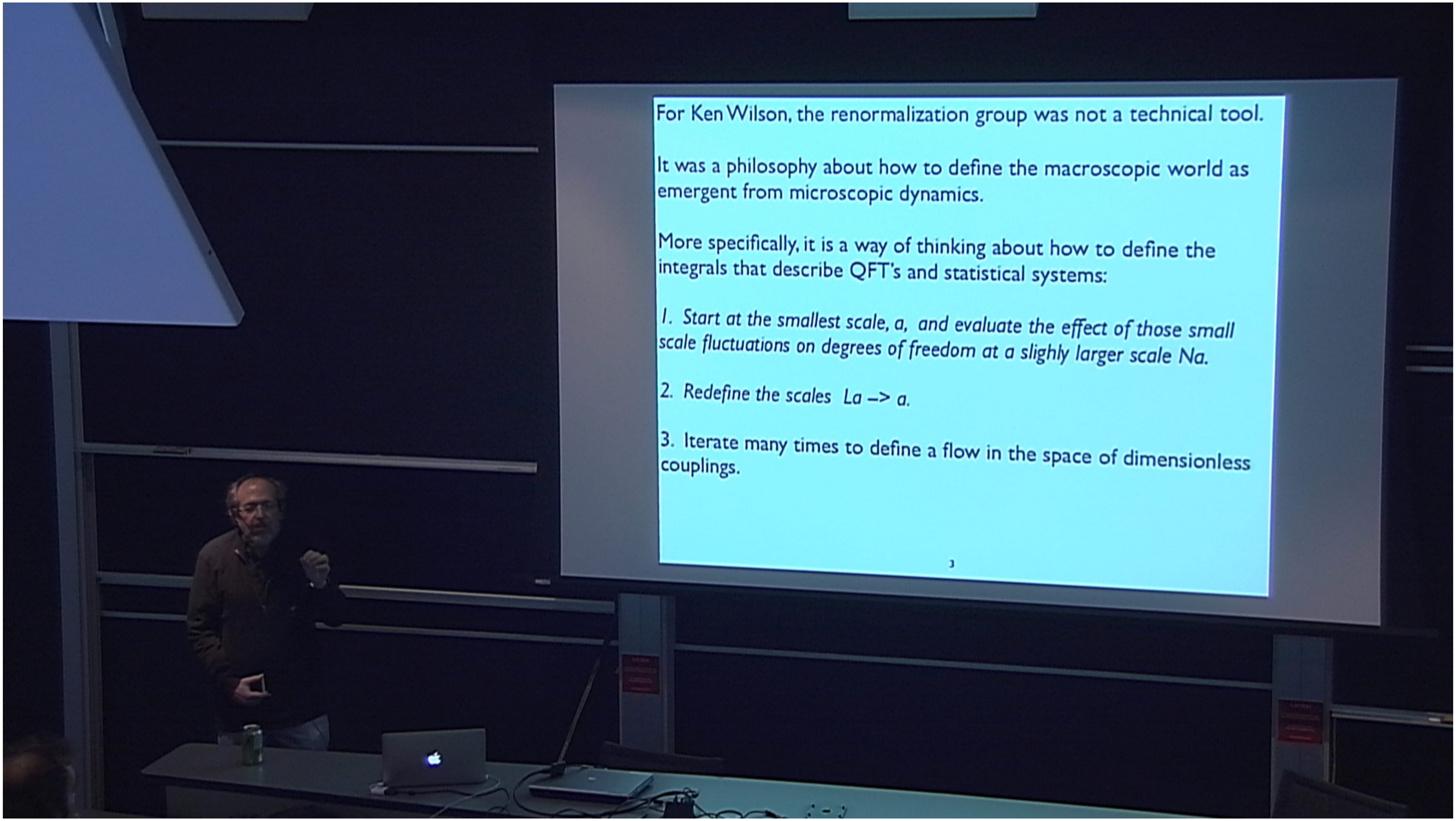
Title: What are the most pressing open questions in the application of the RG to gravity?

Date: Apr 22, 2014 04:50 PM

URL: http://pirsa.org/14040090

Abstract:


For Ken Wilson, the renormalization group was not a technical tool.
It was a philosophy about how to define the macroscopic world as emergent from microscopic dynamics.
More specifically, it is a way of thinking about how to define the integrals that describe QFT's and statistical systems:
1. Start at the smallest scale, a, and evaluate the effect of those small scale fluctuations on degrees of freedom at a slighly larger scale Na.
2. Redefine the scales La –> a.
3. Iterate many times to define a flow in the space of dimensionless couplings.
3

The two meanings of renormalization:

I. Fix a *physical* uv cutoff, $a=l_p$, define the microscopic theory at that scale, and decimate degrees of freedom to derive the long distance dynamics.

II. Take the limit a --> infinity to define a continuum theory.

In both cases we are interested in physics at scales large compared to a, but the viewpoints differ.

- LQG and causal sets do I
- CDT and AS do II

NOTE: The RG is not a group. There is no inverse.
Defined UV --> IR

The two meanings of renormalization:

I. Fix a *physical* uv cutoff, $a=l_p$, define the microscopic theory at that scale, and decimate degrees of freedom to derive the long distance dynamics.

II. Take the limit a --> infinity to define a continuum theory.

In both cases we are interested in physics at scales large compared to a, but the viewpoints differ.

- LQG and causal sets do I
- CDT and AS do II

NOTE: The RG is not a group. There is no inverse.
Defined UV --> IR

The renormalization group and critical phenomena:

A key part of the philosophy of Wilson is that macroscopic degrees of freedom (ie long wavelength, ie massless modes) emerge as a consequence of near scale invariance of critical phenomena. For equilibrium systems this requires tuning the parameters to put the RG trajectory on a critical surface of a second order critical point.

Once this is done the details of the microphysics at the cutoff scale become irrelevant, except those that govern patterns of symmetries and symmetry breaking.

It follows that differences in our models should become irrelevant unless they lie in different universality classes governed by patterns of symmetry breaking. These patterns describe the leading QG corrections to GR. They are the prize we are after.

We should try to identify these universality classes. Phenomenological models such as relative locality can help to do this.

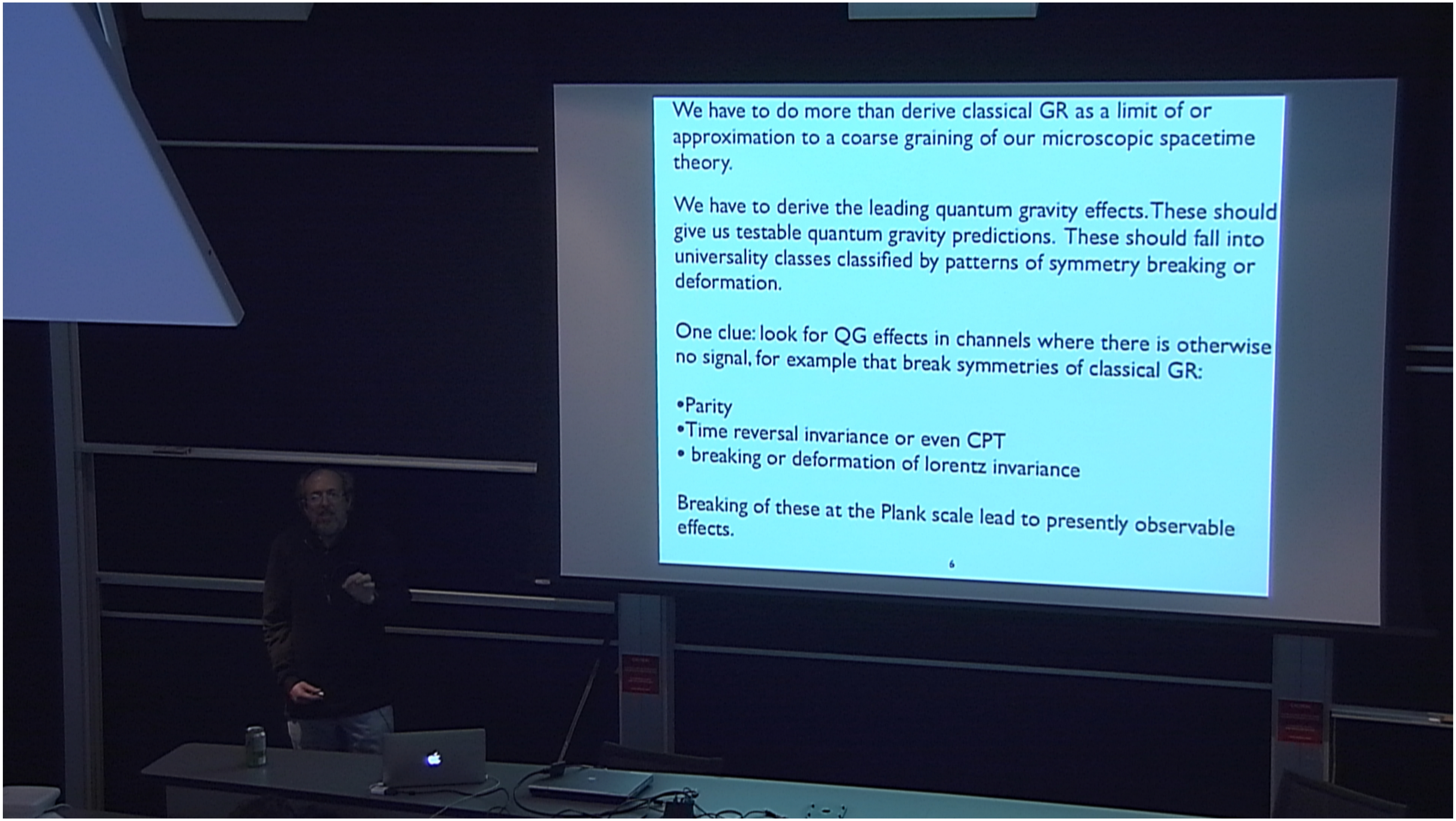
The renormalization group and critical phenomena:

A key part of the philosophy of Wilson is that macroscopic degrees of freedom (ie long wavelength, ie massless modes) emerge as a consequence of near scale invariance of critical phenomena. For equilibrium systems this requires tuning the parameters to put the RG trajectory on a critical surface of a second order critical point.

Once this is done the details of the microphysics at the cutoff scale become irrelevant, except those that govern patterns of symmetries and symmetry breaking.

It follows that differences in our models should become irrelevant unless they lie in different universality classes governed by patterns of symmetry breaking. These patterns describe the leading QG corrections to GR. They are the prize we are after.

We should try to identify these universality classes. Phenomenological models such as relative locality can help to do this.


We have to do more than derive classical GR as a limit of or approximation to a coarse graining of our microscopic spacetime theory.
We have to derive the leading quantum gravity effects. These should give us testable quantum gravity predictions. These should fall into universality classes classified by patterns of symmetry breaking or deformation.
One clue: look for QG effects in channels where there is otherwise no signal, for example that break symmetries of classical GR:
•Parity
•Time reversal invariance or even CPT
• breaking or deformation of lorentz invariance
Breaking of these at the Plank scale lead to presently observable effects.
6

We have to do more than derive classical GR as a limit of or approximation to a coarse graining of our microscopic spacetime theory.

We have to derive the leading quantum gravity effects. These should give us testable quantum gravity predictions. These should fall into universality classes classified by patterns of symmetry breaking or deformation.

One clue: look for QG effects in channels where there is otherwise no signal, for example that break symmetries of classical GR:

- Parity
- Time reversal invariance or even CPT
- breaking or deformation of lorentz invariance

Breaking of these at the Plank scale lead to presently observable effects.

BICEP:

If the leading interpretation is correct (and there are open issues) they are seeing the amplification of quantum fluctuations of of the gravitational field, produced during inflation or a similar era.

THIS IS THE FIRST OBSERVATION OF QUANTUM GRAVITATIONAL PHYSICS, ie Mp is observed.

Much more is coming: (some by October)

- *Parity odd modes (more on this later)*
- *Measurements of r to 1% may be possible.*
- *Spectrum*

We quantum gravity theorists need to be giving detailed predictions for these upcoming measurements. We need to get from the UV to the IR NOW!!!!!!!

BICEP:

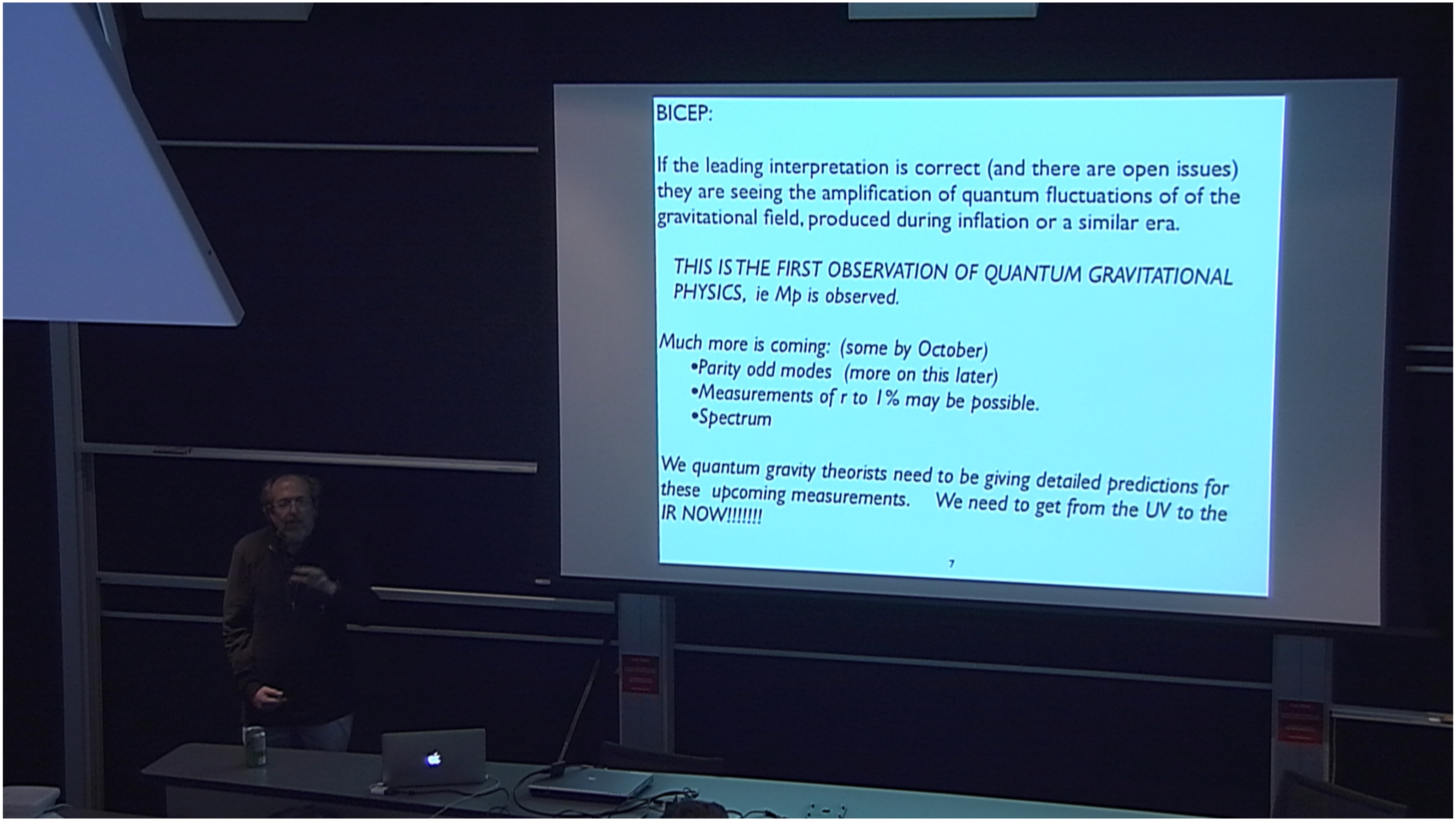
If the leading interpretation is correct (and there are open issues) they are seeing the amplification of quantum fluctuations of of the gravitational field, produced during inflation or a similar era.

THIS IS THE FIRST OBSERVATION OF QUANTUM GRAVITATIONAL PHYSICS, ie Mp is observed.

Much more is coming: (some by October)

- *Parity odd modes (more on this later)*
- *Measurements of r to 1% may be possible.*
- *Spectrum*

We quantum gravity theorists need to be giving detailed predictions for these upcoming measurements. We need to get from the UV to the IR NOW!!!!!!!


BICEP:
If the leading interpretation is correct (and there are open issues) they are seeing the amplification of quantum fluctuations of of the gravitational field, produced during inflation or a similar era.
THIS IS THE FIRST OBSERVATION OF QUANTUM GRAVITATIONAL PHYSICS, ie Mp is observed.
Much more is coming: (some by October)
•Parity odd modes (more on this later)
•Measurements of r to 1% may be possible.
•Spectrum
We quantum gravity theorists need to be giving detailed predictions for these upcoming measurements. We need to get from the UV to the IR NOW!!!!!!!
7

Data from the BICEP paper

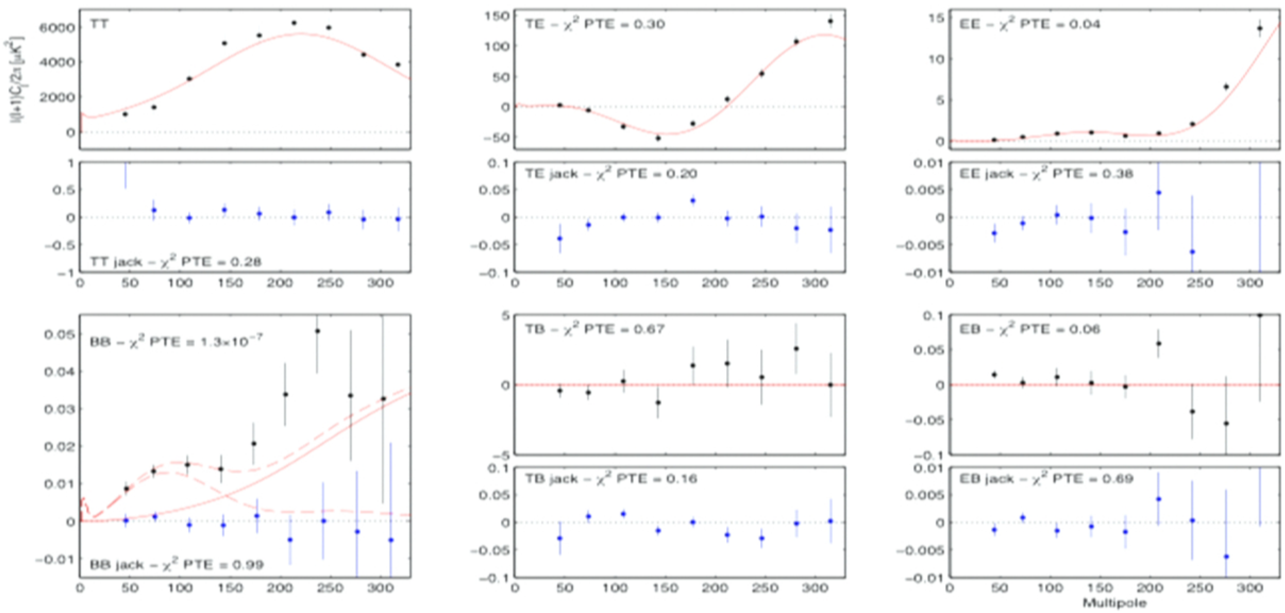


FIG. 2.— BICEP2 power spectrum results for signal (black points) and temporal-split jackknife (blue points). The red curves show the lensed-ΛCDM theory expectations — in the case of *BB* an $r = 0.2$ spectrum is also shown. The error bars are the standard deviations of the lensed-ΛCDM+noise simulations. The probability to exceed (PTE) the observed value of a simple χ^2 statistic is given (as evaluated against the simulations). Note the very different *y*-axis scales for the jackknife spectra (other than *BB*). See the text for additional discussion of the *BB* spectrum.

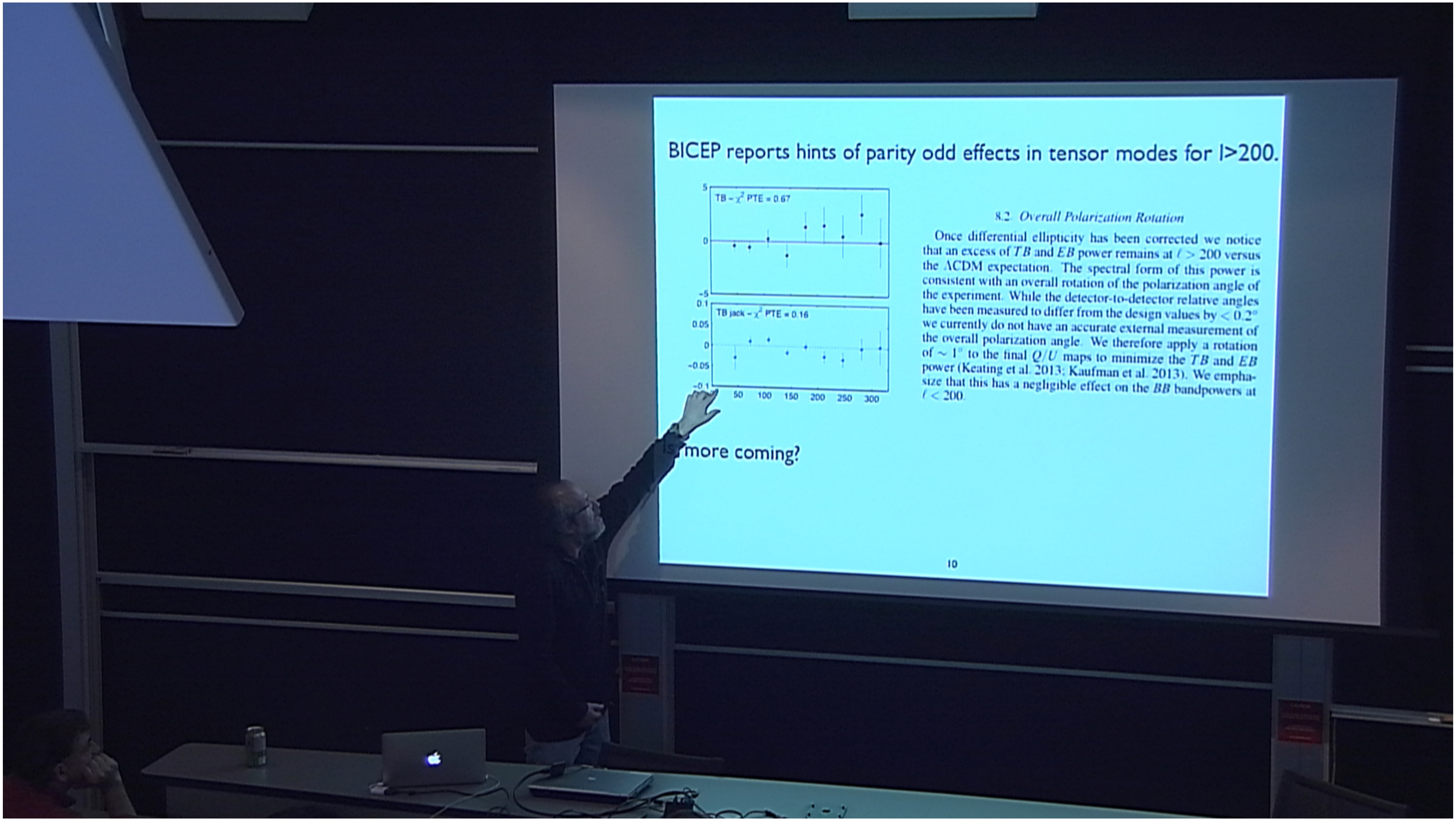
T are the temperature fluctuations. E and B are the electric and magnetic parts of the tensor modes.

T, E are parity even
B is odd

So <TB> and <EB> are parity odd: no classical power there

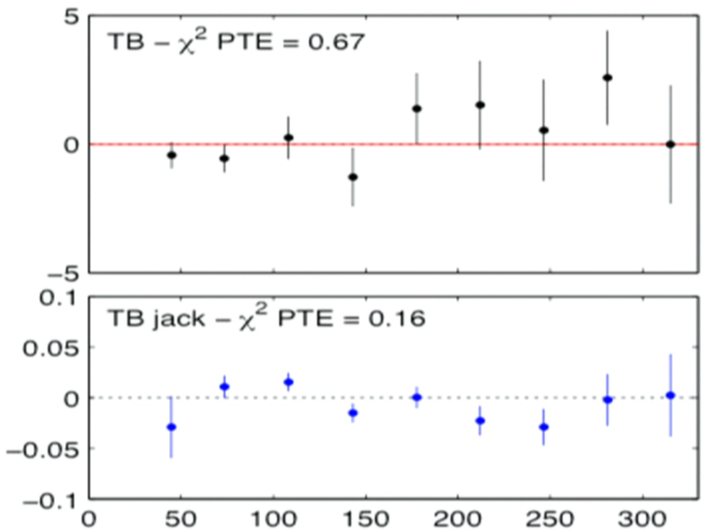
Furthermore if <BB> is down from <TT> by a ratio r ~ .2,

<TB> is only down by $r^{1/2}$, which is larger.



BICEP reports hints of parity odd effects in tensor modes for l>200.
TB – χ² PTE = 0.67
TB jack – χ² PTE = 0.16
50 100 150 200 250 300
8.2. Overall Polarization Rotation
Once differential ellipticity has been corrected we notice that an excess of TB and EB power remains at ℓ > 200 versus the ΛCDM expectation. The spectral form of this power is consistent with an overall rotation of the polarization angle of the experiment. While the detector-to-detector relative angles have been measured to differ from the design values by < 0.2° we currently do not have an accurate external measurement of the overall polarization angle. We therefore apply a rotation of ~ 1° to the final Q/U maps to minimize the TB and EB power (Keating et al. 2013; Kaufman et al. 2013). We emphasize that this has a negligible effect on the BB bandpowers at ℓ < 200.
more coming?
10

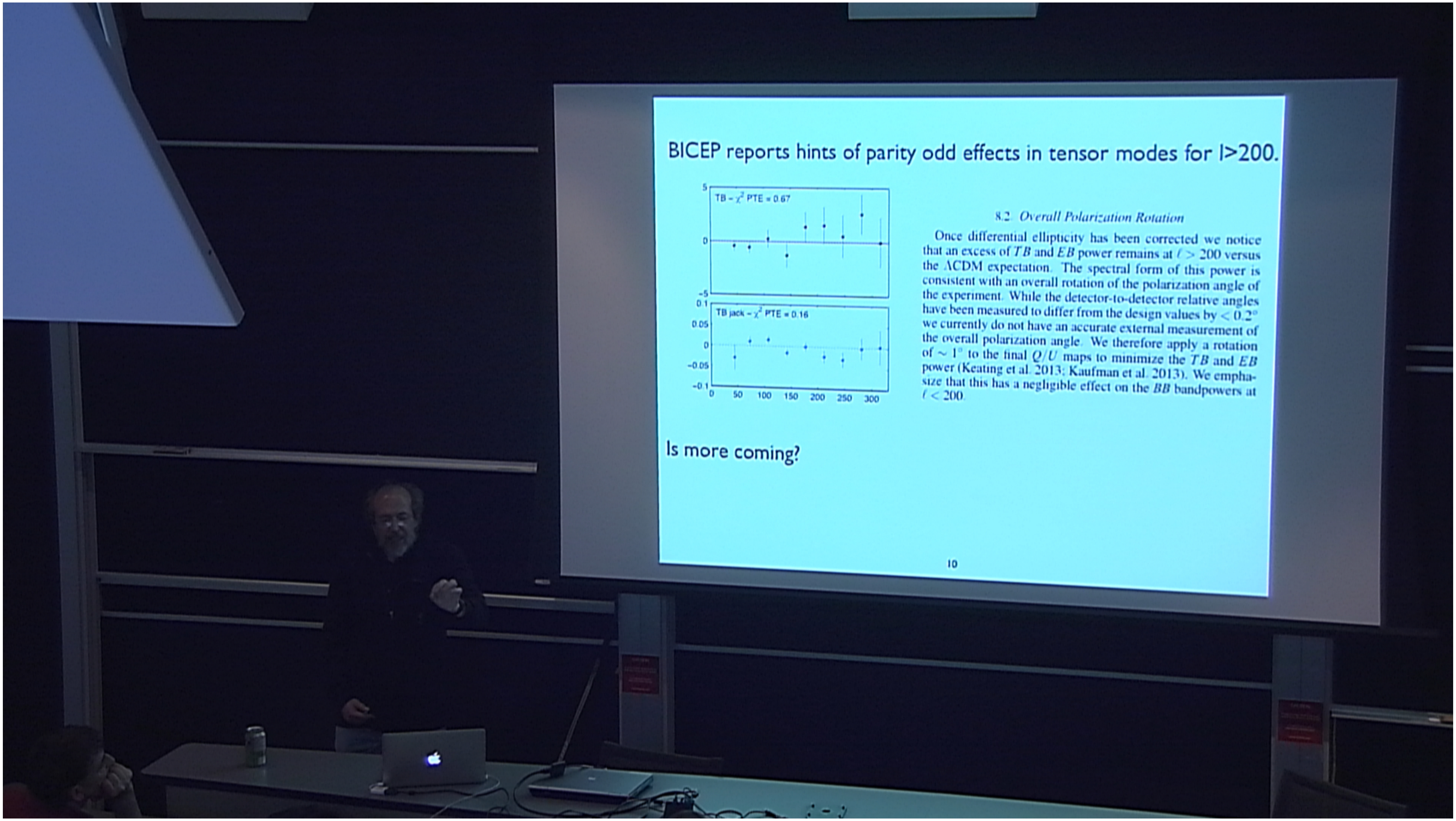
BICEP reports hints of parity odd effects in tensor modes for l>200.



8.2. *Overall Polarization Rotation*

Once differential ellipticity has been corrected we notice that an excess of TB and EB power remains at $\ell > 200$ versus the ΛCDM expectation. The spectral form of this power is consistent with an overall rotation of the polarization angle of the experiment. While the detector-to-detector relative angles have been measured to differ from the design values by $< 0.2^\circ$ we currently do not have an accurate external measurement of the overall polarization angle. We therefore apply a rotation of $\sim 1^\circ$ to the final Q/U maps to minimize the TB and EB power (Keating et al. 2013; Kaufman et al. 2013). We emphasize that this has a negligible effect on the BB bandpowers at $\ell < 200$.

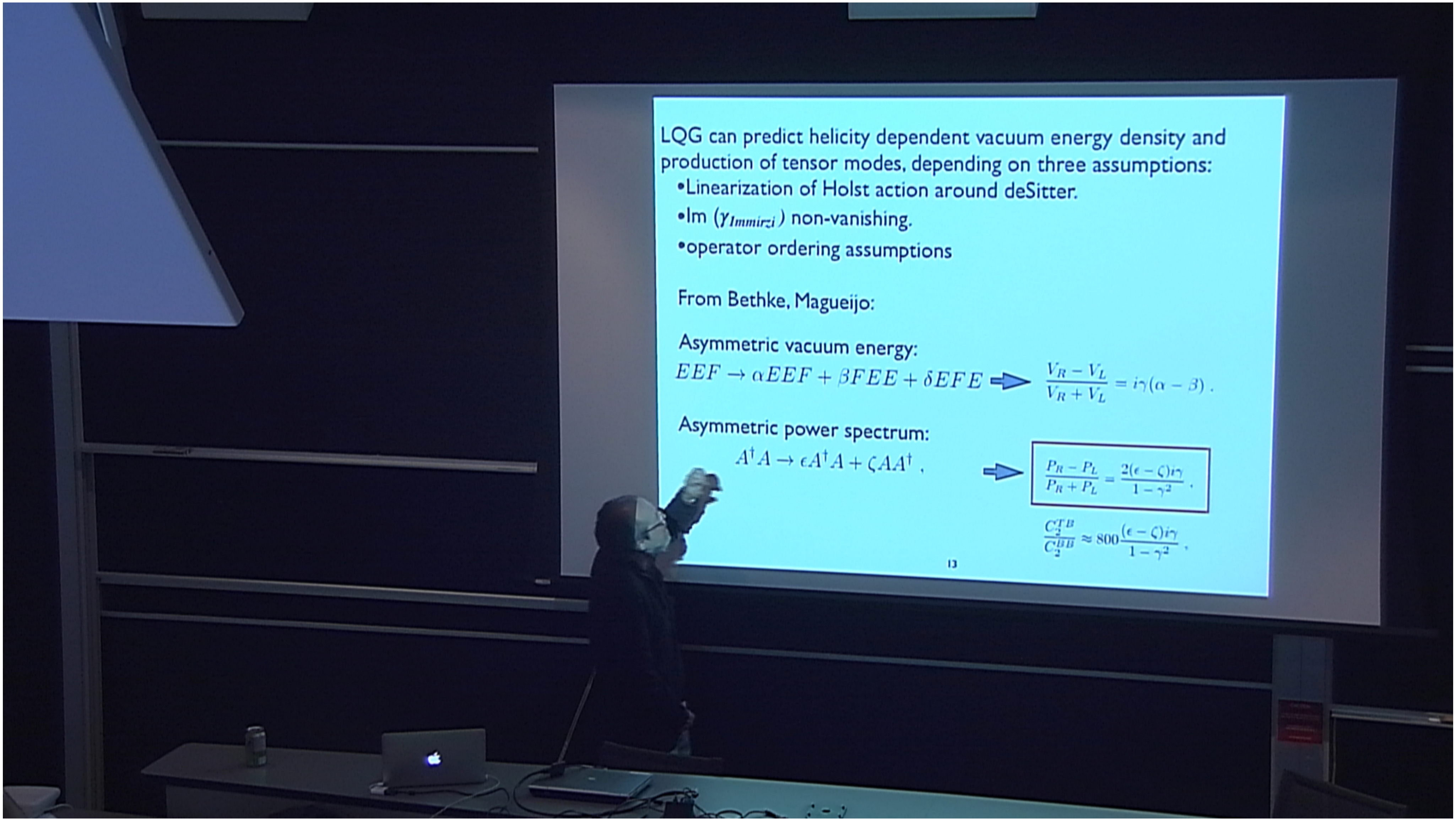
Is more coming?

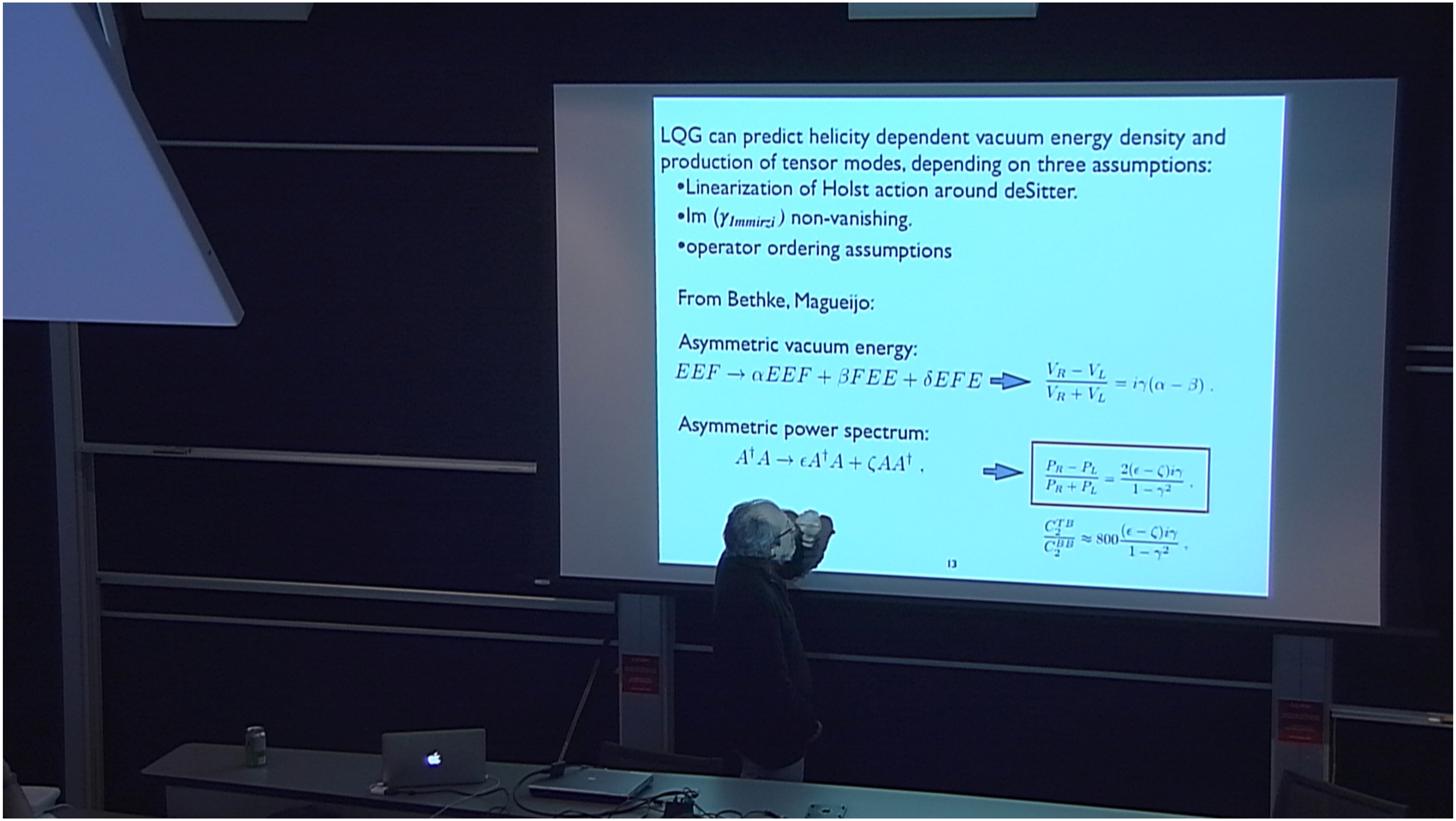

BICEP reports hints of parity odd effects in tensor modes for l>200.
TB – χ² PTE = 0.67
TB jack – χ² PTE = 0.16
8.2. Overall Polarization Rotation
Once differential ellipticity has been corrected we notice that an excess of TB and EB power remains at ℓ > 200 versus the ΛCDM expectation. The spectral form of this power is consistent with an overall rotation of the polarization angle of the experiment. While the detector-to-detector relative angles have been measured to differ from the design values by < 0.2° we currently do not have an accurate external measurement of the overall polarization angle. We therefore apply a rotation of ~ 1° to the final Q/U maps to minimize the TB and EB power (Keating et al. 2013; Kaufman et al. 2013). We emphasize that this has a negligible effect on the BB bandpowers at ℓ < 200.
Is more coming?
10

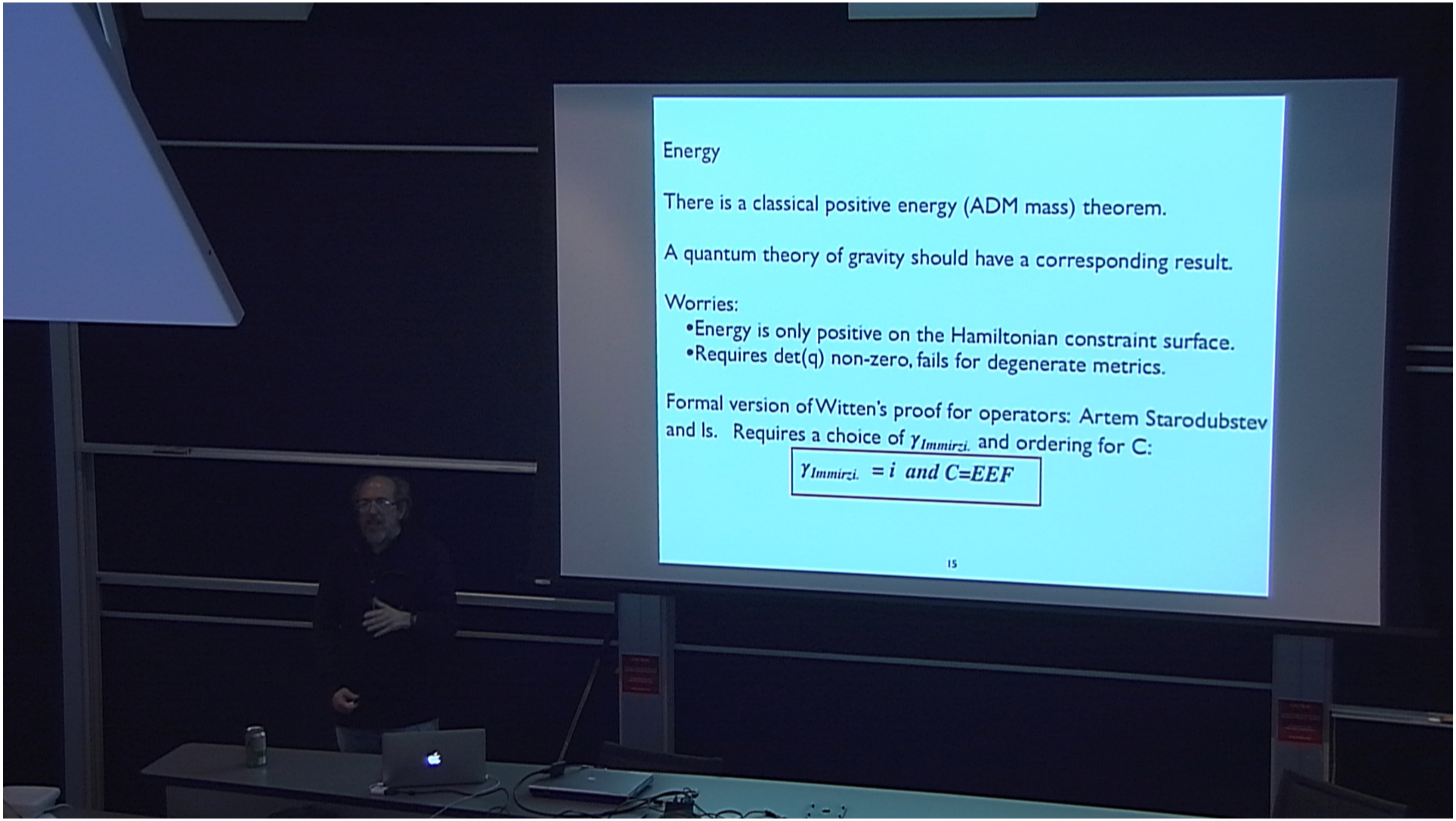
LQG can predict helicity dependent vacuum energy density and production of tensor modes, depending on three assumptions:

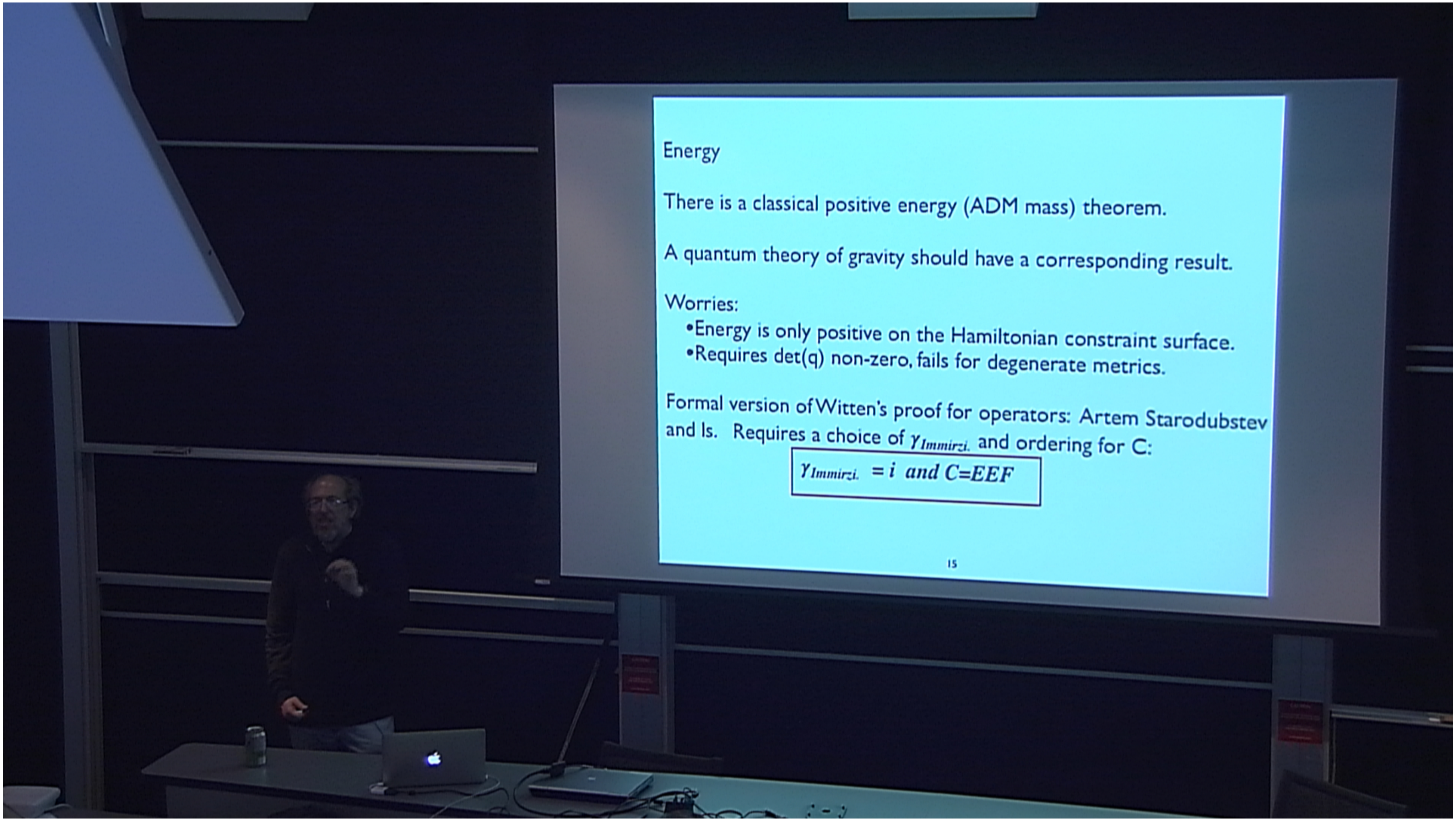
- Linearization of Holst action around deSitter.
- Im ($\gamma_{Immirzi}$) non-vanishing.
- operator ordering assumptions

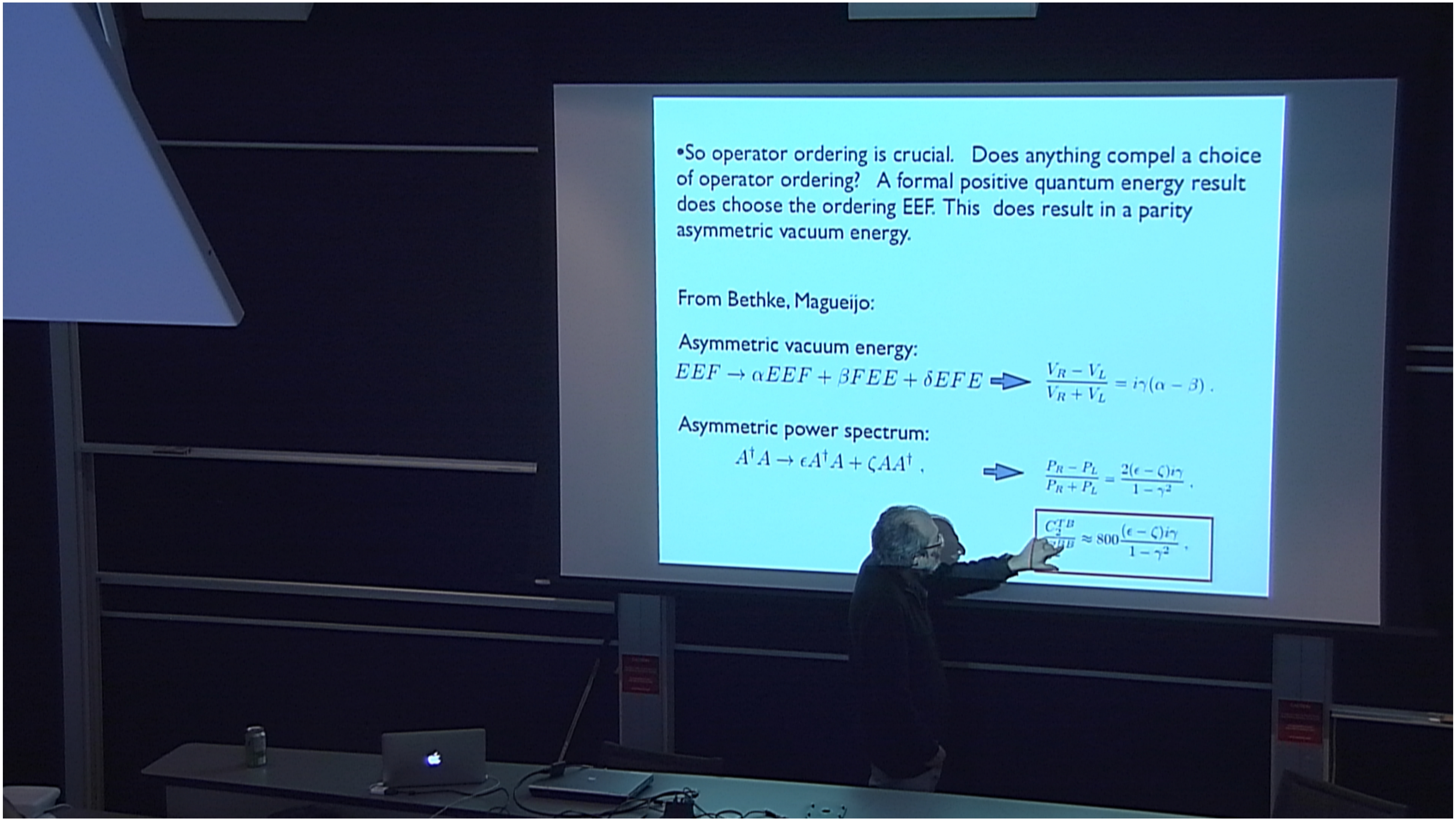
Contaldi, Magueijo, Is 0806.3082 PRL 101:141101, 2008
Magueijo, Benincasa 1010.3552
Bethke, Magueijo 1104.1800


LQG can predict helicity dependent vacuum energy density and production of tensor modes, depending on three assumptions:
•Linearization of Holst action around deSitter.
•Im ($\gamma_{Immirzi}$) non-vanishing.
•operator ordering assumptions
From Bethke, Magueijo:
Asymmetric vacuum energy:
$EEF \to \alpha EEF + \beta FEE + \delta EFE$
$\frac{V_R - V_L}{V_R + V_L} = i\gamma(\alpha - \beta)$.
Asymmetric power spectrum:
$A^\dagger A \to \epsilon A^\dagger A + \zeta A A^\dagger$,
$\frac{P_R - P_L}{P_R + P_L} = \frac{2(\epsilon - \zeta)i\gamma}{1 - \gamma^2}$.
$\frac{C_2^{TB}}{C_2^{BB}} \approx 800 \frac{(\epsilon - \zeta)i\gamma}{1 - \gamma^2}$.
13

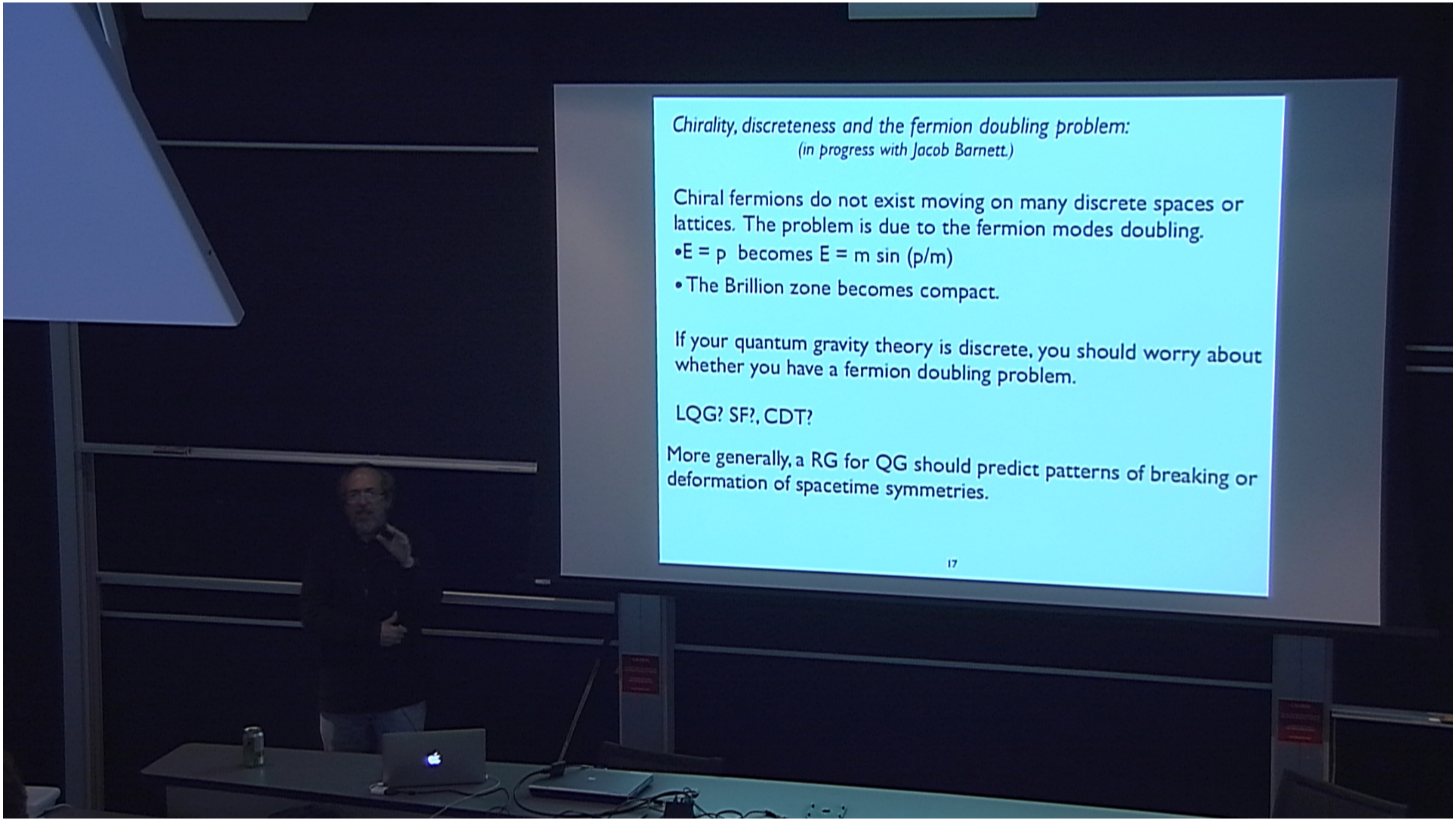

LQG can predict helicity dependent vacuum energy density and production of tensor modes, depending on three assumptions:
•Linearization of Holst action around deSitter.
•Im (γ_Immirzi) non-vanishing.
•operator ordering assumptions
From Bethke, Magueijo:
Asymmetric vacuum energy:
EEF → αEEF + βFEE + δEFE ⇒ (V_R − V_L)/(V_R + V_L) = iγ(α − β) .
Asymmetric power spectrum:
A†A → εA†A + ζAA† . ⇒ (P_R − P_L)/(P_R + P_L) = 2(ε − ζ)iγ/(1 − γ²) .
C_2^TB/C_2^BB ≈ 800 (ε − ζ)iγ/(1 − γ²) .
13

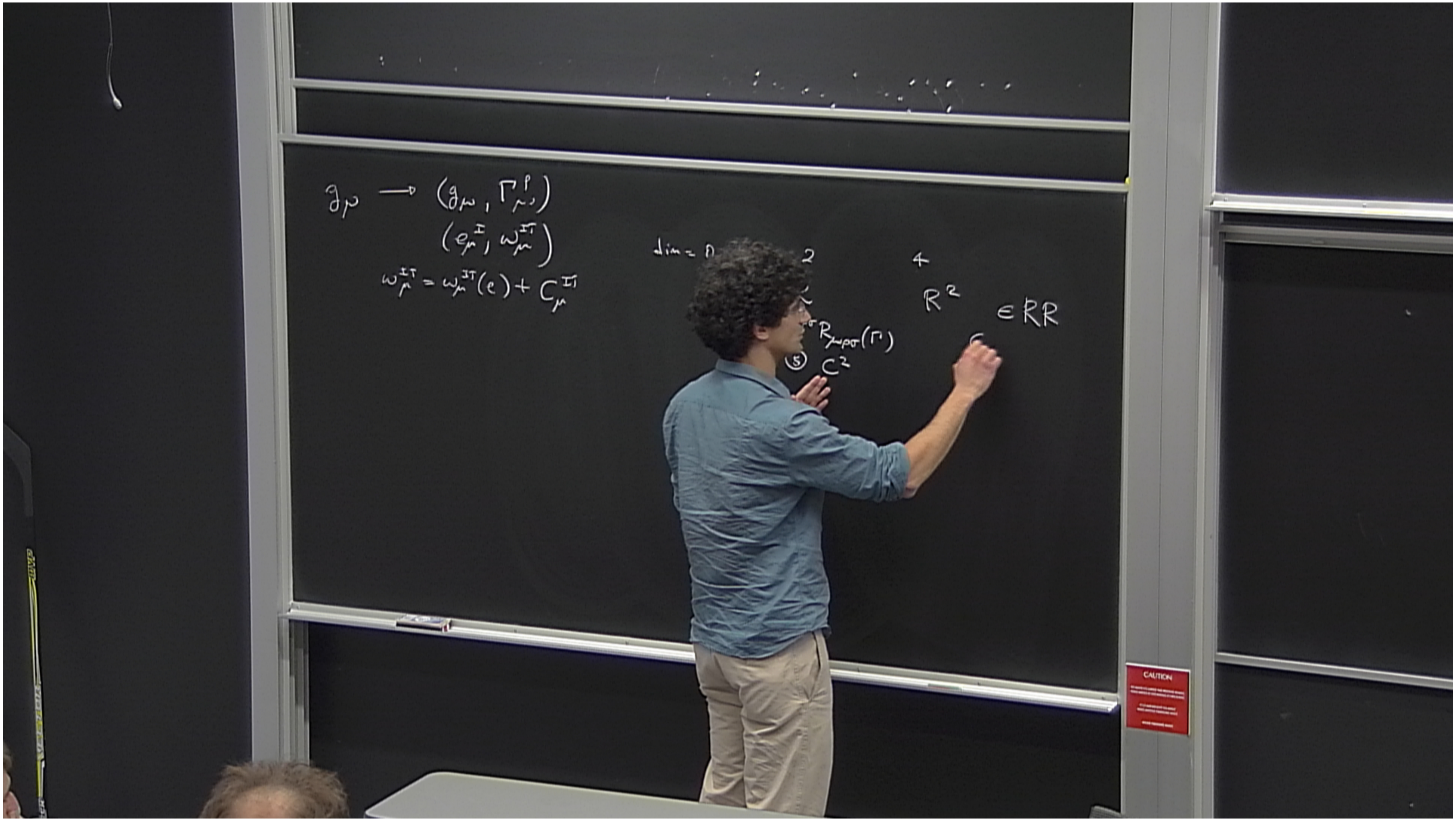

Energy
There is a classical positive energy (ADM mass) theorem.
A quantum theory of gravity should have a corresponding result.
Worries:
•Energy is only positive on the Hamiltonian constraint surface.
•Requires det(q) non-zero, fails for degenerate metrics.
Formal version of Witten's proof for operators: Artem Starodubstev and Is. Requires a choice of $\gamma_{Immirzi.}$ and ordering for C:
$\gamma_{Immirzi.} = i$ and C=EEF
15

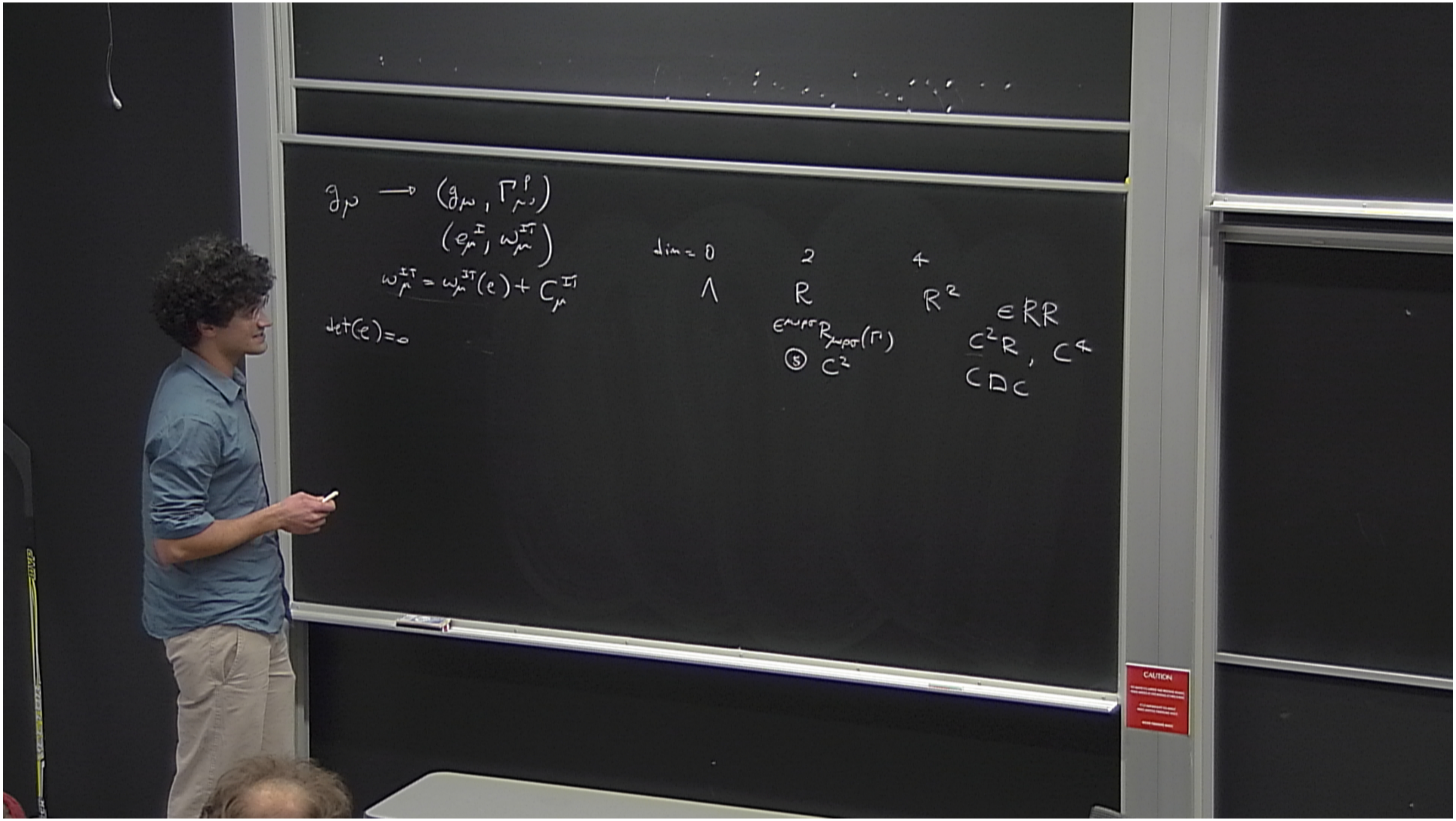

Energy
There is a classical positive energy (ADM mass) theorem.
A quantum theory of gravity should have a corresponding result.
Worries:
•Energy is only positive on the Hamiltonian constraint surface.
•Requires det(q) non-zero, fails for degenerate metrics.
Formal version of Witten's proof for operators: Artem Starodubstev and Is. Requires a choice of γImmirzi. and ordering for C:
γImmirzi. = i and C=EEF
15



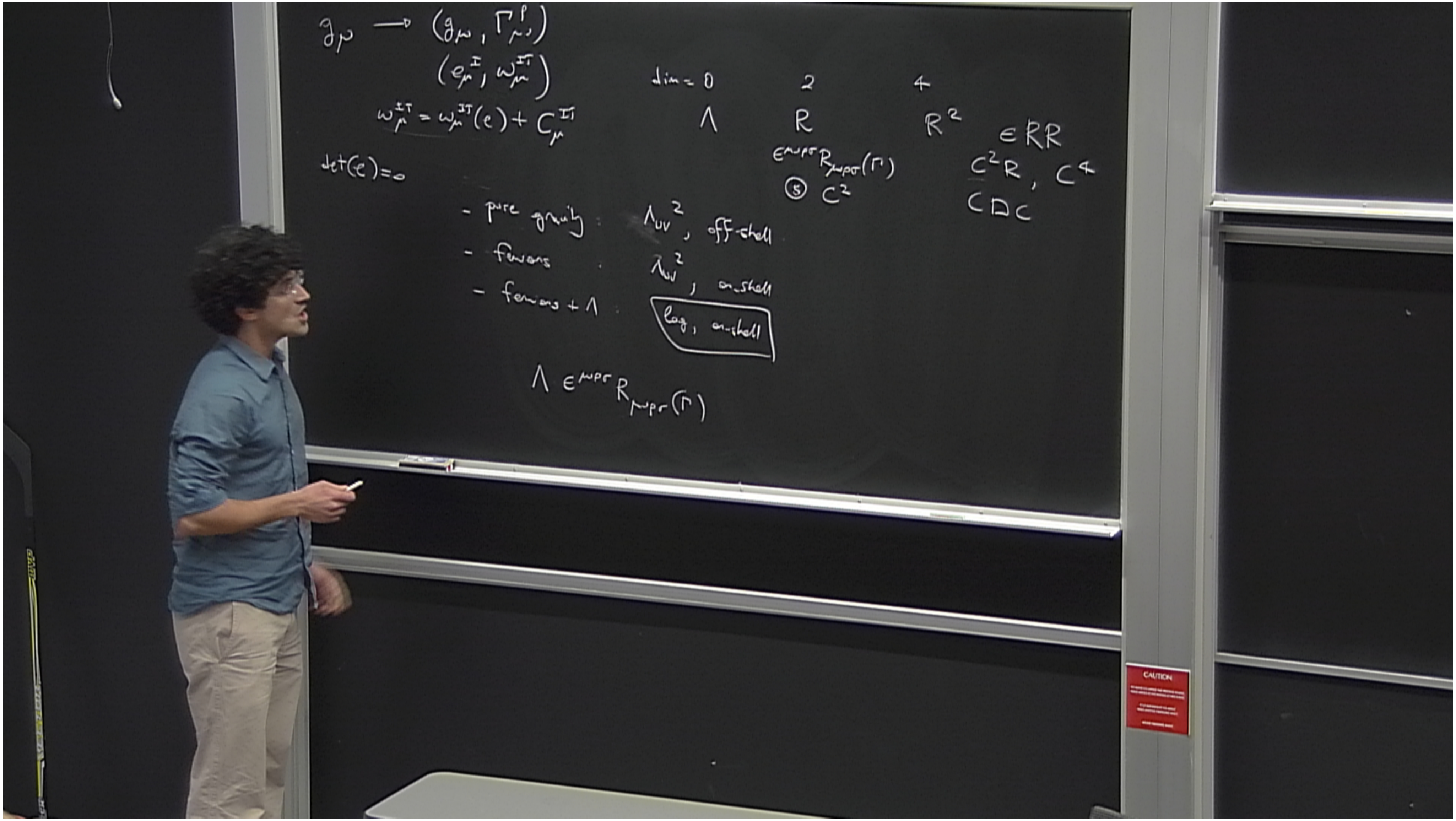
•So operator ordering is crucial. Does anything compel a choice of operator ordering? A formal positive quantum energy result does choose the ordering EEF. This does result in a parity asymmetric vacuum energy.
From Bethke, Magueijo:
Asymmetric vacuum energy:
$EEF \to \alpha EEF + \beta FEE + \delta EFE$
$\frac{V_R - V_L}{V_R + V_L} = i\gamma(\alpha - \beta)$.
Asymmetric power spectrum:
$A^\dagger A \to \epsilon A^\dagger A + \zeta A A^\dagger$,
$\frac{P_R - P_L}{P_R + P_L} = \frac{2(\epsilon - \zeta)i\gamma}{1 - \gamma^2}$.
$\approx 800 \frac{(\epsilon - \zeta)i\gamma}{1 - \gamma^2}$.

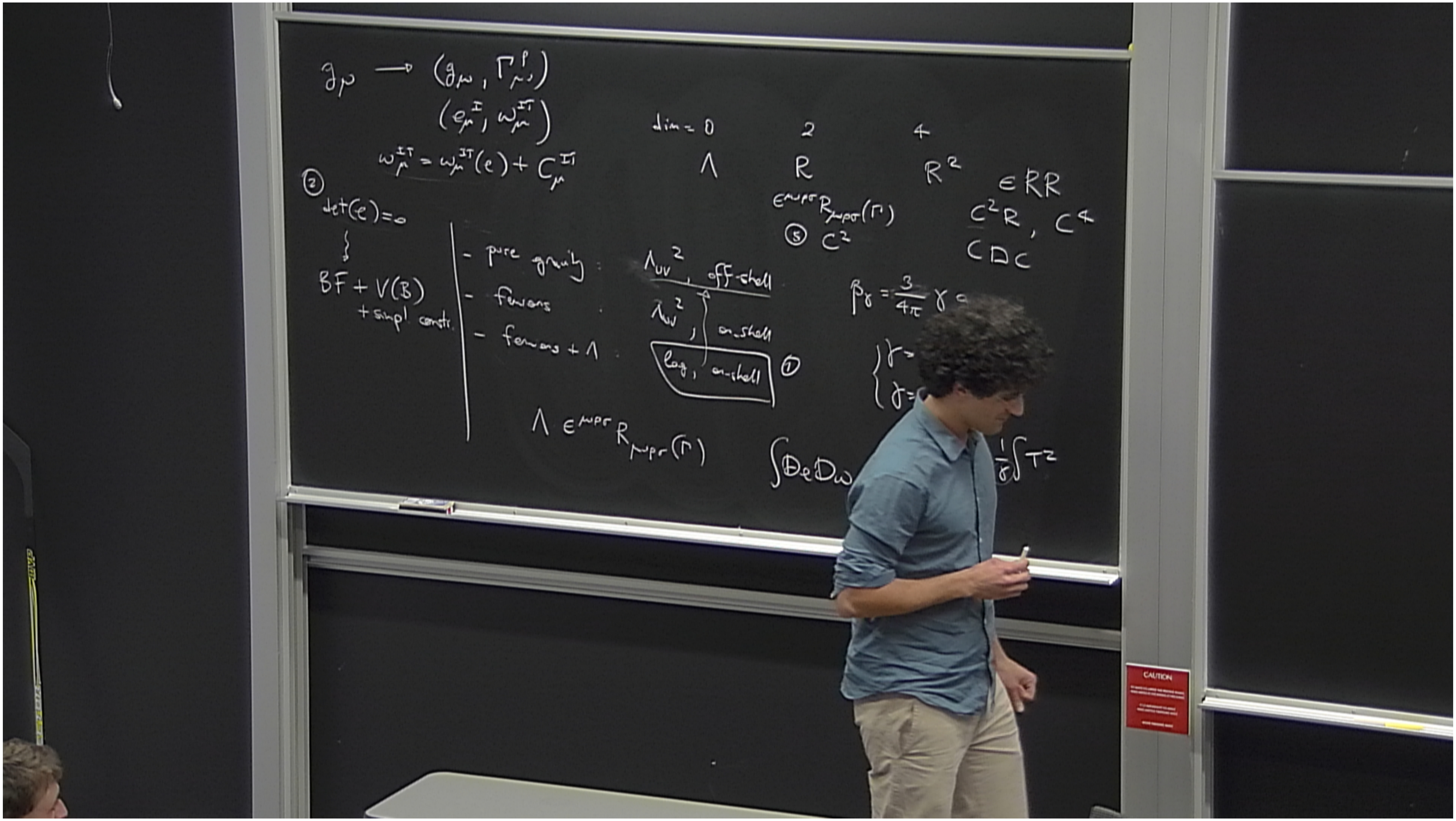

Chirality, discreteness and the fermion doubling problem:
(in progress with Jacob Barnett.)
Chiral fermions do not exist moving on many discrete spaces or lattices. The problem is due to the fermion modes doubling.
•E = p becomes E = m sin (p/m)
• The Brillion zone becomes compact.
If your quantum gravity theory is discrete, you should worry about whether you have a fermion doubling problem.
LQG? SF?, CDT?
More generally, a RG for QG should predict patterns of breaking or deformation of spacetime symmetries.
17





$g_{\mu\nu} \longrightarrow (g_{\mu\nu}, \Gamma^{\rho}_{\mu\nu})$
$(e_\mu^I, \omega_\mu^{IJ})$
$\omega_\mu^{IJ} = \omega_\mu^{IJ}(e) + C_\mu^{IJ}$
$\det(e) = 0$
dim = 0 2 4
Λ R R^2
$\epsilon^{\mu\nu\rho\sigma} R_{\mu\nu\rho\sigma}(\Gamma)$
5 C^2
ϵRR
$C^2 R$, C^4
$C \Box C$
CAUTION


$g_{\mu\nu} \longrightarrow (g_{\mu\nu}, \Gamma^{\rho}_{\mu\nu})$
$(e^{I}_{\mu}, \omega^{IJ}_{\mu})$
$\omega^{IJ}_{\mu} = \omega^{IJ}_{\mu}(e) + C^{IJ}_{\mu}$
$\det(e) = 0$
dim = 0
2
4
Λ
R
R^2
ϵRR
$\epsilon^{\mu\nu\rho\sigma} R_{\mu\nu\rho\sigma}(\Gamma)$
$C^2 R$, C^4
⑤ C^2
$C \Box C$
- pure gravity : Λ_{UV}^2, off-shell
- fermions : Λ_{UV}^2, on-shell
- fermions + Λ : log, on-shell
$\Lambda\ \epsilon^{\mu\nu\rho\sigma} R_{\mu\nu\rho\sigma}(\Gamma)$
CAUTION


dim = 0
2
4
R
R²
∈RR
C²R , C⁴
C□C
- pure gravity :
- fermions
- fermions + Λ
off-shell
on-shell
log , on-shell
BF + V(B)
+ simpl. constr.
det(e) = 0