Title: Vacuogenesis in Discrete Cosomology

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Abstract:

# Vacuogenesis

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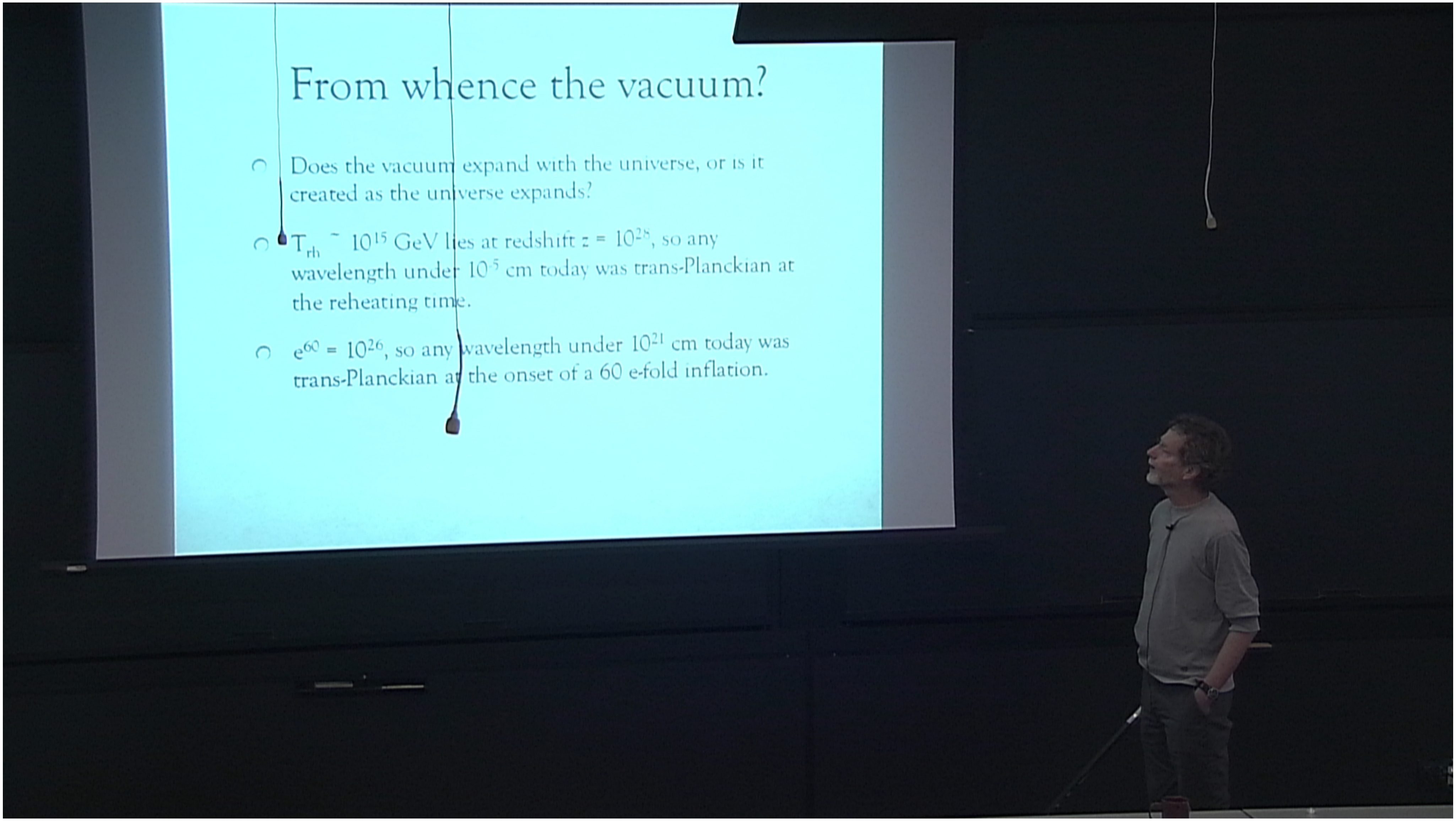
# From whence the vacuum?

- Does the vacuum expand with the universe, or is it created as the universe expands?
- $T_{rh} \sim 10^{15}$ GeV lies at redshift $z = 10^{28}$, so any wavelength under $10^{-5}$ cm today was trans-Planckian at the reheating time.
- $e^{60} = 10^{26}$, so any wavelength under $10^{21}$ cm today was trans-Planckian at the onset of a 60 e-fold inflation.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# Deep reservoir?

- Perhaps there is indeed a trans-Planckian reservoir. How could this be realized?
- Asymptotically Safe QG: infinitely deep reservoir of standard qft modes. (N.B. This creates a problem for black hole entropy. Is it solved by the running of R^2 terms? Let's check!)
- String theory? A background bounce via duality at the string scale does not provide an answer. I don't know whether a string cosmology can answer this question.

# Mode creation?

- Free field model: on a circle of length a(t) the allowed wavenumbers are

$$k(t) = 2\pi\, n/a(t), \text{ with } 1 \le n \le k_{max}a(t)/2\pi,$$

where $k_{max}$ is the maximum wavenumber. When a(t) grows to admit another integer n, create the corresponding mode and place it in its adiabatic ground state.

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# Interactions?

- If field is asymptotically free, or modes are non-interacting at cutoff scale, they can be born in the adiabatic vacuum, then redshifted into interaction. Depending on the relation between mode cutoff, interaction cutoff, and expansion rate, perhaps the unexcited vacuum can emerge.
  - If mode coupling cutoff violates Lorentz symmetry, hypersurface-orthogonal Einstein-aether (khronometric) effective action is generated. (W. Donnelly & TJ, unpublished)
  - If field theory is Lorentz invariant ...?
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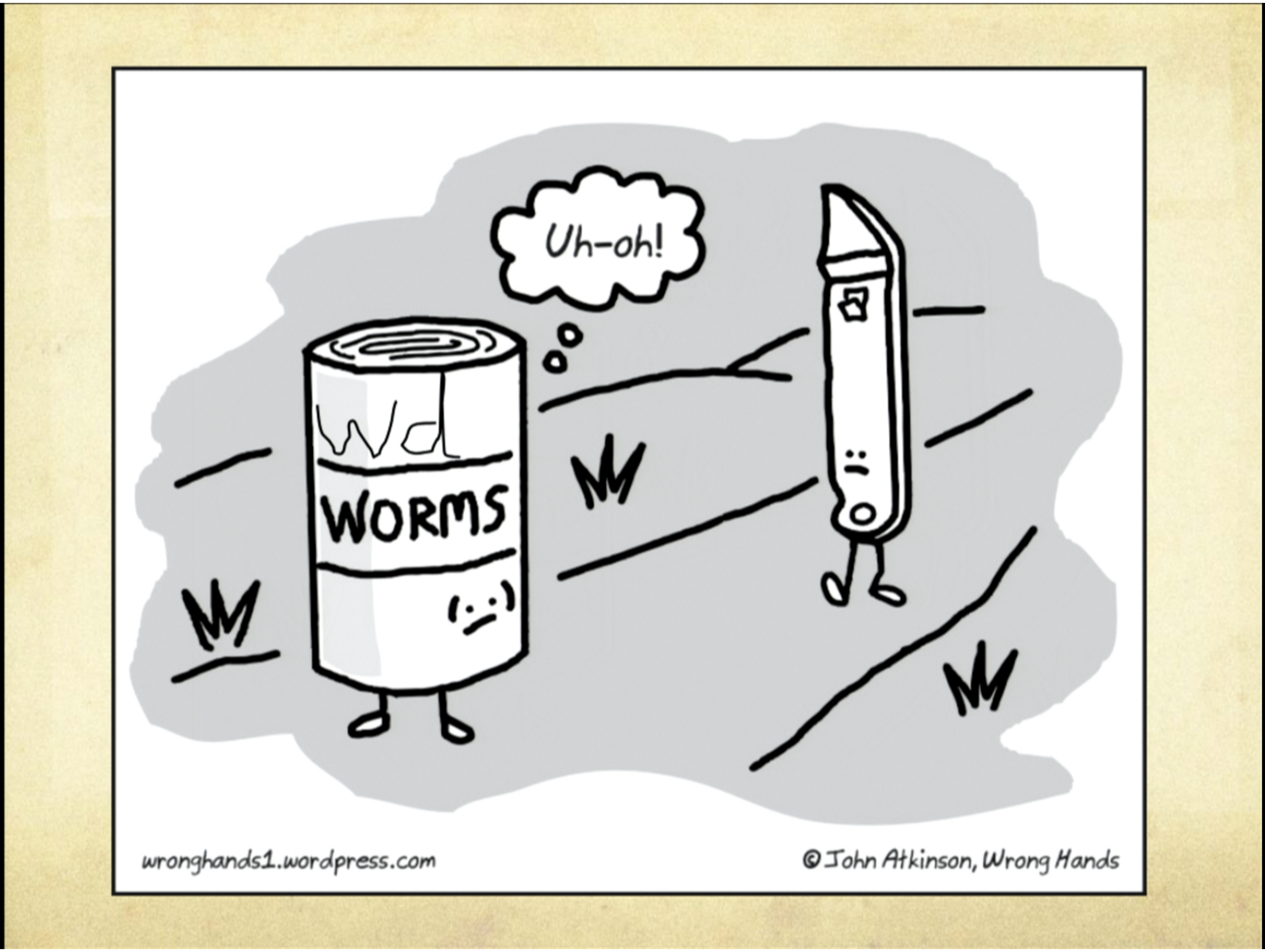
# Zero point energy and gravitation

- Aside from possible interaction energy, each new mode has a zero point energy, which redshifts. Is regularization of the effective action by local counterterms, which ensures general covariance and a consistent semi-classical Einstein equation, compatible with mode birth?
- It seems likely that the answer is "no" unless the mode is born gravitating, i.e. is born into a quantum state satisfying the gravitational Hamiltonian (diffeomorphism) constraint equation (Wheeler-deWitt equation), since that ensures both covariance and zero energy.
- Robert Brout wrote about gravitating mode birth in several papers.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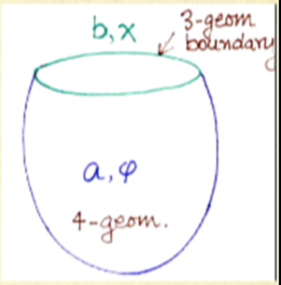
# Wheeler-DeWitt worms

- Can the equation even be mathematically well-defined?
- What does the wave function mean?
- Does it give probabilities? For what?

# No boundary wavefunction

- Hartle & Hawking proposed to specify the solution to the Wheeler-DeWitt equation by a path integral over metrics and matter fields on a 4-manifold with one boundary, corresponding to a spatial hypersurface.




- The contour of integration has been much discussed; I don't know how well it is understood.
- The integral is wildly ill-defined. Might try continuum regularization with spectral cutoff, or discrete regularization a la Regge, CDT, spin-foam, tensor network, or ...
- The integral is both the law and the "initial conditions".

# No boundary vacuougenesis?

- Vacuogenesis appears natural in this setting: boundaries with greater volume would have more "modes" in a regulated version. If the regulator preserves the symmetry enough that the WdW eqn is satisfied, it seems that even non-asymptotically free interacting matter and gravity could be generated in the appropriate (local vacuum) ground state.