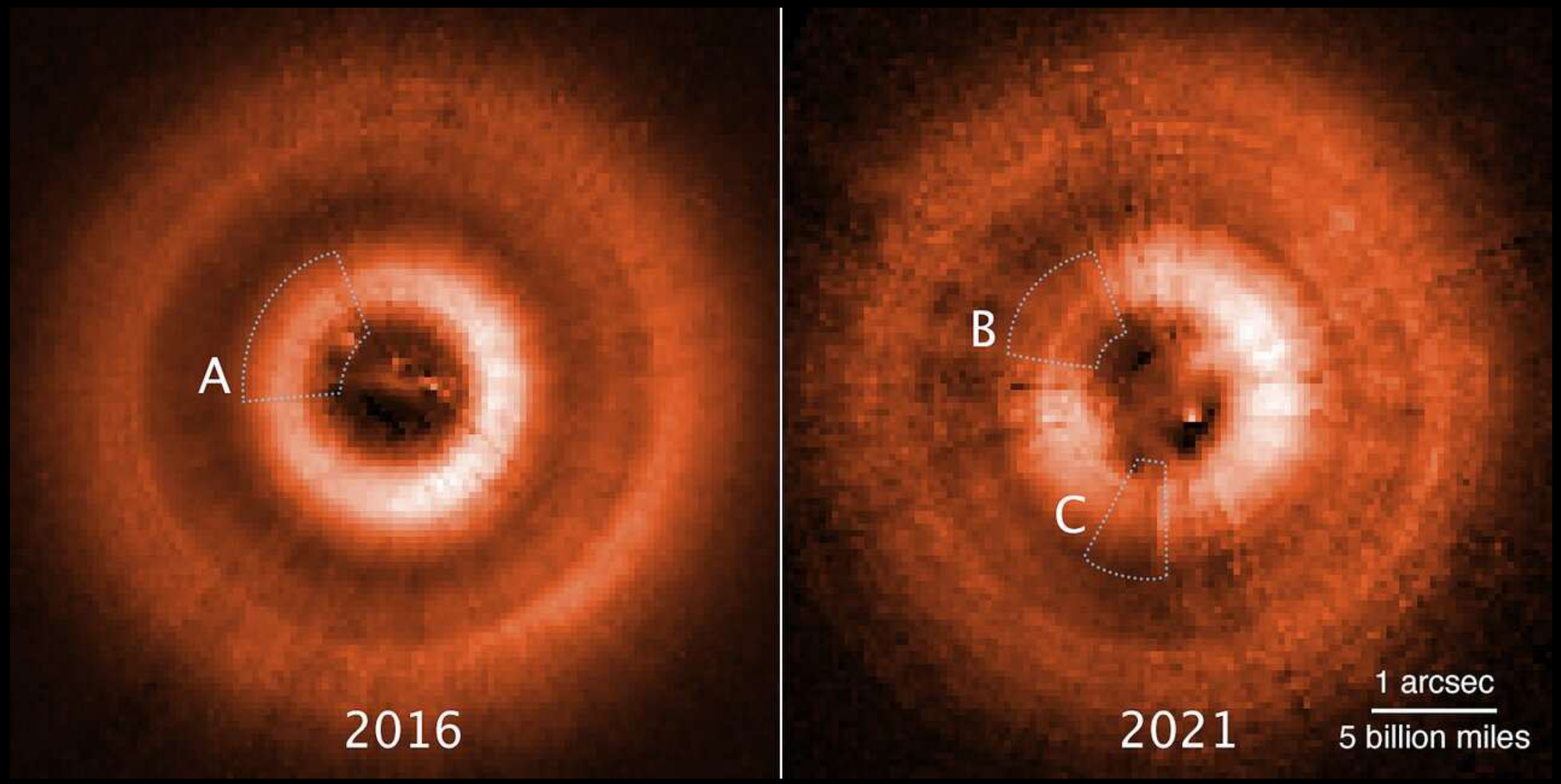
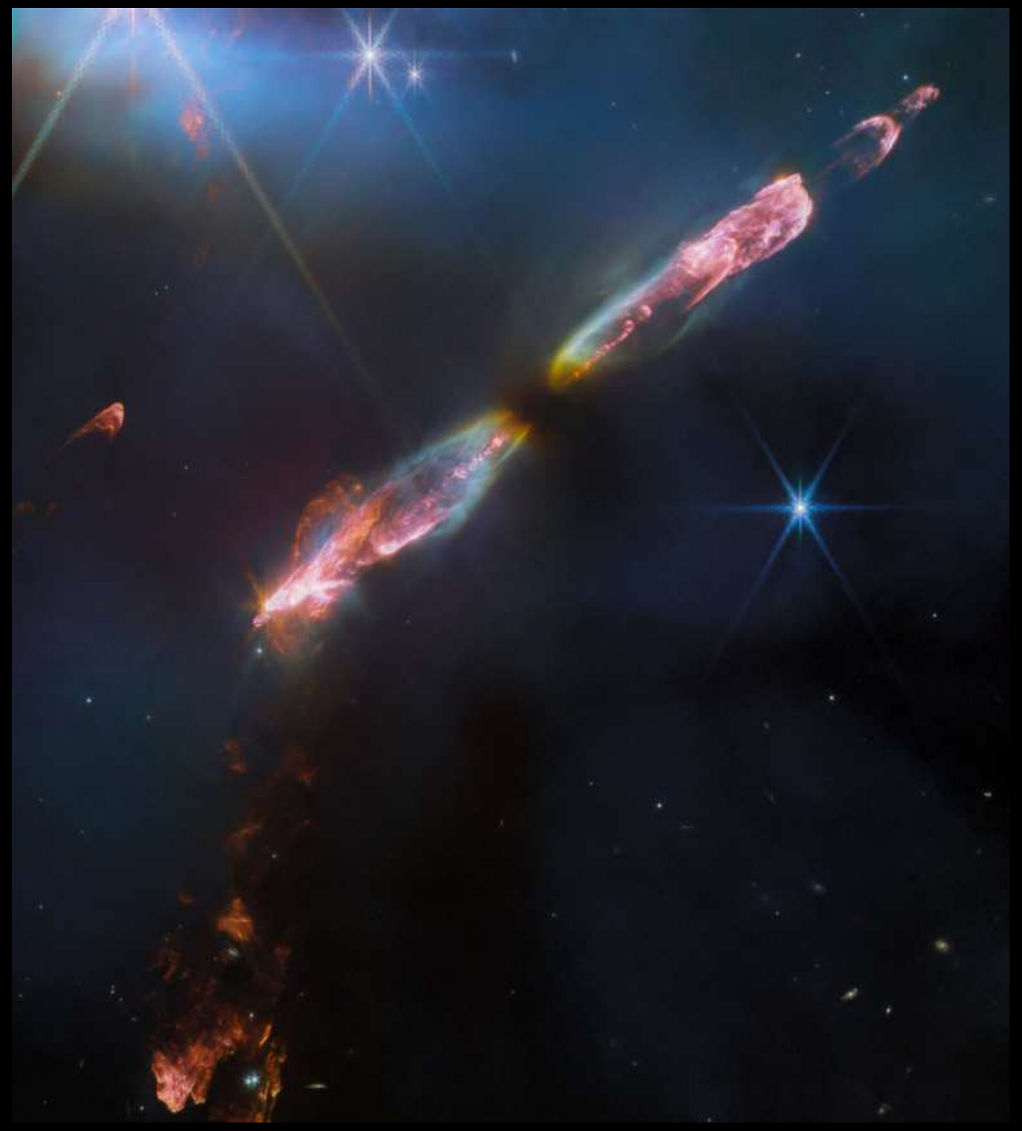
Towards exascale simulations with Shamrock

Yona Lapeyre-Belaredj

Discs with complex geometries

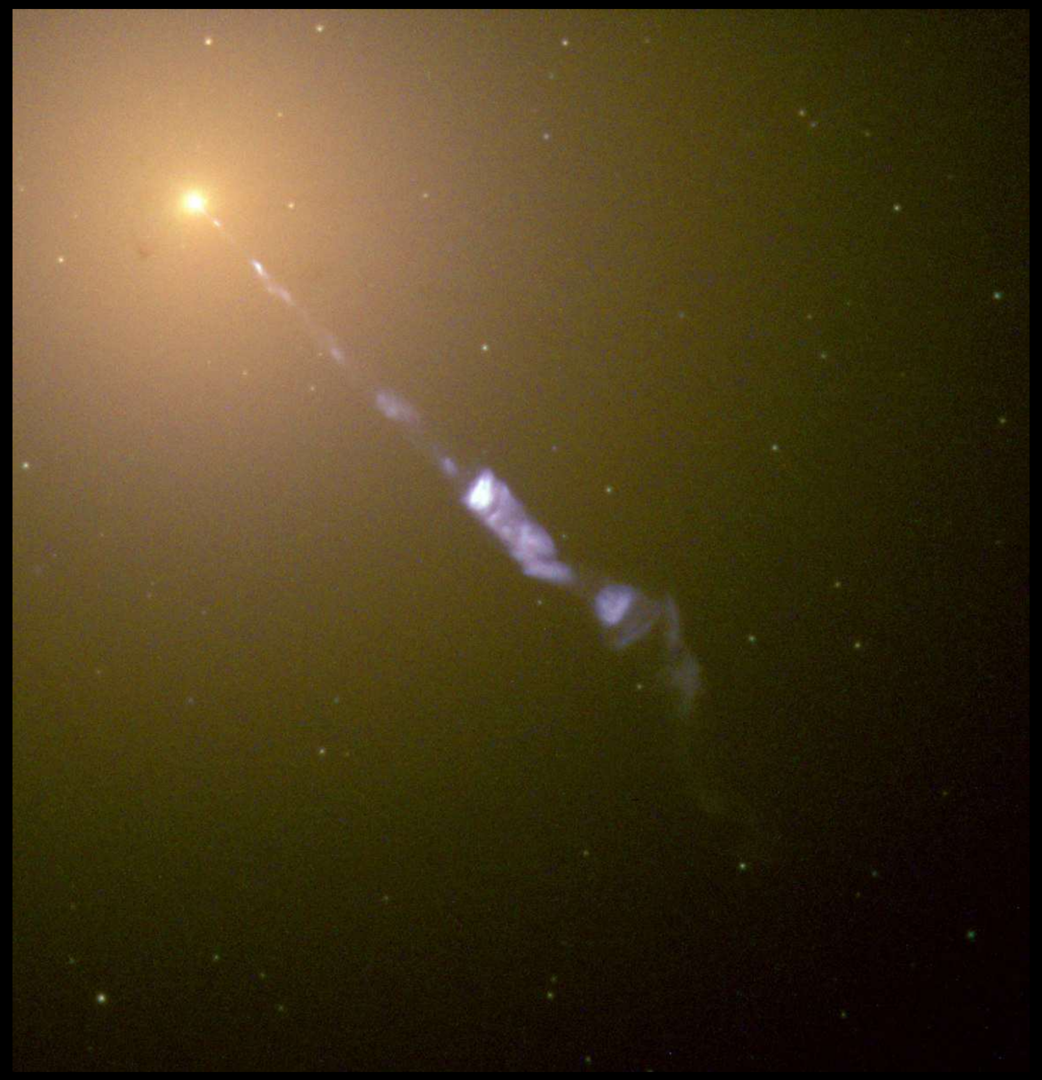


TW Hydrae by HST



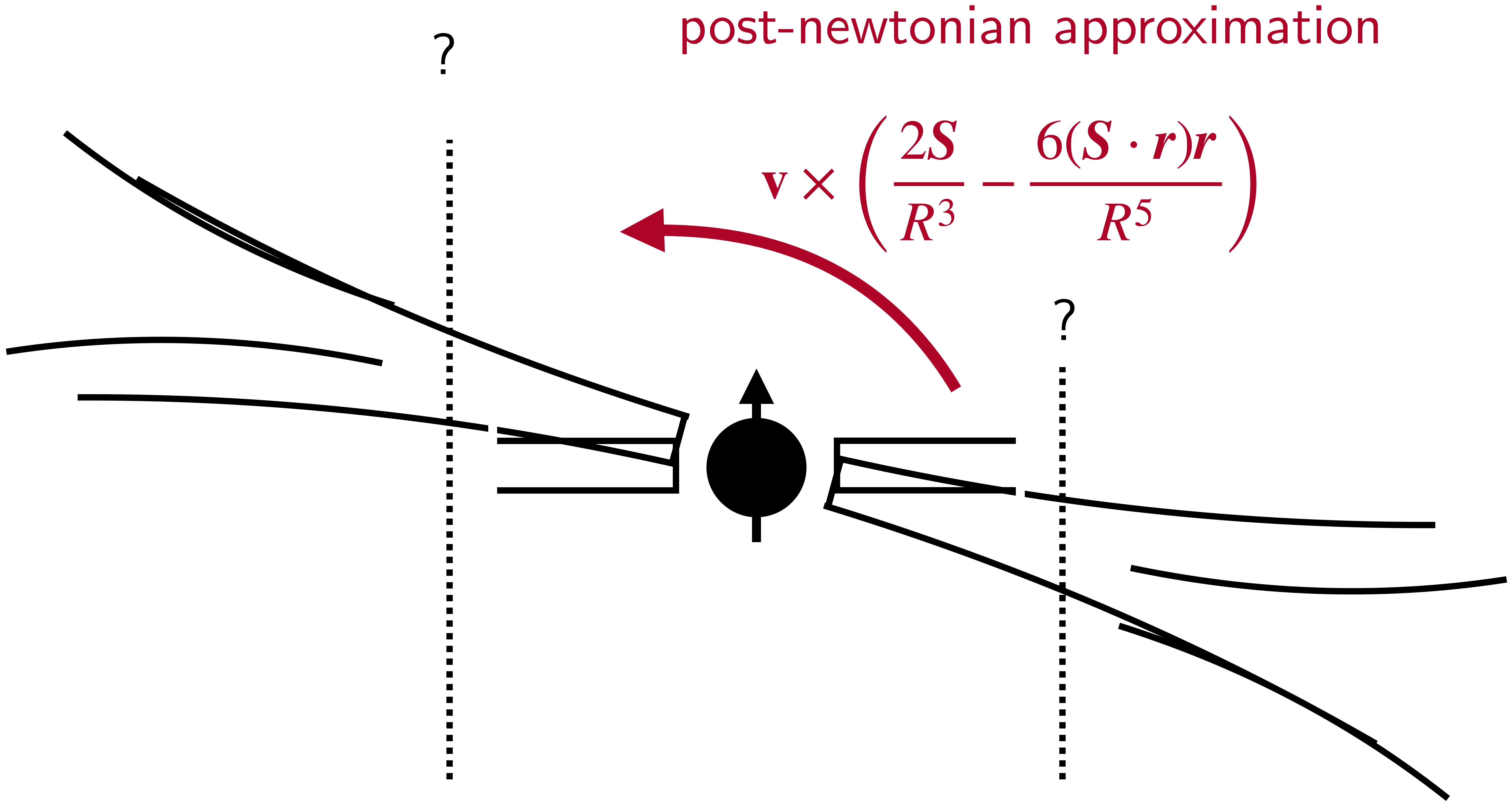
HH221 by JWST

M106 by HST



M87 by HST

The Bardeen-Petterson effect



SPH Simulations: Nealon et. al. (2015)

—> When does the disc break?

—> At what radii?

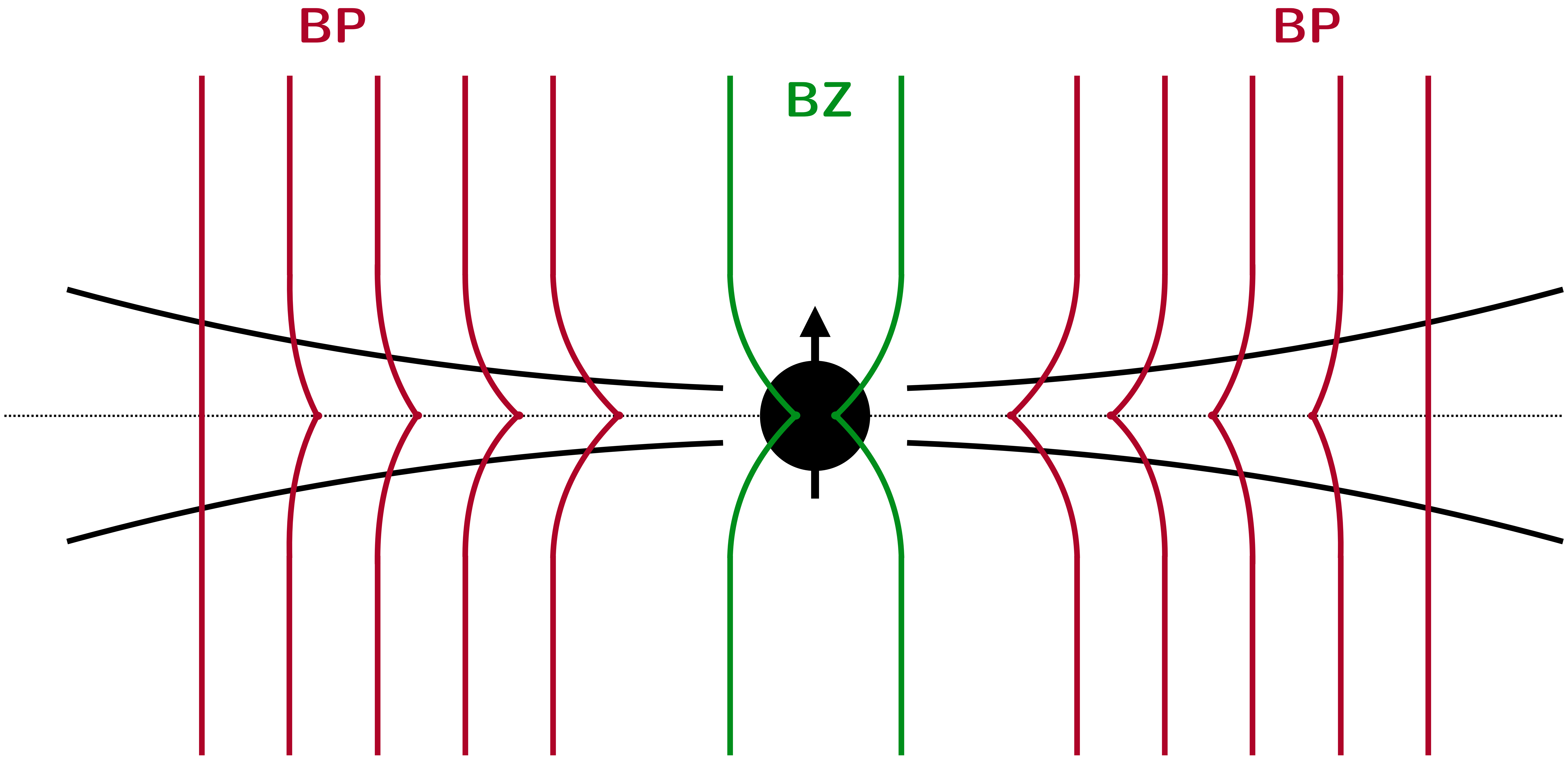
—> Observational signature?

—> accretion rate?

—> instabilities at very small scales?

We need resolution!!

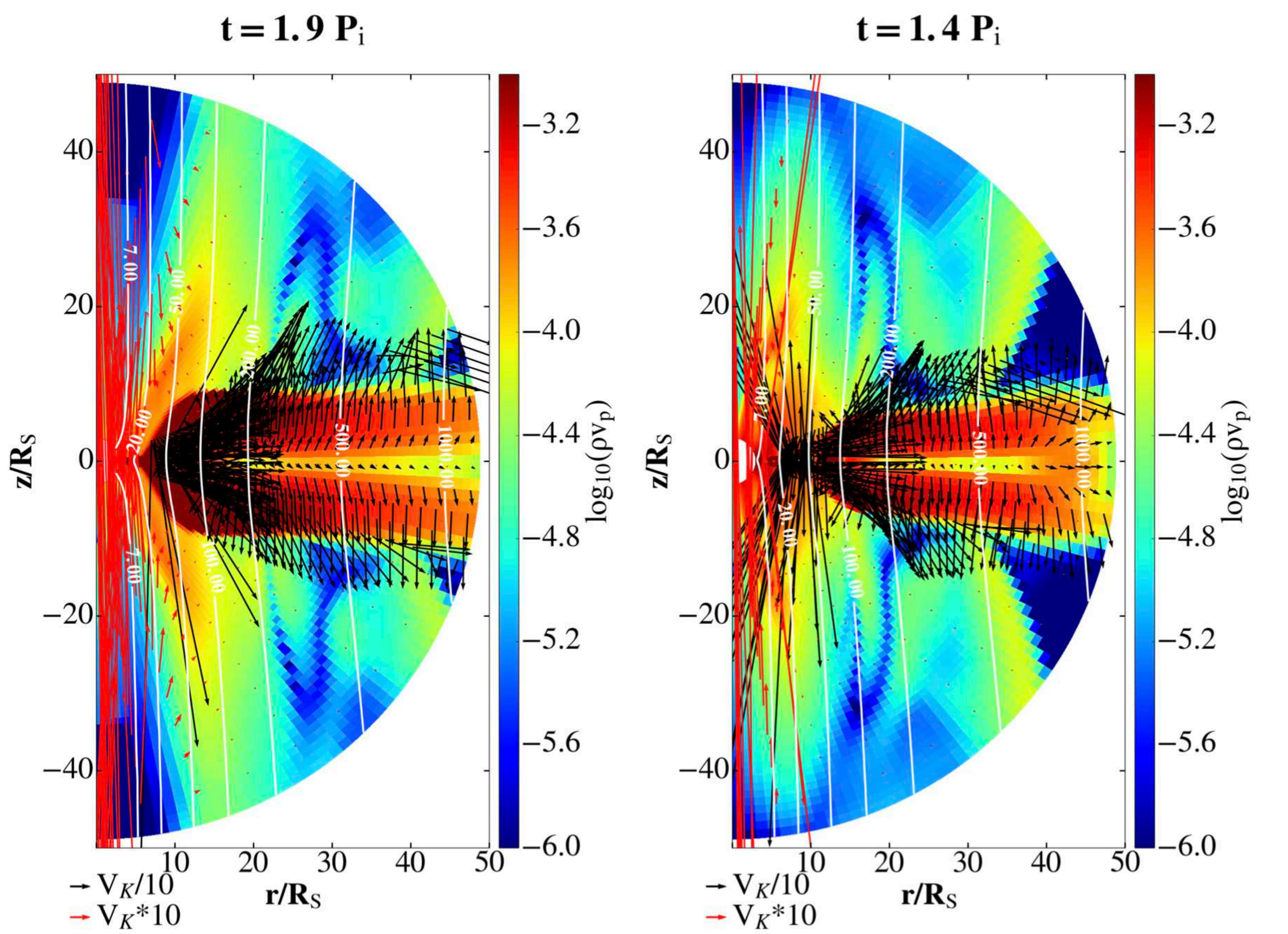
Formation of jets (from black holes)



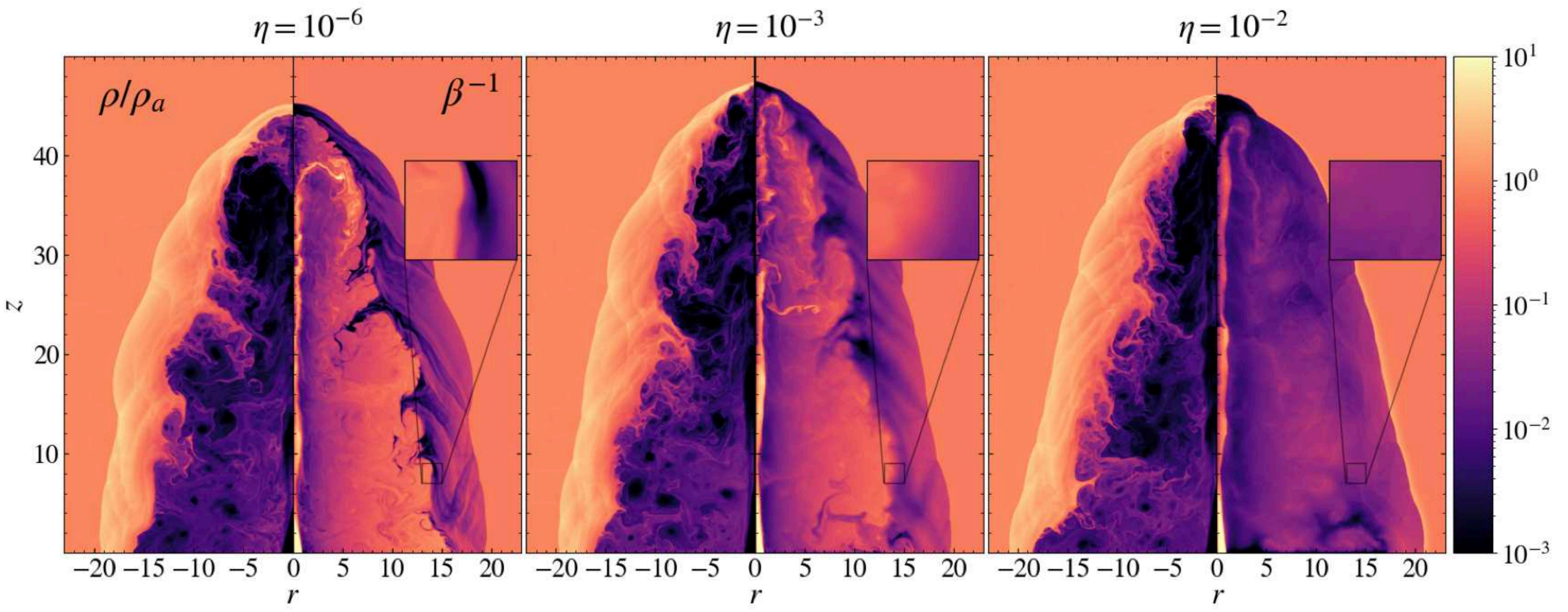
Blandford and Znajek (1977)

Blandford and Payne (1982)

Example: grid simulation using Pluto



M. Jabloski, A. Kotek, M. Cemeljic, W. Kluzniak (2020)



G. Maia et. Al. 2023

—> Jet stability and collimation?

—> Influence of magnetic reconnection? Turbulence?

We need resolution!!

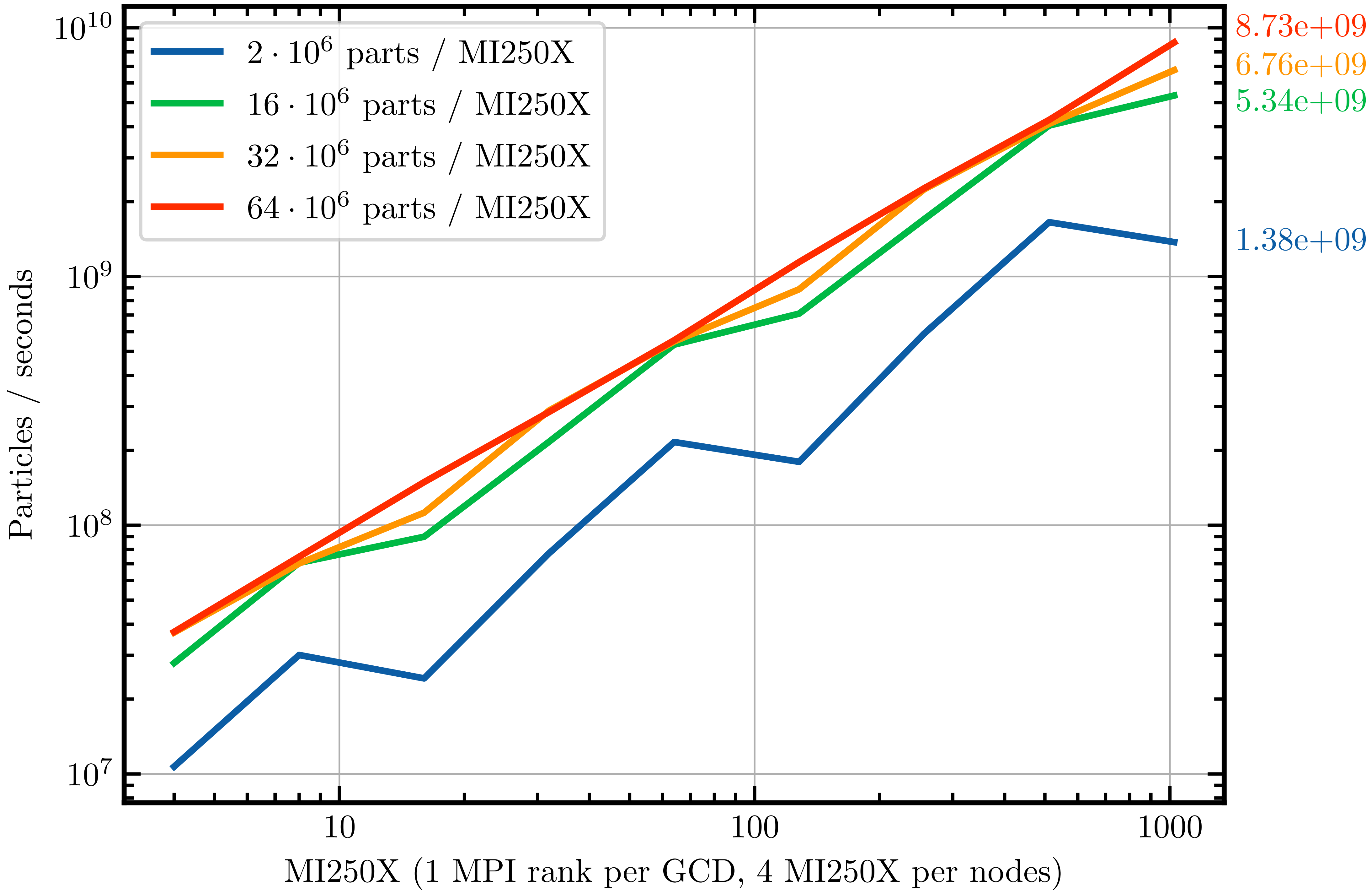
Shamrock: (magneto-)hydro code for exascale architecture

El Capitan
Peak 2.74 exaFlops/s

Shamrock

https://github.com/Shamrock-code/Shamrock

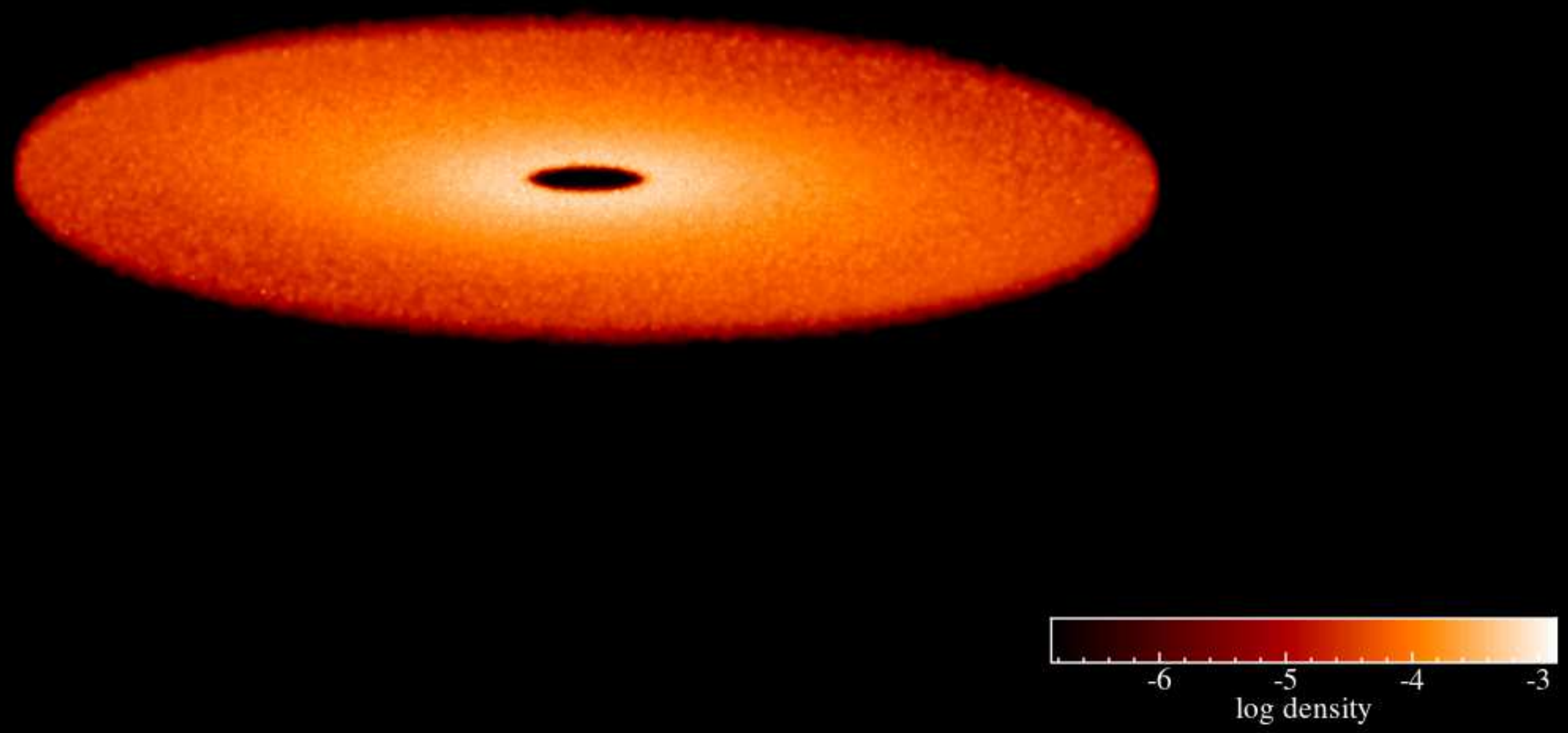
David--Cléris, Laibe, Lapeyre (2025)

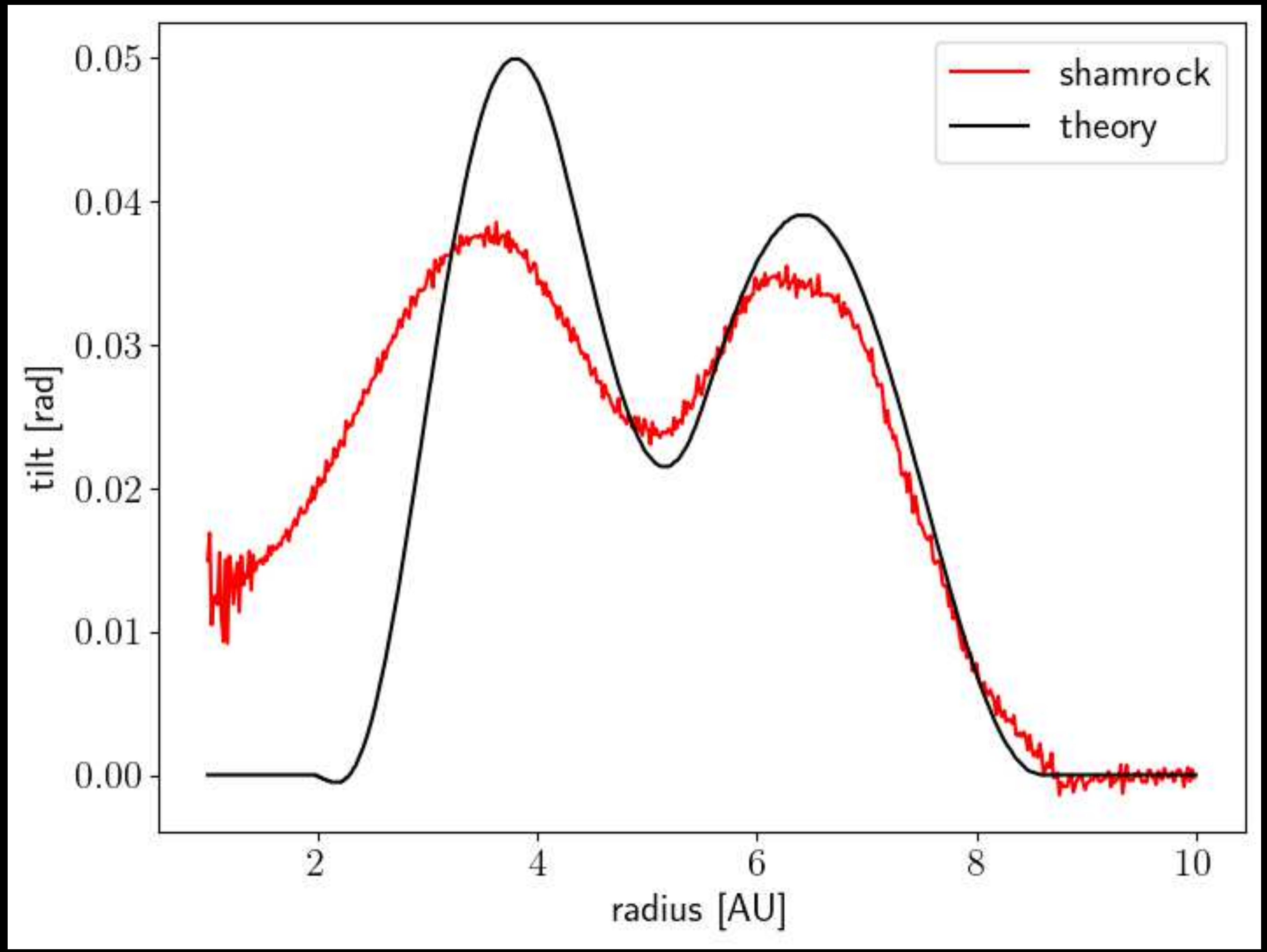


Which ingredients to simulate a disc?

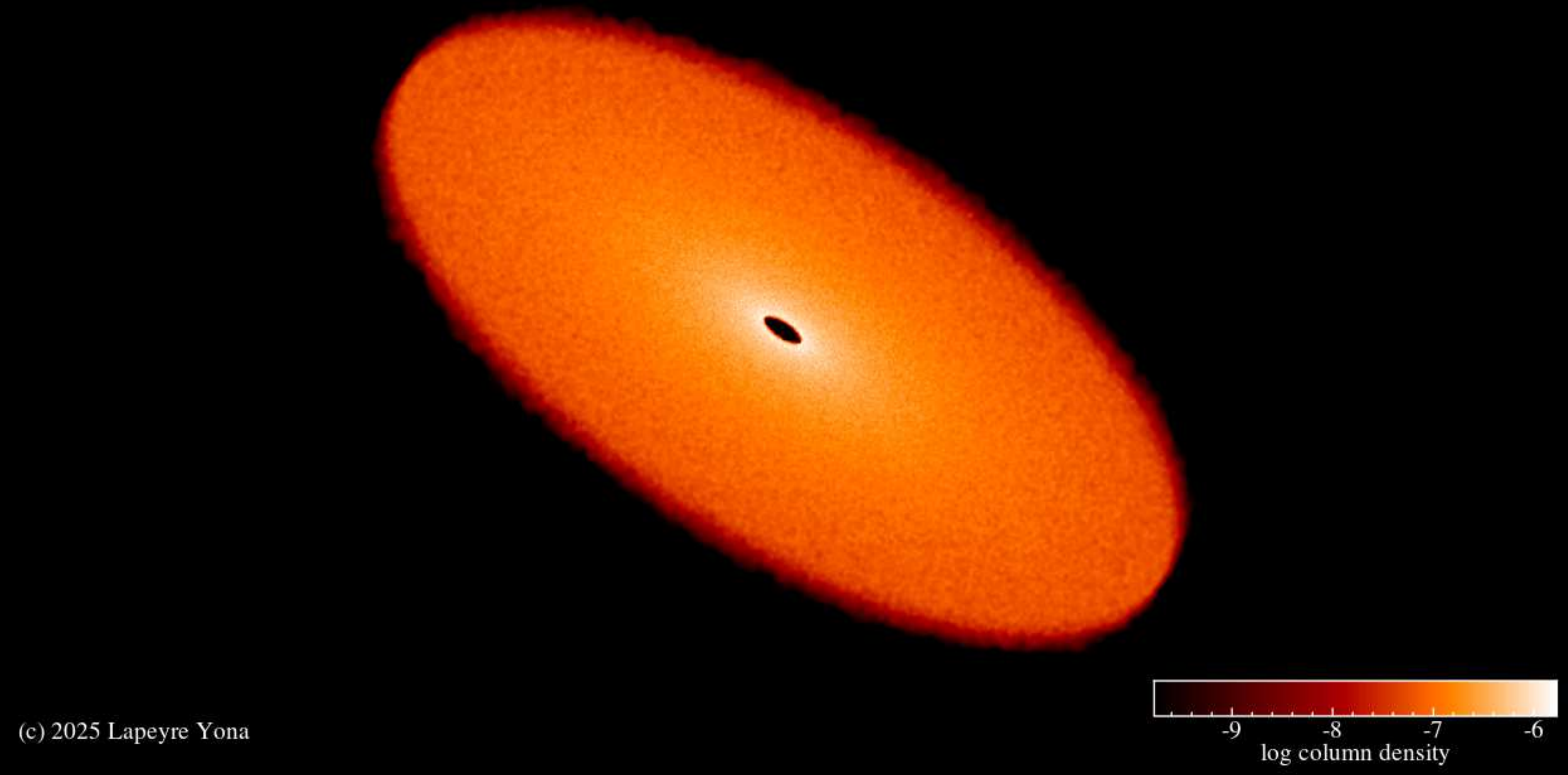
Disc setup:	✓ Monte-Carlo generator + warp modifier
Pressure prescription:	✓ Adiabatic, isothermal, locally isothermal (LP07), Locally isothermal (Farris 2014)
Viscosity prescription:	✓ Constant, MM97, CD10, disc
External forces:	✓ Point mass, Lense-Thirring

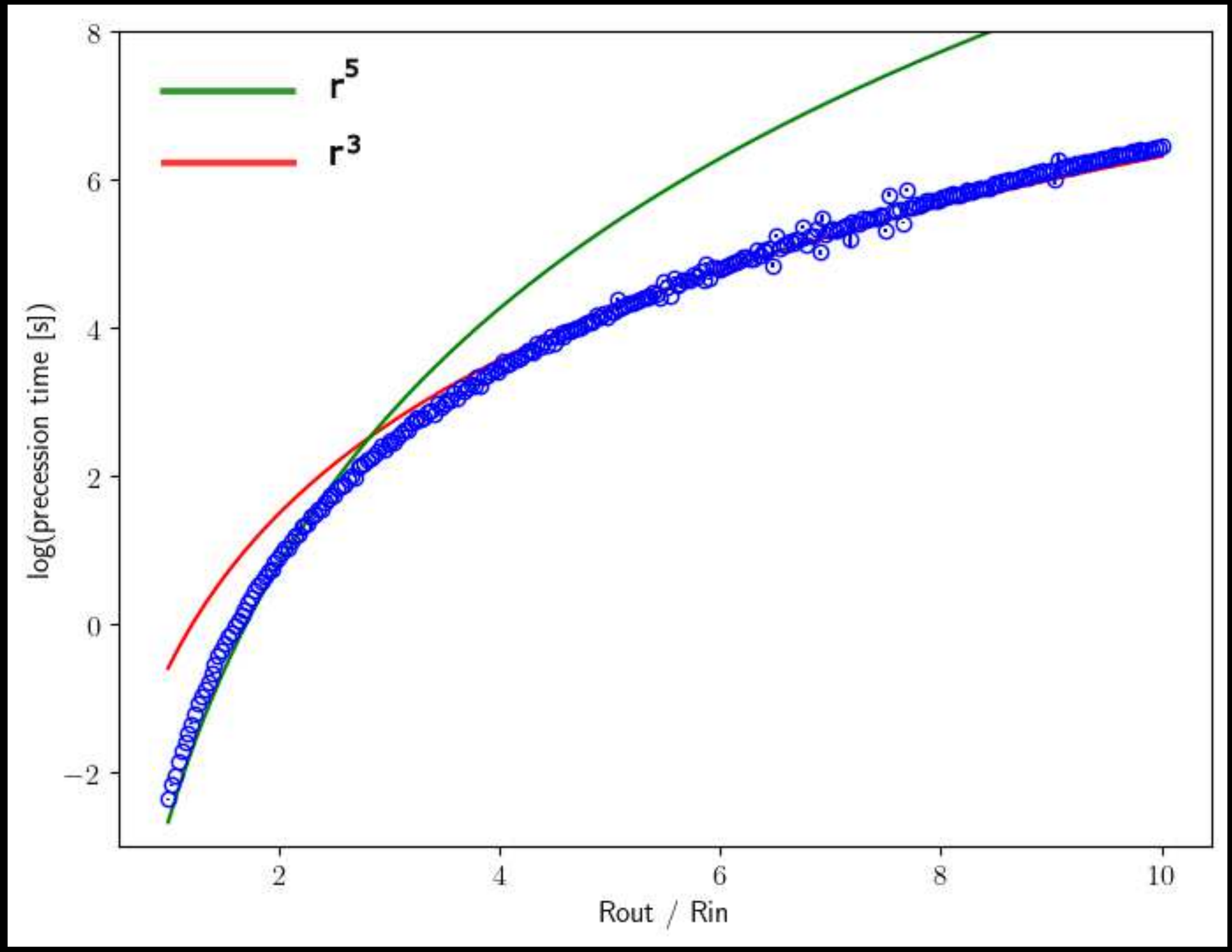
Test: wave-like regime





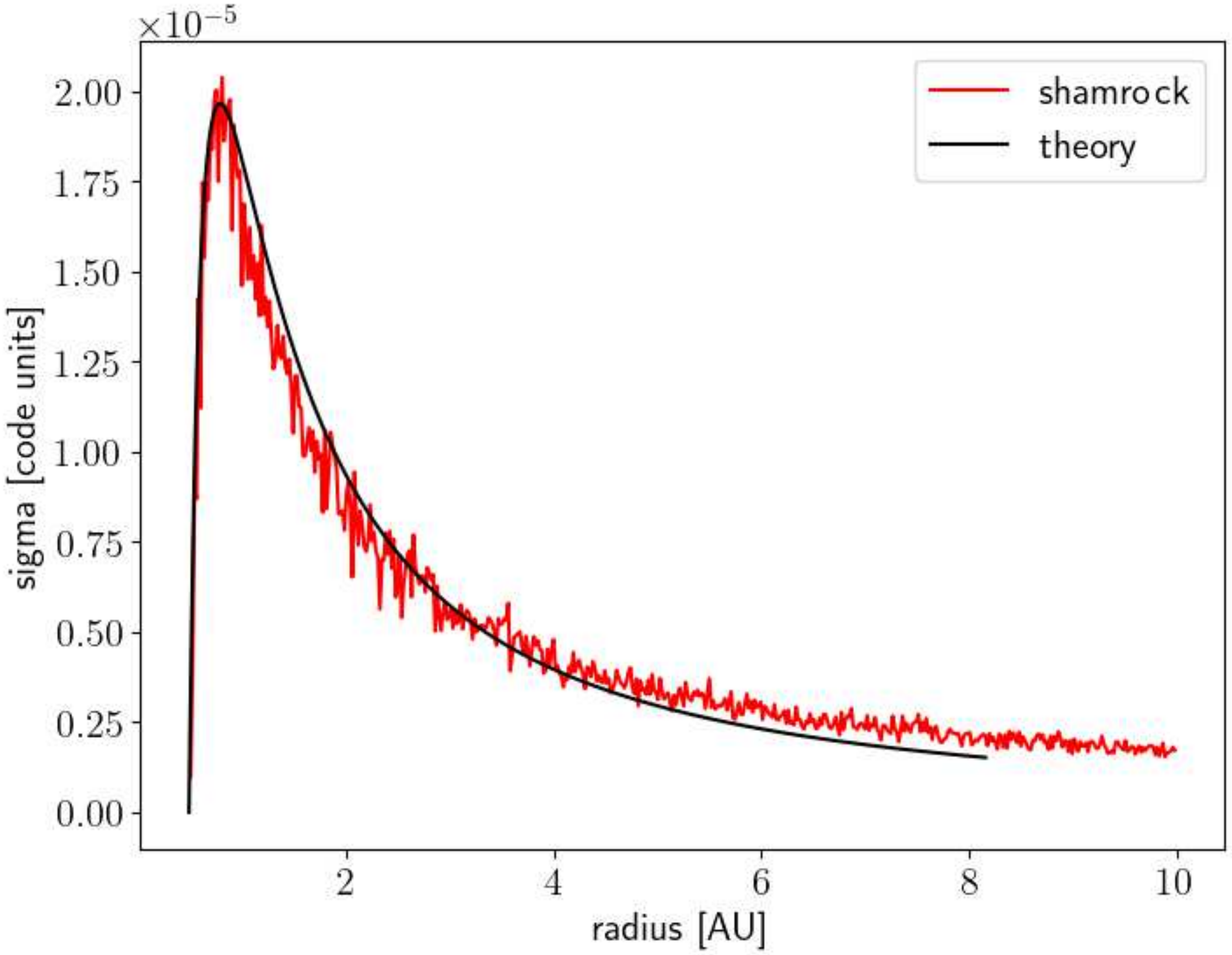
Test: Lense-Thirring precession





Test: diffusive regime

$$\frac{\partial \mathbf{L}}{\partial t} = \frac{3}{R}\frac{\partial}{\partial R}\left[\frac{R^{1/2}}{\Sigma}\frac{\partial}{\partial R}\left(\nu_1 \Sigma R^{1/2}\right)\mathbf{L}\right]$$
$$+\frac{1}{R}\frac{\partial}{\partial R}\left[\left(\nu_2 R^2 \left|\frac{\partial \mathbf{l}}{\partial R}\right|^2 - \frac{3}{2}\nu_1\right)\mathbf{L}\right]$$
$$+\frac{1}{R}\frac{\partial}{\partial R}\left(\frac{1}{2}\nu_2 R |\mathbf{L}| \frac{\partial \mathbf{l}}{\partial R}\right)$$



Bardeen-Petterson effect on a 100M particle disc

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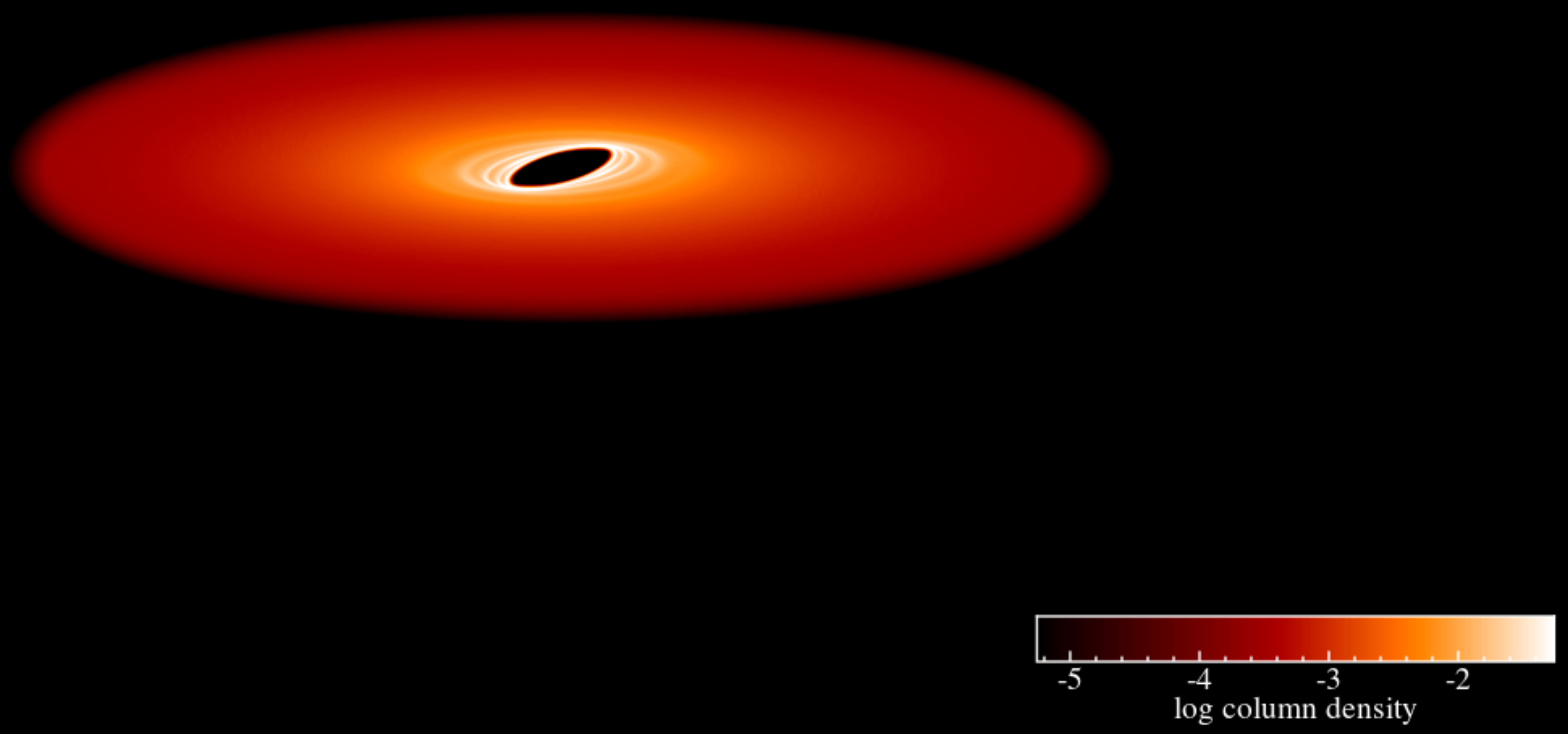


Ideal MHD solver in Shamrock

Same method as in Phantom: constrained hyperbolic-parabolic divergence cleaning

$$\frac{d\mathbf{B}}{dt} = -\mathbf{B}(\nabla \cdot \mathbf{v}) + (\mathbf{B} \cdot \nabla)\mathbf{v} - \nabla \psi$$
$$\frac{d\psi}{dt} = -c_h^2(\nabla \cdot \mathbf{B}) - \frac{\psi}{\tau}$$

Before flagged as production-ready: run tests:

3D circularly polarized Alfvén wave

Shock tube

Blast wave

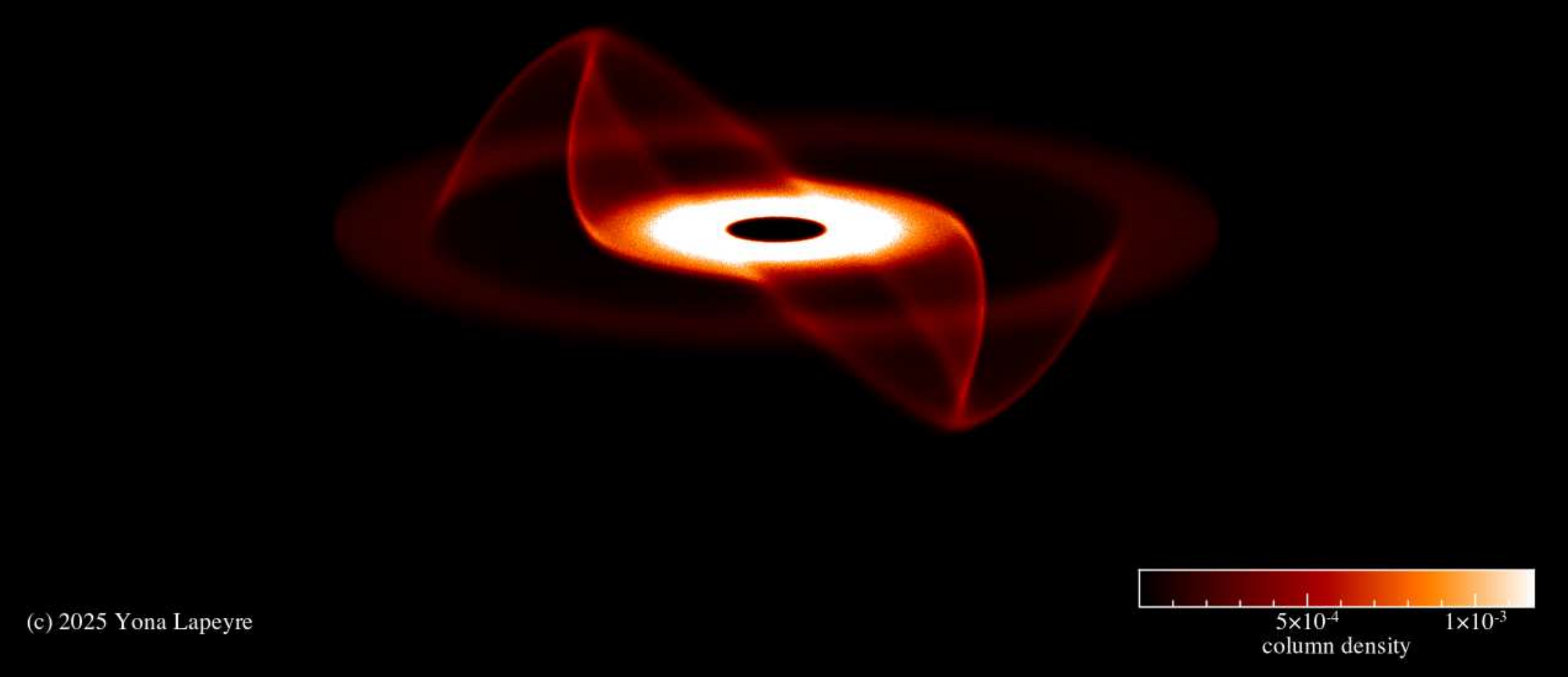
Ad break!

A friendly interface

```python
import shamrock

model = shamrock.get_Model_SPH(context = ctx, vector_type = "f64_3",sph_kernel = "M6")

cfg.set_artif_viscosity_ConstantDisc(alpha_u=1, alpha_AV=1, beta_AV=2)
cfg.set_eos_isothermal(cs=1)
cfg.set_units(si)

gen_disc = setup.make_generator_disc_mc(
        part_mass = pmass,
        disc_mass = disc_mass,
        r_in = rin,
        r_out = rout,
        sigma_profile = sigma_profile,
        H_profile = H_profile,
        rot_profile = rot_profile,
        cs_profile = cs_profile,
        random_seed = 666
    )

warp = setup.warp_disc(setup2warp= gen_disc, Rwarp= Rwarp, Hwarp=Hwarp, inclination=inclination, posangle=0.)
setup.apply_setup(warp)

while present_t < t_target:
    present_t += dt
    model.evolve_until(present_t)
```

Friendly visualization tools

Splash

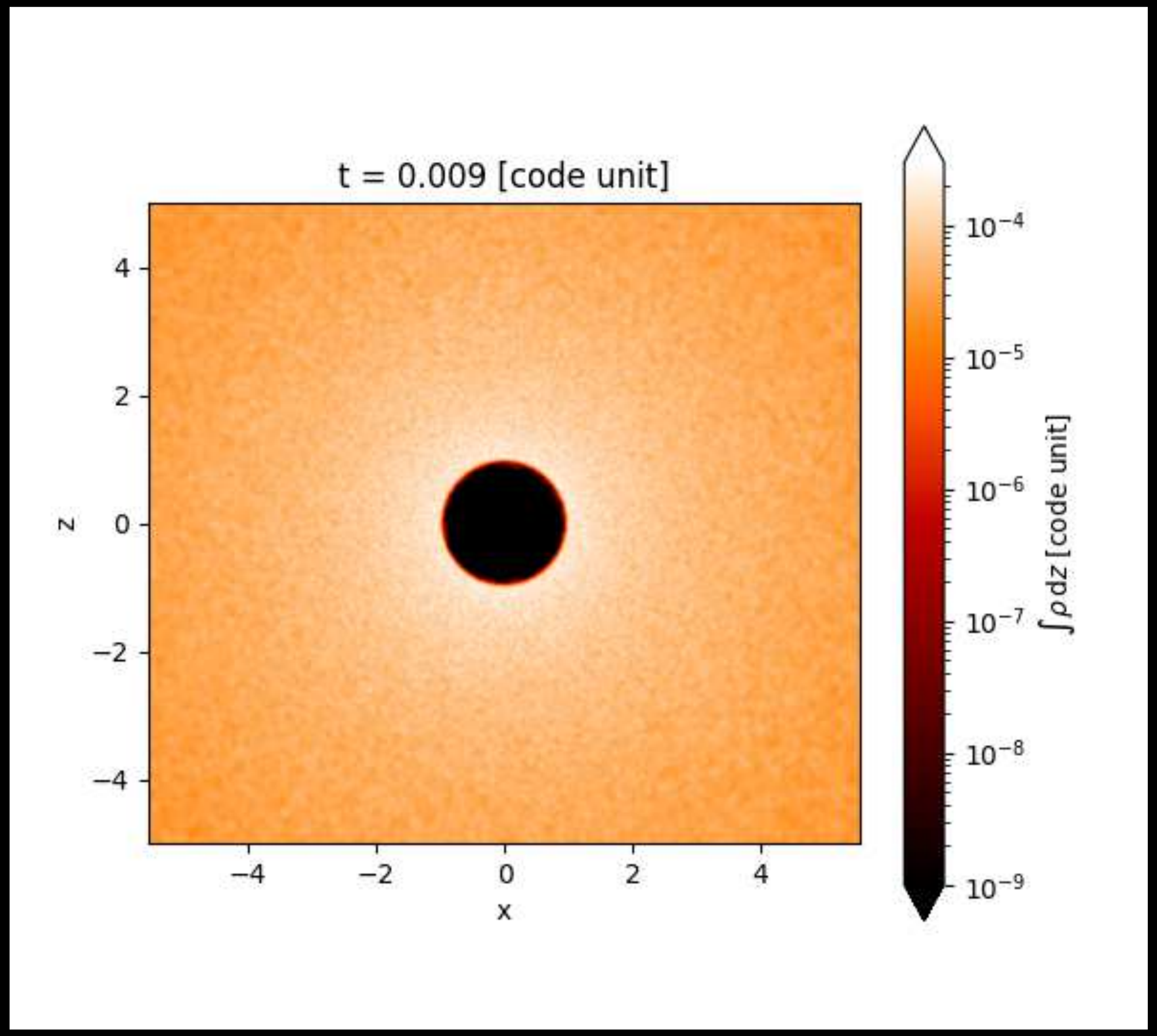


Saracen

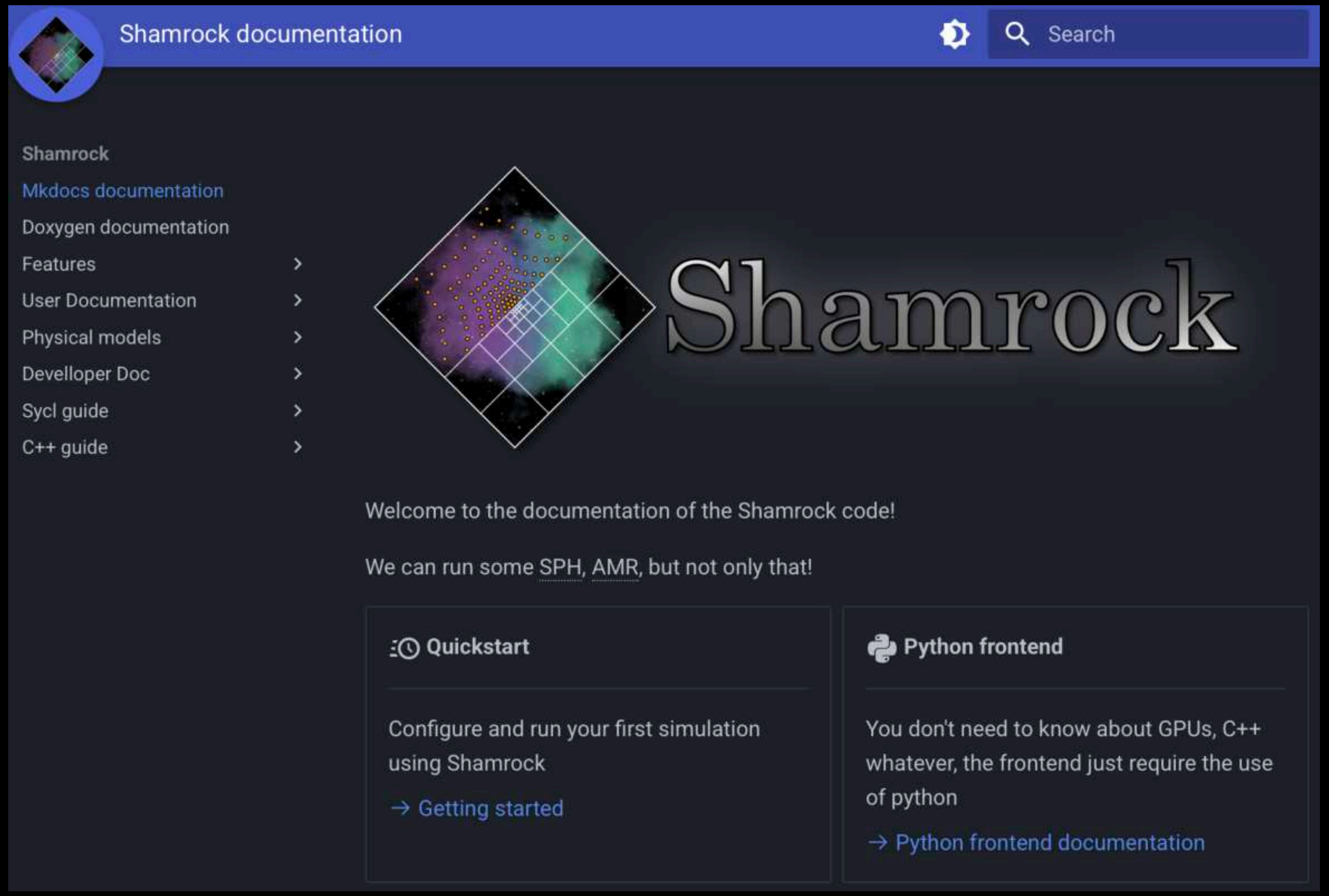
```python
sdf = read_shamrock("disc_0000.sham")
sdf.describe()
```

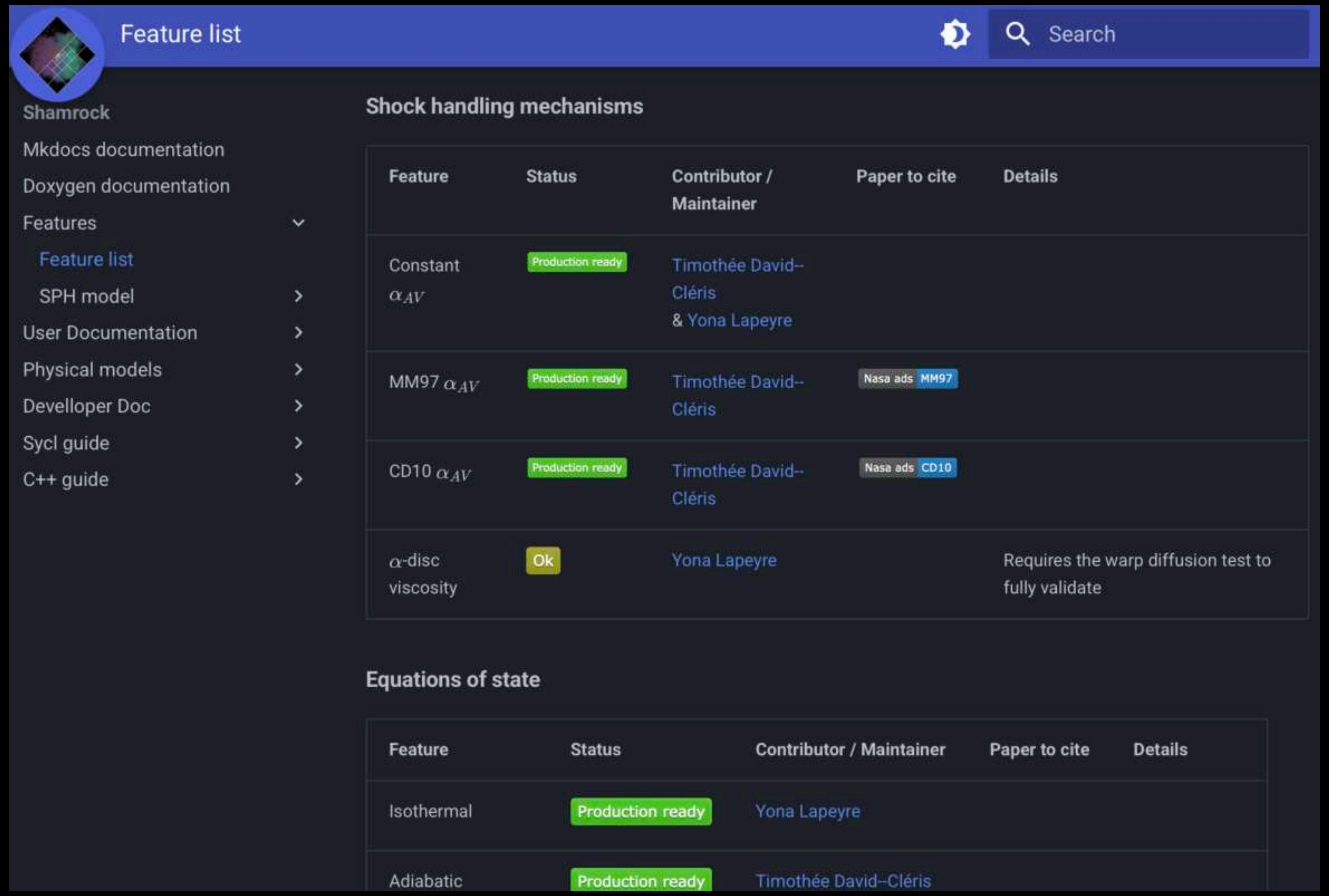
	x	y	z
count	964434.000000	964434.000000	964434.000000
mean	0.003748	0.011469	0.000054
std	4.497603	4.495797	0.327262
min	-16.072591	-16.404245	-2.319049
25%	-3.142610	-3.131178	-0.174549
50%	-0.000939	0.010260	0.000145
75%	3.144735	3.156347	0.174759
max	15.934542	15.972999	2.413390

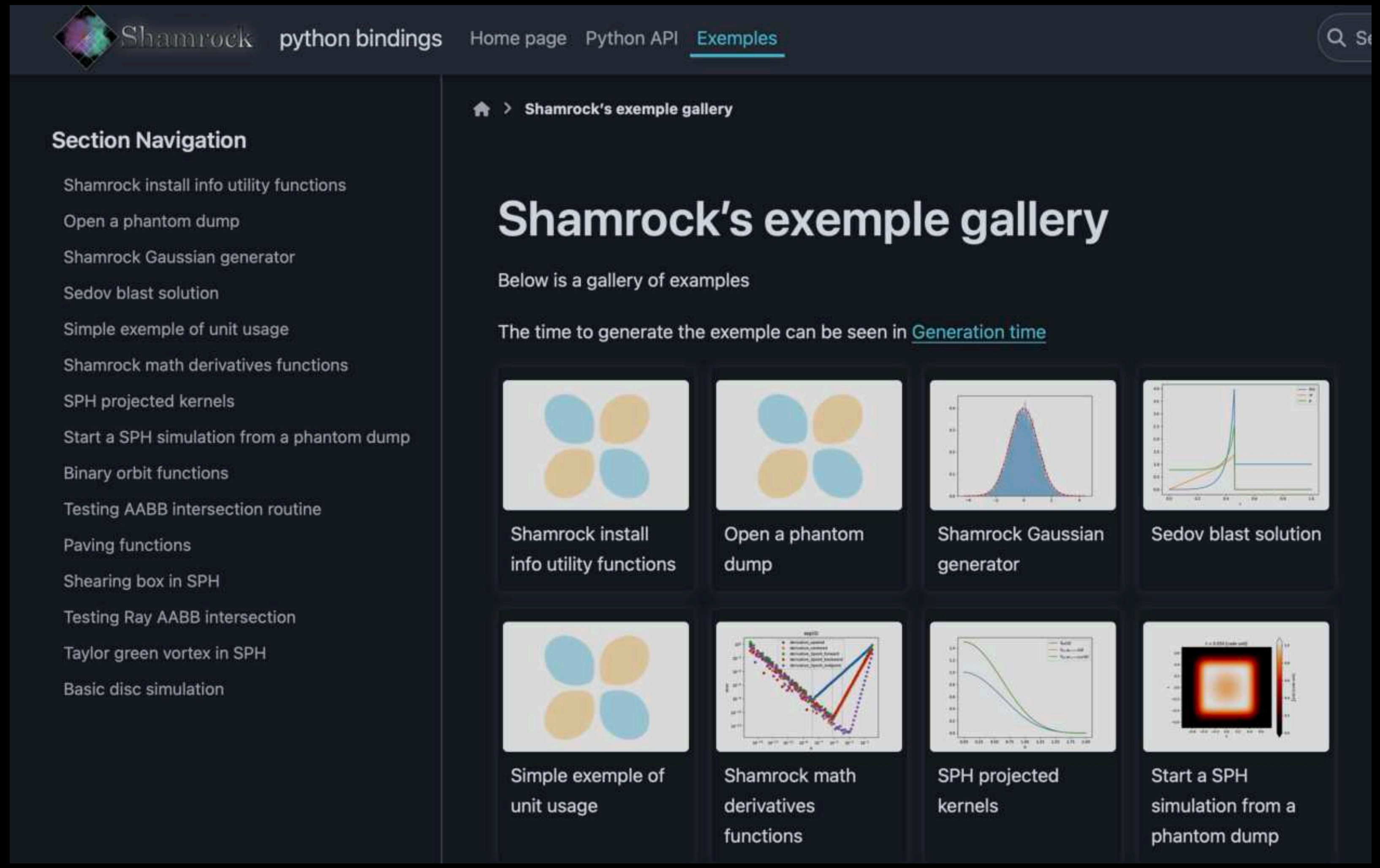
Native



A very friendly team of developers









Conclusion

—> (almost) production ready disc setup!

—> (ideal) MHD solver still in testing phase.

—> Shamrock currently use for physics (Bardeen-Petterson simulations)

Happy to help you simulation your favorite disc with Shamrock!

Thank you!