Critical Collapse in higher dimensions

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Critical Collapse

Choptuik 93

- When increasing the initial amplitude p of a collapsing matter distribution, there will be a critical p_* where black holes begin to form.

- In a *supercritical* collapse ($p>p^*$)

$$m_{bh} \sim (p-p^*)^{(D-3)\gamma}$$

- In a *subcritical* collapse ($p<p^*$)
  (Garfinkle & Duncan 98)

$$R_{max} \sim (p^*-p)^{-2\gamma}$$

- The critical solution is DSS

$$Z^*(r,t)= Z^*(r\, e^{\Delta}, t\, e^{\Delta})$$

- γ,Δ, and the critical solution are universal in the initial configuration space, but depend on the dimension: D.

- In 4D SF collapse, $\gamma \approx 0.38, \Delta \approx 3.44$

•We analyzed critical collapse in $4 \leq D \leq 11$ dimensions.

•The spacetime is asymptotically flat in (D-1)+1 dimensions.

•Matter content is a Spherically symmetric massless scalar field.

•The problem was formulated in double null coordinates, and solved using finite difference methods. The scaling exponent $\gamma(D)$ and the echoing period $\Delta(D)$ were extracted. Previous results for D=4 and D=6 were reproduced.

previous work: Garfinkle *et al* '99, 6D ; Birukou *et al* '02, 5-6D

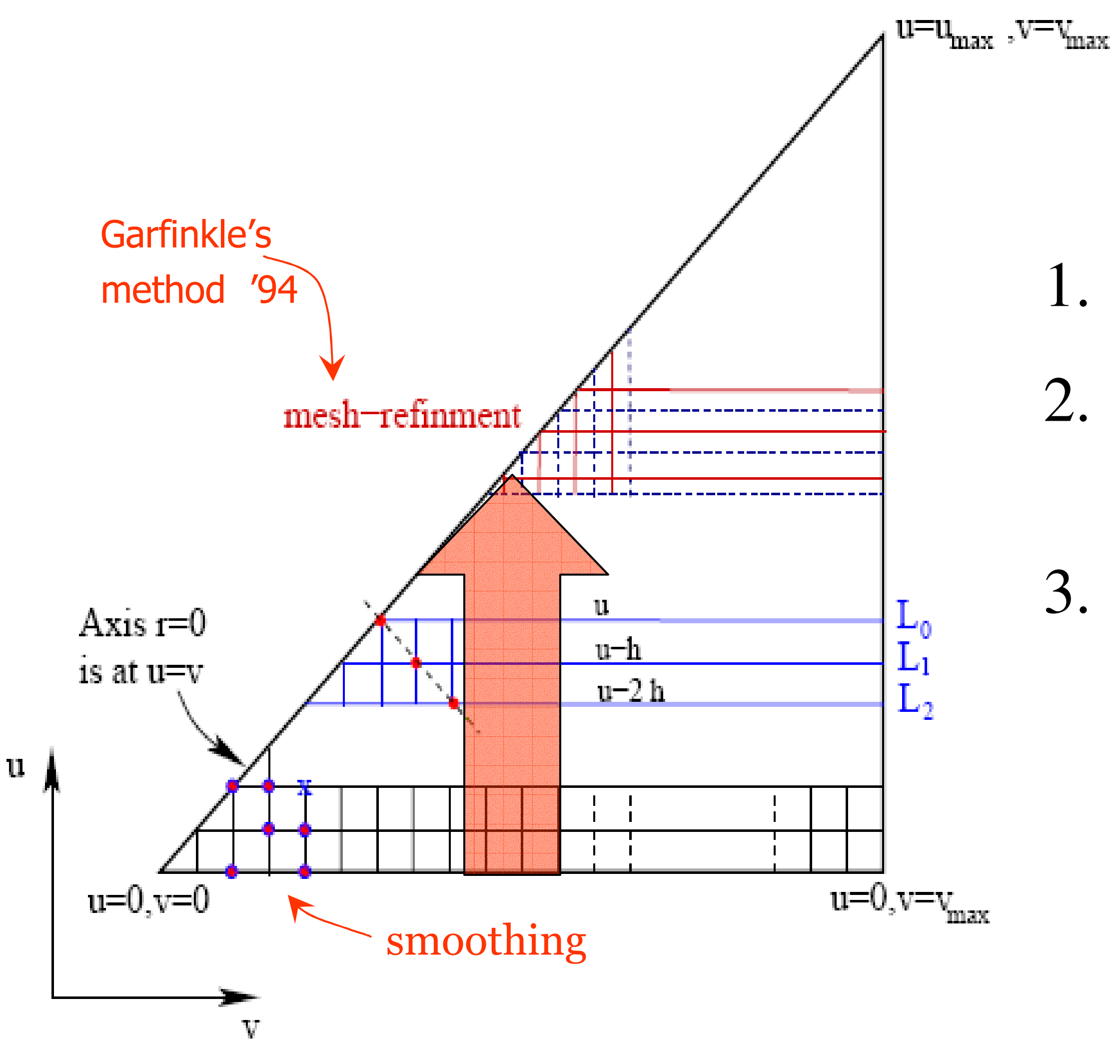
The action: A minimally coupled massless scalar field

$$I = \frac{1}{16\pi G_D}\int R\sqrt{-g}\,dx^D - \frac{1}{2}\int g_{ab}\partial^a\phi\,\partial^b\phi\sqrt{-g}\,dx^D$$

The metric: Spherically symmetric in double null coordinates

$$ds^2 = -\alpha(u,v)^2\,du\,dv + r(u,v)^2\,d\Omega_{D-2}^2$$

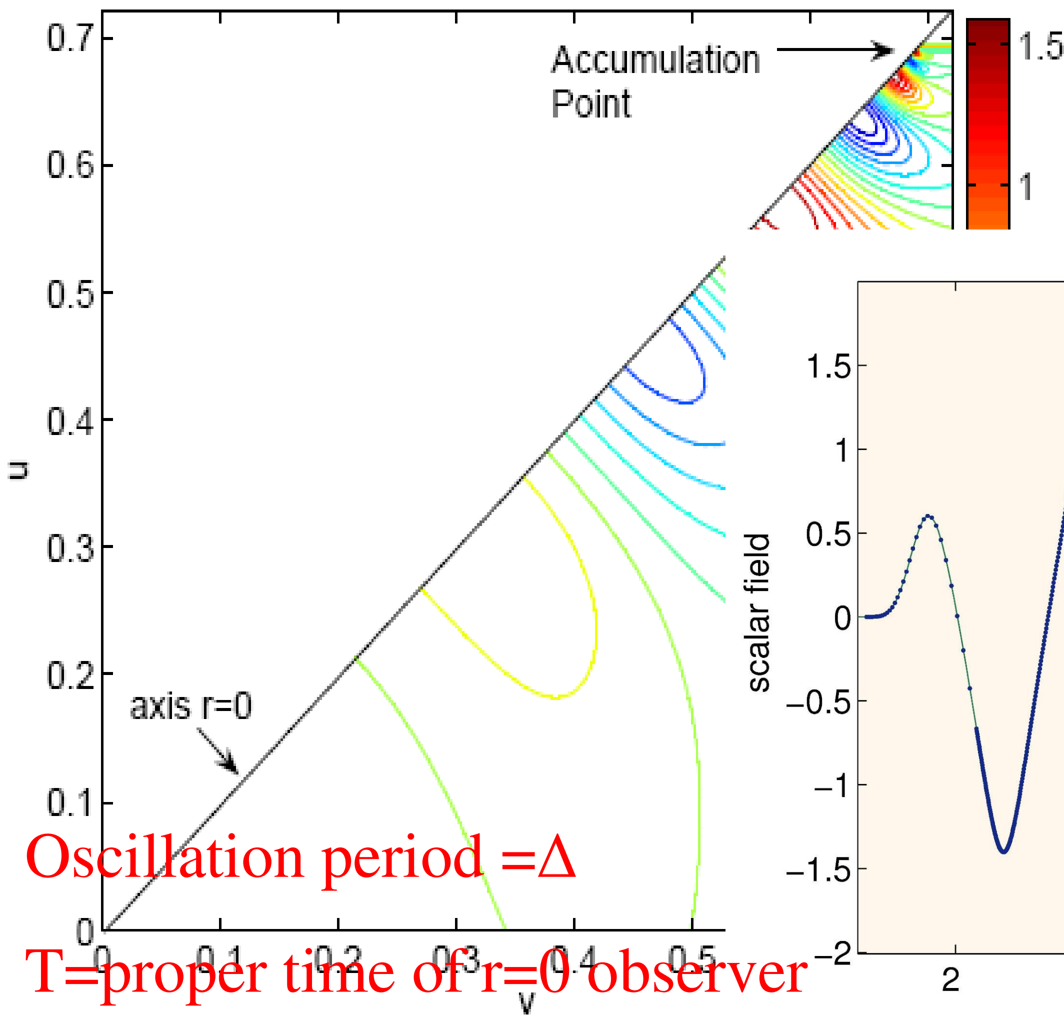
The numerical grid



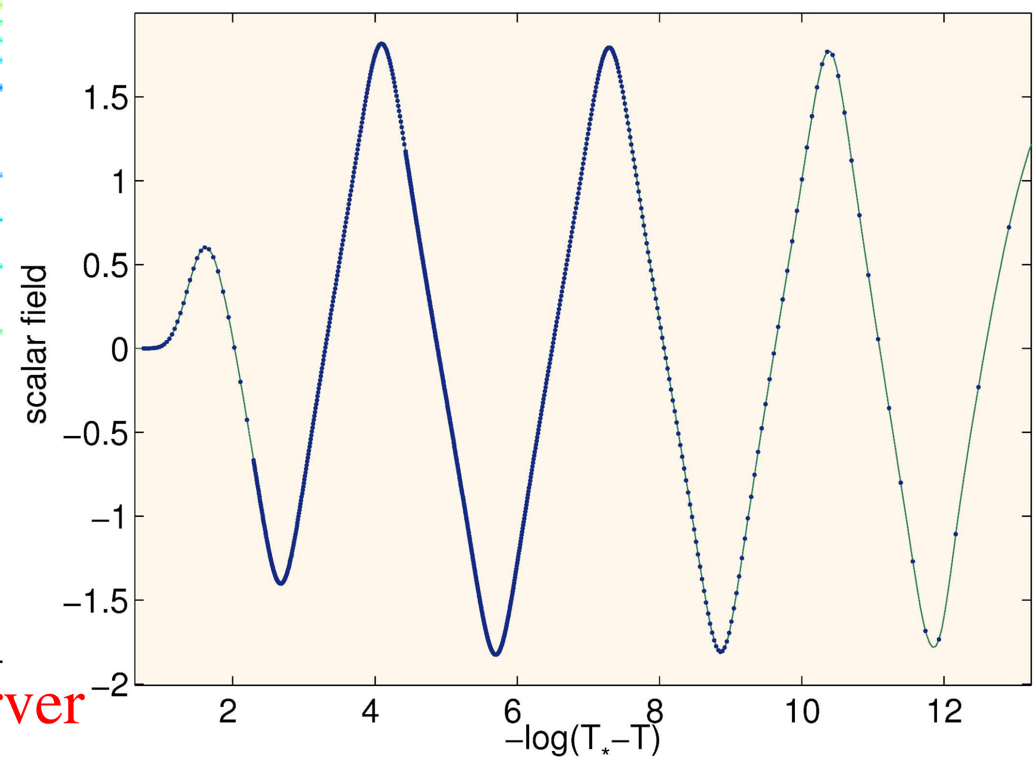
1. Mesh refinement
2. Series expansion near the axis
3. Numerical dissipation

Results

Contours of φ in 6D



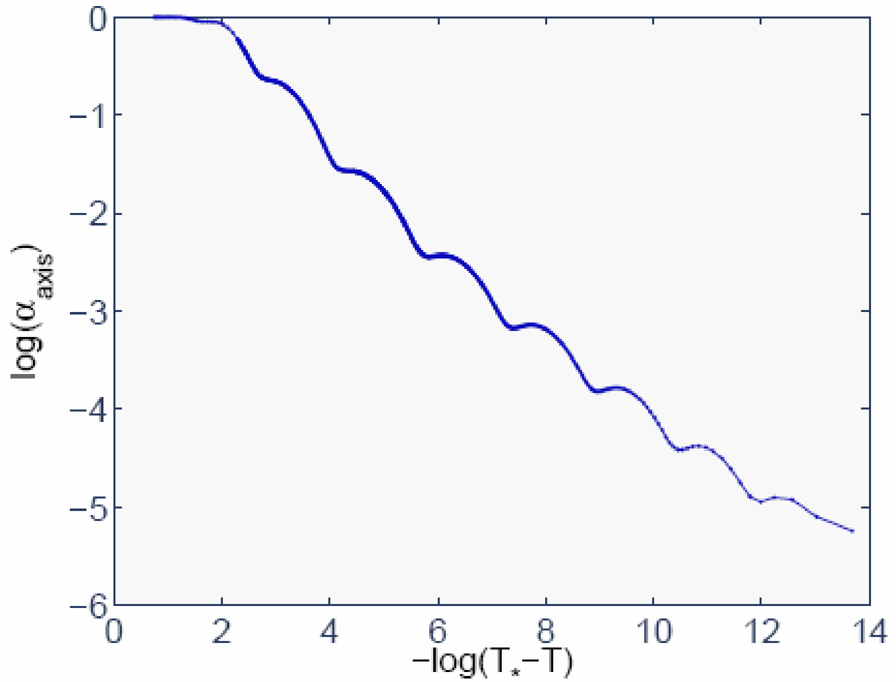
The results indicate that the qualitative features of critical collapse are

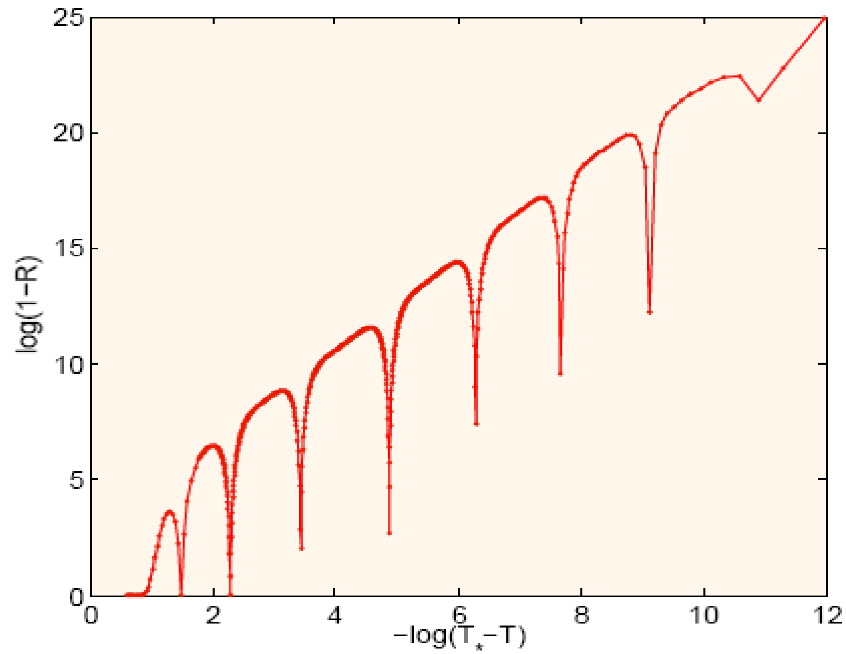


Oscillation period =Δ

T=proper time of r=0 observer

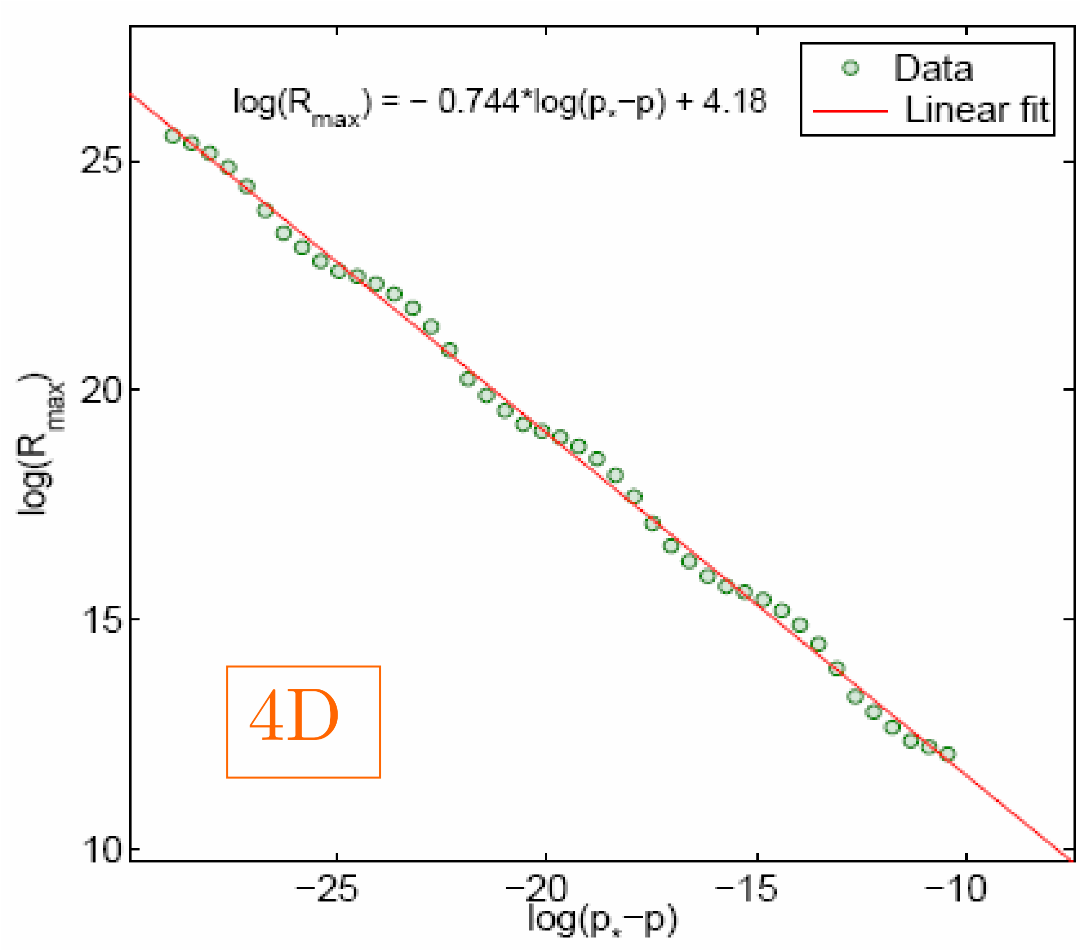
Results





$$ds^2 = -\alpha(u,v)^2 dudv + r(u,v)^2 d\Omega_{D-2}^2$$

Results



Each point in this plot is a separate run with a different amplitude. The slope is -2γ

The "wiggles" about the linear fit have the period

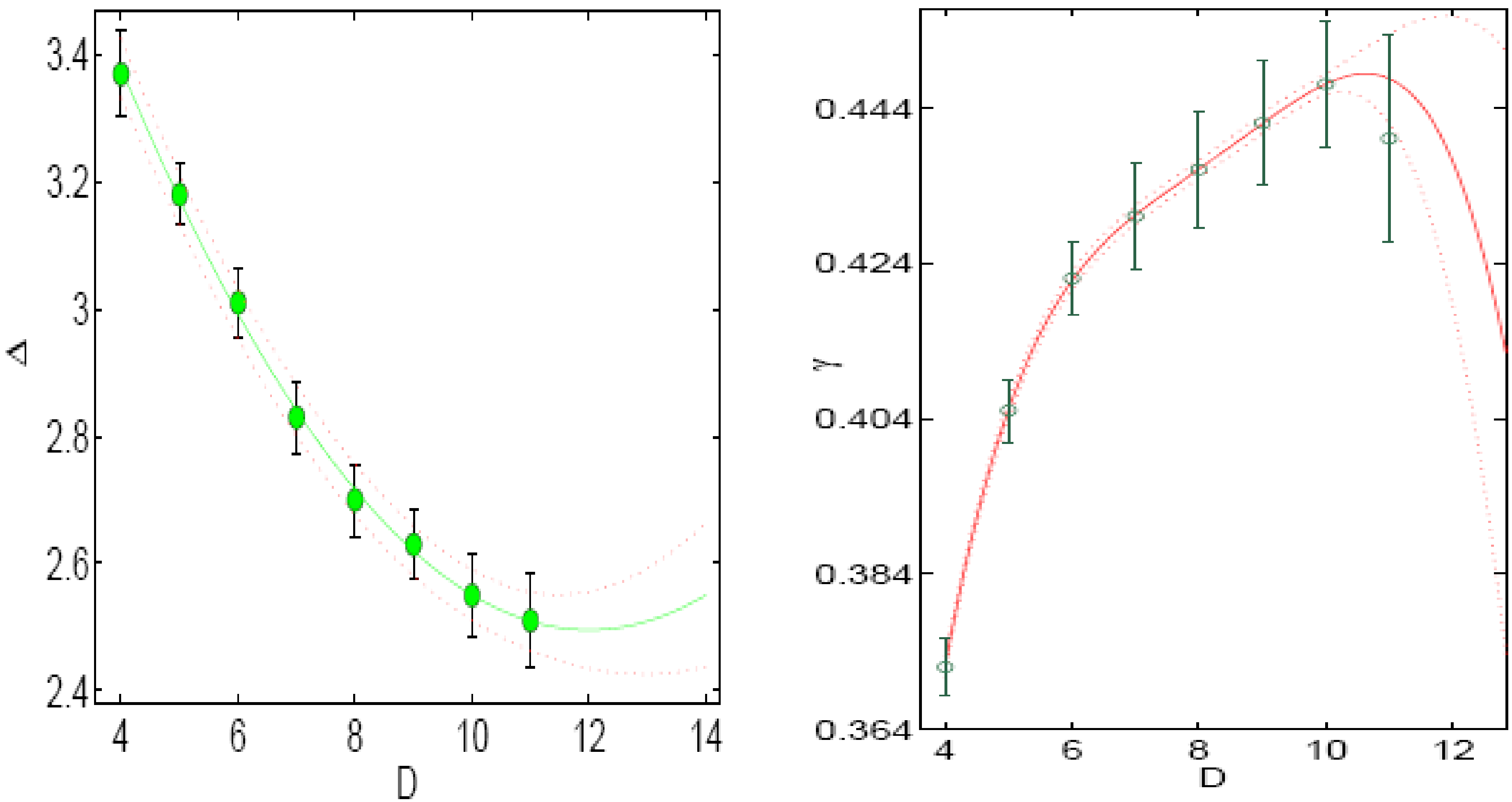
$$\Delta/(2\gamma)$$

[Gundlach 96; Hod & Piran 96]

This gives an alternative and consistent method to derive either Δ or γ.

$$R_{max} \sim (p^{*}-p)^{-2\gamma}$$

Results: the echoing period & scaling exp.



$$\gamma_{mass} = (D-3)\gamma$$

Concluding remarks

• We have obtained the mass scaling exponent and echoing period for $4 \le D \le 11$. The solution is DSS in all this range of dimensions, and shows no sign of changing this behavior.

• These results have since been confirmed and extended in an independent work by Bland et al., which go to $D<14$. They suggest an asymptotically constant value of the critical exponents, but the issue is still not fully resolved. Finer numerics are required.