Higher dimensional black holes

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Motivation

- Black holes in string theory
- Gauge/gravity correspondence

GR in *d* dimensions

- What changes when $d>4$?
- What might have been possible for $d=4$: black hole non-uniqueness, instabilities, cosmic censorship violation
- Some things are simpler for $d>4$
- Explicit $d>4$ solutions may illustrate important physical effects

Myers-Perry black holes 1986

- Vacuum solution - generalization of Kerr solution to *d* dimensions
- Non-rotating limit: Schwarzschild
- Topologically spherical, uniquely parameterized by mass and angular momenta
- Hidden symmetries Frolov, Stojkovic, Krtous, Kubiznak, Page 2002-8

Black rings

Emparan & HSR 2001, Pomeransky & Sen'kov 2006

- d=5
- Rotating loop of black string
- Centrifugal force balances gravity
- Topology $S^1 \times S^2$
- Not uniquely specified by mass, ang. mom.

- d=6,7 black rings found numerically Kleihaus, Kunz & Radu 2012

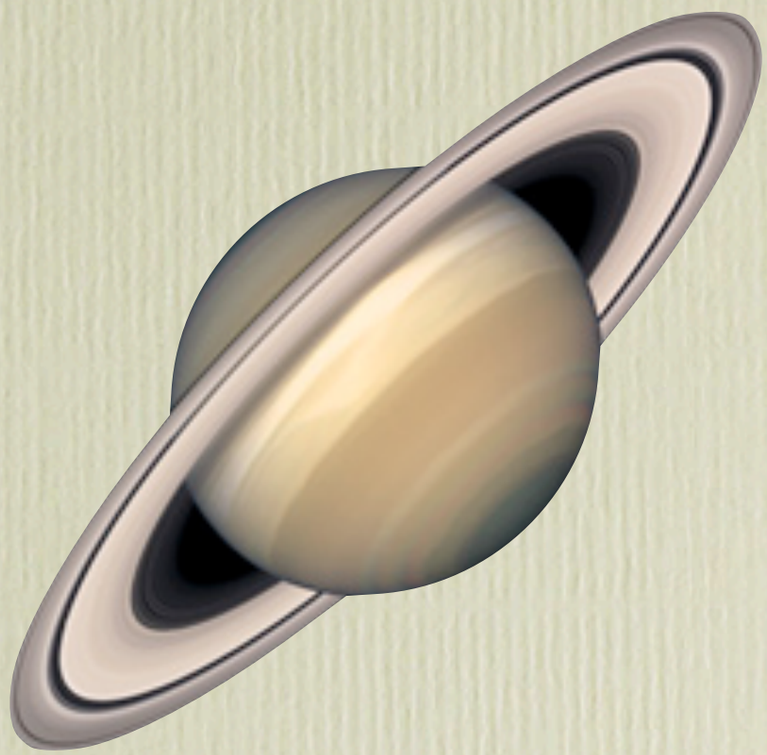
Black Saturn

Elvang & Figueras 2007

- MP black hole with concentric black ring

- First example of regular stationary vacuum multi black hole

- Frame dragging effect



Topology theorem

Galloway & Schoen 2005

- Hawking's topology theorem generalizes to $d>4$ dimensions

- Horizon cross-section must admit metric of positive scalar curvature

- $d=4$: S^2 topology

- $d=5$: S^3 (or quotient), $S^1 \times S^2$, connected sum

Rigidity theorem

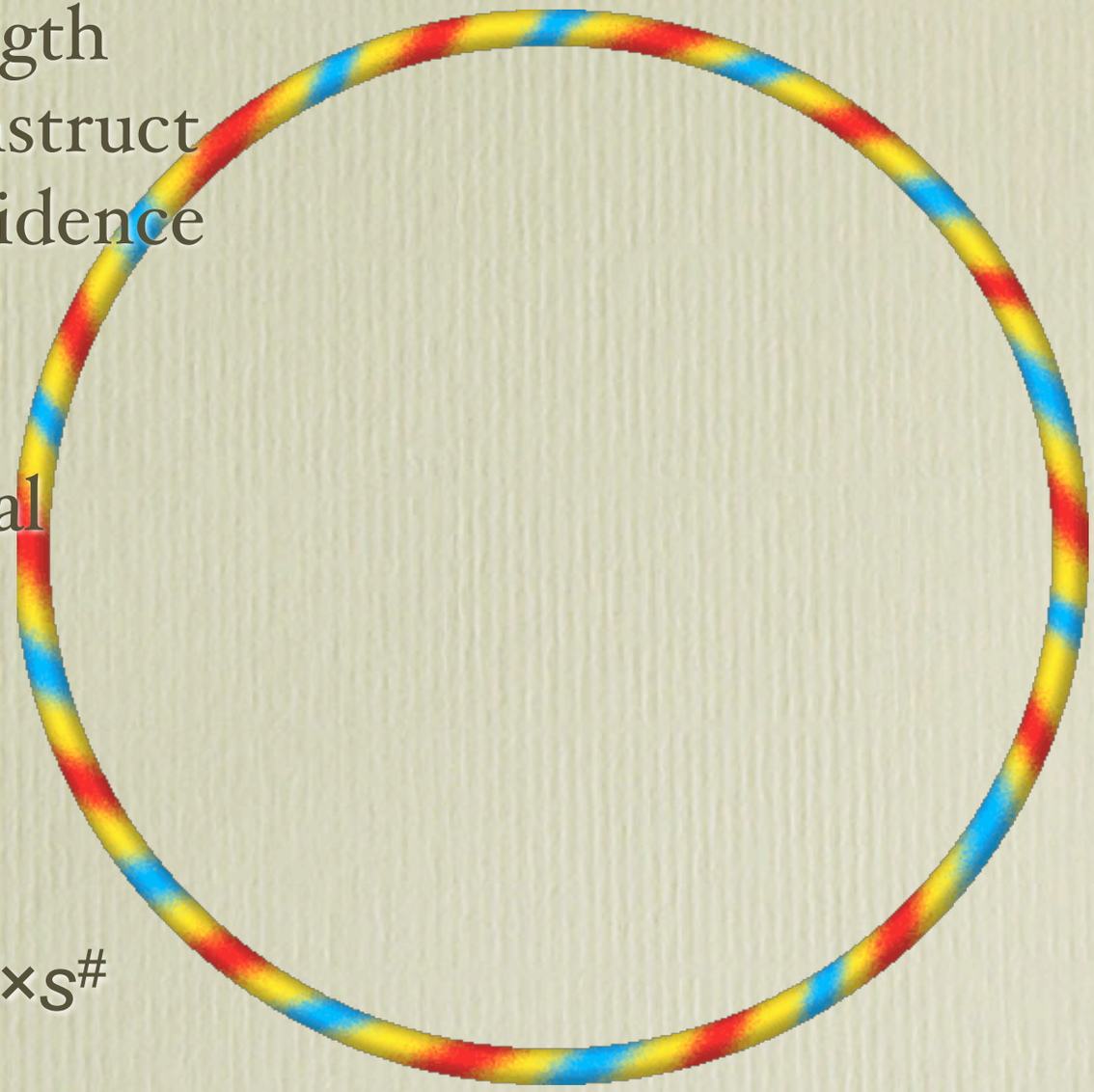
Hollands, Ishibashi & Wald 2006

- Hawking's rigidity theorem generalizes to d>4
- A stationary, rotating, asymptotically flat, vacuum black hole solution must admit a rotational symmetry
- All known d>4 solutions admit *multiple* rotational symmetries
- Perturbative evidence for solutions with just 1 rotational symmetry Dias, Figueras, Monteiro, HSR & Santos 2010

Blackfolds

Emparan, Harmark, Niarchos, Obers 2009-11

- $d>4$ horizon can have 2 length scales with small ratio: construct solution perturbatively. Evidence for:
  - black rings with 1 rotational symmetry
  - $d>5$ black rings
  - new topologies: $S^{\#}\times\ldots\times S^{\#}\times s^{\#}$



Stability: linear

- d>5 Myers-Perry BH: no upper bound on angular momentum. *Ultraspinning* BHs conjectured to be unstable Emparan & Myers 2003

- confirmed by study of rotationally symmetric linearized perturbations Dias, Figueras, Monteiro, Santos & Emparan 2009; Dias, Figueras, Monteiro, HSR & Santos 2010

Stability: nonlinear

Shibata & Yoshino 2009-10

- Nonlinear numerical evolution of non-rotationally symmetric perturbations of MP: emission of gravitational waves, settles down to MP with lower angular momentum

Local Penrose inequality

Figueras, Murata & HSR 2011, Hollands & Wald 2012

- Small perturbation of stable BH will disperse and settle down to stationary BH solution. Penrose argument: Horizon area↑, mass ↓

- Rotationally symmetric initial data describing small perturbation of a stable stationary BH must satisfy $A \leq A_{BH}(M,J)$

- A *stable* black hole is a *local maximum* of horizon area in the space of rotationally symmetric initial data of fixed mass, ang. mom.

Initial data

- Seek rotationally symmetric initial data describing perturbation of BH and violating $A \leq A_{BH}(M,J) \Rightarrow$ instability

- Myers-Perry: local Penrose inequality violated for $d>5$ for sufficiently large J

Black ring stability

- Heuristic arguments indicate rotationally symmetric instability of "fat" rings
- Confirmed by local Penrose inequality argument
- Sufficiently thin rings probably unstable too

Outlook

- Still far from understanding "landscape" of higher-dimensional black holes: which topologies, symmetries are possible?

- Need new methods for solving Einstein eq: numerics, algebraically special solution?

- Applications: black rings in string theory, novel phases of matter via gauge/gravity correspondence