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NEXT EARTH

SHORT REPORT,

Non EXtensive Thermodynamics & Statistical Mechanics in EARTHquake Physics & rock fracture

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1. FINAL PUPLISHABLE SUMMARY REPORT

Europe and its dependent territories include some of the most seismic active regions on Earth. Some millions people live within a seismic active European area, while a major part of the EU population is economically vulnerable to a seismic event. Improved understanding of earthquake mechanisms and related risk will thus directly enhance the quality of life both of European citizens and of vulnerable populations worldwide. Within NEXT EARTH new innovative techniques based on *modern statistical physics principles* for the analysis of laboratory results along with earthquake events catalogues were developed, contributing to improved methodologies for investigating the evolution of earthquake events .

A non-extensive thermodynamics, proposed by Tsallis in 1988, is based on a generalization of the BG entropy. The Tsallis entropy shares with the BG entropy a variety of thermo-dynamically important properties.

There is a wide range of problems in Geophysics, from earthquake prediction to the driving forces of plate tectonics, where it is necessary to understand how rocks deform. The rock physics approach to understanding these geophysical processes is based on the premise that the macroscale behaviour of rocks is governed by microscale interactions. Rocks deformed under an applied stress elastically, plastically, by fracturing and brittle flow and frictional sliding on a fault. The magnitude and direction of the applied stress, the rate and duration of loading, ambient pressure and temperature, the presence of fluids and previous deformation history all control the overall mechanical response

As fracture, the physics of an earthquake is a subject with many unknowns. It is true that we have a good understanding of the propagation of seismic waves through the Earth and that given a large set of seismographic records, we are able to reconstruct a posteriori the history of the fault rupture (the origin of the waves). However, when we consider the physical processes which lead to the initiation of a rupture with a subsequent slip and its growth through a fault system to give rise to an earthquake, then our knowledge is really limited. Not only the friction law and the rupture evolution rules are largely unknown, but the role of many other processes such as plasticity, fluid migration, chemical reactions, etc., and the couplings between them, remain unclear. One may wonder about the physics of many earthquakes in a similar way as with the physics of fractures.

- How do the collective properties of the set defined by all earthquakes [fractures] in a given region,?
- How does seismicity [in rocks AE], which is the structure formed by all earthquakes [fractures], depend on its elementary constituents –the earthquakes [fractures]? And which are these properties?
- Which kind of dynamical process does seismicity/AE constitute?

It may be that these collective properties are largely independent on the physics of the individual earthquakes, in the same way that many of the properties of a gas or a solid do not depend on the constitution of its elementary units. It is natural then to consider that the physics of many earthquakes has to be studied with a different approach than the physics of one earthquake and in this sense we can consider *the use of statistical physics not only appropriate but necessary to understand the collective properties of earthquakes* . Then a natural question arises. *<u>What type of statistical physics is appropriate to commonly describe effects from fracture level to seismicity scale??</u>*

An answer to the above question(s) is given in NEXT EARTH within the frame of the application of non extensive statistical mechanics .

It is well known that earthquakes are among the most relevant paradigms of the so-called self-organized criticality. Despite the complexity of earthquakes, some of the known empirical laws are considerably simple as, for instance, the Omori law for temporal distribution of aftershocks and the Gutenberg-Richter (GR) law for relationship between frequency and magnitude. It has been repeatedly proposed that the occurrence of earthquakes (cf. mainshocks) can be considered as a critical point (second-order phase change), but alternative models based on first-order phase transitions have been also forwarded which are probably more applicable (such a diversity also exists for the brittle rupture which is a phenomenon closely related to earthquakes). Furthermore brittle rupture have been associated with a first-order transition and that it is analogous to a critical point phenomenon too. Both approaches lead to scaling laws or power-law distributions for the dynamical variables (second-order transition demonstrate scaling near a critical point, whereas first order transitions demonstrate scaling when the range of interactions is large (mean-field condition), as is the case with elastic interactions. The non-extensive statistical mechanics offer a consistent theoretical framework, based on a generalization of entropy, We note that this is consistent with a classical thermodynamic approach to natural systems that rapidly attain equilibrium, leading to exponential-law behavior.

Within the consept of NEXT EARTH the following scientific questions addressed

- *Is plate tectonics a case of non-extensive thermodynamics?*
- *A non extensive statistical physics approach to the polarity reversals of the geomagnetic field*
- *Non Extensive statistical physics approach to fault population distribution. A case study from the Southern Hellenic Arc (Central Crete).*
- *A non-extensive statistics of the fault-population at the Valles Marineris extensional province, Mars.*
- *Evidence of non-extensive thermodynamic lithospheric instability at the approach of the 2004 Sumatran- Andaman and 2011 Honshu mega-earthquakes*
- *A spatiotemporal non-extensive investigation of seismicity surrounding the L'Aquila earthquake, M_L5.8, on 6th April 2009*
- *Non-extensivity of the Isothermal Depolarization relaxation Currents in uniaxial compressed rock.*
- *Experimental evidence of a non-extensive statistical physics behaviour of fracture in triaxially deformed Etna basalt using acoustic emissions.*
- *Moving charged dislocations and pressure stimulated currents. From fracture processes to earthquake physics in a non-extensive thermodynamic view.*
- *Evidence of Non extensivity and application of natural Time analysis in the Seismic activity in Eyjafjallajökull volcano.*
- *Non extensivity in PSC from rock sample*

  Furthermore, conferences were attended, tutorial were presented and papers were published.

2 USE AND DISSEMINATION OF FOREGROUND

5. DISSEMINATION ACTIVITIES

- Journal Publications

  Non-extensive statistical physics approach to fault population distribution. A case study from the southern Hellenic arc (Central Crete) , Vallianatos, F., Kokinou, E., Sammonds, P. , 2011, *Acta Geophysica* 59 (4), pp. 770-784

  A non-extensive statistics of the fault-population at the Valles Marineris extensional province, Mars. , Vallianatos, F., Sammonds, P. , 2011, *Tectonophysics*

  Non-extensivity of the isothermal depolarization relaxation currents in uniaxial compressed rocks , Vallianatos, F., Triantis, D., Sammonds, P. , 2011, *EPL* 94 (6), art. no. 68008

  A non-extensive statistical physics approach to the polarity reversals of the geomagnetic field , Vallianatos, F. , 2011, *Physica A: Statistical Mechanics and its Applications* 390 (10), pp. 1773-1778

  Is plate tectonics a case of non-extensive thermodynamics? Vallianatos, F., Sammonds, P. 2010, *Physica A: Statistical Mechanics and its Applications* 389 (21), pp. 4989-4993

- Internation Conference were attended along with poster and oral presentations.
- Filippos Vallianatos, Fundamental properties of fracture and seismicity in a non extensive statistical physics framework., European Geophysical Union Conference, Vienna, 2010.
- Filippos Vallianatos, Alexis Cartwright-Taylor, and Peter Sammonds, A spatiotemporal non-extensive approach to investigate seismicity of 6th April 2009, ML5.8, L'Aquila (Central Italy) earthquake. European Geophysical Union Conference, Vienna, 2011.
- Filippos Vallianatos, George Michas, George Papadakis, and Peter Sammonds, A non extensive statistical physics view to the June 1995, Aigion earthquake (M6.2) aftershock sequence (West Corinth rift). European Geophysical Union Conference, Vienna, 2011.
- Filippos Vallianatos and Peter Sammonds, Non-extensive thermodynamics applied to global seismicity before and after the Sumatran mega-earthquake. European Geophysical Union Conference, Vienna, 2011.
- Participation in Local Tutorial meetings

- Paricipation in UK-Rossia initiative for the stady of seismoelectromagnetic precursors
- Three new UCL PhD students start their research project under common supervision
- A special issue in the scientific journal Acta Geophysica on Statistical Mechanics in Earth Physics and Natural Hazards is in preparation [Prof. F. Vallianatos is a Guest editor]
- An EGU session on “fracture and Earthquake Physics “ has been accepted (Conveners F. vallianatos, P. Sammonds, V. Lapenna)
- Collaboration with other Universities and research institutes in EU and Japan

Journal publications

1
F. Vallianatos EuroPhysics Letters [EPL] 94 (6) IOP EU 2011 no. 68008

2
F. Vallianatos *Physica A: Statistical Mechanics and its Applications* 389 (21), EU 2010 pp. 4989-4993

3
F. vallianatos Tectonophysics in press(7/ 2011) EU

4
F. Vallianatos *Physica A: Statistical Mechanics and its Applications* 390 (10), EU 2011 pp. 1773-1778

5.
F. Vallianatos *Acta Geophysica* 59 (4), EU 2011 pp. 770-784