A new concept of Balmer continuum flux measurement in solar flares

P. Kotrč, P. Heinzel and M. Zapior

Astronomical Institute, AS CR, v.v.i. Ondřejov, Czech Republic

Introduction
White light flares, Balmer/blue continuum
Stellar and solar B.c.flare observations
A new device for B.c. flux measurements
First B.c. observation of flares in 2014
Preliminary results
Prospects

Outline

Increase in the Balmer continuum radiation during solar flares was predicted by various authors, but has never been firmly confirmed observationally using ground-based slit spectrographs. We developed a new post-focal instrument, the image selector. The spectral flux including the Balmer continuum in the spectral range of 350 – 440 nm can be measured from the whole flaring area, in analogy to successful detections of flaring dMe stars. The system was put into operation at the horizontal solar telescope HSFA2 of the Ondřejov Observatory recently. We measure the total flux by a fast spectrometer from a limited but well-defined region on the solar disk. Using a system of changeable diaphragms a precise selection of observed area is possible. Thus, the disturbing contribution of a bright solar disk can be eliminated as much as possible. Our analysis of the data proves that the described device is sufficiently sensitive to detect variations in the Balmer continuum during solar flares. The angular resolution is not crucial for this device. The spectral resolution of the used Ocean Optics spectrometer is 0.35 Angstroem. It is sufficient to resolve even broader spectral lines in that region like the CaII H & K as well as higher Balmer series ones. Dynamic spectra of one solar flare are presented.

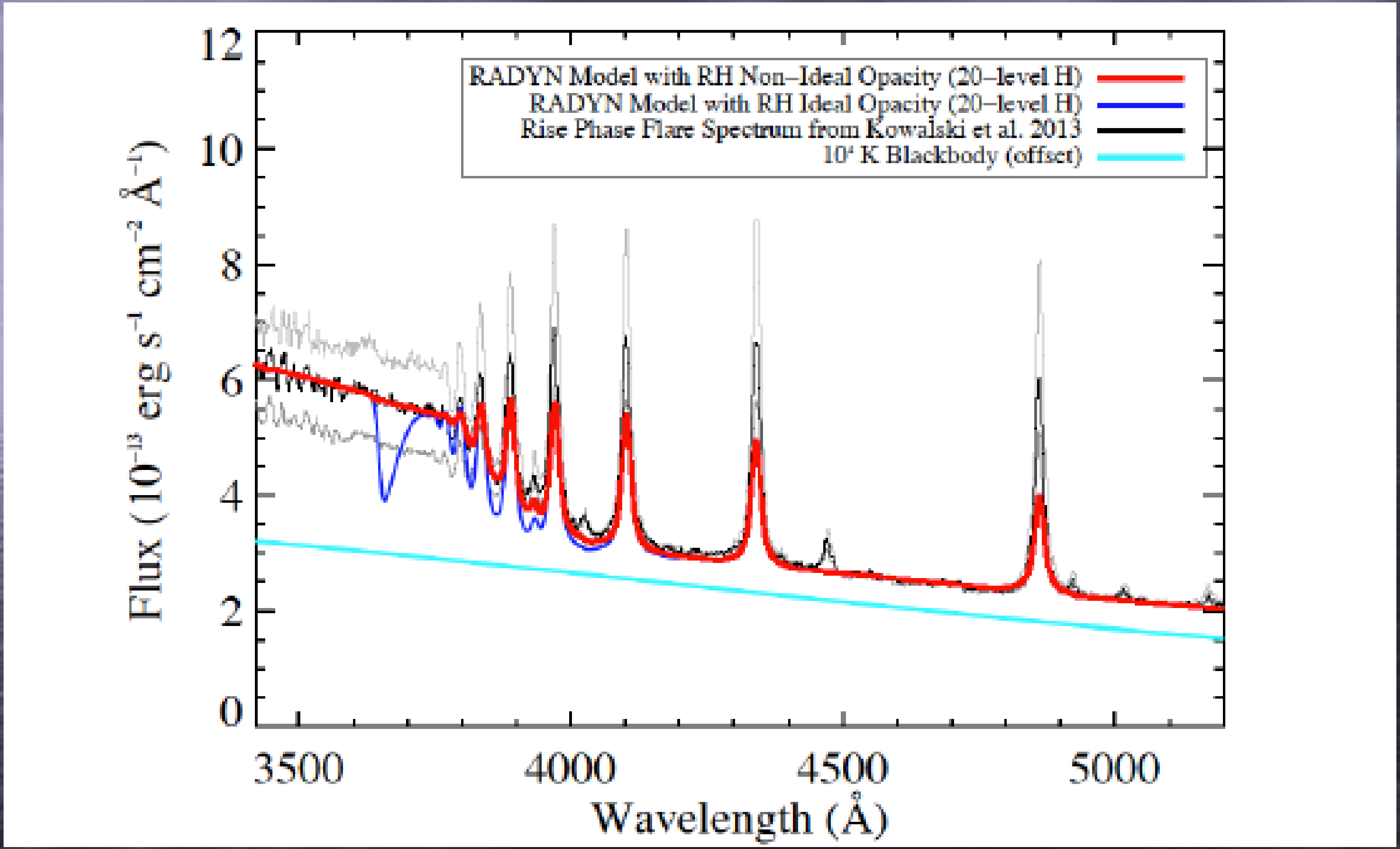
White-light flares (WLFs) / solar

- The Carrington flare on Sept. 1, 1859 = WLF
- WLF - the most energetic flaring events observable in the optical broad-band continuum of the solar spectrum (Wang, 2008)
- Very small white-light kernels <3” (Neidig, 1989)
- Role of atmospheric seeing in difficulties of detection of WLFs
- using ground-based telescope (Hiei, 1982)
- WLFs are associated with more energetic EUV and SXT flares (Neidig and Cliver, 1983)
- WLF mechanisms: (electron beams <20keV, Metcalf et al. 2003? or a back-warming effect in the energy transport from upper chromosphere – to photosphere? (Machado et al. 1989)
- Ding, 2007, 2 classes of WLF, I-photospheric H^- temp. increase, II - chromospheric H recombination

White-light flares (WLFs) / stellar

- White-light flares observed on late types of stars, namely dwarfs type M with emission lines, dMe
- The WL enhancement ends when the impulsive stage of the flare has ceased (Bopp & Moffett,1973), while
- a gradual decay in continuum emission, even after the end of the impulsive phase was found by Hawley & Pettersen (1991)
- A new measurement of Kowalski et al 2013 reported an increase of Balmer continuum in dMe stars.

WLF at dMe star by Kowalski et al.



Raised questions (and problems)

- How to measure blue/Balmer continua flux in solar flares?
- How to increase contrast in flare against the disk?
- Either to use filtergrams or spectral measurements?
- Which device is the best tool for observations of blue continuum?
- What method is more perspective/efficient?
- How to study changes in various parts of blue continuum ?
- How to observe flares at b.c. and in Hα simultaneously?
- Can we detect real changes of blue continuum flux in real time?
- What is time correlation of b. c. with Hα, SXT, EUV, … ?
- Are we able to suggest a simple non expensive device for that task?

An instrument for flux measurement

- Demands:

To follow active region for flares in H-alpha

Good guiding of the telescope

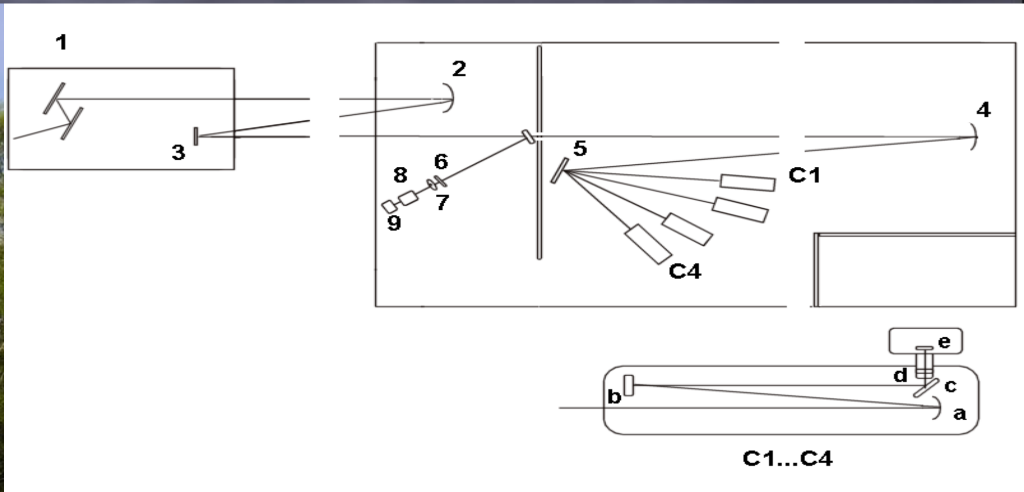
Increased sensitivity in blue continuum

To define the region of measurement

Enable to reduce the disk radiation

High cadence of at least 10 images/second

Ondřejov large horizontal telescope

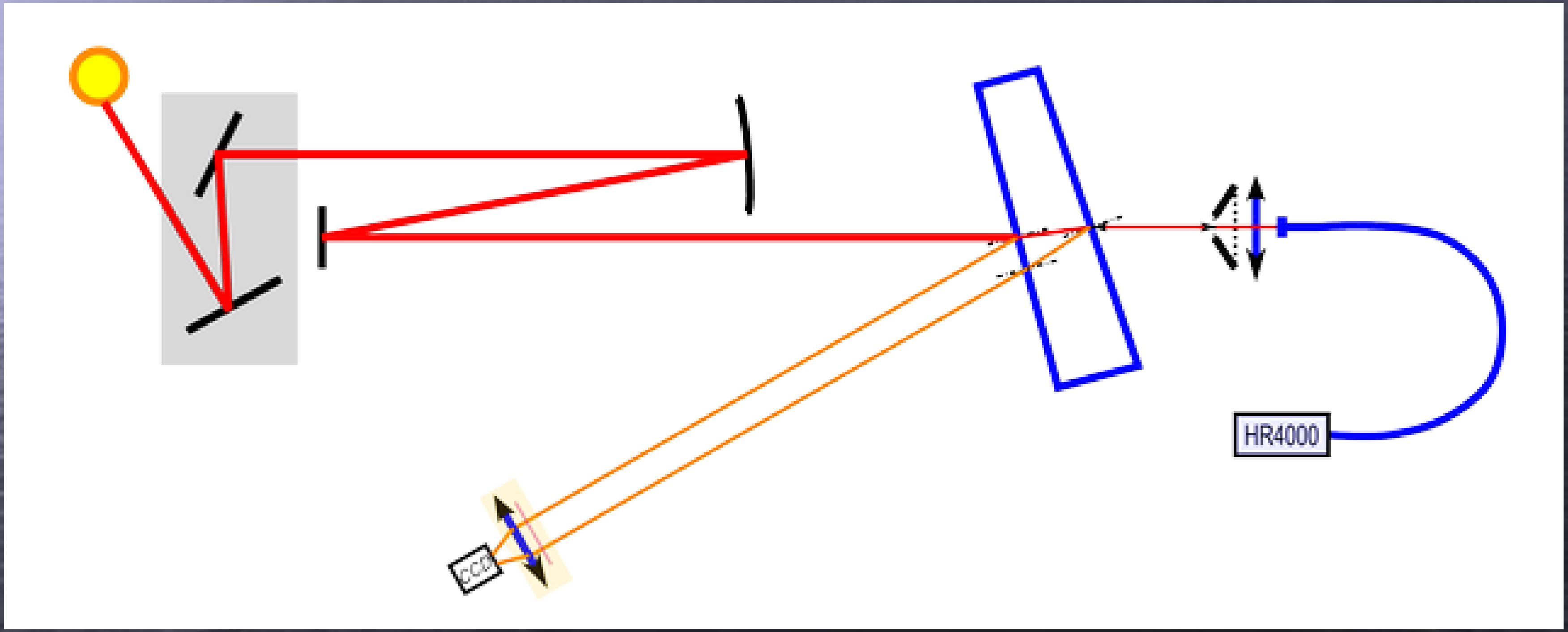


1 – Jensch coelostat, 2 – main objective, 3 – flat mirror, 4 – collimator, 5 – grating, 6 – thermal filter, 7 – slit-jaw objective, 8 – Hα filter, 9 – CCD camera

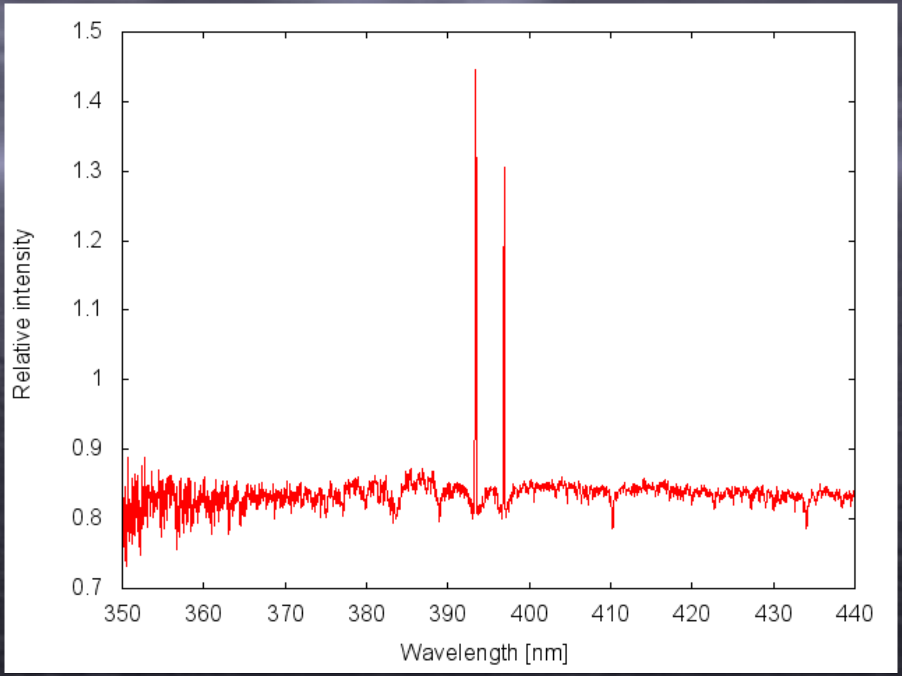
Jensch type coelostat 4 – 6 m above ground, sliding shelter, *Φ* of mirrors 60 cm, M1 *Φ* 50 cm, f 35 m.

Only the telescope was used,
A new post-focus device installed

Optical schema of the device

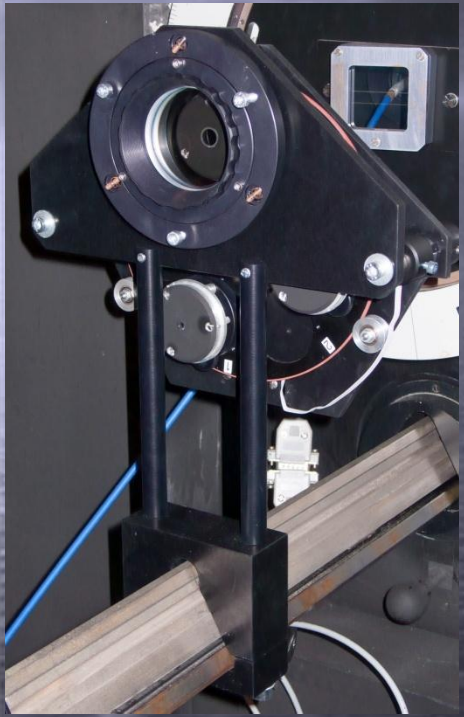


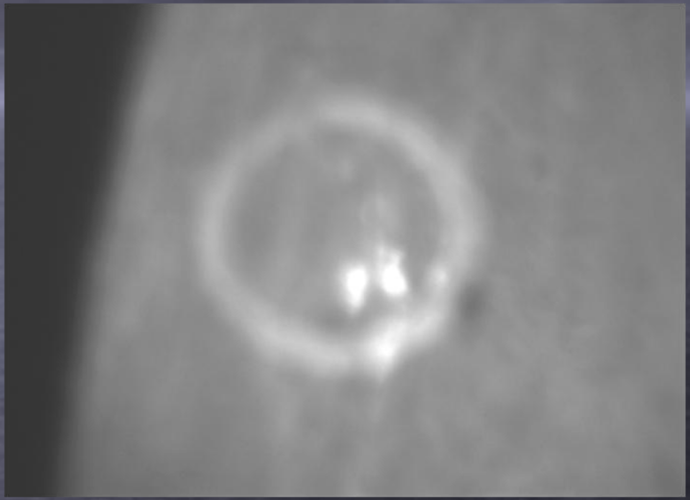
Spectrometer

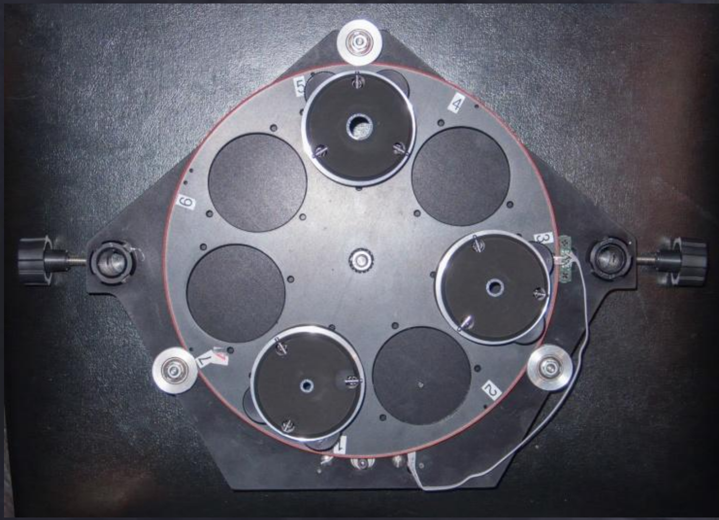


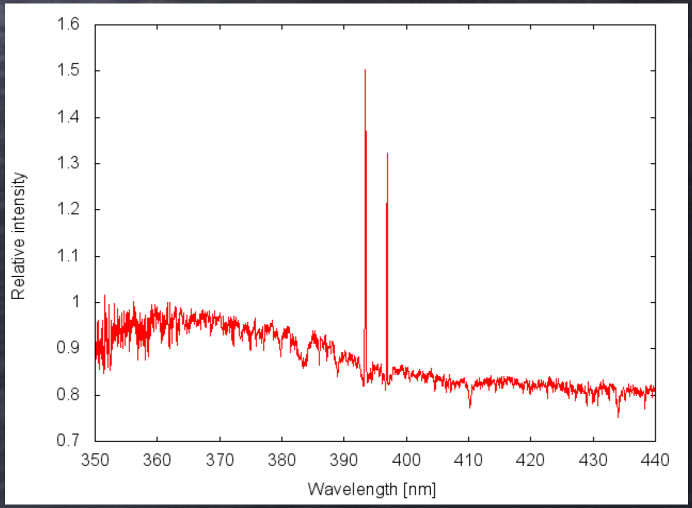
The HR4000 Spectrometer with a 3648-element CCD-array detector Toshiba enables optical resolution of 0.03 nm (FWHM).
Generally it can be responsive from 200-1100 nm, but the specific range and resolution depends on the grating and entrance slit choices.
We selected 350 – 430 nm device (grating 1800 gr./mm) as a first step.

Image selector

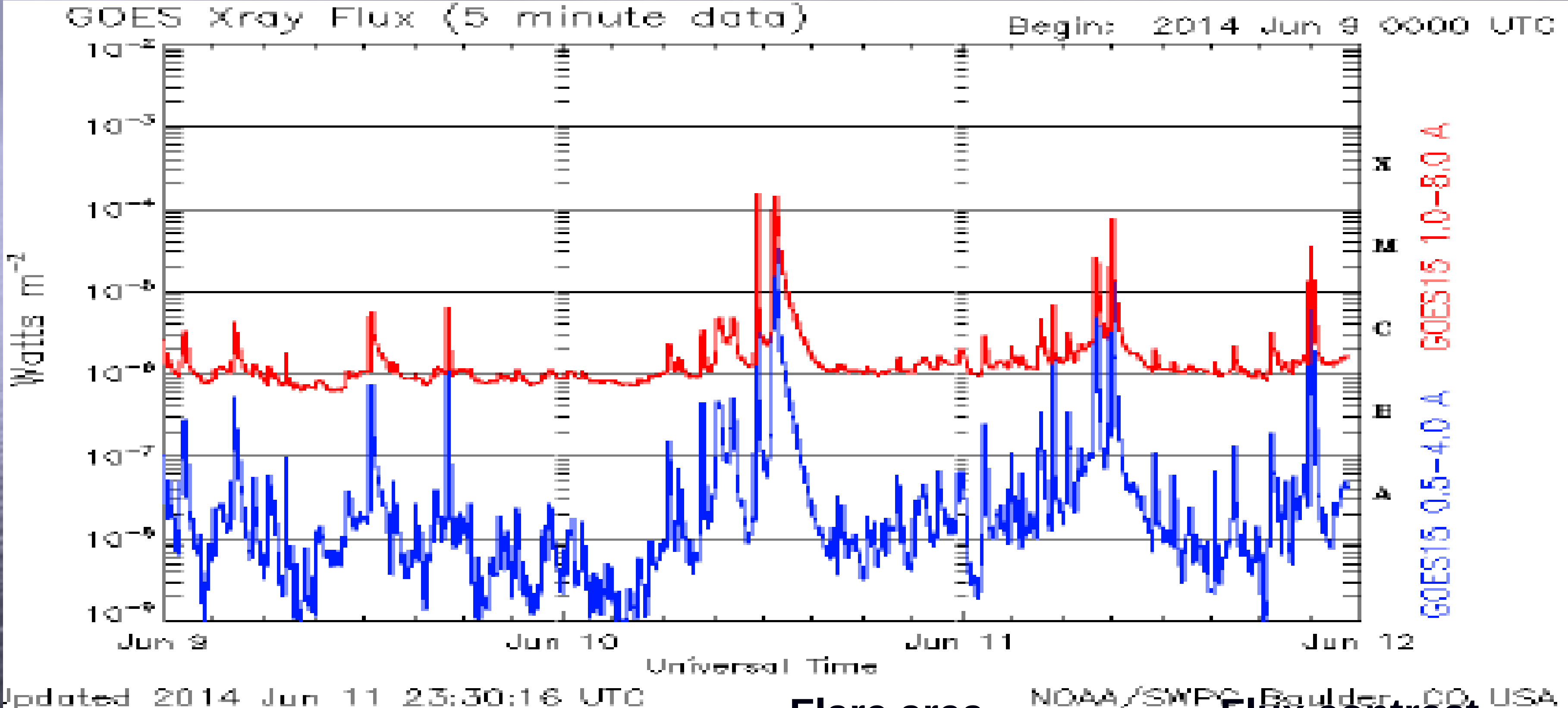






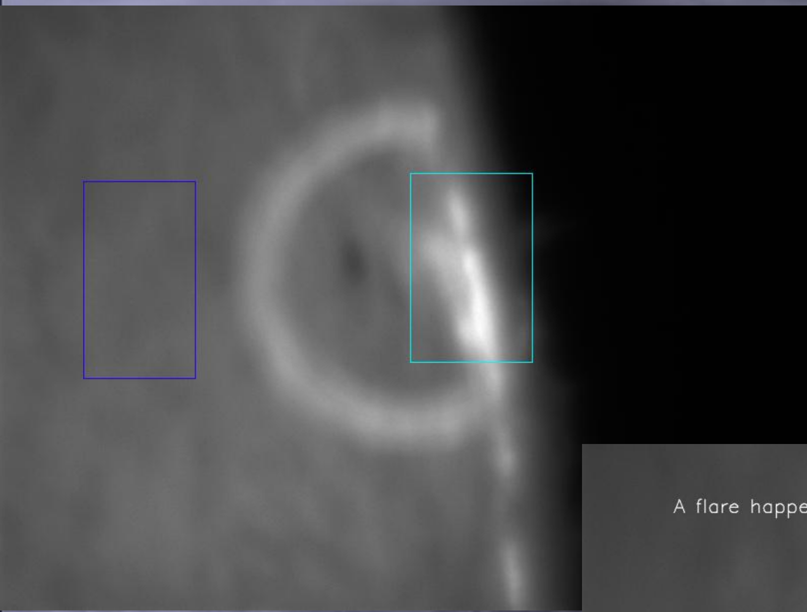


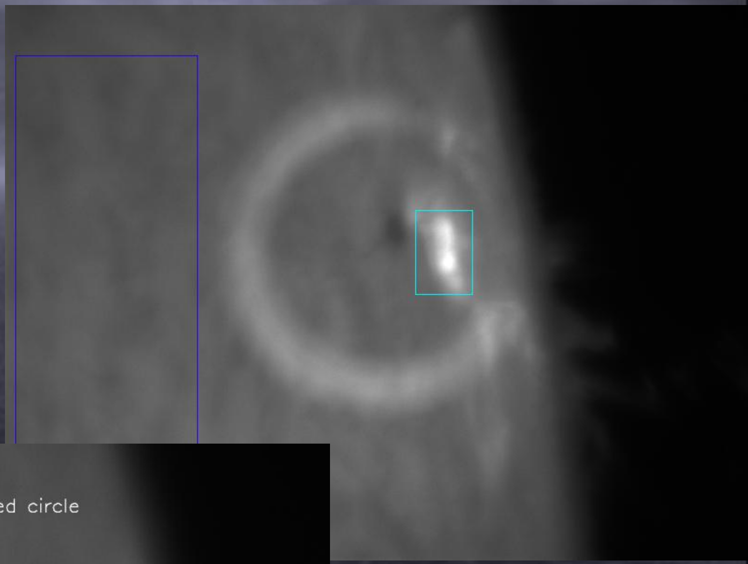
Measured flares in June 2014

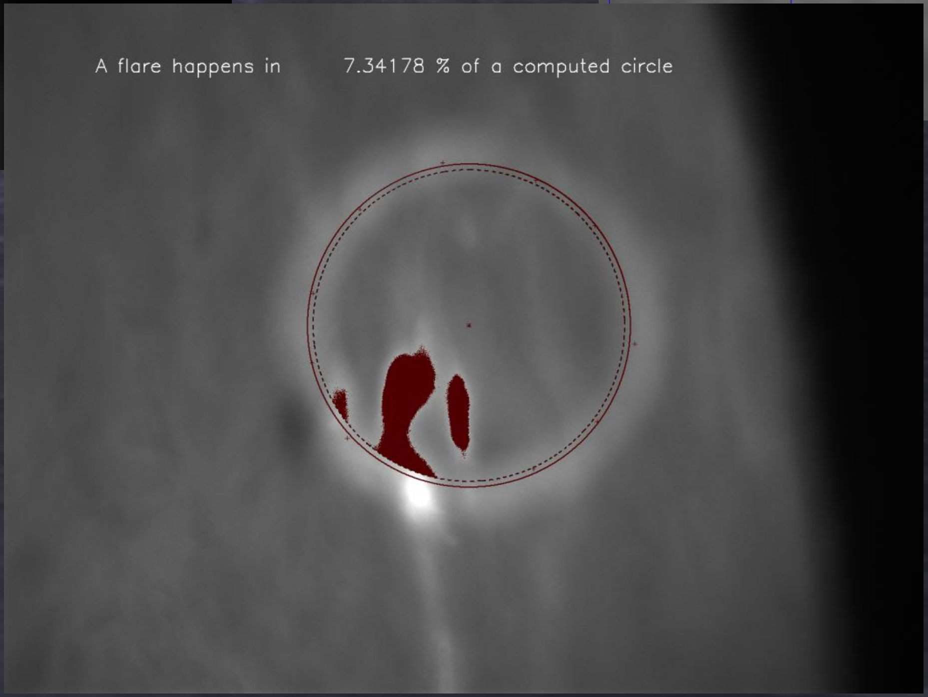


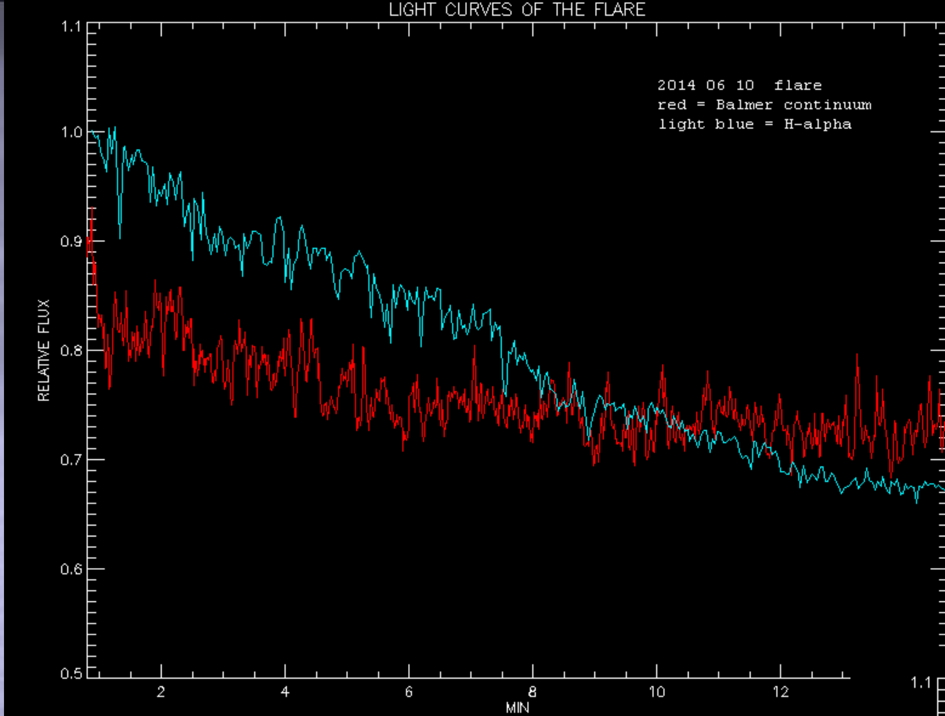
		Flare area	Flux contrast
X2.2	10.6. 11:42 UT	2.86 %	16 %
X1.5	10.6. 12:52 UT	8.46 %	13 %
X1.0	11.6. 9:04 UT	3.8 - 7.4 %	17 - 21 %

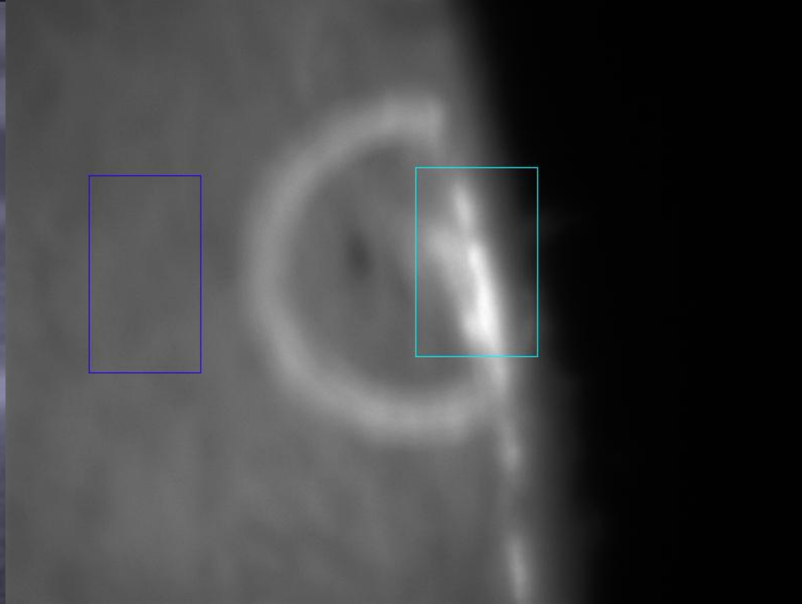
Flare X2.2, X1.5 and X1.0 in Hα

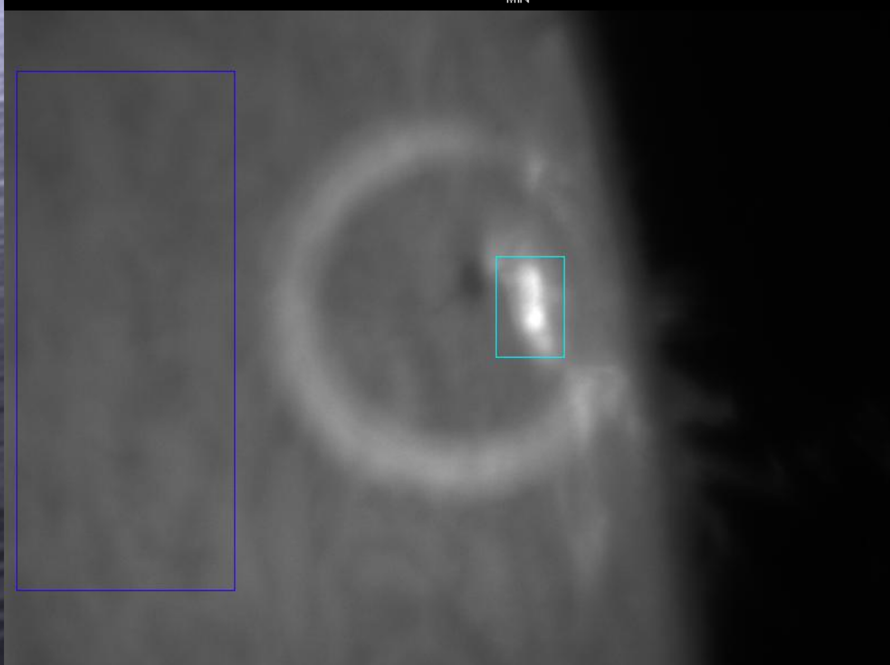


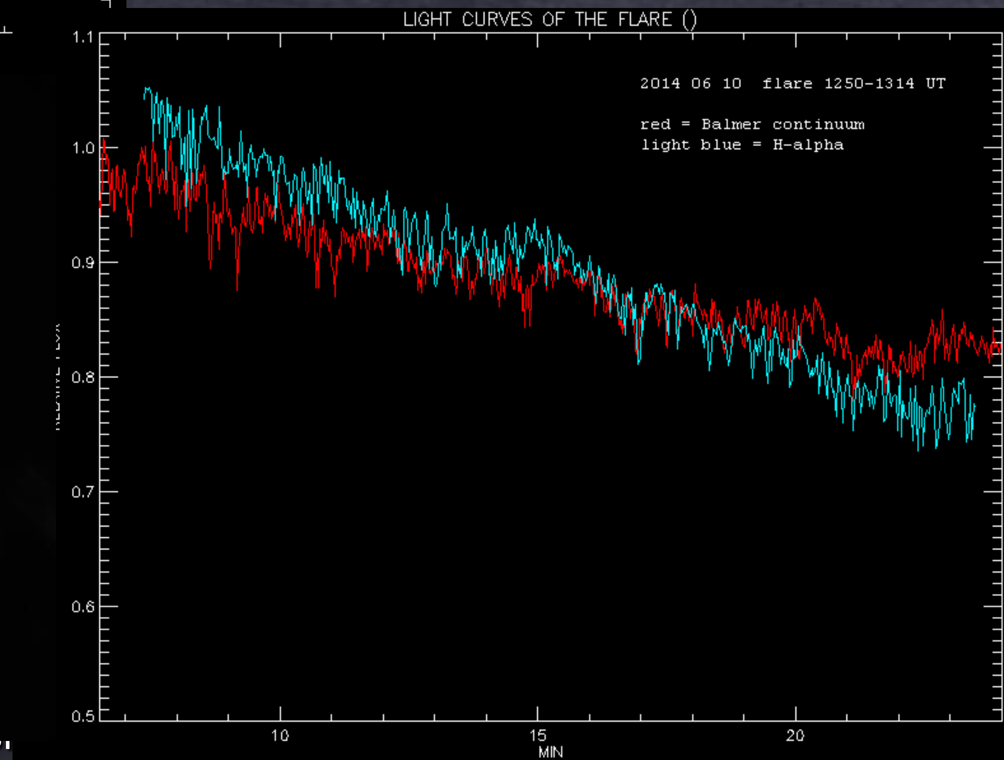


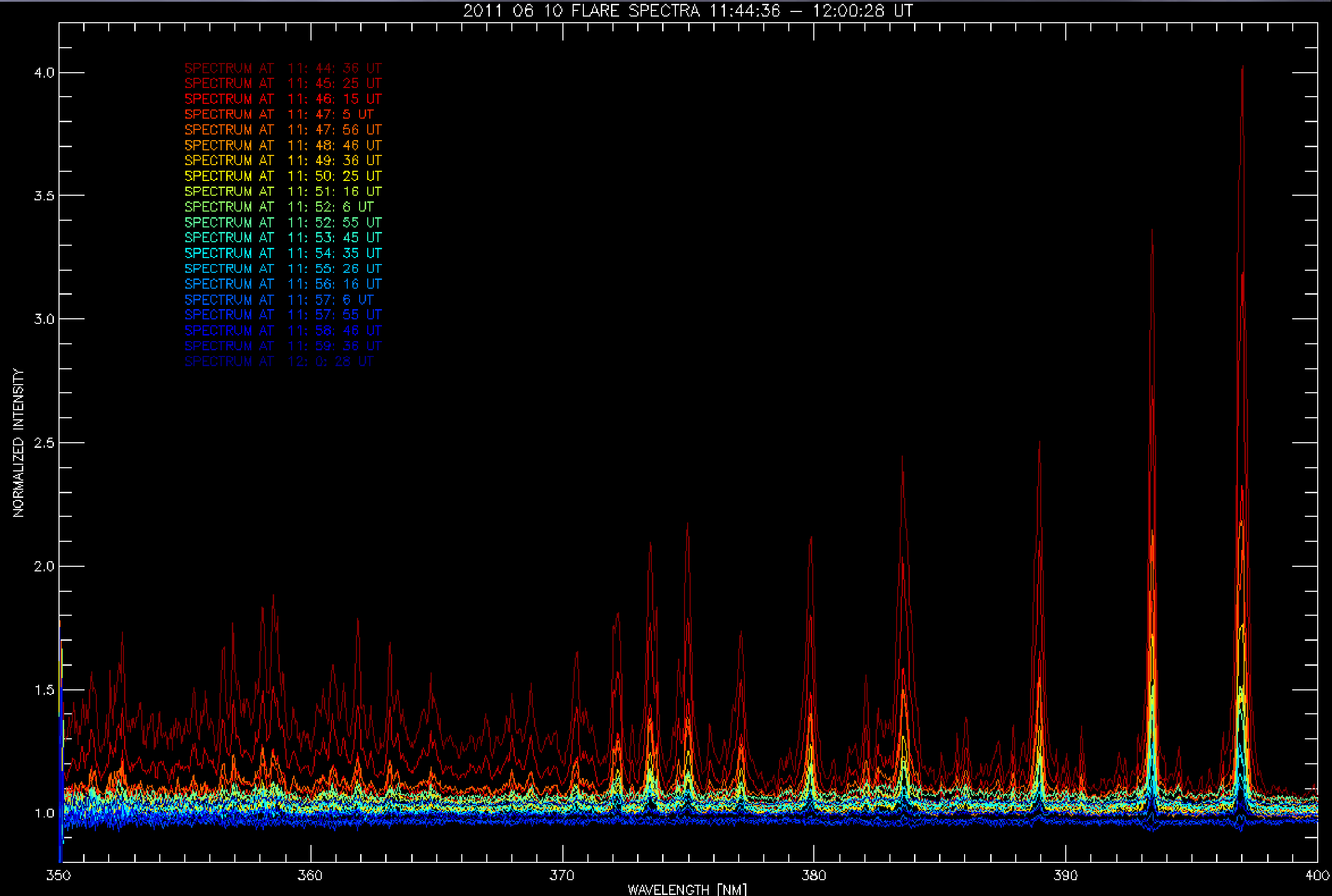


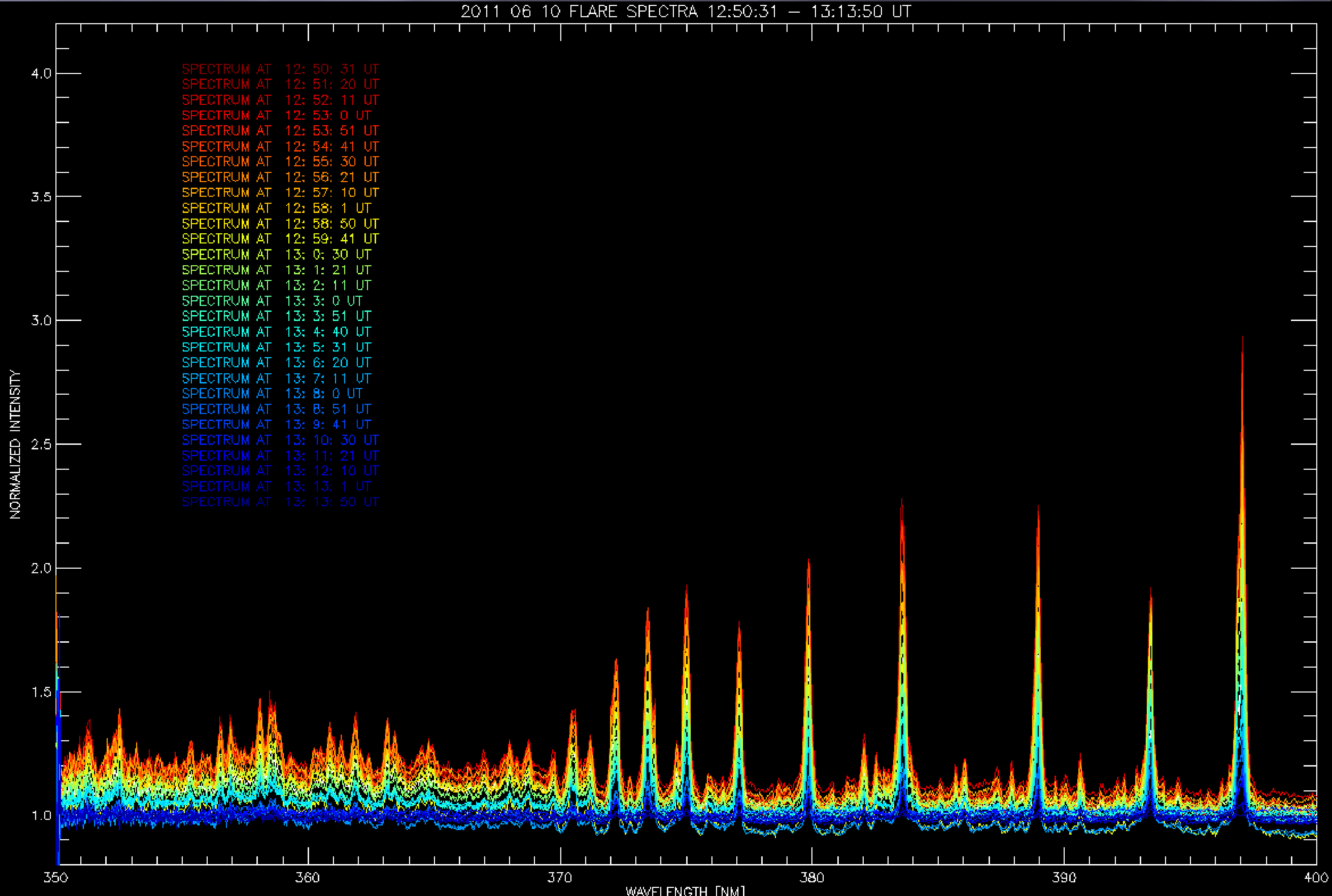

LIGHT CURVES OF THE FLARE
2014 06 10 flare
red = Balmer continuum
light blue = H-alpha
RELATIVE FLUX
MIN
1.1
1.0
0.9
0.8
0.7
0.6
0.5
2
4
6
8
10
12



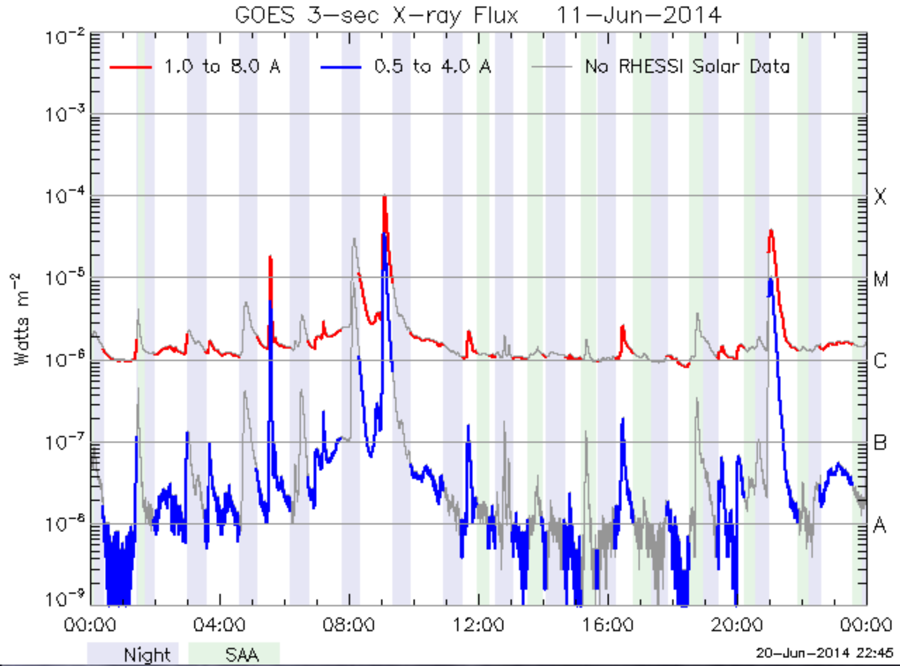


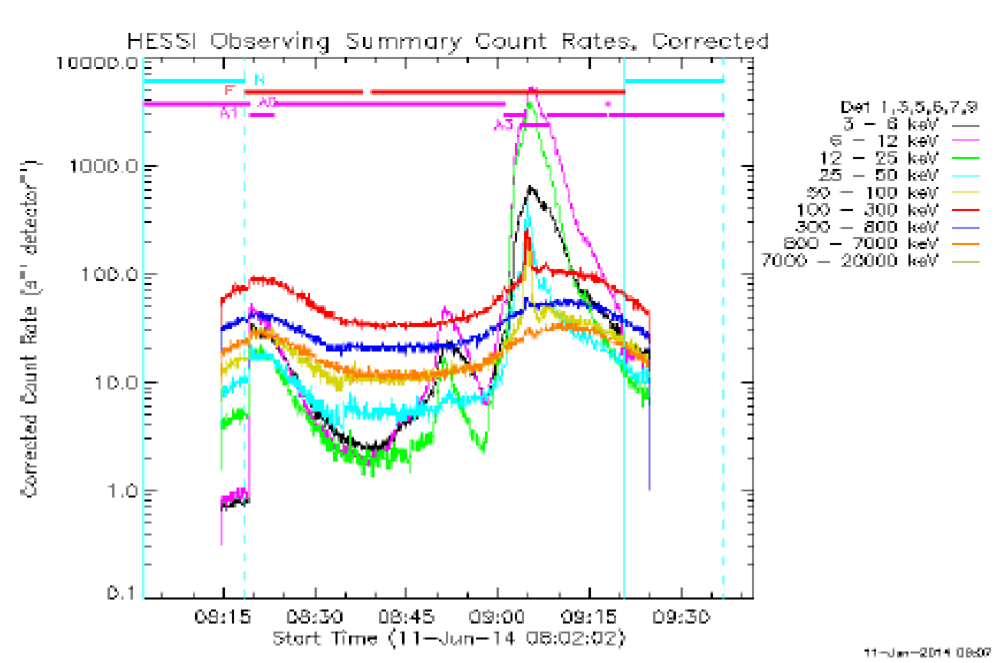

LIGHT CURVES OF THE FLARE ()
2014 06 10 flare 1250-1314 UT
red = Balmer continuum
light blue = H-alpha
MIN
1.1
1.0
0.9
0.8
0.7
0.6
0.5
10
15
20

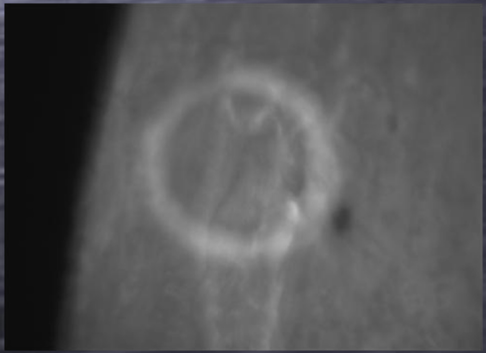

2011 06 10 FLARE SPECTRA 11:44:36 – 12:00:28 UT
SPECTRUM AT 11: 44: 36 UT
SPECTRUM AT 11: 45: 25 UT
SPECTRUM AT 11: 46: 15 UT
SPECTRUM AT 11: 47: 5 UT
SPECTRUM AT 11: 47: 56 UT
SPECTRUM AT 11: 48: 46 UT
SPECTRUM AT 11: 49: 36 UT
SPECTRUM AT 11: 50: 25 UT
SPECTRUM AT 11: 51: 16 UT
SPECTRUM AT 11: 52: 6 UT
SPECTRUM AT 11: 52: 55 UT
SPECTRUM AT 11: 53: 45 UT
SPECTRUM AT 11: 54: 35 UT
SPECTRUM AT 11: 55: 26 UT
SPECTRUM AT 11: 56: 16 UT
SPECTRUM AT 11: 57: 6 UT
SPECTRUM AT 11: 57: 55 UT
SPECTRUM AT 11: 58: 46 UT
SPECTRUM AT 11: 59: 36 UT
SPECTRUM AT 12: 0: 28 UT
NORMALIZED INTENSITY
4.0
3.5
3.0
2.5
2.0
1.5
1.0
350
360
370
380
390
400
WAVELENGTH [NM]


2011 06 10 FLARE SPECTRA 12:50:31 – 13:13:50 UT
SPECTRUM AT 12: 50: 31 UT
SPECTRUM AT 12: 51: 20 UT
SPECTRUM AT 12: 52: 11 UT
SPECTRUM AT 12: 53: 0 UT
SPECTRUM AT 12: 53: 51 UT
SPECTRUM AT 12: 54: 41 UT
SPECTRUM AT 12: 55: 30 UT
SPECTRUM AT 12: 56: 21 UT
SPECTRUM AT 12: 57: 10 UT
SPECTRUM AT 12: 58: 1 UT
SPECTRUM AT 12: 58: 50 UT
SPECTRUM AT 12: 59: 41 UT
SPECTRUM AT 13: 0: 30 UT
SPECTRUM AT 13: 1: 21 UT
SPECTRUM AT 13: 2: 11 UT
SPECTRUM AT 13: 3: 0 UT
SPECTRUM AT 13: 3: 51 UT
SPECTRUM AT 13: 4: 40 UT
SPECTRUM AT 13: 5: 31 UT
SPECTRUM AT 13: 6: 20 UT
SPECTRUM AT 13: 7: 11 UT
SPECTRUM AT 13: 8: 0 UT
SPECTRUM AT 13: 8: 51 UT
SPECTRUM AT 13: 9: 41 UT
SPECTRUM AT 13: 10: 30 UT
SPECTRUM AT 13: 11: 21 UT
SPECTRUM AT 13: 12: 10 UT
SPECTRUM AT 13: 13: 1 UT
SPECTRUM AT 13: 13: 50 UT
NORMALIZED INTENSITY
4.0
3.5
3.0
2.5
2.0
1.5
1.0
350
360
370
380
390
400
WAVELENGTH [NM]

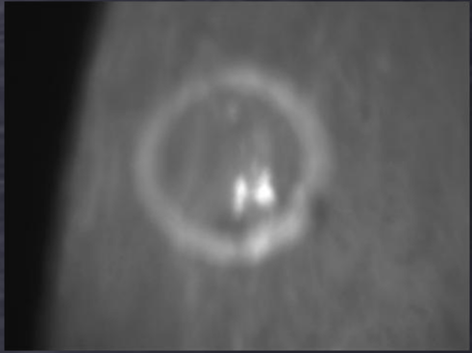
Flare X1.0 on June 11, 2014



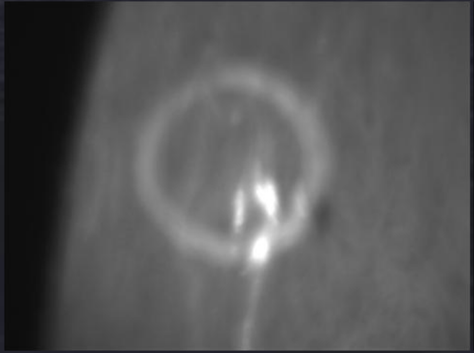




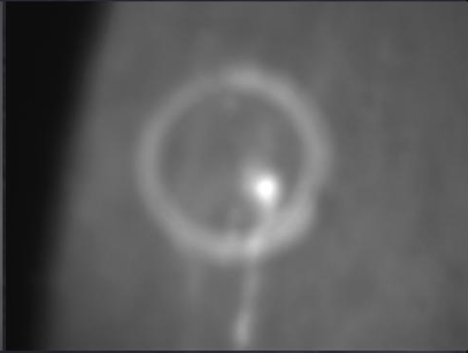
08:43:55 UT



09:02:14 UT

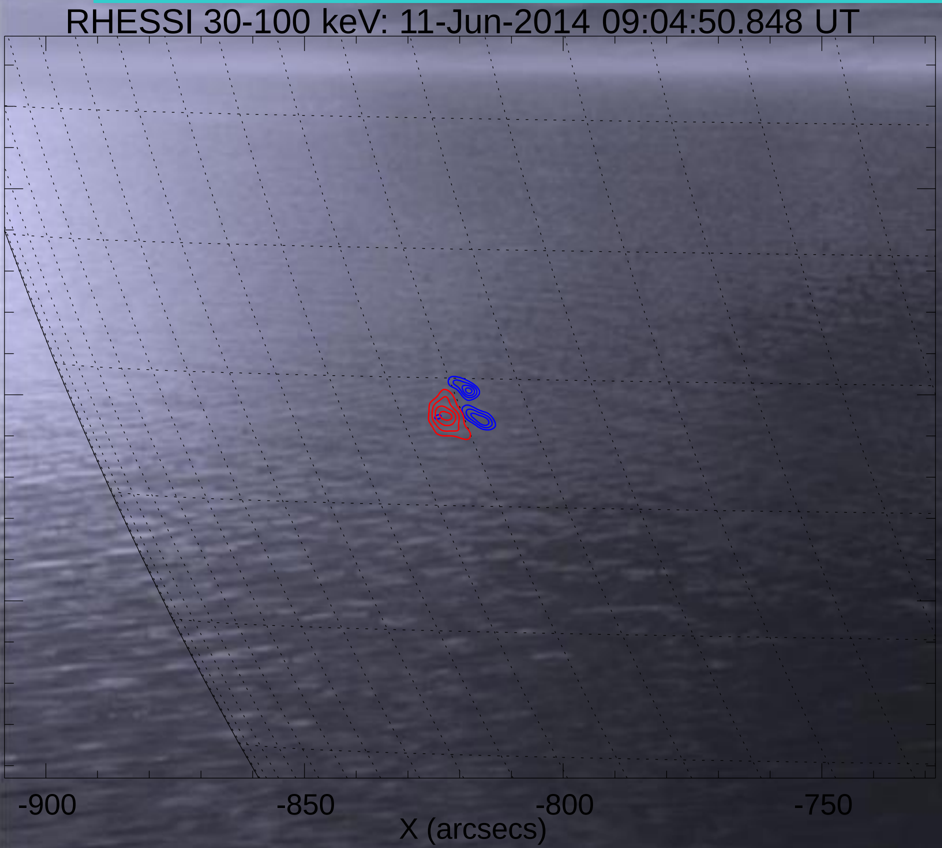


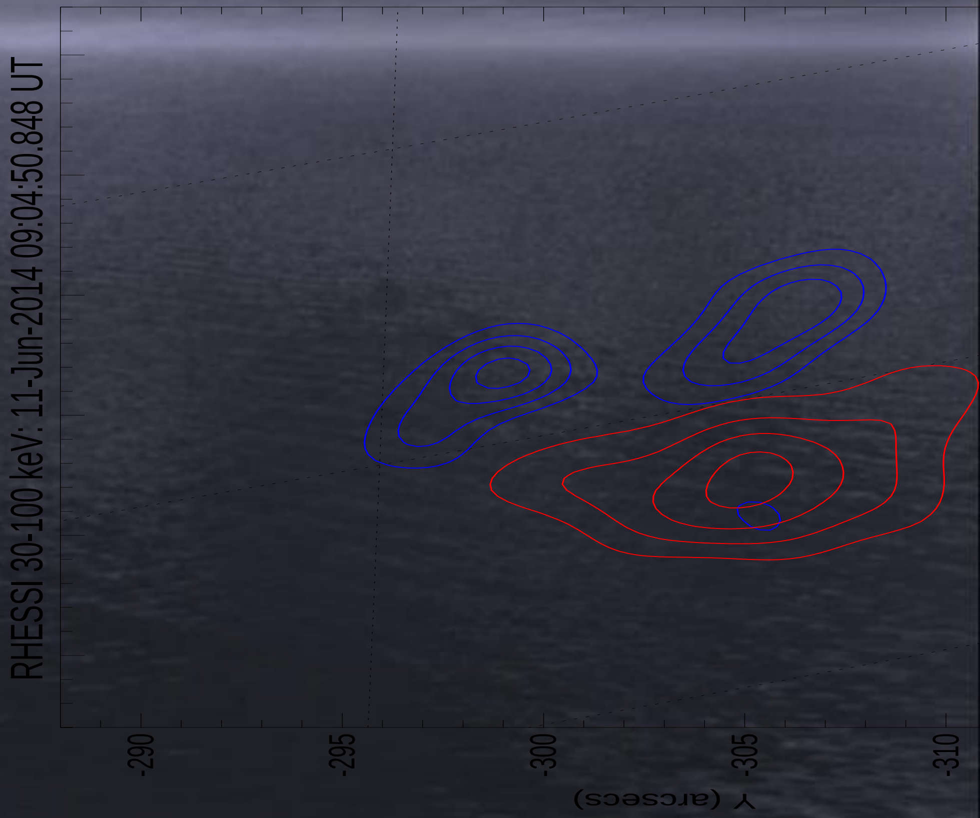
09:04:32 UT



09:09:32 UT

RHESSI imaging - courtesy of Sam Krucker

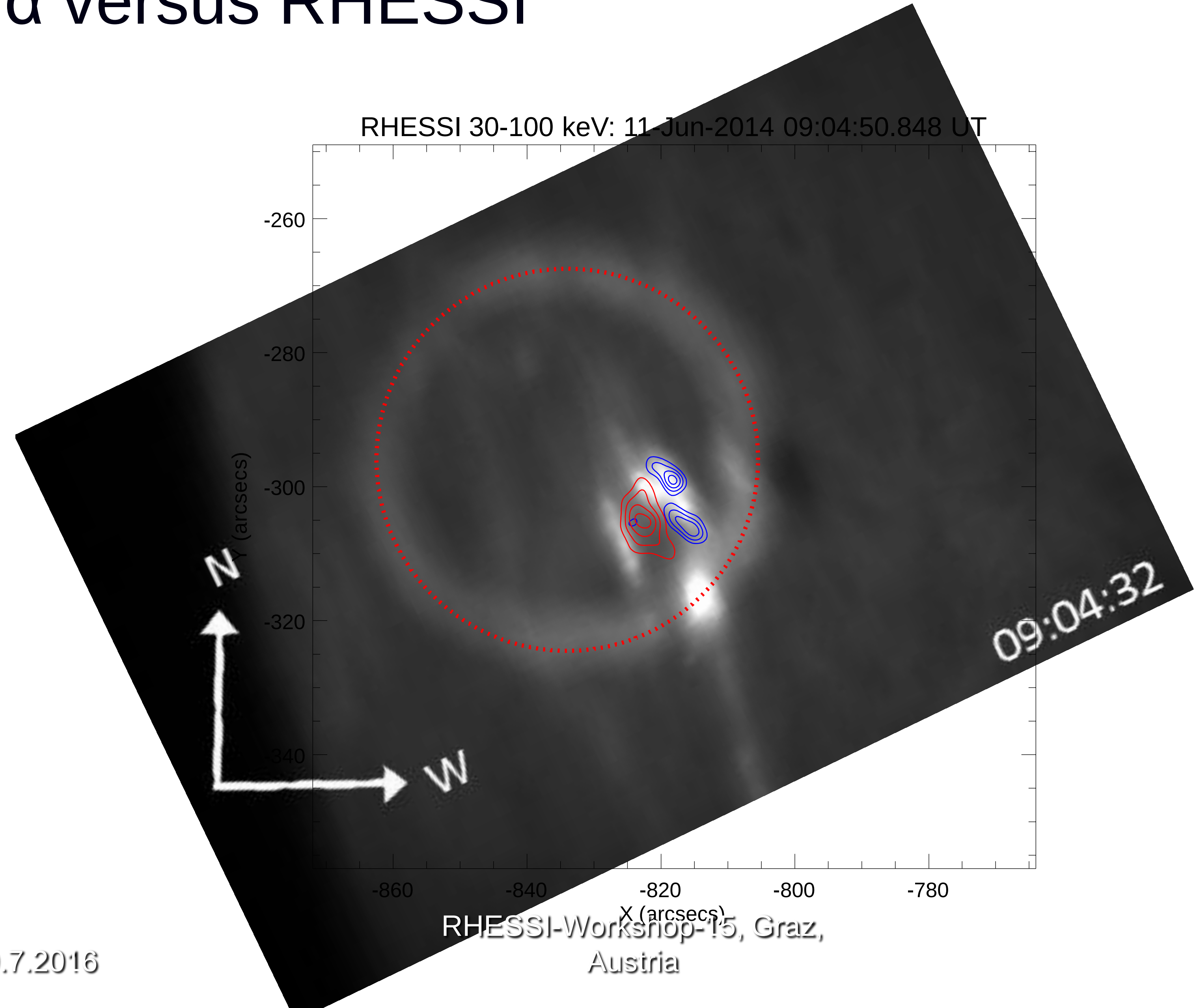


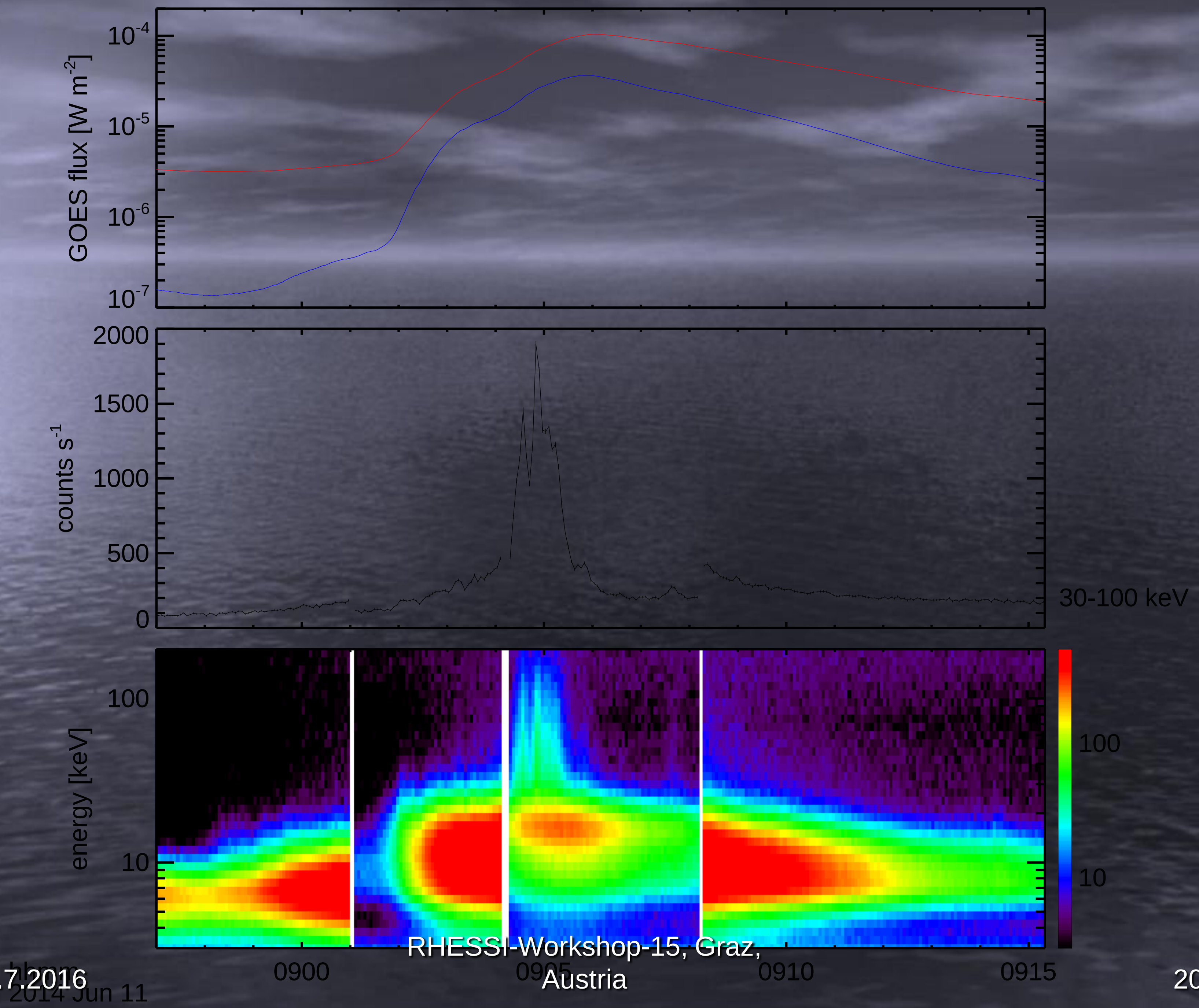


12-15 keV
30-100 keV

12-15 keV
30-100 keV

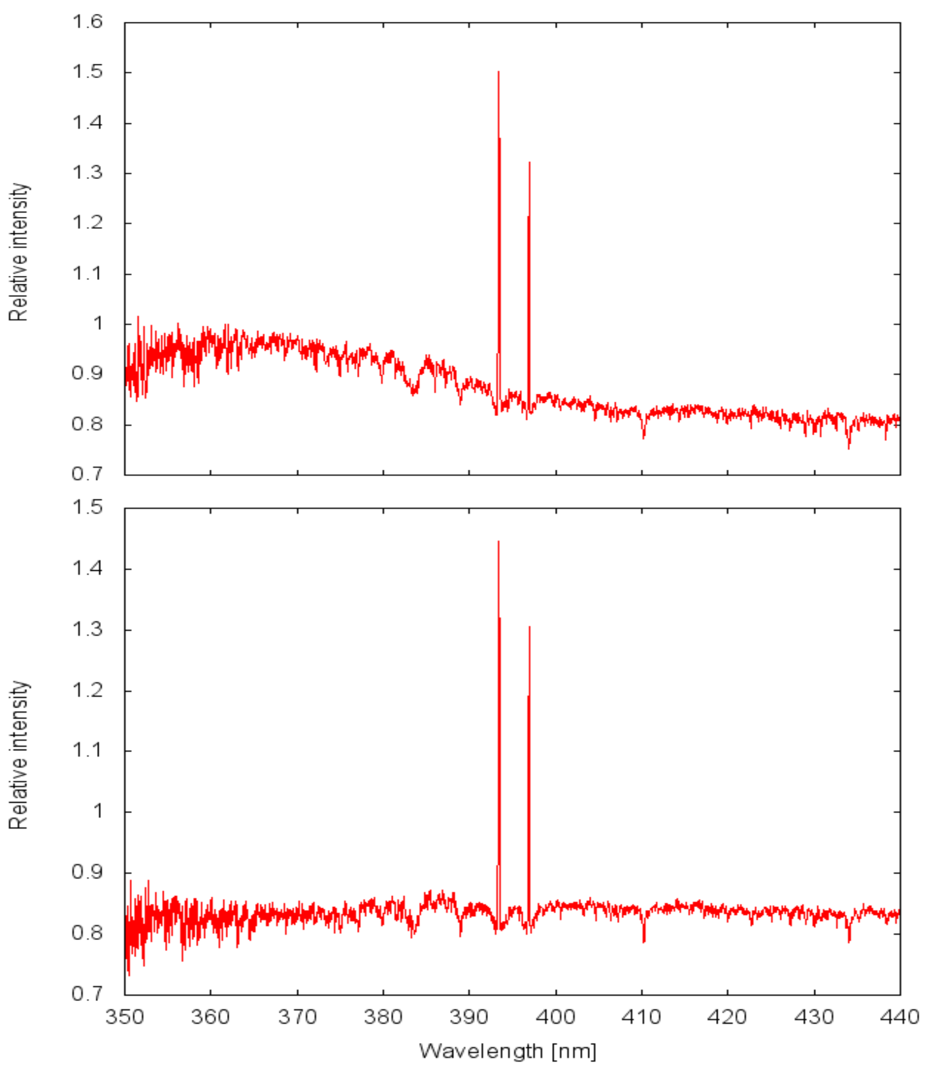
Hα versus RHESSI

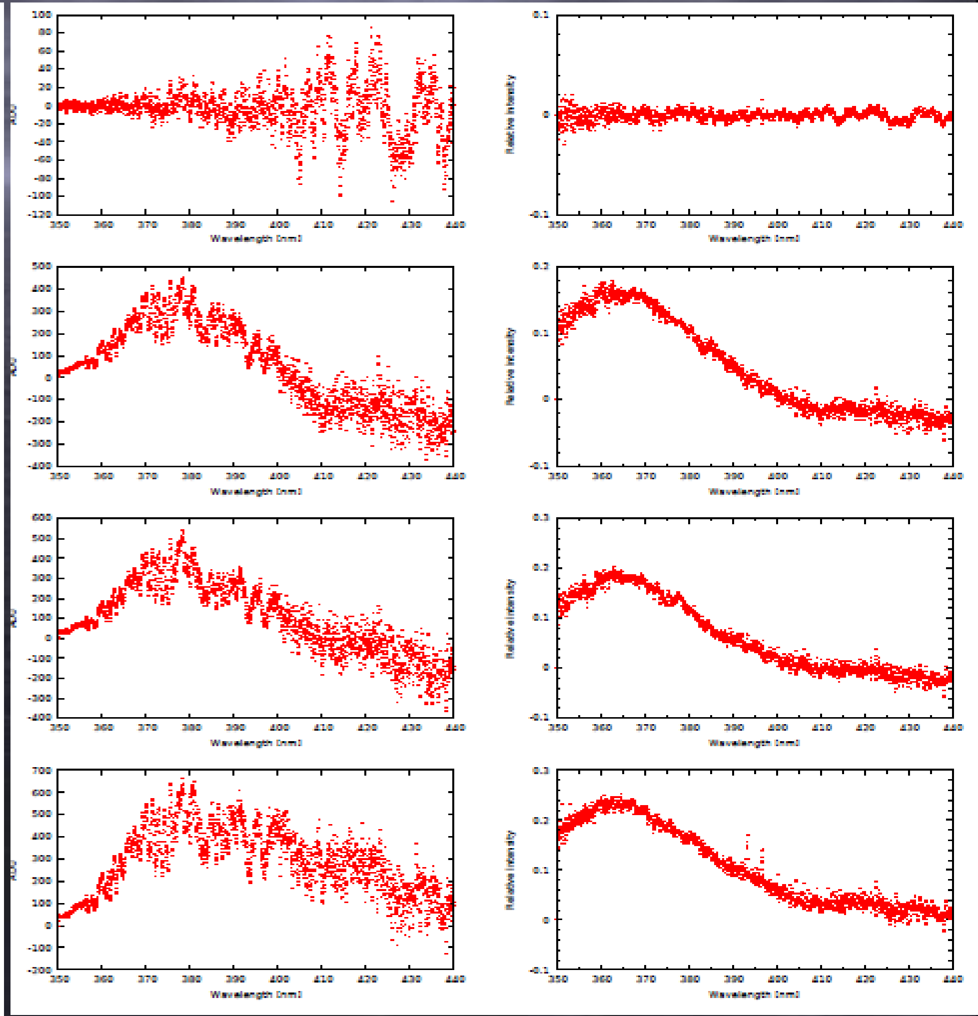




GOES flux [W m-2]
10-4
10-5
10-6
10-7
counts s-1
2000
1500
1000
500
0
30-100 keV
energy [keV]
100
10
100
10
0900
0905
0910
0915
2014 Jun 11

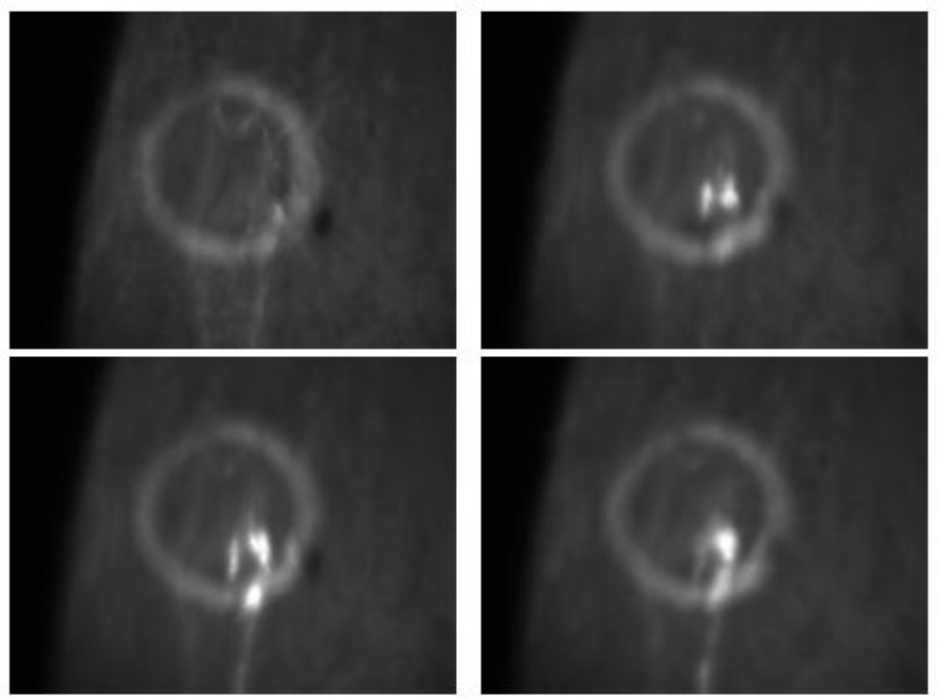
Measurements of blue continuum



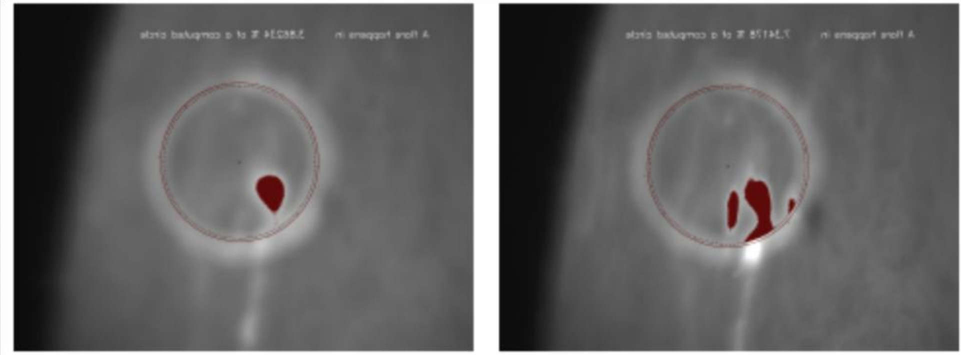


Difference F-QS **(F-QS)/QS**

Balmer continuum flux - contrast



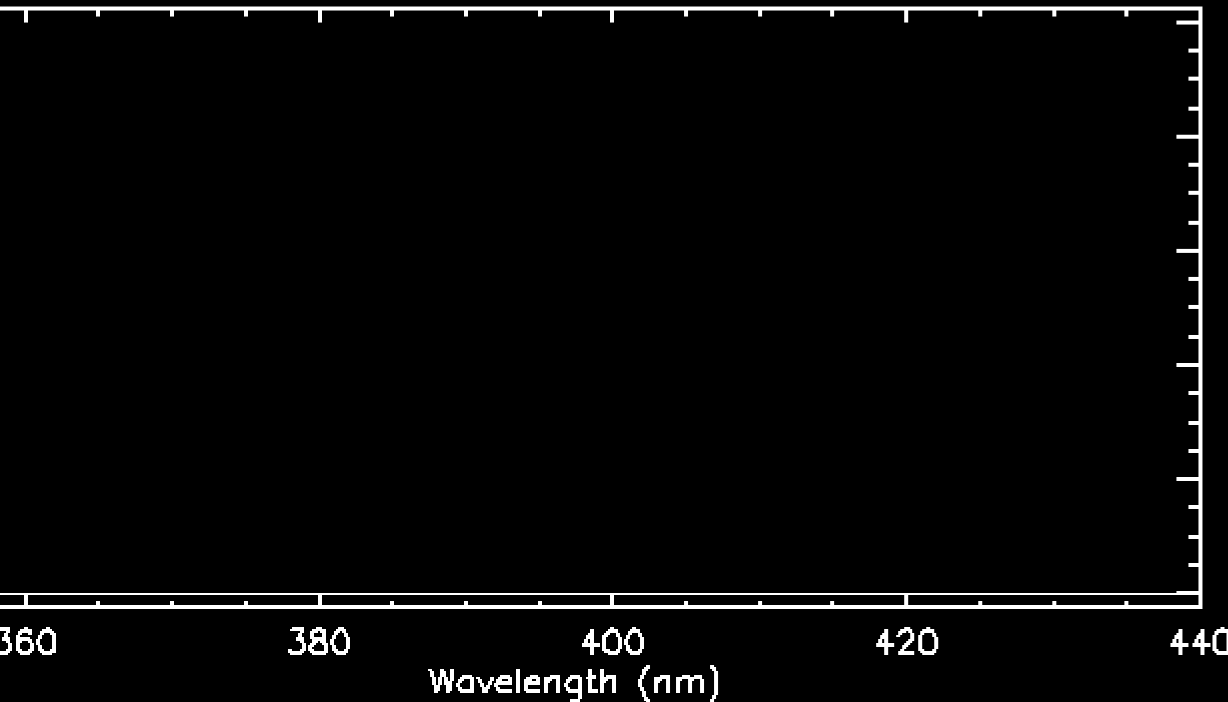
Supposing the plasma material flaring in H-alpha is the same as in Balmer cont., then the contrast in Balmer is about 500 percent.



Třída erupce	Peak dle GOES	Plocha erupce na SJ	Nárůst ve spektru $\lambda = 364.6$ nm
X2.2	10.6. 11:42 UT	2.86 %	16 %
X1.5	10.6. 12:52 UT	8.46 %	13 %
X1.0	11.6. 9:04 UT	3.8 - 7.4 %	17 - 21 %

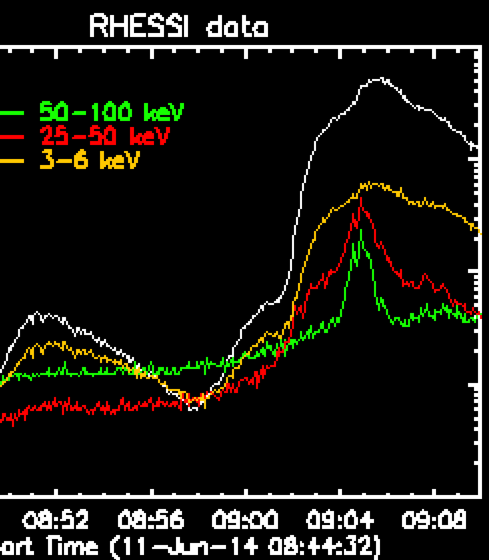
Measurements

11-Jun-2014 08:44:32.00

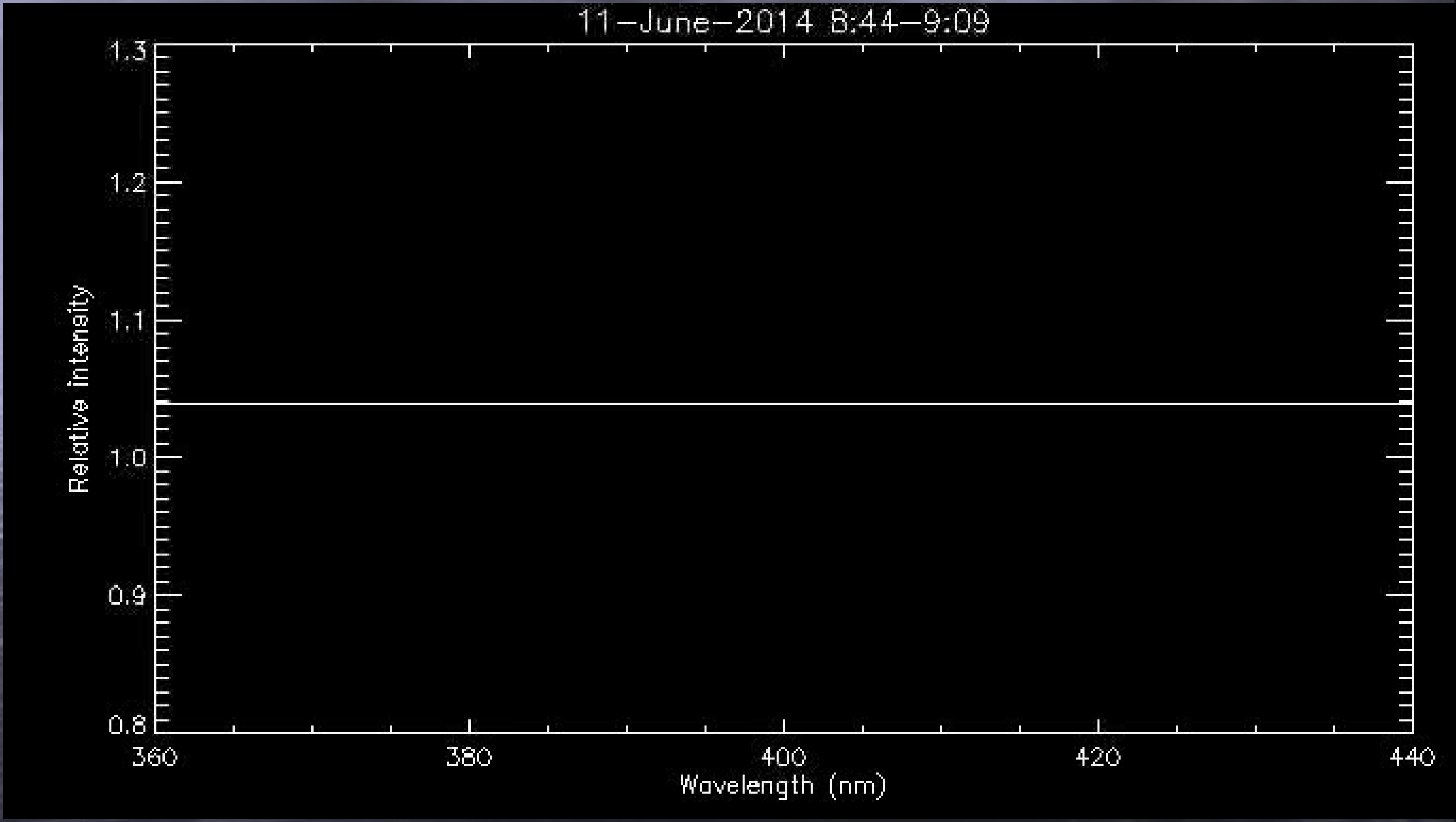


AIA/SDO 304

AIA/SDO 1700



Seeing effects removed



Summary

- A new device for measuring blue continuum in solar flares was developed and put in operation in Ondrejov
- 3 X-class flares we observed, blue continuum was measured
- Contrast in Balmer continuum in flare maximum was evaluated to be 5 x higher than the background radiation
- An increase of flux in Balmer continuum started 16 minutes before the first H-alpha increase
- Further observations and analysis of the data are performed (correlation of channels, presence of QPP, etc.)

Acronym needed suggestions welcomed

Key words:

Ondrejov – **L**ow **D**ispersion – **F**lare **S**pectrograph

A winner receives observing time

Send acronym suggestions to
pkotrc@asu.cas.cz

Prospects

Blue continuum flux measurement in solar flares is a perspective tool for studing a mechanism of energy release in flares.

Now we are splitting the light beam for a second spectrometer measuring simultaneously in the range of 480 – 920 nm (Paschen continuum).

Thank for your attention

Balmer continuum contrast in flare

09:04:32 UT **09:09:30 UT**