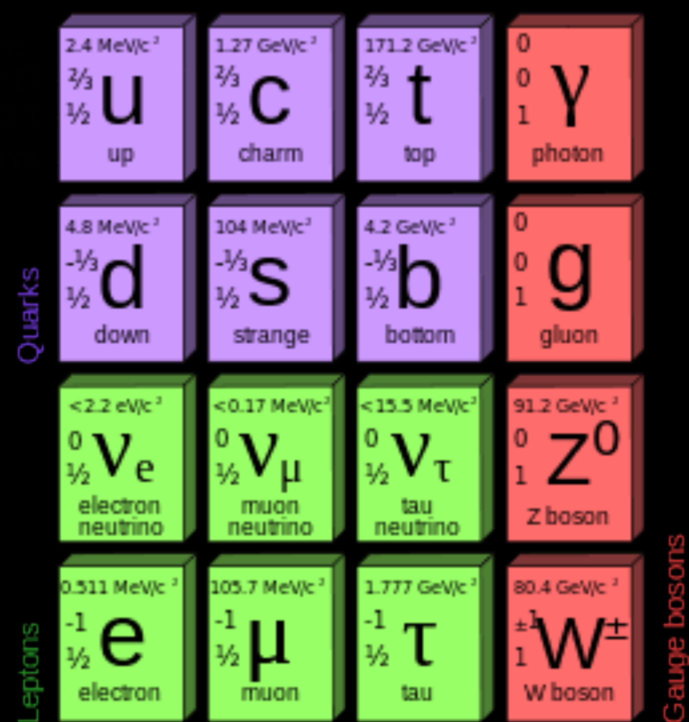
How are we saved from complete annihilation?

Graham White

Based on 2105.11655 (prl) 1908.03227 (prl) 1903.08658 (JHEP) 2111.08750
JHEP (2009.10080) (new) 2206.01120 (to appear) 2208.xxxx (to appear) 2210.xxxx

What about the Universe is known



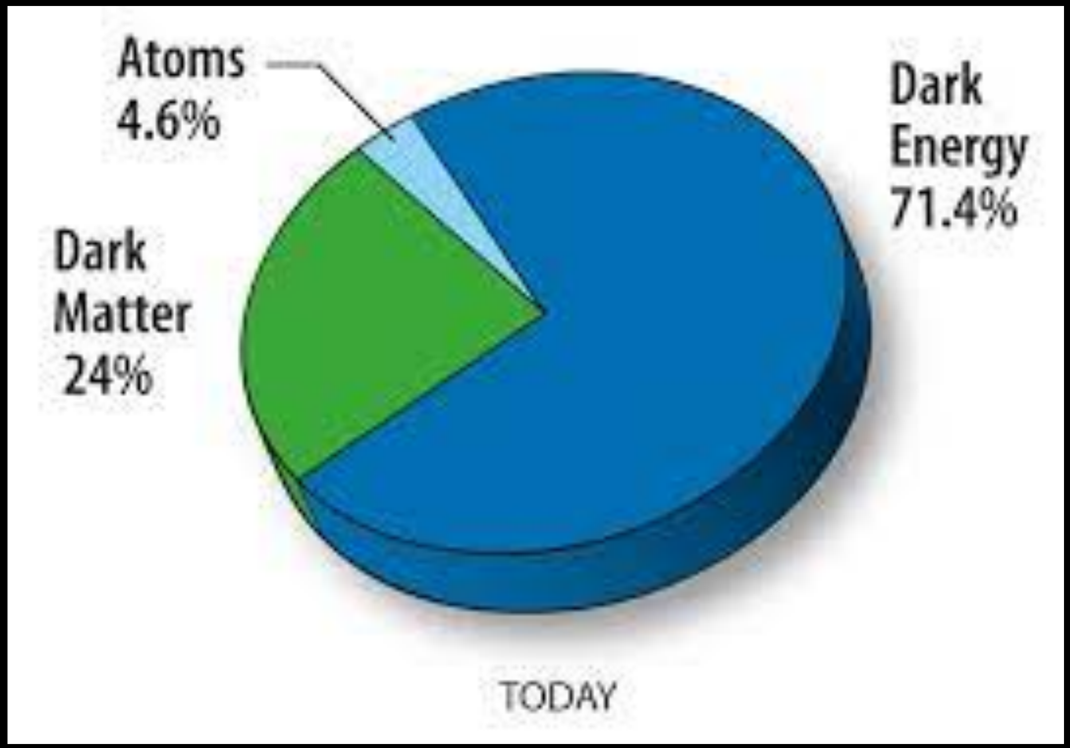
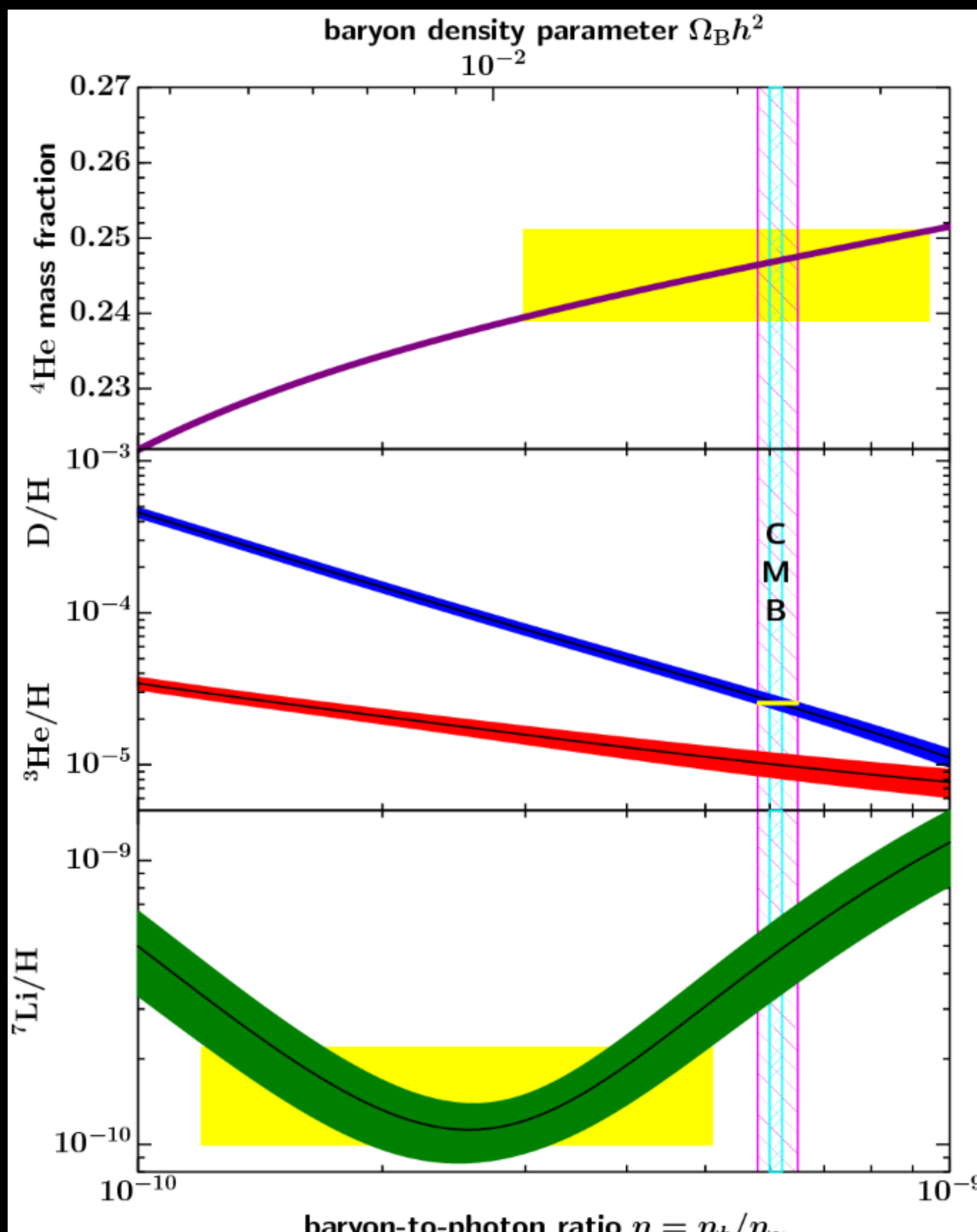
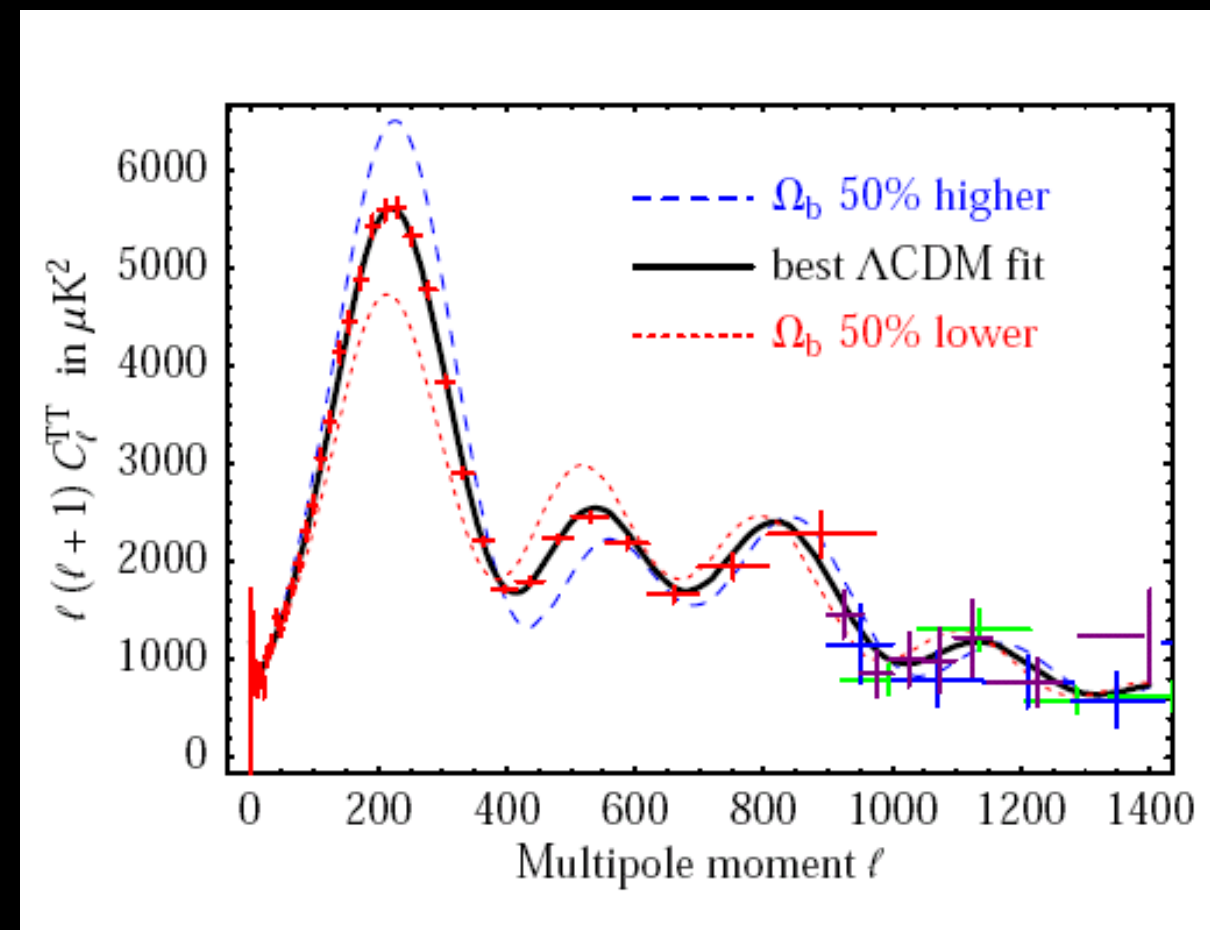


Image credit: materials properties and WMAP

How are we saved from complete annihilation

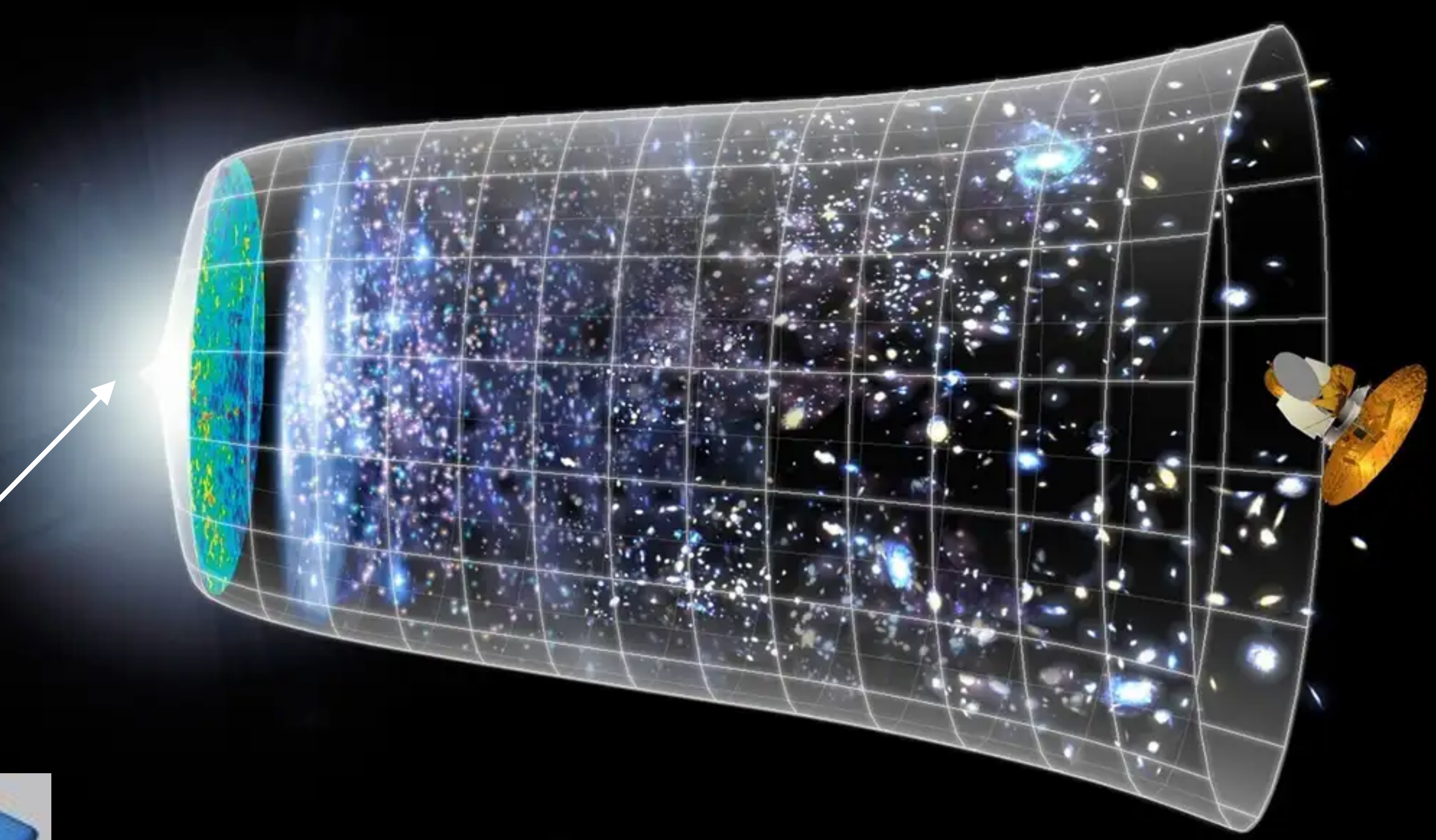




$$Y_B = \frac{n_B - \bar{n}_B}{s} \approx \frac{n_B}{s} = \begin{cases} (7.3 \pm 2.5) \times 10^{-11}, \text{BBN} \\ (9.2 \pm 1.1) \times 10^{-11}, \text{WMAP} \\ (8.59 \pm 0.11) \times 10^{-11}, \text{Planck}\,. \end{cases}$$

Figure credits: PDG and 0807.1408

How are we saved from complete annihilation



Inflation is a cosmic eraser!

Image credit: new scientist

The baryon asymmetry must be produced! How?

Any proposal must satisfy Sakharov conditions:

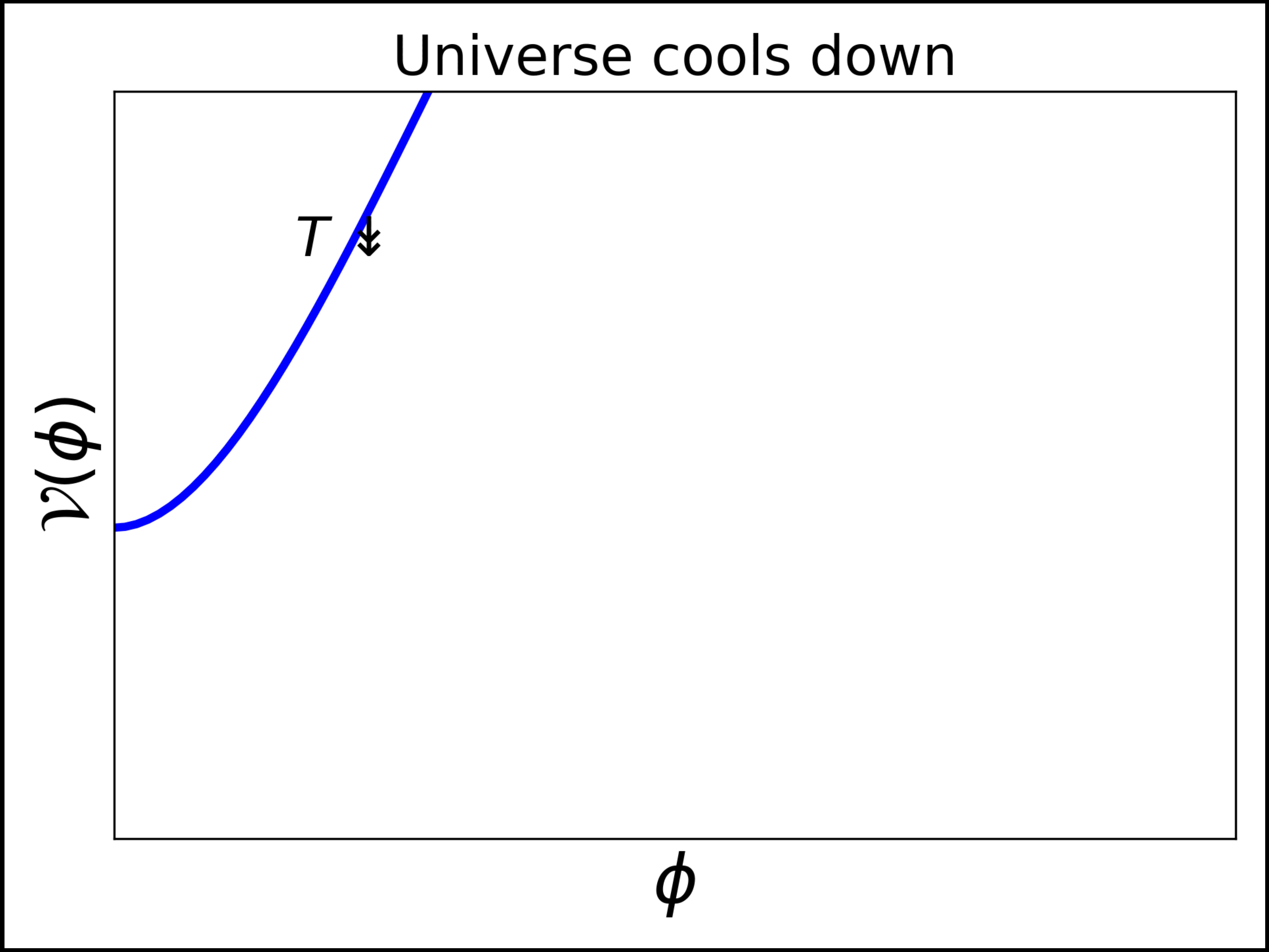
1. C and CP violation
2. B violation
3. Departure from equilibrium

The fate of the Standard Model

1. C and CP violation $\rightarrow$ Not enough
2. B violation ✓
3. Departure from equilibrium X

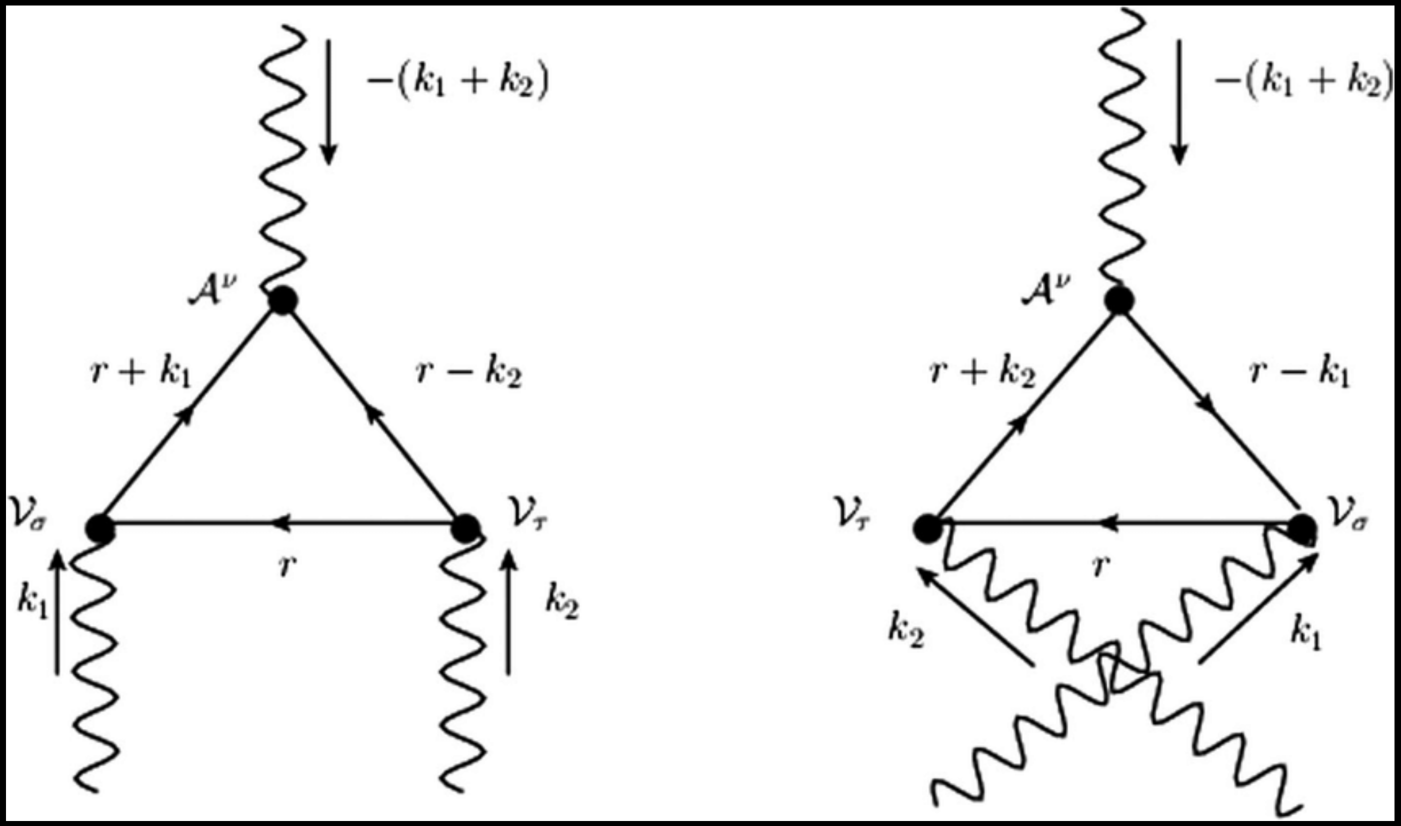
Introduction to Electroweak Baryogenesis

Departure from equilibrium



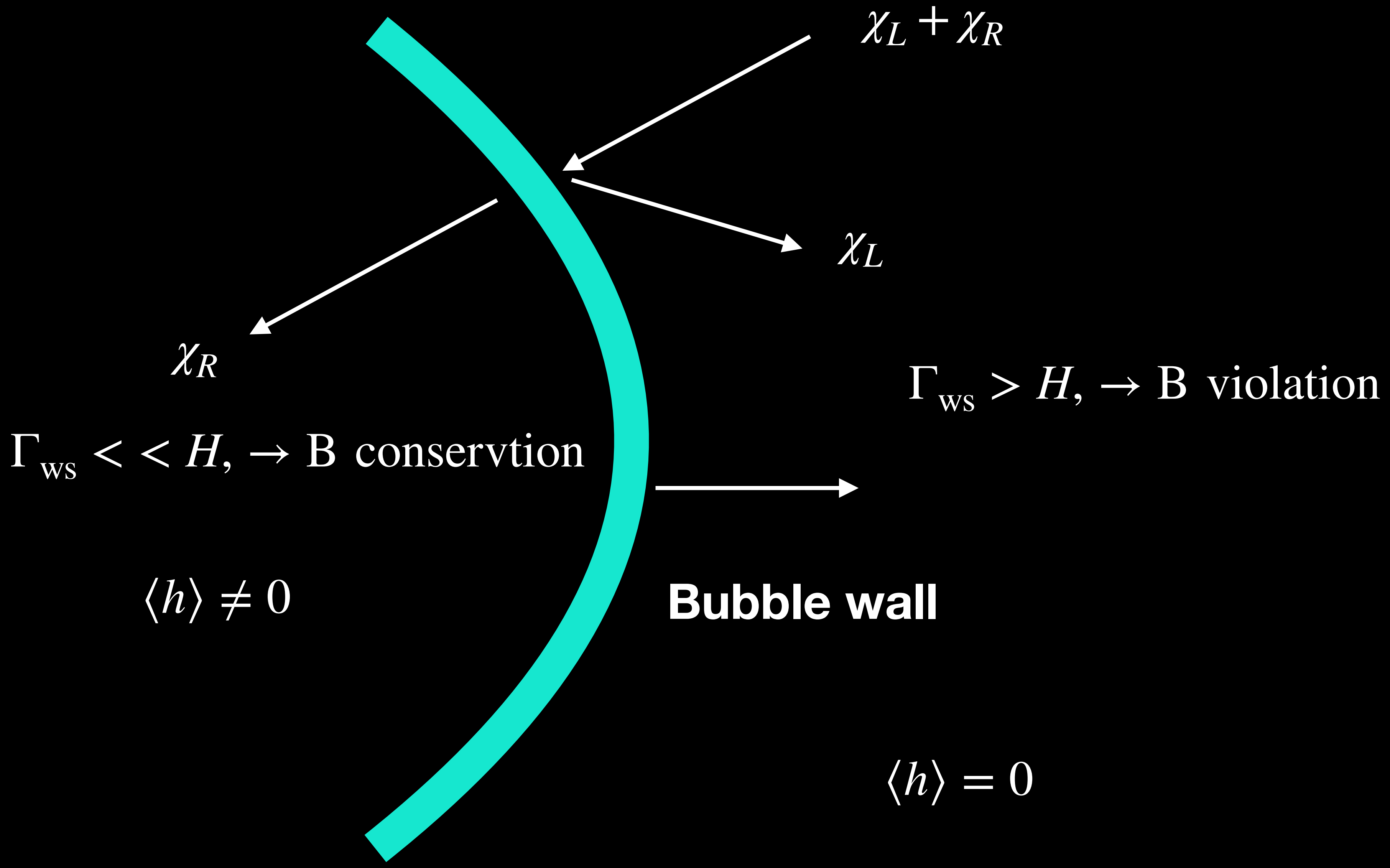
Introduction to Electroweak Baryogenesis

Baryon number non-conservation



Introduction to Electroweak Baryogenesis

Putting it together

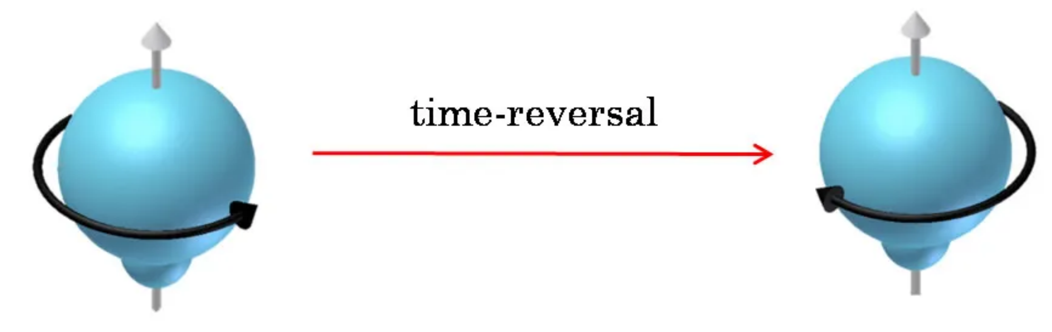


Central paradigm of next generation experiments!

1. Perhaps the only fundamental question a 100 TeV collider can give an answer to is “what is the nature of electroweak symmetry breaking”
2. EDM searches are rapidly improving every decade
3. Next generation gravitational wave detectors are focused on the right frequency if a strong electroweak phase transition left behind a GW background

Part 1: Electroweak Baryogenesis

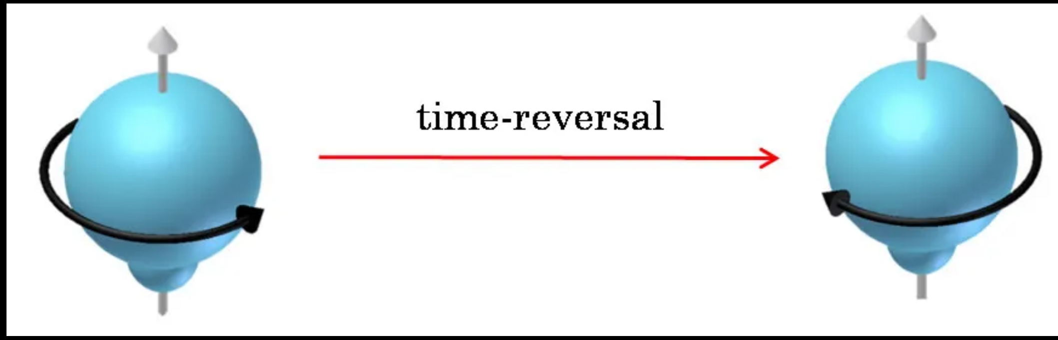
Why prediction is terrible part 1: CPV sources



Acme: $d_e < 1.1 \times 10^{-29} e\text{cm}$

Part 1: Electroweak Baryogenesis

Why prediction is terrible part 1: CPV sources



Acme: $d_e < 1.1 \times 10^{-29} e\text{cm}$

Part 1: Electroweak Baryogenesis

Why prediction is terrible part 1: CPV sources

Propagating degrees of freedom are in the mass basis

$$M^2(x) = \begin{pmatrix} m_L^2(x) & v(x)\, e^{-i\alpha(x)} \\ v(x)\, e^{i\alpha(x)} & m_R^2(x) \end{pmatrix}$$

$$U(x) = \begin{pmatrix} \cos\theta(x) & -\sin\theta(x)\, e^{-i\alpha(x)} \\ \sin\theta(x)\, e^{i\alpha(x)} & \cos\theta(x) \end{pmatrix}$$

Three scales of problem:

1. **Scale of particle interactions**
2. **Scale of when a particle "feels" the change in the mass basis**
3. **Scale of bubble wall movement ~vt**

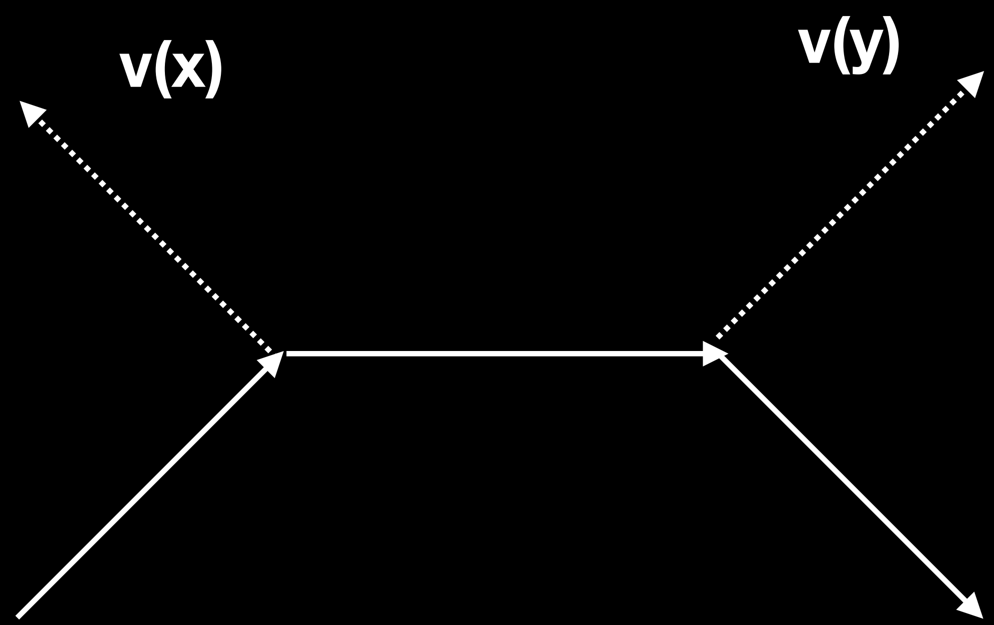
Part 1: Electroweak Baryogenesis

Why prediction is terrible part 1: CPV sources

Method 1:

$$\left(\gamma^{\mu}\partial_{\mu} - m(z)e^{i\phi(z)}\right)\Psi = 0$$

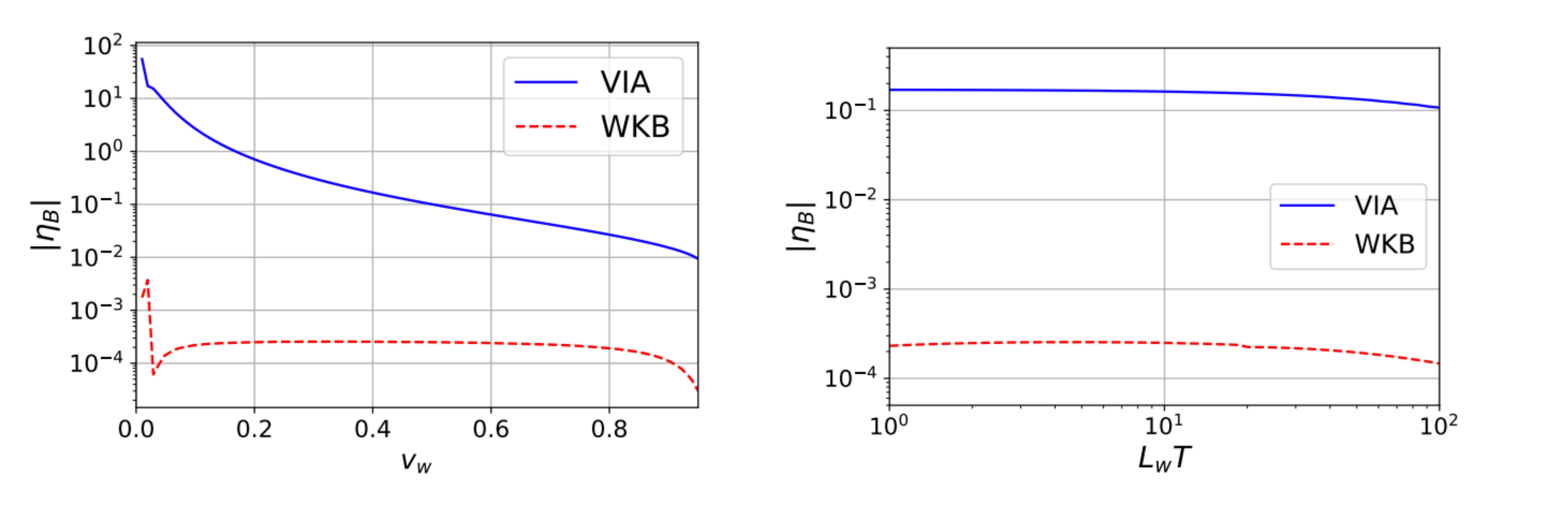
Method 2:



1. Calculate diagrams with spatially varying vev insertions
2. Calculate using d.o.f. of the symmetric phase
3. Assume local physics x~y

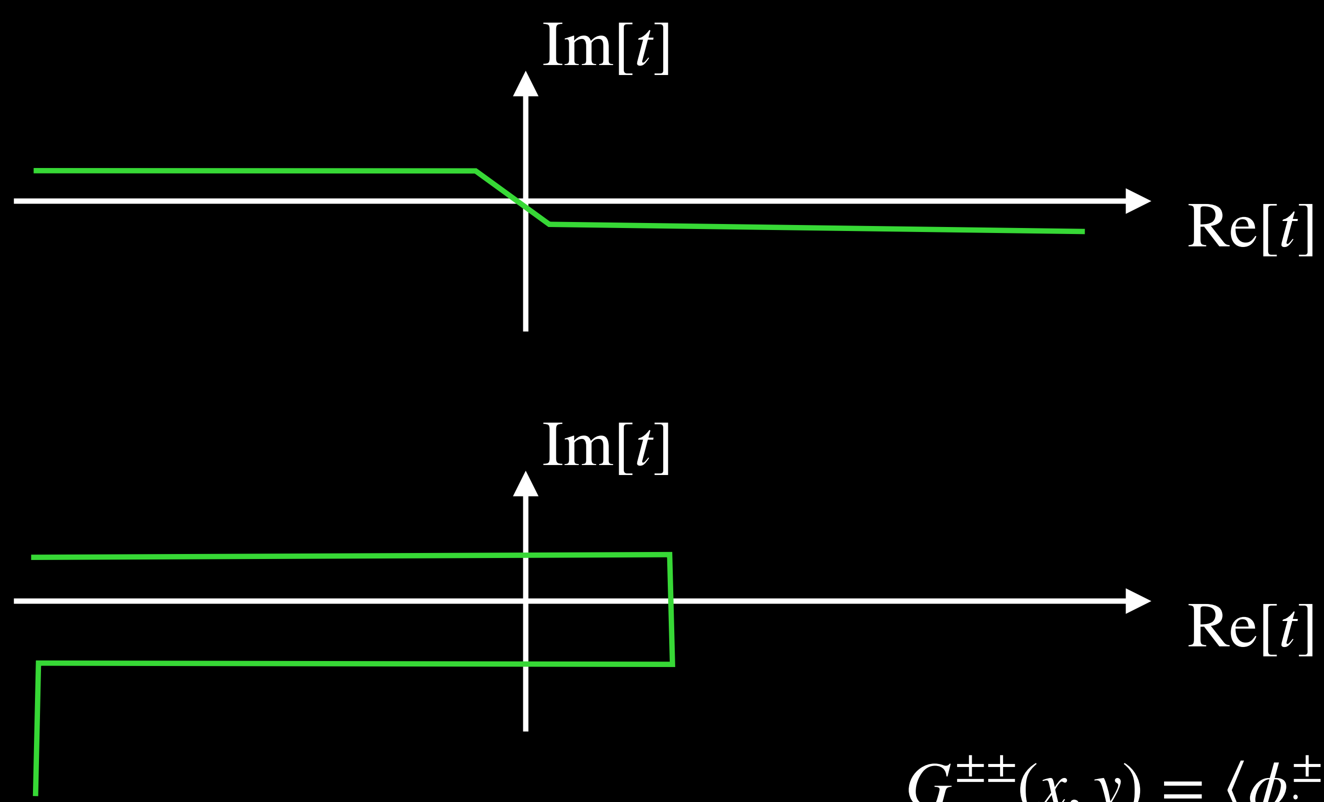
Part 1: Electroweak Baryogenesis

Simple model comparison: 2108.04249



Part 1: Electroweak Baryogenesis

To handle the out of equilibrium nature of the problem use a different time contour



$$G^{\pm\pm}(x,y) = \langle \phi_i^{\pm}(x)\phi_j^{\pm}(y)\rangle$$

Part 1: Electroweak Baryogenesis

Dyson Schwinger equation is still valid out of equilibrium

$$G^x = G_0^x + G^x \odot \Sigma \odot G_0^x$$

Can simplify using equations of motion

$$\mathscr{E} G_0^x = \delta \quad \rightarrow \quad \mathscr{E} G^x = \delta + G^x \odot \Sigma$$

Then transform from $(x, y) \rightarrow (k, X)$ and take the hermitian and anti hermitian parts of the equation

Part 1: Electroweak Baryogenesis

Result for scalars

$$\left(k^2 - \frac{1}{4}\partial^2\right) G^{++} = 1 + \frac{1}{2} e^{-i\diamond} \left(\left\{ M^2 + \Sigma^{++} - \Sigma^h, G^{++} \right\} - \Sigma^{-+} G^{+-} - G^{-+} \Sigma^{+-} \right)$$

$$\diamond (A, B) = \frac{1}{2} \left(\partial A \partial_k B - \partial B \partial_k A \right)$$

Solution gives form of propagator

$$2ik \cdot \partial G^{\pm\mp} = e^{-i\diamond} \left(\left[M^2, S^{\pm,\mp} \right] + \left[\Sigma^{\pm\mp}, G^h \right] + \frac{1}{2} \left(\left\{ \Sigma^{+-}, G^{-+} \right\} - \left\{ \Sigma^{-+}, G^{+-} \right\} \right) \right)$$

Solution gives kinetic equation as

$$i\partial_\mu \int \frac{d^4k}{(2\pi)^4} k^\mu (G^{+-} + G^{-+}) = -\partial_\mu J^\mu \to \partial_t n - D \nabla^2 n$$

How to do a vev insertion consistently

$$G^{ab}_{IJ} = G^{ab}_{(0),IJ} + G^{ab}_{(1),IJ} + G^{ab}_{(2),IJ} + \cdots$$

$$G^{ab}_{(1),IJ} = \sum_{c} cG^{ac}_{(0),II}(\delta M^2)_{IJ}G^{cb}_{(0),JJ}$$

$$G^{ab}_{(2),IJ} = \sum_{cd} cdG^{ac}_{0,II}(\delta M^2)_{IJ}G^{cd}_{(}0), JJ(\delta M^2)_{JI}G^{db}_{(0),II}$$

Vev expand the FULL KB equation

$$2ik \cdot \partial(G^{>} + G^{<})^{(2)} =$$

$$\left[\delta M^2, (G^{>}_{(1)} + G^{<}_{(1)})\right] + \left[M_d^2, (G^{>}_{(2)} + G^{<}_{(2)})\right] + \left[\Pi^{>} + \Pi^{<}, G^{h}_{(2)}\right] + \left(\{\Pi^{>}, G^{<}_{(2)}\} - \{\Pi^{<}, G^{>}_{(2)}\}\right)$$

How to turn this into the usual source

First reverse the Wigner transform

$$\left(\{\Pi^>, G^<_{(2)}\} - \{\Pi^<, G^>_{(2)}\}\right) = -m^2_{LR}m^2_{RL}\left(\left\{G^>_{RR}, G^<_{LL}\right\} - \left\{G^<_{RR}, G^>_{LL}\right\}\right)$$

$$\to -2\int d^4y \mathrm{Re}\left[m^2_{LR}(x)G^<_{RR}(x,y)m^2_{RL}(y)G^>_{LL}(y,x)\right.$$

$$\left. - m^2_{RL}(x)G^>_{RR}(x,y)m^2_{LR}(y)G^<_{LL}(y,x)\right]$$

The part which contributes to the source has the form

$$\sim -2\int d^4y \left(\mathrm{Im}[g(x,y) - g(y,x)]G^<_{RR}(x,y)G^>_{LL}(y,x) - G^>_{RR}(x,y)G^<_{LL}(y,x)\right)$$

Where $g(x,y) = m^2_{LR}(x)m^2_{RL}(y)$

Example: $m^2_{LR}(x) = bv_1(x) + cv_2(x)e^{i\phi},\ m_{RL}(x) = bv_1(x) + cv_2(x)e^{-i\phi}$

$$\mathrm{Im}[g(x,y) - g(y,x)] \sim (x-y)\sin\phi(v_1(x)v_2'(x) - v_1'(x)v_2(x))$$

Final piece of the source is an integral over greens functions.
Greens function to 0th order in vev insertion

$$G^{>,<}_{0,IJ} = g^{>,<}_{II}\rho_{(0),I}\delta_{IJ} \qquad \textbf{Where} \qquad \rho_{(0),I} = \frac{\gamma_I}{(k^2 - m_I^2)^2 - \gamma_I^2/4}$$

Where γ_I **is a thermal width**

To derive self energies, assume the thermal corrections arise from equilibrium physics and are flavor diagonal

$$\Pi^A_{IJ} = \gamma_I \delta_{IJ} \rightarrow \Pi^{<,>}_{IJ} = g^{<,>}_{II}\gamma_I\delta_{IJ}$$

Calculating all relevant sources

$$\left[\delta M^2, (G^{>}_{(1)} + G^{<}_{(1)})\right] = 2m^2_{LR}m^2_{RL}\rho_L\rho_R(n_L - n_R)$$

$$\left(\{\Pi^{>}, G^{<}_{(2)}\} - \{\Pi^{<}, G^{>}_{(2)}\}\right) = -\,2m^2_{LR}m^2_{RL}\rho_L\rho_R(n_L - n_R)$$

Cancels exactly!

Leading order VIA source does not exist!

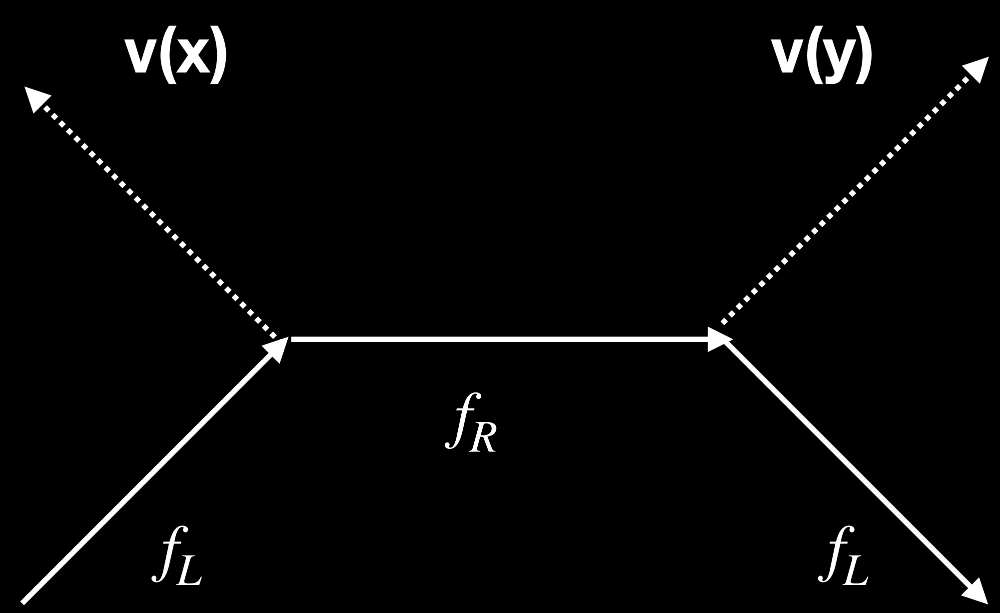
Let’s consider the fermion case

$$\frac{1}{2}\left\{ k\!\!\!/, G^t \right\} = 1 + \frac{1}{2} e^{-i\diamond} \left(\left\{ M + \Pi^t - \Pi^h, G^t \right\} - \Pi^< G^> - G^< \Pi^> \right)$$

$$\frac{i}{2}\left\{ \partial\!\!\!/, S^< \right\} = e^{-i\diamond} \left([M, S^<] + [\Pi^<, G^h] + \frac{1}{2}\left(\left\{ \Pi^>, G^< \right\} - \left\{ \Pi^<, G^> \right\} \right) \right)$$

If we have a thermal mass $m_L \neq m_R \rightarrow [\gamma^i, S] \neq 0,\ [S, M] \neq 0$

Even one flavour system acts like a two flavour system when there are thermal corrections



Solutions to constraint equation

Can be written in terms of helicity components

$$G_{II,\pm}^{<,>} = g_{II}^{<,>} \rho_I^{\pm}$$

$$\rho_I^{\pm} = \frac{\gamma_I}{(k^0 \pm k - \Pi_{II,\pm}^h)^2 - \gamma_I^2/4}$$

Vev insertion approximation

$$S_{(1),LR}^{ab} = m_{LR} \sum_c c \left(S_{LL,+}^{ac} S_{RR,-}^{cb} P_+ + S_{LL,-}^{ac} S_{RR,+}^{cb} P_- \right)$$

$$S_{(2),LL}^{ab} = m_{LR} m_{RL} \sum_{cd} cd \left(S_{LL,+}^{ac} S_{RR,-}^{cd} G_{LL,+}^{db} P_+ + G_{LL,-}^{ac} G_{RR,+}^{cd} G_{LL,-}^{db} P_- \right)$$

In this case the traditional source requires us to take a trace of the KB equation, project onto a helicity and expand to second order in vev insertions

$$S_{LL}^{(2)+} = \mathrm{Tr}\left[P^+\left([M_0, S_{(1)}^> + S_{(1)}^<] + \left(\left\{\Pi^>, G_{(2)}^<\right\} - \left\{\Pi^<, G_{(2)}^>\right\}\right)\right)\right]$$

Once again assuming thermal corrections are near equilibrium we find

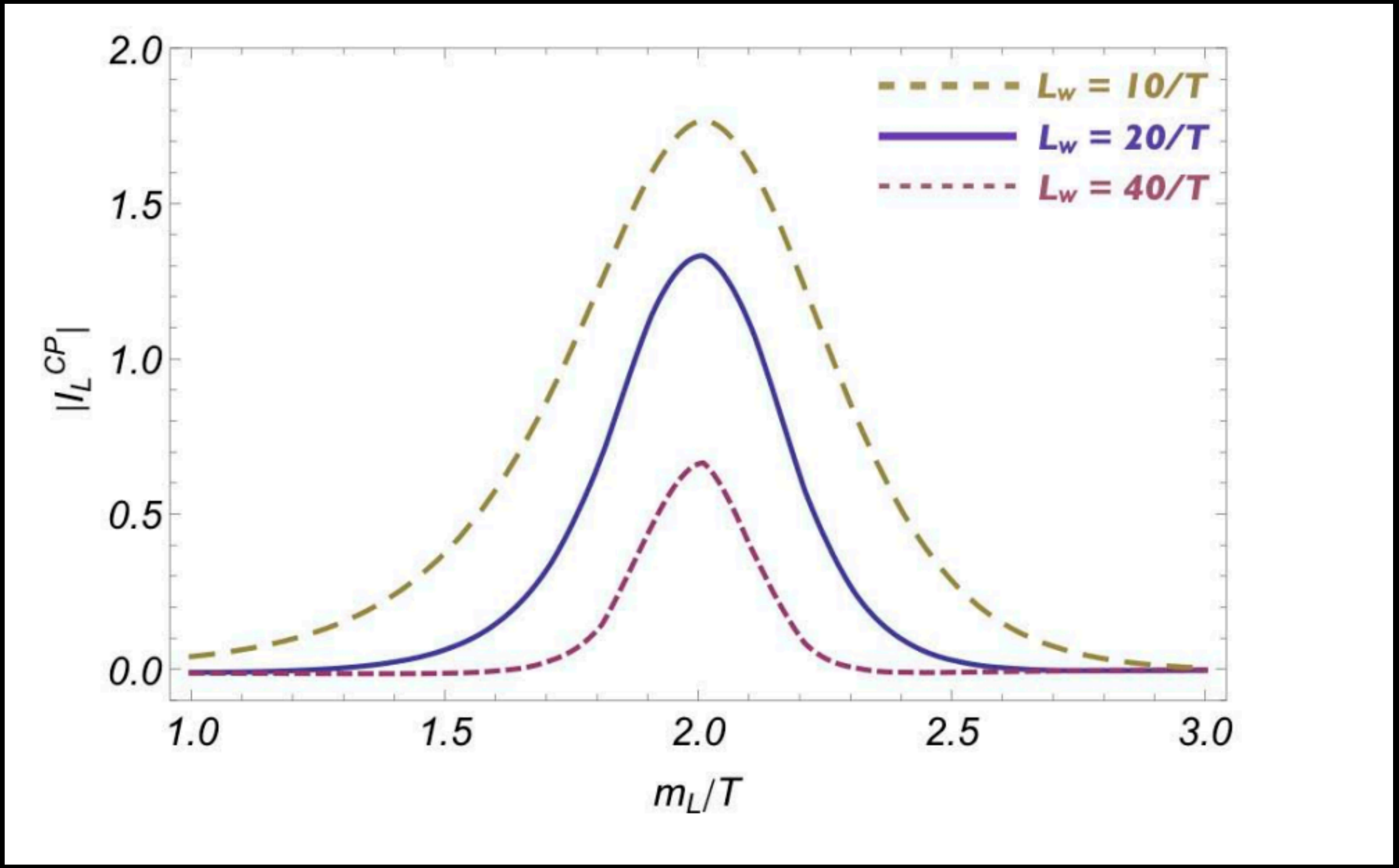
$$\mathrm{Tr}\left[P^+\left([M_0, S_{(1)}^> + S_{(1)}^<]\right)\right] = -2m_{LR}m_{RL}\rho_L^+\rho_R^-(n_L - n_R)$$

$$\mathrm{Tr}\left[P^+\left(\left\{\Pi^>, G_{(2)}^<\right\} - \left\{\Pi^<, G_{(2)}^>\right\}\right)\right] = 2m_{LR}m_{RL}\rho_L^+\rho_R^-(n_L - n_R)$$

Again the total source cancels

But this is confusing:

Consider arXiv:1106.0747



Resonantly enhanced source! Can we derive it?

How to find resonantly enhanced sources

Let's ignore thermal corrections and write a simplified KB equation

$$\left[\not{k} + \frac{i}{2}\not{\partial} - M^H e^{-\frac{i}{2}\partial\cdot\partial_k} - i\gamma^5 M^A e^{-\frac{i}{2}\partial\cdot\partial_k}\right] S^< = 0$$

Perform a helicity decomposition

$$iS_s^< = -P_s\left[s\gamma^3\gamma^5 g_0^s - s\gamma^3 g_3^s + g_1^s - i\gamma^5 g_2^s\right]$$

Taking the trace with respect to $\frac{1}{2}\left\{1, s\gamma^3\gamma^5 - is\gamma^3, -\gamma^5\right\}$ **we have**

$$\begin{aligned}
2\mathrm{i}\hat{k}^0 g_0^s - 2\mathrm{i}s\hat{k}^z g_3^s - 2\mathrm{i}M^{\mathrm{H}}\mathrm{e}^{-\frac{\mathrm{i}}{2}\overleftarrow{\partial}\cdot\overrightarrow{\partial}_k} g_1^s - 2\mathrm{i}M^{\mathrm{A}}\mathrm{e}^{-\frac{\mathrm{i}}{2}\overleftarrow{\partial}\cdot\overrightarrow{\partial}_k} g_2^s &= 0\,,\\
2\mathrm{i}\hat{k}^0 g_1^s - 2s\hat{k}^z g_2^s - 2\mathrm{i}M^{\mathrm{H}}\mathrm{e}^{-\frac{\mathrm{i}}{2}\overleftarrow{\partial}\cdot\overrightarrow{\partial}_k} g_0^s + 2M^{\mathrm{A}}\mathrm{e}^{-\frac{\mathrm{i}}{2}\overleftarrow{\partial}\cdot\overrightarrow{\partial}_k} g_3^s &= 0\,,\\
2\mathrm{i}\hat{k}^0 g_2^s + 2s\hat{k}^z g_1^s - 2M^{H}\mathrm{e}^{-\frac{\mathrm{i}}{2}\overleftarrow{\partial}\cdot\overrightarrow{\partial}_k} g_3^s - 2\mathrm{i}M^{\mathrm{A}}\mathrm{e}^{-\frac{\mathrm{i}}{2}\overleftarrow{\partial}\cdot\overrightarrow{\partial}_k} g_0^s &= 0\,,\\
2\mathrm{i}\hat{k}^0 g_3^s - 2\mathrm{i}s\hat{k}^z g_0^s + 2M^{\mathrm{H}}\mathrm{e}^{-\frac{\mathrm{i}}{2}\overleftarrow{\partial}\cdot\overrightarrow{\partial}_k} g_2^s - 2M^{\mathrm{A}}\mathrm{e}^{-\frac{\mathrm{i}}{2}\overleftarrow{\partial}\cdot\overrightarrow{\partial}_k} g_1^s &= 0\,.
\end{aligned}$$

How to find resonantly enhanced sources

Define $g^s_{L,R} = g^s_0 \mp g^s_3$, solving the set of four equations and expanding to second order in gradients we find

$$
\begin{aligned}
& k^z \frac{\partial}{\partial z} g^s_{\mathrm{L}} + \underbrace{\frac{\mathrm{i}}{2}\left[M M^\dagger, g^s_{\mathrm{L}}\right]}_{\text{mixing term}} \\
& \underbrace{-\frac{1}{4}\left\{\left(M M^\dagger\right)', \partial_{k^z} g^s_{\mathrm{L}}\right\}}_{\text{classical force}} \underbrace{-\frac{1}{4k^z}\left(M' g^s_{\mathrm{R}} M^\dagger + M g^s_{\mathrm{R}} M'^\dagger\right) + \frac{1}{4k^z}\left(M' M^\dagger g^s_{\mathrm{L}} + g^s_{\mathrm{L}} M M'^\dagger\right)}_{\text{gradient-mixing terms}} \\
& \underbrace{+\frac{\mathrm{i}}{8}\left(M'' M^\dagger \partial_{k^3} \frac{g^s_{\mathrm{L}}}{k^z} - \partial_{k^z} \frac{g^s_{\mathrm{L}}}{k^z} M M''^\dagger\right) - \frac{\mathrm{i}}{8}\left(M'' \partial_{k^z} \frac{g^s_{\mathrm{R}}}{k^z} M^\dagger - M \partial_{k^3} \frac{g^s_{\mathrm{R}}}{k^z} M''^\dagger\right)}_{\text{semiclassical force}} \\
& -\frac{\mathrm{i}}{16}\left[\left(M M^\dagger\right)'', \partial^2_{k^z} g^s_{\mathrm{L}}\right] + \frac{\mathrm{i}}{8k^z}\left[M' M'^\dagger, \partial_{k^z} g^s_{\mathrm{L}}\right] = 0\,.
\end{aligned}
$$

But where is the resonant source?

How to find resonantly enhanced sources

Solve iteratively in powers of gradients (suppress spin indices)

$$g_{L/R,ij} = g^{(0)}_{L/R,ij} + g^{(1)}_{L/R,ij} + g^{(2)}_{L/R,ij} + \cdots$$

To leading order in gradients our differential equation is just

$$\frac{i}{2}\left[MM^\dagger, g_{L/R}\right] = 0$$

$$M = \begin{bmatrix} m_1 & \delta m_b(z) \\ \delta m_a(z) & m_2 \end{bmatrix}$$

$$g^{(0)}_{R,12} = \frac{(m_2 \delta m_a^\dagger + \delta m_b m_1)(g_{R,11} - g_{R,22})}{m_1^2 - m_2^2}$$

Resonance comes from feed back of off diagonals onto diagonals!

How to find resonantly enhanced sources

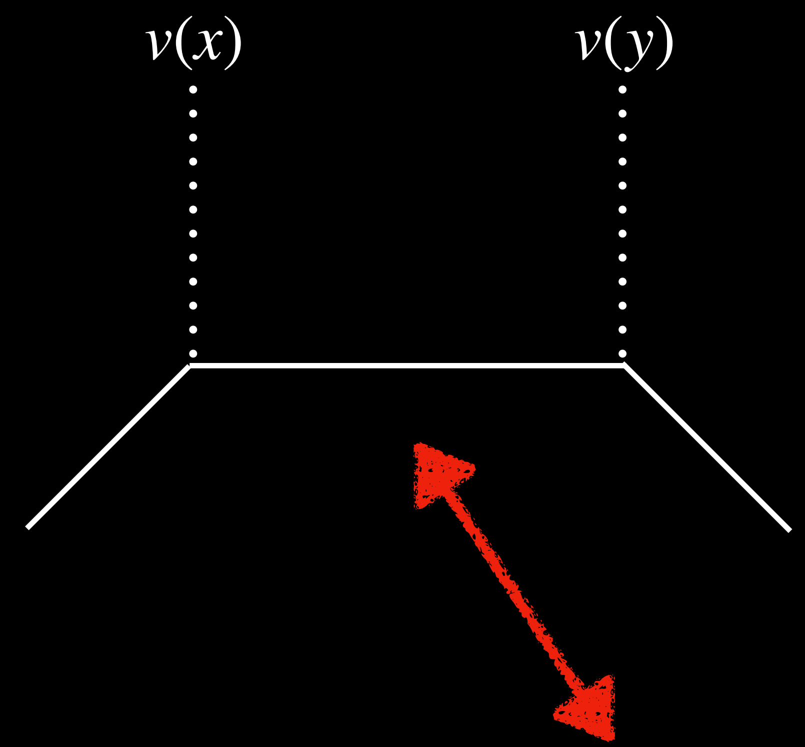
It is straightforward to iteratively solve at each order of gradients

$$(\partial_z j_5^z) \sim \frac{2s\sin\phi m_1 m_2}{k_z(m_1^2 - m_2^2)}\left(2v_1'v_2' + v_1 v_2'' + v_1''v_2\right)\frac{1}{2k_z^2}(1 - k_z\partial_{k_z})g_{3,11}$$

Where we have used $\delta m_a = v_1,\ \delta m_b = v_2 e^{i\phi}, j_5^z = -2(g_0^+ - g_0^-)$

Can we find it with a vev insertion approach?

Resonant mixing source



$$(\not{k}+\frac{i}{2}\not{\partial}-M_0^H)-\delta M_0^H e^{-\frac{i}{2}\partial\cdot\partial_p}S_0^< - i\gamma^5\delta M_A e^{-\frac{i}{2}\partial\cdot\partial_p}S_0^< S^< - e^{-iD}(\delta\Sigma_0^H S_0^< + \delta\Sigma_0^< S_0^H) = 0$$

$$\delta\Sigma^x = (\delta M^H + i\gamma^5\delta M^A)S_0^x(\delta M^H + i\gamma^5\delta M^A)$$

- Too many terms to show in a talk
- Need to sift through the trash for a bit

What does trash and treasure look like

$$\frac{1}{k^2 - M_1^2}\delta(k^2 - M_2^2) = \frac{1}{M_2^2 - M_1^2}$$

$$M_{11}\partial_k^2 \mathrm{Tr}[\gamma^3 S_0^<]_{11}\partial M_{12}\left(\frac{m}{k^2 - m^2}\right)_{22}\partial M_{21} \to \frac{M_1 M_2}{M_1^2 - M_2^2}\partial M_{12}\partial M_{21}\partial_k^2 \mathrm{Tr}[\gamma^3 S_0^<]_{11}$$

$$M_{11}\partial_k^2 \mathrm{Tr}[\gamma^3 S_0^<]_{11}\partial M_{12}^\dagger\left(\frac{m}{k^2 - m^2}\right)_{22}\partial M_{21}^\dagger \to \frac{M_1 M_2}{M_1^2 - M_2^2}\partial M_{12}^\dagger\partial M_{21}^\dagger\partial_k^2 \mathrm{Tr}[\gamma^3 S_0^<]_{11}$$

$$\partial M_{12}\partial_k^i \mathrm{Tr}[\gamma^3 S^<]_{22} M_{22}\left(\frac{m}{k^2 - m^2}\right)_{22}\partial M_{21} \sim \frac{1}{M_2^2 - M_2^2}!!!$$

$\partial M \partial M^\dagger$ etc .

Need 2 equations: $\mathrm{Tr}\left[\gamma^5 \mathscr{K} \,.\, \mathscr{B}\right]$, and $\mathrm{Tr}\left[\gamma^3\gamma^5 \mathscr{K} \,.\, \mathscr{B}\right]$**, just show relevant terms**

$$\mathrm{Tr}\left[\gamma^5 \mathscr{K} \,.\, \mathscr{B}\right]$$

$$-\partial_z j^{5z} - \frac{1}{2} M_0^H \mathrm{Tr}[\gamma^5 S^<] - \frac{1}{2}\mathrm{Tr}[\gamma_5 \mathrm{S}^<] M_0^H$$

$$-\frac{1}{2}(e^{-iD} + e^{iD^\dagger})\left(\left\{\delta M \frac{m}{k^2-m^2}, \delta M \,\mathrm{Tr}[S_0^<]\right\} - \left\{\delta M^\dagger \frac{m}{k^2-m^2}, \delta M^\dagger \mathrm{Tr}[S_0^<]\right\}\right)$$

$$\mathrm{Tr}\left[\gamma^3\gamma^5 \mathscr{K} \,.\, \mathscr{B}\right]$$

$$\mathrm{Tr}[\gamma^5 S^<] \supset \frac{1}{2k_z}\left(\frac{1}{2}e^{-iD}\left[\delta M \frac{m}{k^2-m^2}\delta M \,\mathrm{Tr}[\gamma^3 S_0^<] - \delta M^\dagger \frac{m}{k^2-m^2}\delta M^\dagger \mathrm{Tr}[\gamma^3 S_0^<] - \delta M \,\mathrm{Tr}[S_0^<]\delta M \frac{k_z}{k^2-m^2} + \delta M^\dagger \mathrm{Tr}[S_0^<]\delta M^\dagger \frac{k_z}{k^2-m^2}\right]\right)$$

$$+\frac{1}{2k_z}\left(\frac{1}{2}e^{iD^\dagger}\left[-\delta M^\dagger \mathrm{Tr}[\gamma^3 S_0^<]\delta M^\dagger \frac{m}{k^2-m^2} + \delta M \,\mathrm{Tr}[\gamma^3 S_0^<]\delta M \frac{m}{k^2-m^2} + \delta M^\dagger \frac{k_z}{k^2-m^2}\delta M^\dagger \mathrm{Tr}[S_0^<] - \delta M \frac{k_z}{k^2-m^2}\delta M \,\mathrm{Tr}[S_0^<]\right]\right)$$

Need 2 equations: $\mathrm{Tr}\left[\gamma^5\mathscr{K}\,.\,\mathscr{B}\right]$, and $\mathrm{Tr}\left[\gamma^3\gamma^5\mathscr{K}\,.\,\mathscr{B}\right]$**, just show relevant terms**

$$\mathrm{Tr}\left[\gamma^5\mathscr{K}\,.\,\mathscr{B}\right]$$

$$-\partial_z j^{5z} - \frac{1}{2}M_0\mathrm{Tr}[\gamma^5 S^<] - \frac{1}{2}\mathrm{Tr}[\gamma_5 \mathrm{S}^<]M_0^H$$

$$-\frac{1}{2}(e^{-iD}+e^{iD^\dagger})\left(\left\{\delta M\frac{m}{k^2-m^2}, \delta M\mathrm{Tr}[S_0^<]\right\} - \left\{\delta M^\dagger\frac{m}{k^2-m^2}, \delta M^\dagger\mathrm{Tr}[S_0^<]\right\}\right)$$

Expand to 2nd order:

$$e^{-iD} \supset -\frac{1}{4}\partial M_1\partial M_2(\partial_k^2 S_2 - \partial_k^2 S_1), \quad e^{iD^\dagger} \supset \frac{1}{4}\partial M_1\partial M_2(\partial_k^2 S_1 - \partial_k^2 S_2)$$

Use mass matrix $\mathrm{Diag}[M] = \{M_1, M_2\}$ **and identities**

$$\left(\frac{m}{k^2-m^2}\right)_{11} Tr[\gamma^3 S_0]_{22} = -k_z\frac{M_1}{M_2^2-M_1^2}f_2, \quad \left(\frac{m}{k^2-m^2}\right)_{11} Tr[S_0]_{22} = +\frac{M_1M_2}{M_2^2-M_1^2}f_2$$

Where f is all the stuff within the propagator aside from $\not{k}+m$

Need 2 equations: $\mathrm{Tr}\left[\gamma^5 \mathscr{K} \,.\, \mathscr{B}\right]$, and $\mathrm{Tr}\left[\gamma^3\gamma^5 \mathscr{K} \,.\, \mathscr{B}\right]$**, just show relevant terms**

$$\mathrm{Tr}\left[\gamma^5 \mathscr{K} \,.\, \mathscr{B}\right]$$

$$-\partial_z j^{5z} - \frac{1}{2} M_0 \mathrm{Tr}[\gamma^5 S^<] - \frac{1}{2}\mathrm{Tr}[\gamma_5 \mathrm{S}^<] M_0^H$$

$$-\frac{1}{2}(e^{-iD} + e^{iD^\dagger})\left(\left\{\delta M \frac{m}{k^2 - m^2}, \delta M \,\mathrm{Tr}[S_0^<]\right\} - \left\{\delta M^\dagger \frac{m}{k^2 - m^2}, \delta M^\dagger \mathrm{Tr}[S_0^<]\right\}\right)$$

Adding all pieces and integrating by parts the total is zero

Need 2 equations: $\mathrm{Tr}\left[\gamma^5 \mathscr{K} \,.\, \mathscr{B}\right]$, and $\mathrm{Tr}\left[\gamma^3\gamma^5 \mathscr{K} \,.\, \mathscr{B}\right]$**, just show relevant terms**

$$\mathrm{Tr}\left[\gamma^5 \mathscr{K} \,.\, \mathscr{B}\right]$$

$$-\partial_z j^{5z} - \frac{1}{2} M_0 \mathrm{Tr}[\gamma^5 S^<] - \frac{1}{2}\mathrm{Tr}[\gamma_5 \mathrm{S}^<] M_0^H$$

$$-\frac{1}{2k_z}(e^{-iD} + e^{iD^\dagger})\left(\left\{\delta M \frac{m}{k^2 - m^2}, \delta M \mathrm{Tr}[S_0^<]\right\} - \left\{\delta M^\dagger \frac{m}{k^2 - m^2}, \delta M^\dagger \mathrm{Tr}[S_0^<]\right\}\right)$$

Total is

$$\partial_z j_{11}^{5z} \supset \frac{1}{2}\left(\partial M_{12} \partial M_{21} - \partial M_{12}^\dagger \partial M_{21}^\dagger\right) \frac{M_1 M_2}{M_1^2 - M_2^2} \frac{(-1 + k_z \partial_{k_z}) f_1}{k_z^2}$$

No left over divergences
Same source!

Summary

1. Electroweak Baryogenesis is a key testable paradigm answering a fundamental quesiton
2. Theoretical confusion has existed in the literature for 3 decades!
3. Using CTP formalism and D-S equations allows for a consistent calculation
4. Doing so shows the usual source does not exist
5. A similar source does exist! It is hard to calculate, but only have to do so once!
6. Need to see if new sources appear when thermal corrections appear at non-zero gradients
7. Need to apply to realistic models