Numerical simulations of Mg II lines in solar flares

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F-CHROMA

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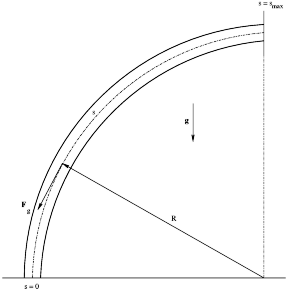
HVĚZDÁRNA A PLANETÁRIUM TEPLICE

Problem formulation

- hydrodynamic and radiative response of the solar atmosphere to the heating by the particle beams
- 1D scenario
- describe state and evolution of plasma along a single loop
- compute time evolution of continuum and line profiles of H, Ca II, and Mg II



Inital hydrostatic atmospheres

- modified VAL C
- atmosphere in equilibrium from RADYN (extra heating at the bottom)

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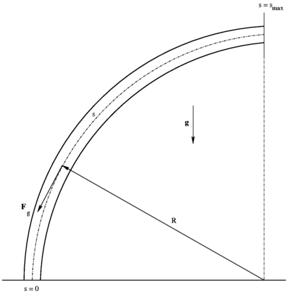

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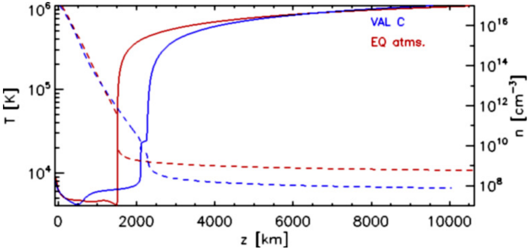

Flarix: non-LTE RHD code

- developed at AsI in Ondřejov, CR (Heinzel, Karlický, Moravec, Varady)

HD

- standard set of 1D HD equations
- advection, Spitzer thermal conduction
- flare heating is given by the beam energy deposit

Beam heating

- modelled by a test particle approach
- power-law beams
- alternatively, the beam energy deposit calculated according to Hawley & Fisher (1994)
- optionally the return current, secondary re-acceleration
- hard X-ray emission of the beam
- Varady et al. (2014)

Flarix: non-LTE RHD code

Non-LTE radiative tranfer

- 1D plane parallel atmosphere in the lower part of the loop
- H, Ca II, and MgII in detail using 5-level + continuum atomic models
- H Lyα and Lyβ treated in CRD with a limited wavelength range to mimic PRD
- MALI method (preconditioning of radiative rates)
- equations of statistical equilibrium (ESE)
  - solved together with radiative transfer eq. and conservation eq.
  - time-dependent ESE for H atom
  - linearised with respect to the level populations and electron density (H atom)
  - ESE for Mg II and Ca II computed using the current time-dependent electron densities
- Varady et al. (ITPS, 2010), Kašparová et al. (A&A, 2009)

Comparison with RADYN

RADYN

- 1D non-LTE RHD code (Carlsson & Stein, 1997)
- main differences from Flarix
  - adaptive spatial grid
  - fully implicit scheme to solve linearized equations
  - more atoms computed in detail (e.g. He)
  - analytical formula or Fokker-Planck approach for the beam heating

Test model

RADYN Flarix

- analytical heating by an electron beam
- identical initial atmosphere (VAL C)
- only H and Ca II computed in detail
- reasonably good agreement at all times

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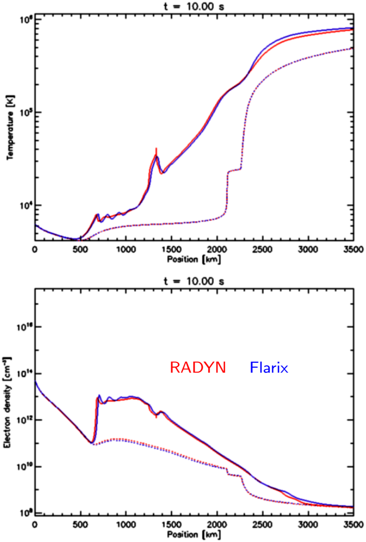

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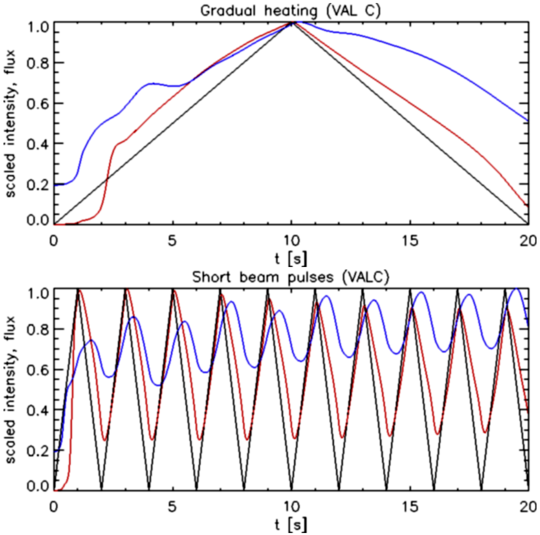
Time evolution - Mg II k line

Time modulation: gradual versus pulse beam heating

- 2 time profiles of 20 s duration
- the same integrated beam flux: 10^{11} erg cm^{-2}
- the line intensity follows the beam flux time modulation
- peak of the wing intensity lags behind the line centre and the beam flux peak
- the same maximum intensity in both cases



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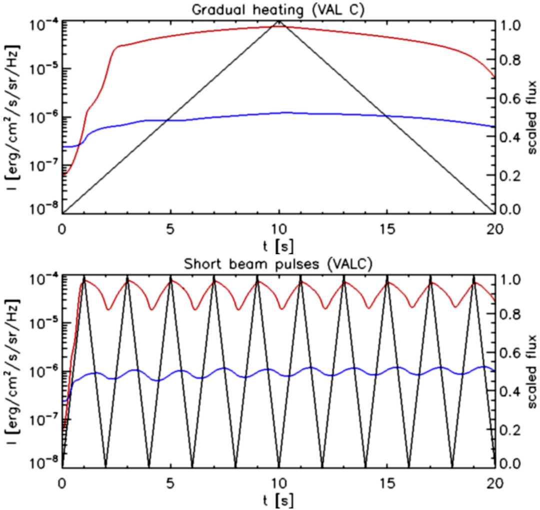
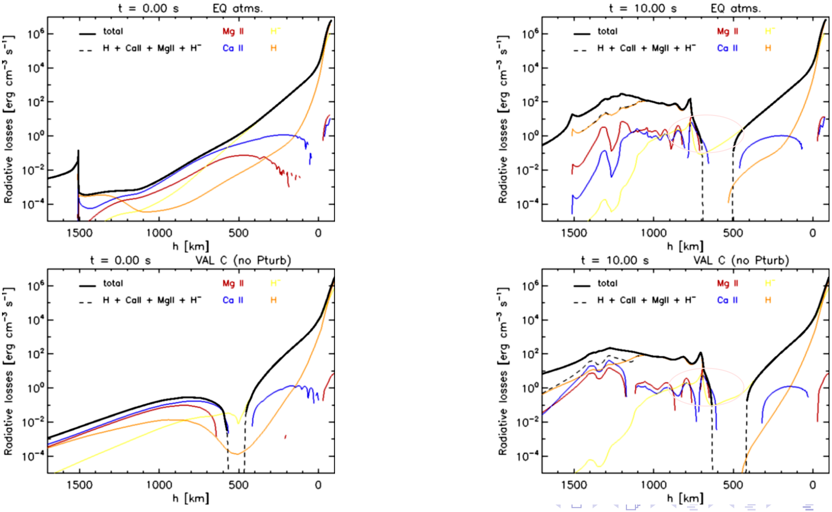


Mg II radiative losses

- Mg II h and k lines are the main contributors
- not a crucial component in the studied cases
- can exceed CaII losses in some parts of the atmosphere



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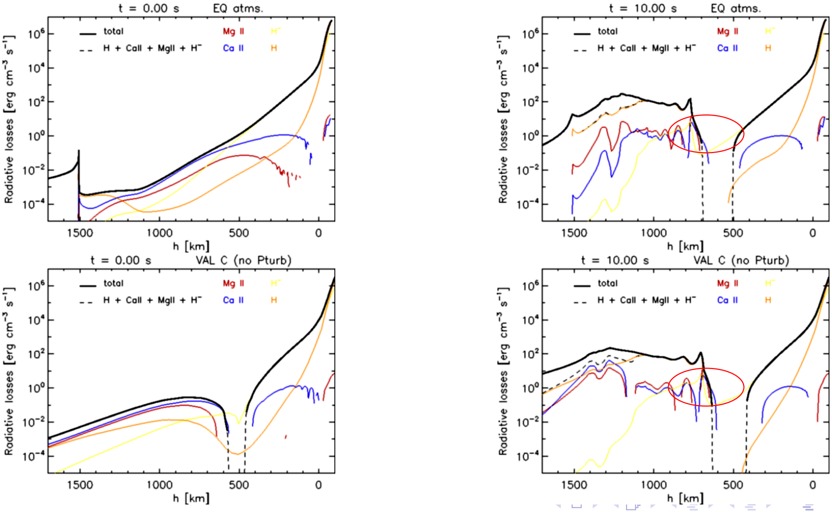
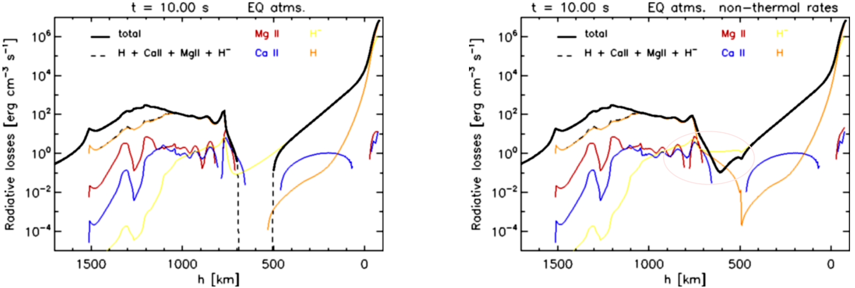


Non-thermal collisional rates C^{nt}

- beam electrons can contribute to collisional transitions

$$C_{ij}^{nt} = \int F(E)\sigma_{ij}(E)\mathrm{d}E$$

- $\sigma_{ij}(E)$ used from F-CHROMA database
  - based on GENIE, CHIANTI, IAEA Aladdin
  - available for H and selected transitions of Ca II, Mg II, He I, He II
- $F(E)$ from analytic formula for thick-target model (Battaglia et al., 2012)
- affect lower part of the atmosphere (500 - 700 km) and H atoms mainly



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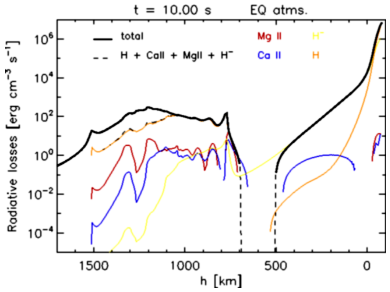
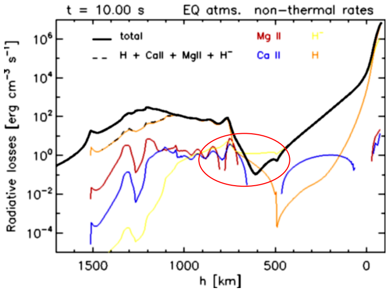
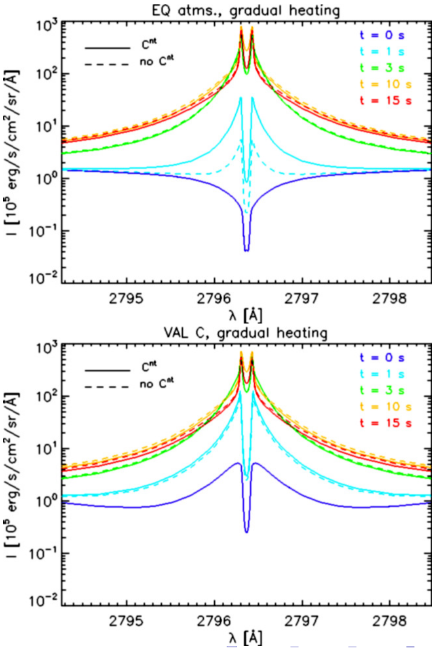




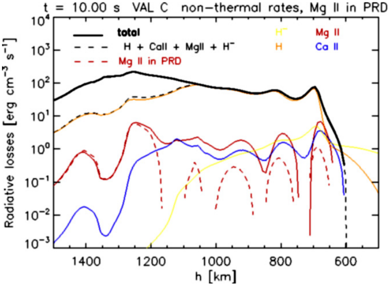
Non-thermal collisional rates C^{nt} - Mg II k

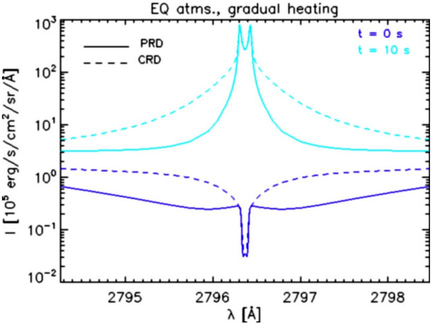
- C^{nt} influence depends on the initial atmosphere
- both the line core and the line wings can be affected
  - C^{nt} change the line wings even in the heated atmosphere
- for the Mg II h and k lines the influence of C^{nt} is not strong

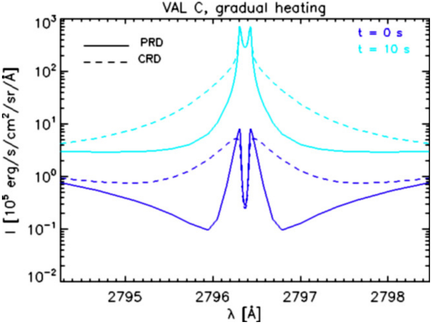


PRD - partial redistribution

- method of Heinzel and Hubeny (1983)
    - high computational cost
- Mg II k and h lines were treated in PRD outside of Flarix
    - starting from the level populations computed within CRD
- change of Mg II radiative losses

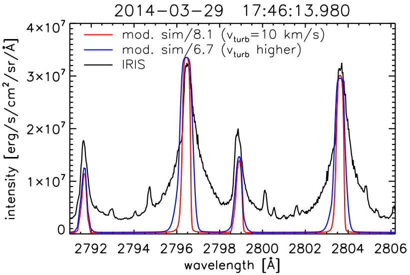




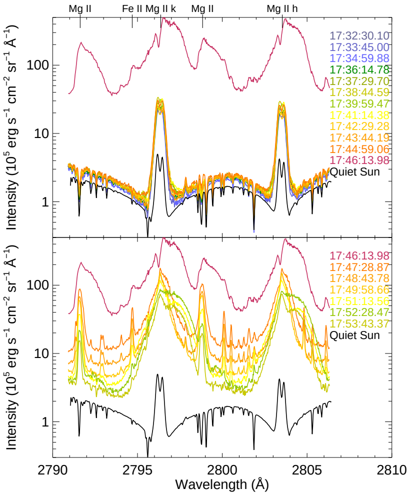


Observations and other modelling

- modelled Mg II h and k lines are much narrower than the observed:
  - Liu et al. (2015)
  - Rubio da Costa et al. (accepted to ApJ)



Rubio da Costa et al. accepted to ApJ, Fig.18



Liu et al. 2015, Fig.6

Conclusions

- Mg II radiative losses may significanty contribute to total losses in some parts of the chromosphere
- C^{nt} play a minor role in Mg II h and k line profiles but are important for hydrogen and thus for the atmosphere evolution
- Mg II h and k line intensities correlate with the time evolution of the beam flux
- PRD strongly affects Mg II h and k line profiles, a study is needed how to mimic it within non-LTE RHD simulations