

Physics-informed AI-driven modelling for binary black hole mergers

Connecting general relativity to astrophysics

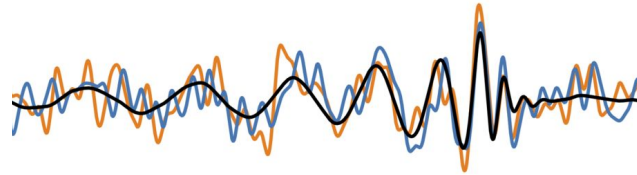
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University of California Santa Barbara



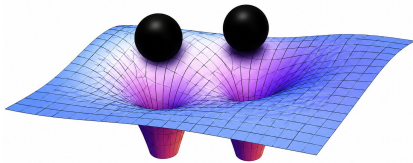
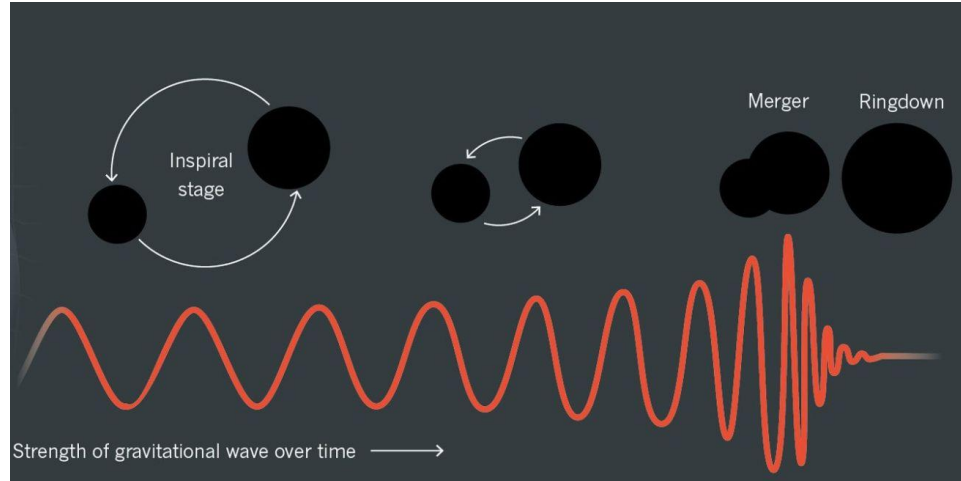
(incoming) Weinberg Fellow
University of Texas Austin

(incoming) Visiting Scholar
Institute for Advanced Study

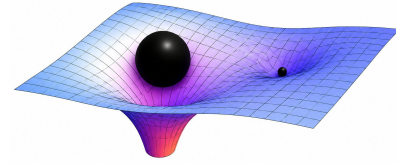


2nd Annual Cosmic Horizon Conference
Charlottesville
July 16, 2026

1.1 Binary black hole merger simulations



Numerical Relativity



Black-hole perturbation theory

1.2 Modelling recoil kicks in precessing binaries



Globular clusters have spherical symmetry

Hard problem

$$v_{\text{kick}} = f^{7\text{D}}(q, |\chi_1|, |\chi_2|, \theta_1, \theta_2, \phi_1, \phi_2)$$

Relatively simpler problem

$$p(v_{\text{kick}}) = g_{\phi}^{3\text{D}}(v_{\text{kick}}|q, |\chi_1|, |\chi_2|)$$

Islam & Wadekar | [arXiv:2511.11536](https://arxiv.org/abs/2511.11536)

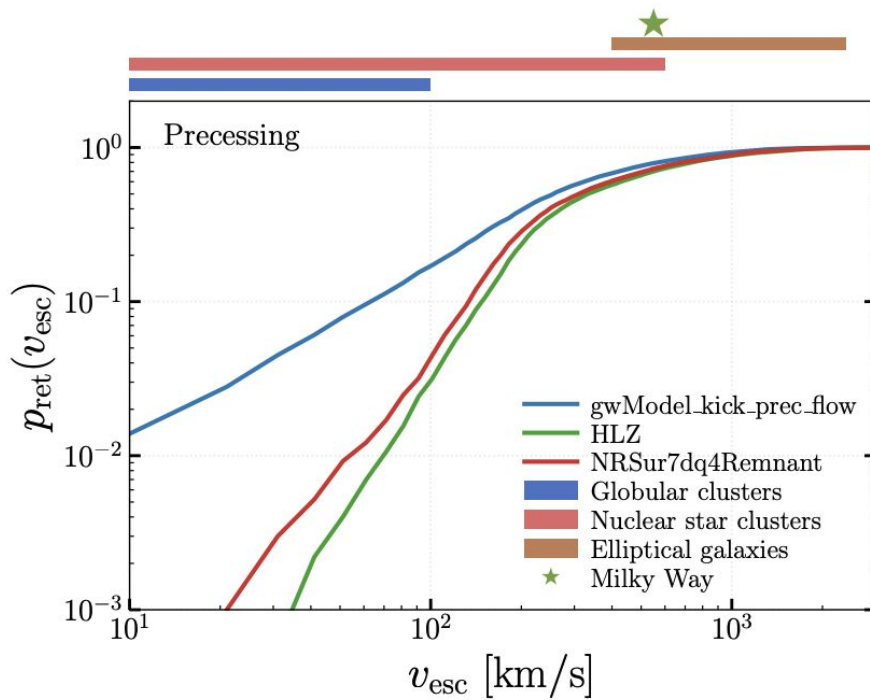
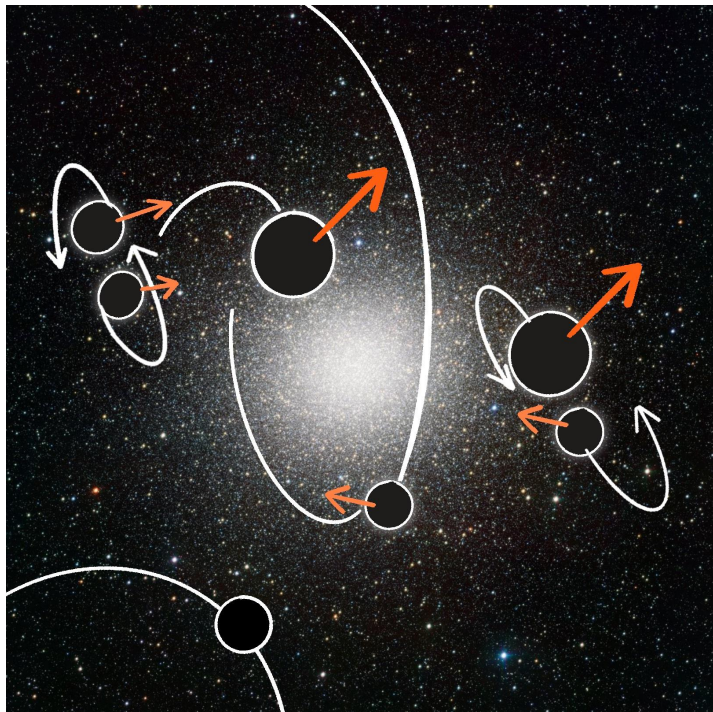
~3000 Numerical
Relativity Simulations

~1000 Perturbation theory
Simulations

Marginalizes spin-angles and
trains a normalizing flow

Uses known symmetry from general
relativity (post-Newtonian)

1.3 Binary black hole mergers in clusters



Islam & Wadekar | [arXiv:2511.11536](https://arxiv.org/abs/2511.11536)

2.1 Hierarchical mergers in clusters

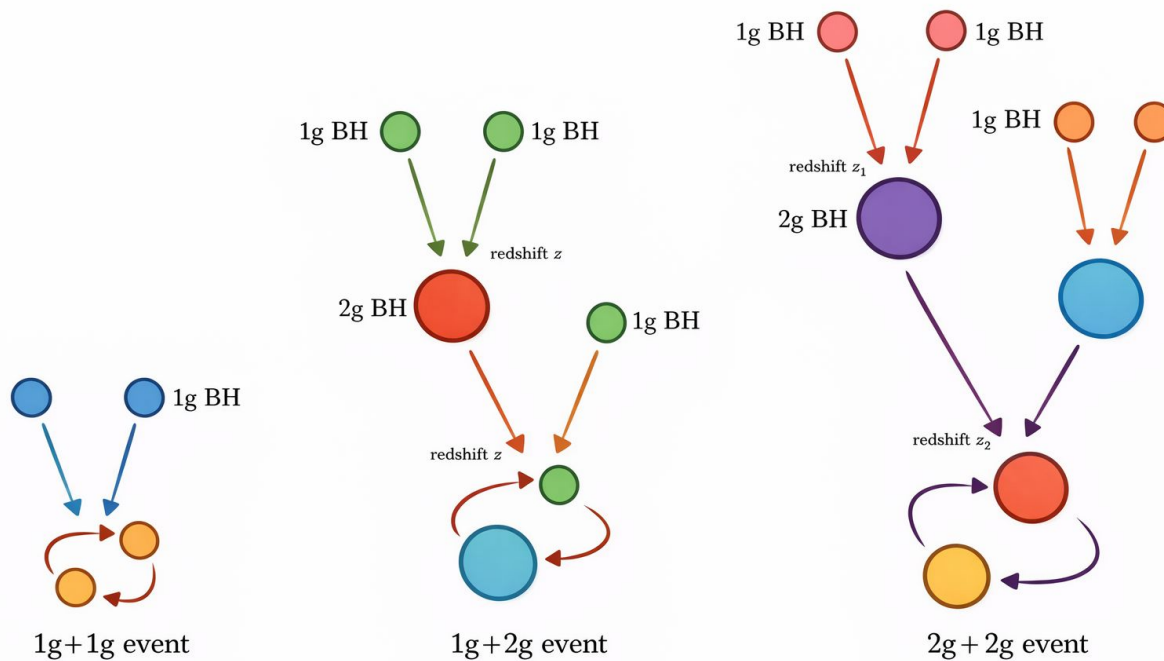
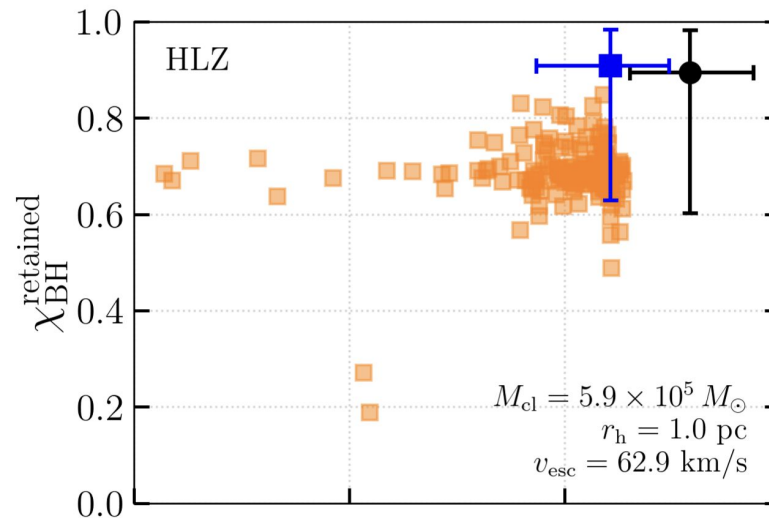
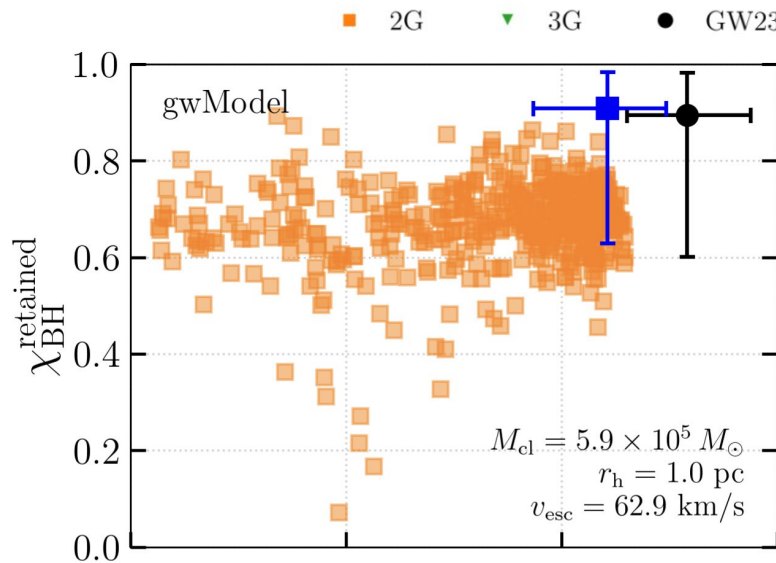


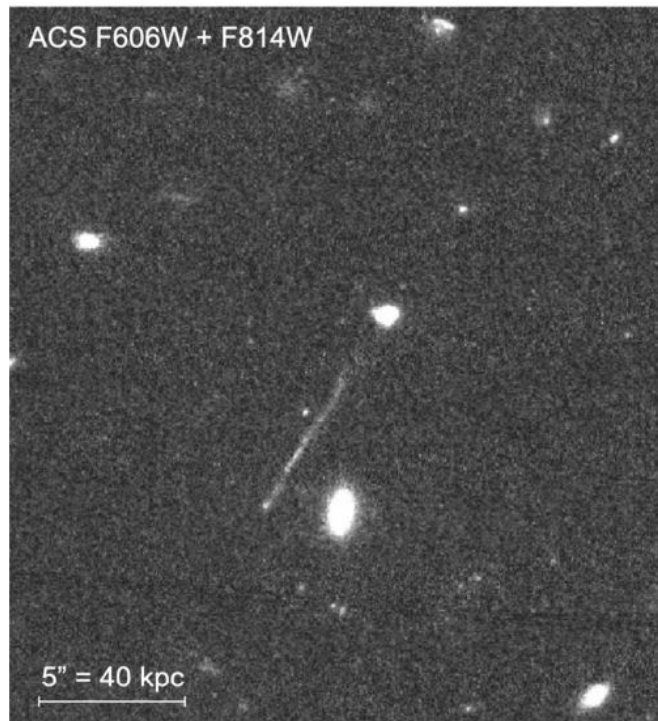
Image Credit: Adapted from Gerosa+

2.2 Simulations of BBH assembly in clusters

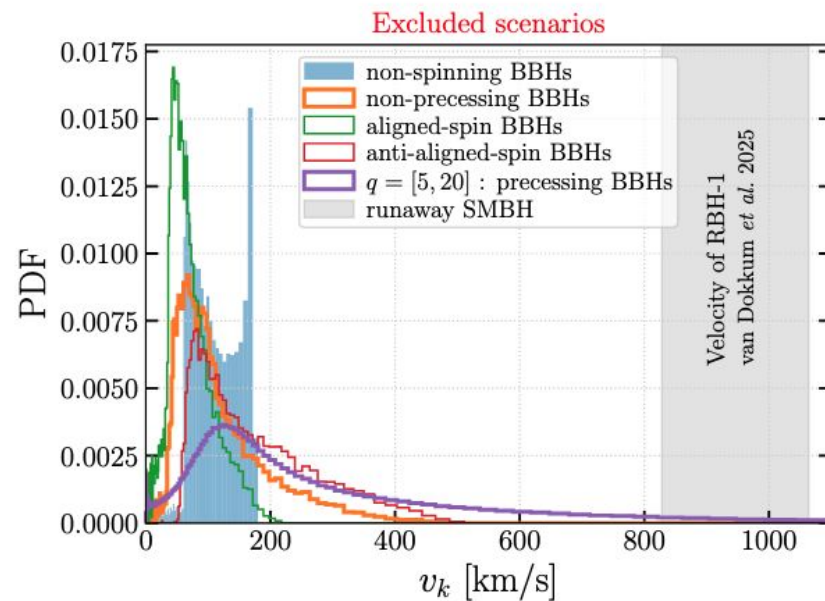


Semi-analytical cluster simulation with Rapster
(<https://github.com/Kkritos/Rapster/>)

3.1 Runaway SMBH : understanding progenitors

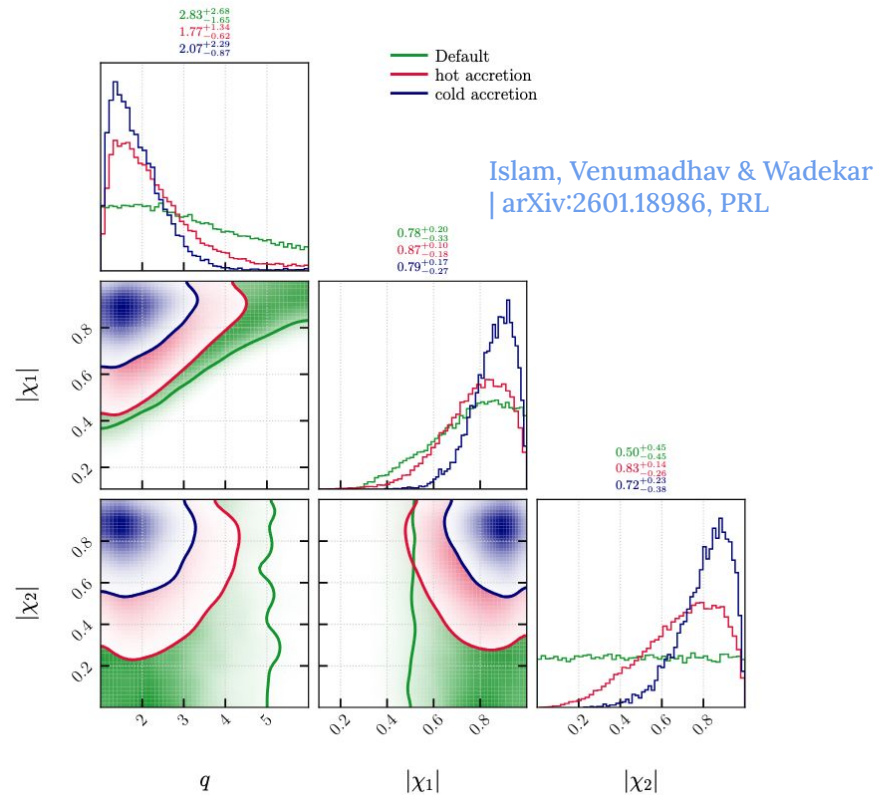
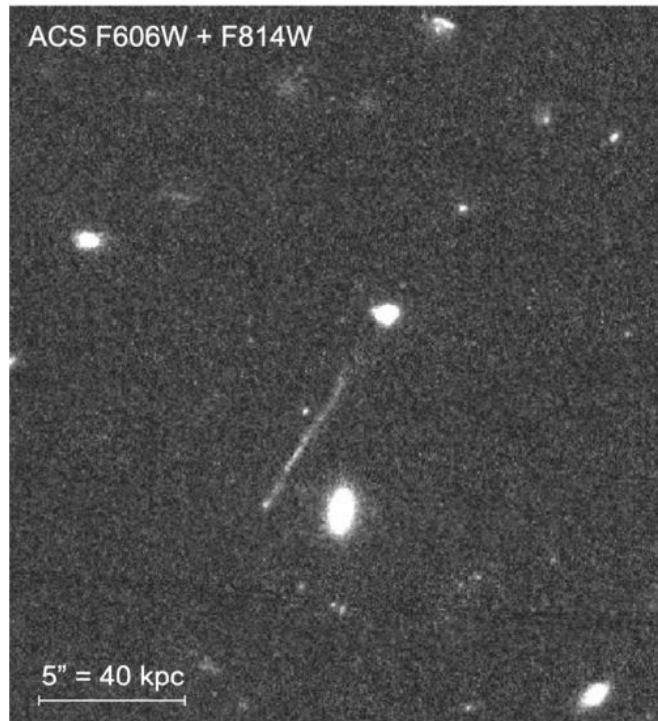


Van Dokkum et al | arXiv:2512.04166, arXiv:2302.04888



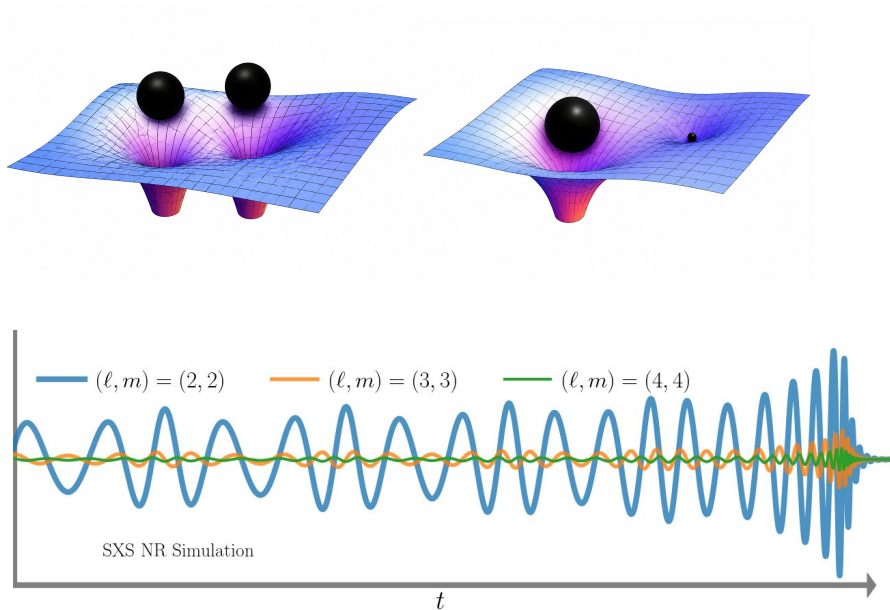
Islam, Venumadhav & Wadekar |
arXiv:2601.18986, PRL

3.2 Runaway SMBH : understanding progenitors



Van Docuum et al | arXiv:2512.04166, arXiv:2302.04888

4. gwModels : home for physics-grounded fits



PYPI PACKAGE

<https://pypi.org/project/gwModels/>



GITHUB REPOSITORY

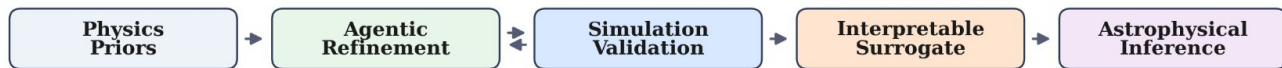
<https://github.com/tousifislam/gwModels/>



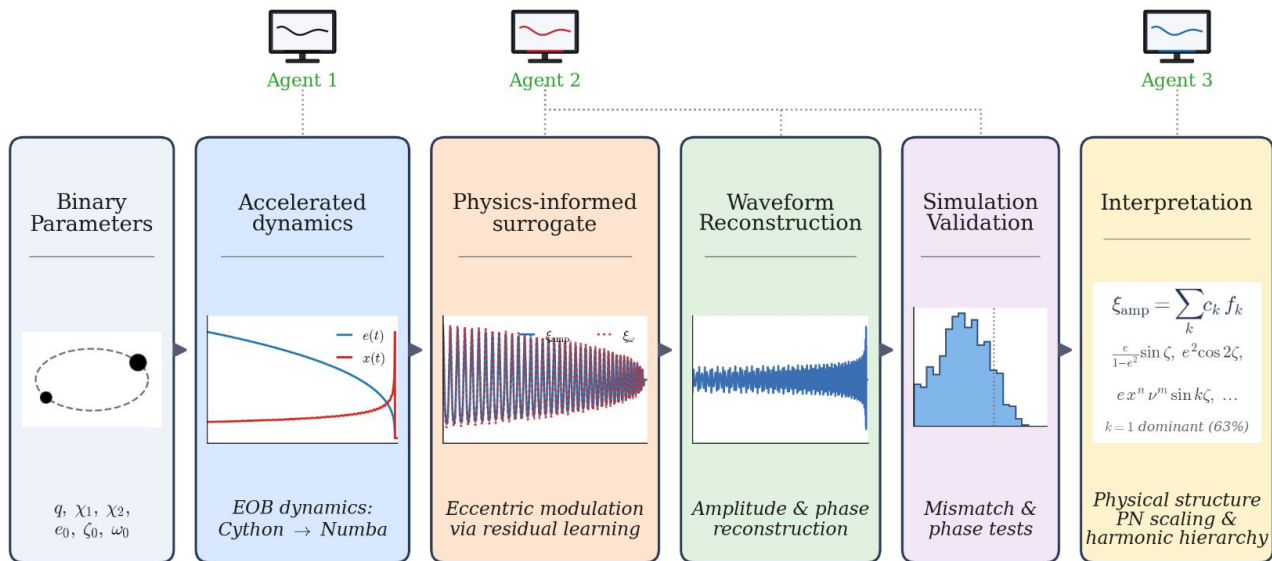
DOCUMENTATION

<https://tousifislam.com/gwModels/>

5.1 Agentic AI for interpretable surrogate

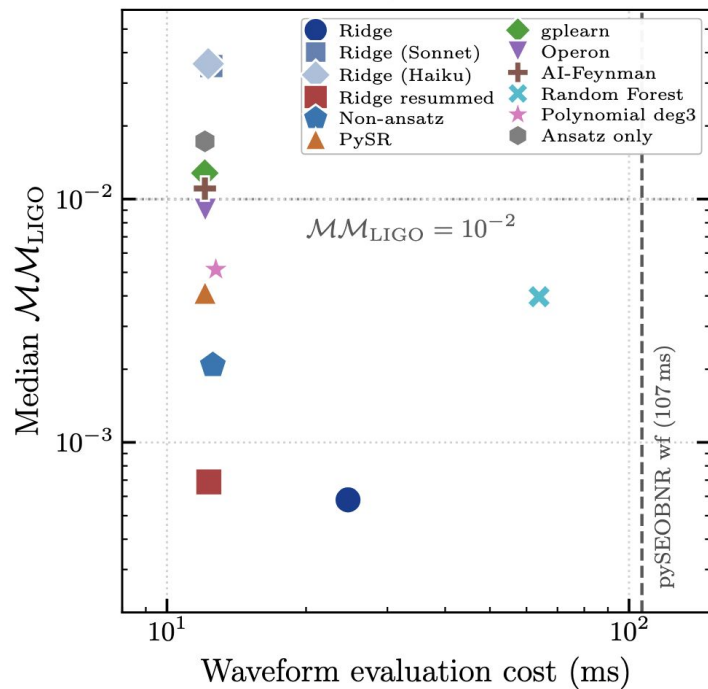


a GWAgent: Agentic surrogate modelling for eccentric spinning BBH mergers



Islam, Wadekar, Venumadhav, Zaldarriaga et al | arXiv:2605.11280

5.2 Agentic AI for interpretable surrogate



The agent-discovered surrogate not only reproduced the simulation data with high fidelity, but also outperformed traditional machine-learning models.

Agentic expression

$$\delta \xi_{\text{amp}} \approx \sum_i \frac{e^{a_i}}{(1 - e^2)^{1/2}} x^{b_i} v^{c_i} \chi_S^{d_i} \chi_A^{f_i} \times \left[c_0^{(i)} + \sum_{k=1}^3 a_k^{(i)} \cos(k\zeta) + \beta_k^{(i)} \sin(k\zeta) \right].$$

pySR expression

$$\delta \xi_{\omega}^{\text{PySR}} = e^2 \left[e(-\cos \zeta - \sin^2 \zeta - 0.079163484) - 0.8009563 + \left(e - \frac{3.1693237 x}{e} \right) x \sin(2\zeta) \left(\frac{-4.4655943}{\cos \zeta} \right) \right].$$

Islam, Wadekar, Venumadhav, Zaldarriaga et al | arXiv:2605.11280

6.1 Benchmarking LLMs for end-to-end scientific tasks

GRAVITATIONAL WAVE ASTRONOMY BENCHMARK SUITE

Can LLM Agents Match Months of PhD Work?

An Eight-Task Benchmark for Gravitational Waves Astronomy

arXiv:2605.11269

gdbenchmarks is a benchmark suite for large language model agents tackling long-horizon, terminal-based astrophysical research problems. Focused on gravitational waves from binary compact object mergers, it evaluates models using fully automated, physics-driven, and quantitatively verifiable metrics on state-of-the-art tasks – providing a direct measure of science readiness.

Investigators: Tousif Islam (KITP, UC Santa Barbara) · Digvijay Wadekar (UT Austin) · Zihan Zhou (Princeton)
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PAPER TITLE
gwBenchmarks: Stress-Testing LLM Agents on High-Precision Gravitational Wave Astronomy



AUTHORS
Tousif Islam, Digvijay Wadekar, Zihan Zhou



ARXIV
<https://arxiv.org/abs/2605.11269>



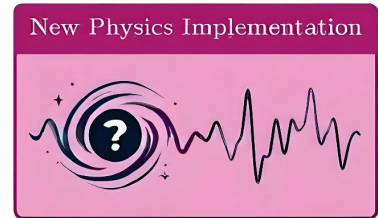
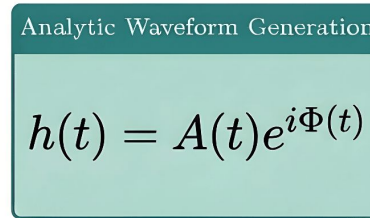
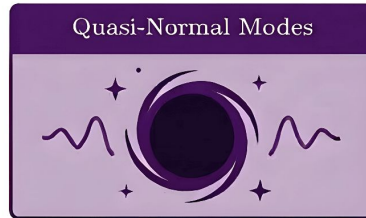
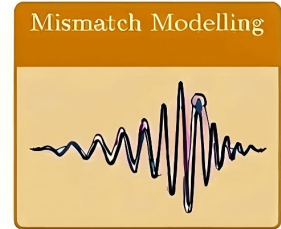
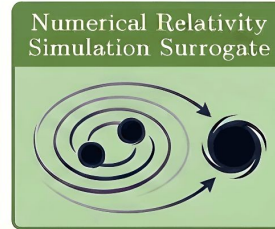
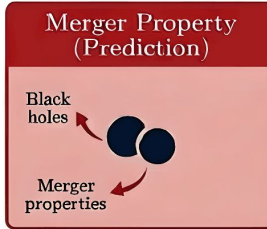
GITHUB REPOSITORY
<https://github.com/tousifislam/gwBenchmarks>



PROJECT WEBSITE
<https://tousifislam.com/gwBenchmarks/>



Agent → Reason → Code → Build → Canonical metric



Islam, Wadekar & Zhou | arXiv:2605.11269



THANK YOU!

