Theoretical Bachelor Projects

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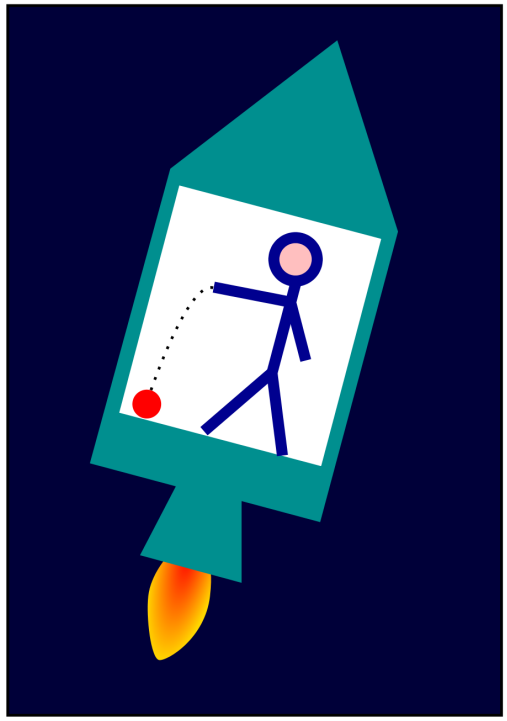

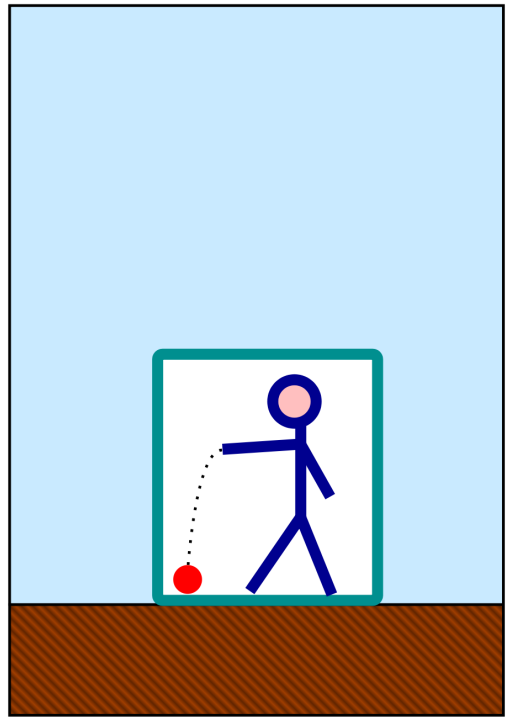

Theoretical Bachelor Projects

1. General remarks
2. Topics in theoretical physics & previous bachelor students
3. Example: Black holes – a theoretical laboratory

Jobs with a degree in theoretical physics?

- Academia is admittedly very competitive, but there are many job opportunities in the private sector, engineering, banking, you name it.

Why theoretical physics?

- To explore, learn, have fun, ...
- Getting a degree should be a consequence of your studies – not the main reason.

Theoretical diploma & PhD project?

- I do supervise them, but today I will focus on bachelor projects.

Why theoretical bachelor project?

- Get an edge in your theoretical studies.
- Get answers to the fundamental questions/topics that have always been on your mind/interest you.
- ...

How to sign up?

- Come to my office.
- I sometimes have camera-ready projects, but usually the project topic is not fixed on the very first day, and is a result of what fits student and superviser best.

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Lagrangian & Hamiltonian formulations, symplectic geometry

- Ondrej Hulik: WKB approximation & Maslov index in QM.
- Samuel Valach: Contact geometry (opponent).

Symmetry, group theory & conservation laws

- David Svoboda: QED Ward identity.
- Martin Skorna: Non-relativistic Goldstone theorem.

QM/QFT/path integral

- Michal Pazderka: Non-commutative QM & Seiberg-Witten map.
- Nikolas Masnicak: Casimir effect.
- Ondrej Kovanda: Batalin-Vilkovisky (BV) formulation of relativistic point particle.
- Jan Merta: Shor algorithm for quantum computers & number theory.

String theory

- Paulina Karlubikova: Regularize string oscillator modes to derive anomaly cancellation in $D = 26$ bosonic string theory.

Supermathematics

-

General relativity

- Tomas Michalik: General relativity modeled over the de-Sitter group $SO(1, 4)$.
- Darek Cidlinsky & Nino Lomtatidze: The mass parameter in the Schwarzschild solution has an interpretation as the total energy.

NB

- Just because a topic already became a thesis, it is usually far from exhausted.

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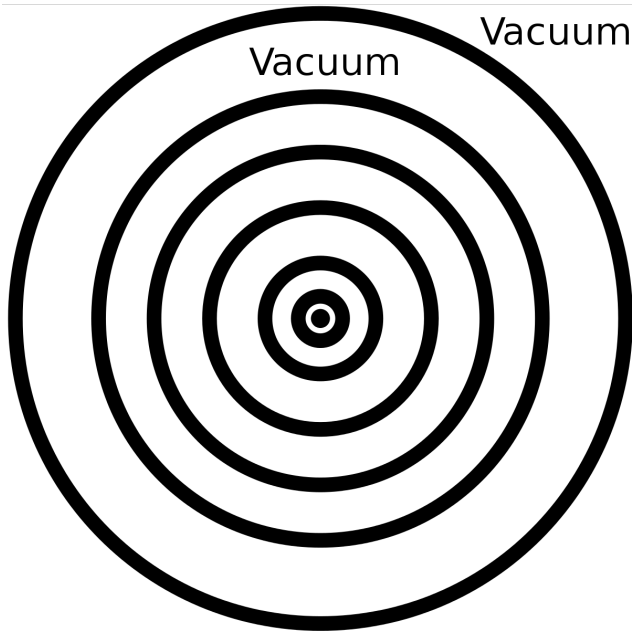
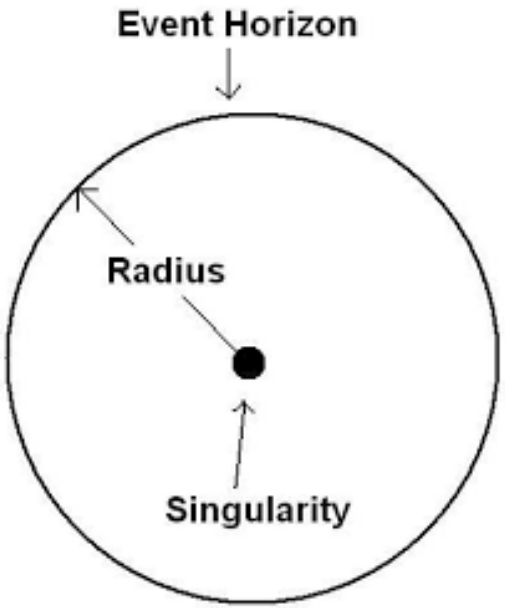
Birkhoff's theorem (BT)

A spherically symmetric spacetime is given by the Schwarzschild metric

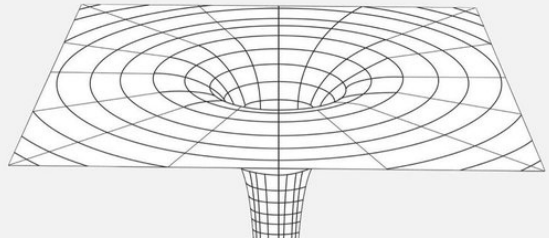
$$ds^2 = -\left(1 - \frac{R_S}{r}\right) c^2 dt^2 + \underbrace{\frac{dr^2}{1 - \frac{R_S}{r}}}_{\text{coord. sing.}} + r^2 d\Omega^2$$

in vacuum regions. Here R_S is a length parameter.





$$R_s = \frac{2GM}{c^2}$$



Schwarzschild radius

$$R_S = \frac{2GM}{c^2}$$

by comparing with Newtonian gravitational potential

$$\frac{V}{m} = -\frac{GM}{r}$$

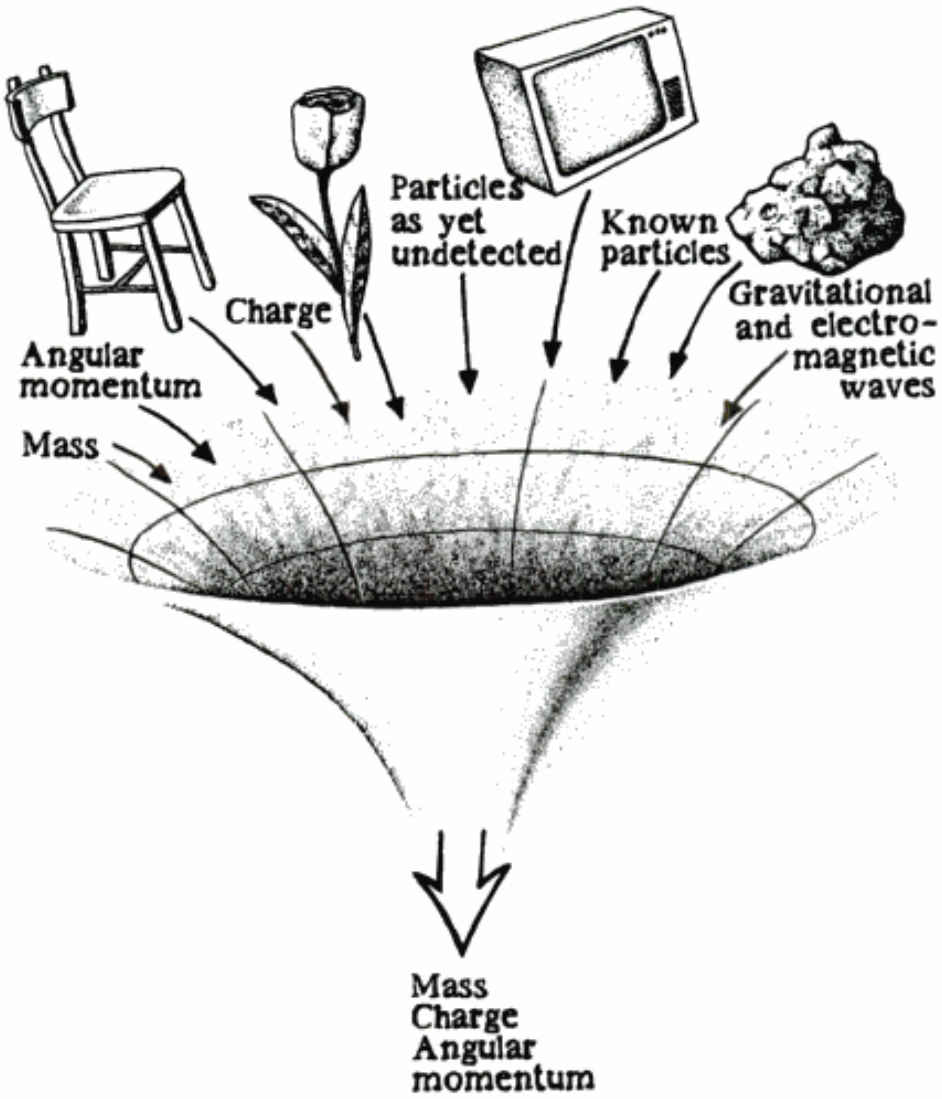
in the asymptotic region $r \to \infty$.

Arnowitt-Deser-Misner (ADM) energy of Schwarzschild black hole (BH)

$$E = Mc^2$$

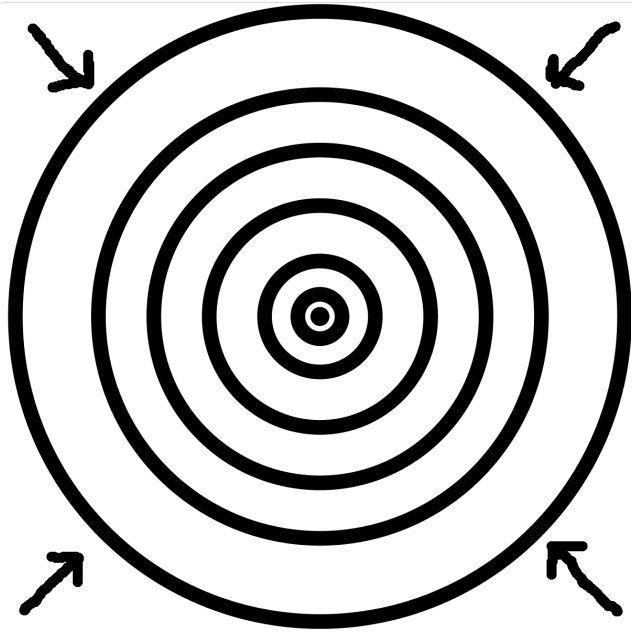
Project/Question

Can we understand E as the sum of energies from the matter (elephants, chairs, etc) that make up the BH?



Idea

- Start with empty Minkowski space.
- Throw in infinitesimally thin concentric shells of matter.
- From BT the vacuum regions between shells are described by the Schwarzschild metric (with possible different length parameters R_S).



Geodesic: Conserved energy of free falling test particle

$$\underbrace{e}_{\text{Tot}} = mc\sqrt{\underbrace{c^2}_{\text{Rest}} + \underbrace{(\frac{dr}{d\tau})^2}_{\text{Kin}} \underbrace{- \frac{2GM}{r}}_{\text{Pot}}}$$

Also true for infinitesimally thin shell.

Israel junction conditions

Match inside "$-$" and outside "$+$" of shell.

Result

$$E_+ - E_- = (M_+ - M_-)c^2 = mc\sqrt{c^2 + (\frac{dr}{d\tau})^2 - \frac{2G}{r}\frac{M_+ + M_-}{2}}$$

The difference in ADM energy is given by the energy of the thin shell propagating in the average of the two neighboring Schwarzschild spacetimes!

Open projects: Extend with

- Cosmological constant?
- Reissner-Nordström charged black hole?
- Other spacetime dimensions?

Děkuji!