Title: Non-Equilibrium Thermodynamics of a Gravitational Screen

Date: Oct 23, 2014 04:30 PM

URL: http://pirsa.org/14100110

Abstract:

Relativistic Hydrodynamics and gravitational screens

Laurent Freidel PI.

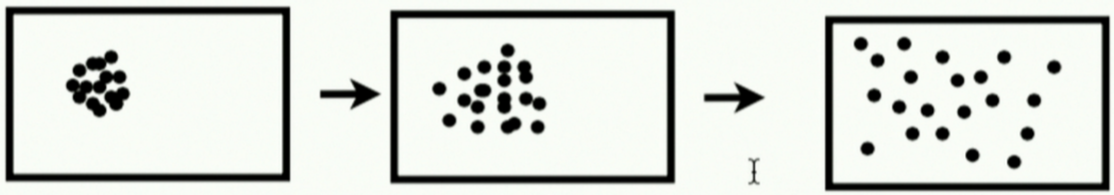
PI-Day 14

arXiv:1312.1538, 1405.4881, ...

The Questions ?

•Can we define the entropy of gravitational systems ?

Time evolution of non gravitational system



low entropy

high entropy

The Questions ?
•Can we define the entropy of gravitational systems ?
Time evolution of non gravitational system
low entropy
high entropy
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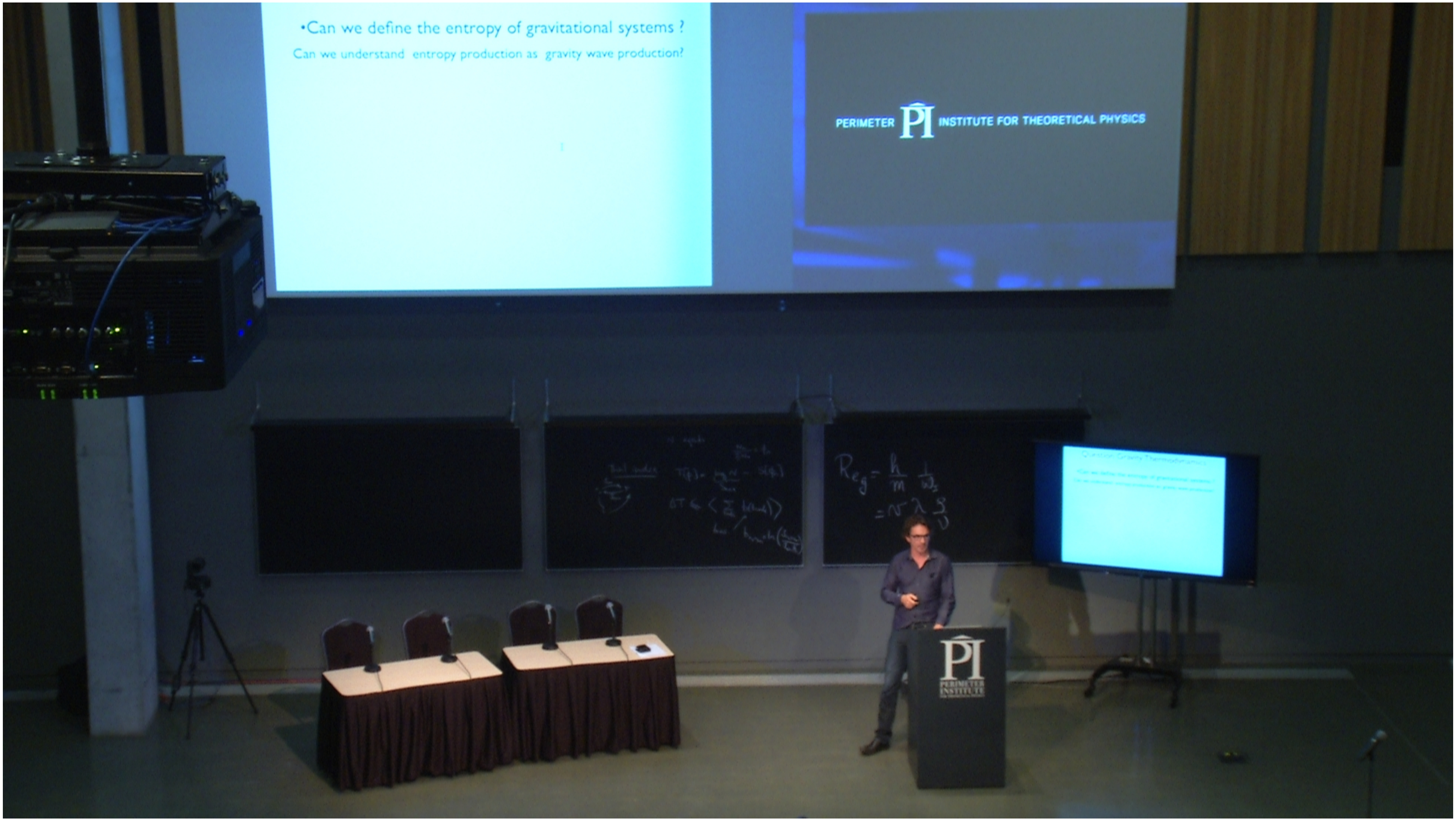
•Can we define the entropy of gravitational systems ?
Can we understand entropy production as gravity wave production?
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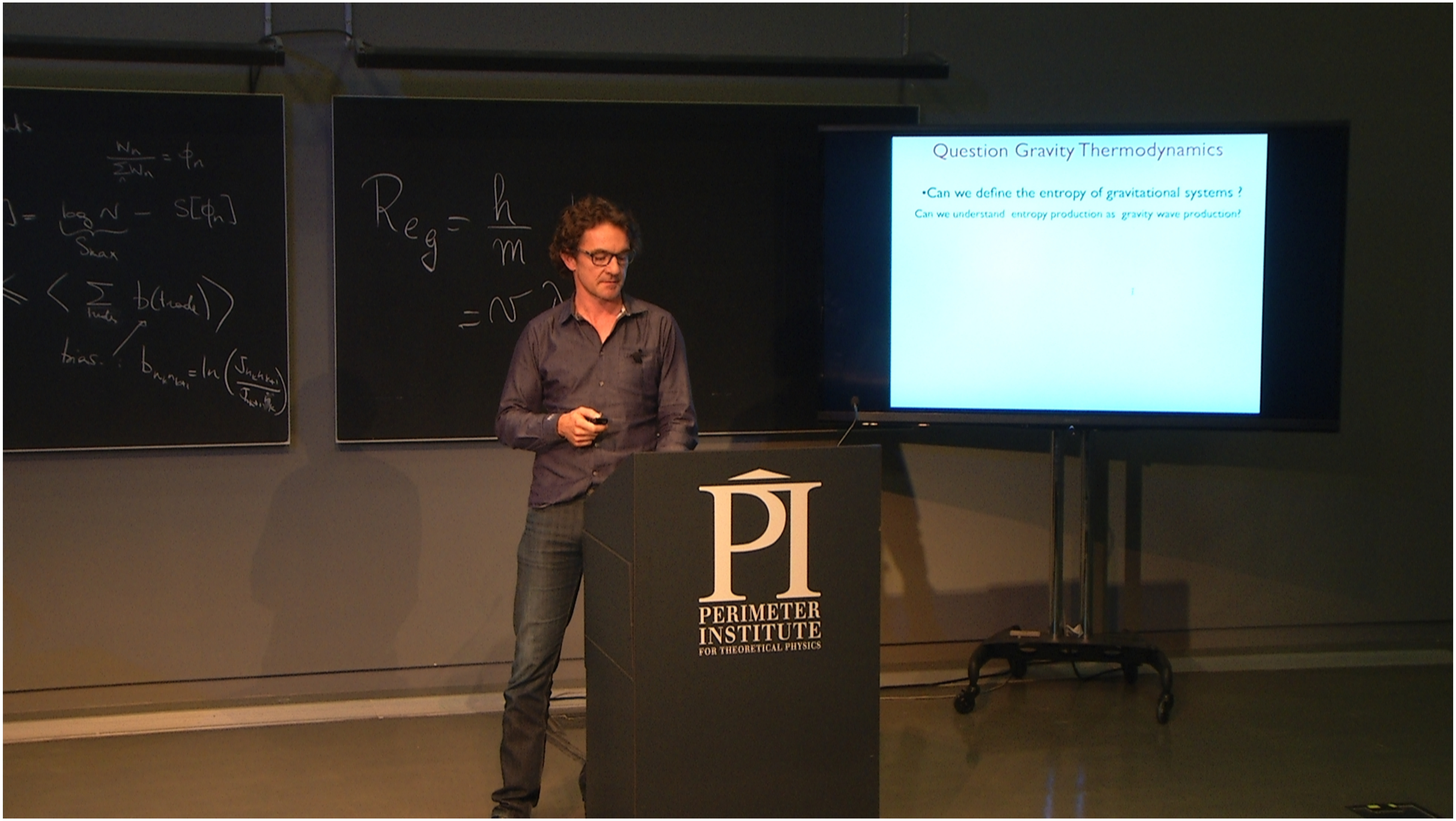
Question Gravity Thermodynamics
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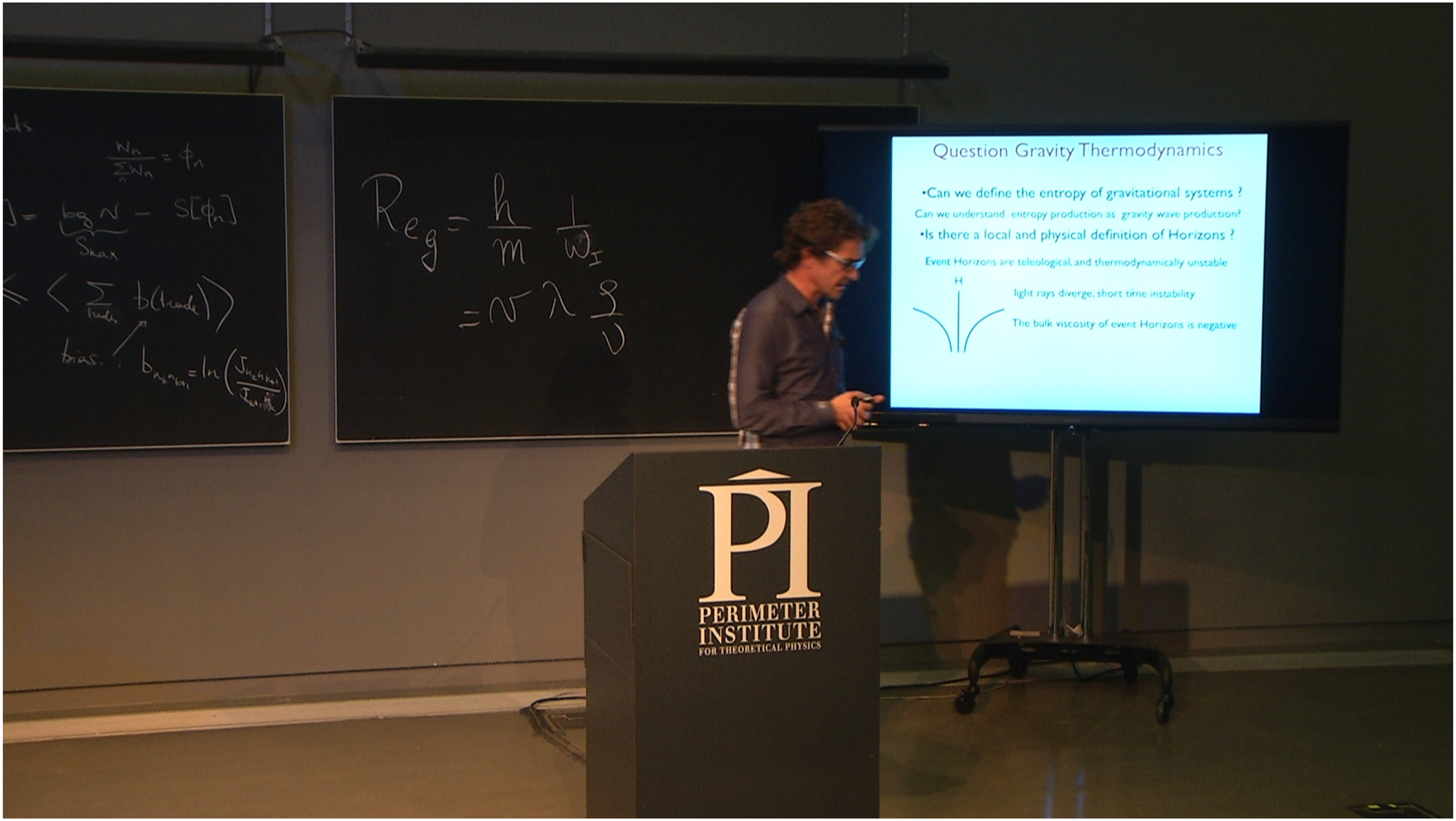
Question Gravity Thermodynamics
•Can we define the entropy of gravitational systems ?
Can we understand entropy production as gravity wave production?
•Is there a local and physical definition of Horizons ?
Event Horizons are teleological, and thermodynamically unstable
H
light rays diverge, short time instability
The bulk viscosity of event Horizons is negative
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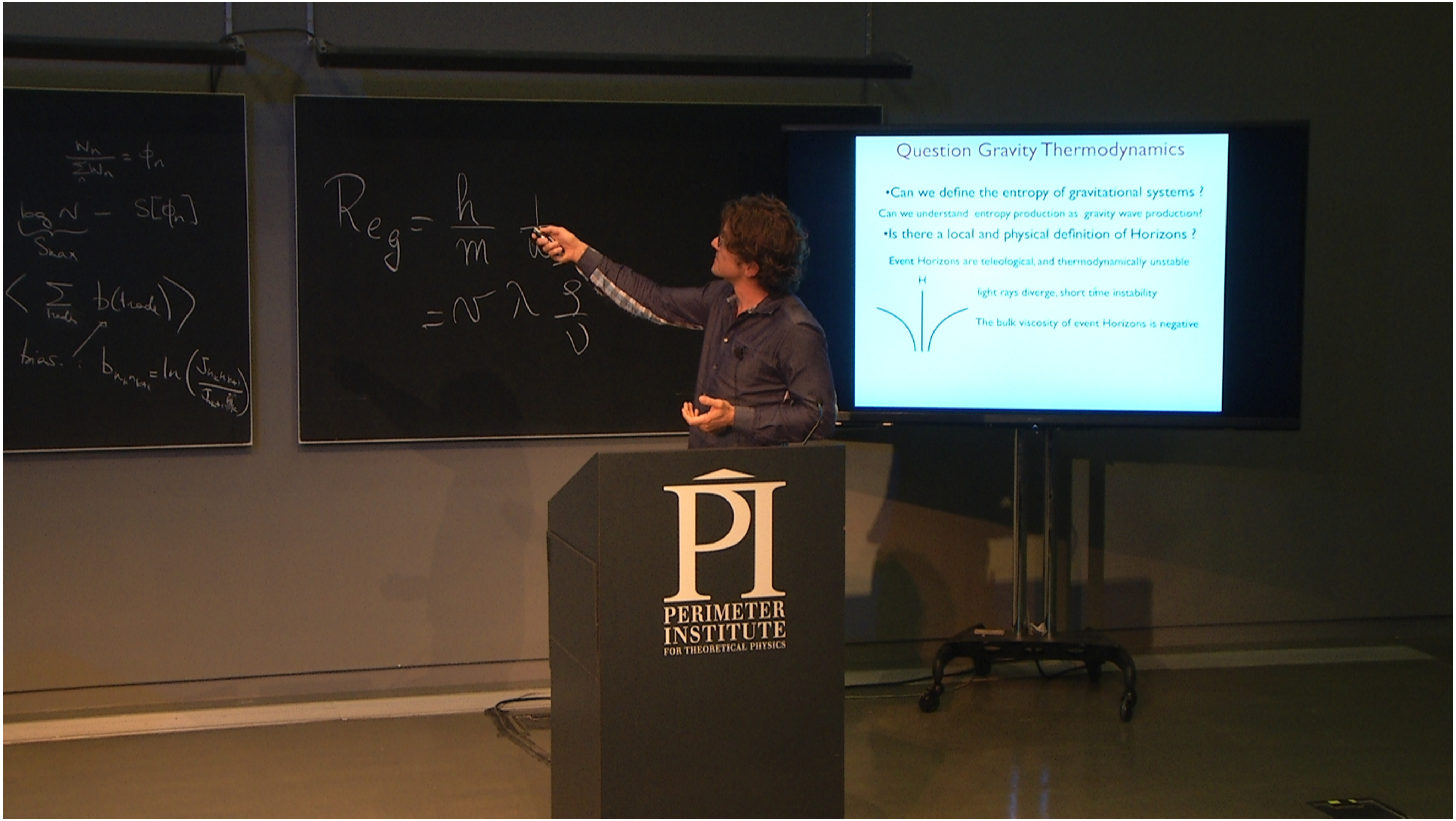

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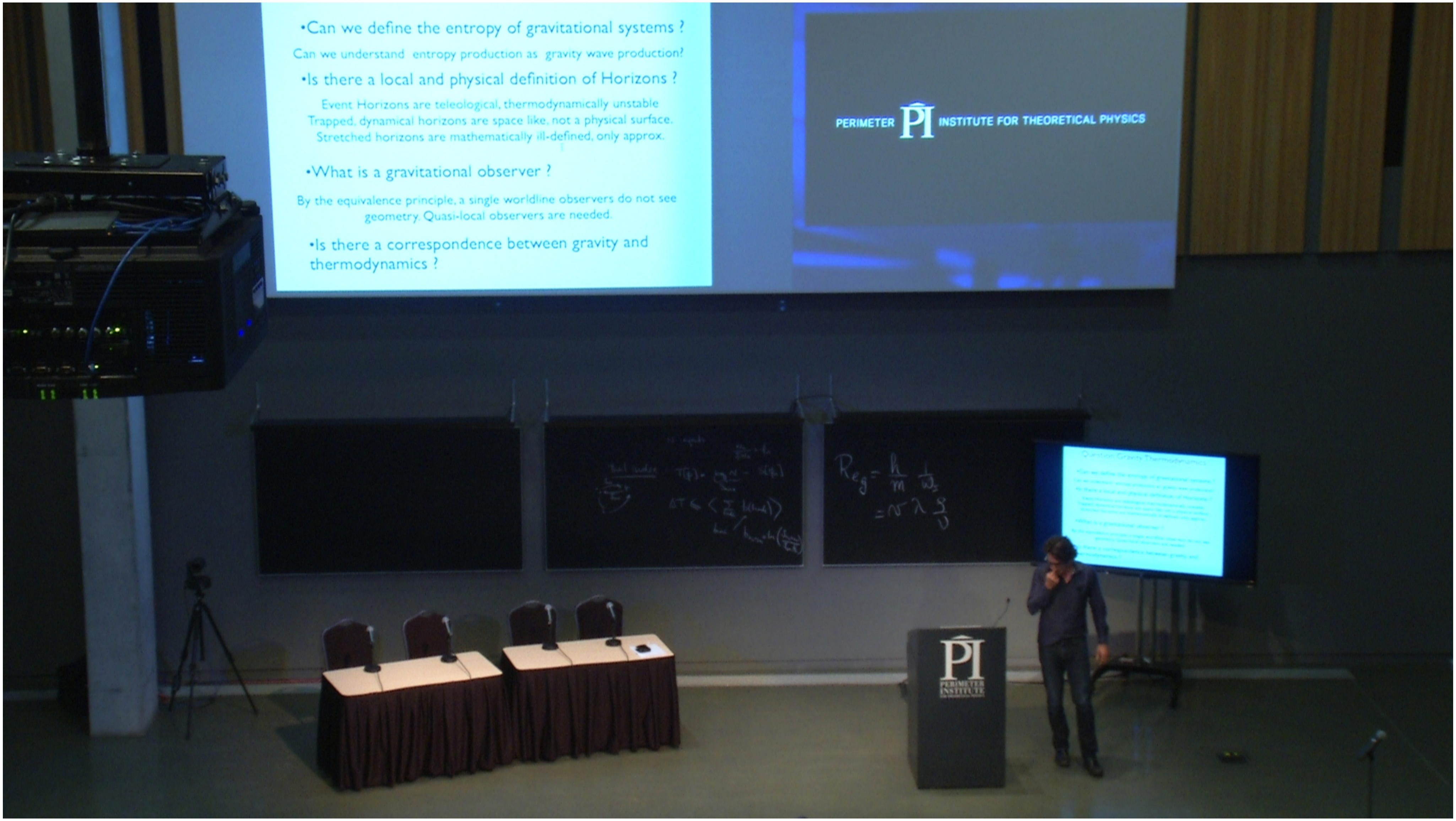
•Can we define the entropy of gravitational systems ?
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•Is there a local and physical definition of Horizons ?
Event Horizons are teleological, thermodynamically unstable
Trapped, dynamical horizons are space like, not a physical surface.
Stretched horizons are mathematically ill-defined, only approx.
•What is a gravitational observer ?
By the equivalence principle, a single worldline observers do not see geometry. Quasi-local observers are needed.
•Is there a correspondence between gravity and thermodynamics ?
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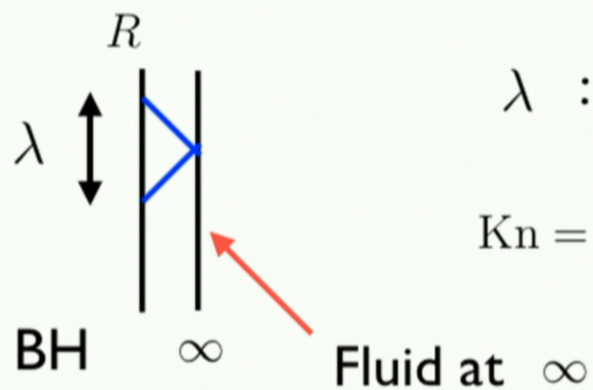
Analogy Gravity-Thermodyamics

- There seems to be lots of evidence of a correspondence between Black Hole physics and eq. thermo-Static.

- Is it just an analogy or is there a deeper correspondence? which is valid locally and beyond equilibrium.

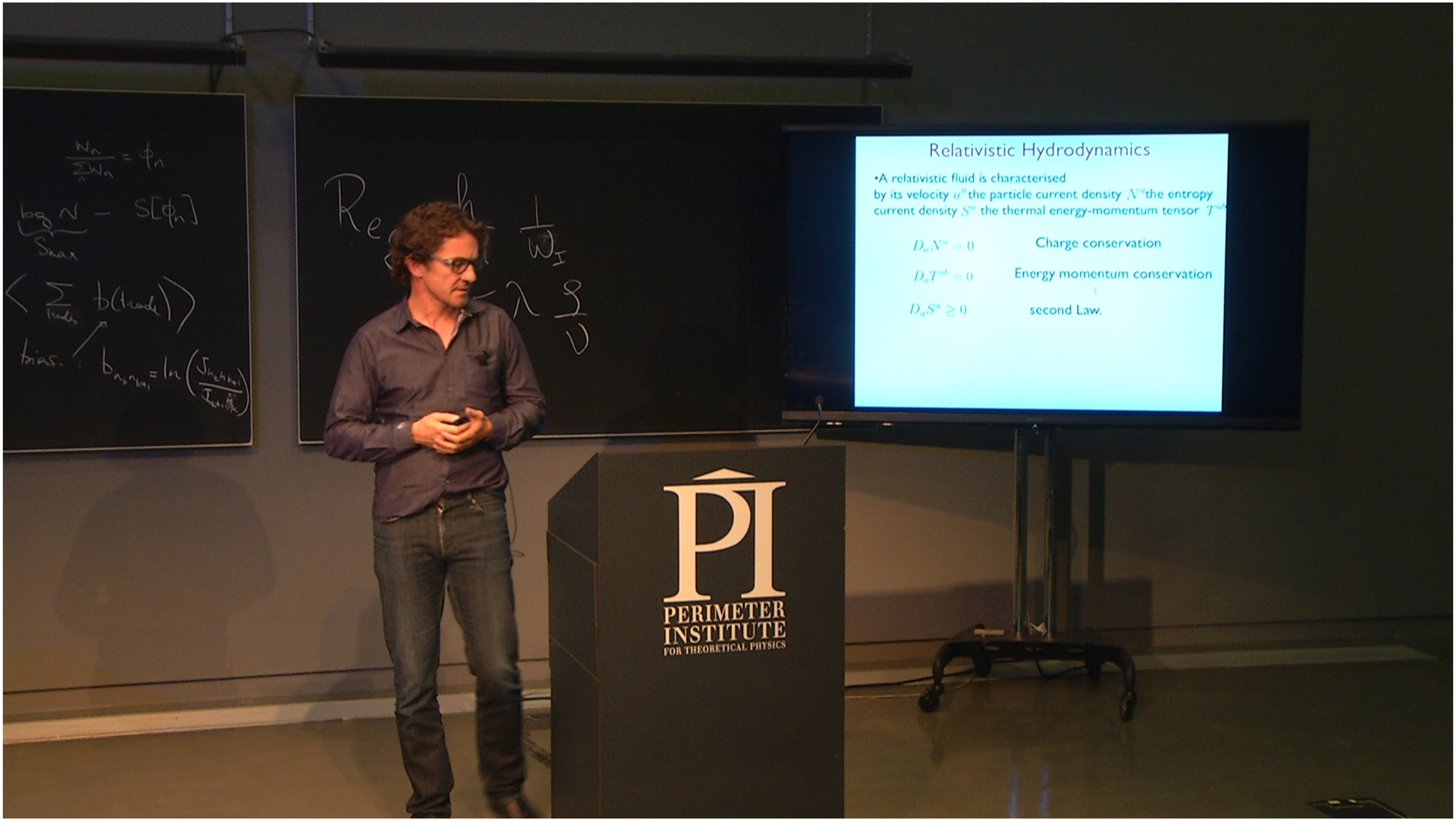
Minwalla- Hubeny

Gravity-Fluid: perturbation of large BH in AdS



λ : Mean free path

$\mathrm{Kn} = \frac{\lambda}{R} << 1$ Hydrodynamic limit


Relativistic Hydrodynamics
•A relativistic fluid is characterised by its velocity u^a the particle current density N^a the entropy current density S^a the thermal energy-momentum tensor T^{ab}
$D_a N^a = 0$ Charge conservation
$D_a T^{ab} = 0$ Energy momentum conservation
$D_a S^a \geq 0$ second Law.
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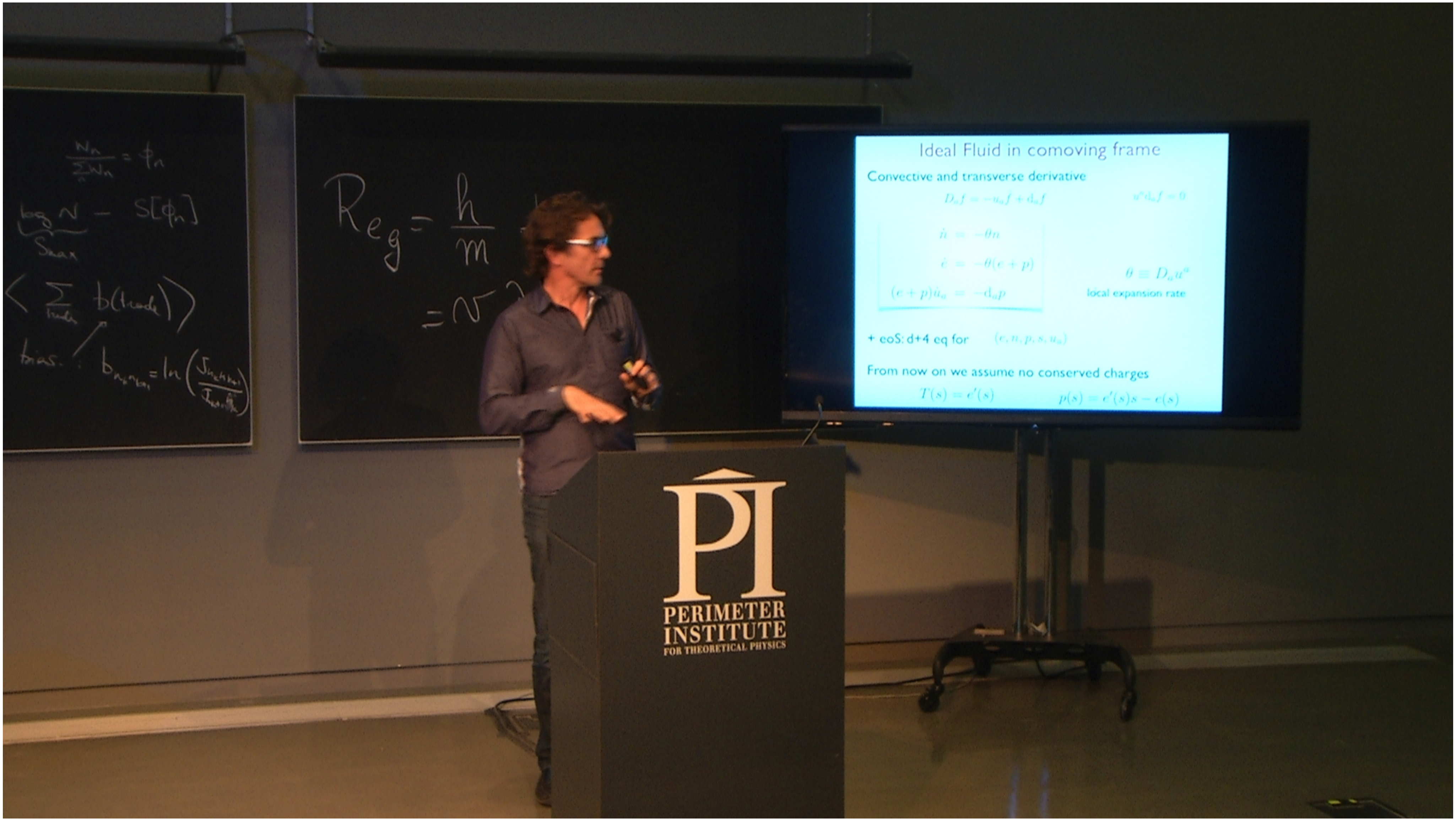
Ideal Fluid in comoving frame
Convective and transverse derivative
+ eoS: d+4 eq for
local expansion rate
From now on we assume no conserved charges
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Ideal Fluid in comoving frame

Convective and transverse derivative

$$D_a f = -u_a \dot{f} + \mathrm{d}_a f \qquad u^a \mathrm{d}_a f = 0$$

$$\begin{aligned} \dot{n} &= -\theta n \\ \dot{e} &= -\theta(e+p) \\ (e+p)\dot{u}_a &= -\mathrm{d}_a p \end{aligned}$$

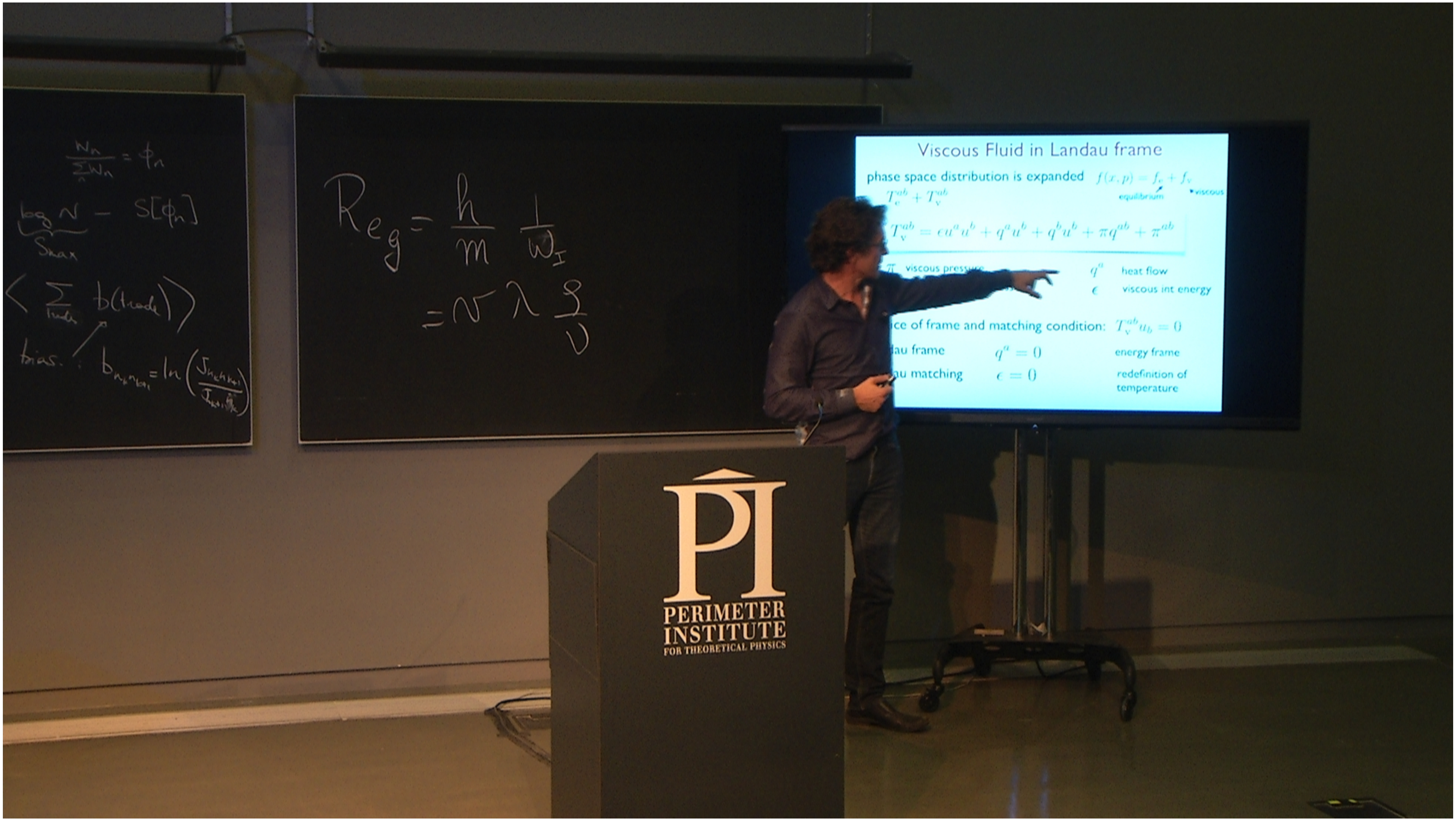
$$\theta \equiv D_a u^a$$

local expansion rate

+ eoS: d+4 eq for (e, n, p, s, u_a)

From now on we assume no conserved charges

$$T(s) = e'(s) \qquad p(s) = e'(s)s - e(s)$$


Viscous Fluid in Landau frame
phase space distribution is expanded
equilibrium
viscous
heat flow
viscous int energy
energy frame
redefinition of temperature
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Viscous Fluid in Landau frame
phase space distribution is expanded $f(x,p) = f_e + f_v$
equilibrium
viscous
$T_e^{ab} + T_v^{ab}$
$T_v^{ab} = \epsilon u^a u^b + q^a u^b + q^b u^b + \pi q^{ab} + \pi^{ab}$
π viscous pressure
Π^{ab} shear stress, traceless
q^a heat flow
ϵ viscous int energy
Choice of frame and matching condition: $T_v^{ab} u_b = 0$
Landau frame $q^a = 0$ energy frame
Landau matching $\epsilon = 0$ redefinition of temperature
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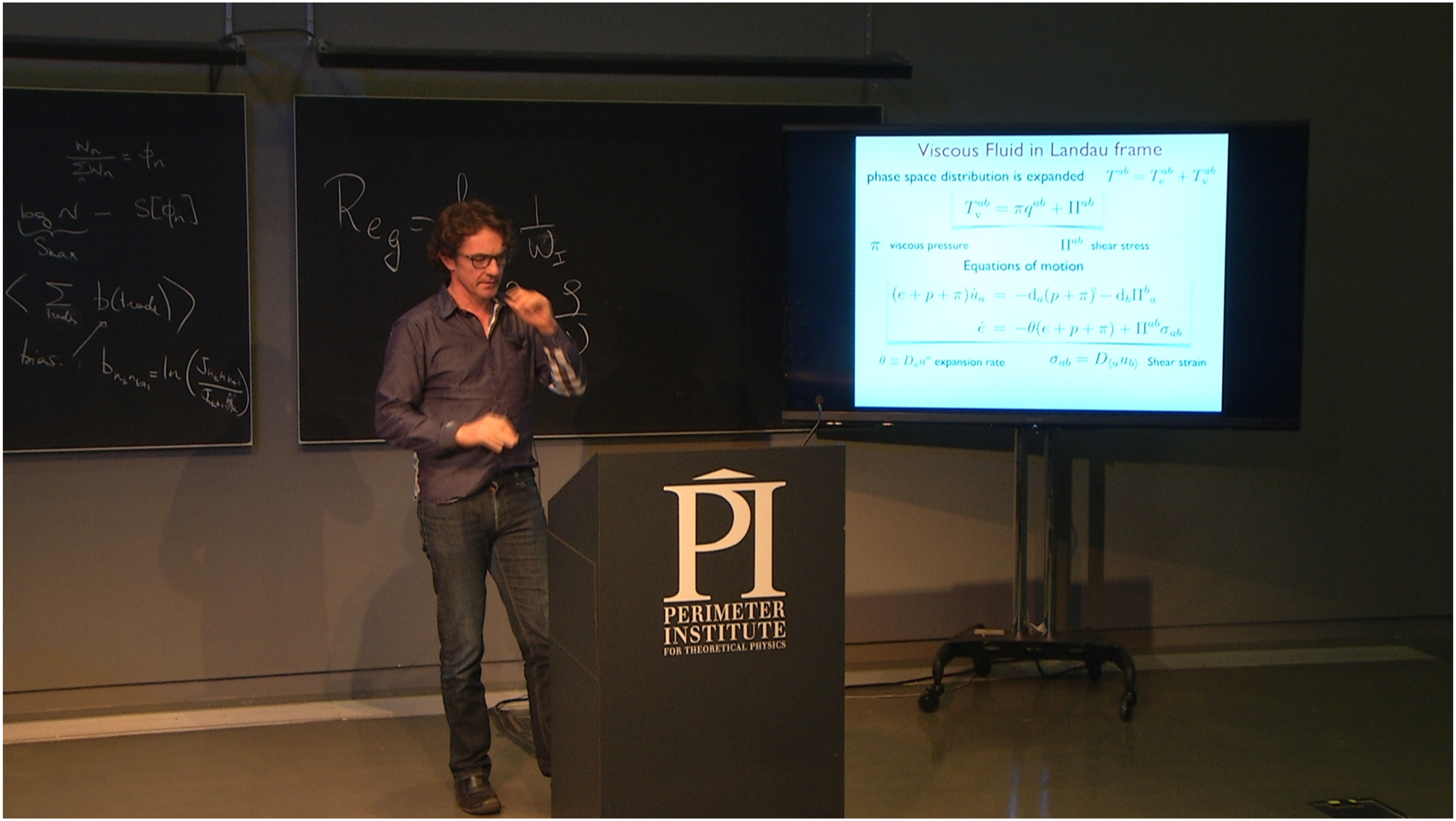
Viscous Fluid in Landau frame
phase space distribution is expanded
viscous pressure
shear stress
Equations of motion
expansion rate
Shear strain
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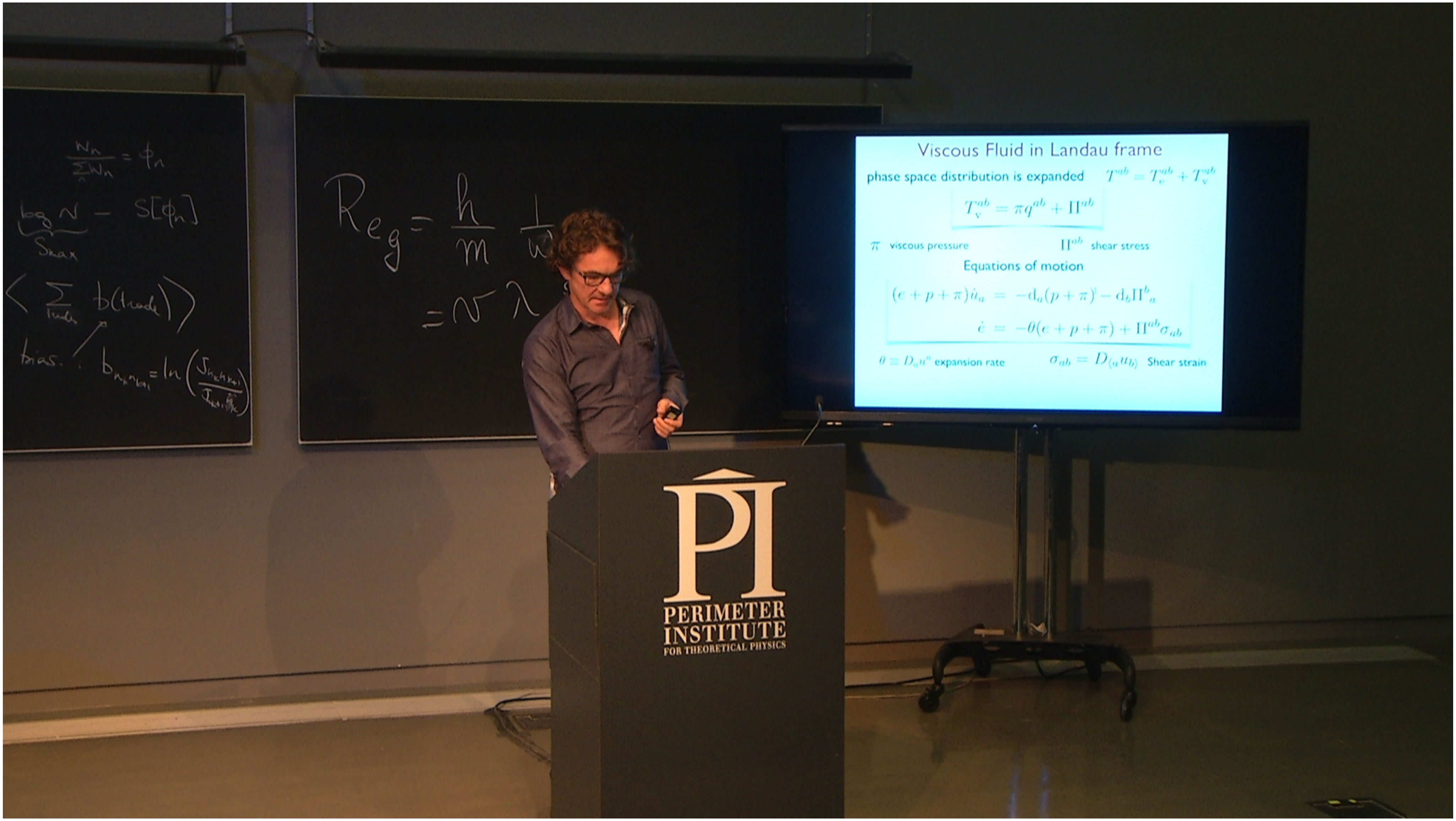
Viscous Fluid in Landau frame
phase space distribution is expanded $T^{ab} = T^{ab}_{e} + T^{ab}_{v}$
$T^{ab}_{v} = \pi q^{ab} + \Pi^{ab}$
π viscous pressure
Π^{ab} shear stress
Equations of motion
$(e + p + \pi)\dot{u}_a = -d_a(p + \pi) - d_b \Pi^b{}_a$
$\dot{e} = -\theta(e + p + \pi) + \Pi^{ab}\sigma_{ab}$
$\theta \equiv D_a u^a$ expansion rate
$\sigma_{ab} = D_{\langle a} u_{b\rangle}$ Shear strain
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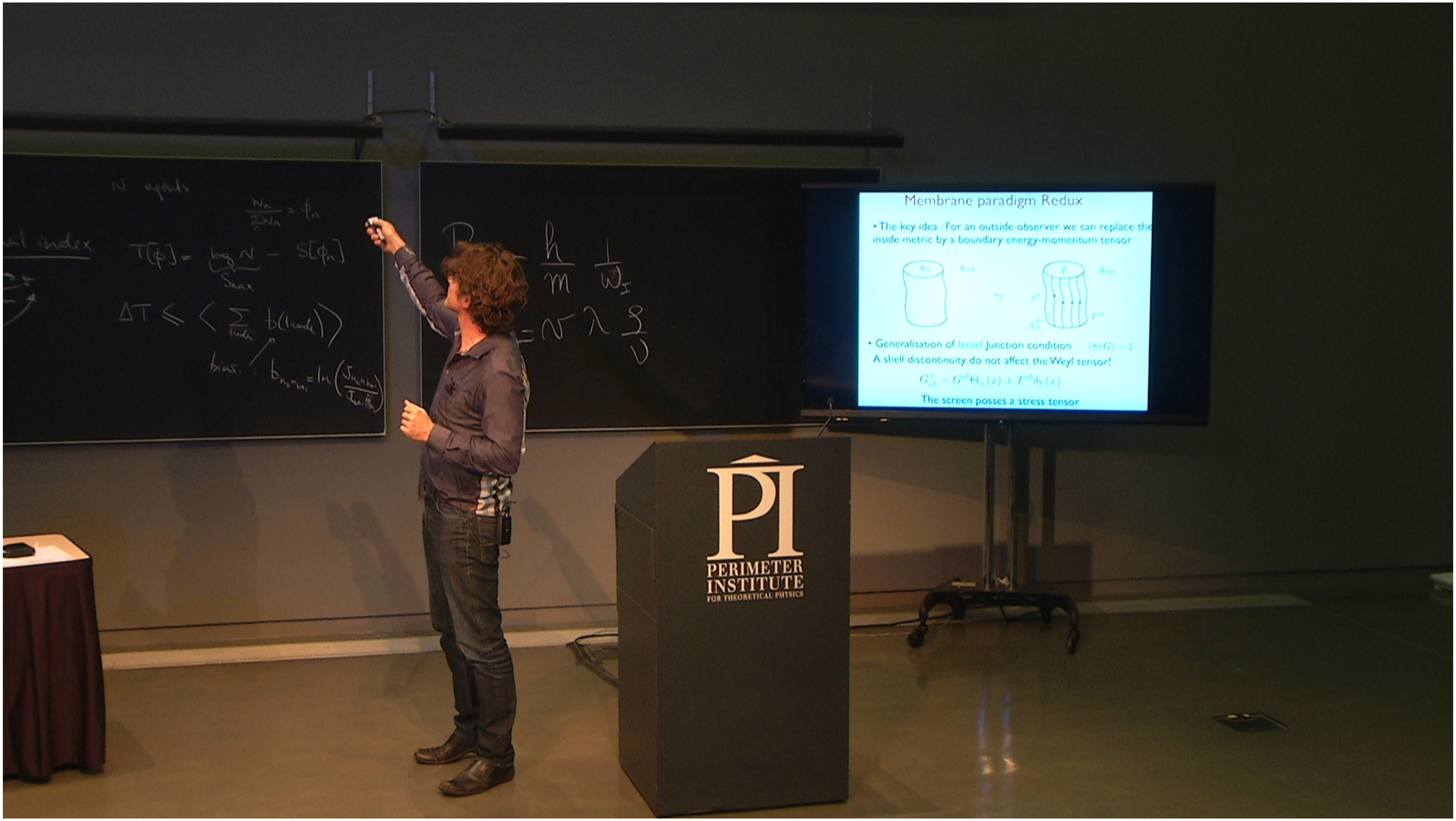
Membrane paradigm Redux
• The key idea : For an outside observer we can replace the inside metric by a boundary energy-momentum tensor
• Generalisation of Israel junction condition
A shell discontinuity do not affect the Weyl tensor!
The screen posses a stress tensor
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Membrane paradigm Redux

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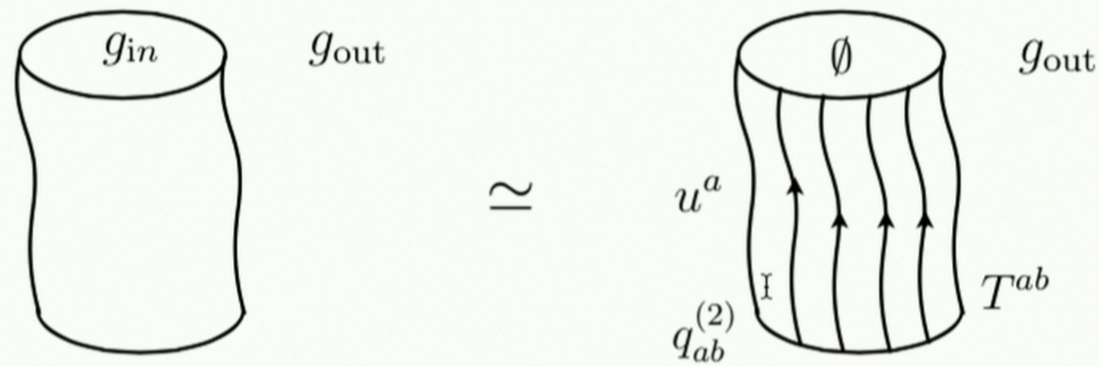
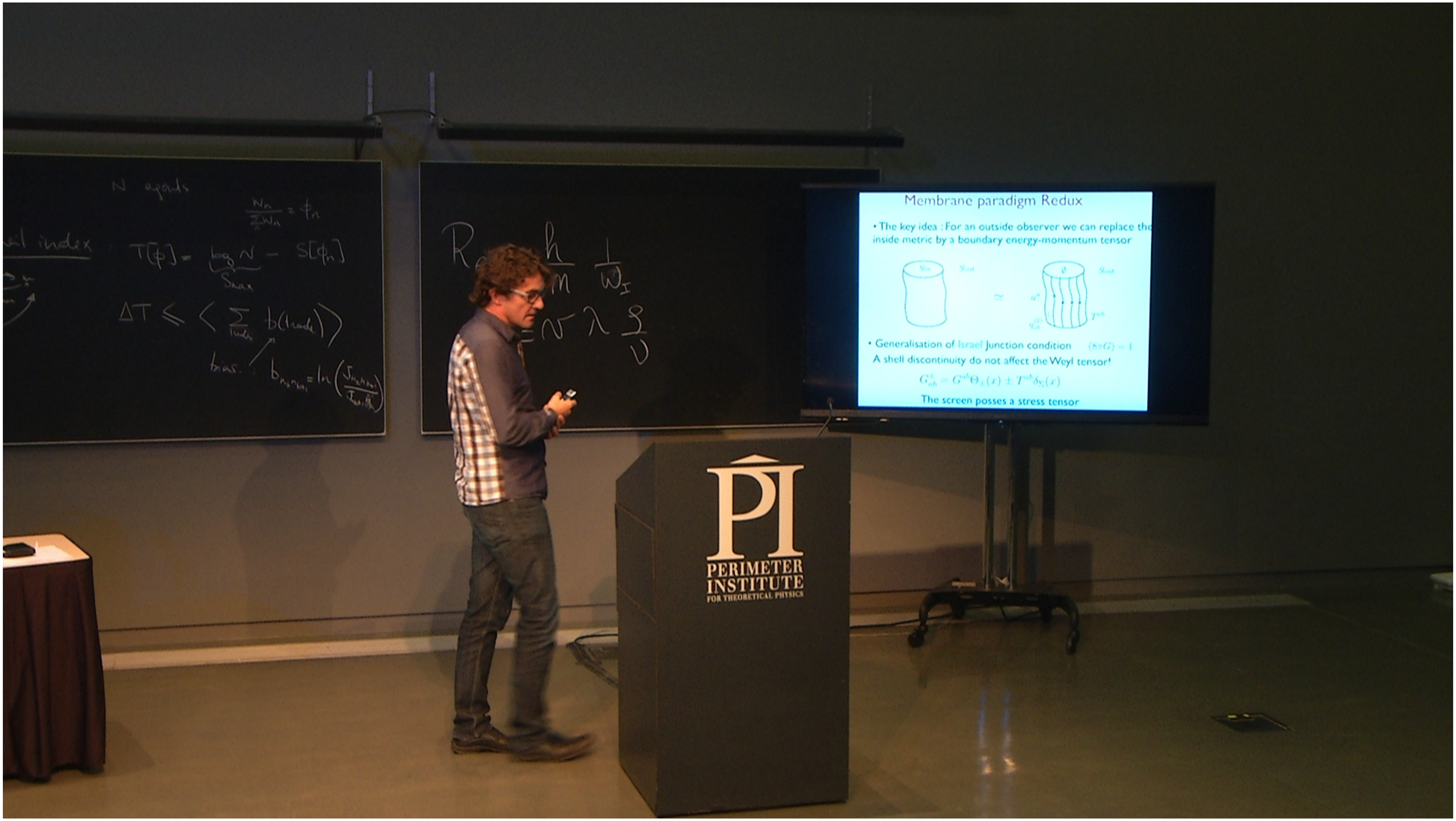


- Generalisation of Israel Junction condition $(8\pi G) = 1$

A shell discontinuity do not affect the Weyl tensor!

$$G_{ab}^{\pm} = G^{ab}\Theta_{\pm}(x) \pm T^{ab}\delta_{\Sigma}(x)$$

The screen posses a stress tensor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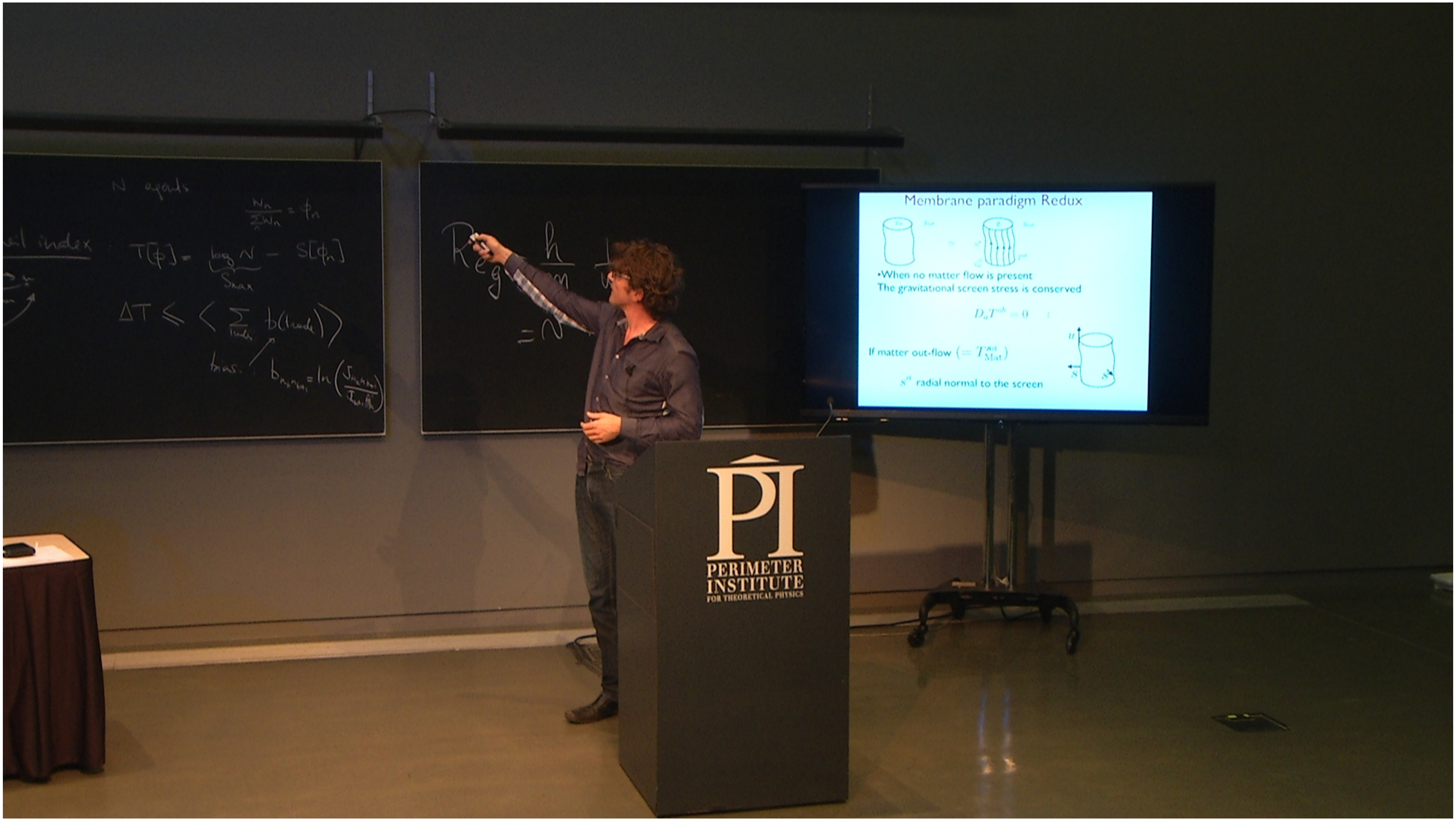
Membrane paradigm Redux
•When no matter flow is present
The gravitational screen stress is conserved
If matter out-flow
radial normal to the screen
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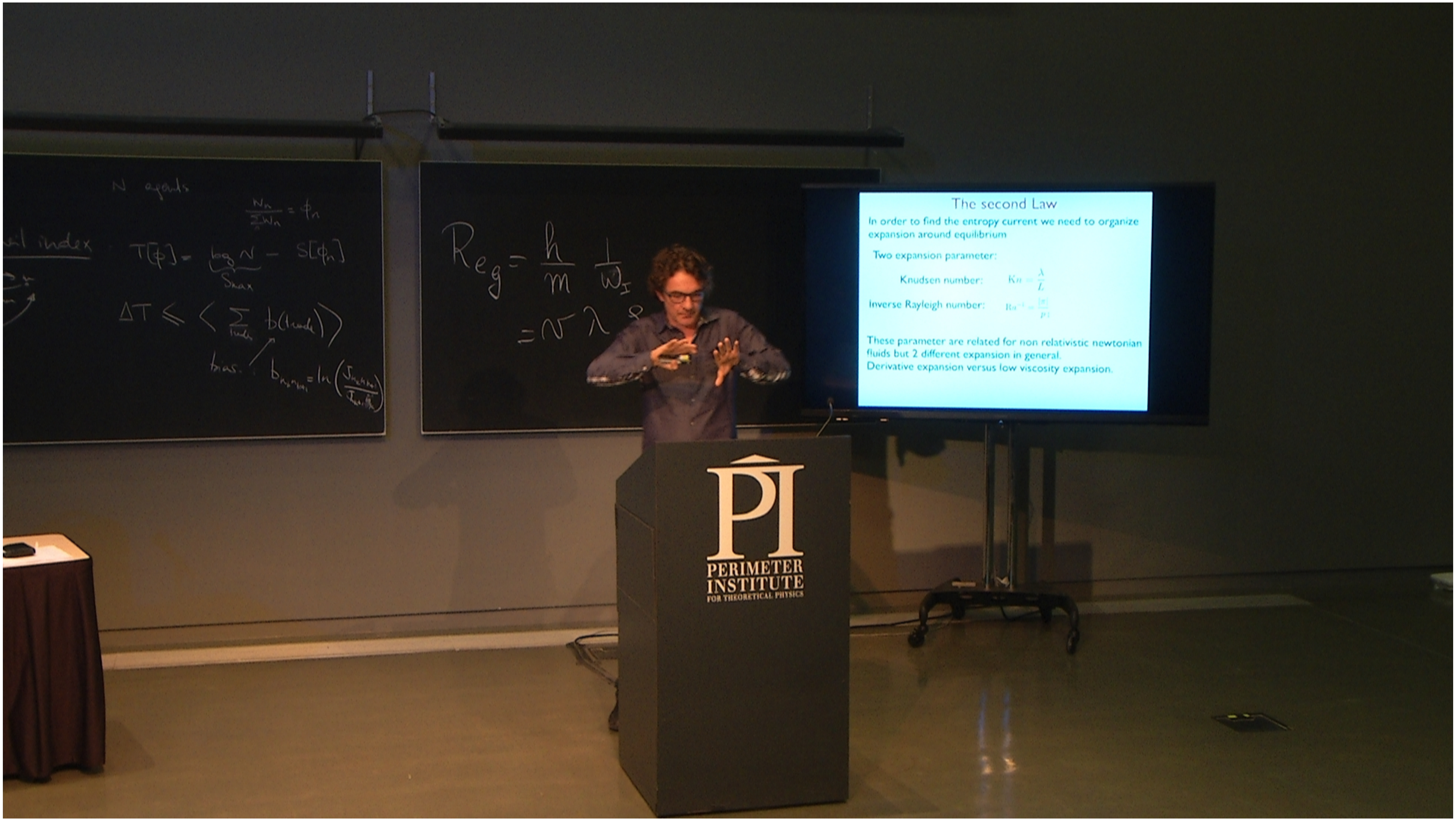
The second Law
In order to find the entropy current we need to organize expansion around equilibrium
Two expansion parameter:
Knudsen number: $Kn = \frac{\lambda}{L}$
Inverse Rayleigh number:
These parameter are related for non relativistic newtonian fluids but 2 different expansion in general.
Derivative expansion versus low viscosity expansion.
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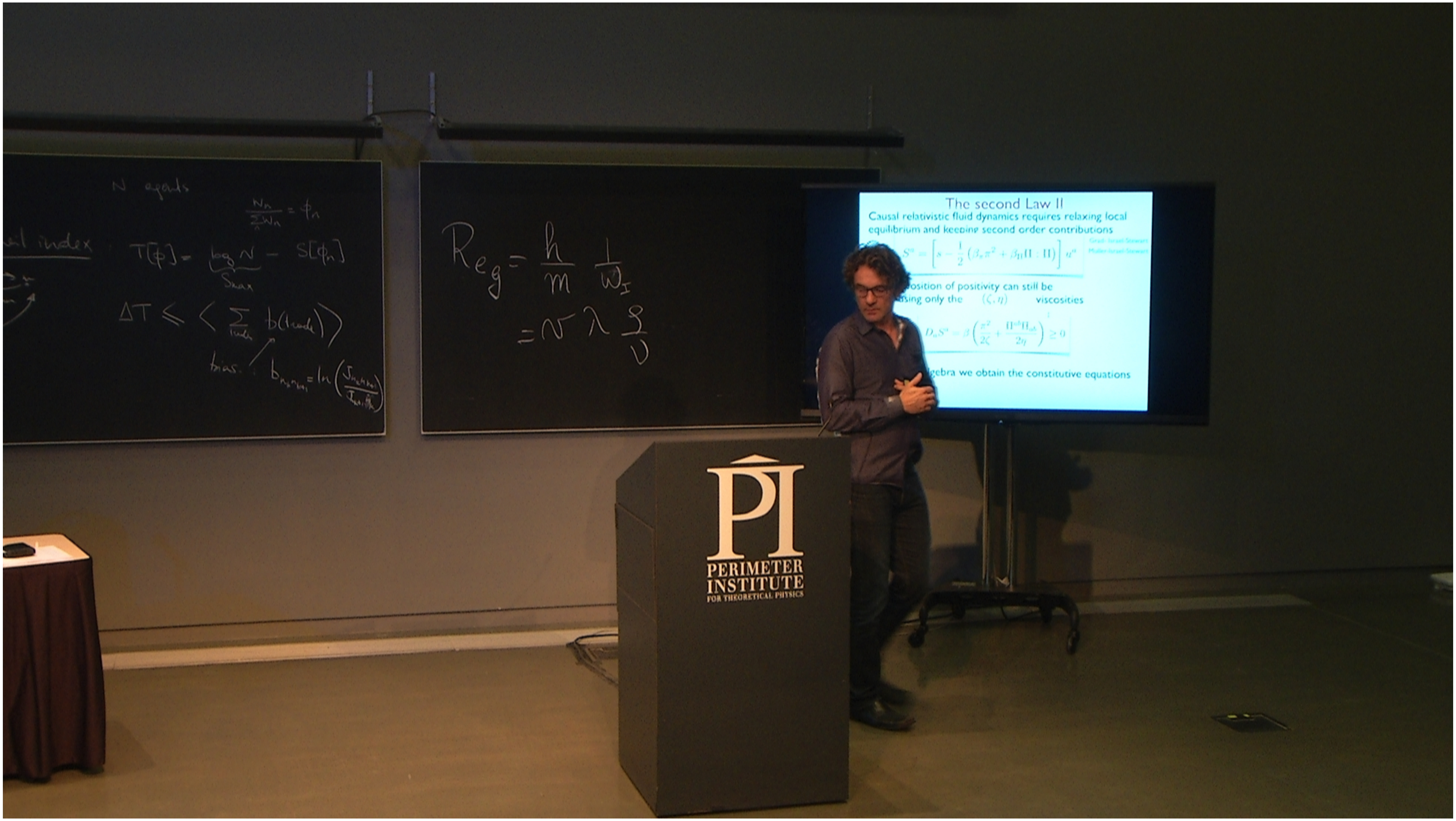
The second Law II
Causal relativistic fluid dynamics requires relaxing local
equilibrium and keeping second order contributions
viscosities
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The second Law II

Causal relativistic fluid dynamics requires relaxing local equilibrium and keeping second order contributions

$$S^a = \left[s - \frac{1}{2} \left(\beta_\pi \pi^2 + \beta_\Pi \Pi : \Pi \right) \right] u^a$$

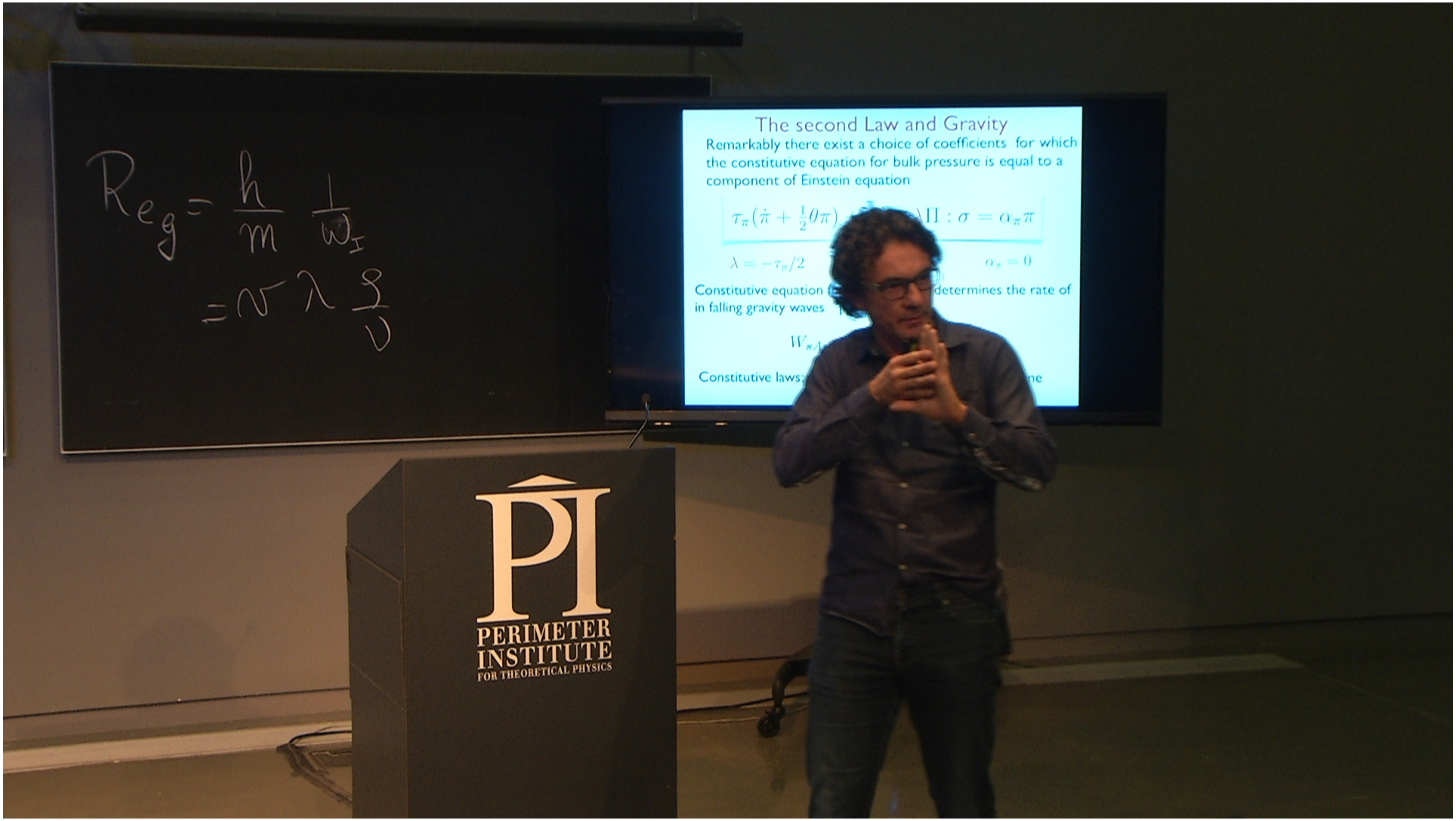
Grad- Israel-Stewart

Muller-Israel-Stewart

The imposition of positivity can still be done using only the (ζ, η) viscosities

$$D_a S^a = \beta \left(\frac{\pi^2}{2\zeta} + \frac{\Pi^{ab}\Pi_{ab}}{2\eta} \right) \geq 0$$

After some algebra we obtain the constitutive equations


The second Law and Gravity
Remarkably there exist a choice of coefficients for which the constitutive equation for bulk pressure is equal to a component of Einstein equation
Constitutive equation
determines the rate of
in falling gravity waves
Constitutive laws:
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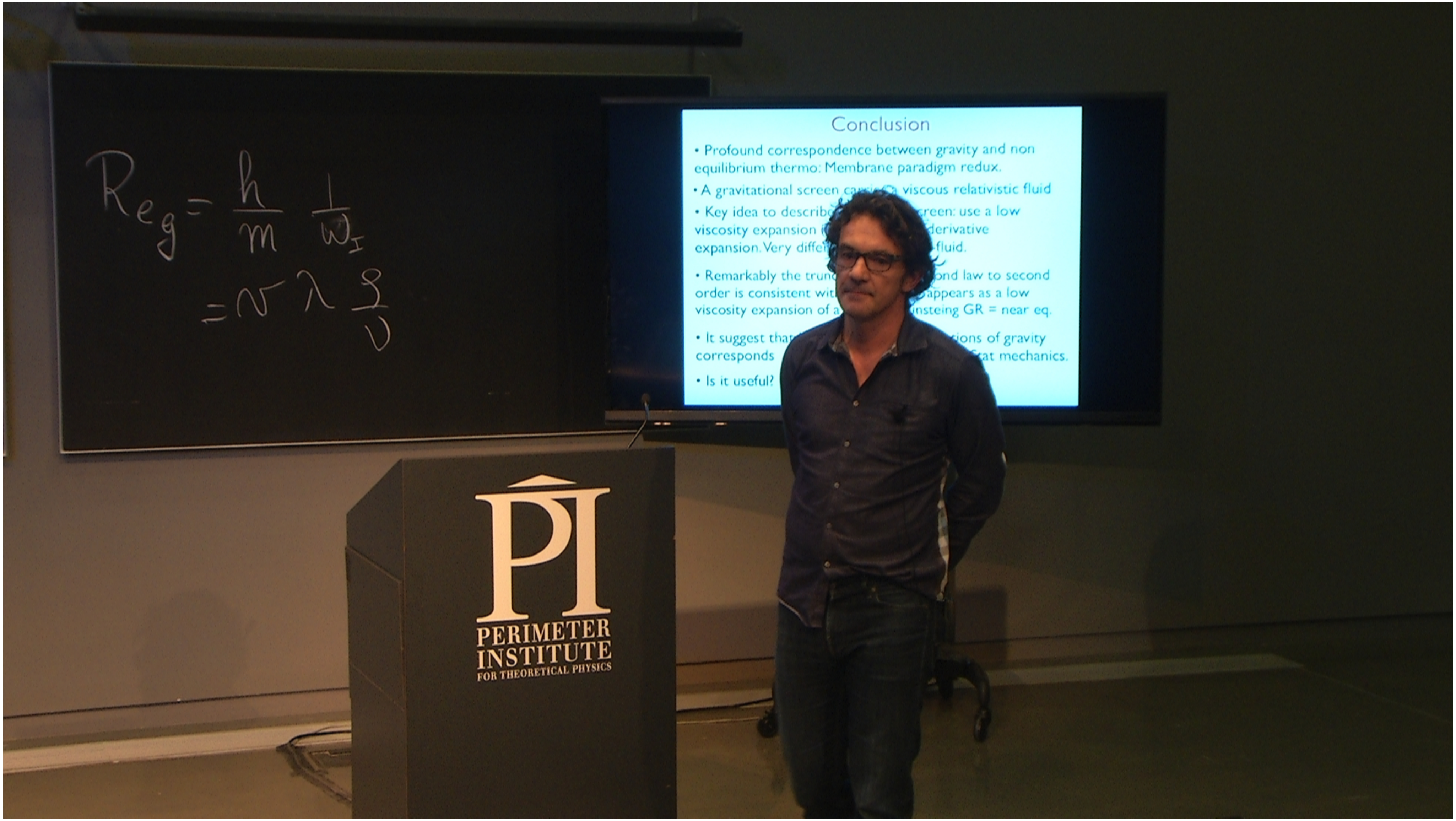
Conclusion
• Profound correspondence between gravity and non equilibrium thermo: Membrane paradigm redux.
• A gravitational screen
viscous relativistic fluid
• Key idea to describ
reen: use a low
viscosity expansion i
derivative
expansion. Very diffe
fluid.
• Remarkably the trun
ond law to second
order is consistent wit
appears as a low
viscosity expansion of a
nsteing GR = near eq.
• It suggest tha
ions of gravity
corresponds
at mechanics.
• Is it useful?
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