Festina Lente and branes

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Based on work in progress
with Saquib Hassan and John March-Russell

Motivation

- Understanding the nature of QG in dS space is one of the big open problems we currently have
- Part of this question is knowing what is the allowed spectrum of particles/objects in dS space
- Top-down results about dS space can be difficult to obtain
- This is why bottom-up arguments, e.g. using black hole physics, are particularly important

Motivation: FL

[Montero, Van Riet, Venken ’19]

- One such example is the Festina Lente (FL) bound
- Festina Lente (= ‘hurry slowly’) refers to the evaporation of “extremal” large charged (Nariai) black holes in dS space
- For these black holes to evaporate without becoming super-extremal one must ensure that charged particles obey:

$$m^2 \gtrsim gqM_{\text{Pl}}H$$

where $H \equiv \sqrt{\Lambda/3}$ is the Hubble rate and Λ is the cosmological constant.

Motivation: WGC

- This has a similar spirit to the Weak Gravity Conjecture (WGC) which is related to the evaporation of extremal BHs in asymptotically flat space

[Arkani-Hamed, Motl, Nicolis, Vafa ’06]

- The WGC requires the existence of a charged particle with:

$$m \lesssim g_d q M_{\rm Pl}^{(d-2)/2}$$

- The WGC also generalizes to extended objects:

$$T_p \lesssim g_{p,d} q M_{\rm Pl}^{(d-2)/2}$$

[Arkani-Hamed, Motl, Nicolis, Vafa ’06]
[Heidenreich, Reece, Rudelius ’15]

Natural question: is there a version of FL bound that applies to branes?

Outline

- Review of the Festina Lente (FL) bound [Montero, Van Riet, Venken '19]
- Festina Lente and branes
  - Branes with world-volume gauge fields
  - Branes without world-volume gauge fields
- Summary and outlook

Festina Lente

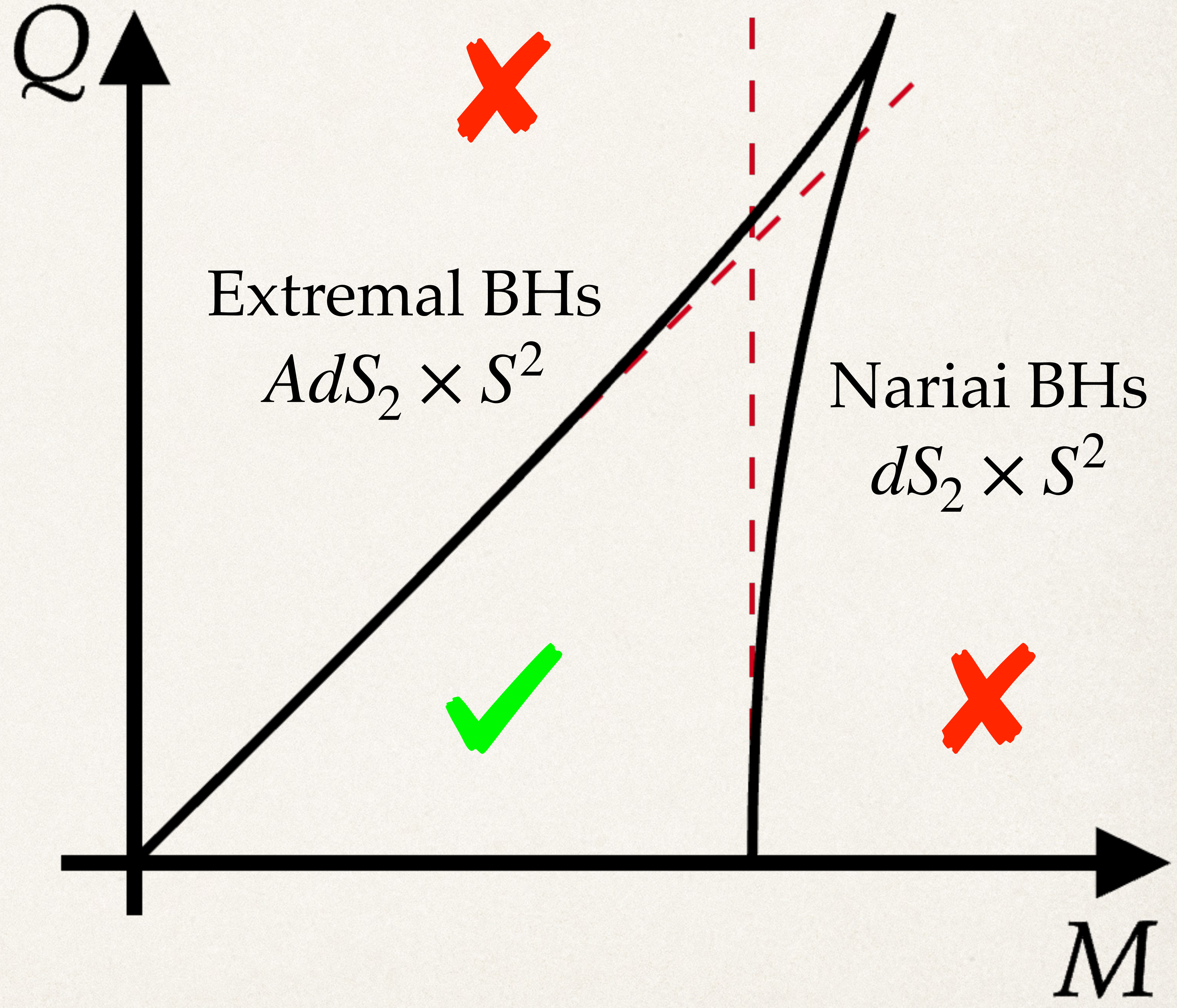
Big picture: study decay of large charged BHs in dS in the presence of matter and prevent these BHs from becoming super-extremal

Festina Lente: Setup

- **Setup:** Einstein-Maxwell theory in dS space with charged matter of mass m

$$\mathscr{L}_{\text{FL}} = \frac{M_{\text{Pl}}^2}{2}(R - 2\Lambda) - \frac{1}{4}F^2 + \begin{array}{c}\text{mass } m\\ \text{charged}\\ \text{matter}\end{array}$$

- This theory has charged BH solutions characterised by two numbers: Q, M



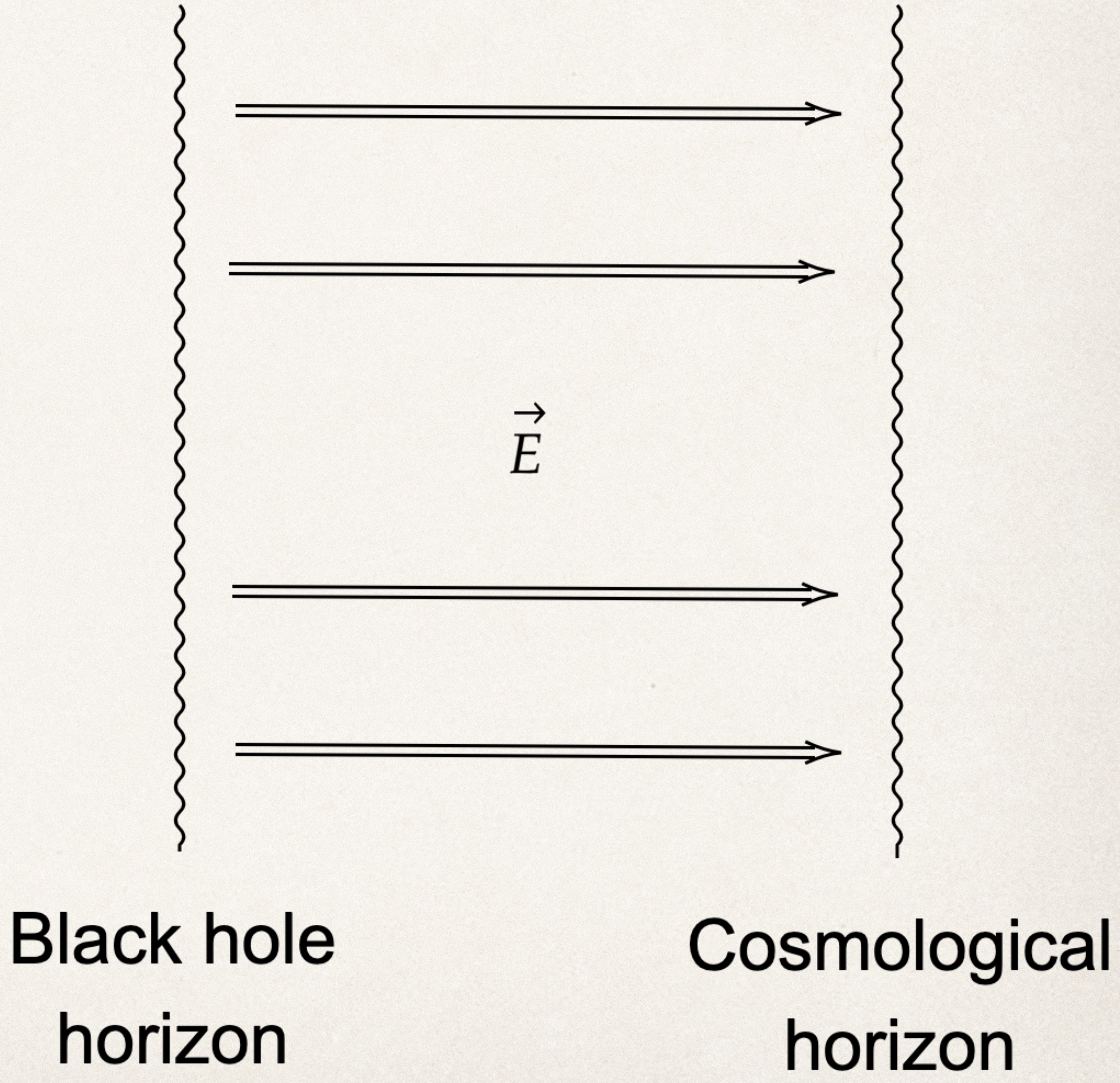
Festina Lente: Nariai Branch

- For the rest of the talk we will focus on the Nariai BHs

- These have a $dS_2 \times S^2$ geometry with a constant electric field

- The magnitude of the electric field is

$$E \sim M_{\rm Pl} H$$



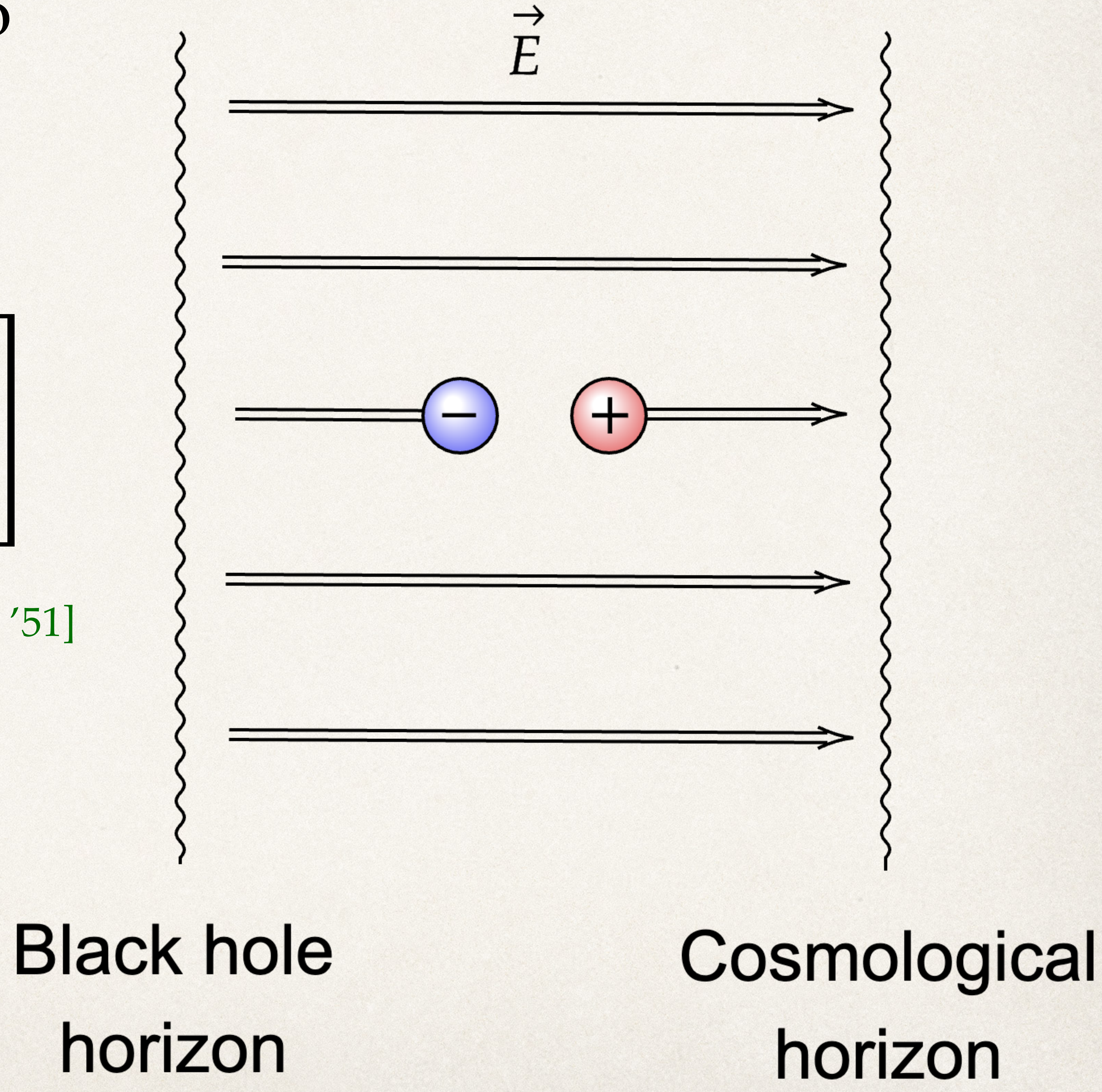
Festina Lente: Nariai BH evaporation

- The Schwinger screening happens locally so we can consider the flat space Schwinger rate:

$$\Gamma_{\text{Schw}} \propto \exp\left[-\frac{m^2}{gqE}\right] \overset{\text{Nariai}}{\sim} \exp\left[-\frac{m^2}{gqM_{\text{Pl}}H}\right]$$

[Schwinger '51]

- There are two important limits:
  - $m^2 \gg gqM_{\text{Pl}}H$ (slow $\Longrightarrow$ OK)
  - $m^2 \ll gqM_{\text{Pl}}H$ (fast $\Longrightarrow$ NOT OK!)



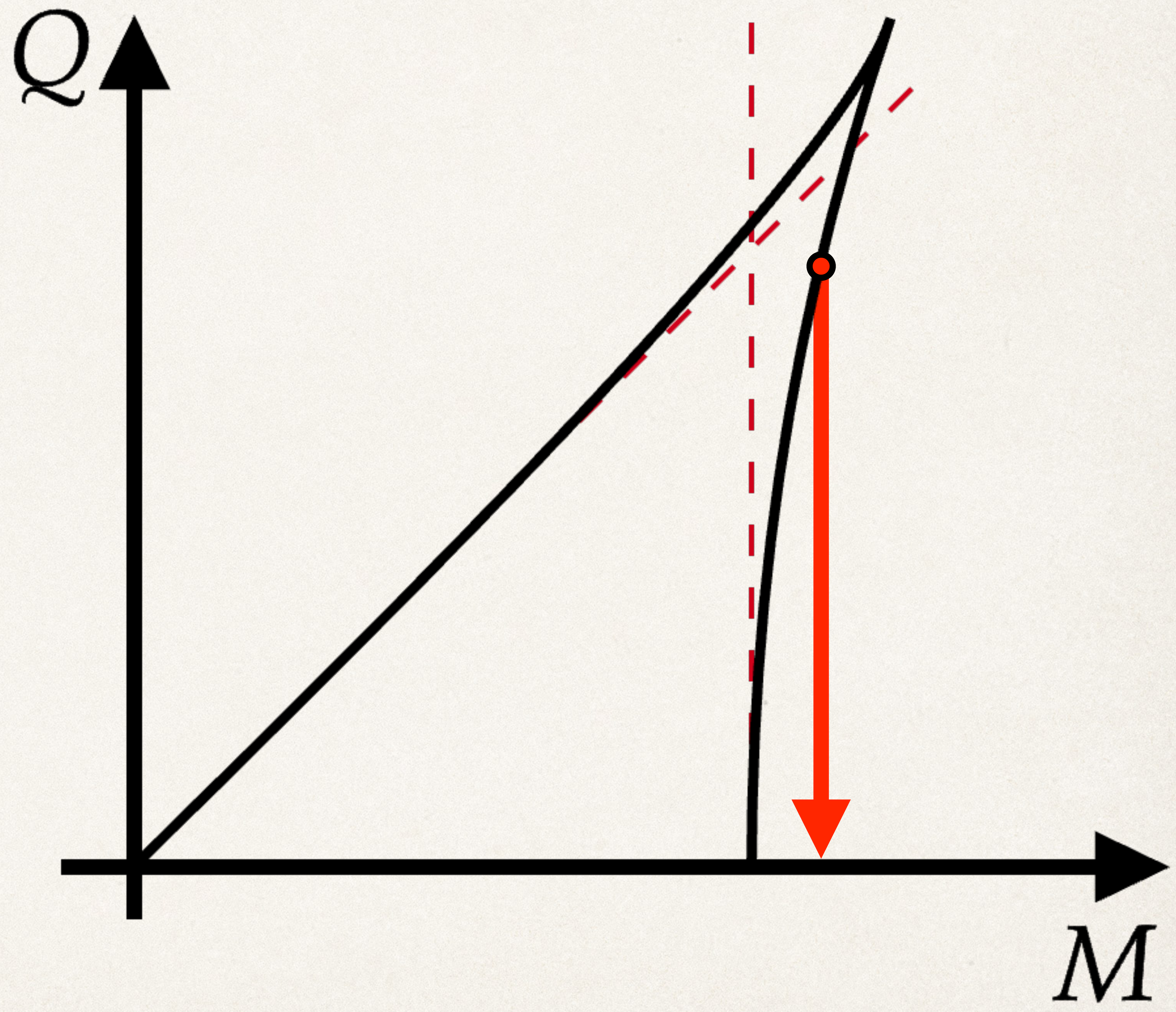
Festina Lente: Nariai BH evaporation

- Evolving the equations of motion in the $m^2 \ll gqM_{\rm Pl}H$ limit leads to a Big Crunch

- The interpretation is that the whole spacetime has 'fallen inside the BH'

- To avoid this fate, we require that all charged particles in dS space have:

$$m^2 \gtrsim gqM_{\rm Pl}H$$



[Montero, Van Riet, Venken '19]

Festina Lente and branes

Big picture: study decay of large charged BHs in dS in the presence of branes and prevent these BHs from becoming super-extremal

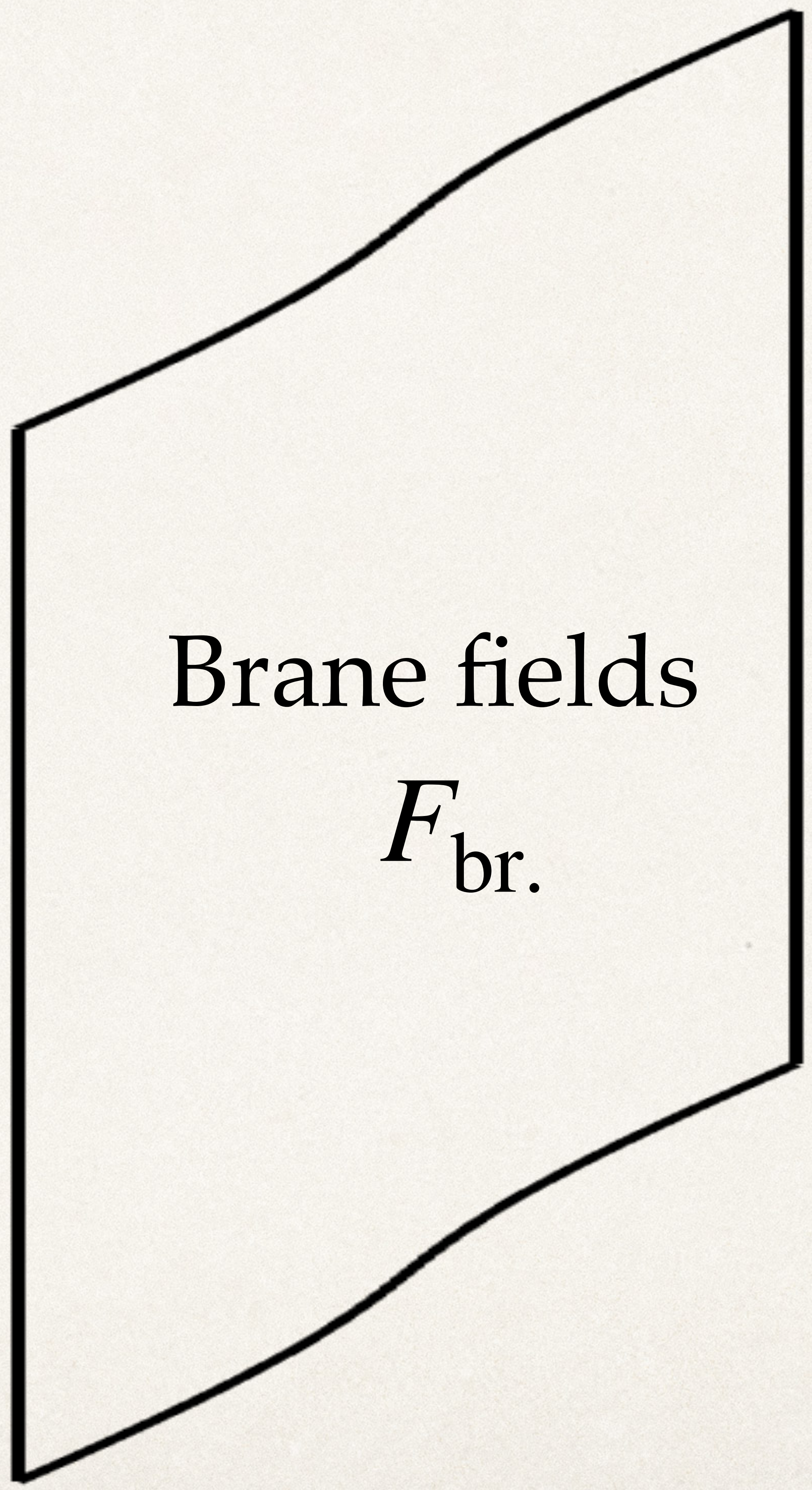
Festina Lente for branes (I)

- There's a similar story if one considers branes instead of particles

$$S^E_{2-\mathrm{brane}} = \int_{\mathrm{WV}} T_2 \star 1 + i\alpha A \wedge F_{\mathrm{br.}} + \frac{1}{2} F_{\mathrm{br.}} \wedge \star F_{\mathrm{br.}}$$

- These can be nucleated and screen the electric field as well

- Again we will consider the nucleation rate in flat space



Bulk fields

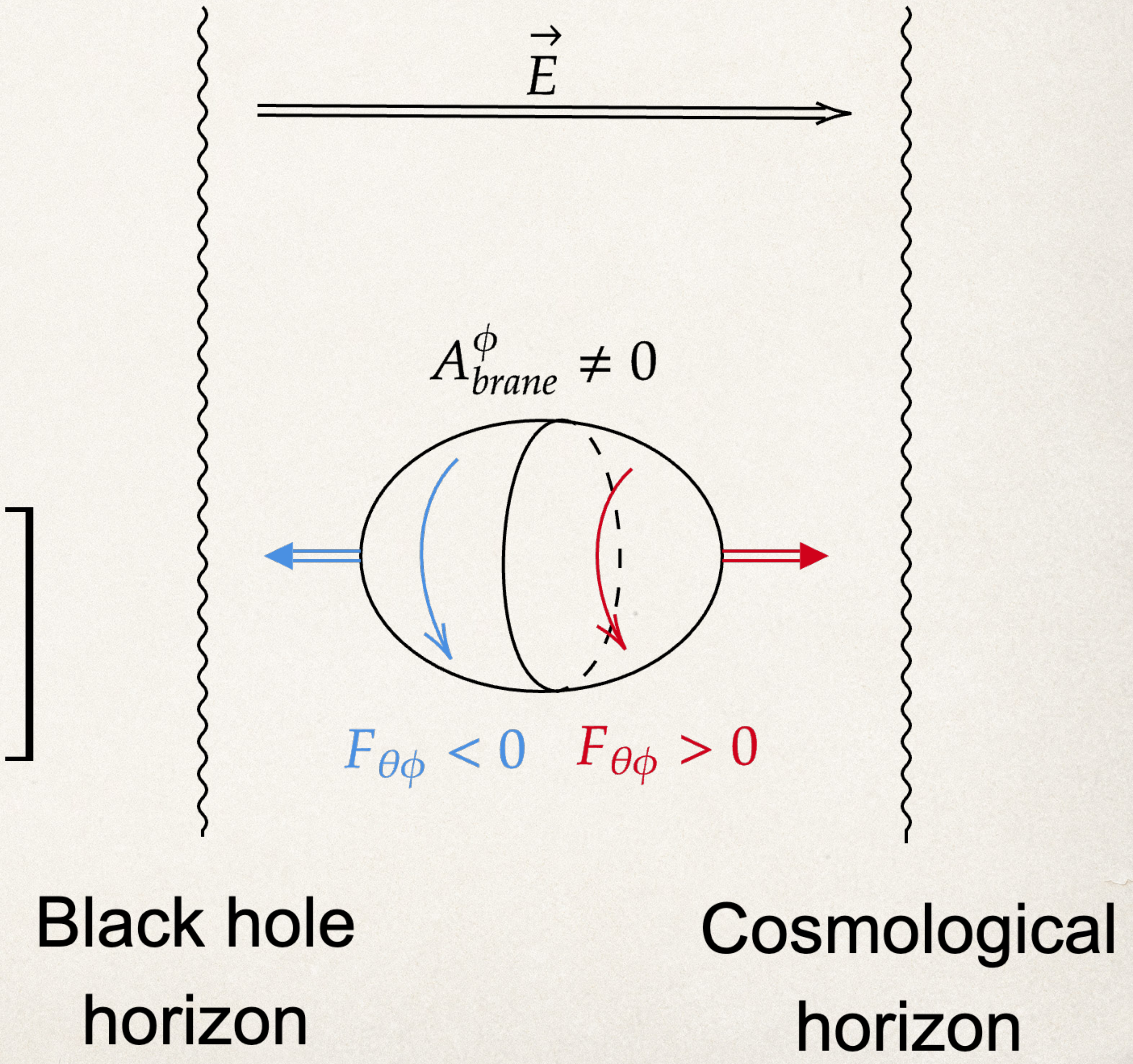
$F = dA$

Festina Lente for branes (I)

- For the brane to be electrically charged, it must have a non-trivial $F_{\text{br.}}$ profile

- We can calculate the nucleation rate:

$$\Gamma_{\text{br.(I)}} \propto \exp\left[-\frac{T_2^{5/2}}{(\alpha E)^3}\right] \overset{\text{Nariai}}{\sim} \exp\left[-\frac{T_2^{5/2}}{(\alpha M_{\text{Pl}} H)^3}\right]$$



Festina Lente for branes (I)

- Demanding that this process is exponentially suppressed means that:

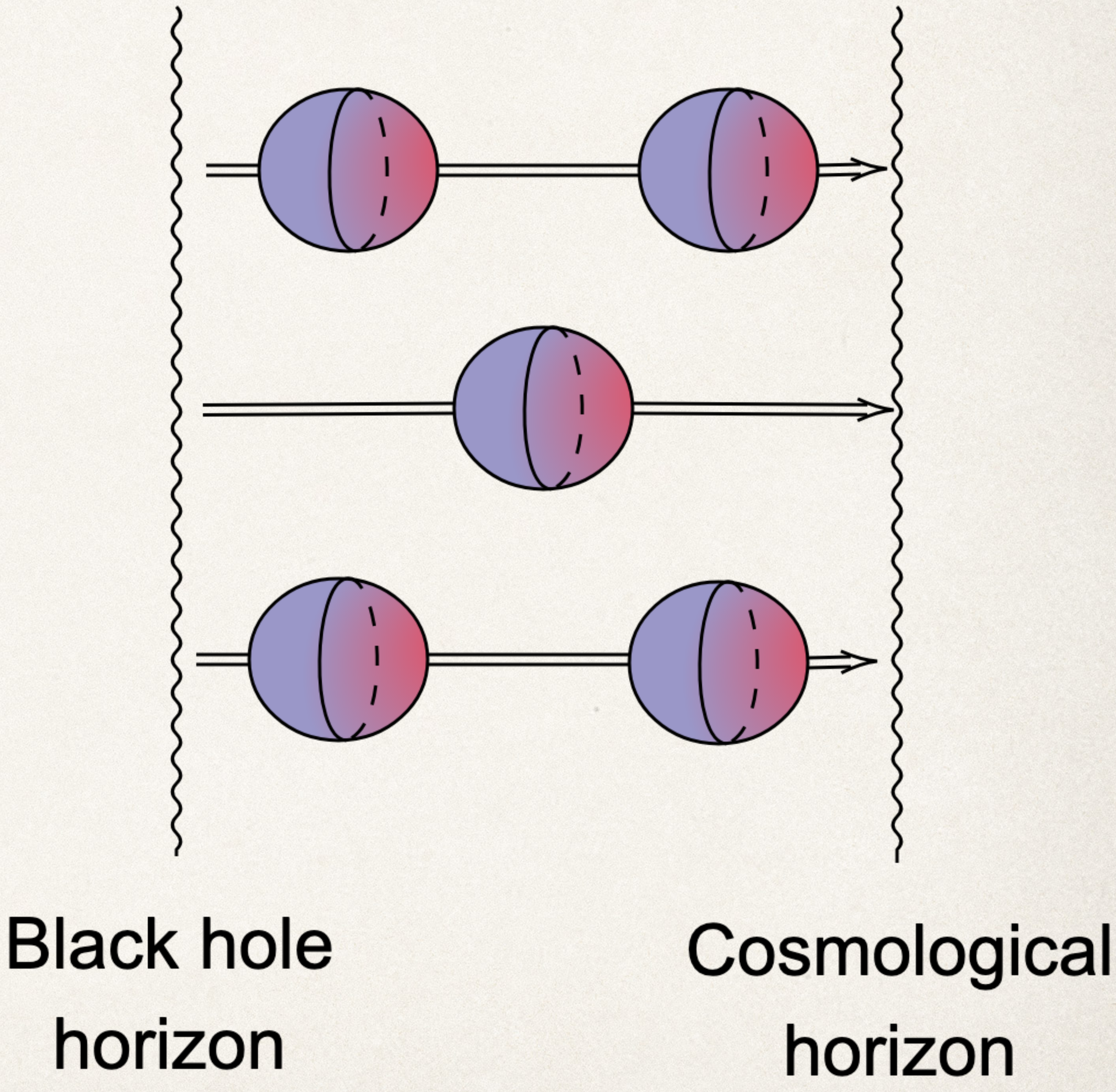
$$T_2 \gtrsim (\alpha M_{\text{Pl}} H)^{6/5}$$

- Either this is true or the nucleated brane does not 'fit' in the Nariai spacetime:

$$R_* \gtrsim H^{-1} \implies T_2 \gtrsim \alpha M_{\text{Pl}}^2$$

- In general, we get:

$$T_2 \gtrsim \min\left[(\alpha M_{\text{Pl}} H)^{6/5}, \alpha M_{\text{Pl}}^2\right]$$



Festina Lente for branes (I)

- Repeat the argument for p-branes in d dimensions ($E \sim M_d^{\frac{d-2}{2}} H$)

  - For p even, we take an action: $S^E_{p-\text{brane}} \supset i\alpha \int A \wedge F_{\text{br.}} \wedge \ldots \wedge F_{\text{br.}}$

$$T_p^{\frac{1}{p+1}+\frac{4-p}{p}} \gtrsim \alpha E \qquad \text{OR} \qquad T_p^{\frac{4-p}{p}} \gtrsim \alpha M_d^{\frac{d-2}{2}} \qquad (p \neq 4)$$

  - For p odd, we take an action: $S^E_{p-\text{brane}} \supset i\alpha \int A \wedge d\theta \wedge F_{\text{br.}} \wedge \ldots \wedge F_{\text{br.}}$

$$T_p^{\frac{1}{p+1}+\frac{3-p}{p}} \gtrsim \alpha E \qquad \text{OR} \qquad T_p^{\frac{3-p}{p}} \gtrsim \alpha M_d^{\frac{d-2}{2}} \qquad (p \neq 3)$$

Festina Lente for branes (II)

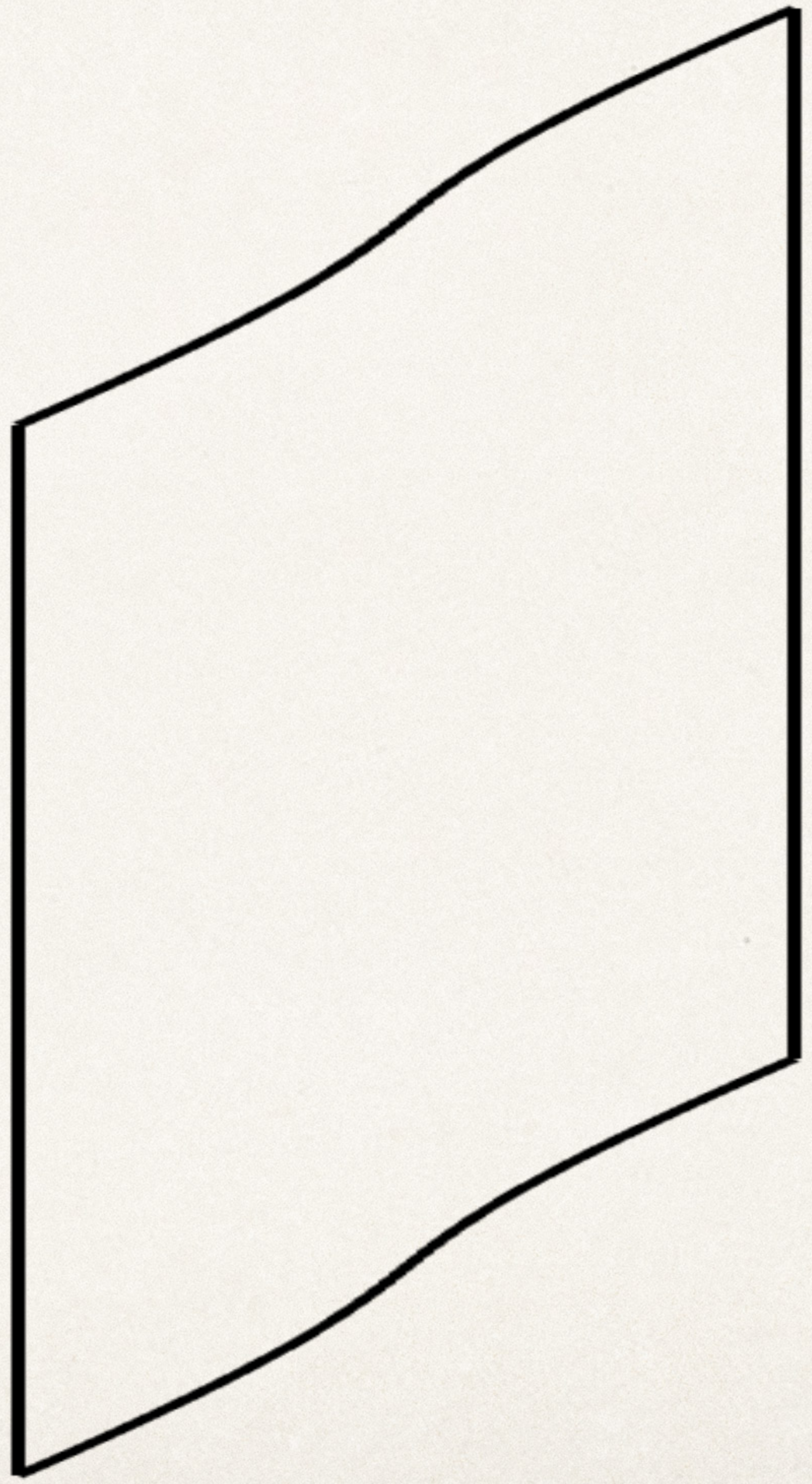
- One can also imagine having branes that couple like the following

$$S_{2-\text{brane}} = \int T_2 \star 1 + \frac{g^2}{4\pi} A \wedge F$$

- These branes get an electric charge in the presence of a magnetic field

[Sikivie '84]

- They can play a role in screening the electric fields of dyonic black holes



Bulk fields

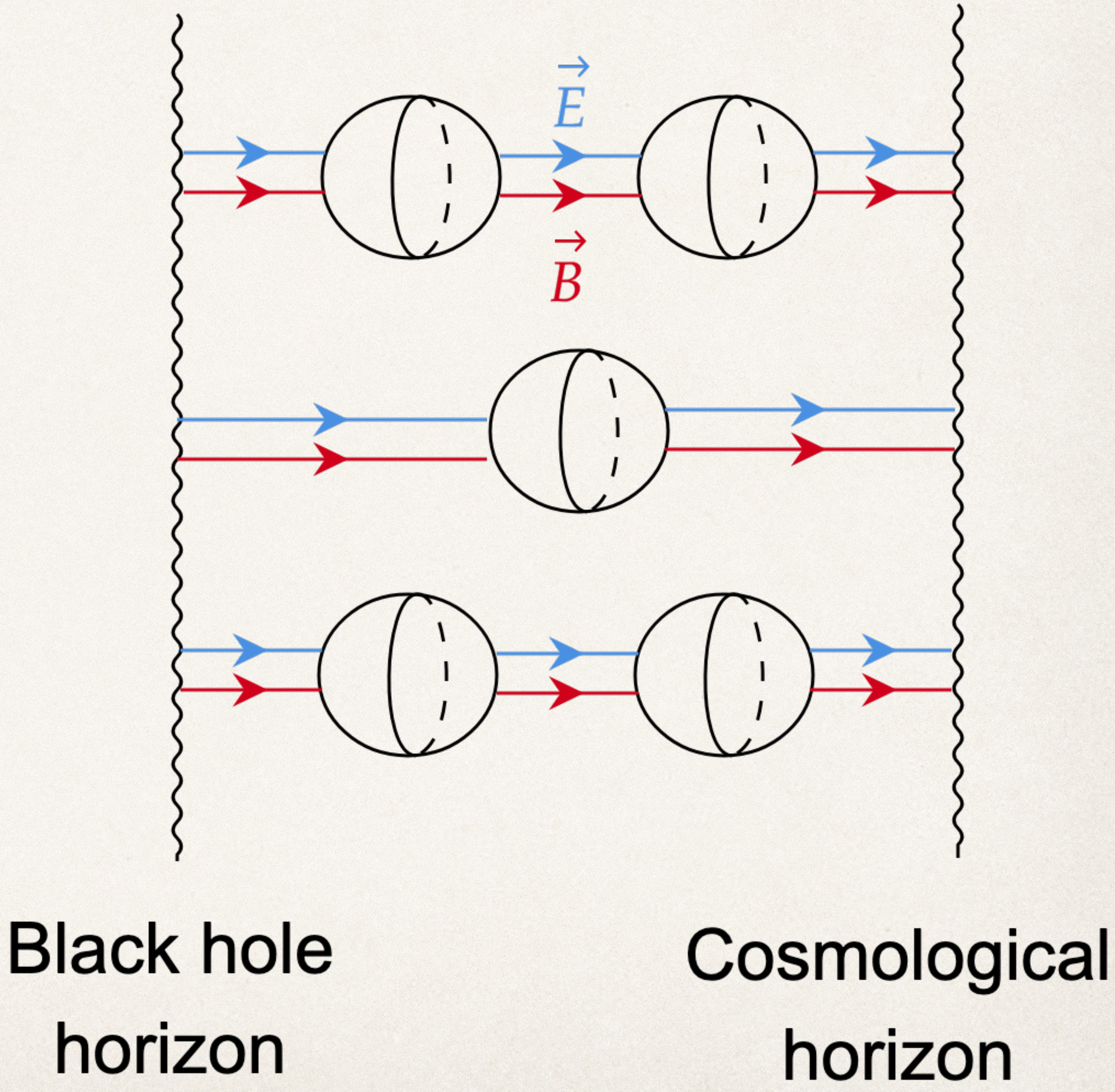
$$F = dA$$

Festina Lente for branes (II)

- Einstein-Maxwell theory in dS also has dyonic Nariai BH ($dS_2 \times S^2$) solutions
- We can consider the flat space rate for the nucleation of these branes and get the bound:

$$T_2 \gtrsim (gM_{\rm Pl}H)^{3/2}$$

- **Unless** there is a light axion (with $\theta F \wedge F$ coupling) that can classically screen the electric field



Axion domain walls?

- The electric field

$$E \sim M_{\rm Pl} H \left(Q_E - \frac{g^2}{4\pi^2} \theta Q_M \right)$$

[Witten '79]

can be much smaller with light axions

- The assumption that the axion does not screen the electric field already implies the bound on the ADW tension:

$$T_{\rm ADW} \sim m f^2 \gtrsim (g M_{\rm Pl} H)^{3/2}$$

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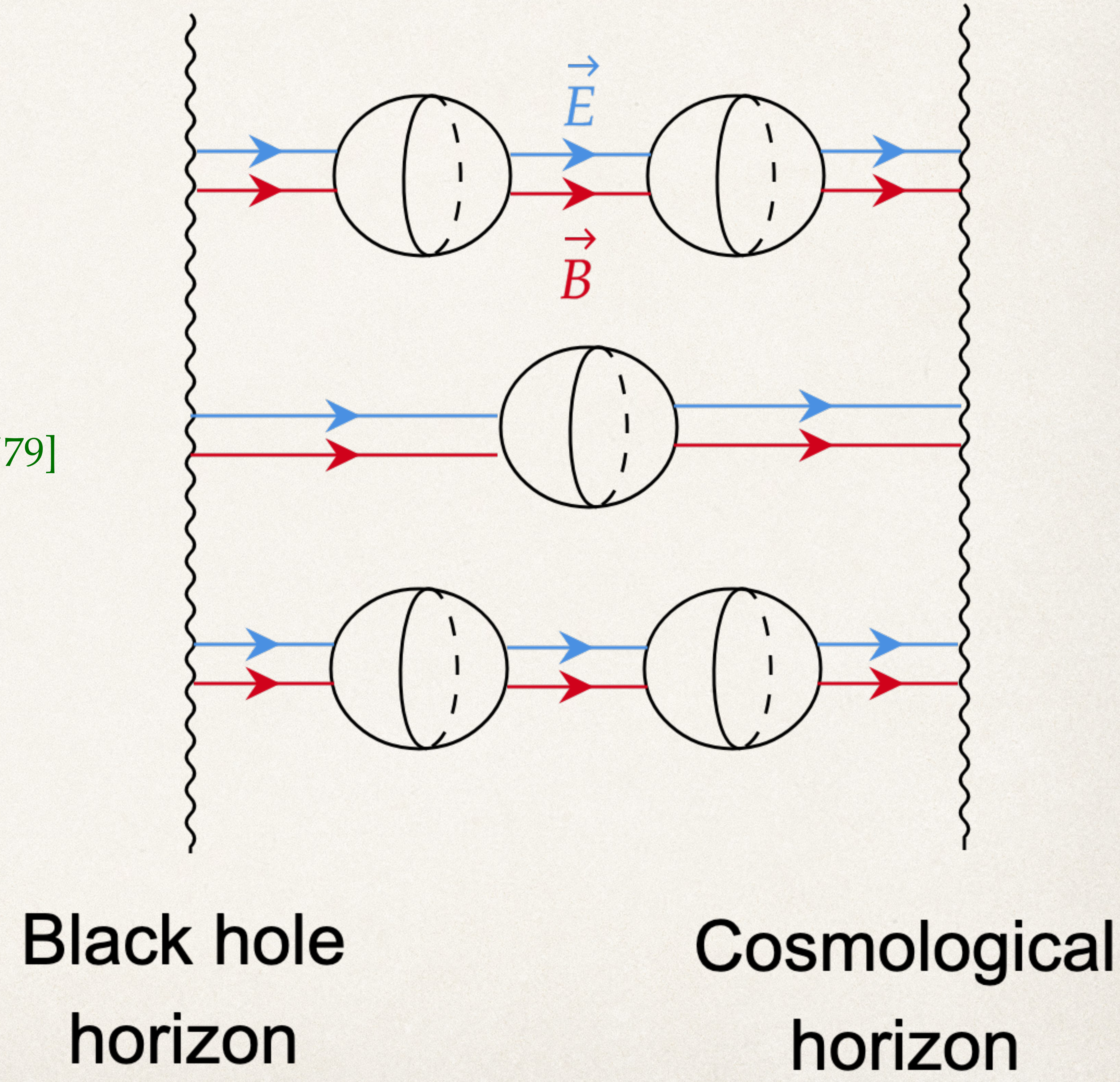

Summary and Outlook

- I presented a bottom up argument as to why the tension of branes in dS space is bounded.
- This is a generalization of the Festina Lente bound to branes
- More things to work out:
  - Charged branes (RR-forms), other couplings (e.g. $A \wedge F \wedge F, \ldots$), axionic BHs, self-energy, dimensional reduction, bound for 3- and 4- branes, relation to other FL conjectures etc.
  - phenomenology?
  - bound for axion domain walls?

Thank you!