F. P. arXiv:1204.4099.

See also arXiv:0907.0765, etc...

Infrared-modified Universe

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Outline

- Motivations (Inflation and Dark Energy unified)
- Strategy (Infrared-modified gravity)
- The basic FRW kinematics without a metric
- Extending the FRW paradigm
- Future directions: expanding metric space

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This Universe...

CDM-Big Bang theory is just great. Except that:

1) Distances($d_L(z), d_A(z)$) are not quite right at high z (``dark energy'')

2) We see homogeneity (and correlations!) on all angular scales (``inflation'')

Taken at face value these are both INFRARED problems: something going on at Hubble scales or beyond...

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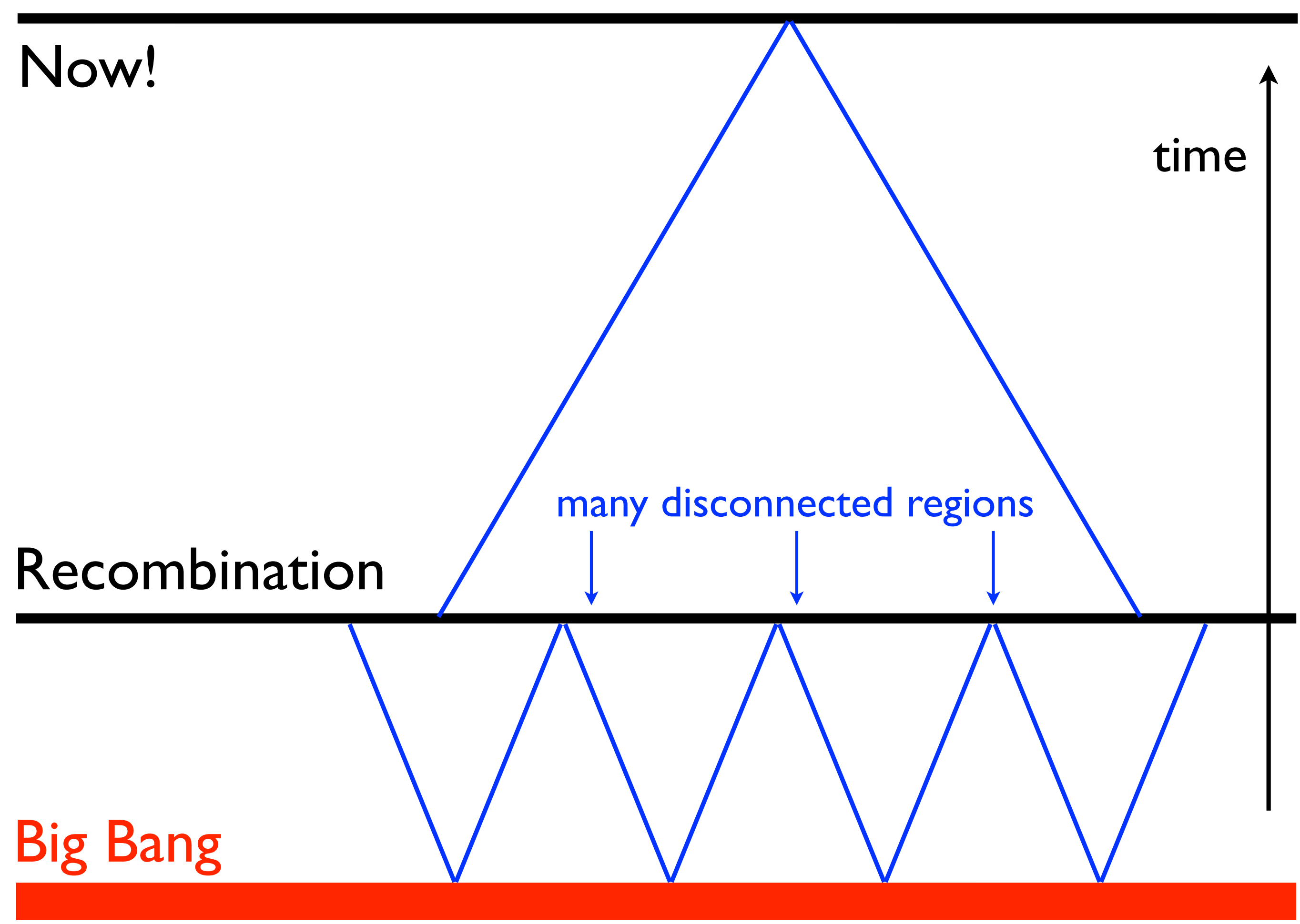
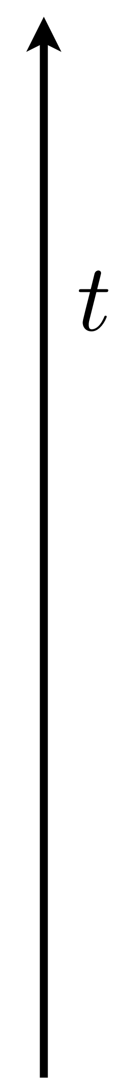
causality follows



Why must they be unrelated phenomena in GR?

1) $\ddot{a}(t) \gtrsim 0$ only recently, for a variety of reasons...

2) But then we cannot explain homogeneity: we need $\ddot{a}(t) \gtrsim 0$ also at beginning



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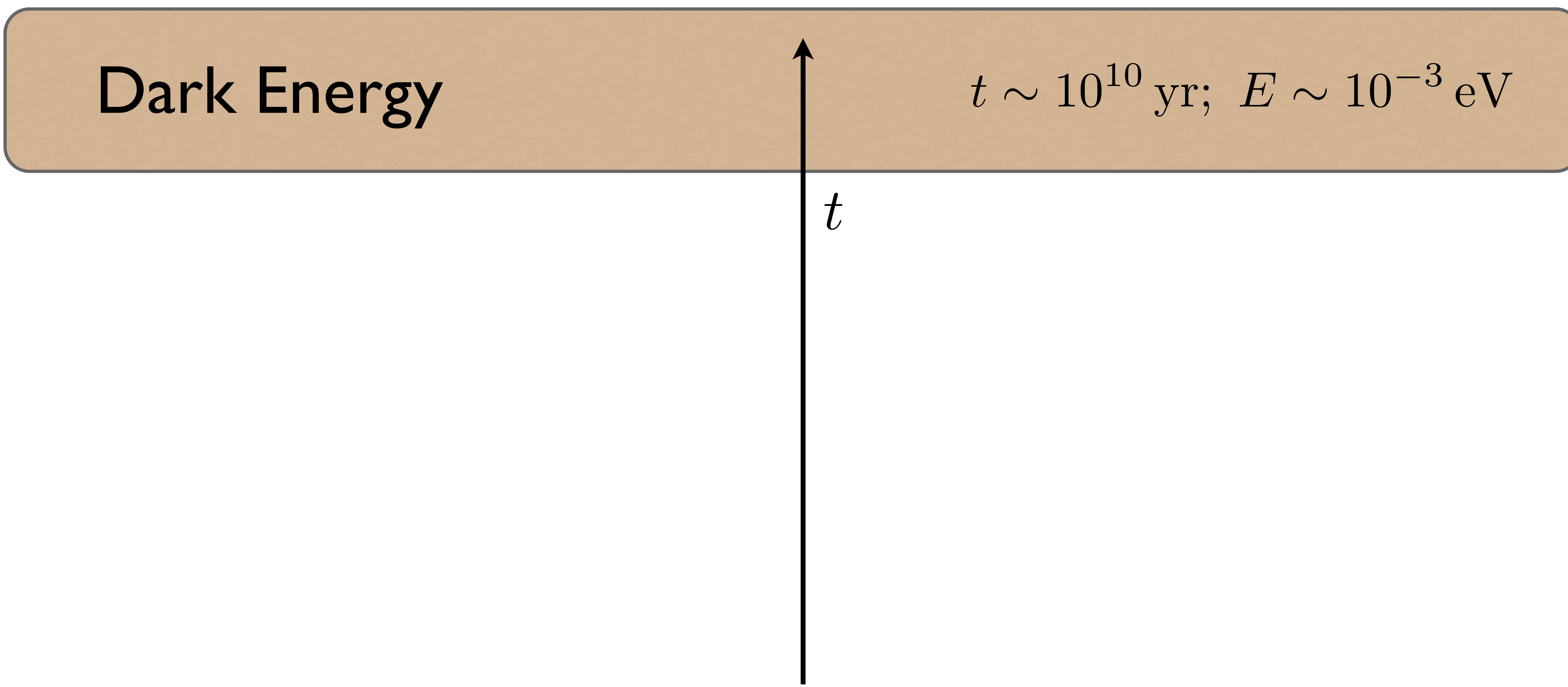

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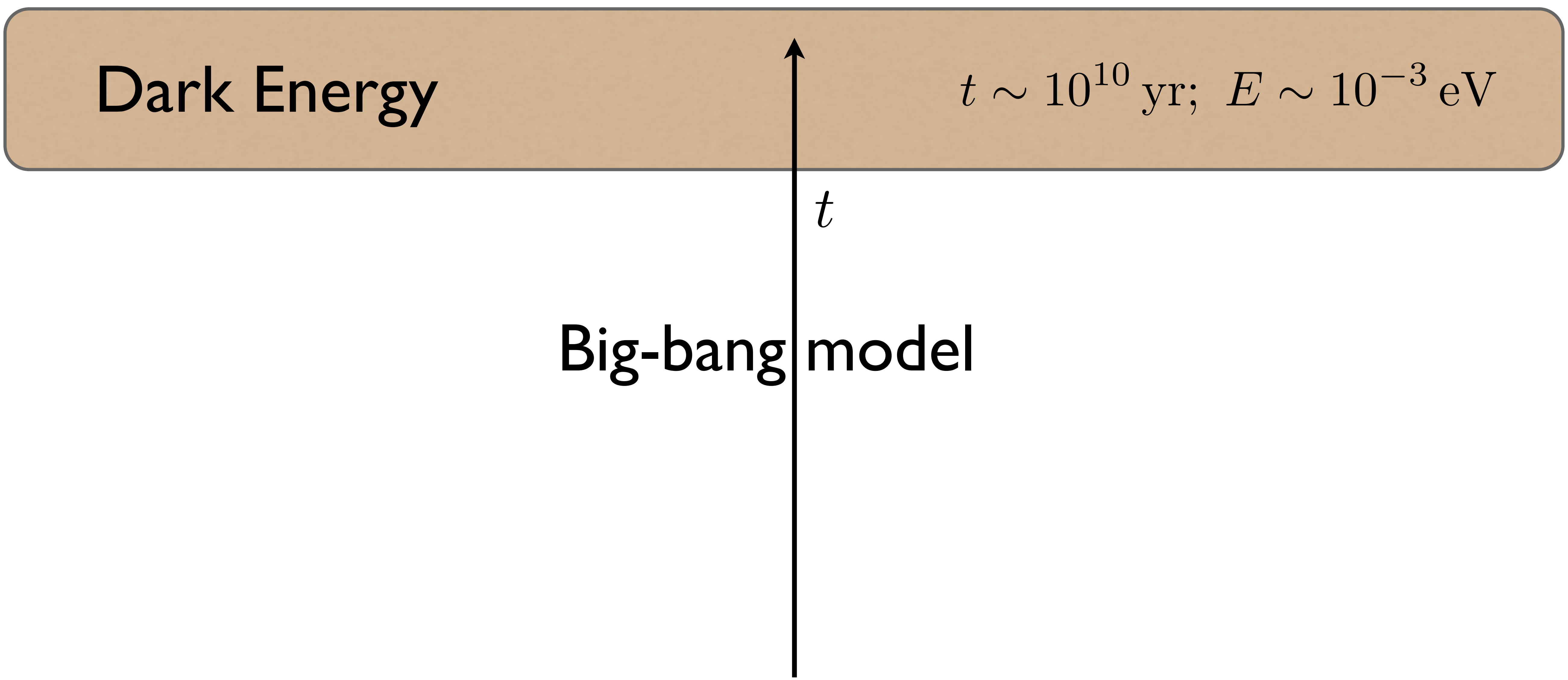

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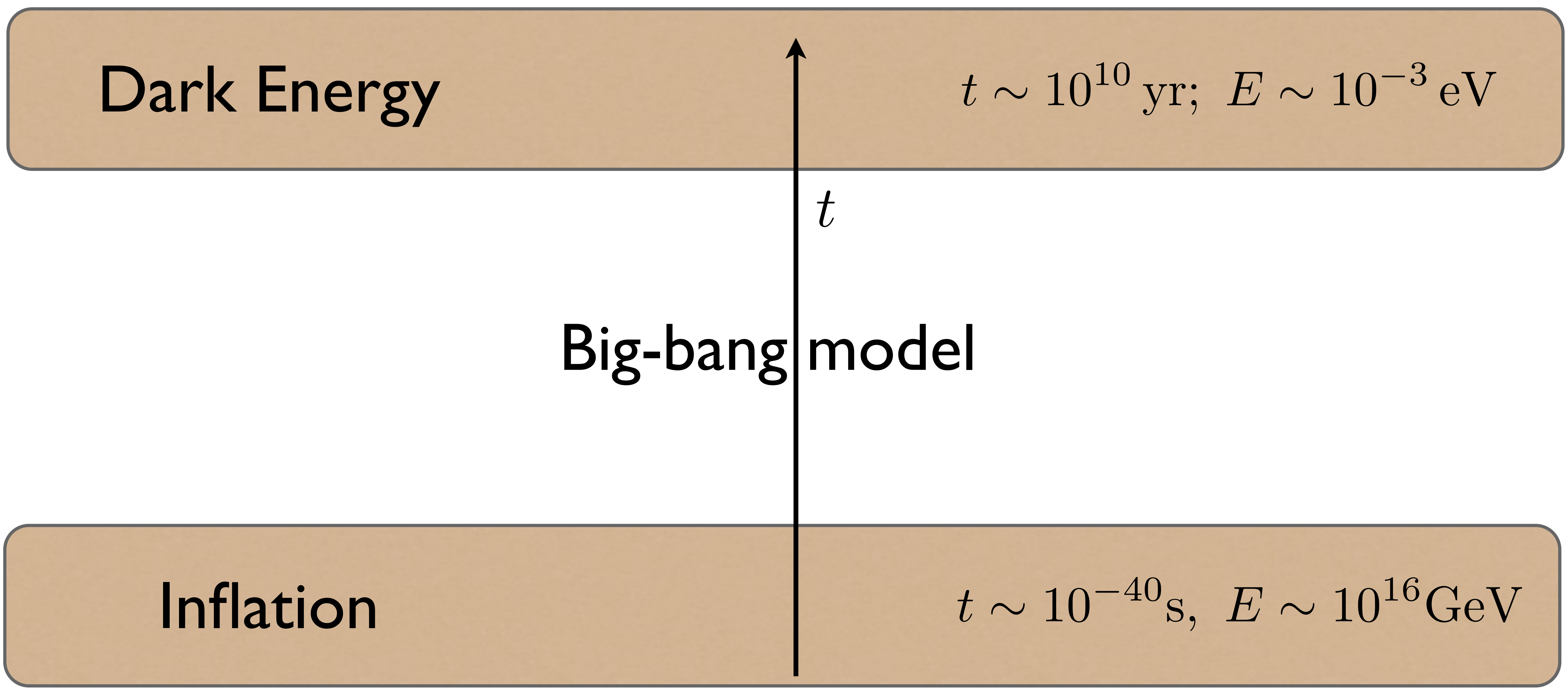

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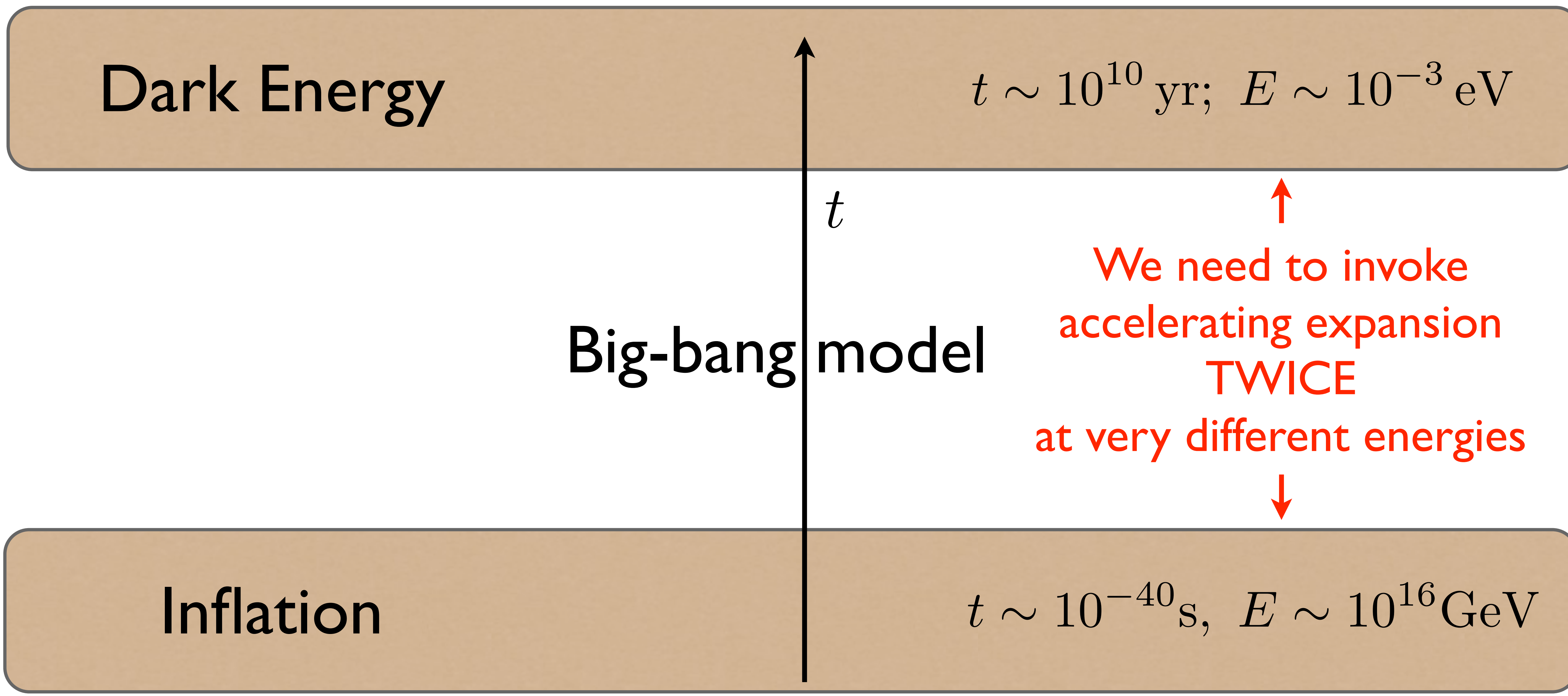

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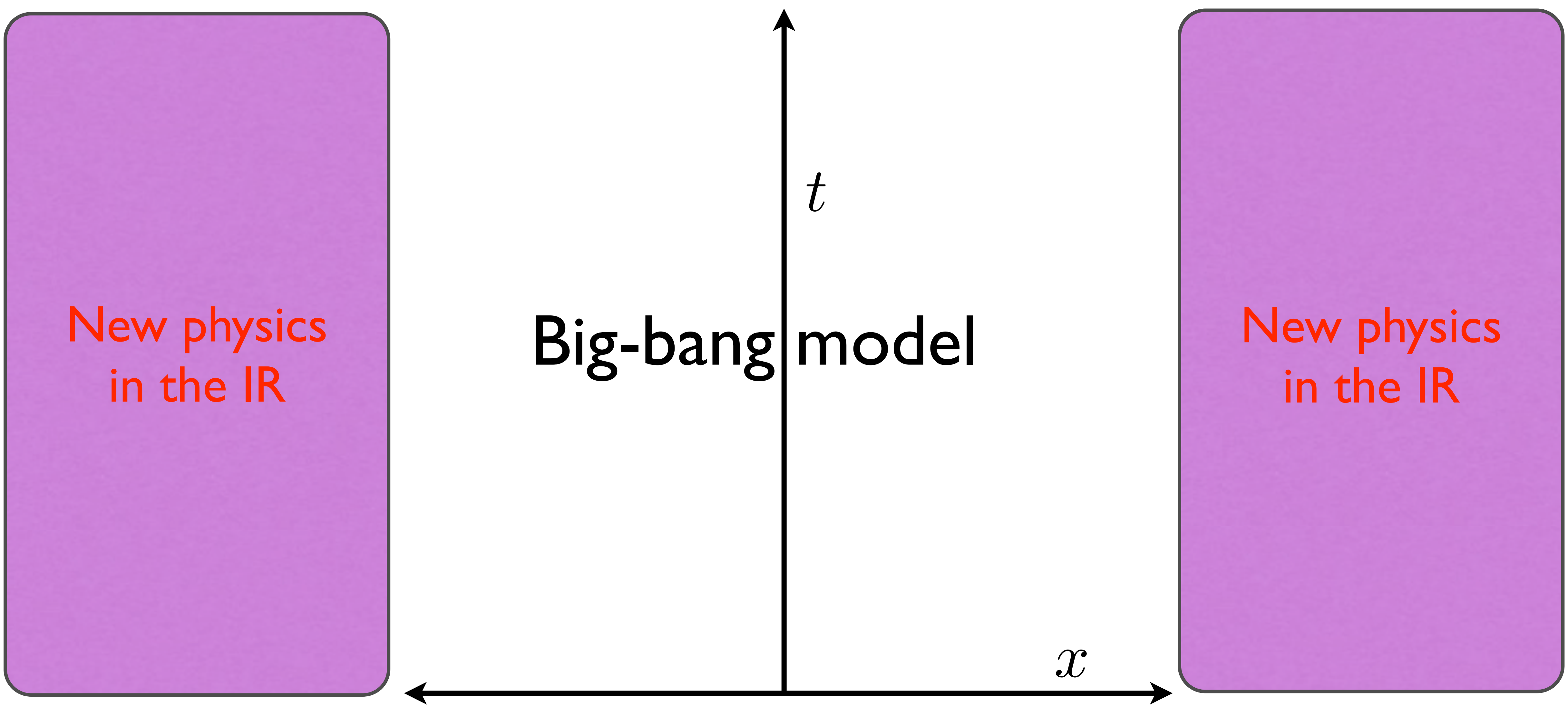
THE IDEA

1) Keep the expansion as in the BB model as a local phenomenon

2) Change the GR geometrical description in the IR, i.e. at $d \sim H^{-1}$



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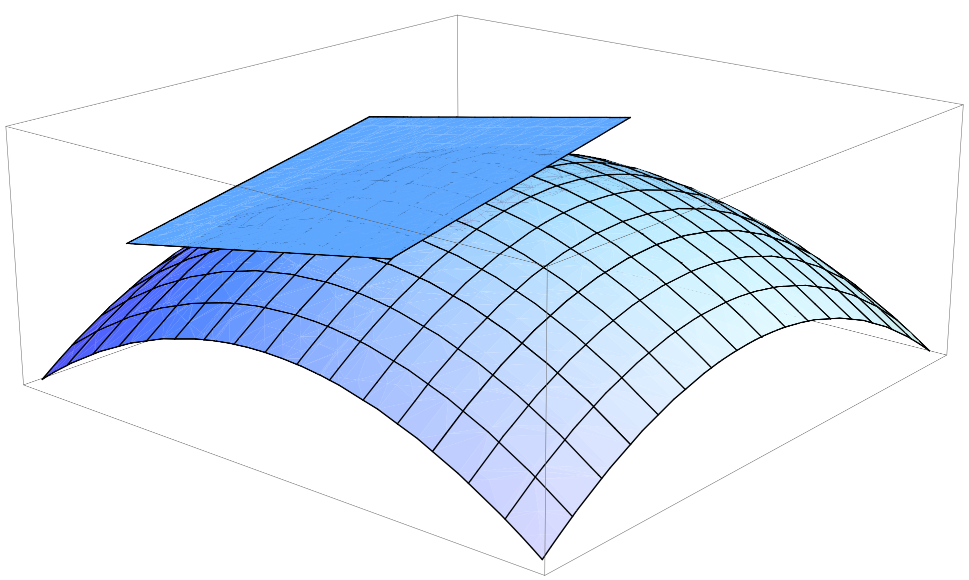

As much as GR is an
IR modification of... flat space!

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5) Analogous to Tolman-Bondi models, but homogeneous!

connection with previous work: The Extreme Equivalence Principle

F.P. arXiv:0907.0765, etc...

$$\langle T^0_0 \rangle_{\rm bare} \quad = \quad \int d^3k \left(k + \frac{f_{\rm quad}(t)}{k} + \frac{f_{\rm log}(t)}{k^3} + \ldots \right)$$

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1) GR static spacetimes are unchanged

2) GR time dependent spacetimes: corrected

$$\dot{\vec{X}} = H\vec{X}(1 + g(X)) \qquad\qquad g(X) \sim H^2X^2 + \mathcal{O}(X^4)$$

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What to do without a metric: recipe

1) Scene: a flat, pre-relativistic (Newtonian) space

2) A set of privileged observers: the comoving ones

3) Consider one observer at $\vec{X} = 0$

4) The Hubble velocity field $\vec{h}(\vec{X})$: the velocity of the other comoving obs.

5) Give a prescription for velocity transformations among comoving obs.

Warm-up: FRW without GR

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Proper distance   comoving coordinates

$$\vec{X}(t) = a(t)\vec{x}$$

Hubble velocity field

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Proper distance → $\vec{X}(t) = a(t)\vec{x}$ ← comoving coordinates

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The expansion looks centered around the origin.
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This will be our definition of homogeneity

Warm-up: FRW without GR

1) Note that velocities can be >1

2) This is fine cause velocities defined somewhere else are not measurable

3) What needs to be at most one is the local velocity

$$v_{\vec{X}}(\vec{X}) \leq 1$$

4) A light ray is a curve $L(t)$ that has always unit local velocity:

$$\frac{d\vec{L}_{\vec{L}}(t)}{dt} = 1 \quad \Rightarrow \quad \frac{dL}{dt} = 1 + HL \quad \Rightarrow \quad \frac{dl}{d\tau} = 1$$

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IR-modified FRW (or: enforcing homogeneity)

Hubble velocity field $\vec{h}(\vec{X}) = H\vec{X}\,[1 + g(X;t)]$

This might happen also in a Tolman-Bondi...
Enforce homogeneity by postulating a velocity transformation

$$\vec{v}_{\vec{A}}(\vec{X}) = \left(\frac{\vec{v}(\vec{X})}{1+g(X)} - H\vec{A}\right)\left(1 + g(|\vec{X} - \vec{A}|)\right)$$

$$\vec{h}_{\vec{A}}(\vec{X}) = \vec{h}(\vec{X} - \vec{A})$$

IR-modified FRW: light rays

As before, light rays have always unit local velocity

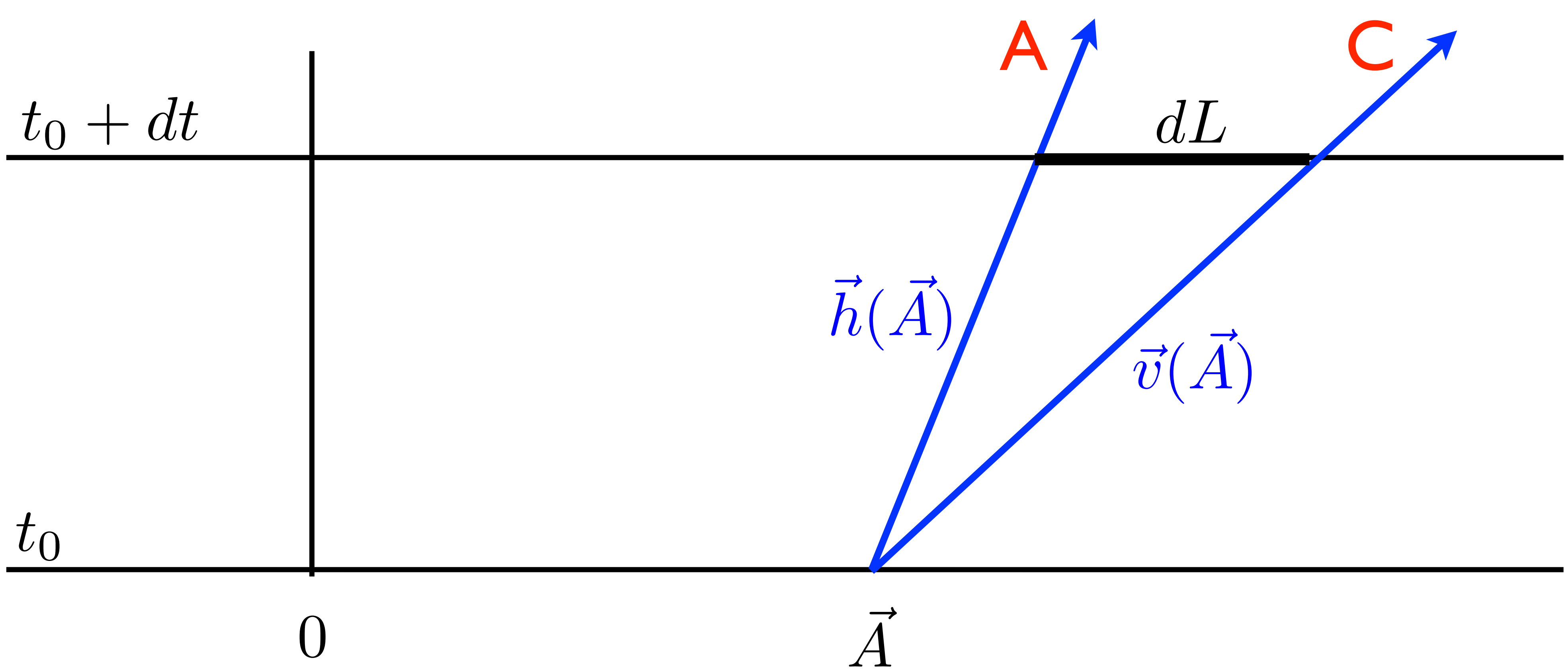
$$\frac{d\vec{L}_{\vec{L}}(t)}{dt} = 1 \quad \Longrightarrow \quad \frac{dL}{dt} = (1 + HL)\,(1 + g(L))$$

IR-modified FRW: the puzzle

1) Take a comoving observer A going with the Hubble flow

2) Take another non-comoving observer with velocity $\vec{v}(\vec{A})$ (from the origin)

3) They are close to each other but very far from 0

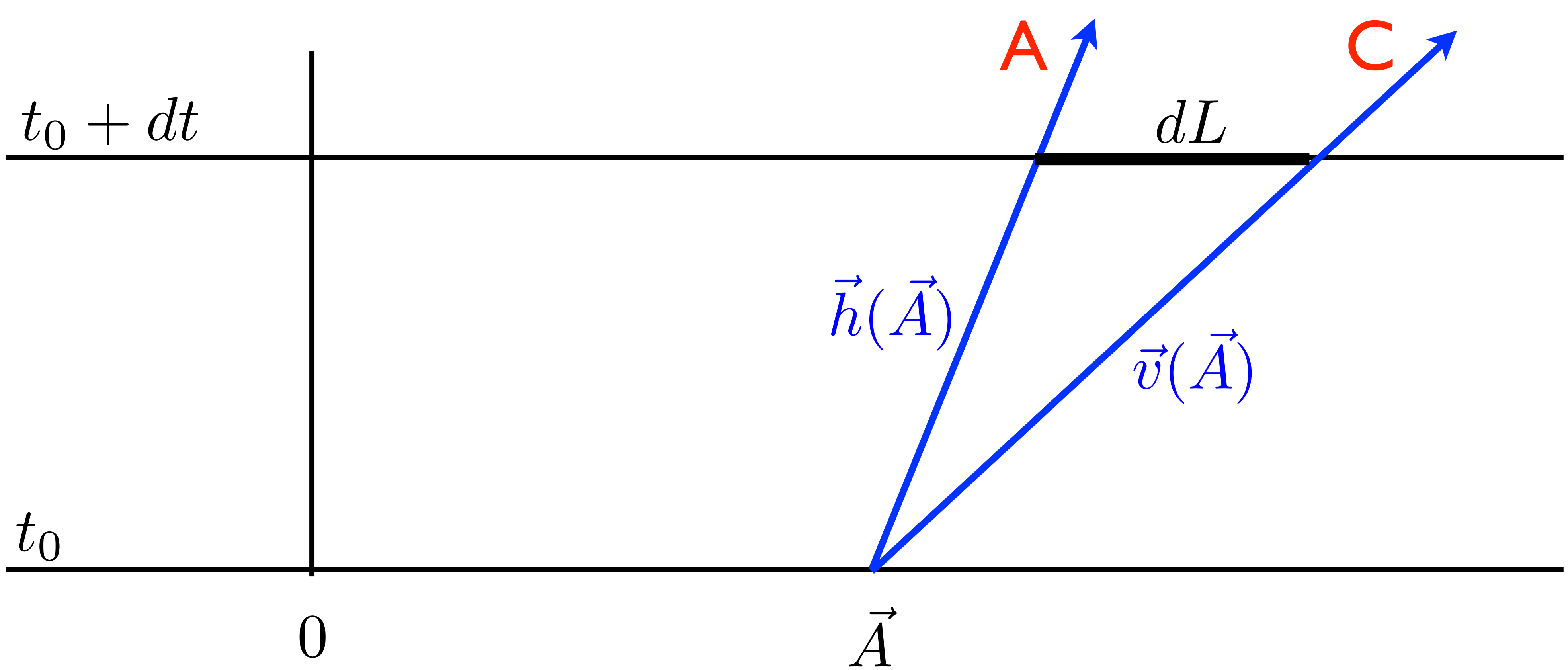


IR-modified FRW: the puzzle

After dt two different accounts of the distance dL:

locally: $d\vec{L} = \vec{v}_{\vec{A}}(\vec{A})dt$ from the distance: $d\vec{L} = (\vec{v}(\vec{A}) - \vec{h}(\vec{A}))dt$

$$d\vec{L}(\text{`seen from distance } X') = (1 + g(X))d\vec{L}$$



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1) In an expanding universe distances on t=const slices do not add up

2) Therefore the observer 0 should not calculate dL by a subtraction

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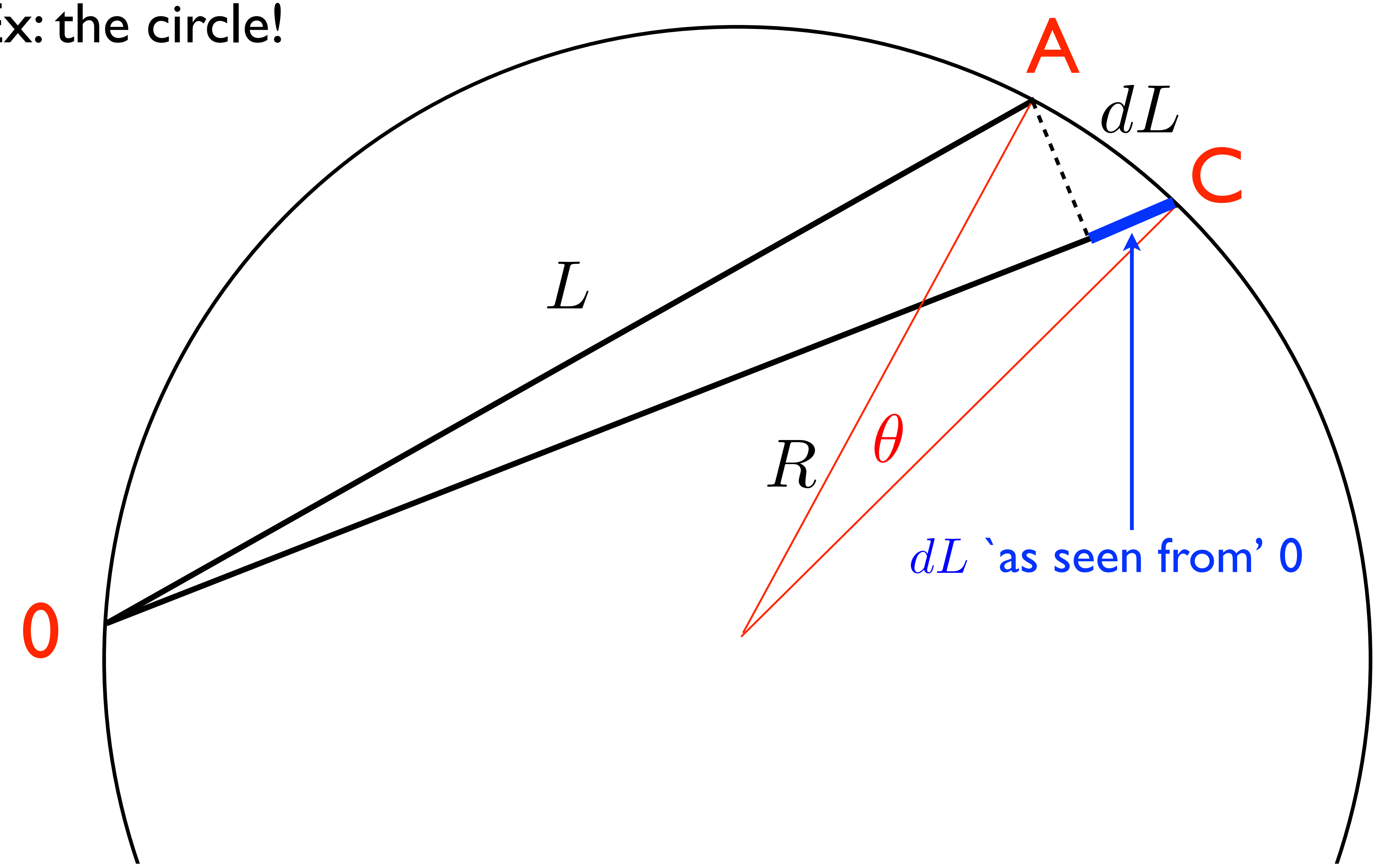
3) Ex: the circle!



F.P. in progress

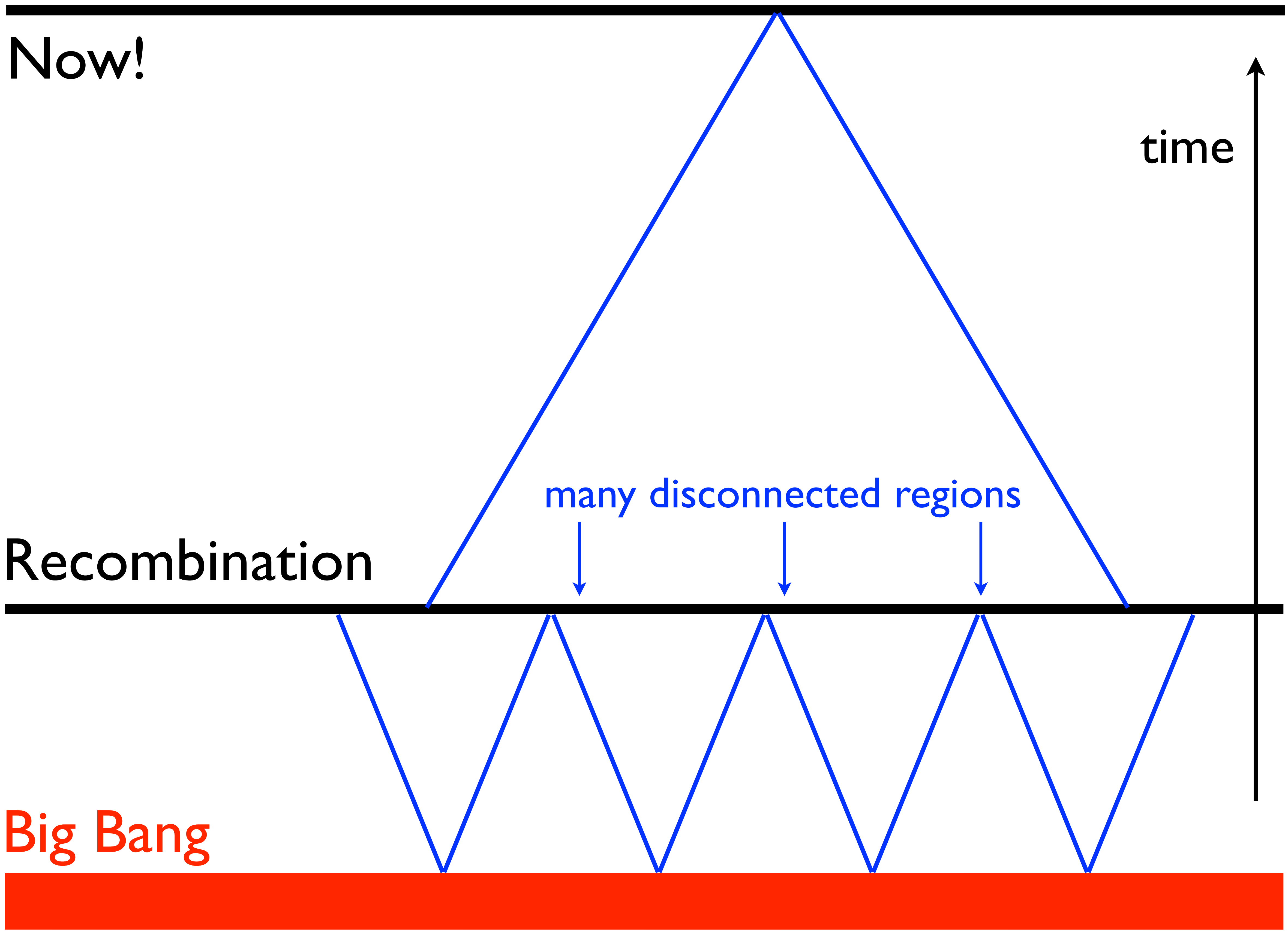
IR-modified FRW: the proposal

1) Take the t=const metric manifold of FRW (e.g. 3d flat space)

2) This is also a metric space at least locally (geodesic distance)

3) Take a concave increasing function of geodesic distance and define a new metric space

4) You can assign distances to any pair of points but not lengths to curves


Now!
time
many disconnected regions
Recombination
Big Bang