EXPLORING NONLINEAR INTERACTIONS BETWEEN CHARGED BLACK HOLES WITH NUMERICAL RELATIVITY: GRAVITATIONAL WAVES & FUNDAMENTAL PHYSICS

October 28, 2022

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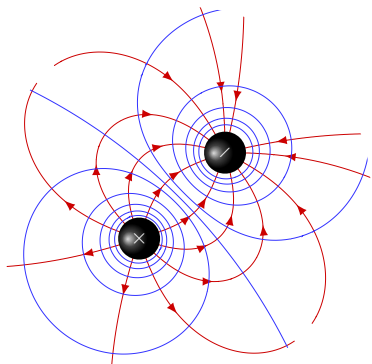
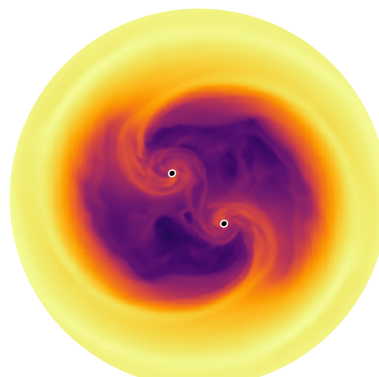
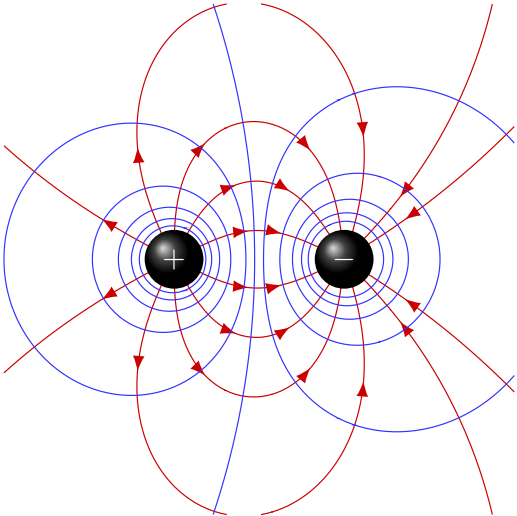
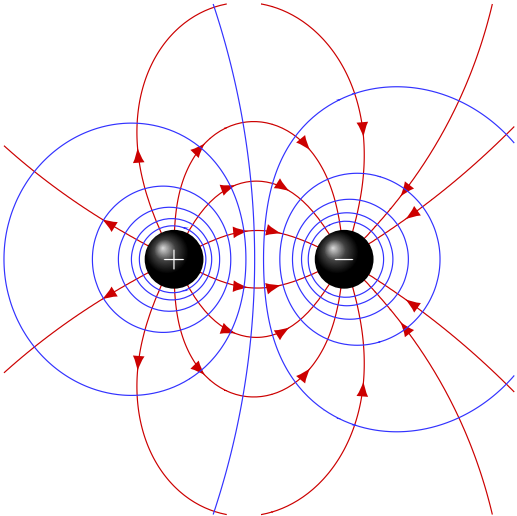






The nonlinear interaction between charged binary black holes is **unexplored**

Orbits? Emission? ...?



The nonlinear interaction between charged binary black holes is **unexplored**

Orbits? Emission? …?

1. Results apply to stellar-mass, supermassive, and microscopic BHs
2. Charge does not have to be electromagnetic

Nonlinear interaction is important for

Astrophysics ⟷ Constraints on charge
GW templates for LIGO-Virgo

→ BH charge is largely unconstrained

→ GW models do include charge

More on this later!

Nonlinear interaction is important for

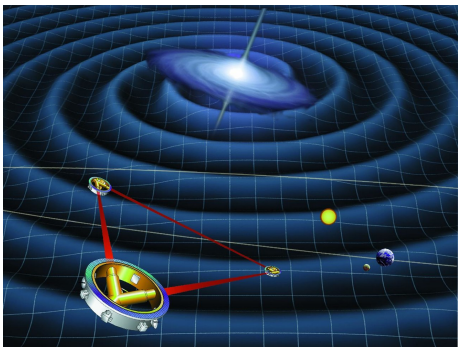
Exotic Astrophysics ⟷ Constraints on charged dark matter and magnetic monopoles

→ Primordial BH could have (electric or magnetic) charge

→ Dark matter could be (darkly) charged

Nonlinear interaction is important for

Modified Gravity ⟷ Springboard and proxy for other theories (e.g. Einstein-Maxwell-Scalar)



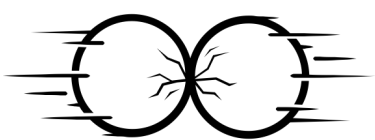
→ Well defined way to go beyond GR

→ Some theories are mathematically identical in specific limits

→ Better understanding for future facilities

Nonlinear interaction is important for

First Principles ⟷ Ultra-relativistic collisions
Scattering
Cosmic censorship

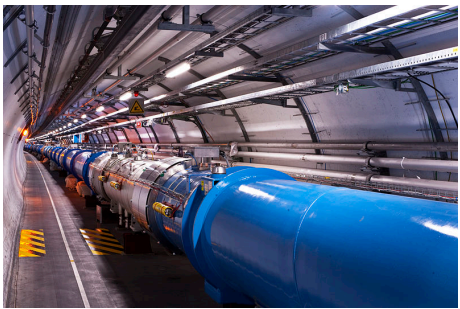


→ Exceptional laboratories for controlled numerical experiments

→ Interplay between extreme electromagnetic and gravitational fields

Nonlinear interaction is important for

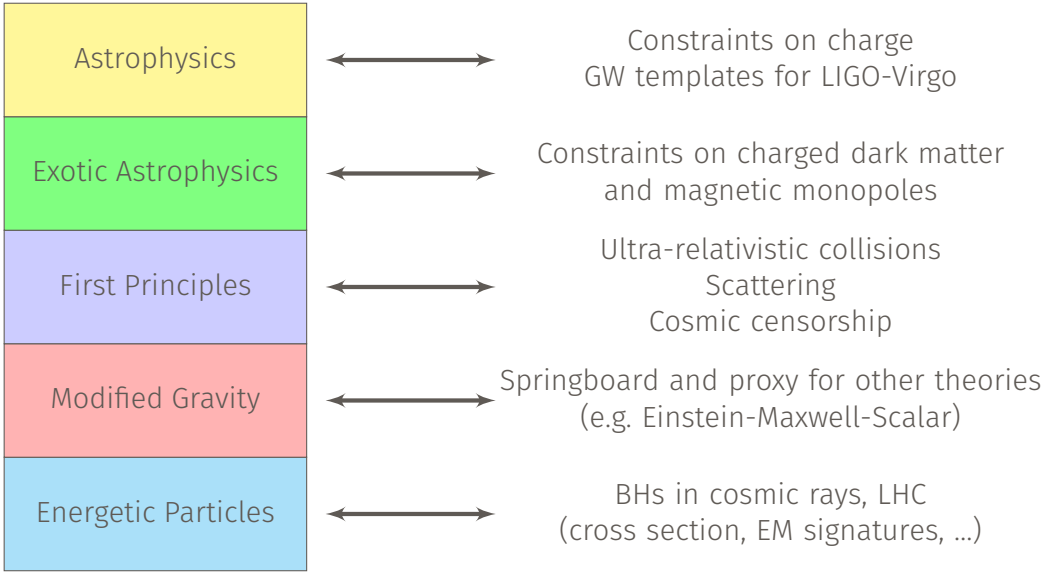
Energetic Particles ⟷ BHs in cosmic rays, LHC (cross section, EM signatures, ...)



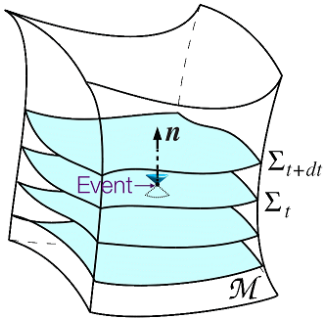
→ Microscopic black hole production and detection

→ Tests of specific grand unified theories

Nonlinear interaction is important for



Exploring nonlinear interactions = Solving Einstein-Maxwell's equations



Numerical solution of Einstein-Maxwell's equations as initial-value-problem

Issues with stability, gauge, initial data, ...

HARD PROBLEM!

Numerical Relativity ⟷ Improved/novel methods

Astrophysical black holes are expected to be neutral...

Discharge limits rely on $\boxed{\frac{1}{\sqrt{G}}\frac{Q_{\rm BH}}{M_{\rm BH}} < \sqrt{G}\frac{m_{\rm proton}}{q_{\rm proton}} \sim 10^{-18}}$

Evaded if:

- → Mini-charged dark matter ($\sqrt{G}m/q \sim 1$)
- → Dark electromagnetism (different EM coupling)
- → Magnetic monopoles (no discharge)
- → Gravitational charge (SVTG*, $Q/(\sqrt{G}M) = \sqrt{\alpha/(1+\alpha)}$, with α coupling)

* = Scalar-Vector-Tensor Gravity

Preskill+ (1984), Moffatt (2006), Feng+ (2009), Cardoso+ (2016), ...

How can we test this?

Charge

⇓

Electromagnetic energy

⇓

Spacetime curvature

Orbital dynamics

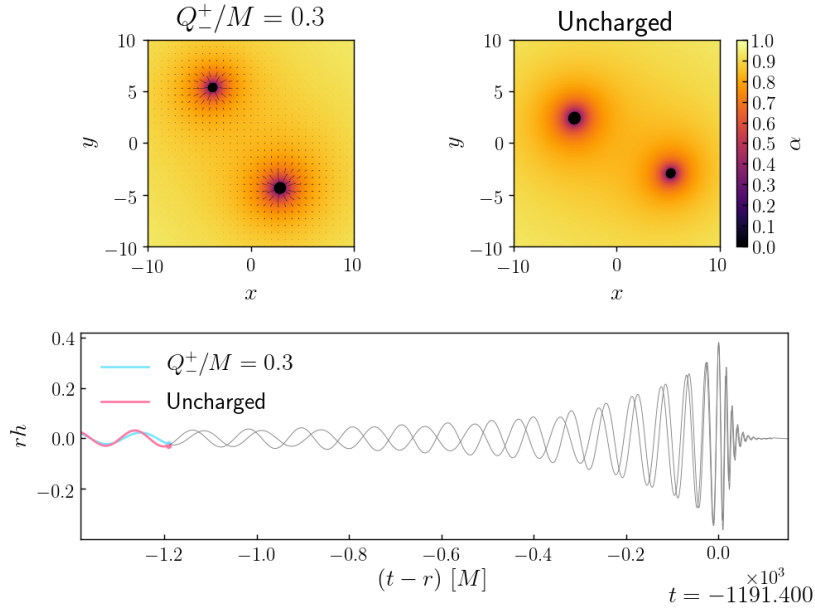
⇓

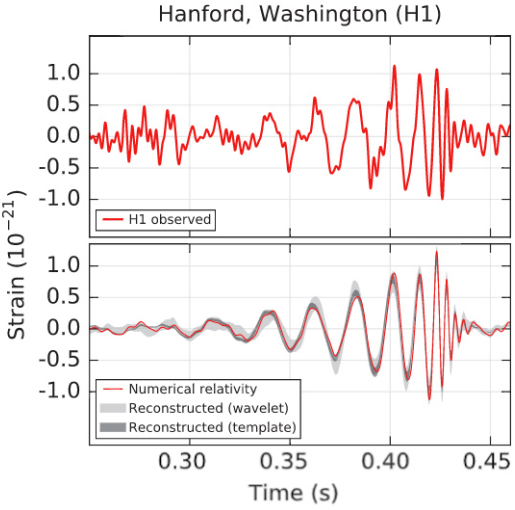
Gravitational waves

GWs know about charge

Strengths:

- → Little modeling required
- → Applicable to exotic astrophysics


$Q_-^+/M = 0.3$
Uncharged
y
x
α
rh
$Q_-^+/M = 0.3$
Uncharged
$(t-r)$ $[M]$
$\times 10^3$
$t = -1191.400$



GW150914:

- → First confirmed GW event
- → Loud and well-characterized (SNR = 25)
- → Mass-ratio $29/36$
- → (Disputed) coincident EM observations

Full Bayesian analysis requires GW templates (= *currently impossible*)

Plot from LIGO (2016)

First constraints on:

Black hole charge from GW150914:

Opposite charge: $\mathbf{Q}/(\sqrt{\mathbf{G}}\mathbf{M}) < \mathbf{0.2}$
Single charge: $\mathbf{Q}/(\sqrt{\mathbf{G}}\mathbf{M}) < \mathbf{0.35}$
Same charge: $\mathbf{Q}/(\sqrt{\mathbf{G}}\mathbf{M}) < \mathbf{0.4}$
(charge imbalance $< 10^{-17}\, M_{\odot}$)

Tightest constraint on STVG
(Scalar-Vector-Tensor Gravity)
in strong-field:

$\alpha < \mathbf{0.19}$ (before $\alpha \lesssim 9$)

Bozzola&Paschalidis (PRL 2021)

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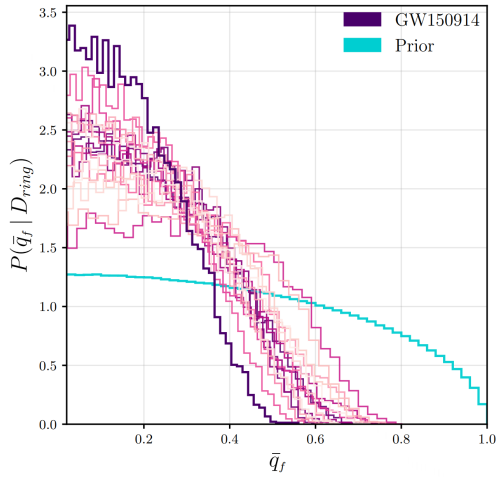
Later confirmed by Carullo+, 2022:



$\bar{q}_f$ = final charge-to-mass-ratio

Why charged BHs?

→ Constraints w/ GWs
→ Testing conjectures
→ Advancing NR

Astrophysics

→ Full NR waveforms
→ Bounds on Q/M

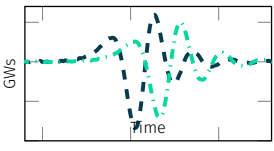
Modified Gravity

→ Bound on SVTG α

Current work

→ GW template bank for LIGO/Virgo
→ Effects of plasma (+ R. Luna, M. Zilhão, V. Cardoso)
→ Quasi-normal-modes and 3G detectors (+ G. Carullo, M. de Amicis, V. Cardoso)
→ Hyperbolic encounters (+ M. Smith)
→ Censorship in quasi-circular mergers (+ C. Worley)

Ask me about:



High-energy collision