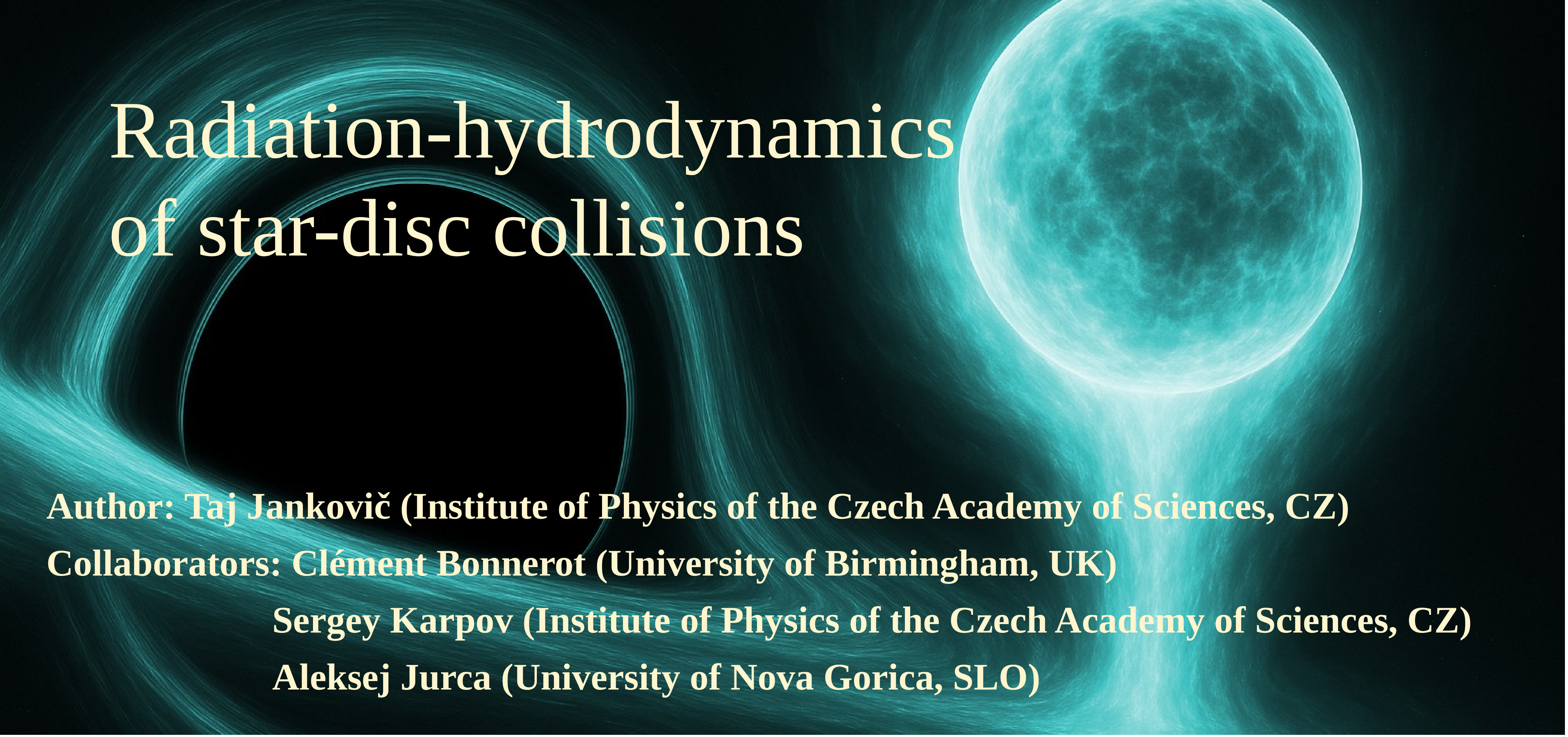


Radiation-hydrodynamics of star-disc collisions

Author: Taj Jankovič (Institute of Physics of the Czech Academy of Sciences, CZ)

Collaborators: Clément Bonnerot (University of Birmingham, UK)

Sergey Karpov (Institute of Physics of the Czech Academy of Sciences, CZ)

Aleksej Jurca (University of Nova Gorica, SLO)

FZU PHYSICS FOR FUTURE

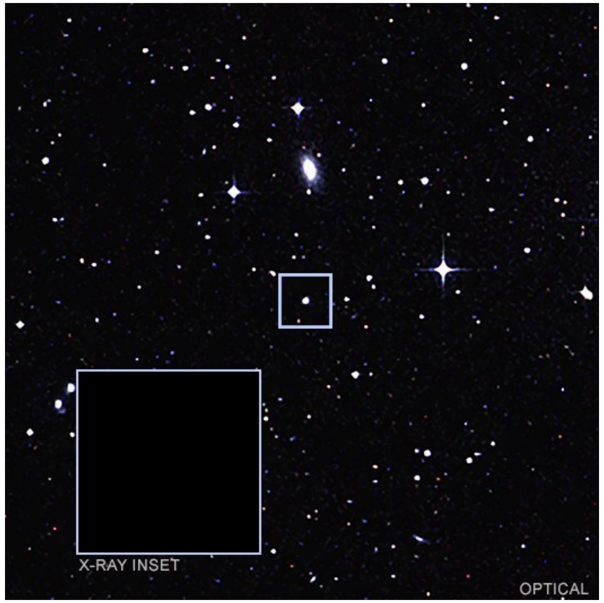
11.5.2026

Co-funded by the European Union

MŠMT MINISTRY OF EDUCATION, YOUTH AND SPORTS

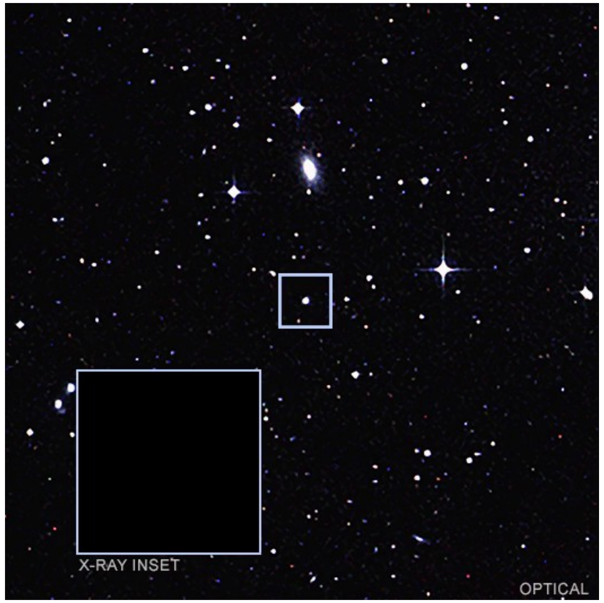
Quasi-periodic eruptions (QPEs)

X-ray: NASA/CXO/CSIC-INTA/Miniutti+ 2019; Optical: DSS

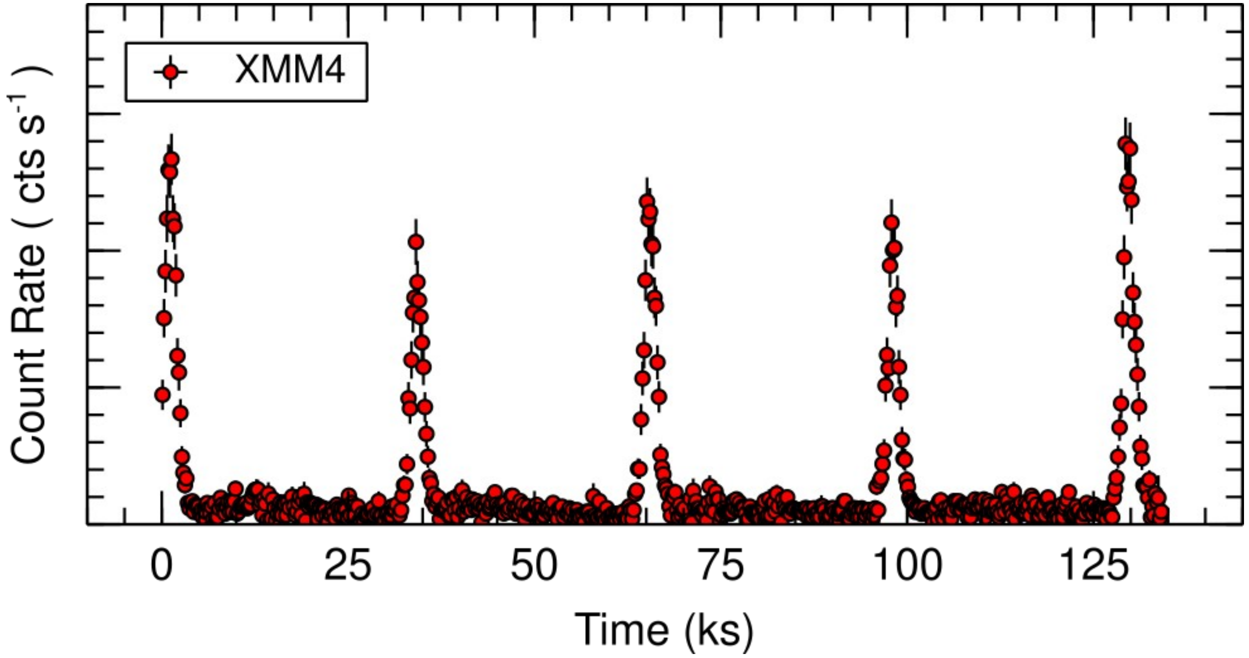


Quasi-periodic eruptions (QPEs)

X-ray: NASA/CXO/CSIC-INTA/Miniutti+ 2019; Optical: DSS



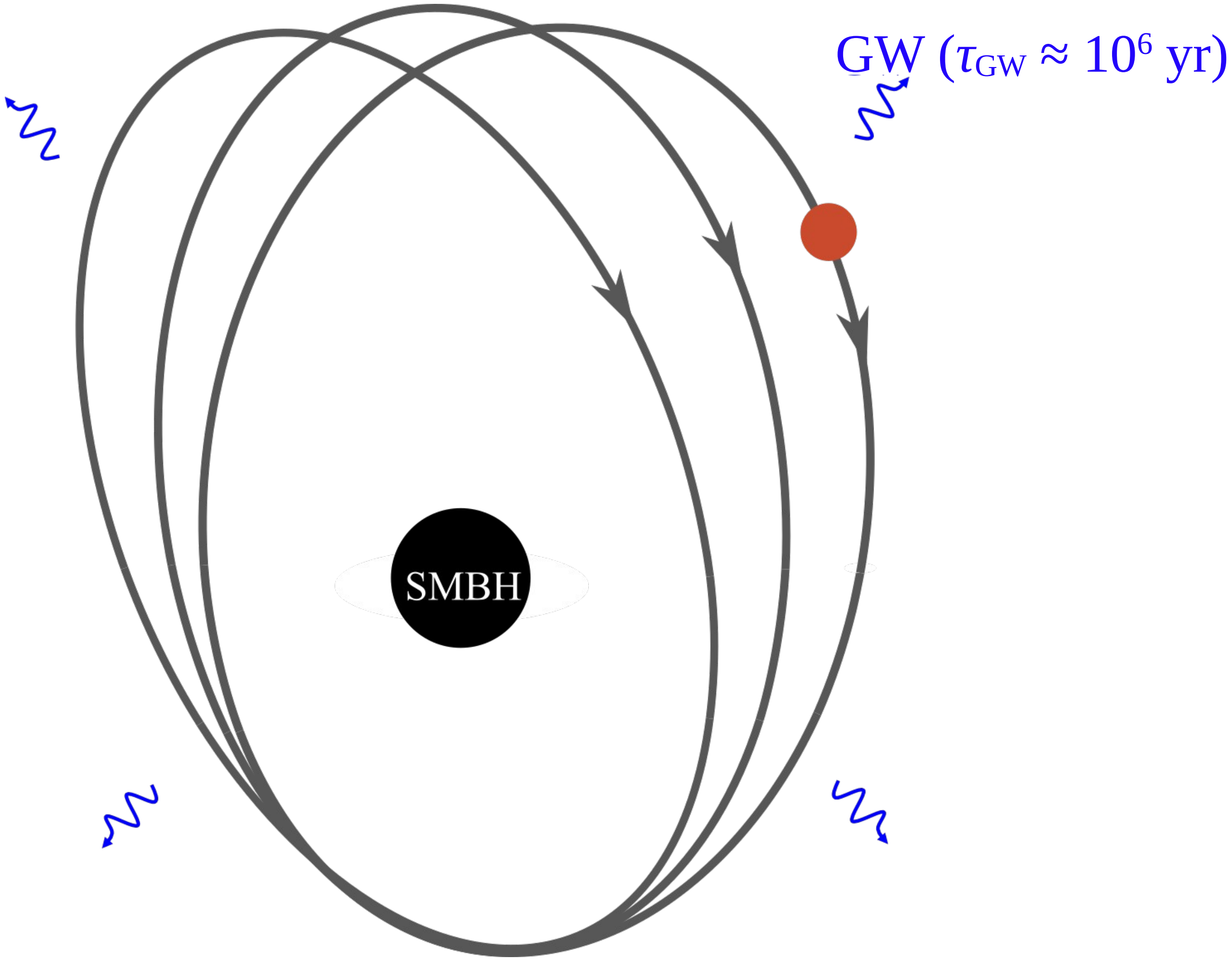
Miniutti+2022



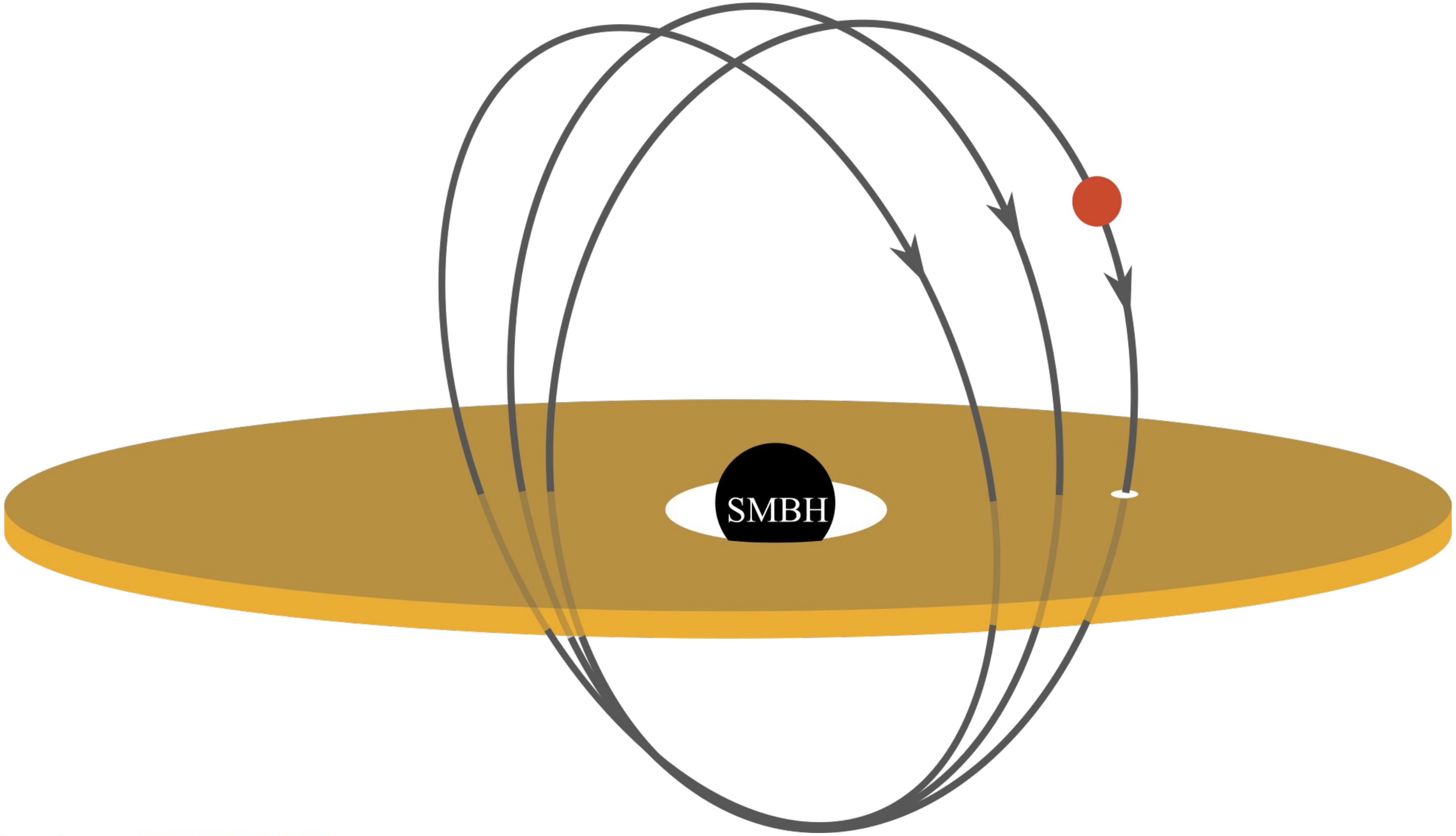
X-ray bursts occurring every ≈ 10 hours and lasting ≈ 1 hour.

“Long-short” patterns between consecutive flares.

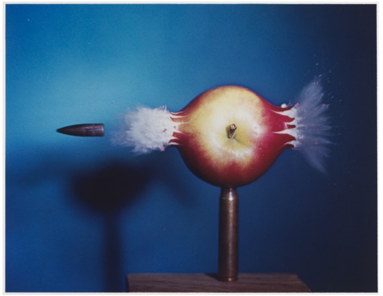
Star-disc collisions model



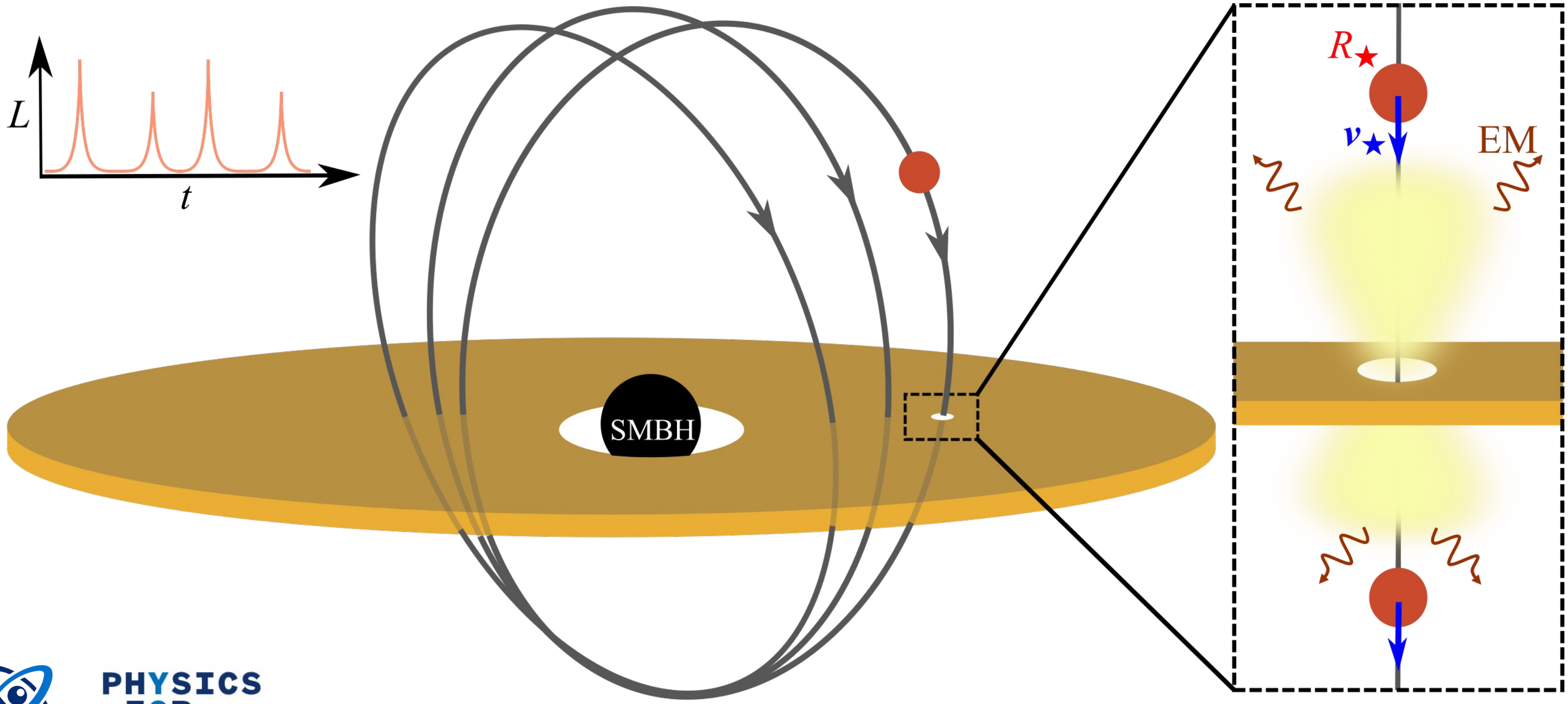
Star-disc collisions model



Star-disc collisions model

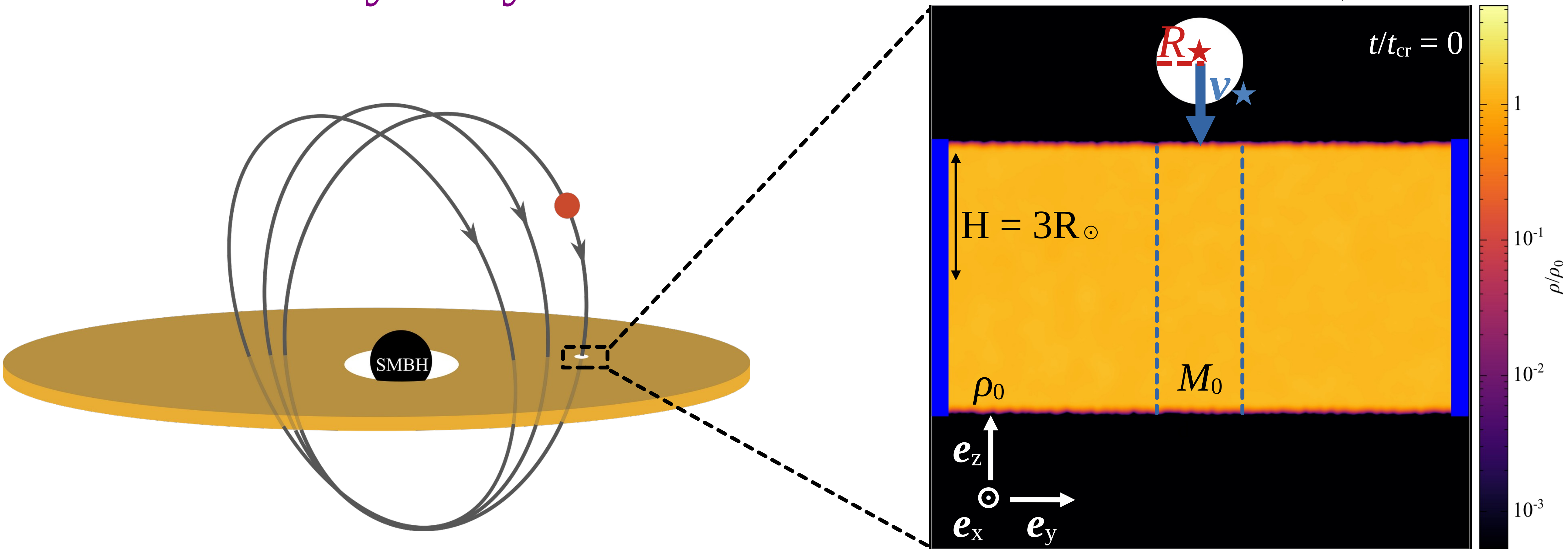


Credit: Gift of the Harold and Esther Edgerton Family Foundation



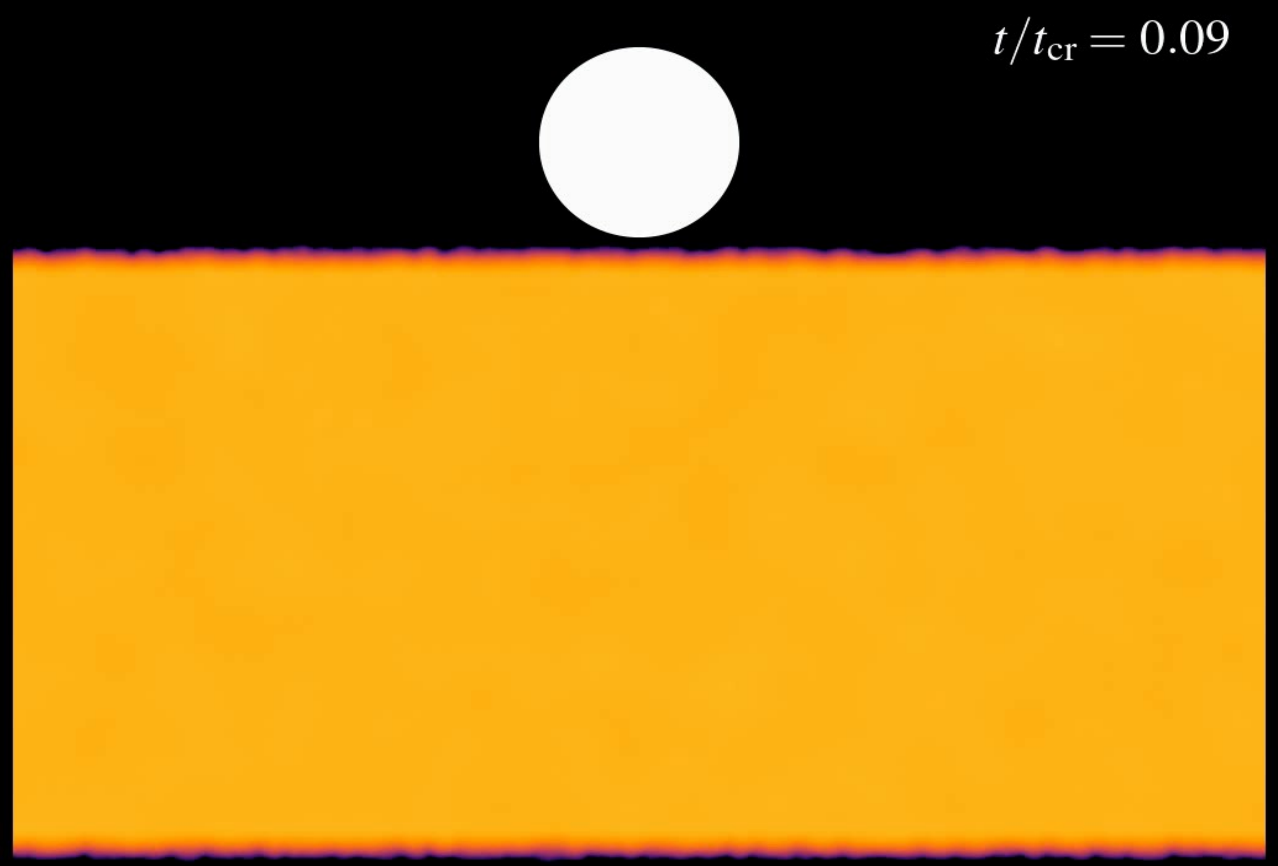
3D radiation-hydrodynamics simulation

$t_{cr} = 2(H+R_\star)/v_\star = 3$ min



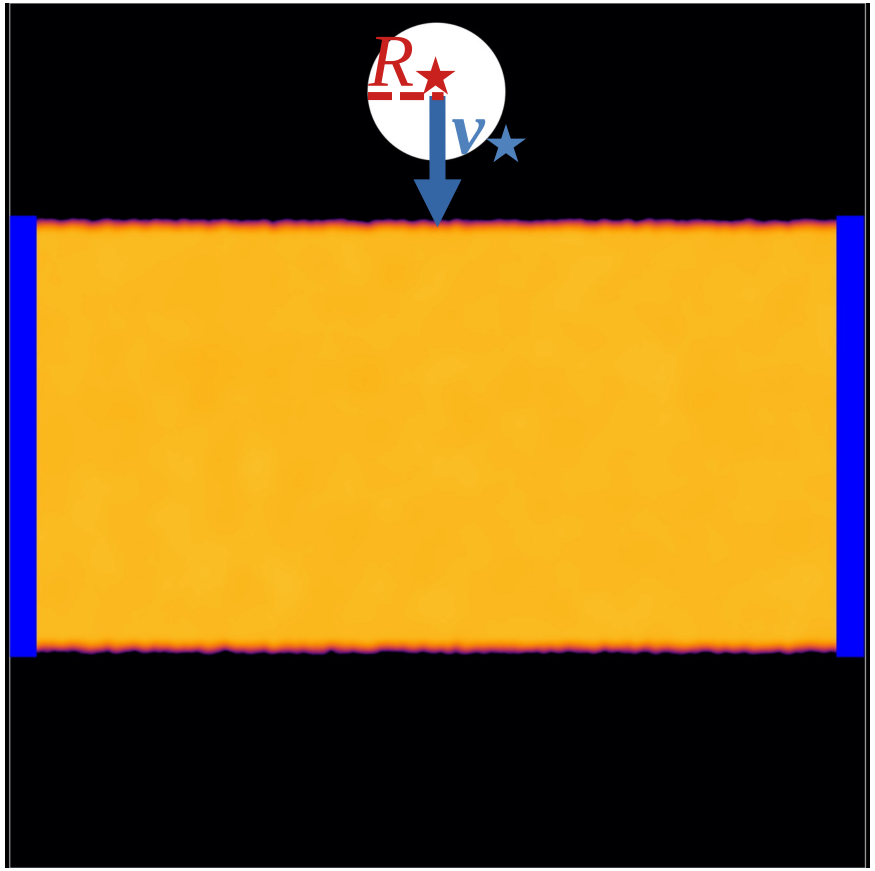
Disc: Stationary, uniform density (mass $M_0 = 10^{-7} M_\odot$), no gravity.

Star: Solid sphere, $R_\star = 1R_\odot$, $v_\star = 0.1c$, no gravity.

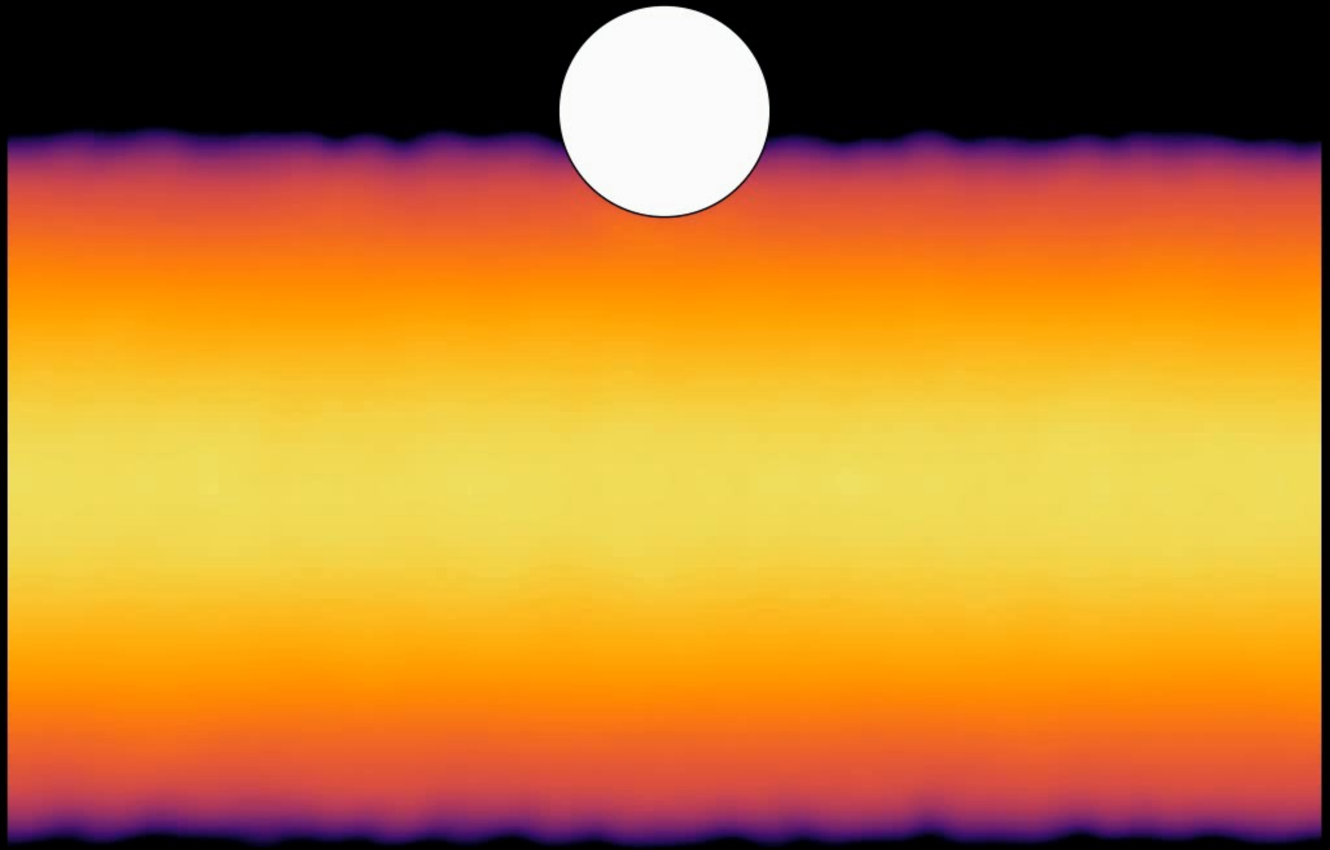

$t/t_{\rm cr} = 0.09$

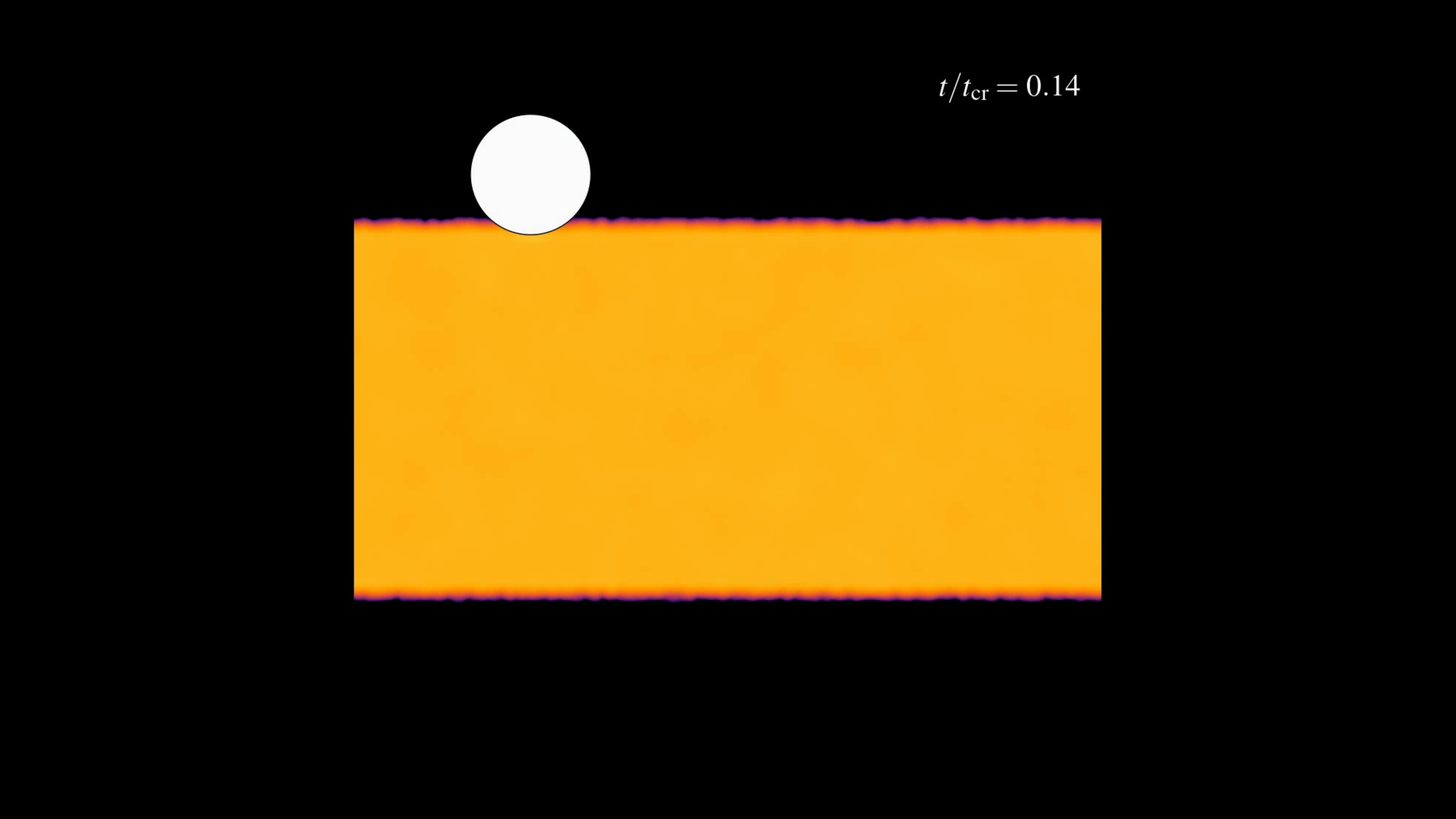
Effect of system parameters

- Stellar velocity
- Disc surface density
- Stellar radius
- Vertical disc density profile
- Inclination of the stellar orbit

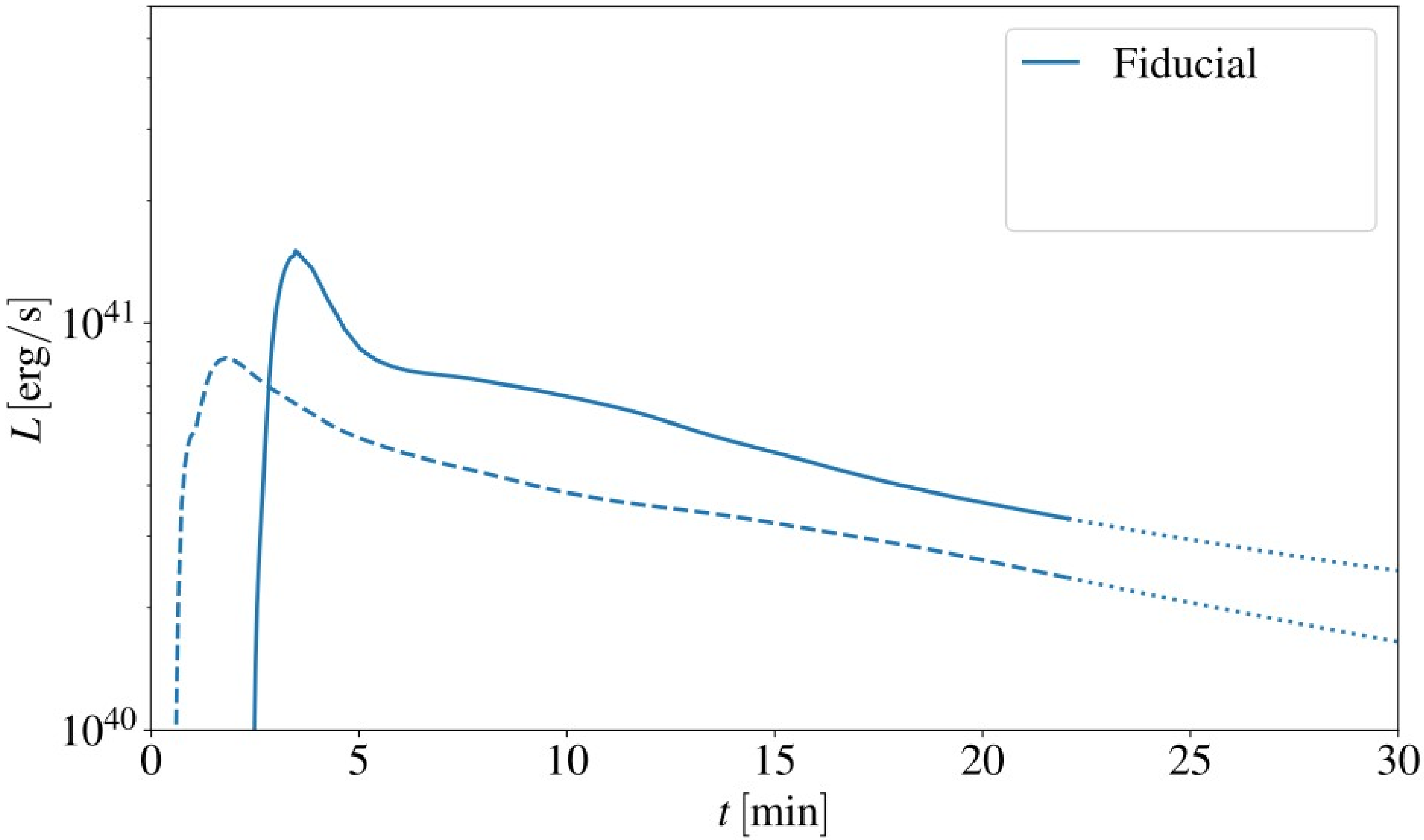


$t/t_{\mathrm{cr}} = 0.18$

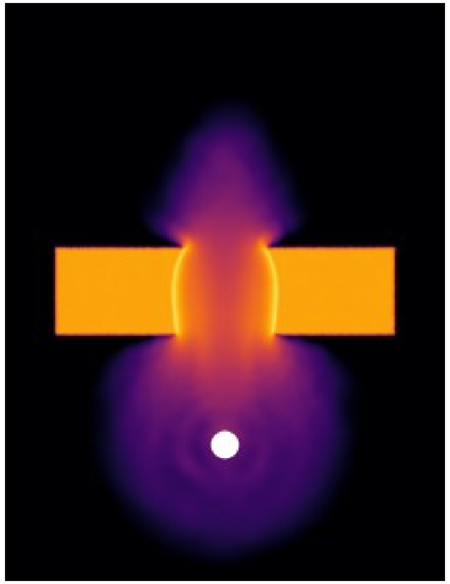



$t/t_{\rm cr} = 0.14$

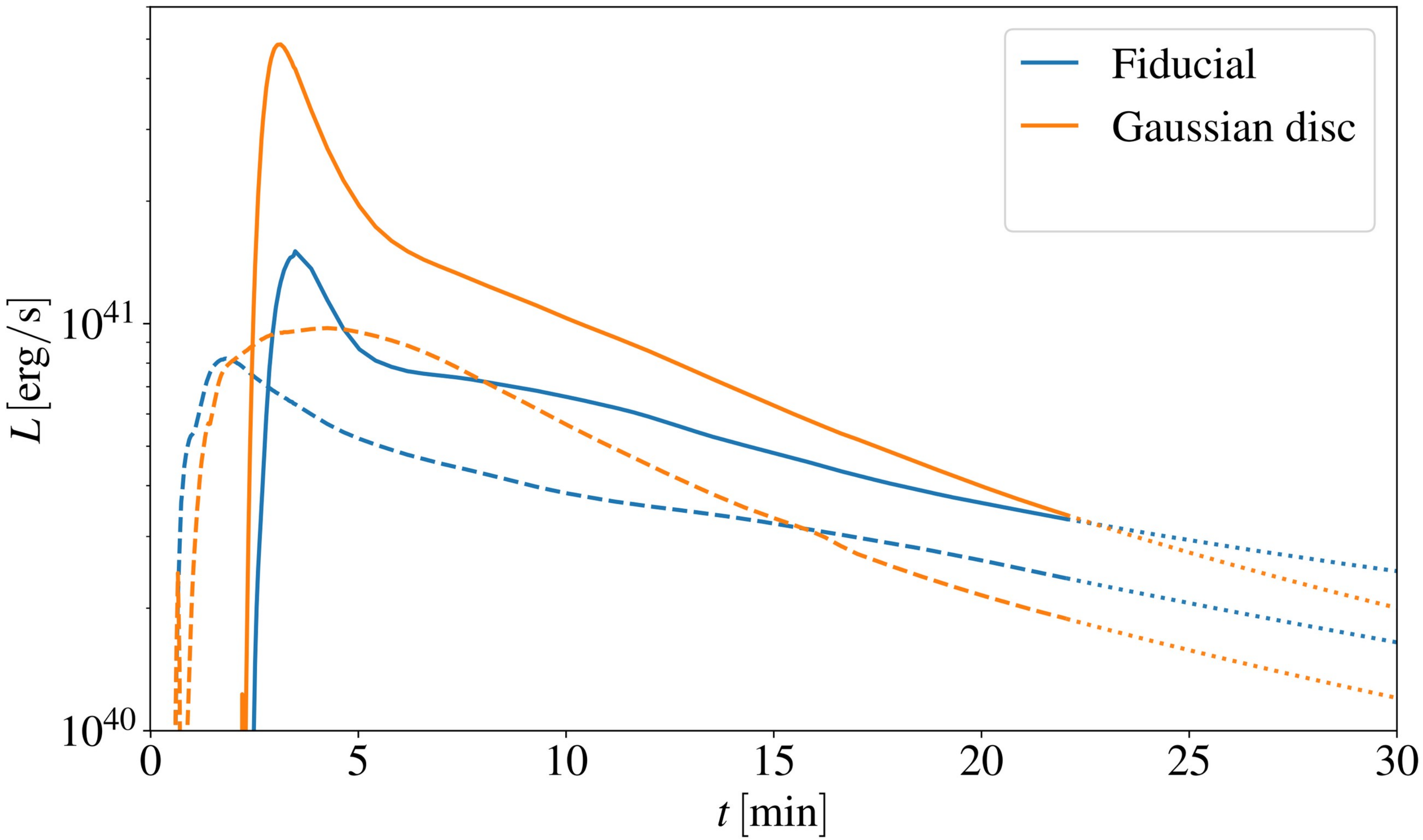
Lightcurve



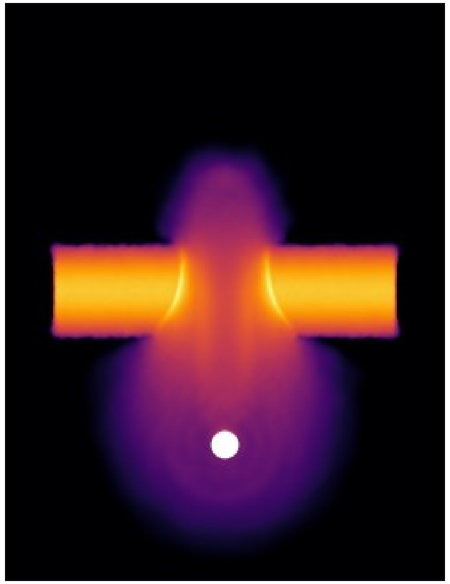
Peak of $L \sim 10^{41}$ erg/s.
Forward outflow $\sim$2x higher L.



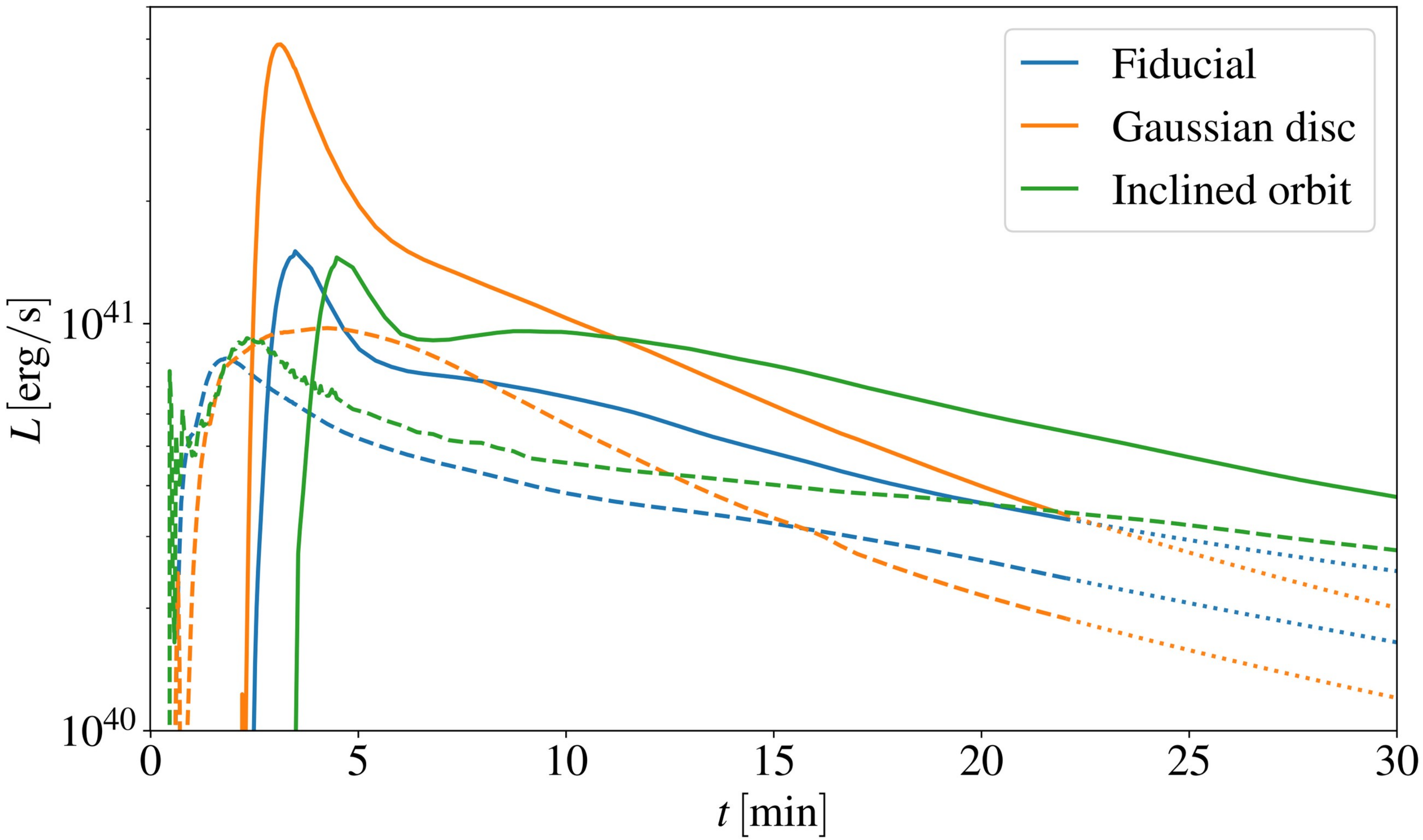
Lightcurve for a Gaussian density profile disc



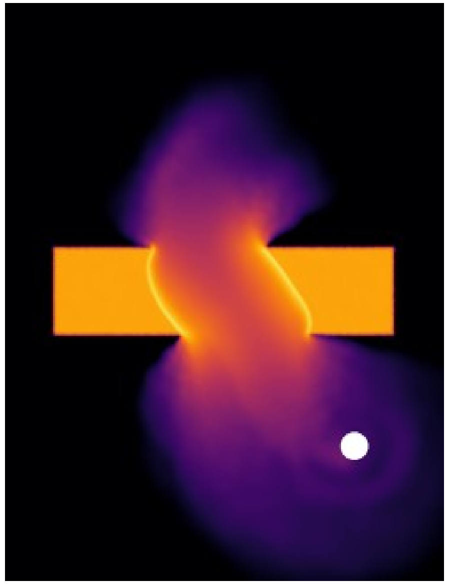
Brighter forward outflow.
Shorter flare durations.



Lightcurve for less inclined stellar orbit

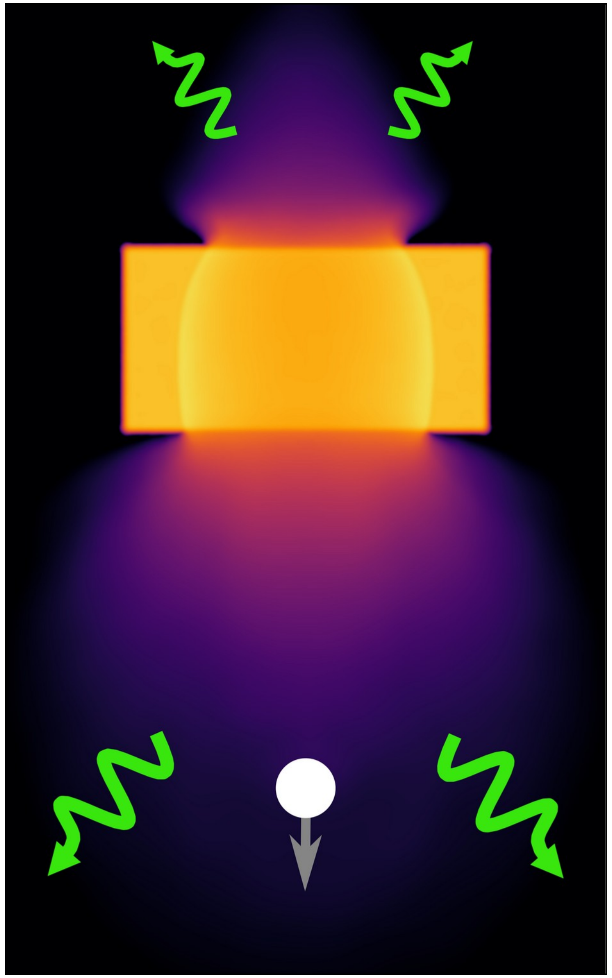


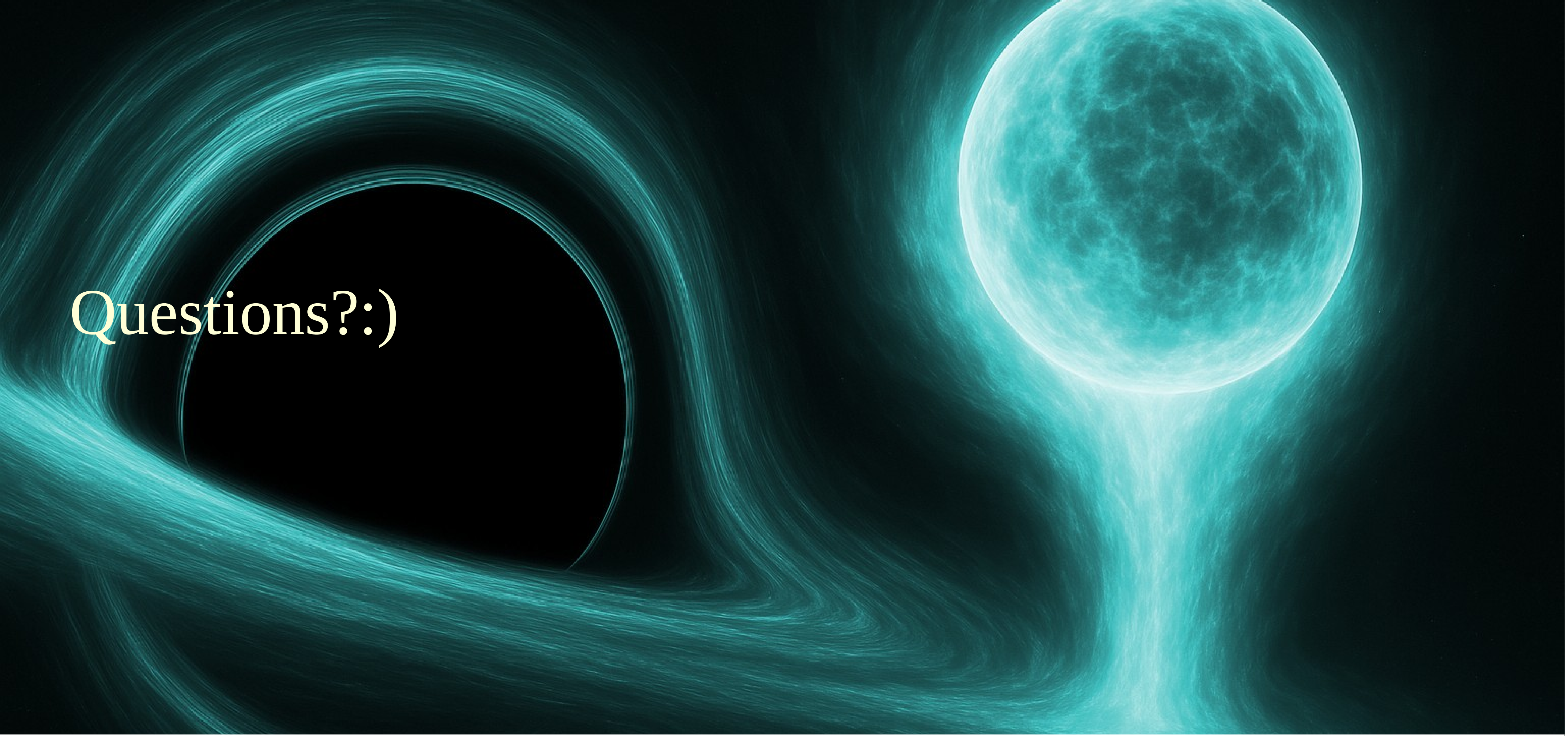
Brighter backward outflow.
Longer flare durations.



Summary

- The collision drives asymmetric outflows of gas.
- Forward outflow carries more momentum.
- Forward outflow is typically brighter.
- Collision is strongly affected by system parameters.
- Star-disc collisions can explain main features of observed QPEs.

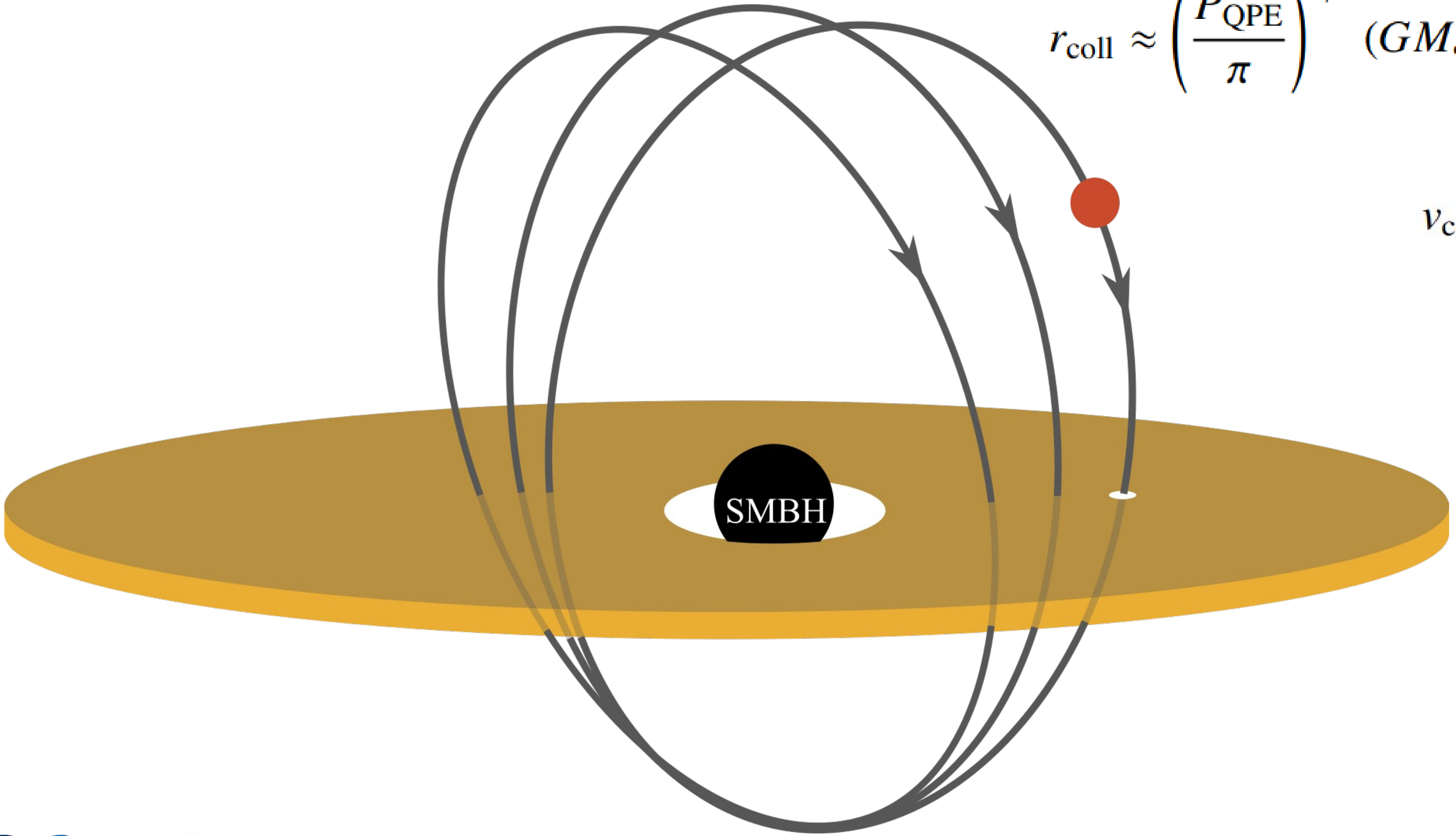




Questions?:)

FZU
PHYSICS FOR FUTURE
Co-funded by the European Union
MŠMT
MINISTRY OF EDUCATION, YOUTH AND SPORTS

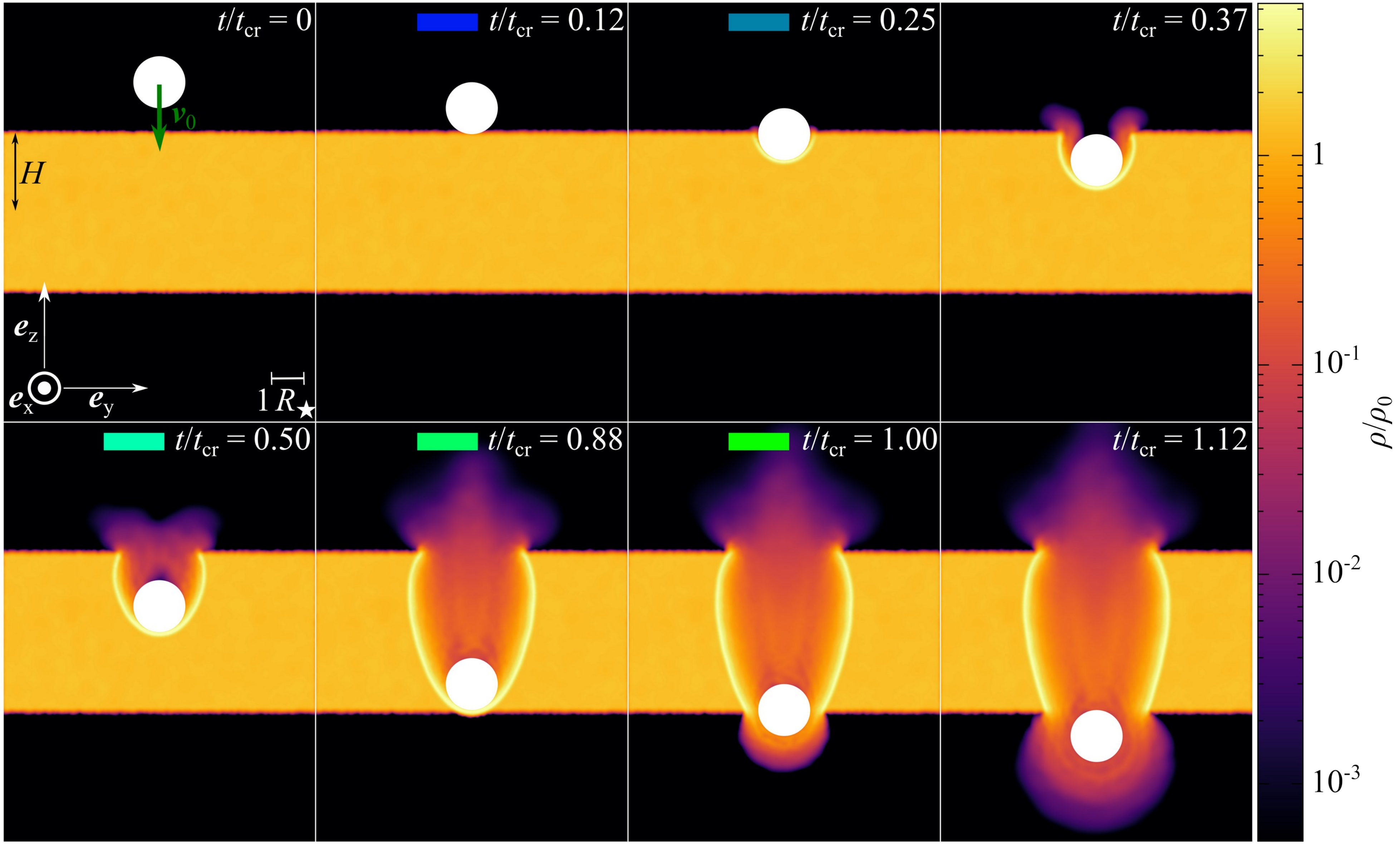
Star-disc collisions model



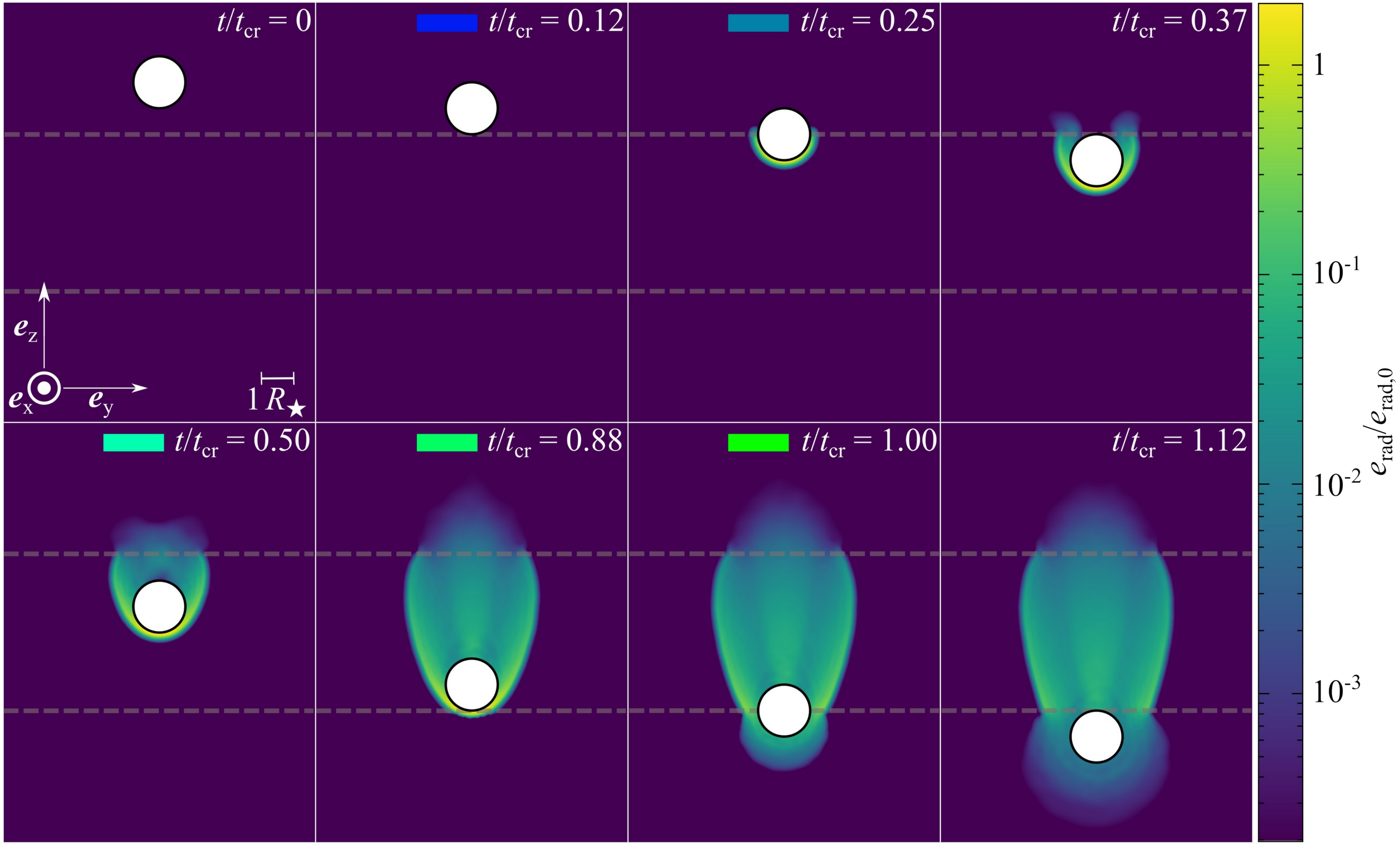
$$r_{\mathrm{coll}} \approx \left(\frac{P_{\mathrm{QPE}}}{\pi}\right)^{2/3} (GM_\bullet)^{1/3} \approx \underline{100R_g} \left(\frac{P_{\mathrm{QPE}}}{4\,\mathrm{h}}\right)^{2/3} \left(\frac{M_{\mathrm{bh}}}{10^6\,M_\odot}\right)^{-2/3}$$

$$v_{\mathrm{coll}} \approx \left(\frac{GM_{\mathrm{bh}}}{r_{\mathrm{coll}}}\right)^{1/2} \approx \underline{0.14c} \left(\frac{r_{\mathrm{coll}}}{100R_g}\right)^{-1/2}$$

$$H \approx \underline{3R_\odot} \left(\frac{M_{\mathrm{bh}}}{10^6\,M_\odot}\right) \left(\frac{\dot{M}}{0.1\dot{M}_{\mathrm{Edd}}}\right)$$



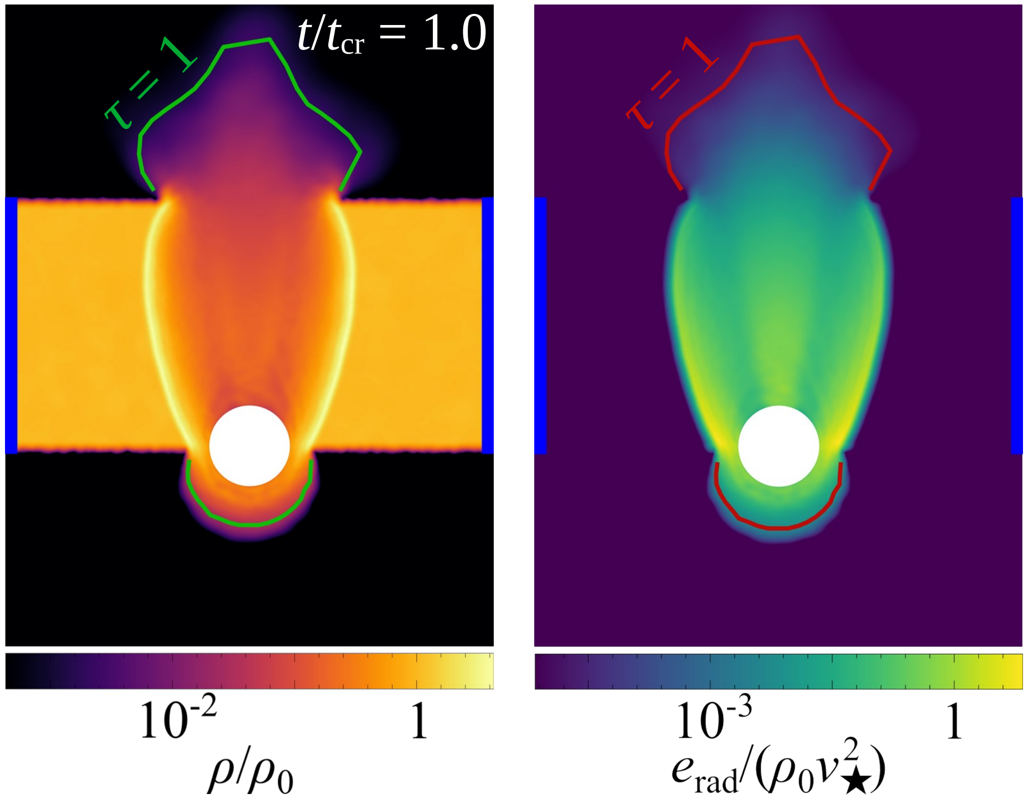
$t/t_{cr} = 0$
$t/t_{cr} = 0.12$
$t/t_{cr} = 0.25$
$t/t_{cr} = 0.37$
$t/t_{cr} = 0.50$
$t/t_{cr} = 0.88$
$t/t_{cr} = 1.00$
$t/t_{cr} = 1.12$
v_0
H
e_z
e_x
e_y
$1\,R_\star$
1
10^{-1}
10^{-2}
10^{-3}
ρ/ρ_0



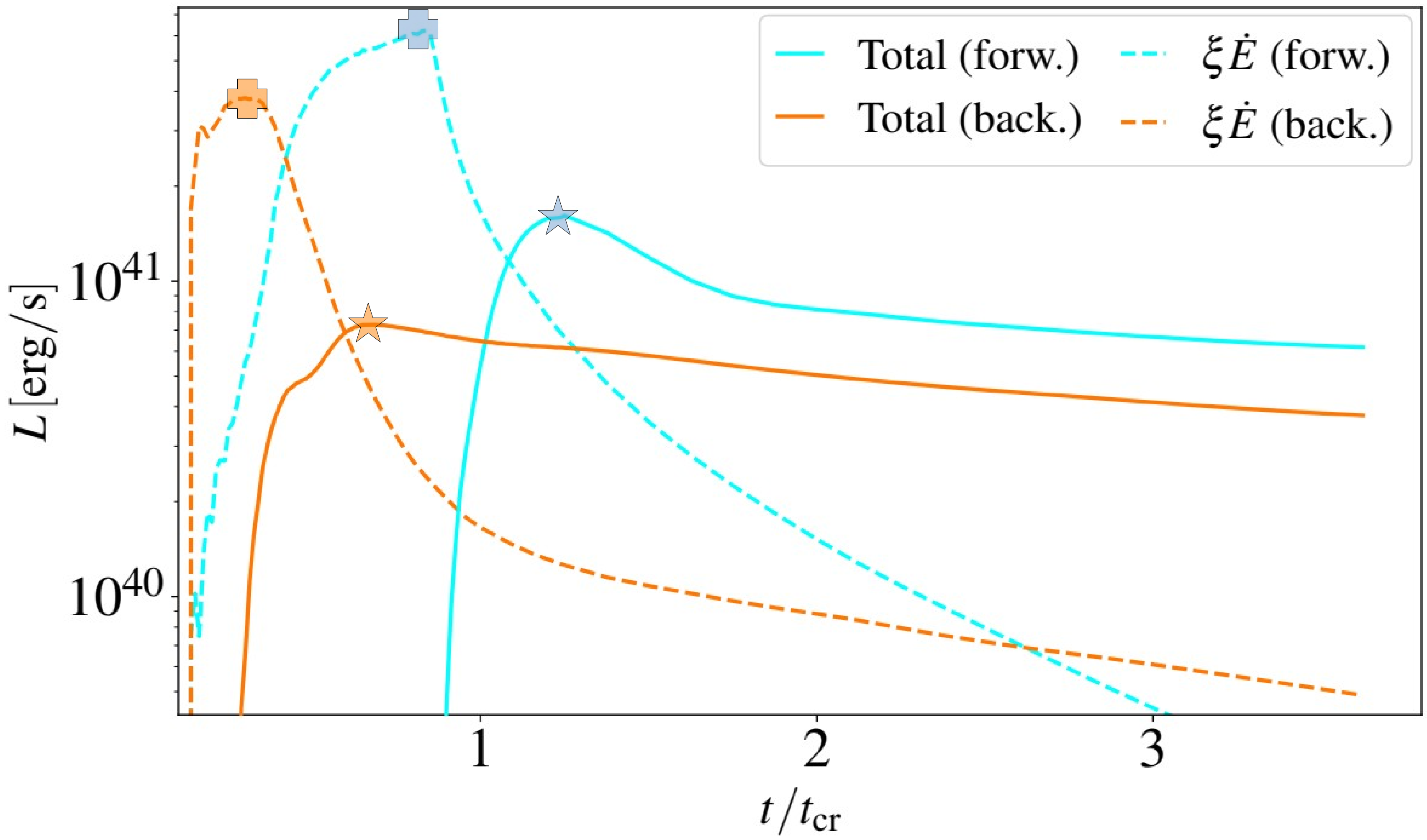
t/t_cr = 0
t/t_cr = 0.12
t/t_cr = 0.25
t/t_cr = 0.37
t/t_cr = 0.50
t/t_cr = 0.88
t/t_cr = 1.00
t/t_cr = 1.12
e_z
e_x
e_y
1 R★
1
10^-1
10^-2
10^-3
e_rad/e_rad,0

Lightcurve

Radiation transported via advection and diffusion.
Luminosity: Integrate total radiation flux across the photosphere (optical depth $\tau = 1$).



Lightcurve



Similar adiabatic losses.
Forward ejected gas ~2x higher shock heating rate $\dot{E}$.

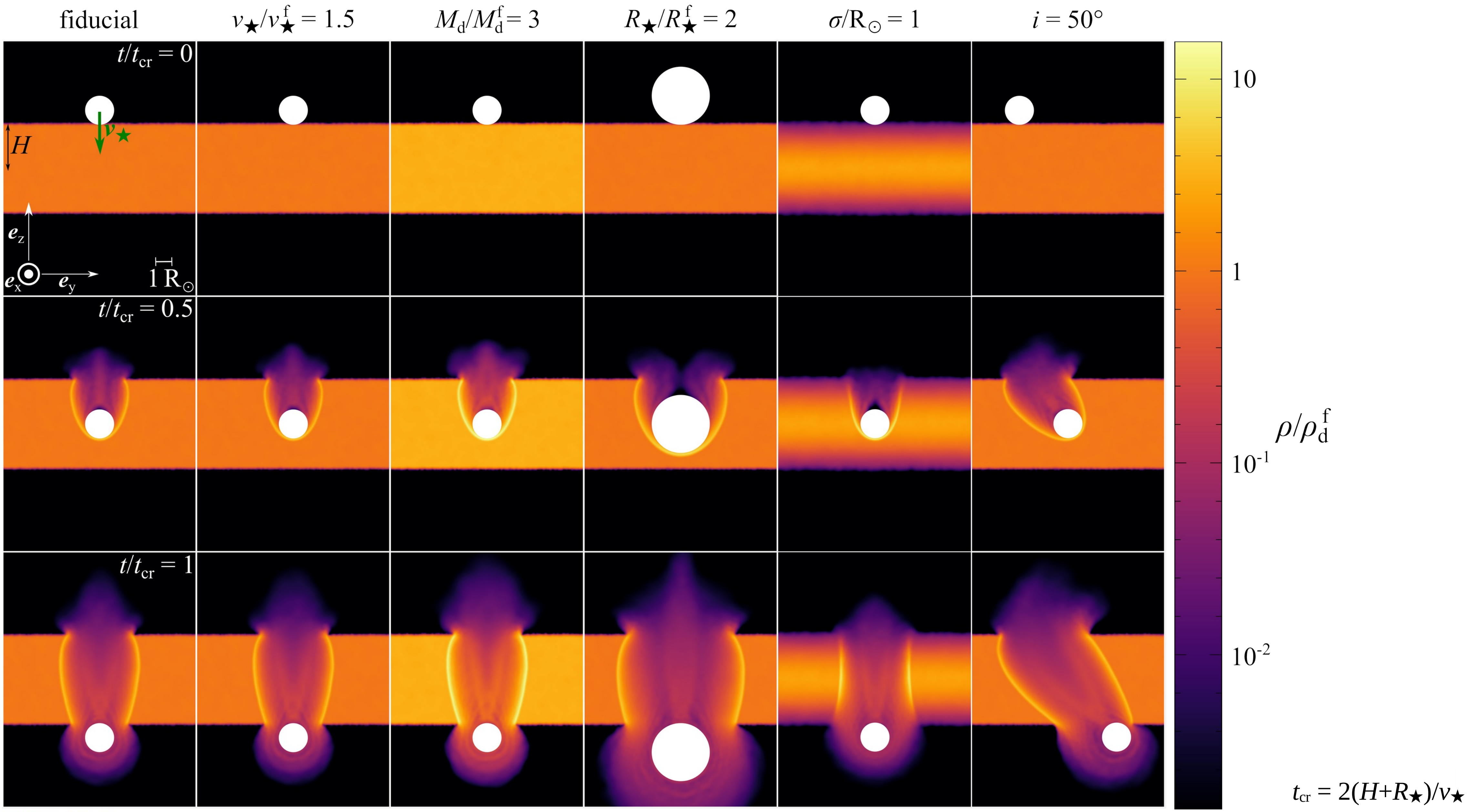
adiabatic losses

$$L \sim \eta \dot{E}_0$$

shock heating rate

Effect of system parameters

Parameter	Fiducial value	Values w.r.t. fiducial
Stellar velocity $v_\star$	$0.1\,c$	0.5, 0.75, 1, 1.25, 1.5
Disc mass M_d	$1.2 \times 10^{-7}\,M_\odot$	1, 3, 10, 30, 100
Stellar radius $R_\star$	$1\,R_\odot$	0.5, 1, 2, 3, 4
Gaussian width $\sigma/R_\odot$	uniform	∞, 2.5, 2, 1.5, 1
Inclination i	90°	90°, 80°, 70°, 60°, 50°


fiducial
$v_\star/v_\star^{\rm f} = 1.5$
$M_{\rm d}/M_{\rm d}^{\rm f} = 3$
$R_\star/R_\star^{\rm f} = 2$
$\sigma/{\rm R}_\odot = 1$
$i = 50°$
$t/t_{\rm cr} = 0$
$t/t_{\rm cr} = 0.5$
$t/t_{\rm cr} = 1$
H
$v_\star$
e_z
e_x
e_y
1 $R_\odot$
10
1
10^{-1}
10^{-2}
$\rho/\rho_{\rm d}^{\rm f}$
$t_{\rm cr} = 2(H+R_\star)/v_\star$

Effect of system parameters