The first comparison of the MSDP spectroscopic observations of a solar flare recorded in the hydrogen H-alpha line with the results of RHD modeling obtained from the FLARIX code

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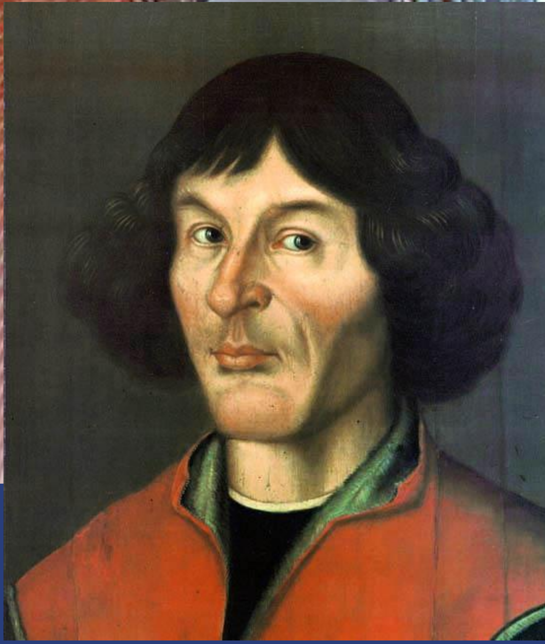
[1] *Astronomical Institute of the University of Wrocław, Poland*

[2] *Astronomical Institute of the Czech Academy of Sciences, Czech Republic*

[3] University of Wrocław, Centre of Scientific Excellence - Solar and Stellar Activity, Poland

Toruń, 12 IX 2023



Toruń, 12 IX 2023

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Toruń, 12 IX 2023

FLARIX code

FLARIX RHD Model

FLARIX is radiation hydrodynamic code

created by scientific group form Ondrejov (Czech Republic):
P. Heinzel, J. Kasparova, M. Varady
(Astronomical Institute of the Czech Academy of Sciences).

Some facts about code:

- fixed, but optimized grid with almost 2000 points (number of points depends on the atmospheric structure)

- hydrodynamic equations and non-LTE equations are solved separately (but the non-LTE problem is also solved implicitly by linearizing the preconditioned kinetic equations and constraint equations)

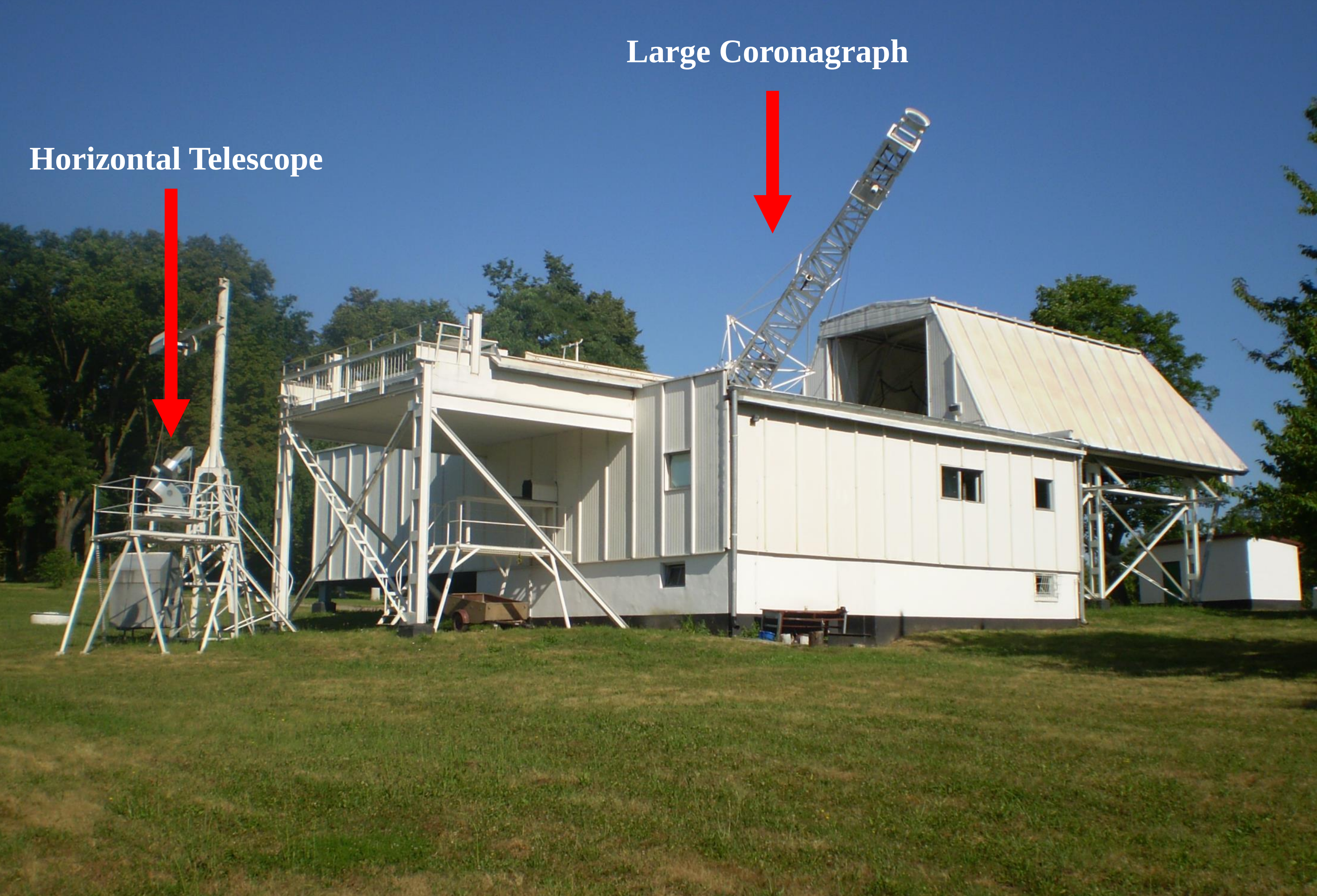
- hybrid test-particle unit which allows realistic simulation of the time-dependent electron/proton beam propagation, scat-tering and energy deposit.

- optically-thick radiative transfer problem is solved using the ALI (Accelerated Lambda Iteration) techniques

etc.

MSDP data ($H\alpha$ line)

Telescopes at Białków Observatory



Horizontal Telescope (HT)

coelostat ∅ = 30 cm

∅ = 15 cm

f_{eff} = 500 cm

MSDP imaging spectrograph

<= **diffraction grating** 600 ll/mm

- size: 206 × 254 mm^2
- 4th order of spectrum
  (angel of reflection = 48˚35')
- $d\lambda = \pm 1.6$Å for Hα line (6562.78 Å)
- effective λ for imaging: $d\lambda = \pm 1.2$ Å

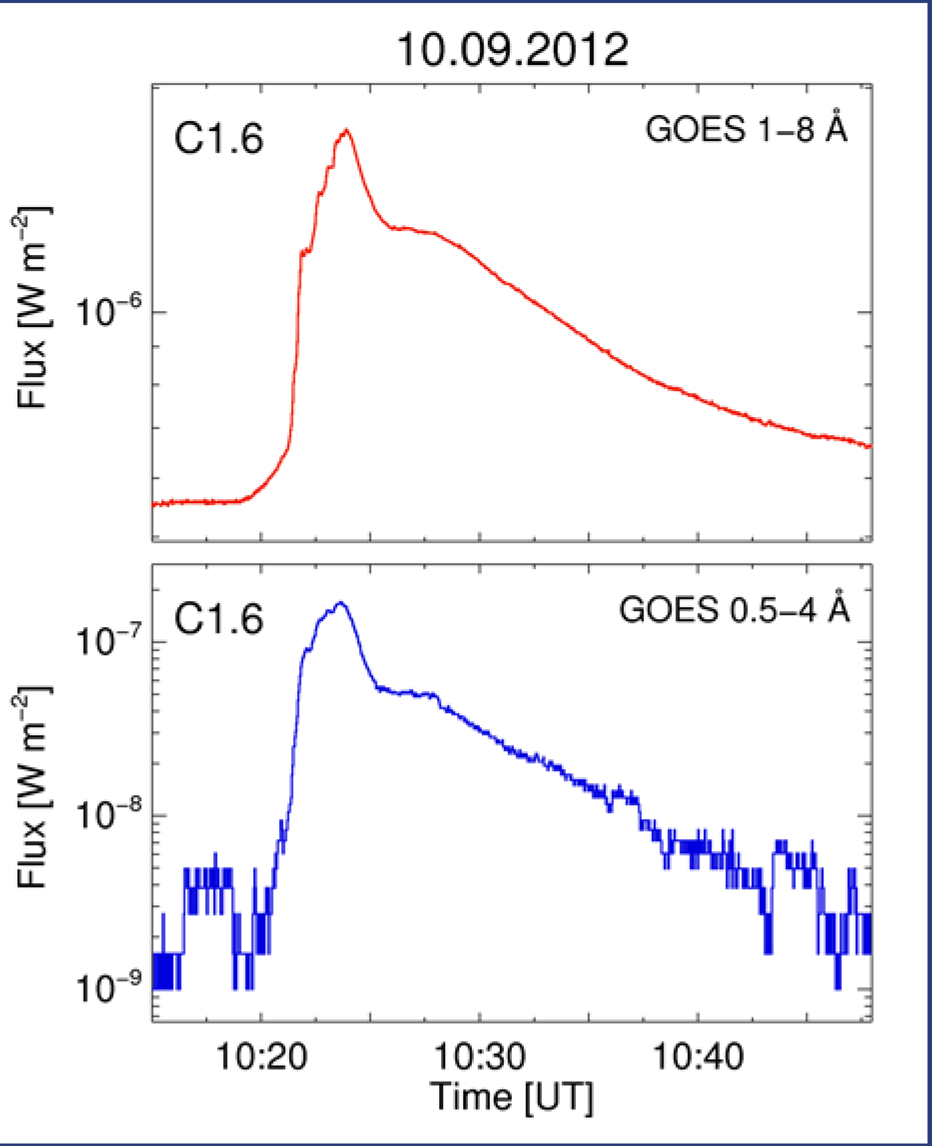
<= **9 channel MSDP prism-box**

- width of channel = 0.4 mm
- separation of channels = 1.2 mm

FLARIX & MSDP

C1.6 GOES-class solar flare

- 10.09.2012, 10:20 UT
- NOAA 11564 (S13 W58)
- HXR up to 70 keV



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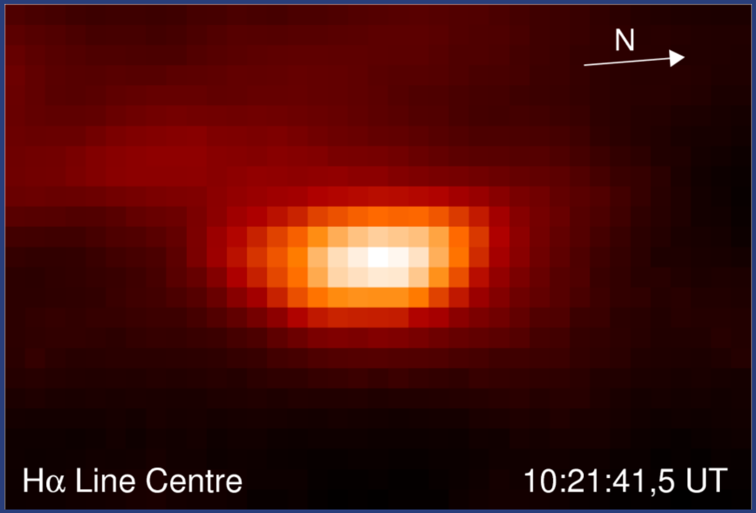
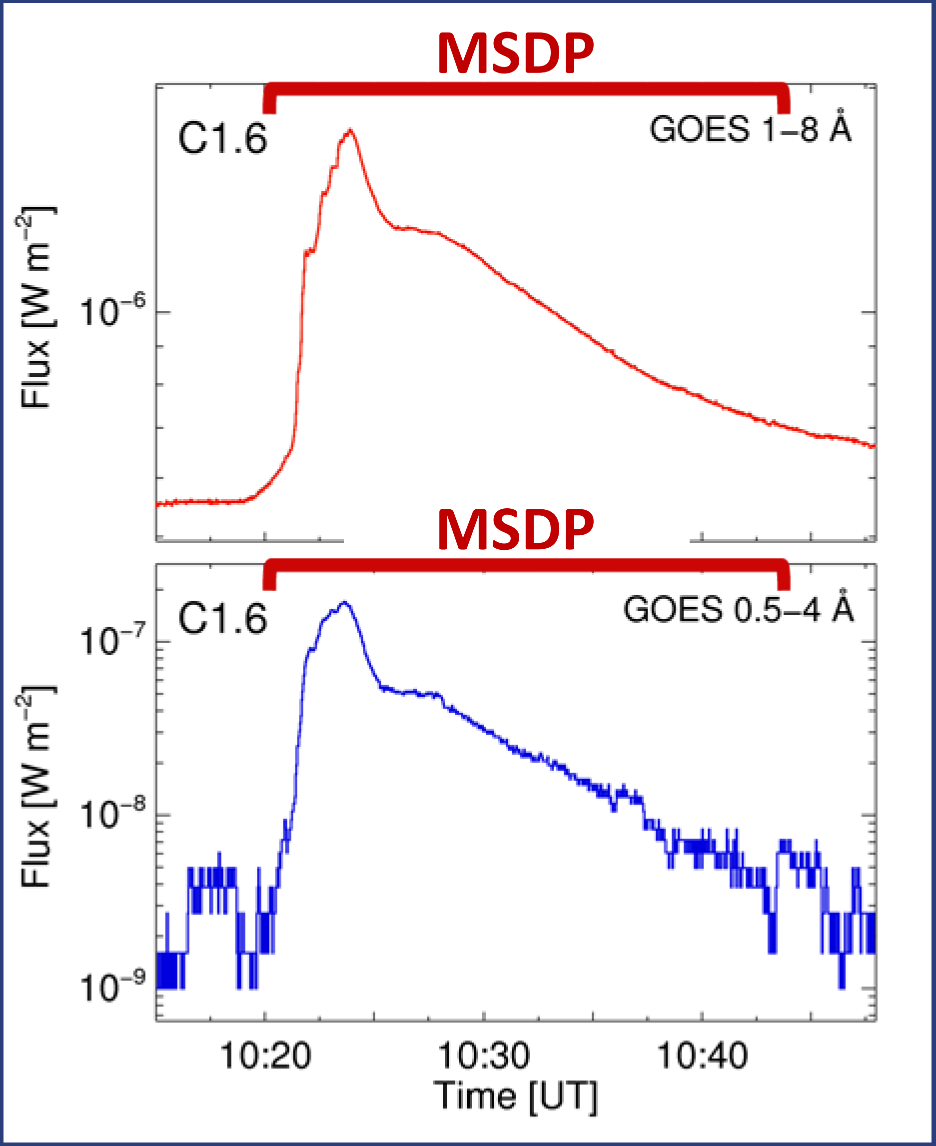
FLARIX & MSDP

C1.6 GOES-class solar flare

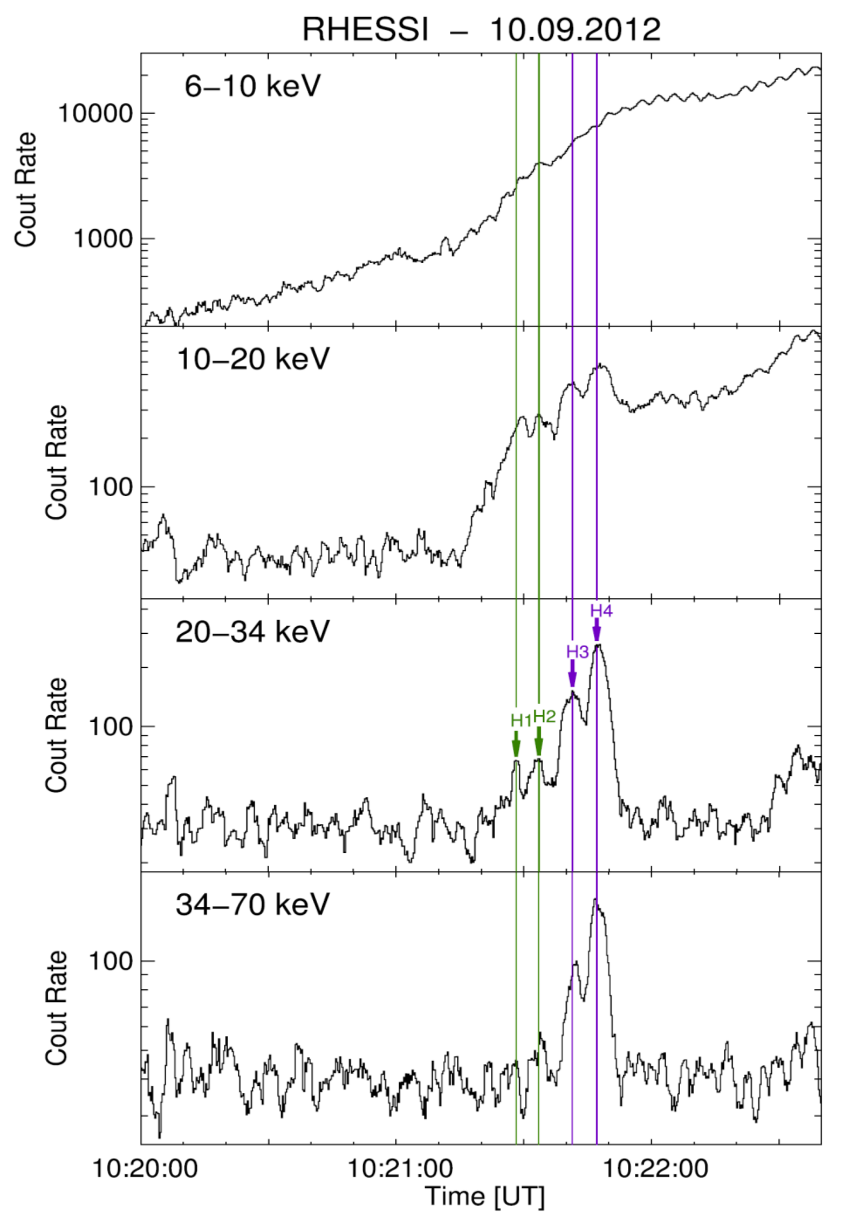
- 10.09.2012, 10:20 UT
- NOAA 11564 (S13 W58)
- HXR up to 70 keV
- MSDP-HT Fast Mode of obs.

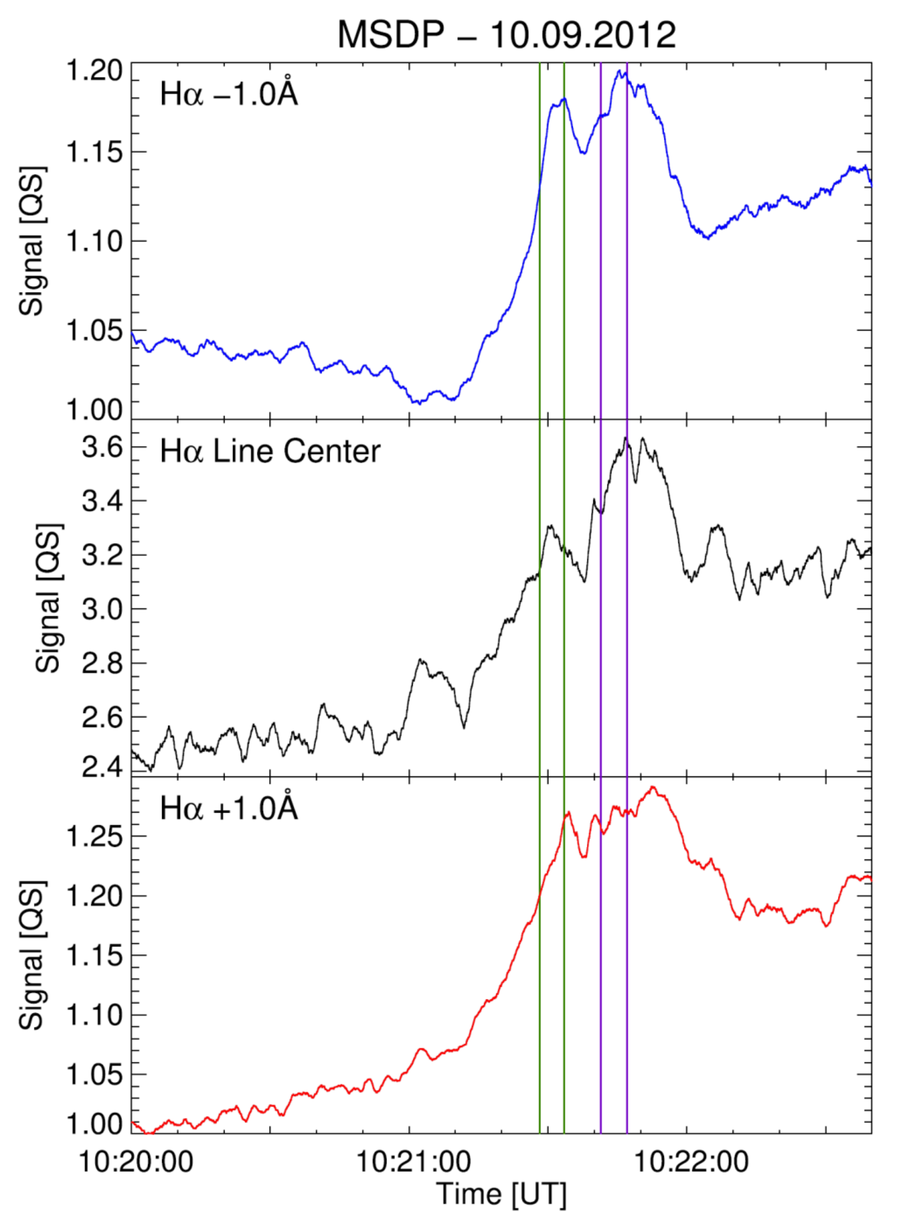




Radziszewski et al. 2020

FLARIX & MSDP

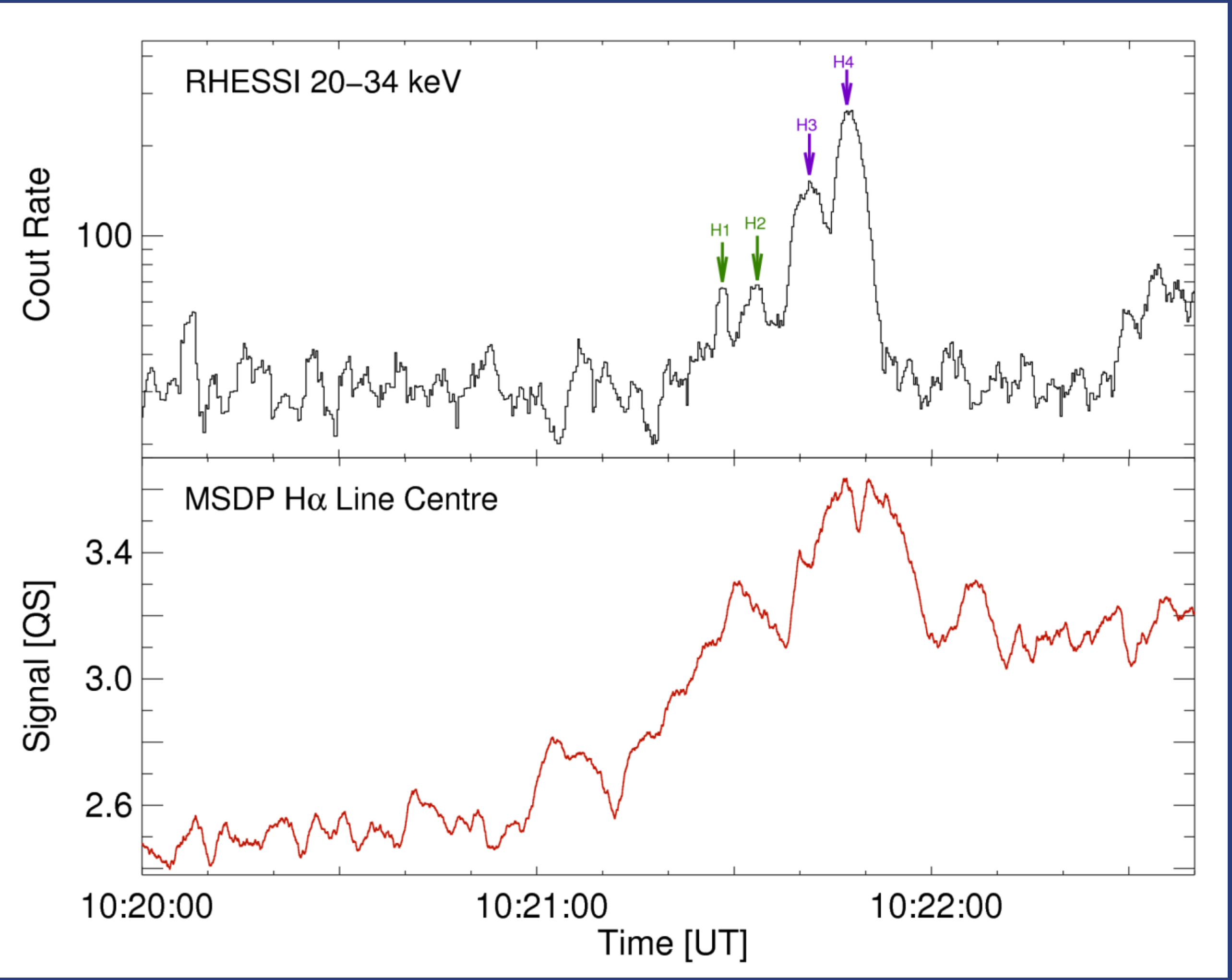

RHESSI – 10.09.2012
6–10 keV
10–20 keV
20–34 keV
34–70 keV
H1
H2
H3
H4
Cout Rate
10000
1000
100
10:20:00
10:21:00
10:22:00
Time [UT]


MSDP – 10.09.2012
Hα –1.0Å
Hα Line Center
Hα +1.0Å
Signal [QS]
1.20
1.15
1.10
1.05
1.00
3.6
3.4
3.2
3.0
2.8
2.6
2.4
1.25
10:20:00
10:21:00
10:22:00
Time [UT]

FLARIX & MSDP

C1.6 flare ; 10.09.2012, 10:20 UT

16 sec => 10:21:36 UT - 10:21:52 UT

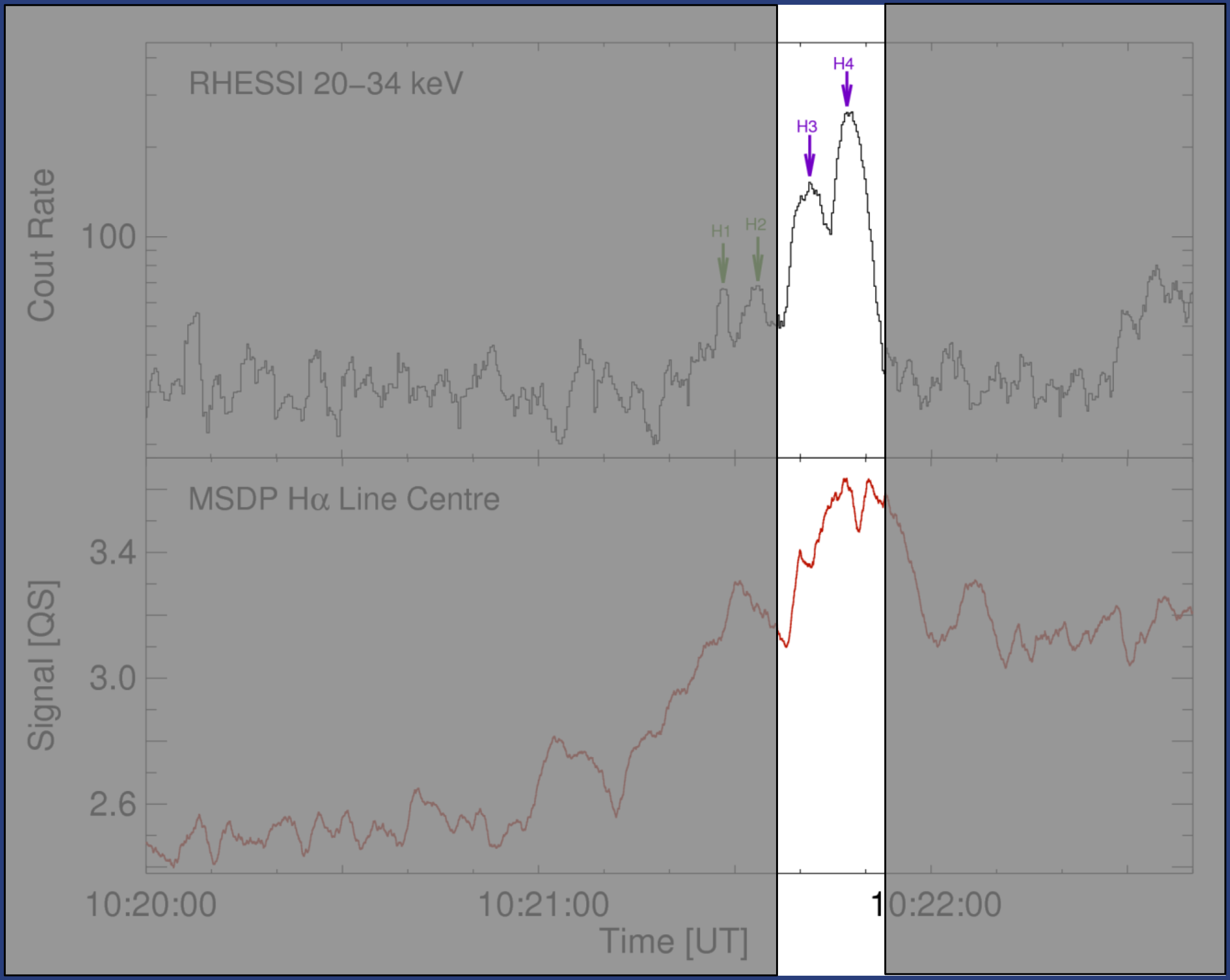


FLARIX & MSDP

FLARIX & MSDP

C1.6 flare ; 10.09.2012, 10:20 UT

16 sec => 10:21:36 UT - 10:21:52 UT

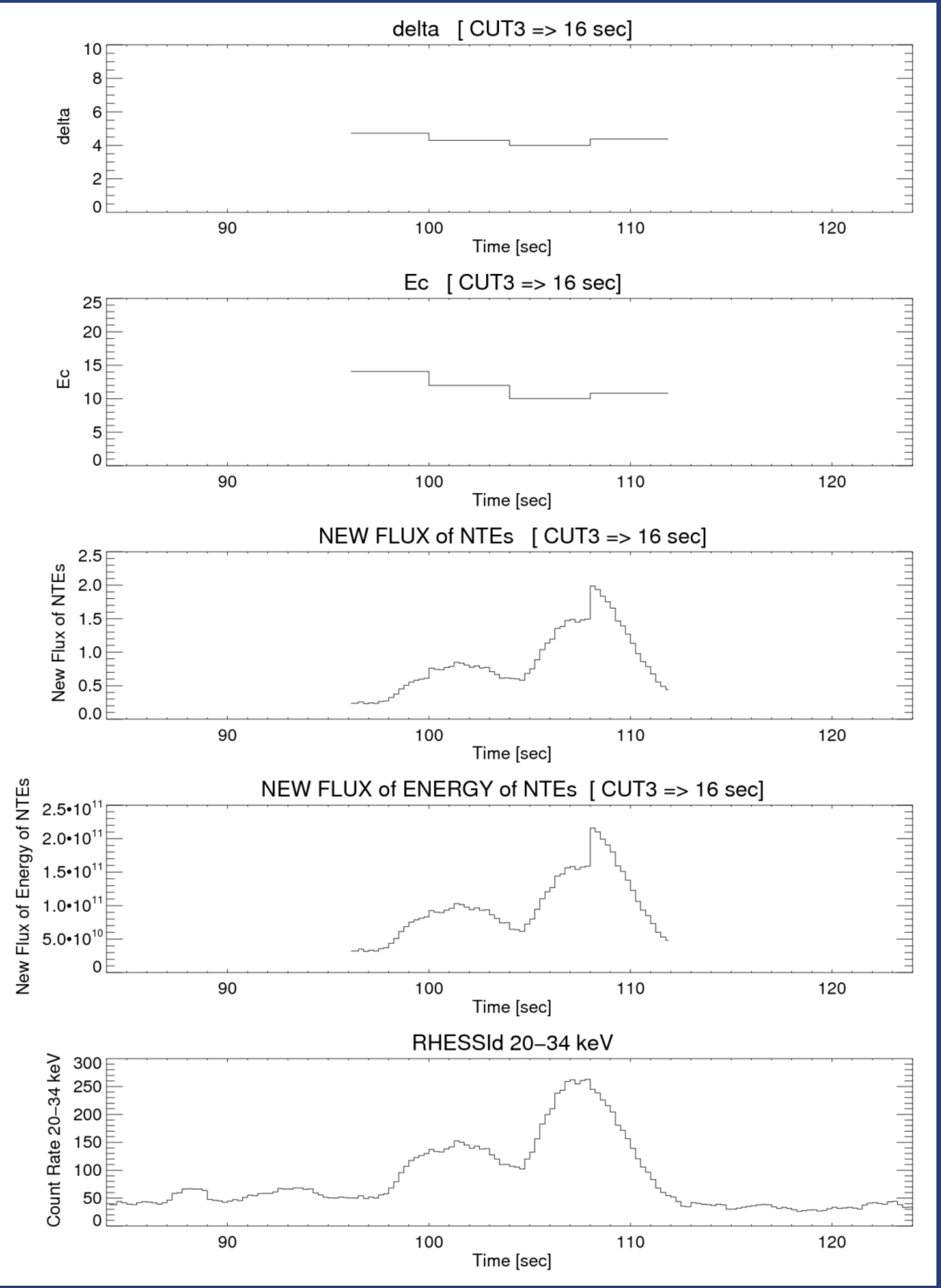


FLARIX & MSDP

C1.6 flare ; 10.09.2012, 10:20 UT

16 sec => 10:21:36 UT - 10:21:52 UT

Modulation of the NTEs flux and the energy flux with the HXR light curve (RHESSI)



FLARIX & MSDP

C1.6 flare ; 10.09.2012, 10:20 UT

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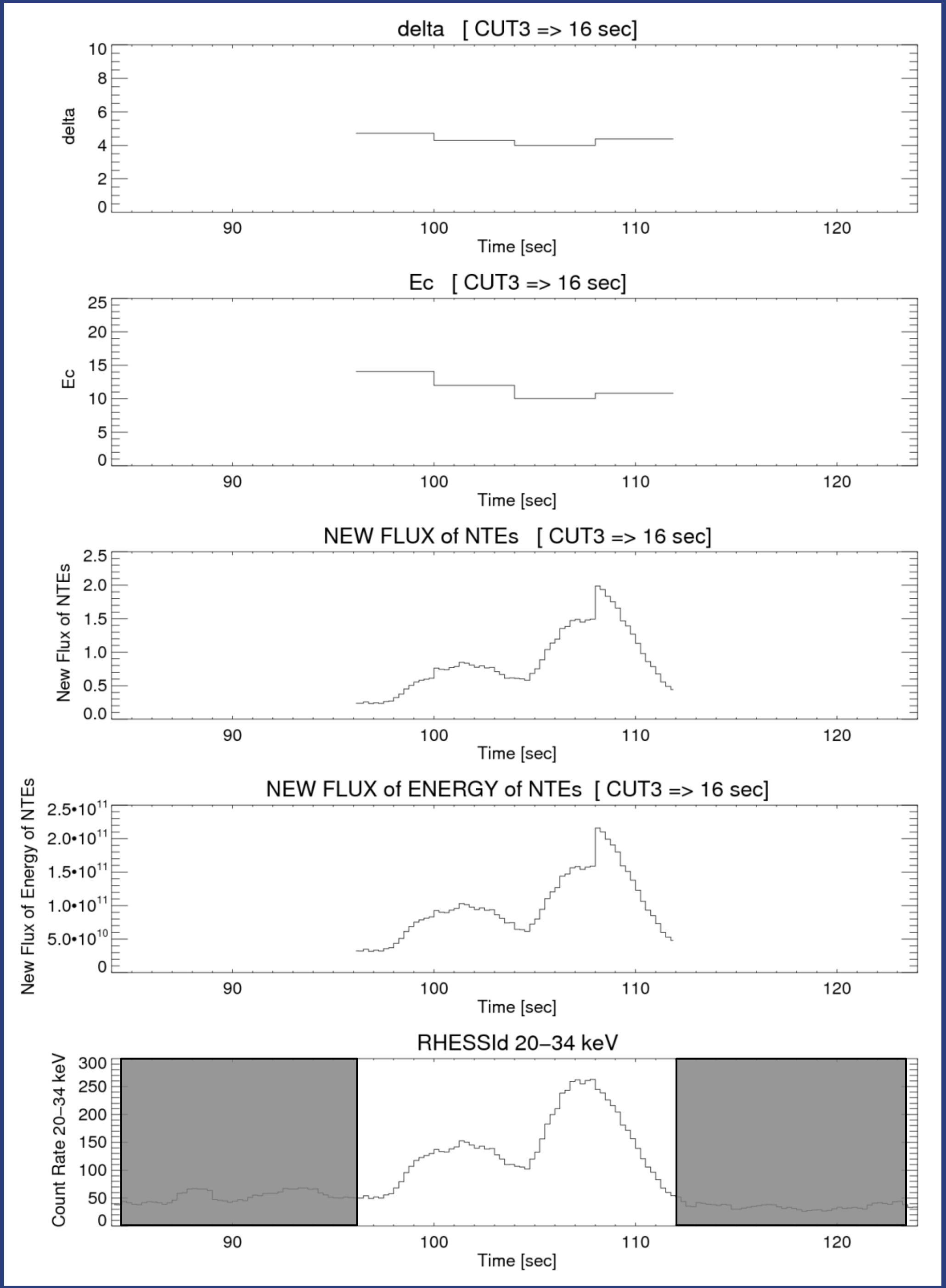
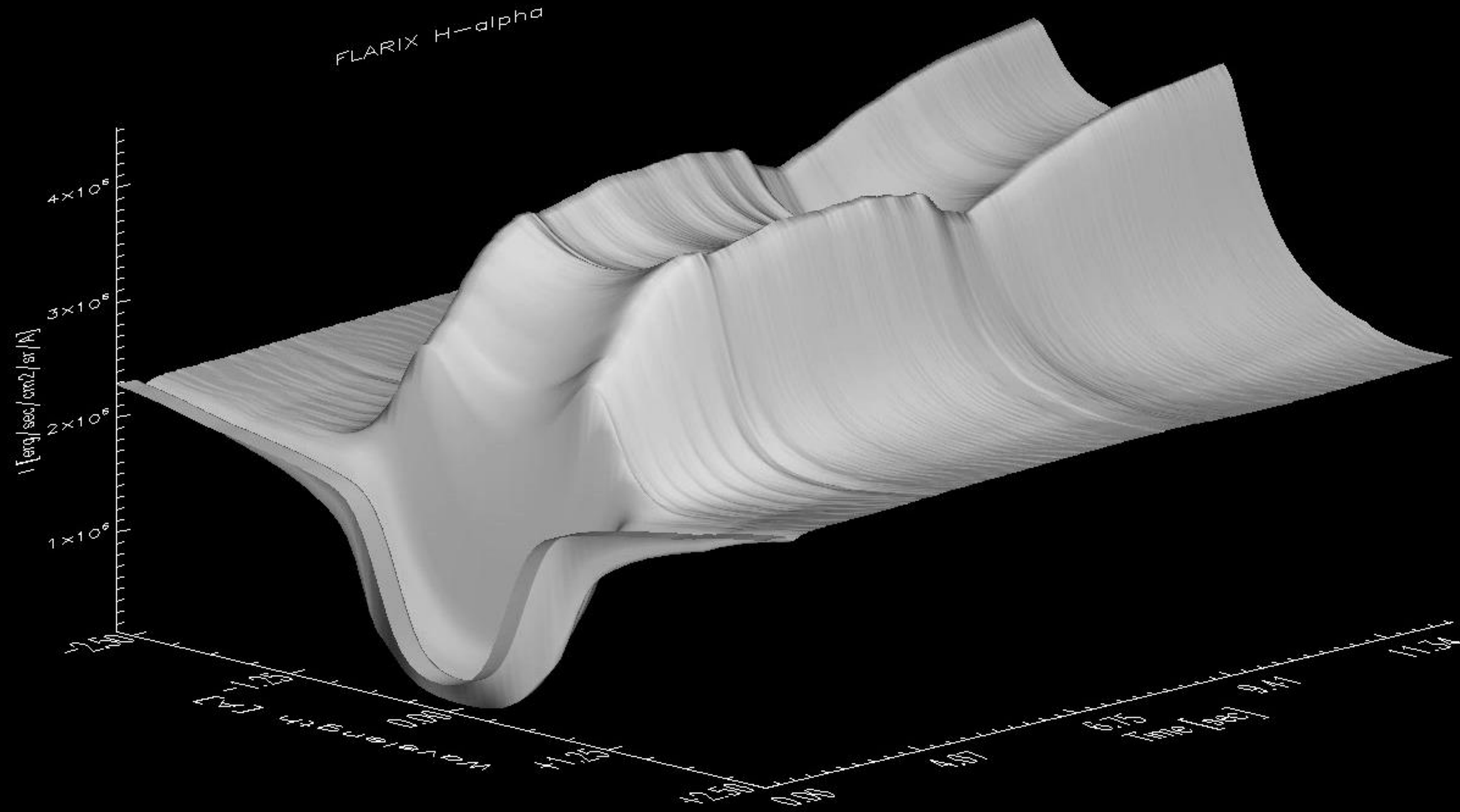
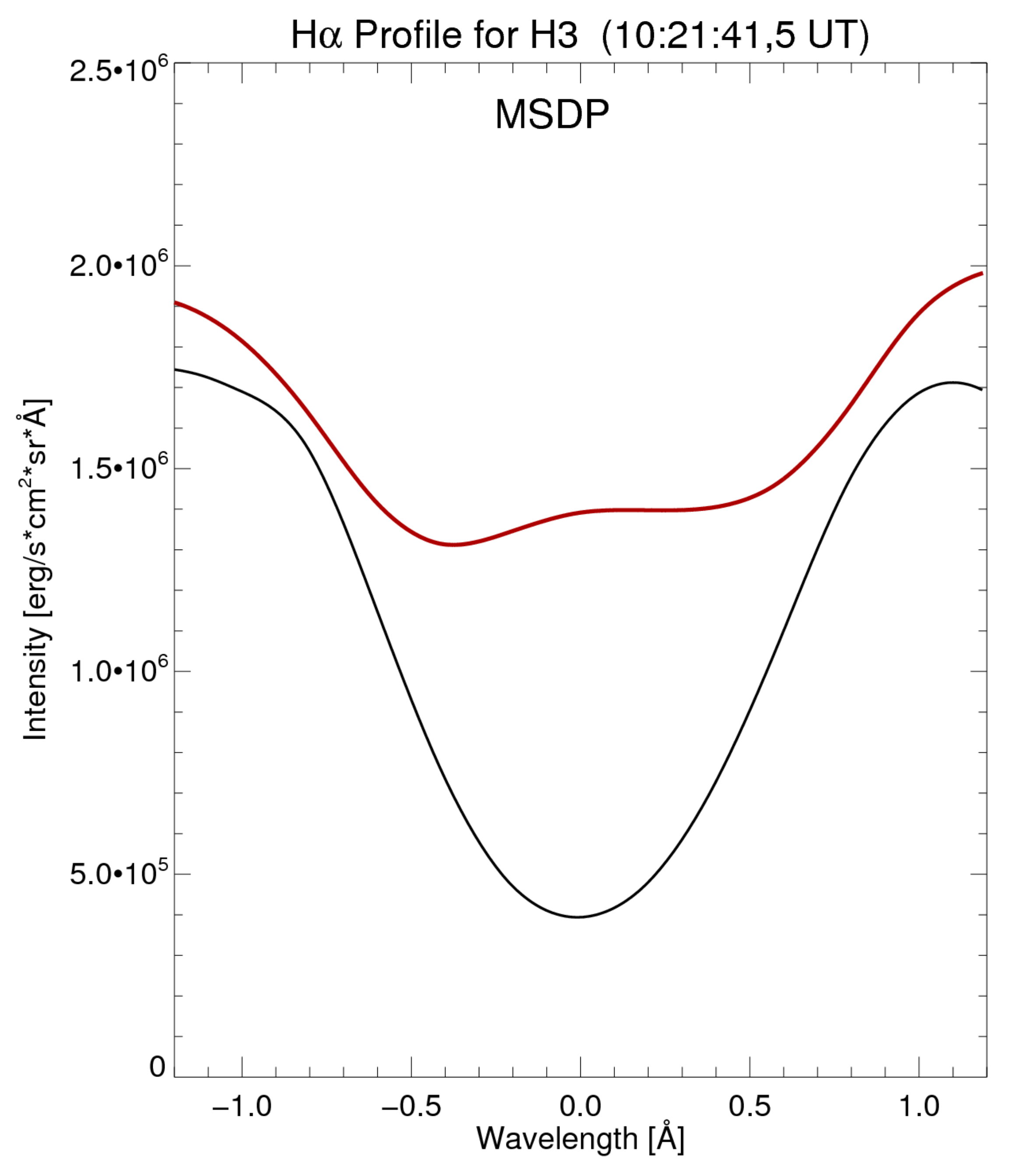


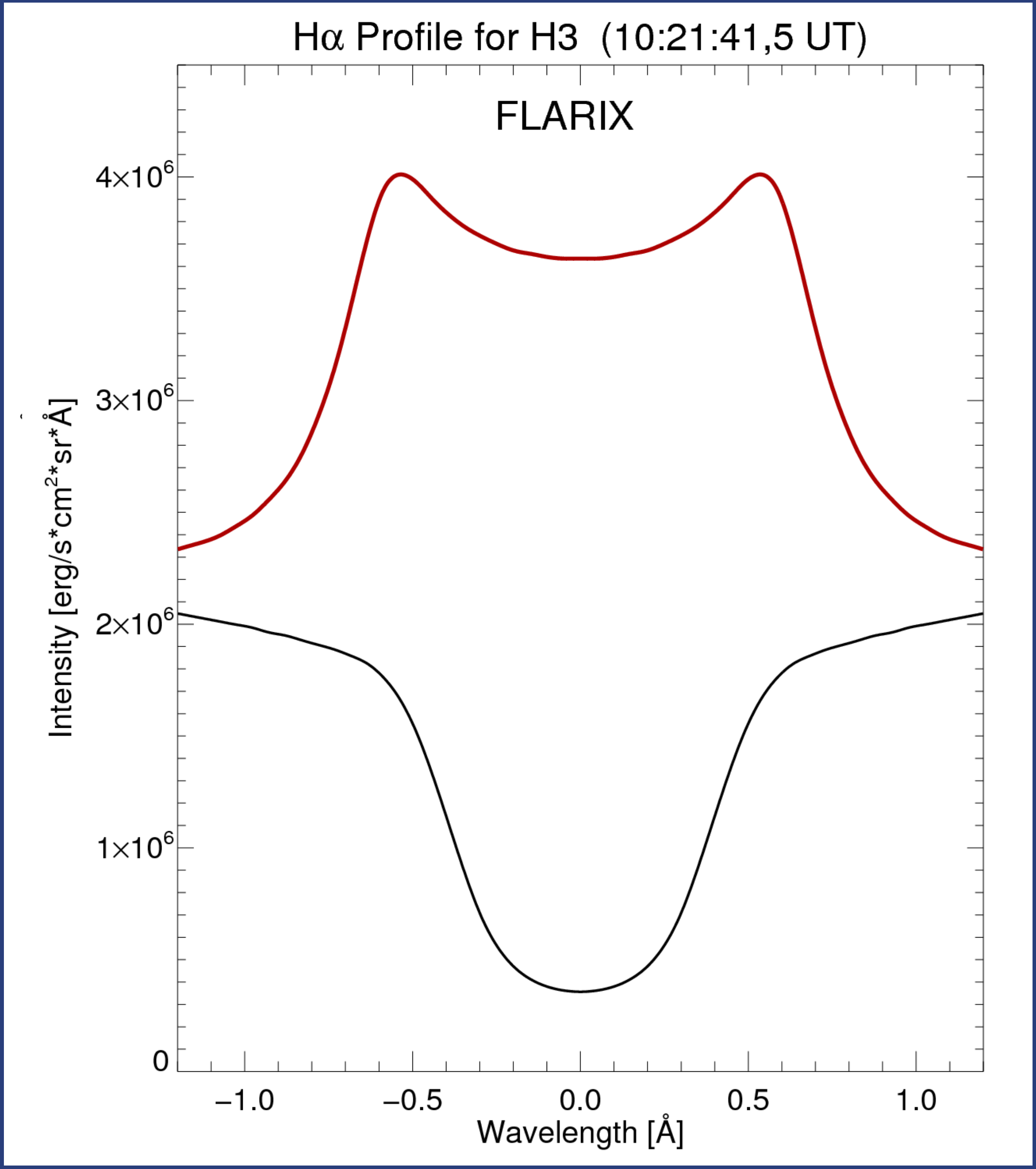
FLARIX - 12 sec of the Hα line profile evolution



Comparison of numerical and observational data


Hα Profile for H3 (10:21:41,5 UT)
MSDP
Intensity [erg/s*cm²*sr*Å]
2.5•10⁶
2.0•10⁶
1.5•10⁶
1.0•10⁶
5.0•10⁵
0
–1.0
–0.5
0.0
0.5
1.0
Wavelength [Å]

μ = 0.56

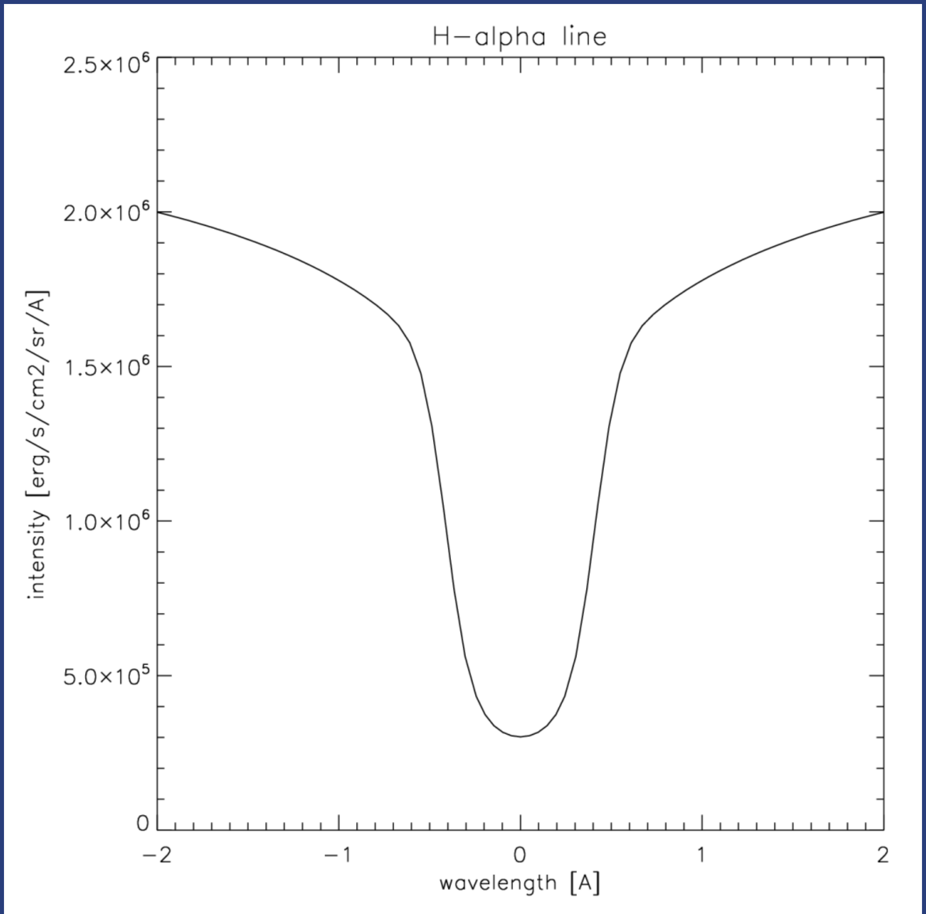


Hα Profile for H3 (10:21:41,5 UT)
FLARIX
4×10⁶
3×10⁶
2×10⁶
1×10⁶
0
Intensity [erg/s*cm²*sr*Å]
−1.0
−0.5
0.0
0.5
1.0
Wavelength [Å]

μ = 1.0

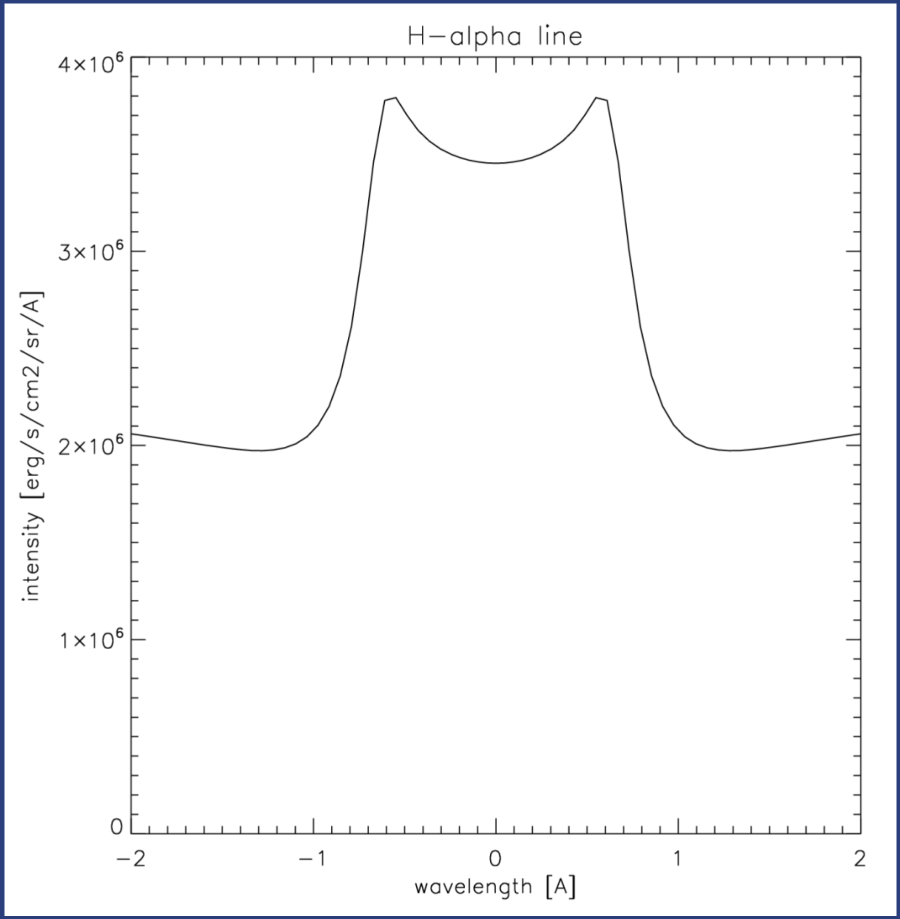
C1.6 flare ; 10.09.2012

FLARIX Hα QCh emission (μ = 0.56)



FLARIX Hα flaring emission (μ = 0.56)

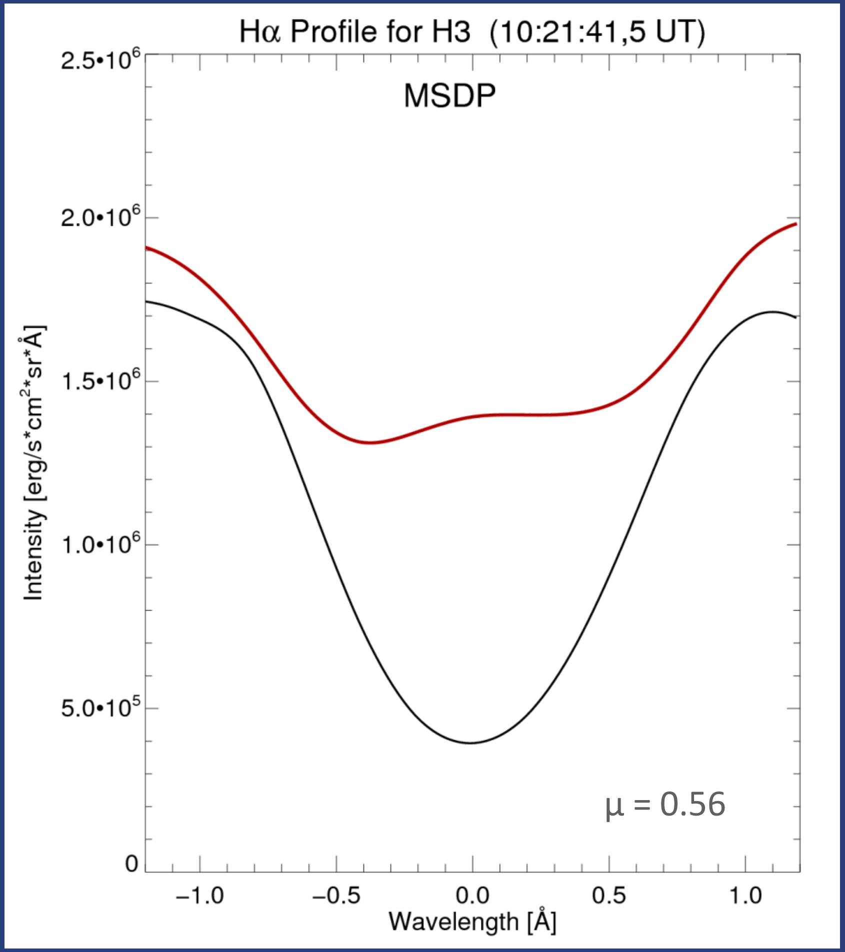
10:21:41,5 UT

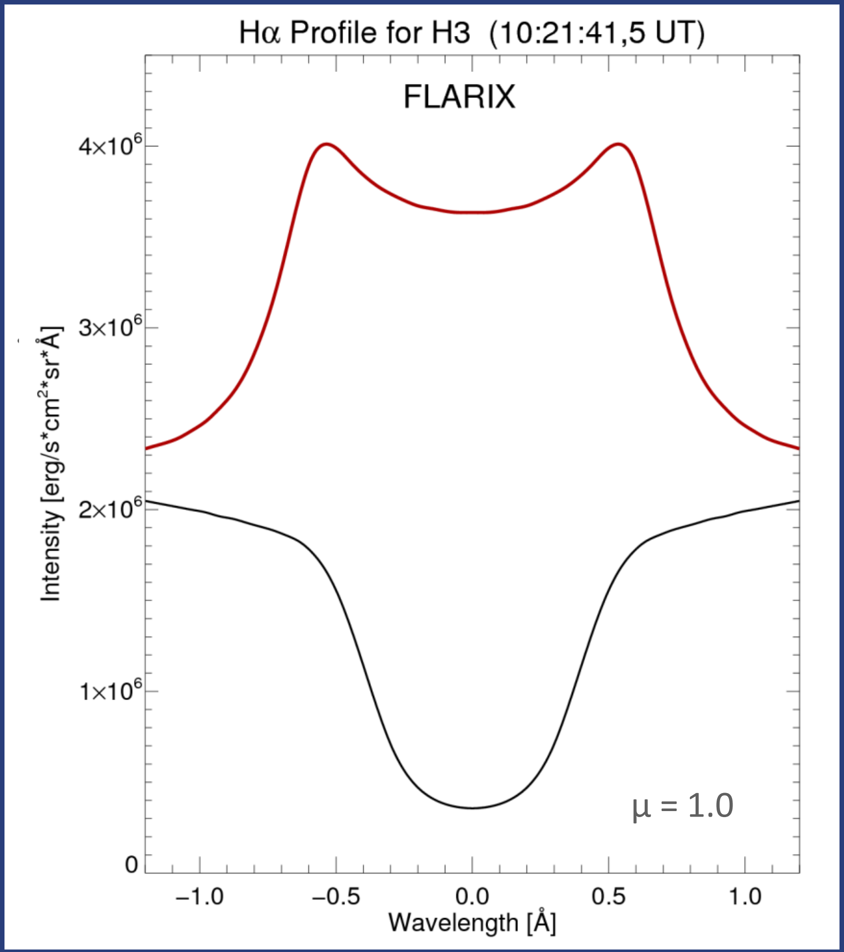


Net emission (integral after subtraction of QCh emission) for H3 peak at 10:21:41.5 UT

MSDP = 1 100 411 [erg/s*cm2*sr]

FLARIX = 4 479 392 [erg/s*cm2*sr]





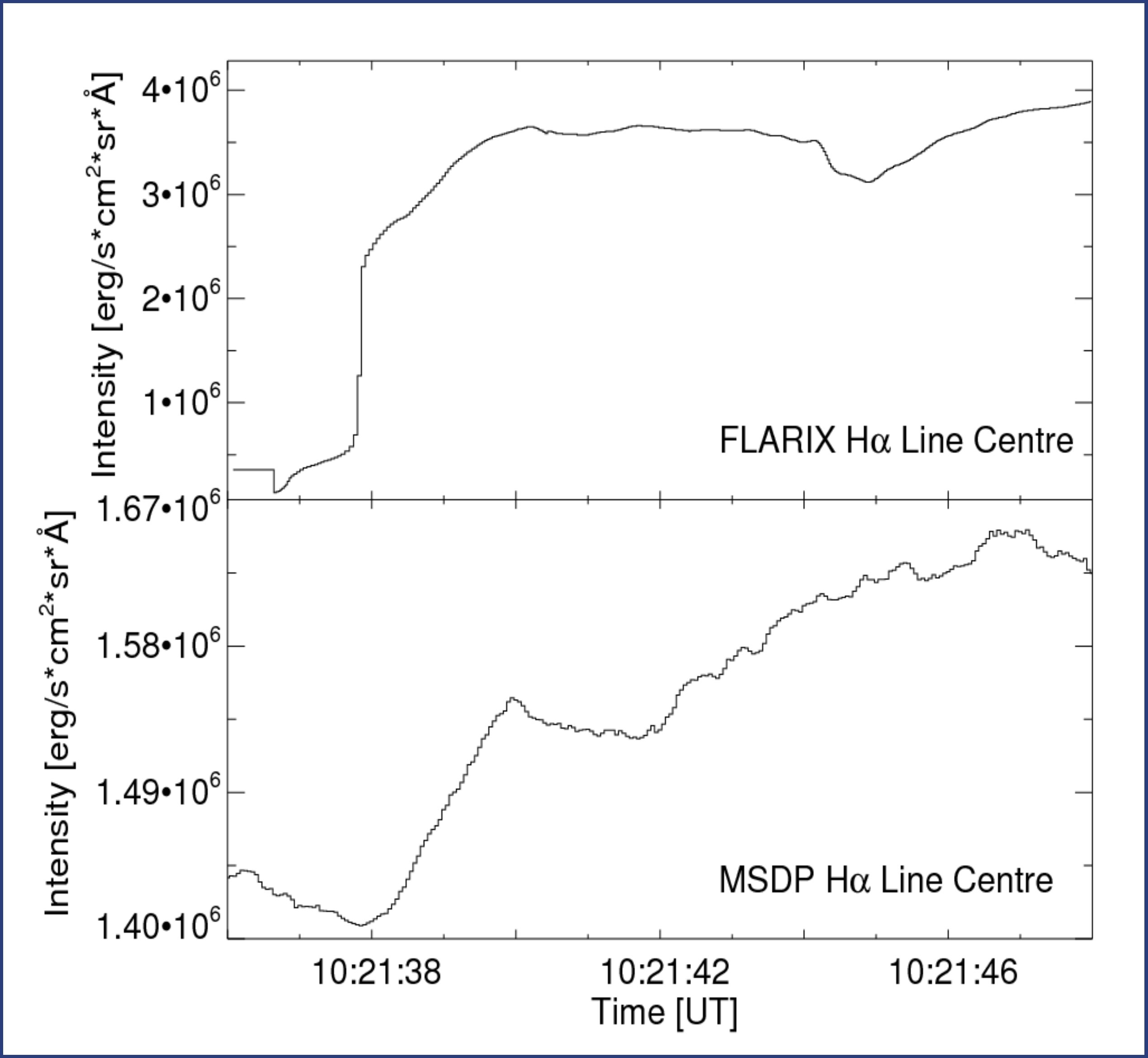
=> observed emission is about 4-times smaller then calculating

FLARIX & MSDP - Light Curves

Time evolution of the synthetic and observational Hα line center intensity:

FLARIX light curve =>

MSDP light curve =>

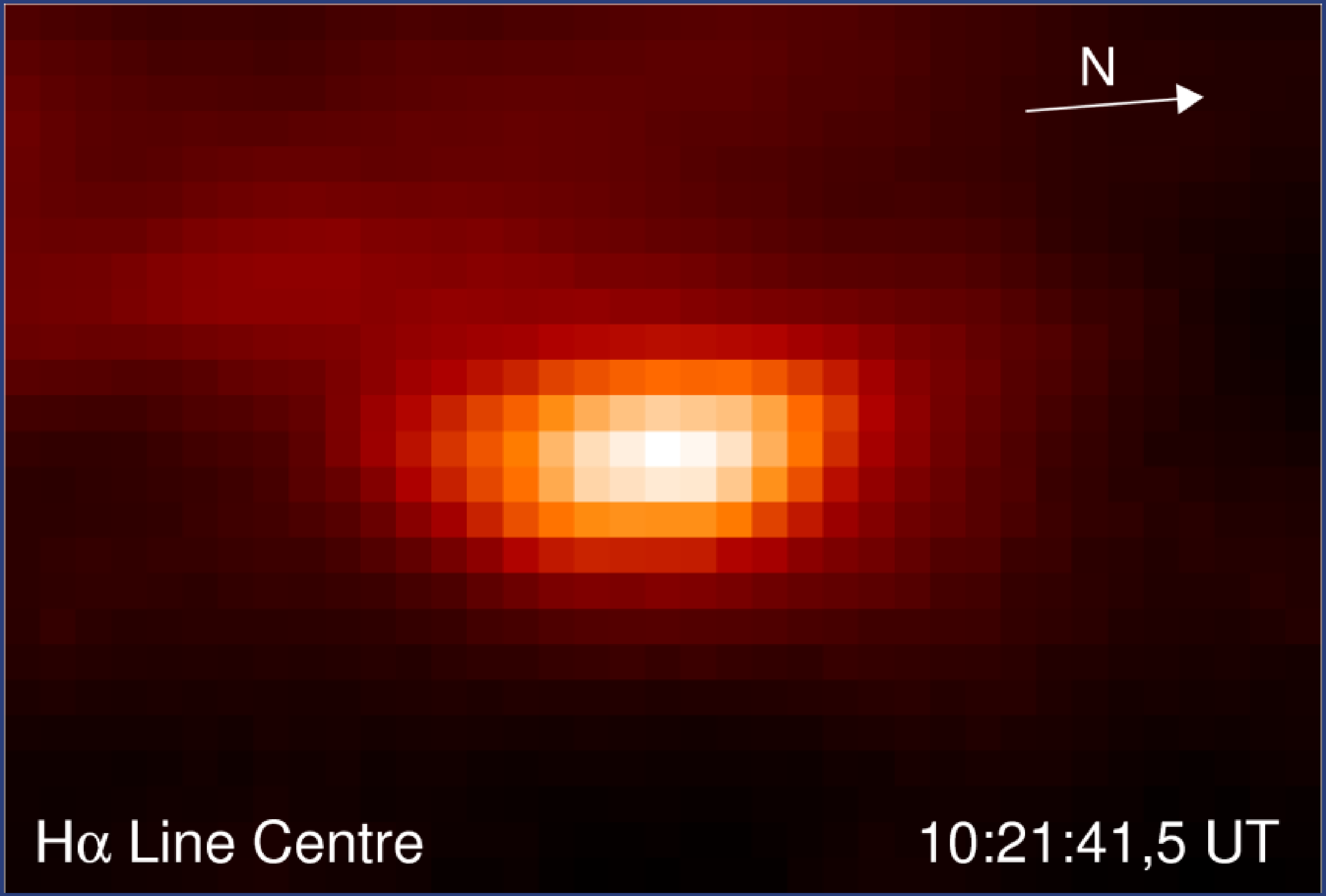


Possible scenarios

1. One or two sources ?

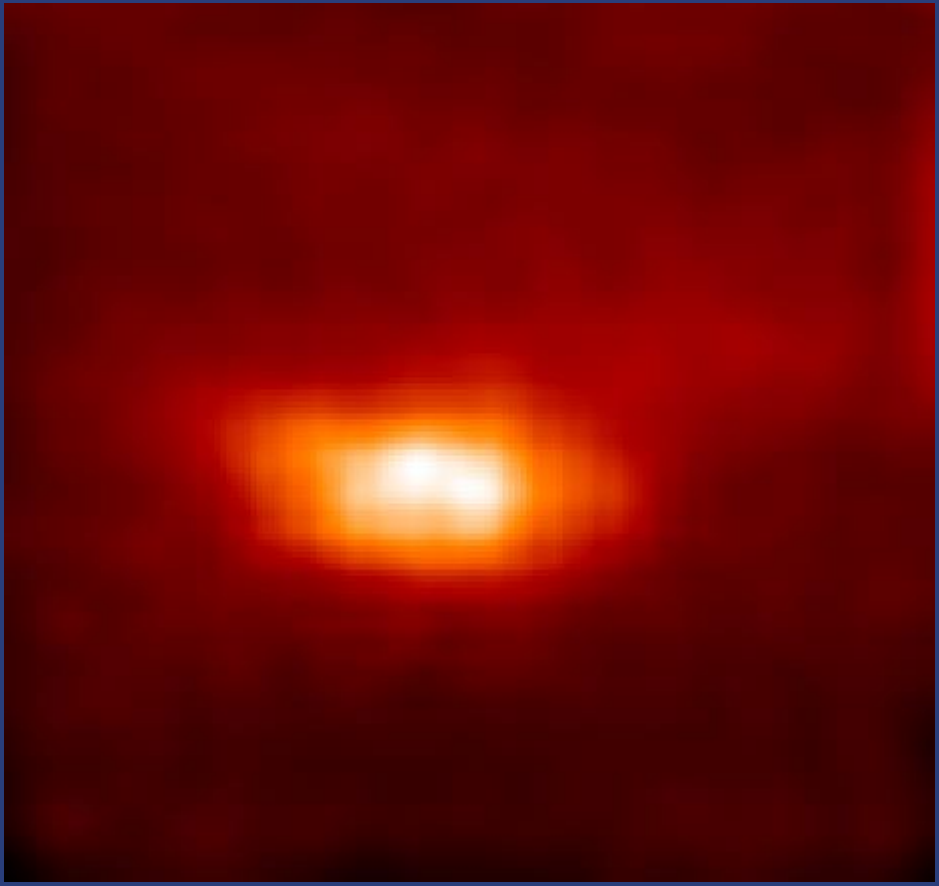
C1.6 flare ; 10.09.2012

1 px = 1.6 x 1.6 arcsec (≈ 1160 x 1160 km)

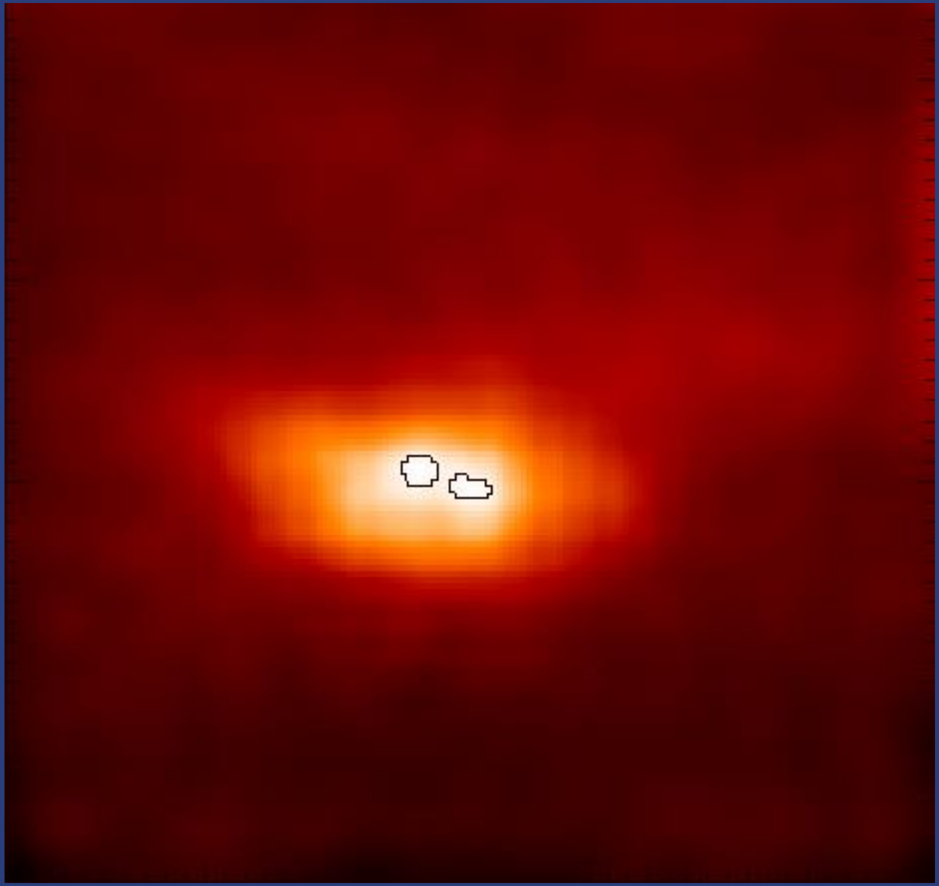


1. One or two sources ?

dekonvolution 1:5



dekonvolution 1:5 + contour 97%

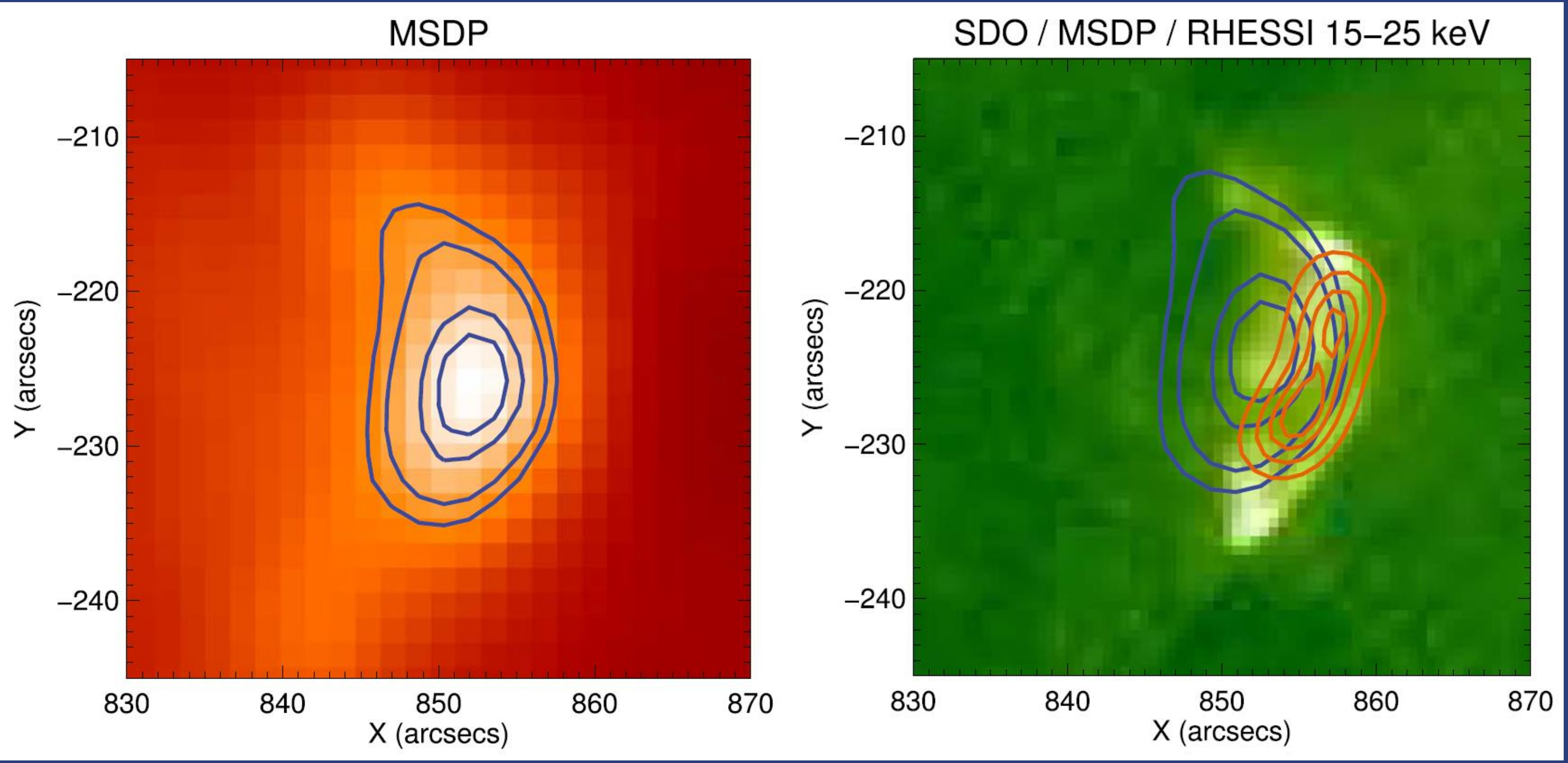


10:21:48 UT

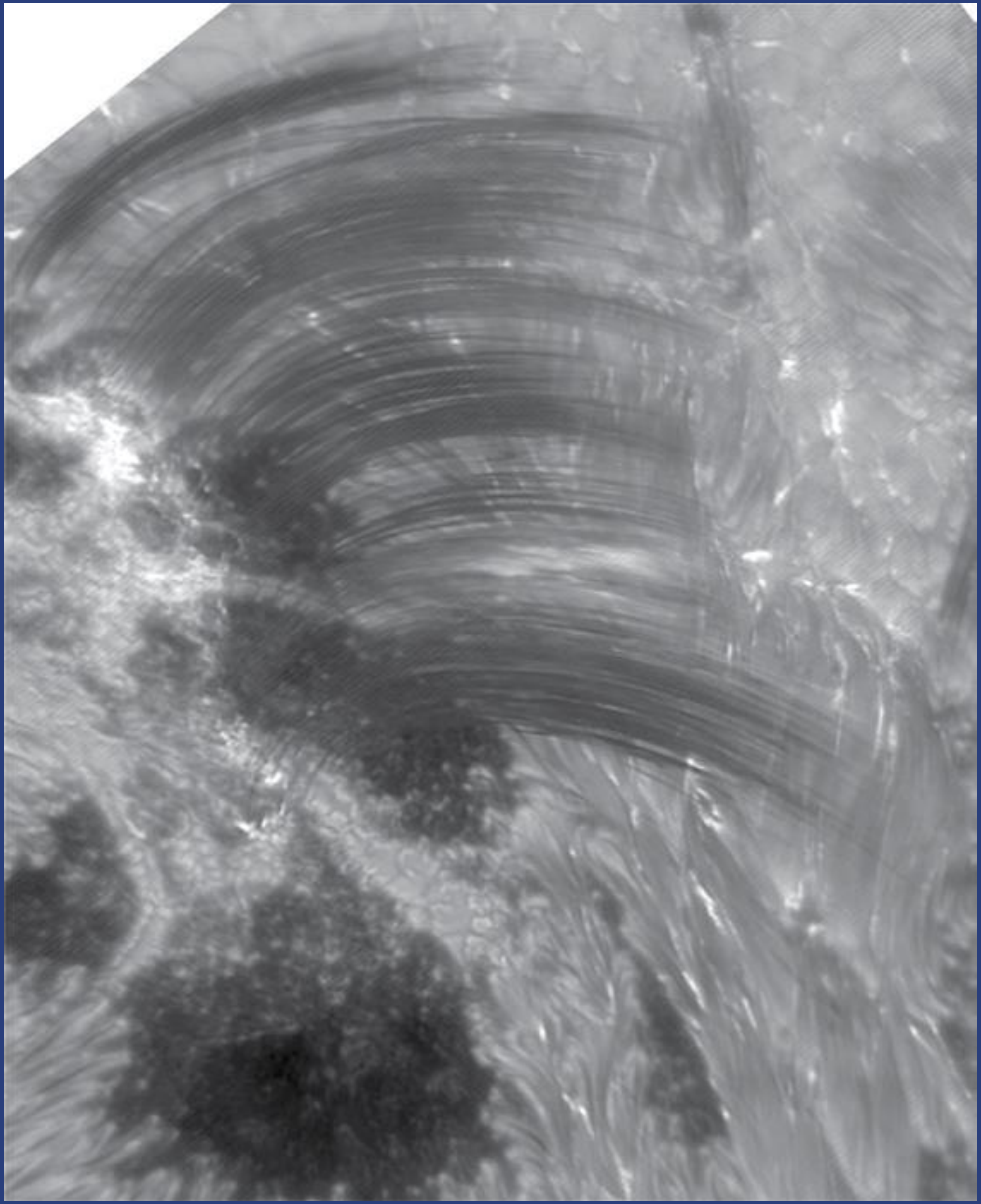
1. One or two sources ?

C1.6 flare ; 10.09.2012 , 10:20 UT

RHESSI 15-25 keV



Radziszewski et al. 2020



Jing et al. 2016

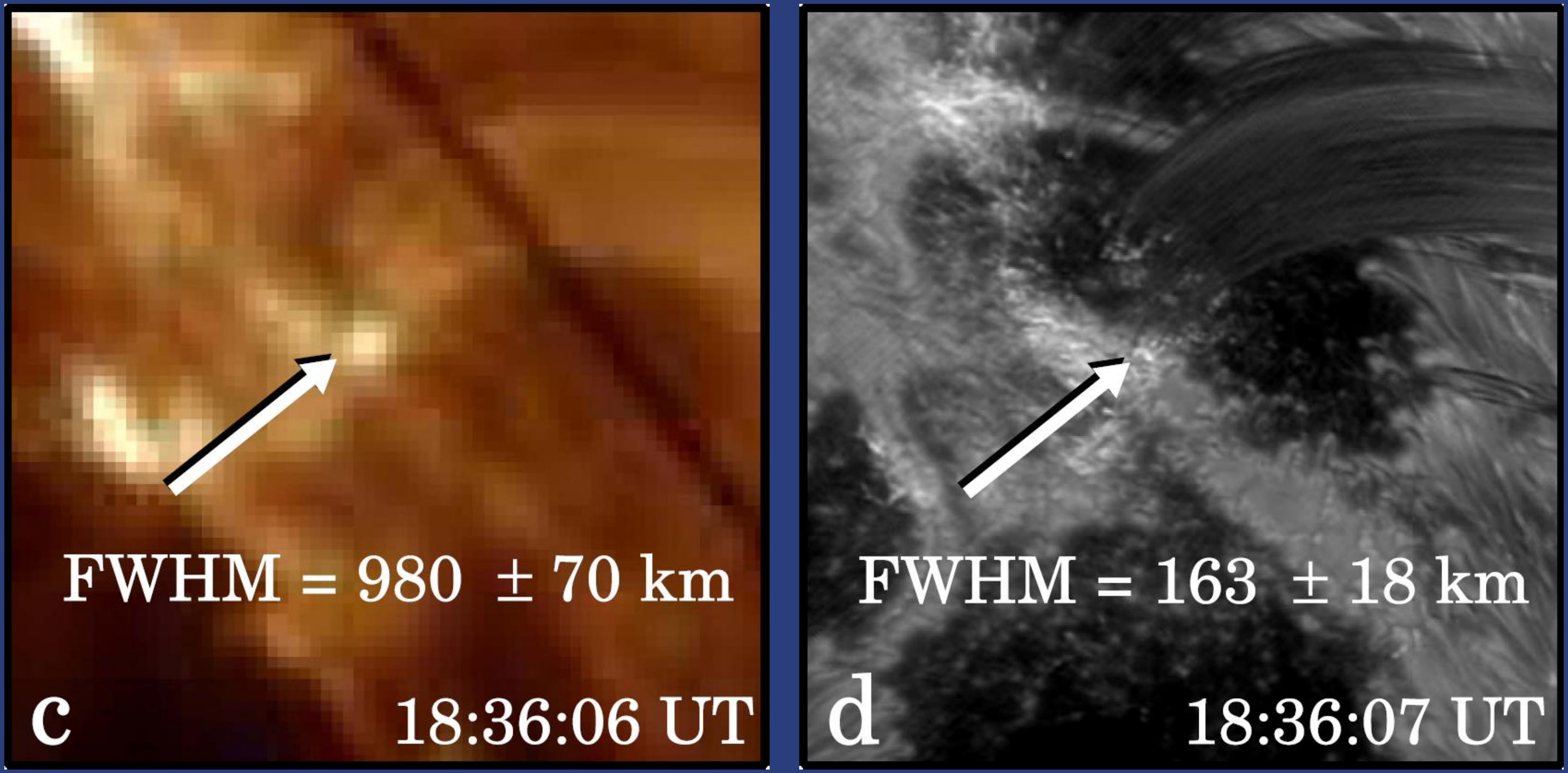
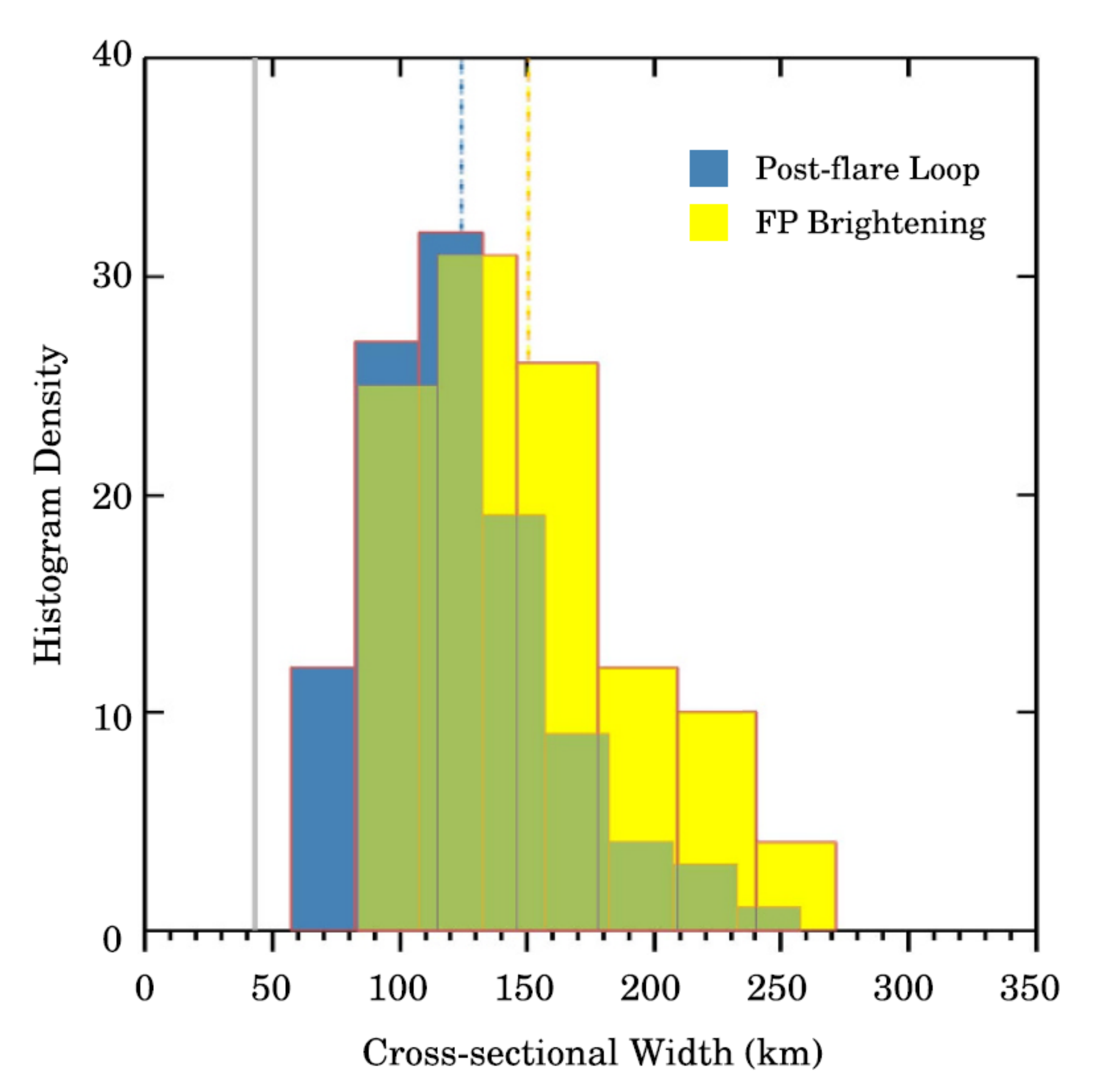


Figure 7. Panels c) and d) the IRIS Mg II k (2796 A) slit-jaw image and the NST Hα image, both have the same FOV and were taken almost at the same time. The brightenings are indicated with arrows. The Gaussian FWHM and +/-3σ are provided. *Jing et al. 2016*



Jing et al. 2016

Figure 6. Cross-sectional Gaussian FWHM distribution of post-flare loops (blue) based on a sample of 107 loops, and that of footpoint(FP) brightenings (yellow) based on a sample of 108 brightenings. The vertical blue/yellow dashed lines represent the mean of each distribution. The vertical grey solid line marks the resolution limit of NST/VIS.

2. Filling factor (ff < 1)

The Astrophysical Journal, 850:36 (11pp), 2017 November 20
https://doi.org/10.3847/1538-4357/aa9187

Hα and Hβ Emission in a C3.3 Solar Flare: Comparison between Observations and Simulations

Vincenzo Capparelli[1], Francesca Zuccarello[1], Paolo Romano[2], Paulo J. A. Simões[3], Lyndsay Fletcher[3], David Kuridze[4], Mihalis Mathioudakis[4], Peter H. Keys[4], Gianna Cauzzi[5], and Mats Carlsson[6]
[1] Dipartimento di Fisica e Astronomia—Sezione Astrofisica, Universitá di Catania, via S. Sofia 78, I-95123 Catania, Italy; vca@oact.inaf.it
[2] INAF—Osservatorio Astrofisico di Catania, via S. Sofia 78, I-95123 Catania, Italy

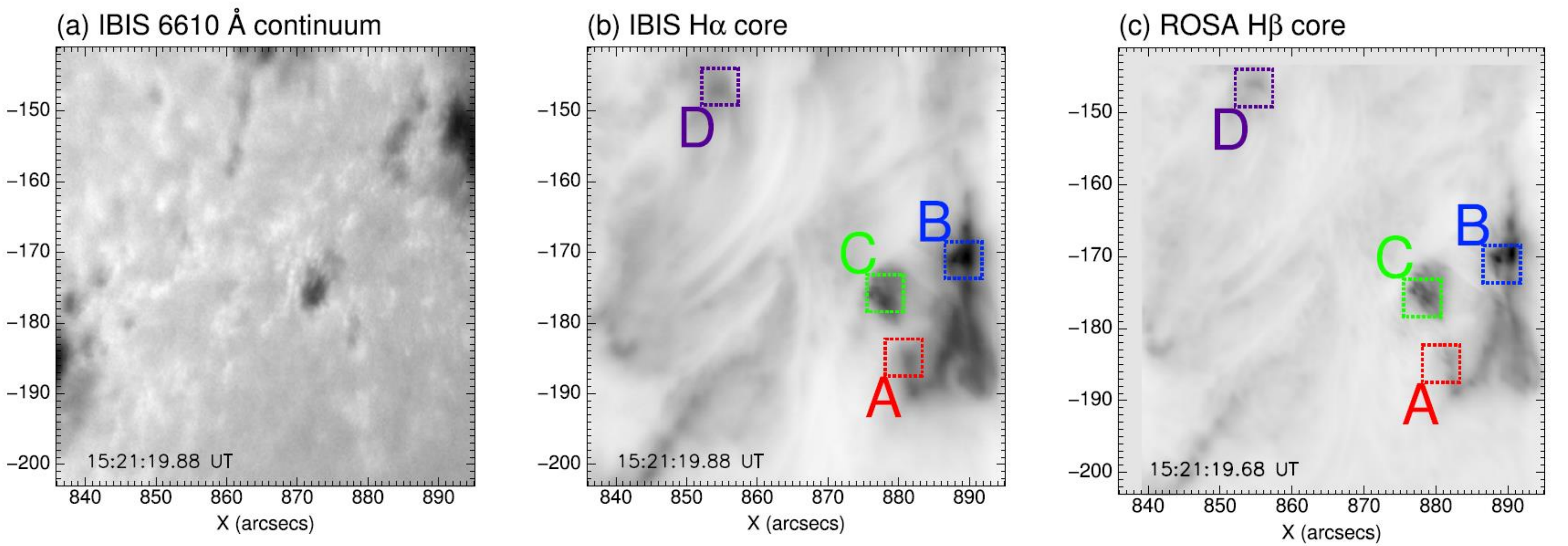


Figure 8. (a) Image acquired in the IBIS continuum at 6610 Å; (b) IBIS Hα image of the same FOV (reversed color); (c) ROSA Hβ image (inverted color) after the alignment procedure with the IBIS corresponding image. The boxes in (b) and (c) indicate the regions A, B, C, and D that are used to determine the intensity evolution (see Figures 9 and 10).

2. Filling factor (ff < 1)

C3.3 flare ; 22.04.2014 , 15:16 UT

DST/IBIS

+ RADYN => two sets of parameters (F9.5 and F10) based on RHESSI X-ray spectra

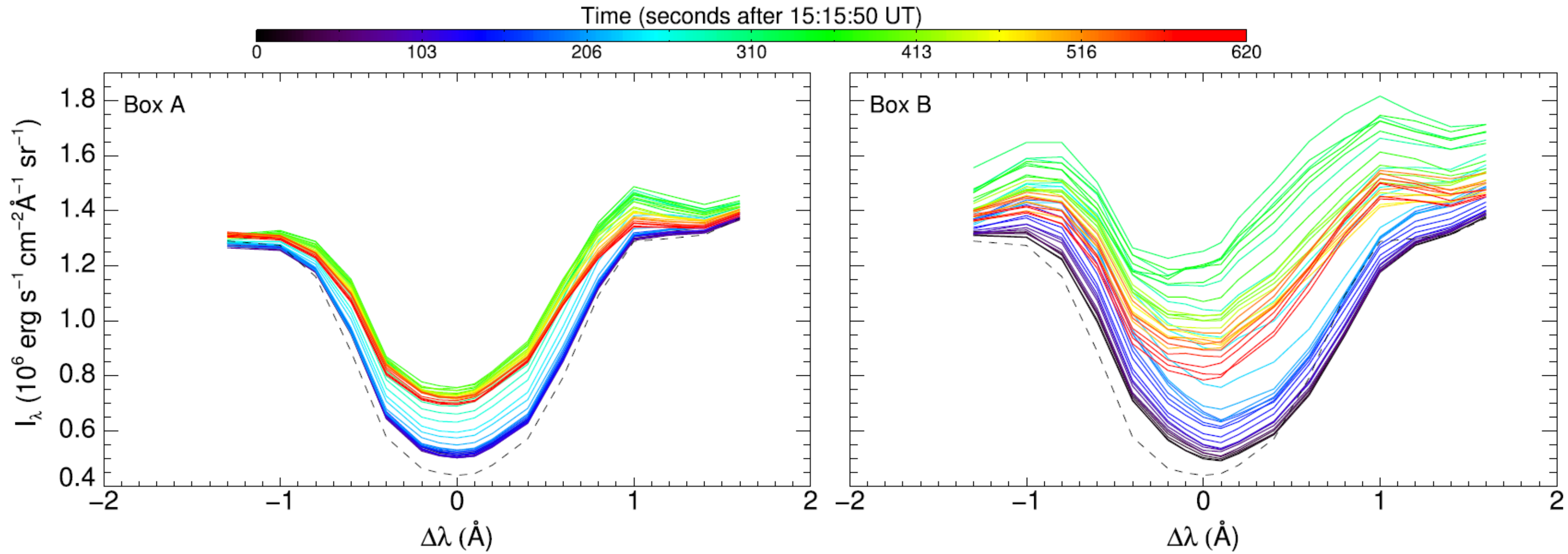


Figure 12. Temporal evolution of the observed Hα profile in box A (left) and box B (right). The intensities are reported in absolute units. Different colors indicate different times (from black, through blue, and green to dark red). The dashed profile results from the average intensity in each box at the beginning of the observing sequence.

Capparelli et al. 2017

Capparelli et al. 2017

2. Filling factor (ff < 1)

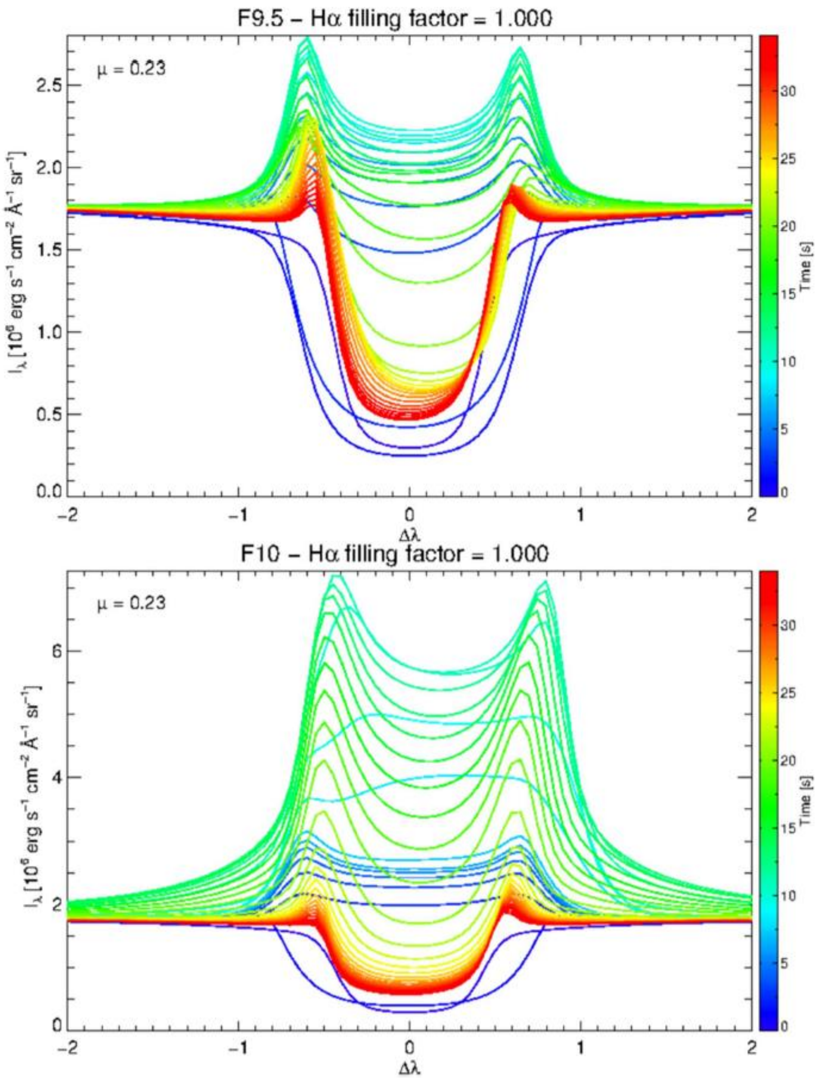


Figure 15. Time evolution of the Hα line profile calculated with RADYN, for the F9.5 (top) and F10 (bottom) flare models.

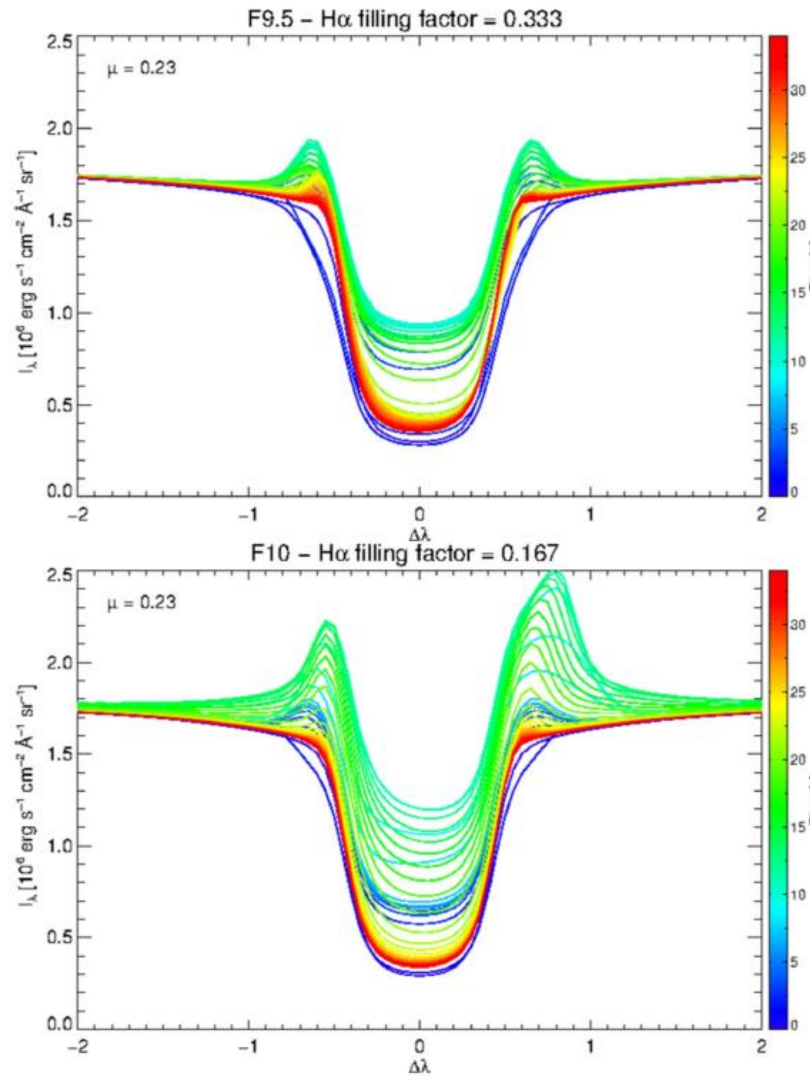
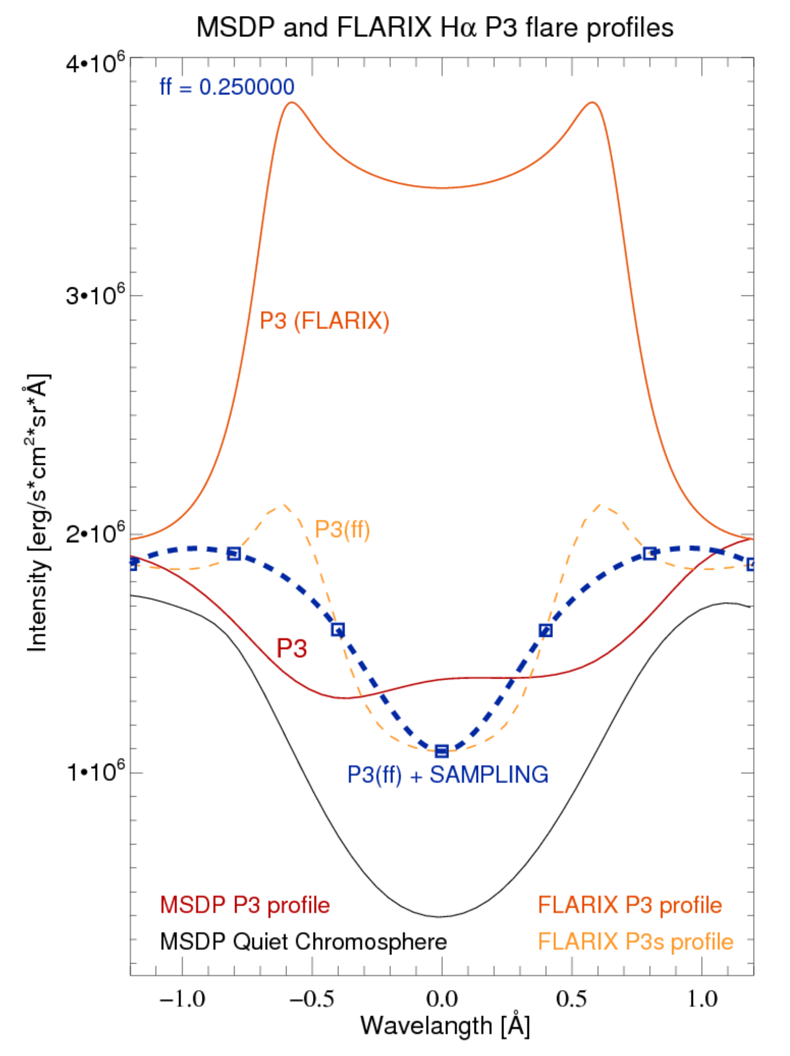
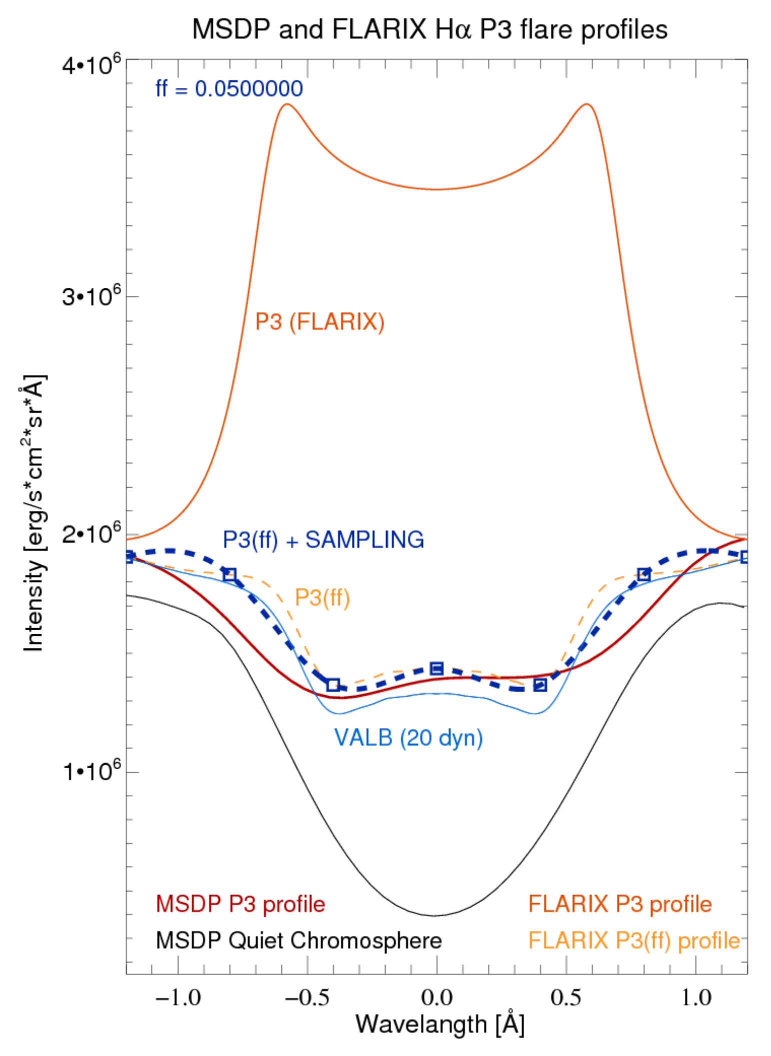


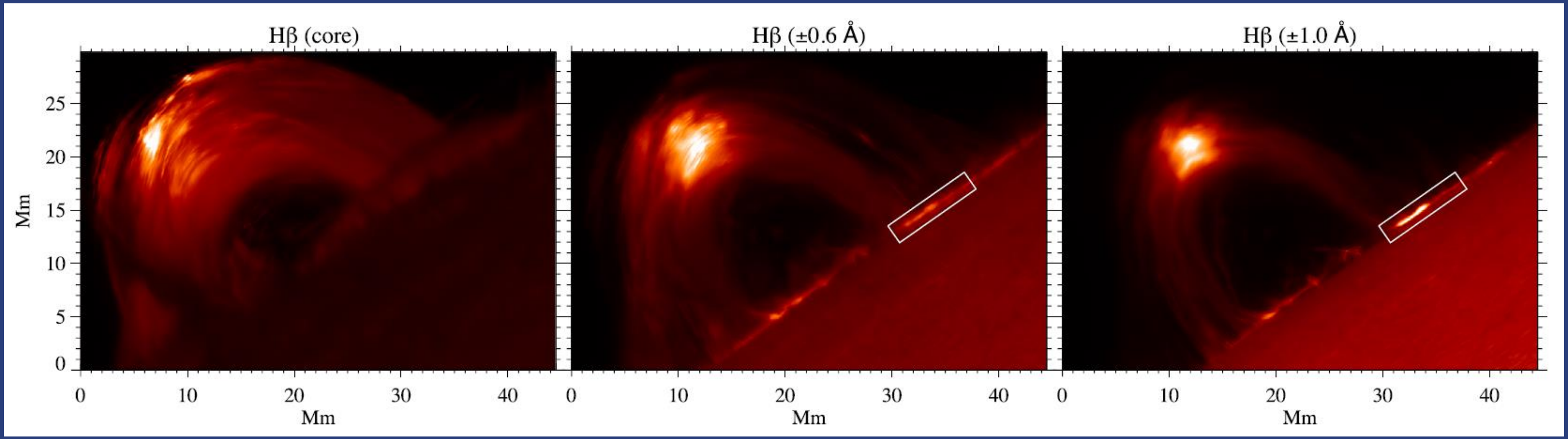
Figure 16. Same as Figure 15, but simulating a filling factor *ff* smaller than 1 (see the text). Top: F9.5 model, *ff* = 0.167. Bottom: F10 model, *ff* = 0.048.

MSDP Hα line profile with „ff” for H3 peak at 10:21:41.5 UT



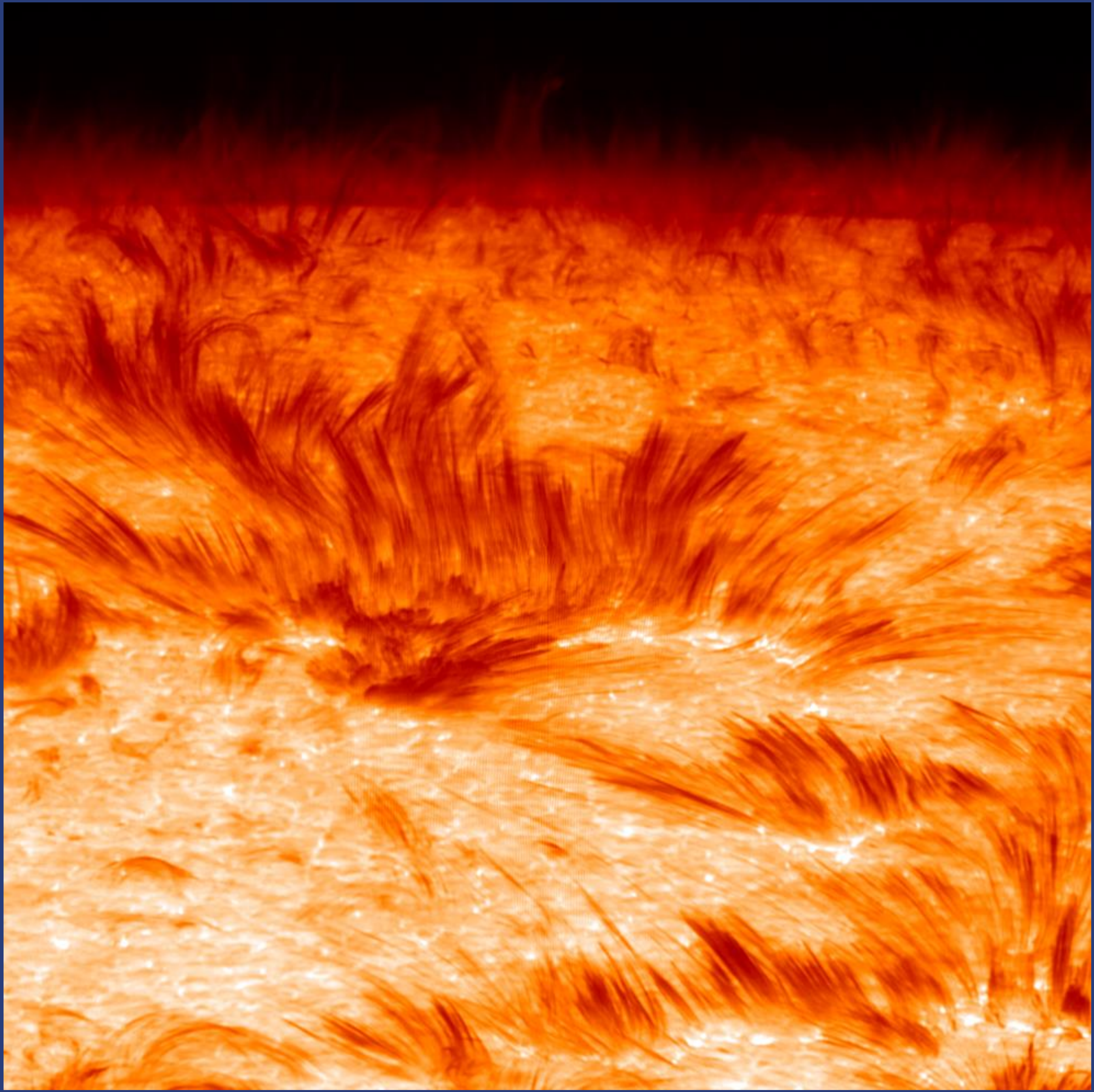


3. Obscuring by chromospheric structures



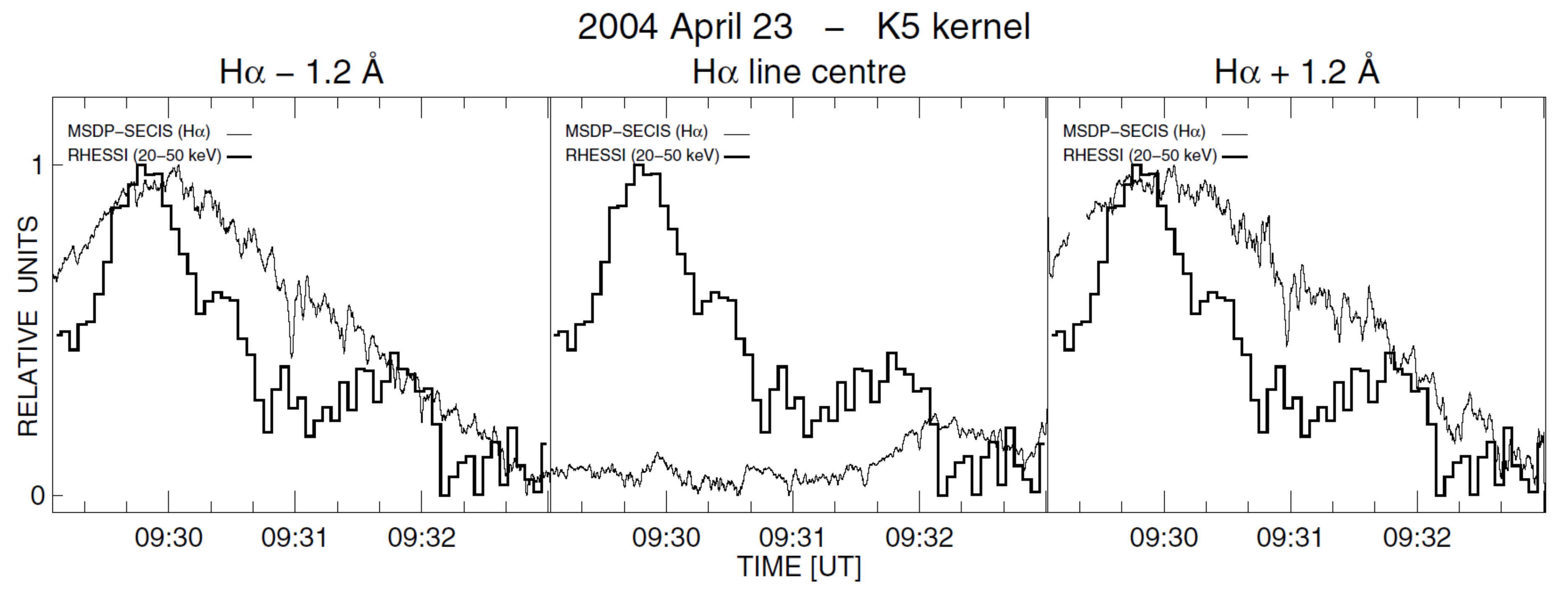
Kuridze et al. 2020

Radiation obscuring
by chromospheric
Structures.



Important angel of LOS

Swedish Solar Telescope
Ha +0,7Å



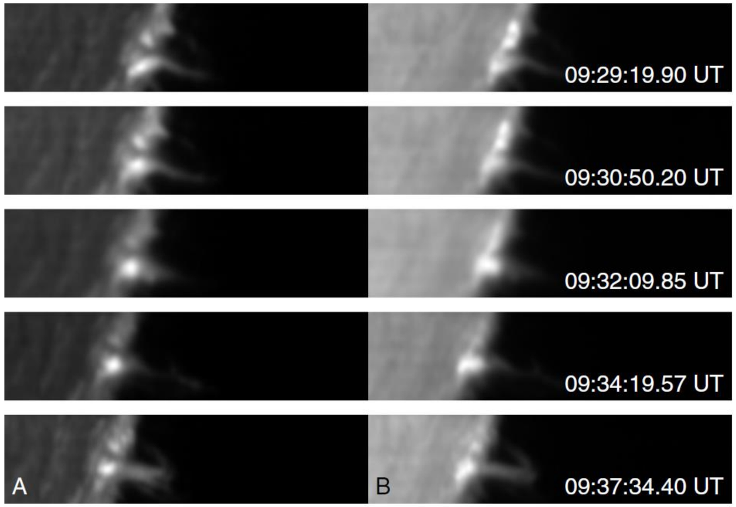


Fig. 5. A) Hα line centre images, **B)** compound images, for the C4.4 flare (flaring kernels K5, K6 and emission source K7) observed on the west limb in active region NOAA 10 597 on 2004 April 23.

Radziszewski et al. 2007

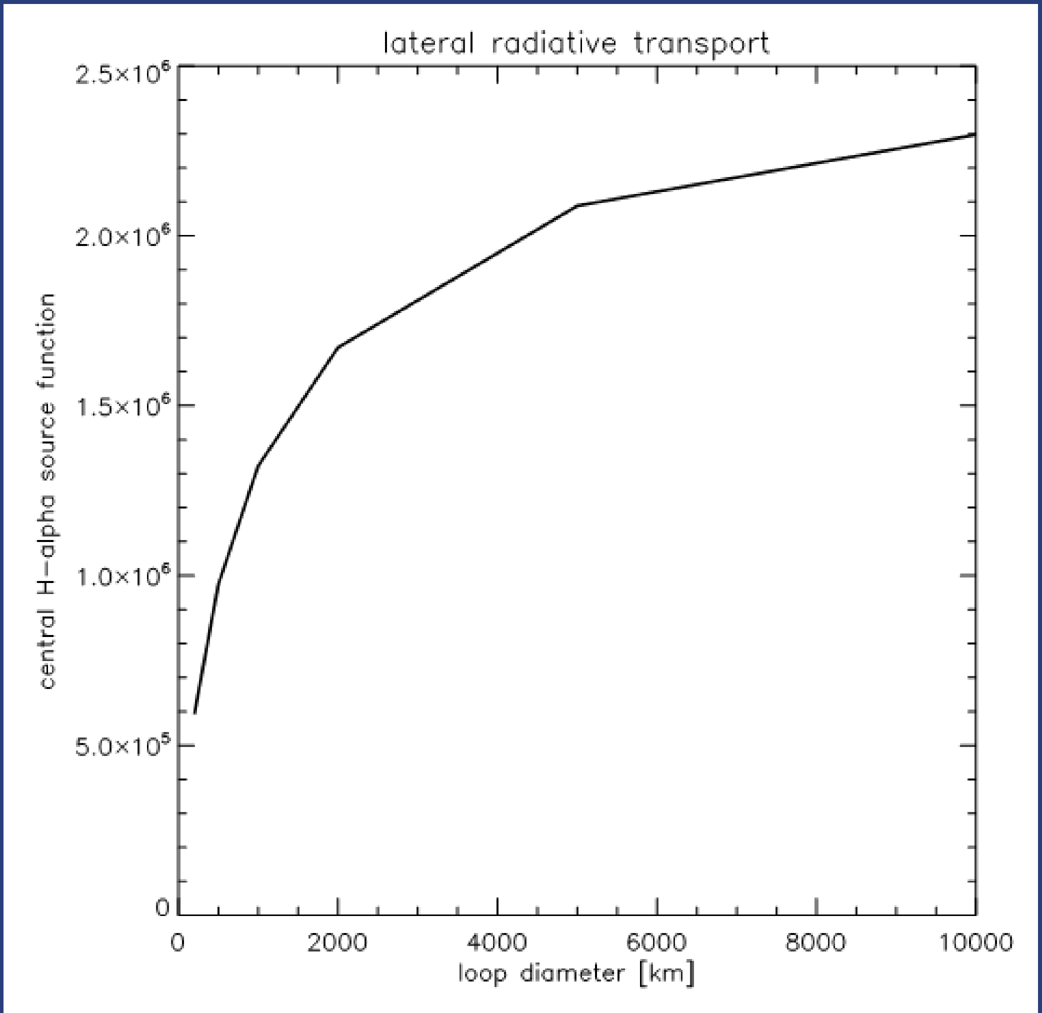
4. Lateral radiation transport

Effect of lateral radiation transport in the Hα line.

For small compact flare kernels the radiation can escape horizontally into the surrounding non-flaring chromo-sphere.

Effect decreasing the line source function in comparison to 1D plane--parallel models like FLARIX or RADYN.

Photon „leakage” is more important in the line wings (in the „peaks” in wings).



Summary

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- Factors affecting the reduction or increase of the observed flare emission:
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    - ff (<1)
    - obscuring
    - effect of lateral radiation transport in the Hα line (will be develope) .

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- Presently FLARIX working quite stable for spectra from RHESSI (as imput).

Summary

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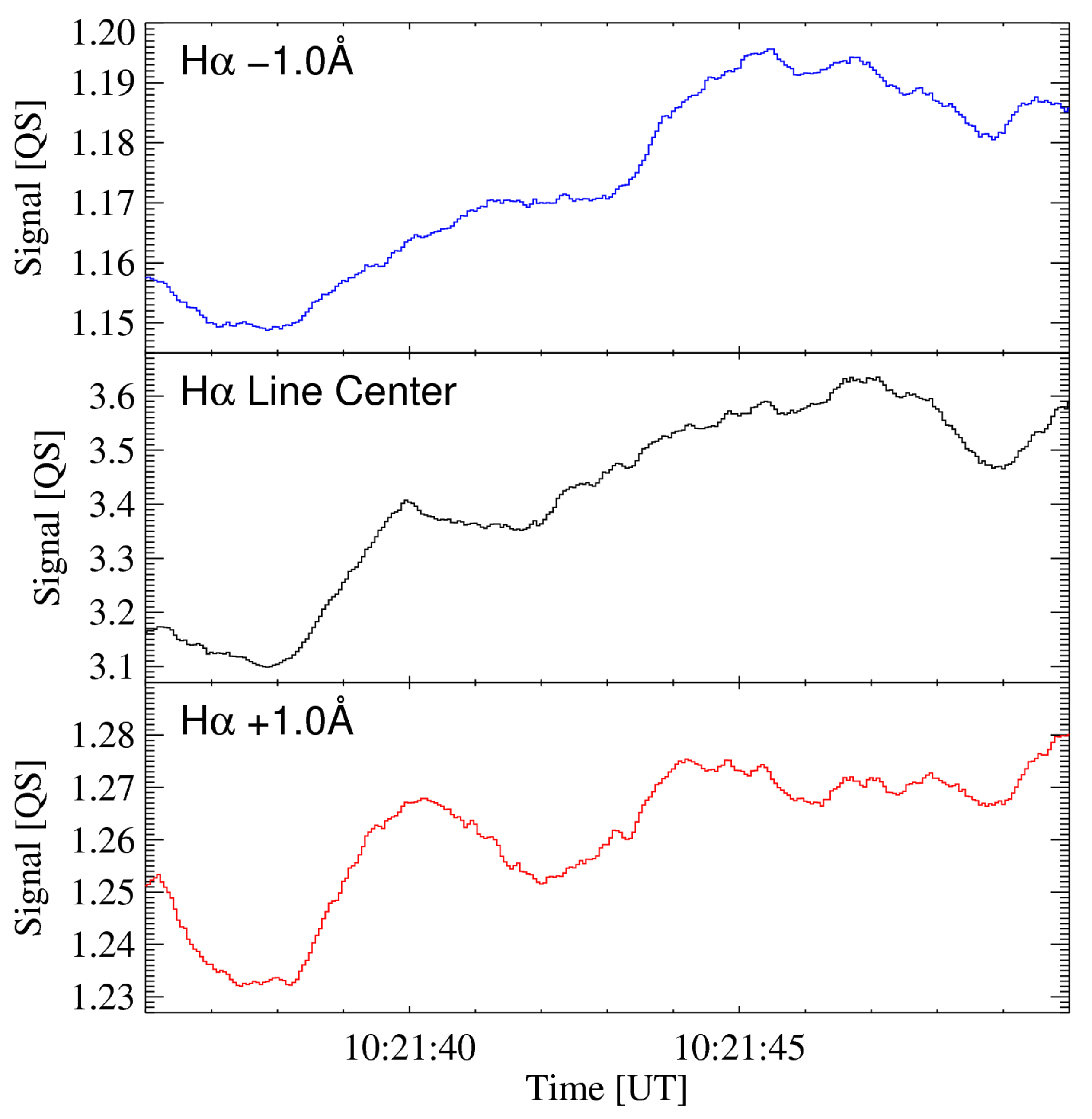
    - effect of lateral radiation transport in the Hα line (will be develope) .

- Presently FLARIX working quite stable for spectra from RHESSI (as imput).

- Further work on comparing models with observations looks promising.

Thank you for attention

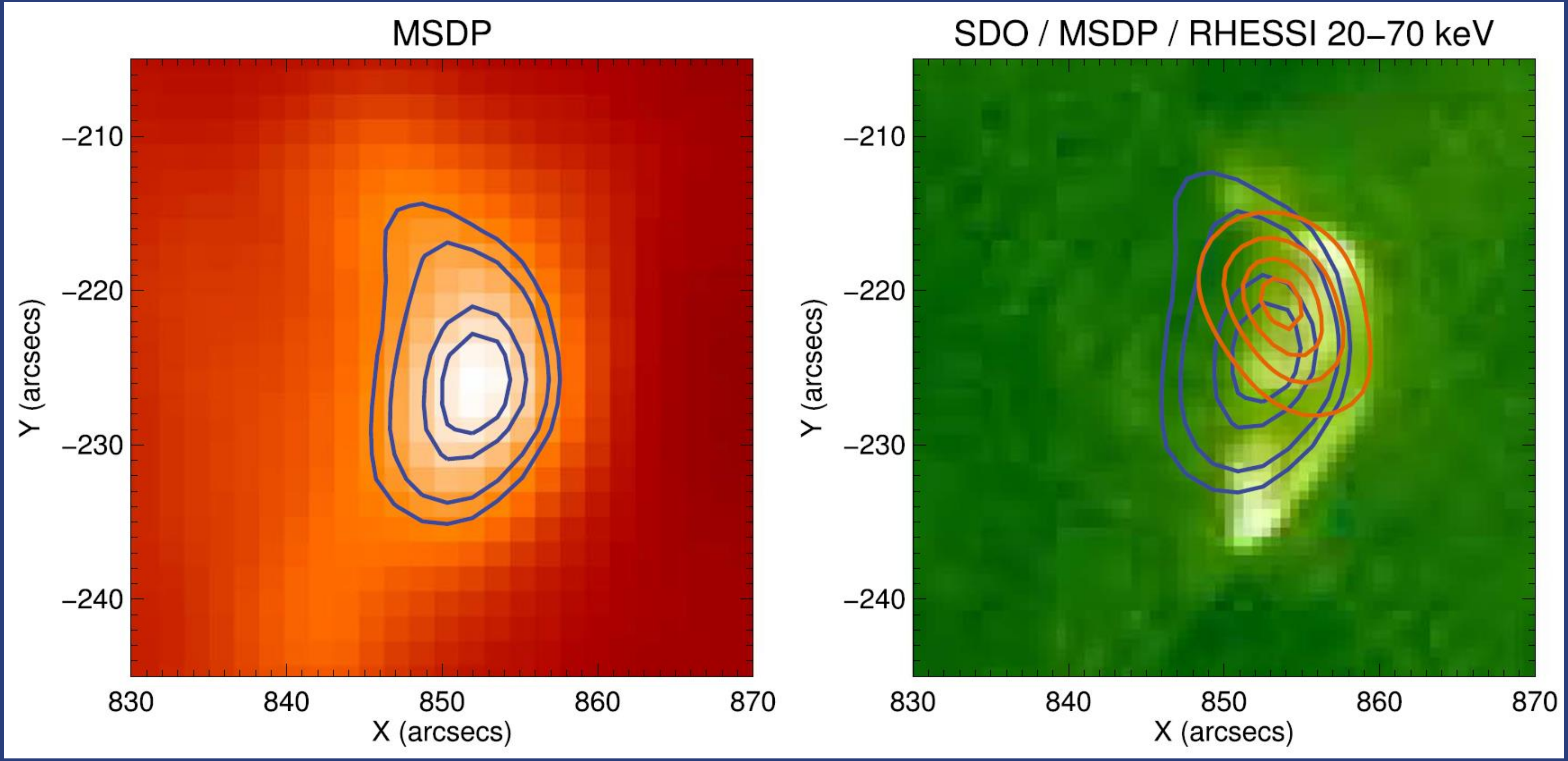


Hα −1.0Å
Hα Line Center
Hα +1.0Å
Signal [QS]
Signal [QS]
Signal [QS]
1.20
1.19
1.18
1.17
1.16
1.15
3.6
3.5
3.4
3.3
3.2
3.1
1.28
1.27
1.26
1.25
1.24
1.23
10:21:40
10:21:45
Time [UT]

1. One or two sources ?

C1.6 flare ; 10.09.2012 , 10:20 UT

RHESSI 20-70 keV



Radziszewski et al. 2020

References

www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

Unprecedented Fine Structure of a Solar Flare Revealed by the 1.6 m New Solar Telescope

Received: 16 January 2016
Accepted: 24 March 2016
Published: 13 April 2016

Ju Jing[1,2], Yan Xu[1,2], Wenda Cao[1,2], Chang Liu[1,2], Dale Gary[1,2] & Haimin Wang[1,2]

Solar flares signify the sudden release of magnetic energy and are sources of so called space weather. The fine structures (below 500 km) of flares are rarely observed and are accessible to only a few instruments world-wide. Here we present observation of a solar flare using exceptionally high resolution images from the 1.6 m New Solar Telescope (NST) equipped with high order adaptive optics at Big Bear Solar Observatory (BBSO). The observation reveals the process of the flare in unprecedented detail, including the flare ribbon propagating across the sunspots, coronal rain (made of condensing plasma) streaming down along the post-flare loops, and the chromosphere's response to the impact of coronal rain, showing fine-scale brightenings at the footpoints of the falling plasma. Taking advantage of the resolving power of the NST, we measure the cross-sectional widths of flare ribbons, post-flare loops and footpoint brighenings, which generally lie in the range of 80–200 km, well below the resolution of most current instruments used for flare studies. Confining the scale of such fine structure provides an essential piece of information in modeling the energy transport mechanism of flares, which is an important issue in solar and plasma physics.

The Astrophysical Journal, 896:120 (14pp), 2020 June 20 https://doi.org/10.3847/1538-4357/ab9603

Spectral Characteristics and Formation Height of Off-limb Flare Ribbons

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Abstract

Flare ribbons are bright manifestations of flare energy dissipation in the lower solar atmosphere. For the first time, we report on high-resolution imaging spectroscopy observations of flare ribbons situated off limb in the Hβ and Ca II 8542 Å lines and make a detailed comparison with radiative hydrodynamic simulations. Observations of the X8.2 class solar flare SOL 2017-09-10T16:06 UT obtained with the Swedish Solar Telescope reveal bright horizontal emission layers in Hβ line-wing images located near the footpoints of the flare loops. The apparent separation

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Hα and Hβ Emission in a C3.3 Solar Flare: Comparison between Observations and Simulations

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Abstract

The hydrogen Balmer series is a basic radiative loss channel from the flaring solar chromosphere. We report here on the analysis of an extremely rare set of simultaneous observations of a solar flare in the Hα and Hβ lines, at high spatial and temporal resolutions, that were acquired at the Dunn Solar Telescope. Images of the C3.3 flare (SOL2014-04-22T15:22) made at various wavelengths along the Hα line profile by the Interferometric Bidimensional Spectrometer (IBIS) and in the Hβ with the Rapid Oscillations in the Solar Atmosphere (ROSA) broadband imager are analyzed to obtain the intensity evolution. The Hα and Hβ intensity excesses in three identified flare footpoints are well-correlated in time. We examine the ratio of Hα to Hβ flare excess, which was

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Modelling of Flare Processes: A Comparison of the Two RHD Codes FLARIX and RADYN

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Abstract. We present a comparison of two autonomous, methodologically different radiation hydrodynamic codes, FLARIX and RADYN, and their use to model the solar flare processes. Both codes can model the time evolution of a 1D atmosphere heated by a specified process, e.g. by electron beams propagating from the injection site in the

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(EN):

The first comparison of the MSDP spectroscopic observations of a solar flare recorded in the hydrogen H-alpha line with the results of RHD modeling obtained from the FLARIX code

Selected aspects of the analysis of a solar flare emission modelling in the hydrogen H-alpha spectral line (6563 A) results obtained from the FLARIX code will be presented during the speach. A compact solar flare of the C1.6 class, observed at the Bialkow Observatory, belonging to the Astronomical Institute of the University of Wroclaw, was selected as the target of numerical modelling. Observational data obtained using the MSDP imaging spectrograph located at Bialkow enabled a unique 2D analysis of hydrogen H-alpha flare emission with a time resolution of 50 ms. Thanks to the possibility of obtaining 2D images and the spectral line profile in each pixel of the field of view (for each single exposure), diagnostics of both the total emission of the flare with high time resolution and the analysis of the line profile shape from individual parts of the flaring area were carried out. The synthetic emission of the flare was calculated using the FLARIX hydrodynamic code (taking into account radiative losses), developed by the heliophysics group led by prof. Petr Heinzel from the Astronomical Institute of the Czech Academy of Sciences at Ondrejov (currently also employed at the University of Wroclaw, in the frame of Incubator of Scientific Excellence - Activity of the Sun and Stars).

(PL):

Pierwsze porównanie spektroskopowych obserwacji MSDP rozbłysku słonecznego zarejestrowanego w linii H-alpha wodoru z wynikami modelowania RHD uzyskanego kodem FLARIX

Wybrane aspekty analizy wyników modelowania emisji rozbłyskowej w zakresie linii widmowej H-alpha wodoru (6563 A) uzyskanych kodem FLARIX, zostaną przedstawione podczas wystąpienia. Jako cel modelowania numerycznego wybrany został kompaktowy rozbłysk słoneczny klasy C1.6, zaobserwowany w Obserwatorium w Białkowie, należącym do Instytutu Astronomicznego Uniwersytetu Wrocławskiego. Dane obserwacje uzyskane przy użyciu spektrografu obrazującego MSDP znajdującego się w Białkowie, umożliwiły unikatową analizę 2D emisji rozbłyskowej w linii H-alpha wodoru z rozdzielczością czasową wynoszącą 50 ms. Dzięki możliwości uzyskania 2D obrazów oraz profilu linii widmowej w każdym pikselu pola widzenia (dla każdej pojedynczej ekspozycji), została przeprowadzona diagnostyka zarówno całkowitej emisji rozbłysku z wysoką rozdzielczością czasową, jak i analiza kształtu profilu linii z poszczególnych fragmentów obszaru rozbłysku. Syntetyczna emisja rozbłysku została policzona kodem hydrodynamicznym FLARIX (z uwzględnieniem strat promienistych), rozwijanym przez grupę heliofizyczną pod kierownictwem prof. Petra Heinzel'a z Instytutu Astronomicznego Czeskiej Akademii Nauk w Ondrejovie (obecnie zatrudnionego również w UWr, w ramach działania Inkubatora Doskonałości Naukowej - Aktywność Słońca i Gwiazd).