

Towards exascale simulations with Shamrock

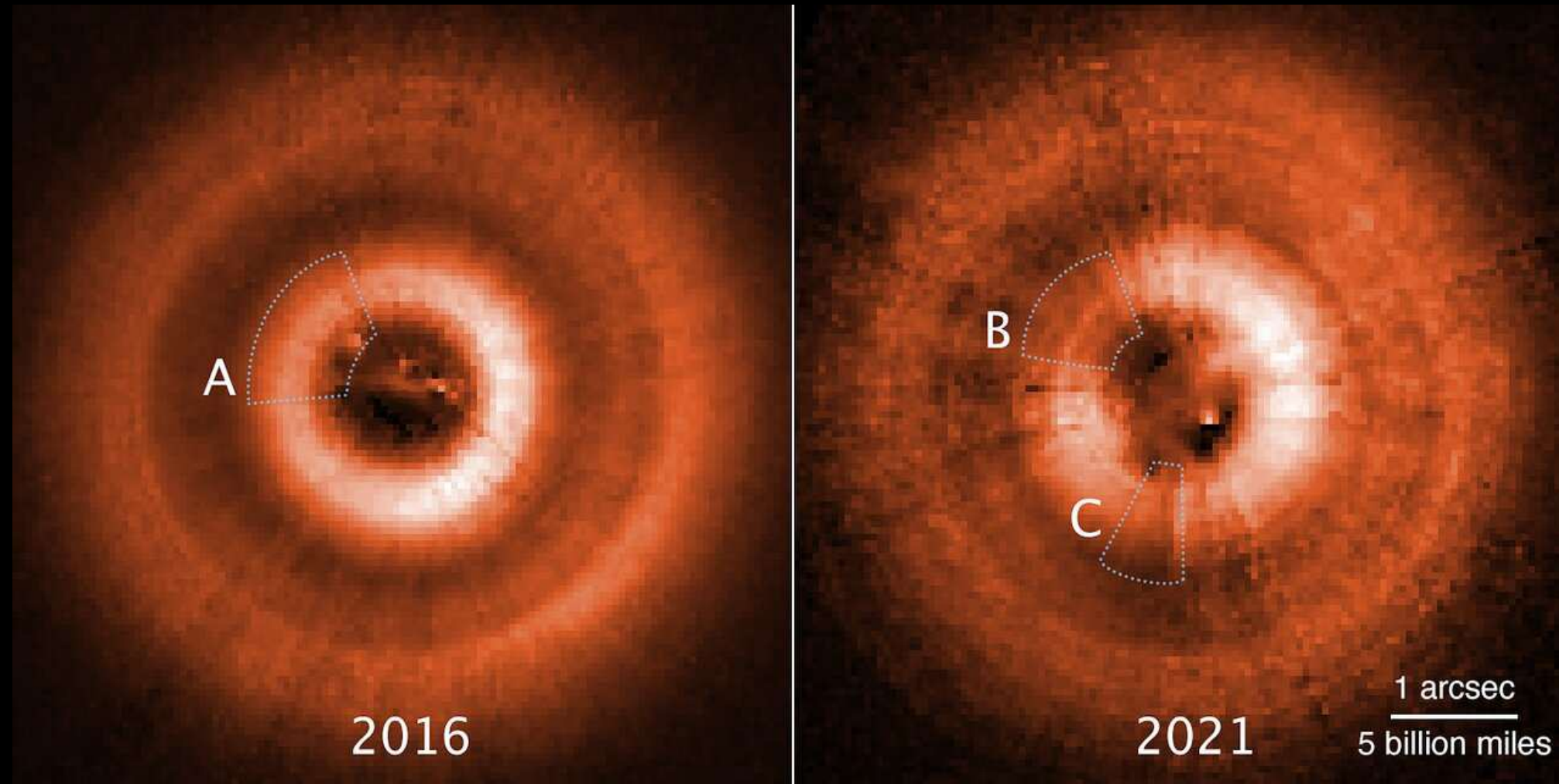
Yona Lapeyre-Belaredj



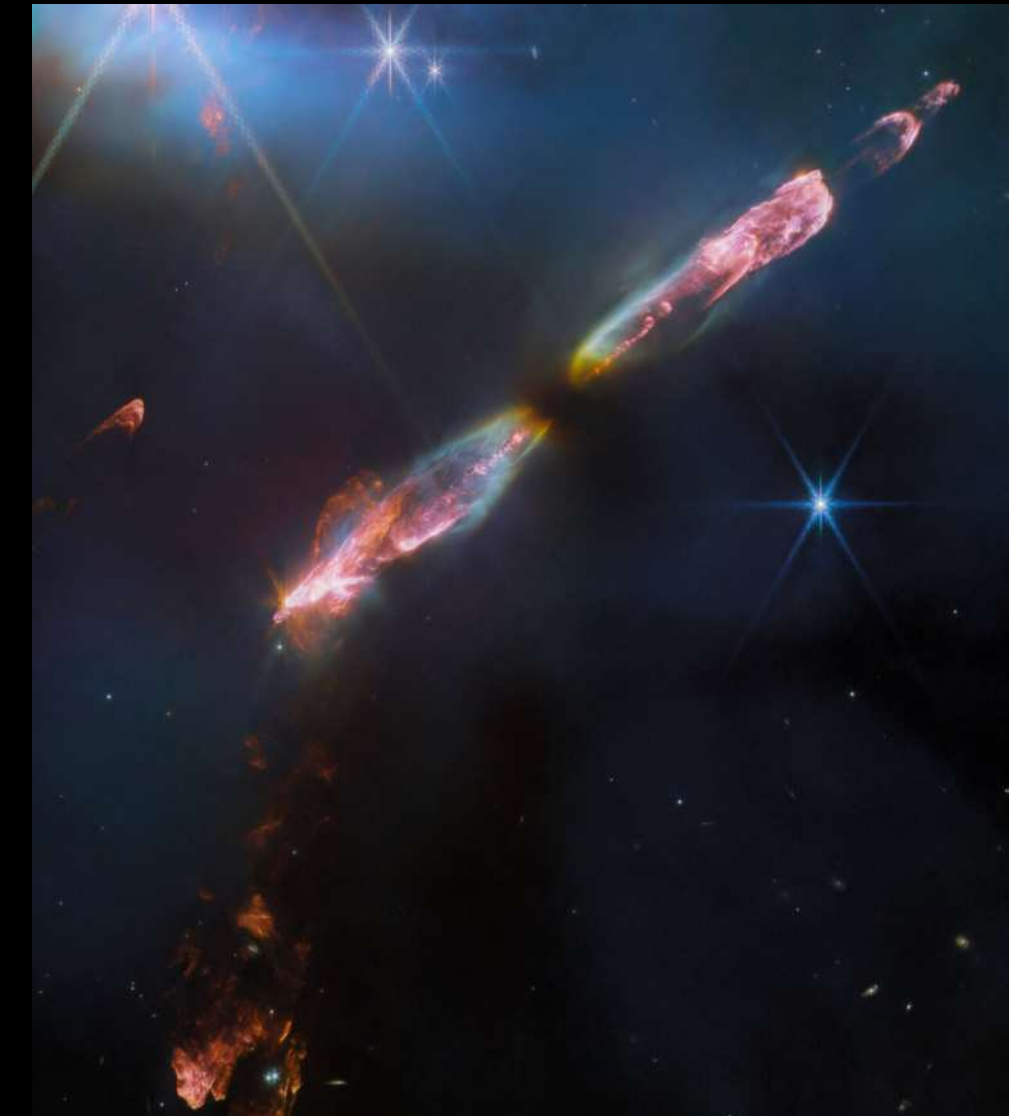
CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON



Discs with complex geometries



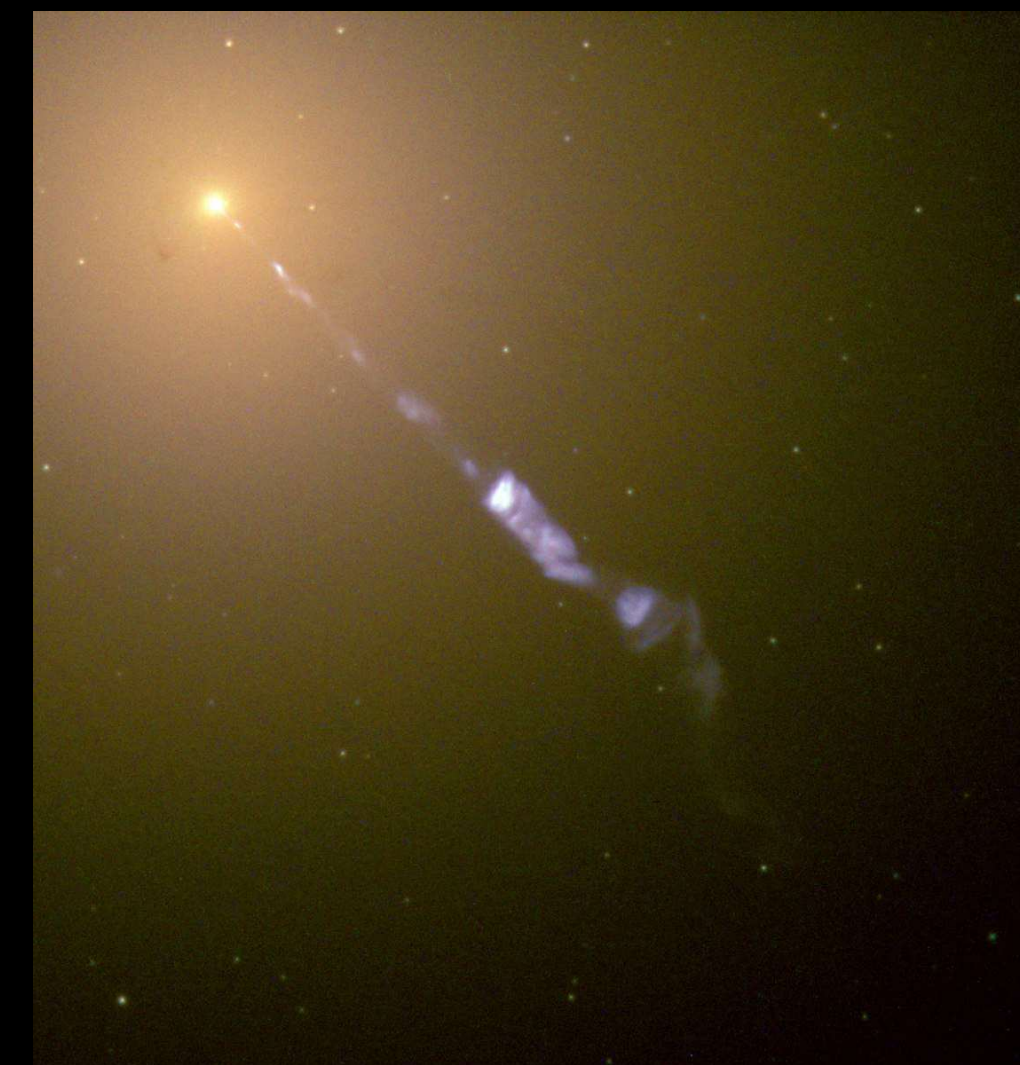
TW Hydrae by HST



HH221 by JWST

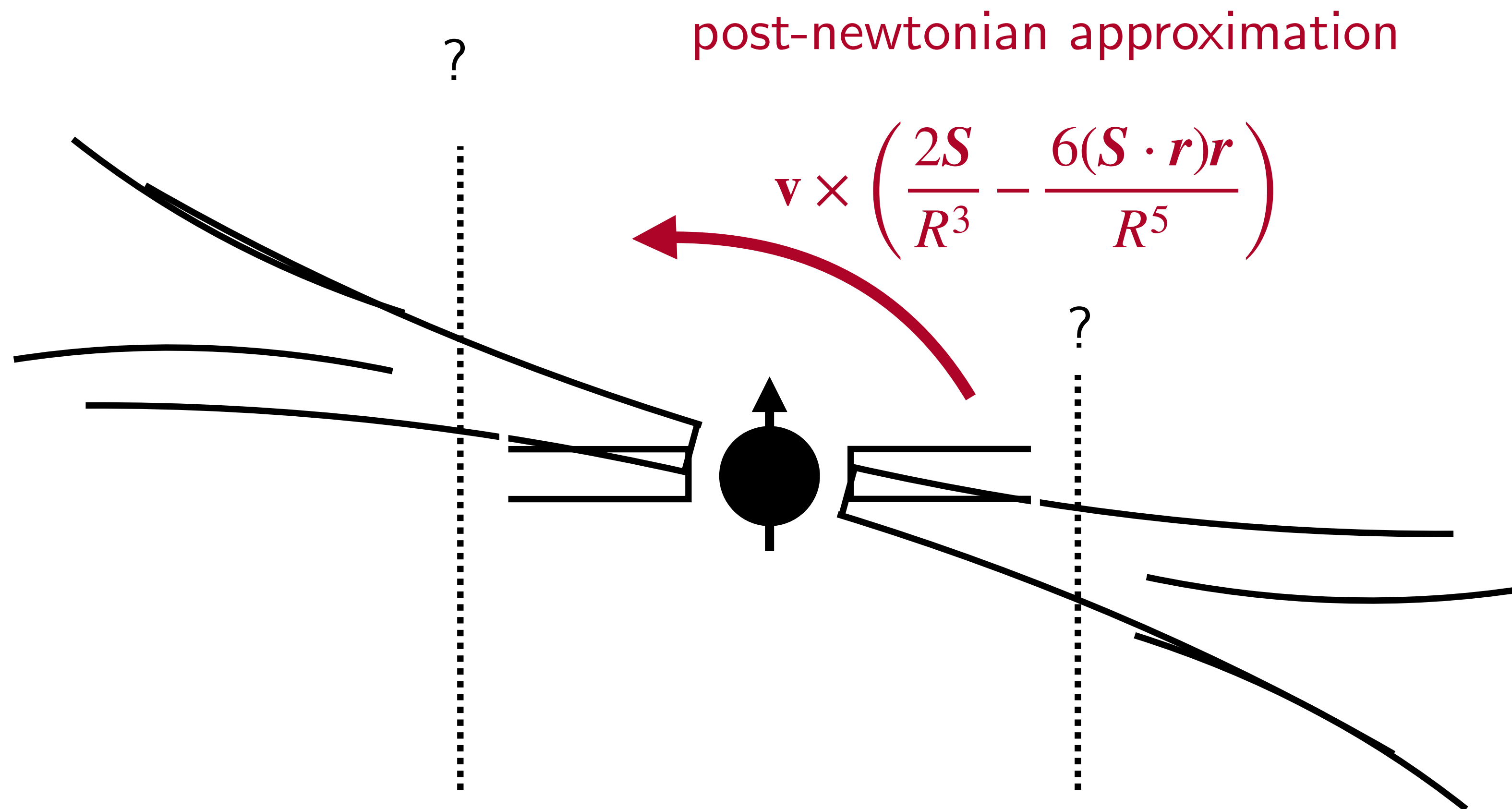


M106 by HST



M87 by HST

The Bardeen-Petterson effect



SPH Simulations: Nealon et. al. (2015)



100,000 particles

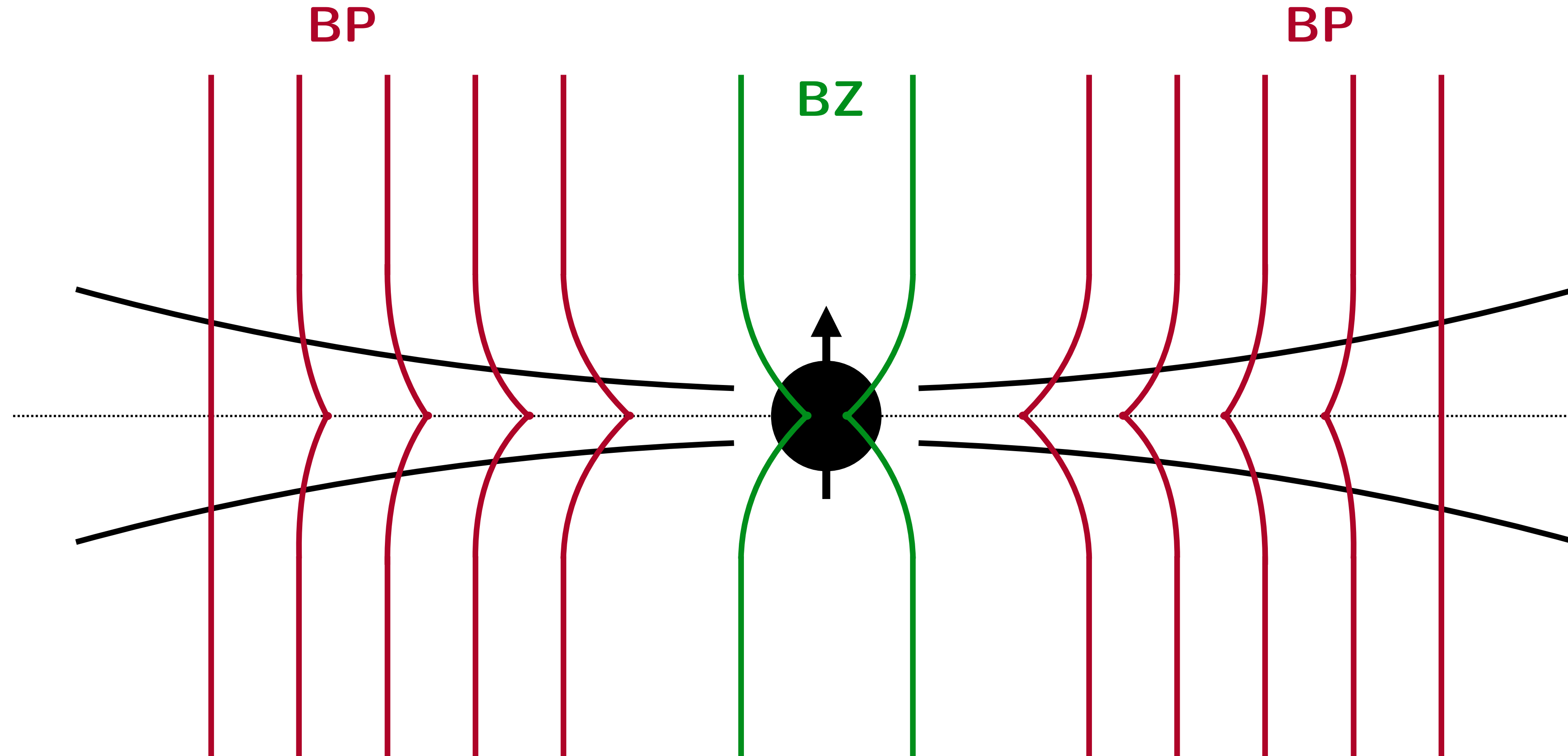
1 million particles

10 million particles

- > When does the disc break?
- > At what radii?
- > Observational signature?
- > accretion rate?
- > instabilities at very small scales?

We need resolution!!

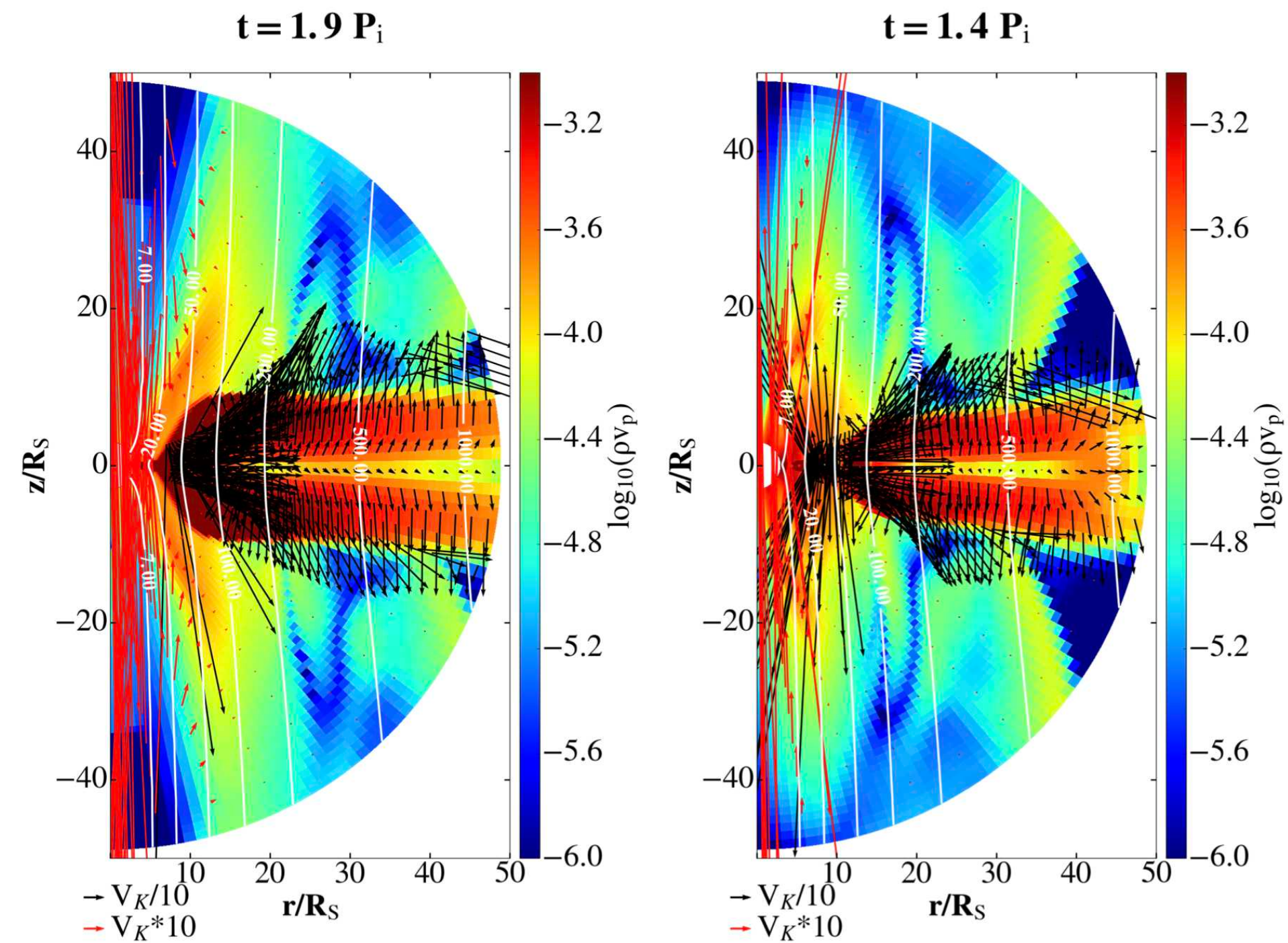
Formation of jets (from black holes)



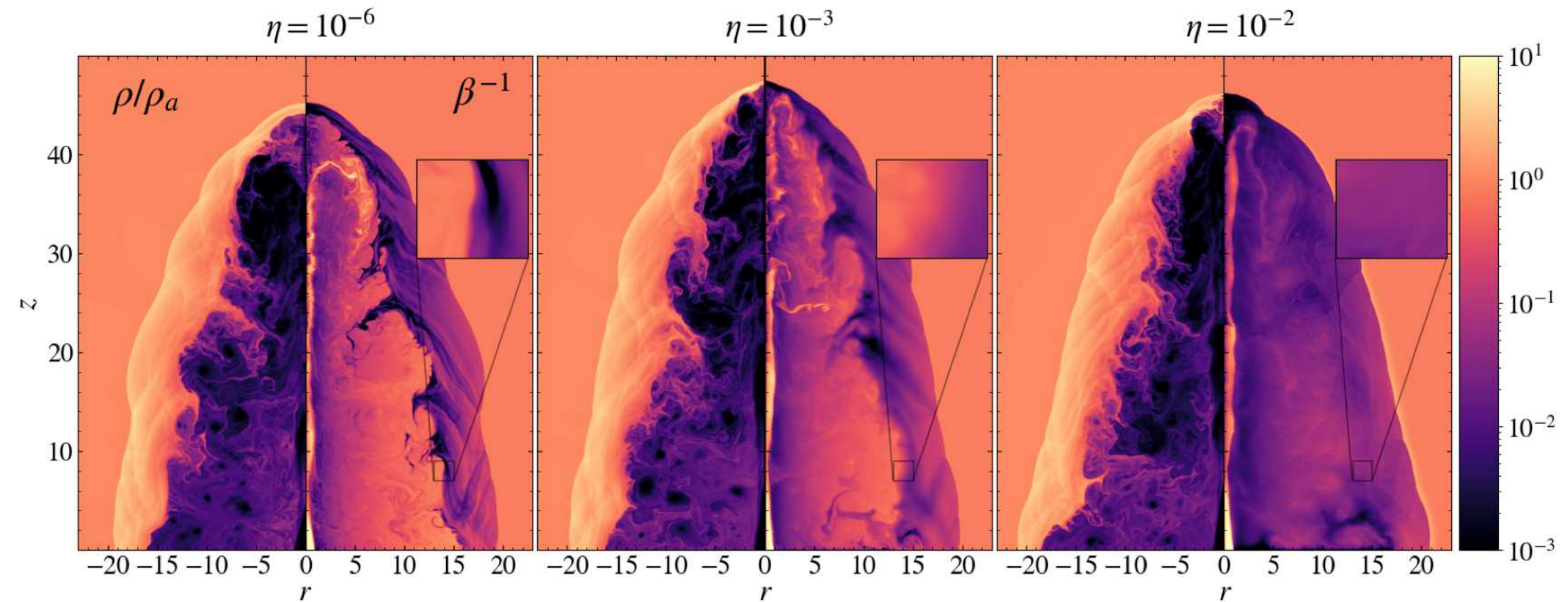
Blandford and Znajek (1977)

Blandford and Payne (1982)

Example: grid simulation using Pluto

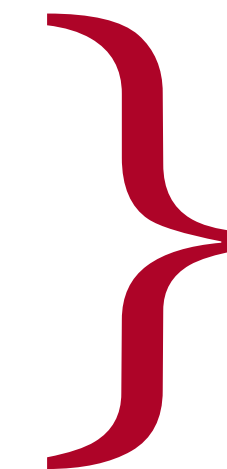


M. Jabloski, A. Kotek, M. Cemeljic, W. Kluzniak
(2020)



G. Maia et. Al. 2023

- > Jet stability and collimation?
- > Influence of magnetic reconnection? Turbulence?

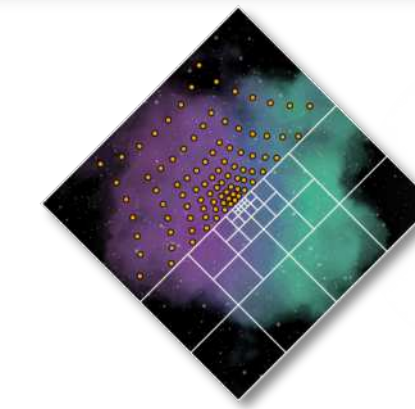


We need resolution!!

Shamrock: (magneto-)hydro code for exascale architecture



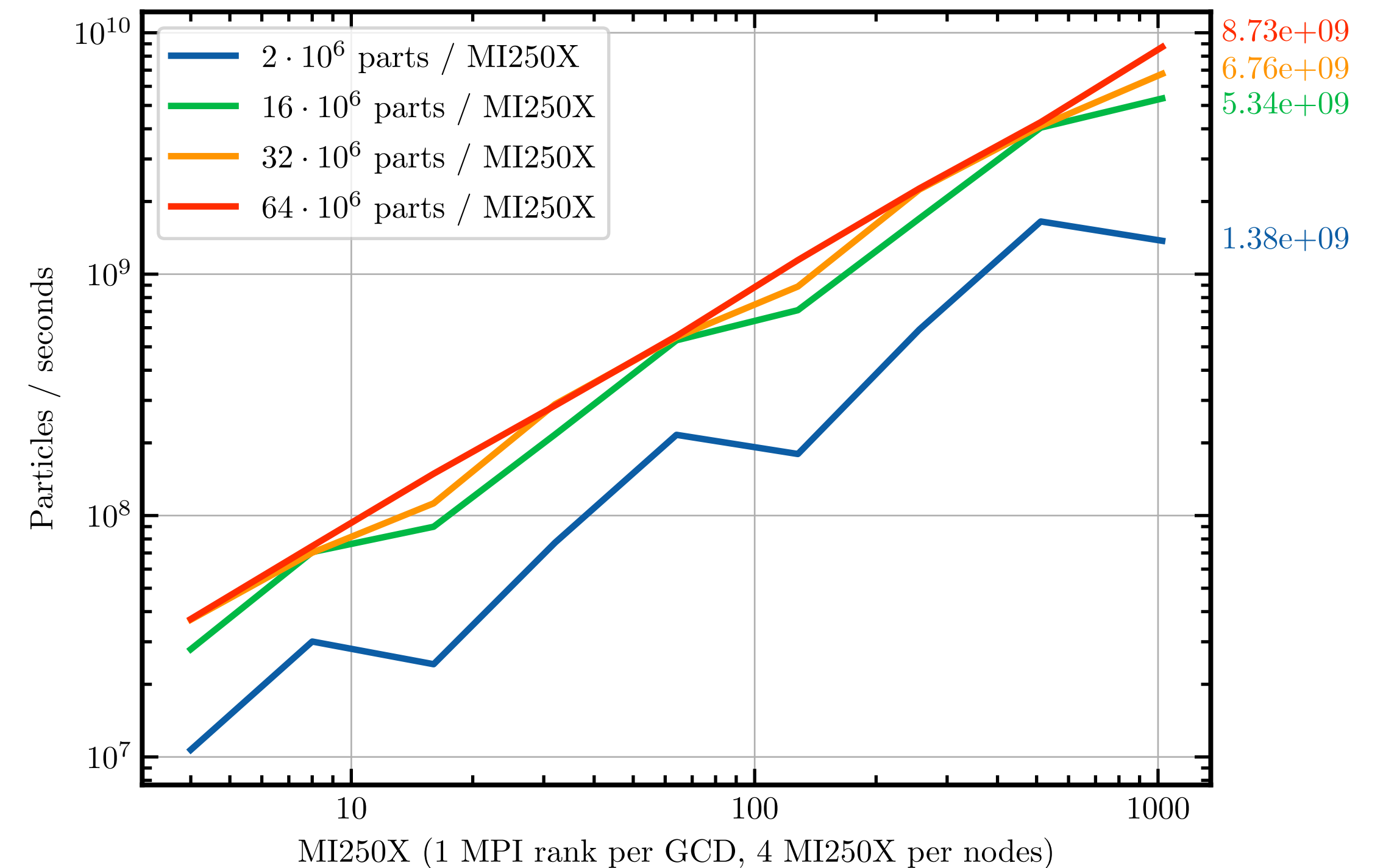
El Capitan
Peak 2.74 exaFlops/s



Shamrock

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

David--Cl  ris, 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)

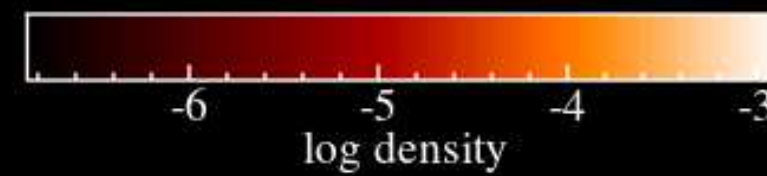
Viscosity prescription:

✓ Constant, MM97, CD10, disc

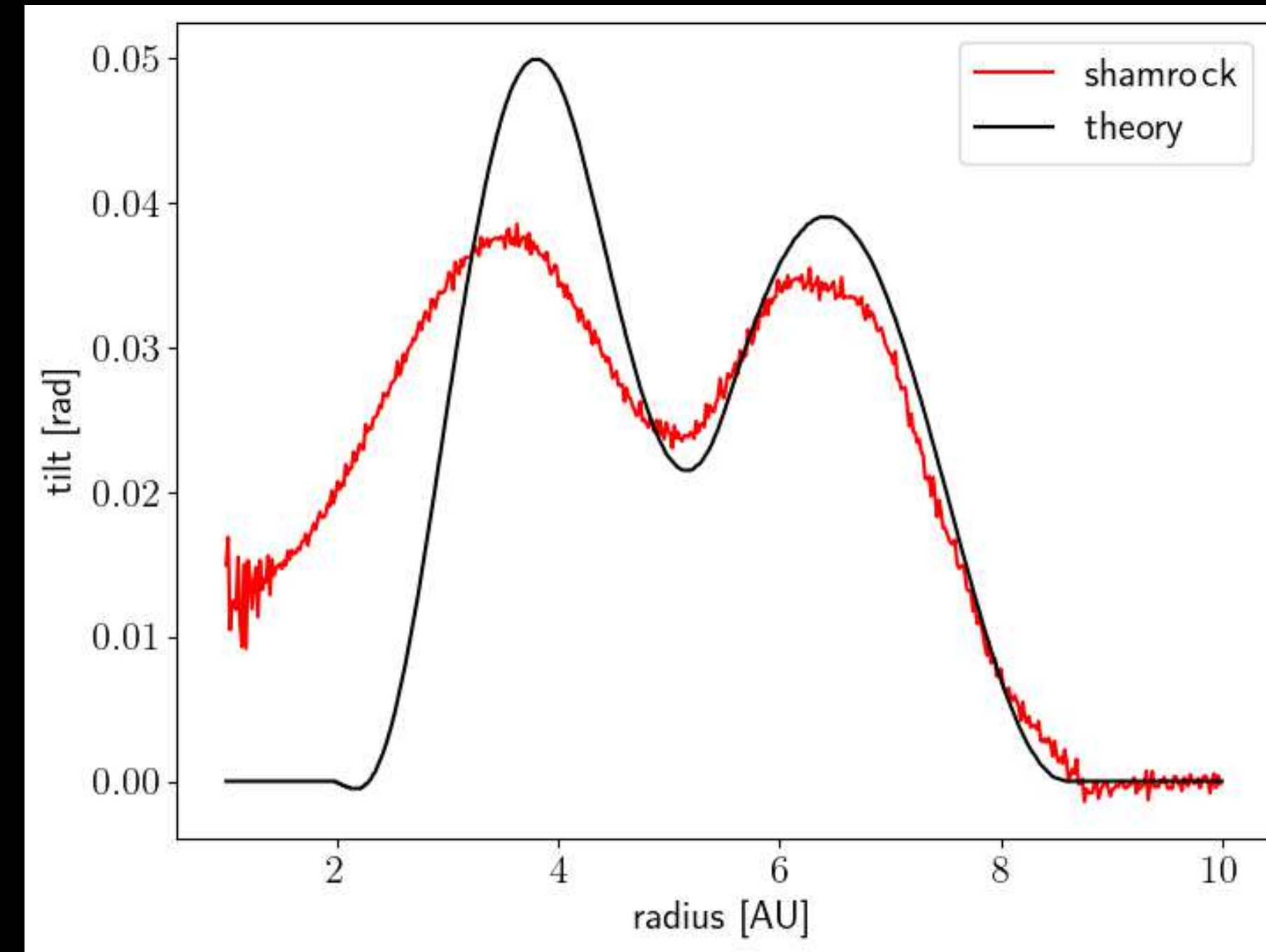
External forces:

✓ Point mass, Lense-Thirring

Test: wave-like regime



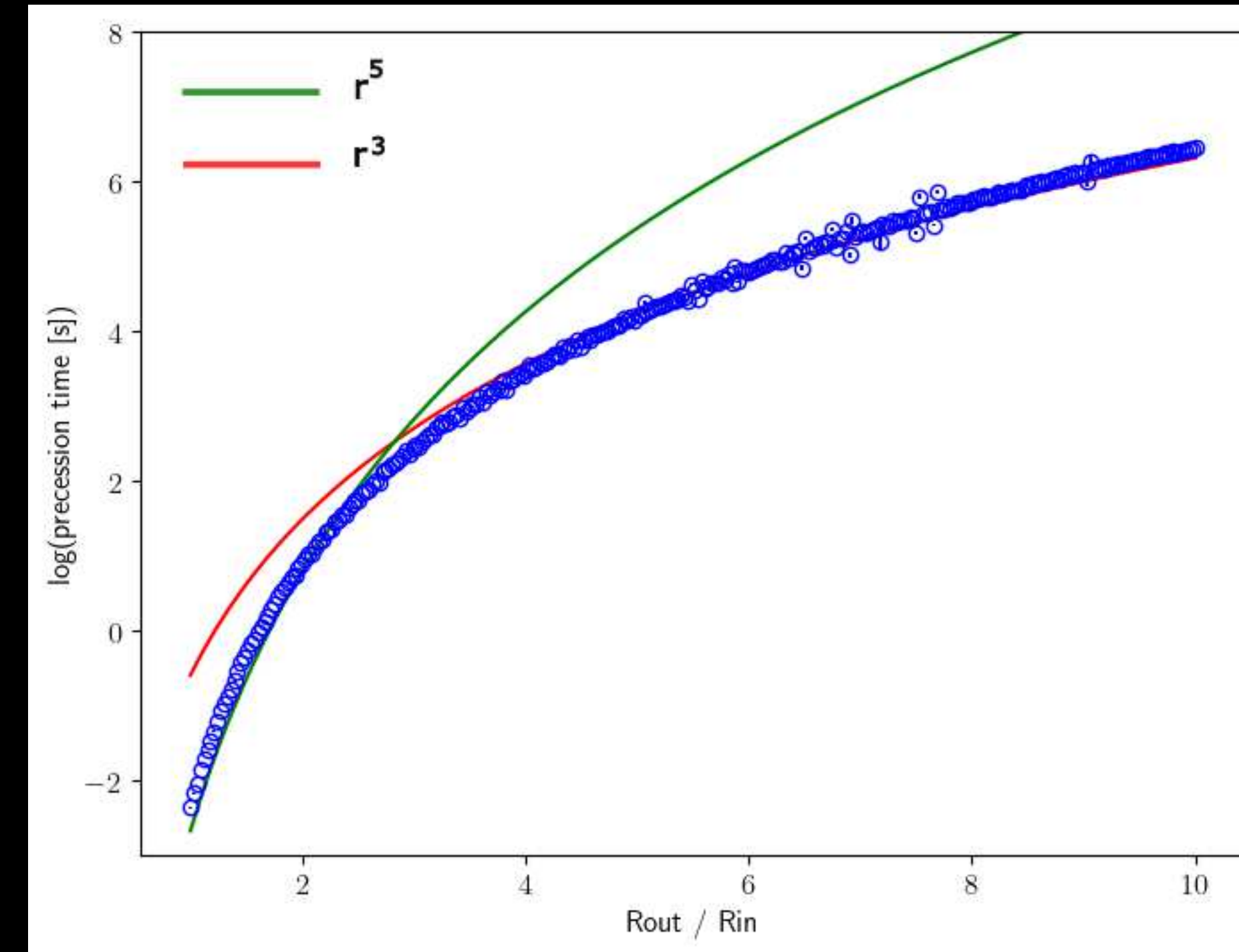
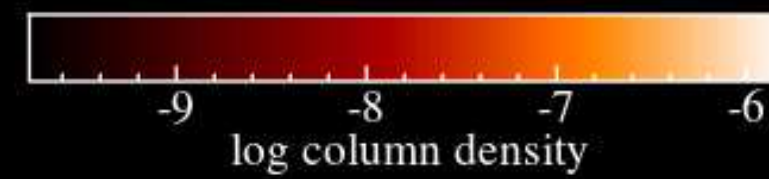
(c) 2025 Lapeyre Yona



Test: Lense-Thirring precession

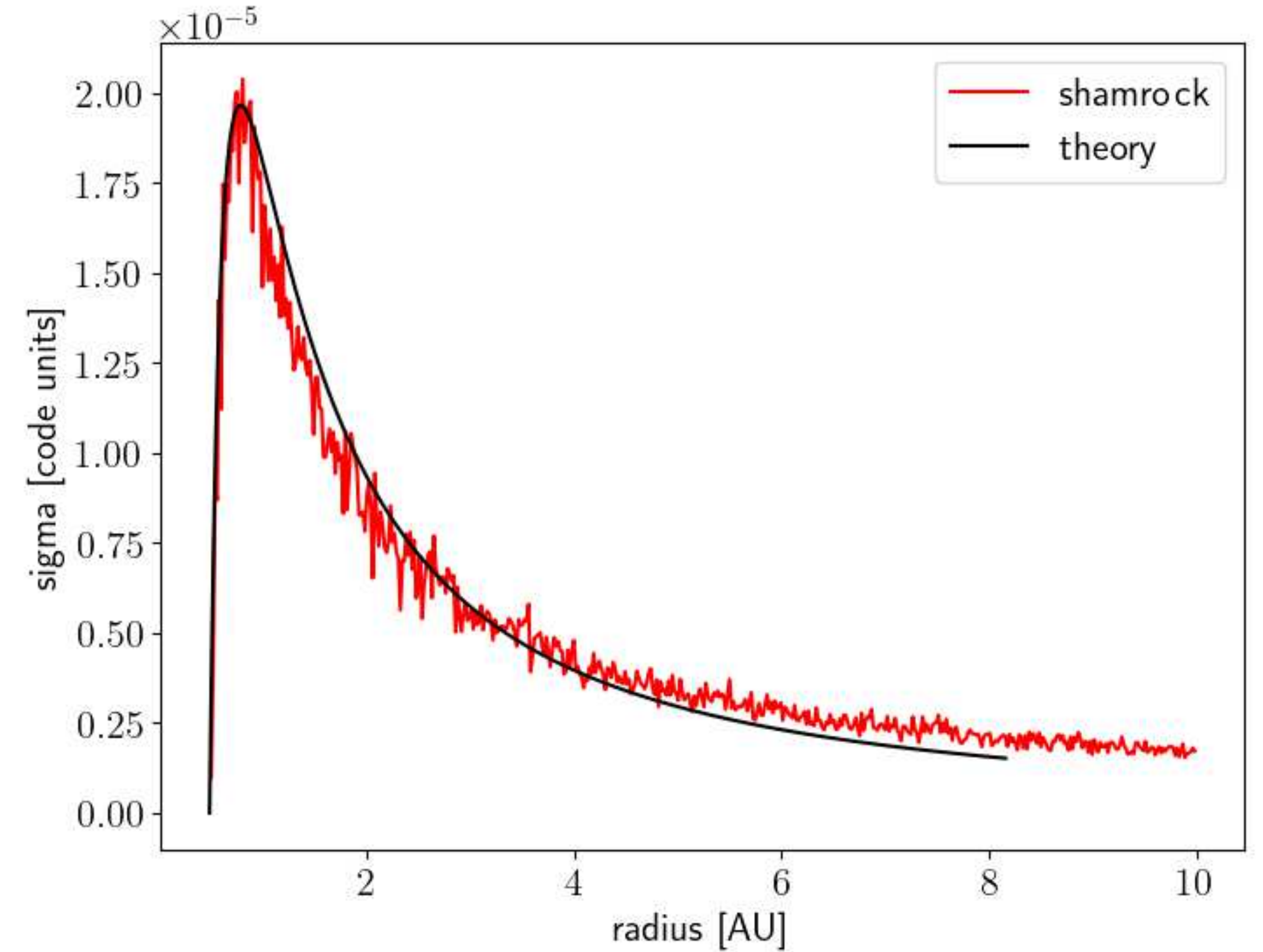


(c) 2025 Lapeyre Yona

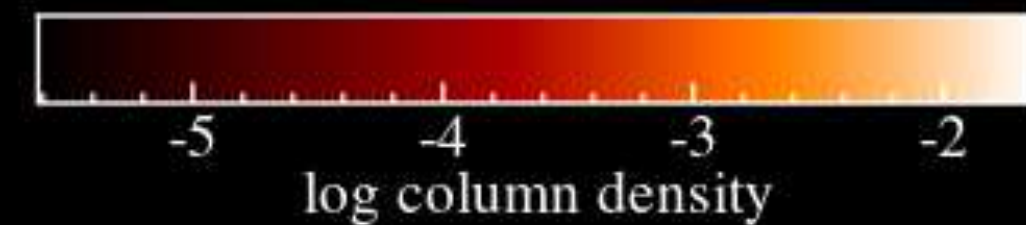


Test: diffusive regime

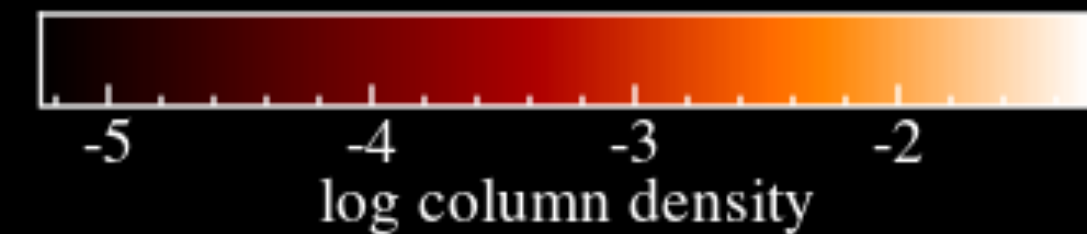
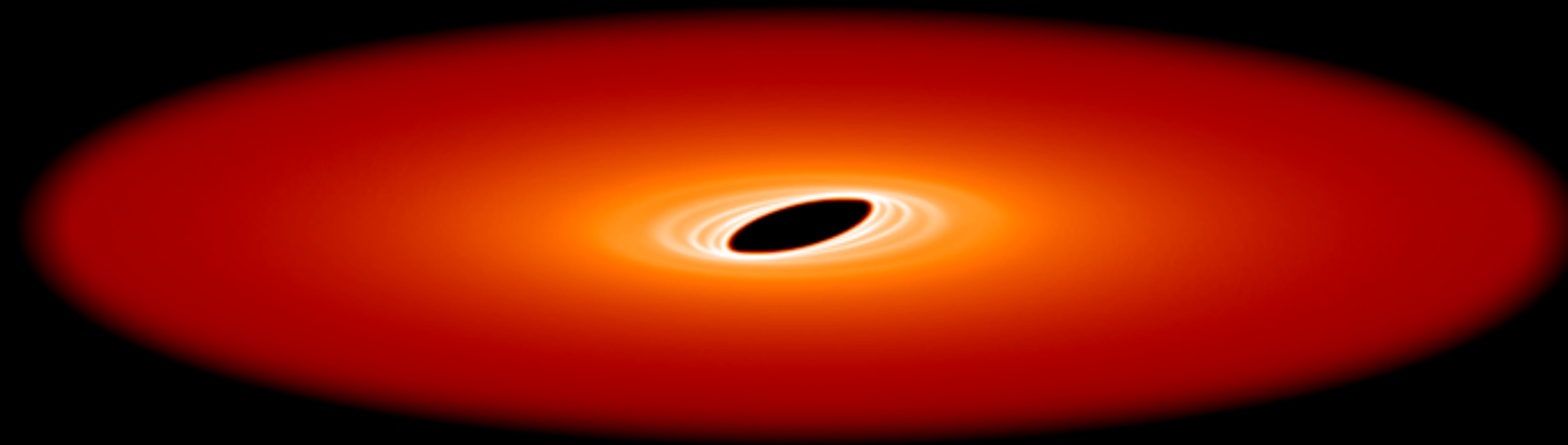
$$\begin{aligned}\frac{\partial \mathbf{L}}{\partial t} = & \frac{3}{R} \frac{\partial}{\partial R} \left[\frac{R^{1/2}}{\Sigma} \frac{\partial}{\partial R} (\nu_1 \Sigma R^{1/2}) \mathbf{L} \right] \\ & + \frac{1}{R} \frac{\partial}{\partial R} \left[\left(\nu_2 R^2 \left| \frac{\partial \mathbf{L}}{\partial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



Bardeen-Petterson effect on a 100M particle disc



Bardeen-Petterson effect on a 100M particle disc



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!

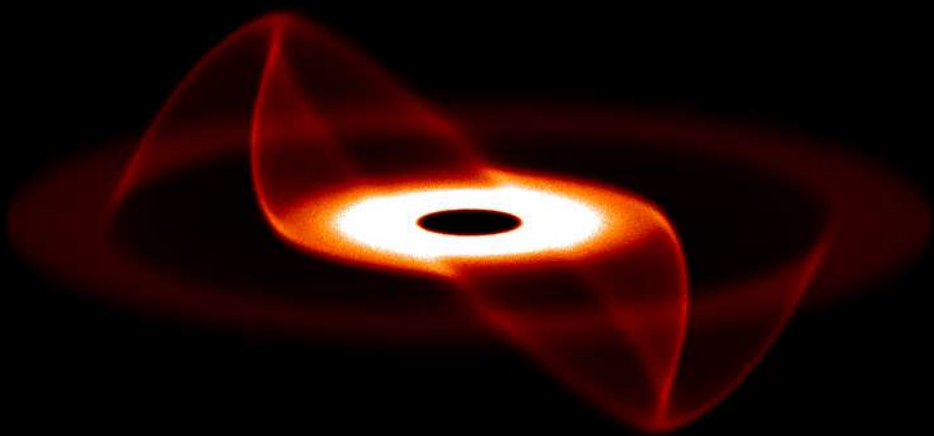
A friendly interface

```
1  import shamrock
2
3  model = shamrock.get_Model_SPH(context = ctx, vector_type = "f64_3", sph_kernel = "M6")
4
5  cfg.set_artif_viscosity_ConstantDisc(alpha_u=1, alpha_AV=1, beta_AV=2)
6  cfg.set_eos_isothermal(cs=1)
7  cfg.set_units(si)
8  💡
9  gen_disc = setup.make_generator_disc_mc(
10      part_mass = pmass,
11      disc_mass = disc_mass,
12      r_in = rin,
13      r_out = rout,
14      sigma_profile = sigma_profile,
15      H_profile = H_profile,
16      rot_profile = rot_profile,
17      cs_profile = cs_profile,
18      random_seed = 666
19  )
20
21  warp = setup.warp_disc(setup2warp= gen_disc, Rwarp= Rwarp, Hwarp=Hwarp, inclination=inclination, posangle=0.)
22  setup.apply_setup(warp)
23
24  while present_t < t_target:
25      present_t += dt
26      model.evolve_until(present_t)
```

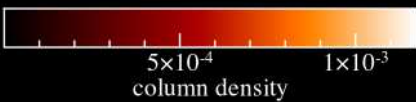
Friendly visualization tools



Splash



(c) 2025 Yona Lapeyre

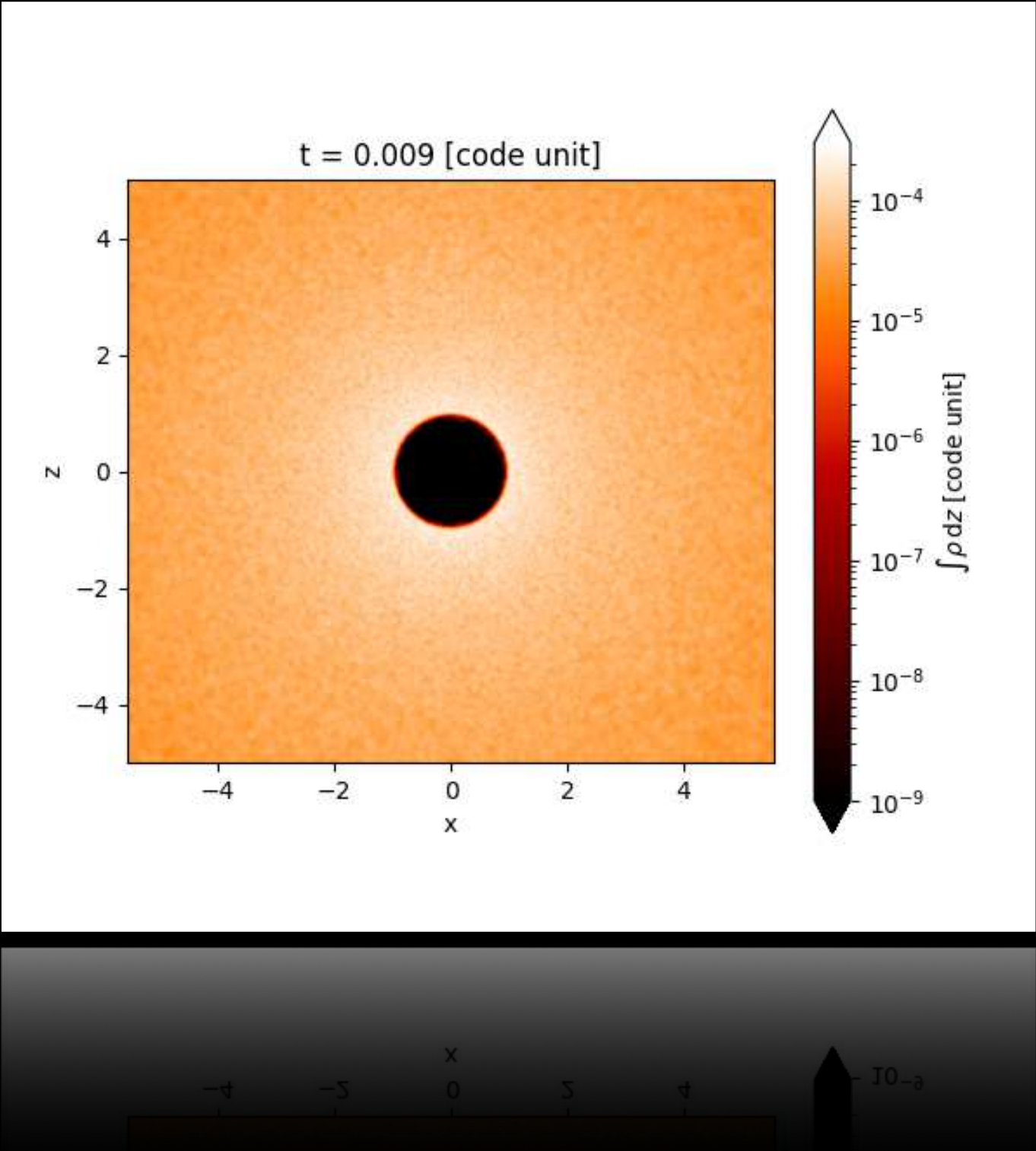


Saracen

```
19 sdf = read_shamrock("disc_0000.sham")
20 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



Shamrock documentation



Search

Shamrock

Mkdocs documentation

Doxygen documentation

Features

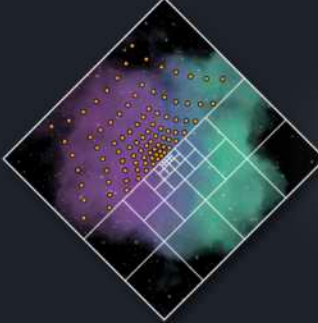
User Documentation

Physical models

Developer Doc

Sycl guide

C++ guide



Shamrock

Welcome to the documentation of the Shamrock code!

We can run some [SPH](#), [AMR](#), but not only that!

 Quickstart

Configure and run your first simulation using Shamrock

[→ Getting started](#)

 Python frontend

You don't need to know about GPUs, C++ whatever, the frontend just require the use of python

[→ Python frontend documentation](#)

Feature list



Search

Shamrock

Mkdocs documentation

Doxygen documentation

Features

Feature list

SPH model

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C++ guide

Shock handling mechanisms

Feature	Status	Contributor / Maintainer	Paper to cite	Details
Constant α_{AV}	Production ready	Timothée David-Cléris & Yona Lapeyre		
MM97 α_{AV}	Production ready	Timothée David-Cléris	Nasa ads MM97	
CD10 α_{AV}	Production ready	Timothée David-Cléris	Nasa ads CD10	
α -disc viscosity	Ok	Yona Lapeyre		Requires the warp diffusion test to fully validate

Equations of state

Feature	Status	Contributor / Maintainer	Paper to cite	Details
Isothermal	Production ready	Yona Lapeyre		
Adiabatic	Production ready	Timothée David-Cléris		

Shamrock python bindings

Home page Python API Examples



Search

Section Navigation

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Shamrock Gaussian generator

Sedov blast solution

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Start a SPH simulation from a phantom dump

Binary orbit functions

Testing AABB intersection routine

Paving functions

Shearing box in SPH

Testing Ray AABB intersection

Taylor green vortex in SPH

Basic disc simulation

Shamrock's exemple gallery

Below is a gallery of exemples

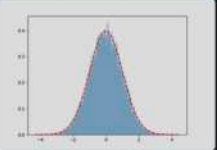
The time to generate the exemple can be seen in [Generation time](#)



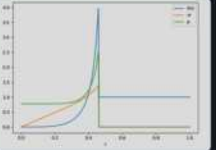
Shamrock install info utility functions



Open a phantom dump



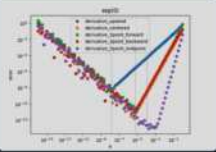
Shamrock Gaussian generator



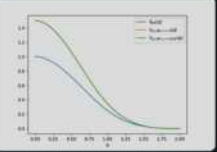
Sedov blast solution



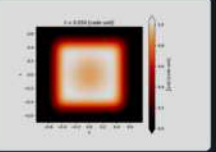
Simple exemple of unit usage



Shamrock math derivatives functions



SPH projected kernels



Start a SPH simulation from a phantom dump



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!