# Thermal fluctuations of the composition in quark nucleation

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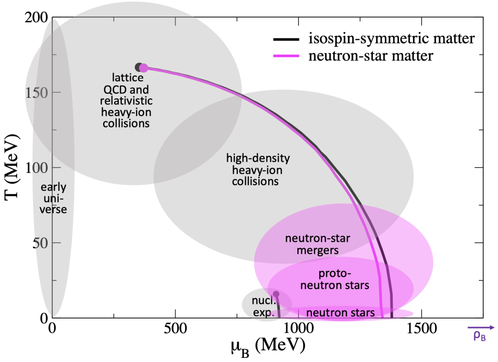
# Deconfinement in astrophysical systems

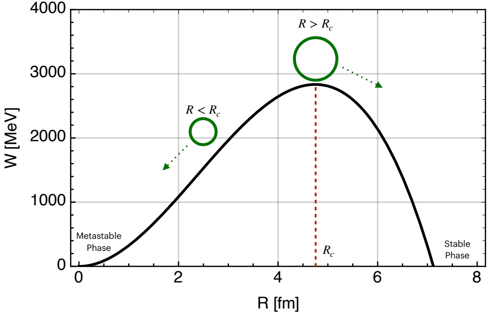



- **Quarks** d.o.f. expected at $n_B \sim$ few $n_0$
- Extreme densities reached in astrophysical phenomena related to **compact objects**
- **Deconfinement** could play a key role in astrophysical phenomena (e.g. BSGs CCSNe, *see Fischer et al. 2018*)

| | $n_B/n_0$ | $T$ [MeV] | $Y_e$ |
|---|---|---|---|
| Isolated NS | $10^{-8} - 8$ | $\sim 0$ | 0.01-0.3 |
| Core Collapse Supernovae (CCSN) | $10^{-8} - 8$ | $0 - 50$ | 0.25-0.55 |
| Proto NS (PNS) | $10^{-8} - 8$ | $0 - 50$ | 0.01-0.3 |
| Binary NS Mergers (BNSM) | $10^{-8} - 8$ | $0 - 100$ | 0.01-0.6 |

# Nucleation: the first seed of a new stable phase

if $\mu_H(P_H) > \mu_Q(P_Q) \Rightarrow H$ is a **metastable phase** $\Rightarrow$ virtual drops of $Q$ created




$$\boxed{W(P,T) = \frac{4}{3}\pi R^3 n_B^Q \left[\mu_Q - \mu_H\right] + 4\pi\sigma R^2}$$

Thermal : $\mathcal{P}_{th} \sim e^{-\frac{W(R_c)}{T}}$

(*Langer et al. 1969* and *Landau et al. 1980*)

Quantum : $\mathcal{P}_q \sim e^{-\frac{A(E_0)}{\hbar}}$

(*Iida et al. 1998*)

**Formation of the first critical quark seed $\Rightarrow$ deconfinement**

# Method

**State of the art** (*Bombaci et al. 2016*)

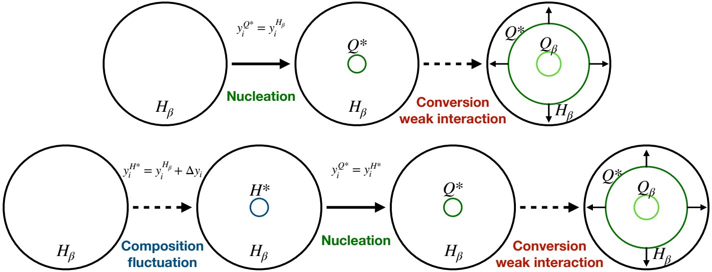
- weak processes are too slow
- flavour composition is **freezed**

$$\boxed{\mathcal{P}(P,T) = \mathcal{P}_{nuc}^{H_\beta \to Q^*}}$$

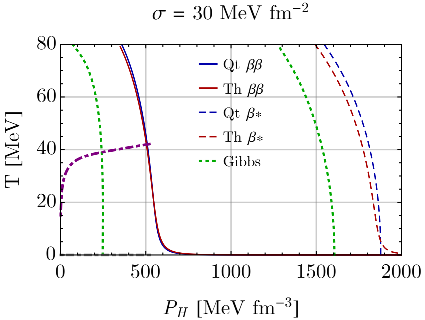
**Our approach** (*Guerrini et al. 2024*)

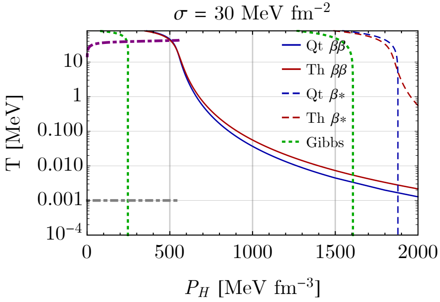
- at $T \neq 0$ hadronic composition **fluctuates** around the average values $\left\langle y_i^{H_\beta} \right\rangle$

$$\boxed{\mathcal{P}(P,T,\Delta y_i) = \mathcal{P}_{nuc}^{H^* \to Q^*} \times \mathcal{P}_{fluc}^{H_\beta \to H^*}}$$



# Application to two flavour case




- $(\beta*)$: $\Delta y_i = 0$ ; $(\beta\beta)$: $\Delta y_i$ such that $y_i^{H^*} = y_i^{Q_\beta}$
- $P$, $T$ such that nucleation time $\sim 1$ s

- fluctuations of the hadronic composition:
  - small T: fluctuations role negligible
  - high T: nucleation starts at a much lower pressure

# Summary

**Introduction**

- exotic degrees of freedom expected at compact object densities
- nucleation is the starting point for the deconfinement process

**State of the art**

- flavour composition freezed during nucleation (*Bombaci et al. 2016*)

**Method**

- at finite $T$ hadronic composition fluctuates around $y_i^{H_\beta}$
- one more step: I. Fluctuation in hadronic composition, II. Nucleation

**Results**

- nucleation starts at a much smaller pressure at high-intermediate T

**Outlooks**

- Application to three flavours
- Conversion process of hadronic to quark matter
- Search observables for the deconfinement (e.g. AT2018cow delayed signal wrt SN)