

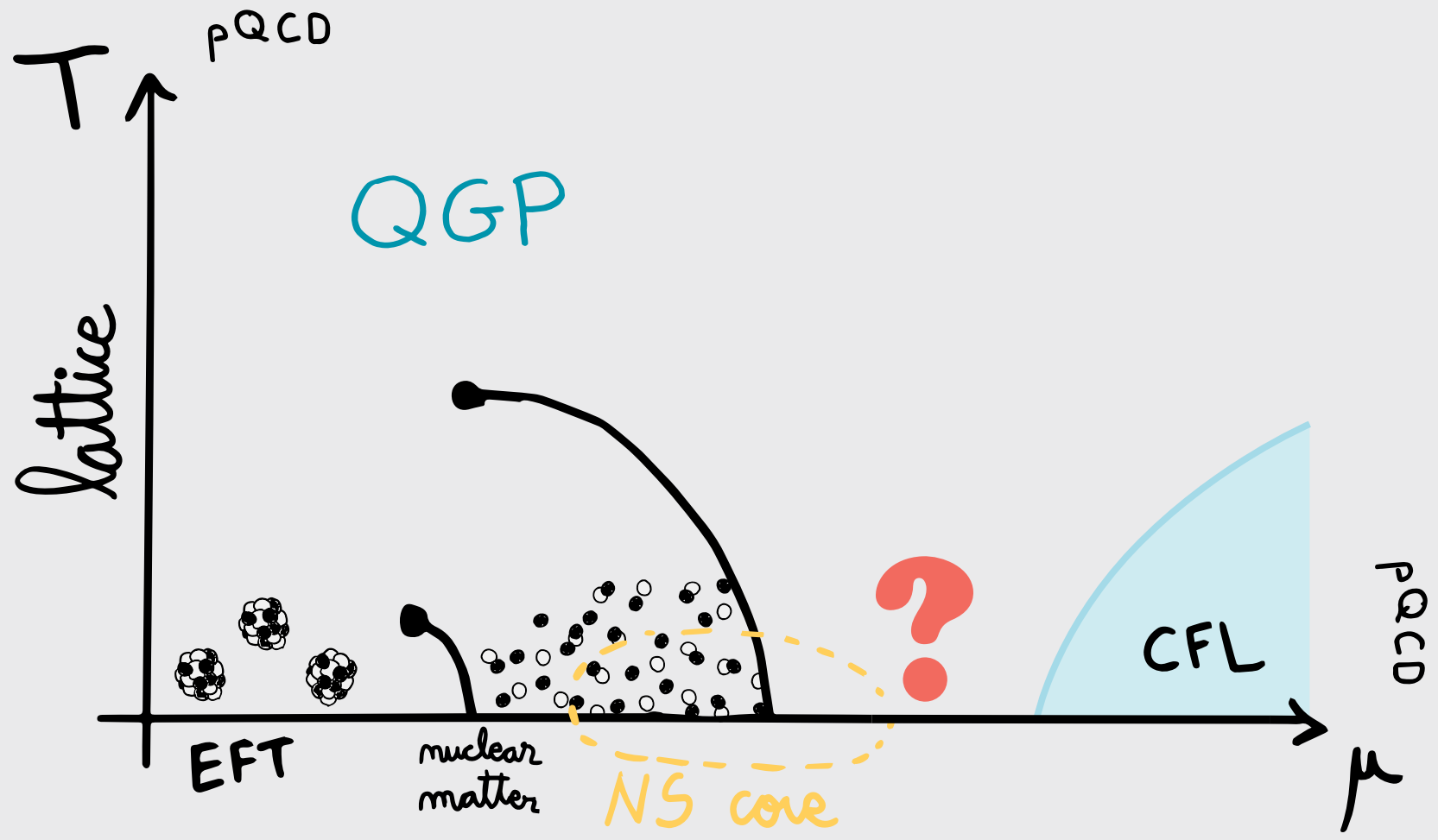
Towards finite baryon density in confining solutions

Javier Subils

Iberian Strings 2023, January 13.
Universidad de Murcia.

In collaboration with Ant3n Faedo and Carlos Hoyos, based in [2212.04996]

Motivation: understand the QCD phase diagram

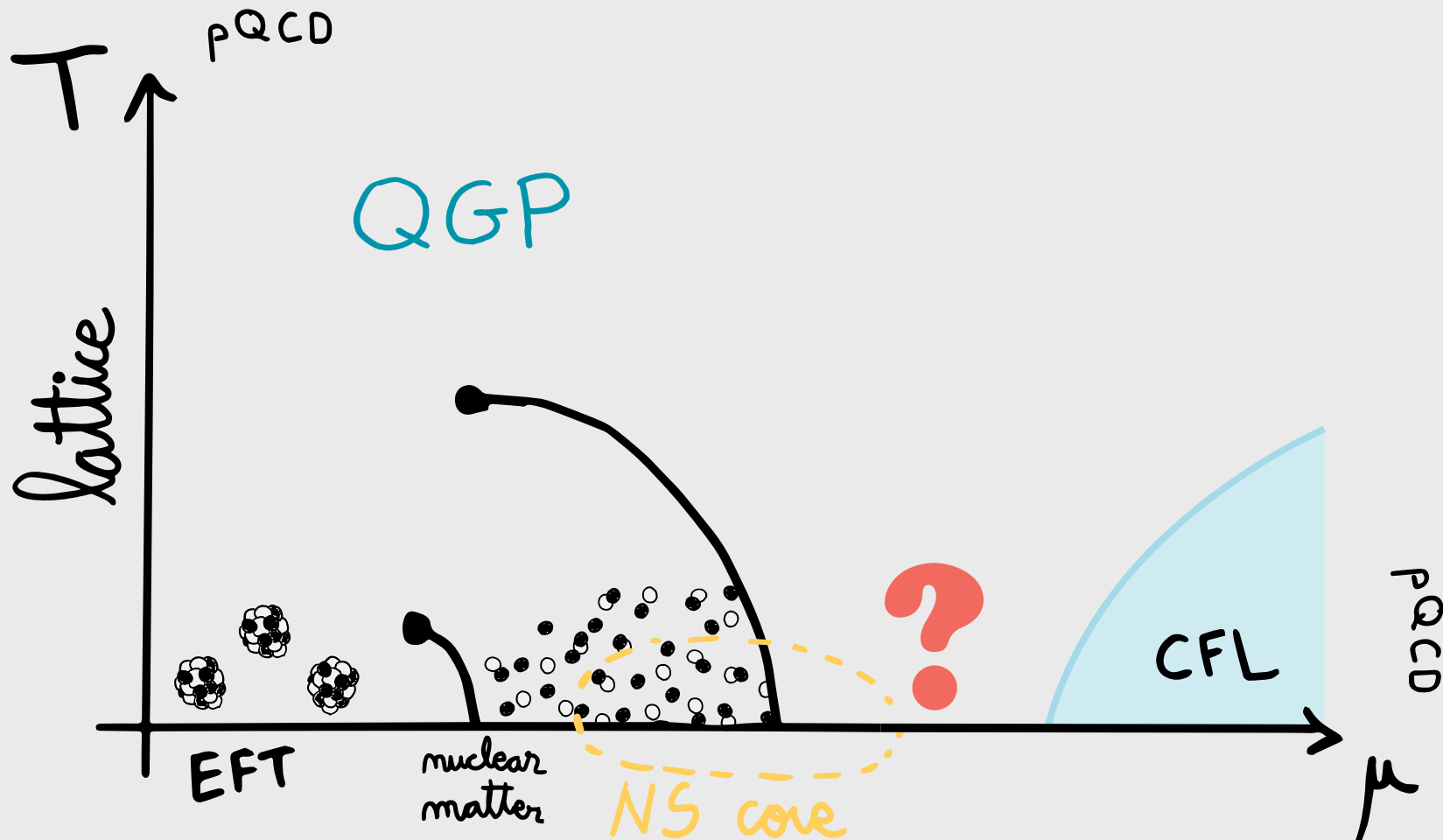


Motivation: understand the QCD phase diagram

Confinement, finite density.

Context:

- “Top-down” models in holography.



Motivation: understand the QCD phase diagram

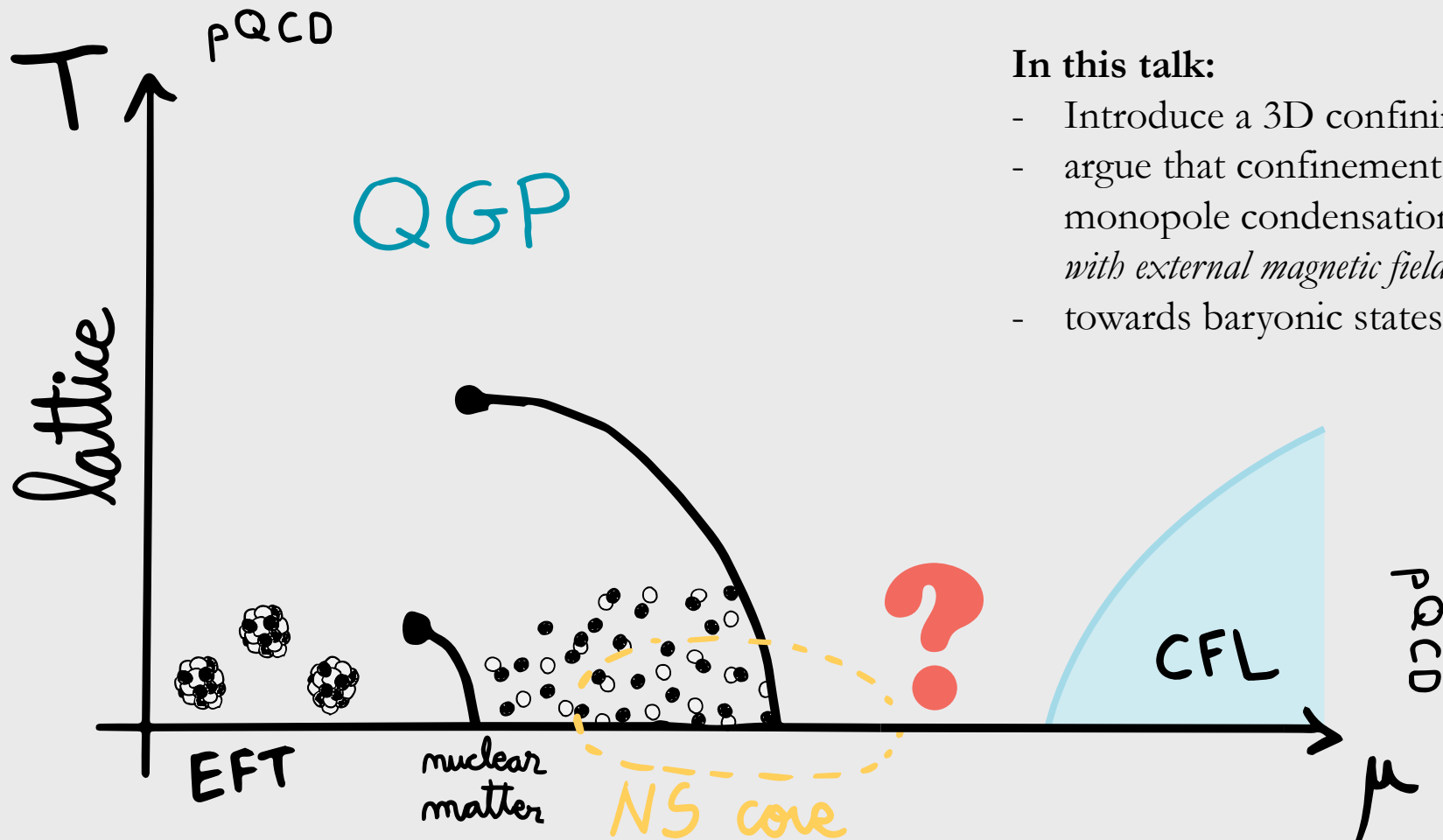
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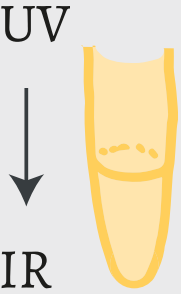
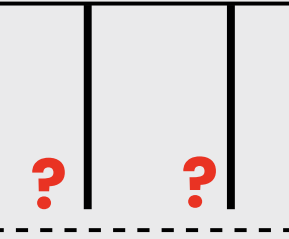
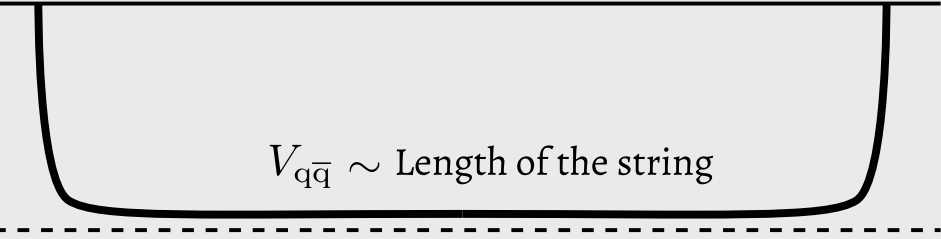
- “Top-down” models in holography.

In this talk:

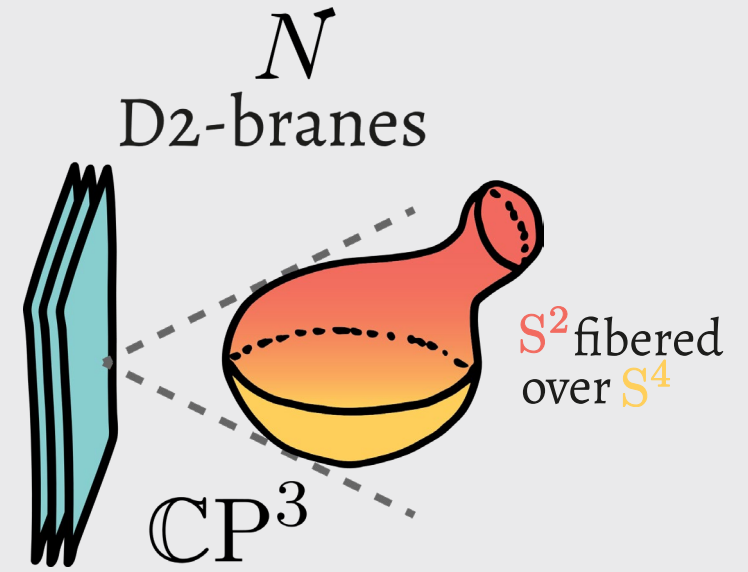
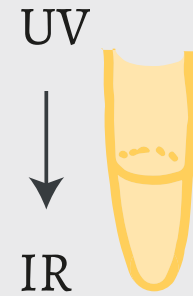
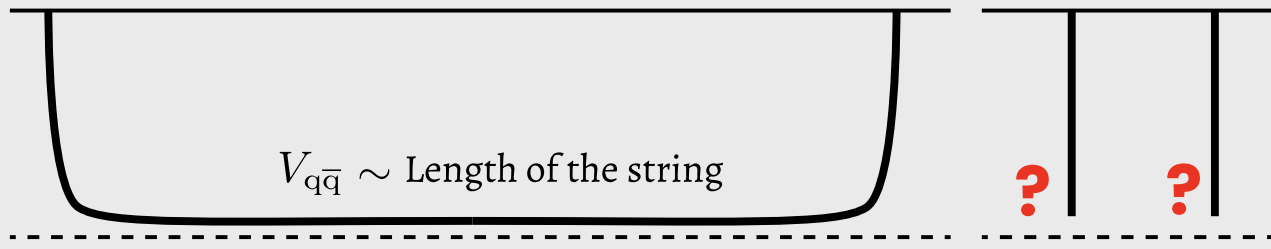
- Introduce a 3D confining theory,
- argue that confinement is caused by monopole condensation, (*phase diagram with external magnetic field*),
- towards baryonic states.



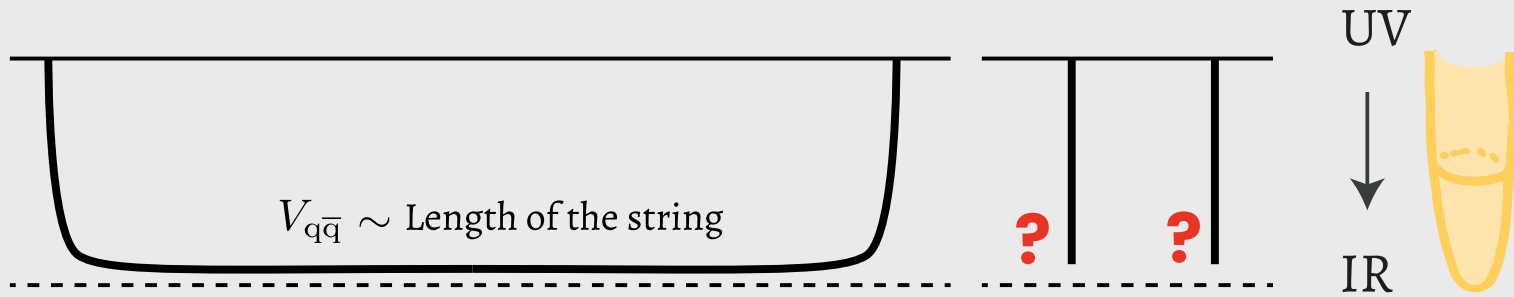
- Confinement in holography:



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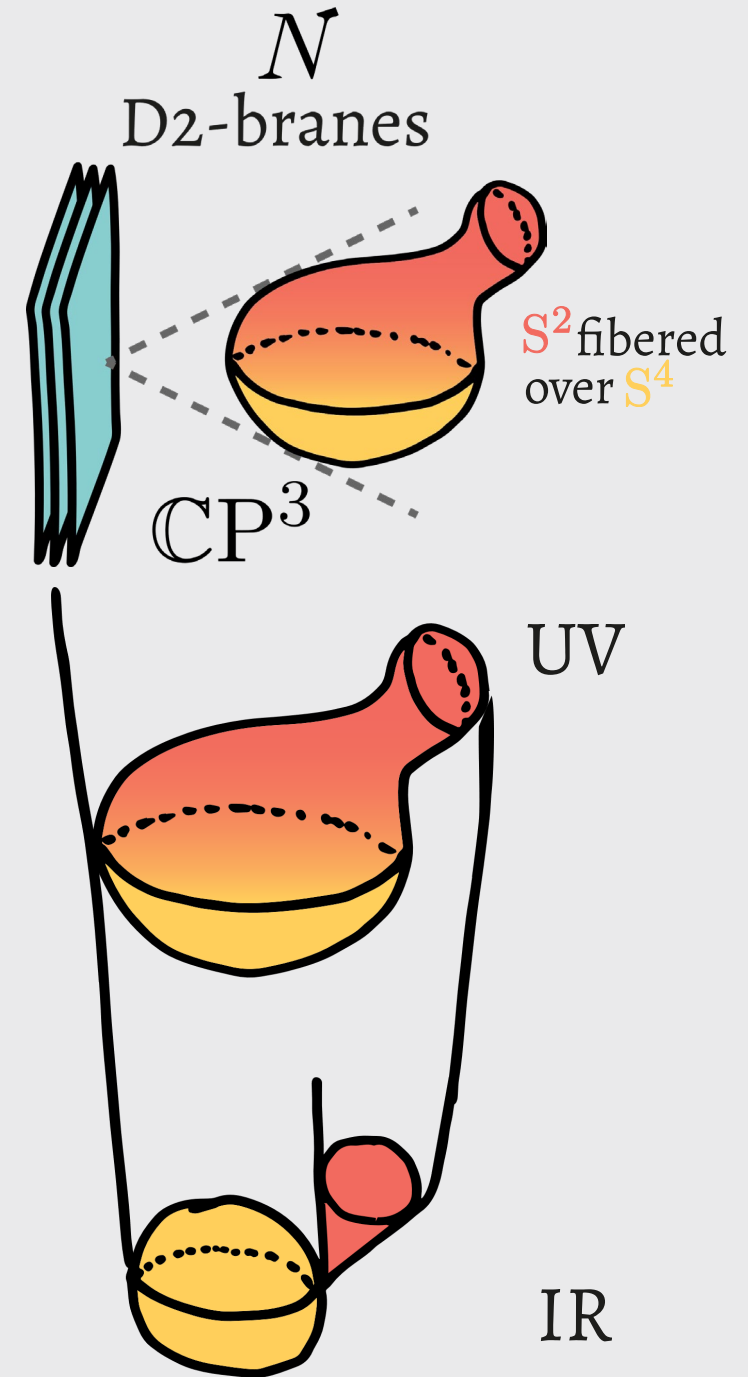


- Solution in type IIA supergravity:

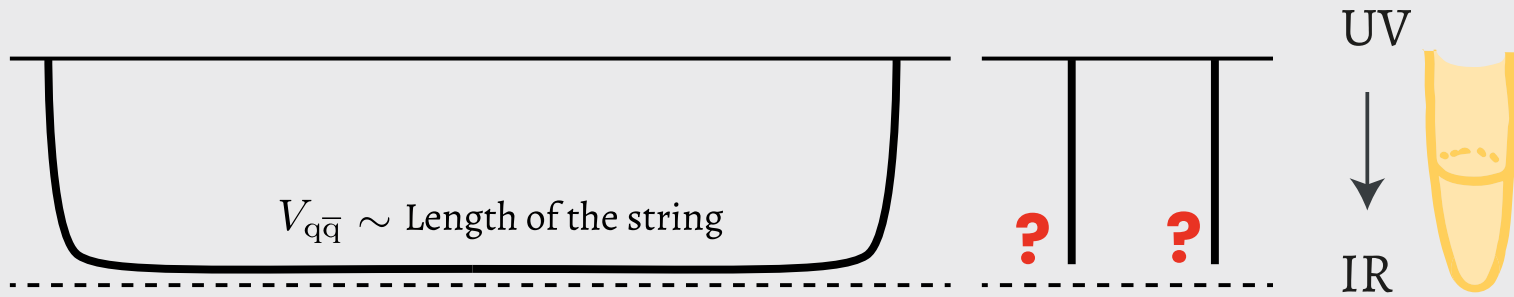
$$F_2 = 0$$

$$H \neq 0$$

$$F_4 \propto * \Omega_{\text{CP}^3} + \text{additional terms}$$



- Confinement in holography:



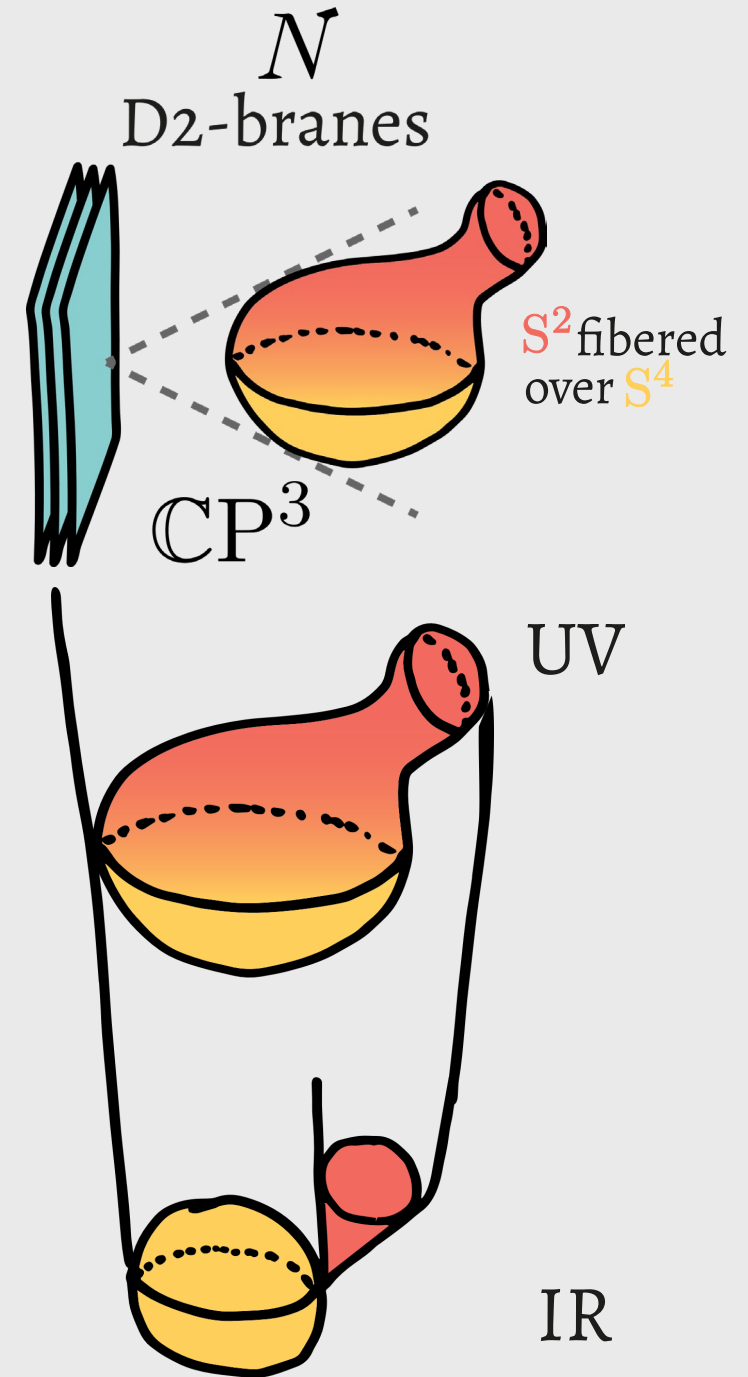
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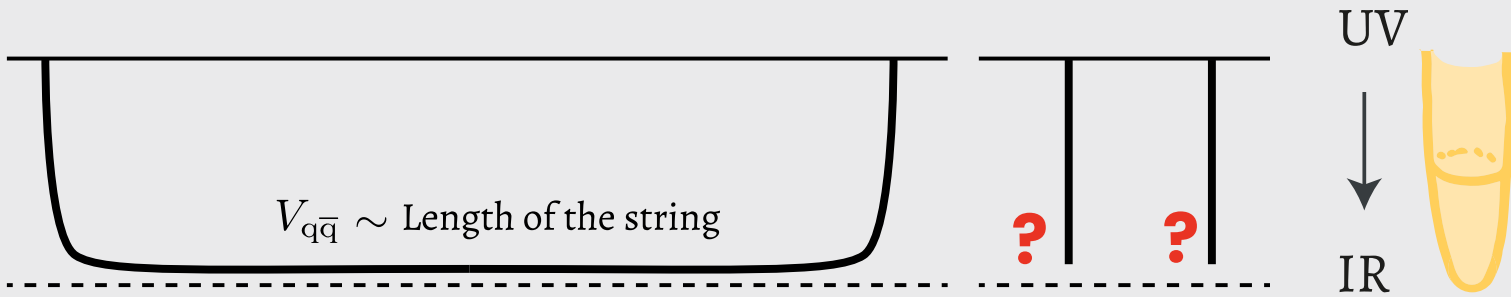
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- *What is the gauge group?*



- Confinement in holography:



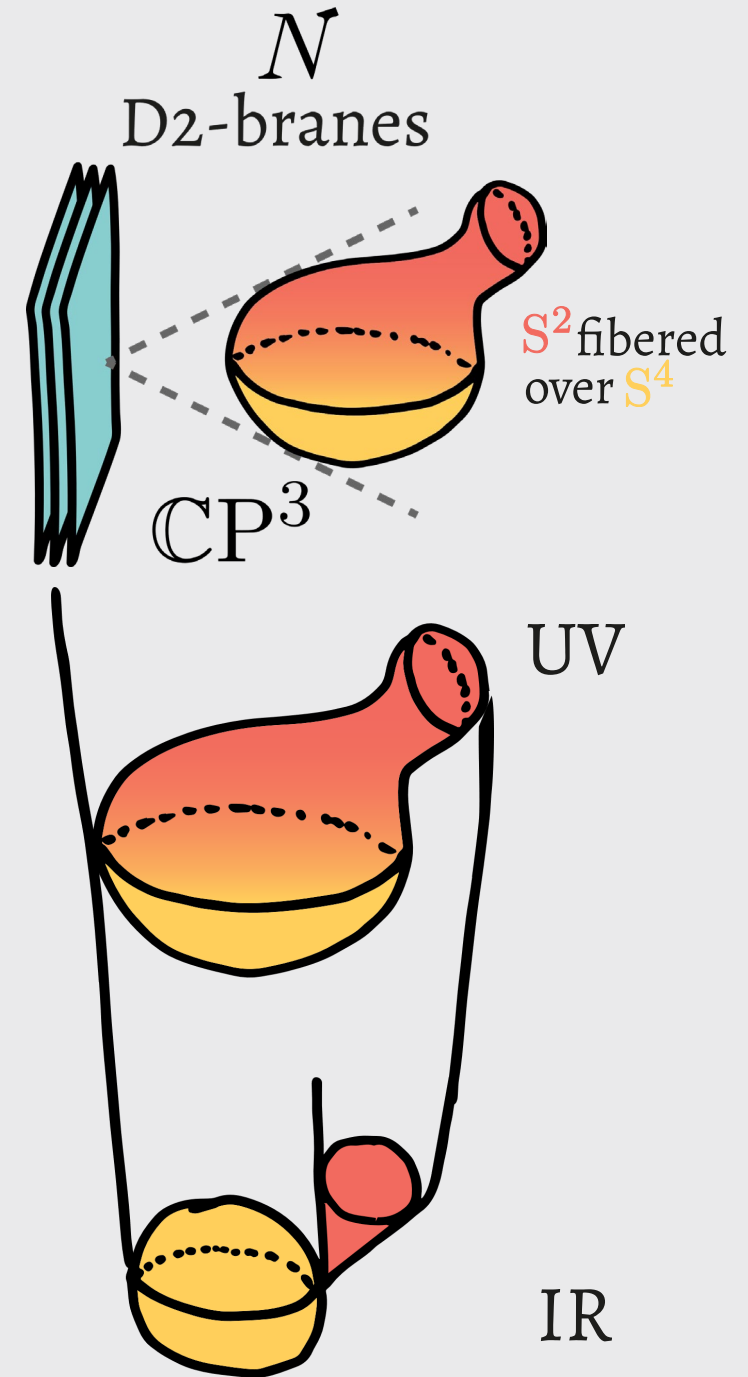
- Solution in type IIA supergravity:

$$F_2 \propto (\text{Kahler form}) \quad H = 0$$

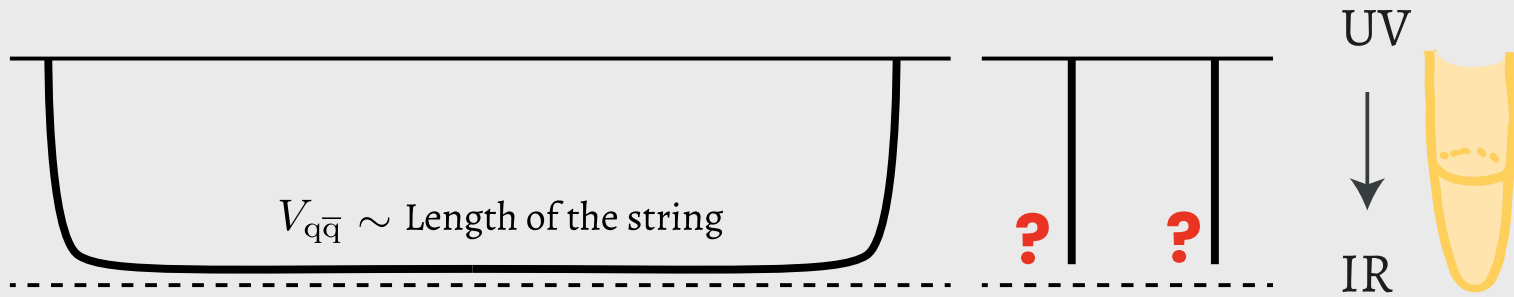
$$F_4 \propto *\Omega_{\mathbb{C}P^3} + \text{additional terms}$$

- *What is the gauge group?*

$$U(N)_k \times U(N)_{-k} \quad (\text{ABJM would be a solution})$$



- Confinement in holography:



- Solution in type IIA supergravity:

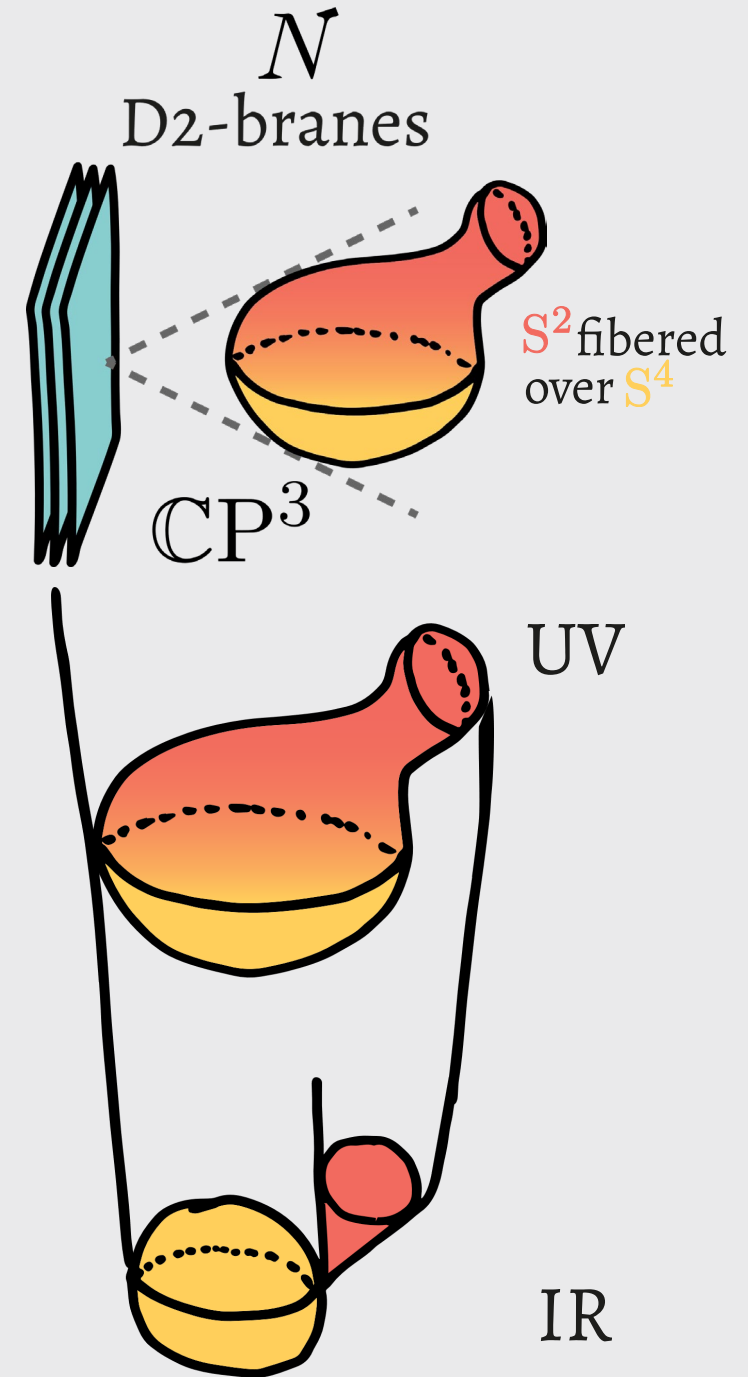
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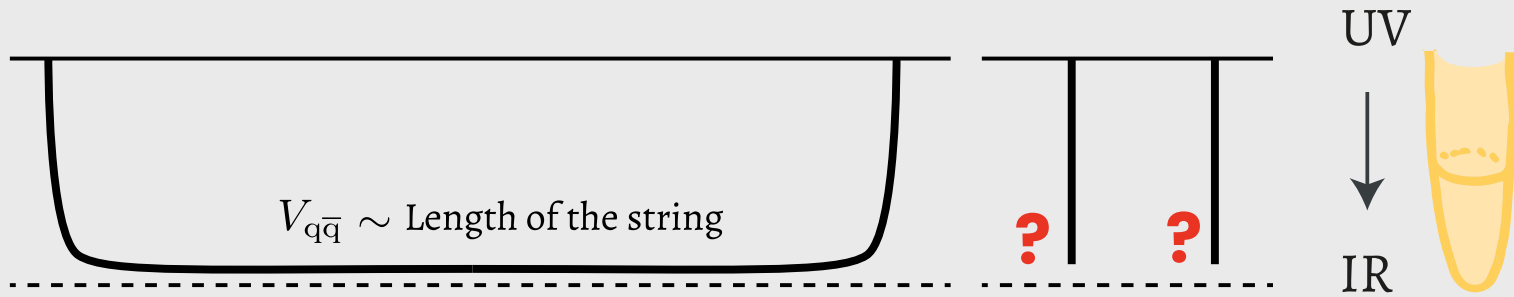
$$F_4 \propto * \Omega_{\mathbb{CP}^3} + \text{additional terms}$$

- *What is the gauge group?*

$$U(N) \times U(N + M), \text{ and preserve } N=1 \text{ SUSY}$$



- Confinement in holography:



- Solution in type IIA supergravity:

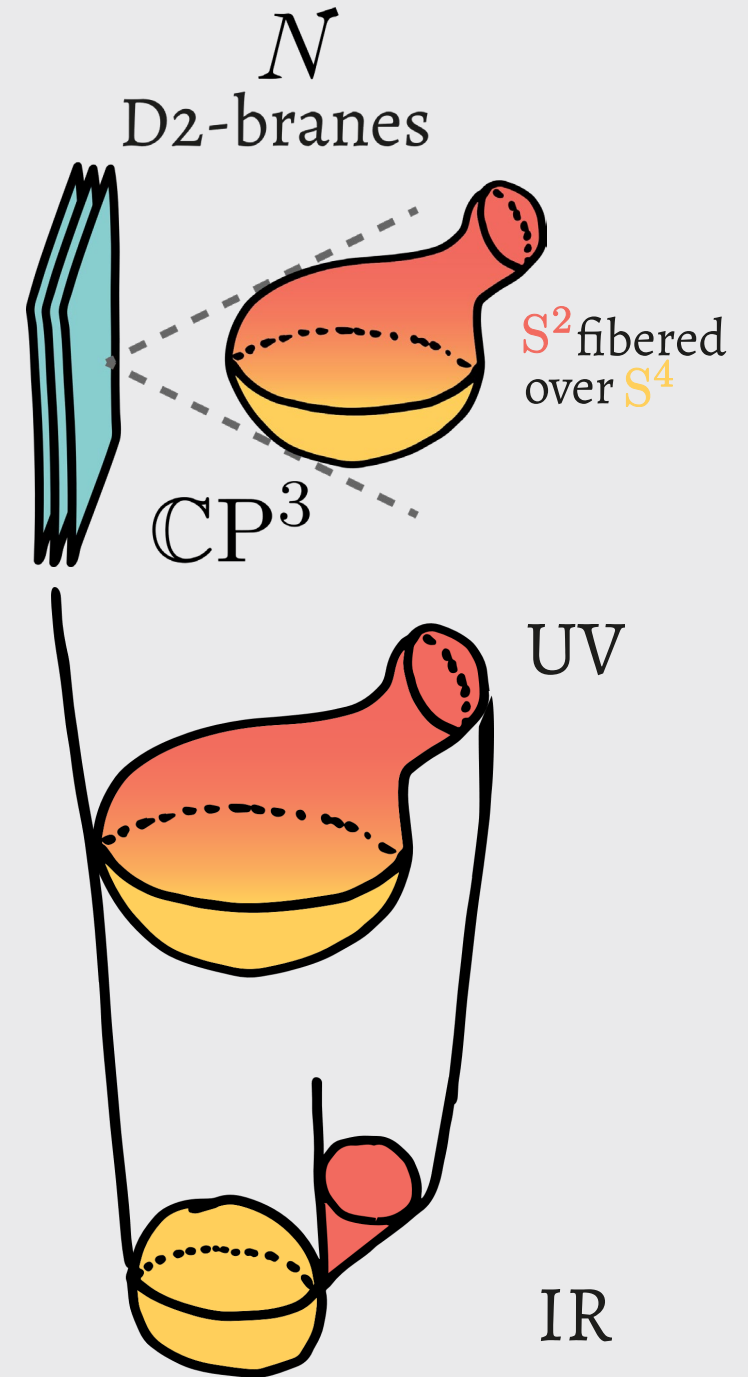
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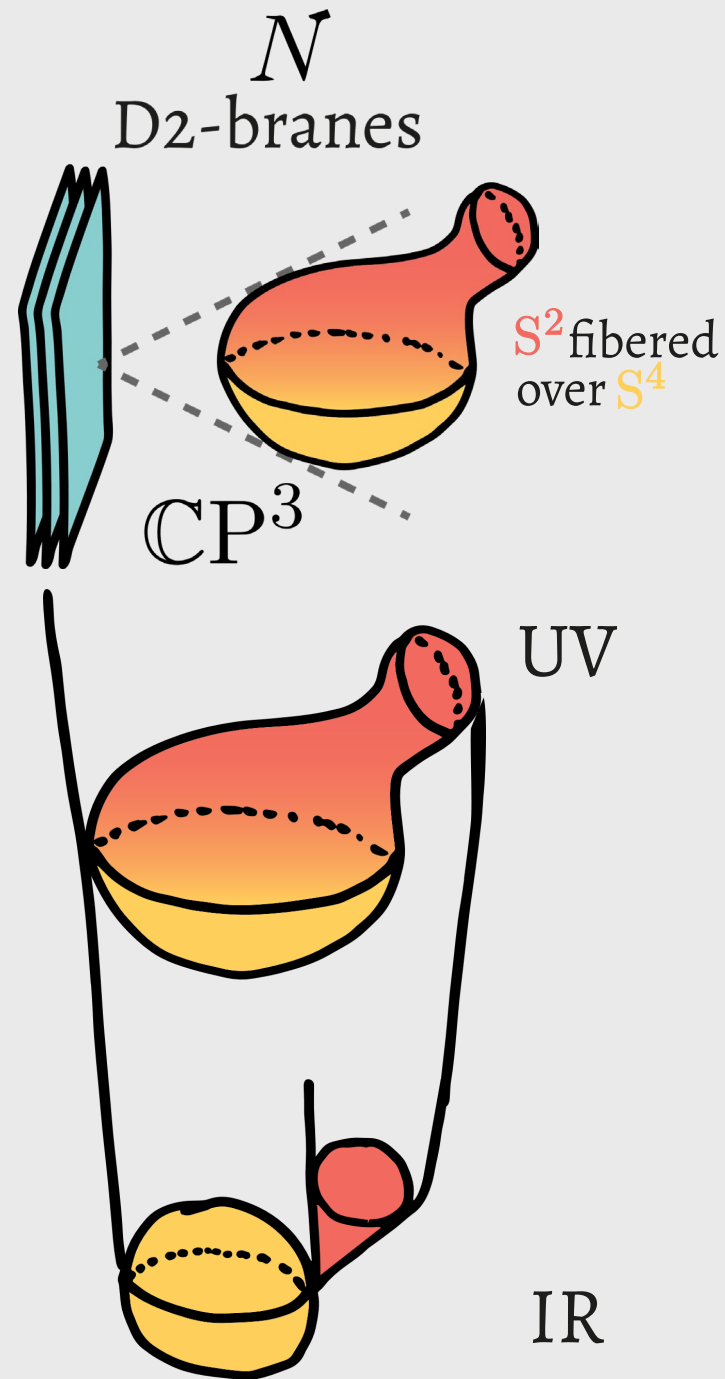
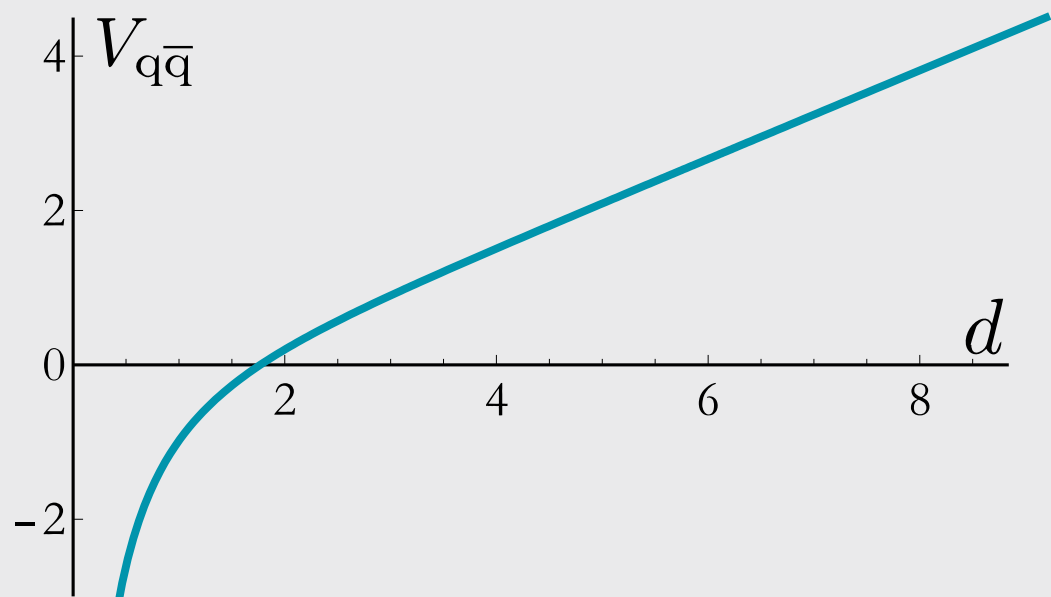
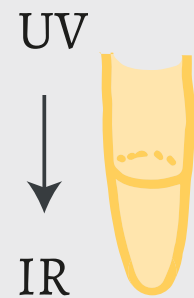
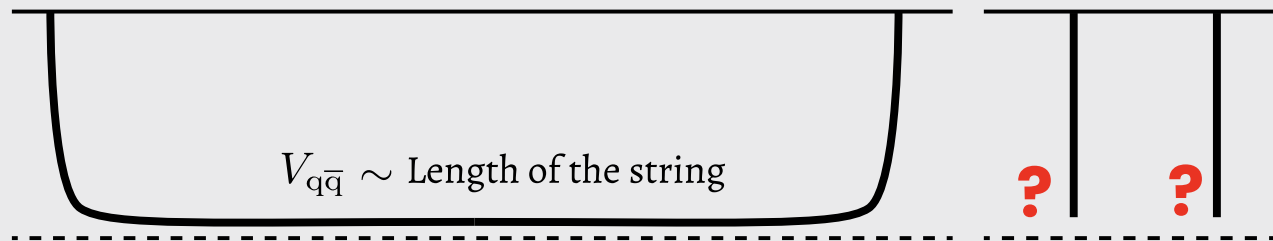
- *What is the gauge group?*

$$U(N) \times U(N + M), \text{ and preserve } N=1 \text{ SUSY}$$

- The theory cascades to $U(M)$ in the IR.



- Confinement in holography:



Monopoles and Confinement (*à la Polyakov*)

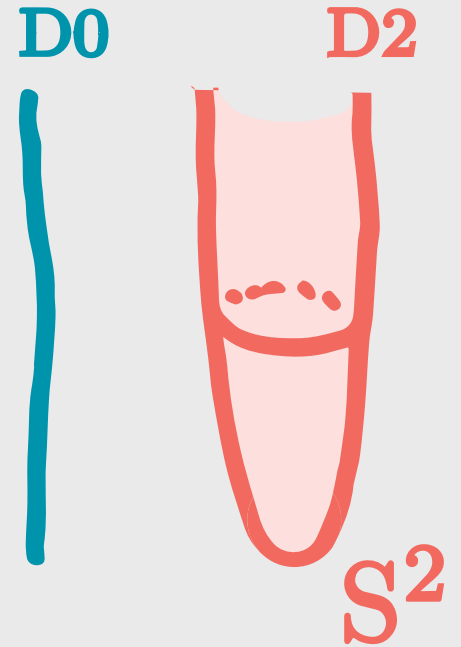
$$U(N) \times U(N+M)$$

- Polyakov proved confinement in QED3. Gas of Abelian monopoles.
- To check this, we can add local magnetic monopole operators (depending on Abelian magnetic flux in each of the groups).

$$T_{1,1}$$

$$T_{1,-1}$$

dual to D0 and D2 “instantonic” branes.



[Polyakov (1977)]

[Bergman, Tachikawa & Zafrir (2020)]

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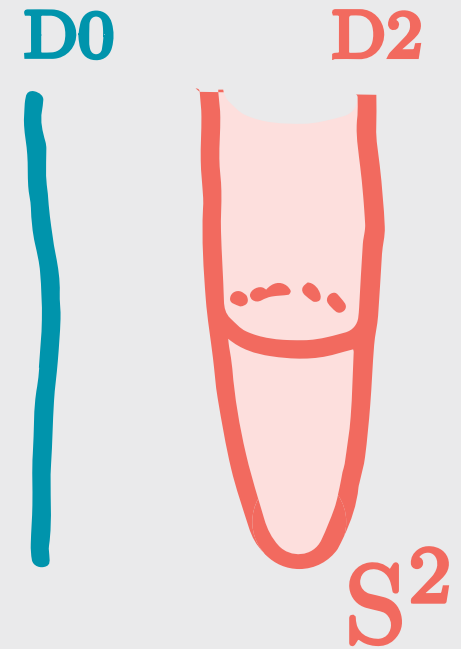
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dual to D0 and D2 “instantonic” branes.

- If monopole condensation causes confinement, we expect that the monopole-antimonopole interaction is screened.



$$\langle T_{1,-1}^\dagger(x) T_{1,-1}(0) \rangle \sim e^{-S_{D2}}$$

[Polyakov (1977)]

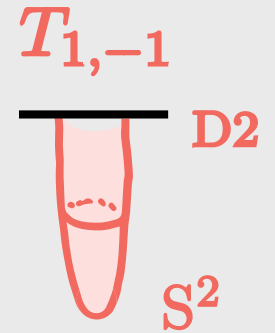
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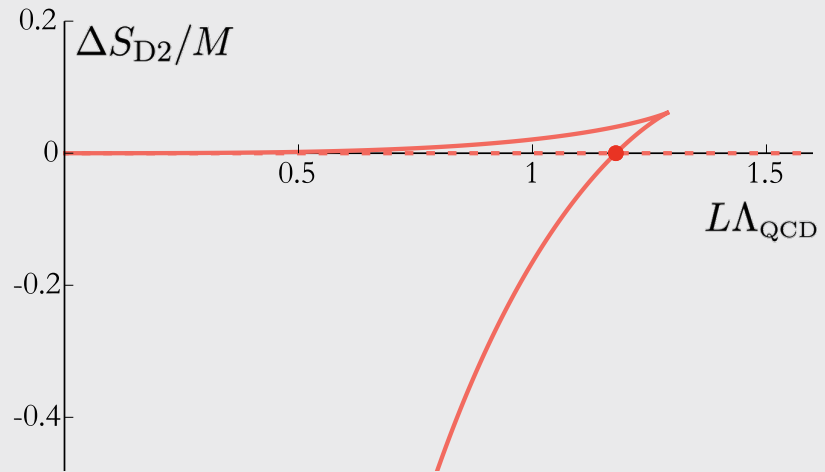
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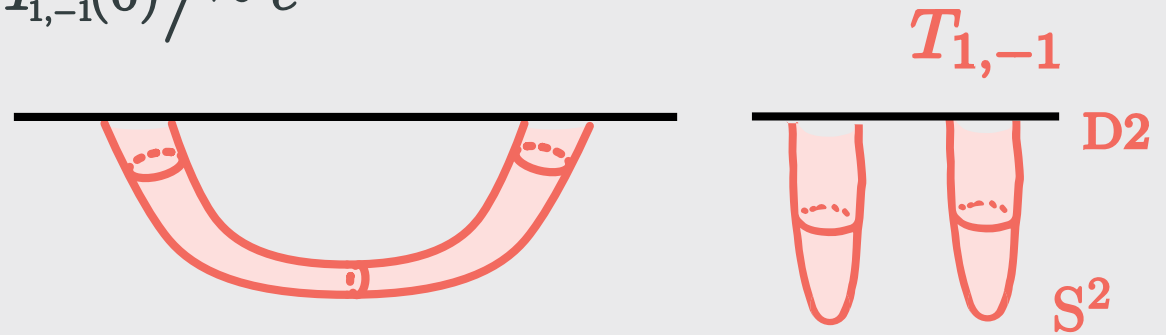
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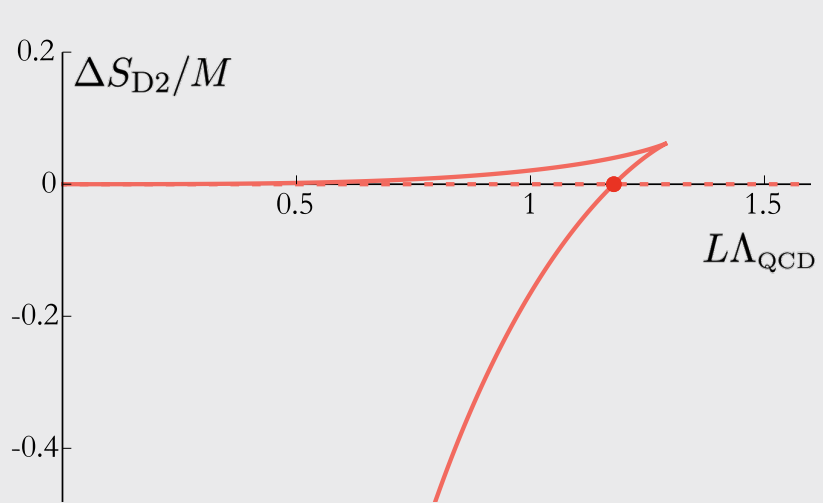
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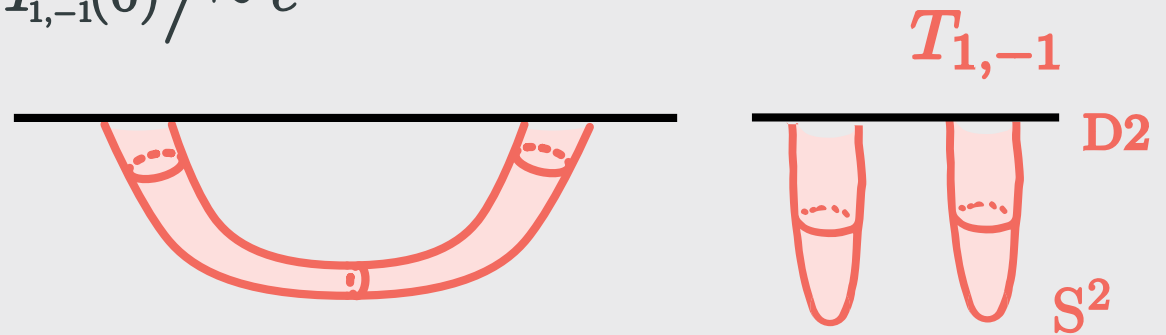
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$$\langle T_{1,-1}^\dagger(x) T_{1,-1}(0) \rangle \sim e^{-S_{D2}}$$



- Turning on an external C_1 will introduce a modification in the action of the D2, potentially leading to deconfinement.

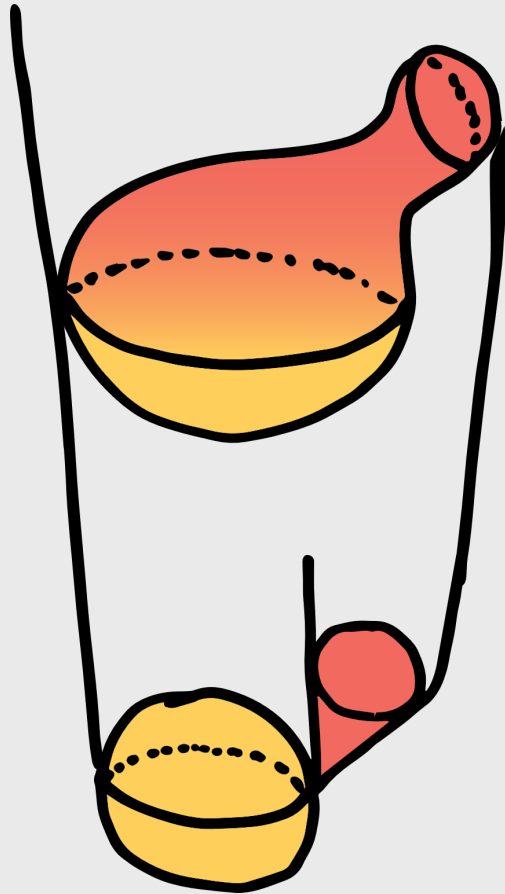
$$F_2 = dC_1$$

$$C_1 = a_t(r) dt + \frac{\beta_1}{2} (x_1 dx_2 - x_2 dx_1)$$

$$S_{D2} = S_{DBI} - \int_{CP^1} B_2 \int C_1$$

- The current should be something like $J = \text{tr}_N \star \mathcal{F}_N + \text{tr}_{N+M} \star \mathcal{F}_{N+M}$

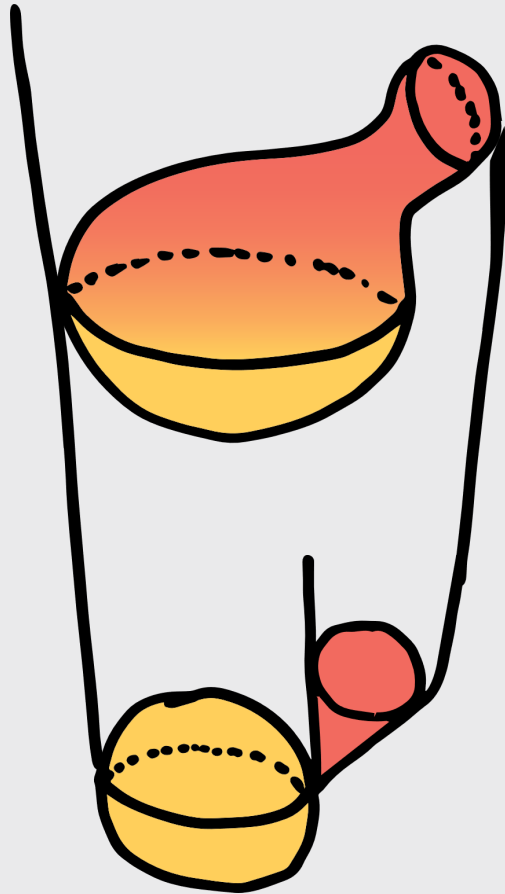
Magnetised
confining phase



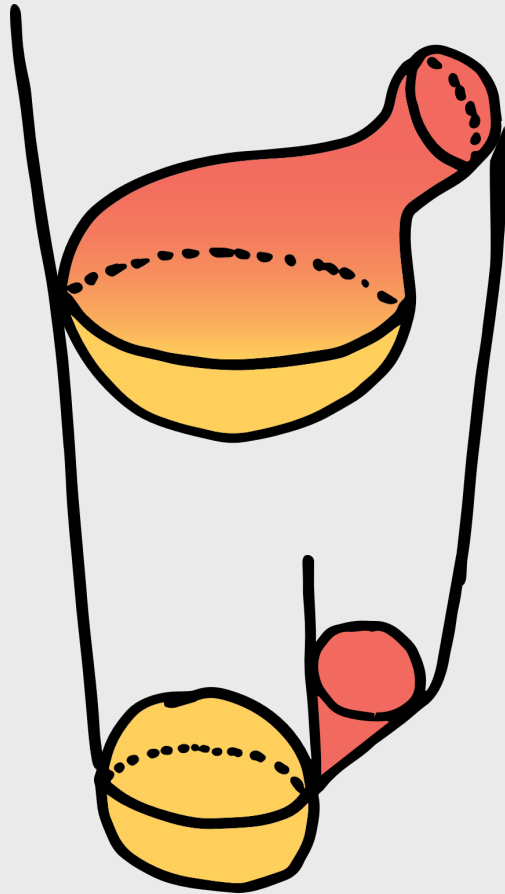
Magnetised
plasma phase



Magnetised confining phase



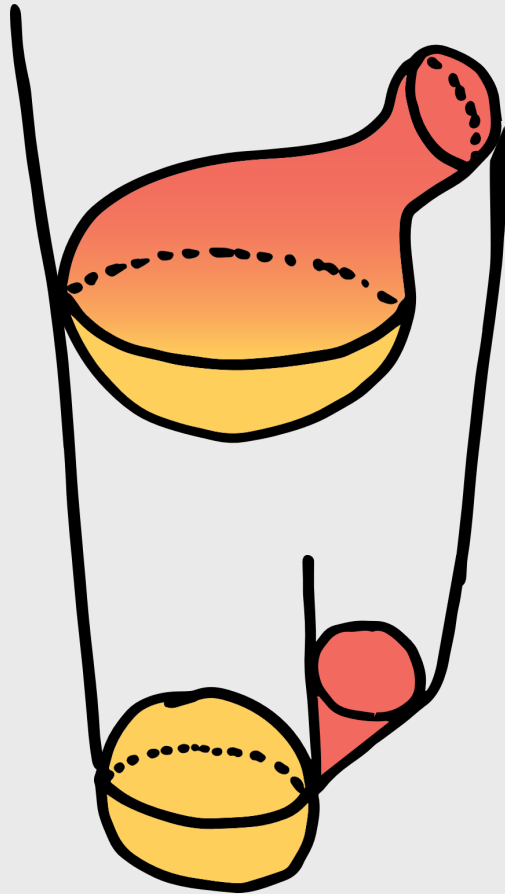
Magnetised confining phase



Boundary conditions:

- D2 brane boundary conditions in the UV.
- Confining IR boundary conditions.
- [Shooting, ~ 20 parameters]

Magnetised confining phase



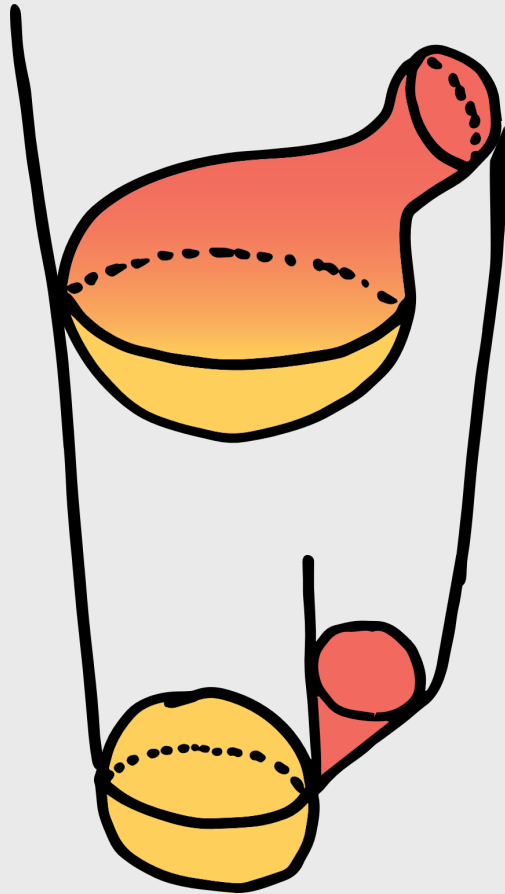
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Properties of the solutions:

- $T \sim$ arbitrary (no horizon)

Magnetised confining phase



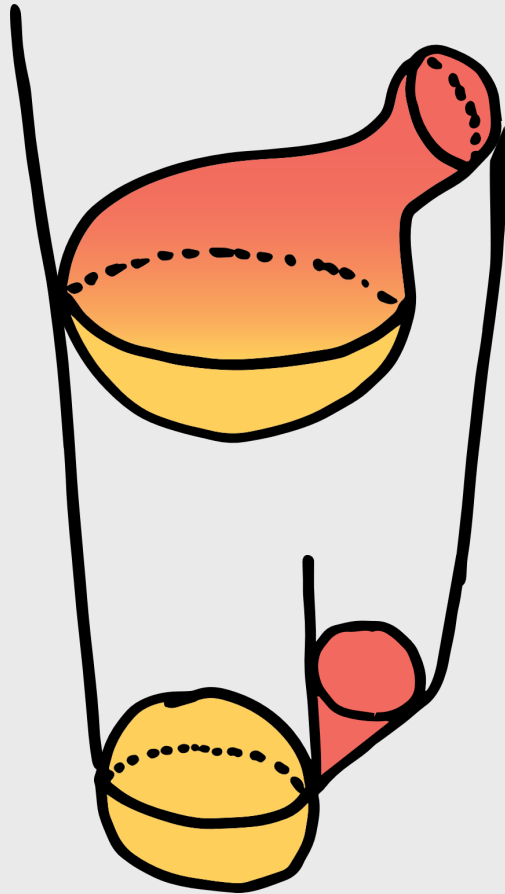
Boundary conditions:

- D2 brane boundary conditions in the UV.
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Properties of the solutions:

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- $\mu \sim$ arbitrary (no horizon)

Magnetised confining phase



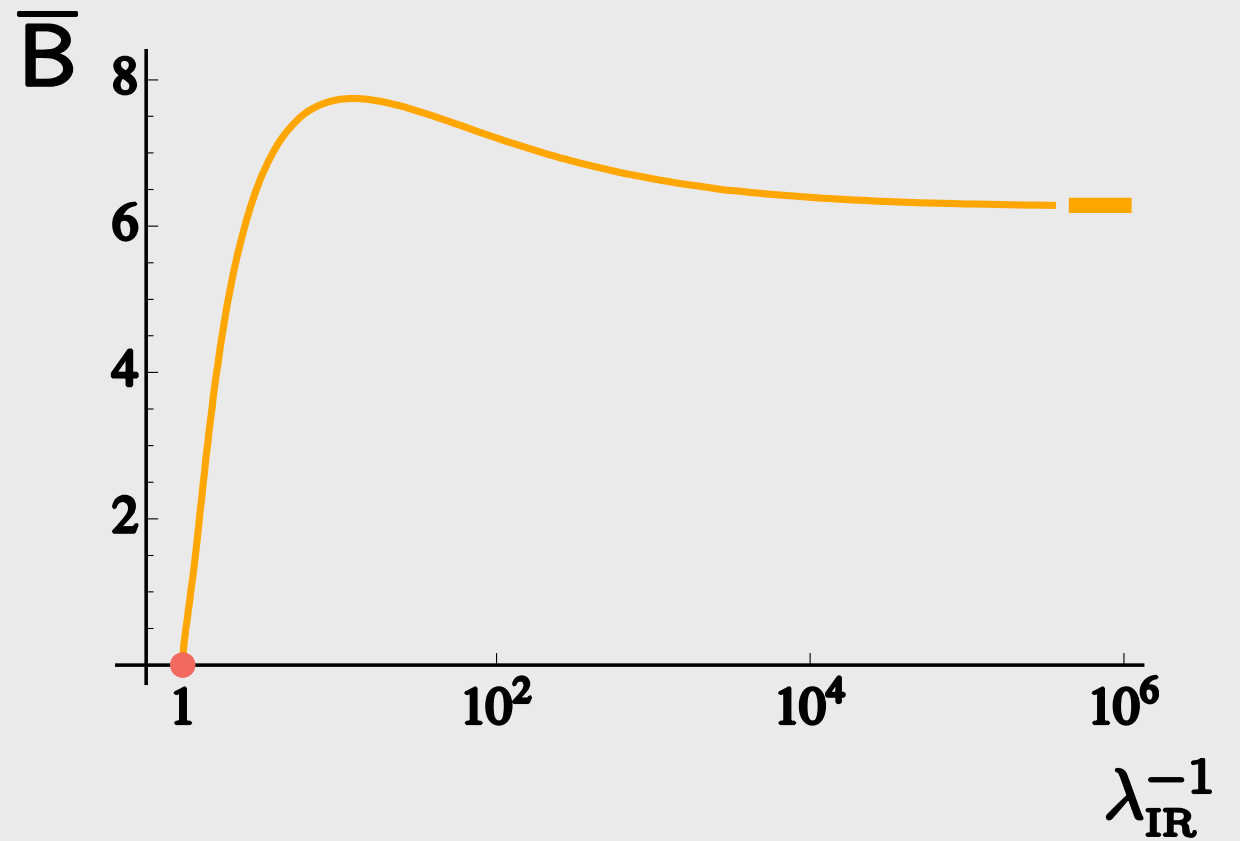
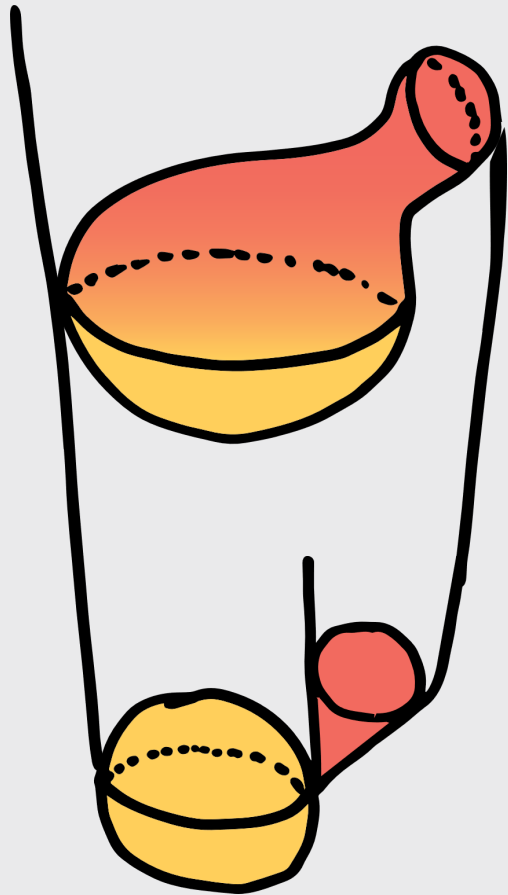
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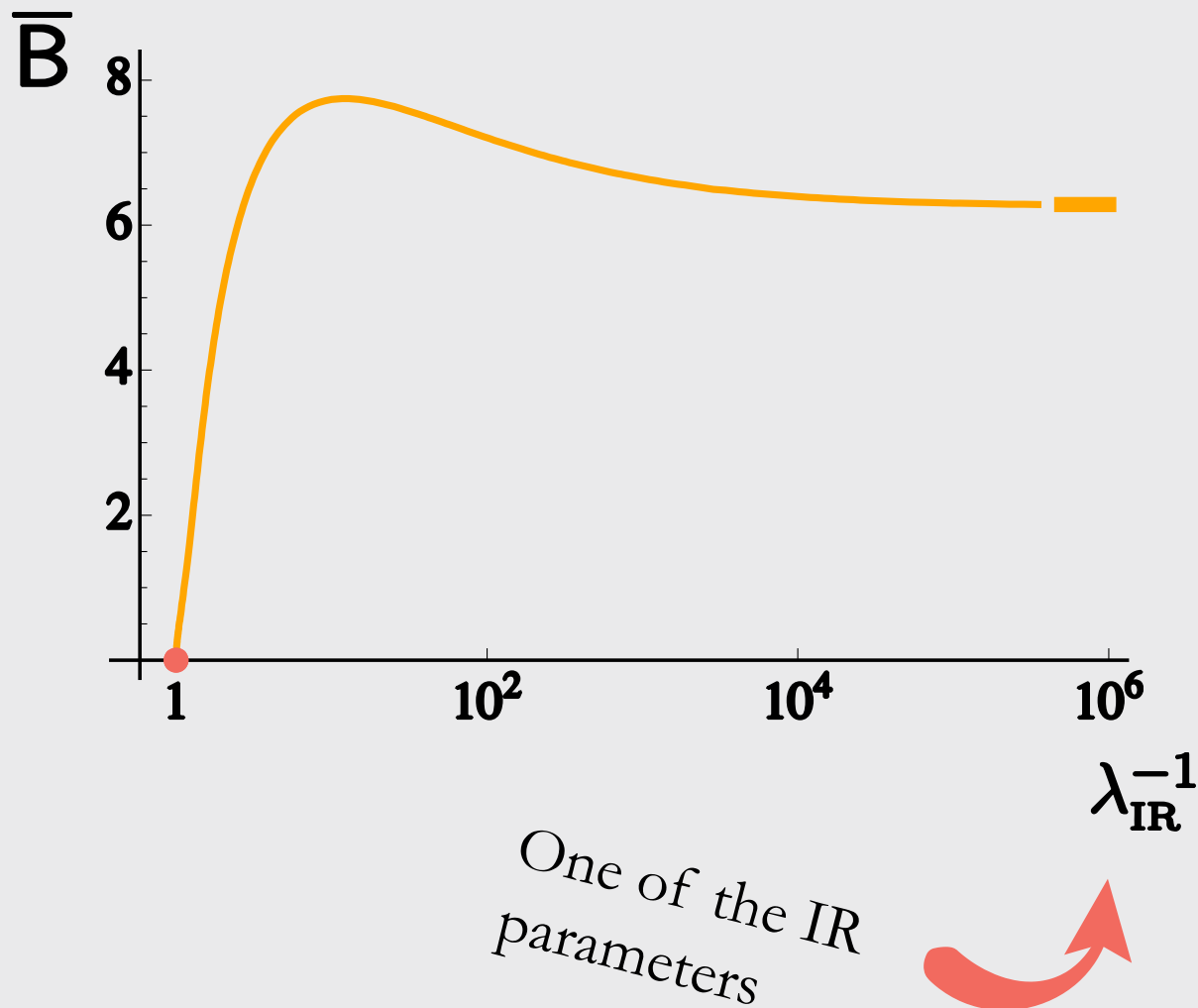
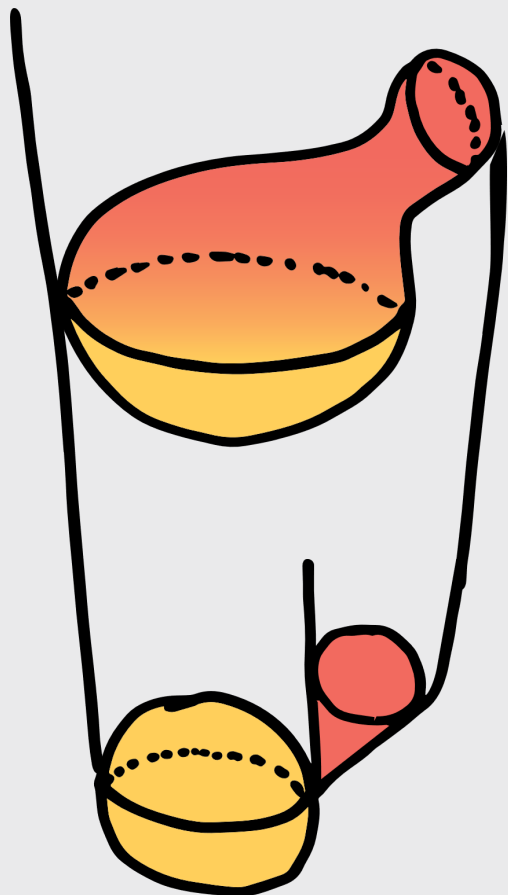
Properties of the solutions:

- $T \sim$ arbitrary (no horizon)
- $\mu \sim$ arbitrary (no horizon)
- The magnetic field is bounded from above.

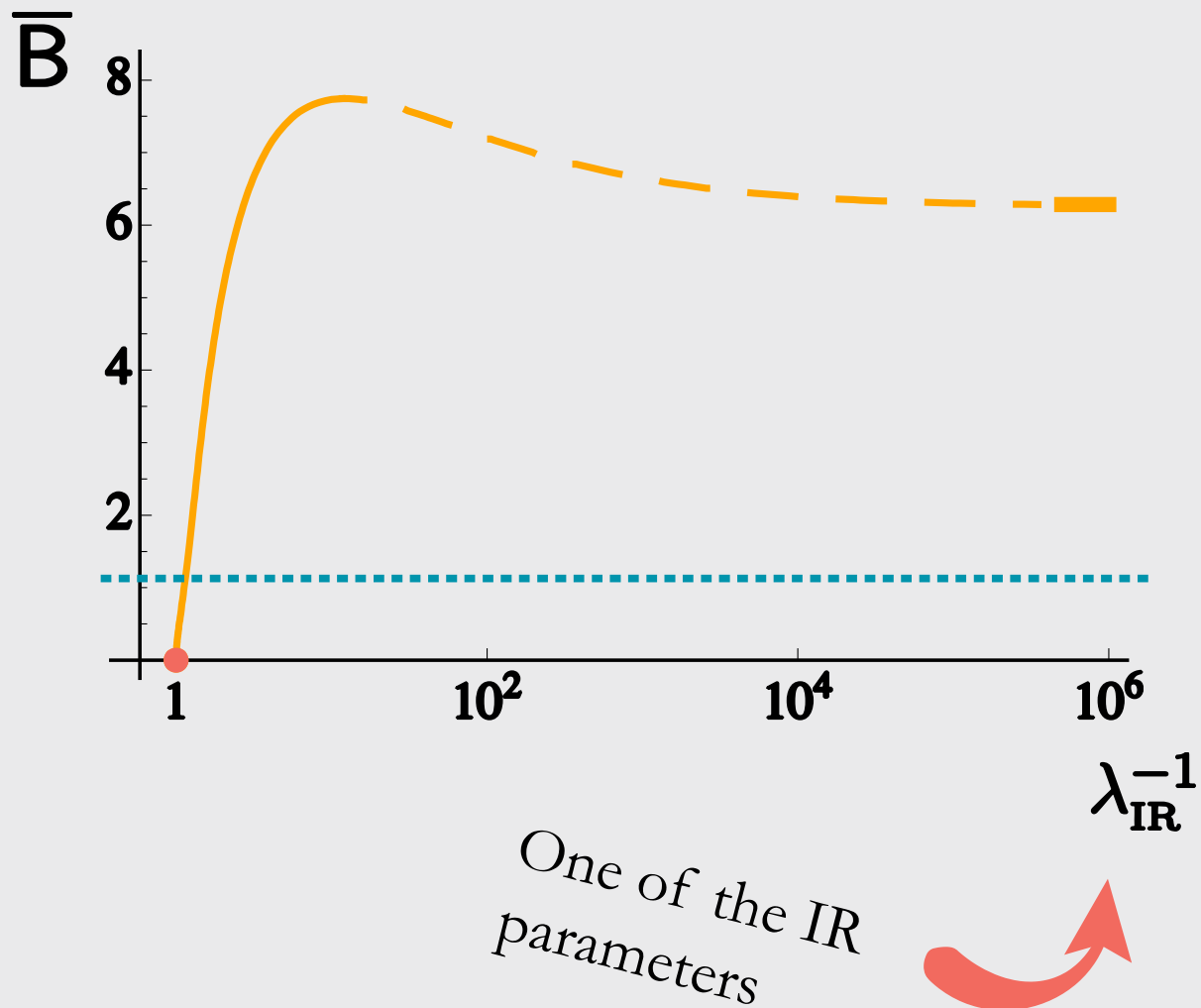
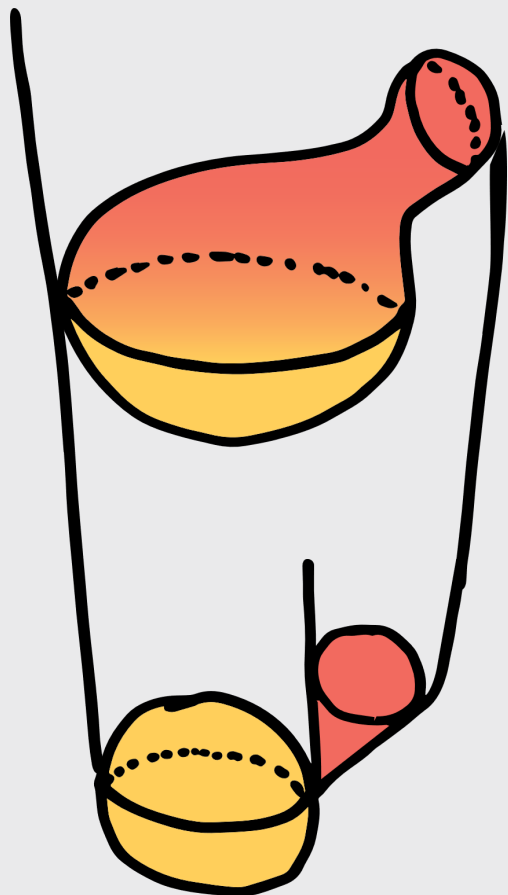
Magnetised confining phase



Magnetised confining phase



Magnetised confining phase



Magnetised plasma phase



Magnetised plasma phase



Boundary conditions:

- D2 brane boundary conditions in the UV.
- Black brane boundary conditions at the IR.
- [Shooting, ~ 20 parameters]

Magnetised plasma phase



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Properties of the solutions:

Magnetised plasma phase



Boundary conditions:

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- $\mu \sim$ fixed by regularity

Magnetised plasma phase



Boundary conditions:

- D2 brane boundary conditions in the UV.
- Black brane boundary conditions at the IR.
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Properties of the solutions:

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Magnetised plasma phase



Boundary conditions:

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Properties of the solutions:

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We focus in $\mu = 0$.

Magnetised plasma phase



Boundary conditions:

- D2 brane boundary conditions in the UV.
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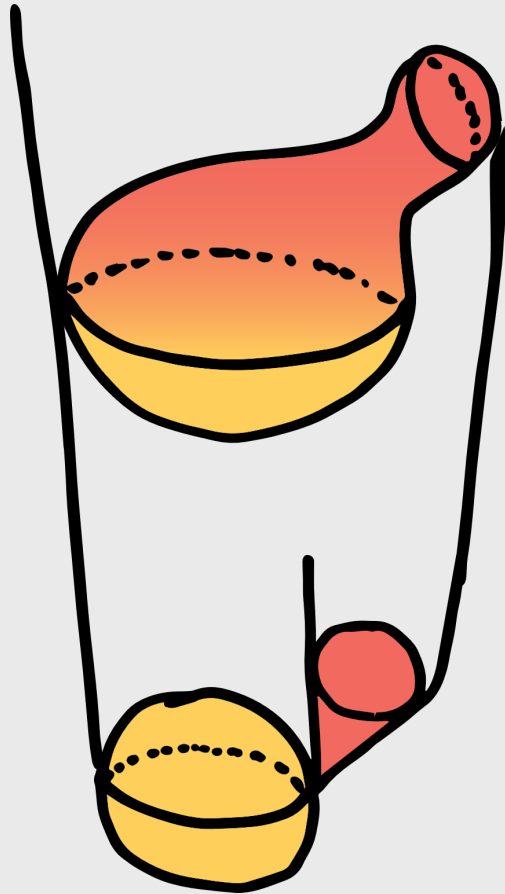
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For every fixed value of B , we find solutions at different T and compare with the other phase.

Magnetised confining phase

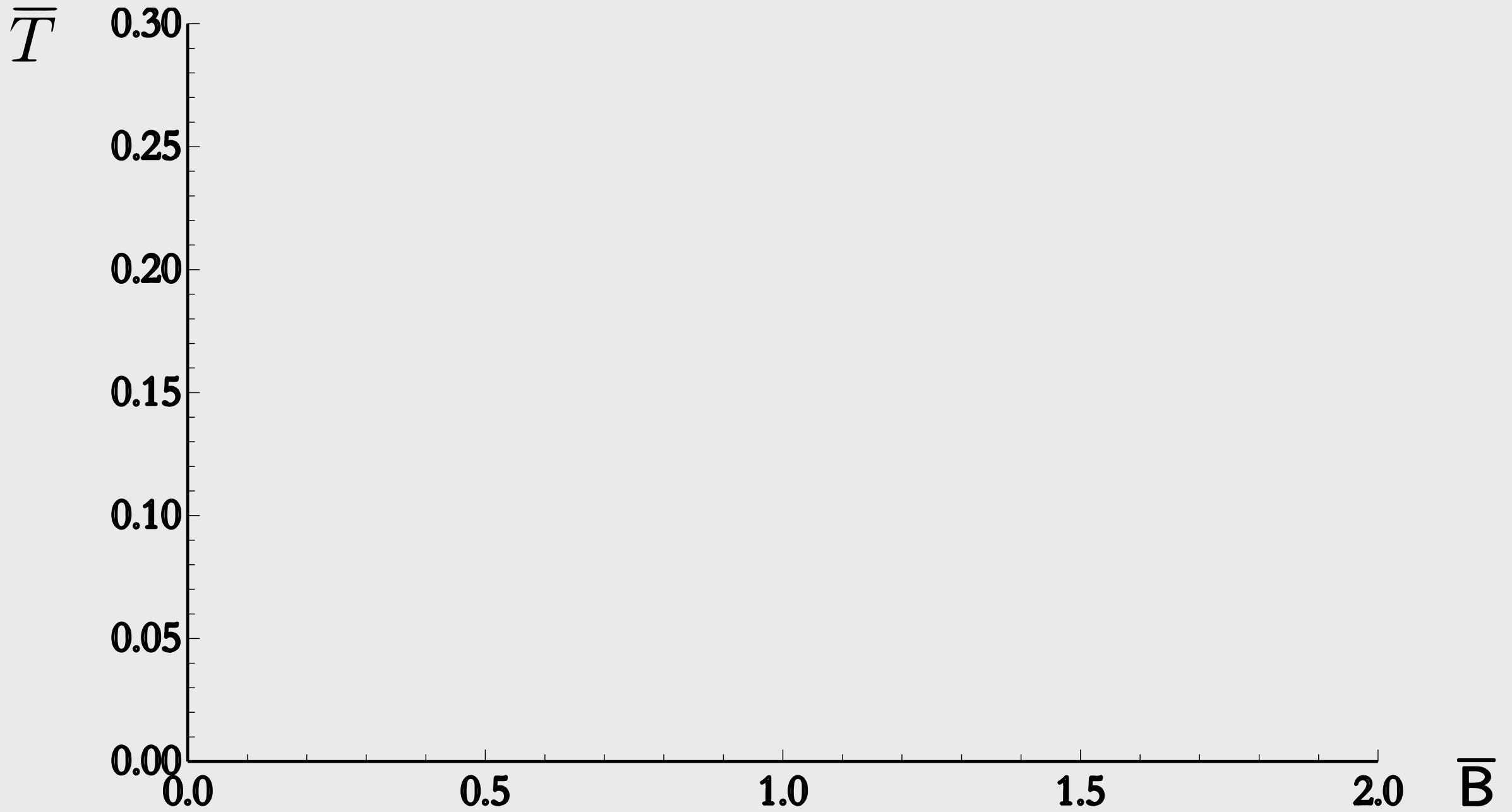


Magnetised plasma phase

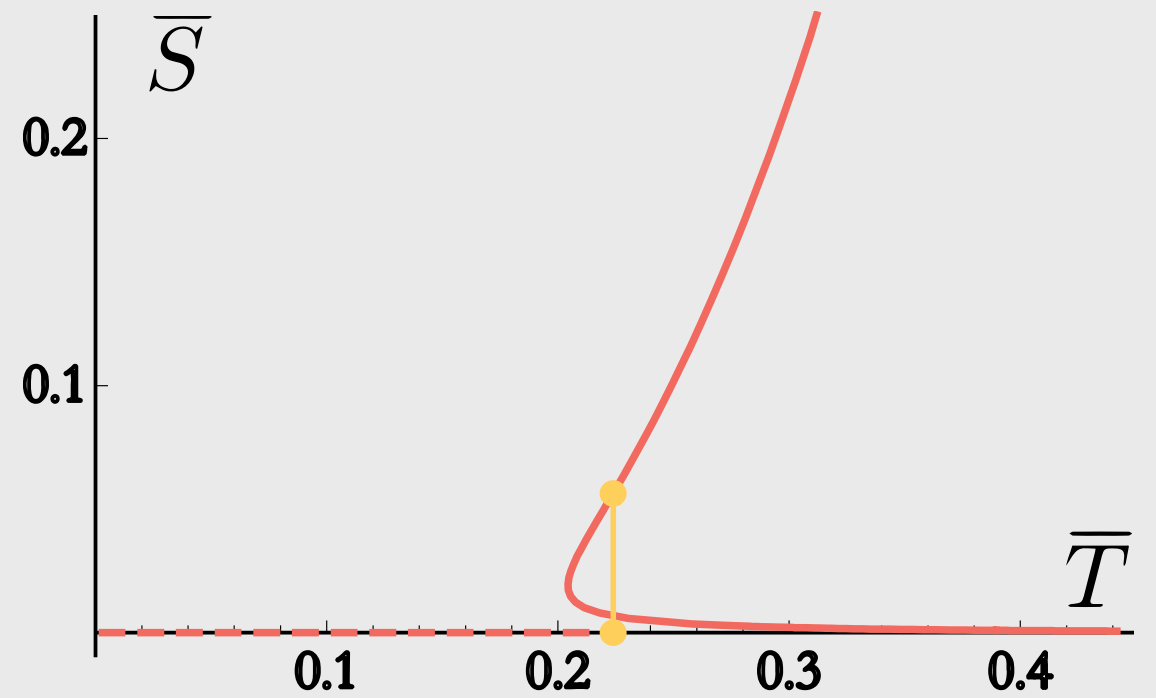
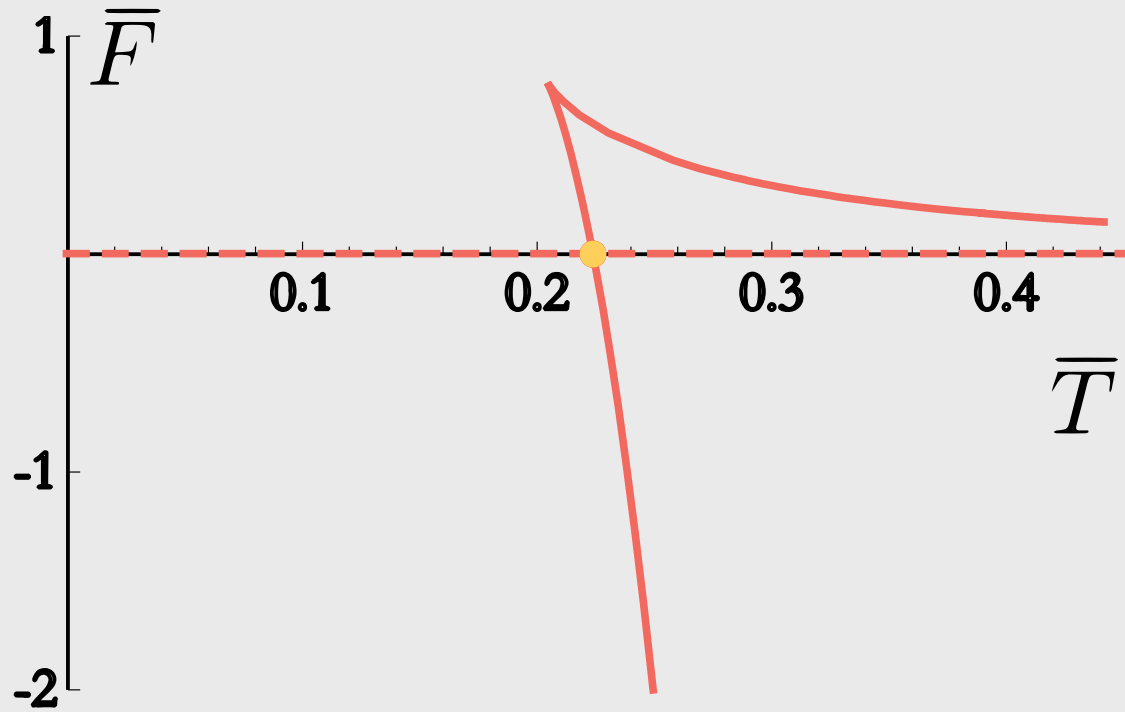


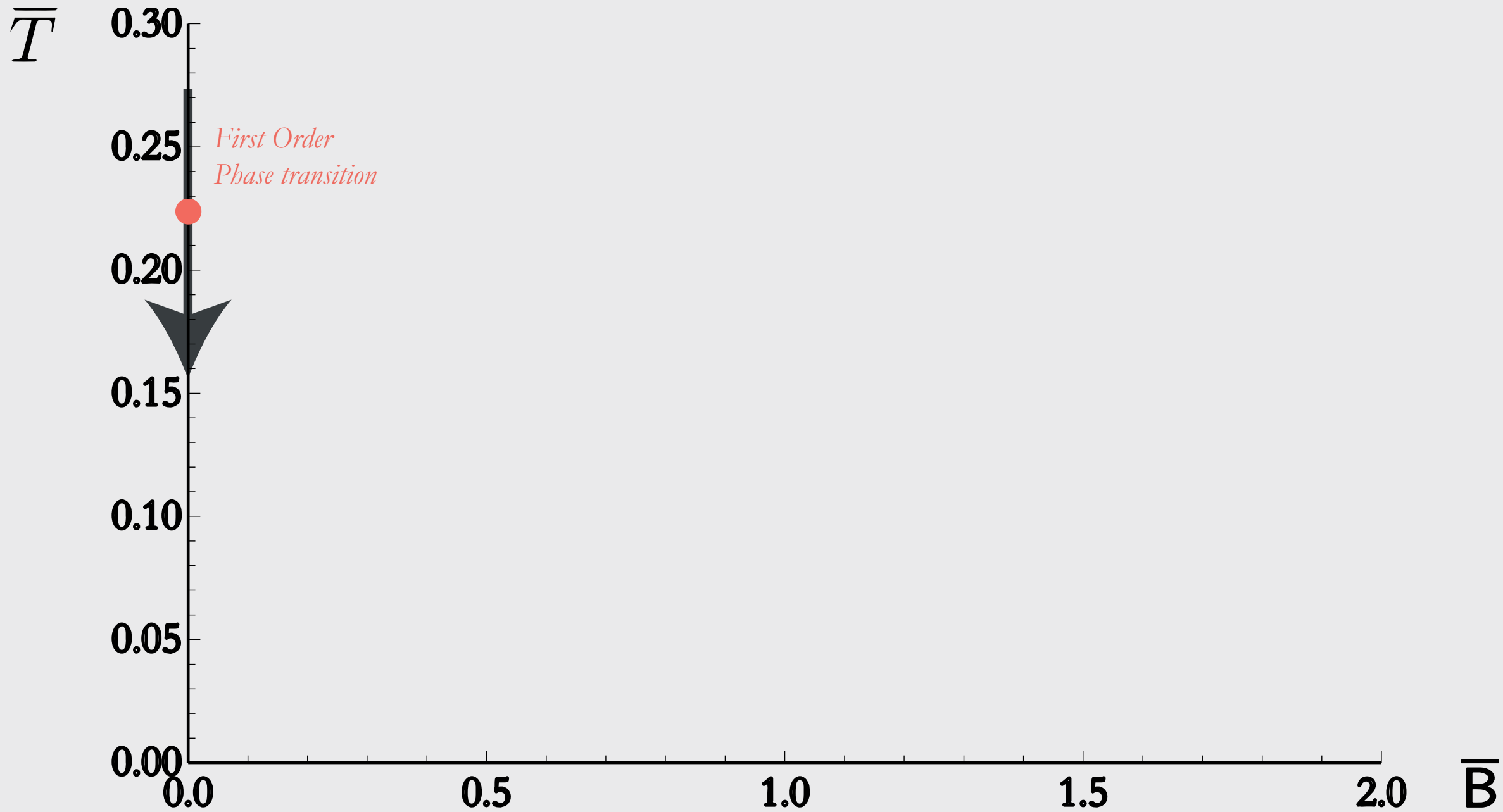
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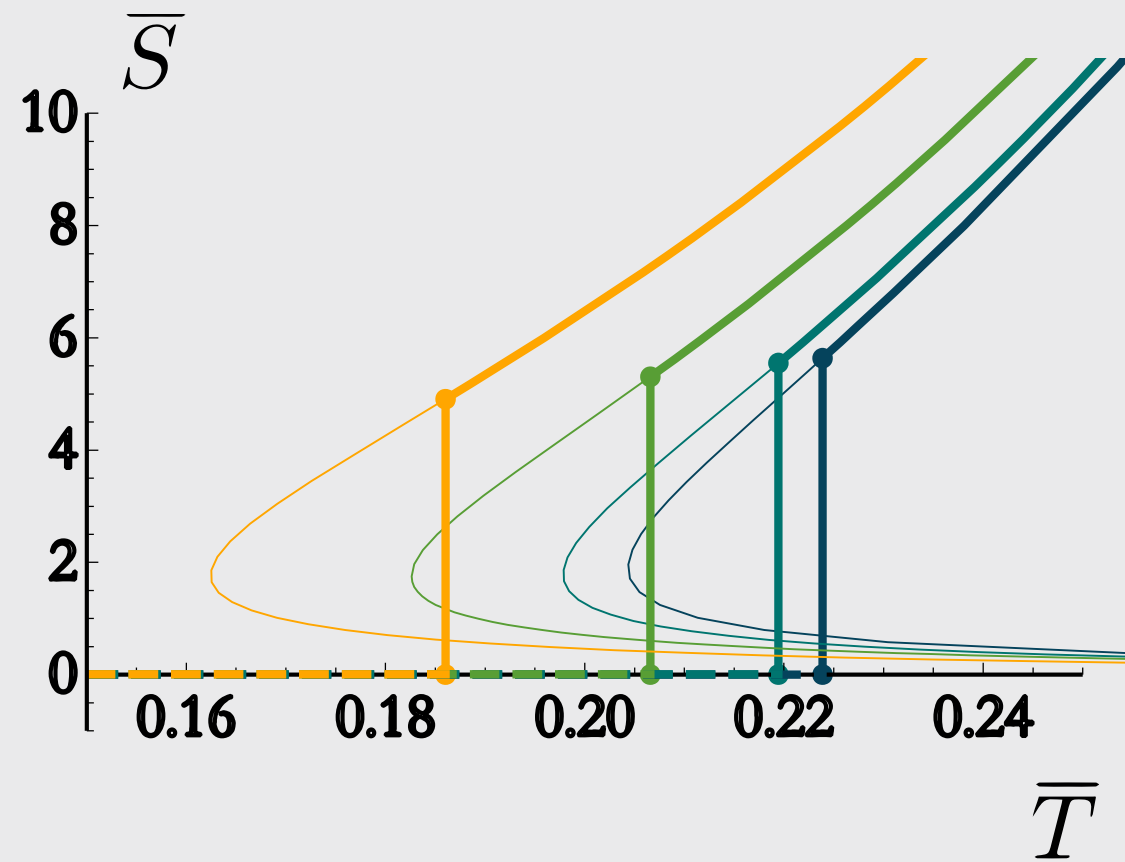
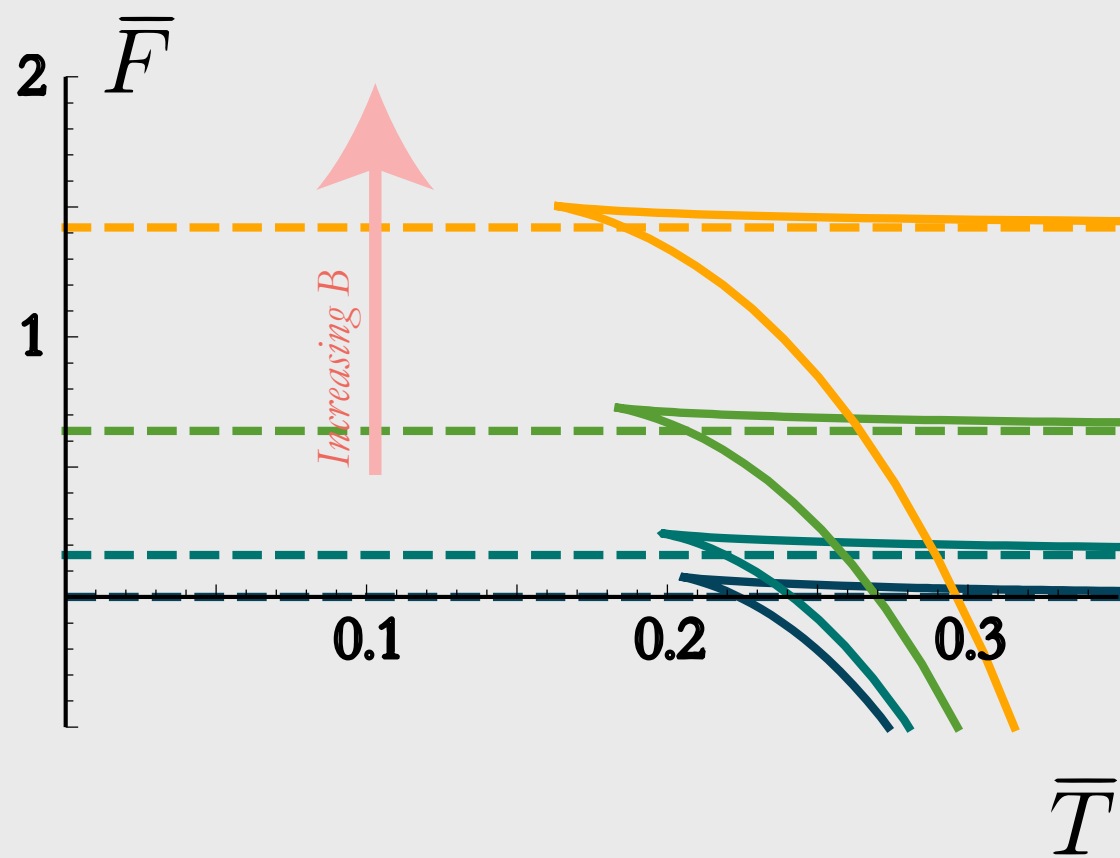


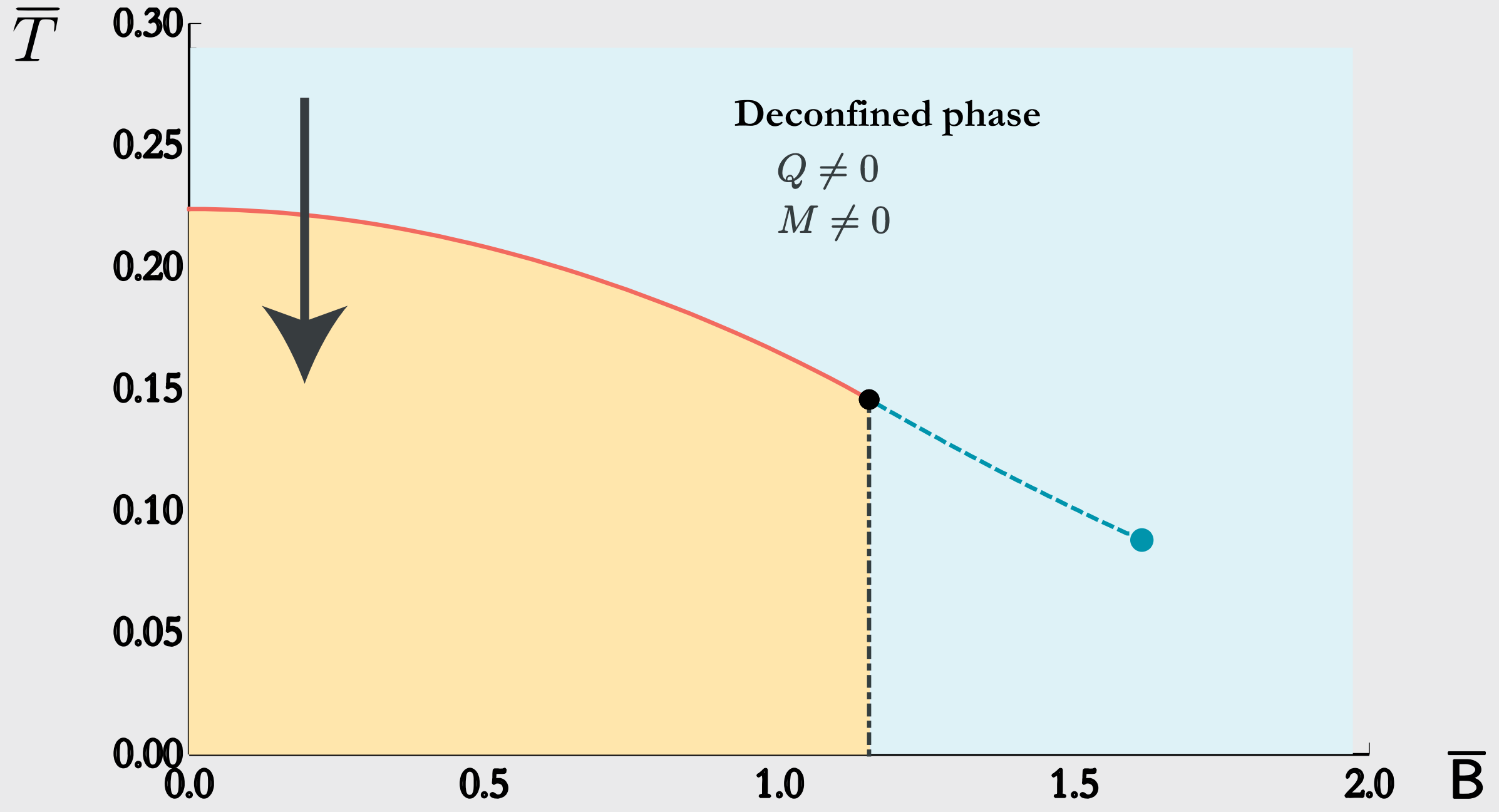
Confinement – Deconfinement phase transitions

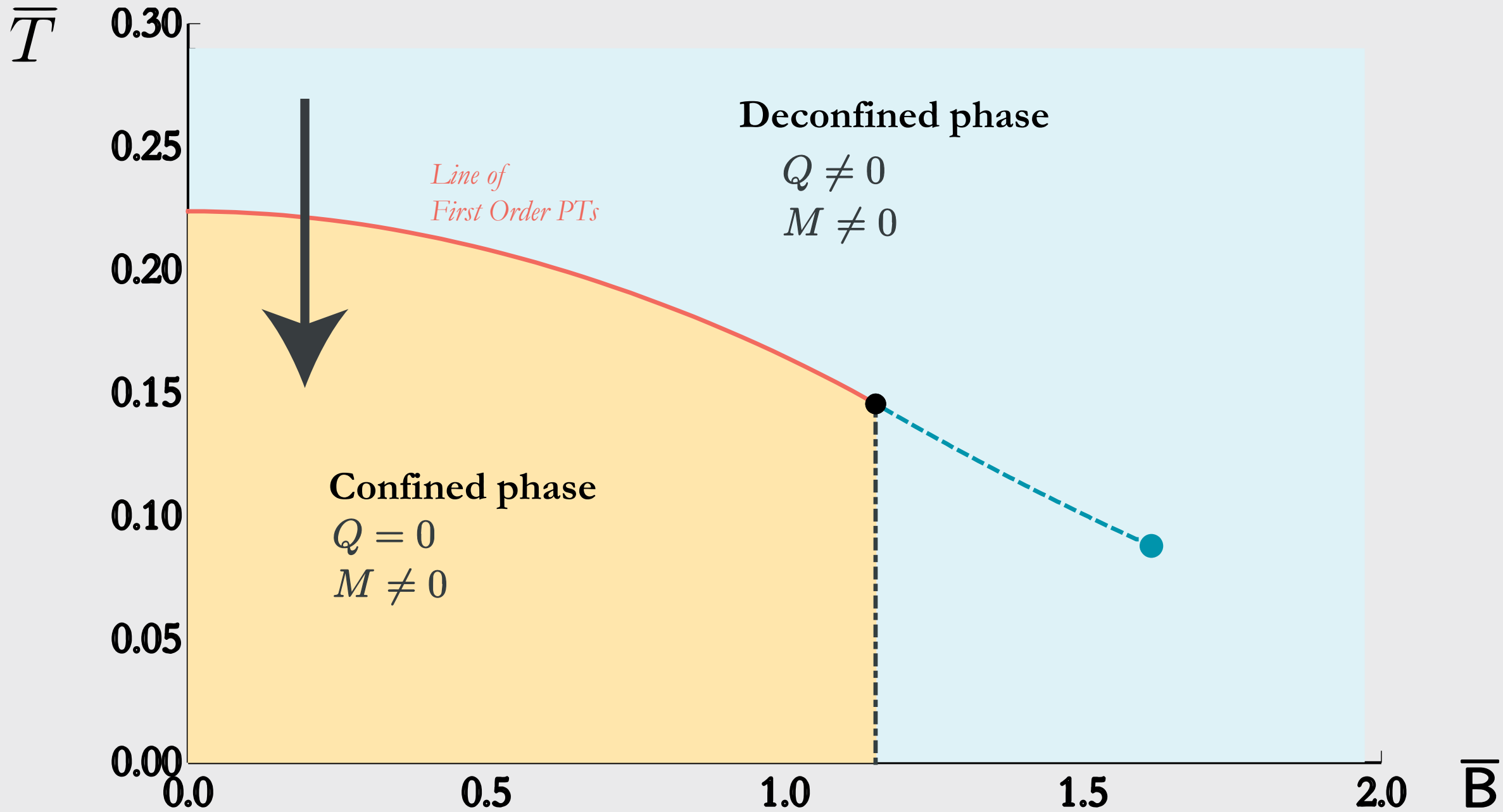




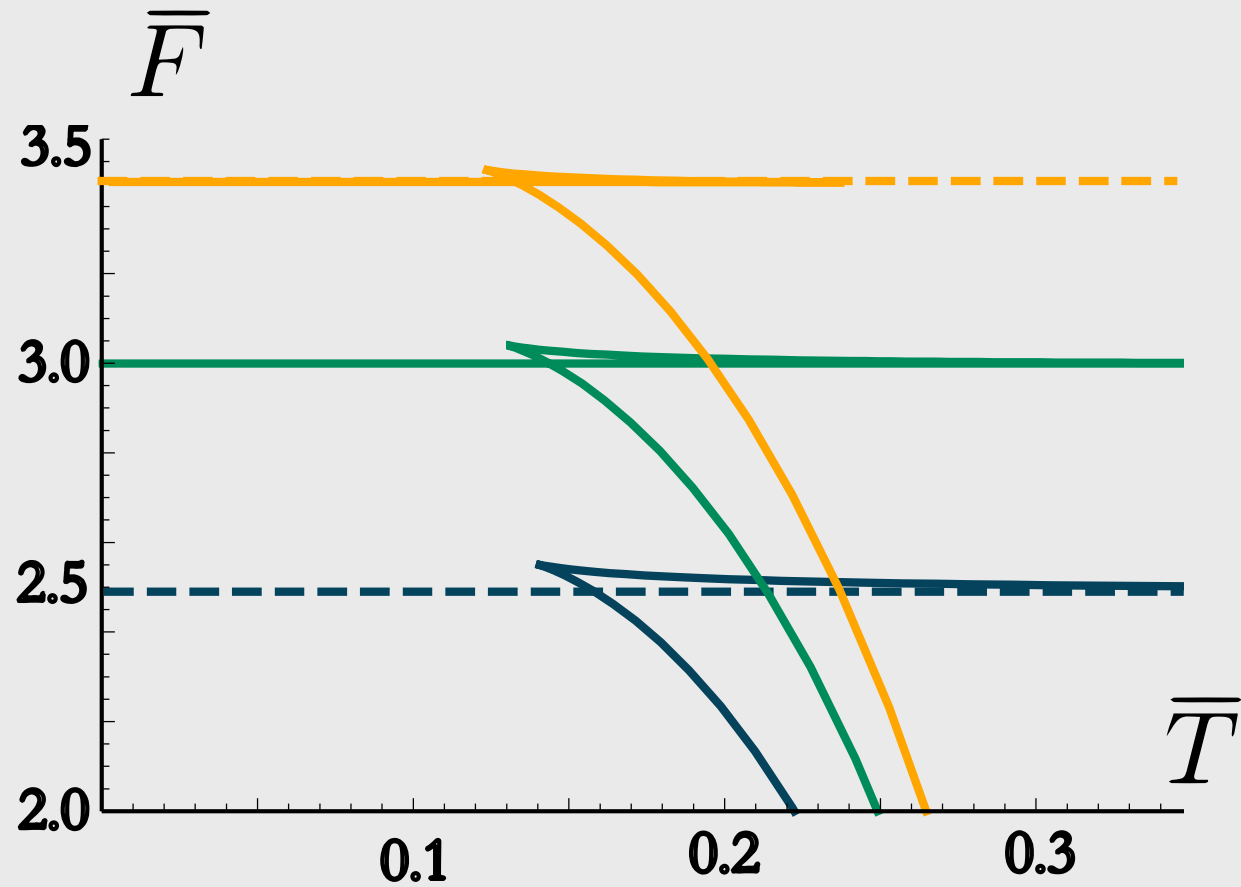
Case A: Confinement / deconfinement phase transition



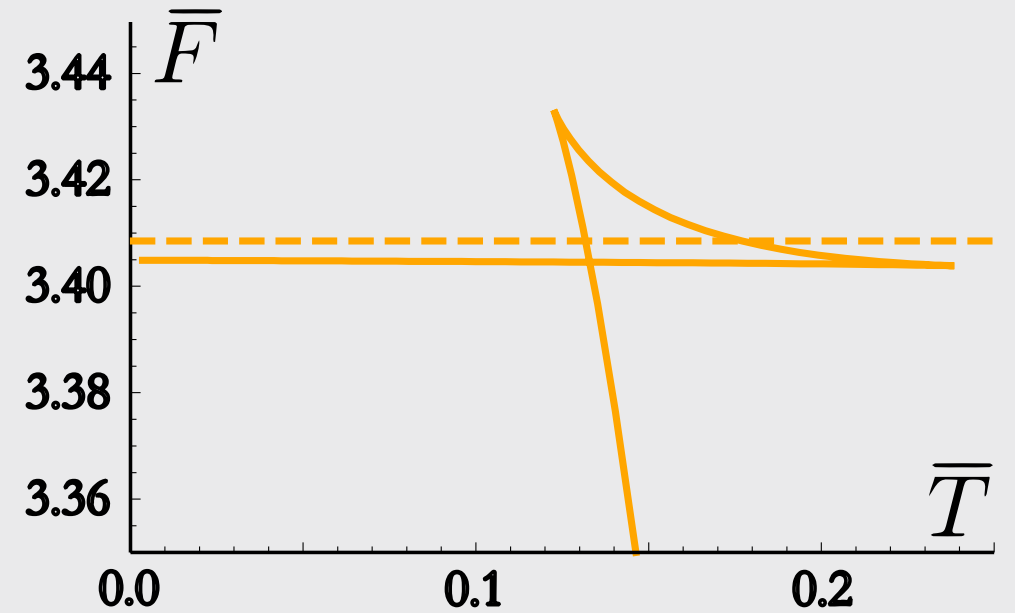
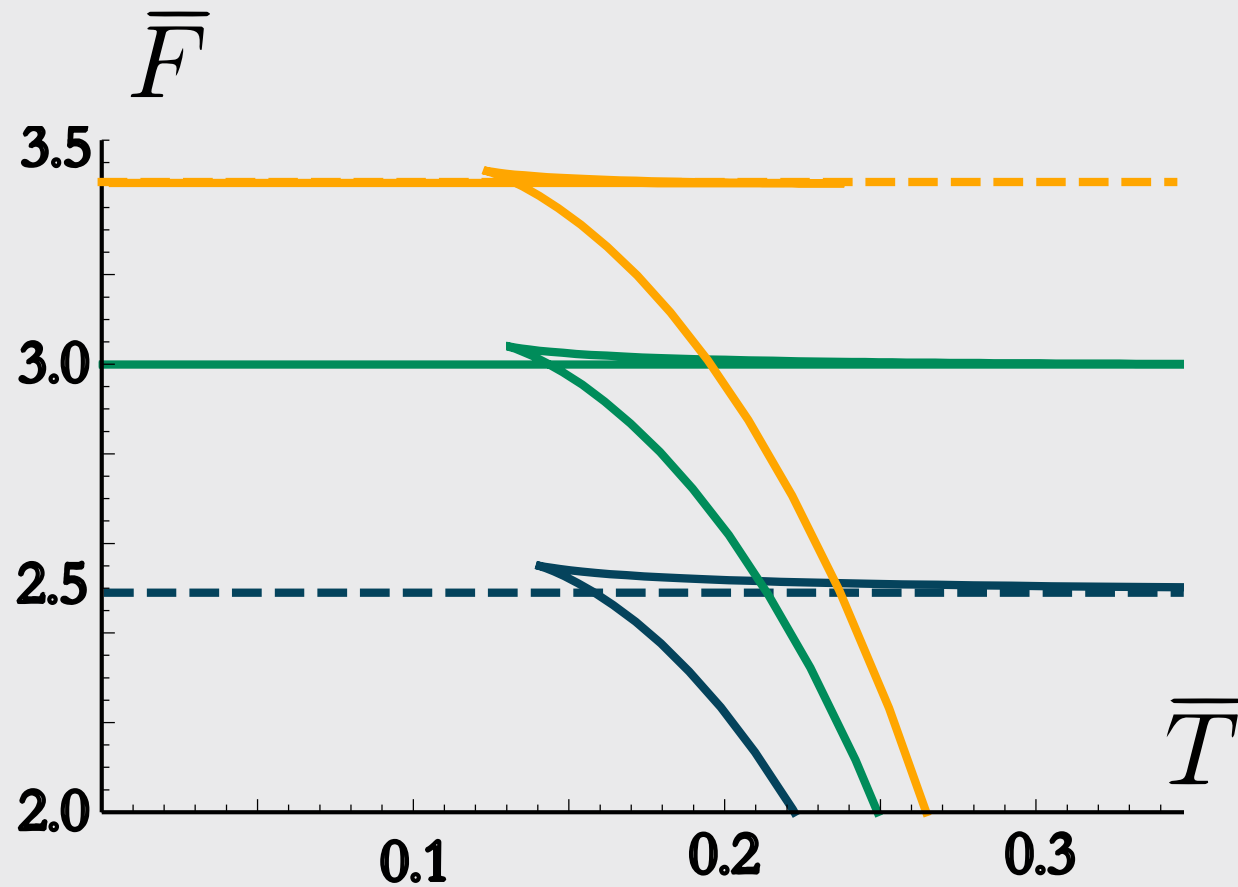


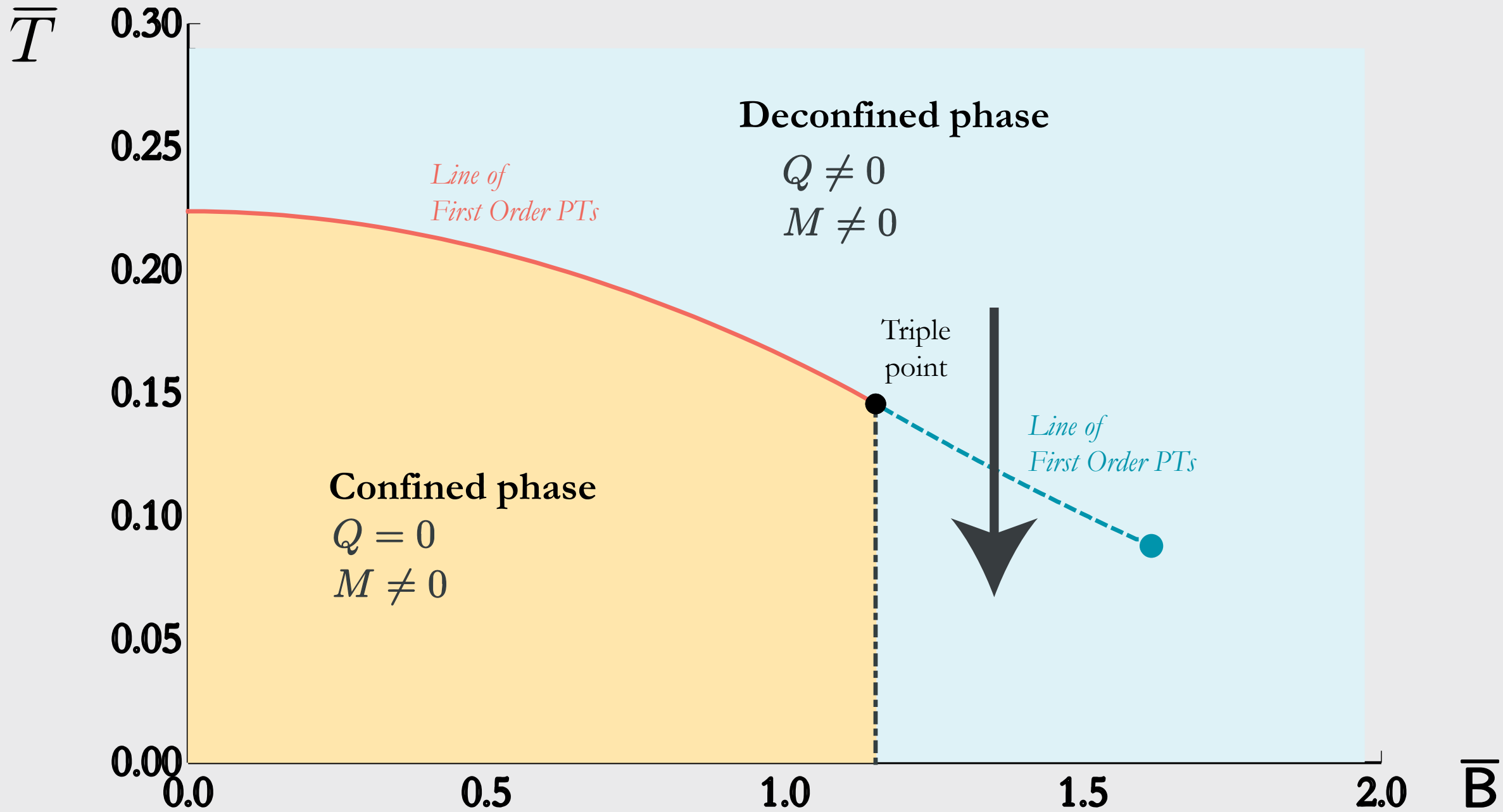


Case B: First order phase transition between two plasma phases

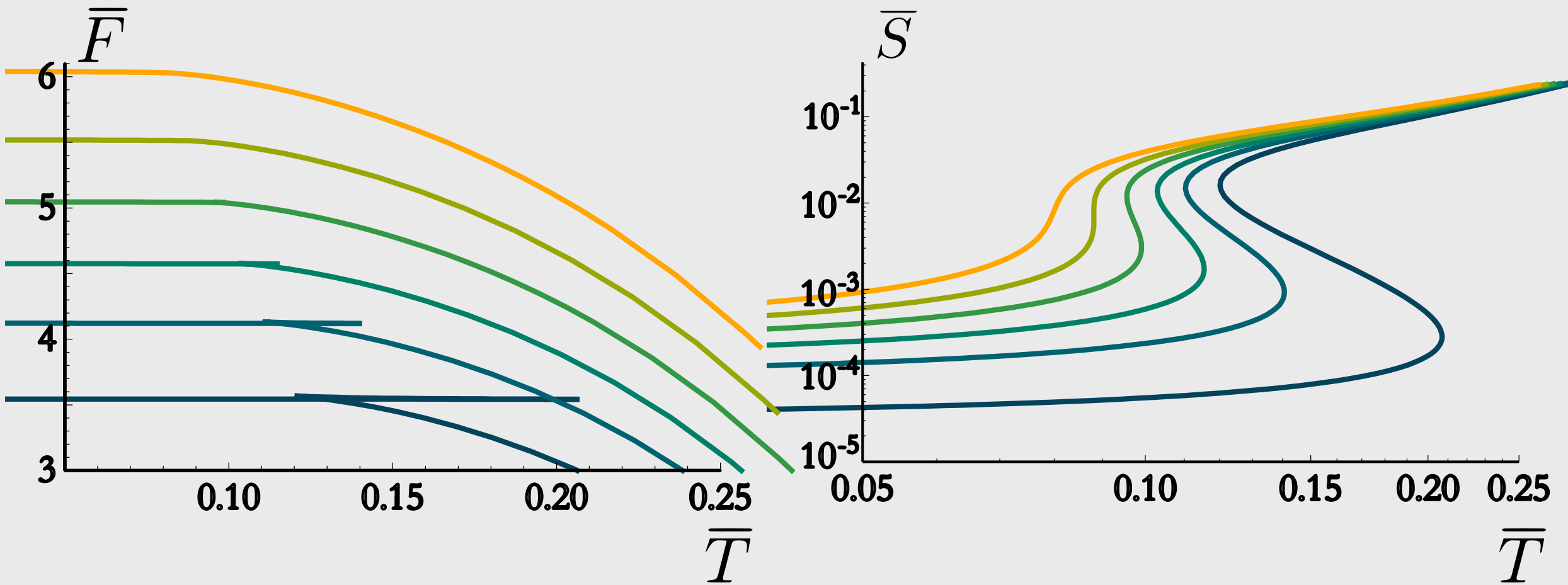


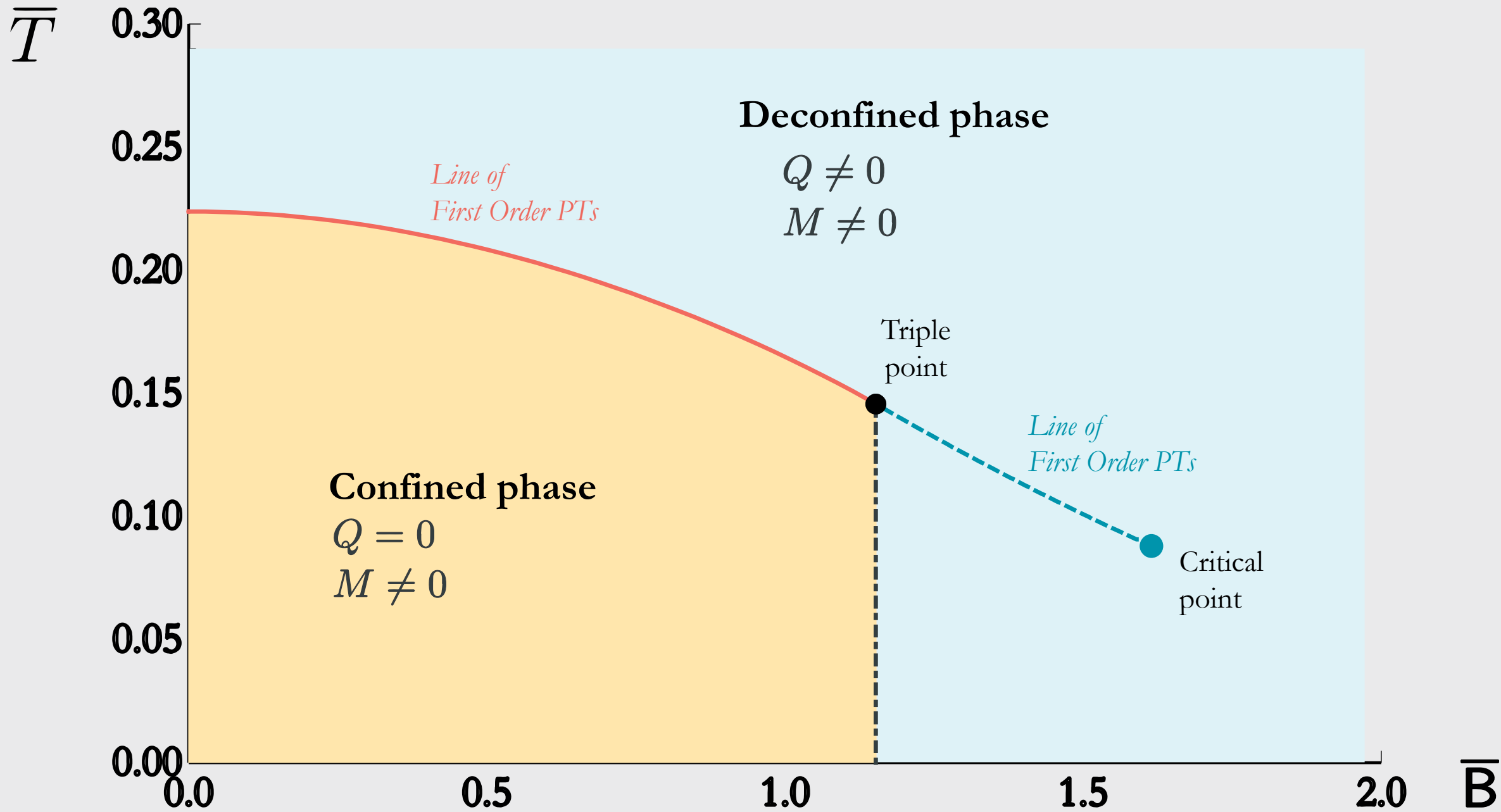
Case B: First order phase transition between two plasma phases





Case C: Smooth crossover between plasma phases





\bar{T}

0.30

0.25

0.20

0.15

0.10

0.05

0.00

0.0

0.5

1.0

1.5

2.0

\bar{B}

Deconfined phase

$Q \neq 0$

$M \neq 0$

*Line of
First Order PTs*

Confined phase

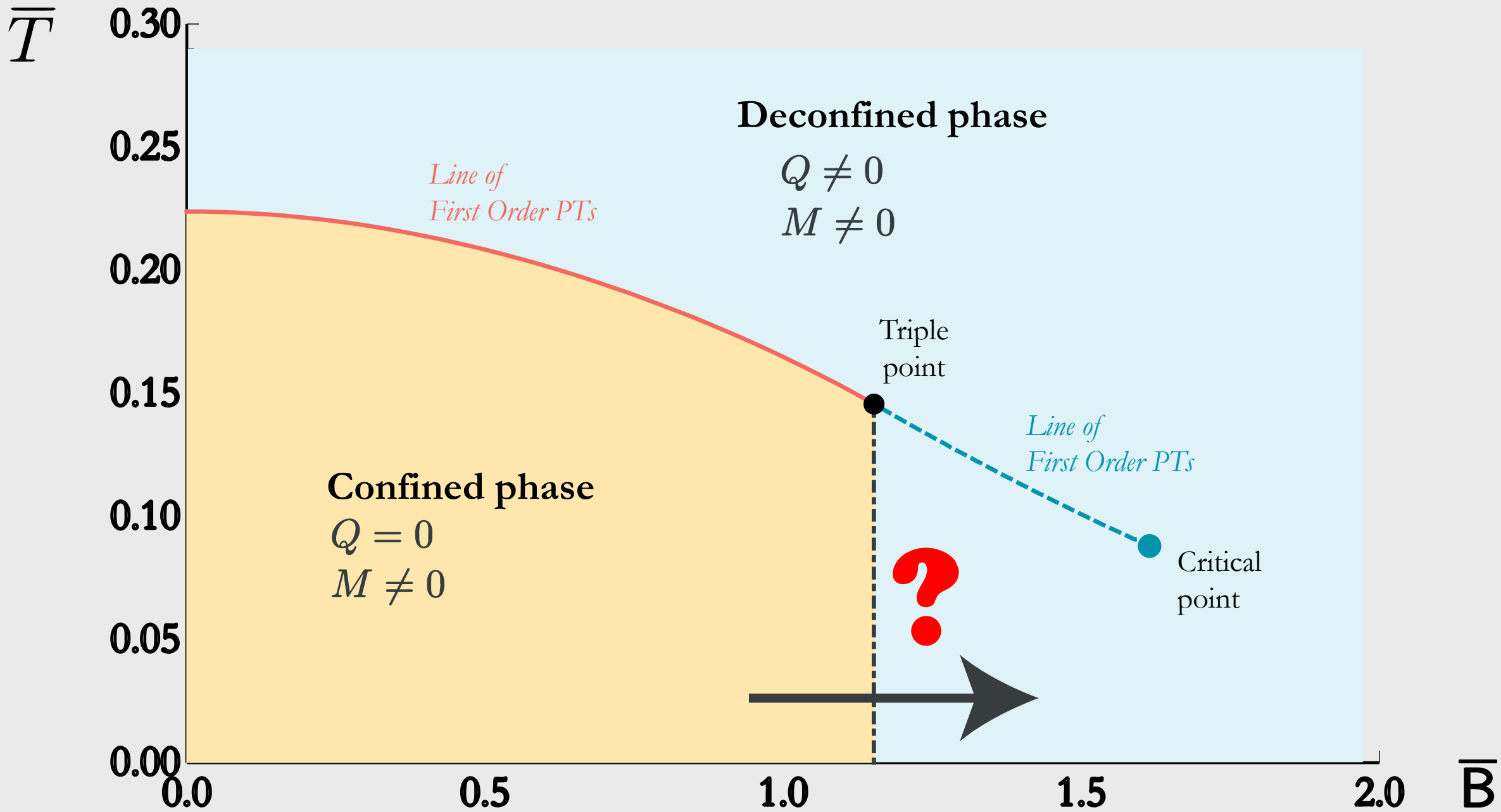
$Q = 0$

$M \neq 0$

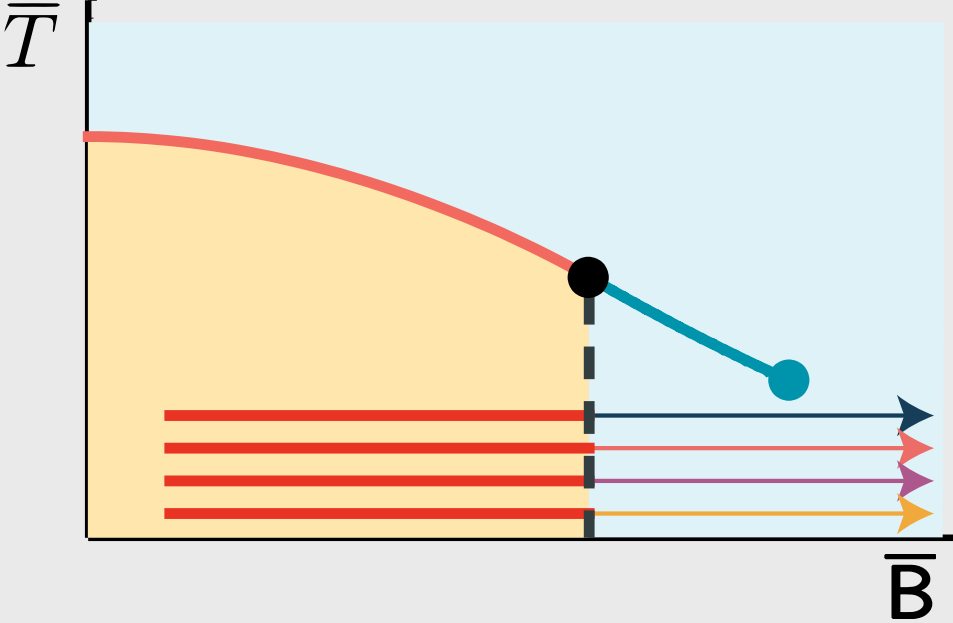
Triple
point

*Line of
First Order PTs*

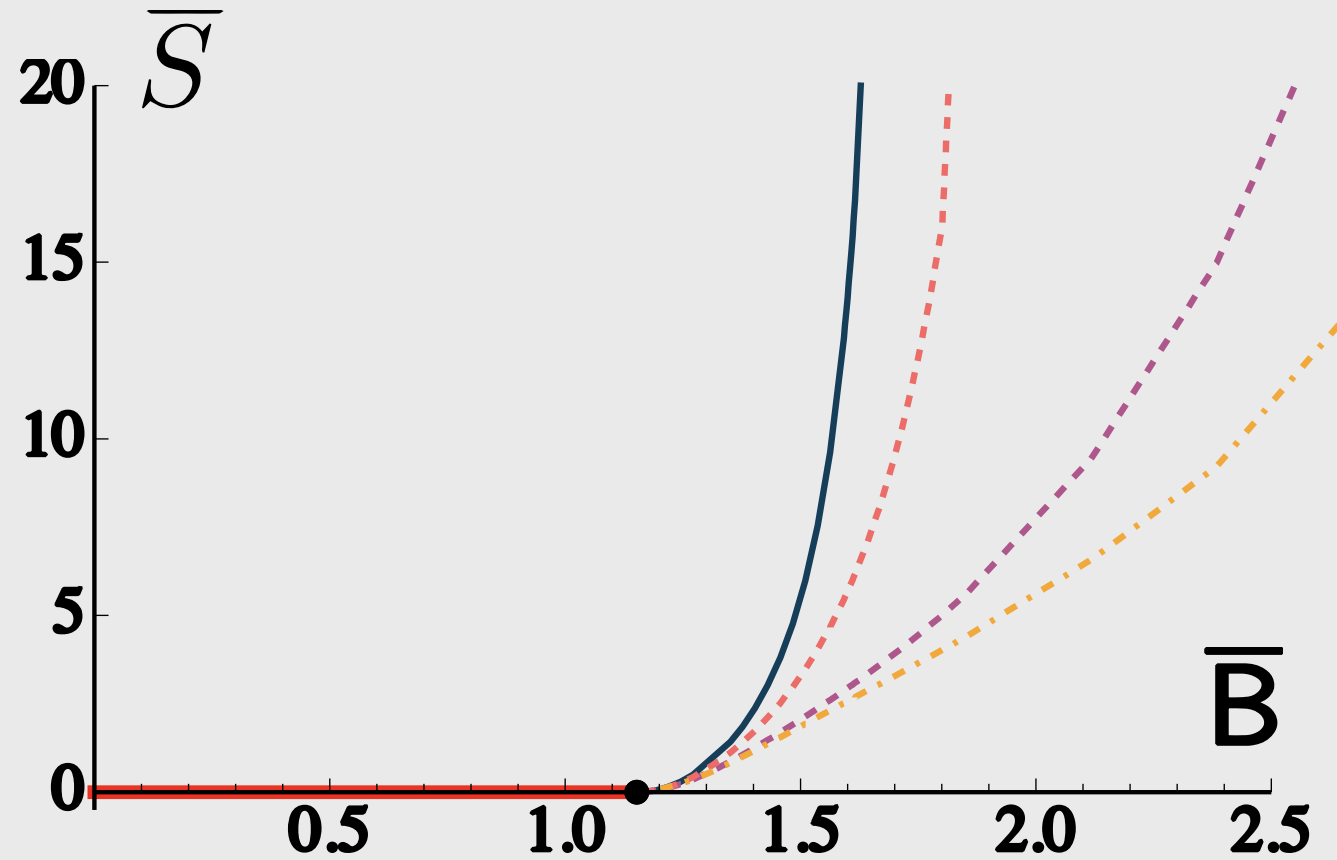
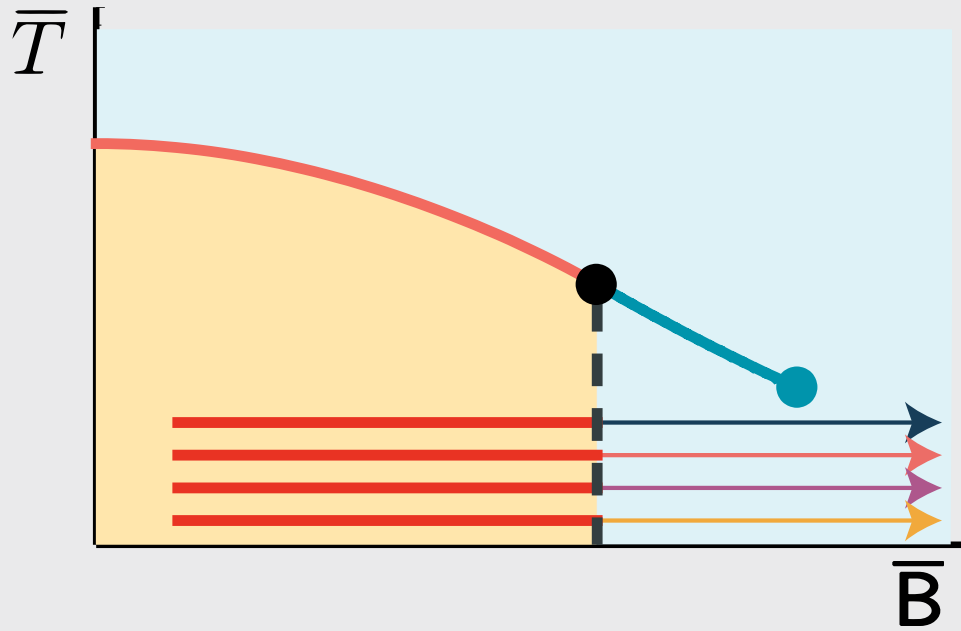
Critical
point



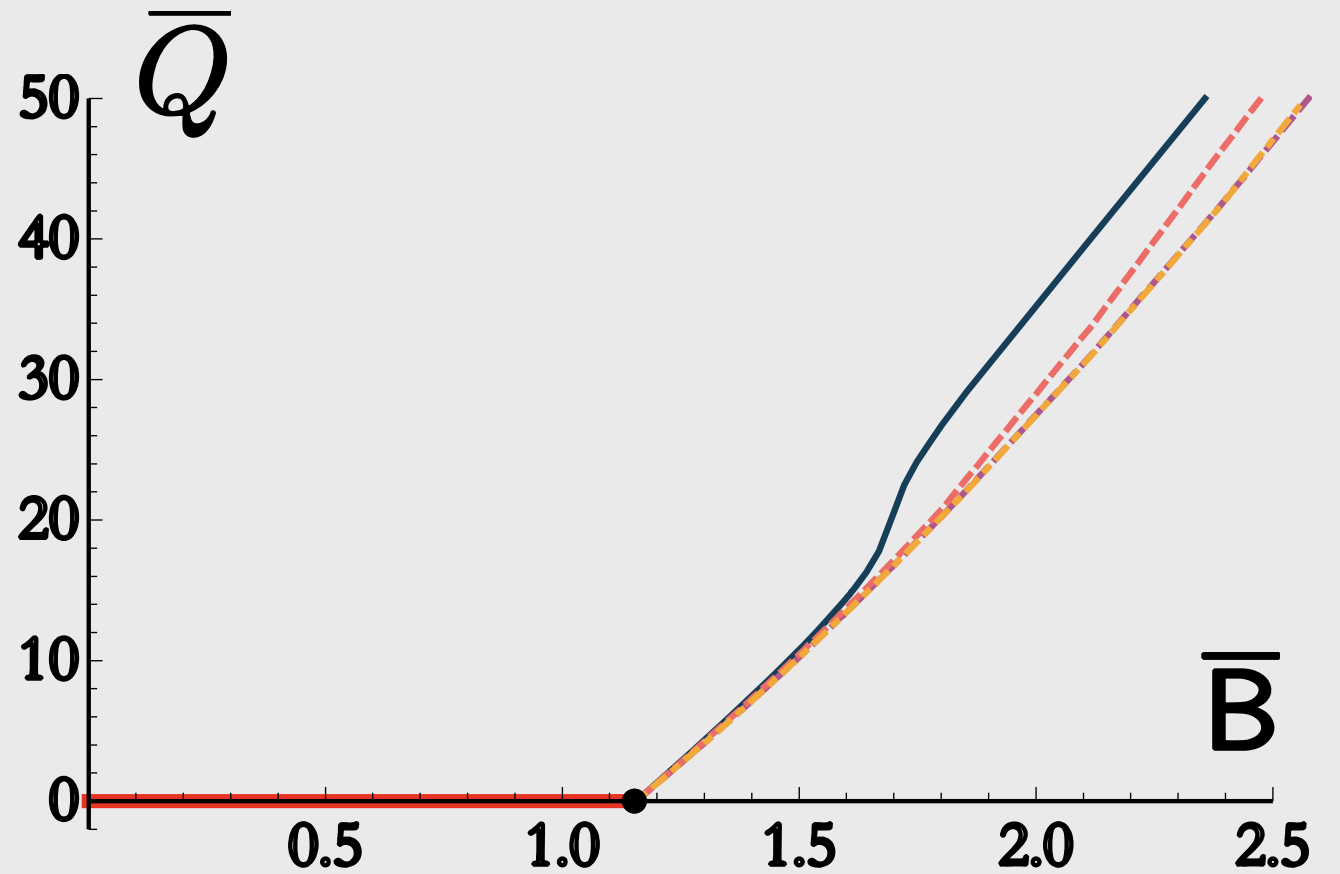
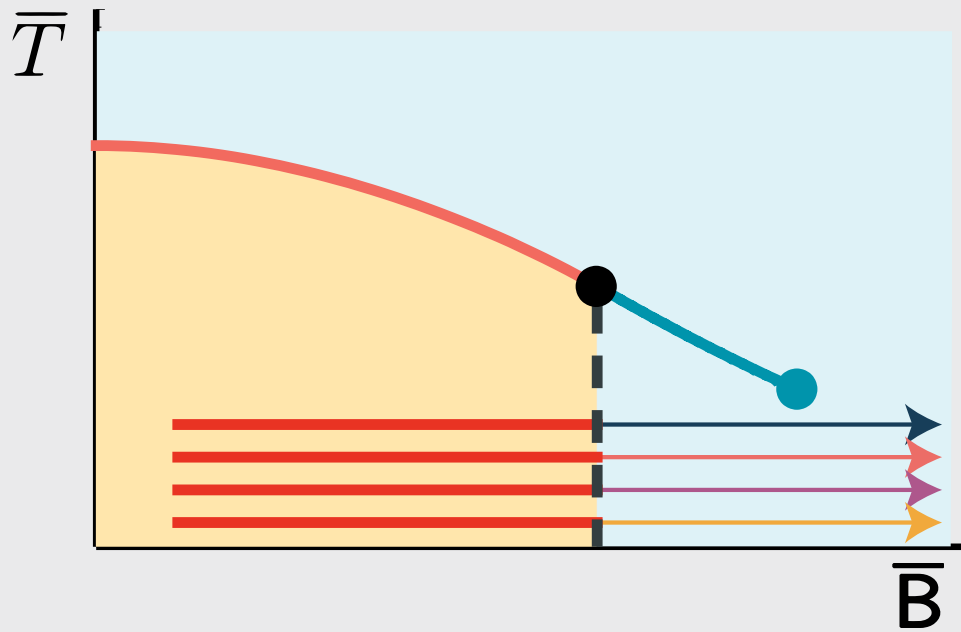
Second order phase transitions at fixed temperature



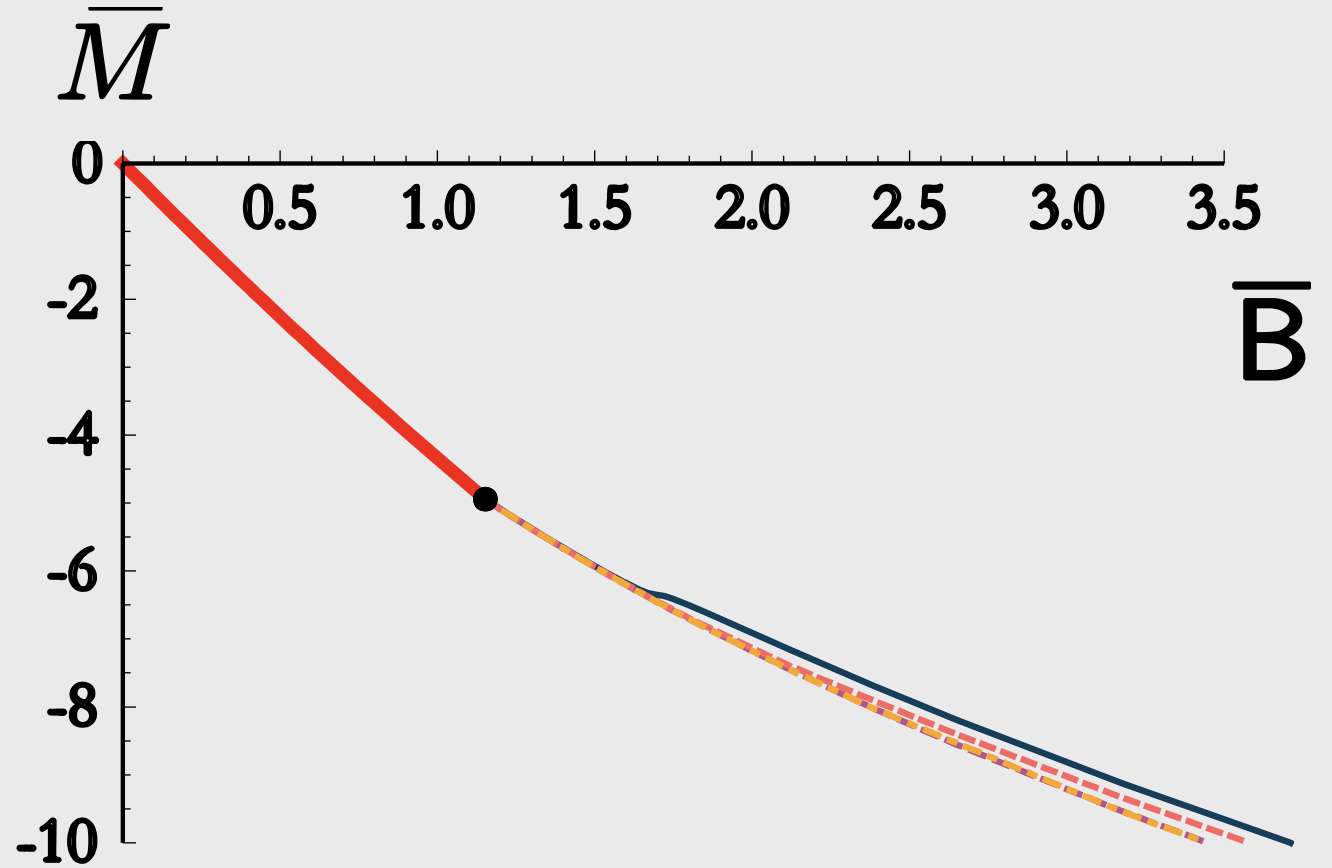
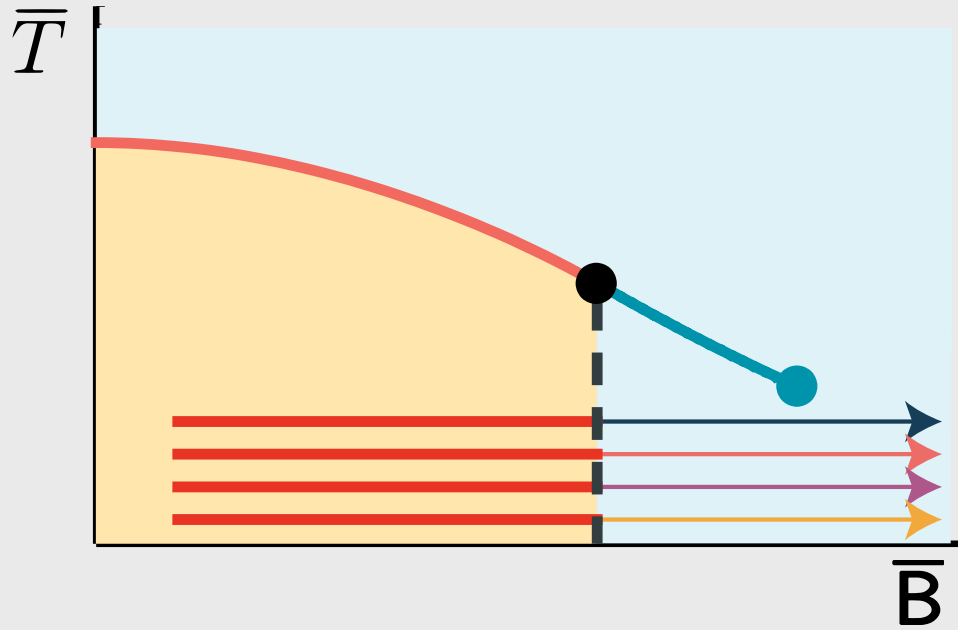
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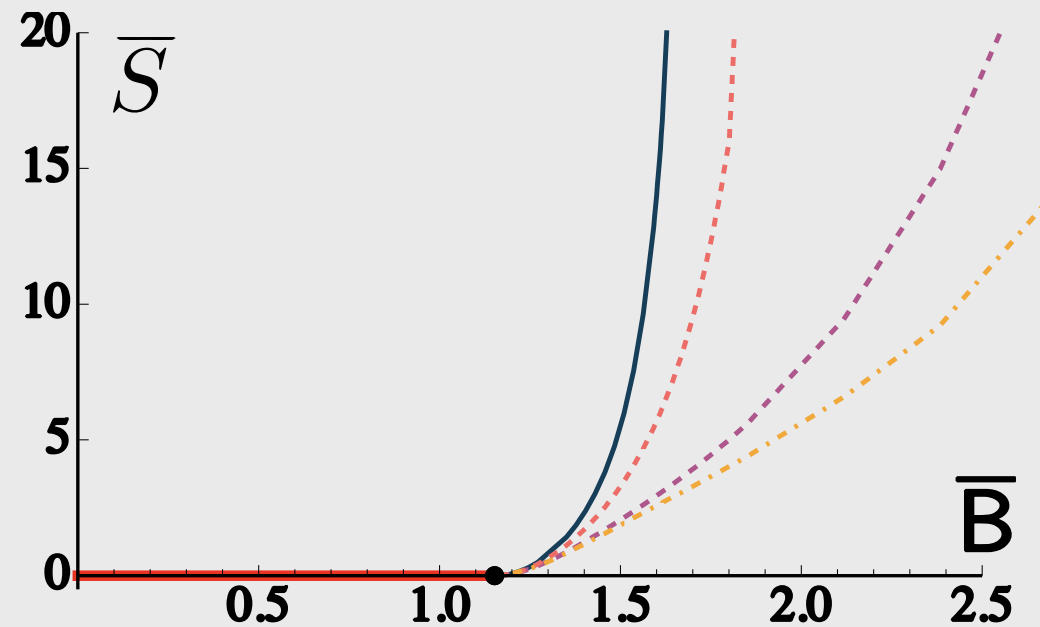
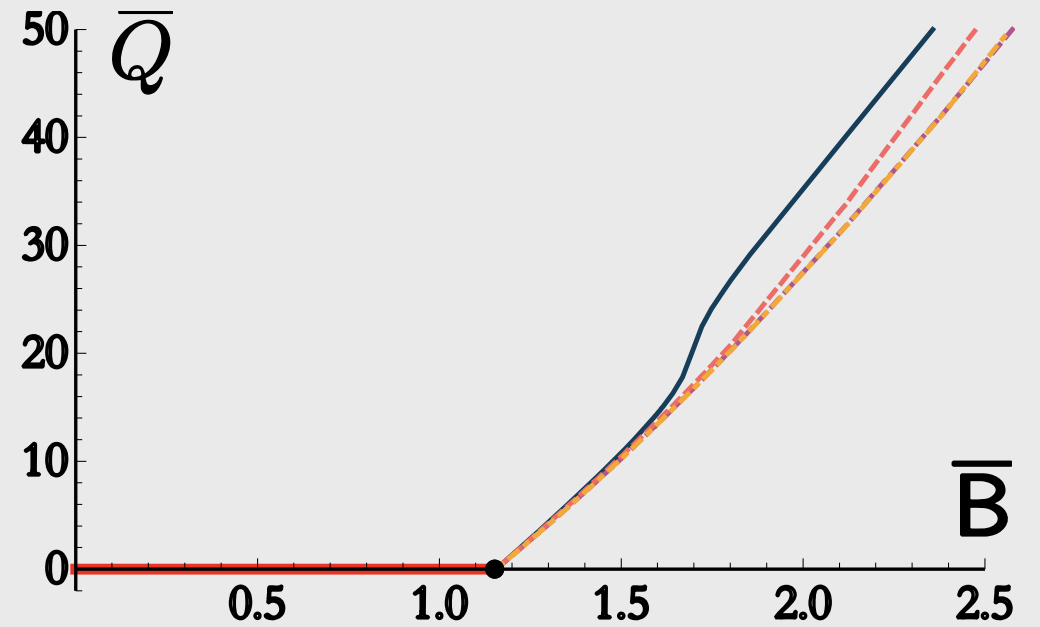
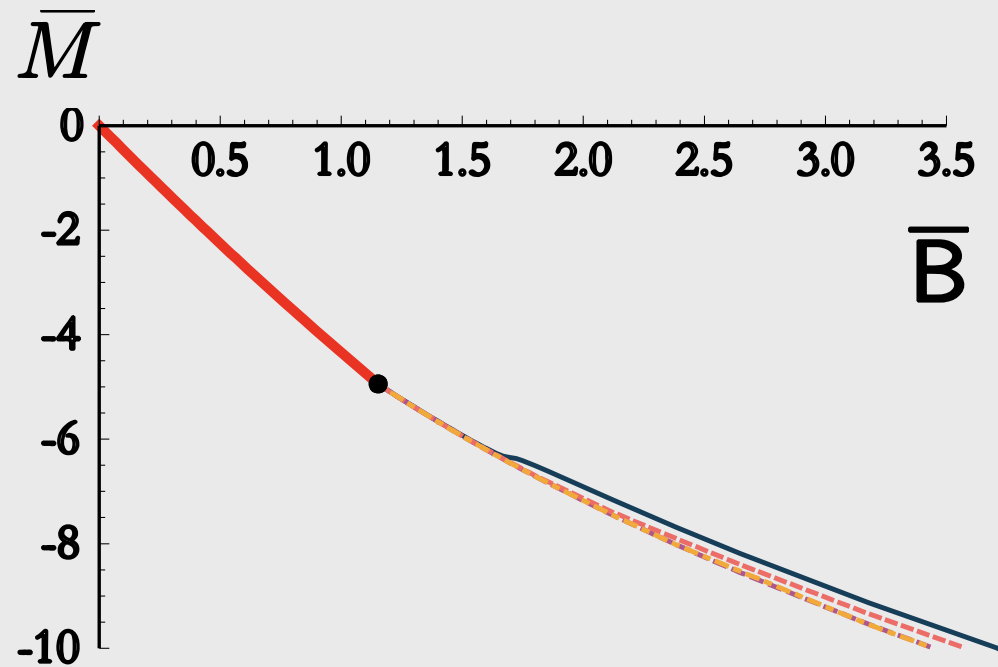
Second order phase transitions at fixed temperature



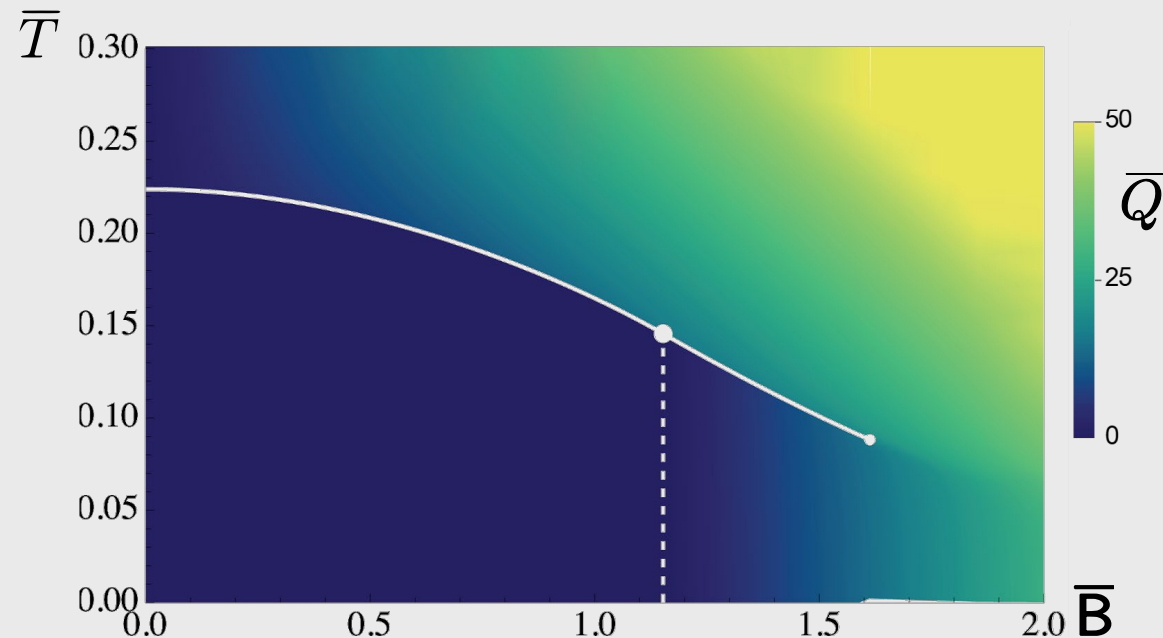
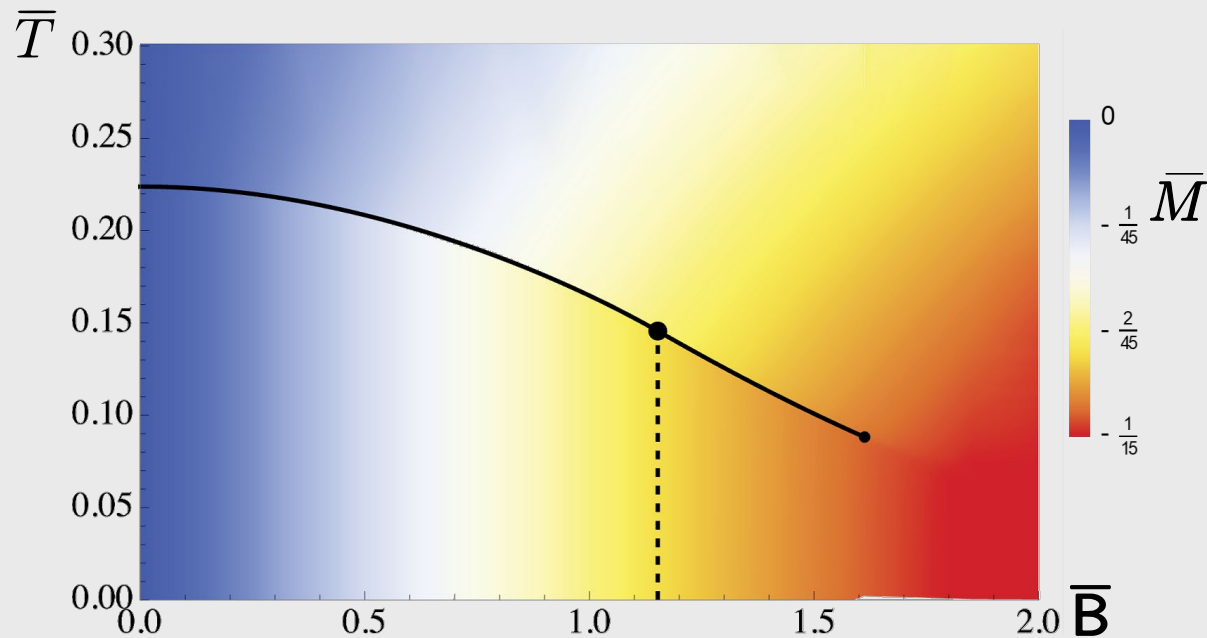
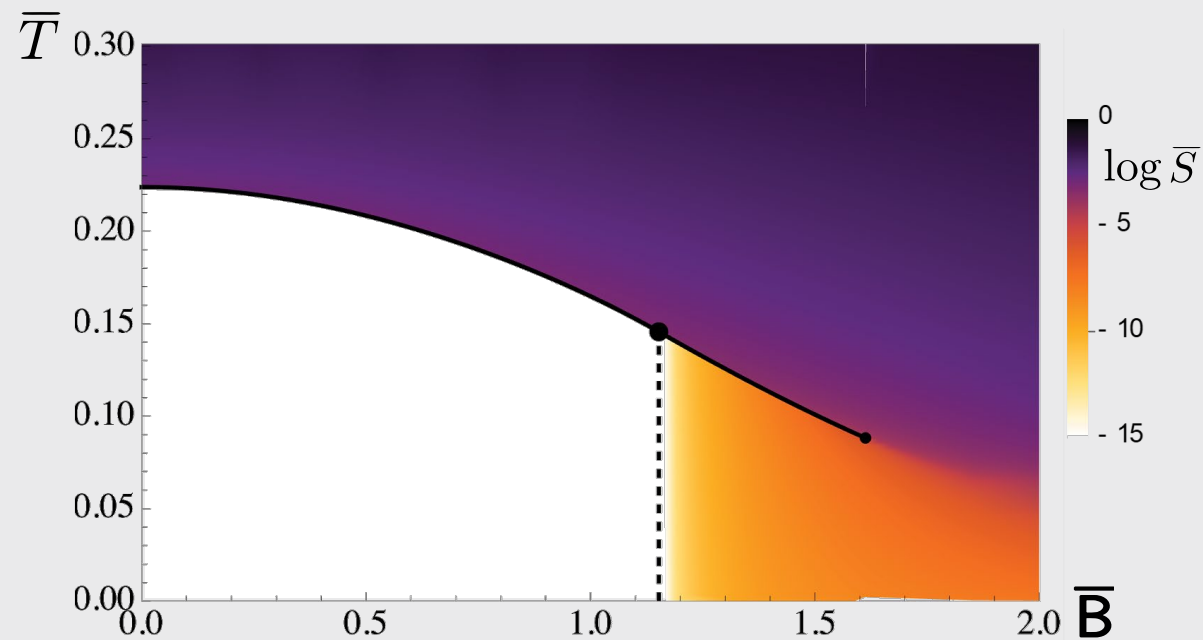
Second order phase transitions at fixed temperature



We conclude that
it is a line of second
order phase transitions.



It is instructive to look at the density plot of different quantities.



Duality transformation (mirror duality, particle-vortex dual)

$$C_1 \leftrightarrow C_7$$

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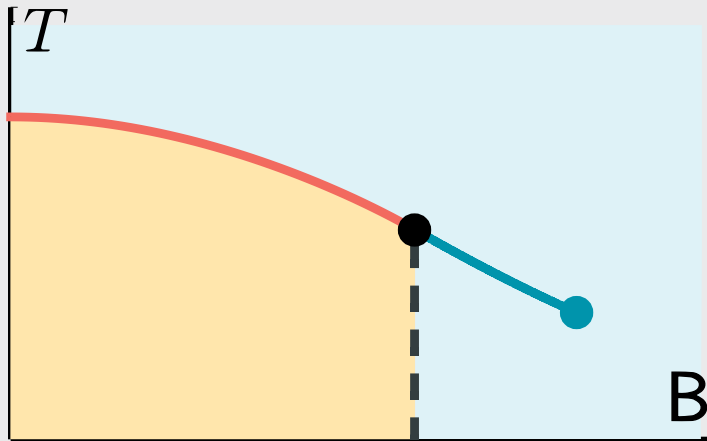
$$B \leftrightarrow \tilde{Q}$$
$$M \leftrightarrow \tilde{\mu}$$

$$Q \leftrightarrow \tilde{B}$$
$$\mu \leftrightarrow \tilde{M}$$

Duality transformation (mirror duality, particle-vortex dual)

Monopoles
(D0, D2 branes)

$U(N) \times U(N+M)$



$$C_1 \leftrightarrow C_7$$

$$a_t(r) \leftrightarrow \tilde{a}_t(r)$$

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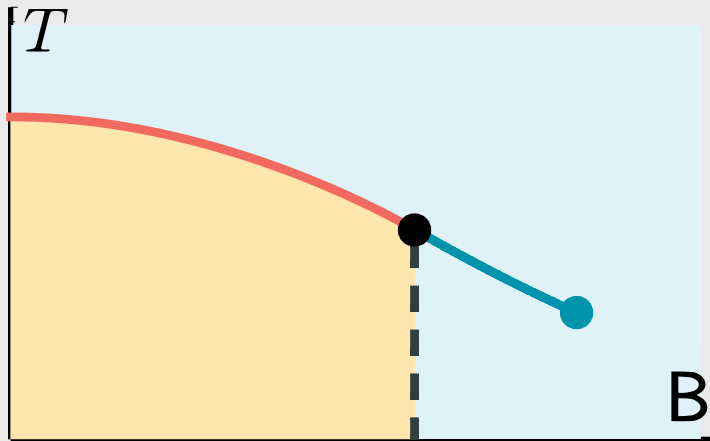
$$Q \leftrightarrow \tilde{B}$$

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Duality transformation (mirror duality, particle-vortex dual)

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(D0, D2 branes)

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$$C_1 \leftrightarrow C_7$$

$$a_t(r) \leftrightarrow \tilde{a}_t(r)$$

Baryons
(D6, D4 branes)

$SU(N) \times SU(N+M)$

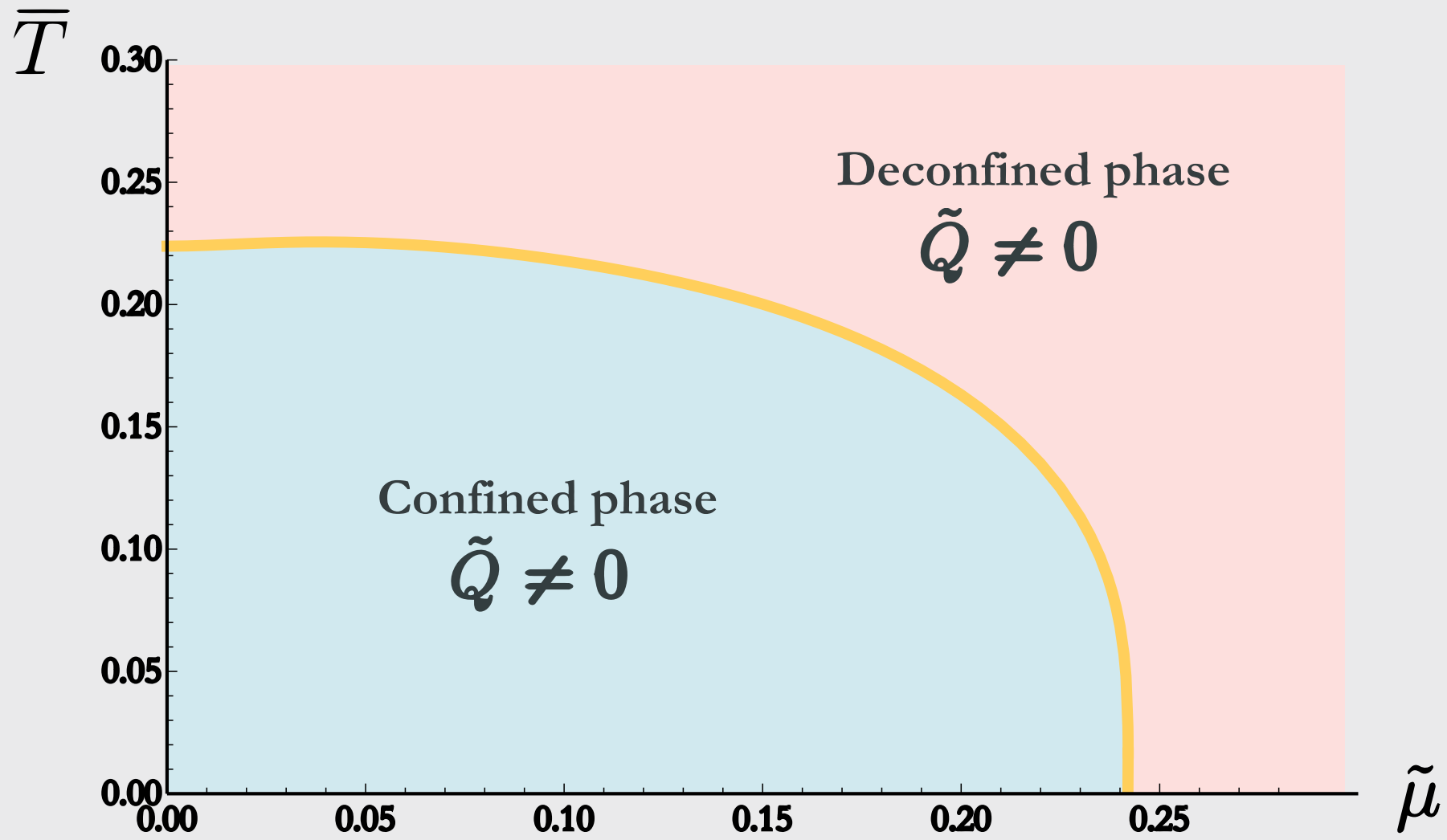
$$B \leftrightarrow \tilde{Q}$$

$$M \leftrightarrow \tilde{\mu}$$

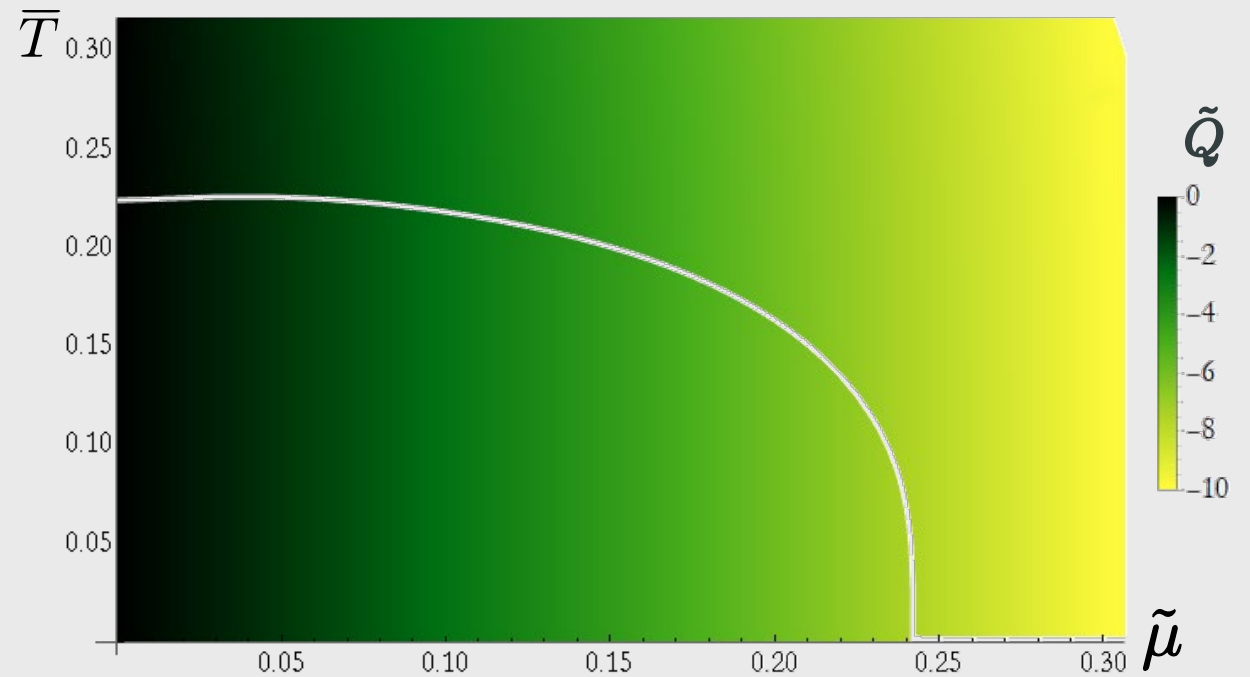
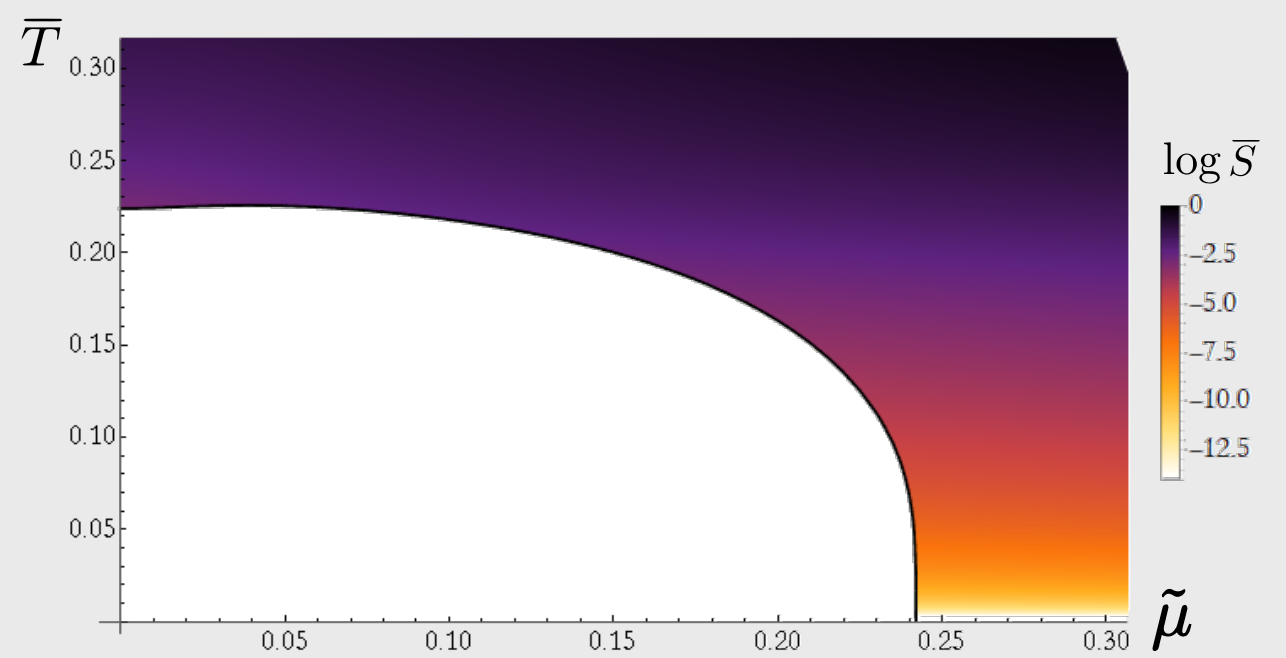
$$Q \leftrightarrow \tilde{B}$$

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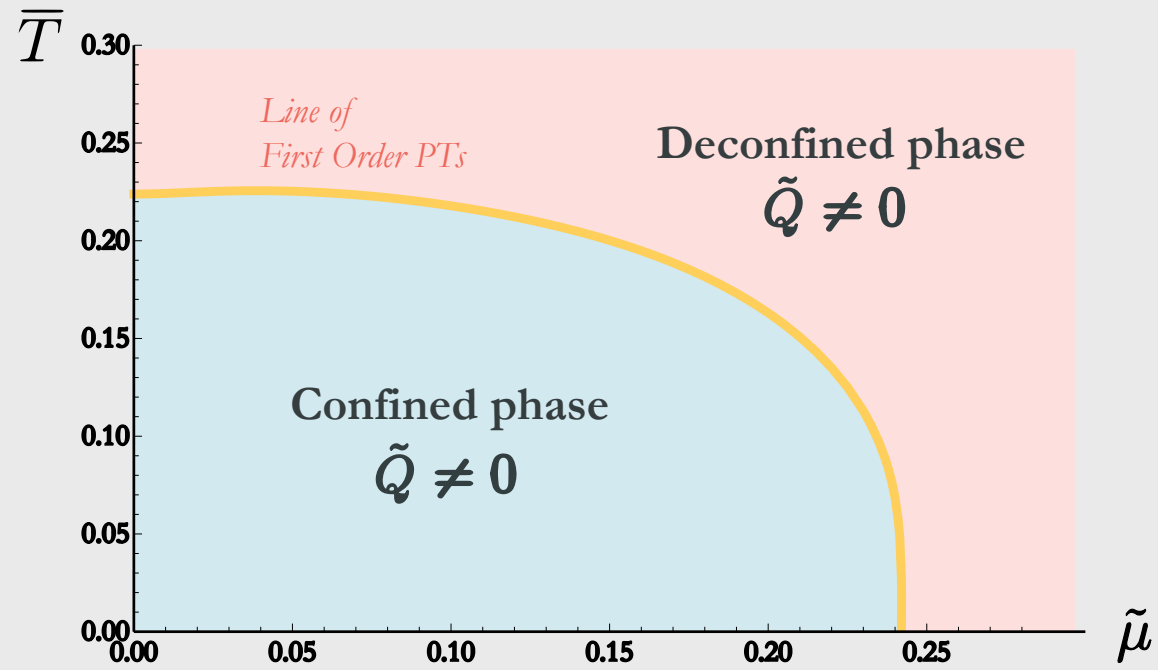
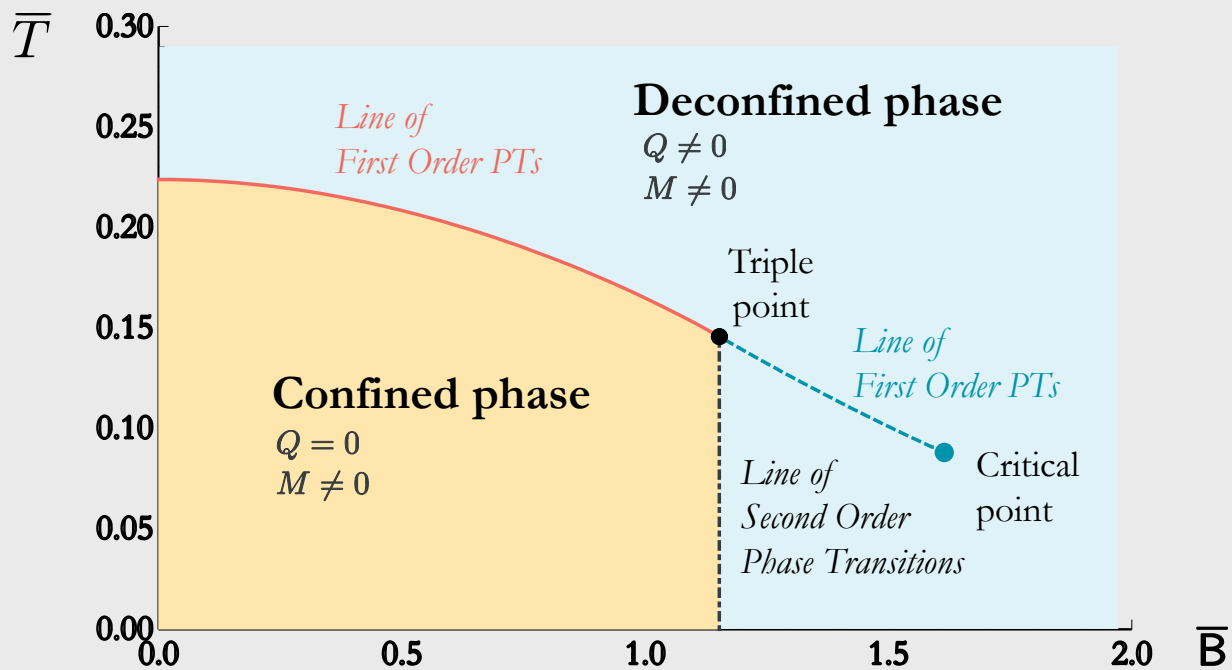


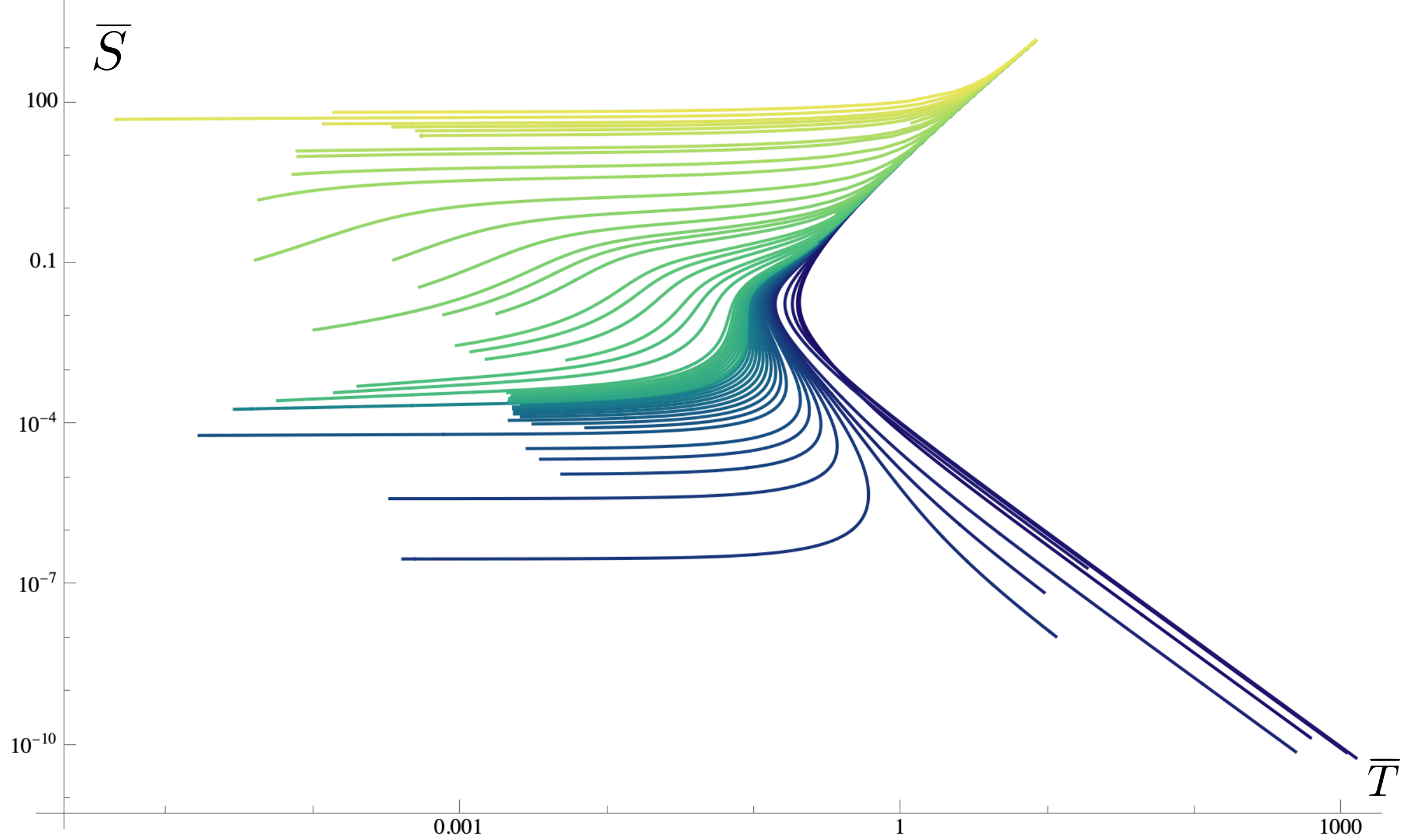


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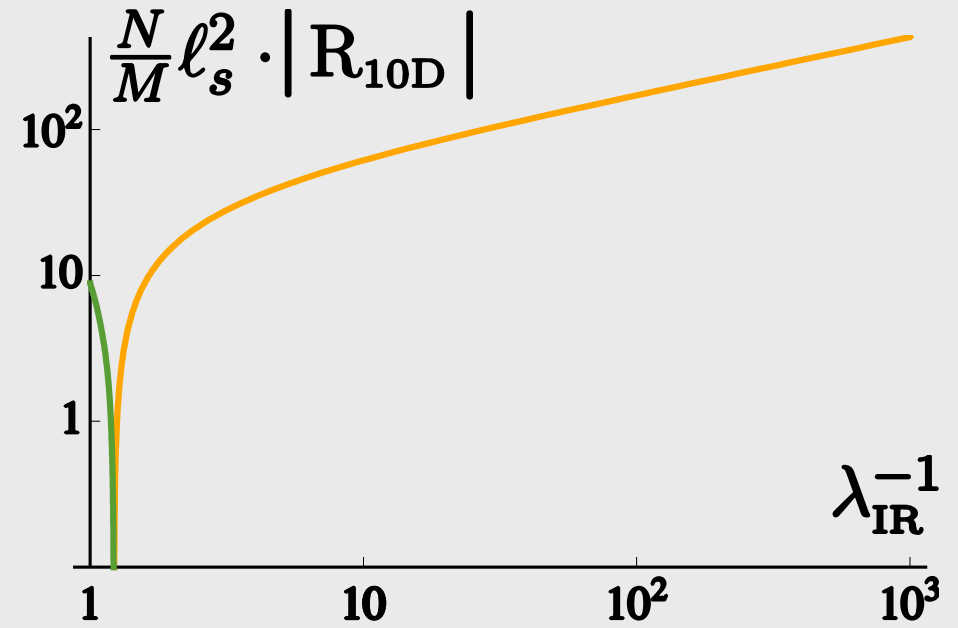
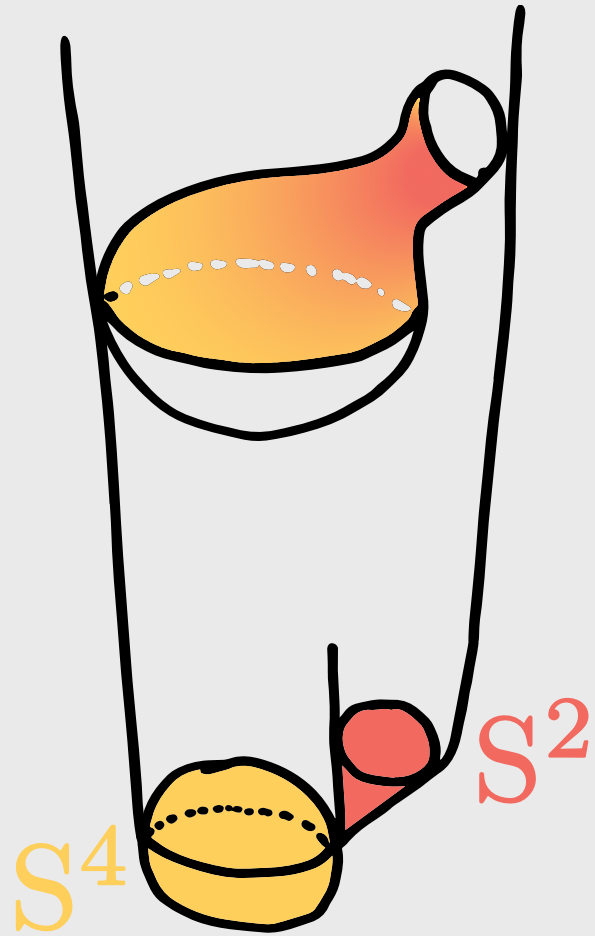


Conclusions

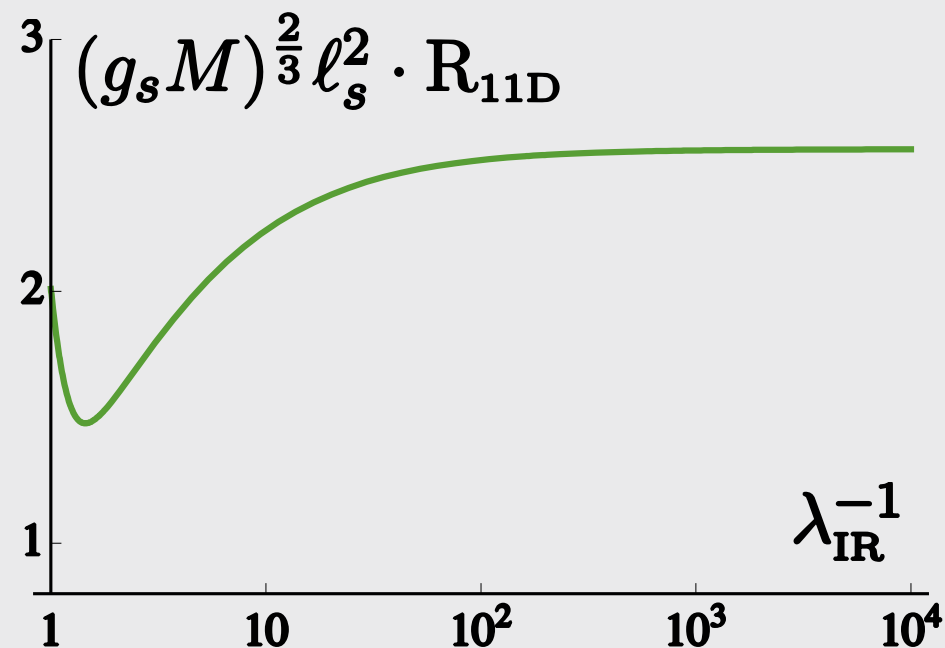
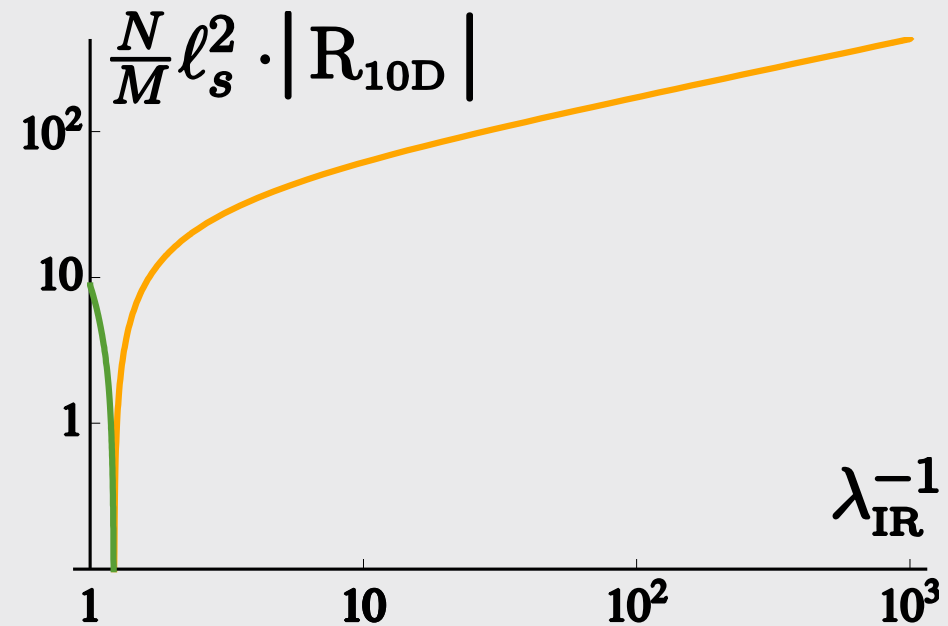
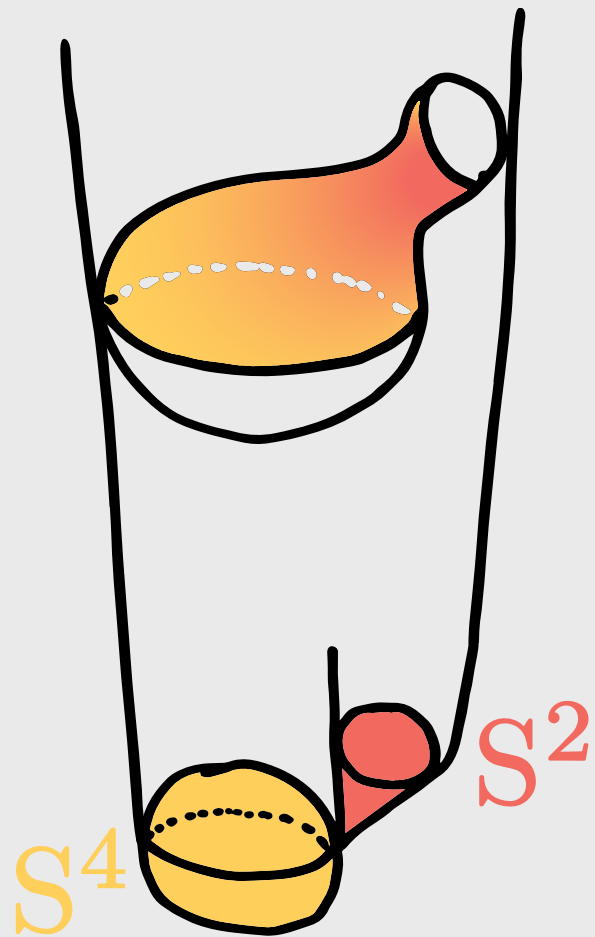




Magnetised confining phase



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Magnetised confining phase

