Investigating the response of loop plasma to nanoflare heating using RADYN simulations

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Outline

Introduction: IRIS diagnostics of coronal heating

Simulations of nanoflare loops

- Motivation
- The RADYN code and the grid of models

Results of sample nanoflare simulations:

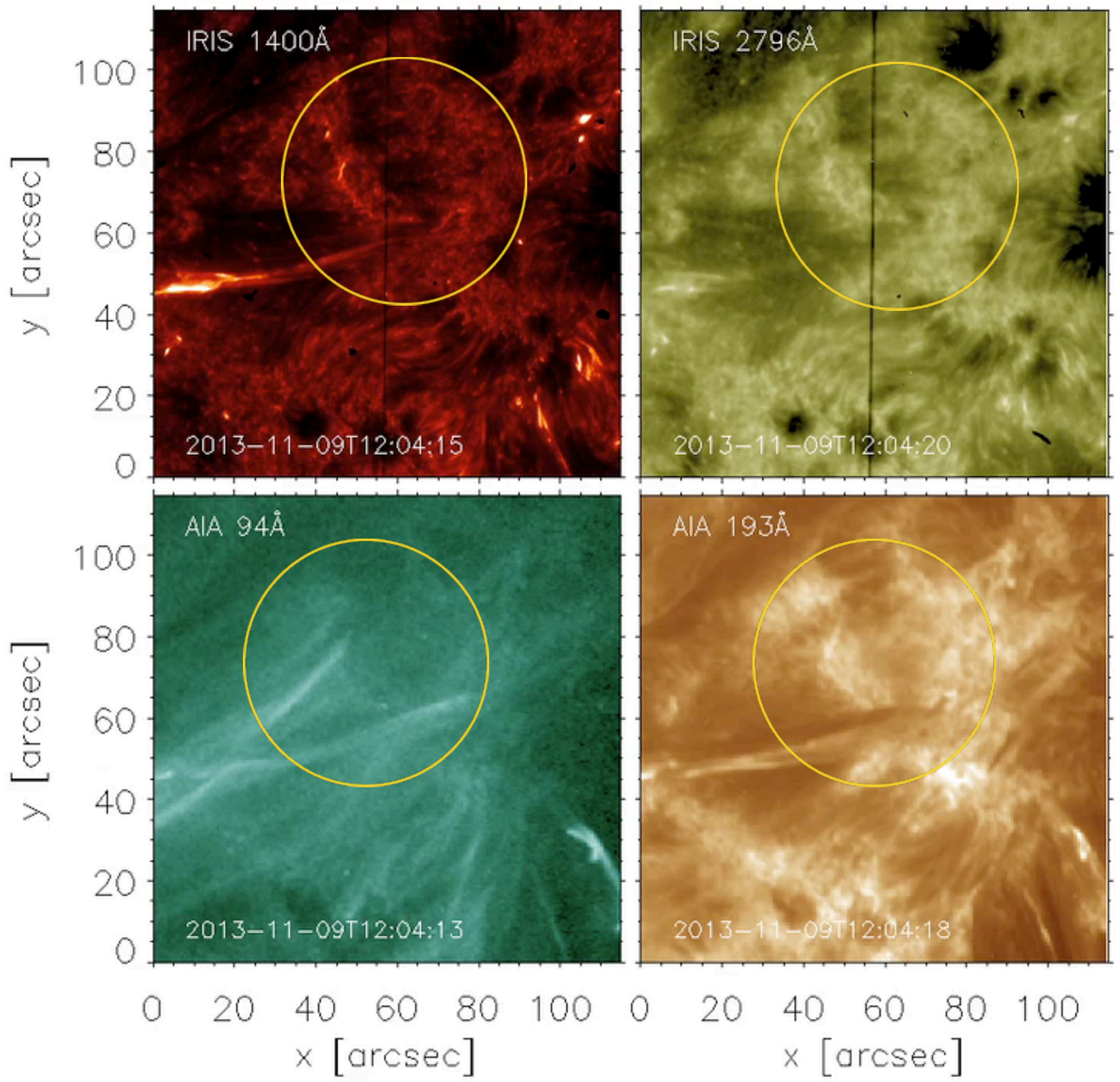
- Atmospheric response
- Forward modelling of IRIS observables

Summary & Conclusions

IRIS diagnostics of coronal heating

(Testa et al. 2014, Science)

- Tracing the signature of heating release in the corona is challenging
- IRIS observations show small short-lived brightenings at the TR footpoint of hot loops -*signatures of coronal heating?*
- Observations of TR spectral lines combined with hydrodynamic modelling can provide important ***constraints on the heating proprieties*** (Testa et al. 2014)



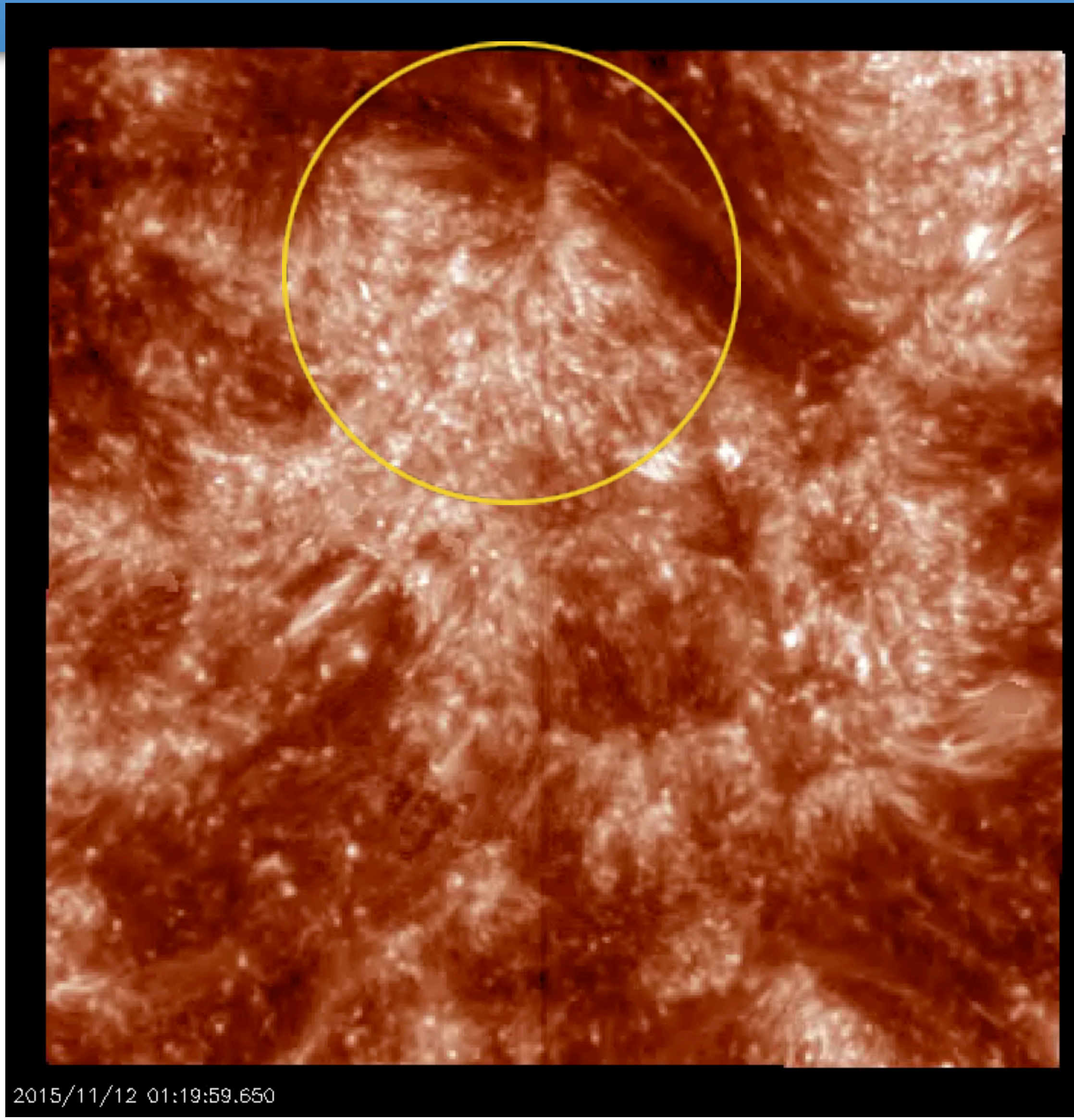
IRIS diagnostics of coronal heating

Statistical study of small heating events shows (Testa, in prep):

- Rapidly variable TR brightenings (<30s)
- Large range of shifts for the IRIS TR Si IV line (from blue to red or no-shift)
- A variety of coronal loop parameters observed by AIA
- Different profiles for the IRIS chromospheric Mg II lines (mostly single-peaked)

Need grid of models to interpret the variety of observations

- Exploration of parameter space
- More realistic modelling of chromospheric emission



Simulations of nanoflare loops with the RADYN code

RADYN (Carlsson & Stein, 1997, Allred et al, 2006) solves the equation of radiation hydrodynamics on a 1D adaptive grid

- Non-LTE radiative transfer for H, He, Ca II
- Allows to model heating by:
  - ***In-situ heating and thermal conduction***
  - ***Beams of accelerated particles with power law distribution –*** characterized by total energy (E_T), low energy cut-off (E_C) and spectral index (δ)
  - ***Alfven waves*** (Kerr et al, 2016)
- Includes Fokker-Planck equations to treat accelerated particles (Allred et al. 2015)
- Allows to include the effects of the return current (Allred et al. 2015)

Simulations of nanoflare loops with the RADYN code

Parameters space of our study:

Heating model

- Electron beam (EB) with parameters:
  $E_T = 6 \cdot 10^{24}$ ergs, $\delta=7$, $E_c=5$, 10 and 15 kev
- Thermal conduction (TC), $E_T=6\cdot10^{24}$ ergs
- Duration of the heating: 10 s

Initial atmosphere

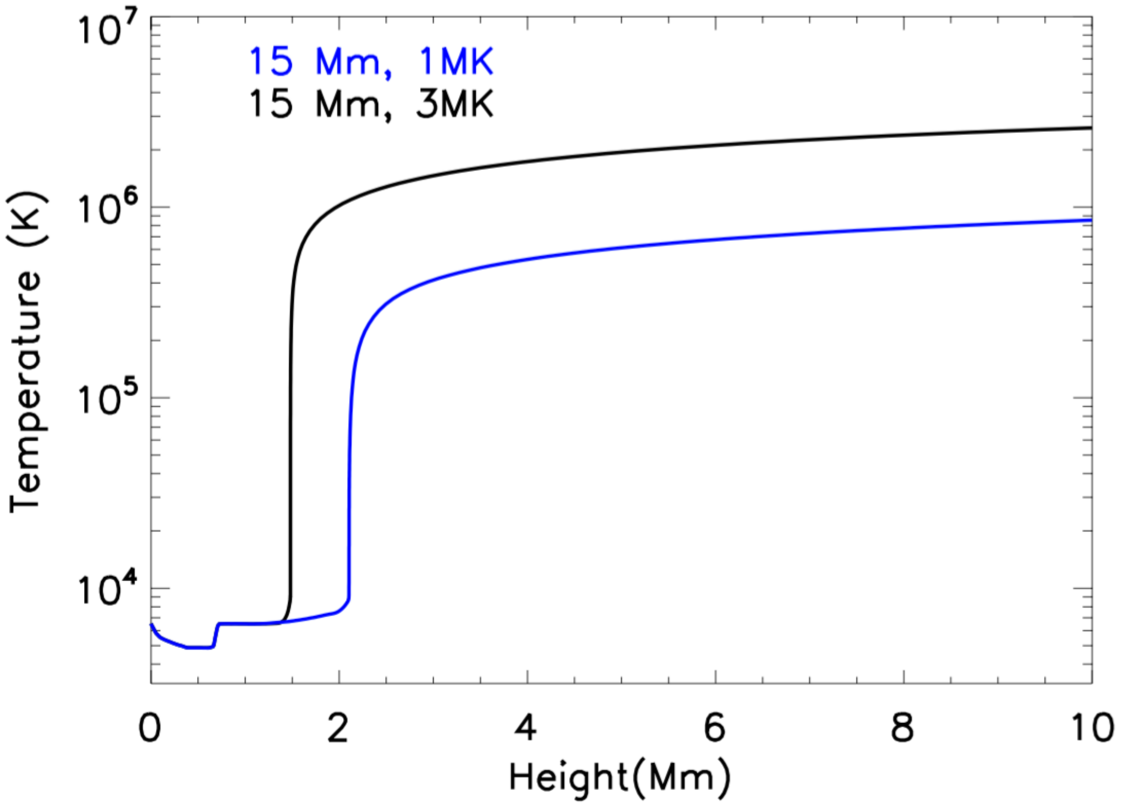
- Quiet sun and plage (Carlsson et al, 2015, ApJ)

Loop half-length

- 15 Mm, 50 Mm and 100 Mm

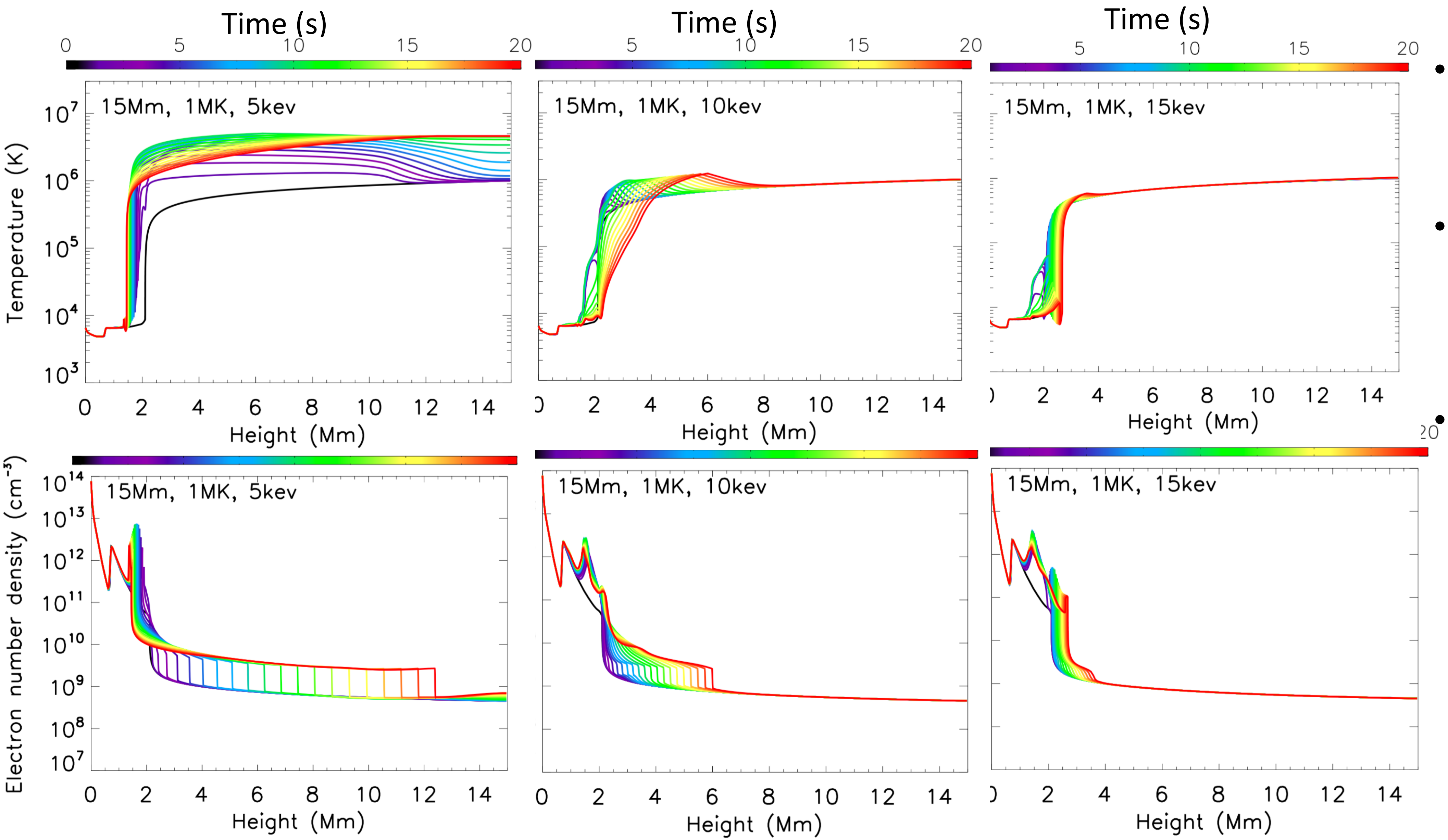
Initial loop temperature

- 1 MK, 3 MK and 5 MK



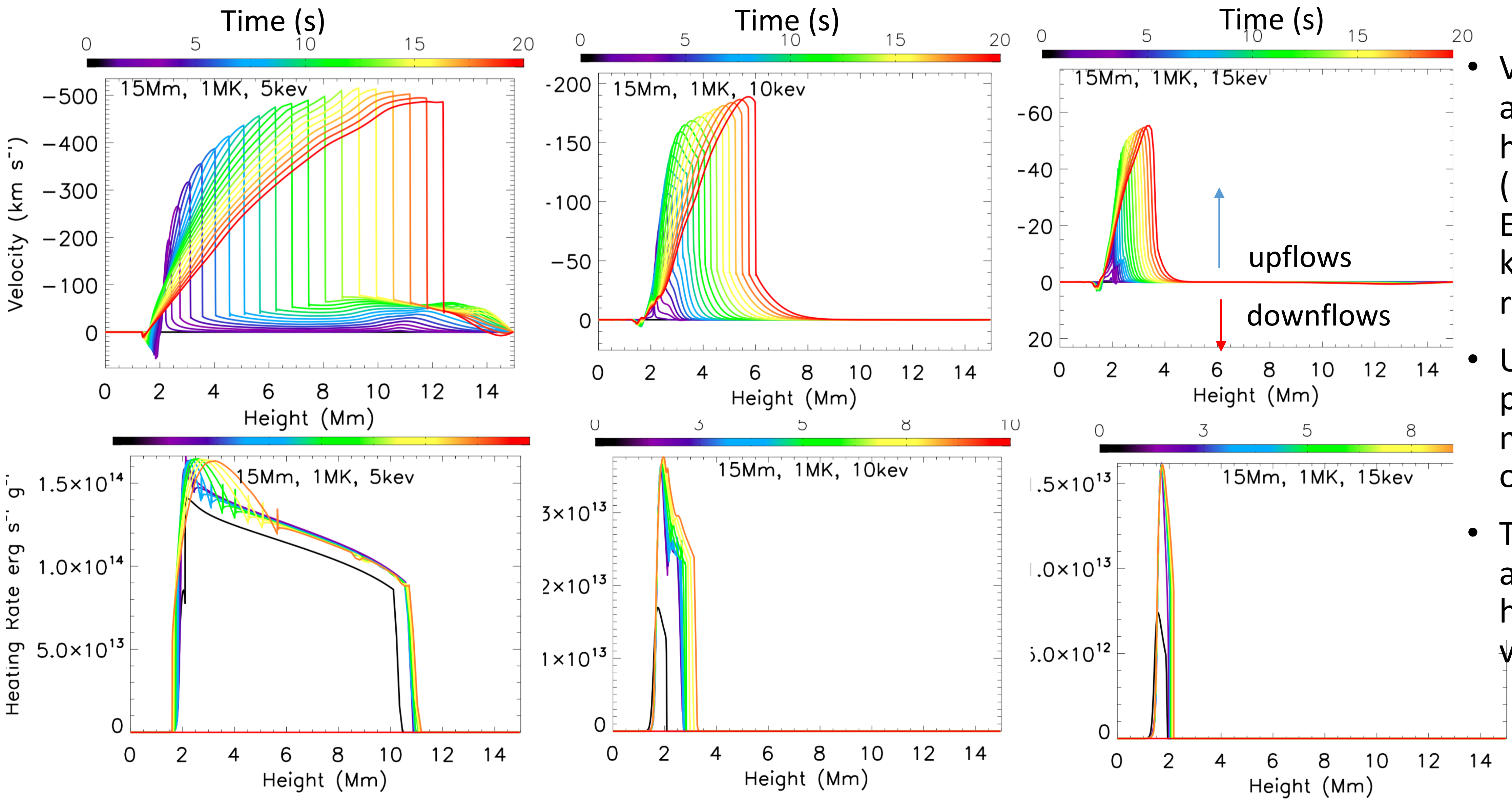
Example of initial atmosphere in plage (Carlsson et al, 2015) for 15 Mm 1MK & 3MK loops

Atmospheric response – 15 Mm 1MK loop, EB



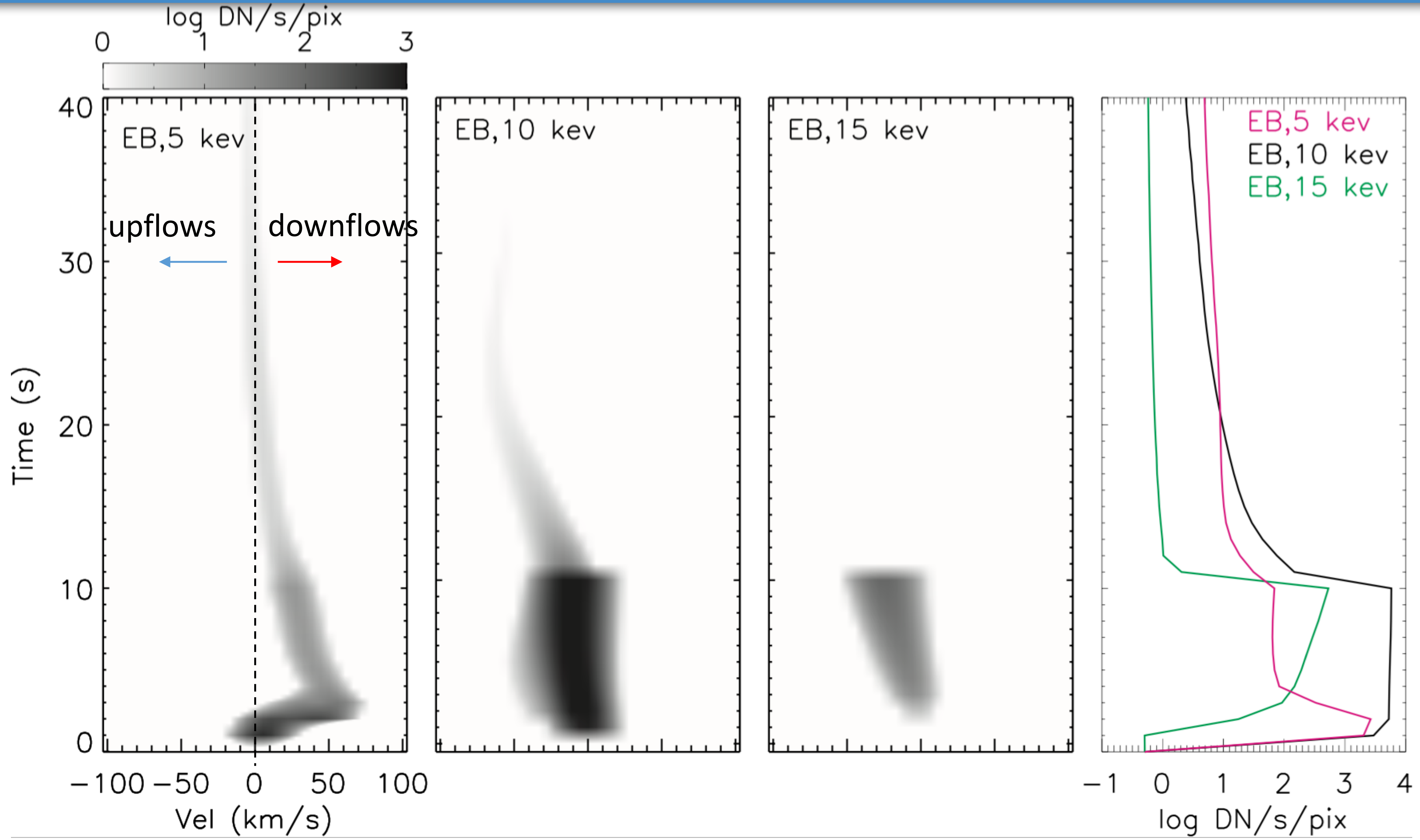
- T (top) and Ne (bottom) for E_c = 5, 10, 15 kev (left to right)
- For E_c =5 kev, some of the energy is deposited in the corona
- For E_c=5, 10 kev, the energy is deposited deeper in the atmosphere

Atmospheric response – 15 Mm 1MK loop, EB



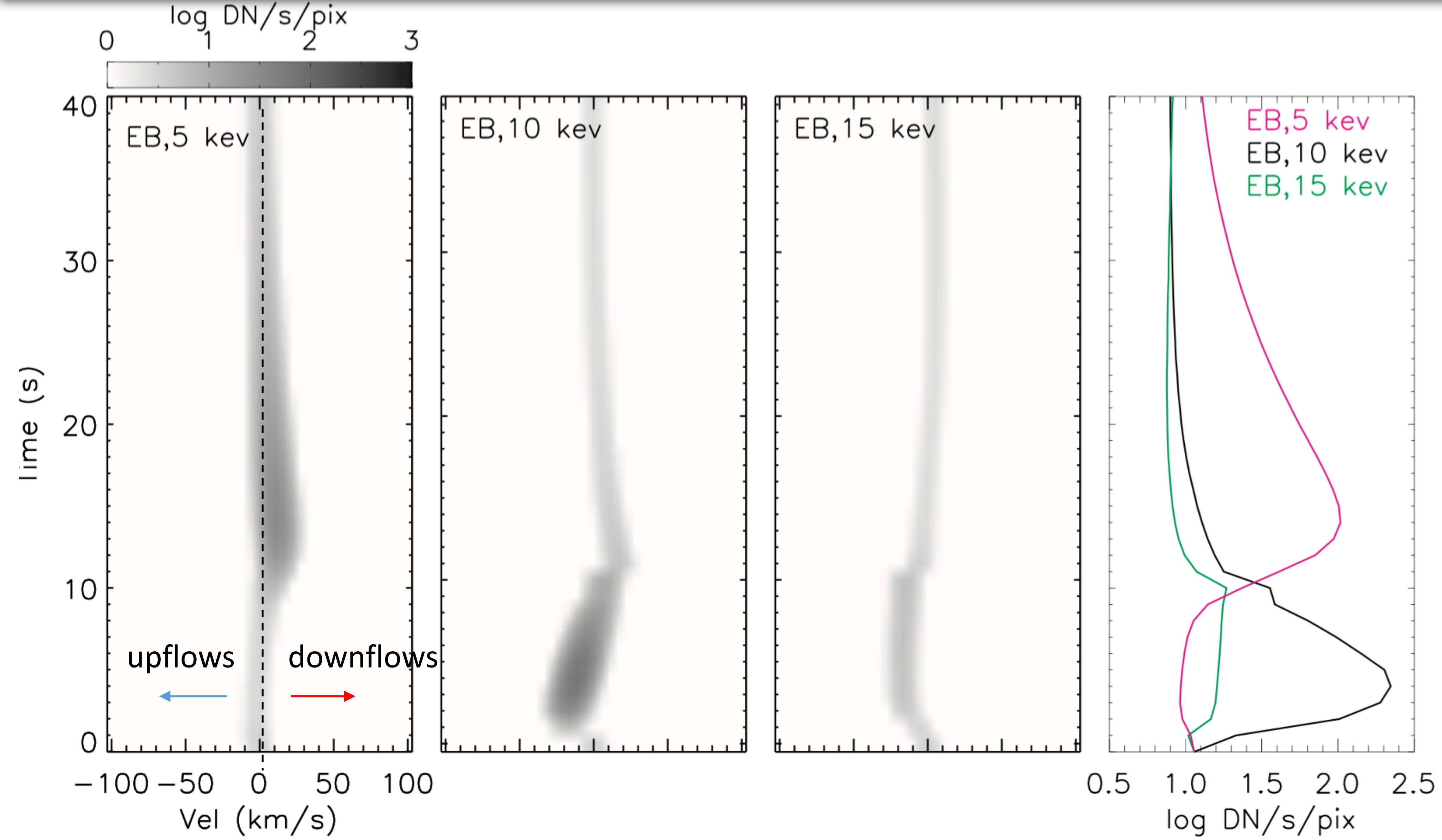
- Velocity (top) and beam heating rate (bottom) for E_c=5, 10, 15 kev (left to right)
- Upward plasma motion due to overpressure
- The velocities are lower for higher E_C values

IRIS Si IV spectra- 15 Mm 1MK loop



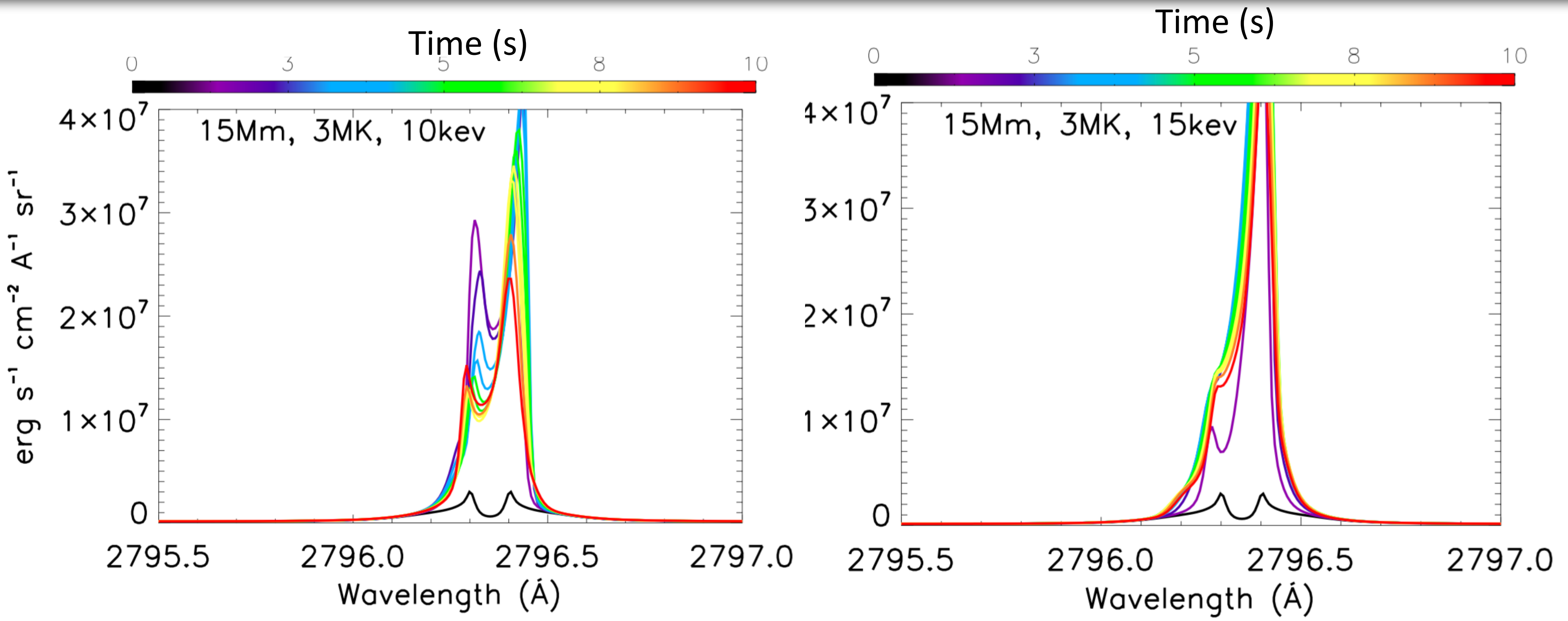
- Forward modeling of IRIS TR SiIV line (~$10^{4.8}$K)
- Brightenings duration ~ 10 s
- E_c =10, 5 kev -> blueshifts (~30 km/s)
- E_c = 5kev -> redshifts (~50 km/s)

IRIS Si IV spectra- 15 Mm 3MK loop



- Forward modeling of IRIS TR SiIV line (~$10^{4.8}$K)
- Lower intensity than in the 1MK case
- For Ec=10, 15 kev -> blueshifts (~20-30 km/s)
- For E_c =5 kev -> redshift (~20 km/s)

IRIS Mg II k-15 Mm 3MK loop



- Modeling of Mg II lines with RH 1.5D (Pereira et al, 2015) in partial redistribution (PRD)
- Large variety of line profiles depending on the heating model and initial conditions
- Initial atmosphere is crucial in order to reproduce realistic initial “plage” Mg II profiles – work in progress

Summary (1/2)

We have run a grid of nanoflare-heated loop models, exploring the effect of different parameters. Preliminary results:

TR observables

- Our models seem to reproduce the short duration of observed TR brightenings
- A large range of Si IV blueshifts can be reproduced depending on electron parameters, initial atmospheric condition and heating model
- Blueshifts cannot be reproduced by thermal conduction only in the cases we analyzed
- EB model with E_c = 5 kev yields similar results than the conduction model
- The initial temperature and density of the loops are crucial parameters, in particular, if the loop is too hot and dense, the simulations show low line intensities and small shifts
- Simulations in loops of different lenghts but same temperature yield some similar results overall (i.e., trend of red/blue shifts vs E_c)

Summary (2/2)

Chromospheric observables

- Mg II line profiles sensitive to the details of the heating
- Work in progress: more realistic initial profiles

Coronal observables

- Electron distributions with high E_c values produce very low AIA 94 A counts, low E_c/TC models are more effective in heating the corona
- Need longer timescales to be modeled than TR emission, should take into account multi thread models and frequency of nanoflares events (e.g., Reep at al, 2013, Cargill et al 2014)