Exterior Structures of Black Holes and Another History of the Universe

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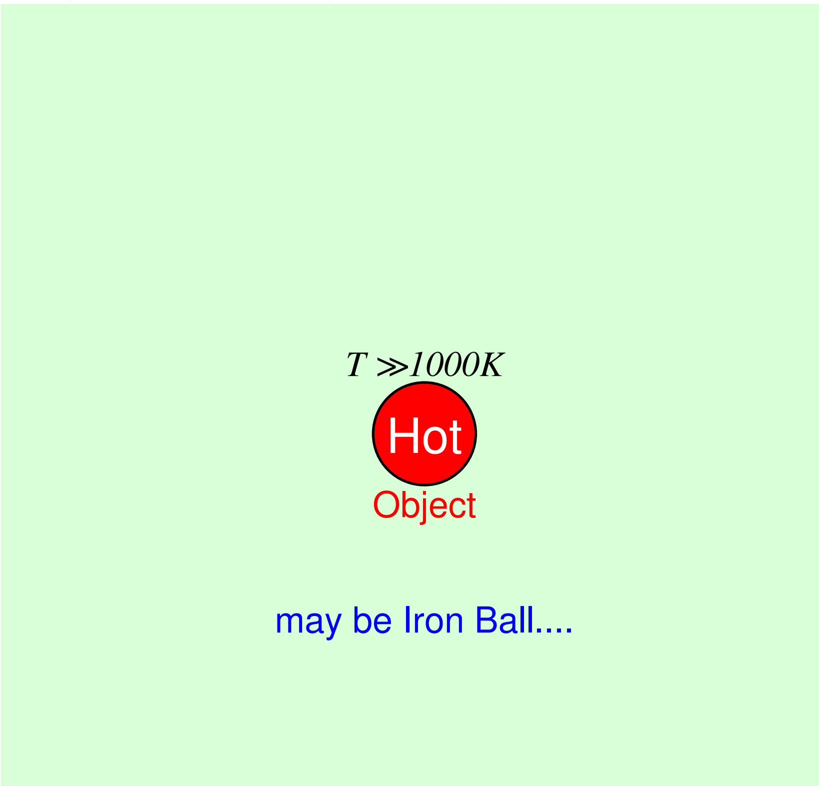
PRD **59** 041301 (1999), hep-ph/0104160, NPB **679** 363-381 (2004), hep-th/0307295, hep-th/0312060, and several unpublished things...

1 The Essence of Idea

A High Temperature Object (e.g. Iron Ball : $T \gg 1000\mathrm{K}$)



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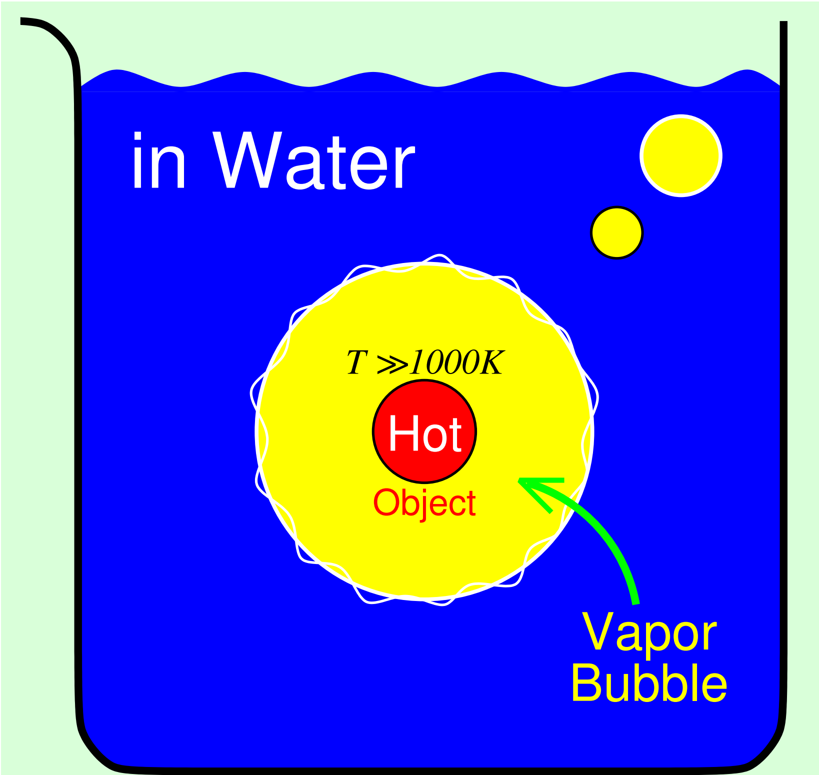
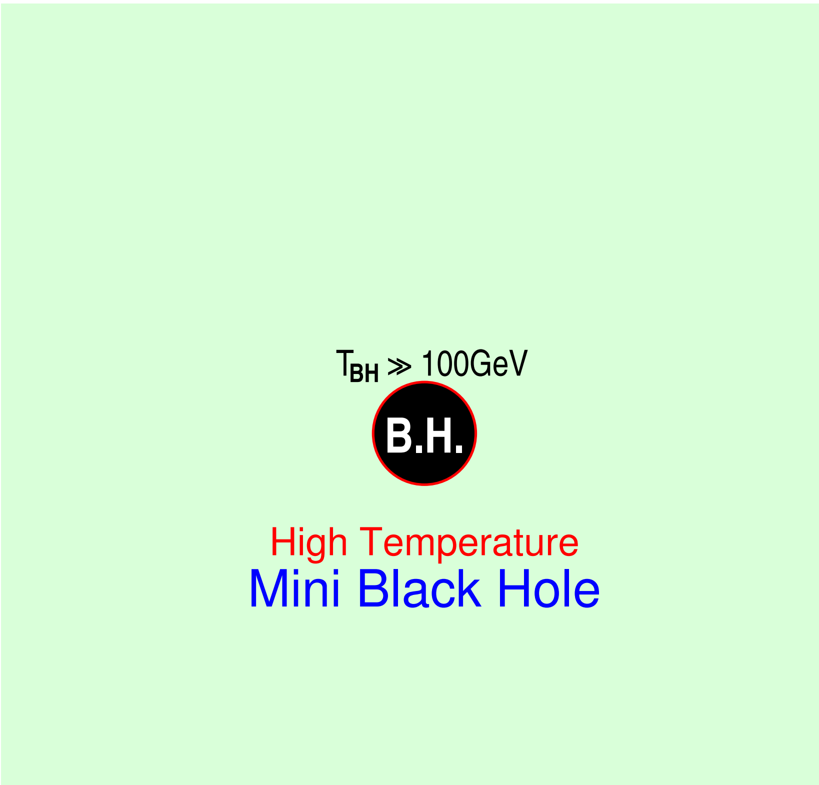


⇒ Vapor Bubble surrounding the Object Appears.

1 The Essence of Idea

A High Hawking Temperature **Black Hole** ($T_{\text{BH}} \gg 100$ GeV)



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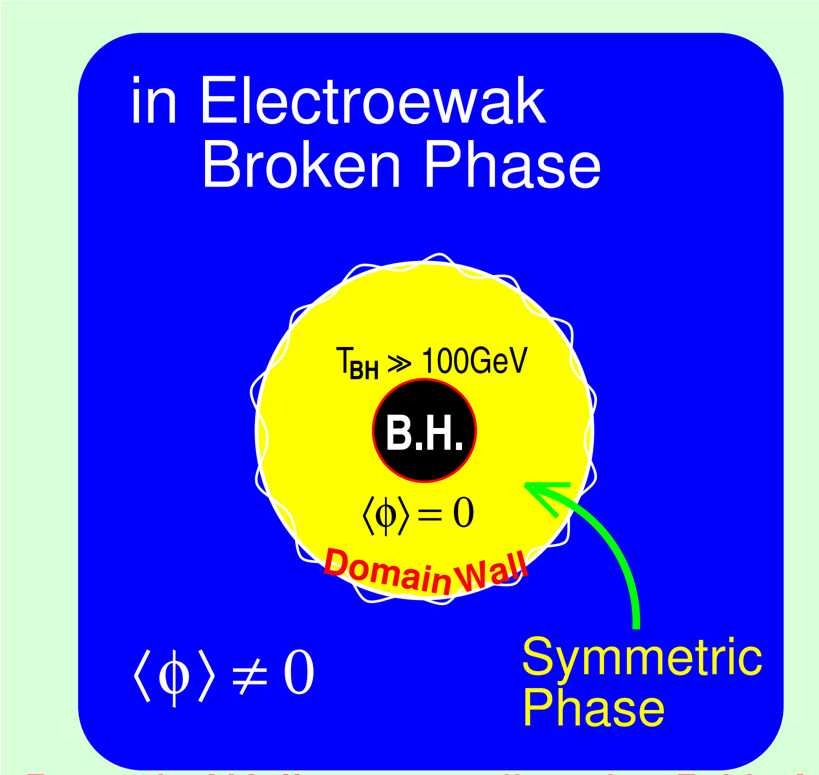


$\Rightarrow$ E.W. Domain Wall surrounding the B.H. Appears.

2 Plan of the Talk

1. Thermal Structure around a BH
2. Two types of Spherical Domain Wall by a BH
   — Thermal & Dynamical —
3. Baryon Number Creation by a BH
4. Spontaneous Charging-up of a BH
5. Application to Cosmology
   Baryogenesis & Dark Matter

3 Parameters of a Black Hole

For a Schwarzschild Black Hole:

Hawking Temp. : $T_{BH} = \frac{1}{8\pi} \frac{m_{pl}^2}{m_{BH}}$

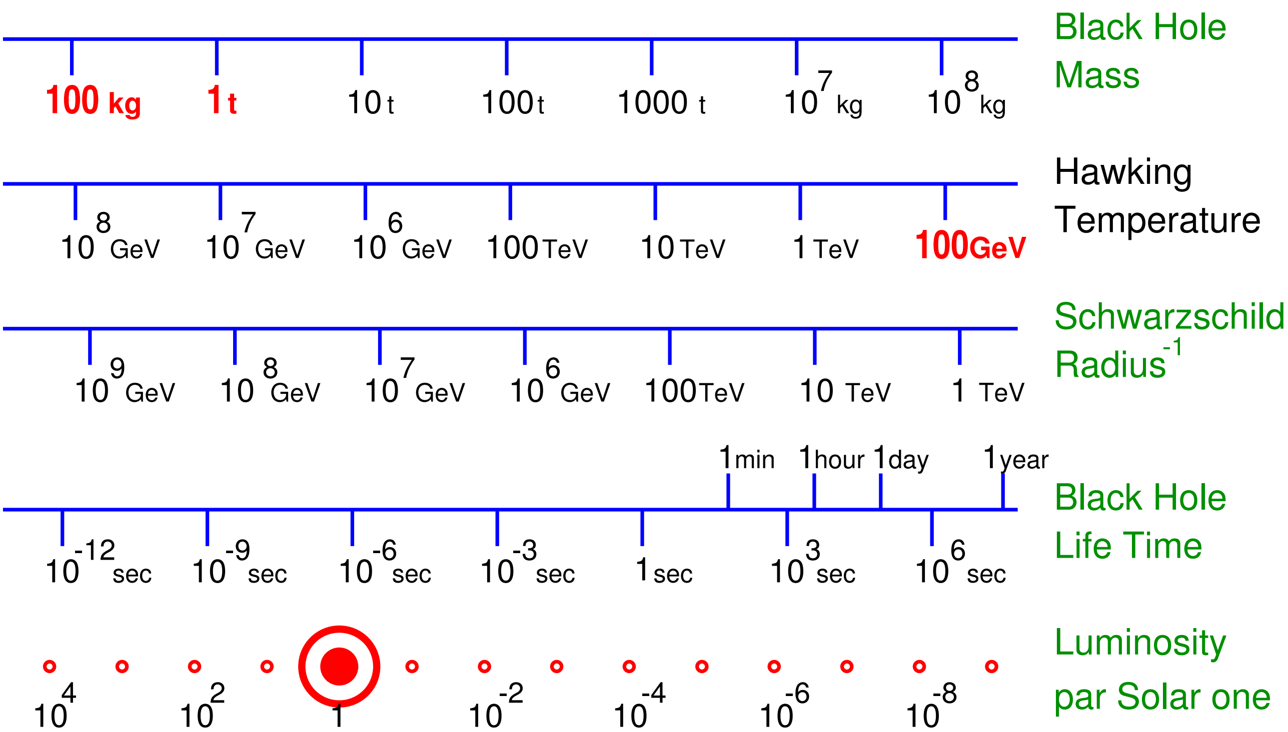
Schwarzschild Radius : $r_{BH} = 1/(4\pi T_{BH})$

Luminosity : $J_{BH} = \frac{\pi^2}{120} g_* T_{BH}^4 \times 4\pi r_{BH}^2$

$= \frac{\pi}{480} g_* T_{BH}{}^2$

Life Time : $\tau_{BH} = \frac{20}{\pi^2 g_*} \frac{m_{pl}^2}{T_{BH}{}^3}$

4 Parameter Table



5 Thermal Structure around a BH

In the Thermal EW Plasma with Temperature T

Mean Free Path:

$$\lambda_f = \left[\sum_F n_F \, \sigma_{F,f} \right]^{-1} \simeq \frac{\beta_f}{T}$$

$$n \propto T^3, \ \sigma \simeq \alpha/s, \ \sqrt{s} \simeq T$$

(α_Y)	$l_R, \ B^\mu$	$\beta_Y \simeq 1000$	} Energy Transfer	
(α_W)	$l_L, \ \nu_L, \ W^\mu, \ \phi$	$\beta_W \simeq 100$		
(α_S)	$quark, \ gluon$	$\beta_S \simeq 10$	Thermalization	

Inject a Particle with Energy E into the Plasma:

Stopping Depth:

$$\tilde{\lambda}_f = \left[\sum_F n_F \, \sigma_{F,f} \right]^{-1} \simeq \frac{\beta_f E}{T^2}$$

$$\sqrt{s} \simeq \sqrt{ET}$$

A Black Hole heats-up its neighborhood $\Rightarrow T < T_{\rm BH}$

Closely Neighborhood of the BH is **NOT** Thermalized.

$$r_{\rm BH} = \frac{1}{4\pi} \frac{1}{T_{\rm BH}} \ll \lambda_f = \frac{\beta_f}{T} \ll \tilde{\lambda}_f = \frac{\beta_f T_{\rm BH}}{T^2}$$

BH Radius — MFP — Stoping Depth

$\Rightarrow$ The Black Hole Freely Hawking-Radiates.

$\Rightarrow$ **Ballistic Particle Region** around the BH.

6 Heat transfer analysis

in the region not near to the BH

a) Local Thermal Equilibrium (L.T.E.) Approximation

MFP $\ll$ system size $\Rightarrow T(r)$

b) Diffusion Parameters:

$D_f(x) = \frac{1}{3}\lambda_f(T(x))$

c) Boundary Condition:

Spherically Symmetric $T(r)$

Hawking Flux $\equiv$ Diffusion Flux

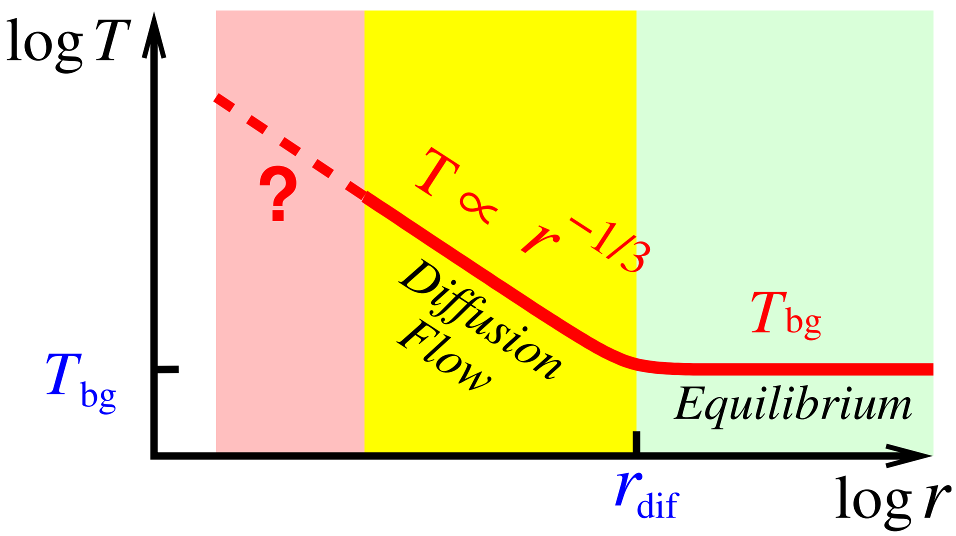
Background Plasma with Temperature $T_{\rm bg}$

Solution of the Heat Transfer Equation:

$$T(r) = \left[{T_{\rm bg}}^3 + \frac{9}{256\pi^2}\frac{1}{\beta}\frac{T_{\rm BH}^2}{r} \right]^{1/3}$$

$$v(r) = \frac{1024\pi^2}{81}\beta^2 \left(\frac{T(r)}{T_{\rm BH}}\right)^2 \times c_{\rm bg}\left[\frac{T(r)}{T_{\rm bg}}\right]$$

$\Rightarrow$ **Thermal Plasma Flow** from near-BH to far-BH



7 Energy transfer from ballistic to thermal

Hawking-radiated Particles are Injected to Thermal Plasma

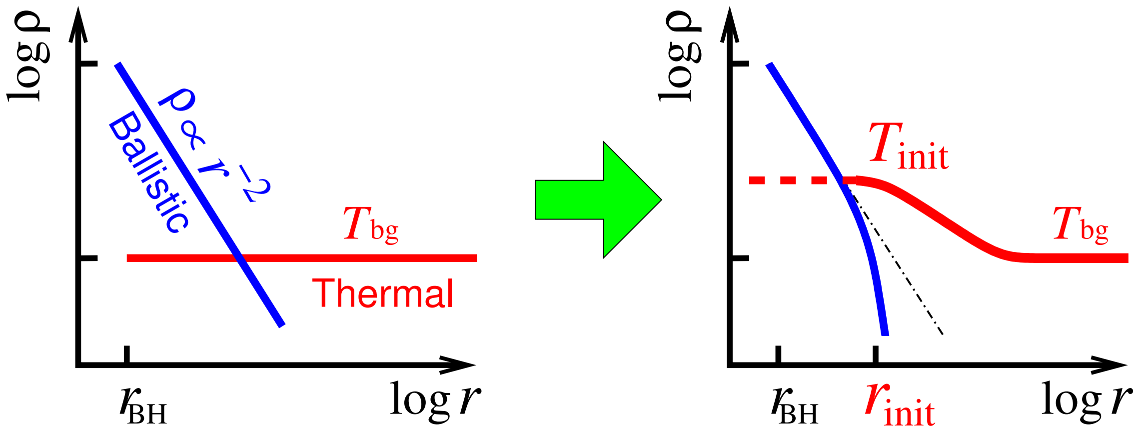
Ballistic Particles T_{BH}	$\Rightarrow$	Thermal Plasma T_{init}

$$\sigma(T_{\mathrm{BH}},\ T_{\mathrm{init}}) \simeq \frac{\alpha}{T_{\mathrm{BH}} T_{\mathrm{init}}}$$

T_{init} : Initial Plasma Temperature

Time evolution to stationary situation:

Radiation Start	$\Rightarrow$	Stationary
$T_{\mathrm{init}} = T_{\mathrm{bg}}$	Local	$T_{\mathrm{init}} = T(r_{\mathrm{init}})$
Put BH into T_{bg} Plasma	Heat-up	Plasma Flow Sol.



Heat-up Depth: $r_{\mathrm{init}} \simeq \tilde{\lambda}(T_{\mathrm{BH}}, T_{\mathrm{init}})$:Stopping Depth

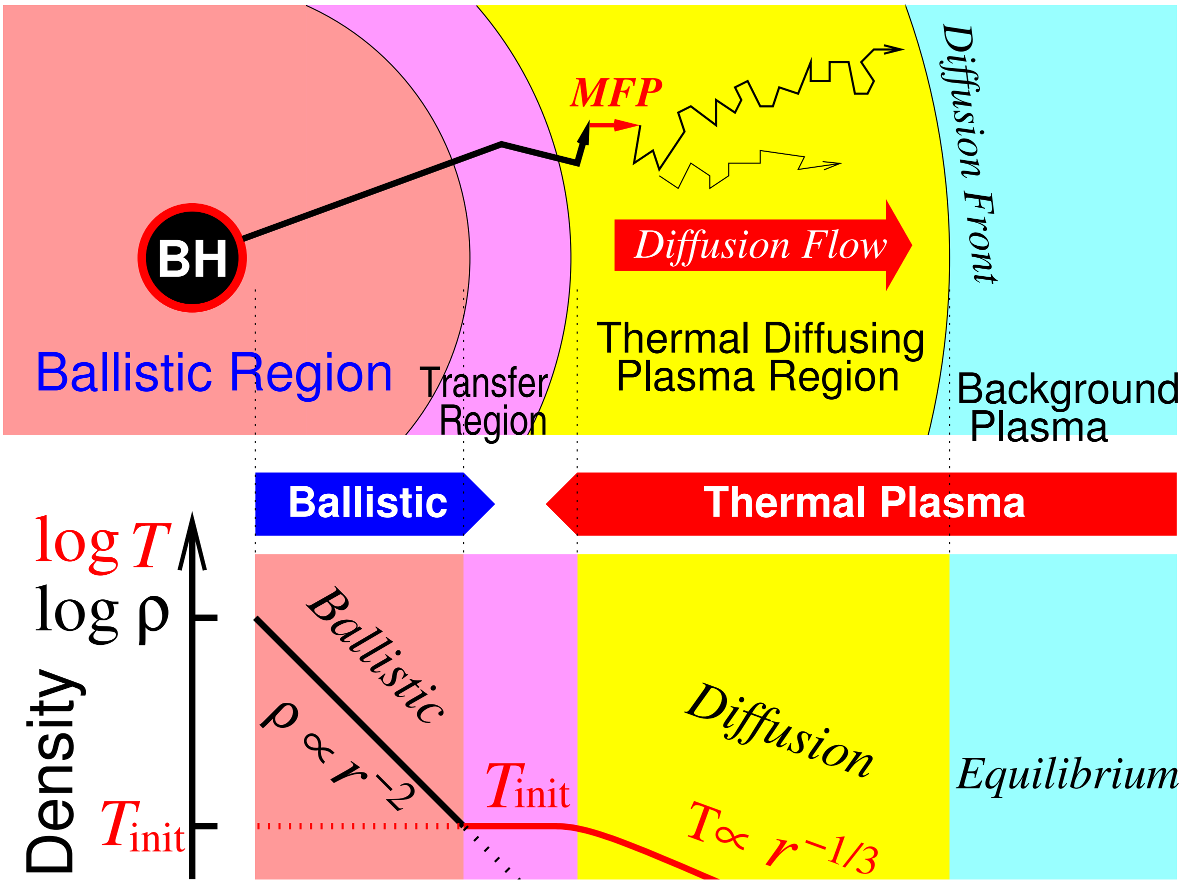
Results from Self-Consistent Analysis:

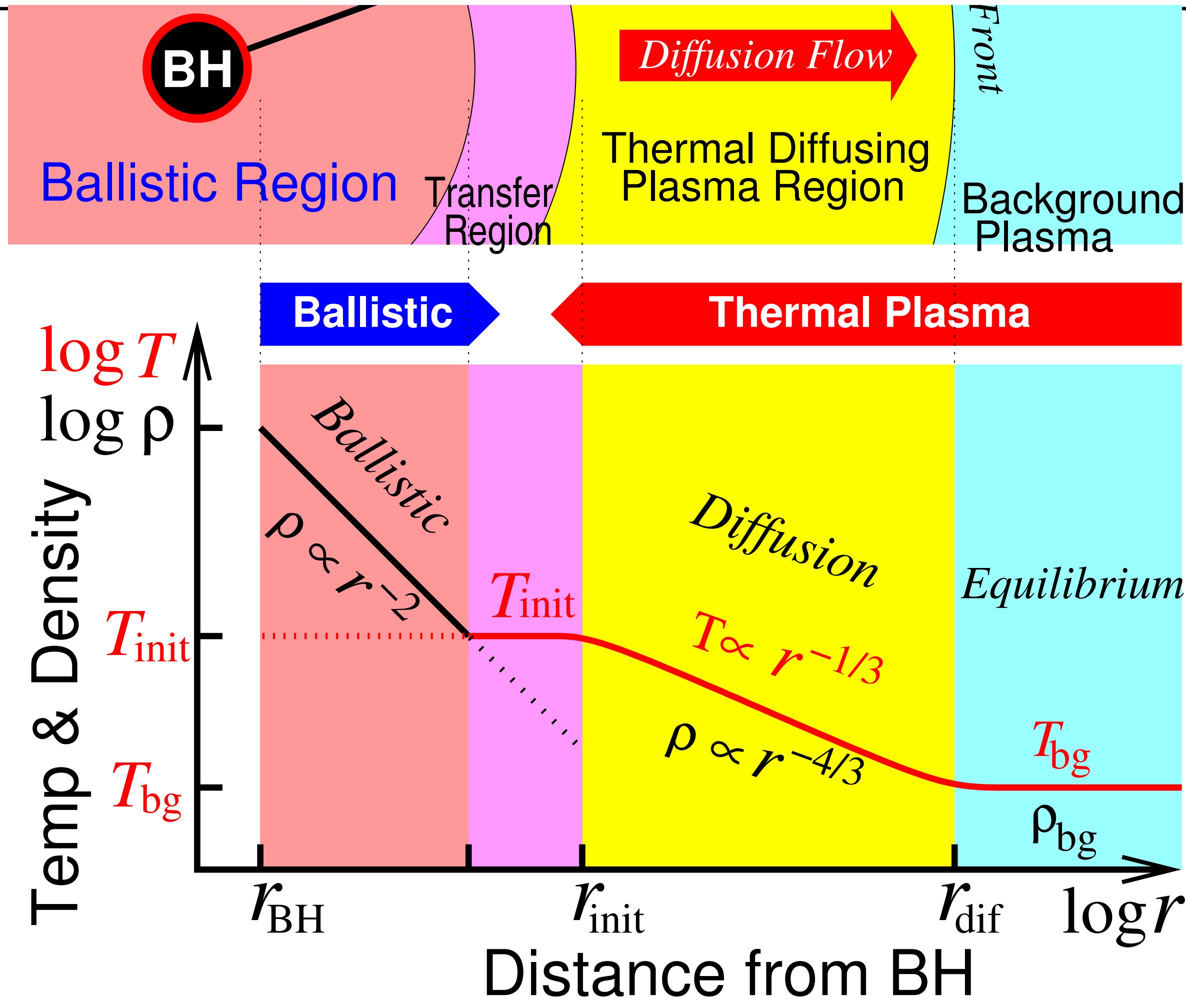
Stationary Initial Thermalization at

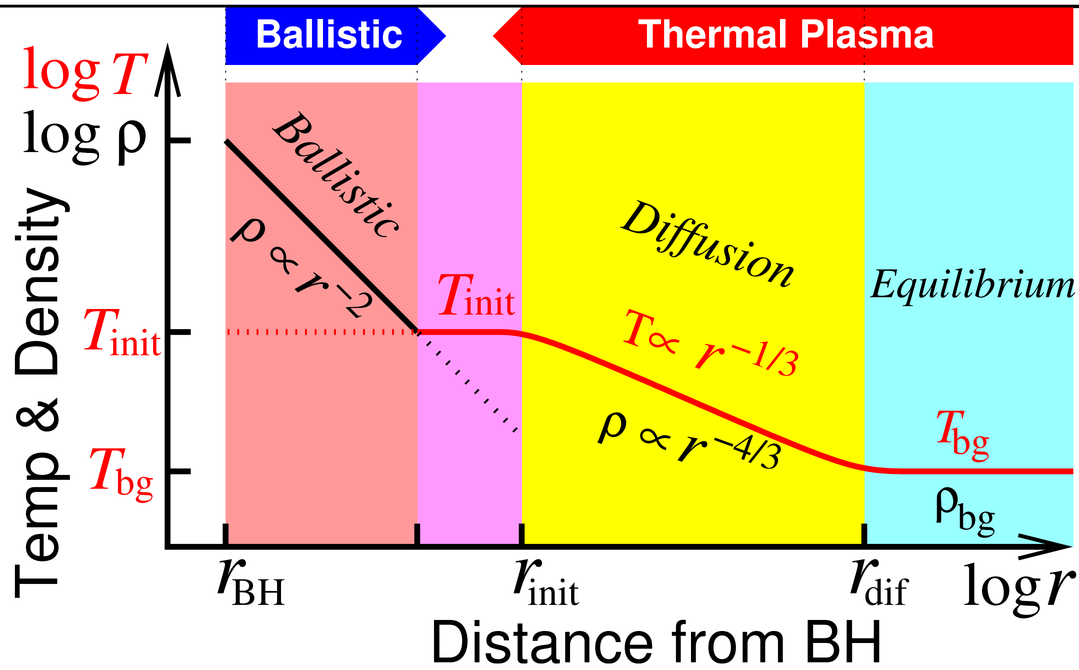
$$T_{\rm init} = \frac{9\zeta(3)}{256\pi^4}\frac{g_*\alpha}{\beta}\, T_{\rm BH} \simeq T_{\rm BH}/(2.3\times 10^4),$$

$$r_{\rm init} = \frac{262144\pi^{11}}{81\zeta(3)^3}\frac{\beta^2}{g_*^3\alpha^3}\, r_{\rm BH} \simeq 5.5\times 10^9\, r_{\rm BH}.$$

8 Overview around a Black Hole







Spherical Electroweak Domain Wall with

1. Thermal Formation $T_{\rm init} > T_{\rm EW} > T_{\rm bg}$
2. Dynamical Formation $T_{\rm BH} > T_{\rm EW} > T_{\rm init}$

9 Electroweak Domain Wall around a BH

L.T.E. Higgs VEV $\langle \phi_i(r) \rangle = \langle \phi_i \rangle_{T=T(r)}$

Black Hole in the EW Broken Phase Plasma

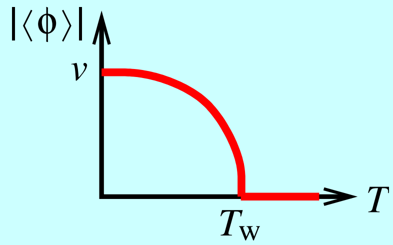
$$T_{\text{init}} > T(r_{\text{near}}) > T_W > T(r_{\text{far}}) > T_{\text{bg}}$$

Sym. Phase /// Broken Phase

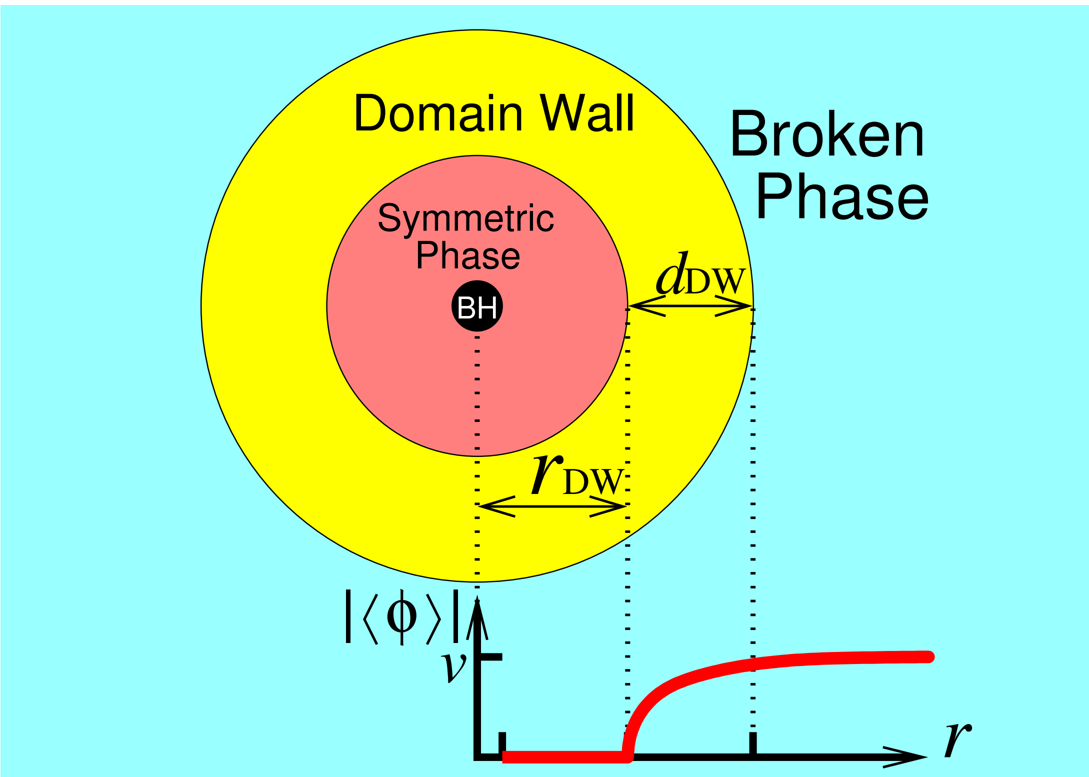
⇒ An Electroweak Domain Wall is formed **without** 1st order phase transition.

Assumption

2nd order Phase Transition
of the Simplest Critical Curve



The Resultant Structure



Domain Wall Radius: $r_{\text{DW}} = \frac{9}{256\pi^2} \frac{1}{\beta c_W} \frac{1}{T_W^3} T_{\text{BH}}^2$

10 Validity of the Wall

I. Stationary Domain Wall Condition

Time Scale of Wall Creation $\ll$ Lifetime of BH

$$\tau_{\mathrm{DW}} = r_{\mathrm{DW}}/v_{\mathrm{DW}}$$

$$1 \ll \tau_{\mathrm{BH}}/\tau_{\mathrm{DW}} = (5\cdot 2^{20}\pi^2/3^6 g_*)\,\beta^3 c_W^3\,(m_{\mathrm{pl}}^2 T_W^5/T_{\mathrm{BH}}^7)$$

$$\Longrightarrow \quad T_{\mathrm{BH}} < 1.4\times 10^8\ \ \mathrm{GeV} \qquad (m_{\mathrm{BH}} > 76\ \mathrm{kg})$$

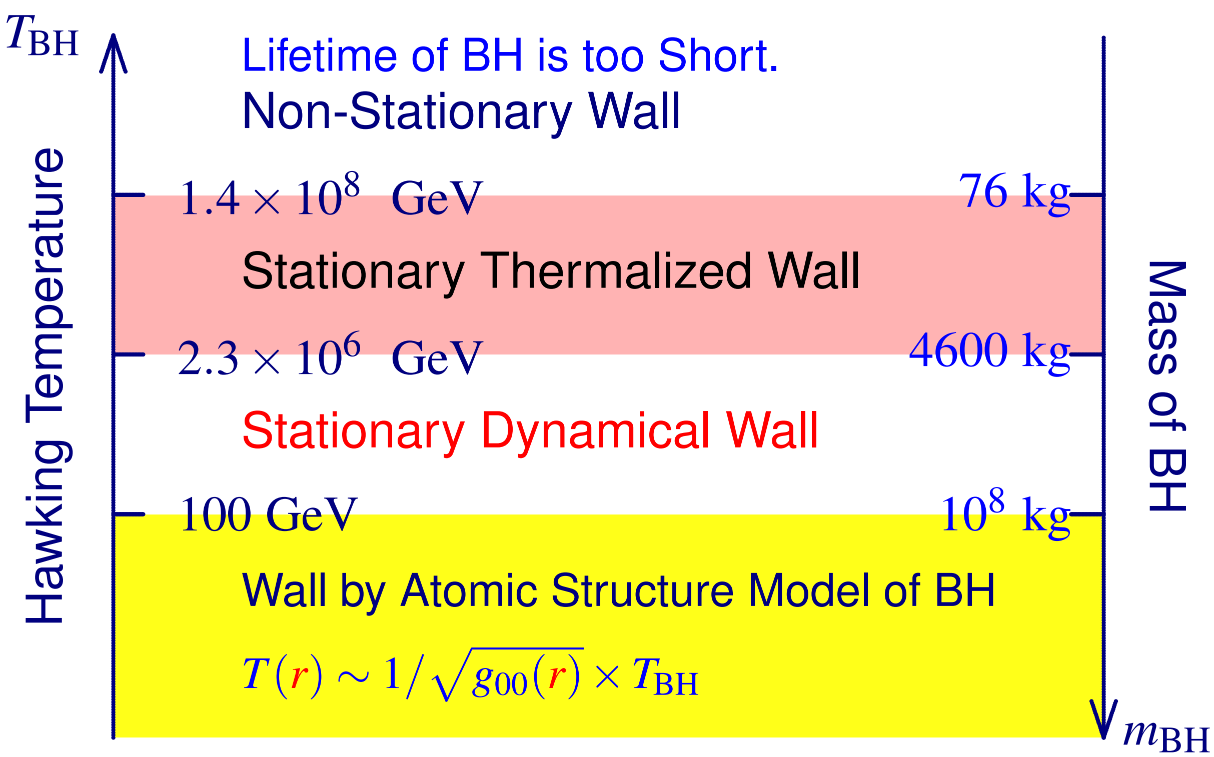
II. Thermalized Wall Condition

Thickness of Wall $\gg$ Heating-up Depth

$$1 \ll r_{\mathrm{DW}}/r_{\mathrm{init}} = (9\zeta(3)/256\pi^4)\,(g_*\alpha/\beta)\,(T_{\mathrm{BH}}/T_W)$$

$$\Longrightarrow \quad T_{\mathrm{BH}} > 2.3\times 10^6\ \ \mathrm{GeV} \qquad (m_{\mathrm{BH}} < 4600\ \mathrm{kg})$$

Allowed Regions



11 Baryon Number Creation by a BH

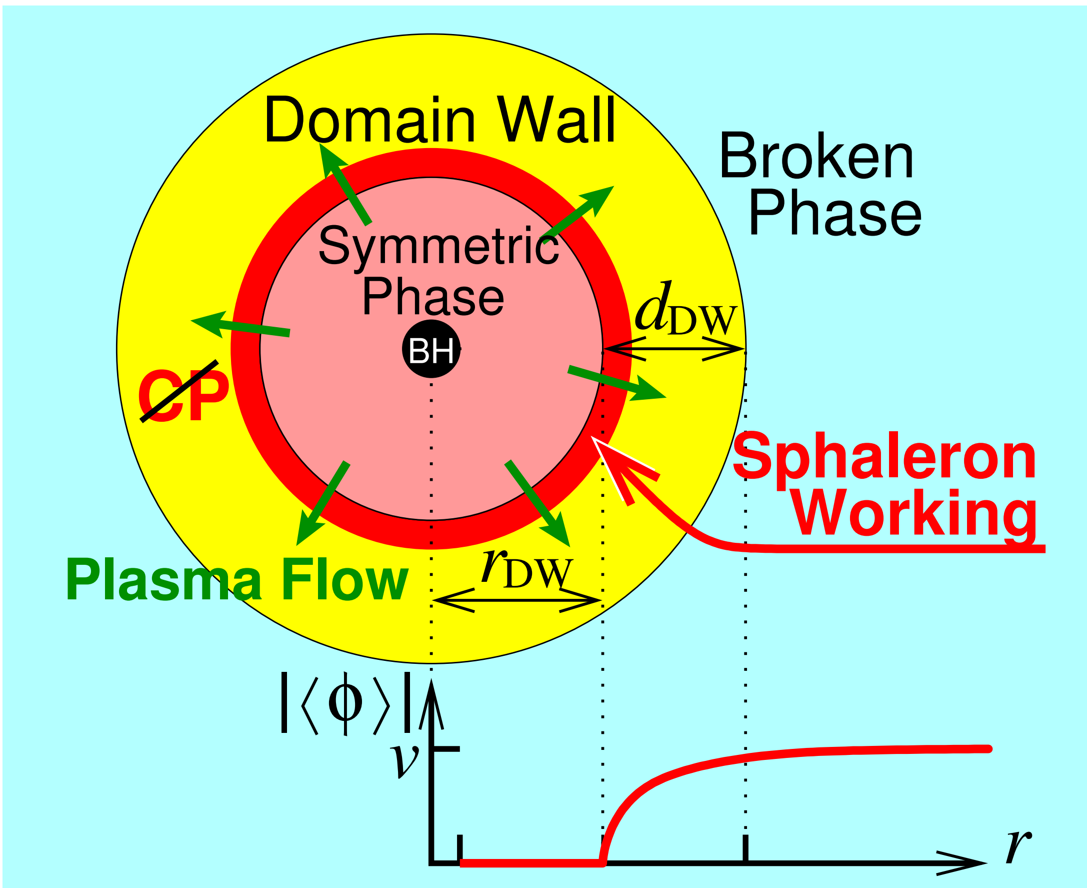
Assume ~~CP~~ Phase $\Delta\theta_{\mathrm{CP}}$ in Wall:

$$\langle\phi(r)\rangle = v f(r)\, \exp\left[\, i\Delta\theta_{\mathrm{CP}}(1 - f(r))\, \right]$$

Sakharov's 3 Criteria for Baryogenesis

1. ~~Baryon~~ : Sphaleron Process in the SM
2. ~~C~~ : The SM is Chiral Theory
   ~~CP~~ : Extension of the SM
   Assume more than 2 Higgs Doublets
3. Non-Equilibrium : **Plasma Flow** from the BH

Sakharov's Criteria around a BH



12 Amount of Baryon Number Creation

Thermalized Wall (M.F.P. $< d_{\rm DW}$)
$\Leftrightarrow$ Thick Wall $\Rightarrow$ Spontaneous Baryogenesis by CKN

CPv Phase on Plasma Flow:

$$\frac{d}{dt}\theta_{\rm CP} = v_{\rm DW}\,\frac{d}{dr}\theta_{\rm CP}$$

$\Rightarrow$ Baryon # Chemical Potential:

$$\mu_B \;=\; \mathcal{N}\,\tfrac{d}{dt}\theta_{\rm CP} \;=\; \mathcal{N}\,v_{\rm DW}\,\tfrac{d}{dr}\theta_{\rm CP}$$

c.f. Thin Wall / Charge Transport Scenario $\rightarrow \mu_B = \tilde{\mathcal{N}}\;Y/T^2$

Sphaleron Rate:

$$\Gamma_{\rm sph} \;=\; \kappa\,\alpha_W^5\,T_W^4\,\exp\left[-100\times\frac{\langle\phi(r)\rangle}{v}\right]$$

Baryon # Creation Rate:

$$\dot{B} \;=\; -\int_{\text{Sphaleron Vol.}} dV\,\frac{\Gamma_{\rm sph}}{T_W}\mu_B$$

Total Baryon Number Creation by a BH:

$$B \;=\; \int^{\text{BH lifetime}} dt\,\dot{B} \;=\; -\frac{15}{4\pi^3 g_*}\mathcal{N}\,\kappa\alpha_W^5\;\varepsilon\Delta\theta_{\rm CP}\,\frac{m_{\rm pl}^2}{T_W T_{\rm BH}}$$

$$\simeq\; 10^{-9}\times\Delta\theta_{\rm CP}\,\frac{m_{\rm BH}}{T_W}$$

This result is valid for $76\,{\rm kg} < m_{\rm BH} < 4600\,{\rm kg}$.

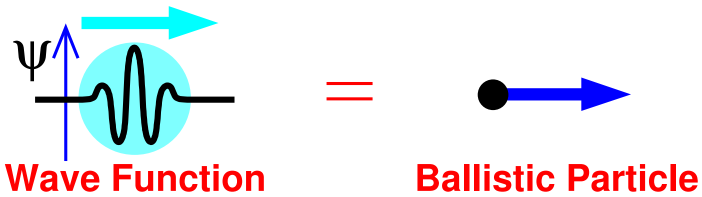
e.g. When the maximum CPv ($\Delta\theta_{\rm CP} = \pi$) is assumed, a black hole of $m_{\rm BH} = 300{\rm kg}$ produces $3\mu{\rm g}$ baryon matter.

13 Ballistic Picture

Hawking radiated particles near a BH:

mean free path $\gg$ system size $>$ wave-length

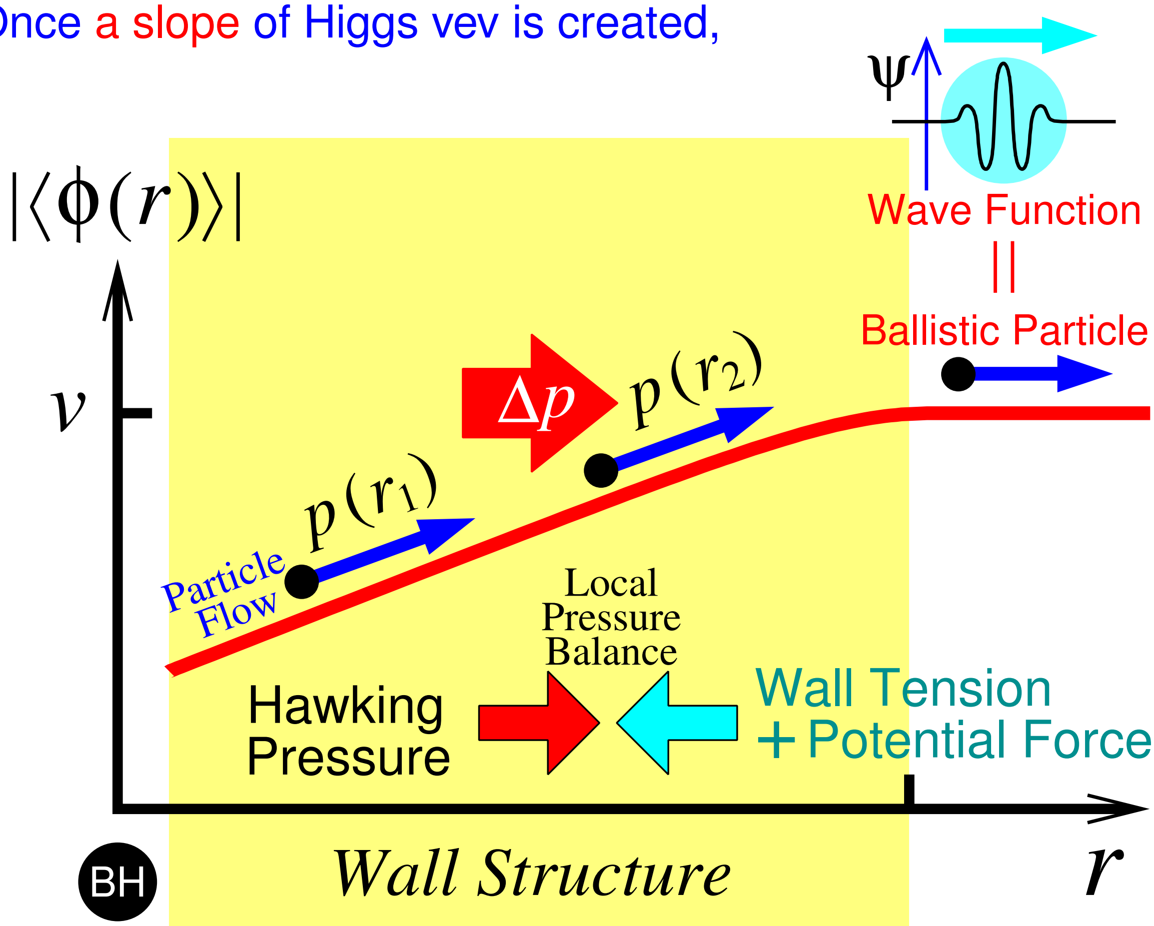
$\Rightarrow$ **Ballistic Picture** of the Radiated Particles

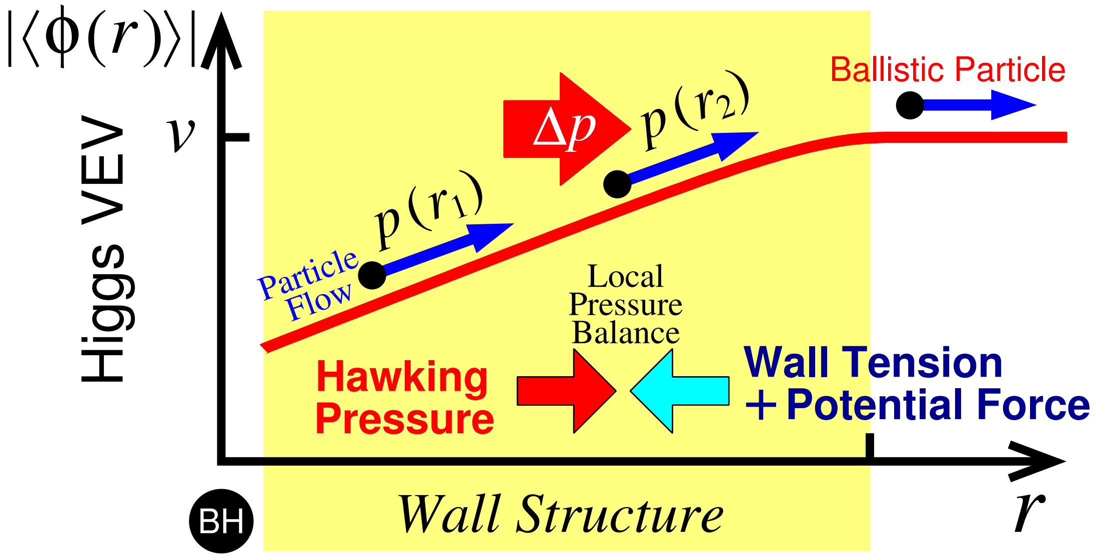


- A BH radiates ballistic point particles.
- The ballistic point particle has mass which is proportional to Higgs vev $|\langle\phi\rangle|$ due to Yukawa/Gauge/Higgs couplings.

is available as an effective description.

Once a slope of Higgs vev is created,





$$p(r) = \sqrt{E^2 - m^2(r)}, \qquad m(r) = Y\,\langle|\phi(r)|\rangle$$

$$\Delta p = p(r_1) - p(r_2) \simeq (m/p)\Delta m$$

$\Rightarrow$ Hawking Radiation Pressure is acting on the wall.

$\Rightarrow$ Balance of the Pressures keeps the Wall Structure.

Idea of Dynamical Wall by a BH.

14 Ballistic Model as an effective theory around a BH

Higgs field $\oplus$ *Massive* Ballistic Particles

$\phi(x)$: Higgs Field

$\{y_i^\mu(s)\}$: Trajectories of the Ballistic Particles

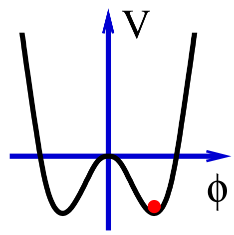
$$S[\phi, y] = \int d^4x\sqrt{g}\left[|\partial\phi|^2 - \tfrac{1}{2}V(\phi)\right] - \sum_i \int ds_i\, Y_i\, |\phi(y_i(s_i))|\, \sqrt{|\dot{y}_i(s_i)|^2}$$

$\sum_i$: sum all over particles around the BH

Y_i : “Yukawa” coupling constant

$V(\phi)$: Higgs Potential

$$V(\phi) = -\mu^2\phi^2 + \frac{\mu^2}{v^2}\phi^4$$



15 Basic Properties of the Ballistic Model

Vacuum: $|\langle\phi\rangle| = v/\sqrt{2}$

Particle Mass in the vacuum: $m_i = Y_i|\langle\phi\rangle| = Y_i v/\sqrt{2}$

$\Rightarrow$ Reproduce relations in Higgs-Yukawa system

e.g. $m_q(x) = Y_q\langle\phi(x)\rangle\,, \quad m_W(x) = \frac{g}{\sqrt{2}}\langle\phi(x)\rangle$

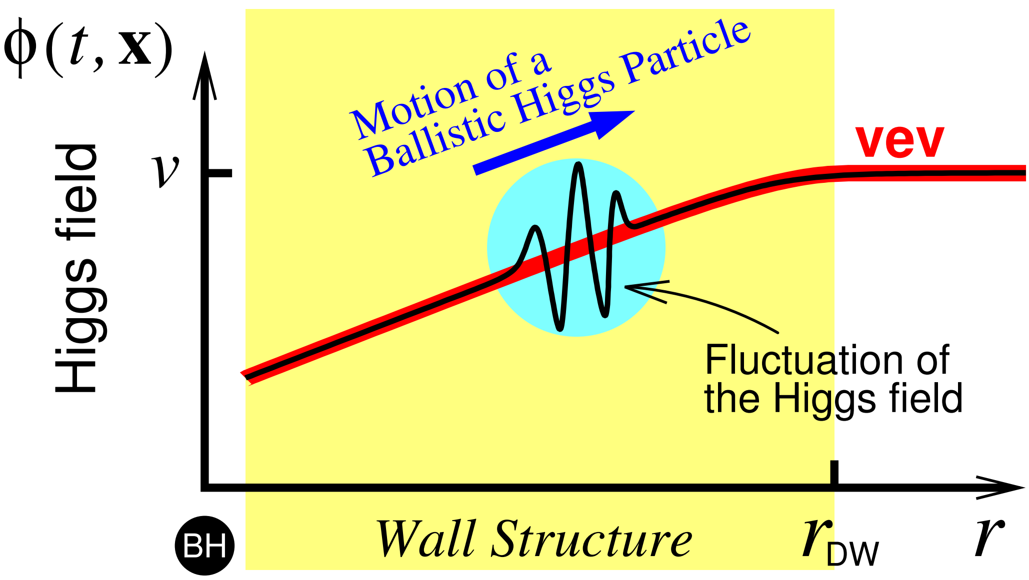
How about Higgs particles itself?

16 Ballistic Higgs Particle

Decomposition of ϕ:

$$\phi(t,\mathbf{x}) = \langle\phi(\mathbf{x})\rangle + \delta\phi(t,\mathbf{x})$$

expect.value prop. mode



$\delta\phi(t,\mathbf{x})$ can be regard as the Ballistic Higgs Particles.

ReDefinition of ϕ and $\{y_i\}$:

$$\begin{aligned} \phi(\mathbf{x}) &\equiv \langle \phi(\mathbf{x}) \rangle \\ \{y_i\} &\equiv \{y_i\} \oplus \{ \textbf{ Ballistic Higgs Particles } \} \end{aligned}$$

Effective Y_i for the Ballistic Higgs Particle:

$$Y_i = \sqrt{3}\,\frac{\mu}{v}$$

All particles in Standard Model
are described by the Ballistic Model.

17 Equations of Motion for $\{y^\mu\}$ and ϕ

EoM for particles: (= Energy Cons. Law)

$$E_i = Y_i\,|\phi(\mathbf{y}_i)|\,\gamma_i\,F(\mathbf{y}_i)$$

EoM for scalar field:

$$-\triangle\phi = -\frac{1}{4}\frac{\partial V}{\partial \phi} - \frac{1}{2}\frac{\partial|\phi|}{\partial\phi}\sum_i \frac{Y_i}{\gamma_i}\,\delta^{(3)}(\mathbf{x}-\mathbf{y}_i(t))$$

Put All Particle Trajectories $\{\mathbf{y}_i\}$ with $\{E_i\}$

$$V_{\text{eff}}(\phi) = V(\phi) + \phi^2 F \sum_i \frac{Y_i^2}{E_i}\,\delta^{(3)}(\mathbf{x}-\mathbf{y}_i(t))$$

Particle Index: $i \Rightarrow$ Species Index: f

By using Differential Particle #-Density: $dE \times \mathcal{N}_f(E;x)$

$$V_{\text{eff}}(\phi) = V(\phi) + \phi^2 F \sum_f Y_f^2 \int \frac{dE}{E} \mathcal{N}_f(E;x)$$

Around a BH with Temperature T_{BH} and Radius r_{BH}, $\mathcal{N}_f(E;x)$ is produced by the Hawking Radiation:

$$dE\,\mathcal{N}_f = \frac{1}{4}\frac{g_f}{(2\pi)^3} f_{T_{\text{BH}}}(E)\, 4\pi E^2 dE \times F^{-1}\left(\frac{r_{\text{BH}}}{r}\right)^2$$

$$f_{T_{\text{BH}}}(E) := \frac{1}{e^{E/T_{\text{BH}}} \pm 1} \quad \text{F.D. or B.E.}$$

Approx. Backreaction is Ignored.

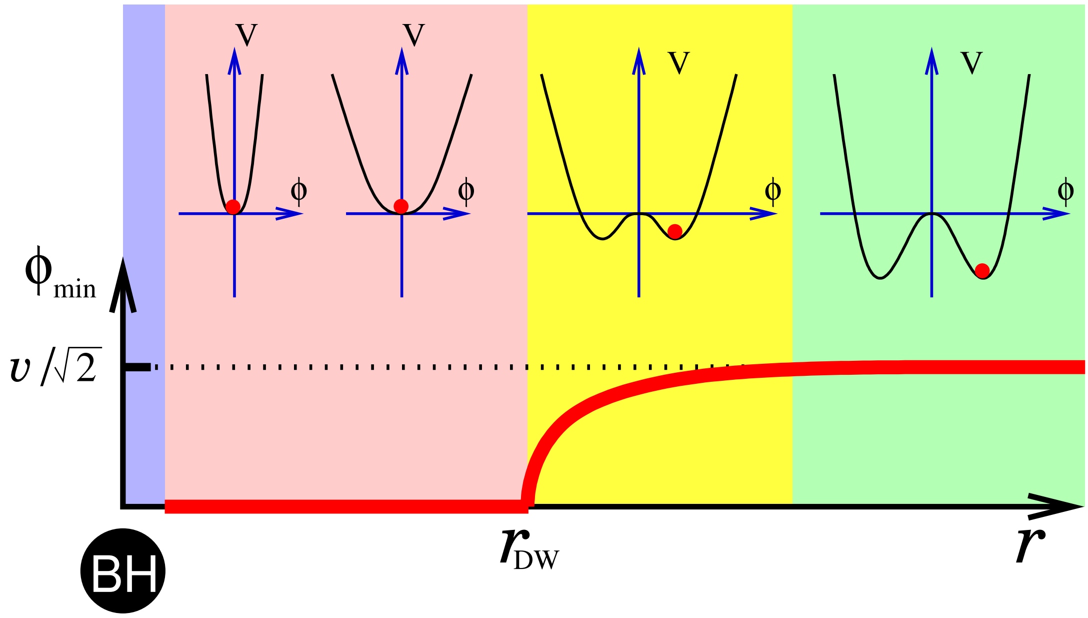
18 Effective Potential around a BH

$$V_{\text{eff}}(\phi, r) = \left(-\mu^2 + \frac{A^2}{r^2}\right)\phi^2 + \frac{\mu^2}{v^2}\phi^4$$

$$A^2 \equiv \frac{1}{768\pi}\sum_f \tilde{g}_f Y_f^2, \qquad \tilde{g}_f = \begin{cases} g_f & (f:\text{boson}) \\ \frac{1}{2}g_f & (f:\text{fermion}) \end{cases}$$

e.g. SM $A^2 \simeq \frac{1}{200}$, SU(5) GUT $A^2 \simeq \frac{1}{60}$

Distribution of the Effective Potential



Characteristic Radius of Wall: $r_{DW} \equiv A/\mu$

Condition for Wall Formation: $r_{DW} > r_{BH}$

$$T_{BH} > T^*_{BH} \equiv \frac{\mu}{4\pi A} \simeq \mu$$

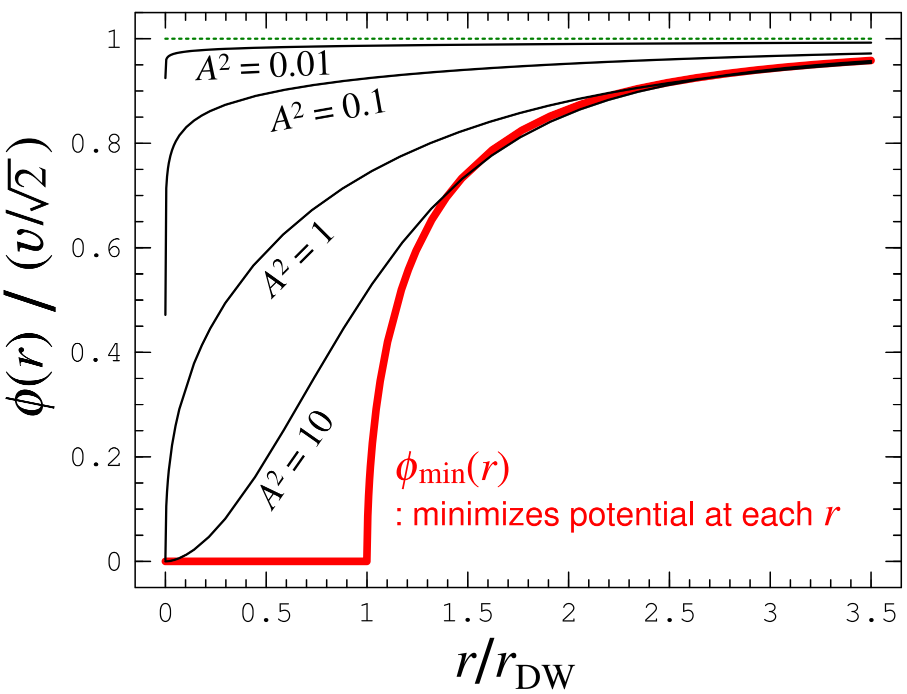
e.g. SM $T^*_{BH} \simeq 100$ GeV, GUT $T^*_{BH} \simeq 10^{16}$ GeV

19 Profile of the Wall

Equation for Higgs vev:

$$\Delta\phi(r) = \frac{1}{4}\frac{\partial}{\partial\phi}V_{eff}(\phi, r)$$

Numerical Solutions:



Contributions to the Profile:

Hawking Pressure	$\propto \mathcal{F}\,\Delta p$	$\propto +1/r^2$
Potential Energy	$\propto \partial_r V/S$	$\propto -\text{const.}$
Wall Tension	$\propto \partial_r S/S$	$\propto -1/r$

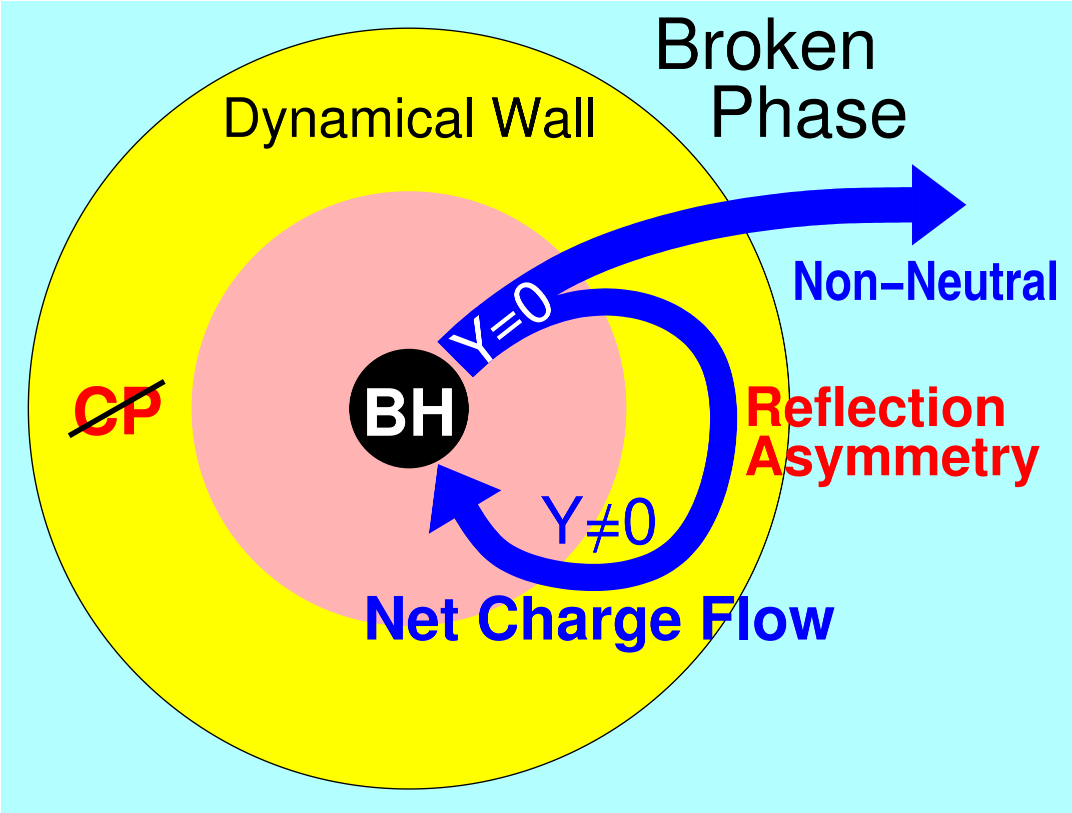
20 Spontaneous Charge-up of BH

as an application of the Dynamical Wall

Assumptions

1. C-violated Theory: Chiral Charge Assignment
2. CP-broken Phase in the Wall : $\Delta\theta_{\mathrm{CP}}$

⇒ (Hyper) Charge Reflection Asymmetry on the Wall



⇒ **Charge Transportation into the Black Hole**

⇒ **Spontaneous Charge-up of the Black Hole**

21 Charge Transportation Rate into BH

Charge Transportation Rate:

$$\frac{dQ}{dt} = \sigma_{\rm BH} \times C_{\rm fcs} F_Q$$

$\sigma_{\rm BH}$: Absorption Cross Section for the B.H.

$C_{\rm fcs}$: Focusing Factor by Spherical Reflection

Charge flux at the wall structure:

$$F_Q = \sum_{f \in \rm Fermions} \int_{E>m_f} dE\, \mathcal{N}_f(E; r_{\rm DW})\, \Delta Q_f\, \Delta R_f(E)$$

$$\Delta Q_f \equiv Q_{f_L} - Q_{f_R}$$

$$\Delta R_f(E) \equiv R_{f_R \to f_L}(E) - R_{\bar{f}_R \to \bar{f}_L}(E)$$

The ref. asym. ΔR_f depends on $\begin{cases} \text{CPv-Phase: } \Delta\theta_{\rm CP} \\ \text{Wall Profile} \end{cases}$

and is calculated *numerically*.

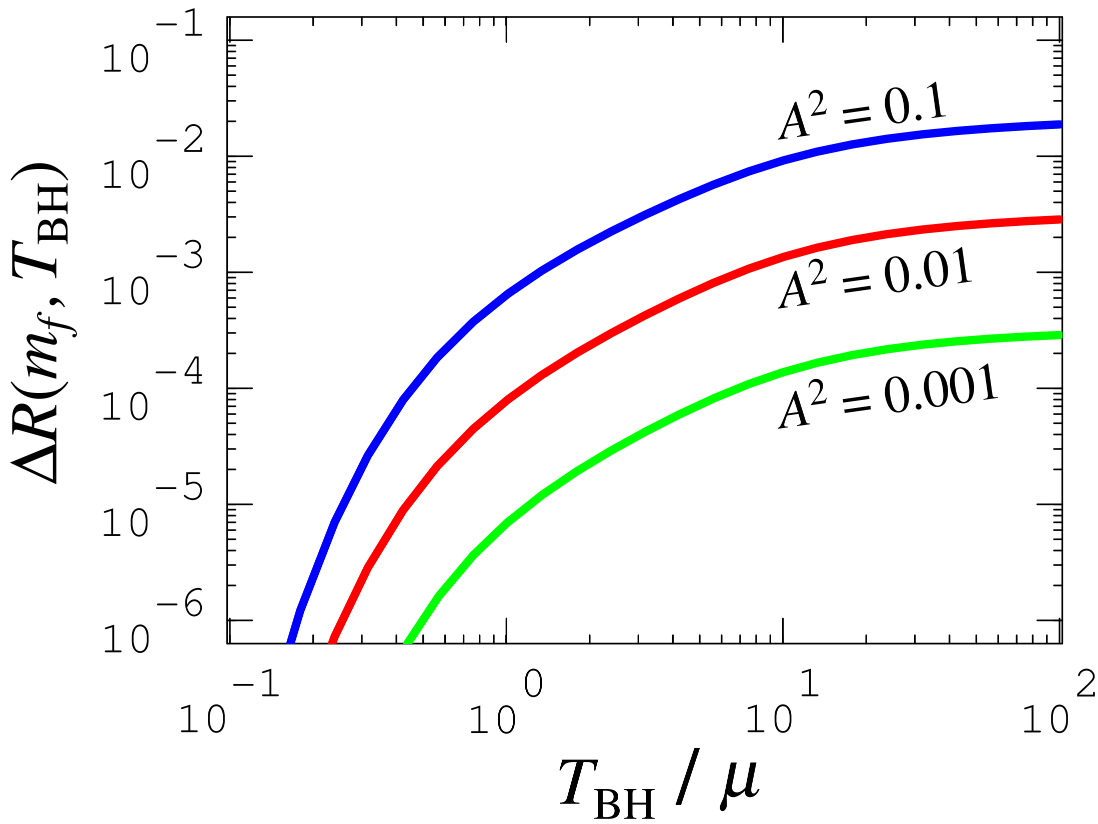
The charge flux is rewritten into:

$$F_Q = \sum_f g_f \Delta Q_f m_f^3 \Delta\mathcal{R}(m_f, T_{\rm BH})$$

Assume CP-broken Phase Profile:

$$\langle \phi(r) \rangle = f(r) \times \exp\left[i\, \Delta\theta_{\rm CP} \left(1 - \frac{f(r)}{f(\infty)} \right) \right]$$

e.g.) Numerical Results for $\Delta\theta_{\rm CP} = \pi$ and $m_f = \mu$:



22 The Total Charge Transported into a BH

of the Hawking temperature $T_{\rm BH} < \mu$, in its lifetime:

$$Q = \int^{\tau_{\rm BH}} dt \frac{dQ}{dt} \simeq 10^{-5} \times \frac{\Delta\theta_{\rm CP}}{\pi} \frac{m_{\rm pl}^2}{\mu^2} \sum_f \frac{g_f \Delta Q_f Y_f}{g_*}$$

GUT: $\mu \simeq 10^{16}$ GeV $\quad Q \simeq O(1) \times \Delta Q\, \Delta\theta_{\rm CP}$

SM: $\mu \simeq 100$ GeV $\quad Q \simeq 10^{25} \times \Delta\theta_{\rm CP}$ Hyper Charge

In the SM, the top quark $(g_{\rm top} = 3,\ \Delta Q_{\rm top} = 1/2,\ Y_{\rm top} \simeq 1)$ mainly contributes.

Even for highly suppression of the KM-phase in the SM: $\Delta\theta_{\rm CP} \sim 10^{-19}$, this can be significant.

Spontaneous Charge-up of Black Hole

$\Rightarrow$ Extremal Black Hole?

Charged Remnant of BH??

after Hawking Radiation.

vs. Schwinger Pair Production,

Spontaneous charge loss of BH.

23 Electroweak Baryogenesis

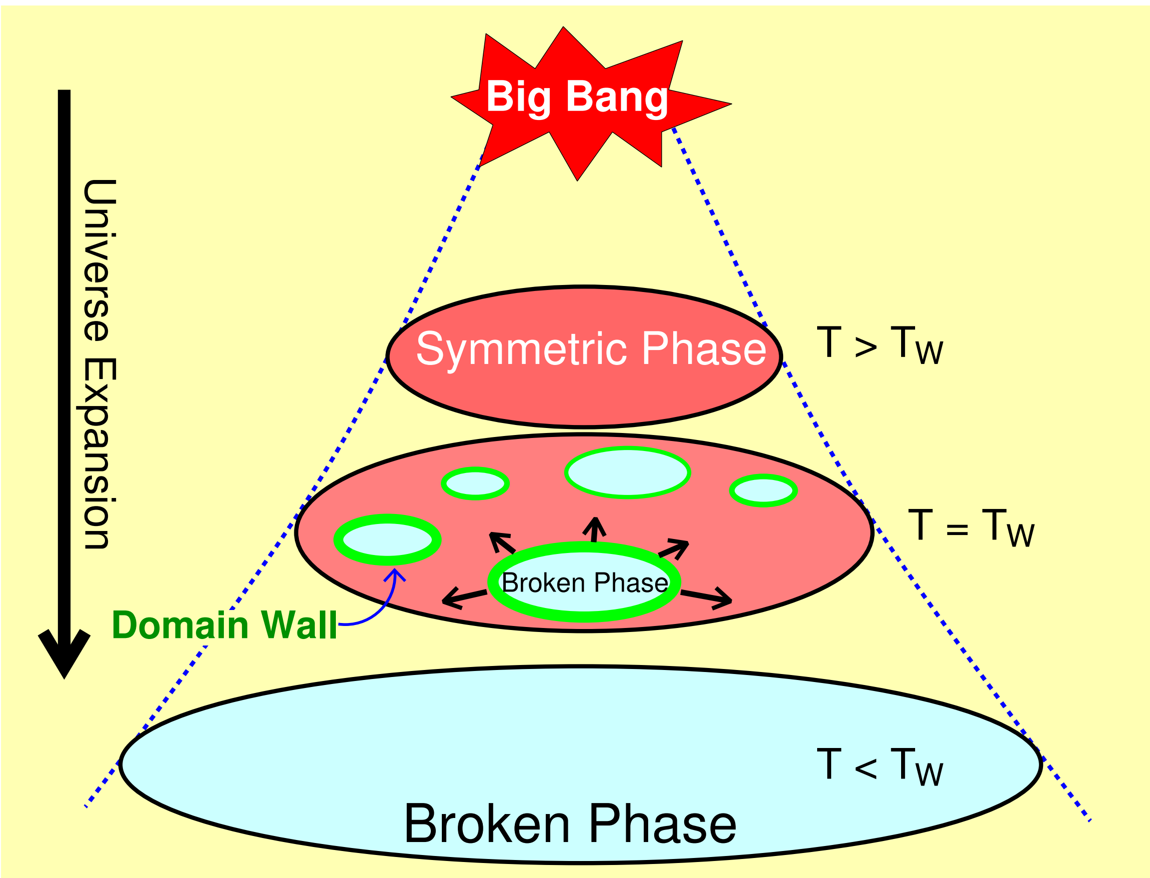
proposed by Cohen Kaplan Nelson (1990).
This can explain the baryon number in the universe:

$$B/S \simeq 10^{-10}.$$

Sakharov's 3 Criteria for Baryogenesis

1. ~~Baryon~~ : Sphaleron Process in the SM
2. ~~C~~ : The SM is Chiral Theory
   ~~CP~~ : Extension of the SM:
   Assume more than 2 Higgs Doublets
3. Non-Equilibrium :
   Assume EW Phase Trans. is **1st order**.

Scenario of the Electroweak Baryogenesis



Our Scenario of the Universe

Assumption

(i) Formation of Black Holes with mass:

$$m_{\rm BH} \sim m_{\rm pl}(m_{\rm pl}/T_W)^{2/3} \simeq \text{Some}\,100\,\text{kg}$$

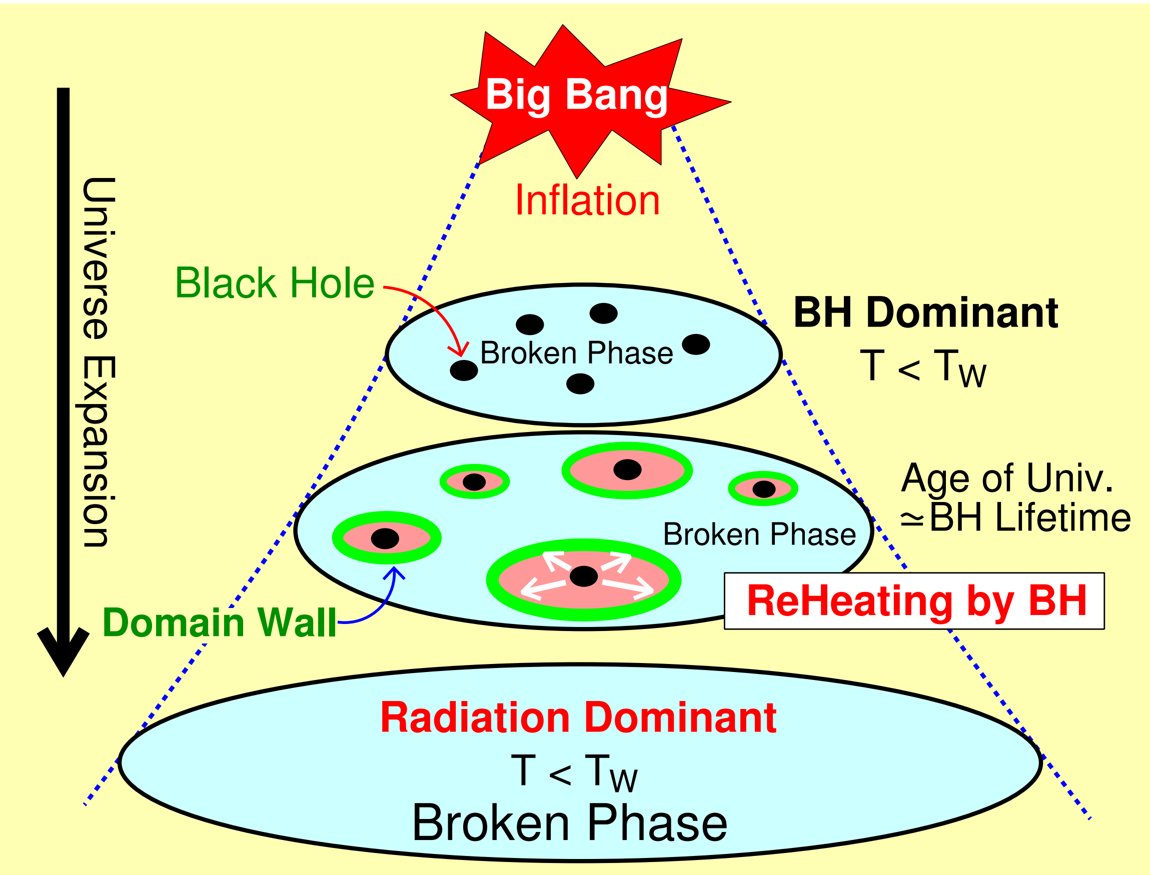
at least density: $\Omega_{\rm BH} \sim 10^{-10}$

after inflation: $t_{\rm univ} \simeq 10^{-33}\,\text{sec}$ ⇑ Horizon Mass

(ii) CPv Phase in Wall : $\Delta\theta_{CP} \sim O(1)$

The assumption (i) results **the Black Hole Dominant Universe** at $t_{\rm univ} \sim \tau_{\rm BH} \sim 10^{-12}\,\text{sec}$.

Our Scenario of the Universe



Baryon Entropy Ratio in the Scenario

BH Mass $\longrightarrow$ BH Life Time $\equiv$ Age of Univ.

(Einstein Eq.) $\downarrow$

Energy Density of BH

$\|$

Energy Density of Rad.

$\downarrow$

ReHeating Temp. of Univ.
Entropy Density

BH Mass $\downarrow$ BH # Density $\Downarrow$ (**CP**) Baryon # Density

Baryon-Entropy Ratio in the Universe

$$b/s \simeq 10^{-9} \times \frac{\Delta\theta}{\pi} \frac{T_{\rm ReHeat}}{T_W}$$

Results of the Scenario

$$m_{\rm BH} \sim m_{\rm pl}(m_{\rm pl}/T_W)^{2/3}$$
$$\simeq 270 \sim 400 \text{ kg}$$
$$\Rightarrow T_{\rm ReHeat} \lesssim 100 \text{ GeV}$$
$$\Rightarrow b/s \sim 10^{-10}$$

This Satisfies the Restrictions:

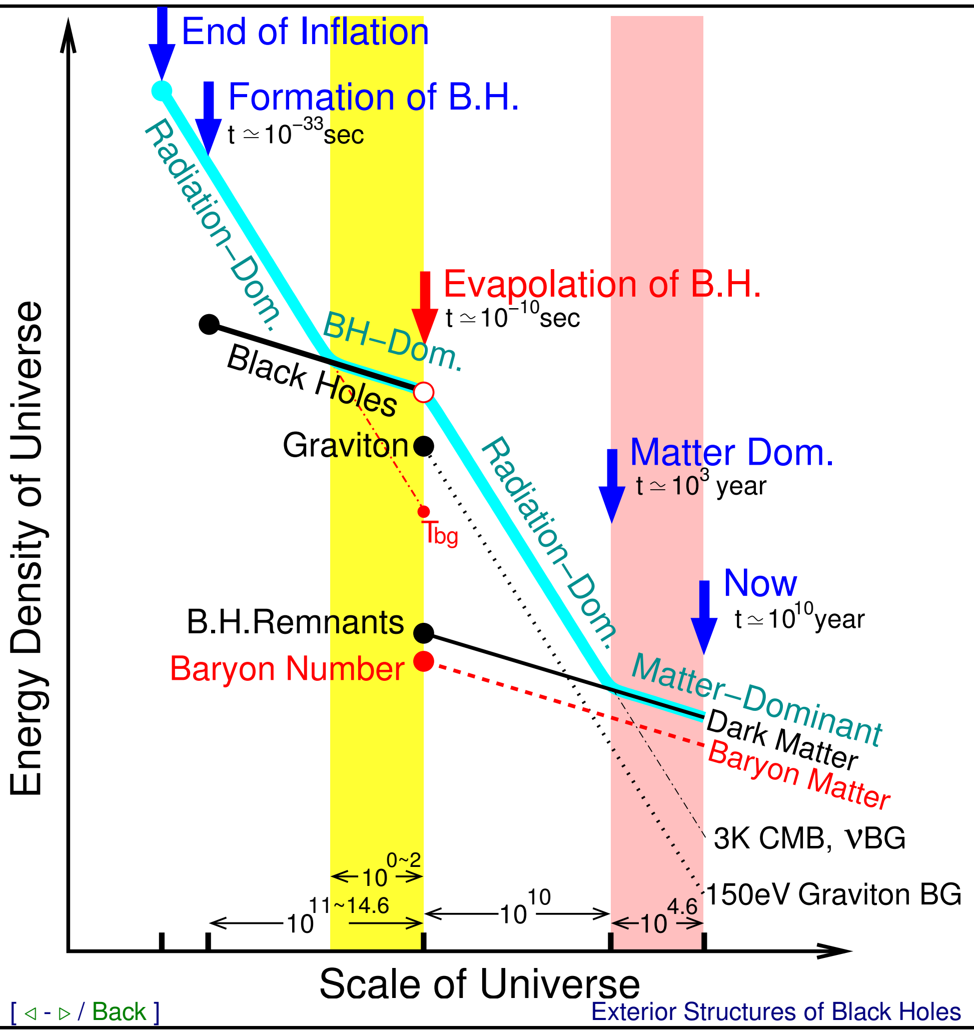
(1) No Wash out: $T_{\rm ReHeat} < T_W$

(2) Nucleosynthesis: $T_{\rm ReHeat} > 10$ MeV & $b/s \simeq 10^{-10}$

(3) Stationary Thermalized Wall Condition:

$$76 \text{ kg} < m_{\rm BH} < 4600 \text{ kg}$$

Density History of the Universe



Cold Dark Matter

Assumption

After the end of evaporation of the black holes,
any black hole left **a Remnant** with a Planck mass.

⇒ The BH Remnants behave as Cold Dark Matter.

Mass of Baryon and Dark Matter produced by a BH:

$$M_B = B\, m_{\rm Nuc} \simeq 10^{-11} \times m_{\rm BH} \simeq 3\mu g$$
$$m_{\rm DM} = \alpha\, m_{\rm pl} \simeq 20\mu g$$

Density Ratio of Dark Matter and Baryon in the Univ.:

$$\rho_{\rm DM}/\rho_B = m_{\rm DM}/M_B \simeq 20 \cdot 10^{11} \times (T_W/m_{\rm pl})^{2/3} \simeq 10$$

c.f.) According to the recent observations:

$\Omega_B \simeq 0.04$ (BBN, CMB, $\cdots$)

$\Omega_{\rm DM} \simeq 0.3$ (CMB, IaSN, $\cdots$)

Our model can explain both the baryon number and the dark matter in the universe.

Remnants number density near the Earth:

$$n_{\rm DMnear} = \rho_{\rm DMnear}/m_{\rm DM} \simeq (1/35\ {\rm km})^3$$

Remnants flux on the Ground:

$$\mathcal{F}_{\rm DMnear} = n_{\rm DMnear} \times v_{\rm DM} \simeq 0.2/{\rm m}^2\ {\rm year}$$

$$\begin{cases} \rho_{\rm DMnear} = 0.3\ {\rm GeV/cm}^{-3}, \\ v_{\rm DM} \simeq 260\ {\rm km/sec} \end{cases}$$

The detectability of the DM is depending on properties of the BH remnant.

24 Does the BH Remnant exist? If it does, what is it??

Will be solved by Quantum Gravity or String Theory.

- Zel'dovich 1984
  Uncertainty Principle: $\Delta m_{\rm BH} \times \Delta r_{\rm BH} > \hbar/2$
  $\Rightarrow m_{\rm BH} > m_{\rm pl}$
  $\Rightarrow$ Hawking Radiation stops at $m_{\rm BH} \simeq m_{\rm pl}$.
- Aharonov Casher Nussinov 1987,
  Banks Dabholker Douglas Loughlin 1992, $\cdots$:
  Information goes to a remnant
  $\Rightarrow$ Very long-lived remnant with a mass $O(m_{\rm pl})$

- Gibbons Maeda 1988, Torii Maeda 1994
  Reissner-Nordström B.H. goes to extremal.
  $\Rightarrow$ Hawking Radiation stops at $m_{\rm BH} \simeq O(m_{\rm pl})$.

⋮

Our Result:
A neutral BH can evolve into a charged BH.

Discussion:
The BH Remnant may be a few-charged extremal BH with $m_{\rm pl}$?

Black Atom as Dark Matter

If the remnant has electric charge Z,
it captures opposite charged particles
and forms atomic structure.

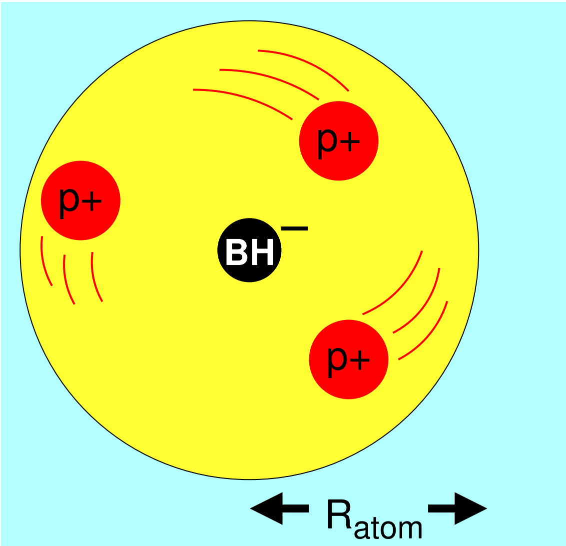
$Z > 0$ The remnant captures electrons,
and forms the $\mathrm{ExBH}^{(+)} - e^-$ atom.

$R_{\mathrm{atom}} \sim \alpha_{\mathrm{em}}/m_e \sim 1$ Å

The flux of them as the Dark Matter is excluded by the experiments. [MICA, OYA, $\cdots$]

$Z < 0$ The remnant captures protons,
and forms the $\mathrm{ExBH}^{(-)} - p^+$ atom

$R_{\mathrm{atom}} \sim \alpha_{\mathrm{em}}/m_p \sim (7\ \mathrm{MeV})^{-1}$



Radius is 1/2000 of ordinary atom.

Not excluded by the experiments.

$\Rightarrow$ **Black Atom**

Ionization Energy of the Black Atoms:

$$E_{\rm ion} \simeq \alpha^2 m_p/2 \sim 25 \text{ keV}$$

c.f.) the ordinary atomic ionization energy ~ 13.6 eV

DM velocity: $v_{\rm DM} \sim 300$ km/ sec

Kinetic Energy of Nucleus into the Black Atom:

$$E_{\rm N} \simeq N m_p v_{\rm DM}^2/2 \sim 0.5N \text{ keV}$$

The nucleon heavier than $N \simeq 50$ can ionize the Black Atoms.

We can detect by experiment ??

The Underground elements:

$^{16}_{8}$O (50%), $^{28}_{14}$Si (25%), $^{27}_{13}$Al (8%), $^{56}_{26}$Fe (5%), $^{40}_{20}$Ca (3%), $\cdots$

Lifetime of the Black Atom

If the central remnant captures the protons,
the remnant may decay like the positronium-decay.

The capture crosssection to ExBH: $\sigma = 16\pi r_{\rm BH}^2$.

A very rough estimation of the lifetime:

$$\tau = \left[\frac{1}{\pi R^3}\sigma v_p\right]^{-1} = \frac{1}{32(Z\alpha)^4}\frac{m_{\rm pl}^2}{m_p^3}$$

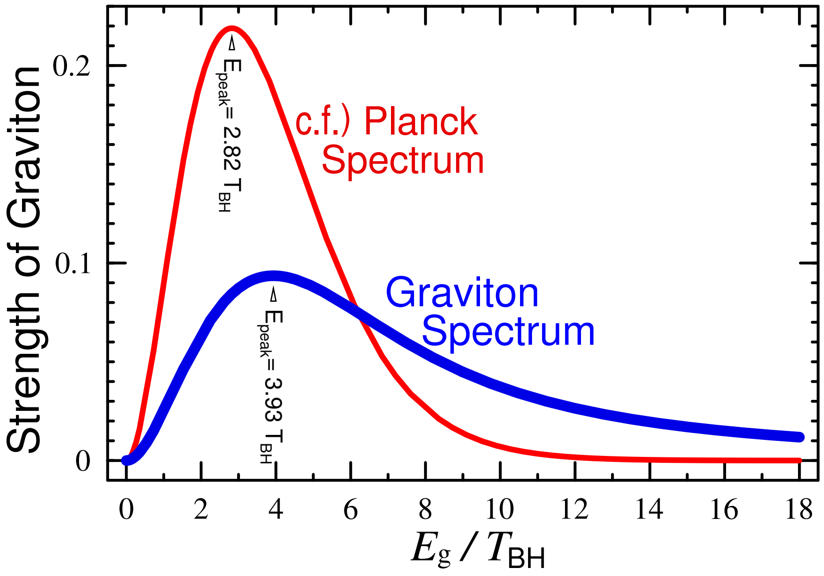
$$\tau \gtrsim 10^{10} \text{ year} \Leftrightarrow Z \lesssim 8$$

age of univ.

$\Rightarrow$ The Black Atoms can be source of
the Ultra High Energy Cosmic Ray?

Cosmological Graviton Background

The black holes also radiate gravitons with $E_g \sim T_{BH}$.



Our model predicts **the Cosmological Graviton BG**:

Energy Density : $\rho_g = \rho_{CMB}/82.2$

Peak Energy : $E_{peak} = 120 \sim 280$ eV

Summary

1. Spherical Domain Wall Formation by BH

	Electroweak	GUT
Thermal	○	×
Dynamical	○	○

2. Baryogenesis by BH (BH&SM&CP)
3. Spontaneous Charge-up of BH (BH&SM/GUT&CP)
4. Cosmological Model by the BH dominant scenario
   - ⊙ Baryogenesis
   - ⊙ Dark Matter
   - ⊙ Graviton BG: $E_g \sim 150$ eV, $\rho_g \simeq \rho_{CMB}/82$

Works to Do

- Origin of the CP-Broken Phase
- Origin of the Black Holes
  - Inflation [Yokoyama '97] [Kawasaki et al '98]
  - 1st Order Phase Transition
- Remnant of the Black Hole

  Charged BH? Weak? Electric? GUT?
  $\Rightarrow$ Planck-massive Extremal BH?
  $\Rightarrow$ Charged Heavy Dark Matter?