Dissecting bombs and bursts: non-LTE inversion of low-atmosphere reconnection in SST-IRIS observations

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Contributed Talk

3. Magnetic coupling and mass flux through the atmosphere

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Ellerman bombs and UV bursts are compact transient brightenings that are ubiquitously observed in the lower atmospheres of active and emerging flux regions. While some Ellerman bombs display clear UV burst signatures, not all have correlated UV signal or vice versa, suggesting the underlying atmospheric and magnetic properties may vary. As both pinpoint sites of magnetic reconnection in reconfiguring fields, understanding their detailed evolution may provide helpful insights in the overall evolution of active regions. Here we present results from observations and non-LTE inversions of SST/CRISP and CHROMIS, as well as IRIS data of several such transient events. Combining information from the Mg II h & k, Si IV, Ca II 8542 Å and Ca II K lines we aim to infer the temperature and velocity stratifications, as well as the magnetic field configuration within which they occur. At unprecedented spatial resolution the CHROMIS Ca II K observations reveal dynamic fine structure suggesting plasmoid-mediated reconnection and we find that the events correspond to average temperature enhancements of order 2500–4000 K, with localised hot pockets of up to 10,000–15,000 K. Several events show clear bi-directional jet signatures with line-of-sight velocities of order 5–15 $\mathrm{km\,s^{-1}}$ and the inversions suggest increased horizontal fields close to the larger temperature enhancements. While a response in Si IV can be reproduced for some cases, this generally comes at the expense of overestimating the emission in the other lines considered. We will address the difficulties of successfully inverting all diagnostics and discuss our results in light of the current debate on the connection between UV bursts and Ellerman bombs, their occurrence heights and in particular the temperatures that they may (or may not) reach.

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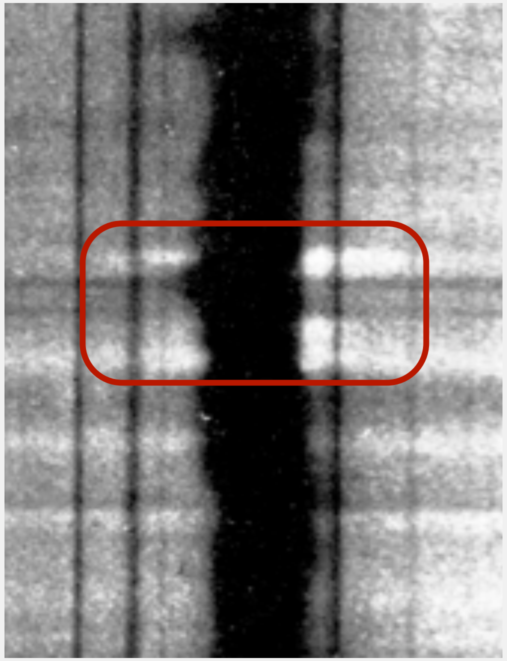
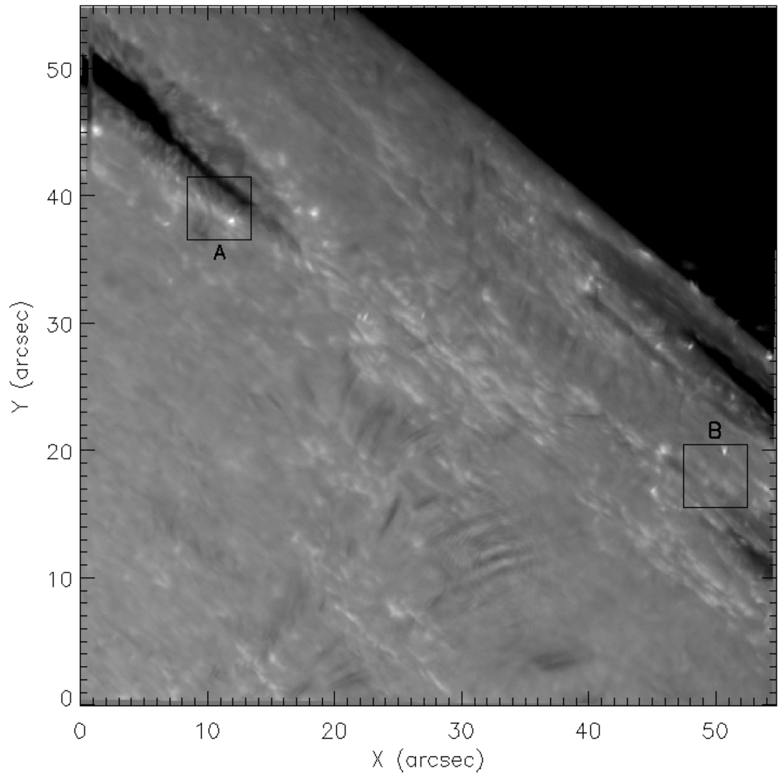
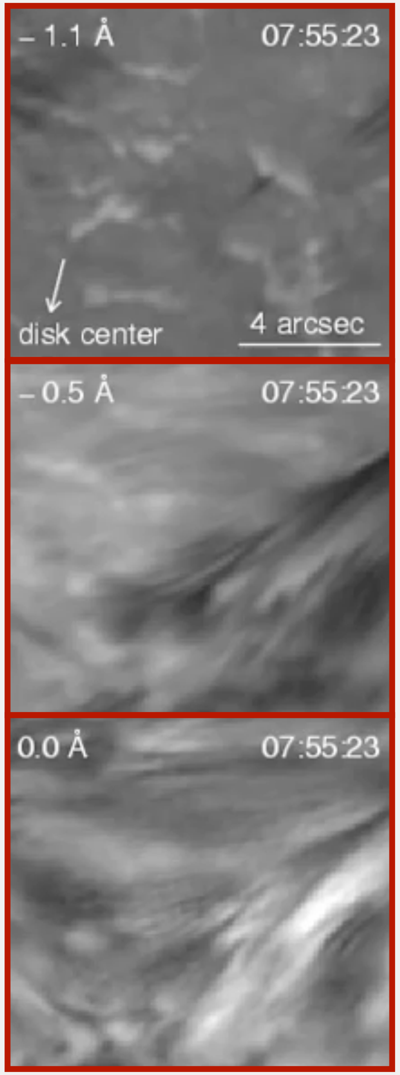
Solar hydrogen “bombs” - bursts with flame-like fine structure evolving within seconds



Ellerman (1917)

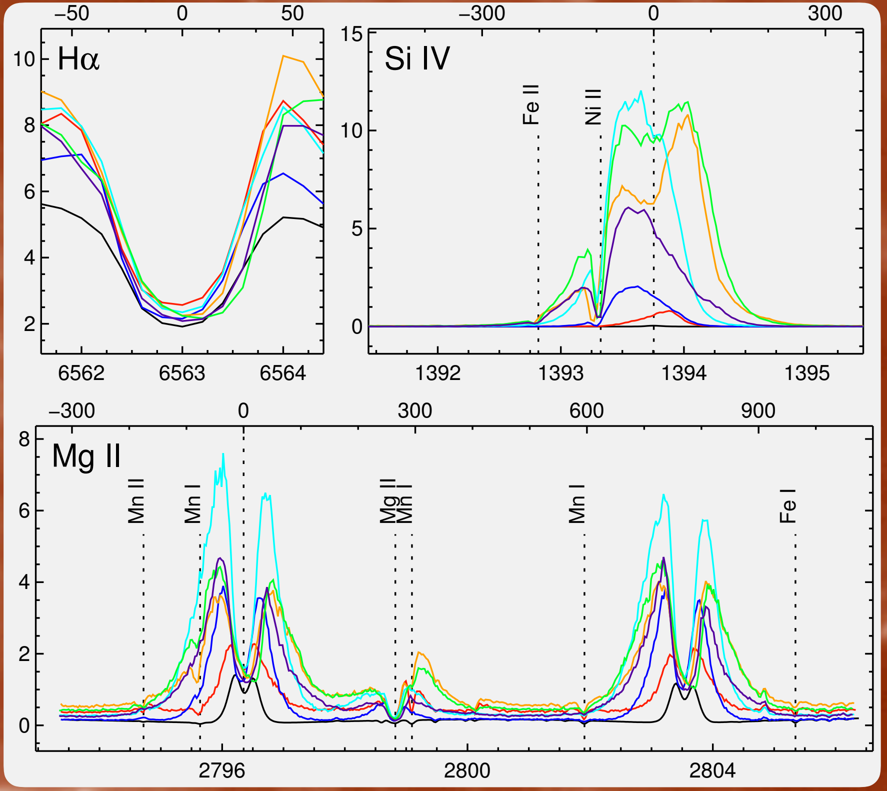


Nelson et al. (2015)
SST/CRISP Hα



Watanabe et al. (2011)
SST/CRISP Hα

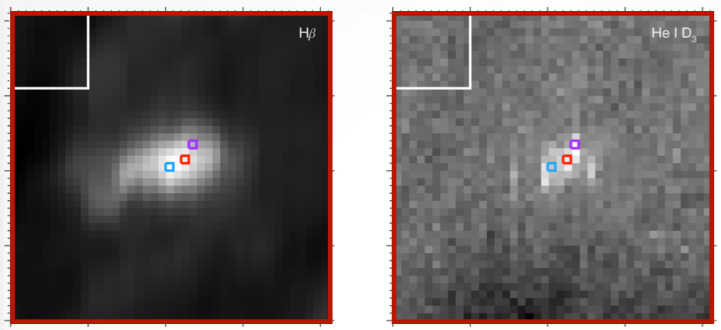
Some Ellerman bombs have a counterpart signature in the UV as observed by IRIS

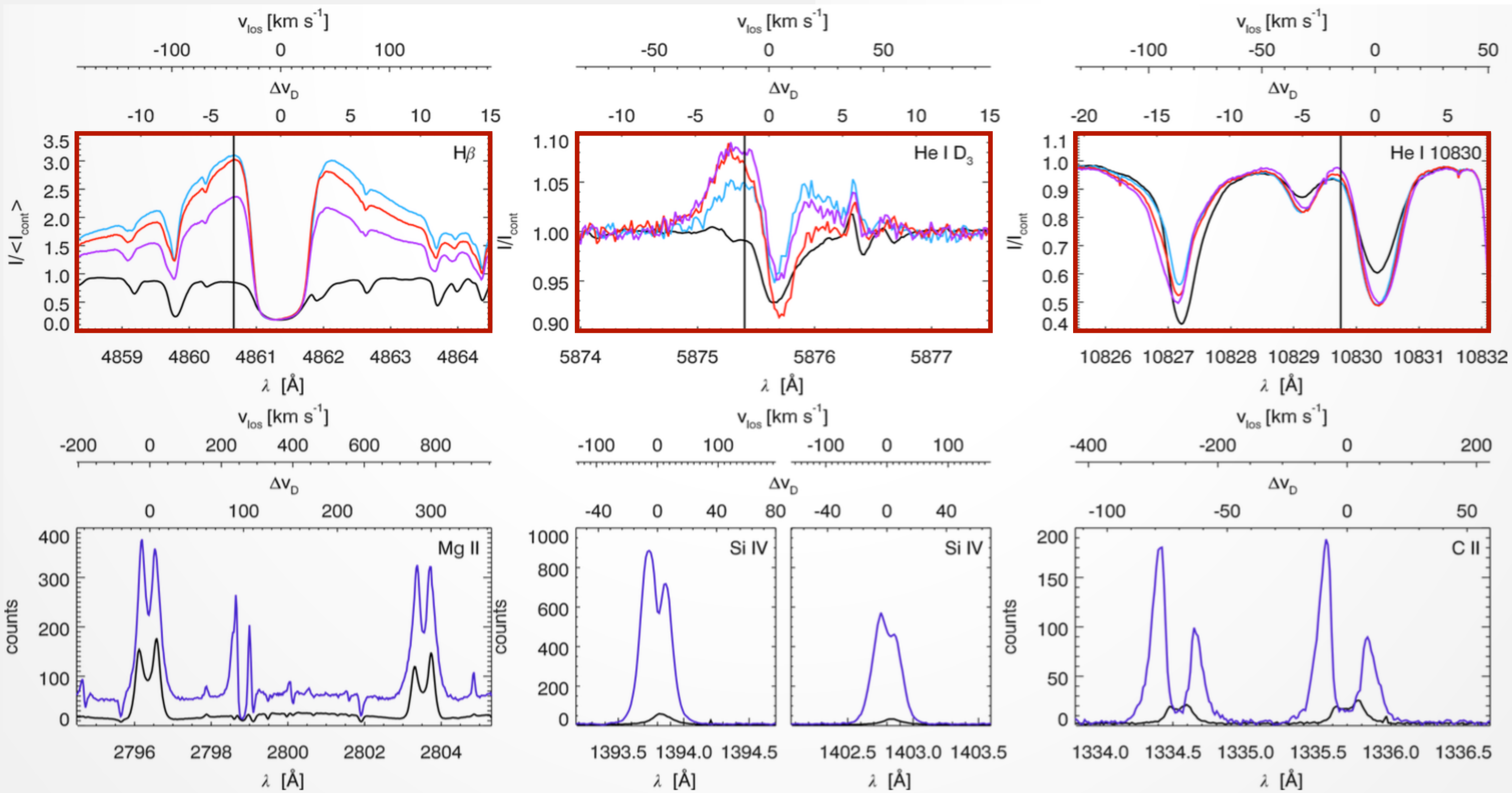


See also, e.g., Tian et al. (2016), Hong et al. (2017), Libbrecht et al. (2017) or Grubecka et al. (2016, non-simultaneous Hα)

Vissers et al. (2015)

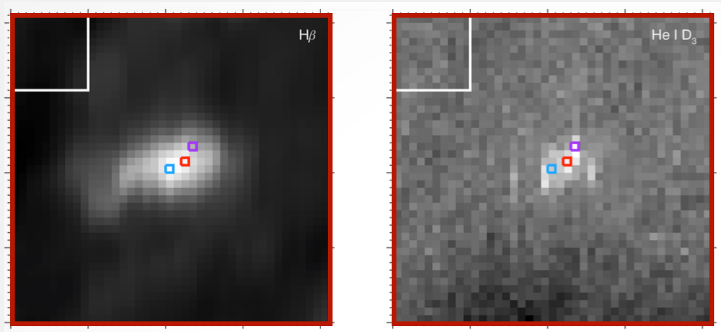
Ellerman bomb visibility in He I D3 suggests higher temperatures

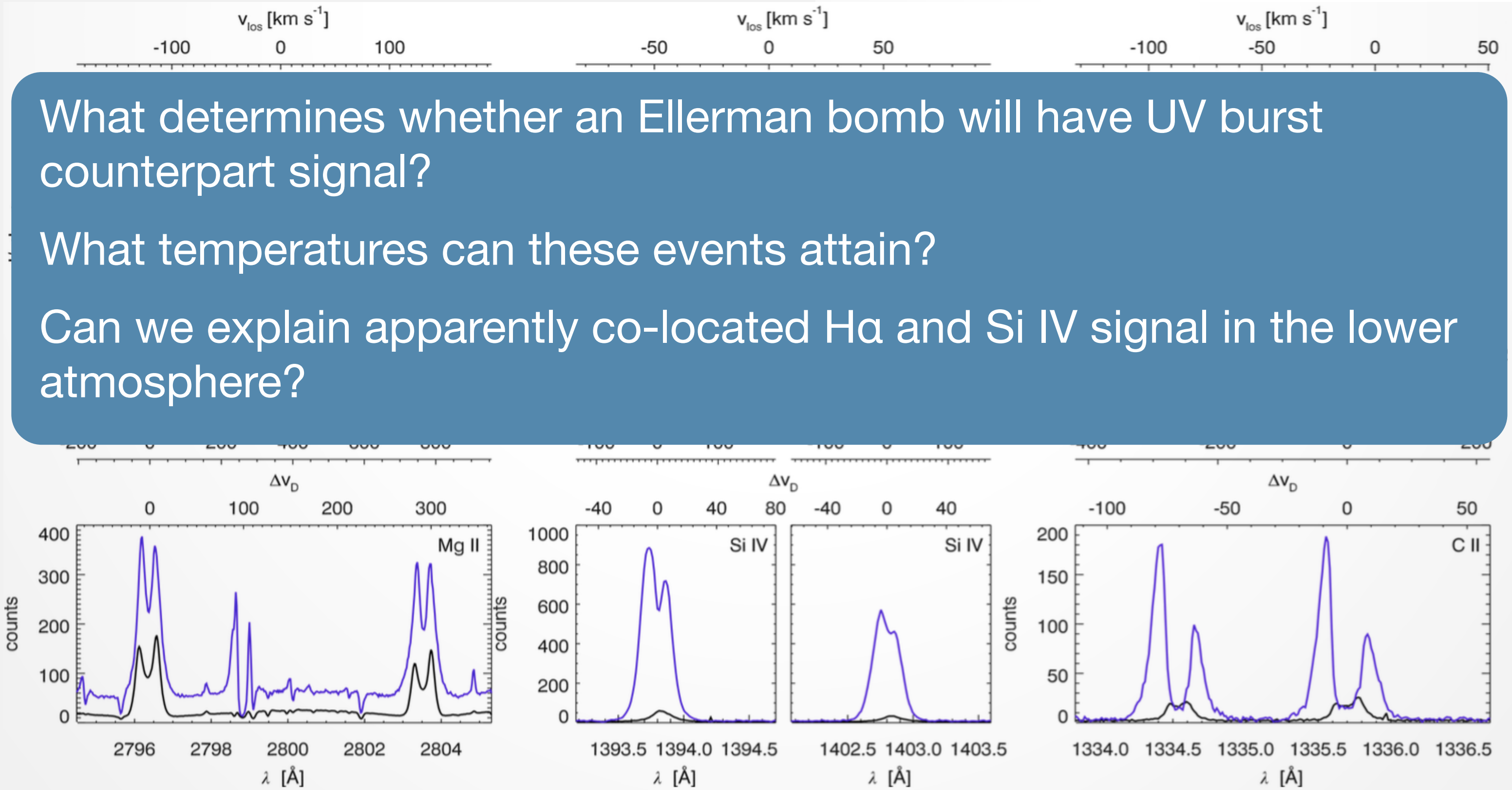




Libbrecht et al. (2017)

Ellerman bomb visibility in He I D₃ suggests higher temperatures



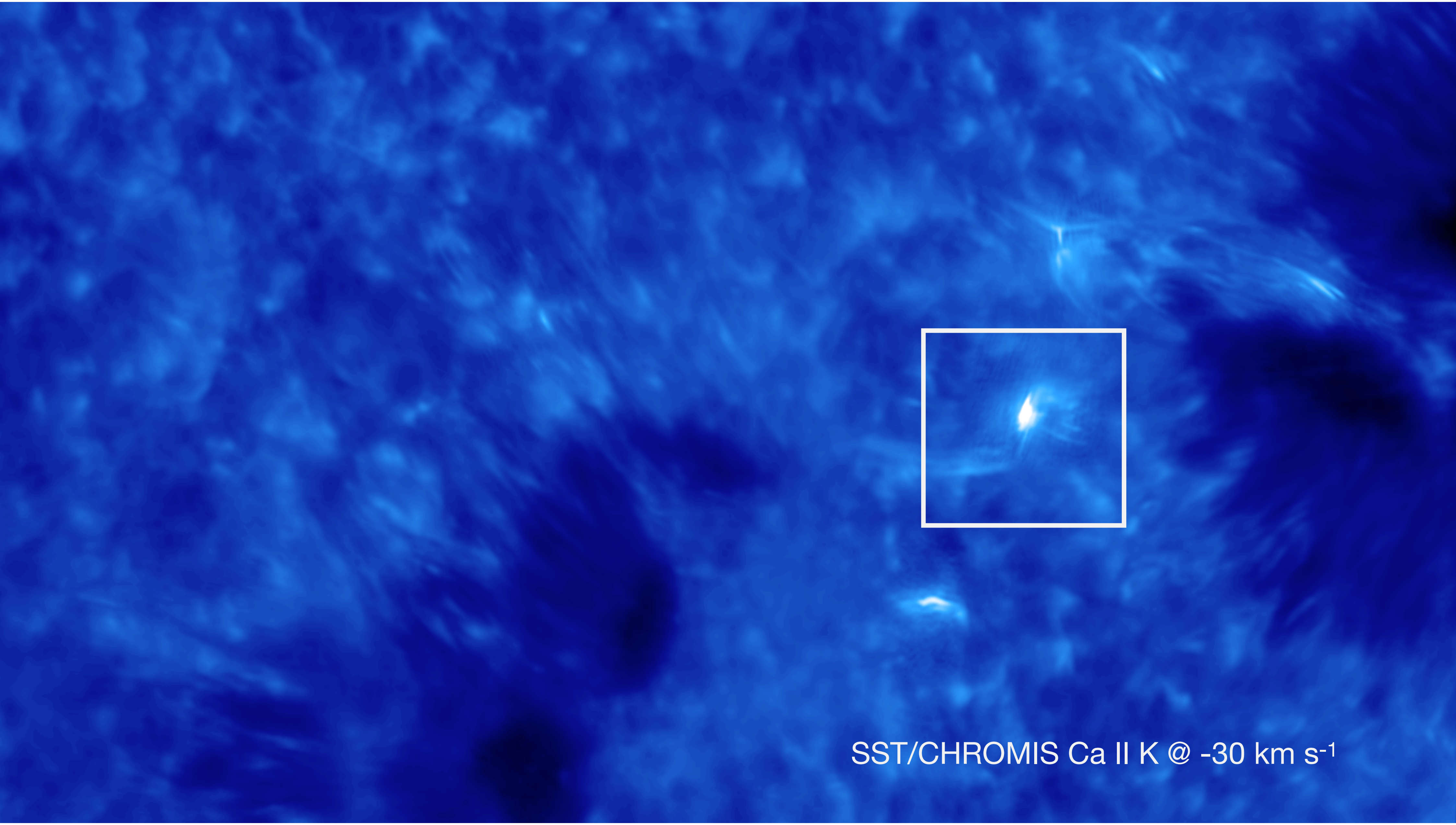


What determines whether an Ellerman bomb will have UV burst counterpart signal?

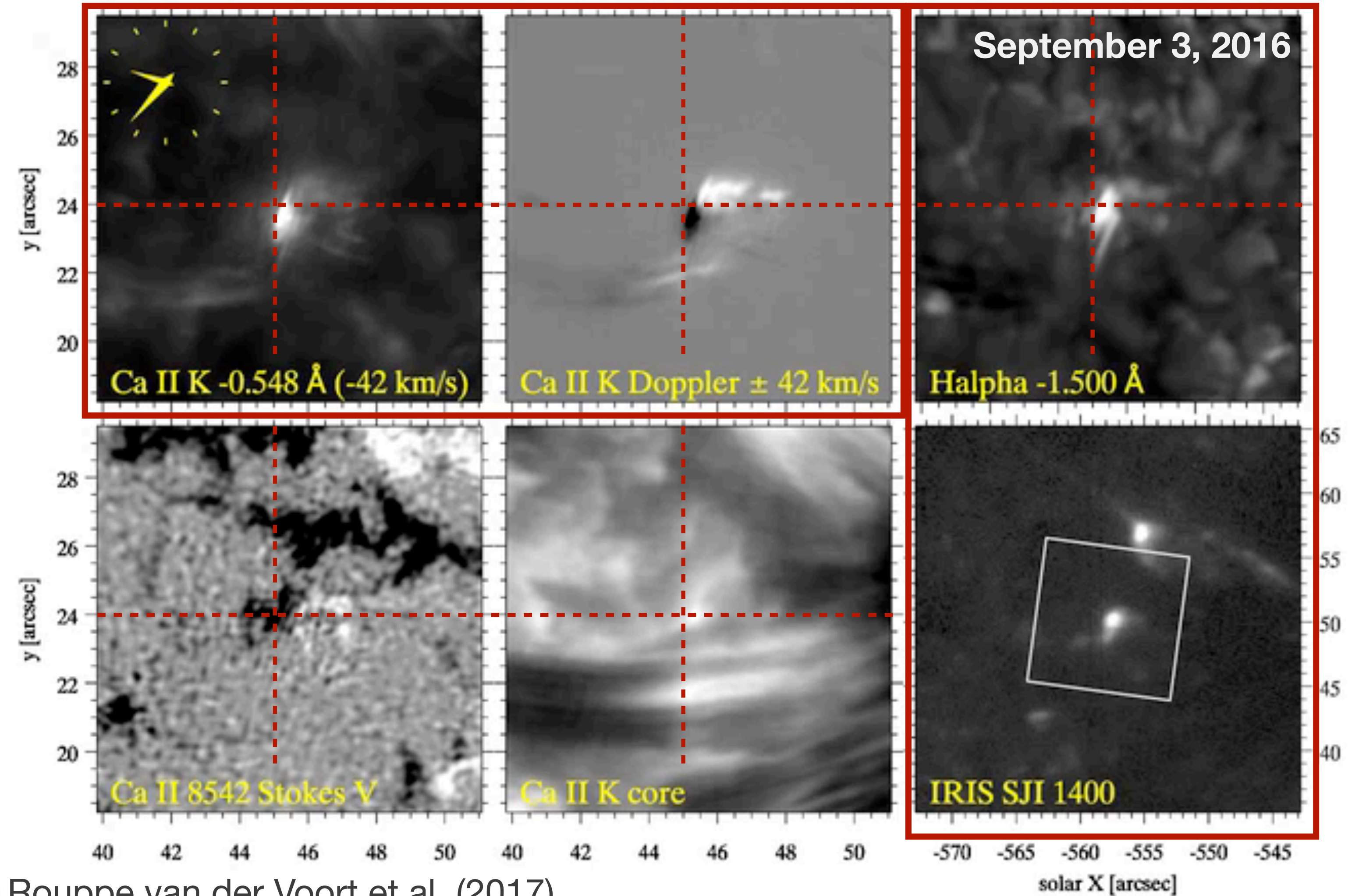
What temperatures can these events attain?

Can we explain apparently co-located Hα and Si IV signal in the lower atmosphere?

Libbrecht et al. (2017)

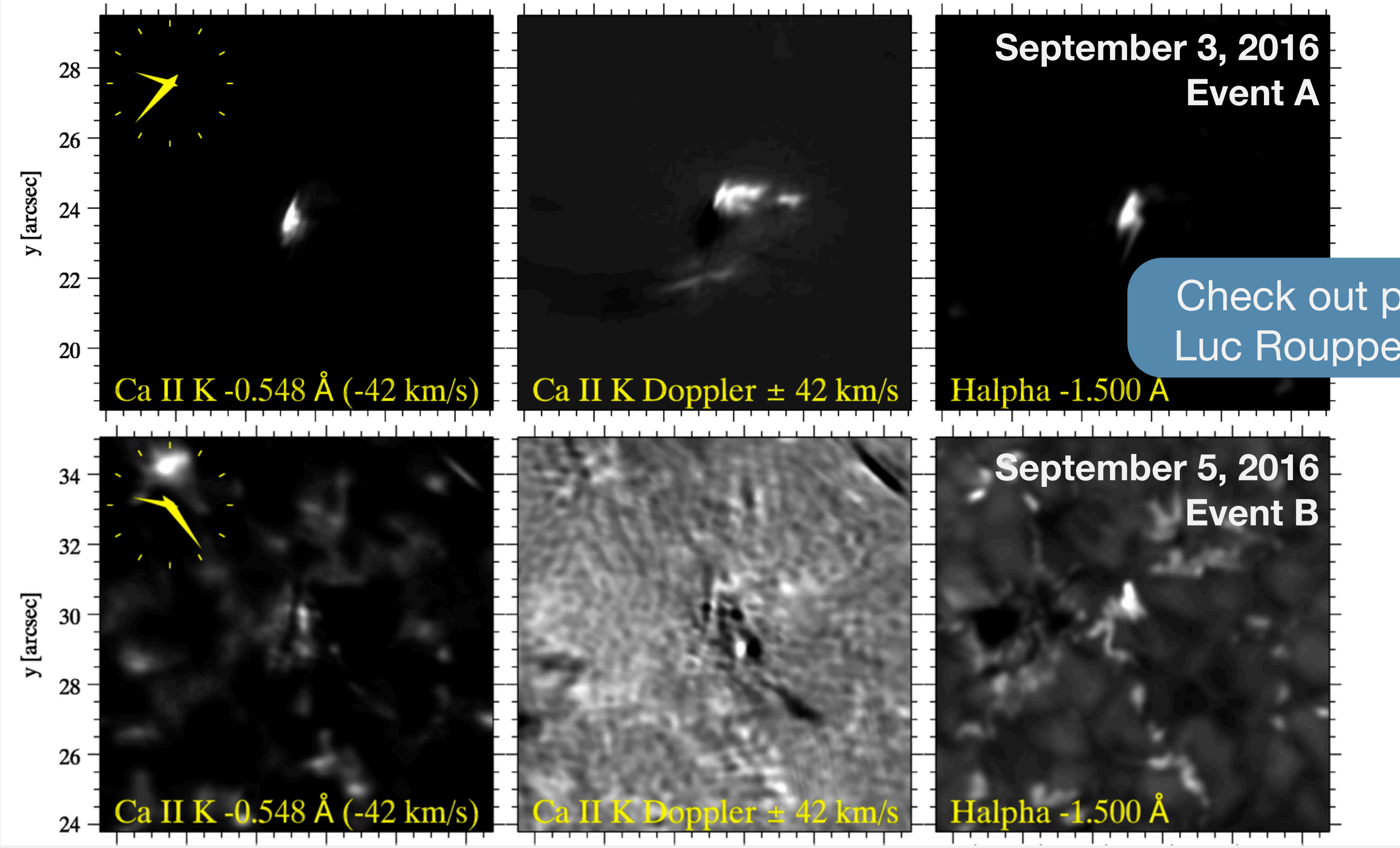

SST/CHROMIS Ca II K @ -30 km s-1

CHROMIS Ca II K observations show additional fine structure, overlapping with Hα and Si IV emission



Rouppe van der Voort et al. (2017)

CHROMIS Ca II K observations show additional fine structure, overlapping with Hα and Si IV emission



Check out poster **P-08** by Luc Rouppe van der Voort

Rouppe van der Voort et al. (2017)

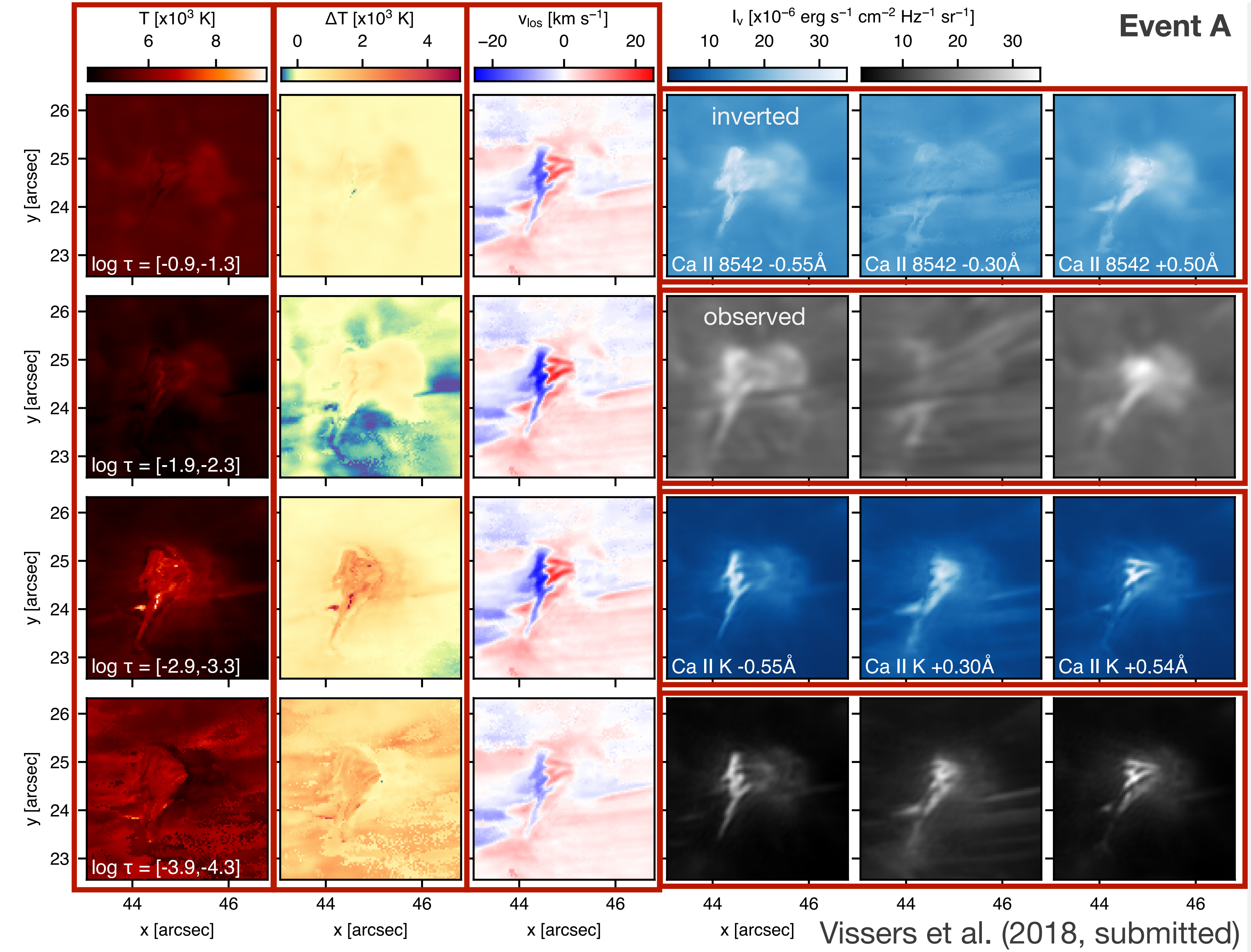
We use STiC to solve the non-LTE radiative transfer problem

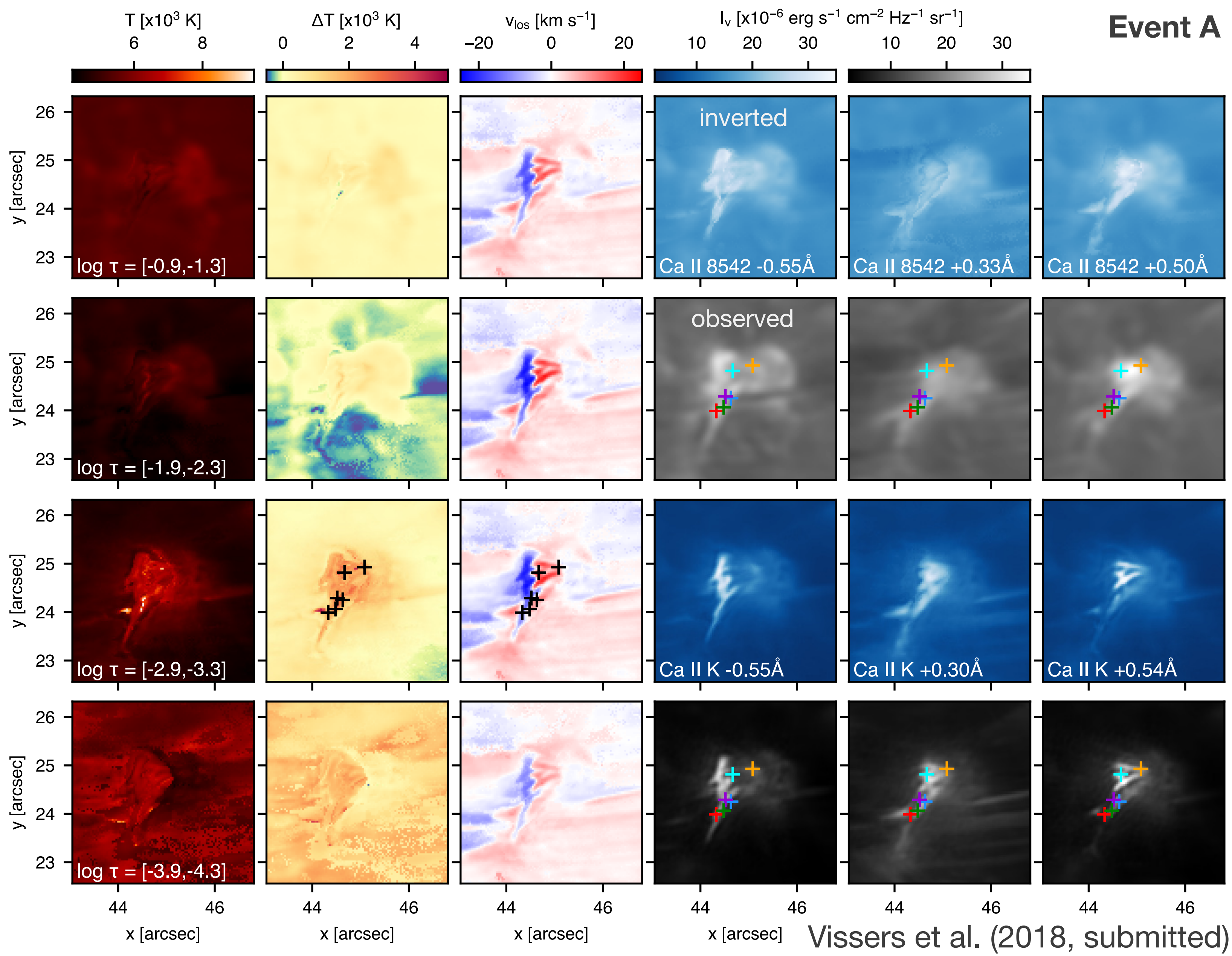
LTE equation of state and hydrostatic equilibrium, non-LTE hydrogen ionisation

Model atmosphere initialised from FALC and plane-parallel geometry

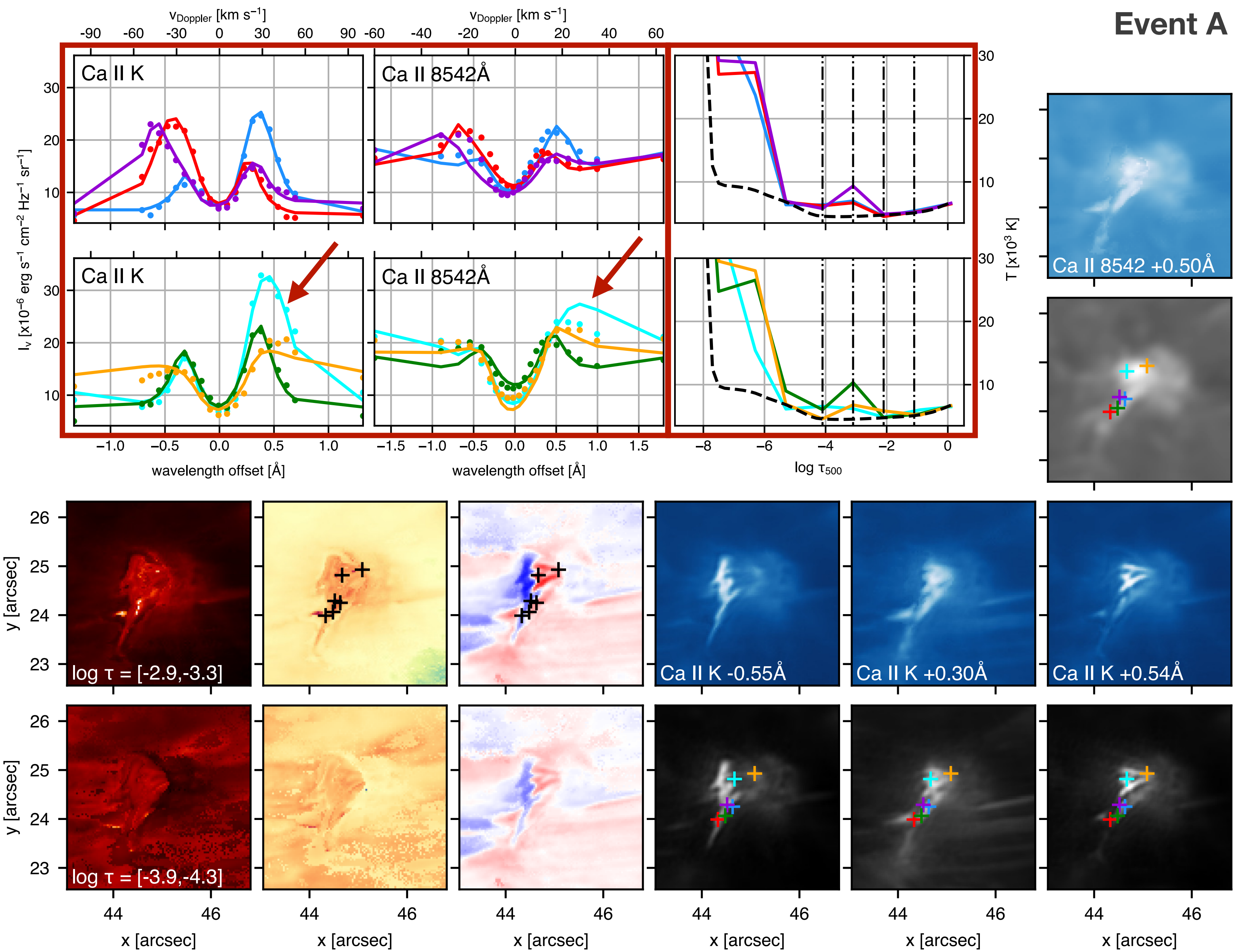
Mg II h & k and Ca II K in PRD
Ca II 8542Å and Si IV in CRD

	Cycle 1	Cycle 2 & 3	Cycle 3 (Si IV)
T	4	9	13
v_{los}	1	4	4
v_{turb}	1	5	5

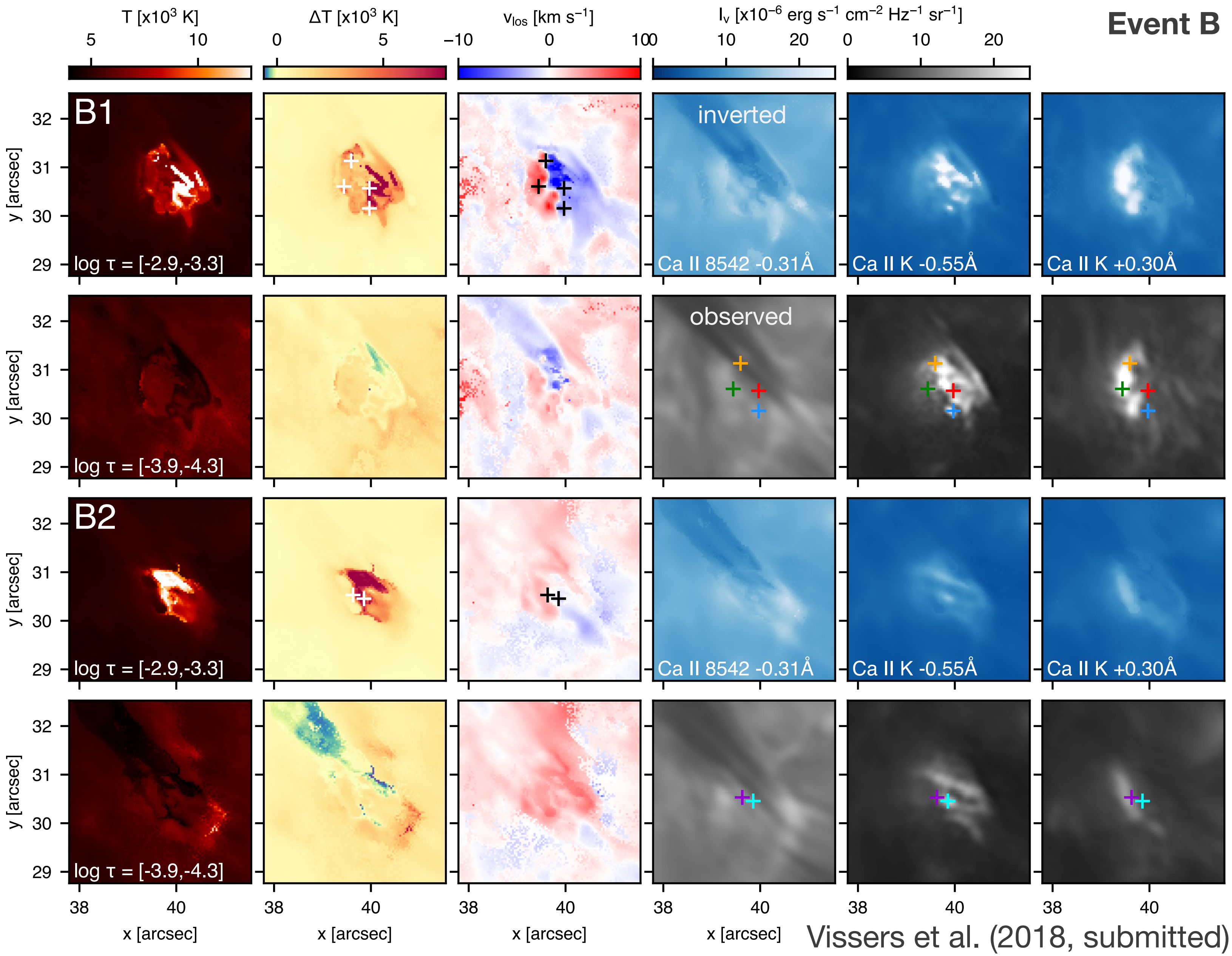

Event A
T [x10³ K]
ΔT [x10³ K]
vlos [km s⁻¹]
Iν [x10⁻⁶ erg s⁻¹ cm⁻² Hz⁻¹ sr⁻¹]
inverted
observed
log τ = [-0.9,-1.3]
log τ = [-1.9,-2.3]
log τ = [-2.9,-3.3]
log τ = [-3.9,-4.3]
Ca II 8542 -0.55Å
Ca II 8542 -0.30Å
Ca II 8542 +0.50Å
Ca II K -0.55Å
Ca II K +0.30Å
Ca II K +0.54Å
y [arcsec]
x [arcsec]
Vissers et al. (2018, submitted)



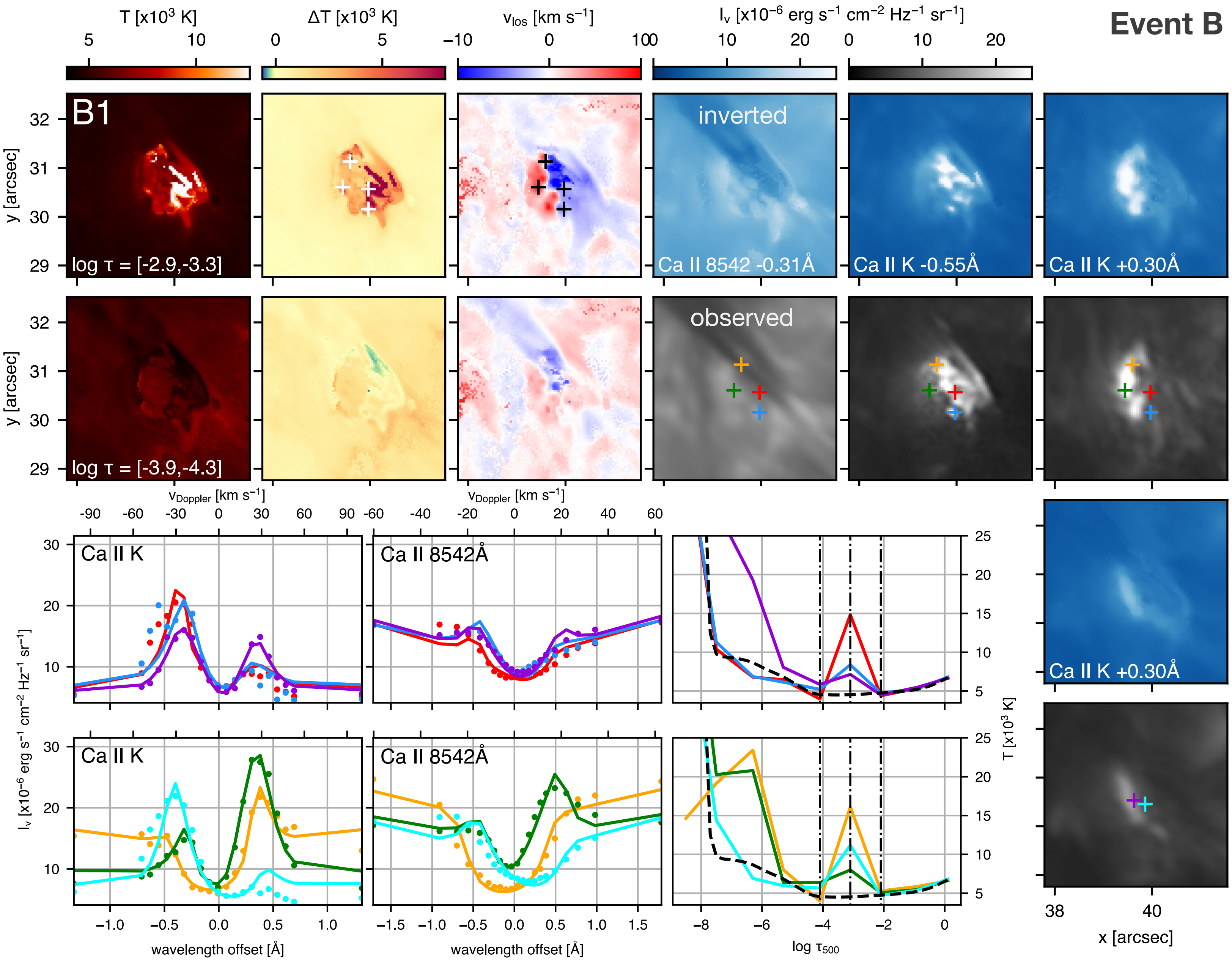
Vissers et al. (2018, submitted)



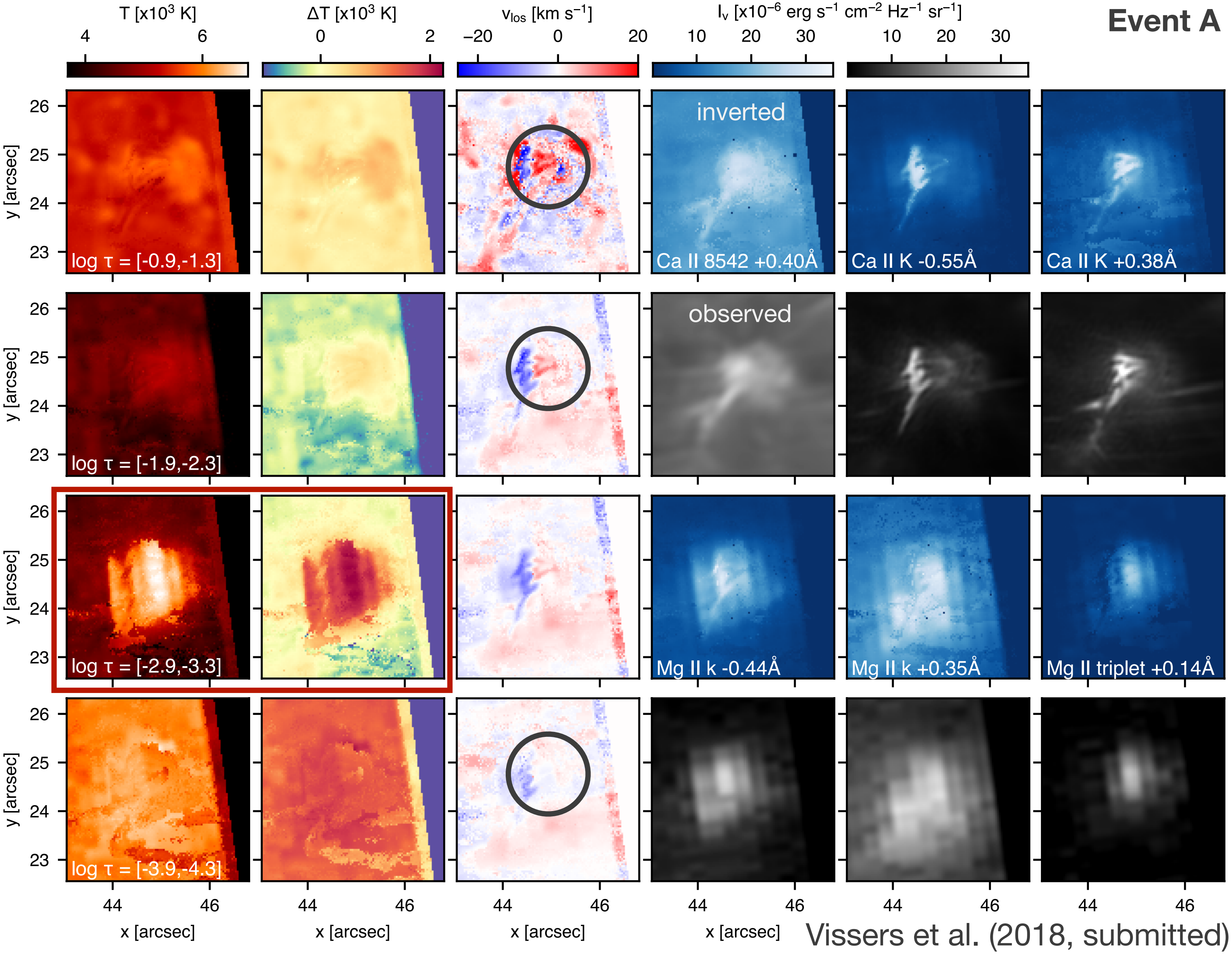
Event A
Ca II K
Ca II 8542Å
Ca II K
Ca II 8542Å
v_Doppler [km s⁻¹]
wavelength offset [Å]
log τ500
T [x10³ K]
Ca II 8542 +0.50Å
log τ = [-2.9,-3.3]
log τ = [-3.9,-4.3]
Ca II K -0.55Å
Ca II K +0.30Å
Ca II K +0.54Å
y [arcsec]
x [arcsec]



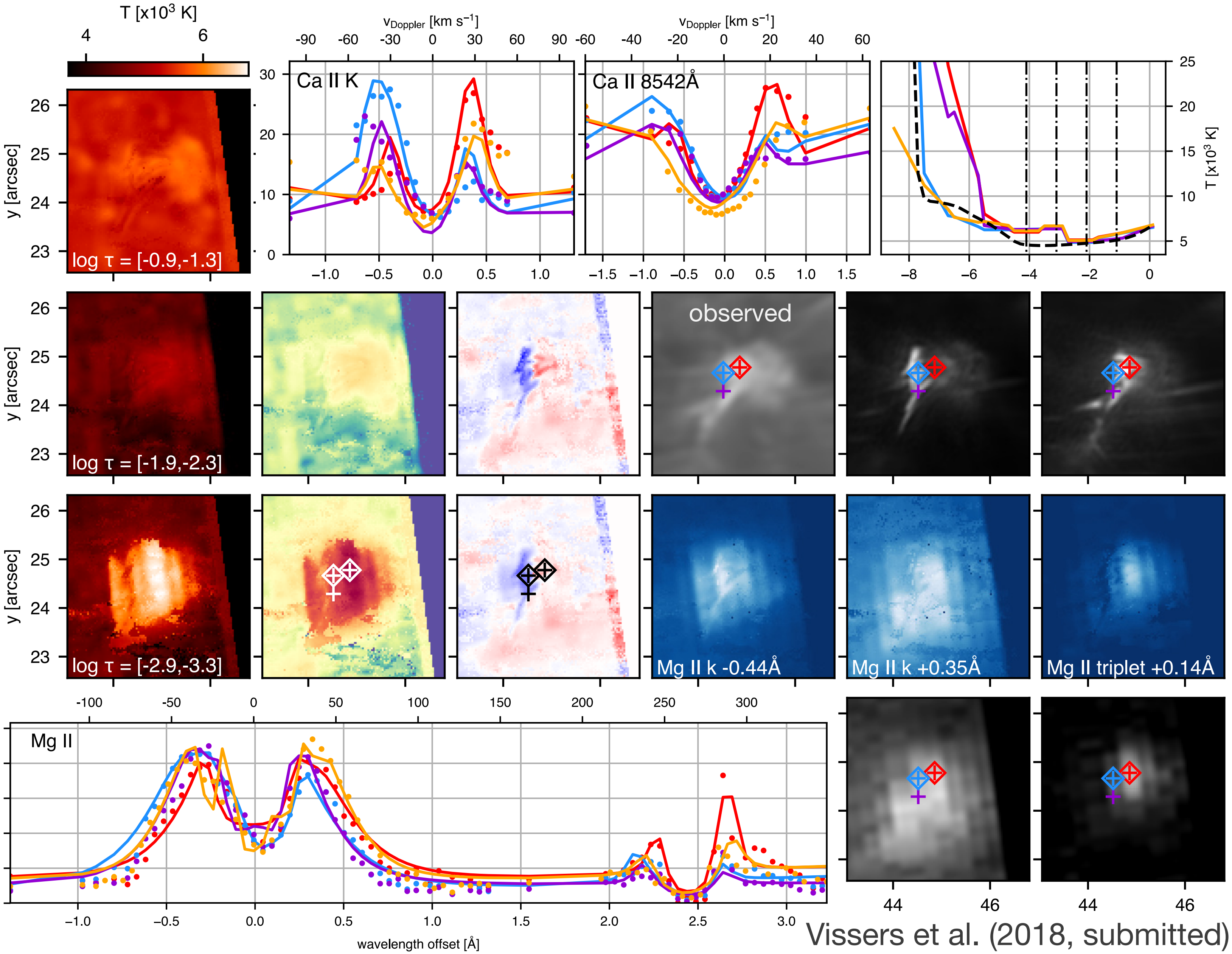
Vissers et al. (2018, submitted)



Event B
T [x10³ K]
ΔT [x10³ K]
v_los [km s⁻¹]
I_ν [x10⁻⁶ erg s⁻¹ cm⁻² Hz⁻¹ sr⁻¹]
B1
log τ = [-2.9,-3.3]
log τ = [-3.9,-4.3]
inverted
observed
Ca II 8542 -0.31Å
Ca II K -0.55Å
Ca II K +0.30Å
Ca II K +0.30Å
y [arcsec]
x [arcsec]
v_Doppler [km s⁻¹]
Ca II K
Ca II 8542Å
wavelength offset [Å]
log τ500
T [x10³ K]

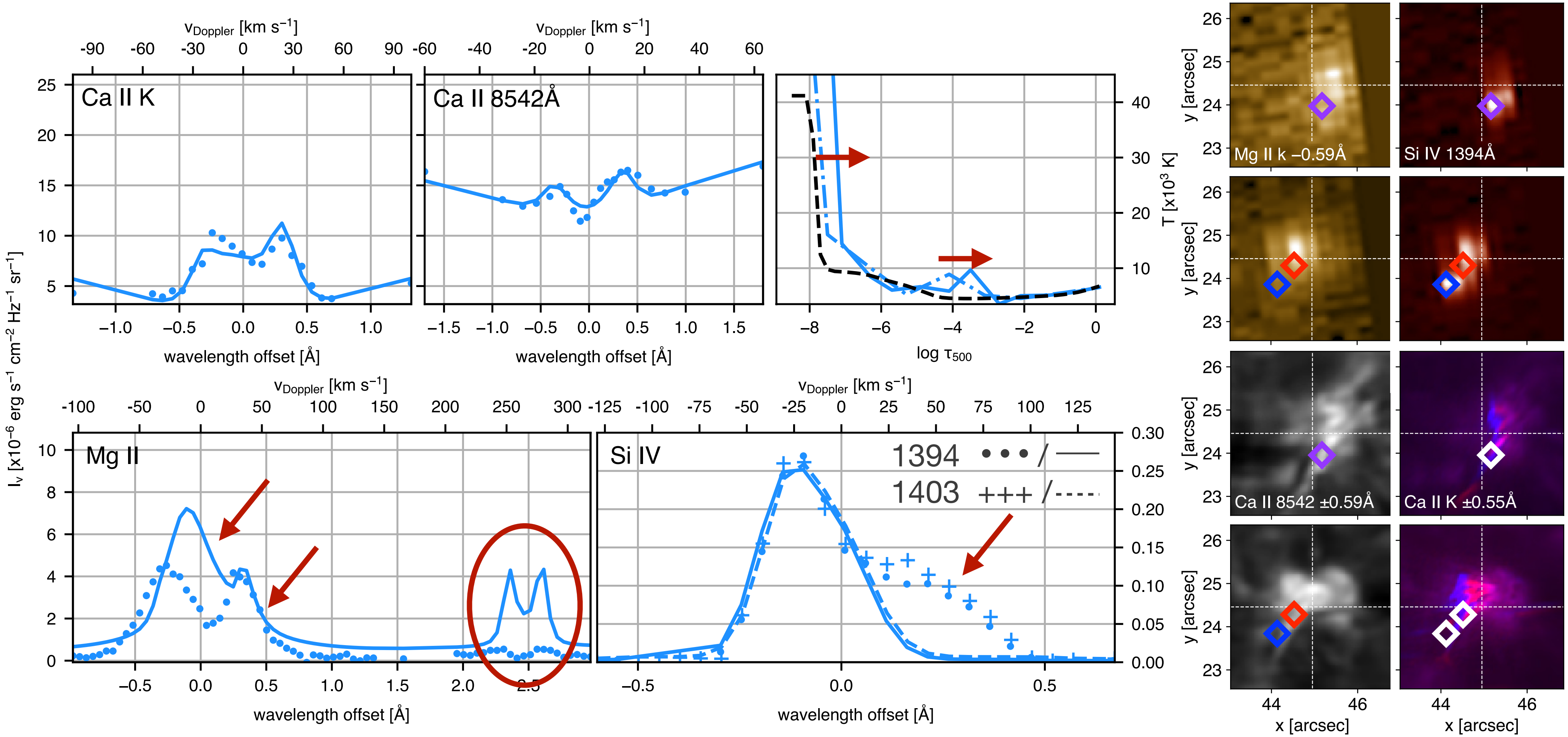


Vissers et al. (2018, submitted)



Vissers et al. (2018, submitted)

Single pixel inversions with Si IV can be made to "work", but reconciling all lines seems impossible



Vissers et al. (2018, submitted)

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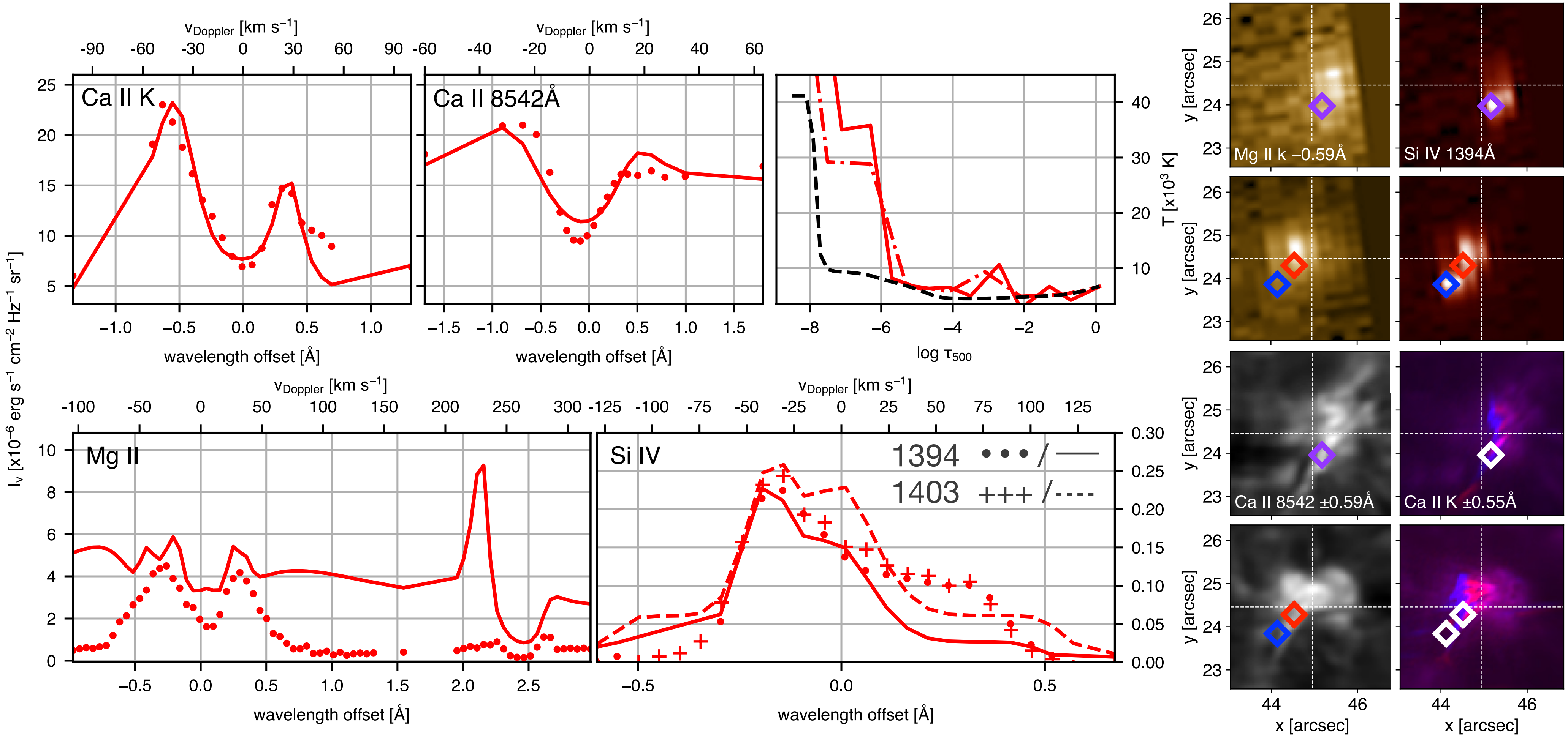

Vissers et al. (2018, submitted)

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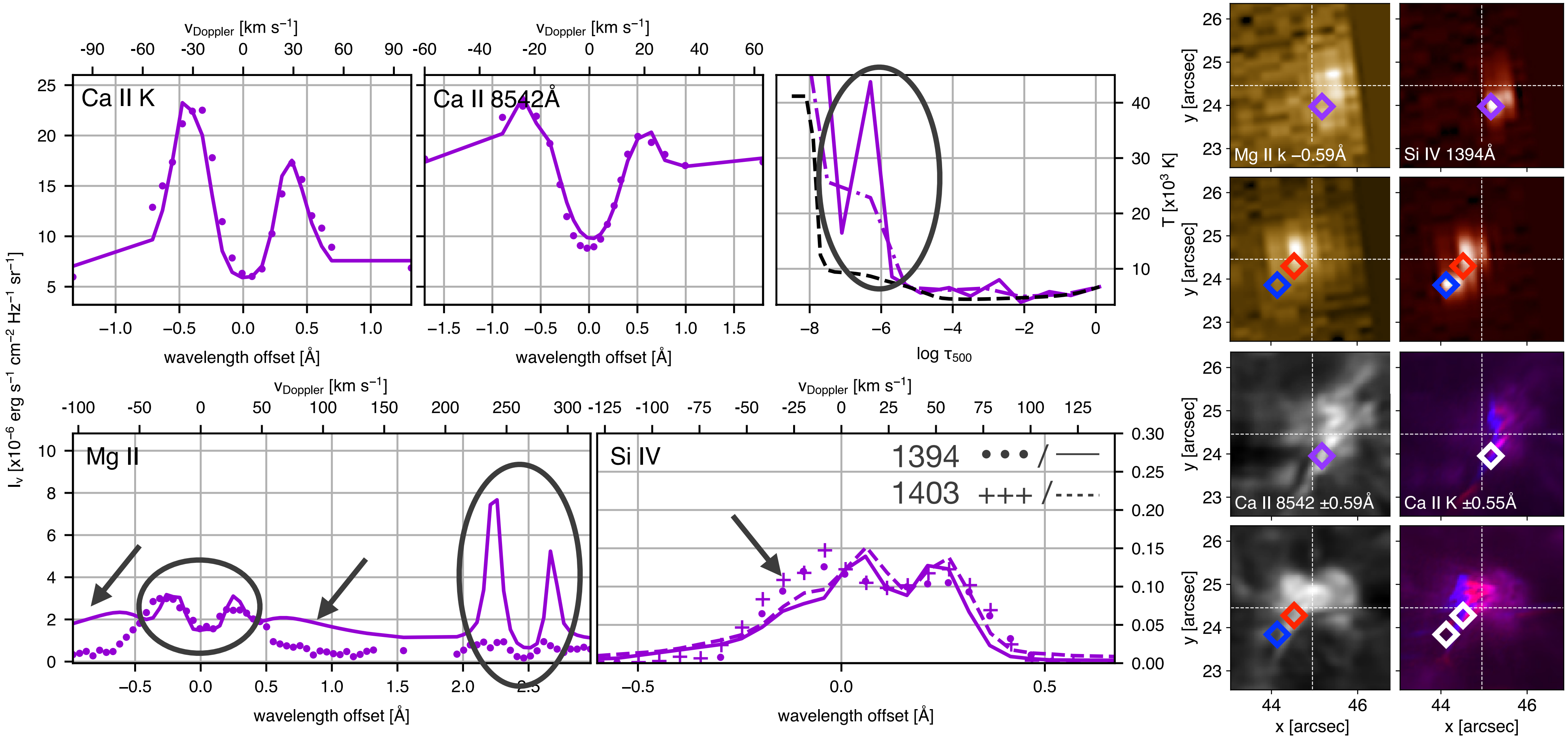
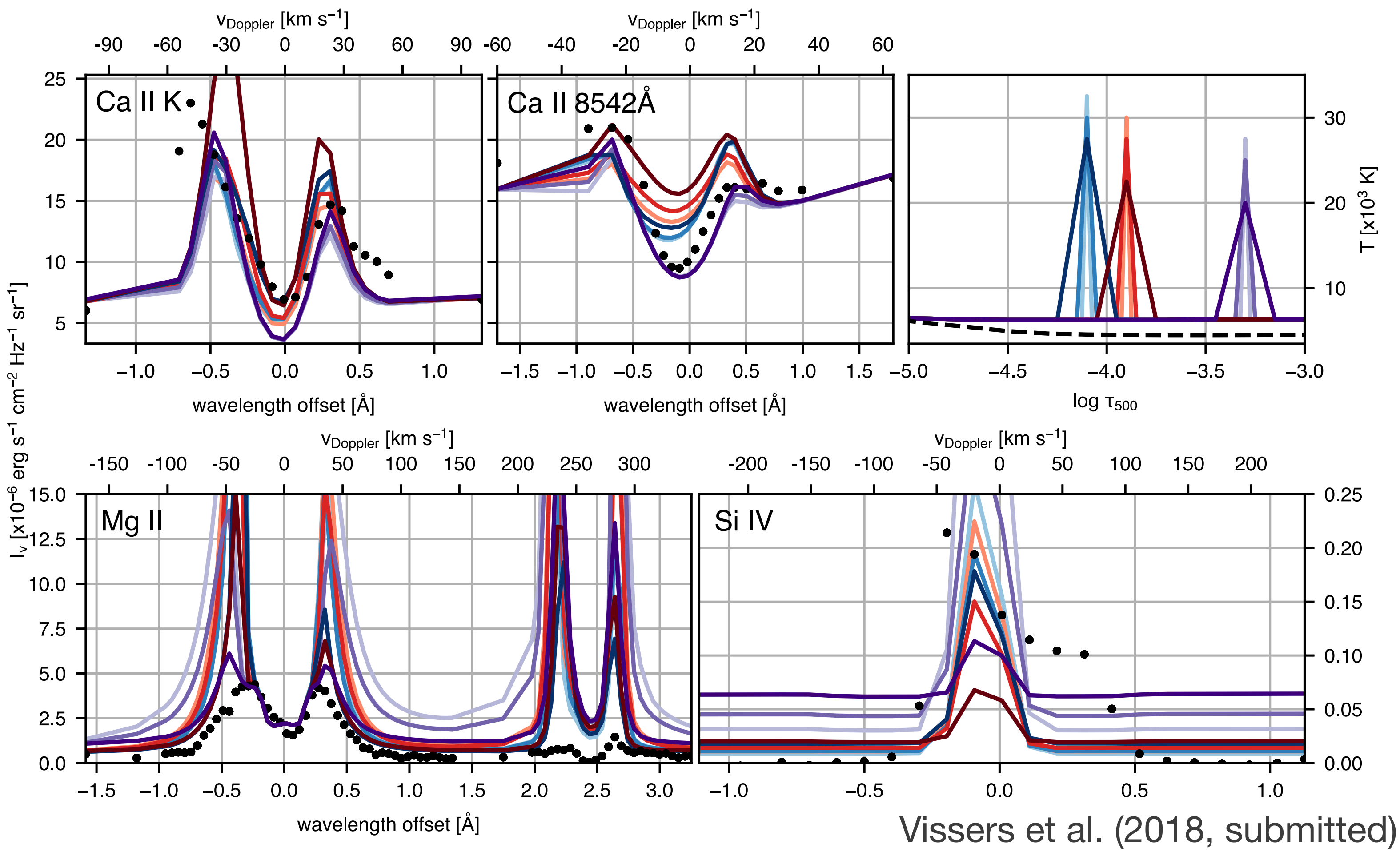


Vissers et al. (2018, submitted)

Adding a sharp temperature peak to get sufficient Si IV intensity could be a solution in some cases



Vissers et al. (2018, submitted)

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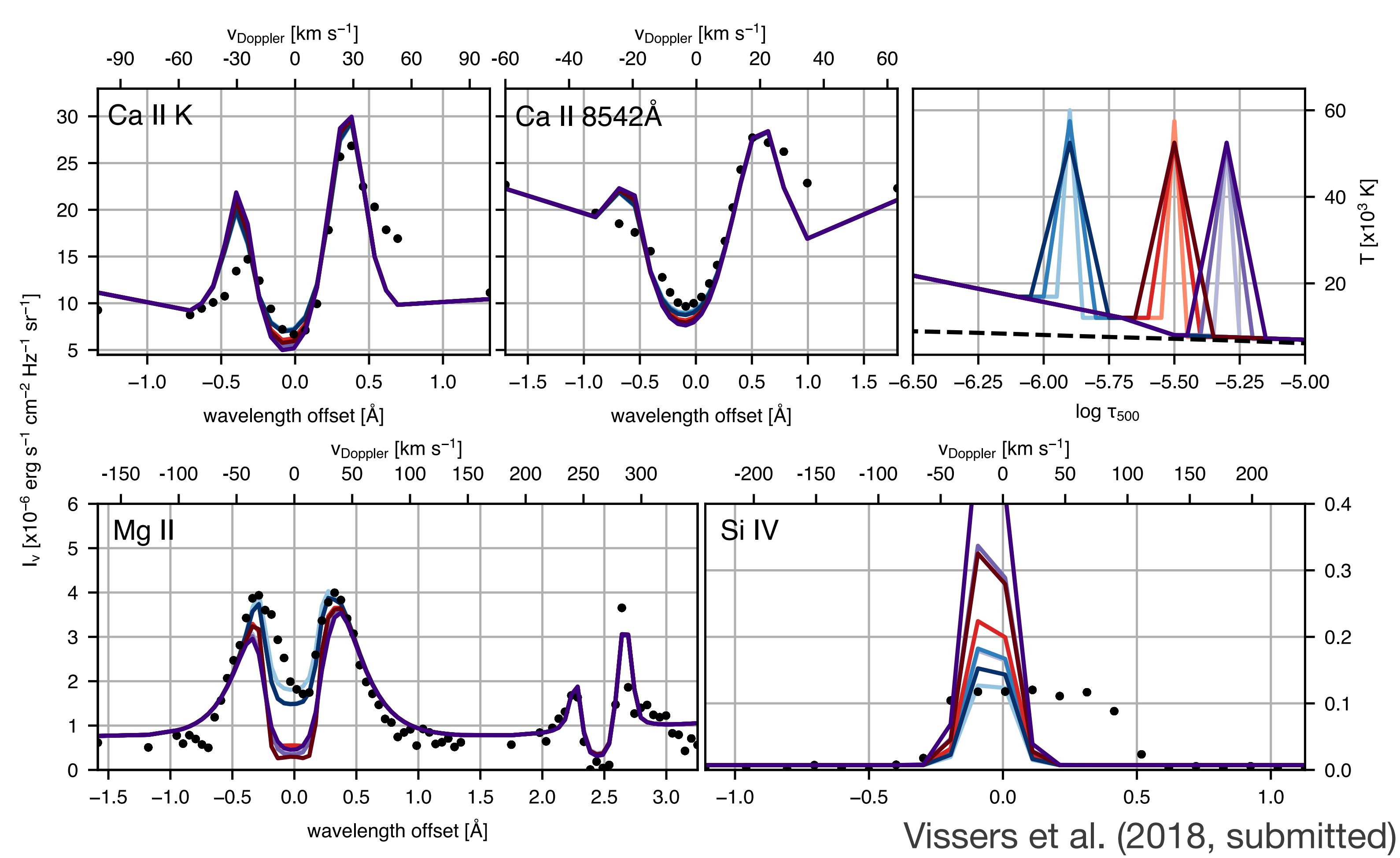


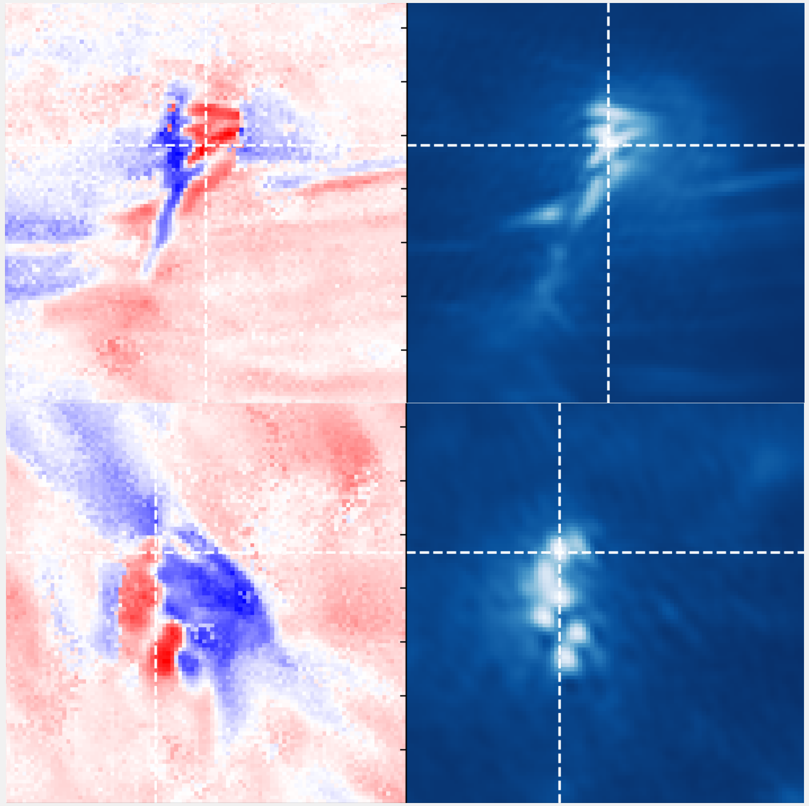
Vissers et al. (2018, submitted)

IRIS profiles pose a challenge in determining UV burst and Ellerman bomb atmospheres from inversions

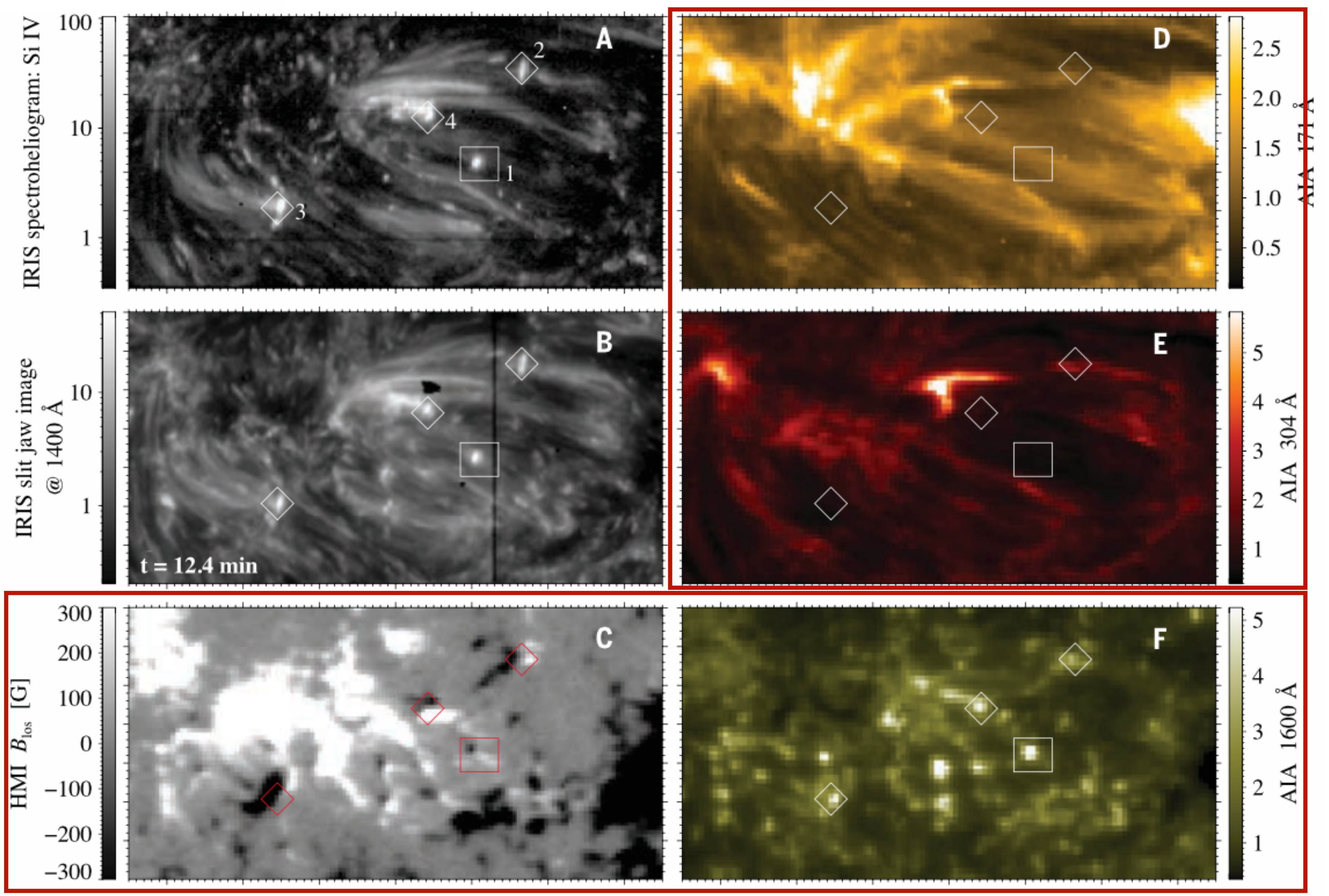
We find average temperature enhancements of a few thousand kelvin and localised heating of up to 10,000-15,000 K

Combining Mg II and Ca II is straightforward and does not change the Ca II-only results significantly

Si IV is more challenging: maybe need to wait for spatially-coupled inversions

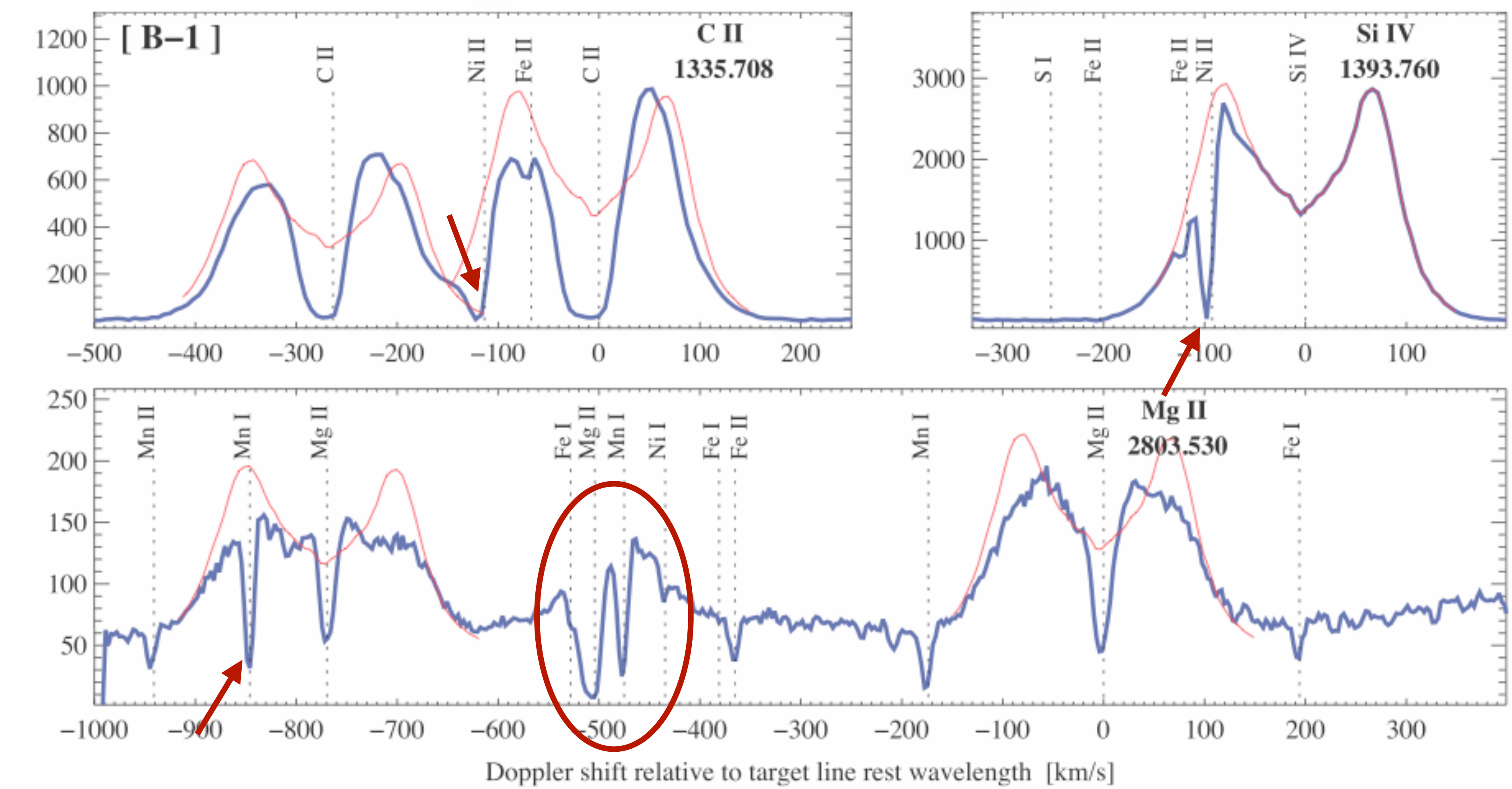


UV bursts have similar morphology and dynamics as Ellerman bombs



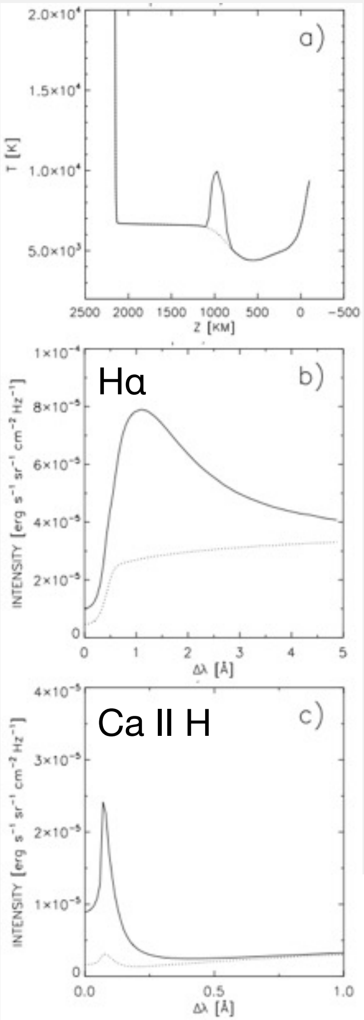
Peter et al. (2014)

Their IRIS line profiles point at bi-directional jets and sub-canopy formation

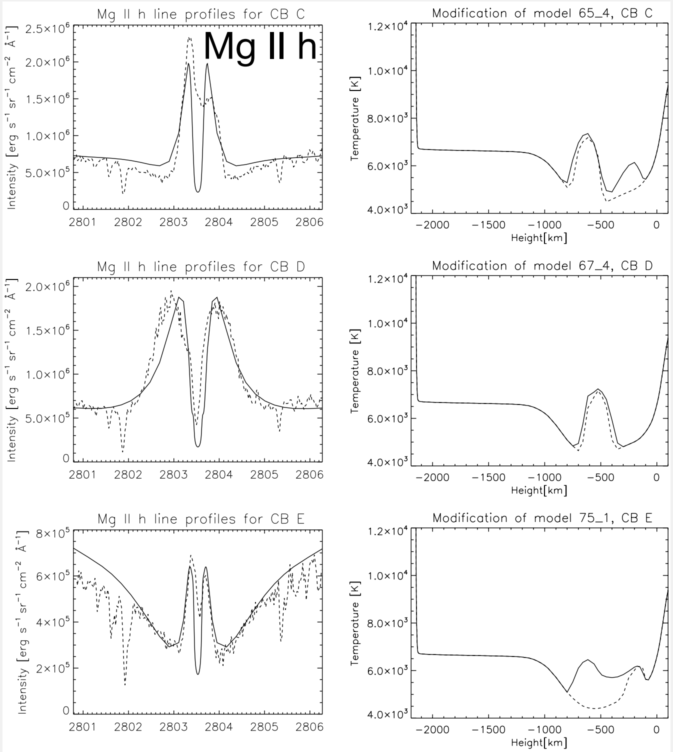


Peter et al. (2014)

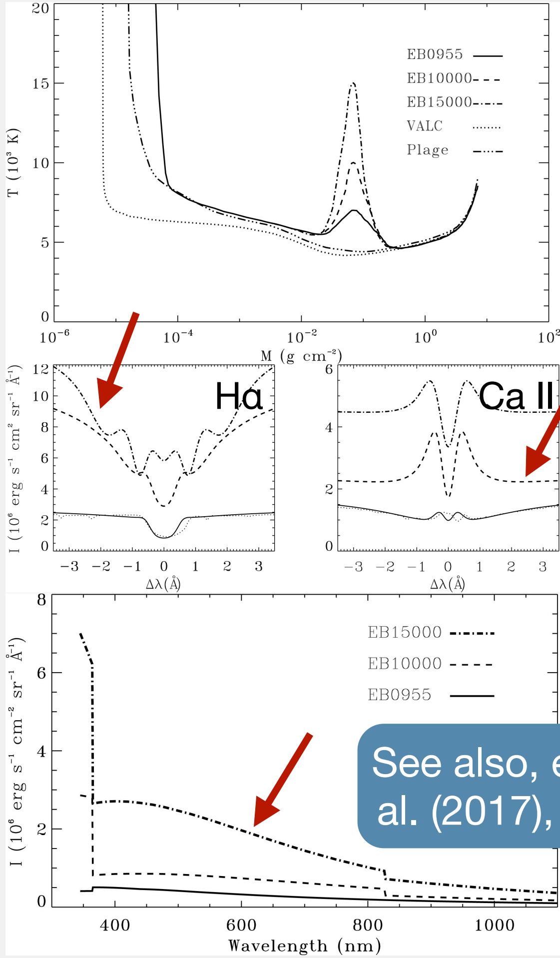
Ad-hoc modifications of temperature can reproduce Hα, Ca 8542Å, Ca II H and Mg II h profiles



Berlicki & Heinzel (2014)
Based on DOT
4000K at ~1Mm



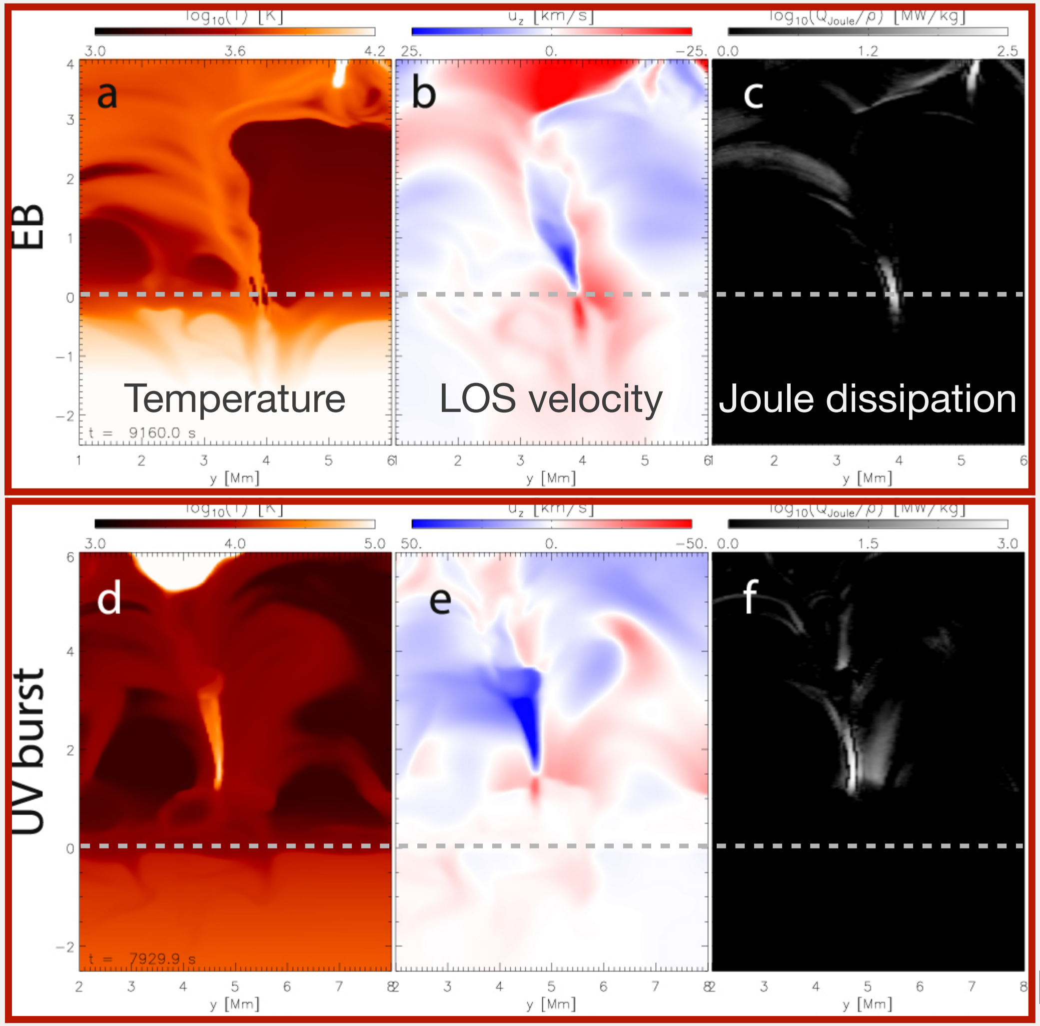
Grubecka et al. (2017)



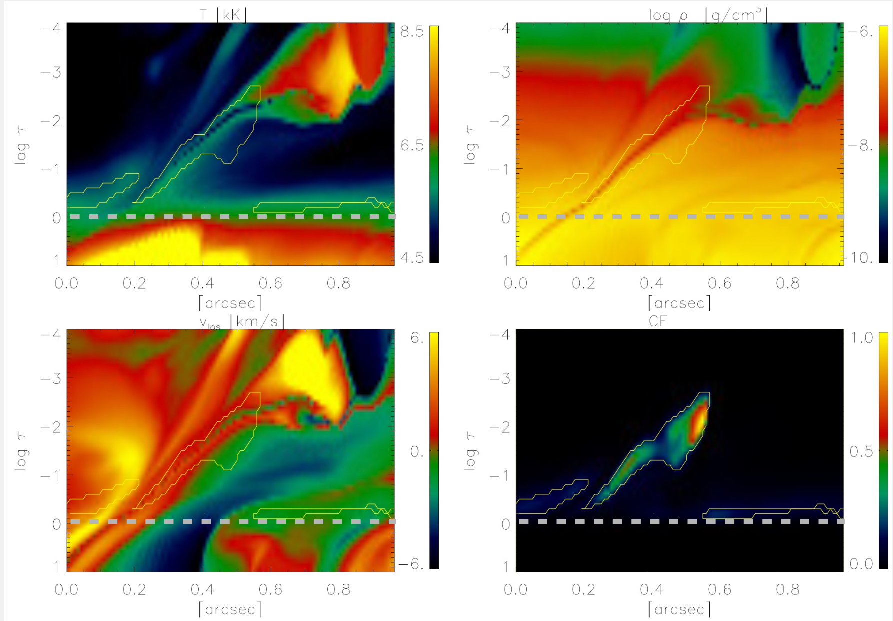
See also, e.g., Reid et al. (2017), Hong et al.

Fang et al. (2017)

Recent simulations are able to reproduce both Ellerman bombs and UV bursts (albeit separately)



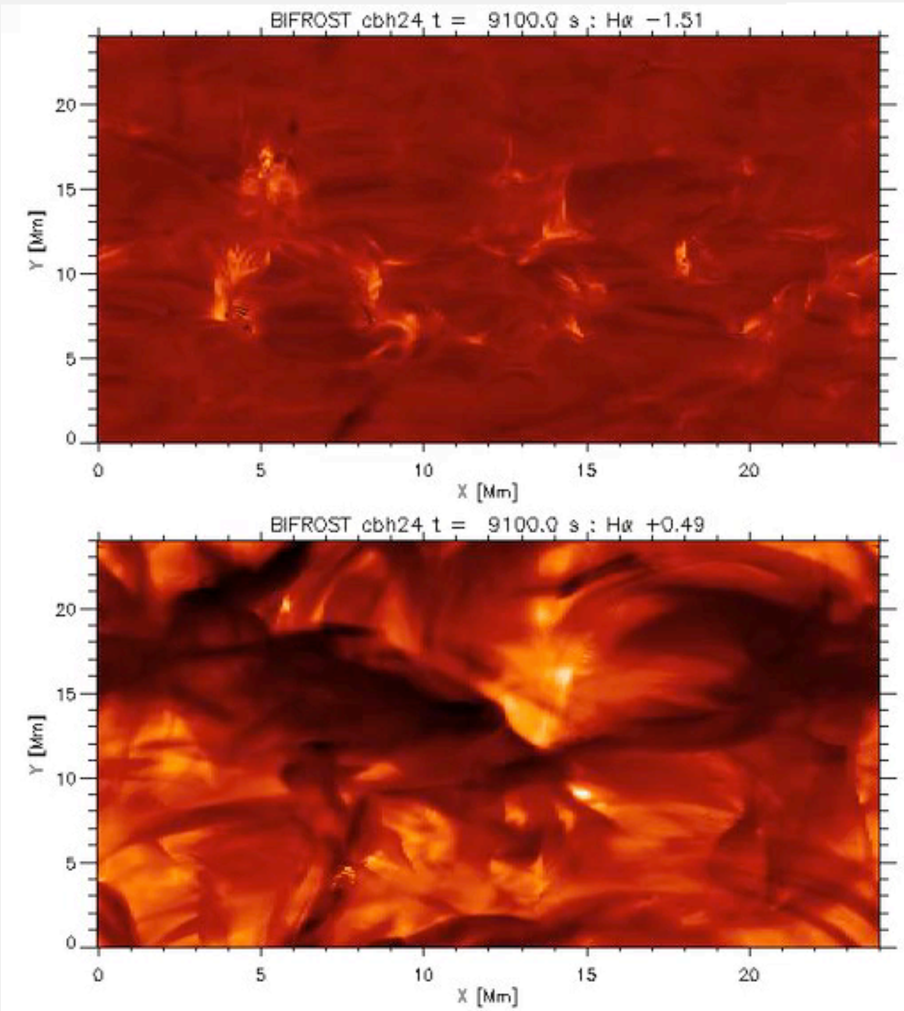
Hansteen et al. (2017)

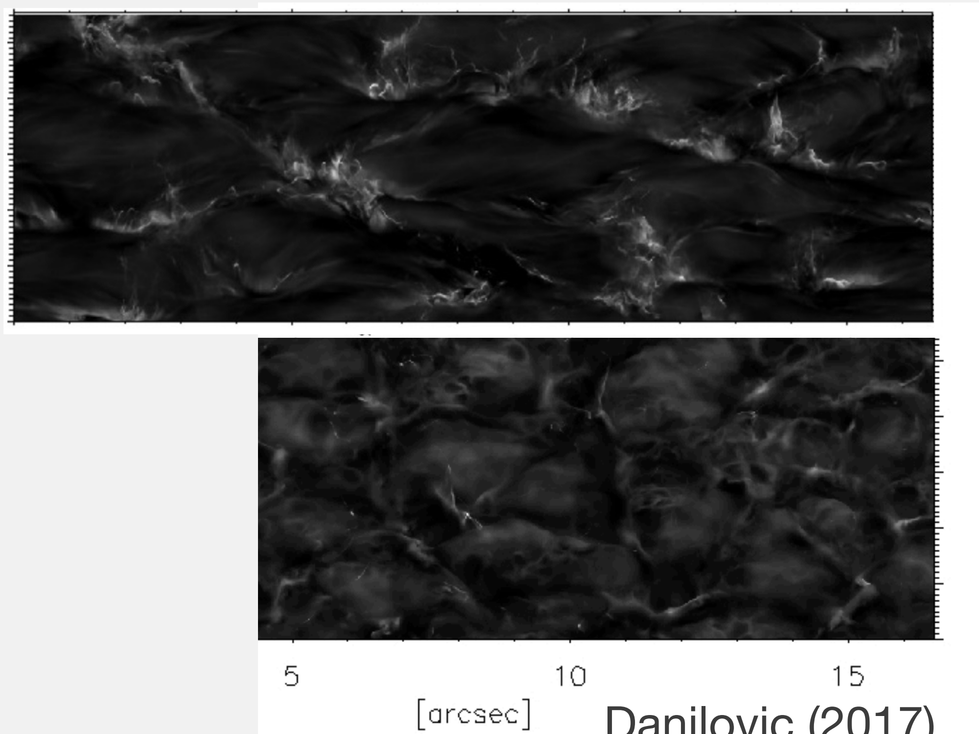


Danilovic (2017)

See also earlier efforts by, e.g., Nozawa et al. (1992), Litvinenko (1999), Cheung et al. (2008, 2010), Archontis & Hood (2009)

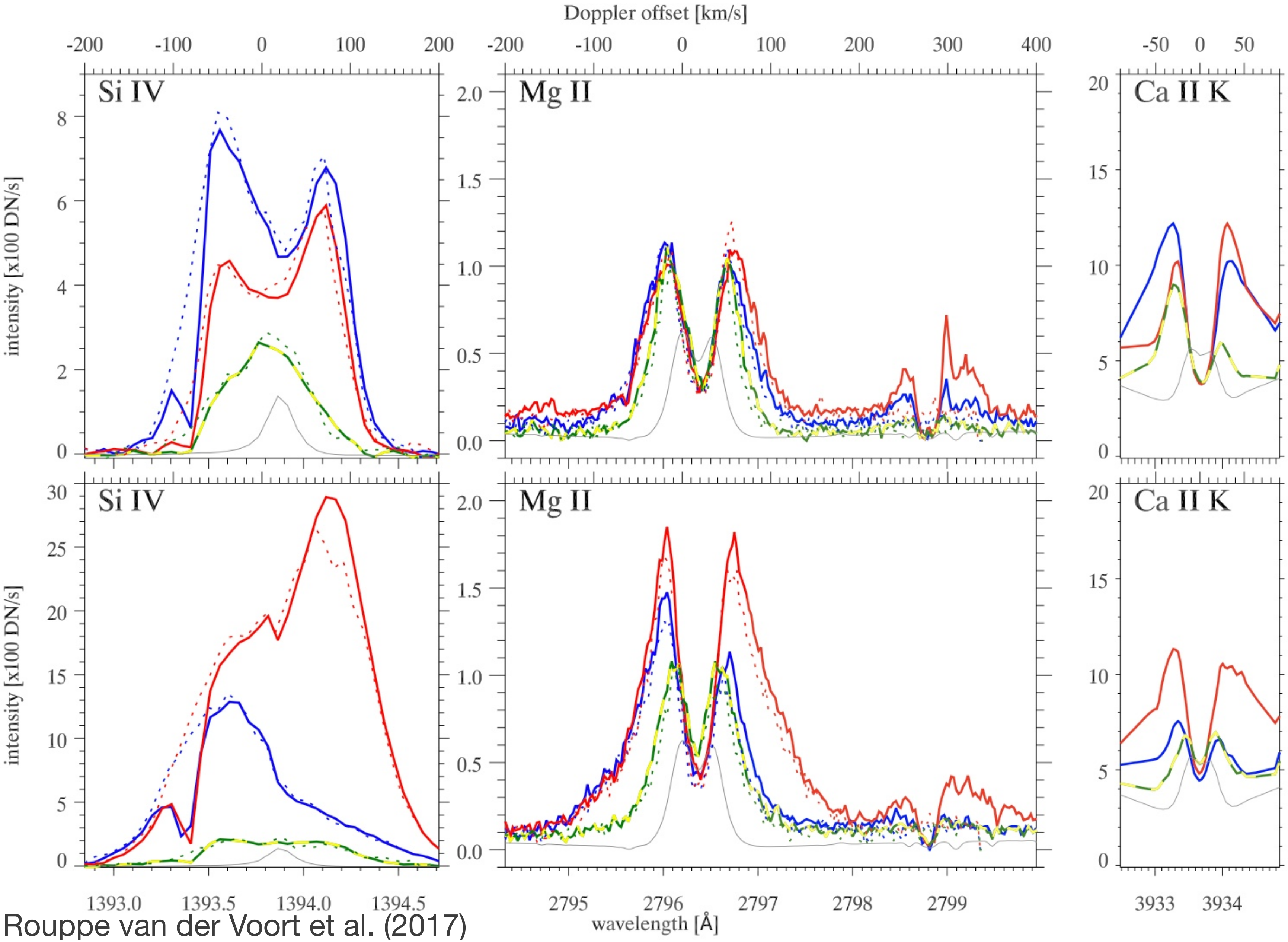
Recent simulations are able to reproduce both Ellerman bombs and UV bursts (albeit separately)



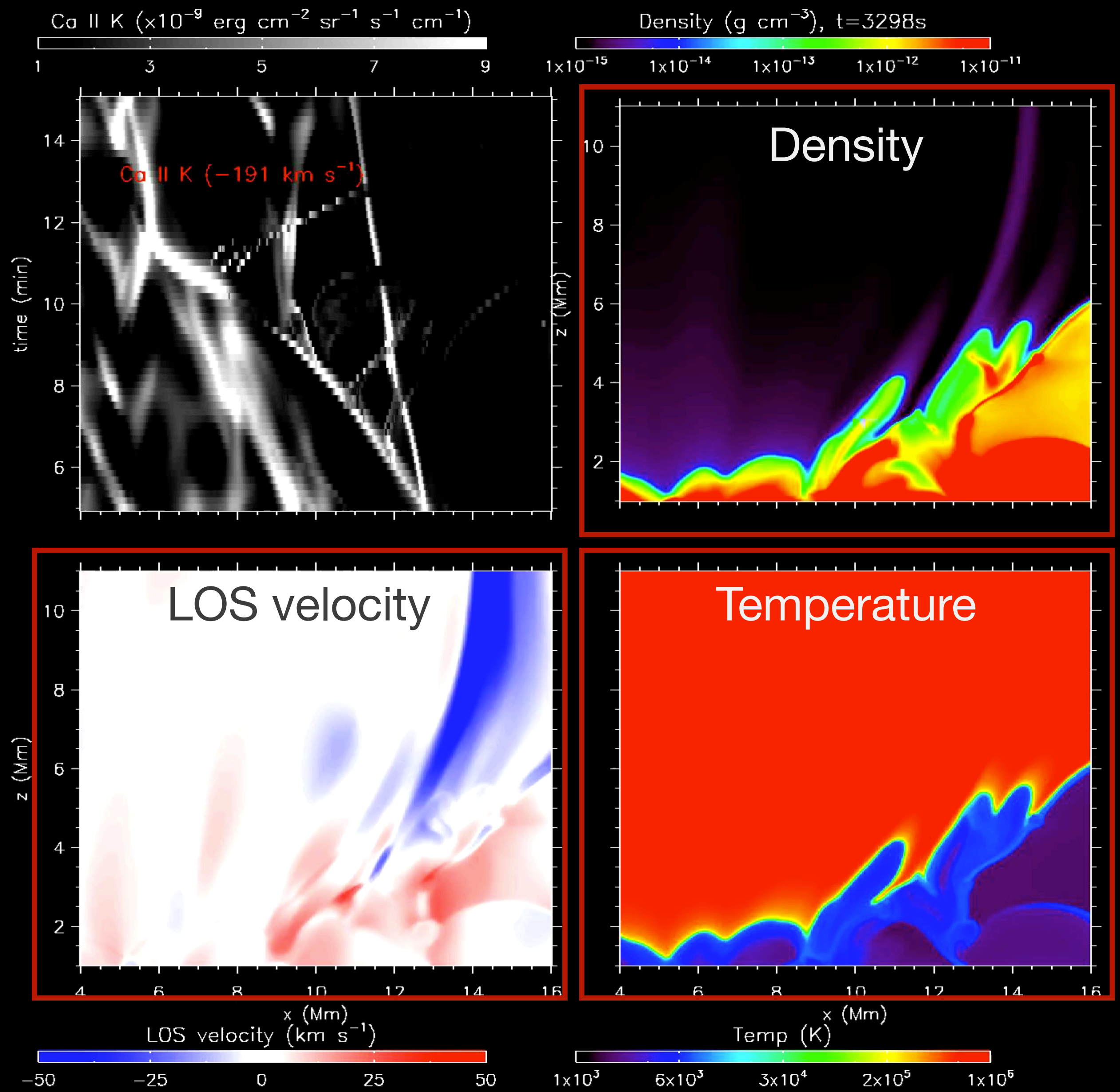


Danilovic (2017)

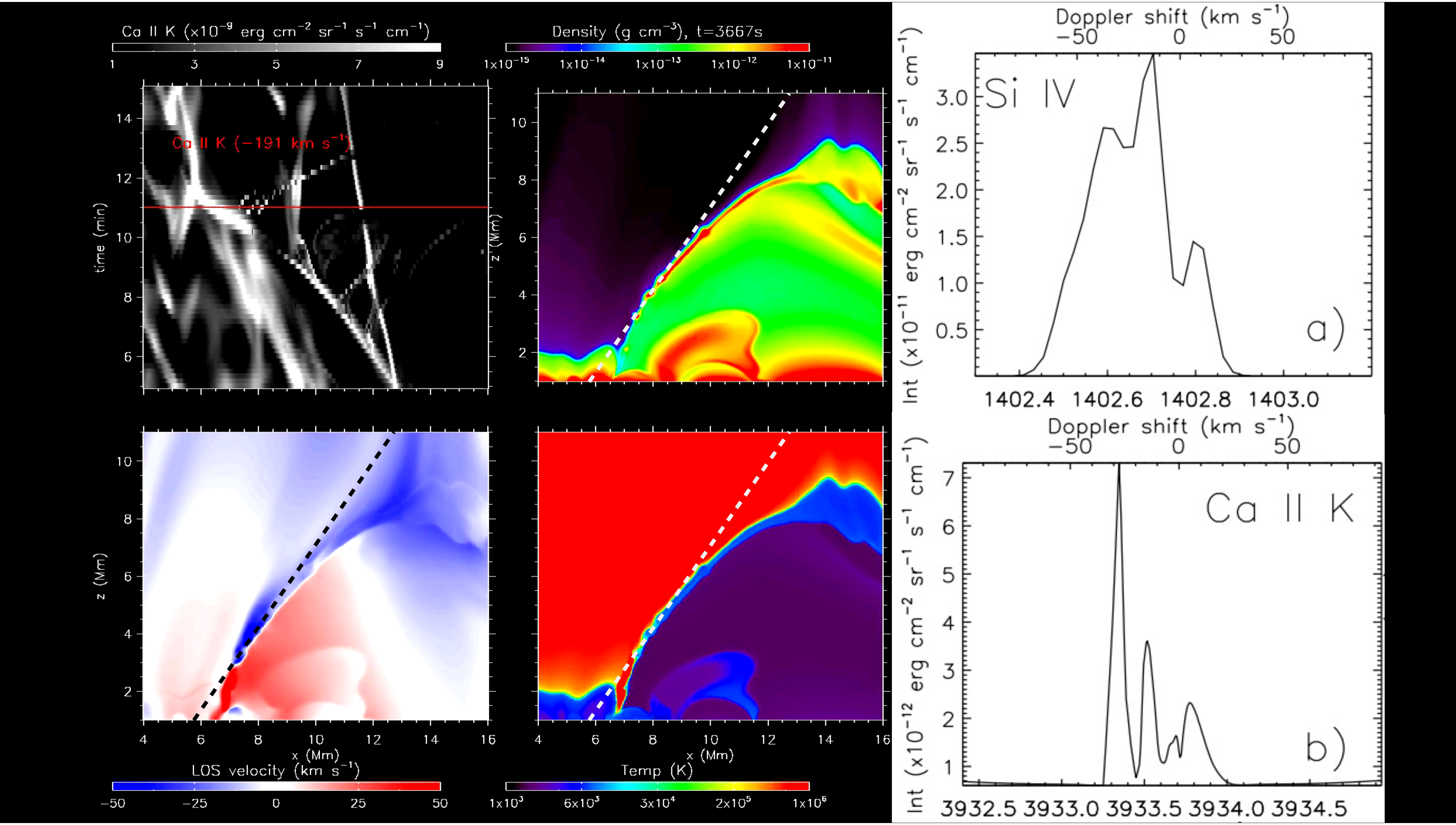
Hansteen et al. (2017)



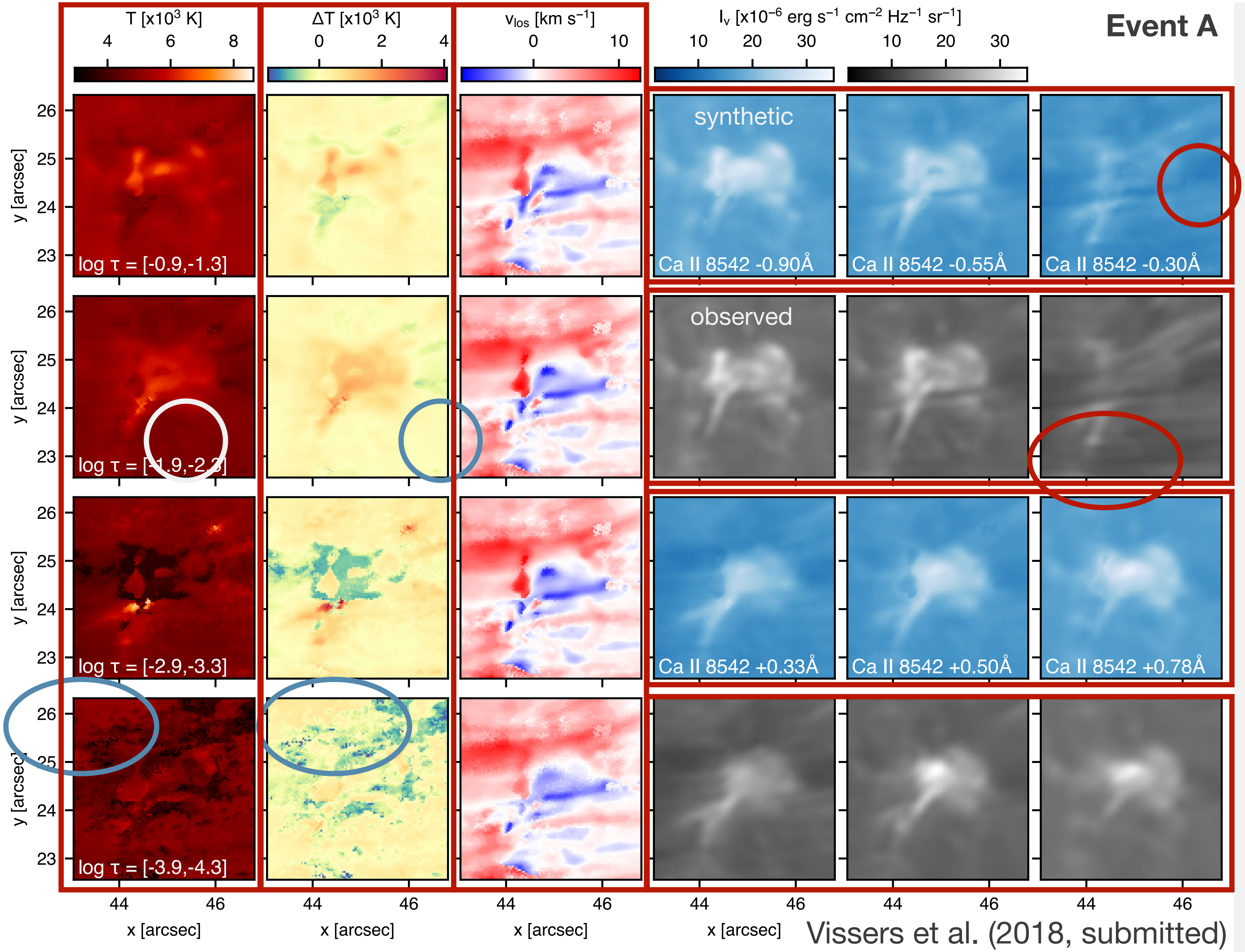
Rouppe van der Voort et al. (2017)



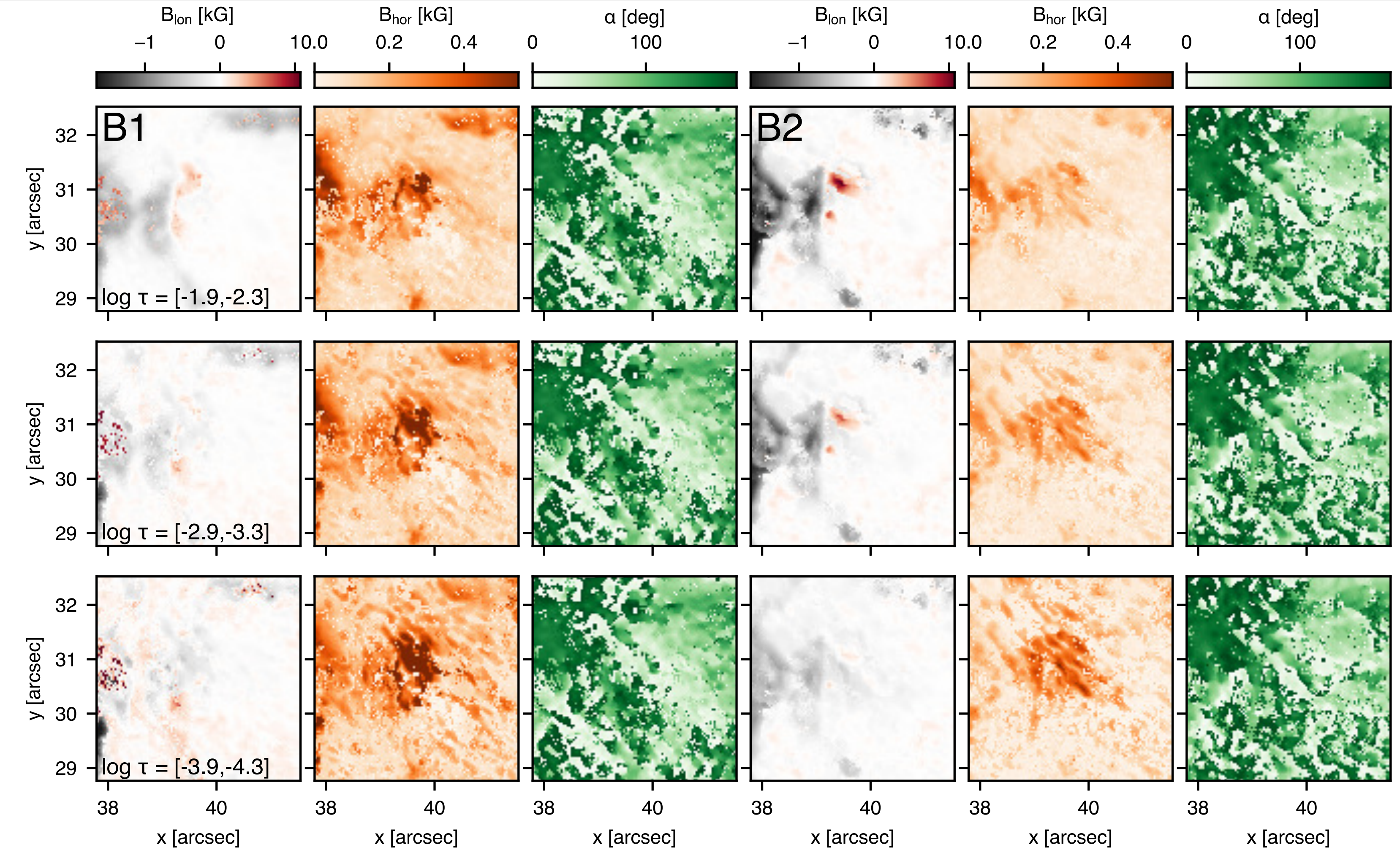
Rouppe van der Voort et al. (2017)



Ca II K (x10^{-9} erg cm^{-2} sr^{-1} s^{-1} cm^{-1})
Density (g cm^{-3}), t=3667s
Ca II K (−191 km s^{-1})
time (min)
z (Mm)
x (Mm)
LOS velocity (km s^{-1})
Temp (K)
Doppler shift (km s^{-1})
Si IV
a)
Ca II K
b)
Int (x10^{-11} erg cm^{-2} sr^{-1} s^{-1} cm^{-1})
Int (x10^{-12} erg cm^{-2} sr^{-1} s^{-1} cm^{-1})

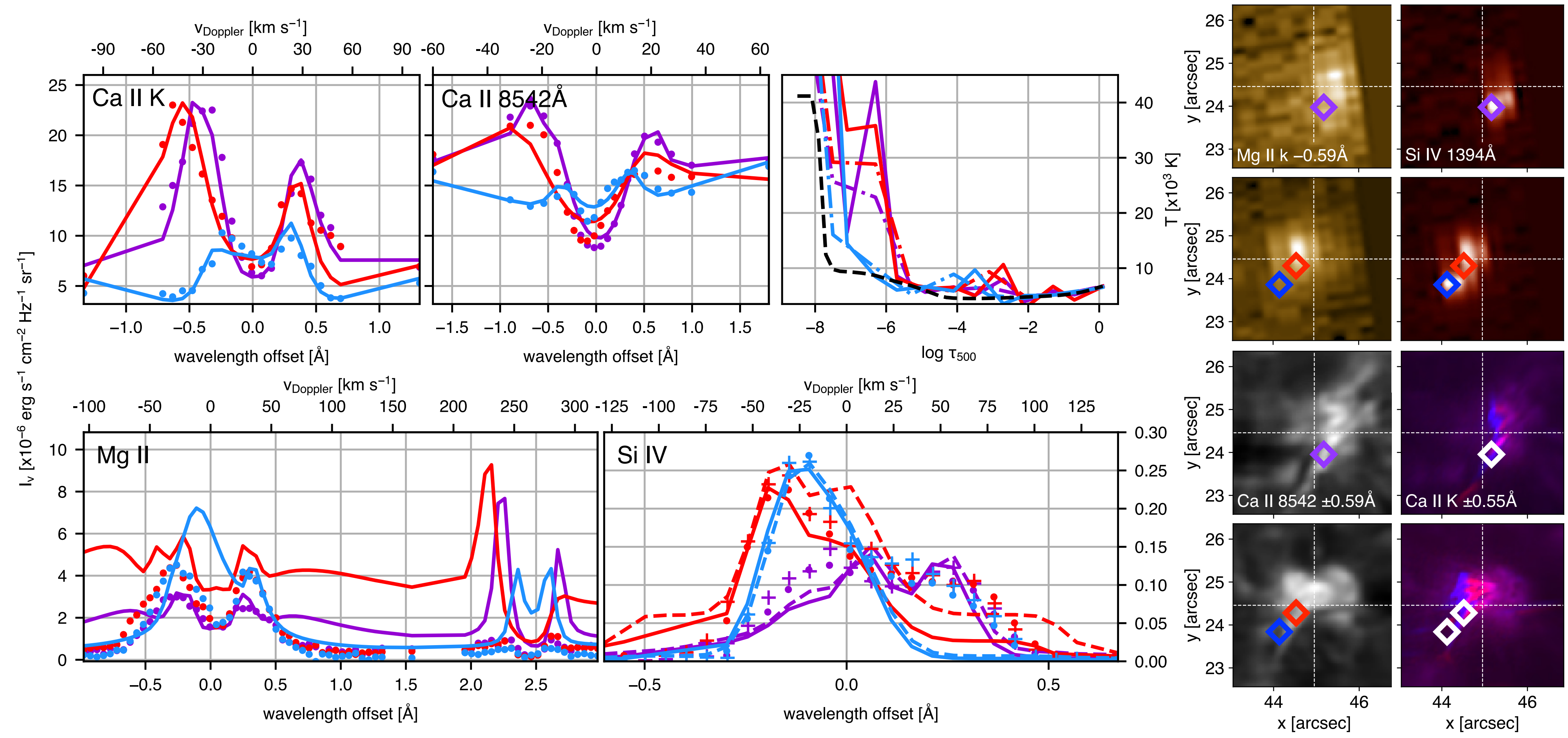


Vissers et al. (2018, submitted)



B1
B2
B_{lon} [kG]
B_{hor} [kG]
α [deg]
log τ = [-1.9,-2.3]
log τ = [-2.9,-3.3]
log τ = [-3.9,-4.3]
y [arcsec]
x [arcsec]

Single pixel inversions with Si IV can be made to “work”, but may require particular node placement



Vissers et al. (2018, submitted)