Spectral modeling of flares on AD Leo

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Outline

Introduction - solar flares

- sudden brightenings on the solar surface
- energy is released due to magnetic reconnection
- typical time-scale tens of minutes to hours
- phases:
  - pre-flare
  - impulse
  - gradual

Introduction - stellar flares

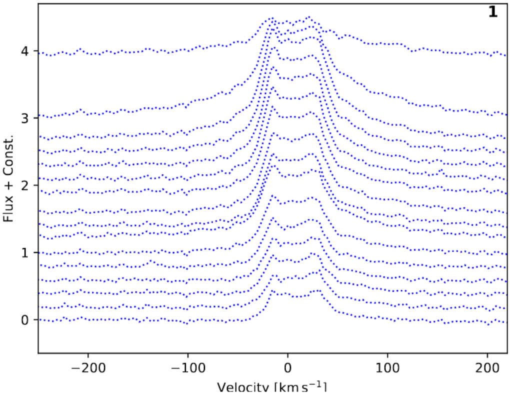
- most common on K and M stars
- compared to Sun they tend to have vast and strong magnetic fields
- energy released during solar flares - $10^{28} – 10^{32}$ erg
- energy released during typical stellar flares on M stars $10^{31} – 10^{34}$ erg (super-flares up to 10^{36} erg)

Introduction - stellar flares - why study them

- expand our knowledge of processes in stellar atmospheres
- every other M type star has a planet in habitable zone (Tuomi et al., 2019)
- flares affect planet's habitability, especially their atmosphere

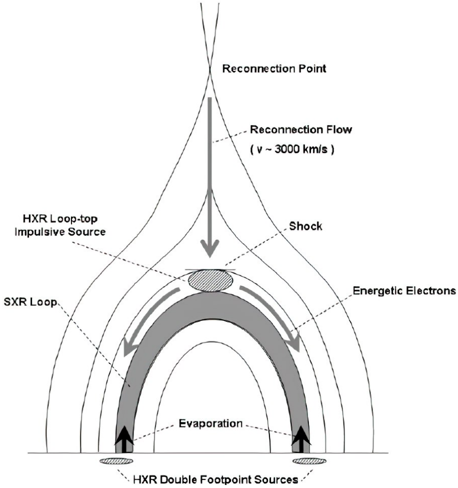
Introduction - stellar flares - spectral line asymmetries

- some spectral lines show asymmetrical profile compared to the rest profile during flares - origin is not well understood
- we assume they are caused by chromospheric flows of plasma



Source: Muheki et al. (2020)

Introduction - solar flares - standard model



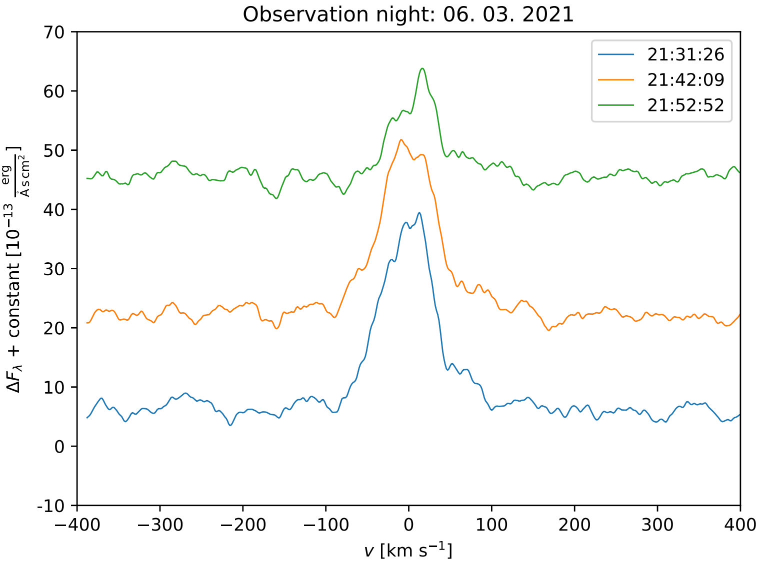
Introduction - solar flares

- video - coronal rain

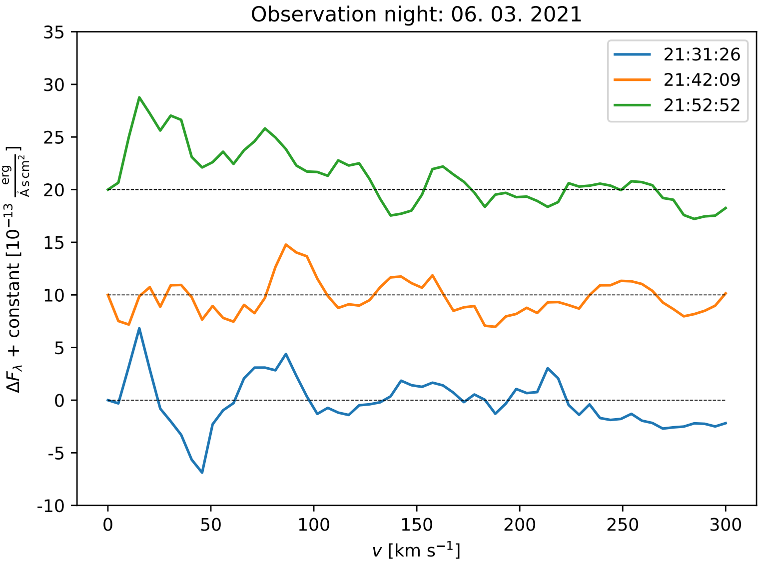
Observations - AD Leo

- spectral type dM3.5eV
- m $\approx$ 0.4 $M_{\odot}$
- frequently studied star
- statistically a flare occurs once every two hours
- spectra in visible region with exposure time 10 - 15 minute using 2m Perek telescope in Ondřejov

Observations - Hα profile changes



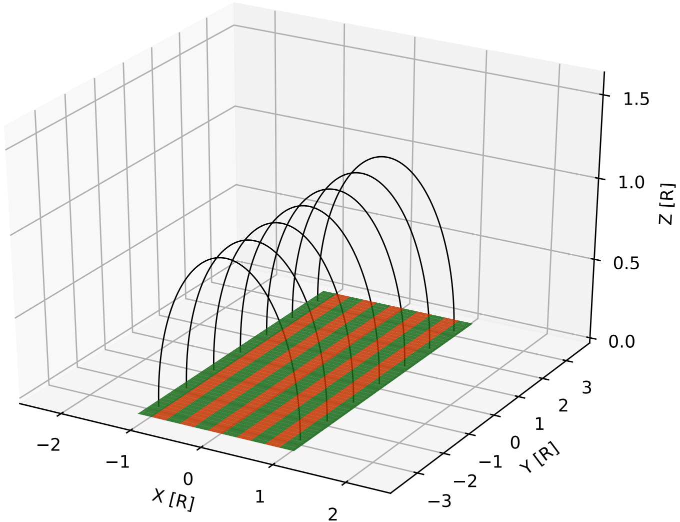
Observations - Hα profile changes



Model - Setup

- aims to probe origin of asymmetry of spectral lines profiles
- current implementation solves Hα line
- solution of radiation transfer through flare loops using approximation of cloud model
- clouds move along circular loops
- flare occurs at the stellar disc center with respect to the observer

Model - Setup



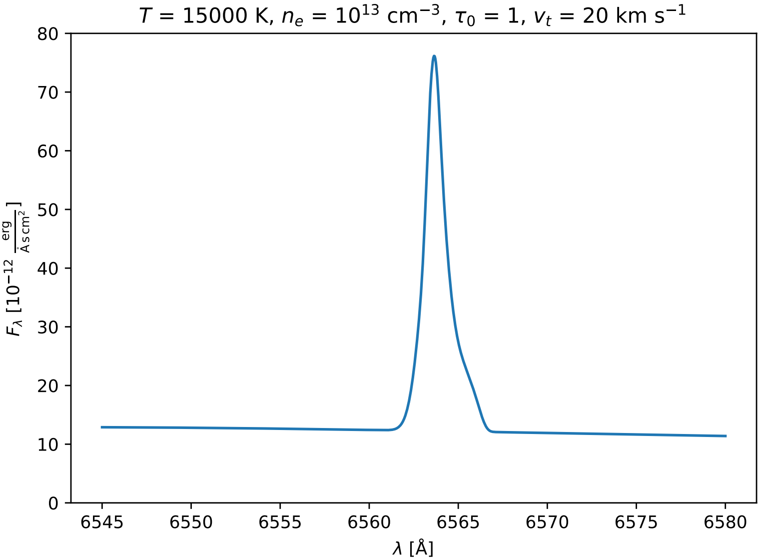
Model - Setup - specific intensity

- approximation of two-level atom and constant source function through a single cloud
- $S = \epsilon B(\lambda_0) + (1 - \epsilon)\bar{J}$
- source function depends on velocity of cloud with respect to the stellar surface
- $I_\lambda(0) = I_\lambda(\tau_\lambda)e^{-\tau_\lambda} + S(v)(1 - e^{-\tau_\lambda})$
- parameters: temperature, optical thickness, electron density, radius of circular loop, turbulent velocity

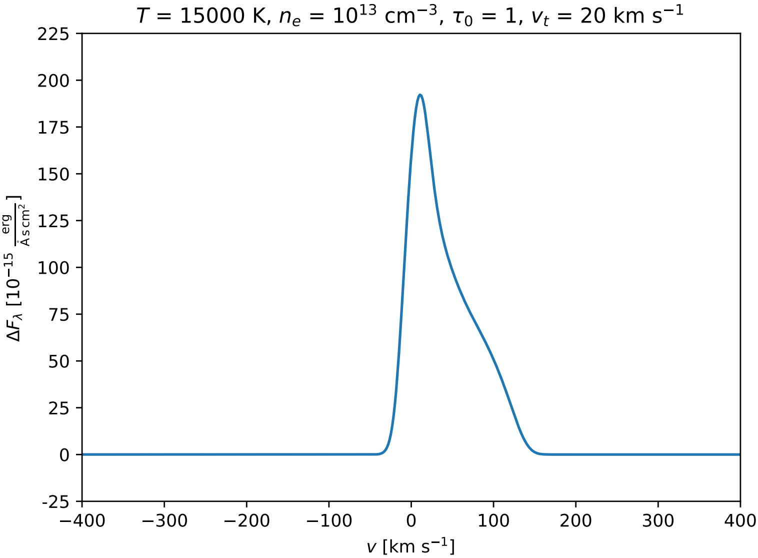
Model - Preliminary results - single cloud spectrum

- video

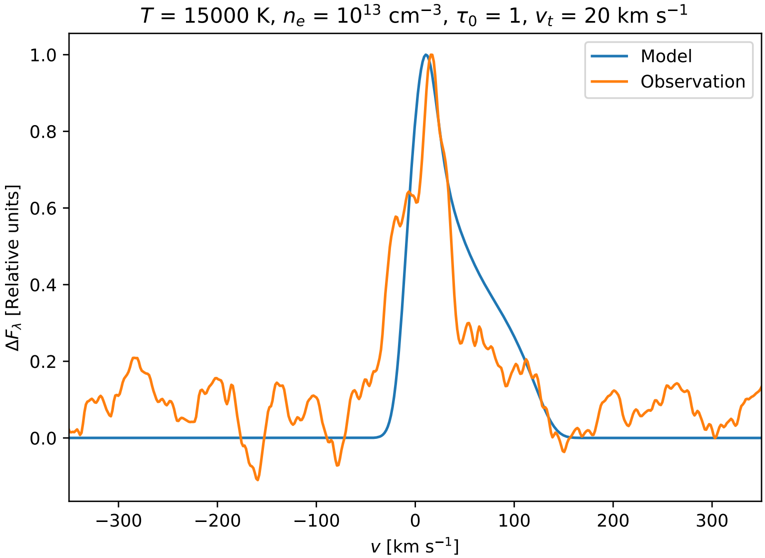
Model - Preliminary results - spectrum of flare arcade



Model - Preliminary results - flare spectral line effect



Model - Comparison with observations



Conclusions

- we observed asymmetrical profiles of Hα
- simple model of radiation of circular flare loops yields asymmetrical profile that matches *some* observations

Future work

- simulate synthetic spectra using RHD code Flarix
- generalise location of flare on the stellar disc with respect to the observer
- use more robust methods of plasma motion simulation along flare loops