# MAGNETIC CROCHET ASSOCIATED TO THE SEISMICALLY ACTIVE FLARE OF MARCH 29, 2014

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On March 29, 2014 *GOES* detected a X1.0 solar flare in the central north-western part of the solar disk. We present here its main characteristics and several interesting effects in the Earth's magnetosphere and ionosphere. We chose this flare because of its seismic emission (a recent discovery in solar physics which is not yet fully understood) and its many associations with different wavelength signatures. Seismic signatures share the same location (projected on the solar disk) as the hard X-ray emission suggesting that the energy released by the electrons is responsible for the excitation of the acoustic emission. Ground based instruments have detected a disturbance in the propagation of the terrestrial radio transmission. A flash in the extreme UV radiation influenced the ionization in the Earth's upper atmosphere and was seen as a sudden ionospheric disturbance (SID). Several ground based magnetometers have detected a magnetic crochet. We investigate the main emissions characteristics of the flare, its seismic emission associated, the CME that was registered about half an hour later, and its induced terrestrial effects: SIDs and magnetic crochets.

*Key words:* magnetic crochet, solar flare, CME, SID

## 1. Introduction

Solar flares are the most energetic phenomena produced by the Sun. The first solar flare to have been observed was in 1859 as a localized brightening in a sunspot group by two independent observers, Carrington (1859) and Hodgson (1859). It was a white light flare, the only type visible at the time that seemed to have covered a large part of the sunspot group. Cliver (2006), in a historical review, state that a magnetic crochet also accompanied this flare. For this event people noticed a direct link between a solar event and a geomagnetic storm, also, for the first time. Since then solar flares have been noticed to have direct or indirect impact on our lives, one of these consequences being the magnetic crochet.

A magnetic crochet (or solar flare effect) represents a magnetic variation in the geomagnetic field due to a solar flare. It is a ripple in the Earth's magnetic field caused by electric currents flowing in air 60 km to 100 km altitude. For the last 70 years they have been continuously observed.

Unlike geomagnetic disturbances that are produced by coronal mass ejections (CMEs) days after they are observed at the Sun, a magnetic crochet occurs while the flare is in progress. They tend to occur during fast impulsive flares such as the selected event.

The flare not only blacked out terrestrial radio signals, but also produced some radio signals of its own. The explosion above sunspot AR2017 sent shock waves racing through the Sun's atmosphere at speeds as high as 4800 km/s.

## 2. The Event

### *2.1 The Flare*

On March 29, 2014 at 17:35 UT an X1.0-class flare erupted above NOAA AR2017 situated at N11W32 on the solar disk. Its integrated X-ray flux 1-8 Å as seen by GOES peaked at 17:48 UT and ended at 17:54 UT, making this a short – 19 minutes – flare. In the Rhessi flare list the onset of the flare is seen at 17:35:28 UT. The maximum emission is at 17:47:18 UT and ends at 18:14:36 UT, just a little longer than 39 minutes. The active region hosting this flare had nine other flares in the same day, but only one of X-class, the remaining eight being C-class ones.

This flare was found to have a seismic signature with a peak acoustic emission at 17:48 UT at 5.5 mHz and 17:51 UT at 6 mHz by Judge *et al.* (2014). The seismic emission has the same location (projected on solar disk) as the hard X-ray emission (Donea *et al.*, 2014, in preparation).

Kleint *et al.* (2015) have proved that a filament eruption was responsible for the triggering of this flare. Figure 1 shows the flare as seen by SDO in a superposition of images taken in 171, 193 and 211 Å and over-imposed on an HMI magnetograme of the line-of-sight magnetic field intensity.

Figure 1 shows the ignition of the flare, an extremely bright enhancement, in the northwestern region. This flare was extensively studied by Liu *et al.* (2015) where it was shown that following a rapid filament eruption, two major hard X-ray (HXR) sources formed around its central dip portion and a circular ribbon brightened sequentially.

There have been reports of chromospheric evaporation during this flare (Li *et al.*, 2015, Battaglia *et al.*, 2015).

### *2.2 The CME*

On March 29 at 18:12 UT LASCO detected a halo CME (see Fig. 2) with a linear speed of 528 km/s and a second order speed of 461 km/s measured at the height of 27 Rs (Rs = solar radii). During its propagation in the LASCO field of view it was decelerated by 4.1 m/s$^2$.

This CME was not detected by any spacecraft as an interplanetary coronal mass ejection (ICME) probably because it was deflected while propagating into the interplanetary space or it was too weak to be observed.

This event was not detected as a clear SEP event. But this temporal succession of events the increase in the high energy proton flux (although not strong enough to reach the SEP event threshold) suggests that the solar flare, the proton event and the CME could be related to the same magnetic source in the solar atmosphere.

### 2.3 *The Radio Emission*

Figure 3 shows the emission in radio wavelengths as seen by the STEREO satellite (Stereo A – first row, Stereo B – second row). The STEREO/WAVES and

WIND/WAVES show strong type III radio bursts (signatures of fast electrons propagating along open field lines) associated with the impulsive phase of the flare at about 17:45 UT, and type II radio bursts (Fig. 3) starting at about the same time.

The type II emission is patchy and rather fragmented, however the radio signatures can be traced until about 06 UT on March 30.

*2.4 Sudden Ionospheric Disturbances*

Earth's ionosphere reacts to the intense X-ray and ultraviolet radiation released during a solar flare. The ionospheric disturbance enhances the very long frequency (VLF) radio propagation. By using a receiver to monitor the signal strength from distant VLF transmitters, sudden ionospheric disturbances (SIDs) are recorded. They indicate a recent solar flare event.

The Solar Center, Solar Observatories Group, from Stanford University, USA has organised a network of space weather monitors with monitors recording the VLF signal in several frequencies (ex: 17.8 kHz, 19.8 kHz, 21.4 kHz, 24.6 kHz).

We studied the records from stations all around the world that were available on the Solar Centre's website (http://sid.stanford.edu/database-browser/). From these we noticed 11 stations with clear signatures of a SID around 18:00 UT.

We plotted their location in Figure 4. There are four in USA, four in Europe, two in Africa and one in New Zealand. They are all situated on the day-side. Considering the fact that the monitors are not uniformly spread, we can not say anything about the significance of these positions.

*2.5 Extreme Ultraviolet Irradiance*

At the time of the analysed flare, the EVE instrument onboard of the SDO satellite registered a sudden increase in the ultraviolet irradiance in the 131, 171, 193 Å lines, starting with 17:48 UT. The irradiance averaged over one minute is plotted in Figure 5 showing a sharp peak at the time of the flare emission.

*2.6 The Magnetic disturbances*

We analysed geomagnetic data from 121 observatories available online at http://www.intermagnet.org. We studied the magnetic variations of the vertical component of the geomagnetic field and found several locations were some variation was registered around 18:00 UT. Figure 6 shows the locations where a perturbation was observed in the geomagnetic vertical component. The amplitude of these magnetic disturbances varies from 1 nT to 20 nT, some being positives and others negatives, in accordance with the solar zenithal angle.

The locations shown in Figure 6 are not the same with the locations where SIDs were recorded.

## 3. Summary

We have presented here an interesting case of magnetic crochet at the Earth surface that followed a powerful X-class solar flare from March 29, 2014, one of only 16 X-type solar flares in 2014, a year of maximum activity in solar cycle 24.

This flare was interesting because it had a seismic source detected in the hosting active region, had been associated with sudden ionospheric disturbances, has been followed by a CME and some geomagnetic disturbances.

Table 1 shows a summary of the peak emission times in various wavelengths such as described in the previous sections. From this table we can see that the peak times are coincident with the flash phase of the flare (the so-called phase II of the solar flare such as defined by Liu *et al.* (2015) – starting with 17:46 UT, seen as a separate peak in several bins).

The flare has triggered chromospheric evaporation related to non-thermal electrons shown by the non-thermal hard X-ray emission up to 100 keV (Li *et al.*, 2015).

We noticed that SIDs and magnetic crochets were registered before the CME detection in LASCO field of view. The locations of the observed SIDs were different than the location of the magnetic disturbances, but they were concomitant (within five minutes temporal differences).

The flash in EUV, in the 131 Å line showed an increase of more than double the quiet time levels, much more than the 28%, respectively 91% increase in the other two lines that we analysed here (Fig. 5). The EUV and X radiation are responsible for the excess ionisation in the Earth's ionosphere. For this flare the EUV radiation and the soft X-ray radiation triggered an enhancement of the ionospheric current, which influenced the variations observed on terrestrial magnetometer traces (this is the solar flare effect – magnetic crochet). The intensity of the magnetic crochet varies inversely with the solar zenith angle resulting in different values between 1 – 20 nT in different locations.

We also noticed that SIDs and the magnetic crochets are related to phase I of the solar flare (such as defined by Liu *et al.* (2015) – starting with 17:43 UT, seen as a separate peak in several bins before the flash phase of the flare).

Aschwanden (2015) computed the free magnetic energy during this flare and found a peak of $45 \pm 2 \times 10^{30}$ ergs. He also states that the consistency of free energies measured from different EUV and UV wavelengths demonstrates that vertical electric currents can be detected and measured.

We can assume that the system of terrestrial electric currents variations in intensity or changes in distribution in the ionosphere due to the arrival of the excess radiation from the Sun is a valid mechanism in this case too (Chapman, 1951; Rastogi, 1997).

*Table 1*

Summary of different peak times related to the flare event of March 29, 2014

| **Wavelength** | **Peak Time** |
|---|---|
| Hα | 17:46:00 UT |
| IR Continuum (Judge *et al.*, 2014) | 17:46:10 UT |
| IR He core (Judge *et al.*, 2014) | 17:46:10 UT |
| EUV 171Å | 17:46:30 UT |
| IR Si core (Judge *et al.*, 2014) | 17:46:37 UT |
| WL G-Band (Judge *et al.*, 2014) | 17:46:44 UT |
| Rhessi 30-70 keV | 17:47:16 UT |
| EUV 193Å | 17:47:30 UT |
| SQ @ 5.5 mHz | 17:48:00 UT |
| X-ray 1-8 Å | 17:48:00 UT |
| EUV 131 Å | 17:50:30 UT |
| SQ @ 6 mHz | 17:51:00 UT |

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EXPLICATII FIGURI

Fig. 1 – Solar flare of March 29, 2014 as seen by SDO in a superposition of AIA (171, 193 and 293 Å) and HMI (B-los). 17:45:07, 17:50:07, 17:55:07, 18:00:07. Images from the daily movies available at http://sdo.gsfc.nasa.gov/data/aiahmi/.

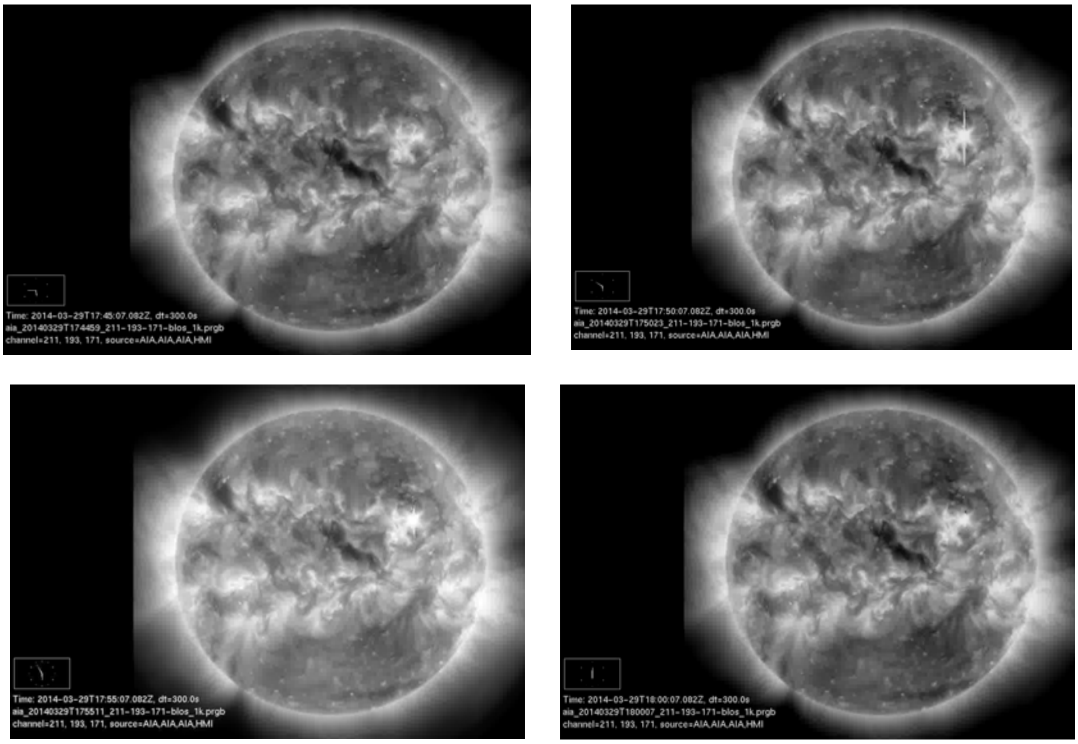
Fig. 2 – Running-differences of LASCO-C2 white-light images for the CME on March 29, 2014. Images from http://cdaw.gsfc.nasa.gov/CME_list/.

Fig. 3 – Radio emission as seen by STEREO A (first row), STEREO B (second row) and Wind (third row). Detected CMEs are shown in the last row.

Fig. 4 – SID receptor locations.

Fig. 5 – EUV lines 131 (straight line), 171 (dotted line), 193 (dashed line) Å as registered by AIA/EVE onboard of SDO.

Fig. 6 – Locations of geomagnetic disturbances.

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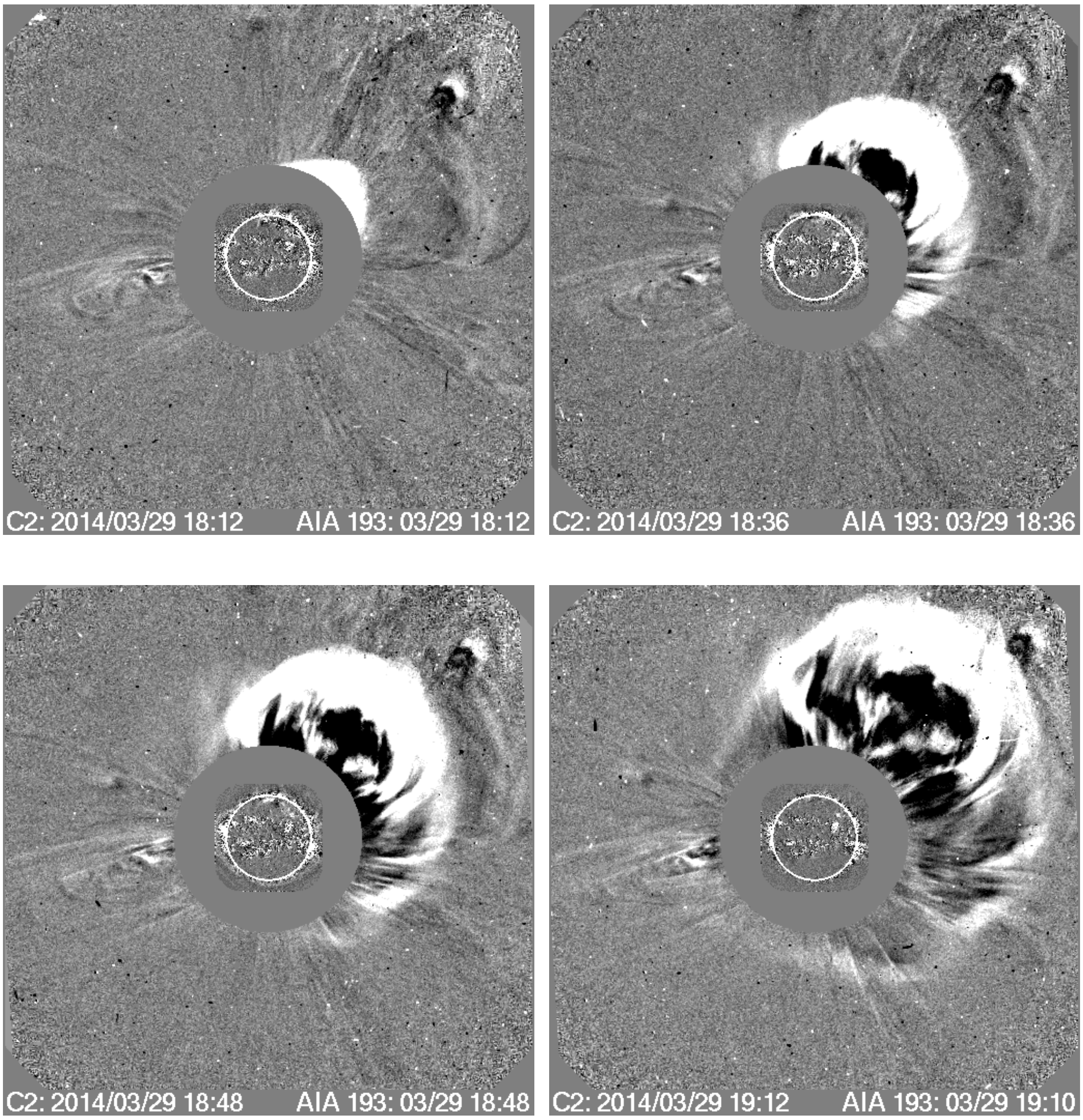


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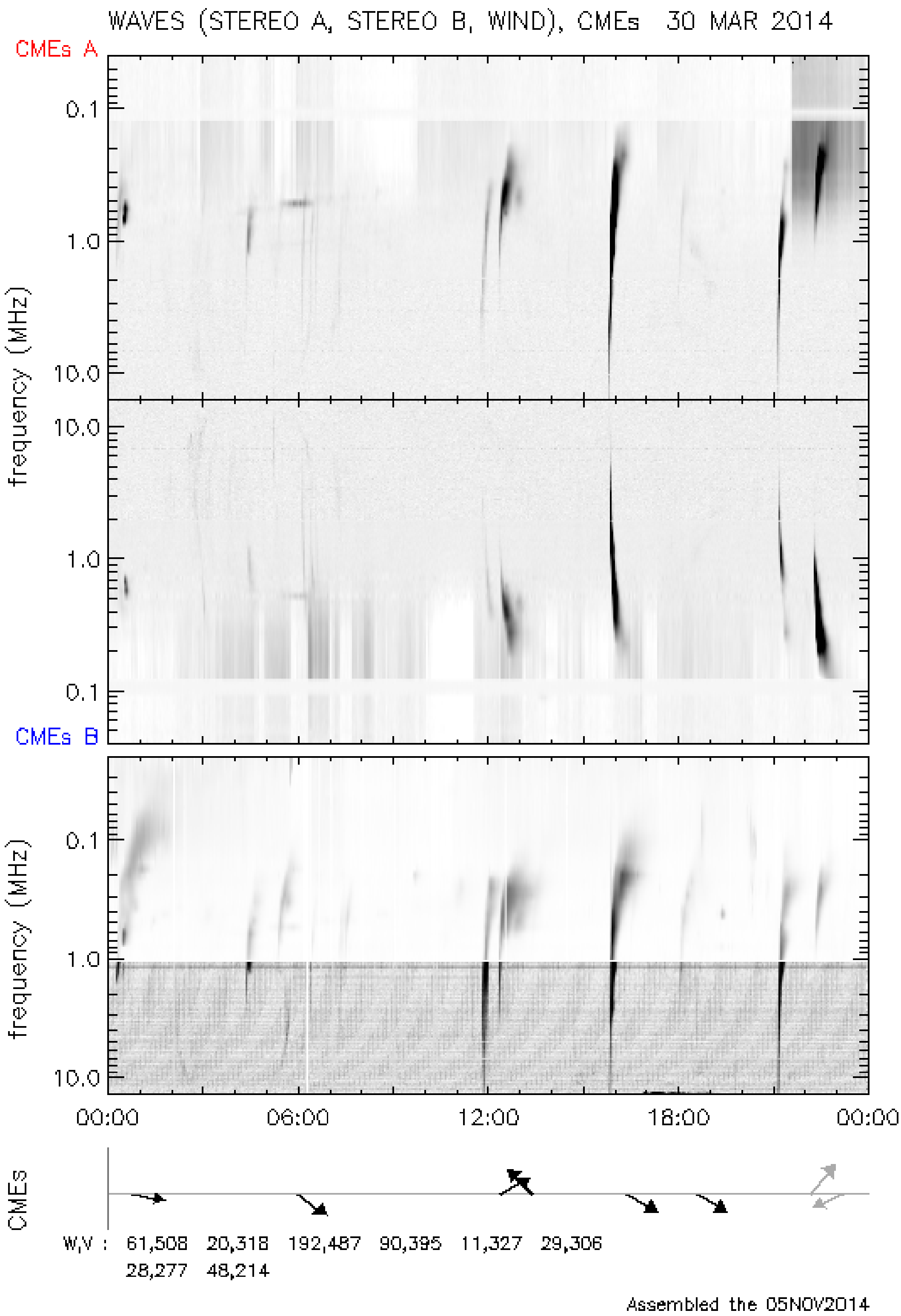


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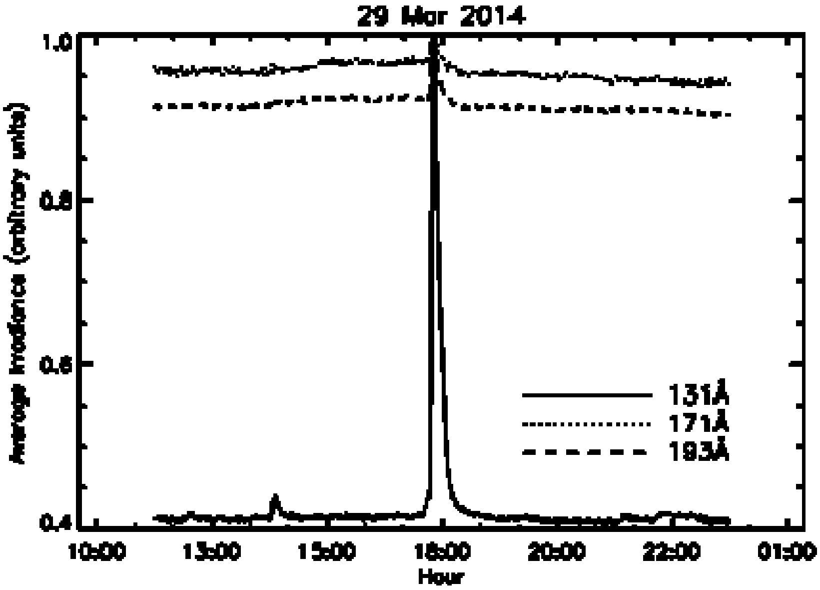


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