Title: Quantum Gravity Effects in the (Early and Late) Universe

Date: Oct 23, 2012 10:20 AM

URL: http://pirsa.org/12100090

Abstract: Quantum Gravity at the origin of seeds of cosmic structure?
This meeting shows a our impatience for uncovering at long last any signal of unknown physics that might have a quantum gravitational origin. I will argue that the transition from a homogenous and isotropic state characterizing the mid-early parts of inflation (i.e. the regime after sufficient e- folds of inflation have elapsed so that all traces of the pre-inflationary state are erased), to those eras, where the primordial inhomogeneities have appears might hold ins testing clues about the nature of quantum gravity

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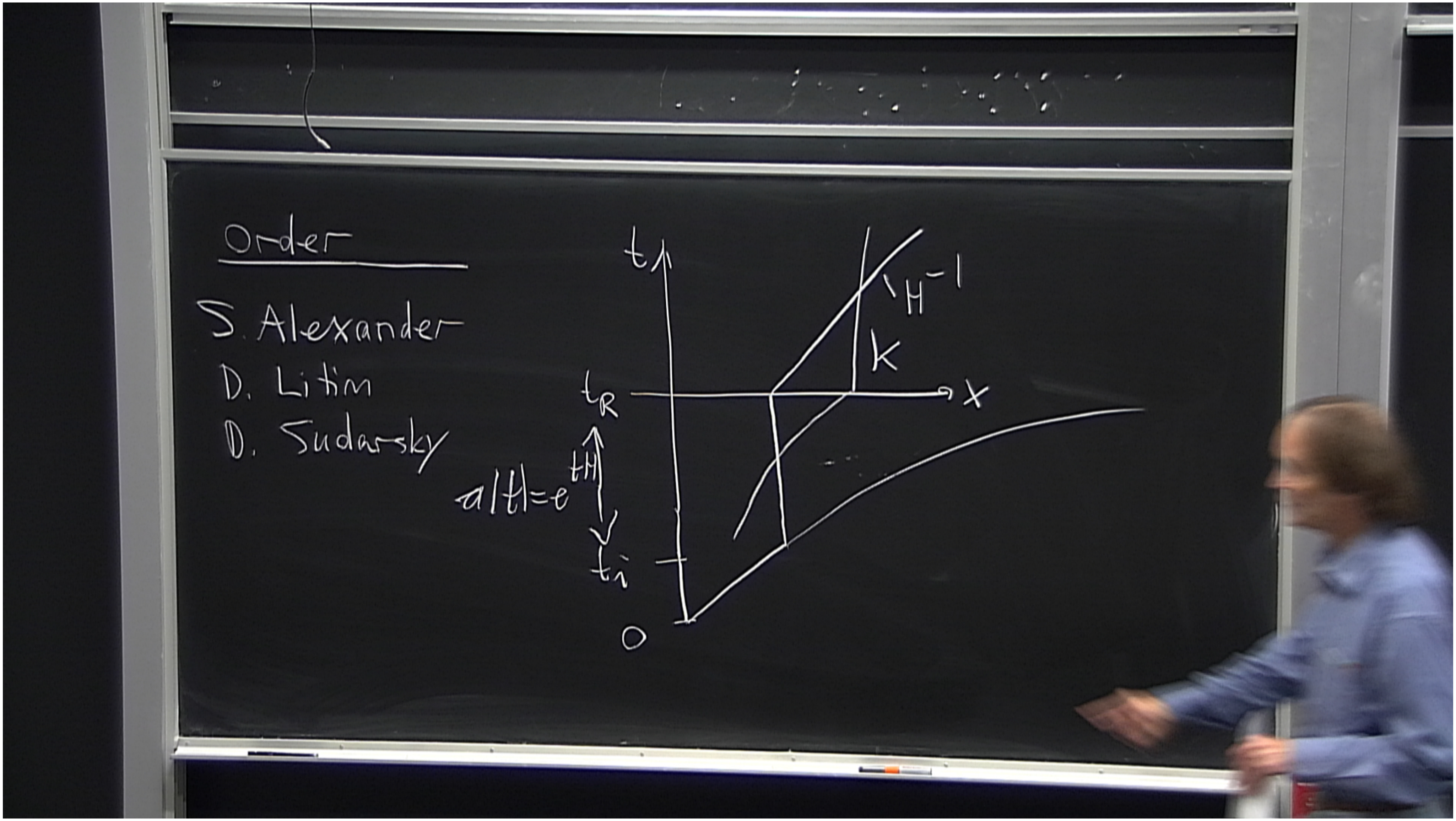
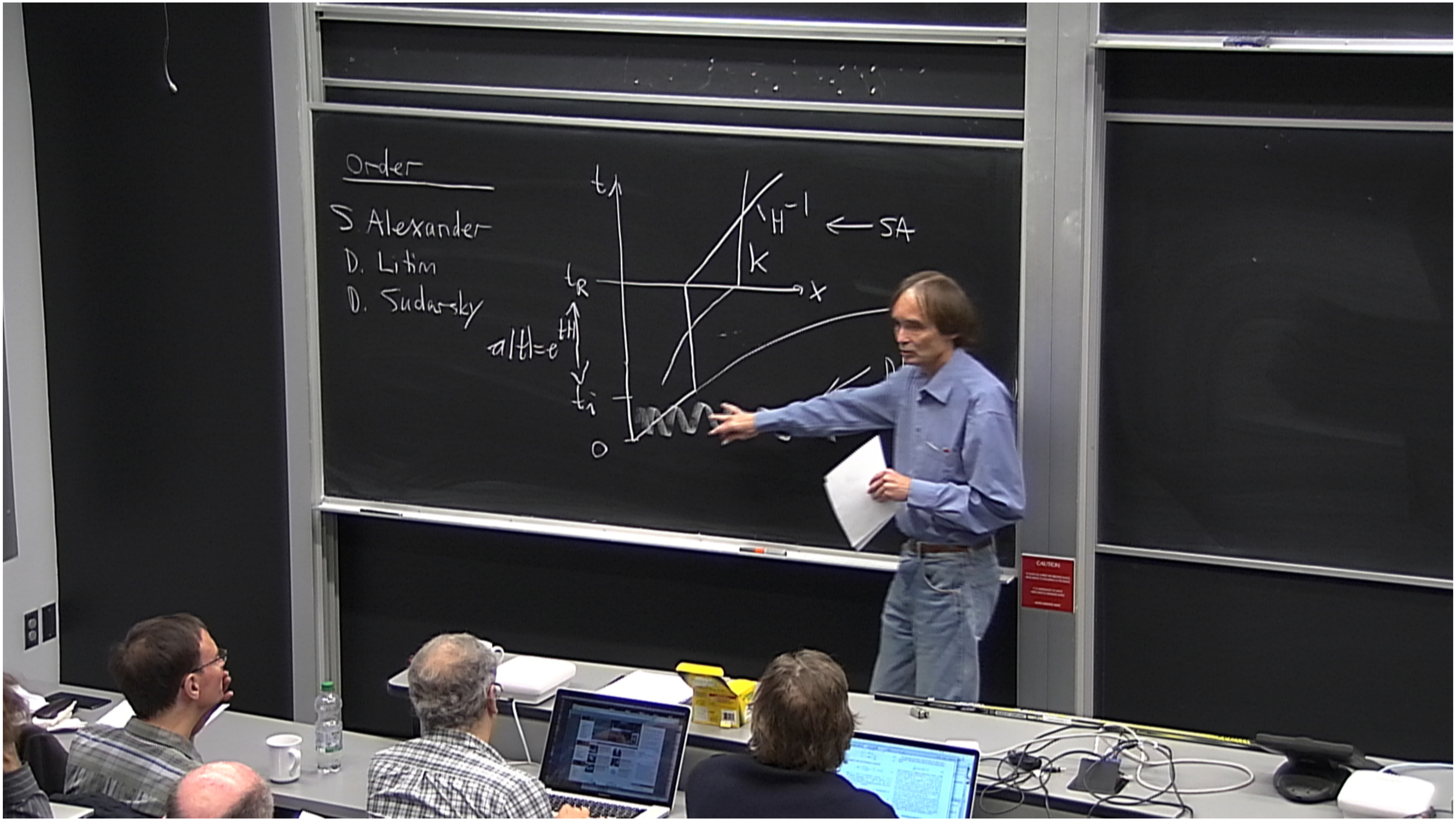
Quantum gravity and cosmology
In the light of upcoming high-precision data from the Planck
mission and possible trans-Planckian signatures encoded in eg the
microwave background radiation, and in view of possible large-distance
modifications of gravity and the accelearted expansion of the universe



Order
S. Alexander
D. Litim
D. Sudarsky
t
x
H^{-1}
k
t_R
$a(t) = e^{tH}$
t_i
0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a(t)=e^tH
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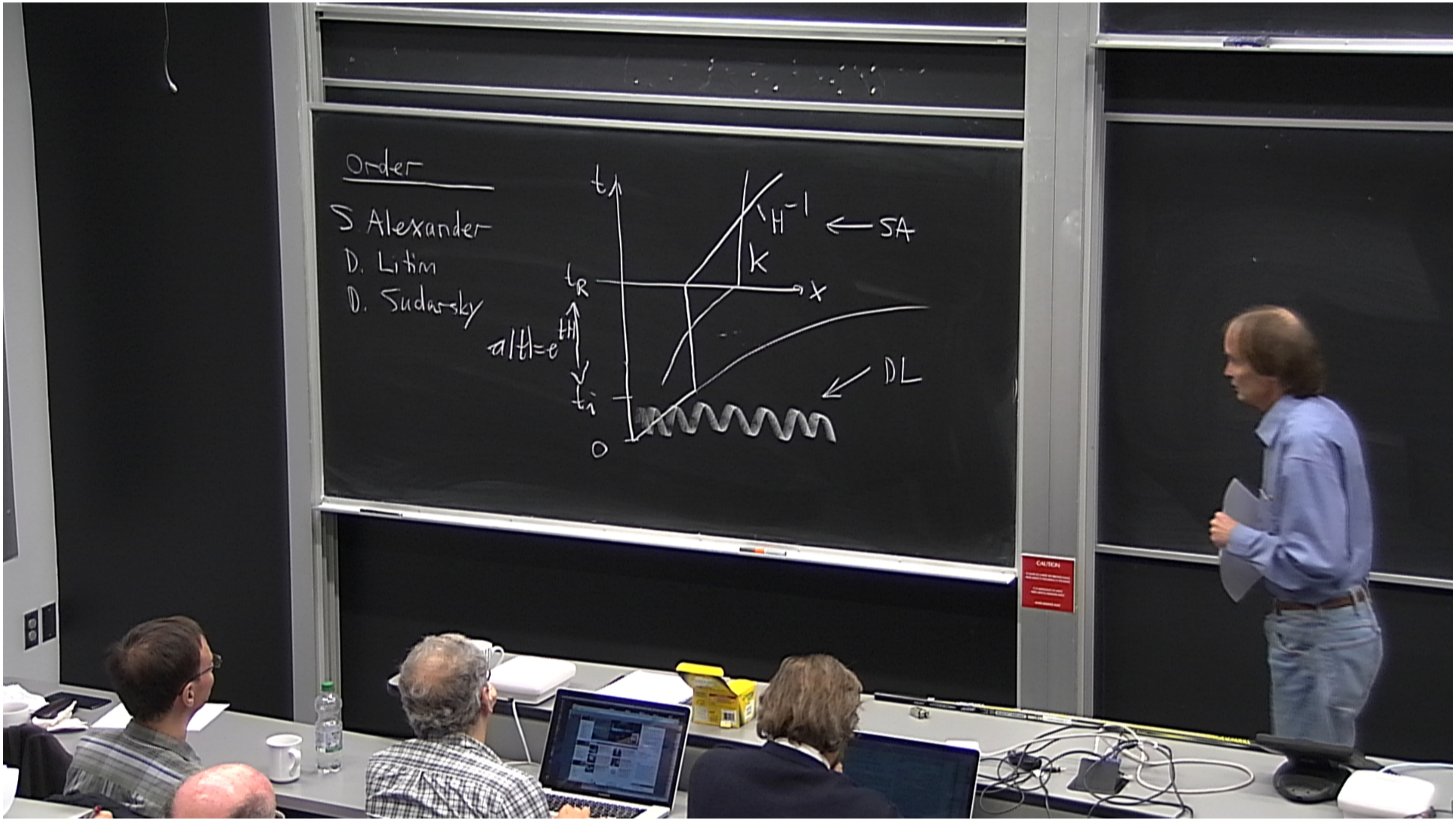
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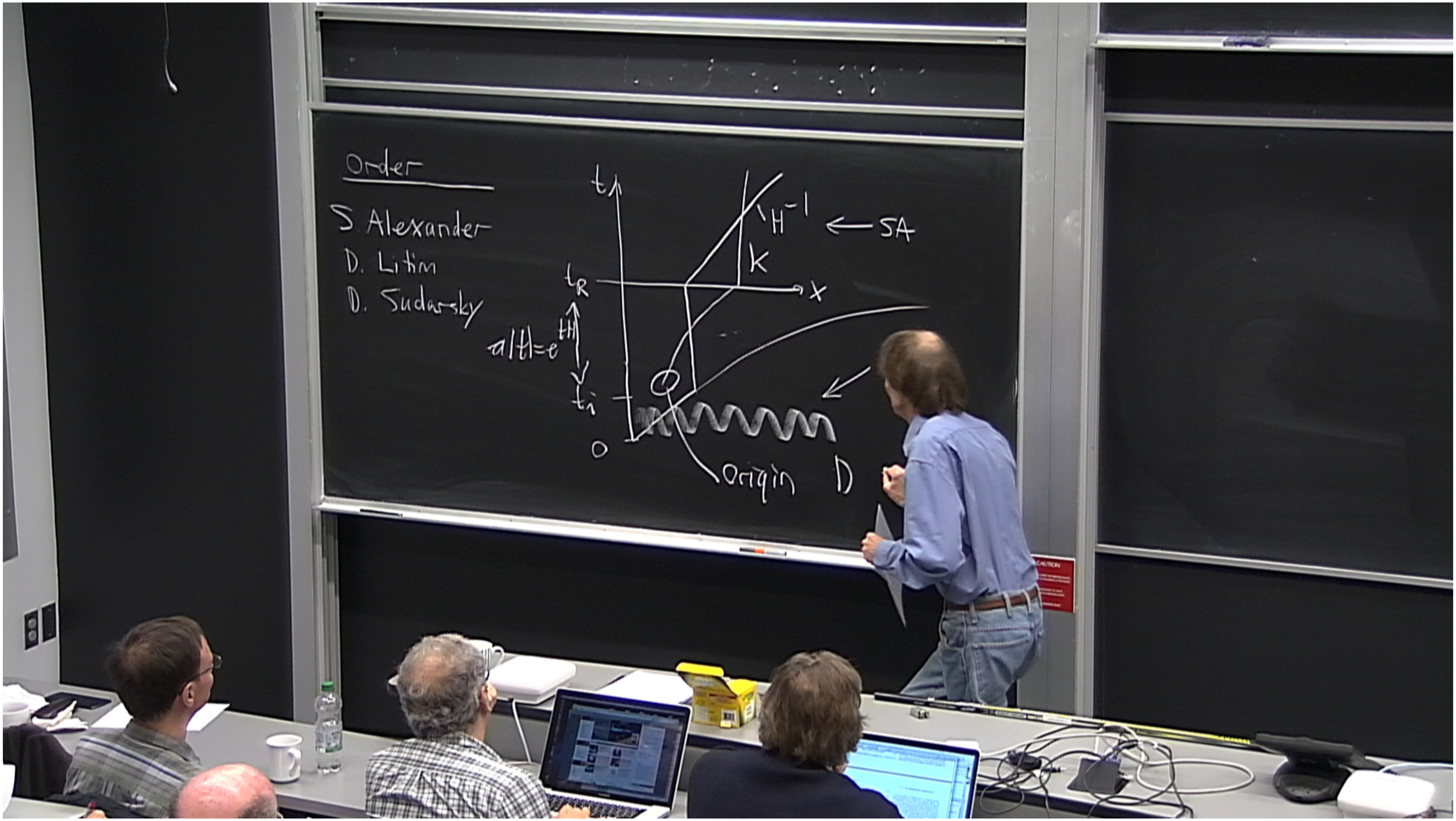
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origin
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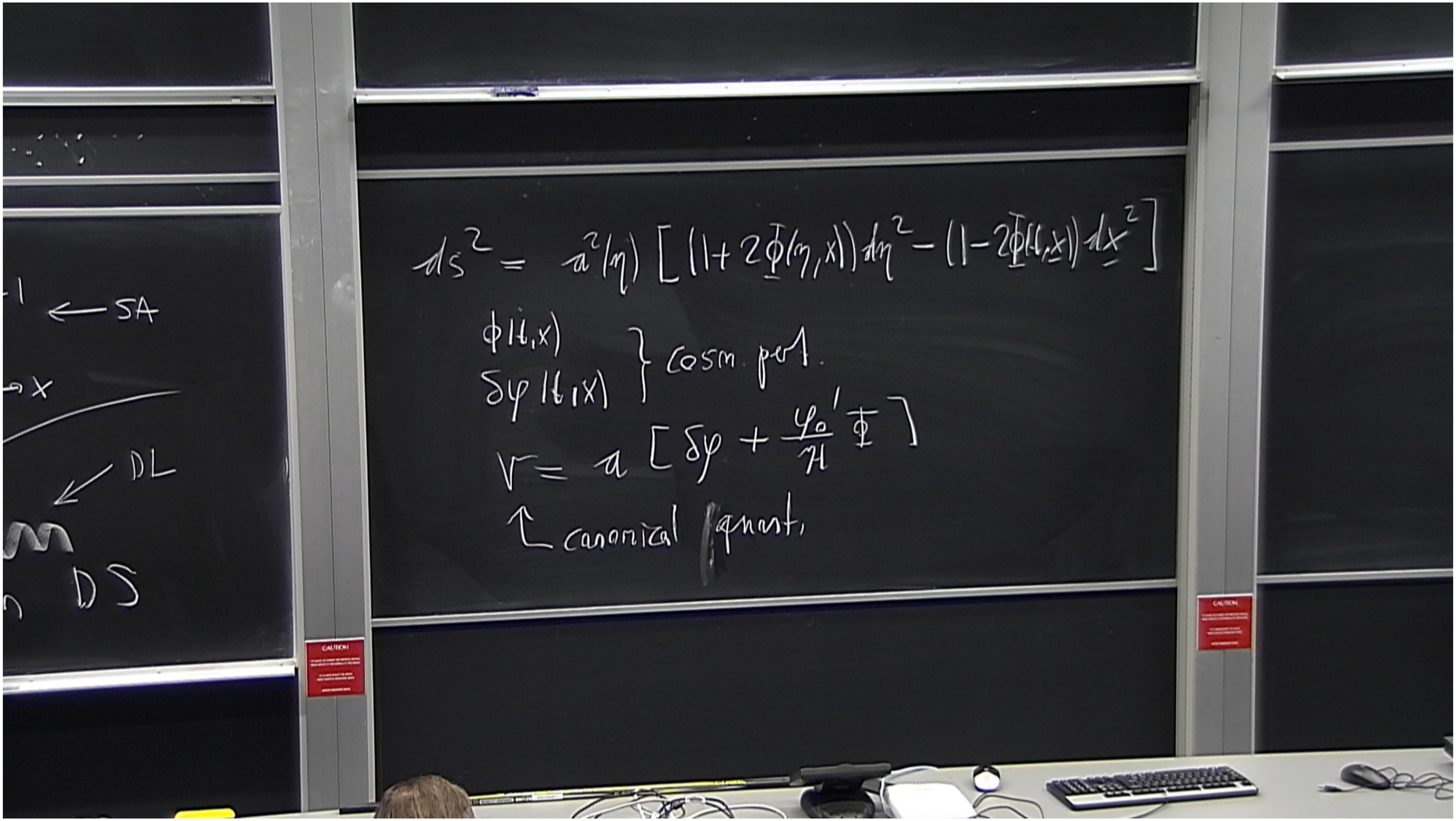
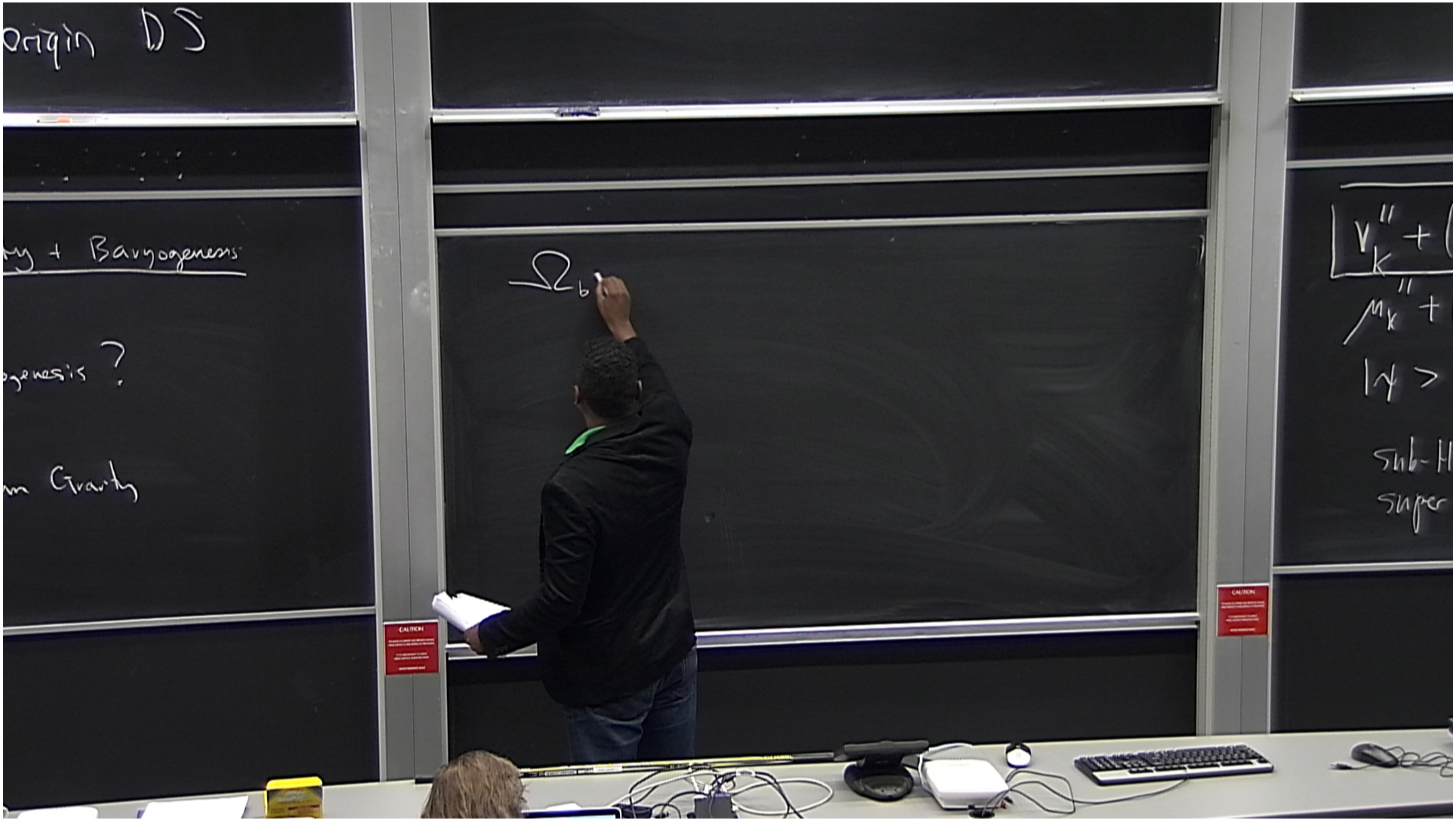
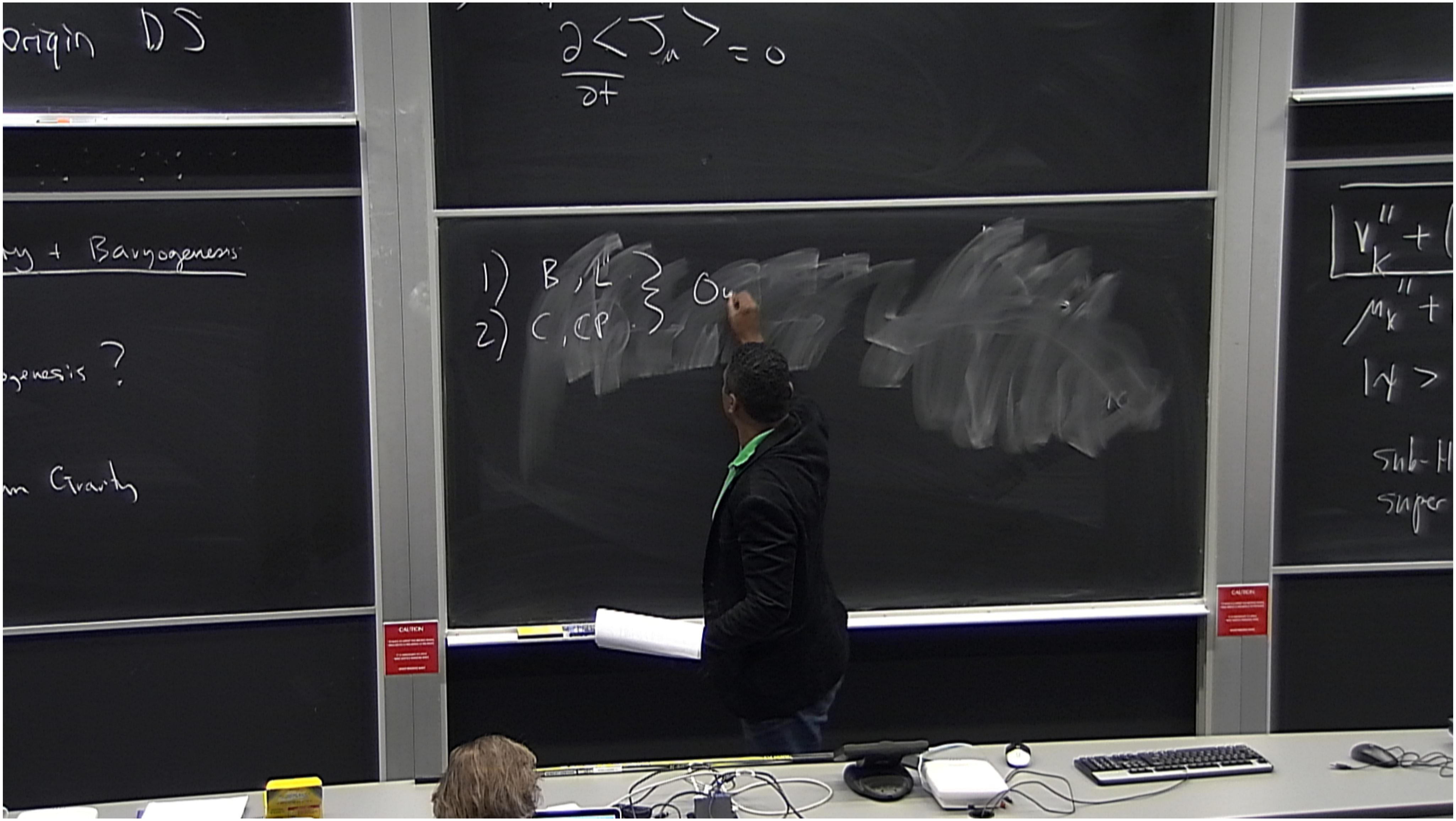
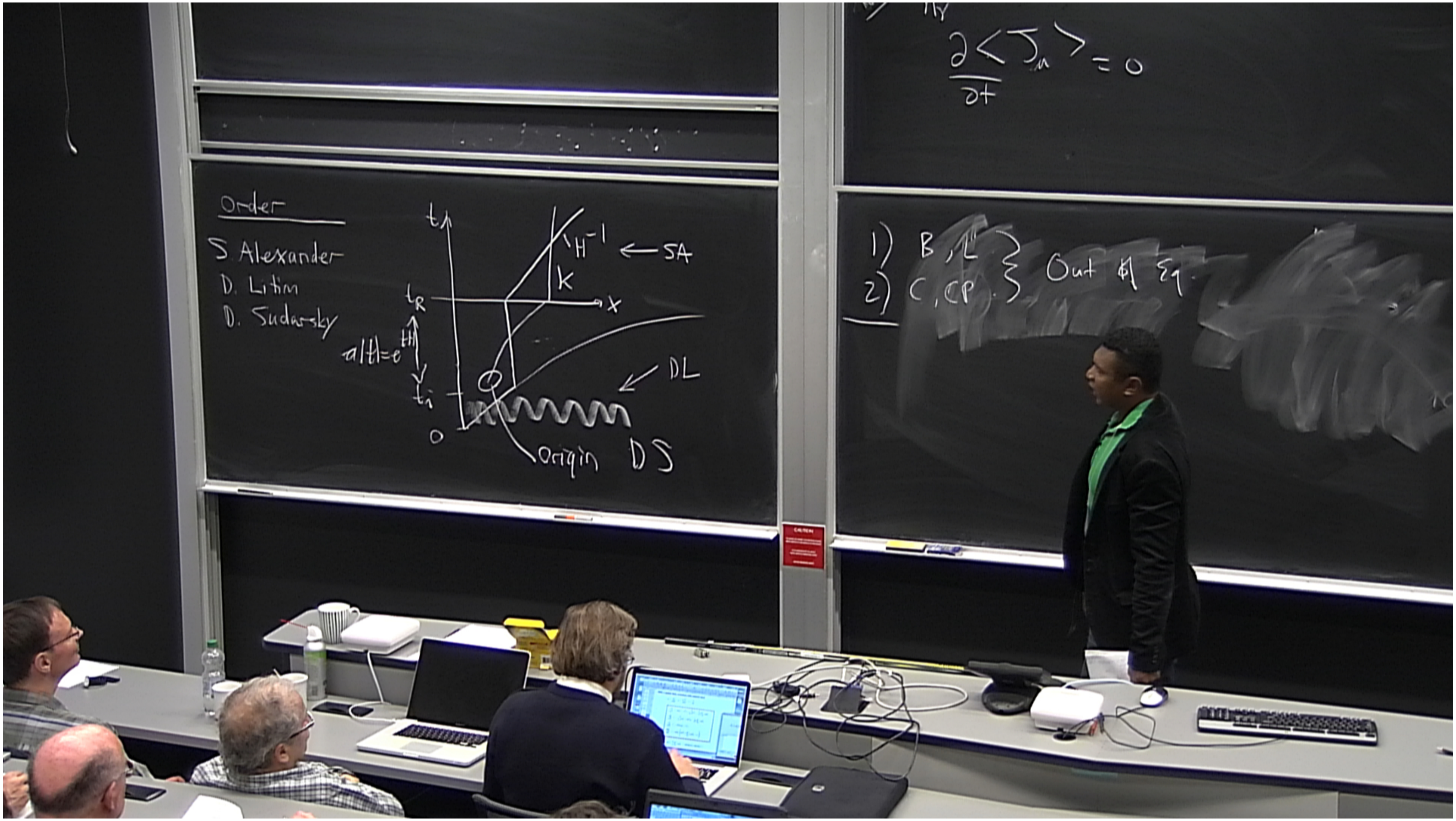

$ds^2 = a^2(\eta)\left[(1+2\Phi(\eta,x))d\eta^2 - (1-2\Phi(t,\underline{x}))d\underline{x}^2\right]$
$\phi(t,x)$
$\delta\varphi(t,x)$
} cosm. pert.
$v = a\left[\delta\varphi + \frac{\varphi_0'}{\mathcal{H}}\Phi\right]$
canonical quant.
← SA
DL
DS


origin DS
Baryogenesis
Gravity
Ω_b



origin DS
∂<J_μ>/∂t = 0
Baryogenesis
1) B, L
2) C, CP
Gravity


Order
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D. Sudarsky
H^-1 ← SA
K
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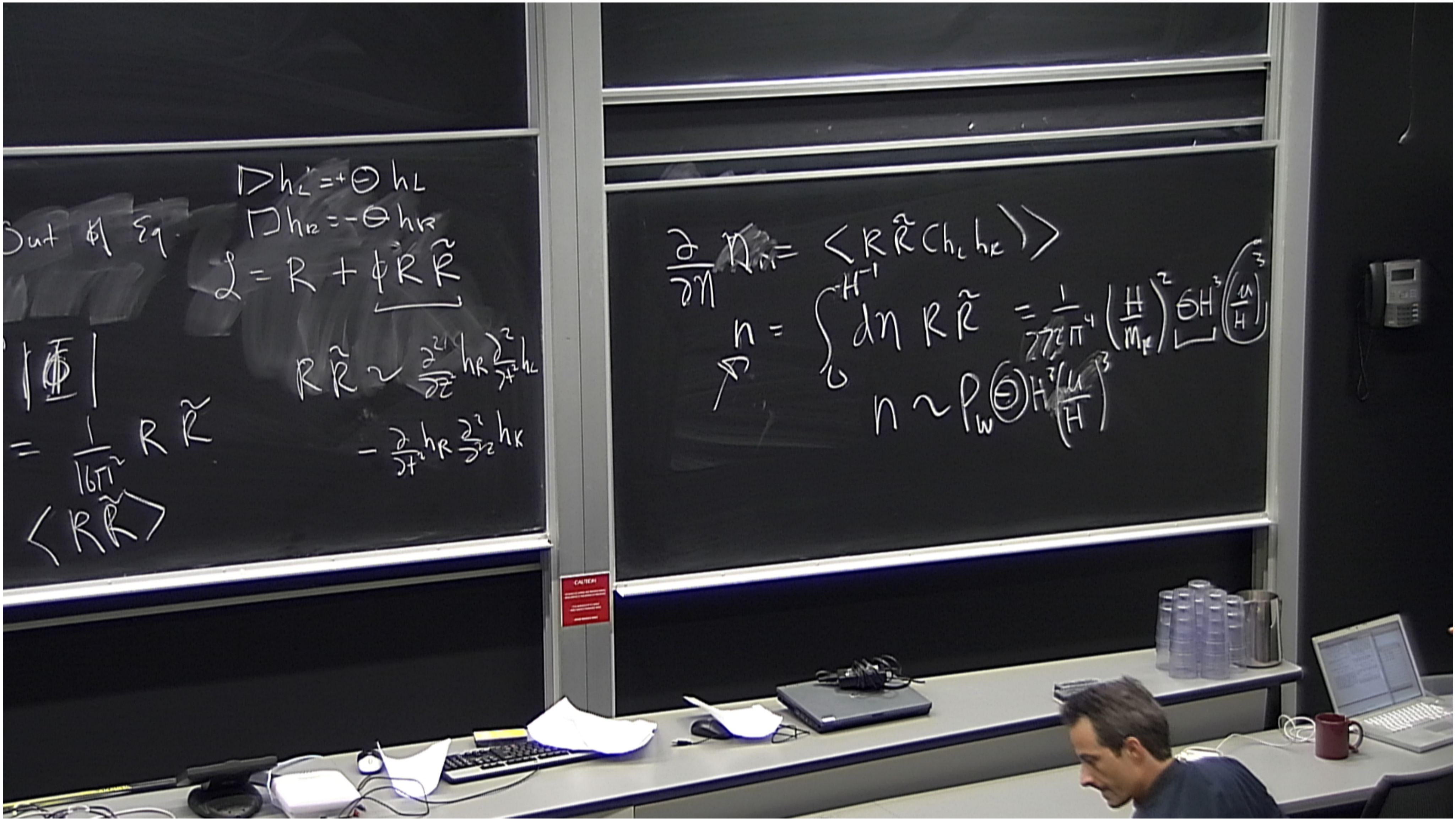
x
DL
t_i
origin
DS
∂<J_μ>/∂t = 0
1) B, L
2) C, CP
Out of Eq.


□h_L = +Θ h_L
□h_R = -Θ h_R
L = R + φRR̃
RR̃
< RR̃ >
∂/∂η n = < RR̃ (h_L h_R) >
n = ∫ dη RR̃
n ~ P_W Θ H^3 (μ/H)^3

gravitation

physics of classical gravity

Einstein's theory $G_N = 6.7 \times 10^{-11} \frac{m^3}{\mathrm{kg}\, s^2}$

physics of quantum gravity

``length scale of ignorance''

Planck length $\ell_{\mathrm{Pl}} = \left(\frac{\hbar G_N}{c^3}\right)^{1/2} \approx 10^{-33}\,\mathrm{cm}$

Planck mass $M_{\mathrm{Pl}} \approx 10^{19}\mathrm{GeV}$

Planck time $t_{\mathrm{Pl}} \approx 10^{-44}\,\mathrm{s}$

Planck temperature $T_{\mathrm{Pl}} \approx 10^{32}\,\mathrm{K}$

expect **quantum modifications** at energy scales M_{Pl}

quantum field theory

running couplings

quantum fluctuations modify interactions

couplings depend on eg. energy or distance

gravitation

replace

$$G_N \to G(\mu)$$

$$g_{\text{eff}} = G_N\, \mu^2 \to g(\mu) \equiv G(\mu)\, \mu^2$$

asymptotic safety

$$G(\mu) \to g_* / \mu^2$$

anti-screening

quantum field theory

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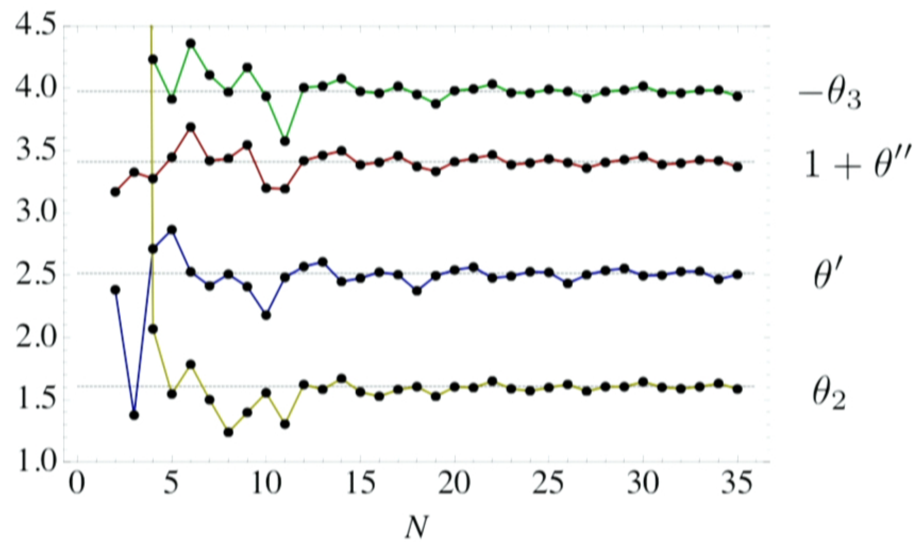
gravitation

RG study

UV fixed point for e.g.

$$f = \sum_{n=0}^{N-1} \lambda_n (R/k^2)^n$$

with scaling exponents:



(Falls, DL, Nikolakopoulos, Rahmede '12, in prep.)

UV - IR connection

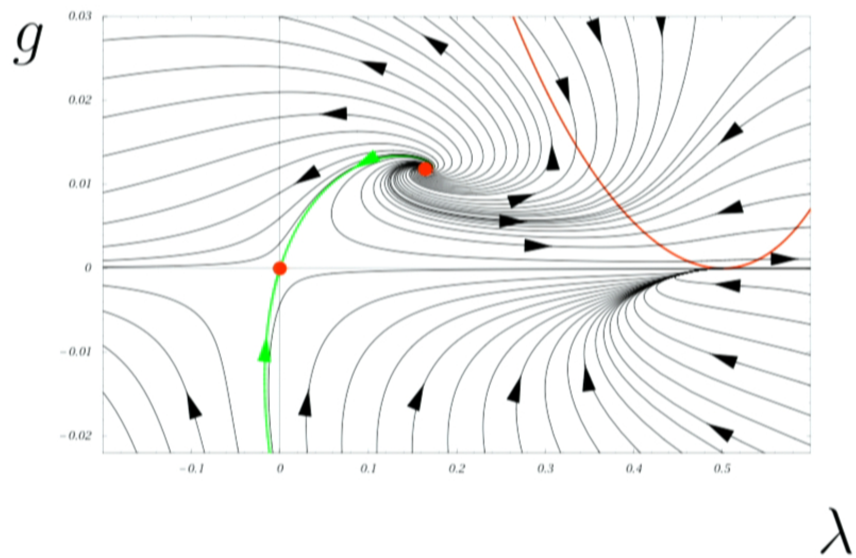
UV-IR connection

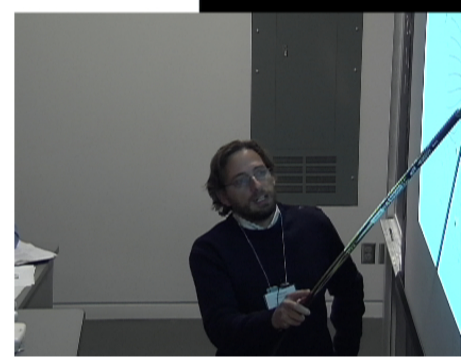
effective action

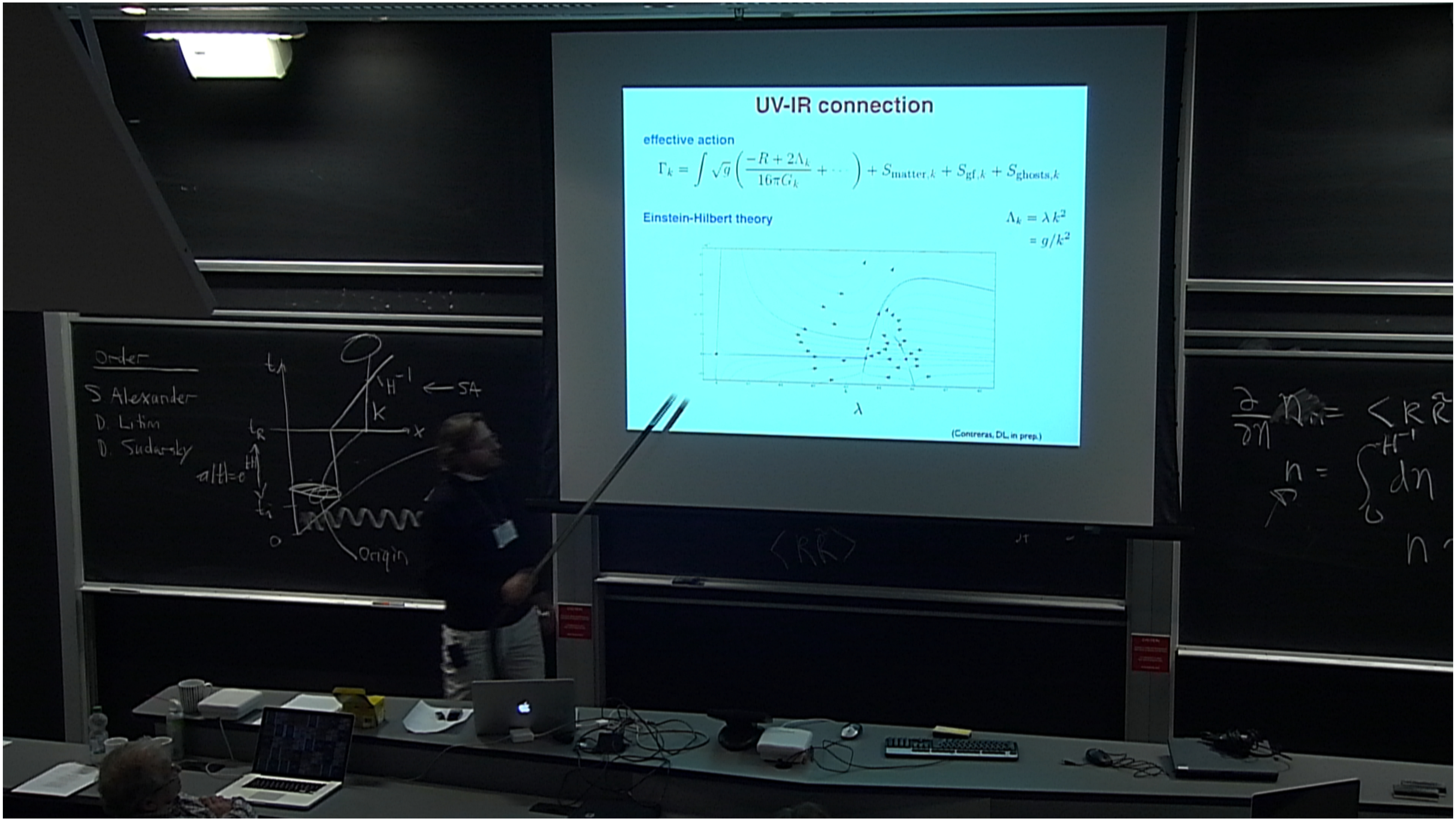
$$\Gamma_k = \int \sqrt{g}\left(\frac{-R + 2\Lambda_k}{16\pi G_k} + \cdots\right) + S_{\mathrm{matter},k} + S_{\mathrm{gf},k} + S_{\mathrm{ghosts},k}$$

Einstein-Hilbert theory

$$\Lambda_k = \lambda\, k^2$$
$$G_k = g/k^2$$



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Einstein-Hilbert theory
$\Lambda_k = \lambda k^2$
$= g/k^2$
λ
(Contreras, DL, in prep.)
Order
S. Alexander
D. Litim
D. Sudarsky
Origin

scalar field cosmology

classical cosmological fixed points

$$x = \frac{\kappa\dot{\phi}}{\sqrt{6}H}, \quad y = \frac{\kappa\sqrt{V}}{\sqrt{3}H}, \quad z = \frac{V'}{\kappa V}$$

Case	x	y	z	Ω_γ	existence	type
(a)	0	1	0	0	all γ	potential
(b)	± 1	0	$z_\bullet$	0	all γ and $z_\bullet$	kinetic
(c)	$-\frac{z_\bullet}{\sqrt{6}}$	$\sqrt{1-\frac{z_\bullet^2}{6}}$	$z_\bullet$	0	$z_\bullet^2 \leq 6$	mixed
(d)	$-\sqrt{\frac{3}{2}}\frac{\gamma}{z_\bullet}$	$\sqrt{\frac{3}{2}\frac{\gamma(2-\gamma)}{z_\bullet^2}}$	$z_\bullet$	$1-\frac{3\gamma}{z_\bullet^2}$	$z_\bullet^2 \geq 3\gamma$	scaling
(e)	0	0	–	1	$\gamma \neq 0$	fluid

TABLE I: Classical cosmological fixed points for a scalar field and one other barotropic fluid with equation of state parameter $\gamma = 1 + w$. In all cases, $z_\bullet$ is a solution to the equation $\eta(z) = z^2$, see (8). Fixed point (d) exists only for $z_\bullet^2 < 6$. Fixed point (e) exists only if $z_\bullet^2 > 3\gamma$. For the case of an exponential potential, these fixed points and eigenvalues agree with Copeland et al. [33]. Note that for $z_\bullet = 0$ fixed point (a) is just a special case of (c). Fixed point (e) corresponds to the fluid dominated solution, fixed points (a), (b), (c) to scalar field dominated solutions with either potential term (a) or kinetic term (b) dominating or a mixture (c), and fixed point (d) is known as the "scaling" or solution.

RG cosmology

(Hindmarsh, DL, Rahmede, '11)

RG quantum corrections

$$\eta_{\rm RG} = \frac{\partial \ln G_k}{\partial \ln k}, \quad \nu_{\rm RG} = \frac{\partial \ln V_k}{\partial \ln k}, \quad \sigma_{\rm RG} = \frac{\partial \ln V_k'}{\partial \ln k}$$

assumption

$$k = k(N)$$

consistency condition (Bianchi identity)

$$\frac{d \ln k}{dN} = \frac{1}{\alpha_{\rm RG}} \left[\frac{\sigma_{\rm RG}}{\nu_{\rm RG}} \sqrt{\frac{3}{2}} xz + 3x^2 + \frac{3}{2} \sum_i \gamma_i \Omega_i \right]$$

RG cosmology

Case	x	y	z	Ω_γ	$\frac{d\ln k}{dN}$	existence	type
(a)	0	1	0	0	-	$-\frac{\eta_{RG}}{\nu_{RG}}=1$	potential
(b)	± 1	0	z_*	0	$\frac{6}{\nu_{RG}}\left(1\pm\left(\frac{\sigma_{RG}}{\nu_{RG}}\right)\frac{z_*}{\sqrt{6}}\right)$	$\eta_{RG}=0$	kinetic
(c1)	$\pm\left(1+\frac{\eta_{RG}}{\nu_{RG}}\right)^{\frac{1}{2}}$	$\left(-\frac{\eta_{RG}}{\nu_{RG}}\right)^{\frac{1}{2}}$	0	0	$\frac{6}{\nu_{RG}}$	$\eta(0)=0$	mixed
(c2)	$\pm\left(1+\frac{\eta_{RG}}{\nu_{RG}}\right)^{\frac{1}{2}}$	$\left(-\frac{\eta_{RG}}{\nu_{RG}}\right)^{\frac{1}{2}}$	z_*	0	$\frac{6}{\nu_{RG}}\left(1+\frac{z_*}{\sqrt{6}x_*}\right)$	$\sigma_{RG}=\nu_{RG}$	mixed
(d1)	0	$\left(-\frac{\eta_{RG}}{\nu_{RG}}\right)^{\frac{1}{2}}$	0	$1+\frac{\eta_{RG}}{\nu_{RG}}$	$\frac{3\gamma}{\nu_{RG}}$	$\gamma\neq 0$	scaling
(d2)	$\pm\left(-\frac{\eta_{RG}}{\nu_{RG}}\frac{\gamma}{2-\gamma}\right)^{\frac{1}{2}}$	$\left(-\frac{\eta_{RG}}{\nu_{RG}}\right)^{\frac{1}{2}}$	$-\sqrt{\frac{3}{2}\frac{\gamma}{x_*}}$	$1+\frac{\eta_{RG}}{\nu_{RG}}\frac{2}{2-\gamma}$	0	$\sigma_{RG}=\nu_{RG}$	scaling

TABLE II: Renormalisation group improved cosmological fixed points for Einstein gravity with a scalar field and one other barotropic fluid. We adopt the classification of Tab. I. The RG parameters are defined in (16). In case (a), the conditions for $d\ln k/dN$ are discussed in Sec. V C. In case (b), z_* is a solution to (31), and in case (c2) z_* is a solution to (34) (see text).

RG cosmology

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summary

quantum gravity

increasing evidence for asymptotic safety
metric field remains fundamental carrier of gravitational force
UV-IR connection

cosmology

cosmological vs RG fixed points
late-time acceleration, IR fixed points
very early universe, UV fixed points, inflation
asymptotically safe cosmology

thank you!

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thank you!

The inflationary origin of the seeds of cosmic structure: quantum theory and the need for novel physics.

Daniel Sudarsky, Inst. for Nuclear Sciences, UNAM, México
Collaborations with: M. Castagnino (U. Buenos Aires, Arg.) , R. Laura (U. Rosario, Arg.) , H. Sahlman (U. Utrecht, Ndr.), A. Perez (U. of Marseille Fr.), A. de Unanue (ICN- UNAM), G. León (ICN-UNAM), A. Diez-Tejedor (U. Guanajuato, Mx.), S. Landau (U. Buenos Aires, Arg.) & C. Scoccola (Inst. Astr. Canarias, Sp.)

Experimental Search for Quantum Gravity: the hard facts.,
October , 2012

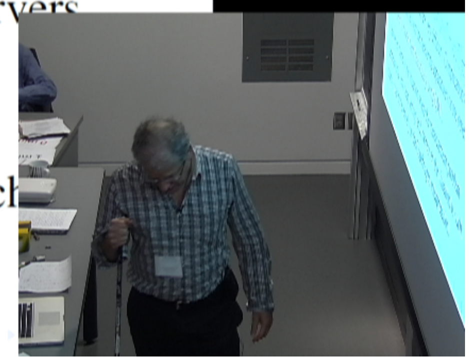
Where to look for QG related phenomena? Where do we see things we can not explain?

One of the most conspicuous is the **Measurement Problem in QM**.
Quoting J. Bell (1987):
"Either the wave function as given by Schrödinger equation is not everything, or it is not right": (J Bell 1987)
R. Penrose and L Diosi have argued that the resolution of this issue is likely tied to aspects of QG.
Time of existence of supperposition of two mass distributions is of order $\delta T = \hbar / E_\delta$ where:

$$E_\delta = G_N \int d^3x d^3y [\rho_1(\vec{x}) - \rho_2(\vec{x})][\rho_1(\vec{y}) - \rho_2(\vec{y})] \frac{1}{|\vec{x}-\vec{y}|}.$$

Ideas for experiments (which are very difficult). Complications if one needs to take into account the measuring apparatuses or the observers (i.e. need to model them realistically using QM?).

However, there is one situation where the measurement problem appears in a very clean setting, and, moreover, the situation is such that we can not even rely on the Copehnagen interpretation.



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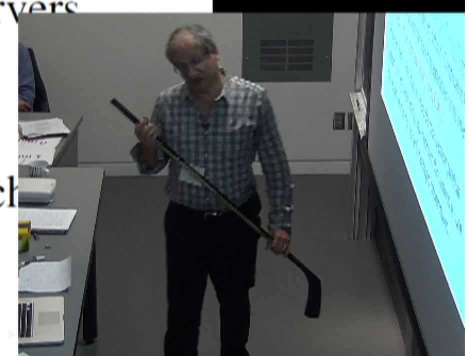


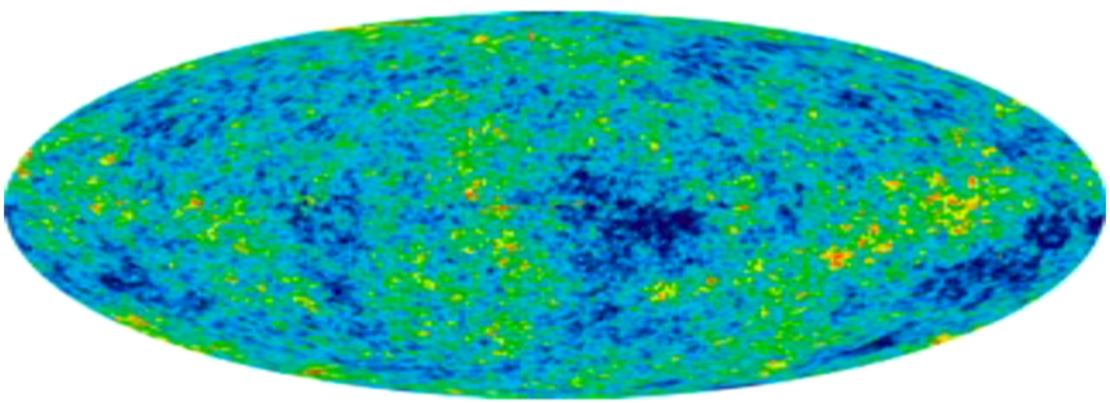
The Data. Simplified characterization:

The CMB photons emitted by the LSS. They are essentially at a local $T \approx 3000K^0$, but are subjected to the redshift by the cosmological expansion down to $T \approx 2.7K^0$. However, besides that, there is an extra red shift associated with their emergence from the local well in the Newtonian potential.

Then:

$\frac{\delta T}{T_0}(\theta, \varphi) = \frac{1}{3}\psi(\eta_D, \vec{x}_D)$, gives us a picture of Newtonian Potential on the LSS.

060913_320.jpg 320×160 píxeles



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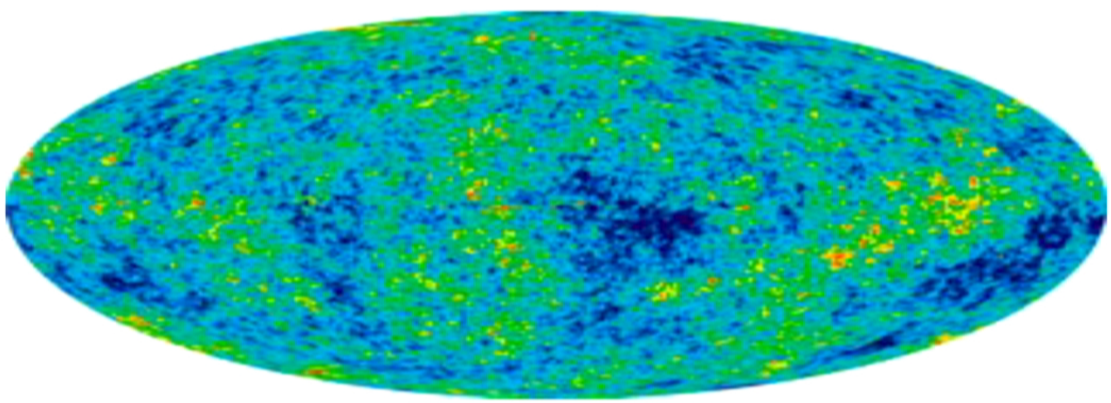


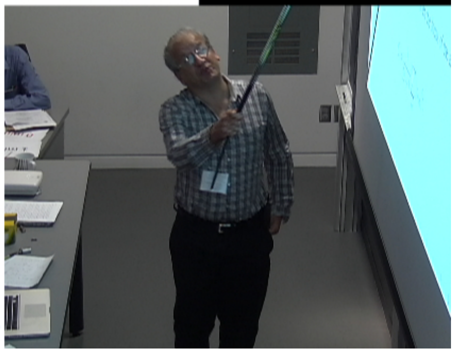
We characterize this map in terms of the spherical harmonic functions, and write: $\frac{\delta T}{T_0}(\theta,\varphi) = \sum_{lm} \alpha_{lm} Y_{lm}(\theta,\varphi)$.
The coefficients are thus :

$$\alpha_{lm} = \frac{1}{3} \int d\Omega^2 \psi(\eta_D, \vec{x}_D) Y^*_{lm}(\theta,\varphi) \tag{1}$$

This is what is measured. The measurements allow us to extract the detailed map we saw and from which we extract the individual quantities α_{lm}).

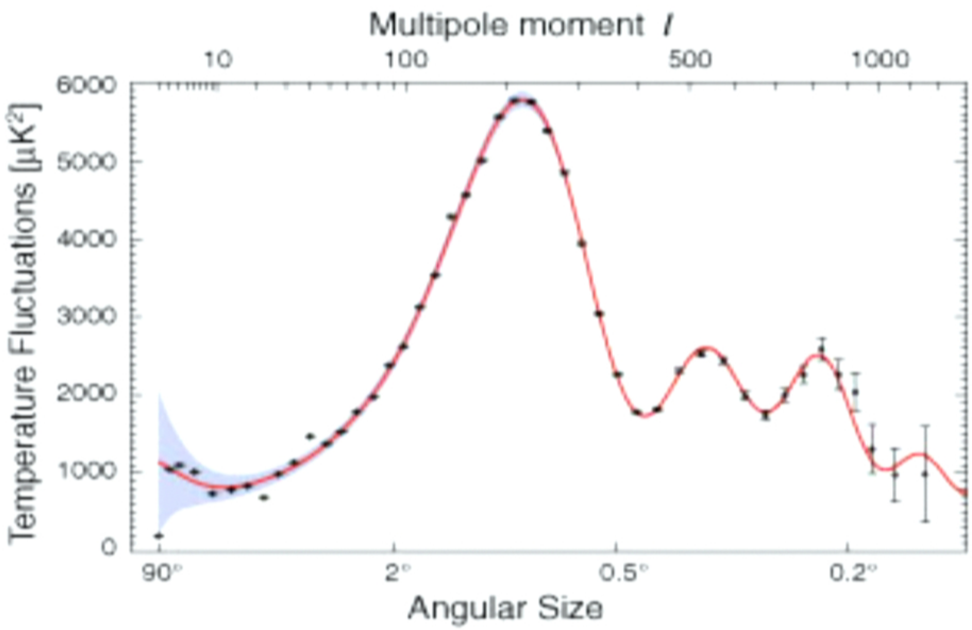
On the other hand, the quantity that is often the focus of the analysis is:

$$C_l = \frac{1}{2l+1} \sum_m |\alpha_{lm}|^2.$$



The standard analysis leads to a remarkable agreement with observations:

111133_7yr_PowerSpectrum_320.jpg 320×224 píxeles



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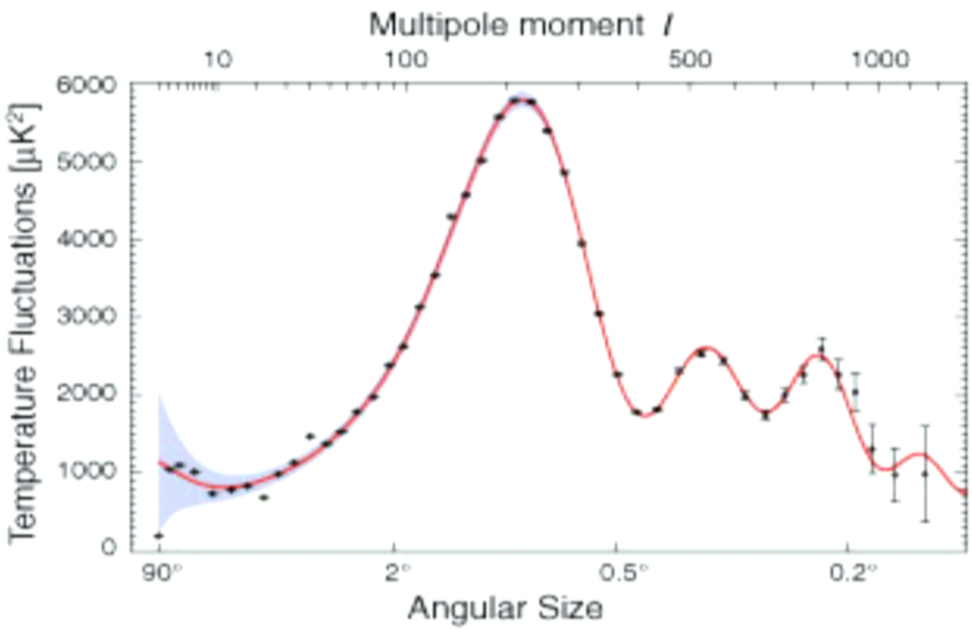
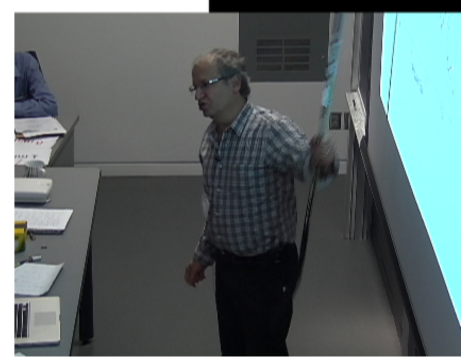
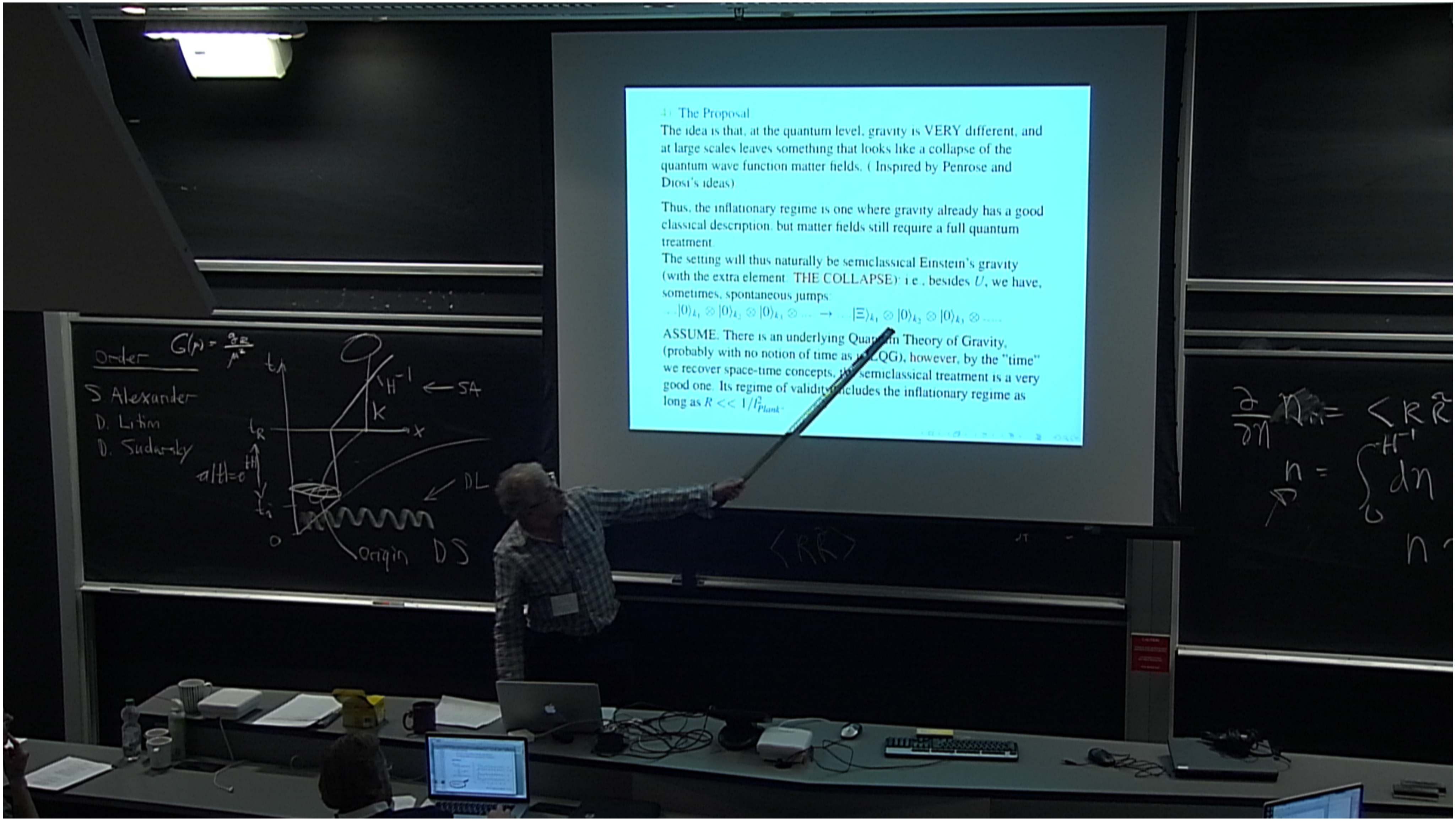




Most people working on this topic compute the, so called, decoherence functionals, apparently without focussing too much on these issues.
However, even W Zurek tells us: *"The interpretation based on the ideas of decoherence and ein-selection has not really been spelled out to date in any detail. I have made a few half-hearted attempts in this direction, but, frankly, I was hoping to postpone this task, since the ultimate questions tend to involve such "anthropic" attributes of the "observership" as "perception," "awareness," or "consciousness," which, at present, cannot be modeled with a desirable degree of rigor."*

We need to understand the breakdown of the initial homogeneity and isotropy, if we really want to understand the source of the seeds of the cosmic structure (which eventually lead to galaxies, stars, and, planets, where we can find the conditions for the emergence of life, and, eventually, intelligent :-) beings like ourselves.) .


4 The Proposal
The idea is that, at the quantum level, gravity is VERY different, and at large scales leaves something that looks like a collapse of the quantum wave function matter fields. (Inspired by Penrose and Diosi's ideas)
Thus, the inflationary regime is one where gravity already has a good classical description, but matter fields still require a full quantum treatment.
The setting will thus naturally be semiclassical Einstein's gravity (with the extra element: THE COLLAPSE): i.e., besides U, we have, sometimes, spontaneous jumps:
$\ldots|0\rangle_{k_1} \otimes |0\rangle_{k_2} \otimes |0\rangle_{k_3} \otimes \ldots \rightarrow \ldots|\Xi\rangle_{k_1} \otimes |0\rangle_{k_2} \otimes |0\rangle_{k_3} \otimes \ldots$
ASSUME: There is an underlying Qua… Theory of Gravity, (probably with no notion of time as … QG), however, by the "time" we recover space-time concepts, … semiclassical treatment is a very good one. Its regime of validity …cludes the inflationary regime as long as $R << 1/l^2_{Plank}$.
Order
S. Alexander
D. Litim
D. Sudarsky
origin
DS
DL
SA

For Model 1