Gravitational collapse: confined geometries

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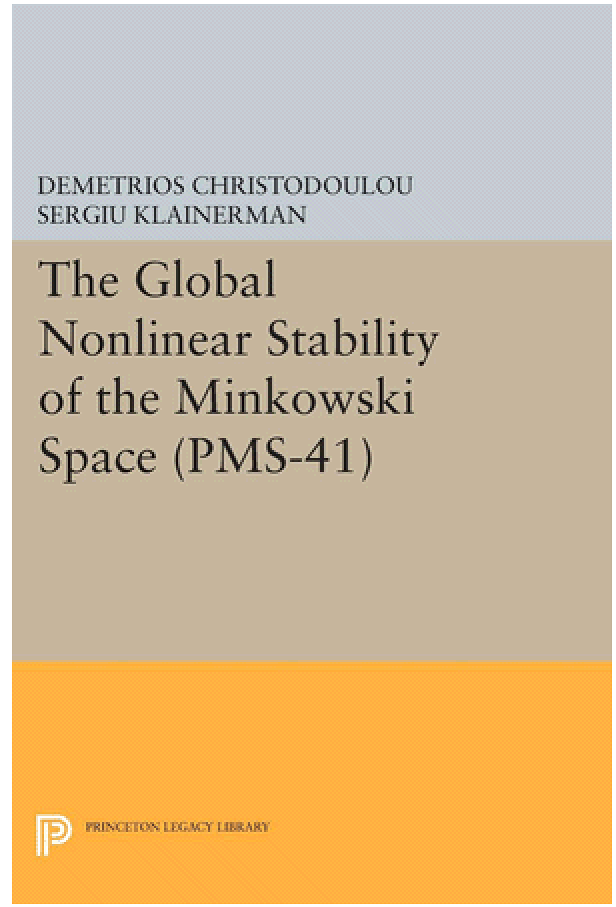
Cosmic Censorship

Horizon formation

Spacetime stability



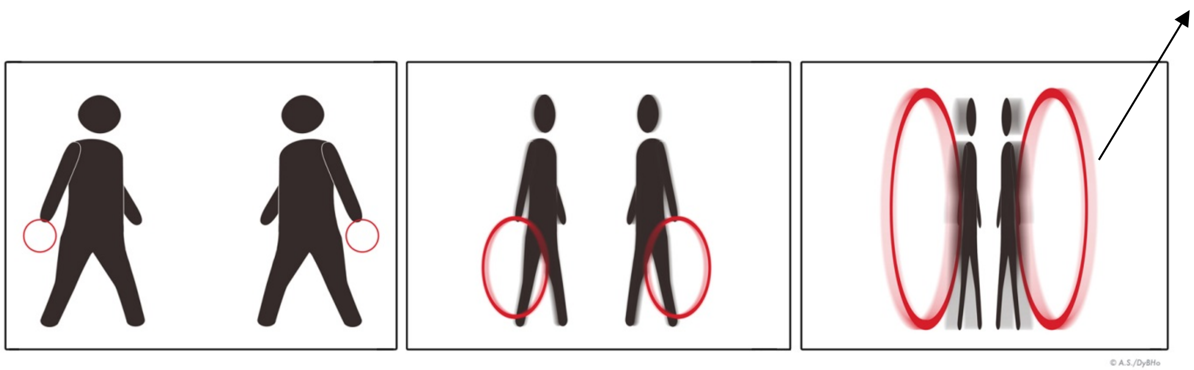
Hoop Conjecture

(Thorne 1972)

"An imploding object forms a BH when, and only when, a circular hoop with circumference 2π the Schwarzschild radius of the object can be made that encloses the object in all directions."

Large amount of energy in small region

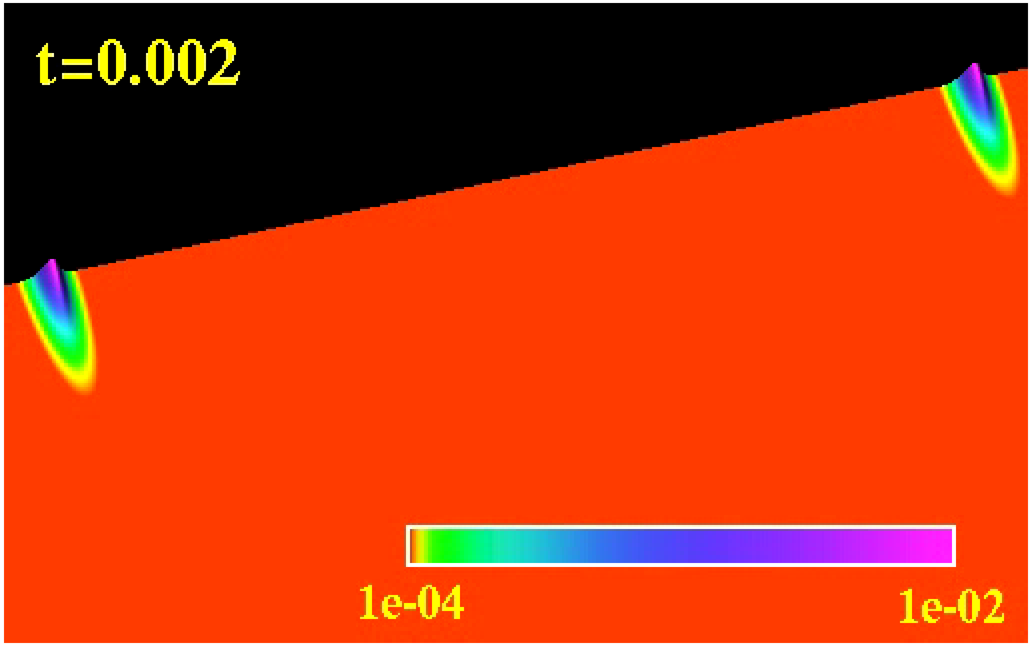
Hoop $R=2GM/c^2$



Size of electron: 10^(-17) cm

Schwarzschild radius: 10^(-55) cm

$$2M/R = 1/20 \Longrightarrow \gamma_{\rm crit} \sim 10$$



(Choptuik & Pretorius 2010, East & Pretorius 2012, Rezzolla & Takami 2012)

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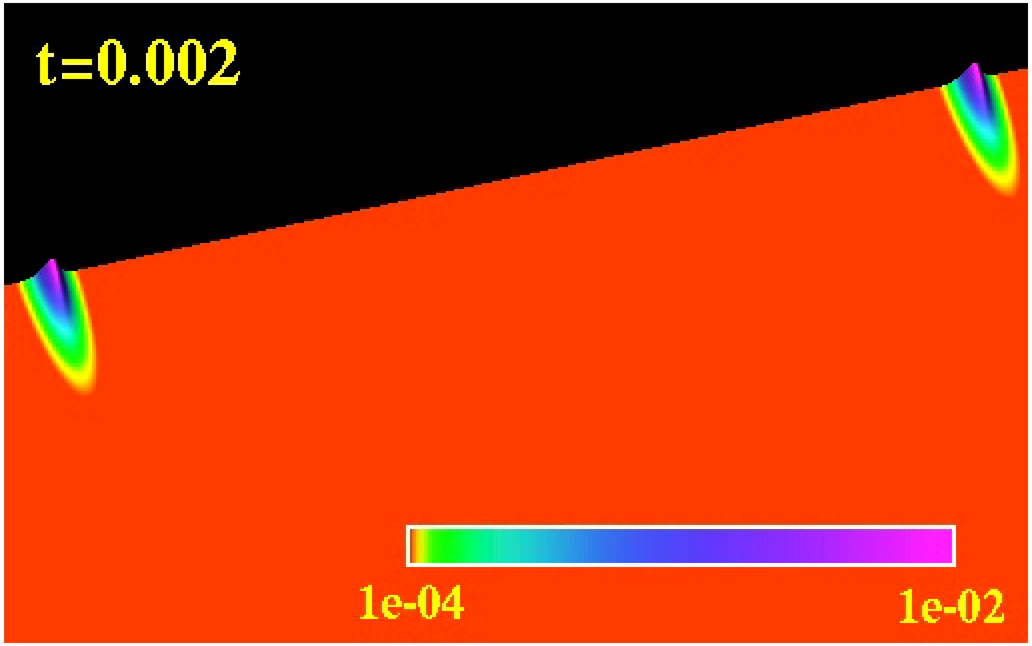

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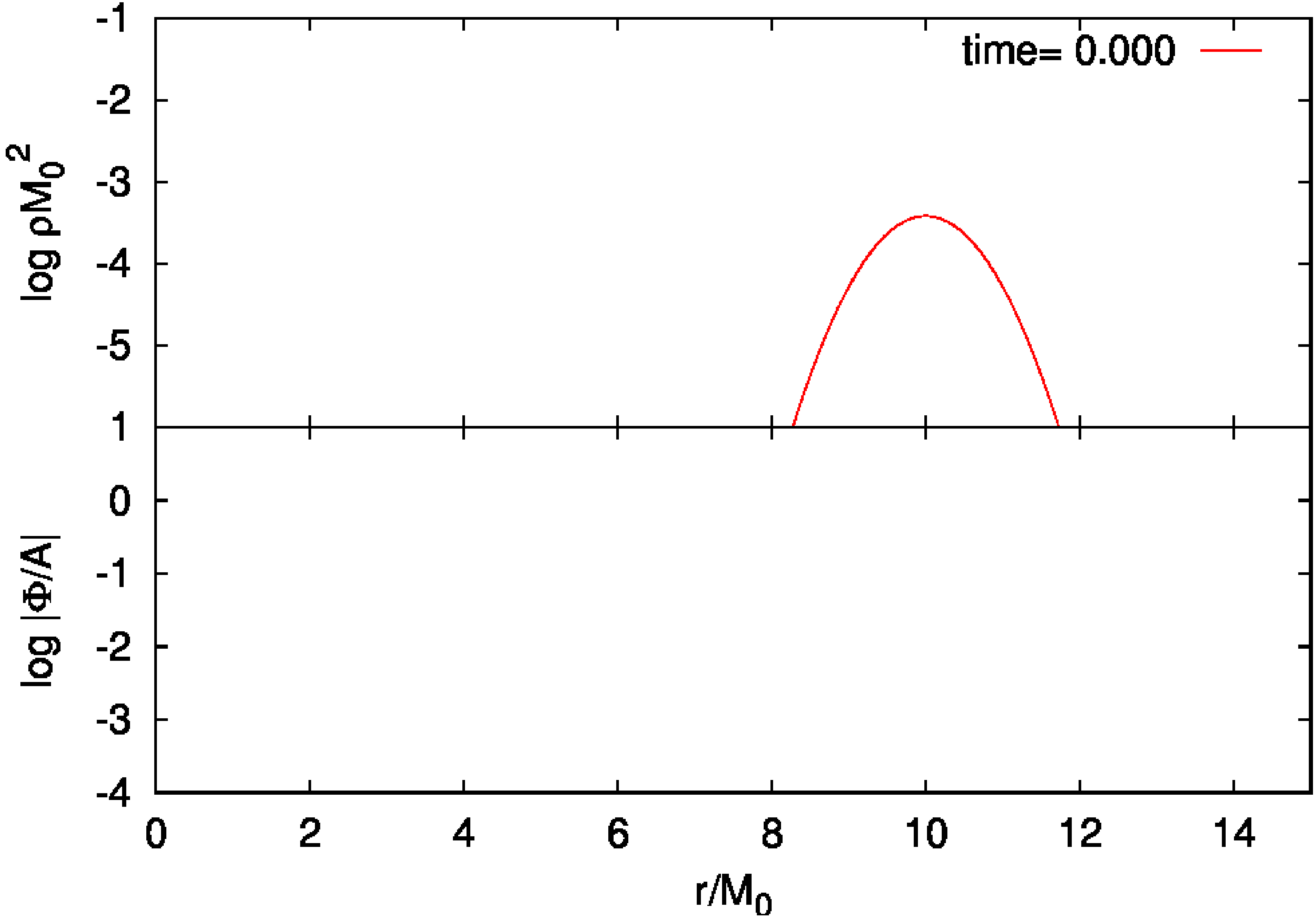
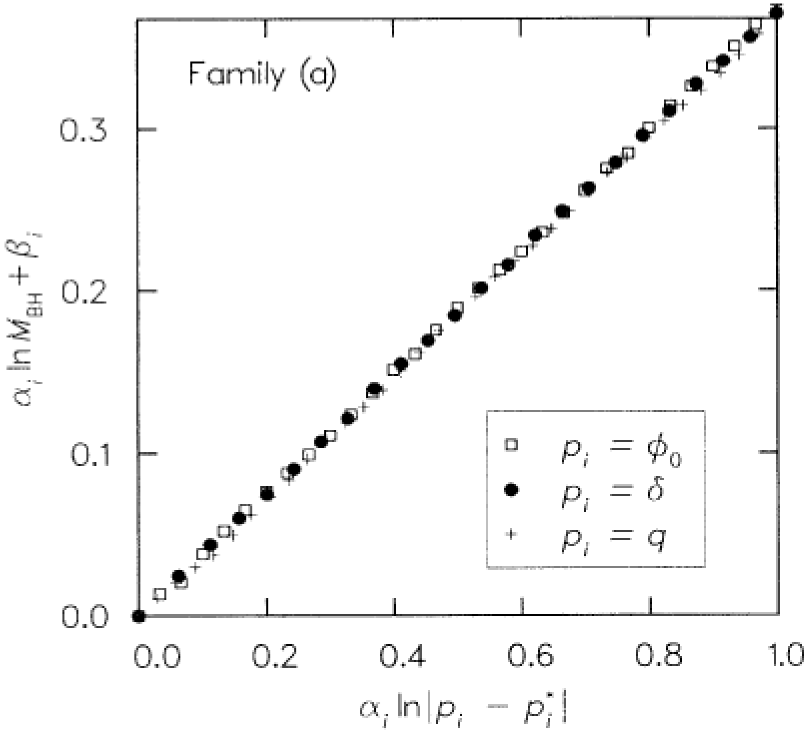


time= 0.000
log ρM0 2
-1
-2
-3
-4
-5
1
0
-1
-2
-3
-4
log |Φ/A|
0
2
4
6
8
10
12
14
r/M0

Collapse of massless scalar fields



$$\phi = \phi_0 r^3 \exp\left(-\left[(r - r_0)/\delta\right]^q\right)$$

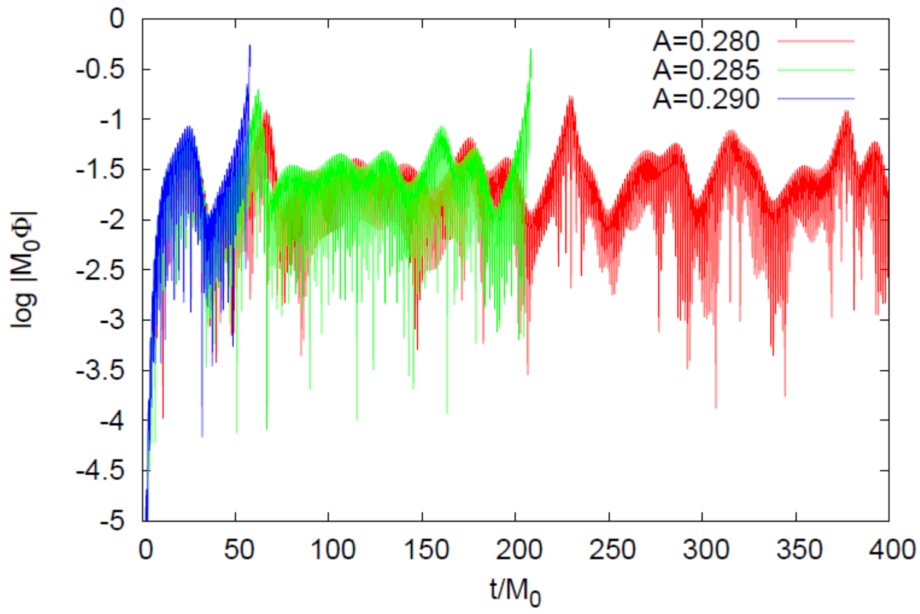
$$M \propto (p - p_*)^\gamma$$

Choptuik 1993

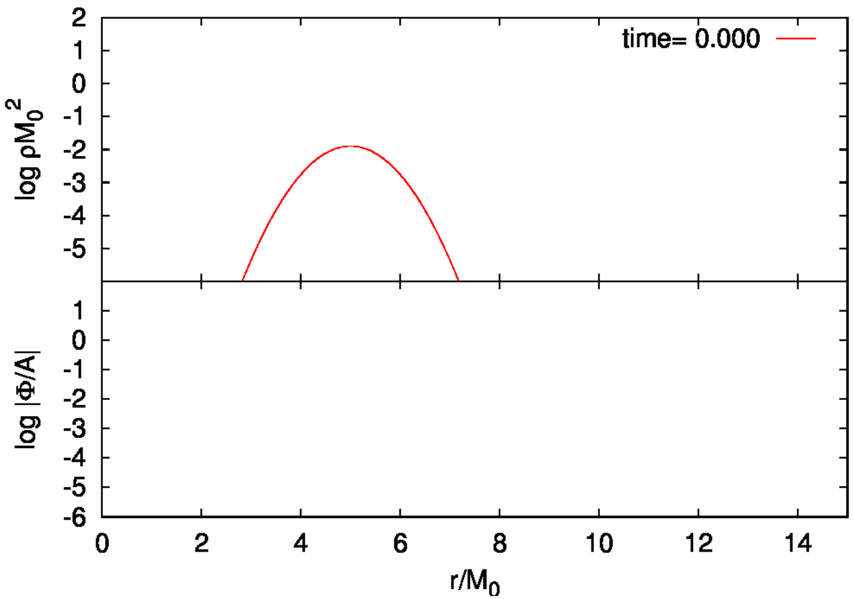
Confined geometries

Expect generically to favour collapse

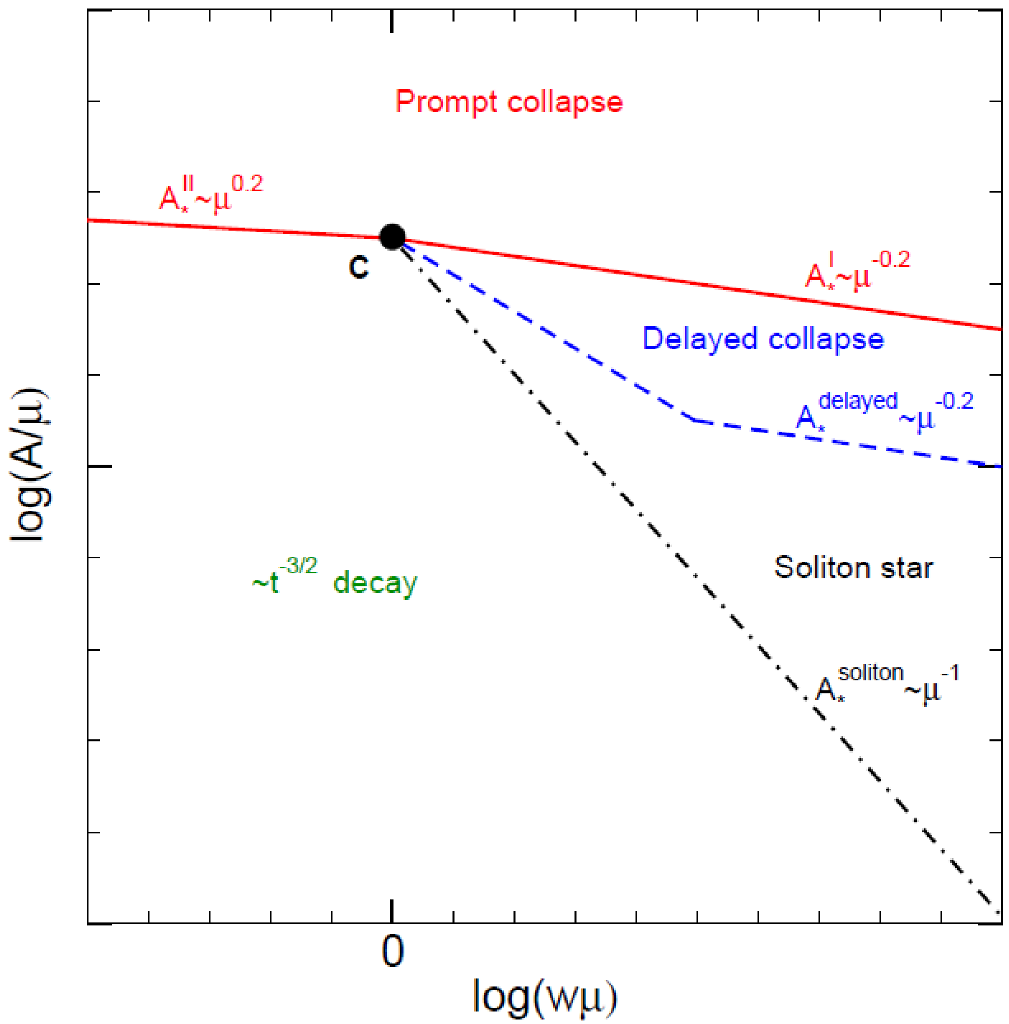
Important for some realistic setups: stars, massive fields, AdS



$r_0 = 5, w = 1.25$ and $\mu = 2$



Okawa, Cardoso & Pani , PRD89, 041502 (2014)



Okawa, Cardoso & Pani , PRD89, 041502 (2014)

Collapse in anti-de Sitter

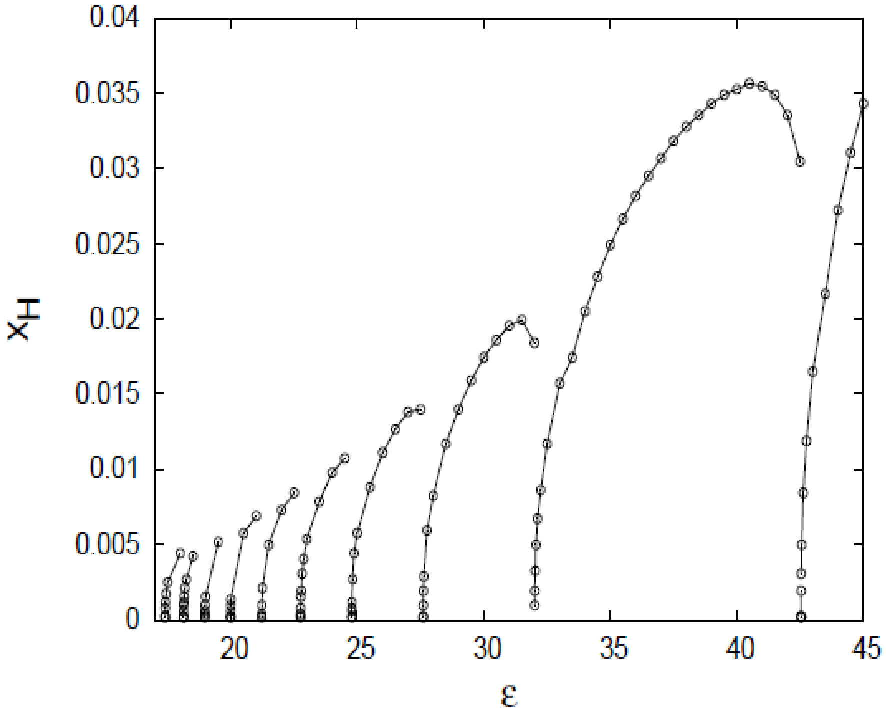
Maximally symmetric manifold, with constant negative scalar curvature

(the Lorentzian analogue of an hyperboloid)

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

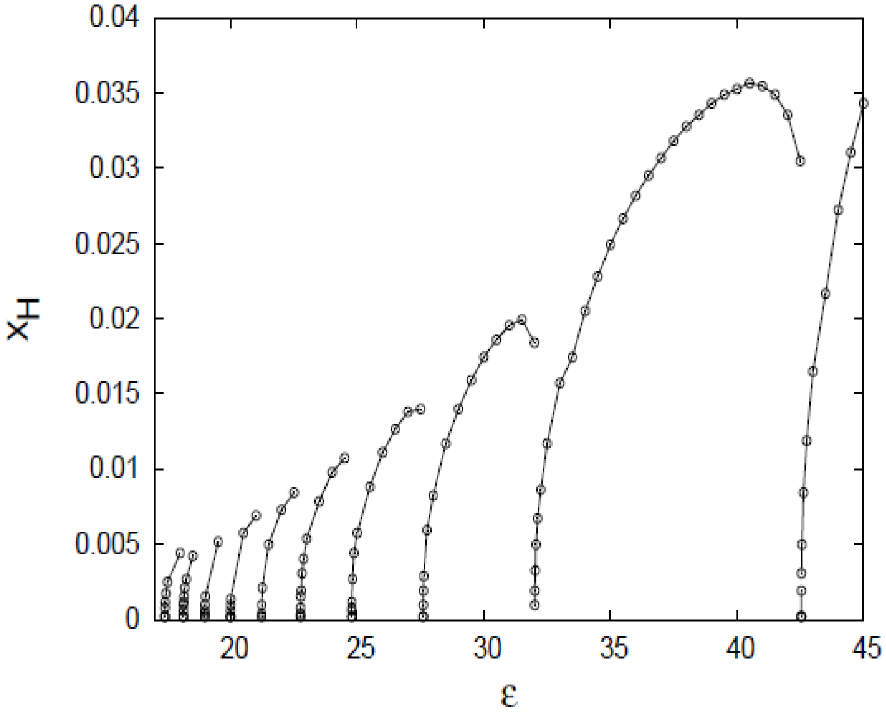
$$dr/dt = r^2/L^2 + 1\,, \quad t_{\rm travel} = \pi\, L/2$$

Collapse in anti-de Sitter



Bizon and Rostworowski 2011

Collapse in anti-de Sitter



...AdS is nonlinearly unstable!

Bizon and Rostworowski 2011

Resonances?

$$G_{\mu\nu} + \Lambda\, g_{\mu\nu} = 8\pi G \left(\partial_\mu \phi \partial_\nu \phi - \frac{1}{2} g_{\mu\nu} (\partial\phi)^2 \right)$$

$$\Box\phi = 0$$

$$ds^2 = \frac{\ell^2}{\cos^2 x} \left(-Ae^{-2\delta} dt^2 + A^{-1} dx^2 + \sin^2 x d\Omega^2 \right)$$

$$\phi(t,x) = \sum_{j=0}^{\infty} \phi_{2j+1} \epsilon^{2j+1} \,, A = 1 - \sum_{j=1}^{\infty} A_{2j} \epsilon^{2j} \,, \delta = \sum_{j=1}^{\infty} \delta_{2j} \epsilon^{2j}$$

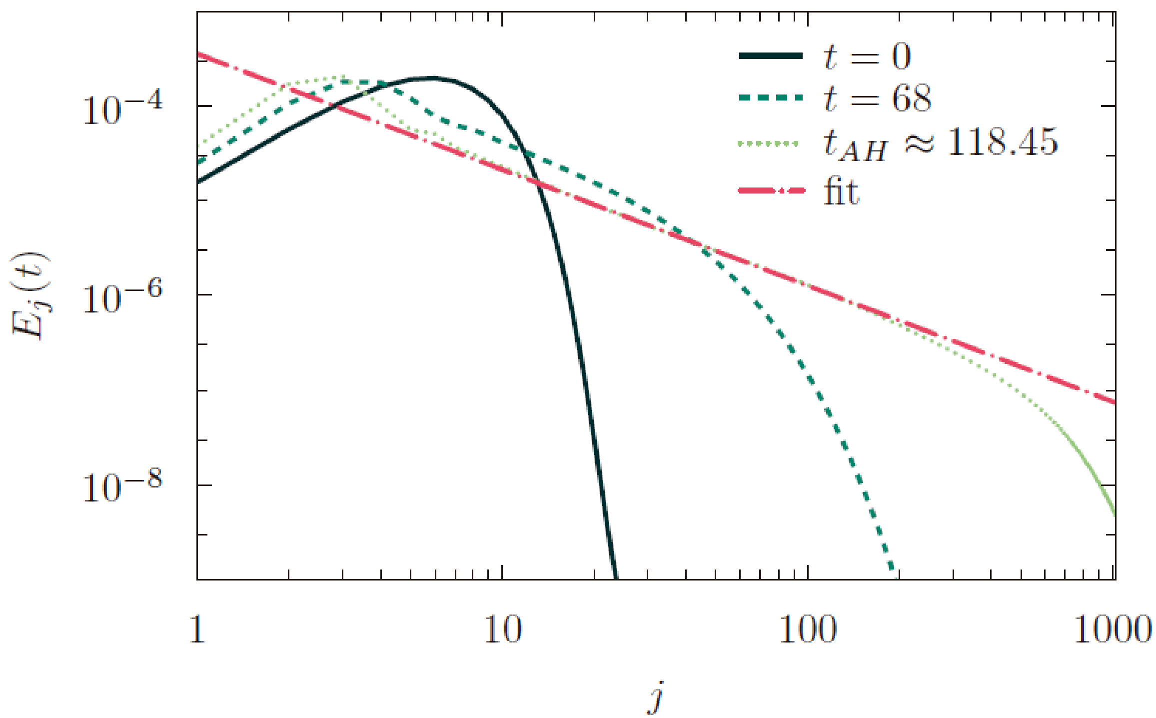
$$\phi_1(t,x) = \sum_{j=0}^{\infty} a_j \cos(\omega_j t + \beta_j)\, e_j(x)$$

$$\ddot{\phi}_3 + L\phi_3 = S(\phi_1, A_2, \delta_2)$$

Resonances appear whenever $\omega_j = \omega_{j_1} + \omega_{j_2} - \omega_{j_3}$

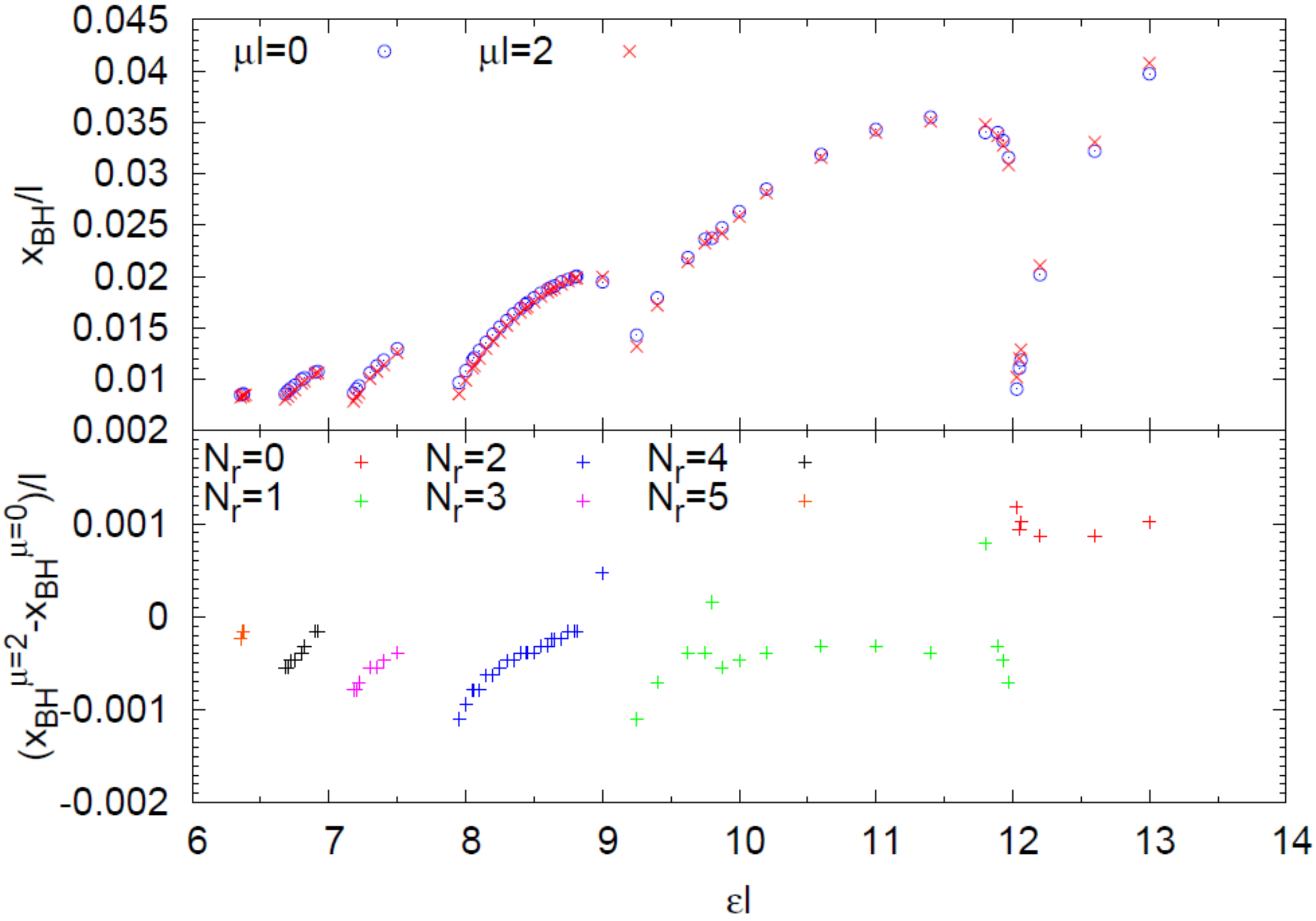
Weak turbulence?

Resonances appear whenever $\omega_j = \omega_{j_1} + \omega_{j_2} - \omega_{j_3}$



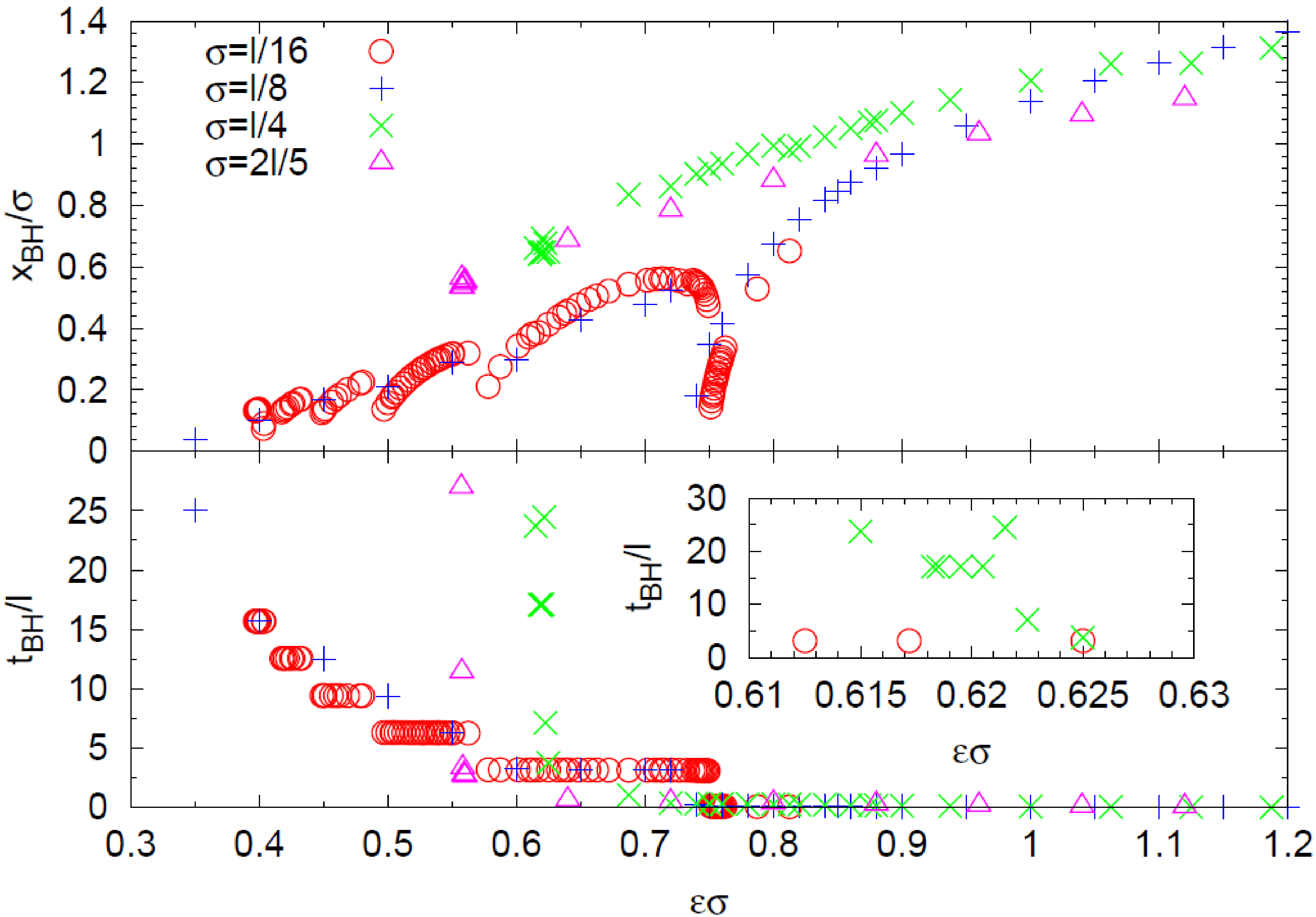
Maliborski 2012

Massive fields?

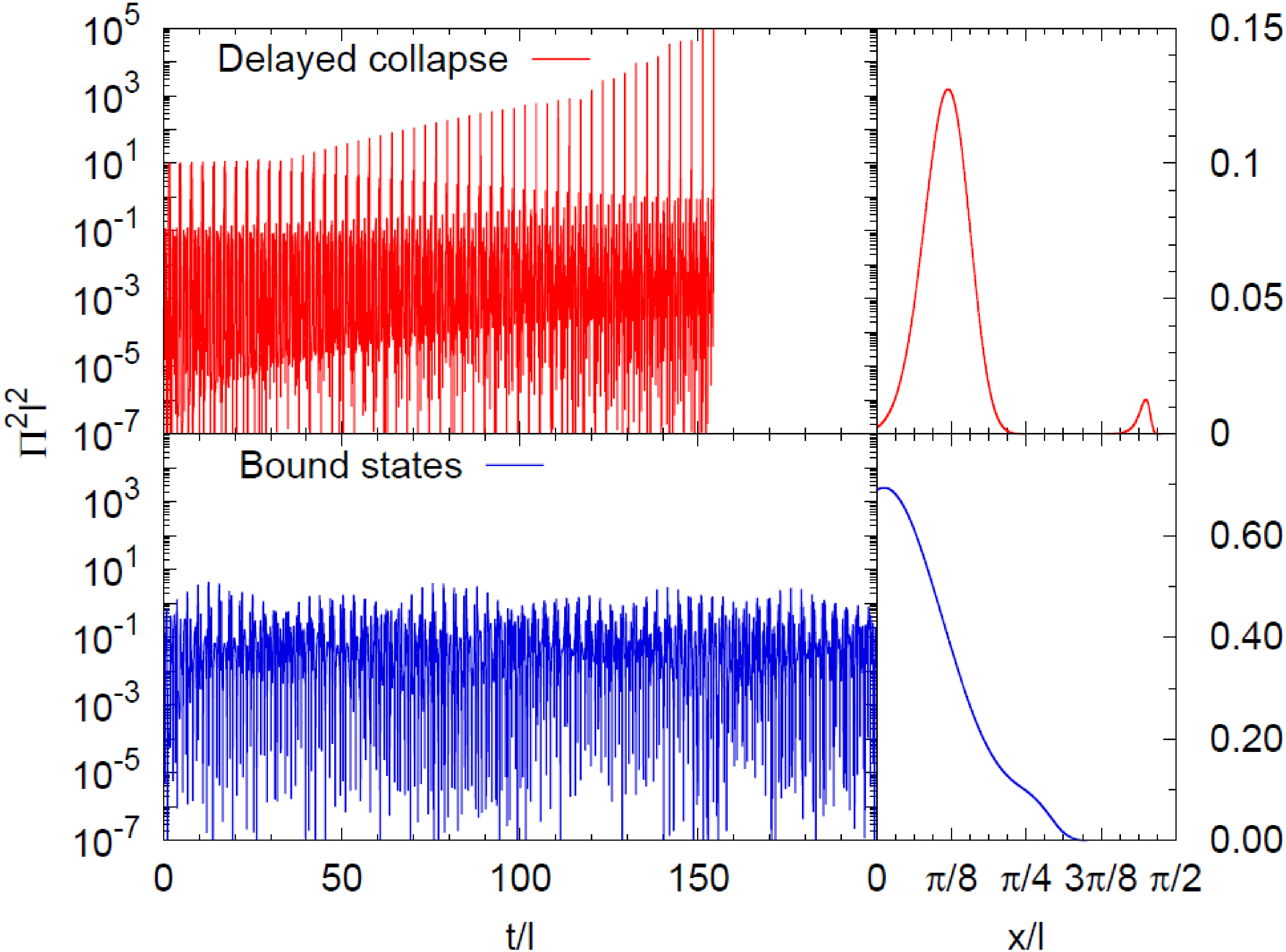


Resonances suggest that massive fields should also be turbulent...checked!

Okawa, Lopes & Cardoso 2015

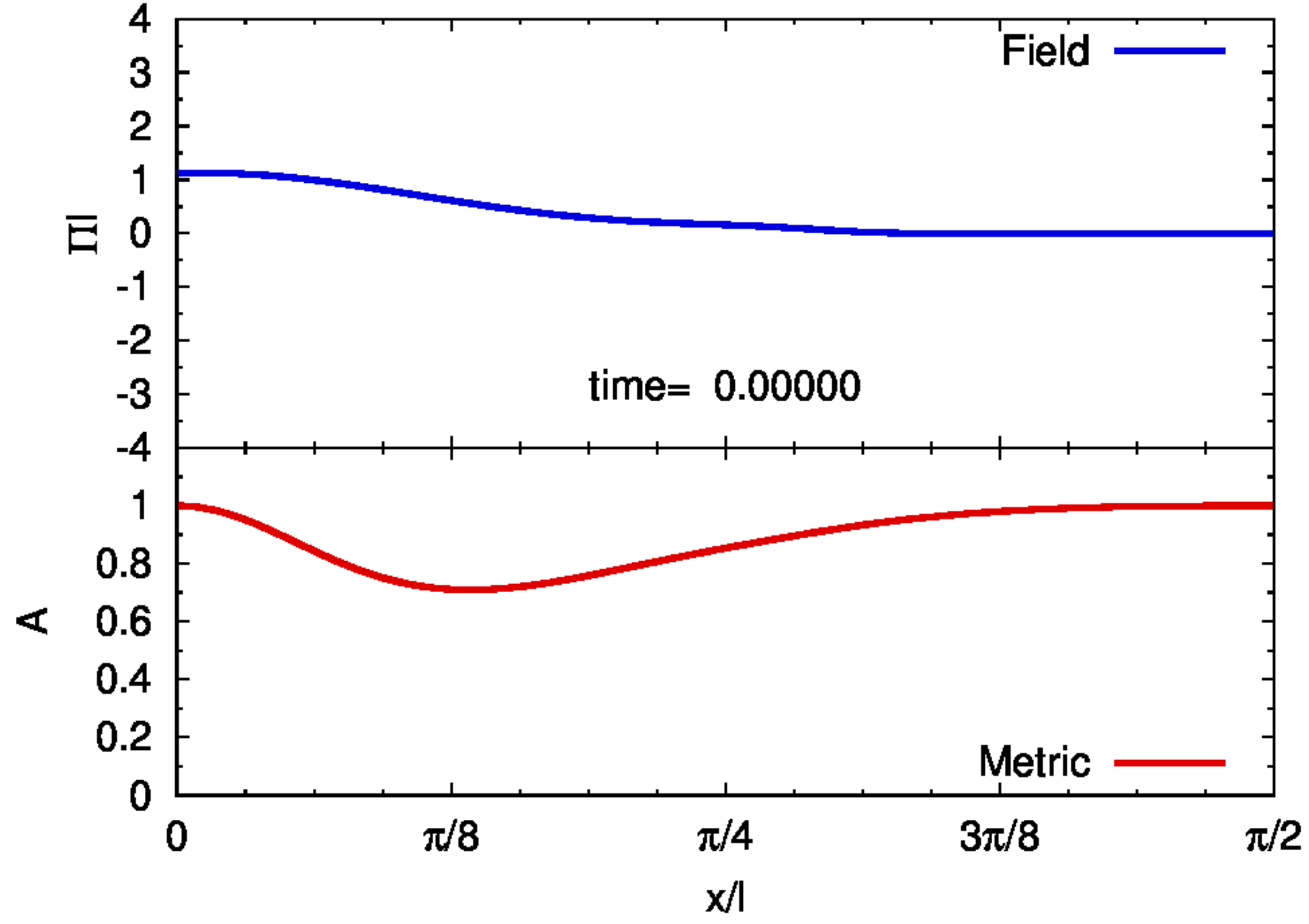


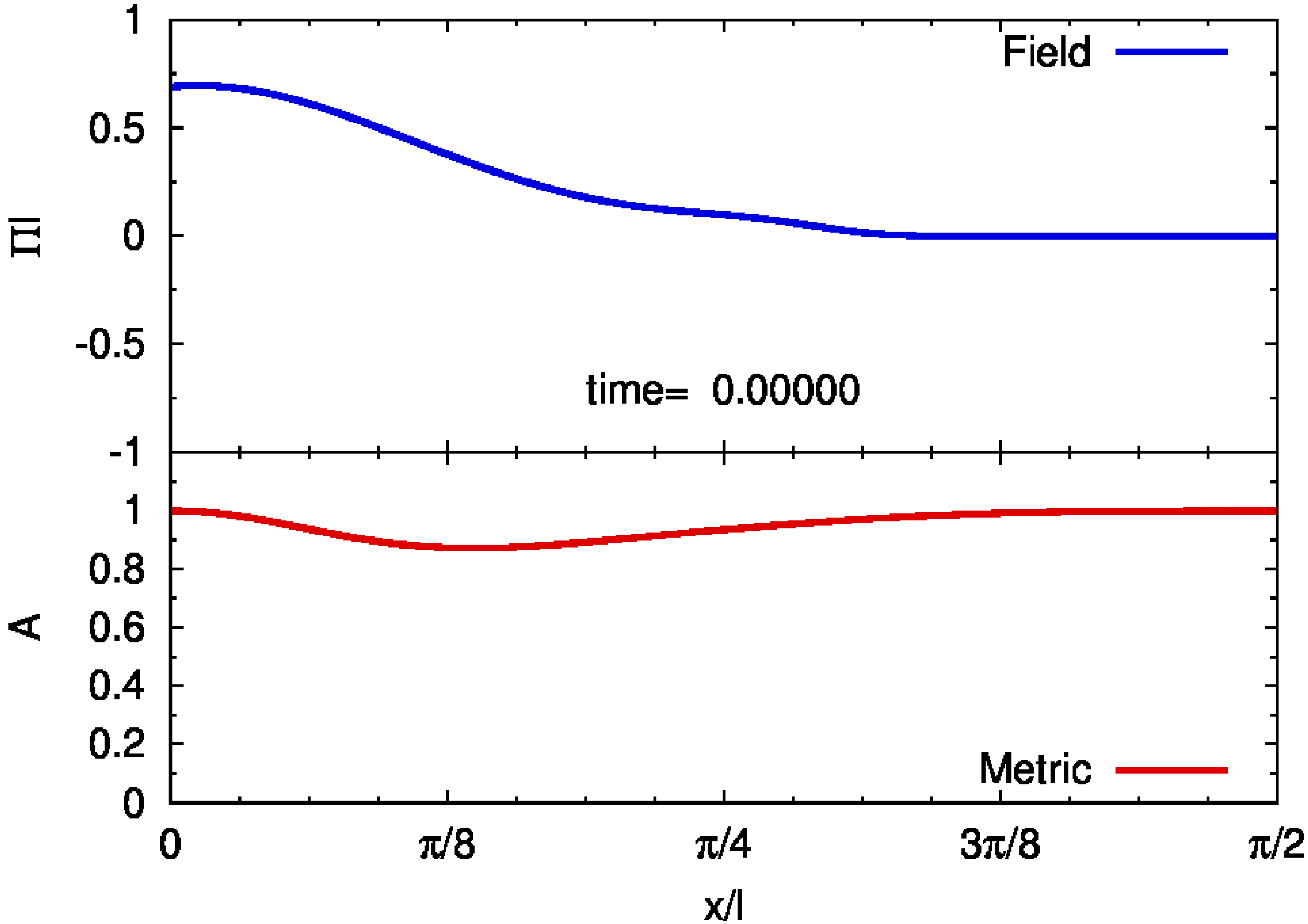
Wide initial data does not collapse...similar to oscillons of massive fields?...



Delayed collapse
Bound states
$|\Pi^2|^2$
Π
t/l
x/l
10^{5}
10^{3}
10^{1}
10^{-1}
10^{-3}
10^{-5}
10^{-7}
0
50
100
150
π/8
π/4
3π/8
π/2
0.15
0.1
0.05
0.60
0.40
0.20
0.00

Three wavepackets: collapse





Okawa, Lopes & Cardoso 2015

Strong field gravity is a fascinating topic

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Collapse close to critical points is of a self-similar nature and leads to a naked singularity (while not violating cosmic censorship in spirit). Collapse in confined geometries either forms nonlinearly-stable structures, or collapses at arbitrarily-small amplitudes.

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Delayed collapse of small amplitude fields remains a mystery. There are consequences for the gauge-gravity duality (essential thermalization of any field theory), are there consequences for astrophysics? Consequences for stability of stars?

Thank you