Plasma Instabilities as a Result of Charge Exchange in the Downstream of SNR Shocks

^and the precursor

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Ohira et al., 2009, ApJ, 703, L59

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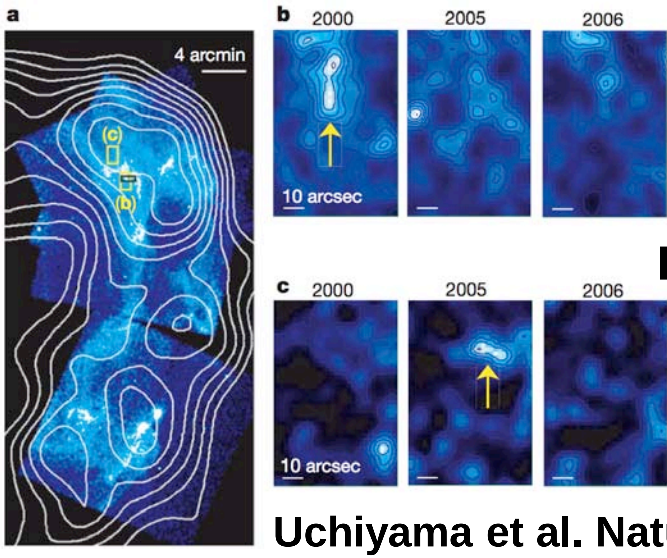
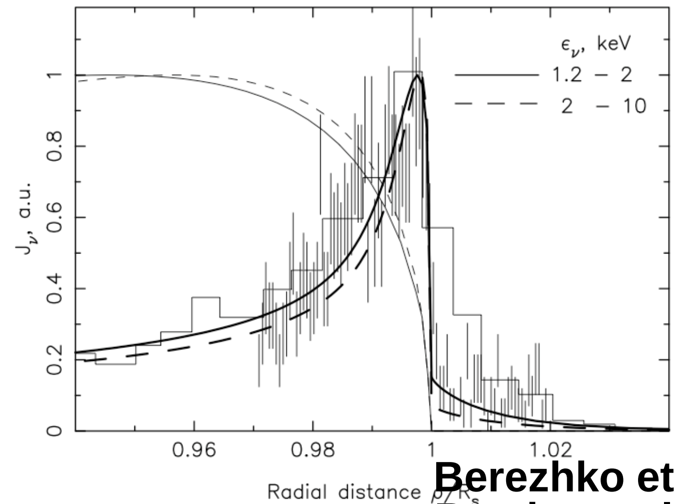
Evidences of the large magnetic field



RXJ 1713

Uchiyama et al. Nature, 2007



SN1006

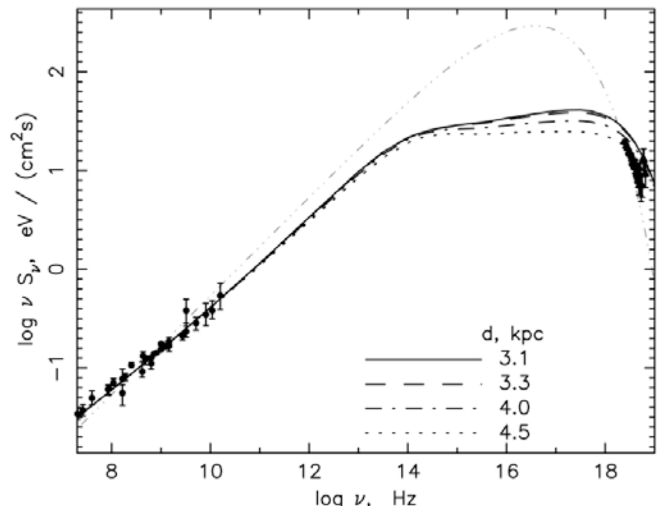
Berezhko et al. A&A 2003
Bamba et al. ApJ 2003

Time scale of X-ray variability ∽ 1 year

Spatial scale of X-ray filament ∽ $10^{16\text{-}17}$ cm

radio and X-ray synchrotron

B = 3μG → 100μG ∽ 1mG
in the "downstream"

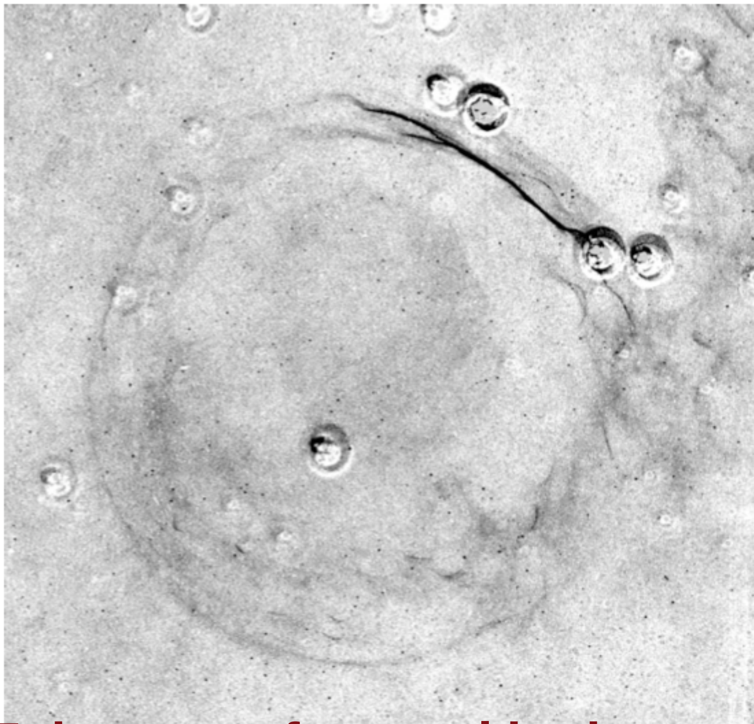


Tycho

Völk et al. A&A 2008

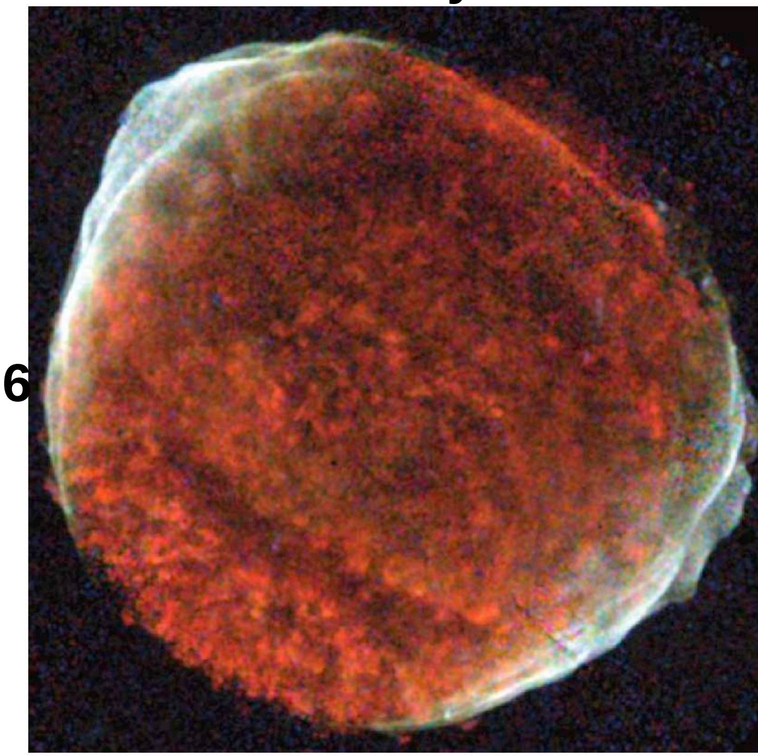
Existence of neutral hydrogen around SNRs

Hα



SN1006

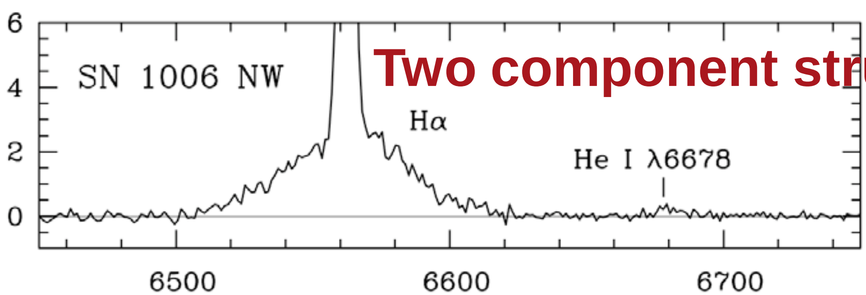
X-ray



Existence of neutral hydrogens

Winkler et al. ApJ 2003

Cassam-Chenai et al. ApJ 2008



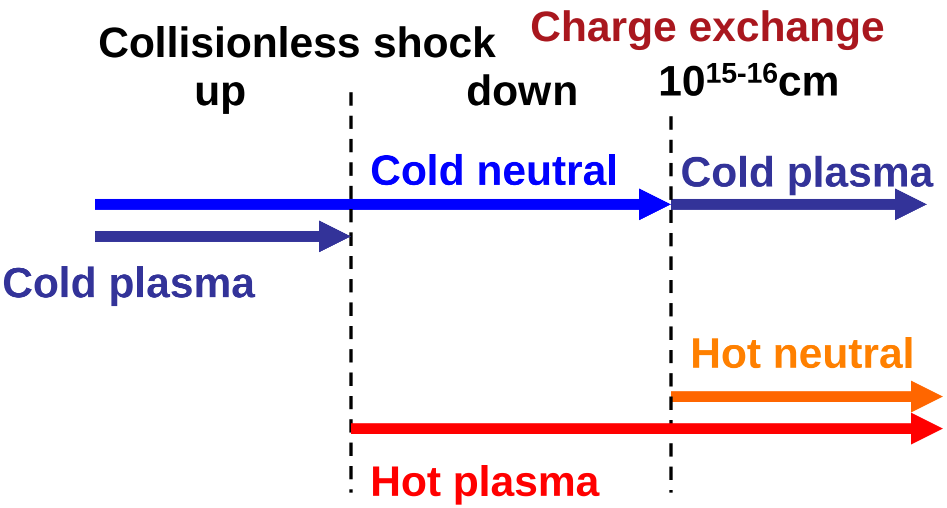
Two component structure

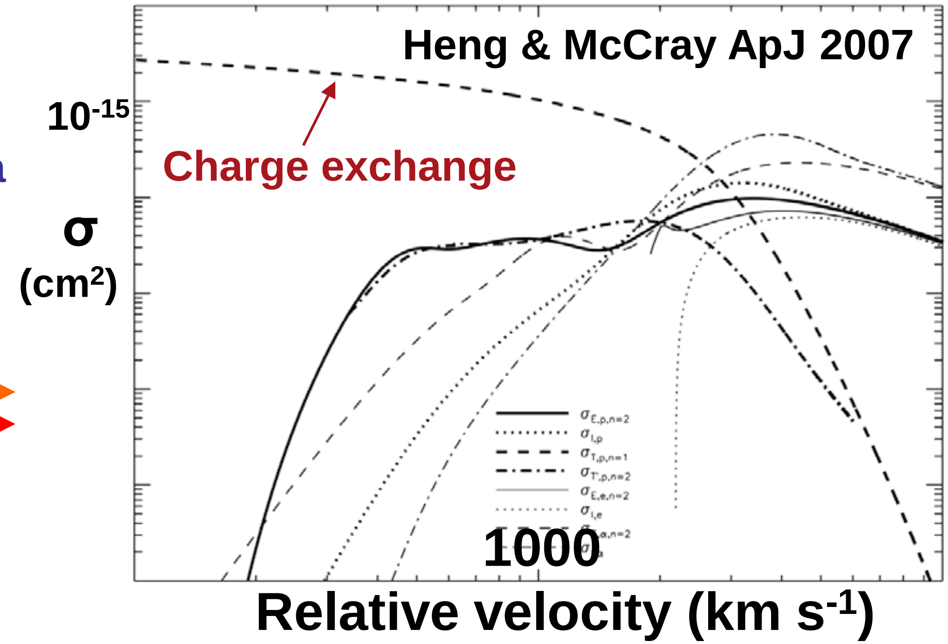
Å

The neutral fraction is order of unity.

Ghavamian et al. ApJ 2000
2002

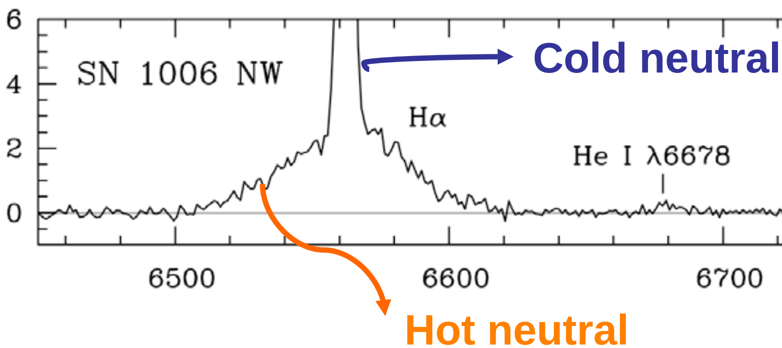
Origin of Hα with two components (Chevalier & Raymond 1978)





Cold neutral → narrow Hα

Hot neutral → broad Hα

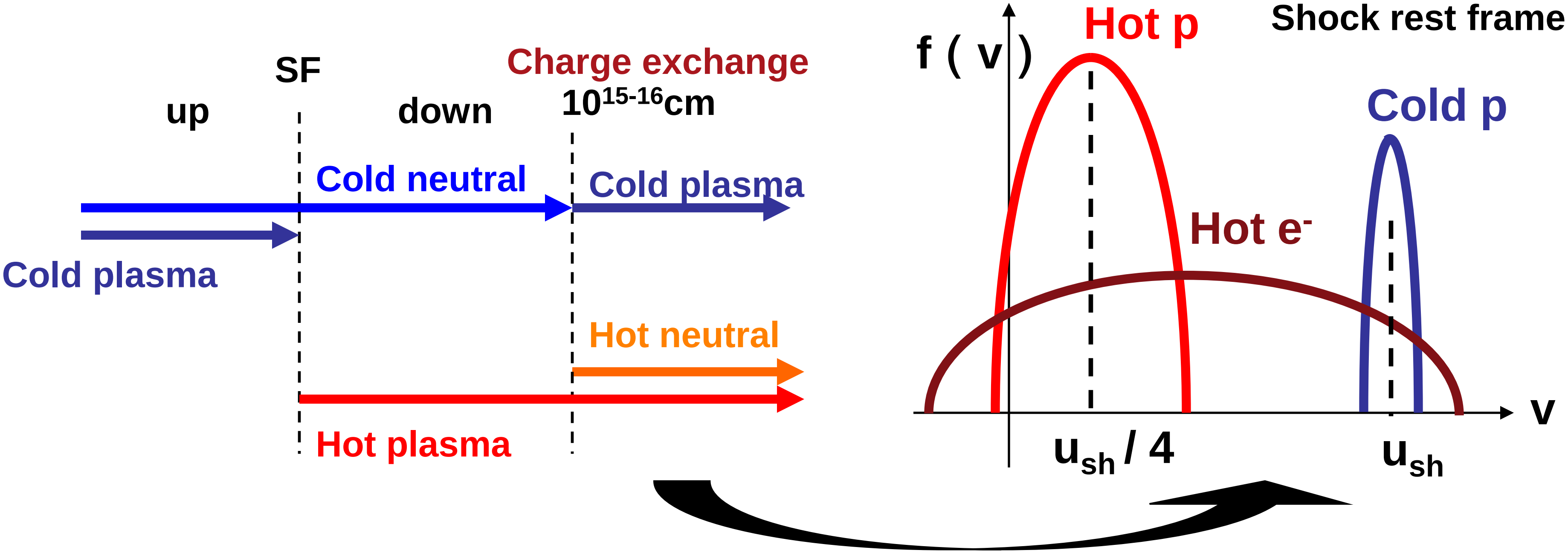


V_{rel} < 3000km/s

The charge exchange is dominant process.

$\sigma_{C.E.} \sim 10^{-15} cm^2$

Instabilities at the downstream



We expect plasma instabilities.

For B // u_{sh},

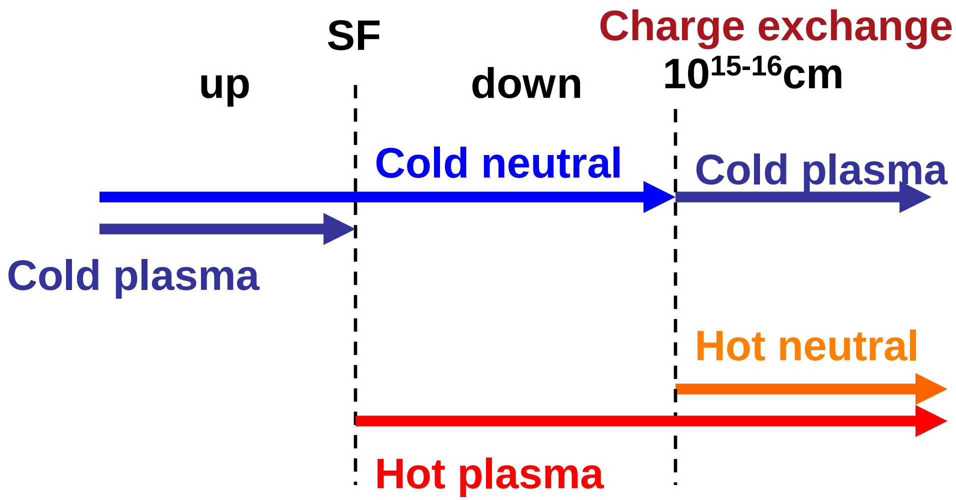
Electrostatic mode → Ion Acoustic Instability (k // B)

Electromagnetic modes → Weibel Instability (k ⊥ B)

Resonant Instability (k

Non-resonant Instability (k // B)

Background plasma conditions



We use typical values for young SNRs.

$B_{ISM} = 3\mu G$

$n_e = n_p = 1.0 \,/\, cm^3$

$T_{p,hot} = \frac{3}{16} m_p u_{sh}$, $u_{sh} = 0.01c$

$T_{p,cold} = 1eV$

$T_e = 0.03\, T_{p,hot}$

Electron rest frame

$$V_{d,hot} = \frac{3n_{p,cold}}{n_{p,hot} + n_{p,cold}} u_{sh}$$

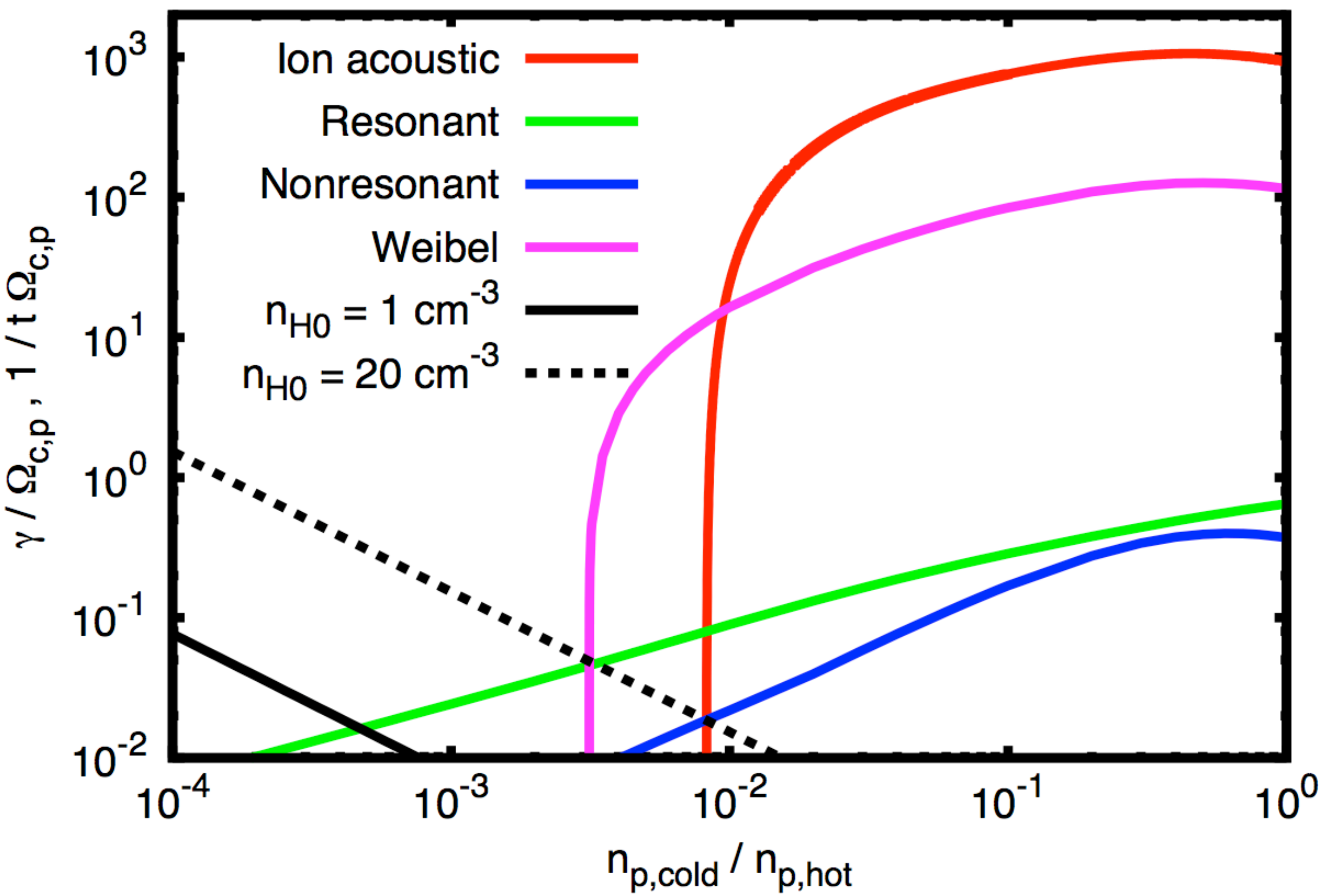
$$V_{d,cold} = \frac{3n_{p,hot}}{n_{p,hot} + n_{p,cold}} u_{sh}$$

Growth rates

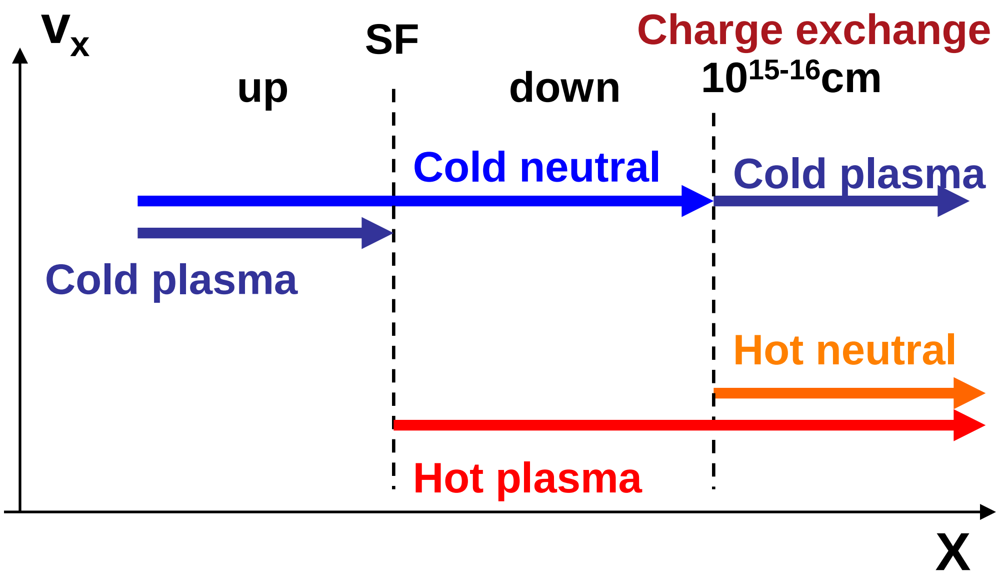
$$\frac{Dn_{p,cold}}{D\,t} = n_H n_{p,hot} \sigma_{C.E.} v_{rel} \xrightarrow{n_{p,cold} \ll n_{p,hot}\ ,\ n_{H0}} n_{p,cold} \propto t$$

For $n_{H0} = 1/cm^3$,
the resonant ins.

For $n_{H0} > 20/cm^3$,
the Weibel ins.



Amplification of the magnetic field

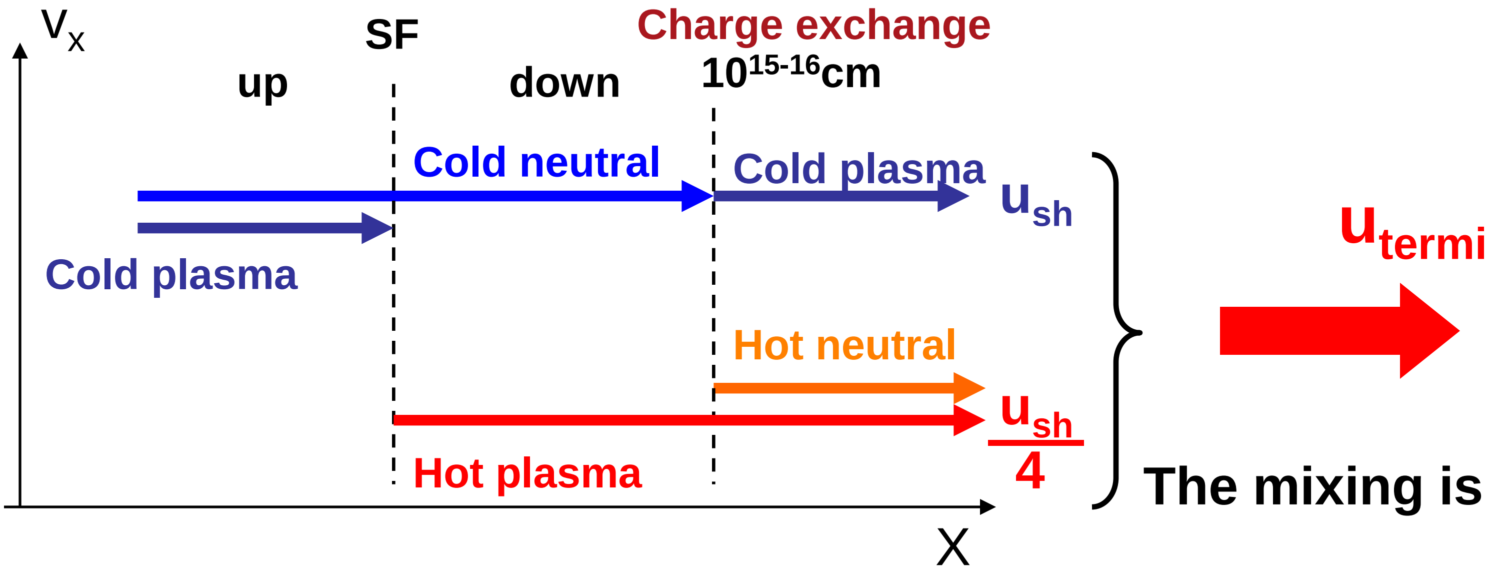


The large fraction of free energy can be converted to the magnetic energy.

$$U_B \sim \varepsilon_B \frac{1}{2} \rho_{H0} \left(\frac{3u_{sh}}{4} \right)^2$$

$$\delta B \sim 100\ \mu G \left(\frac{\varepsilon_B}{0.01} \right)^{1/2} \left(\frac{n_{H0}}{0.4\mathrm{cm}^{-3}} \right)^{1/2} \left(\frac{u_{sh}}{3000\mathrm{km/s}} \right)$$

Shock structure in the downstream



The mixing is not understood.

For example

the terminal flow velocity → the velocity of the center of mass

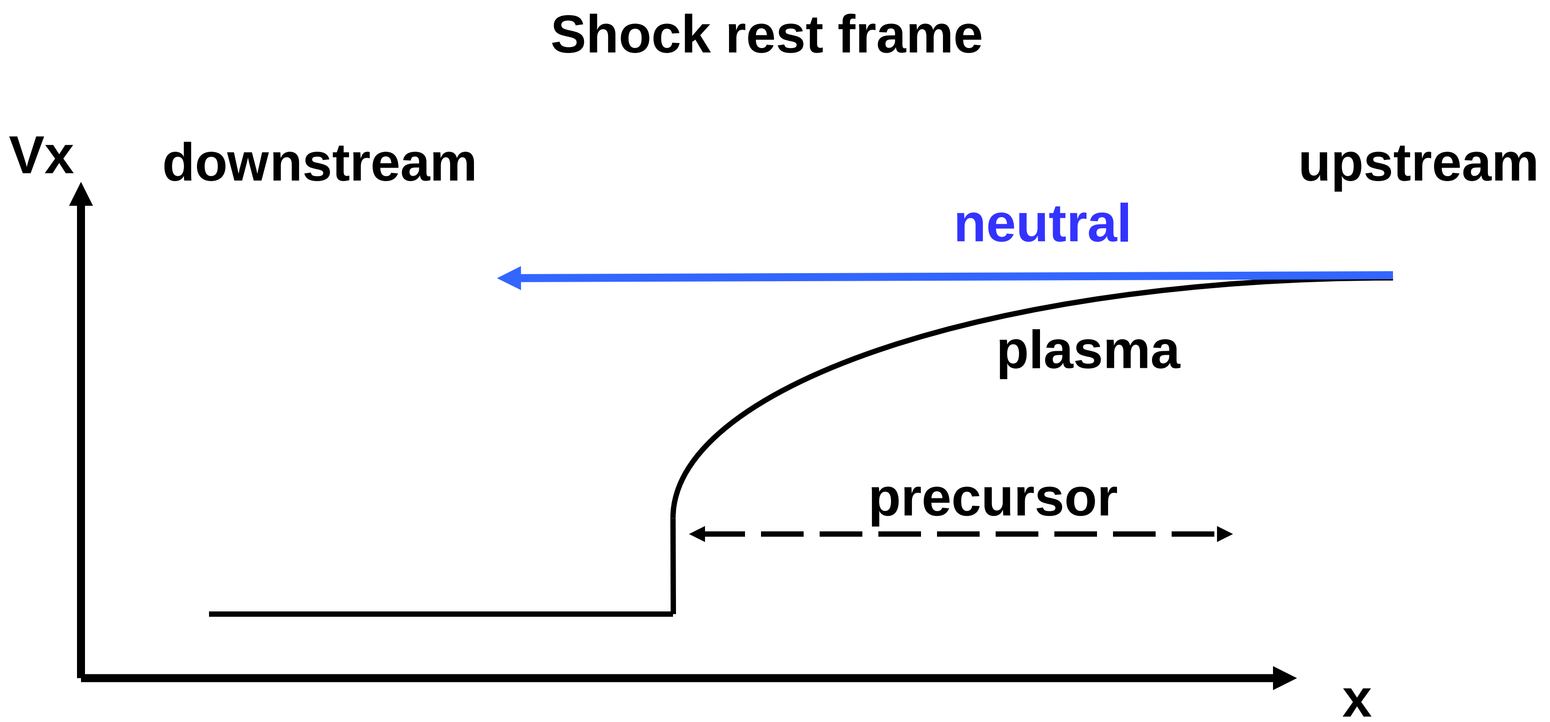
$$u_{terminal} = \frac{1}{1+3\chi} u_{sh} \qquad \chi = \frac{n_i}{n_i + n_H} \leqq 1$$

Diffusive shock acceleration

$$N(E) \propto E^{-p} \qquad p = 1 + \frac{1}{\chi} \geqq 2$$

Softening!

Charge exchange at the precursor

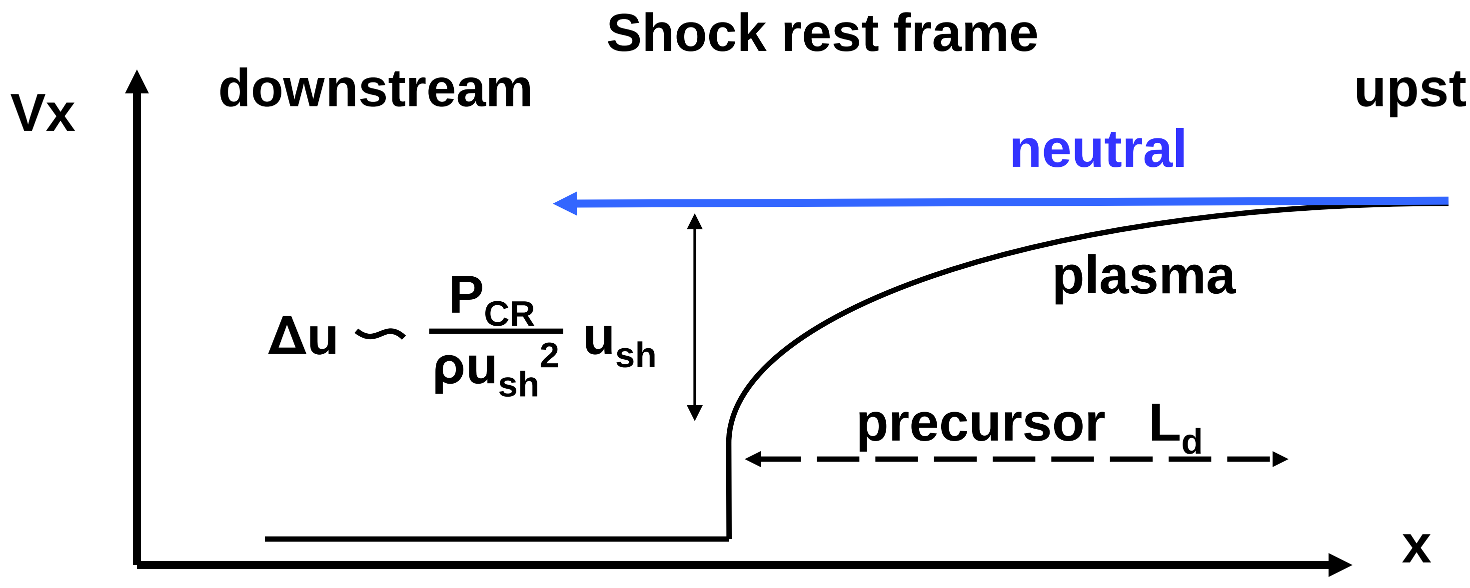


In the precursor,

the charge exchange and magnetic field amplification can occur

there are the pickup ions

Pickup ions at the precursor



Number density $n_{PI} \sim n_H \frac{L_{C.E.}}{L_d}$, $L_{C.E.} = (n_p \sigma_{C.E})^{-1} \sim 10^{15}$cm

Pressure $P_{PI} \sim m n_{PI} (\Delta u)^2$ If $\frac{P_{PI}}{\rho u_{sh}^2} \sim 0.01\text{-}1$,

$$\frac{P_{PI}}{\rho u_{sh}^2} \sim \frac{\rho_H}{\rho} \frac{L_{C.E.}}{L_d} \left(\frac{P_{CR}}{\rho u_{sh}^2} \right)^2$$

Magnetic field amplifications
Changing the jump of the subshock
Injection into the particle acceleration

Summary

- Neutral hydrogens exist around SNRs
- The hydrogens make the cold ions.
- The cold ions

    amplify the magnetic field more than 100μG,

    change the shock structure, (subshock and downstream)

    change the cosmic-ray spectrum, (softening)

    are important for the injection into DSA.

- The neutral is important in not only the downstream but also the precursor.