Solar Plasma Spectroscopy: Achievements and Future Challenges

EUV spectral lines properties in impulsively heated multi-stranded coronal loops

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Introduction

- EUV spectral line observations in AR coronal loops (Hinode/EIS, SOHO/SUMER, SOHO/CDS)
  - Asymmetric profiles (e.g. Peter 2010)
  - Persistent red-shifts (10-20 km/s) in lines at TR temperatures (e.g. Del Zanna 2008) at the footpoints of AR loops
  - Moderate blue-shifts (5-10 km/s) of coronal lines at the base of loops (e.g. Hara et al. 2008) and in the moss within active regions (e.g. Brooks & Warren, 2009)
  - Note that Peter 2010 found large upflows (50 km/s) as a minor component in the blue wing of Fe XV line (2.5 MK) in the footpoints regions of the loops

Introduction

- Narrow-band TRACE observations
  - AR loops do not show small-scale intensity structure (López Fuentes et al. 2008, Klimchuk 2000) … but falling bright knots are sometimes observed (O'Shea et al. 2007)
  - Flat temperature profiles are obtained with the filter-ratio technique (Lenz et al. 1999, Aschwanden 2001)

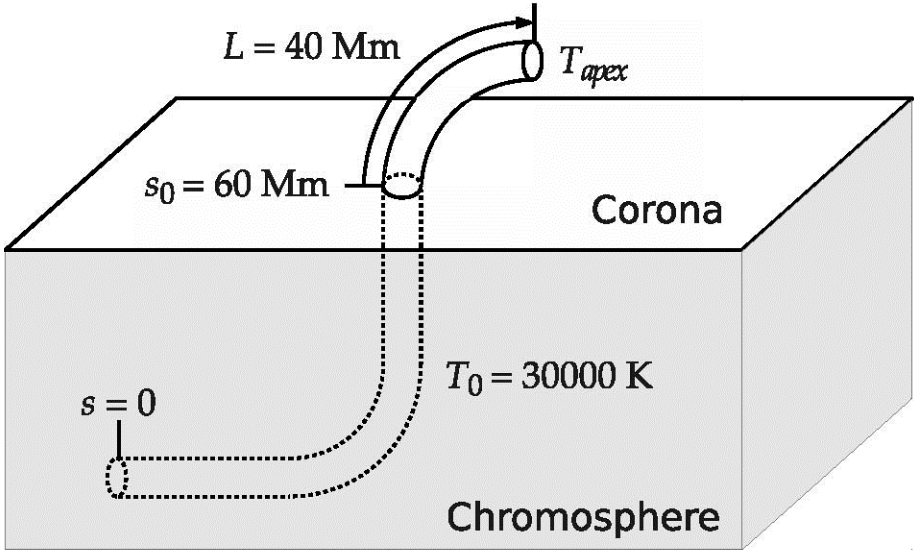
Motivation and methods

- Attempt to constrain loop plasma heating through the exploration of its parameters and the analysis of its signatures on observable spectral quantities derived from a multi-stranded loop model

- 1D hydro simulations of a sub-resolution magnetic strand with impulsive heating
  - ARGOS hydro-code with adaptive grid
- EUV emission synthesis with time-dependent ionisation
- Multi-stranded loop model derived from simulations
  - Emissivity profiles and Doppler-shifts

Numerical model

- Arch-shaped flux tube (L = 40 Mm), with two 60 Mm long chromospheric segments on each side, kept at uniform temperature T_0 = 30000 K



Numerical model

- Initial static loop ($T_{apex} \simeq 0.75$ MK)
  - Estimated cooling-time $\tau_{cool} \simeq 1000$ s

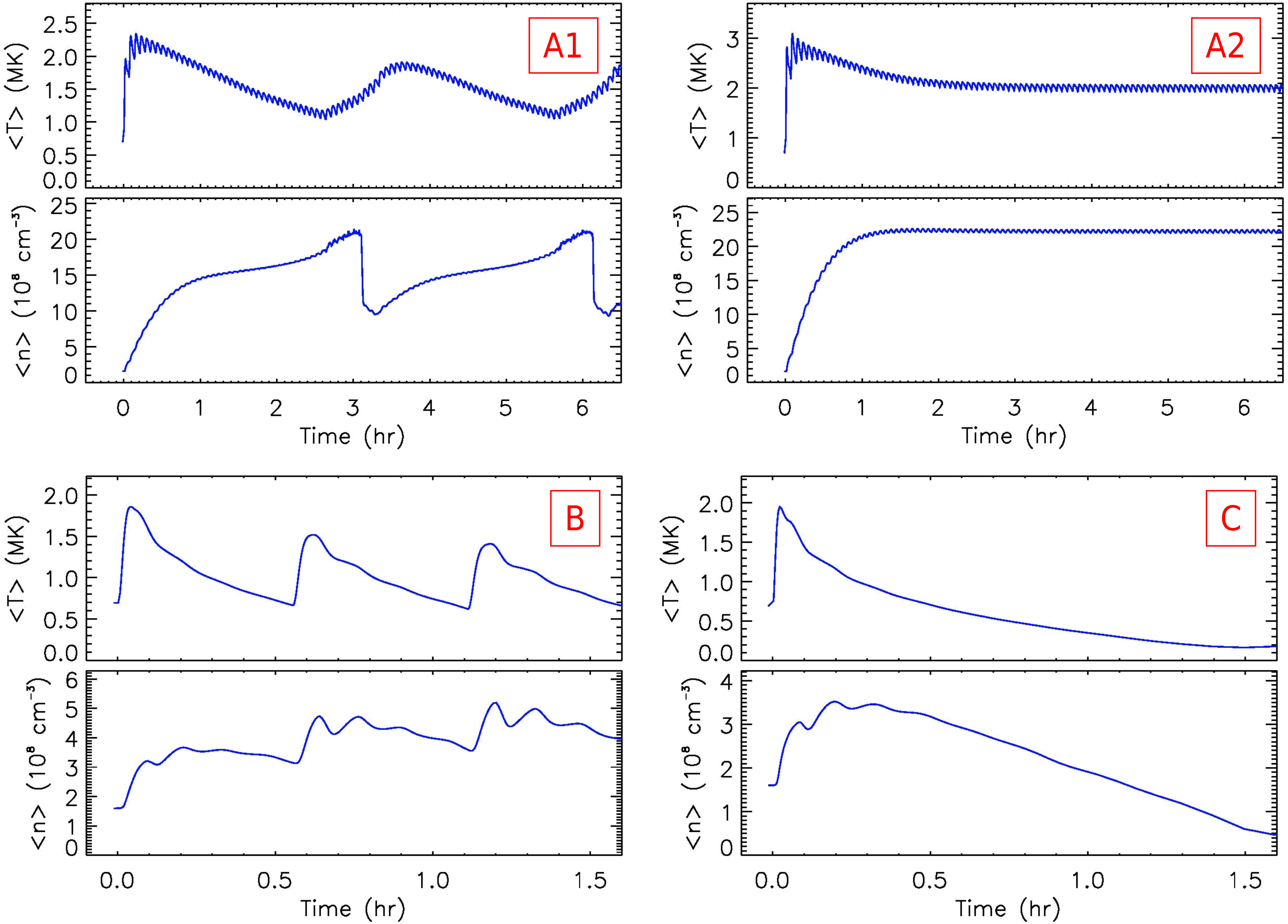
- Additional heating:
  - Sequence of identical pulses / single pulse
  - Footpoint-localised heating with damping length $\lambda = 10$ Mm and 75% asymmetry (stronger heating in the LEFT footpoint)
  - Maxwellian-shaped pulses with duration of ~ 125 s
  - Pulse energy (E_P) and cadence time (t_C) are varied

Simulations

Run	Heating regime	Cadence time	Pulse energy	Description
A1	Pulse sequence	250 s $\simeq$ ¼ τ_{cool}	E_0[a]	Condensation-forming run
A2	Pulse sequence	250 s $\simeq$ ¼ τ_{cool}	2 E_0	No condensation, hot loop
B	Pulse sequence	2000 s $\simeq$ 2 τ_{cool}	E_0	No condensation, highly dynamic loop
C	Single pulse	-	E_0	Typical cooling loop

[a] $E_0 = 10^{24}$ erg

Susino et al. 2010
Susino et al., in preparation

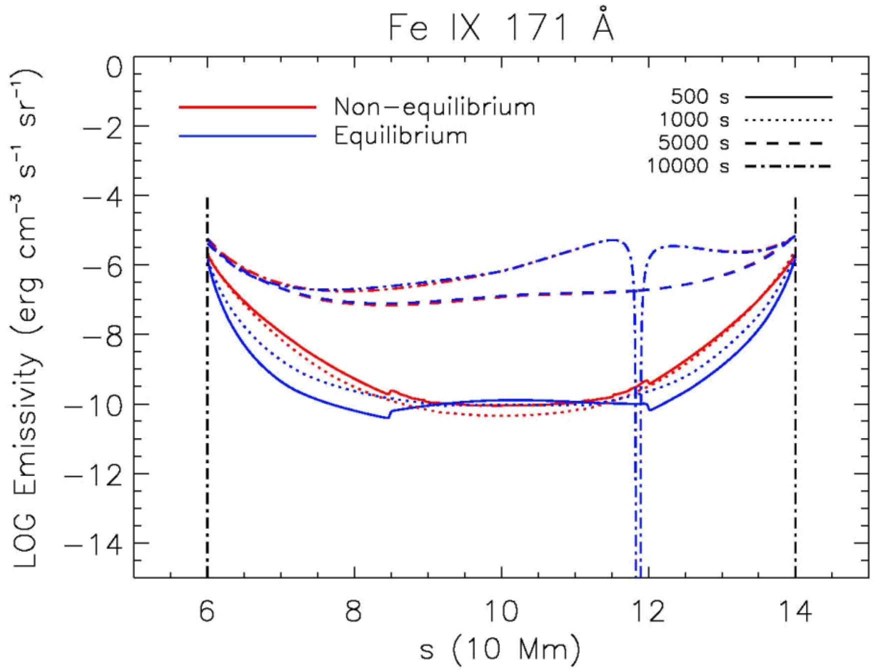

A1
A2
B
C
<T> (MK)
<n> (10^8 cm^{-3})
Time (hr)

EUV emission synthesis

- Post-process solution of the statistical balance equations
  - Populations computed using the collisional-radiative theory approach (see, e.g., Lanza et al. 2001)
  - Ionisation and recombination coefficients from ADAS
  - Local Gaussian profiles including thermal broadening and Doppler-shift

Line	Formation temp.	Rest wavelength
C IV	0.1 MK	1548 Å
O V	0.25 MK	629 Å
Fe IX	1.0 MK	171 Å
Fe XII	1.5 MK	195 Å

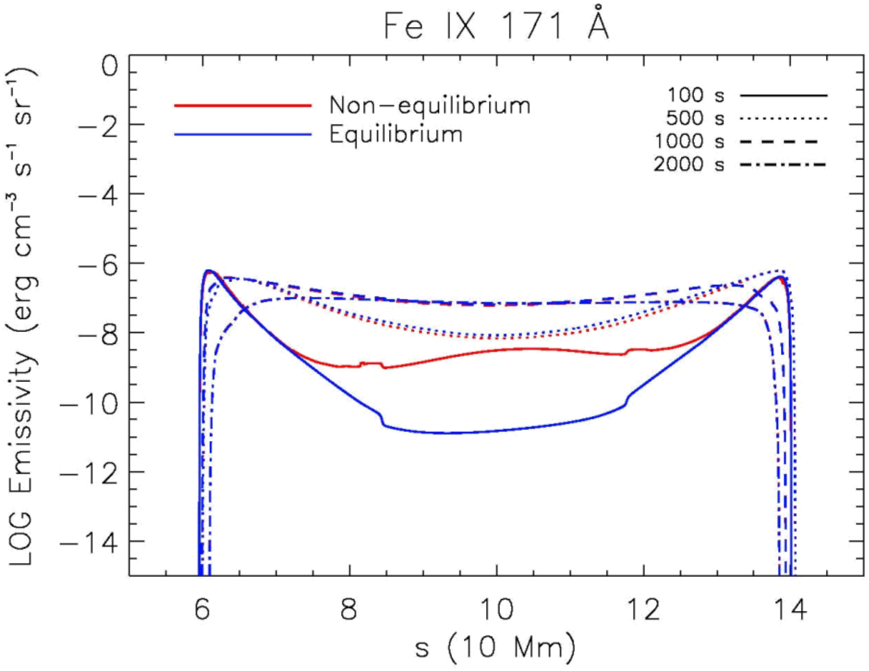
- Multi-stranded loop model
  - Average of instantaneous intensities and profiles at N = 300 random time-steps selected throughout the simulation



A1

Pulse sequence with condensation

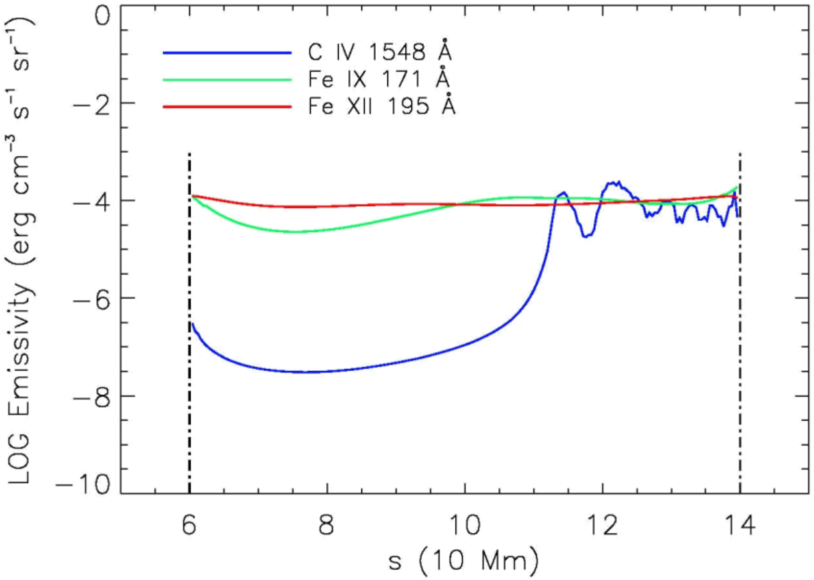
Single strand emissivities



C

Single pulse

Multi-stranded loop model results

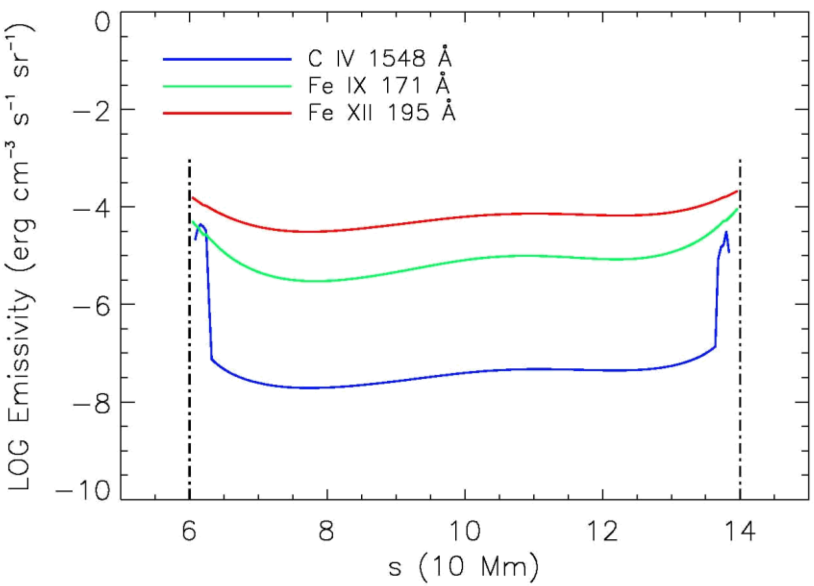


A1

Pulse sequence with condensation

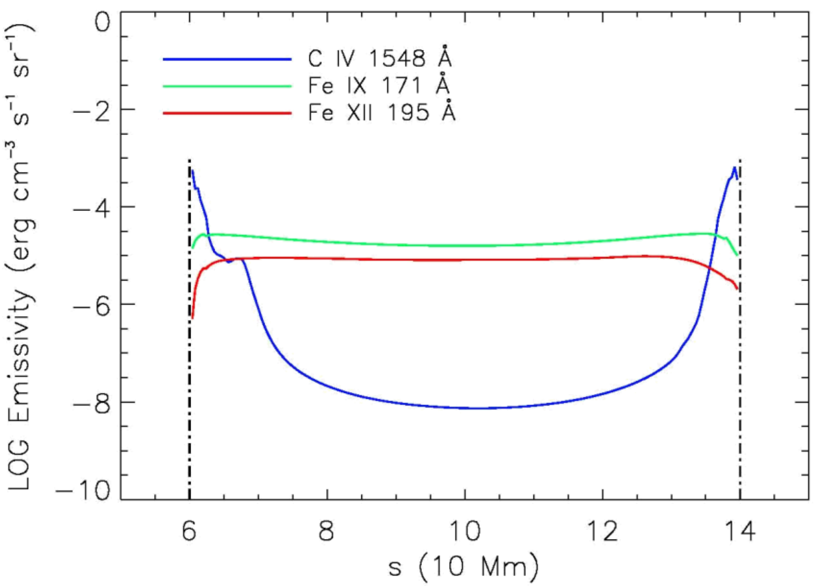
A2

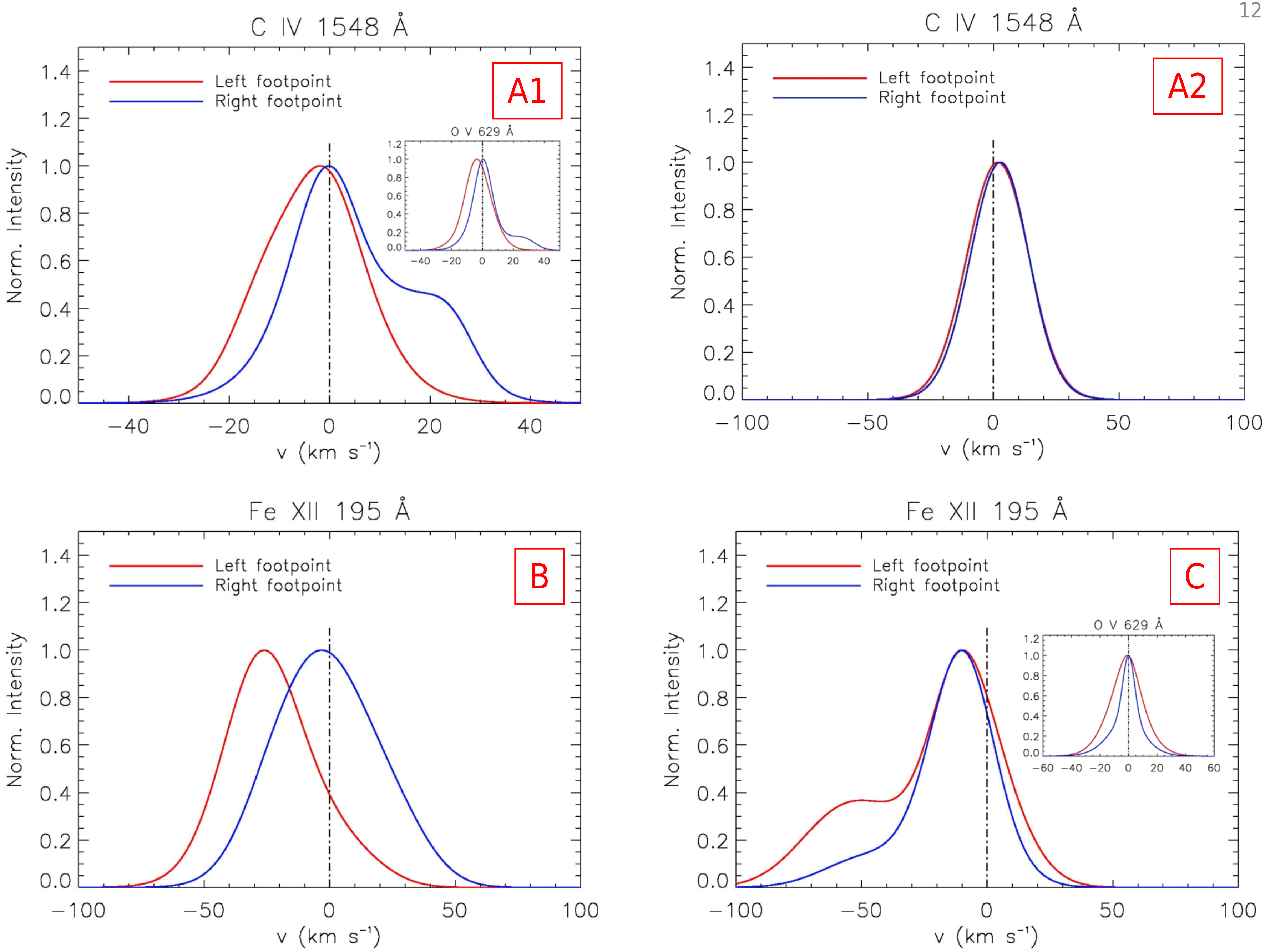
Pulse sequence without condensation

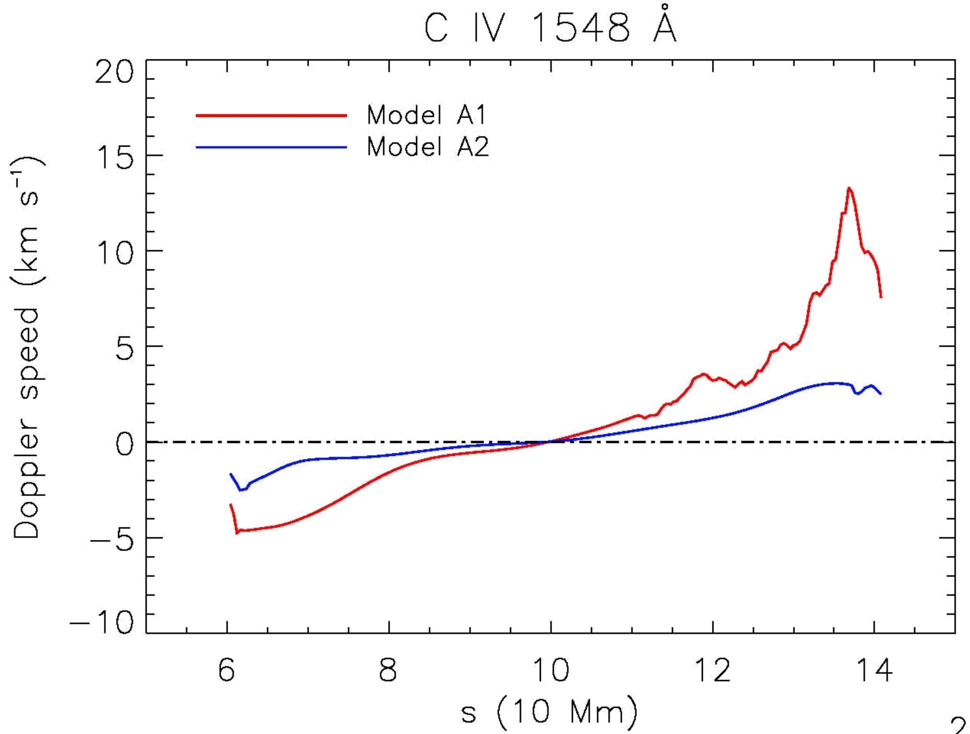


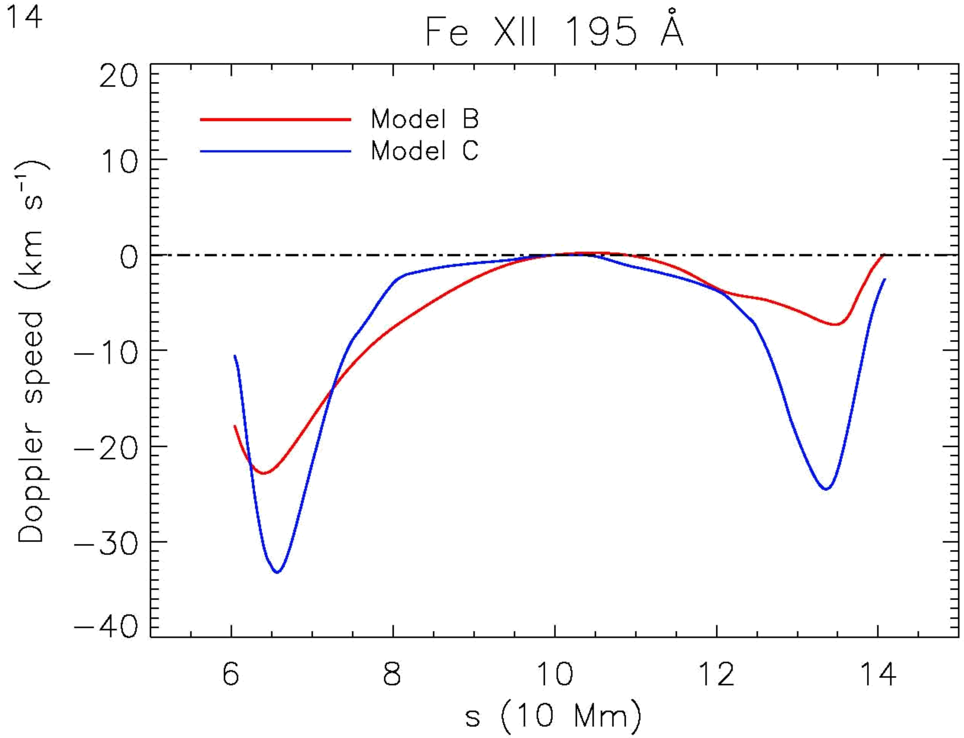
Single pulse

C




C IV 1548 Å
Left footpoint
Right footpoint
A1
O V 629 Å
Norm. Intensity
v (km s⁻¹)
C IV 1548 Å
Left footpoint
Right footpoint
A2
Norm. Intensity
v (km s⁻¹)
Fe XII 195 Å
Left footpoint
Right footpoint
B
Norm. Intensity
v (km s⁻¹)
Fe XII 195 Å
Left footpoint
Right footpoint
C
O V 629 Å
Norm. Intensity
v (km s⁻¹)


C IV 1548 Å
Model A1
Model A2
Doppler speed (km s⁻¹)
s (10 Mm)
20
15
10
5
0
−5
−10
6
8
10
12
14


Fe XII 195 Å
Model B
Model C
Doppler speed (km s⁻¹)
s (10 Mm)
20
10
0
−10
−20
−30
−40
6
8
10
12
14

Conclusions

- The assumption of ionisation equilibrium is fairly valid in our models
  - Ionisation and recombination timescales generally lower than the hydrodynamic timescale, except in the early stages of the model evolution
  - Previous studies confirmed (e.g. Peter et al. 2006)

- Emissivity spatial profiles are very uniform for coronal lines in all cases, but they result too structured for TR lines

- Asymmetric line profiles
  - Minor blue-shifted component in the hot lines (Fe XII), red-shifted in the cool ones (C IV, O V)
  - Doppler-shifts appear to be influenced by the heating regime

Thank you!