SELF-ELF Electromagnetic signals correlated to M5+ Italian Earthquakes occurred on August 24, 2016 and January 18, 2017

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Abstract: The authors of this study want to verify the existence of a possible relationship between the natural radio emission observed between the SELF (Super Extremely Low Frequency band; 3Hz>f>0Hz) and the ELF (Extremely Low Frequency; 3Hz≤f≤30Hz) and earthquakes of medium-high intensity registered in Central Italy on August 24, 2016 and on January 18, 2017: 1) M6.2 occurred on August 24, 2016 at 01:36:32 UTC near Norcia (PG); 2) M5.6 occurred on August 24, 2016 at 02:33:29 UTC near Norcia (PG); 3) M5.3 occurred on January 18, 2017 at 09:25:41 UTC near Amatrice (RI); 4) M5.7 occurred on January 18, 2017 at 10:14:11 UTC near Amatrice (RI); 5) M5.6 occurred on January 18, 2017 at 10:25:25 UTC near Amatrice (RI); 6)M5.2 occurred on January 18, 2017 at 13:33:37 UTC near Montereale (AQ). The study results revealed that the six earthquakes occurred in Central Italy on August 24, 2016 and on January 18, 2017 were preceded by a few days by the appearance of SELF-ELF radio emissions not related to the variation of the geomagnetic field and solar activity in general, much less to human activity. Instead, it is considered that the detected signals may be considered potential candidates pre-seismic.

Keywords: *Central Italy earthquakes, SELF-ELF Radio anomalies, VLF radio anomalies, seismic electromagnetic precursors (SEPs), seismic precursors.*

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Introduction

Between August 24, 2016 and January 18, 2016 the Central Italy was hit by nine M5+ earthquakes of variable intensity between M5.2 and M6.6 (**Fig. 1**) caused by the movement of fault segments with high structural complexity. The seismic sequence caused damage in 131 Italian cities located in territory of Lazio, Umbria, Marche and Abruzzo. The earthquakes killed more than 300 people. Italy is currently classified as one of the countries with the highest seismic risk present in the European continent and it is necessary that the scientific community make every effort so that research on earthquake prediction comes close, from a methodological and conceptual point of view, to United States and Japan and it is on new consideration that is grafted the electromagnetic monitoring.

On the Italian territory, there are two electromagnetic monitoring networks created for studying the pre-seismic radio emissions: the first, located in Central Italy in the province of Rome, at the foot of the famous Latium Volcano is managed by Dr. Gabriele Cataldi and Dr. Daniele Cataldi as part of project called "Radio Emissions Project"; the second, located in the North-East of Italy, in the province of Udine is managed by Friuli Experimental Seismic Network (FESN) Group. The two networks are an integral part of a major project of electromagnetic monitoring called "*Project SDT - Signals from the Earth*", promoted in 2007 by the Italian Radio Amateurs Association (ARI) and realized by FESN, through which the authors of this work and other Italian collaborators constantly monitor the natural electromagnetic background of the SELF (Super Extremely Low Frequency) band and VLF (Very Low Frequency) band (0<f<30kHz) in search of electromagnetic signals with seismic predictive characteristics, ie pre-seismic radio signals: the so-called "Seismic Electromagnetic precursors". The electromagnetic monitoring stations of FESN and

Radio Emissions Project are active 24h7 and allow to automatically store data obtained from the monitoring activity on informatic support. Following are shown the technical characteristics of the stations:

1) SELF-ELF (0-15Hz) monitoring station, Trasaghis (UD), FESN.
   - Induction magnetometer (18-bit), coil antenna, vertical polarization (Bz).
2) SELF-ELF (0-15Hz) monitoring station, Pasian Di Prato (UD), FESN.
   - Induction magnetometer (18-bit), coil antenna, vertical polarization (Bz).
3) VLF (300-30000Hz) monitoring station, Albano Laziale (RM), Radio Emissions Project.
   - VLF receiver (24-bit), loop antenna, horizontal polarization (41°N-E).
4) SELF-ELF (0-5Hz) monitoring station, Lariano (RM), Radio Emissions Project.
   - Induction magnetometer (24-bit), coil antenna, vertical polarization (Bz).

Fig. 1 – Central Italy earthquakes: The picture shows (red arrow) the seismic epicentres (orange circles) of M5+ earthquakes occurred in Central Italy between 24 August 2016 and 18 January 2017. At the top, the two yellow round icons indicate the two SELF-ELF electromagnetic monitoring stations realized by "Friuli Experimental Seismic Network" (FESN) located in Trasaghis, Udine (the top one) and at Pasian Di Prato, Udine (the lower). The two colored icons visible on the bottom of the image indicate the electromagnetic monitoring stations of Radio Emissions Project located at Albano Laziale, Roma (the green icon) and in Lariano, Rome (the red icon).

Methods and Data

To verify whether the Italian seismic sequence occurred between August 2016 and January 2017 was preceded by pre-seismic radio emissions, the authors analyzed the data on electromagnetic monitoring products through the SDT Project, between August 2016 and January 2017, and in particular the data produced by the stations of Pasian Di Prato (UD), Trasaghis (UD), Albano Laziale (RM) and Lariano (RM). These data were compared with data on M5+ seismic activity recorded in Central Italy between 24 August 2016 and 18 January 2017 by United States Geological Survey (USGS).

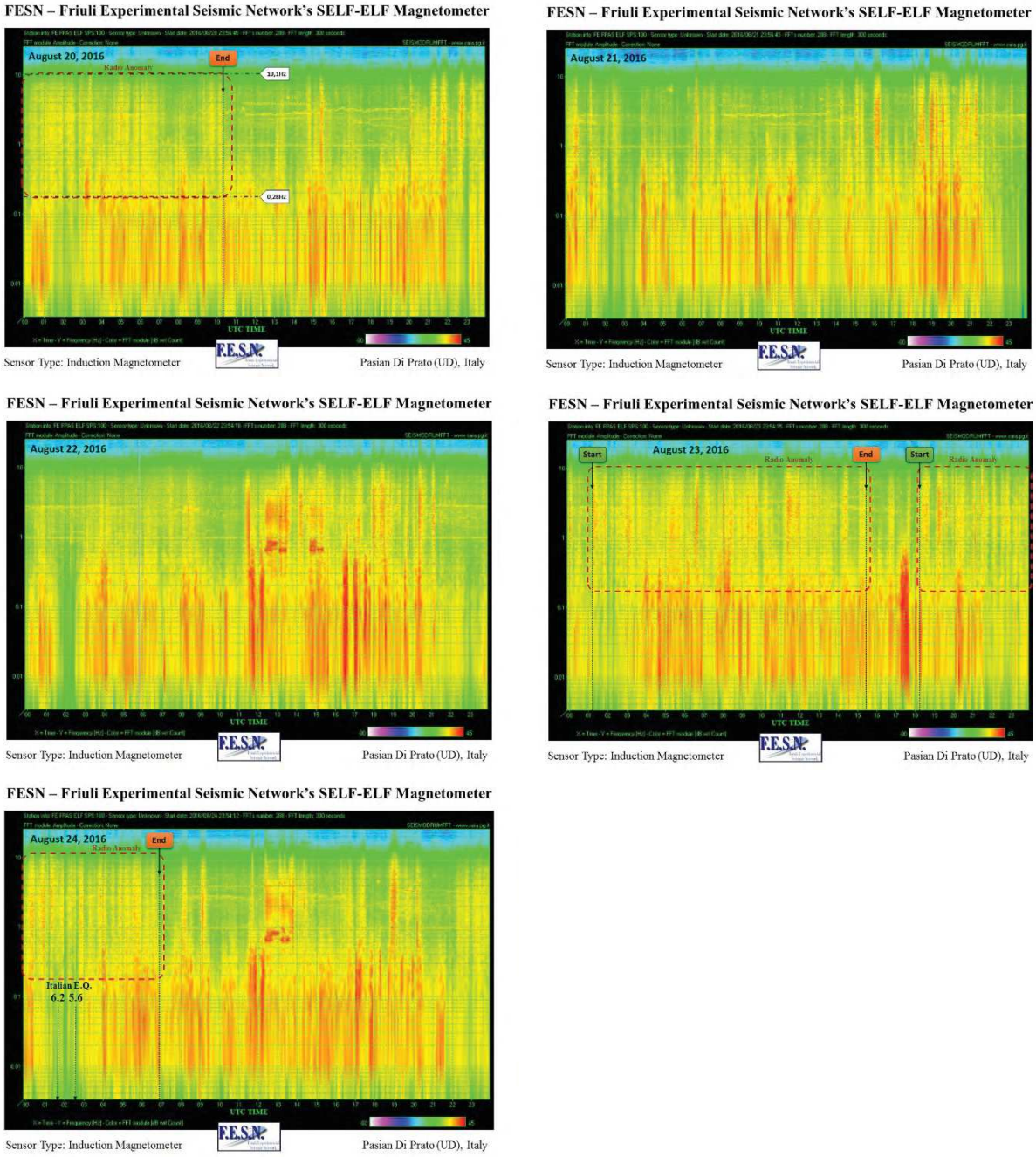

Fig. 2 – Seismic Electromagnetic Precursor of seismic sequence recorded in Central Italy on August 24, 2016. The picture shows five dynamic spectrograms related to electromagnetic environmental monitoring realized by the Friuli Experimental Seismic Network (FESN) between 20 and 24 August 2016 through the monitoring station located in Pasian Di Prato (UD). The areas of the circumscribed spectrogram with the red dotted line represents pre-seismic electromagnetic emissions that preceded the M5+ seismic sequence of August 24, 2016. "Start" and "End" labels indicate respectively the start and end of the Electromagnetic earthquake precursor registered precede earthquakes.

Results

The study results confirmed that, with the exception of earthquakes occurred in Central Italy between 26 and 30 October 2016, the earthquakes that occurred on August 24, 2016 and on January 18, 2017 were preceded by radio emissions that could not be associated to anthropogenic broadcasters or emissions of geomagnetic nature:

- M6.2 and M5.6 Central Italy earthquakes occurred on August 24, 2016: the electromagnetic monitoring station of Pasian Di Prato (UD) has detected an electromagnetic emission equivalent to an increase of natural electromagnetic background

between 0.28 to 10,1Hz at a maximum intensity centered around 3Hz. This radio signal appeared on August 20, 2016 just after 00:00 UTC and ended at 10:20 UTC of the same day. Then it was re-recorded on August 23, 2016 between 01:15 UTC and 15:25 UTC; and then between 18:14 UTC on August 23, 2016 for terminate at 06:54 UTC on August 24, 2016 (**Fig. 2**).

- M6.2 and M5.6 Central Italy earthquakes occurred on August 24, 2016: the electromagnetic monitoring station of Albano Laziale (RM) has detected an electromagnetic emission with wide bandwidth (13,37kHz). This electromagnetic anomaly that has been recorded on August 18, 2016 between 02:47 UTC and 06:21 UTC, thus remained visible for about 3 hours and 34 minutes between 9.63 kHz and 23kHz, with greater intensity between 9.63 kHz and 20,5kHz and preceded the Italian M6.2 earthquake of the August 24, 2016 of 142 hours and 49 minutes (almost 6 days) (**Fig. 3**).
- M6.2 and M5.6 Central Italy earthquakes occurred on August 24, 2016: the electromagnetic monitoring station located in Lariano (RM) has detected a number of electromagnetic emissions within the SELF (Super Extremely Low Frequency) band, some of which preceded the major seismic events (M6.2 e M5.6) and others are taking place close to other earthquakes with small magnitude (**Fig. 4**). The M6.2 earthquake was preceded about 70 minutes by an increase of the electromagnetic background with a bandwidth comprised between 0 and 0,6Hz. The most intense pre-seismic electromagnetic emission, however, was recorded 17 hours before the M6.2 earthquake and had a duration of 40 minutes.
- M5.3, M5.7, M5.7 and M5.2 Central Italy earthquakes occurred on January 18, 2017: the electromagnetic monitoring station of Pasian Di Prato (UD) has detected an electromagnetic emission with very tight bandwidth, centered at 4,8Hz. This emission was registered for the first time on January 13, 2017 at 11:30 UTC and disappeared on January 18, 2017 at 09:10 UTC, about 15 minutes before the M5.3 earthquake occurred at 09:25 hours: 41 UTC (**Fig. 5**).

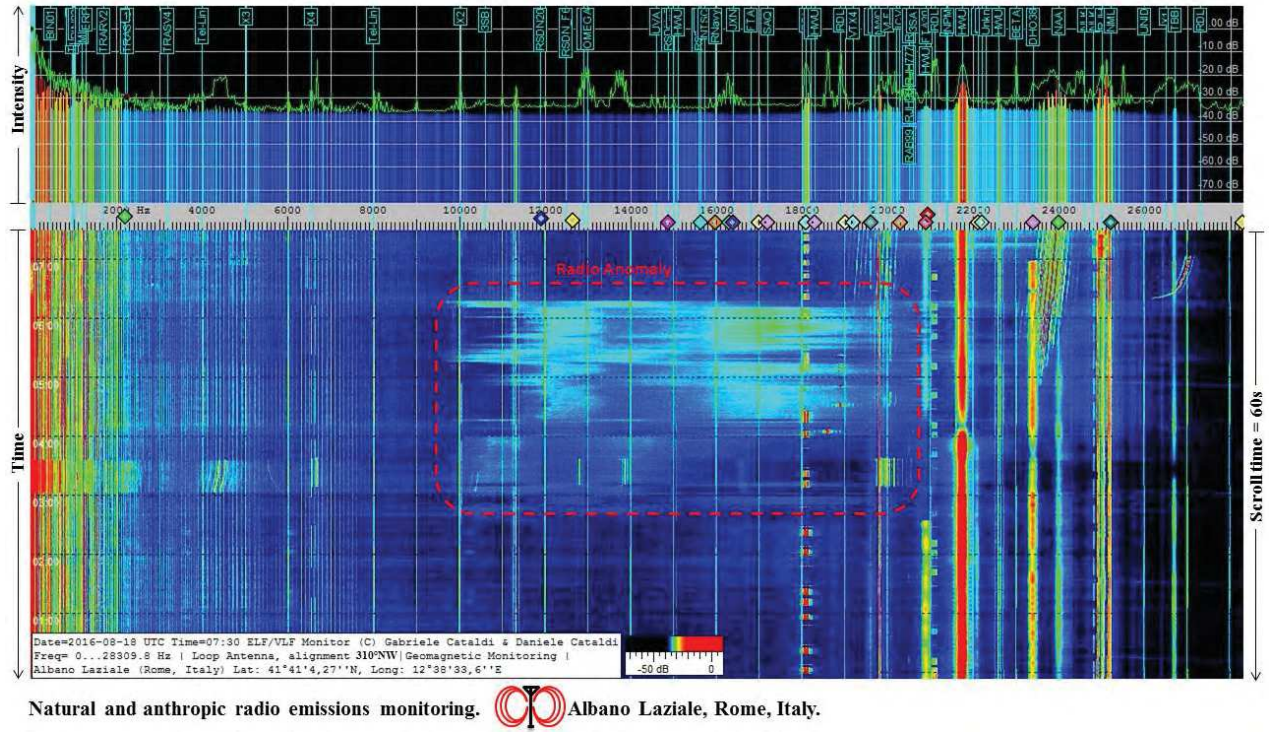

Fig. 3 – ULF-VLF Pre-Seismic Radio Emissions: The picture shows the dynamic spectrogram of the Earth's electromagnetic field recorded on August 18, 2016 between 00:00 and 07:30 UTC from the ULF-VLF electromagnetic environment monitoring station of Radio Emissions Project, located at Albano Laziale (RM), Italy. At the center of the spectrogram, inside the red dotted line, is present the radio anomaly that has been recorded precede the M6.2 Italian earthquake occurred on August 24, 2016 at 01:36 UTC. The emission appeared at 02:47 UTC and disappeared at 06:21 UTC. The labels at the top of the spectrogram (in light blue) indicate known radio stations, prevalently of anthropic type. On the Y axis of the spectrogram indicates the UTC time of the registration: this proceeds from top to bottom at 1 horizontal line to minutes. On the X axis is instead reported the emission

frequency of the radio signals (the frequency increases going to the right): these are represented in different colors according to their intensity.

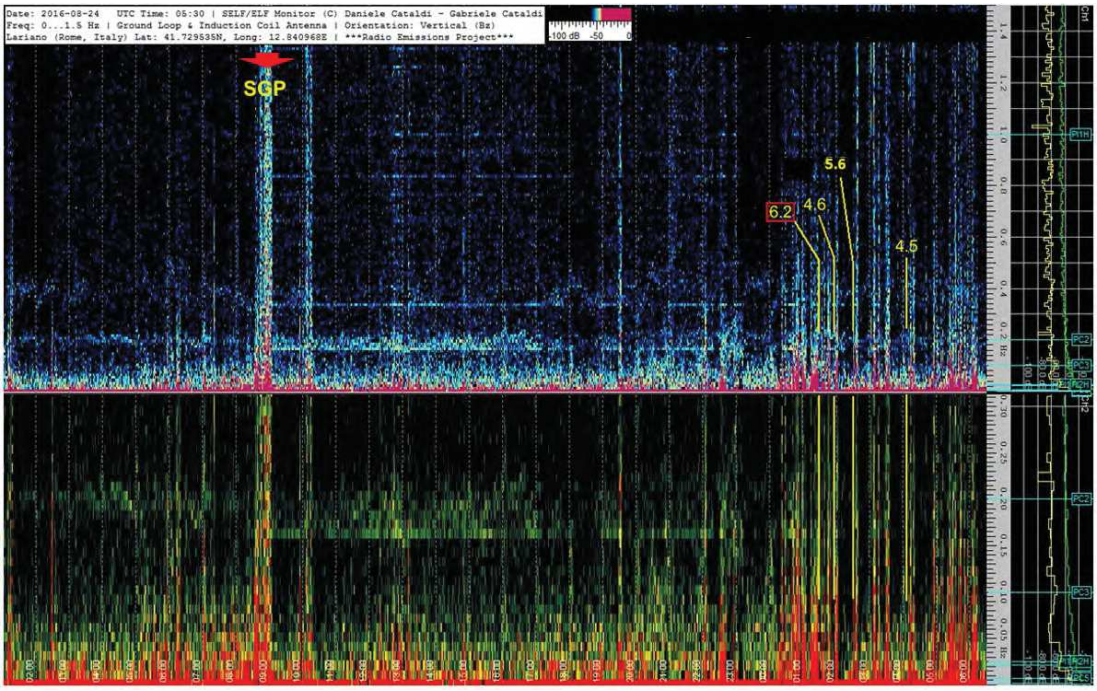

Fig. 4 – SELF-ELF Monitor: The image represents the dynamic spectrogram of the Earth's electromagnetic field registered between 02:00 UTC on August 23, 2016 and 06:30 UTC on August 24, 2016 by environmental electromagnetic monitoring station of Radio Emissions Project, located in Lariano (RM), Italy; it monitors the band SELF and ELF with a resolution of 10.1 mHz. The upper portion of the spectrogram is centered in the SELF band between 0 and 1.5Hz, while the lower portion is centered in the SELF band between 0 and 0.31Hz. The spectrogram is acquired through a radio receiver prototype developed by Gabriele Cataldi designed to work efficiently between the SELF band (0<f<3 Hz) and the ELF band (3-30Hz). The used antenna is a coil antenna aligned vertically (Bz geomagnetic component). The word "SGP", indicated by the vertical red arrow, is an acronym coined by the authors that identifies the radio emission of geomagnetic nature that was observed to precede large earthquakes (Seismic Geomagnetic Precursor): this electromagnetic emission preceded the M6.2 Italian earthquake of approximately 17 hours and had a duration of about 40 minutes.

The monitoring stations located in Trasaghis (UD) was not set properly to get comparable readings (data) with those of Pasian Di Prato (UD).

Fulmination

To confirm the objectivity of the electromagnetic monitoring related data, the authors have verified if in the vicinity of the Radio Emissions Project's ULF-VLF and SELF-ELF monitoring stations had occurred storms on August 18, 2016. The radio signals produced by lightning, in fact, can be detected by radio receivers tuned to a wide range of frequencies, for this reason it is essential to reject the hypothesis that electromagnetic anomalies detected near the (VLF and SELF-ELF) electromagnetic monitoring station of Radio Emissions Project are in reality the marks left by a storm. To run this check, were utilized weather data provided by the Italian Air Force (AMI) and found that on August 18, 2016 there were no thunderstorms near the ULF-VLF and SELF-ELF monitoring stations located in Central Italy, but light rain were recorded in Northern Italy. Also the Regional Agency for Environmental Protection of Friuli Venezia Giulia (ARPA-FVG) has confirmed that in the days when the Pasian Di Prato (UD) monitoring station has detected anomalies there were no storms on the site station. Identical results were obtained by verifying the weather conditions for the period from 13 to 18 January 2017. Moreover, from a spectrographic point of view, on ULF-VLF spectrogram and are not found typical signals related to lightning discharges, ie the so-called "Spherics" (abbreviation of "atmospherics", also known as "statics").

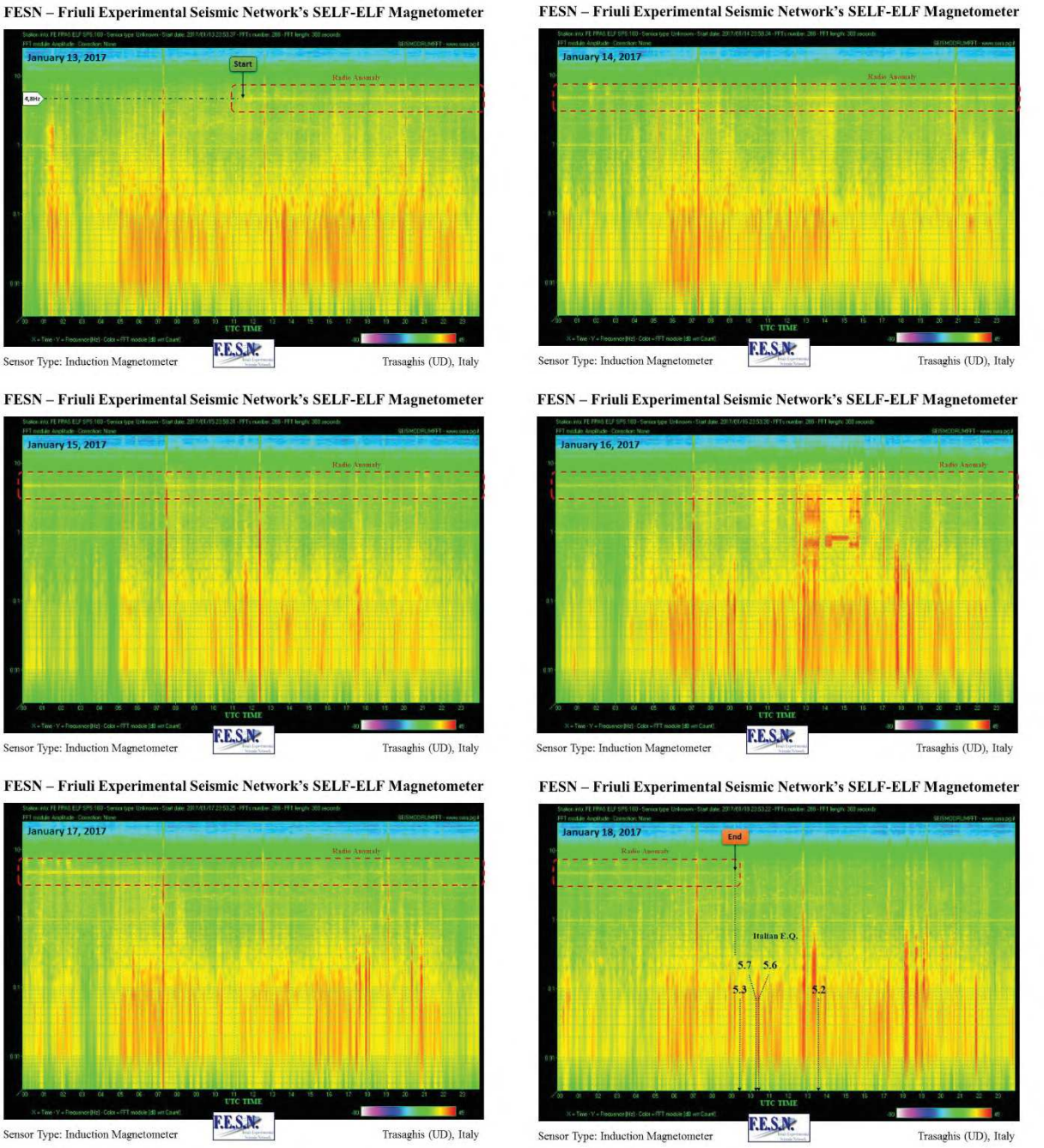

Fig. 5 – Seismic Electromagnetic Precursor of seismic sequence recorded in Central Italy on January 18, 2017: The picture shows five dynamic spectrograms related to electromagnetic environmental monitoring realized by the Friuli Experimental Seismic Network (FESN) between 20 and 24 August 2016 through the monitoring station located in Pasian Di Prato (UD). The areas of the circumscribed spectrogram with the red dotted line represents pre-seismic electromagnetic emissions that preceded the M5+ seismic sequence of August 24, 2016. The vertical black arrows represent the temporal markers of M5+ earthquakes occurred in Central Italy on January 18, 2017. The label says "Start" and "End" respectively indicate the start and end of the electromagnetic earthquake precursor registered precede the earthquakes.

Discussion

Radio emissions with seismic predictive characteristics were observed for the first time in 1880 (Milne, 1890). Today we know that there are two main families of pre-seismic radio emissions: 1) those of "local" type produced as a result of the creation of micro-fractures in the focal zone of the earthquake (piezoelectricity); 2) those of "non-local" type detectable from anywhere on the Earth's surface because they are assimilated to the terrestrial geomagnetic field disturbances (Cataldi et al., 2016).

In the specific case the radio emissions detected by SDT stations of Pasian Di Prato (UD), Albano Laziale (RM) and Lariano (RM) with exception for the electromagnetic emission identified by the

acronym "SGP" (Seismic Geomagnetic Precursors) recorded on August 23, 2016 at 09:00 UTC, do not have any spectrographic and spectrometric characteristics that allows us to establish that it is related to electromagnetic phenomena correlated to Earth's geomagnetic activity, so it is very likely that this is electromagnetic emissions produced locally, i.e. in the focal zone of earthquake sequence. This is because the radio emissions associated to geomagnetic activity (and therefore to solar activity), are observed with greater intensity within the SELF (Super Extremely Low Frequency) band becoming less intense as the frequency increases.

The anomalies recorded precede earthquakes of August 24, 2016 and January 18, 2017 have features that are incompatible with those of a geomagnetic disturbance:

1) the radio emission related to Italian seismic sequence of January 18, 2017 (recording made through the electromagnetic monitoring station of Pasian Di Prato, Udine), was recorded during a state of solar quiet, in fact, the ion density of the interplanetary medium was at its lowest. In addition, the signal bandwidth is too tight (only 0.4 Hz) to hypothesize that it may be a emission of a geomagnetic nature, also considering that this signal has remained visible uninterruptedly for almost five days.

2) the SELF-ELF anomaly registered by Pasian Di Prato station precede the seismic sequence of August 24, 2016 has, on the contrary, a wide bandwidth (9.82 Hz) This signal may be produced by the earthquake preparation processes (piezoelectric effect) but we have no large series about, especially for Pasian Di Prato's Monitoring Station with the maximum centered around 3Hz. This anomaly has been detected three times from 20 to 24 August 2016 and ended four hours and 30 minutes after the last M5+ earthquake recorded on August 24, 2016, also its intensity has increased from August 23, 2016. From a spectrographic point of view, this radio signal has not undergone morphological variations and this fact allows us to exclude that it may be an emission of geomagnetic nature.

3) The station of Lariano (RM), although it was the only electromagnetic monitoring station to record emission comparable to a geomagnetic disturbance (in fact between 18 and 23 August 2016 was found an increase of "gradual" type of interplanetary medium ion density near Earth). It is possible but the Lariano's station has detected disturbances in the SELF-ELF band even for the earthquakes to tens of thousands of kilometers away; We consider them non-local seismic precursors that preceded the M6.2 earthquake of August 24, 2016 (01:36:32 UTC), approximately 17 hours, has also allowed us to record a series of impulsive emissions of the natural electromagnetic background that preceded the M6.2 earthquake about 70 minutes remaining visible at least up to 06:30 UTC of 24 August 2016.

These impulsive emissions have had a shorter duration and a narrower bandwidth in respect to tie electromagnetic emissions that the authors associated with a variation of the geomagnetic field that was recorded at 09:00 UTC of 23 August 2016, therefore, the signal must be of local origin, is generated in the focal zone of seismic sequence recorded on August 24, 2016. Observing spectrograms can be calculated the time lag that elapsing between the pre-seismic radio emissions have appeared and the time at which it started the seismic sequence in Central Italy (**Fig. 6**):

- Respect to the monitoring data provided by the station of Pasian Di Prato (UD), the pre-seismic electromagnetic anomaly has appeared 120 hours and 30 minutes before the M5+ earthquake sequence recorded on January 18, 2017.
- Respect to the monitoring data provided by the station of Pasian Di Prato (UD), the pre-seismic electromagnetic anomaly appeared about 97 hours before the M6.2 earthquake recorded on August 24, 2016.
- Respect to the monitoring data provided by stations of Lariano (RM), the pre-seismic electromagnetic anomaly appeared about 17 hours before the M6.2 earthquake recorded on August 24, 2016.

- Respect to the monitoring data provided by the station of Albano Laziale (RM), the pre-seismic electromagnetic anomaly appeared about 143 hours before the M6.2 earthquake recorded on August 24, 2016.

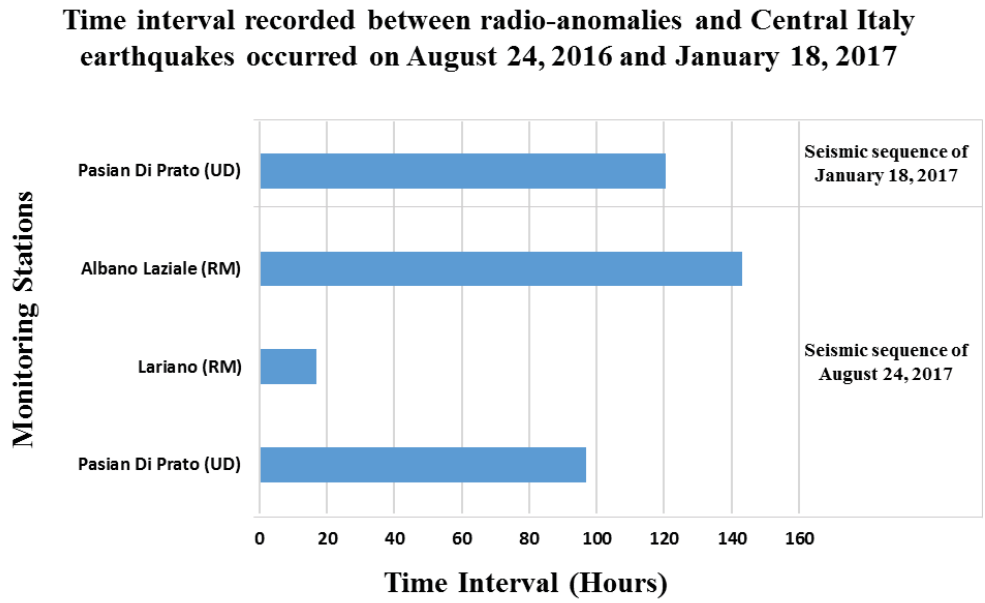

Fig. 6 – Time interval between radio-anomalies and Central Italy seismic activity: The graph shows the time intervals recorded between radio anomalies (pre-seismic radio emissions) and the Central Italy seismic sequences recorded on August 24, 2016 and on January 18, 2017. The data were provided through the "SDT Project". The monitoring station of Pasian Di Prato (UD) was the only one to detect pre-seismic electromagnetic anomalies that preceded the seismic sequences of January 18, 2017

Conclusions

In recent decades, many nations of the world are making substantial efforts to try to develop an innovative seismic forecasting methodology that separates definitively from seismometric data. To achieve this goal, however, it is essential realize an interdisciplinary and multidisciplinary research project shared globally in which research on pre-seismic radio emissions, the monitoring of space weather and the heliophysics study must be integrated in the same context and interpreted by a team of researchers with undisputed expertise. The authors of this study have proposed many times at national and international level, the creation of a research project on seismic precursors that is shared globally.

In Italy this scientific approach is not widely shared among researchers and this made it impossible to create a center for the study of pre-seismic radio emissions recognized in academic or governmental level. Currently in Italy the research on pre-seismic radio emission is performed by amateurs, technicians of various kinds, amateur radio operators and researchers who fully self-financed their work producing important scientific studies. The Radio Emissions Project and the Friuli Experimental Seismic network (FESN) are two Italian teams of researchers who dedicate a part of their lives to the study of pre-seismic radio emissions. Together with other researchers and enthusiasts are an integral part of an electromagnetic monitoring network designed to monitor the environmental electromagnetic background between 0 and 22 kHz; this network (born in 2007) has been called "SDT Project - Signals From The Earth" and all monitoring stations that are part of it must have specific technical requirements to ensure that the network is able to perform an electromagnetic monitoring more objective possible. This new approach aimed at pre-seismic radio emissions has allowed in recent years to produce some very interesting and important scientific papers on electromagnetic seismic precursors (SEP) and on seismic geomagnetic precursor (SGP), (Straser et al., 2016; Cataldi et al, 2016-2017).

The analysis of the electromagnetic spectrum between 0 and 22 kHz, especially between the SELF band and the ELF band (Ohta et al., 2013) allows to monitor the pre-seismic electromagnetic emissions associated with large earthquakes (M6+), to understand their characteristics and develop best electronic devices, in the perspective to realize a seismic prediction method based on monitoring and on understanding of these radio signals; in fact it is impossible to think that the future of research on seismic prediction has yet to be essentially linked to the historical data of seismometric measurements and to the geodynamics and geological characteristics of the faults..

The SDT Project has shown that it is possible to detect pre-seismic radio signals that occur on Italian territory and it is hoped that this monitoring network undergoes a rapid expansion in the coming years: this will allow us to get a lot more electromagnetic data associated by seismic activity that occurs in our country enabling us to better understand the characteristics of these radio emissions. A technology that must be integrated in this system is the Radio Direction Finding (RDF), because it is currently possible to realize radio receivers that allow to understand from which direction spreads an electromagnetic emission; this technology allowed to identify the seismic epicenter of the famous M9.0 Japanese earthquake that occurred on March 11, 2011 at 14:46:24 UTC+9 (Ohta et al, 2013). Italy, along with Greece, is the European area of high seismic risk, and this has to be translated into opportunities for Italian researchers: a seismic district with these characteristics allows us to make an imposing study on electromagnetic seismic precursors that can certainly produce significant results. Those produced under the "SDT" Project in August 2016 and January 2017 are an example of the great results that can be achieved by exploiting technological potential and the right ideas in a country, Italy, which has the potential to become among one of the first countries in the world where it can be conducted innovative research on seismic prevision.

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