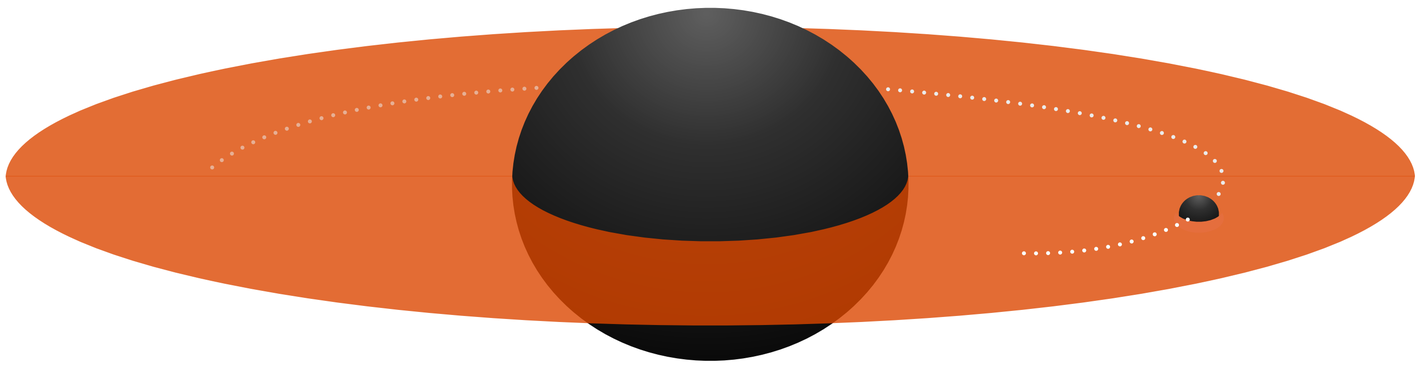
Extreme mass ratio inspirals in accretion disks



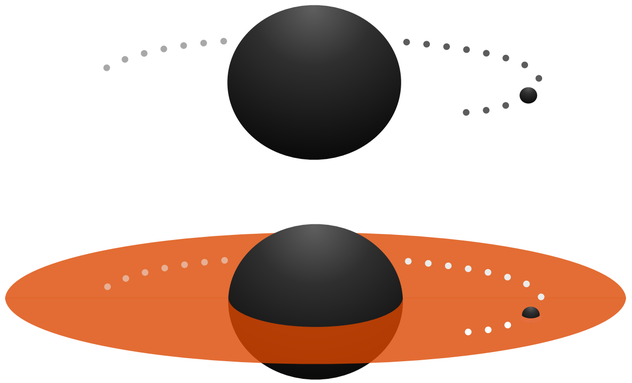
Laura Sberna (Max Planck Institute for Gravitational Physics, Potsdam)

Asymmetric Binaries meet Fundamental Astro-Physics
GSSI, L'Aquila
September 2023

INTERACTIONS WITH THE DISK

(Unknown) **fraction** of all EMRIs detectable by LISA

[Dittmann, Miller 2019, Pan+ 2021, Derdzinski, Mayer 2022]



PHYSICAL REVIEW D **84,** 024032 (2011)

Observable signatures of extreme mass-ratio inspiral black hole binaries embedded in thin accretion disks

Bence Kocsis,[1] Nicolás Yunes,[2,1] and Abraham Loeb[1]

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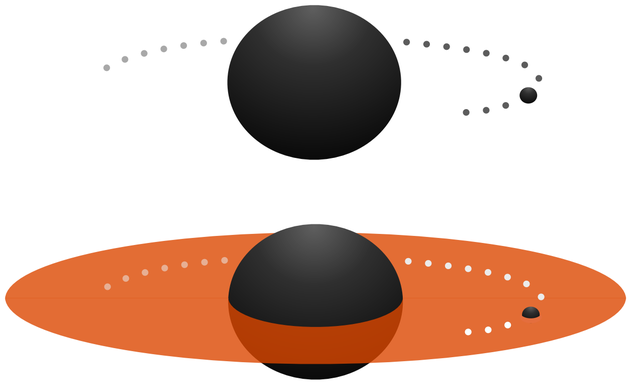
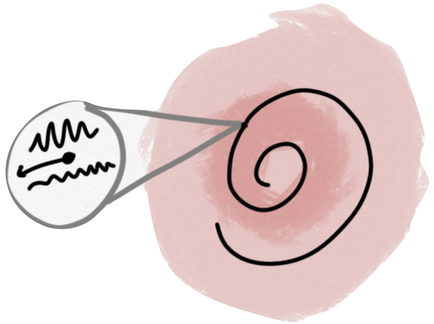


Migration (I, II)



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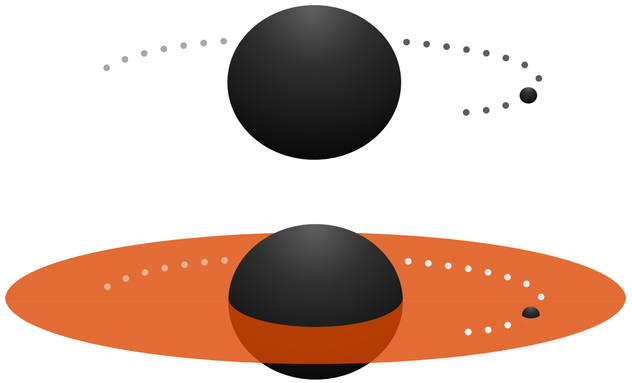

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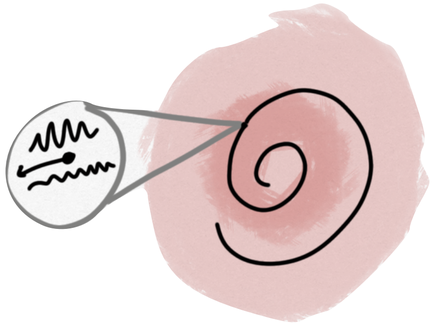

Accretion and “wind”

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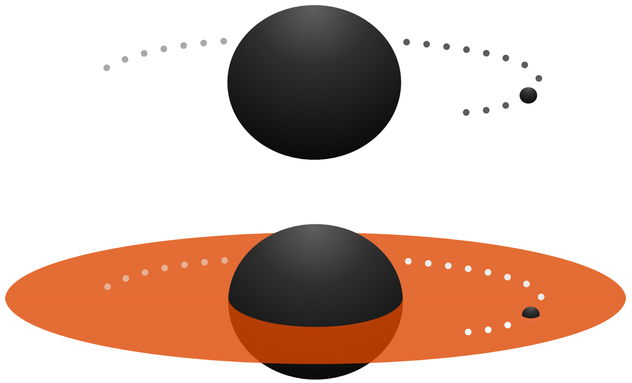

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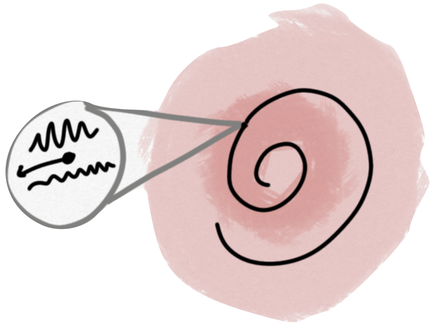

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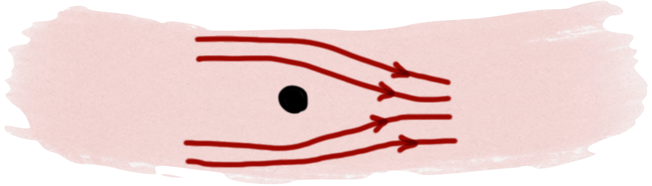
Dynamical friction



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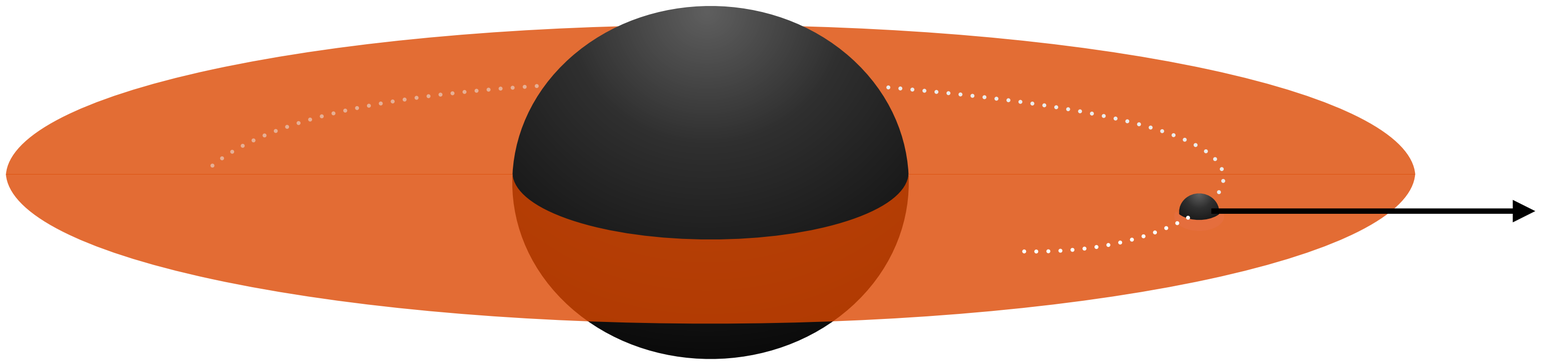
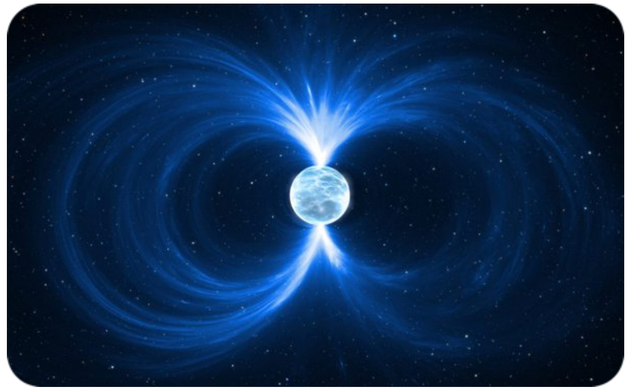
LET'S BECOME ASTROPHYSICISTS, WITH ONE EXAMPLE



Magnetised Neutron Star

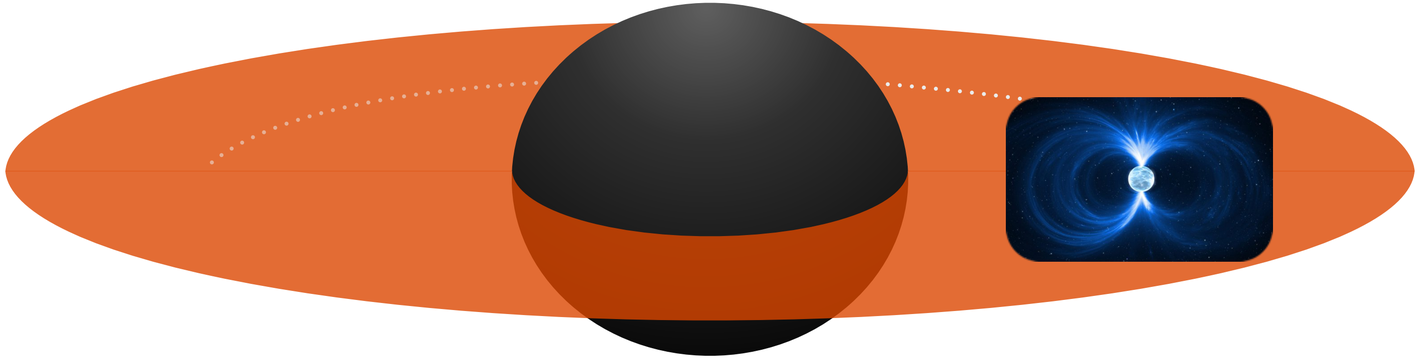


$B \sim 10^{14}$ Gauss

Work in progress
with L. Speri
and C. Miller

DOES THE MAGNETIC FIELD MATTER?

NS versus disk magnetic field



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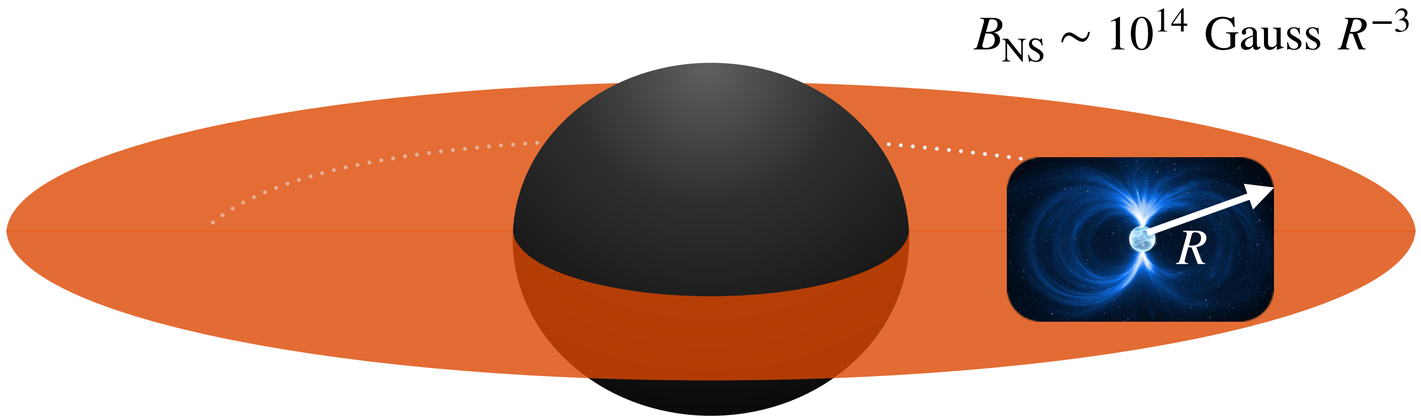

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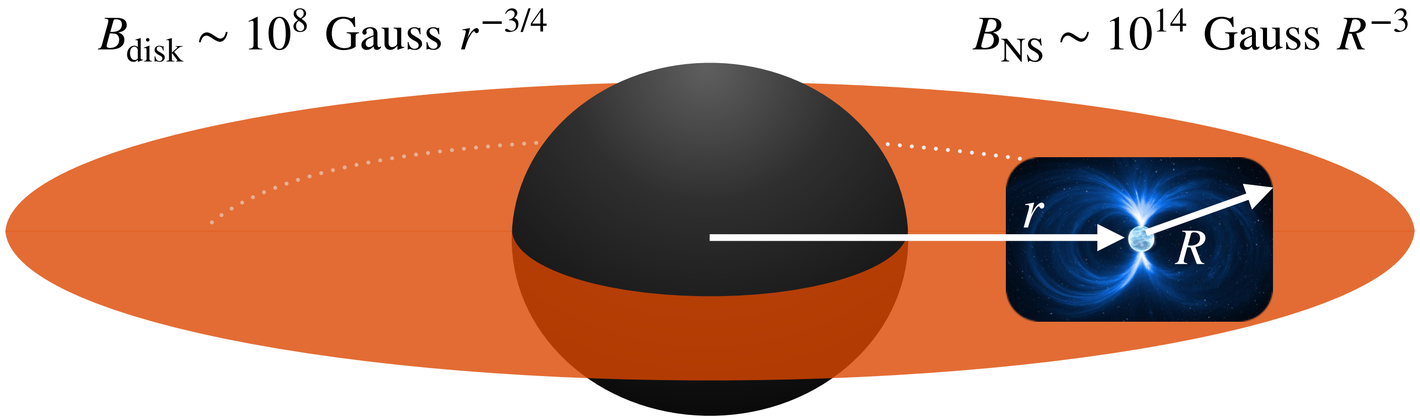

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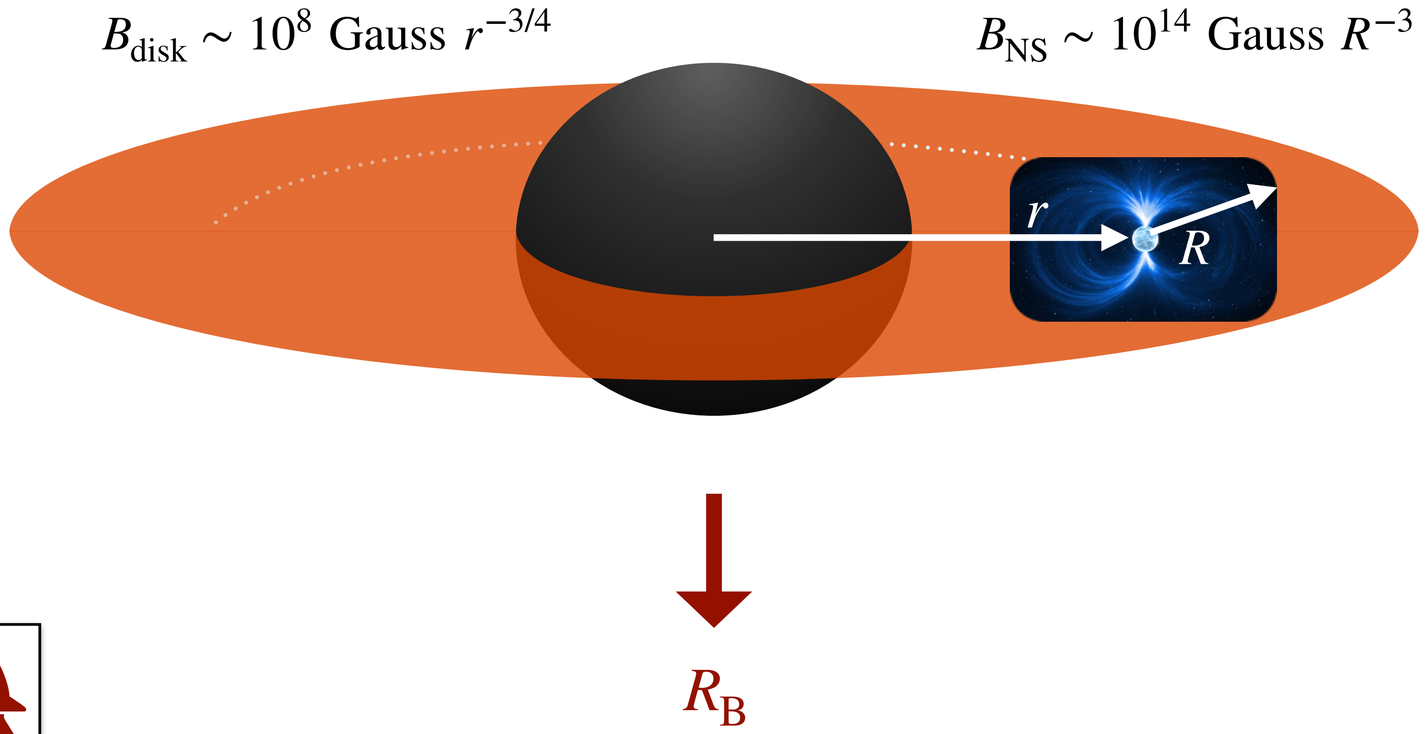

Work in progress
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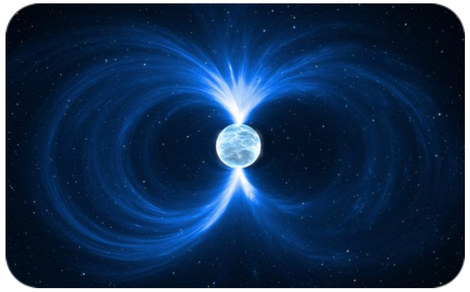
and C. Miller

DOES THE MAGNETIC FIELD MATTER?

magnetic versus gravitational attraction

R_{B}



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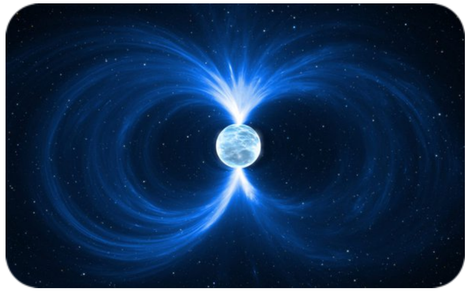

$R_{\text{gravity (Bondi)}} = M_{\mathrm{NS}}/c_s^2$

Work in progress
with L. Speri
and C. Miller

DOES THE MAGNETIC FIELD MATTER?

magnetic versus gravitational attraction

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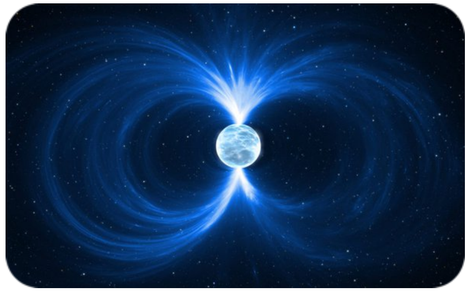
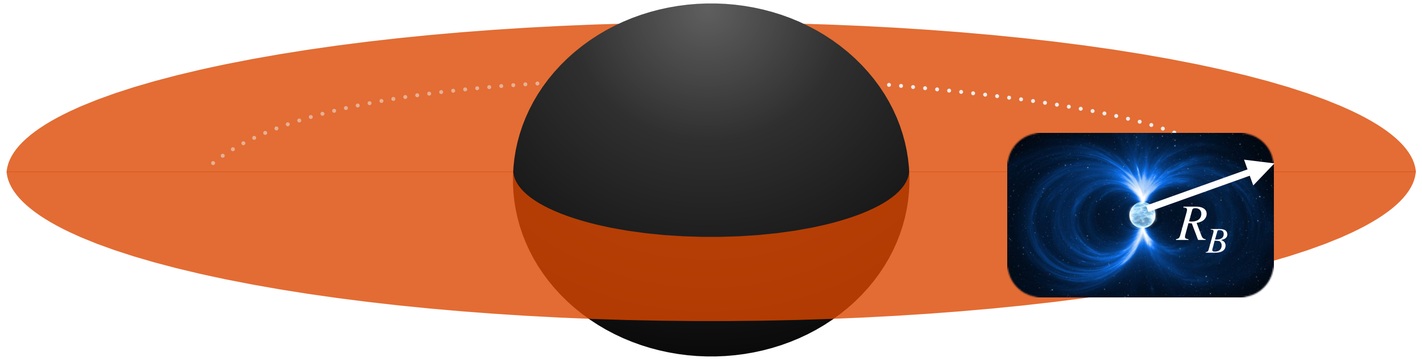


viable disk and NS parameter space

Work in progress
with L. Speri
and C. Miller

MAGNETIC DRAG

$$\dot{L}_{\text{magnetic}} = \pi \, \rho_{\text{disk}} \, c_s \, R_B^2$$



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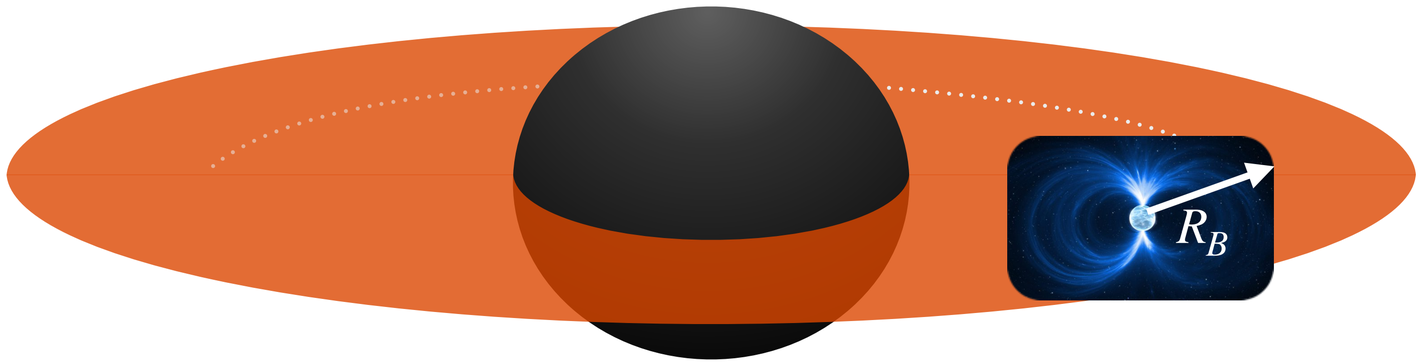


$$\dot{L}_{\rm magnetic}/\dot{L}_{\rm GW} \simeq 3\times 10^{-5} \left(\frac{r}{10\,M}\right)^{5/2}$$

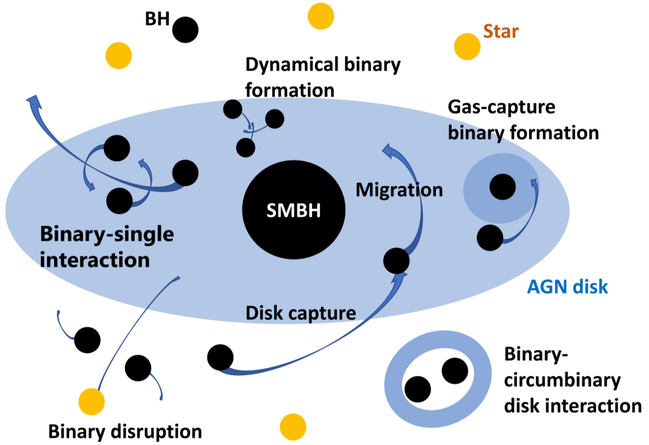
negative PN

Disk parameters: $f_{\rm Edd} = 0.1,\, \alpha = 0.01;\, B_{NS} = 10^{14}\,{\rm Gauss}$

Work in progress
with L. Speri
and C. Miller

THE IMPLICATIONS OF AN ENVIRONMENTAL EFFECT

Formation of NS EMRIs or tidal disruption events:
migrate faster towards the central black hole



[Tagawa+2020]

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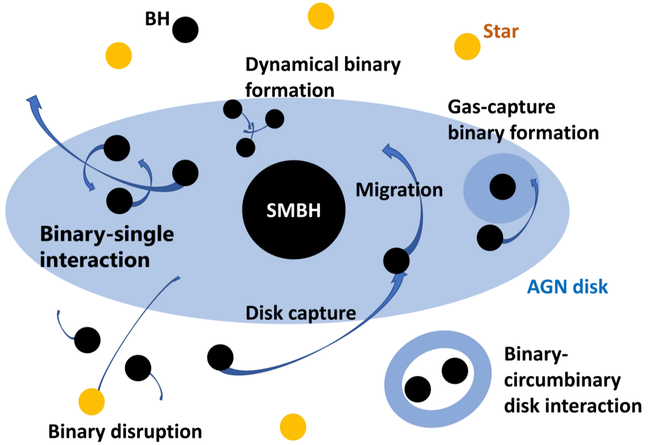


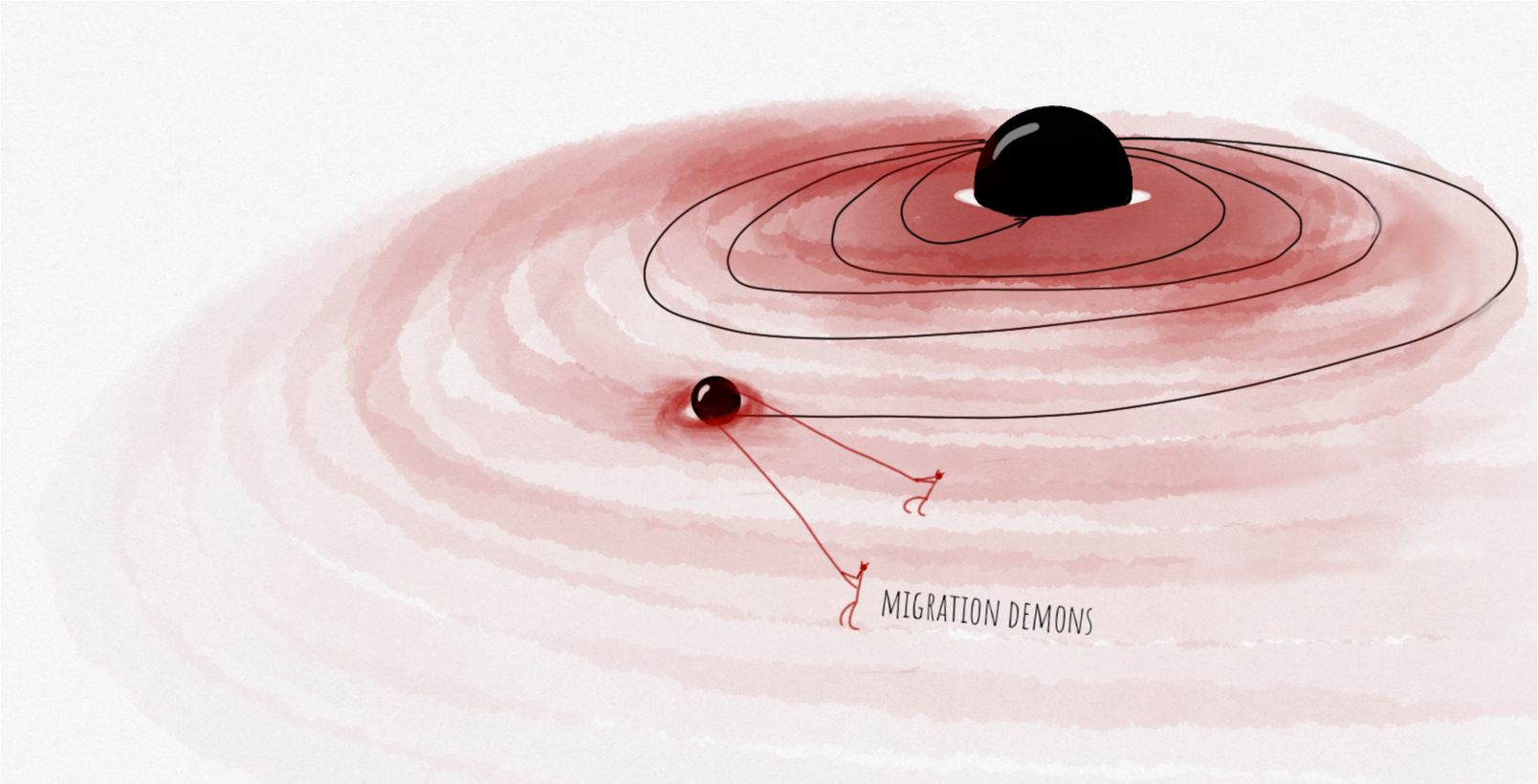
[Tagawa+2020]

lisa detection: rest of the talk!

THE LARGEST EFFECT

Planetary-like migration

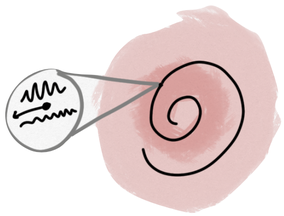
[Goodman, Rafikov 2001; GWs: Kocsis+ 2011, Yunes+ 2011]



EXTREME MASS RATIO INSPIRALS IN ACCRETION DISKS: THE PROBLEM

Analytic models borrowed from planetary science

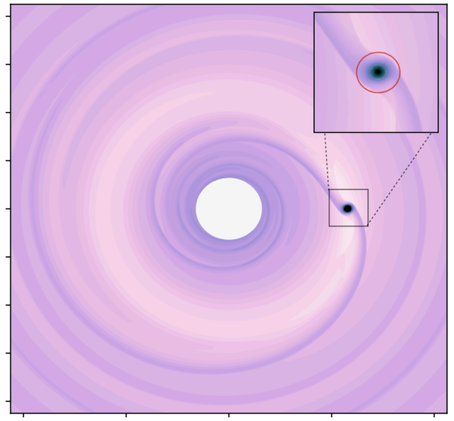
[Kocsis+ 2011]



Few **simulations**,

don't capture all the physics

[Derdzinski+, 2020]



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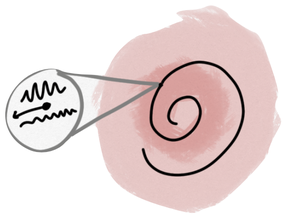

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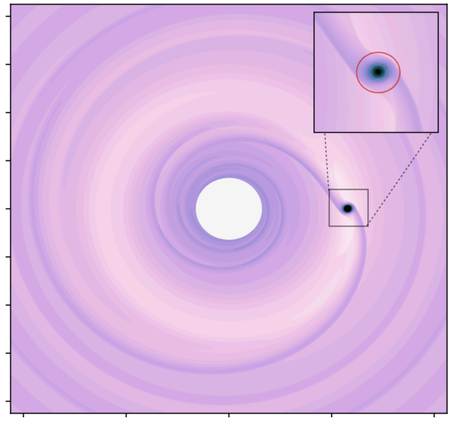
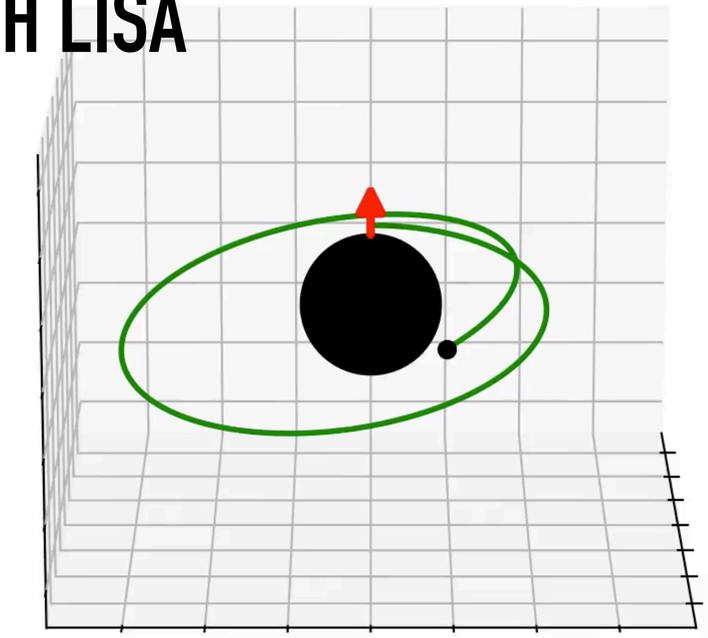


$$\frac{\dot{L}_{\rm environment}}{\dot{L}_{\rm GW}} = A(f_{\rm edd}, \alpha; M_i)\, r^{n_r}$$

disk viscosity

disk accretion rate

DETECTING EXTREME MASS RATIO INSPIRALS WITH LISA



Our **waveform model**:

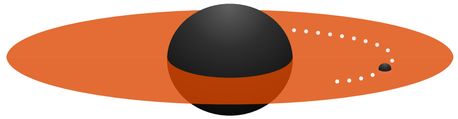
`FastEMRIWaveforms` (FEW)

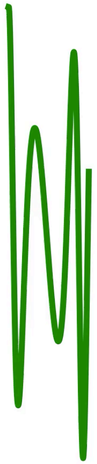
[Katz+ 2021, https://bhptoolkit.org]

Kerr, *circular, equatorial*

Adiabatic trajectories (LISA: post-adiabatic)

AAK waveforms (weak field amplitudes)





Courtesy of L. Speri

[Speri, LS et al. 2207.10086]

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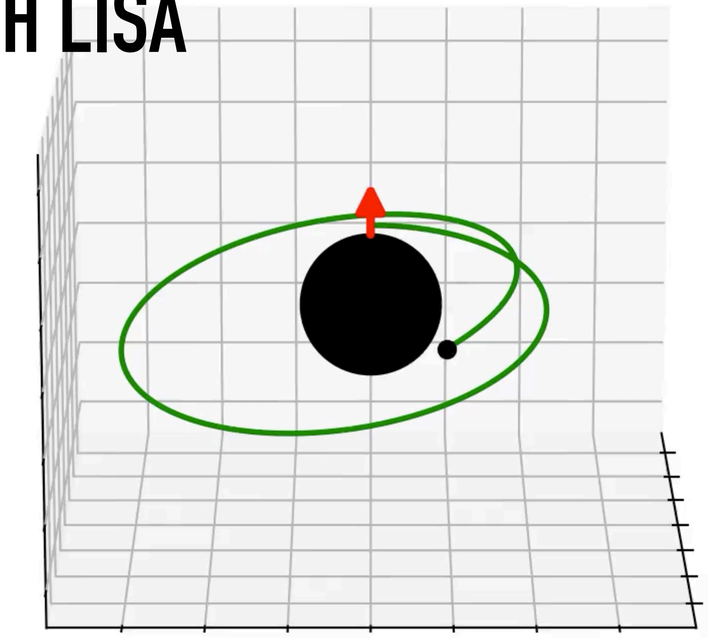

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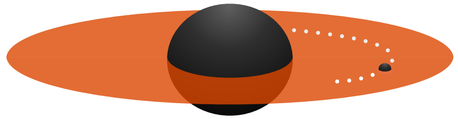

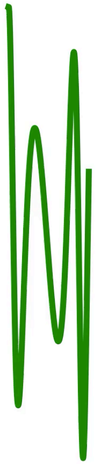

Courtesy of L. Speri

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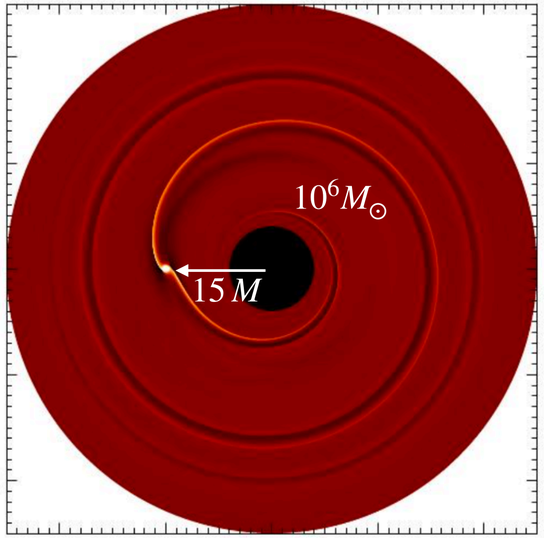
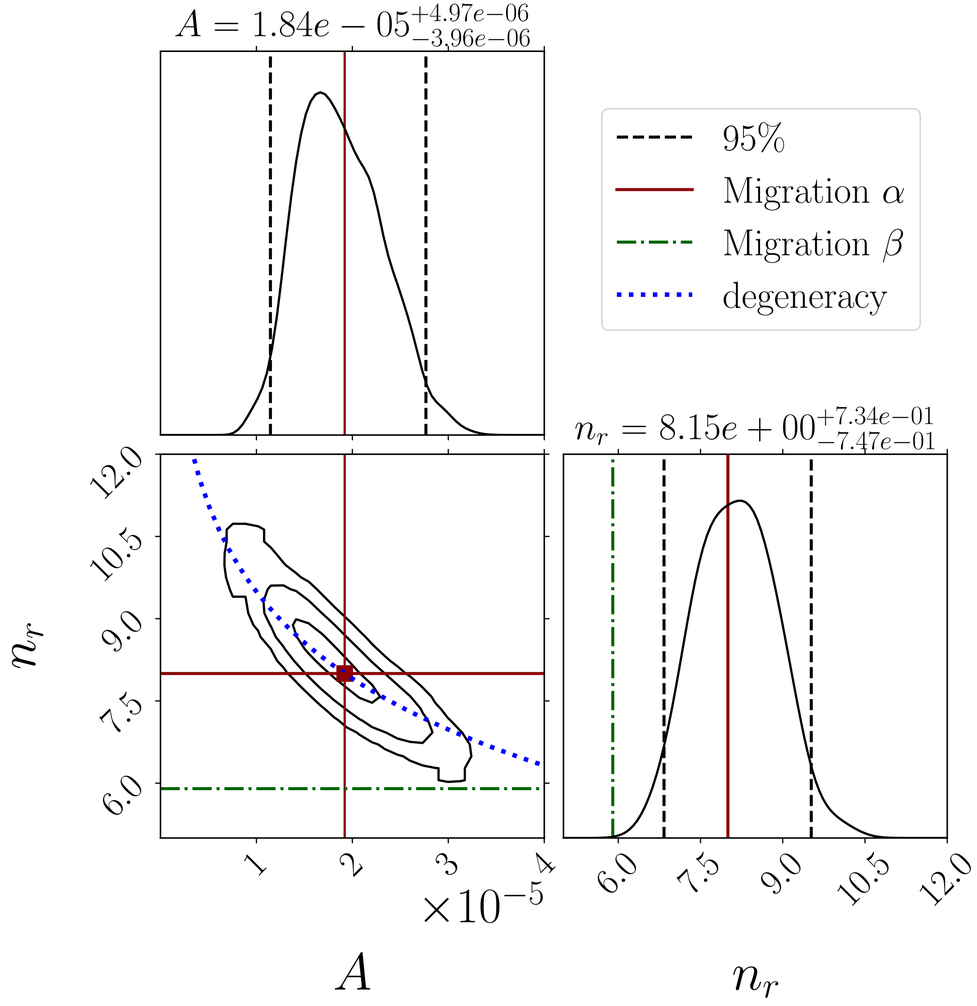
EXTREME MASS RATIO INSPIRALS IN ACCRETION DISKS: A REALISTIC ANALYSIS



[Nelson 2018]



$$\frac{\dot{L}_{\text{environment}}}{\dot{L}_{\text{GW}}} = A\, r^{n_r}$$

[Speri, LS et al. 2207.10086]

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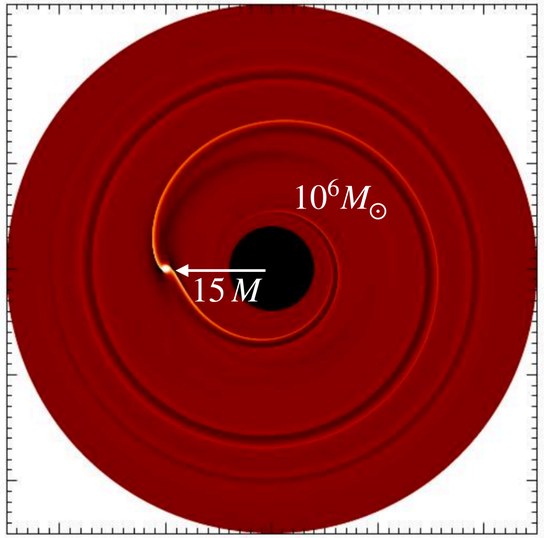

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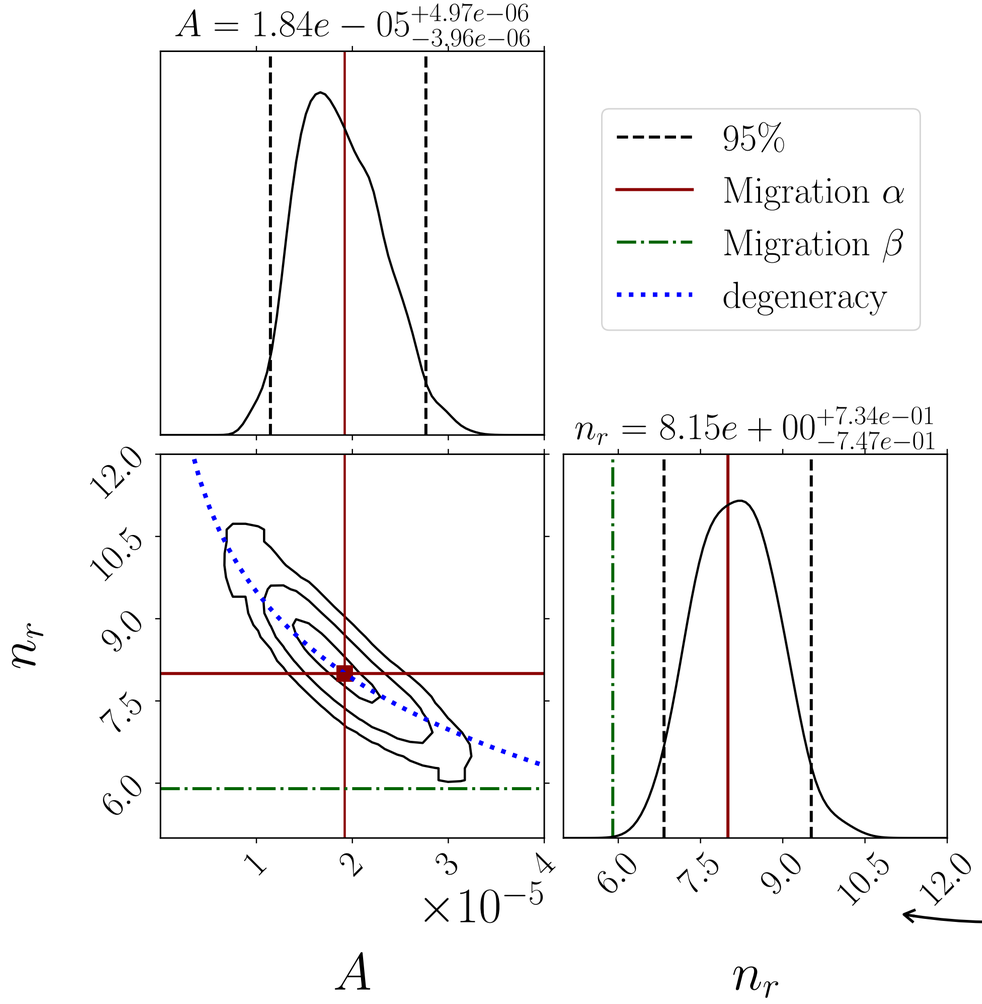


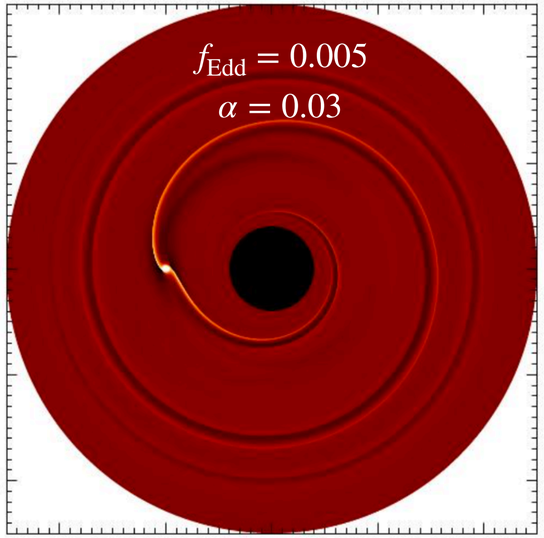
$$\frac{\dot{L}_{\text{environment}}}{\dot{L}_{\text{GW}}} = A\, r^{n_r}$$

Disk/effect model selection!

[Speri, LS et al. 2207.10086]

MEASURING THE DISK WITH GRAVITATIONAL WAVES ALONE

Disk parameters:
accretion rate and viscosity



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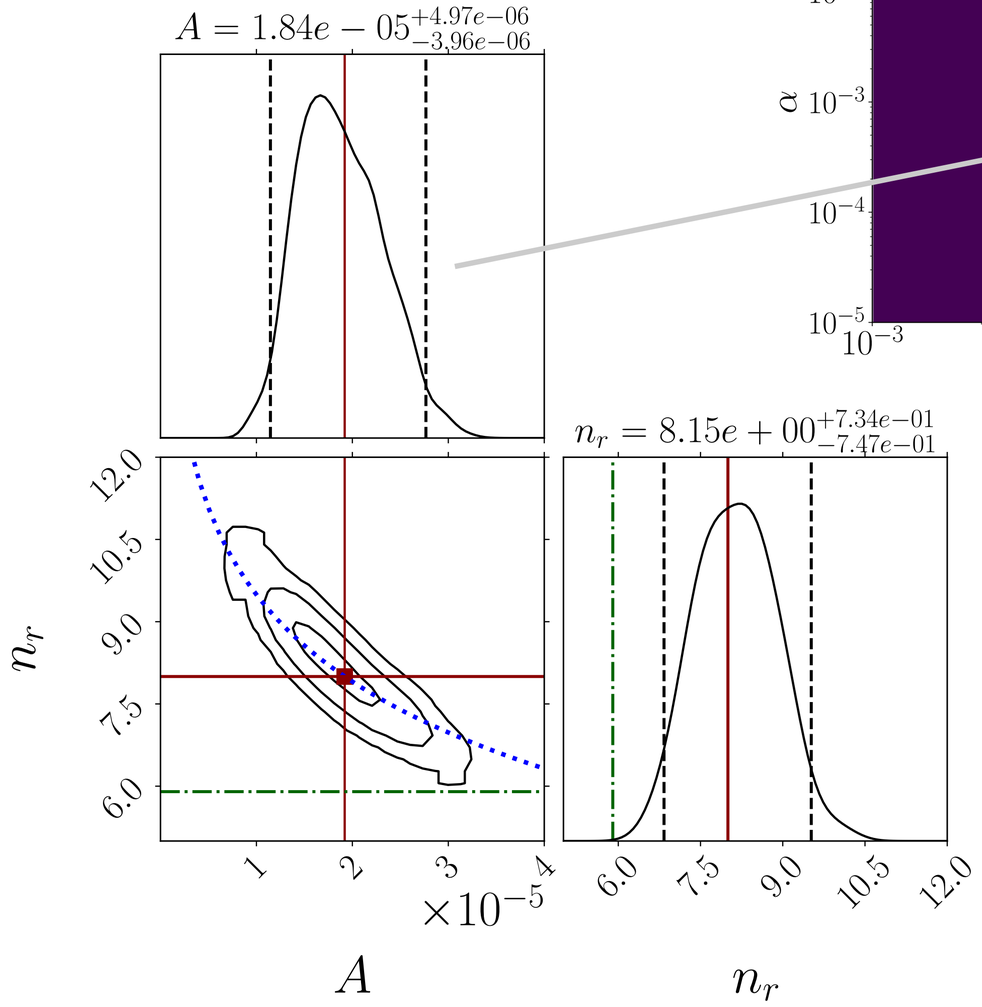
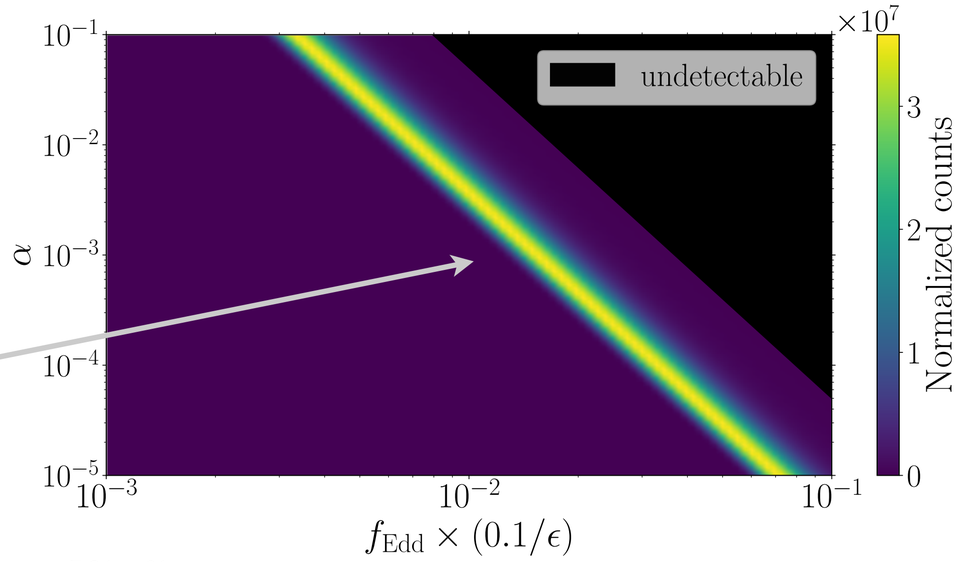
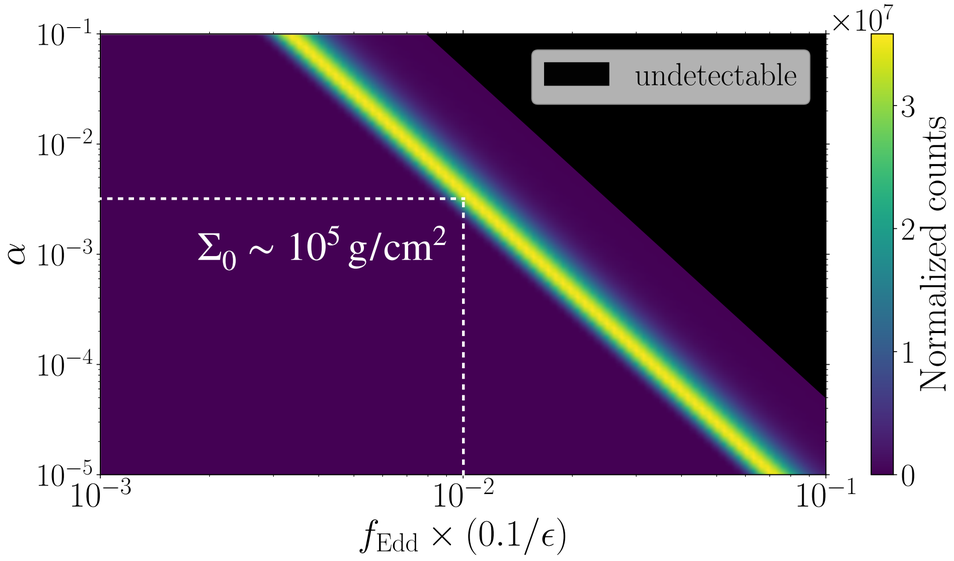




[Speri, LS et al. 2207.10086]

GRAVITATIONAL WAVES + ELECTROMAGNETIC OBSERVATIONS

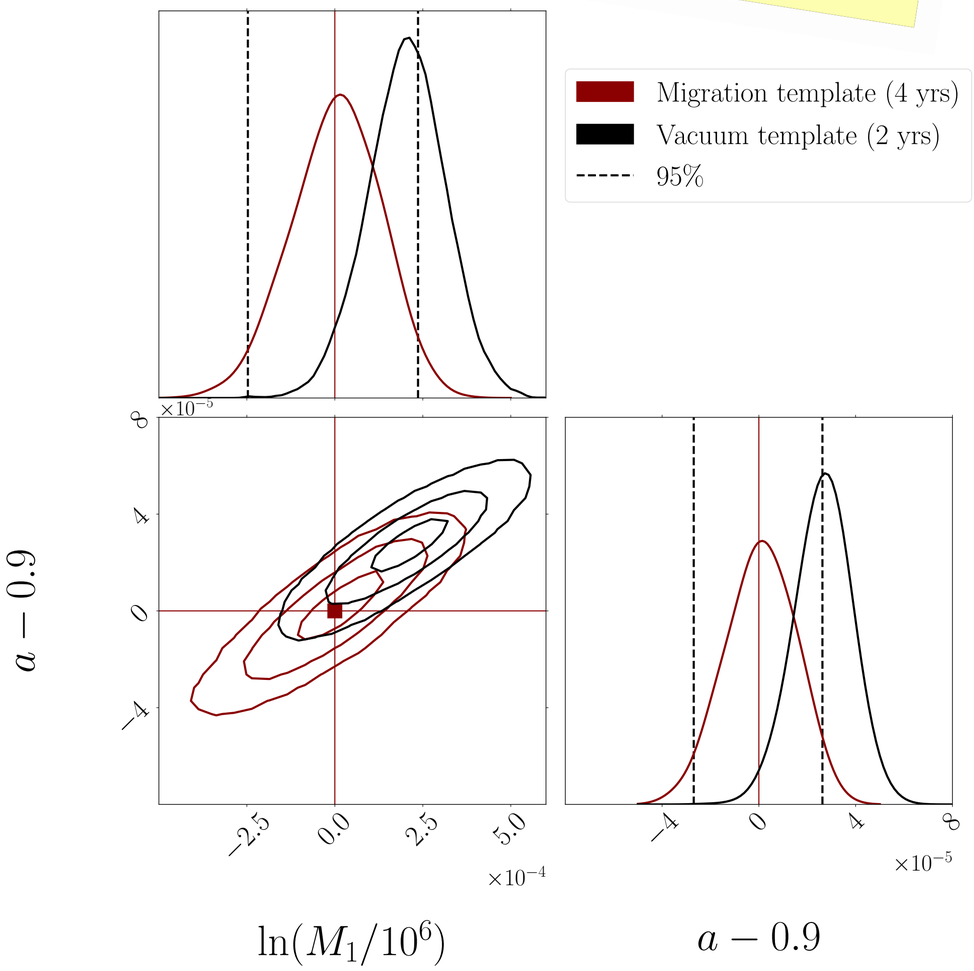


Golden scenario:
host **identification** and **measurement** of the bolometric luminosity

[Speri, LS et al. 2207.10086]

EXTREME MASS RATIO INSPIRALS IN ACCRETION DISKS: THE RISKS

Bias with a vacuum template



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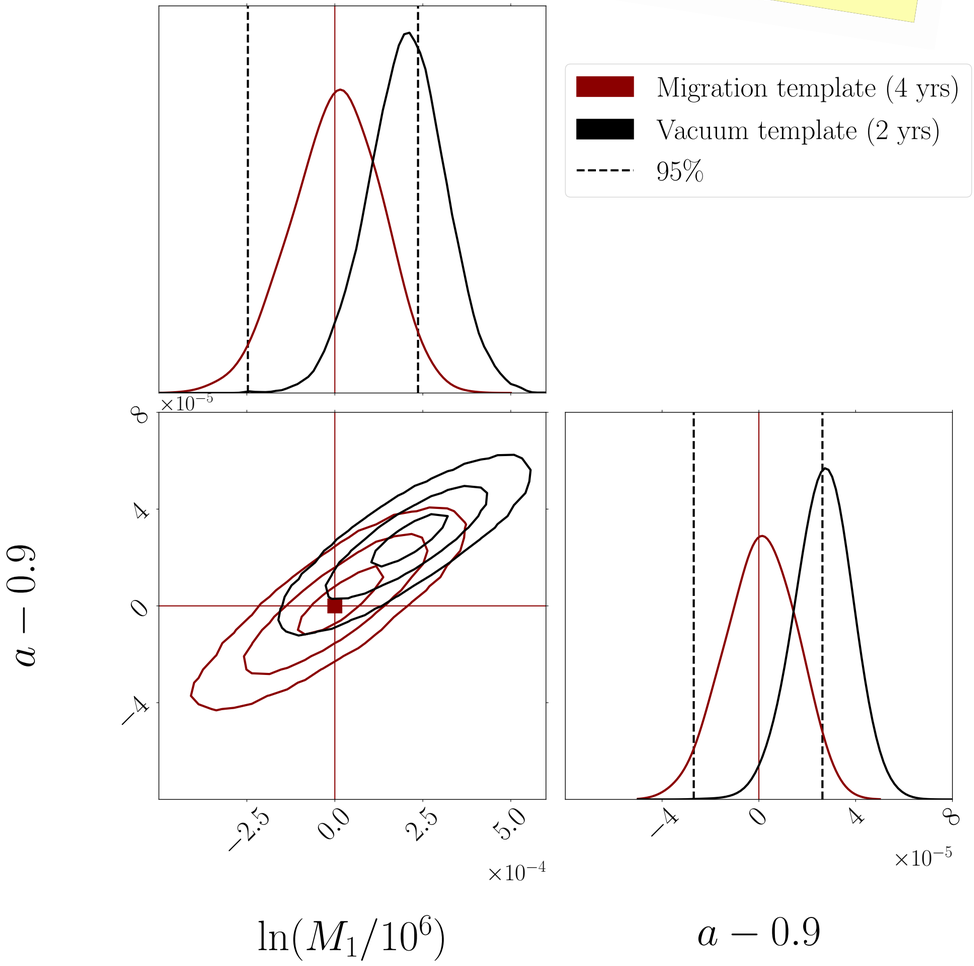
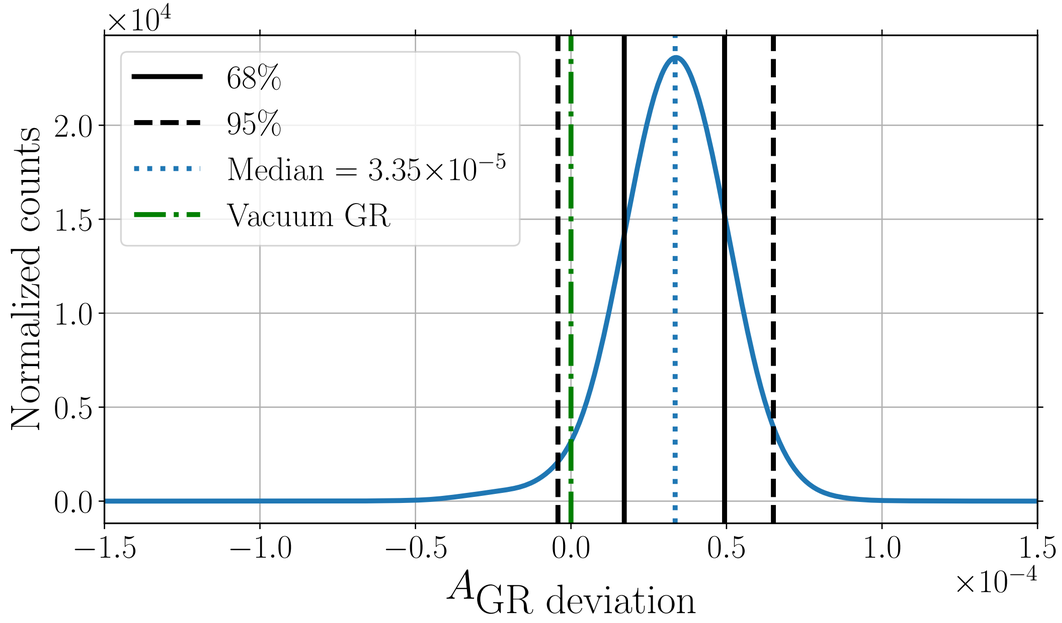
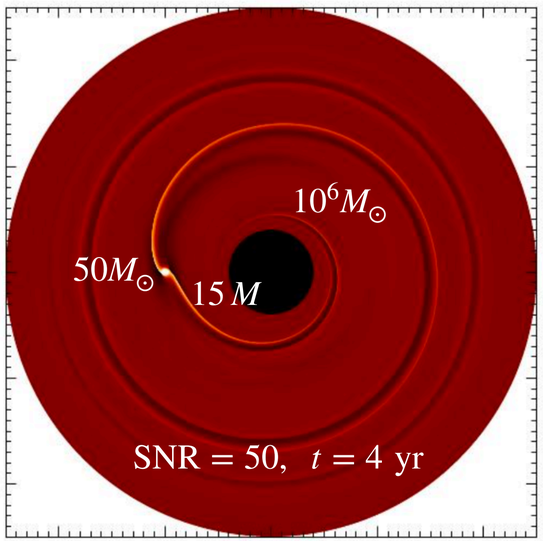


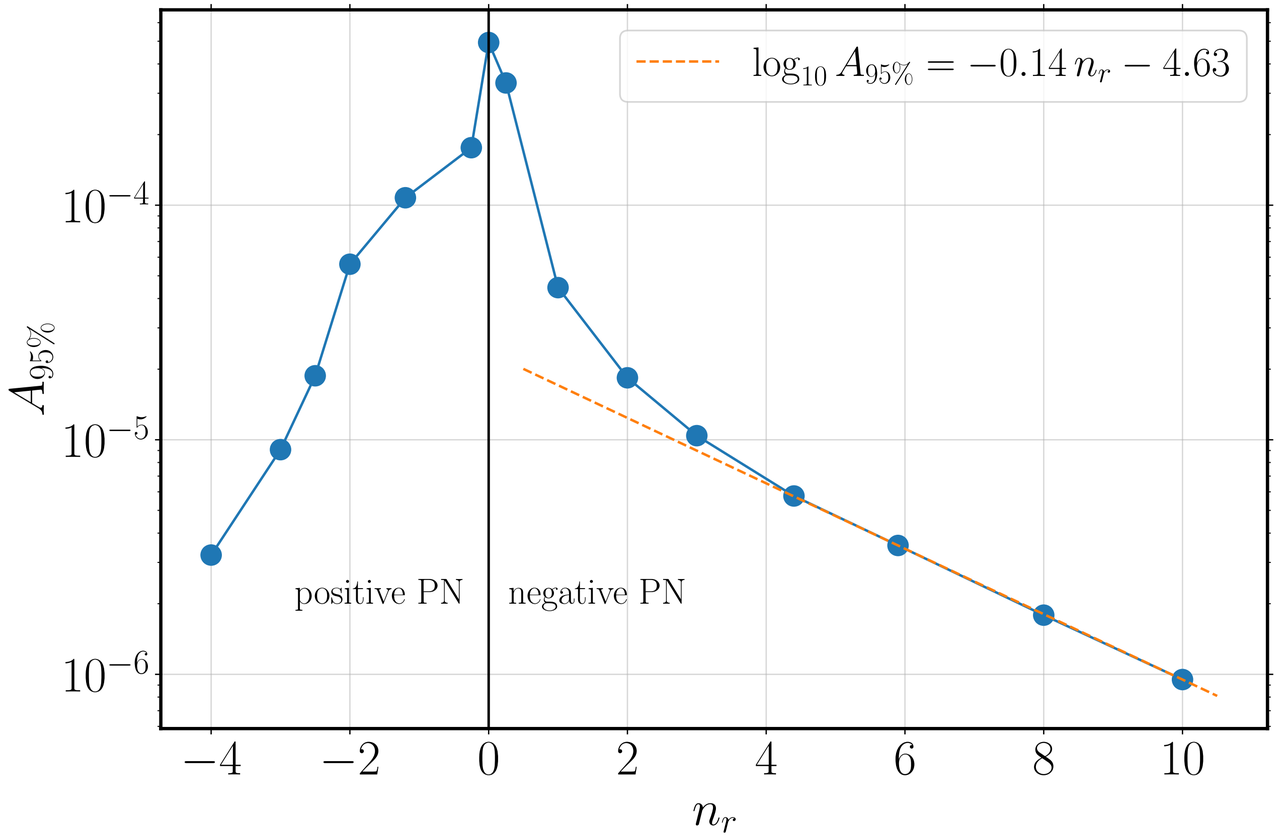
False hint at modification of gravity



[Speri, LS et al. 2207.10086]

GENERAL RESULT





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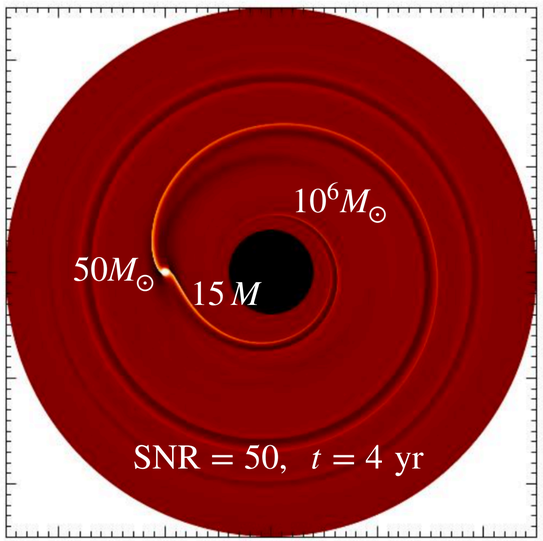
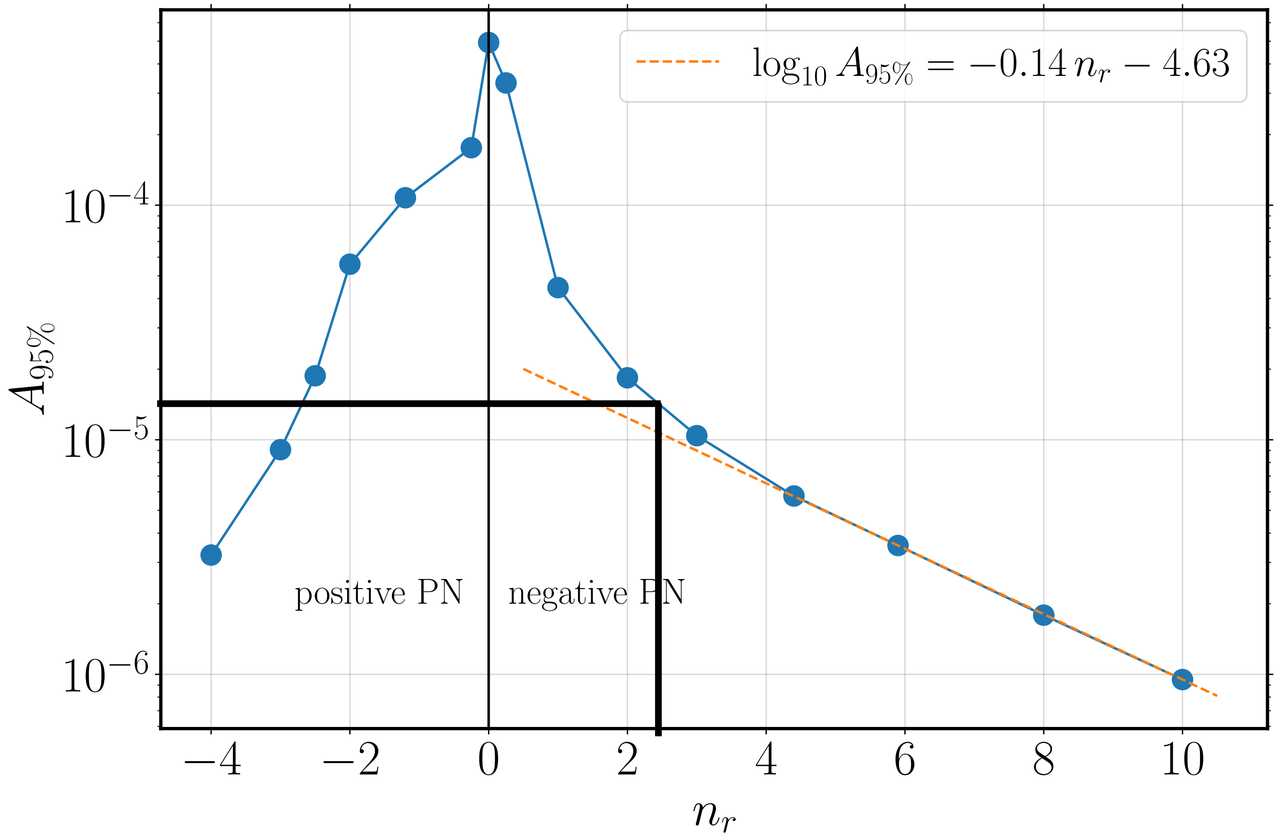
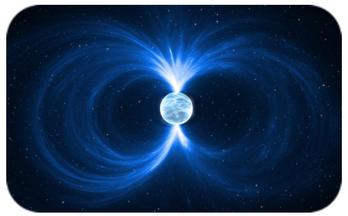




$$\dot{L}_{\rm magnetic}/\dot{L}_{\rm GW} \simeq 3\times 10^{-5}\left(\frac{r}{10\,M}\right)^{5/2}$$



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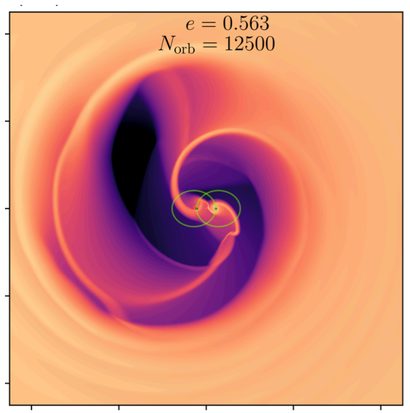
ASTROPHYSICAL ENVIRONMENTS IN THE NEAR FUTURE

- **Eccentricity** (could enhance prospects!) [Xuan+ 2022]



[D'Orazio, Duffell 2021]

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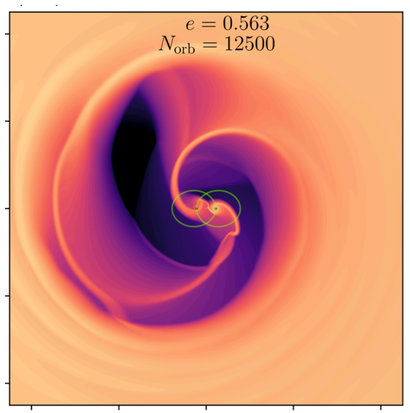

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Current limitations in simulations:

- *intermediate mass ratio*
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- *leading order orbit decay*
- *no radiation, no magnetic fields*
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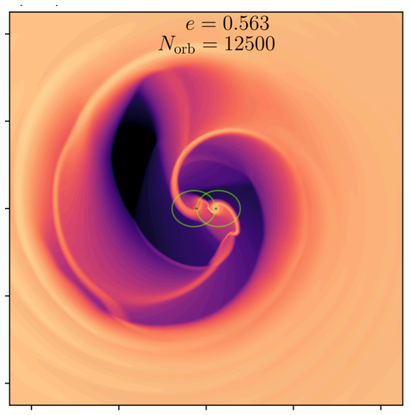

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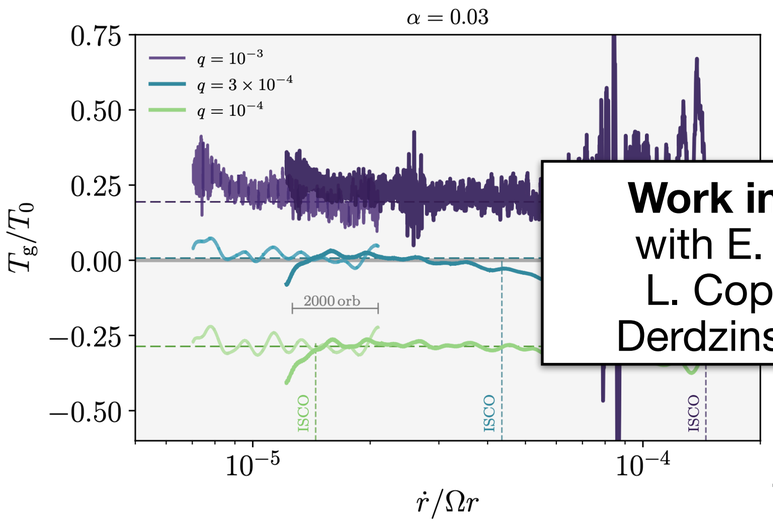
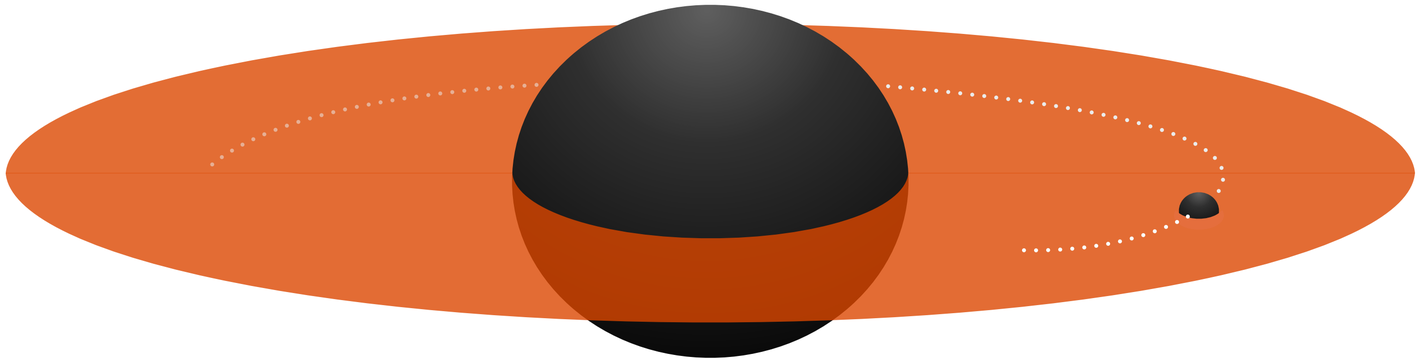


Work in progress
with E. Barausse, L. Copparoni, A. Derdzinski, L. Speri

Thank you!



Laura Sberna (Max Planck Institute for Gravitational Physics, Potsdam)

Asymmetric Binaries meet Fundamental Astro-Physics
GSSI, L'Aquila
September 2023