**Proposal of the Habilitation Commission for naming**

**Mgr. Martin Gális, PhD.,**
senior researcher in the Department of Astronomy, Physics of the Earth and Meteorology, Faculty of Mathematics, Physics and Informatics, Comenius University in Bratislava

**Docent (Associate Professor) in Physics.**

Based on the decision of the Scientific Council of FMFI UK in Bratislava, the Chairman of the Scientific Council and Dean of the FMFI UK, Professor RNDr. Daniel Ševčovič, DrSc., appointed on March 15, 2021 the Habilitation Commission and reviewers for the commencement of the habilitation procedure of Mgr. Martin Gális, PhD., in the scientific discipline "4.1.1 Physics":

Habilitation Commission:

**Professor RNDr. Peter Moczo, DrSc.**, Chairman
    FMFI UK Bratislava

**Professor Dr. Götz Bokelmann**
    Faculty of Earth Sciences, Geography and Astronomy, Universität Wien, Wien, Austria

**Assoc. Professor RNDr. Ctirad Matyska, DrSc.**
    Faculty of Mathematics and Physics, Charles University in Prague, Czech Republic

Reviewers:

**Professor RNDr. Ondřej Čadek, CSc.**
    Faculty of Mathematics and Physics, Charles University in Prague, Czech Republic

**Professor Víctor Manuel Cruz-Atienza, PhD.**
    Insituto de Geofísica, Universidad Nacional Autónoma de México, Mexico City, Mexico

**Professor Ing. Roman Martoňák, DrSc.**
    FMFI UK Bratislava

Habilitation lecture of Dr. Martin Gális on "*Seismic hazard due to human-induced earthquakes*" took place on August 12, 2021 at 15.30 at FMFI UK and online via MS Teams.

After the lecture, the defense of the Habilitation Thesis "*Numerical Simulation of Earthquake Rupture and Seismic Wave Propagation*" took place.

The Habilitation Commission met on August 12, 2021 after the habilitation lecture and the defense of the Habilitation Thesis. After getting acquainted with all the submitted documents and available information, the Habilitation Commission evaluated the scientific and pedagogical activities of Dr. Martin Gális, and presents the following report.

**Scientific and pedagogical competence**

1. Education and academic qualification
    **Mgr.** (equivalent of MSc) in Physics: 2002, FMFI UK Bratislava
    **PhD.** in Geophysics: 2008, FMFI UK Bratislava
    Scientific qualification level **IIa**: 2017

## 2. Employments

2002-2012  researcher, Geophysical Institute, Slovak Academy of Sciences
2007-2012  researcher, FMFI UK Bratislava
2012-2017  post-doctoral fellow, KAUST - King Abdullah University of Science and
         Technology, Thuwal, Saudi Arabia
Since 2017 researcher, FMFI UK Bratislava
Since 2017 researcher, Earth Science Institute, Slovak Academy of Sciences


## 3. Teaching activities

Courses for Master study programs 'Geophysics' and 'Physics of the Earth'
at Faculty of Mathematics, Physics and Informatics, Comenius University in Bratislava

| acad. year | sem. | course | lecture/ practicals | credits |
|---|---|---|---|---|
| 2008/09 | WS | Computer methods | 1/1 | 2 |
| | | Inverse methods in geophysics | 2/0 | 2 |
| | SS | Temperature and heat flow in the Earth | 2/0 | 2 |
| 2009/10 | WS | Computer methods | 1/1 | 2 |
| | | Programming languages | 1/1 | 3 |
| | | Inverse methods in geophysics | 2/0 | 2 |
| | SS | Temperature and heat flow in the Earth | 2/0 | 2 |
| 2010/11 | WS | Computer methods | 1/1 | 2 |
| | | Programming languages | 1/1 | 3 |
| | | Inverse methods in geophysics | 2/0 | 2 |
| 2011/12 | WS | Mathematical methods in geophysics (1) | 2/1 | 4 |
| | | Signal analysis (1) | 2/1 | 3 |
| | | Programming languages | 1/1 | 3 |
| | SS | Seismic waves and earthquake physics (1) | 0/1 | 4 |
| | | Computer methods | 1/1 | 3 |
| | | TOTAL | 21/10 | |

*Note: WS – Winter Semester, SS – Summer Semester*

Courses for the Joint Master study 'Physics of the Earth' at Faculty of Mathematics,
Physics and Informatics, Comenius University and University of Vienna

| acad. year | sem. | course | lecture/ practicals | credits |
|---|---|---|---|---|
| 2017/18 | SS | Digital Filtering in Geophysics | 2/1 | 4 |
| | | Numerical Modeling of Seismic Wavefields | 2/0 | 3 |
| 2018/19 | SS | Digital Filtering in Geophysics | 2/1 | 4 |
| 2019/20 | SS | Digital Filtering in Geophysics | 2/1 | 4 |
| 2020/21 | SS | Numerical Modeling of Seismic Wavefields | 2/0 | 3 |
| | | TOTAL | 10/3 | |

*Note: WS – Winter Semester, SS – Summer Semester*

Participation in courses for Bachelor study program 'Physics'
at Faculty of Mathematics, Physics and Informatics, Comenius University in Bratislava

During winter semesters of the academic years 2018/19, 2019/20 a 2020/21, Dr. Gális gave
several lectures as a part of course 'Computer simulations in Physics". During winter

semester of the academic year 2020/21, Dr. Gális gave 2 lectures as a part of course 'Physics of the planet Earth".

Total semester-hours: **44**

4. Scientific field

Geophysics, seismology, earthquake ground motion, physics of seismic ruptures

5. The most important scientific results

As a member of the excellent team recognized by Slovak Academy of Sciences, Comenius University in Bratislava and The Accreditation Commission of Slovak Republic, awarded with The Minister of Education Prize, dr. Gális significantly contributed to development of numerical methods for simulation of propagation of seismic rupture and seismic waves. The most important contributions are:
a) finite-element (FE) algorithm based on restoring-force concept, with significantly lower memory requirements compared to the standard stiffness-matrix concept,
b) implementation of realistic attenuation based on rheology of generalized Maxwell body,
c) implementation of the traction-at-split-nodes method for simulation of nucleation and spontaneous propagation of seismic ruptures,
d) adaptive smoothing algorithm for suppressing of the spurious high-frequency oscillations during simulations of rupture propagation
e) computational program FESDv3 written in Fortran with MPI-parallelization
f) new FD-FE hybrid method for efficient simulation of seismic wave propagation, combining versatility of finite-element (FE) method with high efficiency of finite-difference (FD) method.

In the field of physics of the seismic rupture propagation, contributions of Dr. Gális can be summarized as follows:
a) Criterion for nucleation of spontaneous rupture propagation
   • The area of overstressed asperity is the main criterium for nucleation of so-called runaway ruptures (ruptures that propagate until stopped by a strong barrier).
   • Analytical formulae for estimating the critical overstress and critical area of the asperity leading to the so-called runaway ruptures.
b) Physics-based estimates of the size of arrested ruptures
   • Physical model for estimating the size of arrested ruptures (ruptures that start propagating but stop at a finite distance, even on a fault with homogenous conditions).
   • Application of the model in the context of the fluid-injection induced seismicity suggests that almost all induced events so far have propagated as arrested ruptures.
c) Effect of fault roughness on rupture propagation and radiation of seismic waves
   • Approximation of the rough-fault effect in physically consistent kinematic rupture models with realistic radiation of seismic waves in a broad range of frequencies.
   • Compared to planar faults, rough faults need a larger stress drop to produce an earthquake of the same magnitude. If this effect is not accounted for, the seismic estimates of stress drop may be biased.
   • Coherency of Mach waves radiated by super-shear ruptures is significantly diminished due to wave scattering. This may indicate that super-shear ruptures are more common than currently reported.

**The most important publications**
Dr. Gális selected three most cited journal publications that he co-authored as the first author (as per Register of publications, FMFI UK, on Jan. 19, 2021).

**1. Gális, Ampuero, Mai, Cappa, 2017. Induced seismicity provides insight into why earthquake ruptures stop.** *Science Advances*, Vol 3, No 12, eaap7528 (ADC11)
**77 citations**
Dr. Gális contributed to the development of the theoretical estimates of the size of ruptures induced by localized pore-pressure perturbations and propagating on prestressed faults. He also contributed to development of a theoretical scaling relation between the largest magnitude of self-arrested earthquakes and the injected volume. Consistency of the found scaling relation with observed maximum magnitudes of injection-induced earthquakes over a broad range of injected volumes suggests that, although runaway ruptures are possible, most injection-induced events so far have been self-arrested ruptures.

**2. Gális, Moczo, Kristek, 2008. A 3-D hybrid finite-difference—finite-element viscoelastic modelling of seismic wave motion.** *Geophysical Journal International*, **175(1) (ADC02)**
**37 citations**
Dr. Gális was the main author of the algorithm of the smooth transition zone for a causal communication between the FE and FD (finite-difference) methods in the developed hybrid FD-FE method. The smooth transition zone is the key feature of the hybrid method because the algorithmically minimal transition zone produced visible numerical noise.

**3. Gális, Pelties, Kristek, Moczo, Ampuero, Mai, 2015. On the initiation of sustained slip-weakening ruptures by localized stresses.** *Geophysical Journal International*, **200(2) (ADC08)**
**15 citations**
Dr. Gális performed the extensive parametric study to estimate critical and optimal parameters of the overstressed asperity for efficient initiation of spontaneous rupture propagation. Dr. Gális contributed to development of the analytical estimate of the critical size of the asperity for configurations with low background stress, which is in excellent agreement with numerical simulations.

## 6. Publications

Register of publications, FMFI UK, as on Feb. 15, 2021
Statistics of categories (Total: **17**):
- AAA    Scientific monographs published by foreign publishers (**1**)
- ABB    Scientific monographs (and similar studies) in journals and proceedings published by domestic publishers (**1**)
- ADC    Scientific papers in foreign journals registered in Current Contents Connect database (**15**)

FMFI UK criterion for Physics: **at least 15 Current Contents Connect publications**

## 7. Citations

Register of publications FMFI UK as on Feb. 15, 2021
Statistics of responses (**601**):
- [o1] Citations in foreign publications registered in citation indexes (**600**)
- [o3] Citations in foreign publications not registered in citation indexes (**1**)

FMFI UK criterion for Physics: **at least 50 Scientific Citation Index citations**

### 8. Principal investigator

| | |
|---|---|
| 2004 | Grant of the Comenius University in Bratislava, UK/68/2004, *Parametric comparison of numerical methods for simulation of rupture propagation on seismoactive fault* |
| 2020-2023 | VEGA Grant Project, 2/0046/20, *An analysis of robustness of selected structural parameters in relation to earthquake ground motion in local near-surface structures with stochastic perturbations of material parameters* |

### 9. Investigator

13 international and 5 national research projects

## Habilitation lecture

The habilitation lecture of Mgr. Martin Gális, PhD., on "Seismic hazard due to human-induced earthquakes" took place on August 12, 2021, at 15:30 in Lecture Hall C at FMFI UK Bratislava and online via MS Teams.

The habilitation lecture of Mgr. Martin Gális, PhD., provided a highly qualified overview of the topic. Dr. Gális first explained the basic principles of origin of tectonic earthquakes and earthquakes induced by human activities. He clarified the problem of earthquakes induced by fluid injection, explained the physical principle of origin of such earthquakes, and mentioned industrial activities that can induce earthquakes. Then he focused on selected problems related to assessment of seismic hazard due to induced earthquakes. Eventually he explained alternative approaches in estimating maximum magnitude of the fluid-injection-induced earthquakes.

The lecture by Dr. Gális had a high professional level, it was understandable for non-specialists as well as for the present students. At the same time, the lecture gave a very good view of his scientific work and pedagogical skills. Dr. Gális well answered all the questions raised after his lecture.

The present members of the Scientific Council of the Faculty of Mathematics, Physics and Informatics of the Comenius University in Bratislava highly evaluated both the scientific and didactic levels of the habilitation lecture by Dr. Gális. The habilitation lecture demonstrated that Dr. Gális is a distinctive scientific and pedagogical personality who met all the requirements on the habilitation lecture.

## Defense of the habilitation thesis

The defense took place after the public Habilitation lecture on August 12, 2021 in the Lecture Hall C at FMFI UK and online via MS Teams.

The candidate briefly presented the main results of the Habilitation thesis. The thesis is based on 9 scientific papers published between 2007 and 2019 in peer-reviewed journals.

In the first part of the presentation, the candidate summarised his contributions to the development of the finite-element and hybrid finite-difference—finite-element methods for simulation of seismic waves and spontaneous rupture propagation. In the second part, the candidate presented results from analyses of conditions for nucleation and arrest of earthquake ruptures, including efficient initiation of spontaneous rupture propagation in numerical simulations and application of fracture-mechanics-based model of estimating size of arrested ruptures in the field of fluid-injection induced seismicity. In the last part, the candidate presented results of three studies. The first, addressing the effect of fault roughness on the size

of resulting earthquake, the second, devoted to efficient representation of rough-fault effects in planar kinematic models, and the third, focusing on analysis of Mach waves radiated by heterogeneous rupture models and propagating in a medium with small-scale heterogeneities.

The candidate was able to convincingly defend the results to the full satisfaction of the Habilitation Commission, members of the Scientific Council as well as present guests.

For the reasons stated above, the members of the Habilitation Commission and reviewers unanimously agreed that Dr. Martin Gális in his successfully defended Habilitation Thesis demonstrated that he has an excellent overview of the numerical modelling of earthquake rupture propagation and seismic wave propagation.

The defense of the Habilitation Thesis clearly demonstrated that Dr. Martin Gális is an internationally recognized scientific personality with a clear impact on the scientific community.

**Conclusion**

The Habilitation Commission declares that Mgr. Martin Gális, PhD., is fulfilling all criteria of Faculty of Mathematics, Physics and Informatics, Comenius University in Bratislava for obtaining a scientific-pedagogical title Docent (Associate Professor) in Physics. Based on assessment of the pedagogical, scientific, professional, and moral profiles of the candidate and evaluation of the habilitation lecture and defense of the Habilitation Thesis, the Habilitation Commission unanimously and reviewers (based on the ADoodle anonymous voting) recommends to the Scientific Council of FMFI UK in Bratislava awarding the scientific-pedagogical title Docent (Associate Professor) in Physics to Mgr. Martin Gális, PhD.

Bratislava August 12, 2021

Habilitation Commission

**Professor RNDr. Peter Moczo, DrSc.** _____

**Professor Dr. Götz Bokelmann** _____

**Assoc. Professor RNDr. Ctirad Matyska, DrSc.** _____

Reviewers

**Professor RNDr. Ondřej Čadek, CSc.** _____

**Professor Víctor Manuel Cruz-Atienza, PhD.** _____

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