RADIO SIGNALS AND CHANGES OF FLOW OF RADON GAS (RN_{222}) WHICH LED THE SEISMIC SEQUENCE AND THE EARTHQUAKE OF MAGNITUDE MW 4.4 THAT HAS BEEN RECORDED IN CENTRAL ITALY (BALSORANO, L'AQUILA) ON NOVEMBER 7, 2019.

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ABSTRACT

Through this work the authors want to ascertain the possible relationship have theorized that between the pre-seismic increase of Radon gas (Rn_{222}) and the production of radio-pre-seismic anomalies in the Apennines Central Italy: phenomena that have a substrate common, namely the creation of fractures and micro-fractures of the crust due to tectonic stress. The radio-pre-seismic anomalies (Electromagnetic Seismic Precursors or ESPs) are of natural radio emissions generated through the deformation and rupture (microfractures and fractures) of the crystalline lattices present in the rocks that make up the earth's crust. The Rn_{222} gas is, instead, is the only gaseous element produced by dell'Uranio238 decay which is able to filter from the mantle to the ground through the earth's crust in thermodynamic function of the energy produced in the mantle and in relation to the permeability (fractures and geological characteristics) of the earth's crust. Central Italy is dotted with numerous faults and micro-faults capable of generating destructive earthquakes. Under this scenario, it is convenient to install a network of multi-parametric monitoring in Central Italy for the study of so-called "Electromagnetic Seismic Precursors" (ESPs) and "Chemical Seismic Precursors" (CSPs), in our case, identifiable by variations Rn_{222} of the gas flow. This paper will present the correlation data on electromagnetic anomalies (ESPs) and chemical (Rn_{222}) that have been observed to precede the seismic sequence and the Mw 4.4 earthquake that was recorded in Balsorano (AQ) November 7, 2019 at 17:35:21 UTC (**Fig. 1**)

Keywords: RDF system, earthquake prevision, Gas Radon, Central Italy, Multi-parametric monitoring.

INTRODUCTION

Since 2017 the researchers of the Radio Emissions Project, developed a terrestrial geomagnetic field monitoring system that has been implemented with the technology RDF (Radio Direction Finding) (Straser V. et al., 2019). This technology is able to identify the direction of arrival of electromagnetic signals coming at the level crustal (Straser V. et al., 2019). Following these studies, which lasted about a year, the RDF system was tested in the following two years and has provided important information on the electromagnetic signals observed before strong earthquakes (Cataldi D. et al., 2019). Since November 2019 it was possible to investigate the presence of candidates seismic precursors with the use of a multi-parametric monitoring system characterized mainly by RDF monitoring network of Radio Emissions Project and the detection system of the Rn_{222} density, managed by the "Permanent Foundation G. Giuliani". In this regard, the trial began in November of 2019 and has focused on the detection of electromagnetic signals having arrival azimuth as the area of the center of Italy, in the vicinity of the gas detection sensors Rn_{222} (Central Apennines, aquilana area). In this case, the study has wanted to confirm the presence of a close relationship between the increase of the density of the flow Rn_{222} in crustal surface and the emission of electromagnetic signals from the said area, prior to the occurrence of medium-low

intensity earthquakes within 50 km away from Rn_{222} monitoring stations considered in this study. This was the first ever worldwide experimentation on the correlation between data from a multi-parametric monitoring system equipped with an electromagnetic tracking system incorporating RDF technology and a density of the monitoring system of the Rn_{222} gas flow.
The observation of transient variations between the gas flow Radon (Rn_{222}), measured by the range of the "Permanent Foundation G. Giuliani" sensors (already used in previous studies technique - Giuliani G. et al., 2012), and measures of electromagnetic sensors of Radio Emissions Project is a phenomenon that has already been observed by the authors precede ML3.1 earthquake that was recorded October 12, 2019 at 12:29:55 (UTC) 2 km South from Capitignano (AQ); Lat. +42.5N; Long. +13.3E; (INGV data). In both cases, the seismic epicentres were identified before the earthquake associated with them: it is a result that has no precedent in the world.

Methods and Data

This study was carried out by monitoring the concentration of Radon gas stream (Rn_{222}) at the surface and by monitoring the ambient electromagnetic activity "continuous" through a multi-parametric experimental monitoring network situated between Tuscany, Abruzzo and Lazio, where there are three stations:

1. **First station:** Radon Station (Rn_{222}) located in Ripa-Fagnano (AQ) (Lat. +42.265663N, Long. +13.583765E). It is equipped with a gamma detector, capable of recording variations of the gas hourly flow Rn_{222} in a radius of action for small and medium grade Richter events, amounting to 0-50 km. Always in the Ripa-Fagnano station (AQ) a sensor has been installed for monitoring the electromagnetic "continuous" broadband, implemented with RDF technology (Radio Direction Finding). The technology developed by the Radio Emissions Project, for the monitoring of the pre-seismic radio emissions, it is able to identify the target arrival direction (azimuth) of the electromagnetic signals picked up between the band SELF (Super-Extremely-Low-Frequency: $0 < f < 3$Hz) and the first portion of the band LF (Low-Frequency; $30 < f \leq 300$kHz) reaching 96kHz (total bandwidth ≈ 96kHz; $0 < f \leq 96$ kHz) with a resolution <1Hz, an analog-to-digital conversion 24-bit and a digital sampling to 192kHz. The multi-parametric station is positioned in an area of high seismic risk.

2. **Second Station:** Radon Station (Rn_{222}) located in Coppito (AQ) (Lat. +42.367509N, Long. +13.342659E). It is equipped with 2 gamma detector, capable of recording the gas hourly flow variation Rn_{222} in a range for small and medium Richter scale events, pariah 0-50 km.

3. **Third Station:** Pontedera RDF station (PI) (Lat. +43.672479N, Long. +10.640259E) **(Fig. 7**); Located 286 km away (NW) from the two radon stations considered in this study and located in the province of L'Aquila (Ripa Fagnano-: Lat. + 42.265663N, Long. + 13.583765E; Coppito: Lat. +42.367509N, Long. +13.342659E). The Pontedera RDF station (PI) has the same technical characteristics of the RDF station Ripa-Fagnano (AQ).

The testing of this multi-parametric monitoring network began October 6, 2019 with the installation of RDF radio receiver at the Ripa-Fagnano (AQ) station, already equipped with sensor range for the measurement of gas flow Rn_{222} (Giuliani G. et al., 2013). The trial aims, for the first time in the world, to detect any changes in the natural electromagnetic field that may be related to changes in thermodynamic energy, detected by variations of the Rn_{222} flow measured at the surface near seismically active areas of Central Italy. In other words, the study aims to put in their relationship between the pre-seismic electromagnetic anomalies (defined by the authors as “Electromagnetic Seismic Precursors or ESPs) (Cataldi G., 2019) and the pre-seismic changes of Rn_{222} gas concentration (defined by the authors as Chemical Seismic Precursors or CSPs) on the hourly moving average, starting from a consideration relating to seismogenesis: earthquakes are the result of the accumulation of crustal stress that is responsible for creating micro-fractures and fractures of the crust. This event explains why it is possible to observe of Rn_{222} gas increments before a seismic event and also explains how it is possible to produce in the radio frequency of the earthquake preparation area (and adjacent areas) through the phenomenon of piezoelectricity. It is conceivable that the crustal movements favor the propagation velocity of the gas through the Earth's crust Rn_{222} until reaching the surface, as well as the increase of the tectonic stress between the fault planes may generate electromagnetic emissions starting from the deformation of the crystal lattices of up to arrive at their complete breakage. If you want to include in this reasoning also a reference to geo-dynamics, it would not be wrong to say that both phenomena monitored the authors have a common geodynamic substrate.

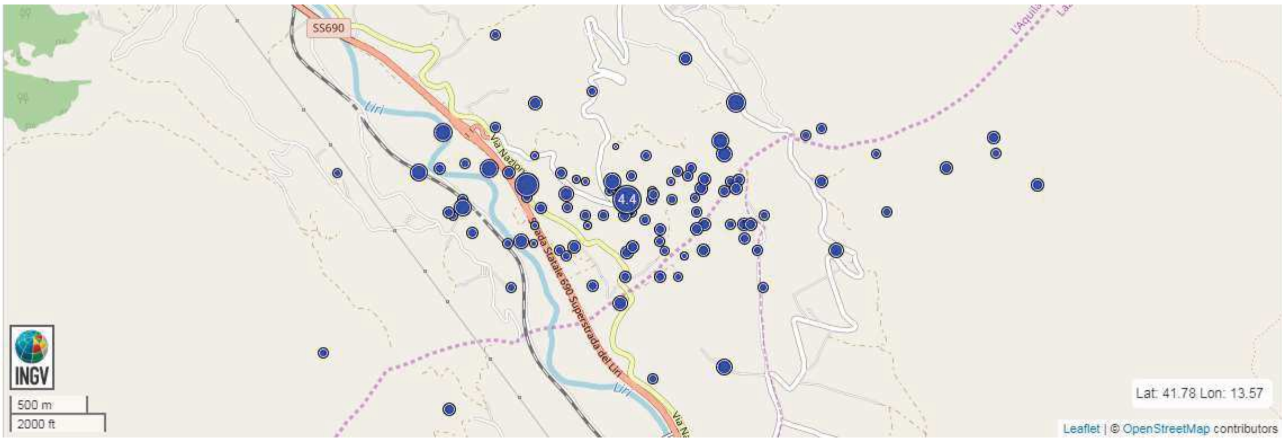

Fig. 1 - Map of the earthquake sequence recorded between 7 and 9 November 2019*, in the municipality of Balsorano (AQ), Central Italy, with maximum magnitude up to 4.4 Mw. Credits: INGV.*

Electromagnetic data provide important information to start from November 4, 2019 at 07:00 UTC, just from electromagnetic monitoring station Ripa-Fagnano (AQ) (Station #2), equipped with technology RDF (Radio Direction Finding): It has been detected a general increase in the electromagnetic background between 33 kHz and 35 kHz, having as its azimuth precisely the earthquake epicenter Mw 4.4 that will be recorded about 82 hours later, and precisely November 7, 2019 at 17:35:21 UTC. In **Fig. 2** is visible precisely this radio signal.

The electromagnetic increase recorded by the RDF station of Ripa-Fagnano (AQ) was confirmed by the readings of the RDF station Lariano (RM) (n.3 station) (**Fig. 3**), which between 01:40 UTC and 13:30 UTC November 4, 2019 registered a particular electromagnetic increase having azimuth turquoise, thereby confirming (through a triangulation) the seismic epicenter where within a few hours has begun seismic sequence shown in **Fig. 1**. the radio emissions recorded by the RDF station Lariano (RM) and related seismic epicenter of Balsorano (AQ), were distributed in 4 different times and have had different bandwidths (**Fig. 3**):

- ~ 01:40-02:20 UTC; 52 kHz,
- ~ 06:50-09:10 UTC; 92 kHz.
- ~ 11:45-12:30 UTC; 12 kHz.
- ~ 13:00-13:30 UTC; 68 kHz,

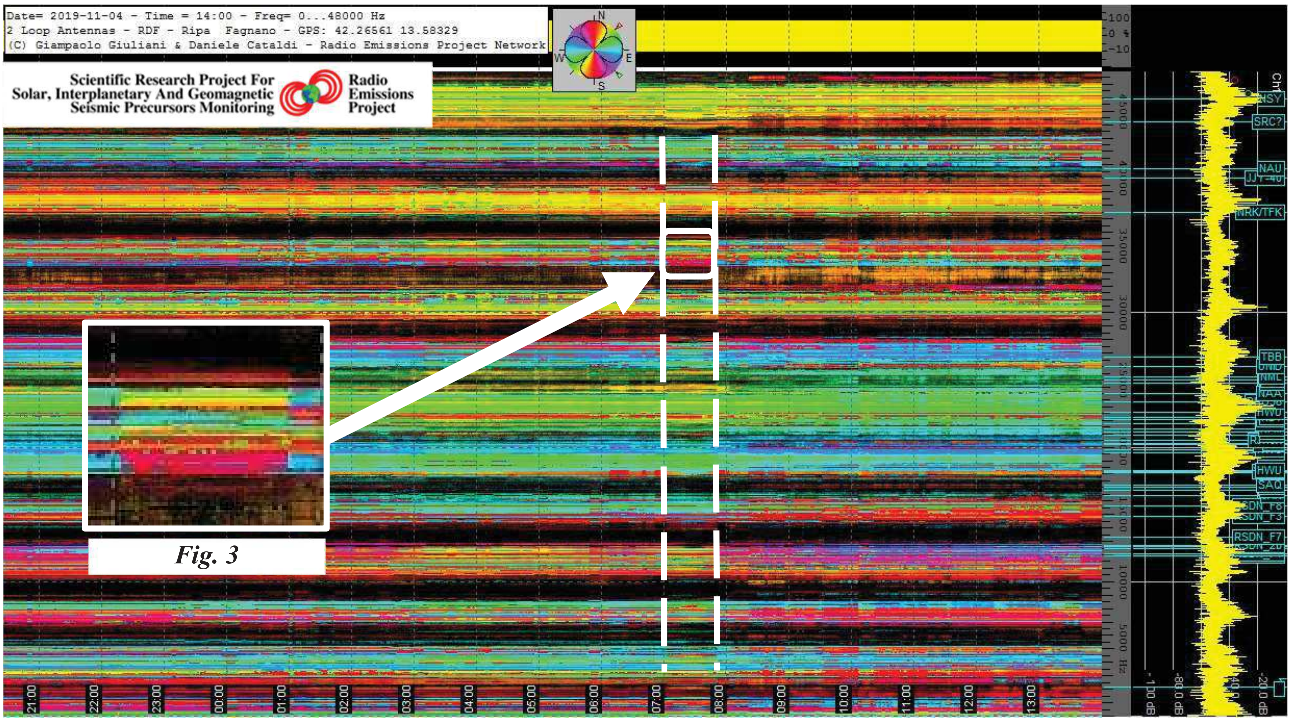

Fig. 2 - Spectrogram of RDF-station Ripa Fagnano (AQ). *At the top visible spectrogram (recorded between 3 and on November 4, 2019) has been highlighted (white rectangle with continuous line) the electromagnetic anomaly associated azimuth coincides with the azimuth of the geographical area where 82 hours later is started seismic sequence that was followed by a 4.4 Mw earthquake. There **Fig. 3** shows a magnification of the anomaly. Credits: Radio Emissions Project; Permanent Foundation G. Giuliani.*

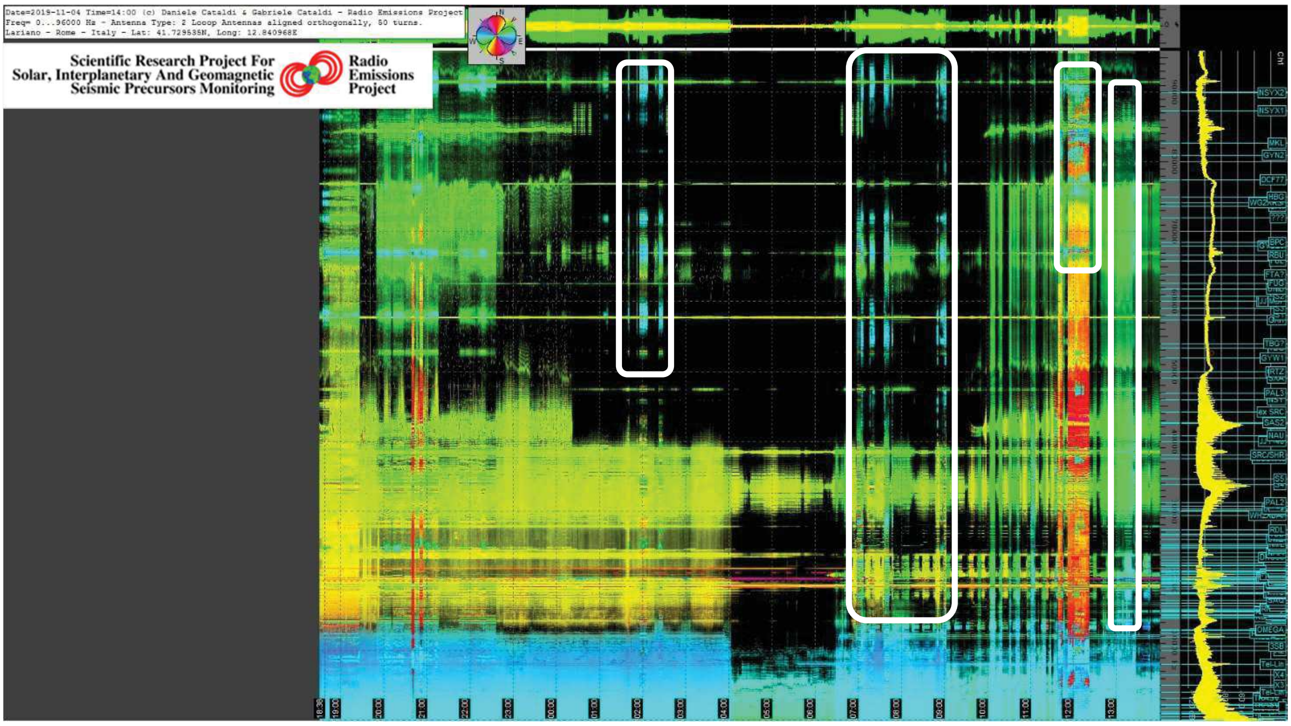

Fig. 4 - Spectrogram recorded of Lariano RDF station (RM) between the 3 and on November 4, 2019. *In the spectrogram at the top they have been highlighted the electromagnetic signals that possess azimuth compatible with the seismic epicenter of the seismic sequence that preceded the earthquake Mw 4.4 pè that was recorded in Balsorano (AQ) November 7, 2019 at 17:35:21 UTC. Source: Radio Emissions Project; Permanent Foundation G. Giuliani.*

A few days later, the RDF station Lariano (RM) has detected other electromagnetic increments with azimuth compatible with seismic epicenter of Balsorano (AQ): between 05:00 UTC and 09:30 UTC on November 7, 2019 was recorded another increment de electromagnetic background (**Fig. 5**). In this case, the RDF data provided by the station Lariano (RM), confirming the data obtained in previous days, suggested that it was possible to expect a localized seismic event sull'azimut turquoise, that is compatible with the city of Balsorano (AQ).

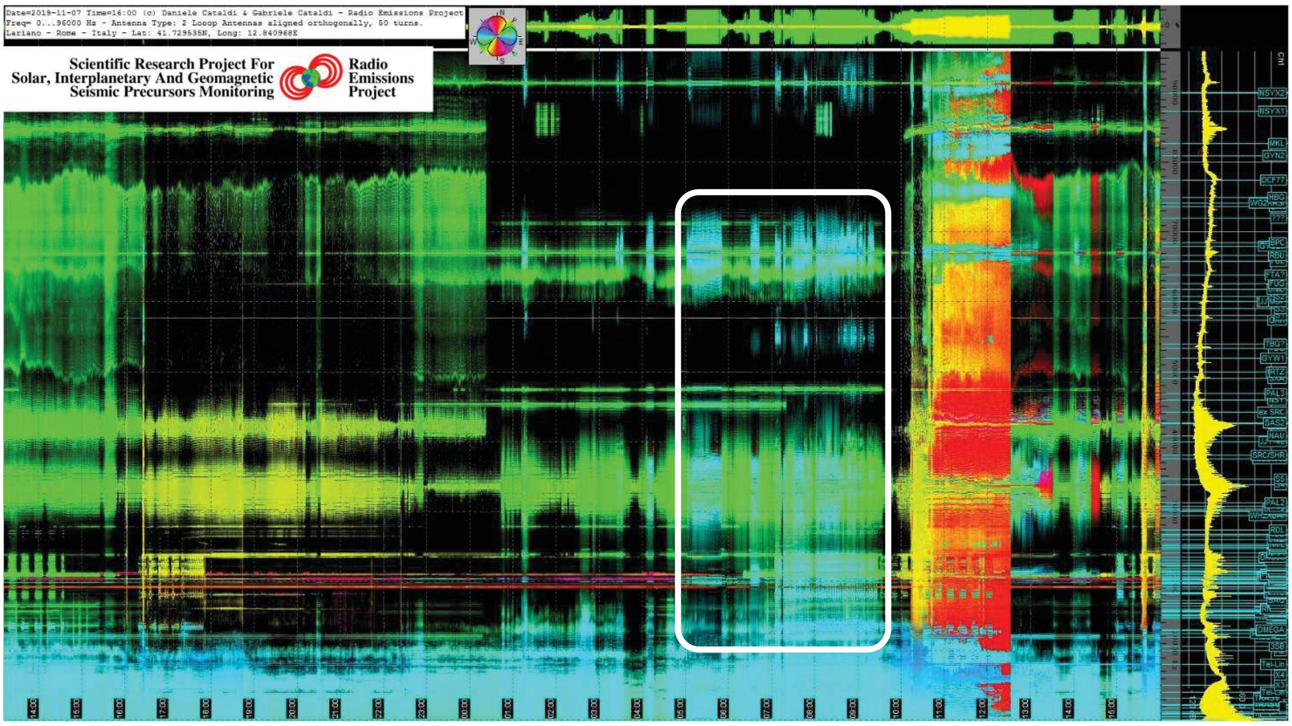

Fig. 5 – Spectrogram recorded by RDF station Lariano (RM) between 6 and November 7, 2019. *The spectrogram above shows the electromagnetic increase recorded a few hours before the Mw 4.4 magnitude earthquake occurred in Balsorano (AQ) November 7, 2019 at 17:35:21 UTC. Credits: Radio Emissions Project; Permanent Foundation G. Giuliani.*

The triangulation of the radio signals detected with RDF technology was accomplished through two electromagnetic monitoring stations (**Fig. 6**):

1. RDF Station Ripa-Fagnano (AQ). Azimut Red.
2. RDF Station Lariano (RM). Azimut Turquoise.

Confirming the geographical area identified by the RDF stations installed in Central Italy readings were obtained on the change in the gas flow Rn_{222} located in pairs sensors of Coppito (AQ) Station and Ripa-Fagnano (AQ) (**Fig. 7, 7a, 7b**): These essentially confirmed the expectations of the authors. On November 4, 2019, the flow of Rn_{222}, detected by the monitoring station of Ripa-Fagnano (AQ), is started to increase. This station is one that is closest to the epicenter Mw 4.4 earthquake (Balsorano AQ) with an estimated distance of ~ 53.8 km, which is close to the limit of the operating range of the station itself.

Data on Rn_{222} gas flow, however, indicated that it was possible to expect an earthquake of medium to low intensity. The increase of the density Rn_{222} has lasted for a few hours after the Mw 4.4 earthquake occurred in Balsorano (AQ) November 7, 2019 at 17:35:21 UTC, reaching an average count rate of ~ 62,000 before starting to decrease. The fact that the Mw 4.4 earthquake was preceded with an increase of Rn_{222} flow and radio frequency with azimuth compatible with the epicentral area confirmed the question of the authors, namely that both the flow of Rn_{222} that pre-seismic electromagnetic anomalies have a substrate common: the formation of micro cracks and fractures in the earth's crust that occur of earthquake preparation area.

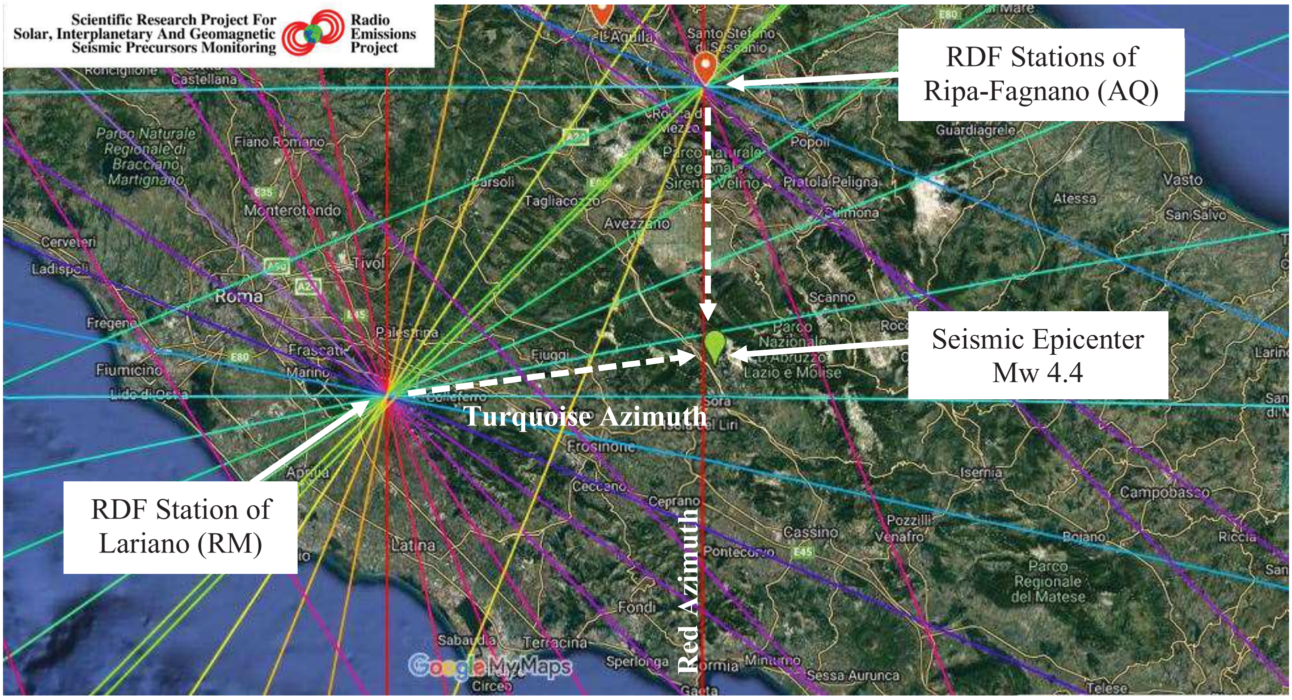

Fig. 6 – ***Map colorimetric RDF system and triangulation of radio signals.*** *In the map above you can see the colors associated azimuth of the two RDF monitoring systems located in Central Italy (Ripa-Fagnano, L'Aquila, Lariano, Rome). Following the color scale associated with the electromagnetic signals detected by RDF stations between 4 and 7 November 2019, it is possible to identify the geographical area in Central Italy (Balsorano, AQ) in which then November 7, 2019 at 17:35:21 UTC has been a Mw 4.4 earthquake. Credits: Radio Emissions Project.*

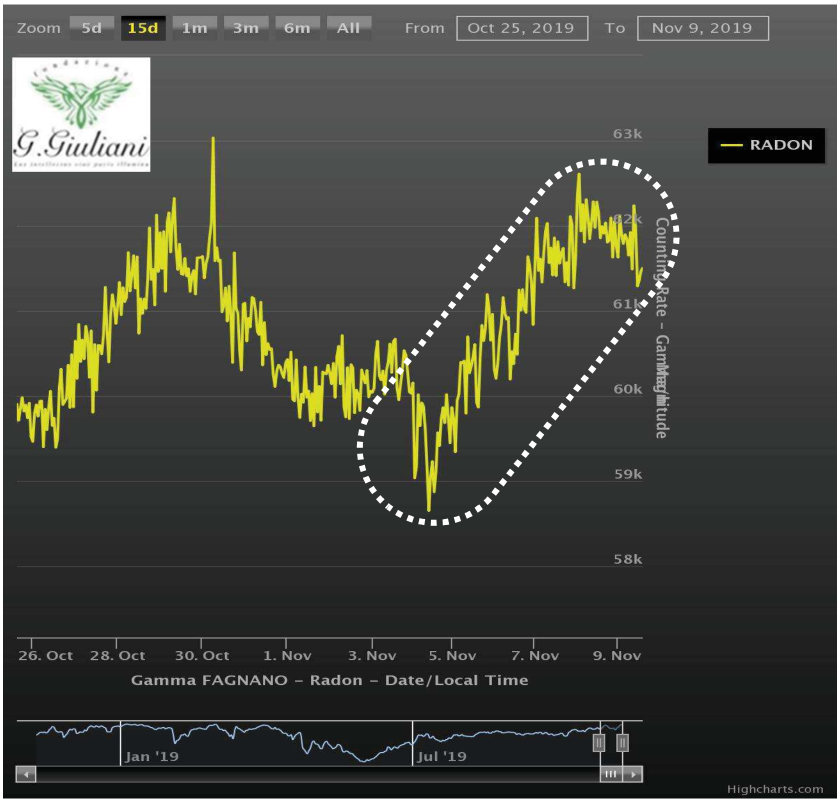

Fig. 7 – The gas flow Variation Rn_{222}. *In the graph at the top is visible Rn_{222} the variation of the flow registered by the monitoring station of Ripa-Fagnano (AQ), between 26 October and on 9 November 2019. Inside the dashed white line is visible the increase related to the earthquake Mw 4.4. Credits: Permanent Foundation G. Giuliani.*

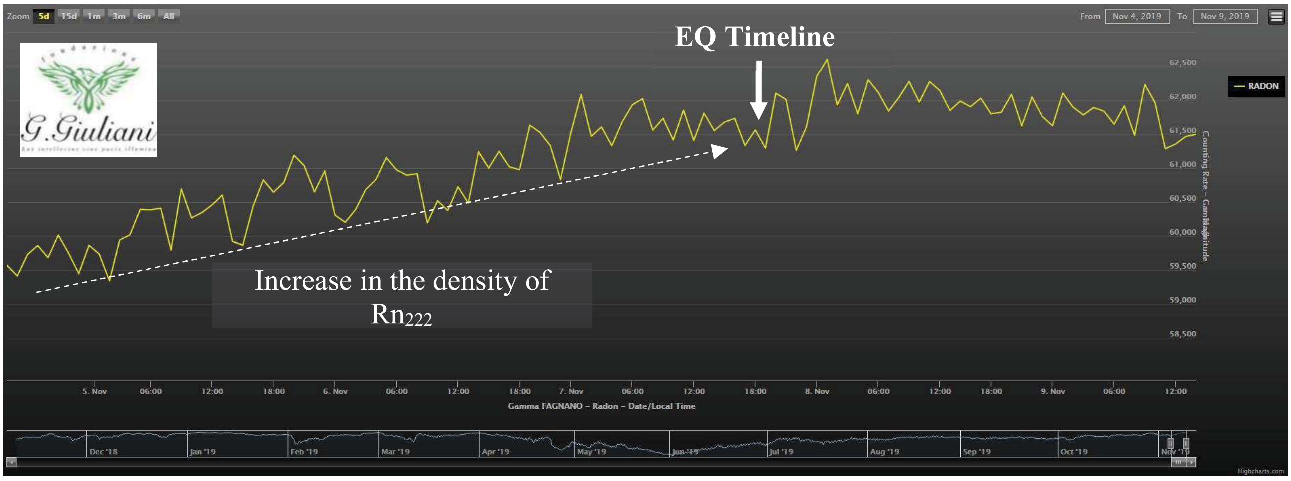

Fig. 7a – the gas flow Variation $\boldsymbol{Rn_{222}}$***.*** *In the graph at the top is visible* Rn_{222} *the variation of the flow registered by the monitoring station of Ripa-Fagnano (AQ), between 4 and 9 November 2019. The vertical white arrow indicates the temporal marker of the earthquake Mw 4.4 recorded in Balsorano (AQ) November 7, 2019 at 17:35:21 UTC, a little more than 50 km away from Ripa Fagnano-detection station (AQ). Credits: Permanent Foundation G. Giuliani.*

The gas flow monitoring station Rn_{222} situated in pairs sensors of Coppito (AQ) station (**Fig. 7b**) Has confirmed the increase of flow observed from Ripa-Fagnano (AQ) station. The increase detected by Coppito (AQ) station, is certainly more modest than the one observed from Ripa-Fagnano (AQ) station, probably due to the increased detection distance (69 km) from the epicenter area.

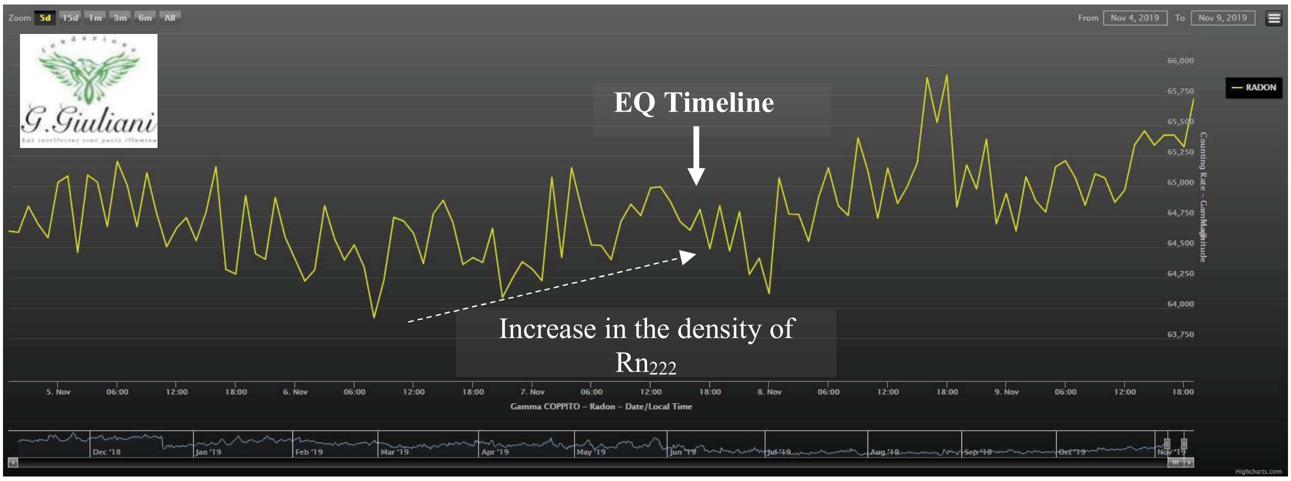

Fig. 7b – the gas flow Variation $\boldsymbol{Rn_{222}}$***.*** *In the graph at the top is visible* Rn_{222} *the variation of the flow registered by the monitoring station of Coppito (AQ), between 4 and 9 November 2019. The vertical white arrow indicates the temporal marker of the earthquake Mw 4.4 recorded in Balsorano (AQ) the November 7, 2019 at 17:35:21 UTC, just over 69 km away from the station of torque detection (AQ). Credits: Permanent Foundation G. Giuliani.*

DISCUSSION

1. The pre-seismic electromagnetic anomalies (Electromagnetic Sesismic Precursors or ESPs) are a class of natural electromagnetic phenomena observed for the first time in 1880 (Milne J., 1890) that are emitted through the phenomenon of piezoelectricity. This phenomenon is observed when crystals is applied on some of the mechanical stress in certain crystallographic directions: the opposite sides of the crystals we load instantly (Finkelstein D. et al., 1973). Inside of the preparation area to the earthquake and in the neighboring areas, the tectonic stress deforms and creates micro-fractures in the rocks that make up the earth's crust that, through the phenomenon of piezoelectricity, emit radiofrequency. Experiments conducted in the laboratory have confirmed this phenomenon (Freund F., 2002). The electromagnetic

emission intensity generated through the phenomenon of piezoelectricity is such that it can be detected with much ease above the earth's surface via radio receivers designed to work in the band SELF-VLF (0 <f≤30 kHz): ie the more convenient and band as that where the pre-seismic electromagnetic emissions possess greater intensity (Cataldi G., 2019).

2. According to Lay T. and Wallace T.C. (Lay T. et al., 1995), in fact, only 1-10% of the energy and seismic moment contained in earthquake zones preparation is converted into seismic waves, so it is conceivable that a part of this energy can be converted into radio frequency. Taking as a reference an earthquake of magnitude 5, this has an energy and a seismic moment between 1012 and 1018 Nm (Lay T. et al., 1995). Considering that it is not possible to quantify the energy losses of the system in terms of thermodynamic efficiency and the efficiency of the tectonic energy conversion into other forms of energy, and assuming that only 50% of the energy residual theorized by Lay T. and Wallace T.C. can be converted into radio frequency, this may be between 500,000 and 500,000,000,000 MW / know MJ (1 MW = 106 W; 1 MJ = 106 J): an amount of energy that can generate radio frequency for 1 hour with a power ranging between ~ 139 ~ 138,889 MW and GW.
3. This electromagnetic source can be localized and monitored using electromagnetic detection stations equipped with RDF technology (Radio Direction Finding). The authors use RDF detection stations from 2017 to monitor the pre-seismic radio interference (Electromagnetic Seismic Precursors or ESPs) of type “local”, that is generated by the piezoelectric effect (pre-seismic radio emission of type “non-local” they are represented by geomagnetic nature emissions; Cataldi G. et al., 2013-2019; Straser V. et al., 2014-2017; Straser V. 2011-2012). Using two or more RDF stations may perform a triangulation of azimuth data provided by each station and positively identified specific radio-frequency sources, discriminating radio signals that do not have an azimuth compatible with seismically active areas, or that have a high seismic risk (Straser V. et al., 2019). In this work we have been presented the results of a multi-parametric monitoring system dedicated to seismic precursors of electromagnetic and chemical type, which has provided the use of a network of RDF detection stations to identify seismic epicentres in the geographical area of ' Central Italy also using the data on the concentration of the gas supplied by Rn_{222} Permanent Foundation G. Giuliani. These monitoring stations are part of a multi-parametric monitoring network established in November 2019 it was able to identify a few days prior to the geographical area in which subsequently have registered two earthquakes M3 and M4 + +:ML 3.1 – Capitignano (AQ); 12 Ottobre 2019 alle 12:29:55 UTC,
4. Mw 4.4 – Balsorano (AQ); 7 Novembre 2019 alle 17:35:21 UTC.

More Rn_{222} concentrations of gas in Central register when the Earth's crust least resistance to the rise of this gas. This occurs when the earth's crust increases the density of microcracks and fractures as a result of tectonic stress: a phenomenon that, as has been already mentioned in the previous chapters, it has the property of producing radiofrequency.

CONCLUSIONS

The study has shown that the increments of the Radon gas stream (Rn_{222}) and electromagnetic emissions recorded through the multi-parametric monitoring network, have allowed to identify, with a few days' notice, the geographical area in which then was recorded seismic sequence and the Mw 4.4 earthquake (November 7, 2019 at 17:35:21 UTC). The hypothesis that a low to medium intensity earthquake could be registered in Balsorano (AQ) was founded through the analysis of RDF data provided by Larian stations (RM) and Ripa-Fagnano (AQ), and the gas flow data Rn_{222} have confirmed this hypothesis. It is therefore evident that through the use of a multi-parametric monitoring network of this type it is possible to provide the seismic predictions correct with respect to the epicenter seismic and seismic events that have an intensity not less than the magnitude 3. It is desirable that in the future throughout Italy it is equipped with a multi-parametric monitoring network of this type.

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