Rotating black holes in 5D Einstein-Maxwell-Chern-Simons theory with negative cosmological constant

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RESEARCH TRAINING GROUP
Models of Gravity

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Rotating black holes in 5D Einstein-Maxwell-Chern-Simons theory with negative cosmological constant

1. Introduction

2. Near-horizon formalism

3. Exploring the global solutions

   EM-AdS vs EMCS-AdS $\lambda=1$ (SUGRA) vs EMCS-AdS $\lambda=1.5$

   Global solutions and branch structure for $\lambda>2$

1. Introduction

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Black holes in D=5 dimensions in
Einstein-Maxwell-Chern-Simons theory with negative cosmological constant

Asymptotically anti-de-Sitter space-times:
Interesting in the context of the AdS/CFT correspondence

Gravitating fields propagating in an AdS space-time

Fields propagating in a conformal field theory

Known analytical solutions:

- Myers-Perry black hole (uncharged)
- 5D Reissner-Nordström black hole (static)
- Cvetič-Lu-Pope black hole (rotating and charged, SUGRA) (PLB598 273) (PRL95 161301)

What are the properties of black holes connecting these solutions?

|| 1. Introduction ||

We are interested in the higher dimensional generalization of the Kerr-Newman black holes in 5D EMCS-AdS theory:

$$I = \frac{1}{16\pi G_5}\int d^5x\left[\sqrt{-g}(R - F^2 - 2\Lambda) - \frac{2\lambda}{3\sqrt{3}}\varepsilon^{\mu\nu\alpha\beta\gamma}A_\mu F_{\nu\alpha}F_{\beta\gamma}\right]$$

R = curvature scalar

U(1) electro-magnetic potential A_μ

F = field strength tensor

Λ = cosmological constant

λ = Chern-Simons coupling parameter

|| 1. Introduction ||

$$I = \frac{1}{16\pi G_5} \int d^5x \left[\sqrt{-g}(R - F^2 - 2\Lambda) - \frac{2\lambda}{3\sqrt{3}} \varepsilon^{\mu\nu\alpha\beta\gamma} A_\mu F_{\nu\alpha} F_{\beta\gamma} \right]$$

Einstein-Maxwell-Chern-Simons theory in 5 dimensions

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 2\left(F_{\mu\rho} F^{\rho}{}_{\nu} - \frac{1}{4} F^2 \right)$$

Einstein equations

$$G_5 = 1$$

$$\nabla_\nu F^{\mu\nu} + \frac{\lambda}{2\sqrt{3}} \varepsilon^{\mu\nu\alpha\beta\gamma} F_{\nu\alpha} F_{\beta\gamma} = 0$$

Maxwell equations

Ansatz constraints:

1. Axially symmetric and stationary: $U(1)^N$ symmetry
   In D dimensions N = [(D-1)/2] (planes of rotation)

2. All angular momenta of equal magnitude: enhanced *U(N)* symmetry

$$| J_{(1)} | = | J_{(2)} | = \dots = | J_{(N)} | = J$$

3. Event horizon with spherical topology

4. Asymptotically AdS

|| 1. Introduction ||

Ansatz for the metric (5D):

$$ds^2 = -b(r)dt^2 + \frac{1}{u(r)}dr^2 + g(r)d\theta^2 + p(r)\sin^2\theta\left(d\varphi_1 - \frac{\omega(r)}{r}dt\right)^2$$
$$+p(r)\cos^2\theta\left(d\varphi_2 - \frac{\omega(r)}{r}dt\right)^2 + (g(r) - p(r))\sin^2\theta\cos^2\theta(d\varphi_1 - d\varphi_2)^2$$

$$\theta \in [0, \pi/2],\ \varphi_1 \in [0, 2\pi]\ \text{and}\ \varphi_2 \in [0, 2\pi]$$

Lewis-Papapetrou coordinates. The radial coordinate **r** is quasi-isotropic.

Ansatz for the gauge field:

$$A_\mu dx^\mu = a_0(r)dt + a_\varphi(r)(\sin^2\theta d\varphi_1 + \cos^2\theta d\varphi_2)$$

System of second order ordinary differential equations + constraints

|| 1. Introduction ||

Global Charges:

Mass

$$M = -\frac{\pi}{8}\frac{\beta - 3\alpha}{L^2}$$

(Ashtekar-Magnon-Das conformal mass)

Angular Momenum

$$J_{(k)} = \int_{S^3_\infty} \beta_{(k)}$$

$$\beta_{(k)\mu_1\mu_2\mu_3} \equiv \epsilon_{\mu_1\mu_2\mu_3\rho\sigma}\nabla^\rho \eta^\sigma_{(k)}$$

$$|J_{(k)}| = J$$

Electric charge

$$Q = -\frac{1}{2}\int_{S^3_\infty} \tilde{F}$$

$$\tilde{F}_{\mu_1\mu_2\mu_3} \equiv \epsilon_{\mu_1\mu_2\mu_3\rho\sigma} F^{\rho\sigma}$$

|| 1. Introduction ||

Horizon Charges:

Area

$$A_{\mathrm{H}} = \int_{\mathcal{H}} \sqrt{|g^{(3)}|} = 2\pi^2 r_{\mathrm{H}}^3 \lim_{r \to r_{\mathrm{H}}} \sqrt{\frac{m^2 n}{f^3}}$$

Entropy

$S = 4\pi A_{\mathrm{H}}$

Horizon Mass

$$M_{\mathrm{H}} = -\frac{3}{2} \int_{\mathcal{H}} \alpha = \lim_{r \to r_{\mathrm{H}}} 2\pi^2 r^3 \sqrt{\frac{mn}{f^3}} \left[\frac{n\omega}{f} \left(\frac{\omega}{r} - \omega' \right) + f' \left(1 + \frac{r^2}{L^2} \right) + \frac{2rf}{L^2} \right]$$

Horizon Angular Momenta

$$J_{\mathrm{H}(k)} = \int_{\mathcal{H}} \beta_{(k)} = \lim_{r \to r_{\mathrm{H}}} \pi^2 r^3 \sqrt{\frac{mn^3}{f^5}} \left[\omega - r\omega' \right]$$

2. Near-horizon formalism

|| 2. Near Horizon Formalism ||

Properties of the near-horizon geometry of extremal black holes.

H. K. Kunduri and J. Lucietti, Living Reviews in Relativity 16 (2013)

- The near-horizon geometry of extremal black holes with spherical topology is the product of two independent spaces.

$$AdS_2 \times S^{D-2}$$

Isometries: $SO(2,1) \times SO(D-1)$ static case (sphere)

$SO(2,1) \times U(1)^N$ rotation (squashed sphere)

This factorization is obtained for all the known examples of topologically spherical black holes

|| 2. Near Horizon Formalism ||

Hence we can assume such factorization in our black holes (extremal case)

Metric:

$$ds^2 = v_1(dr^2/r^2 - r^2dt^2) + v_2[4d\theta^2 + \sin^2 2\theta(d\phi_2 - d\phi_1)^2]$$
$$+v_2\eta[d\phi_1 + d\phi_2 + \cos^2 2\theta(d\phi_2 - d\phi_1) - \alpha r dt]^2$$

Gauge potential:

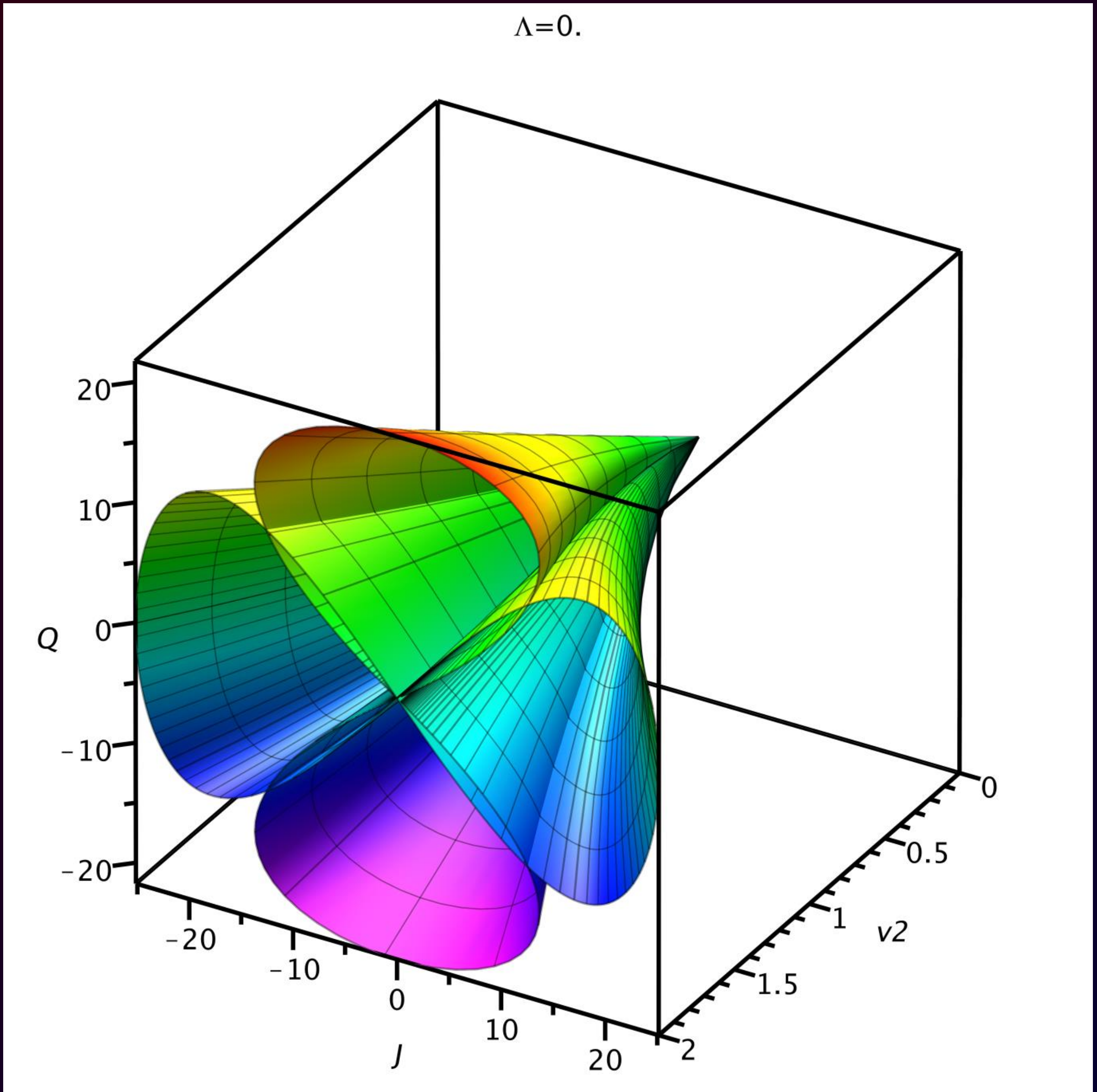
$$A = -(\rho + p\alpha)rdt + 2p(\sin^2\theta d\phi_1 + \cos^2\theta d\phi_2)$$

- Field equations + Ansatz: algebraic relations for the Ansatz parameters

- Global charges can be calculated: **(J, Q)**
- Horizon charges: area, horizon angular momentum

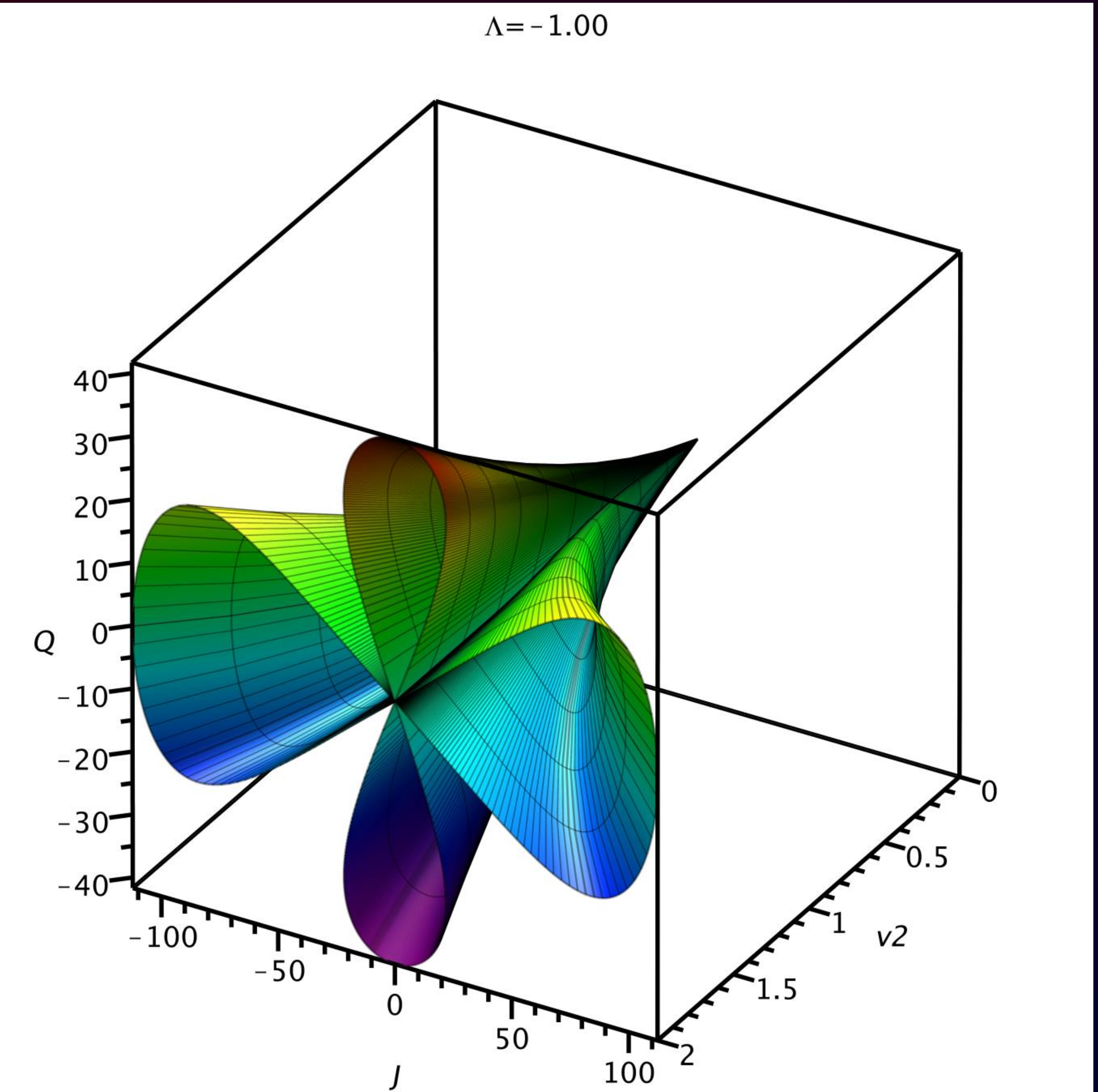
- Parameters related to the asymptotical structure of the global solution cannot be calculated: Mass, angular velocity

Near-horizon geometry branch structure: EM flat



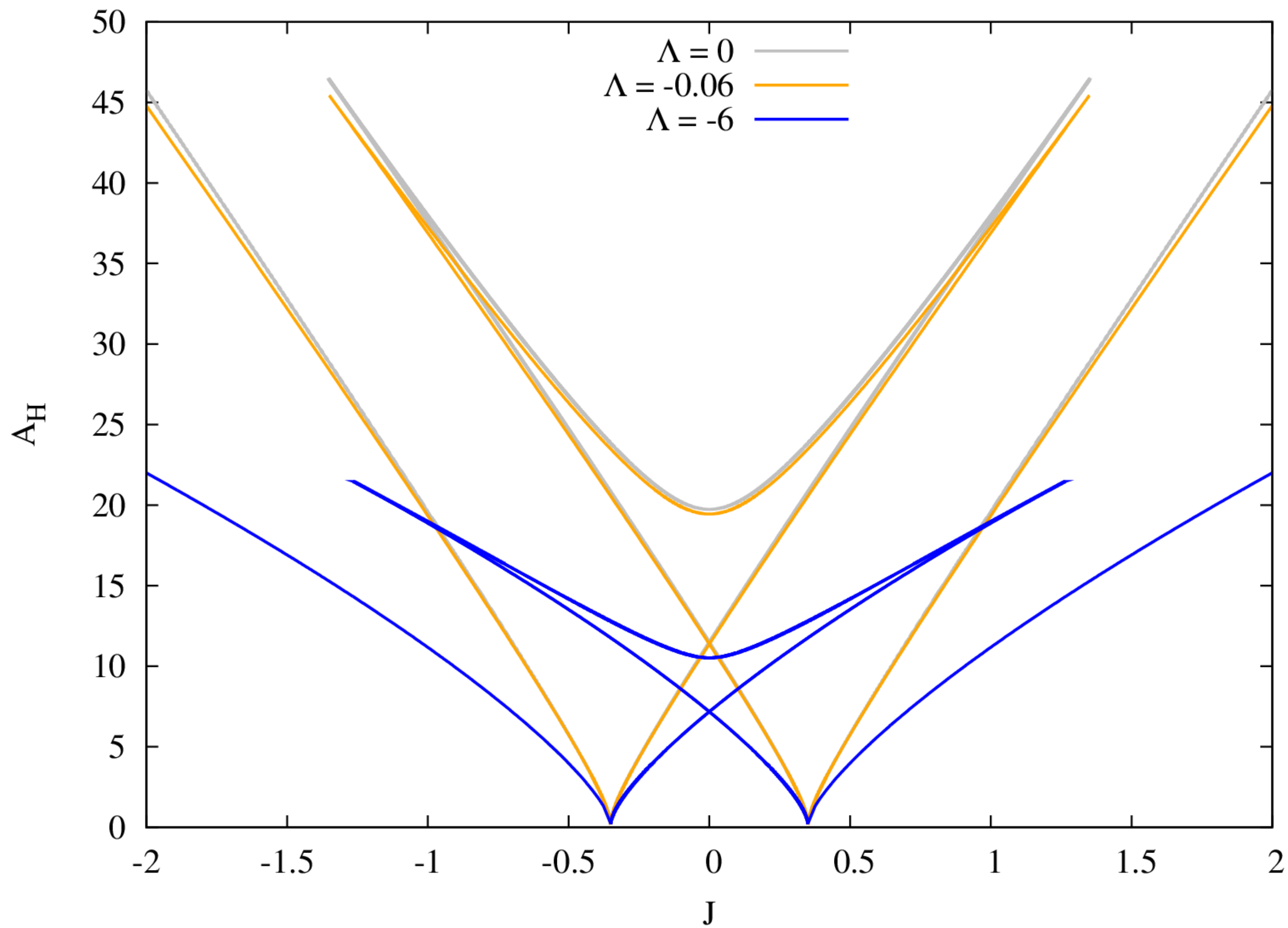
|| 2. Near Horizon Formalism ||

Near-horizon geometry branch structure: EM-AdS



|| 2. Near Horizon Formalism ||

Near-horizon geometry branch structure: EMCS-AdS, Q=2.720699, λ=5



3. Exploring the global solutions

EM-AdS

vs

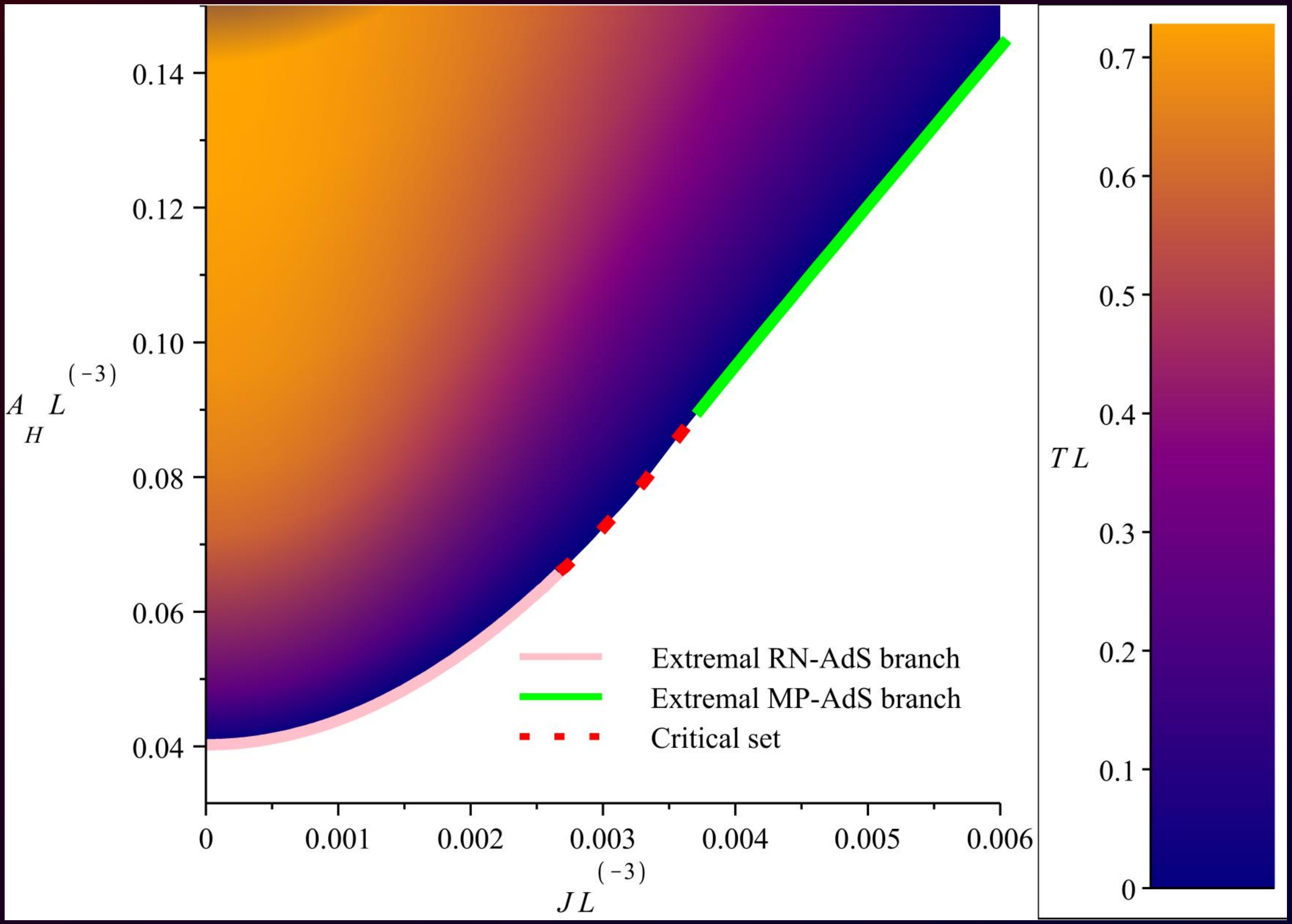
EMCS-AdS $\lambda=1$ (SUGRA)

vs

EMCS-AdS $\lambda=1.5$

|| 3. Exploring the global solutions ||

EM-AdS black holes with Q=0.044, L=1



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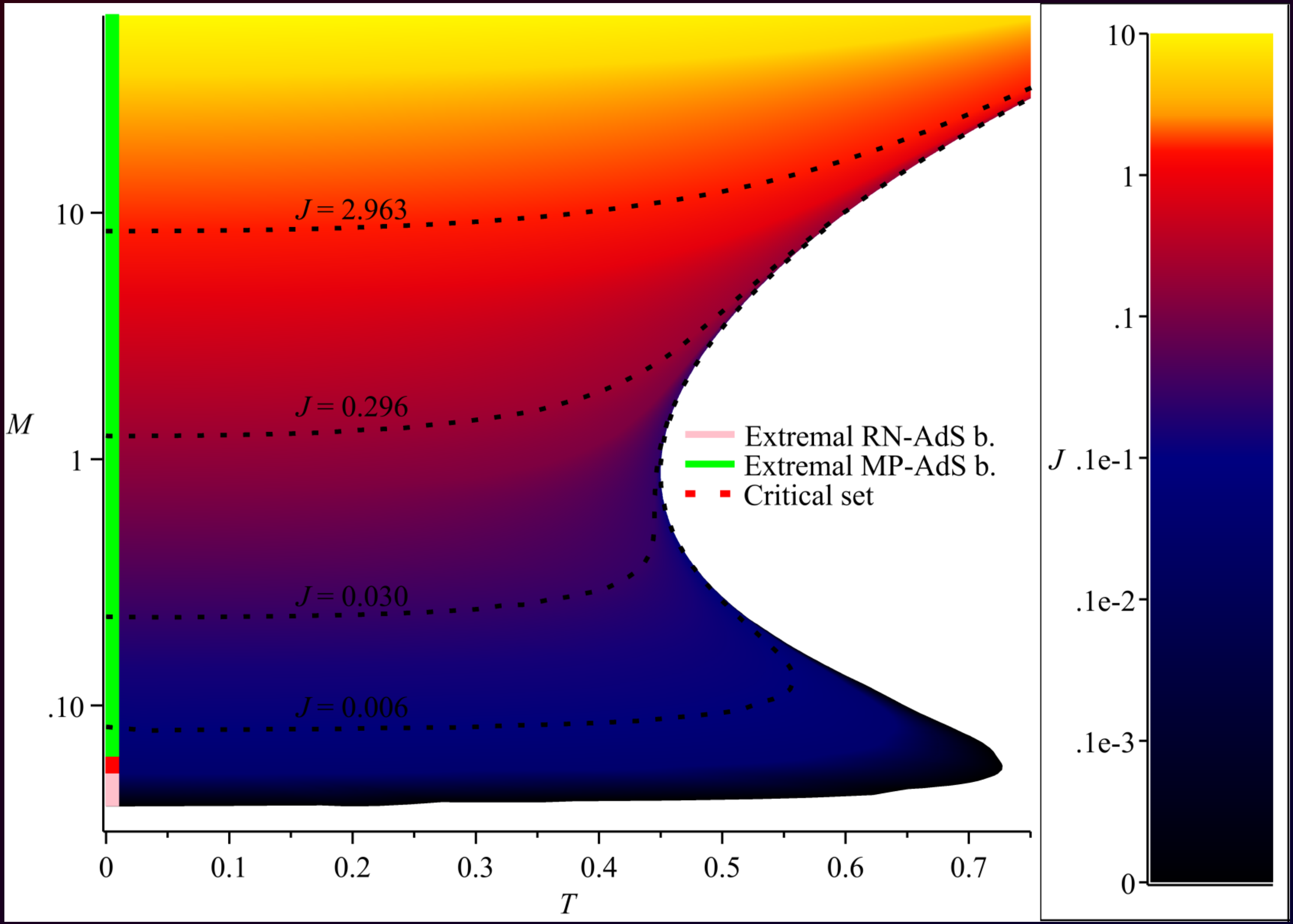
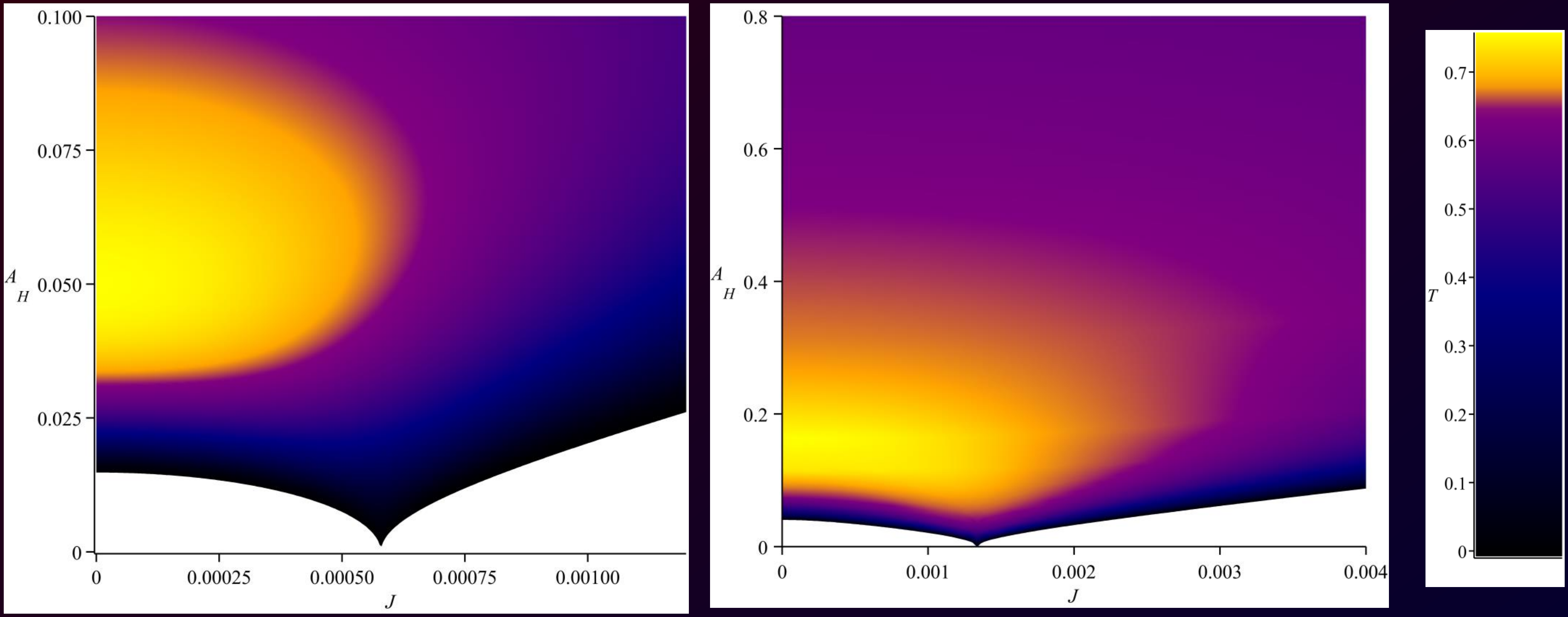
EM-AdS black holes with Q=0.044, L=1



|| 3. Exploring the global solutions ||

EMCS-AdS black holes with Q=0.044, L=1

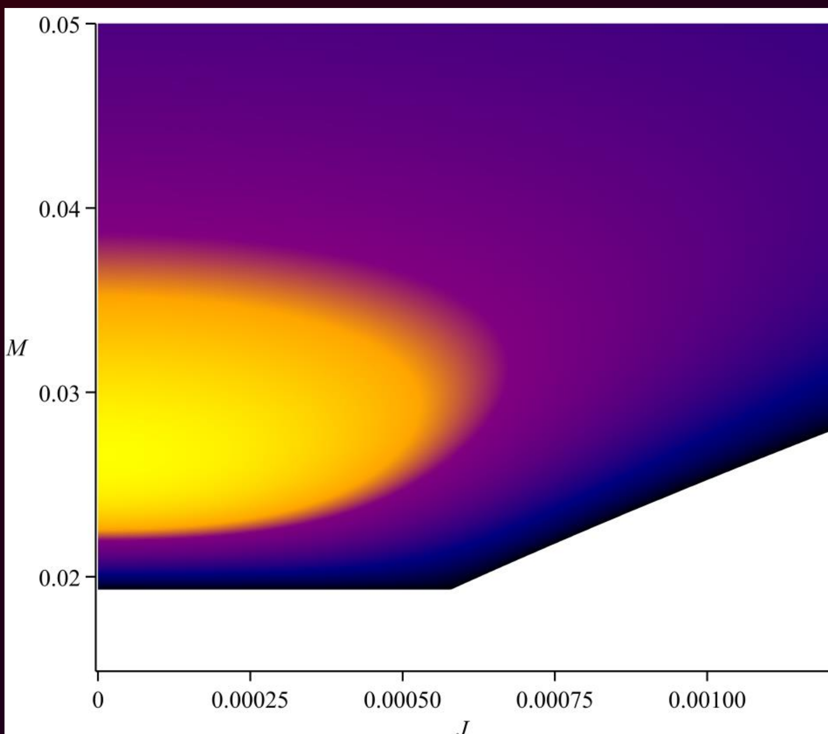
λ=1 (SUGRA) λ=1.5



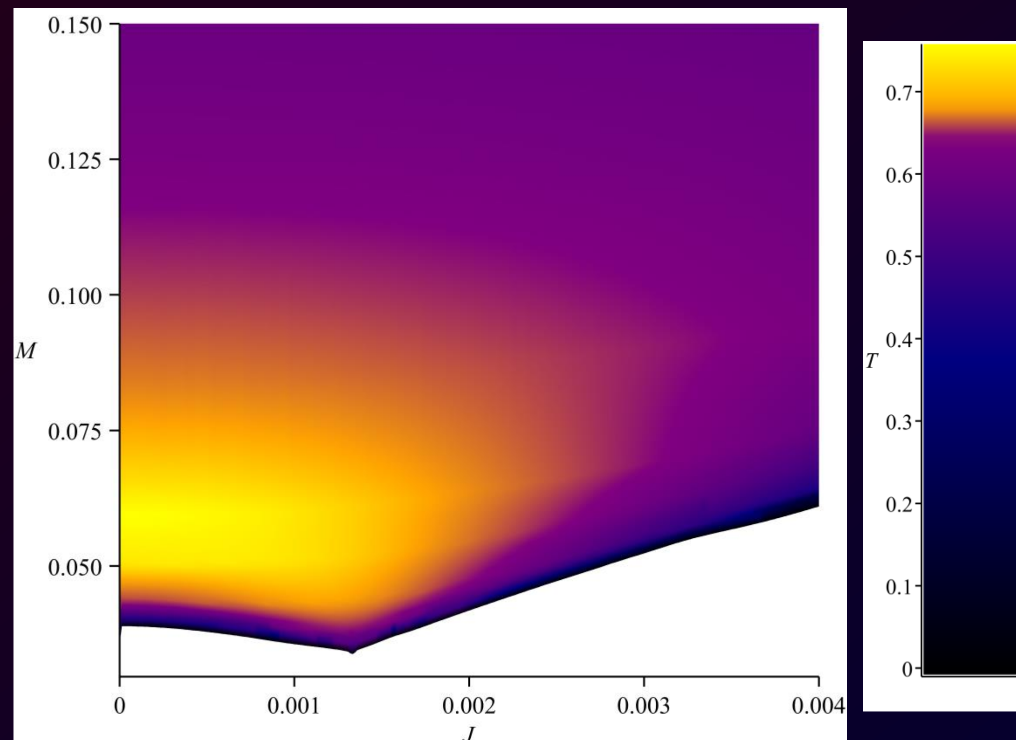
|| 3. Exploring the global solutions ||

EMCS-AdS black holes with Q=0.044, L=1

λ=1 (SUGRA)

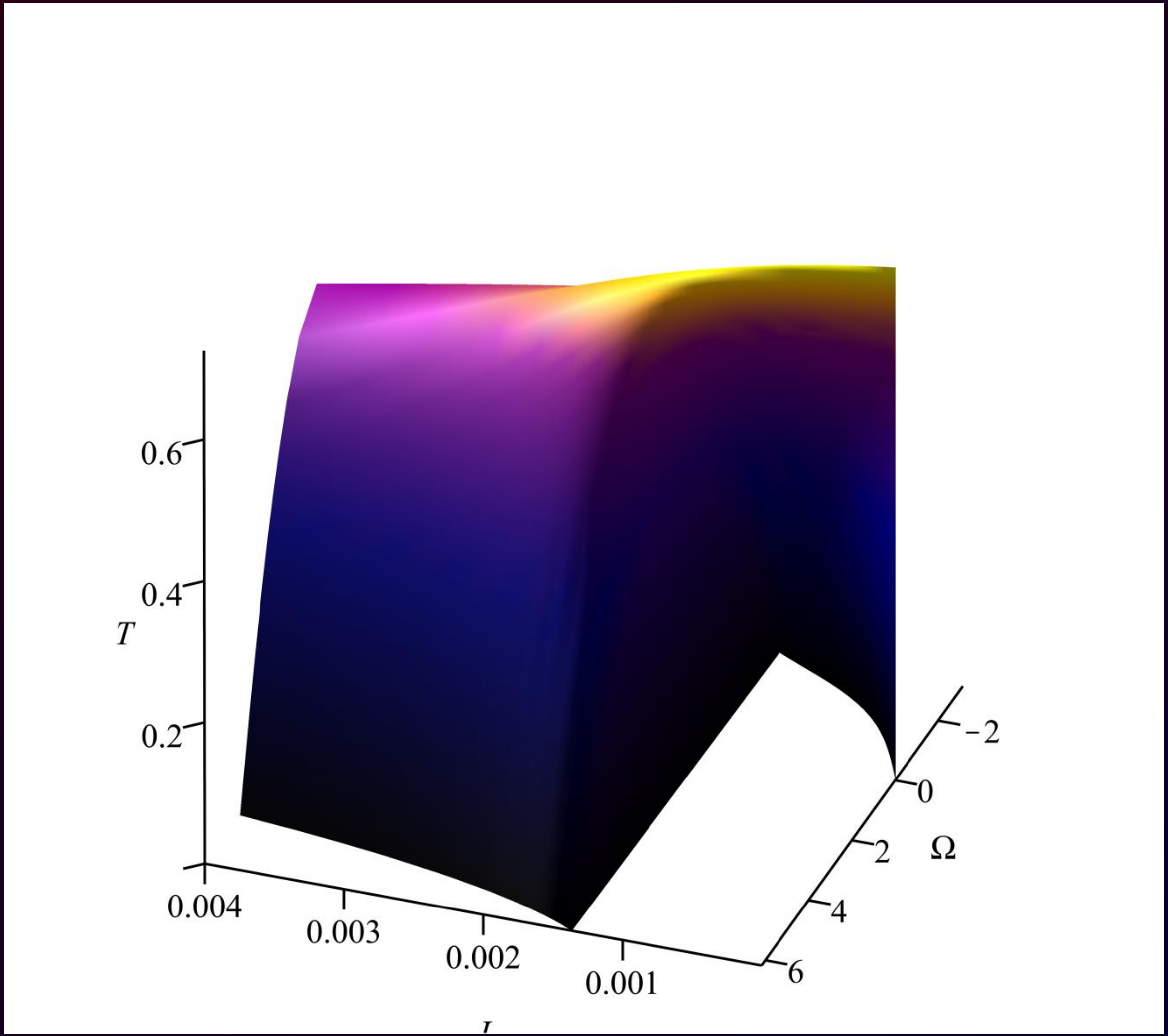


λ=1.5



|| 3. Exploring the global solutions ||

EMCS-AdS black holes with Q=0.044, L=1, λ=1.5

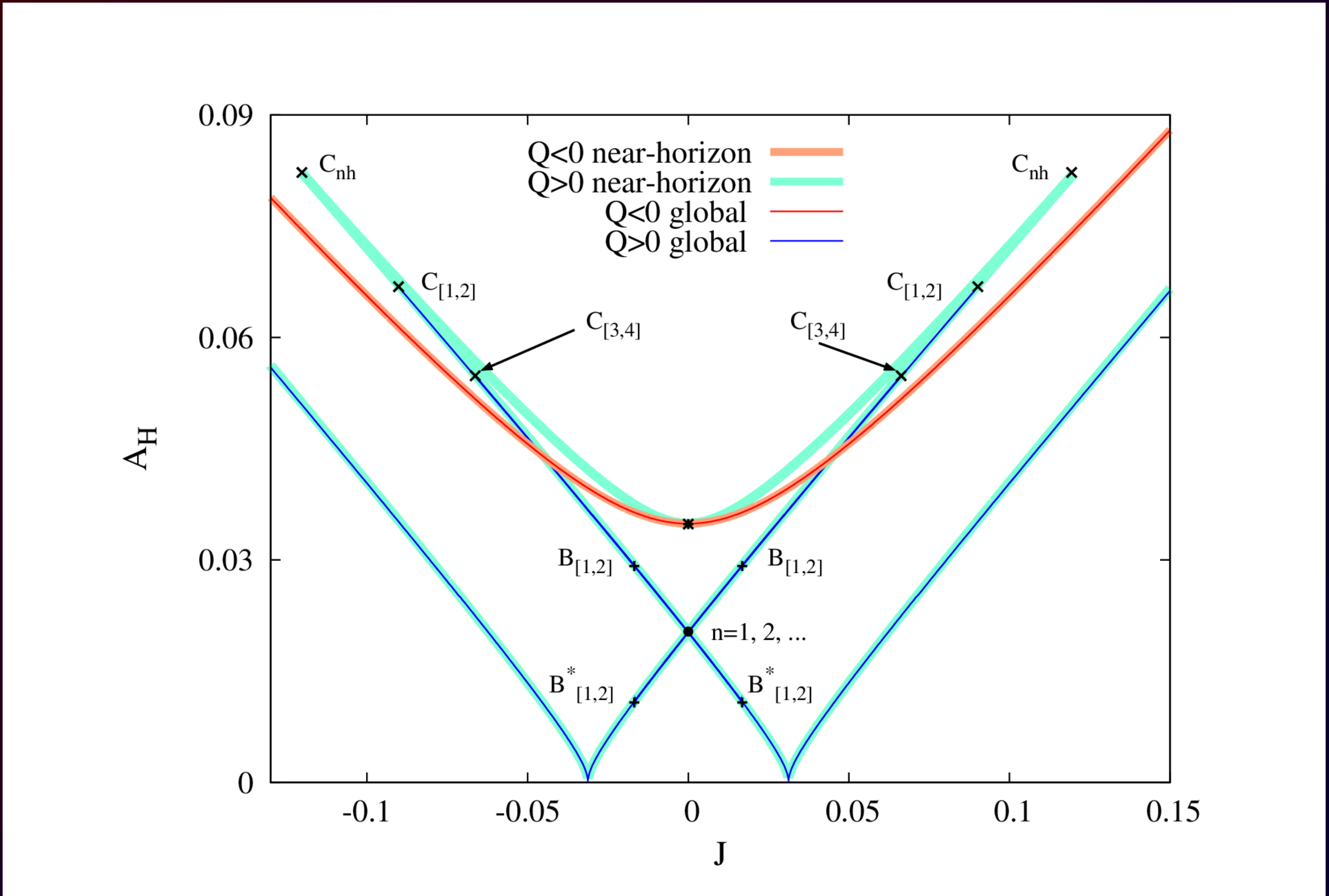


3. Exploring the global solutions

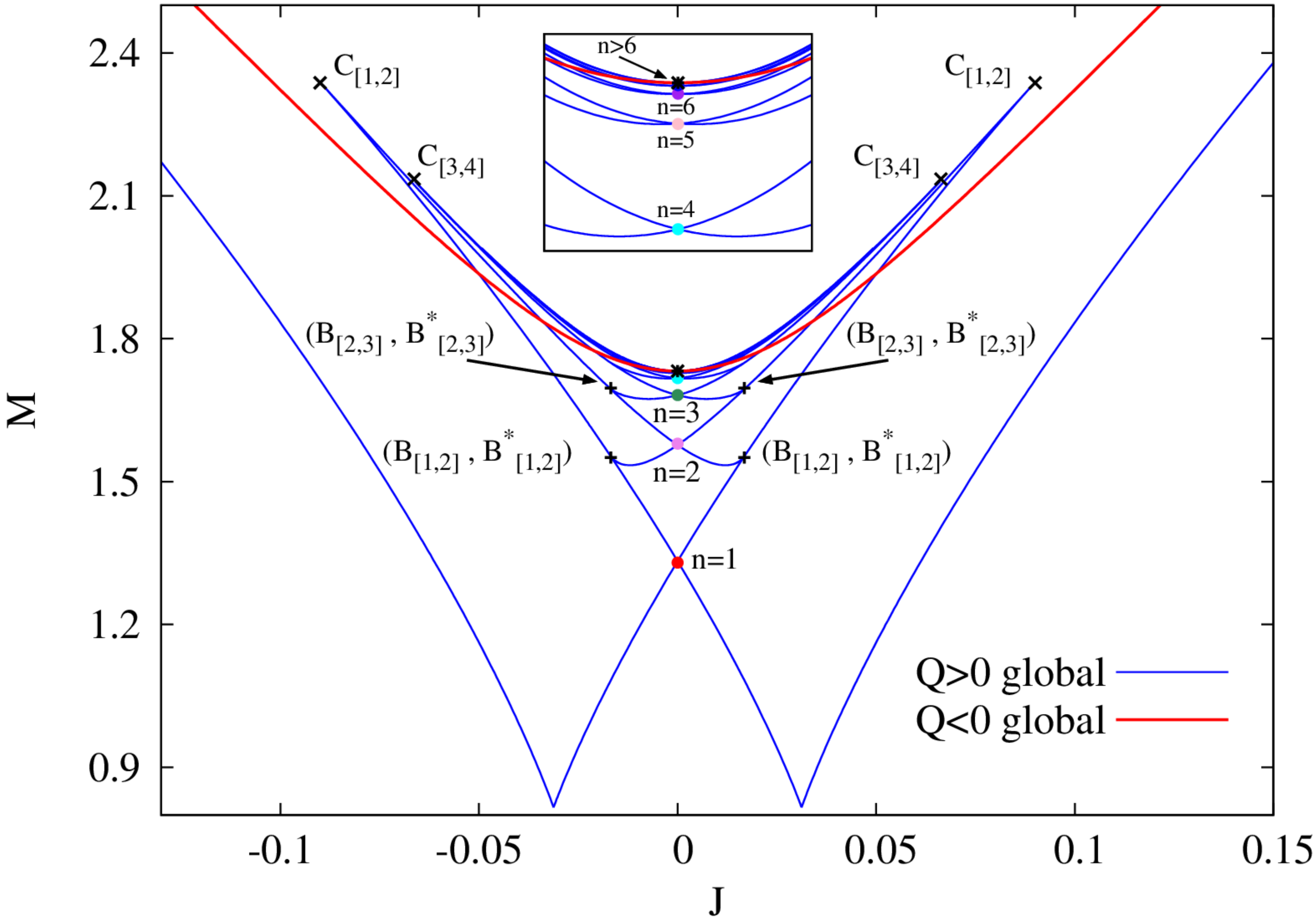
Global solutions and branch structure for $\lambda > 2$

|| 3. Exploring the global solutions ||

Global and NH solutions, λ>2 scheme:

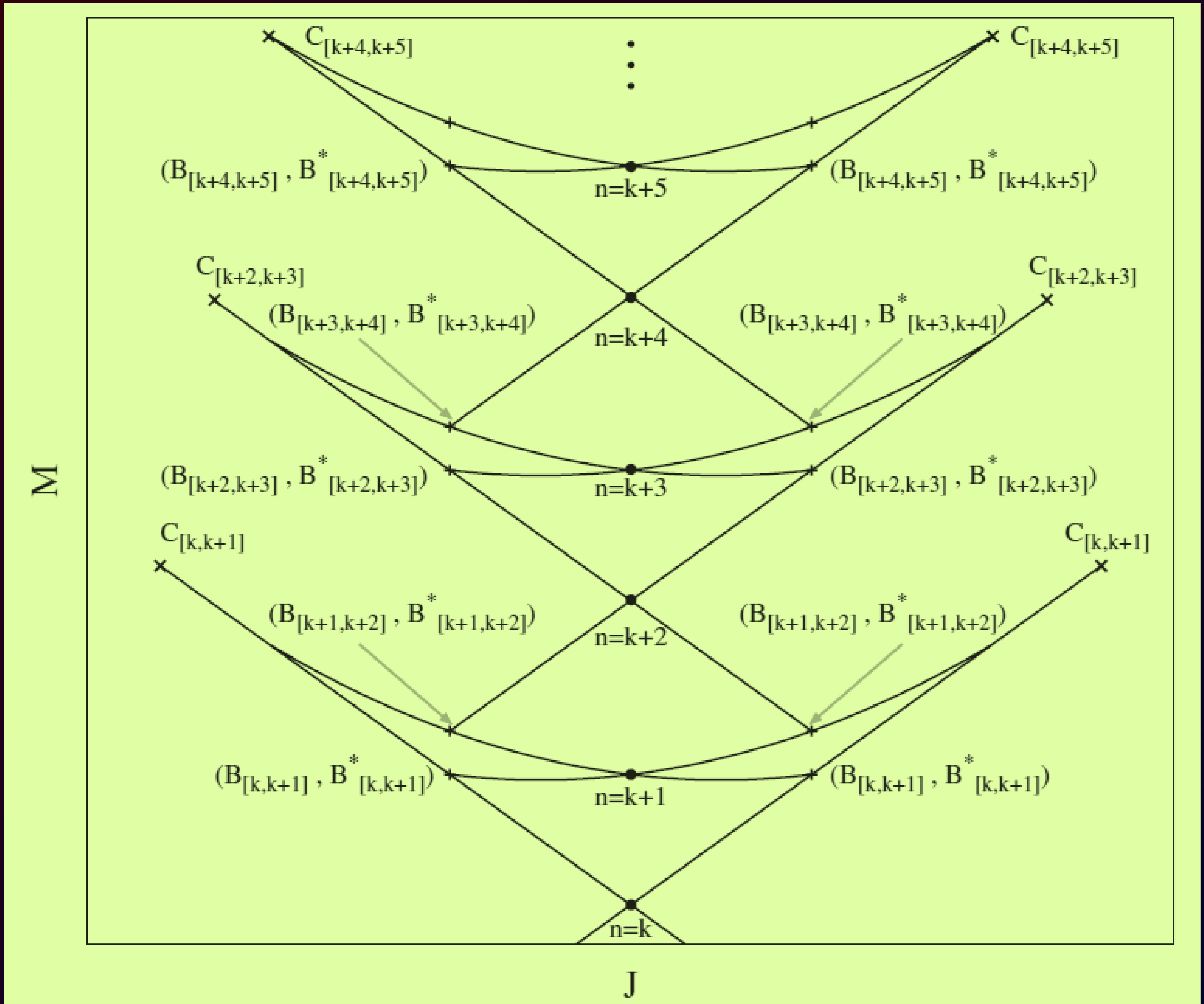


Global extremal black holes, λ>2 scheme:

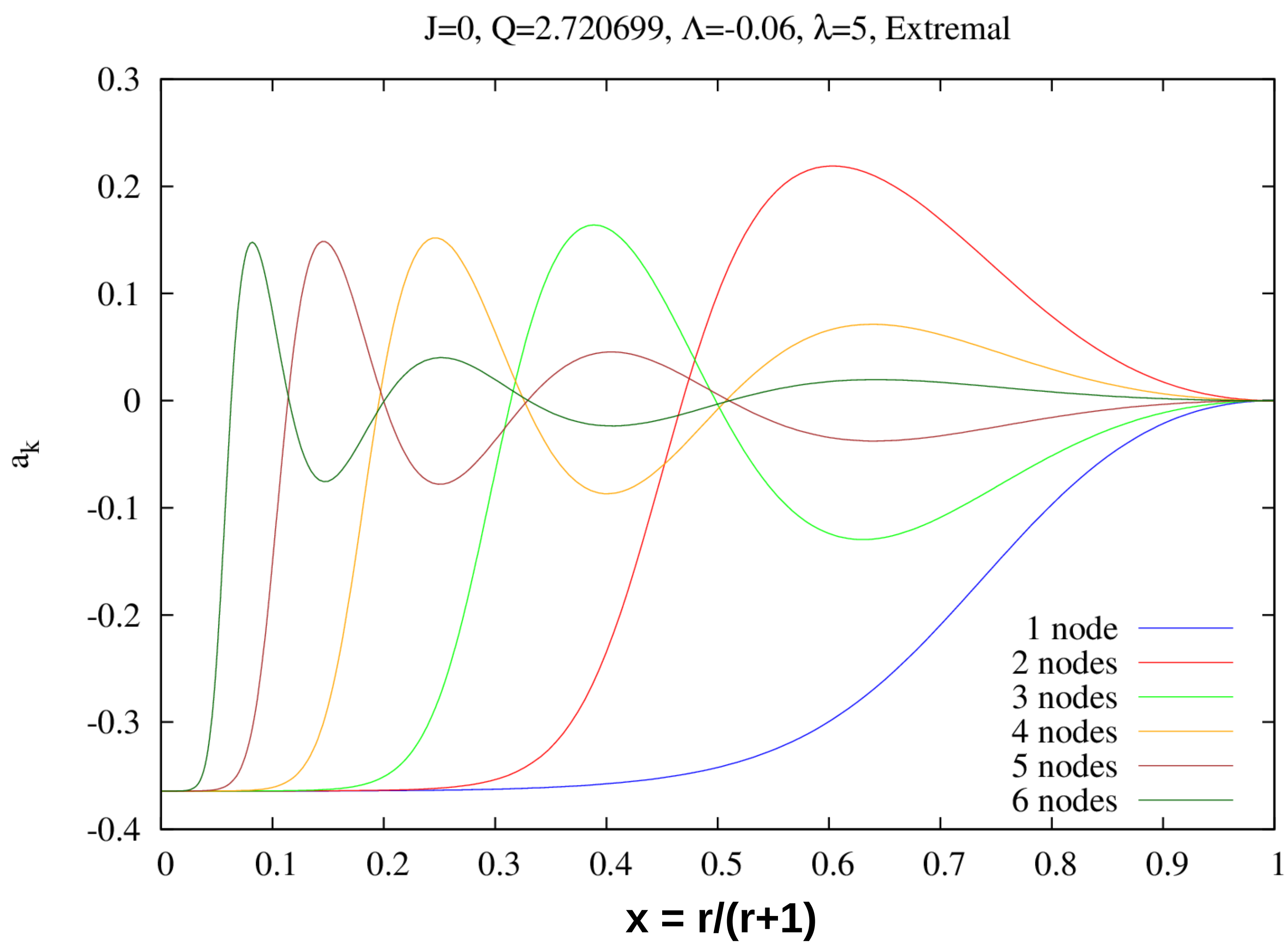


|| 3. Exploring the global solutions ||

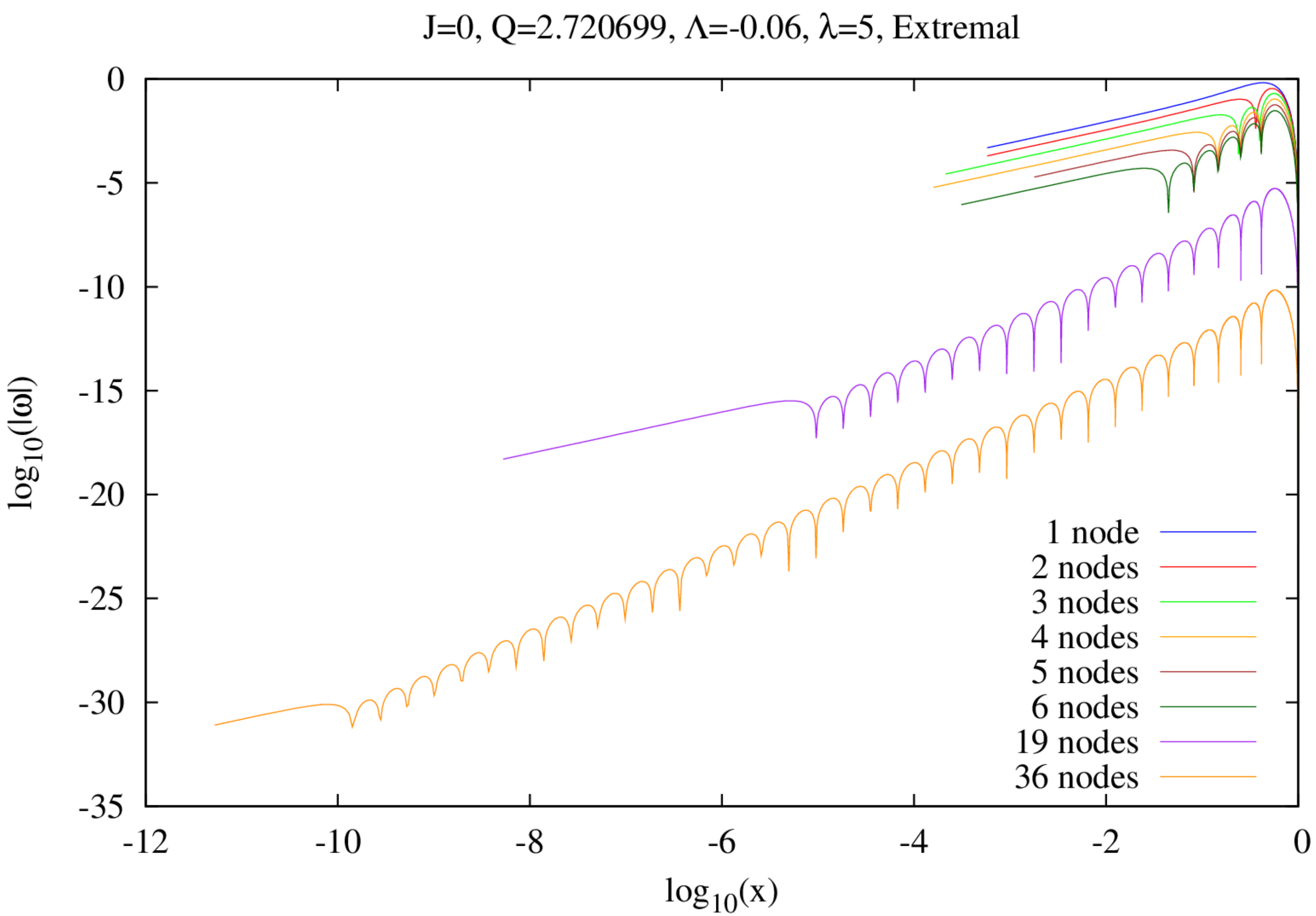
Branch structure, λ>2 scheme:



|| 3. Exploring the global solutions ||



|| 3. Exploring the global solutions ||



Thank you for your attention!

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