Ultra Fast Neutron Stars

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Stars with very high velocities

Hills Mechanism
(Hills 1988)

Confirmation hyper velocity stars

Modified:
Semi-relativistic hypervelocity stars

SHS

$V \sim \frac{1}{3} c$

Guillochon & Loeb (2015)
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

$$M = 1.4 \text{ Msun}$$
$$V = 40,000 \text{ km/s}$$
$$E_{\text{kin}} = 10^{52} \text{ erg}!$$

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Magnetic energy: Reconnection
Shocks: Heat medium
Particle Acceleration
Interaction with the medium

Non-rotating magnetized star, dipole

\[ \frac{B^2_*}{8 \pi} \left( \frac{R_*}{R} \right)^6 = \rho V_*^2 \]

\[ R_s = \left( \frac{B^2_*}{8 \pi \rho V_*^2} \right)^{1/6} R_* \]

\( \sim 2.5e4 \ R_{\text{star}} \)

e.g., Toropina et al. 2001

“Magnetic plow”
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
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

\[ V = \frac{1}{3}c \]
\[ K_{sh} = 3 \times 10^{30} \text{ erg/s} \]
\[ R_s = 5 \times 10^{10} \text{ cm} \]
\[ B(R_s) = 6 \text{ G} \]
\[ E_{\text{max},p} = 10 \text{ TeV} \]
\[ E_{\text{max},e} = 17 \text{ MeV} \]
\[ n = 1 \times 10^4 \text{ 1/cm}^3 \]

Magnetic Reconnection occurs in several regions:
cylinder (1pc): \(1 \times 10^{24} \text{ erg/s}, 1 \times 10^{26} \text{ erg/s}\)

Elongated structure

\[ V = 4 \times 10^4 \text{ km/s} \]
\[ K_{sh} = 3 \times 10^{27} \text{ erg/s} \]
\[ R_s = 2 \times 10^{10} \text{ cm} \]
\[ B(R_s) = 0.08 \text{ G} \]
\[ E_{\text{max},p} = 0.6 \text{ TeV} \]
\[ E_{\text{max},e} = 62 \text{ MeV} \]
\[ n = 10 \text{ 1/cm}^3 \]
Thermal emission

$T \sim 1 \times 10^8$ K →

X-rays $\sim 8$ keV

Cross section is too small!

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

1e26, whole cloud 5e27 erg/s
Thermal emission

\[ T \sim 1 \times 10^8 \text{ K} \rightarrow \]

X-rays \( \sim 8 \text{ keV} \)

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

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

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 $\rightarrow$ background CRs

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

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, $R_{sr} > 6e8$ $Rs$!
Thanks!
\[ y = 0, \ z = -20 \]
The case of a WD

Larger cross-section

$B = 100 \, \text{G}$

$R = 6e8 \, \text{cm}$

$E_{\text{kin}} = 6e52 \, \text{erg}$

$V_{\text{ol}} (> 7 \, \text{ofm})$
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
Simulation Results: the structure

Magnetic field

\[ J^2 \]