High Energy Particles from Supercooled Phase Transitions

Maximilian DICHTL

LPTHE Paris, Sorbonne

Work in progress with

Filippo SALA

IRN Terascale @ Bonn
29.03.2022

Heavy Dark Matter

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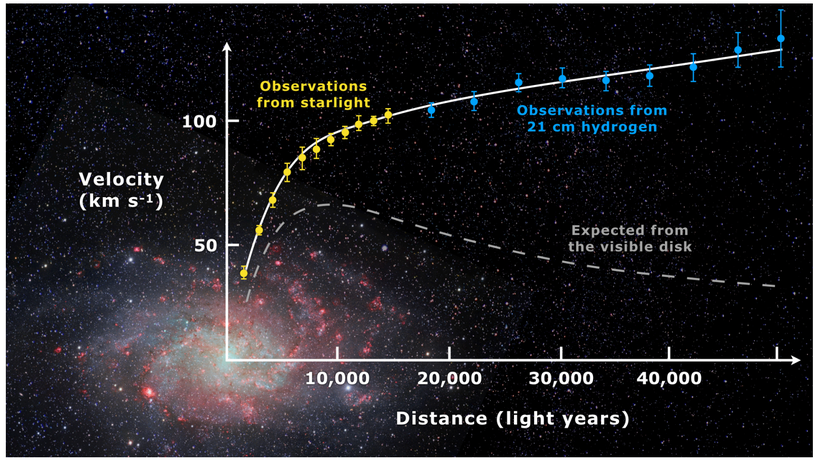
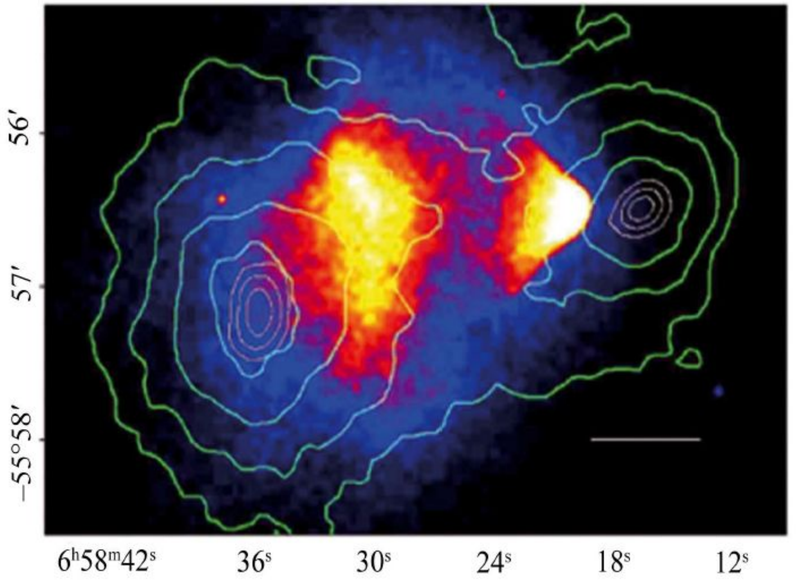
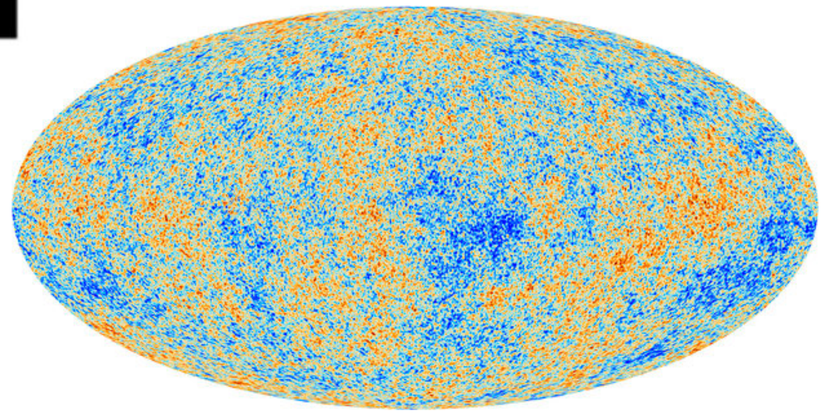
Experimental Evidence for Dark Matter





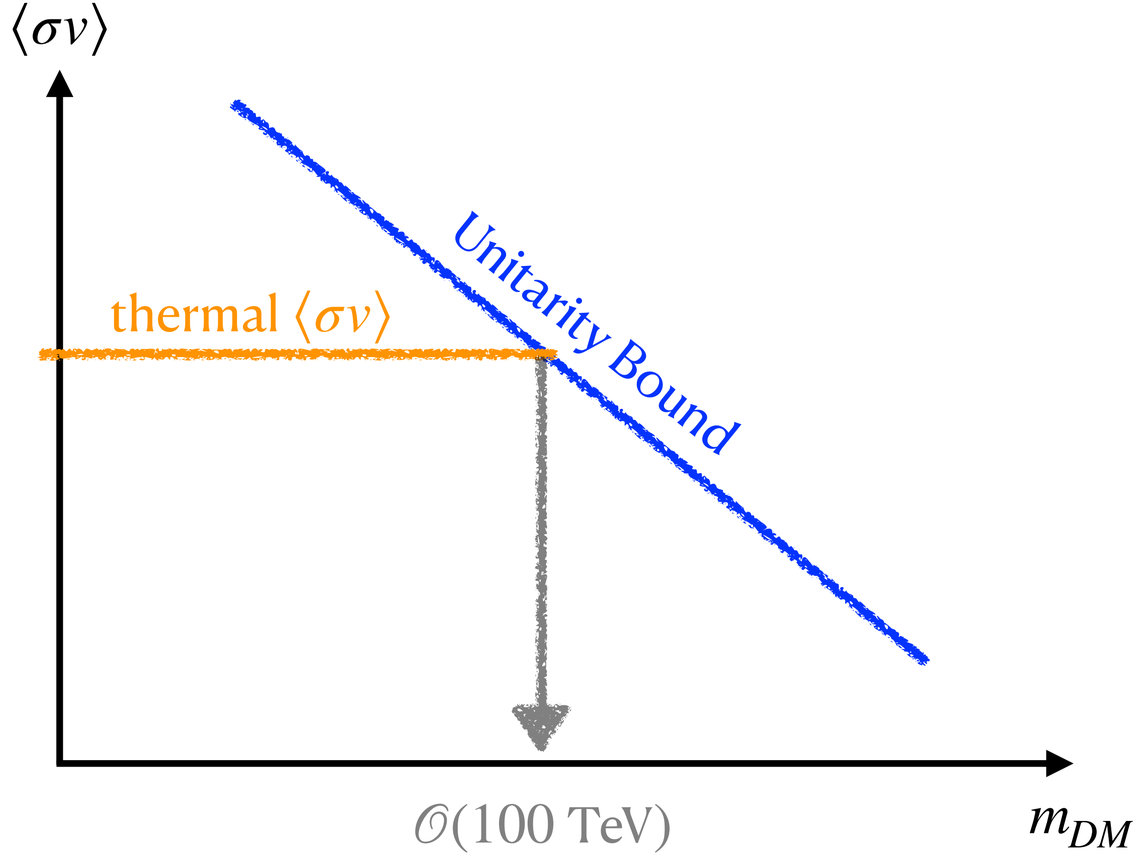


Unitarity Bound

Implication for thermal relic

$$\sigma v \lesssim \frac{4\pi(2J+1)}{v}\frac{1}{m_{DM}^2}$$

$$\Omega_{DM} \propto \frac{1}{\sigma v}$$



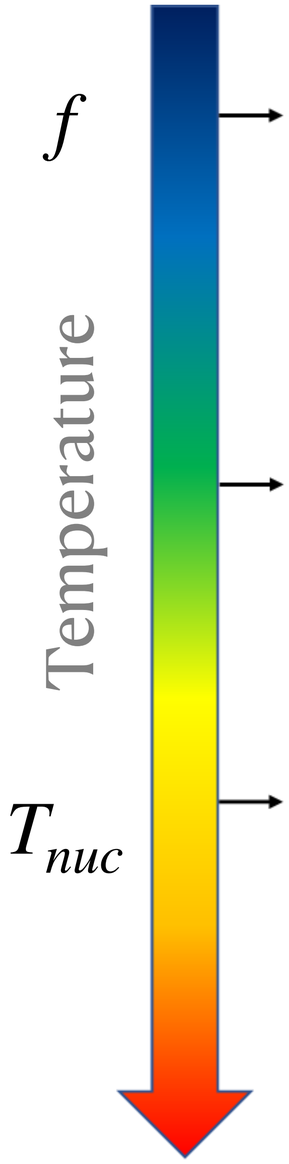
Ways Out

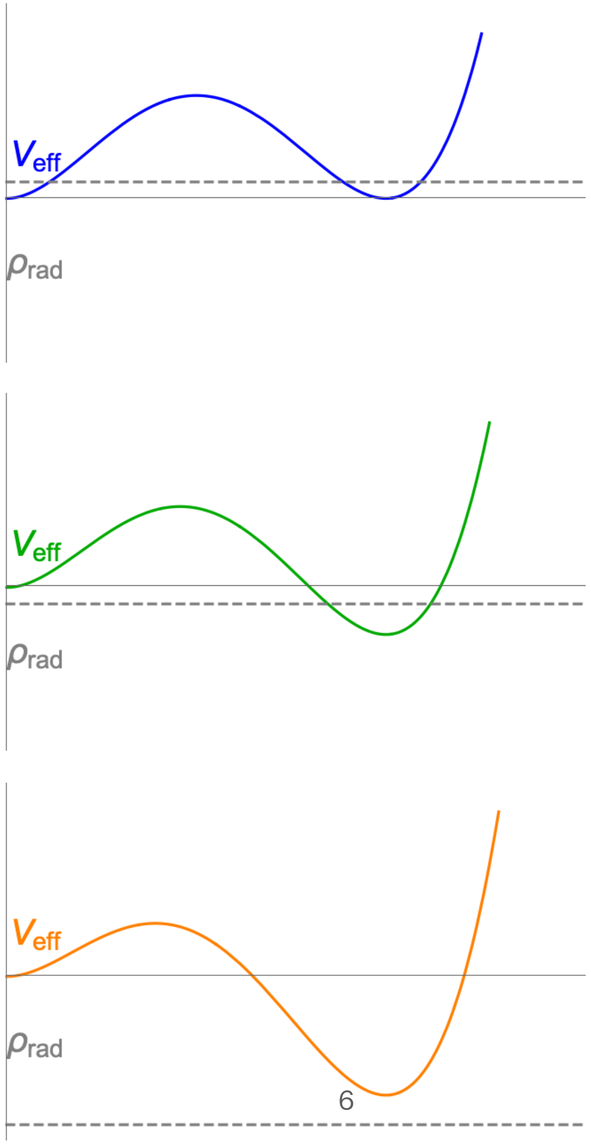
- Non-standard cosmological history before BBN
  - Early phase of matter domination
  - Vacuum Energy Domination
- No thermal contact / Out-of-equilibrium production

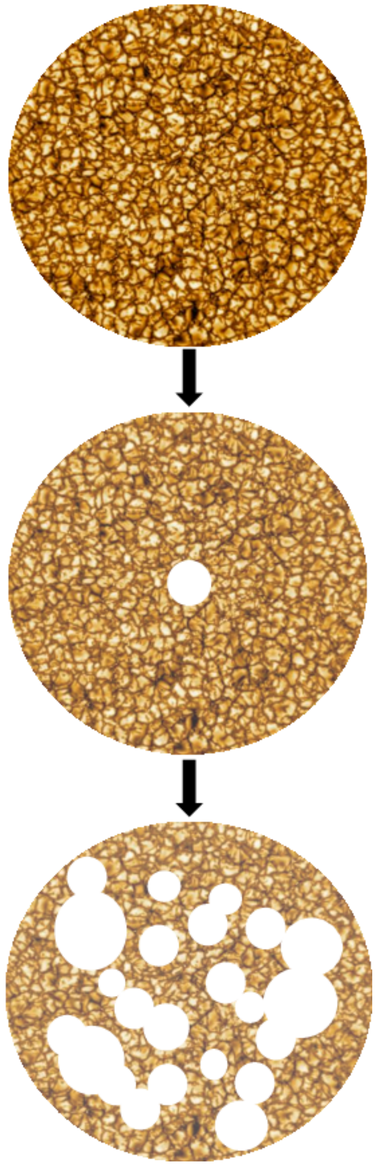
Outline

- Supercooled Phase Transitions
- High Energy Particles
- Example: Heavy Dark Matter

Supercooled Phase Transitions







adapted from
Wang+ arXiv:2003.08892

Supercooled Phase Transitions

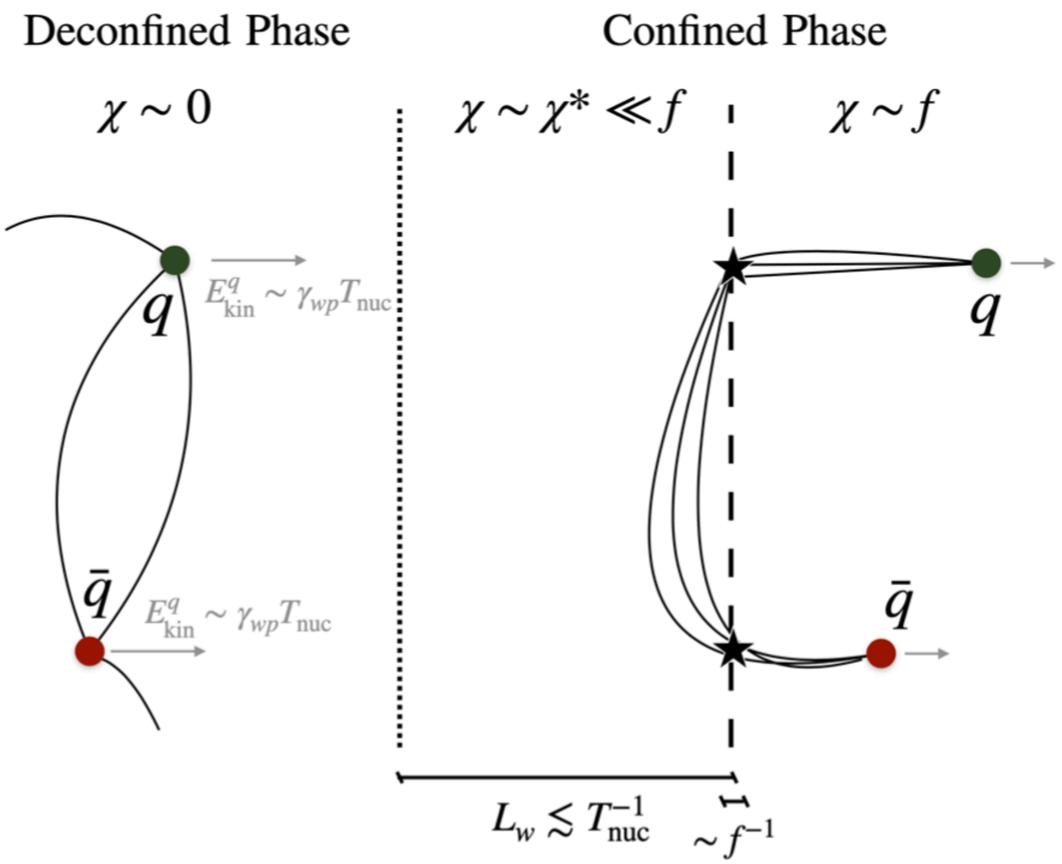
Main Parameters:

- Energy Scale of the Phase Transition f
- Nucleation Temperature $T_{nuc} \ll f$
- Wall Velocity $\gamma_w(T_{nuc}, f)$

Confining Sectors

String Fragmentation

I.Baldes, Y.Gouttenoire, F.Sala
arXiv:2007.08440



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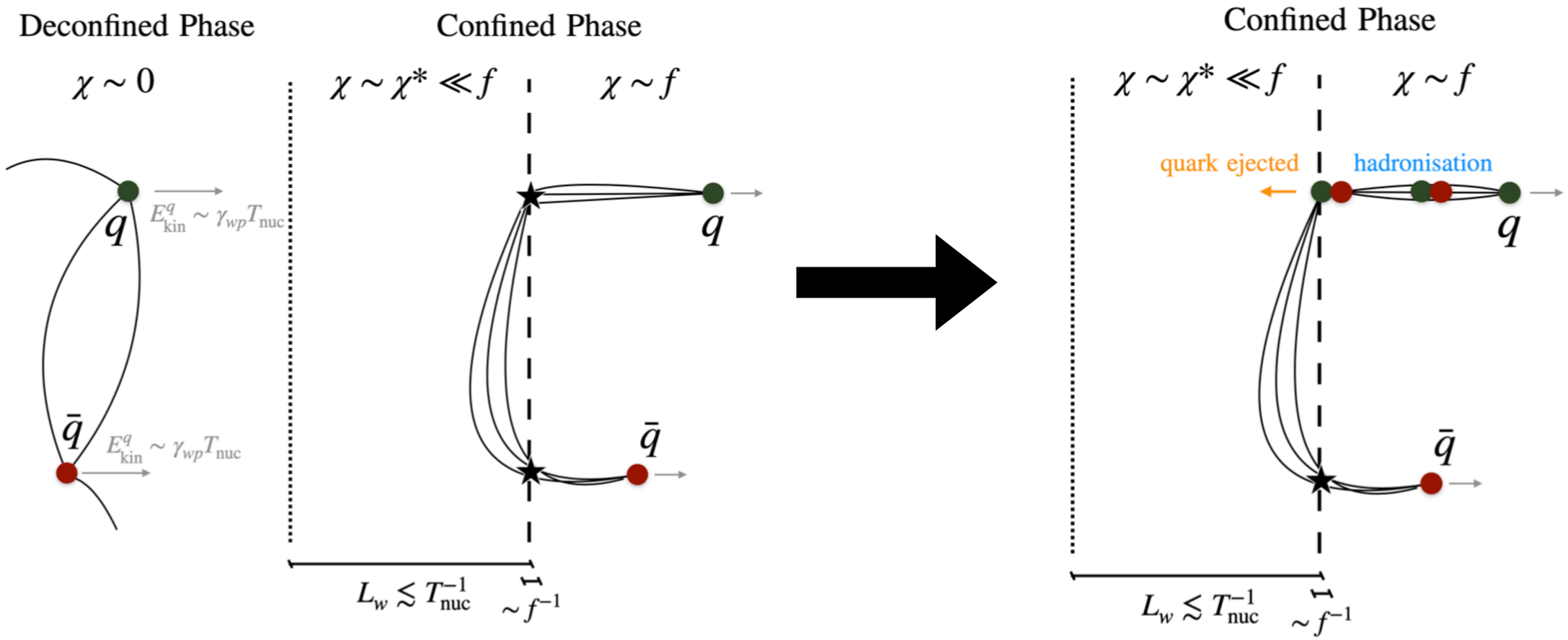
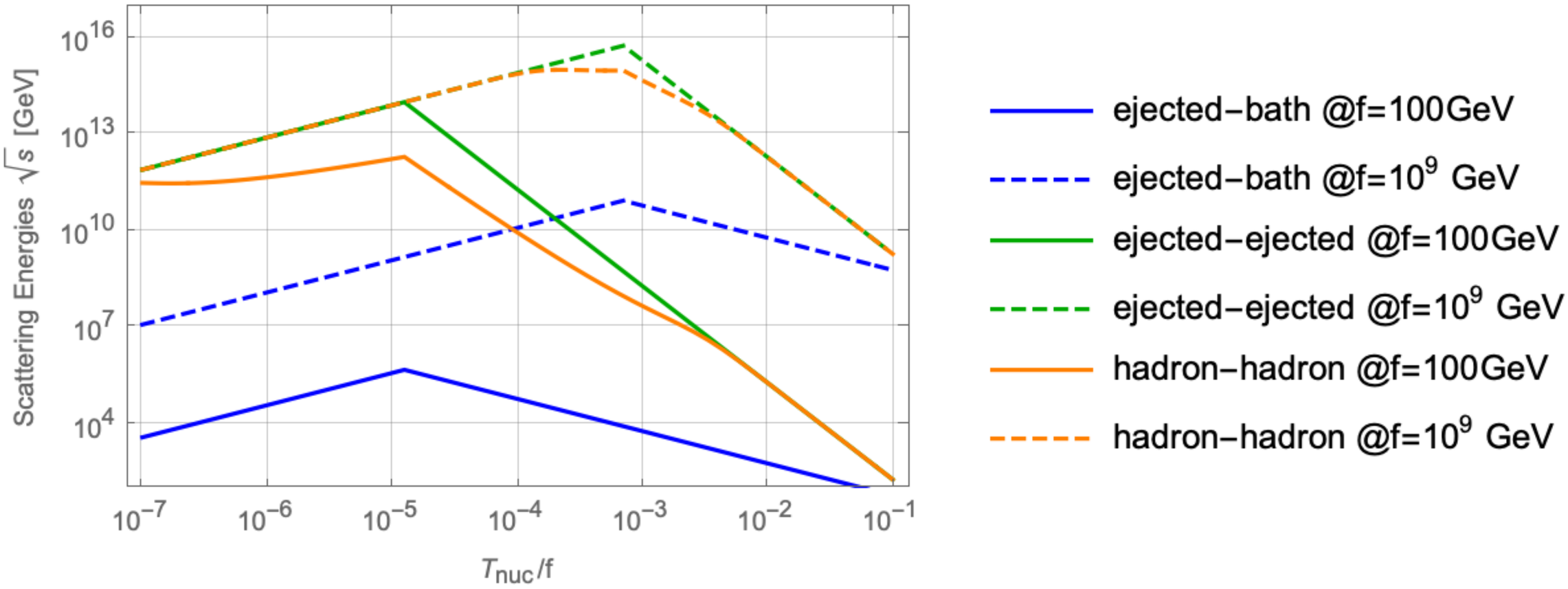


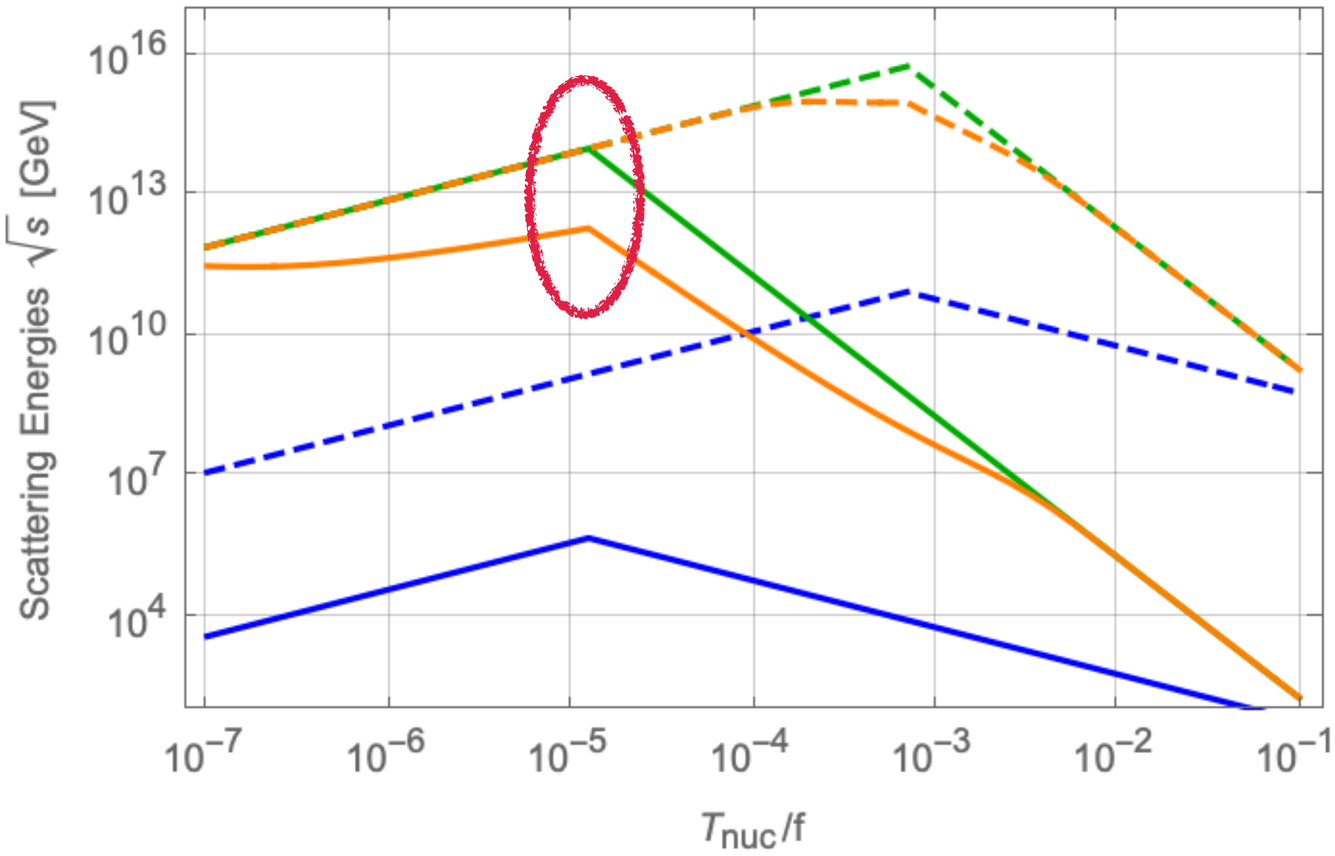
Particle Content

- Bath Particles (typical energies T_{nuc})
- Ejected Particles (typical energies $\gamma_w f$)
- Hadrons (typical energies $\gamma_w f / N_{\text{hadrons}}$)

Typical Scattering Energies



Typical Scattering Energies



ejected–bath @f=100GeV

ejected–bath @f=10^9 GeV

ejected–ejected @f=100GeV

ejected–ejected @f=10^9 GeV

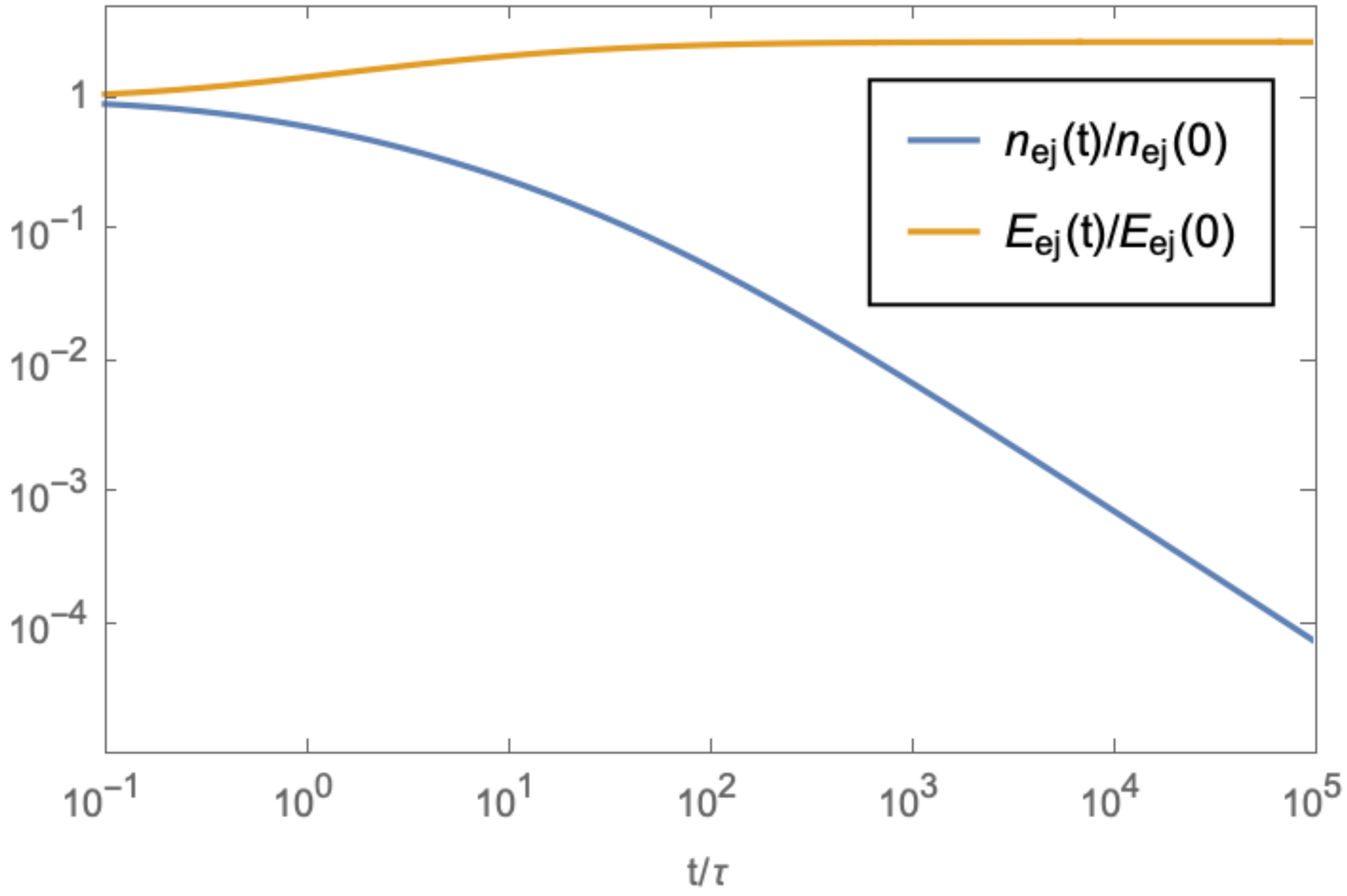
hadron–hadron @f=100GeV

hadron–hadron @f=10^9 GeV

Evolution of High Energy Particles

- Number changing interactions
- Reduce the number of highly energetic particles

Evolution of High Energy Particles



Evolution of High Energy Particles

- Number changing interactions
- Reduce the number of highly energetic particles

Largest contribution to DM production: Last moment production before collision

Heavy Dark Matter

Dark Matter Production

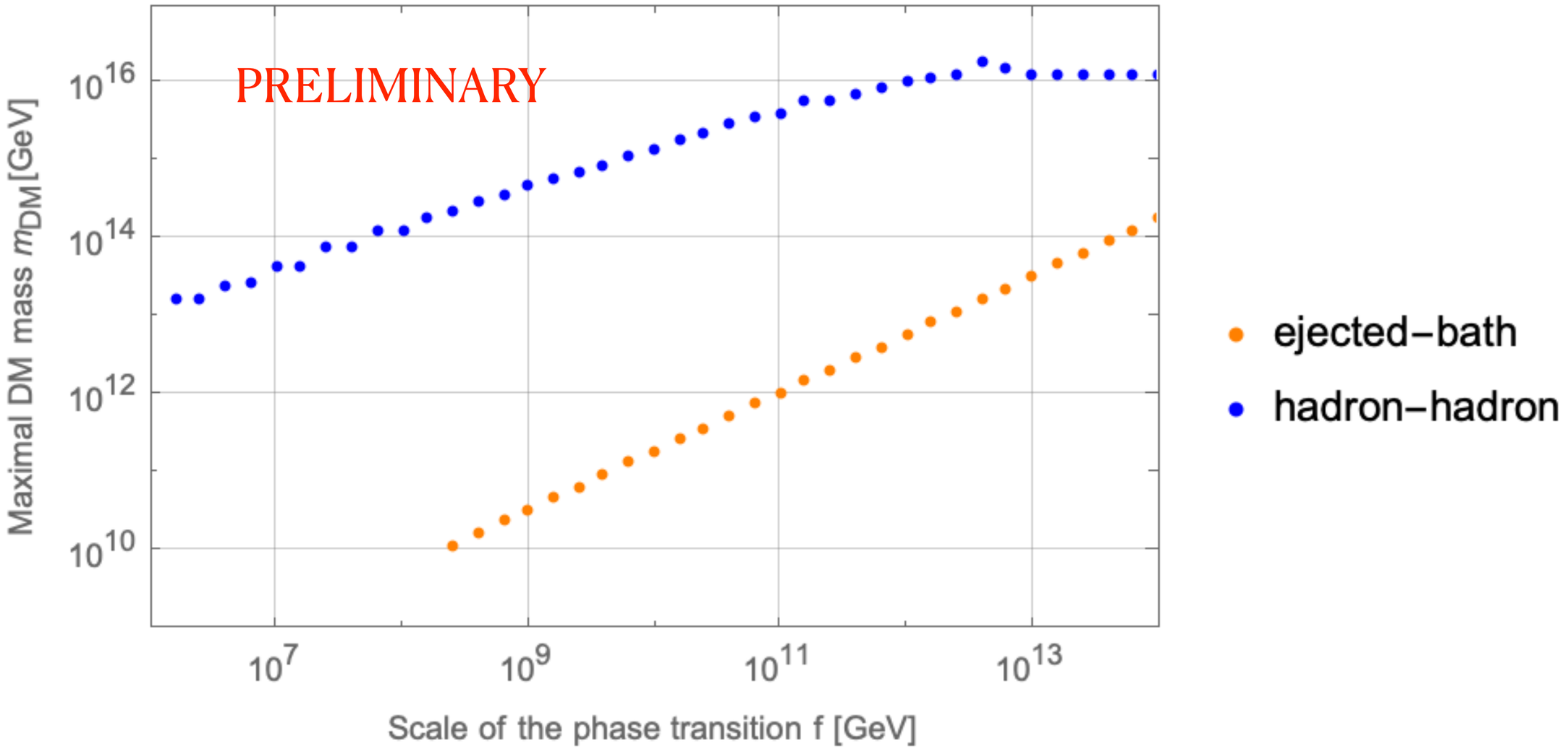
Effective Interacting Theory between

- BSM quarks, and
- Dark Matter

$$\mathcal{O} = \frac{1}{\Lambda^2}(\bar{q}q)(\bar{\Psi}\Psi) \quad , \quad \mathcal{O} = \frac{1}{\Lambda^2}(\bar{q}\gamma^{\mu}q)(\bar{\Psi}\gamma_{mu}\Psi)$$

$$\sigma(\bar{q}q \to \bar{\Psi}\Psi) \simeq \frac{1}{8\pi}\frac{s}{\Lambda^4}$$

Maximal Dark Matter Mass



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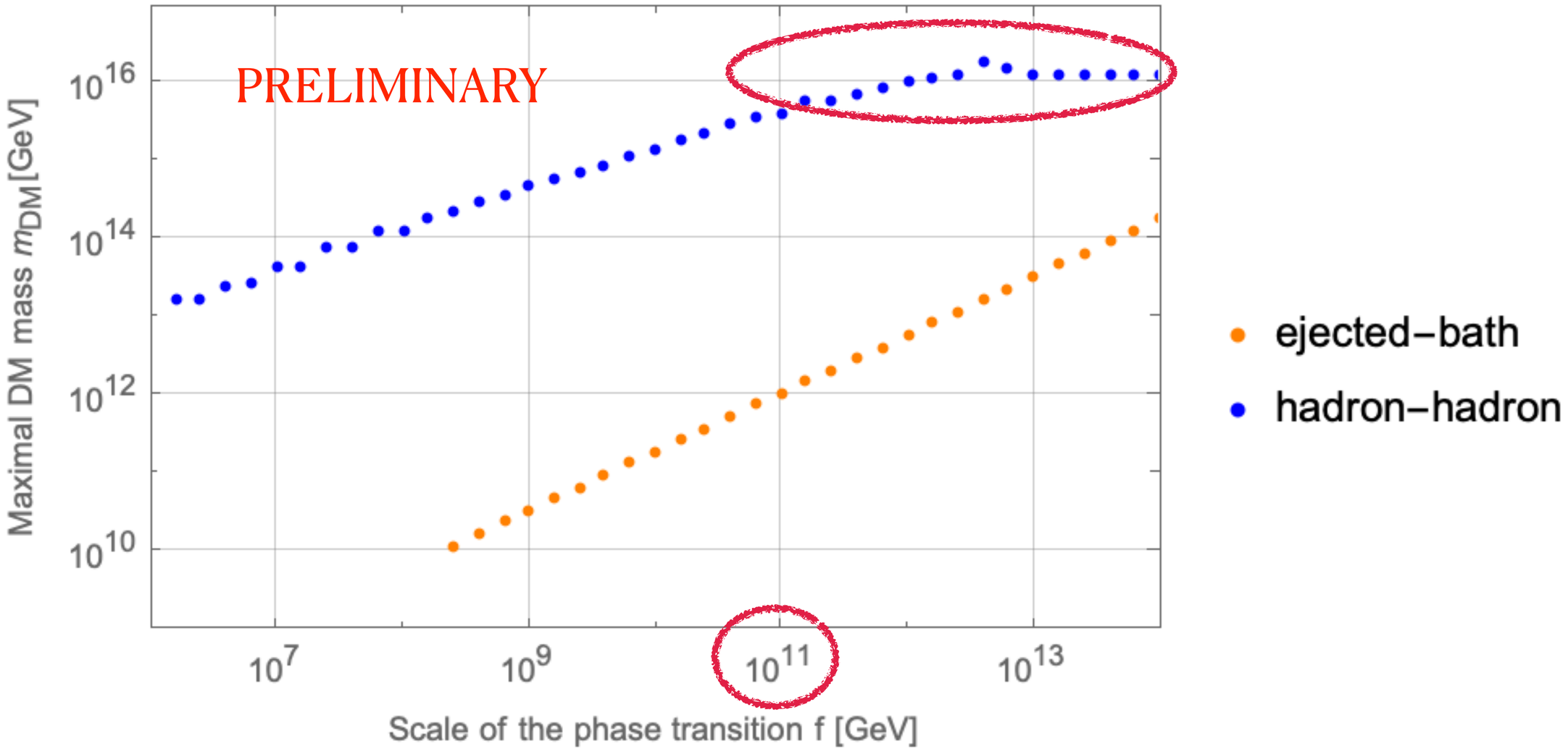

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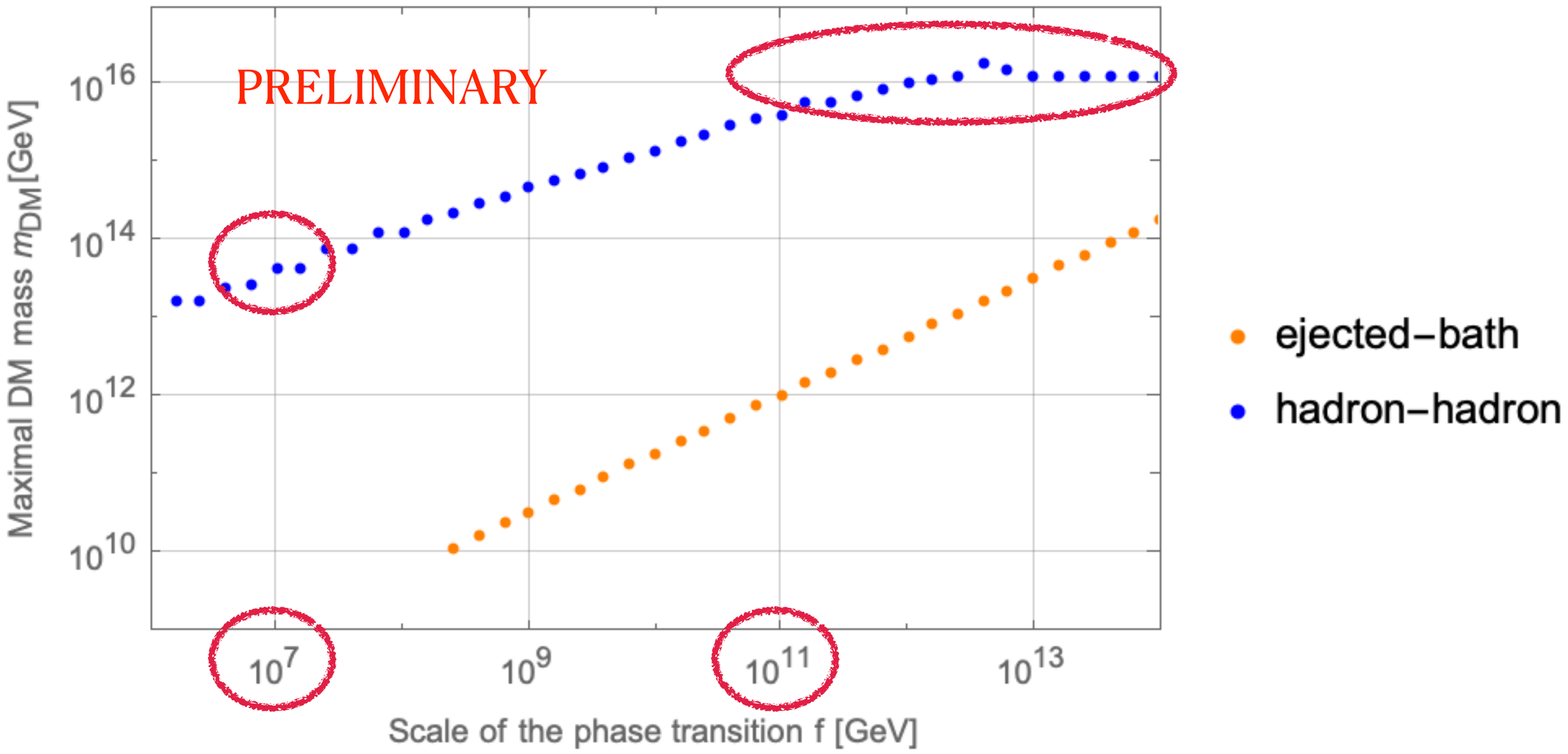
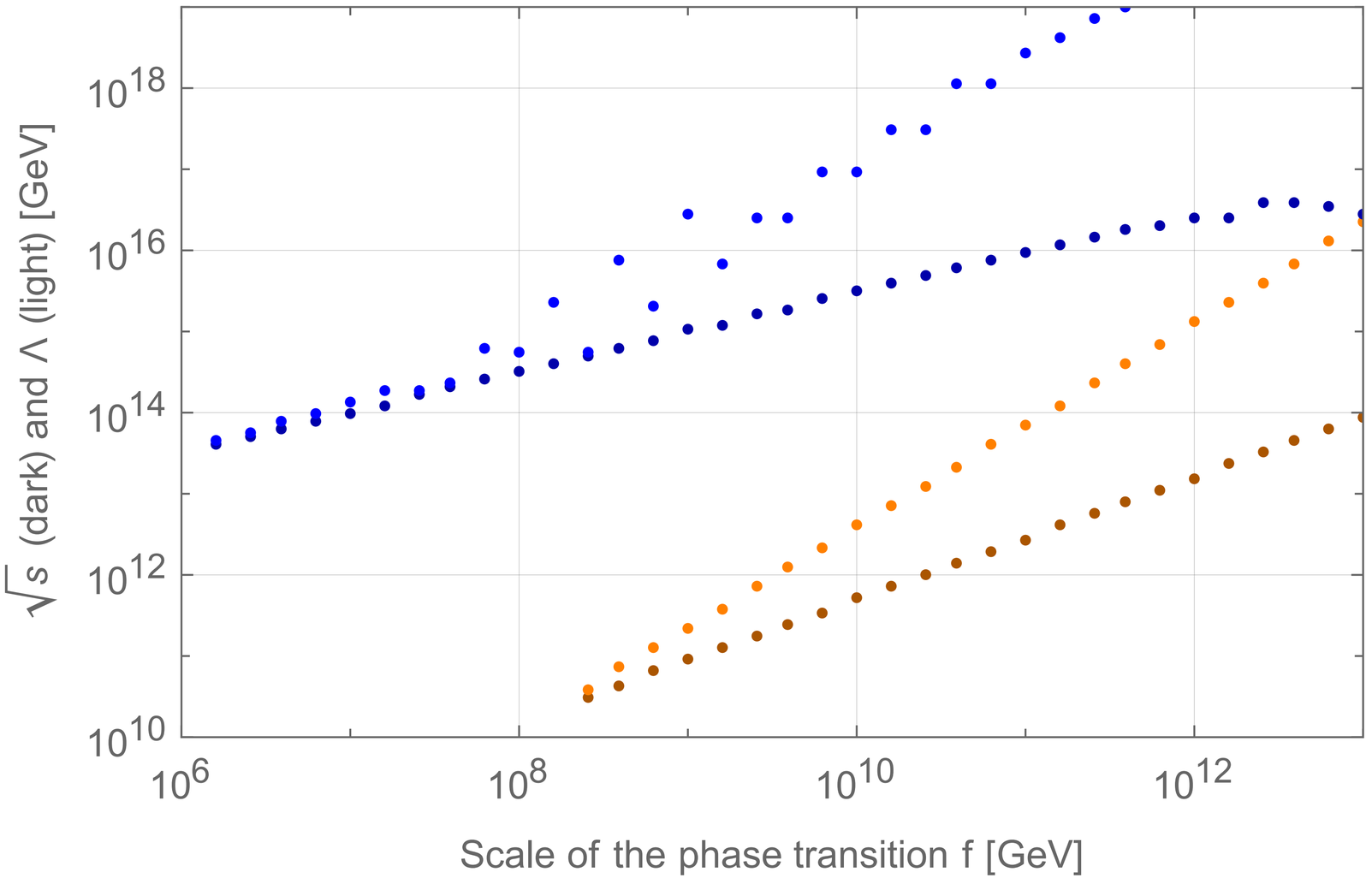


Outlook

- Concrete Models
- Non-confining phase transitions
- Signals for GW detectors
- Baryogenesis

Backup

Scattering / Interaction Scale



Nucleation Temperature