Tackling the gravitational wave – collider inverse problem

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In collaboration with:
L. S. Friedrich, M. J. Ramsey-Musolf and V. Q. Tran
based on [2203.05889]
(and build upon [2005.11332], [2009.10080] and [2104.04399])

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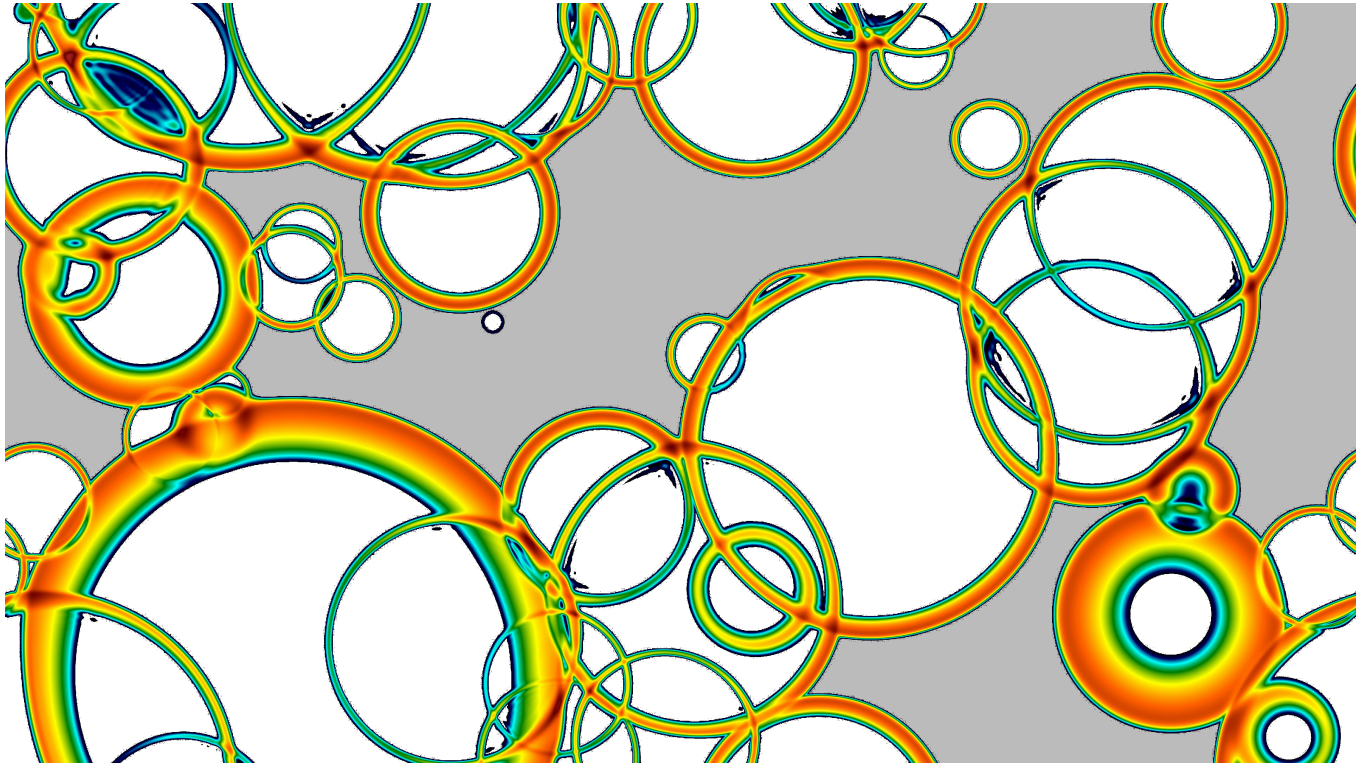
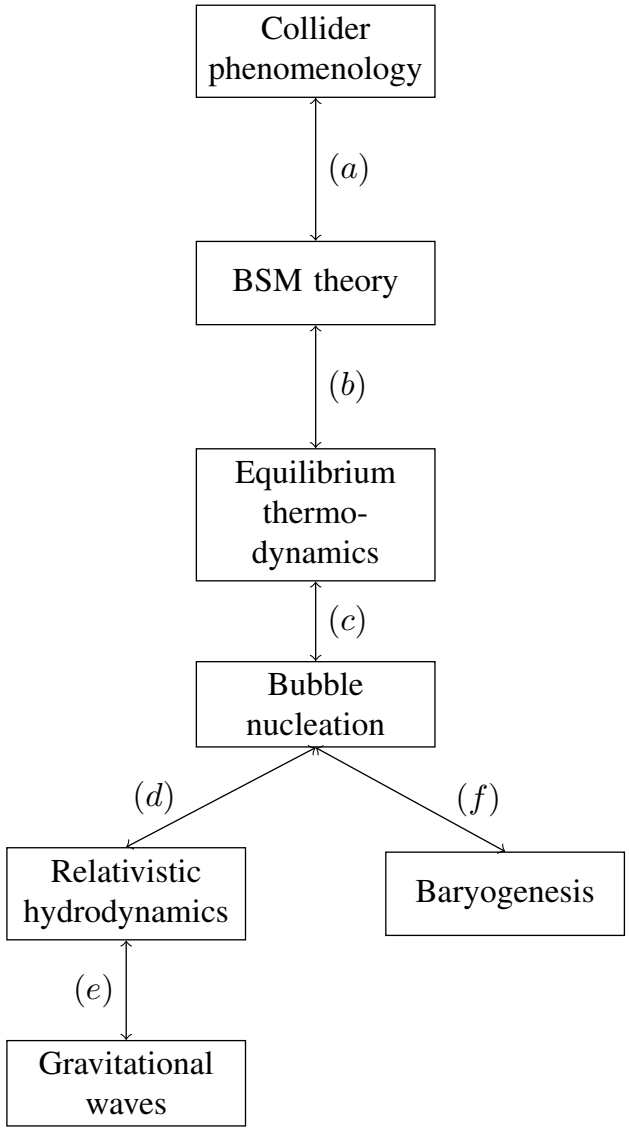
1st order cosmological phase transition (fig. from David J. Weir)

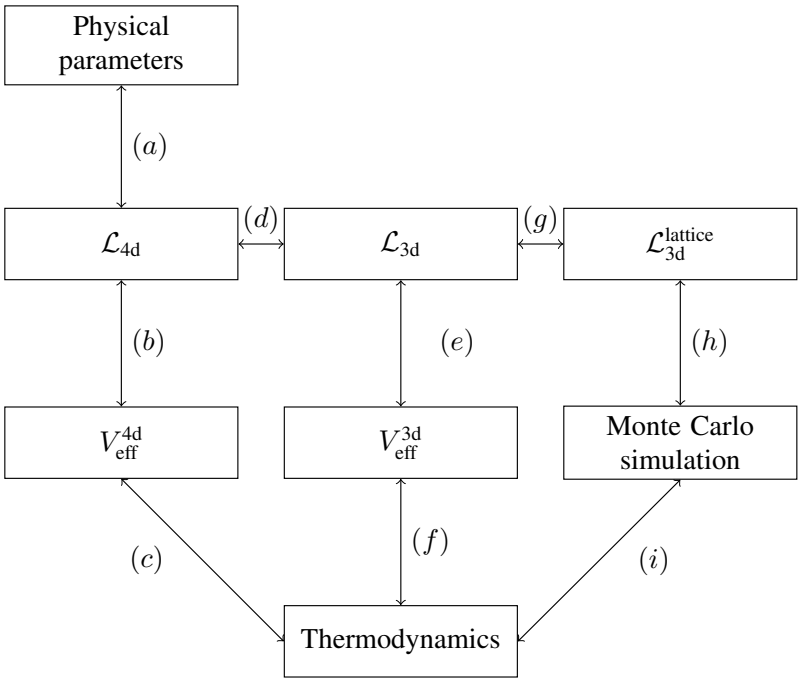


GW background – collider inverse problem $\rightarrow$ a pipeline from collider phenomenology to cosmological gravitational wave production. And vice versa? Aim: pushing state-of-the-art description.

Pipeline: EWPT in BSM theories.



How do I resum thee? (weak coupling g: $\mathcal{O}(g^n)$)



- "4d approach" or 1-loop V_{eff} with daisy resummation: (a)-(b)-(c): $\mathcal{O}(g^3)$
- Perturbative (dimensionally reduced) 3d EFT approach: (a)-(d)-(e)-(f): $\mathcal{O}(g^4)$ (2-loop) or $\mathcal{O}(g^5)$ (3-loop).
- Non-perturbative 3d EFT approach: (a)-(d)-(g)-(h)-(i): $\mathcal{O}(g^6)$ and captures non-perturbative IR physics.

Does the accuracy matter..?

... short answer: YES! $\rightarrow$ three orders-of-magnitude uncertainty in the peak gravitational wave amplitude! (cf. [1904.01329], [2009.10080], [2104.04399])

Convergence in g is slow at high-T: need higher loop orders.

Generic models: 3d EFT in Mathematica within seconds

DRalgo: a package for effective field theory approach for thermal phase transitions

[2205.08815]: `https://github.com/DR-algo/DRalgo`

Bubble nucleation rate computation still needs to be improved

Recent developments in [2104.11804], [2108.04377], [2112.05472], [2112.08912].

Also the bubble wall speed should be derived as a function of BSM model parameters.

SM + triplet scalar Σ^a: collider phenomenology

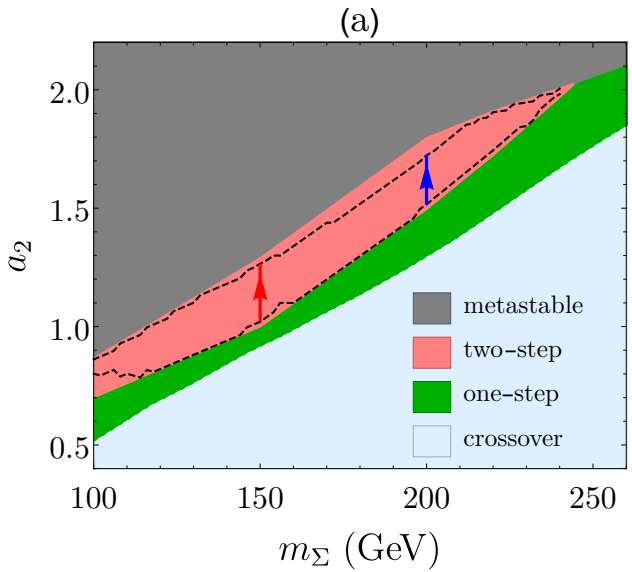
- Portal to Higgs by coupling a_2: $\mathcal{L}_{\text{SM}} + \mathcal{L}_\Sigma + \frac{1}{2} a_2 H^\dagger H (\Sigma^a \Sigma^a)$
- Possible pheno targets for future colliders: triplet mass, deviation to Higgs to digamma decay rate, branching fraction $\Sigma^0 \to ZZ$.

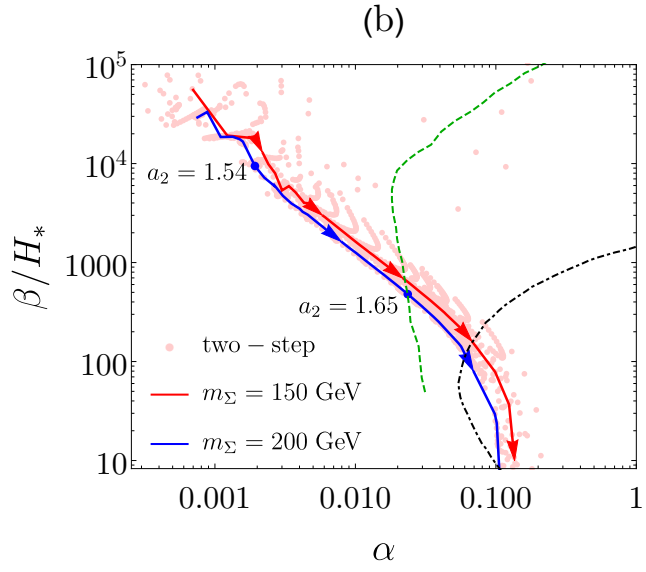
Envision a future measurement:

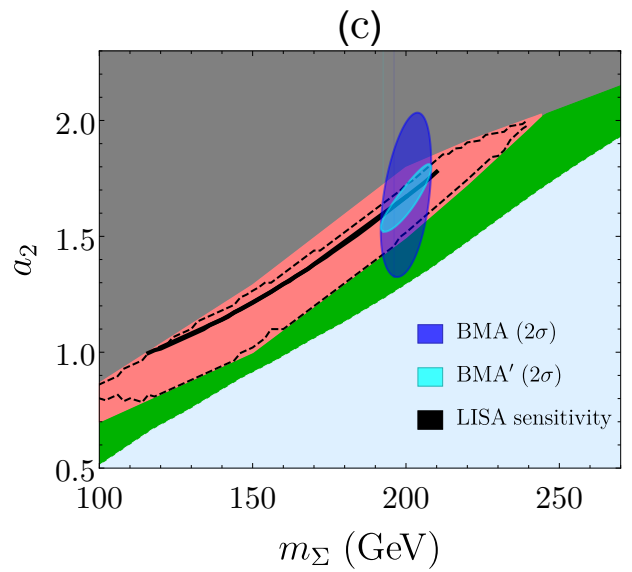
$$\begin{aligned} m_\Sigma &= (\ldots) \pm (\ldots) \\ \delta_{\gamma\gamma} &= (\ldots) \pm (\ldots) \\ \text{BR}(\Sigma^0 \to ZZ) &= (\ldots) \pm (\ldots) \end{aligned}$$

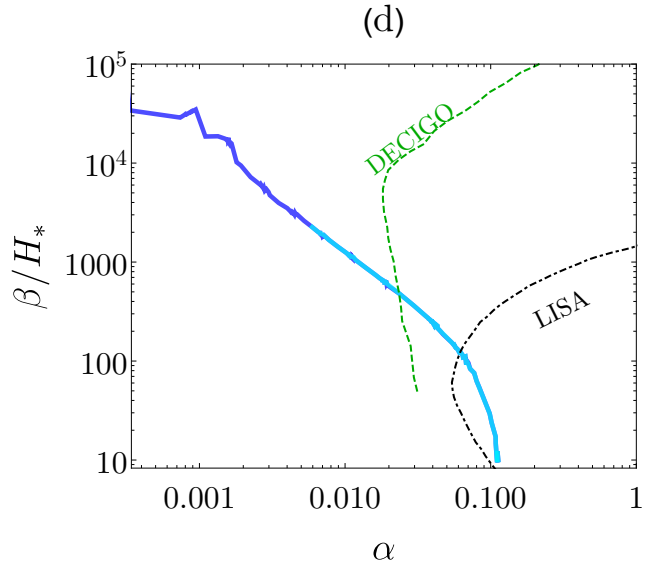
Relate to a_2 (usual $T = 0$ QFT).

pheno $\rightarrow (m_\Sigma, a_2) \rightarrow (T_*, \alpha, \beta/H_*, v_w) \rightarrow$ LISA SNR









Key points

- Need to go beyond 1-loop approximations in perturbation theory.
- A first order transition during the second step could generate a signal accessible to LISA generation detectors.
- Possible GW signal displays a strong sensitivity to the portal coupling between the new scalar and the Higgs boson.

Summary

- Proof of concept for collider – GW interplay: combination of direct and indirect measurements of the new scalar properties, in combination with the presence or absence of a GW detection, could test the model and identify the values of the model parameters.

  $\rightarrow$ future work still needed, for comprehensive statistical analysis!

- Also future: fully non-perturbative study still needed.

- Dimensional reduction and use of 3d EFT is systematic way to organise thermal resummations and attack the IR problem and slow convergence at high-T.

Thanks!