1 Production runs on Stampede2

1.1 AstroBEAR code versions

1.1.1 J20

File name astrobear_20200724_1008. Three tracers tracking feedback, envelope, and ambient materials.

1.1.2 M21

File name astrobear_march2021update_20210402_1008. Mass of the companion particle m_2 reduces at the same rate as the jet adding material to the grids, $-\,\mathrm{d}m_2/\mathrm{d}t = \dot{M}_\mathrm{j}$.

1.1.3 A21

File name astrobear_april2021update_20210423_1008. Turn on accretion onto the companion particle.

- KRUMHOLZ_ACCRETION.
- Added a new parameter Fraction_MaxAccretionRate ($f_\mathrm{max,acc}$) in ParticleData of problem.data.
- Jet_masslossrate ($\dot{M}_\mathrm{j}$) is specified in JetData of problem.data.
- Particle%Feedback%MassLossRate is set to $\dot{M}_\mathrm{j}$ in problem.f90
- $\dot{M}_\mathrm{max,acc} = f_\mathrm{max,acc} \cdot \dot{M}_\mathrm{j}$
- $\dot{M}_\mathrm{acc} = \min\left(\dot{M}_\mathrm{BHL},\, \dot{M}_\mathrm{max,acc}\right)$
- The jet has fixed mass loss rate during the entire simulation. If the accretion alone cannot supply the jet ($\dot{M}_\mathrm{acc} < \dot{M}_\mathrm{j}$), then additional mass is taken from the companion particle m_2, that is: $-\,\mathrm{d}m_2/\mathrm{d}t = \dot{M}_\mathrm{j} - \dot{M}_\mathrm{acc}$.
- Default $f_\mathrm{max,acc} = 10$. Since we chose the fiducial value of $\dot{M}_\mathrm{j} = \dot{M}_\mathrm{Edd}$, the max accretion rate is then 10 times the Eddington rate.
- See Fig. 1

An alternative way to power the jet is to supply it by accretion alone. The jet will gradually build up to its full power $\dot{M}_\mathrm{j}$ at the beginning of the simulation when $\dot{M}_\mathrm{acc} \le \dot{M}_\mathrm{j}$:

- Do not specify Particle%Feedback%MassLossRate in problem.f90
- Instead, set Particle%Feedback%Efficiency ($f_\mathrm{jet,eff}$) in problem.f90
- Default $f_\mathrm{jet,eff} = 1/f_\mathrm{max,acc} = 0.1$, so that
- When $\dot{M}_\mathrm{acc} \le 10 \times \dot{M}_\mathrm{Edd}$, $\dot{M}_\mathrm{j}(t) = 0.1 \times \dot{M}_\mathrm{acc} \le \dot{M}_\mathrm{Edd}$

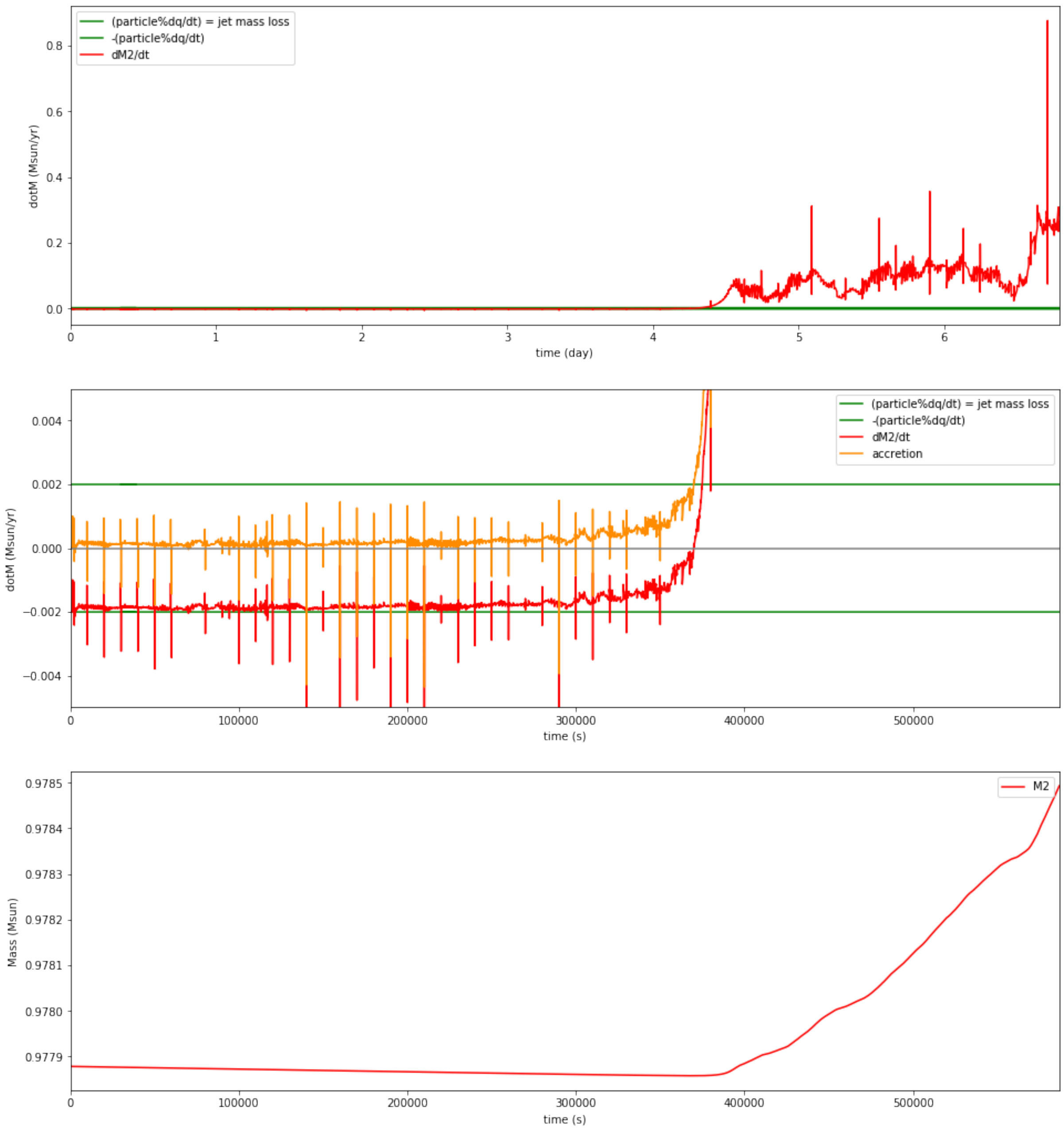

Figure 1: Test `astrobear_april2021update` with accretion turned on

$L_{\rm box}$	8×10^{13} cm	$1.15 \times 10^{3}\,{\rm R}_\odot$	
$l_{\rm base}$	1.562×10^{11} cm	$2.246\,{\rm R}_\odot$	
l_0	9.766×10^{9} cm	$0.1404\,{\rm R}_\odot$	level 4 cell
$r_{\rm soft}$	1.676×10^{11} cm	$2.409\,{\rm R}_\odot$	17.16 cells
R_1	3.350×10^{12} cm	$48.15\,{\rm R}_\odot$	
a_0	3.409×10^{12} cm	$49\,{\rm R}_\odot$	
m_1	7.298×10^{32} g	$0.367\,{\rm M}_\odot$	
m_2	1.945×10^{33} g	$0.978\,{\rm M}_\odot$	
$r_{\rm j}$	1.562×10^{11} cm	$2.246\,{\rm R}_\odot$	16 cells
$\theta_{\rm h}$	$\pi/12$	15°	
$T_{\rm j}$	1×10^{4} K		Tempscale = 1.53948e-8
$\dot{M}_{\rm j}$	$1.261 \times 10^{23}\,{\rm g\,s^{-1}}$	$2 \times 10^{-3}\,{\rm M}_\odot\ {\rm yr}^{-1}$	
$v_{\rm j}$	$8.64 \times 10^{7}\,{\rm cm\,s^{-1}}$	$864\,{\rm km\,s^{-1}}$	

Table 1: Parameters for the new jet models J1 (Run016) and J3 (Run015), with conversions between cgs units and common units.

Run#	Code	Model	Type	$M_2(t=0)$ [$0.978\,\mathrm{M}_\odot$]	r_j [δ_0]	$\dot{M}_\mathrm{j}$ [$10^{-3}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$]	$\dot{M}_\mathrm{acc}$ (1)	$\dot{M}_2$	v_j [$\mathrm{km\,s^{-1}}$]	θ_h [°]	$\dot{M}_\mathrm{j}/\dot{M}_\mathrm{Edd}$	R_2 [$\mathrm{R}_\odot$]	Q	Q_eff
016	M21	J1	MS	1	1	2	0	$-\dot{M}_\mathrm{j}$	864	15	~ 1	1	2	2
011	J20	NJ1	—	1	—	—	—	—	—	—	—	—	—	—
019	M21	J2	MS	0.5	1	2	0	$-\dot{M}_\mathrm{j}$	864	15	~ 2	0.5	≈ 2.24	2
013	J20	NJ2	—	0.5	—	—	—	—	—	—	—	—	—	—
015	M21	J3	MS	1	1	2	0	0	864	15	~ 1	1	2	2
021	A21	J4	MS	1	1	2	Y	$\boldsymbol{\dot{M}_\mathrm{acc} - \dot{M}_\mathrm{j}}$	864	15	~ 1	1	2	2
020	A21	J5	MS	1	1	**20**	Y	$\boldsymbol{\dot{M}_\mathrm{acc} - \dot{M}_\mathrm{j}}$	864	15	$\boldsymbol{\sim 10}$	1	2	2
017	M21	J6	MS	1	1	2	0	$-\dot{M}_\mathrm{j}$	1728	15	~ 1	1	4	4
018	M21	J7	MS	1	1	2	0	$-\dot{M}_\mathrm{j}$	864	30	~ 1	1	2	2
	A21	J8	WD	1	1	0.02	Y	$\boldsymbol{\dot{M}_\mathrm{acc} - \dot{M}_\mathrm{j}}$	8640	15	~ 1	0.01	≈ 2.45	2
	A21	J9	NS	1	1	0.32	Y	$\boldsymbol{\dot{M}_\mathrm{acc} - \dot{M}_\mathrm{j}}$	3×10^4	15	$\sim 10^4$	1.6×10^{-5}	≈ 1.44	≈ 0.278
	A21	J10	NS	1	1	**32**	Y	$\boldsymbol{\dot{M}_\mathrm{acc} - \dot{M}_\mathrm{j}}$	3×10^4	15	$\boldsymbol{\sim 10^6}$	1.6×10^{-5}	≈ 1.44	≈ 0.278

Table 2: Models labeled with 'J' refer to runs with a jet, and those labeled with 'NJ' refer to runs without a jet. For all runs, $r_\mathrm{soft} = 2.41\,\mathrm{R}_\odot$ and $T = 10^4\,\mathrm{K}$. The base resolution $\delta_0 = 2.25\,\mathrm{R}_\odot$. Model J8 with $R_2 = 0.01\,\mathrm{R}_\odot$ is the WD model. Model J9 with $R_2 = 1.6 \times 10^{-5}\,\mathrm{R}_\odot = 11.1\,\mathrm{km}$ is the NS model. The jet radial velocity is given by $v_\mathrm{j} = Q_\mathrm{eff}\sqrt{GM_2/R_2}$. (1): 'Y' means $\dot{M}_\mathrm{acc} = \boldsymbol{\min(10\dot{M}_\mathrm{j},\, \dot{M}_\mathrm{BHL})}$

Run#	Code	Model	$\dot{M}_\mathrm{j}$ [$10^{-3}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$]	v_j [$\mathrm{km\,s^{-1}}$]	t_vel [s]	ρ_j $\mathrm{g\,cm^{-3}}$]	t_adv s	t_den s
016	M21	J1	2	864	30	5×10^{-7}	2000	2000
		J2	2	864	30	5×10^{-7}	2000	2000
015	M21	J3	2	864	30	5×10^{-7}	2000	2000
		J4	2	748	30	2×10^{-7}	4000	4000
		J5	0.2	864	300	5×10^{-8}	2000	2000
017	M21	J6	2	1728	30	3×10^{-7}	1000	1000
018	M21	J7	2	864	120	1×10^{-7}	2000	2000
		J8	0.02	8640	3000	5×10^{-10}	200	200
		J9	0.32	3×10^4	200	2×10^{-9}	50	50

Table 3: Estimated jet initialization properties: Time required for jet to attain its input velocity $t_\mathrm{vel} \sim [4\pi\rho_\mathrm{amb} r_\mathrm{j}^3(1-\cos\theta_\mathrm{h})]/3\dot{M}_\mathrm{j}$; final density of jet $\rho_\mathrm{j} \sim \dot{M}_\mathrm{j}/2Av_\mathrm{j}$; time for the jet to advect out of the jet initialization region $t_\mathrm{adv} \sim r_\mathrm{j}/v_\mathrm{j}$, which is roughly equal to the time it takes for the density in the jet to reach ρ_j, i.e. $t_\mathrm{den} \sim 2V\rho_\mathrm{j}/\dot{M}_\mathrm{j} \sim V/Av_\mathrm{j} \sim r_\mathrm{j}/v_\mathrm{j}$.

2 BlueHive test runs

In test run we set the jet mass loss rate at $\dot{M} = 2\times10^{-3}$ $\mathrm{M}_\odot$ yr^{-1}, and the radial velocity at $v_j = 864$ $\mathrm{km\,s^{-1}}$

Each of the jet launching region is a spherical cone with radius of $r_j = 16$ grid cells, and (half) opening angle of $\theta = 30°$. Density of the jet material in the cone region is then

$\rho_j = \dot{M}/(2A_{cap}v_j) = \dot{M}/(2\times 2\pi r_j^2(1-\cos(\theta))\cdot v_j) = 3.5\times10^{-8}$ $\mathrm{g\,cm^{-3}}$

Ram pressure of the jet is $P_{ram} = \rho_j v_j^2 \sim 2.8\times10^8$ $\mathrm{dyn\,cm^{-2}}$ and force $F = \dot{M}v_j/2$. To accelerate the ambient material in each jet cone to v_j,

$t_{\rm acc} = v_j(\rho_{\rm amb}V_{\rm cone})/F \sim 355$ sec

run dir	run #	final time	final frame	Rjet	collimation	Mdot	Vjet	m2	rho_cone	p_th	p_ram	t_acc	t_vel
testnewfiducial	#14	1	1	16	pi/12	2d-3	864	0.978	1.396d-7	3.46d4	1.03d9	551	638
J3 (J1)	#15	100	10	16	pi/12	2d-3	864	0.978					
	#16	1000	100	16	pi/12	2d-3	864	0.978					
	#17	1d5	100	16	pi/12	2d-3	864	0.978					
testsmallP2	#31	1	1	16	pi/12	2d-3	864	0.489	1.40d-7	3.46d5	1.04d9	551	591
J2	#32	1000	100	16	pi/12	2d-3	864	0.489					
	#33	1d5	100	16	pi/12	2d-3	864	0.489					
testlargeRjet	#28	1	1	32	pi/12	2d-3	864	0.978	3.49d-8	8.65d4	2.58d8	4412	6056
J4	#29	1000	100	32	pi/12	2d-3	864	0.978					
	#30	1d5	100	32	pi/12	2d-3	864	0.978					
testlowMdot	#22	1	1	16	pi/12	2d-4	864	0.978	1.396d-8	3.46d4	1.03d8	5515	-15429
J5	#23	1000	100	16	pi/12	2d-4	864	0.978					
	#24	1d5	100	16	pi/12	2d-4	864	0.978					
testdoubleVr	#37	1	1	16	pi/12	2d-3	1728	0.978	6.98d-8	1.73d5	2.09d9	551	591
J6	#38	1000	100	16	pi/12	2d-3	1728	0.978					
	#39	1d5	100	16	pi/12	2d-3	1728	0.978					
testlargeangle	#11	100	10	16	pi/6	2d-3	864	0.978	3.55d-8	8.80d4	2.63d8	355	390
J7	#12	1000	100	16	pi/6	2d-3	864	0.978					
	#13	1d5	100	16	pi/6	2d-3	864	0.978					
testWD	#40	1	1	16	pi/36	2d-5	8640	0.978	1.25d-9	3096	9.34d8	73793	-90415
J8	#41	1000	100	16	pi/36	2d-5	8640	0.978					
	#42	1d5	100	16	pi/36	2d-5	8640	0.978					
testlowtemp	#18	1	1	16	pi/12	2d-3	864	0.978	1.396d-7	3.46d3	1.03d9	551	638
	#19	1000	100	16	pi/12	2d-3	864	0.978					
	#20	1d5	100	16	pi/12	2d-3	864	0.978					
	#21			16	pi/12	2d-3	864	0.978					
testpenciljet	#25	1	1	16	pi/36	2d-3	864	0.978	1.25d-6	3.10d6	9.34d9	737	901
	#26	1000	100	16	pi/36	2d-3	864	0.978					
	#27	1d5	100	16	pi/36	2d-3	864	0.978					

Table 4: Test runs on BlueHive.

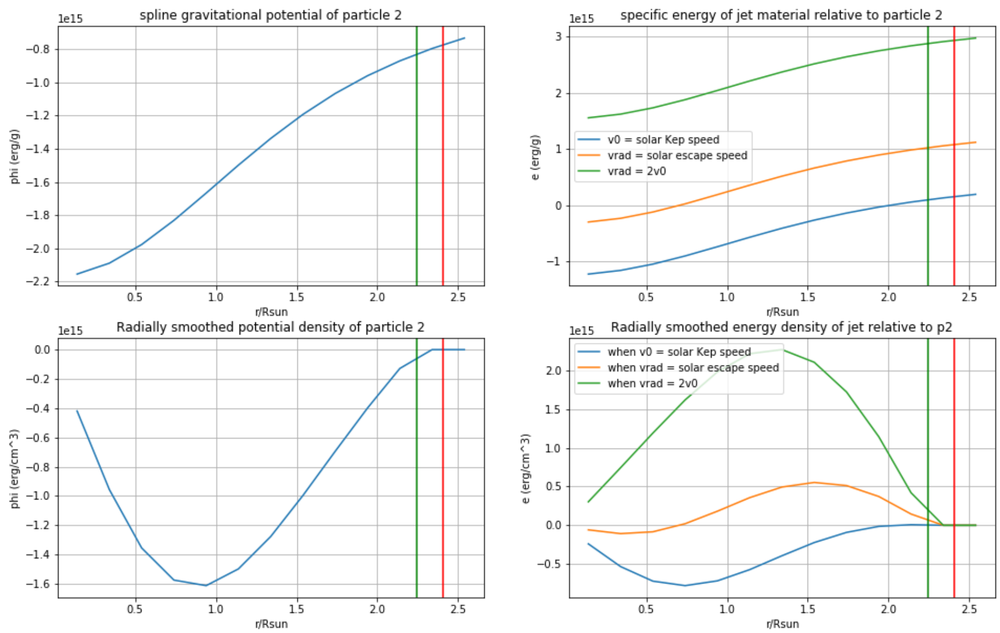

Figure 2: Jet potential relative to particle 2

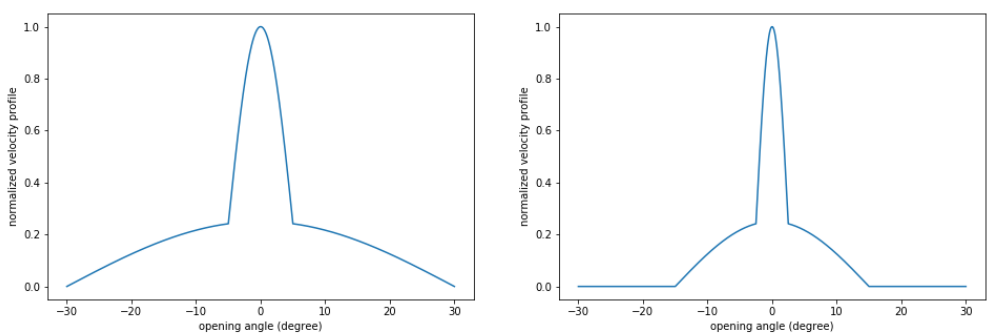

Figure 3: Angular distribution of normalized jet radial speed

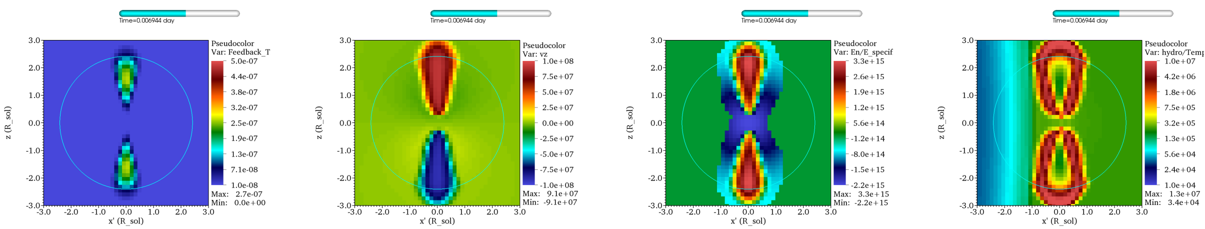

Figure 4: Test J3 (J1) as new fiducial, 600 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

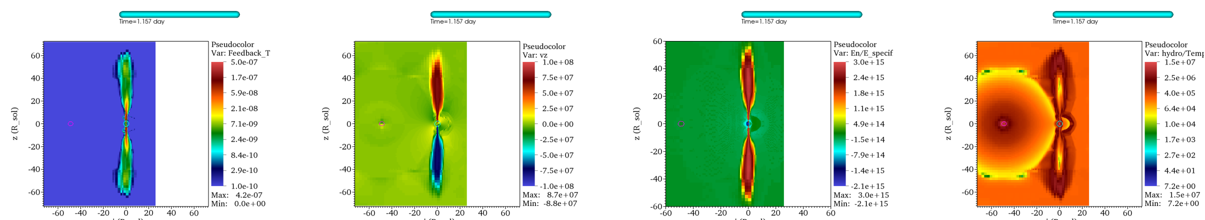

Figure 5: 1d5 sec

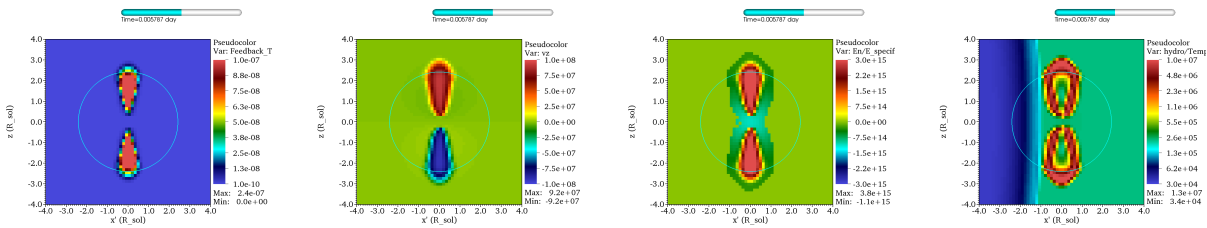

Figure 6: Test J2, M2=0.5Msun, 500 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

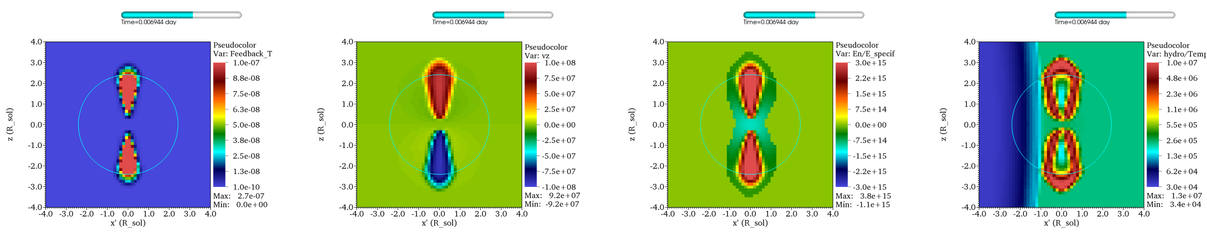

Figure 7: 600 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

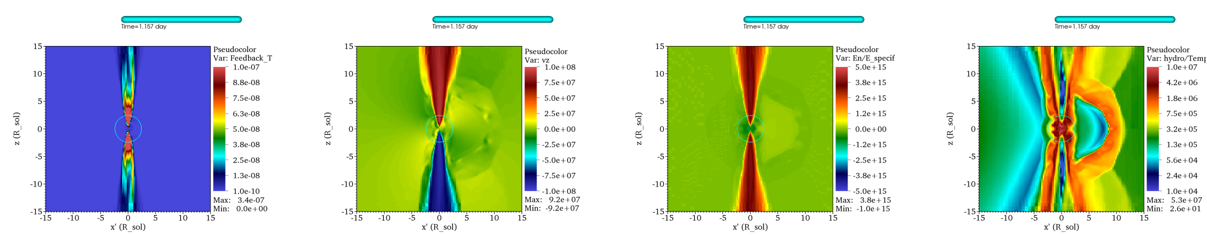

Figure 8: 1d5 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

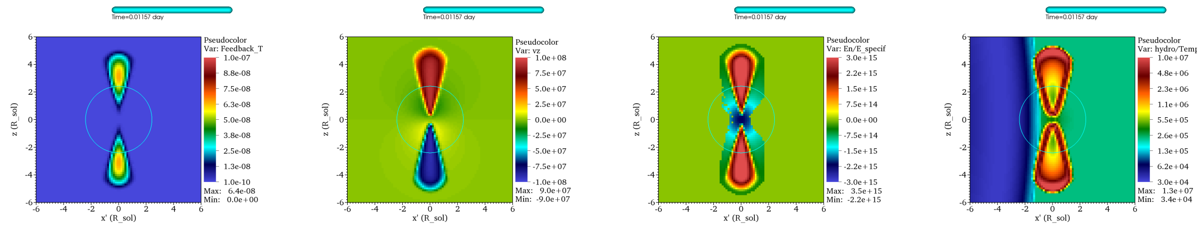

Figure 9: Test J4, Rjet=32, 1000 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

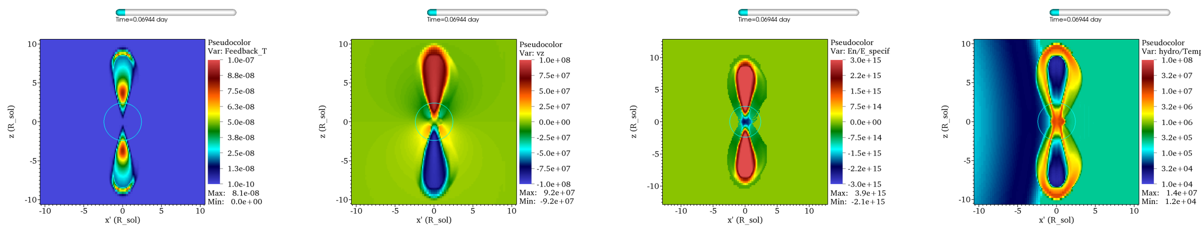

Figure 10: 6000 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

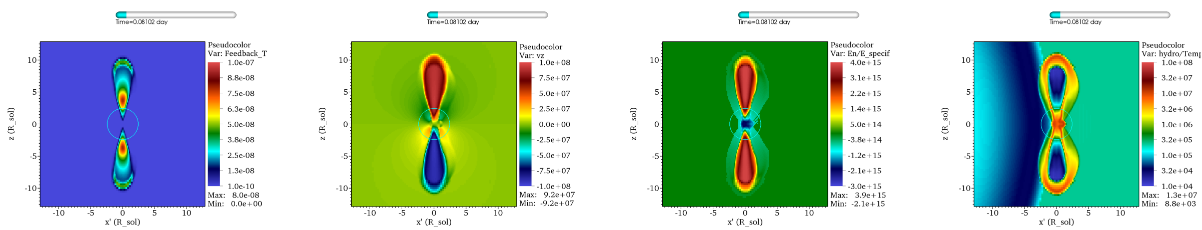

Figure 11: 7000 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

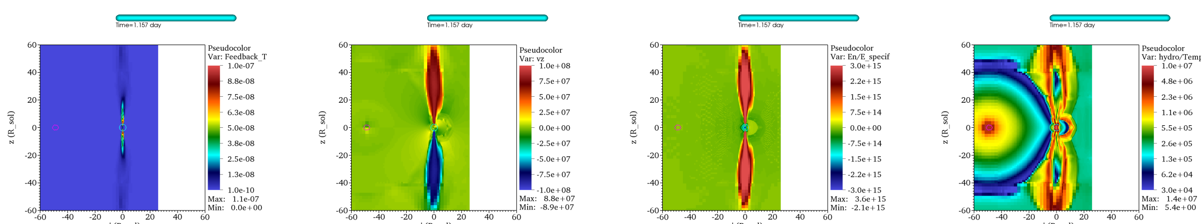

Figure 12: 1d5 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

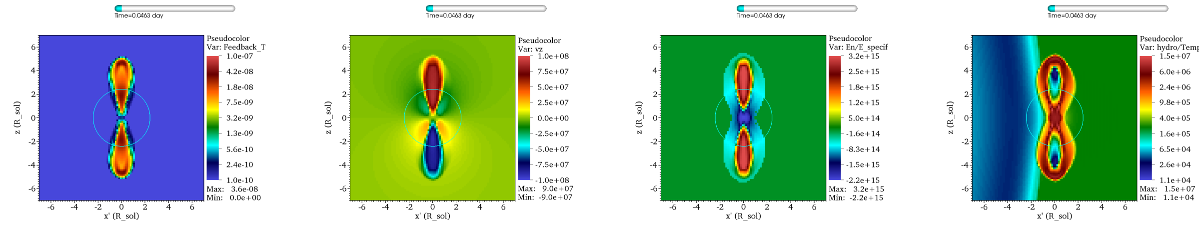

Figure 13: Test J5, lower Mdot = 2d-4, 4000 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

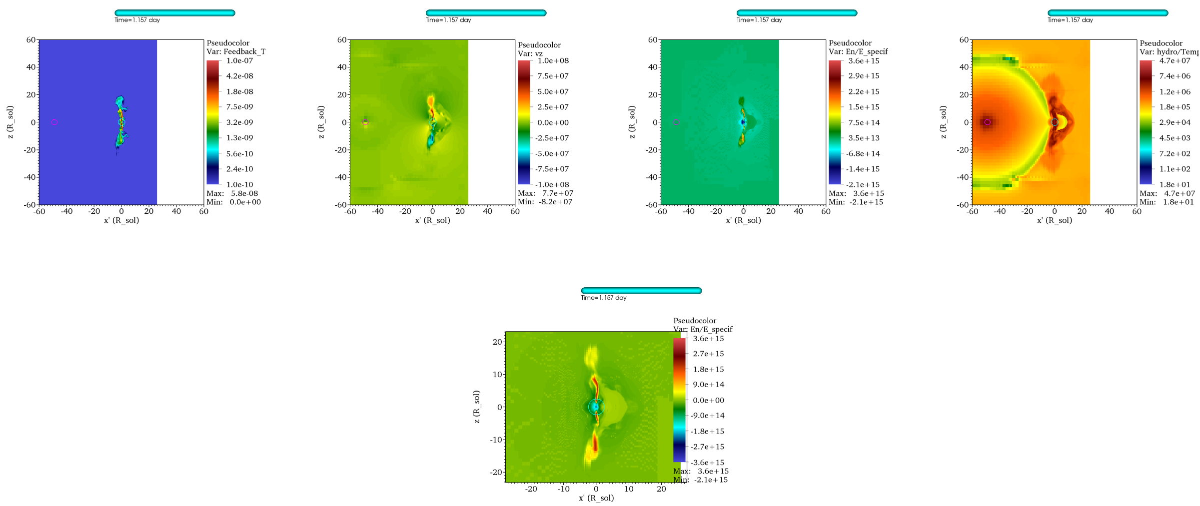

Figure 14: 1d5 sec

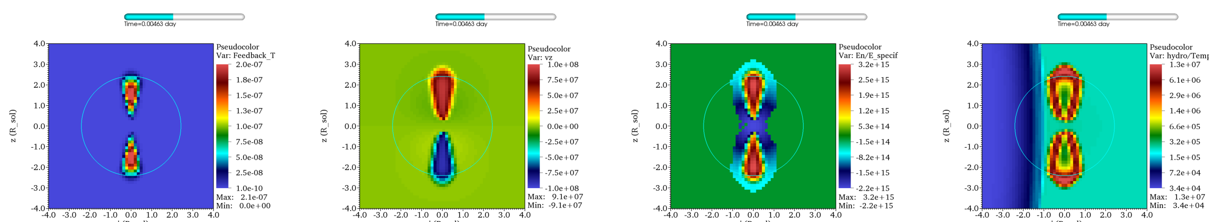

Figure 15: Test J6, double Vjet=1728, 400 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

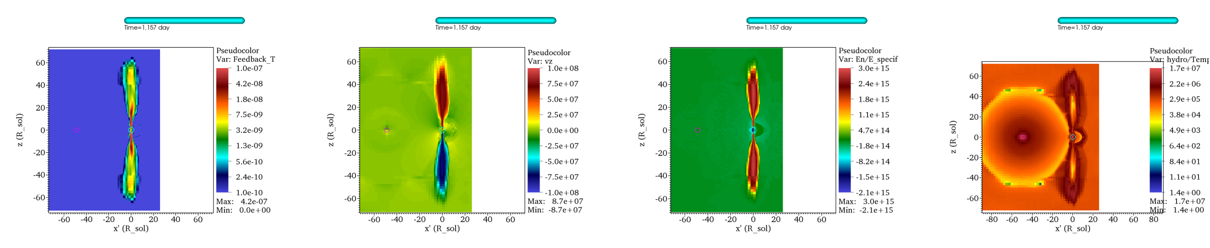

Figure 16: 1d5 sec

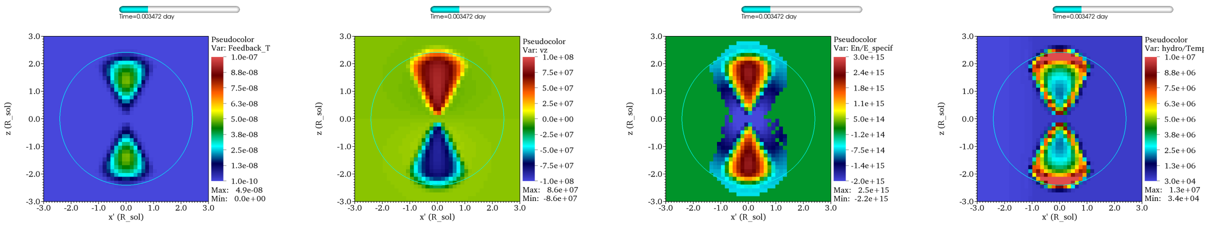

Figure 17: Test J7, theta=30, 300 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

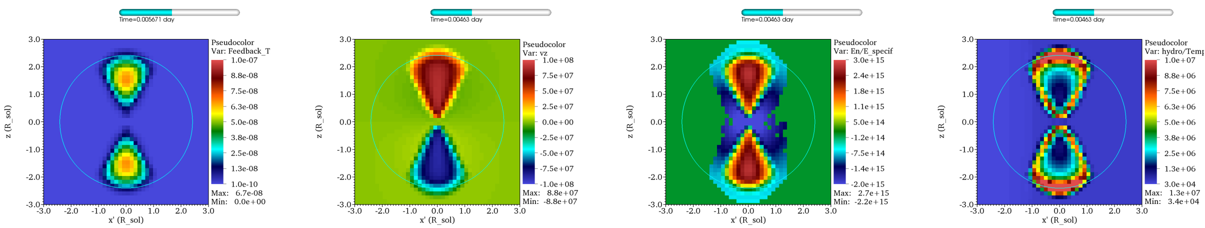

Figure 18: 400 sec

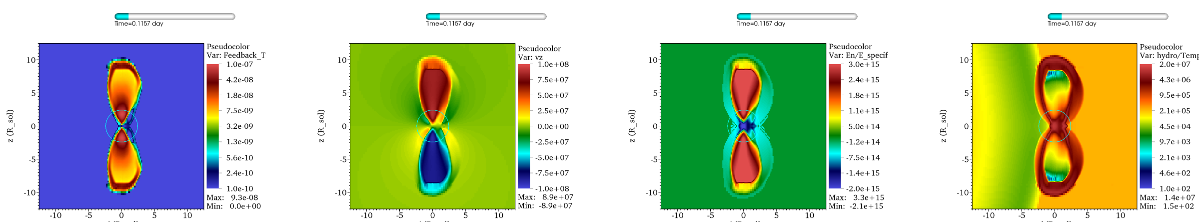

Figure 19: 1d4 sec

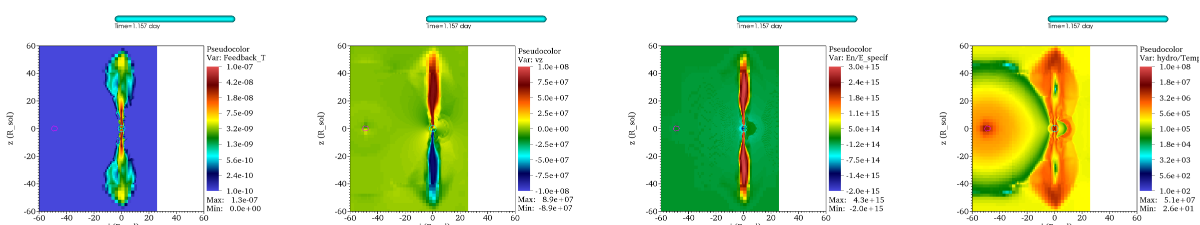

Figure 20: 1d5 sec

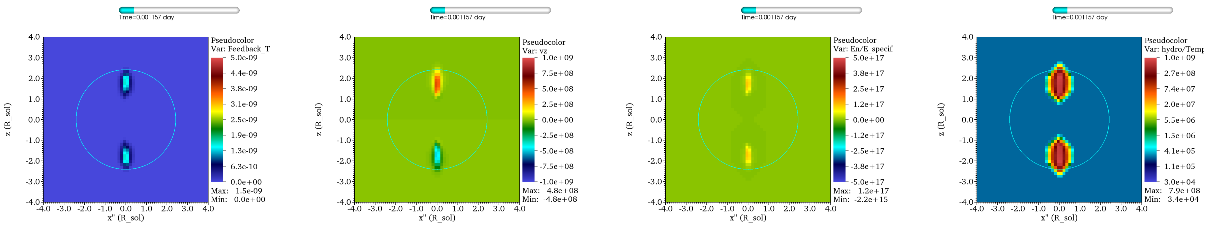

Figure 21: Test WD pencil beam, 100 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

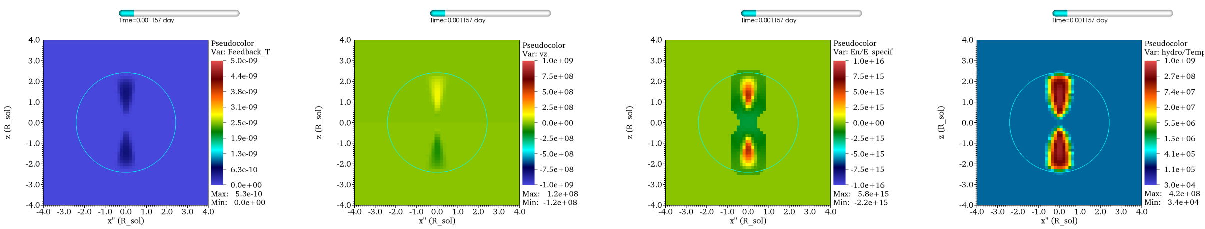

Figure 22: Test WD, J8, 100 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

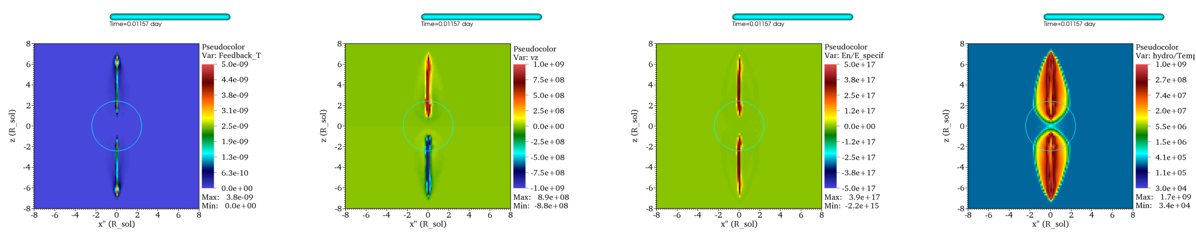

Figure 23: Test WD pencil beam 1000 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

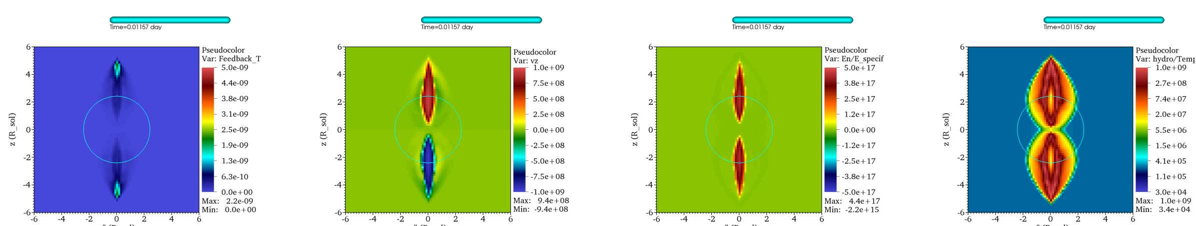

Figure 24: Test WD, J8, 1000 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

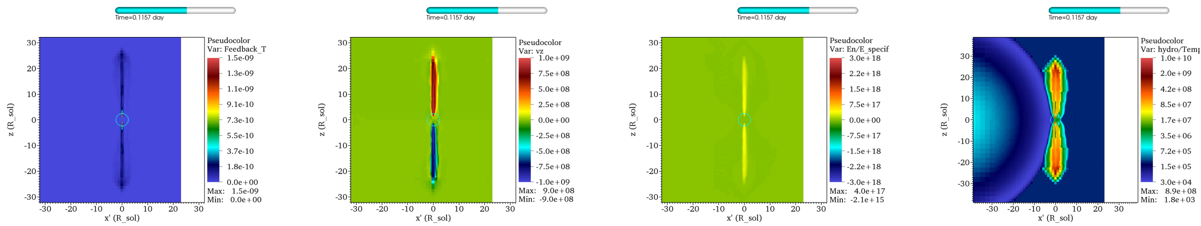

Figure 25: 1d4 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

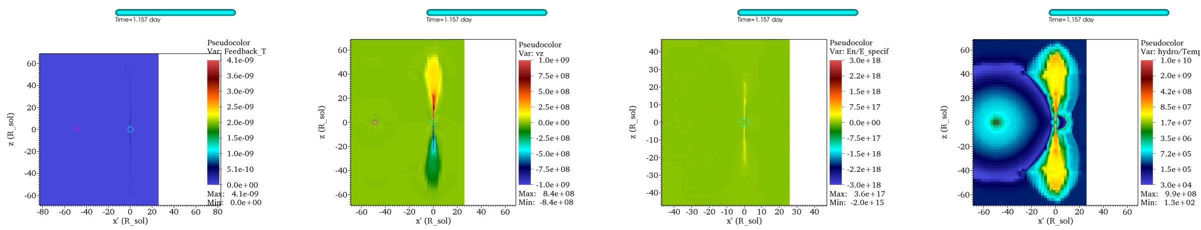

Figure 26: 1d5 sec. 1: Jet density. 2: gas vz. 3: jet specific energy (bulk + potential relative to particle 2). 4: gas temperature.

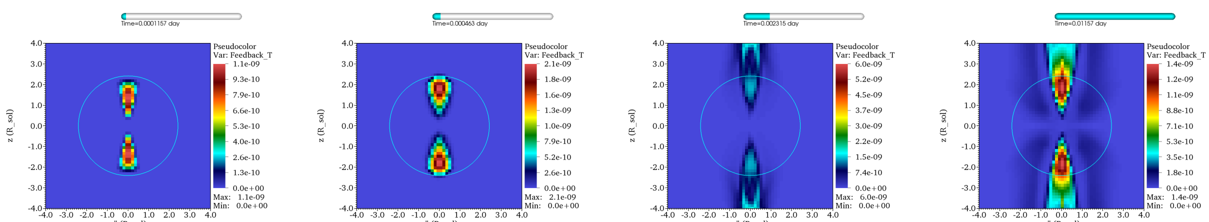

Figure 27: Test, NS, jet density at time 10, 40, 200, 1000 seconds.

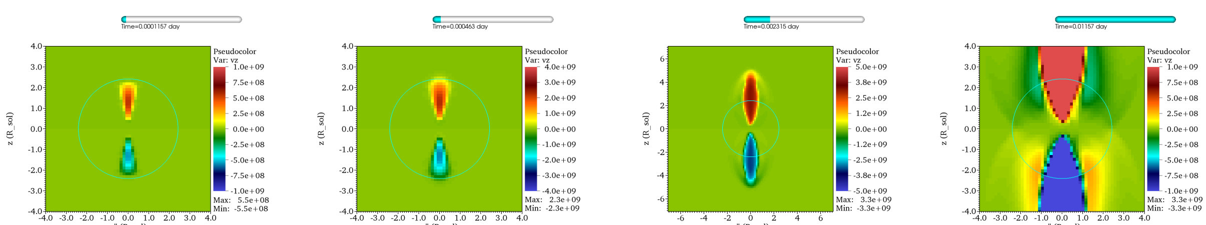

Figure 28: Test, NS, jet density at time 10, 40, 200, 1000 seconds.