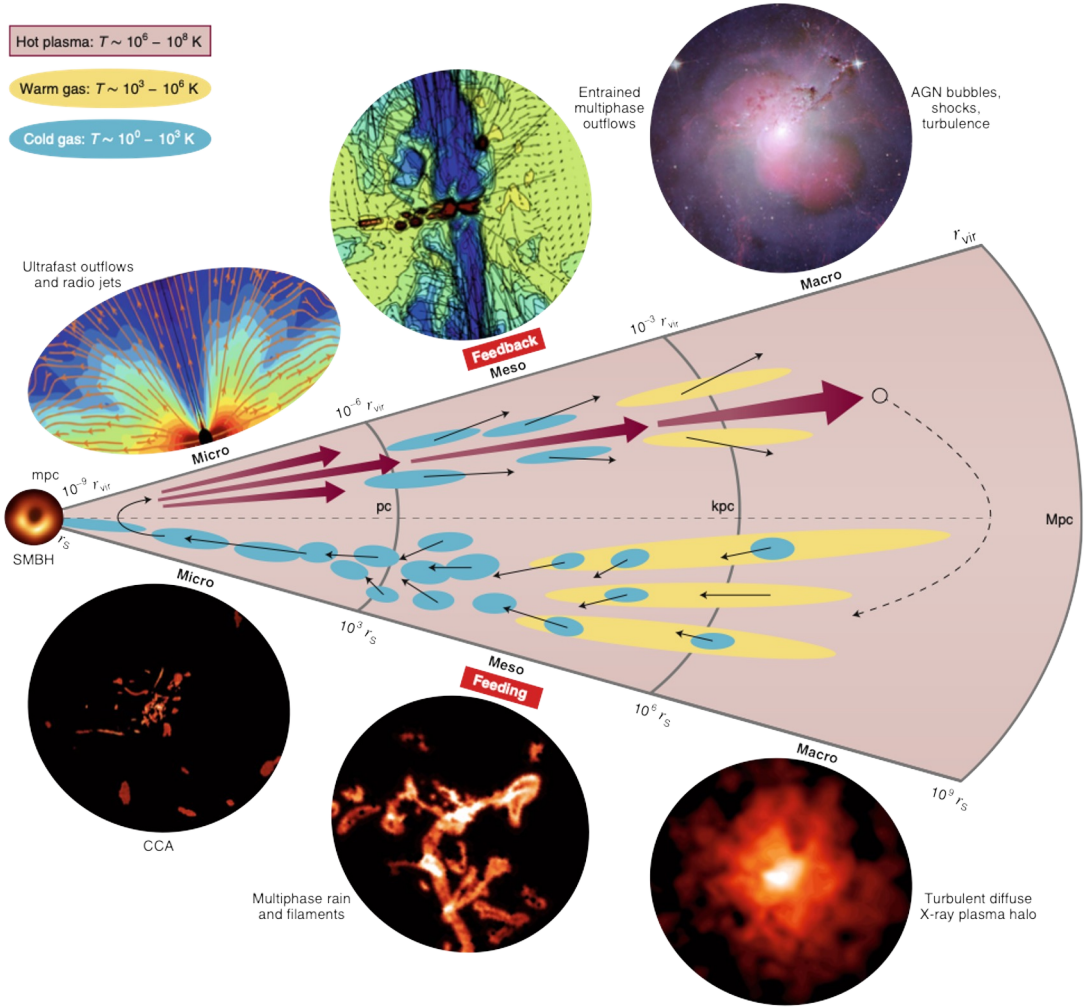
Connecting Different Scales

Binary 2022 Conference – March 17, 2022

Your Moderators:
Laura Blecha & Scott Noble

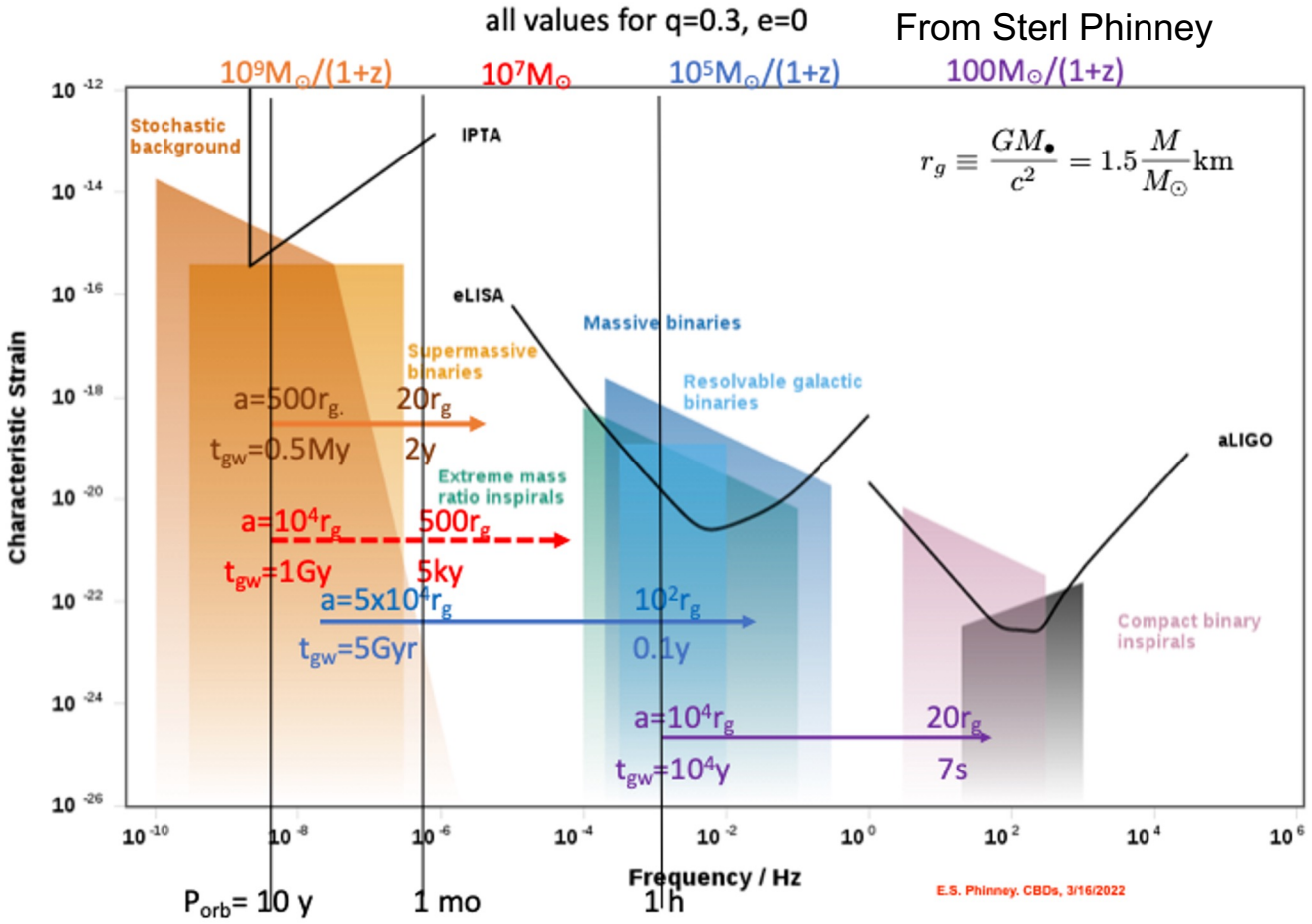
Possible Discussion Topics/Questions

- **Connecting galactic-scale sims to MBH scales** (Slides from Alessandro Lupi & Aneesh Sivasankaran)
  - **Host galaxy influence on MBHB accretion & hardening** (chaotic vs coherent accretion, clumpy ISM, stellar feedback, multiple mergers, …)
  - **When/where/if there is a final (kilo?)parsec problem** (efficiency of dyn. friction, stellar & gas hardening processes, role of triple MBHs, wandering BHs)
  - **Role of AGN feedback in MBHB evolution?** (different feedback mechanisms, relative role of AGN vs stellar feedback? Are binaries messier feeders? Or different from single AGN?)
- **Connecting GR to Newtonian scales** (Slides from Scott Noble)
- **Observational prospects/limitations?** (connection b/t galactic and MBH merger rates, dual AGN, host dilution of AGN luminosity & variability, obscuration, …)
- **Numerical techniques: prospects & limitations?** (missing physics, sub-resolution models, zoom sims, multi-scale sim suites, realistic initial conditions, …)



Gaspari, Tombesi, and Cappi, NatAs, 4, 10, (2020).

- Easier question first: How are single AGN fed?
- How does binarity affect this picture?
- How does chaotic cold accretion regulate feeding and binary evolution? Does a binary feedback or feed in a way that alters this picture?

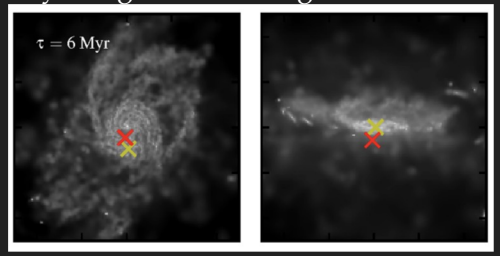


- Class of BBH accretors span vast dynamic range in time, from blips to human lifespans;
- What are the best strategies of finding BBH accretors given disparate time scales between dynamics and observational cadences/lifetimes?
  - Eccentric binaries are bursty GW/EM emittors so need to be careful in determining their likelihoods for detection;
- Are we confident that BBHs will be driven to near equal mass ratio and have ~0.4 eccentricity? Are these the likeliest to be observed? Where does accretion decoupling and GW inspiral occur/overlap/compete?

Matching different scales

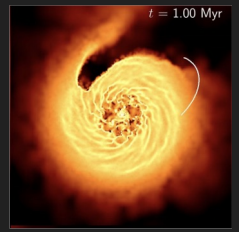
The huge dynamic range involved in the dynamical evolution of MBHBs prevents us from studying this process as a whole, and requires us to split it into simpler problems on different scales.

Galaxy mergers/cosmological simulations (~10 pc-Mpc)

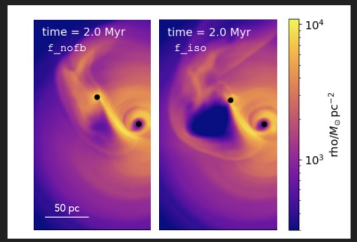


(Roskar et al. 2015)

Binary pairing in galaxy nuclei (0.1-100 pc)

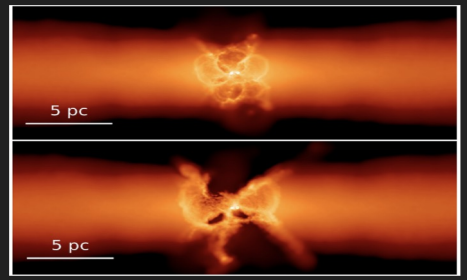


(Souza-Lima et al. 2017)



(Bollati et al. in prep.)

Binary shrinking/expansion in circumbinary discs (<~10 pc)



(Del Valle & Volonteri 2018)

Are we getting close to match (partially at least) different scales/regimes?

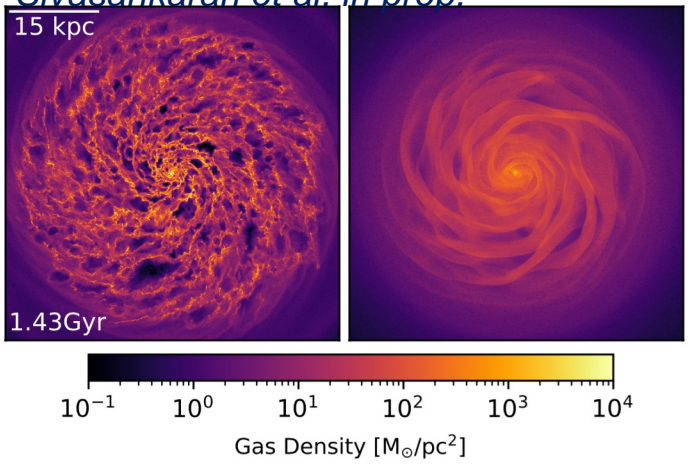
Can we use the results at the resolution limit of larger scale simulations to infer boundary conditions for the smaller scale ones?

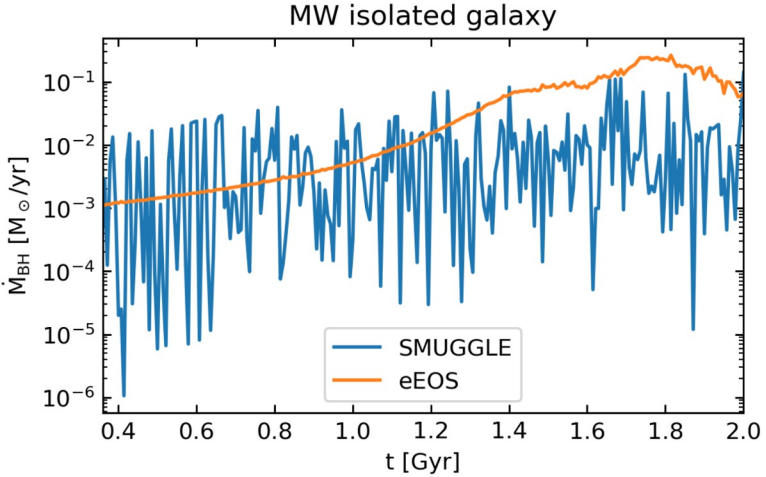
What is the impact of the different physical assumptions on the results?

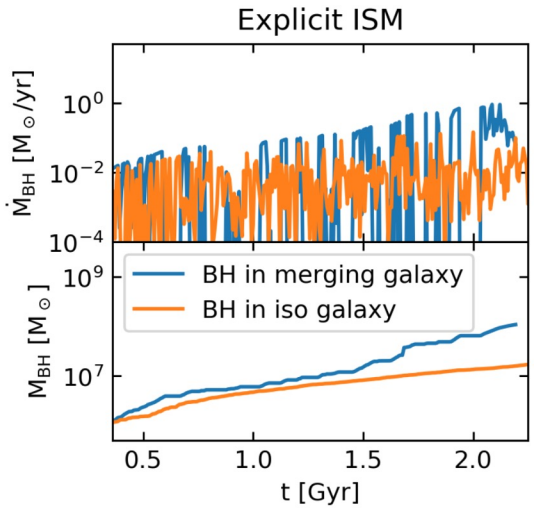
SMBH Fueling in Idealized Galaxy Simulations

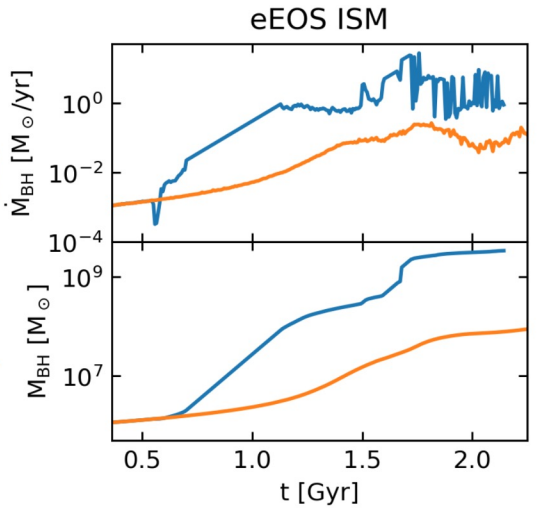
Aneesh Sivasankaran (University of Florida)

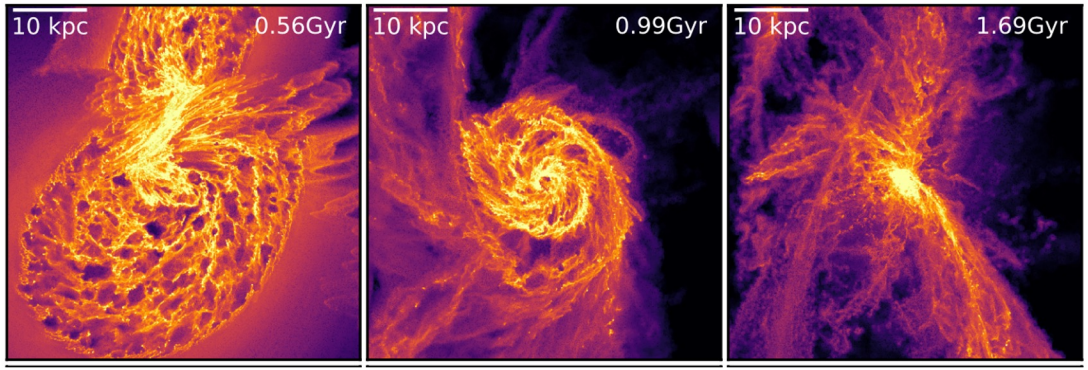
Sivasankaran et al. in prep.











GR to Newtonian Scales

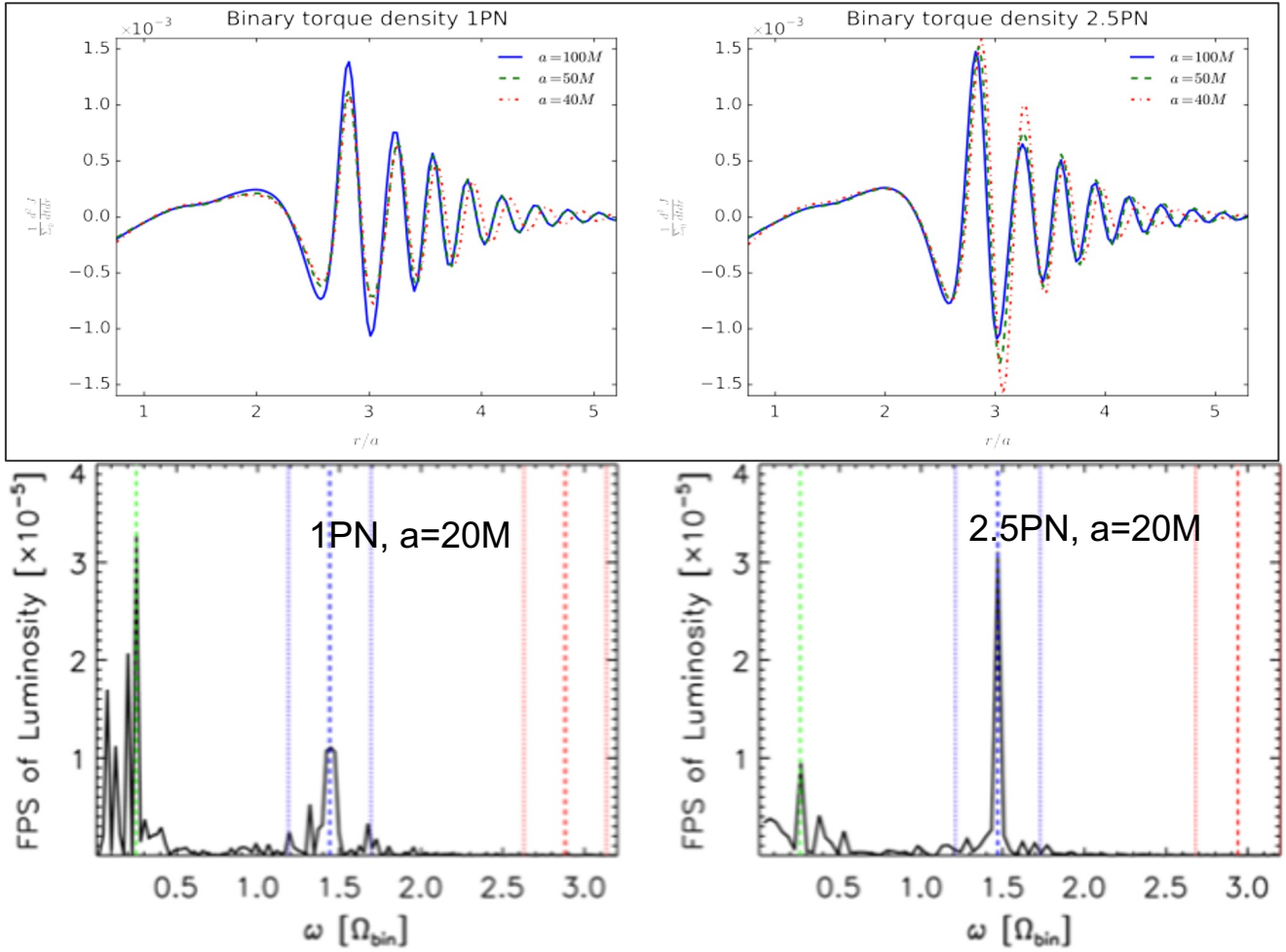
Zilhão, Noble, Campanelli, and Zlochower, PhRvD, 91, 024034, (2015).

When is or what conditions are GR important? How do we determine this?

Torque density differences for 2D hydrostationary tori including different Post-Newtonian terms at different separations.

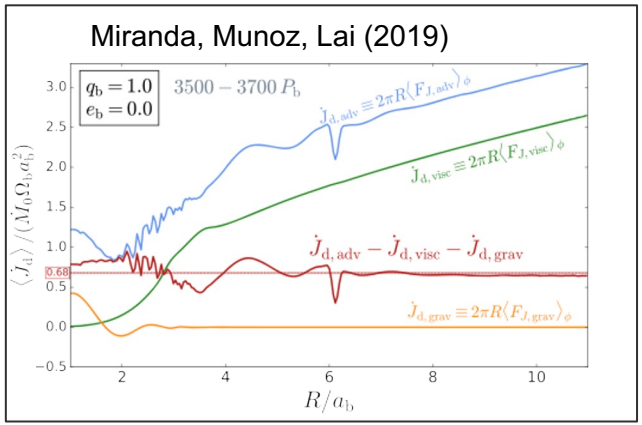
Fourier power spectra of light curves from differentt 3D GRMHD CBDs using different Post-Newtonian orders at a=20M, ala Noble++2012

Transition in torques and importance of higher-order PN terms seems to be around a=30-40M for q=1;



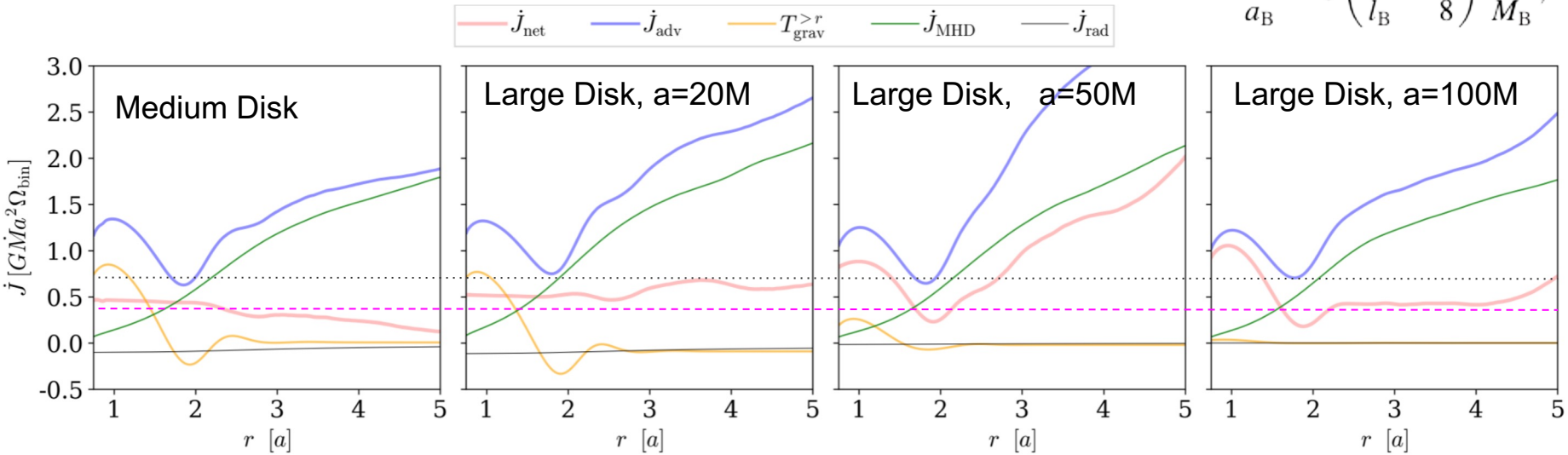
GR to Newtonian Scales

Gladkova, SCN++ in progress



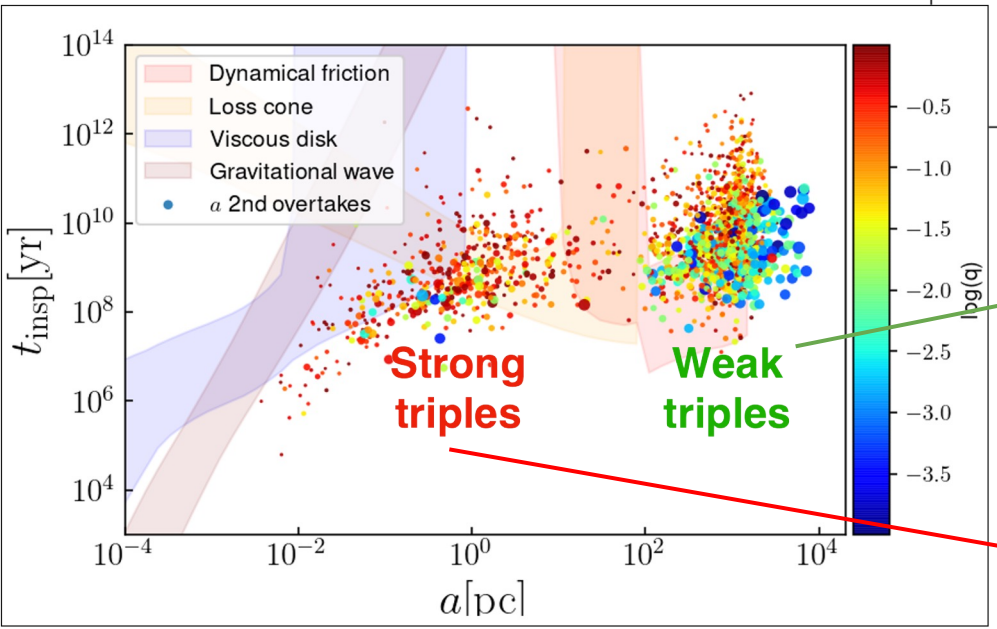
- Does inspiral vs. outspiral depend on separation? MHD vs. viscosity?
- How do we reconcile need for mass inflow equilibrium and the likely fact that AGN have "short" periods of activity and may have stochastic feeding processes (e.g., TDEs, misaligned annuli, …) ?

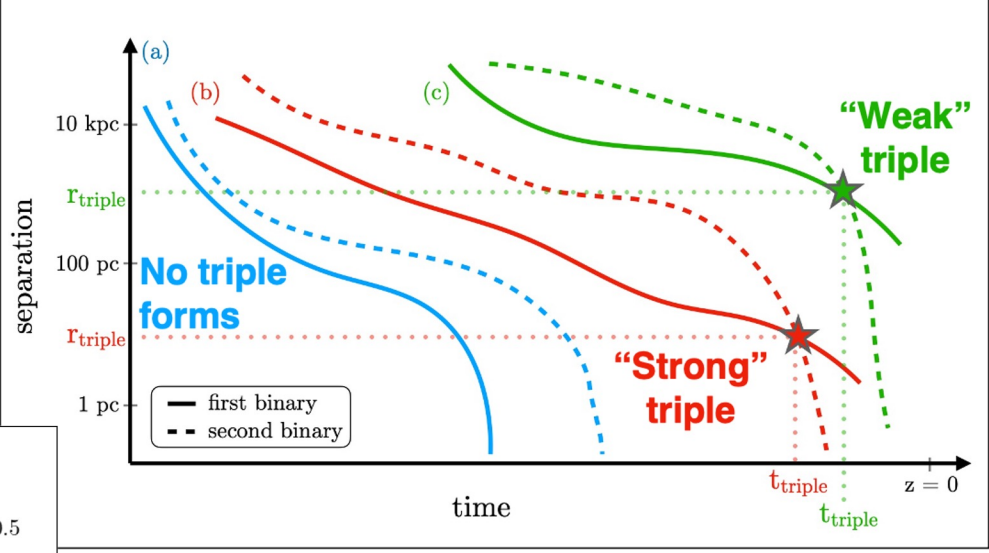
$$\frac{\dot{a}_B}{a_B} = 8\left(\frac{l_0}{l_B} - \frac{3}{8}\right)\frac{\dot{M}_B}{M_B},$$

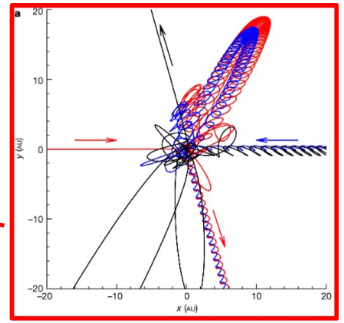


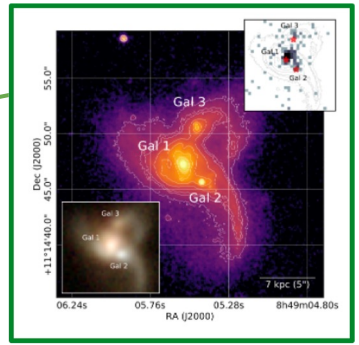
Triple SMBH Systems

Sayeb, Blecha, & Kelley in prep.









(Pfeifle+19b)

(Stone & Leigh 19)

EXTRA SLIDES

SMBH Fueling in Galaxy Merger Simulations

Aneesh Sivasankaran (University of Florida)

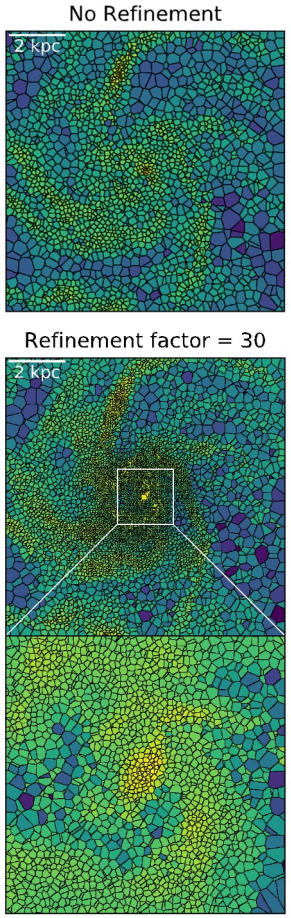
Methods

- We studied gas inflows onto SMBHs in hydrodynamics simulations of idealized isolated and merging galaxies.
- ISM and stellar evolution are modelled explicitly using the Stars and Multiphase Gas in Galaxies (SMUGGLE) model.
- BH accretion rate is estimated using the Eddington limited Bondi-Hoyle prescription:

$$\dot{M}_{\rm Bondi} = \frac{4\pi\alpha G^2 M_{\rm BH}^2 \rho}{c_s^3}$$

- We implemented a super-Largrangian refinement scheme that increases the gas mass resolution in the immediate neighborhood of the black holes (BHs) to accurately resolve gas accretion.

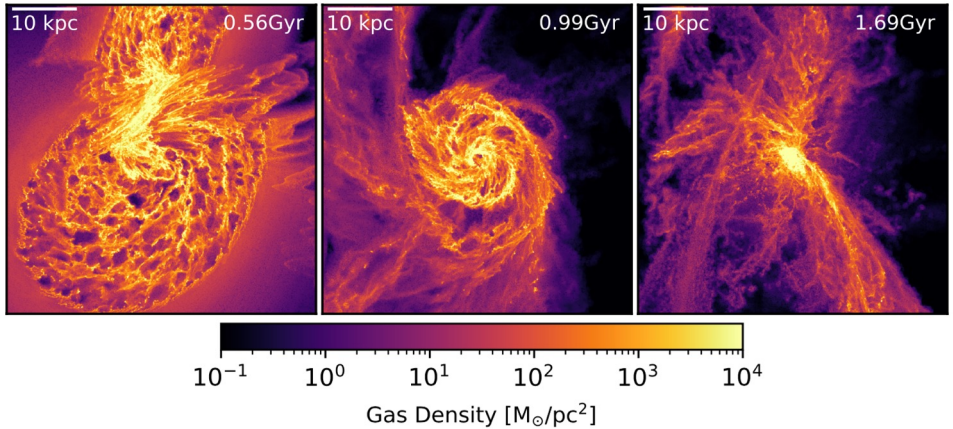
Sivasankaran et al. in prep



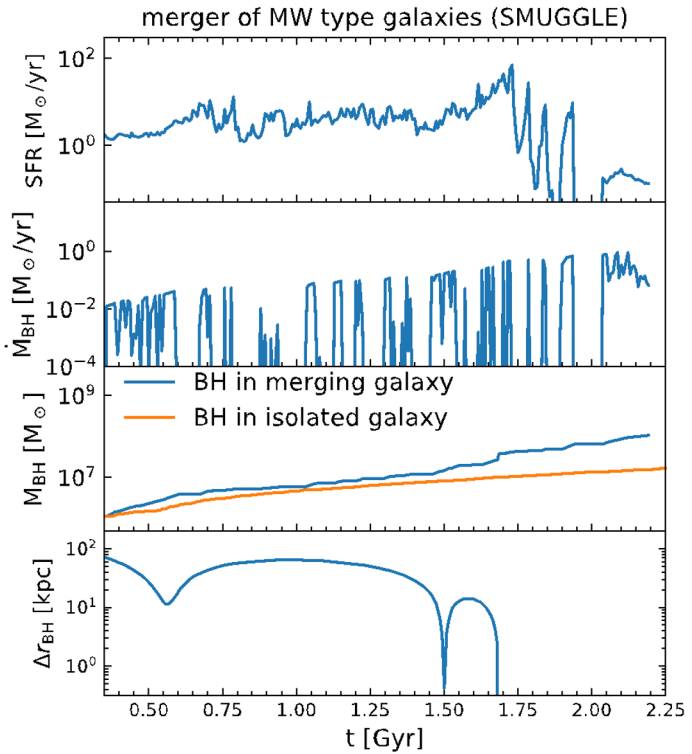
RESULTS

Simulations with explicit ISM

- BH accretion is highly variable over short timescales (~Myr) due to the turbulent nature of the ISM.
- Interaction of the galaxies trigger gas inflows to the galactic centers enhancing the BH accretion rates.
- Enhancements are small (factor of ~4) as strong and bursty stellar feedback counteracts the inflows.



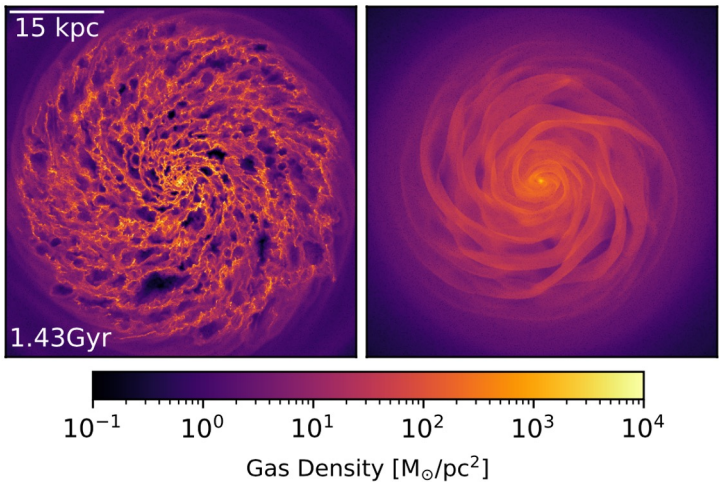
Sivasankaran et al. in prep



RESULTS

Comparison to simulations with eEOS ISM

- Effective equation of state models ISM (models used in Illustris, IllustrisTNG and Auriga simulations) produces smooth gas density profiles (right).
- This leads to steady accretion rates and significant overestimation of merger induced enhancement of accretion (by an order of magnitude in this setup).



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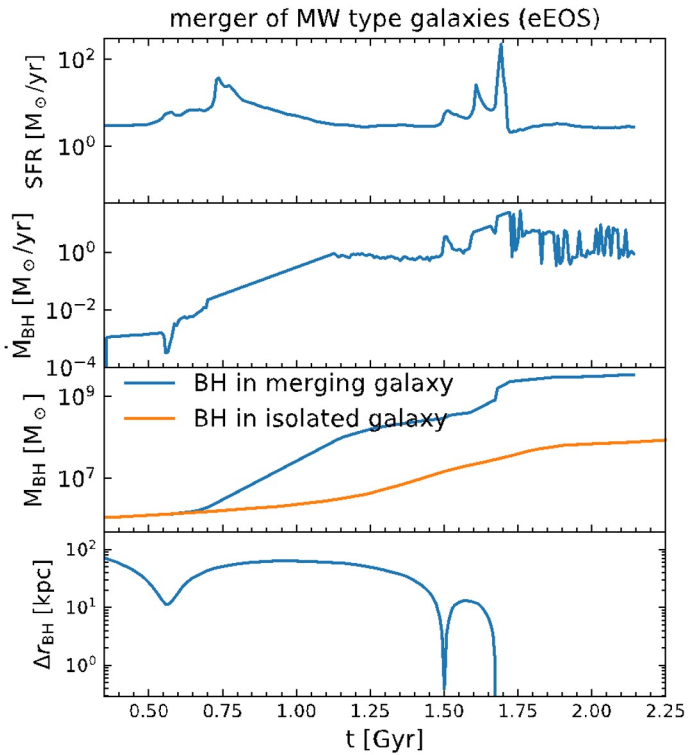
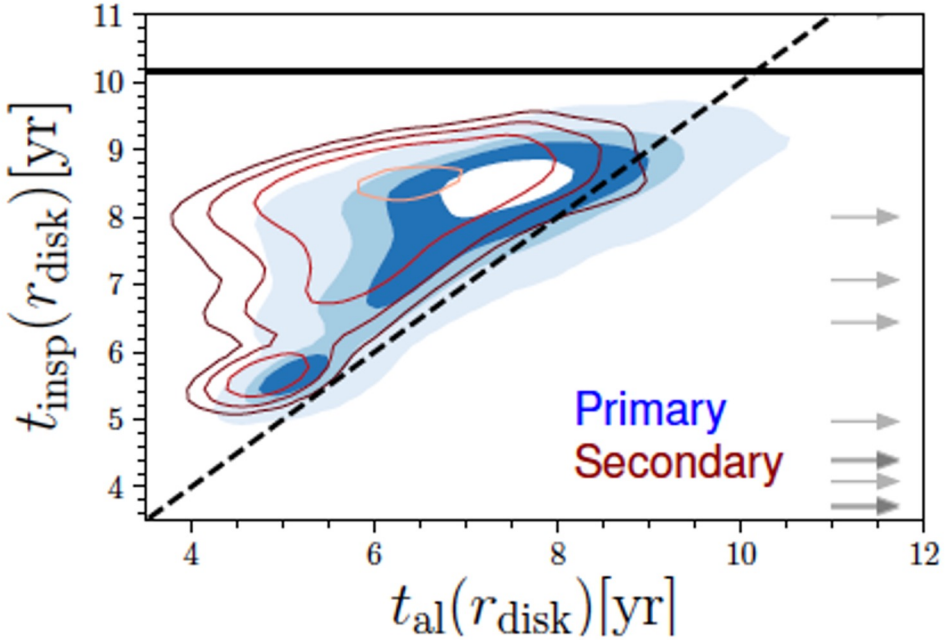


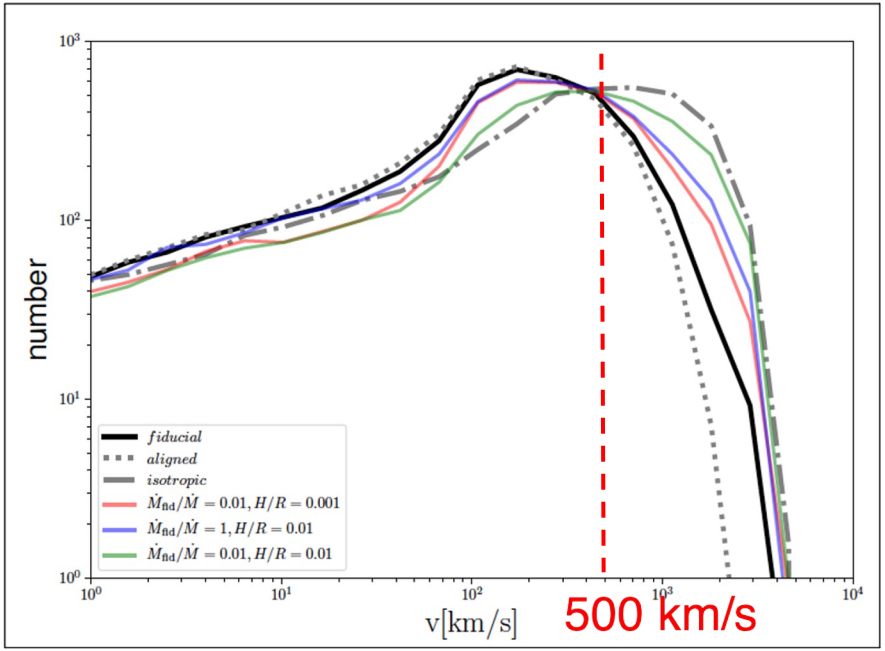
Gas- and GW-driven BH binary spin evolution

Sayeb et al. 2021

BH spin alignment vs. inspiral timescales
in the gas-dominated phase

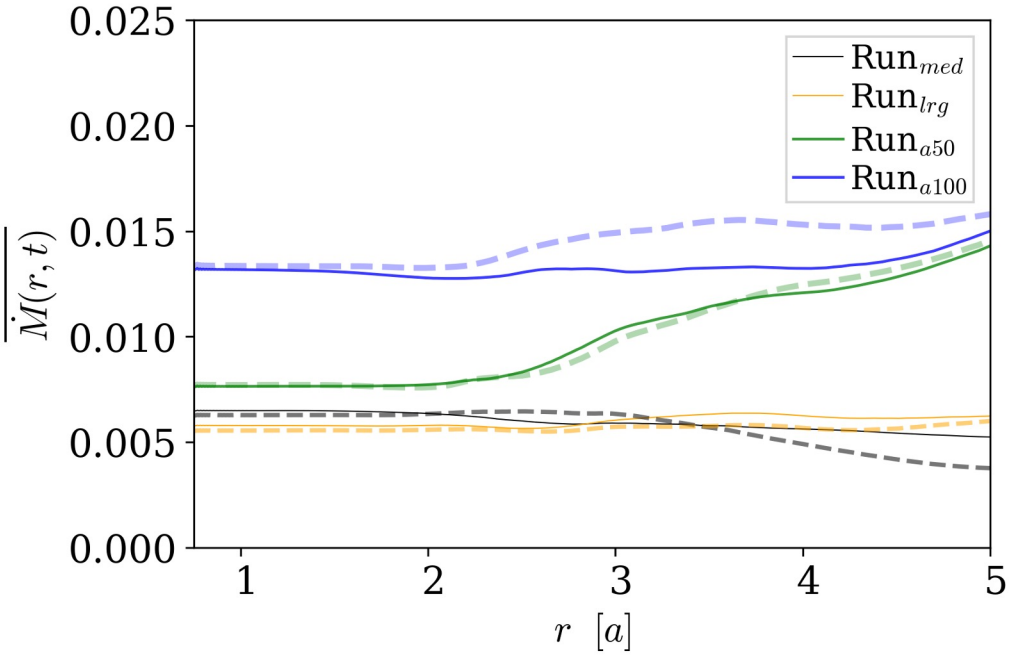


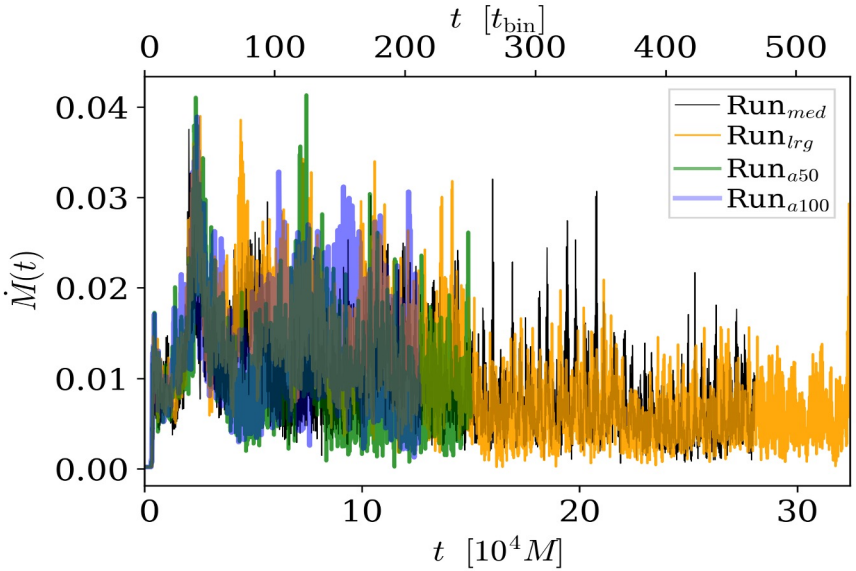
GW recoil velocities

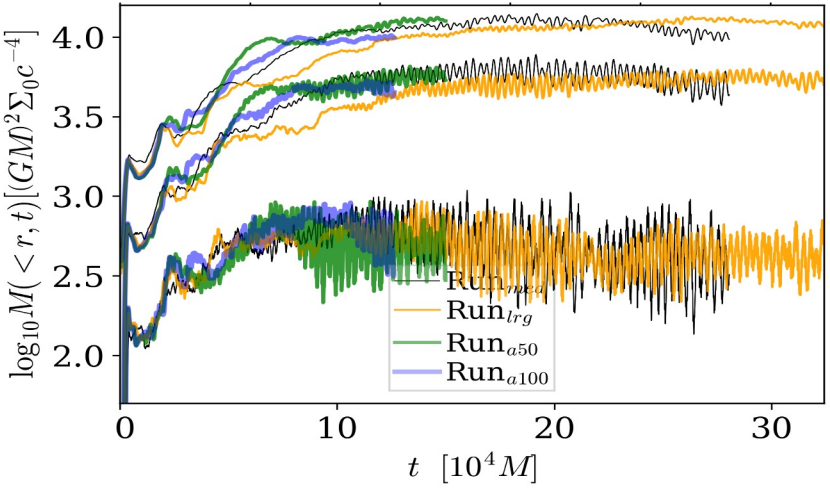


Mass Inflow Equilibrium in GR Regime w/ MHD

Gladkova, SCN++ in progress







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