
Electroweak Phase Transition Dynamics

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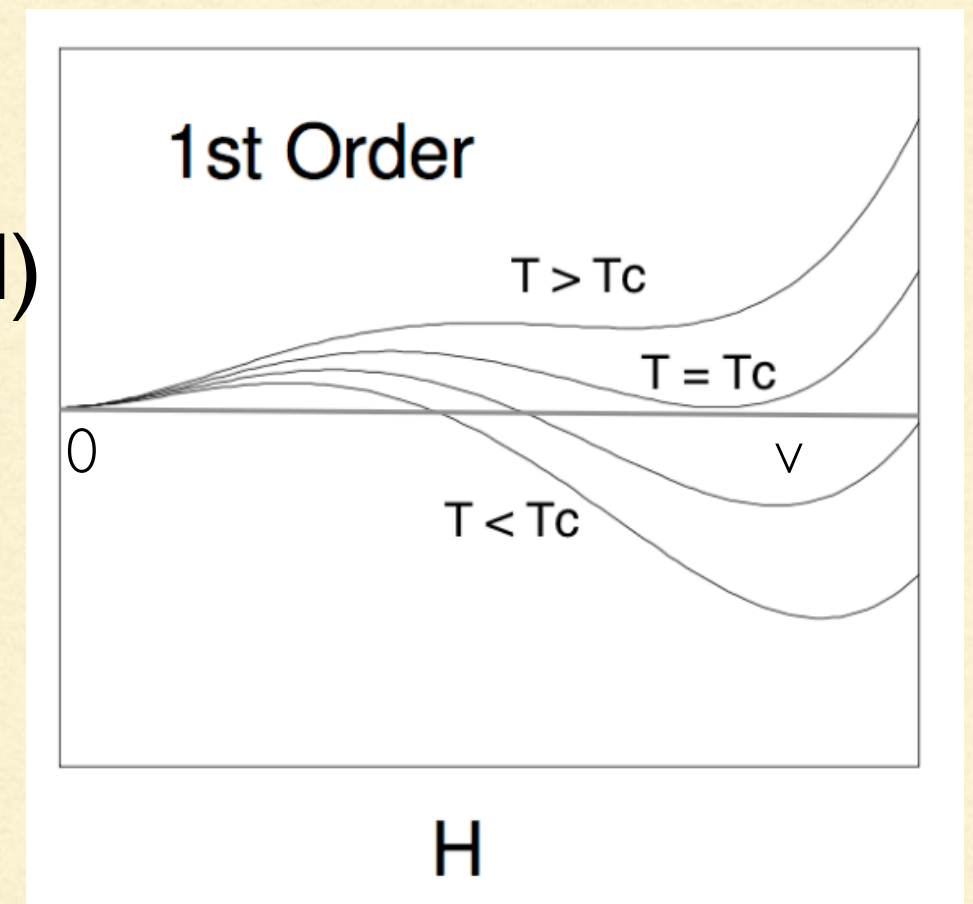
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The electroweak phase transition

- The universe transitions from $\langle\phi\rangle = 0$ to $\langle\phi\rangle = v$.
- $T \sim 100\text{GeV}$, $t \sim 10^{-12}\text{s}$.
- Universe filled with quark gluon plasma.
- EWPT is a crossover in the MSM, but first order in many extensions!

$V(H)$



First Order Phase Transition

Bubbles!

- Necessitates BSM (typically dark sector) physics
- Source of matter-antimatter asymmetry
- Gravitational wave signal might be observable by LISA!

How fast do the bubbles expand?

The bubble wall velocity is a measurable parameter of the gravitational wave signal.

It also affects the generation of matter-antimatter asymmetry!

Can we calculate the wall velocity for specific particle physics models?

- The evolution of the distribution function in the semiclassical approximation is described by the Boltzmann equation:

$$(\partial_t + v_g \partial_z + F_z \partial_{k_z}) f_i = C[f_i]$$

- The transition is driven by a scalar field ϕ . Its equation of motion is

$$\square \phi + \frac{\partial V(\phi)}{\partial \phi} + \sum_i \frac{dm_i^2}{d\phi} \int \frac{d^3 p}{(2\pi)^3 2E_p} f_i(p, x) = 0.$$

- Inserting $f = f_0 + \delta f$, we get

$$\square \phi + \frac{\partial V(\phi, T)}{\partial \phi} = - \sum_i \frac{dm_i^2}{d\phi} \int \frac{d^3 p}{(2\pi)^3 2E_p} \delta f.$$

The CP-even perturbation away from equilibrium sources the friction.

Baryogenesis

Why is there more matter than antimatter in the universe?

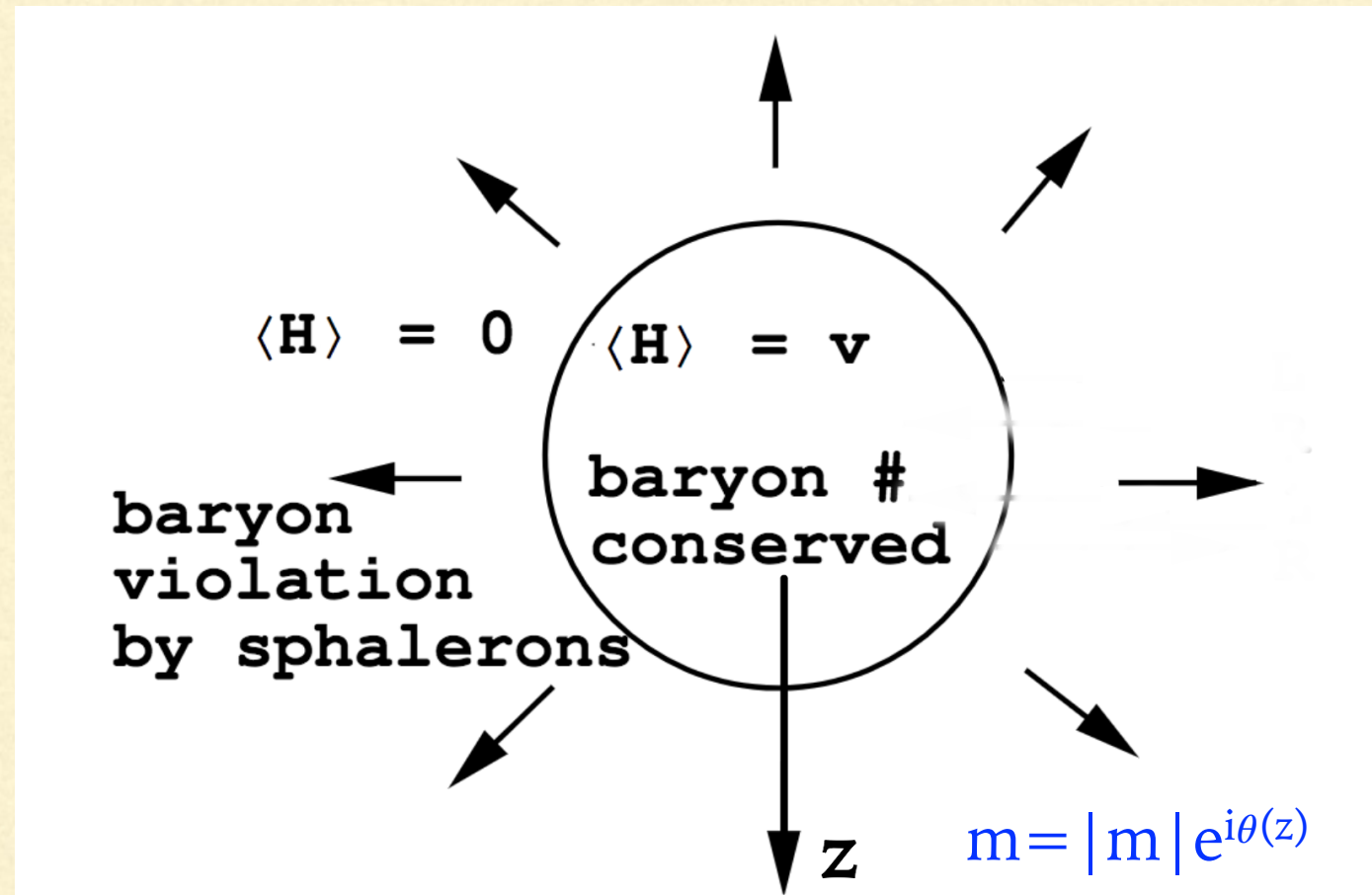
Unexplained by the Standard Model and Λ CDM!

Electroweak Baryogenesis

- First order EWPT: a possible fulfilment of Sakharov's baryogenesis conditions?
 - Baryon number violation: **sphalerons at high T**
 - C and CP-symmetry violation: **MSM + BSM physics**
 - out-of-equilibrium conditions: **first-order phase transition**
- Sphalerons: non-perturbative B violation **in the MSM**

Sakharov, 1967;

McLerran, Shaposhnikov, Turok & Voloshin, 1991; Shaposhnikov, 1994



Thank you!

How EWBG works

- CP-violation generates a **chiral asymmetry** in front of the wall.
- Sphalerons convert the chiral asymmetry to **baryon asymmetry** in front of the wall.
- Sphalerons are shut off behind the wall if $v > 1.1T$, so the asymmetry is preserved.

McLerran, Shaposhnikov, Turok & Voloshin, 1991;
Shaposhnikov, 1994; Moore, 1998