# Happy birthday Zdeněk !!!



My talk

**THE CONCEPT OF THE EFFECTIVE POTENTIAL BEYOND NEWTON AND EINSTEIN: A POSSIBLE QUANTUM GRAVITY CONNECTION**

is dedicated

to professor Zdeněk Stuchlík

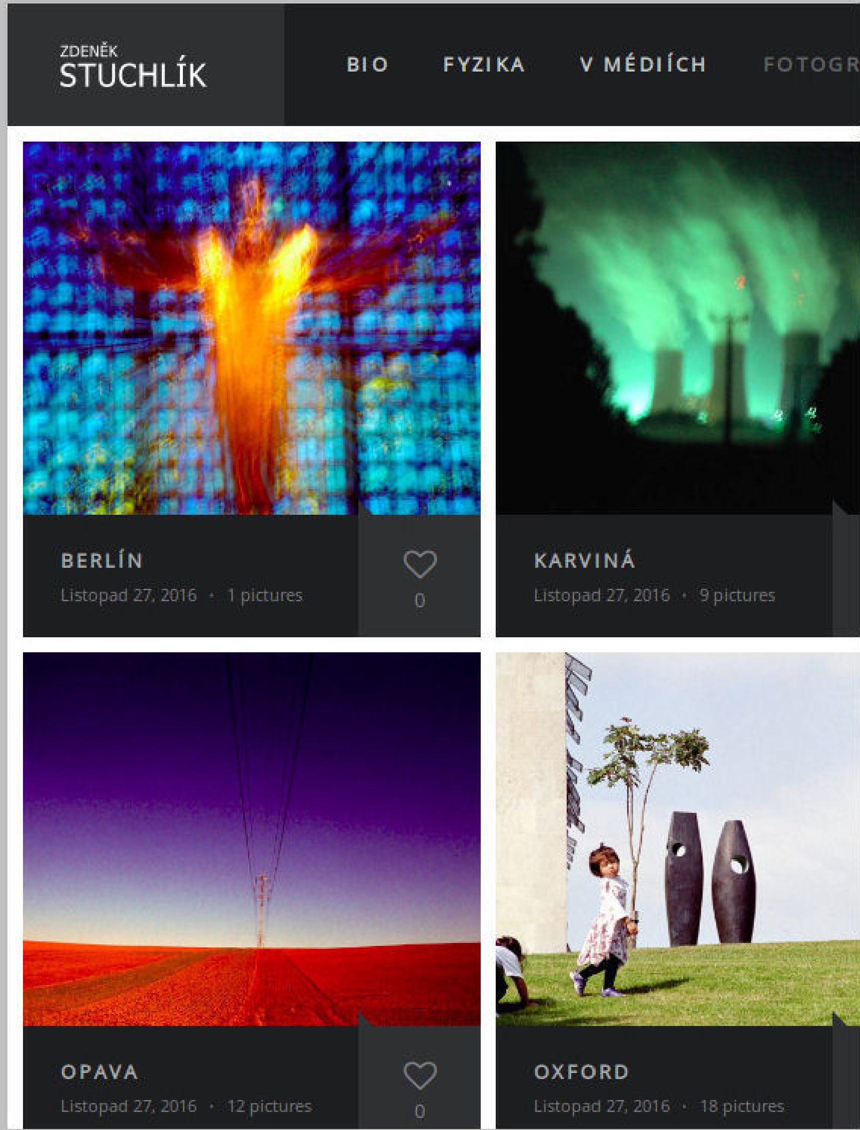
on the occasion

of his birthday

# Happy birthday Zdeněk !!!



http://zdenekstuchlik.com/fotografie/



# Silhouettes



# My Opava connection 15 yrs ago and a past birthday




Birthday on red. Picasso on green.

# Zdenek is cited even in the Covid-19 research!

## A Characterization of the COVID-19 Pandemic Impact on a Mobile Network Operator Traffic

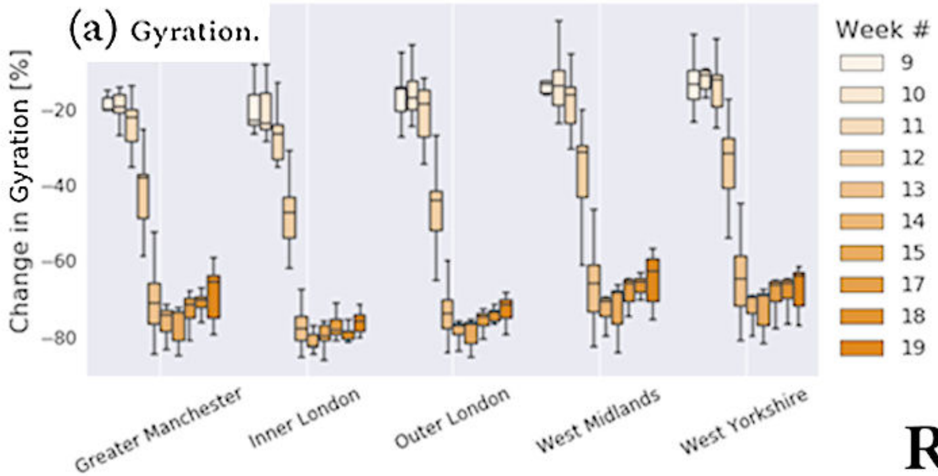

Andra Lutu
Telefonica Research

Diego Perino
Telefonica Research

Marcelo Bagnulo
Universidad Carlos III de Madrid

Enrique Frias-Martinez
Telefonica Research

Javad Khangosstar
Telefonica UK


arXiv:2010.02781v1 [cs.NI] 6 Oct 2020

## REFERENCES


[1] 3GPP. [n. d.]. 3rd Generation Partnership Project (3GPP). ([n. d.]). Retrieved May 14, 2020 from https://www.3gpp.org

[2] MA Abramowicz, JC Miller, and Z Stuchlík. 1993. Concept of radius of gyration in general relativity. *Physical Review D* 47, 4 (1993), 1440.

# Summary & Conclusions



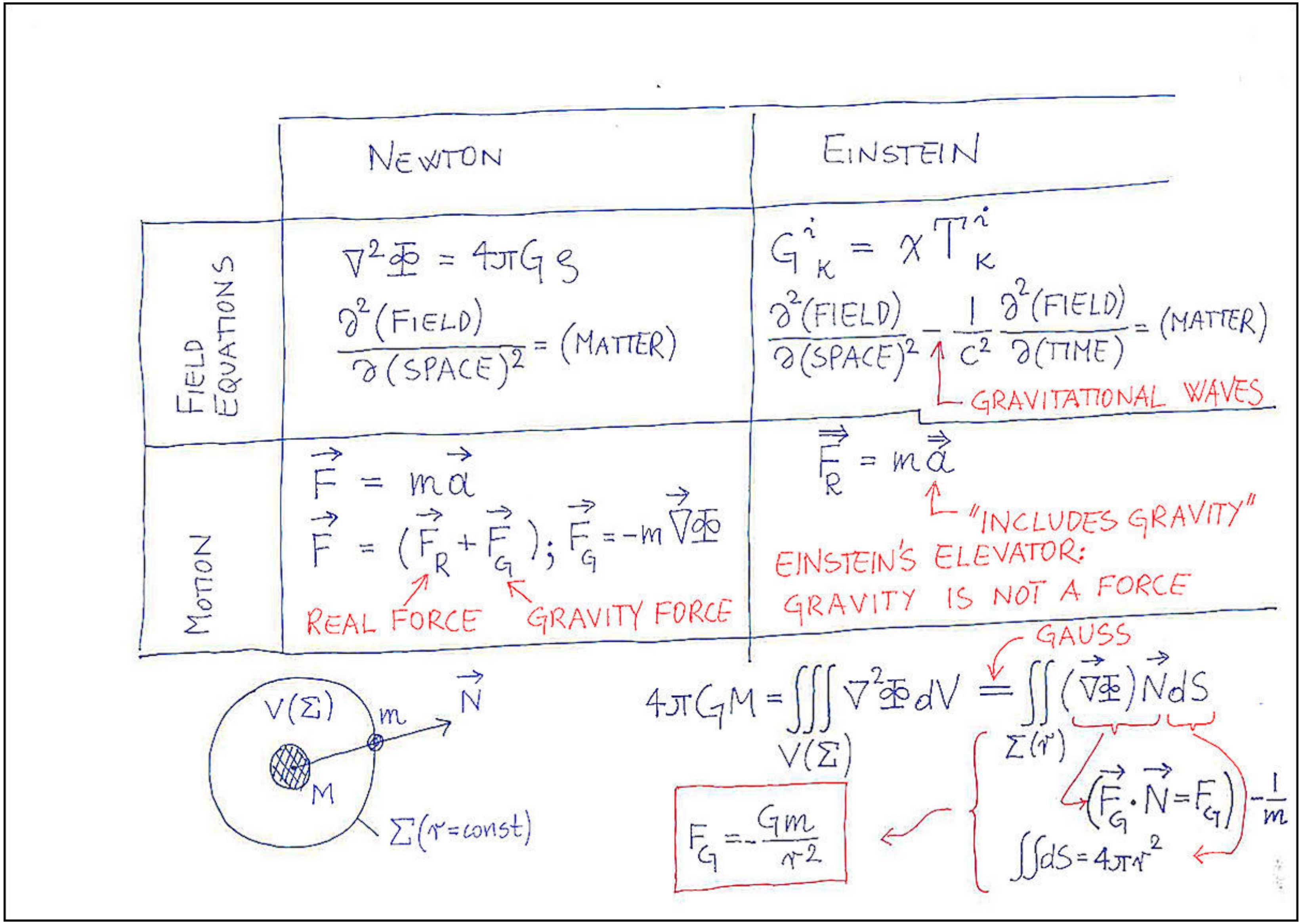
I shortly describe the concept of the effective potential in Newton's theory and show that even if one does not know Einstein's general relativity, one may correctly guess the topology of the potential in Einstein's theory from Newton's theory.

This allows one to discover, without solving any of Einstein's equations, all "relativistic effects" in particles' and photons' motion around compact objects in the strong field limit.

Here I speculate that the same is true for quantum effects in strong gravity: even without knowing Quantum Gravity (QG) theory, one may guess all classes of all the QG effects, in principle observable in particles' and photons' motion around compact Quantum Gravity objects. This may be relevant for interpreting the EHT images (in particular secondary rings) and the LIGO-Virgo results (in particular ringdowns and echoes).

# Newton & Einstein: a short reminder





# Our approach: exact topology, no approximations



Now, we will use only Newtonian arguments plus an extra one: that speed of light is an upper limit for physical velocities.

From this we will derive most important aspects of Einstein's celestial dynamics in the strong field.

This approach is different from all approximate approaches: it is toologically exact.

# Energy & momentum conservation



NEWTON: CONSERVATION OF ENERGY $\mathcal{E}$ AND ANGULAR MOMENTUM $\ell$

$$\frac{\partial(\text{field})}{\partial t} = 0 \Rightarrow \text{ENERGY CONSERVATION} \quad \frac{d\mathcal{E}}{dt} = 0$$

$$\frac{\partial(\text{field})}{\partial \varphi} = 0 \Rightarrow \text{ANGULAR MOMENTUM CONSERVATION} \quad \frac{d\ell}{dt} = 0$$

$$\frac{d\Phi}{dt} = \frac{\partial \Phi}{\partial t} + \frac{\partial \Phi}{\partial x}\frac{dx}{dt} = -V\frac{dV}{dt} = -\frac{d}{dt}\left(\frac{1}{2}V^2\right) \Rightarrow \frac{d}{dt}\left(\Phi + \frac{1}{2}V^2\right) = 0$$

$\frac{\partial \Phi}{\partial t} = 0$, $\frac{dx}{dt} = V$, $\frac{\partial \Phi}{\partial x} = -a = -\frac{dV}{dt}$, $\Phi + \frac{1}{2}V^2 = \mathcal{E}$

$$\frac{d\ell}{dt} = \frac{d}{dt}\left(\Omega r^2\right) = \frac{d}{dt}\left(\frac{d\varphi}{dt} r^2\right) = \frac{d^2\varphi}{dt^2} r^2 + 2\frac{d\varphi}{dt}\frac{dr}{dt} r = a_\varphi$$

$$a_\varphi = -\frac{1}{r}\frac{\partial \Phi}{\partial \varphi} = 0 \Rightarrow \frac{d\ell}{dt} = 0$$

# Effective potential in Newton's theory (1)



THE EFFECTIVE POTENTIAL IN NEWTON'S THEORY

$$\mathcal{E} = \frac{E}{m} = \Phi + \frac{1}{2}V^2 = \Phi + \frac{1}{2}V_r^2 + \frac{1}{2}V_\varphi^2 ; \quad V_\varphi^2 = \left(\frac{\ell}{r}\right)^2$$

$$\mathcal{E} = \Phi + \frac{1}{2}V_r^2 + \frac{1}{2}\left(\frac{\ell^2}{r^2}\right)$$

$$0 \leq \frac{1}{2}V^2 = \mathcal{E} - \left[\Phi + \frac{1}{2}\frac{\ell^2}{r^2}\right]$$

$$\left[\Phi + \frac{1}{2}\frac{\ell^2}{r^2}\right] = \mathcal{U}(r, \ell) = \text{effective}$$

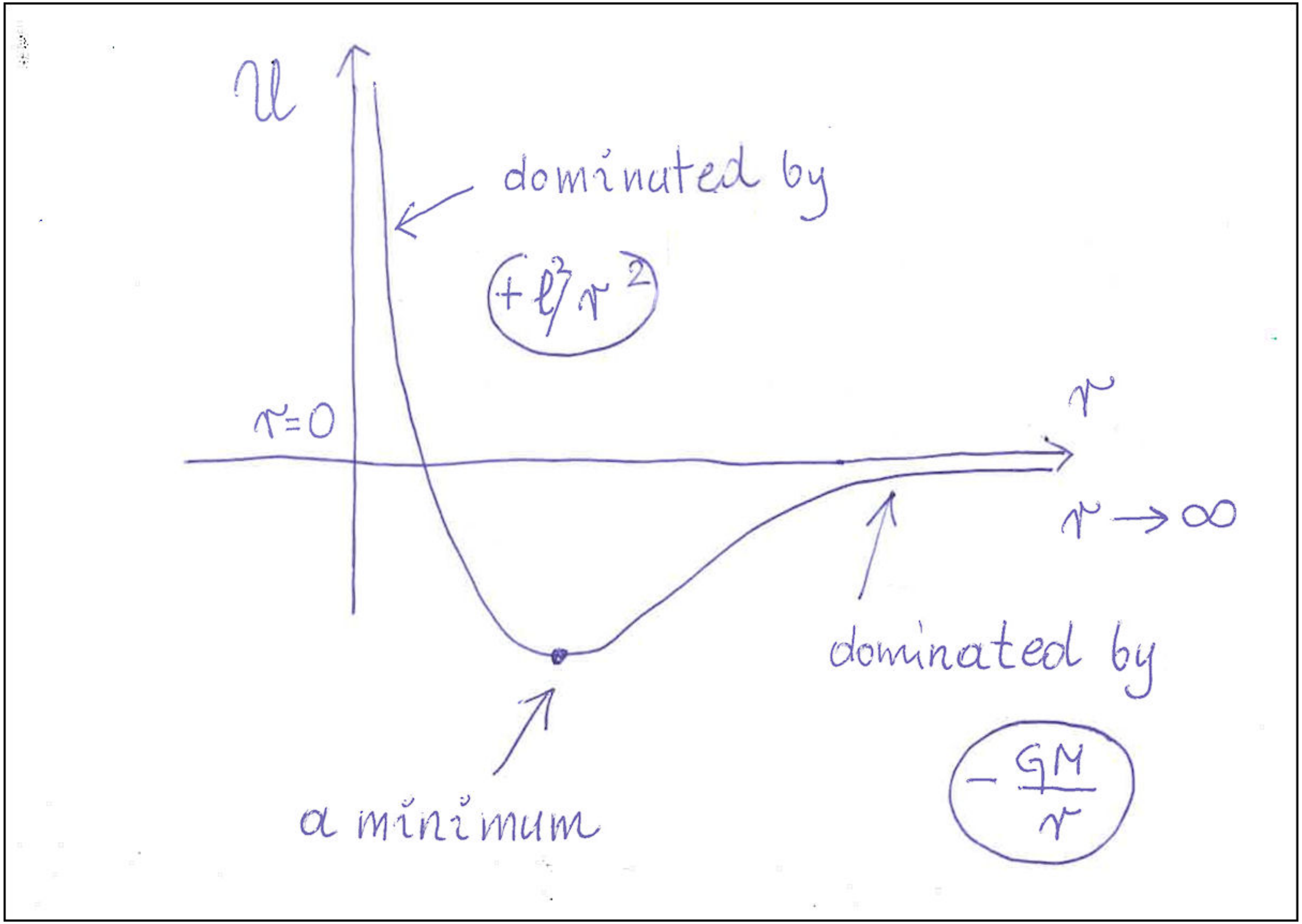
$$\mathcal{E} \geq \mathcal{U}(r, \ell) \leftarrow \text{CONDITION FOR MOTION}$$

For the potential $-\frac{GM}{r}$

$$\mathcal{U} = \mathcal{U}(r, \ell) = -\frac{GM}{r} + \frac{1}{2}(\ell^2/r^2)$$

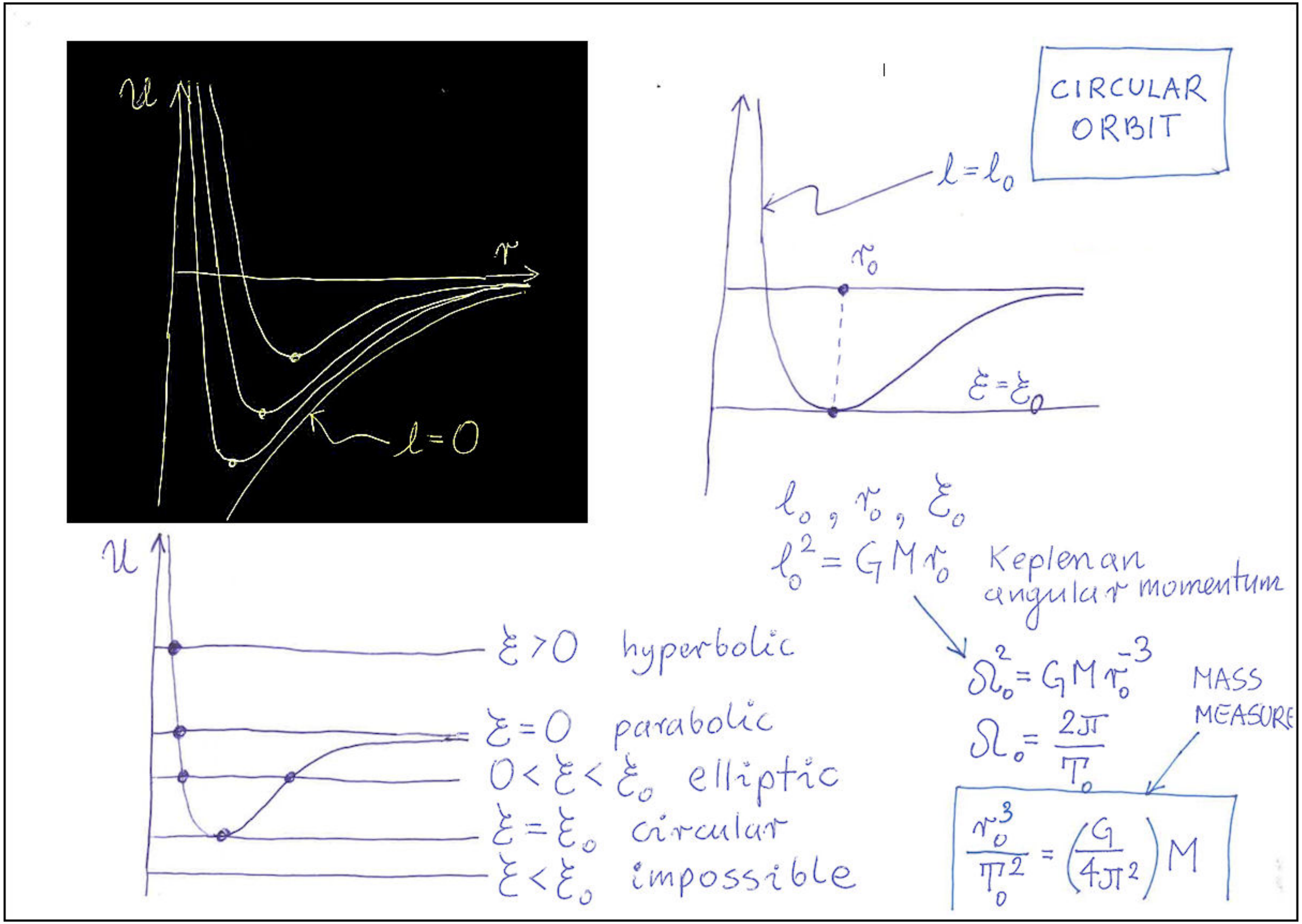
# Effective potential in Newton's theory (2)





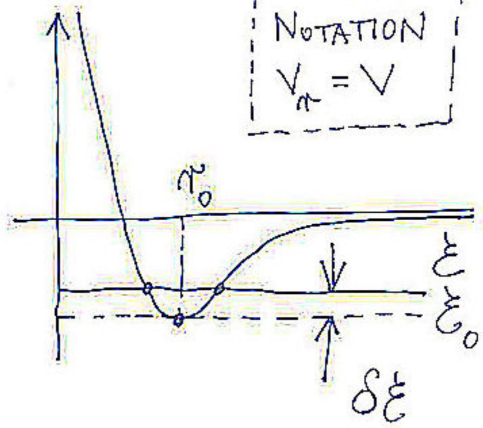
# Effective potential in Newton's theory (3)





# Almost circular orbits (1)

NOTATION
$V_r = V$




$$r = r(t) = r_0 + \delta r(t)$$

$$V = \dot{r} \equiv \frac{dr}{dt} = \delta\dot{r}$$

$$\frac{1}{2}V^2 = \mathcal{E} - \mathcal{U}$$

$$\frac{1}{2}(\delta\dot{r})^2 = \delta\mathcal{E} - \delta\mathcal{U}$$

$$\delta\mathcal{U} = \mathcal{U}(\ell_0, r_0 + \delta r) - \mathcal{U}(\ell_0, r_0) = $$

$$= \underbrace{\left(\frac{\partial \mathcal{U}}{\partial r}\right)}_{=0}\delta r + \frac{1}{2}\left(\frac{\partial^2 \mathcal{U}}{\partial r^2}\right)\delta r^2$$

$$\frac{1}{2}(\delta\dot{r})^2 = \delta\mathcal{E} - \frac{1}{2}\left(\frac{\partial^2 \mathcal{U}}{\partial r^2}\right)\delta r^2$$

$$\delta\ddot{r}\,\delta\dot{r} = -\left(\frac{\partial^2 \mathcal{U}}{\partial r^2}\right)\delta r\,\delta\dot{r}$$

$$\boxed{\delta\ddot{r} + \left(\frac{\partial^2 \mathcal{U}}{\partial r^2}\right)\delta r = 0}$$

HARMONIC OSCILLATOR

# Almost circular orbits (2)



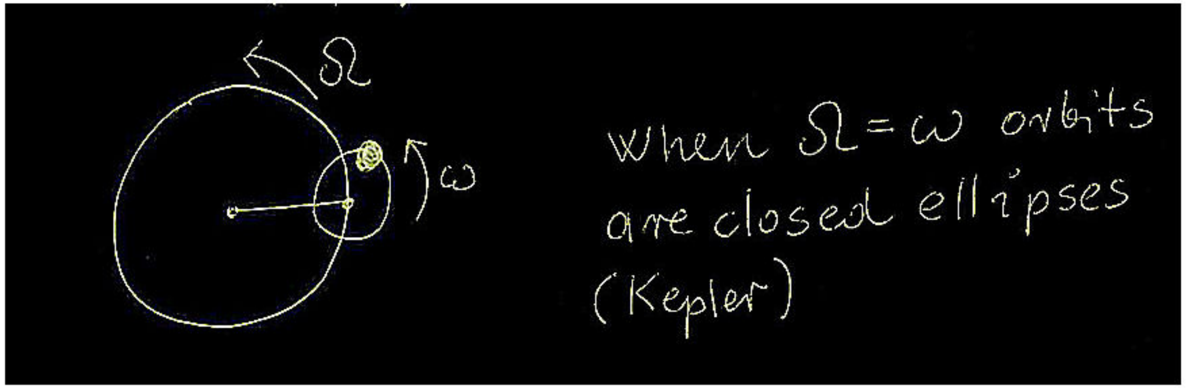
$$\delta\ddot{r} + \left(\frac{\partial^2 U}{\partial r^2}\right)\delta r = 0$$

$= \omega^2 =$ epicyclic frequency

$\omega^2 >$ for stability

In Newton's potential $\Phi = -\dfrac{GM}{r}$

$$\Omega \doteq \left(\frac{GM}{r^3}\right)^{\frac{1}{2}} \qquad \omega = \left(\frac{GM}{r^3}\right)^{\frac{1}{2}} = \Omega$$



# Newton summary

$$\nabla^2 \Phi = 4\pi G \rho \,, \quad \vec{F} = m\vec{a} \,, \quad \vec{a} = \frac{d\vec{v}}{dt} \,, \quad \vec{v} = \frac{d\vec{x}}{dt}$$

$$\frac{\partial \Phi}{\partial t} = 0 \Rightarrow \frac{d\mathcal{E}}{dt} = 0 \,, \quad \frac{\partial \Phi}{\partial \varphi} = 0 \Rightarrow \frac{d\ell}{dt} = 0$$

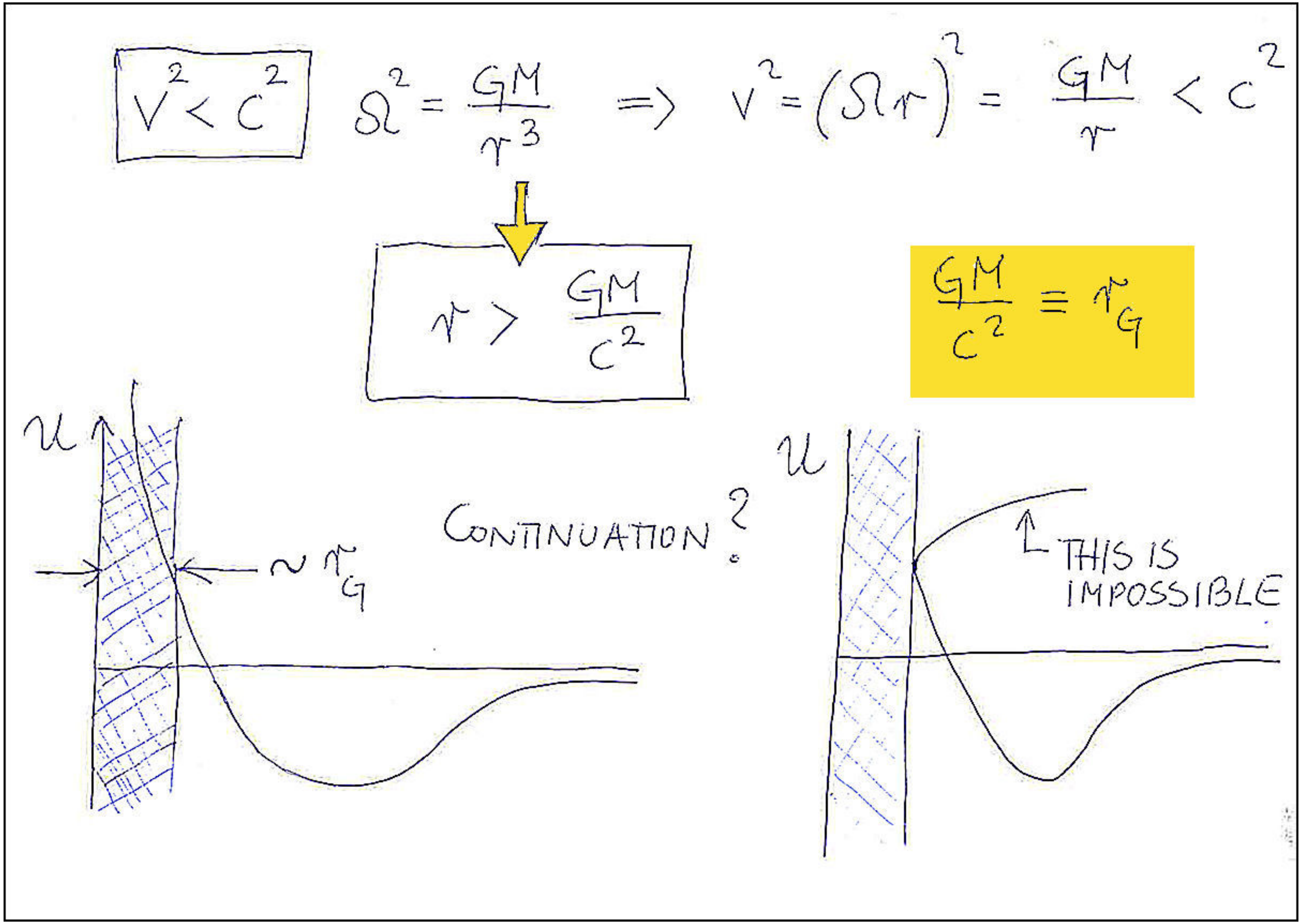
$$\mathcal{E} = \Phi + \frac{1}{2}V_r^2 + \frac{1}{2}\left(\frac{\ell}{r}\right)^2 \Rightarrow \frac{1}{2}V_r^2 = \mathcal{E} - \left[\Phi + \frac{1}{2}\left(\frac{\ell}{r}\right)^2\right]$$

$$\nwarrow = \mathcal{U}(r, \ell)$$

$$\left(\frac{\partial \mathcal{U}}{\partial r}\right) = 0 = \Omega^2 = \frac{GM}{r^3} \,,$$

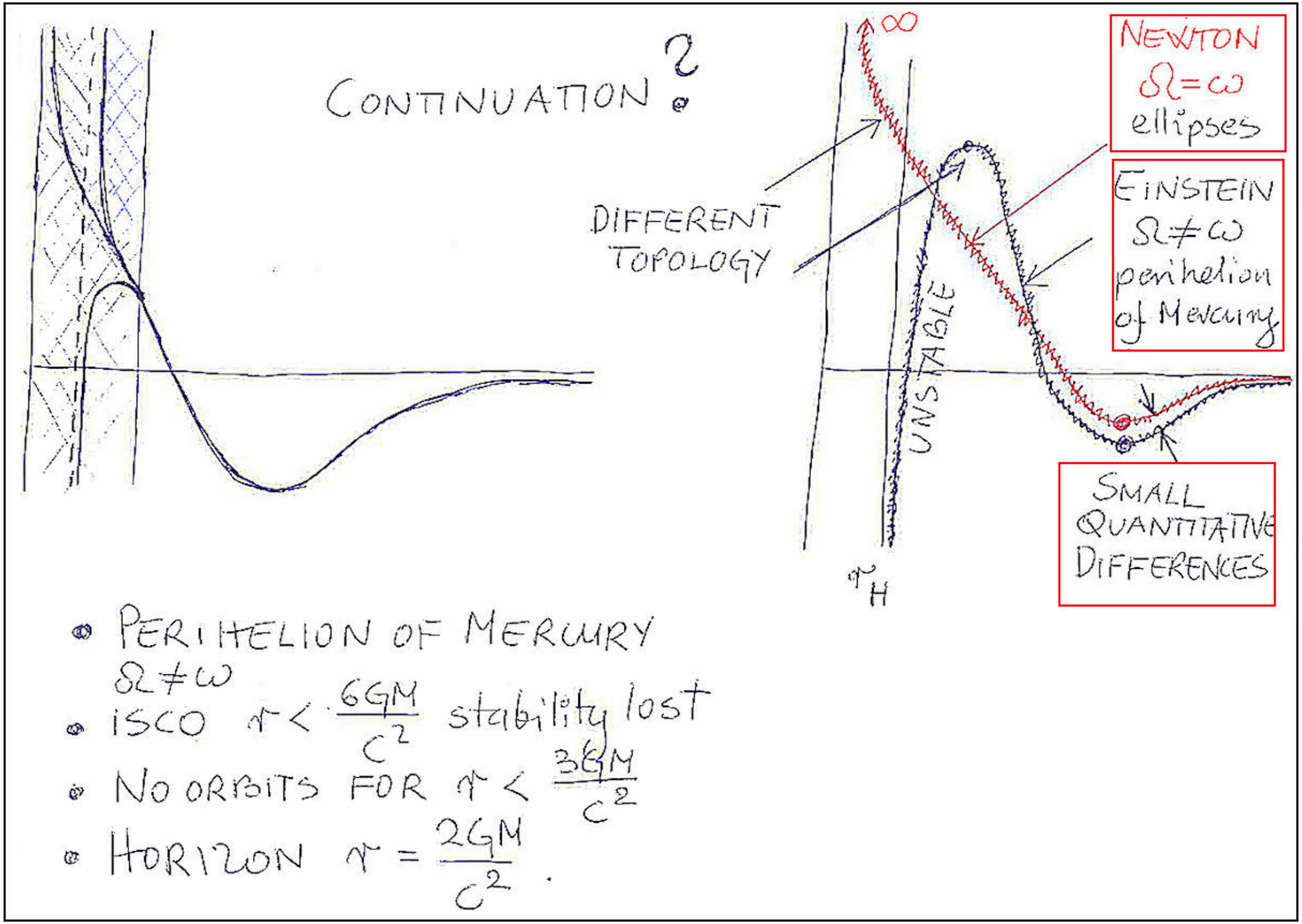
$$\left(\frac{\partial^2 \mathcal{U}}{\partial r^2}\right) = \omega^2 = \frac{GM}{r^3} \qquad \Omega = \omega$$

# LIMITS OF APPLICABILITY



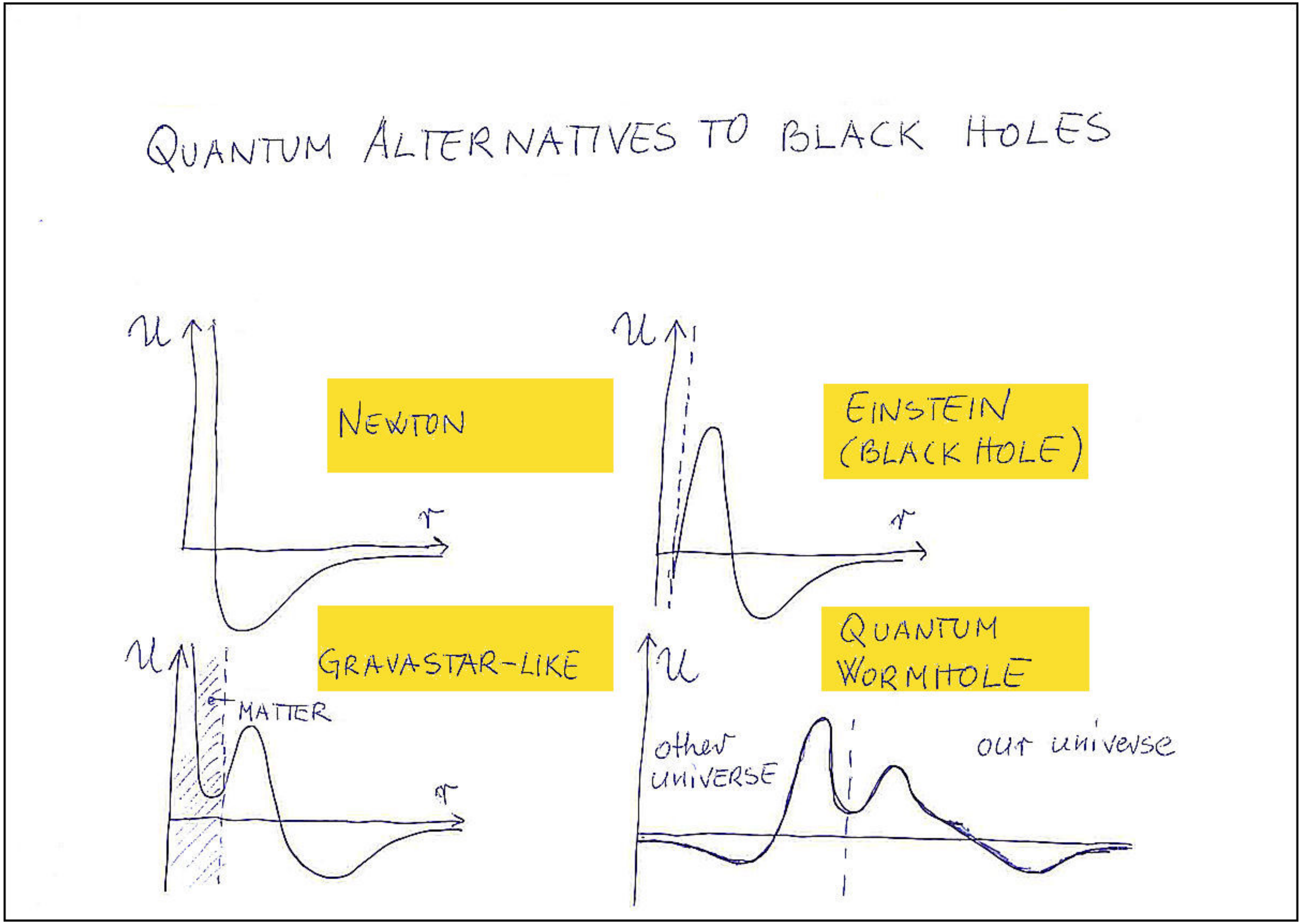
# Guess Einstein





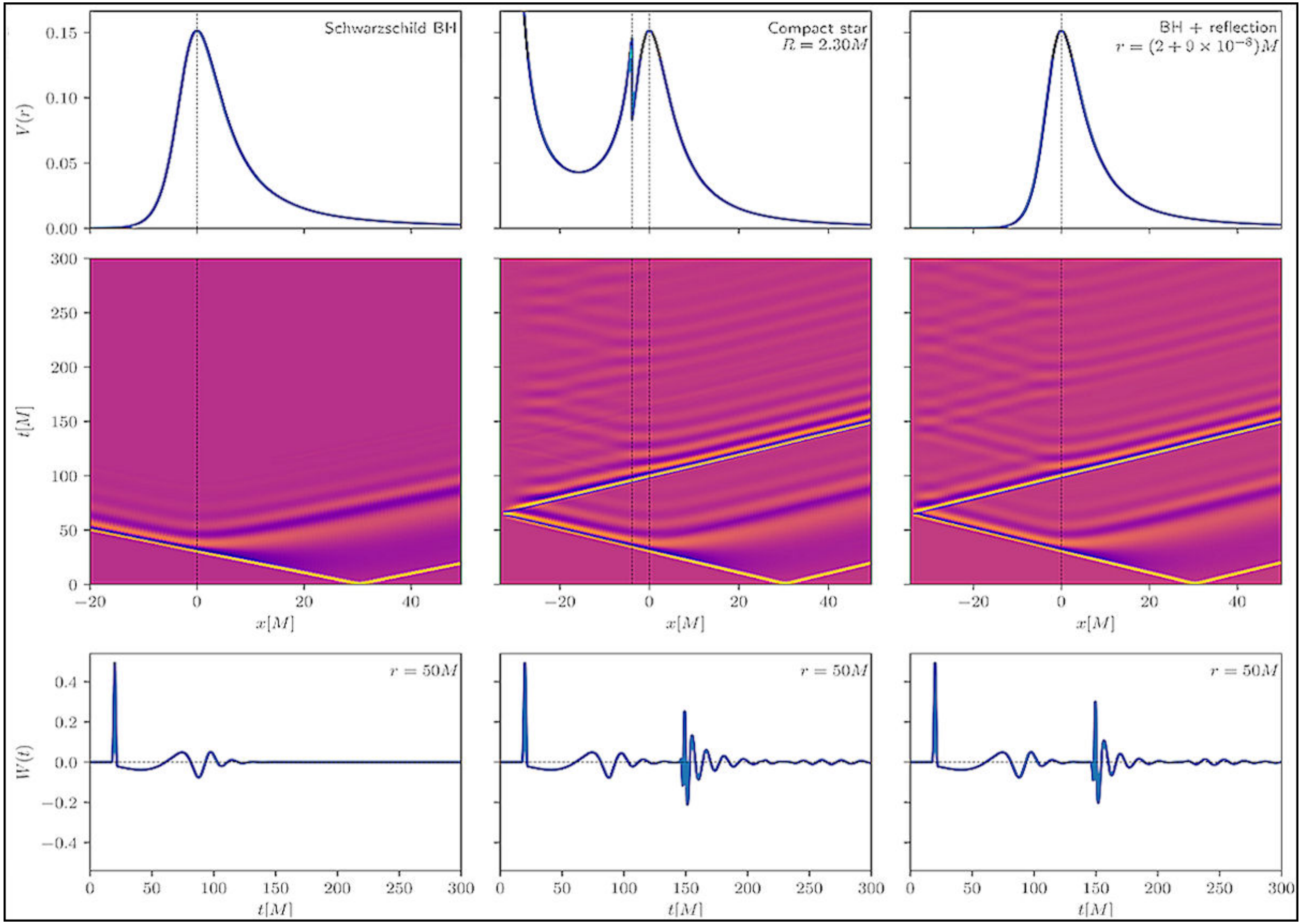
# Guess quantum gravity





# Gravitational waves

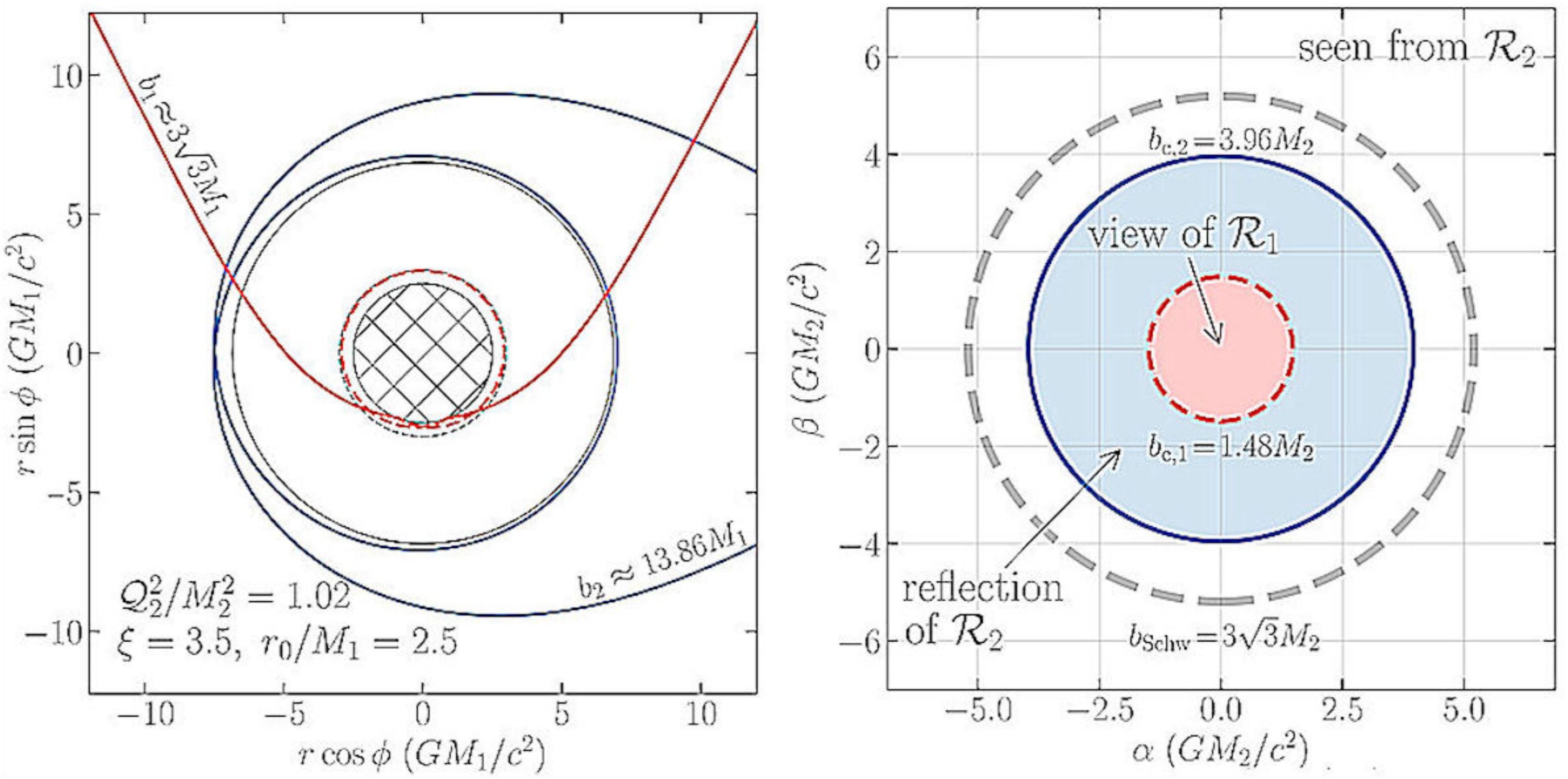





**J.Horak, K.Goluchova, M.A.: Ringdowns and echoes from ultracompact stars**

# Secondary rings in the EHT images

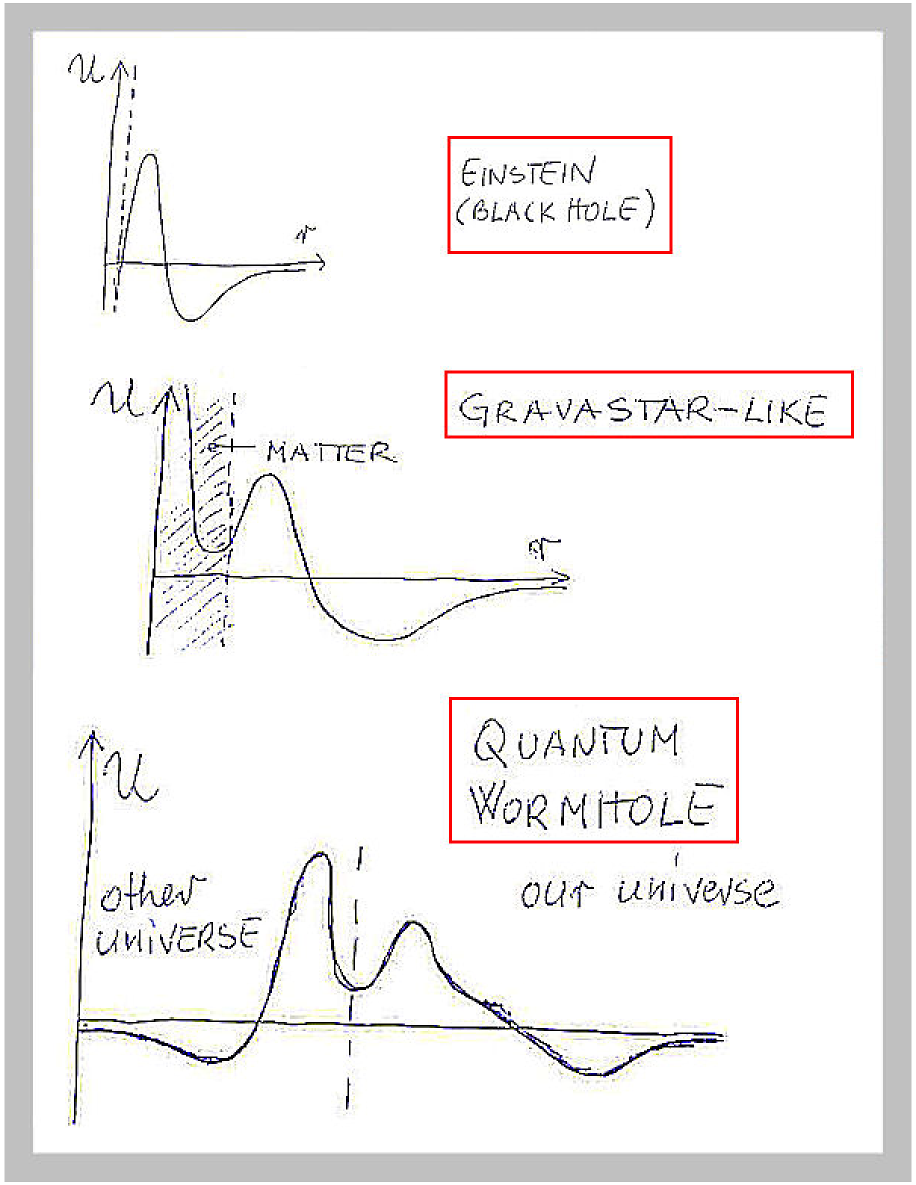


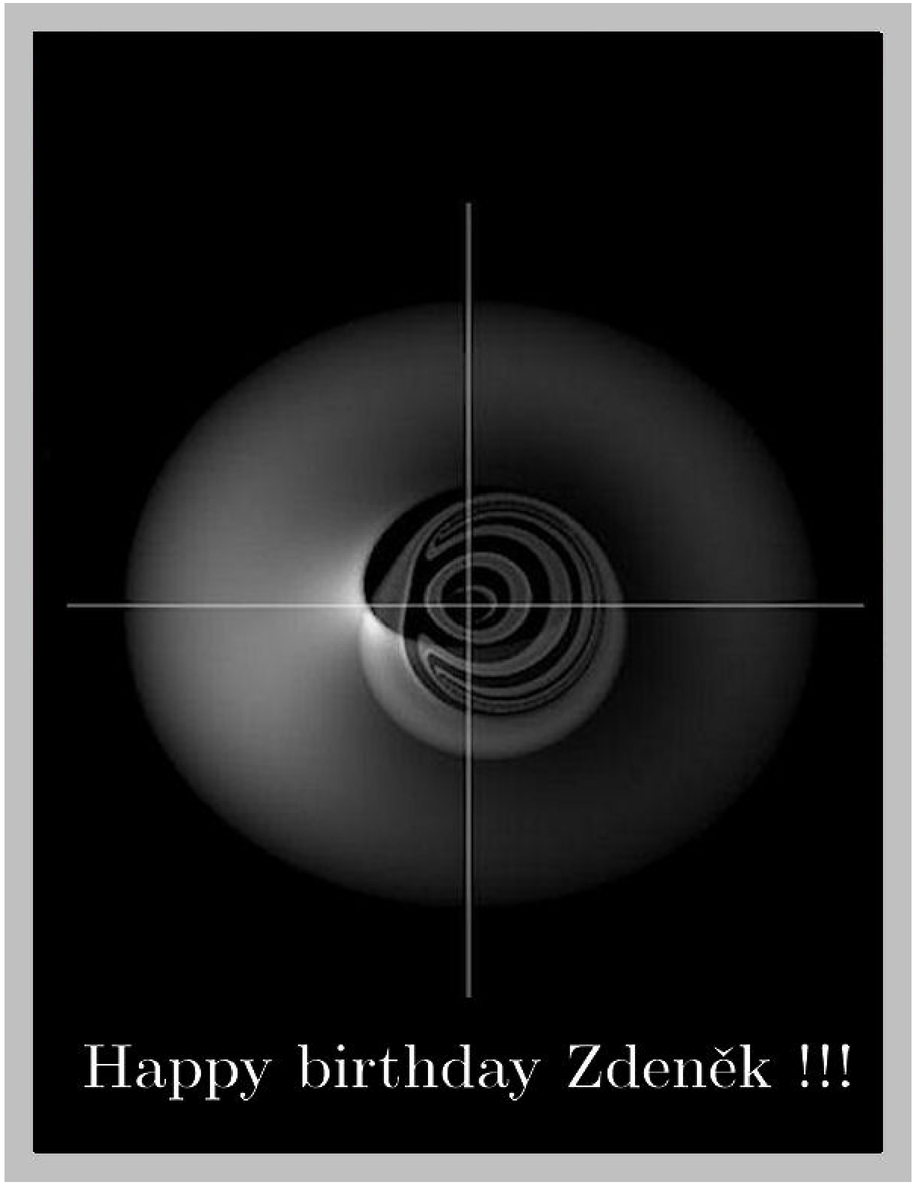



**M.Wielgus, J.Horak, F.Vincent, M.A.: Wormholes**

# Final conclusions





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