Radio, Magnetic and (Possible) X-Ray Observations of the X1 Solar Flare on 29 March 2014

Whitham D. Reeve

1. Introduction

The observations reported here are of an impulsive class X1 flare that occurred at solar active region 2017 on 29 March 2014. This flare peaked at 1748 UTC (Coordinated Universal Time) and produced emissions over a wide frequency range for almost 30 minutes. The radio and magnetic observations are certainly associated with the flare, but the radiation observations could be a coincidence as discussed later.

"*A flare is defined as a sudden, rapid, and intense variation in brightness. A solar flare occurs when magnetic energy that has built up in the solar atmosphere is suddenly released. Radiation is emitted across virtually the entire electromagnetic spectrum, from radio waves at the long wavelength end, through optical emission to x-rays and gamma rays at the short wavelength end. The amount of energy released is the equivalent of millions of 100-megaton hydrogen bombs exploding at the same time!*" (from "*What is a Solar Flare* {NASA1}; see also the *NASA Solar Flare Theory* educational web page {NASA2}).

Note: Links in braces { } and references in brackets [ ] are provided in **section 6**.

2. Reported Details

The X1 flare was summarized by Space Weather Prediction Center (SWPC) as a "*complex Castelli-U radio burst signature with a notable burst of 110,000 sfu on 245 MHz*" {SWPC1}. SWPC provided additional details in the events list for 29 March {SWPC2} (table 1).

Table 1 ~ Events reported by Space Weather Prediction Center for the X1 flare on 29 March 2014

#Event	Begin	Max	End	Obs	Q	Type	Loc/Frq	Particulars		Reg#
8690	1735	1748	1754	G15	5	XRA	1-8A	X1.0	4.2E-02	2017
8690	1738	1746	1816	HOL	3	FLA	N11W32	2B	ERU	2017
8690	1745	1747	1748	SAG	G	RBR	4995	650	CastelliU	2017
8690	1745	1746	1749	SAG	G	RBR	8800	1100	CastelliU	2017
8690	1745	1746	1748	SAG	G	RBR	15400	1000	CastelliU	2017
8690	1745	1746	1748	SAG	G	RBR	2695	360	CastelliU	2017
8690	1745	////	1749	SAG	C	RSP	025-180	III/3		2017
8690	1745	1747	1749	SAG	G	RBR	410	1100	CastelliU	2017
8690	1745	1746	1748	SAG	G	RBR	1415	280	CastelliU	2017
8690	1745	1747	1751	SAG	G	RBR	245	110000	CastelliU	2017
8690	1745	1746	1748	SAG	G	RBR	610	420	CastelliU	2017
8690	1753	////	1801	SAG	C	RSP	025-180	II/3	4508	2017

Key to Events table:

Begin, Max, End	Times for event beginning, maximum and ending
Obs	Observatory: G15 = GOES 15; HOL = Holloman AFB, New Mexico USA; SAG = Sagamore Hill, Massachusetts USA
Q	Quality for optical: 1 (lowest) to 5 (highest); G = Good, C = Corrected report
Type	XRA = X-ray event from GOES spacecraft; FLA = Optical flare in H-alpha; RBR = Fixed frequency radio burst; RSP = Sweep frequency radio burst
Loc/Freq	Location or Frequency:

Particulars	Additional information on the basis of report type: For radio bursts: Flux in sfu; For radio sweeps: Burst type and intensity; for XRA: X-ray class; for FLA: Importance and brightness
Reg#	Solar region number assigned by SWPC

3. Observations

Solar flares are unpredictable and the ones I have detected all produced surprising and interesting results. For this flare, I observed HF spot frequencies 20.0 and 25.2 MHz, HF spectrum from 18 to 30 MHz, geomagnetic effects at 0.1 Hz sampling rate and possible radiation effects at gamma or x-ray energies above 7 keV. I also refer to spectrum observations from 45 to 80 MHz and 220 to 450 MHz by fellow e-Callisto observer and colleague Stan Nelson in Roswell, New Mexico (see {Meteor}). Instrumentation is briefly described in **section 4**. For additional information on e-Callisto solar radio spectrometer network see {e-Callisto} and for e-Callisto data see {eC-Data}.

Abbreviations

HF:	High frequency (3 ~ 30 MHz)
UHF	Ultra-High Frequency (30 ~ 300 MHz
UTC	Coordinated Universal Time
VHF	Very Higher Frequency (300 ~ 3000 MHz)

HF Spot Frequencies: Two spot frequencies, 20.0 and 25.2 MHz, were recorded (figure 1). Peak noise temperatures reached slightly above 82 million kelvin at 20 MHz and 30 million kelvin at 25.2 MHz.

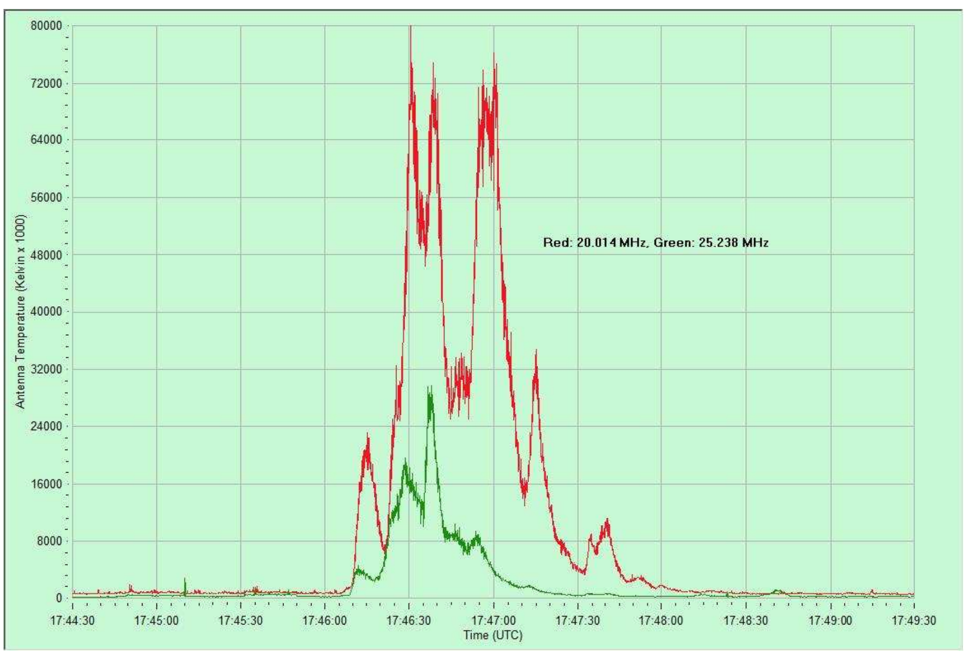

Figure 1 ~ Calibrated Radio-SkyPipe chart showing spot frequency noise temperature for a 5 min period centered on the solar flare time. Peak intensity received by this system was slightly more than 82 million kelvin at 20.0 MHz and 30 million kelvin at 25.2 MHz.

HF Spectrum: Continuous coverage from 18 to 30 MHz was recorded with 30 kHz resolution (figure 2). The spectrogram shows a series of radio bursts whose lower frequency slowly drifts upward over a 3 minute period.

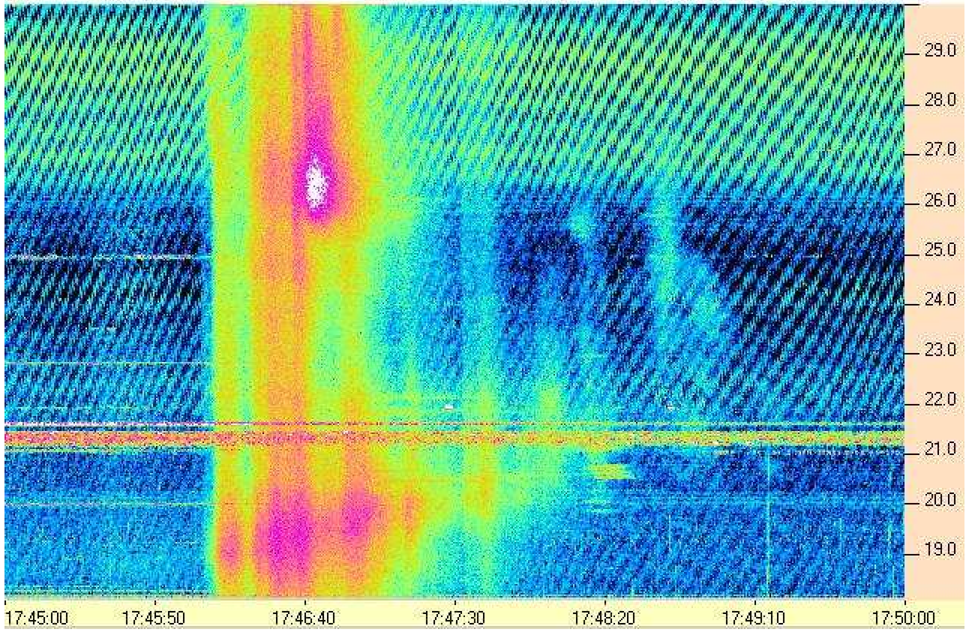

Figure 2 ~ Uncalibrated RadioSky-Spectrograph spectrogram showing continuous frequency coverage from 18 to 30 MHz (30 kHz resolution). The color gain on the spectrogram was turned up to bring out the radio burst features but also brought out the radio frequency interference. The diagonal striping is thought to be from powerline noise and is evident throughout the spectrum, and additional RFI is shown by the thick horizontal line at 21.3 MHz.

VHF Spectrum: Continuous coverage from 45 to 80 MHz was recorded with 175 kHz resolution at Roswell, New Mexico USA (figure 3). The solar radio burst associated with the flare had a complex spectral shape with a deep dip in background noise at 1748. SWPC reported Type III (fast sweep) radio bursts from 1745 to 1749 and Type II (slow sweep) radio burst from 1753 to 1801 within the frequency range 25 and 180 MHz.

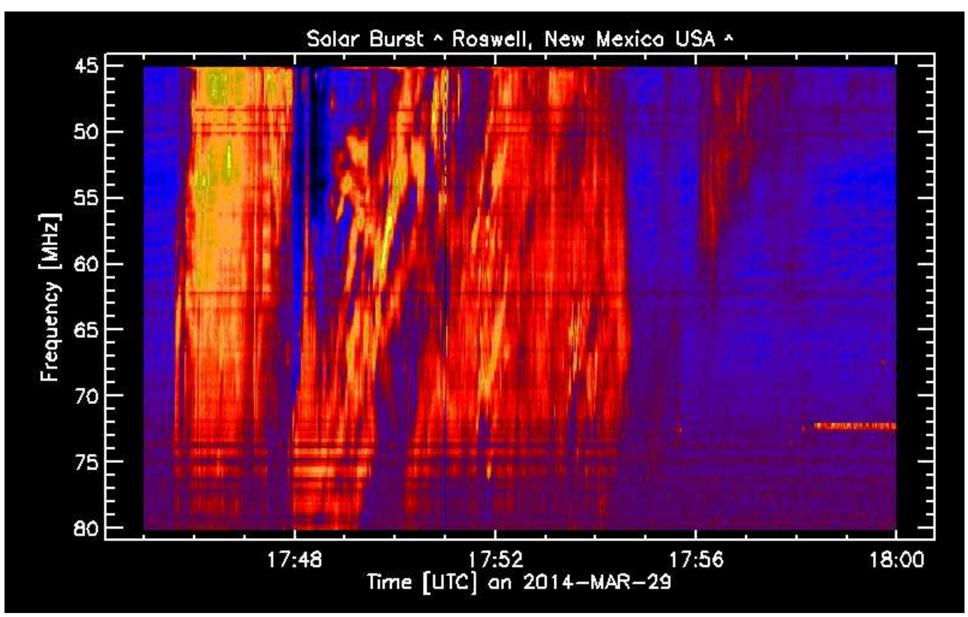

Figure 3 ~ Uncalibrated spectrogram showing continuous frequency coverage from 45 to 80 MHz. This spectrogram was prepared using Callisto data provided by Stan Nelson in Roswell, New Mexico. Note the deep dip in background noise between 45 and 55 MHz at 1748.

VHF/UHF Spectrum: Continuous coverage from 220 to 450 MHz was recorded with 1.15 MHz resolution at Roswell, New Mexico USA (figure 4). The spectrum at these higher frequencies was not as complex as at lower frequencies. The radio flux density at 245 MHz was reported by SWPC as 110 000 sfu (solar flux unit, where 1 sfu = 10^{-22} W/(m^2-Hz)).

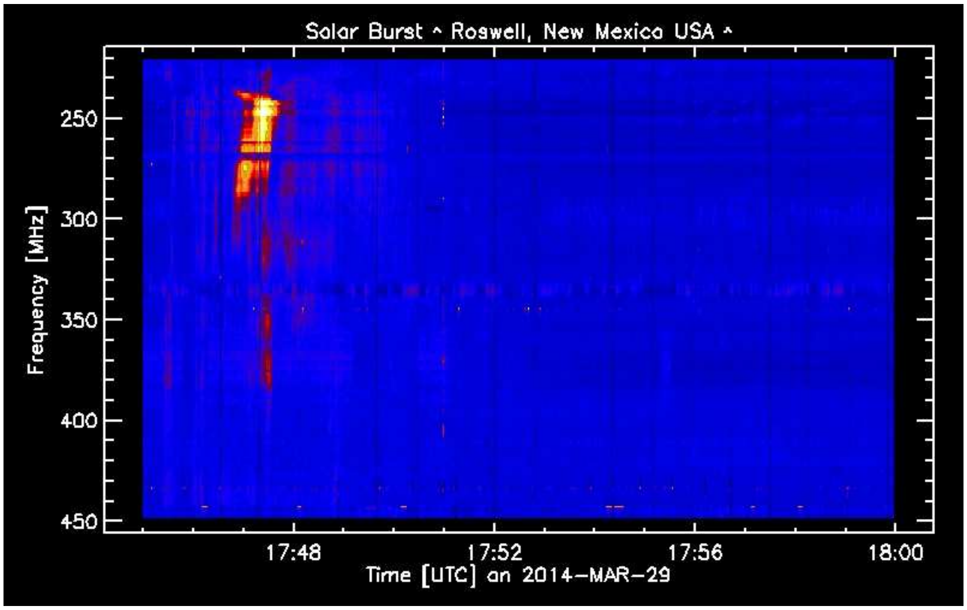

Figure 4 ~ Uncalibrated spectrogram showing continuous frequency coverage from 220 to 450 MHz. The peak intensity (yellow area) occurred near 245 MHz at 1748, the same time reported by SWPC for peak x-ray flux.

Geomagnetic Effects: Geomagnetic effects from a solar flare generally occur only if an Earth-directed coronal mass ejection (CME) is associated with it, and those effects occur 2 to 9 days afterwards due to the relatively slow speed of the CME. However, occasionally, simultaneous effects are registered if the geomagnetic observatory is on the sunlit side of Earth at the time of a strong flare. I have observed these effects 1 or 2 times per year. In the case of the 29 March flare, a rare magnetic crochet registered on my magnetometer (figure 5). The name is given because the trace looks like a crochet hook, which is a tool used to draw thread or yarn through knotted loops.

Radiation: Radiation observations are obtained in counts per minute – a relative indicator of the amount of radiation present. The coincidence monitor in this system logged 9 counts/min of simultaneous radiation detection by two sensors at about 2015 on 29 March, 2.5 h after the solar flare, and also at about 1106 on 31 March, 42 hours after the flare (figure 6). The detector has been in operation since May 2011, and I have never before seen 9 counts per minute of coincidence. Peak coincidence counts/min of 4, 5 and 6 are fairly common. The two high count episodes could have been due to natural local radiation sources. On the other hand, sources of gamma-rays and x-rays on Earth include secondary radiation from atmospheric interactions with cosmic ray particles, and it is

Gamma and X-Rays

Gamma rays generally are energetic photons considered to have energies > 100 keV and, according to the Planck relation, have frequencies on the order of > 10^{19} Hz (10 EHz) or wavelengths < 10^{-11} m (10 pm). Similarly, x-rays have energies on the order of 100 eV to 100 keV with corresponding frequencies in the range 10^{16} to 10^{19} Hz (10 PHz to 10 EHz) or wavelengths in the range 10^{-11} to 10^{-8} m (10 pm to 10 nm). There is no sharp distinction between gamma- and x-rays and their definitions include considerable overlap.

possible radiation from the solar flare led to the two episodes of unusually high counts/min. Not all energetic particles travel from Sun to Earth at the speed of light ($3 \cdot 10^8$ m/s) and arrive in a little more than 8 min. The time can range from 15 minutes to a couple days – so recording a high radiation event due to a flare 2.5 and 42 h after the flare is plausible [RAE].

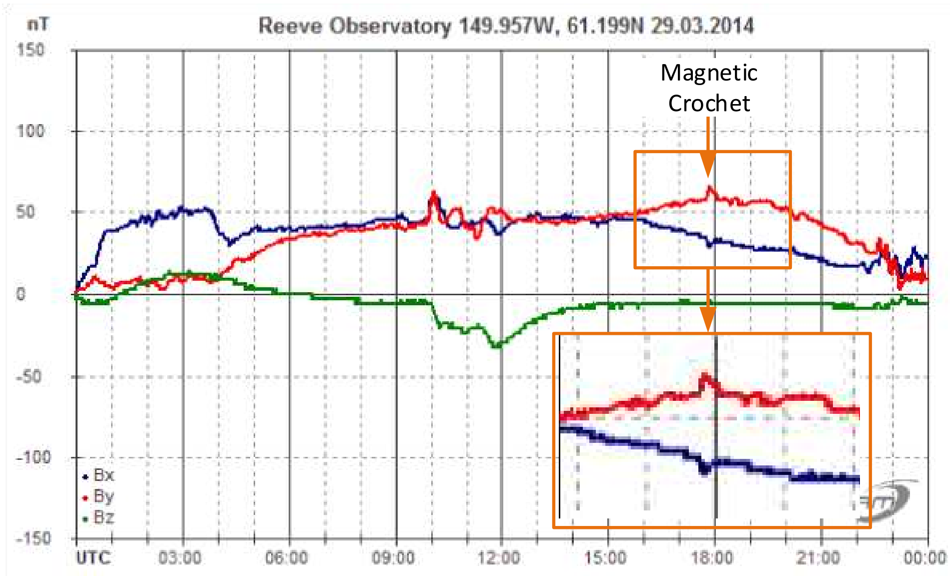

Figure 5 ~ Magnetogram showing the geomagnetic field as measured at Anchorage, Alaska for the 24 h period on 29 March. The solar flare caused a rare magnetic crochet as shown in the colored boxes (lower box is a magnified view).

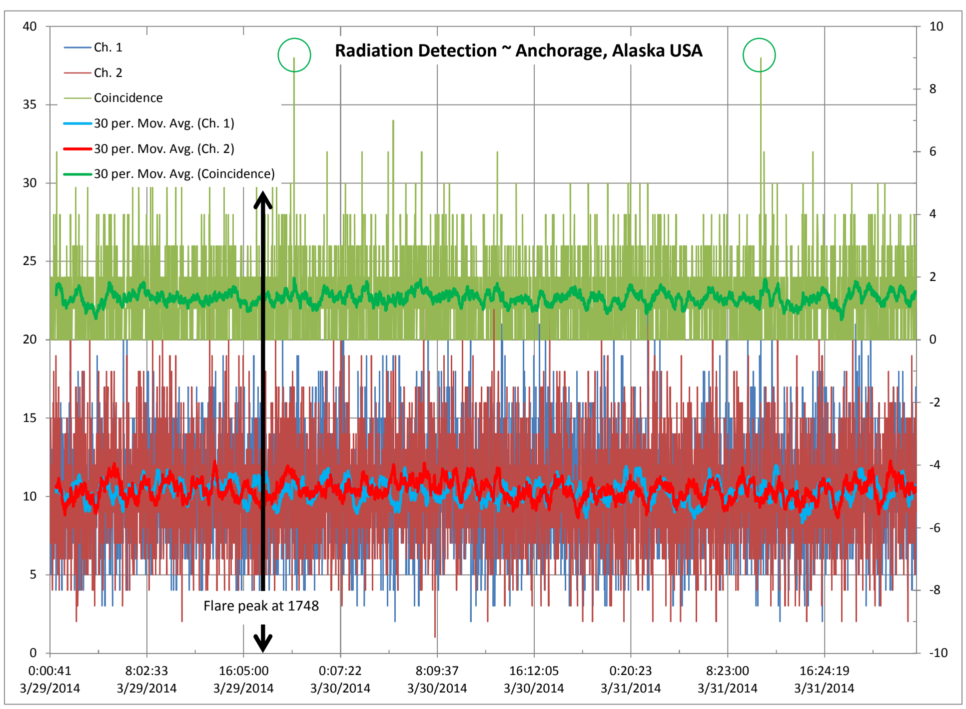

Figure 6 ~ Detected radiation counts starting at midnight (UTC) prior to the 29 March 2014 X1 solar flare. The lower traces show channel 1 and 2 radiation counts/min (left vertical scale). The coincidence counts/min shown by the upper trace (right vertical scale) indicates two events with elevated counts (circled) that occurred simultaneously on the two channels and could have possible cosmic origin. Background coincidences for this installation typically average 1.3 counts/min and coincidence counts of 4 and 5 are common; however, the peaks of 9 counts/min near 2015 on 29 March and 1106 on 31 March have never before been observed. The thick traces are moving average trendlines (period of 30), and show no obvious trends after the flare time (thick black line).

4. Instrumentation

HF Spot Frequencies: Icom R-75 general coverage receivers set to LSB with AGC Off; KMA1832 log periodic antenna (18 to 32 MHz) connected through a multicoupler to the receivers; owned and operated by author in Anchorage, Alaska USA.

HF solar radio spectrometer: RF Associates FSX-5 with RadioSky Spectrograph software, connected through a multicoupler to the KMA1832 antenna (above); owned and operated by author in Anchorage, Alaska USA.

VHF/UHF solar radio spectrometer: Callisto with CLP5130-1N log periodic antenna (50 to 1300 MHz); owned and operated by Stan Nelson in Roswell, New Mexico USA.

HF/VHF solar radio spectrometer: Callisto with Long Wavelength Array antenna (10 to 90 MHz); owned and operated by Stan Nelson in Roswell, New Mexico USA.

Geomagnetometer: SAM-III with three FMG-3 magnetic sensors, owned and operated by author in Anchorage, Alaska USA. The magnetometer is configured to sample each sensor every 10 sec (0.1 Hz sample rate).

Radiation: BlackCat Systems GM-10 with 2-Channel Anti-Coincidence Monitor (ACM), owned and operated by author in Anchorage, Alaska USA. Two identical GM-10 detectors are used. The GM-10 uses a non-directional thin window Geiger-Müller tube, which detects alpha, beta, gamma and x-ray radiation by the ionization produced by a radioactive particle. When one of these high-energy particles enters the window, it is detected, counted and logged. The number of counts per minute is related to the amount of radiation present. The ACM monitors the output from each detector. Simultaneous detection of a radiation event by the ACM indicates the source of radiation likely is of cosmic origin. The radiation detection thresholds are: Alpha > 3 MeV; Beta > 50 keV; gamma/x-ray > 7 keV. For additional detail, see {GM10}.

5. Conclusions

The X1 solar flare of 29 March 2013 was observed over a very wide radio frequency range and caused a rarely observed simultaneous geomagnetic effect called a magnetic crochet. Also, a radiation detector at Anchorage, Alaska measured elevated coincidental counts from two independent radiation detectors 2.5 and 42 hours after the burst. Whether or not these counts were direct effects of the solar flare is inconclusive.

6. References and Links

[RAE] Royal Academy of Engineering, Extreme Space Weather: Impacts on Engineered Systems and Infrastructure, February 2013, ISBN 1-903496-95-0

{e-Callisto} http://www.e-callisto.org/
{eC-Data} http://soleil.i4ds.ch/solarradio/callistoQuicklooks/
{GM10} http://www.blackcatsystems.com/GM/page5.html
{Meteor} http://www.roswellmeteor.com/
{NASA1} http://hesperia.gsfc.nasa.gov/sftheory/flare.htm
{NASA2} http://hesperia.gsfc.nasa.gov/sftheory/frame1.htm
{SWPC1} http://www.swpc.noaa.gov/ftpdir/forecasts/discussion/03291230forecast_discussion.txt
{SWPC2} http://www.swpc.noaa.gov/ftpdir/indices/events/20140329events.txt

7. Acknowledgements

I am grateful to Stan Nelson of Roswell, New Mexico for the use of his Callisto data.