

Einstein's Dream

Falk Hassler



NARODOWE
CENTRUM
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Uniwersytet
Wrocławski

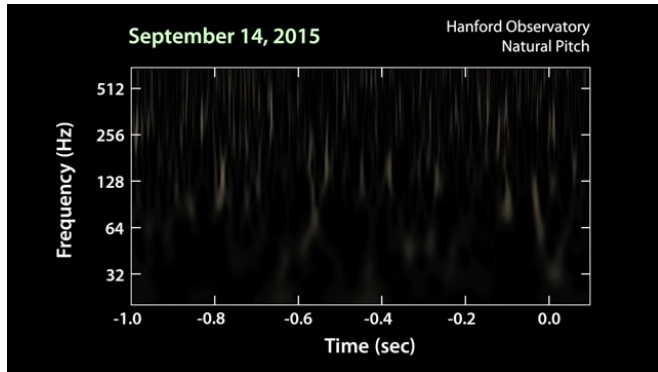
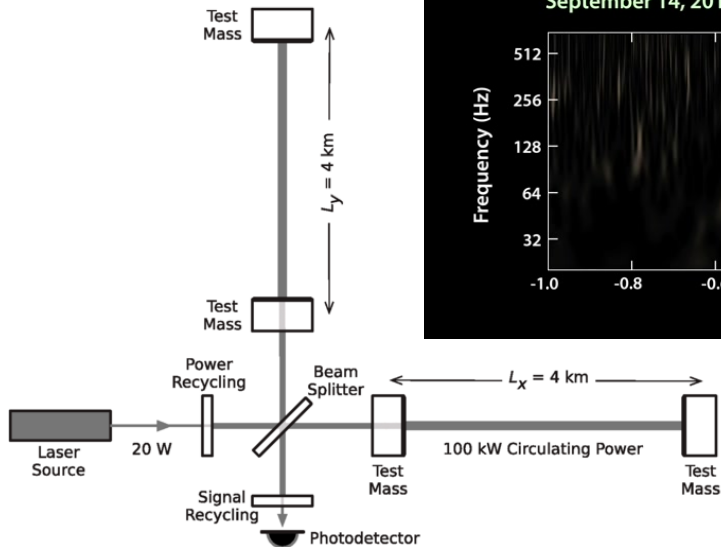
A deep space photograph showing a vast field of stars of various colors (blue, white, orange) against a dark background. On the right side, a portion of a galaxy is visible, characterized by a bright yellowish-white core and a diffuse, reddish-brown and orange glow. The text "The Edge of All We Know" is overlaid in the center in a white, outlined font.

The Edge of All We Know

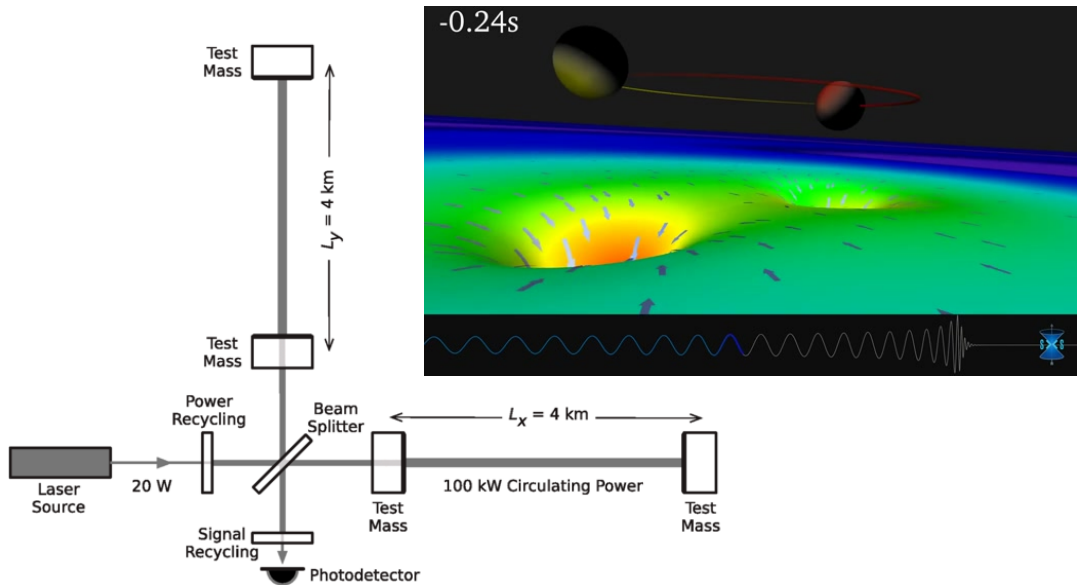
14th September 2015: first observation of gravitational waves



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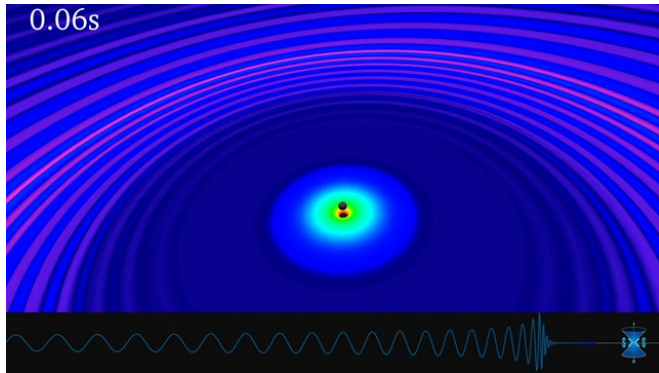
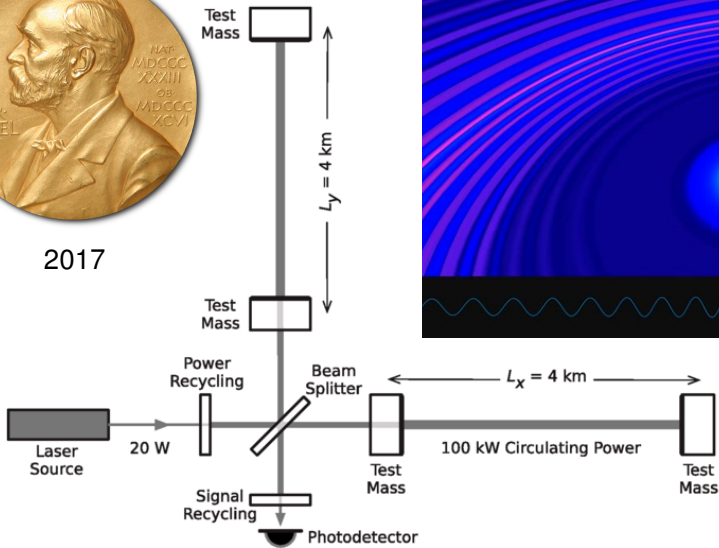
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2017



10th April 2019: first image of a black hole (M87*)



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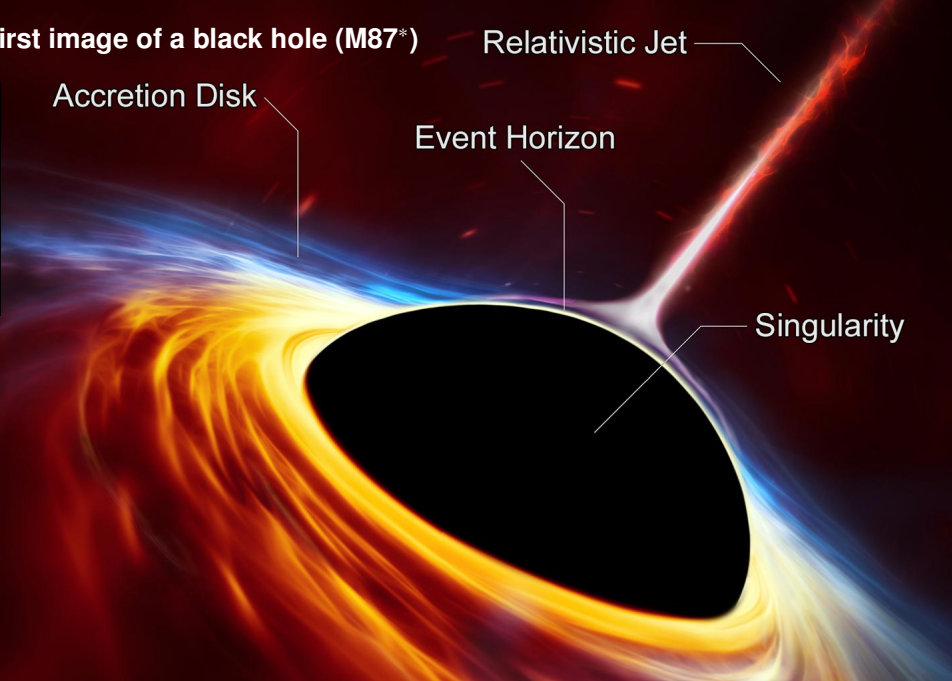


Accretion Disk

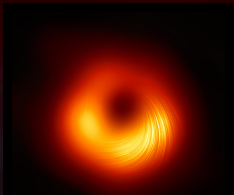
Event Horizon

Relativistic Jet

Singularity



10th April 2019: first image of a black hole (M87*)

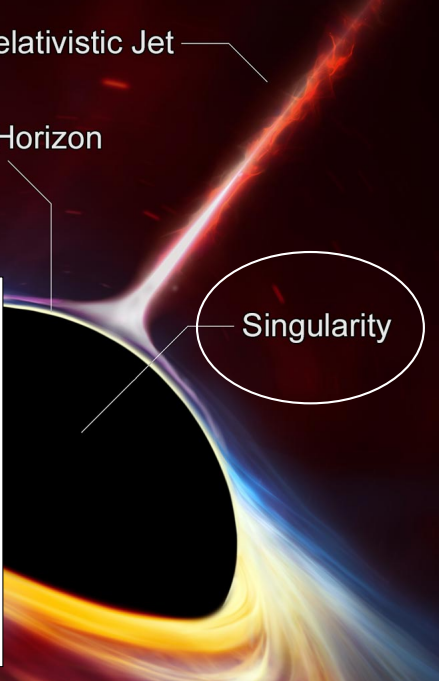
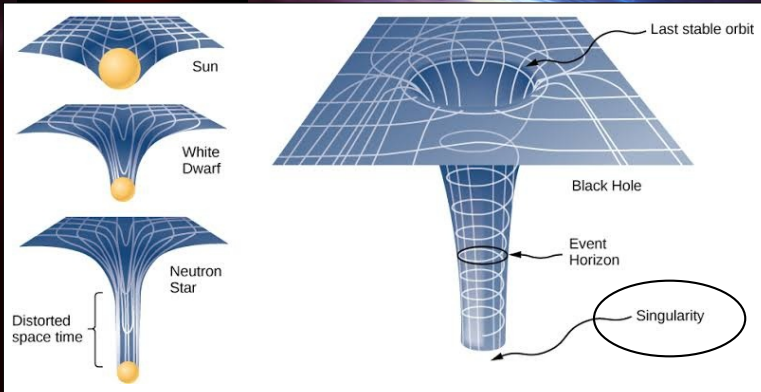


Accretion Disk

Relativistic Jet

Event Horizon

Singularity



Why all the fuss about the singularity?

- ▶ Everything that ever fell into the BH is compressed to a point, the singularity.
- ▶ General relativity breaks down and needs to be altered, but how?
- ▶ Penrose-Hawking singularity theorems: “Occurrence of singularities is inevitable in GR”

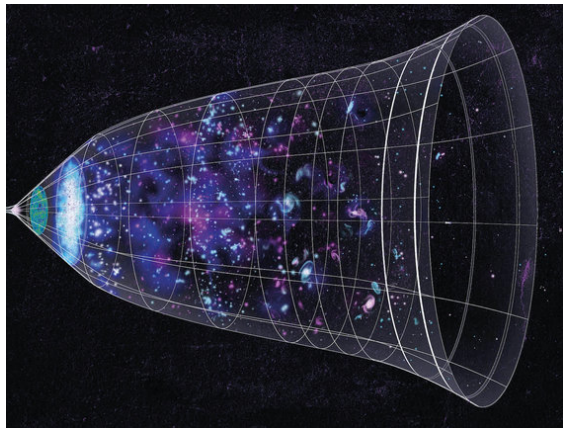
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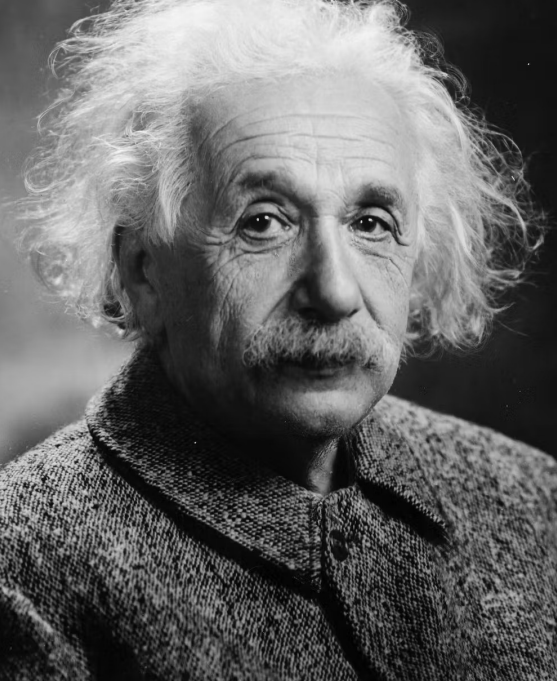
2020

Big Bang



QFT and GR

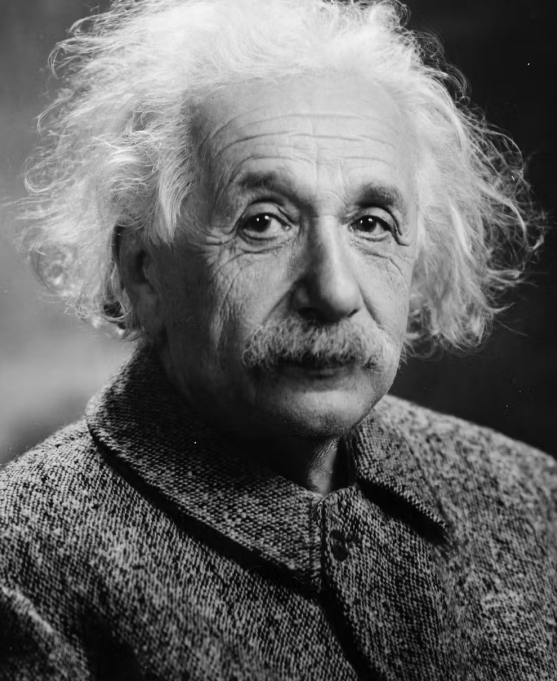




Special and General Relativity

- ▶ speed of light c = cosmical speed limit
- ▶ mass-energy equivalence

$$E = mc^2$$



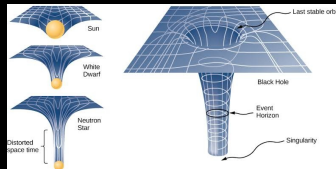
Special and General Relativity

- ▶ speed of light c = cosmical speed limit
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$$E = mc^2$$

- ▶ speed limit also applies for gravity
- energy cruves space and time
- Einstein field equations

$$R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$



Quantum Mechanics

- ▶ nothing is certain
- ▶ Heisenberg's uncertainty principle

$$\Delta x \cdot \Delta p \geq \frac{\hbar}{2}$$



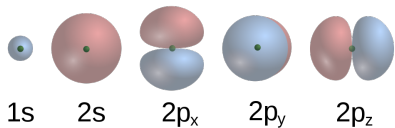
Quantum Mechanics

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- ▶ particles are described by wave function $\Psi(t, x)$
- ▶ governed by Schrödinger equation

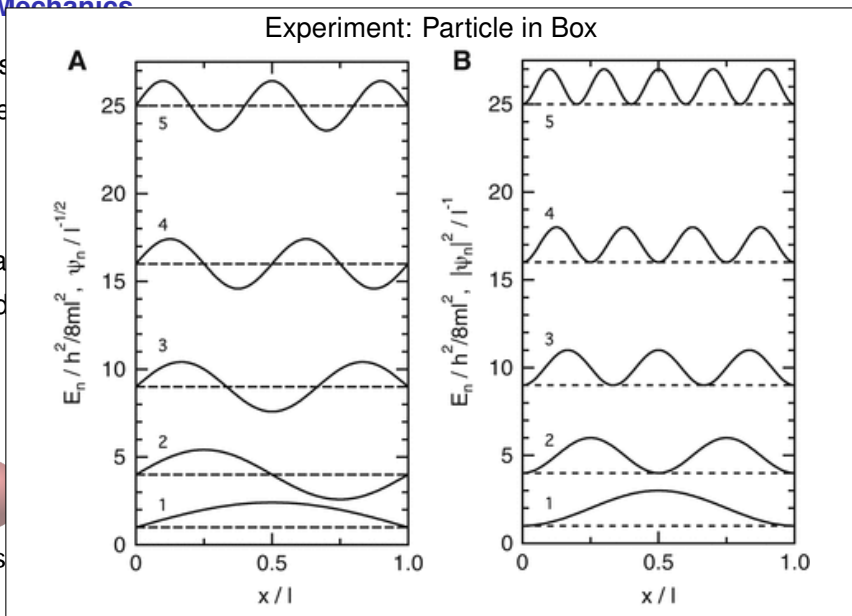
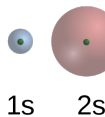
$$i\hbar \frac{\partial}{\partial t} \Psi(t, x) = H\Psi(t, x)$$



Quantum Mechanics

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- ▶ particle a
- ▶ governed



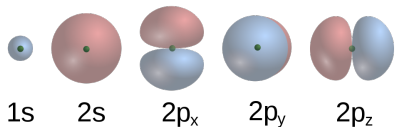
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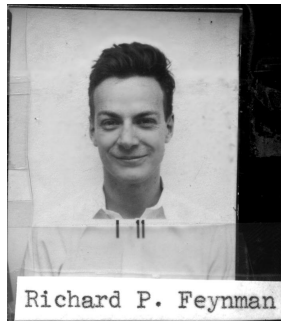
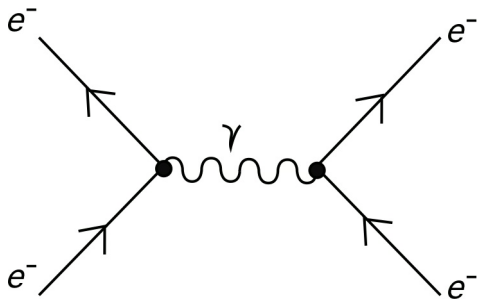


- ▶ **Can we unify QM and SR?**



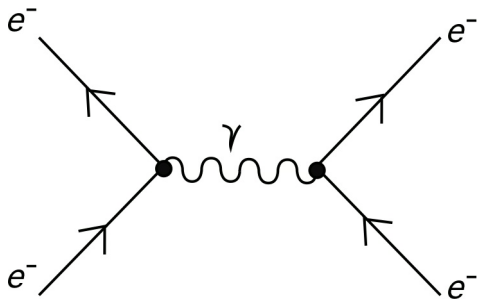
Quantum Field Theory

- ▶ particles can be created and annihilated (destroyed)
- ▶ interactions can be drawn as Feynman diagrams

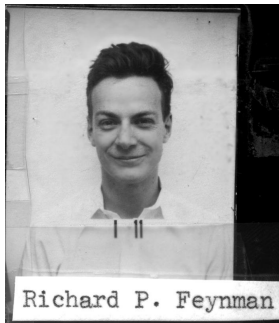


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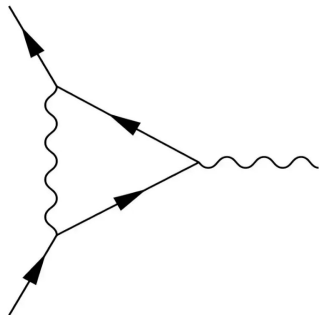
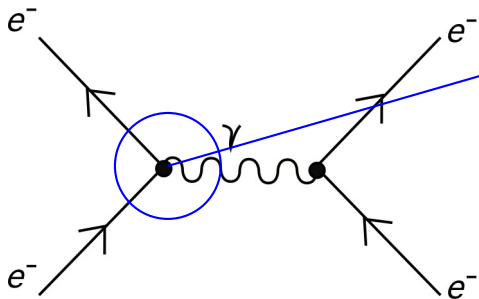


- ▶ virtual particles “borrow” energy from vacuum
→ renormalisation



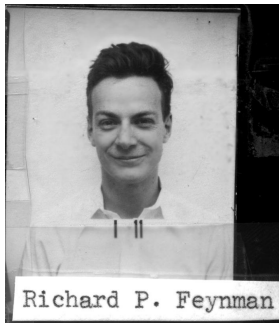
Quantum Field Theory

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▶ **This is where the trouble starts!**



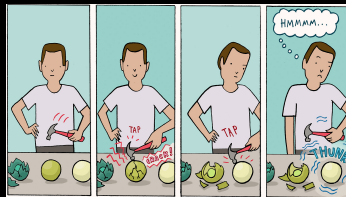


GR is not renormalisable

- ▶ quantum mechanics corrects (renormalises) Einstein field equations

$$R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} + \dots = \frac{8\pi G}{c^4} T_{\mu\nu}$$

- ▶ happens for all fundamental forces
- ▶ but only for gravity ∞ -many corrections
- not applicable at
 - high energies
 - small distances $\sim 10^{-35}$ m

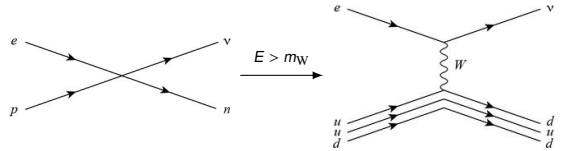




Is the singularity an artifact of an incomplete description?

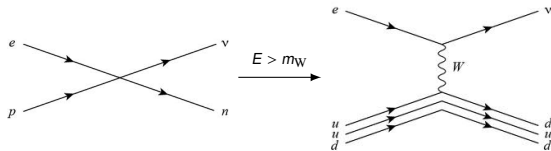
Is the singularity an artifact of an incomplete description?

example Fermi theory of β -decay



Is the singularity an artifact of an incomplete description?

example Fermi theory of β -decay



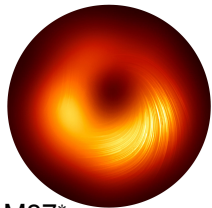
My research is driven by:

- ▶ Can we resolve the singularity?
- ▶ Effects on the notion of space and time, the fabric of cosmos?
- ▶ What are observable consequences?

The background of the image is a dark, almost black, field filled with a dense, chaotic pattern of colorful, wavy lines. These lines, representing strings, are in various colors including yellow, blue, green, orange, and brown. Some lines are straight and wavy, while others form circular or star-like shapes, suggesting different vibrational modes or topologies of strings. The overall effect is a vibrant, abstract representation of the complex mathematics of string theory.

String Theory

Smaller and smaller and smaller...



M87*

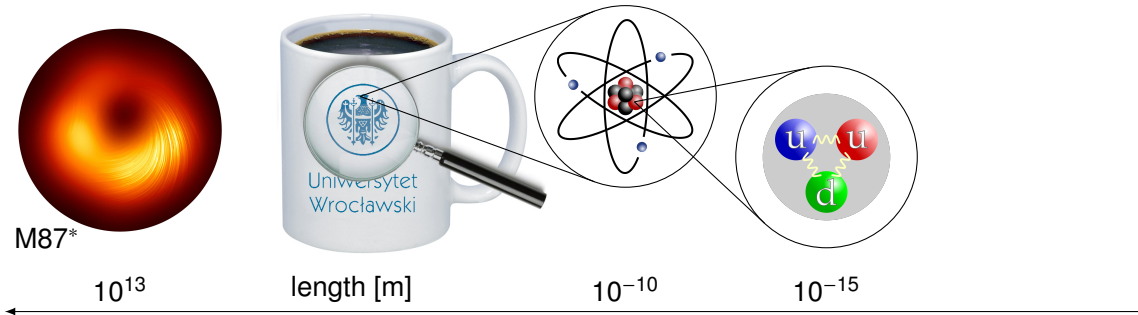


length [m]

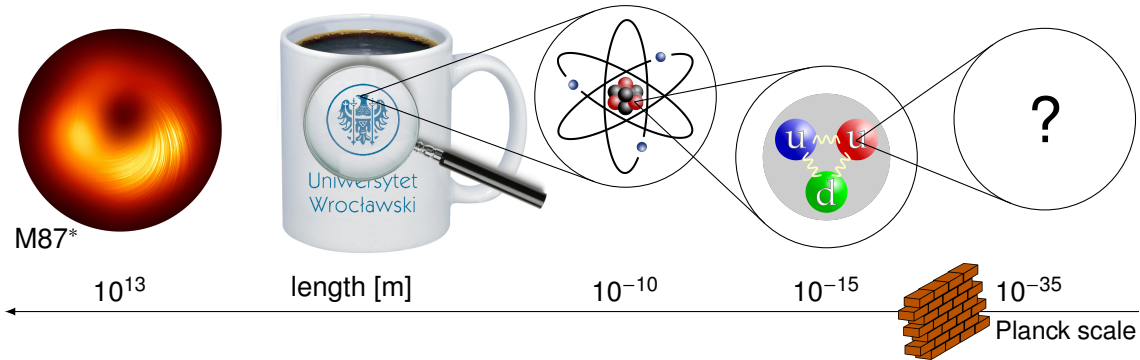
10^{13}



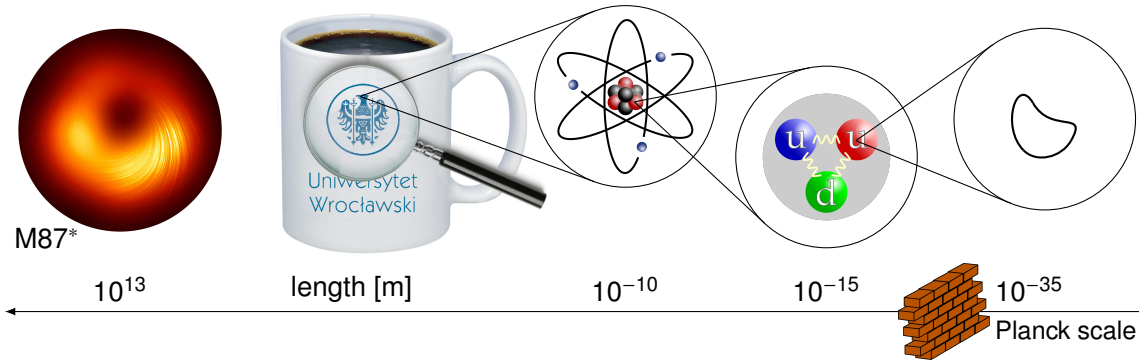
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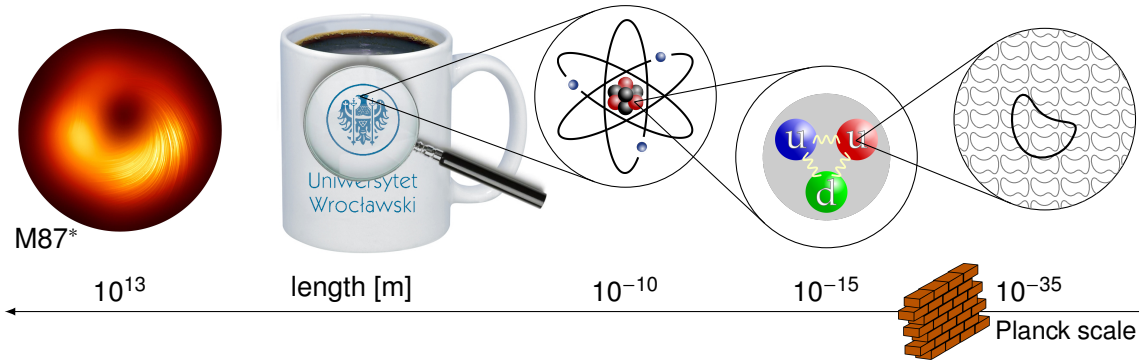
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Smaller and smaller and smaller...

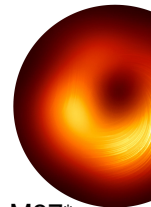


Smaller and smaller and smaller...



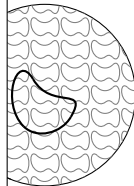
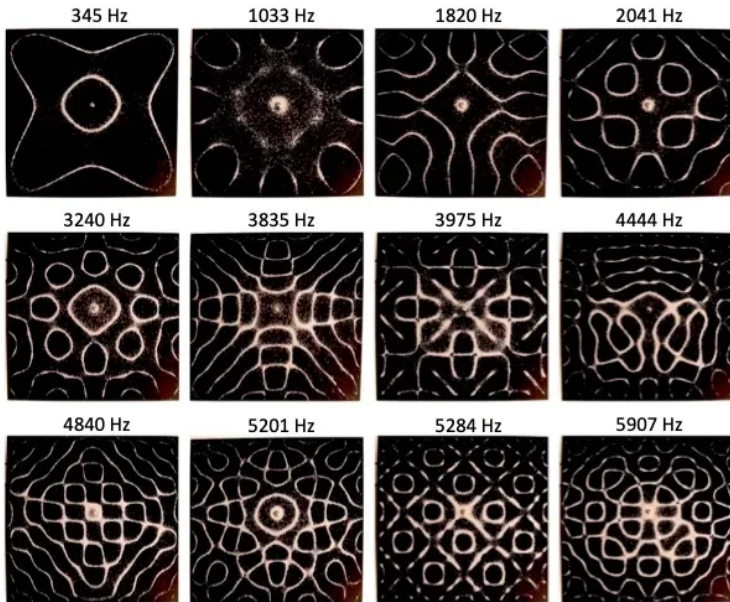
Smaller an

Experiment: Cymatics



M87*

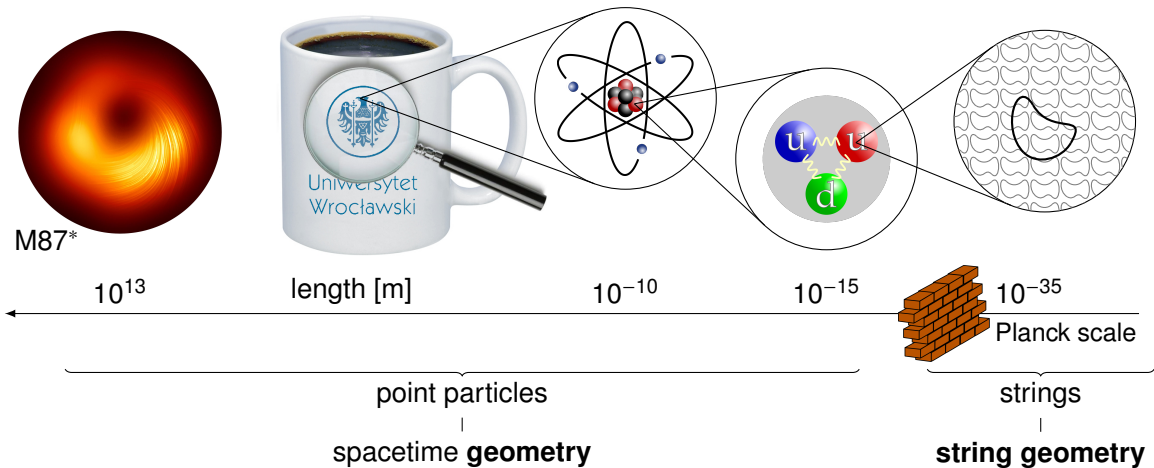
10^{13}



0-35

Planck scale

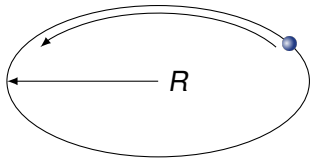
Smaller and smaller and smaller...



What do we learn from this new paradigm?

Abelian T-duality

point particle



\neq



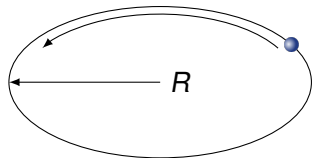
$$E_n \sim \frac{n^2}{R}$$



Abelian T-duality



point particle

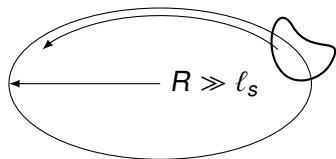


\neq



$$E_n \sim \frac{n^2}{R}$$

string



$=$

T-duality

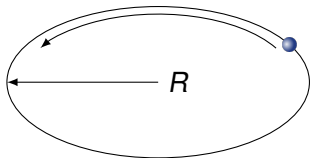


$$E_{nm} \sim \frac{n^2}{R} + \frac{m^2 R}{l_s^2}$$

Abelian T-duality



point particle

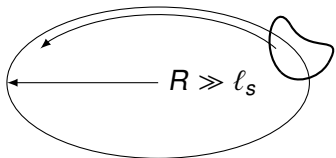


\neq



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T-duality



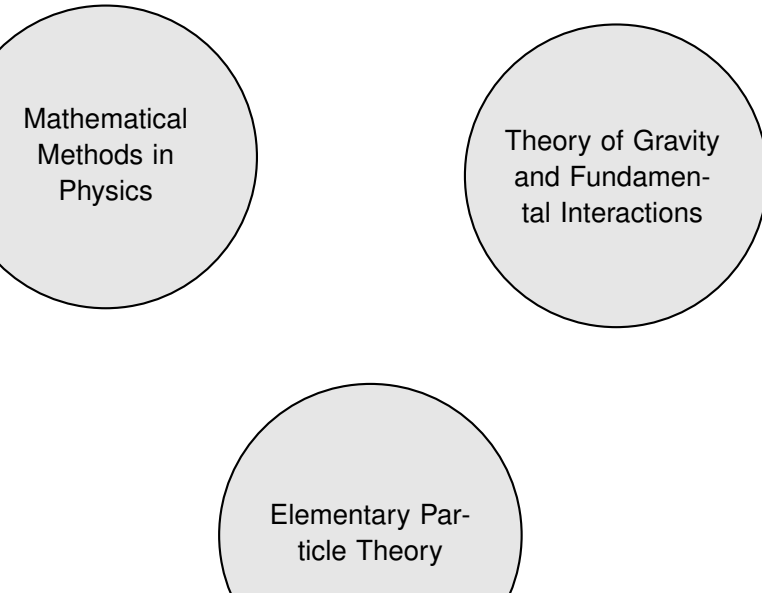
$$E_{nm} \sim \frac{n^2}{R} + \frac{m^2 R}{l_s^2}$$



only works for circles and flat tori

A glowing crystal ball is held by two hands, one on each side. The crystal ball is illuminated from within, creating a bright orange and yellow glow that fades into a blue light. The word "Future?" is written across the center of the crystal ball in a white, outlined font. The background is dark, making the glowing elements stand out.

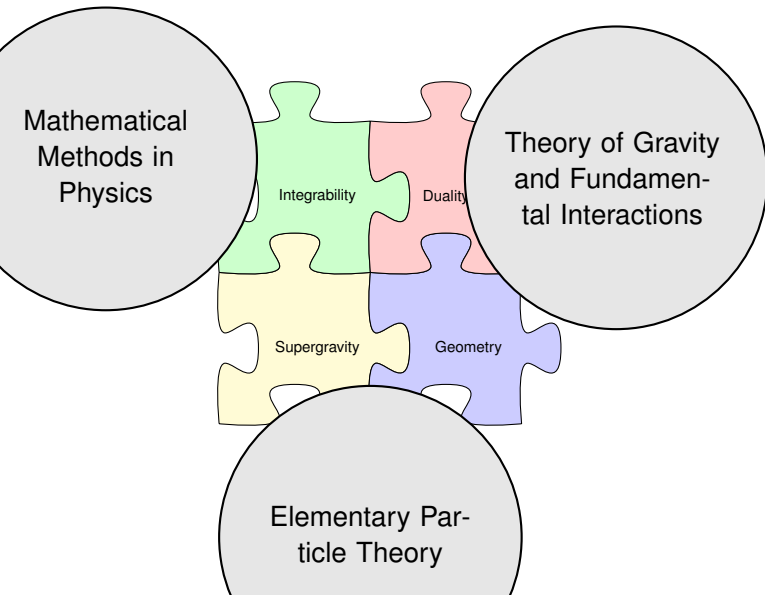
Future?

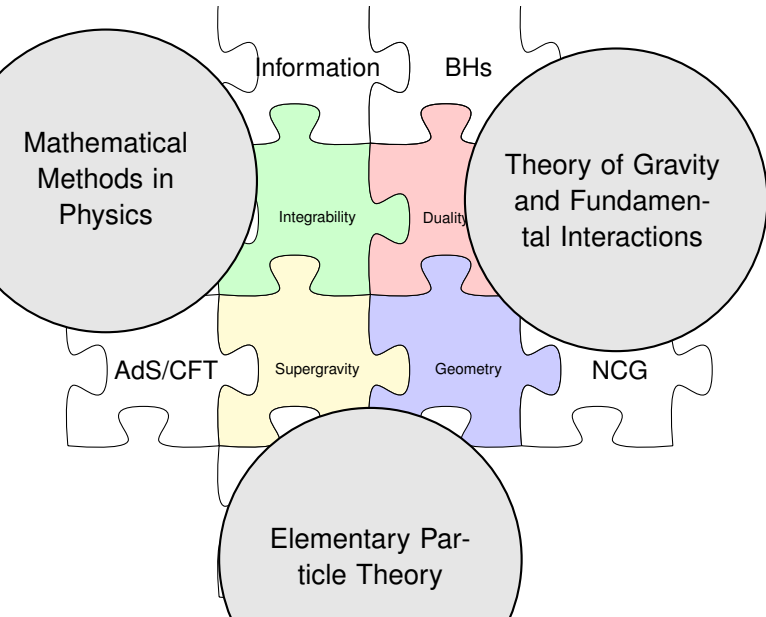


Mathematical
Methods in
Physics

Theory of Gravity
and Fundamen-
tal Interactions

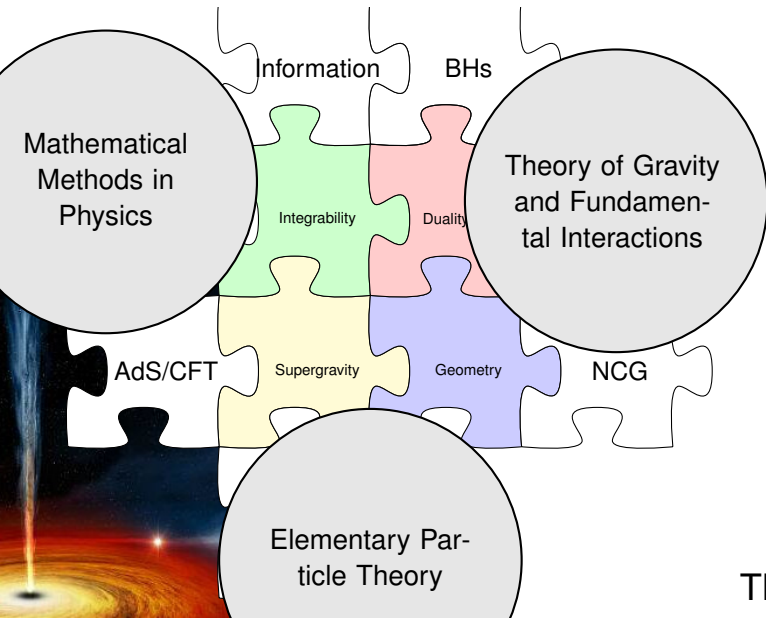
Elementary Par-
ticle Theory





- ▶ Work on these topic is done here in Wrocław...
- ▶ ...and all over the world.
- ▶ SONATA BIS 11 grant





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Thank you for your attention!