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Space Weather: The role of cold ions on magnetic reconnection at the terrestrial magnetopause

fully kinetic simulations

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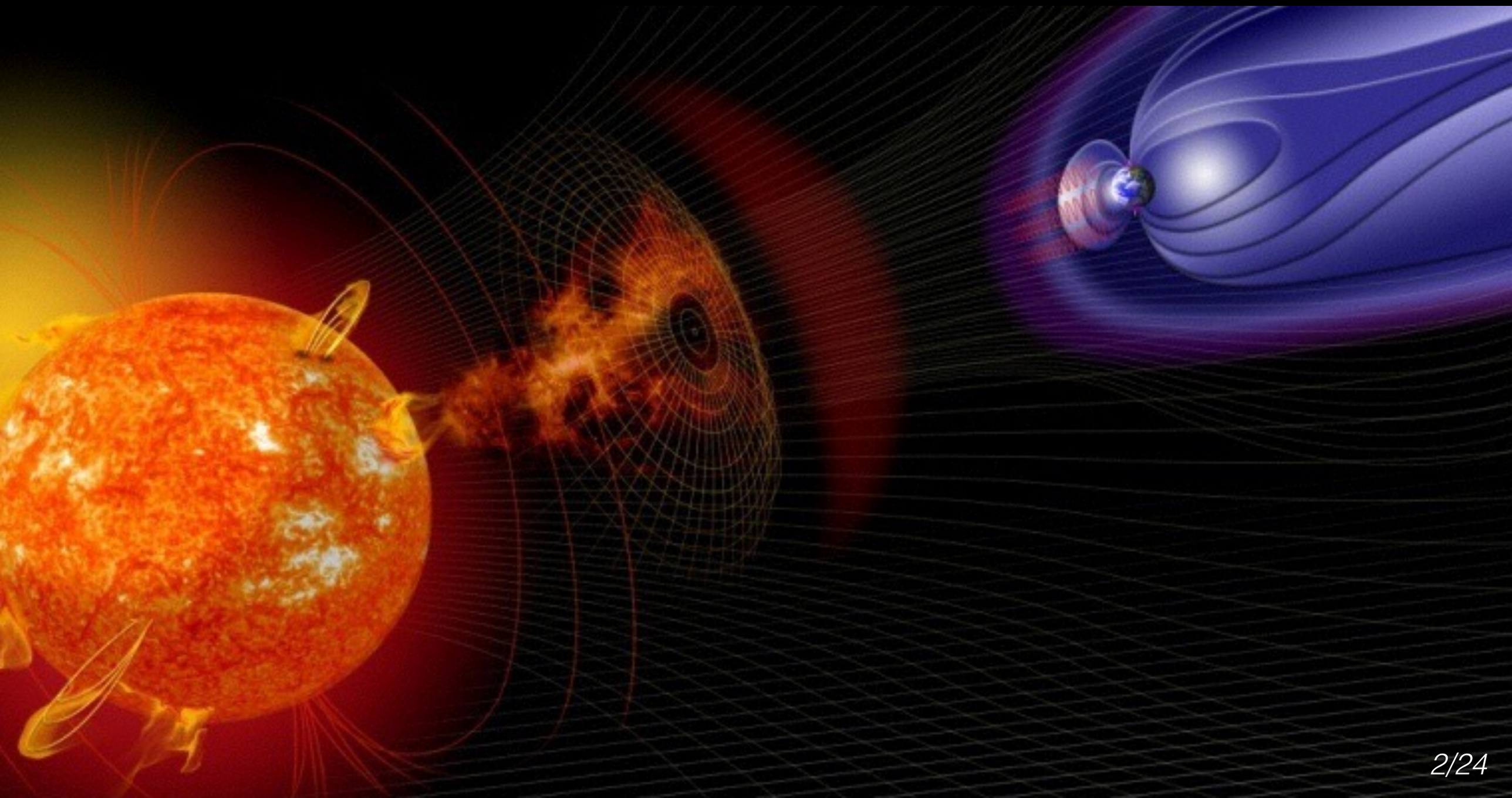
Space weather:
Science of Sun-Earth interactions

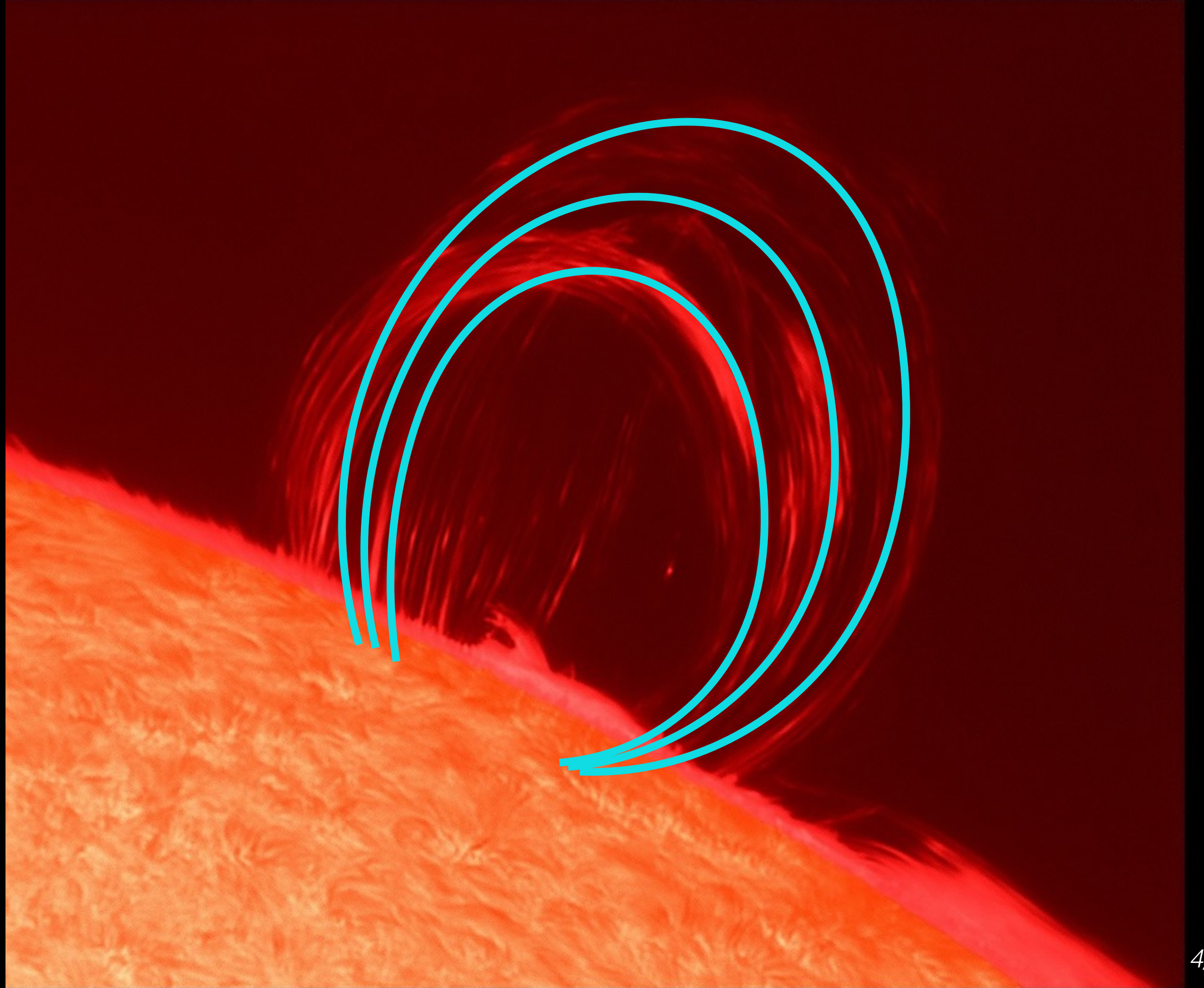


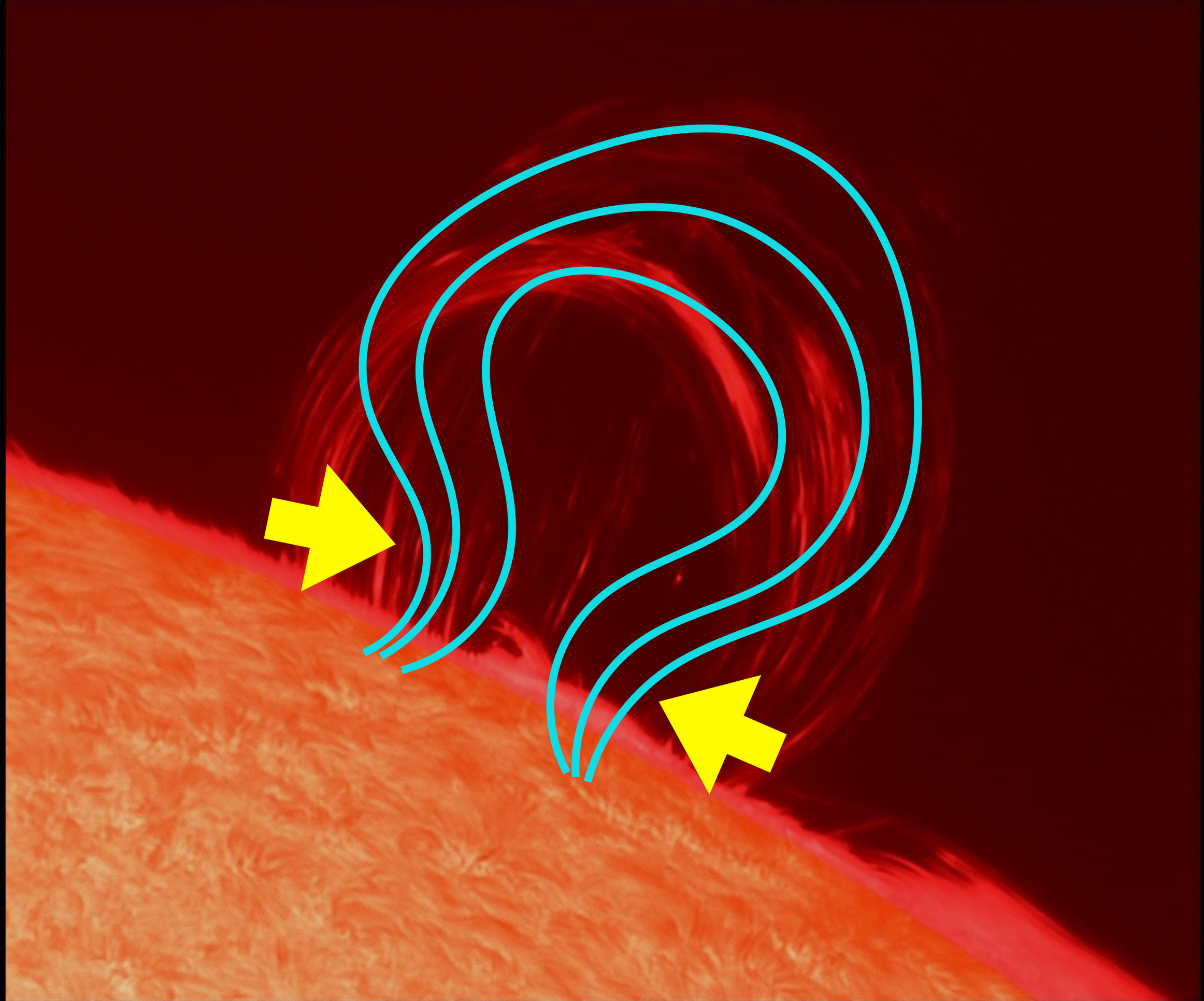
The Sun : an active star

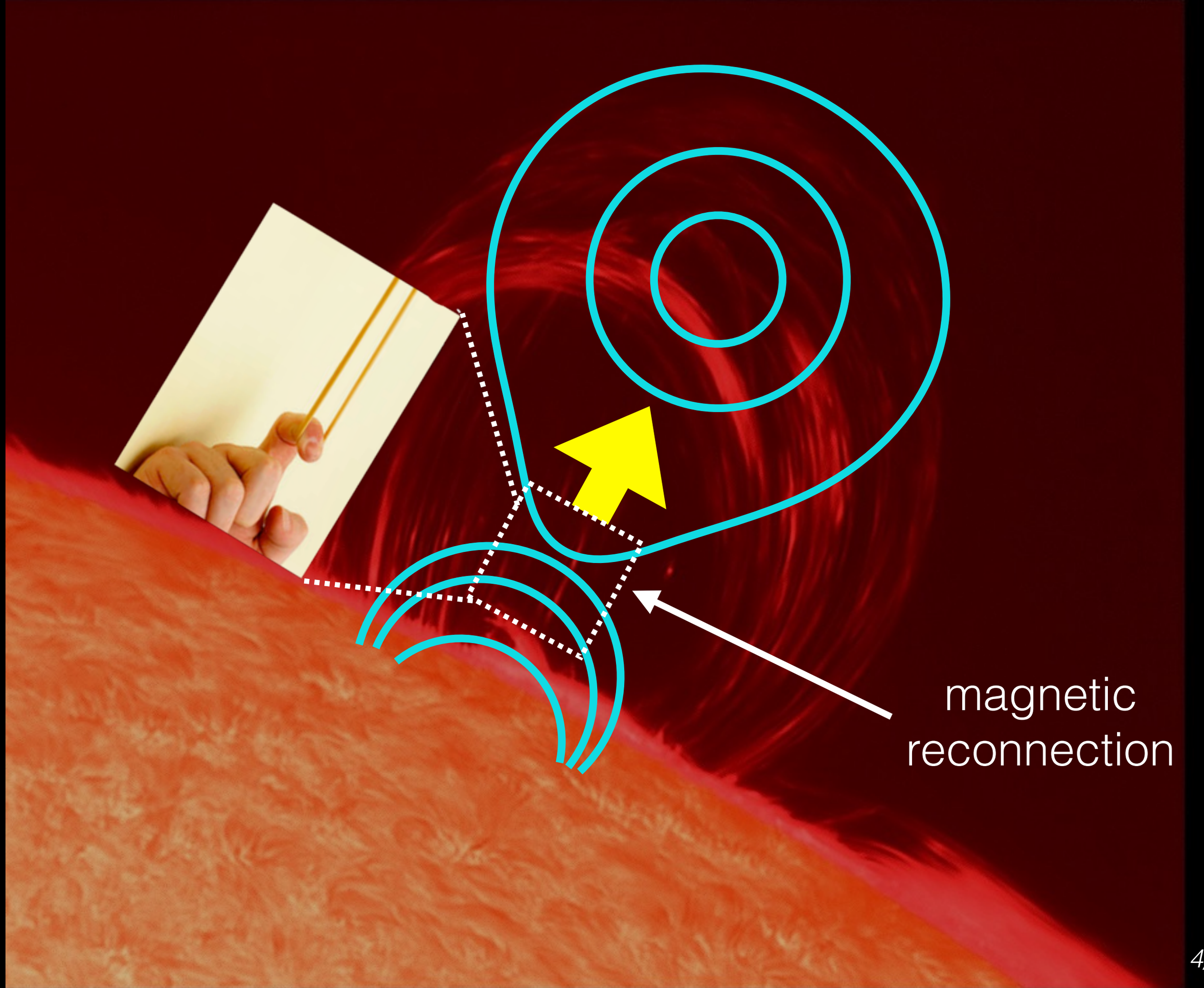
Solar wind emission : 10^9 kg.s^{-1}

The Sun : an active star

surface activity

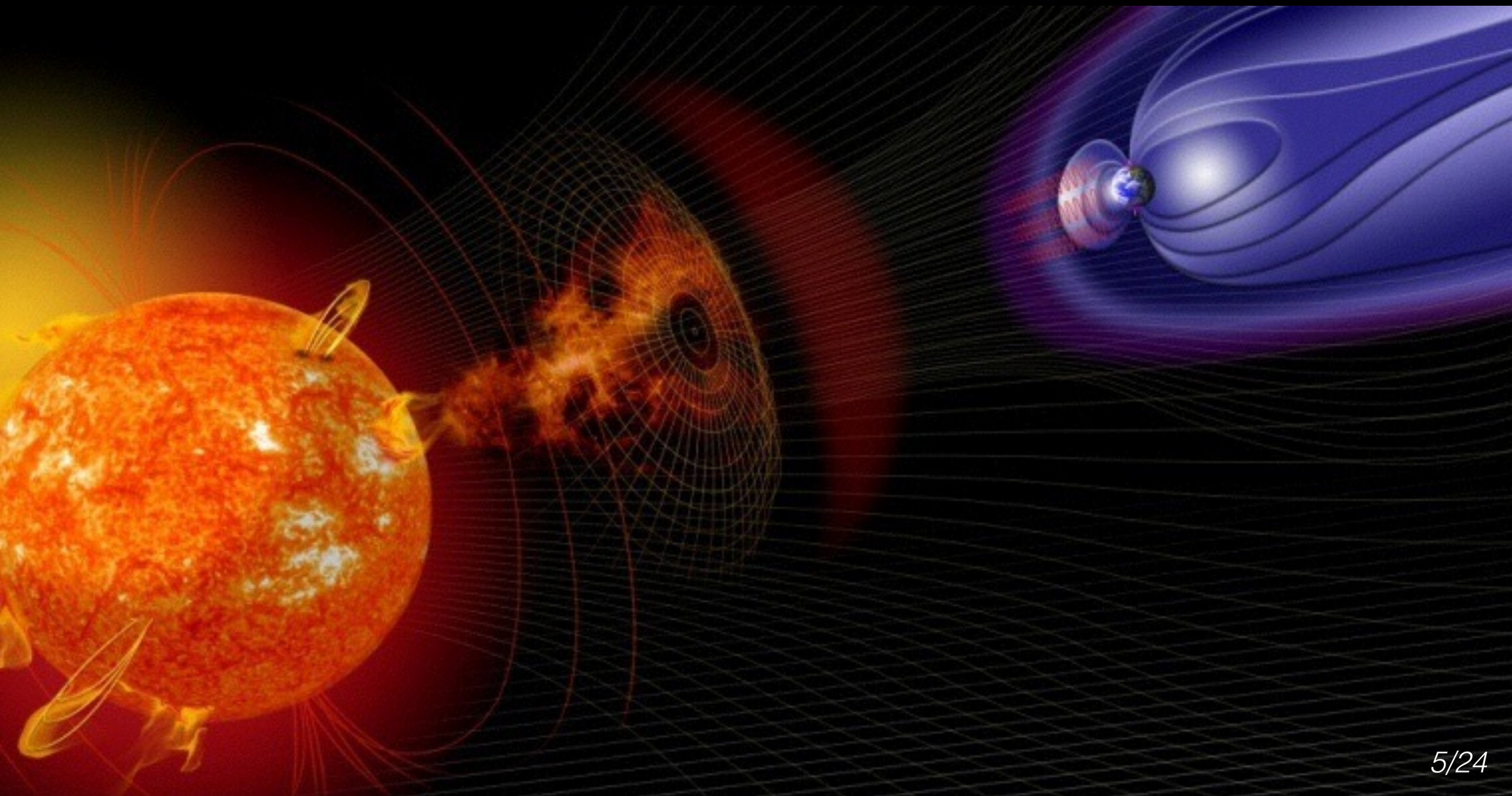




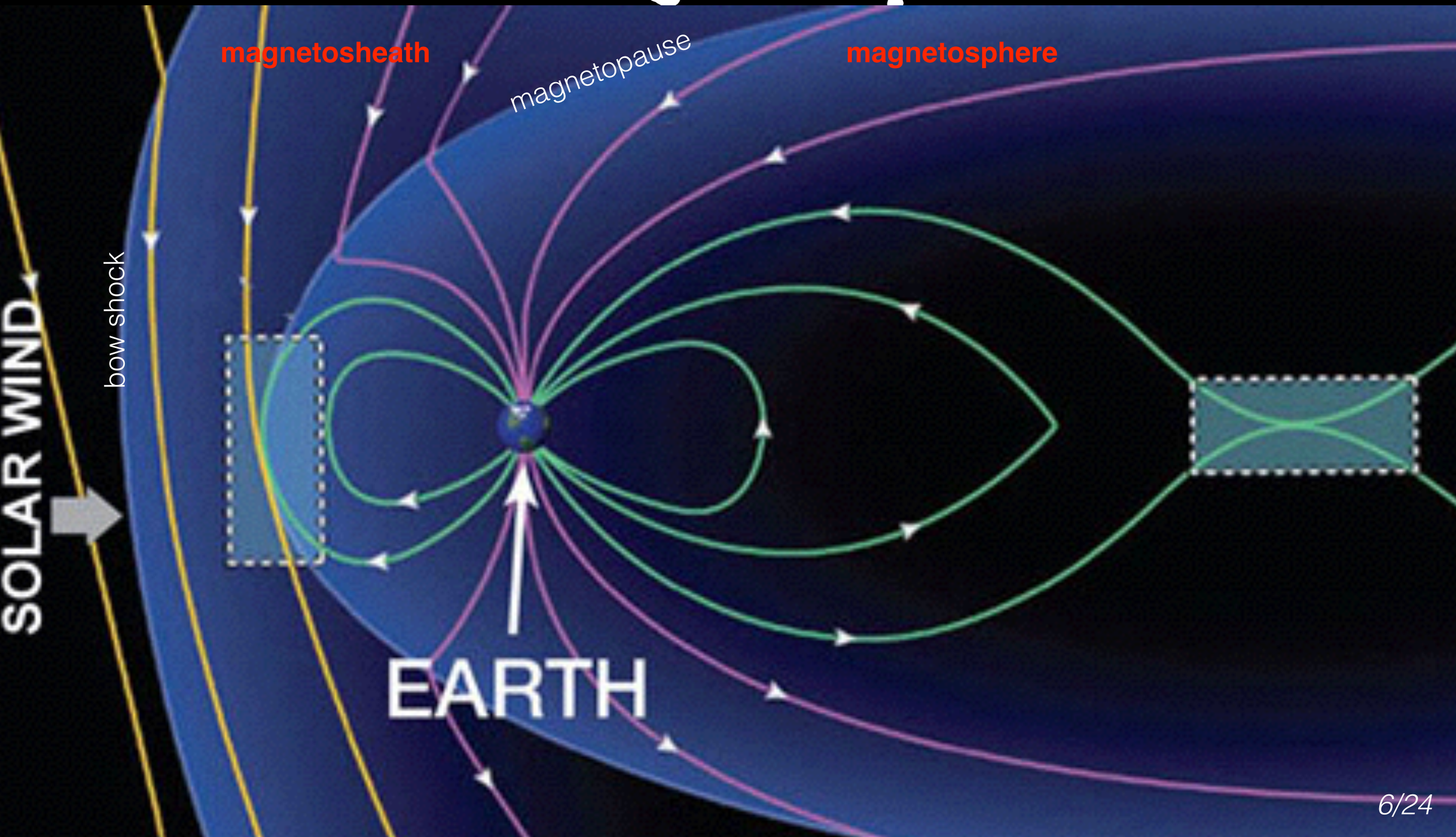

magnetic
reconnection

Coronal Mass Ejection (CME)

- Solar surface activity results in plasma ejection



Magnetic reconnection at the magnetopause



Geomagnetic storm and their effects

Energetic Electrons

Solar Flare Protons

Damage to Spacecraft Electronics

Ionospheric Currents

GPS Signal Scintillation

Radiation Effects on Avionics

Geomagnetically Induced Current in Power Systems

Induced Effects in Submarine Cables

Telluric Currents in Pipelines

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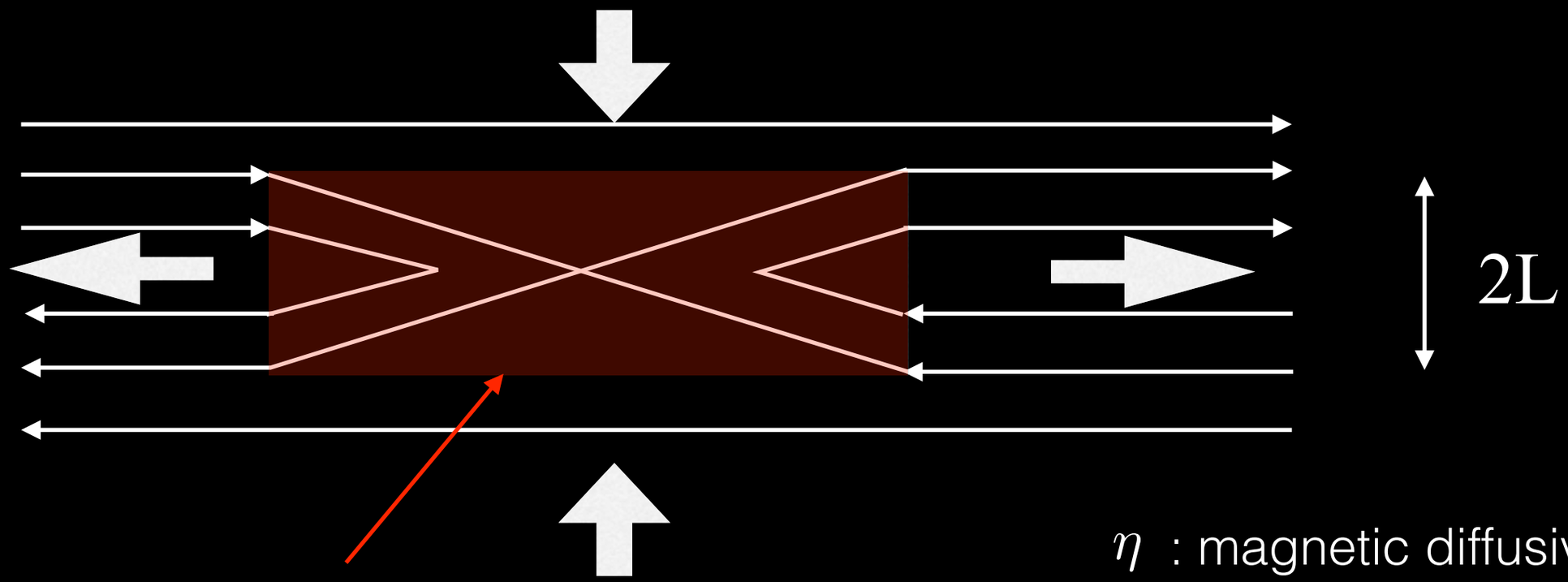
The reconnection rate

$$R \sim v_{in}/v_{out}$$

- Sweet-Parker model :
  the ideal MHD with resistive region

$$R \sim \sqrt{\eta/v_A L}$$



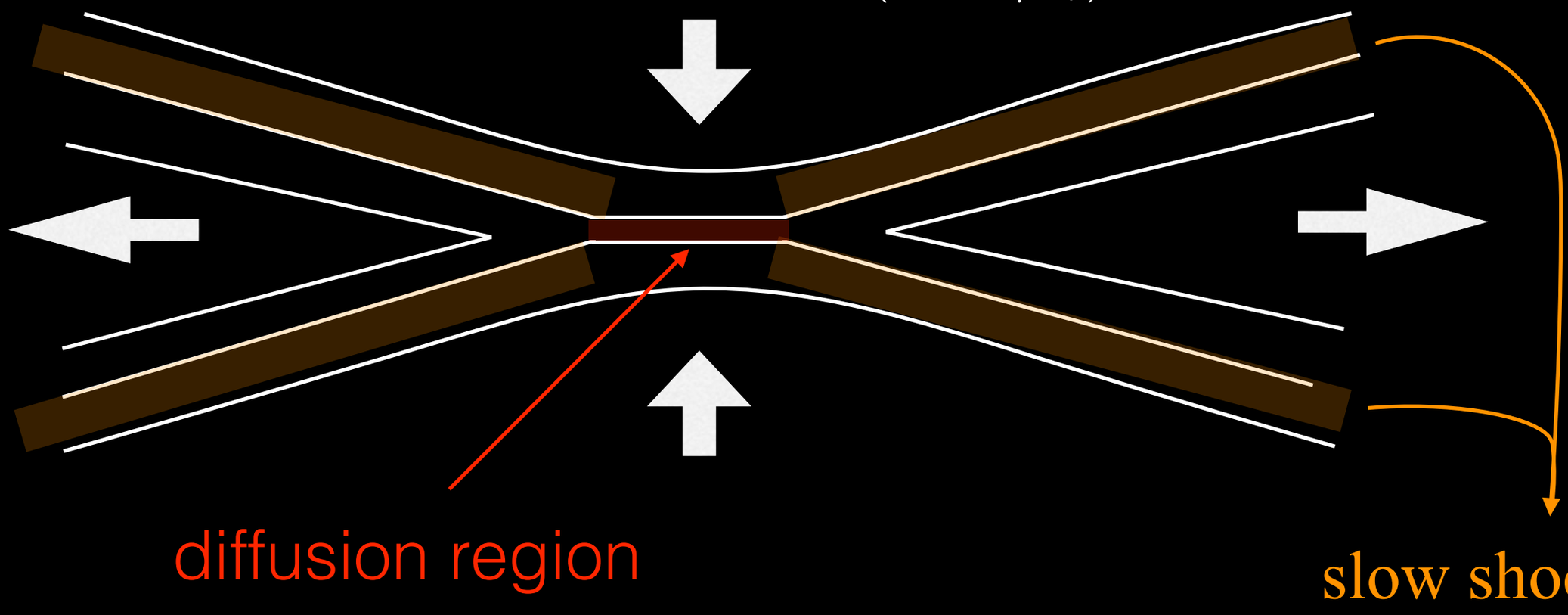
η : magnetic diffusivity
v_A : Alfvén velocity

The reconnection rate

- Sweet-Parker reconnection rate too low to explain solar flare, dayside reconnection, etc…

- Petschek model : smaller diffusion region + slow shock

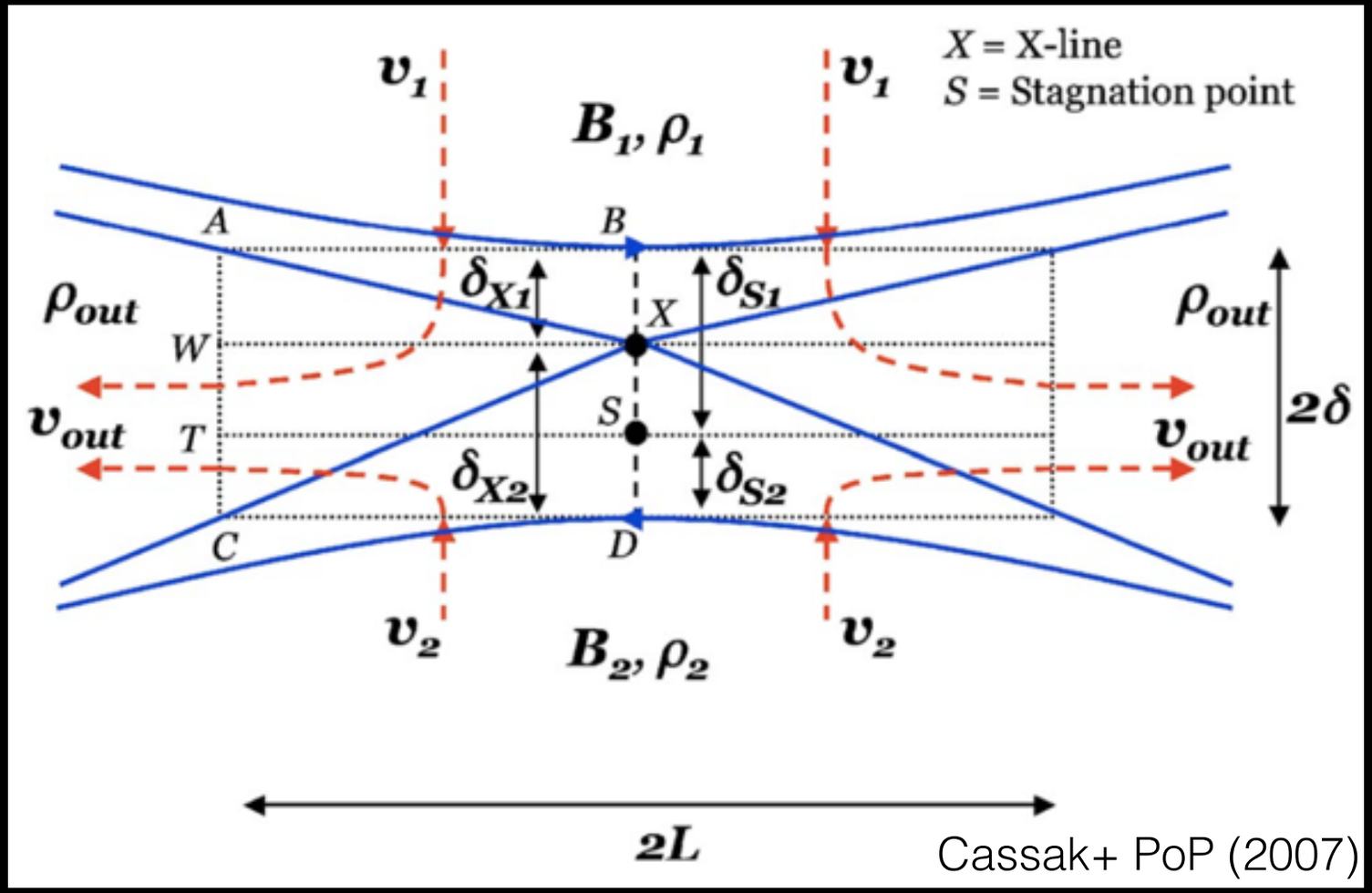
$$R \sim v_{in}/v_A \approx \frac{\pi}{8 \ln(L v_A/\eta)}$$



The reconnection rate

- Asymmetric magnetic reconnection
- Cassak-Shay semi-empirical formula:

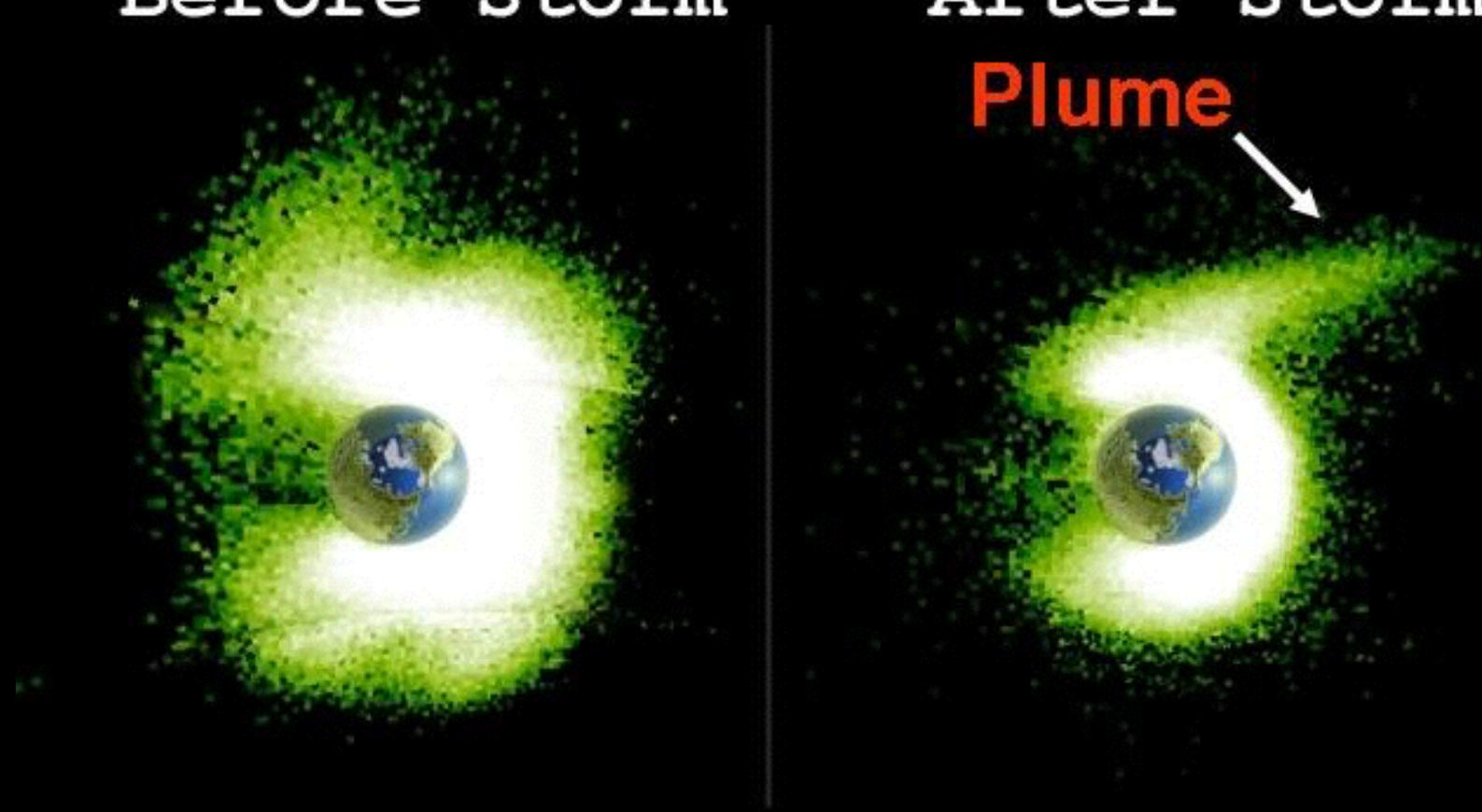
$$R \sim \frac{\delta}{\sqrt{\pi} c L} \frac{(B_1 B_2)^{3/2}}{\sqrt{(\rho_1 B2 + \rho_2 B_1)(B_1 + B_2)}}$$



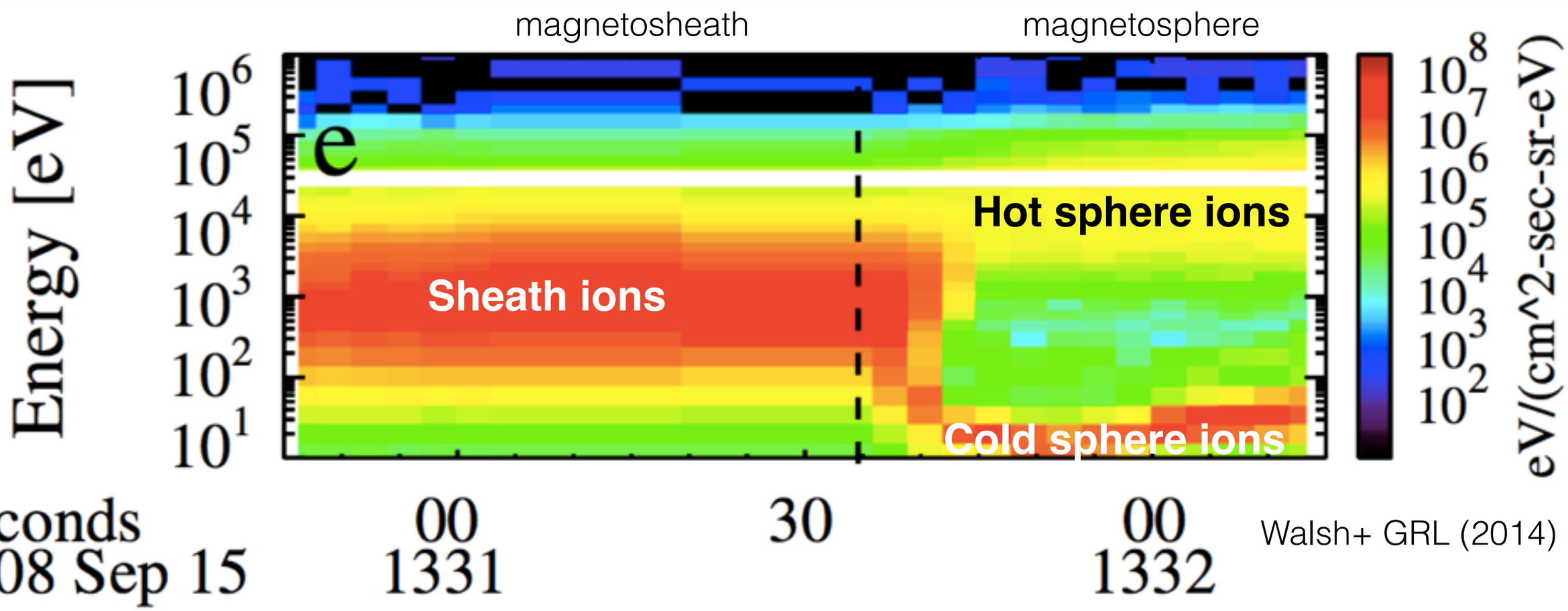
Cassak+ PoP (2007)

The plasmaspheric plumes

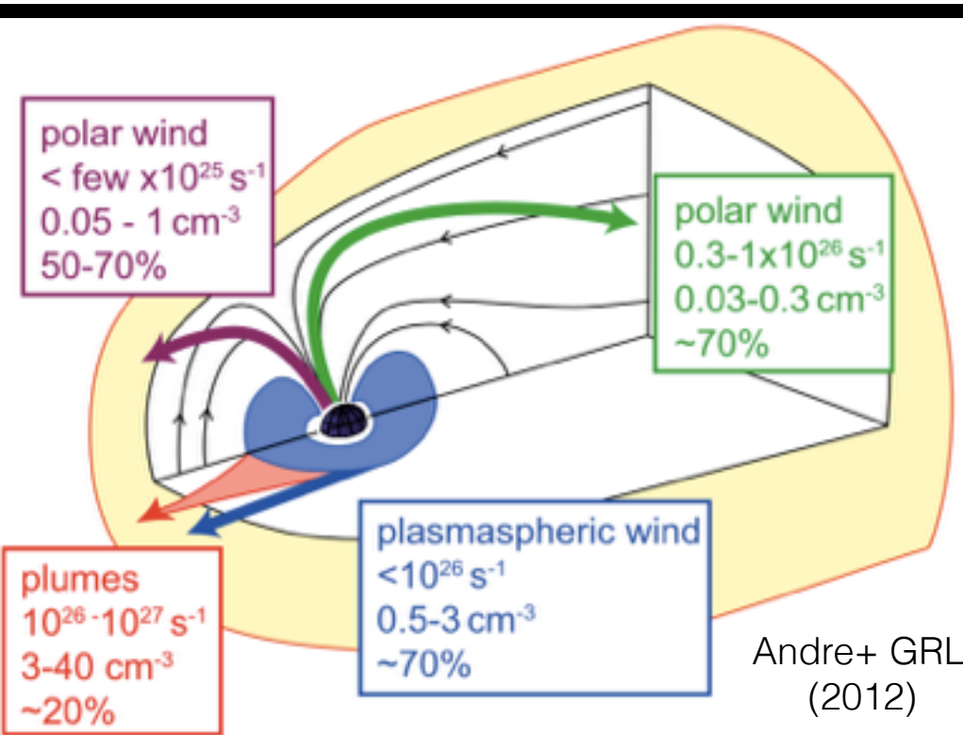
- Dense and cold plasma from the ionosphere
- Happens after geomagnetic storm



Cold ions : a non-negligible population



Walsh+ GRL (2014)



Andre+ GRL (2012)

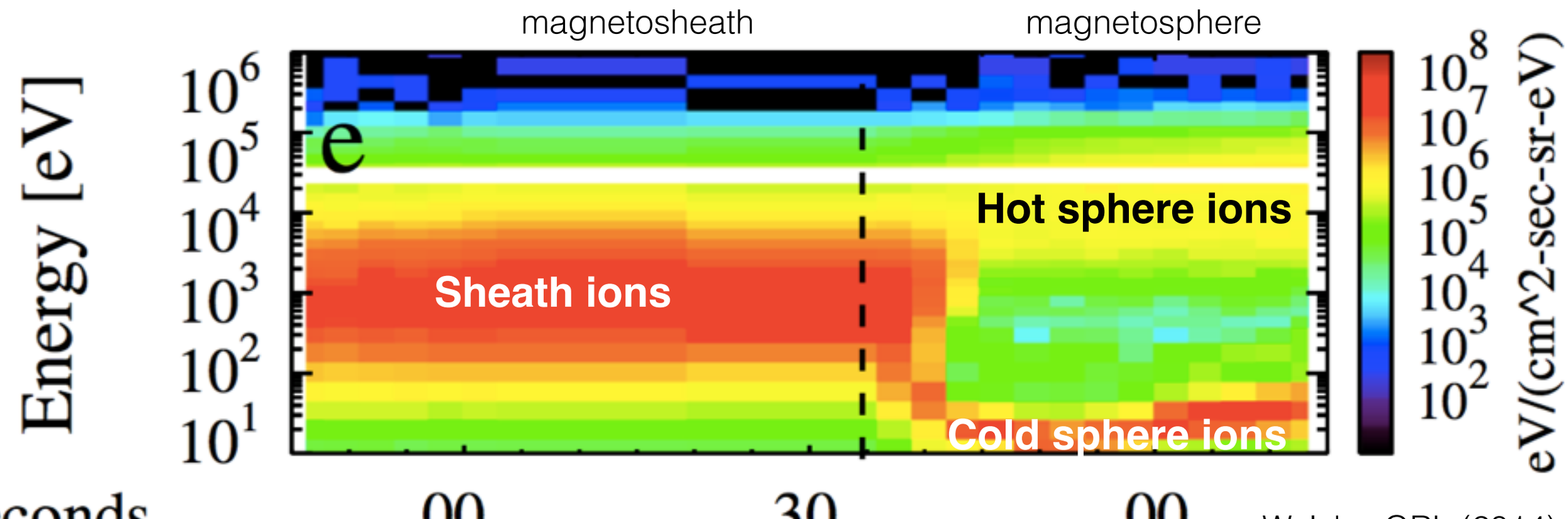
Influence of cold ions :

- Major contribution to the density
- New scales in magnetic reconnection (Toledo-Redondo+ GRL 2015)
- Others unknown effects?

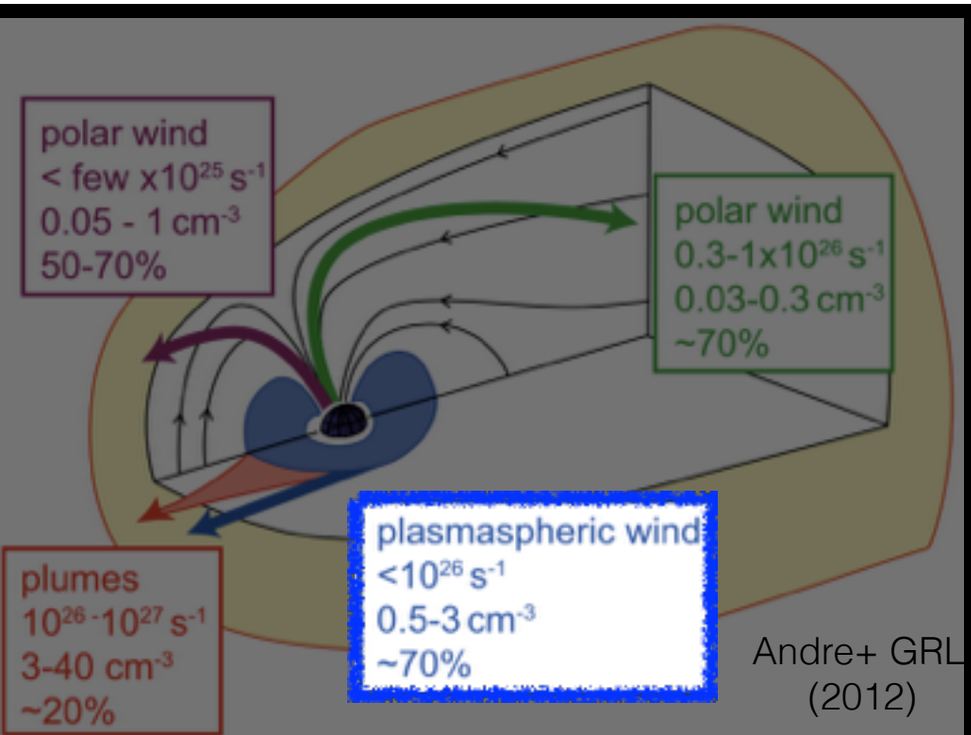
Question:

What is the effect of cold ions on signatures of magnetic reconnection?

Cold ions : a non-negligible population



Walsh+ GRL (2014)



Andre+ GRL (2012)

Influence of cold ions :

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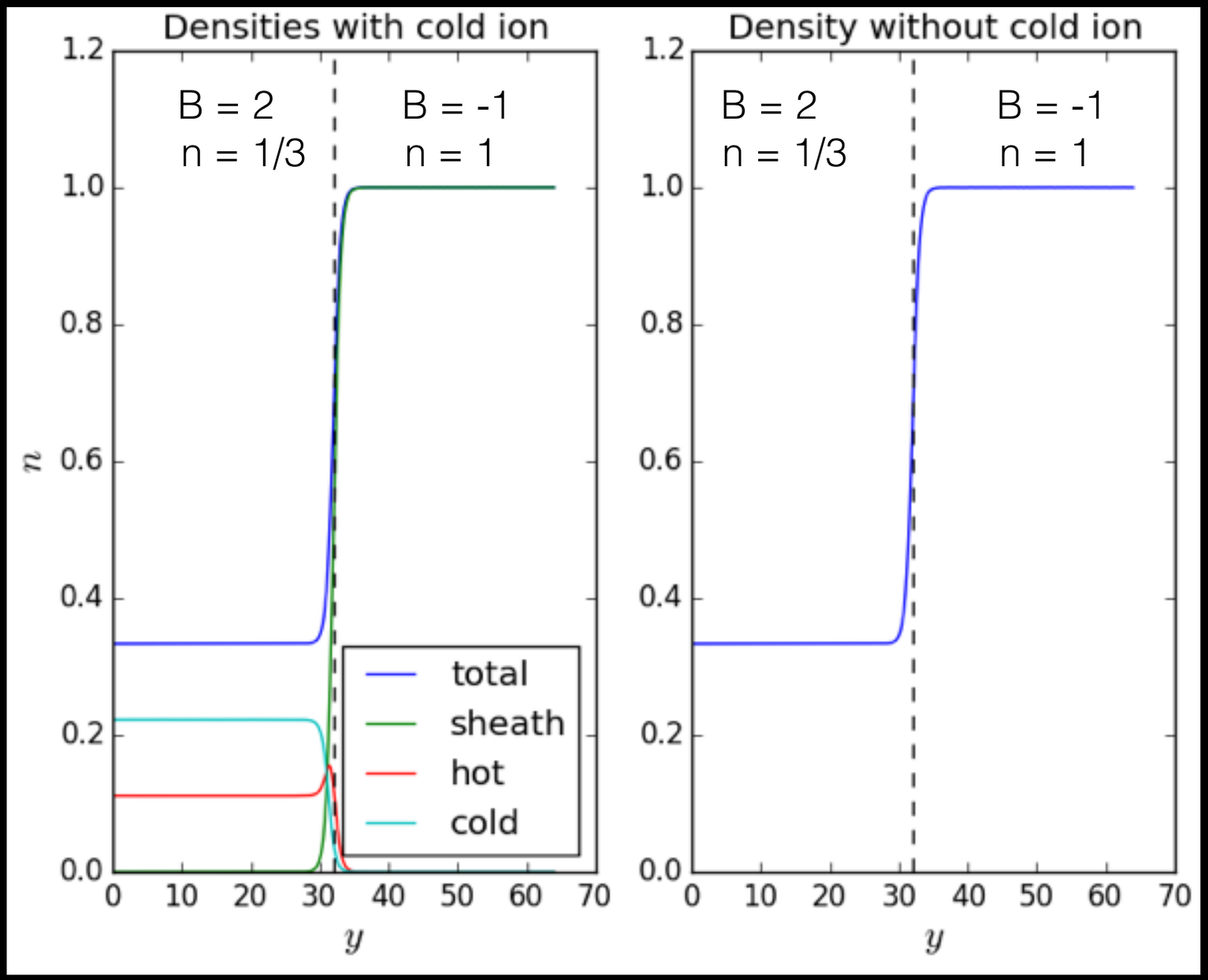
Simulation initial setup



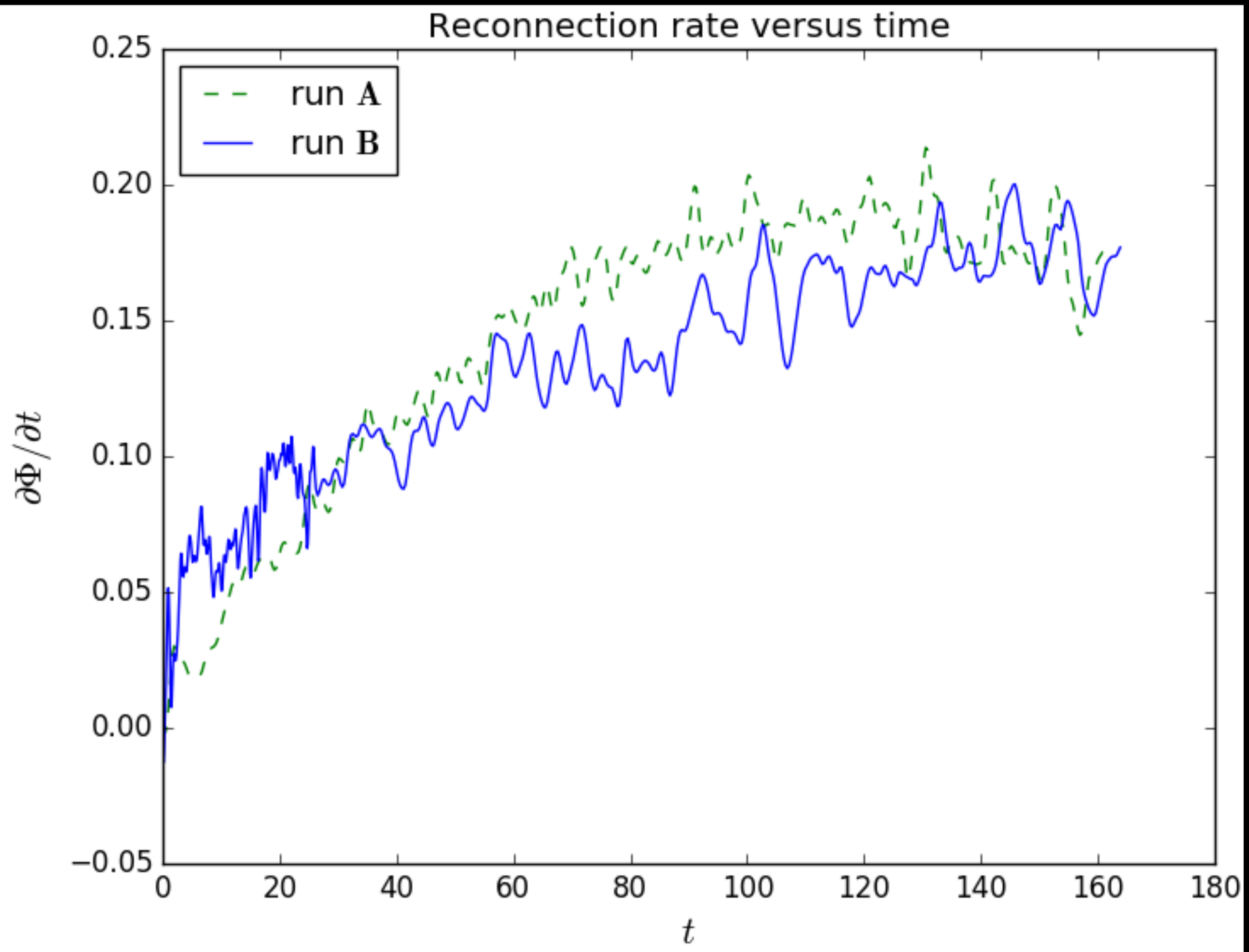
$m_i/m_e = 25$ $\quad T_{hot}/T_{cold} = 500$

$T_e/T_i = 0.2$ $\quad n_{hot}/n_{cold} = 0.5$

system size : $(320 \times 64)\delta_i$

- Two 2D fully kinetic simulations:
  - with cold ions
  - without cold ions
- Same total density, total temperature and magnetic field.
- Only difference : species on magnetospheric side
- Initialisation done with regards on observations (Toledo-Redondo+ GRL 2015)

Reconnection rates

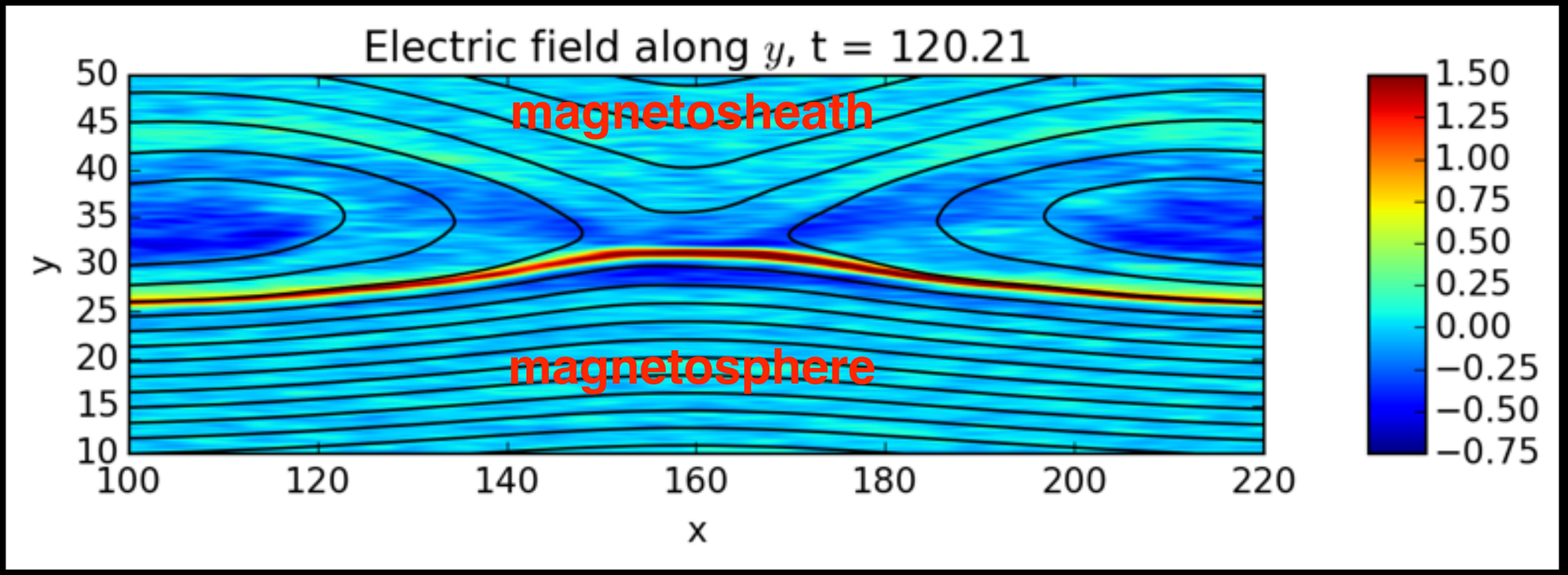


run A : without cold ions
run B : with cold ions

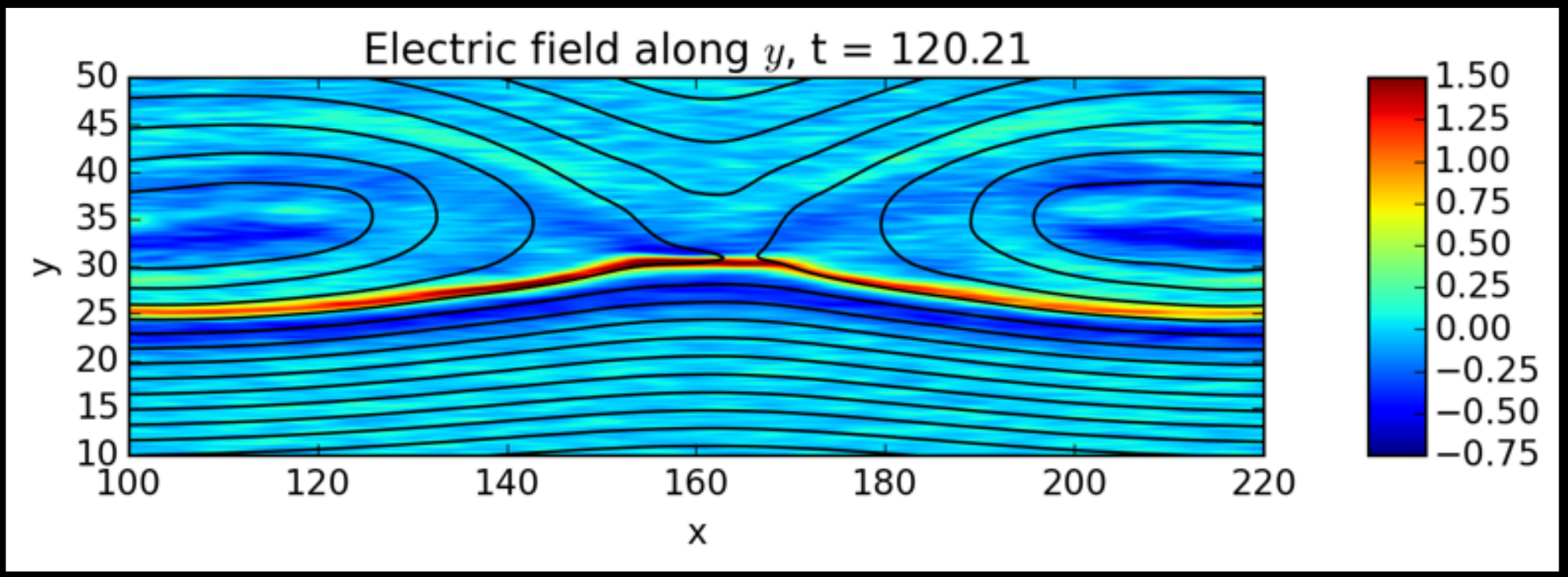
- No real effect of cold ions on the reconnection rate

Cold ion effects on the electric field

Extended « Larmor » electric field



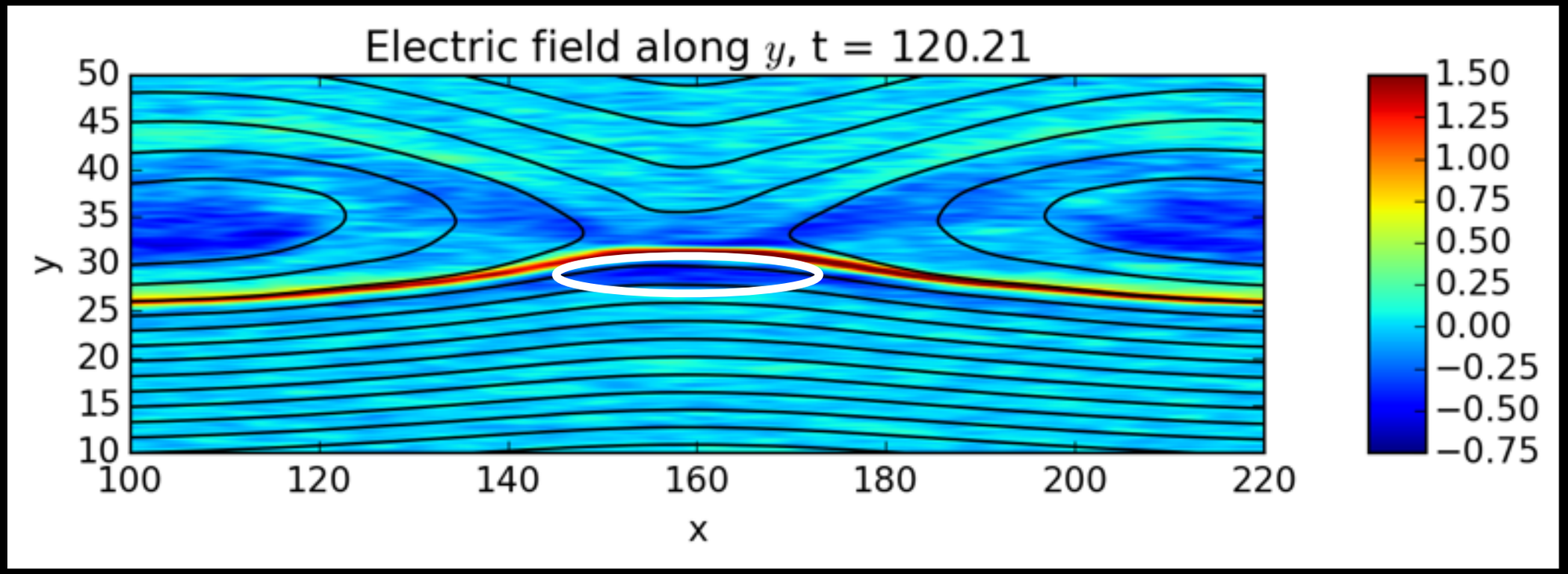
without cold ions



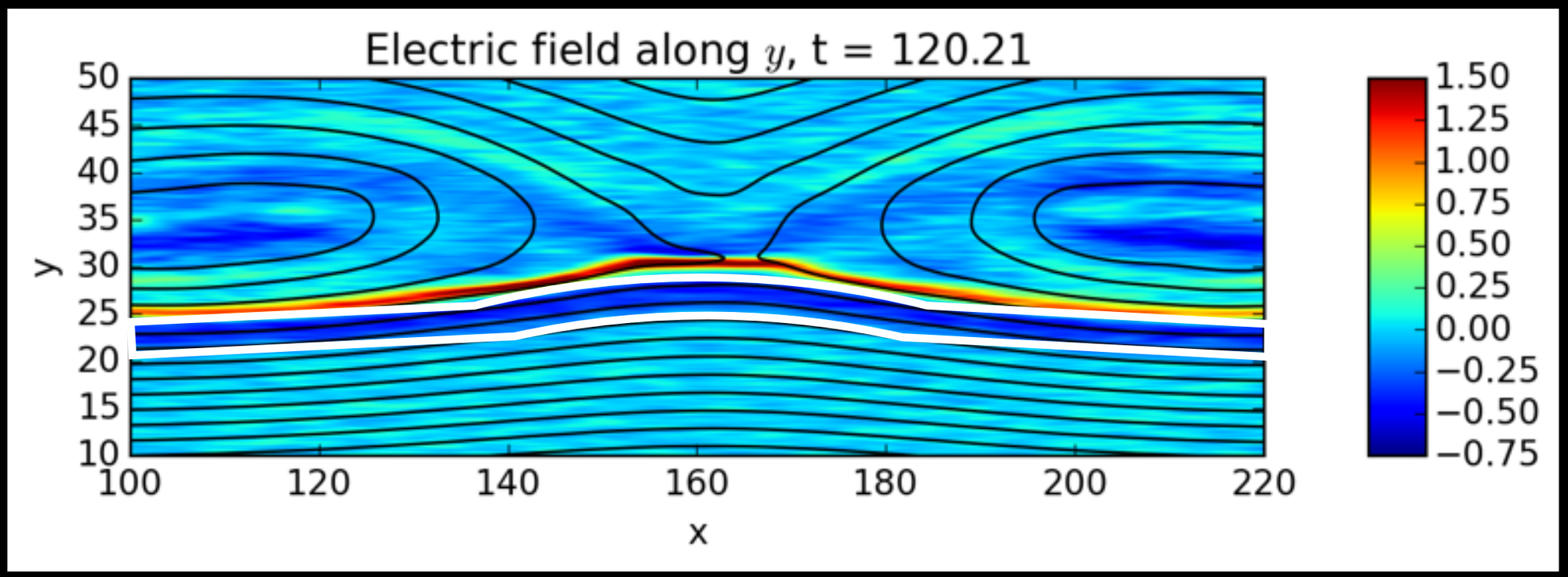
with cold ions

Cold ion effects on the electric field

Extended « Larmor » electric field



without cold ions

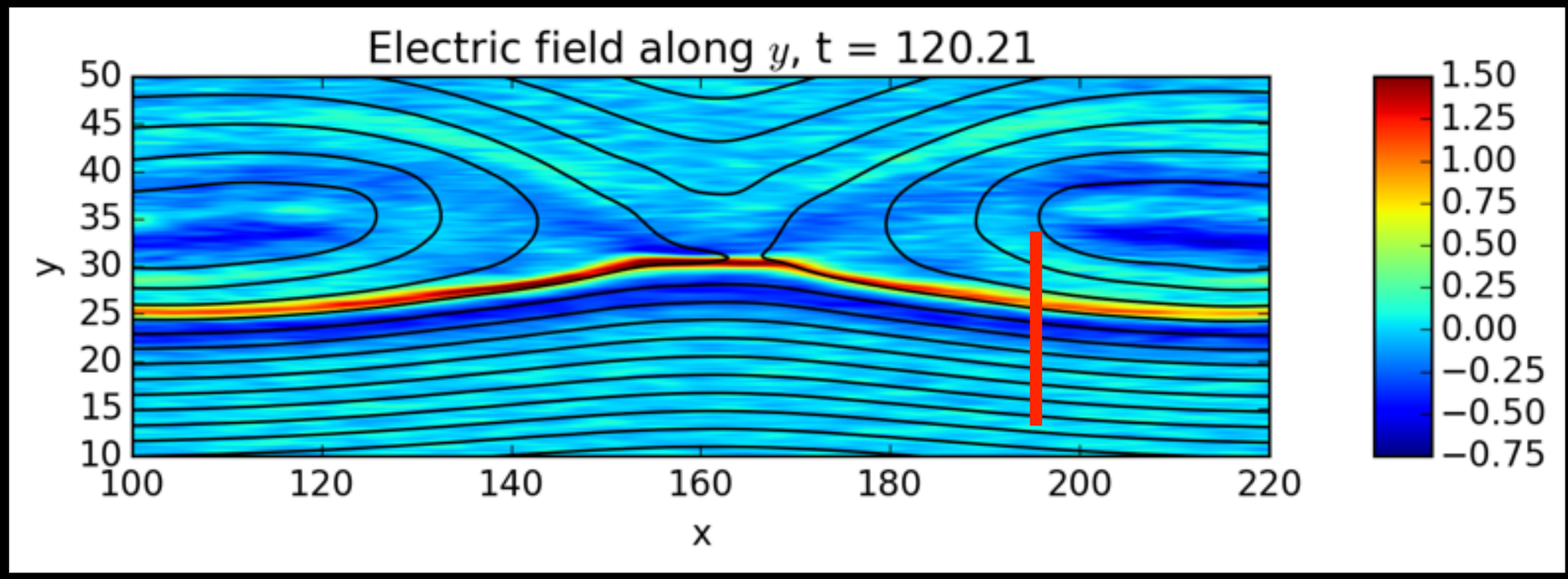


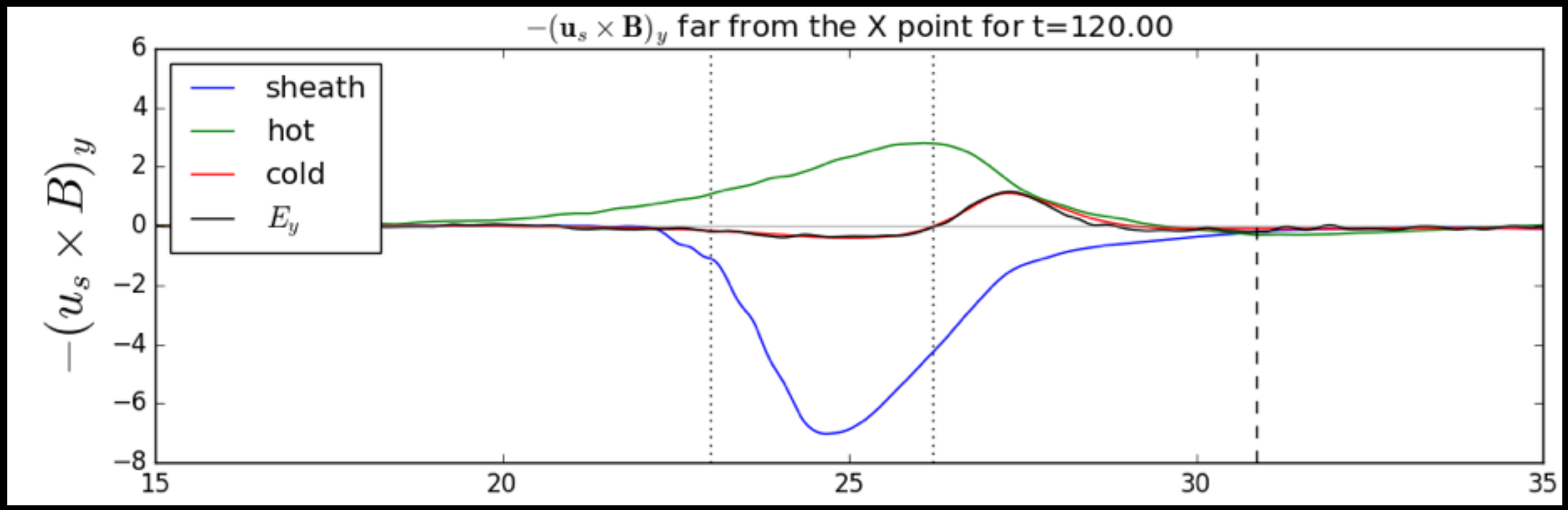
with cold ions

Cold ions and E-field far from the X-line

Frozen-in cold ions

- Cut far from the X line
- Only cold ions are frozen-in



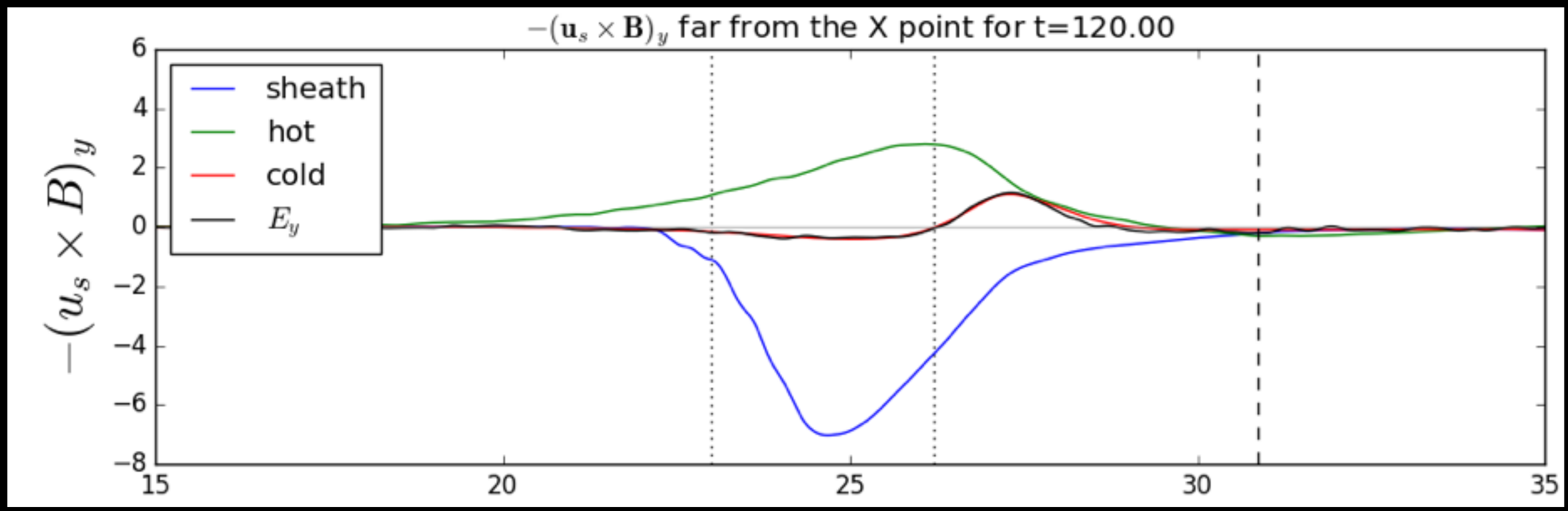


Cold ions and E-field far from the X-line

Frozen-in cold ions

- Frozen-in cold ions —> drift in the E field

→ v_{iz} is modified



Origin of the new electric field

Generalized Ohm's law

Hall term

Pressure term
(≈ 0)

$$E_y = \frac{1}{en}(\mathbf{j}\times\mathbf{B})_y - \frac{1}{en}\left(\boldsymbol{\nabla}\cdot\overrightarrow{\overrightarrow{P}}_d\right)_y$$

$$-\frac{n_{ic}}{n}(\mathbf{u}_{ic}\times\mathbf{B})_y - \frac{n_{ih}}{n}(\mathbf{u}_{ih}\times\mathbf{B})_y - \frac{n_{ish}}{n}(\mathbf{u}_{ish}\times\mathbf{B})_y$$

Cold ion ideal term

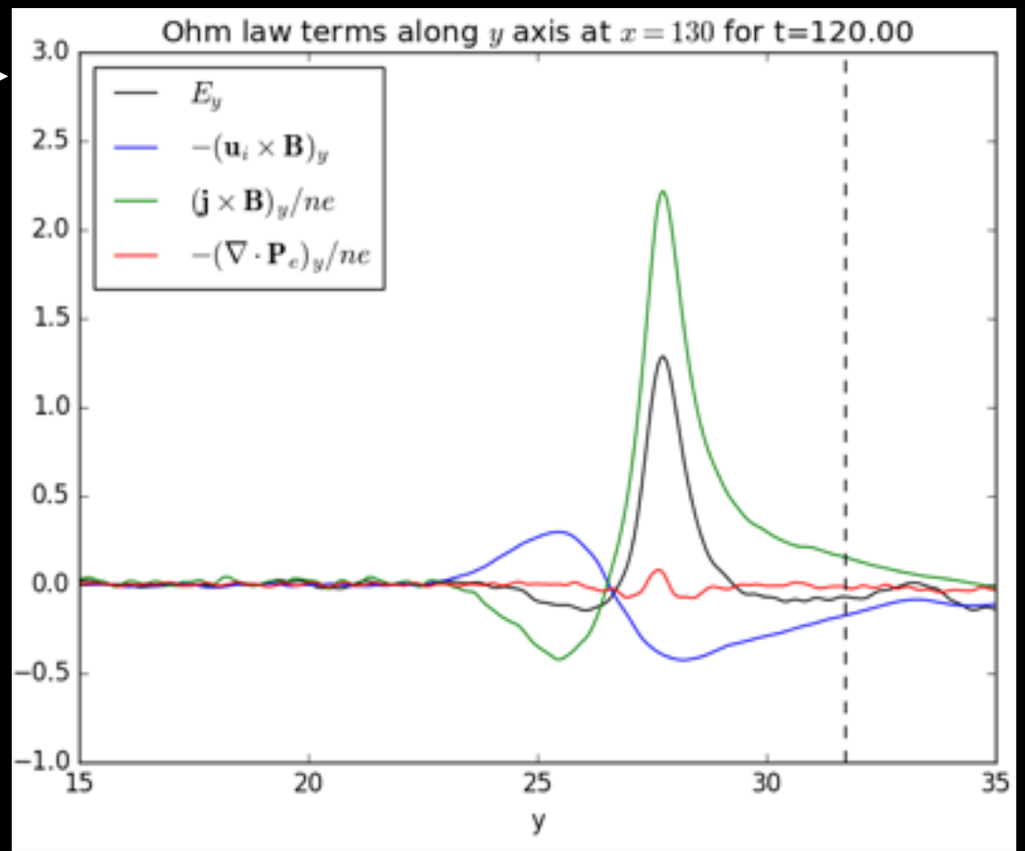
Hot ion ideal term

Sheath ion ideal term

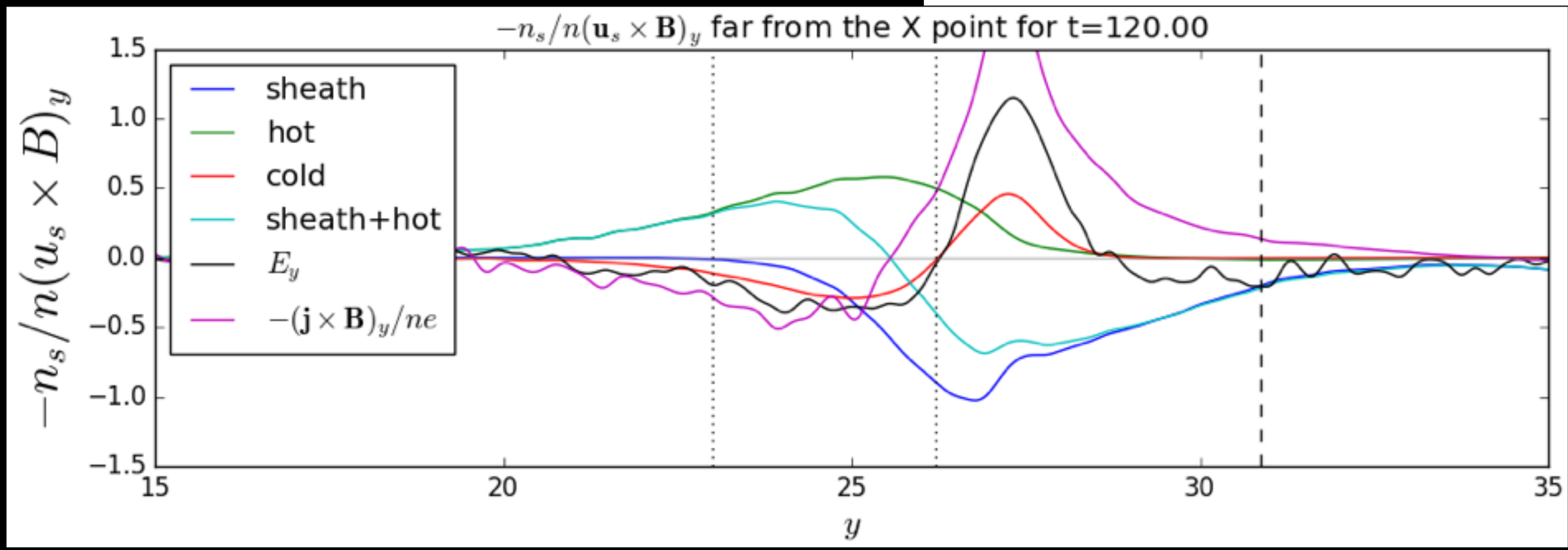
Demagnetized ion ideal term

Origin of the new electric field

without cold ions →

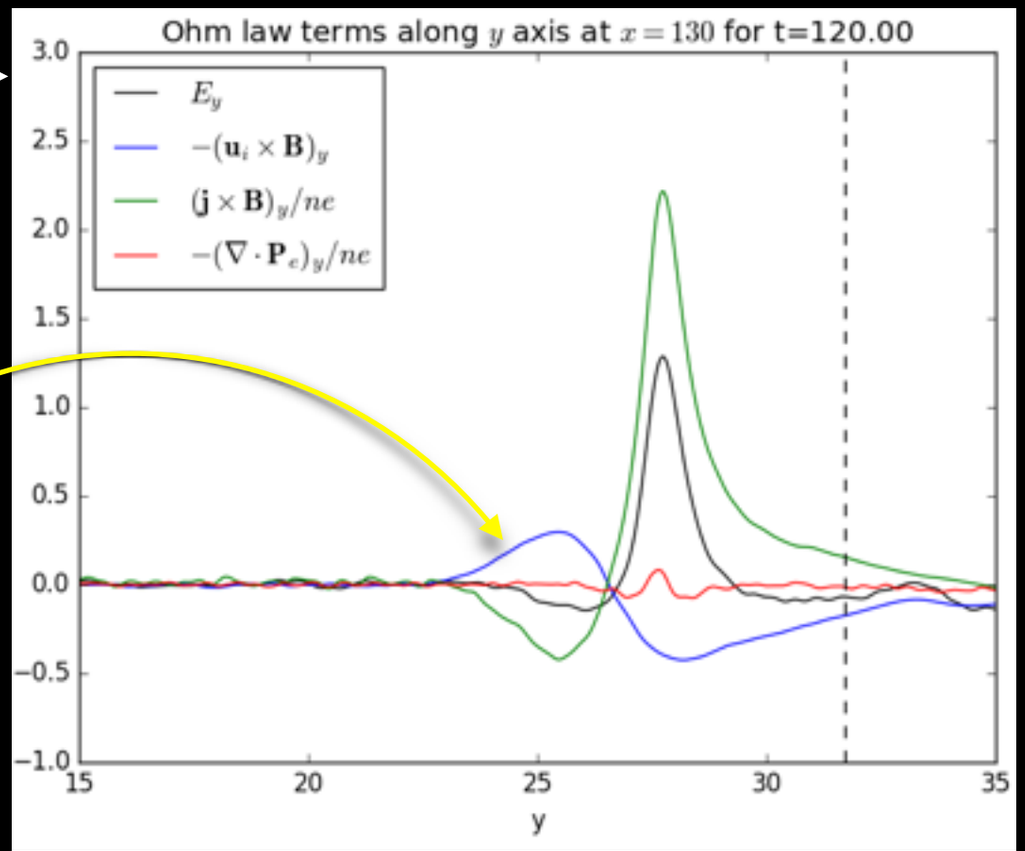


with cold ions ↓



Origin of the new electric field

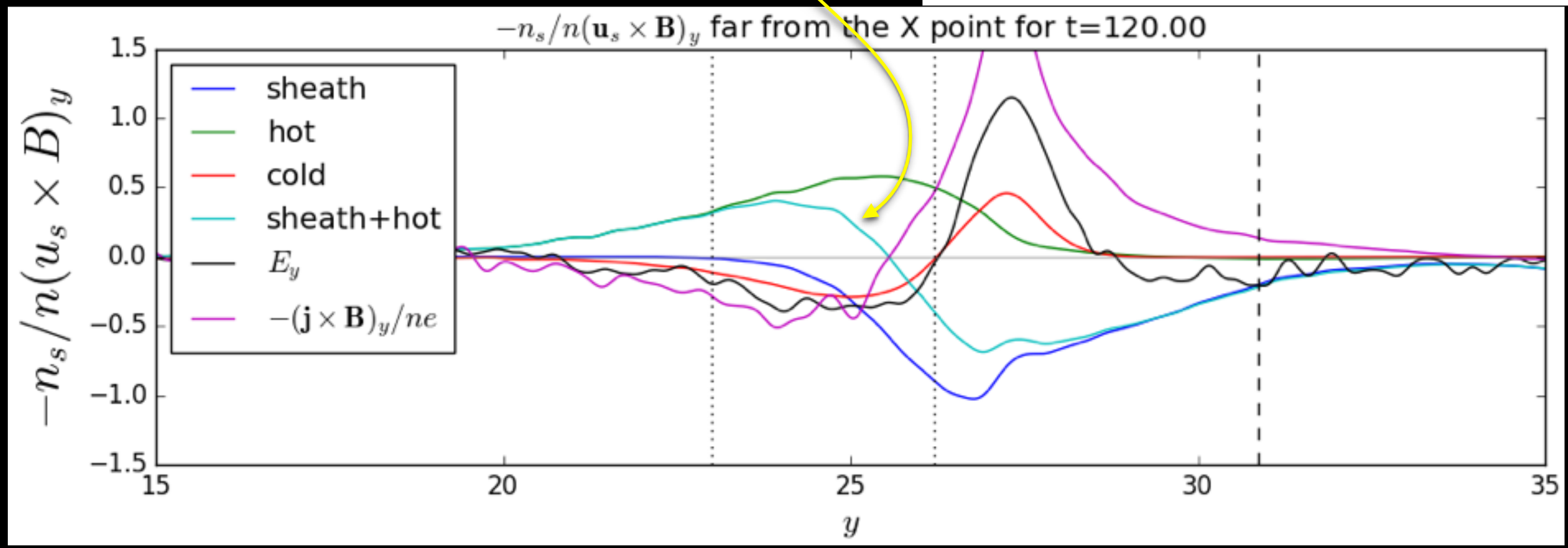
without cold ions →



Demagnetized ions ideal term:

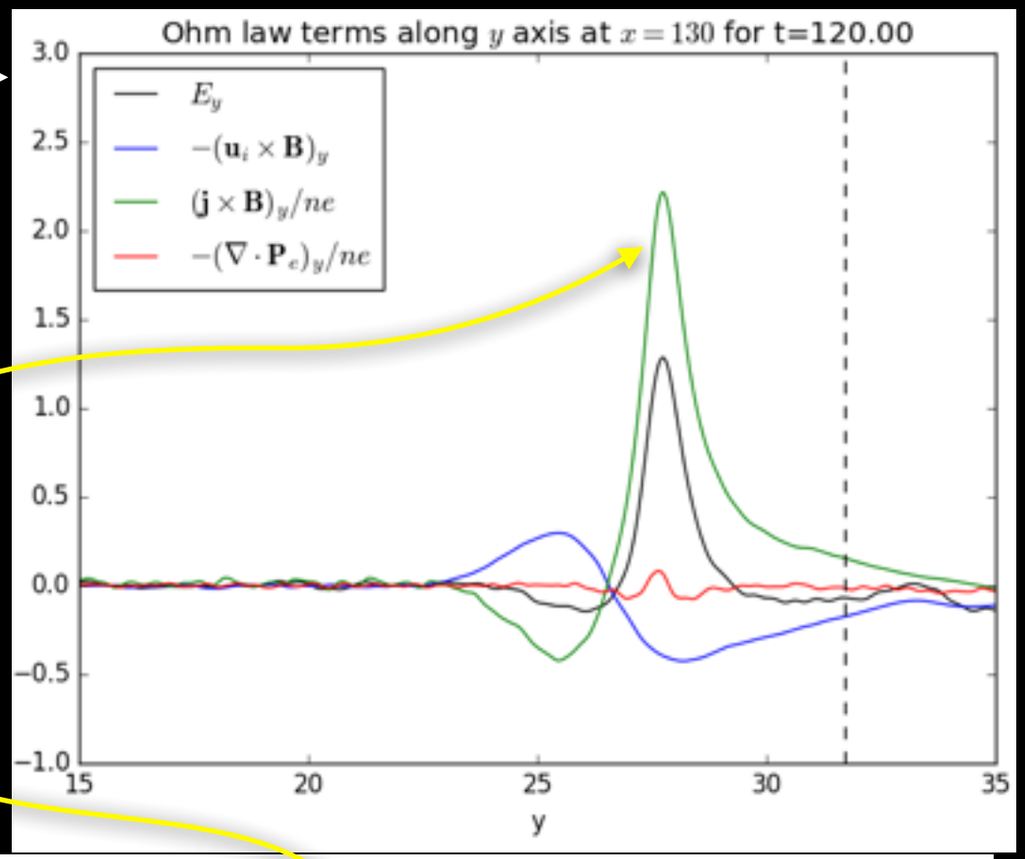
≈

with cold ions



Origin of the new electric field

without cold ions →

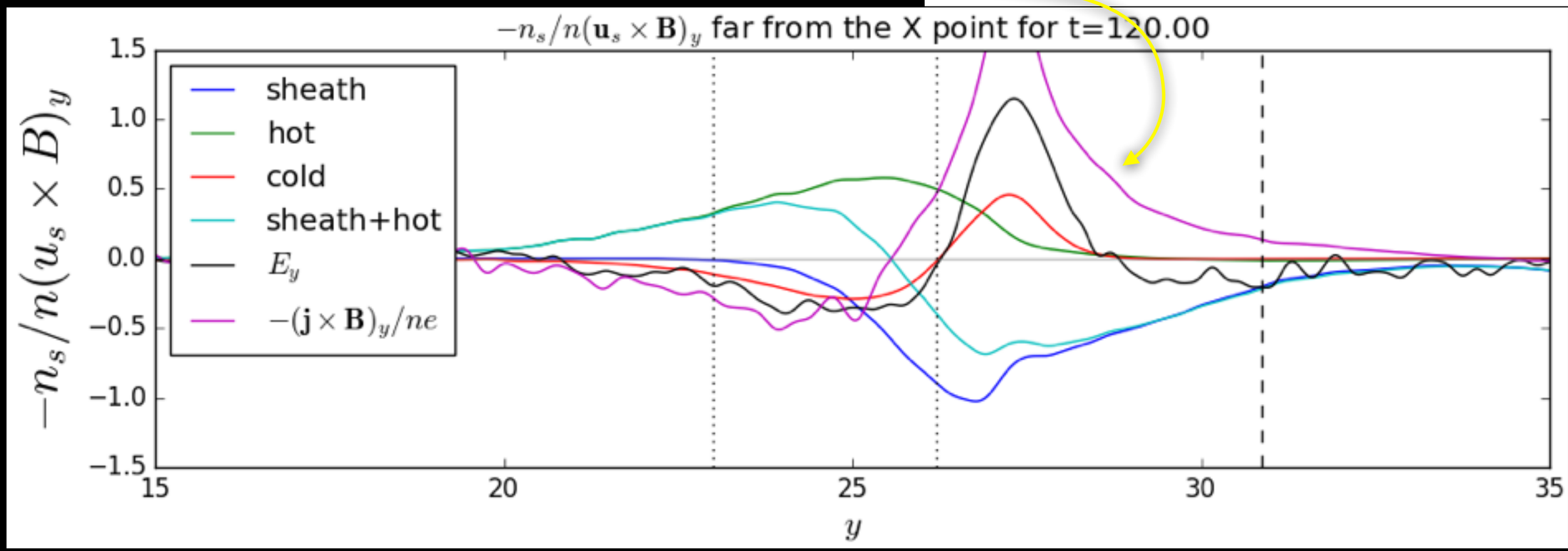


Hall term:

≈

with cold ions

↓



Origin of the new electric field

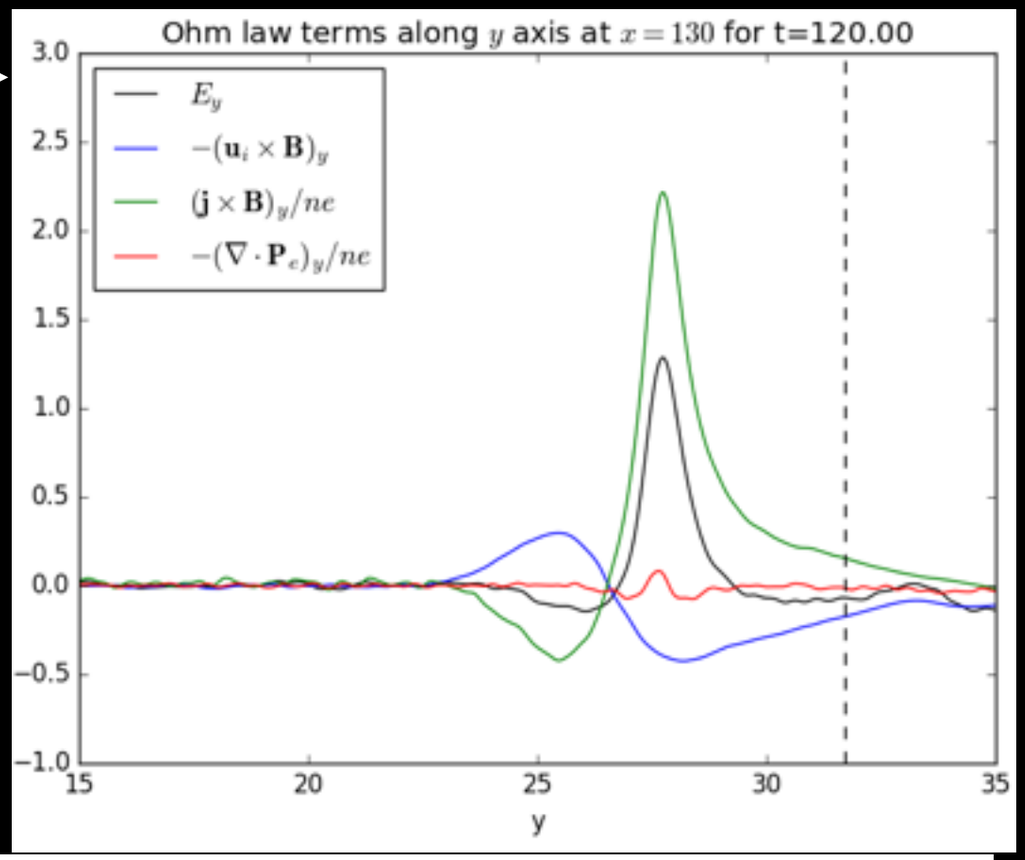
without cold ions →

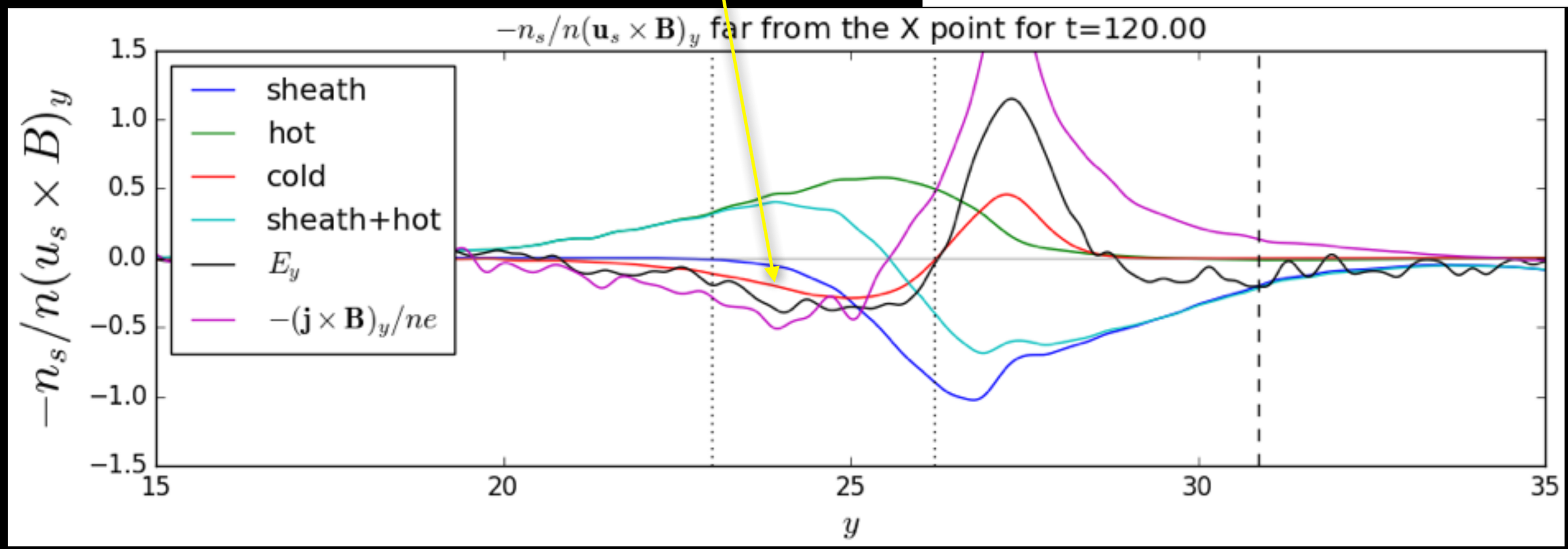
Cold ions ideal term:

≈

Negative electric field

with cold ions



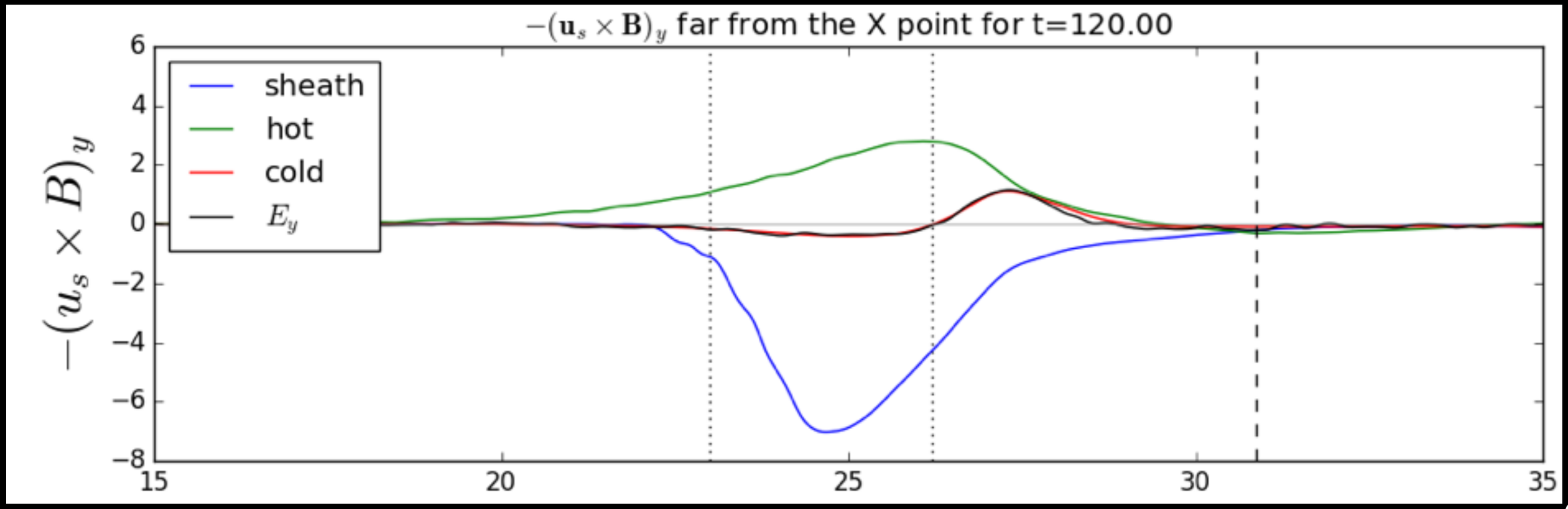


Origin of the new electric field

- Cold ions are frozen in E-field at small scales

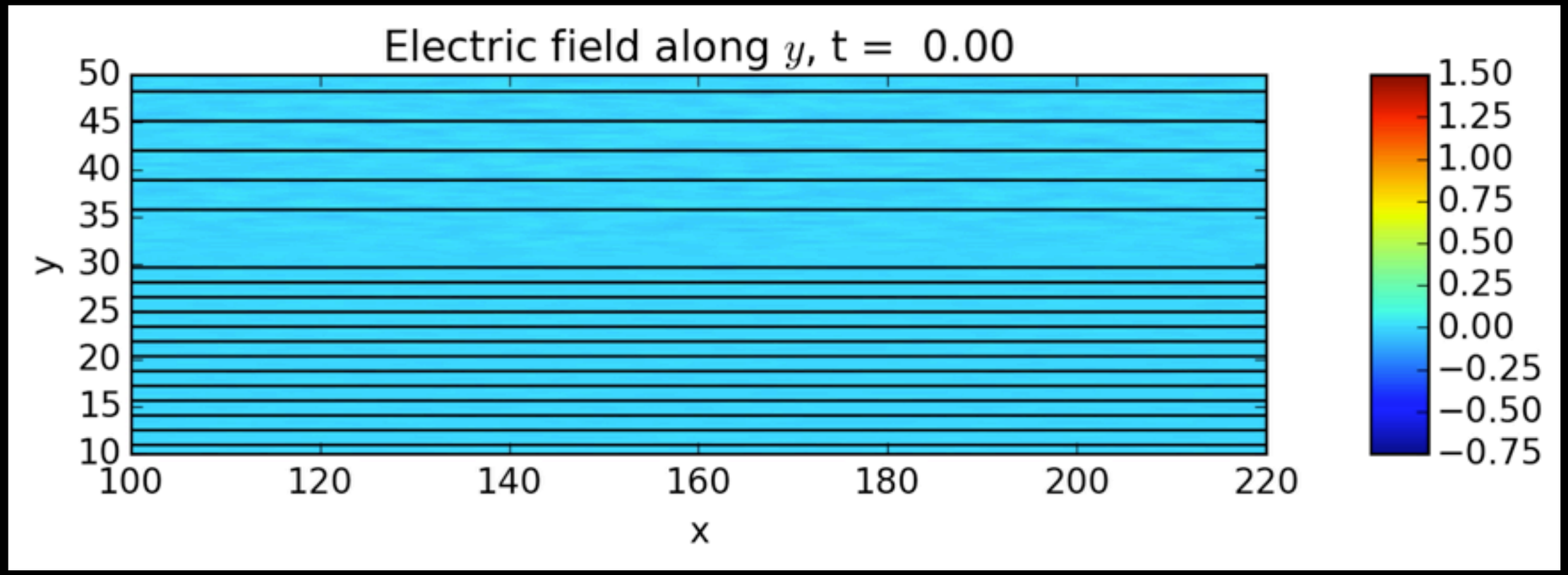
  —> They drift in small scale electric fields

  —> Their drift motion maintains those fields



Origin of the new electric field

without cold ions



The initial electric field does not disappear in the simulation with cold ions

—> Origin of the elongated negative electric field

Conclusion

- Cold ions temperature does not seem to affect the reconnection rate
- Cold ions have an effect on small scale electromagnetic fields

Future works…

Plume simulation