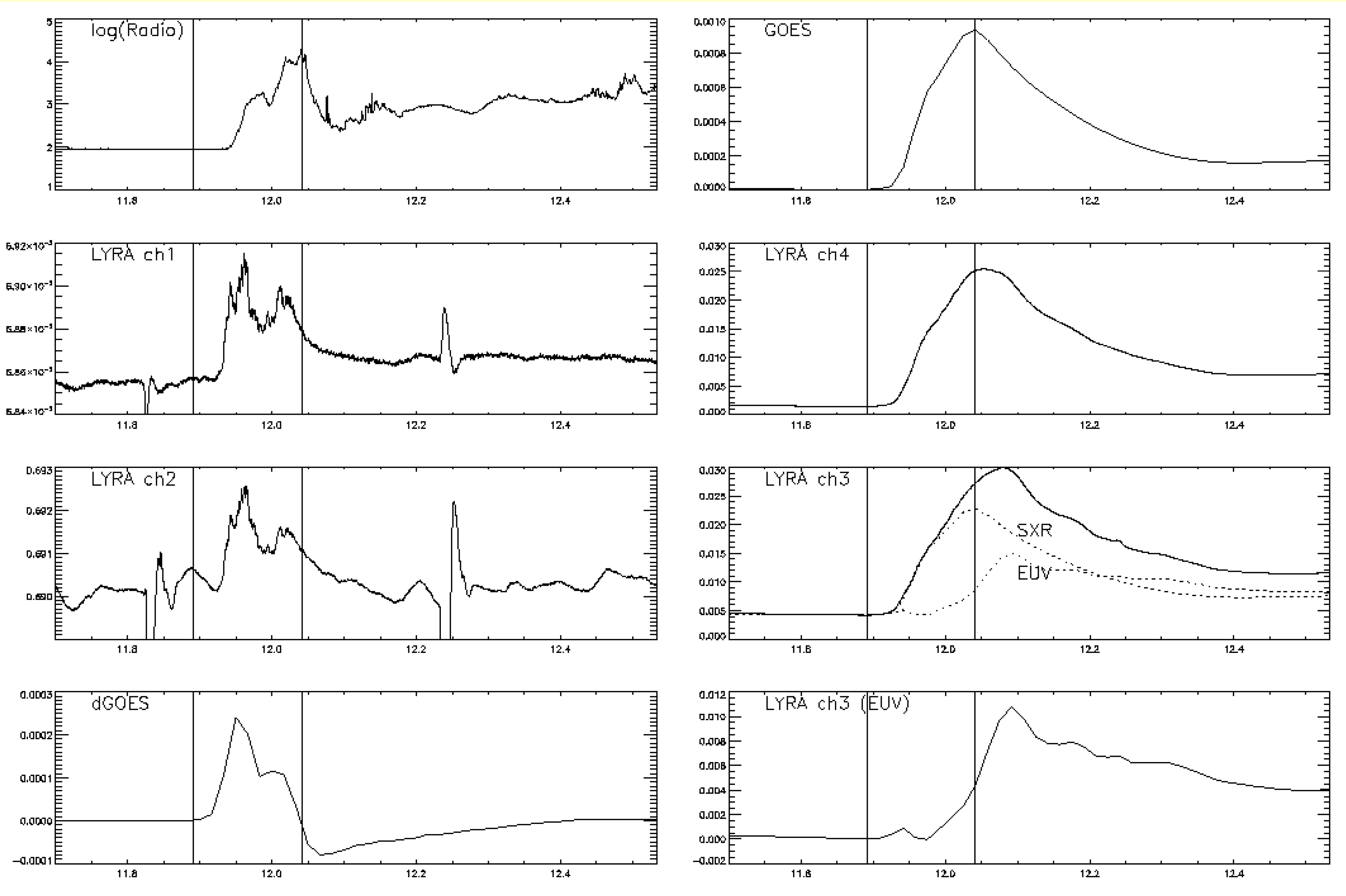
Multi-instrument observations of an X9.3 flare

I.E. Dammasch, M. Dominique, J. Magdalenic, C. Marqué
(Royal Observatory of Belgium)

Abstract: The radiometer LYRA on PROBA2 observed the X9.3 flare of 06 Sep 2017, the strongest flare of this solar cycle. We found flare signatures in all of LYRA's spectral channels: Lyman-alpha (120-123nm), Herzberg continuum (190-222nm), as well as EUV and SXR. These observations are compared with GOES observations, and radio observations by the local HUMAIN station.

Observations:



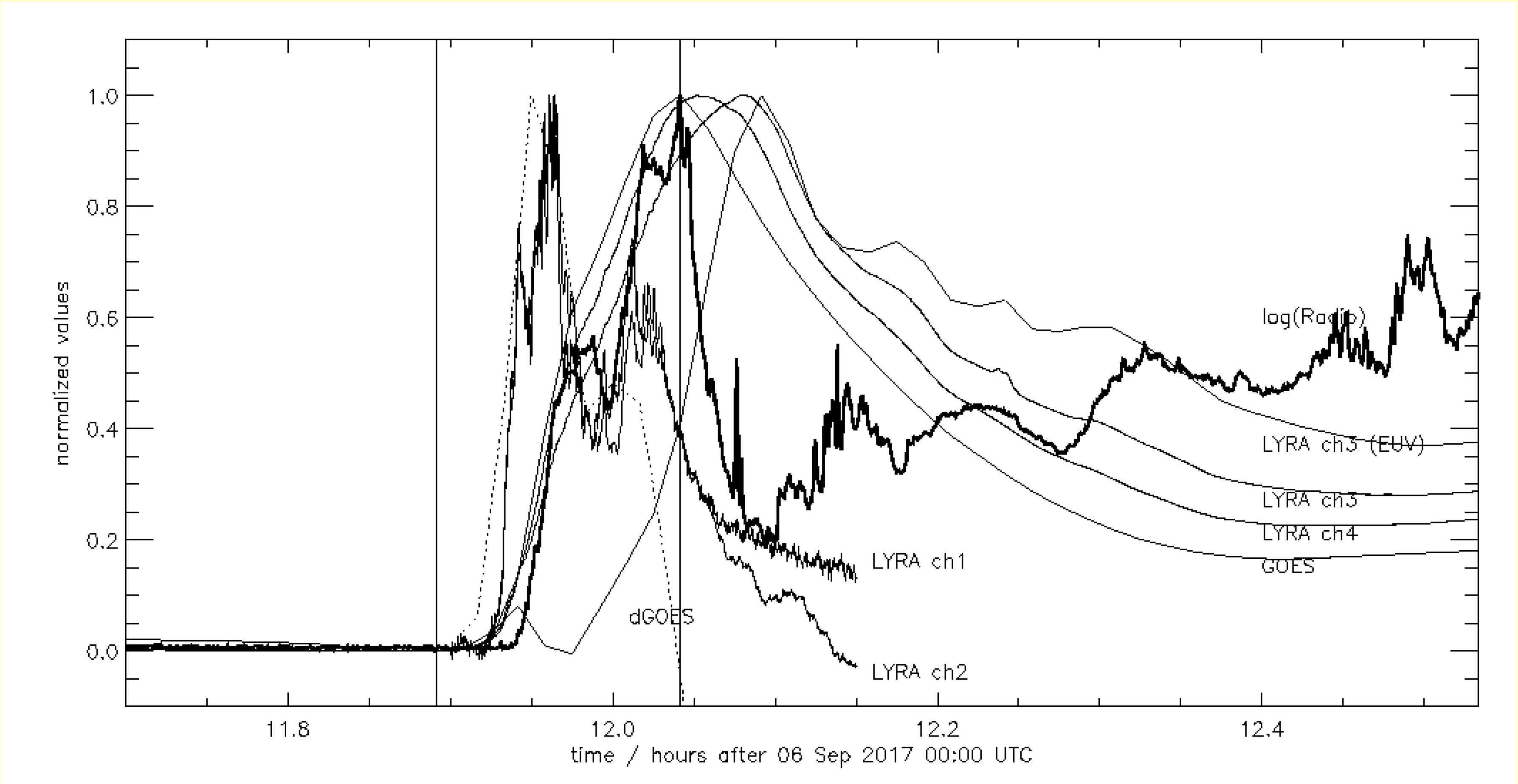


Figure 2 shows the eight normalized light curves, prepared in this way to allow a more straightforward comparison of the flare development

Figure 1 shows different light curves vs. time between 11:42 and 12:32 UTC. The left-hand column corresponds to the signature of the impulsive phase of the flare when non-thermal electrons impact the inner solar corona. We see the result in Lyman-alpha, and possibly its indirect signature in radio. The right hand side corresponds approximately to the cooling of the plasma (after the peak time) witnessed by the GOES and LYRA curves. Using the "Events" list of the NOAA Space Weather Prediction Center, the beginning of the flare (11:53) and the flare peak (12:02) are marked with vertical lines. Solar irradiances are in W m^-2.

Radio
This is emission in 1413.5 MHz, i.e, the mid of the 1400-1427 MHz astronomical band, from HUMAIN radioastronomy station, in 2.8 second time resolution, in solar flux unit (10^-22 W m^-2 Hz^-1), plotted in logarithmic scale. The time line is extracted from a time/frequency spectrum of the Sun, recorded by a digital radio spectrometer. The original time resolution is about 0.25s. The flux was calibrated based on Quiet Sun values observed prior to the event. An assumption is made that the radio event is unpolarized.

LYRA ch1
This is the "Lyman-alpha" channel of the LYRA instrument which observes the H I 121.5nm line between 120 and 123nm, in 1 second time resolution (the original resolution is 20ms). Possibly we do not see a thermal signature of a chromosphere or transition region temperature where this line is formed, but a non-thermal signature, like free-free emission or "Bremsstrahlung" (Feldman et al, 2003), or coming from hydrogen recombination in Balmer continuum (Heinzel et al, 2016). Observations like these are relatively rare, LYRA saw about a dozen of these (Kretzschmar et al, 2012)

LYRA ch2
This is the "Herzberg continuum" channel of LYRA, observing the spectral interval 190-222nm, which in the past years did not show flare signatures. It needed this exceptionally strong flare to catch the ch2 signature, and the spare unit which has only been used for calibration purposes and is therefore almost non-degraded. We see basically the same information as in LYRA ch1, possibly coming from a similar source: hydrogen recombination in Balmer continuum (Dominique et al, in prep). - The abrupt oscillations after 11.8 and 12.2 UTC in ch1 and ch2 are instrument artifacts due to satellite roll maneuvers.

dGOES
This is the first derivative of the GOES curve. In accordance with the Neupert effect, it can be used as a proxy for non-thermal signatures (hard X-ray) in particular when there are no other observations, like in this event. But in this case, the two LYRA observations above do exist, and the similarity with dGOES shows that these observations are indeed showing non-thermal flare signatures.

GOES
This is the 0.1-0.8nm soft X-ray flux of the GOES instrument, in 1 minute time resolution. It represents the hottest flare plasma (10^7 K). The GOES curve is the first thermal curve to peak, during the minute following 12:02 UTC.

LYRA ch4
This is the "Zirconium filter" channel of LYRA, observing two intervals: below 2nm, and 6-20nm. Its curve is therefore more similar to the GOES observation than LYRA ch3, and peaks between GOES and LYRA ch3.

LYRA ch3
This is the "Aluminium filter" channel of LYRA, also observing two spectral intervals: below 5nm (SXR), and 17-80nm (EUV). Because this channel has hardly been used in the past, it is almost non-degraded and the EUV part of the spectral input is still strong. Due to this influence, LYRA ch3 again peaks later.

LYRA ch3 (EUV)
With the help of the GOES curve, the influence of the two different components was estimated, the EUV part being responsible for relatively cooler plasma than the SXR part. The little peak before the flare probably shows the heating-up phase of the plasma, the peaks after the flare show the cooling-down phase.

Results:

The radio curve shows a delay in time, i.e. it rises about one to two minutes later than the other three flare profiles observed in "non-thermal" lines. These flare light curves show a similar shape with two distinct peaks. The second radio peak is co-temporal with the GOES peak and it is somewhat stronger than the first peak. Like the other non-thermal curves, it shows faster decrease than the thermal curves. Then it starts rising again, showing oscillations like the EUV curve, but also somewhat later. - The radio curve shows several components that can be analyzed only by looking at the full spectrum. Prior to the peak time of the flare, the radio emission is surely non-thermal, but it is likely to be a mix of plasma emissions and possible the lower end of very high frequency synchrotron emission of high energy electrons (or non-thermal "Bremsstrahlung"?) One can drive this hypothesis as Ondrejov radio observatory observes up to 5 GHz intense emissions. RSTN observations also report high frequency emissions up to 15 GHz during the event. Later on, after the flare peak time, a type IV radio burst is observed, which could be considered as the radio counterpart of the post-flare loops observed in EUV.

References:

Feldman et al, Astrophysical Journal 593, 1226 (2003)
Heinzel et al, Proceedings IAU 320, 233 (2016)
Kretzschmar et al, Solar Physics 286, 221 (2013)

Additional info on the LYRA instrument and its degradation
BenMoussa et al, Solar Physics 288, 389 (2013)
Dominique et al, Solar Physics 286, 21 (2013)