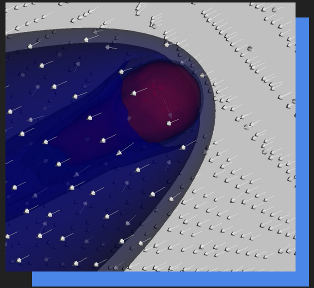
INSTITUTO DE ASTRONOMIA, GEOFÍSICA E CIÊNCIAS ATMOSFÉRICAS

Ultra Fast Neutron Stars



Maria Victoria del Valle

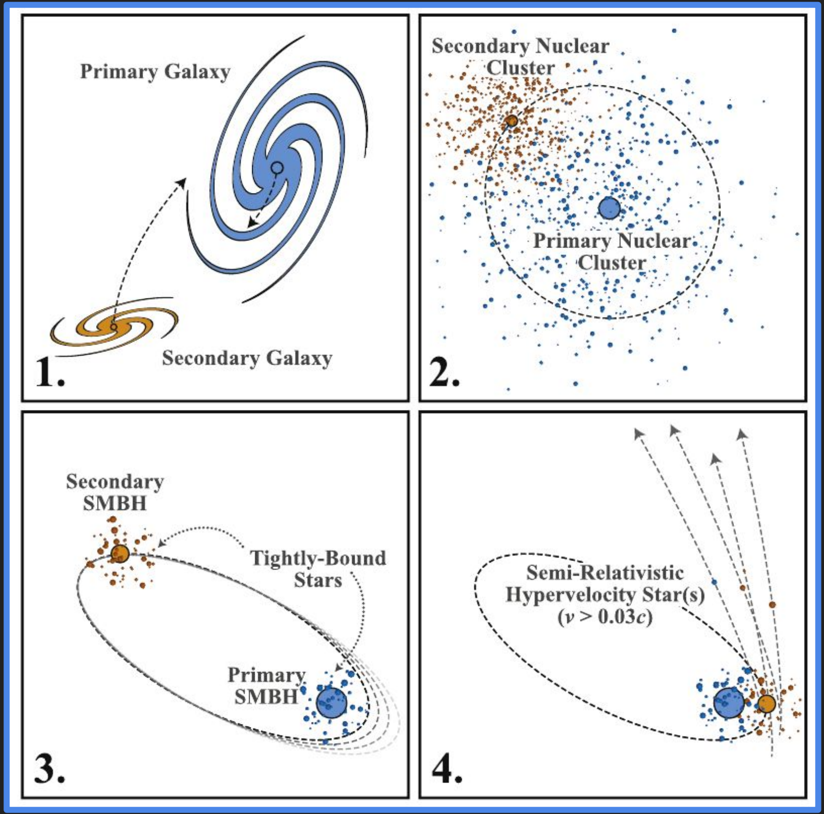
IAG Universidade de São Paulo

Flor Vieyro & Gustavo Romero

HEPRO VIII

Stars with very high velocities

Hills Mechanism
(Hills 1988)



Guillochon & Loeb (2015)

Confirmation hyper velocity stars

Modified:

Semi-relativistic hypervelocity stars

SHS

V ~ ⅓ c

Implications

Mechanism produces SHS

Statistic indicates that the density is enough for detection at a few Mpc

- The only mechanism such high velocities
- Can be used as cosmological messengers

Stars evolve, becoming compact objects:

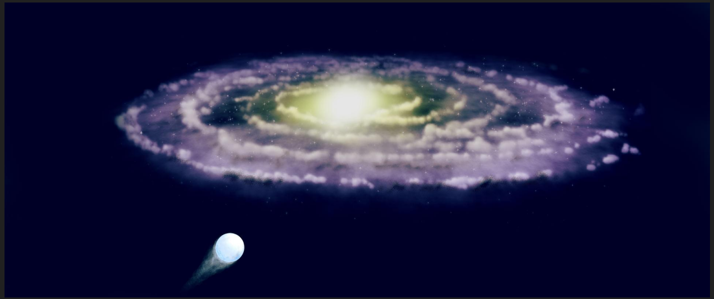
How can we detect a SH-neutron star?

Kinetic energy carried

M = 1.4 Msun

V = 40 000 km/s

E_{kin} = 10^52 erg !



M = 1.4 Msun

V = 100 000 km/s

E_{kin} = 10^53 erg !

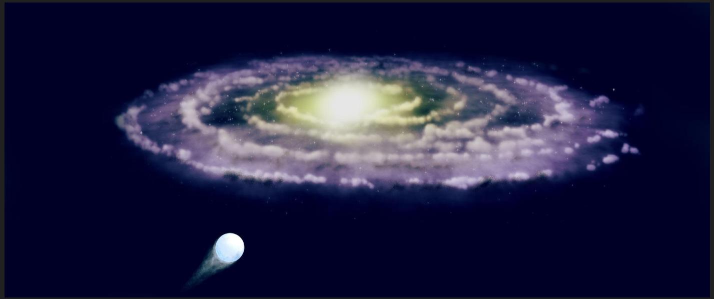
How can this energy be deposited into the ISM?

Kinetic energy carried

M = 1.4 Msun

V = 40 000 km/s

E_{kin} = 10^52 erg !



M = 1.4 Msun

V = 100 000 km/s

E_{kin} = 10^53 erg !

Magnetic energy: Reconnection

Shocks: Heat medium

Particle Acceleration

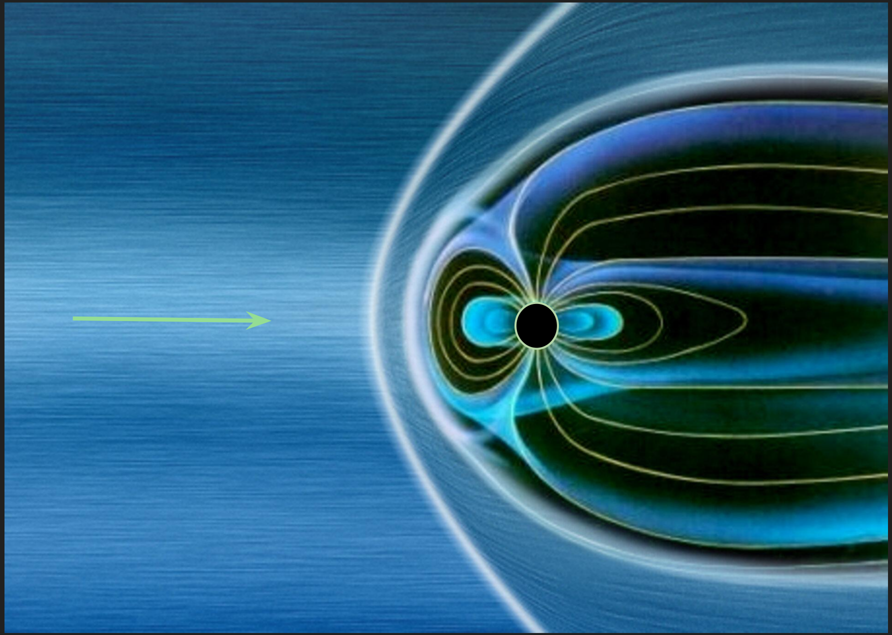
Interaction with the medium

Non-rotating magnetized star, dipole

$$\frac{B_\star^2}{8\pi}\left(\frac{R_\star}{R}\right)^6 = \rho V_\star^2$$

$$R_s = \left(\frac{B_\star^2}{8\pi\rho V_\star^2}\right)^{1/6} R_\star$$

~ 2.5e4 Rstar

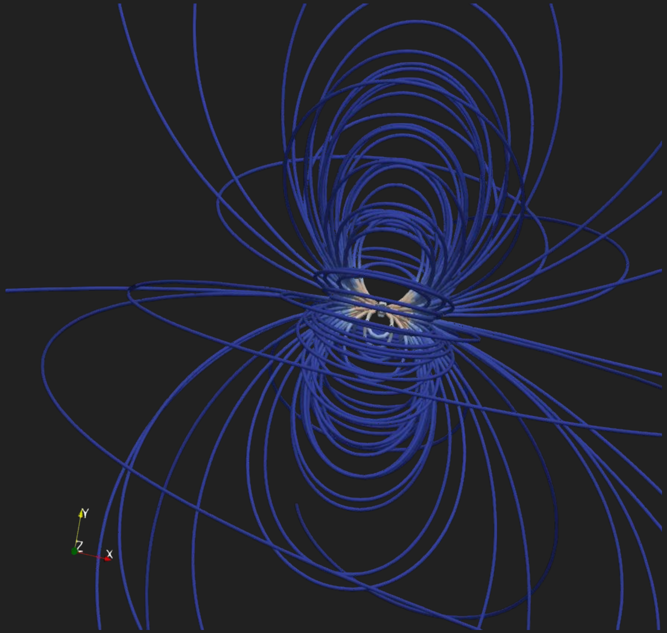


Rs >> Racc

"Magnetic plow"

e.g., Toropina et al. 2001

Simulation initial conditions

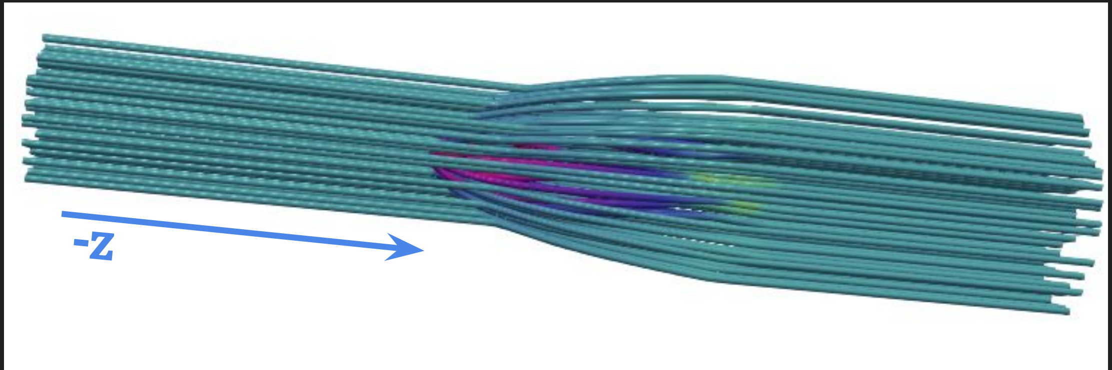


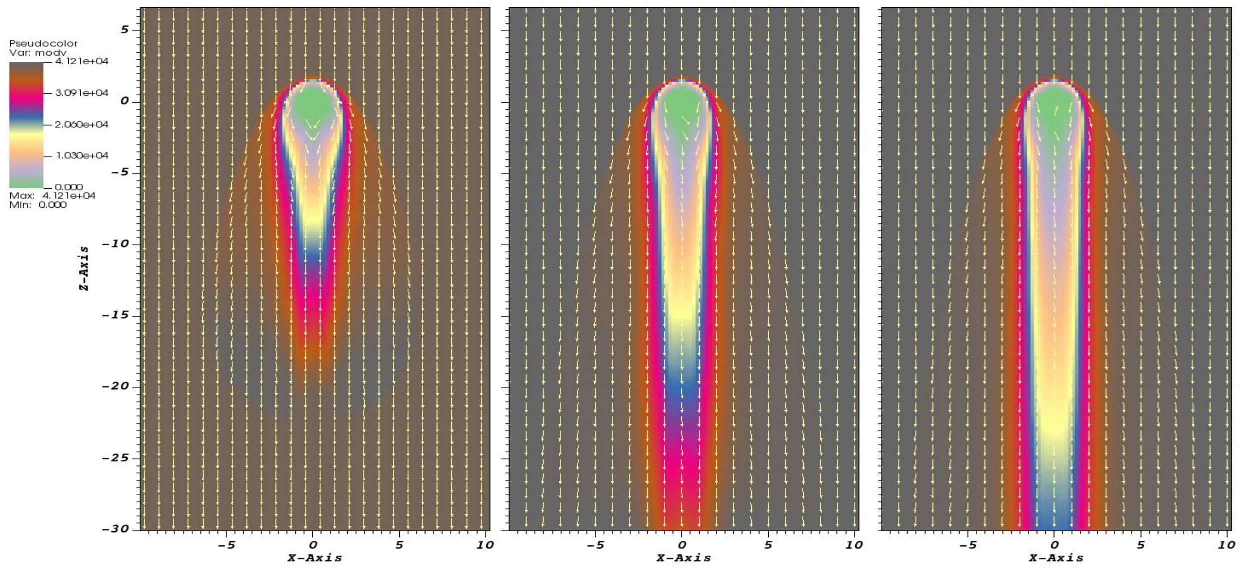
Neutron star Rs = 1e6, B = 1e12 G
Rs = 2.3e10 cm
B(Rs) = 0.08 G
Racc = 23.5 Rstar
3D cartesian
Dipole: plane xy
V = 40 000 km/s, z direction
Mcs = 4000
n_ism = 10 1/cm^3, B_ism = 5 muG
Cooling

PLUTO v. 4.3

Establishing a Steady State

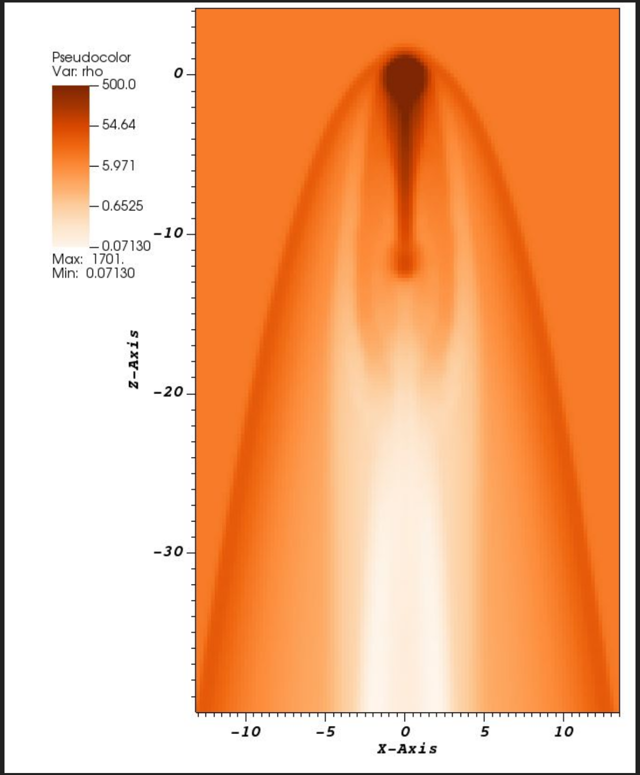
Velocity



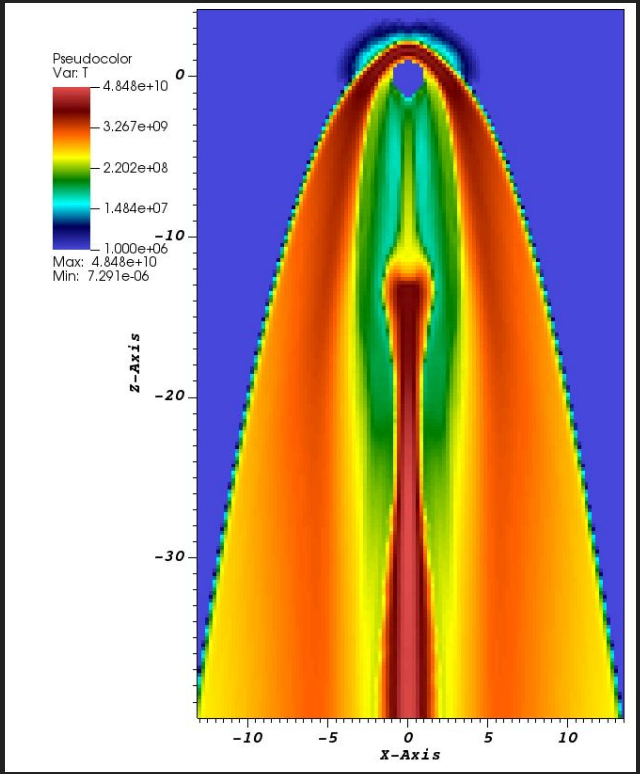


Simulation Results: the structure

Density

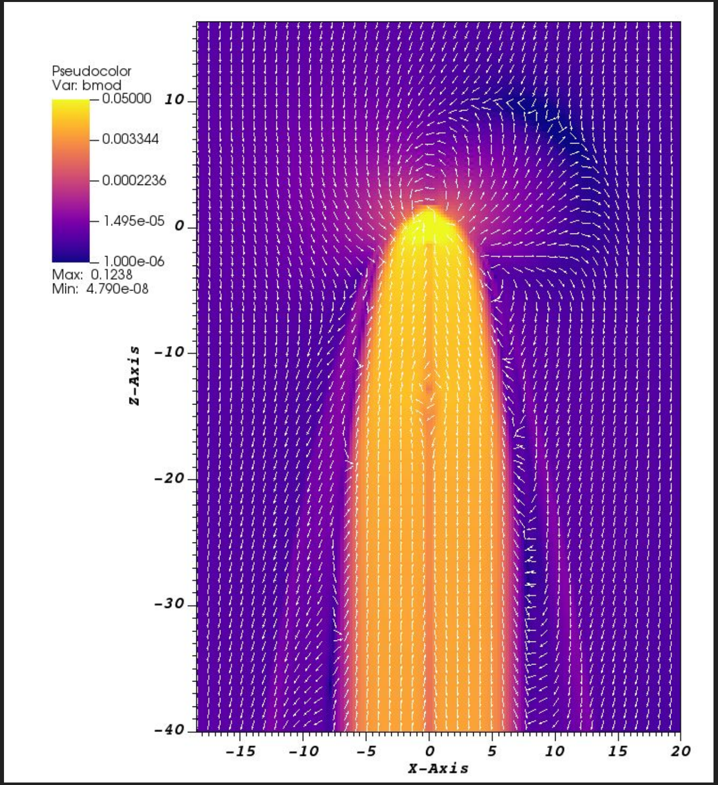


Temperature

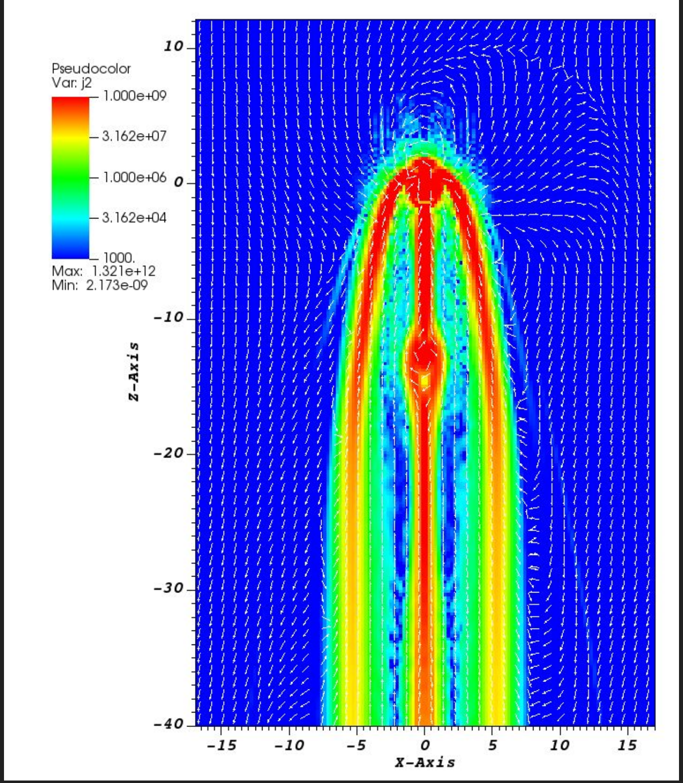


Simulation Results: the structure

Magnetic field

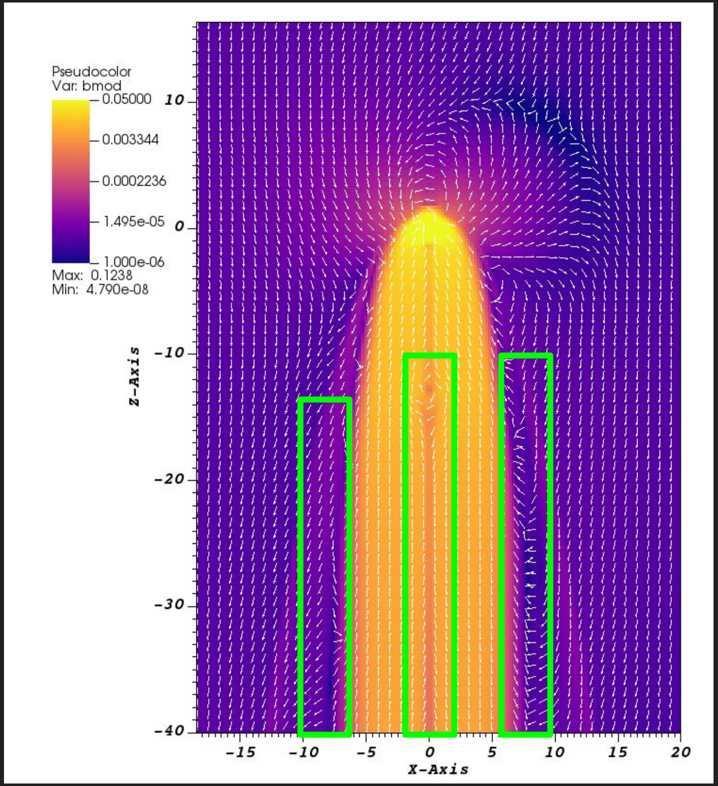


J^2

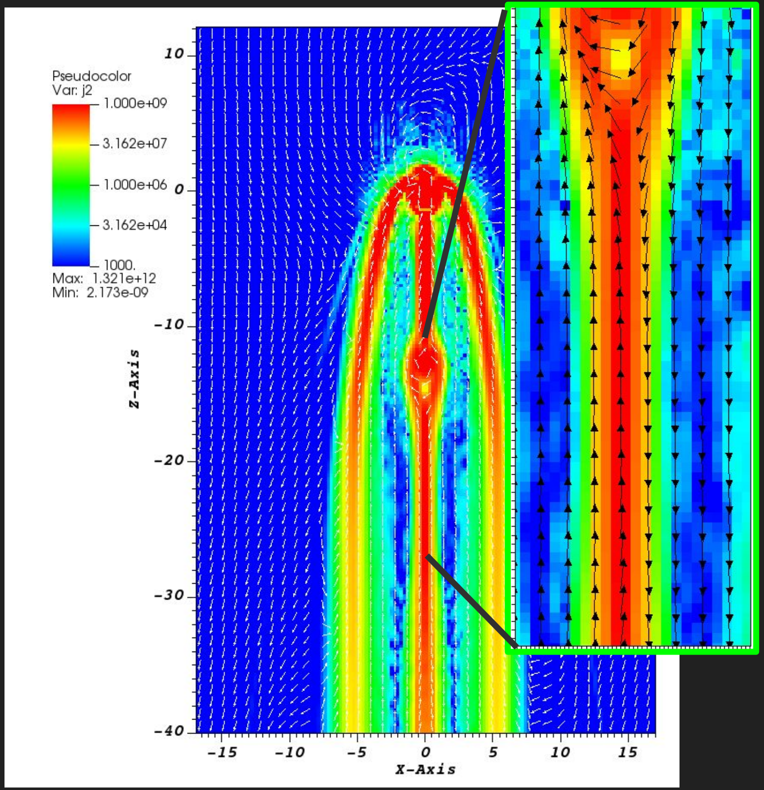


Simulation Results: the structure

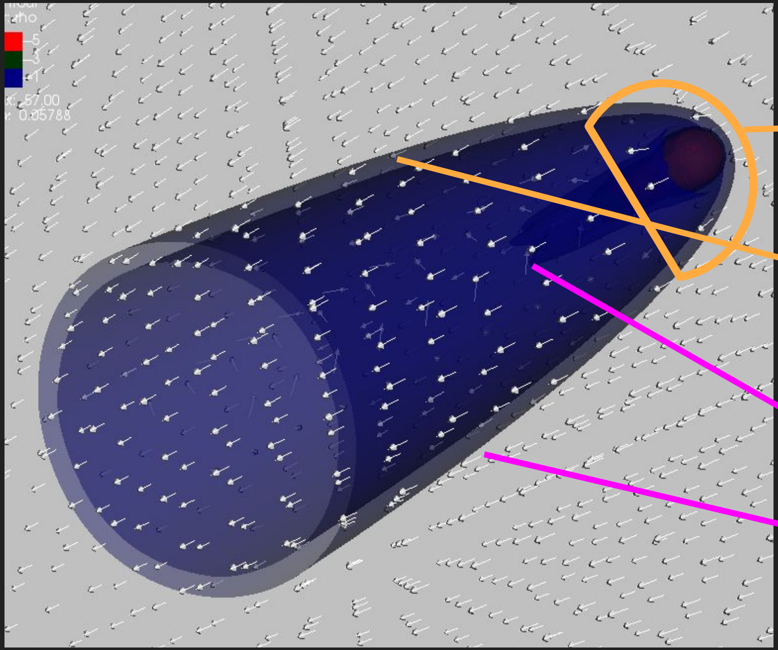
Magnetic field



J^2



Sites for particle acceleration



Bow shock

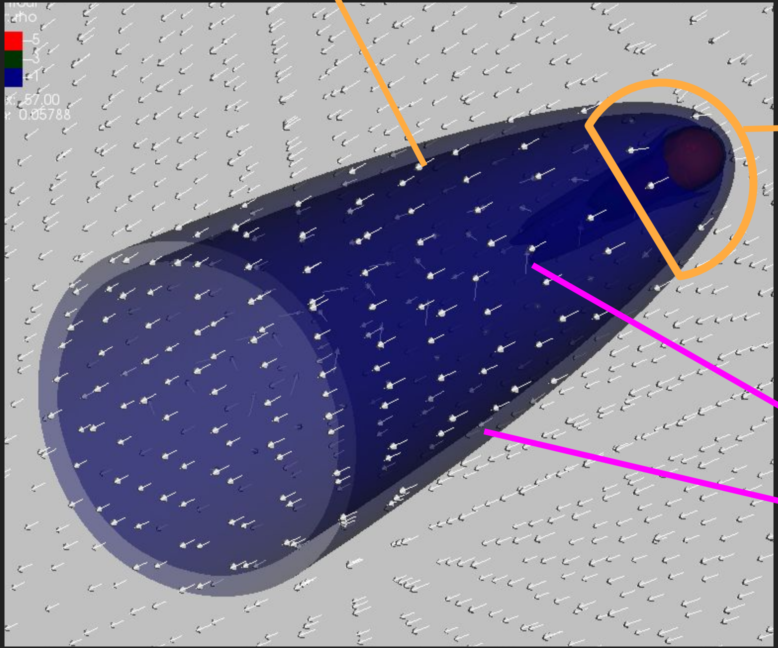
Shocks along the walls of the “jet”

Magnetic Reconnection occurs in multiple regions

Shear, turbulence, compression ...

Sites for particle acceleration

Shocks along the walls of the jet are weak



Power Budget & Maximum Energies: depends on the medium & velocity

Bow shock: accelerated particles are advected down

V = ⅓ c	V = 4e4 km/s
K_sh = 3e30 erg/s	K_sh = 3e27 erg/s
Rs = 5e10 cm	Rs = 2e10 cm
B(Rs) = 6 G	B(Rs) = 0.08 G
Emax,p = 10 TeV	Emax,p = 0.6 TeV
Emax,e = 17 MeV	Emax,e = 62 MeV
n = 1e4 $1/cm^3$	n = 10 $1/cm^3$

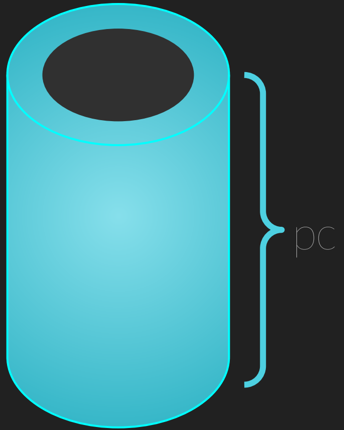
Magnetic Reconnection occurs in several regions:
cylinder (1pc): 1e24 erg/s, 1e26 erg/s

Elongated structure

Thermal emission

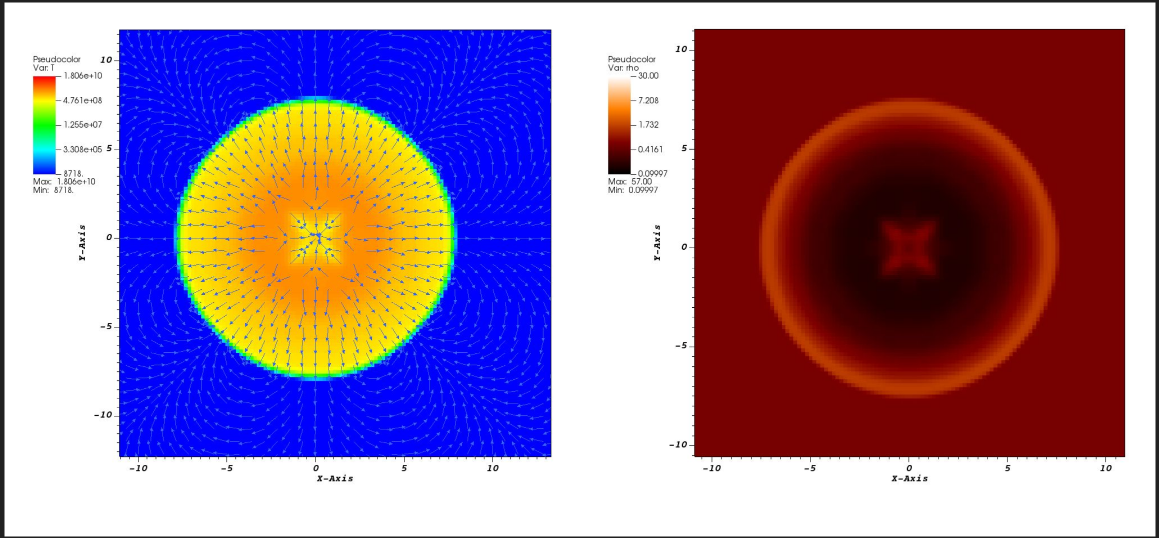
T ~ 1e8 K →

X-rays ~ 8 keV



Hot cylinder

Cross section is too small!



Cross section

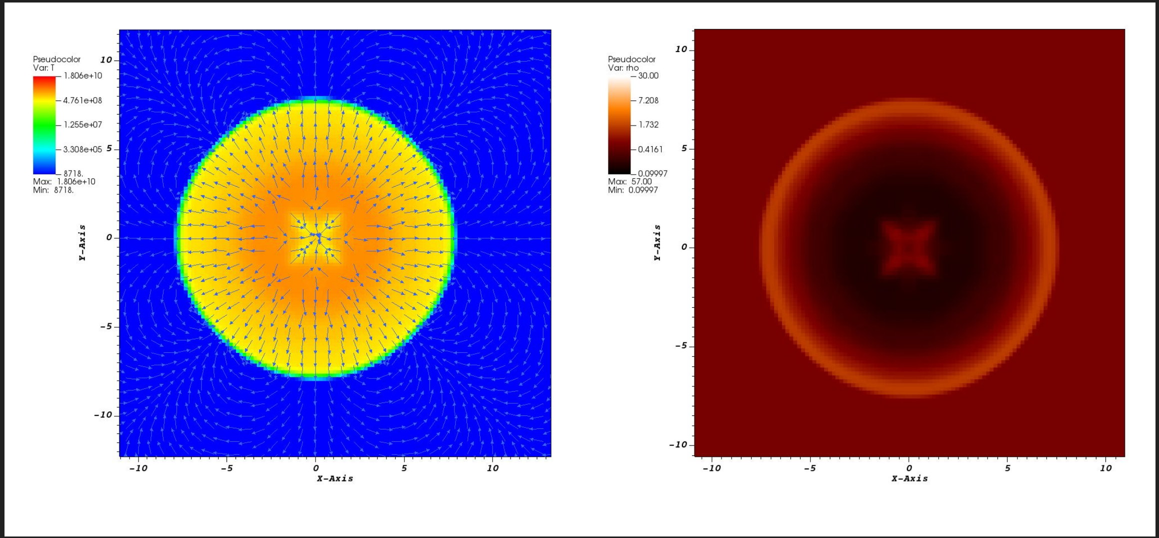
$$\approx 1.43 \times 10^{-27} N_e N_i T^{1/2} V Z^2 g \quad \text{erg sec}^{-1}$$

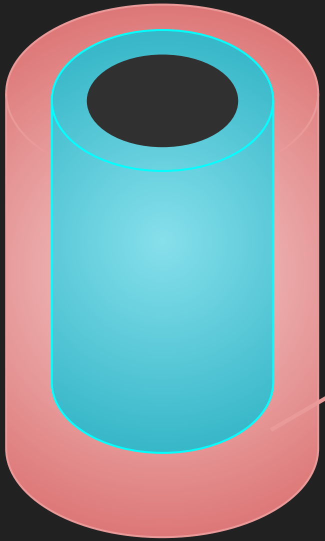
1e26, whole cloud 5e27 erg/s

Thermal emission

T ~ 1e8 K →

X-rays ~ 8 keV





X-rays ionize the medium: radio, H-alpha

$$L_{\min} \approx 10^{-21} N_e N_i T^{-1/2} V Z^4 \ \text{erg sec}^{-1}$$

1e25, whole cloud 5e26 erg/s

Photons > 10 keV should be free to escape

Dense medium, molecular cloud: absorption -> optical, UV

Emission regions becomes wider!

Additional channel: Nonthermal emission

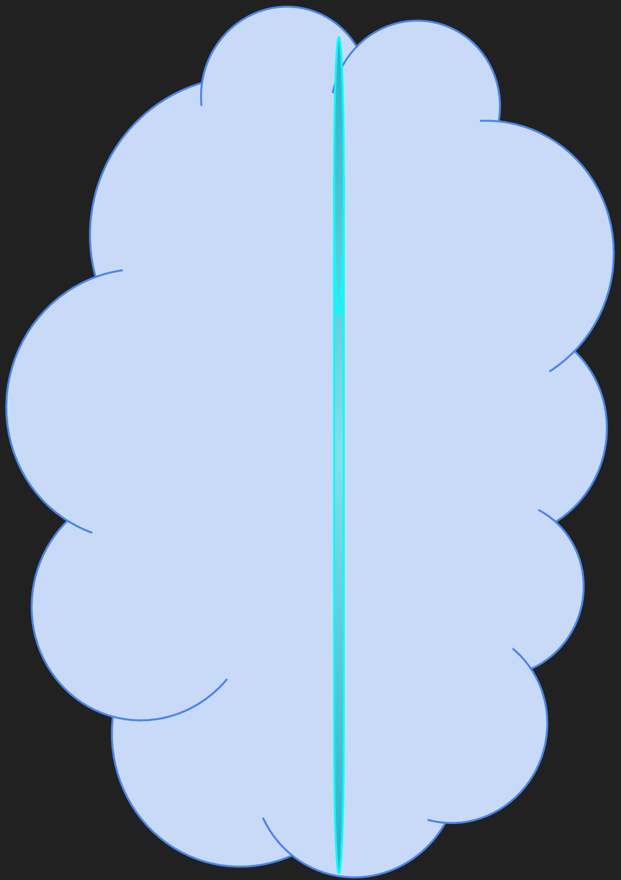
Compression → background CRs

$$n_{\rm ad}(p) = s^{2/3} n_{\rm acc}(s^{-1/3} p).$$

Enhancement of particles locally:

- Synchrotron + IC (CMB)
- P-P

Needs dense environment, competes with other processes



Summary

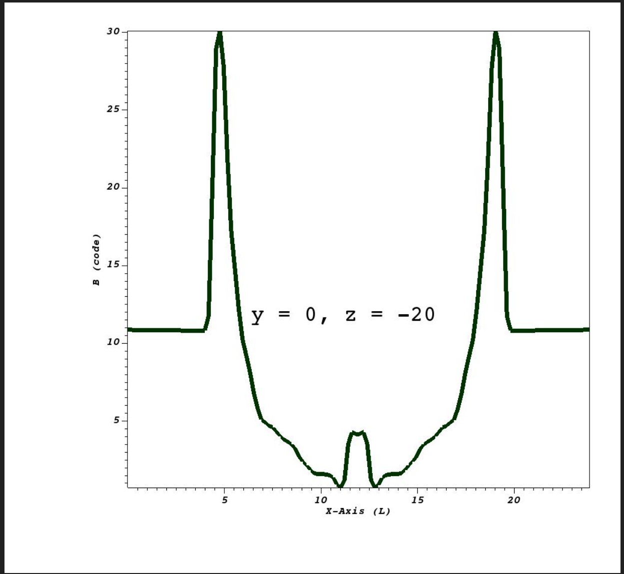
Our preliminary results show that:

- Interaction produces a "jet"
- Very hot gas, small emitting volume
- Particle acceleration: bowshock, reconnection, compression
- Weak radiation signal

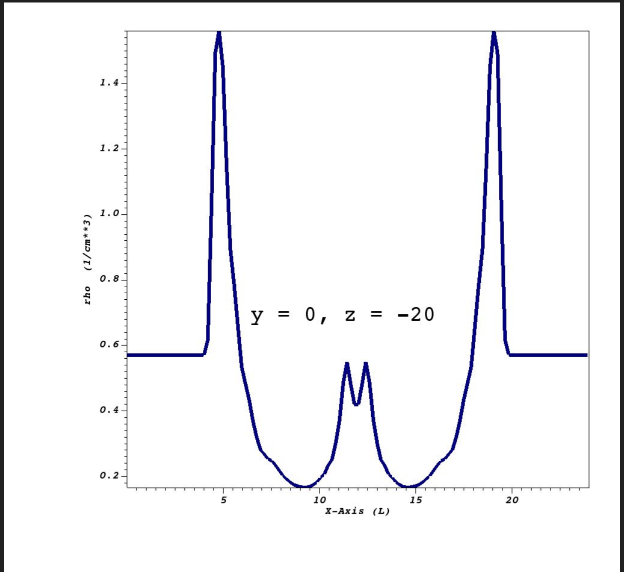
Future work:

- Radiation transfer calculations, transport of relativistic particles.
- Explore relativistic flow effects (are they important?)
- Explore rotating star scenario, Rsr > 6e8 Rs !

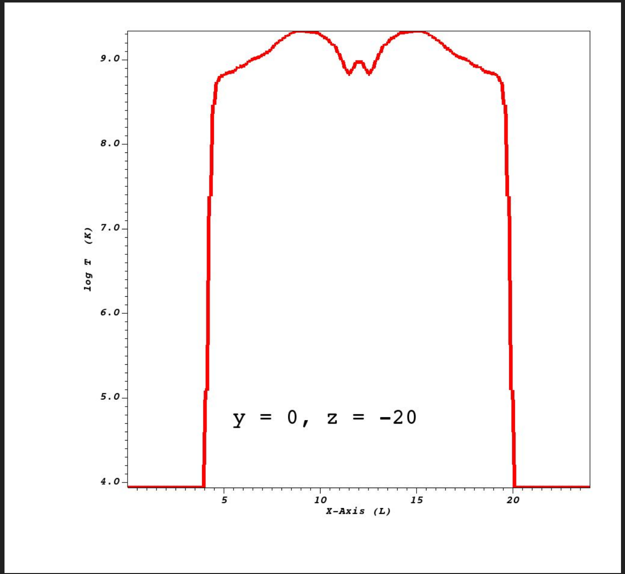
Thanks!



B (code)
X-Axis (L)
y = 0, z = -20



rho (1/cm**3)
X-Axis (L)
y = 0, z = -20



log T (K)
X-Axis (L)
y = 0, z = -20

The case of a WD

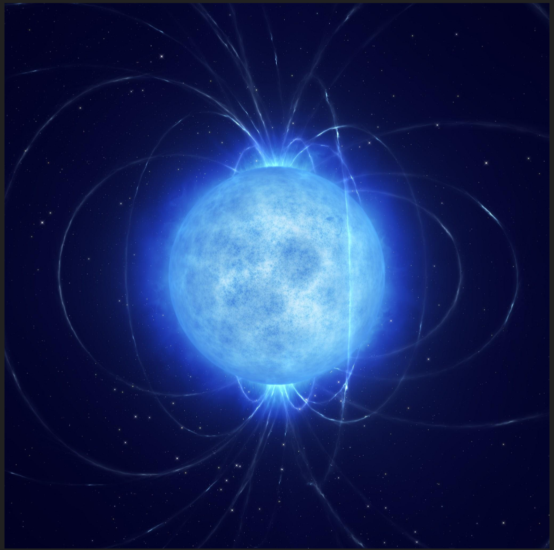
Larger cross-section

B = 100 G

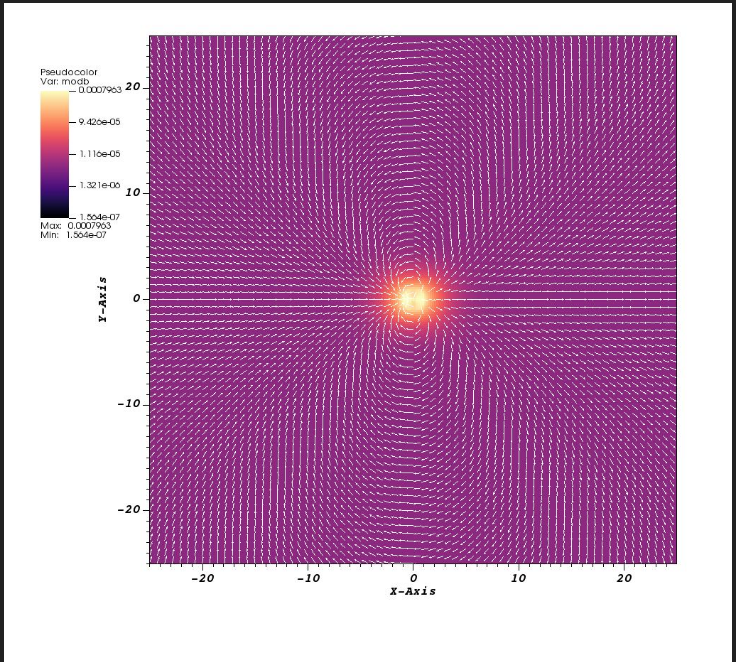
R = 6e8 cm

Ekin = 6e52 erg

Vol (> 7 ofm)



Simulation initial conditions



3D cartesian

Dipole: plane xy

V = 40 000 km/s, z direction

Mcs = 4000

Bs = 0.1 G

Rs = 1e6

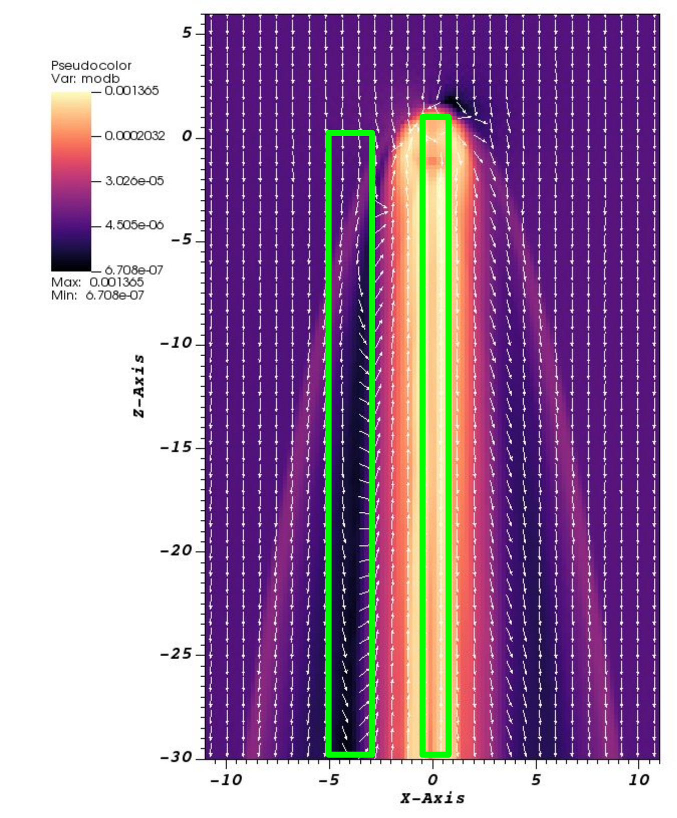
n_ism = 0.57

Cooling

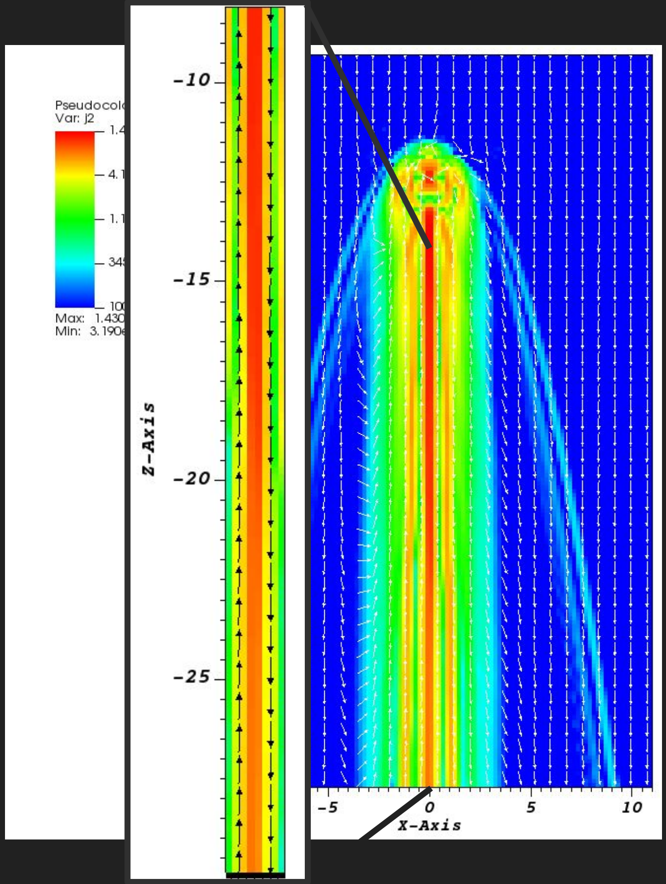
v. 4.3

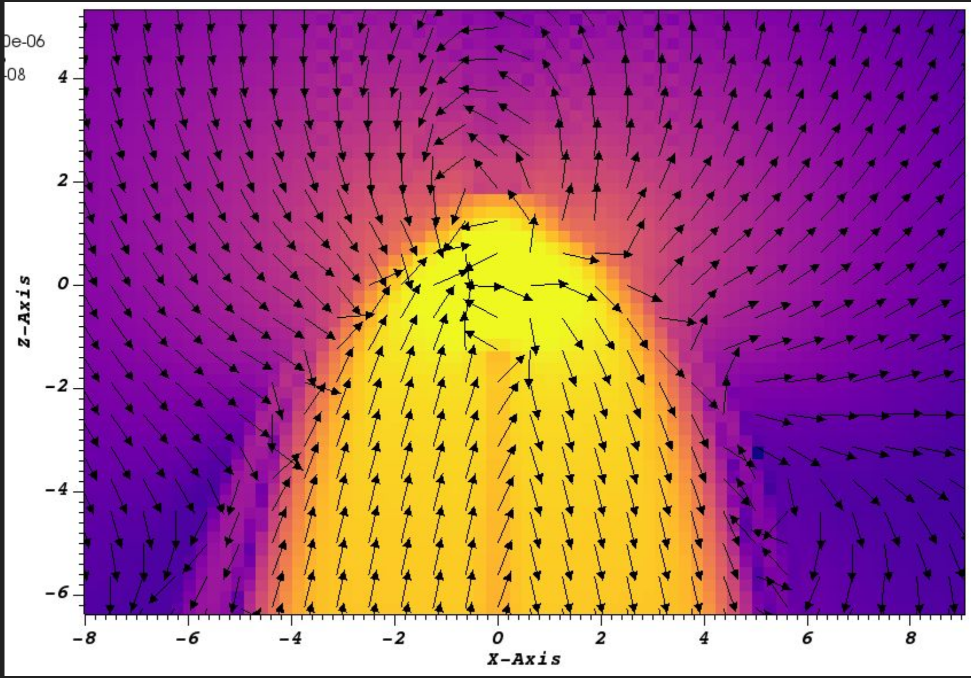
Simulation Results: the structure

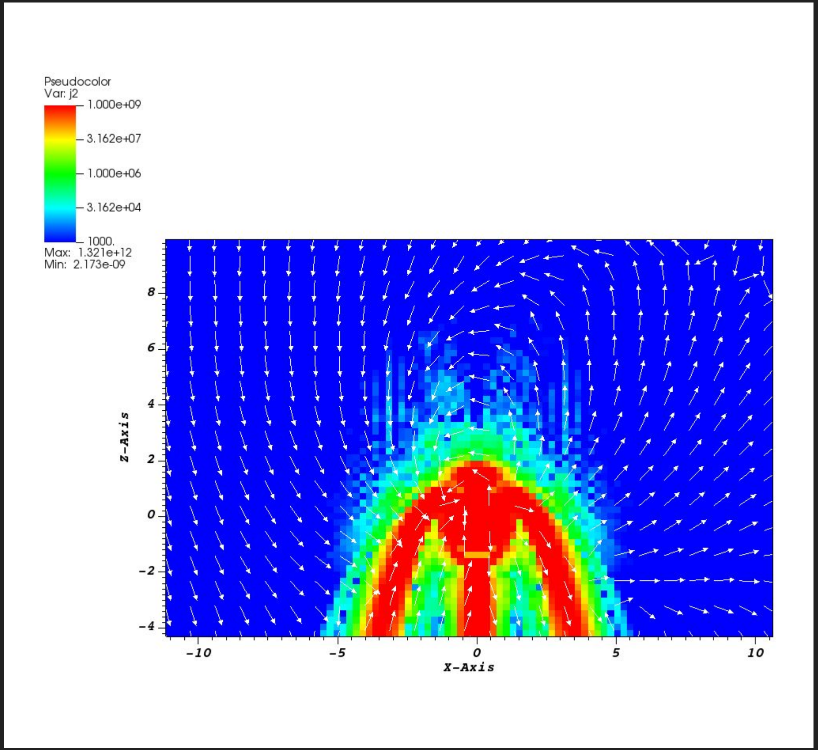
Magnetic field

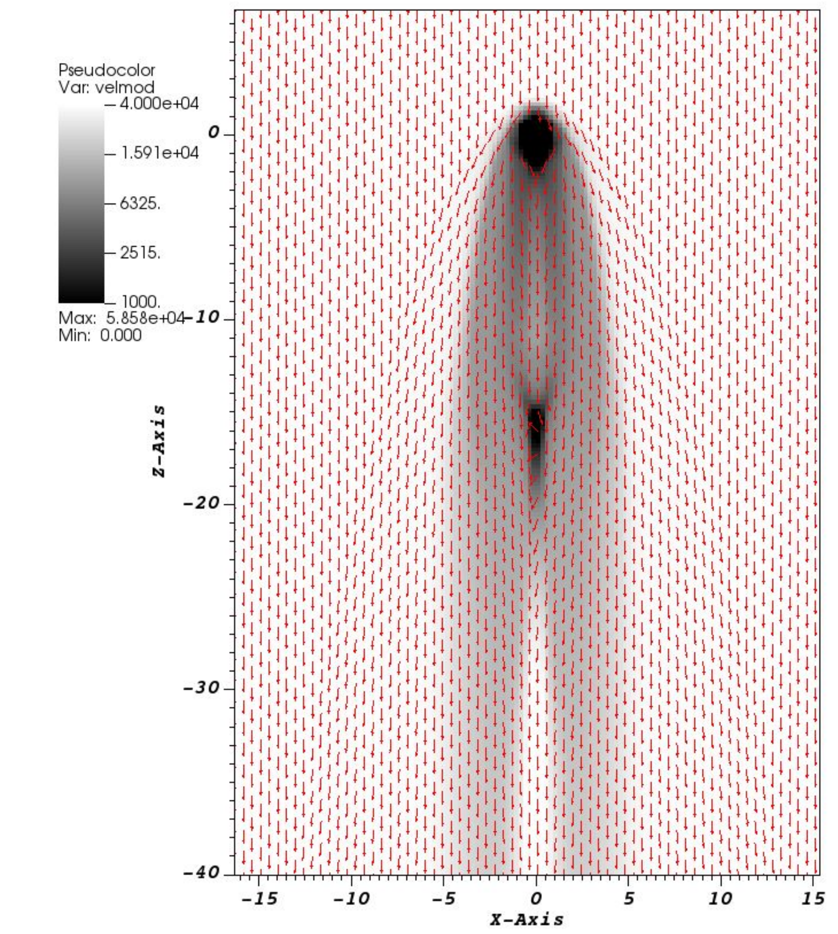


J^2




0e-06
-08
Z-Axis
X-Axis


Pseudocolor
Var: j2
1.000e+09
3.162e+07
1.000e+06
3.162e+04
1000.
Max: 1.321e+12
Min: 2.173e-09
Z-Axis
X-Axis



Pseudocolor
Var: velmod
4.000e+04
1.591e+04
6325.
2515.
1000.
Max: 5.858e+04
Min: 0.000
0
-10
-20
-30
-40
Z-Axis
-15
-10
-5
0
5
10
15
X-Axis