STARS EATEN UP

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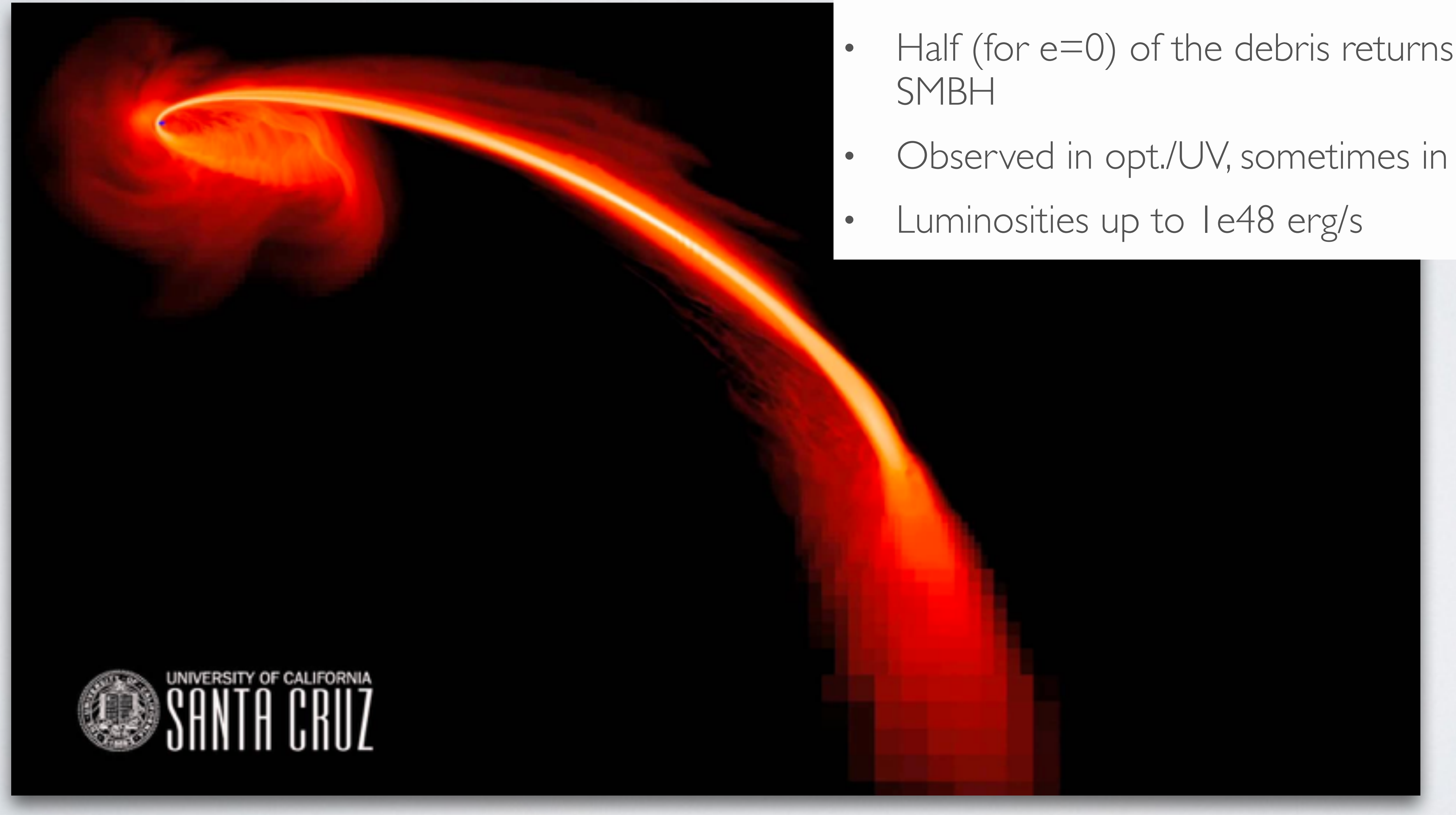
Outline:

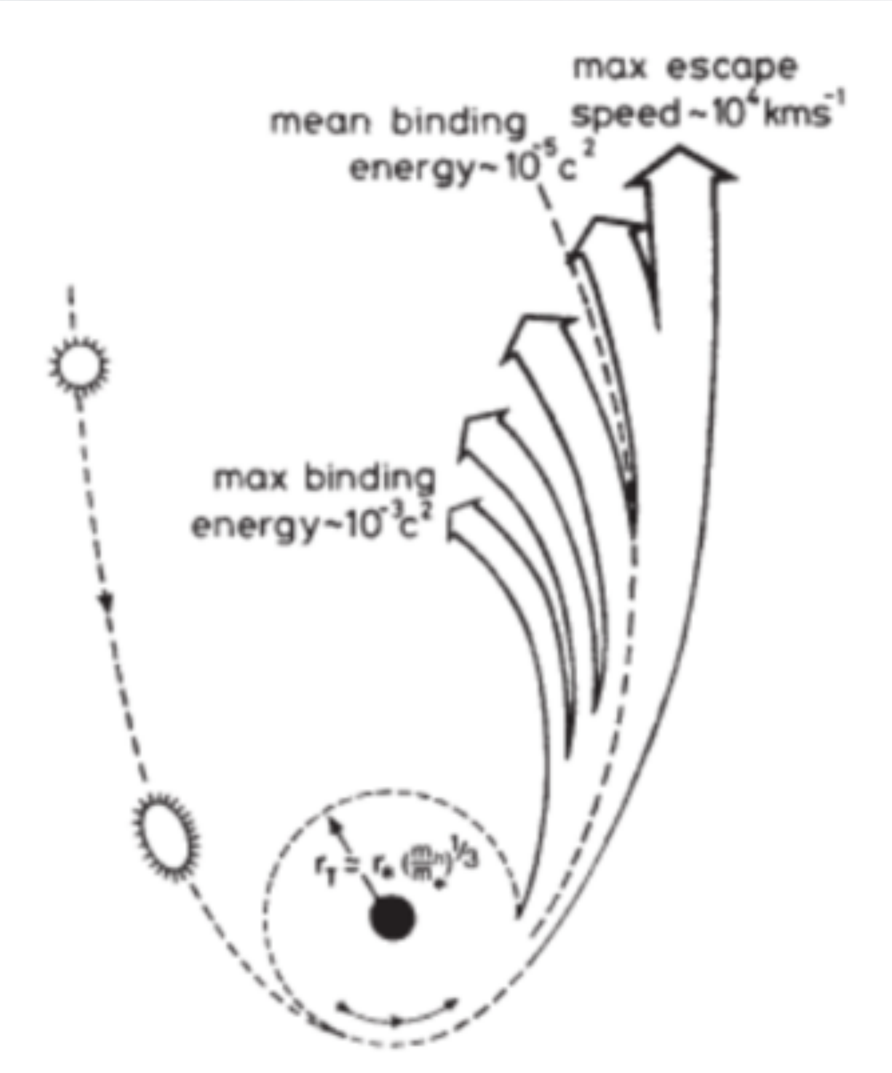
1. Introduction
2. Results
3. Summary

TIDAL DISRUPTION EVENTS



- Stars get disrupted if they get within the tidal radius of a SMBH
- Relativistic precession affects the orbit for close encounters
- Half (for e=0) of the debris returns to the SMBH
- Observed in opt./UV, sometimes in X-rays
- Luminosities up to 1e48 erg/s

DEBRIS RETURN RATE



- If energy uniformly distributed in the star then the debris return rate given by,

$$\dot{M} \propto t^{-5/3}$$

- The return rate is not the accretion rate
- Gas would have to form the accretion disk first or hit the SMBH directly
- Predicted initial accretion rates can be significantly super-Eddington

$$\dot{M}_{\rm Edd} = \frac{L_{\rm Edd}}{\eta c^2} = 2.4 \cdot 10^{18} \frac{M_{\rm BH}}{M_\odot}\ {\rm g/s}$$

TDE ENERGETICS

- Typical mass of a disrupted star:

$$0.5M_\odot$$

- Amount of debris falling on the BH:

$$0.25M_\odot$$

- Accretion efficiency:

$$10\%$$

- Total predicted emitted energy:

$$10\% \cdot 0.25 \cdot M_\odot c^2 = 4 \cdot 10^{52}\,\mathrm{erg}$$

- Observed energies:

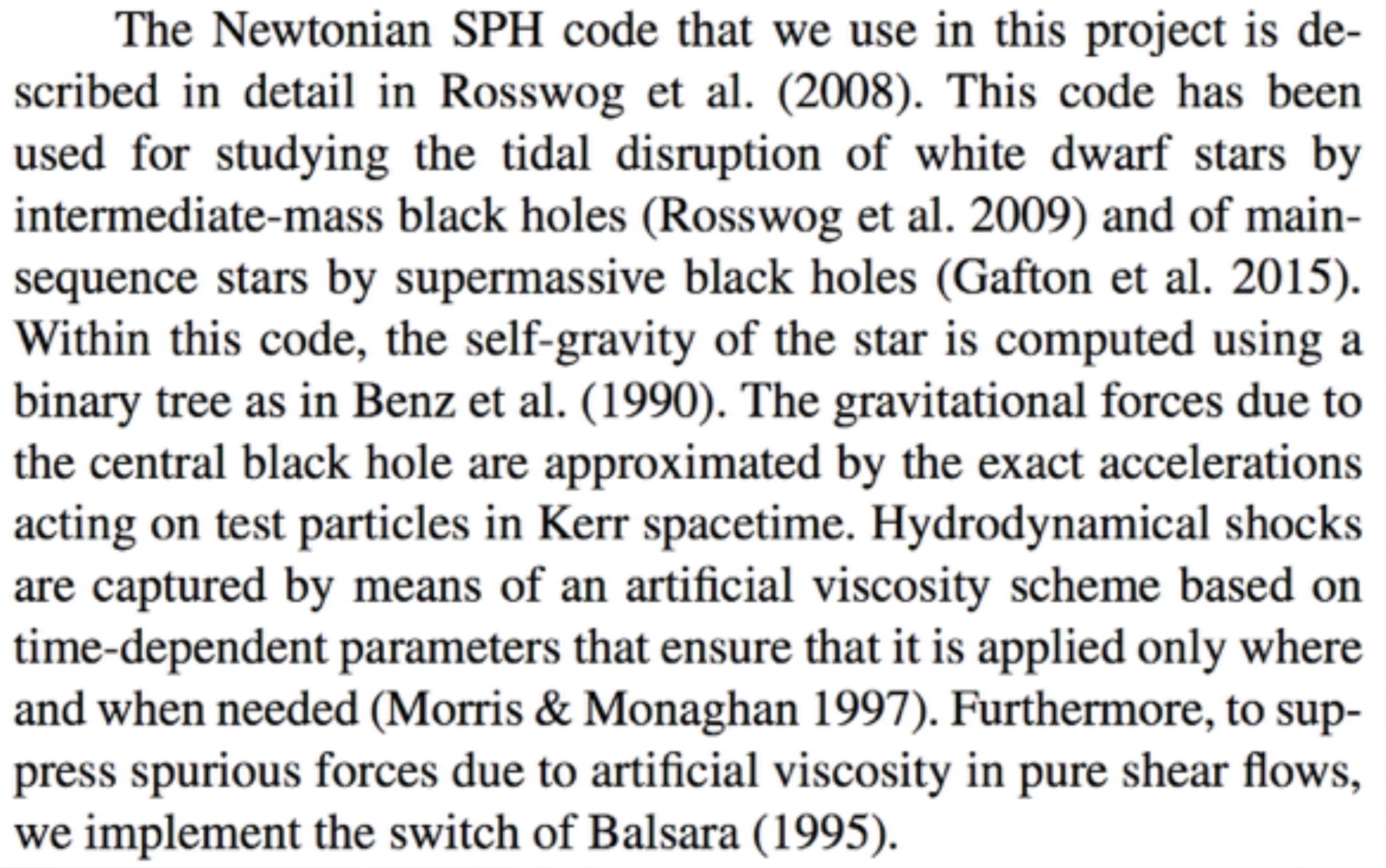
$$\sim 10^{50} - 10^{51}\,\mathrm{erg}$$

credit: Museum of Natural History

THE METHOD

SPH + GRRMHD

SPH



The Newtonian SPH code that we use in this project is described in detail in Rosswog et al. (2008). This code has been used for studying the tidal disruption of white dwarf stars by intermediate-mass black holes (Rosswog et al. 2009) and of main-sequence stars by supermassive black holes (Gafton et al. 2015). Within this code, the self-gravity of the star is computed using a binary tree as in Benz et al. (1990). The gravitational forces due to the central black hole are approximated by the exact accelerations acting on test particles in Kerr spacetime. Hydrodynamical shocks are captured by means of an artificial viscosity scheme based on time-dependent parameters that ensure that it is applied only where and when needed (Morris & Monaghan 1997). Furthermore, to suppress spurious forces due to artificial viscosity in pure shear flows, we implement the switch of Balsara (1995).

+ relativistic potential of Tejeda & Rosswog

Rosswog 09

GRRMHD

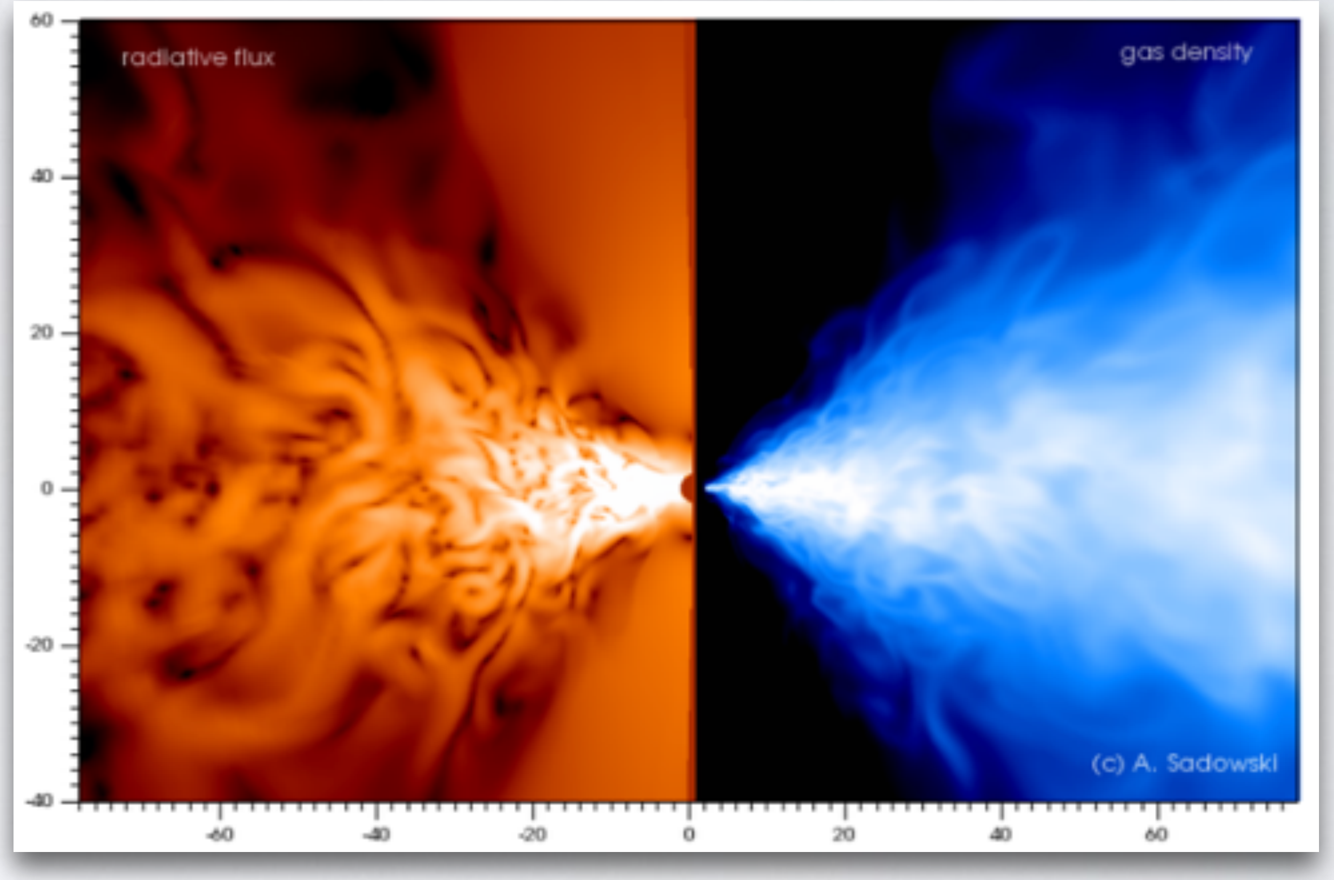
(general relativistic radiation magnetohydrodynamics)

- magnetohydrodynamics (MHD) — gas + magneto rotational instability (MRI)
- radiation transfer — cooling + pressure support
- general relativity — black hole
- global fluid dynamics code

KORAL

first GR radiation (ideal)
MHD code + M1 closure
(Sadowski+13,+14)

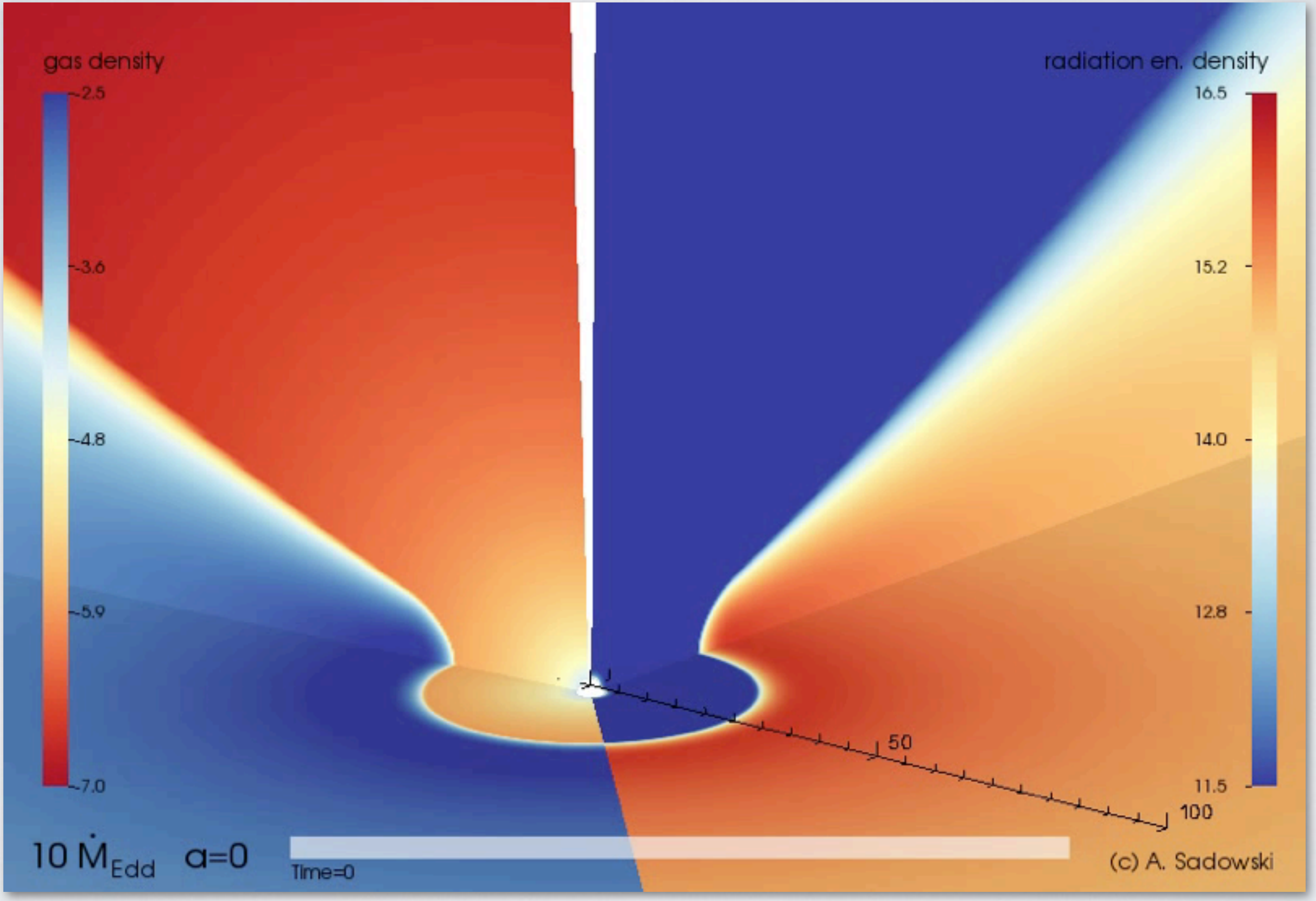
other groups:
Ohsuga+, McKinney+, Jiang+, Fragile+



Sadowski+15

KORAL

(KOd RAdiacyjny L)



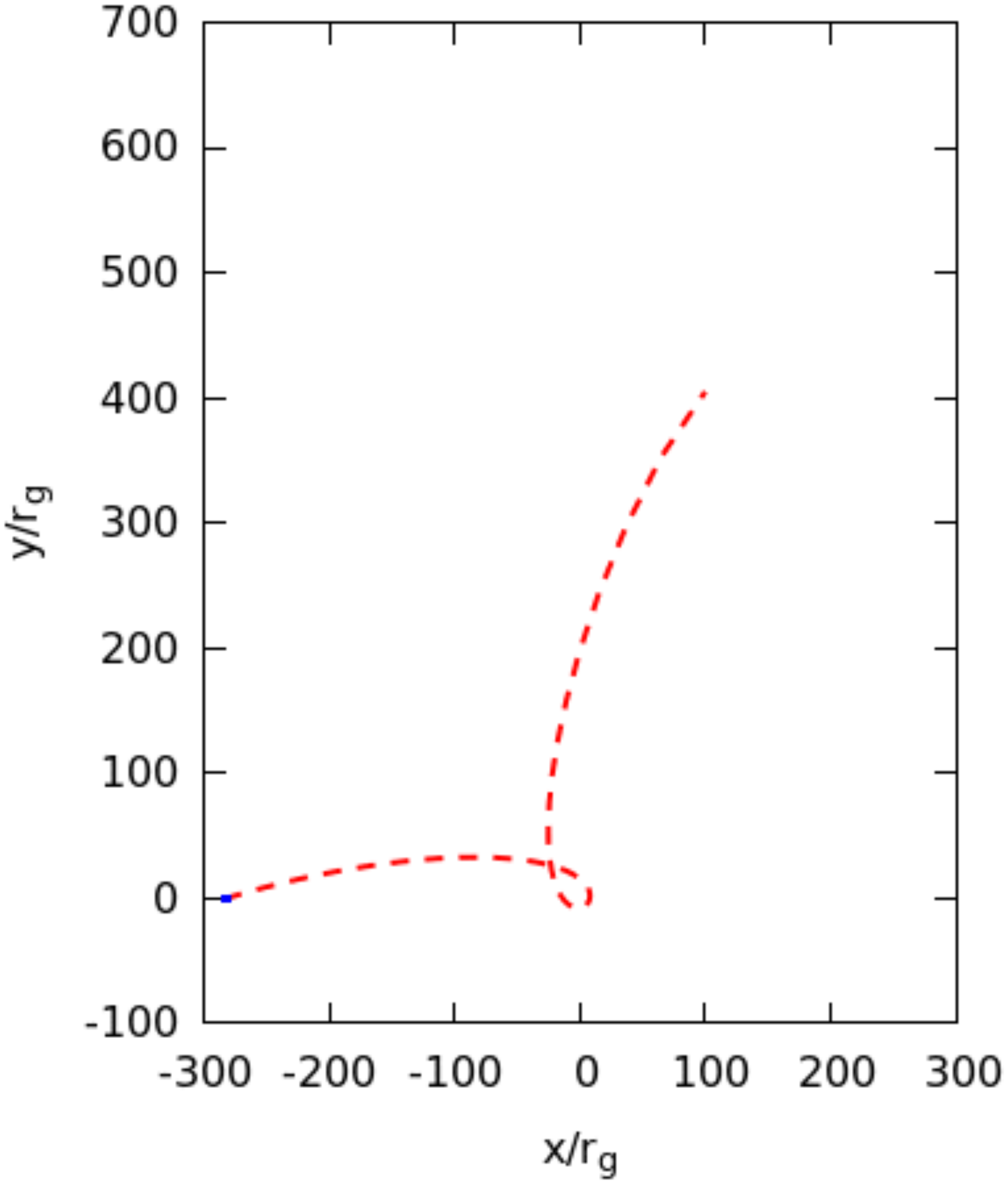
LIMITS FOR SIMULATING TDES

- Resolving BH horizon requires small time step - limited total duration of simulation
- Finite resolution - thick debris stream

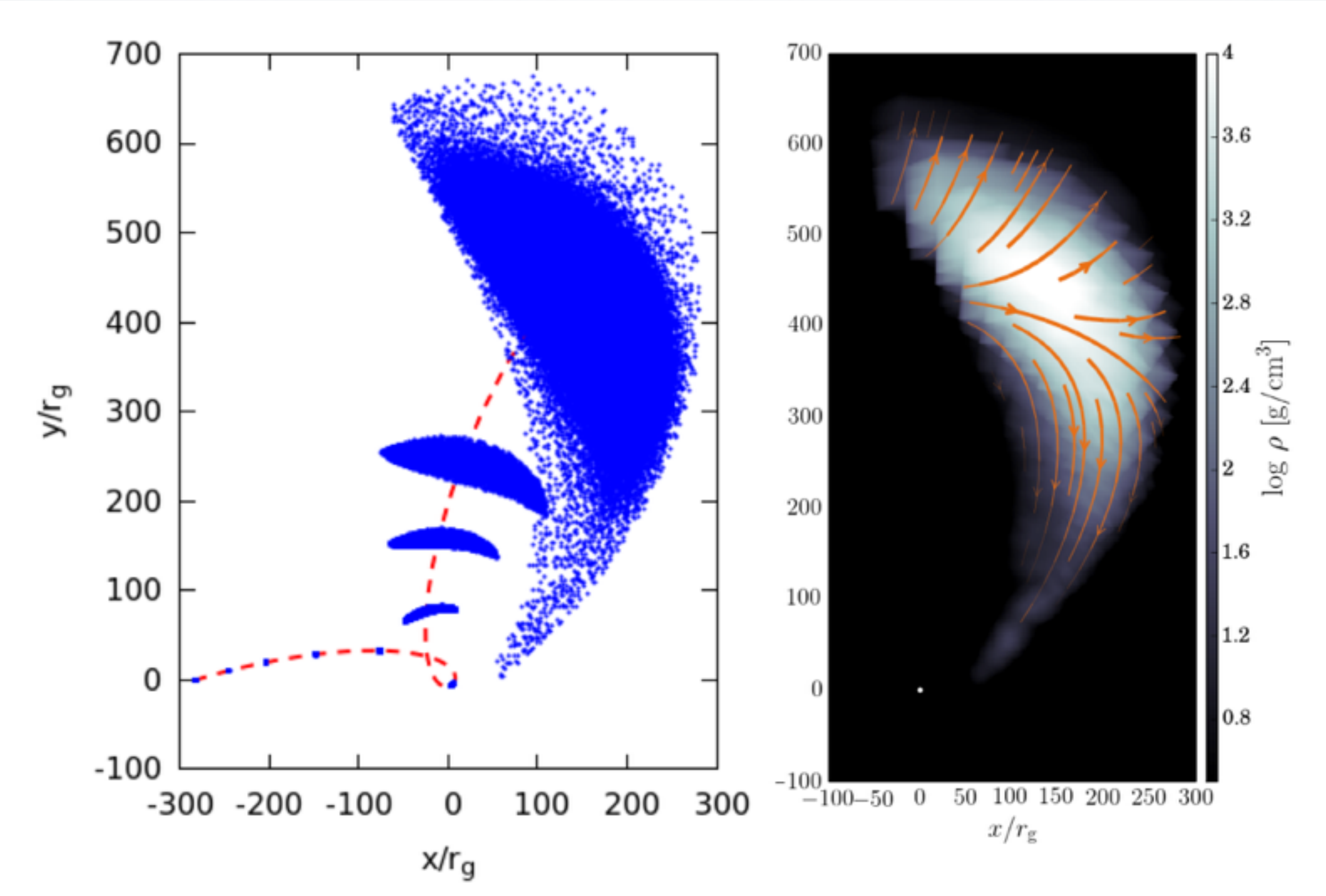
- Elliptical orbit
- Large impact parameter
- Relatively small mass ratio

THE DISRUPTION

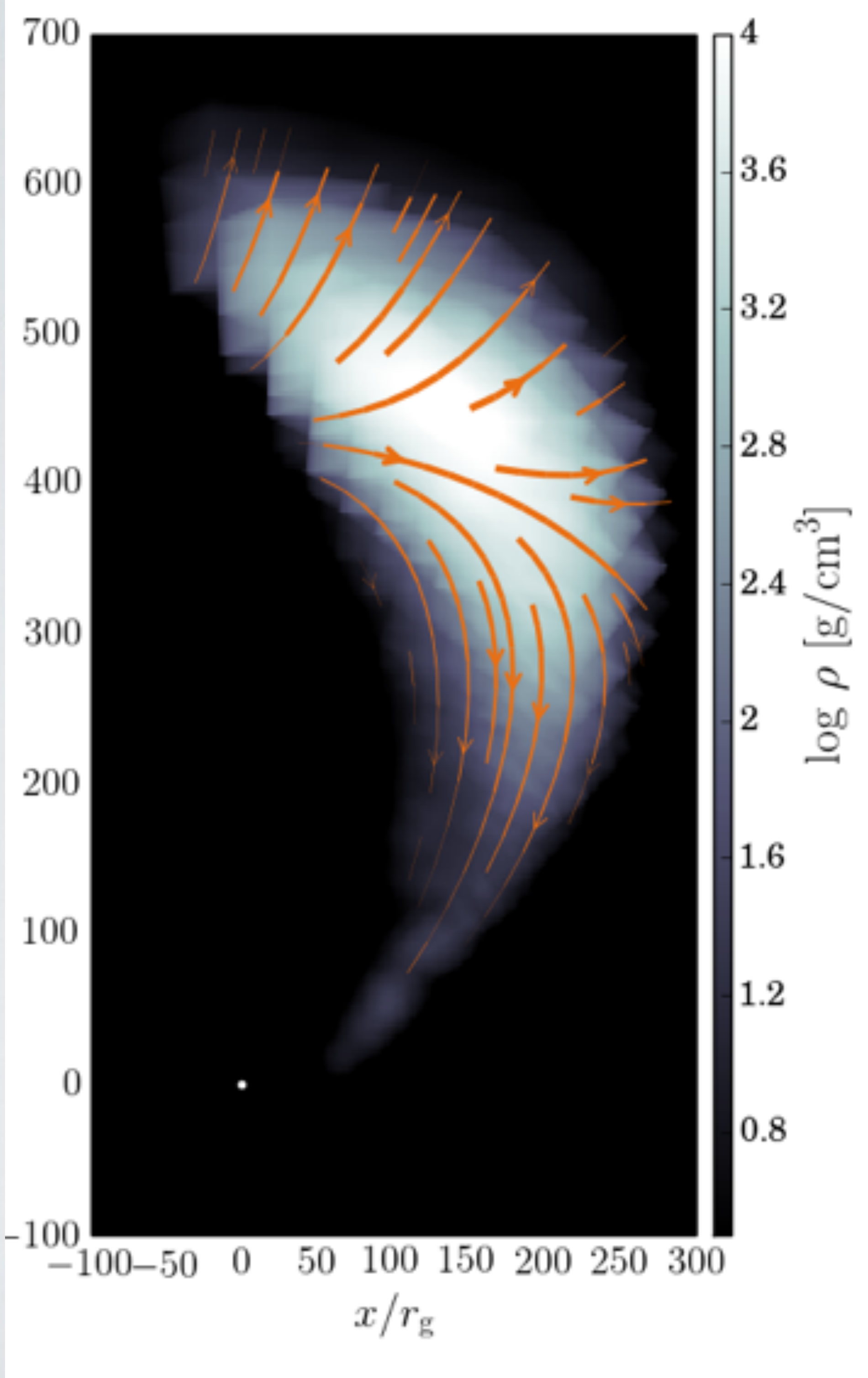
$$M_{\rm BH} = 10^5\,M_\odot$$
$$a_* = 0$$
$$M_* = 0.1\,M_\odot$$
$$R_* = 0.15\,R_\odot$$
$$e = 0.97$$
$$\beta = 10$$
$$r_{\rm per} = 7r_{\rm g}$$



THE ONSET OF KORAL



THE SIMULATIONS

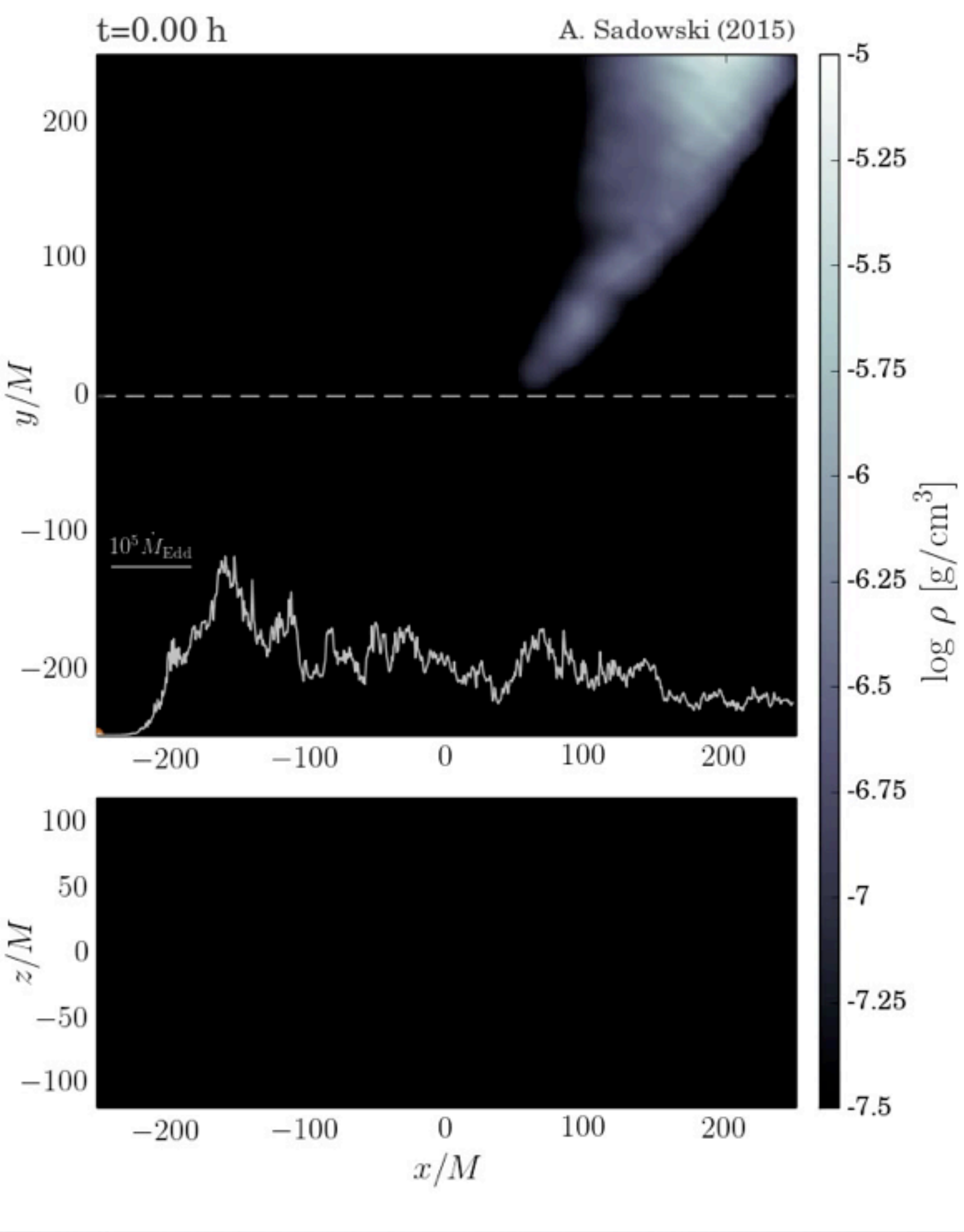


1. HD
2. MHD
3. (radiative?)

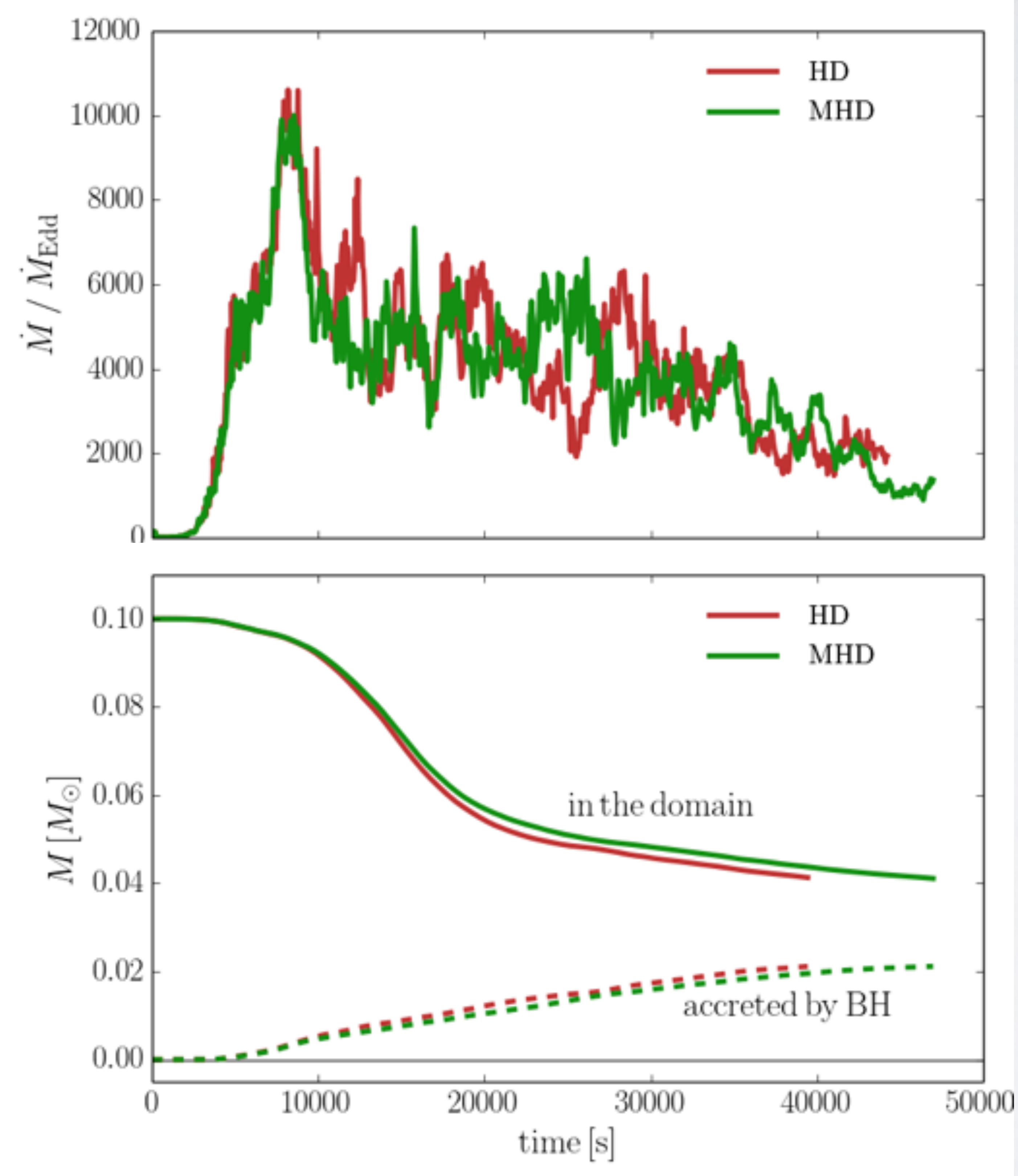
Common parameters:

$$r_{\rm in} = 1.85 r_{\rm g}$$
$$r_{\rm out} = 1000 r_{\rm g}$$
$$224 \times 128 \times 96$$
$$t_{\rm end} \approx 10^5 \frac{GM}{c^3} \approx 13h$$

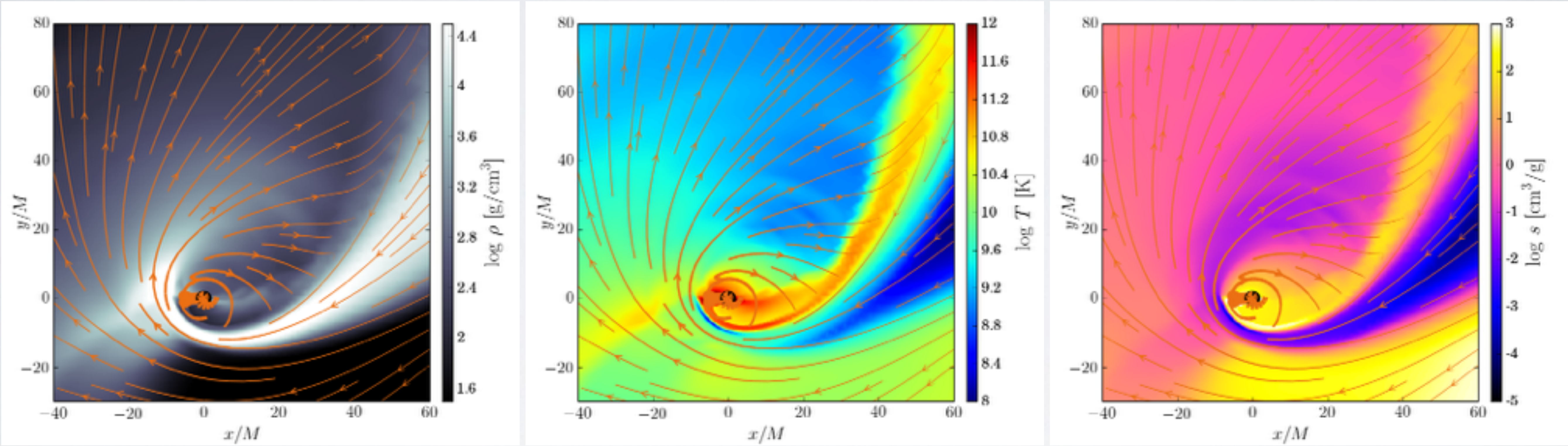
HD


t=0.00 h
A. Sadowski (2015)
$10^5\dot{M}_{\rm Edd}$
y/M
z/M
x/M
log ρ [g/cm³]
-5
-5.25
-5.5
-5.75
-6
-6.25
-6.5
-6.75
-7
-7.25
-7.5
200
100
0
−100
−200
50
−50

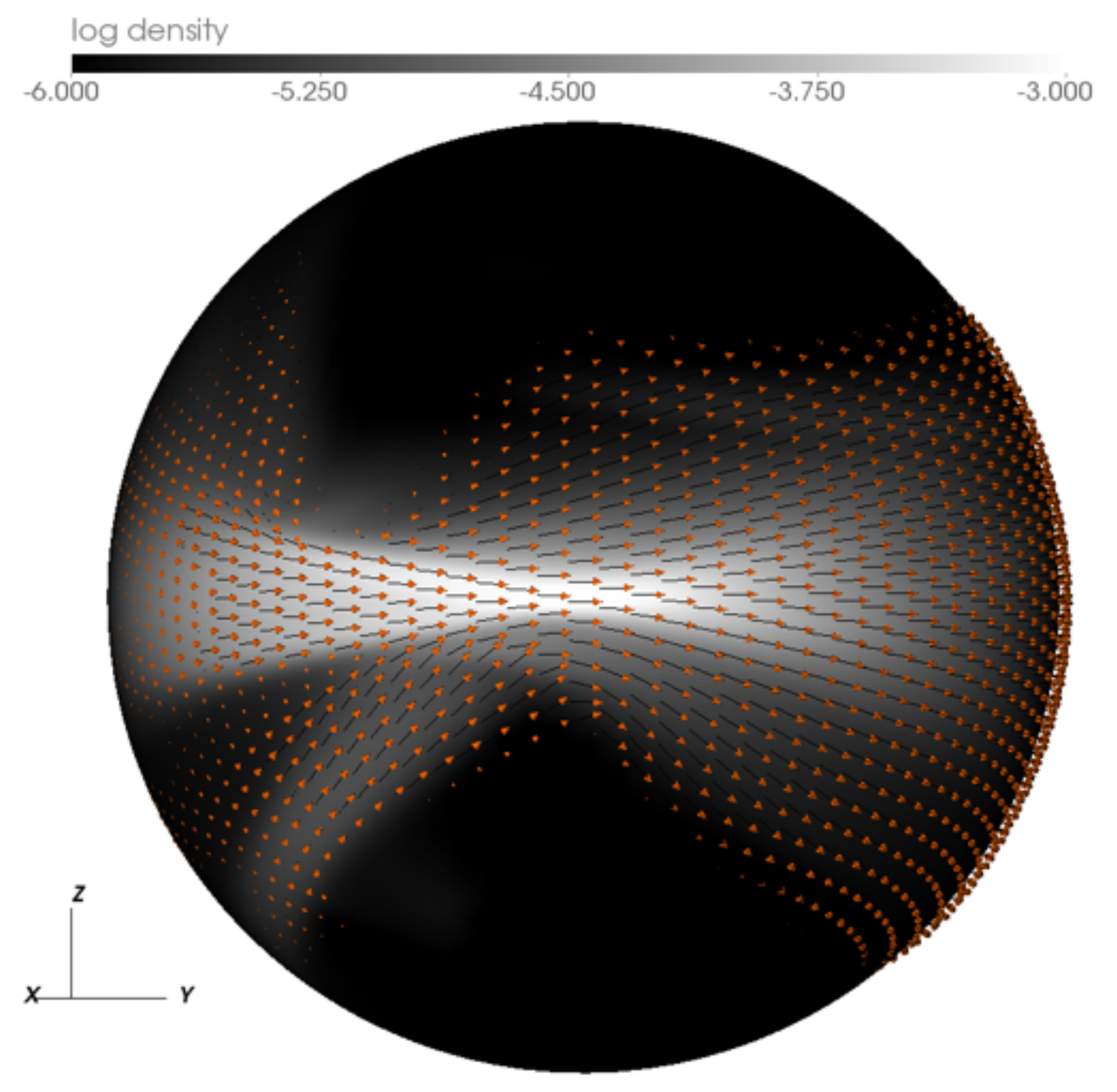
THE ACCRETION



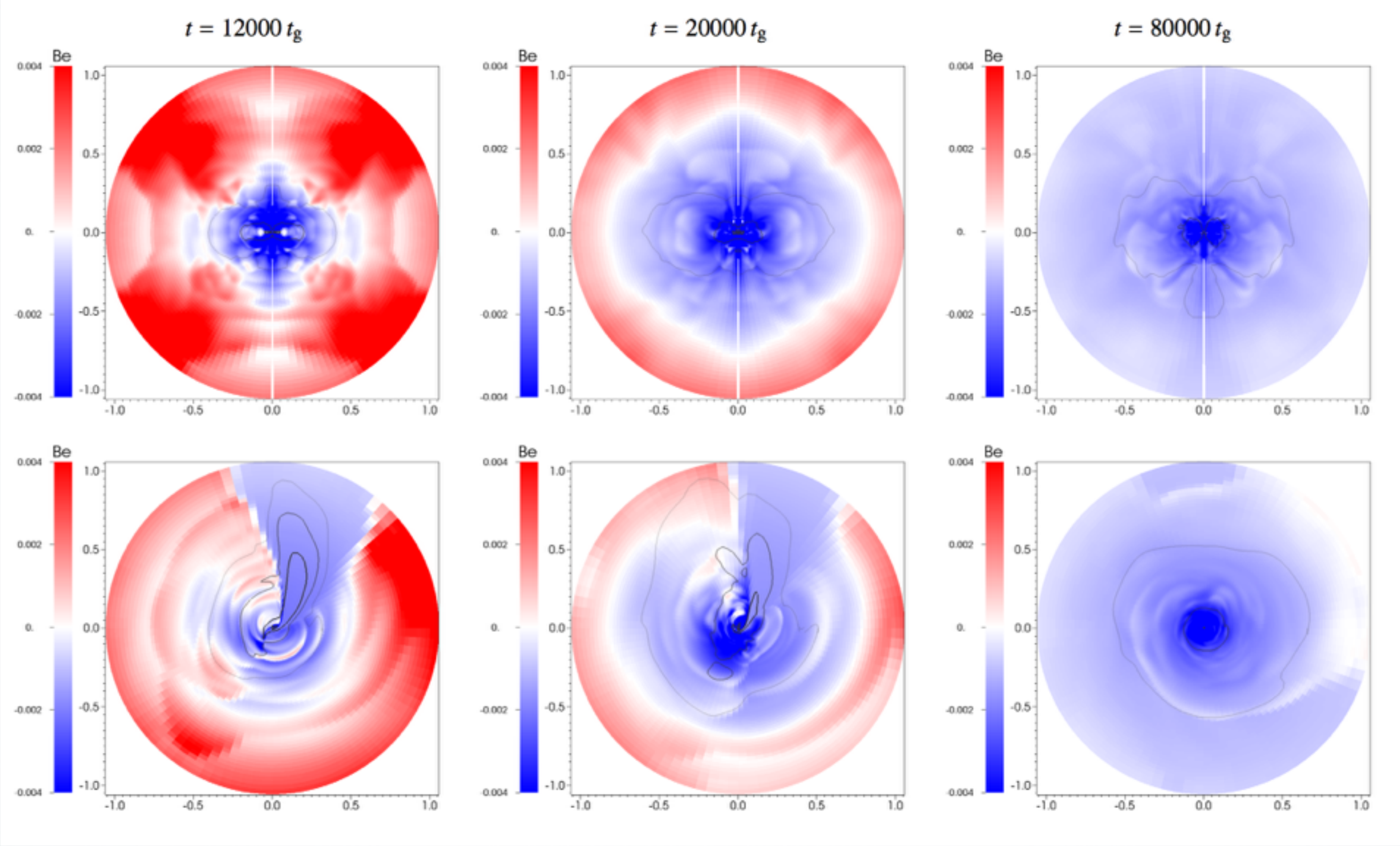
THE SELF-CROSSING



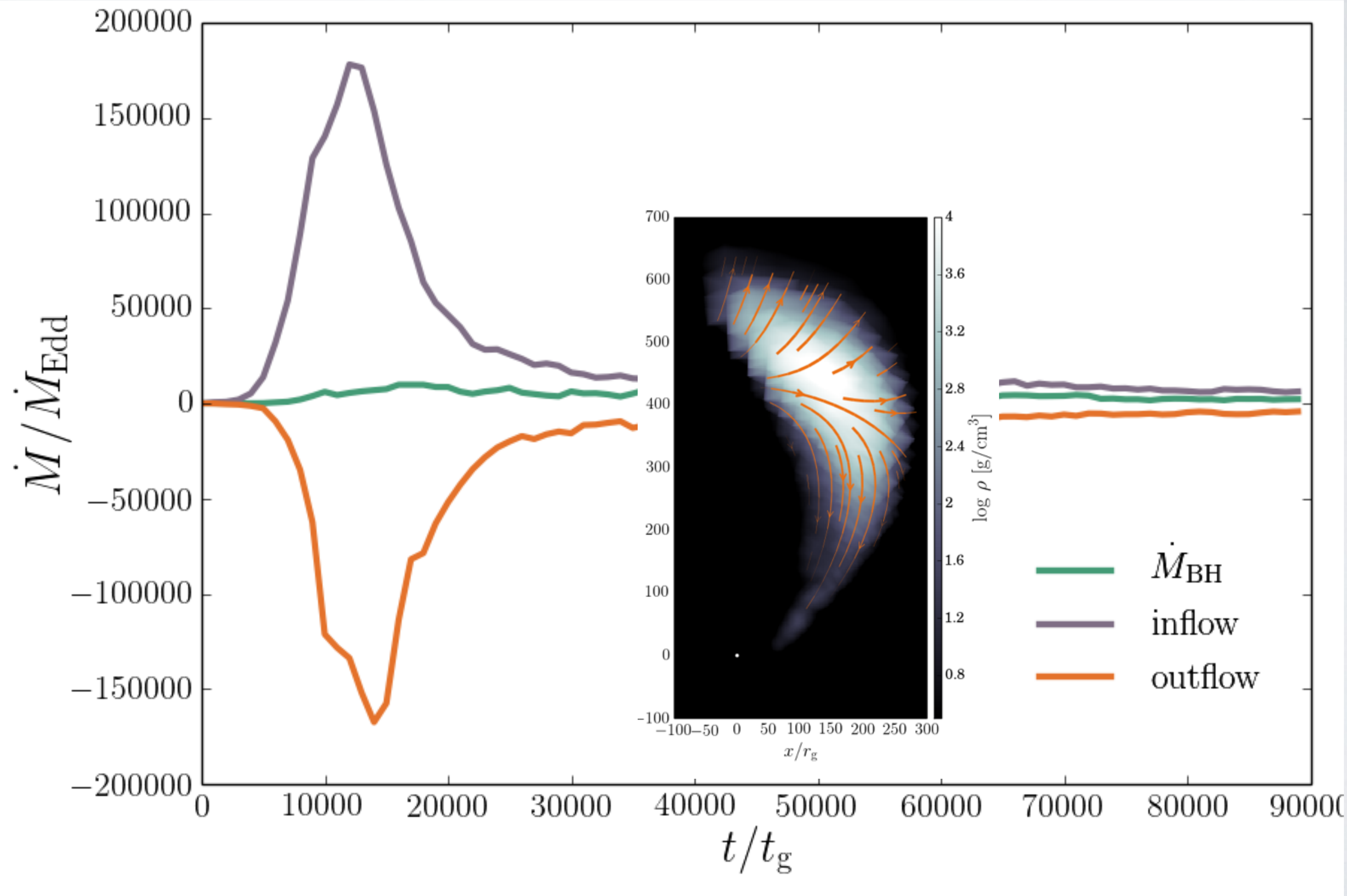
THE NOZZLE



THE OUTFLOW

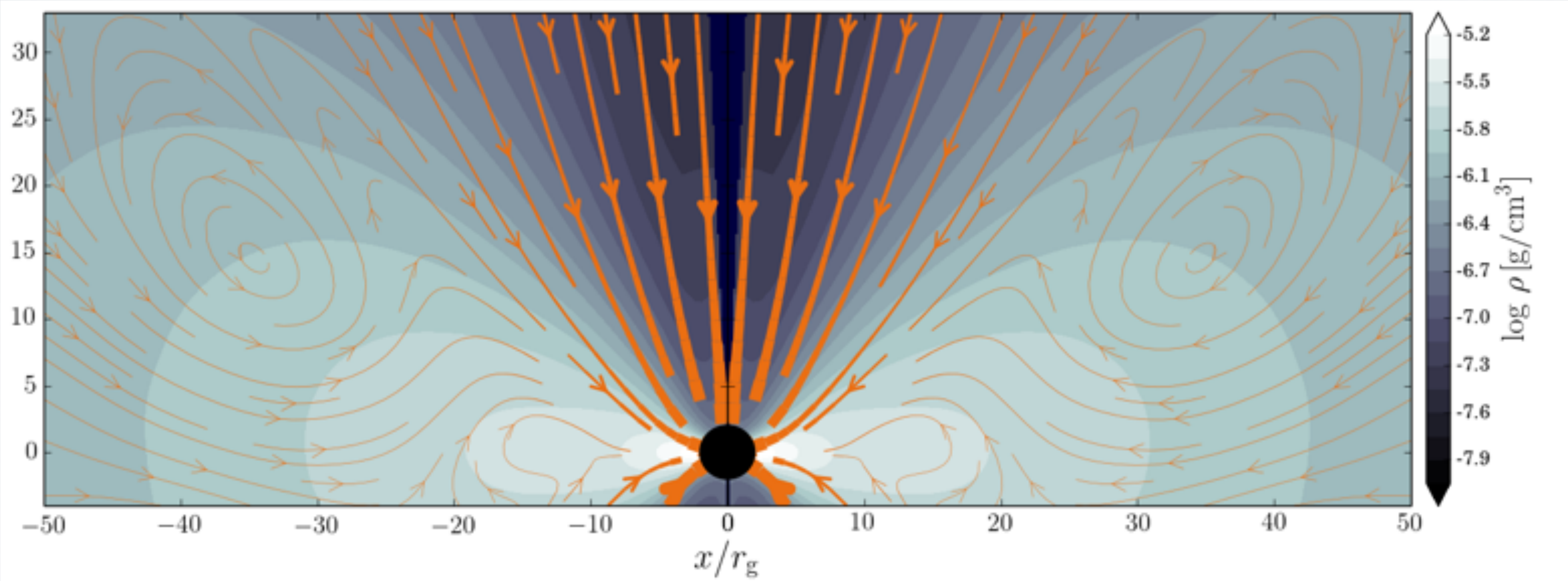

t = 12000 t_g
t = 20000 t_g
t = 80000 t_g
Be
0.004
0.002
0.
-0.002
-0.004
1.0
0.5
0.0
-0.5
-1.0

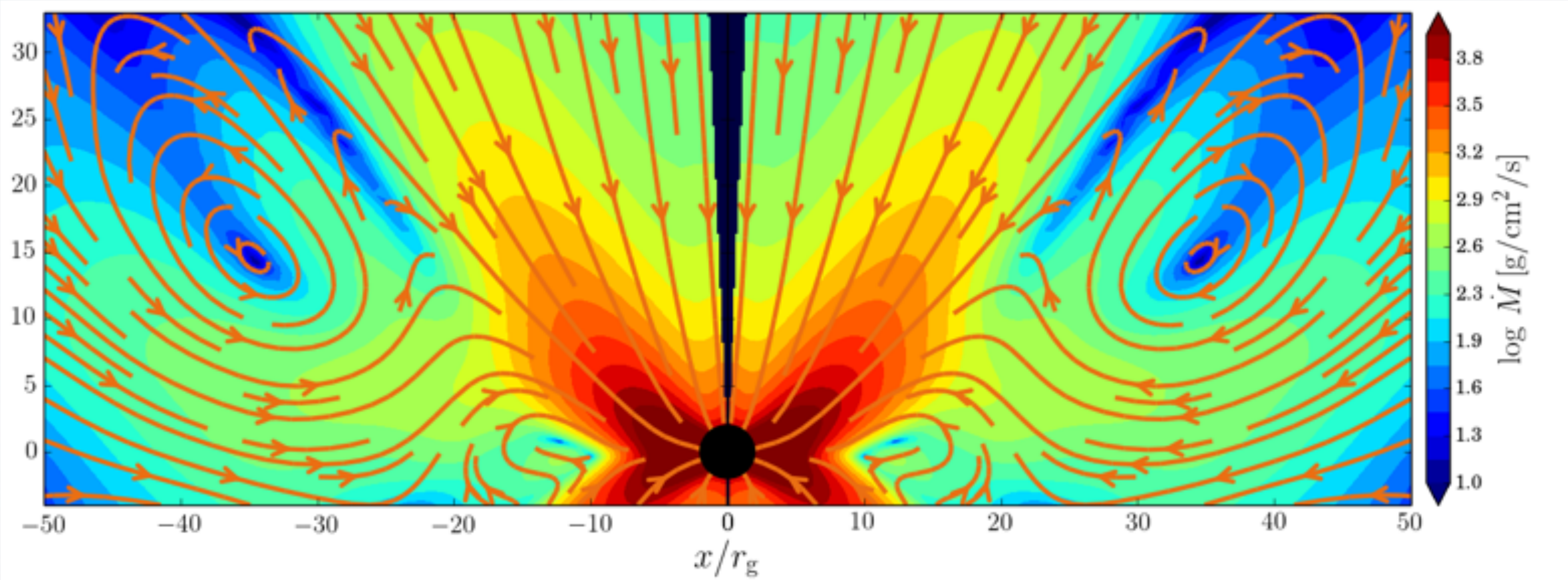
THE INFLOW



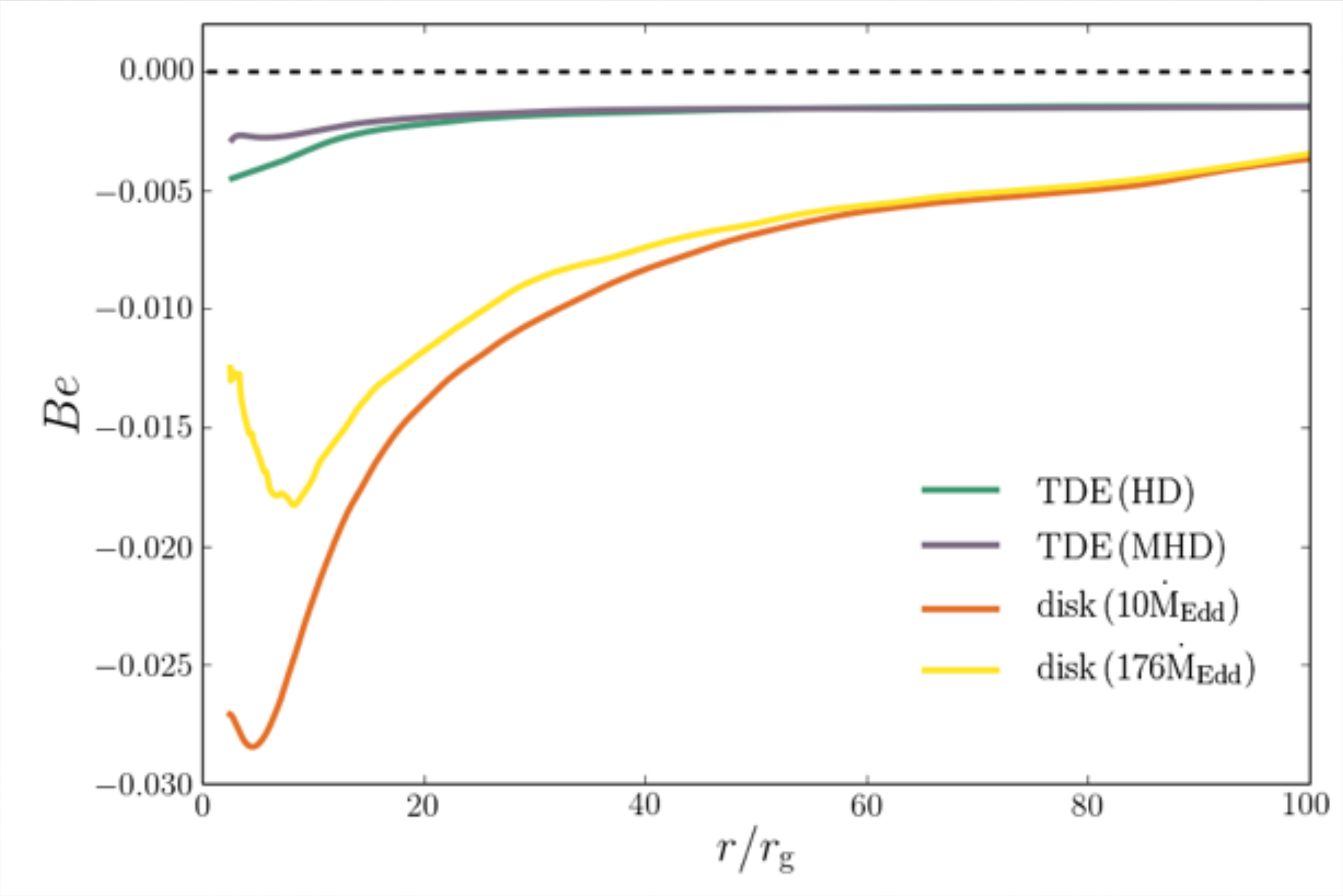
200000
150000
100000
50000
0
−50000
−100000
−150000
−200000
$\dot{M}/\dot{M}_{\rm Edd}$
0
10000
20000
30000
40000
50000
60000
70000
80000
$t/t_{\rm g}$
$\dot{M}_{\rm BH}$
inflow
outflow
700
600
500
400
300
200
100
0
−100
−100
−50
0
50
100
150
200
250
300
$x/r_{\rm g}$
4
3.6
3.2
2.8
2.4
2
1.6
1.2
0.8
$\log\rho$ [g/cm^3]

THE CIRCULARIZED DISK



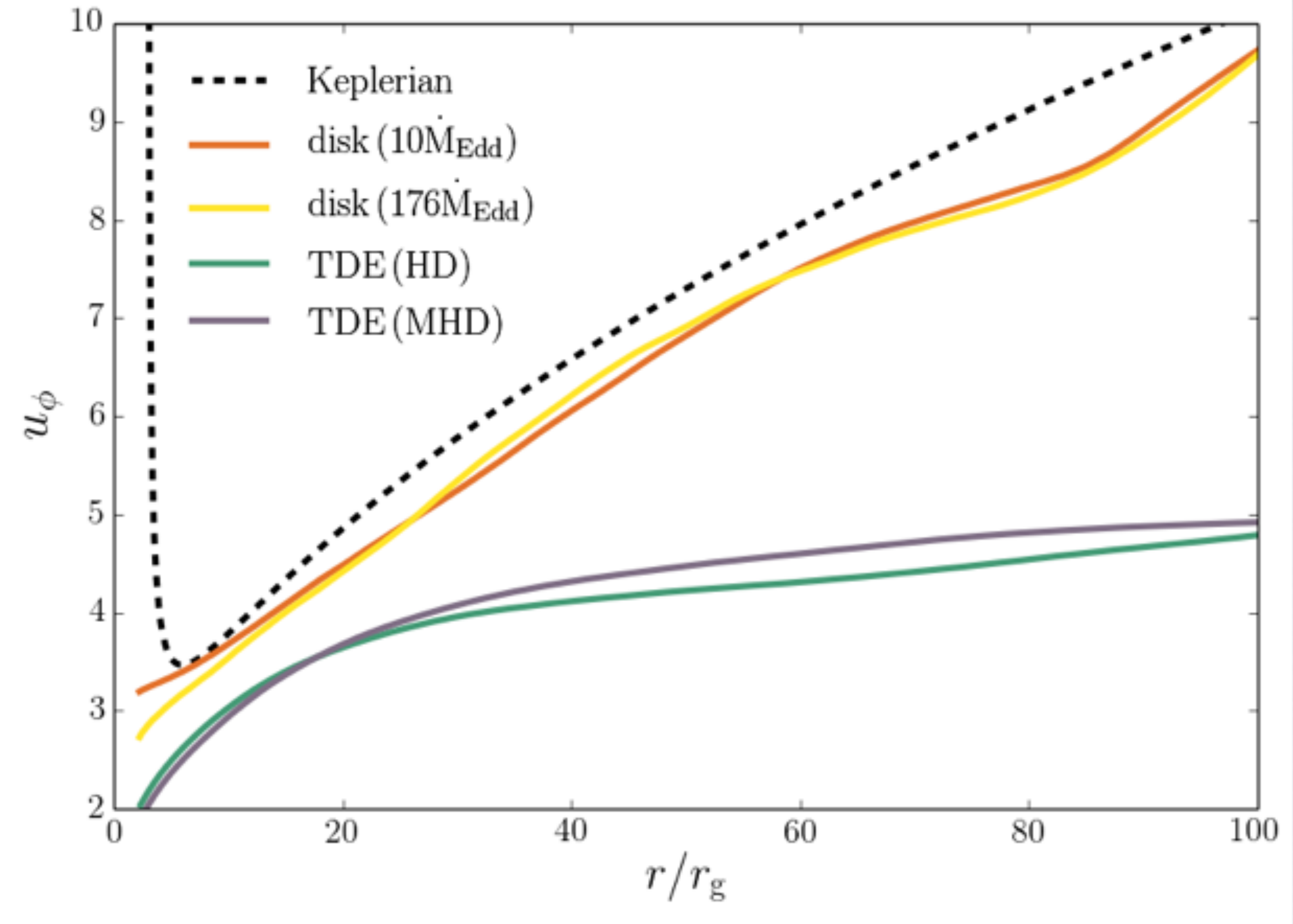


(ALMOST) ZERO BERNOULLI EQUILIBRIUM TORUS - ZEBRA



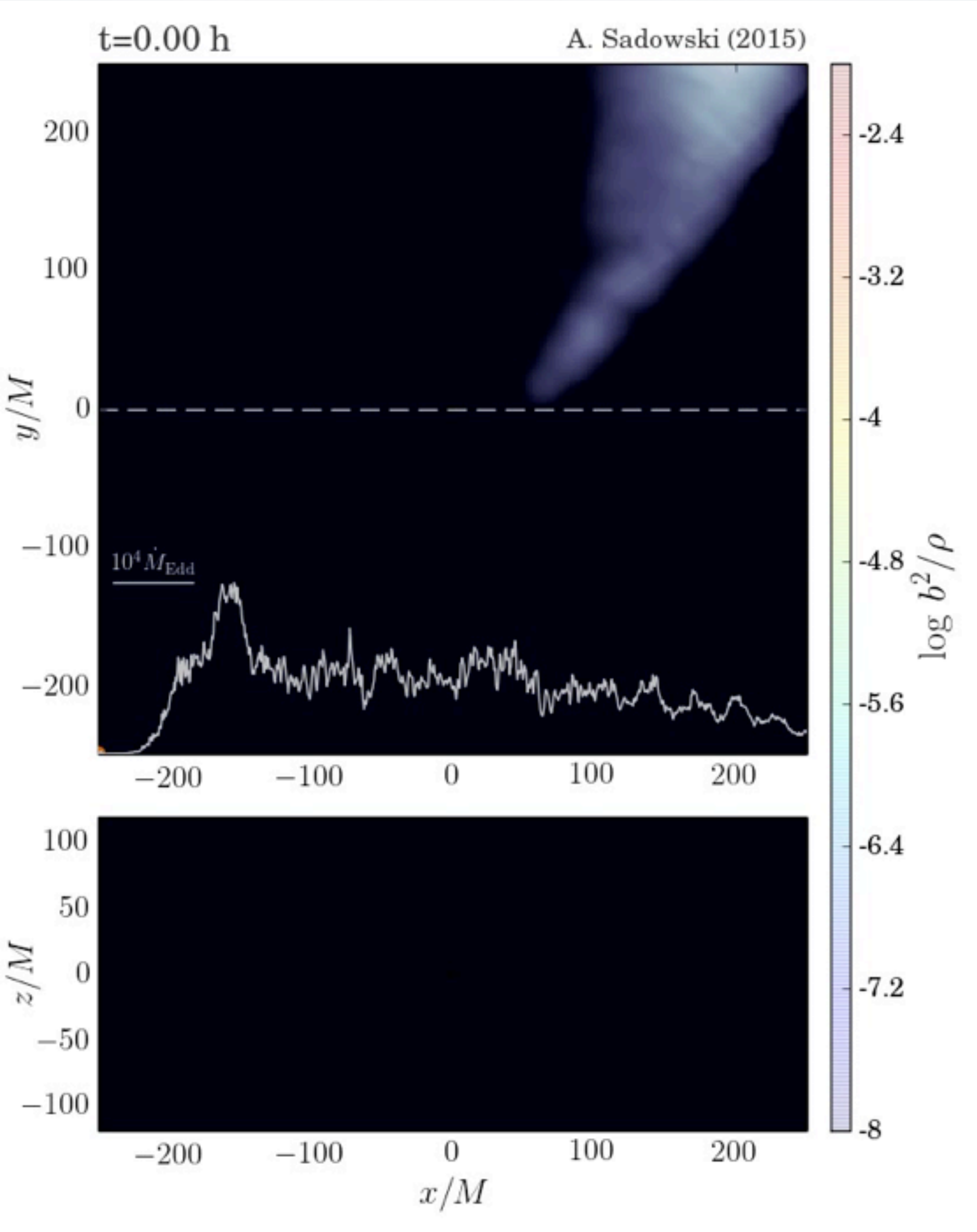
Bernoulli function

(ALMOST) ZERO BERNOULLI EQUILIBRIUM TORUS - ZEBRA

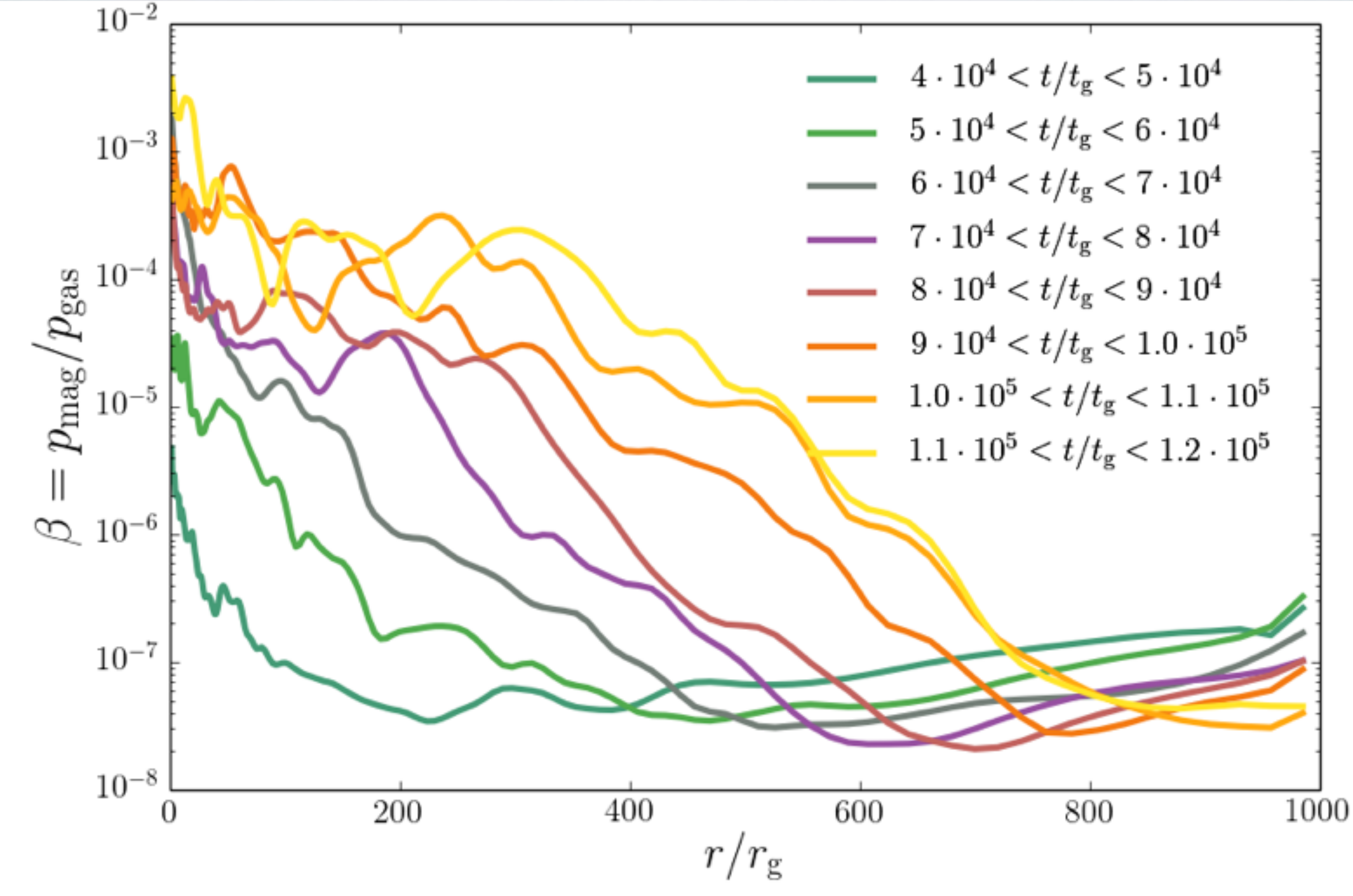


angular momentum

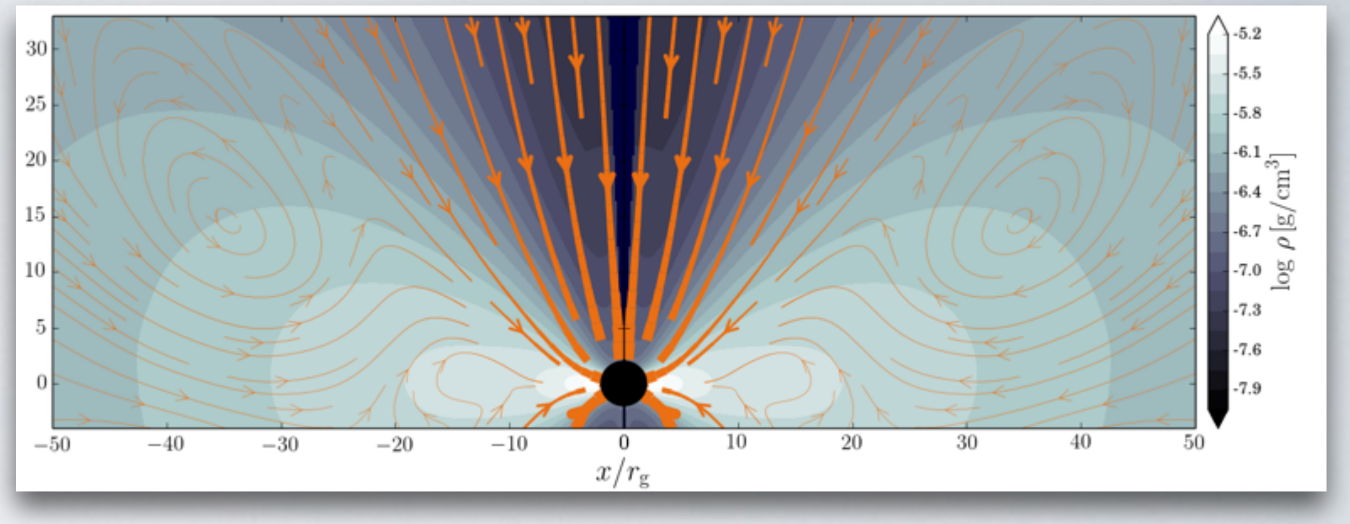
MHD


t=0.00 h
A. Sadowski (2015)
y/M
200
100
0
−100
−200
$10^4 \dot{M}_{\rm Edd}$
−200
−100
0
100
200
z/M
100
50
0
−50
−100
x/M
log b^2/ρ
-2.4
-3.2
-4
-4.8
-5.6
-6.4
-7.2
-8

MAGNETIZATION



THE SUMMARY



- GRMHD simulations of a red dwarf disrupted by a SMBH in a close encounter
- Strong relativistic precession makes the self-intersection violent
- Significant amount of unbound gas released out of the plane in the initial phase
- Gas settles down in a quasi-disk - low angular momentum, marginally bound, thick, turbulent torus - ZEBRA
- Hardly any accretion in the torus - turbulent stress inefficient
- Gas eaten by the BH comes initially from angular momentum cancellation. In the quasi-steady stage bound debris falls down on the BH along the torus edge.
- Initially weakly magnetized star brings B into the torus where it builds up because of differential rotation
- However, B saturates at a low level - low effective viscosity (MRI not resolved)
- Debris very optically thick - quasi-steady state radiatively inefficient