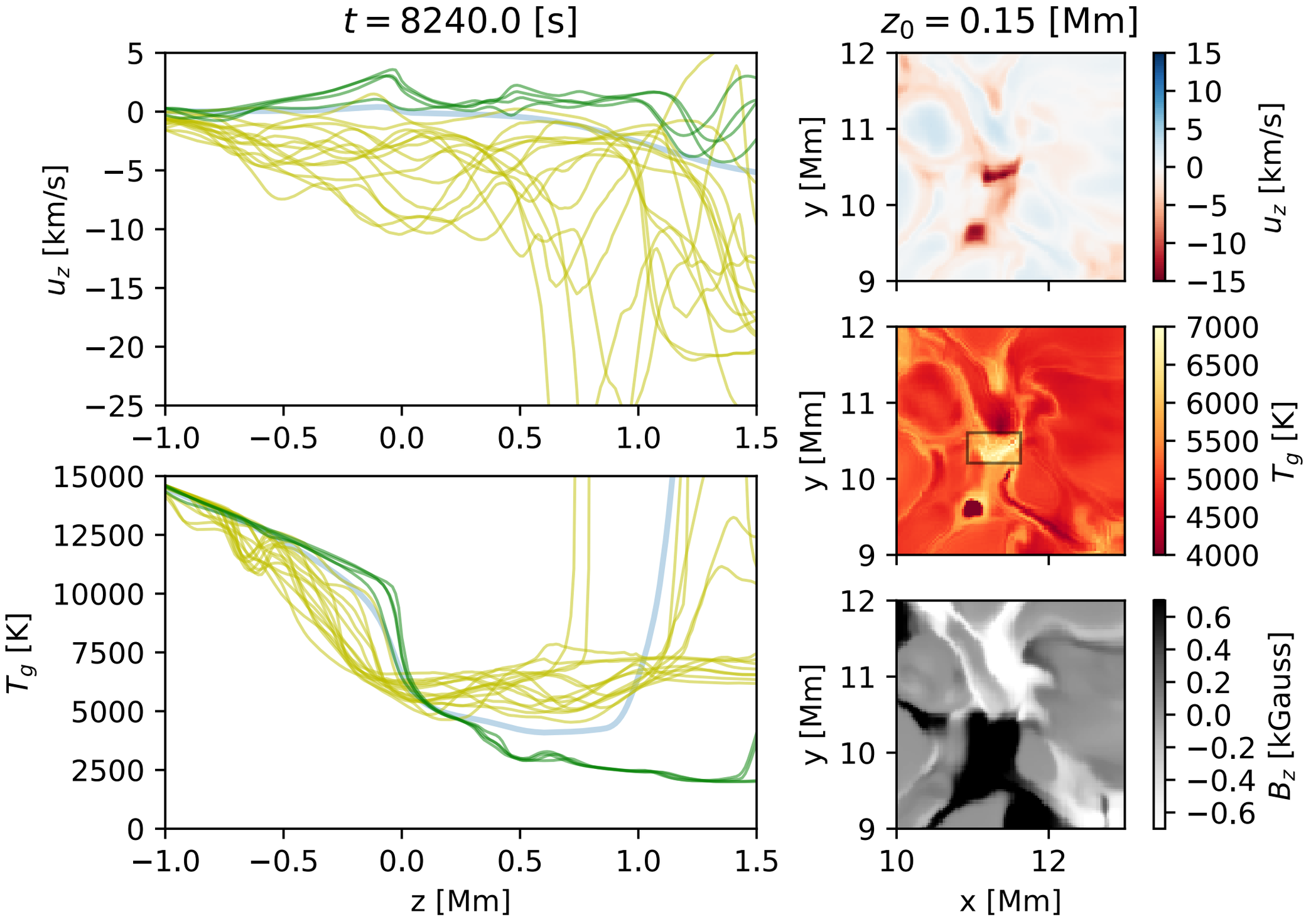


Courtesy of Johan Bjørgen

Hα line core, during height of UV burst



Courtesy of Johan Bjørgen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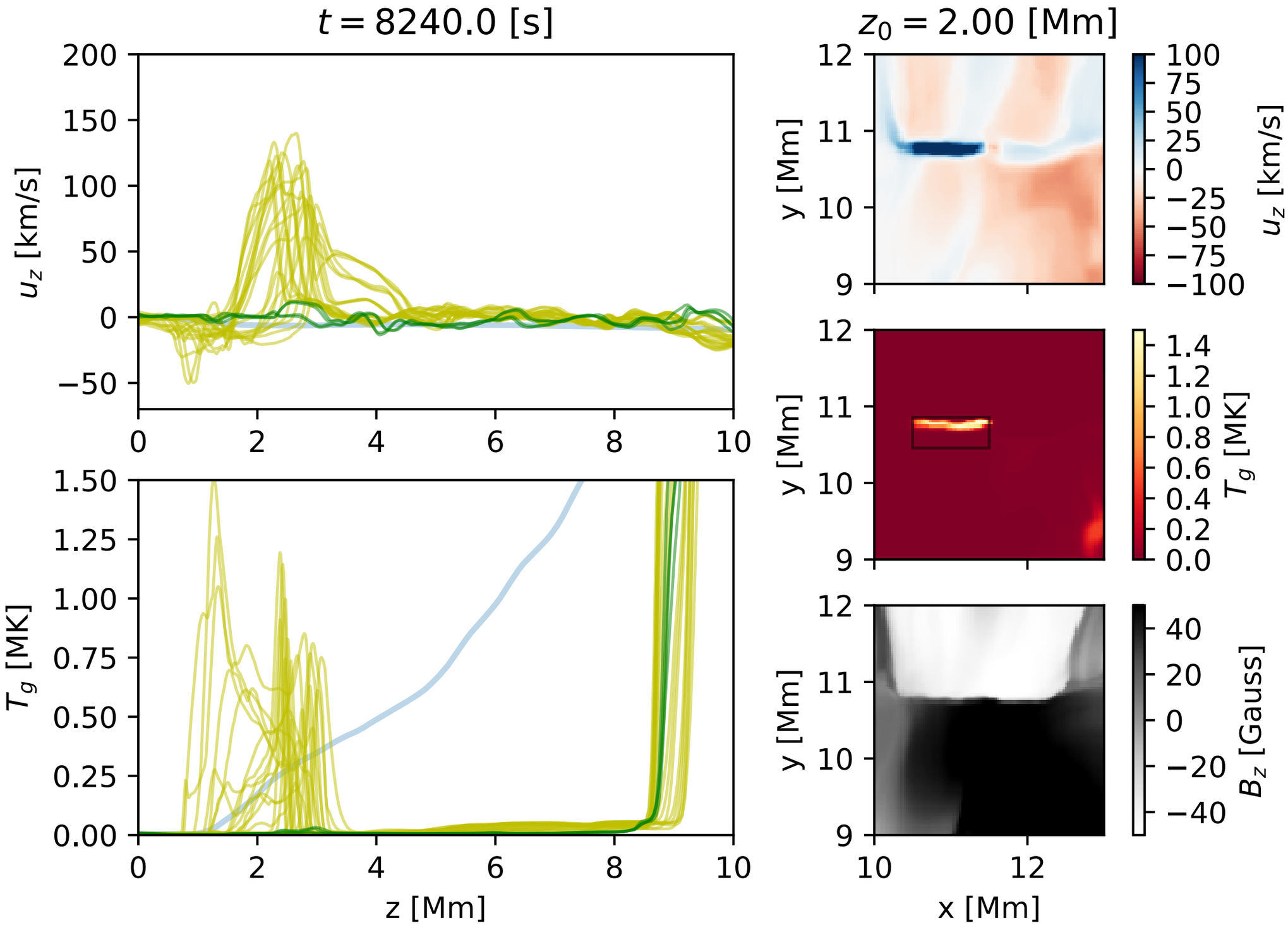
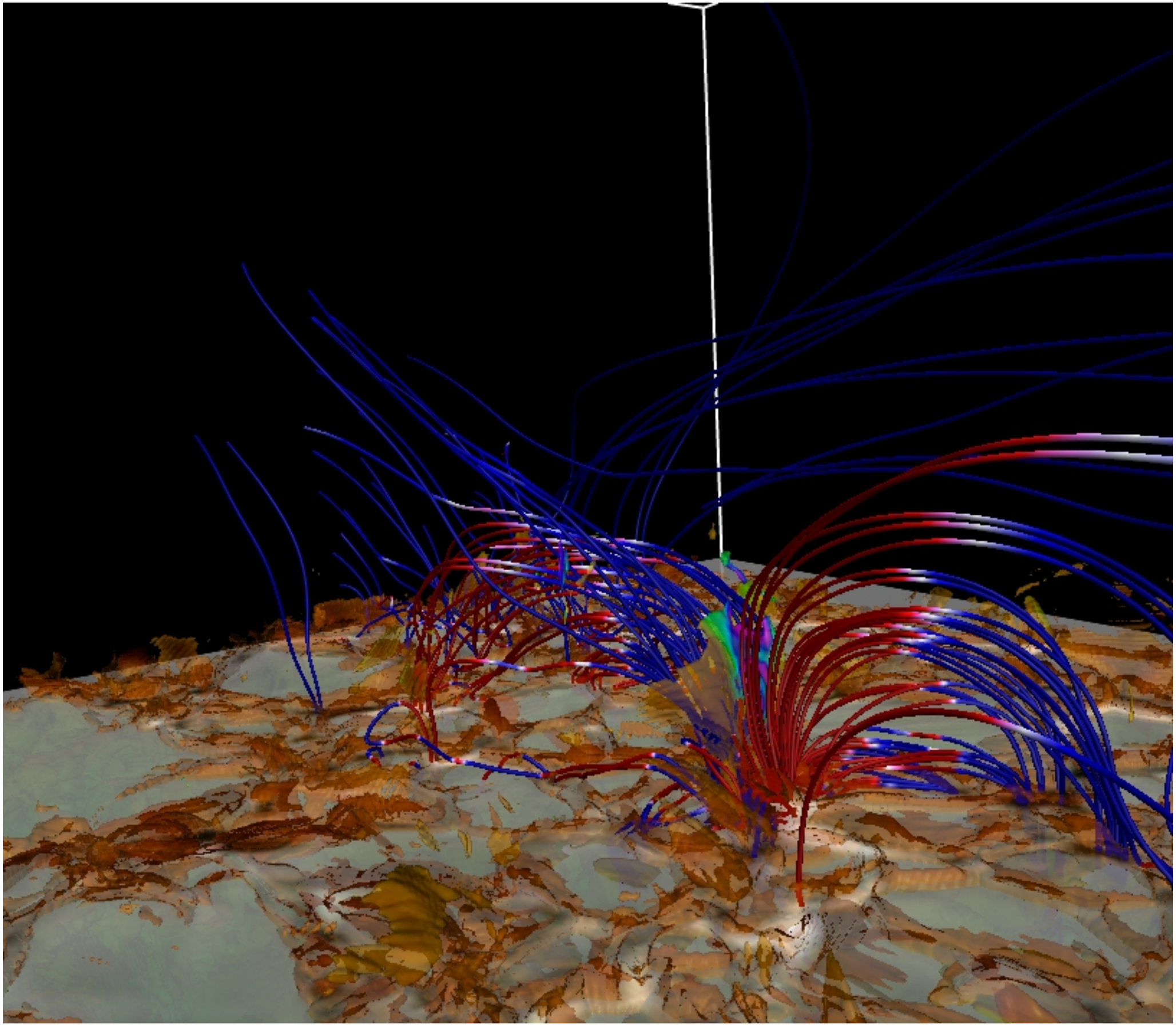
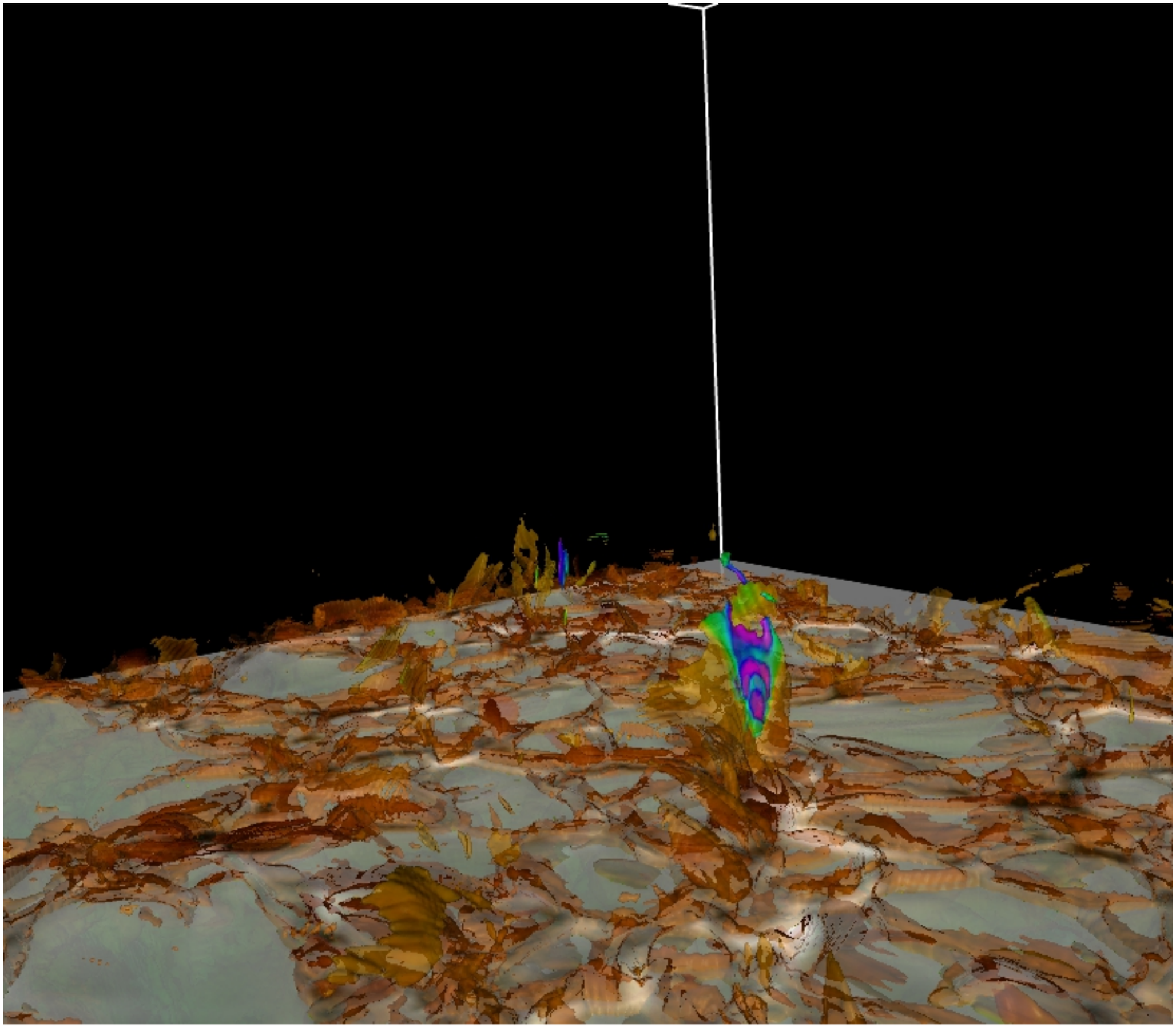
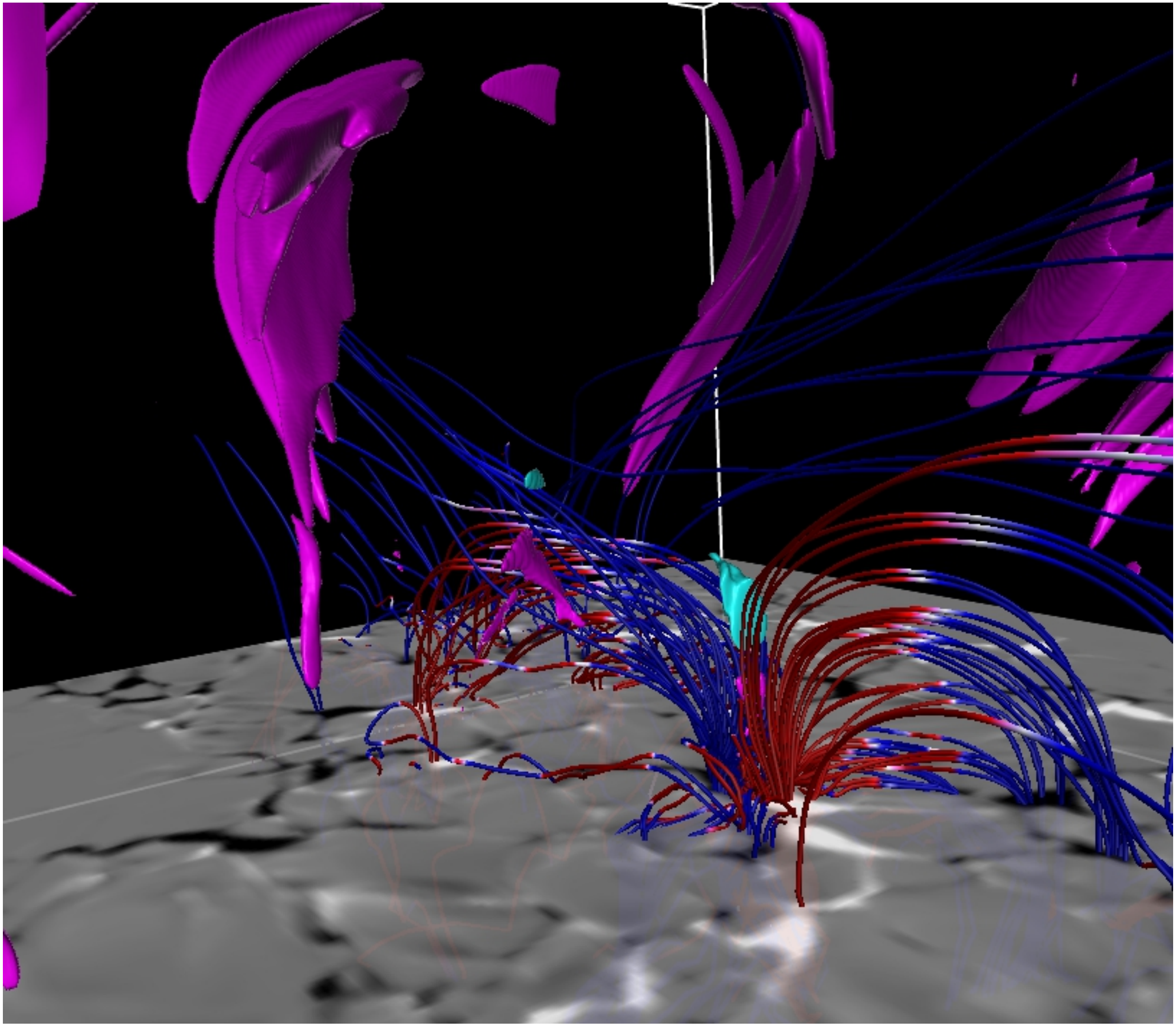
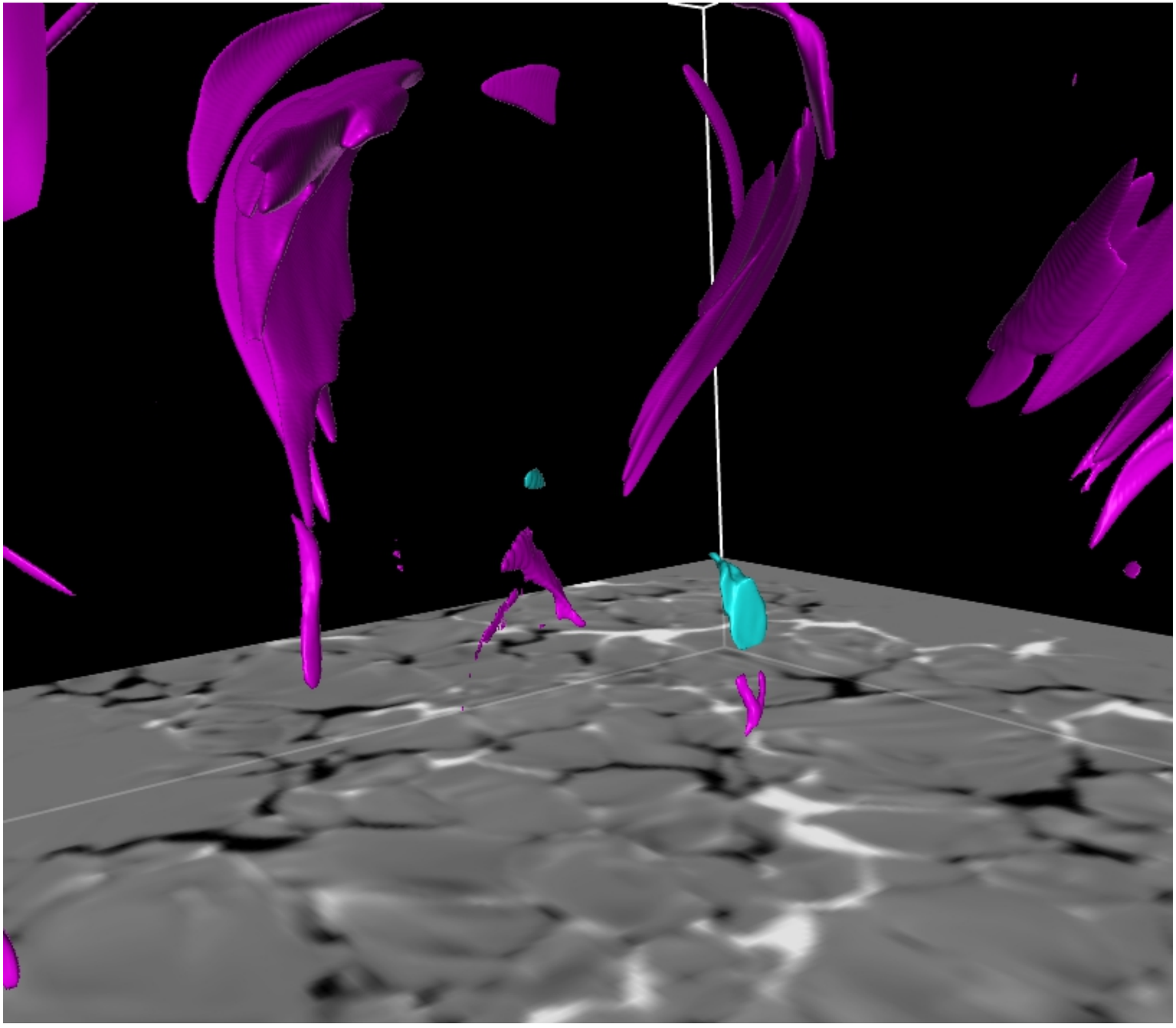
u_z [km/s]
5
0
−5
−10
−15
−20
−25
−1.0
−0.5
0.0
0.5
1.0
1.5
T_g [K]
15000
12500
10000
7500
5000
2500
0
z [Mm]
$z_0 = 0.15$ [Mm]
y [Mm]
12
11
10
9
15
10
5
0
−5
−10
−15
u_z [km/s]
7000
6500
6000
5500
5000
4500
4000
T_g [K]
x [Mm]
10
12
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
B_z [kGauss]

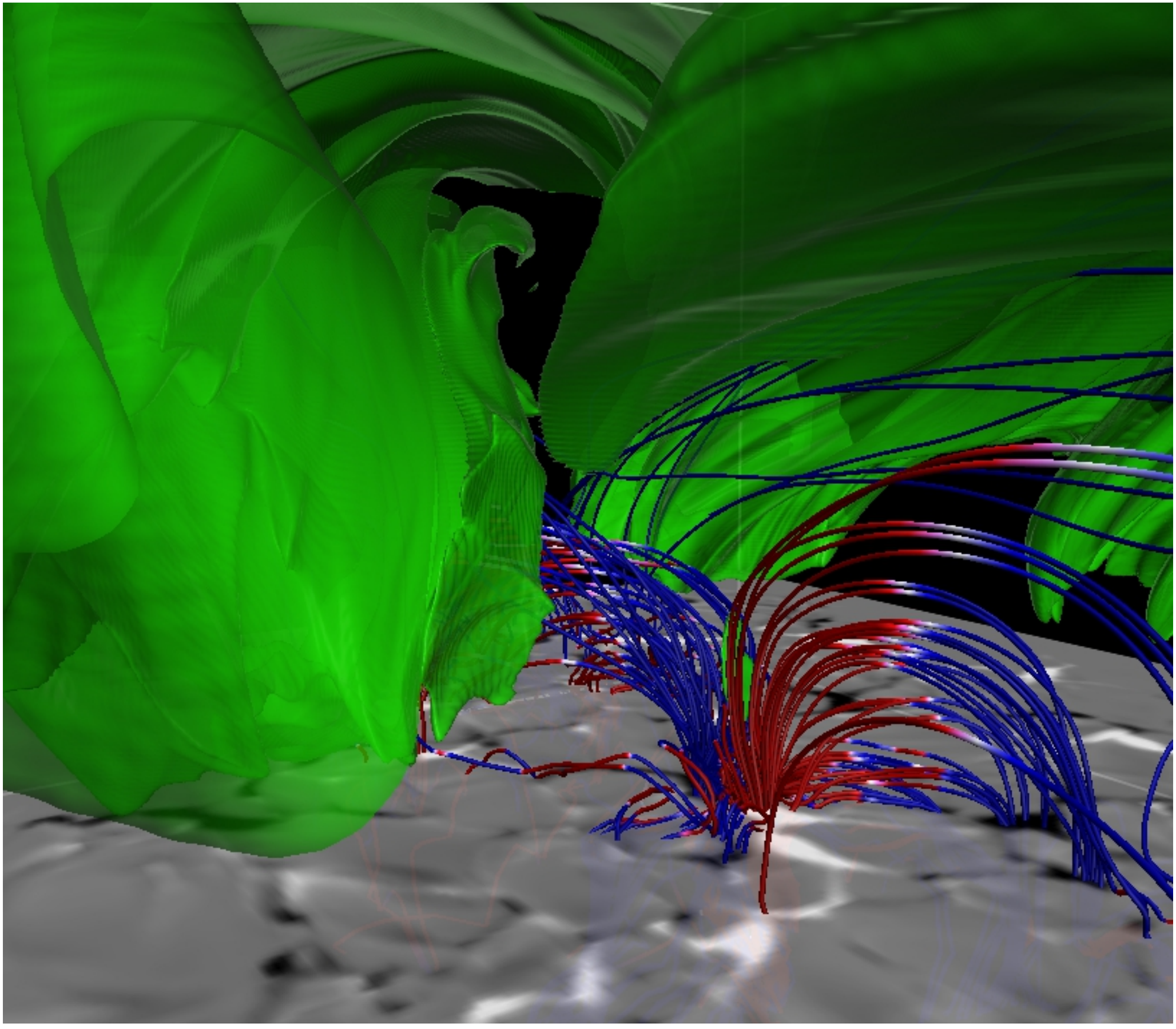

$t = 8240.0$ [s]
u_z [km/s]
200
150
100
50
0
−50
0
2
4
6
8
10
T_g [MK]
1.50
1.25
1.00
0.75
0.50
0.25
0.00
z [Mm]
$z_0 = 2.00$ [Mm]
y [Mm]
12
11
10
9
100
75
50
25
0
−25
−50
−75
−100
u_z [km/s]
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
T_g [MK]
40
20
0
−20
−40
B_z [Gauss]
x [Mm]

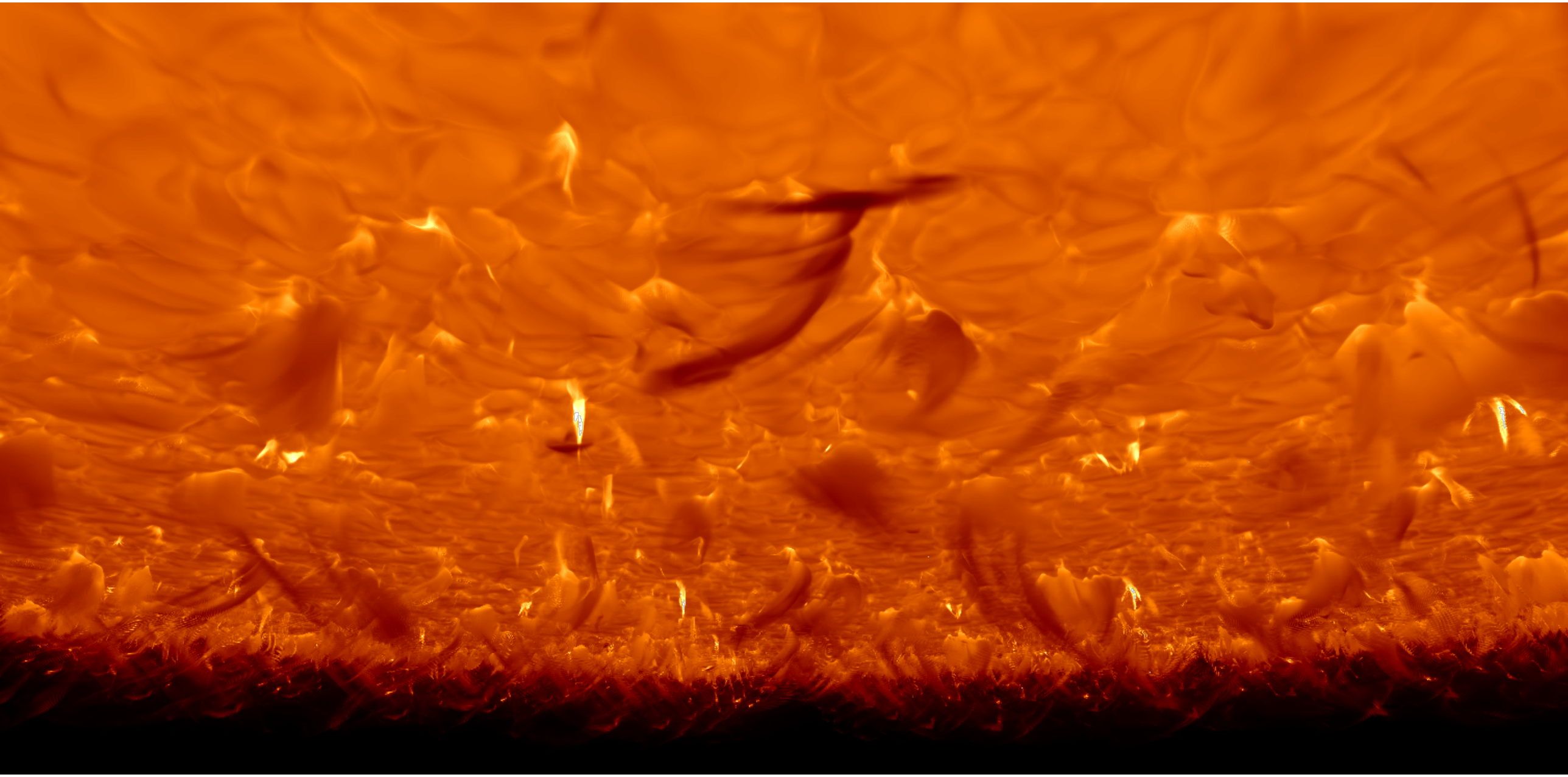






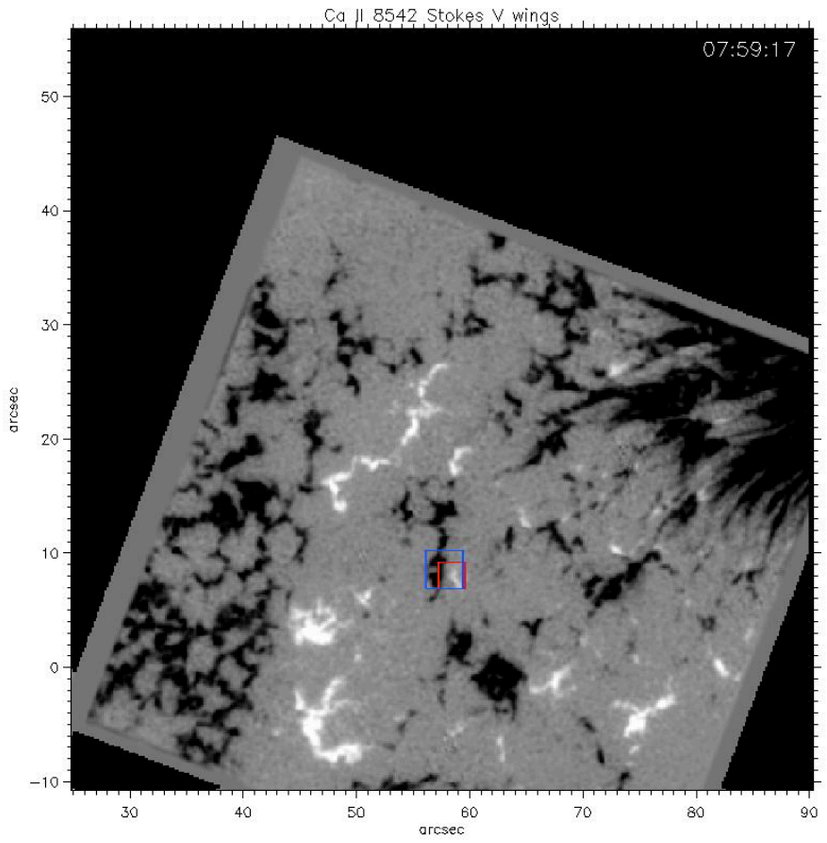


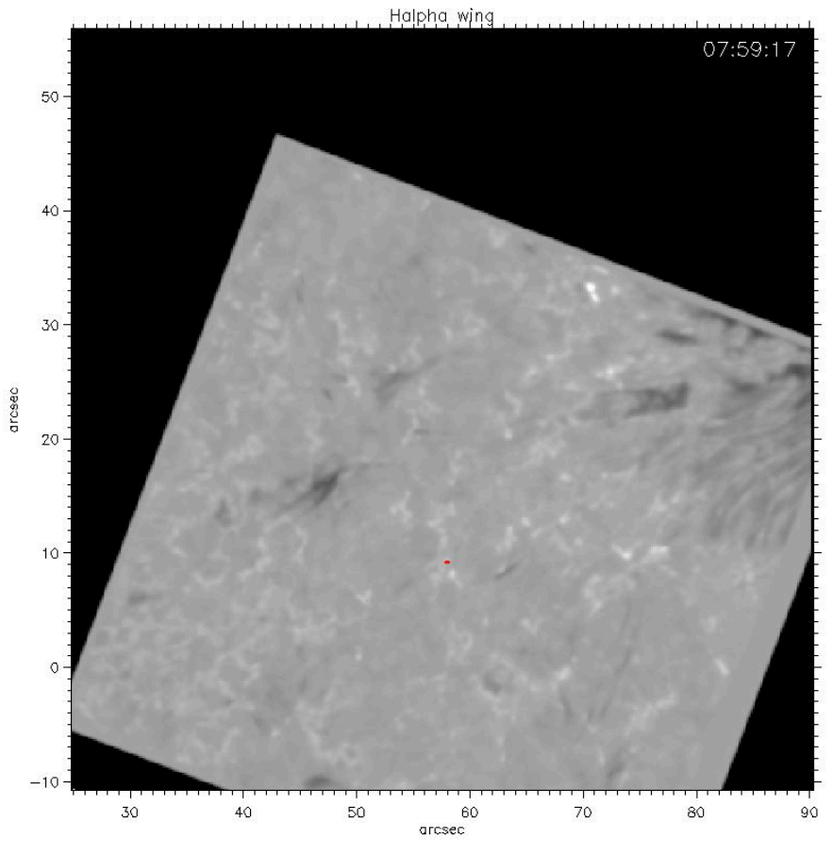


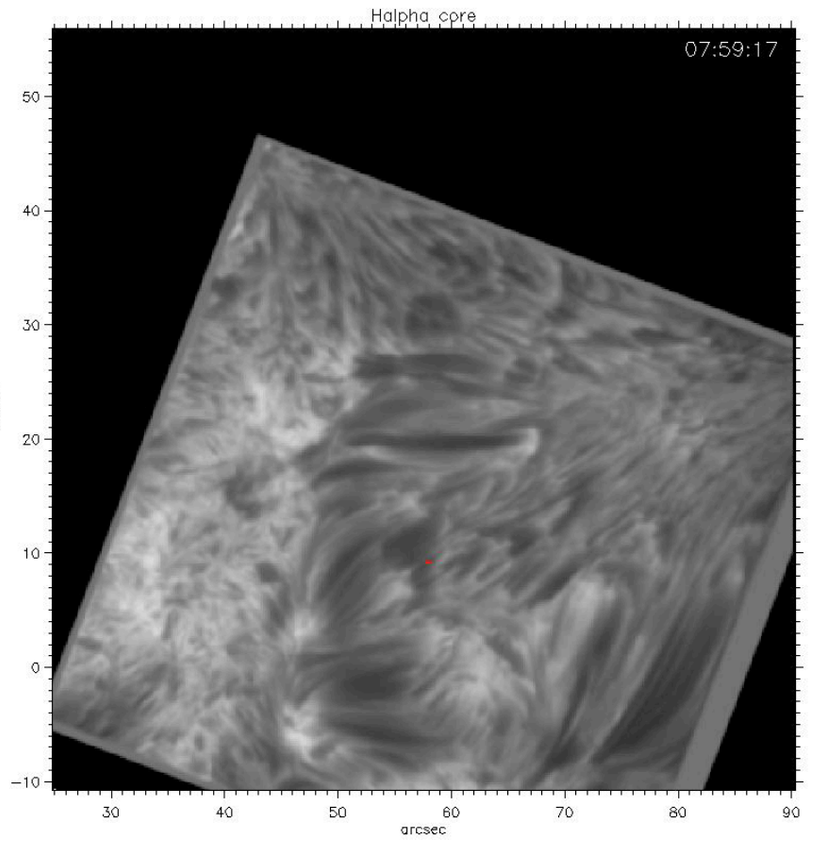


6th September 2016:
20 minutes from 7:59 UT

Total spatial coincidence between EB and UV burst







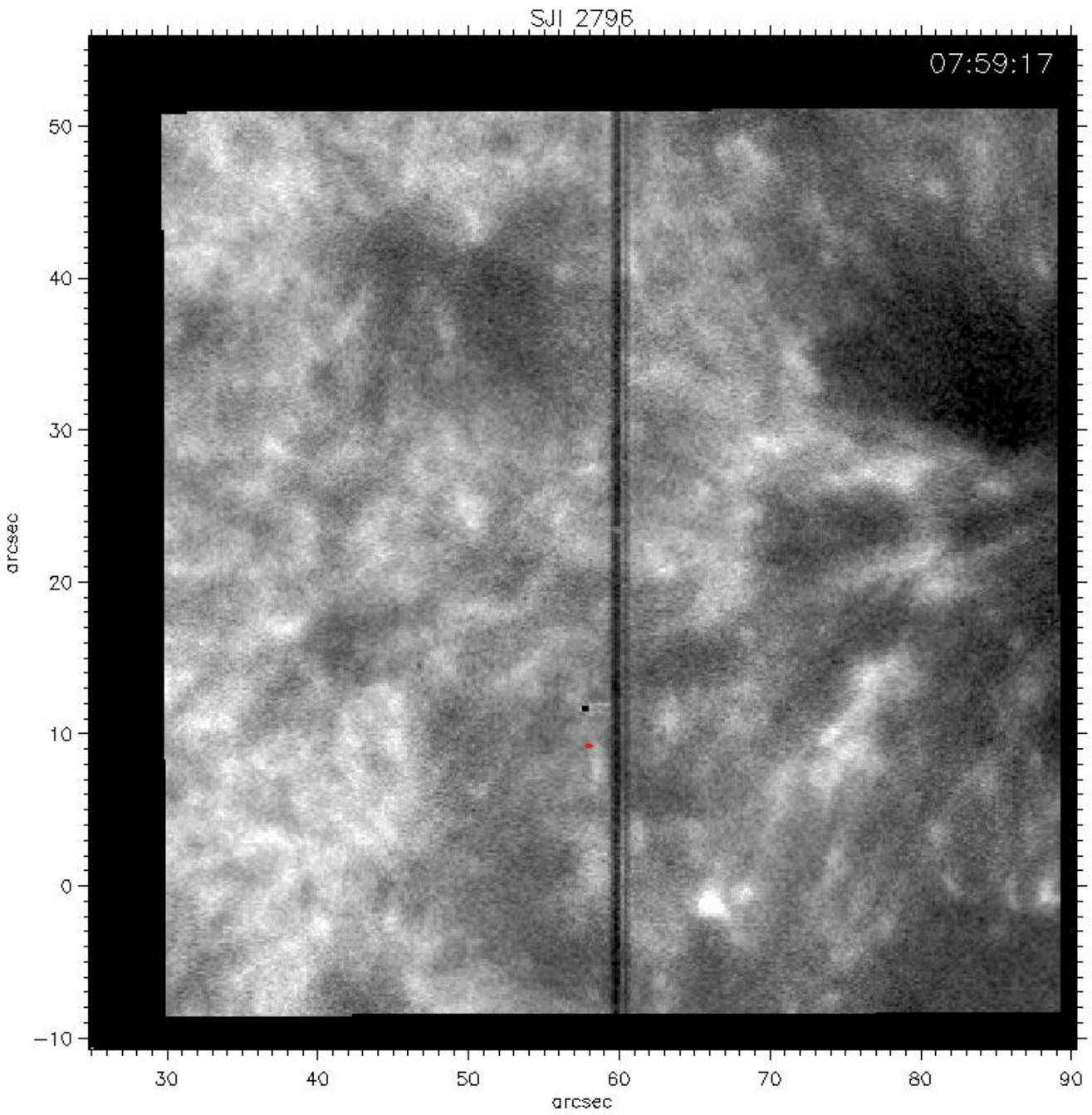
EB boundary

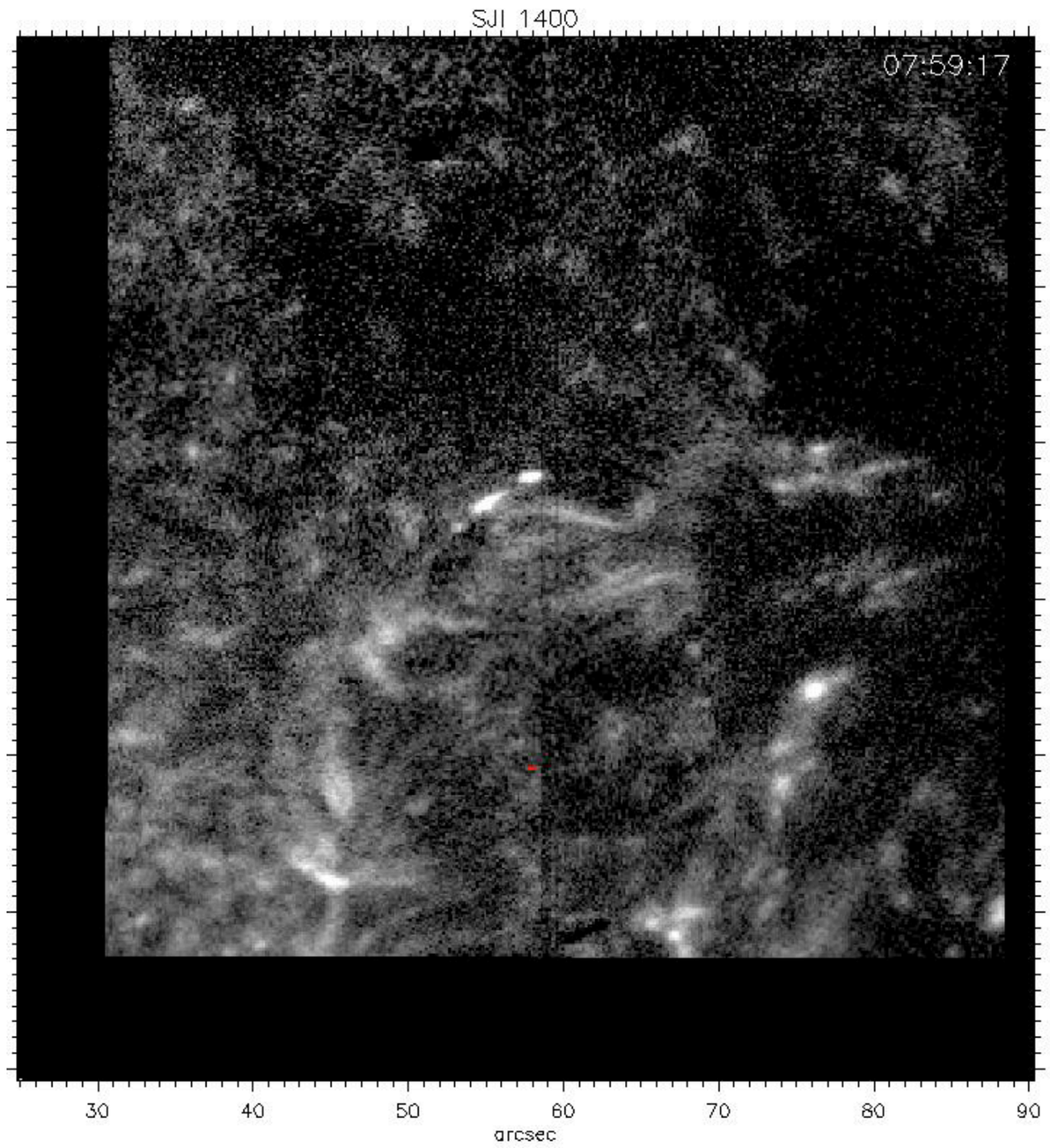
UV burst boundary

R C S

6th September 2016

Total spatial coincidence between EB and UV burst



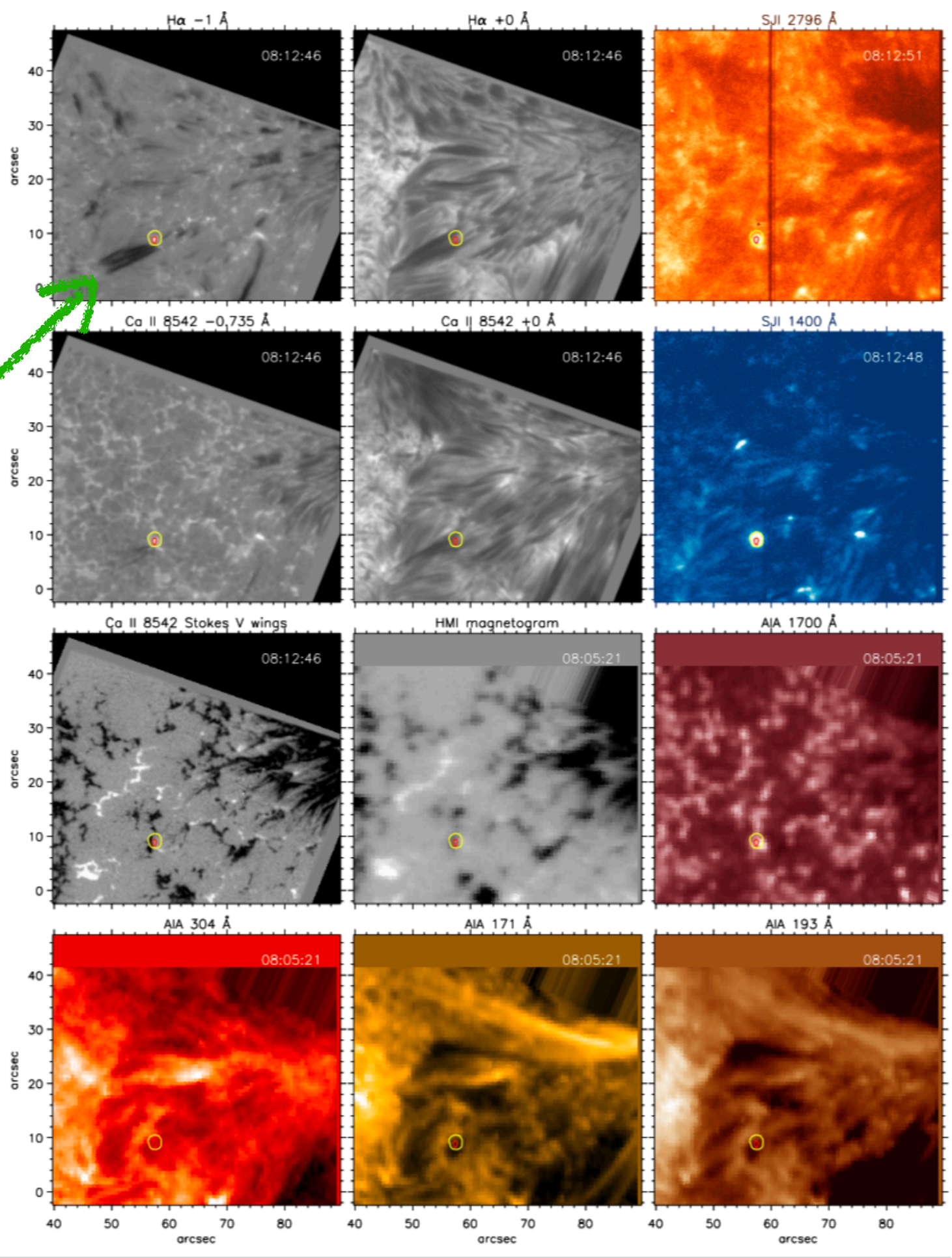


EB boundary

UV burst boundary

R C S

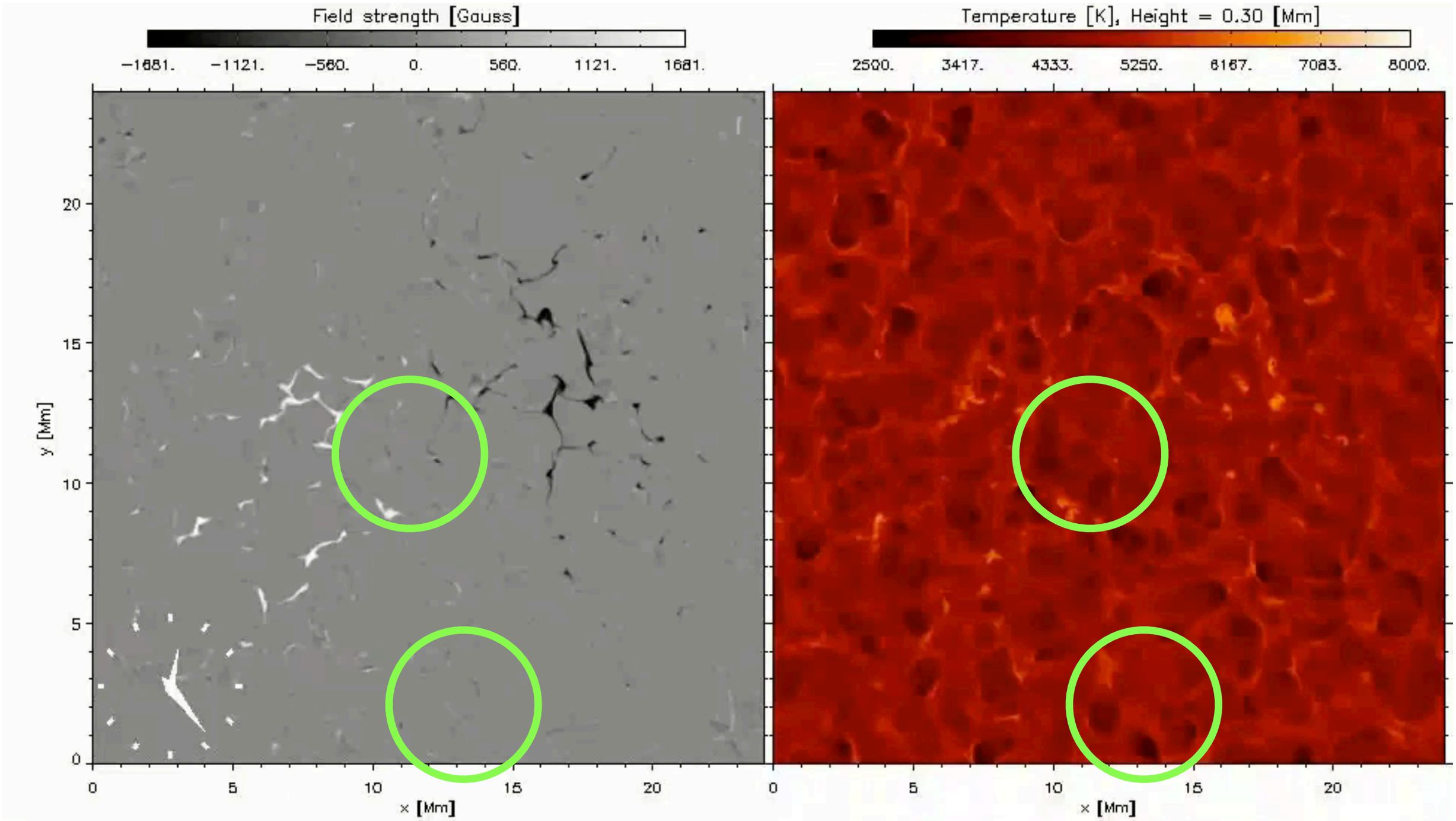
6th September 2016

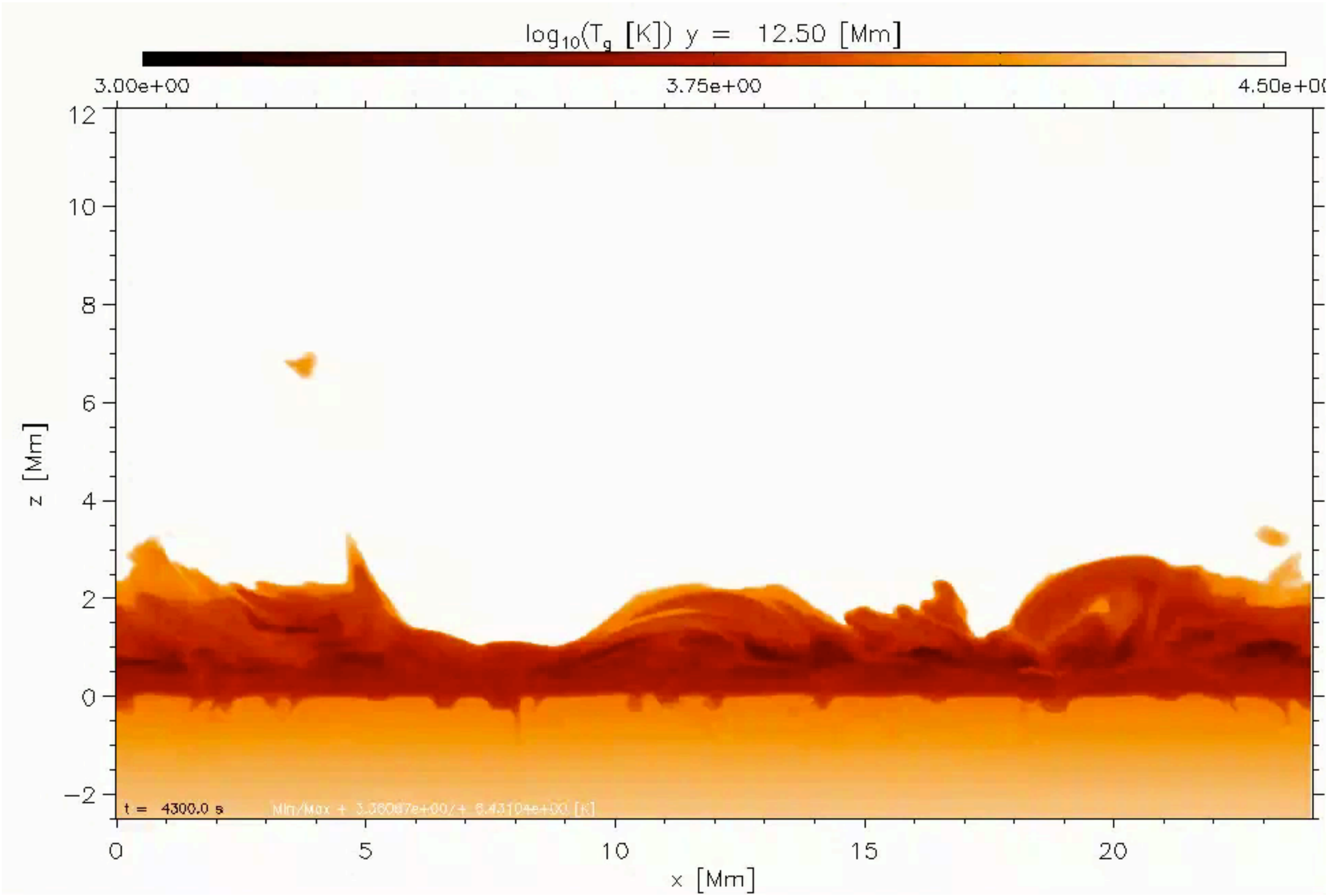


Another surge!

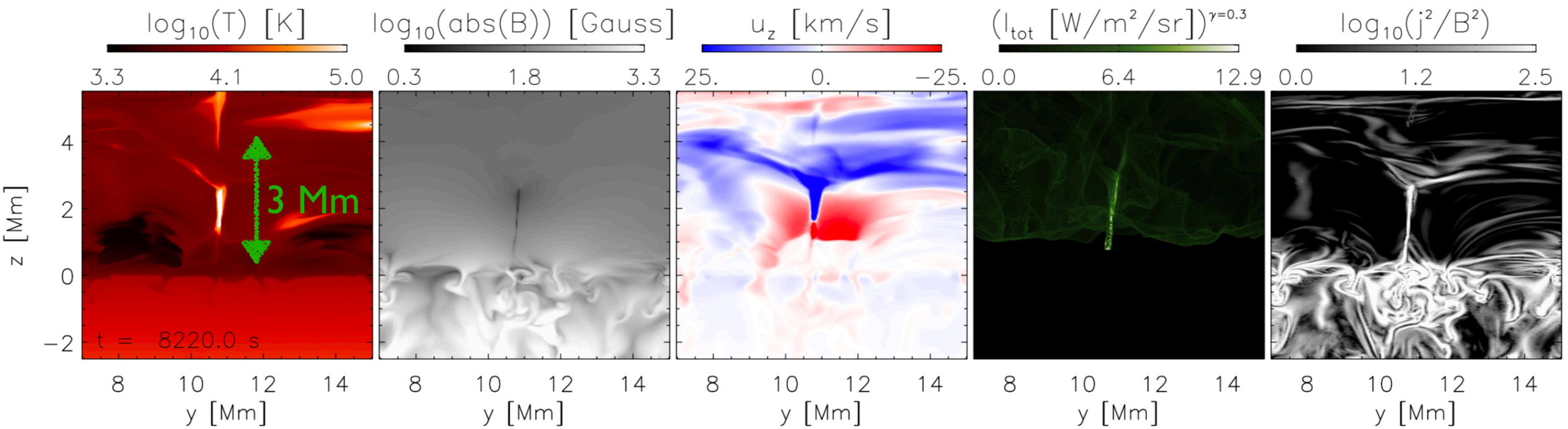
R C S

Flux emergence simulation based on public Bifrost model: EBs?, UV Bursts?, etc(?)




log10(Tg [K]) y = 12.50 [Mm]
3.00e+00
3.75e+00
4.50e+00
12
10
8
6
4
2
0
−2
z [Mm]
t = 4300.0 s
Min/Max = 3.360887e+00/+ 6.431044e+00 [K]
0
5
10
15
20
x [Mm]

The solution: a 3000 km reconnection wall



Reconnection happens **along a wall of about 3000 km** tall, where EBs and UV bursts occur co-spatially but at different layers with around 1500 km difference

R C S

Photosphere 392.31 nm

Ca II triplet wing 854.14 nm

Ca II triplet 854.21 nm

Disturbed granulation

From the photosphere to the corona…

Cold surge

Fibrils formed

Si IV 139.38 nm

Fe XII 19.51 nm

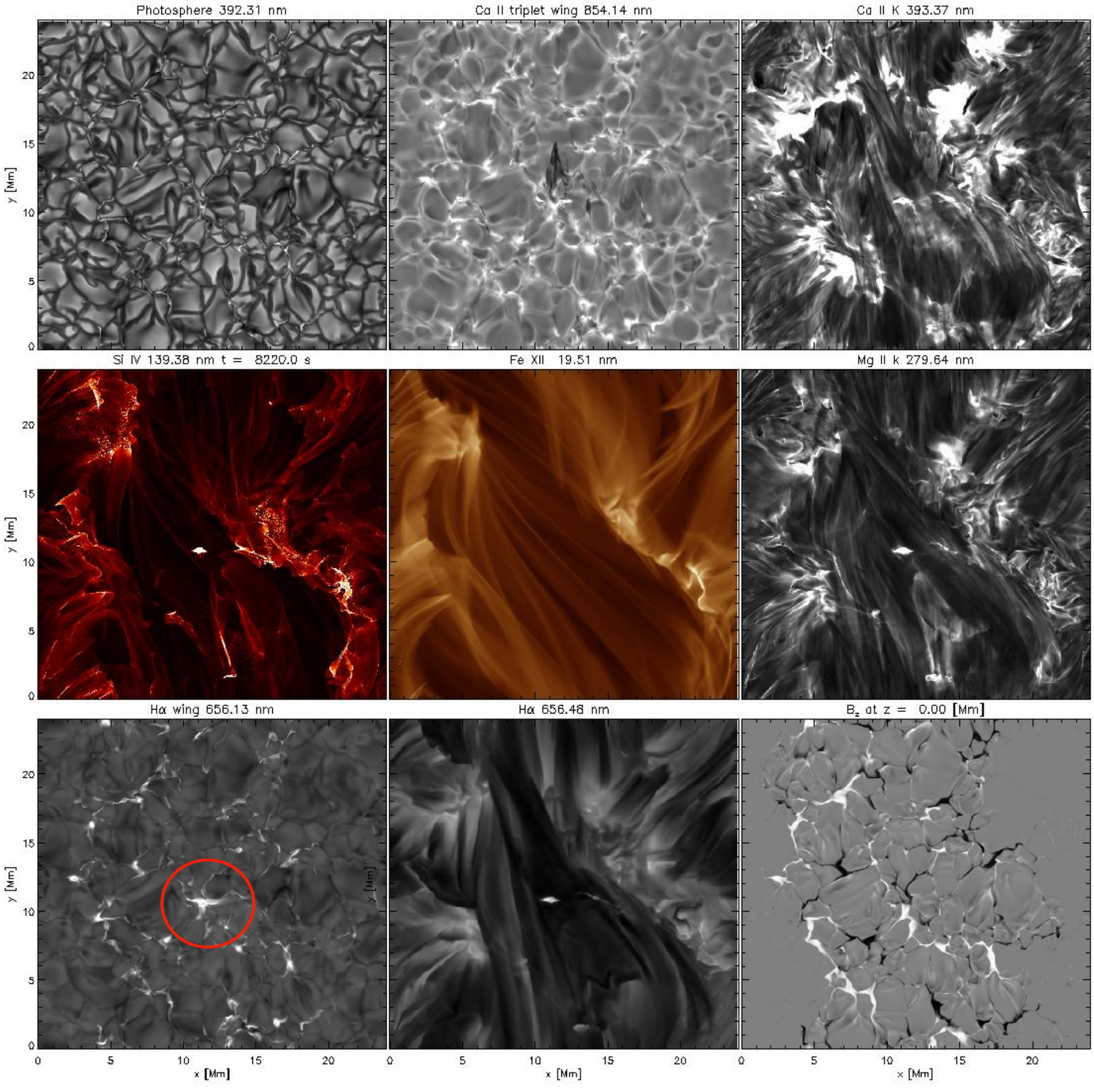
Ca II K 393.37 nm

UV bursts

No burst signal in coronal line though T>1 MK in burst

y [Mm]

x [Mm]



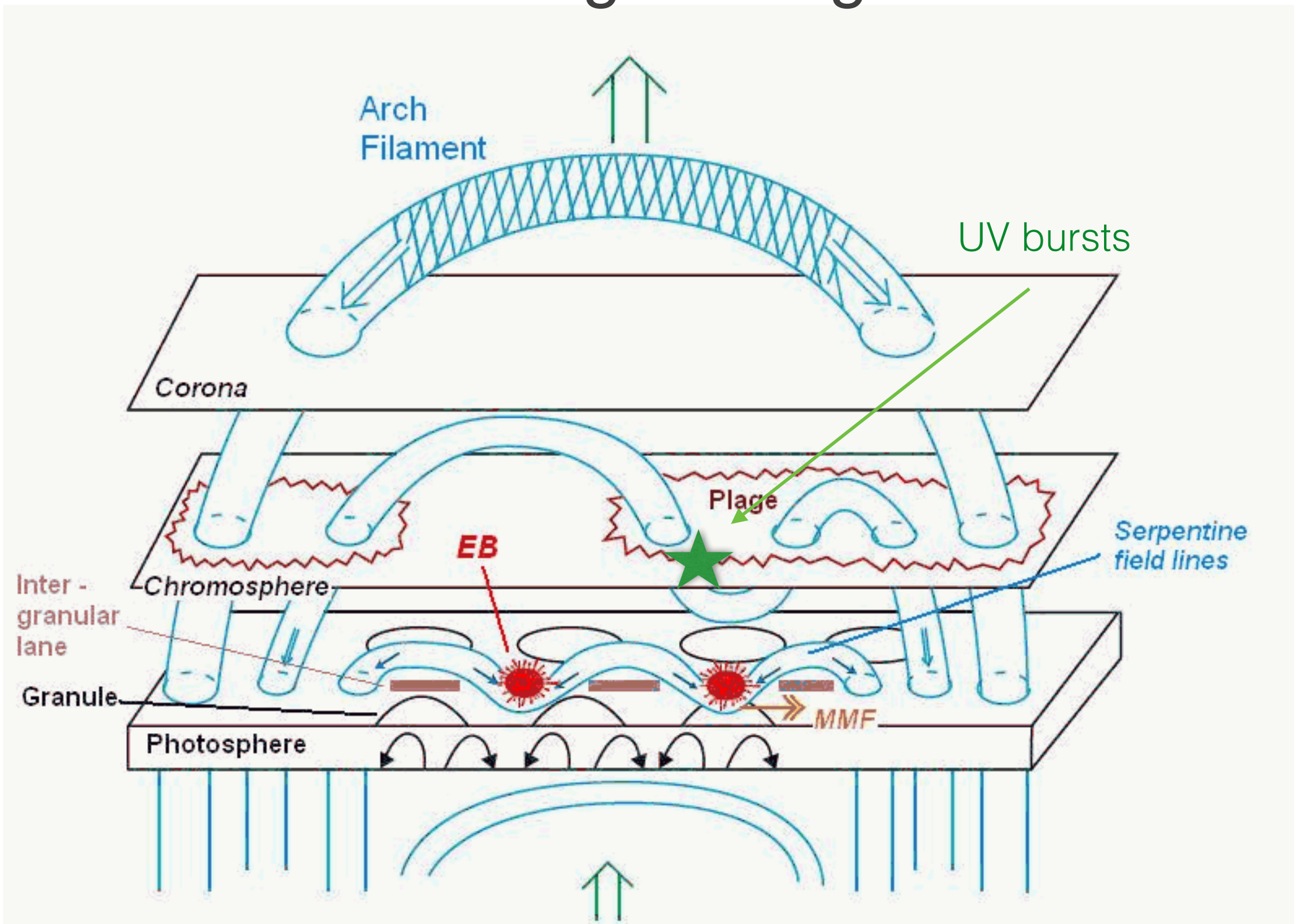
How about Hα?

Several EB's visible co-located with UV-bursts

Here synthetic profiles calculated with MULTI3D, courtesy of Johan Pires Bjørgen, Stockholm University and now RoCS

EB not visible in line core at μ=0.5

Sites of strong flux emergence, formation of coronal active region magnetic field



Schmieder & Pariat 2007 Scholarpedia 2(12):4335 (Shibata's cartoon, slightly modified)

Discussion/Summary

- Flux emergence carries high density cold material high into chromosphere.
- “Ellerman bombs” reproduced through reconnection at photospheric level.
- Temperature rise of some 2 - 5000 K above photosphere.
- Large velocity (20 km/s in photosphere) jet.
- Hα emission looks right, Si IV emission from above photospheric EB can occur.
- “Hierarchical” reconnection/jets as field expands into corona forming long fibrils/coronal loops - UV bursts (and Hα microflares?) arise at chromospheric heights (“level 2”)?
- Densities high enough even at 800 - 2000 km to reproduce measured Si IV intensities. Cool Ni II absorption from high lying cool gas seen.
- “Level 2” jet velocities of order 200 km/s or higher.