



Astronomy 353
(Spring 2007)

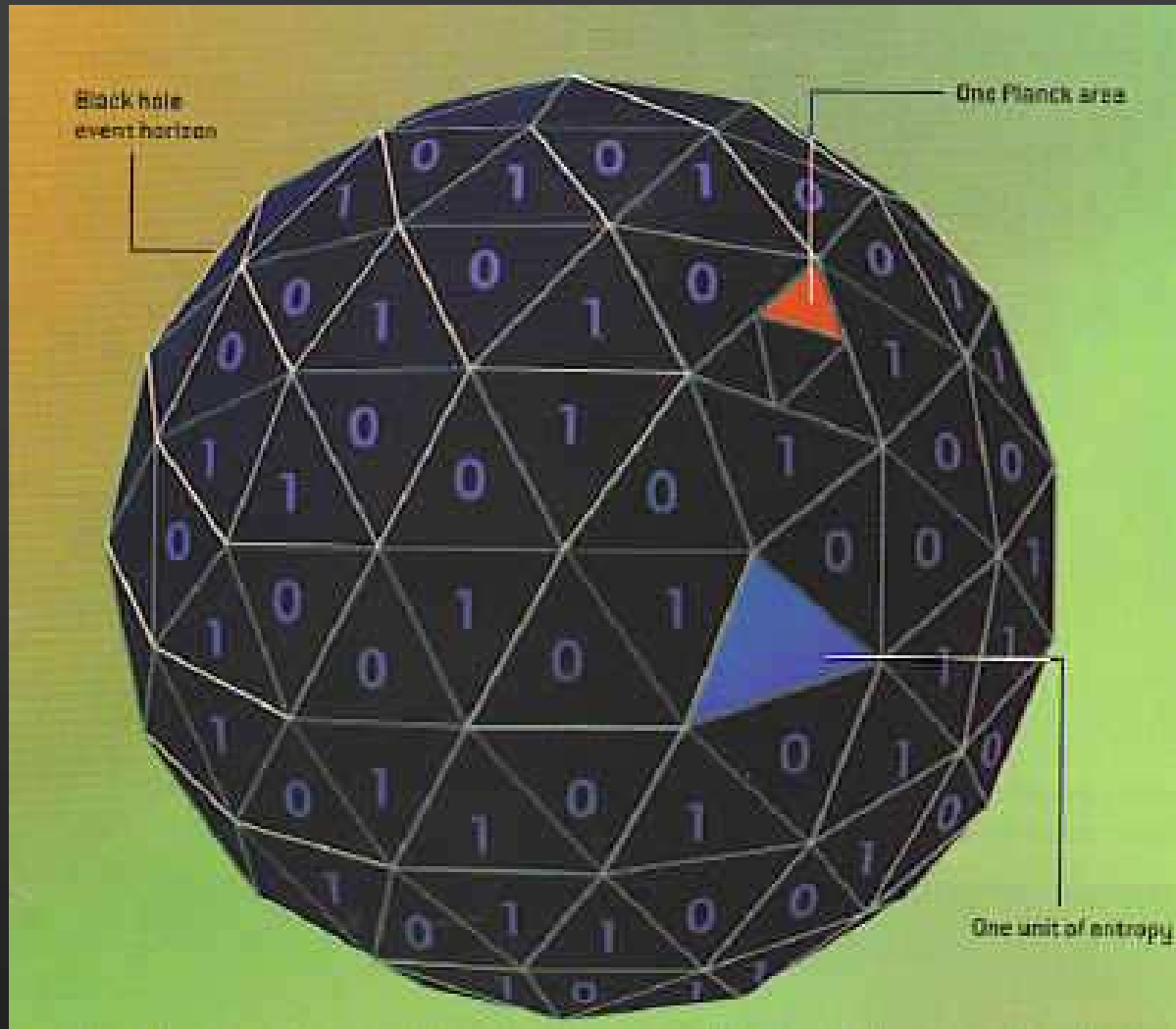


ASTROPHYSICS:
From Black Holes
to the First Stars
(Lecture 26: Epilogue:
The Cosmic Frontier)

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Information Content of Black Holes



$$S_{\text{BH}} = k_B \frac{1}{4} \frac{A_{\text{BH}}}{A_{\text{PL}}}$$

Information Content of Black Holes

- Calculate BH entropy:

$$S_{\text{BH}} = k_B 10^{77} (M/M_\odot)^2$$

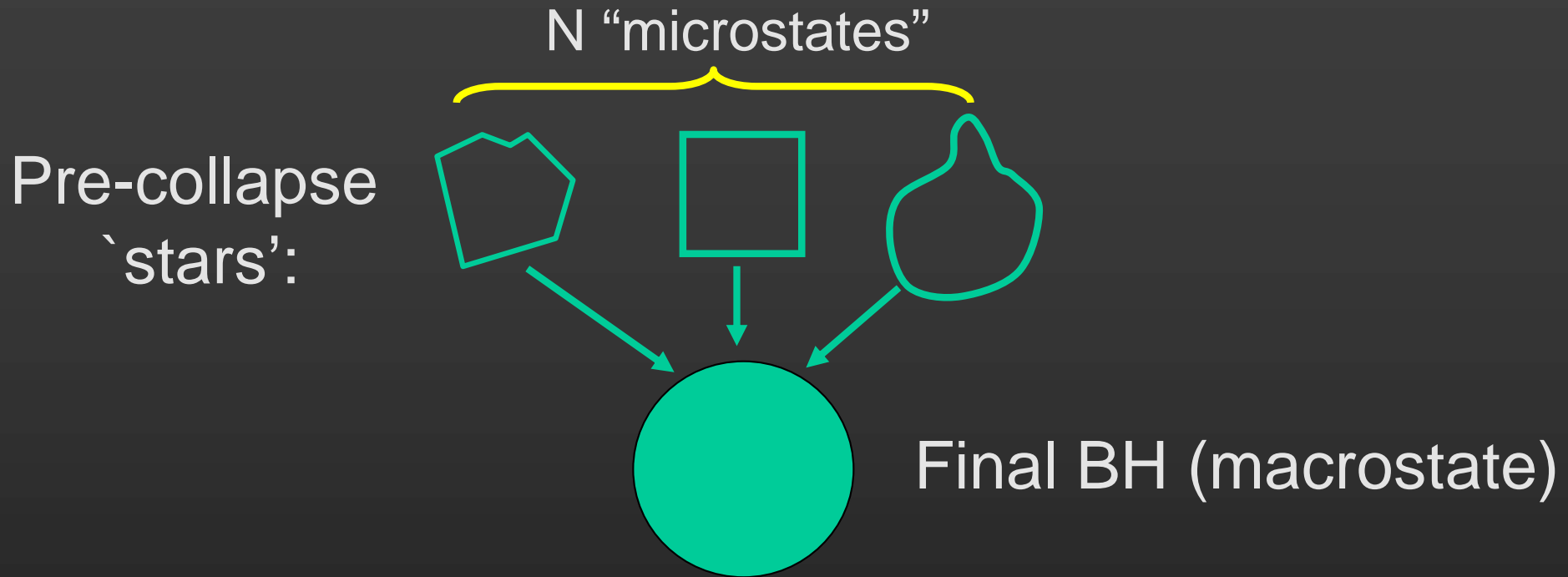
à This is HUGE! (Cf. Sun's entropy: $S_\odot \sim k_B 10^{58}$)

-Q: Why is BH entropy so large?

à A: connected to 'no-hair theorem'!

Information Content of Black Holes

- Interpretation of BH entropy:



-No-hair theorem: Almost all pre-collapse stars (microstates) will end up as SAME BH (macrostate)!

$$k_B 10^{77} \sim S = k_B \ln N$$

$$\Rightarrow N \sim \exp(10^{77}) \sim 10^{10^{77}}$$

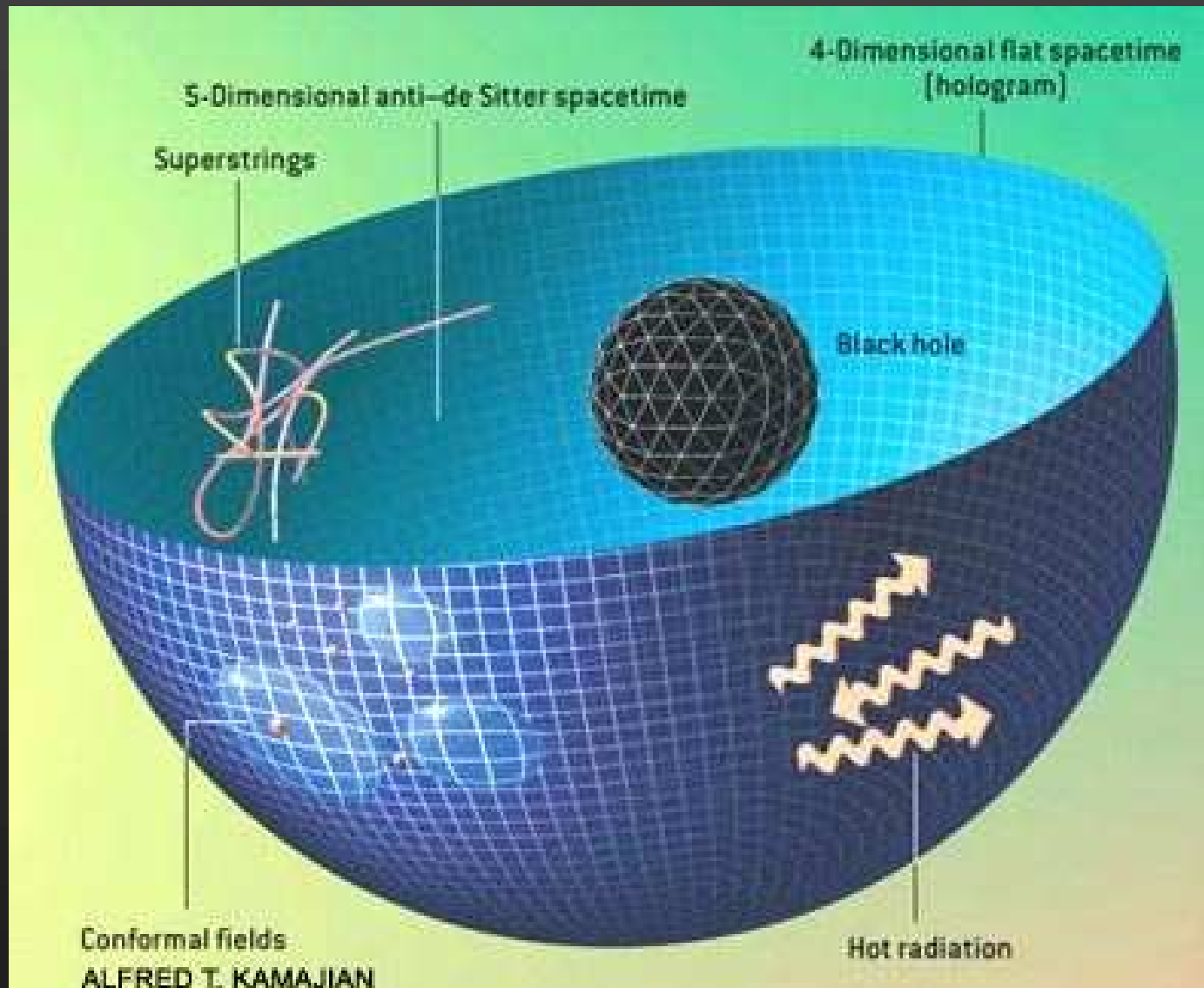
Black Holes and the Holographic Principle



hologram

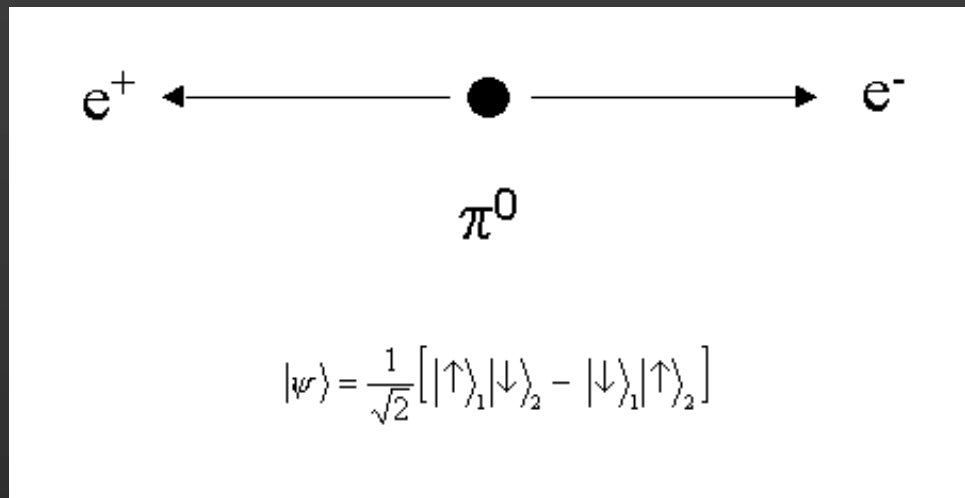
-Holographic principle: physics in interior n D spacetime
equivalent to physics on $(n-1)$ D surface spacetime!

Black Holes and the Holographic Principle



Black Hole Computers

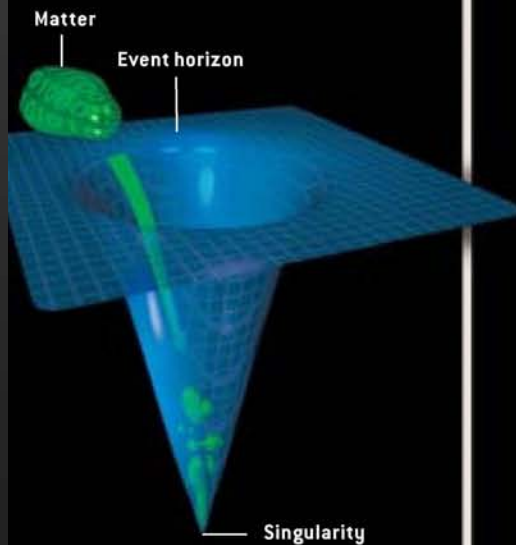
EPR (Einstein-Podolski-Rosen) pair



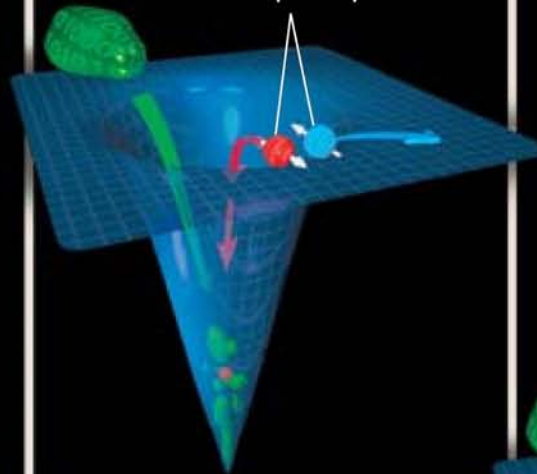
- (quantum-) entangled state
- Measurement at location of one particle immediately known at partner particle
à “Quantum teleportation”

Black Hole Computers

CLASSICAL VIEW, based on prequantum physics, holds that a blob of matter falling through the hole's outer rim—the event horizon—can neither escape nor send out its information. It hits the center of the hole—the singularity—where its mass is assimilated and its information lost.

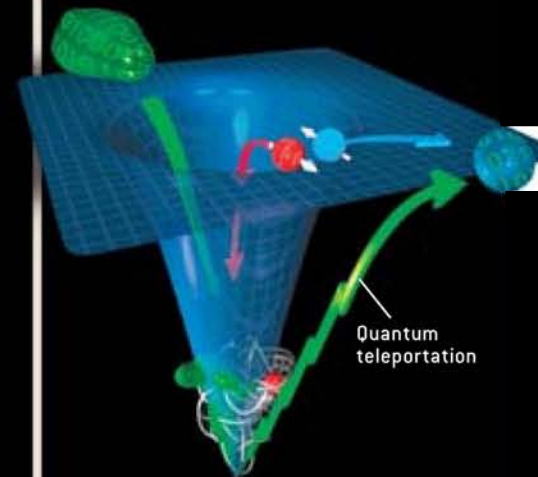


Virtual-particle pair






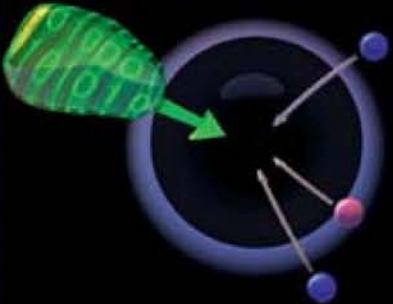

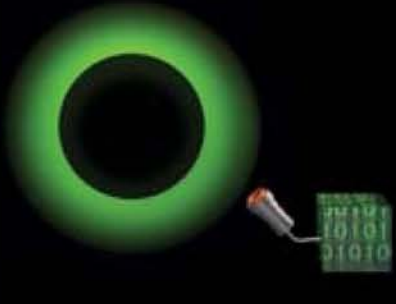
HOROWITZ-MALDACENA MODEL suggests that the outgoing particle carries away not just raw mass but also information. The particle is quantum-mechanically entangled with its infalling partner, which in turn gets entangled with the blob. The entanglement beams the blob's information out.

HAWKING MODEL is a first stab at considering quantum effects. Pairs of virtual particles materialize at the event horizon (*red and blue balls*). One member of each pair, like other matter, falls to the singularity. Its partner flies outward. The particle spins are random and do not carry any information about the infalling blob.



Black Hole Computers

Three steps of computation

	INPUT	COMPUTATION	OUTPUT
ORDINARY LAPTOP SPEED: 10^9 hertz ■ MEMORY: 10^{12} bits	 <p>A keyboard and associated circuitry encode information as voltage pulses in a wire.</p>	 <p>The pulses interact, guided by devices such as transistors, which perform logical operations such as NOT.</p>	 <p>The pulses, having been processed, are translated into meaningful patterns of light.</p>
BLACK HOLE SPEED: 10^{35} hertz ■ MEMORY: 10^{46} bits	 <p>This black hole consists of one kilogram in a volume 10^{-27} meter in radius. Data and instructions are encoded in matter and dropped in.</p>	 <p>On their descent, particles interact much as in the ultimate laptop, except that gravity also plays a role. The governing laws are not yet understood.</p>	 <p>The hole emits radiation, named after physicist Stephen Hawking. New theories suggest that the radiation carries the computational output.</p>

Perspectives:

- Astrophysics is a fantastic subject!
- Black holes lead us to the frontier of modern physics
- First Stars lead us to the frontier of cosmology
- We are entering a golden age of discovery

