Methods for Detecting Gravitational Waves from mini-Extreme-Mass-Ratio Inspirals:

A Spectral-Leakage-Aware Framework

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Based on collaborative works: arXiv:2512.21738 · arXiv:2512.21739

From EMRI to mini-EMRI system

Standard EMRI



Stellar-mass compact object

SMBH
$\sim 10^6 M_\odot$

Supermassive black hole

$m \longrightarrow 10^{-5} m$

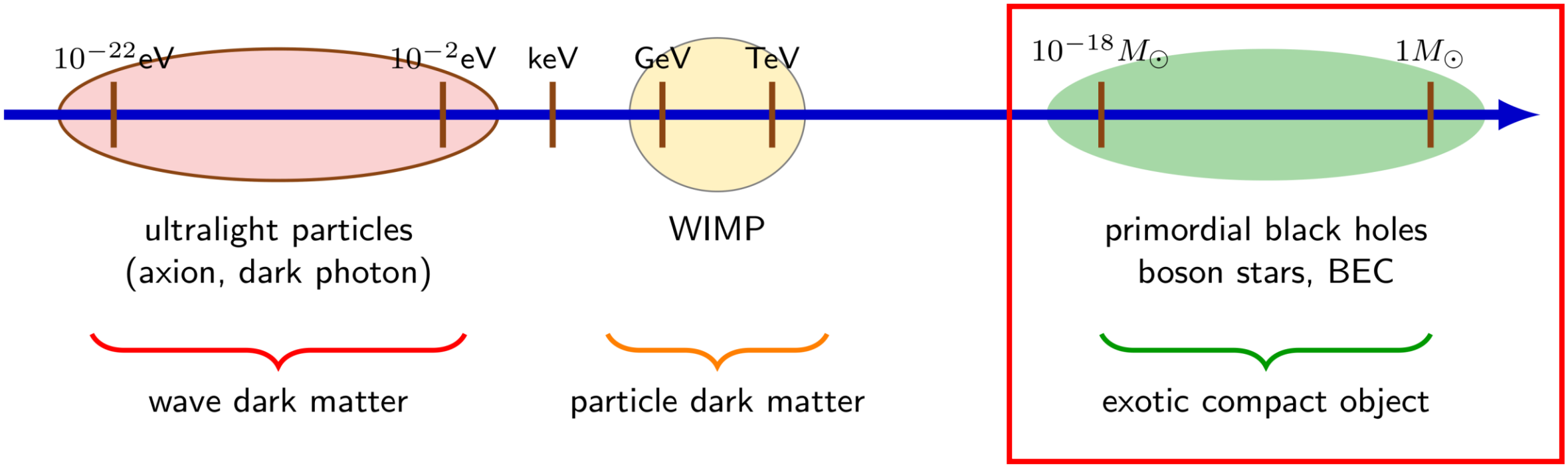
mini-EMRI

Exotic compact object
$\mathcal{O}(10^{-7} \sim 10^{-4})\, M_\odot$

Stellar-mass BH / NS
$\mathcal{O}(1 \sim 10)\, M_\odot$

ECO as Dark Matter Candidate

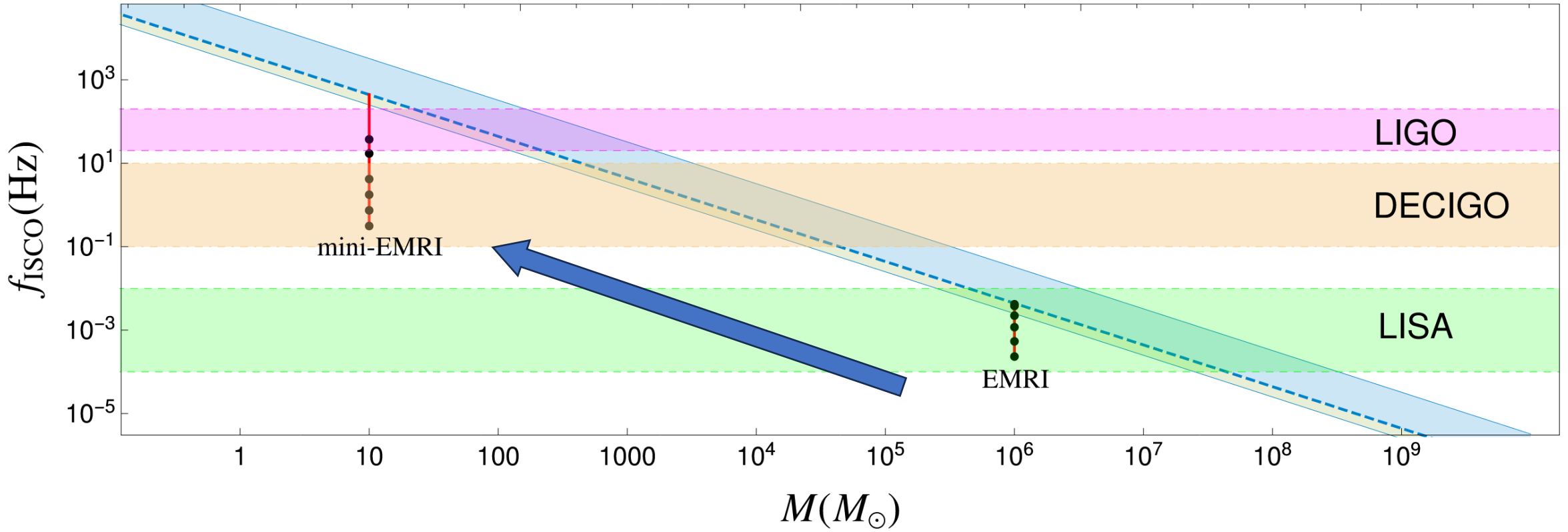
Subsolar compact-object detection can point to new physics



mini-EMRI companion → primordial black hole, boson star, or another ECO

From Space-Based EMRIs to Ground-Based mini-EMRIs

Smaller mass scale → higher characteristic GW frequency



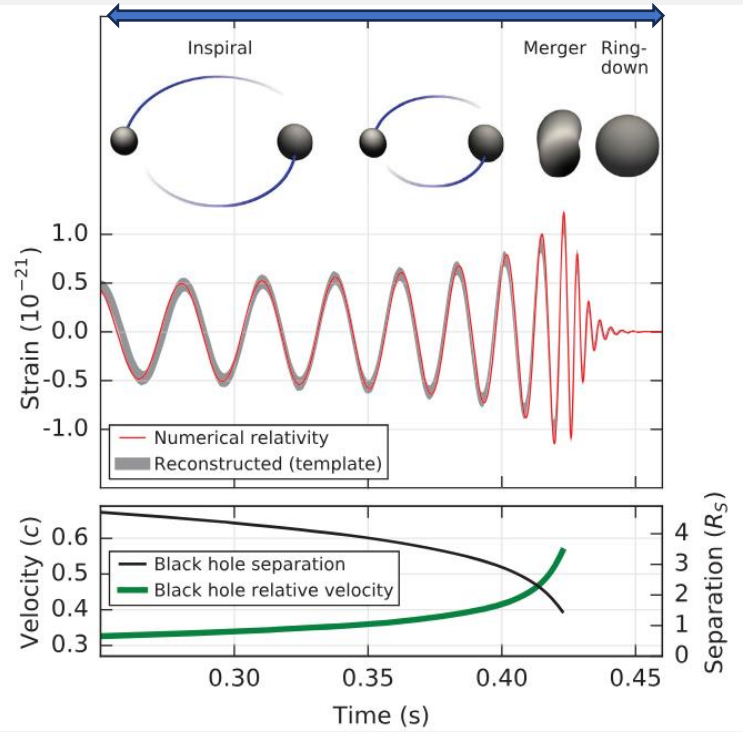
Guo & Miller, arXiv:2205.10359

Long-Transient Signals: Between CBCs and CWs

CBC

Short · Rapid chirp

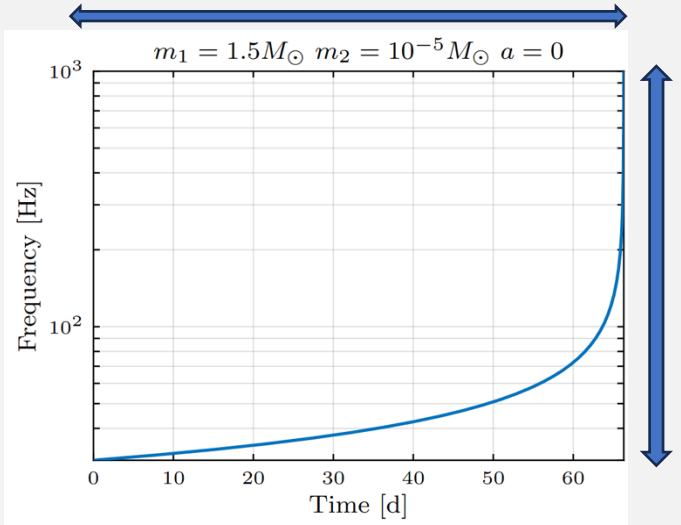
$\mathcal{O}(1-10^3)$ s



Long-Transient: Mini-EMRI

Locally quasi-monochromatic, but globally chirping

$\mathcal{O}(1-10^2)$ day

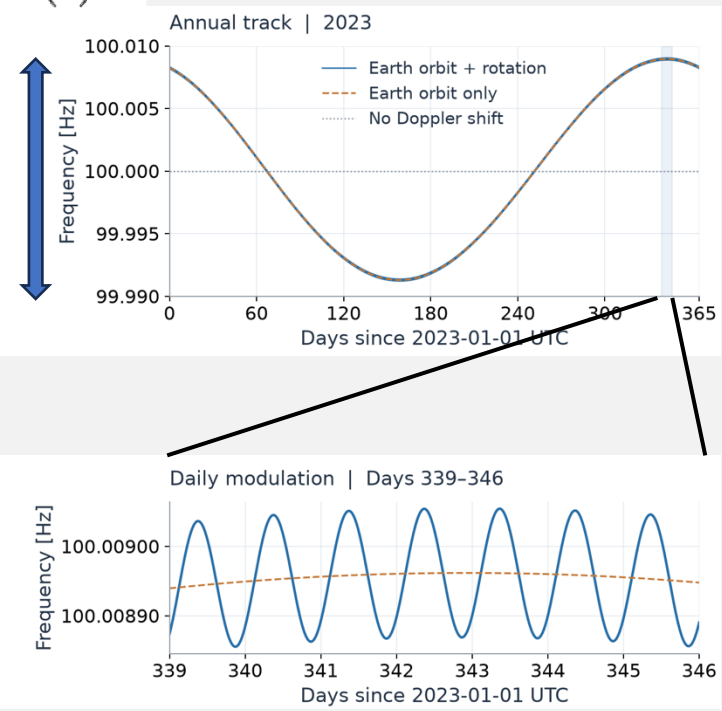


crossing the ground band

CW

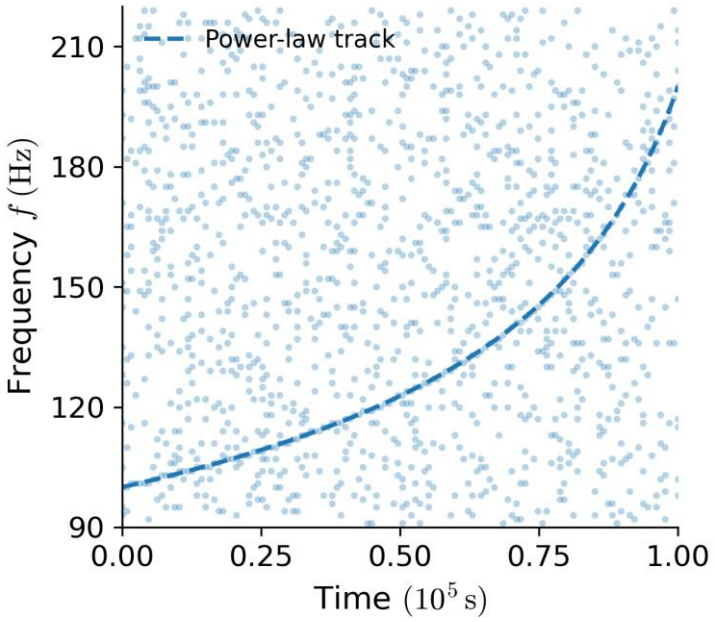
Long · Slow evolution

$\Delta f < \mathcal{O}(1)$Hz

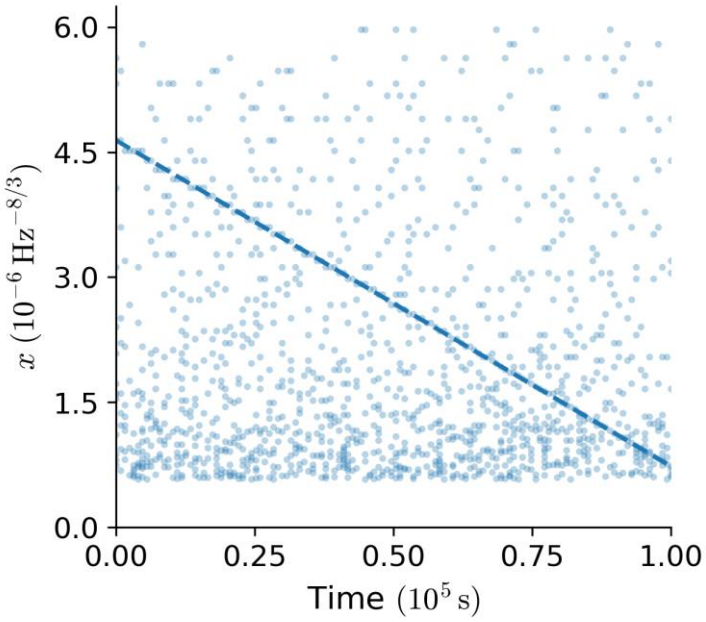


Generalized Hough Search

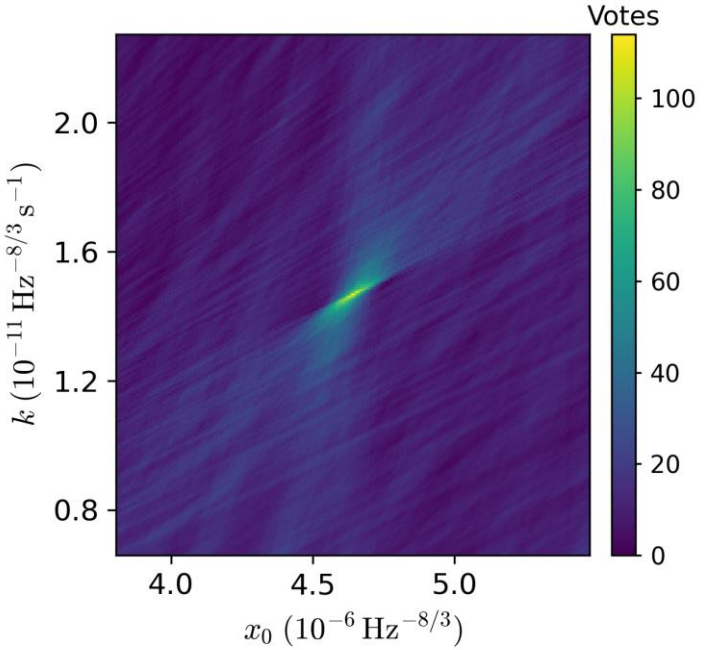
Power-law peakmap



Linearized peakmap



G-Hough accumulator



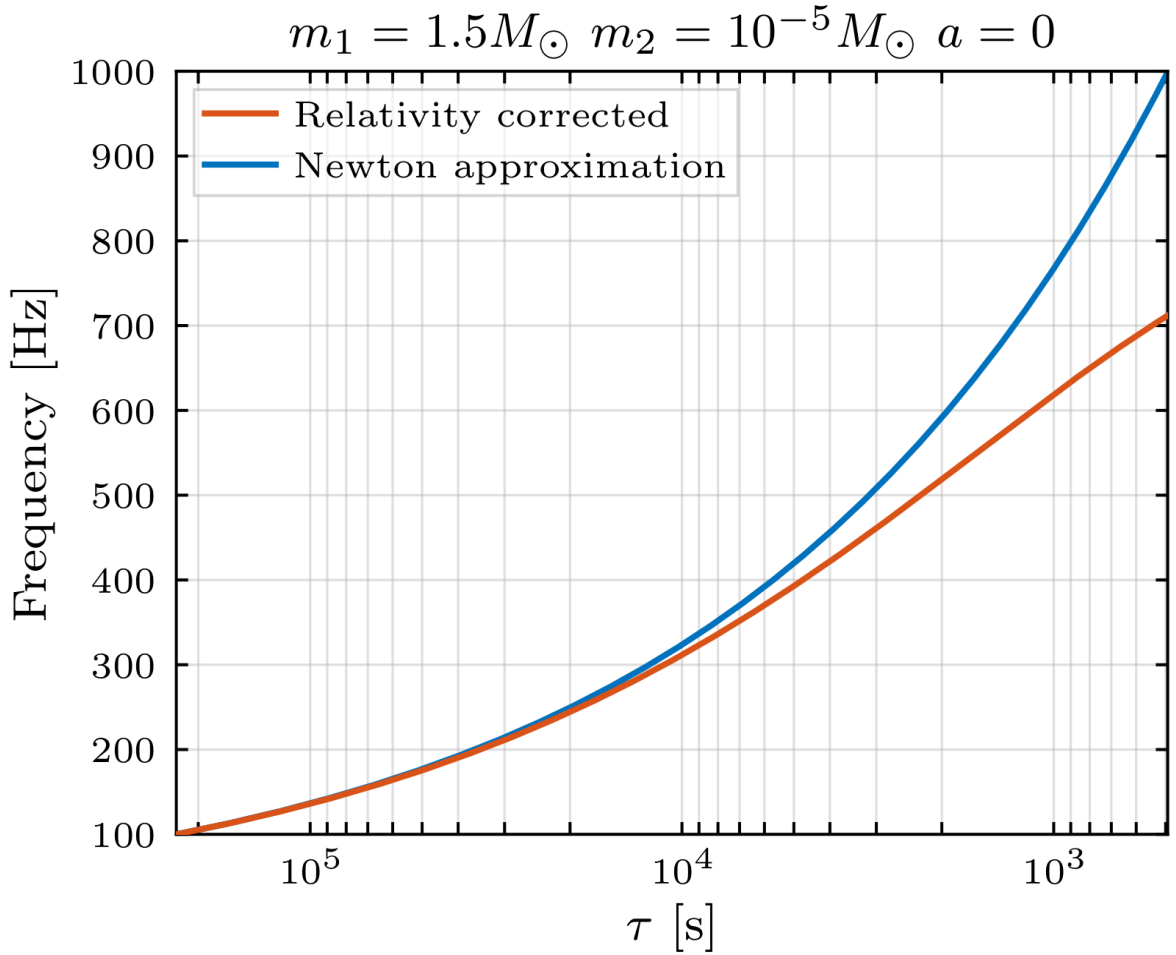
$$\dot{f} = k f^n, \qquad x = f^{1-n}, \qquad x(t) = x_0 + (1-n)k(t-t_0)$$

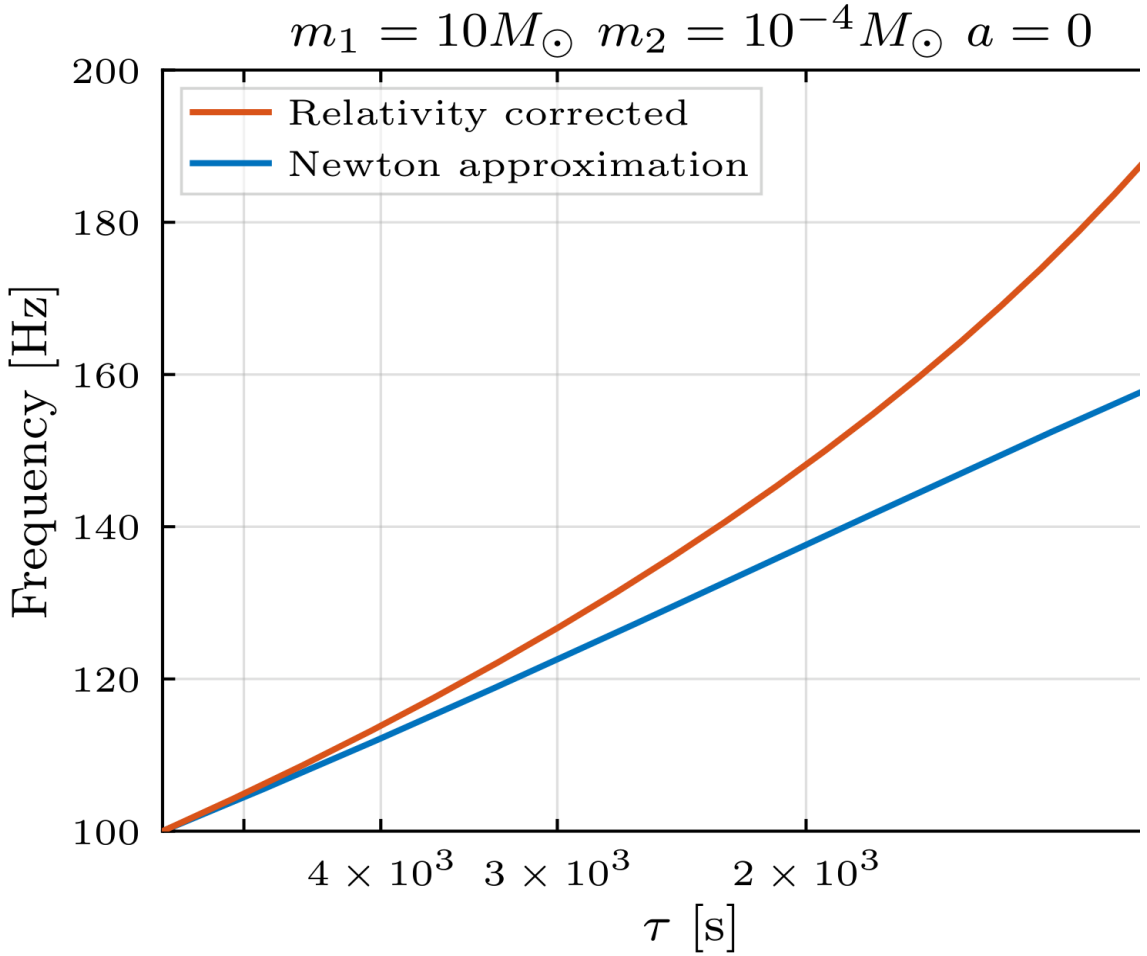
The simplification relies on a transformable dynamical law (for example, a fixed power law).

Miller et al., Phys. Rev. D 98, 102004 (2018) · arXiv:1810.09784
Miller et al., Phys. Rev. D 110, 082004 (2024) · arXiv:2407.17052
Miller & Pierini, Phys. Rev. D 114, 022002 (2026) · arXiv:2512.10539

Beyond the Leading-Order Power Law

$$\dot{f} = k f^n C_f(f, M, a)$$ Relativistic corrections accumulate into a visibly different long-term track.

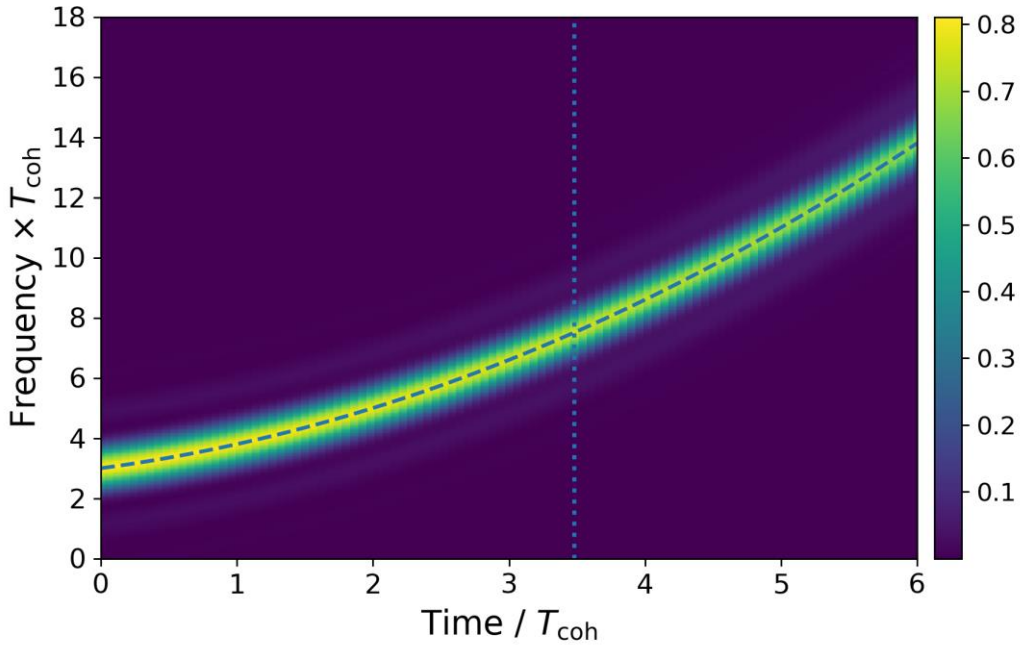


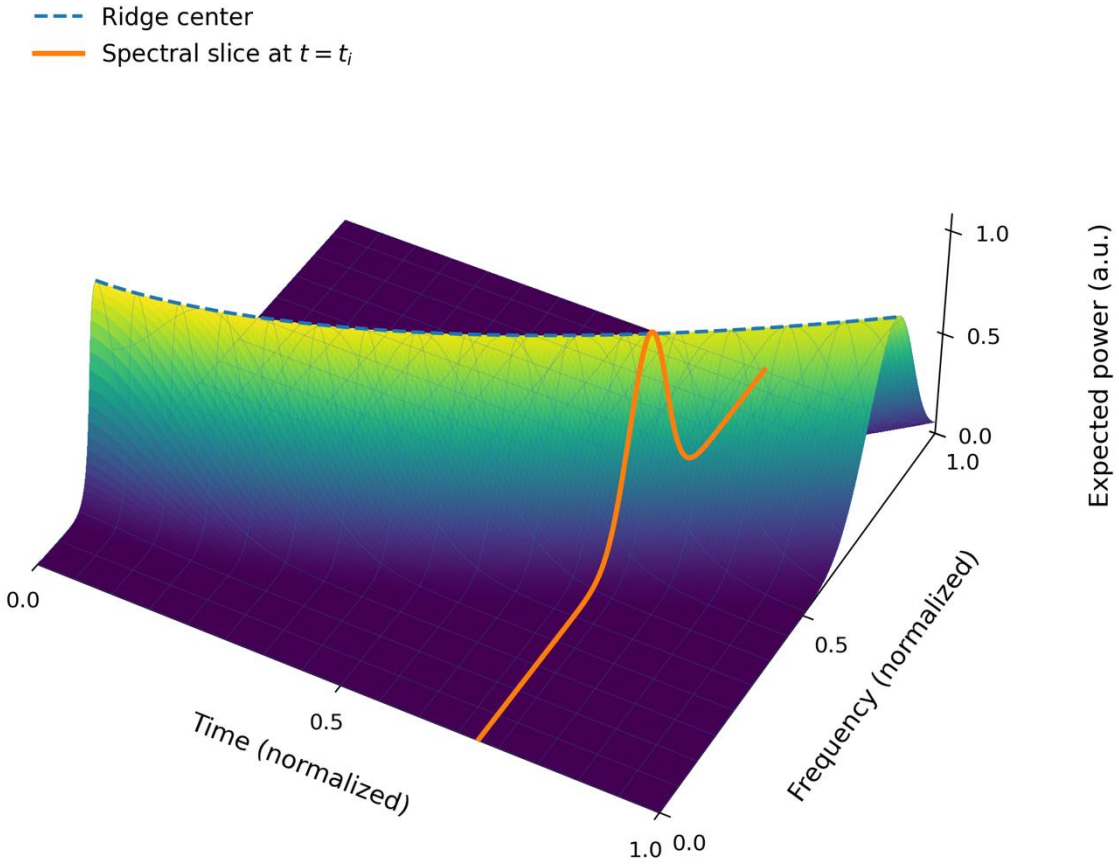


A Signal Track Is a Power Ridge

A finite-time Fourier transform gives the track a measurable spectral width

signal power spectrogram





Illustrative Gaussian ridge — not a physical leakage model

From Fitting Factor to a Template-Bank Metric

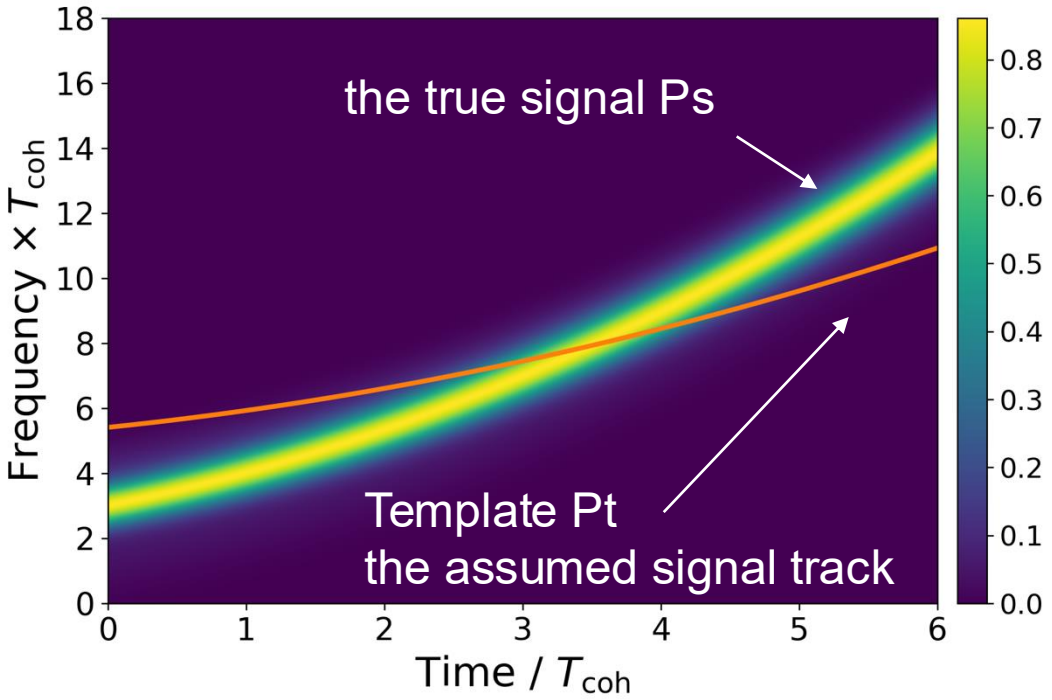
Statistical match

$$\mathrm{FF}(\mathcal{P}_\mathrm{s}|\mathcal{P}_\mathrm{t}) = \frac{\mathbb{E}[\mathrm{CR}(\mathcal{P}_\mathrm{t}|\mathcal{P}_\mathrm{s})]}{\mathbb{E}[\mathrm{CR}(\mathcal{P}_\mathrm{s}|\mathcal{P}_\mathrm{s})]}$$

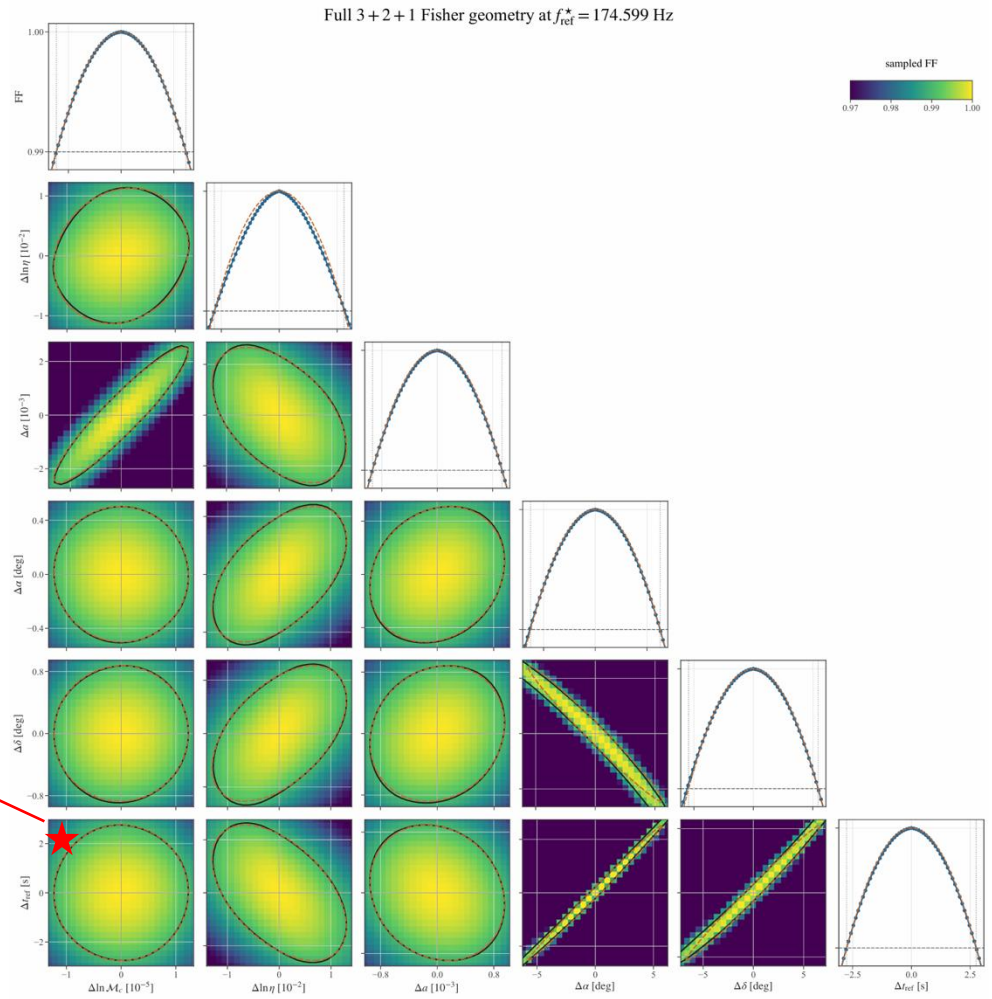
$$\mathrm{CR} = \frac{S - \mu_0}{\sigma_0}$$

$$\mathcal{P} = (\theta_\mathrm{intr}, t_\mathrm{ref})$$

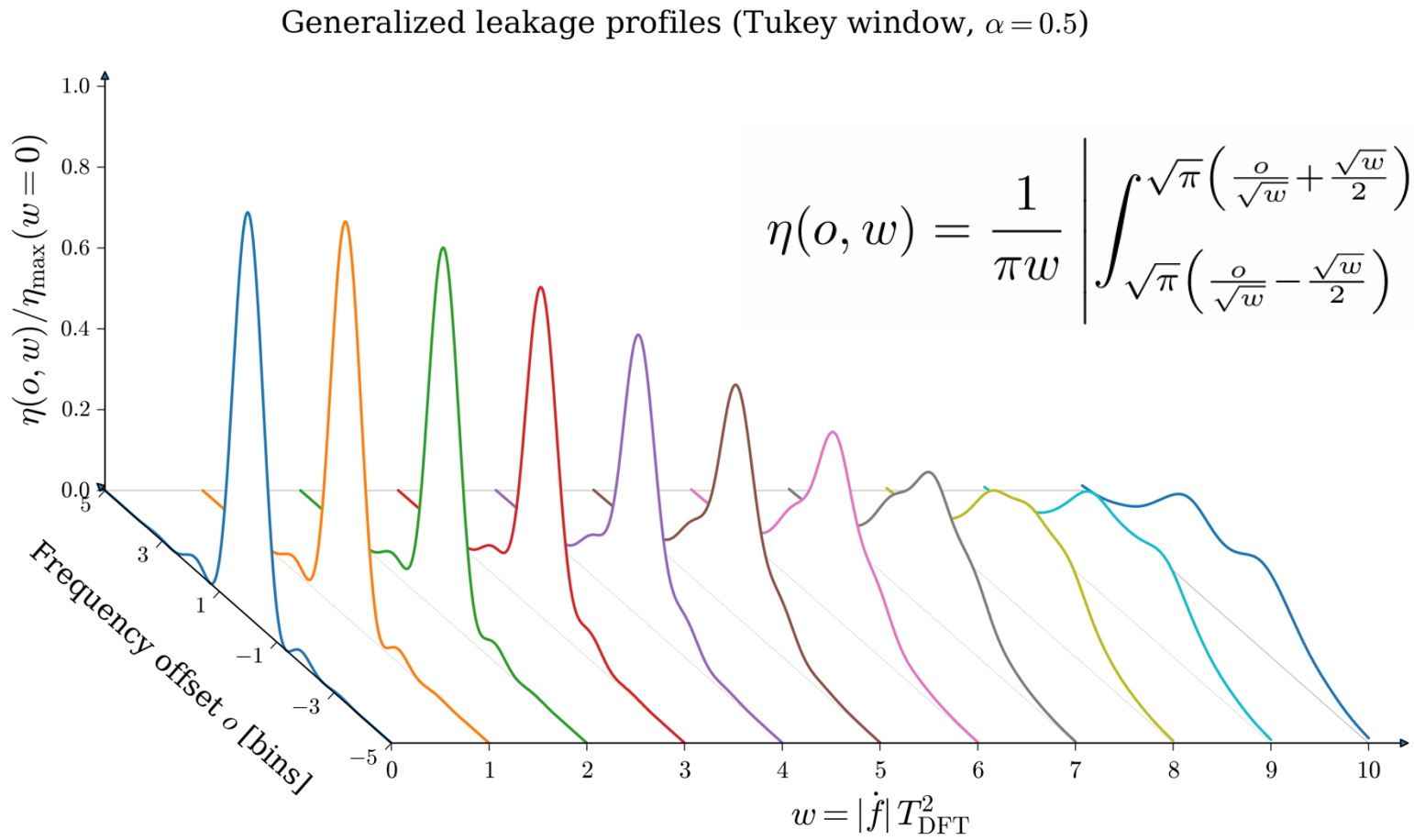
$$s = \text{signal}, \mathrm{t} = \text{tamplate}$$



Numerical FF and local metric geometry



The Spectral Leakage Function η(o, w)

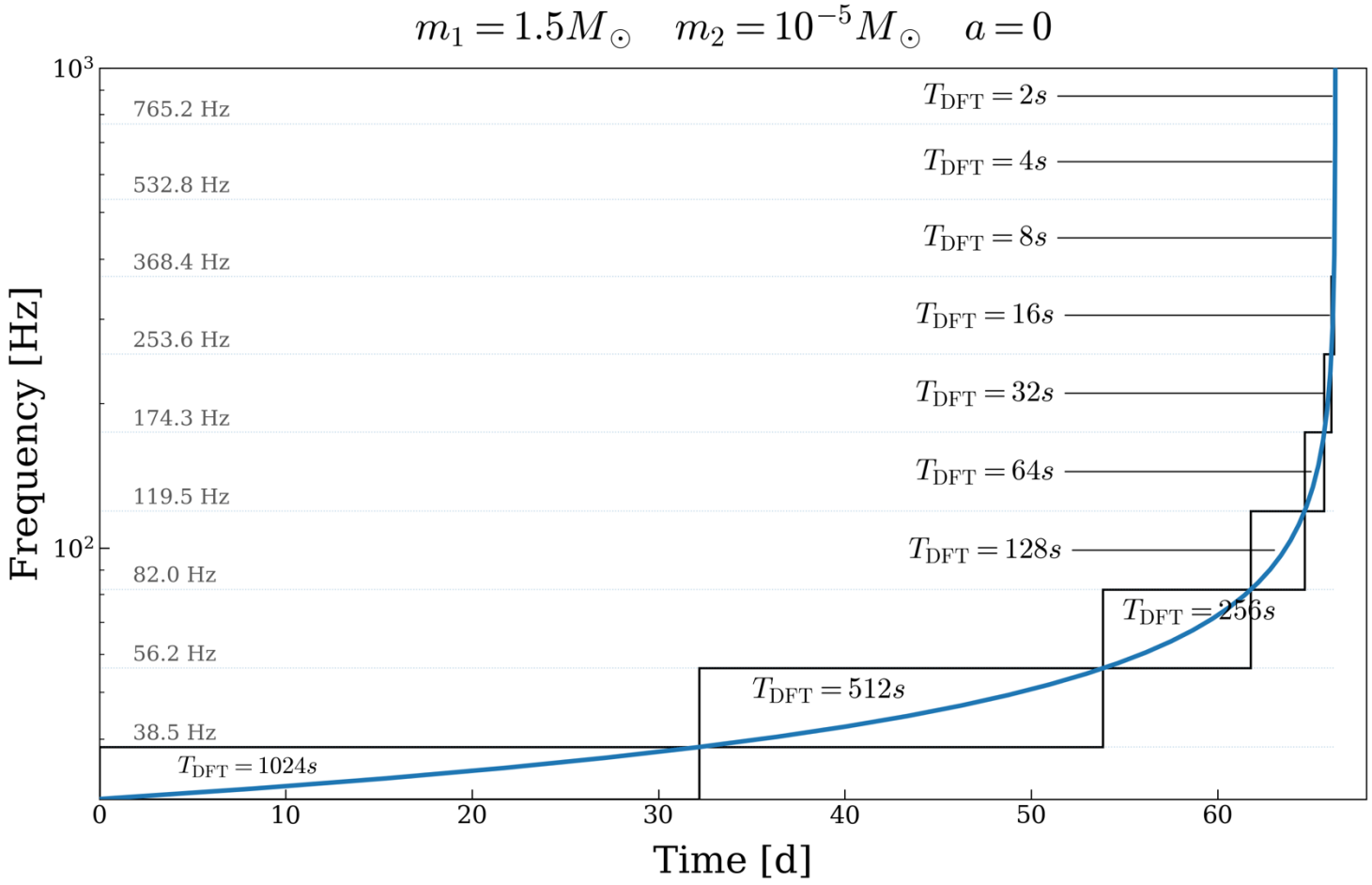


$$\eta(o,w) = \frac{1}{\pi w}\left|\int_{\sqrt{\pi}\left(\frac{o}{\sqrt{w}}-\frac{\sqrt{w}}{2}\right)}^{\sqrt{\pi}\left(\frac{o}{\sqrt{w}}+\frac{\sqrt{w}}{2}\right)} W\left(\frac{u}{\sqrt{\pi w}}-\frac{o}{w}\right) e^{iu^2}\,du\right|^2$$

$$w = \frac{\Delta f}{f_{\mathrm{bin}}} = \frac{\dot{f} T_{\mathrm{DFT}}}{1/T_{\mathrm{DFT}}}$$

Broadband Strategy: Frequency Layering

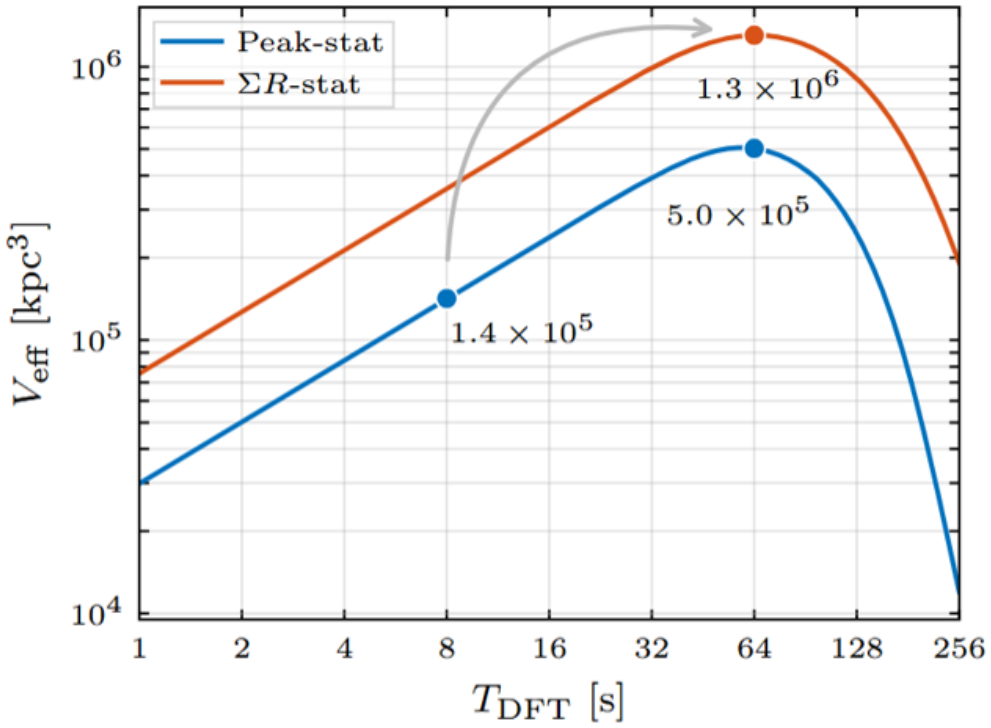
Adaptively set the coherent time across different stages



Total Gain: Order of Magnitude Improvement

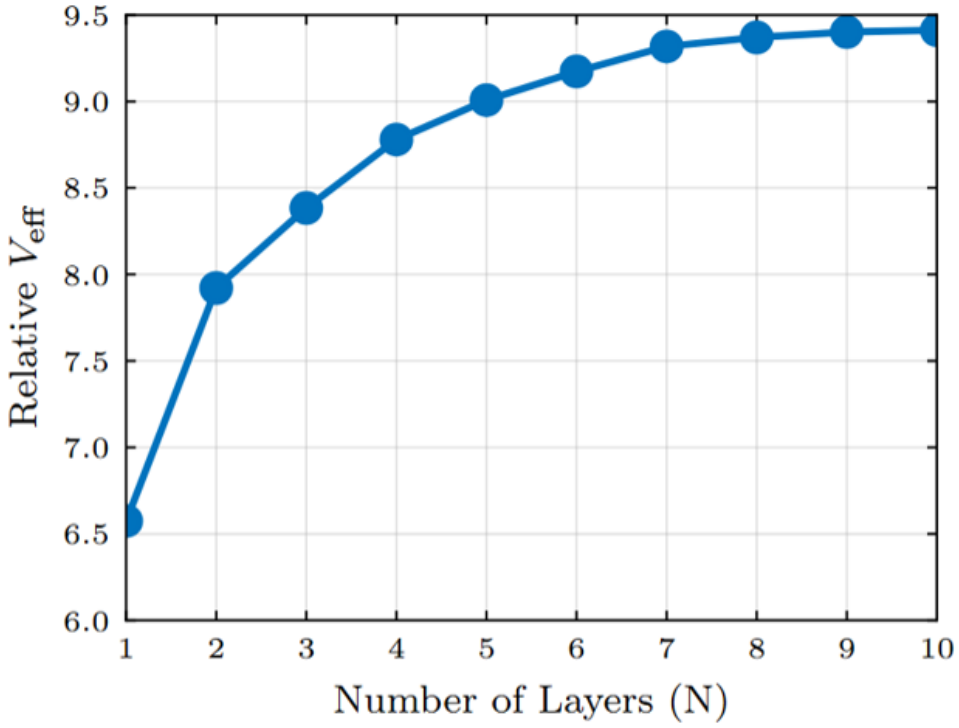
100–200 Hz

Single-layer search



30–1000 Hz

Frequency-layered search



Fiducial mini-EMRI: detection reach ≈ 80 kpc (Milky-Way scale).

≈ 10× effective detection volume over the optimized Hough baseline

Thank you

Questions?