Emergent gravity

Could gravity be an entropic force?

*Astrolunch talk by Tom Bakx**

* in case you forgot my name

How does the universe work?

- 1686: Newton wrote Principia Mathematica
- ~1900: People thought they had figured it out

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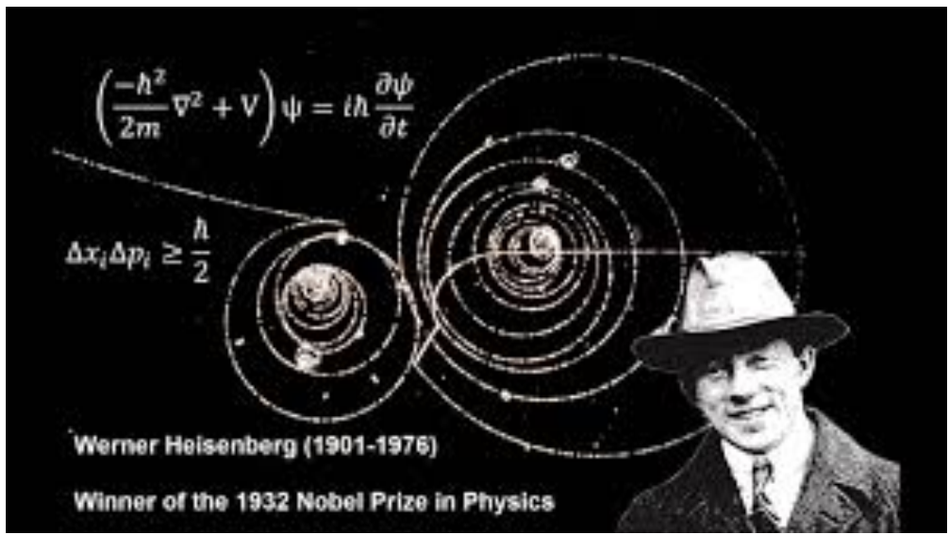
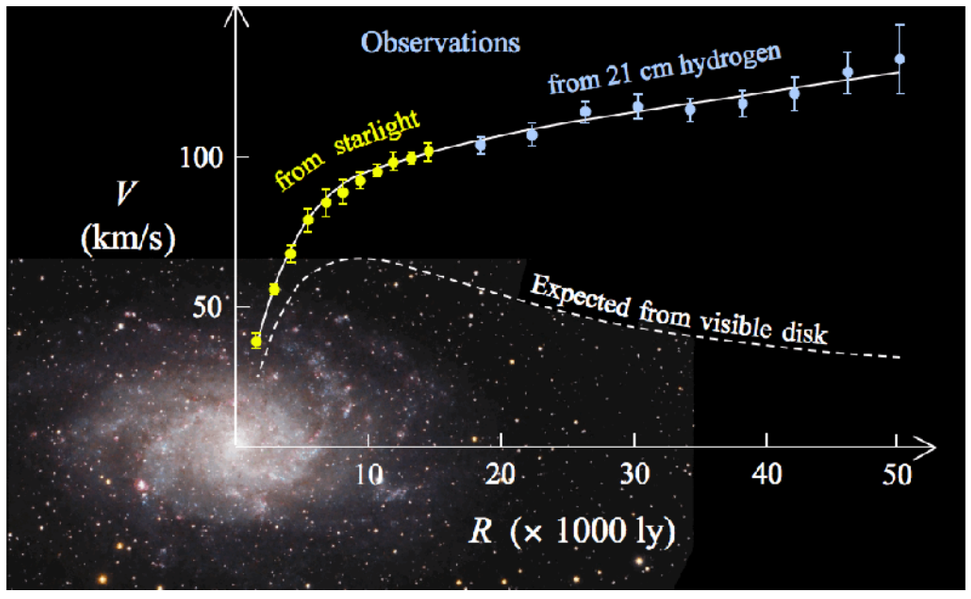
- >1900: Start of quantum mechanics
- ~1915: Einstein discovered General Relativity
- ~1933: Fritz Zwicky's measurements suggest dark matter

GR and QM don’t play nice



Long

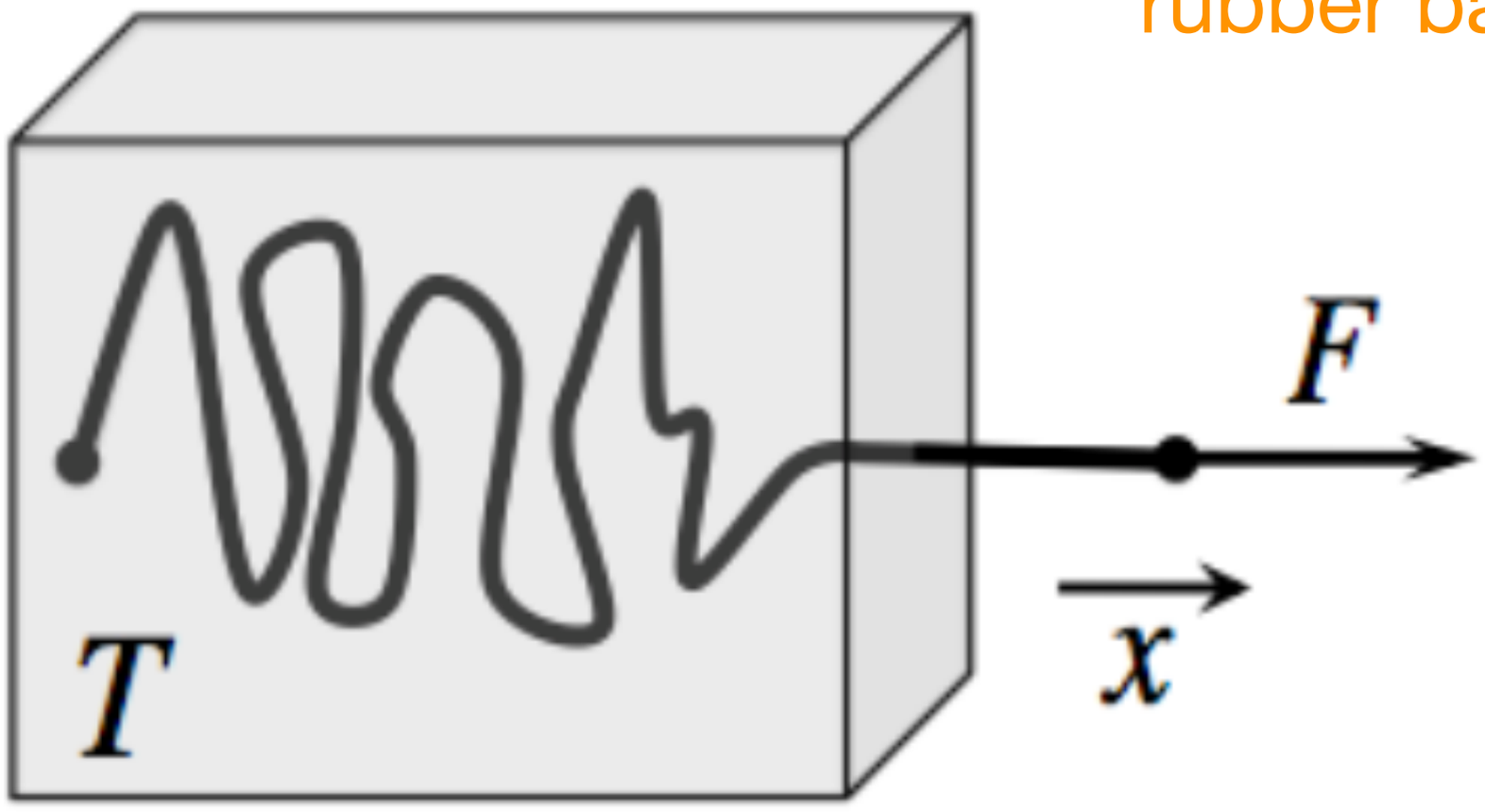
Short



QM & GR meet at the event horizon

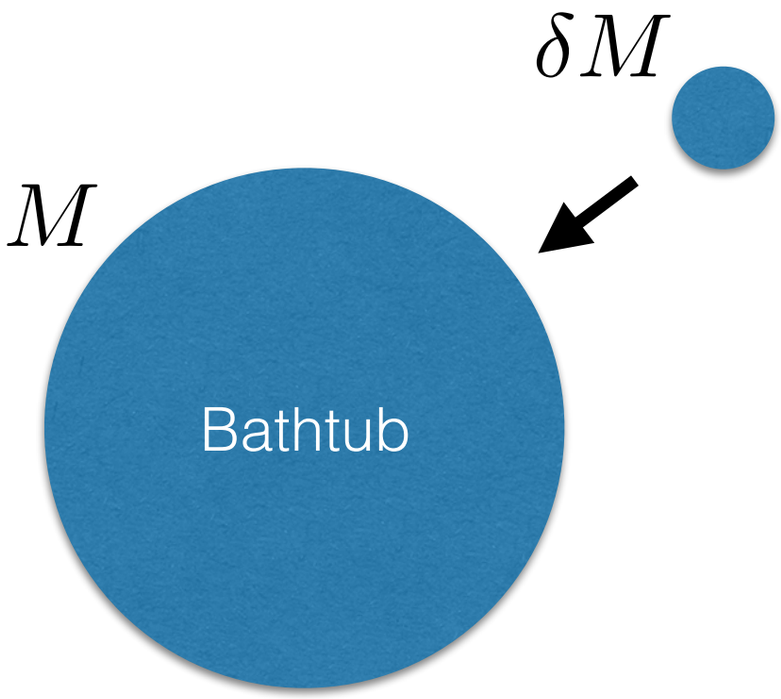
Now, what is an entropic force?

For example -
rubber bands



Holograpic Principle

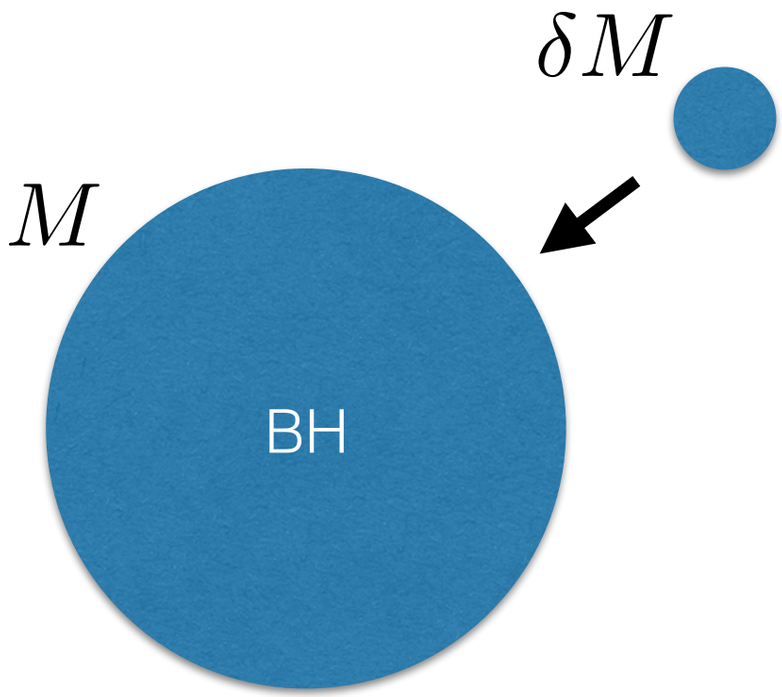
A bathtub is volume limited



Bathtubs,
common sense,
$V \sim N$ etc.

Holograpic Principle

Information is surface-limited



Bathtubs,
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Black holes

$$A \sim N$$

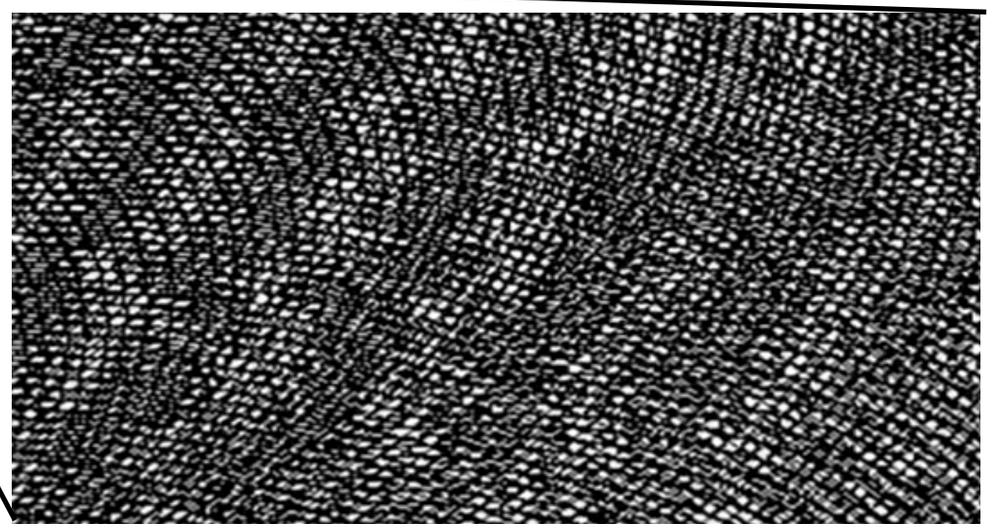
$$N = \frac{c^3}{G\hbar} A$$

Holograms

All the information can be expressed on the surface

$$A \sim N$$

$$N = \frac{c^3}{G\hbar} A$$

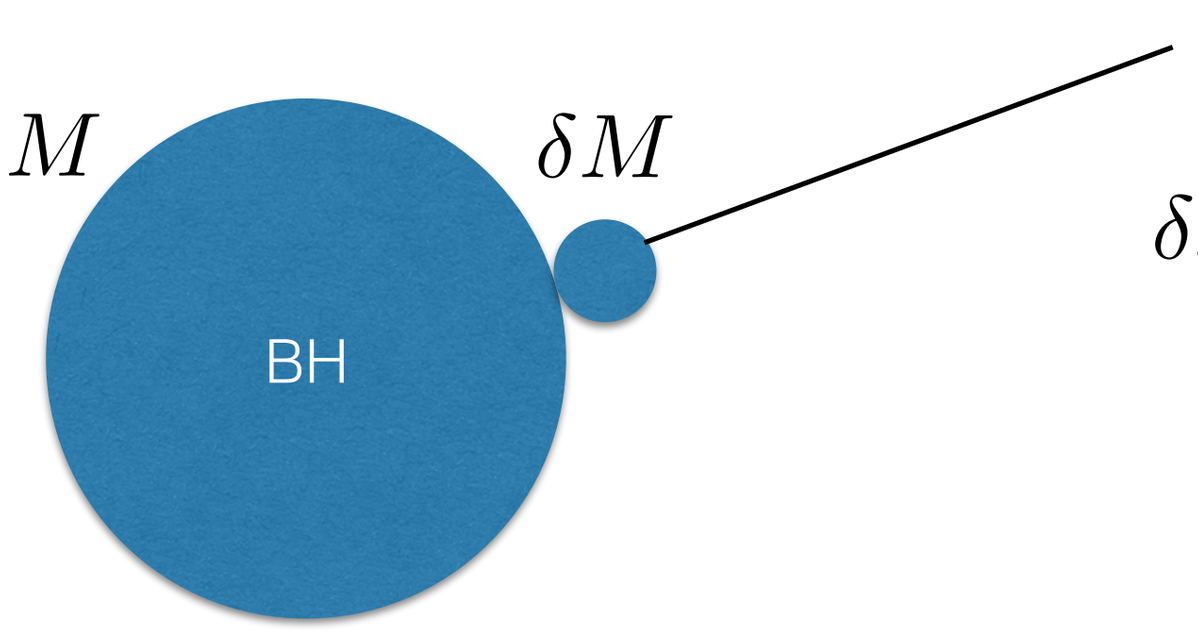


Each bit occupies
one unit cell

Gravitational entropy of a black hole

Slowly lowering a mass into a black hole

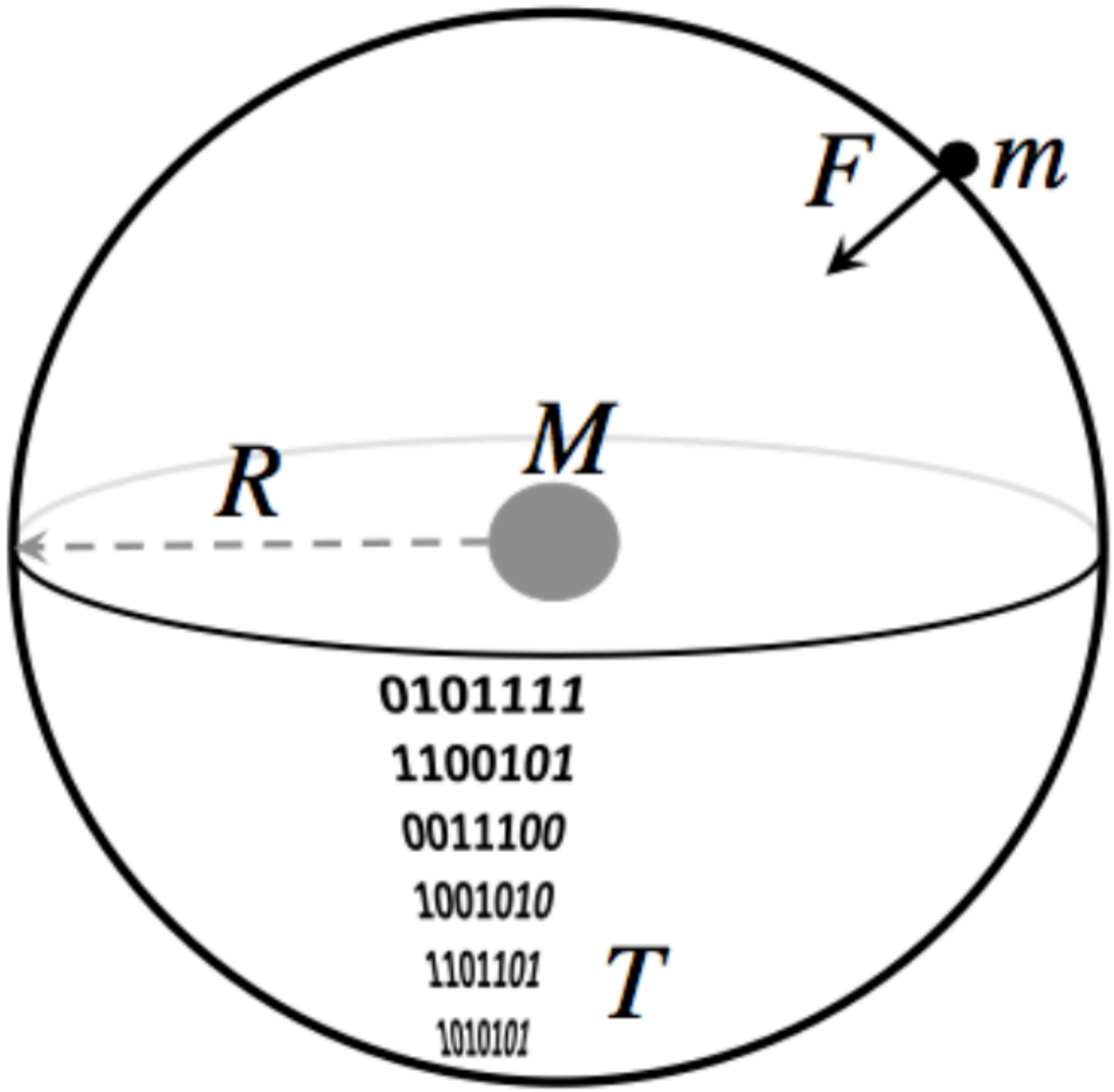
$$\Delta S = 2\pi k_B \delta x$$



$$\delta x = \lambda_c = \frac{\hbar}{mc}$$

Deriving gravity:

A falling test particle on a radial shell



Deriving gravity:

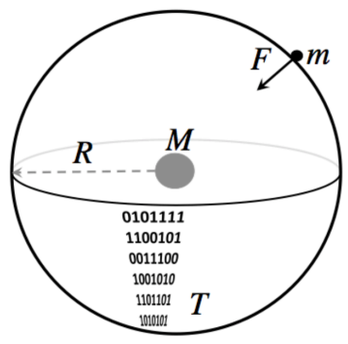
The assumptions going in

1. Area law: $$N = \frac{c^3}{G\hbar} A$$

2. Equipartition of energy $$E = \frac{1}{2} N k_B T$$

3. Total energy: $$E = Mc^2$$

4. Entropic formula: $$\Delta S = 2\pi k_B \frac{\Delta x}{\lambda_c}$$



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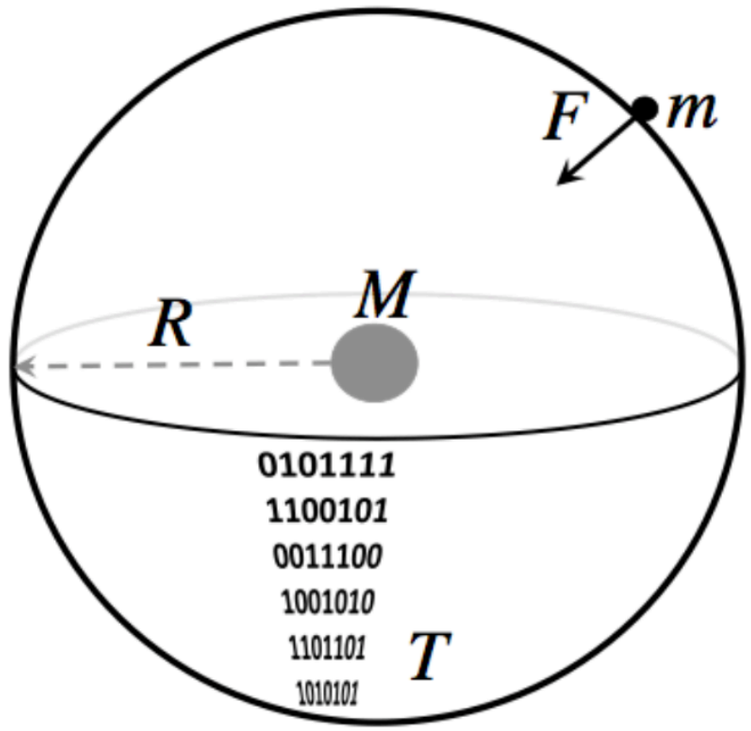

$$\Delta E = 0 = T\Delta S - F\Delta x$$

$$F = T\frac{\Delta S}{\Delta x}$$

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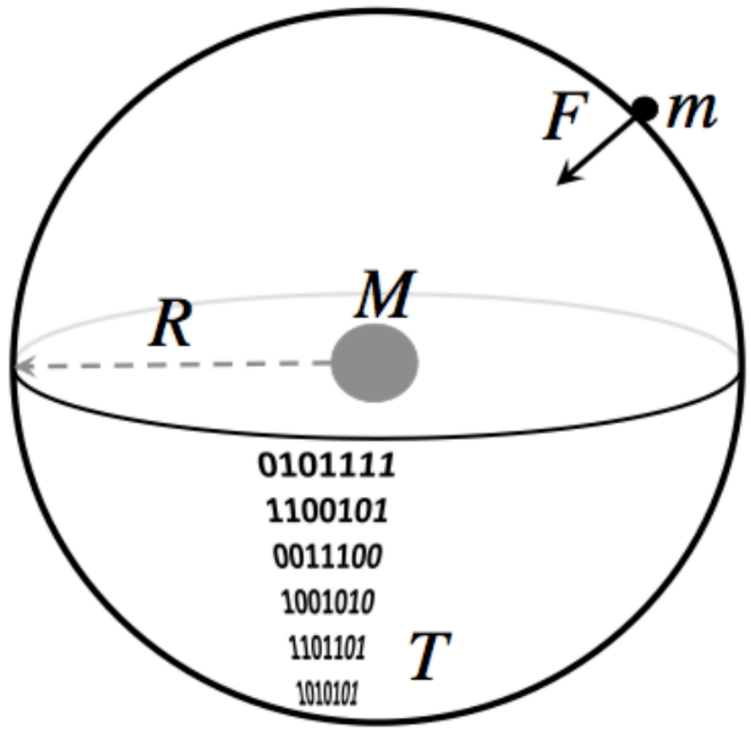


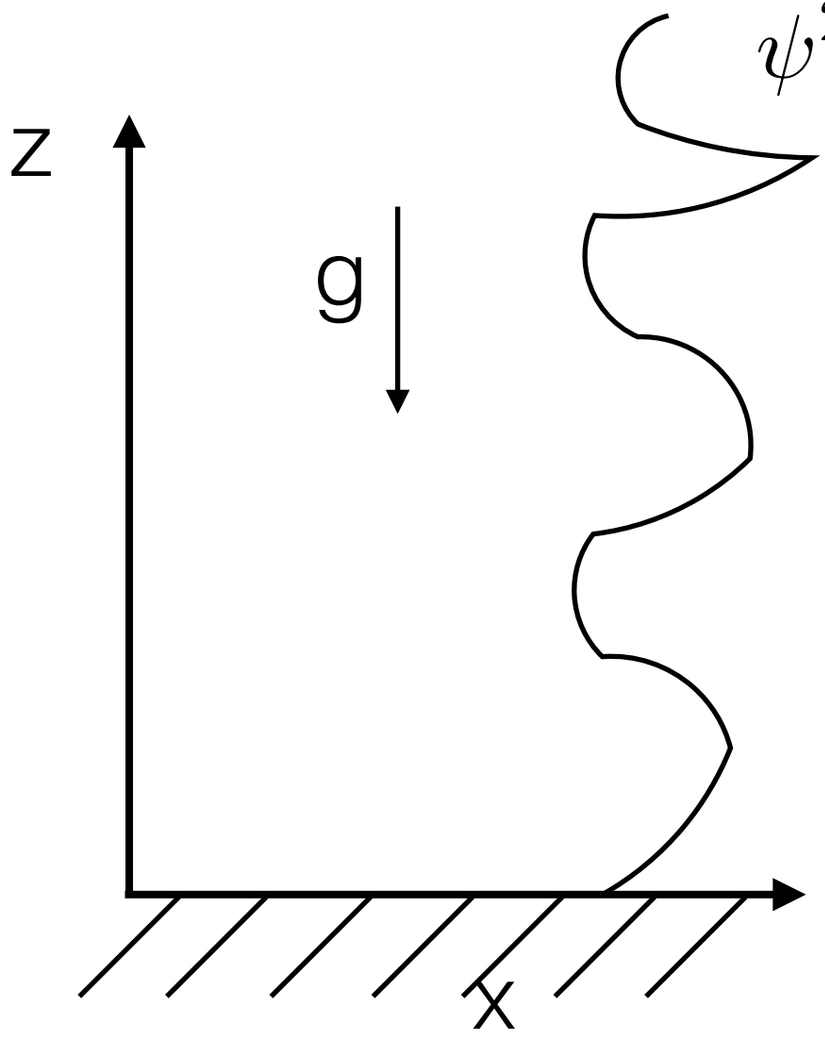
$$\Delta E = 0 = T\Delta S - F\Delta x$$

$$F = T\frac{\Delta S}{\Delta x}$$

$$= \frac{GMm}{R^2}$$

A rather *complicated* experiment ‘disproves’ the theory

insert Tom rambling about something he really doesn’t understand



$$[\frac{p_z^2}{2m} + V(z)]\psi(z) = E\psi(z)$$

$$V(x) = \begin{cases} mgz & \text{if } z \geq 0; \\ \infty & \text{if } z < 0. \end{cases}$$

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$S_N(z + \Delta z) - S_N(z)$ = not 0

$$e^{ip_z \Delta z}$$

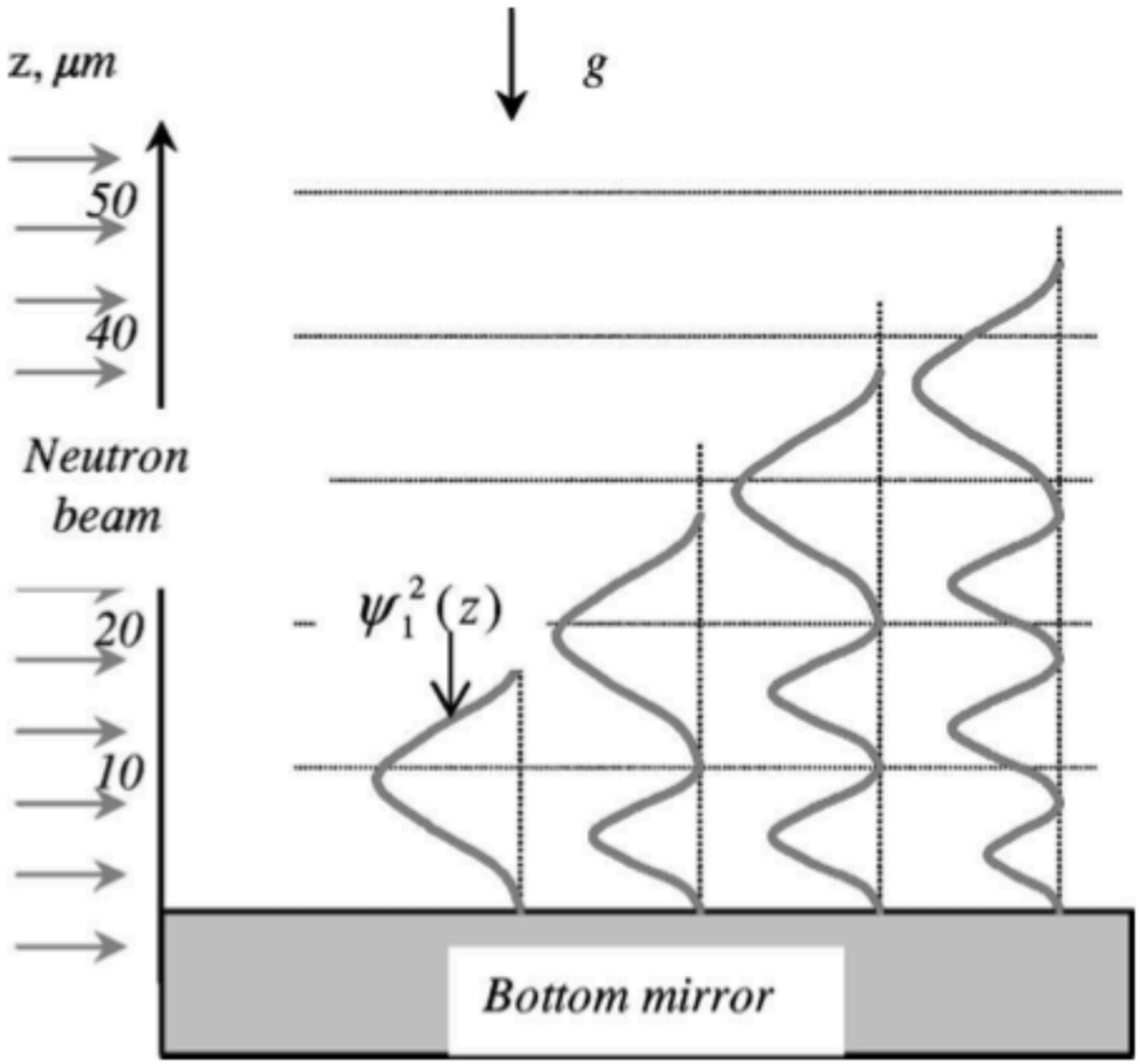
its translation operator is not hermitian

$$p_z = -i\hbar\frac{\partial}{\partial z} - i2\pi mc$$

ergo, neutrons become a mixed state over compton wavelengths

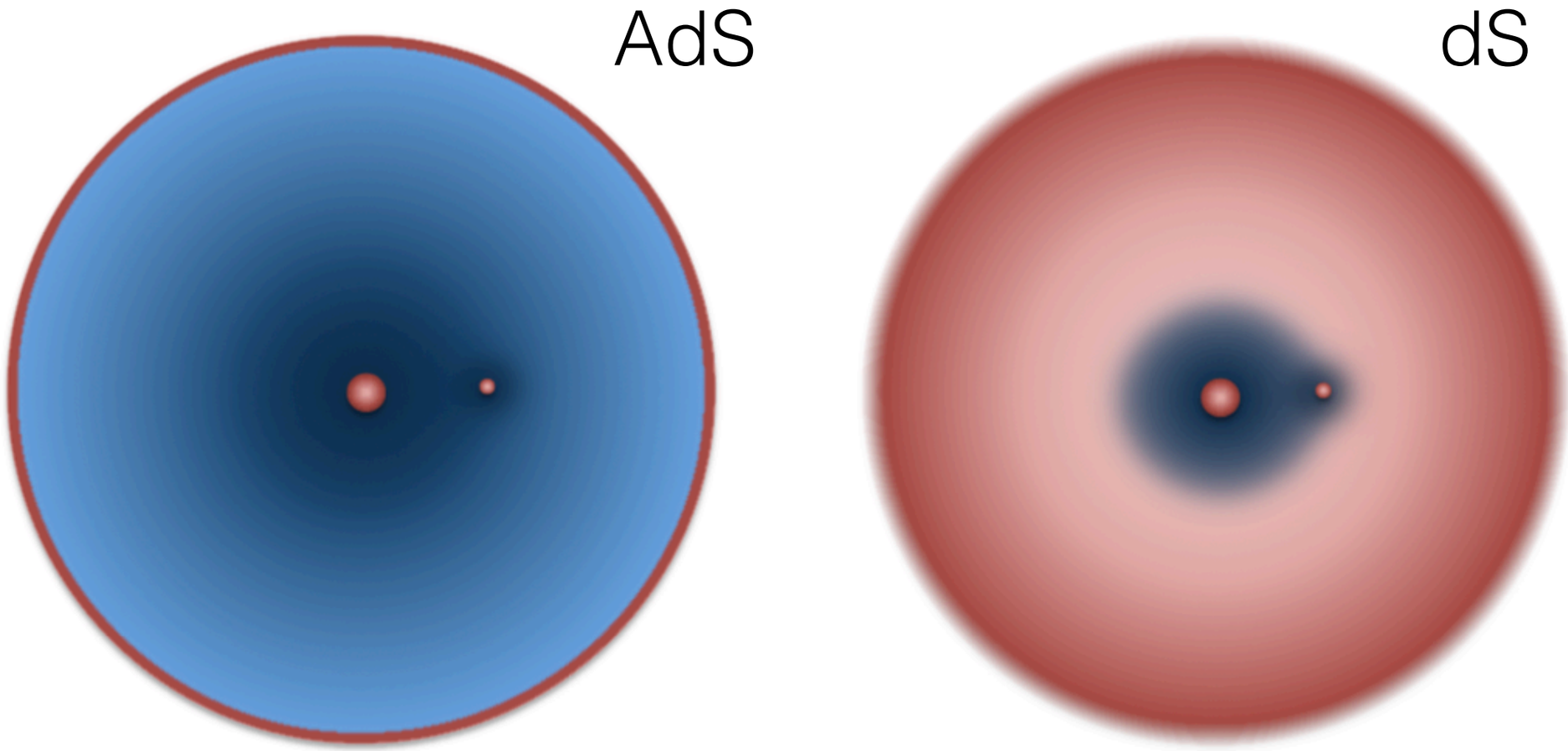
A rather *complicated* experiment ‘disproves’ the theory

o.m.g., is he still talking?



Apparent dark matter

The dS universe has two horizons



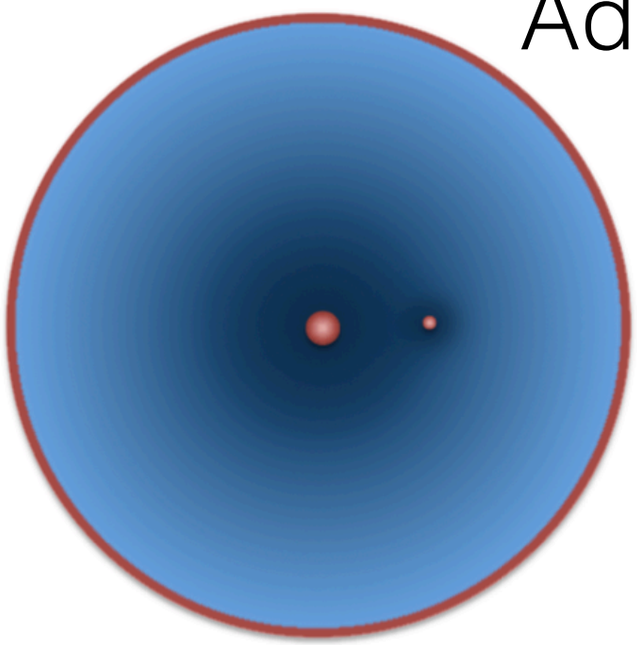
Apparent dark matter

The extra effect works on long scales
-> apparent dark matter

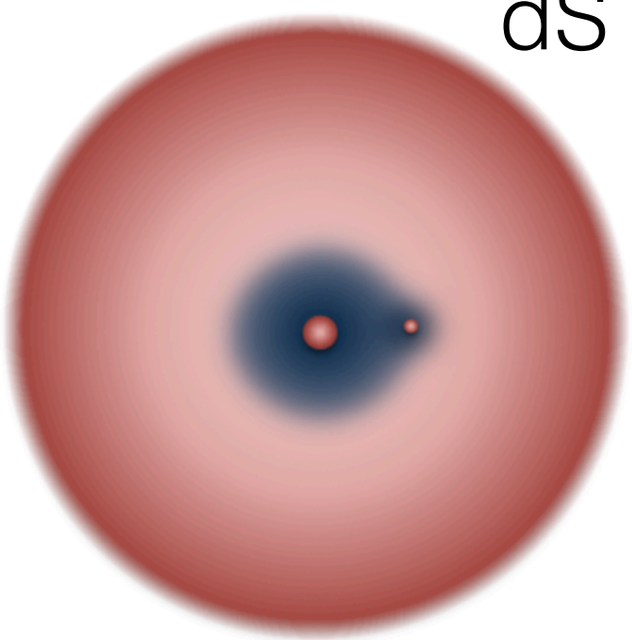
“The observed phenomena that are currently attributed to dark matter are the consequence of the emergent nature of gravity and are caused by an elastic response due to the volume law contribution to the entanglement entropy in our universe”

- Verlinde 2016

AdS

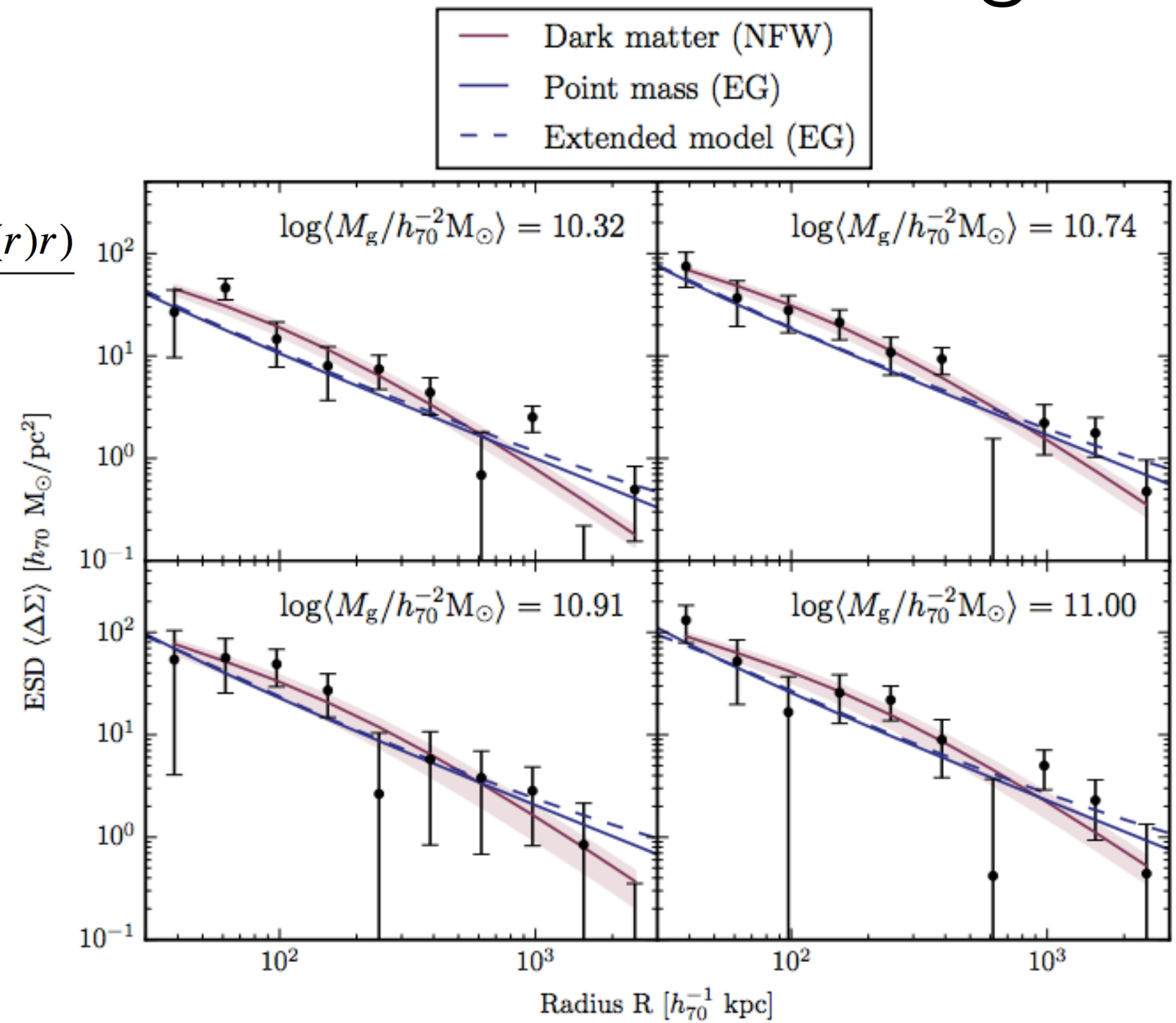


dS



Brouwer 2017 shows both models agree with KIDS weak lensing

$$M_{\mathrm{D}}^2(r) = \frac{cH_0r^2}{6G}\frac{d\left(M_{\mathrm{b}}(r)r\right)}{\mathrm{d}r}$$



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