Study of White-light Emission During the X9.3 Flare on September 06, 2017

J. Kašparová[1], L. Mravcová[1,2], M. Švanda[2,1], J. Jurčák[1], P. Heinzel[1]

[1]Astronomical Institute of the CAS, Ondřejov, Czech Republic

[2]Astronomical Institute of Charles University, Prague, Czech Republic

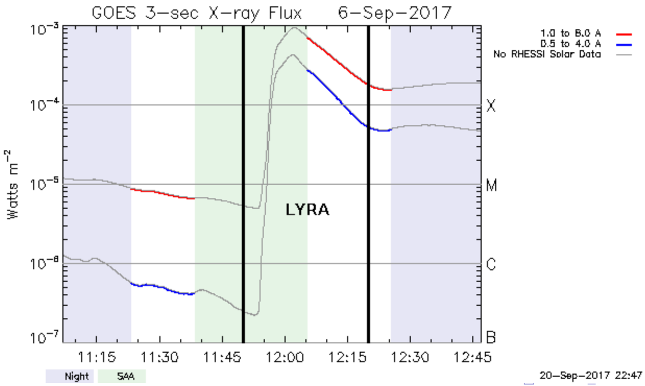
Astronomical Institute of the Czech Academy of Sciences

FACULTY OF MATHEMATICS AND PHYSICS Charles University

ESPM-16, virtual, Sep 6-10, 2021

September 6, 2017 X9.3 flare

- the largest flare of 24^{th} solar cycle
- start at $\sim 11:53$ UT
- detected by several instruments, e.g.:
  - RHESSI, Fermi: gradual phase only
  - Hinode: SOT/SP
  - *SDO*/HMI: white-light pseudo-continuum
  - LYRA: solar irradiance in UV range

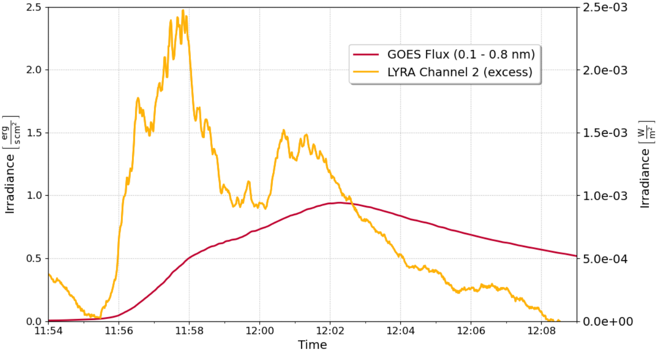


Proba 2/LYRA Channel 2 data

- Large Yield RAdiometer (LYRA) on board Proba 2 (Hochedez et al., 2006)
    - solar irradiance at 4 channels
    - Channel 2: Herzberg channel, 1990 - 2200 Å, temporal cadence 20 Hz

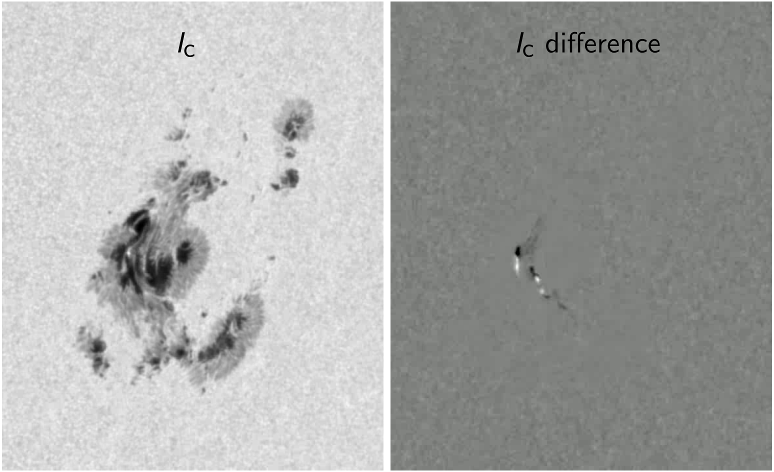
Sep 6, 2017 flare - Dominique et al. (2018)

- the first flare detected in Channel 2
- emission consistent with hydrogen Balmer continuum



HMI pseudo-continuum I_C

- HMI data product from Fe I 617.3 nm scans
- 45 s time cadence, 0.5″ spatial sampling



Hydrogen continuum emission

Assumptions

- optically thin emission from a layer of thickness L
- intensity of recombination continua

  (Heinzel et al. 2017; Dominique et al., 2018)

i=2,3,4.. Balmer, Paschen, Brackett,..

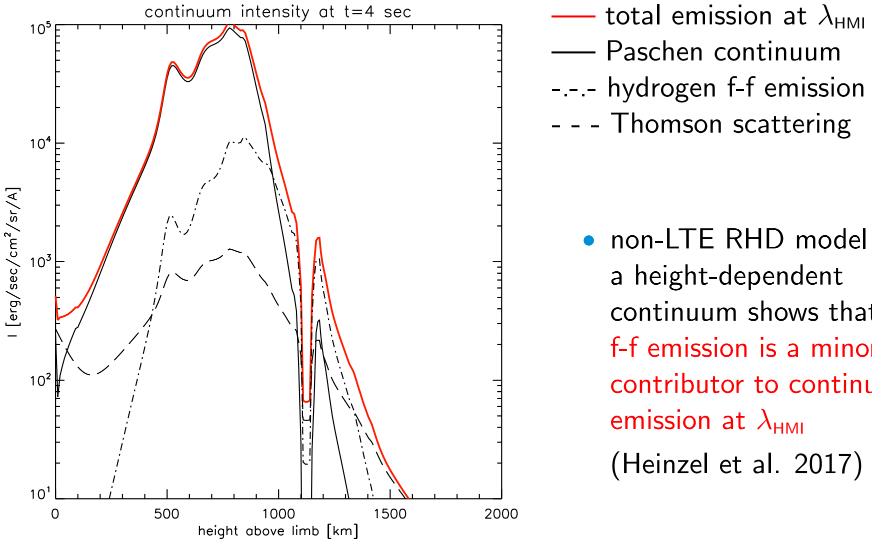
$$I_\nu = n_\mathrm{e}^2 F_i(\nu, T) L$$

$$F_i(\nu, T) \sim B_\nu(T) T^{-3/2} e^{h\nu_i/kT} (1 - e^{h\nu/kT})/(i\nu)^3$$

continuum heads: $\lambda_2 = 364.6\,\mathrm{nm}$ $\lambda_3 = 820.4\,\mathrm{nm}$ $\lambda_4 = 1458\,\mathrm{nm}$

emission data: $\lambda_{\mathrm{LYRA}} = 200\,\mathrm{nm}$ $\lambda_{\mathrm{HMI}} = 617.3\,\mathrm{nm}$

Hydrogen continuum emission



- non-LTE RHD model of a height-dependent continuum shows that f-f emission is a minor contributor to continuum emission at λ_{HMI} (Heinzel et al. 2017)

Predicted LYRA emission from HMI data

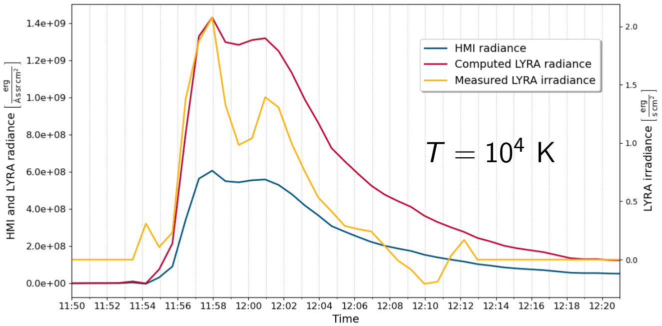
- for a given T, HMI gives emission measure $[n_e^2 L](t)$

$$[n_e^2 L](t) = \sum_{\text{flare pixels}} I_{\text{HMI}}(t) / \left[F_3(\nu_{\text{HMI}}, T) + F_4(\nu_{\text{HMI}}, T\right]$$

$$I_{\text{LYRA}}(t) = [n_e^2 L](t) \left[F_2(\nu_{\text{LYRA}}, T) + F_3(\nu_{\text{LYRA}}, T) + F_4(\nu_{\text{LYRA}}, T\right]$$

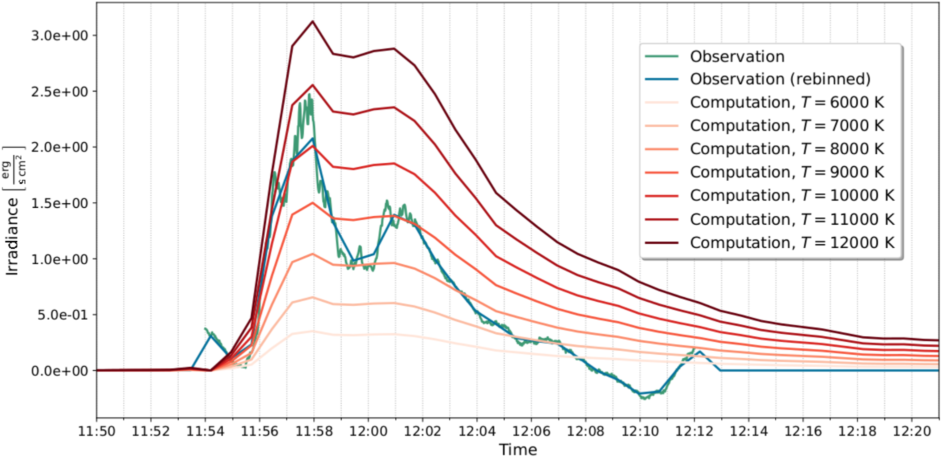
- predicted LYRA irradiance $E_2(t)$ using Dominique et al. (2018)

$$E_2(t) \sim \int_\lambda S_2(\lambda) I_{\text{LYRA}}(t) \, \mathrm{d}\lambda \qquad S_2(\lambda) \ldots \text{ eff. area}$$



Predicted LYRA emission for several T

- predicted LYRA irradiance $E_2(t)$ for a set of T



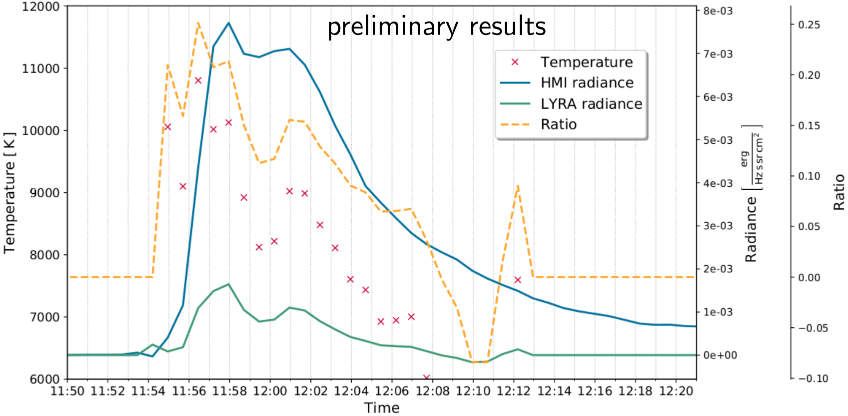
- $E_2(t)$ sensitive to T

Temperature evolution

Assumptions

- I_C and E_2 given by hydrogen recombination continua
- continua formed within the same optically thin layer

$$\Rightarrow \text{ratio } I_C/E_2 \equiv f(T) \Rightarrow \text{mean } T(t)$$



Conclusions

- HMI and LYRA data were used to study flare continuum emission
- assuming the emission is due to hydrogen recombination, mean temperature in the flaring area can be determined

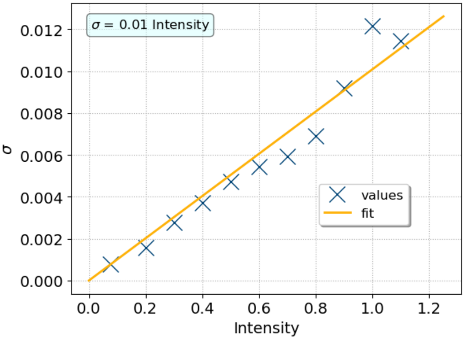
- preliminary results show $T(t) \sim 7\,000 - 11\,000$ K during the impulsive phase of an X9.3 flare

HMI flare emission

- space-temporal analysis
- based on I_C difference above a threshold

$$I_\mathrm{C}^{\mathrm{diff}}(x,y) > 5\,k\,I_\mathrm{C}^{\mathrm{PF}}(x,y)\,,$$
$$k = 0.01,$$
$$I_\mathrm{C}^{\mathrm{PF}} = \overline{I_\mathrm{C}(11{:}30 - 11{:}40)}$$

- a flare pixel must
  - have at least 2 neighbours at start
  - occur on 3 subsequent frames at least
- end of a flare pixel light curve defined as time when $\overline{I_\mathrm{C}}(x,y)$ reached $I_\mathrm{C}^{PF}(x,y)$ within 5%
  - a box car over 5 frames



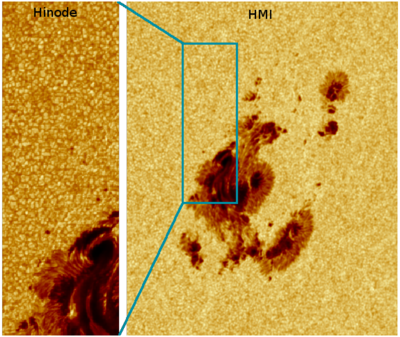
I_C at 10:00 and 11:30 UT

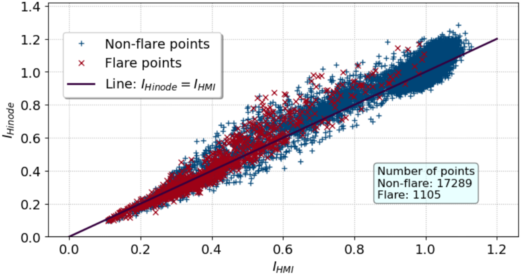
$\sigma(I_\mathrm{C}) = kI_\mathrm{C}$

$\Rightarrow$ Flare pixel light curves

HMI versus Hinode data check

- Švanda et al. (2018) showed HMI product I_C can be off from continuum intensity close to Fe I 630 nm lines observed by Hinode





- no systematic offset of I_C
- no correction applied