

# **Black ringoids: new higher dimensional black objects with non-spherical horizon topology**

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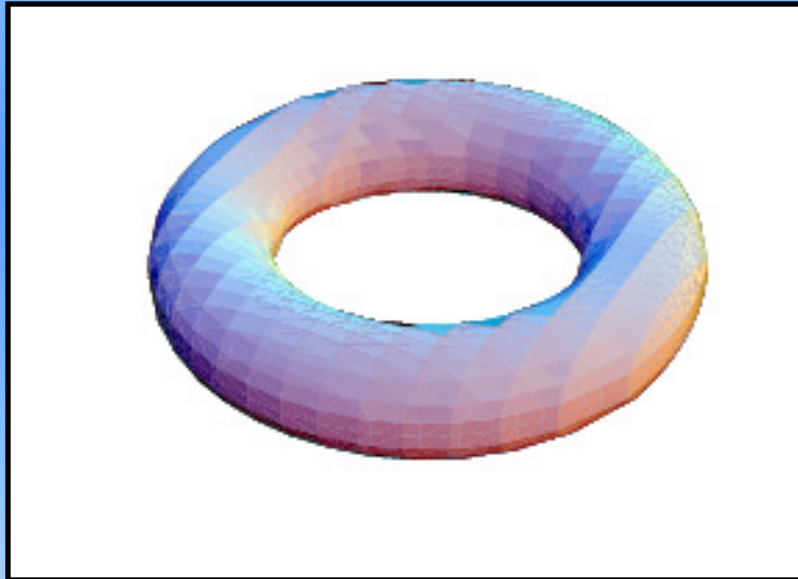
*based on **arXiv:1410.0581** -- work done together with*

***B. Kleihaus** and **J. Kunz** (Oldenburg University, Germany)*

# Black Holes in higher dimensions $d > 4$ :

(*asymptotically flat + vacuum + single black objects*)

- important field of research
- rapid progress following the discovery of the  *$d=5$  Black Ring*

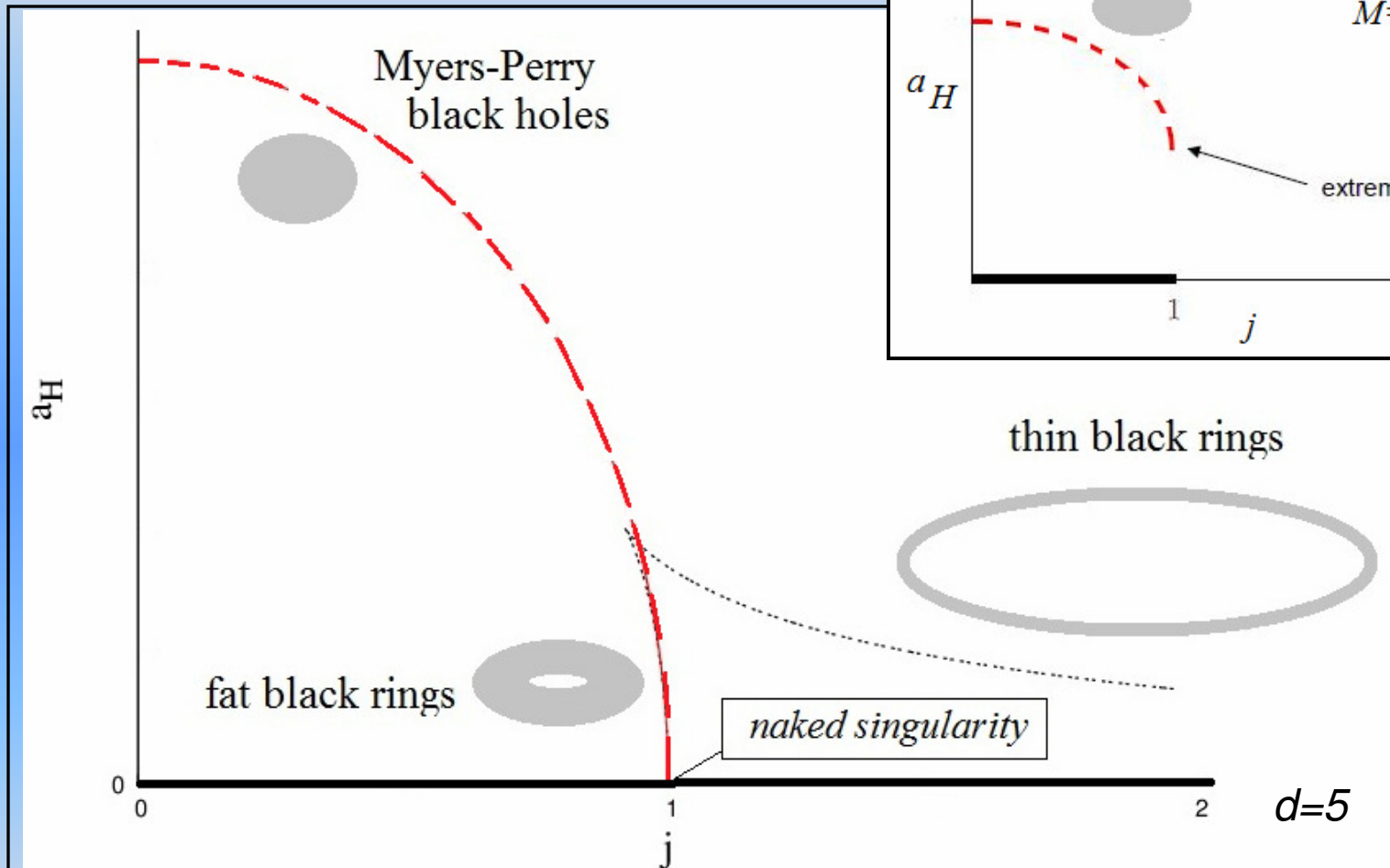


$S^2 \times S^1$   
horizon topology

- *exact solution!*
- *has led to a reconsideration of a number of basic results in black hole physics*

# One-black hole phases in five dimensions:

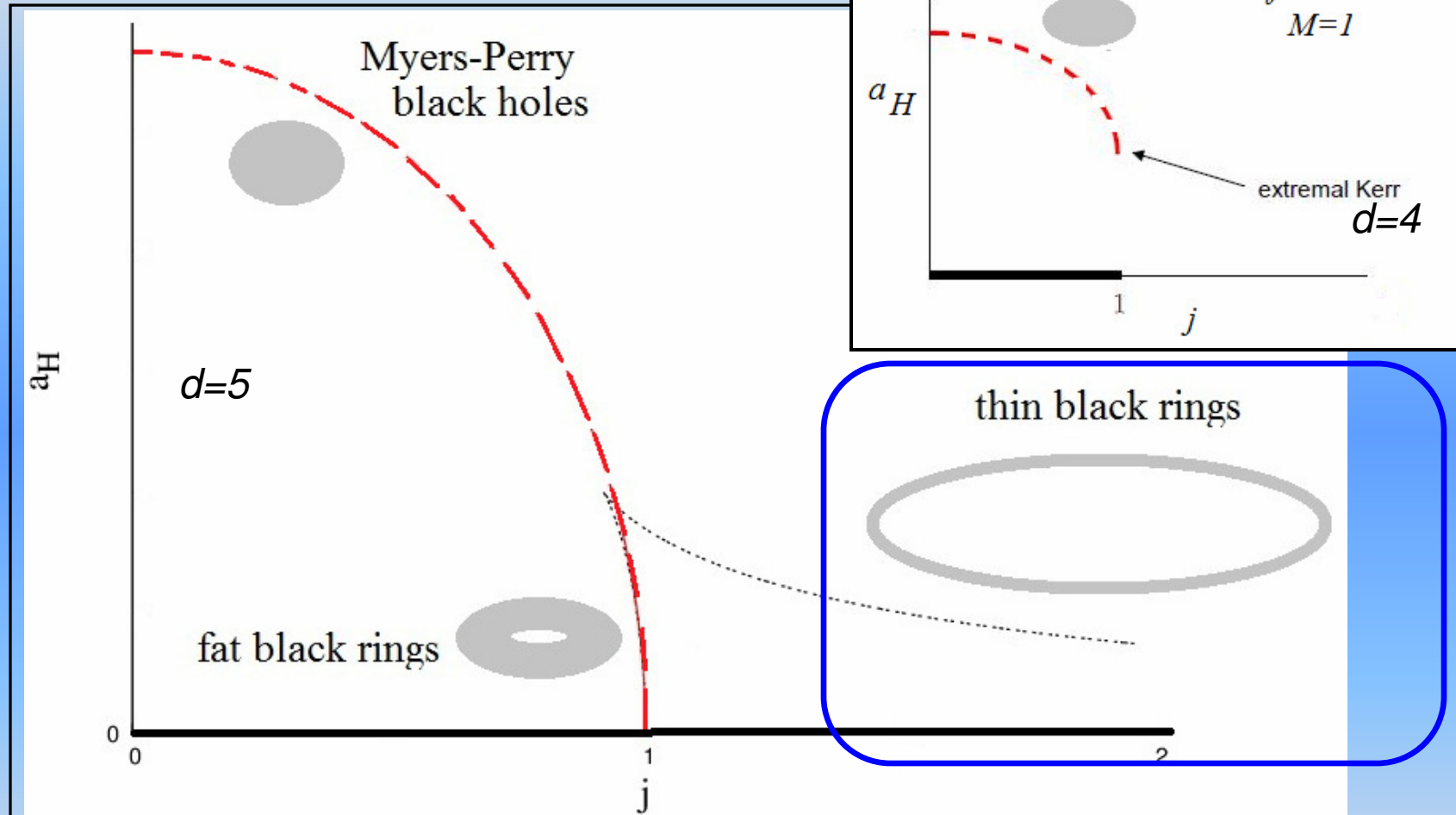
(rotation in a single plane)



- *three different black holes with the same value of  $(M, J)$*
- *non uniqueness!*

# One-black hole phases in five dimensions:

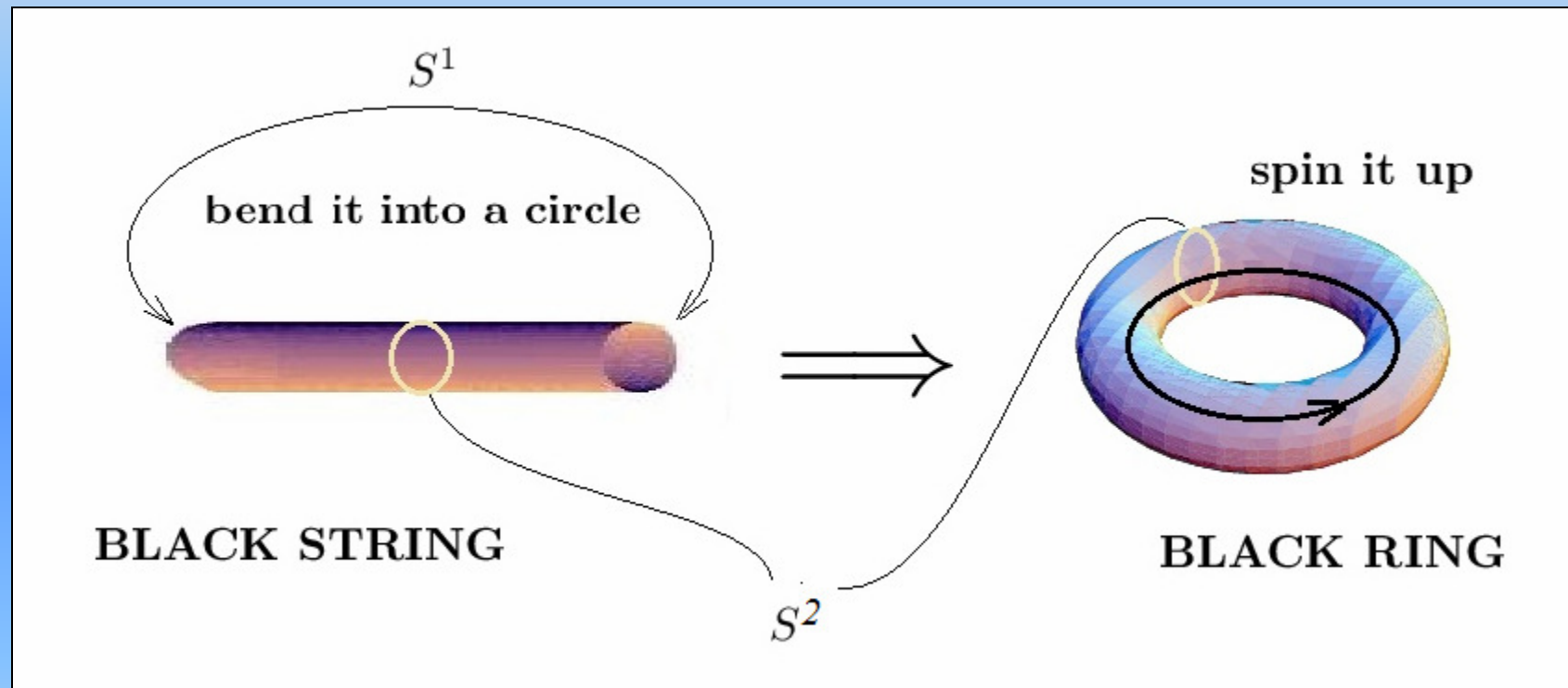
(rotation in a single plane)



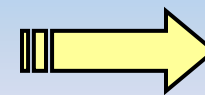
- *three different black holes with the same value of  $(M, J)$*
- *non uniqueness!*

## thin black rings: heuristic construction

Schwarzschild black hole in 4-dimensions  $\Rightarrow$  black string in 5-dimensions



- there is an explicit realisation
- the same construction holds for  $d > 5$ :  $S^{d-3} \times S^1$
- predicts also other horizon topologies



***blackfold  
approach***

(Emparan et al.)

*also other arguments: a large spectrum of  $d>5$  exotic BHs*

*however, no exact solutions:*

- only the Myers-Perry BHs are known in closed form
- the  $d=4,5$  formalism+generation techniques do not work for  $d>5$

$d>5$  non-spherical horizon topology

all knowledge: from **blackfolds**

*also other arguments: a large spectrum of  $d>5$  exotic BHs*

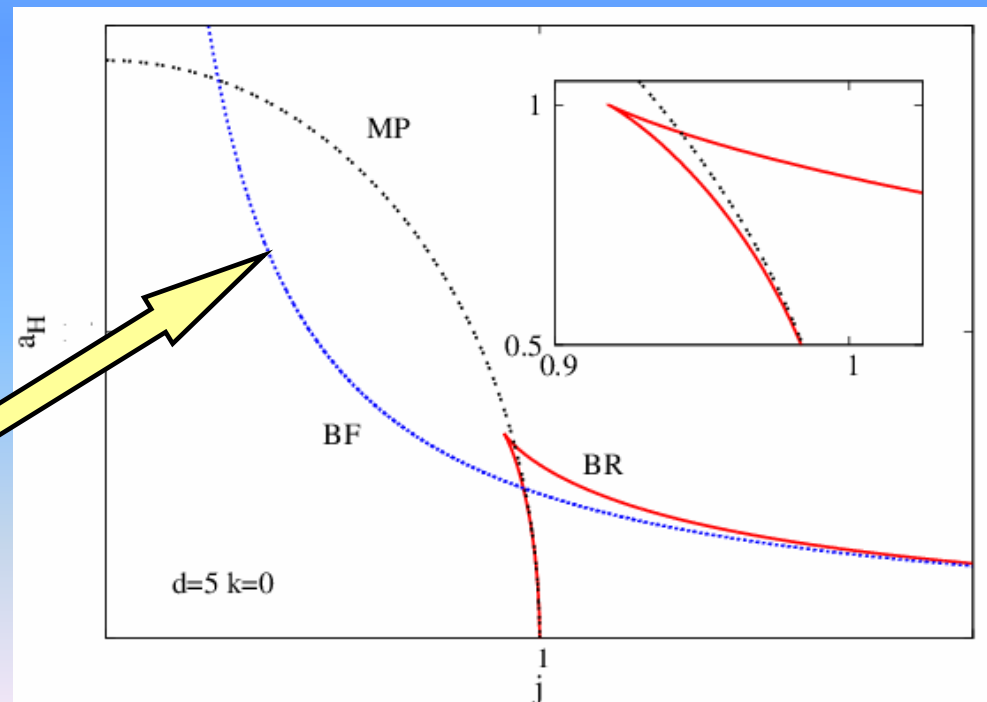
*however, no exact solutions:*

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- the  $d=4,5$  formalism+generation techniques do not work for  $d>5$

$d>5$  non-spherical horizon topology: **blackfolds**

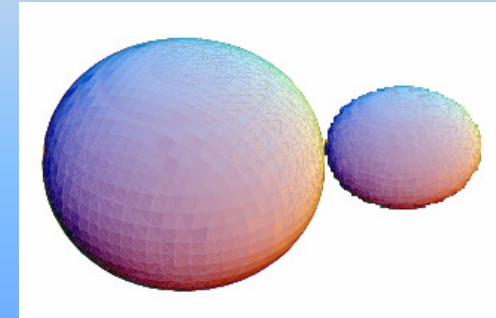
however, clear limits  
e.g.  $d=5$  black rings

*blackfold  
predictions*



our proposal: NON-PERTURBATIVE NUMERICAL APPROACH

general framework for black holes  
with  $S^p \times S^q$  horizon topology



i) vacuum, spinning solutions:

$$S^{d-(2k+3)} \times S^{2k+1}$$

ii) static black holes:

(Einstein-Maxwell theory)

$$S^{d-4} \times S^2$$

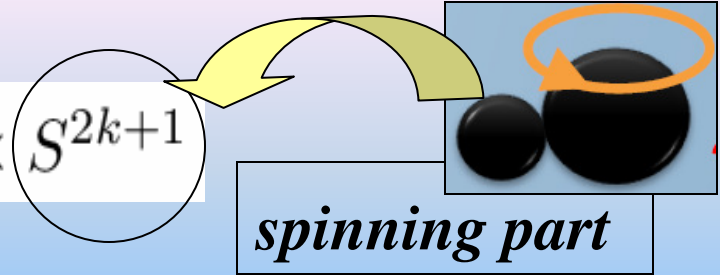


*what one can study:*  $S^{d-(2k+3)} \times S^{2k+1}$

	<i>spherical horizon</i>	<i>black rings</i>	<i>black ringoids</i>		
	MP/‘pinched’	$k = 0$	$k = 1$	$k = 2$	$k = 3$
$d = 5$	$S^3$	$\mathbf{S}^2 \times \mathbf{S}^1$			
$d = 6$	$S^4$	$S^3 \times S^1$			
$d = 7$	$S^5$	$S^4 \times S^1$	$\mathbf{S}^2 \times \mathbf{S}^3$		
$d = 8$	$S^6$	$S^5 \times S^1$	$S^3 \times S^3$		
$d = 9$	$S^7$	$S^6 \times S^1$	$S^4 \times S^3$	$\mathbf{S}^2 \times \mathbf{S}^5$	
$d = 10$	$S^8$	$S^7 \times S^1$	$S^5 \times S^3$	$S^3 \times S^5$	
$d = 11$	$S^9$	$S^8 \times S^1$	$S^6 \times S^3$	$S^4 \times S^5$	$\mathbf{S}^2 \times \mathbf{S}^7$

*what one can study:*

$$S^{d-(2k+3)} \times S^{2k+1}$$



	<i>spherical horizon</i>	<i>black rings</i>	<i>black ringoids</i>		
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$d = 7$	$S^5$	$S^4 \times S^1$	$S^2 \times S^3$		
$d = 8$	$S^6$	$S^5 \times S^1$	$S^3 \times S^3$		
$d = 9$	$S^7$	$S^6 \times S^1$	$S^4 \times S^3$	$S^2 \times S^5$	
$d = 10$	$S^8$	$S^7 \times S^1$	$S^5 \times S^3$	$S^3 \times S^5$	
$d = 11$	$S^9$	$S^8 \times S^1$	$S^6 \times S^3$	$S^4 \times S^5$	$S^2 \times S^7$

***regular solutions!***  
 (no (conical) singularities etc)

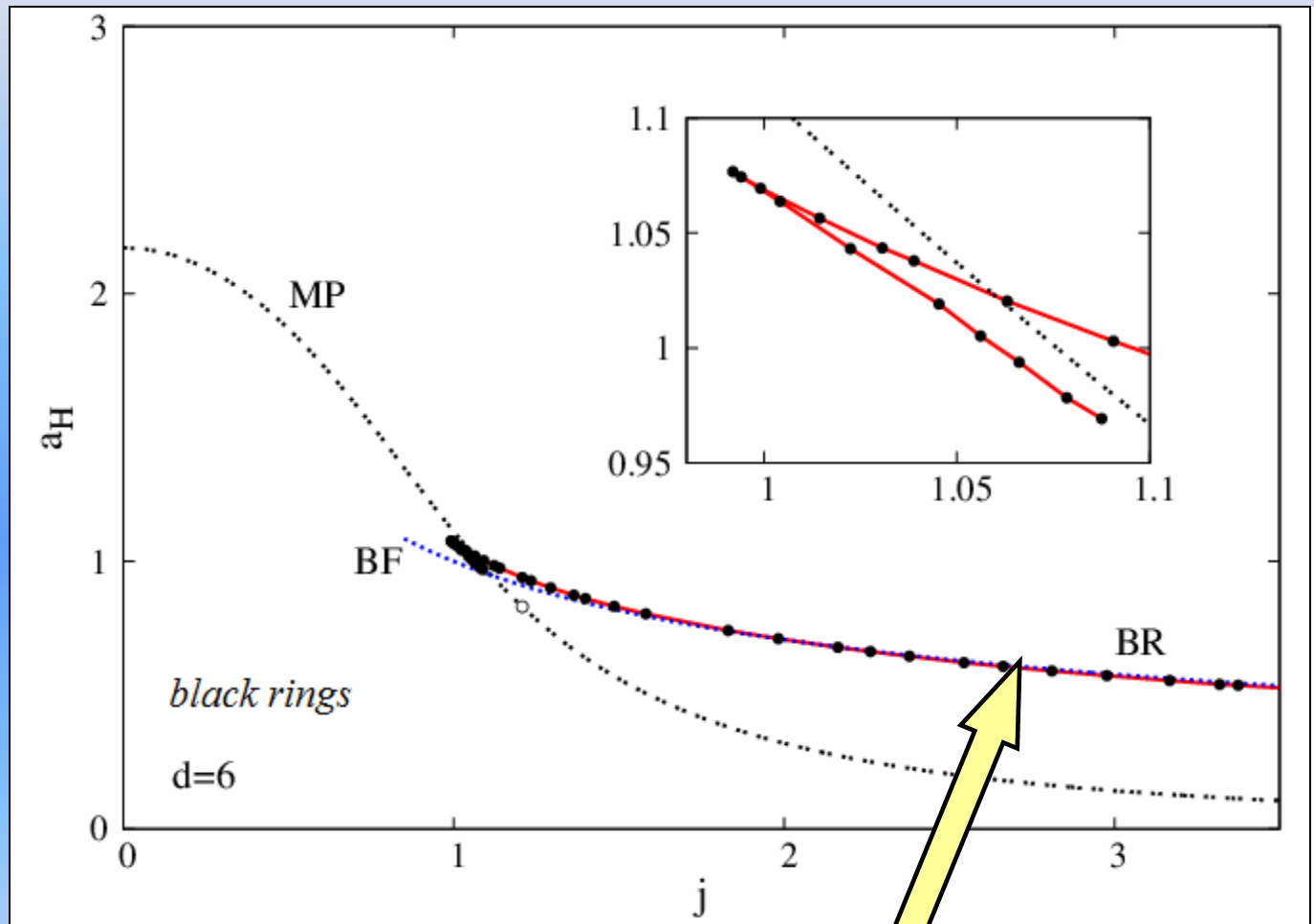
*our results (i):*

- cases we have considered so far:

	<i>black rings</i>	<i>black ringoids</i>		
	$k = 0$	$k = 1$	$k = 2$	$k = 3$
$d = 5$	$S^2 \times S^1$			
$d = 6$	$S^3 \times S^1$			
$d = 7$	$S^4 \times S^1$	$S^2 \times S^3$		
$d = 8$	$S^5 \times S^1$	$S^3 \times S^3$		
$d = 9$	$S^6 \times S^1$	$S^4 \times S^3$	$S^2 \times S^5$	
$d = 10$	$S^7 \times S^1$	$S^5 \times S^3$	$S^3 \times S^5$	
$d = 11$	$S^8 \times S^1$	$S^6 \times S^3$	$S^4 \times S^5$	$S^2 \times S^7$

(details in [arXiv:1410.0581](https://arxiv.org/abs/1410.0581))

*our results (ii):*

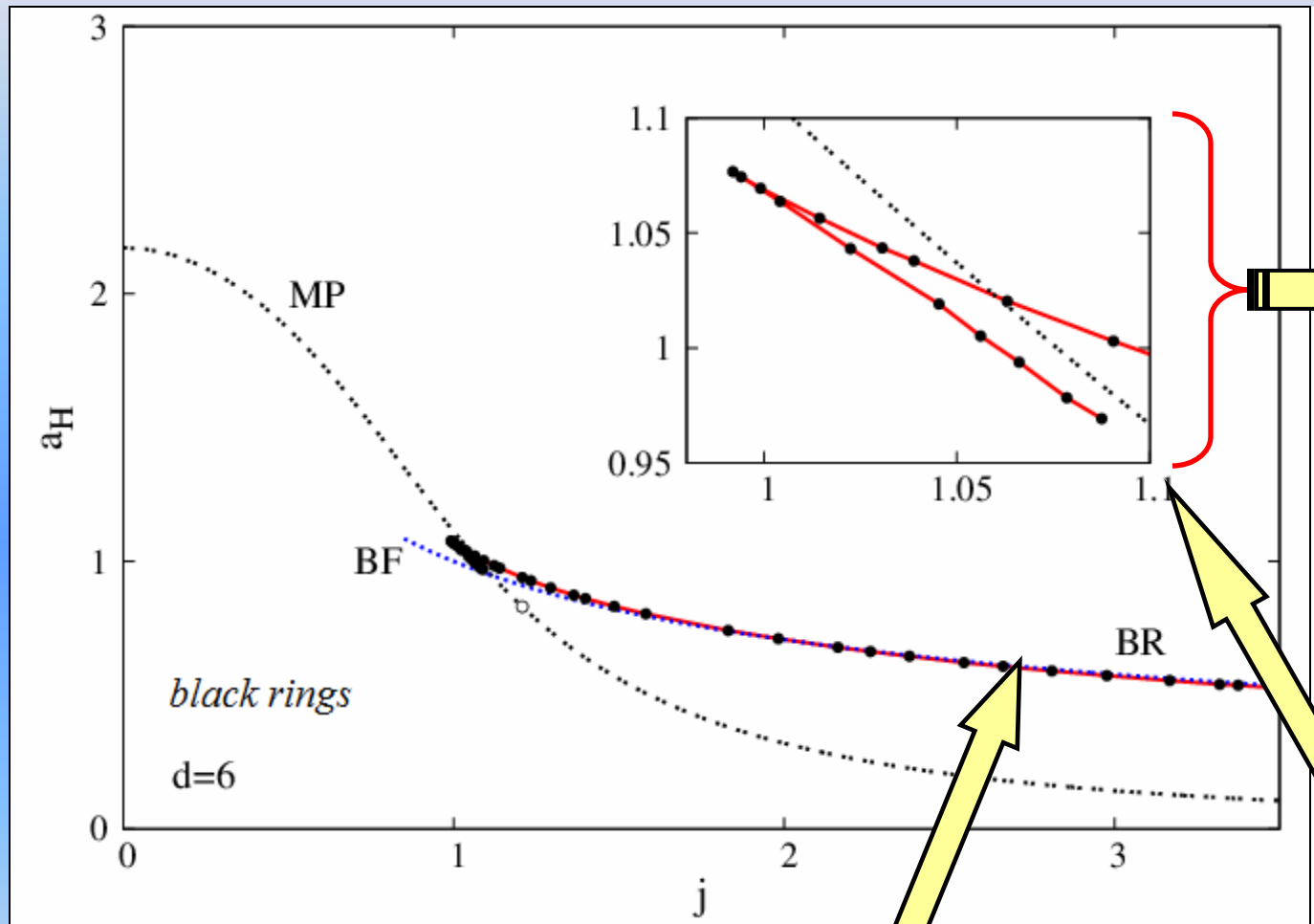


always:

*very good agreement with the blackfolds*

(for large  $j$ )

*our results (ii):*



2<sup>nd</sup> branch always

$j > j_{\min}$

*very good agreement with the blackfolds*

*however, new features*

*our results (iii):*

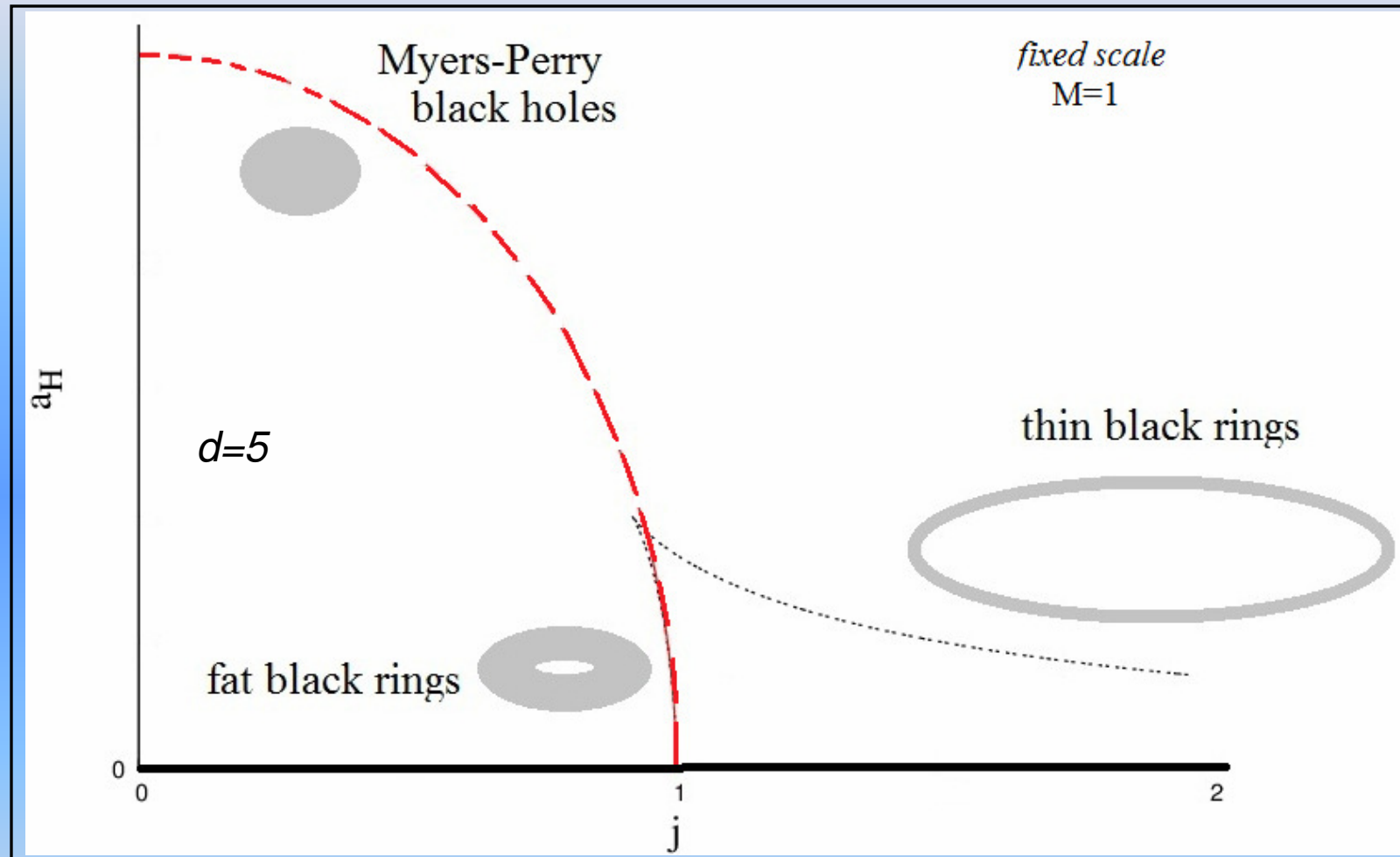
**emerging picture** ( + *Myers-Perry solutions*)

	<i>black rings</i>	<i>black ringoids</i>		
	$k = 0$	$k = 1$	$k = 2$	$k = 3$
$d = 5$	$S^2 \times S^1$			
$d = 6$	$S^3 \times S^1$			
$d = 7$	$S^4 \times S^1$	$S^2 \times S^3$		
$d = 8$	$S^5 \times S^1$	$S^3 \times S^3$		
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$d = 10$	$S^7 \times S^1$	$S^5 \times S^3$	$S^3 \times S^5$	
$d = 11$	$S^8 \times S^1$	$S^6 \times S^3$	$S^4 \times S^5$	$S^2 \times S^7$

$S^2 \times S^{d-4}$  : *special properties*

*the pattern of  $d=5$  black rings+MP*

*emerging picture:*



$S^2 \times S^{d-4}$  : special properties

*the pattern of  $d=5$  black rings+MP*

*our results (iii):*

**emerging picture ( + Myers-Perry solutions)**

	<i>black rings</i>	<i>black ringoids</i>		
	$k = 0$	$k = 1$	$k = 2$	$k = 3$
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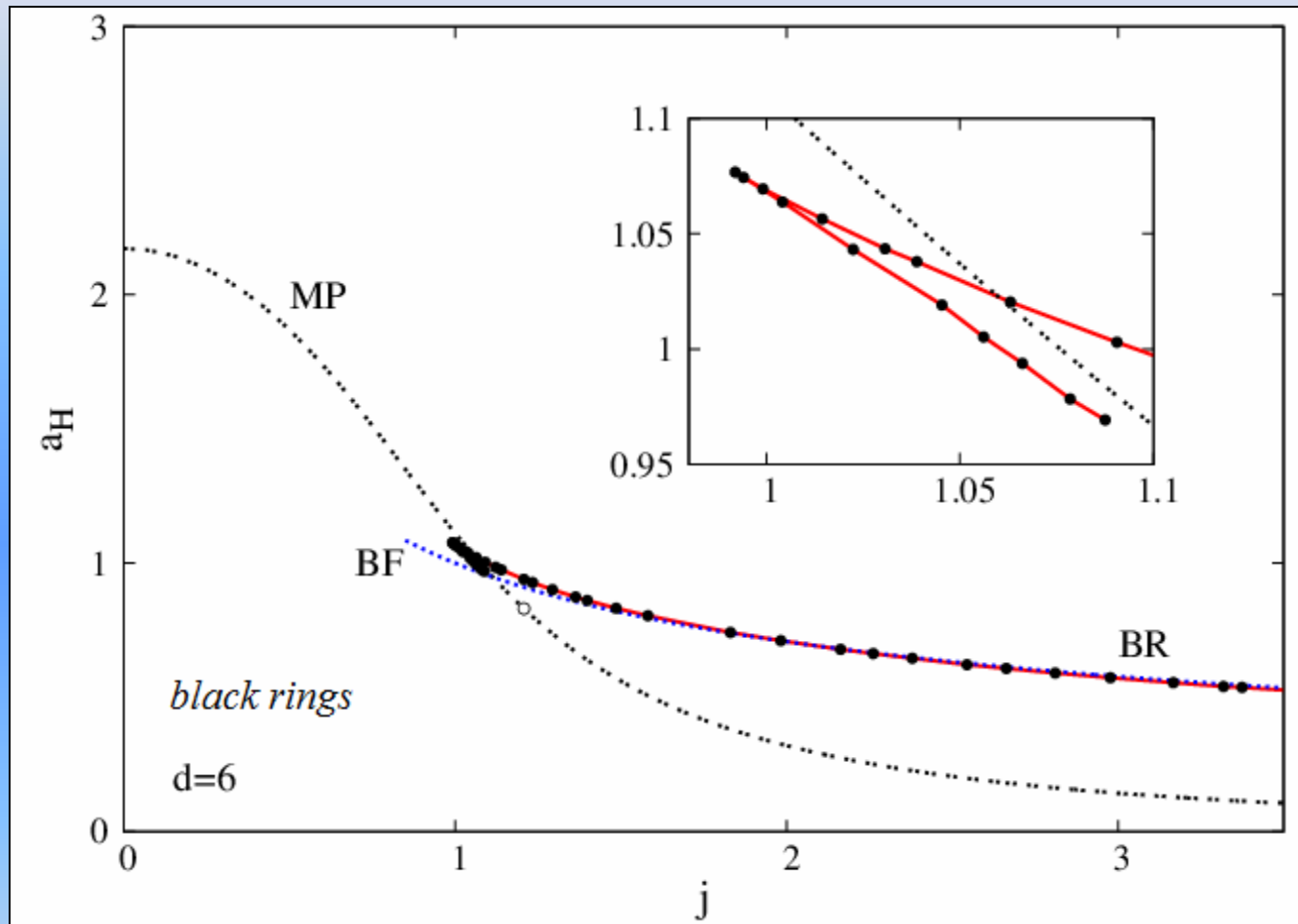
*generic  $S^p \times S^q$  solutions:*

$p > 2$

*the pattern of  $d=6$  black rings+MP*



*emerging picture:*



*generic  $S^p \times S^q$  solutions:*

$p > 2$

*the pattern of  $d=6$  black rings+MP*

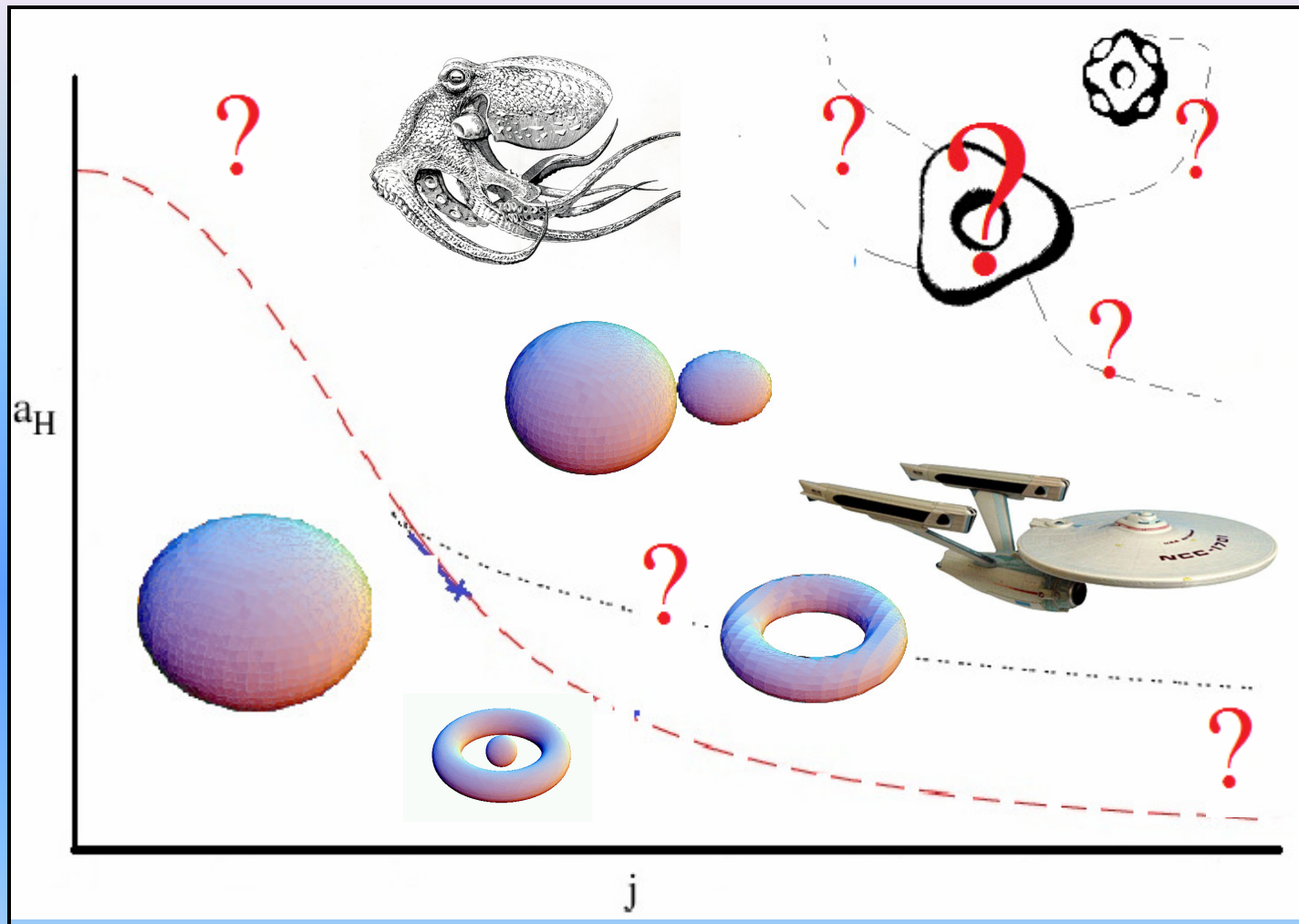
*finally* (speculation!):

*towards a periodic table of black objects?*

The image shows a standard periodic table of elements, color-coded by groups. The elements are arranged in rows and columns, with atomic numbers and symbols provided for each. The table is enclosed in a black border. Below the main table, the lanthanide and actinide series are shown in two separate rows.

1																	18														
1 H 1.01																	2 He 4.00														
3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18														
11 Na 22.99	12 Mg 24.30											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 36.95														
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80														
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (97.91)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.29														
55 Cs 132.91	56 Ba 137.33	57 La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.20	83 Bi 208.98	84 Po (209)	85 At (209.99)	86 Rn (222.02)														
87 Fr (223.02)	88 Ra (226.03)	89 Ac (227.03)	104 Rf (261.11)	105 Ha (262.11)	106 Sg (263.12)																										
																		58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (144.91)	62 Sm 150.36	63 Eu 151.97	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
																		90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237.05)	94 Pu (244.06)	95 Am (243.06)	96 Cm (247.07)	97 Bk (247.07)	98 Cf (251.08)	99 Es (252.08)	100 Fm (257.10)	101 Md (258.10)	102 No (259.10)	103 Lr (262.11)

*a black holes classification based  
on a finite number of simple features ?*



***THANK YOU VERY MUCH  
FOR YOUR ATTENTION!***