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A year of operation of Melibea e-Callisto Solar Radio Telescope

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Abstract. The e-CALLISTO (Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory) is a worldwide radio-spectrograph network with 24 hours a day solar radio burst monitoring. The e-CALLISTO network is led by the Swiss Federal Institute of Technology Zurich (ETHZ Zurich), which work up collaborations with local host institutions. In 2013 the University of Alcalá joined the e-CALLISTO network with the installation of two Solar Radio Telescopes (SRT): the EA4RKU-SRT that was located at the University of Alcalá from January 2013 till June 2013 and the Melibea-SRT that is located at Peralejos de las Truchas (Guadalajara) in operation from June 2013. The Spanish e-Callisto SRTs provide routine data to the network. We present examples of type III and type II radio-bursts observed by Melibea during its first year of operation and study their relation with soft X-ray flares observed by GOES and Coronal Mass Ejections (CMEs) and Solar Energetic Particle (SEP) events observed by space-borne instrumentation.

1. Introduction

Solar Radio Telescopes (SRT) can be developed with a low-cost budget in comparison with other solar instrumentation. Solar radio burst associated with solar cosmic rays are observed from Earth with radio equipment based on commercial components (spectrograph + antenna).

CALLISTO (Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory) is rather a very good patrol device allowing to monitor solar radio emission around the day (24 hours). These spectrometers allow to recognise the main types of solar radio bursts, like type III bursts as signatures of accelerated electrons and type II bursts as signatures of shock waves produced by flares or/and CMEs. Nevertheless, most of the CALLISTO-based telescopes have limitations in frequency and/or time resolution, and/or in sensitivity to study some kinds of faint radio emissions. These limitations are mainly due to low effective area of antennas and noisy locations of the stations.

The Space Research Group (SRG) of the University of Alcalá joined the e-CALLISTO network thanks to the set up of the EA4RKU-SRT in January 2013. The EA4RKU-SRT was initially installed at the Technical School building of the University of Alcalá de Henares [1]. The EA4RKU-SRT was in operation for 6 months and served as test bench of the final e-CALLISTO SRT. After this period, the instrument performances as remote operated SRT were satisfactory,



and then, it was moved to the Peralejos de las Truchas Astronomical Observatory (OAPT from the Spanish acronym).

2. e-CALLISTO Worldwide Network

e-CALLISTO is an European-led worldwide network which aims 24 hours monitoring of solar radio emission [2]. The e-CALLISTO network is led by the Swiss Federal Institute of Technology Zurich (ETHZ Zurich), which works up collaborations with local host institutions, which operates an e-CALLISTO SRT. Thanks to the Instrument Deployment Program managed by the International Space Weather Initiative (ISWI), e-CALLISTO is able to continuously observe the solar radio spectrum. Figure 1 shows the geographical distribution of the e-CALLISTO stations on December 2014, currently more than 69 instruments in more than 38 locations. However, there are two issues which should be mentioned. On one hand, the coverage on America, Africa and Asia, sometimes, depends on a unique station. On this regard, the network is placing efforts on increasing the number of stations in these three continents. Particularly, the SRG is working on two parallel projects which are focussed on the installation of e-CALLISTO stations: one on Argentina (Catamarca desert) and, the other one, on Chile (Atacama desert). On the other hand, some of the stations are located on an area with very high background radio emission from terrestrial emitters, which reduce the quality of the observed data.

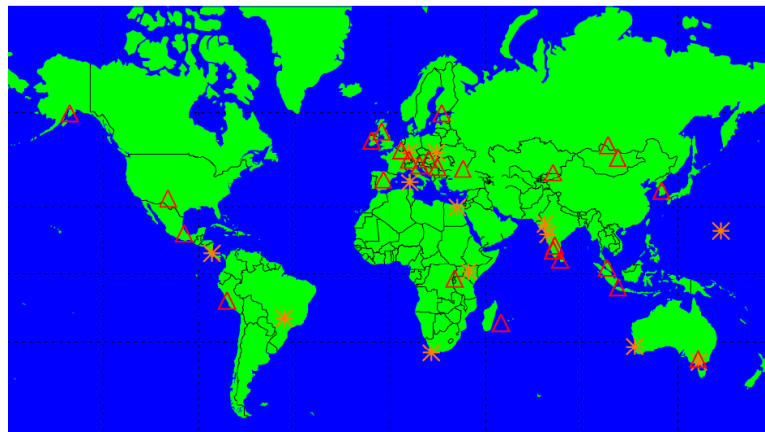


Figure 1. Map of current distribution of CALLISTO instruments in December 2014. Red triangles: stations providing data, orange star: stations do not providing data yet/anymore (<http://www.e-callisto.org>).

The CALLISTO spectrometer [3] was built in the framework of IHY2007 (International Heliophysics Year) and the ISWI by former Radio and Plasma Physics Group (Principal Investigator Christian Monstein) at Institute for Astronomy, ETH Zurich. This spectrometer is considered the standard for the e-CALLISTO network. The instrument operates between 45 and 870 MHz using a modern, commercially available broadband cable-TV tuner. The CALLISTO operational spectral range can be tuned within the full range. This tuning capability is useful when the antenna frequency response window does not cover the full CALLISTO range or when certain frequency windows are strongly affected by RFI. Table 1 details the main characteristics of the CALLISTO spectrometer. CALLISTO provides good quality data for scientific purposes with a remarkable low cost. As an example, data from the CALLISTO SRT at Birr Castle in Ireland [4] has been recently used in a possible explanation for a quasi-periodic acceleration of electrons by a plasmoid-driven shock in the solar atmosphere [5].

Table 1. CALLISTO spectrometer main characteristics.

Option	Description
Frequency range	45.0 - 870.0 MHz (34 cm - 6.7 m) (tunable)
Frequency step size	62.5 kHz
Integration Time	1 msec
Dynamic range	higher than 50 dB
Noise figure	lower than 10 dB
Measuring rate	800 pixels/sec maximum
Sweep length	1-400 Channels
Power consumption	12 V 225 mA (2.7 W)
Cost	Hardware around 300 Euro (only spectrometer)

The e-CALLISTO network presents areas which are covered by several SRTs (e.g. Europe and India). This network feature is known as geographic redundancy. The geographic redundancy replicates systems between two geographically distant stations so that the observed data are acquired from several stations. That assures the observation of a possible event in case of failure of one of the stations. This geographic redundancy is very reliable from the point of view of both, solar science and space weather. As an example, Europe has large geographic redundancy providing high reliability of the network (see Figure 1).

3. Spanish contribution to e-CALLISTO Network

In 2012, several Radio Frequency Interference (RFI) (background radio emission from terrestrial emitters) measurements were performed on several places of the province of Guadalajara (central Spain) in order to find the most suitable location of an e-CALLISTO SRT. The lowest RFI measurement was found at Peralejos de las Truchas (200 km East from Alcalá de Henares). During the last quarter of 2014, new RFI measurements were done on the area. The Figure 2 shows the 2014 RFI measurement once the instrumental background has been subtracted. The left plot of the figure shows the measurement at the University of Alcalá with strong interference by terrestrial radio emitters. The University of Alcalá is nearby Madrid city (33 km) and Barajas International Airport (10 km). Therefore, this location is not suitable for radio solar observations. The right plot shows the RFI at the OAPT. This location is more appropriate for solar observations due to the lower RFI, except for the frequency range for the commercial Frequency Modulation (FM). The FM frequency range can be rejected using a notch filter in order to avoid cross modulation (harmonics of FM frequency range). The background measurements were done with a system composed by a 25-1300 MHz Discone type antenna connected to a CALLISTO spectrometer.

At the beginning of 2013, the SRG developed a prototype of an e-CALLISTO based SRT which was in operation for 6 months at Alcalá de Henares. The prototype was designed as EA4RKU-SRT and their data are available on the e-CALLISTO repository. After the testing period, the prototype EA4RKU-SRT was moved to its final location at the OAPT. The name of this new station is Melibea-SRT.

The Melibea-SRT is operating at OAPT since May 2013. The location of the Melibea-SRT is N40°35' W01°15' world geodetic coordinates and 1240 metres above sea level near the village of Peralejos de las Truchas (Guadalajara).

The Melibea-SRT is based on a horizontally polarized log-periodic antenna mounted on an automatic Sun-tracking system (see figure 3 left). The antenna has a forward gain of 10-12 dBi.

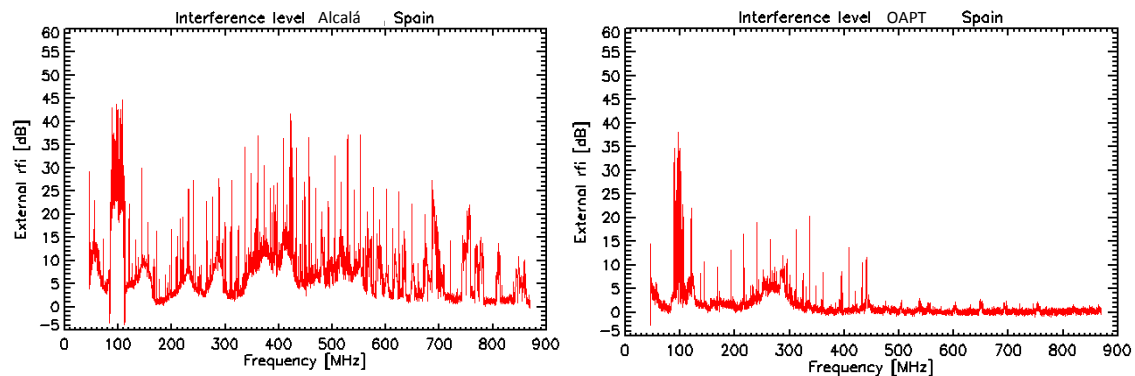


Figure 2. RFI measurements at central Spain with discone antenna and CALLISTO spectrometer. Left: RFI measurements in the University of Alcalá Campus (Alcalá de Henares). Right: RFI measurements in OAPT (Peralejos de las Truchas)

The antenna is pointed by a Sun tracking system based on two (azimuth and elevation) rotors which are driven by an AVRSCOM control system. The software used for the sun tracking is the SUM provided with the SatPC32 software developed for radio amateur operators. The antenna is connected to a CALLISTO spectrometer by 25 meters of coaxial cable (attenuation: 93 dB/km@200 MHz; 138 dB/km@400 MHz). The CALLISTO spectrometer operates in a frequency range between 45 MHz and 870 MHz with 200 channels on 1.25 ms time resolution per channel. The system is configured by the CALLISTO V116 software. All the software is running in a unique Windows 7 workstation. The Melibea SRT antenna is installed on the roof of the observatory building (see figure 3 right). In order to reduce RFI, the antenna will be moved to ground in a near future.

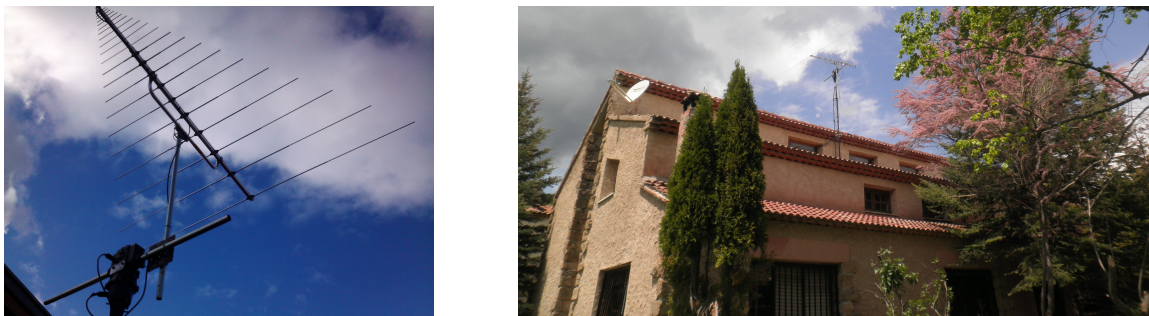


Figure 3. Melibea Solar Radio telescope at Peralejos de las Truchas Astronomy Observatory: left antenna and right its location on the Observatory building

As an example of the scientific measurements provided by CALLISTO, we show a type IV radio burst observed by Melibea-SRT. This burst was associated with an X-ray solar flare with M1.3 intensity at 08:14 UT on 5th June 2013. The X-ray solar flare was identified by the NOAA Space Weather Prediction Center (SWPC, <http://www.swpc.noaa.gov/>) from the 1762 Active Region (AR), located at heliographic coordinates S31W52. This flare was accompanied by a type III radio-burst and a partial halo CME. Accelerated electrons are bounced between side-to-side in large magnetic arches producing the type IV emission.

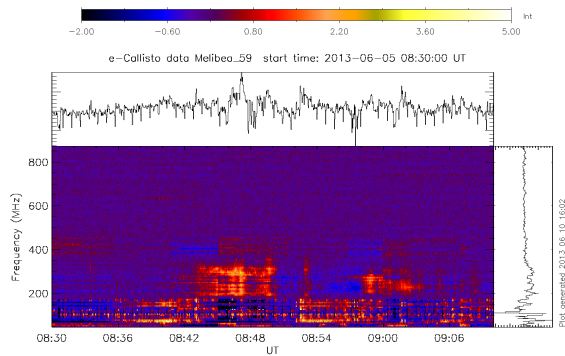


Figure 4. Type IV radio burst associated with the M1.3 X-ray flare from active region 1762. This event was observed the 5th June 2013 by Melibea-SRT on the OAPT, Guadalajara.

4. Applications in the field of Solar Energetic Particles

Observations of solar radio bursts provide relevant information for the understanding of particle acceleration during solar eruptive phenomena. In order to illustrate the relevance of the e-CALLISTO network for the understanding of Solar Energetic Particle (SEP) events, we will briefly discuss observations during 18th April 2014 SEP event.

The event on 18th April 2014 corresponds to an X-Ray solar flare with M7.3 intensity observed at 12:31 UT in NOAA AR 2036, located at S20W34 heliographic coordinates. The event was accompanied by several radio bursts (Type II, III, IV and V) which were clearly observed by several stations of the e-CALLISTO network, including Melibea-SRT. Type III and type II radio bursts were observed by many of the radio spectrometer telescopes of the e-CALLISTO network in Europe.

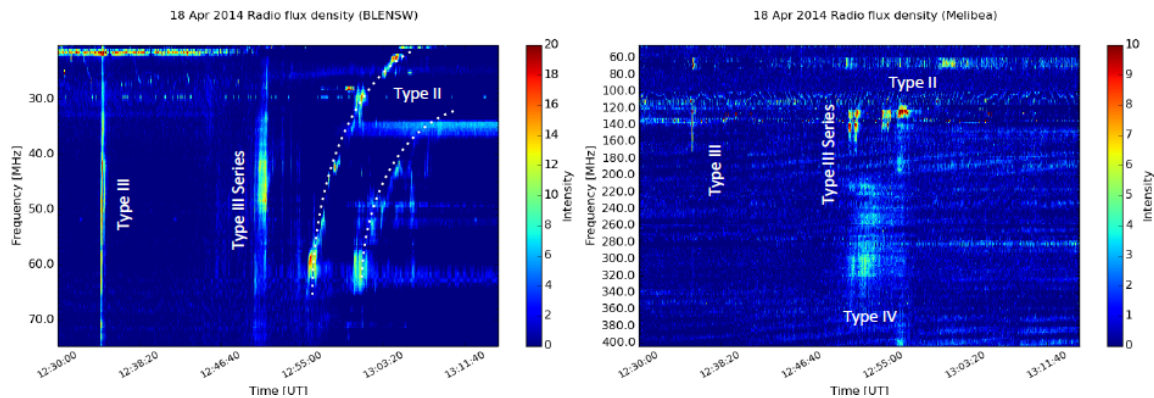


Figure 5. Sequence of Radio Bursts of 18th April 2014 event observed by e-CALLISTO stations.

The figure 5 shows the associated radio signatures of the 18th April 2014 solar event. An early Type III, seen at 12:30 UT, was not accompanied by a significant X-Ray flux increase nor a CME (clearly shown in left part of each plot). The M7.3 X-ray flare was accompanied by a series of Type III radio bursts, followed by a Type IV radio burst (clearly seen on the right figure).

The different configuration (antenna, frequency range and integration time) of each of the radio telescopes on the e-CALLISTO network provides large information about prompt phases of the electrons acceleration. Moreover, geographic redundancy is available for this event with several SRTs; see figure 6. The e-CALLISTO stations are synchronized and provide data between 12:30-13:15 UT over 20 MHz to 1430 MHz spectral range. The KRIM e-CALLISTO SRT only have data available until 13:00 UT.

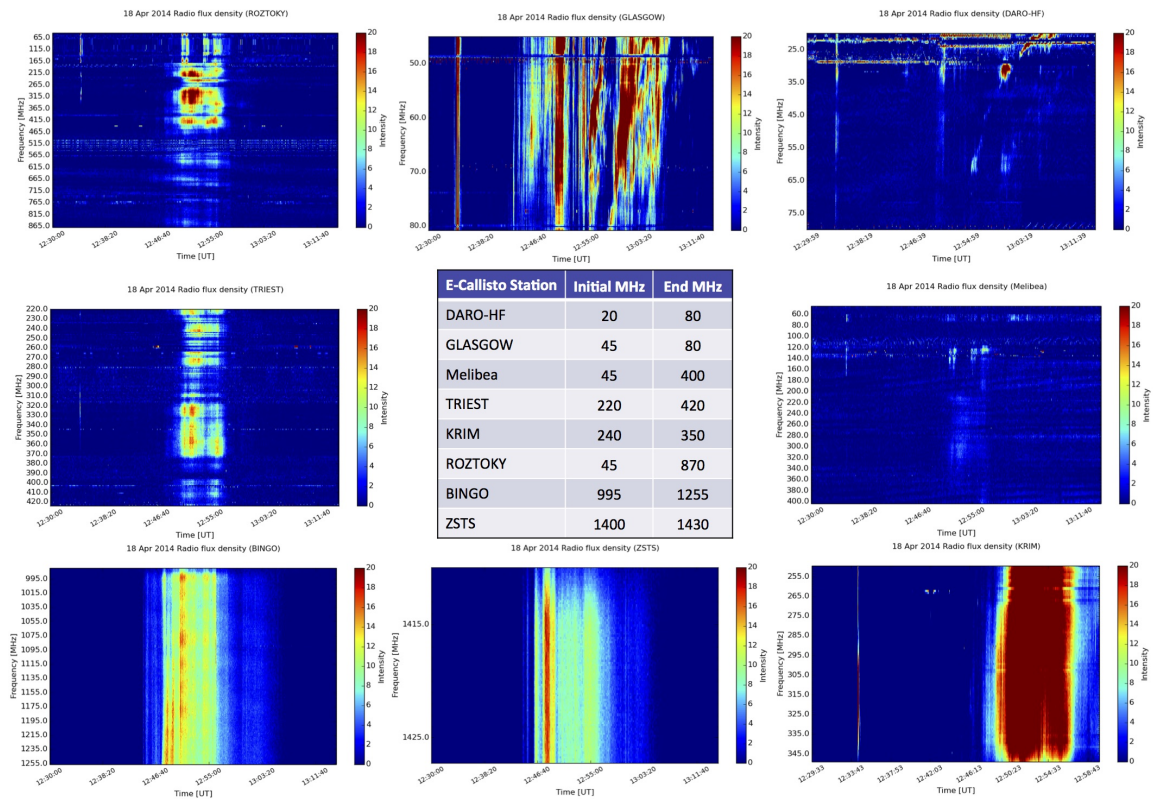


Figure 6. Solar radio event observed by e-CALLISTO instruments over 20 MHz to 1430 MHz on 18th April 2014. The KRIM e-CALLISTO SRT only have data available until 13:00 UT

These e-CALLISTO radio spectra are produced by a web-based tool currently under development by the SRG/UAH for quick look plotting. A preliminary version is available at <http://www.sorbete.srg.uah.es/sorbitools/ecallisto>.

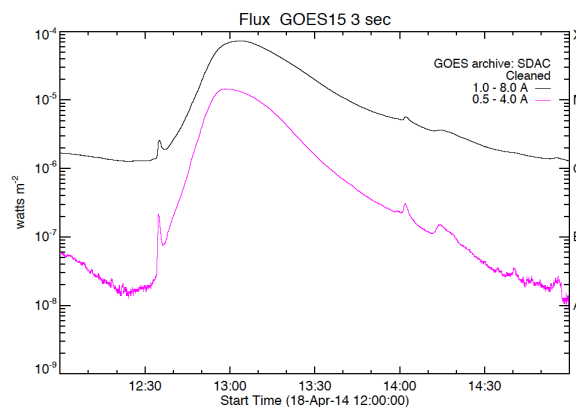


Figure 7. GOES15 3 seconds X-Ray flux of the observed event on 18th April 2014: pink line 0.5 - 4 A and black line 1.0 - 8.0 A.

The soft X-ray flux was measured by GOES satellites during this period, the observation is correlated with the type III radio burst measured by the e-CALLISTO stations. Figure 7 shows

soft X-ray measurements during this period by the GOES 15 satellite in the 1-8 Angstroms (0.1-0.8 nm) and 0.5-4.0 Angstroms (0.05-0.4 nm) passband.

This event was also accompanied by a fast CME propagating southward, which was observed by the COR2 coronagraph onboard STEREO-B Spacecraft [6] and by LASCO [7] onboard SOHO [8]. Figure 9 shows a sequence starting by LASCO-C2 observation at 13:48 UT and COR2 observations for the time interval 13:54-15:54 UT. According to the CACTUS catalog [9], the CME had a position angle of 194° (114° angular width) and a median velocity of 812 km/s. The estimated CME onset time at 13:25 UT.

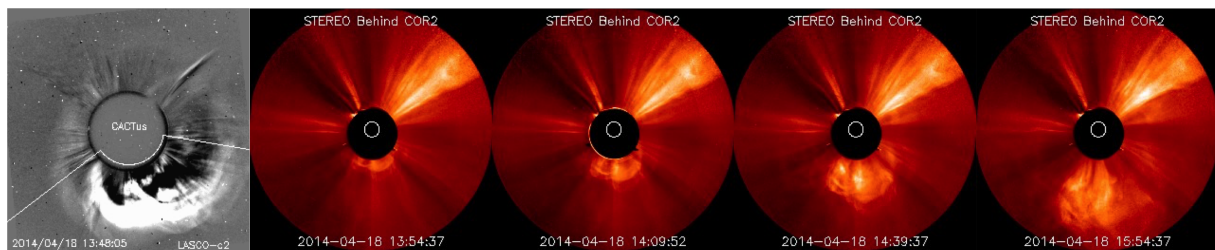


Figure 8. Left: LASCO-C2 observation of the observed event on 18th April 2014 . Right: STB/COR2 sequence of COR2 observations of the same event

Figure 9 left shows a summary of 10-minute averaged solar energetic particle observations by the solar Electron Proton Instrument (EPHIN) [10] onboard SOHO. Temporal profiles of 250-700 keV electrons, 4.3-7.8 MeV protons and 4.3-7.8 MeV/n Helium intensities are shown as red, green and blue lines, respectively. SOHO was relatively well connected to the flare and it observed a clear SEP event, reaching proton energies above 50 MeV (not shown in the figure). The electron flux started to increase at SOHO location at 13:00 UT +/- 2 min.

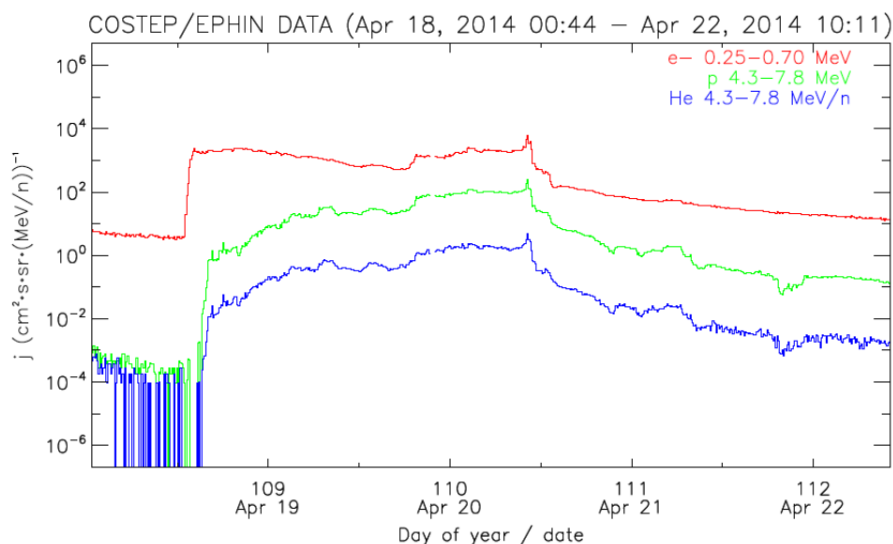


Figure 9. 18th April 2014 10-minute averaged solar energetic particle observations by the solar Electron Proton Instrument (EPHIN) onboard SOHO

5. Summary and future work

The Melibea-SRT is already in operation and integrated as a part of the e-CALLISTO network by the University of Alcalá. The e-CALLISTO stations have been proved to be sensitive to the most intense solar radio bursts with large geographic redundancy, with significant spectral and temporal resolution and with low cost. We have also shown how the system can provide valuable data for the study of SEP events. Such data are particularly useful in order to determine the physical phenomena responsible for the particle acceleration in the Sun (e.g. coronal shocks and solar flares). As future activity, the Celestina-SRT is already under development for covering the frequency range between 20-90 MHz for better data link with the data provided by the space-based instruments. Celestina-SRT will be installed in the OAPT during 2015 (near the location of Melibea-SRT).

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