problems of horizon in effective gravity

G. Volovik

Helsinki U. Technology

Landau Institute

Russian Academy of Sciences
L.D Landau
Institute for Theoretical Physics

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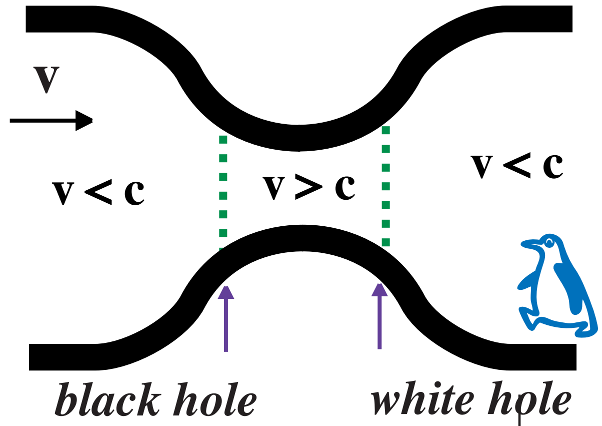

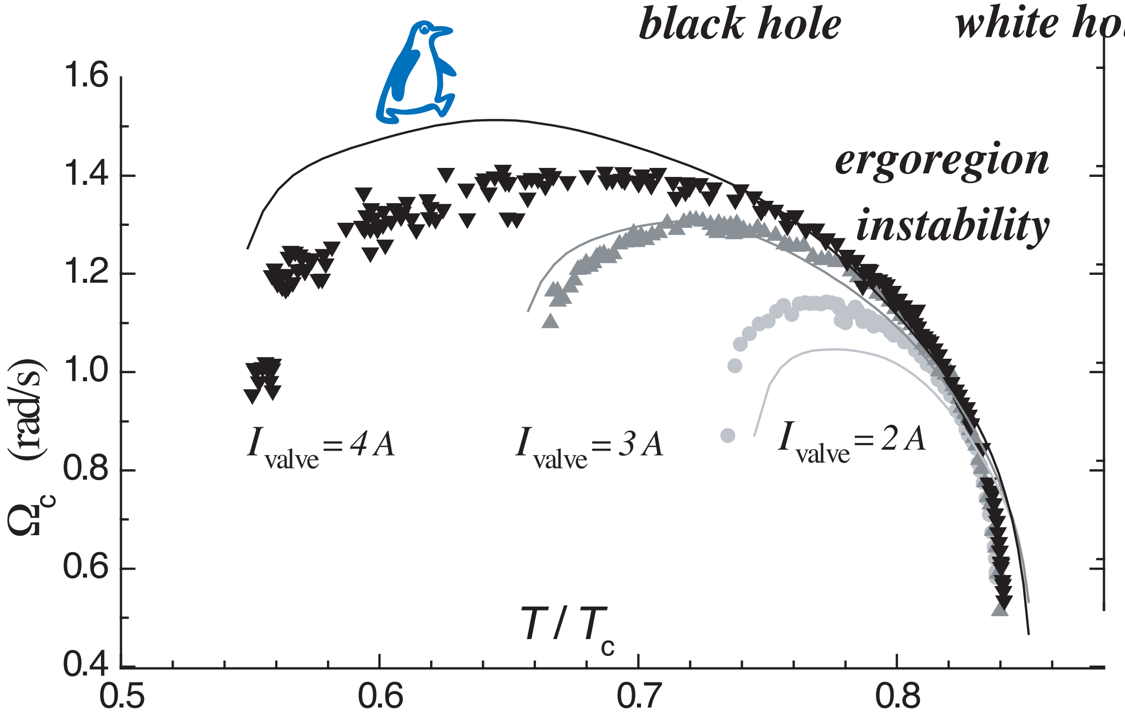

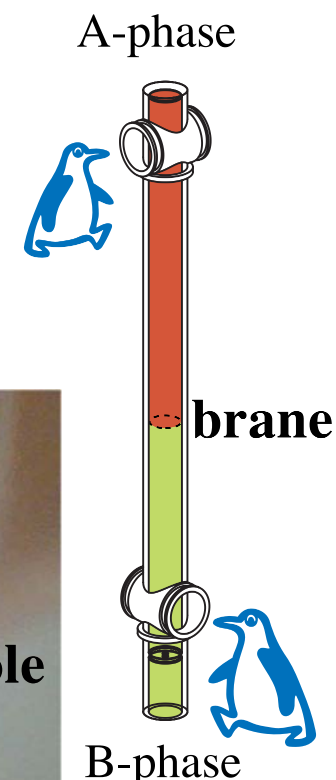

problems of horizon in effective gravity

Russian Academy of Sciences
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Physics

* sources of effective gravity in condensed matter

* black and white hole horizons

* Hawking radiation as quantum tunneling

* analog of Zeldovich-Starobinsky radiation from rotating BH

* vacuum instability in the presence of horizons & ergoregions

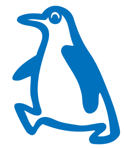
* from condensed matter to quantum gravity:
  quantum vacuum as self-sustained Lorentz invariant medium

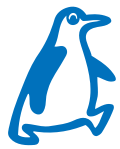
* possible instability of astronomical black holes

sources of effective gravity in condensed matter

*** Fermi point gravity**

*** acoustic gravity**





*** ripplon 2+1 gravity**

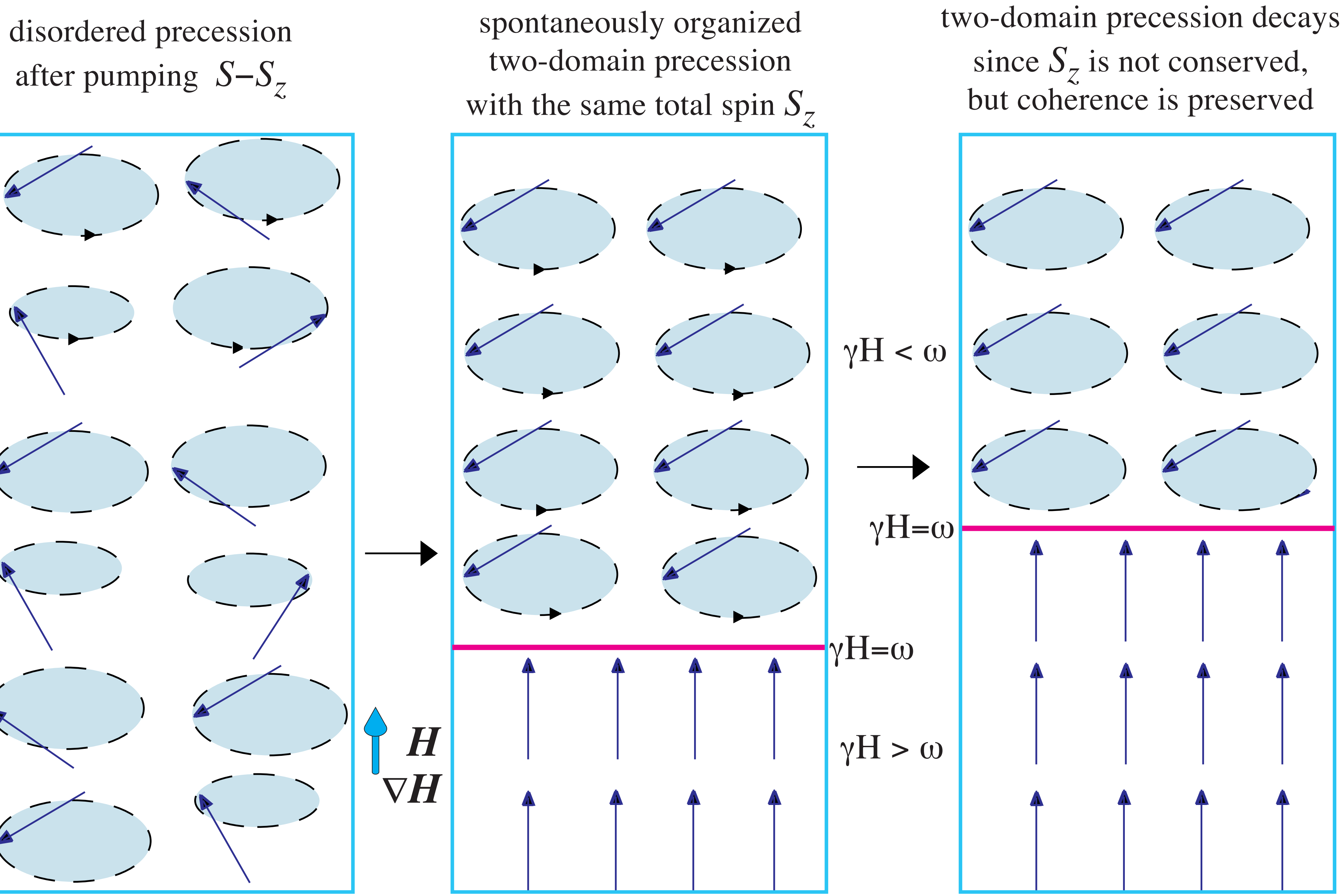
*** magnon BEC gravity** *(application of Cornell idea to magnon BEC)*

...

*** optical space-times**
moving dielectric, optical solitons, slow light ...

*** elasticity theory of dislocations and disclinations**
4D *world crystal*

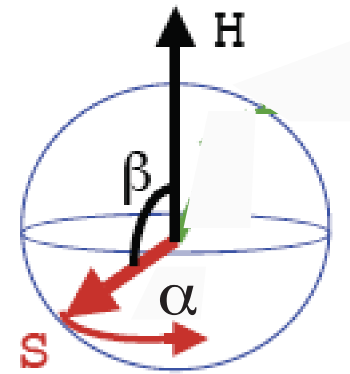
Spontaneous phase-coherent precession



Ginzburg-Landau energy for magnon BEC

$$\Psi = |\Psi|\, e^{i\alpha(t)}$$

phase of precession
≡ condensate phase



$$n = |\Psi|^2 = \frac{S - S_z}{\hbar}$$

deficit of
spin projection
along field
≡ magnon number

$$\alpha(t) = \omega t + \alpha_0$$

$$F_{GL} = \frac{|\nabla\Psi|^2}{2m} + (\omega_L(\mathbf{r}) - \omega)\, |\Psi|^2 + F_D\, (|\Psi|^2)$$

- $2m$: magnon mass
- $\omega_L(\mathbf{r})$: local Larmor frequency ≡ external potential
- ω: frequency of coherent precession ≡ chemical potential
- F_D: spin-orbit energy ≡ interaction between magnons

$$\dot{\alpha} = \omega$$

$$\dot{\alpha} = \mu$$

$$F_{GL} = \frac{|\nabla\Psi|^2}{2m} + (U(\mathbf{r}) - \mu)\, |\Psi|^2 + F\, (|\Psi|^2)$$

spontaneous coherent precession
=
magnon BEC

Sonic metric: effective metric in Landau two-fluid hydrodynamics

Doppler shifted phonon spectrum in moving superfluid and BEC

review:
Barcelo, Liberati & Visser, ***Analogue Gravity***
Living Rev. Rel. **8** (2005) 12

$$E = cp + \mathbf{p} \cdot \mathbf{v}_s$$

c speed of sound

$\mathbf{v}_s$ superfluid velocity

move $\mathbf{p}\cdot\mathbf{v}_s$ *to the left*

$$E - \mathbf{p} \cdot \mathbf{v}_s = cp$$

take square

$$(E - \mathbf{p} \cdot \mathbf{v}_s)^2 - c^2 p^2 = 0 \quad \longrightarrow \quad g^{\mu\nu} p_\mu p_\nu = 0$$

$$p_\nu = (-E, \ \mathbf{p})$$

$$g^{00} = -1 \qquad g^{0i} = -v_s^{\,i} \qquad g^{ij} = c^2 \delta^{ij} - v_s^{\,i} v_s^{\,j}$$

effective metric

inverse metric $g_{\mu\nu}$ determines effective spacetime
in which phonons move along geodesic curves

$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu \quad \longrightarrow \quad ds^2 = -c^2 dt^2 + (d\mathbf{r} - \mathbf{v}_s dt)^2$$

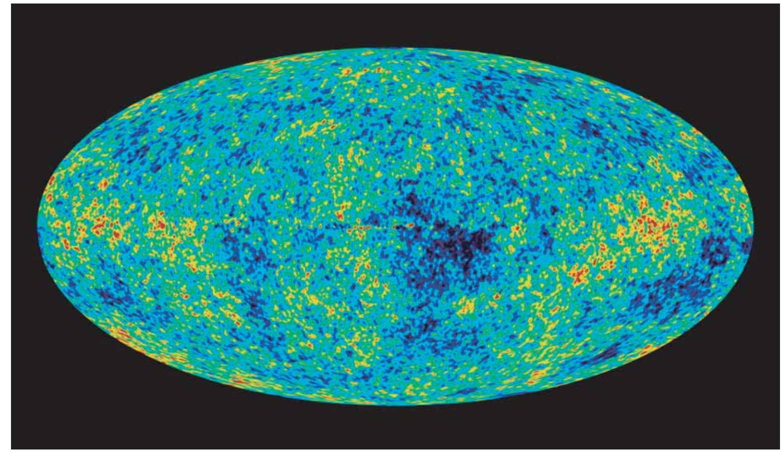
reference frame for phonon is dragged
by moving liquid

geometry is emergent

Superfluid 4He and BEC

acoustic gravity

Universe



general relativity

metric theories of gravity

geometry of effective space time for quasiparticles (phonons) — $g_{\mu\nu}$ — geometry of space time for matter

geodesics for phonons — $ds^2 = g_{\mu\nu} dx^\mu dx^\nu = 0$ — geodesics for photons

Landau two-fluid equations

$$\dot{\rho} + \nabla \cdot (\rho \mathbf{v}_s + \mathbf{P}^{\rm Matter}) = 0$$

$$\dot{\mathbf{v}}_s + \nabla(\mu + \mathbf{v}_s^2/2) = 0$$

equations for superfluid component

dynamic equations for metric field $g_{\mu\upsilon}$

Einstein equations of GR

$$\frac{1}{8\pi G}\left(R_{\mu\nu} - g_{\mu\nu}R/2\right) = T^{\rm Matter}_{\mu\nu}$$

equation for normal component

$$T^{\mu\nu}_{;\nu\,\rm Matter} = 0$$

equation for matter

1/2 of GR

message from: **cond-mat** to: quantum **gravity**

is gravity fundamental ?

it may emerge as classical output of underlying quantum system

as hydrodynamics ?

underlying microscopic quantum system at high energy

↓

emergent low-energy effective theory

superfluid helium → **classical 2-fluid hydrodynamics**

quantum vacuum → **classical general relativity**

$$\dot{\rho} + \nabla\cdot\left(\rho \mathbf{v}_s + \mathbf{P}^{\mathrm{Matter}}\right) = 0$$

$$\dot{\mathbf{v}}_s + \nabla\left(\mu + \mathbf{v}_s^2/2\right) = 0$$

$$\nabla_\nu T^{\mu\nu}_{\mathrm{Matter}} = 0$$

$$\frac{1}{8\pi G}\left(R_{\mu\nu} - g_{\mu\nu}R/2\right) - \Lambda g_{\mu\nu} = T^{\mathrm{Matter}}_{\mu\nu}$$

Schwarzschild-Painleve-Gulstrand acoustics

Superfluid 4He & BEC | *Gravity*

speed of sound — c — speed of light

phonon spectrum

$$g^{\mu\nu}p_\mu p_\nu = 0$$

$g^{\mu\nu}$ — $g_{\mu\nu}$

geometry

$$ds^2 = g_{\mu\nu}dx^\mu dx^\nu$$

$$ds^2 = -\,dt^2\,c^2 + (d\mathbf{r}-\mathbf{v}dt)^2$$

Acoustic metric for phonons propagating in radial flow $v(r)$

$$ds^2 = -\,dt^2\,(c^2-v^2) + 2\,v\,dr\,dt + dr^2 + r^2 d\Omega^2$$

g_{00} g_{0r}

Painleve-Gulstrand metric outside gravitating body of mass M

$$ds^2 = -\,dt^2\,(c^2-v^2) + 2\,v\,dr\,dt + dr^2 + r^2 d\Omega^2$$

g_{00} g_{0r}

after transformation

$$dt = dt - vdr/(c^2-v^2)$$

Schwarzschild metric is obtained:

$$ds^2 = -\,dt^2\,(c^2-v^2) + dr^2/(c^2-v^2) + r^2 d\Omega^2$$

g_{00} g_{rr}

$$v^2(r) = \frac{2GM}{r}$$

Kinetic energy of superflow = potential of gravitational field

Sonic Black Hole

Liquids, BEC & superfluids

acoustic horizon

(Unruh, 1981)

Gravity

black hole horizon

Painleve-Gulstrand metric

$$ds^2 = -\,dt^2\,(c^2-v^2) \;+\; 2\,v\,dr\,dt \;+ dr^2 +\; r^2 d\Omega^2$$

g_{00} ↑   ↑ g_{0r}

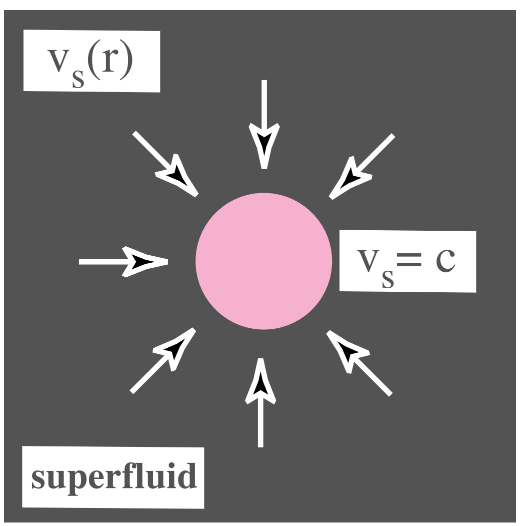
Schwarzschild metric

$$ds^2 = -\,dt^2\,(c^2-v^2) \;+\; dr^2/(c^2-v^2) \;+\; r^2 d\Omega^2$$

g_{00} ↑   ↑ g_{rr}

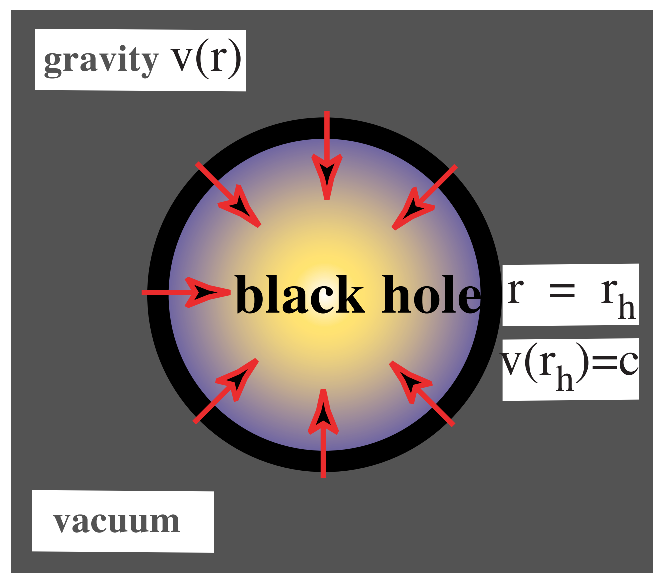
$$v^2(r) = c^2\,\frac{r_h}{r}$$

$$v^2(r) = \frac{2GM}{r} = c^2\,\frac{r_h}{r}$$



Information from interior region cannot be transferred by light or sound

horizon at $g_{00} = 0$
(or $v(r_h) = c$)



Landau critical velocity = black hole horizon

BEC, superfluid ^{4}He

Painleve-Gulstrand metric

$$ds^2 = -\,dt^2\,(c^2 - v^2) \;+\; 2\,v\,dr\,dt \;+\; dr^2 \;+\; r^2 d\Omega^2$$

g_{00} g_{0r}

Gravity

acoustic horizon

$$v^2(r) = c^2\,\frac{r_h}{r}$$

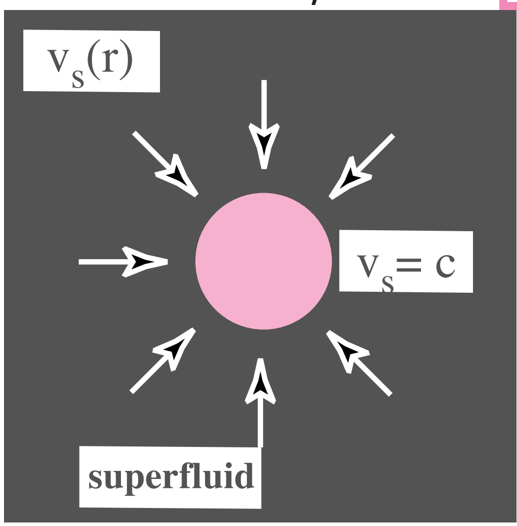
Schwarzschild metric

$$ds^2 = -\,dt^2\,(c^2 - v^2) \;+\; dr^2/(c^2 - v^2) \;+\; r^2 d\Omega^2$$

g_{00} g_{rr}

black hole horizon

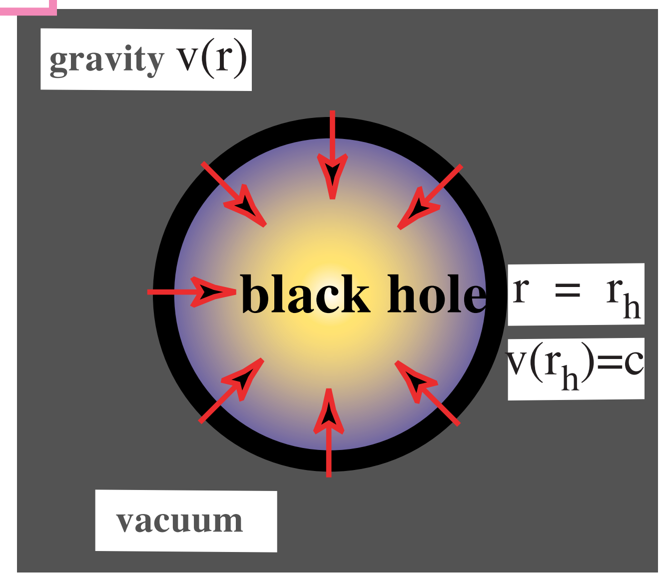
$$v^2(r) = \frac{2GM}{r} = c^2\,\frac{r_h}{r}$$



(Unruh, 1981)

horizon at $g_{00} = 0$
where flow velocity
(velocity of local frame in GR)
reaches Landau critical velocity

$$v(r_h) = v_{Landau} = c$$



Hawking radiation is phonon/photon creation
above Landau critical velocity

gravity emerging near Fermi point

Atiyah-Bott-Shapiro construction:

linear expansion of Hamiltonian near the nodes in terms of Dirac γ-matrices

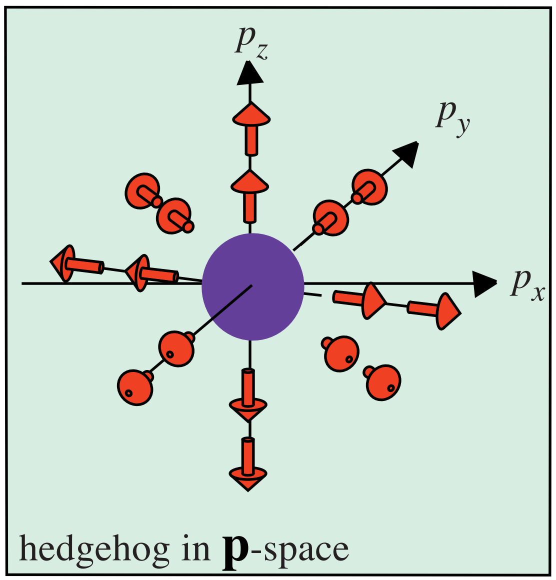
emergent relativity

linear expansion near Fermi point

$$H = e_i^k \, \Gamma^i \cdot (p_k - p_k^0)$$

e_i^k → emergent fierbein gravity

Γ^i → emergent γ– matrices



hedgehog in **p**-space

$$g^{\mu\nu}(p_\mu - eA_\mu - e\tau \cdot \mathbf{W}_\mu)(p_\nu - eA_\nu - e\tau \cdot \mathbf{W}_\nu) = 0$$

$g^{\mu\nu}$ → effective metric: emergent gravity

A_μ → effective electromagnetic field

$\mathbf{W}_\mu$ → effective $SU(2)$ gauge field

e → effective electric charge $e = +1$ or -1

τ → effective isotopic spin

all ingredients of Standard Model :
chiral fermions & gauge fields
emerge in low-energy corner
together with spin, Dirac Γ–matrices, gravity & physical laws:
Lorentz & gauge invariance, equivalence principle, etc

gravity & gauge fields are collective modes of vacua with Fermi point

crossover from hydrodynamics to Einstein general relativity

they represent two different limits of hydrodynamic type equations

equations for $g^{\mu\nu}$ depend on hierarchy of ultraviolet cut-off's:
Planck energy scale $E_{\rm Planck}$ vs Lorentz violating scale $E_{\rm Lorentz}$

$E_{\rm Planck} >> E_{\rm Lorentz}$

emergent hydrodynamics

$E_{\rm Planck} << E_{\rm Lorentz}$

emergent general relativity

^{3}He-A with Fermi point

$E_{\rm Lorentz} << E_{\rm Planck}$

$E_{\rm Lorentz} \sim 10^{-3} E_{\rm Planck}$

Universe

$E_{\rm Lorentz} >> E_{\rm Planck}$

$E_{\rm Lorentz} > 10^{9} E_{\rm Planck}$

Fermionic horizons:
horizon in flowing 3He film & in moving soliton

Quasiparticle energy spectrum in moving texture (Doppler shift)

$$(E - vp_z)^2 = c_x^2 (p_x - p_F)^2 + c_z^2(z) p_z^2 + c_y^2 p_y^2$$

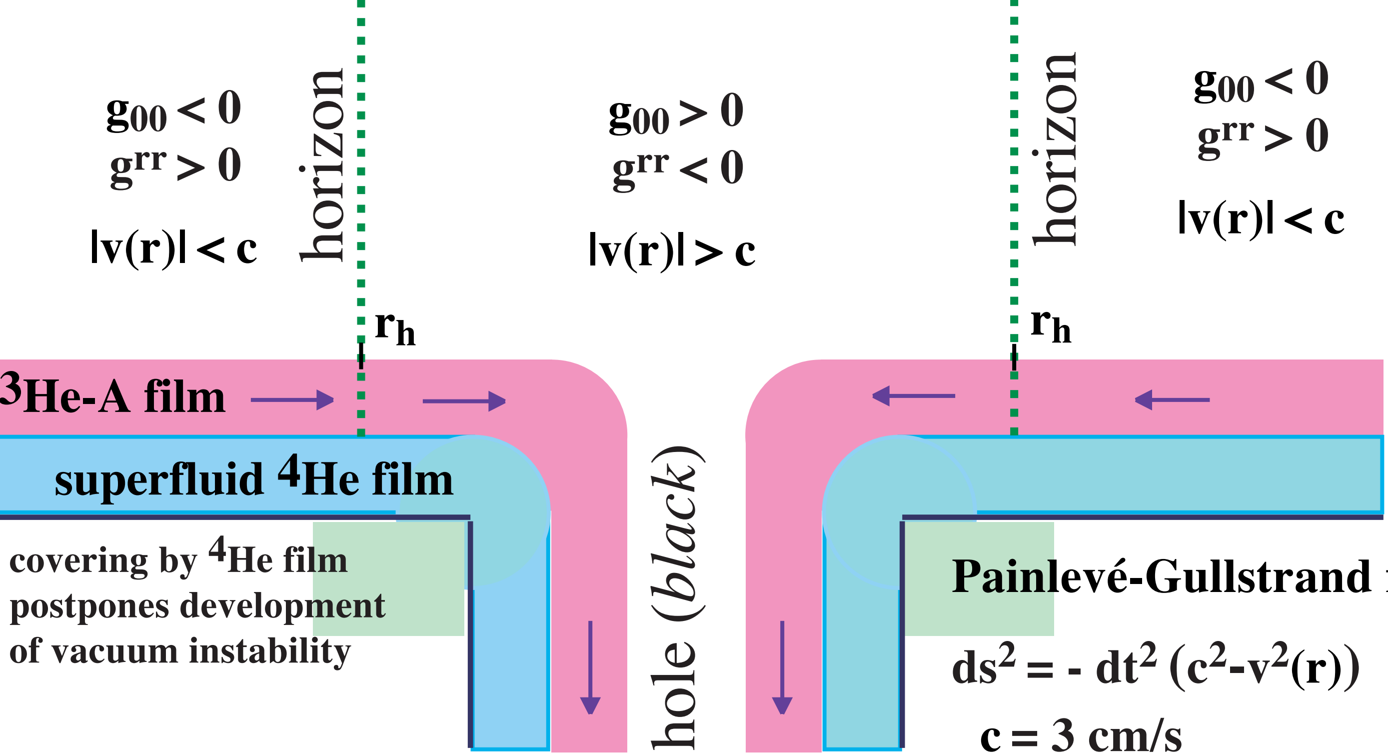
$$ds^2 = - dt^2 \left(1 - v^2/c_z^2(z)\right) - 2\left(v/c_z^2(z)\right) dz\,dt + c_x^{-2} dx^2 + c_y^{-2} dy^2 + c_z^{-2}(z) dz^2$$

Soliton: speed of light $c_z(z)$ **changes sign across the soliton**

Hawking temperature $T_H = (\hbar/2\pi)\,(dc_z/dz)_{hor}$

Jacobson-GV, PRD **58**, 064021 (1998)

black hole in ^{3}He-A film

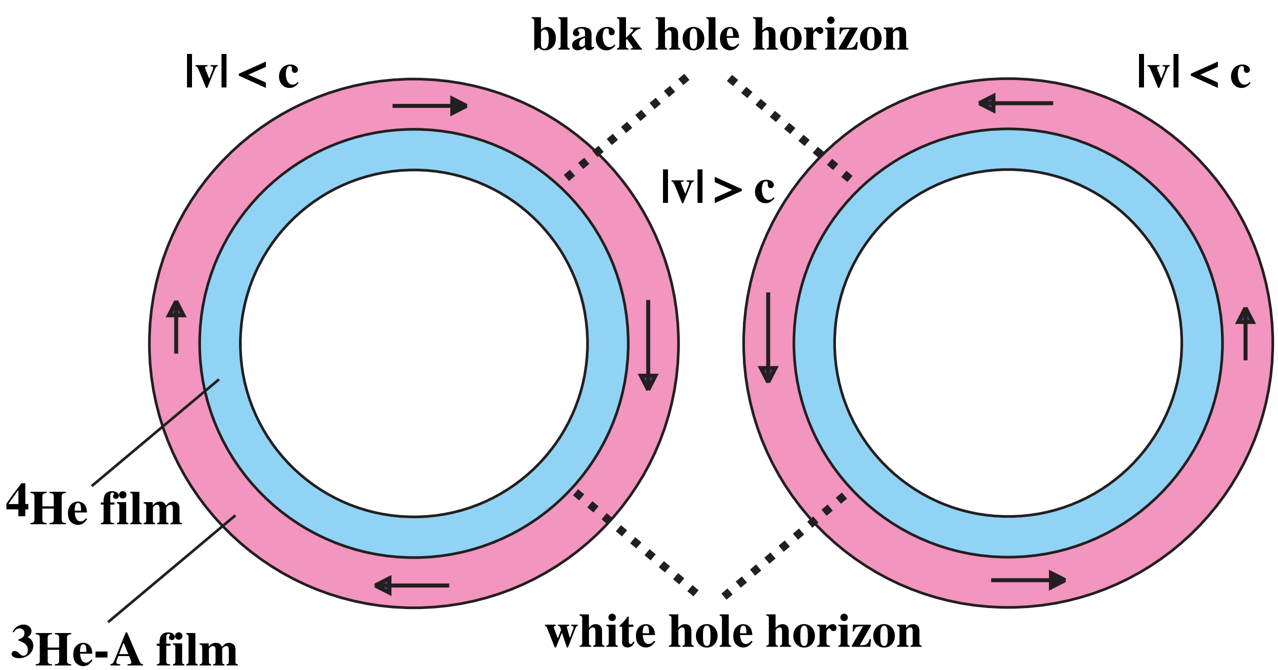


Painlevé-Gullstrand form of 2D black hole:

$$ds^2 = - dt^2 (c^2 - v^2(r)) + 2v(r)\, dr\, dt + dr^2 + r^2 d\phi^2$$

$c = 3$ cm/s

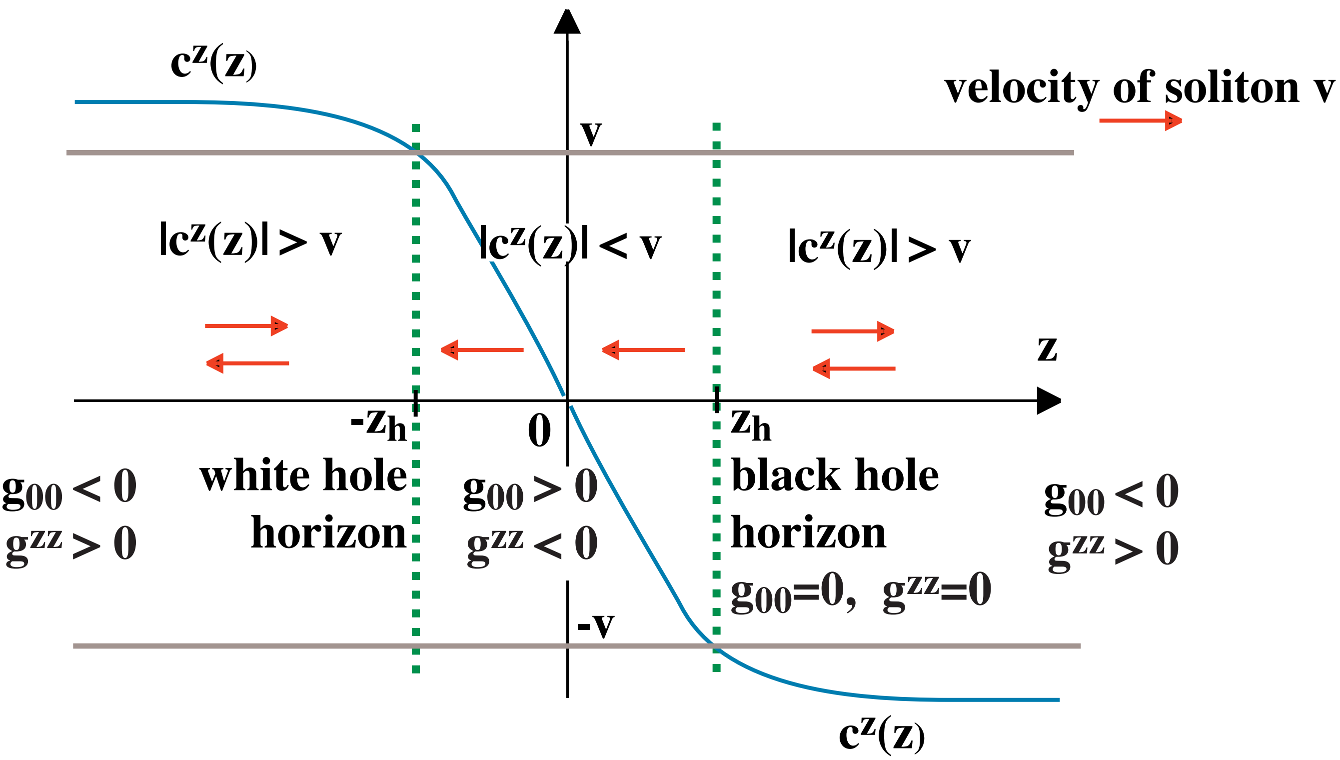
If ^{3}He-A film is moving to the hole $v(r) = b / r$ horizon is at $r_h = b / c$



Horizon in moving soliton

Jacobson-GV, PRD **58**, 064021 (1998)

speed of light $c_z(z)$ **changes sign across the soliton**



Hawking radiation leads to deceleration of soliton until horizons shrink leaving bare singularity

physical consequence of Hawking radiation is the decay of horizon

this is what to be measured

effective metric

$$ds^2 = - dt^2 \, (1 - v^2/c_z^2(z)) - 2(v/c_z^2(z))dzdt + c_x^{-2}dx^2 + c_y^{-2}dy^2 + c_z^{-2}(z)dz^2$$

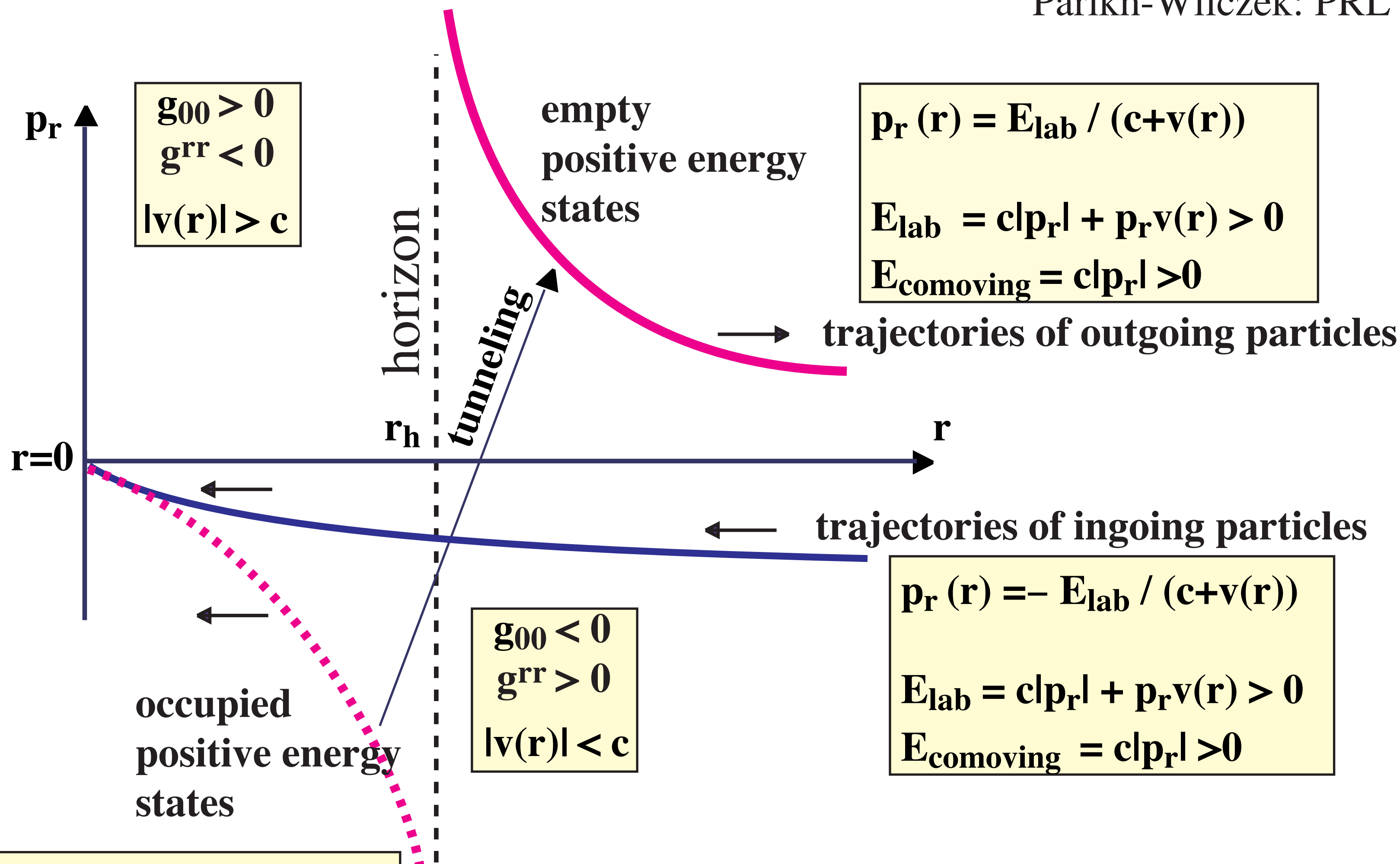
horizons **at** $c_z(z_h) = \pm v$ $\quad g_{00}=0 \quad g^{zz}=0$ **between horizons particles move in one direction**

z=0 - curvature singularity **:** $c_z(z)=0$

Hawking radiation in semiclassical description: quantum tunneling between classical trajectories

GV: JETP Lett. ***69***,705 (1999)

Parikh-Wilczek: PRL ***85***,5042 (2000)



$p_r(r) = E_{lab} / (c+v(r))$

$E_{lab} = -\,c|p_r| + p_r v(r) > 0$

$E_{comoving} = -\,c|p_r| < 0$

tunneling exponent and Hawking temperature

$$S(E) = 2\,\mathrm{Im}\int dr\, p_r\,(r) = 2E\,\mathrm{Im}\int dr/(c+v\,(r)) = E\,/T_\mathrm{H}$$

$$W = we^{-S(E)} = we^{-E/T_H} \qquad T_\mathrm{H} = \mathrm{v}'/2\pi$$

problem of Hawking radiation in de Sitter universe

GV: 0803.3367

$ds^2 = - dt^2 c^2 + (d\mathbf{r} - \mathbf{v} dt)^2$ $ds^2 = - dt^2 (c^2 - H^2 r^2) + 2 Hr\, dr\, dt + dr^2 + r^2 d\Omega^2$

$\mathbf{v}(\mathbf{r}) = H\mathbf{r}$ **de Sitter expansion**

*** tunneling approach**

outside de Sitter horizon $r > c/H$

$\mathbf{p_r}(\mathbf{r}) = \mathbf{E} / (-\mathbf{c} + \mathbf{v}(\mathbf{r})) > 0$

$\mathbf{E} = -\mathbf{c}|\mathbf{p_r}| + \mathbf{p_r}\mathbf{v}(\mathbf{r}) > 0$

$\mathbf{E_{comoving}} = -\mathbf{c}|\mathbf{p_r}| < 0$

tunneling from occupied positive energy states →

inside de Sitter horizon $r < c/H$

$\mathbf{p_r}(\mathbf{r}) = \mathbf{E} / (-\mathbf{c} + \mathbf{v}(\mathbf{r})) < 0$

$\mathbf{E} = \mathbf{c}|\mathbf{p_r}| + \mathbf{p_r}\mathbf{v}(\mathbf{r}) > 0$

$\mathbf{E_{comoving}} = \mathbf{c}|\mathbf{p_r}| > 0$

$$S(E) = 2\,\mathrm{Im}\int dr\, p_r(r) = 2E\,\mathrm{Im}\int dr/(-c+Hr) = 2\pi E/H$$

$$W = w e^{-S(E)} = w e^{-E/T_H} \qquad T_H = H/2\pi$$

*** Does Hawking radiation really occur in de Sitter universe ?**

BH has preferred reference frame, de Sitter Universe does not

*** cond-mat simulation** $ds^2 = - dt^2 + d\mathbf{r}^2 / c^2$ $c(t) = e^{-Ht}$

Schutzhold: PRL **95** (2005) 135703; GV: J.Low.Temp.Phys. **113** (1998) 667

activation in de Sitter space-time

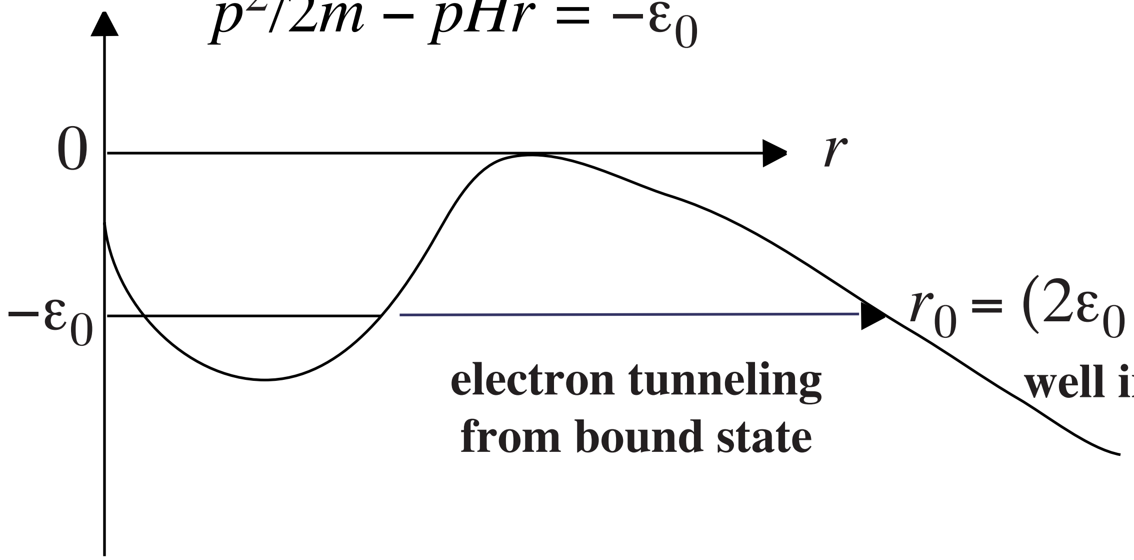
GV: 0803.3367

$ds^2 = -dt^2 c^2 + (d\mathbf{r} - \mathbf{v}dt)^2$ $\qquad$ $ds^2 = -dt^2 \boxed{(c^2 - H^2 r^2)} + 2Hr\,dr\,dt + dr^2 + r^2 d\Omega^2$

$\mathbf{v}(\mathbf{r}) = H\mathbf{r}$ **de Sitter expansion**

*** ionization rate of an atom from electron at atomic level $-\varepsilon_0$**

$p^2/2m - pHr = -\varepsilon_0$



$r_0 = (2\varepsilon_0/m)^{1/2} H << c/H$

electron tunneling from bound state

well inside de Sitter horizon

$$S(-\varepsilon_0) = 2\,\mathrm{Im}\int_0^{r_0} dr\, p_r(r) = \pi\,\varepsilon_0/H$$

$$W = we^{-S(-\varepsilon_0)} = we^{-\varepsilon_0/T}$$

effective activation temperature $\boxed{T = H/\pi}$

is twice the Hawking temperature $\boxed{T_H = H/2\pi}$

suggestion for Hawking type radiation in de Sitter space-time GV: 0803.3367

$ds^2 = - dt^2 c^2 + (d\mathbf{r}-\mathbf{v}dt)^2$ $\qquad ds^2 = -dt^2 \boxed{(c^2-H^2r^2)} + 2\,Hr\,dr\,dt + dr^2 + r^2 d\Omega^2$

$\mathbf{v}(\mathbf{r}) = H\mathbf{r}$ **de Sitter expansion**

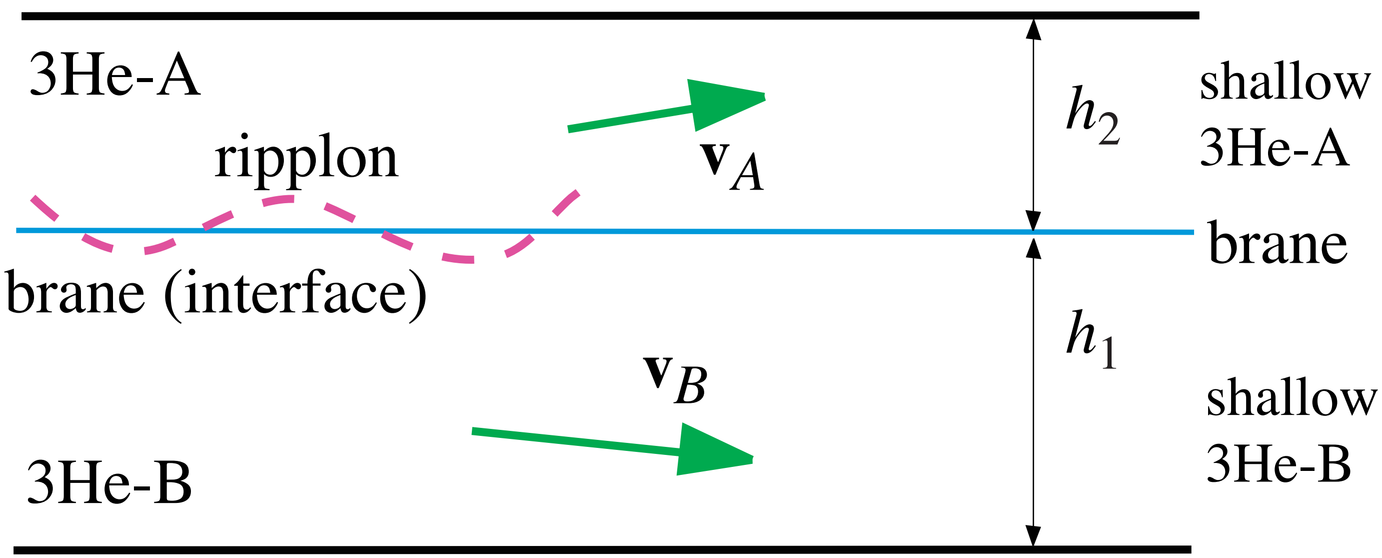
pure de Sitter vacuum does not radiate

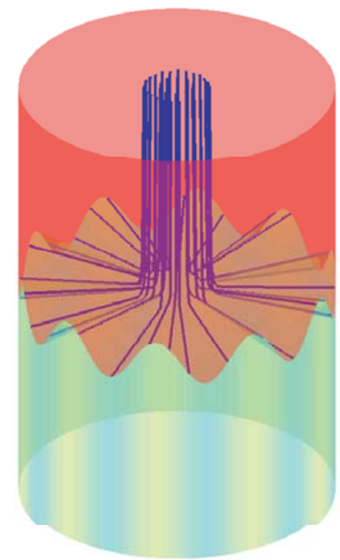
but observer views thermal bath with twice the Hawking temperature because he/she violates de Sitter symmetry

effective activation temperature $\boxed{T = H/\pi}$

is twice the Hawking temperature $\boxed{T_H = H/2\pi}$

Relativistic ripplons living on brane between two shallow superfluids





Spectrum of ripplons $g^{\mu\nu}p_\mu p_\nu = 0$

$$\alpha_1(\omega-\mathbf{k}\cdot\mathbf{v}_A)^2+\alpha_2(\omega-\mathbf{k}\cdot\mathbf{v}_B)^2 = c^2k^2$$

Effective metric for ripplons

$$ds^2 = g_{\mu\nu}dx^\mu dx^\nu$$

Speed of light

$$c^2=(F/\rho_s)h_1h_2/(h_1+h_2)$$

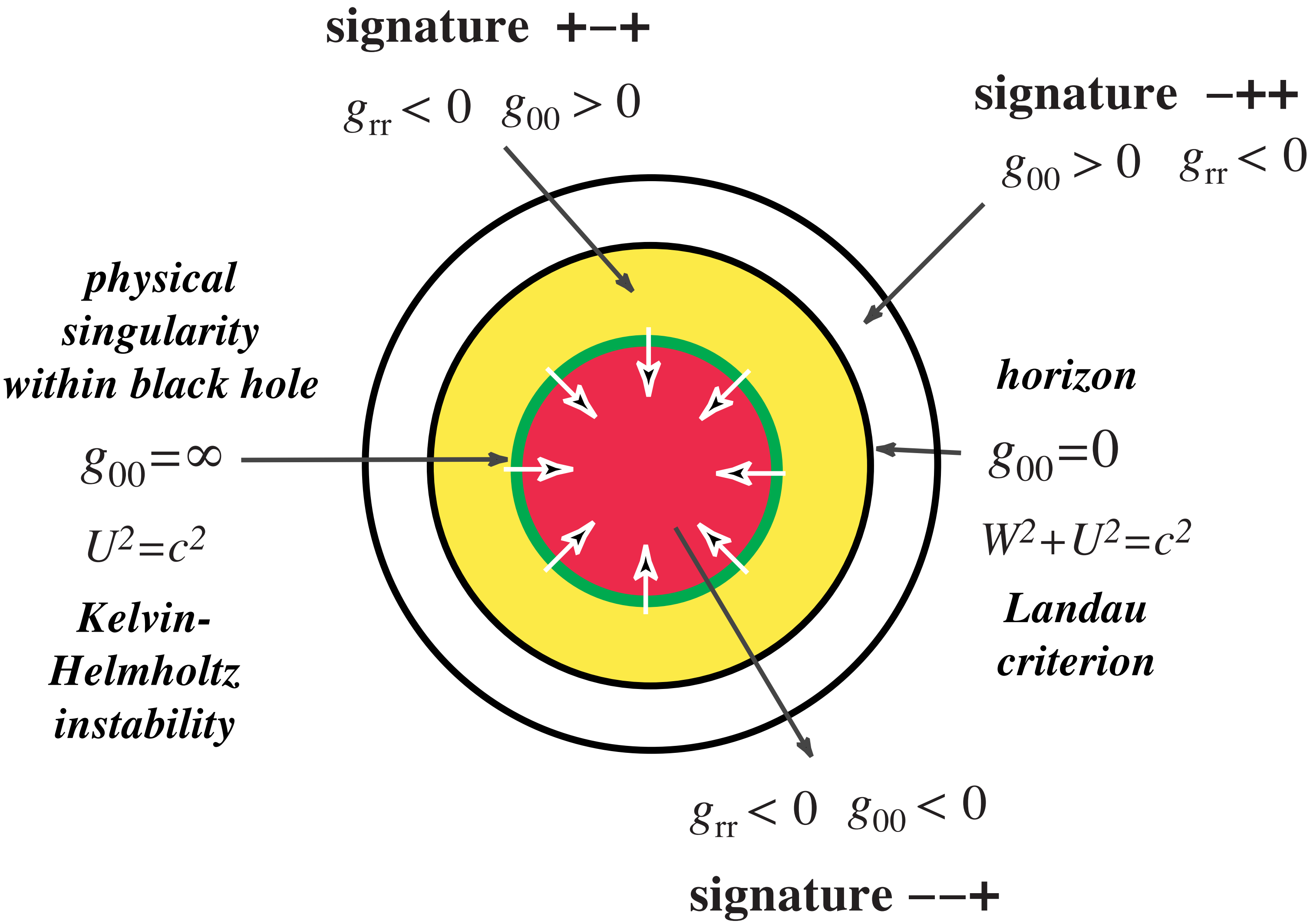
F is restoring force:
either gravity or gradient of magnetic field

$$ds^2 = -dt^2\,\frac{c^2-W^2-U^2}{c^2-U^2} + dr^2\,\frac{1}{c^2-W^2-U^2} + r^2\,d\phi^2$$

$$U^2 = \alpha_1\alpha_2(\mathbf{v}_\mathrm{A}-\mathbf{v}_\mathrm{B})^2 \qquad \mathbf{W} = \alpha_1\mathbf{v}_\mathrm{A}+\alpha_2\mathbf{v}_\mathrm{B}$$

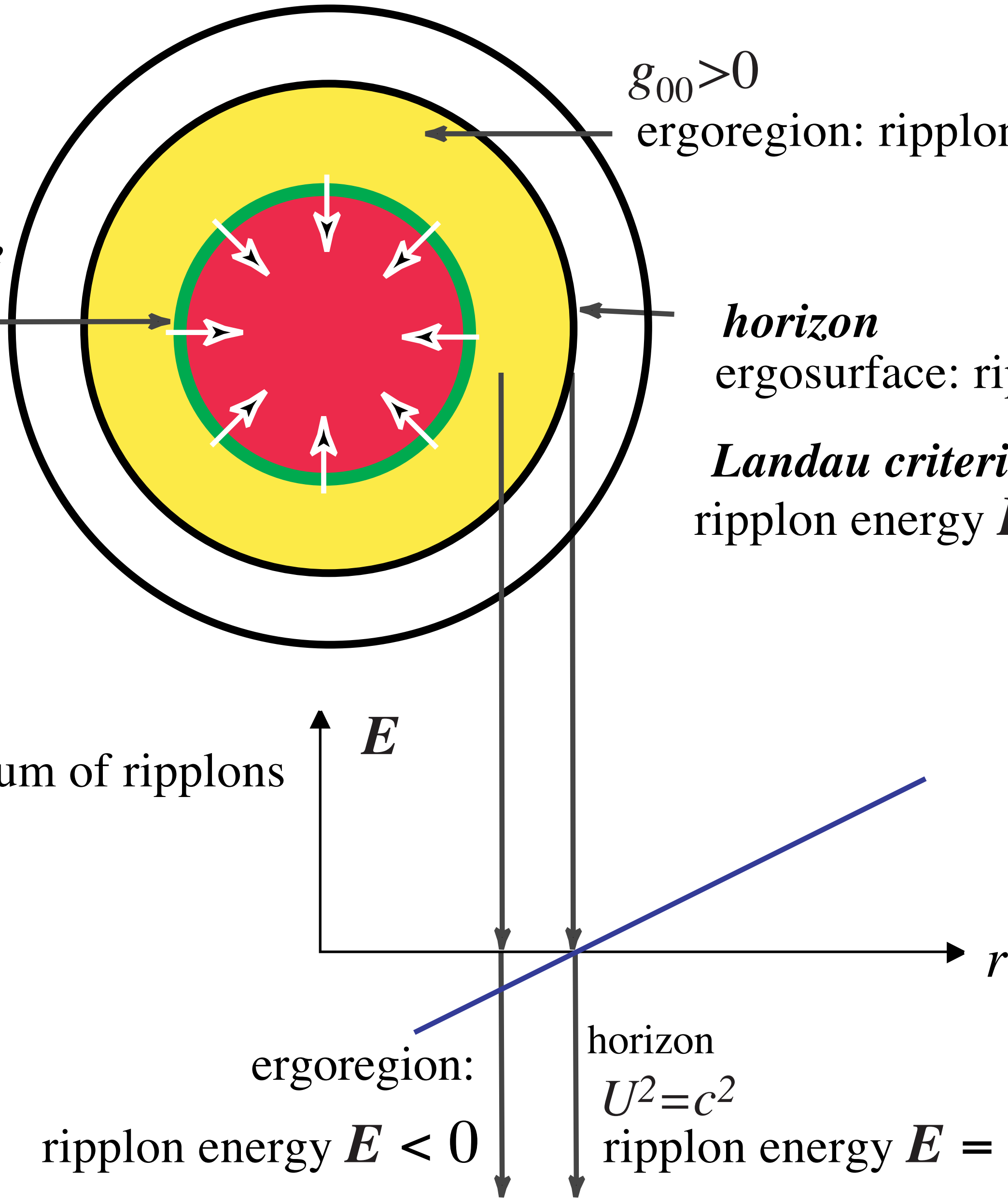
black hole for ripplons at AB-brane

$$ds^2 = -dt^2 \frac{c^2-W^2-U^2}{c^2-U^2} + dr^2 \frac{1}{c^2-W^2-U^2} + r^2\, d\phi^2$$



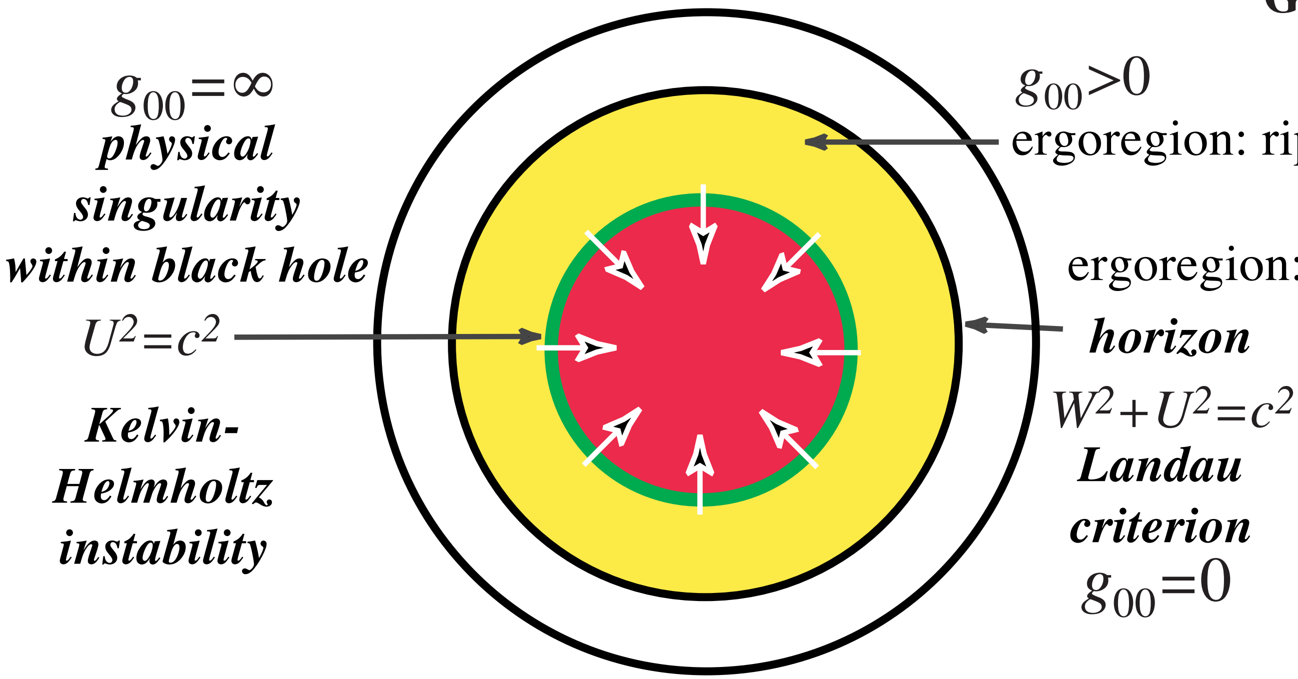
horizon as ergosurface

$$ds^2 = -dt^2\,\frac{c^2-W^2-U^2}{c^2-U^2} + dr^2\,\frac{1}{c^2-W^2-U^2} + r^2\,d\phi^2$$



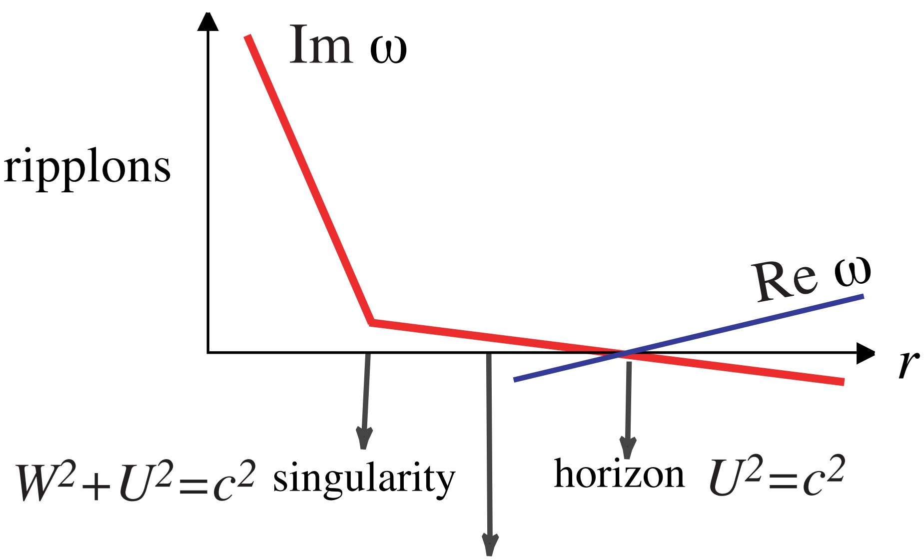
instability in ergosurface

Schutzhold-Unruh: PRD 66, 044019 (2002)
GV: JETP Lett. 75, 418 (2002)



lesson from AB-brane:

Black hole
may collapse due to
vacuum instability
in ergoregion

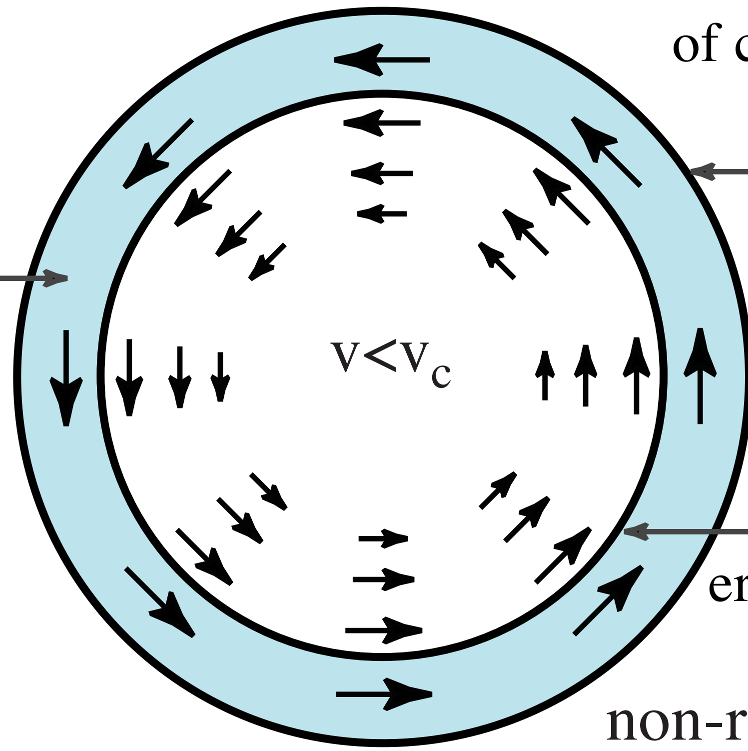


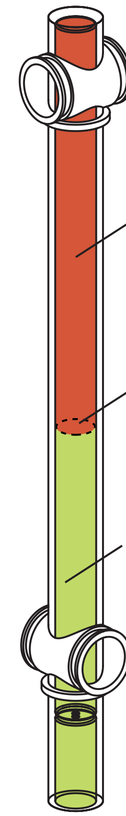
Im ω & Re ω
cross 0 simultaneously:
behind horizon
attenuation transforms
to amplification

ergoregion: ripplon energy E =Re ω < 0
also Im ω < 0 which means instability

Ergoregion instability at the AB-brane in Helsinki experiments

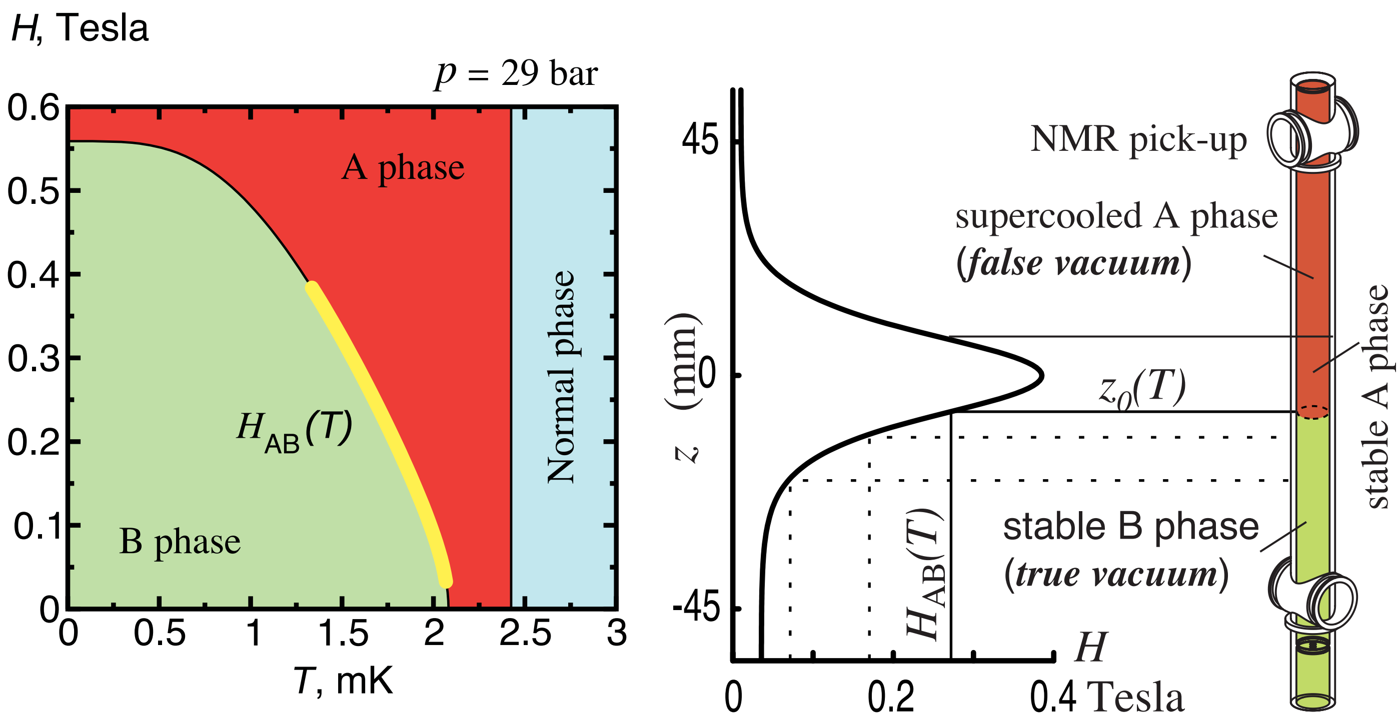
interface between static B-phase and A phase circulating with solid-body velocity $v=\Omega r$
(velocity is shown by arrows)





experimental Landau criterion of ripplon ergregion instability

experimental set-up

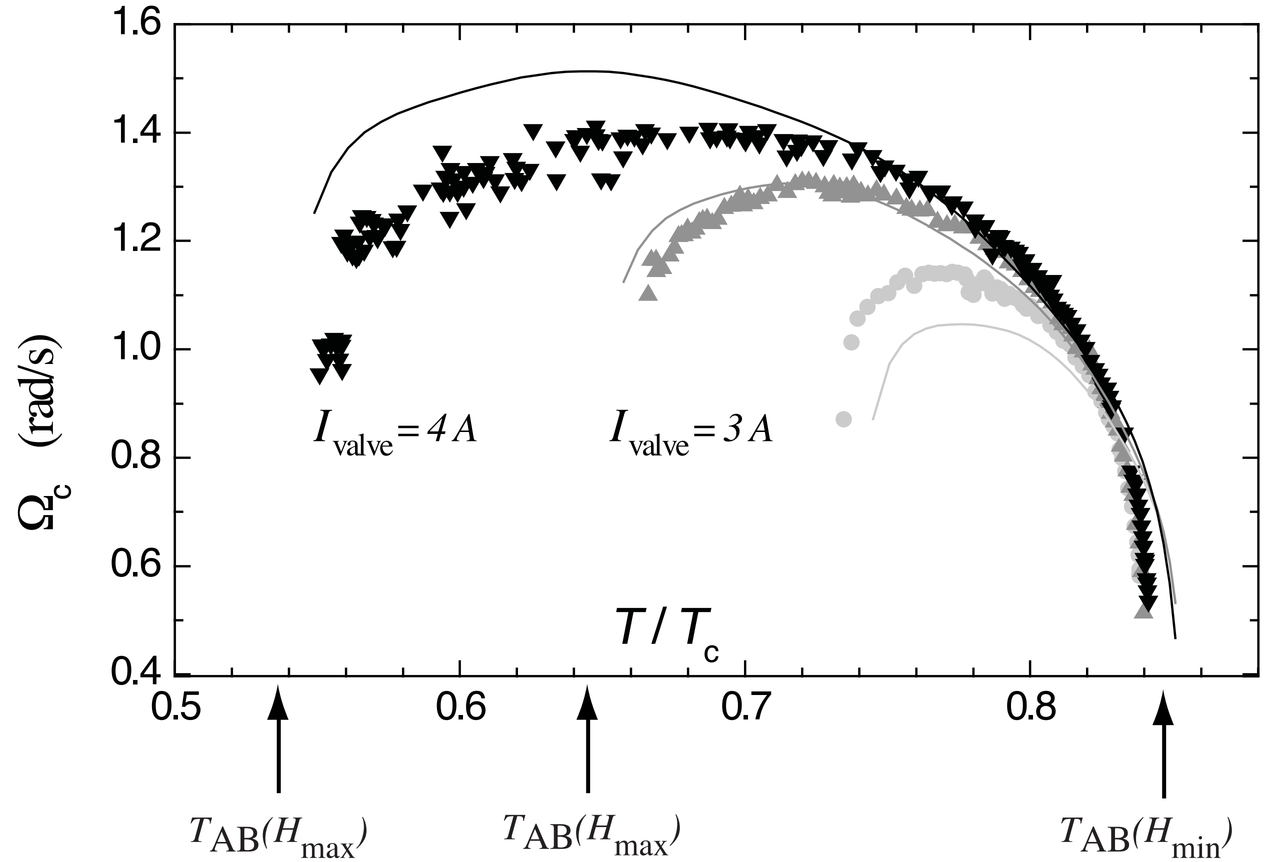


Landau criterion

$$\rho_{sB}(v_{sB}-v_n)^2+\rho_{sA}(v_{sA}-v_n)^2=2\sqrt{F\sigma}$$

critical value $v_{sB}(T)$ depends on T via $\rho_{sB}(T)$, $F(T)$, $\sigma(T)$

experimental Landau criterion of ripplon ergregion instability

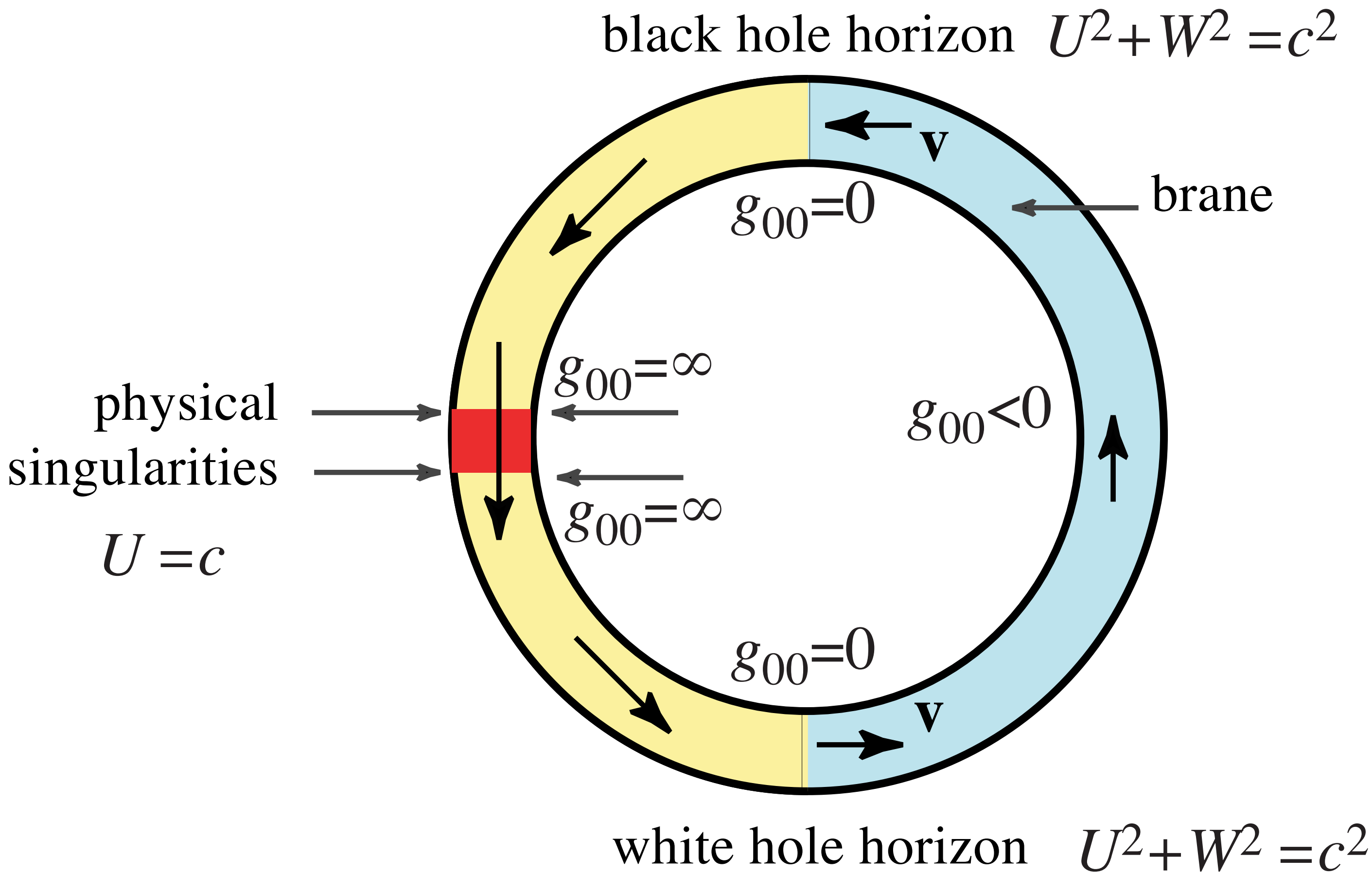


lines - theoretical values without fitting

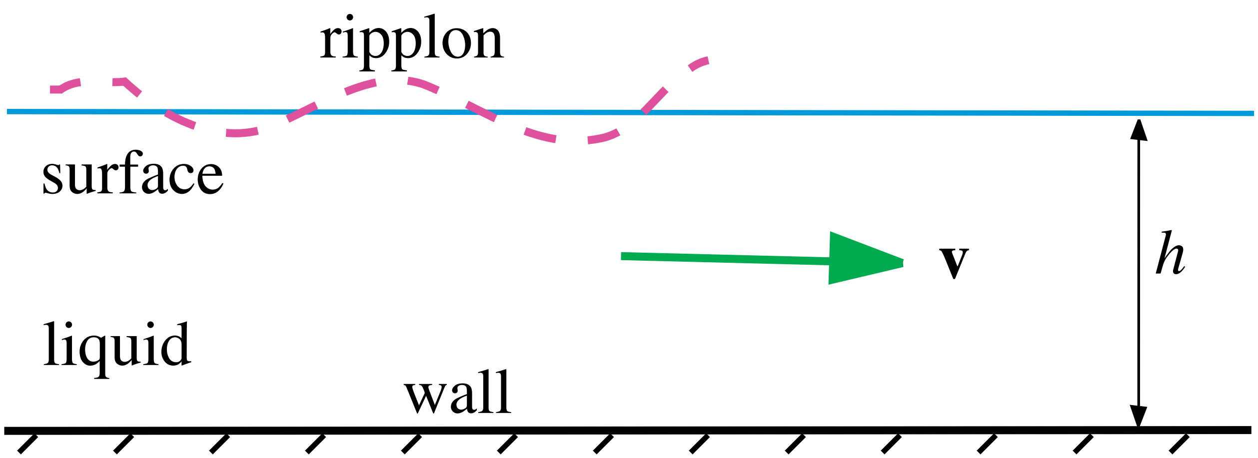
$$\rho_{sB}(v_{sB} - v_n)^2 + \rho_{sA}(v_{sA} - v_n)^2 = 2\sqrt{F\sigma}$$

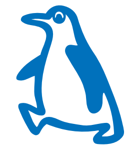
Proposal for black hole for ripplons at AB-brane (azimuthal flow)

$$ds^2 = -dt^2 \frac{c^2 - W^2 - U^2}{c^2 - U^2} + \frac{r^2\, d\phi^2}{c^2 - W^2 - U^2} + dr^2$$



Relativistic ripplons in shallow water





Spectrum of ripplons $g^{\mu\nu}p_\mu p_\nu = 0$

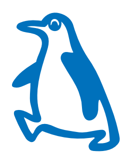
$$\boxed{(\omega - \mathbf{k}\cdot\mathbf{v})^2 = c^2k^2} + c^2k^4(\sigma/\rho g - h^2/3)$$

$$k << k_c = \sqrt{\rho g/\sigma}$$

$$kh << 1$$

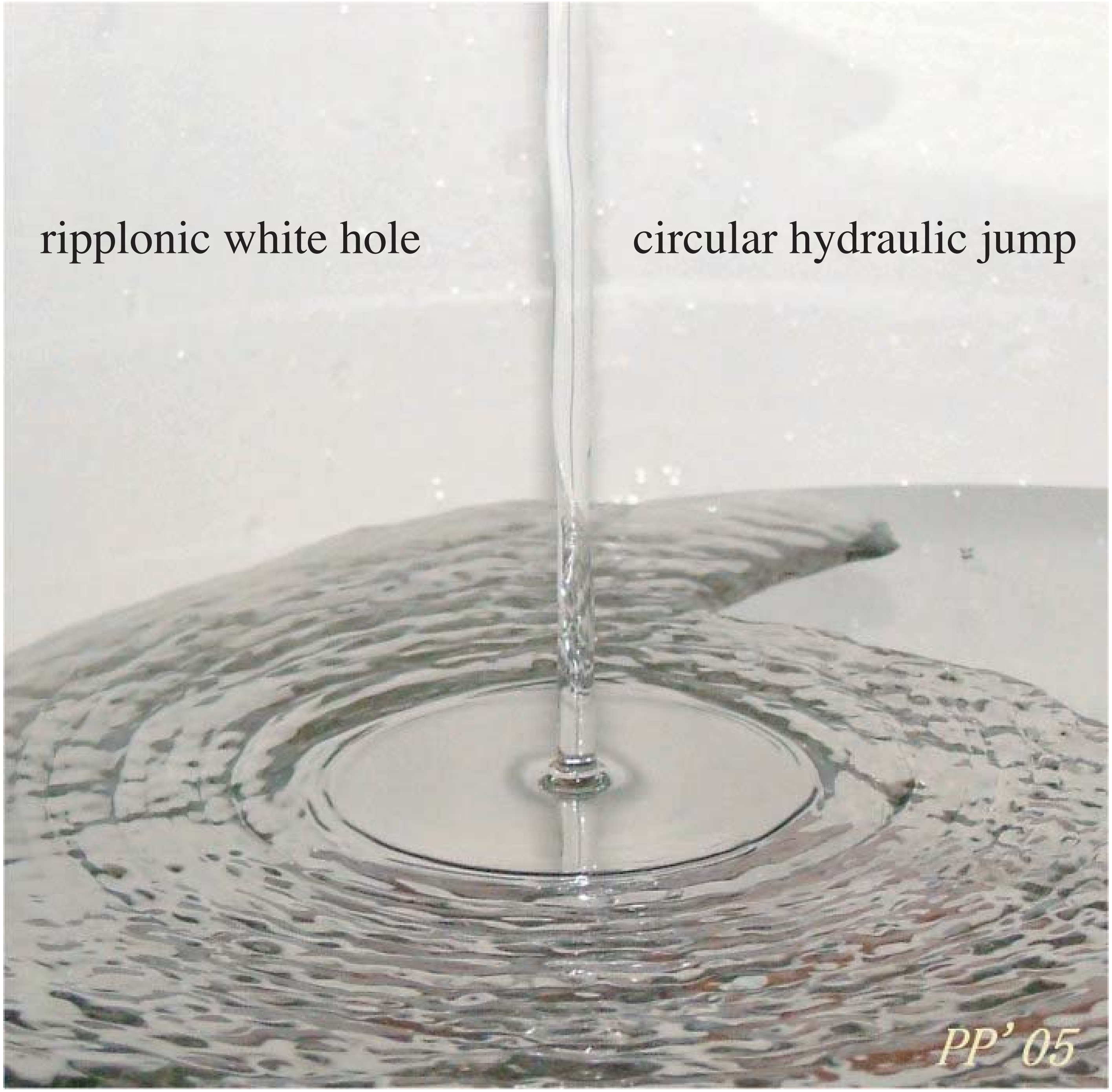
Effective metric for ripplons $ds^2 = g_{\mu\nu}dx^\mu dx^\nu$

$$ds^2 = -dt^2\,(1-v^2/c^2) + dr^2\,\frac{1}{c^2-v^2} + r^2\,d\phi^2$$



Speed of "light"

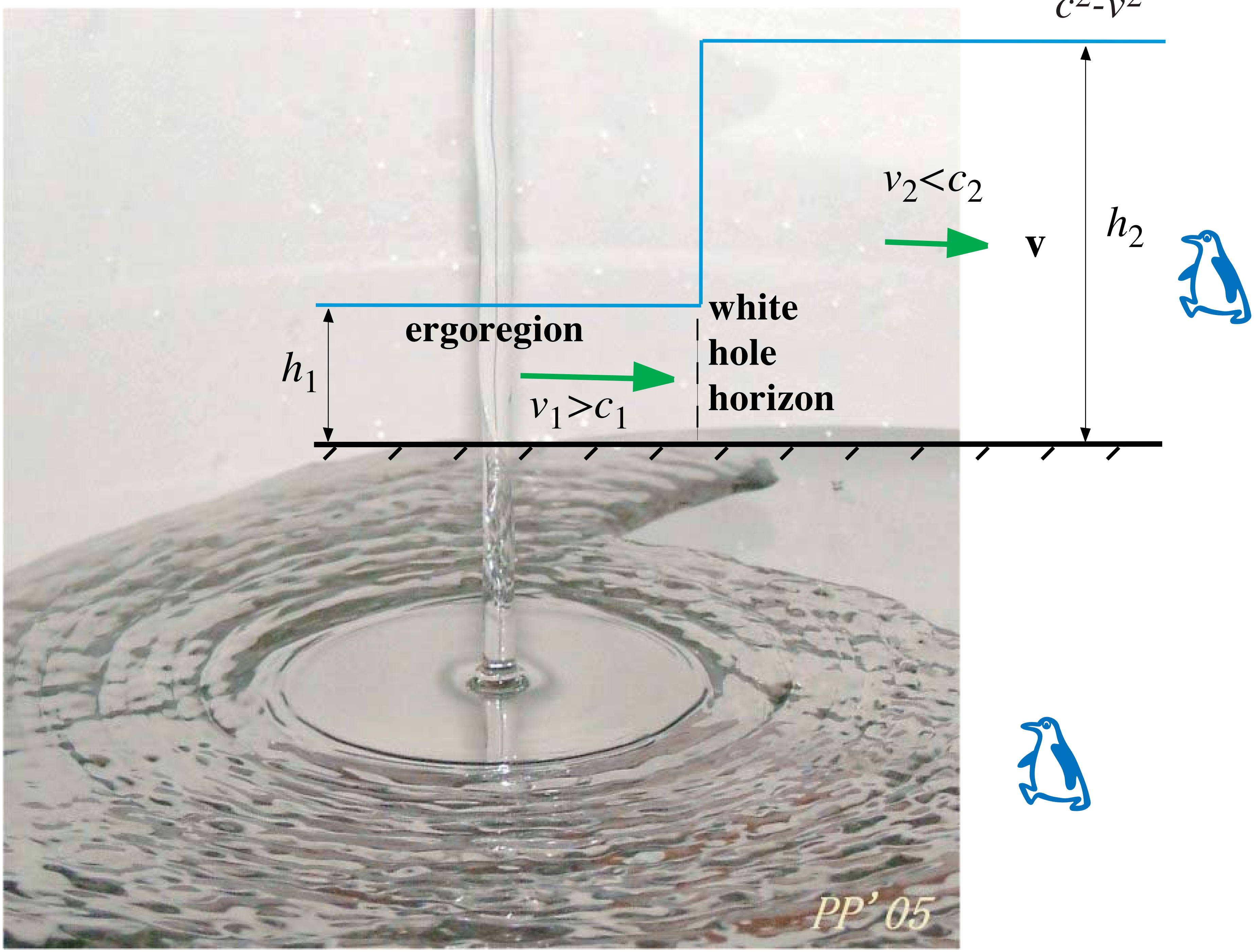
$$\boxed{c^2 = gh}$$



Courtesy Piotr Pieranski

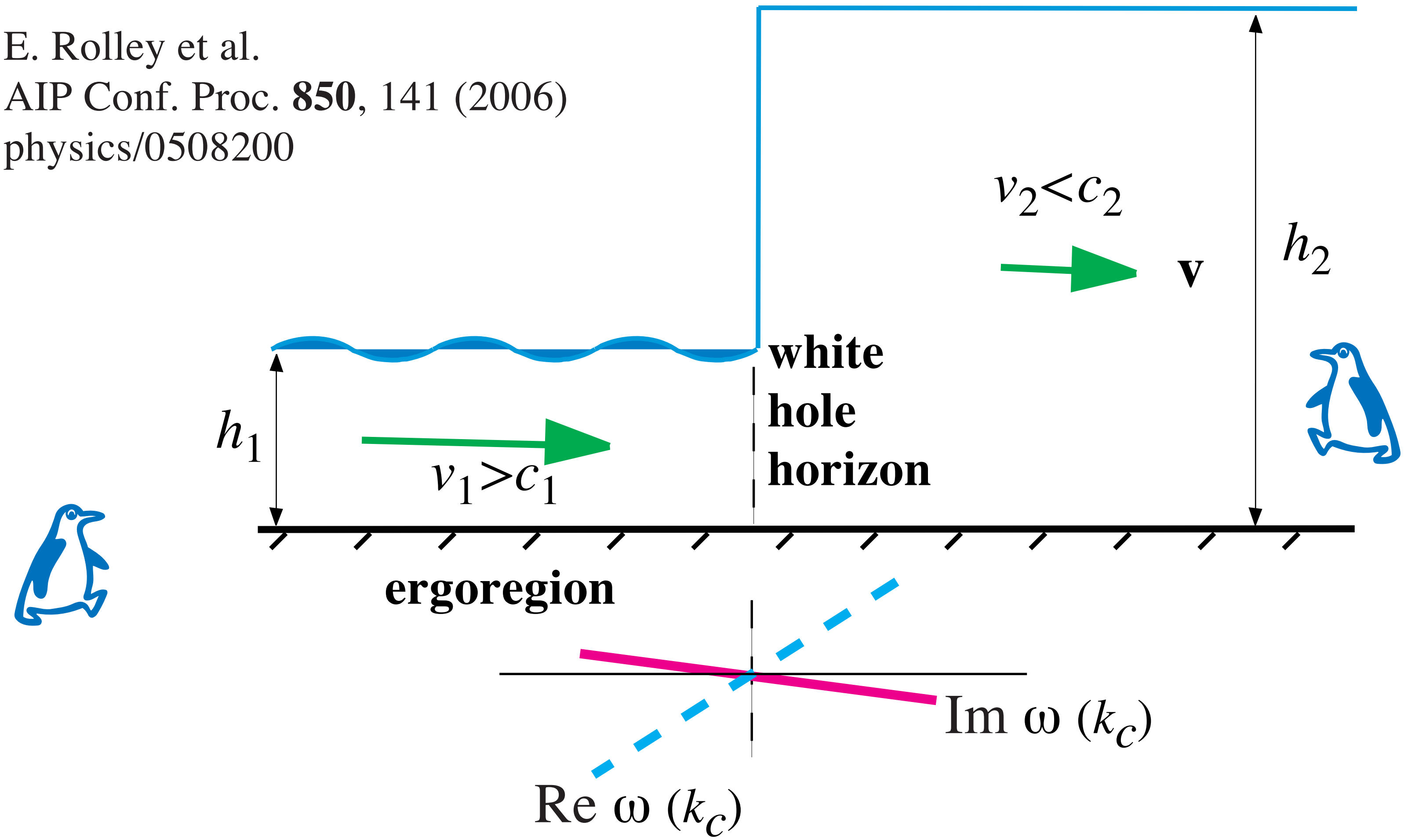
Hydraulic jump as white hole

$$ds^2 = -dt^2\,(1-v^2/c^2) + dr^2\,\frac{1}{c^2-v^2} + r^2\,d\phi^2$$



Observation of instability in the ergoregion in superfluid ^{4}He

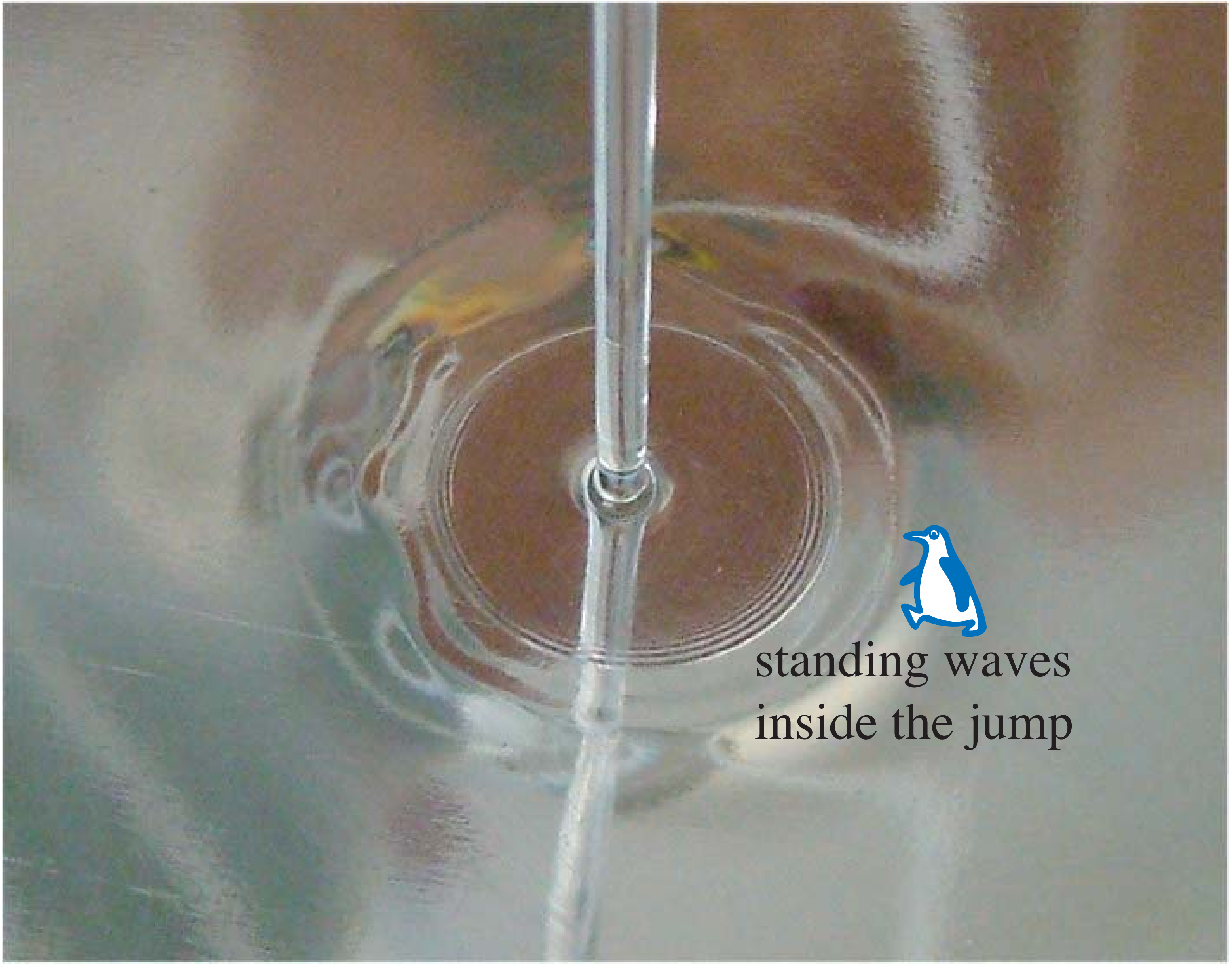
E. Rolley et al.
AIP Conf. Proc. **850**, 141 (2006)
physics/0508200



in the ergoregion
attenuation of ripplon
transforms to amplification

standing waves
are excited
in the ergoregion with
Re ω (k_c)=0

ergoregion instability inside the "white hole" in shallow water



Courtesy Piotr Pieranski

Zeldovich-Starobinsky effect, rotational Unruh effect & ergorgion instability

Radiation by object rotating in quantum vacuum & by circulating superflow

Analog to Kerr Black Hole

Hawking radiation
looks as thermal with
$T_H \sim hg/c$
where g is gravity

Unruh effect:
radiation looks as thermal with
$T_U \sim ha/c$
where a is acceleration of a body

metric in rotating frame

$$ds^2 = - dt^2 c^2 + (d\mathbf{r} - \mathbf{v} dt)^2$$

$$\mathbf{v}(\mathbf{r}) = \boldsymbol{\Omega} \times \mathbf{r}$$

H. Takeuchi, M. Tsubota and GV
Zel'dovich-Starobinsky Effect in Atomic Bose-Einstein Condensates: Analogy to Kerr Black Hole
J. Low Temp. Phys. **150**, 624 (2008)

$$ds^2 = - dt^2 \boxed{(c^2 - \Omega^2\rho^2)} + 2\Omega\rho^2 \, d\phi \, dt + \rho^2 d\phi^2 + d\rho^2 + dz^2$$

tunneling approach

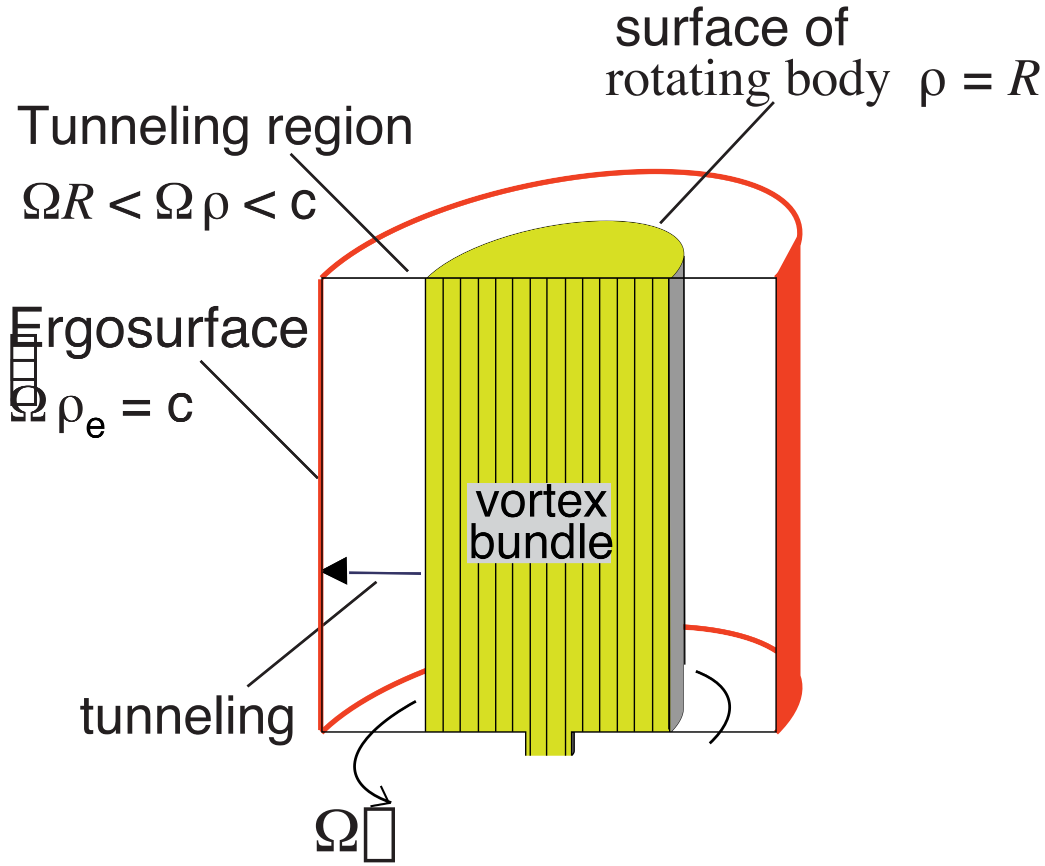
$$ds^2 = -\,dt^2\,(c^2 - \Omega^2\rho^2) + 2\Omega\rho^2\, d\phi\, dt + \rho^2 d\phi^2 + d\rho^2 + dz^2$$

normal region $\rho < c/\Omega$ **ergoregion** $\rho > c/\Omega$

body surface $R < c/\Omega$ → **ergosurface** $\rho = c/\Omega$

tunneling from zero energy state at the body
to zero energy state at the ergosurface

Radiation by object rotating in quantum vacuum



optical potential made by
blue or red detuned laser
moving in static BEC
or vortex cluster rotating in static BEC

potential or a vortex moves with
linear velocity $\Omega R < c$,
but it radiates via quantum tunneling
to the ergoregion

Analog to Kerr Black Hole

tunneling exponent

$$ds^2 = -dt^2 (c^2 - \Omega^2 \rho^2) + 2\Omega\rho^2 \, d\phi \, dt + \rho^2 d\phi^2 + d\rho^2 + dz^2$$

body surface $R < c/\Omega$ → **ergosurface** $\rho = c/\Omega$

tunneling from zero energy state at the body to the zero energy state at the ergosurface

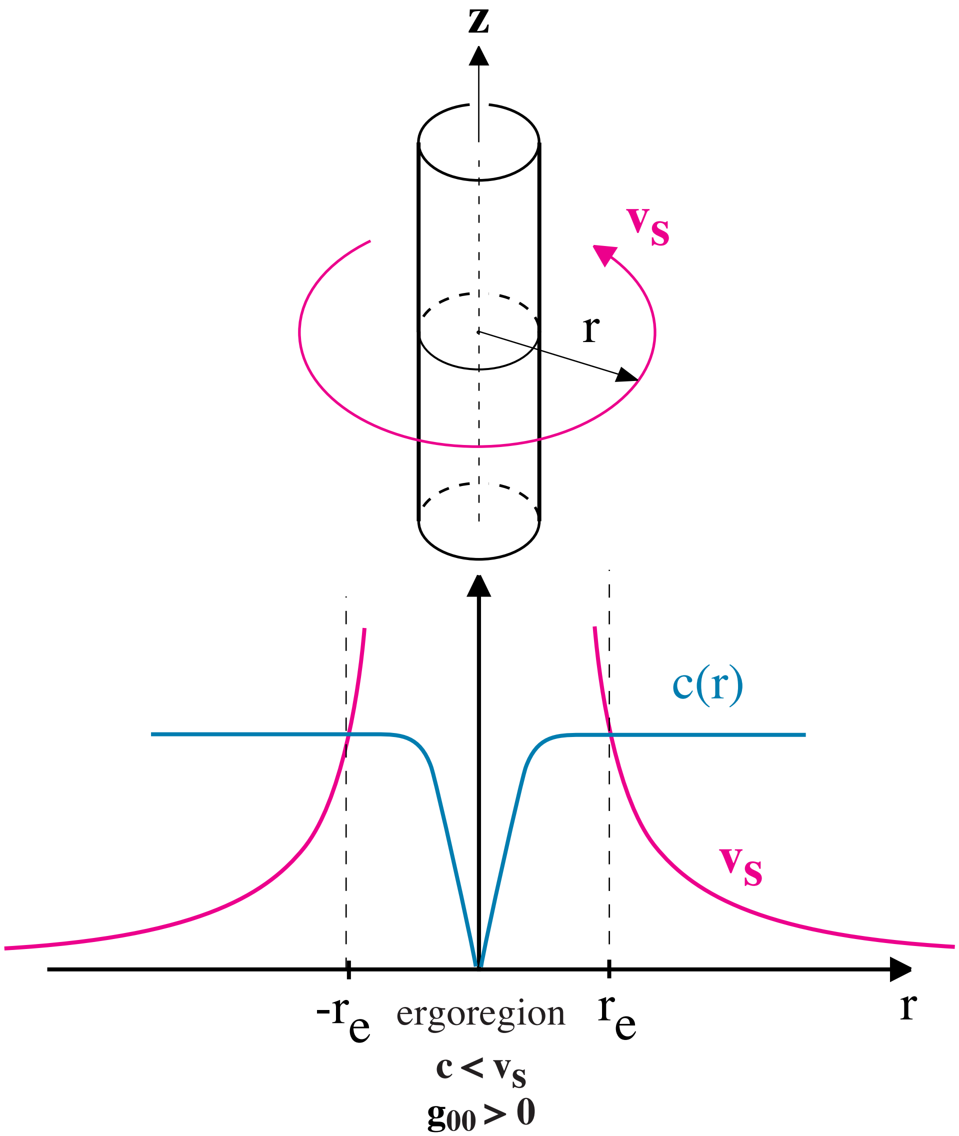
$$S(E{=}0) = 2\,\mathrm{Im}\int d\rho\, p_\rho(\rho) = 2\,\mathrm{Im}\int_R^{c/\Omega} d\rho (L^2/\rho^2 - L^2\Omega^2/c^2)^{1/2} = 2L \ln (c/\Omega R)$$

$$W = we^{-S(E=0)} = w\,(\Omega R/c)^{2L} = w\,(\omega R/cL)^{2L}$$

$$\omega = \Omega L$$ **Zeldovich resonance condition**

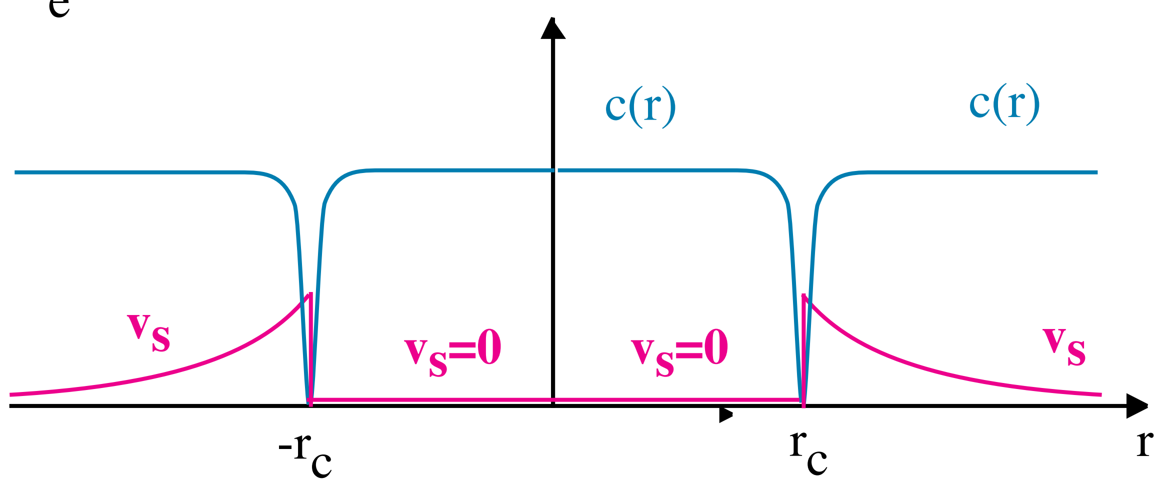
Calogeracos-GV: JETP Lett. **69** (1999) 281

Vacuum instability in ergoregion



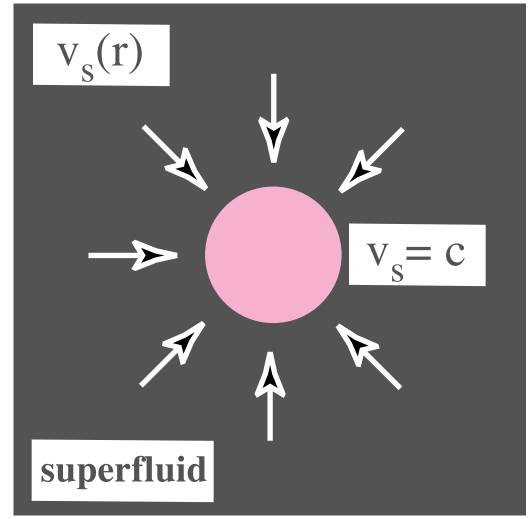
instability of ergoregion
in vortex core with N>>1:
no stable vacuum if $v_s > c$

reconstruction of vacuum
in the vortex core with N>>1:
ergoregion disappears, $v_s < c$ everywhere,
shell of Planck size and Planck energy
separates vacua with different $g_{\mu\nu}$



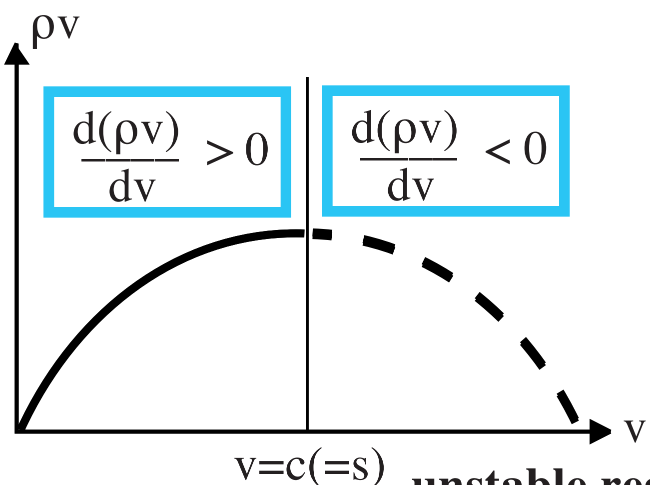
Vacuum resistance to formation of horizons

spherical acoustic black or white holes
are not solutions of hydrodynamic equations



equation along the stream line of stationary flow:

$$\frac{d(\rho v)}{dv} = \rho(1-v^2(r)/c^2)$$



unstable region behind horizon

horizon cannot be achieved because continuity equation

$$\rho v = \mathrm{Const} / r^2$$

requires

$$\frac{d(\rho v)}{dv} > 0$$

everywhere

Hydrodynamic instability is absent if speed of "light" $c < s$ speed of sound

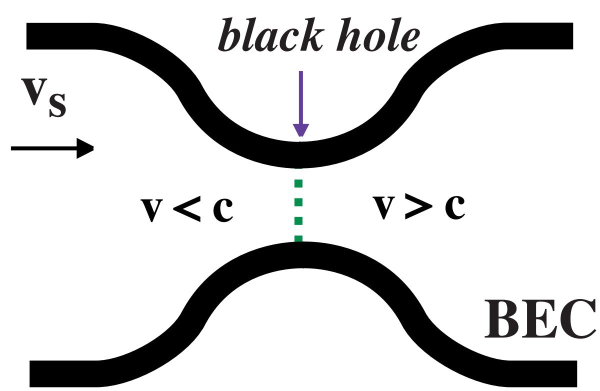
in Fermi superfluids $c << s$

possible horizons

Painleve-Gulstrand metric

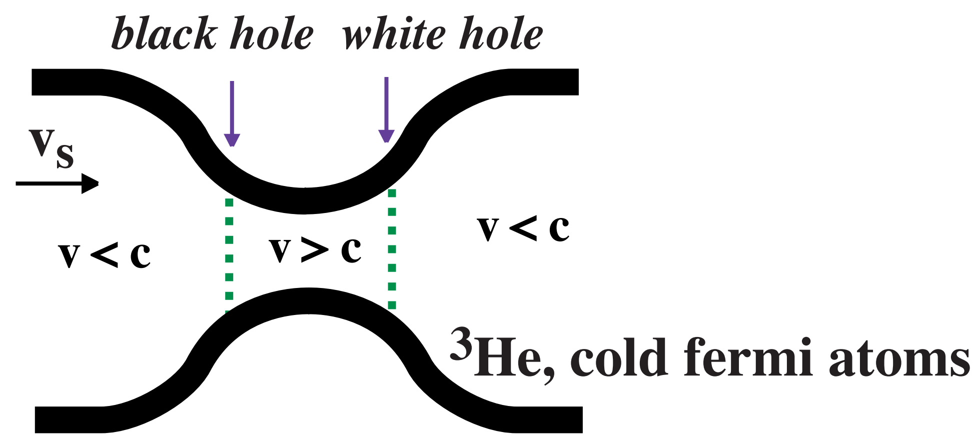
$$ds^2 = -\,dt^2\,(c^2 - v^2) \;+\; 2\,v\,dr\,dt \;+\; dr^2 \;+\; r^2 d\Omega^2$$

Acoustic horizon in Laval nozzle



horizon can be exactly in the middle

Horizons for fermionic quasiparticles

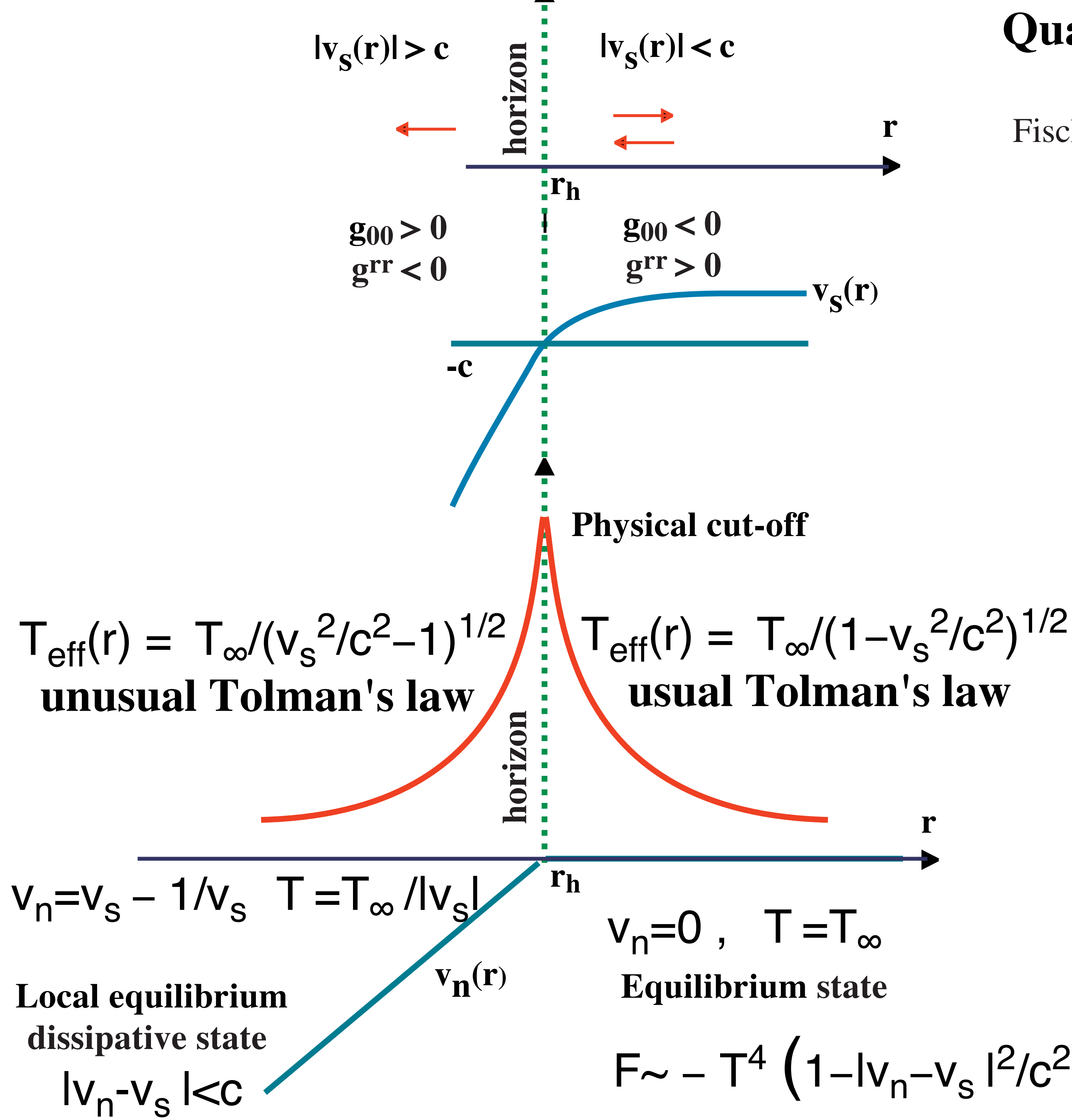


speed of "light" < speed of sound

no hydrodynamic instability

Quasiequilibrium state behind horizon

Fischer-GV: IJMP ***D10***,57 (2001



$$F \sim - T^4 \left(1-|v_n-v_s|^2/c^2\right)^{-2} = T^4 \, |g_{00}|^{-2} = T^4_{eff}(r)$$

conclusion

* **cond-mat sources:**
  sonic gravity, ripplon gravity, fermionic gravity

* **messages from cond-mat to GR:**

  black hole is radiating, de Sitter is not GV: "On dS radiation via quantum tunneling" 0803.3367
  but detector embedded in de Sitter sees radiation

  vacuum resists to formation of horizon

  vacuum may be unstable behind the horizon

* **we need relativistic theory of quantum vacuum**

black holes in dynamics of quantum vacuum

F.R. Klinkhamer and GV
"Self-tuning vacuum variable and cosmological constant", Phys. Rev. D **77**, 085015 (2008)
"Dynamic vacuum variable and equilibrium approach in cosmology", Phys. Rev. D; arXiv:0806.2805
"f(R) cosmology from q-theory", Pis'ma ZhETF **88**, 339 (2008)

*** quantum vacuum as self-sustained Lorentz invariant medium**

*** conserved vacuum charge**

*** thermodynamics of relativistic quantum vacuum**

*** dynamics of relativistic quantum vacuum**

*** application to cosmology:**
relaxation of cosmological constant from Planck scale to present value

*** future application to black hole**
physics of BH singularity

action

$$S = \int d^4x\, (-g)^{1/2} \left[\, \varepsilon(q) + K(q)R \,\right] + S_{\rm matter}$$

gravitational coupling $K(q)$ is determined by vacuum and thus depends on vacuum variable q

dynamic equations

equation for q

$$d\varepsilon/dq + R\, dK/dq = \mu$$

integration constant

Einstein equations

$$K\left(Rg_{\mu\nu} - 2R_{\mu\nu}\right) + \left(\varepsilon - \mu q\right)g_{\mu\nu} - 2\left(\nabla_\mu\nabla_\nu - g_{\mu\nu}\nabla^\lambda\nabla_\lambda\right)K = T_{\mu\nu}$$

gravitational coupling (K) — **Einstein tensor** ($Rg_{\mu\nu} - 2R_{\mu\nu}$) — **cosmological term** ($(\varepsilon - \mu q)g_{\mu\nu}$) — **matter** ($T_{\mu\nu}$)

$$\nabla_\mu T^{\mu\nu} = 0$$