Title: Stirring the event horizon: Planckian turbulence in strange metals.
Tagline: Study of nanoscale turbulence rooted in the quantum thermalization of strange metals by gravity simulations of the holographic black hole dual.
Subscriber: Prof. Dr. J. Zaanen, Instituut-Lorentz, Leiden University; jan@lorentz.leidenuniv.nl
Funding request: 3 year postdoc (207,117), Benchfee (5,000), Running budget (25,000, including 10,000 for high performance computer, production video), total EUR 237,117.
Proposal: Strange metals as observed in for instance cuprate high Tc superconductors are believed to be densely many-body entangled forms of quantum matter [1]. Insights from string theory have led to holography, translating the physics of strange metals (as well as the quark-gluon plasma) to the gravitational physics in a dual space-time with an extra dimension. This translates strange metal physics to the dynamics of black hole horizons [2] and reveals thereby the principle of Planckian dissipation [3]: extremely fast eigenstate thermalization leading to the "minimal viscosity" $\eta \propto (\hbar/k_B)\, s$ (s is entropy density) which appears to be at work in the quark-gluon plasma. Since the entropy is very small in cuprate strange metals, this "Planckian" viscosity should become so small [4] that turbulent flows may occur *even on the nanoscale*. The nano-probes presently under development in NANOFRONT (Allan and Oosterkamp, Leiden) make it possible to study this highly unusual electronic transport regime directly. It is far from clear how this works in detail and to guide these future experiments I propose to study this using numerical GR simulations of the holographic bulk physics. This is in turn a cutting edge study of general relativity in a realm that is not addressed in a cosmological context [2]: an intense beams of gravitons and phonons impinges on the inhomogeneous (mimicking spatial disorder) horizon of a charged black hole that responds by chaotic metric fluctuations [5] ("hair" allowed by the AdS asymptotics), being dual to the turbulence in the Planckian fluid.
Duration: 3 years in the NWA time-frame.
Link to route criteria: This project is precisely at the focus point of "theorie van zwaartekracht": its eventual target is the connections between geometry and quantum information, revolving around emergence principles in quantum matter, mobilizing cutting edge nano physics to test it in the laboratory, exploiting the mathematical power of GR. The nano-scale turbulence is a smoking gun prediction and it would be a game changer in condensed matter when observed. Proof of principle has been delivered that numerical GR can be mobilized to study such non-equilibrium quantum matter [5-7] but it is barely explored especially in this context. Given the available resources it should be possible to have significant results in 2 years.
Link to NWA criteria: This represents a frontier of fundamental physics which is already strongly represented in the Netherlands (e.g., FOM "strange metals" and "New horizons" programs), while the PI has played a prominent role in this development. This project is quite feasible given the limited time and resources; it has been conceived as a pilot project aiming at establishing a tradition using numerical GR for the study of non-equilibrium quantum matter. We can count on help especially by Wilke van der Schee who will return from MIT (postdoc) to Utrecht in 2018. He is very experienced with holographic numerical RG in the context of heavy ion collisions [7], making it possible to jump start this project. Further active collaboration will be pursued in the string theory community (e.g., Schalm in Leiden) and the numerical GR community, as well as the quantum information and experimental communities. With regard to the broader impact, undeniably the capacity to visualize the eerie GR phenomena have contributed much to the present popularity of gravitational physics (e.g., the movie "Interstellar"). Kip Thorne himself was greatly intrigued by holography when he was in Leiden as Lorentz professor since it uncovers regimes of gravity that do not occur in the astronomical realms like the "turbulent hair" of the present black hole. To produce such appealing graphical material will be a high priority as means to communicate the excitement at this frontier of physics to the public and I request extra resources both for a high performance computer and to realize professional video material. With regard to industry, there is an inherent potential since we are dealing with electrons in solids although it is too early to discern practical applications. The nearest application horizon is in quantum technology: intellectual leaders such as Mathias Troyer are acutely aware of these developments that may offer initial benchmarks for the testing of the quantum computer.
References:
1. B. Keimer, S. A. Kivelson, M.R. Norman, S. Uchida, J. Zaanen, Nature **518**, 179 (2015)
2. J. Zaanen, Y.-W. Sun, Y. Liu, K.Schalm, "*Holographic duality in condensed matter physics*", (Cambridge Univ. Press, 2015).
3. J. Zaanen, Nature **430**, 512 (2004).
4. R. Davison, K. Schalm, J. Zaanen, Phys. Rev. B **89**,245116 (2014).
5. P.M. Chesler, L.G. Yaffe, JHEP **07**, 086 (2014) [arXiv:1309.1439]; see Paul Chesler's Black Hole Initiative colloquium: http://www.youtube.com/watch?v=xv2xb4E3Tf4&feature=em-share_video_user
6. A.Adams P. Chesler, H. Liu, Science **341**, 368 (2013)
7. J. Casalderrey-Solana, M.P. Heller, D. Mateos, W. van der Schee, Phys. Rev. Letters **111**, 181601 (2013), see also lectures: https://sites.google.com/site/wilkevanderschee/ads-numerics