Title: Gravitational Physics Lecture

Speakers: Ruth Gregory

Collection: Gravitational Physics

Date: February 05, 2024 - 9:00 AM

URL: https://pirsa.org/24020025

Expt can access a huge range of scales.

Solar system : weak field , A.U. scale.

light bending, perihelion precession G.P.S

Cosmology : The FRW universe.

Standard cosmological Model.

Excellent agreement, but requires Dark Matter + Energy.

$\sim 28\%$ $\sim 70\%$

Late time acceleration (SN data)

$\longrightarrow \Lambda$

CMB - flat U / Temp fluctuations

Inflation - early rapid expansion.

Structure formation - confirms DM content

+ growth of perturbations.

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GR, Λ, DM, ptn theory.

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$\longrightarrow \Lambda \sim 10^{-122} M_p^4$

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Inflation requires scalar(s) with vacuum energy. Paradigm.

Requires a split of "classical" background + quantisation.

Late time acceleration (SN data)

$\rightarrow \Lambda \sim 10^{-122} M_P^4$

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$\rightarrow$ Hubble Tension

Direct measurement of H_0 differs from CMB.

Black Holes: Strong Gravity

Event Horizon Telescope - imaging

SMBH's Very Long Baseline Interferometry.

(Earth). Impressive, but "fuzzy" Will improve

LIGO: Black hole mergers - superb agreement

with GR, but again

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LIGO: Black hole mergers - superb agreement
with GR, but again generally low signal: noise.

Here, more templates need to be developed

Smaller scales? Lab tests.

Atom Interferometry: uses quantum superposition of different states, sensitive to "5^{th} forces".

s need to

ales? Lab tests.

ometry: uses quantum

different states, sensitive

Quantum Gravity? Can we access?

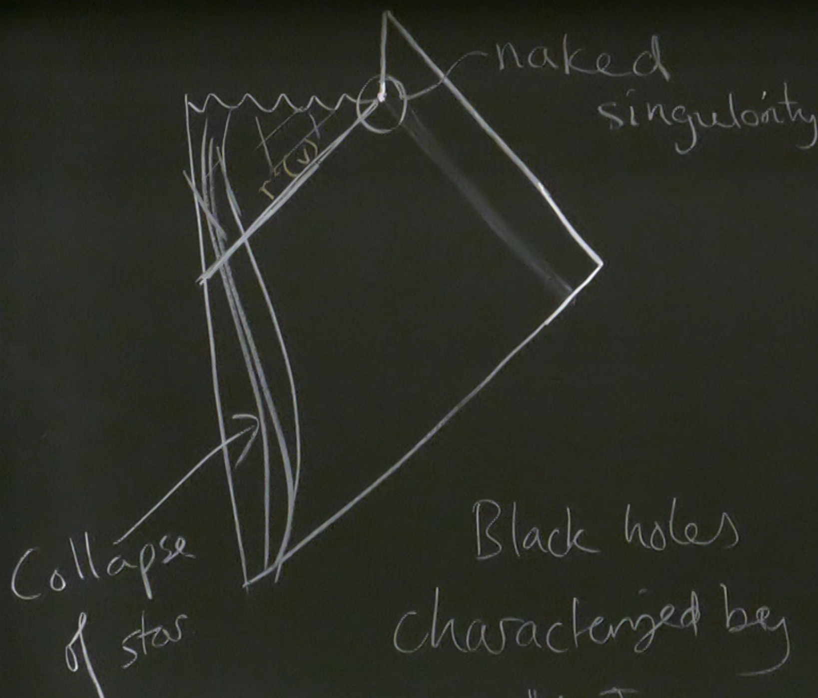
Black hole information paradox:

$T \propto 1/M$, so $\dot{M} \propto T^4 \times A \propto \frac{1}{M^4} \cdot M^2$

$$\Rightarrow M \propto \frac{1}{(M_0^3 - ct)^{1/3}}$$

or $\tau \propto 1/M_0^3$

with GR, but again generally low signal : noise.



Black holes characterized by $M\ J\ Q$.

Other ideas:

Quantised horizon area?

Only certain λ can be absorbed

$\longrightarrow$ Echoes.

Event horizon as defined i

not local - teleological - se

nerally low signal : noise.

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Quantised horizon area?

Only certain λ can be absorbed

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Event horizon as defined is

not local - teleological - seen at ∞.

Analog Systems

$/M_0^3$

Analog Systems

① Scalar field

$\phi \in \mathbb{R}$

$$S = \int d^4x \sqrt{-g}\left(\frac{R}{16\pi G} - \frac{1}{2}\partial_\mu \phi \partial^\mu \phi\right)$$

$\delta g^{\mu\nu}$: $G_{\mu\nu} = 8\pi G T_{\mu\nu}$,

KG eq$^{\underline{n}}$

$\delta\phi$: $\frac{1}{\sqrt{-g}}\partial_\mu\left(\sqrt{-g}\, g^{\mu\nu}\partial_\nu \phi\right) = 0$

Analog Systems

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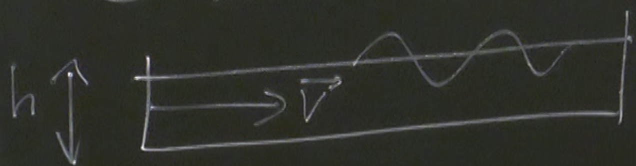
② Analogy for surface wave



$$\nabla \times v = 0$$

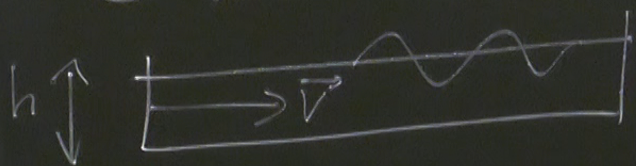
$$v = \nabla \Phi \quad \leftarrow \text{velocity potential.}$$

$$\partial_t \Phi + \frac{1}{2} v^2 + g h = \text{const.}$$

$$\partial_t h + \nabla \cdot (h v) = 0$$

$$\nabla = \begin{pmatrix} \partial_x \\ \partial_y \end{pmatrix}$$

(2) Analogy for surface wave



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$$\Phi \to \Phi_0 + \phi$$

$$h \to h_0 + \delta h$$

$$(\partial_t + v_0 \cdot \nabla)\phi + g h = 0$$

$$(\partial_t + \nabla \cdot v_0)\delta h + \nabla \cdot (h_0 \nabla \phi) = 0$$

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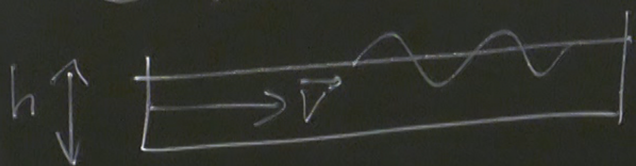

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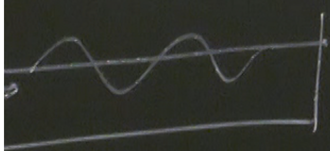


$\nabla \times v = 0$

$v = \nabla \Phi$ ← velocity potential.

$^2 + gh = \text{const.}$

$(hv) = 0$

$\Phi \to \Phi_0 + \phi$

$h \to h_0 + \delta h$

$(\partial_t + v_0 \cdot \nabla)\phi + g\delta h = 0$

$(\partial_t + \nabla \cdot v_0)\delta h + \nabla \cdot (h_0 \nabla \phi) = 0$

$$\boxed{(\partial_t + \nabla \cdot v_0)(\partial_t + v_0 \cdot \nabla)\phi - g\nabla \cdot (h_0 \nabla \phi) = 0}$$

$$\boxed{(\partial_t + \nabla\cdot v_0)(\partial_t + v_0\cdot\nabla)\phi - g\nabla\cdot(h_0\nabla\phi) = 0}$$

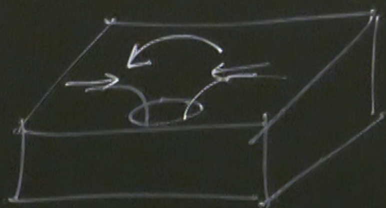
$$g_{\mu\nu} = \begin{pmatrix} -c^2+v_0^2 & -v_{0i} \\ -v_{0j} & \delta_{ij} \end{pmatrix}, \quad c=\sqrt{gh_0}, \quad h_0 \simeq \text{const.}$$

-ity

-ntial.

$= 0)$

③ Draining vortex



$h_0 =$ const.

drain

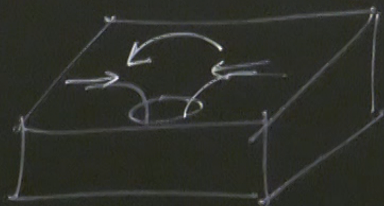
$\nabla \cdot v_0 = 0 \longrightarrow v_r = -D/r$

circulation

$\nabla \times v_0 = 0 \longrightarrow v_\varphi = C/r$

$v_0 = v_r \hat{e}_r + v_\varphi \hat{e}_\varphi$

③ Draining vortex



$h_0 = \text{const.}$

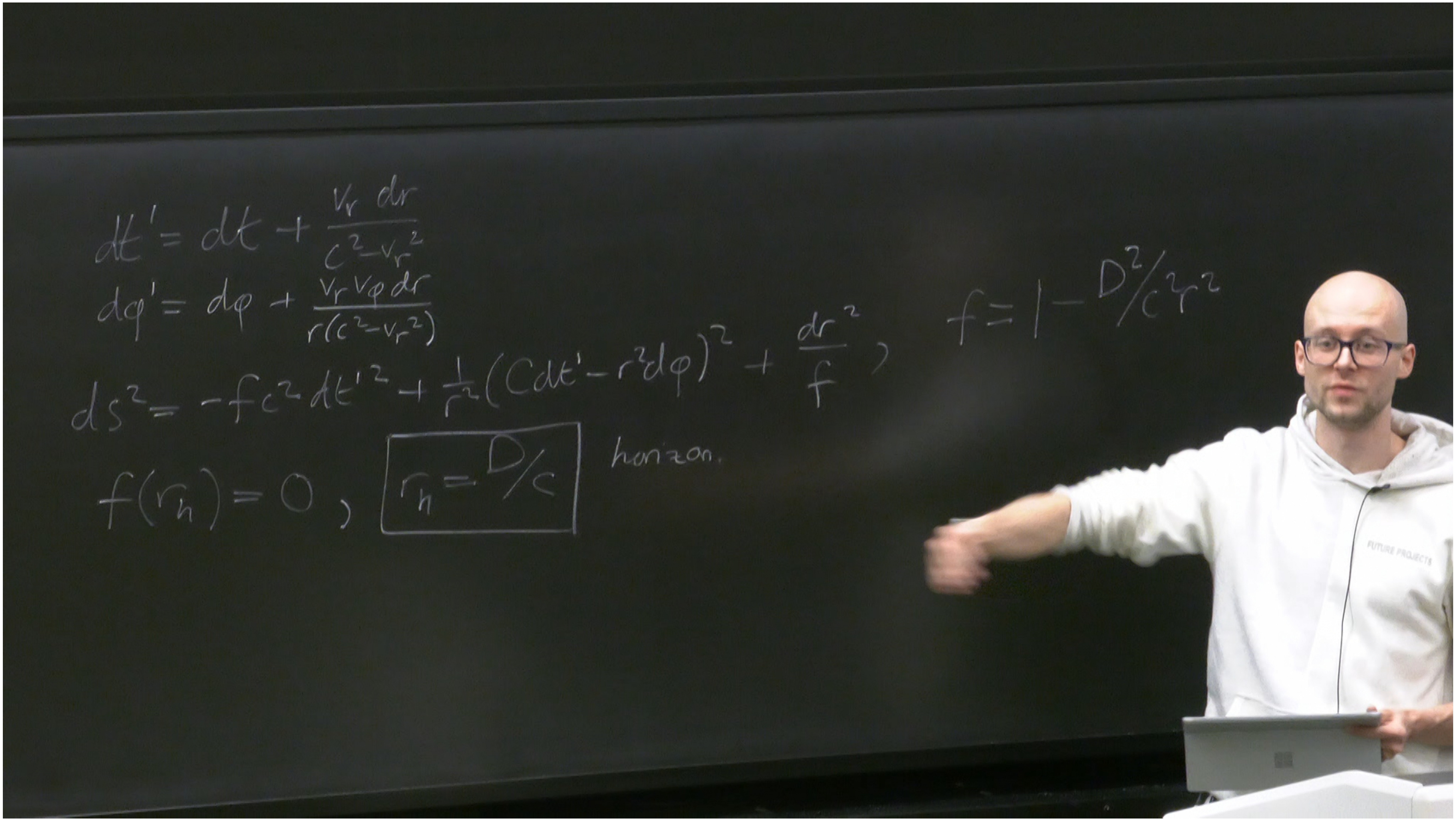
$\nabla \cdot v_0 = 0 \longrightarrow v_r = -D/r$ ← drain

$\nabla \times v_0 = 0 \longrightarrow v_\varphi = C/r$ ← circulation

$v_0 = v_r \hat{e}_r + v_\varphi \hat{e}_\varphi$ $\quad (h_0, v_0) \leftarrow$ background.

$$ds^2 = -c^2 dt^2 + \left(r\,d\varphi - \frac{C}{r}dt\right)^2 + \left(dr + \frac{D}{r}dt\right)^2 + r^2 d\varphi^2$$

(r, φ, t) $\quad$ PG


$dt' = dt + \frac{v_r\, dr}{c^2 - v_r^2}$
$d\varphi' = d\varphi + \frac{v_r v_\varphi\, dr}{r(c^2 - v_r^2)}$
$ds^2 = -f c^2 dt'^2 + \frac{1}{r^2}(C dt' - r^2 d\varphi)^2 + \frac{dr^2}{f}$,
$f = 1 - D^2/c^2 r^2$
$f(r_h) = 0$, $\boxed{r_h = D/c}$
horizon.
FUTURE PROJECTS

$$d\varphi' = d\varphi + \frac{v_r v_\varphi \, dr}{r(c^2 - v_r^2)}$$

$$ds^2 = -f c^2 dt'^2 + \frac{1}{r^2}\left(C\,dt' - r^2 d\varphi\right)^2 + \frac{dr^2}{f}, \quad f = 1 - D^2/c^2 r^2$$

$$f(r_h) = 0, \quad \boxed{r_h = D/c}$$ horizon.

$$\xi^\mu \partial_\mu = \partial_{t'}, \quad g_{\mu\nu}\xi^\mu \xi^\nu = -f + C^2/r^2 = -c^2 + \frac{C^2 + D^2}{r^2}$$

$$\boxed{r_e = \frac{\sqrt{C^2 + D^2}}{c}}$$

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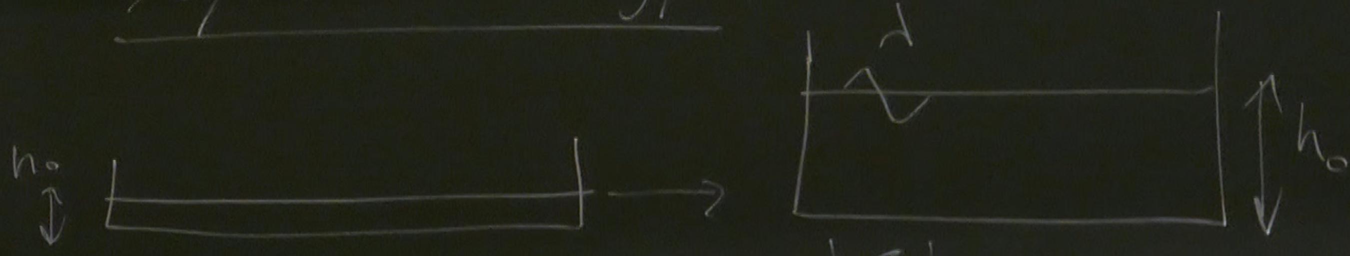
ergosphere $\longleftarrow$ $\boxed{r_e = \frac{\sqrt{C^2 + D^2}}{c}}$

$$(\partial_t + \nabla\cdot v_0)\delta h + \nabla\cdot(\ldots) = 0$$

Beyond the analogy

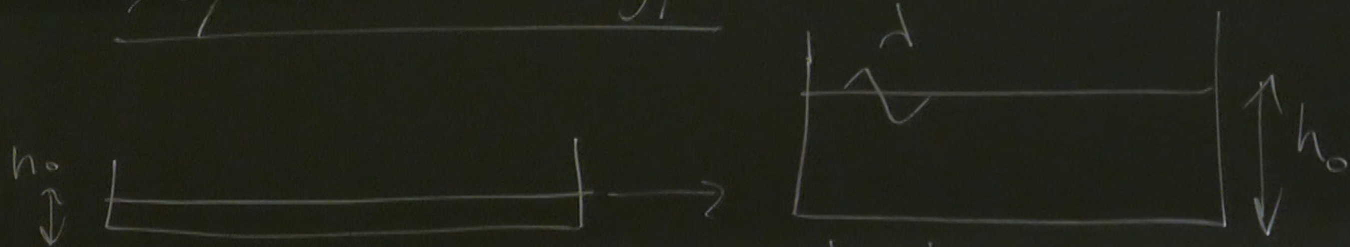


$$\lambda \lesssim h_0$$

$$(\partial_t + v_0\cdot\nabla)\phi + g\,\delta h - \frac{\sigma}{\rho}\nabla^2\delta h = 0$$

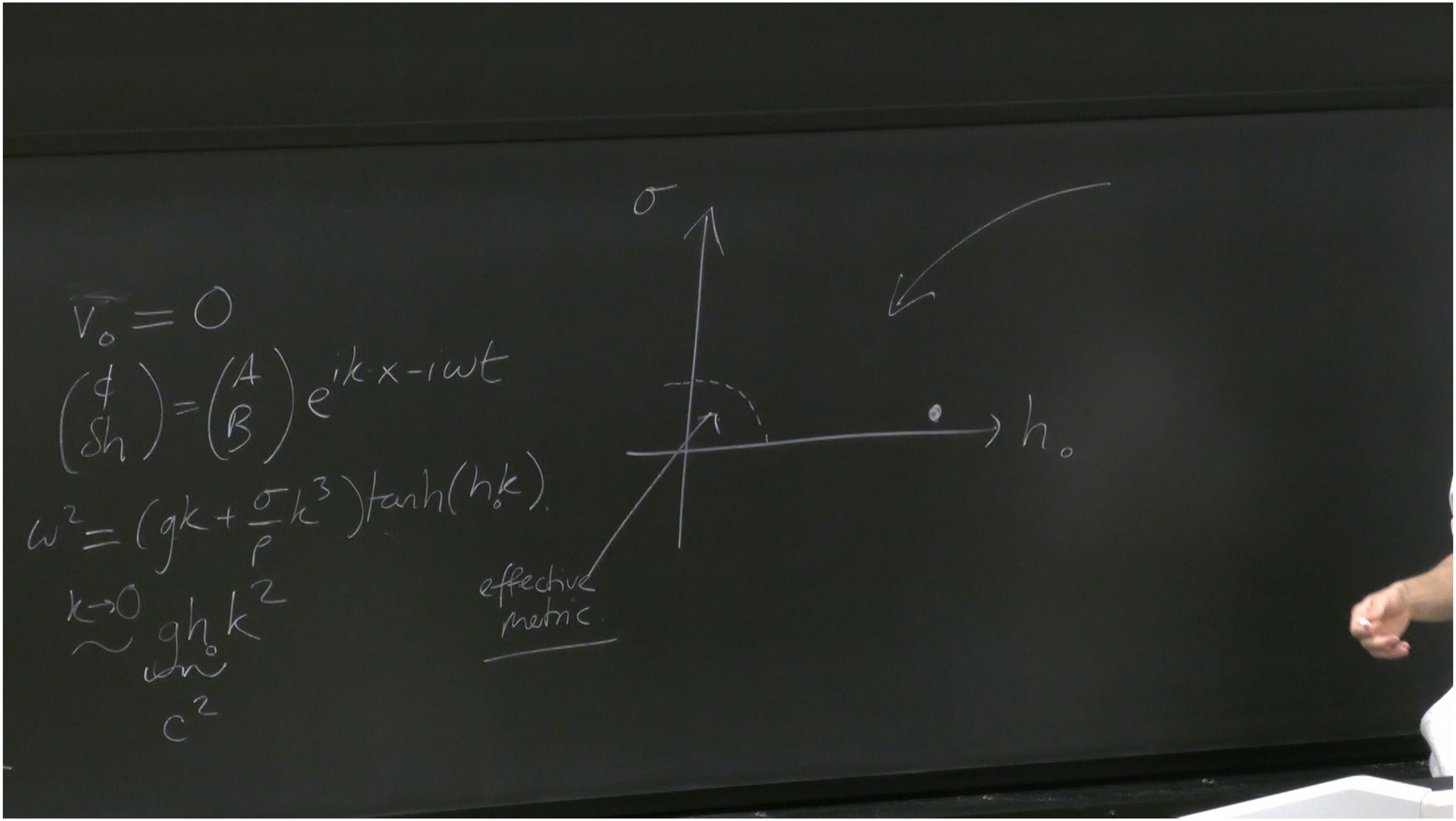
$$(\partial_t + \nabla\cdot v_0)\delta h + i\,\nabla\cdot\tanh(-i h_0\nabla)\phi = 0$$

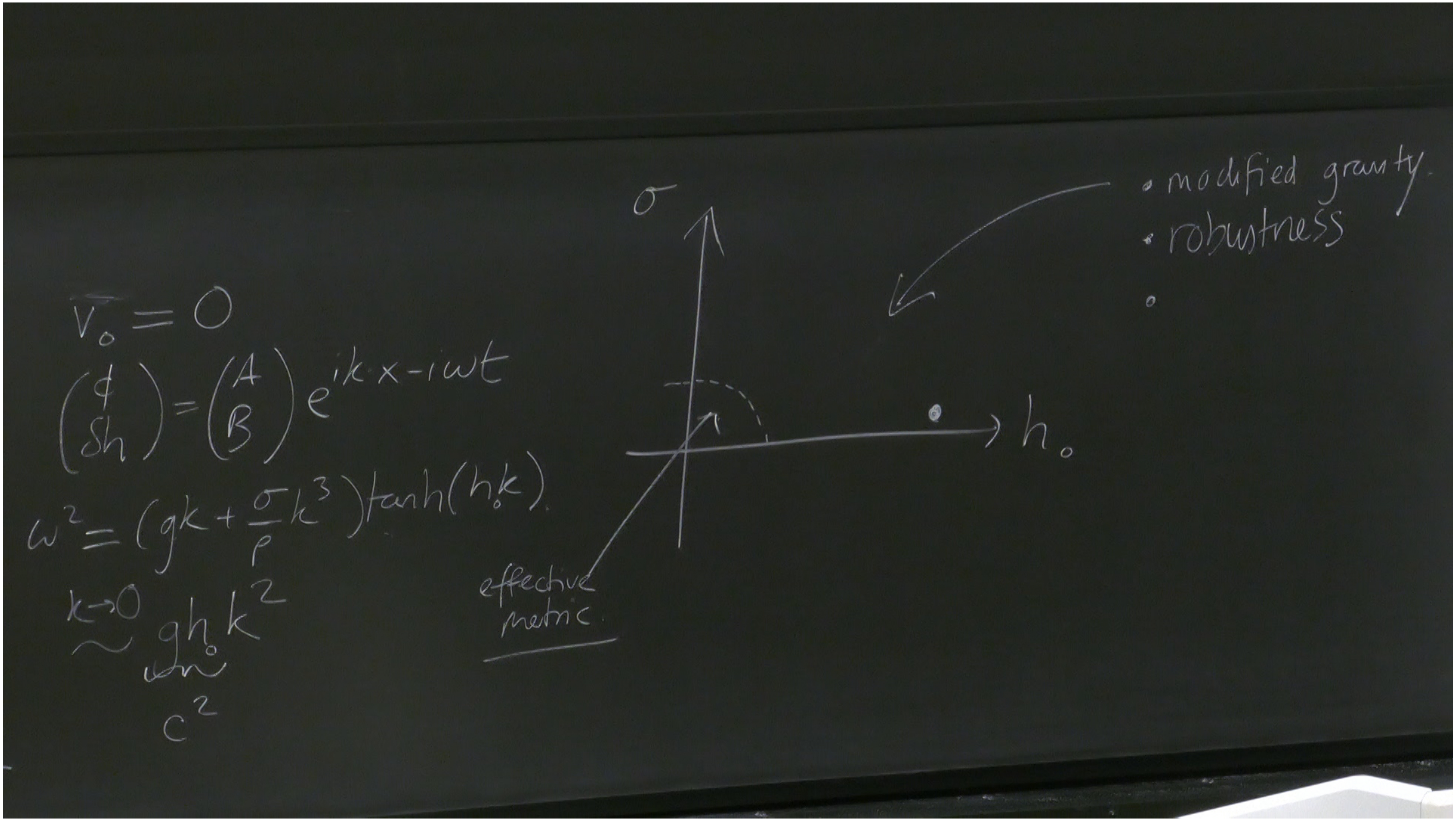
Beyond the analogy



$\lambda \lesssim h_0$

$$\left.\begin{aligned}&(\partial_t + v_0\cdot\nabla)\phi + g\,\delta h - \frac{\sigma}{\rho}\nabla^2\delta h = 0\\&(\partial_t + \nabla\cdot v_0)\,\delta h + i\,\nabla\cdot\tanh(-i h_0\nabla)\,\phi = 0\end{aligned}\right\}\ \text{Breaks Lorentz Invariance.}$$


$\bar{V}_0 = 0$
$\begin{pmatrix}\phi \\ \delta h\end{pmatrix} = \begin{pmatrix}A \\ B\end{pmatrix} e^{ik\cdot x - i\omega t}$
$\omega^2 = \left(gk + \frac{\sigma}{\rho}k^3\right)\tanh(h_0 k)$
$\underset{k\to 0}{\sim} \underbrace{g h_0}_{c^2} k^2$
σ
h_0
effective metric


• modified gravity
• robustness
•
σ
h_0
effective metric
$\vec{v}_0 = 0$
$\begin{pmatrix} \phi \\ \delta h \end{pmatrix} = \begin{pmatrix} A \\ B \end{pmatrix} e^{ik\cdot x - i\omega t}$
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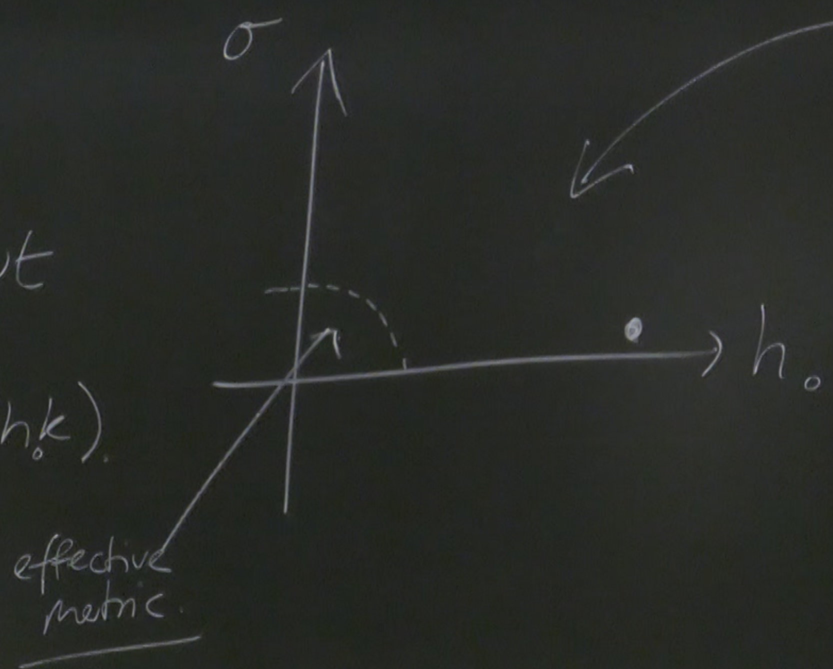
$$\xrightarrow{k\to 0} \sim \underbrace{g h_0}_{c^2} k^2$$



- modified gravity.
- robustness
- nonlinearities
- quantum D.o.F.