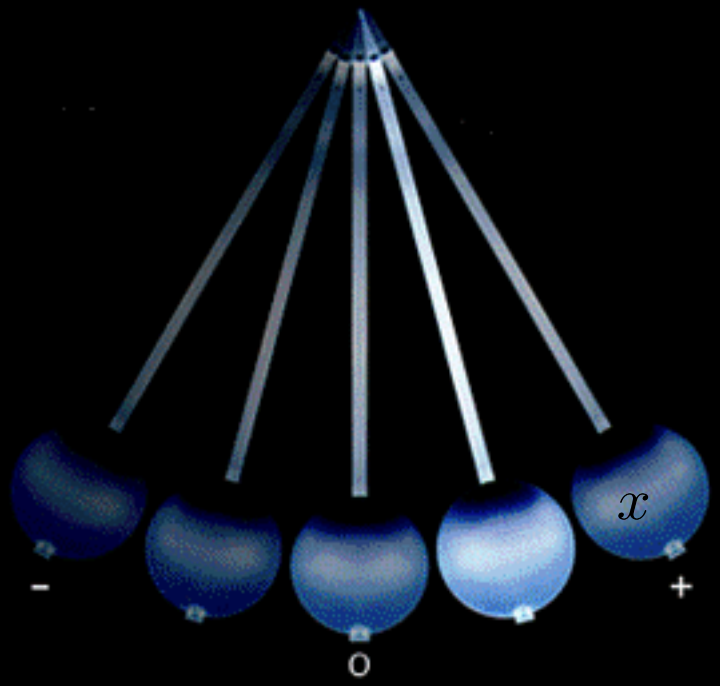
RELATIONAL

TIME

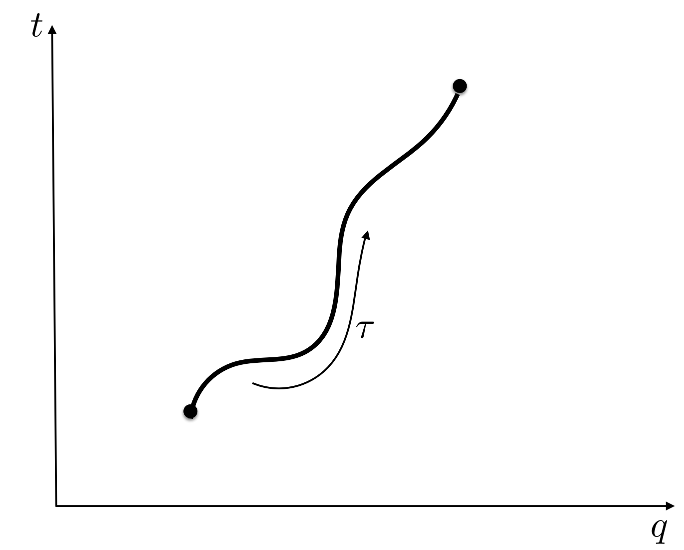


MEASURED
VARIABLES

TIME IS JUST A VARIABLE LIKE ANY OTHER...

General covariant mechanics

$$q(t) \to \begin{cases} q(\tau) = f(\tau)^2 \\ t(\tau) = f(\tau)^3 \end{cases}$$



"large" gauge invariance: redundancy of the parametrization

$$\mathcal{S}[q] = \int_t^{t'} d\tilde{t}\, \mathcal{L}\left(q(\tilde{t}), \dot{q}(\tilde{t})\right) \qquad \mathcal{S}[q,t] = \int_\tau^{\tau'} d\tilde{\tau}\, \frac{dt(\tilde{\tau})}{d\tilde{\tau}}\, \mathcal{L}\left(q(\tilde{\tau}), \frac{dq(\tilde{\tau})/d\tilde{\tau}}{dt(\tilde{\tau})/d\tilde{\tau}}\right)$$

$$\mathcal{L}(q,\dot{q}) = \frac{1}{2}m\dot{q}^2 - V(q) \qquad \mathcal{L}(q,t,\dot{q},\dot{t}) = \frac{1}{2}m\frac{\dot{q}^2}{\dot{t}} - \dot{t}V(q)$$

$$H_o(p_q,q) = \frac{p_q^2}{2m} + V(q) \qquad H = \dot{q}\,\frac{\partial\mathcal{L}}{\partial\dot{q}} + \dot{t}\,\frac{\partial\mathcal{L}}{\partial\dot{t}} - \mathcal{L} = 0$$

$$q:\ \frac{\mathrm{d}}{\mathrm{d}\tau}m\frac{\dot{q}}{\dot{t}} + \dot{t}\,\nabla_q V = 0$$ Newton equation

$$t:\ \frac{\mathrm{d}}{\mathrm{d}\tau}\left(-\frac{1}{2}m\left(\frac{\dot{q}}{\dot{t}}\right)^2 - V(q)\right) = 0$$ Energy conservation

$$p_q = \frac{\partial\mathcal{L}}{\partial\dot{q}} = m\frac{\dot{q}}{\dot{t}}$$

$$p_t = \frac{\partial\mathcal{L}}{\partial\dot{t}} = -\frac{1}{2}m\left(\frac{\dot{q}}{\dot{t}}\right)^2 - V(q)$$

$(\dot{t},\dot{q}) \to (p_t,p_q)$ is not invertible: only where the constraint $C = p_t + H_o(p_q,q) = 0$ holds!

General covariant mechanics

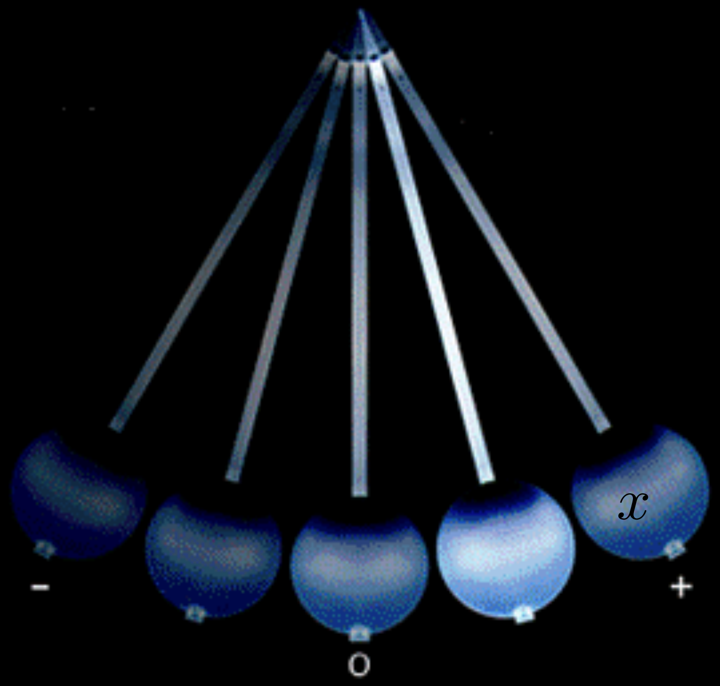
$$H = 0$$

- a change in τ is pure gauge, the generator of a gauge transformation vanishes (weakly)
- no "frozen dynamics", just relational evolution
- $\frac{dA}{d\tau} = \{A, C\}$ the Poisson bracket with C gives the eq. of motion

Special Relativity: $\mathcal{S} = m \int d\tau \sqrt{\dot{x}^\mu \, \dot{x}_\mu}$ $\qquad C = p^2 - m^2 = 0$

General Relativity: $S[g] = \int d^4x \sqrt{-\det g} \, R[g]$

- The canonical hamiltonian vanishes and the dynamics is coded in the constraints.
- The dynamics does not describe the evolution of the gravitational field $\boldsymbol{g_{\mu\nu}(x)}$
  and other matter fields, as functions of $\boldsymbol{x}$ (this is just gauge),
  but rather the relative evolution of the fields with respect to one another.



MEASURED
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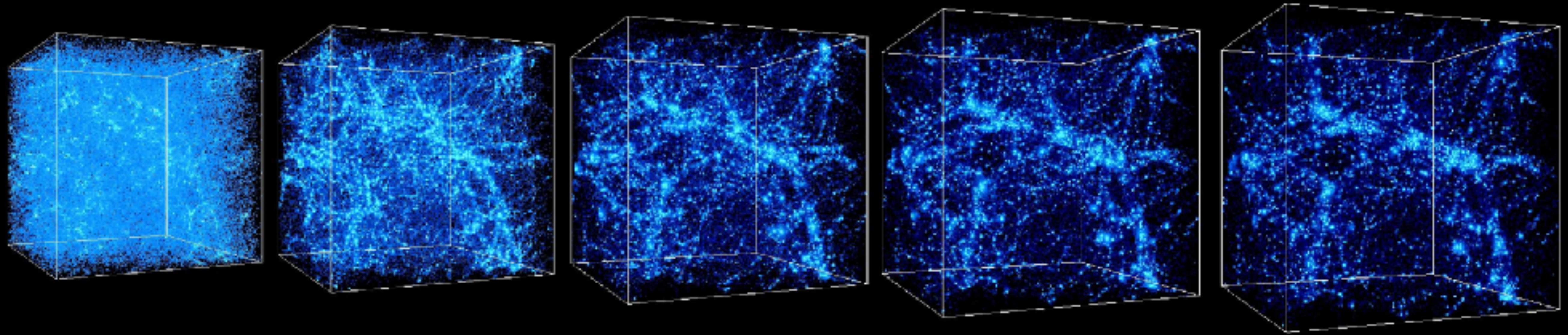
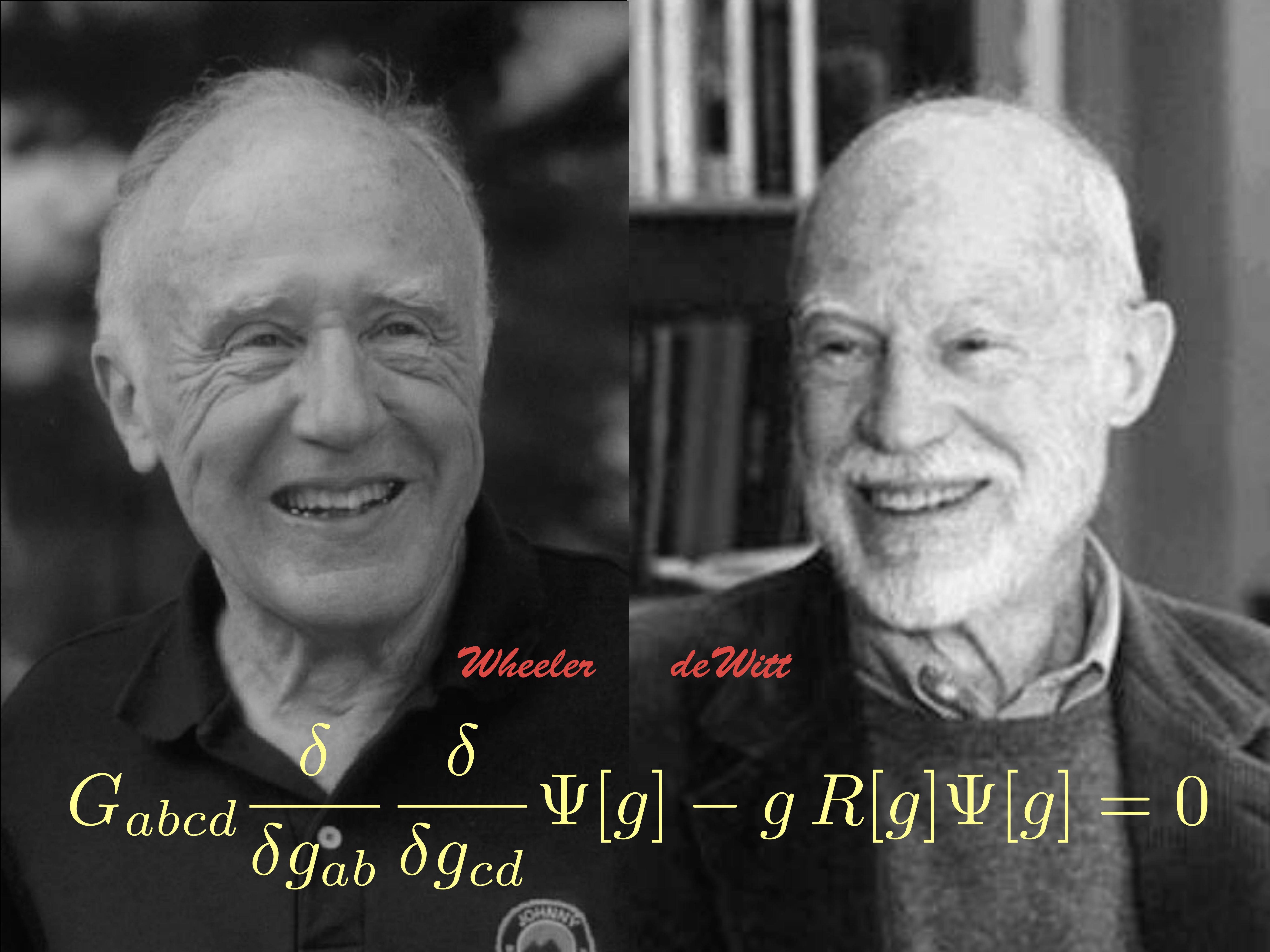


TIME IN
QUANTUM GRAVITY


Wheeler
deWitt
$$G_{abcd}\frac{\delta}{\delta g_{ab}}\frac{\delta}{\delta g_{cd}}\Psi[g] - g\,R[g]\Psi[g] = 0$$

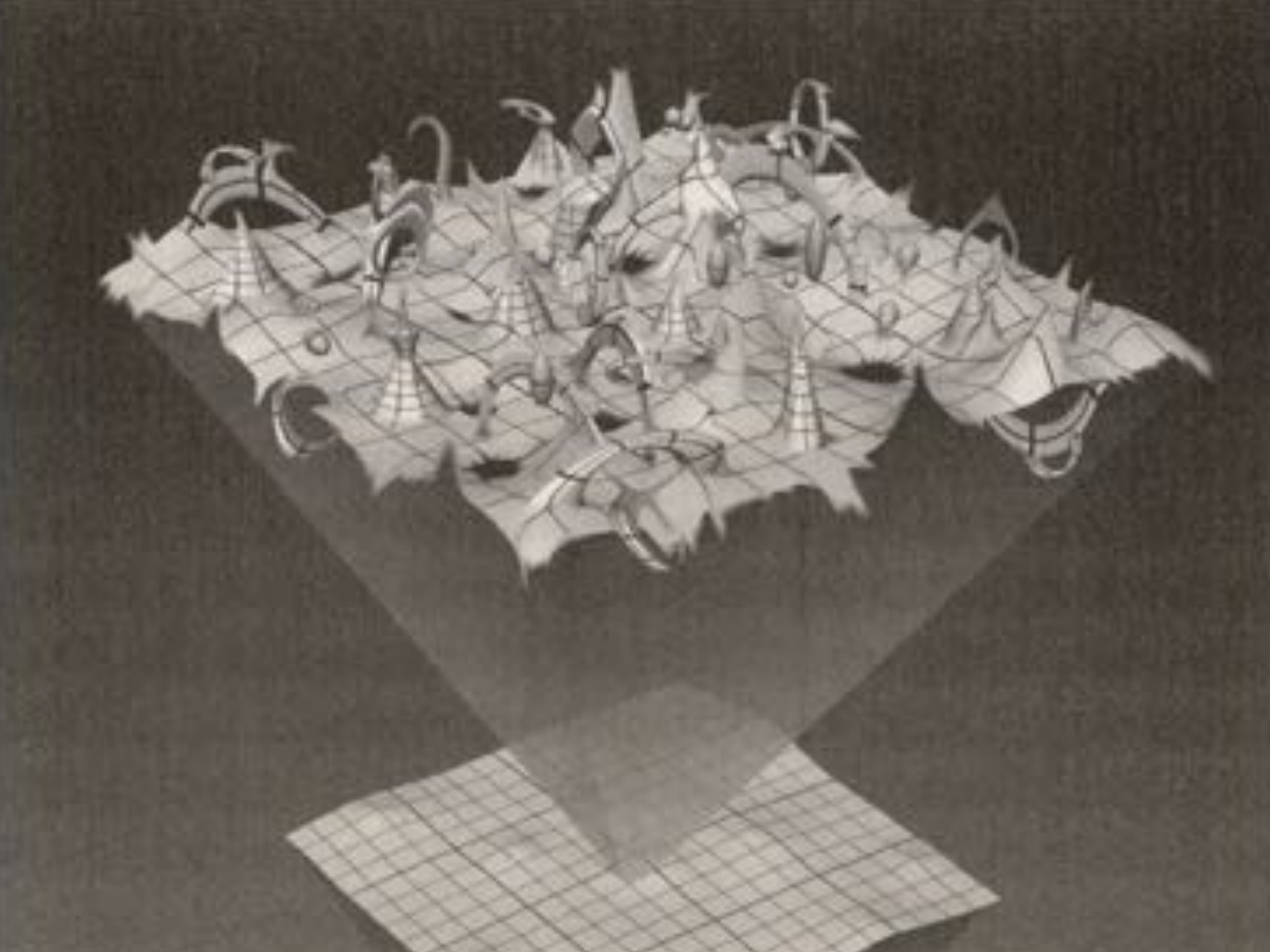
Quantum General Covariance

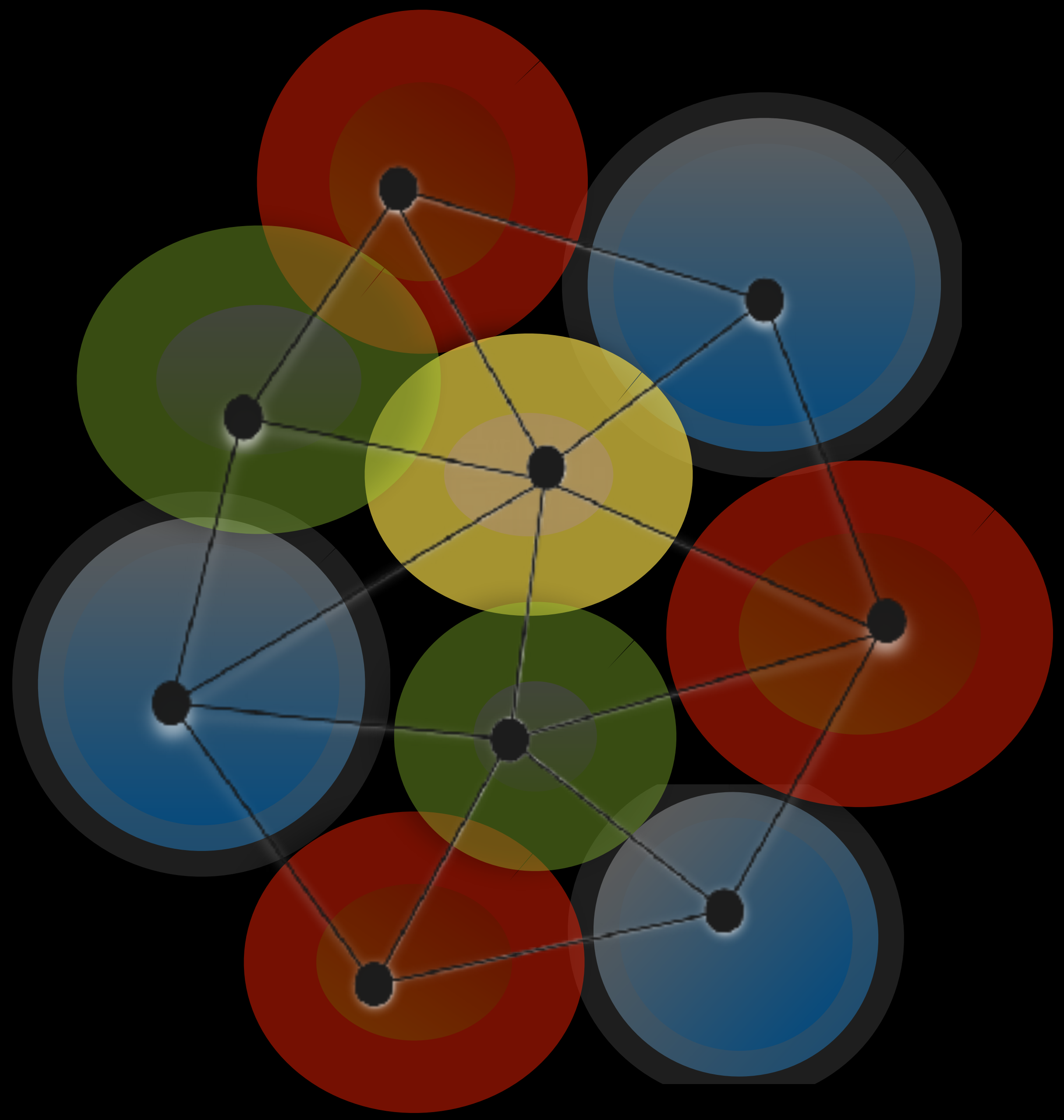
$$\hat{H} = 0$$

- The Hamiltonian operator is the generator of time translation
- Time is pure gauge, the Hamiltonian operator vanishes
- But again: no "frozen dynamics", just relational evolution

$$\hat{H}|\psi >= 0$$

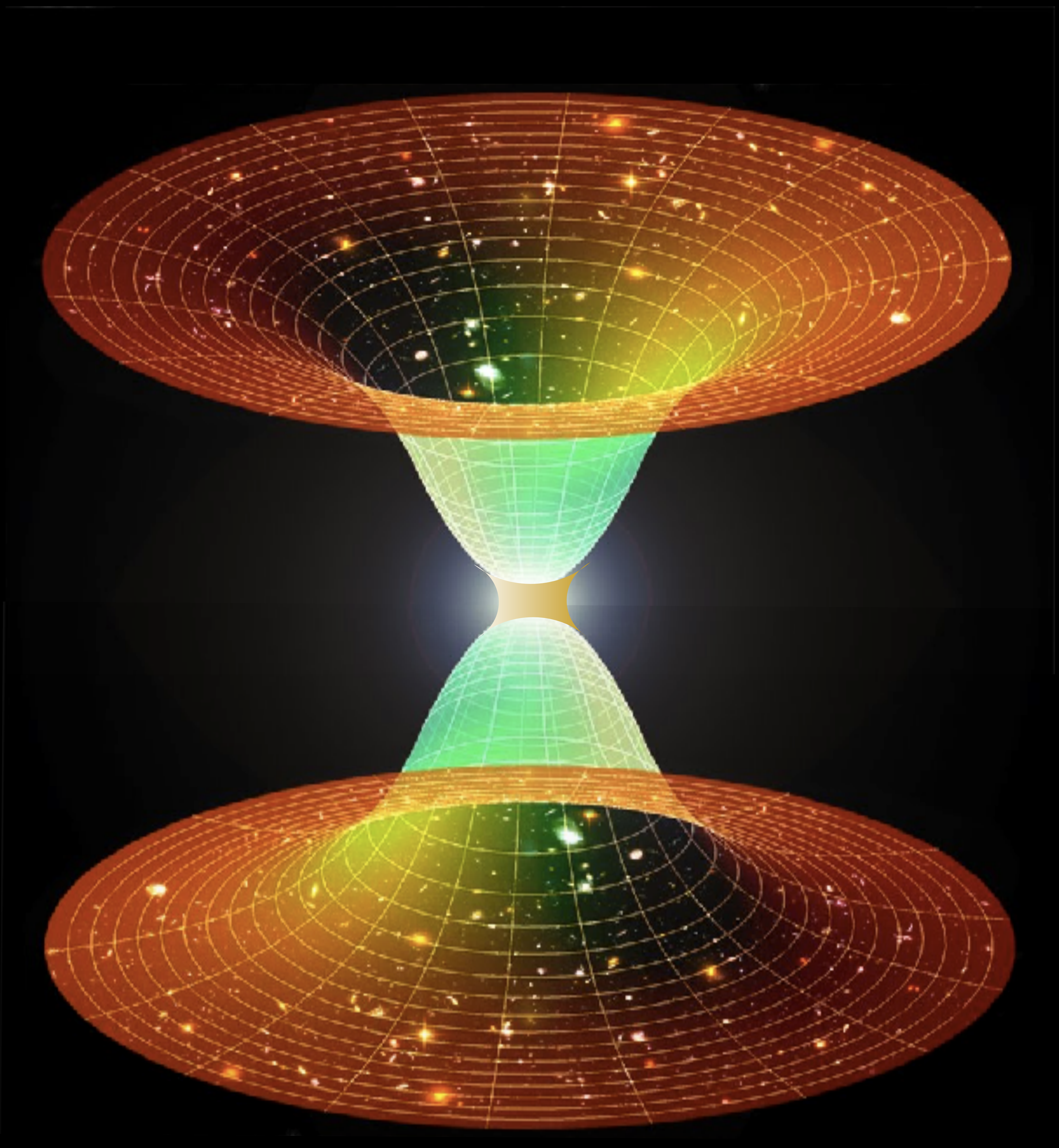
DISCRETE
TIME

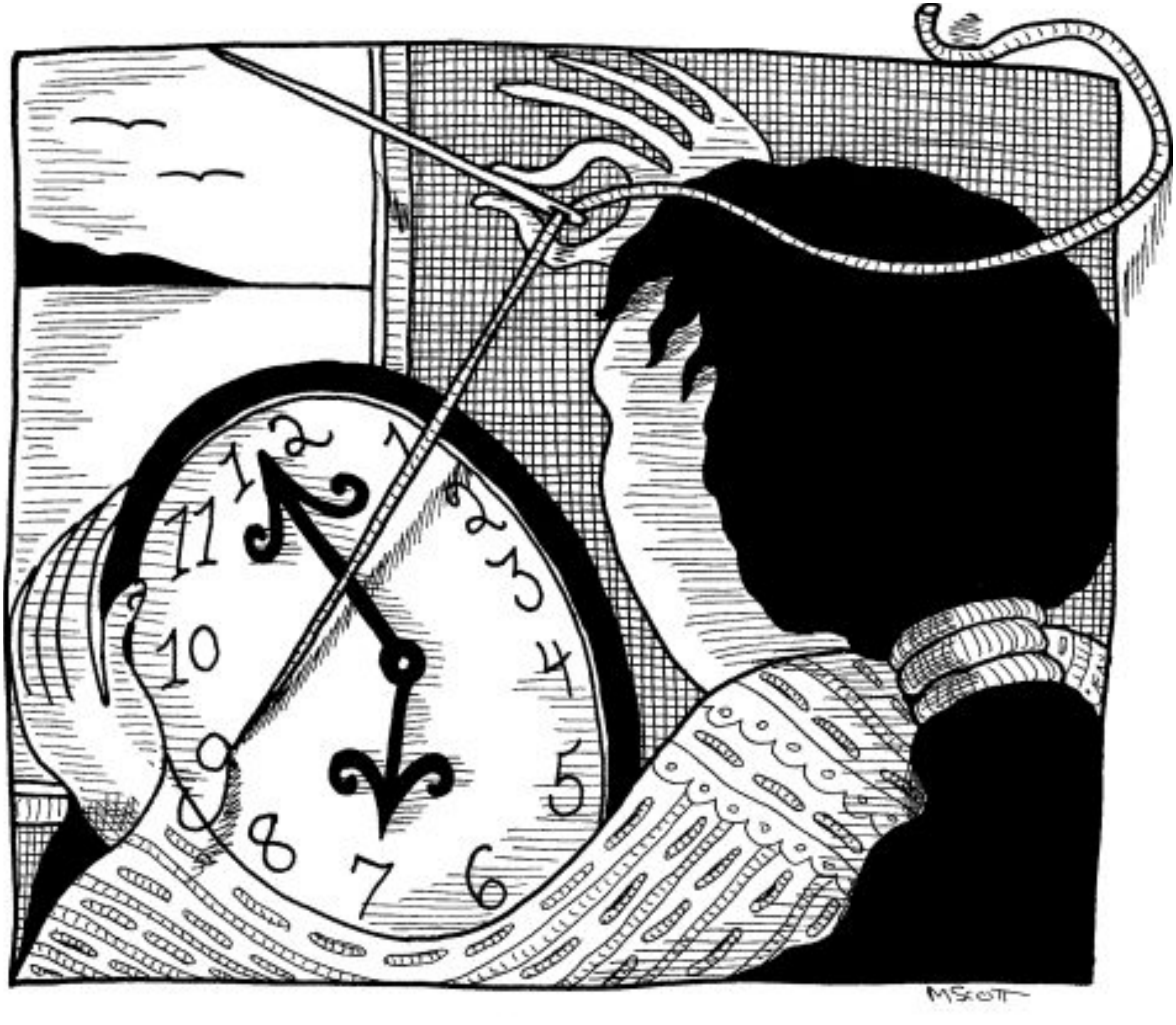




ontology of Events, not objects,

SPARSE, LOCAL, RELATIONAL




MSCOTT

LA RECHERCHE
DU TEMPS
(PERDU ?)

THERMAL

TIME


Connes


Rovelli

Time is the informations we don't have

Time is our ignorance

Thermal Time

Connes&Rovelli gr-qc/9406019

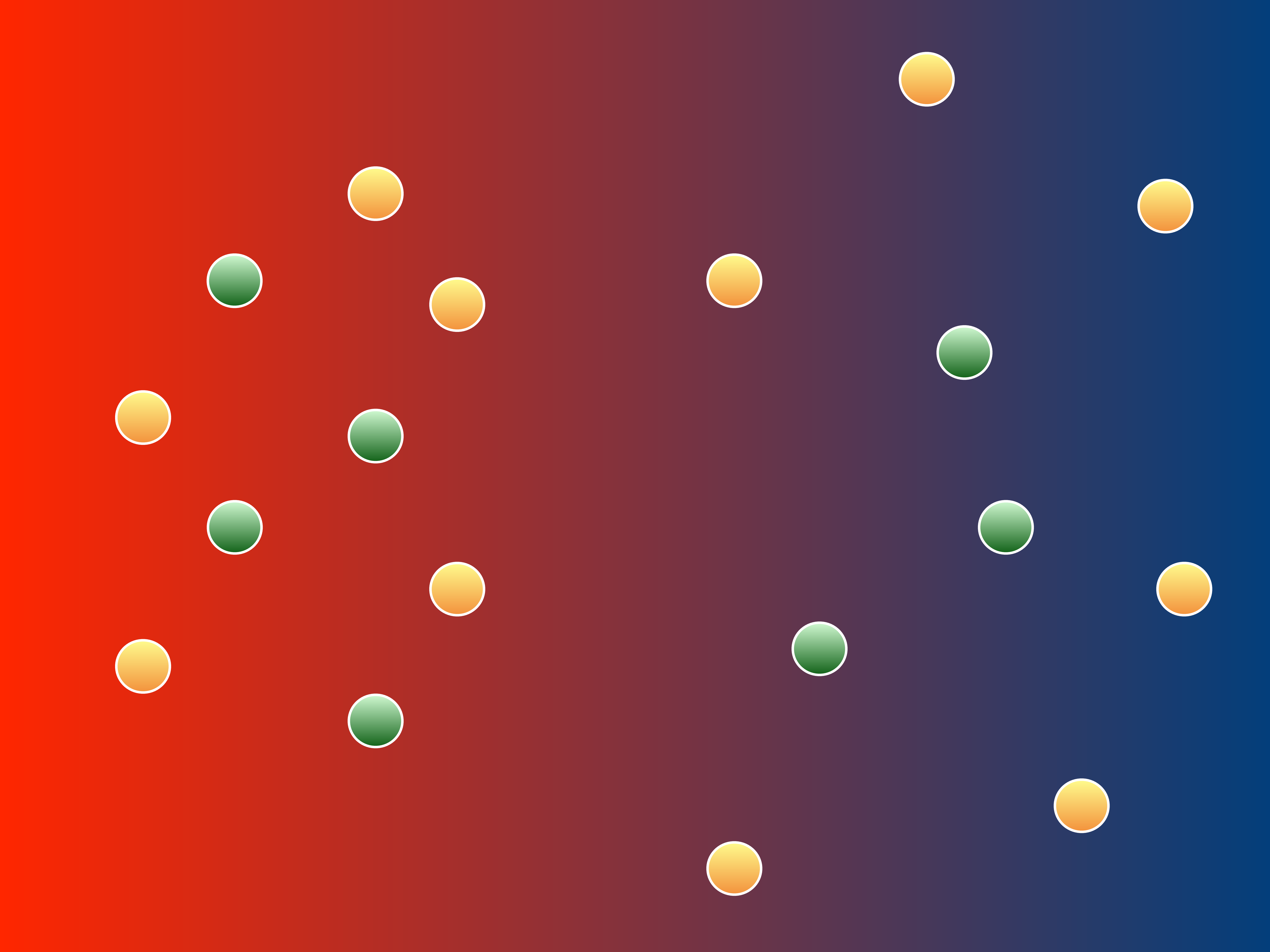
- **Macroscopic Observables** interact with the system
- Coarse grain: microscopic dof are traced out
- Appearance of a density matrix ⇒ thermal properties

$$\rho = e^{-\beta H} \qquad \beta = 1/k_b T$$

There is a classical hamiltonian H that generates the Hamilton evolution, and that the state ϱ is related to this hamiltonian by the Gibbs relation.

PERSPECTIVAL

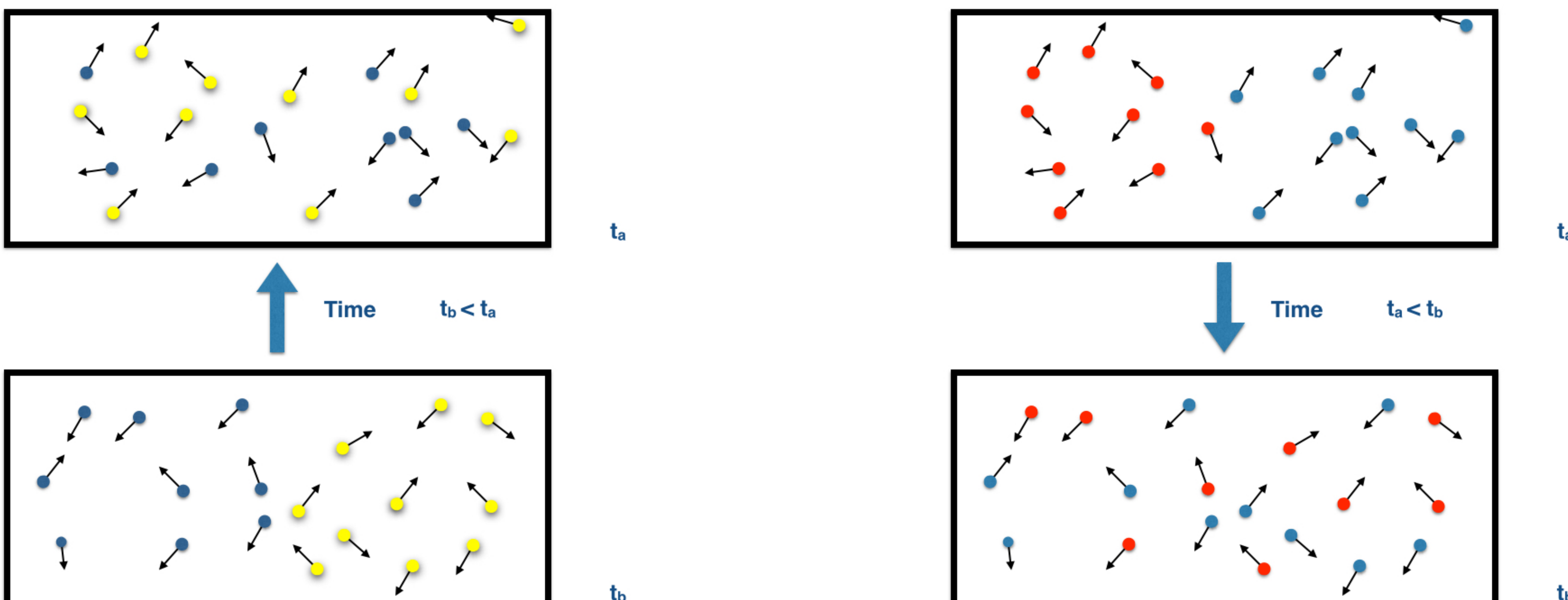
TIME'S ARROW



Perspectival Time's Arrow

Rovelli 1505.01125

- Conjecture: In a sufficiently complex system, there is always some subsystem whose interaction with the rest determines a coarse graining with respect to which the system satisfies the second law of thermodynamics (in some time direction).



Summary:

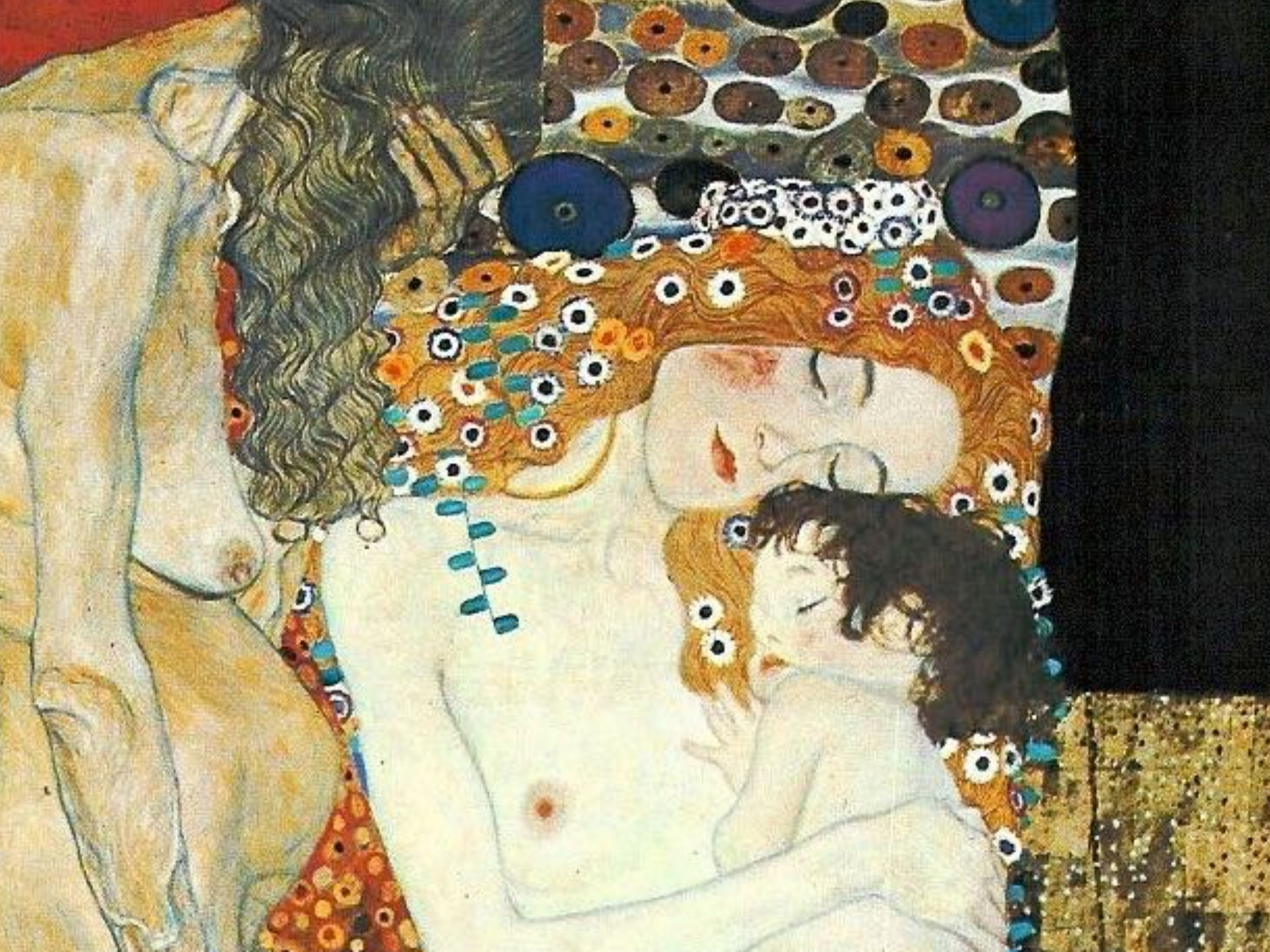
1. General Relativity

   Time disappears already at the classical level because of covariance

2. Quantum Gravity

   Time cannot be recovered, only relationally

3. Thermodynamics
4. Relational & Perspectival



Feminist Empiricist Standpoint Theory

knowledge is situated but not less objective