The trichotomy of PBH initial conditions

Dark Matter and Black Holes 2025

[arXiv:2510.02006v1 - C. Germani, **LM**]

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Primordial Black Holes formed in the very early Universe

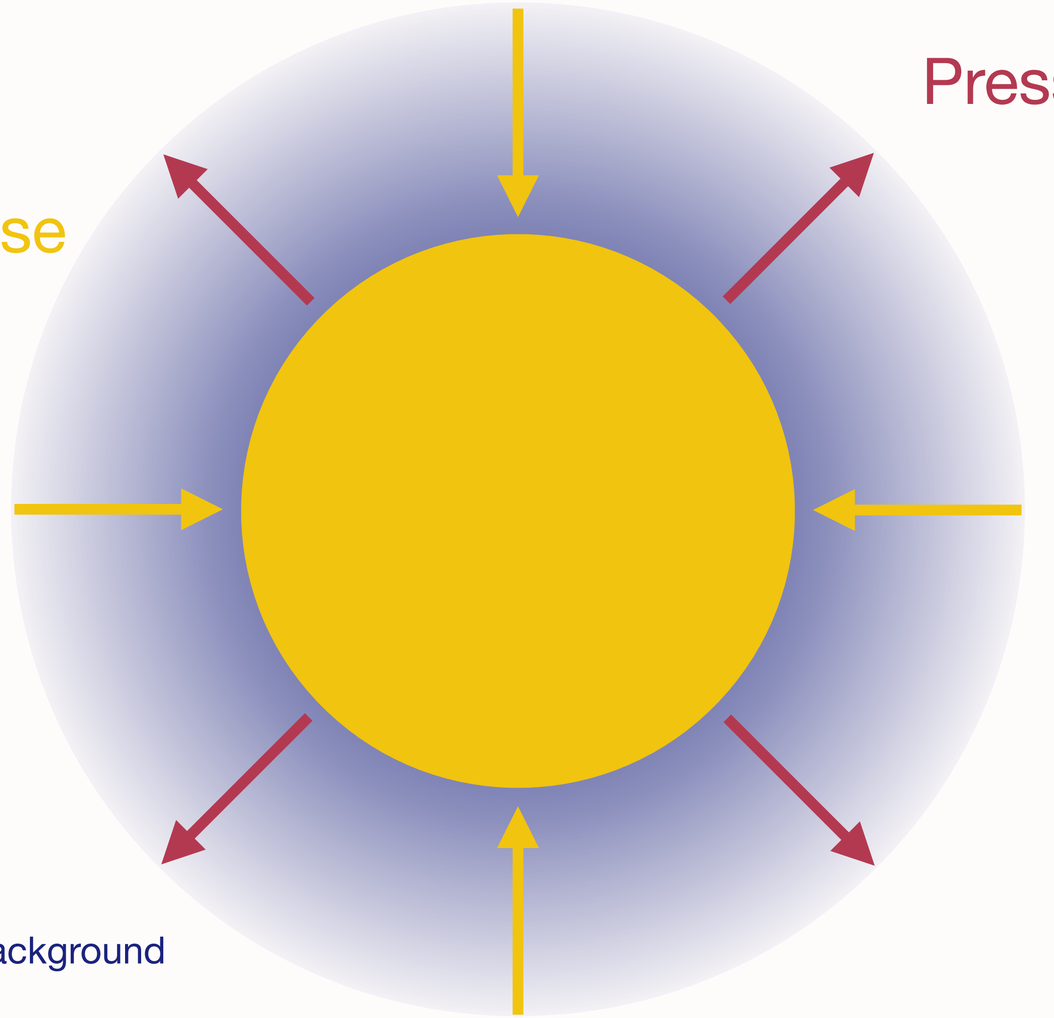
Assume those are formed by rare fluctuations during the radiation epoch

implies spherical symmetry

A super-horizon perturbation could collapse once it re-enter the horizon

Pressure Gradients

Gravitational Collapse

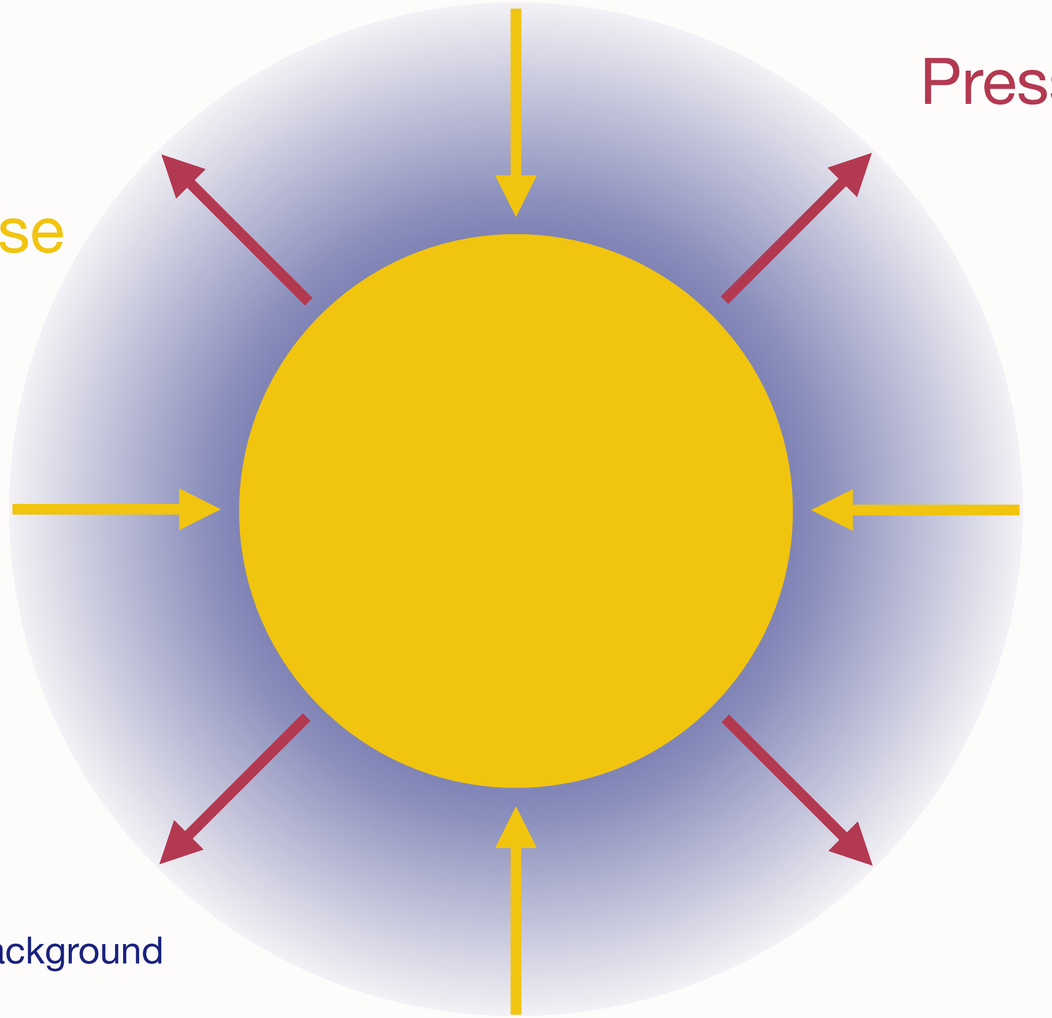


Expanding FRW background

Fight between the gravitational collapse and the expansion of the Universe

Pressure Gradients

Gravitational Collapse



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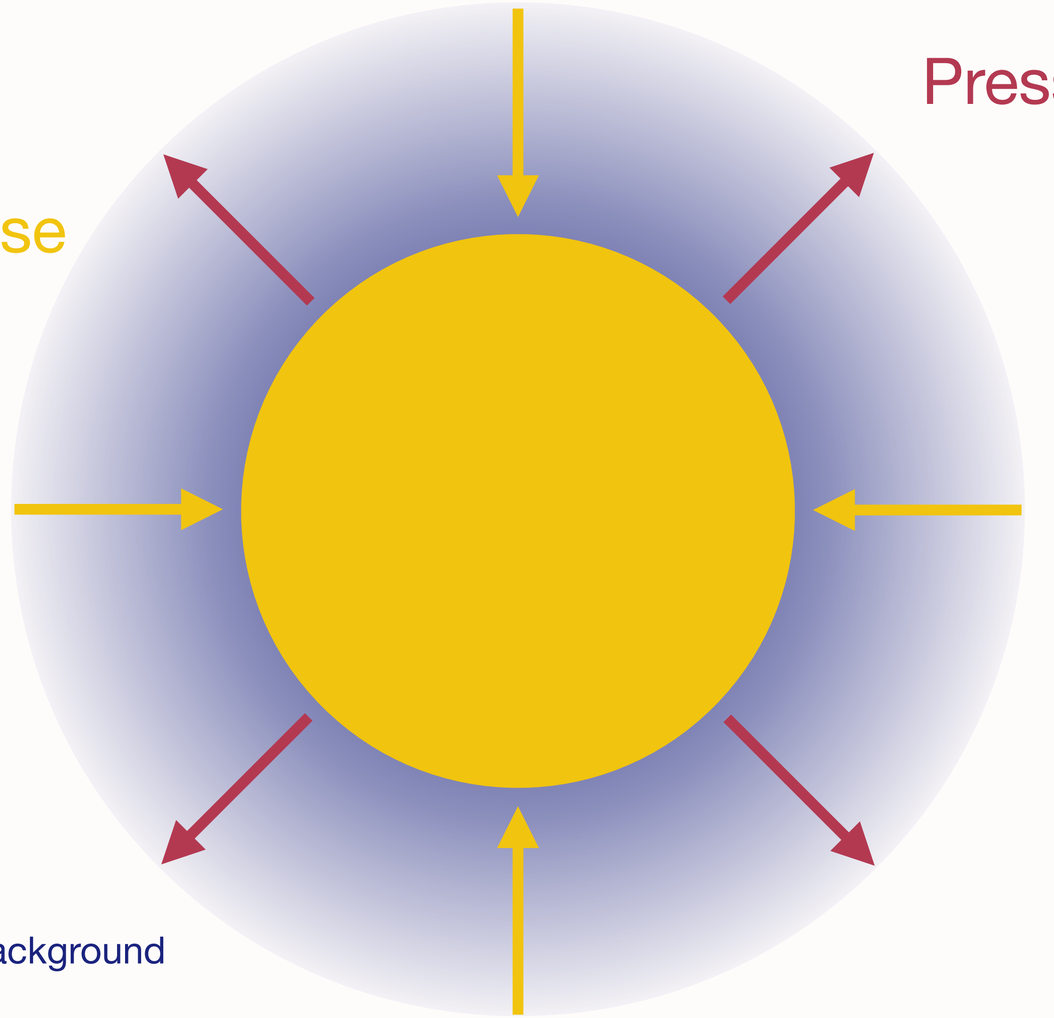
Threshold for the collapse

Pressure Gradients

Gravitational Collapse



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BH formation condition

$$\mathscr{C} = 2\frac{M - M_b}{R} \sim 1$$

Implies the formation of a trapped horizon

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BH formation condition

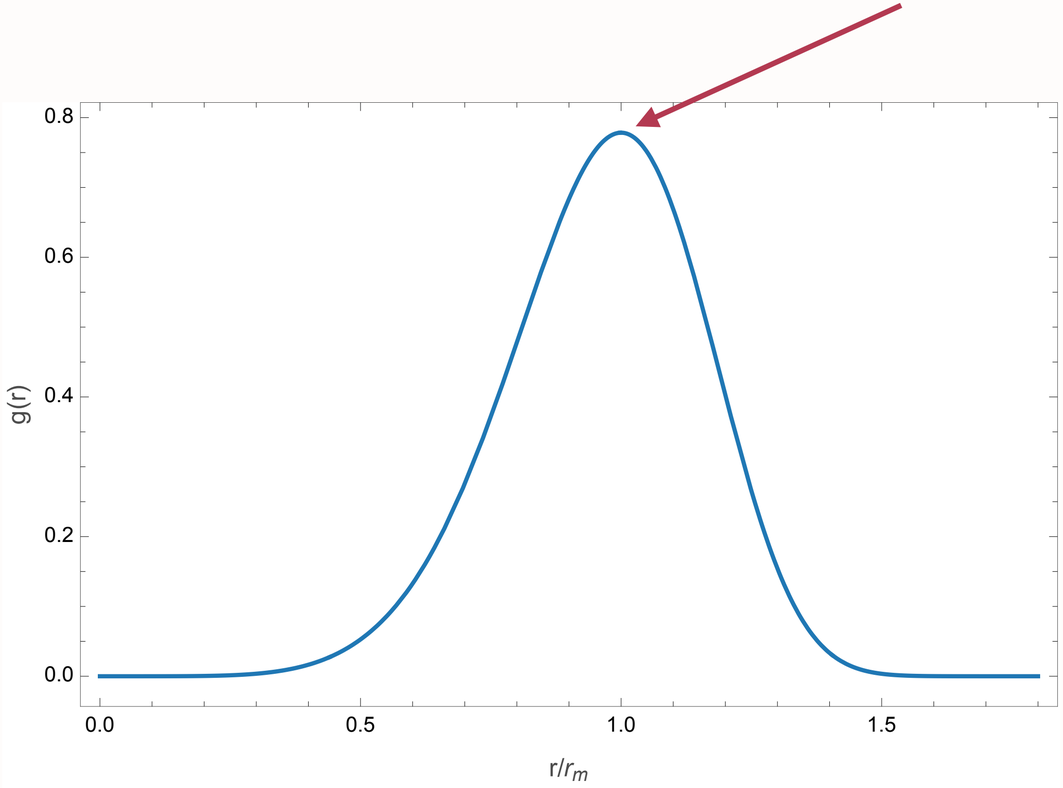
Related to the smoothed linear over-density

$$g \propto r^2 \int d\vec{x} \frac{\delta\rho(\vec{x}, t)}{\rho_b(t)}$$

$$\mathscr{C} = g\left(1 - \frac{3}{8}g\right) \sim 1$$

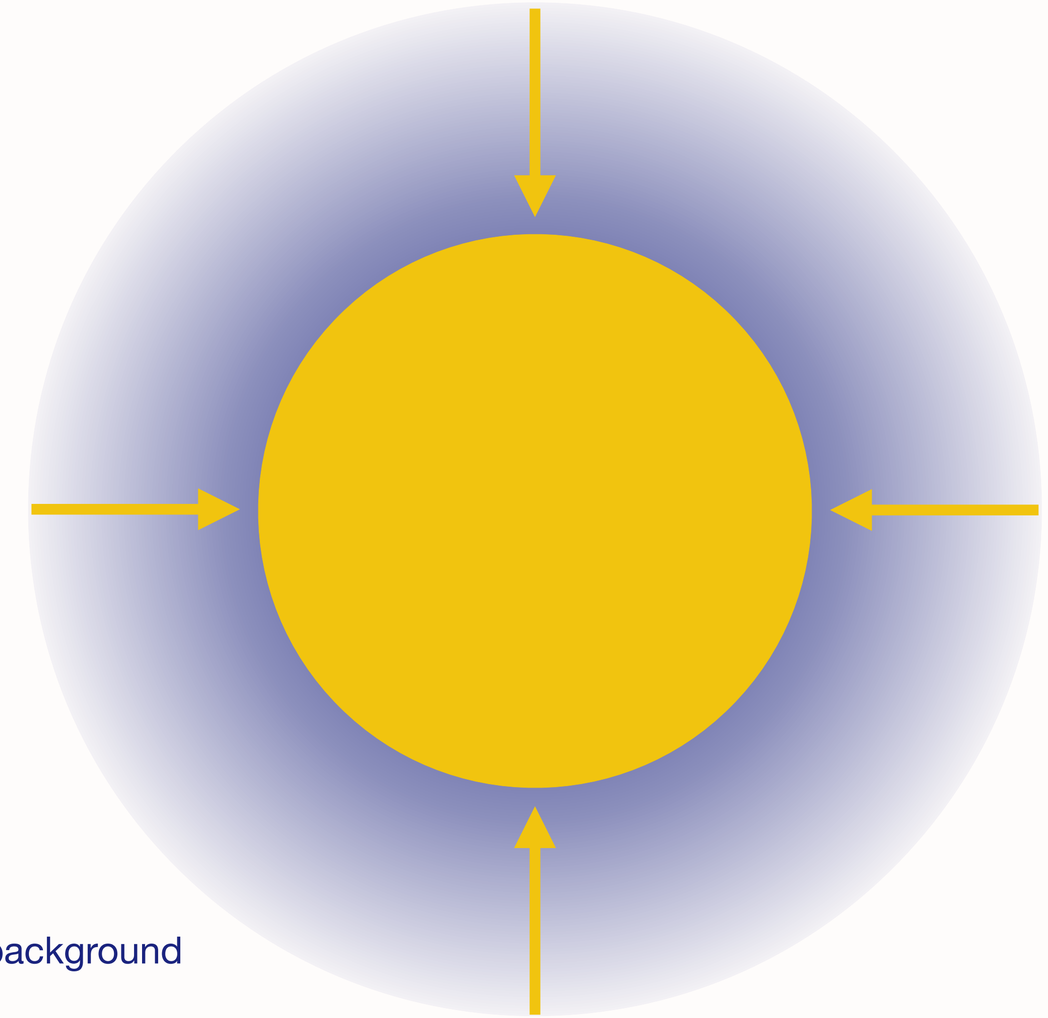
Implies the formation of a trapped horizon

It was thought that all physics should only depend on the maximum, g_{max}



[Escrivà, Germani, Sheth arXiv:1907.13311]

Let’s consider an isolated spherically symmetric perturbation



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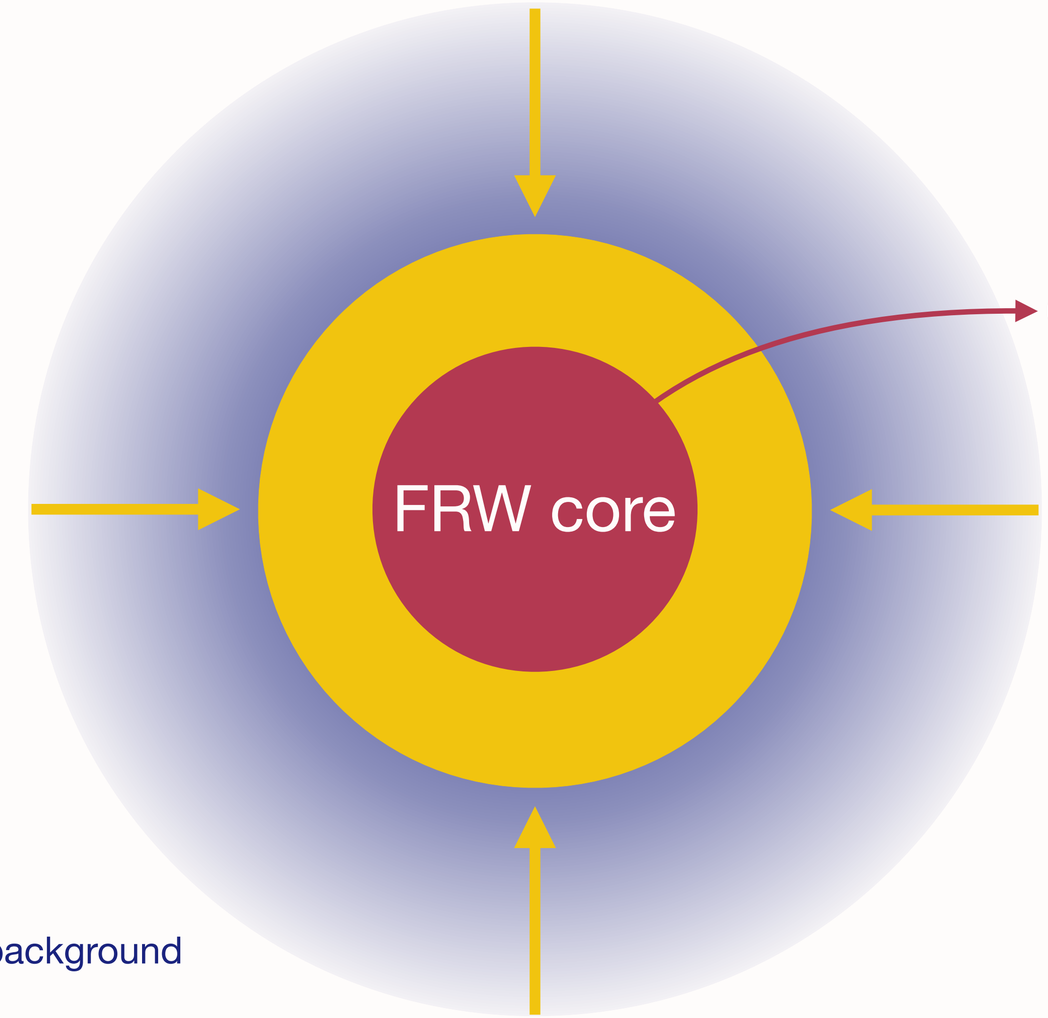
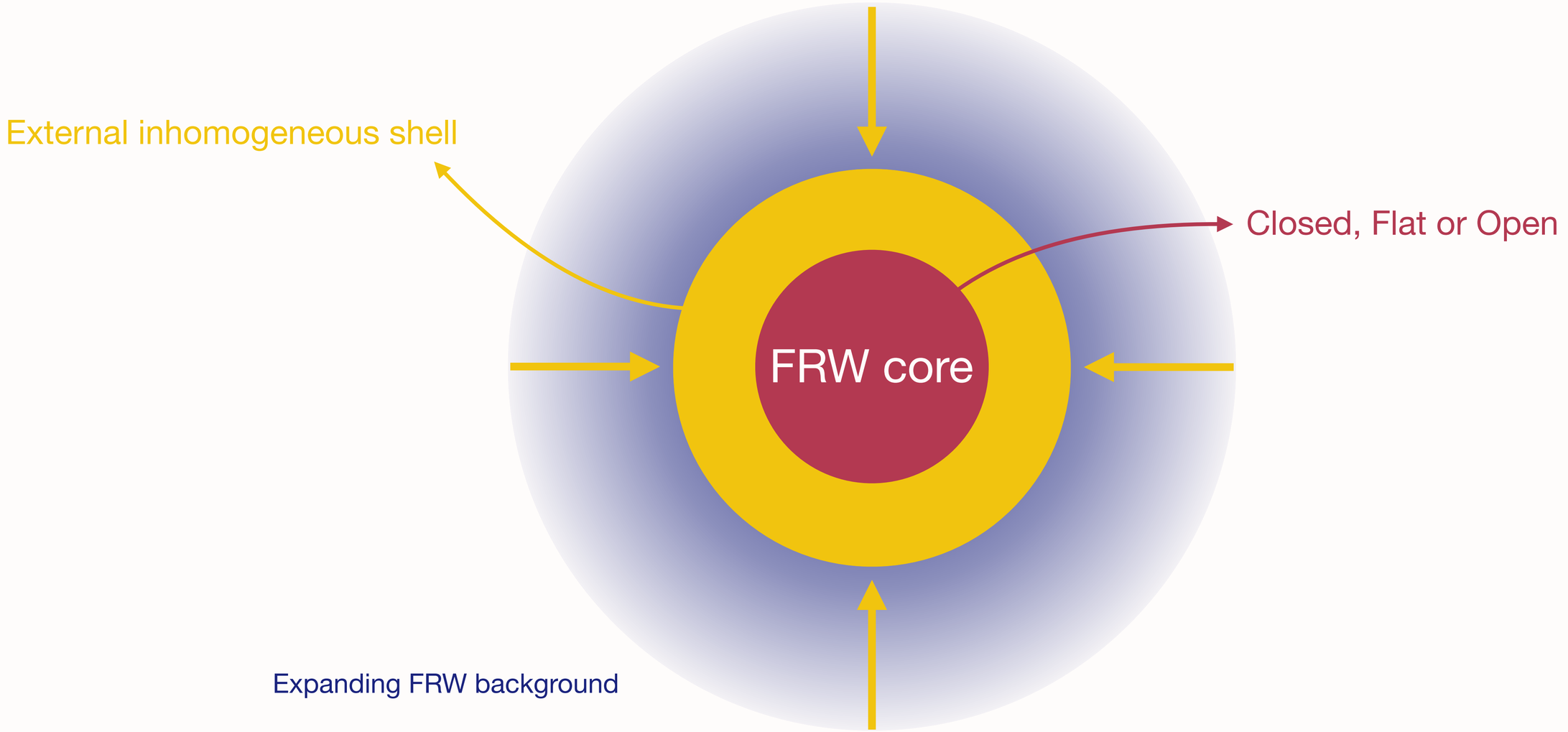
At super-horizon scales a local patch ≈ FRW

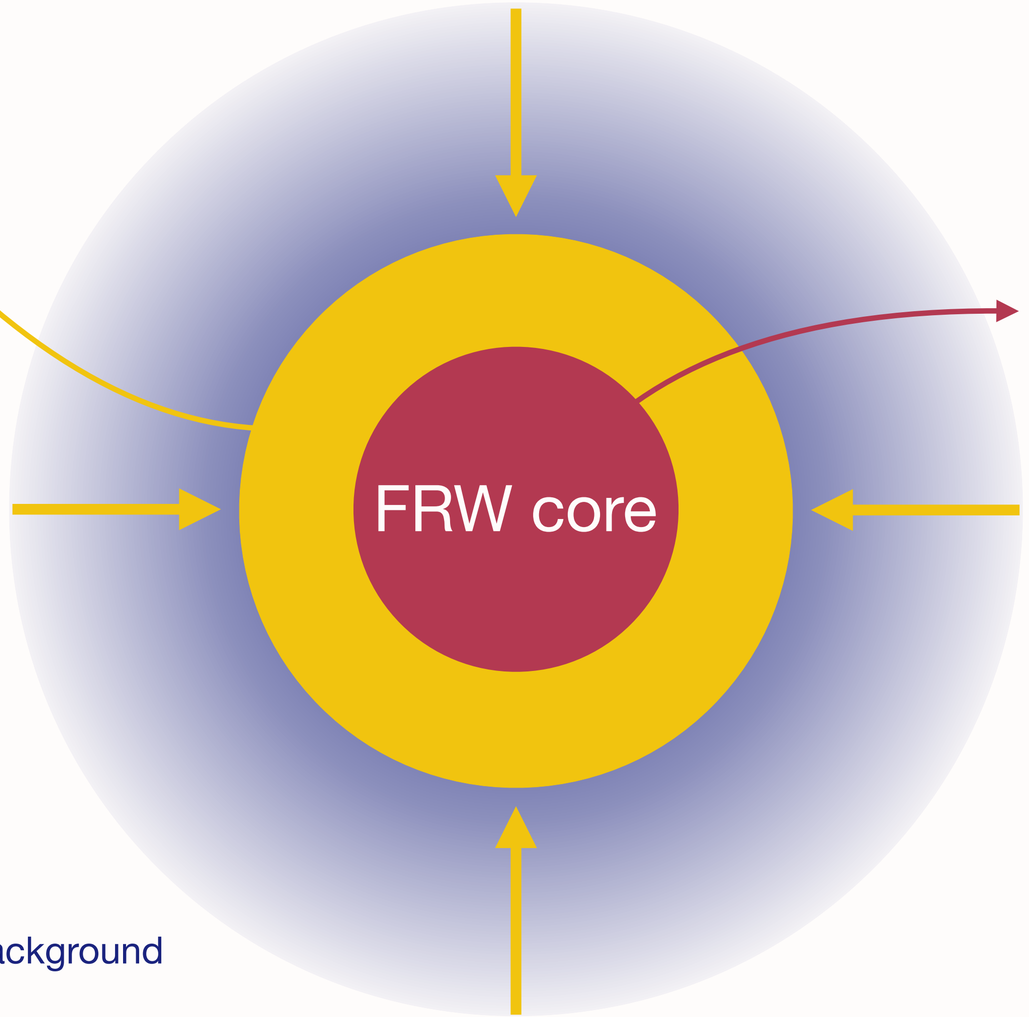


Spacetime becomes inhomogeneous as we move away from the center



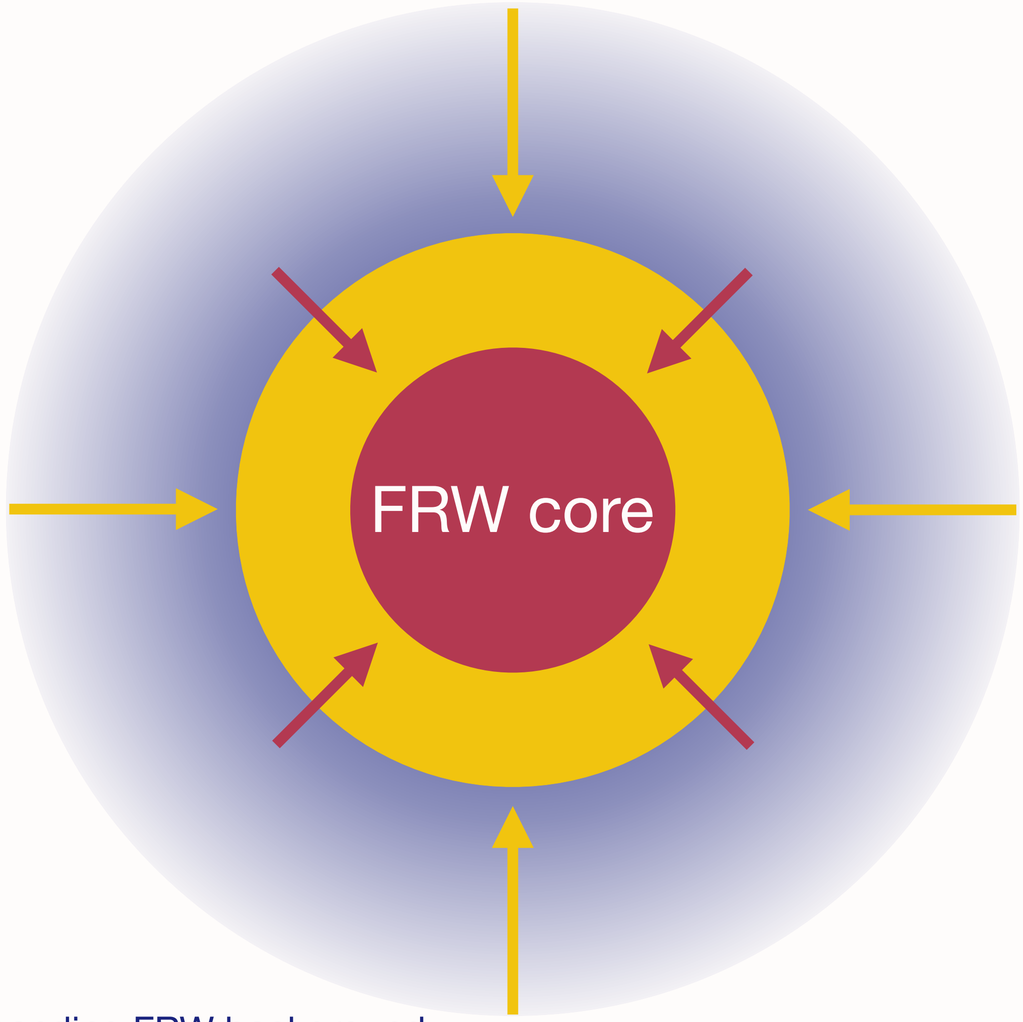
External shell triggers the collapse

External inhomogeneous shell



Closed, Flat or Open

Expanding FRW background



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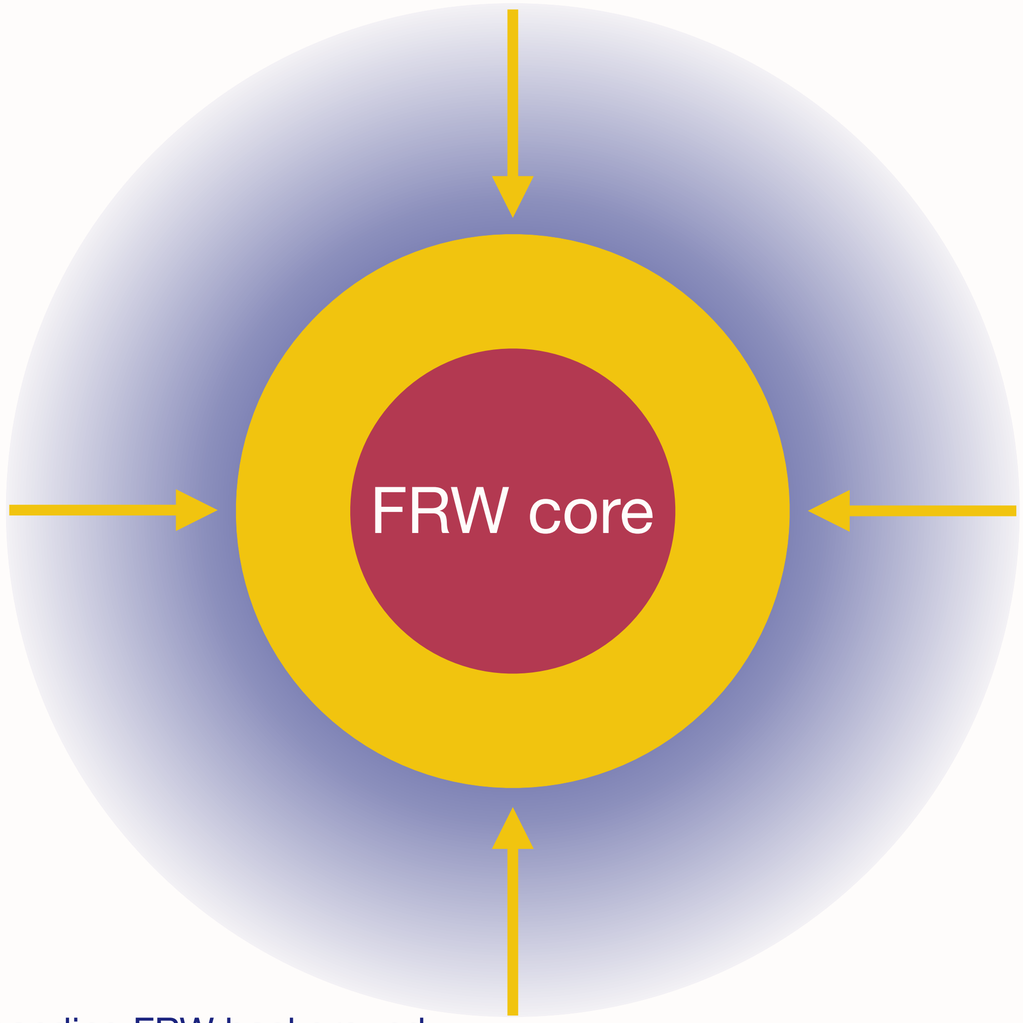
Closed FRW: Type-C



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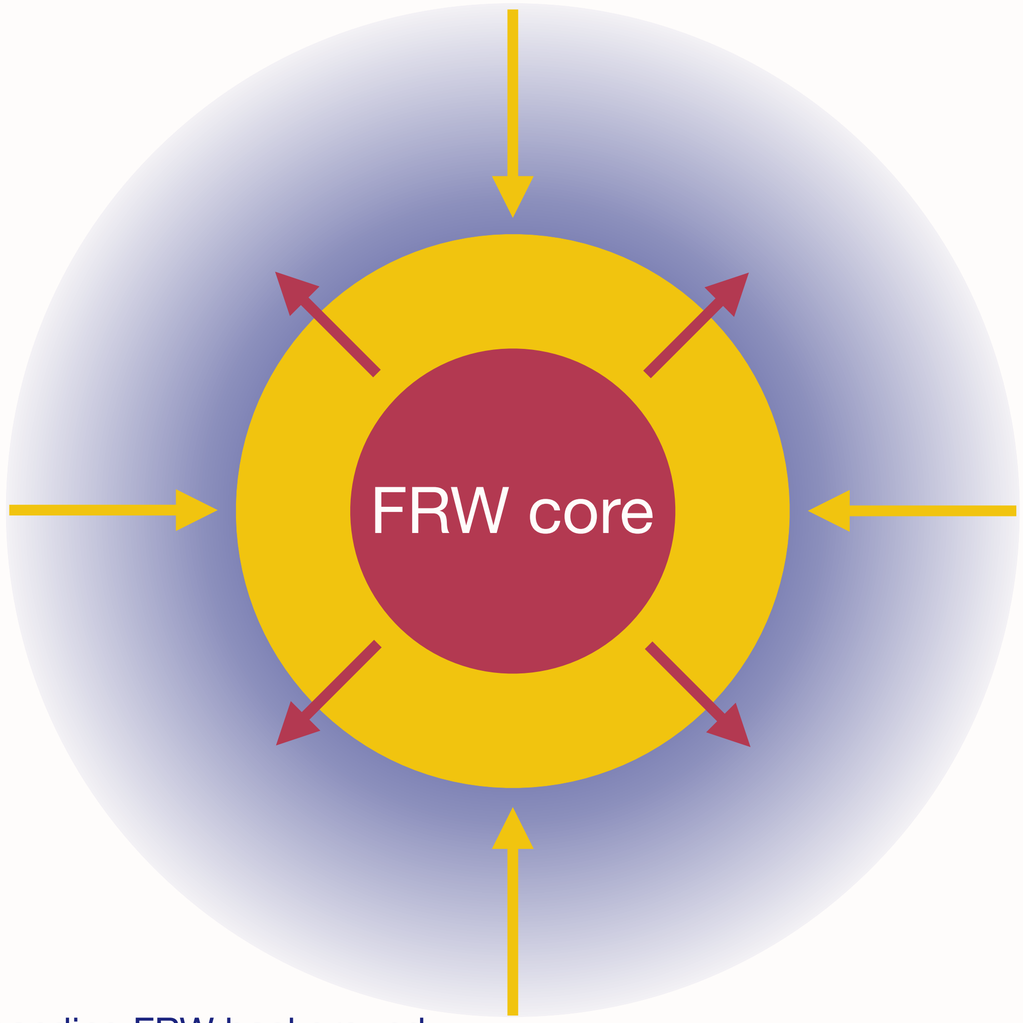
Flat FRW: Type-F



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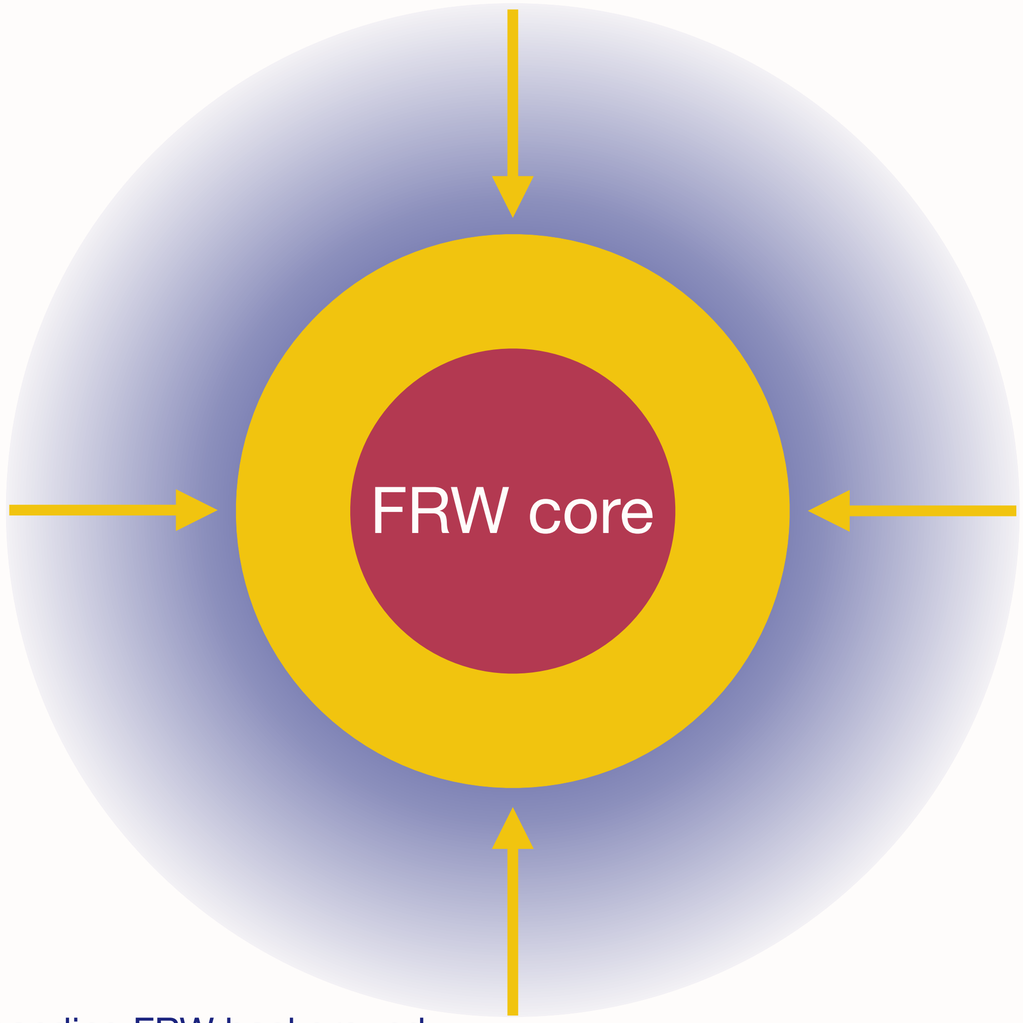
Open FRW: Type-O



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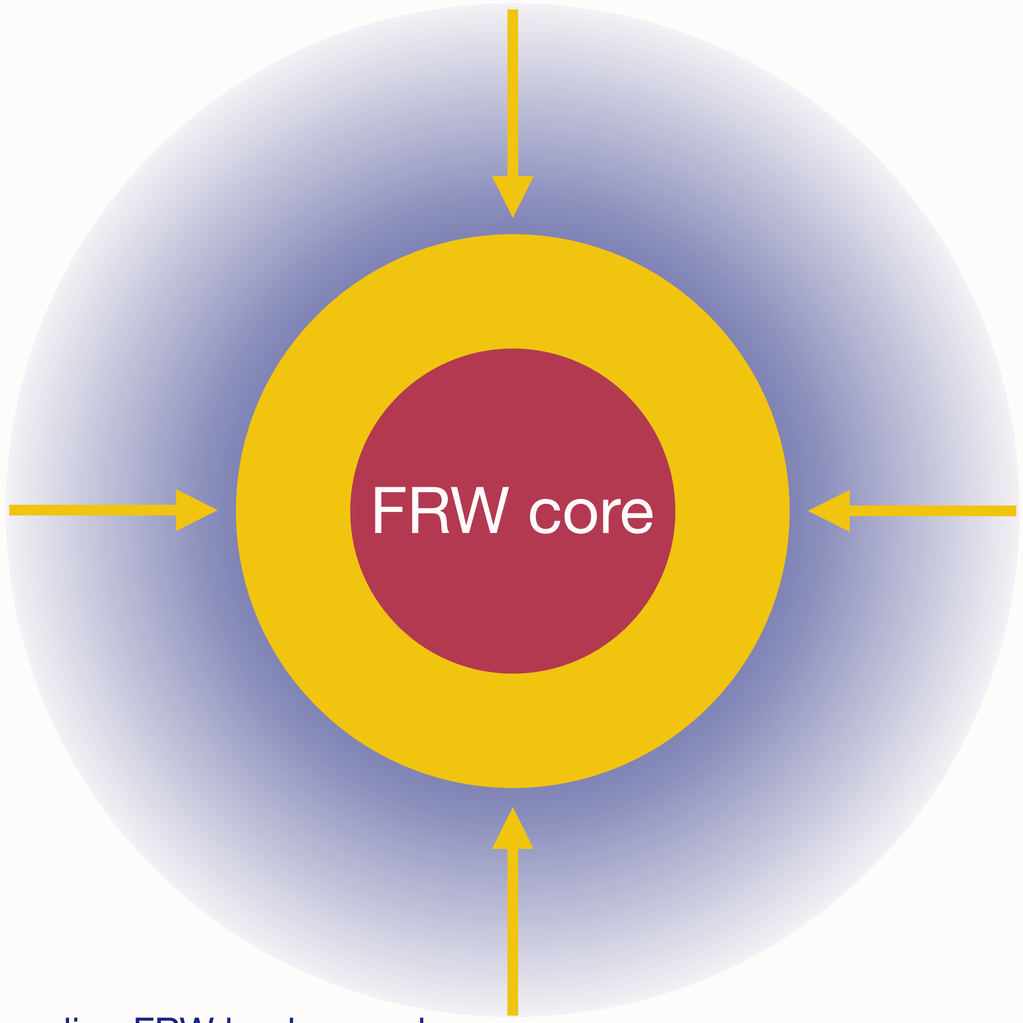
Same curvature for g_{max}

but three different thresholds

Type-O > Type-F > Type-C



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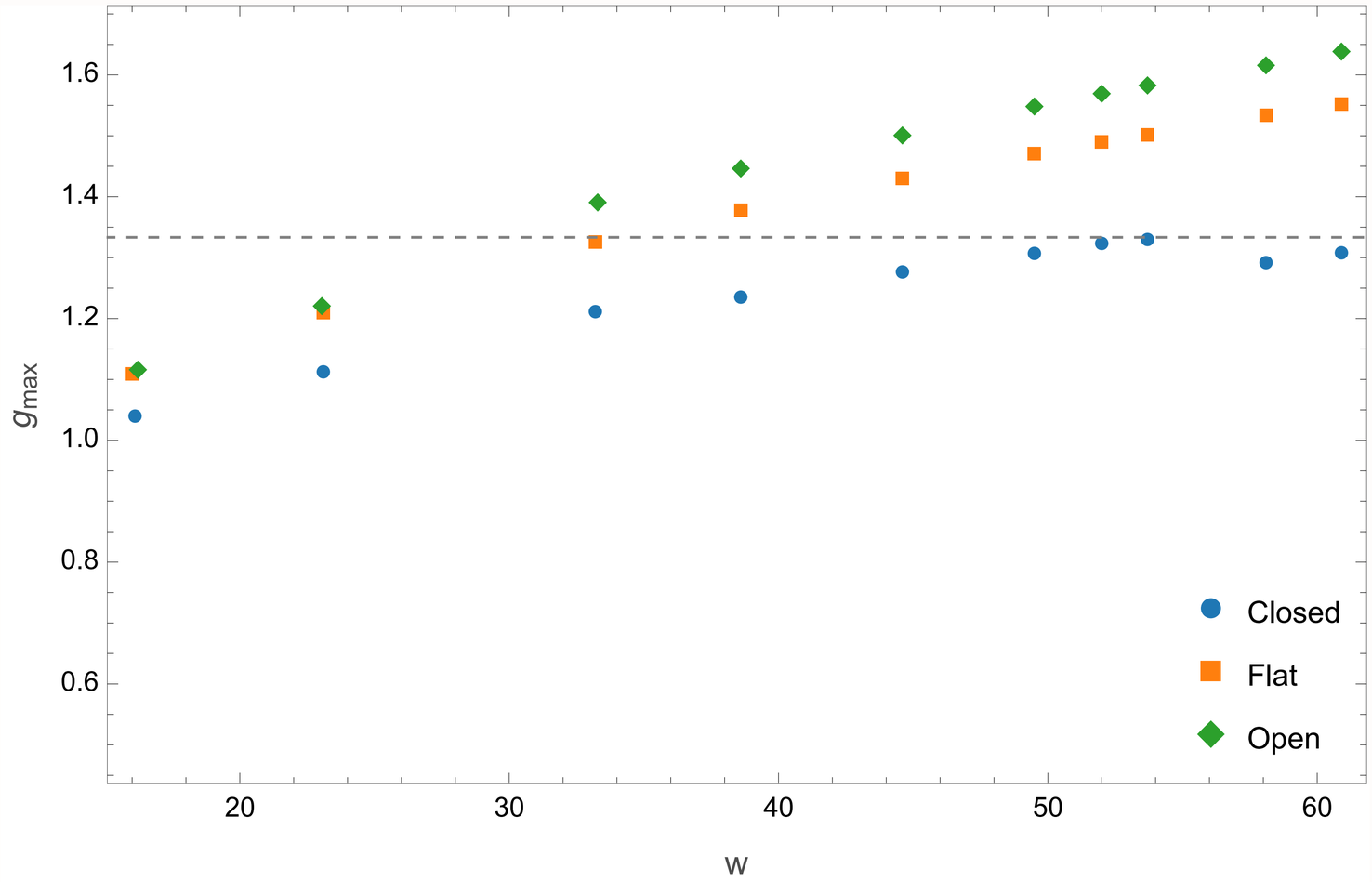
Trichotomy of initial conditions

Type-O > Type-F > Type-C

Thresholds

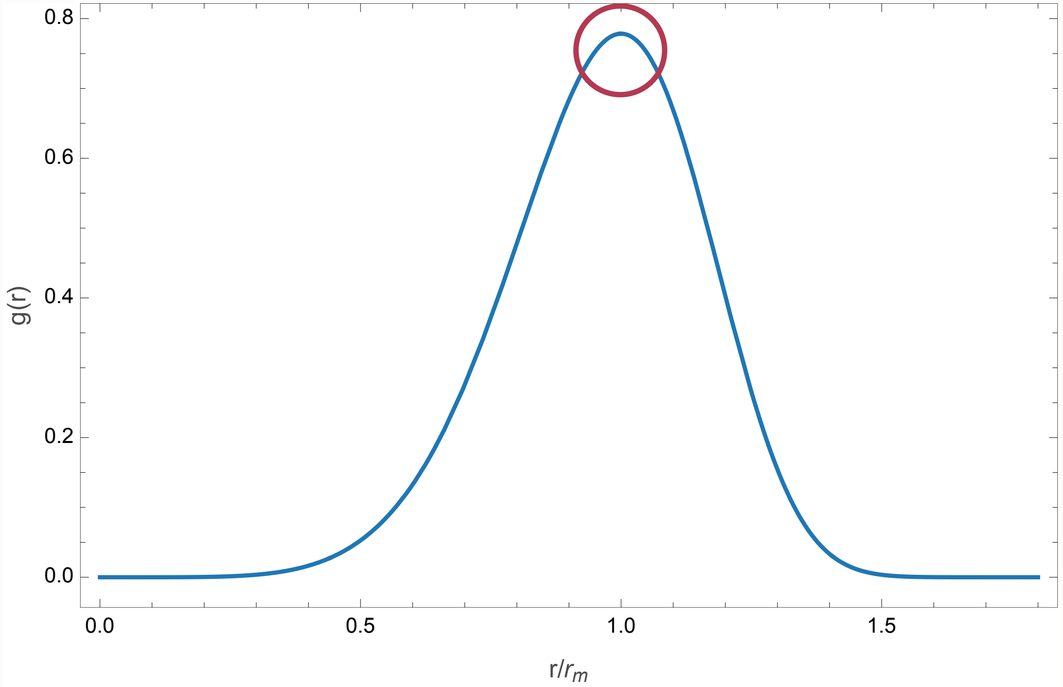


related to g_{max}'s curvature

$$w = -r^2 \frac{d^2 g(r)}{dr^2}\bigg|_{max}$$

All the information about the collapse is not contained in g_{max}

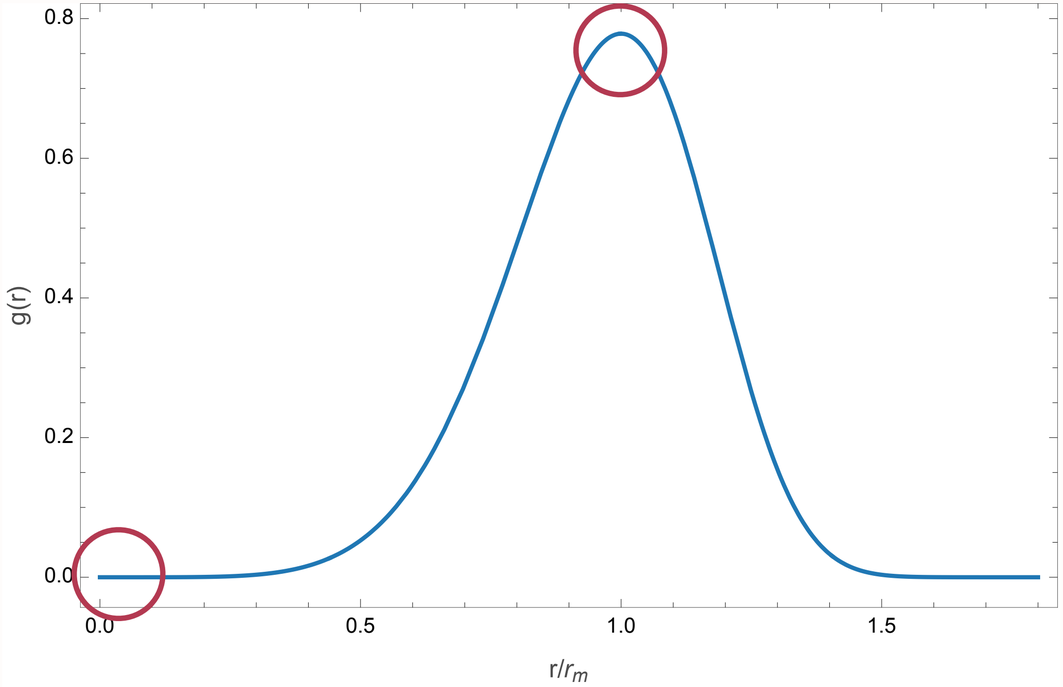
It is lost somewhere

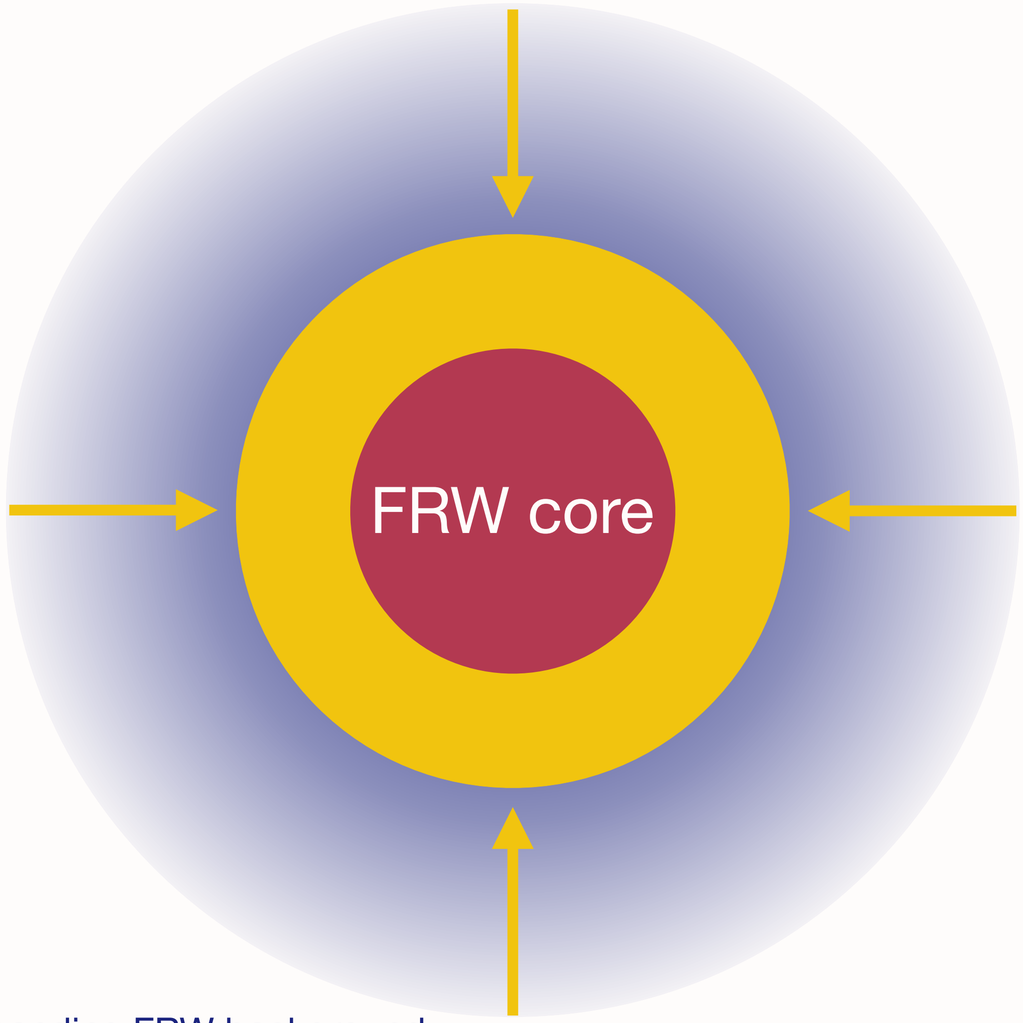


g does not contain information about the center

$$g\Big|_{r\to 0} \to 0$$

no info about the center!





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Threshold for PBH formation should account for the core behaviour

Conclusions

- Unveil center behaviour
- New perturbation classification: Type-C, Type-F and Type-O
- Still give the threshold in terms of g_{max}

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