WORMHOLES: SCIENCE OR FICTION?

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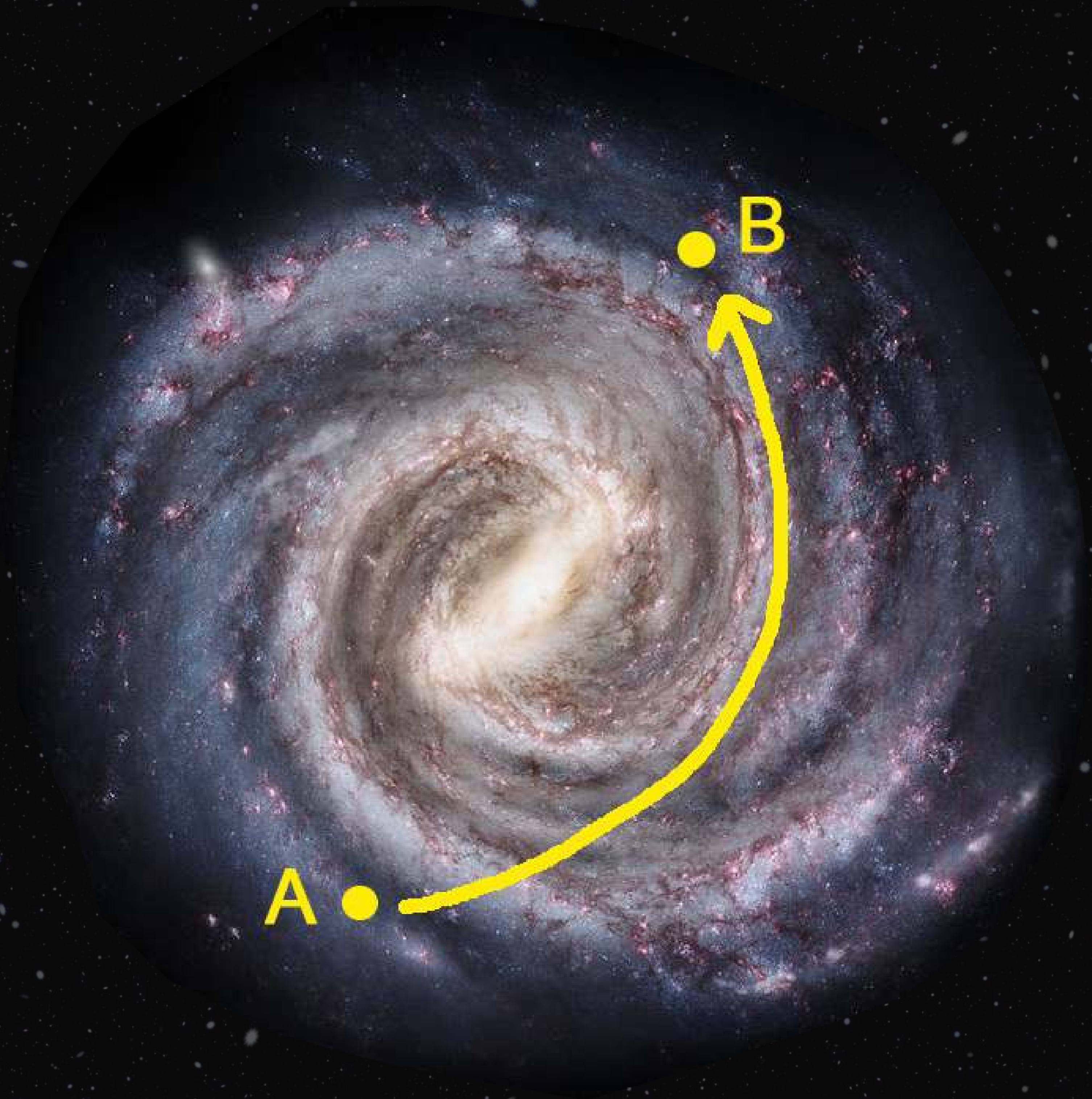
MOTIVATION

EARTH-SUN TRAVEL

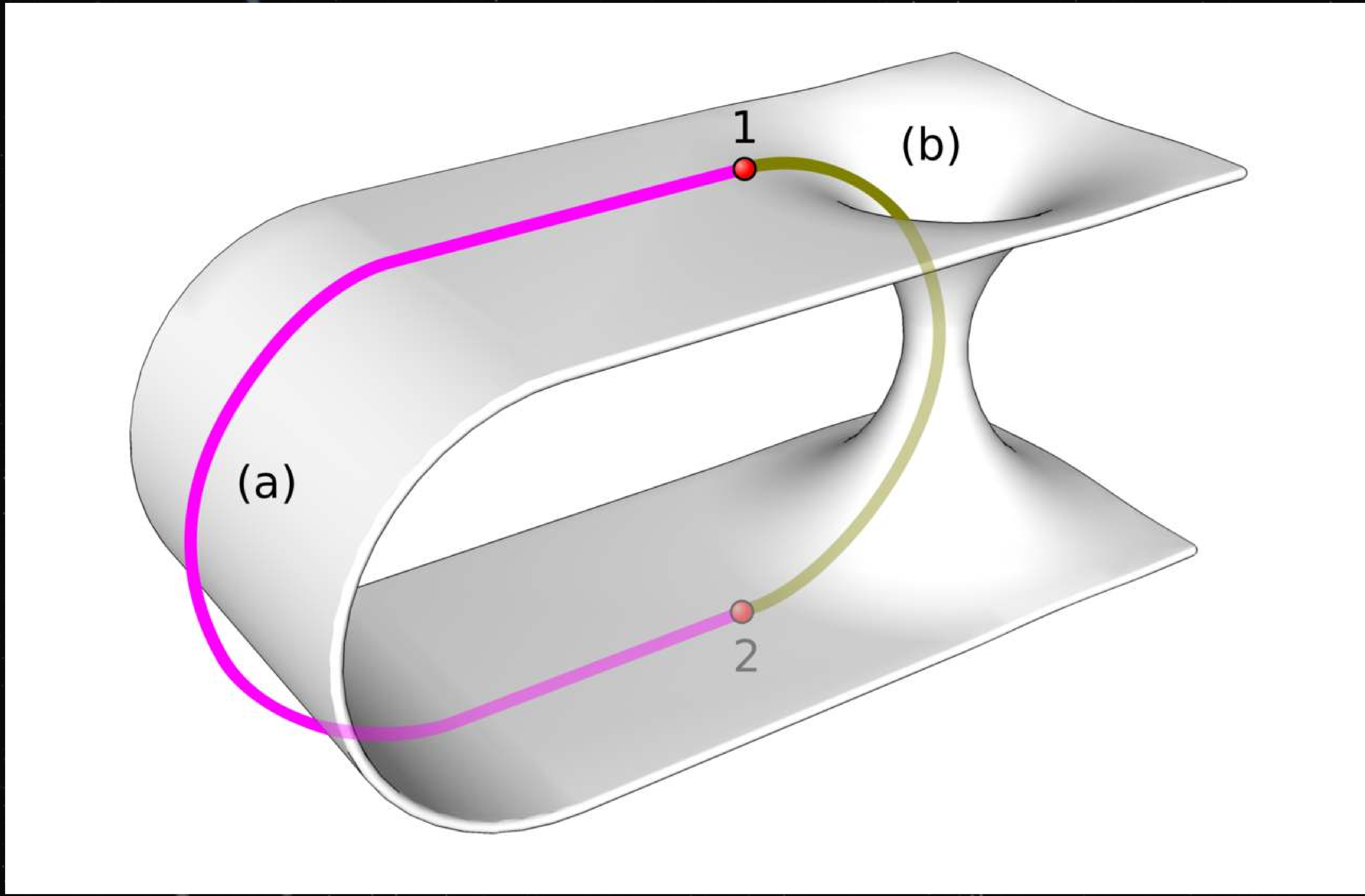
~ 8 min

TRAVEL ACROSS THE GALAXY



$\sim$ 100k years

WORMHOLE

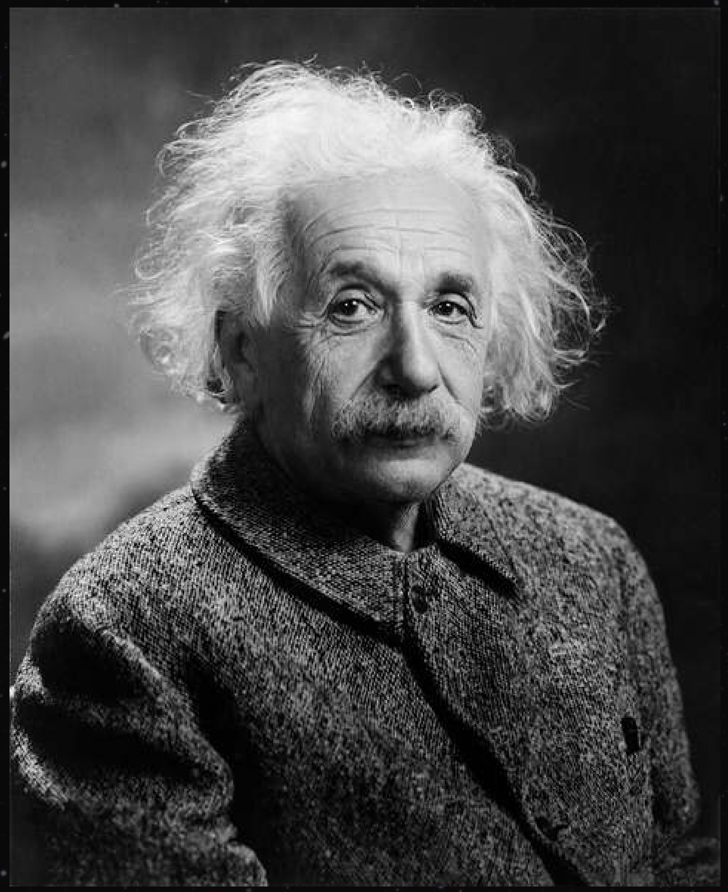


CAN WHS EXIST IN NATURE?

THE THEORY

- The best theory of gravity that we have is General Relativity

$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$



- Wormholes are solutions of the field equations if we add extra fields

ELLIS-BRONNIKOV WORMHOLES

- They are solutions of GR + scalar (phantom field)

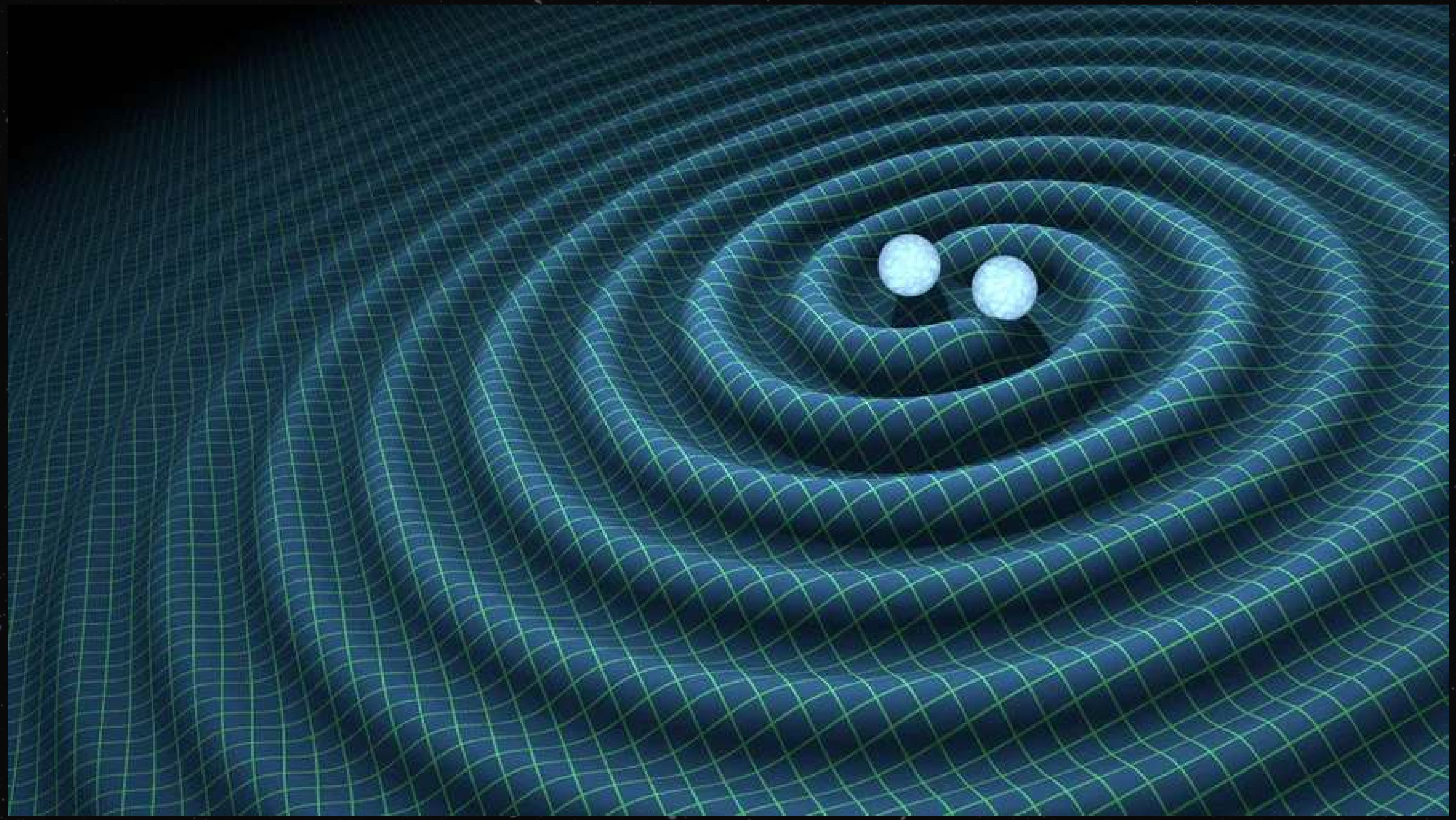
$$S = \frac{1}{16\pi}\int d^4x\sqrt{-g}\left[R + 2(\nabla\varphi)^2\right]$$

- The phantom field violates energy conditions
- Ellis-Bronnikov solutions are static and spherically symmetric

HOW COULD WE DETECT THEM?

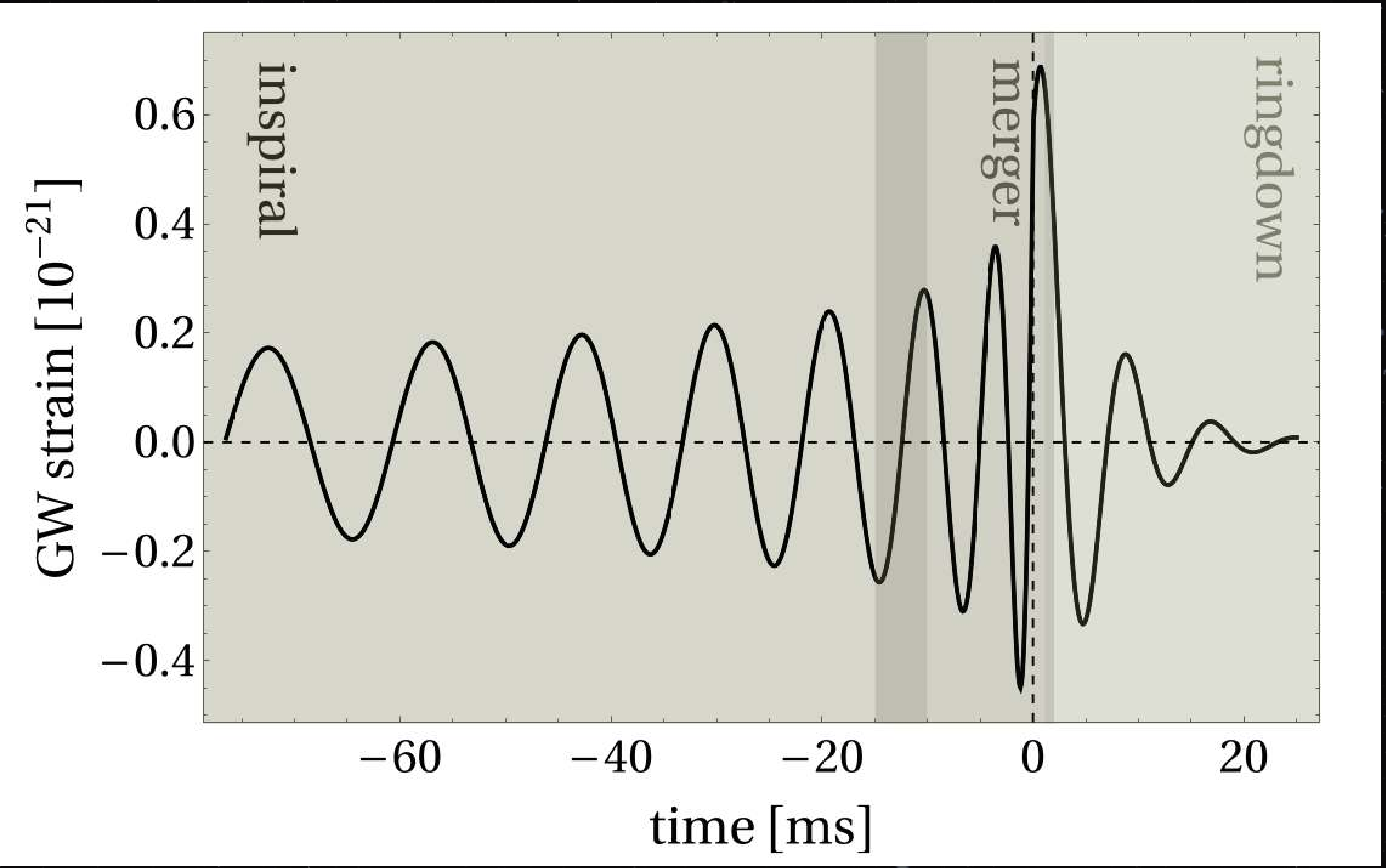
HOW COULD WE DETECT THEM?

Gravitational Waves



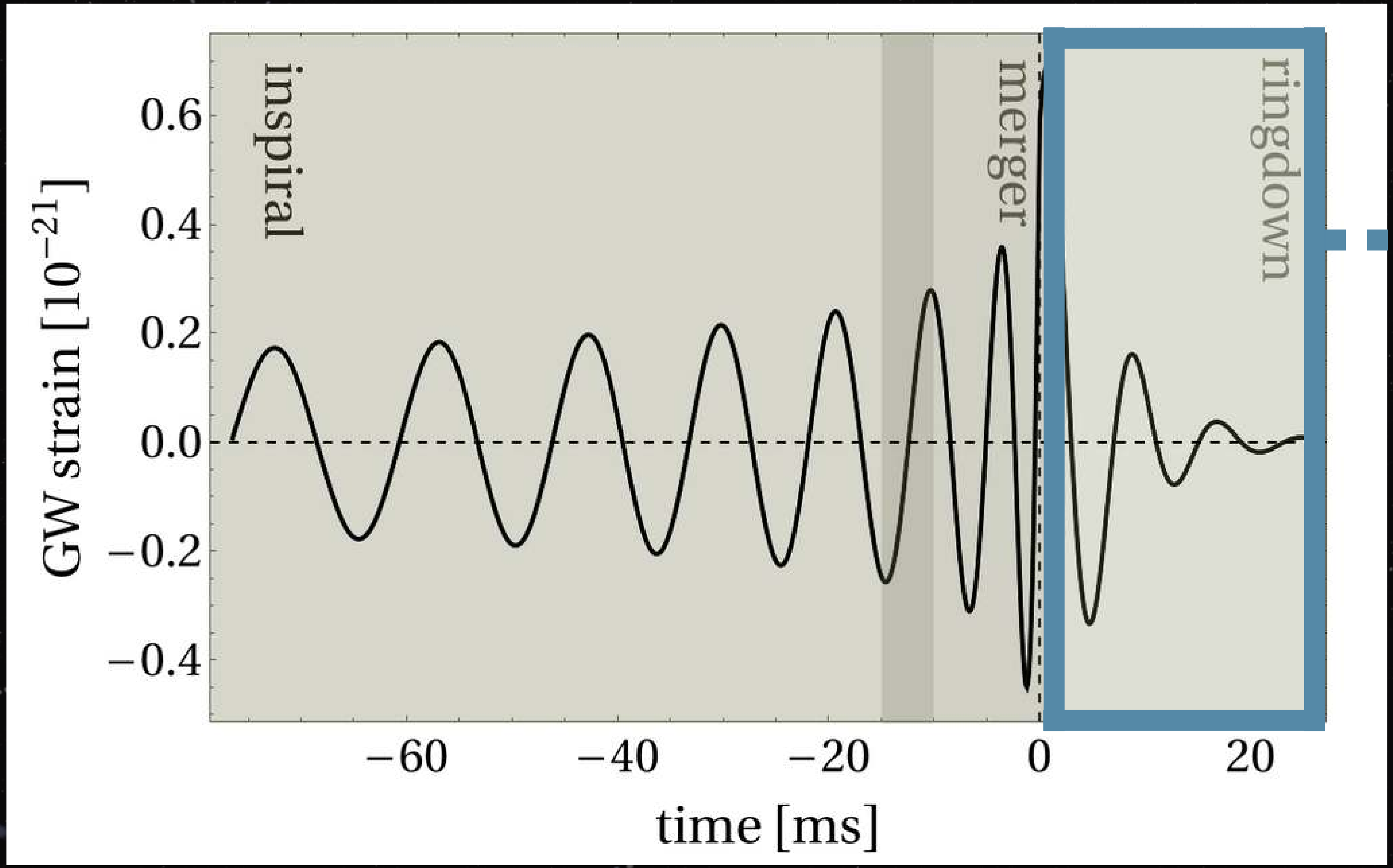
[1] Gravitational Waves Discovered from Colliding Black Holes, Scientific American

MERGER OF TWO COMPACT OBJECTS



[2] V. Ferrari, L. Gualtieri and P. Pani, General Relativity and its Applications, CRC Press, 2020

PERTURBATION THEORY



We are interested in the "ringdown" phase (QNMs)

$$g_{\mu\nu} = g^0_{\mu\nu} + \delta g_{\mu\nu}$$

$$A_\mu = A^0_\mu + \delta A_\mu$$

$$\varphi = \varphi^0 + \delta\varphi$$

PERTURBATION THEORY

Stability

$$F_i \sim e^{-i\omega t} = e^{\omega_I t} e^{-i\omega_R t} \begin{cases} \omega_I \leq 0 & \text{damped oscillation} \\ \omega_I > 0 & \text{unstable mode} \end{cases}$$

- Decay time is given by $\tau = 1/\left|\omega_I\right|$
- The frequency is ω_R

SPECTRAL METHOD

- We decompose the perturbations into Chebyshev polynomials $T_k(x)$

Spherically Symmetric Object

$$F_i(x) = \sum_k C_{i,k} T_k(x)$$

ODE's $\longrightarrow$ algebraic equations

Axially Symmetric Object

$$F_i(x,y) = \sum_{k,l} C_{i,k,l} T_k(x) P_l(y)$$

PDE's $\longrightarrow$ algebraic equations

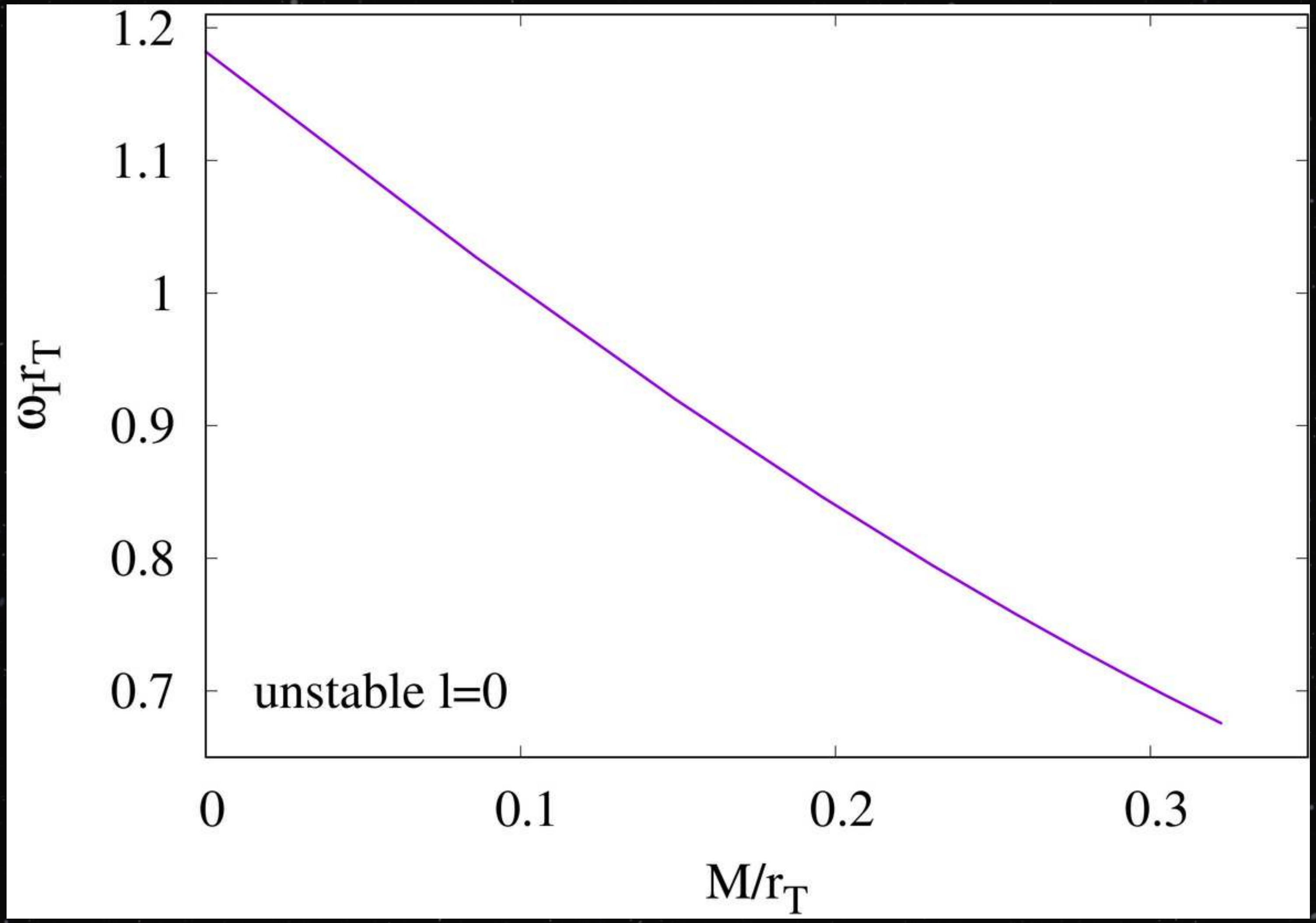
- The system can be written as a **Quadratic Eigenvalue Problem**

$$(\mathcal{M}_0 + \mathcal{M}_1 \omega + \mathcal{M}_2 \omega^2) C = 0$$

RESULTS

RESULTS

- It was already known that Ellis-Bronnikov solutions are unstable under radial perturbations



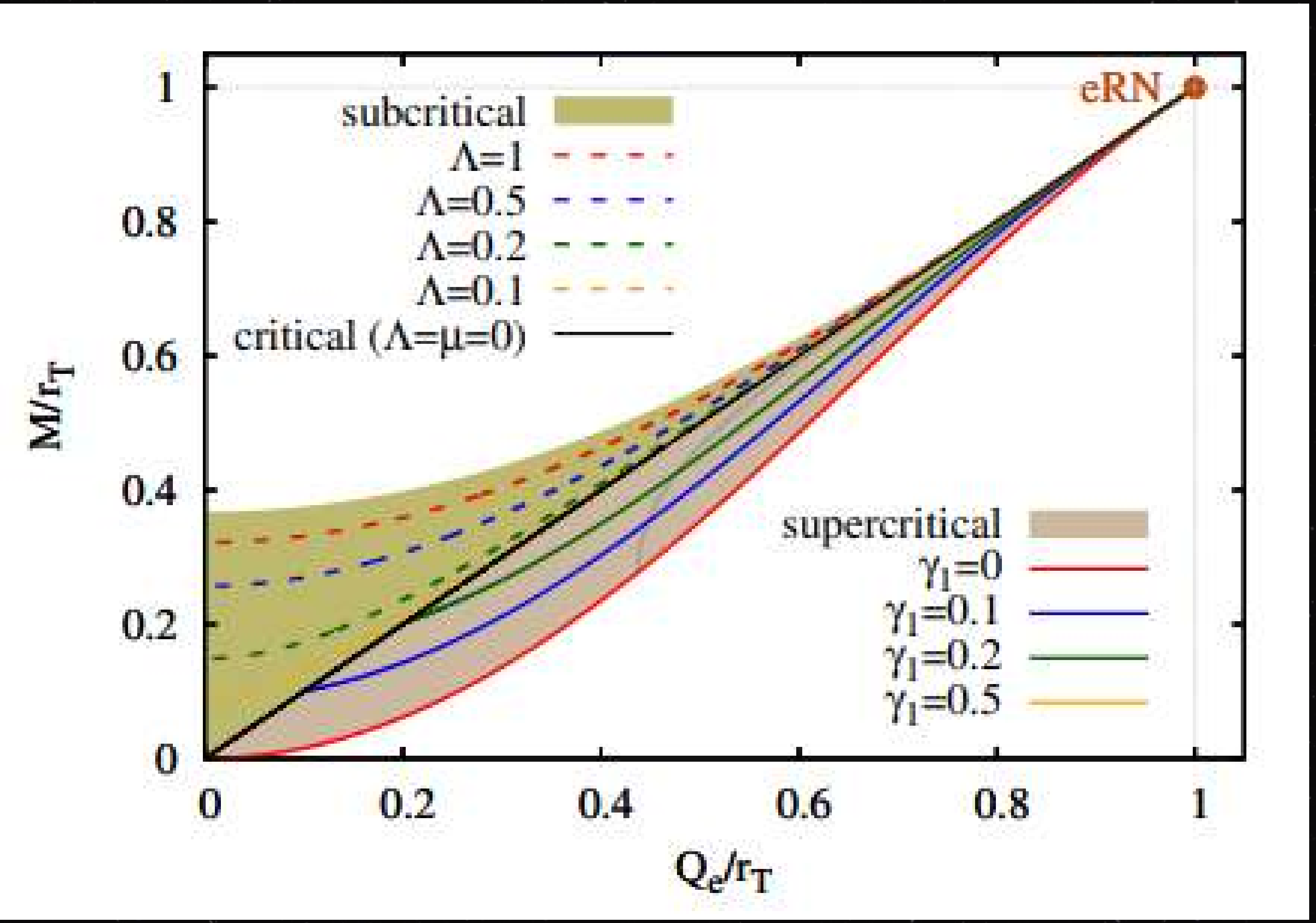
RESULTS

- Adding an EM field might help to decrease the instabilities

$$S = \frac{1}{16\pi}\int d^4x\sqrt{-g}\left[R + F^2 + 2(\nabla\varphi)^2\right]$$

- The parameter space is richer

- eRN solution limit



[3] J. L. Blázquez-Salcedo, et al, Charged wormholes can be long-lived, [arXiv:2510.11406 [gr-qc]]

RESULTS

Metric

$$ds^2 = -G(r)dt^2 + G(r)^{-1}\left[dr^2 + (r^2 + r_0^2)d\Omega^2\right]$$

Scalar Field

$$\varphi = \frac{Q_s}{r_0}\left[\arctan\left(\frac{r}{r_0}\right) - \frac{\pi}{2}\right]$$

EM Field

$$F = \frac{2Q_e}{r^2 + r_0^2} G(r) dt \wedge dr + 2Q_m \sin\theta d\theta \wedge d\phi$$

[4] J. A. González, et al, Instability of charged wormholes supported by a ghost scalar field, Physical Review D 80 (2) (2009) 024023

RESULTS

Metric

$(r^2 + r_0^2)d\Omega^2]$

We don't consider Q_m!
It leads to a coupled system for polar and axial perturbations!

Scalar Field

EM Field

$$F = \frac{2Q_e}{r^2 + r_0^2} G(r) dt \wedge dr + 2Q_m \sin\theta d\theta \wedge d\phi$$

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RESULTS

- The metric components are given by:

$$G(r) = \begin{cases} \left[\cosh(\Lambda y) - \gamma \frac{\sinh(\Lambda y)}{\Lambda}\right]^{-2} c_0 & \text{subcritical} \\ \left[\cos(\mu y) - \gamma \frac{\sin(\mu y)}{\mu}\right]^{-2} c_0 & \text{supercritical} \end{cases}$$

Parameters

$(\Lambda, \mu, \gamma, r_0)$

$\downarrow$

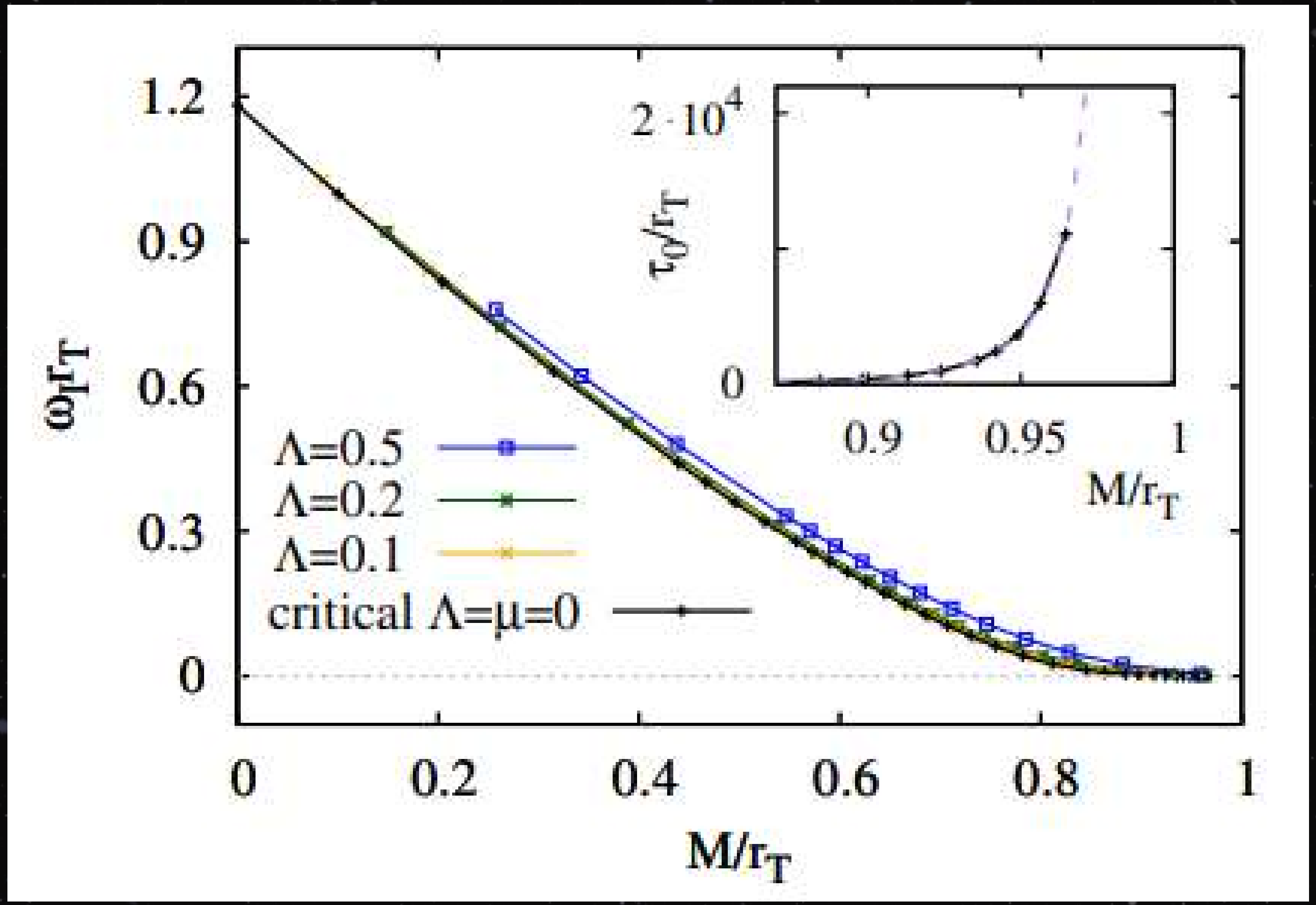
(M, r_T, r_0) Physical ones

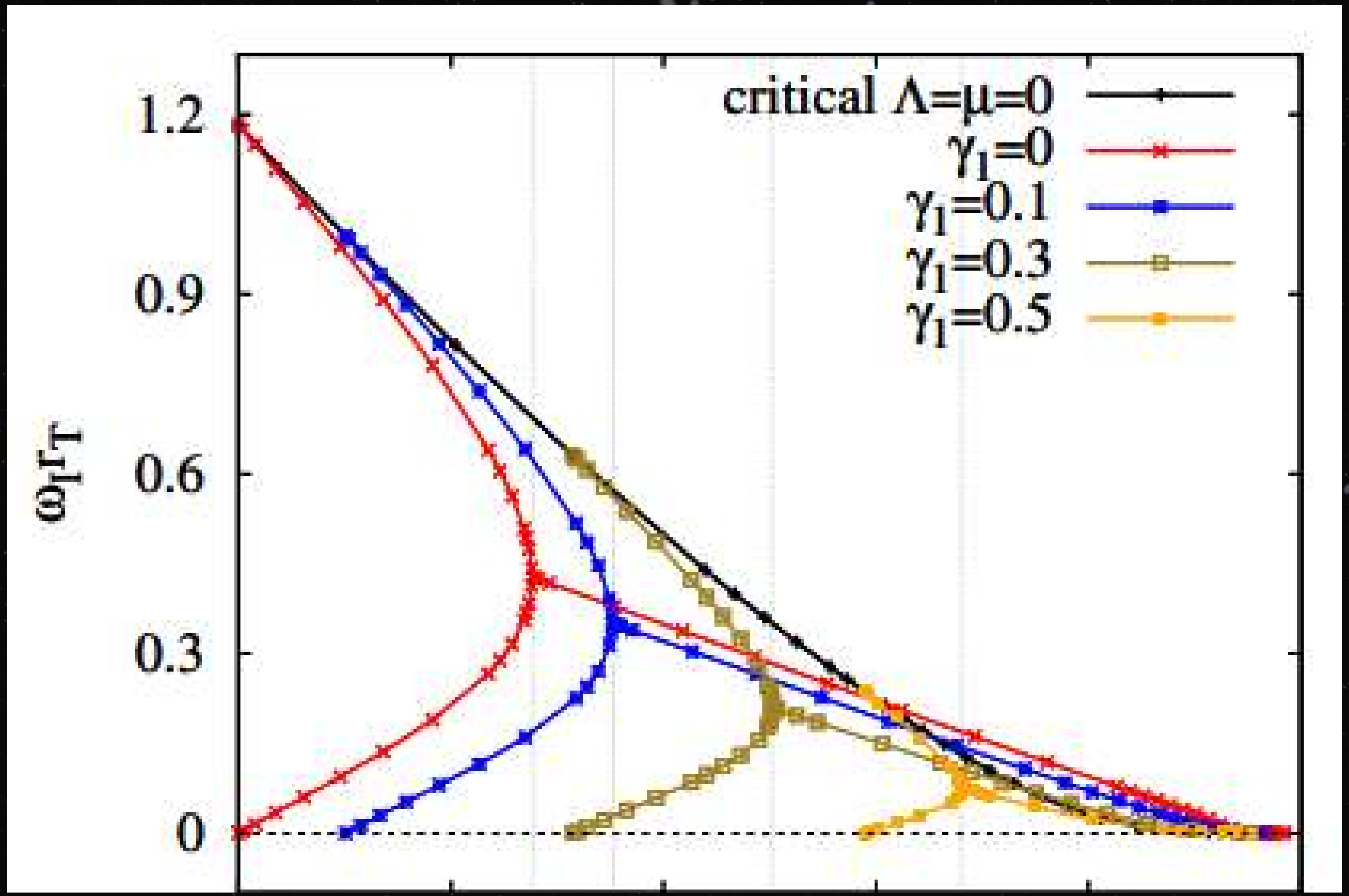
- From the field equations follow:

$$\gamma = \frac{1}{r_0}\sqrt{Q_s^2 + Q_e^2 - r_0^2} \qquad Q_s = \begin{cases} r_0\sqrt{\Lambda^2+1} & \text{subcritical} \\ r_0\sqrt{1-\mu^2} & \text{supercritical} \end{cases}$$

RESULTS

- We find that, under radial perturbations, the instabilities decrease with the electric charge Q_e





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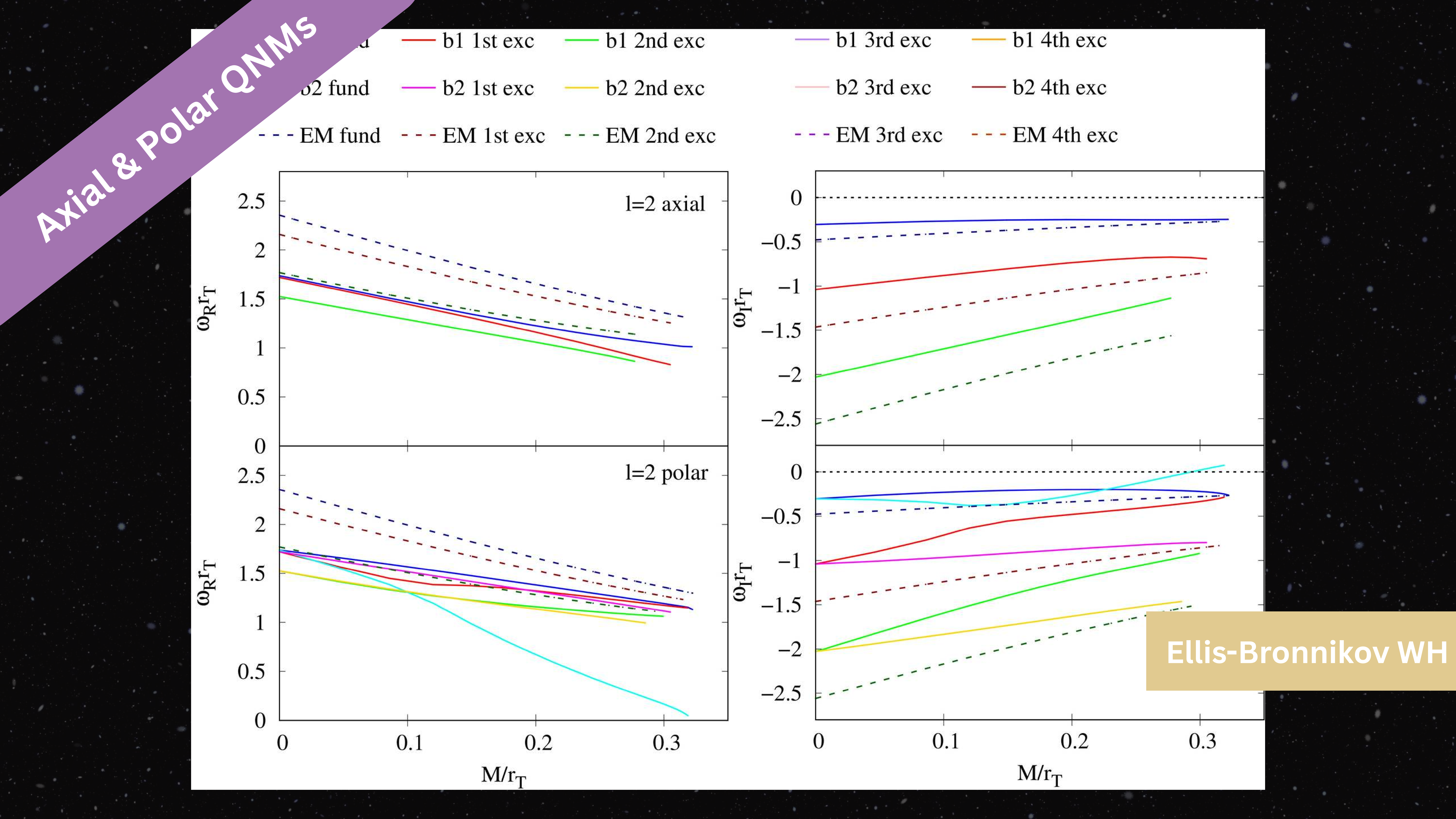
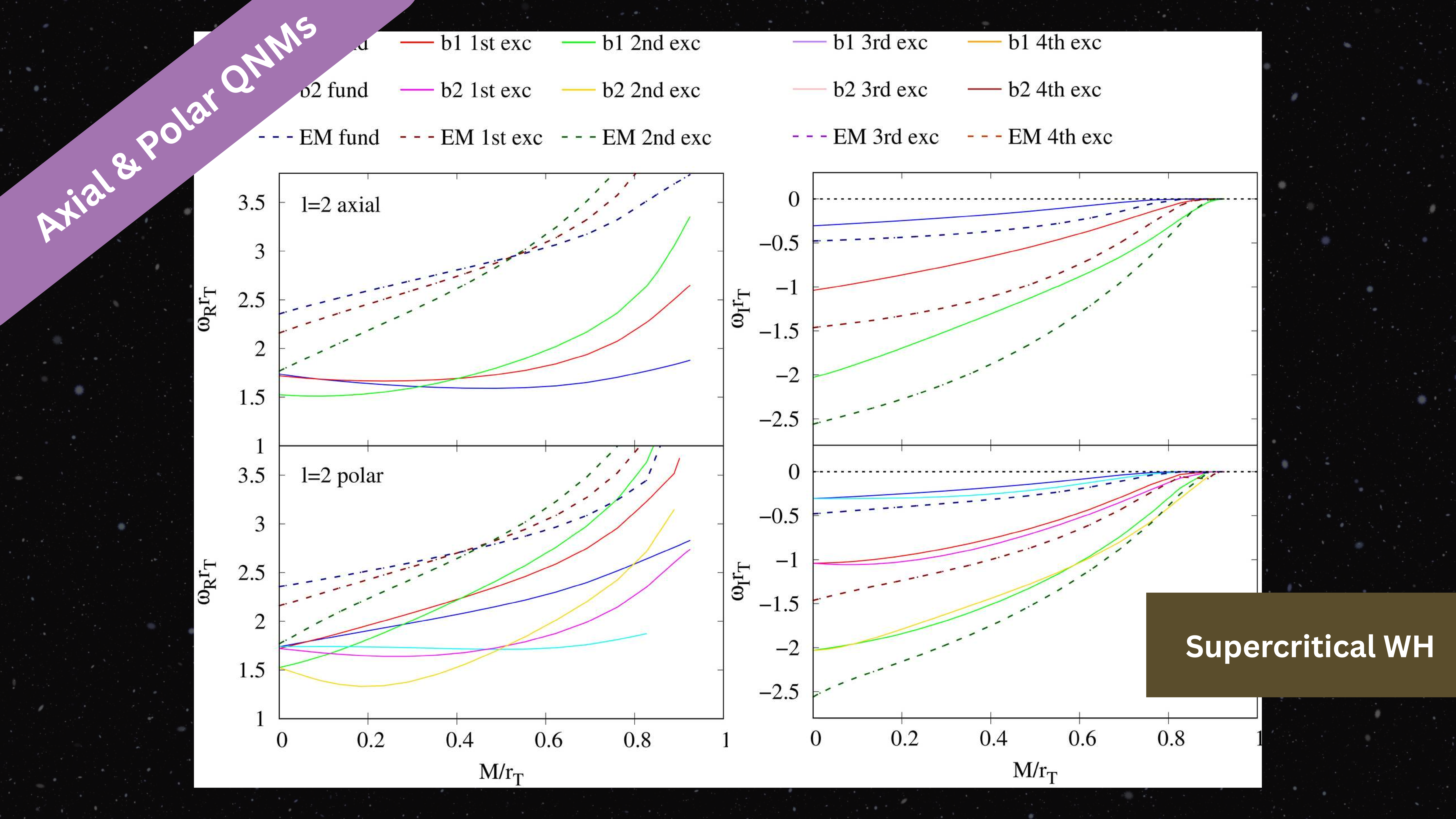


Axial & Polar QNMs
b2 fund
b1 1st exc
b1 2nd exc
b1 3rd exc
b1 4th exc
b2 1st exc
b2 2nd exc
b2 3rd exc
b2 4th exc
EM fund
EM 1st exc
EM 2nd exc
EM 3rd exc
EM 4th exc
l=2 axial
l=2 polar
$\omega_R r_T$
$\omega_I r_T$
M/r_T
Ellis-Bronnikov WH


Axial & Polar QNMs
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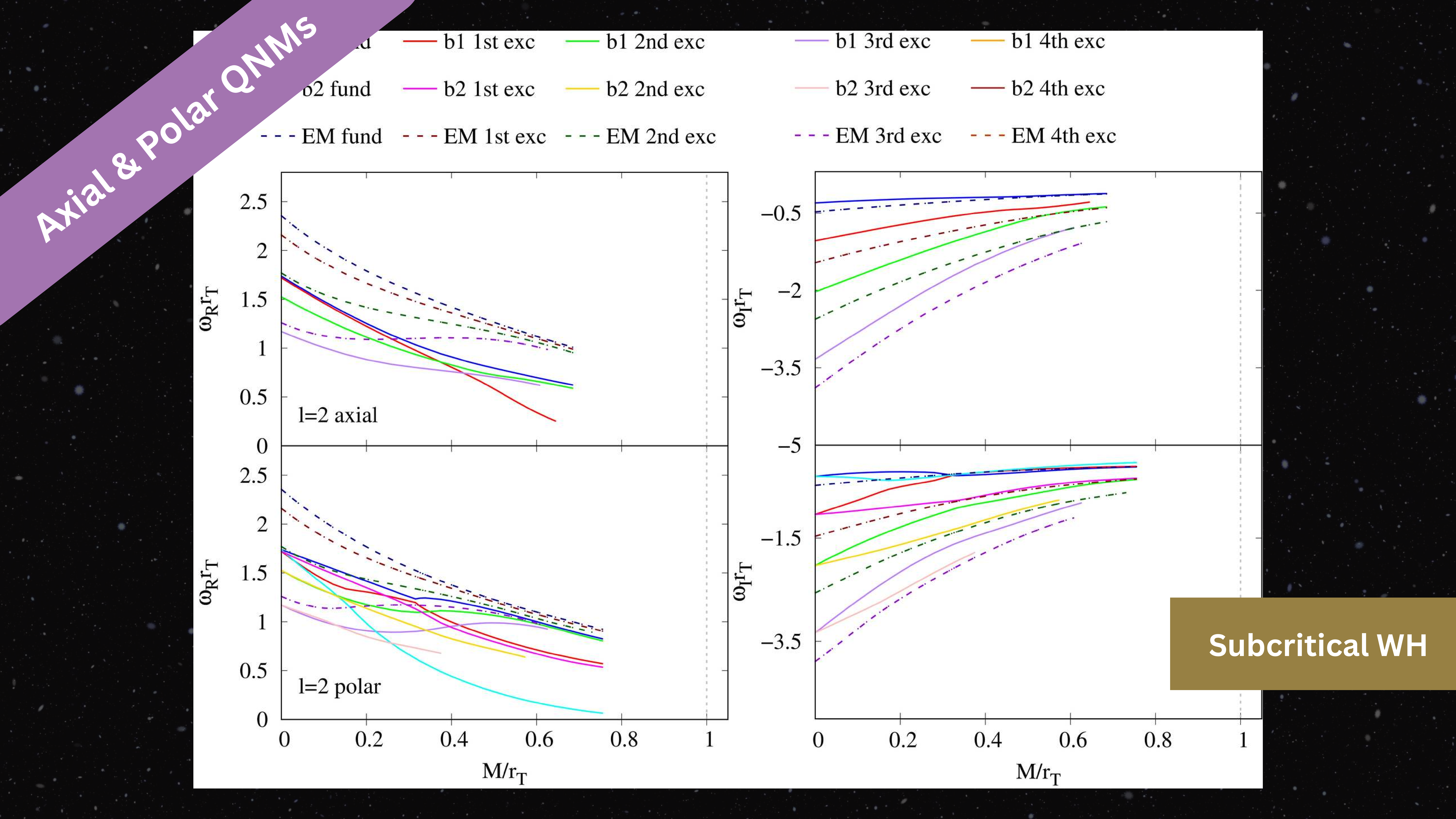
b1 4th exc
b2 fund
b2 1st exc
b2 2nd exc
b2 3rd exc
b2 4th exc
EM fund
EM 1st exc
EM 2nd exc
EM 3rd exc
EM 4th exc
l=2 axial
l=2 polar
$\omega_R r_T$
$\omega_I r_T$
M/r_T
Supercritical WH


Axial & Polar QNMs
b1 1st exc
b1 2nd exc
b1 3rd exc
b1 4th exc
b2 fund
b2 1st exc
b2 2nd exc
b2 3rd exc
b2 4th exc
EM fund
EM 1st exc
EM 2nd exc
EM 3rd exc
EM 4th exc
l=2 axial
l=2 polar
$\omega_R r_T$
$\omega_I r_T$
M/r_T
Subcritical WH

SUMMARY

- We computed the full quasinormal-mode spectrum of different classes of charged and static wormholes using spectral methods
- We found a new instability in the EB WH spectrum
- We studied how charged solutions relax the instabilities, showing that eRN is recovered
- We found that supercritical WHs exhibit a particularly interesting radial spectrum
- This study is generalizable to rotating configurations or other compact objects (work in progress)

THANK YOU!