Wet Eccentric EMRIs

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7th November 2024, LISA Astrophysics WG Meeting

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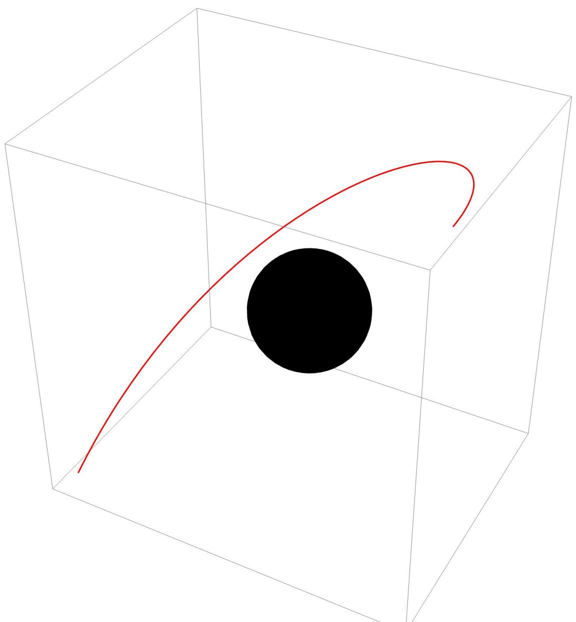
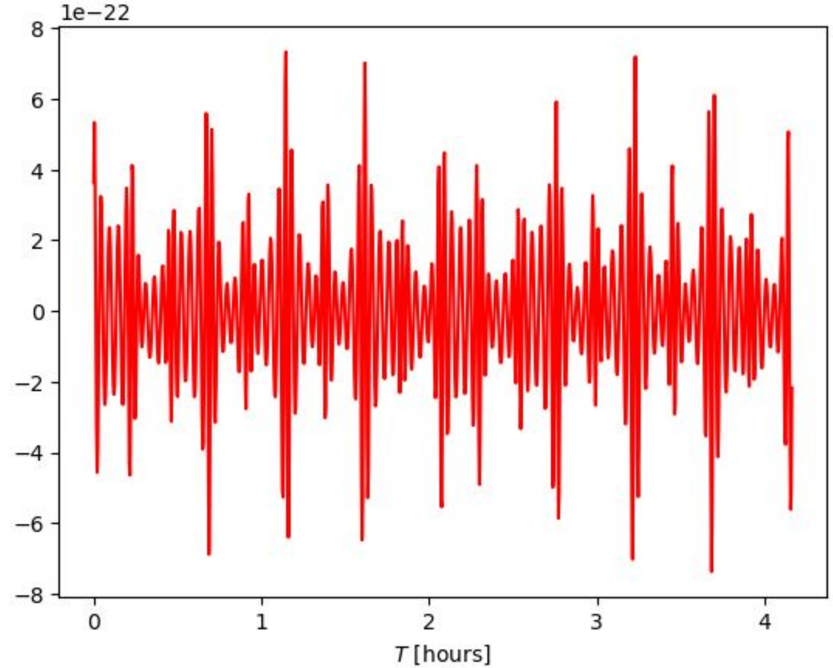
Extreme-Mass-Ratio Inspirals (EMRIs)

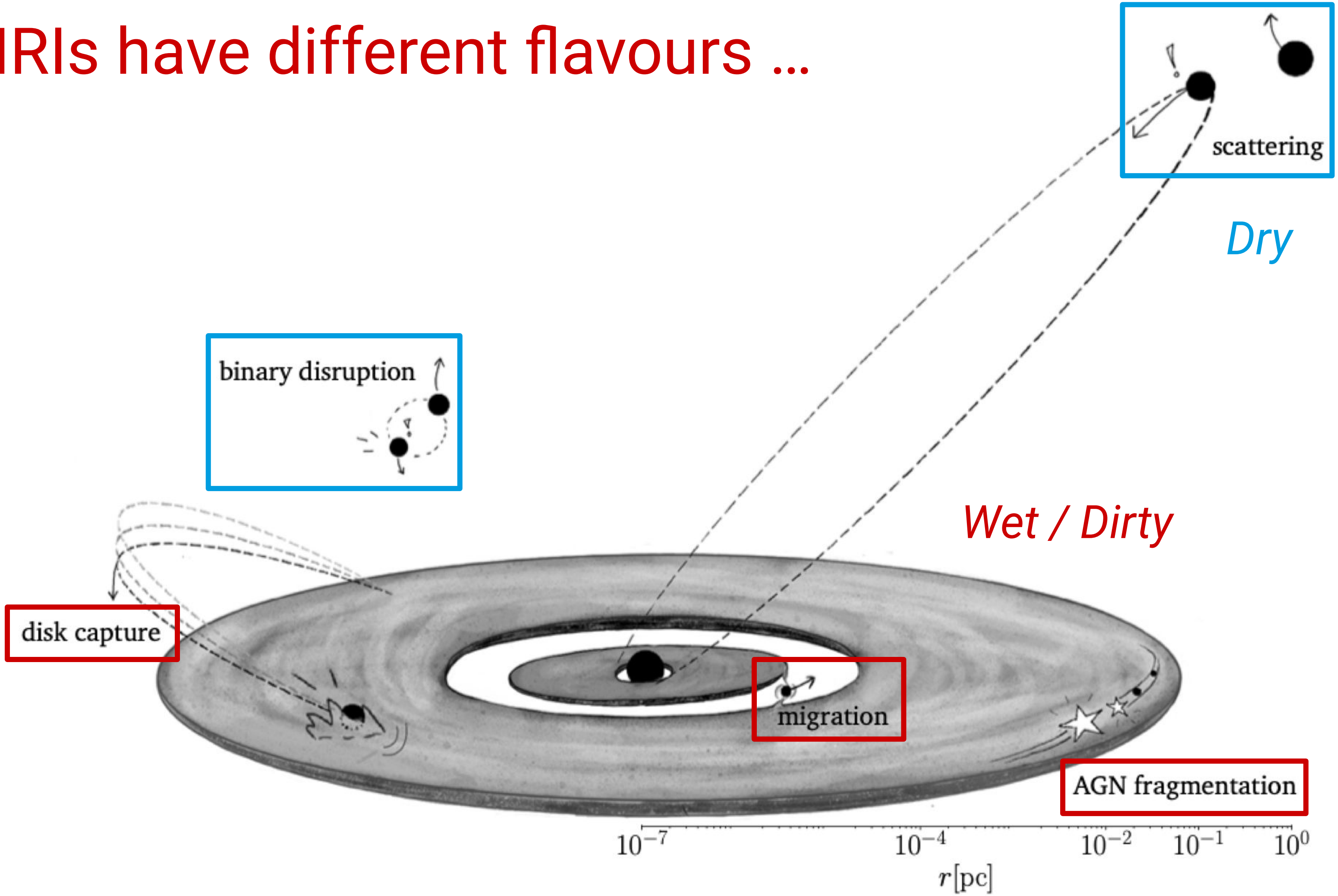


Produced w/ Black Hole Perturbation Toolkit

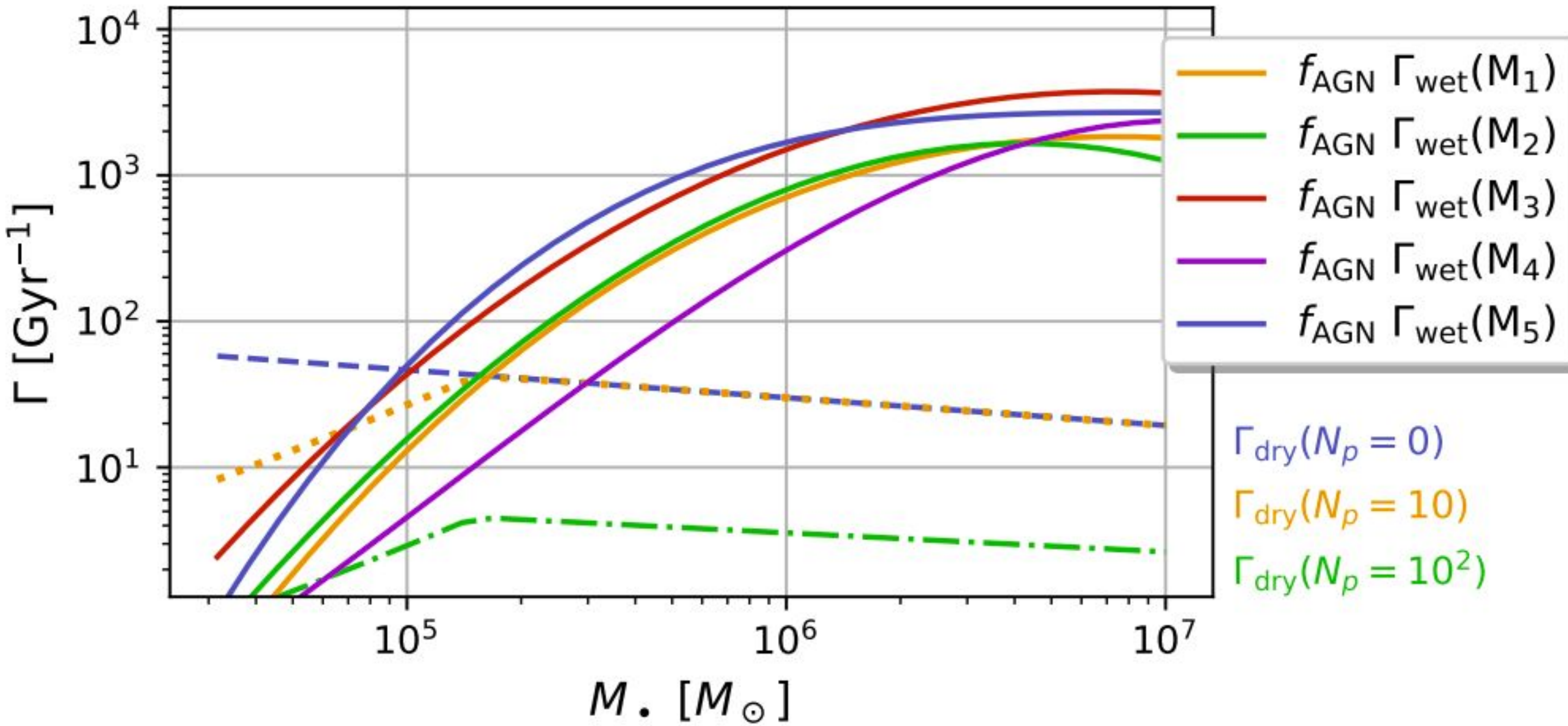


$$g_{\mu\nu}^{\text{exact}} = g_{\mu\nu} + \epsilon h_{\mu\nu}^{(1)} + \epsilon^2 h_{\mu\nu}^{(2)} + \mathcal{O}(\epsilon^3) \qquad \epsilon = \mu/M$$

EMRIs have different flavours ...



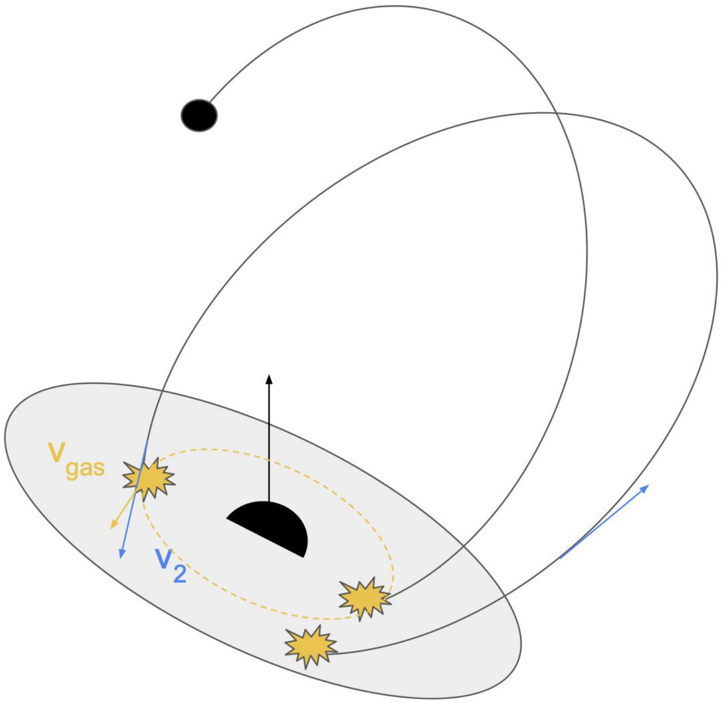
Derdzinski & Zwick arXiv:2310.16900 (2023)

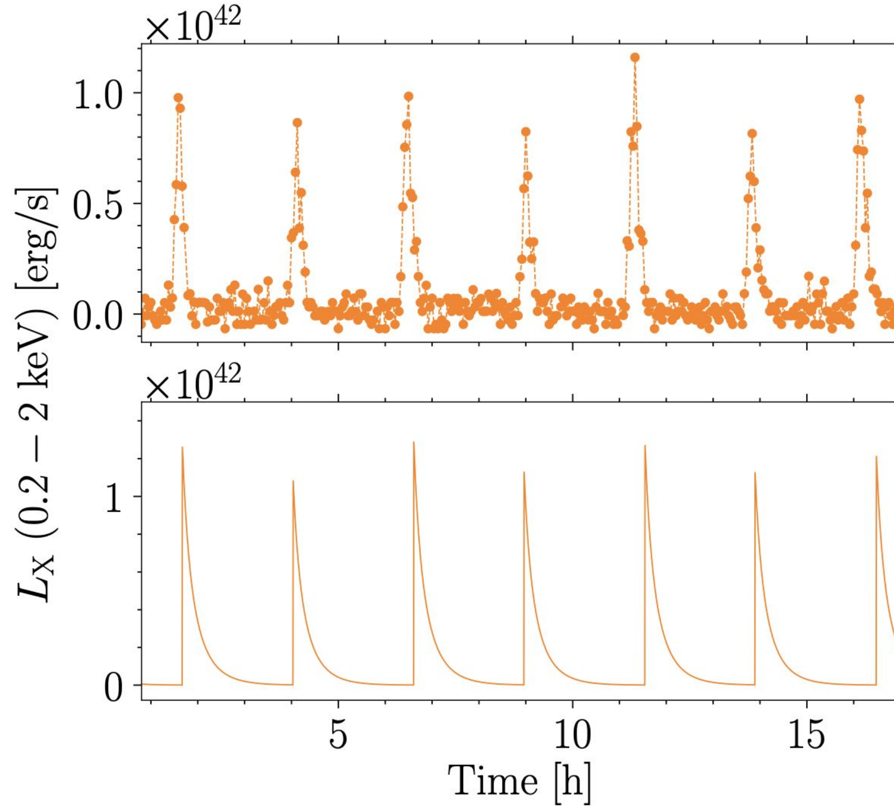


Accretion disk usually boosts the EMRI formation rate per individual MBH by ~10^1-10^3

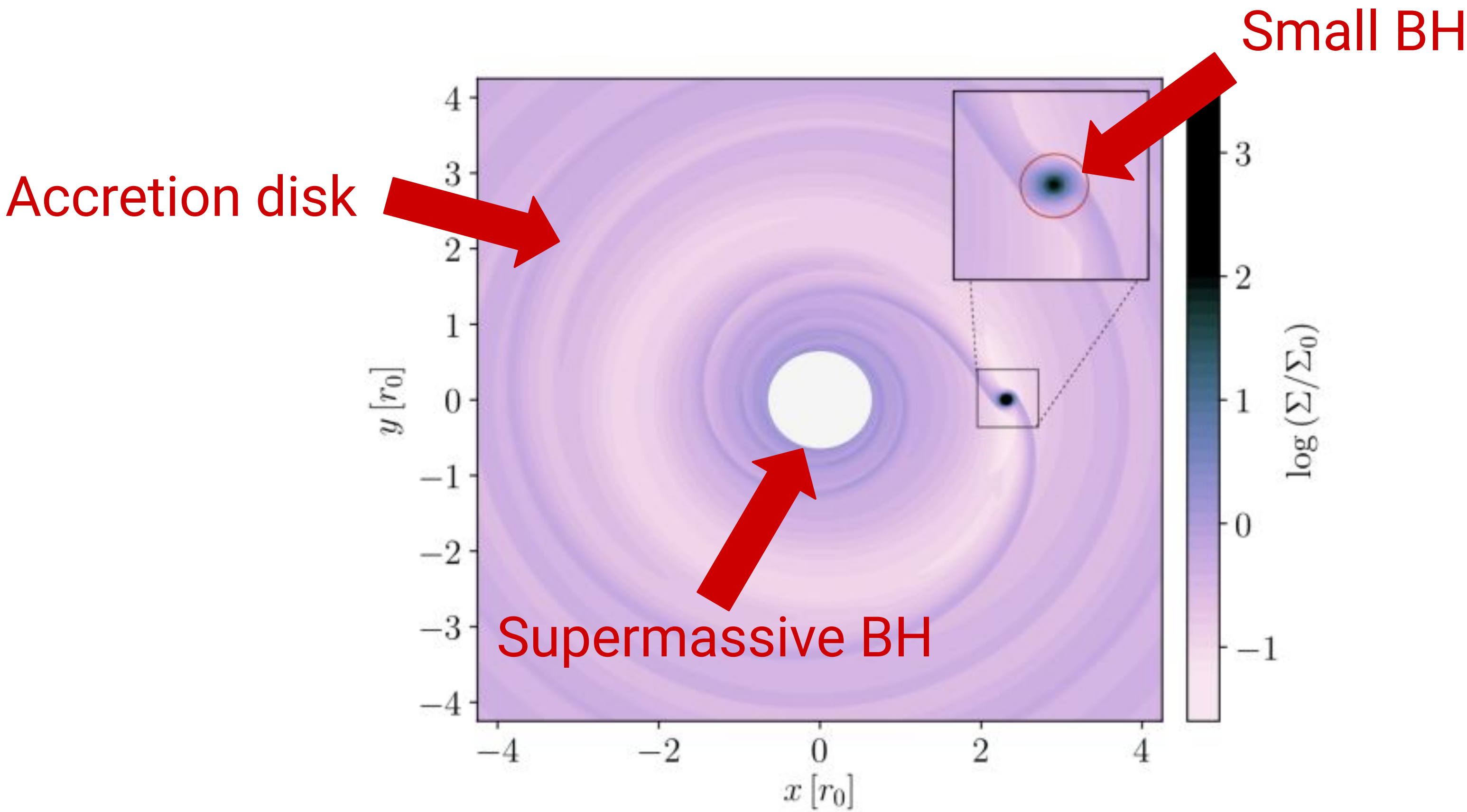
Pan et al. PRD 104, 063007 (2021)

Quase-Periodic Eruptions = Wet EMRIs (??)

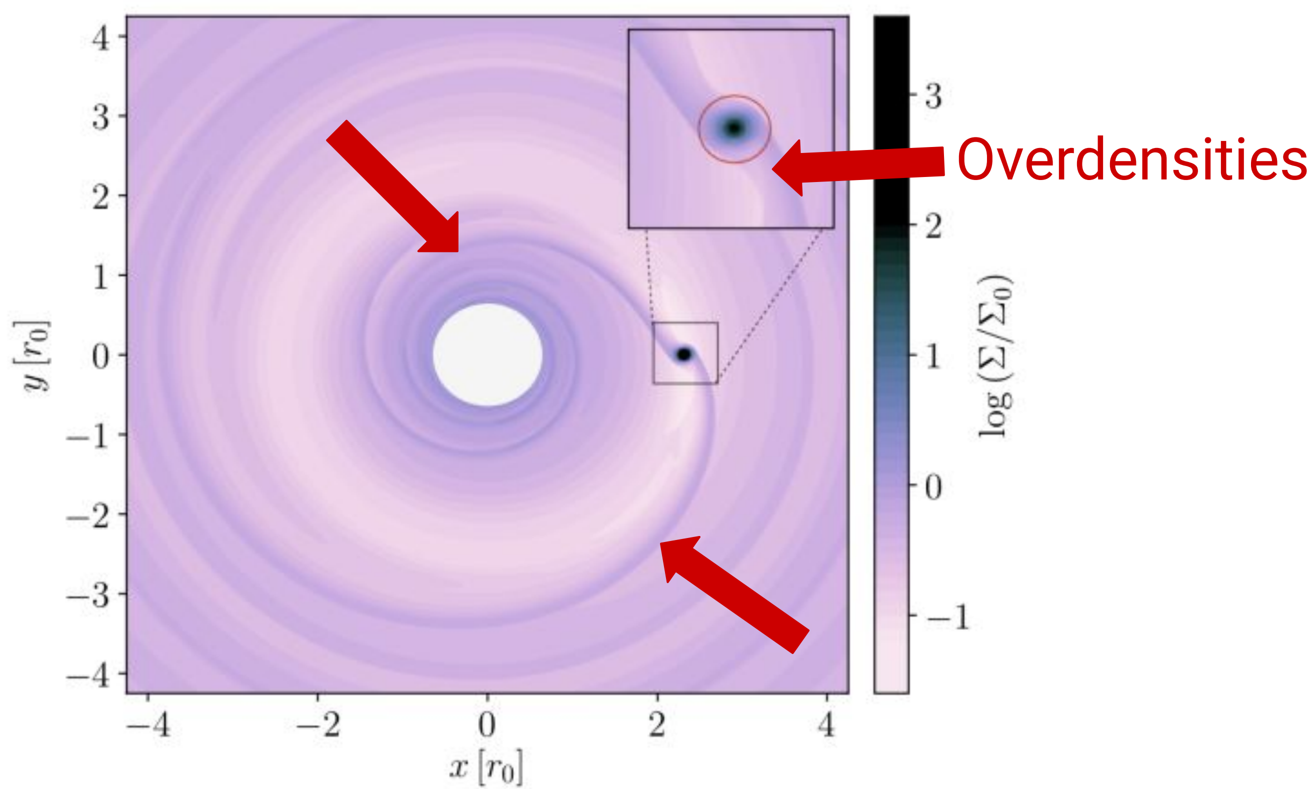




Franchini et al. A&A 675, A100 (2023)

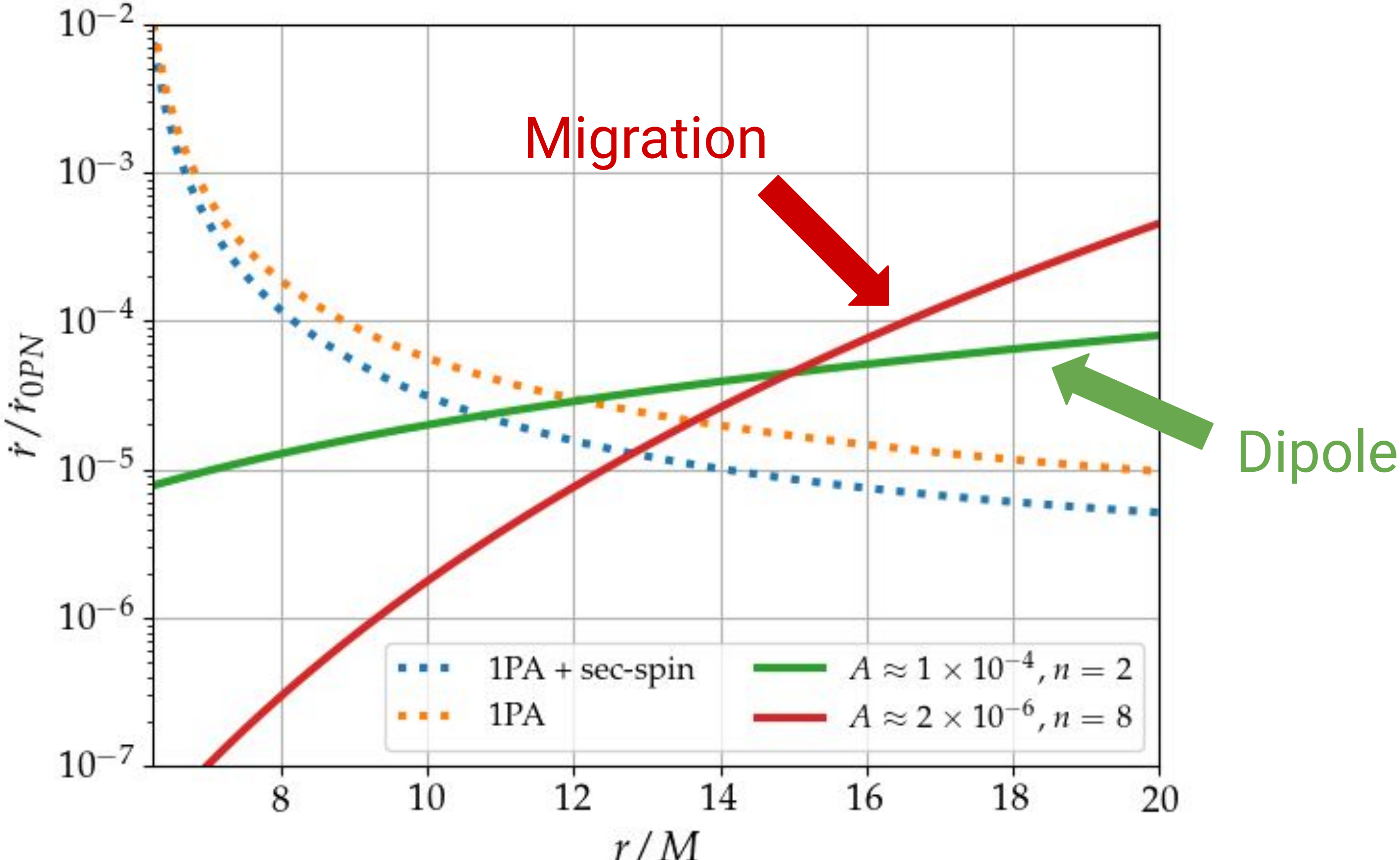


Derdzinski et al. MNRAS 501, 3540 (2021)



Derdzinski et al. MNRAS 501, 3540 (2021)

Beyond-vacuum GR effects compete with 2nd-order SF

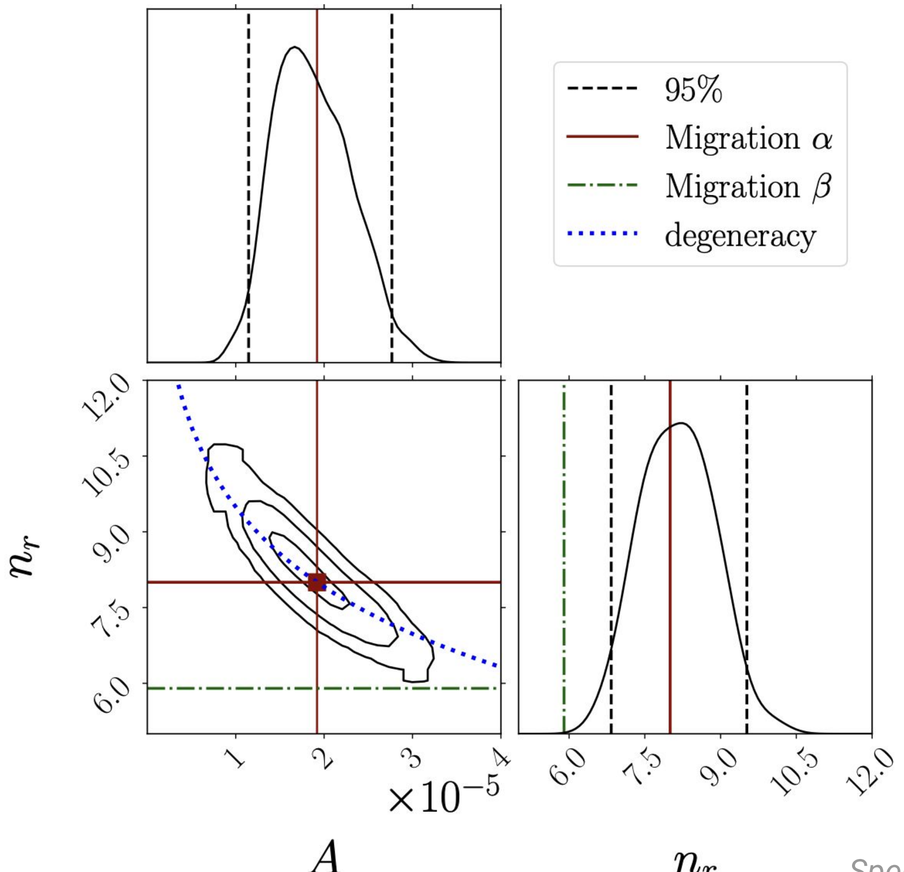


*Uses the **F**ast**E**MRI**W**aveform package*

Katz et al. PRD 104, 064047 (2021)

$$\dot{L} = \dot{L}_{\rm GW} + \dot{L}_{\rm gas}$$

$$\dot{L}_{\rm disk} = A \left(\frac{r}{10M}\right)^{n_r} \dot{L}^{(0)}_{\rm GW}$$



$$M = 10^6 M_\odot$$

$$\mu = 50 M_\odot$$

$$\mathrm{SNR} = 50$$

$$T_{\rm obs} = 4\,\mathrm{yrs}$$

Speri et al. PRX 13, 021035 (2023)

Relative velocity of the secondary w.r.t. to the gas flow

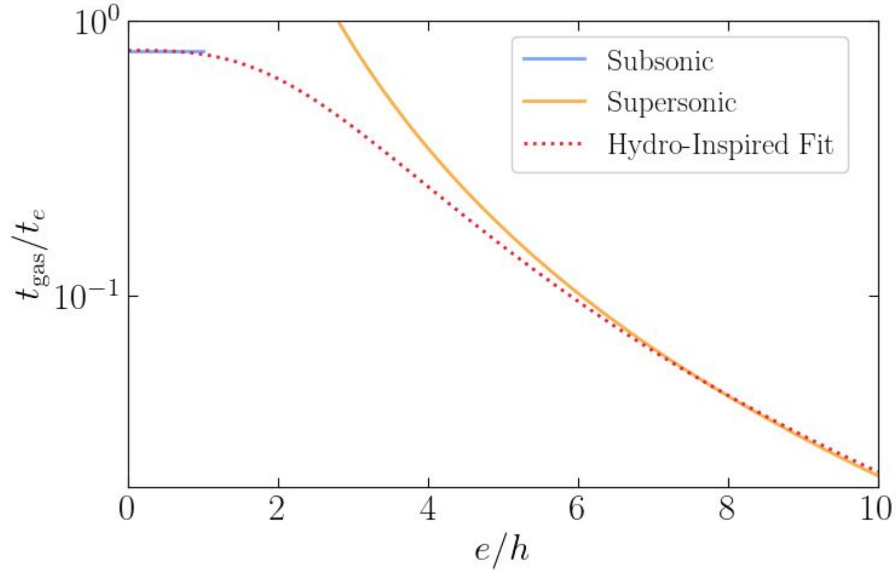
$$\Delta v \approx e v_K = e r \Omega_K = e r \frac{r}{H} c_s = \frac{e}{h} c_s$$

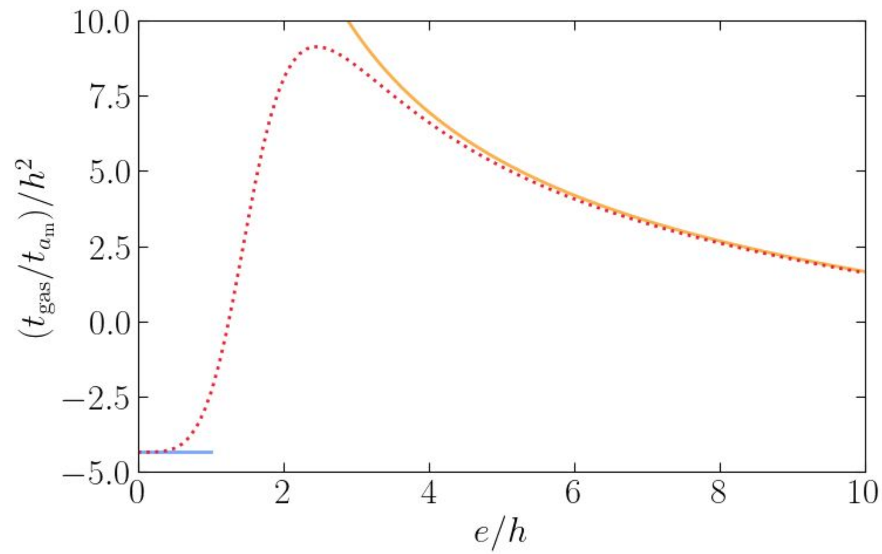
$h \sim 0.02 - 0.1$ in inner disk region

EMRIs are supersonic at moderate eccentricity

$e < h$	$e > h$
Subsonic	Supersonic
(Global) Migration Torques	(Local) Dynamical Friction

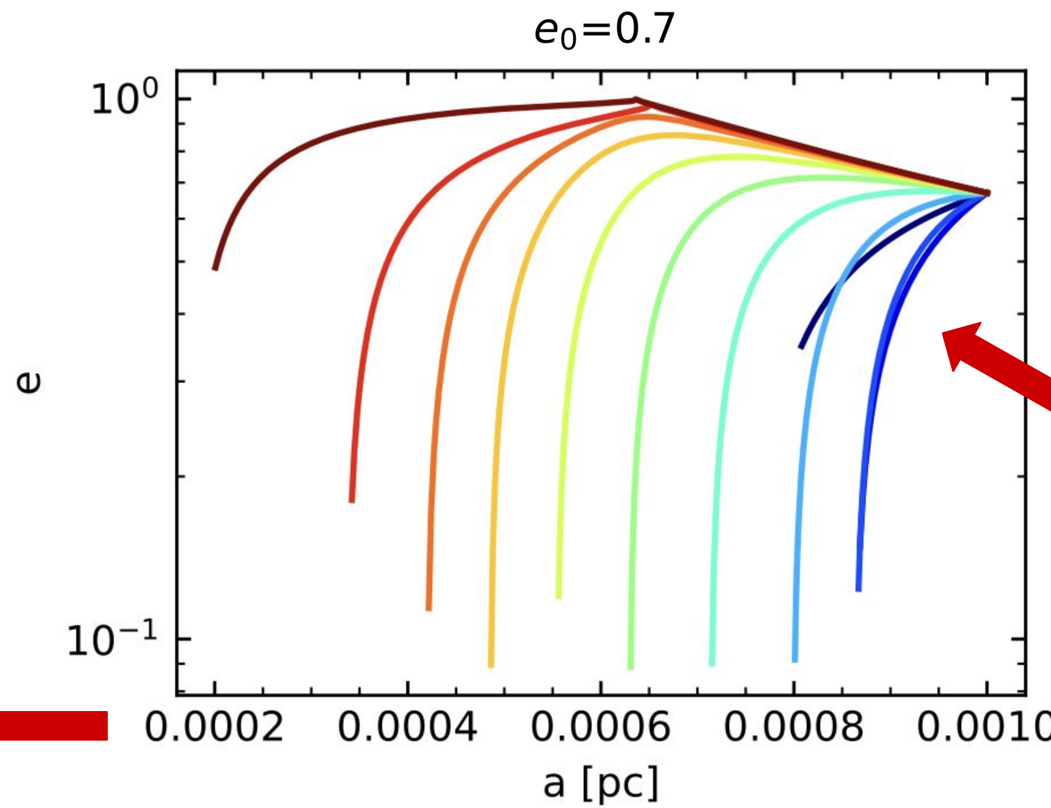
$$t_X = X / \left\langle \dot{X} \right\rangle$$





hydro-inspired fits that match the asymptotic analytics

For supersonic motion, migration timescale << damping of eccentricity



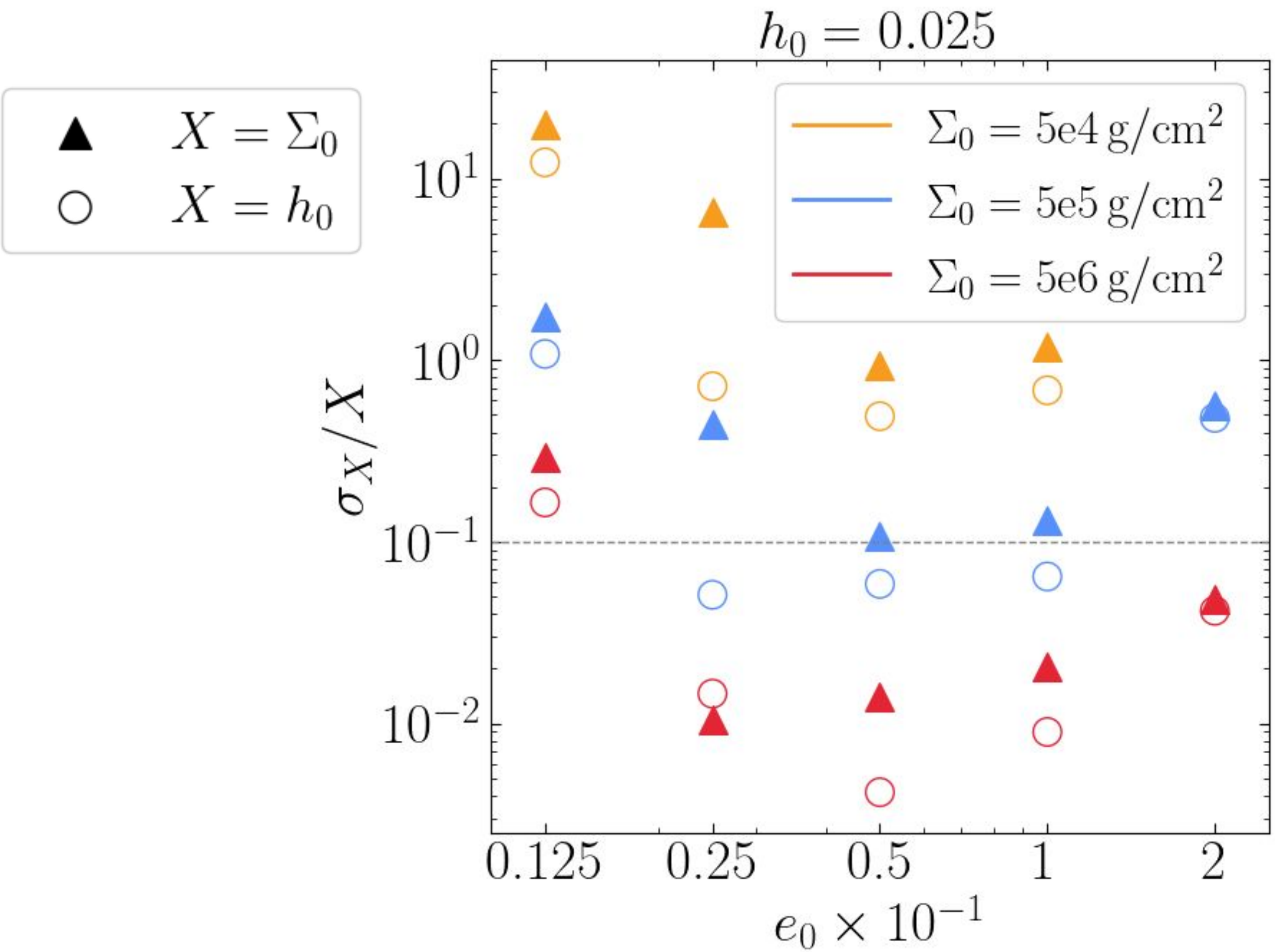
Different Inclinations

40 *M*

Since the eccentricity damping may not be as efficient as inclination damping, there might be some eccentricity residual on captured BHs

Wang et al., arXiv:2308.09129

$$\dot{a} = \dot{a}_{\mathrm{GW}} + \dot{a}_{\mathrm{gas}} \qquad \dot{e} = \dot{e}_{\mathrm{GW}} + \dot{e}_{\mathrm{gas}}$$



$M = 10^6 M_\odot$

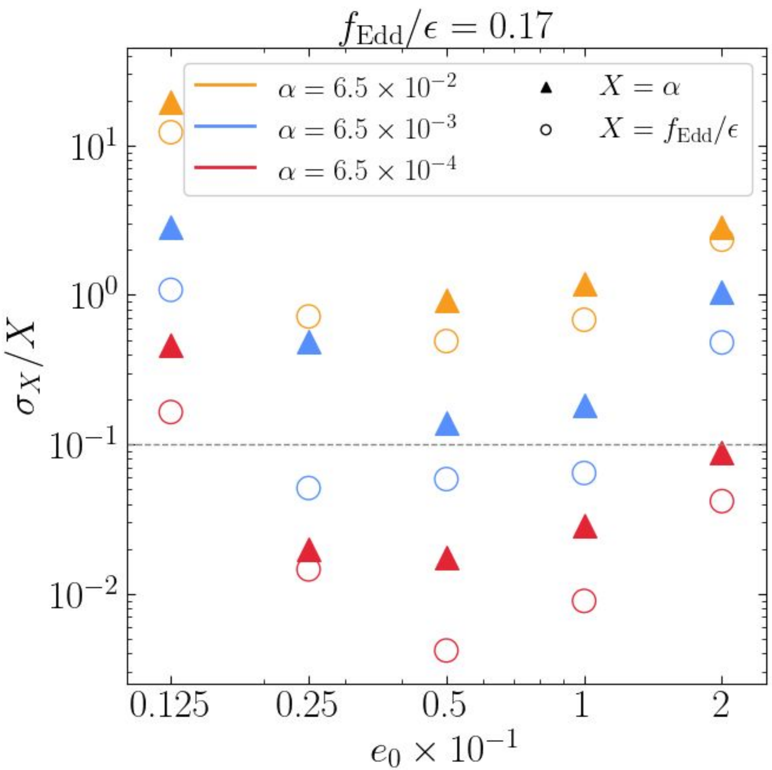
$\mu = 50 M_\odot$

$p_0 = 16.83M$

$\mathrm{SNR} = 50$

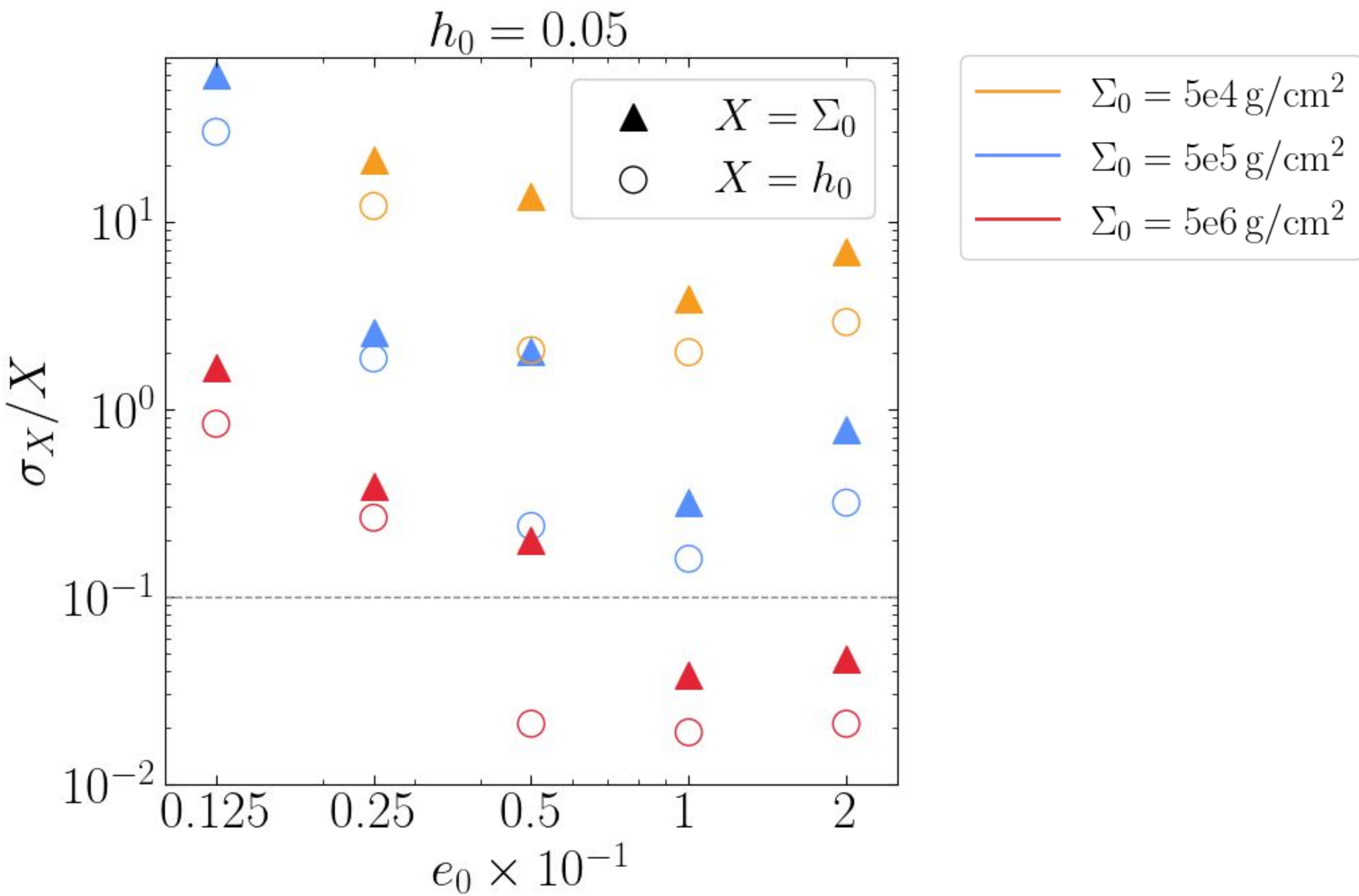
$T_{\mathrm{obs}} = 4\,\mathrm{yrs}$

$$\Sigma_0^\alpha = 5.4 \times 10^3 \left(\frac{0.1}{\alpha}\right)\left(\frac{0.1}{f_{\rm Edd}}\frac{\epsilon}{0.1}\right)\left[\frac{\rm g}{\rm cm^2}\right] \qquad h_0^\alpha = 0.15\left(\frac{f_{\rm Edd}}{0.1}\frac{0.1}{\epsilon}\right)$$



Can constrain accretion rate **and** viscosity **simultaneously**

Not possible for **circular** motion w/ migration torques



Inference optimized when there is **transition** from super to subsonic

Multimessenger Wet EMRIs: Improved sirens?

If GW-content gives us info on $f_{\rm Edd}/\epsilon$

Mass/Spin measure → ϵ estimate → $f_{\rm Edd}$ estimate

Luminosity estimate

Magnitude estimate from GW only

$\Delta f_{\rm Edd}/f_{\rm Edd} \sim 0.1$ → $\Delta m_{\rm AGN,\ Rubin}/m_{\rm AGN,\ Rubin} \sim 0.01$

Could assist host galaxy / EM counterpart (QPE) identification

Physics we missed

1. Relativistic effects in dynamics + disk structure
2. Wake's curvature
3. Stochasticity (magnetic fields?)
4. Radiative/thermal effects
5. Retrograde orbits (eccentricity excitation)

↓

Corrections of $\mathcal{O}(1-10)$?

Take-home message

Formation/Inference of Wet EMRIs is still in quite unexplored

Many questions to explore and understand better but so far…

More detailed modelling ➡ More interesting phenomenology

But unclear how to search for extra physics in the Global Fit

Strong-field + astro + data community **should (*need*) to talk more**

Inner region α - disk: $\Sigma(r) = \Sigma_0 \left(\frac{r}{10M}\right)^{3/2}$ $h(r) = h_0 \left(\frac{10M}{r}\right)$

$e < h$	$e > h$
Subsonic	Supersonic
(Global) Migration Torques	(Local) Dynamical Friction
$\langle \dot{a} \rangle \propto -(\Sigma_0/h_0^2)a^5$	$\langle \dot{a} \rangle \propto (\Sigma_0/h_0)\, a^4/e$
$\langle \dot{e} \rangle \propto -(\Sigma_0/h_0^4)a^6 e$	$\langle \dot{e} \rangle \propto -(\Sigma_0/h_0)a^3/e^{7/4}$
$t_X = X/\langle \dot{X} \rangle$ $t_e/t_a \sim h^2 \ll 1$	$t_e/t_a \sim (e/h)^2 \gg 1$

For supersonic motion, migration timescale << damping of eccentricity