Understanding exact space-times

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By Jiří Podolský

General relativity is a unique gem, Einstein's most brilliant idea, and his greatest gift to humankind. Conceived in 1915, it still remains the best theory of gravity. I'm sure Einstein himself would be surprised how remarkably well it describes reality, even in the most violent and dynamical situations. Just recall its recent spectacular vindication by the first direct detection of gravitational waves from binary black hole mergers at cosmological distances. What an achievement! Gravitational waves, black holes, cosmology – all three main ingredients and predictions of Einstein's theory combined together.

Exact space-times

As we all know, Einstein's equations determine the space-time geometry, which is the gravitational field. And we must take all their predictions seriously. Exact solutions to Einstein's field equations include the mathematical truth about the physical reality. Unfortunately, it is often obscured, usually very deeply hidden. To dig out the physically measurable invariant quantities and consequences, is a painful mining process involving various techniques and methods. It is the real art of science.

— It is essential to be well-equipped for the investigation of exact space-times. Nevertheless, here we are preparing to descend old silver mines in Kutná Hora, the source of great wealth of the Kingdom of Bohemia in the Middle Ages. (Jerry Griffiths and Jiří Podolský, April 2006)

In the ultimate monograph [1], an amazing number of exact solutions is listed and classified into hundreds of distinct families and subfamilies. This encyclopaedia is of enormous benefit to our community. Yet, what do all these solutions mean physically? What are their geometric properties and global structure? How do test particles and fields behave in them? Apart from the most important and widely used exact solutions (such as Schwarzschild, Kerr or Friedmann) the majority of others have not yet been fully (or even partially) understood.

These problems brought us, Jerry Griffiths and Jiří Podolský, together. Our collaboration started in 1996. At that time, Jerry was already a renowned Professor at Loughborough University while I was a young postdoc in Prague at

Charles University. In the following years, we have published 24 research papers, mostly on exact impulsive gravitational waves and accelerating black holes with any cosmological constant.

In 2006 Jerry came up with the idea of writing a book summarizing not only our new results but also the most basic classes of space-times in Einstein's theory, with an emphasis on their physical interpretation. Our intention was to apply a pedagogical style accessible to students of general relativity and colleagues from closely related branches of physics. And we decided to draw as much illustrations as possible. This monograph was published in 2009 by Cambridge University Press [2], and in a paperback edition with corrections and updates in 2012. Altogether, our joint work on 24 papers and 1 book required 13 visits of Jerry to Prague and 15 visits of Jiří to "Lboro", ending in 2010 after Jerry retired.

The story of our latest paper

While writing Chapter 16 of our book, dedicated to the large family of *Plebański-Demiański solutions* of algebraic type D [3], we realized that its *non-expanding (Kundt) subclass* had not been studied in detail. So we decided to publish a specific paper on this topic. Its first draft was written in April 2010 during my 15th visit to England.

In fact, it was my last visit to Loughborough, and it turned out to be quite dramatic. The eruption of the Icelandic volcano Eyjafjallajökull ejected extremely fine ash particles high into the atmosphere. In response to concerns that it would damage aircraft engines, the European airspace was closed, resulting in the largest air-traffic shut-down since World War II [4]. I could not return to Prague as planned. The mighty Nordic volcano thus gave us one more week during which we were able to finish the first half of the paper [5] containing the most general metric form and the nature of Minkowski background coordinates.

But another obstacle occurred. Having taken early retirement the previous September, in March 2010 Jerry successfully passed an official assessment and became a "qualified Mountain Leader". Soon after that he started a new (very active) period of life, which left no time for academic research. So our professional contacts stopped.

— Jerry Griffiths reaching the Himalayan summit of Mera Peak (6 476 m), the highest trekking peak in Nepal. Everest is just out of shot. (Jerry Griffiths, October 2012)

To finish the paper [5], a big question remained open concerning the cosmological constant. What is the meaning of such solutions? How to identify the corresponding de Sitter and anti-de Sitter background spaces, expressed in entirely unfamiliar coordinates? These were the problems I suggested to my student Ondřej Hruška in 2013. After two years of intensive work, he clarified many questions and finished his 200-pages-long master's thesis [6]. Based on this, we published paper [7] (which in June 2017 was selected as Editors' Suggestion by Physical Review D) and finally we completed the second part of paper [5] with Jerry Griffiths, a further 8 years since my 'volcanic vacations'.

We have now also finished the third paper [8] on physical interpretation of *A* and *B*-metrics with Λ as gravitational field of a tachyon in (anti-)de Sitter universe, generalizing the 1974 work [9] by John Richard Gott III to any cosmological constant. The trio of related papers [5], [7], [8] considerably extends Subsection 16.4 of our book [2] on physical understanding of generalized *B*-metrics, and the structure of the left part of its Fig. 16.2 is now fully clarified.

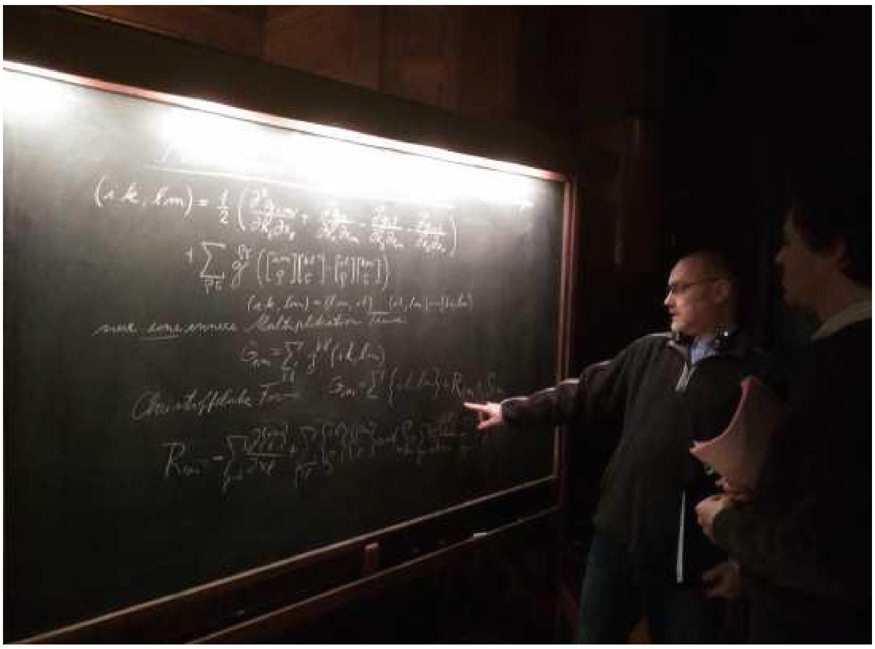
The personal story of us

Soon after finishing the book [2], Jerry Griffiths retired from Loughborough University as Professor Emeritus and became a mountain leader. He started intensive exercising in the Scottish Highlands, performing "Munro bagging" [10] that is climbing all 282 listed mountains in Scotland with a height over 3,000 feet (914 m). Apart from becoming Munroist, he began to travel around Europe and the world (mostly Africa and Asia). Jerry is walking, climbing various mountains, leading groups of people or being himself lead to the highest peaks. Moreover, he is a keen and experienced birdwatcher. I receive sporadic email messages from him, usually when he returns home for a few days, informing me that he has just spent several weeks climbing in Scotland, Corsica, Croatia, Albania, the Tatras, the Alps, the Atlas, the Himalayas, or that he was leading birdwatching tours in Orkney, Morocco or Trinidad and Tobago. Just now he is in Mongolia, climbing the highest peaks in the Altai Range on the borders with China and Russia.

By the way: Did you know that the highest point on Earth, as measured from its centre, is the top of inactive stratovolcano Chimborazo in Ecuador? Due to the centrifugal force, our planet is oblate at its equator, so that the summit of Chimborazo is over 6,800 feet (2,072 m) farther from the Earth's centre than the peak of Everest [11]. Jerry wrote to me about this rather surprising fact after he had climbed Chimborazo in 2016. He thus got as close to the stars as it is possible on Earth.

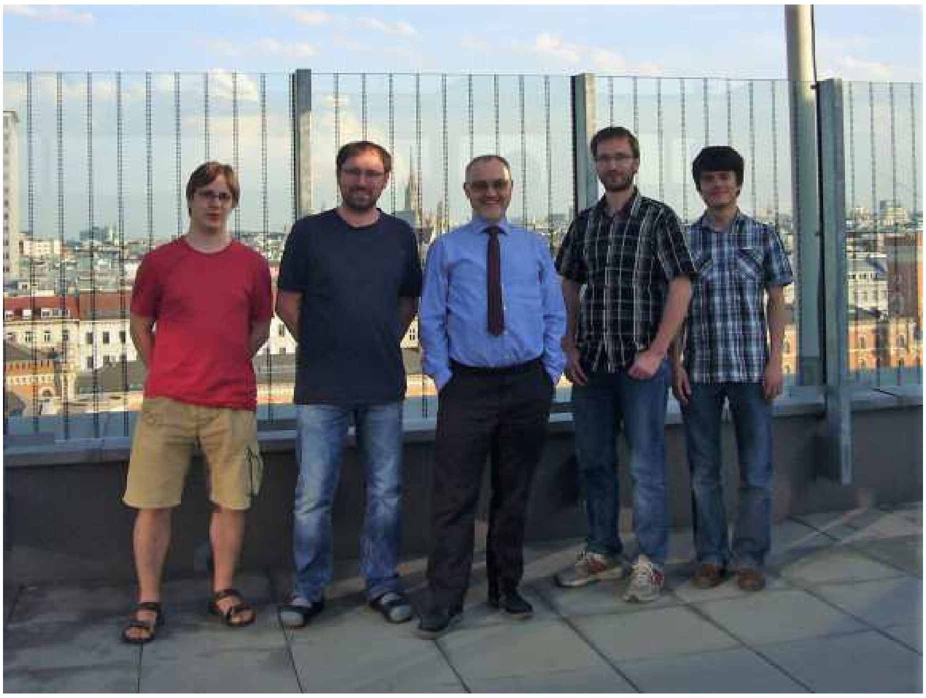
In the meantime, I became a Professor of theoretical physics in Prague in 2011. By a pure coincidence, it happened exactly 100 years after Einstein became a Professor of theoretical physics in Prague. And even more surprisingly, I had the privilege to meet him personally here. He had two incarnations: I met both young Einstein and old Einstein. Moreover, I was preparing what Einstein should write on blackboards during his lectures, most importantly during the presentations in November 1915 in Berlin, finishing his theory of general relativity.

Do these statements sound totally crazy to you? Well, sometimes destiny arranges even impossible things. In this case, I was happy to become a science advisor for the TV series *Genius: Einstein* produced by the National Geographic [12]. All its ten episodes were shot in and around Prague between September 2016 and March 2017. This gave me a unique opportunity to meet Johnny Flynn (younger Einstein), Geoffrey Rush (elder Einstein), the directors Ron Howard, Kenneth Biller, and many others. To describe this incredible adventure (for me personally maybe comparable to climbing the summit of Mera Peak) would, however, be another long story.



— Jiří Podolský giving advice to Albert Einstein at the Prussian Academy of Sciences in Berlin in November 1915, namely how to write the Ricci tensor and how to formulate the unique field equations of general relativity. This event actually happened in the Liberec Town Hall during the shooting of Episode 7, Season 1 of the National Geographic TV series *Genius: Einstein*. (Jiří Podolský and Johnny Flynn aka younger Albert Einstein, January 2017)

As I already wrote, after Jerry's retirement our professional collaboration stopped. I have continued research with my PhD students Robert Švarc and Ondřej Hruška. We also established very close contacts with the "Vienna relativity circle", namely Roland Steinbauer and Clemens Sämann from the Faculty of Mathematics at the University of Vienna. Since 2014 we have published 6 joint research papers, mostly on rigorous properties of geodesics crossing impulsive gravitational waves. These are deeper, mathematically sound investigations of those exact space-times we started to study with Jerry Griffiths in 1996. References concerning this topic can be found on my website [13].



— Prague and Vienna relativity circles connection. Our collaboration focuses on rigorous studies of exact space-times representing impulsive gravitational waves with any cosmological constant. (Stefan Palenta, Roland Steinbauer, Jiří Podolský, Robert Švarc and Ondřej Hruška, April 2018)

Read the full CQG article here.

References

[1] Stephani H., Kramer D., MacCallum M., Hoenselaers C. and Herlt E. (2003). *Exact Solutions of Einstein's Field Equations*, 2nd edition (Cambridge University Press, Cambridge).

[2] Griffiths J. B. and Podolský J. (2009). *Exact Space-Times in Einstein's General Relativity* (Cambridge University Press, Cambridge).

[3] Griffiths J. B. and Podolský J. (2006). A new look at the Plebański–Demiański family of solutions. Int. J. Mod. Phys. D **15**, 335-69.

[4] https://en.wikipedia.org/wiki/Air_travel_disruption_after_the_2010_ Eyjafjallajökull_eruption

[5] Podolský J., Hruška O. and Griffiths J. B. (2018). Non-expanding Plebański–Demiański space-times. Class. Quantum Grav. **35,** 165011 (35pp).

[6] Hruška O. (2015). The study of exact spacetimes with a cosmological constant. Master's Thesis, Charles University, Faculty of Mathematics and Physics, Prague (193pp).

[7] Podolský J. and Hruška O. (2017). Yet another family of diagonal metrics for de Sitter and anti-de Sitter spacetimes. Phys. Rev. D **95**, 124052 (29pp).

[8] Hruška O. and Podolský J. (2018). Interpreting *A* and *B*-metrics with Λ as gravitational field of a tachyon in (anti-)de Sitter universe. arXiv:1808.03508 (30pp).

[9] Gott J. R. (1974). Tachyon singularity: A spacelike counterpart of the Schwarzschild black hole. Nuovo Cimento B **22**, 49-69.

[10] https://en.wikipedia.org/wiki/Munro

[11] https://oceanservice.noaa.gov/facts/highestpoint.html

[12] http://www.natgeotv.com/int/genius

[13] http://utf.mff.cuni.cz/~podolsky/

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