SOLARNET IV MEETING, Lanzarote, Spain, 16-20 January 2017

F-CHROMA

Hα AND Hβ EMISSION IN A C3.3 SOLAR FLARE: COMPARISON BETWEEN OBSERVATIONS AND SIMULATIONS

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University of Glasgow

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AIM OF THE WORK

- ❑ Clarify some aspects related to energy release and re-distribution in the chromospheric layer during a solar flare

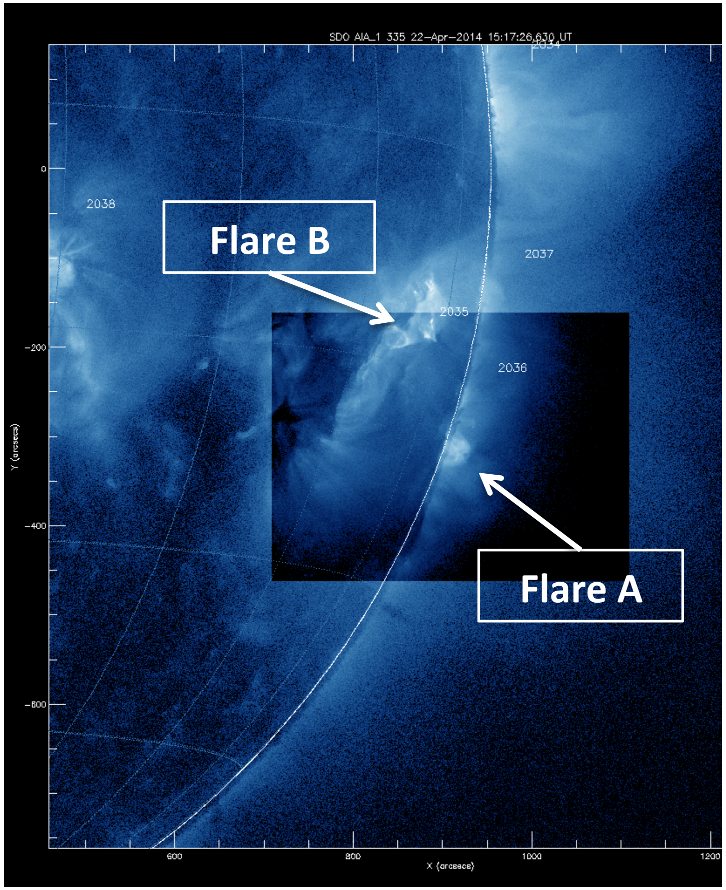
- ❑ Investigate the chromosphere response to the sudden energy input

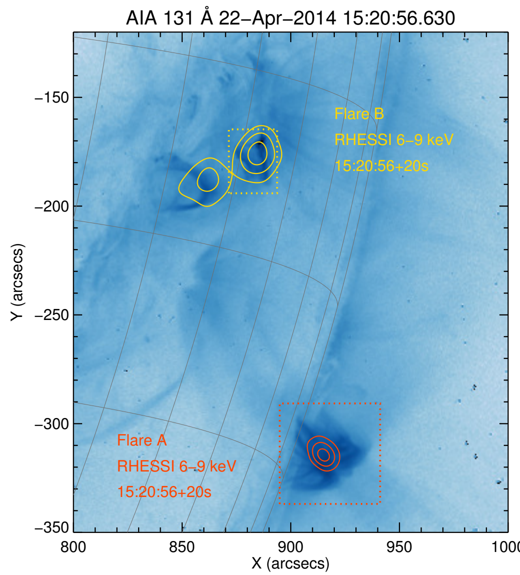
METHOD

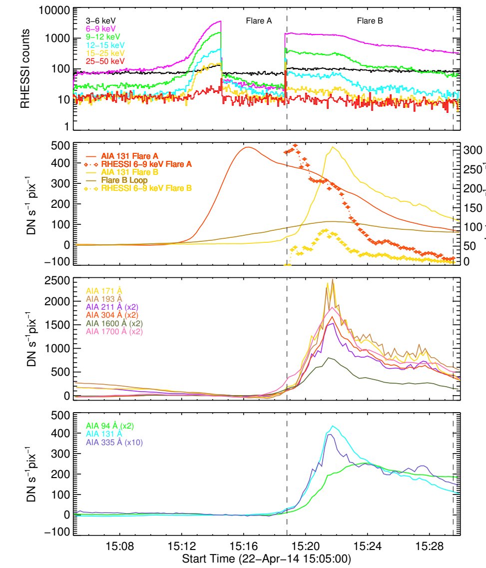
- ✓ Acquisitions and analysis of ground-based observations carried out at different chromospheric lines during a solar flare

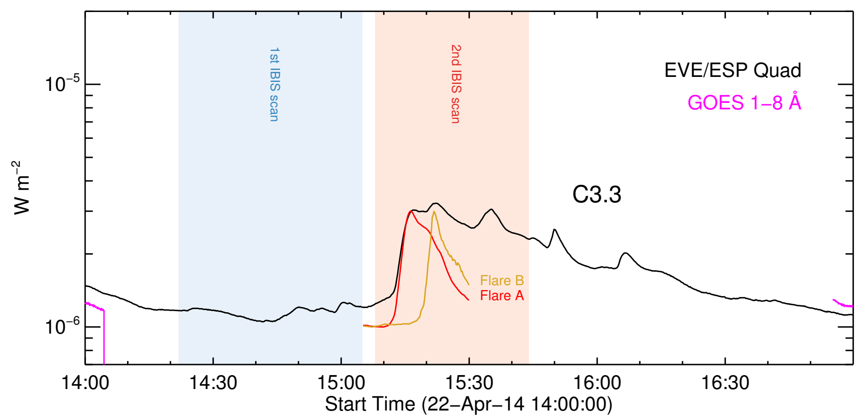
- ✓ Compare the results by models

April 22, 2014 - two flaring regions







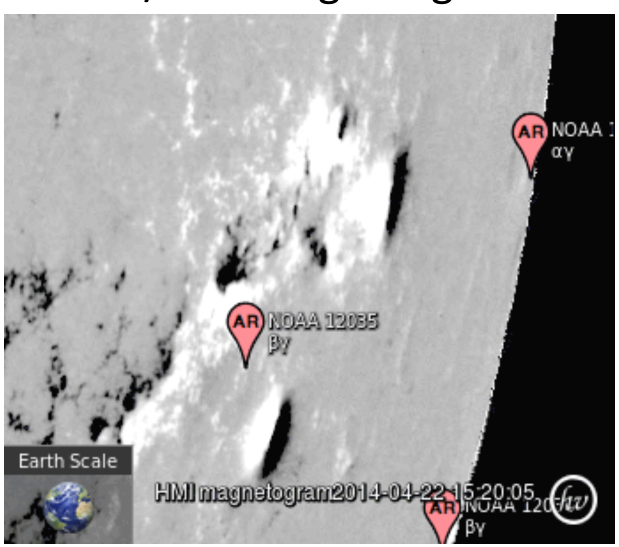


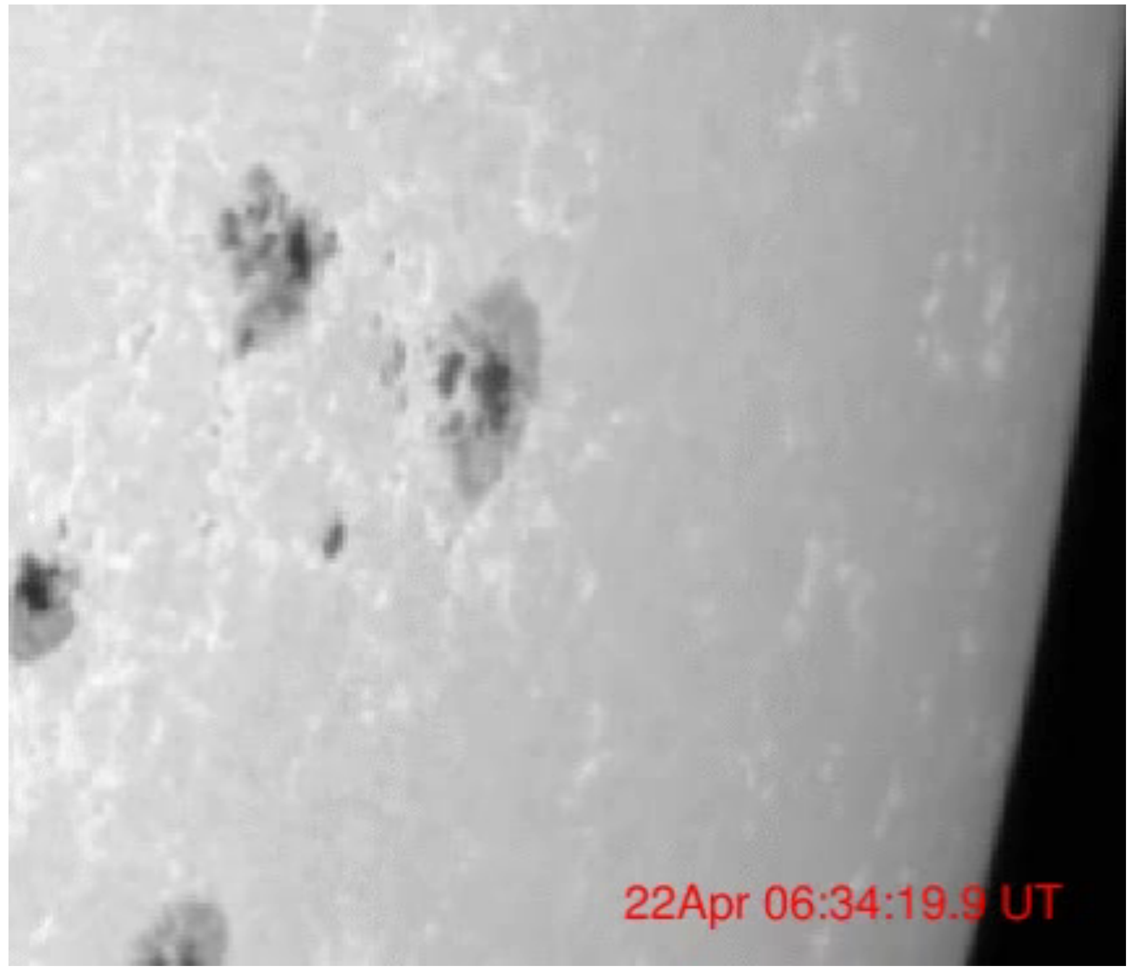
- ➢ Limb flare (A) in AR 2036 starts to become visible at ~ 15:12, peaks ~ 15:17 UT
- ➢ Flare (B) in AR 2035 starts to become visible at ~ 15:18, peaks ~ 15:22 UT

AR 12035, South 12.4 West 67.7

SDO/HMI continuum

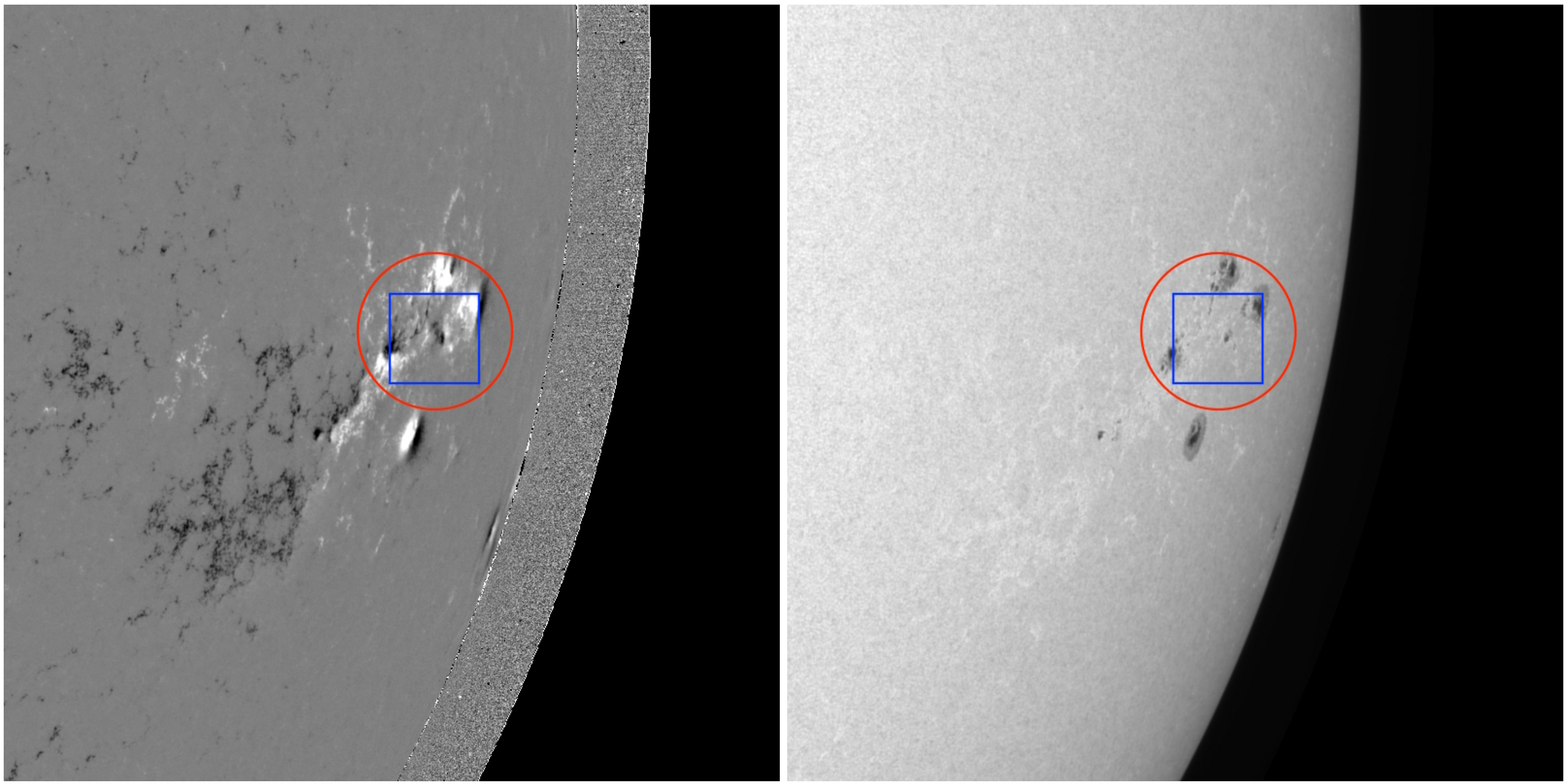
SDO/HMI magnetogram





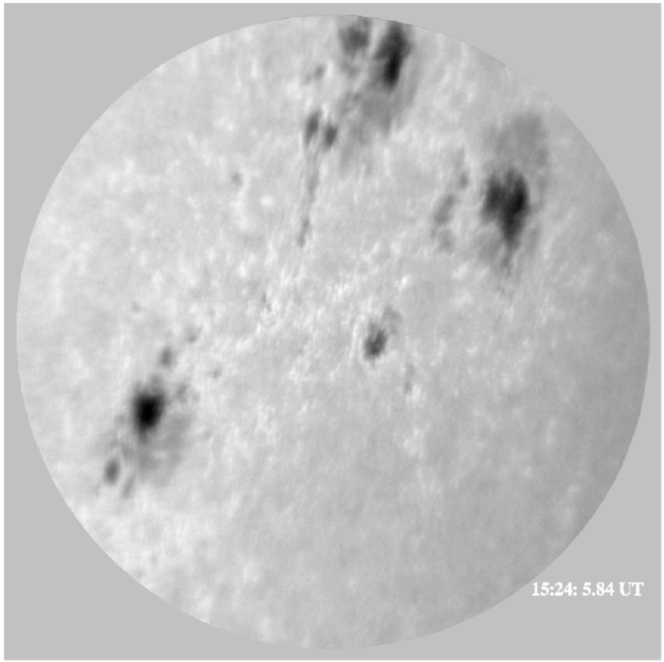
GROUND-BASED OBSERVATIONS (DST – NSO Sacramento Peak)

- Hα line from Interferometric BIdimensional Spectropolarimeter (IBIS) instrument
- Hβ line from Rapid Oscillations in the Solar Atmosphere (ROSA) instrument

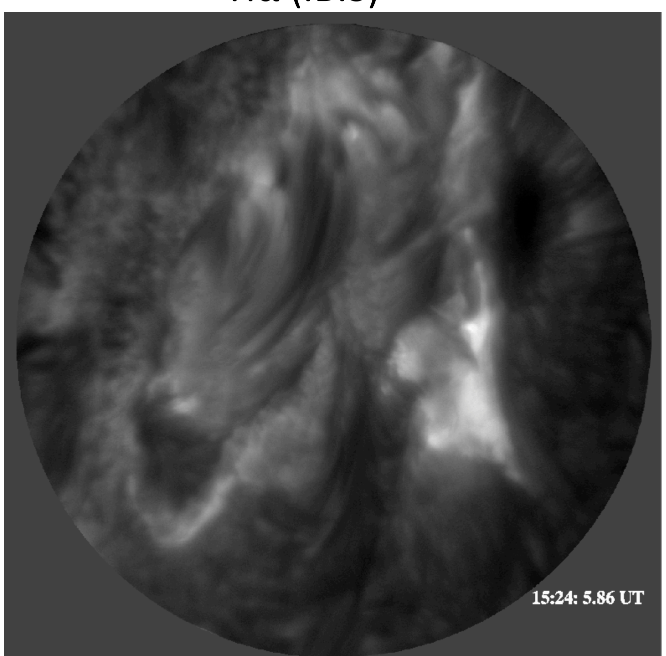


This combined dataset is quite rare (if not unique)!

Continuum IBIS



Hα (IBIS)



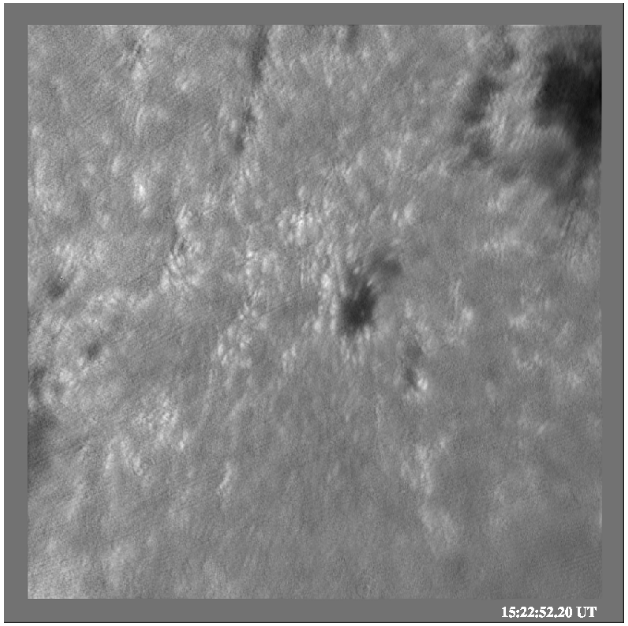
IBIS observations (Hα line + Broadband)

- 900 scans of Hα spectral line profile (core at 6562.83 Å)
- Each spectral profile has been sampled with a total of 17 wavelength points (average step = 0.02 Å)

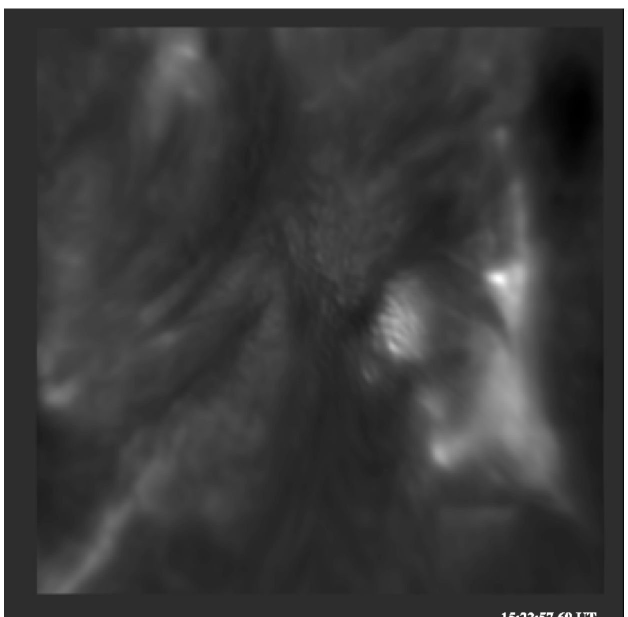
Hα Dataset :

- ➢ from 15:08 to 15:44 UT
- ➢ pointing: S12.4 W67.7
- ➢ 900 images, cadence 2.6 s (scan)
- ➢ camera 1000x1000 pixels
- ➢ spatial resolution 0.18”/pixel

Continuum ROSA



Hβ (ROSA)



ROSA observations (Hβ line + Broadband)

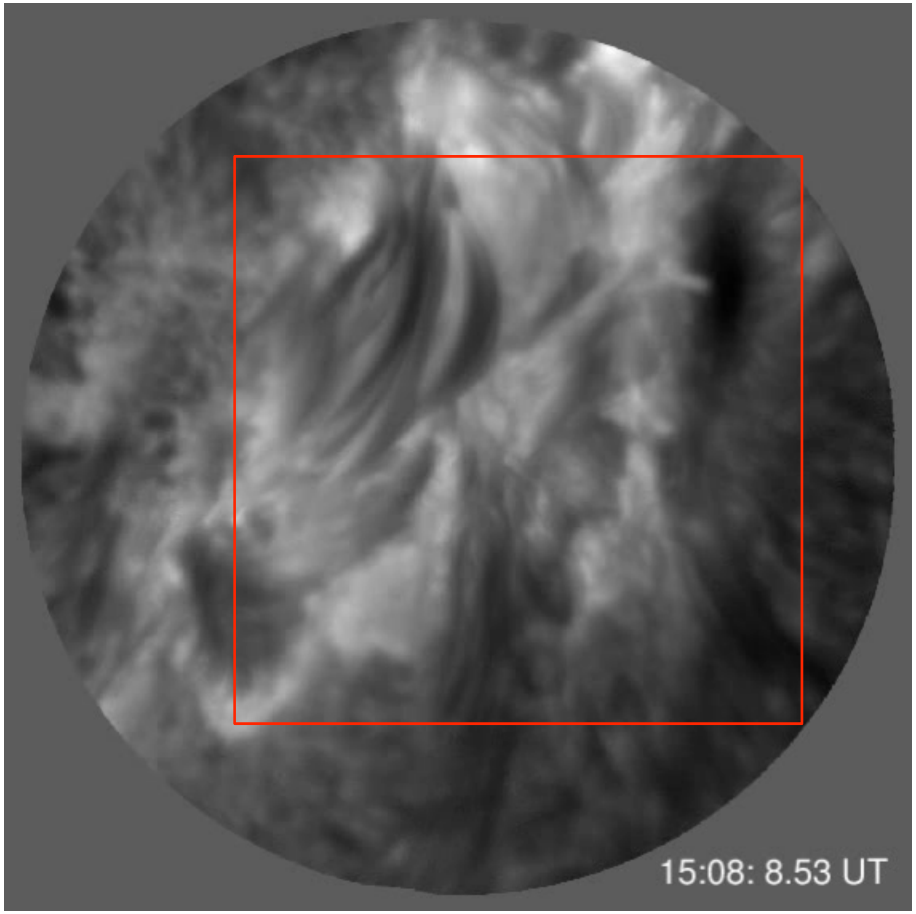
Images at Hβ core (4861 Å) with a passband of 0.21 Å obtained through the UBF filter

Hβ Dataset (3° batch):

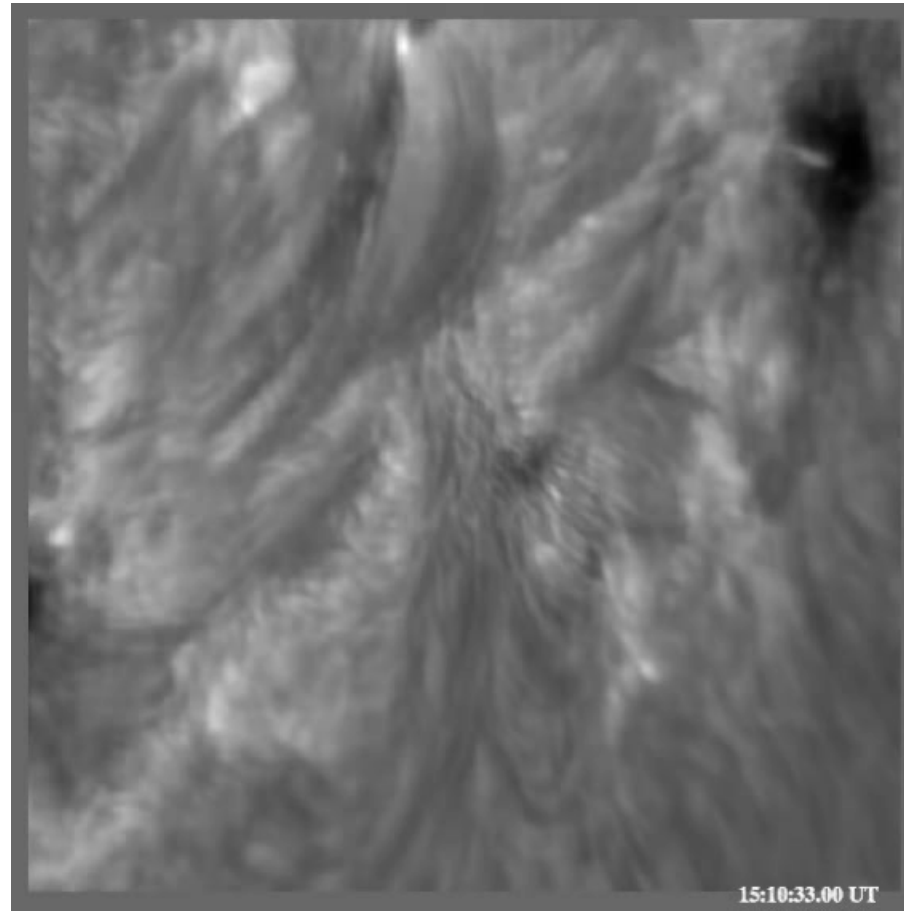
- from 15:11 to 15:45 UT
- pointing: S12.4 W67.3
- 8317 images, cadence 0.263 s
- camera 512x512 pixels
- spatial resolution 0.138"/pixel

Hα and Hβ movies

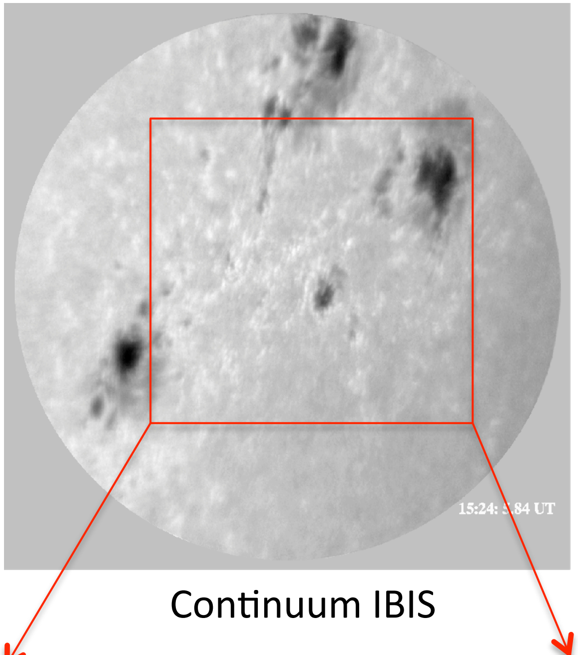
Hα (IBIS)



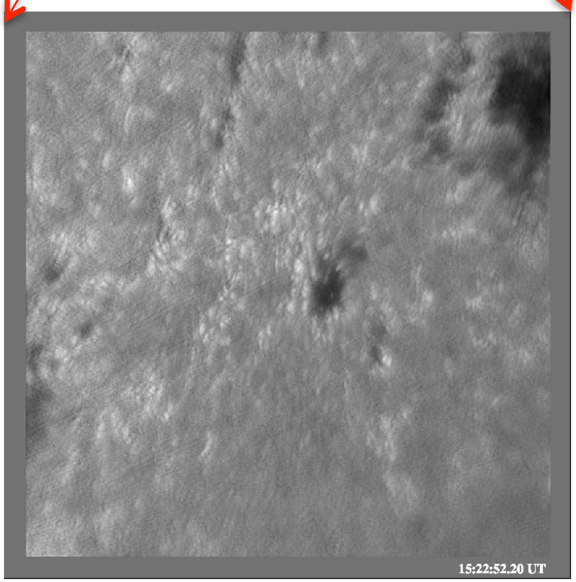
Hβ (ROSA)



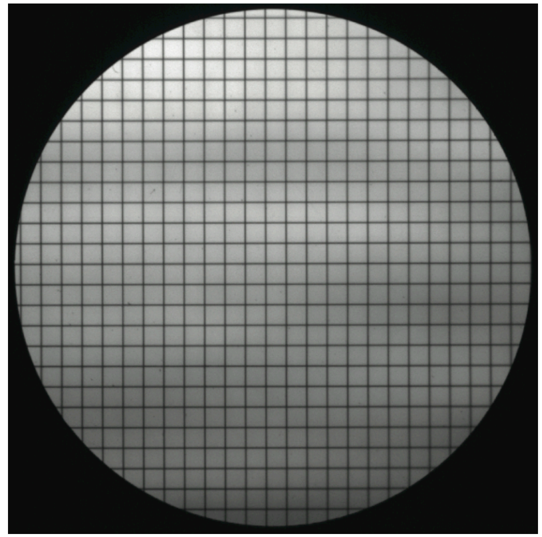
Alignment between Hα (IBIS) and Hβ (ROSA) images

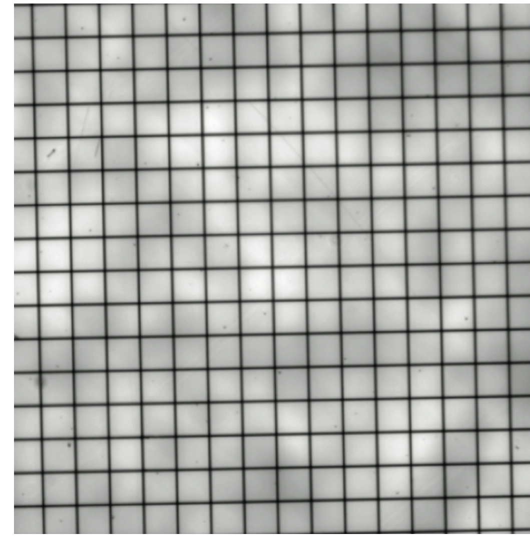


Continuum IBIS



Continuum ROSA

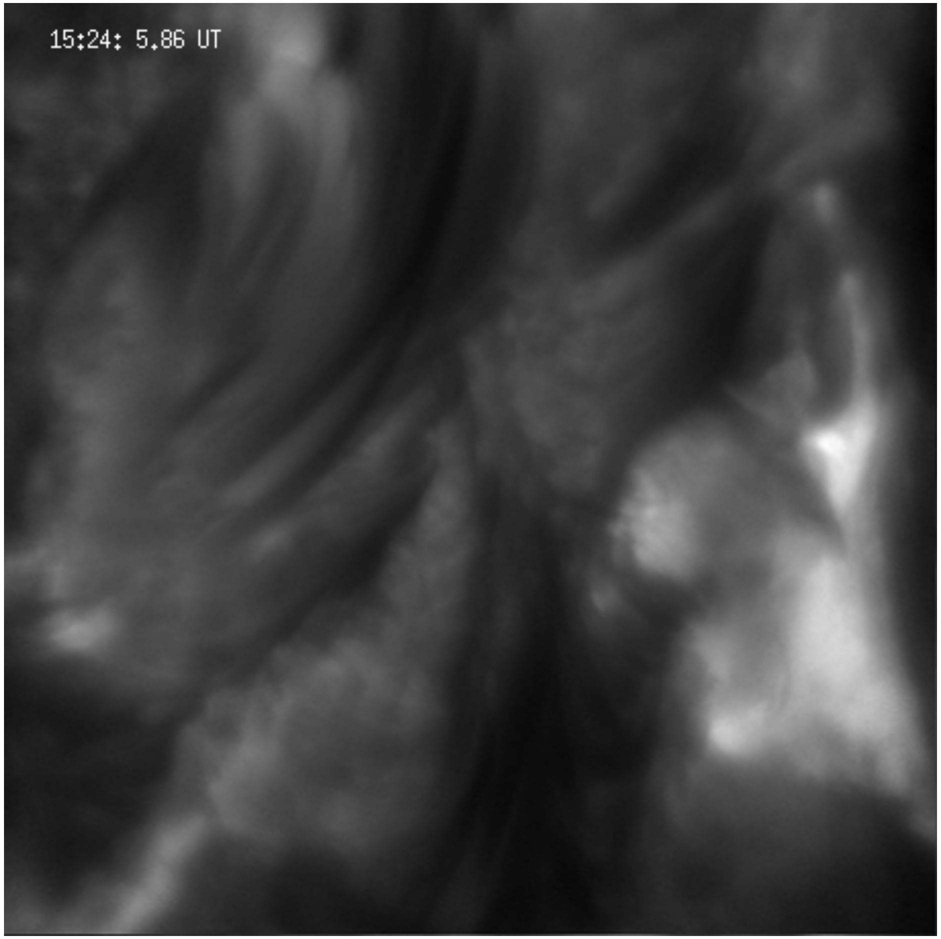




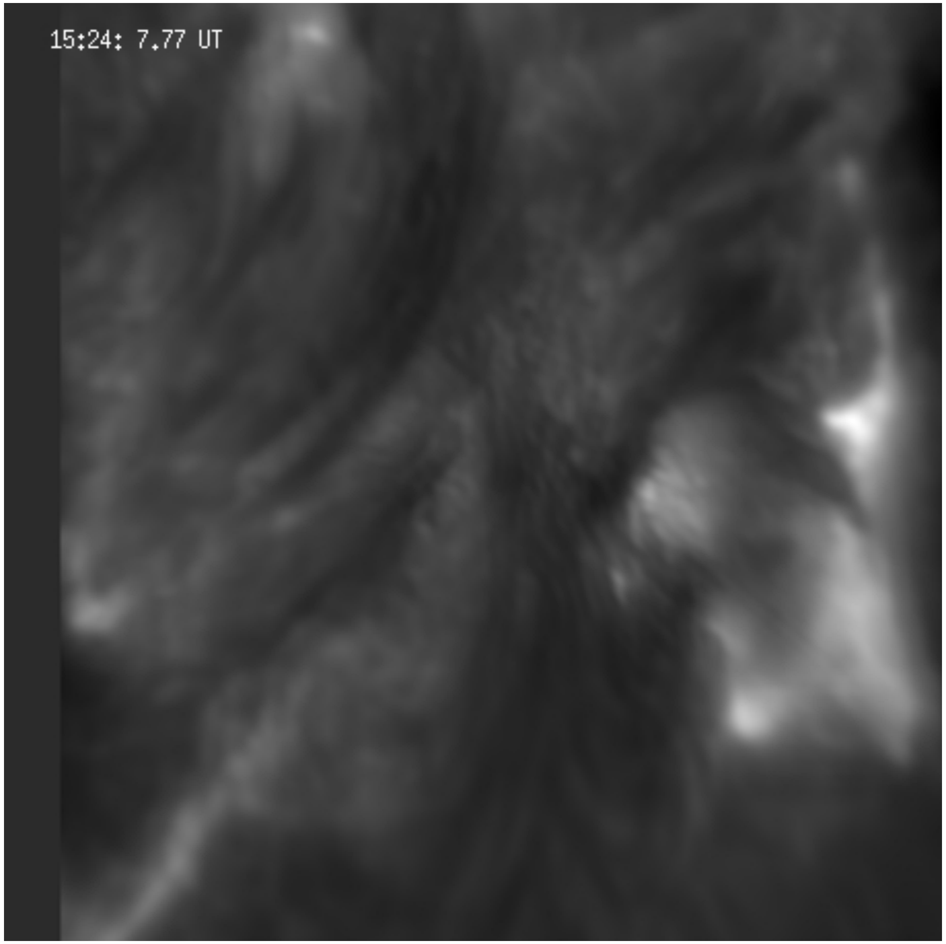
Rescale, rotate and shift Hα dataset through the comparison between grid and target images of the two channels

Alignment between Hα (IBIS) and Hβ (ROSA) images

Hα (IBIS) after alignment



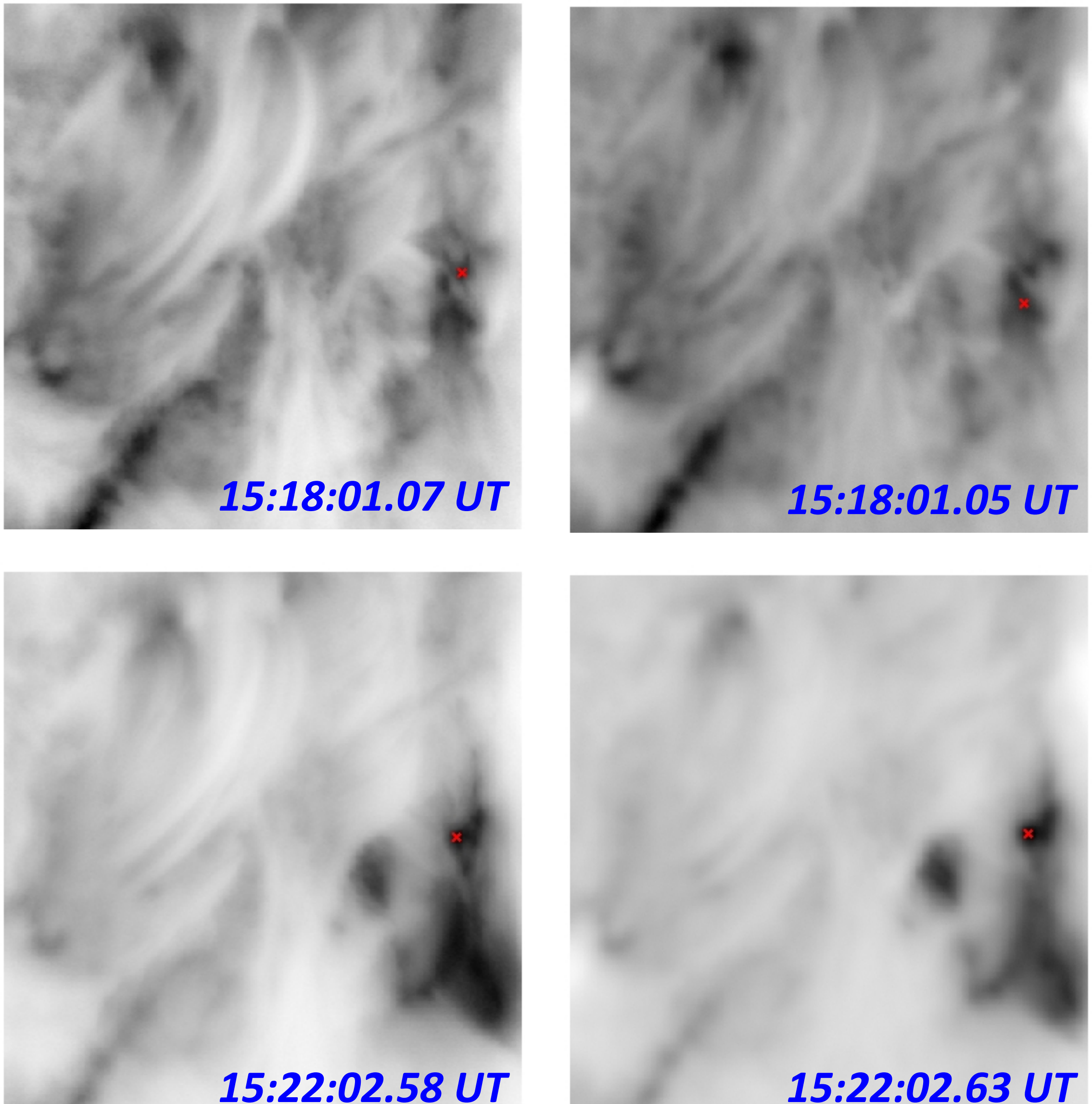
Hβ (ROSA) after alignment



Result: aligned images of 456x478 pixels and spatial resolution 0.138"/pixel

SPATIAL OFFSET DURING THE FLARE

Hα Hβ



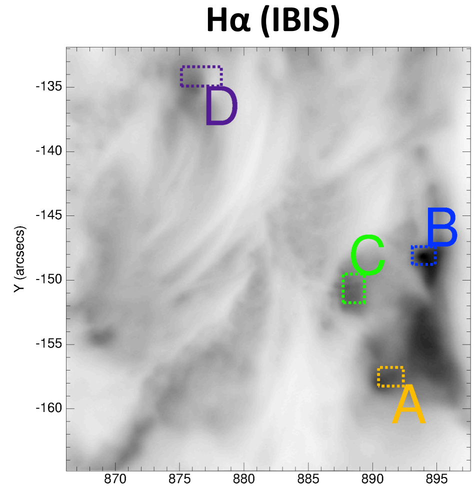
The distance between the brightest points at:

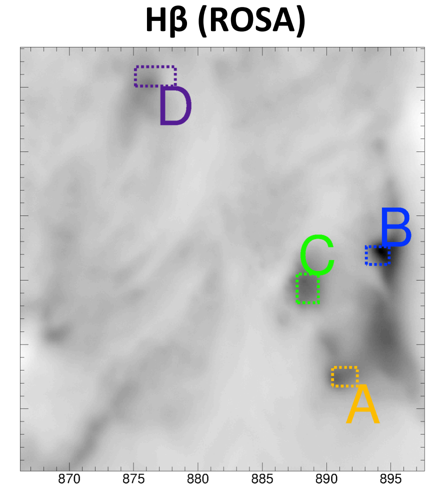
- **Flare beginning**
  3.5" (~2500 km)
- **Flare peak**
  1"(~725 km)

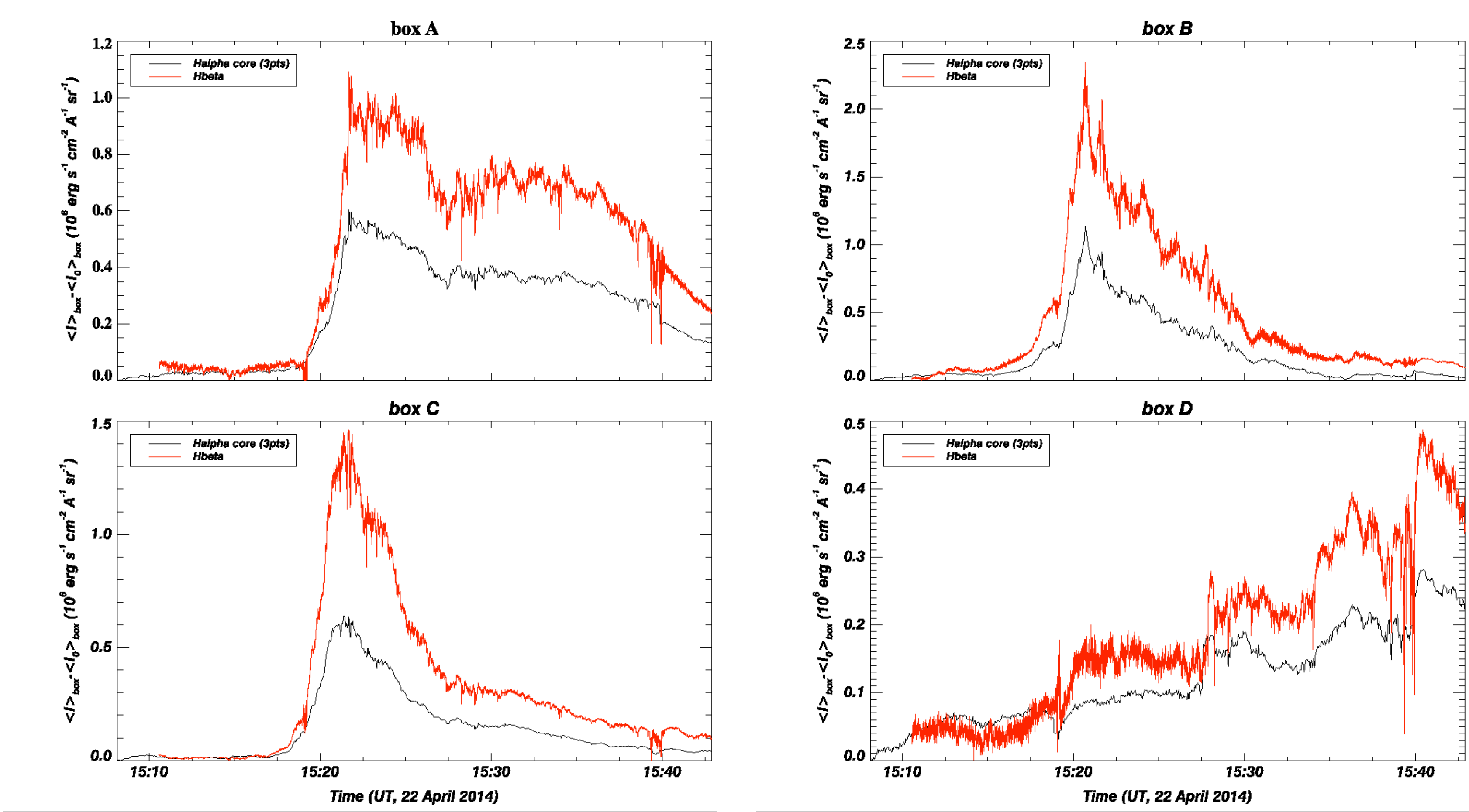
LIGHTCURVES:
Hα vs Hβ

Boxes: *A (1.93"x1.45")* *B (1.79"x1.38")*
C (1.66"x2.21") *D (3.11"x1.52")*

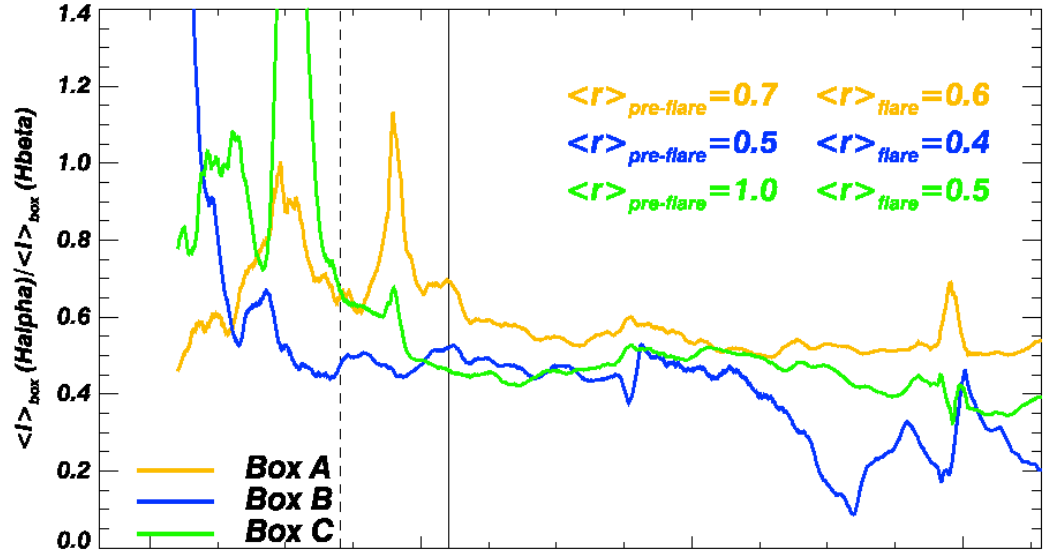
<u>All lightcurves show the intensity with pre-flare value subtracted</u>





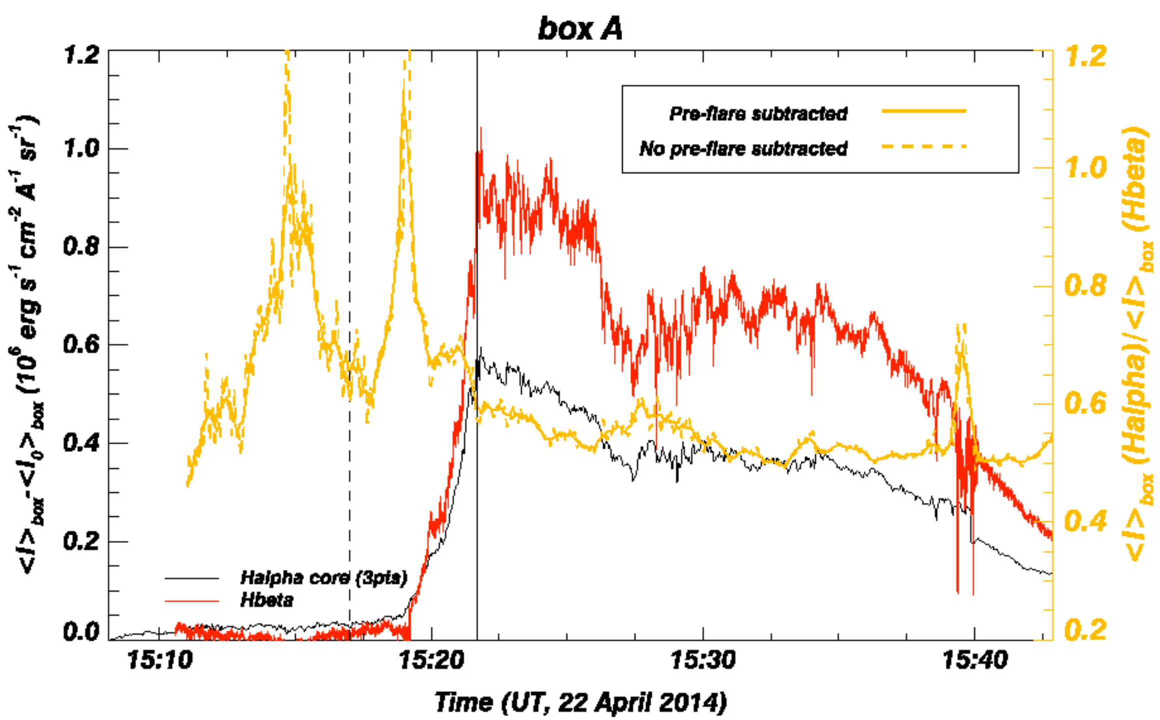


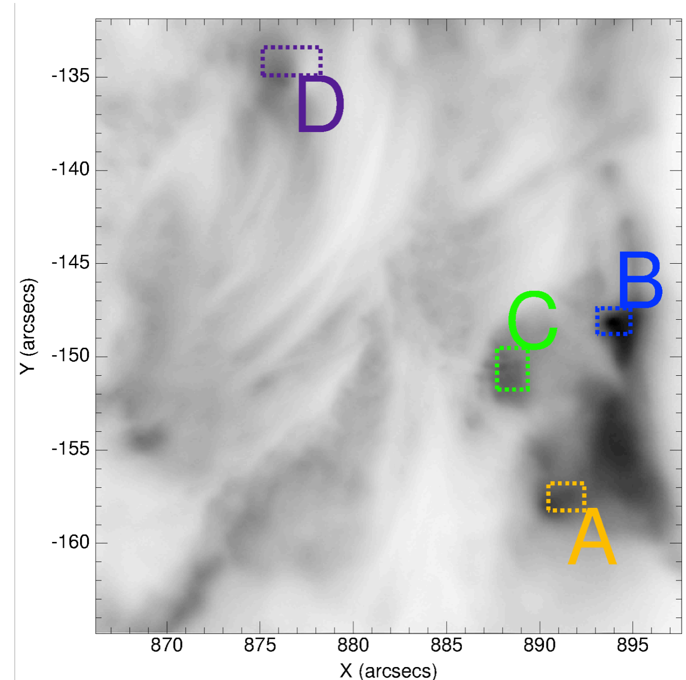
LIGHTCURVES: Hα/Hβ ratio



- The Hα/Hβ ratio is higher before the flare and is around 0.5 value during the flare for all the boxes into the flaring region

- After the flare energy peak, the ratios tend to a fix value





RADIATIVE HYDRODYNAMIC SIMULATIONS: **RADYN code**

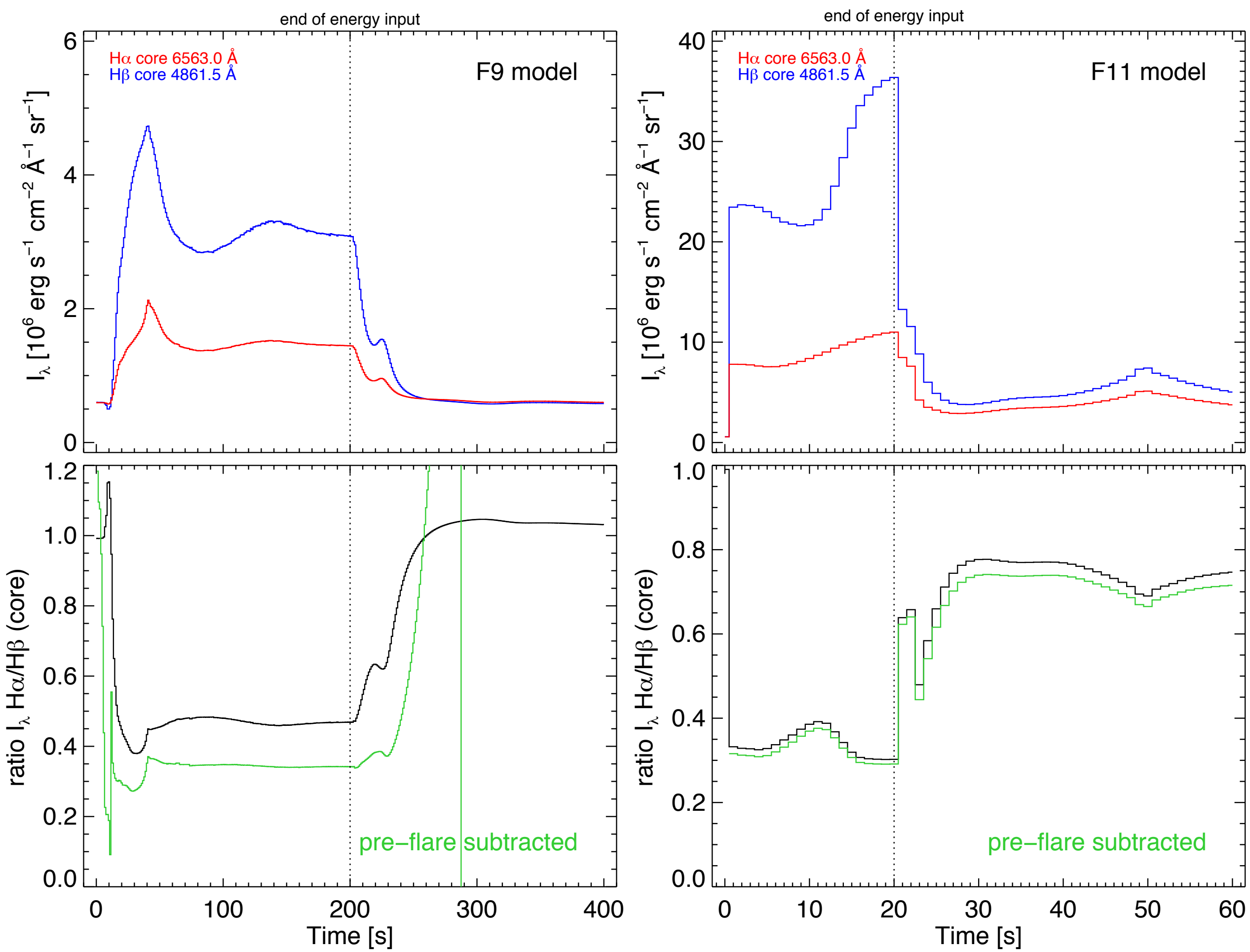
(Carlsson & Stein 1995, Allred et al. 2005, 2015)

- ❑ RADYN code solves the equations of radiative hydrodynamics on an adaptive mesh in one spatial dimension and evolves them in time
- ❑ RADYN calculates detailed (non-LTE) transitions for H, He, Ca II, Mg II (lines and continua)
- ❑ A time dependent collisional heating can be applied by a beam of non-thermal electrons, defined by:
  - total energy flux ($erg/s/cm^2$)
  - low energy cutoff
  - energy spectral index

RADYN Simulations: Hα vs Hβ

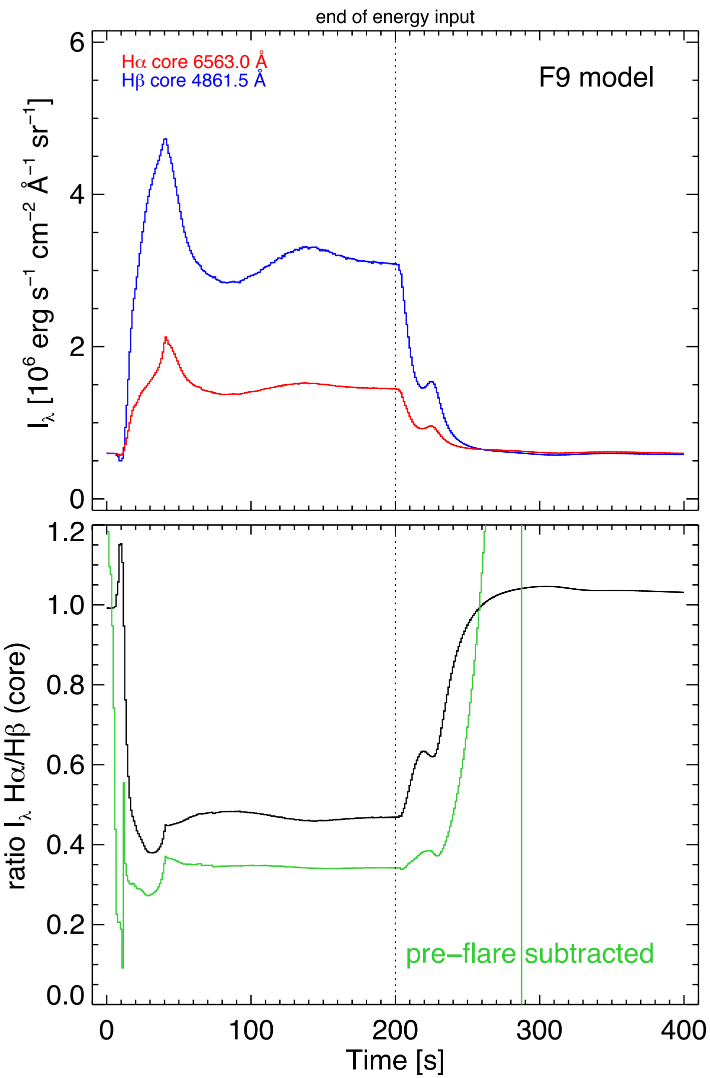
Compare two RADYN simulations with Ec=25 KeV and δ=4.2:

- **F9 model → 200s Gaussian heating pulse, with energy flux of $F=10^9$ ergs cm^{-2} s^{-1}**
- **F11 model → 20s Gaussian heating pulse, with energy flux of $F=10^{11}$ ergs cm^{-2} s^{-1}**



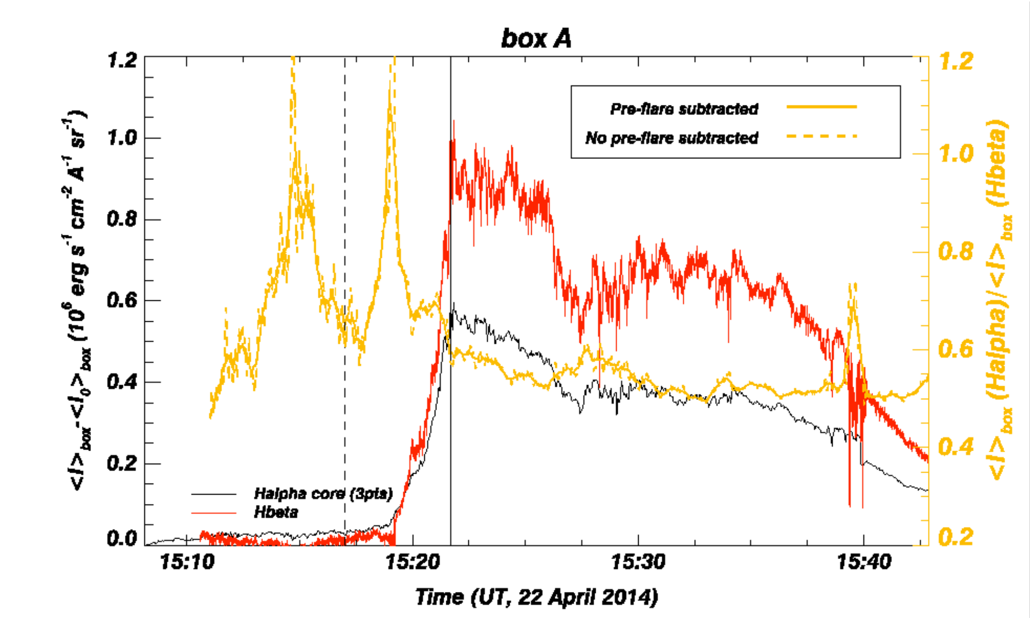
- The Hβ intensity is greater than Hα during the energy input in both models
- In both model the ratio is smaller than 1 during the energy input
- The ratios is the same during the energy input but not after

Observations and F9 RADYN model

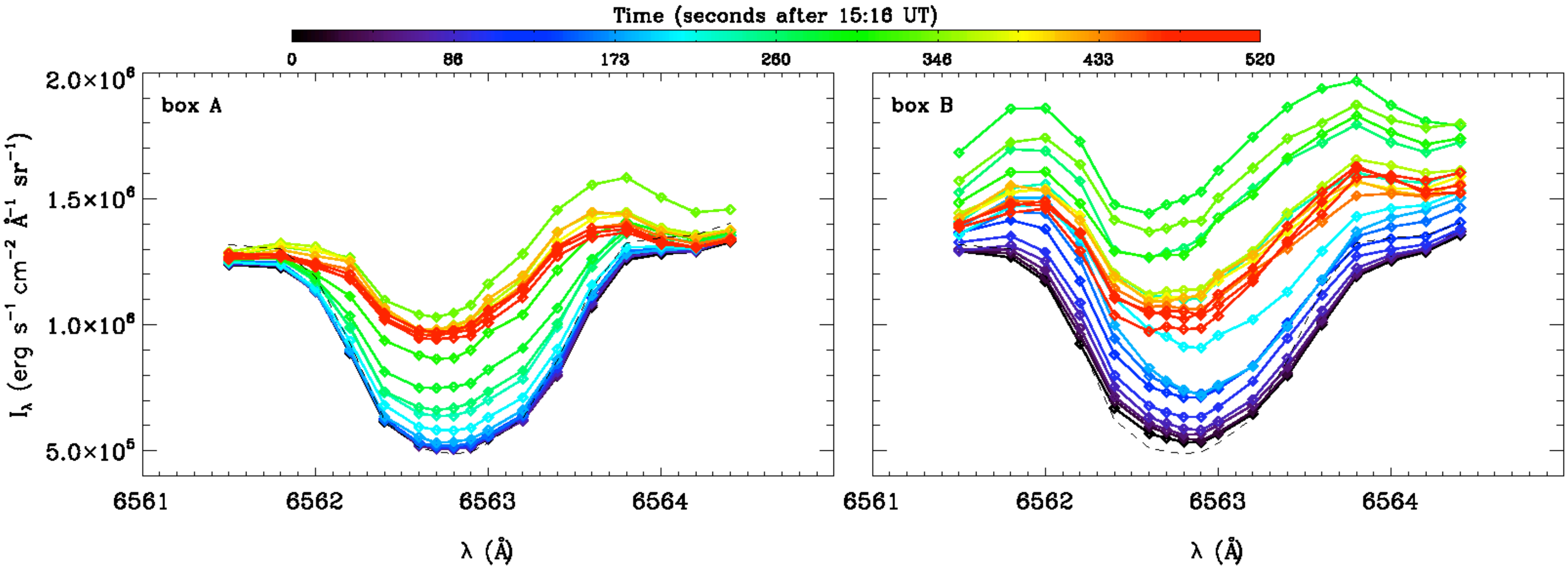


- The F9 RADYN model shows Hα and Hβ intensity values comparable with the observations

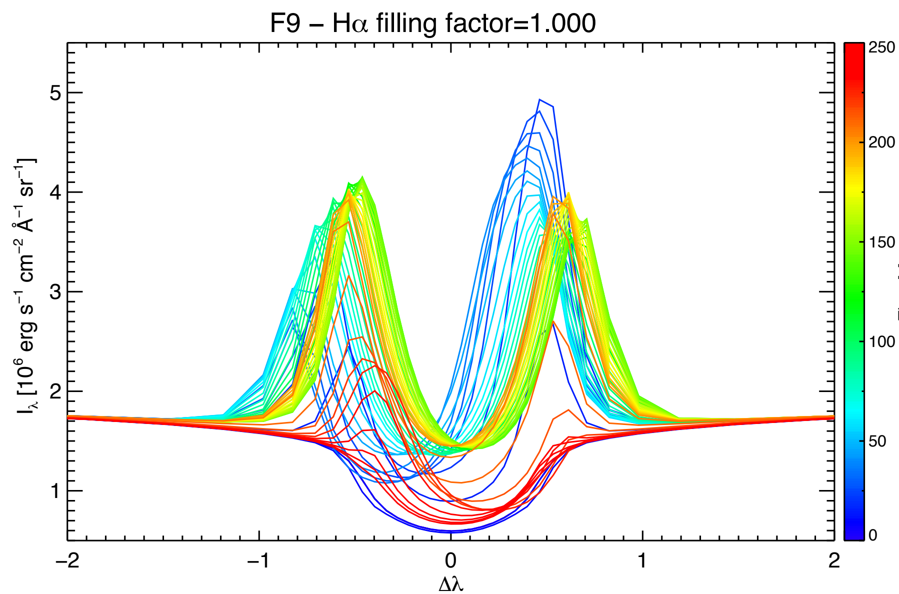
- The F9 RADYN Hα/Hβ ratio has the same value of the observed ratio during the energy input



Hα line profile evolution: Observations and F9 RADYN model



- In the box A the wings do not show significant rising with respect to the line center
- In the box B the wings intensity increases, red/blue asymmetry is more pronounced and the line center is shifted towards shorter wavelengths
- In F9 RADYN model the intensity is greater, the wings and the line center rises considerably



Summary

- **Spatial offset between Hα and Hβ lines during solar flare: 2500 km at the beginning of the rising phase and 725 km at the peak**

- **In the flaring region the observed intensity of Hβ is greater than Hα during the flare evolution**

- **The observed Hα/Hβ ratio is higher before the flare and is around 0.5 value during the energy input for all the boxes into the flaring region**

- **The F9 RADYN model shows Hα and Hβ intensity values comparable with the observations**

- **The F9 RADYN Hα/Hβ ratio has the same value of the observed ratio during the energy input**

AIM OF THE WORK

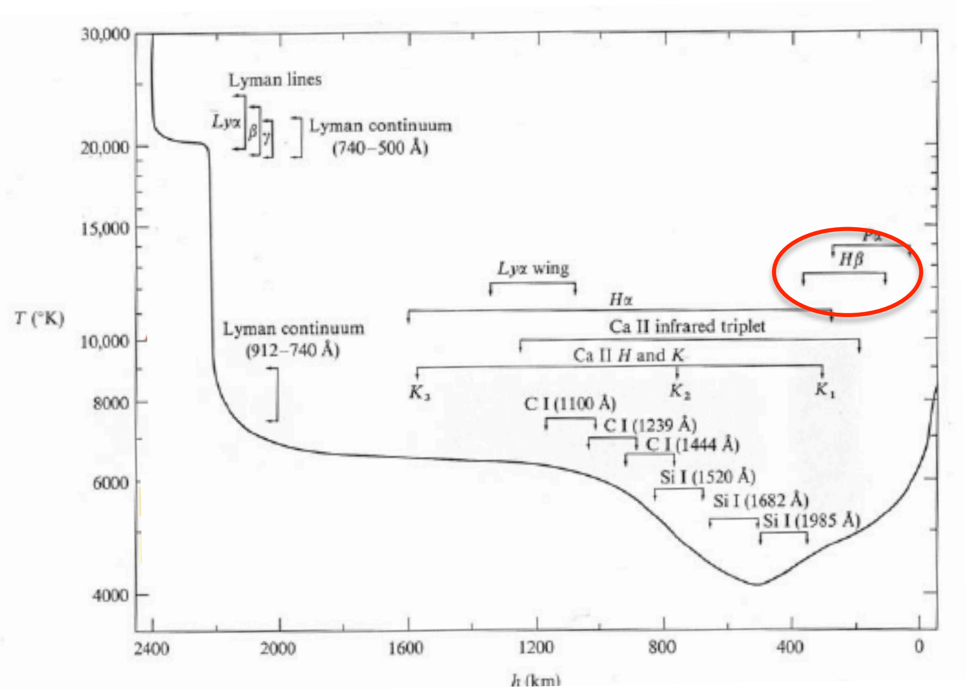
- ❑ Clarify some aspects related to energy release and re-distribution in the chromospheric layer during a solar flare
- ❑ Investigate the chromosphere response to the sudden energy input

RESULTS

- ✓ **A spatial offset between Hα and Hβ lines during solar flare was detected**
- ✓ **No delay in time**
- ✓ **The similar ratios indicate how the Hα and Hβ lines are affected similarly by the amount of energy**

Discussion

- Clarify some aspects related to energy release and re-distribution in the chromospheric layer during a solar flare
- Investigate the chromosphere response to the sudden energy input



Heights of Elements in Chromosphere from Lengths of Arcs

Element.	Radiation.	Lockyer. 1899	Mitchell. 1905	Davidson and Stratton. 1926
		Km.	Km.	Km.
H	λ6563 Hα	7500	..	8400
	λ4861 Hβ	..	8000	8400
	λ4341 Hγ	..	8000	8000
He	λ4713	..	3900	6000
	λ5876(D_3)	..	7500	7500
	λ4471	6500	7500	7400
	λ4026	4500	6000	4400
He^+	λ4686	..	1580	2200
Na	λ5896, λ5890(D_1,D_2)	..	1200	1000
Ca	λ4227	3500	5000	2500
Ca^+	λ3968, λ3933 (H,K)	9500	14000	9200
Sr^+	λ4215, λ4077	4500	6000	5200

Hβ height formation problem in the solar atmosphere