Title: Black holes: To be or not be, that is the question

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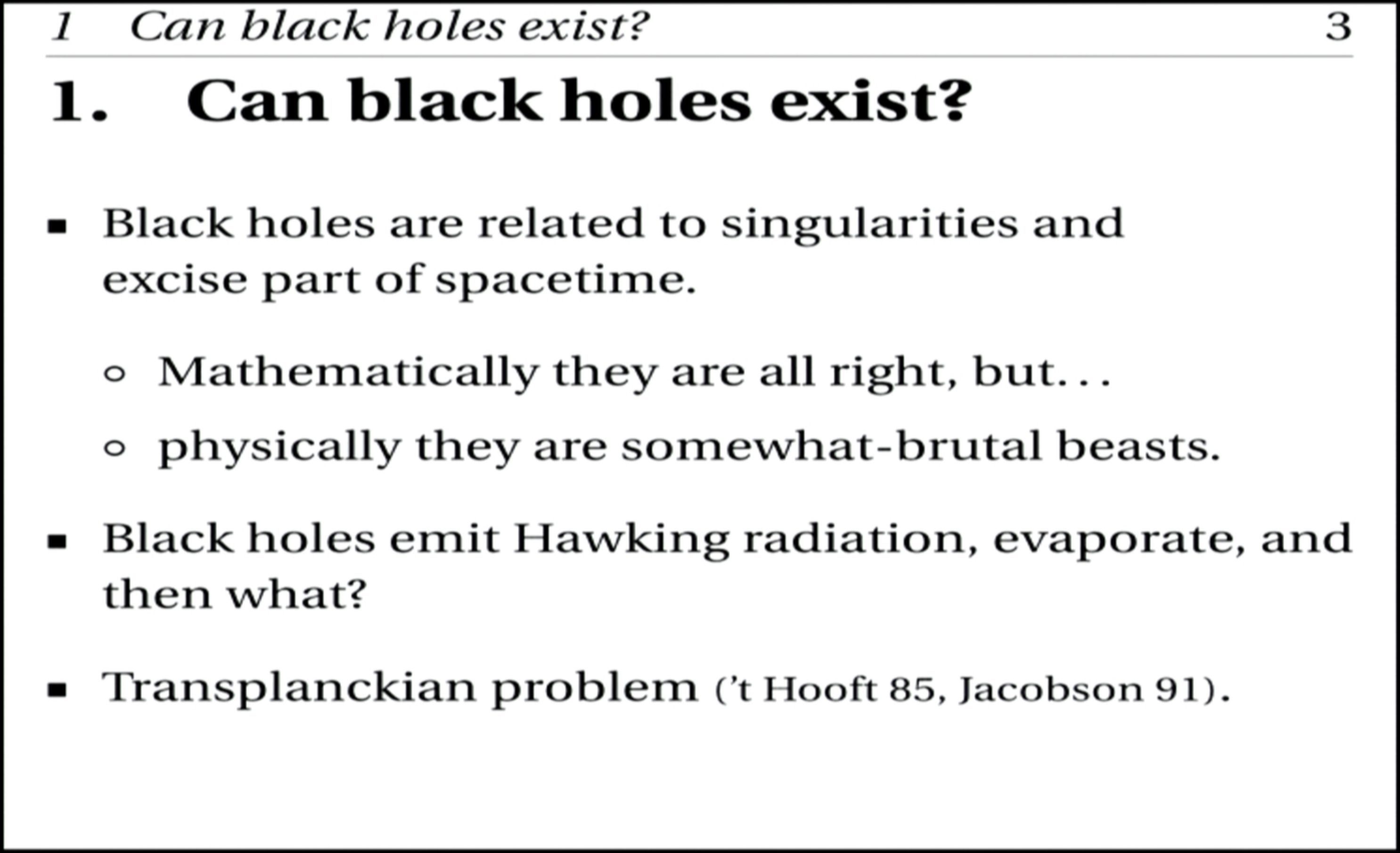
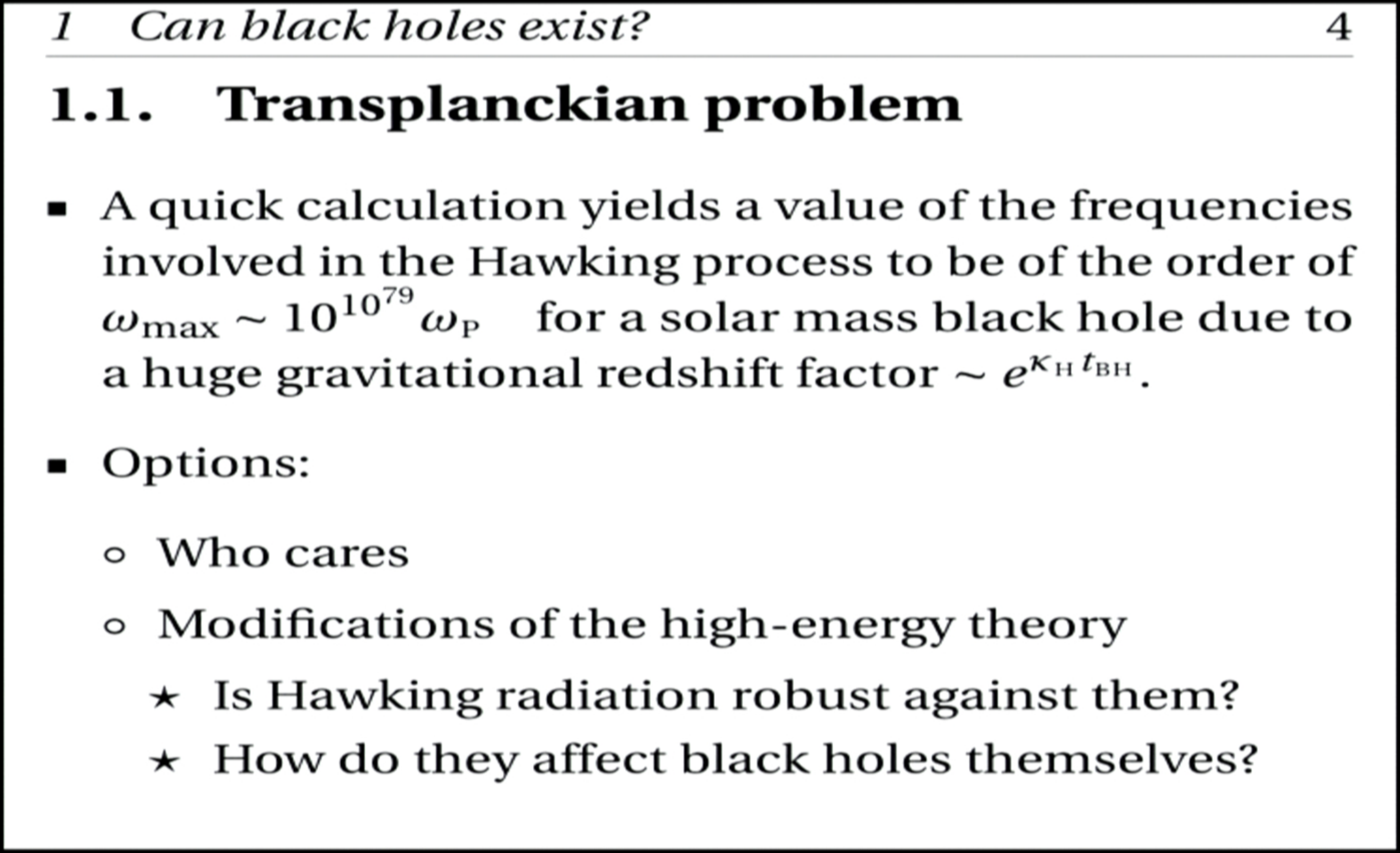
Abstract:



1. Can black holes exist?

- Black holes are related to singularities and excise part of spacetime.
  - Mathematically they are all right, but. . .
  - physically they are somewhat-brutal beasts.
- Black holes emit Hawking radiation, evaporate, and then what?
- Transplanckian problem ('t Hooft 85, Jacobson 91).



1.1. Transplanckian problem

- A quick calculation yields a value of the frequencies involved in the Hawking process to be of the order of $\omega_{\mathrm{max}} \sim 10^{10^{79}} \omega_{\mathrm{P}}$ for a solar mass black hole due to a huge gravitational redshift factor $\sim e^{\kappa_{\mathrm{H}} t_{\mathrm{BH}}}$.
- Options:
  - Who cares
  - Modifications of the high-energy theory
    - ⋆ Is Hawking radiation robust against them?
    - ⋆ How do they affect black holes themselves?

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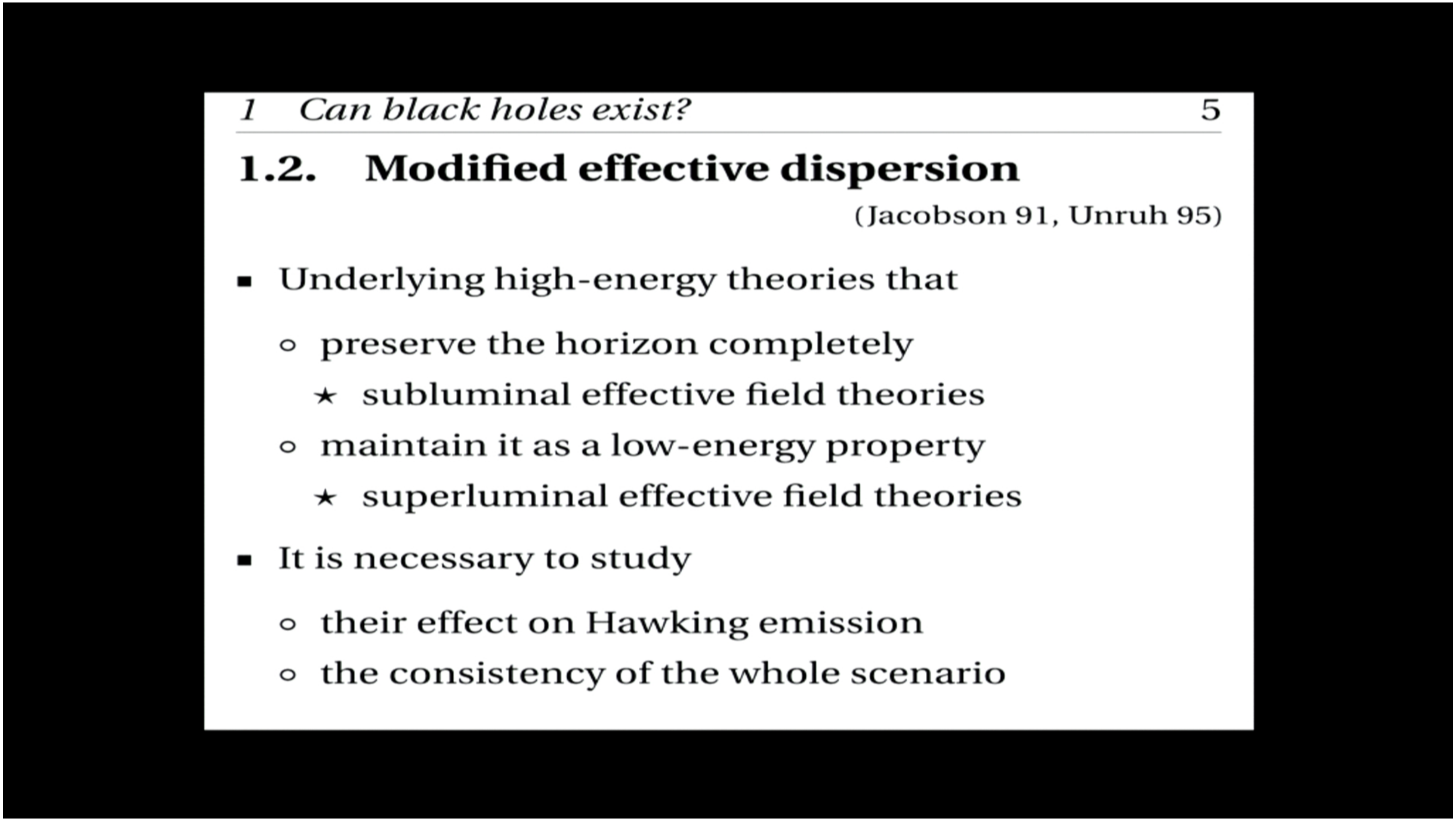
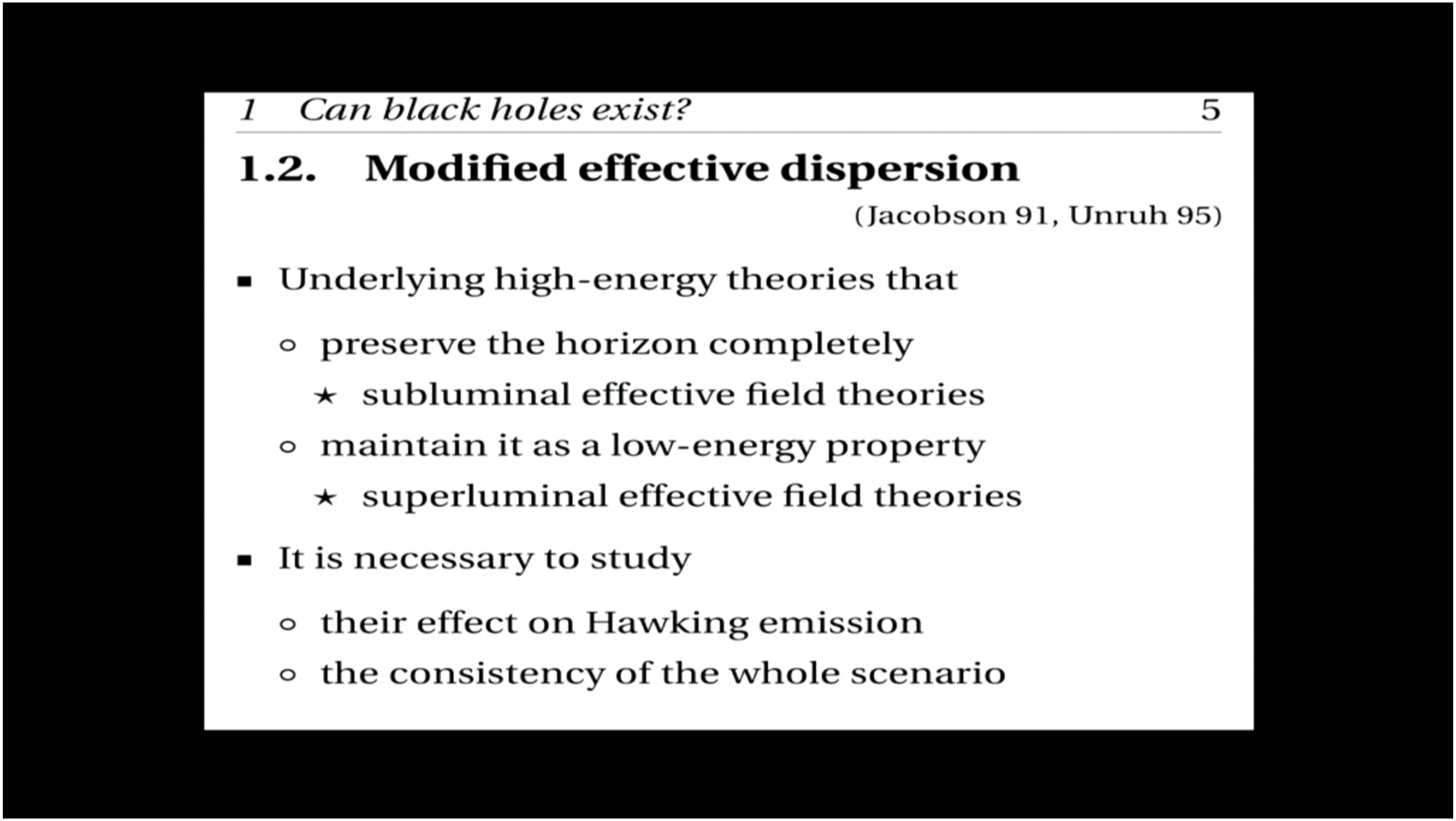


1.2. Modified effective dispersion

(Jacobson 91, Unruh 95)

- Underlying high-energy theories that
  - preserve the horizon completely
    - ⋆ subluminal effective field theories
  - maintain it as a low-energy property
    - ⋆ superluminal effective field theories
- It is necessary to study
  - their effect on Hawking emission
  - the consistency of the whole scenario



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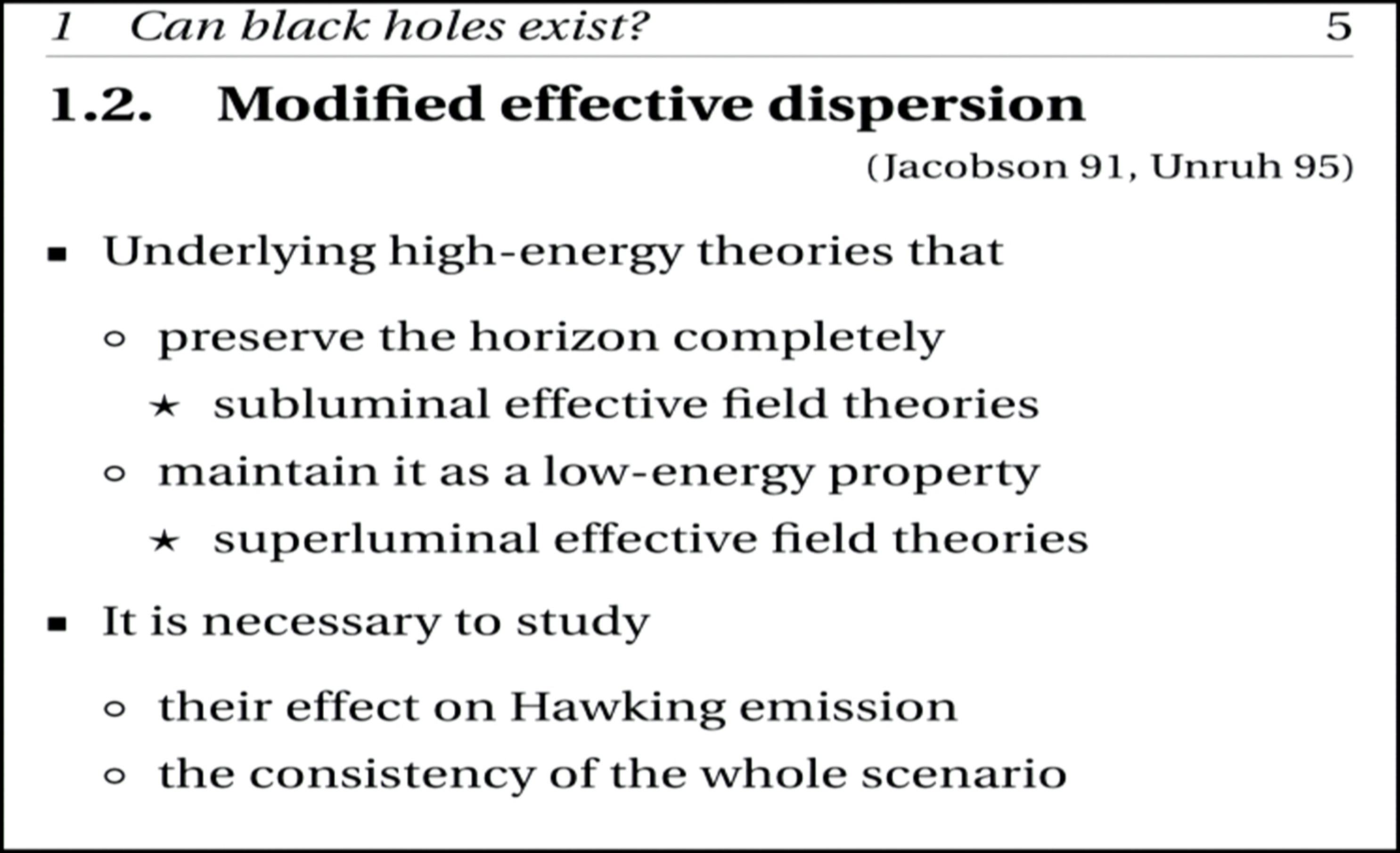

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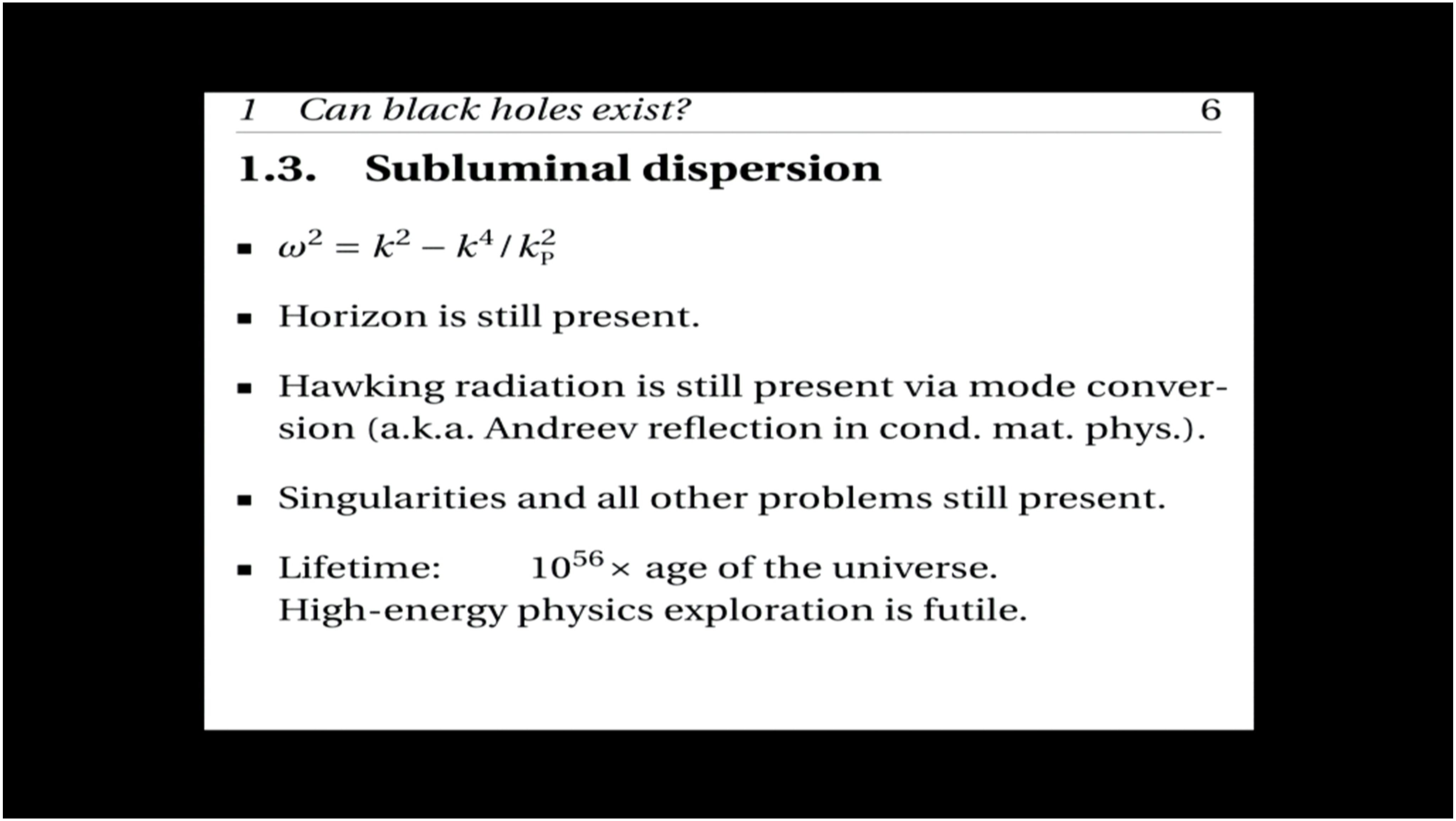
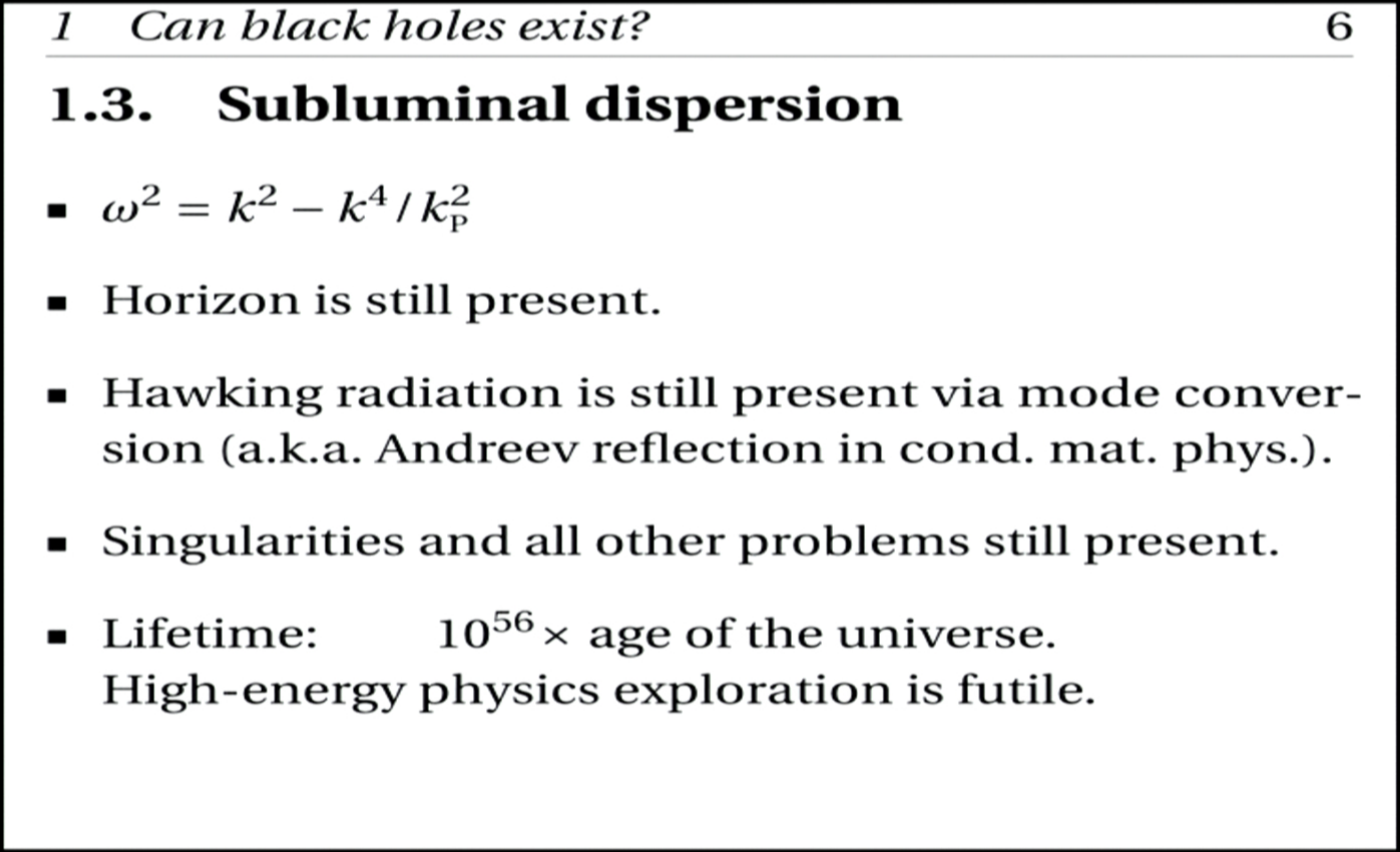


1.3. Subluminal dispersion

- $\omega^2 = k^2 - k^4 / k_\mathrm{p}^2$
- Horizon is still present.
- Hawking radiation is still present via mode conversion (a.k.a. Andreev reflection in cond. mat. phys.).
- Singularities and all other problems still present.
- Lifetime: $10^{56} \times$ age of the universe.
  High-energy physics exploration is futile.



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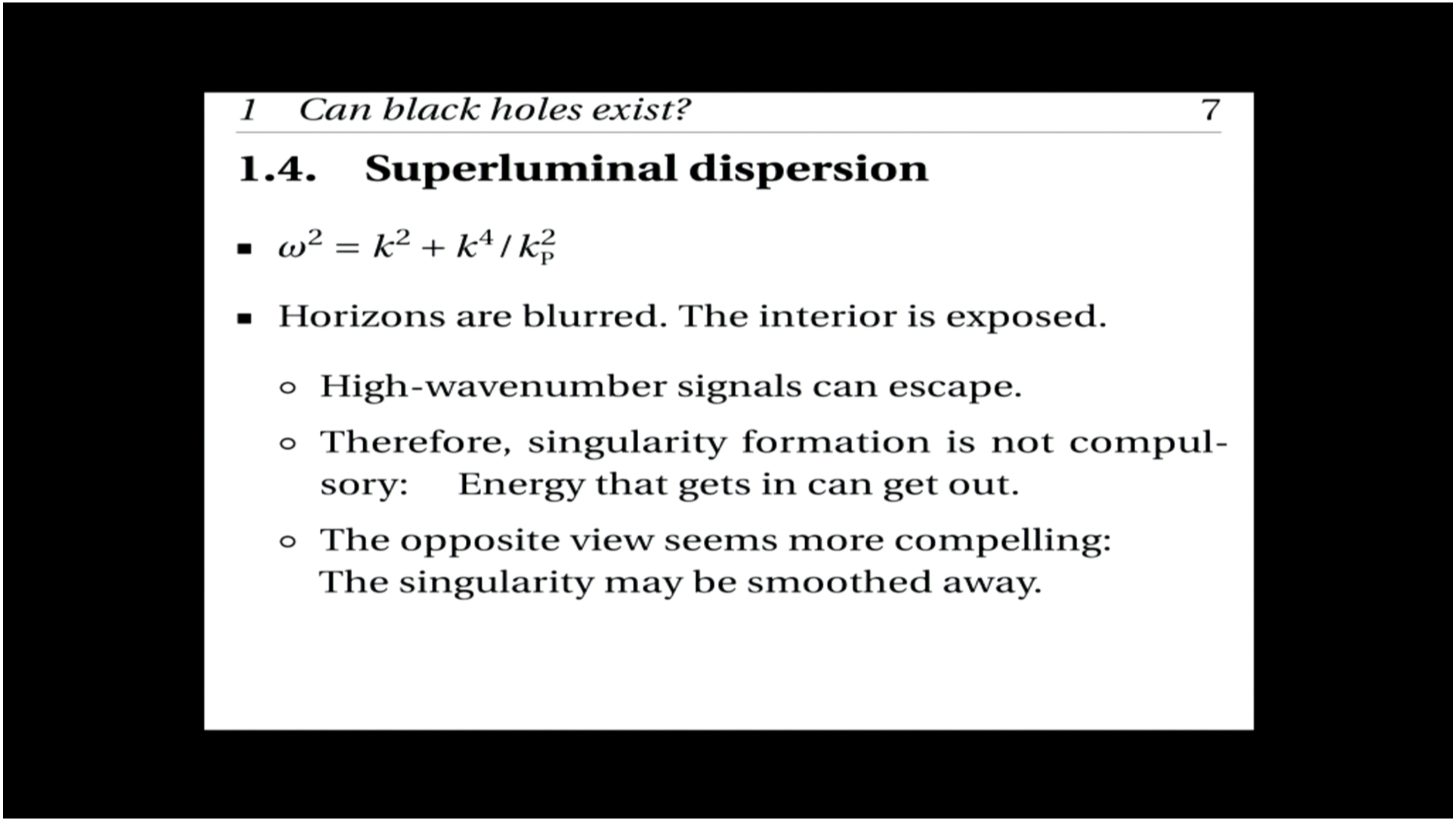
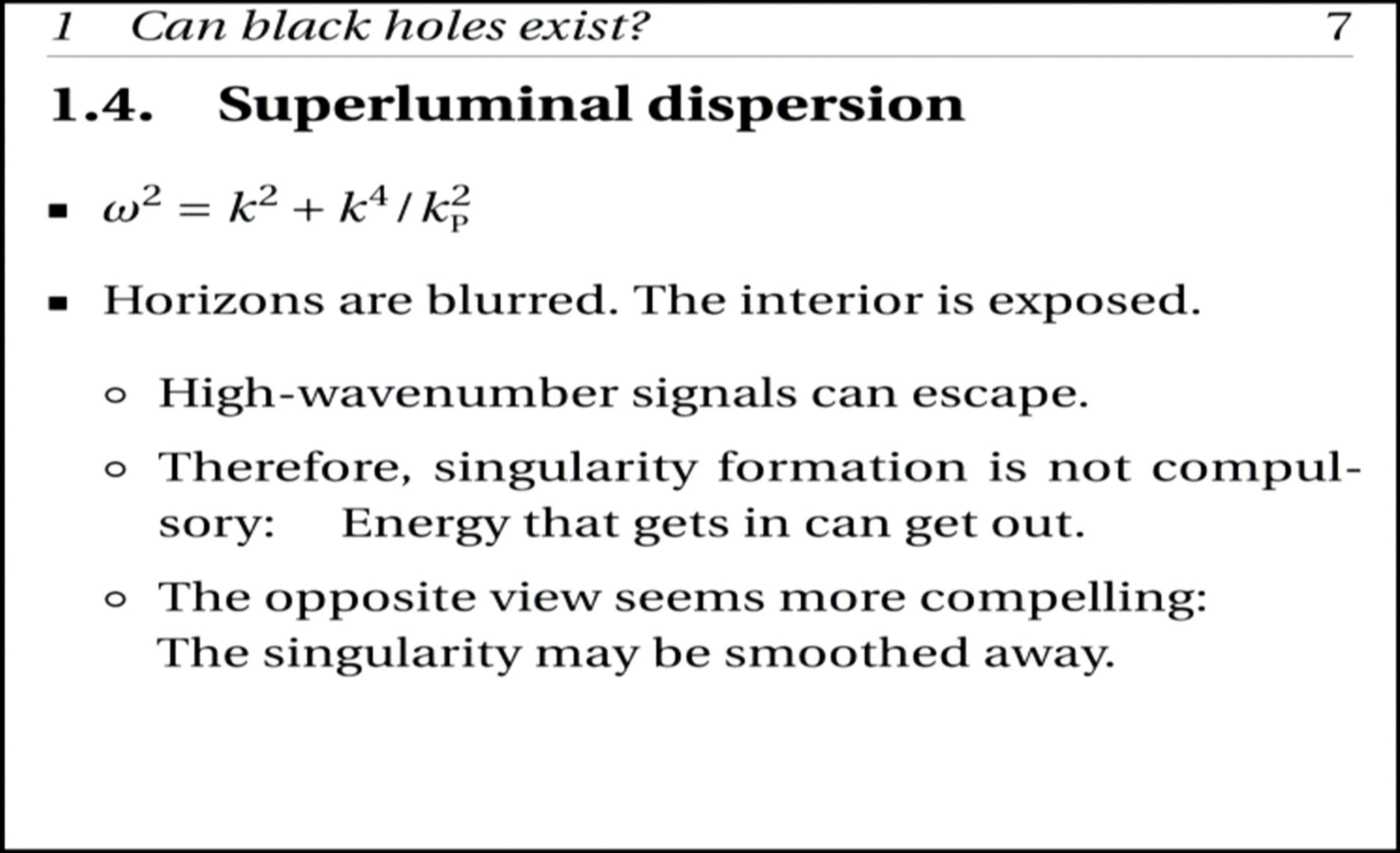


1.4. Superluminal dispersion

- $\omega^2 = k^2 + k^4 / k_\mathrm{p}^2$
- Horizons are blurred. The interior is exposed.
  - High-wavenumber signals can escape.
  - Therefore, singularity formation is not compulsory: Energy that gets in can get out.
  - The opposite view seems more compelling: The singularity may be smoothed away.



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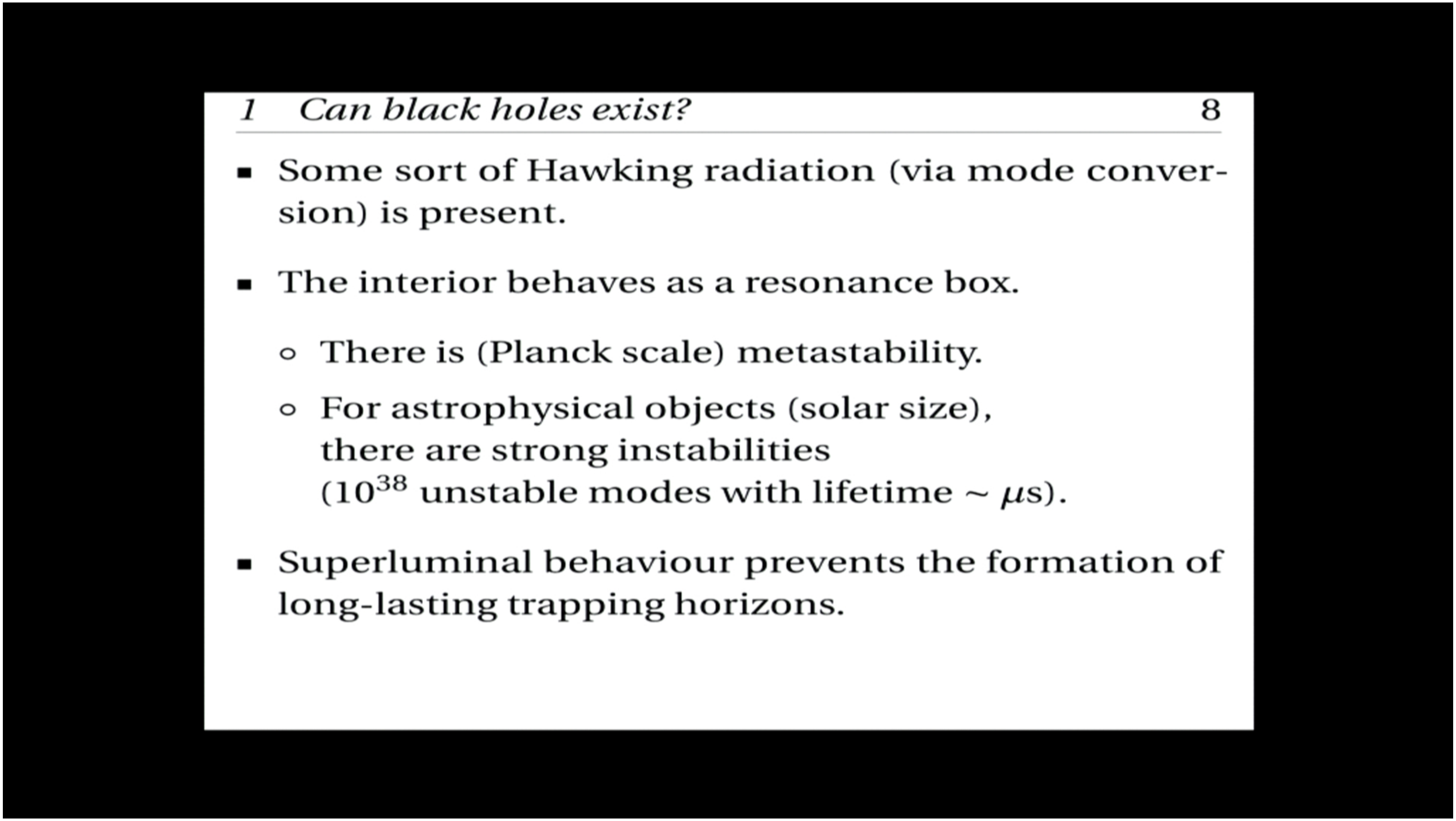
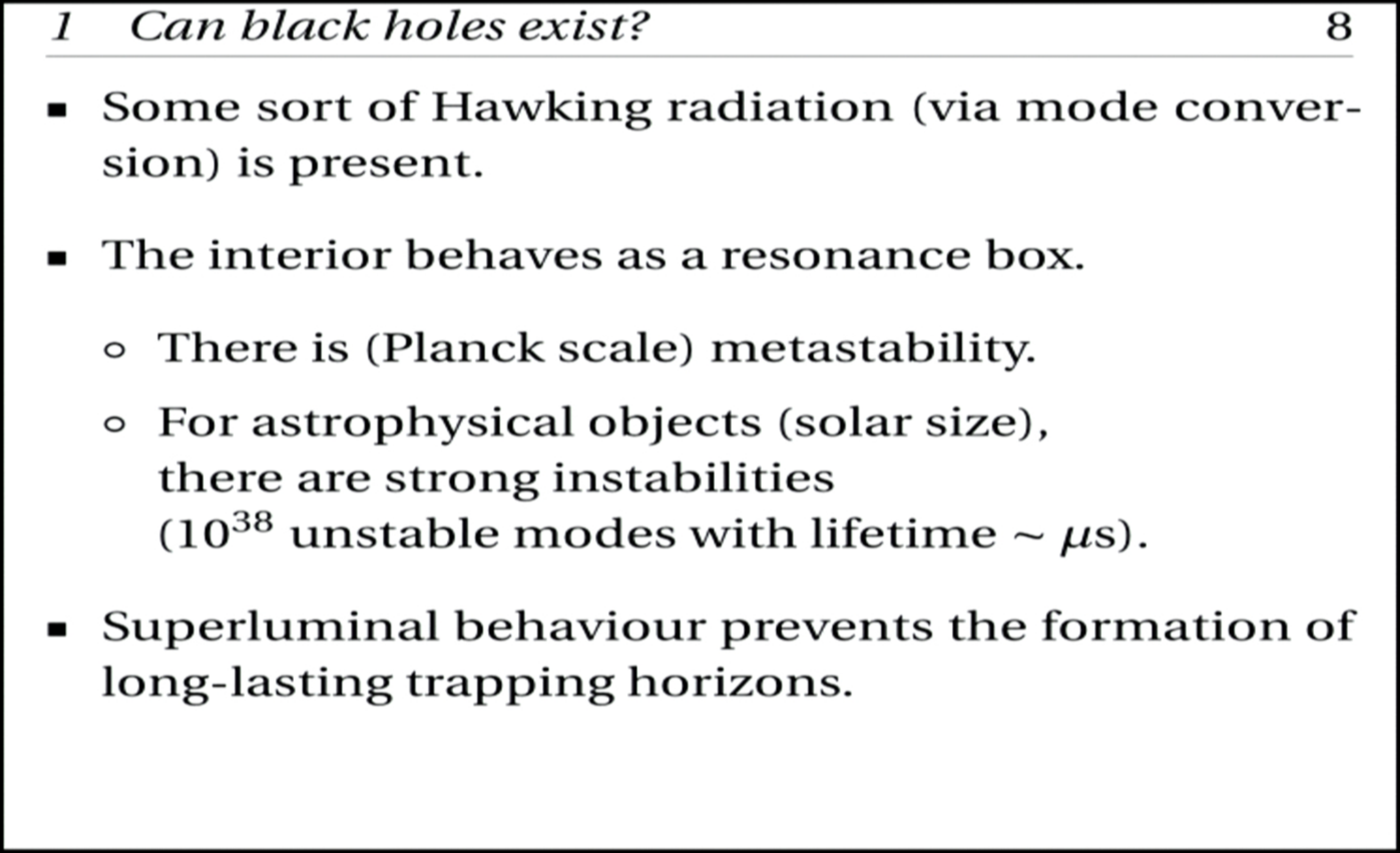


1 Can black holes exist?

- Some sort of Hawking radiation (via mode conversion) is present.
- The interior behaves as a resonance box.
    - There is (Planck scale) metastability.
    - For astrophysical objects (solar size), there are strong instabilities (10^{38} unstable modes with lifetime $\sim \mu$s).
- Superluminal behaviour prevents the formation of long-lasting trapping horizons.



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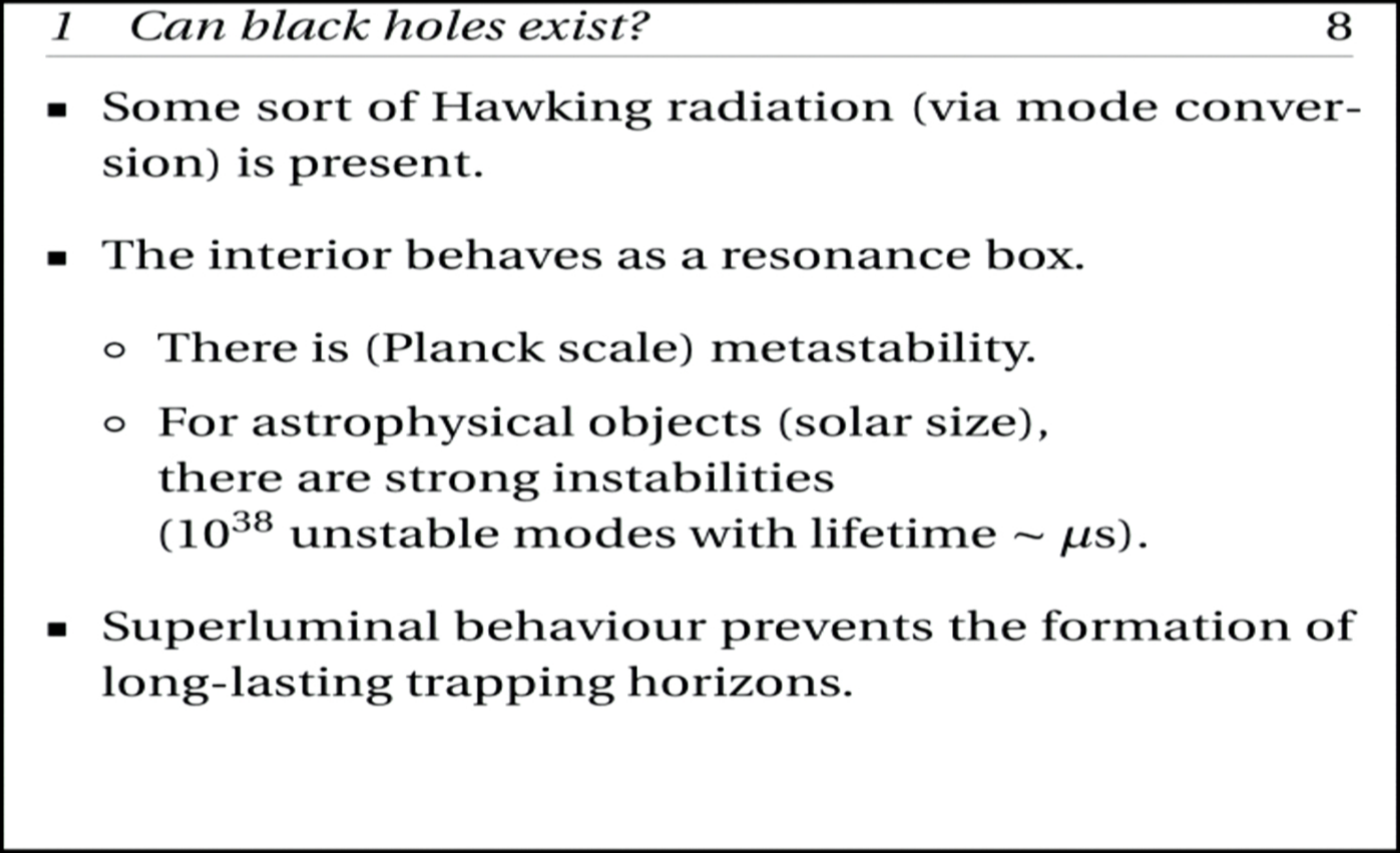

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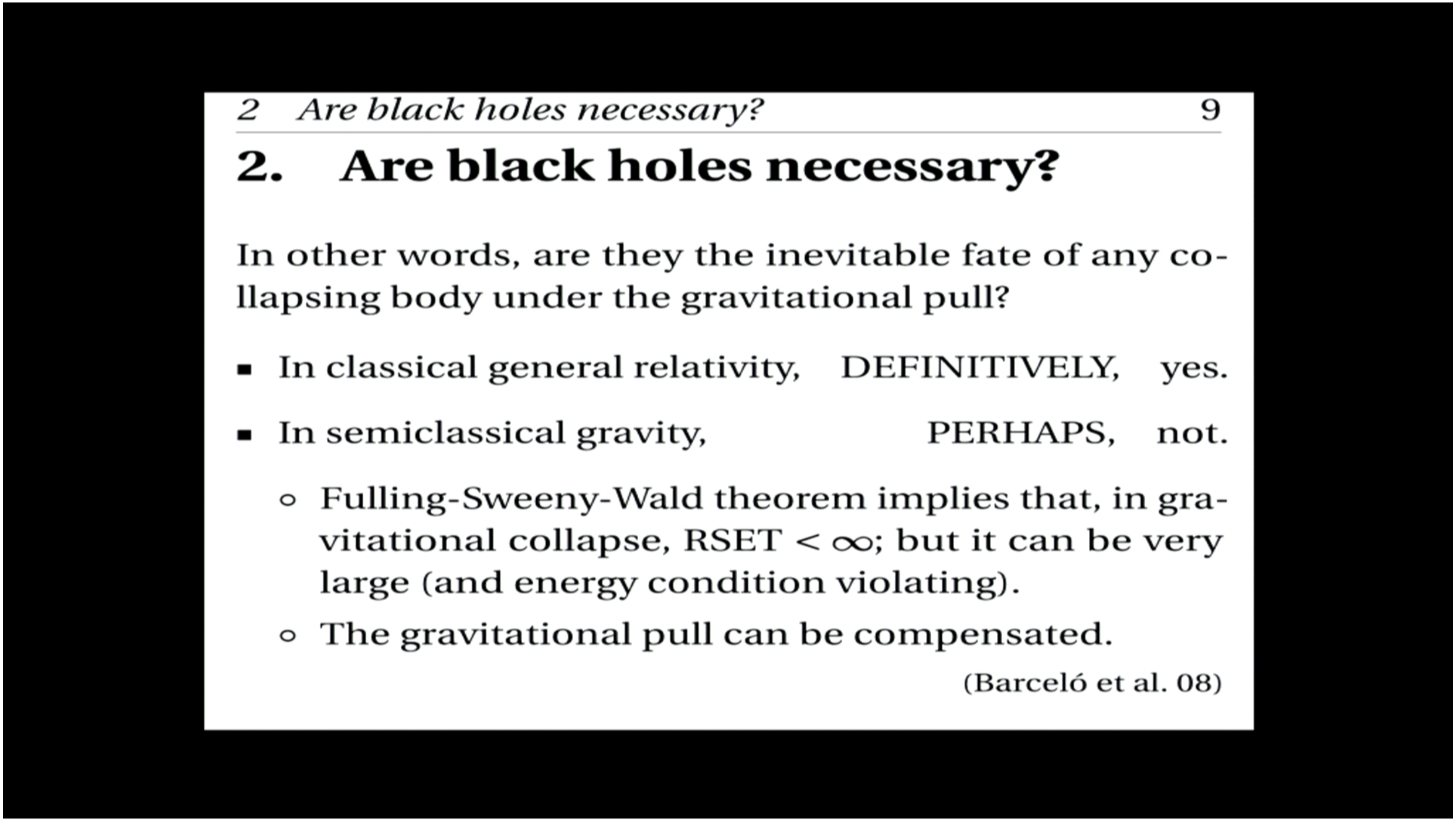
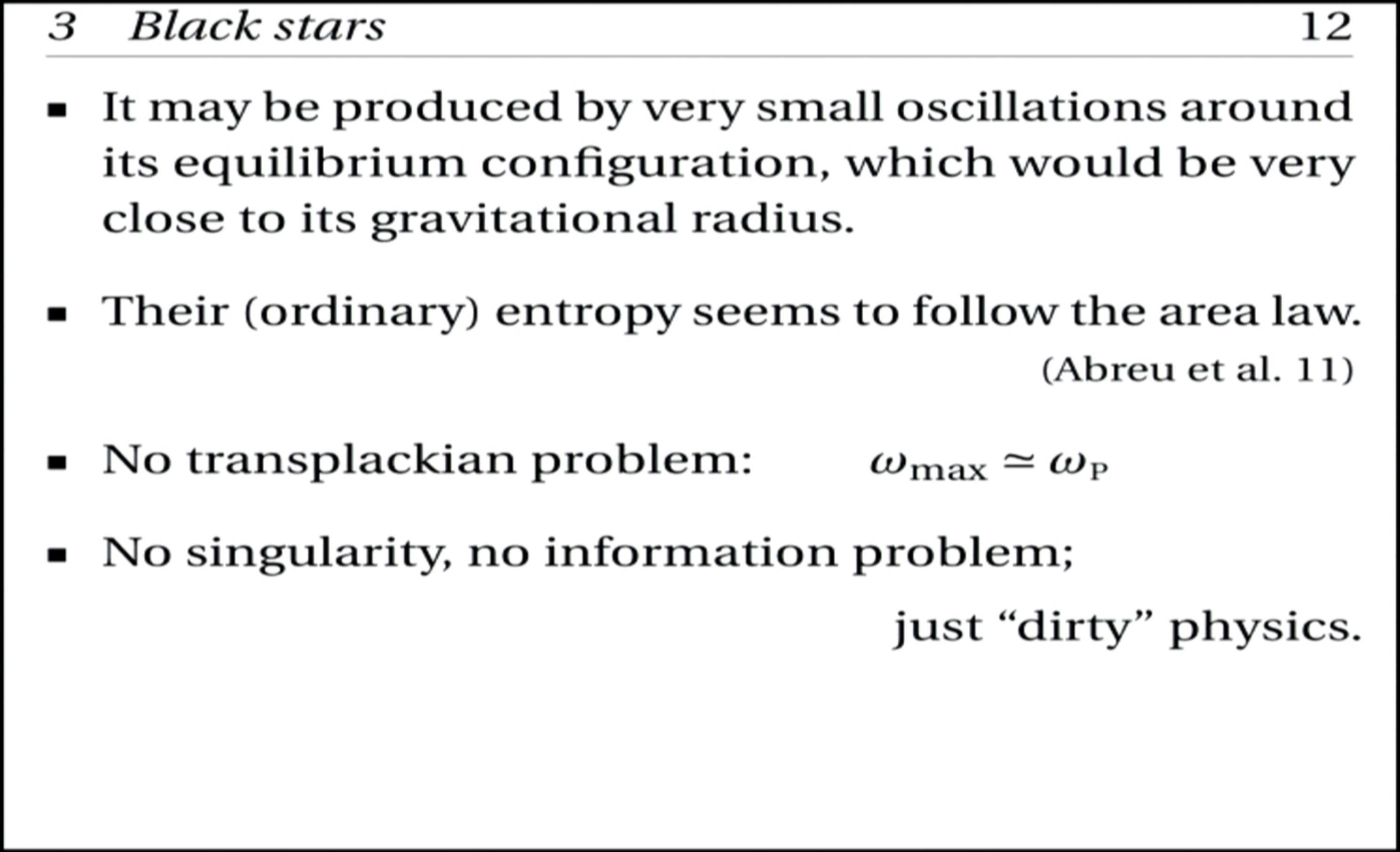


2. Are black holes necessary?

In other words, are they the inevitable fate of any collapsing body under the gravitational pull?

- In classical general relativity, DEFINITIVELY, yes.
- In semiclassical gravity, PERHAPS, not.
  - Fulling-Sweeny-Wald theorem implies that, in gravitational collapse, RSET $< \infty$; but it can be very large (and energy condition violating).
  - The gravitational pull can be compensated.

(Barceló et al. 08)



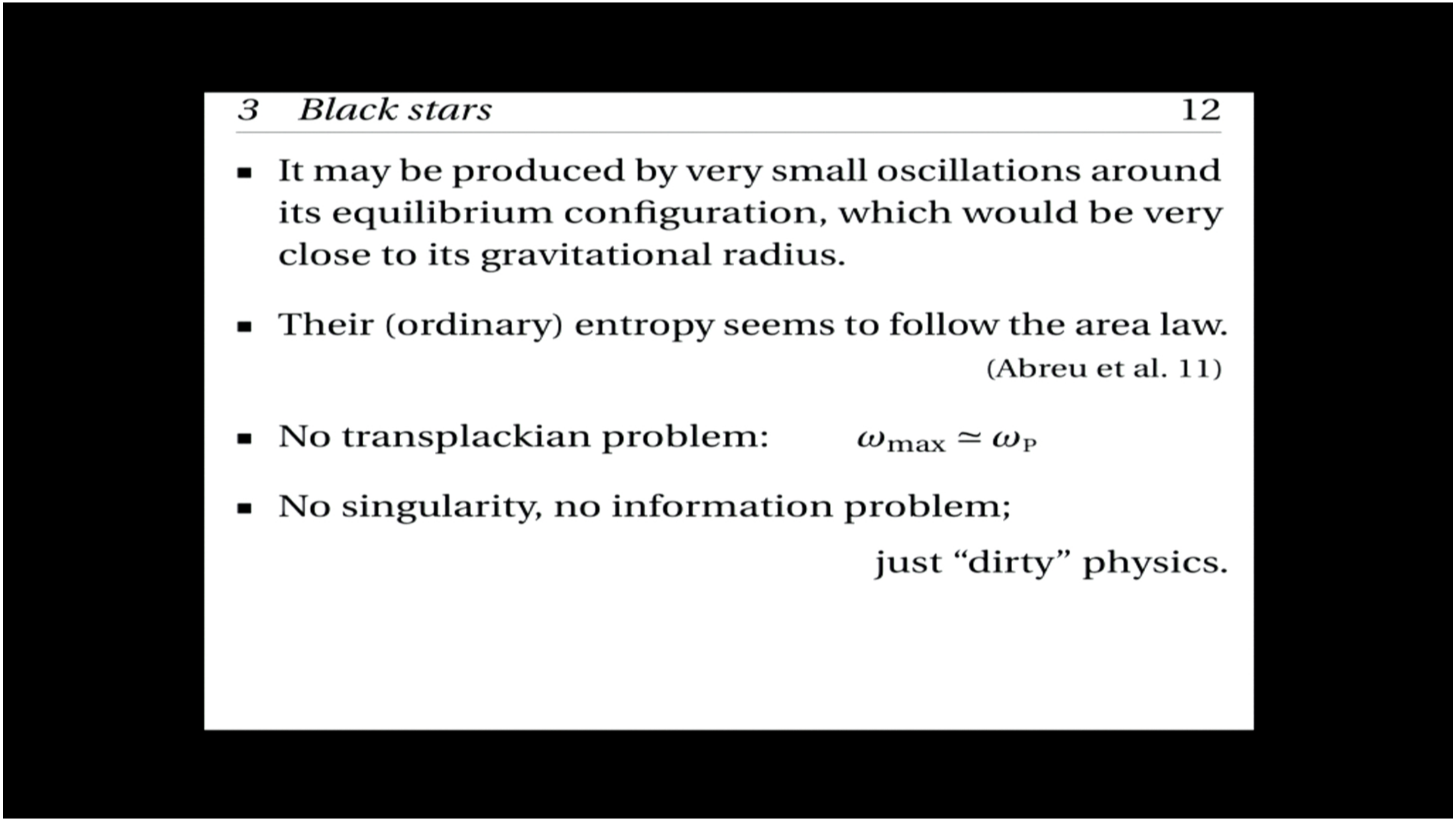
3 *Black stars*

- It may be produced by very small oscillations around its equilibrium configuration, which would be very close to its gravitational radius.
- Their (ordinary) entropy seems to follow the area law.

(Abreu et al. 11)

- No transplackian problem: $\omega_{\mathrm{max}} \simeq \omega_{\mathrm{P}}$
- No singularity, no information problem;

just “dirty” physics.



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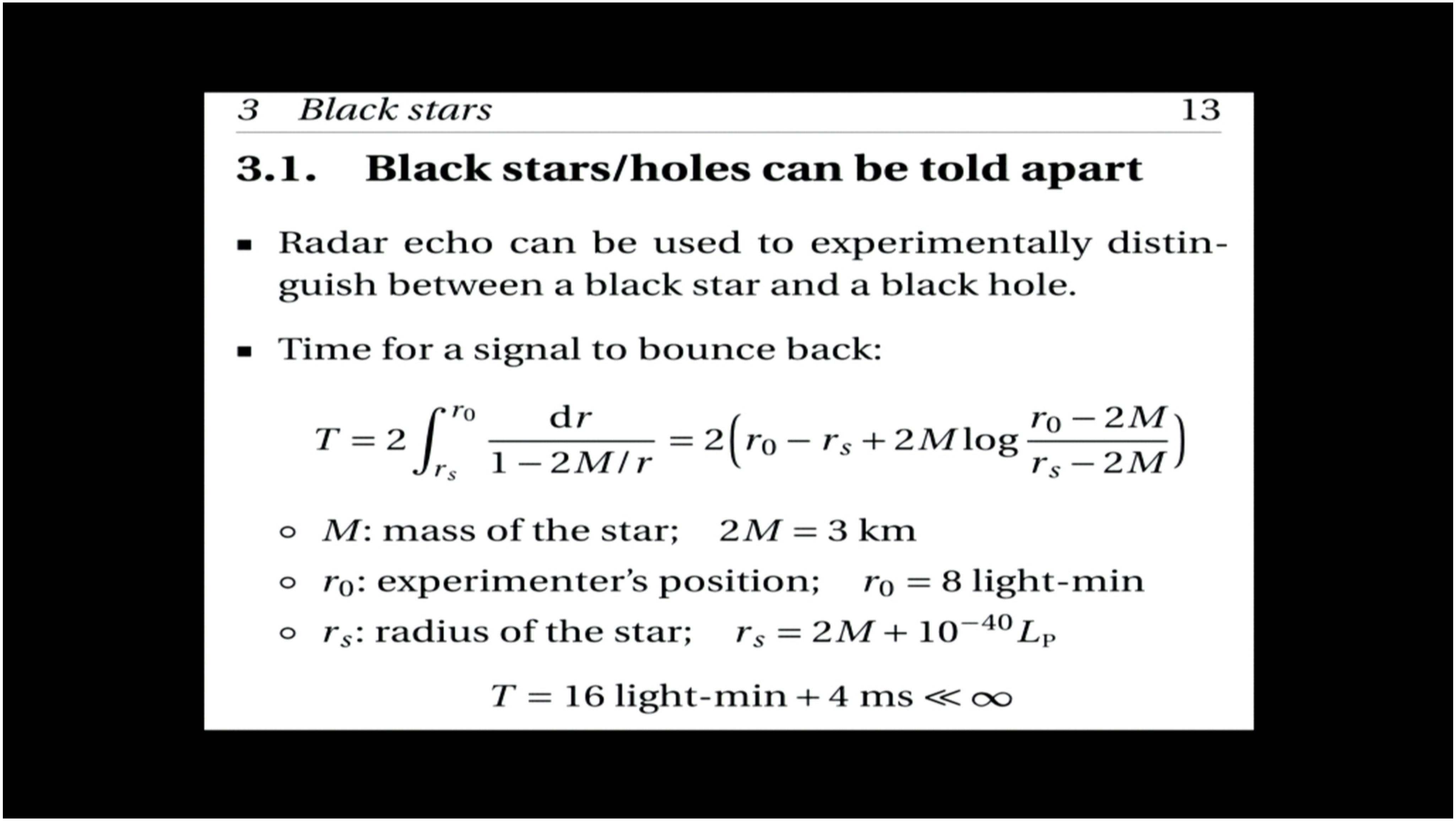


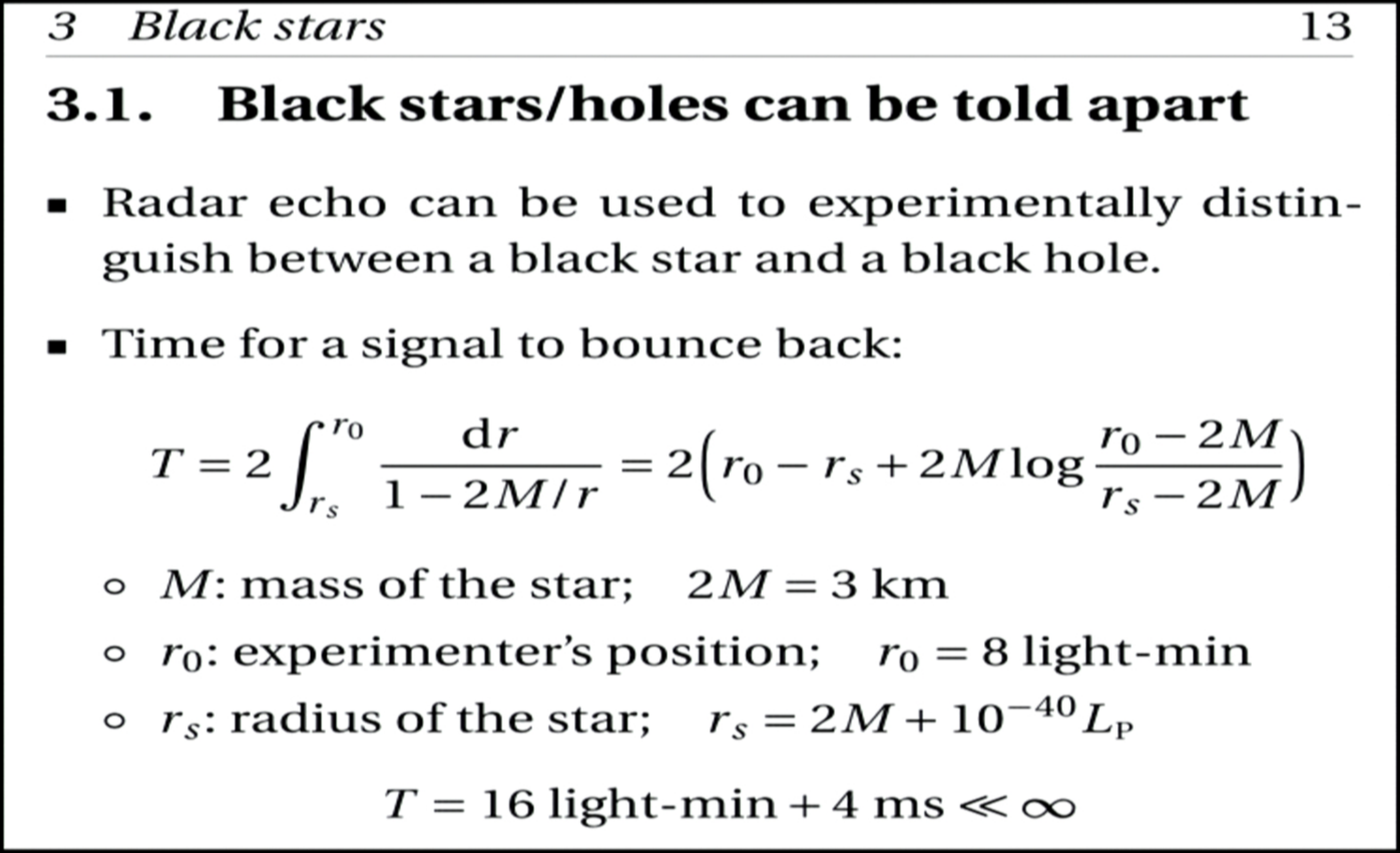
3.1. Black stars/holes can be told apart

- Radar echo can be used to experimentally distinguish between a black star and a black hole.
- Time for a signal to bounce back:

$$T = 2\int_{r_s}^{r_0} \frac{\mathrm{d}r}{1-2M/r} = 2\Big(r_0 - r_s + 2M\log\frac{r_0-2M}{r_s-2M}\Big)$$

  - M: mass of the star; $2M = 3\ \text{km}$
  - r_0: experimenter's position; $r_0 = 8$ light-min
  - r_s: radius of the star; $r_s = 2M + 10^{-40}L_\text{P}$

$$T = 16\ \text{light-min} + 4\ \text{ms} \ll \infty$$



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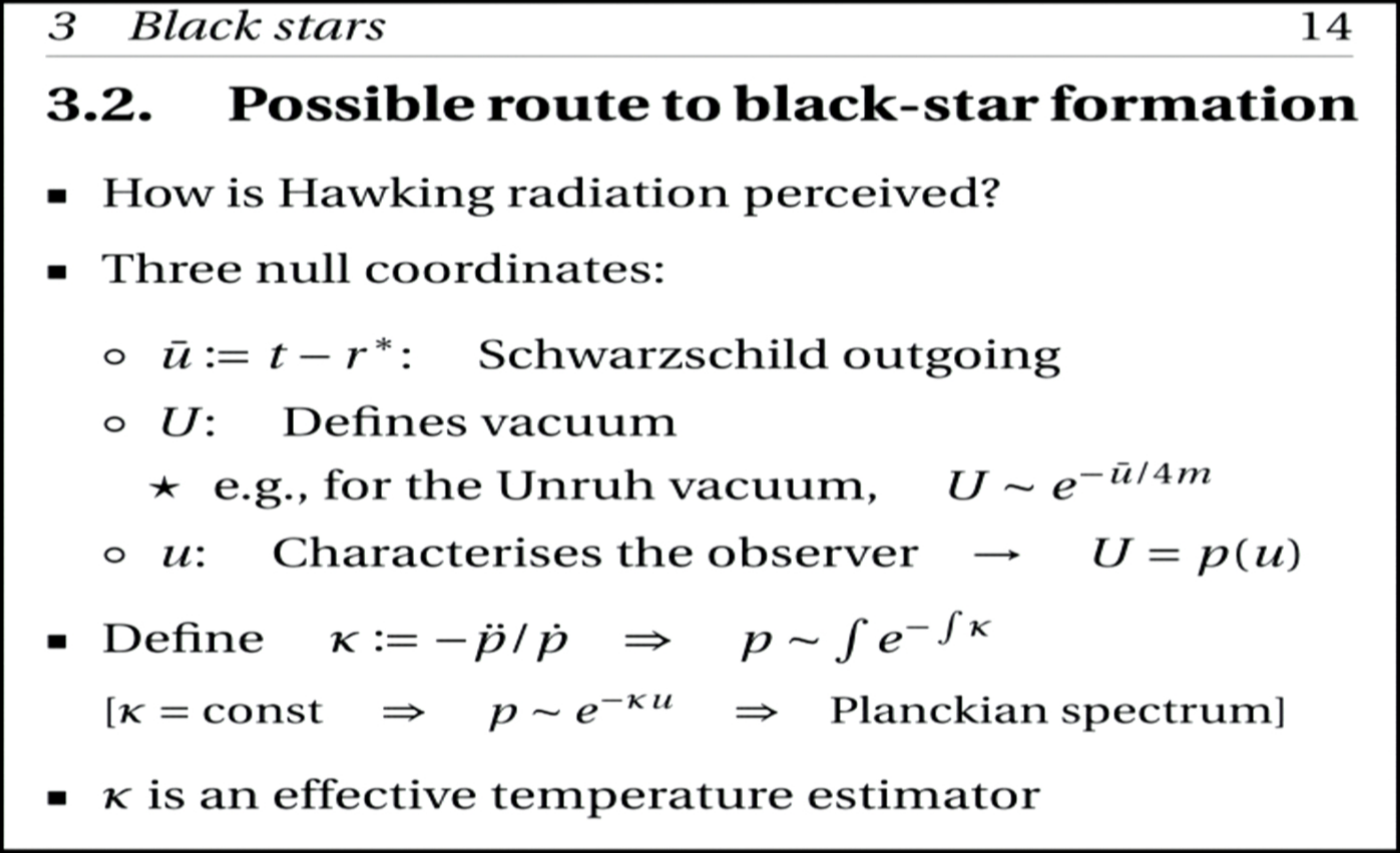
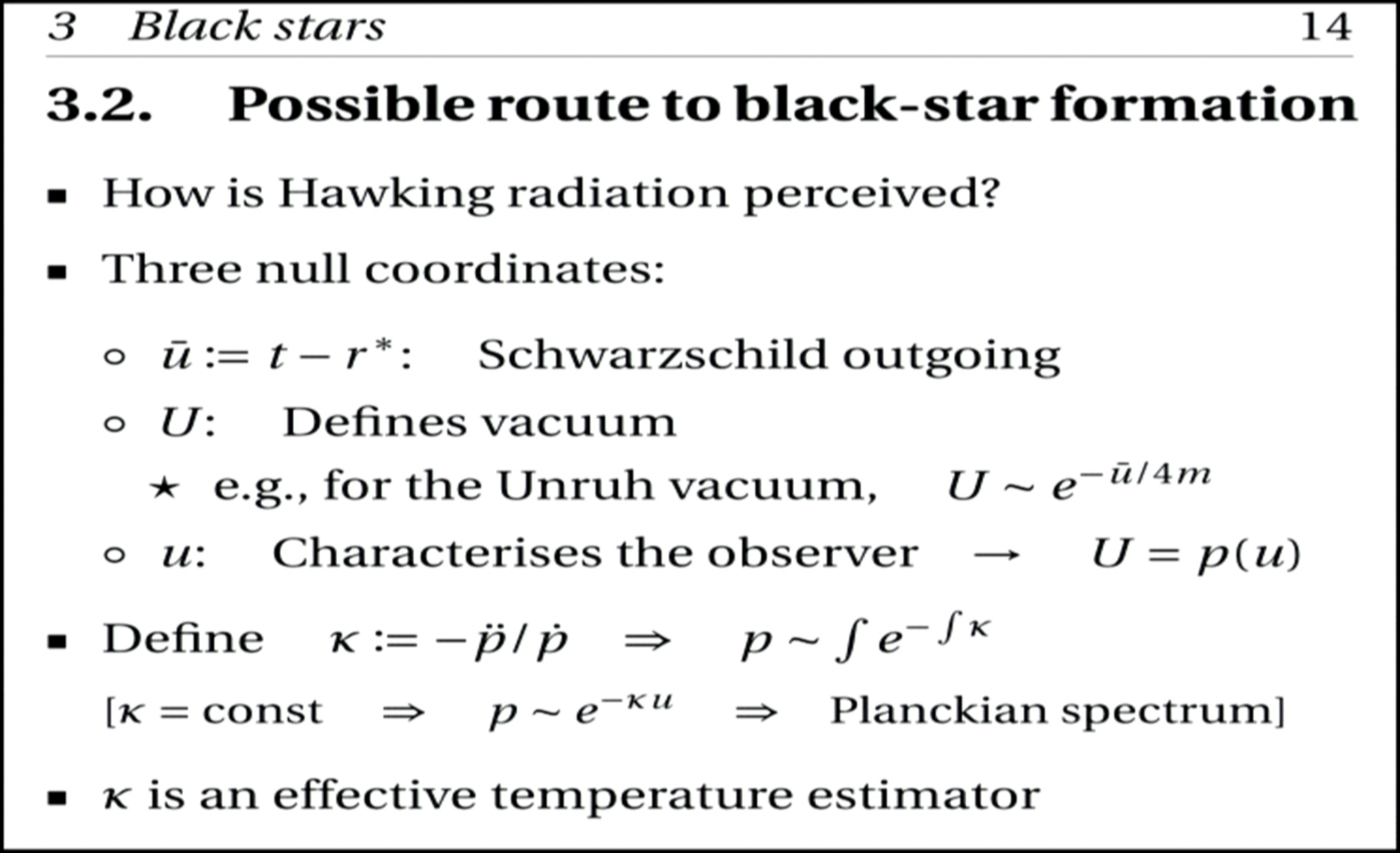


3.2. Possible route to black-star formation

- How is Hawking radiation perceived?
- Three null coordinates:
  - $\bar{u} := t - r^*$: Schwarzschild outgoing
  - U: Defines vacuum
    - ⋆ e.g., for the Unruh vacuum, $U \sim e^{-\bar{u}/4m}$
  - u: Characterises the observer → $U = p(u)$
- Define $\kappa := -\ddot{p}/\dot{p} \quad \Rightarrow \quad p \sim \int e^{-\int \kappa}$

  [$\kappa = \text{const} \quad \Rightarrow \quad p \sim e^{-\kappa u} \quad \Rightarrow$ Planckian spectrum]
- κ is an effective temperature estimator



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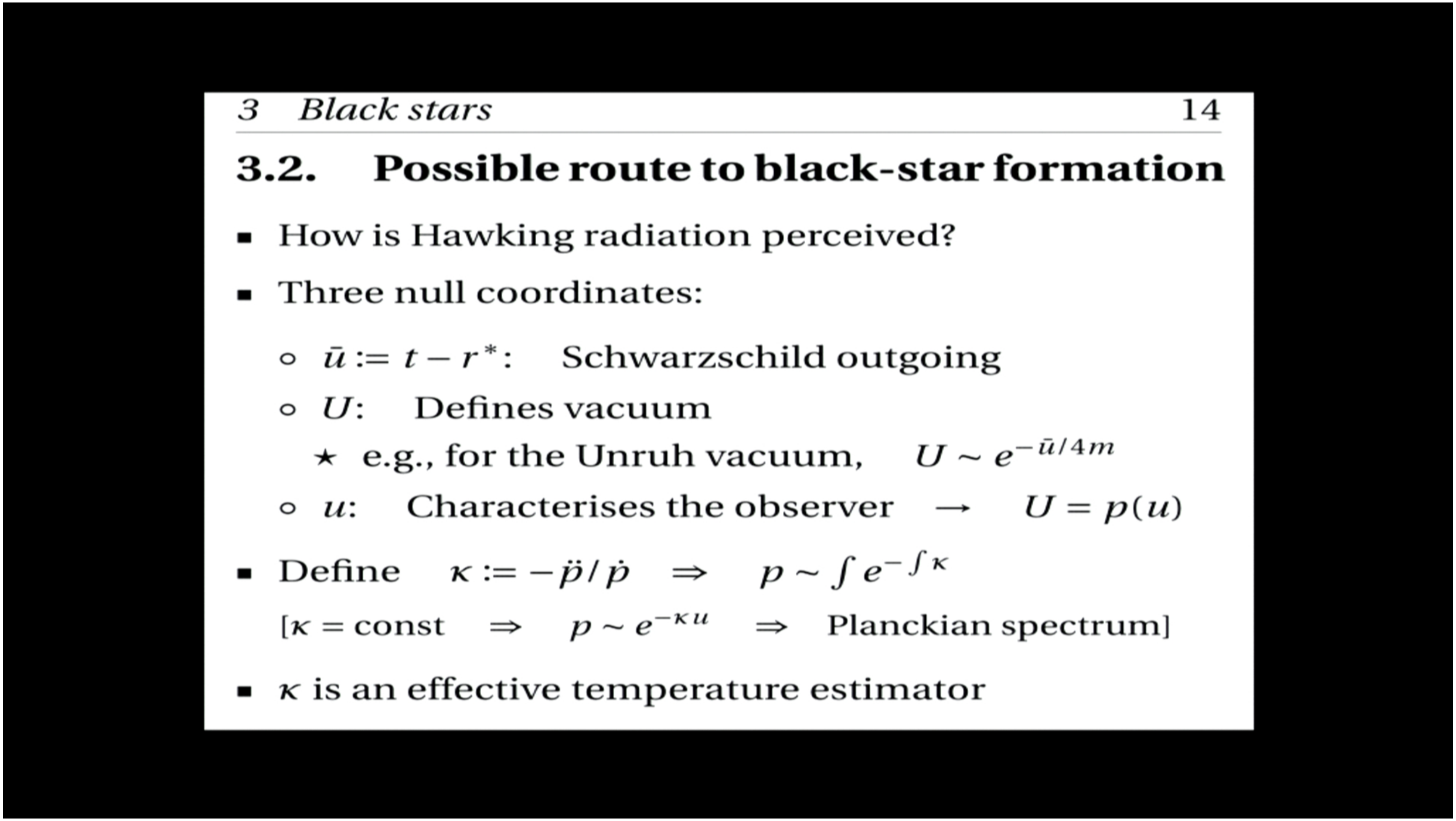

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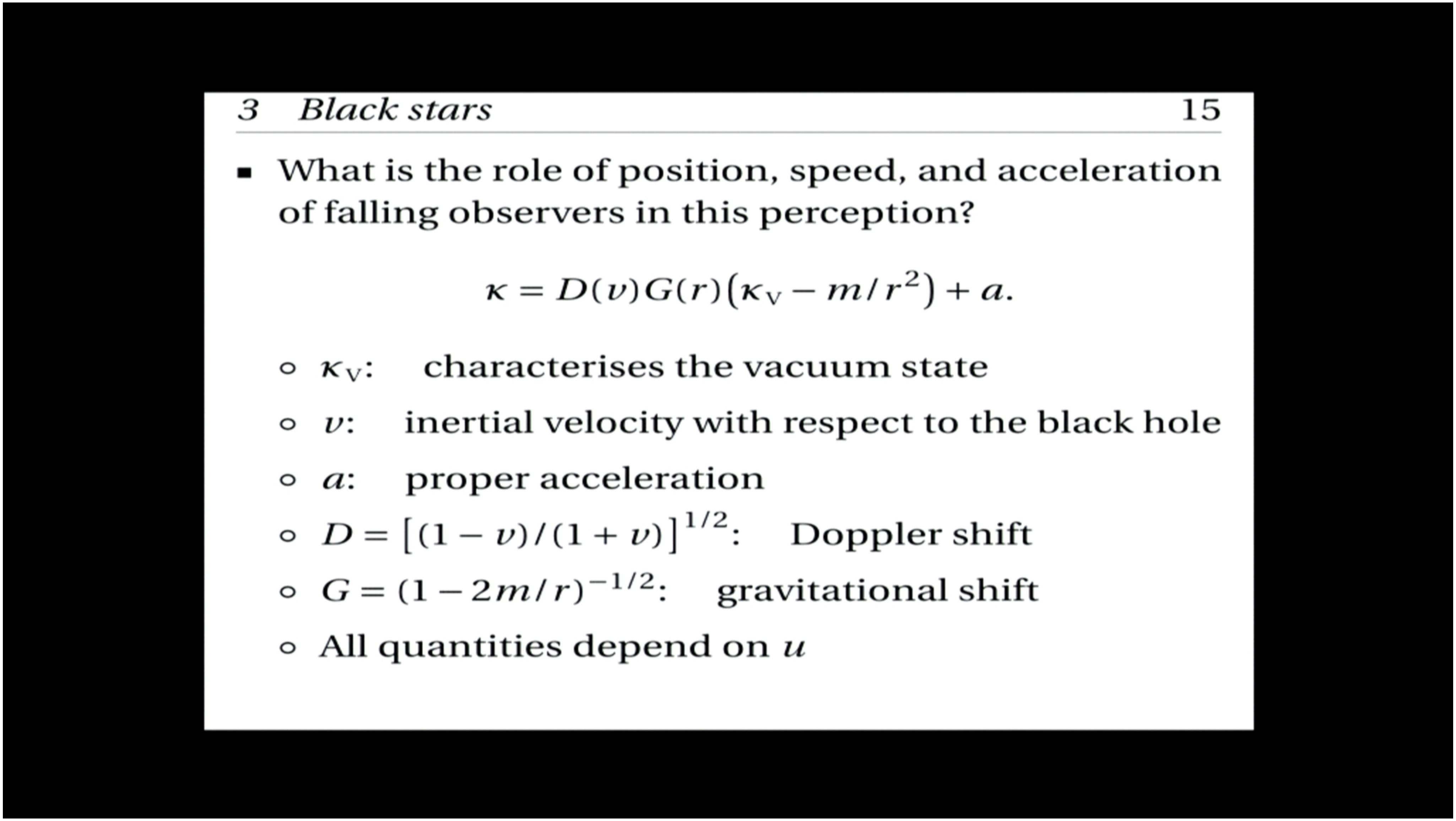
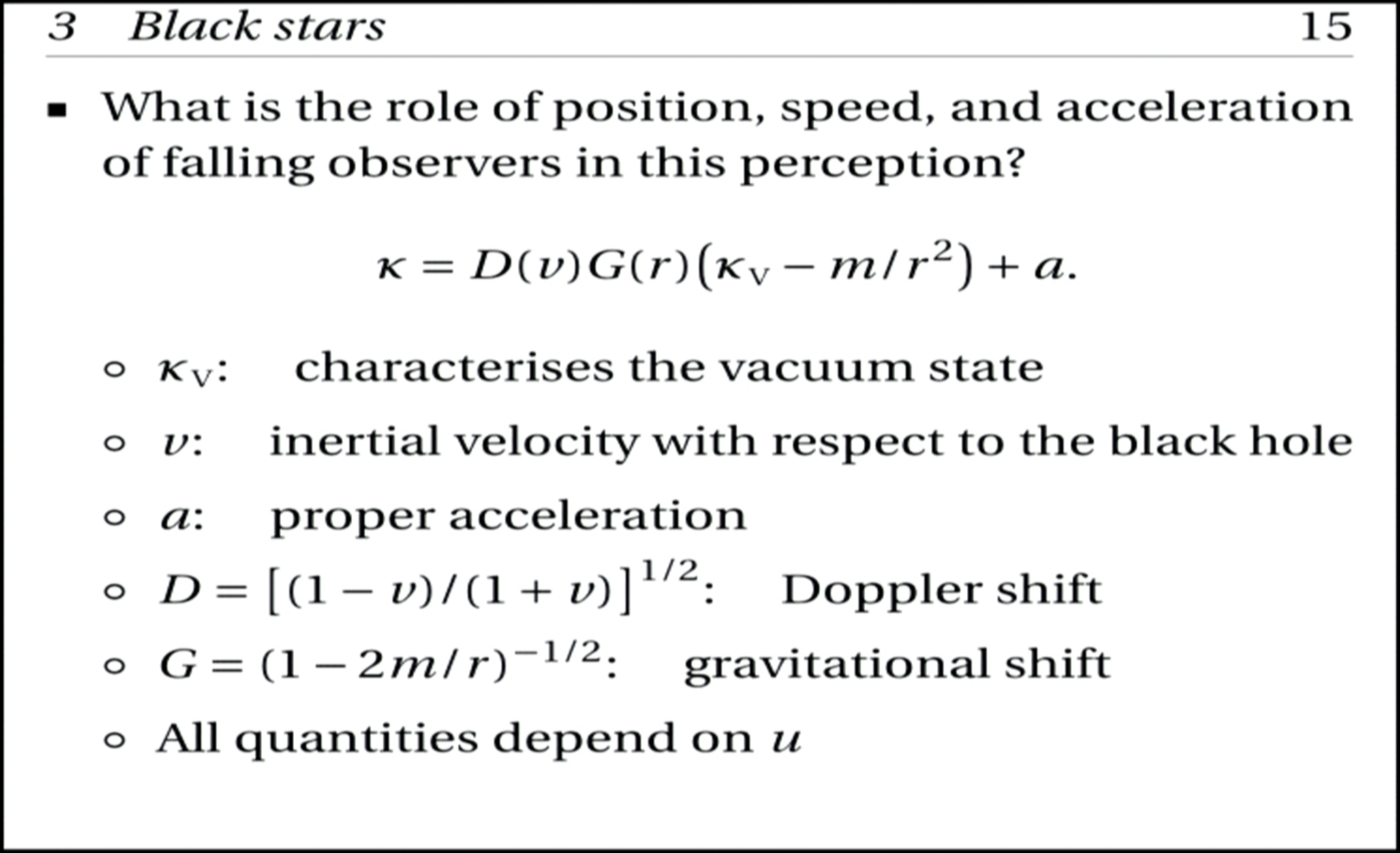


- What is the role of position, speed, and acceleration of falling observers in this perception?

$$\kappa = D(v)G(r)\big(\kappa_{\mathrm{V}} - m/r^2\big) + a.$$

  - κ_{V}: characterises the vacuum state
  - v: inertial velocity with respect to the black hole
  - a: proper acceleration
  - $D = \big[(1-v)/(1+v)\big]^{1/2}$: Doppler shift
  - $G = (1-2m/r)^{-1/2}$: gravitational shift
  - All quantities depend on u



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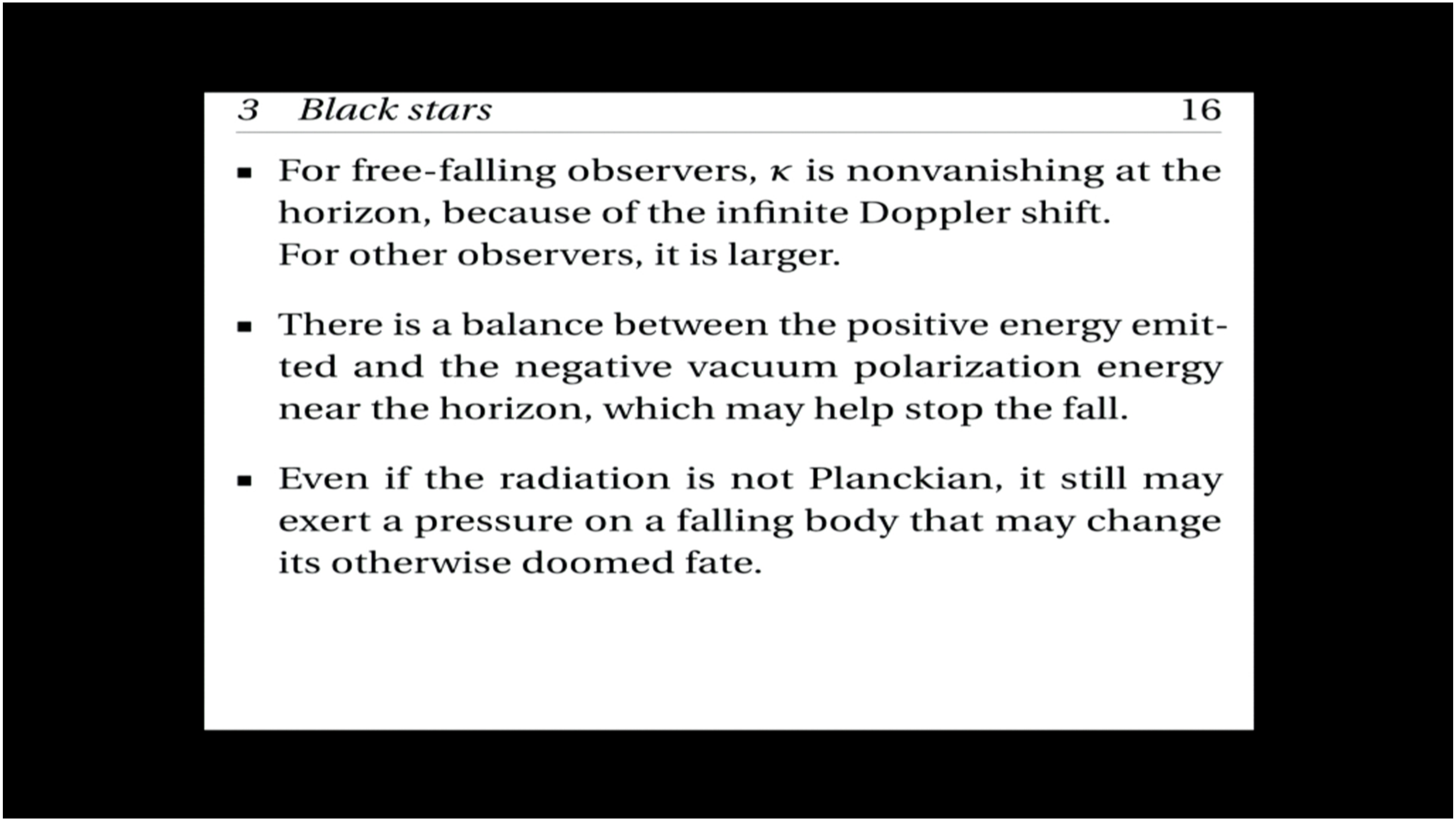
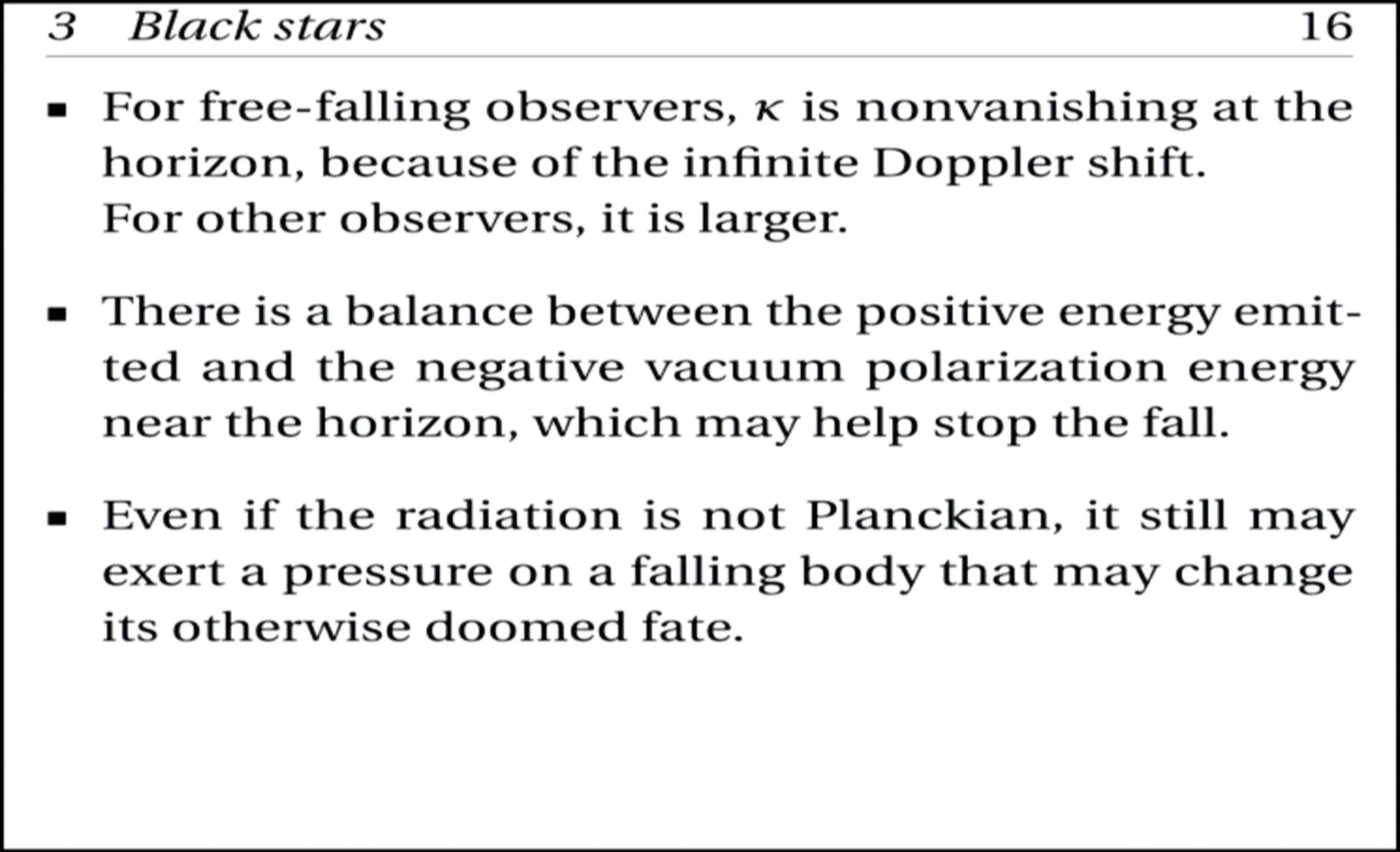


- For free-falling observers, κ is nonvanishing at the horizon, because of the infinite Doppler shift.
  For other observers, it is larger.
- There is a balance between the positive energy emitted and the negative vacuum polarization energy near the horizon, which may help stop the fall.
- Even if the radiation is not Planckian, it still may exert a pressure on a falling body that may change its otherwise doomed fate.



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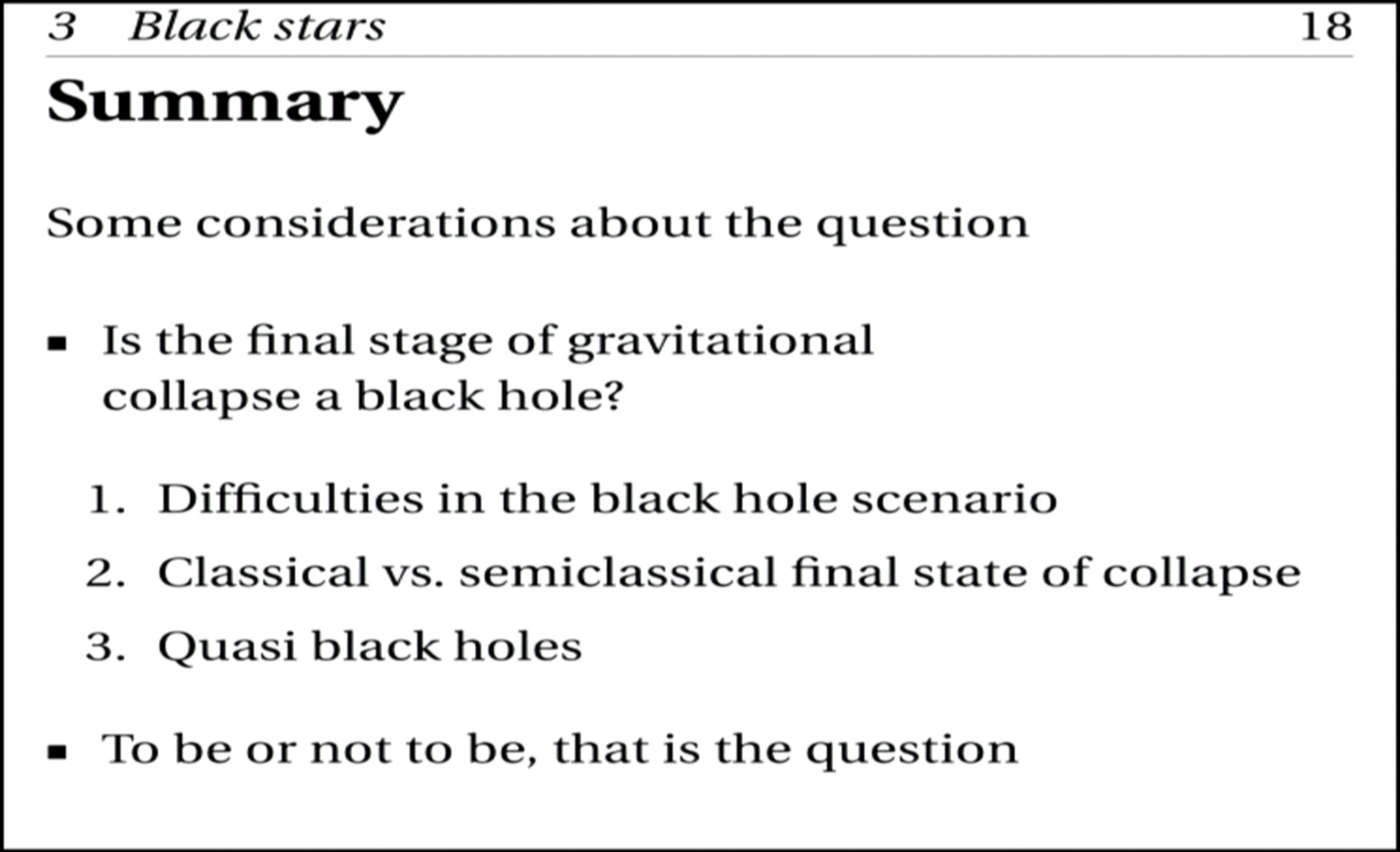

Summary

Some considerations about the question

- Is the final stage of gravitational collapse a black hole?

  1. Difficulties in the black hole scenario
  2. Classical vs. semiclassical final state of collapse
  3. Quasi black holes

- To be or not to be, that is the question