# GRAVITY CONJECTURES AND BLACK HOLE EVAPORATION IN DE SITTER SPACE

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- But sometimes we also understand the underlying **principle**
- E.g. we don’t think (B-L) is an exact symmetry in the real world, even if we don’t know the right compactification

# EVIDENCE FOR WGC

- True in all **known examples**.
- Proof of mild form in worldsheet (proven stronger statement, a **lattice** version) **[Heidenreich-Reece-Rudelius ’15, ’16, MM-Shiu-Soler ’16, Aalsma-Cole-Shiu '19]**.
- Arguments from holography [**MM‘18**].
- Connection to Cosmic Censorship in AdS **[Crisford, Santos, Horowitz ’17-’18-’19]**
- IR consistency/Unitarity **[Cheung-Remmen ’18-19, Andriolo-Junghans-Noumi-Shiu ’18, Hamada-Noumi-Shiu ’18,Charles ’19]**
- Strong enough breaking of global symmetries **[See Tom’s talk]**, connections to SDC **[Heidenreich-Reece-Rudelius ’18,Valenzuela-Palti-Grimm ‘18]**

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These support **principle**: It is bad if black holes are not (marginally) unstable

- In work with **T. Van Riet** and **G. Venken**, we took first steps to understand **WGC** in (quasi)-**dS** spacetimes.
- Tools available:
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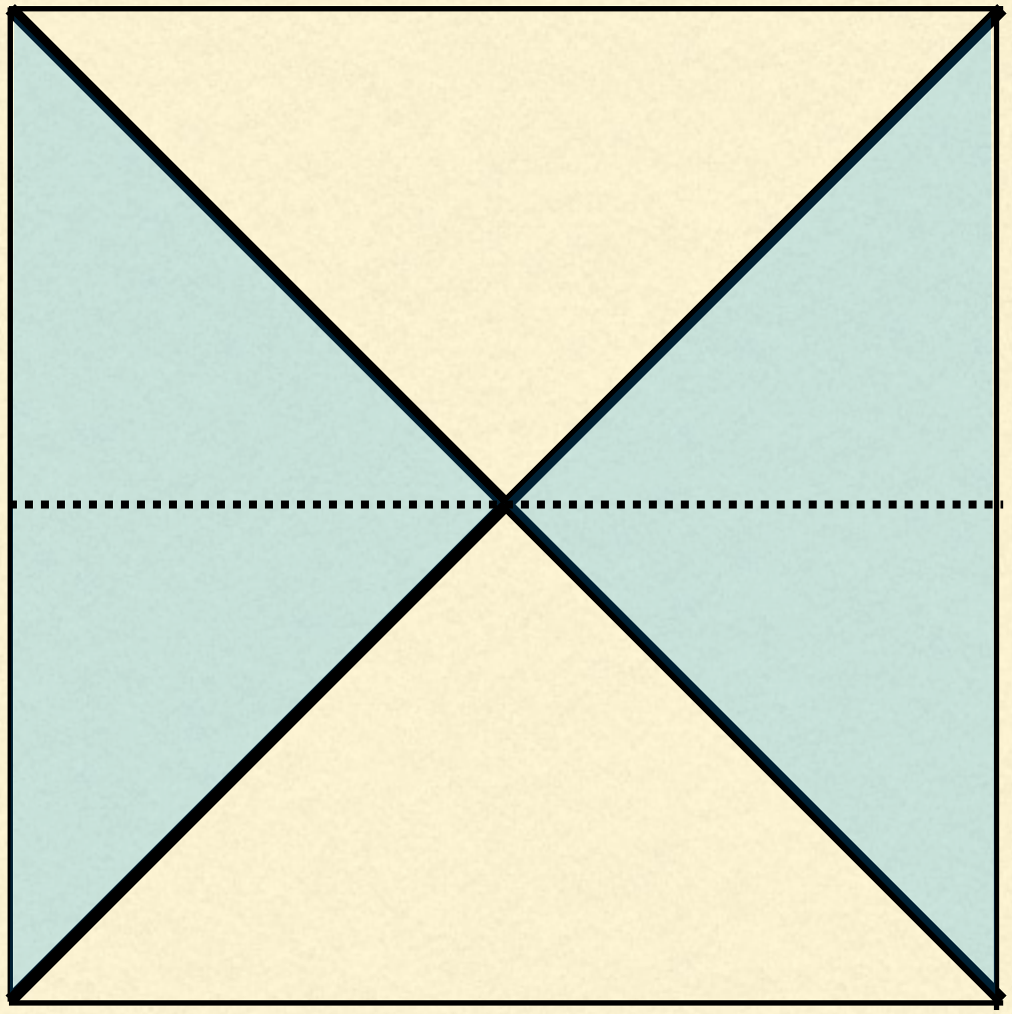
[See Tom Banks' talk]

# DE SITTER 101

- Good review: **[Anninos '12]**
- **Static patch**: What a local observer in dS can see

$$ds^2 = -\left(1 - \frac{r^2}{\ell^2}\right) dt^2 + \frac{dr^2}{1 - \frac{r^2}{\ell^2}} + d\Omega^2$$

- There is a **cosmological horizon**
    - **Radiates** at a temperature T=H/(2π)



- **Observation/Principle** **[Gibbons-Hawking ’83, Banks ’00-’03-’05, Witten ’07...]**

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- Thermalization of long-wavelength modes with incoming radiation
- Finite horizon area suggests finite entropy
- Static patch is ``finite”: Maximum energy, charge…
- **Black hole physics**: Horizon area backreaction, black hole evaporation, Schottky anomaly **[Dinsmore-Draper-Kastor-Qiu-Traschen ’19, Johnson ‘19]**

**[See Tom Banks’ talk]**

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In this talk:

- Second implies (particular case of) the first
- Leads to a new **constraint** on the EFT.

To establish this, we will study **charged black hole evaporation in dS**

# BH'S IN DE SITTER

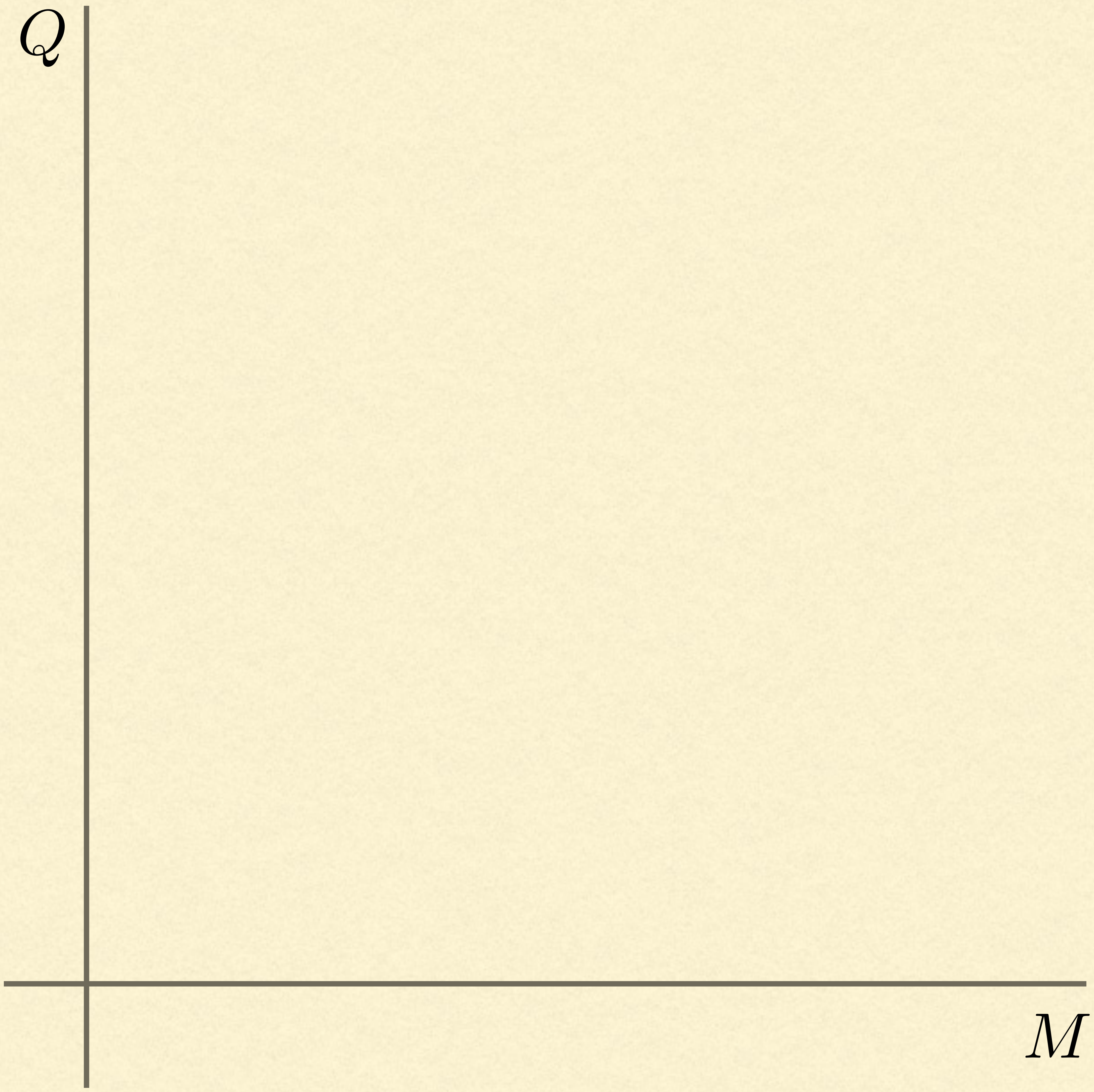
- We have **RN-dS** black holes

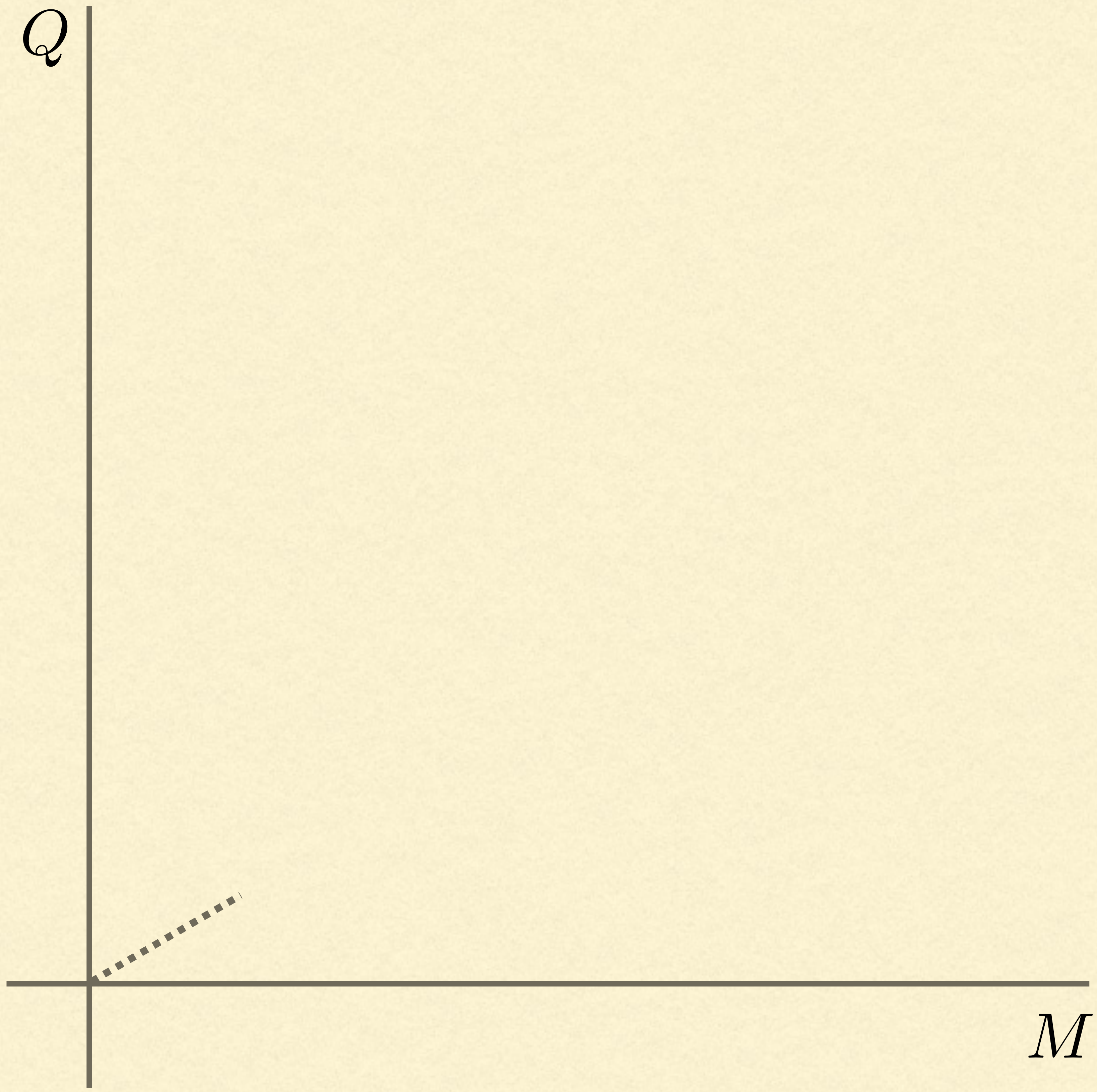
$$ds^2 = -U(r)dt^2 + U^{-1}(r)dr^2 + r^2 d\Omega^2$$

$$U(r) = 1 - \frac{2M}{r} + \frac{Q^2}{r^2} - r^2$$

$$Q \equiv \frac{G(gQ_e)^2}{\ell^2}, \quad M \equiv \frac{GM_r}{\ell}$$

- First thing you do is to **draw extremality curve.**


$Q$
$M$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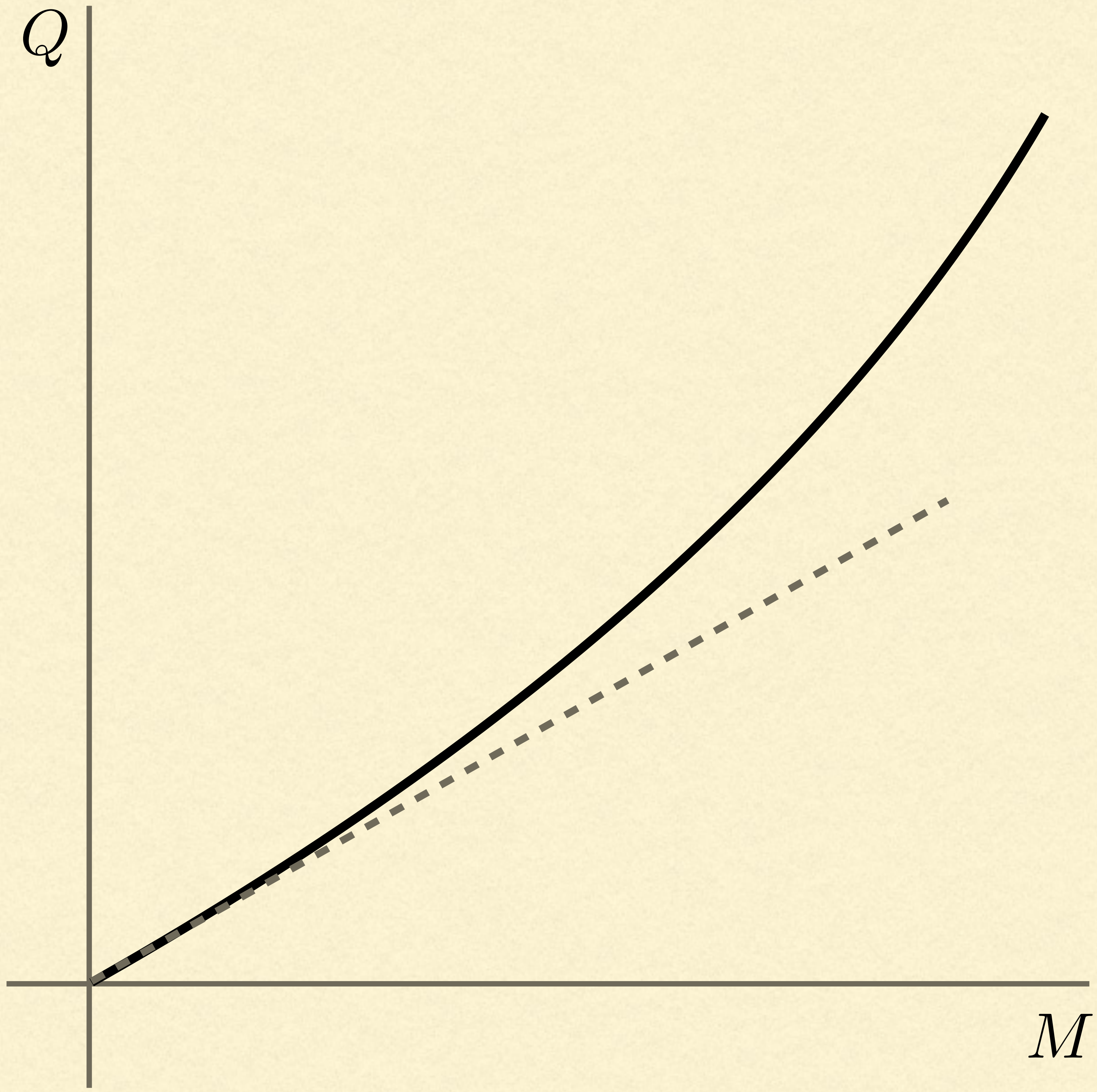
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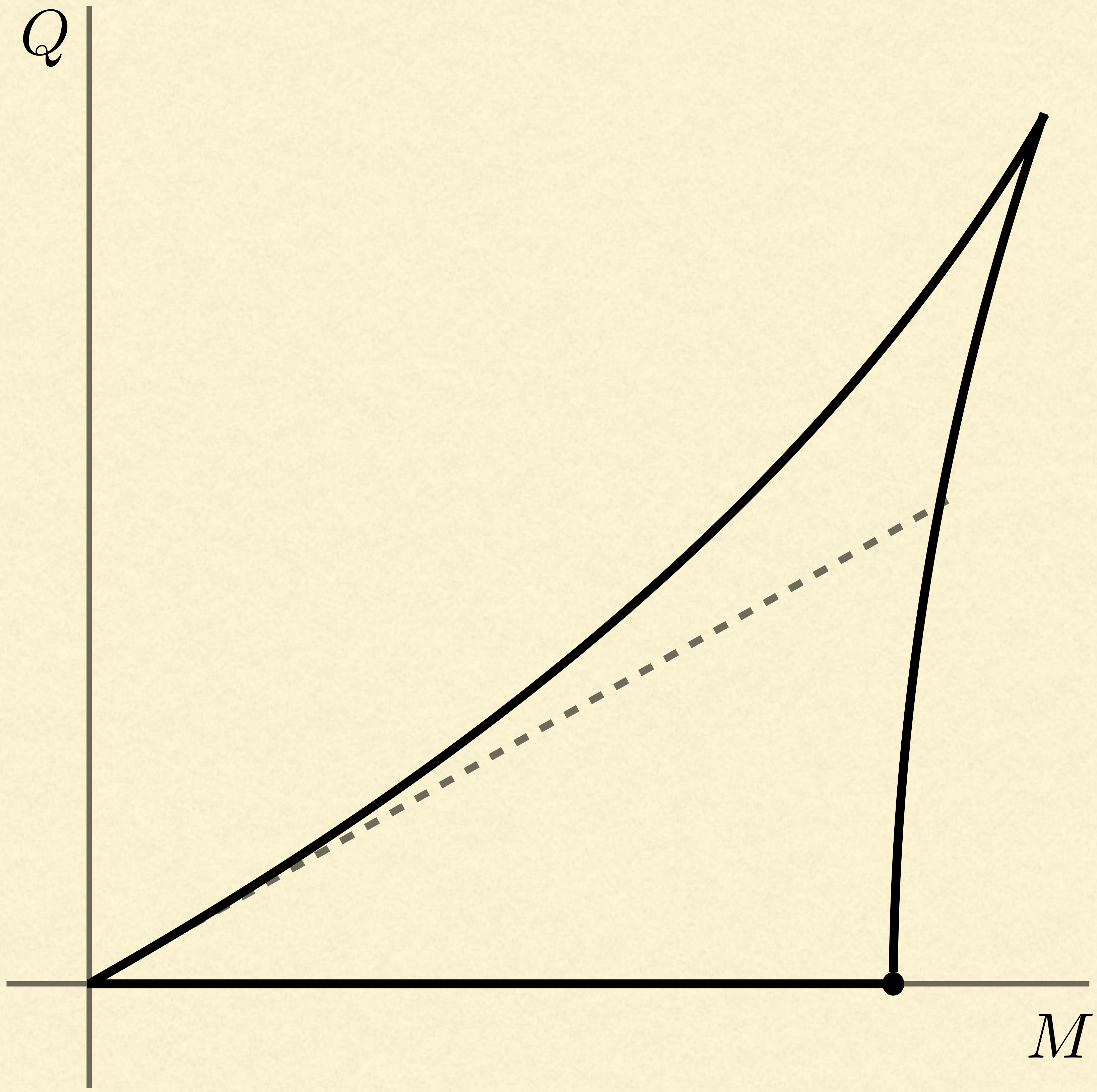
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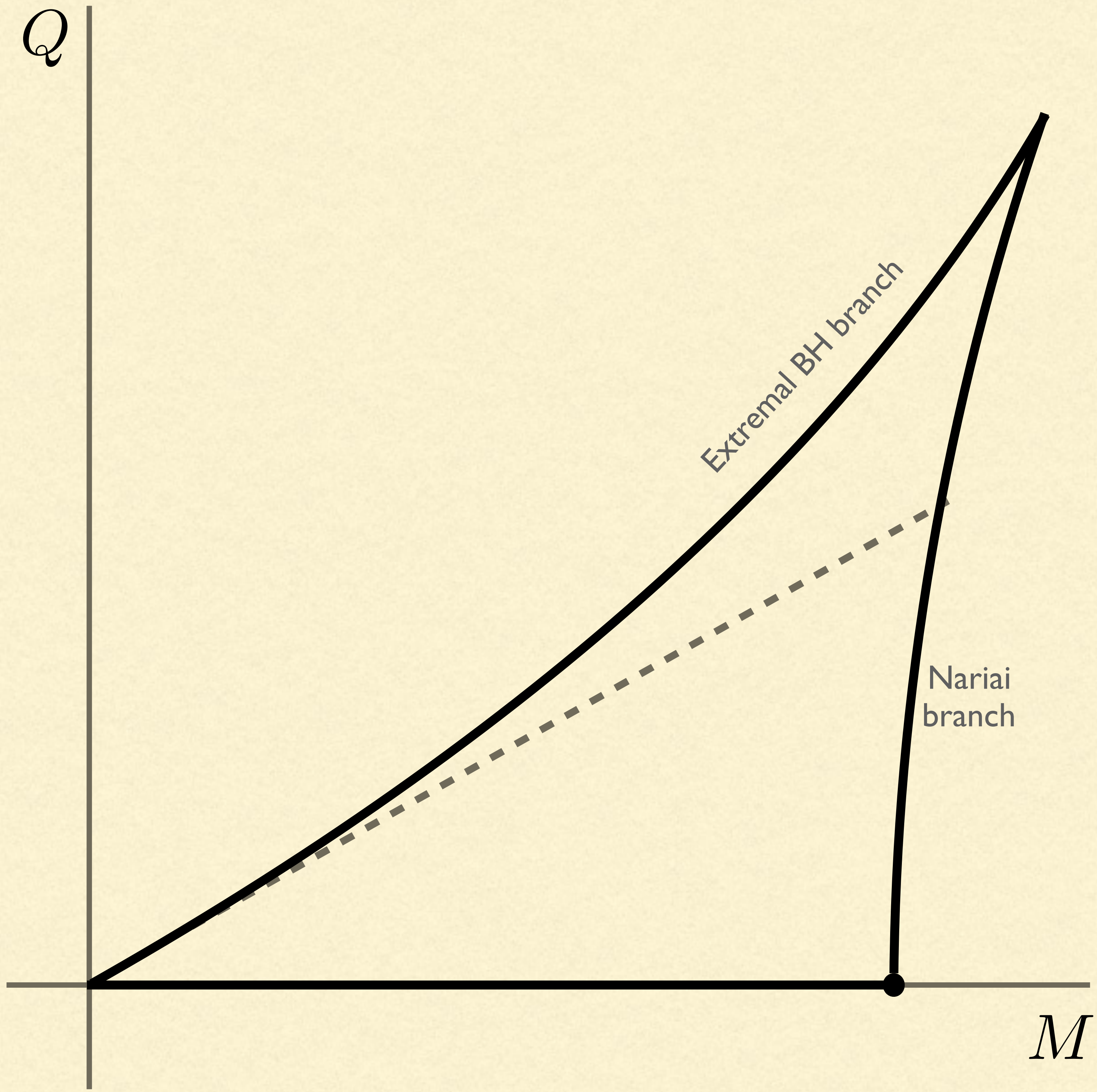
Q
Extremal BH branch
Nariai
branch
M

- We have **two families** of extremal solutions
    - Usual extremal ($AdS_2 x S^2$)
    - Nariai solutions ($dS_2 x S^2$): **Biggest black hole that fits**
- **Problem**: How do they evaporate?
    - Exchange mass via **Hawking radiation**
    - Shed charge via **Schwinger effect** (particle of mass m, ch. q)
    - **Difficulties:** Both horizons contribute, no asymptotic

      **[see Hiscock-Weems '90 for flat space case]**

- Hawking radiation is always small (except for tiny BH’s).

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- But Schwinger current is controlled by

$$\mathcal{J} \sim e^{-\pi \frac{m^2}{qE}}$$

So there are **two regimes**, depending on whether

$$m^2 \gg qE$$

or

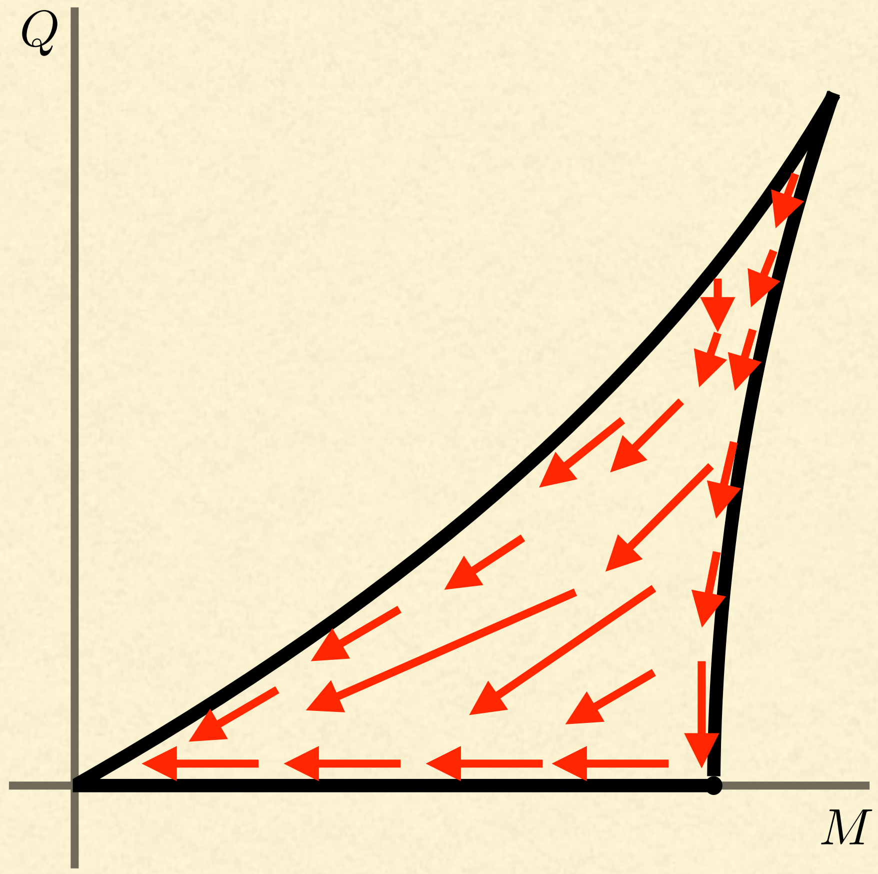
$$m^2 \ll qE$$

We will analyze **both.**

- Suppose charge and mass flux is small, so solutions evolve **slowly**
- Einstein eqs. turn into **quasistatic** evolution equations on the (M,Q) plane

$$\dot{Q} = -4\pi r_g^2 \mathscr{J}\,, \quad \dot{M} = -4\pi r_g^2 \left( G\sqrt{U(r_g)}\mathscr{T} + \frac{Q}{r_g}\mathscr{J} \right)$$

- Flow on **Nariai branch** stays there
- Very simple physics: $dS_2 x S^2$ with constant electric field given by the charge of the black hole

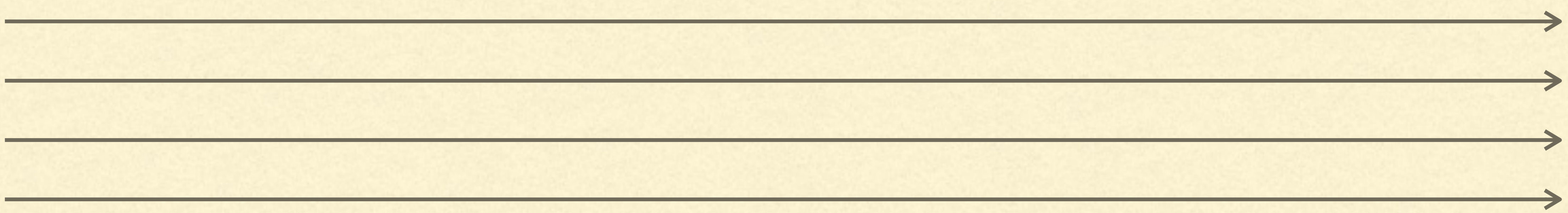


- These equations are only valid for weak currents,

$$m^2 \gg qE$$

- In the opposite limit, a different (**adiabiatic)** approximation works: Electric field discharges instantaneously,  gets replaced by radiation

$$\vec{E}$$



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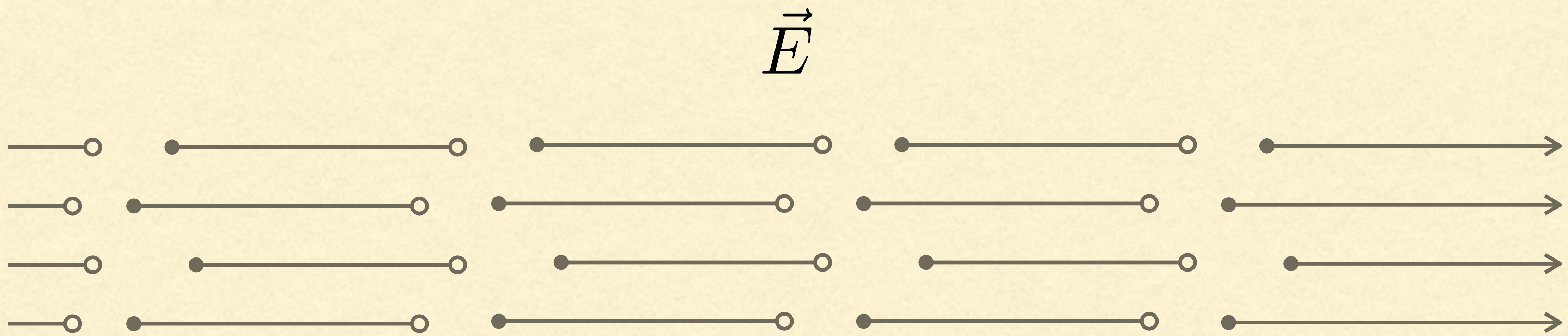

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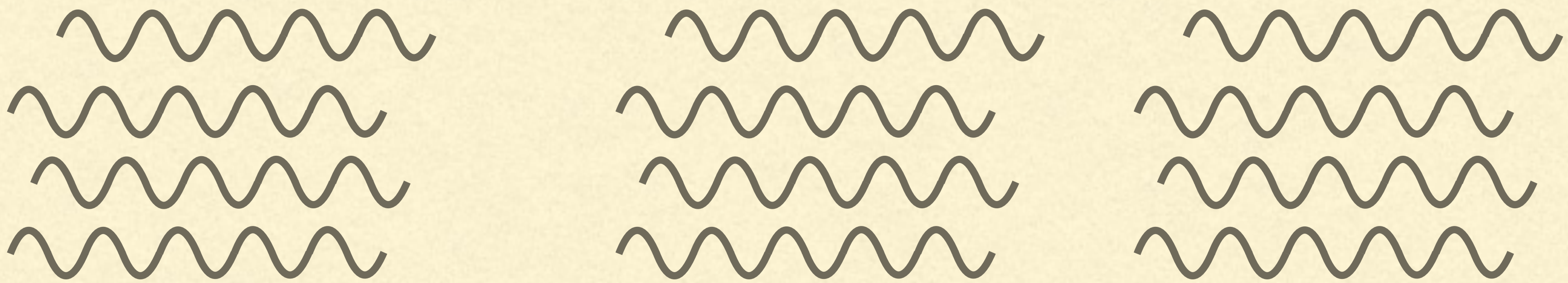

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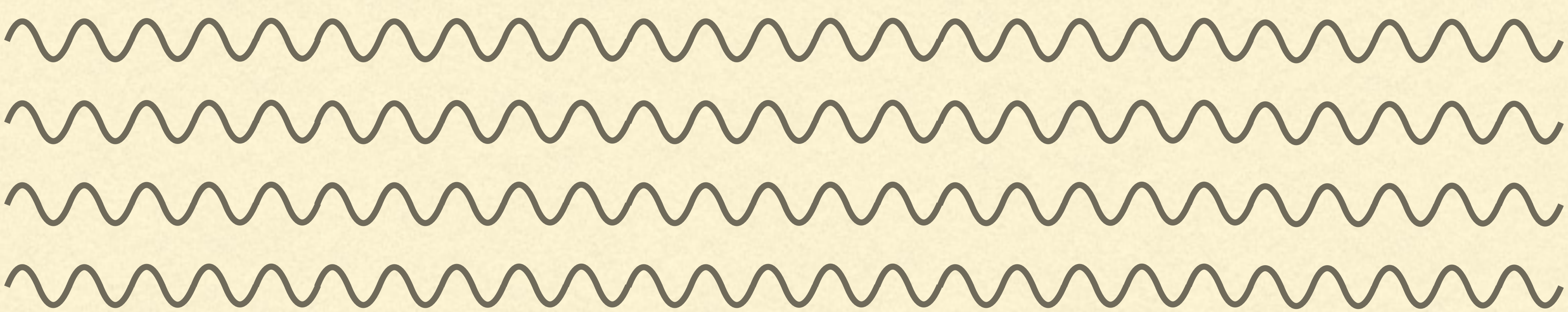

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- The 2d energy density is above the **critical value.**
- The whole spacetime collapses to a **Big Crunch.**

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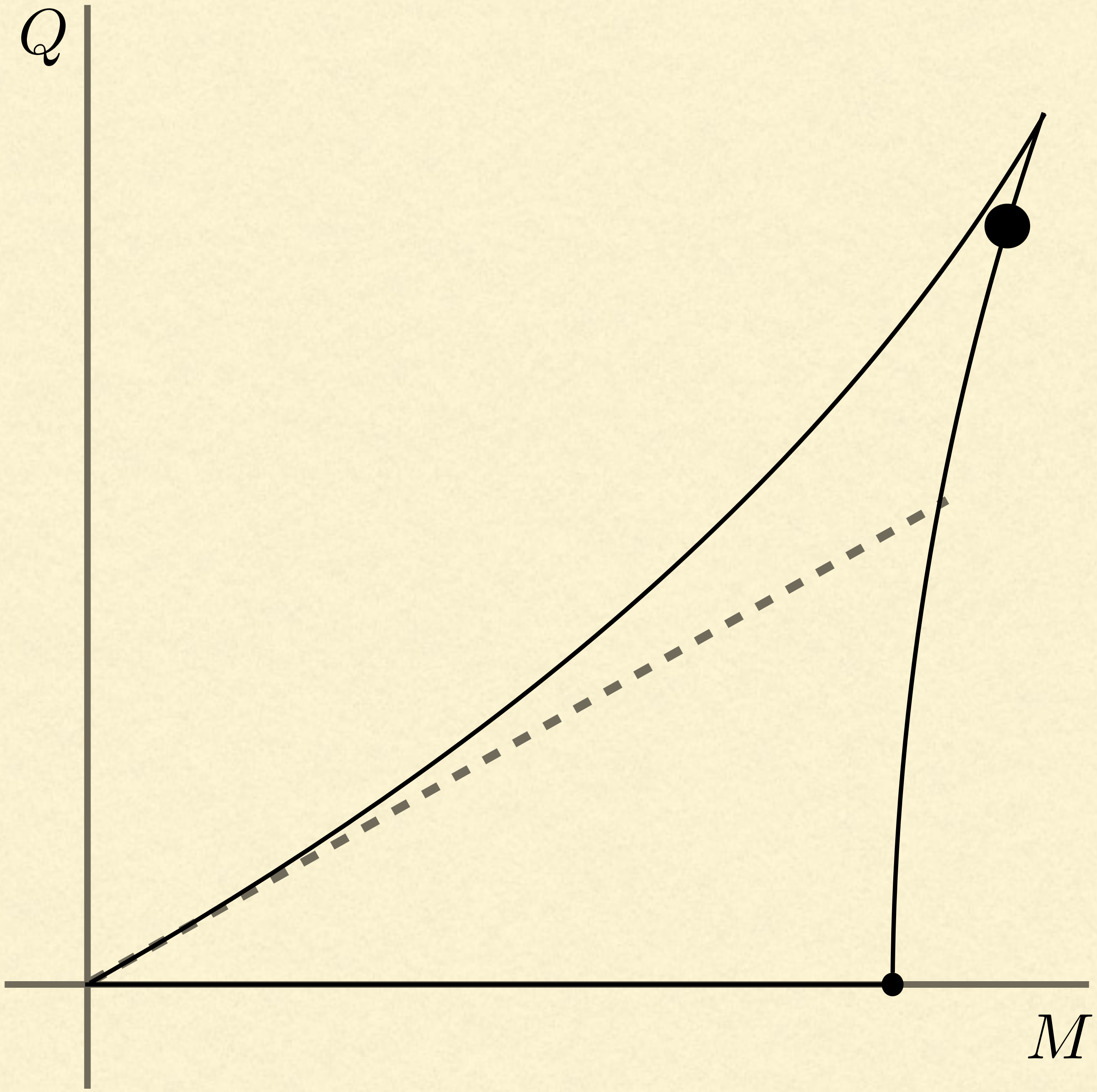

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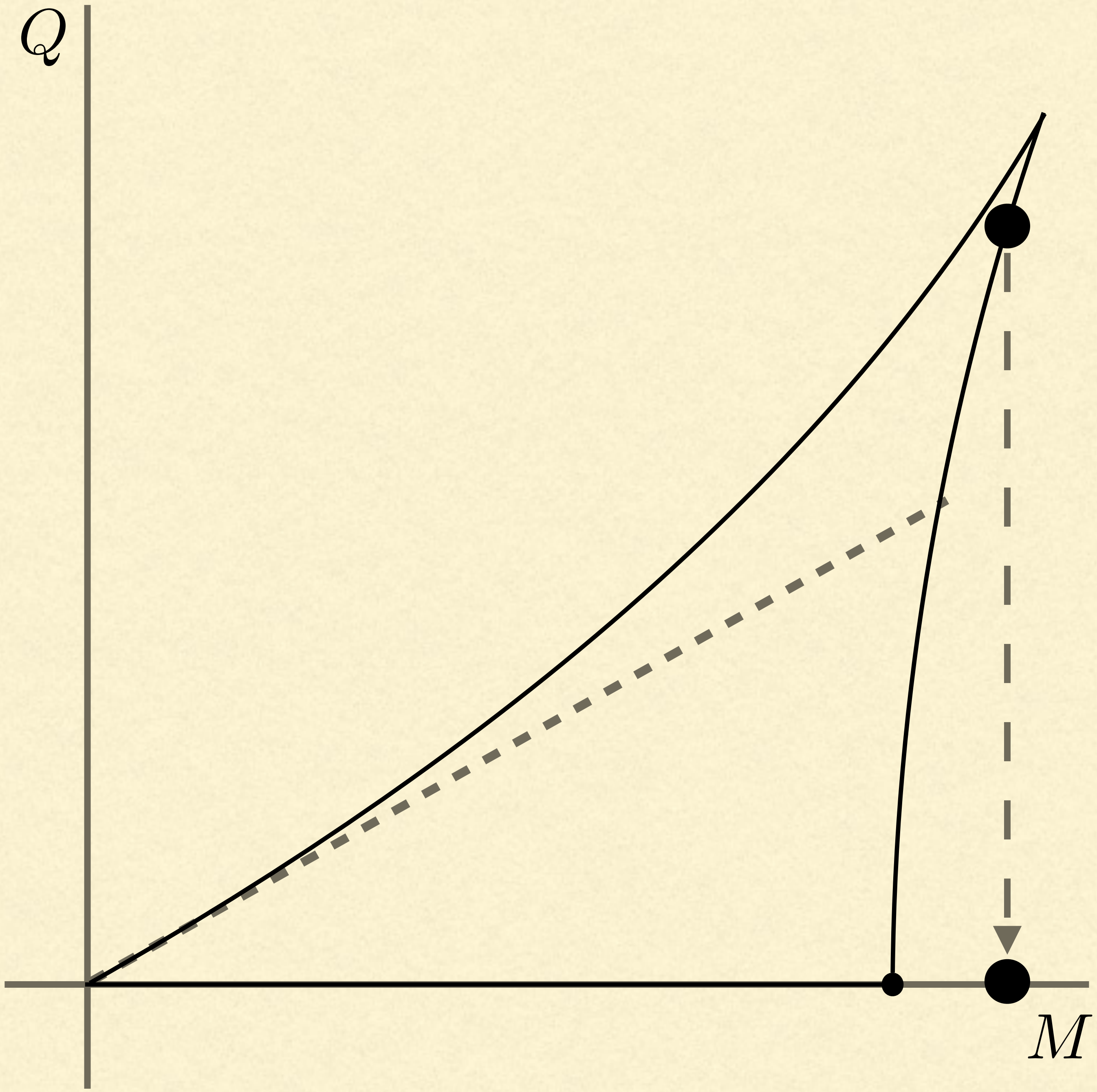

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## To recap:

- **Quasi-static** decay is OK with black hole sub-extremality and thermodynamic picture of dS
- **Adiabatic is not.**
- Perhaps the crunch magically thermalizes and goes back to dS.
- Perhaps one should not think about charged black holes in theories with very light charged particles.
- Perhaps the adiabatic regime is pathological, and avoiding it leads to a Swamp-like constraint.

Electric field on Nariai branch is $gM_PH$. If the crunch is pathological, we are forced to conclude that

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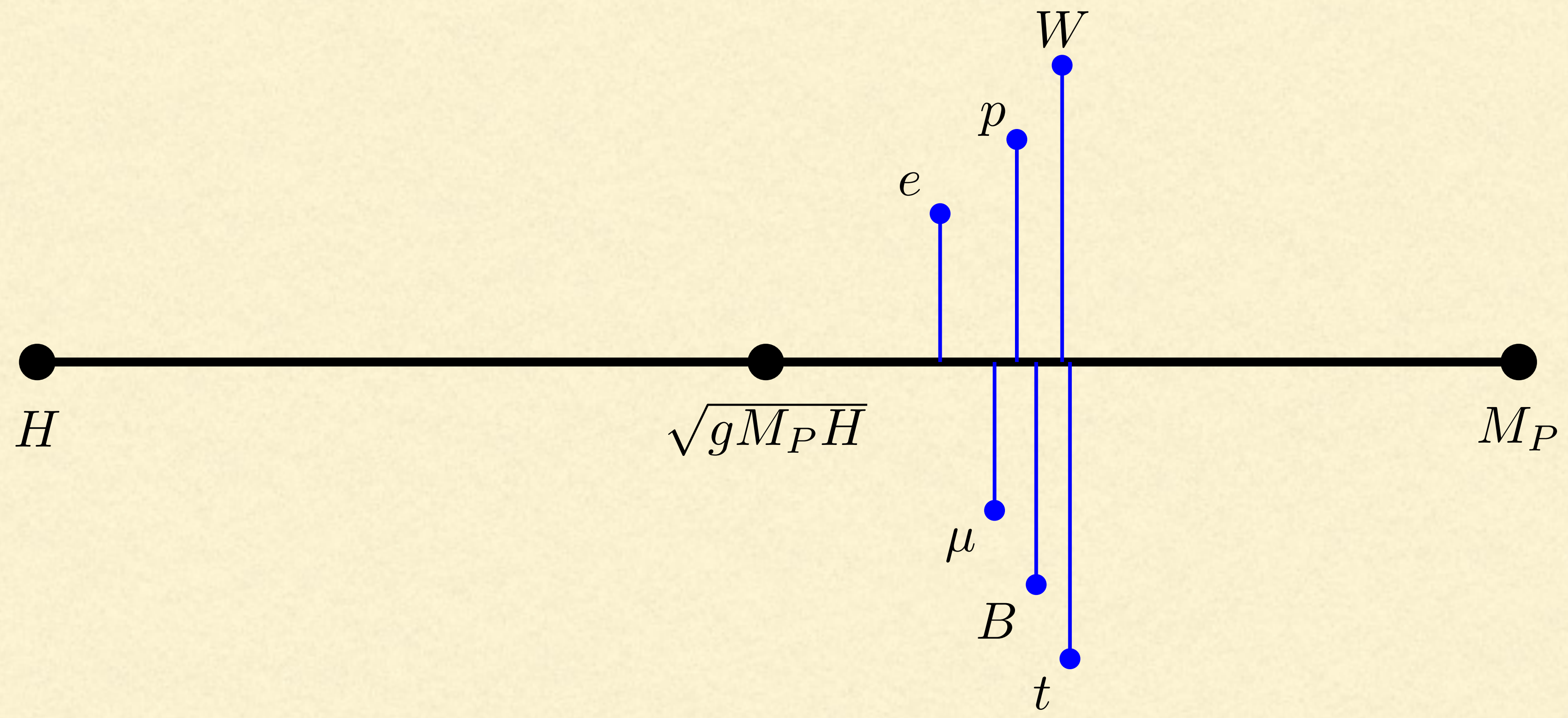
- **Flavor** of a Swampland constraint, but we cannot check against stringy examples
- Becomes trivial in flat-space limit.
- Black holes satisfy the bound
- Crunch is not avoided by slow-roll quintessence (so it applies to not-so-long-lived dS **[Dvali-Gomez-Zell'17,Obied-Ooguri-Spodyenko-Vafa'18, Bedroya-Vafa '19]**)

- Taking the U(1) to be electromagnetism, the constraint is satisfied by all charged fields in the SM.




- Since in SM masses are related to Higgs vev, it alleviates electroweak hierarchy problem **[See Isabel's talk]**:

$$y\, v \gtrsim g\rho_{\mathrm{vac.}}^{1/4}$$

- Constraints on mili-charged dark matter, but uninteresting
- Constrains inflationary models. Some ways out:
    - Small field inflation ($\rho^{1/4} \sim 10^9$ GeV)

      **[Similar bounds in Bedraya-Vafa ’19, Tom Banks’ talk]**

    - Higgs inflation with specific, flat potentials
    - Coupling of gauge fields to inflaton (very small nongaussianities)

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- For g small enough, we go **adiabatic** again.

# CONCLUSIONS

- Worked out the dynamics of evaporating RN-dS black holes
- Too fast evaporation of charged black holes leads to tension with thermal behavior of dS and superextremal-like crunches
- Avoiding this leads to a **constraint** on the EFT that is satisfied today and constrains inflation.
- It also leads to requiring **extremal BH's to be unstable (WGC).**

# Thank you!