

Did our universe collide with another universe?

A search for bubble universe collision signatures in the *Planck* CMB

Jahanvi Maheshwari

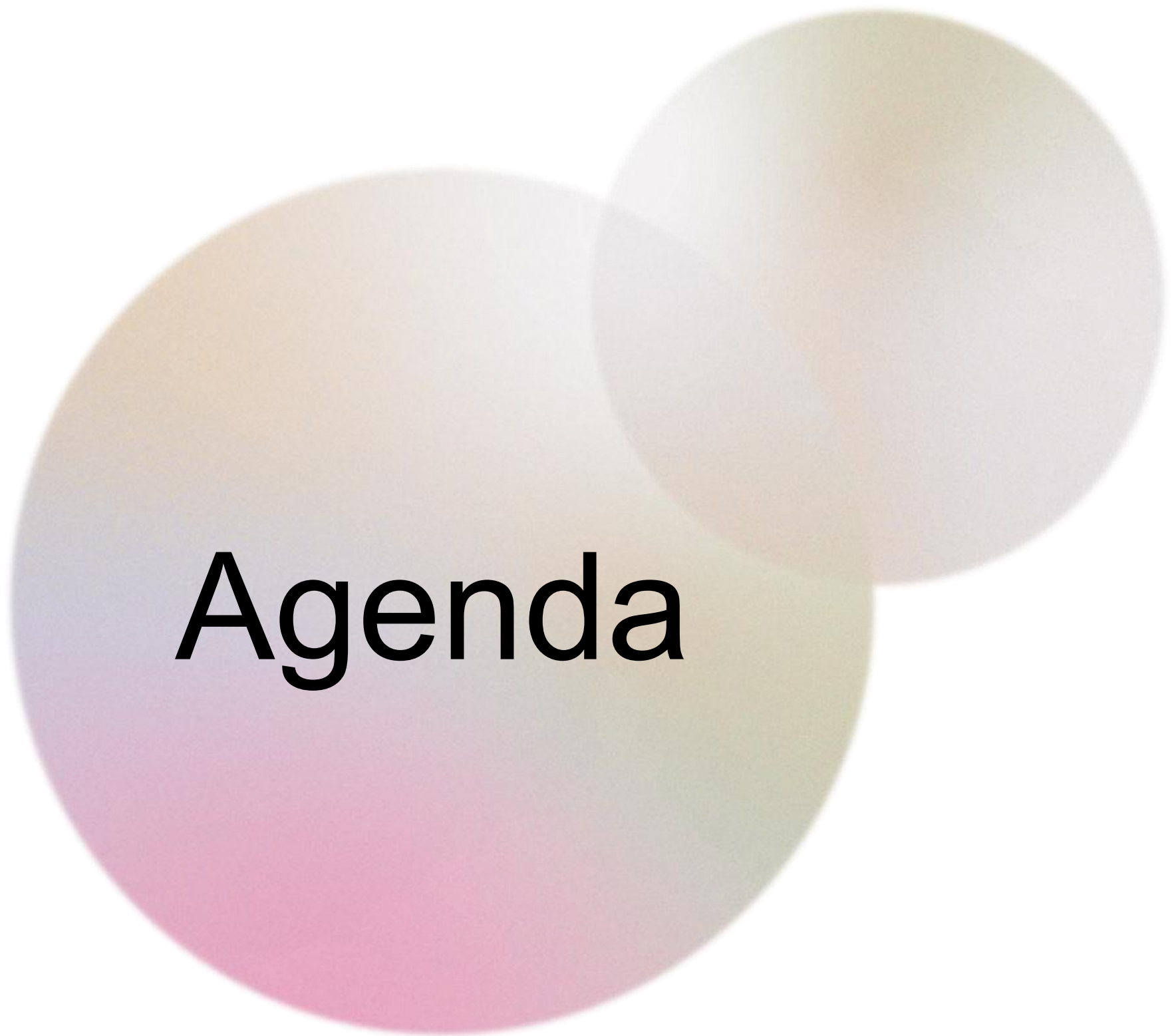
PhD Candidate,
UNSW School of Physics, CPPC- Sydney

Supervisor: Dr. Jan Hamann

UNSW School of Physics, CPPC- Sydney

PPC 2026

***XIX International Conference on Interconnections between Particle
Physics and Cosmology
4th Gordon Godfrey Workshop on Astroparticle Physics***

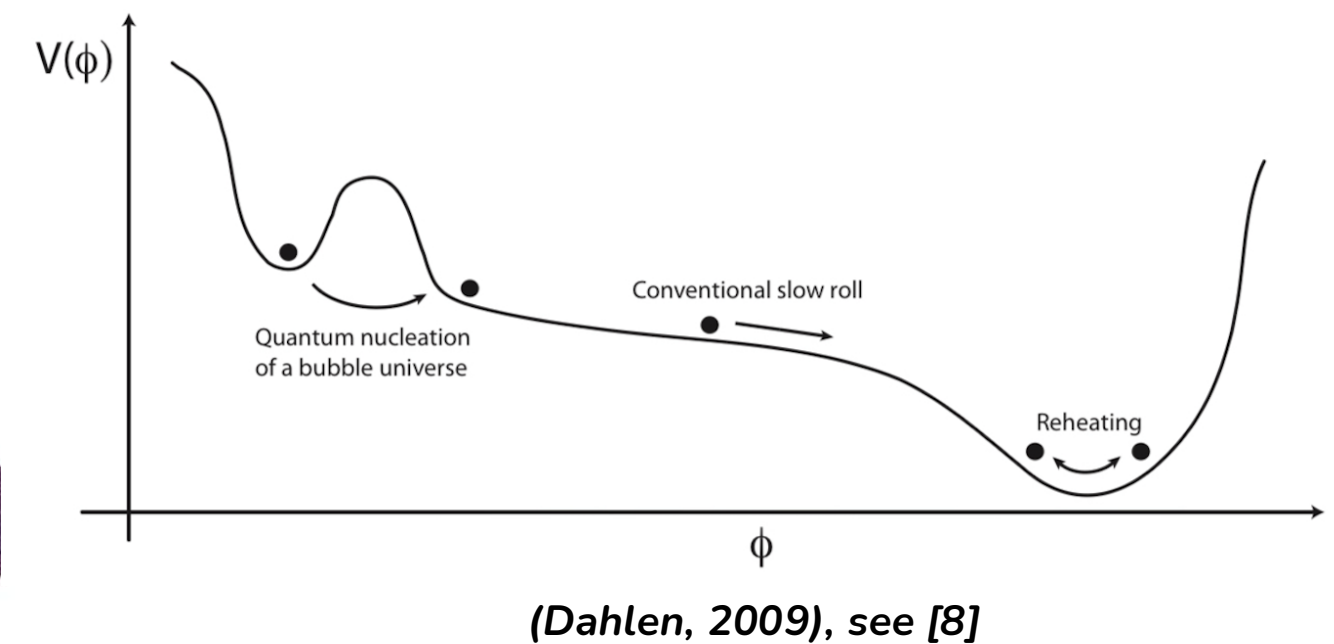
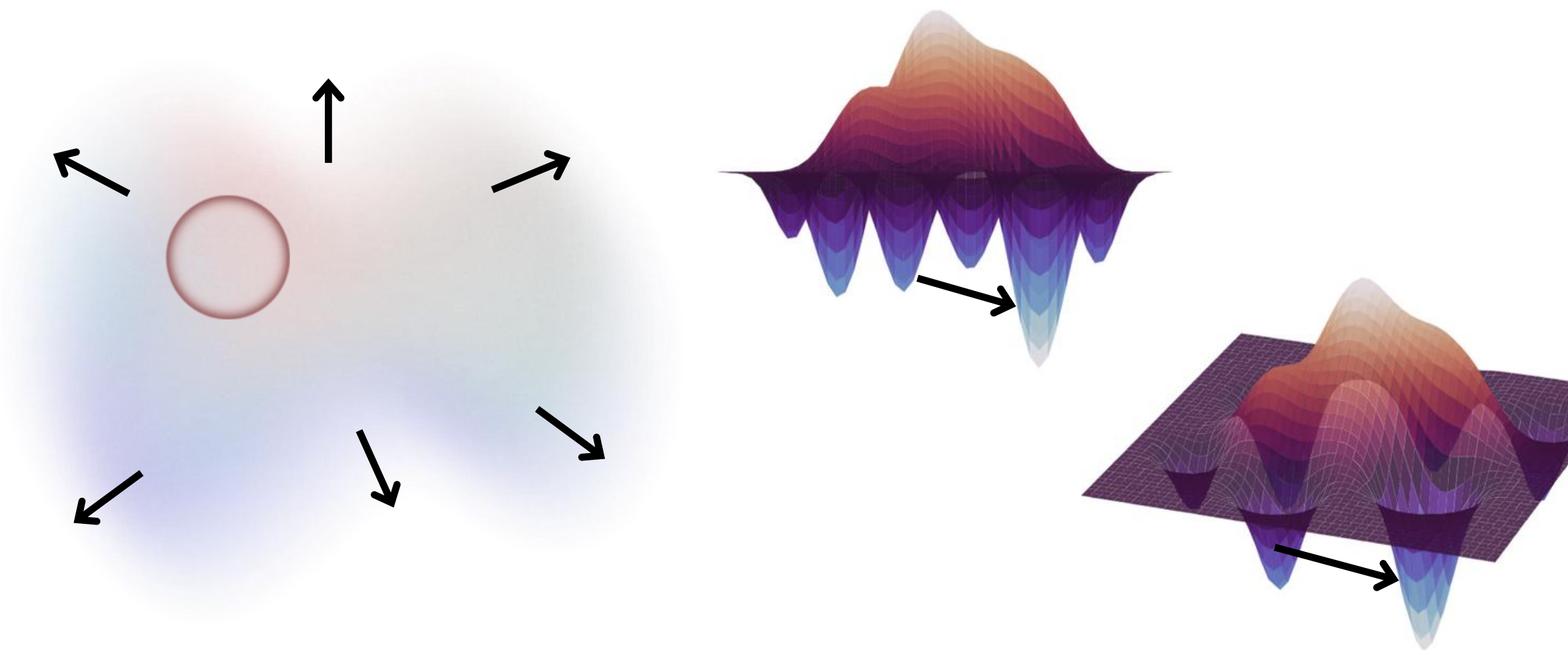
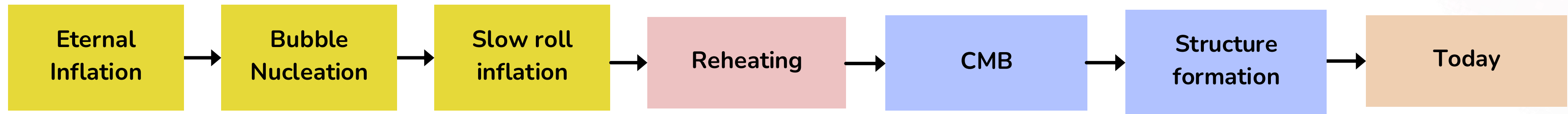


Agenda

- The Problem
- Detection Mechanisms
- Modified Method
- Current Conclusions
- Future Directions

Inflation → Eternal Inflation

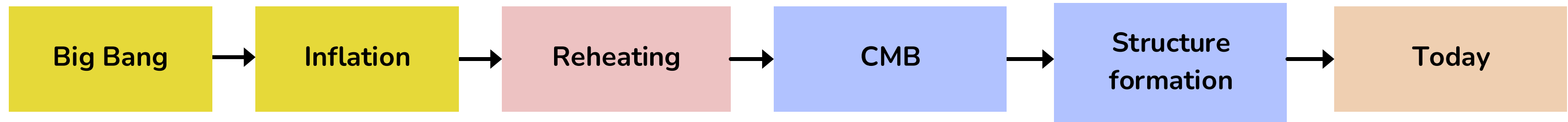
Multiverse $\rightarrow$ Bubble universes



Inflation → Eternal Inflation

Inflation + Big Bang Cosmology

- Explains large scale uniformity
- Predicts mass density of universe to <1% accuracy
- Explains CMB anisotropies (quantum fluctuations)
- What “bang” → Inflation



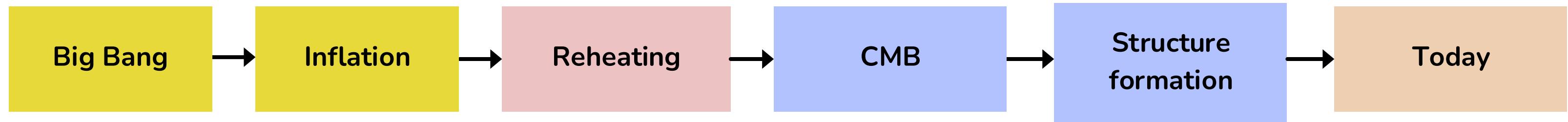
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WHY “BANG” → ??????????

ETERNAL INFLATION



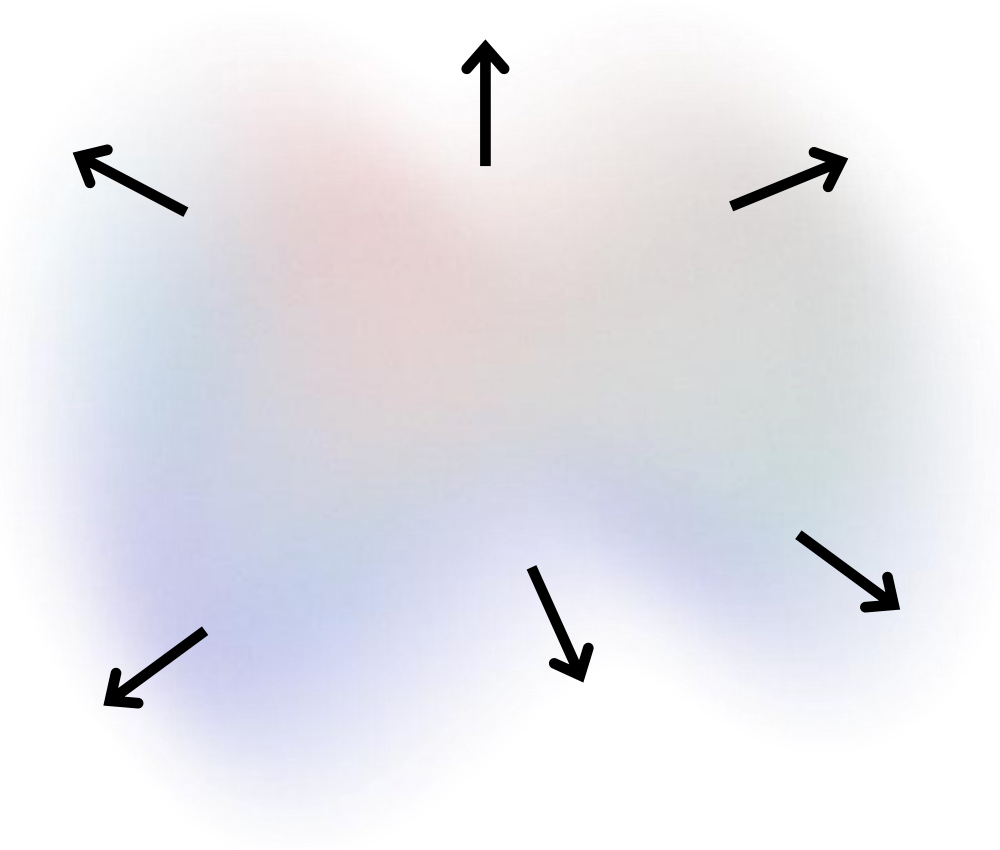
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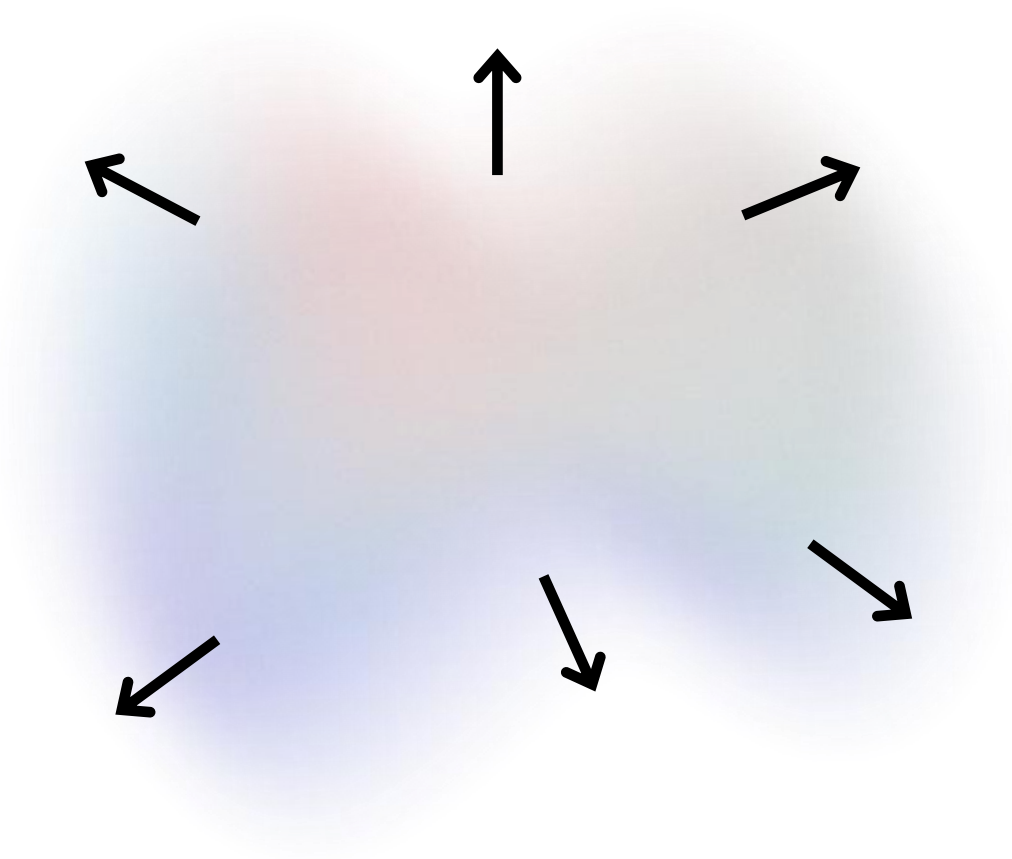
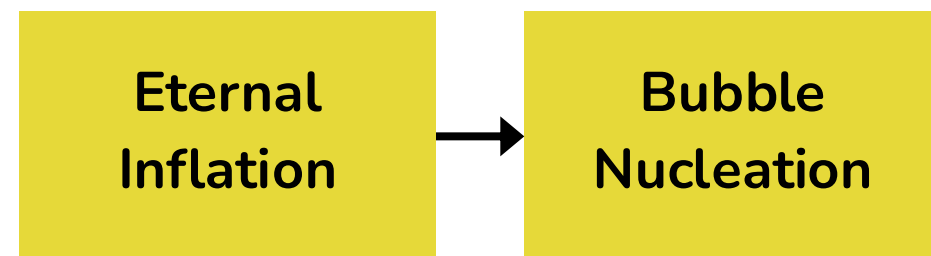
Eternal
Inflation

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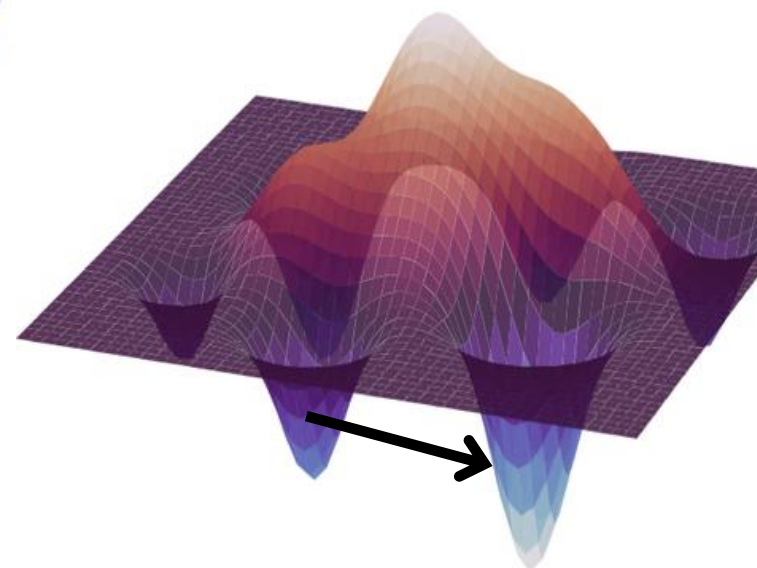
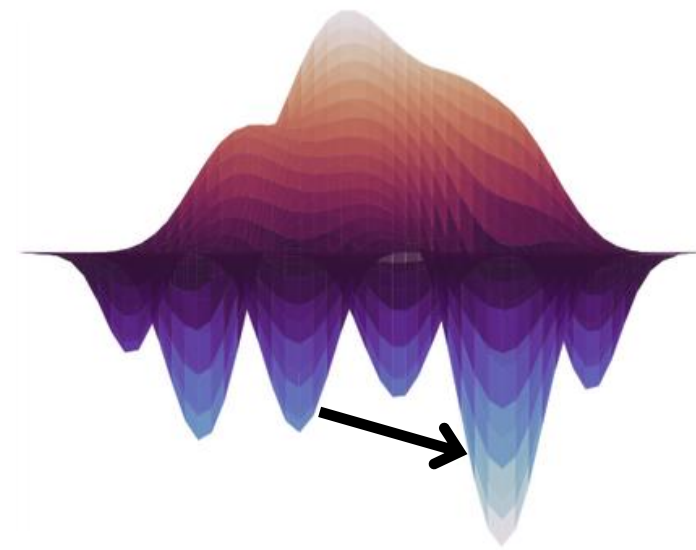
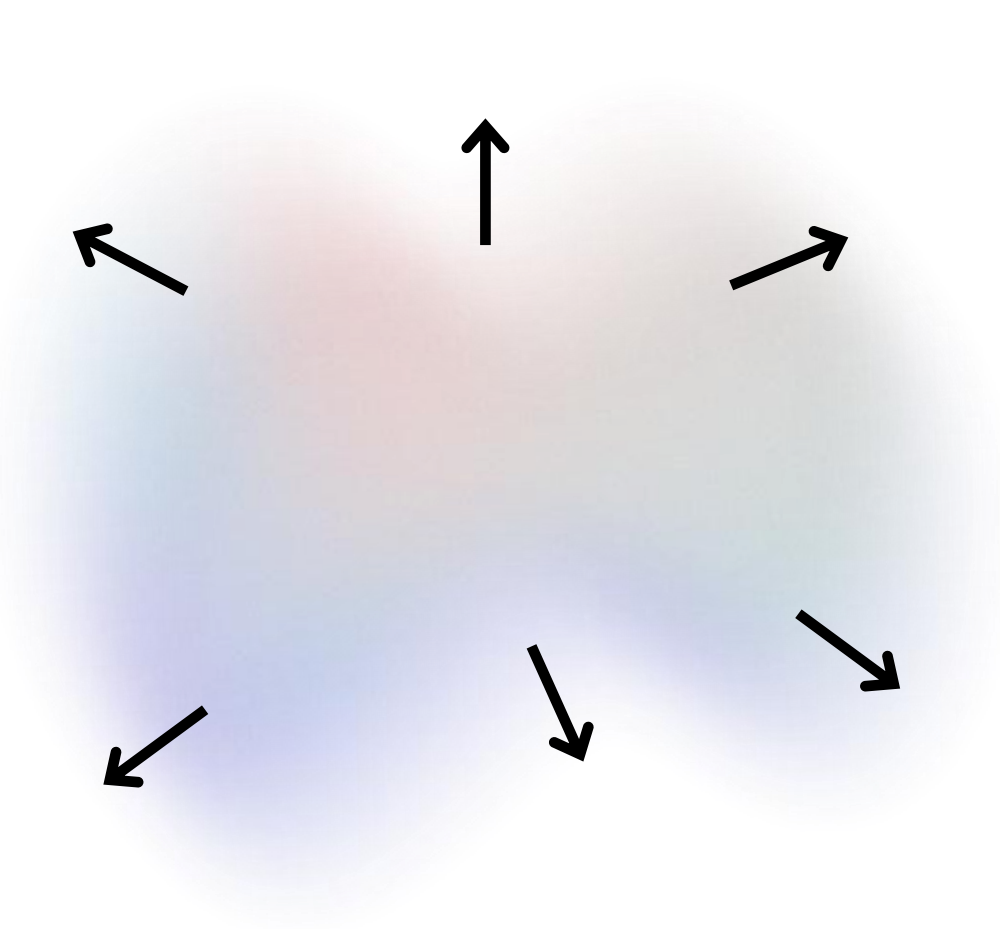
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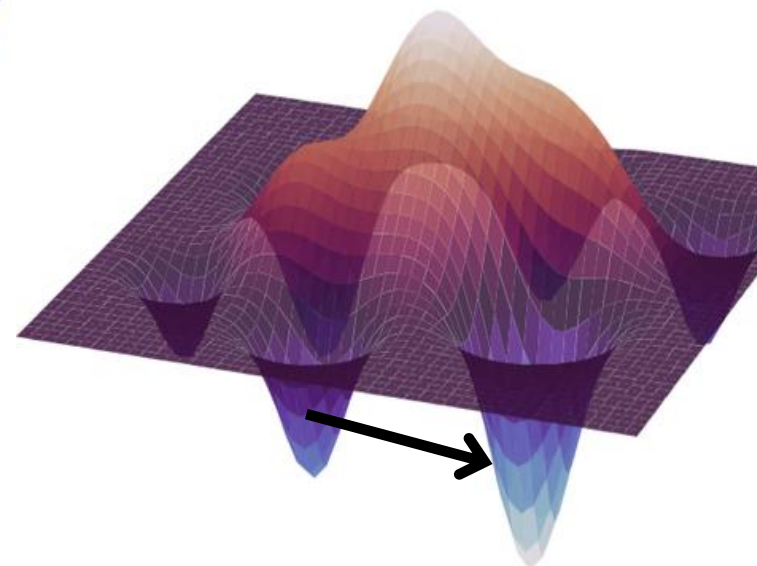
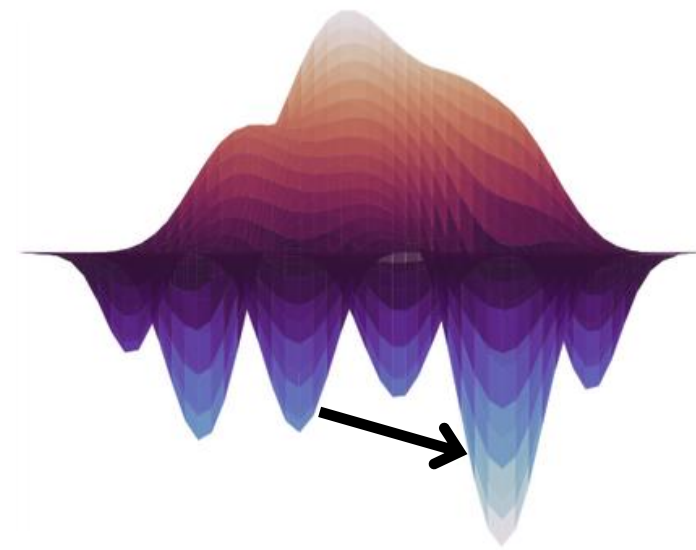
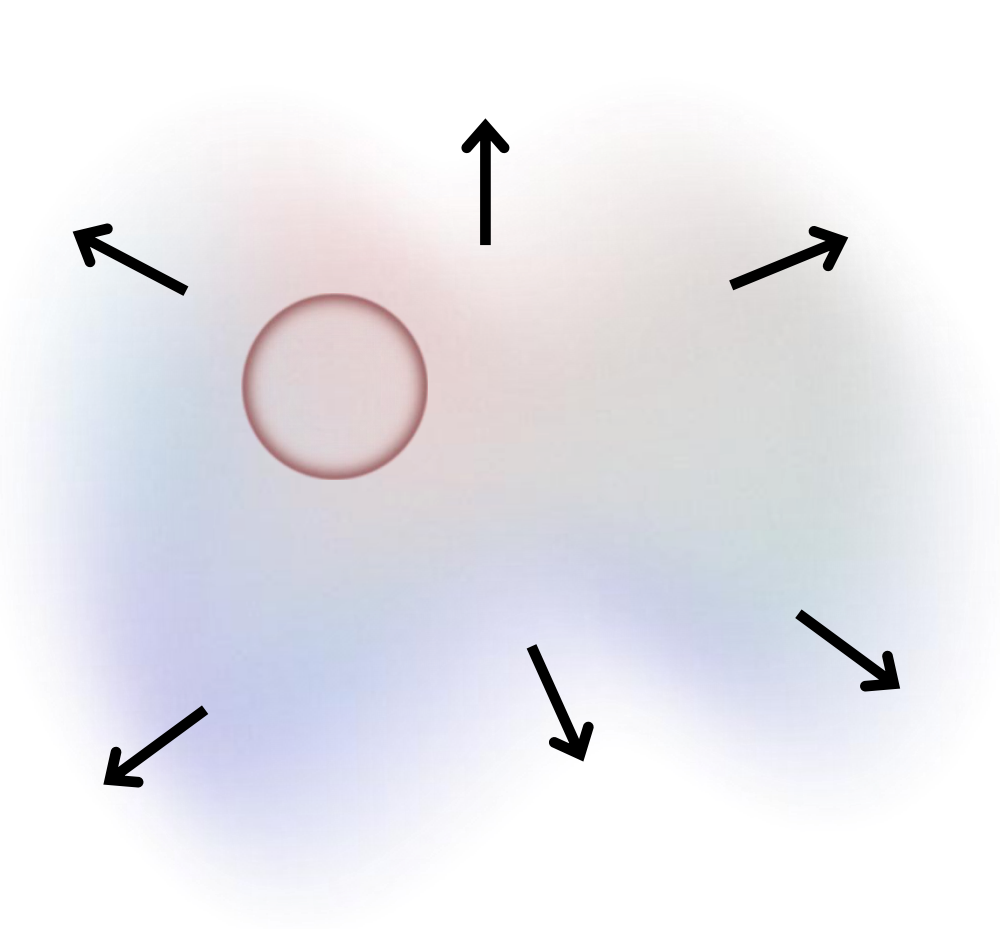
Bubble
Nucleation



Multiverse $\rightarrow$ Bubble universes

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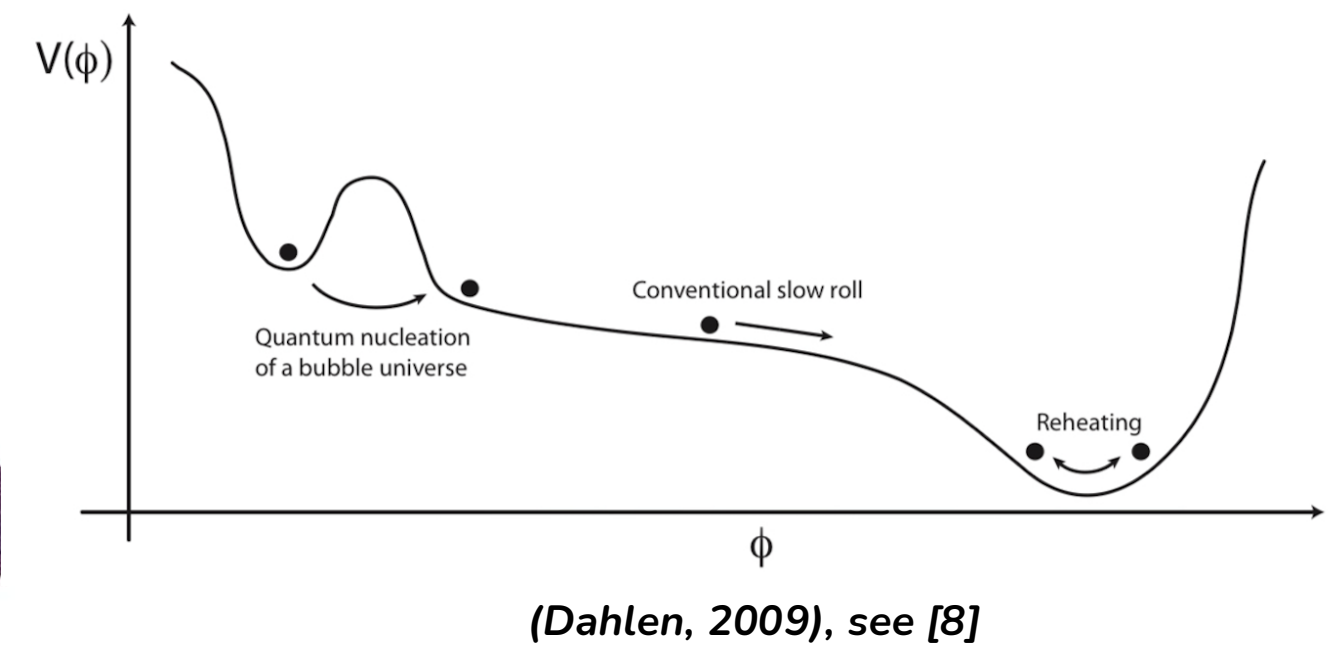
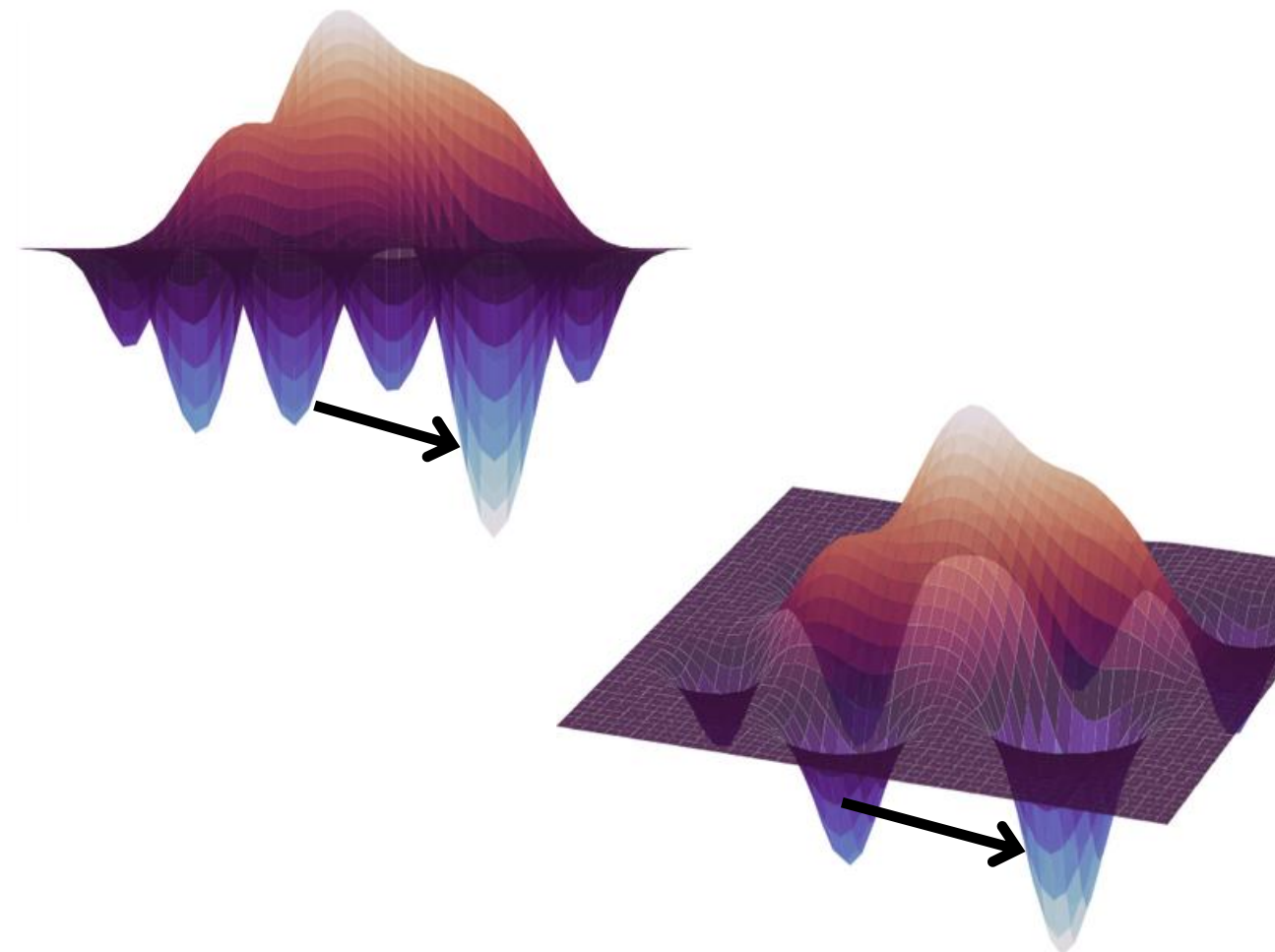
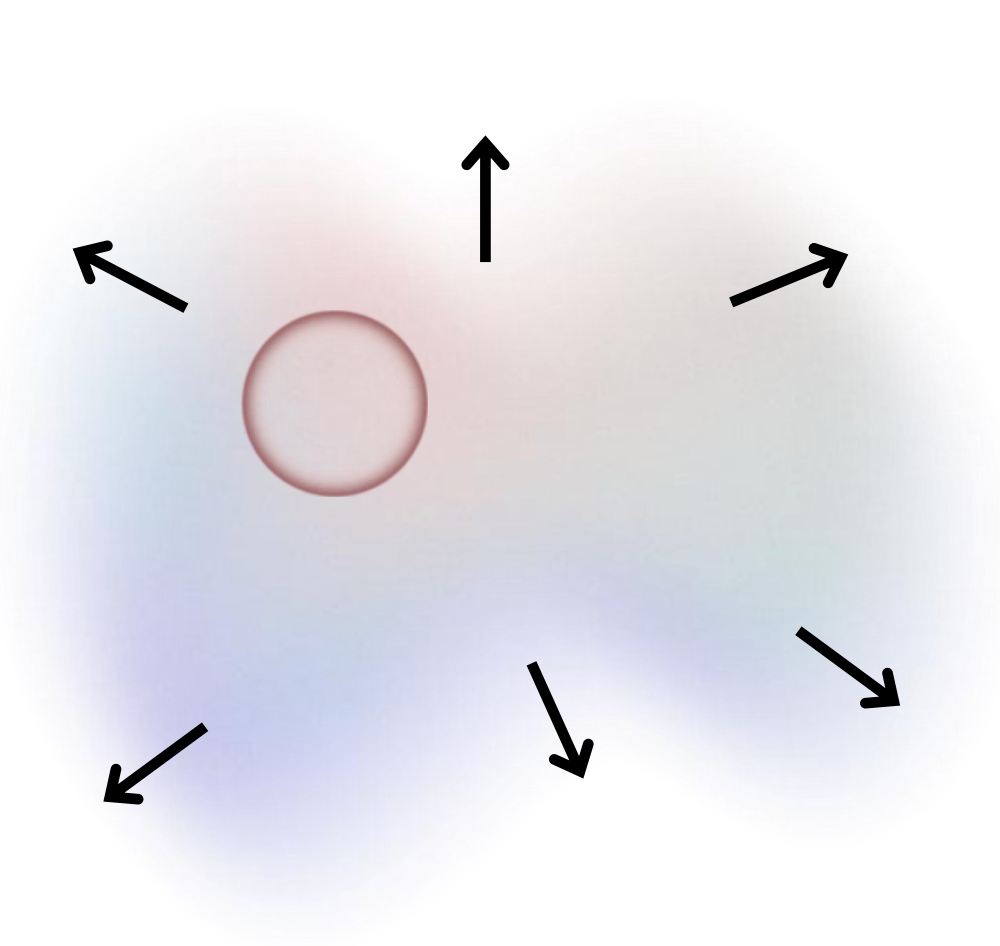
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Multiverse $\rightarrow$ Bubble universes

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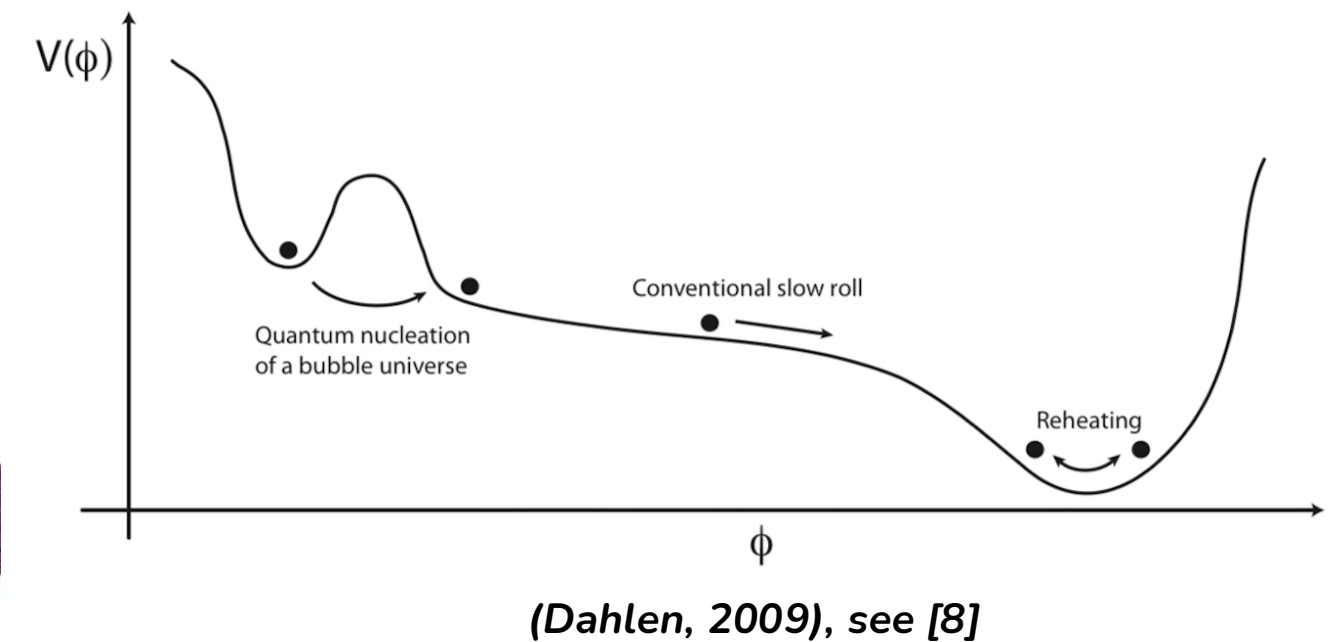
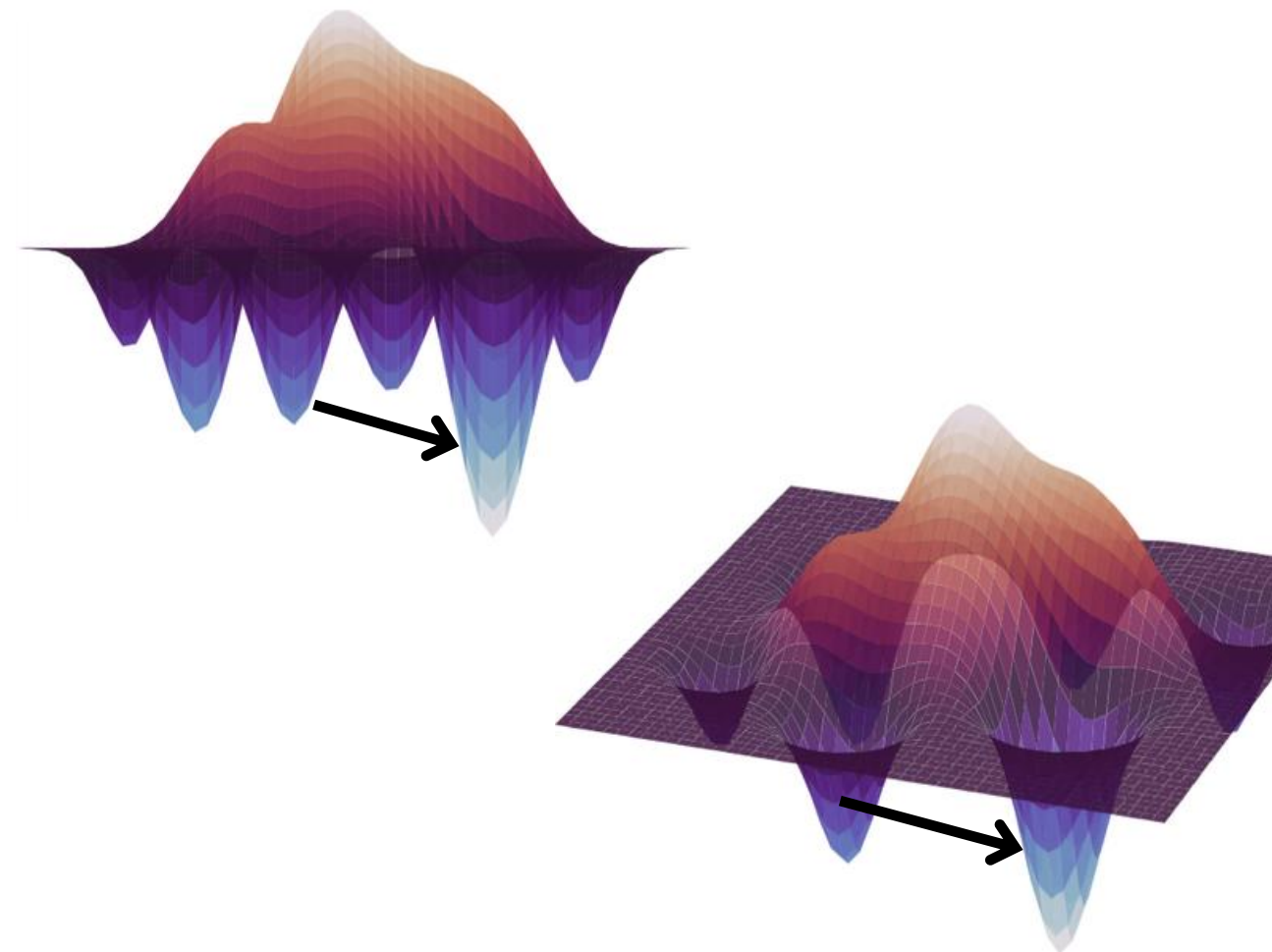
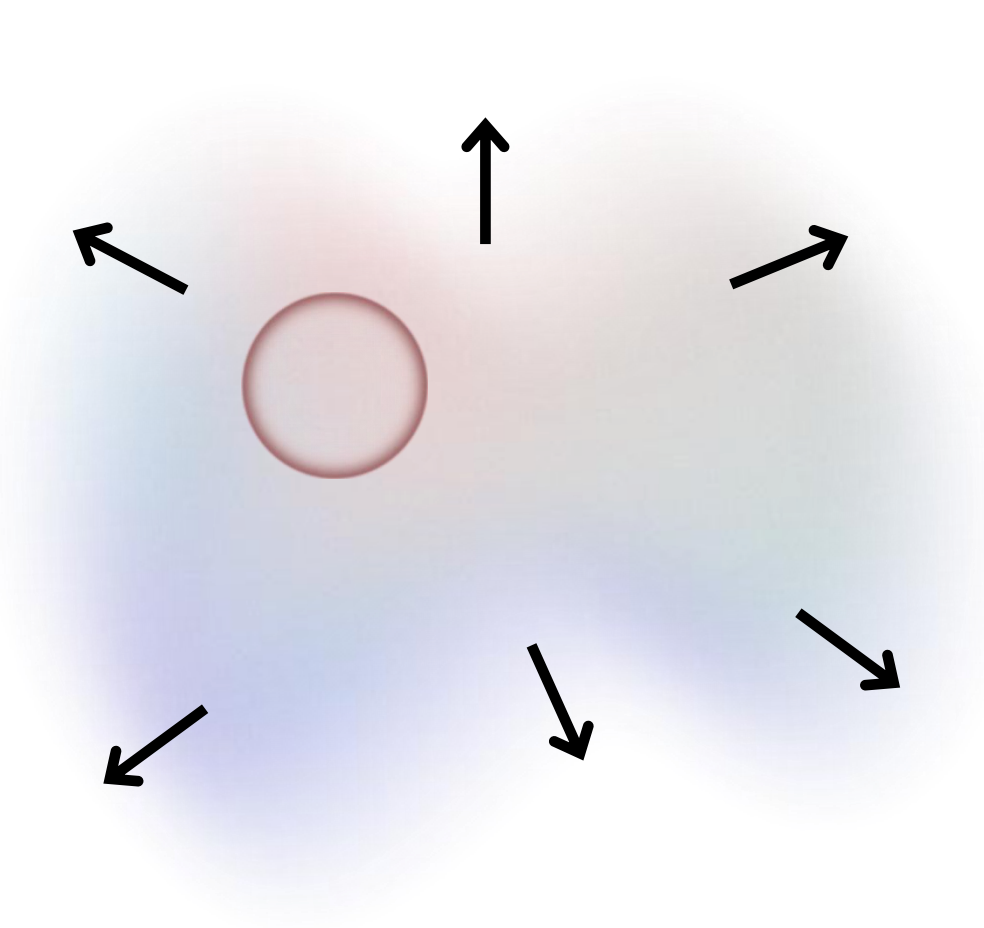


Multiverse $\rightarrow$ Bubble universes

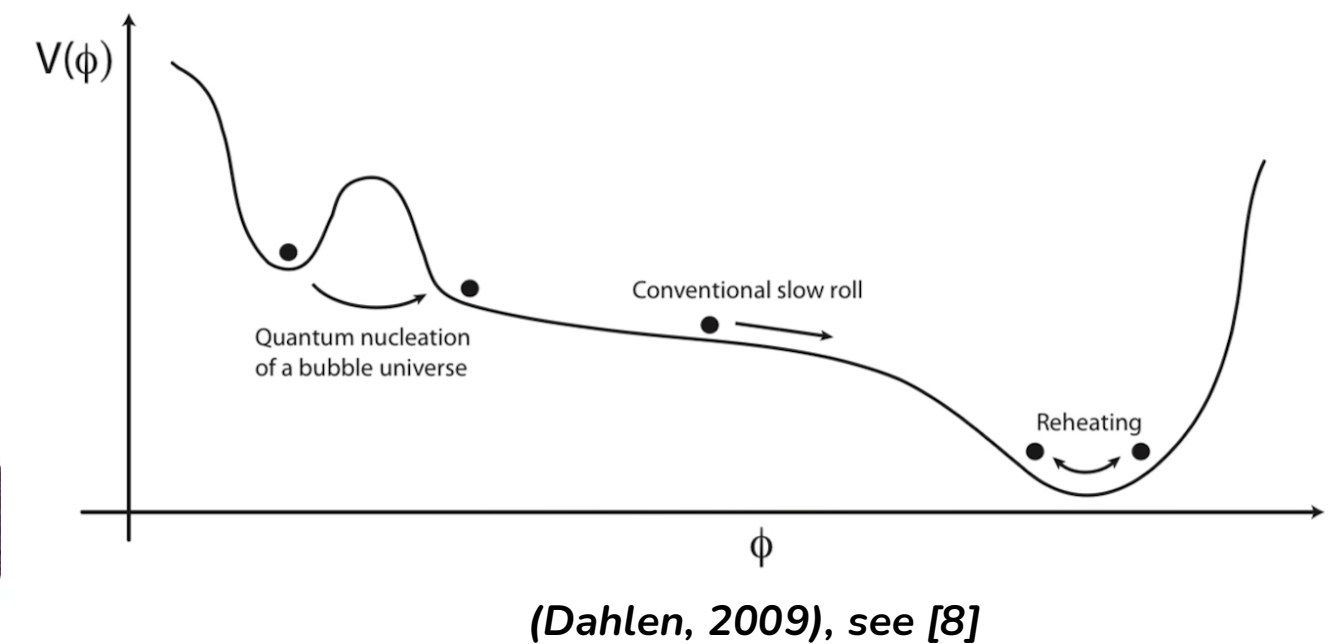
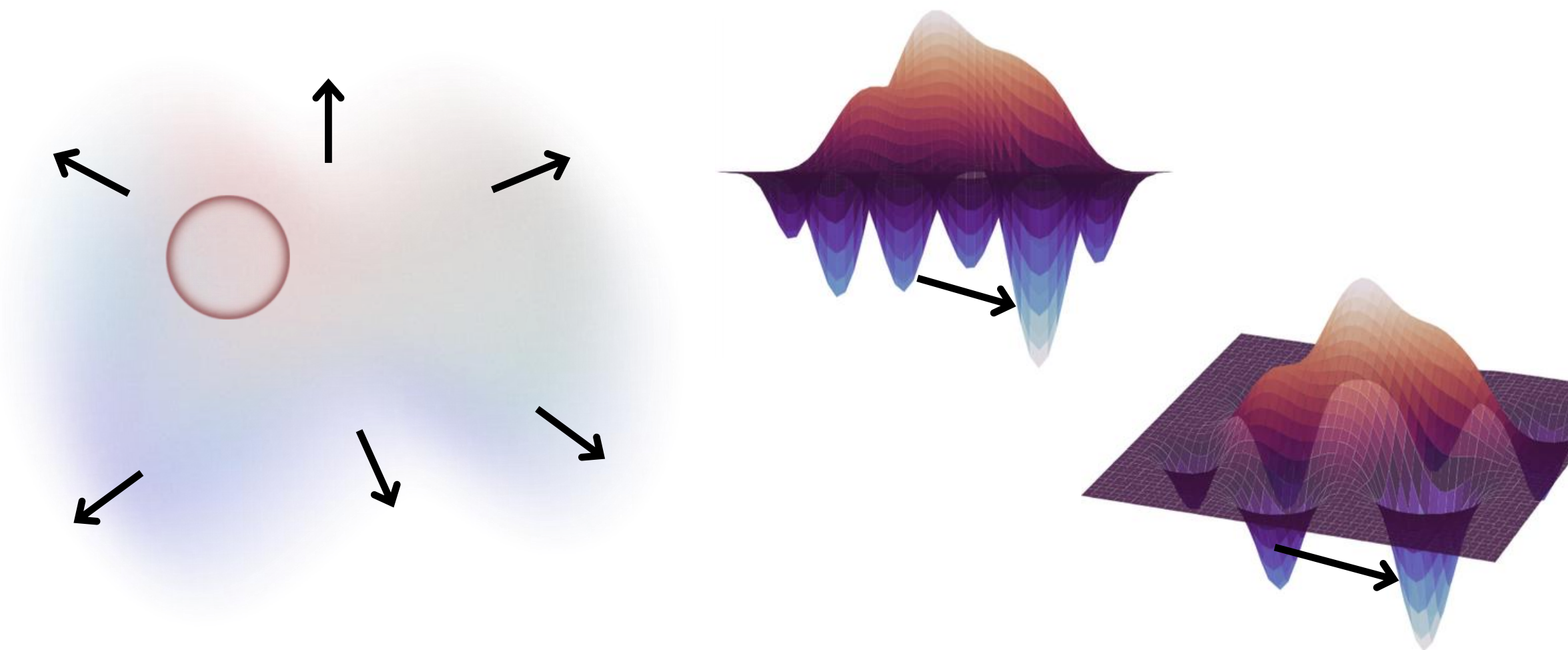
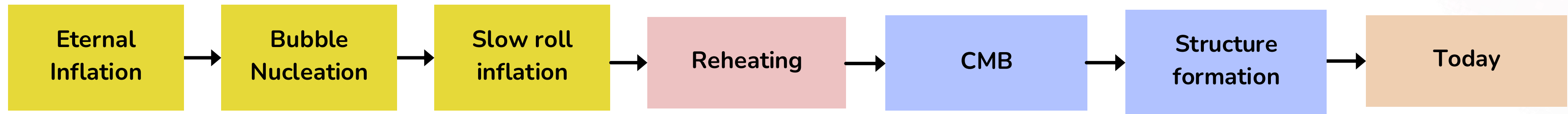
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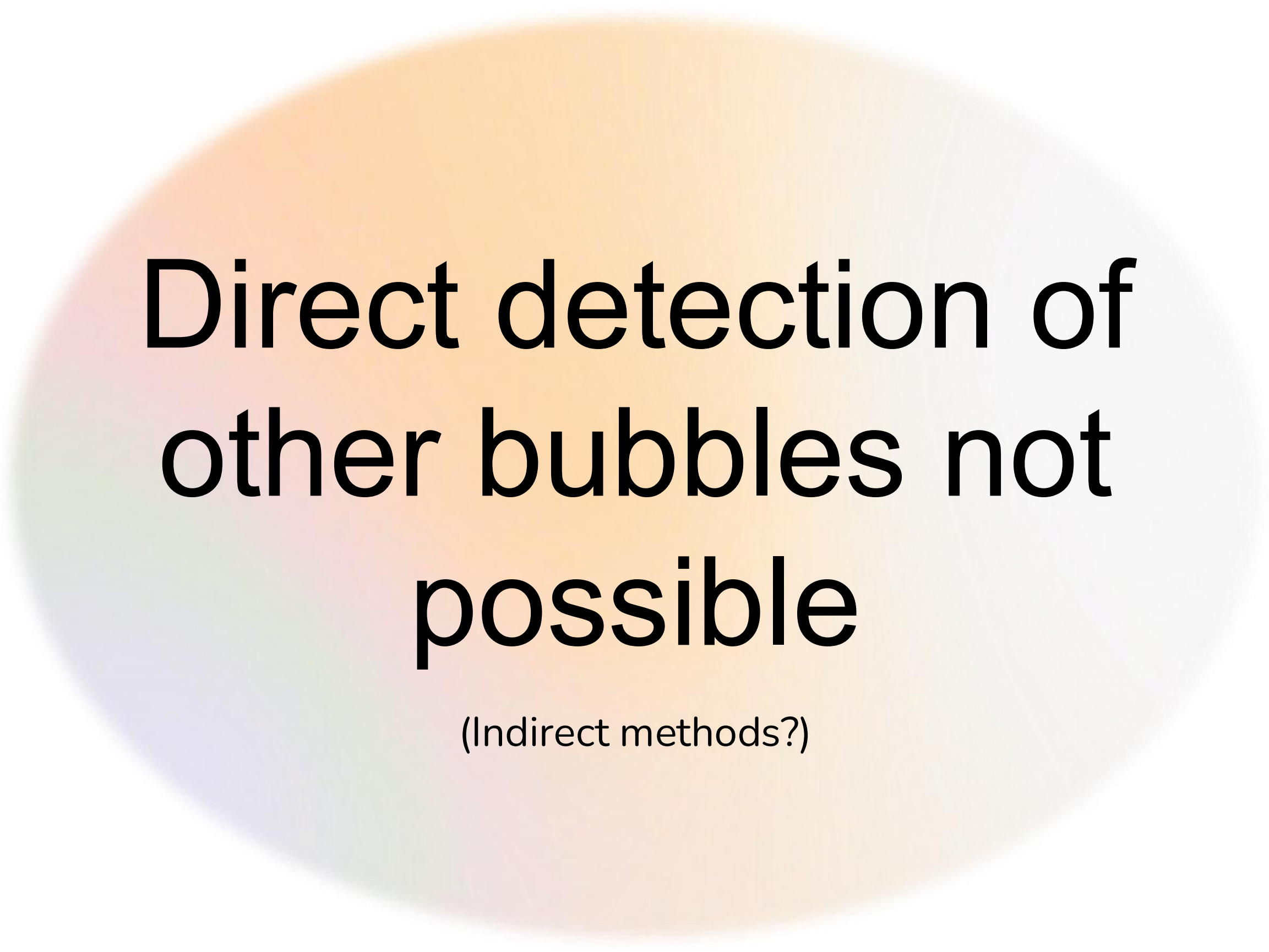
Bubble
Nucleation

Slow roll
inflation



Multiverse $\rightarrow$ Bubble universes

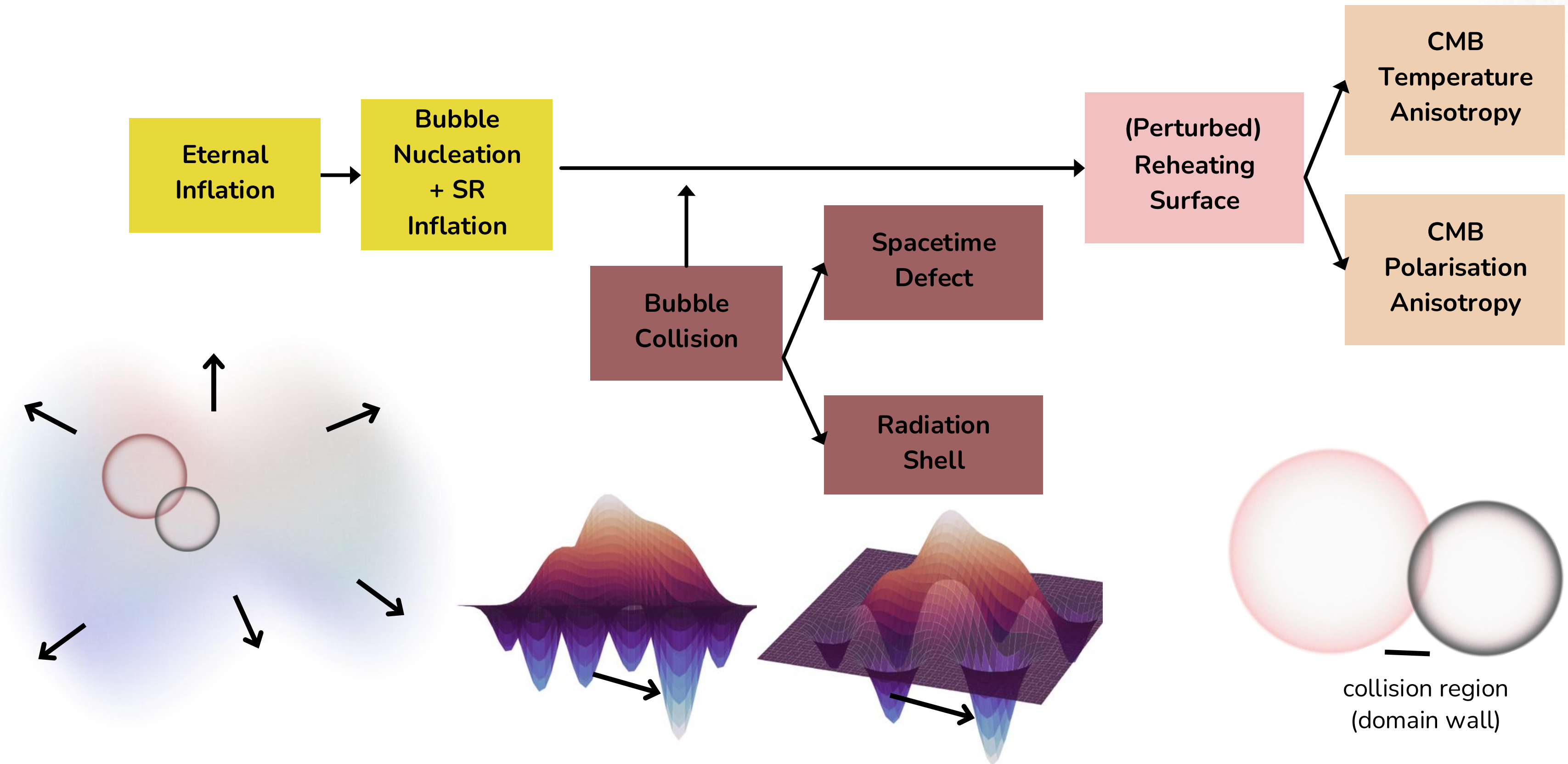




Direct detection of
other bubbles not
possible

(Indirect methods?)

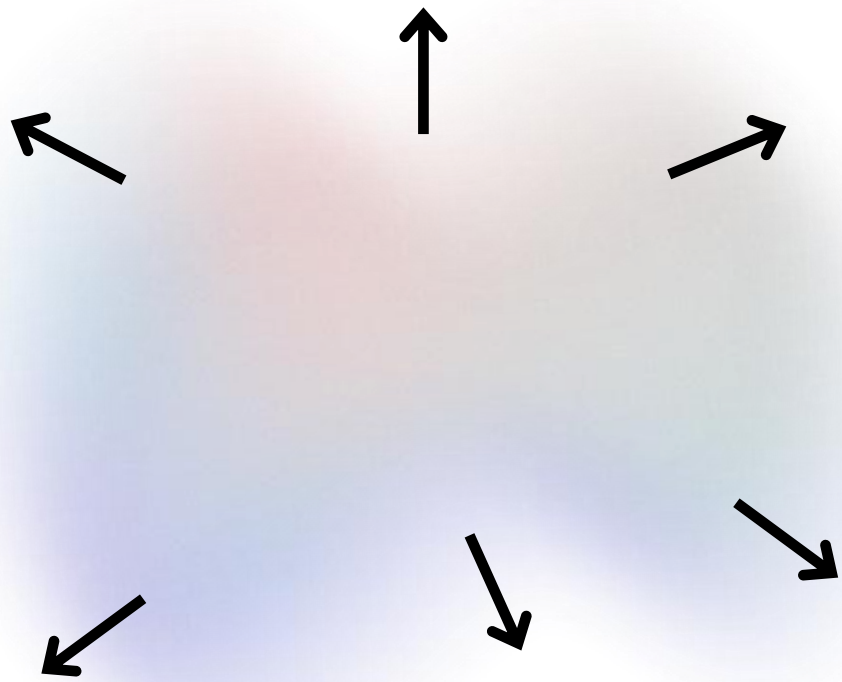
Observable multiverse signature



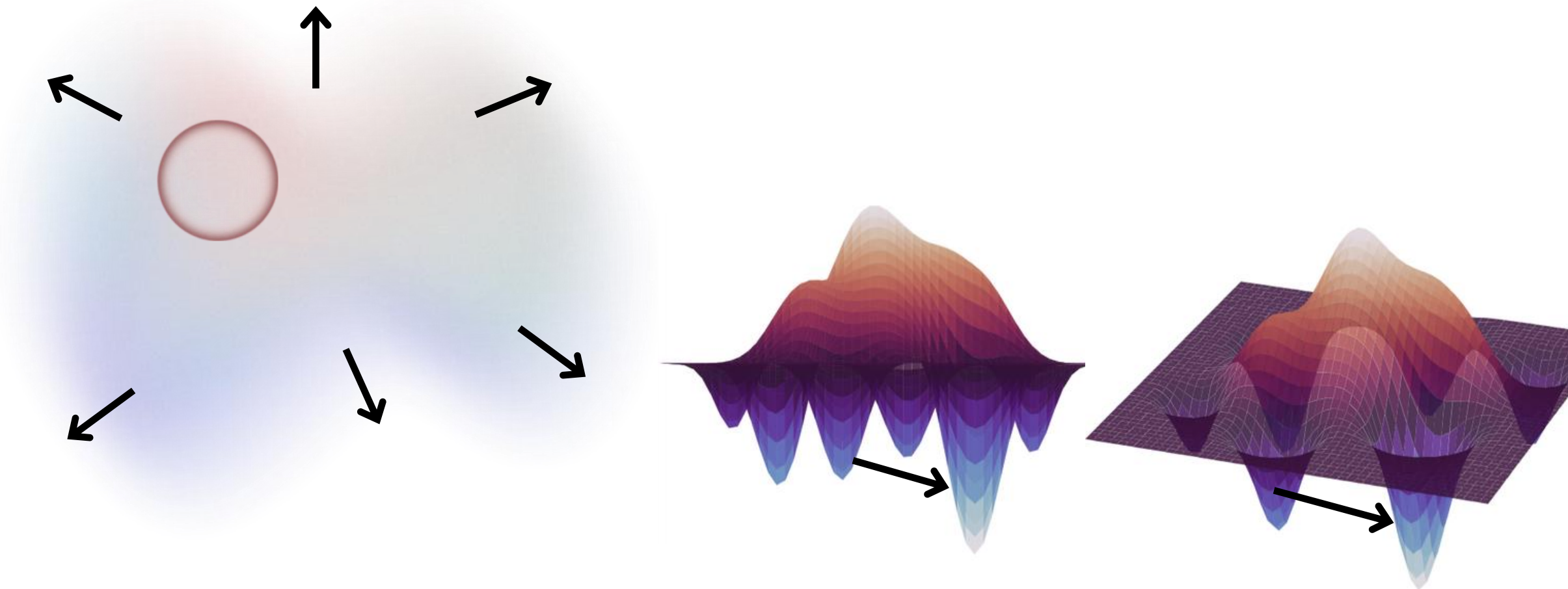
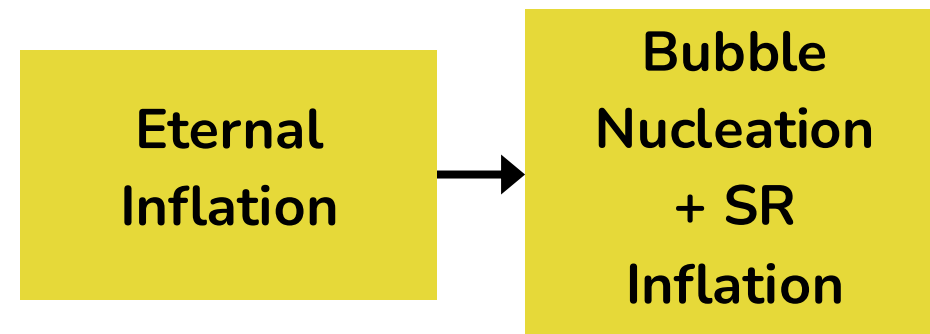
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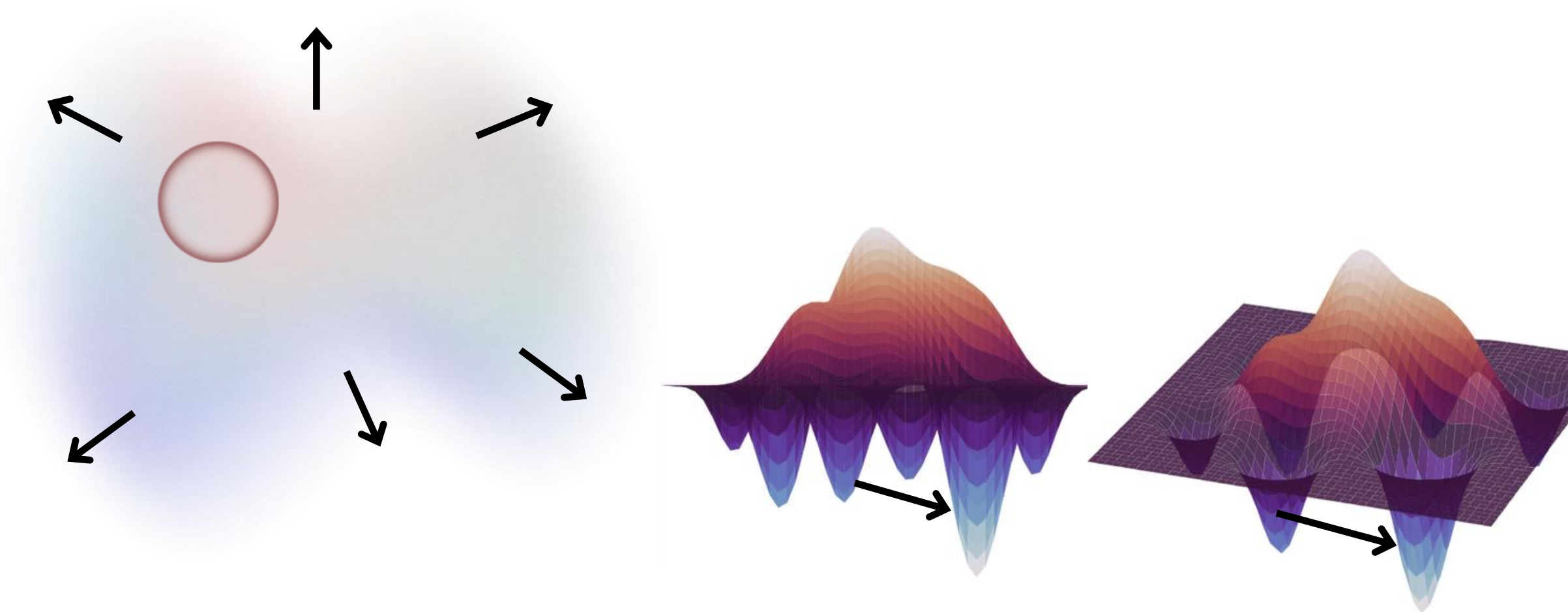
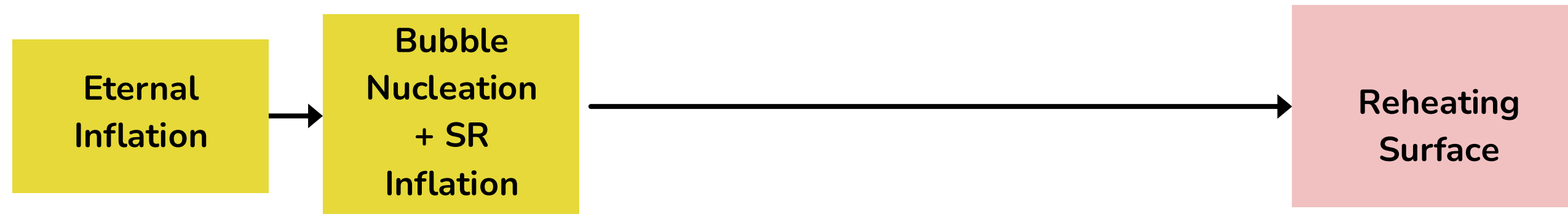
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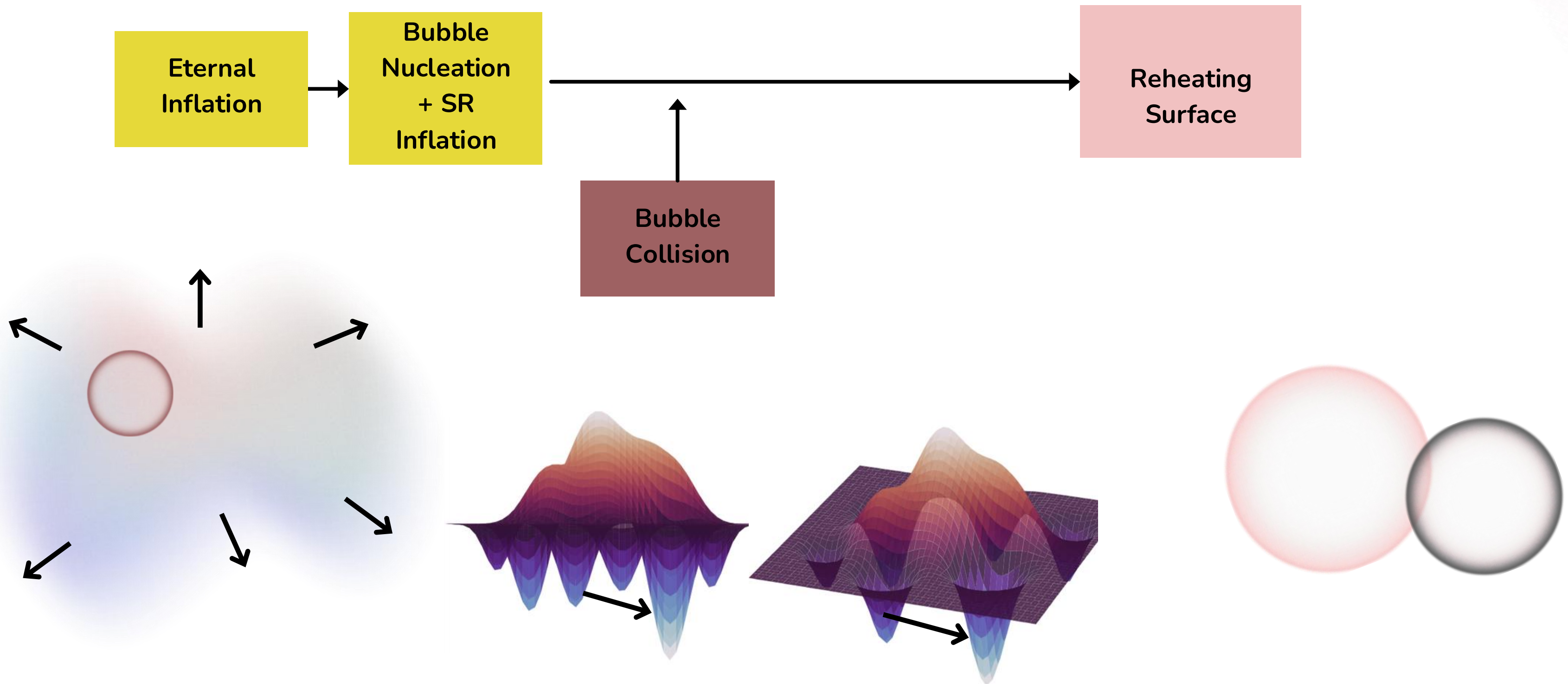
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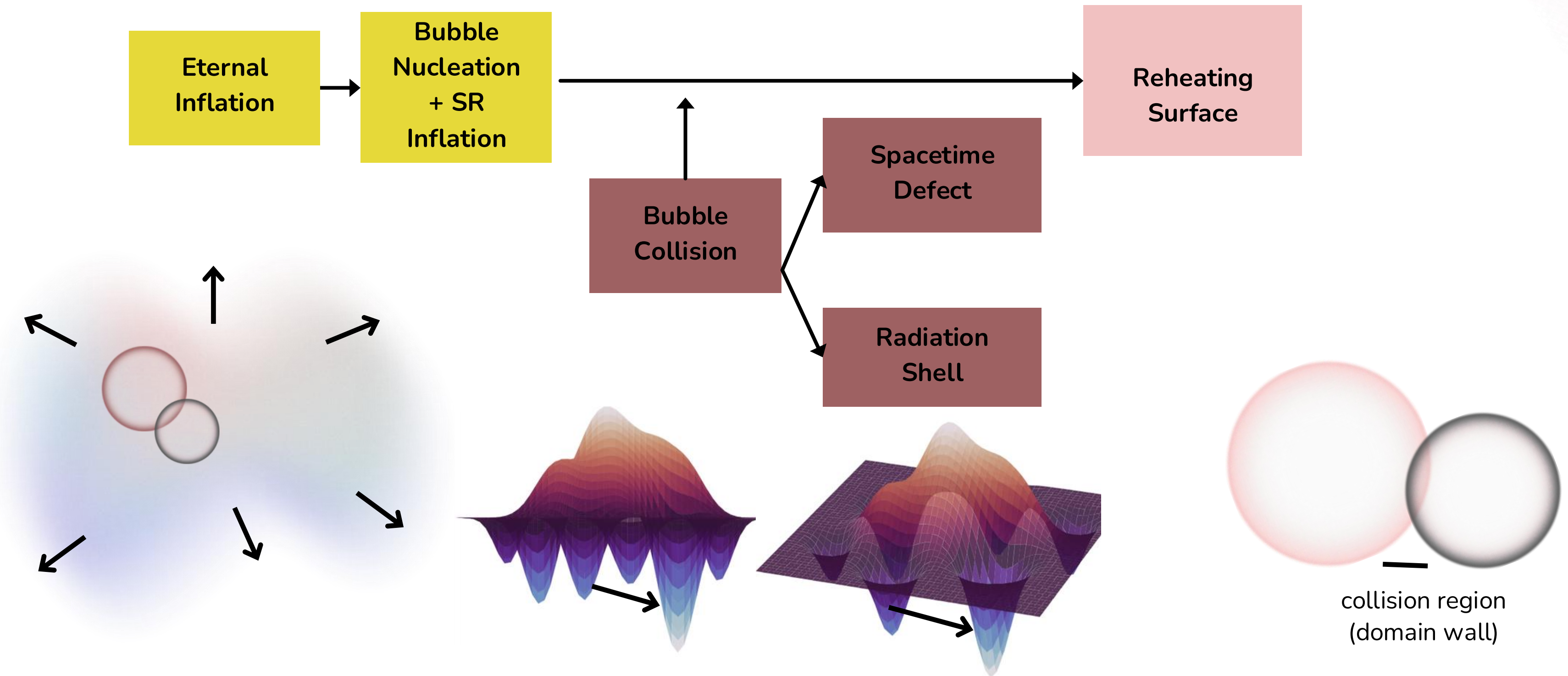
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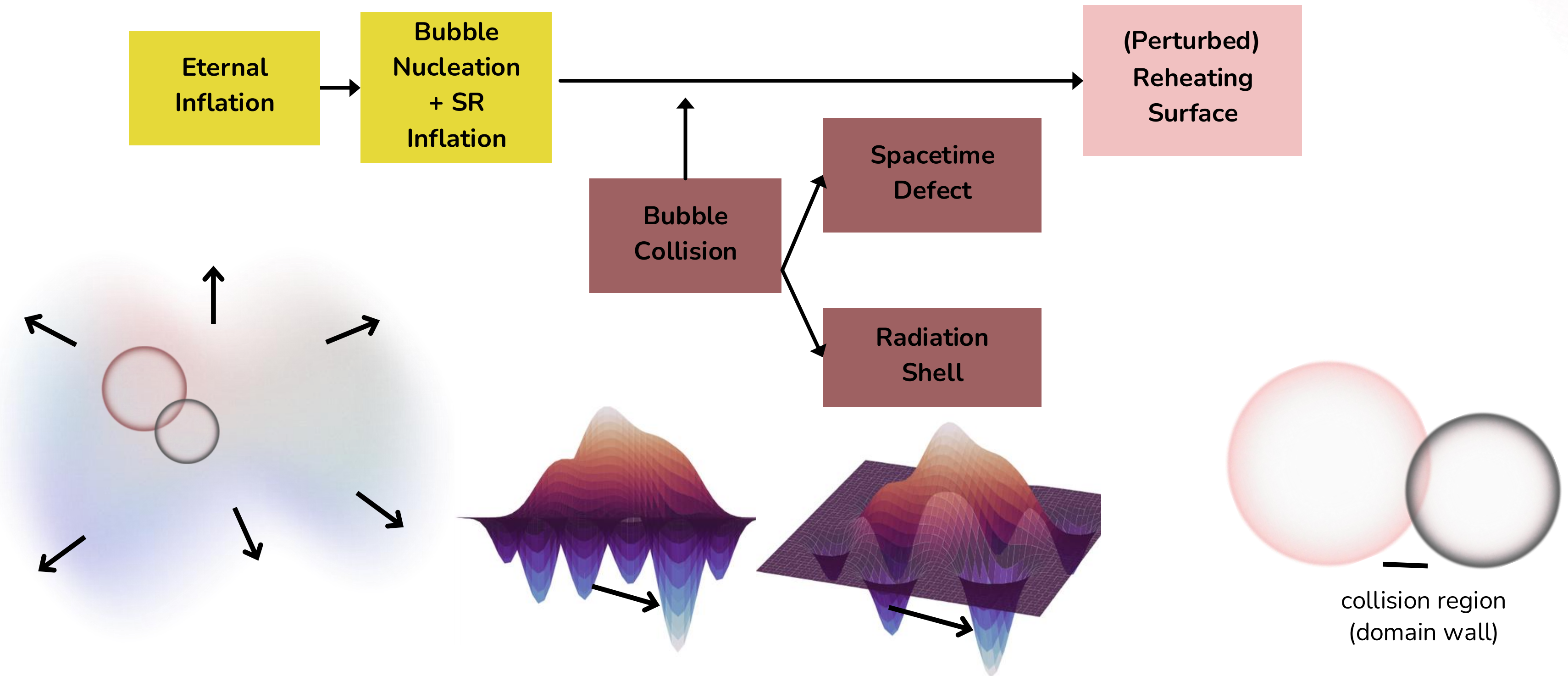
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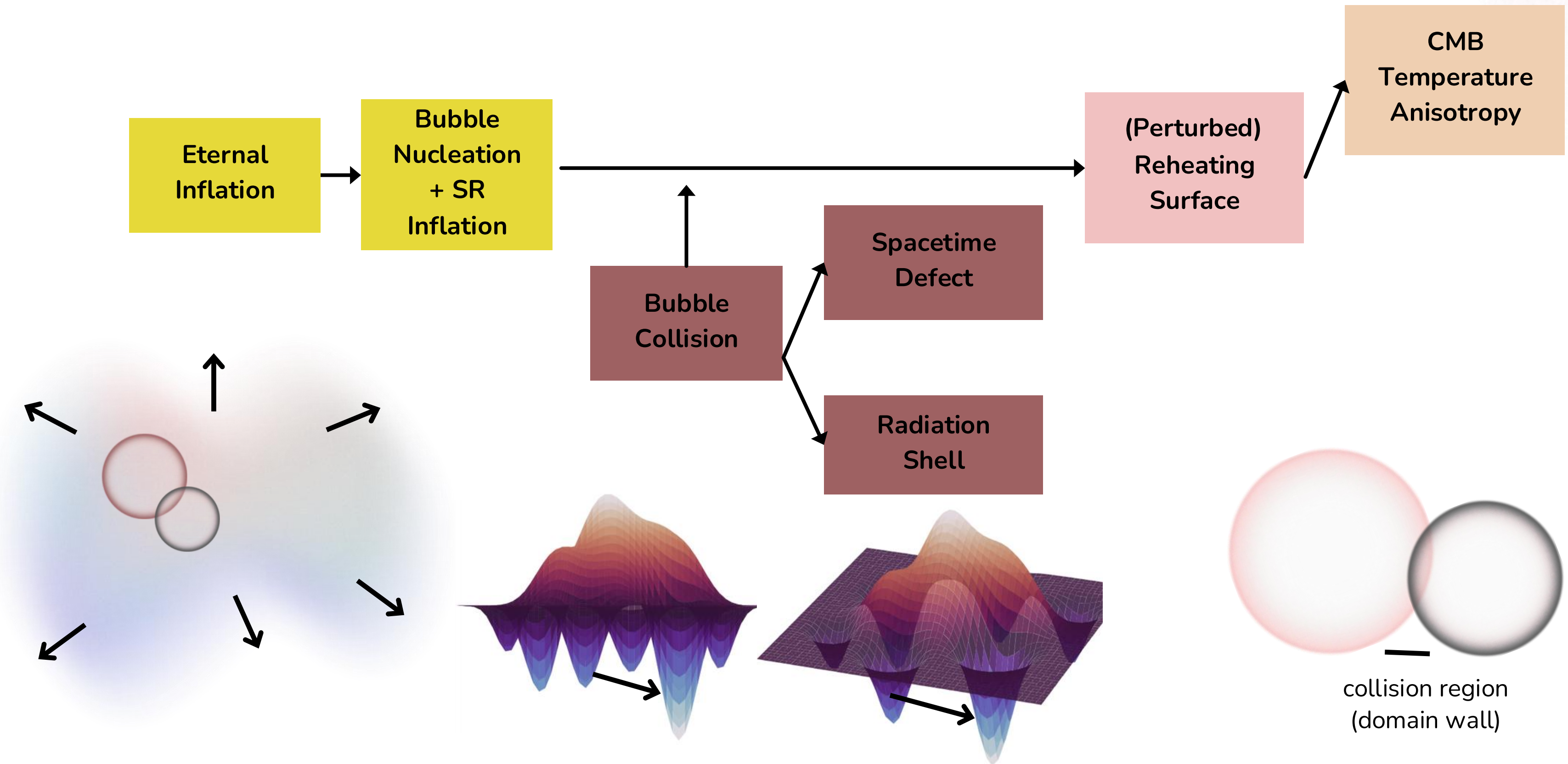
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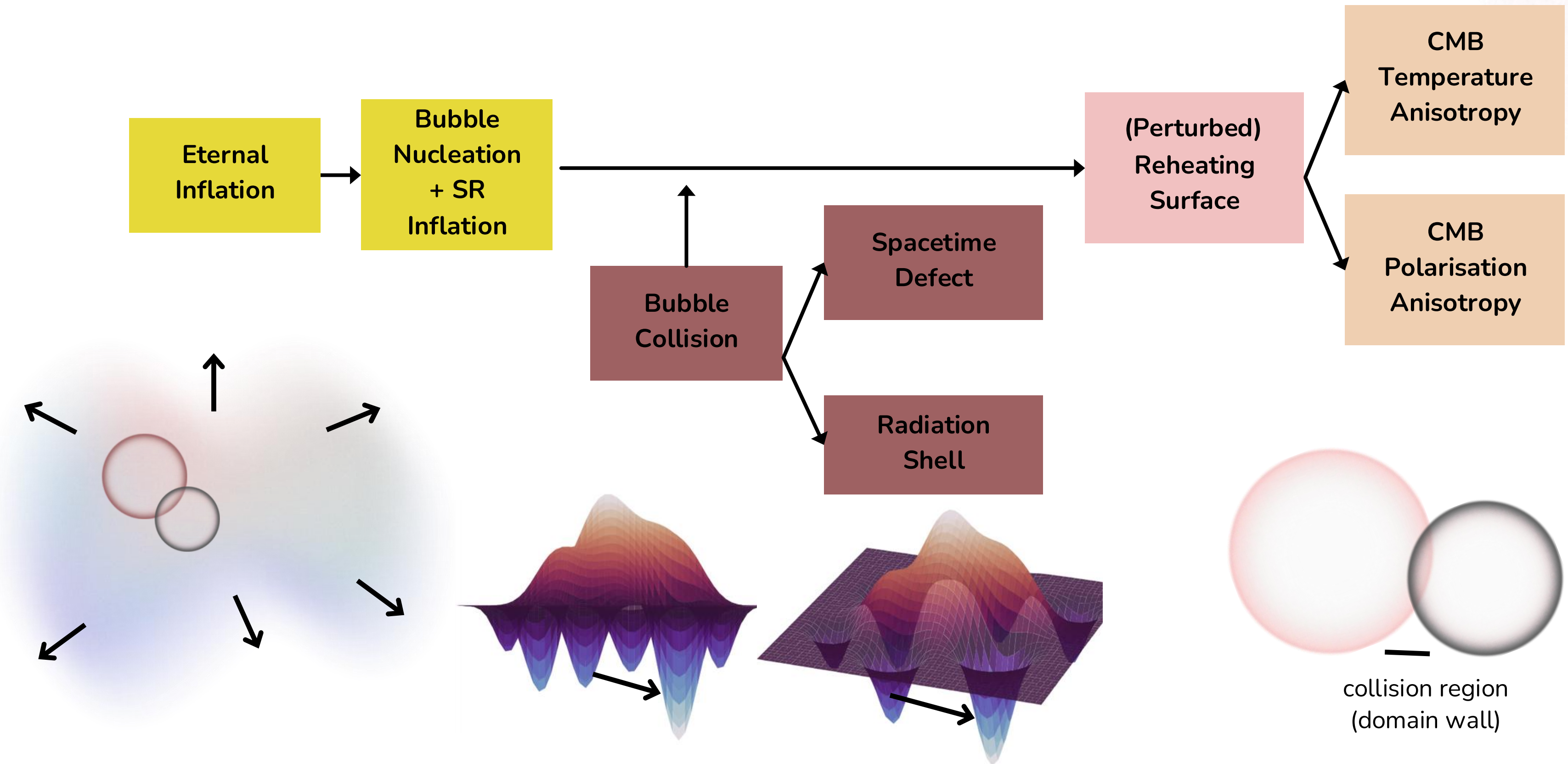
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'Crash' Course

Effects of collision

- **SW effect**- (ignores ISW, Doppler effect due to bulk vel., diffusion damping)
- **Reheating surface perturbation**: SMALL (linear effects only)
- **Pure scalar perturbation**: NO tensor component
- **Single bubble collision at a single point**: NO interference patterns

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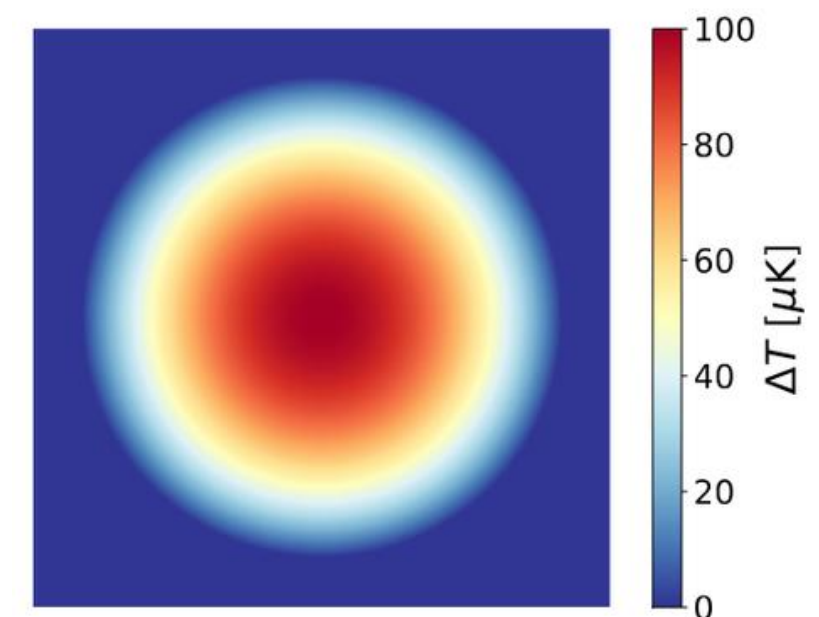
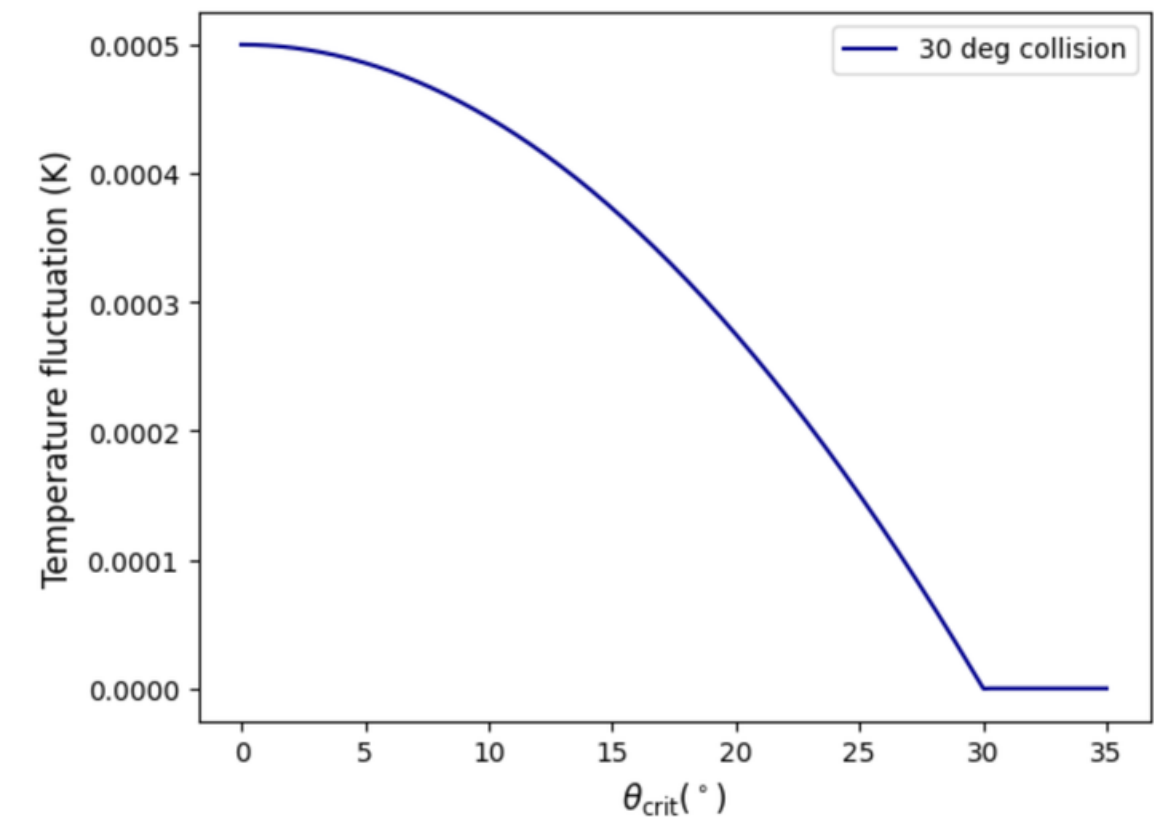
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On topic of observation

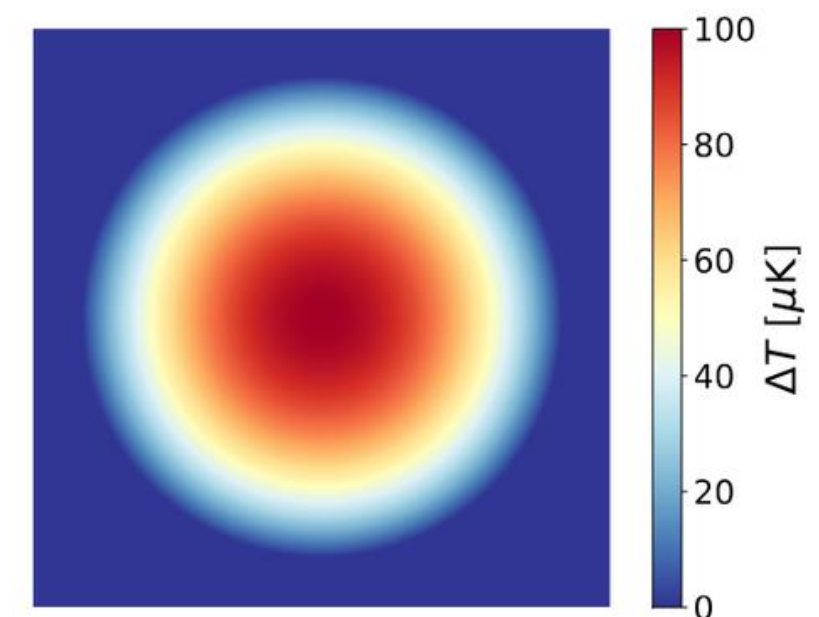
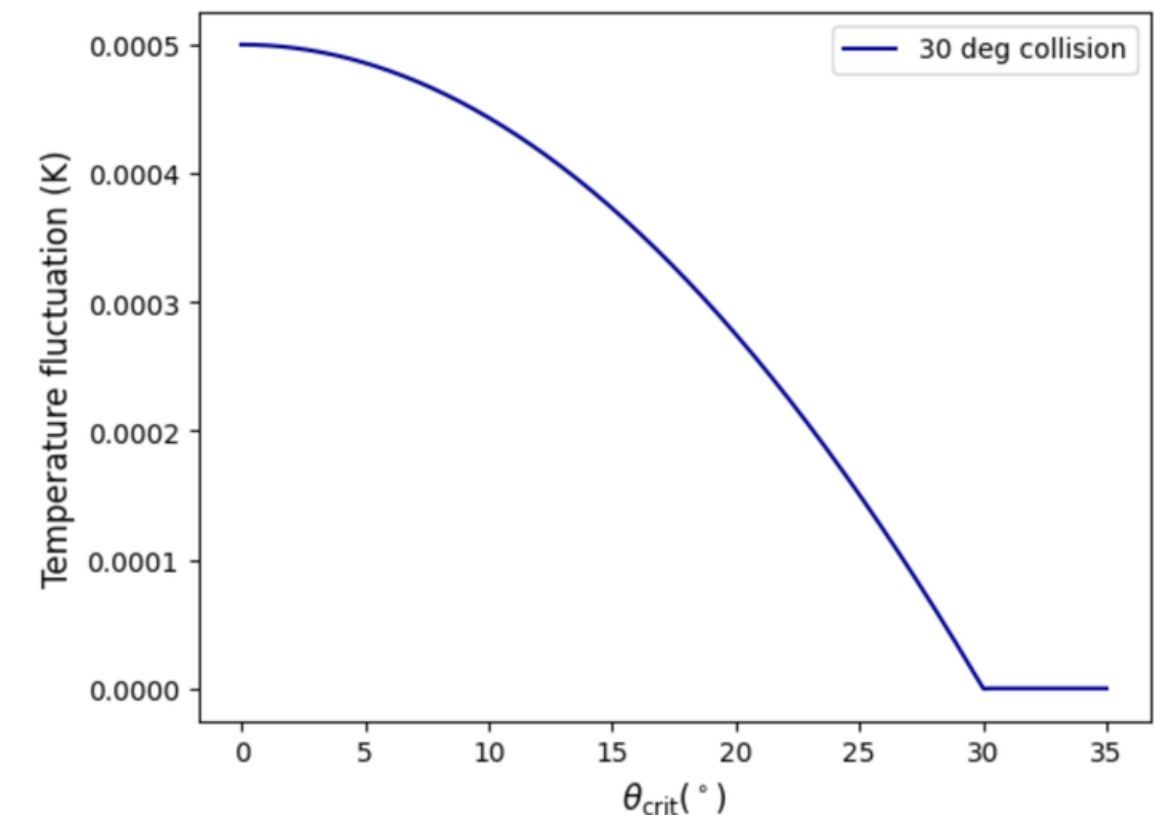
Compatibility: region must undergo reheating after collision

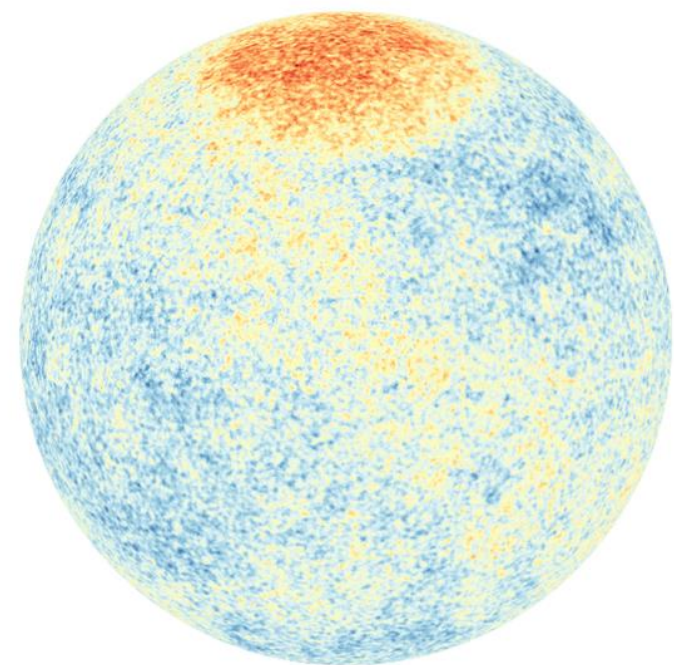
Probability: we should be able to see it

Observability: effects cannot be diluted away due to expansion

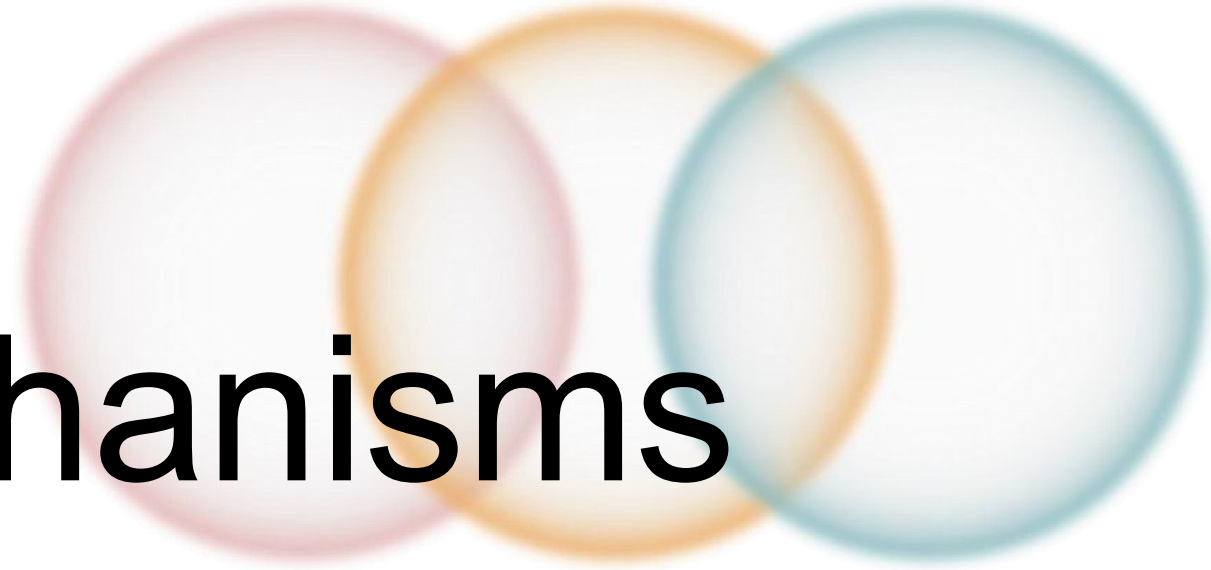
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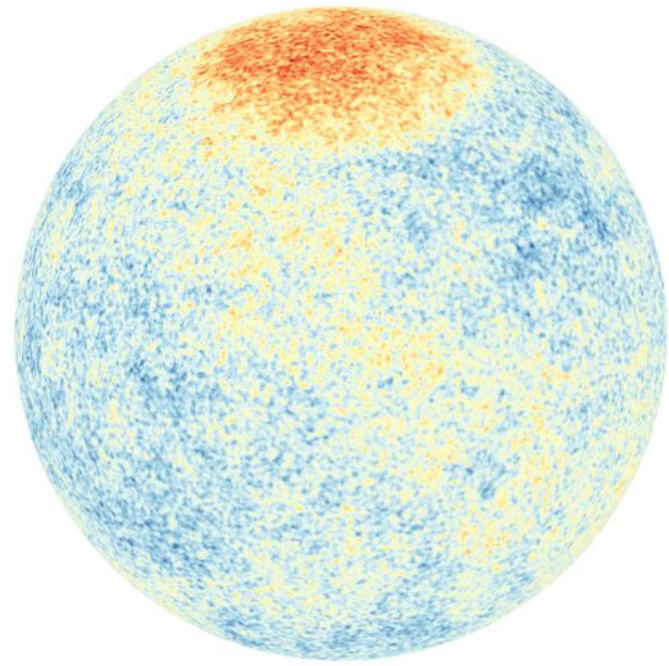
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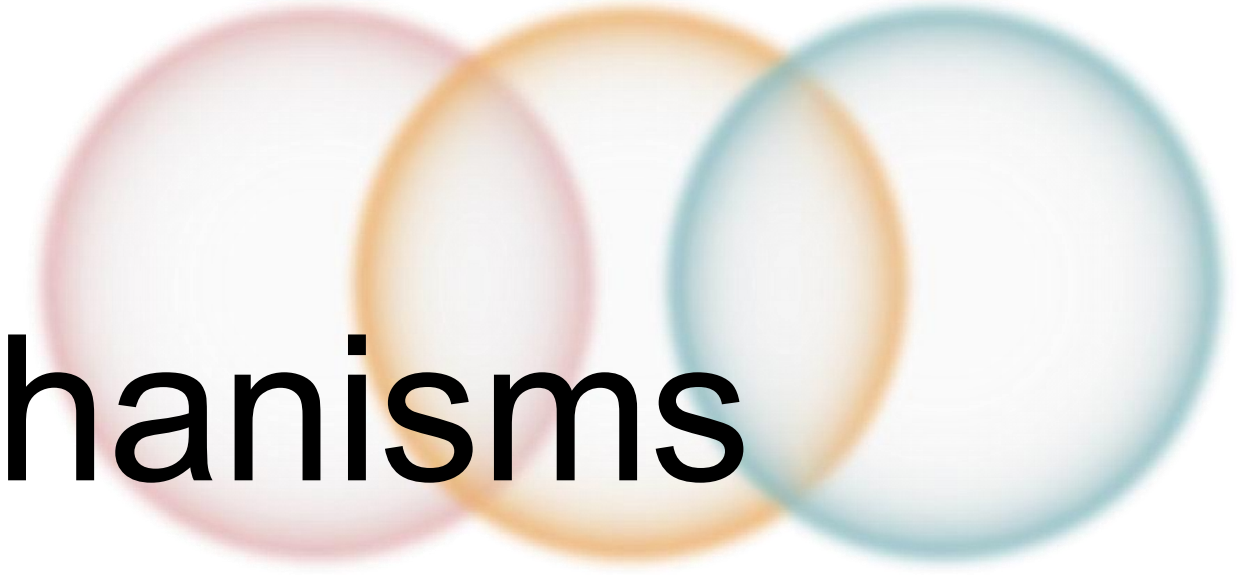


Detection Mechanisms





Detection Mechanisms

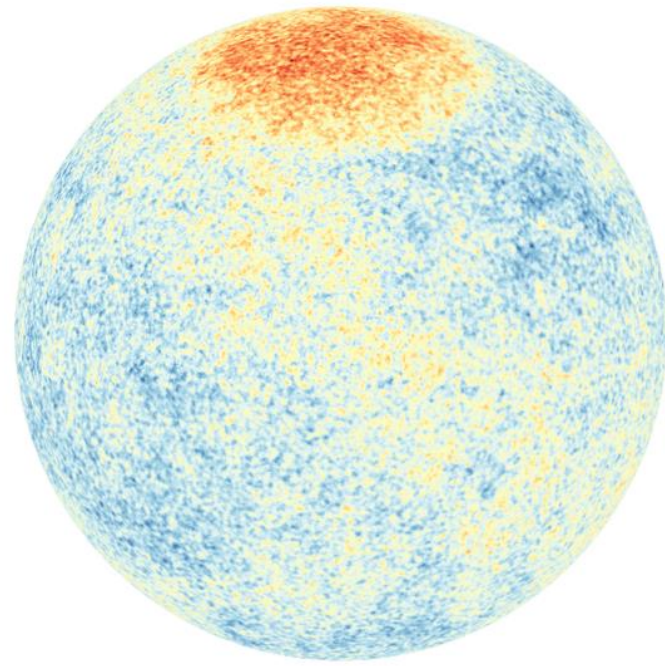


Highlighting hidden signals

Spherical transform

Filtering methods

- Needlet filtering
- Optimal filtering



Detection Mechanisms

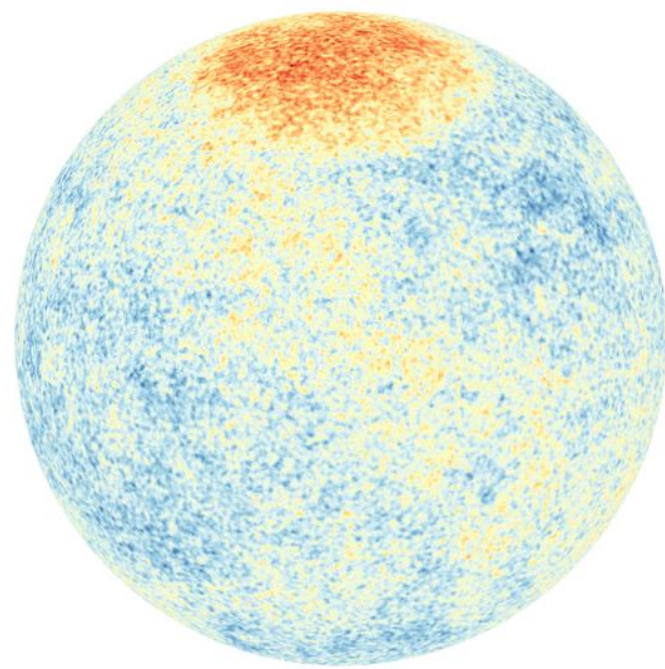
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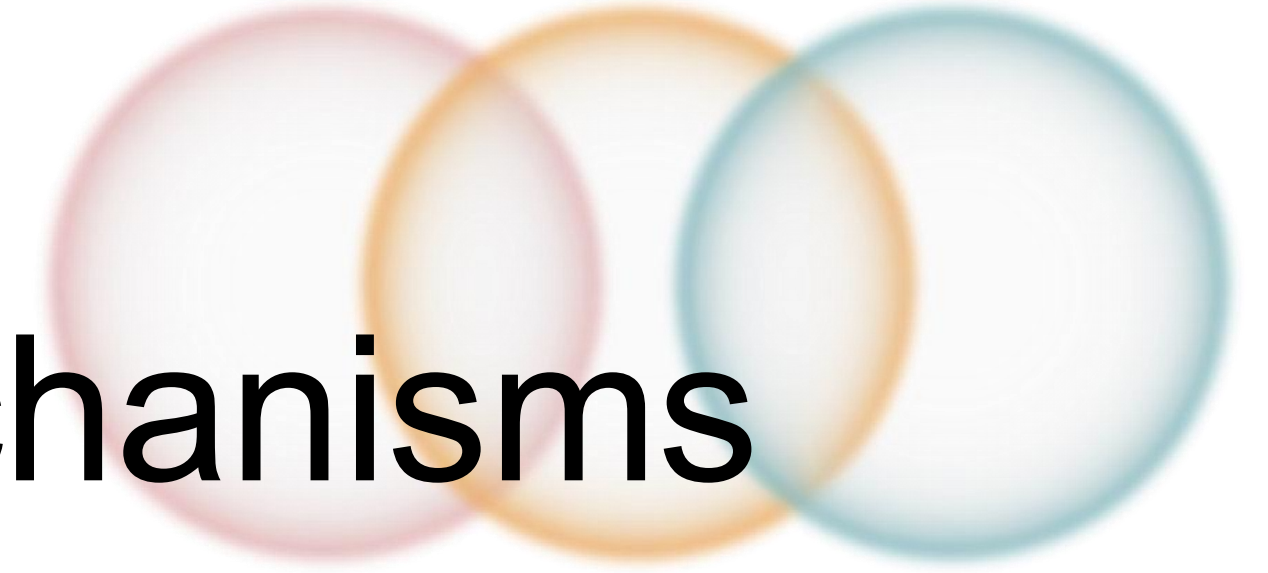
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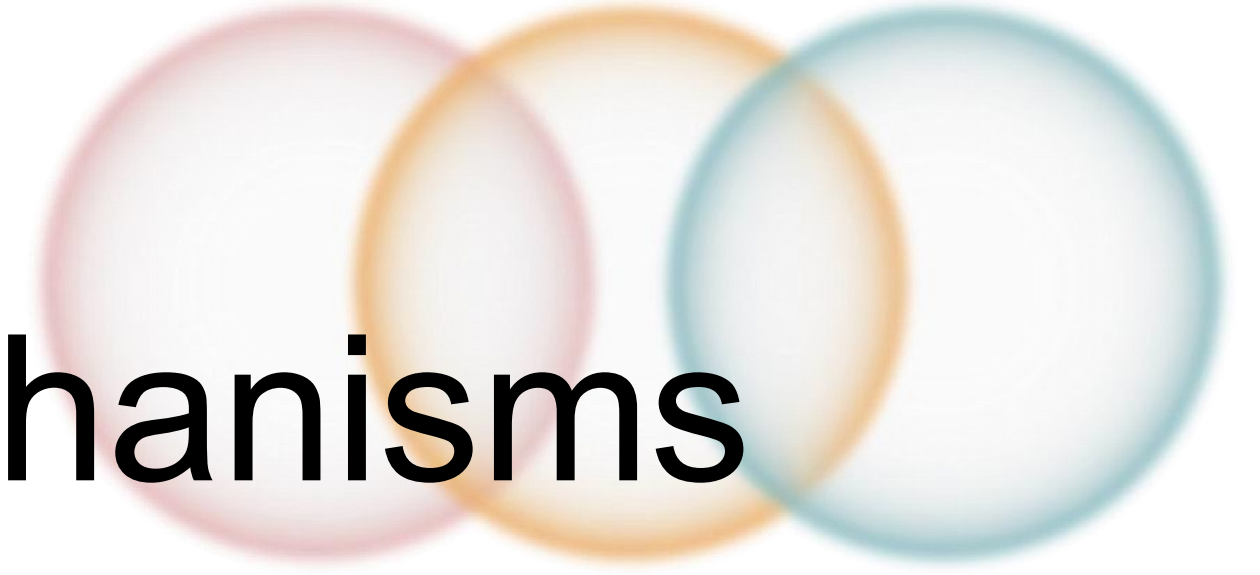
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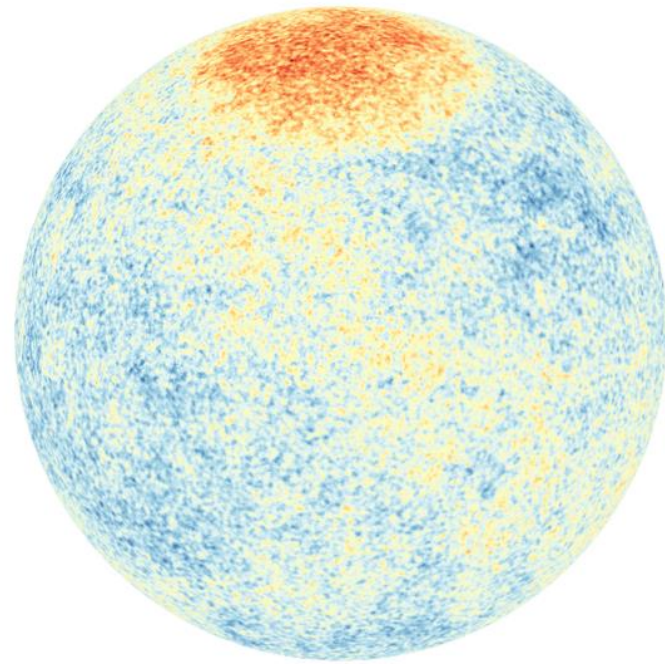
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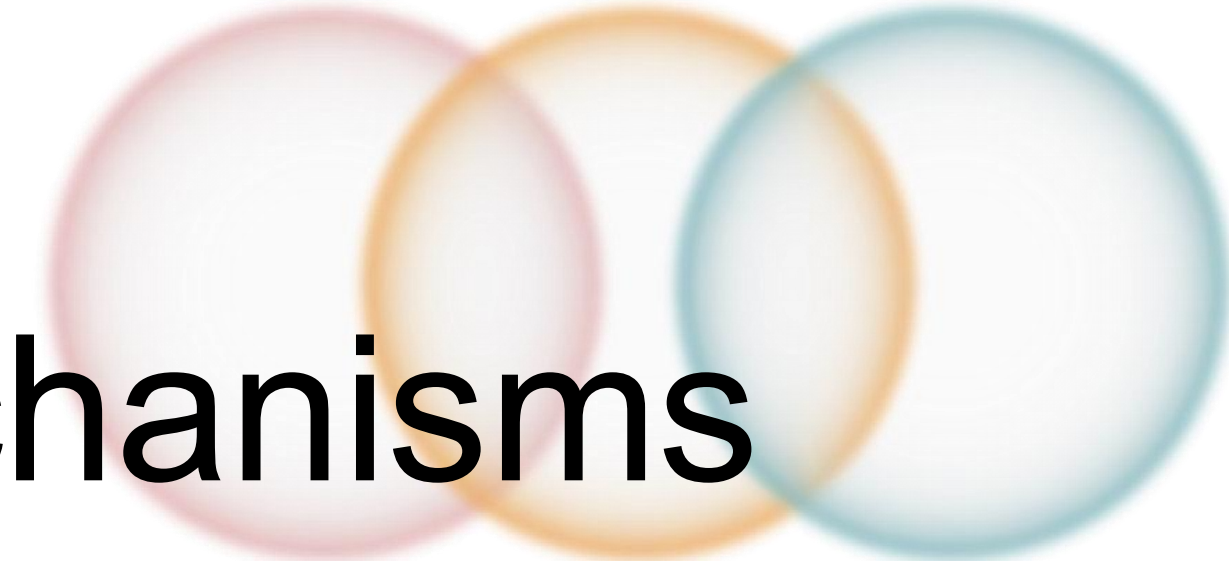
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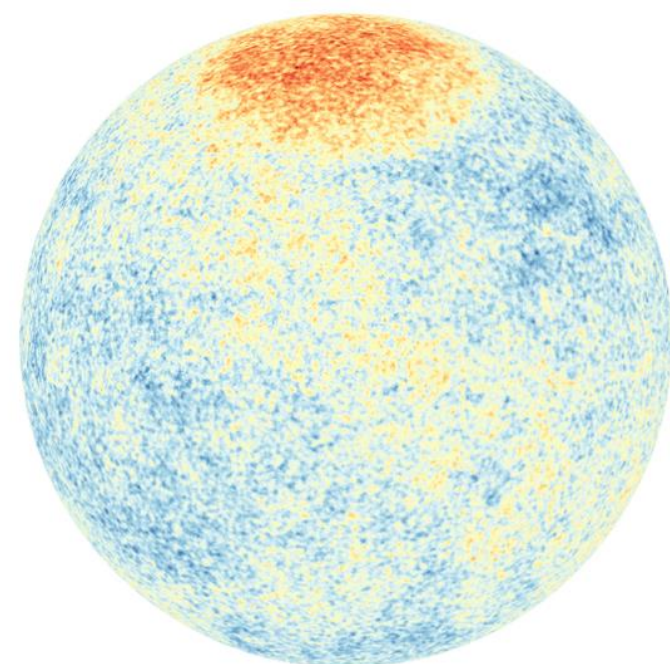
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$$(\Psi_R^{\text{MF}})_{\ell m} = \frac{\tau_{\ell m}}{\alpha C_{\ell}},$$

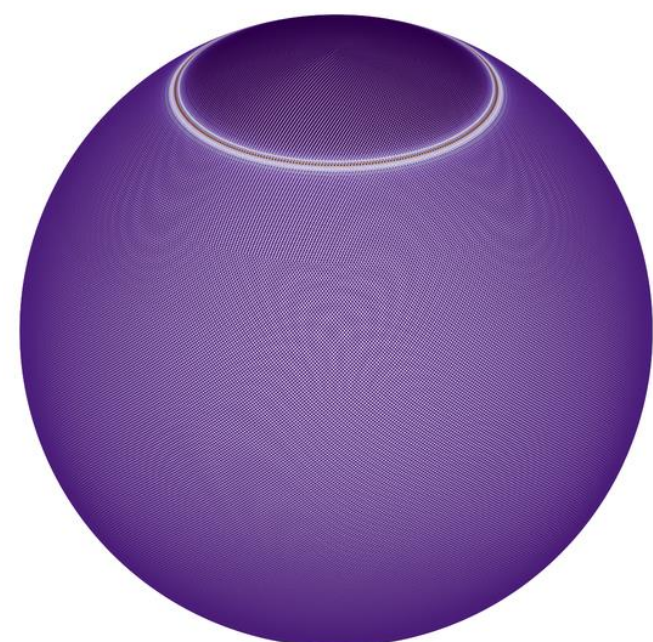


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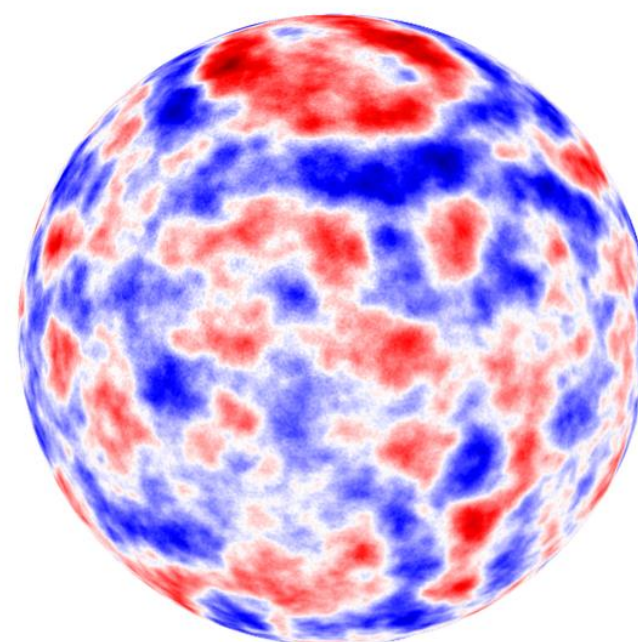
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$$(F_R)_{\ell m} = \sqrt{\frac{4\pi}{2\ell+1}} a_{\ell m} (\Psi_R)_{\ell 0}^*.$$

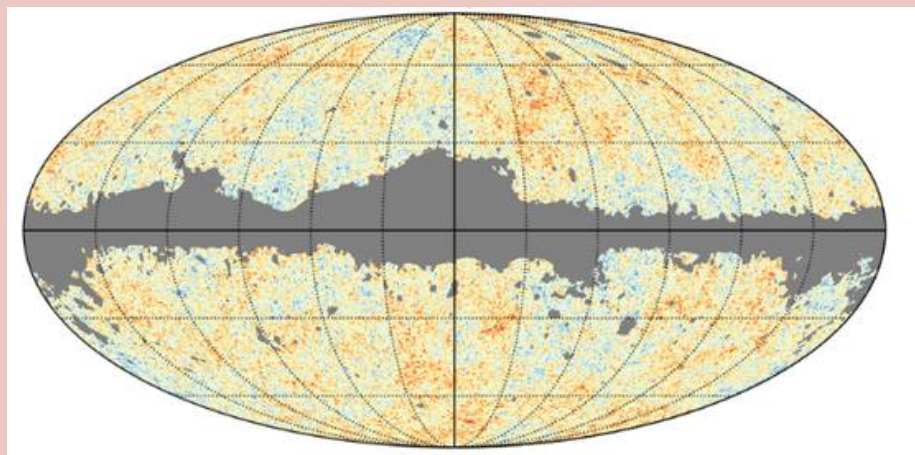
Modified Method

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Planck-like Simulation

Realistic CMB maps

Modelling instrumentation noise

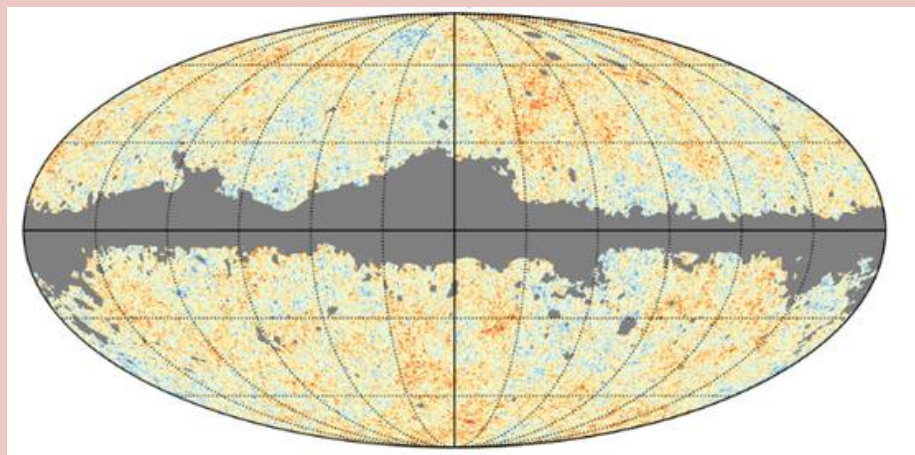


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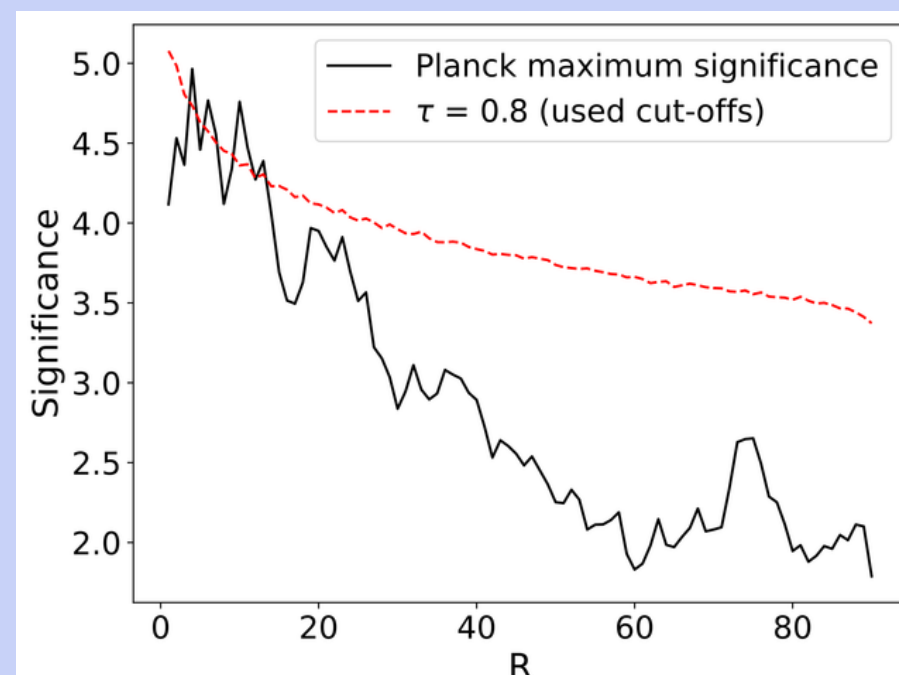
Threshold Generation

Filtered maps → Local significance

Thresholds (80%) and Disc Maps

Adjacency Analysis

Parameter Reconstruction

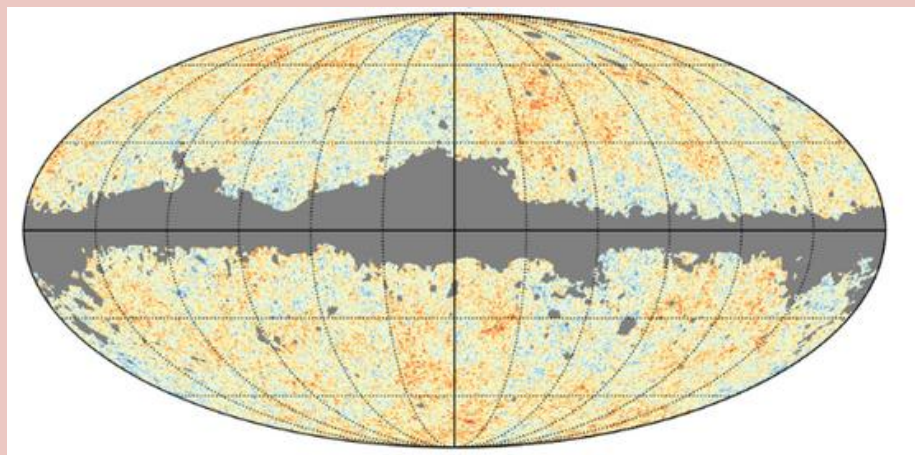


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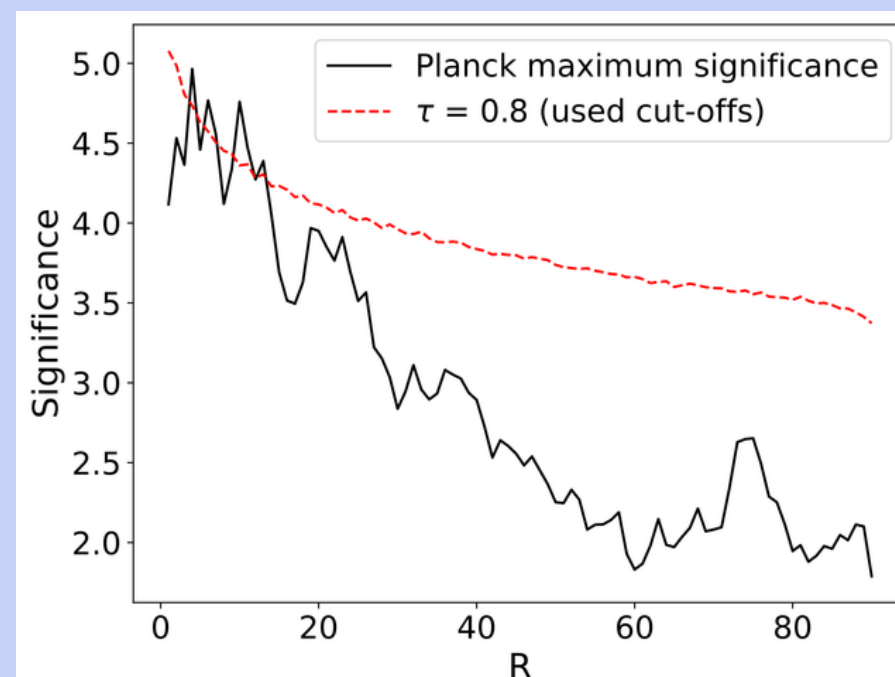
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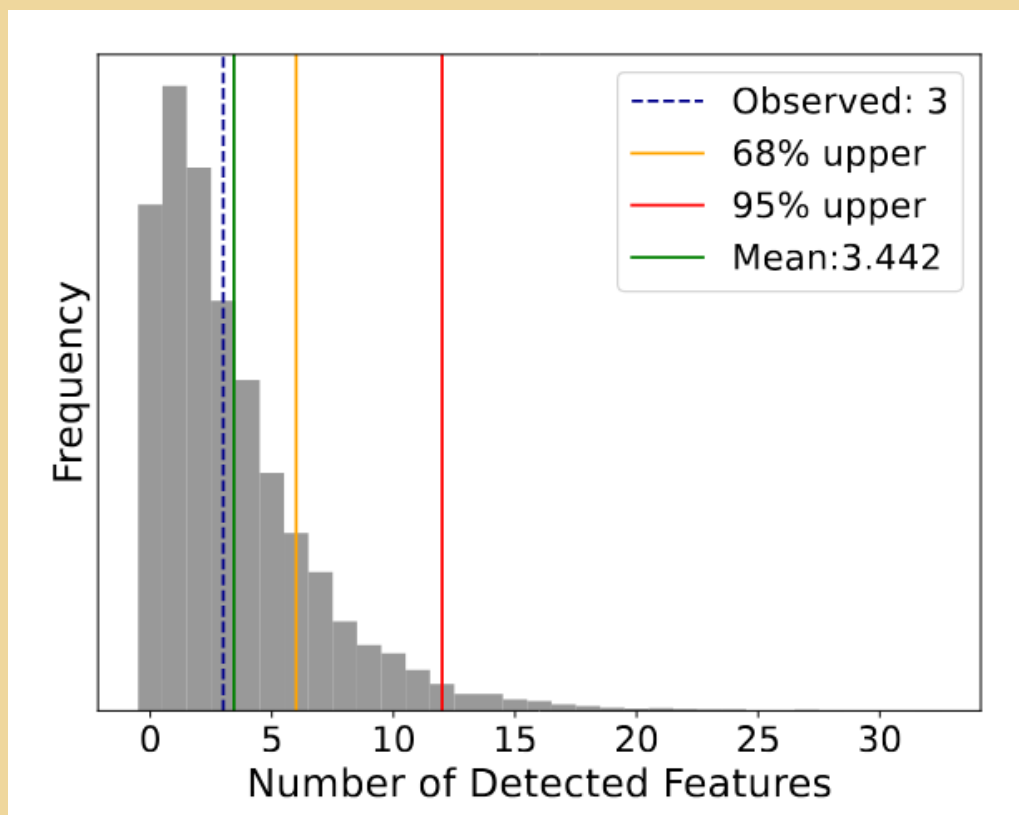
Application and Results

Filtering of *Planck* CMB

Frequentist Analysis

Validation with *WMAP* CMB

Future directions



Results

Results

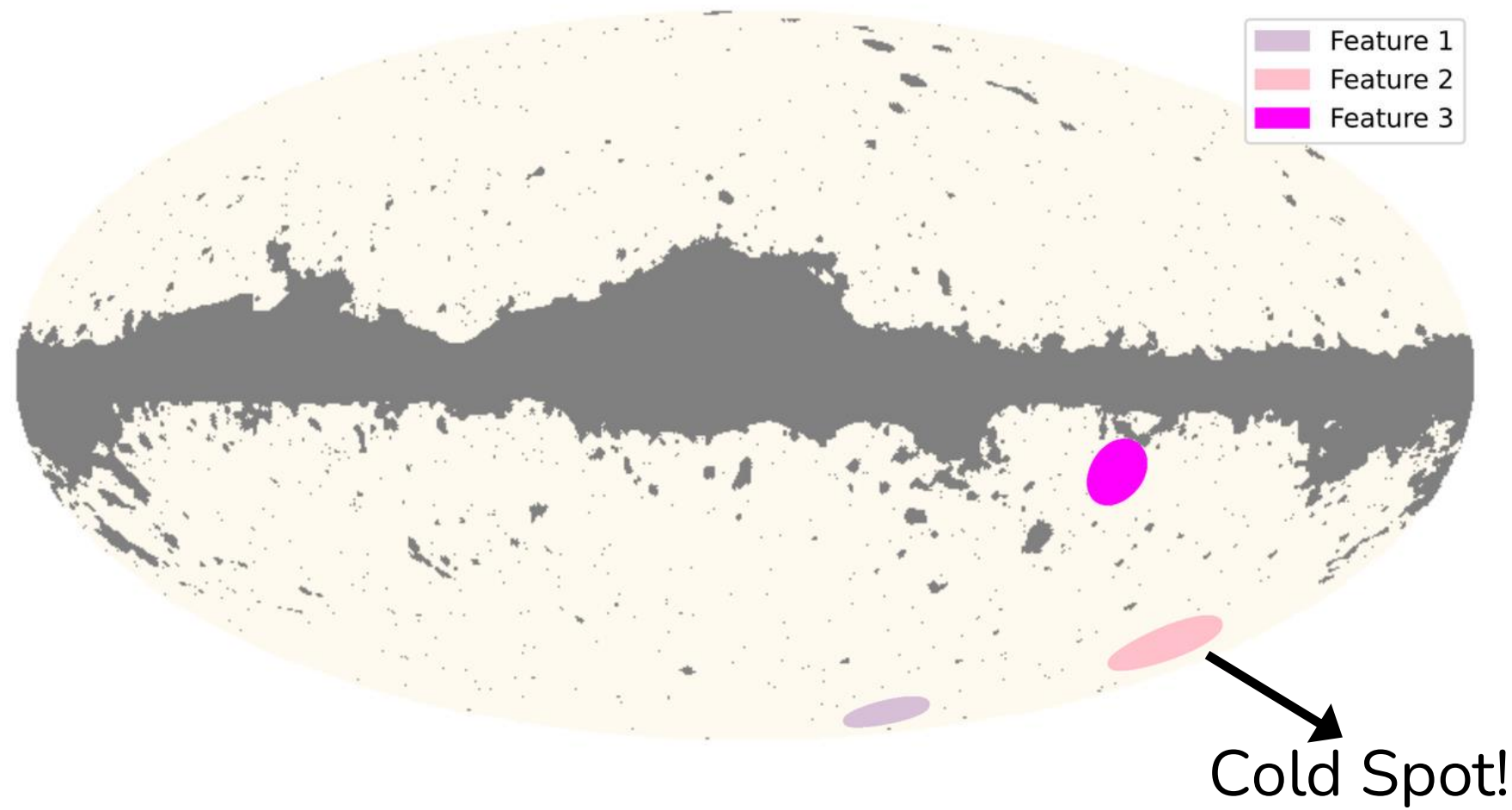
3 features reported

Frequentist Analysis: 3.6 expected

Maximum significances <
Frequentist expected values

CMB Cold Spot detected!

Results

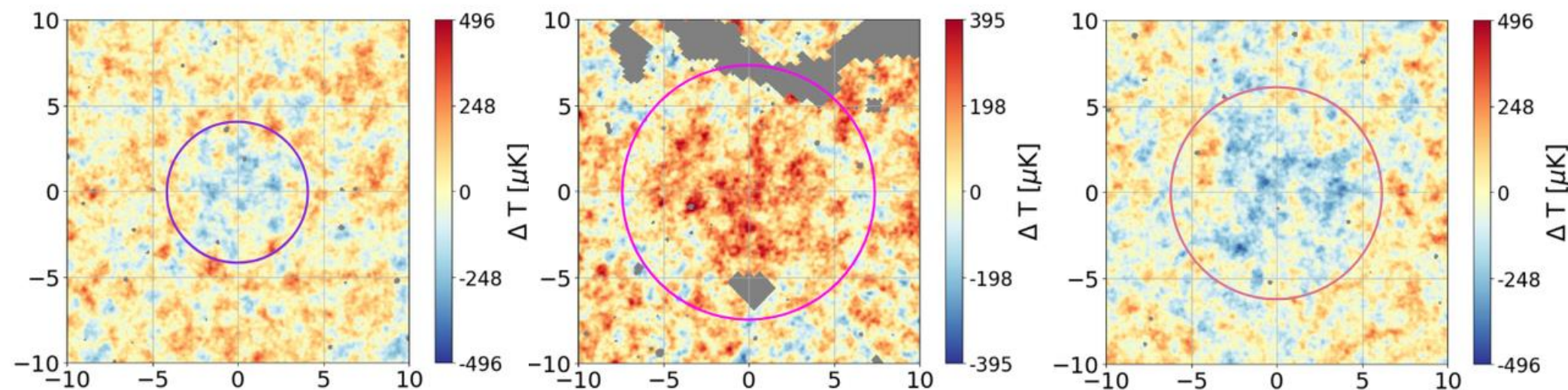


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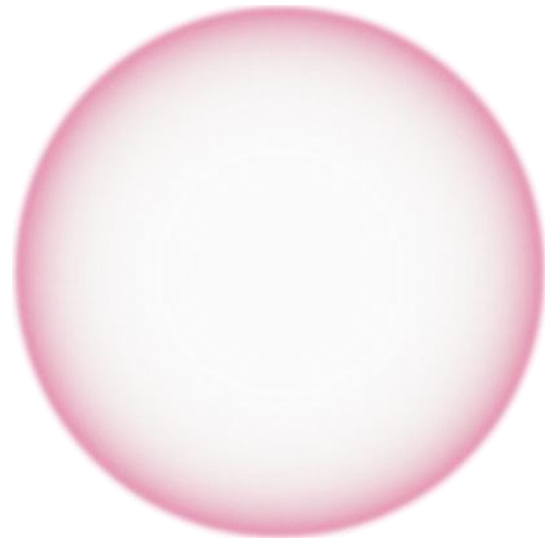
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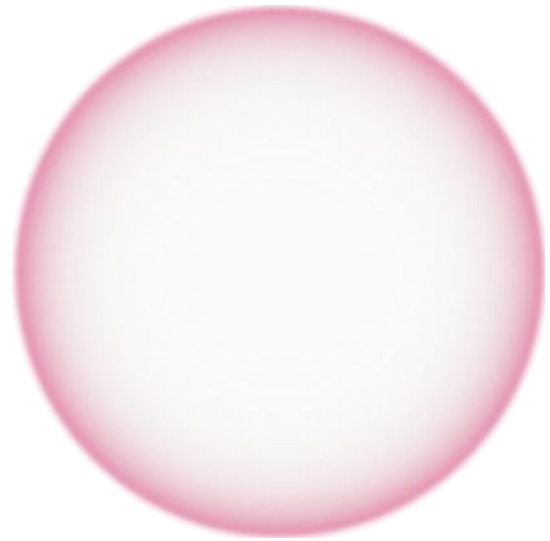
Current Conclusions

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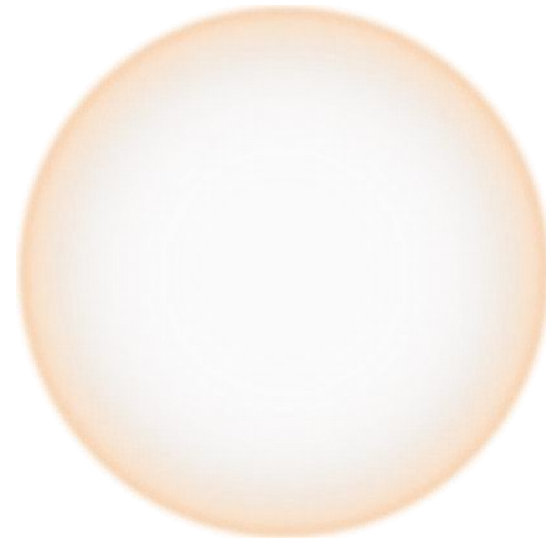


Null hypothesis
favoured

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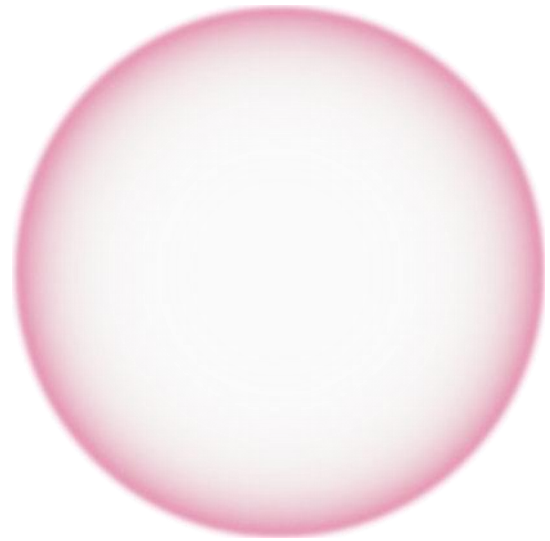


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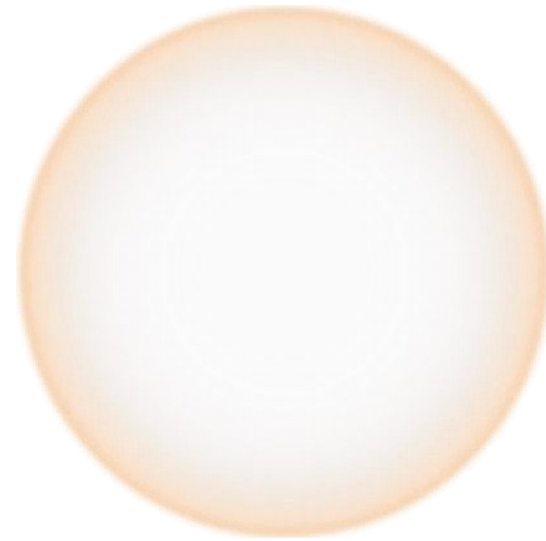


CMB Cold Spot

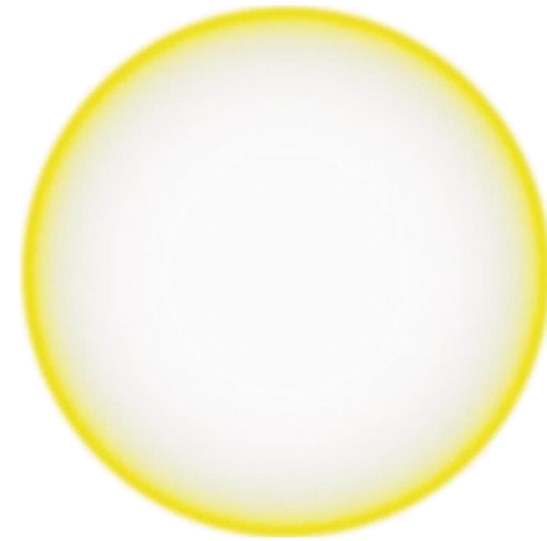
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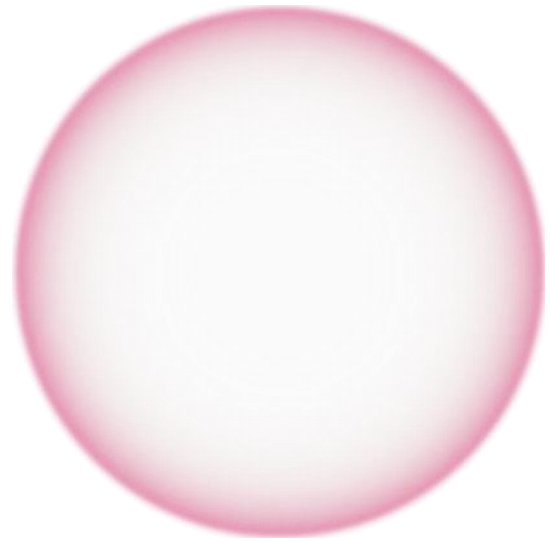


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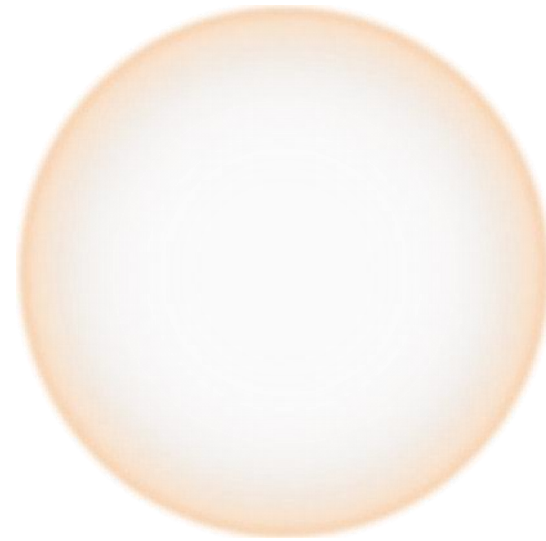


Southern hemisphere
power asymmetry

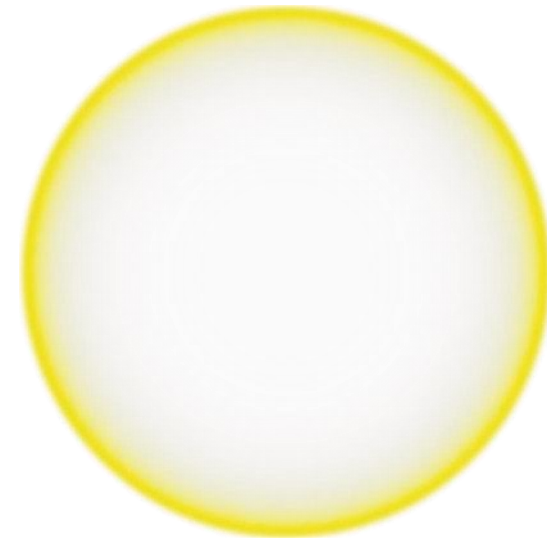
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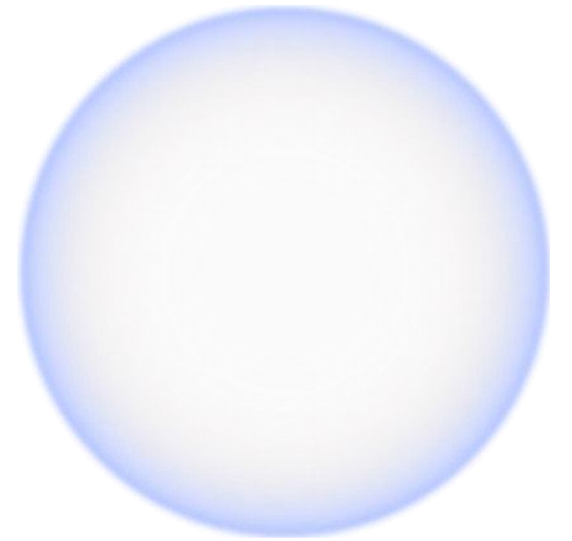
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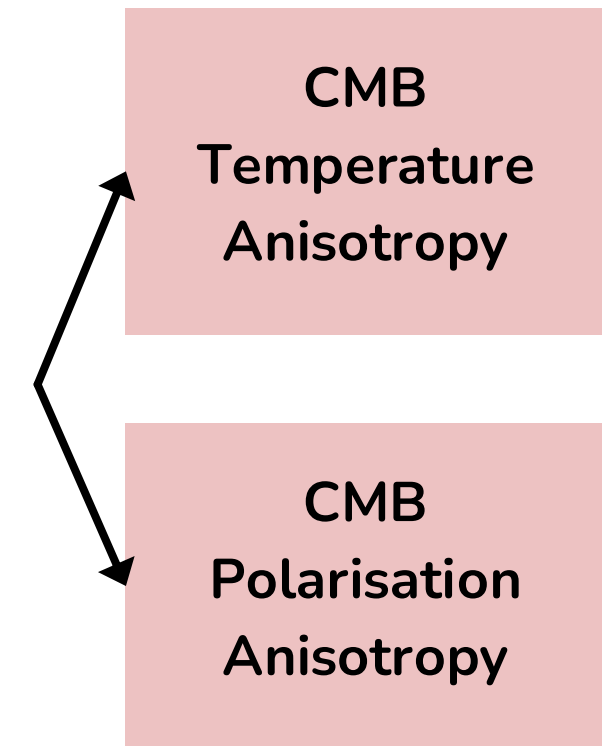
Southern hemisphere
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Other data
signatures

Future directions

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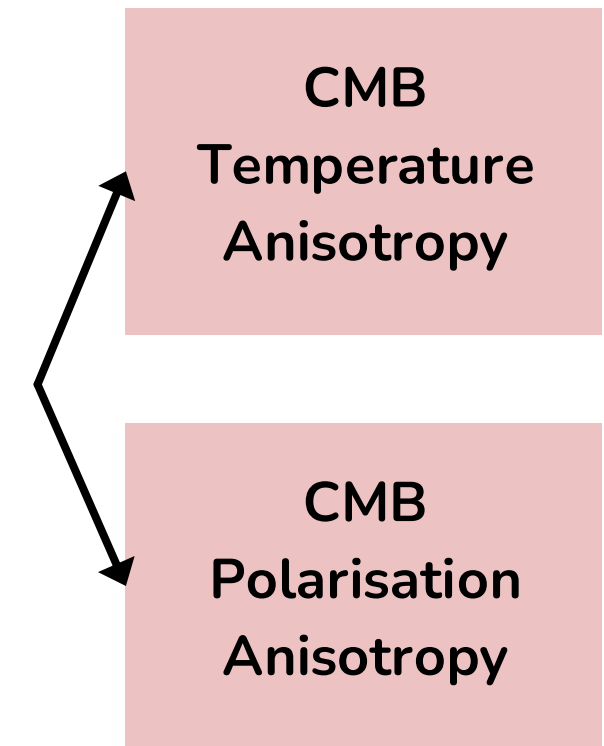


Future directions

E-mode, scalar perturbation

Forecasting constraints on detectability

Optimal filtering on *Planck* E-mode data

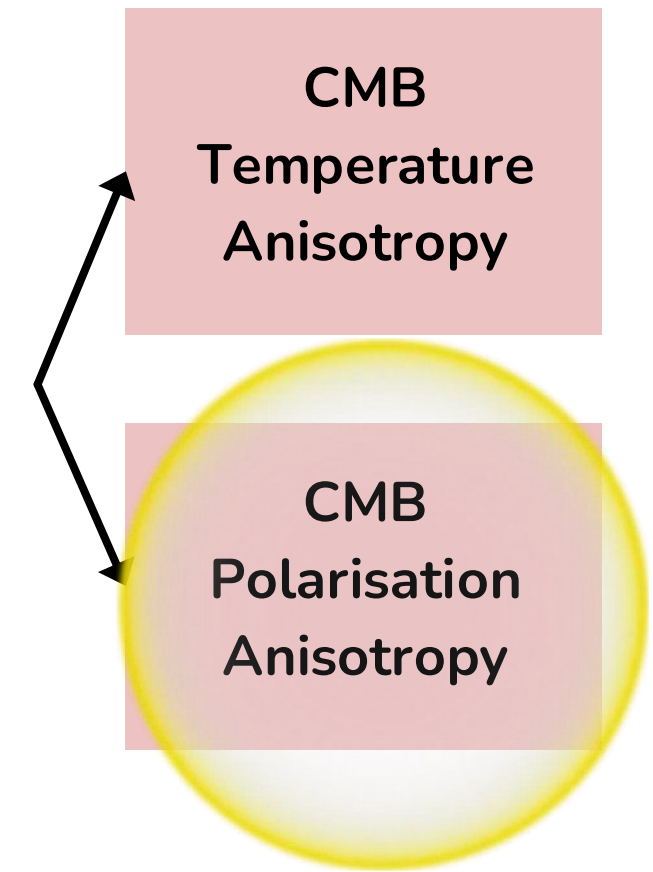


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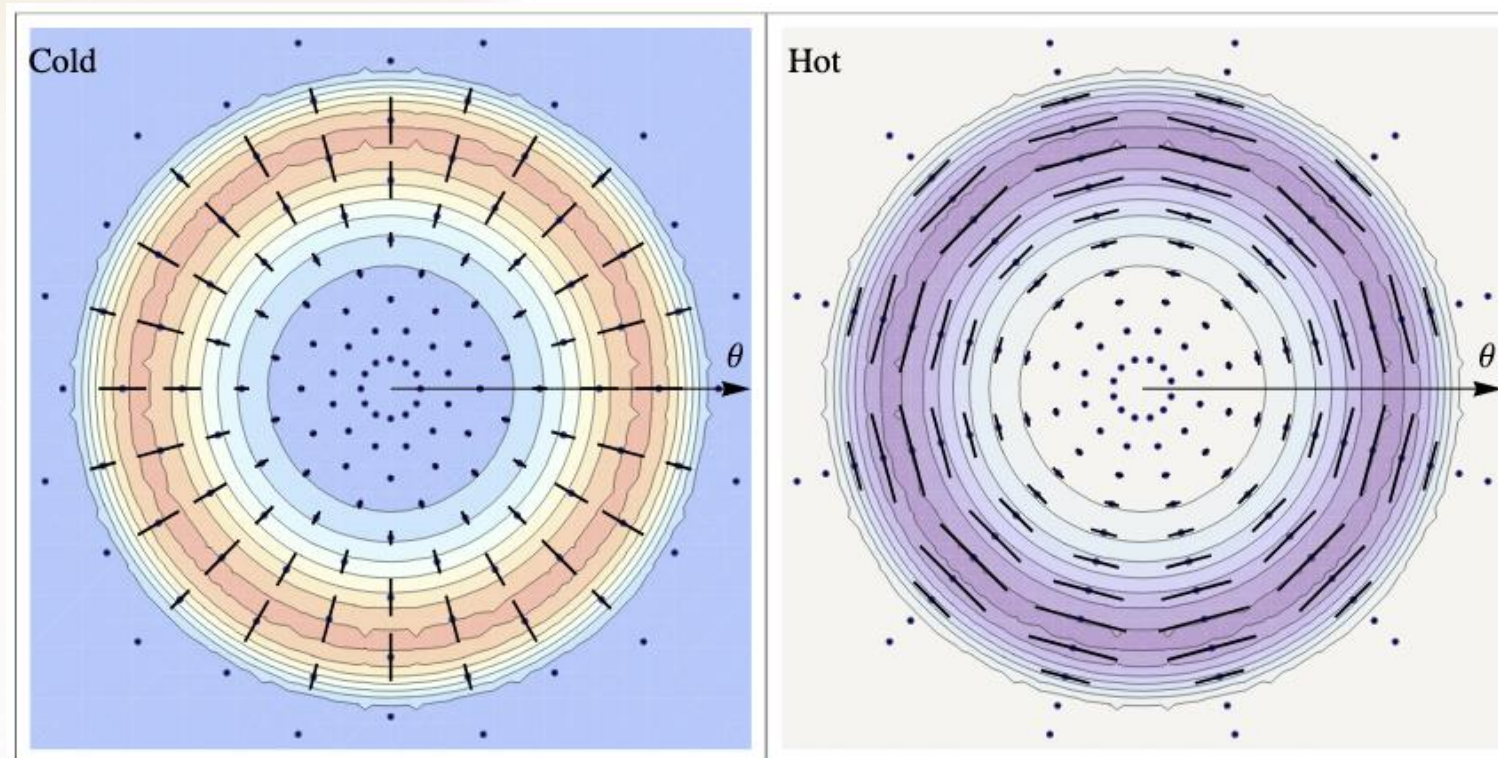


Future directions

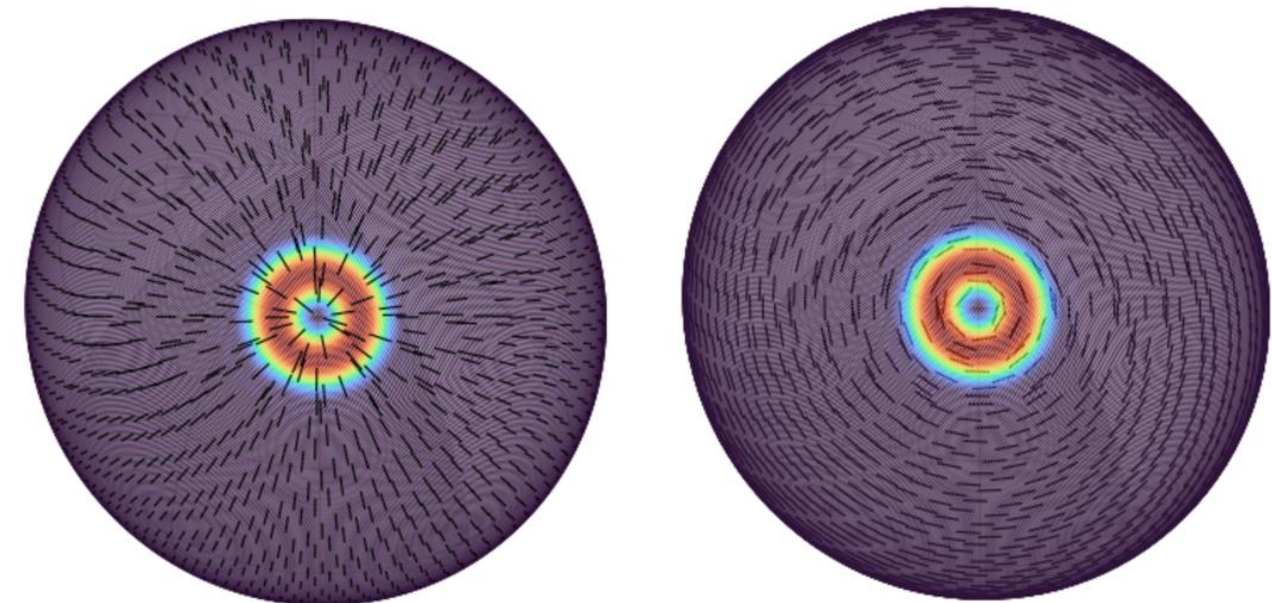
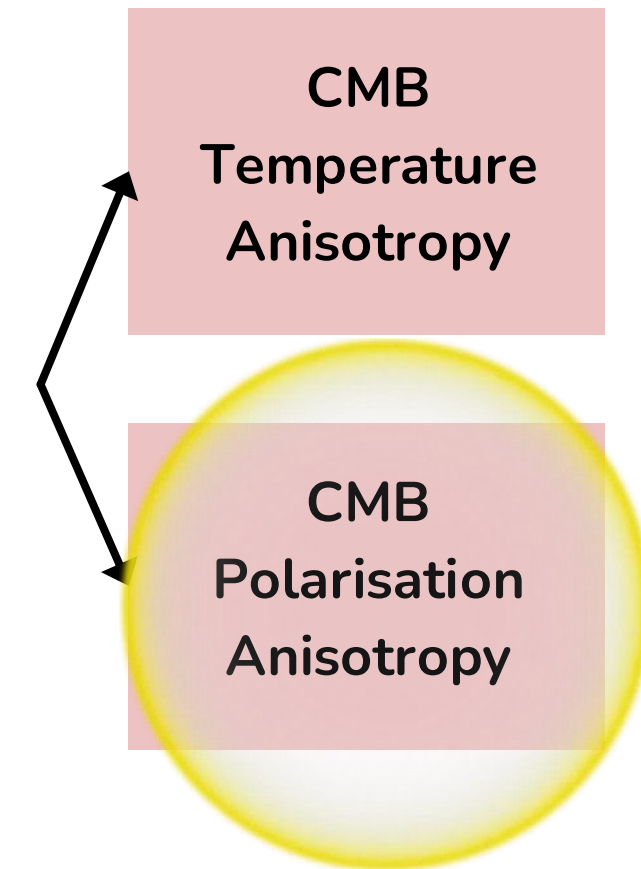
E-mode, scalar perturbation

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(Czech et. al, 2010), see [6]



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[6] Bartłomiej Czech et al. “**Polarizing bubble collisions**”. In: Journal of Cosmology and Astroparticle Physics 2010.12 (Dec. 2010), pp. 023–023. issn: 1475-7516. doi: 10.1088/1475-7516/2010/12/023. url: <http://dx.doi.org/10.1088/1475-7516/2010/12/023>

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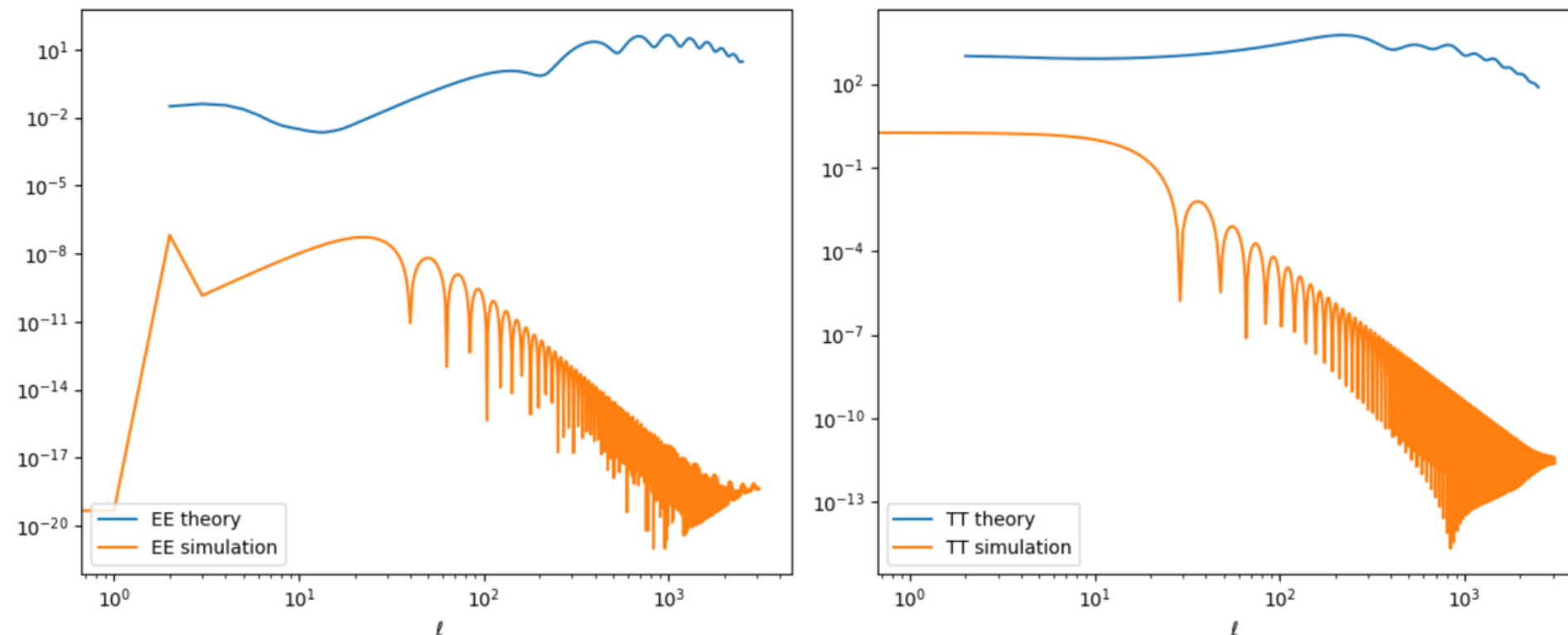
[8] A. Dahlen. “**Odds of observing the multiverse**”. 2009 arXiv: 0812.0414 .

Extra slides

Power spectrum and lensing

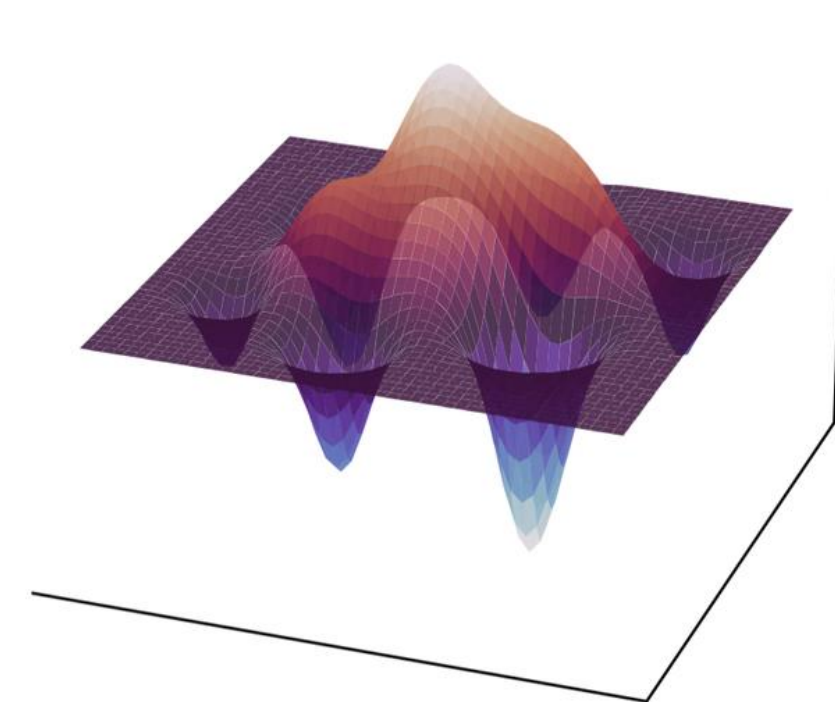
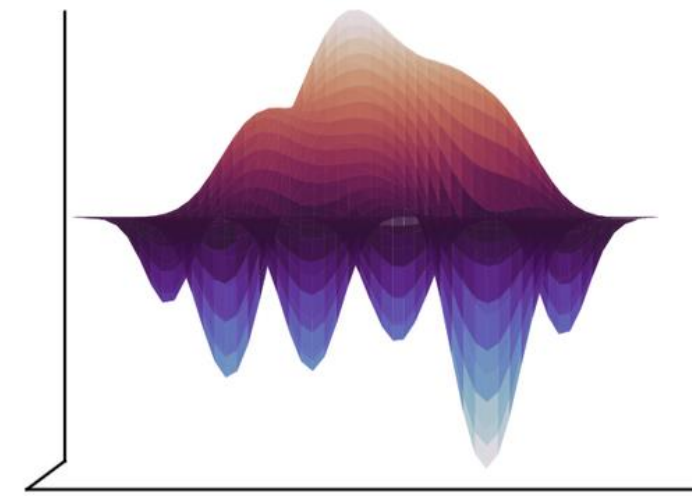
5 Lensing of CMB polarization

The presence of a non-zero photon quadrupole at last scattering means that there will be an interesting polarization signal. As for the temperature, the observed polarization field will have been lensed by potential gradients along the line of sight, and we need to model this effect.



String theory landscape

Borrowing from string theory (which I do not know much about), there is no unique vacuum, and there could be around 10^{500} long lived metastable states, any of which could be a bubble universe. This constitutes the potential landscape. Eternal inflation can produce an infinite number of bubbles of every type populating the landscape. So string theory would govern everywhere, but each bubble would have it's own low energy physics, standard model and vacuum energy density. [1]

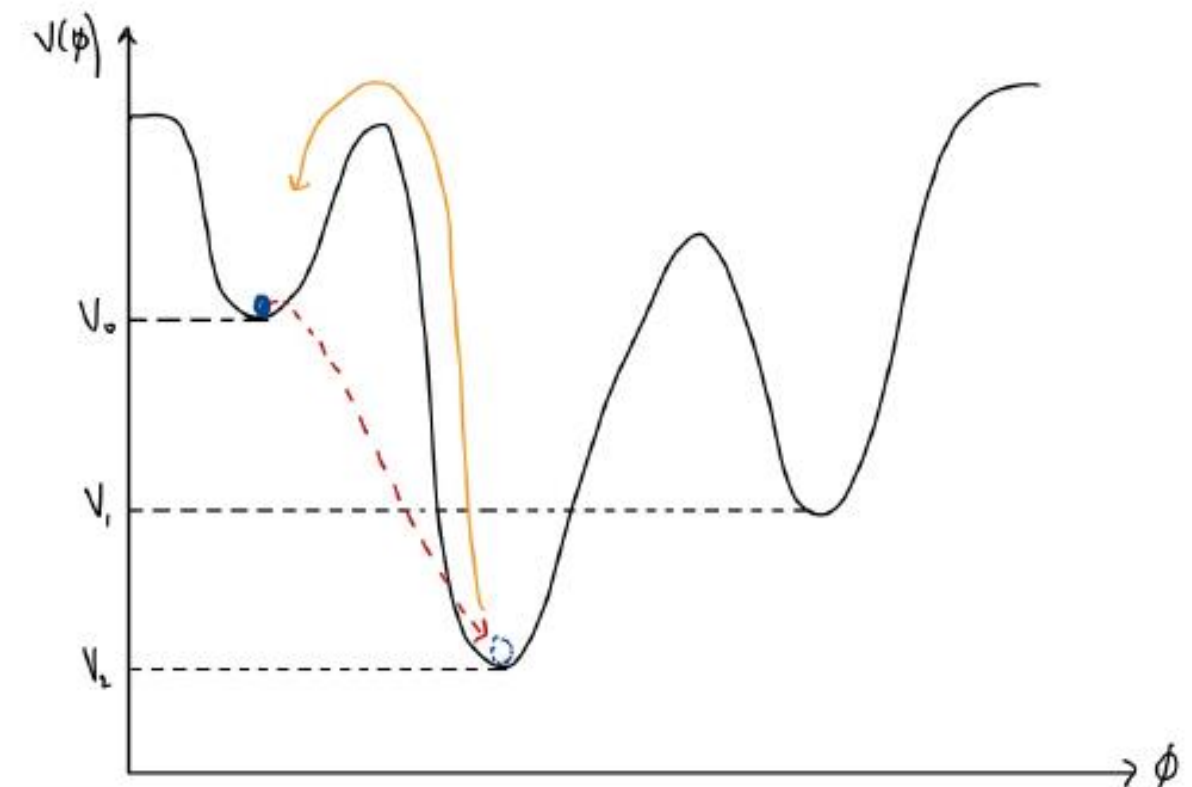
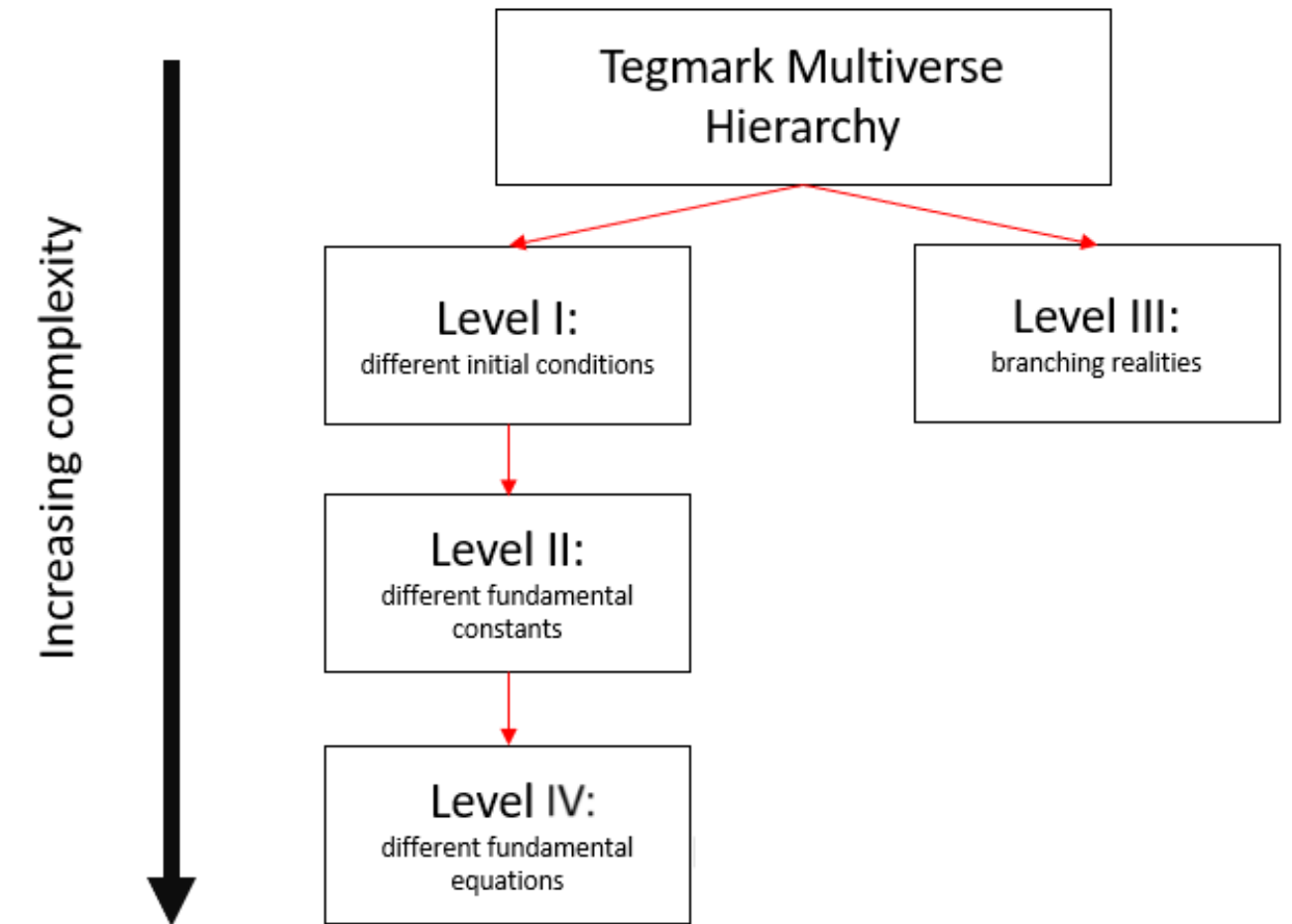


Anthropic Principle

If we have 10^{500} vacua, and a fraction of 10^{-120} have small vacuum energy densities, then we expect $\sim 10^{380}$ vacua with low energy densities like our own. [1]

Weinberg (1987) explained that vacuum energy density can be explained like a selection effect, the vacuum energy density could be large in most bubble universes, but since this energy causes rapid expansion, if large and negative, universe collapses, if large and positive we cannot have structure formation. So a “critical” value is needed for life to exist (very close to 0).

Anthropic explanation should be the last resort explanation, as they become relevant when deterministic arguments have failed. [1]



Eternal Inflation

Inflation + Big Bang Theory

- Explains large scale uniformity
- Predicts mass density of universe to $<1\%$ accuracy
- Explains CMB anisotropies (quantum fluctuations)
- What “bang”. Why “bang”?!

Multiverse Theory

- All inflationary models are eternal (i.e. it does not stop) → bubble universes
- Universe accelerated expansion, vacuum energy non-zero, Why?
- String theory motivation: no unique vacuum
- Anthropic argument, “selection effect:
- Deterministic methods?

'Crash' Course

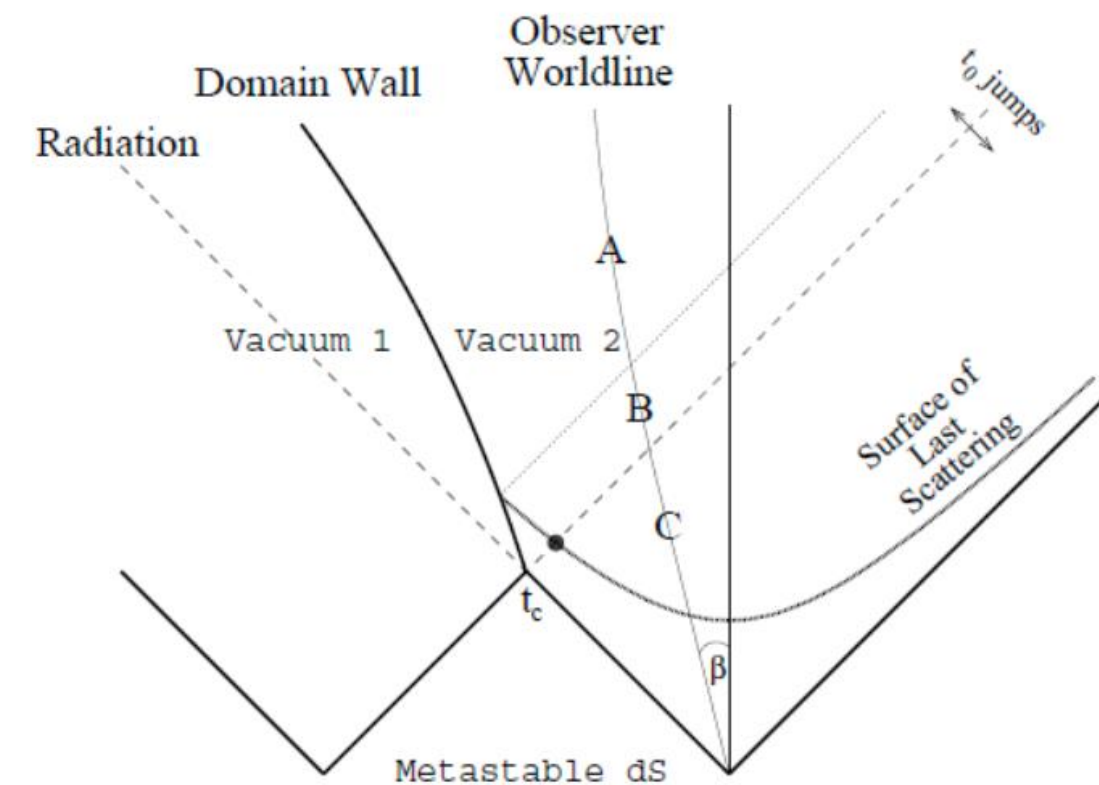
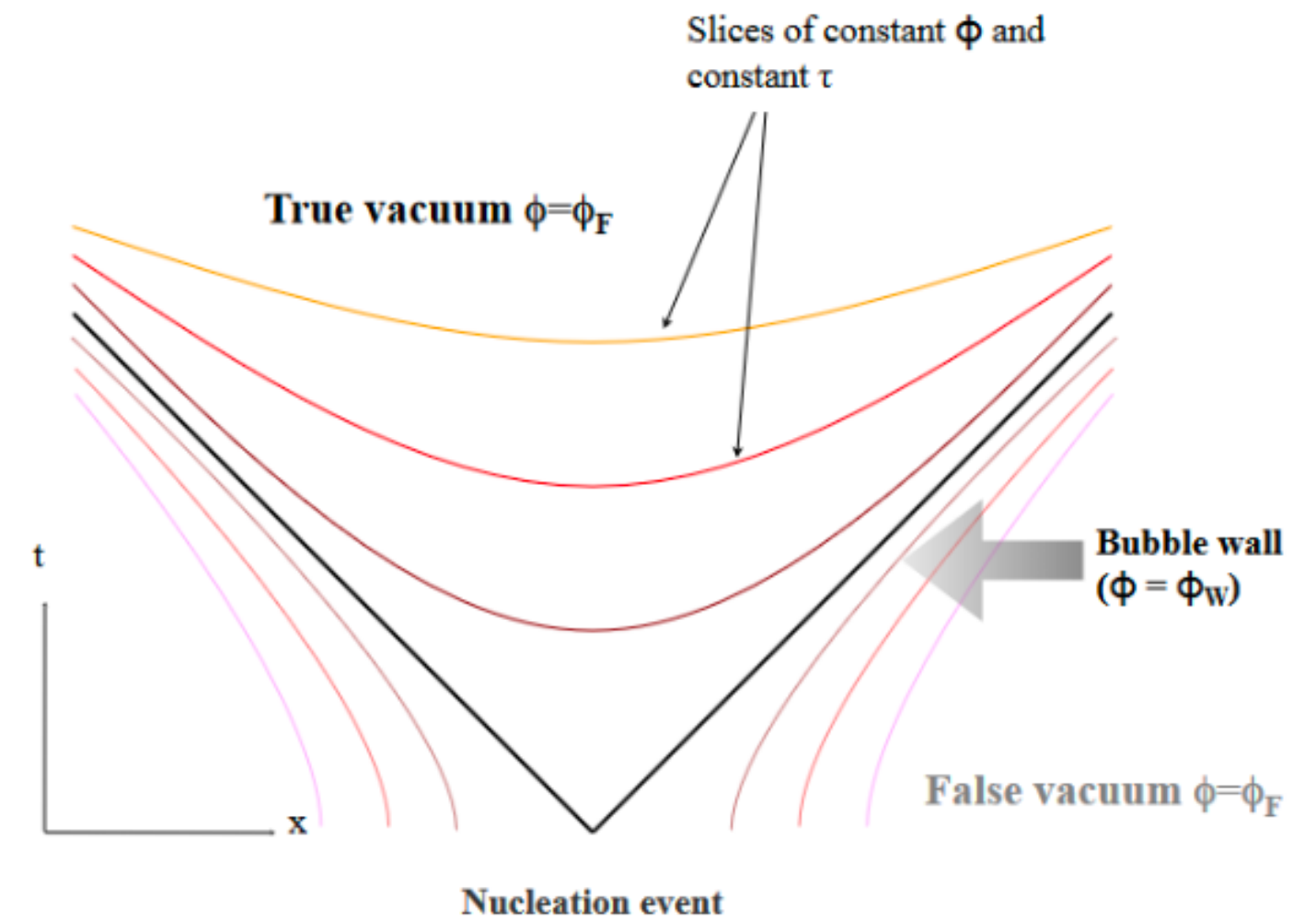
Collision region
+ Domain wall dynamics

dS - dS spacetime collision $\rightarrow$ Physical
energy barrier - two vacuum states =
domain wall

Thin-wall approximation

Timescale of collision small compared to
expansion

Signature survives beyond 50-60 e-folds of
inflation



Diagrams from [7] and [2] respectively

Collisions of two same bubbles

Collide and merge together

- The two bubbles have formed not too far apart with the same vacuum energy
- They evolve and collide before the energy from expansion has time to build up on the walls
- Once two bubbles collide, the walls do not have enough energy to “kick” the collision region to any other minima.
- They merge and form a non-spherical bubble-like geometry

Collide and classically transition to lower vacua

- Two bubbles formed far apart, so they have had time to expand a lot more, and more energy to be stored in the bubble walls
- Two bubbles collide and the walls convert the potential energy in the walls to kinetic energy which provides a “kick” that allows the field to go over the energy barrier to a lower minima than the one the bubbles formed in
- A new bubble of even lower minima than the parent bubbles forms

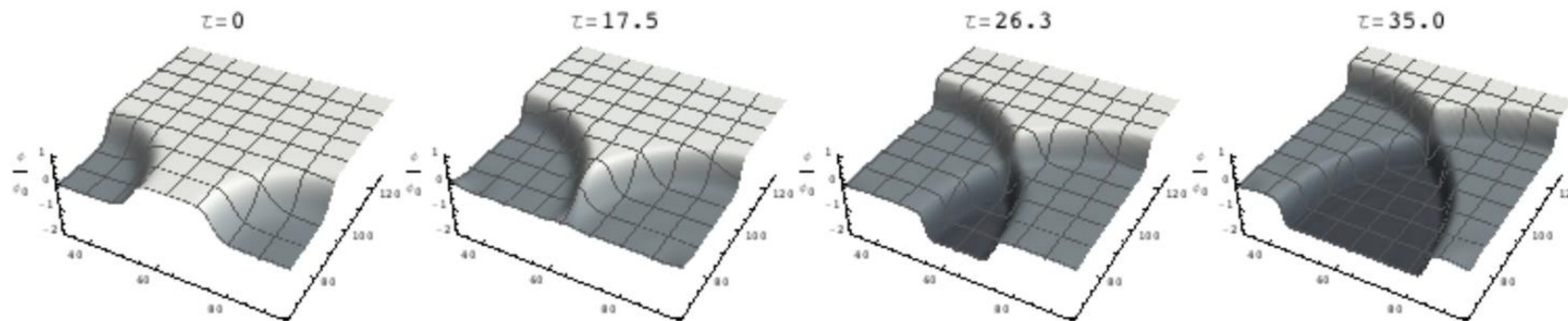
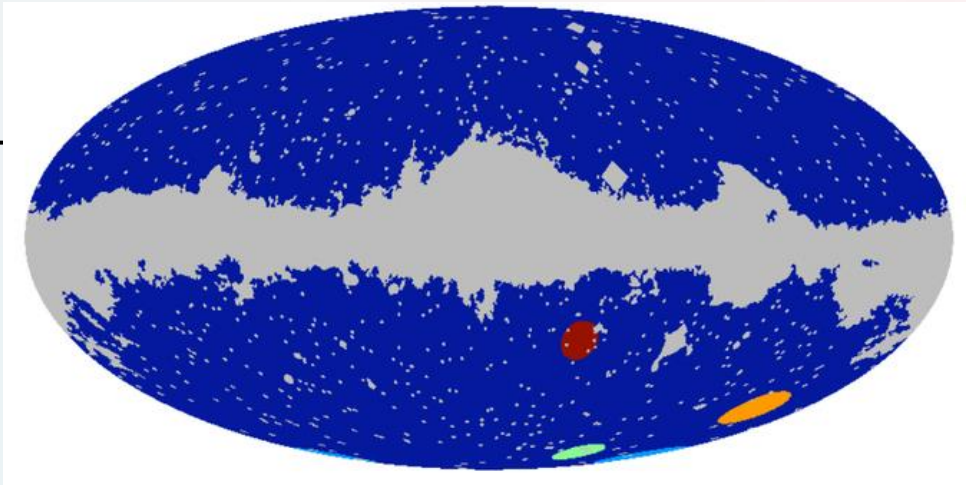
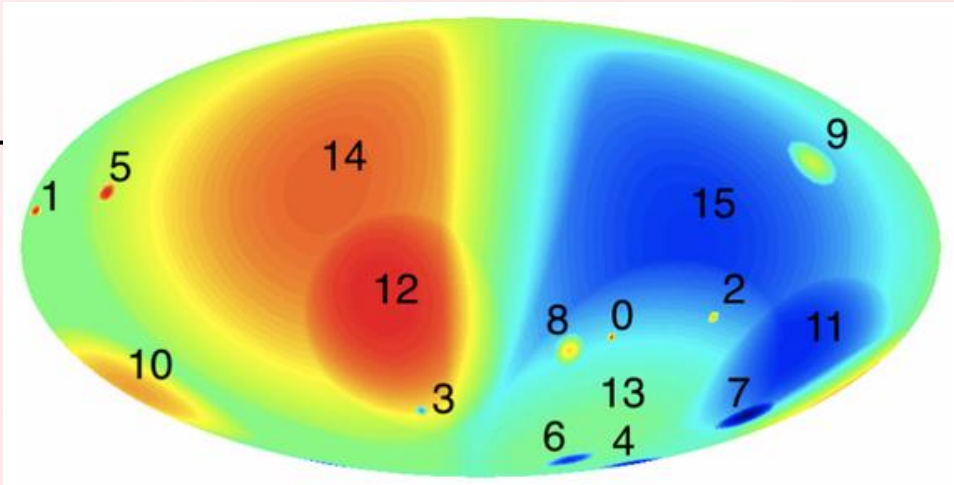
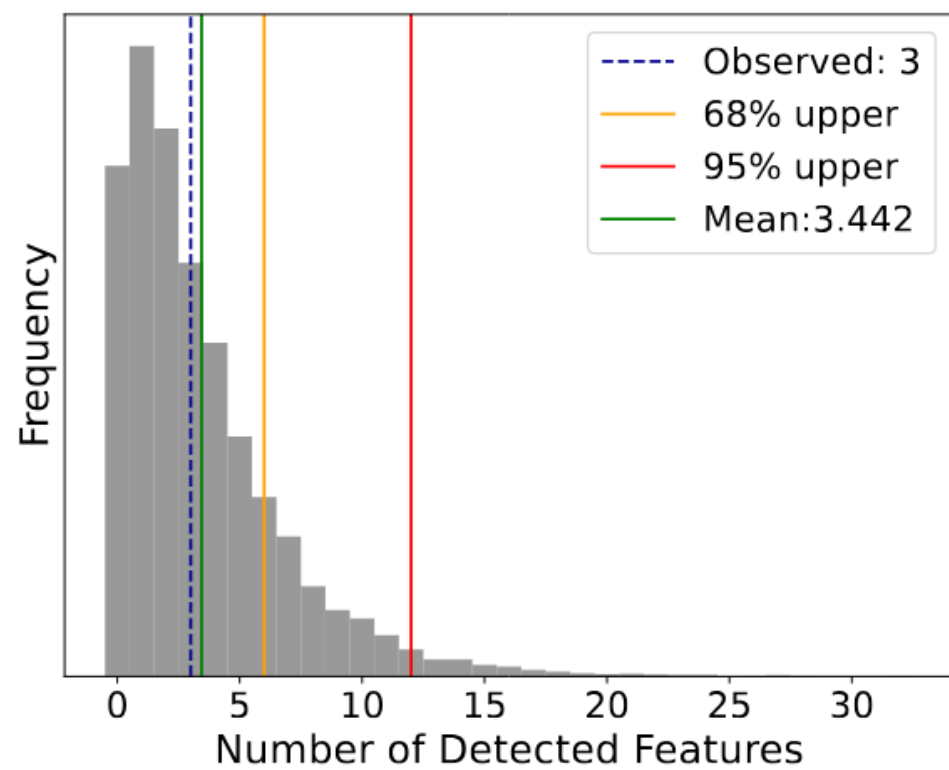


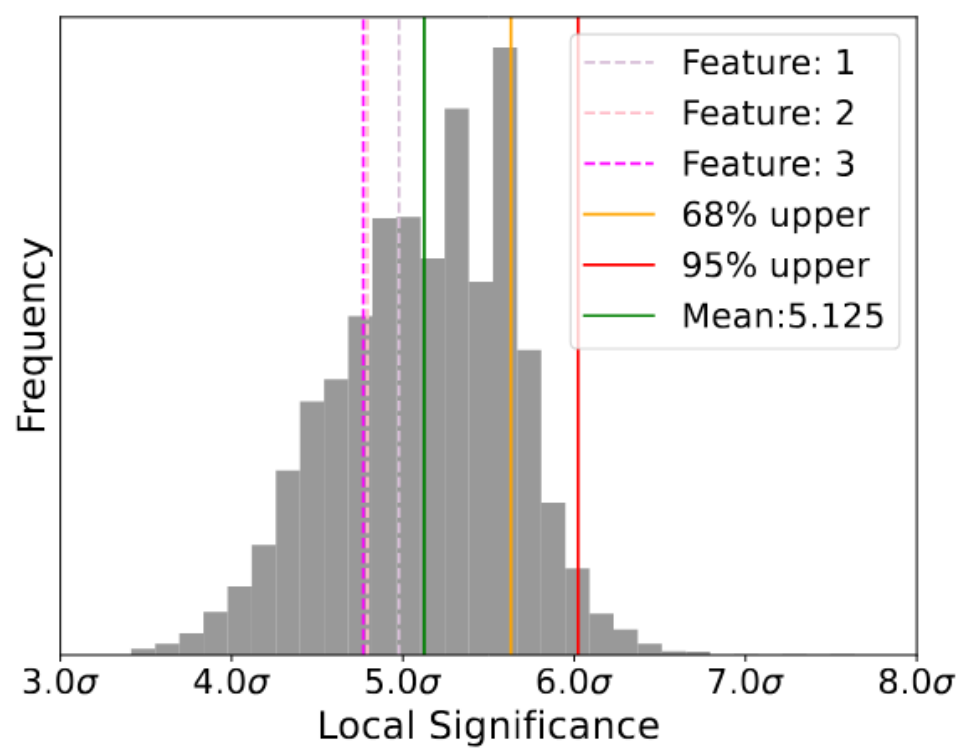
FIG. 4: Time evolution of two bubbles whose centers are $\sim .45H_0^{-1}$ apart at nucleation. When these bubbles collide (at $\tau \approx 17.5$) the walls have a Lorentz factor $\gamma = 1.8$. We use a conformal time $a(t)d\tau = \sqrt{\lambda}\phi_0^2 dt$, where $a(0) = 1$ at the beginning of the simulation and dt is the usual proper time of an FRW spacetime. **Diagram from: arXiv: 0907.3234**

WMAP (pub.) Results

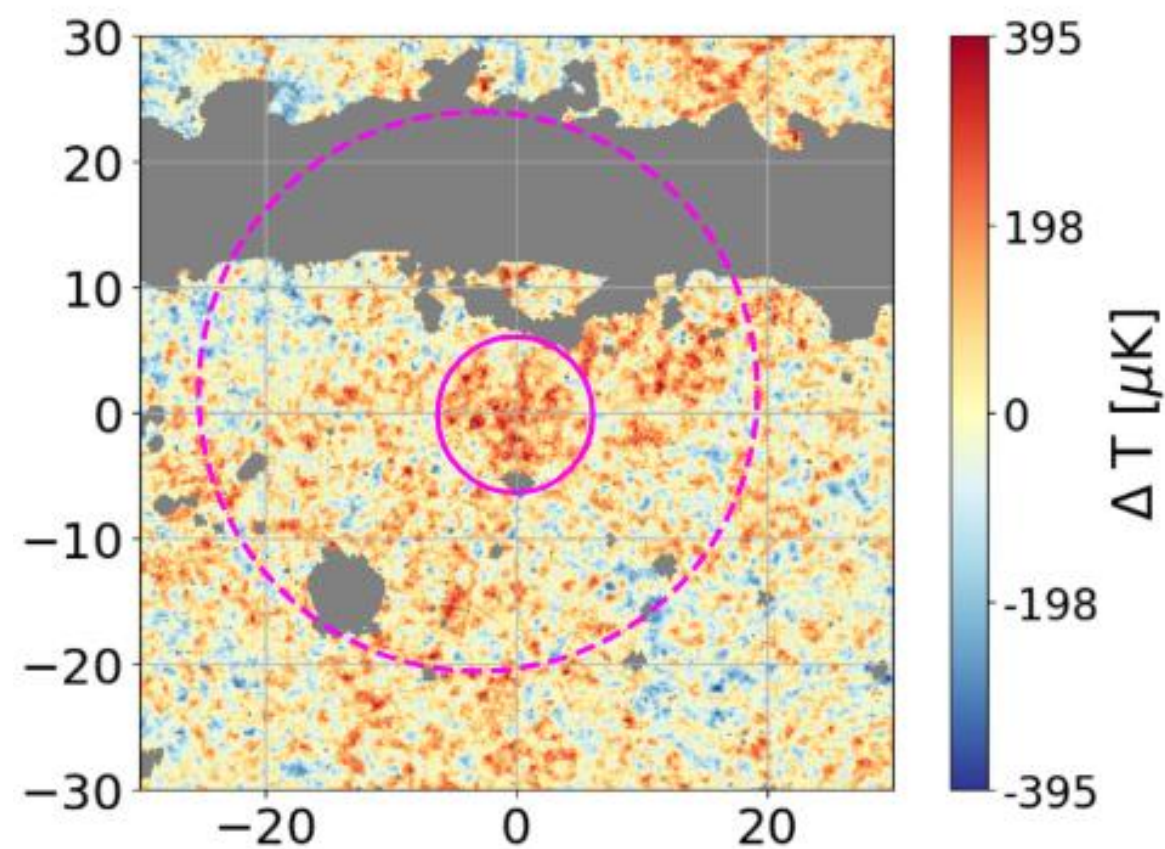
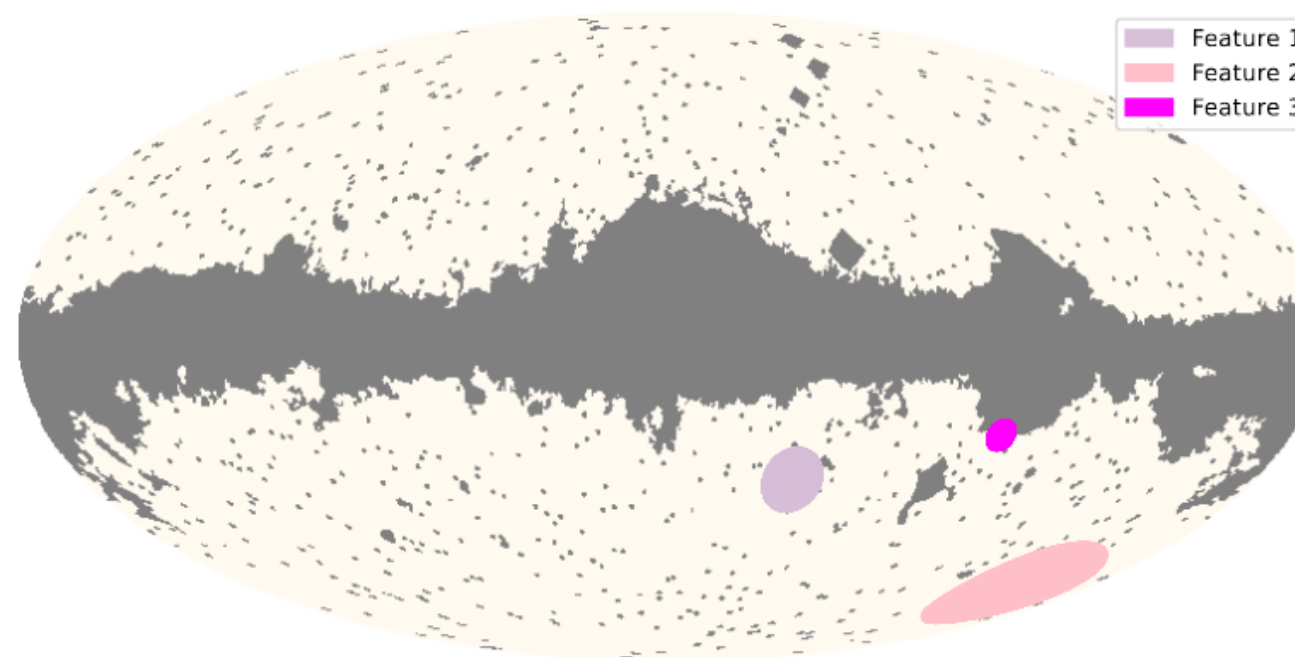
Feeney et. al. (2011) [3]	Mcewen et. al. (2012) [4]
Needlet analysis Edge detection algorithm 18 signatures reported Bayesian statistics on 4 most prominent features Null hypothesis favoured 	Optimal filter analysis Established superior SNR 14 signatures reported No freq/Bayes study Open ended usage and future direction 



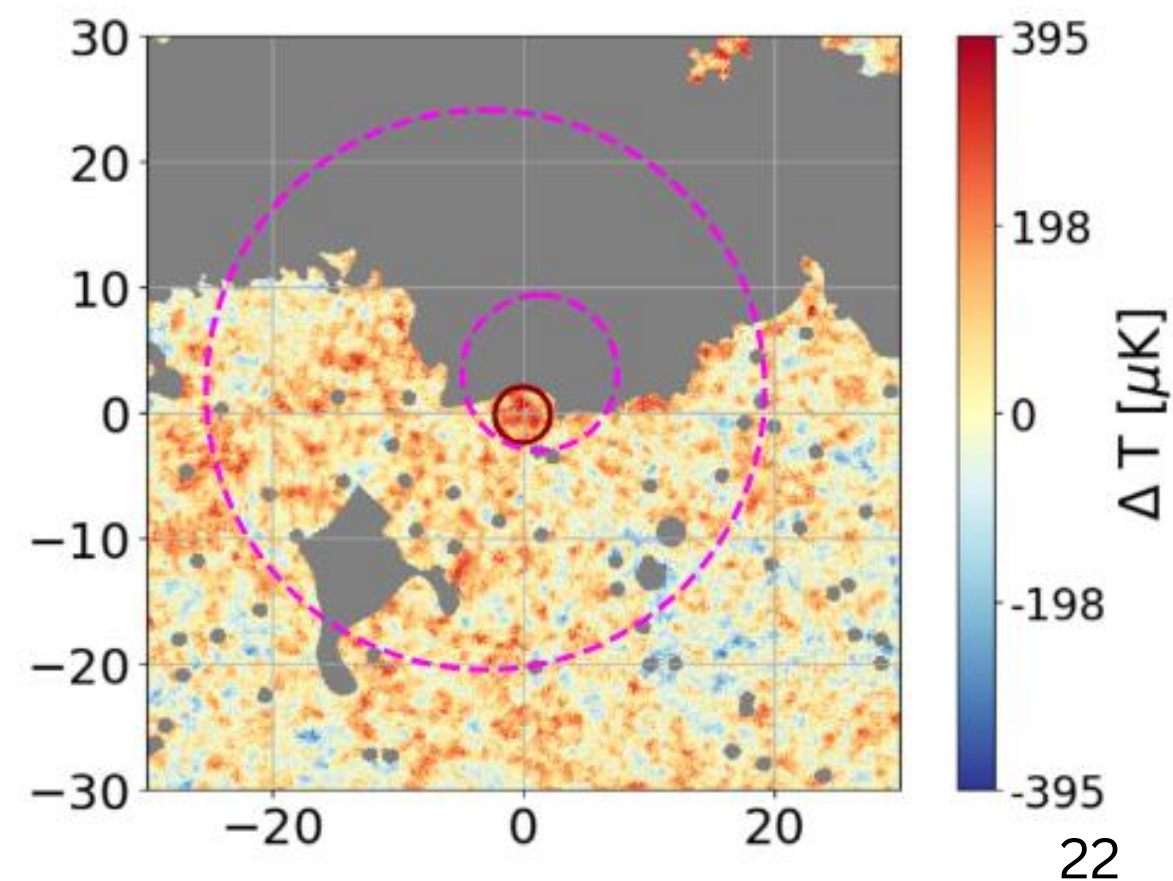
(a) Detected features study



(b) Maximal significance study



(a) Feature 3 in *Planck*



(b) Feature 3 in *WMAP*

