Title: Gravitational aether as a solution to the CC problem and more!

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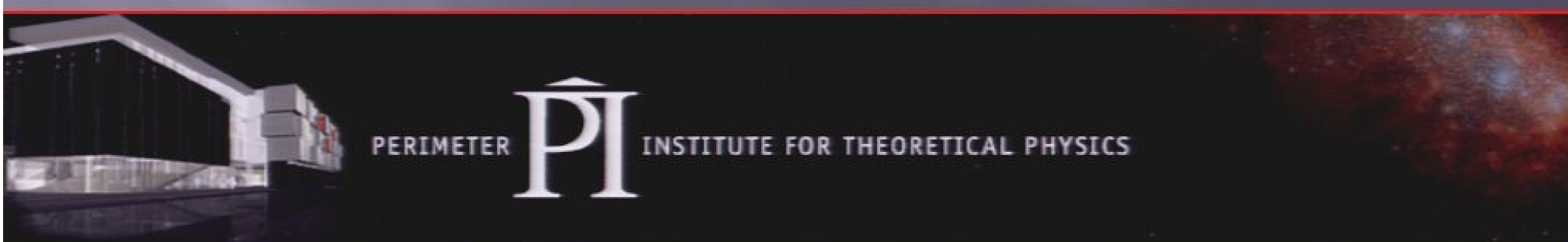
Abstract:

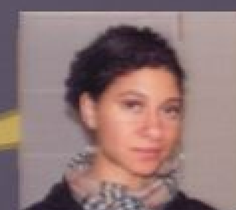
GRAVITATIONAL AETHER AS A SOLUTION TO THE CC PROBLEM, AND MORE!

Niayesh Afshordi



Collaborators

- Michael Balogh (U-Waterloo)
- Tom Giblin (Perimeter)
- Brendan Foster (Utrecht)
- Kazunory Kohri (Lancaster)
- Chanda Prescod-Weinstein (Perimeter)
- Georg Robbers (Heidelberg → MPA)
- Andrew Tolley (Perimeter)



NA; arXiv:0807.2639

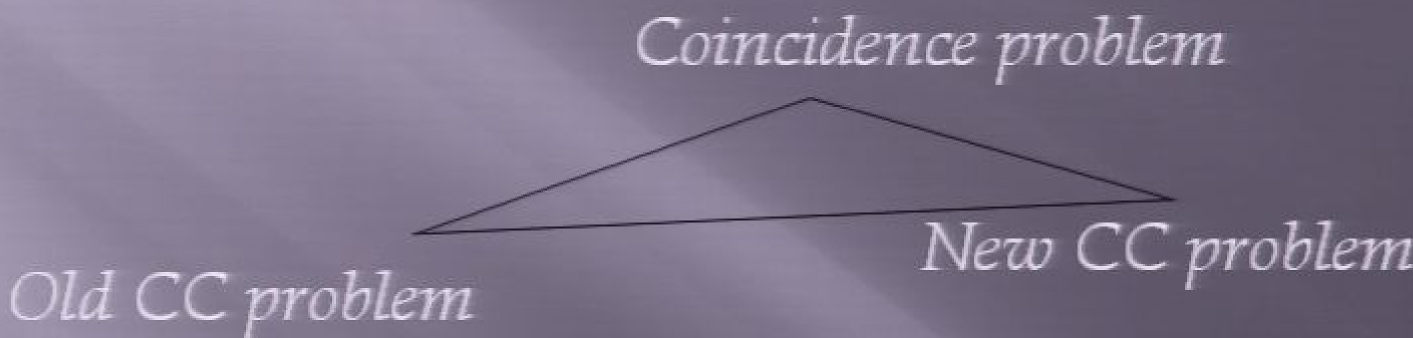
Prescod-Weinstein, NA, & Balogh; arXiv:0905.3551

…

Outline

- Introduction
- Degravitating the quantum vacuum and the Gravitational Aether
- Discrete Clocks and Quantum Gravity
- Testing the Aether
- Stellar black holes and cosmic acceleration
- Conclusions and the Missing Links

The CC Conundrum



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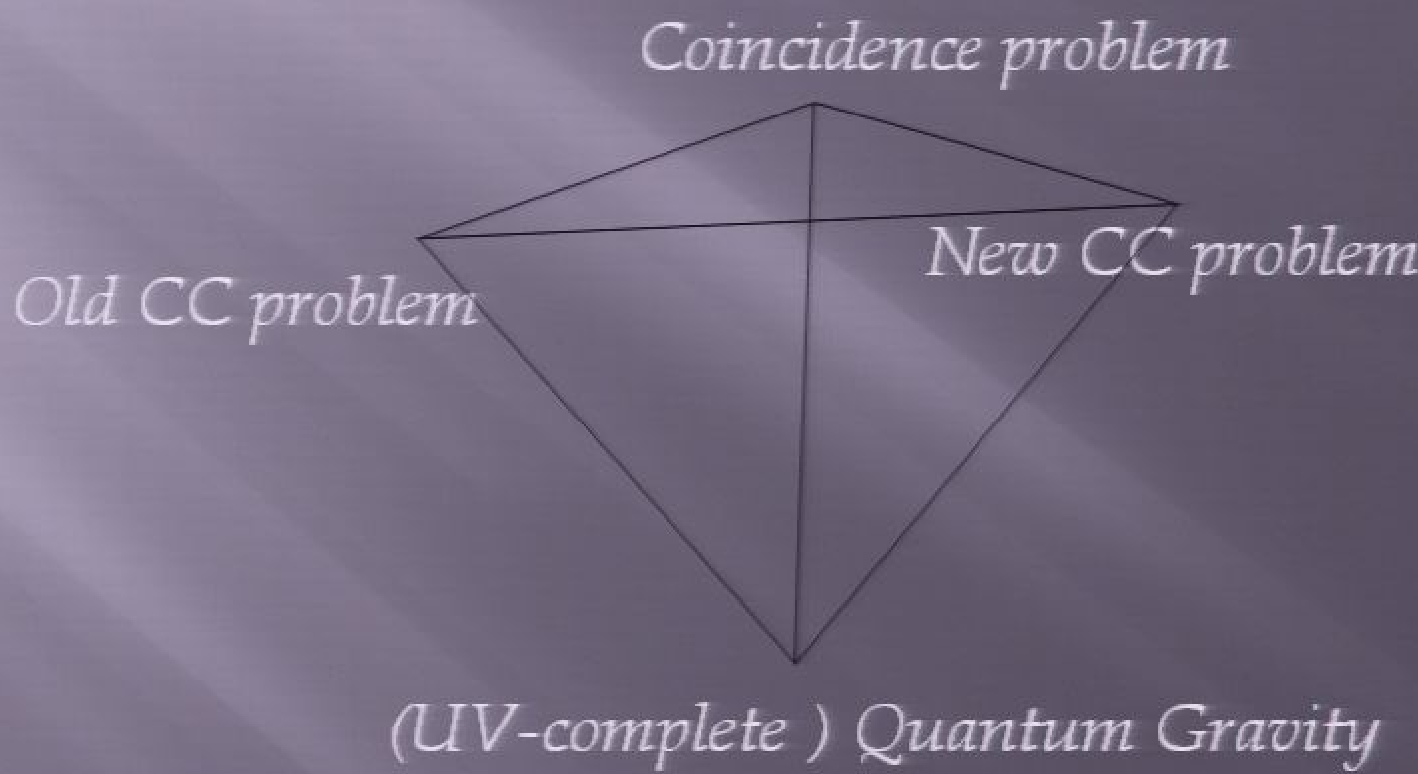

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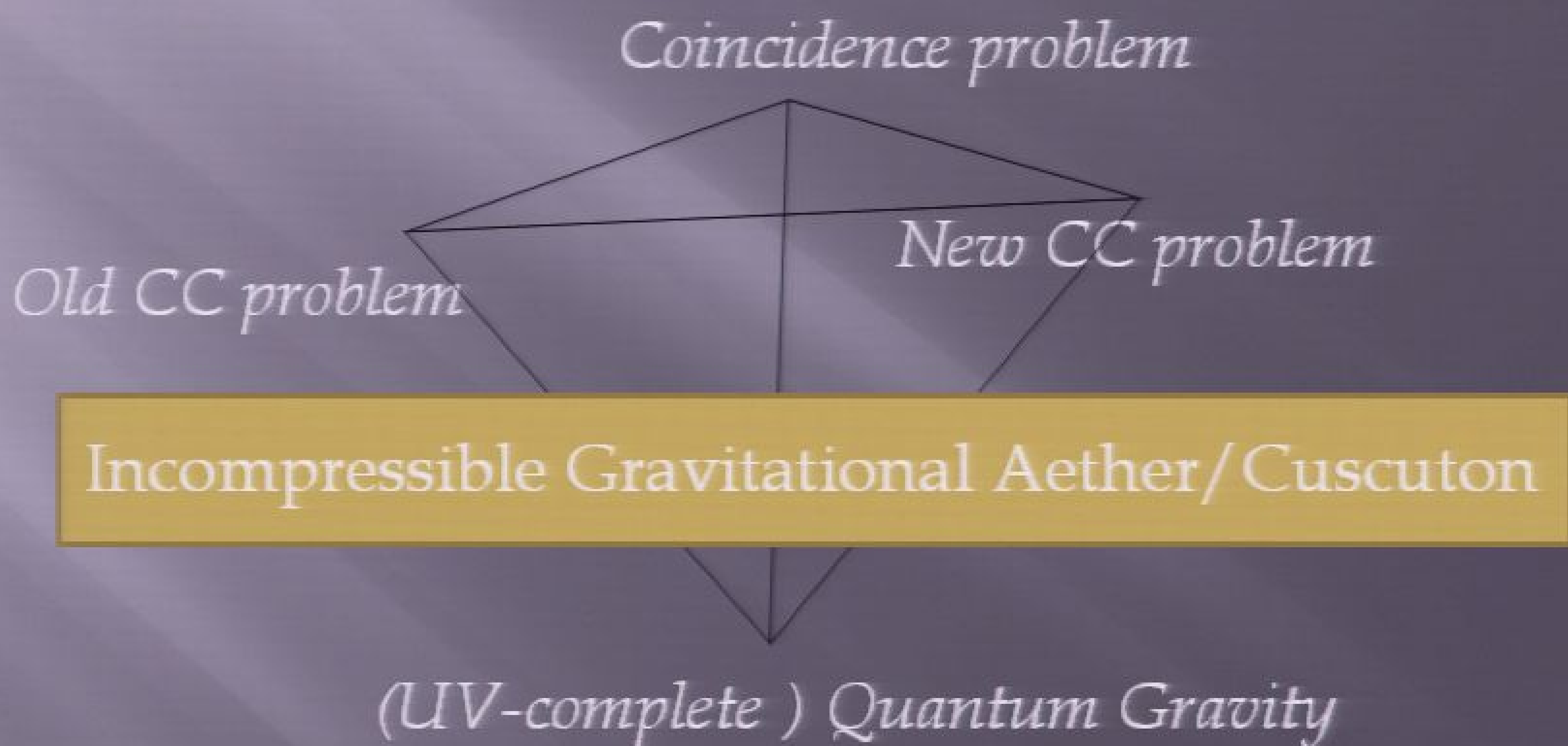

Cosmological constant problem

- Einstein Equation

$$G_{\mu\nu} = \langle T_{\mu\nu} \rangle$$

space-time curvature:
$(10^{-3}\,\mathrm{eV})^4$

vacuum energy density :
$\gtrsim \pm (100\ \mathrm{GeV})^4$
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  - Λ curves 2 compact extra dimensions (r $\sim$ 10 μm)
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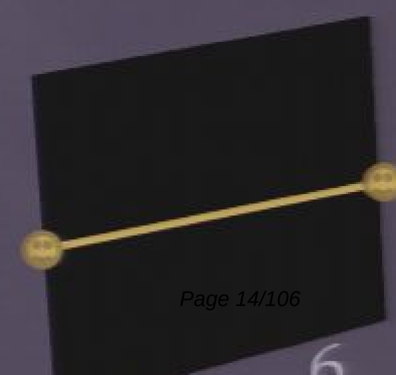

Extra dimensions and CC problem: score card

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- I will next introduce a degravitation model with no extra free parameters/dynamical deg. of freedom

Here is an alternative: Gravitational Aether

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NA 2008

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NA 2008

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- Further assume incompressible fluid:

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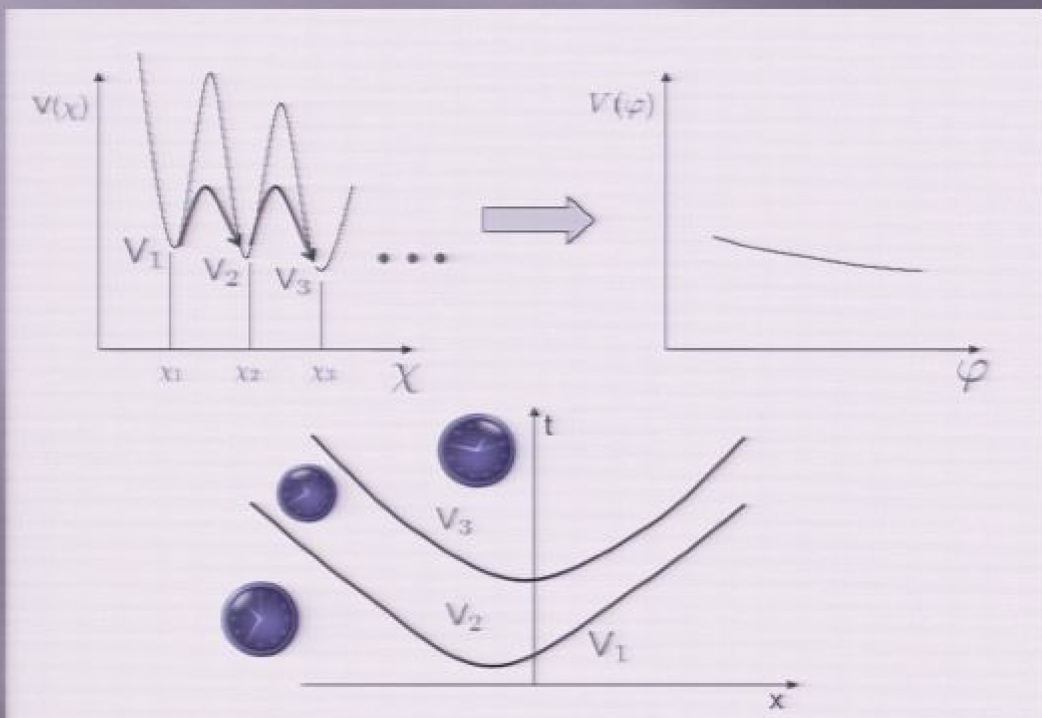
(tests of gravity severely constrain new deg's of freedom)

A Discrete Clock Field

- Imagine a discrete clock field



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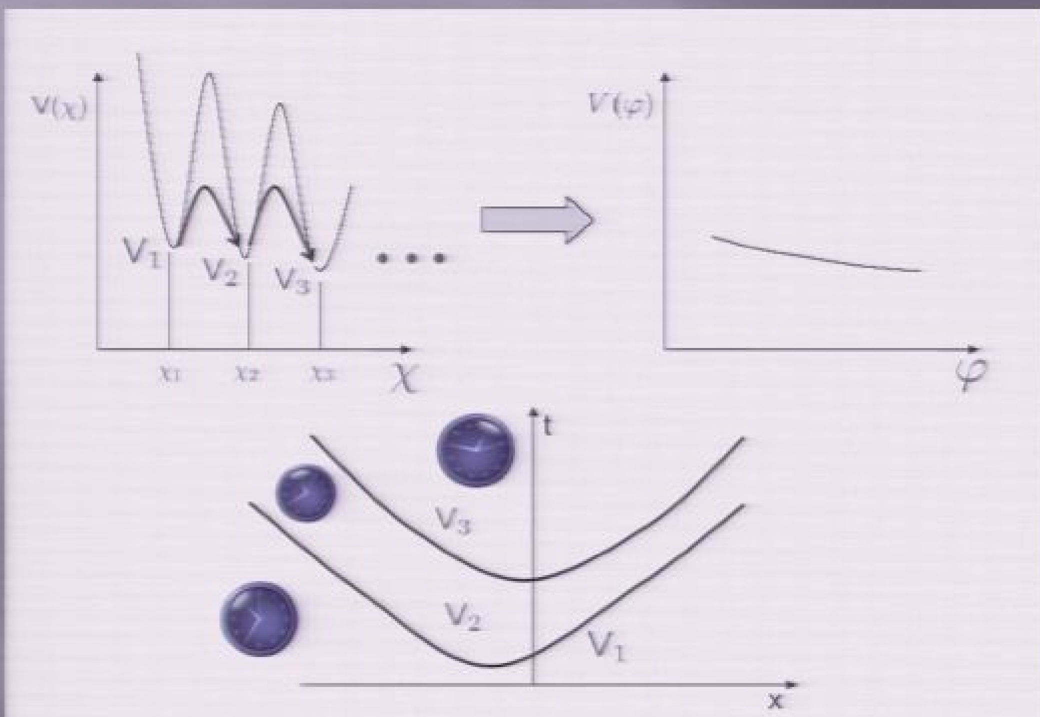

$$S_{\text{eff}} \simeq \mu^2 \sum_i (\varphi_{i+1} - \varphi_i) \int d\Sigma_i - \int d^4x \; V(\varphi),$$

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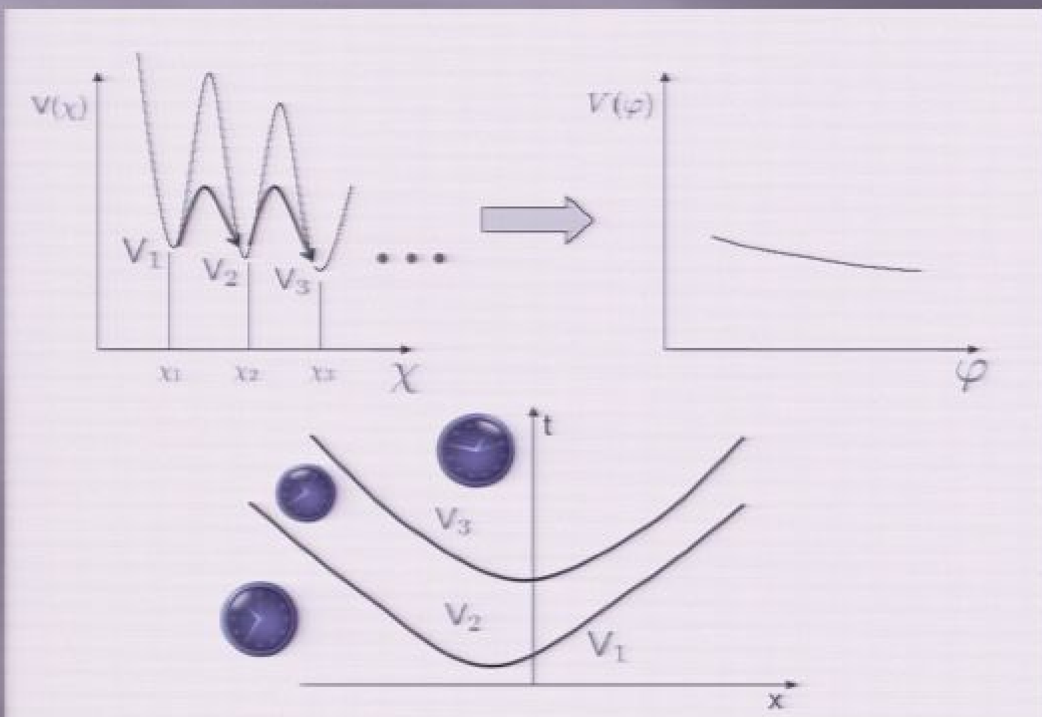

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interface areas

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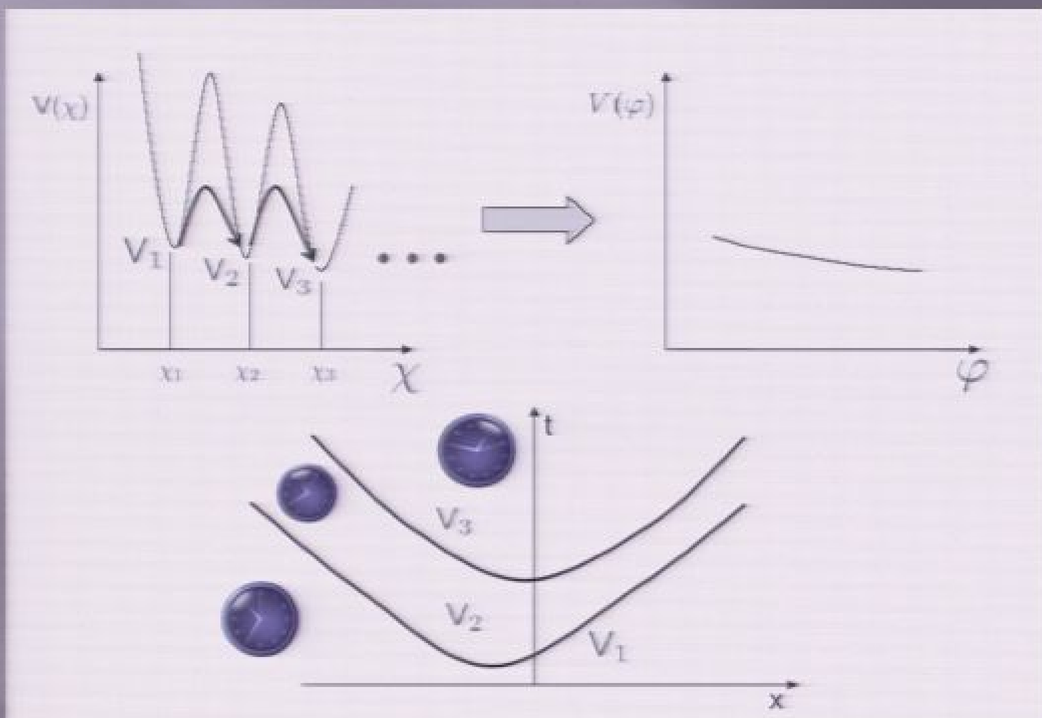

Cuscuton Action

$$S_\varphi = \int d^4x \sqrt{-g}\left[\mu^2 \sqrt{|g^{\mu\nu}\partial_\mu\varphi\partial_\nu\varphi|} - V(\varphi)\right]$$

continuous limit

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Cuscuton and Quantum Gravity

- *Cuscuton:* the only modification of GR that does not introduce new perturbative degrees of freedom ($c_s \rightarrow \infty$)

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A. Tolley

Cuscuton and Quantum Gravity

Quantum Gravity at a Lifshitz Point

Petr Hořava

Berkeley Center for Theoretical Physics and Department of Physics
University of California, Berkeley, CA, 94720-7300
and
Theoretical Physics Group, Lawrence Berkeley National Laboratory
Berkeley, CA 94720-8162, USA

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$$S = \int dt\, d^3\mathbf{x}\, \sqrt{g} N \left\{ \frac{2}{\kappa^2}\left(K_{ij}K^{ij} - \lambda K^2\right) - \frac{\kappa^2}{2w^4} C_{ij}C^{ij} + \frac{\kappa^2 \mu}{2w^2} \varepsilon^{ijk} R_{i\ell} \nabla_j R^{\ell}_{k} - \frac{\kappa^2\mu^2}{8} R_{ij}R^{ij} + \frac{\kappa^2\mu^2}{8(1-3\lambda)} \left(\frac{1-4\lambda}{4} R^2 + \Lambda_W R - 3\Lambda_W^2 \right) \right\}.$$

low energies

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$|\lambda-1| < 0.007$ (95%CL)

FRW cosmology with Gravitational Aether

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$$G_N/G_R = 0.97 \pm 0.09$$

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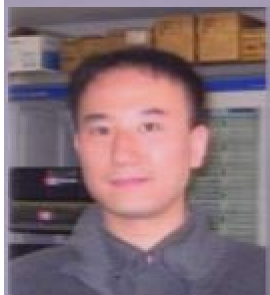
- Ly-α+WMAP3 (Seljak, Slosar, McDonald 2006):

$$G_N/G_R = 0.73 \pm 0.04$$

The *Real* BBN Constraints



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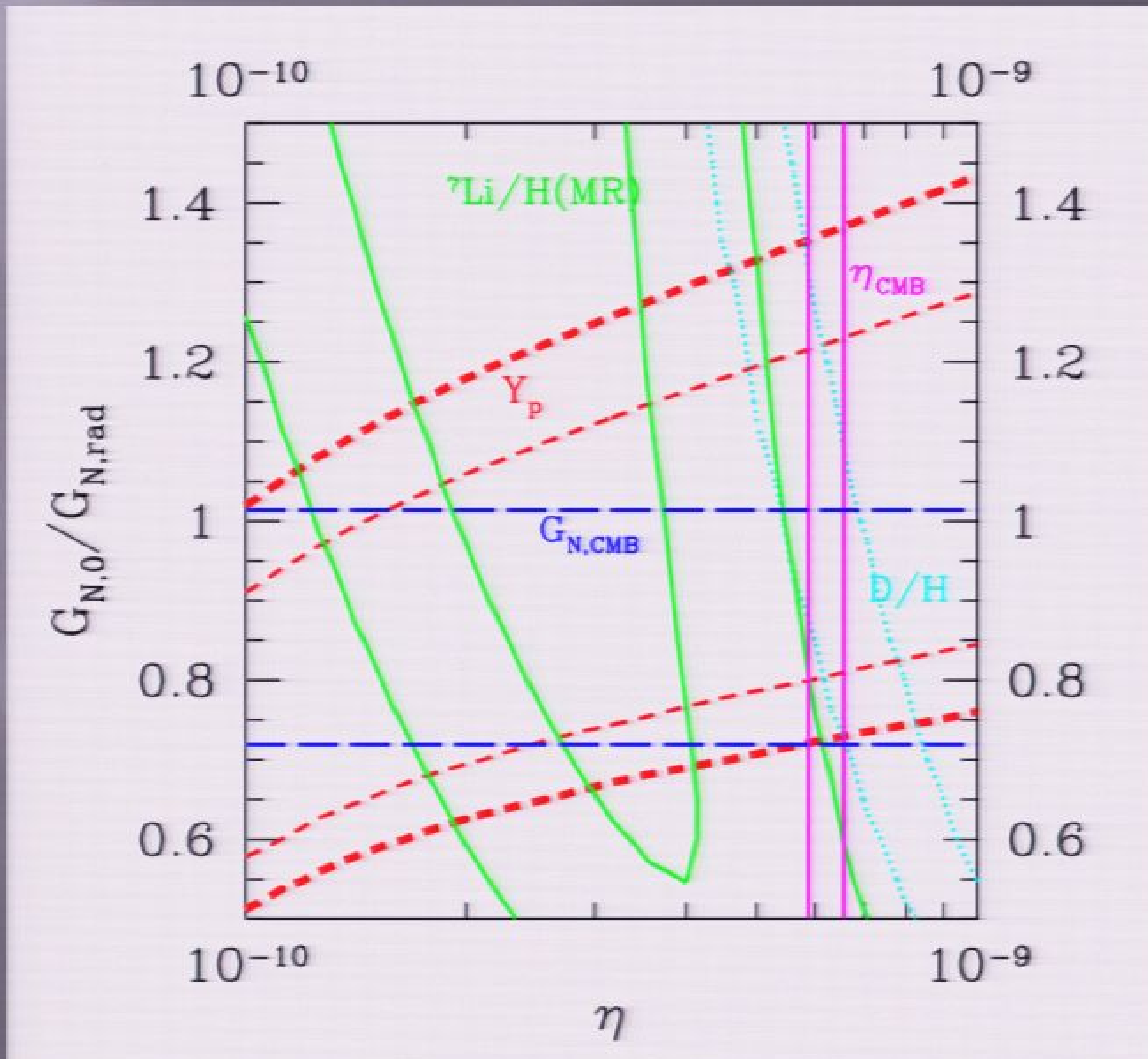

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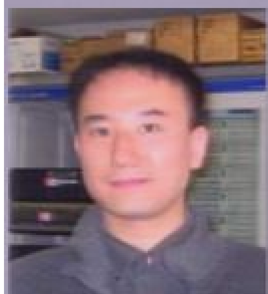

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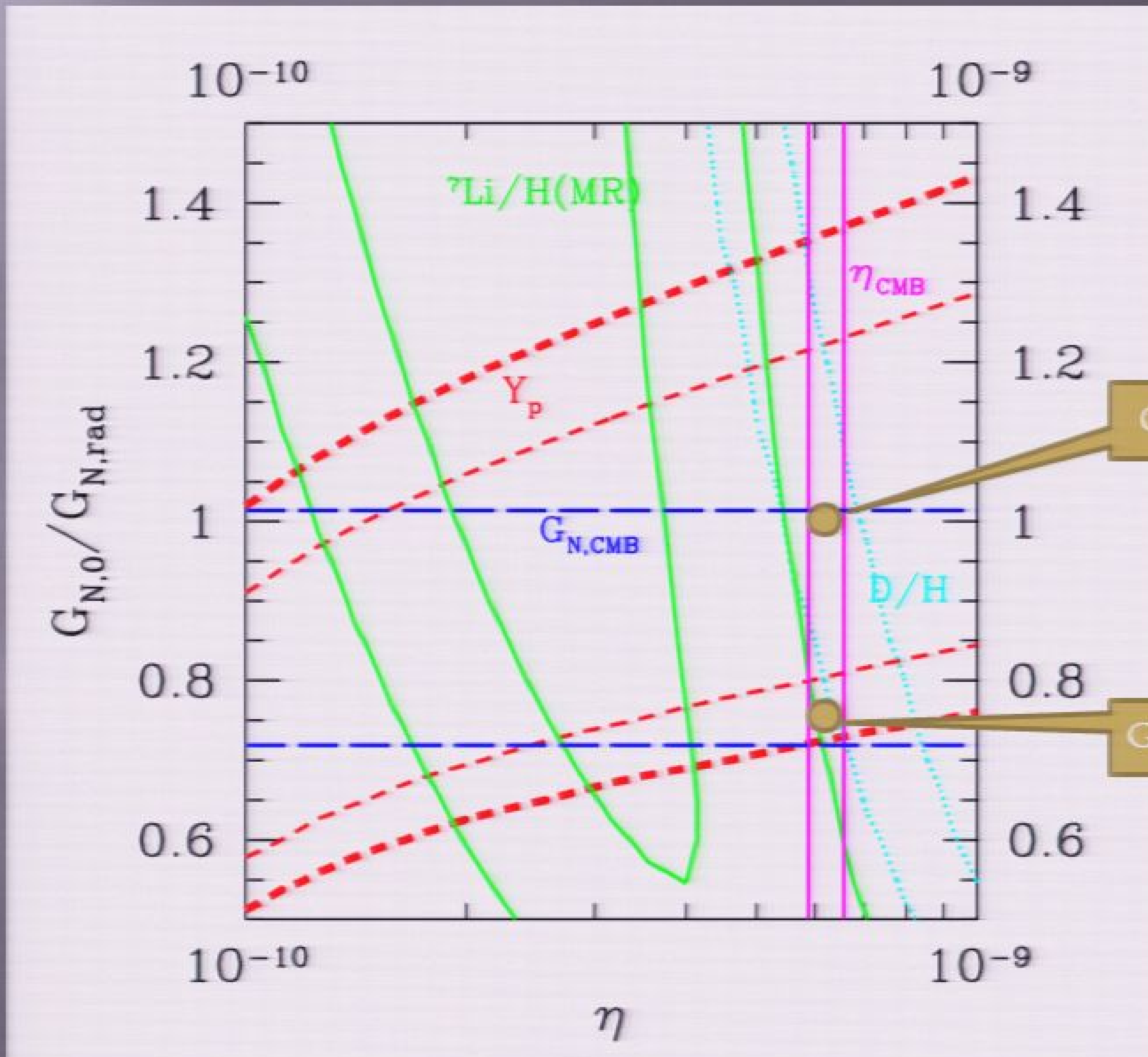

General Relativity

Gravitational Aether

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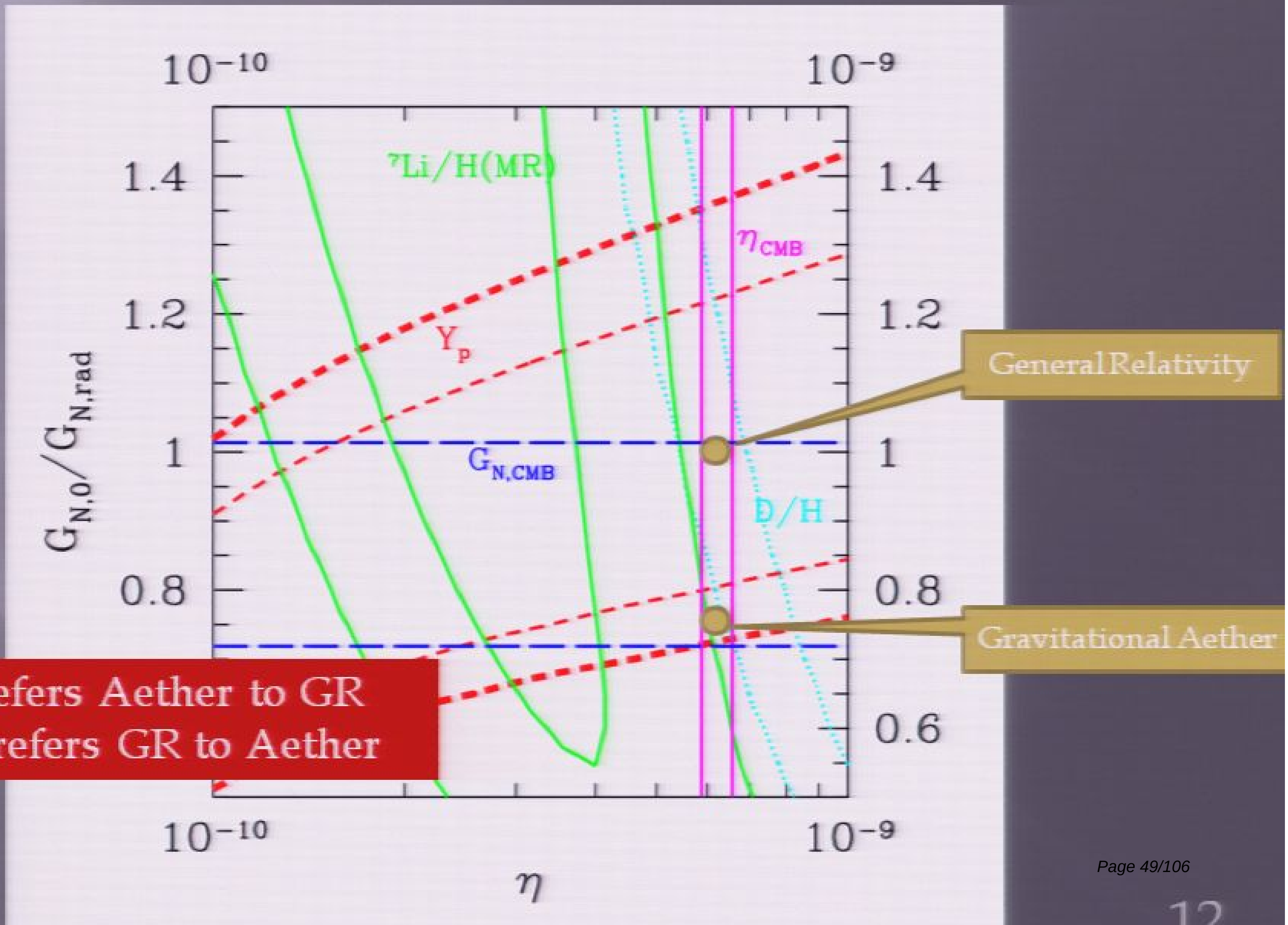
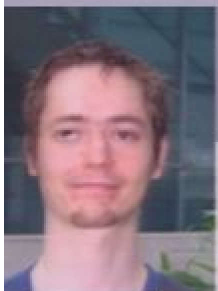


- ➢Li7 prefers Aether to GR
- ➢He4 prefers GR to Aether

Ly-α forest + WMAP5



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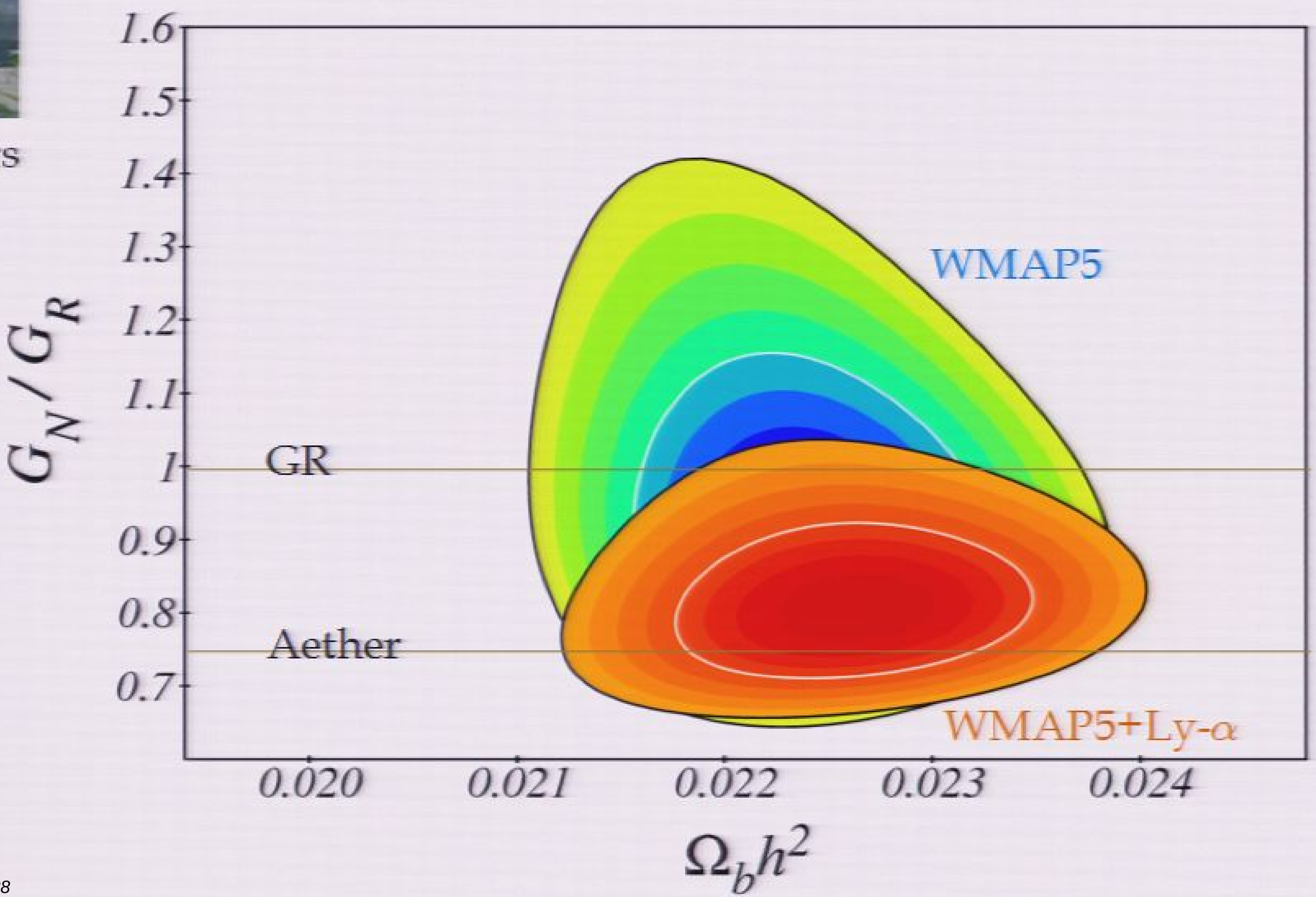

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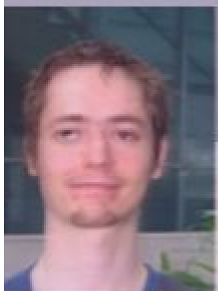

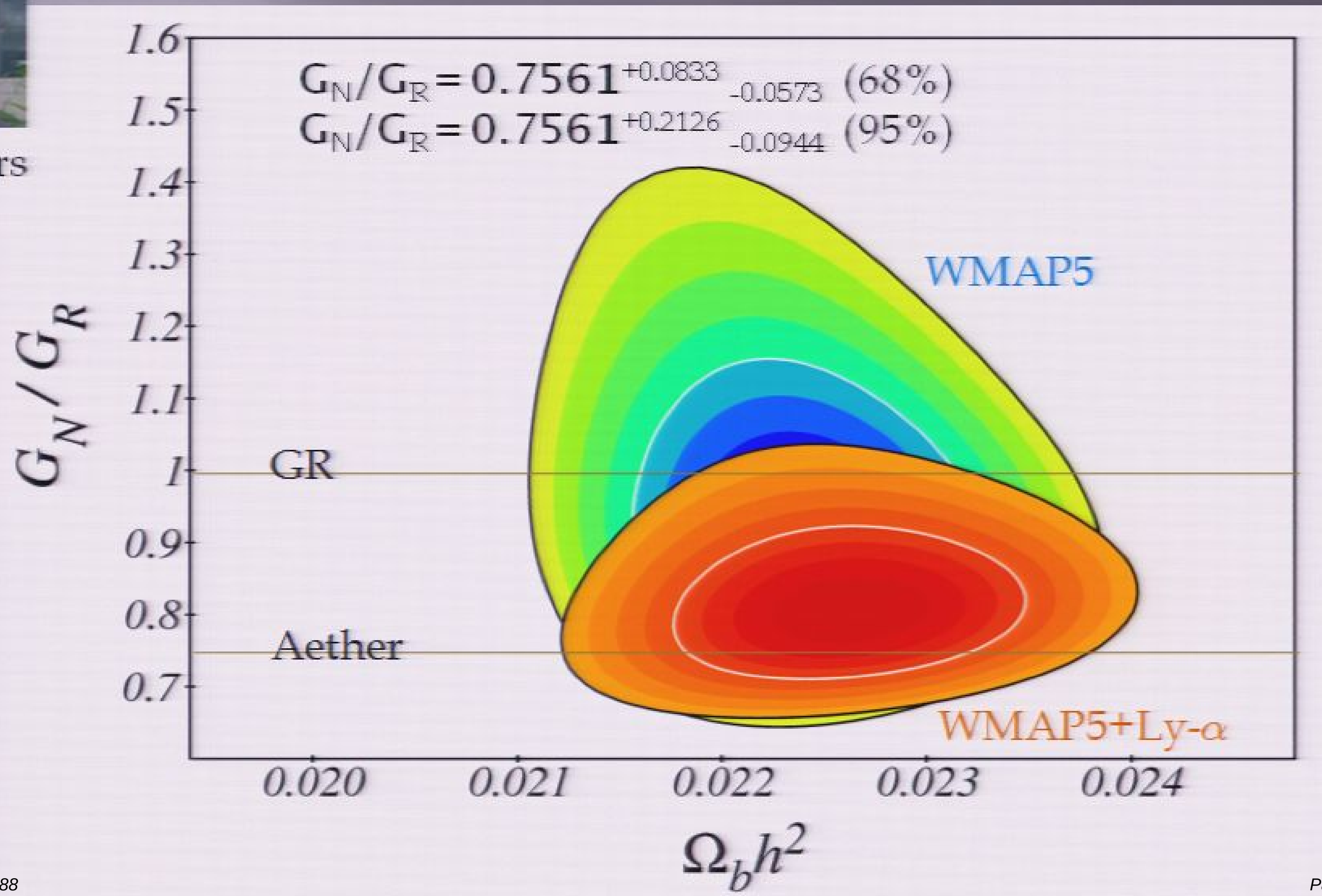

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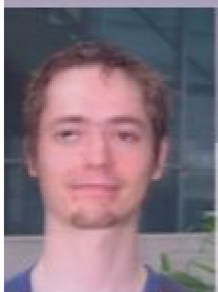

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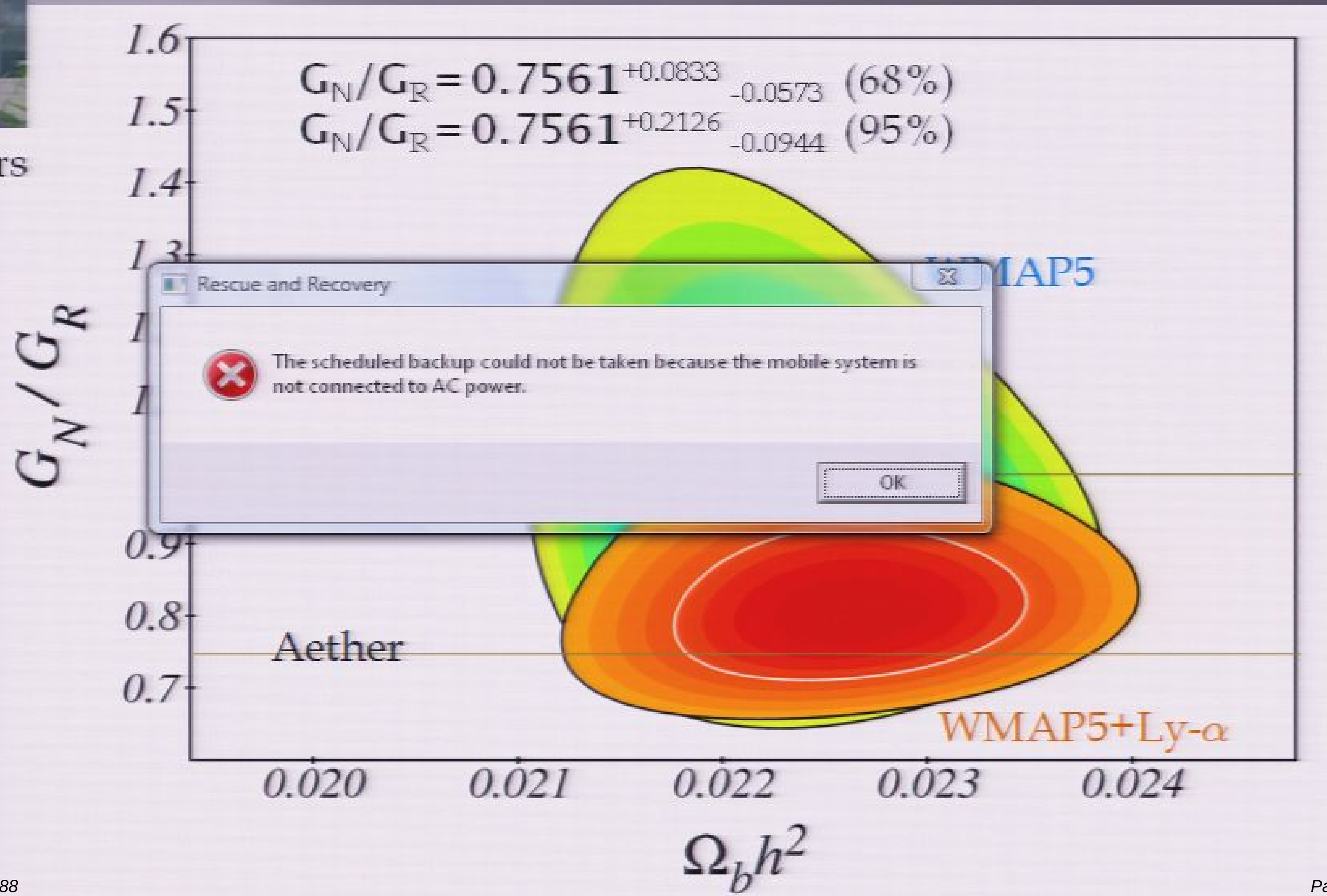

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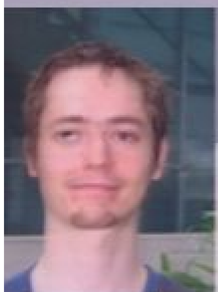

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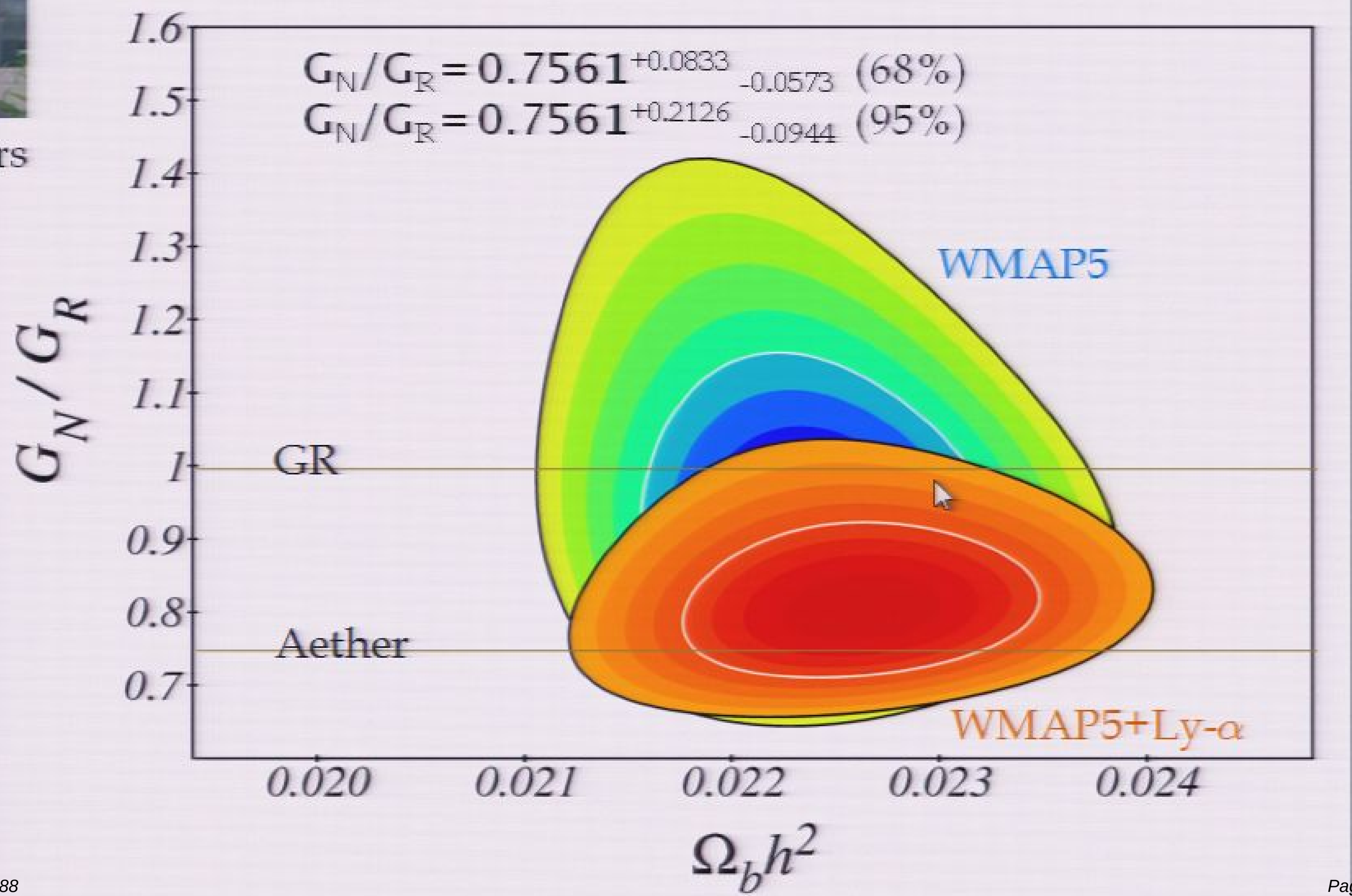

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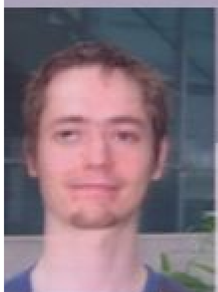

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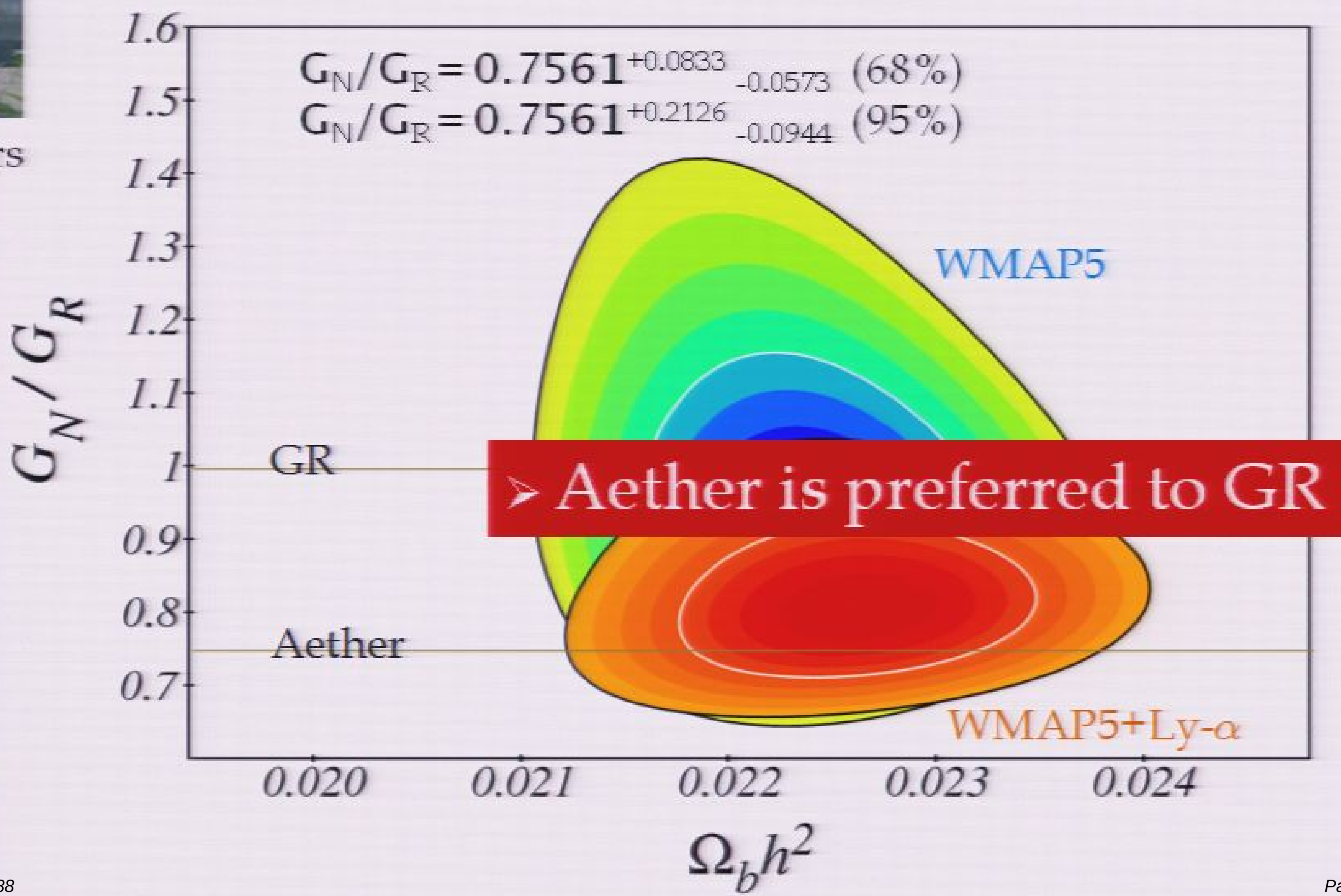
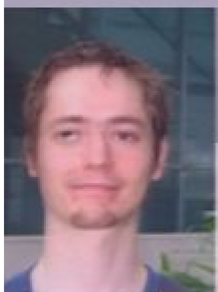


➢ Aether is preferred to GR

Ly-α forest + WMAP5



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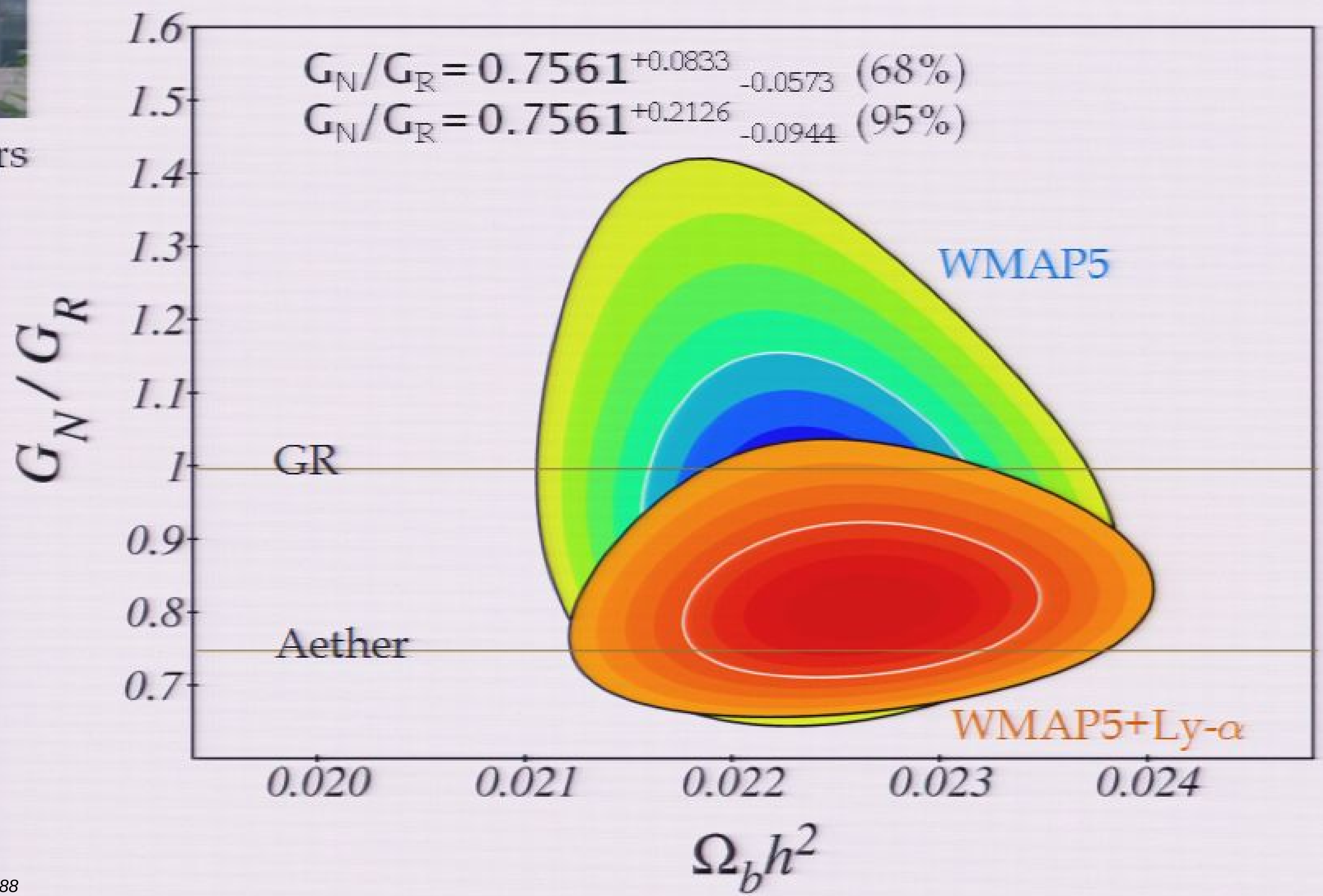

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Non-relatvistic Perturbations:

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$$\frac{\partial^2 T\mathbf{u}}{\partial t^2} = \omega \nabla \nabla \cdot (T\mathbf{u})$$

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- Gravitational constant depends on pressure:
  $G_{eff} \propto (1+w)\, G$, (modifies ζ_4: unconstrained PPN parameter)

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- As long as:
  - Aether tracks matter
  - Internal pressure is negligible

→ Aether is indistinguishable from GR

- But:
  - Aether is irrotational → e.g. observing gravito-magnetic effect due to earth rotation can test it (Gravity Probe B)
  - Internal structure of self-gravitating objects with relativistic pressure (e.g. neutron stars, supernovae) will be sensitive to aether

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Biggest hurdle for UV-completion of the theory!

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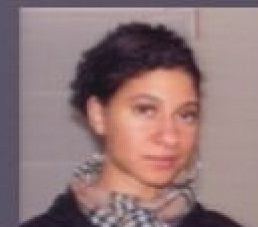
Aether and Black Holes



C. Prescod-Weinstei

- Aether around a spherical Black Hole:

$$ds^2 = -e^{2\phi}dt^2 + (1 - \frac{2m}{r})^{-1}dr^2 + r^2 d\Omega^2$$

$$e^{\phi(r)} = \left(1 - \frac{2m}{r}\right)^{\frac{1}{2}} [4\pi p_0 f(r) + 1]$$

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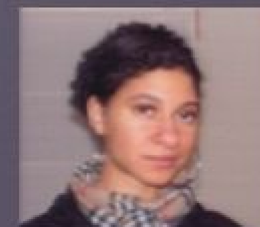

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- Limits far from and close to the horizon:

$$f(r) = \frac{r^2}{2} + 3mr + \mathcal{O}[m^2].$$

$r \gg 2m$

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$r - 2m \ll 2m$

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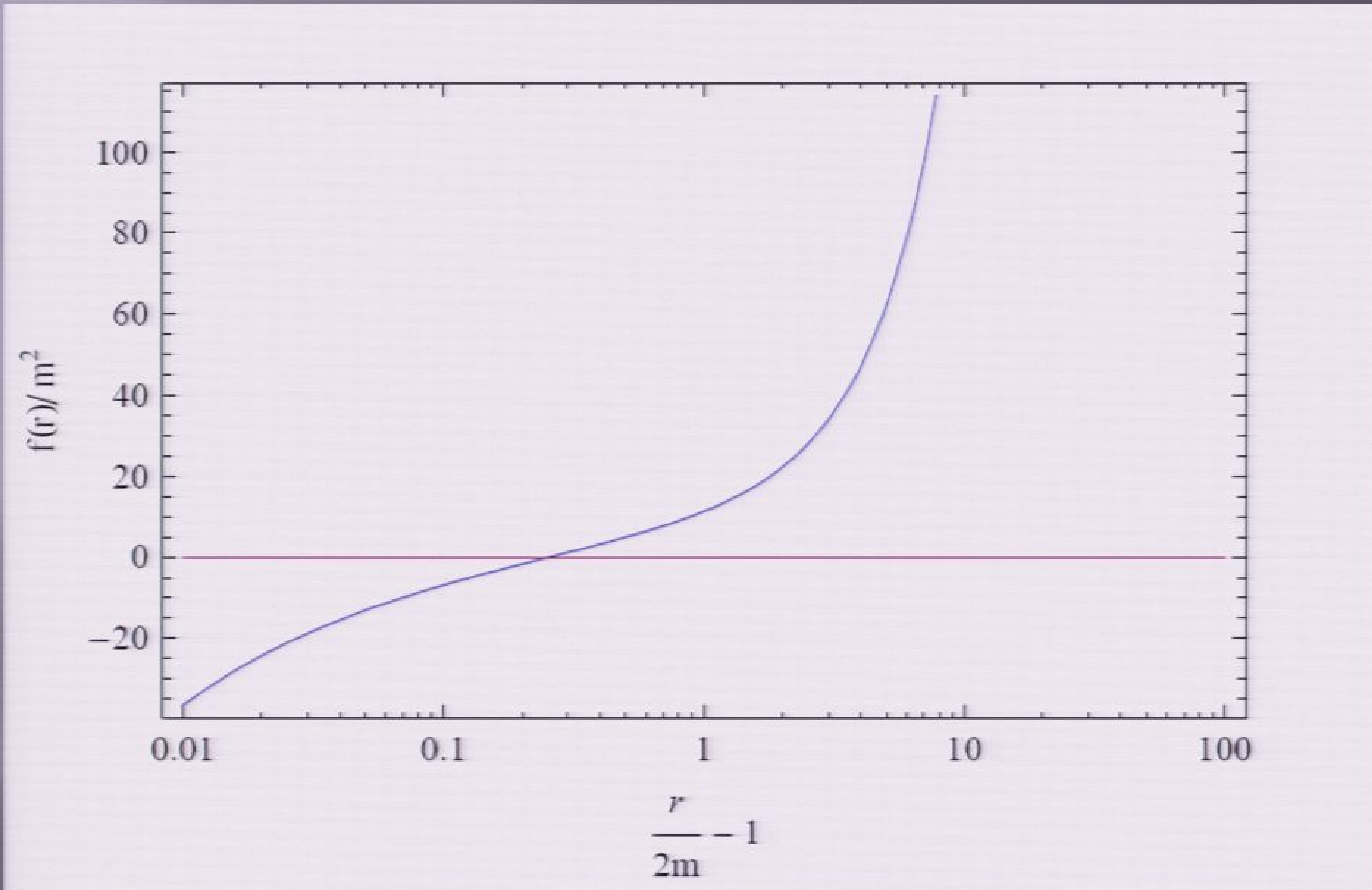

100
80
60
40
20
0
−20
f(r)/ m²
0.01
0.1
1
10
100
r/2m − 1

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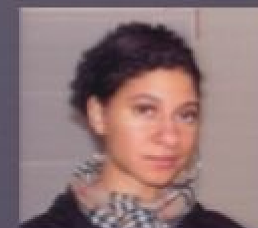

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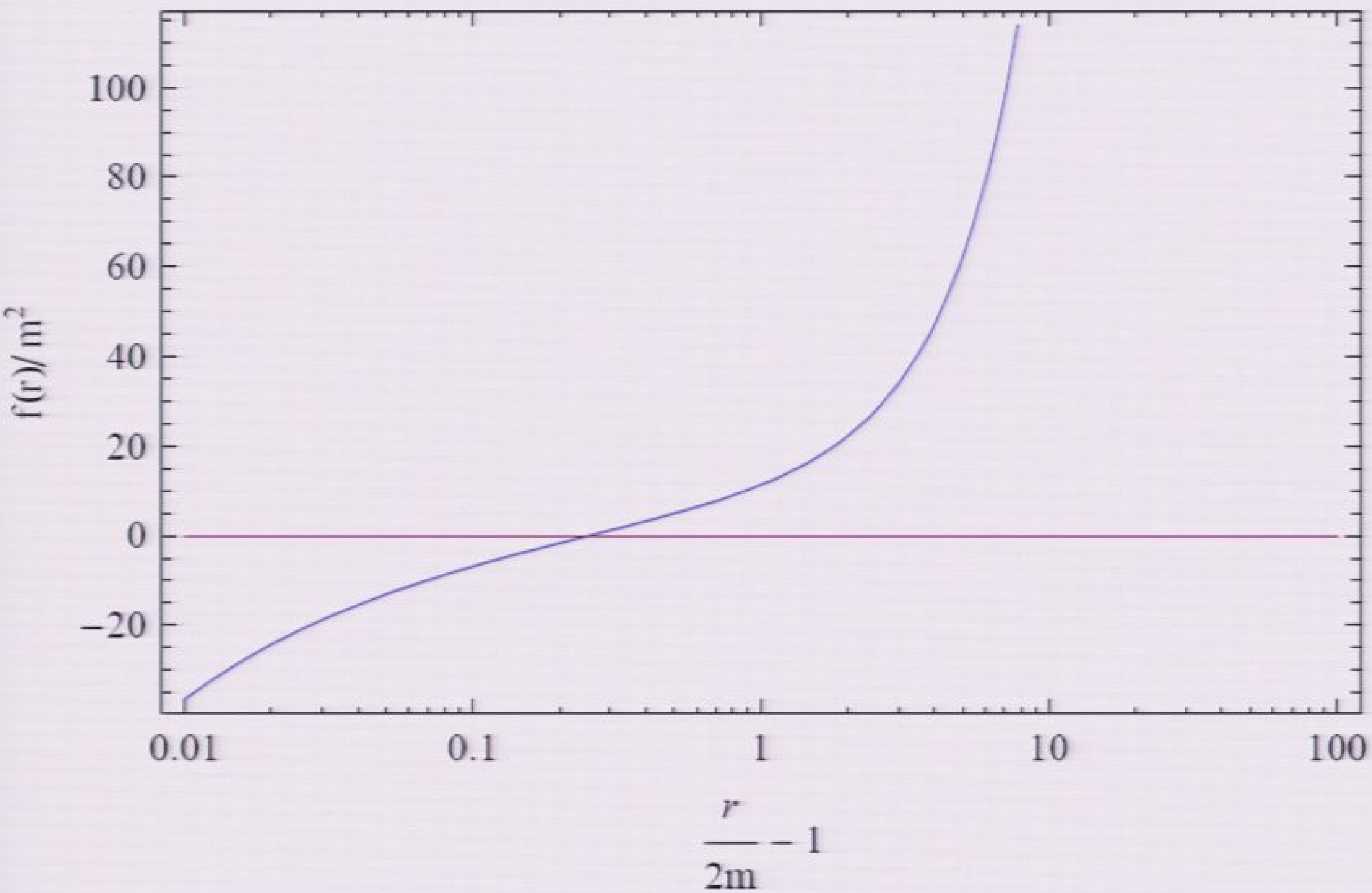

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Prescod-Weinstein, NA, & Balogh 2009

Stellar BH's and cosmic acceleration

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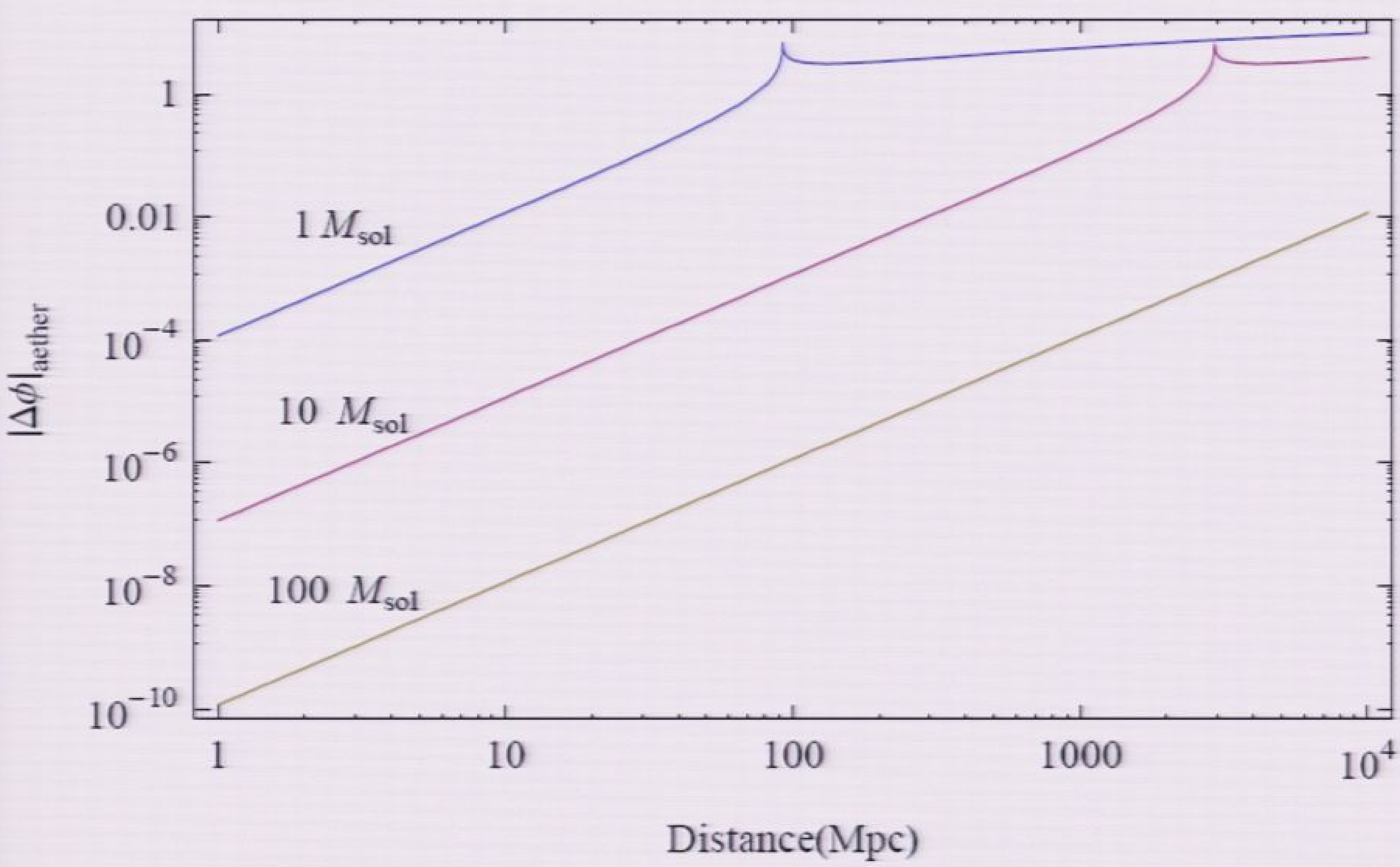
1
0.01
10^{-4}
10^{-6}
10^{-8}
10^{-10}
$|\Delta\phi|_{aether}$
1 M_{sol}
10 M_{sol}
100 M_{sol}
1
10
100
1000
10^4
Distance(Mpc)

Late-time Acceleration scenario

$$\text{deSitter}: \quad ds^2 = -(1 - 4\pi\rho_\Lambda r^2)dt^2 + (1 - 4\pi\rho_\Lambda)^{-1}dr^2 + r^2 d\Omega^2$$

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- g_{00} around the black hole ($m \ll r \ll H^{-1}$) looks like de-Sitter space, so slow-moving particles (i.e. stars/galaxies) accelerate away from the center
- As this happens around every BH, the coarse-grained Universe should look like Λ + matter with $\rho_\Lambda = -p_0$

Effective Dark Energy

- multiple black holes:
  $\log m_* = \langle \log m \rangle_{\text{mass weighted}}$
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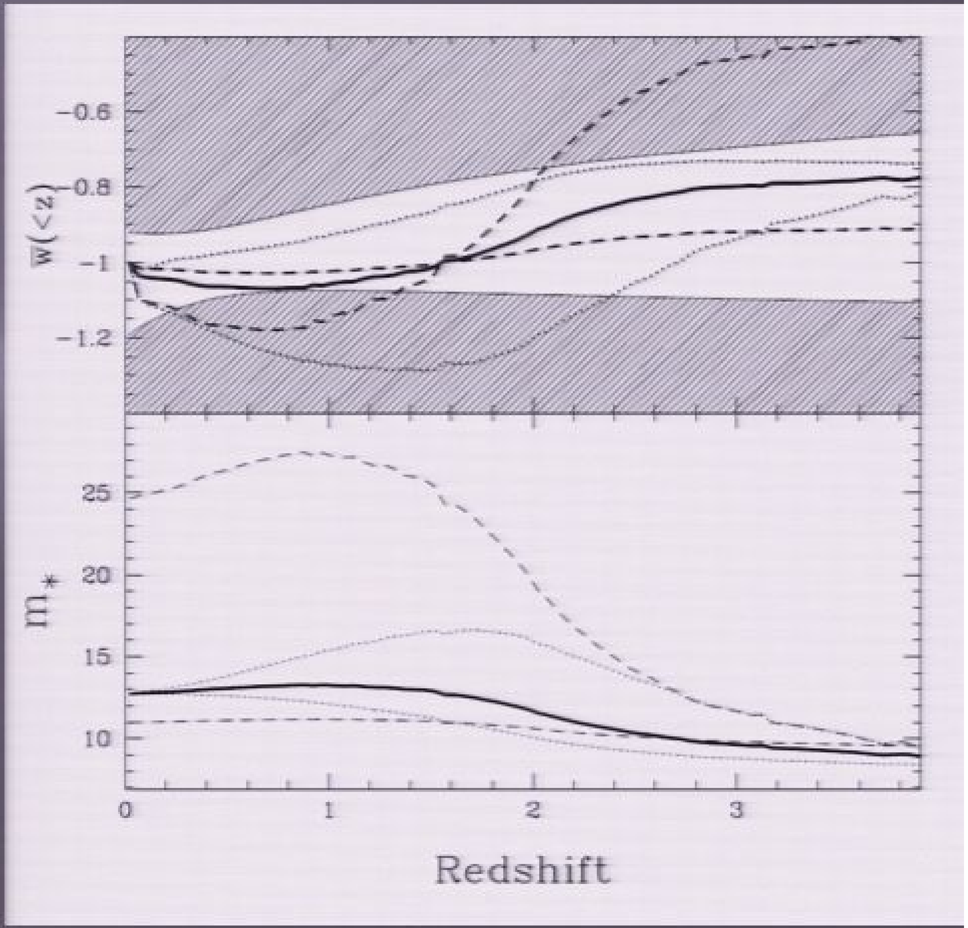

M. Balogh

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- Follows dust matter, and can satisfy tests of General Relativity *

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- *Should we revisit our assumptions for constructing Effective Theories? (e.g. locality/action)*
- *Should we re-evaluate our Dark Energy program?*

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No!

- $G_{eff} \propto (1+w)\,G$
- →since $w \neq -1$ during inflation, one could still get inflation with slight modifications