1st Asia-Pacific Conference on Plasma Physics

Electrodynamic coupling processes in the solar–terrestrial environment

Lou-Chuang Lee
Institute of Earth Sciences, Academia Sinica

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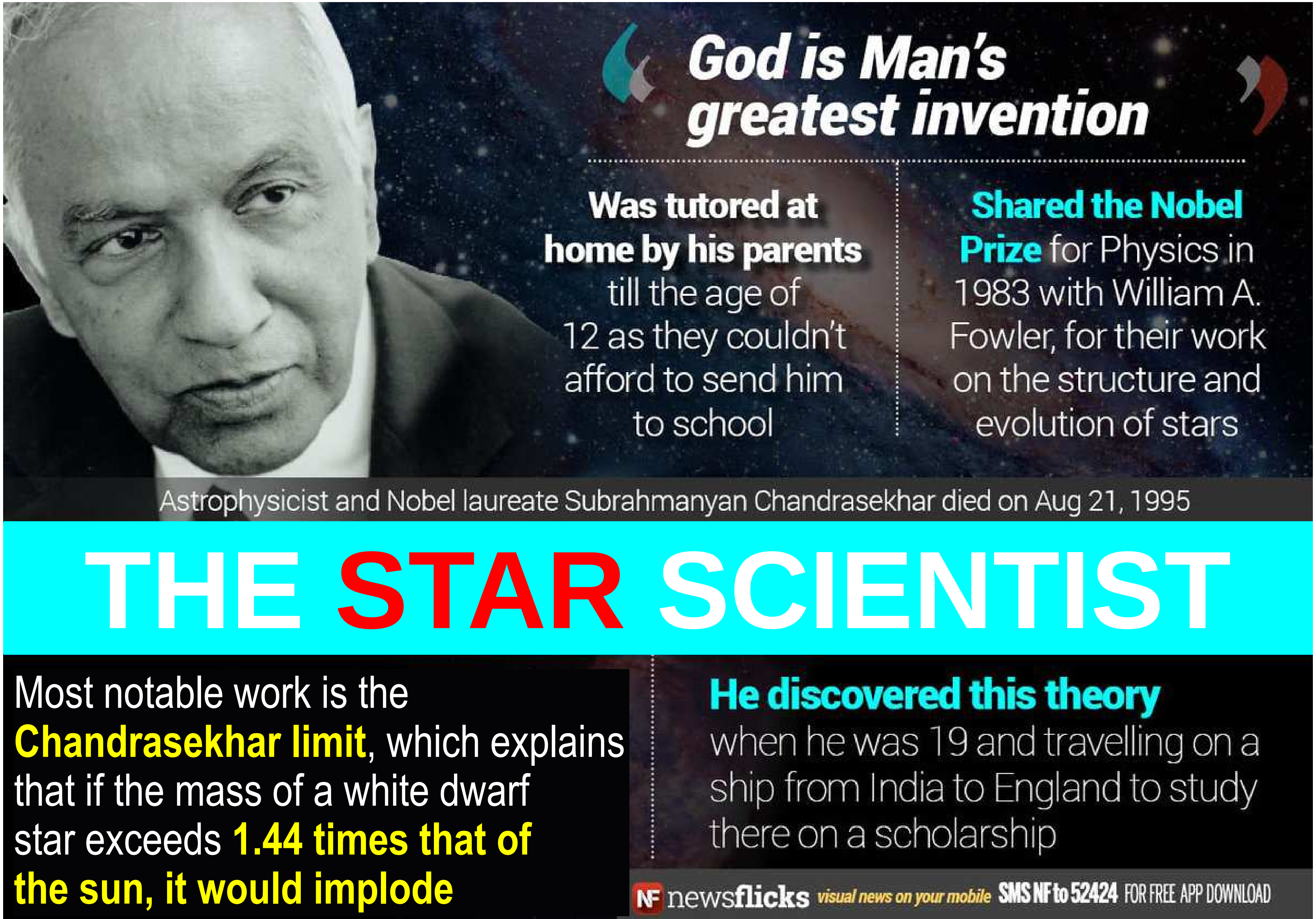
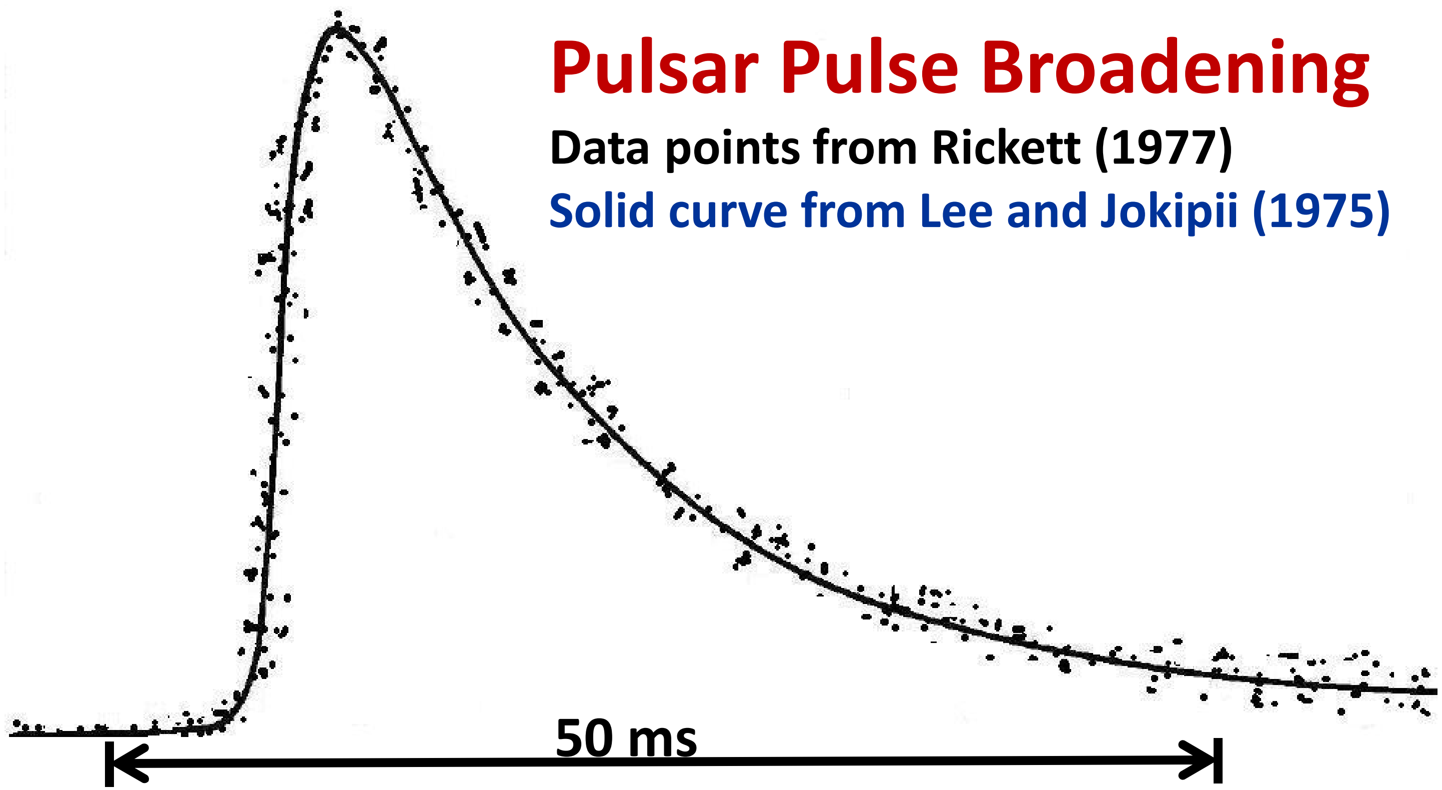
2017 Chandrasekhar Prize of Plasma Physics by the Association of Asia Pacific Physical Societies



Strong scintillation theory

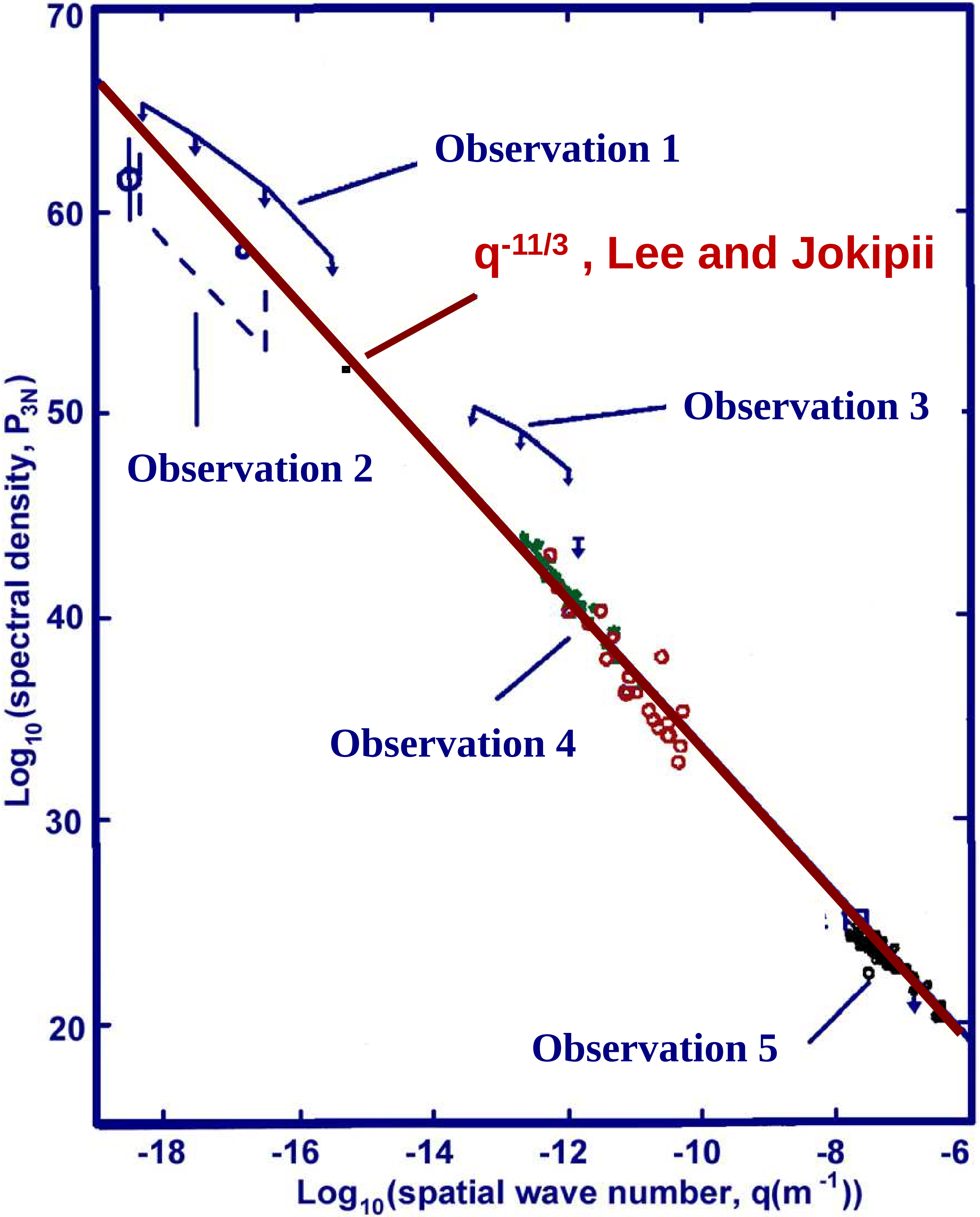
The pulsar (Bell and Hewish, 1967) radio intensity shows strong scintillations caused by interstellar plasma turbulence. Lee and Jokipii in 1975 developed a strong scintillation theory for wave intensity scintillation, angular broadening and pulse broadening.



The Astrophysical Journal, 206, 735-746, 1976

The Irregularity Spectrum in Interstellar Space

- Lee and Jokipii proposed that the interstellar turbulent plasma medium has a Kolmogorov-like spectrum (~ $q^{-11/3}$) with wavelengths extending from 10^8 m to 10^{18} m.
- This is confirmed by observations in the past 40 years.
- This is a pioneer paper on the turbulent plasma density spectrum in the interstellar space.



Observation 1: Rotational measure (RM) fluctuations (Lazio et al., Ap. J., 363, 515, 1990)

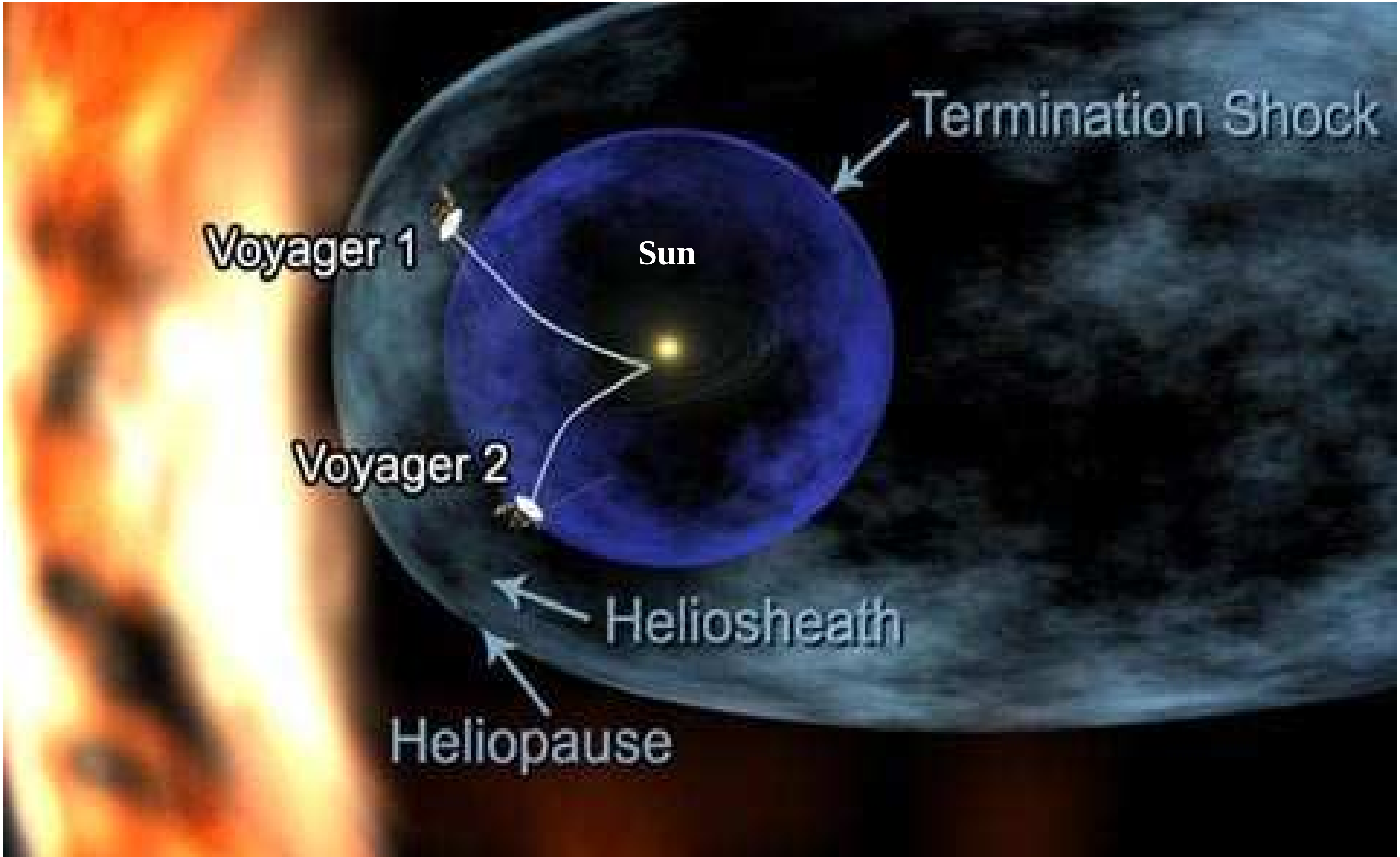
Observation 2: Interstellar medium (ISM) velocity fluctuations (Larson, MNRAS, 186, 479, 1979)

Observation 3: Dispersion measure (DM) fluctuations (Phillips and Wolszczan, Ap. J., 382, L27, 1991)

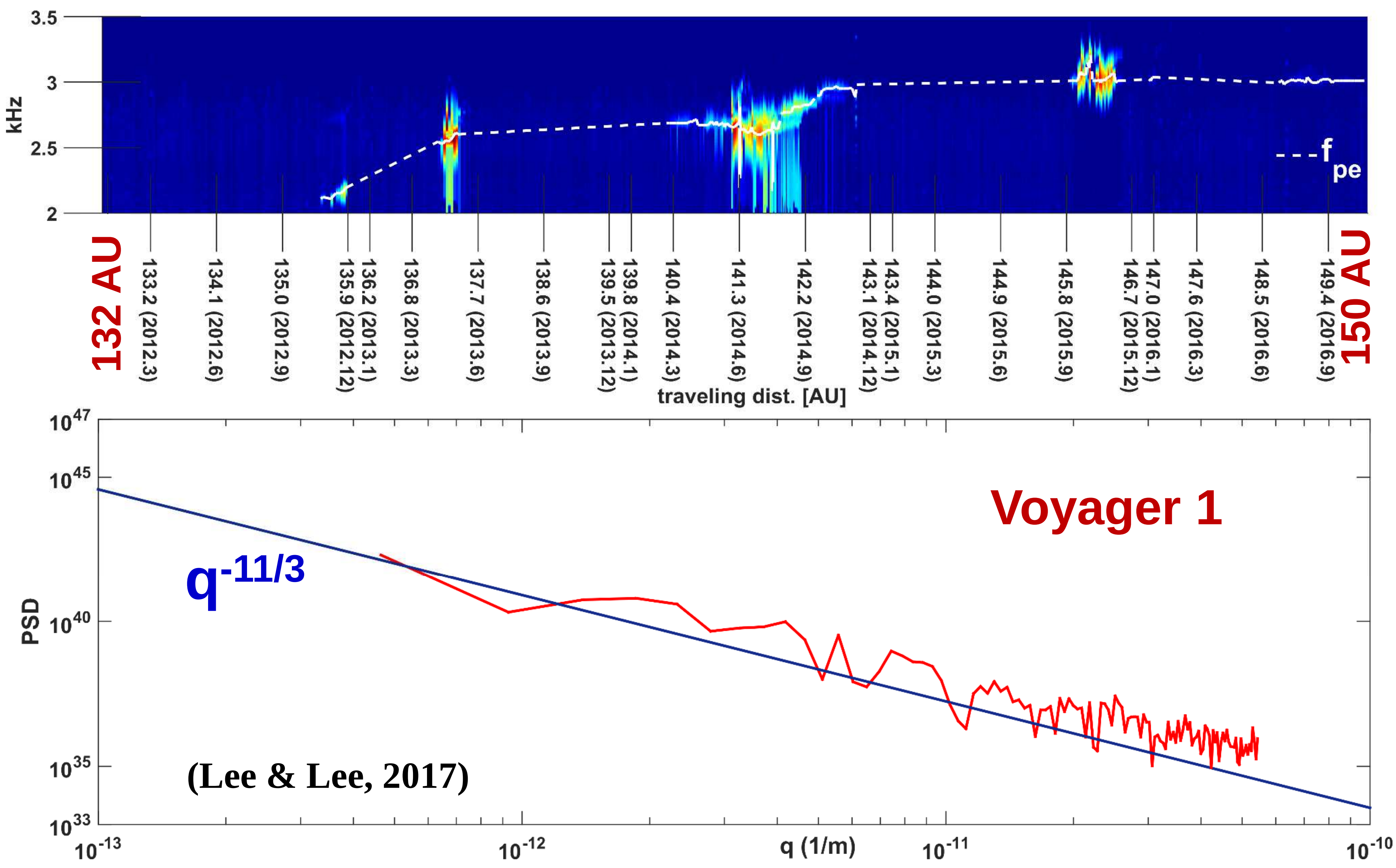
Observation 4: Refractive scintillation index (Gupta et al., Ap. J., 403, 183, 1993)

Observation 5: Decorrelation bandwidth and angular Broadening (Cordes et al., Nature, 354, 121, 1991)

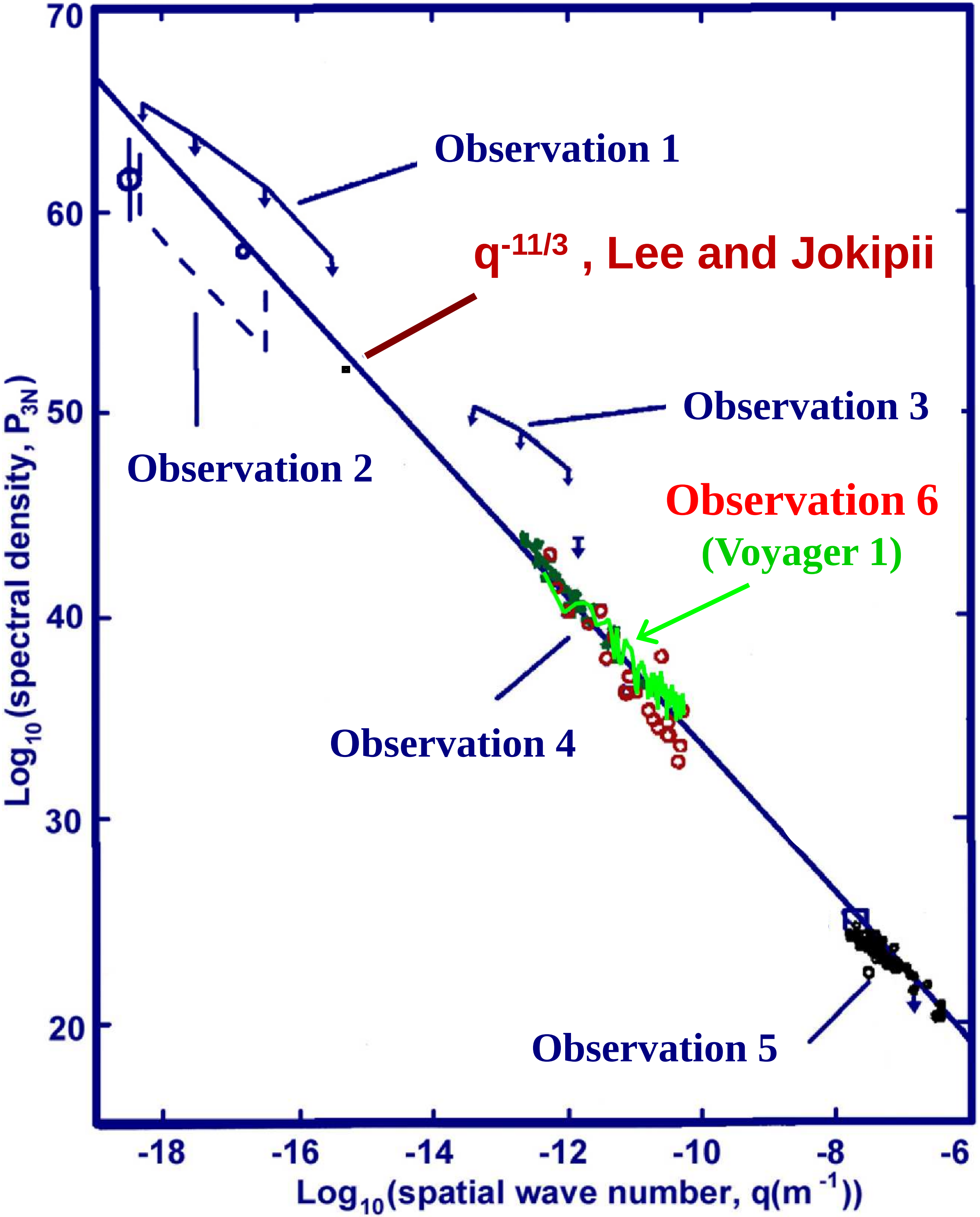
Voyager 1 left interplanetary space into interstellar medium on August 25, 2012



Plasma waves measured from December 2011 to October 2016



The inferred electron density profile can be used to obtain the in-situ power of electron density fluctuations.



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(Cordes et al., Nature, 354, 121, 1991)

Observation 6: Voyager 1
(Lee and Lee, 2017)

< Content >

(A) Flows in the solar photosphere lead to the formation and eruption of solar prominences.

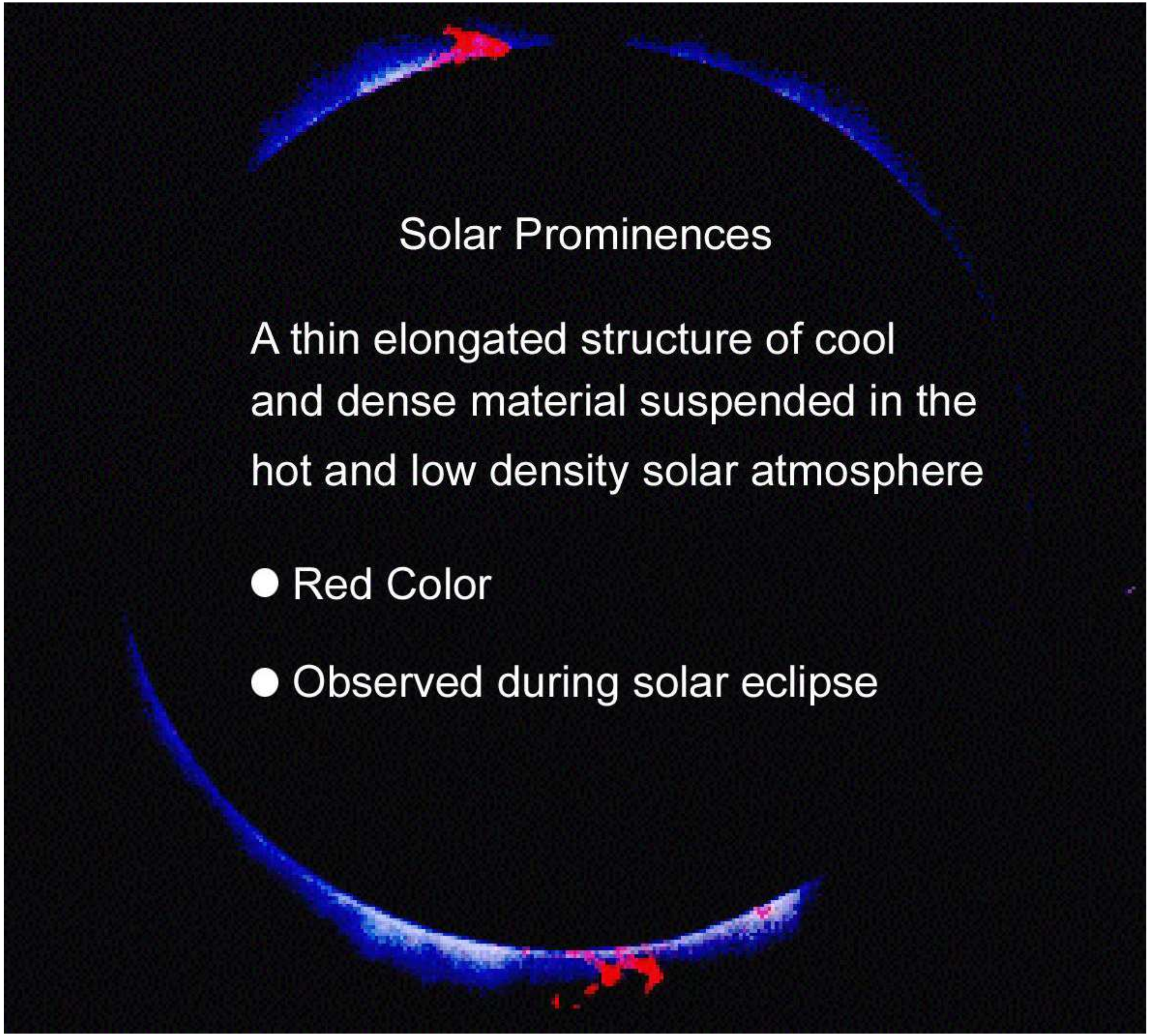
(B) Transport of particles and energy from the solar wind to magnetosphere through magnetic reconnection.

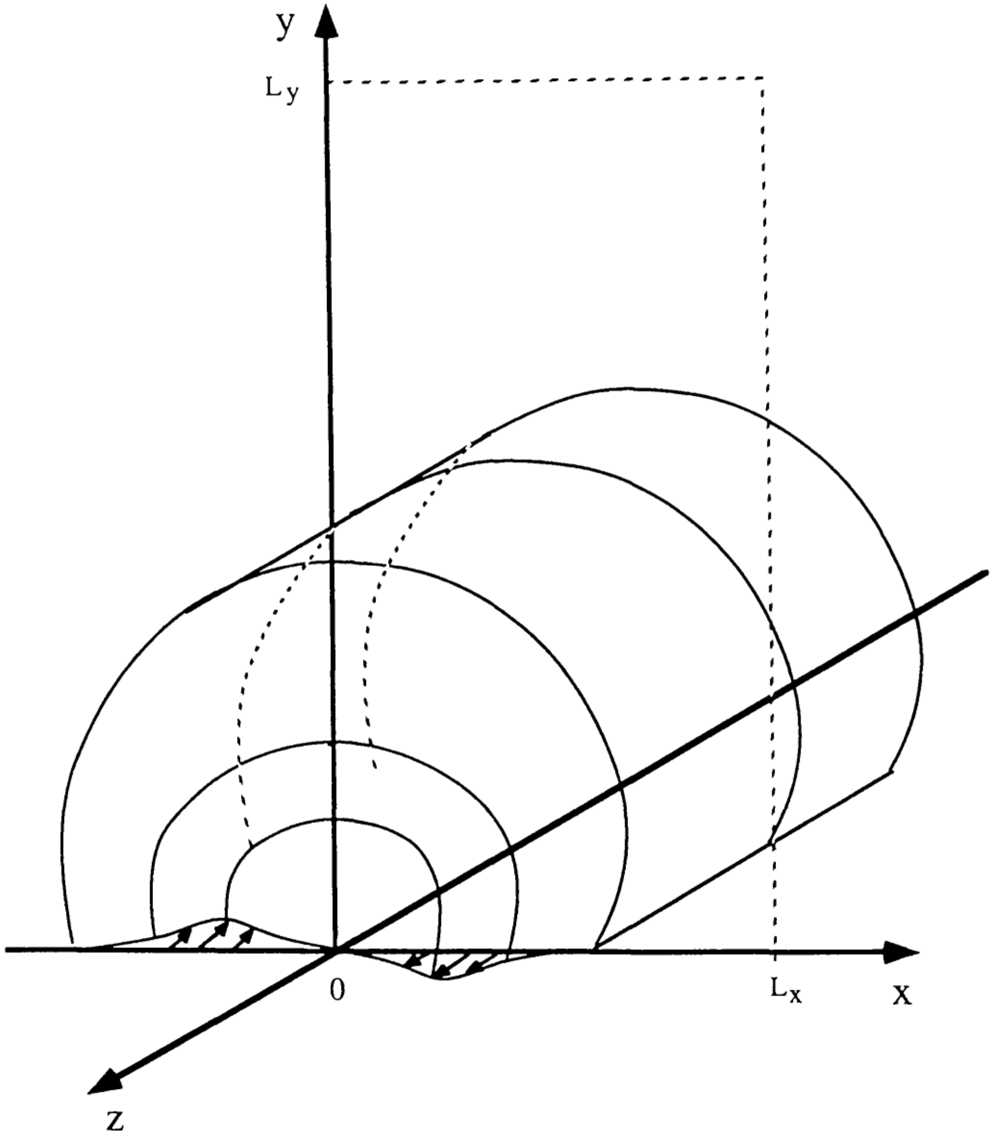
(C) Magnetosphere-ionosphere coupling leads to magnetospheric substorms, auroras and auroral kilometric radiation.

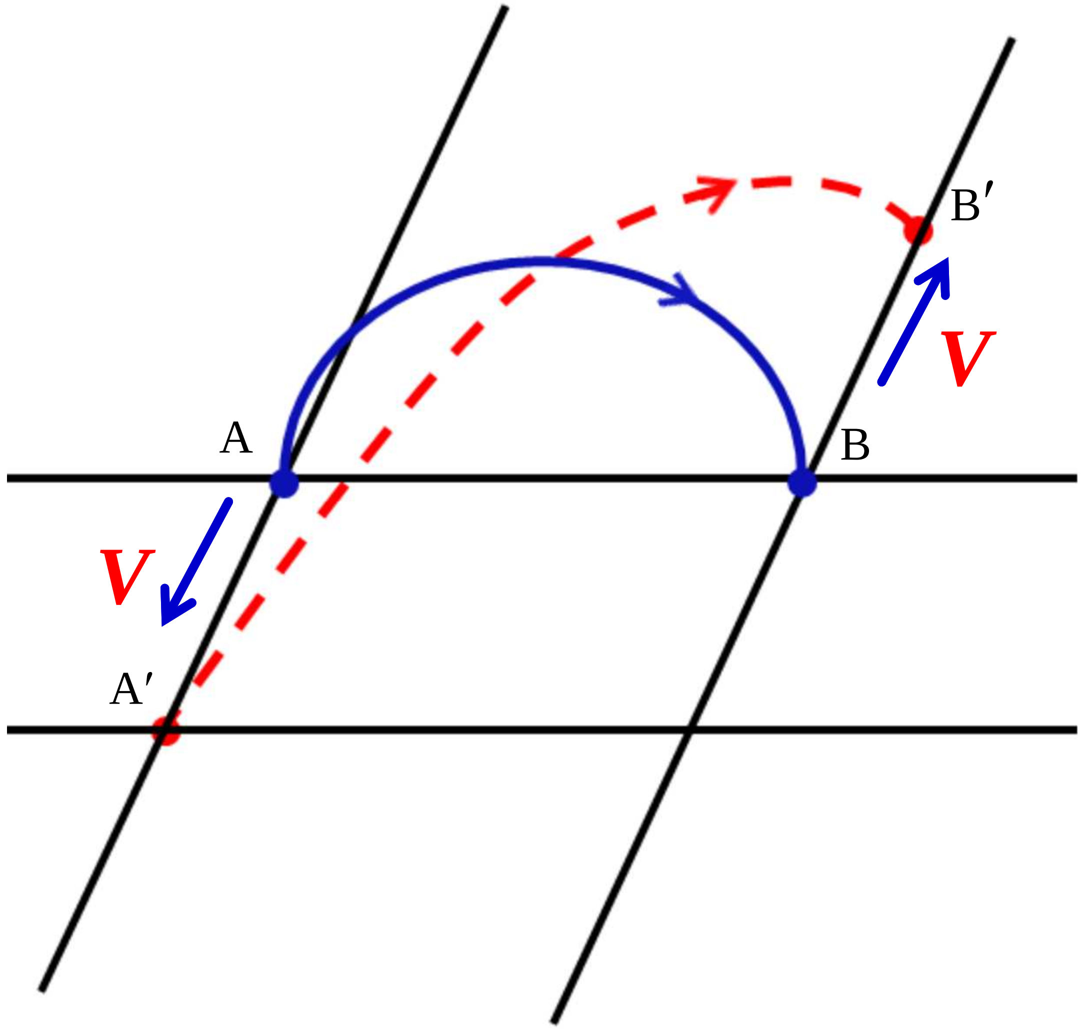
(D) The micro-scale processes provide electric resistivity for macro-scale magnetic reconnection and ion heating for shocks in collisionless plasma.

(A) *Choe and Lee : Solar Physics, 138: 291-329, 1992*

A Theory on the Formation of Solar Prominences by Photospheric Shearing Motions (solar surface)

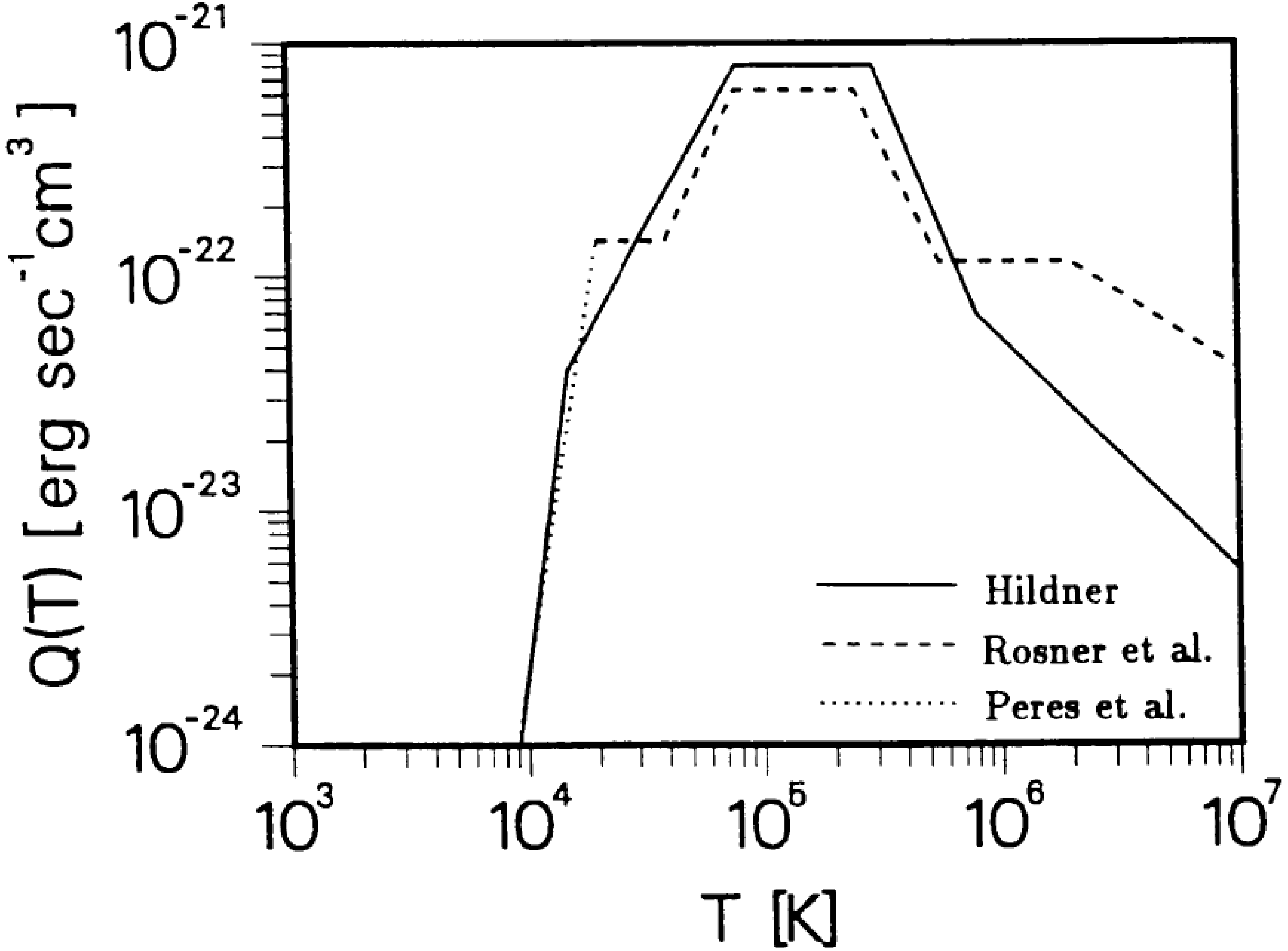


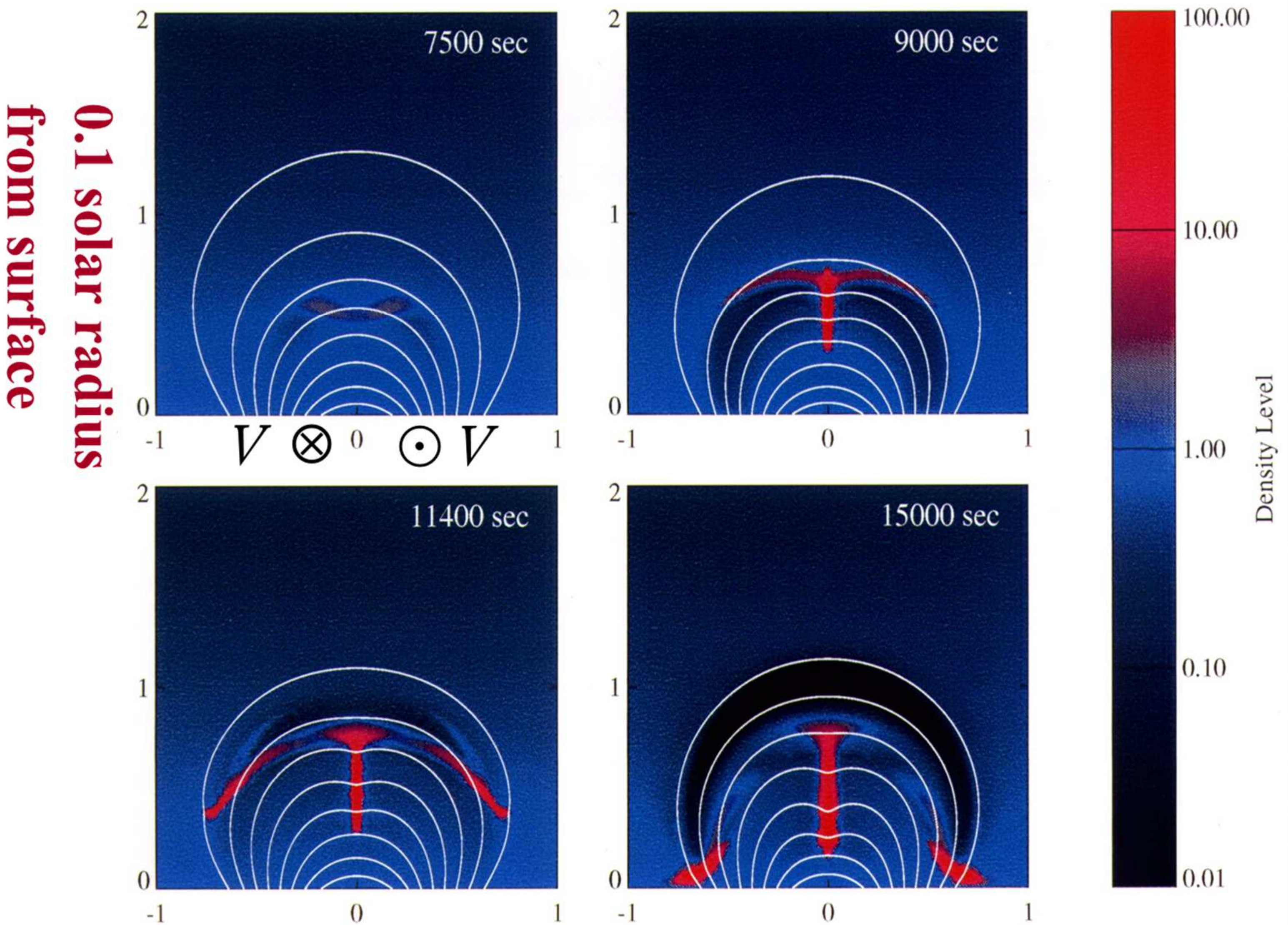




Shear flow leads to the axial magnetic field

Radiative Cooling





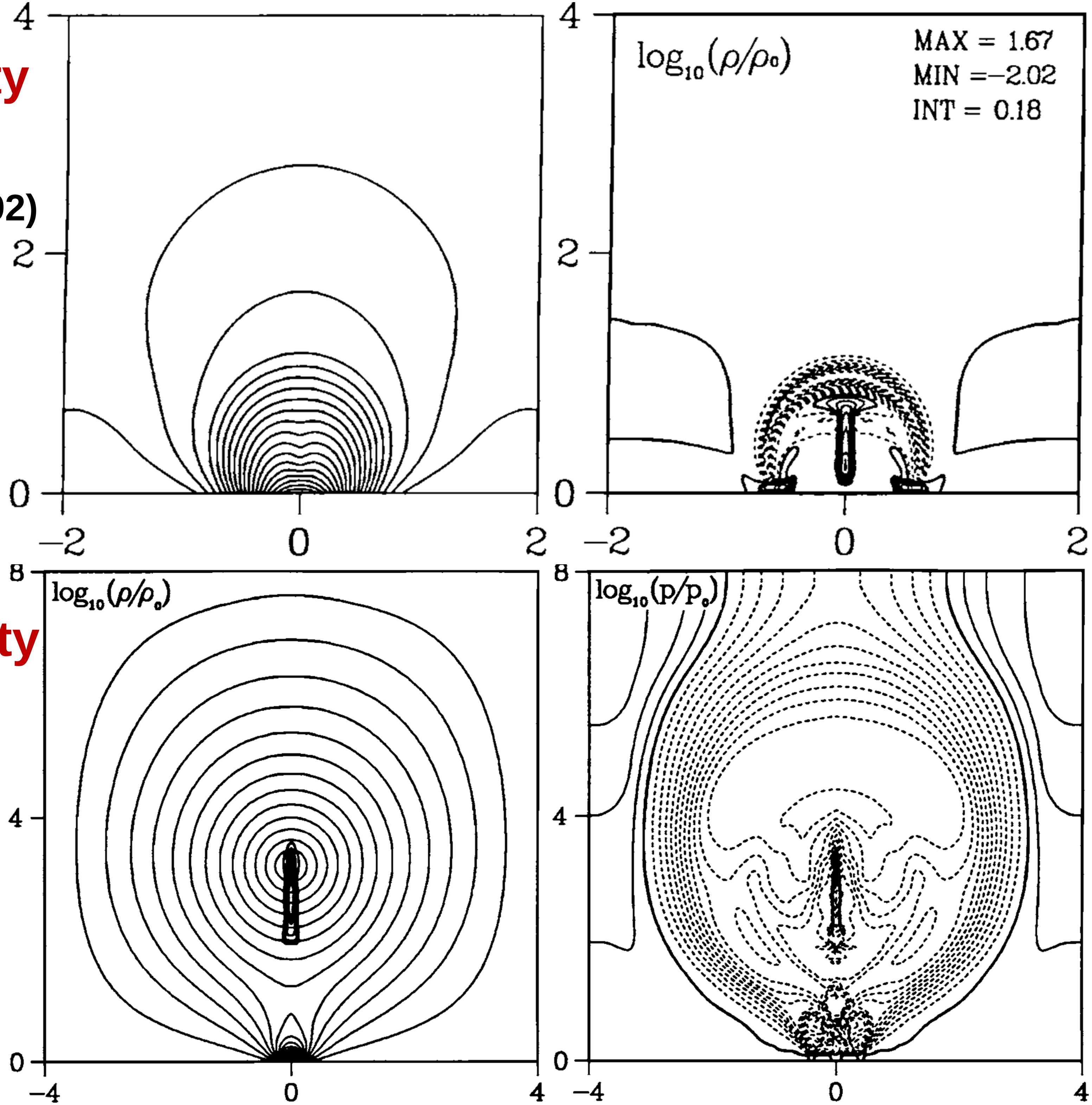
- **Choe and Lee proposed the time-dependent formation of solar prominence within a magnetic arcade (near sunspot) with shear plasma flow on the solar surface.**
- **Prominence mass is found to be supplied through siphon-type flow induced by "thermal instability".**

Normal polarity prominences

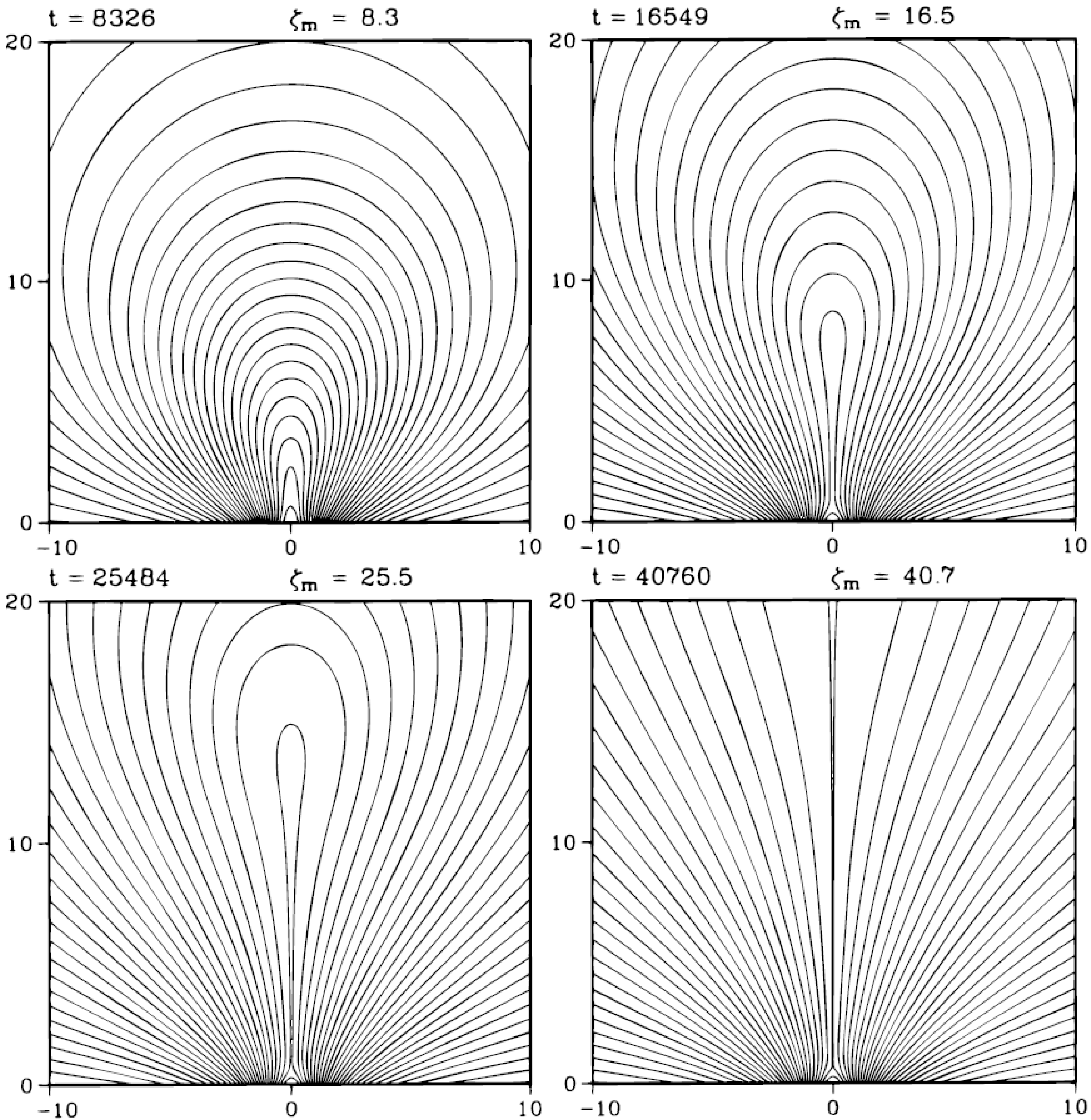
(Choe and Lee, 1992)

Inverse polarity prominences

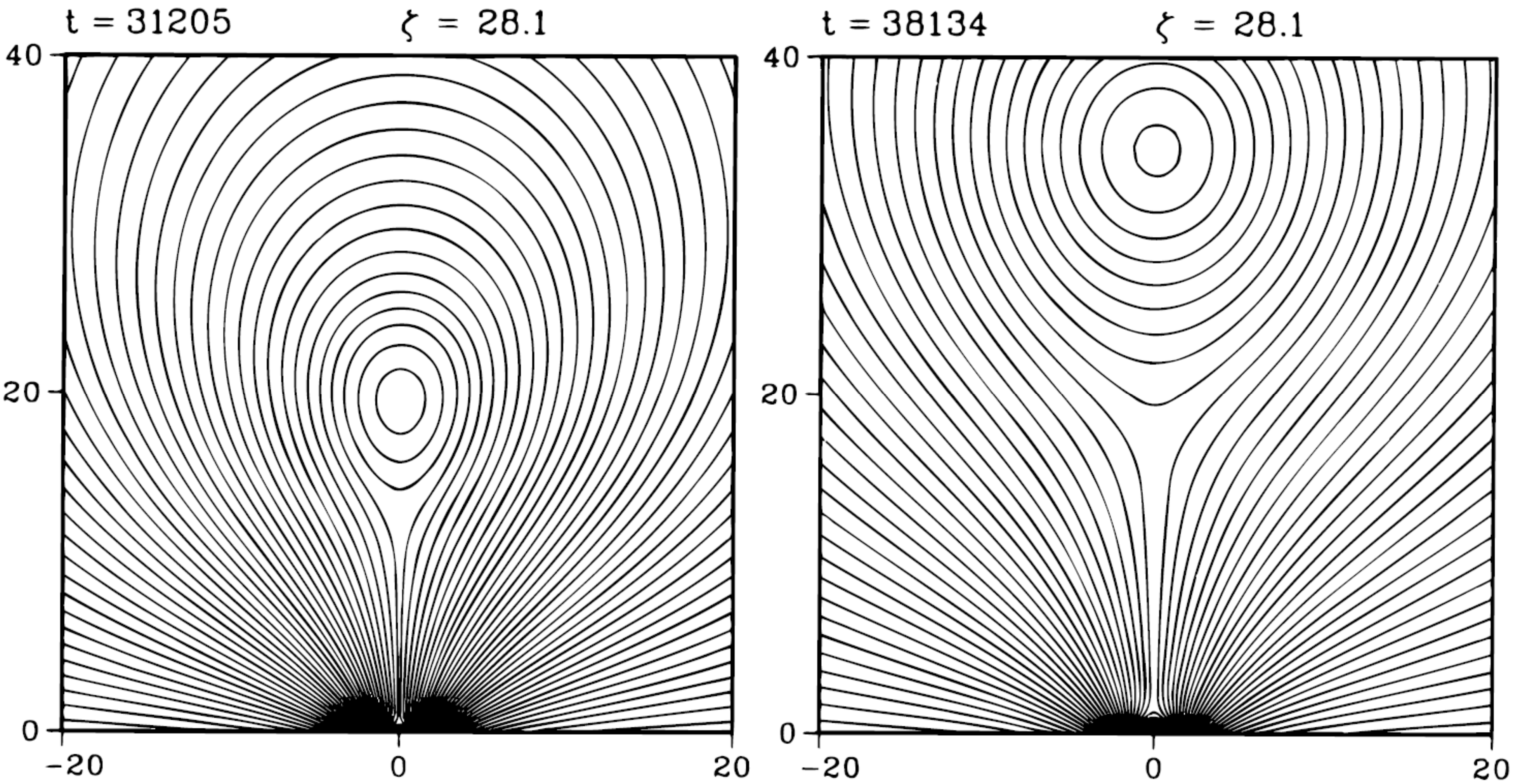
(Lee, Choe & Akasofu, 1992)



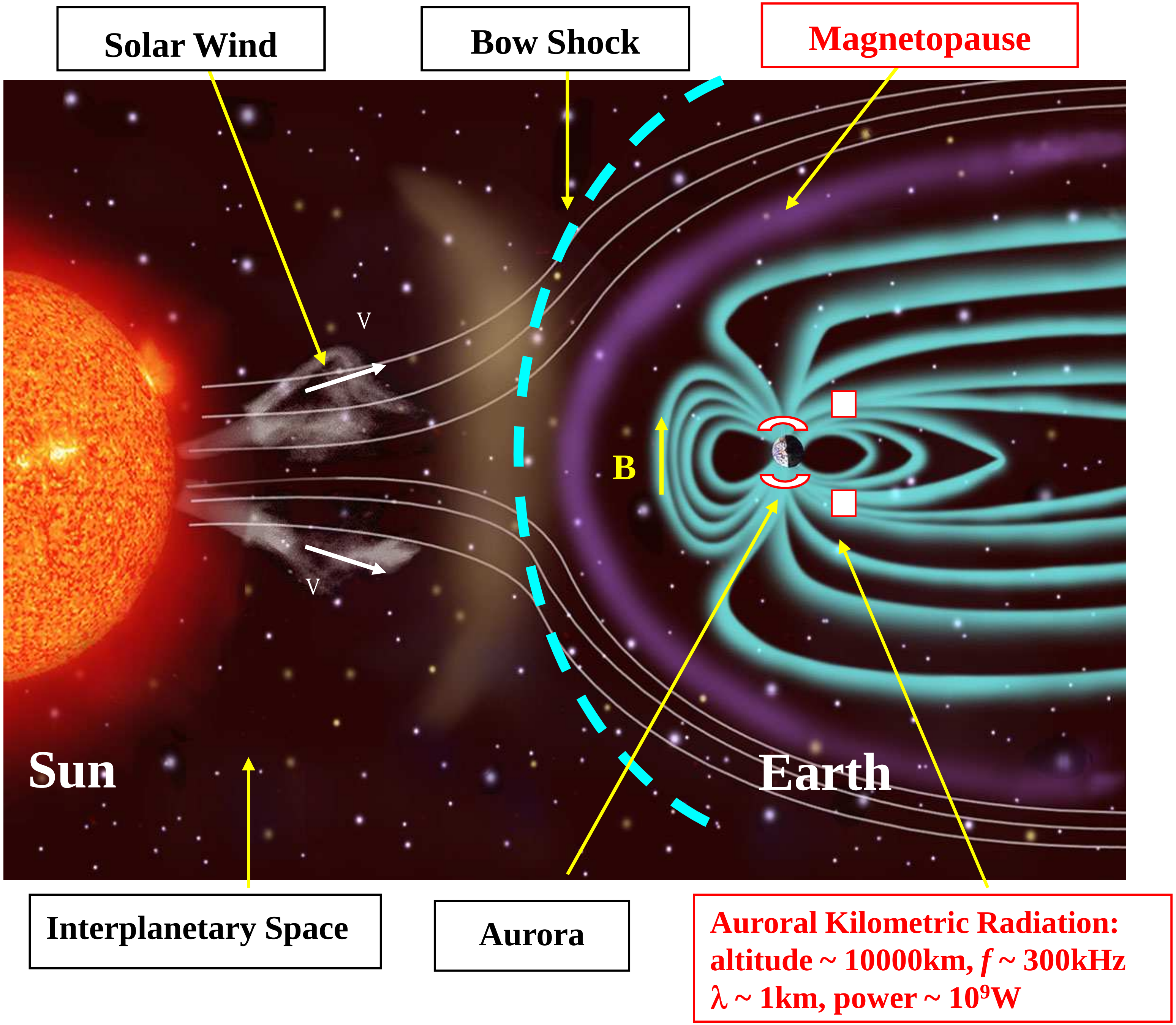
Shear flow leads to thinning of current sheet



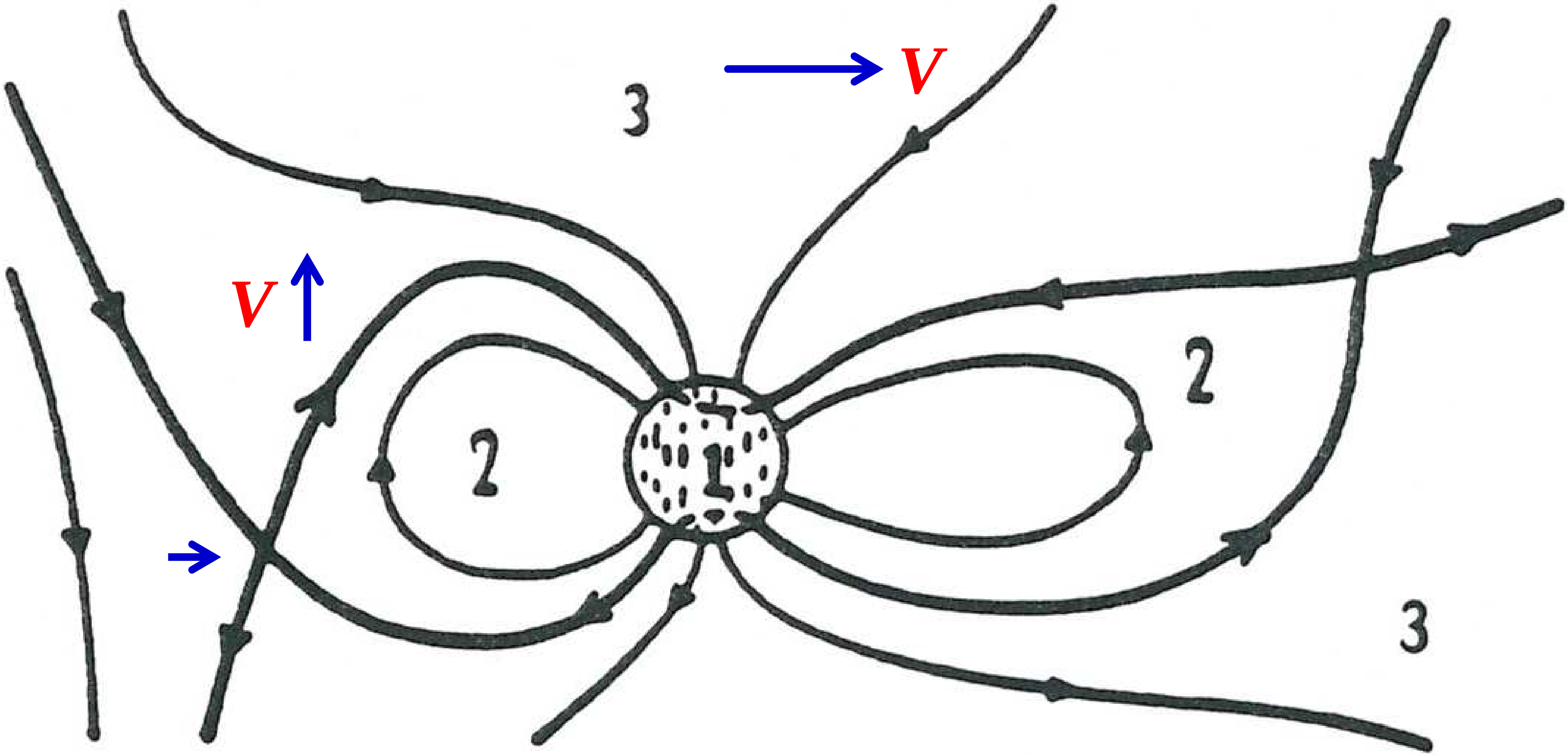
In the presence of resistivity, thin current sheet leads to reconnection/eruption



(B) Transport of particles and energy from the solar wind to magnetosphere provides energy for solar wind-magnetosphere-ionosphere coupling.



Open Magnetopause



Dungey (1961)

Dayside Magnetopause

(a) Single X-line Reconnection:

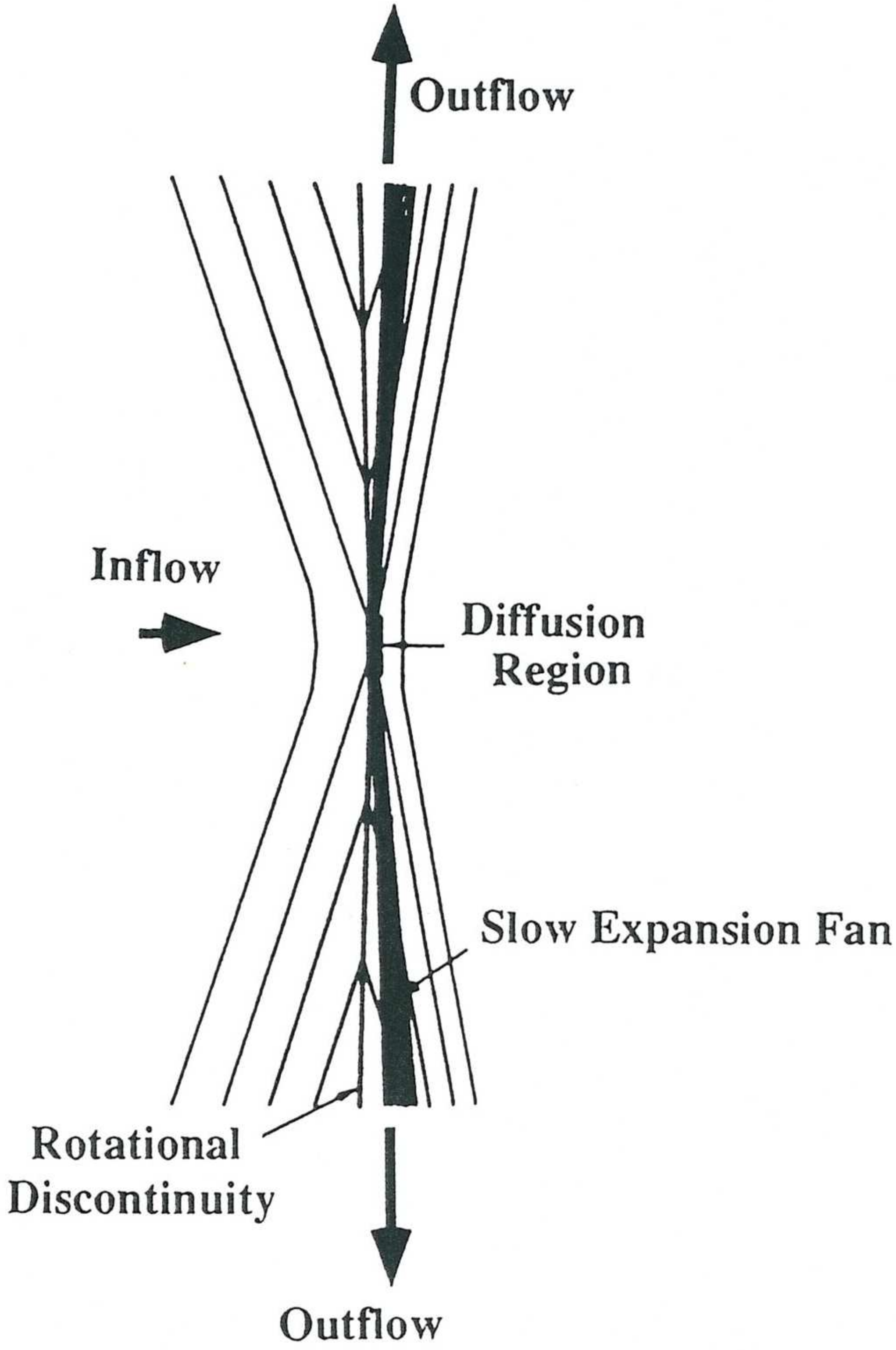
RD + Slow Expansion Fan

Levy et al. (1965)

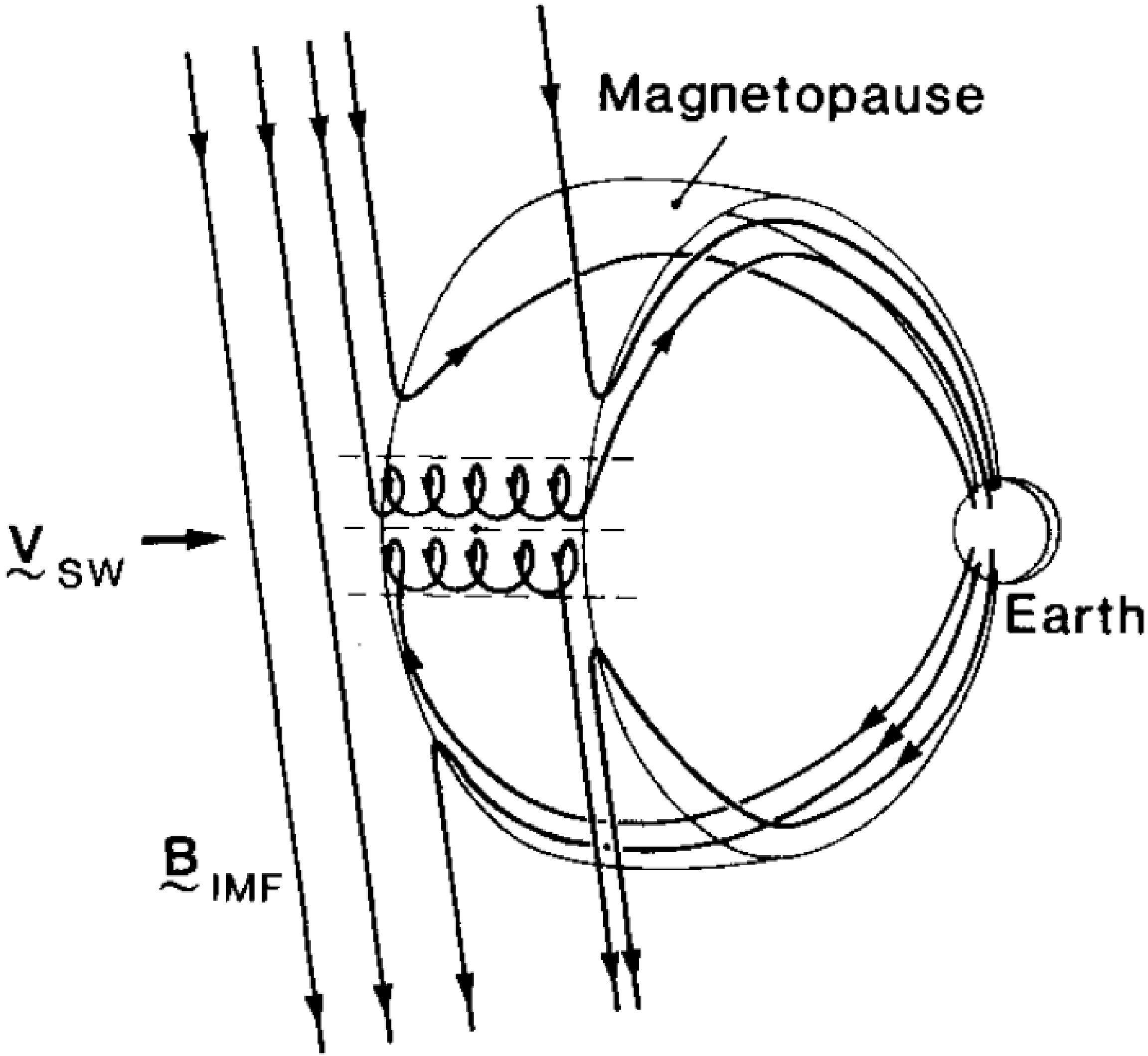
(b)Flux Transfer Events (FTEs)

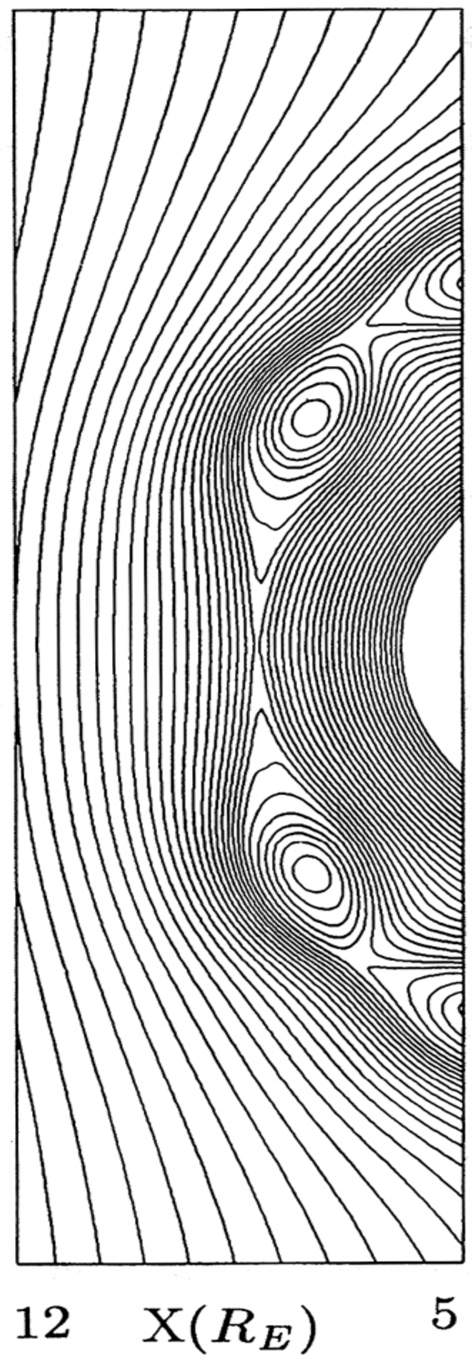
once every ~10 minutes

Russell and Elphie (1979)

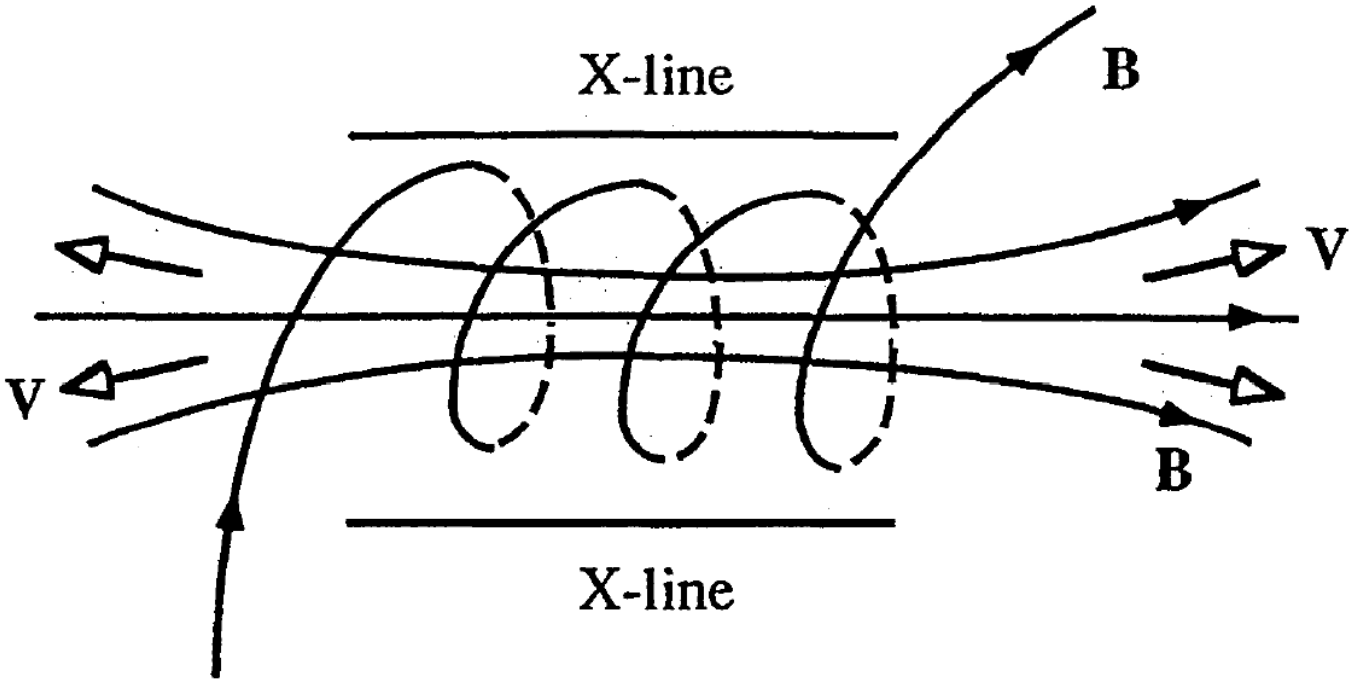


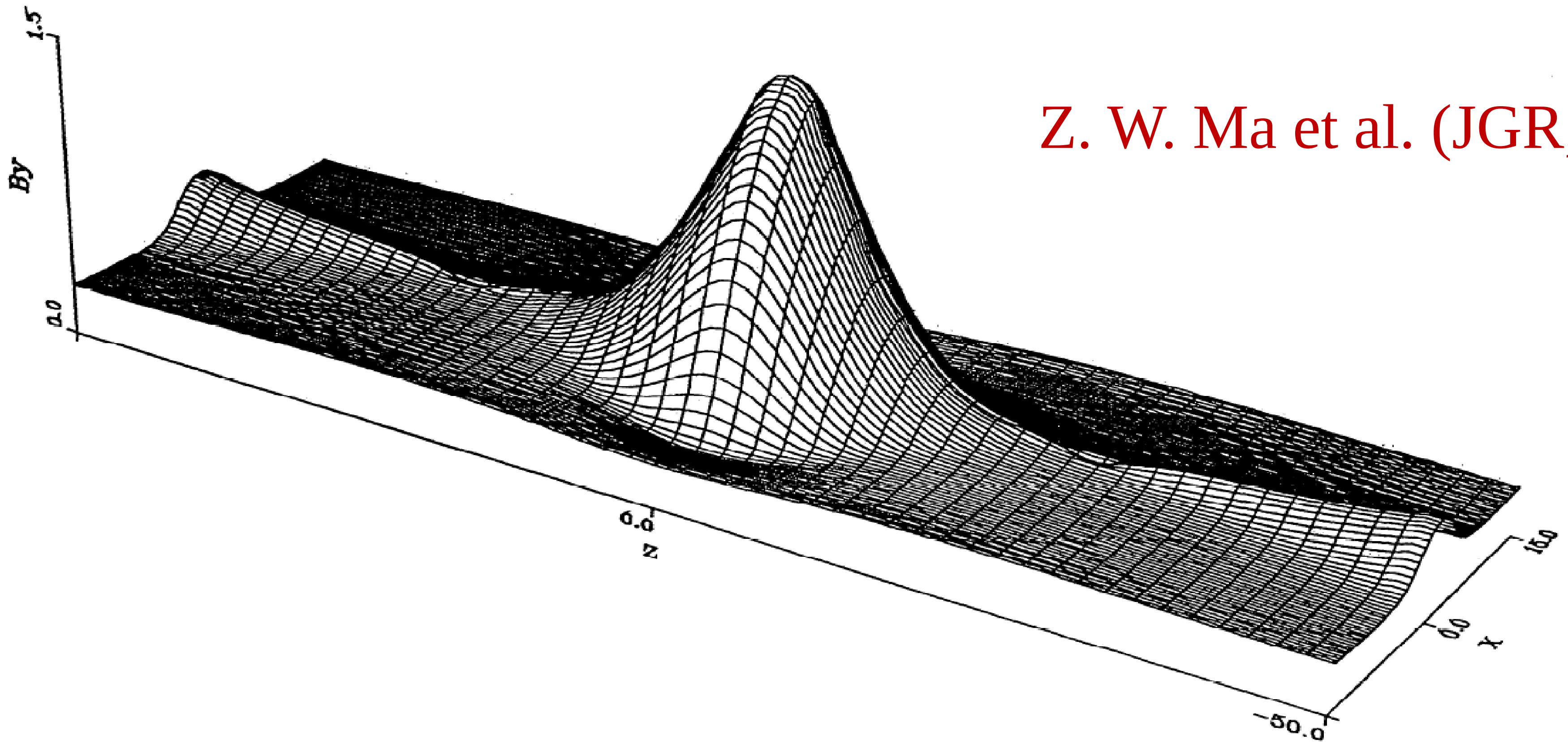
Multiple X-line Reconnection (MXR)





L. C. Lee and Z. F. FU (1985)

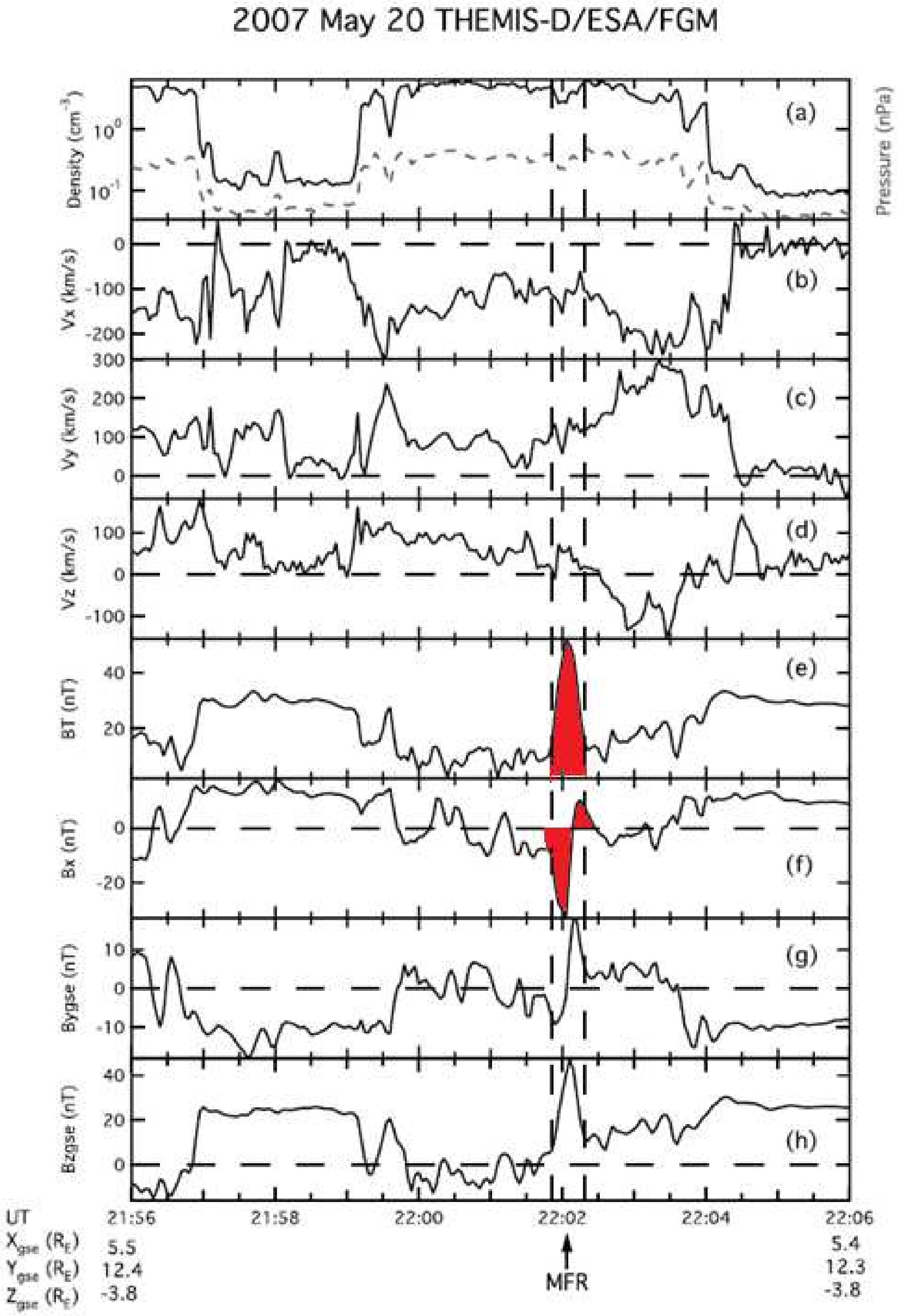




Z. W. Ma et al. (JGR, 1994)

Bt

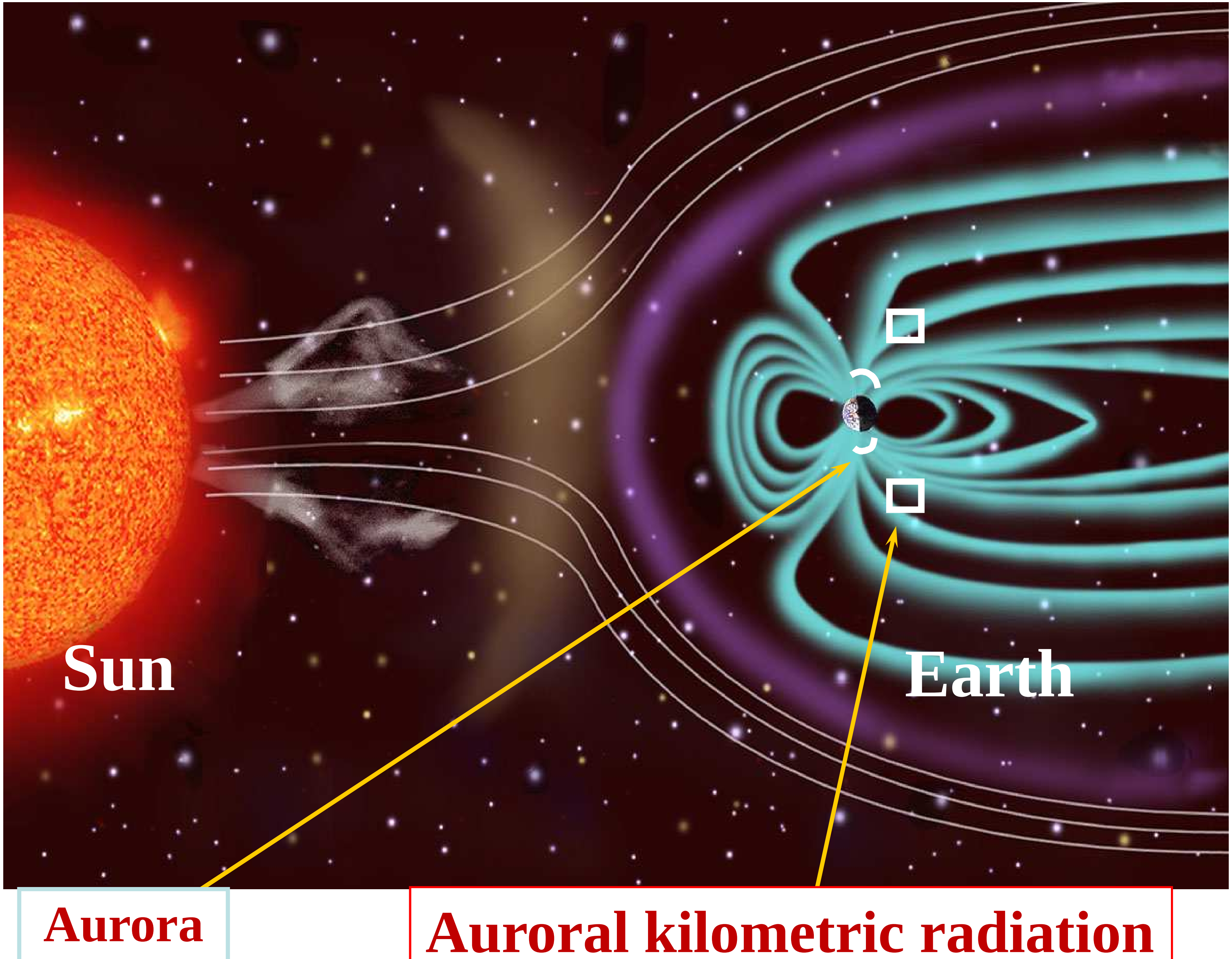
Bx



Very large magnetic flux rope observed by THEMIS.

Lui et al. (2008)

(C) Magnetosphere-ionosphere coupling leads to auroras and auroral kilometric radiation

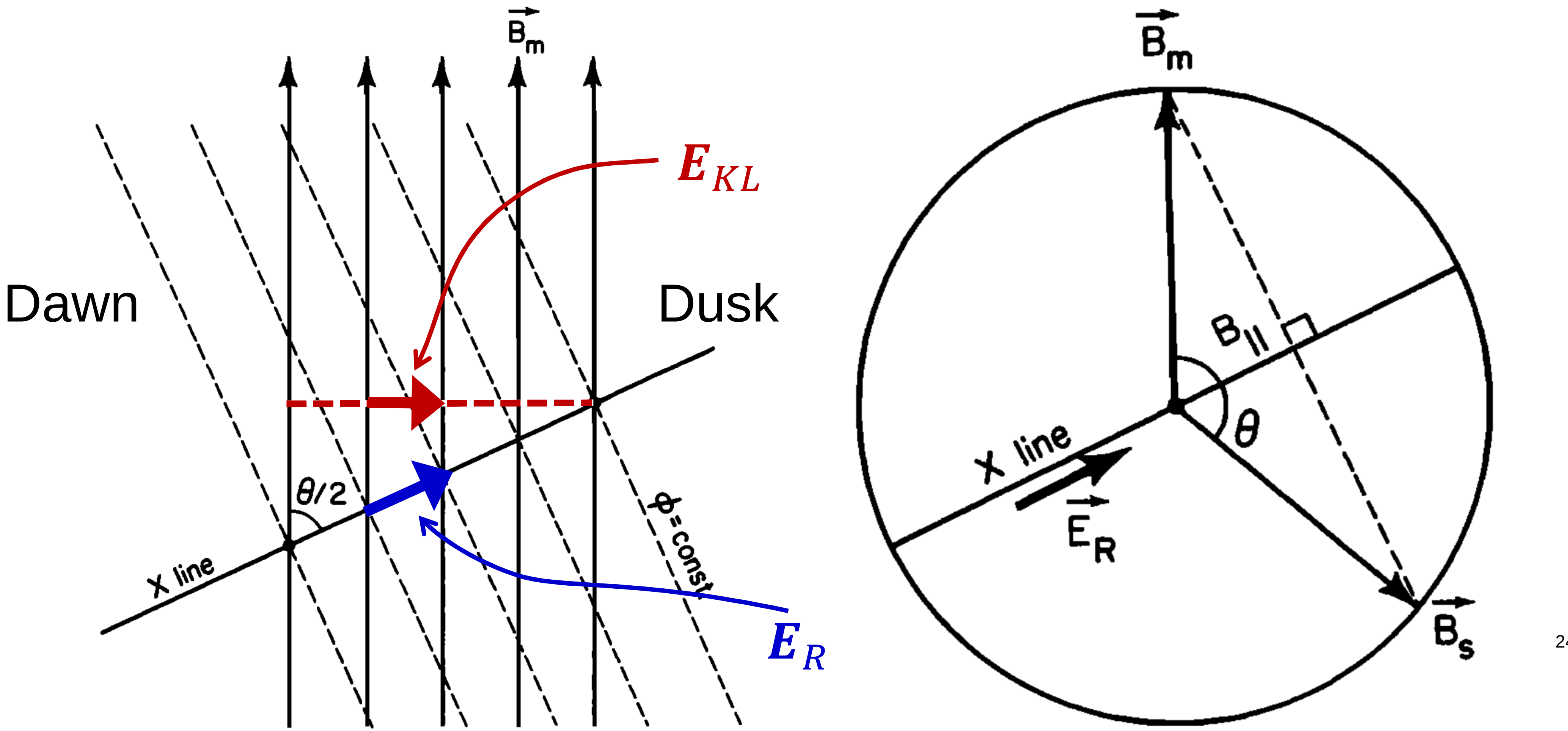


Reconnection electric field projected to the polar cap: Kan-Lee electric field (GRL,1979)

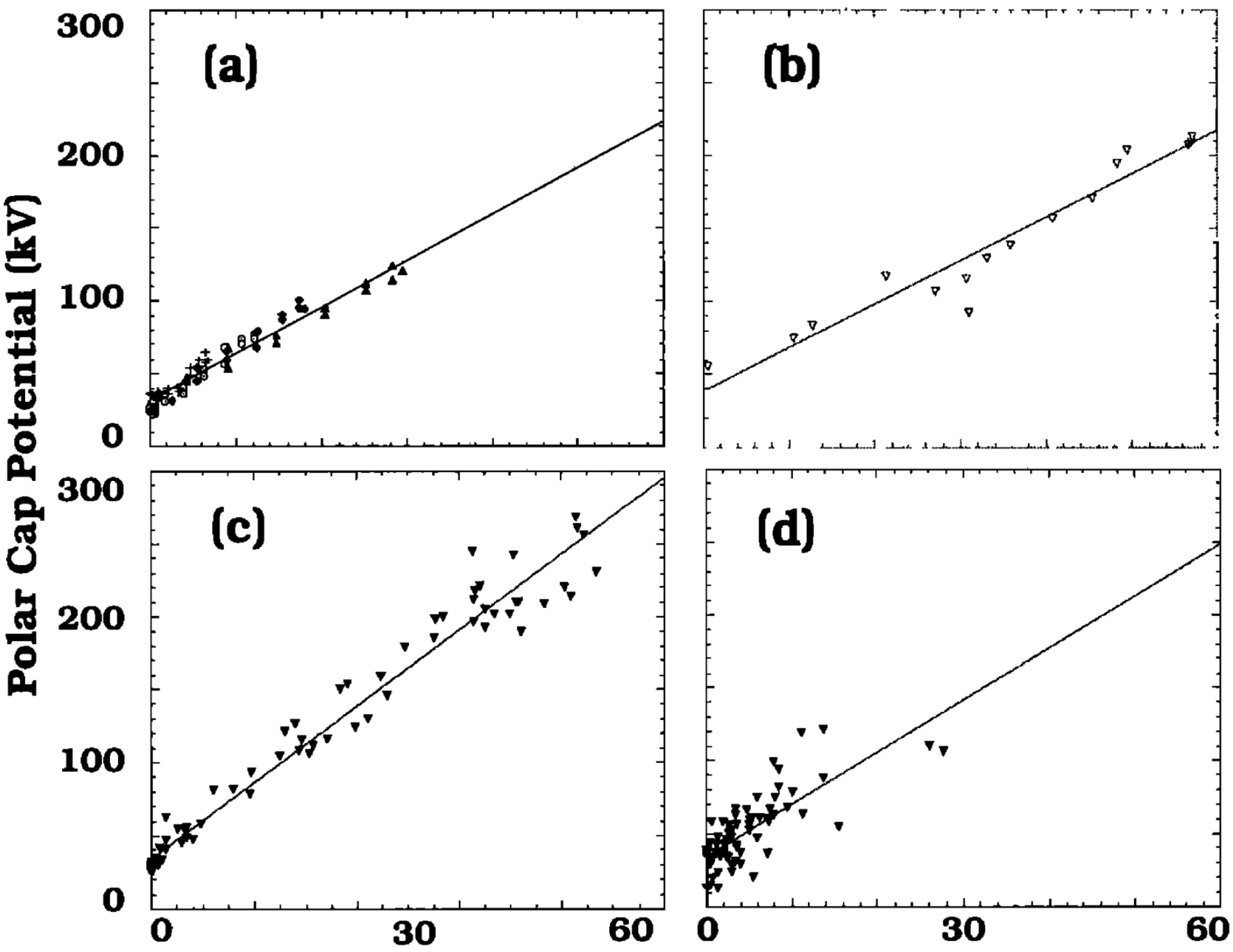
(a) Reconnection electric field along X-line: $E_R = V_s B_s \sin(\theta/2)$

(b) Component of $\boldsymbol{E}_R$ perpendicular to geomagnetic field:

$$E_{KL} = E_R \sin(\theta/2) = V_s B_s \sin^2(\theta/2)$$



Polar cap potential vs E_{KL}

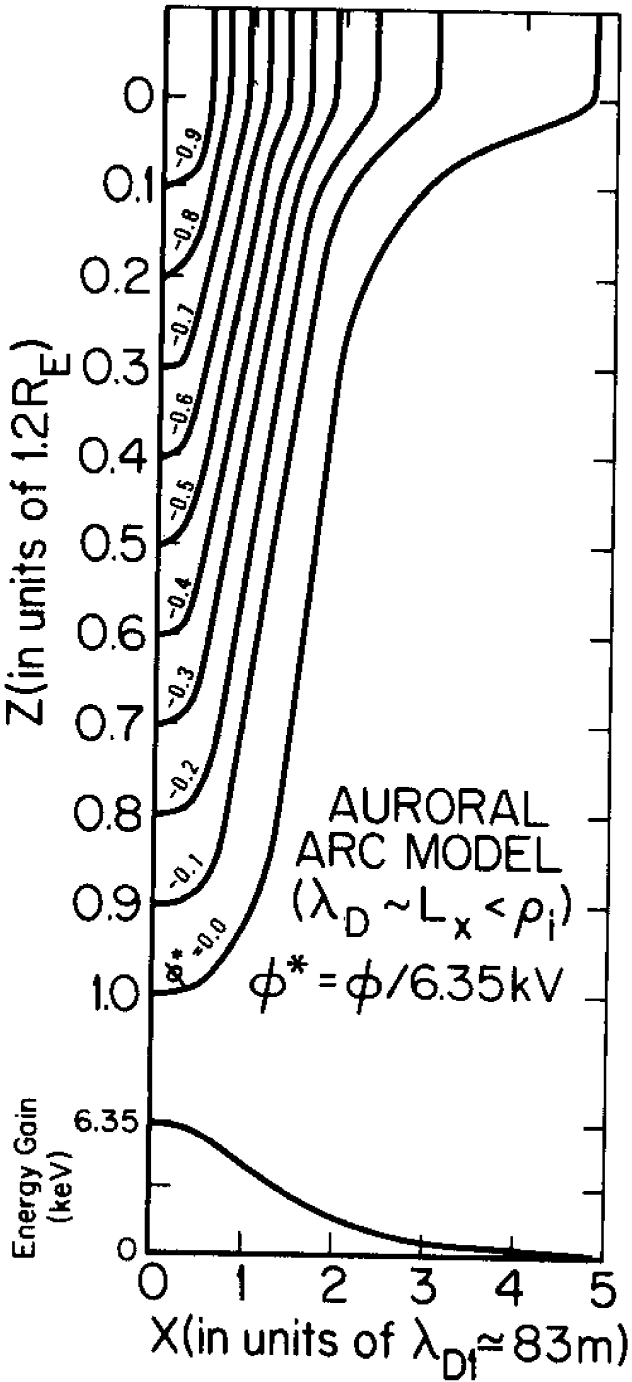


$E_{KL}(\mathrm{kV}/R_E)$

Burke et al., JGR, 1999

2D double layer and discrete aurora

Kan, Lee & Akasofu (JGR, 1979)



(a) Field-aligned potential drop ($\Delta\phi$) enhanced the current carried by magnetosphere electrons (Knight, PSS, 1973).

(b) Field-aligned potential drop ($\Delta\phi$) in the double layer accelerates auroral electrons to ~10keV, producing aurora.

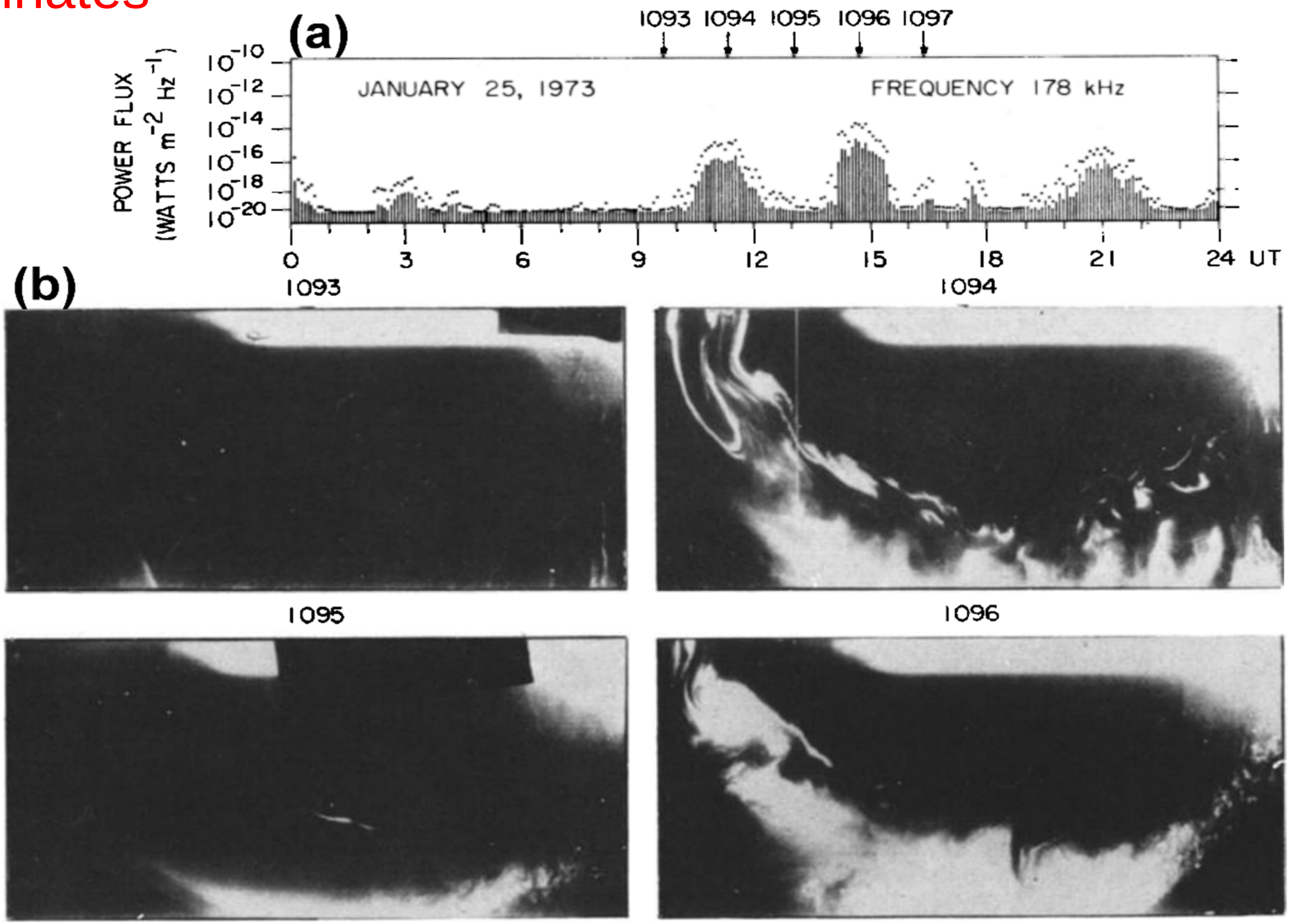
(c) This potential drop ($\Delta\phi$) prevents ionospheric electrons from entering the double layer, leading to $\omega_{pe}/\Omega_{ce} < 0.3$.

(d) Loss-cone (or horse-shoe) electrons are formed by mirror effects of geomagnetic field.

(e) Auroral kilometric radiation (AKR) is generated by loss-cone electrons in the plasma depleted region.

Auroral Kilometric Radiation (AKR)

- f~100-600 kHz (~local electron cyclotron frequency)
- X mode dominates
- $\omega_{pe} < 0.3\omega_{ce}$



[Gurnett, JGR, 1974]

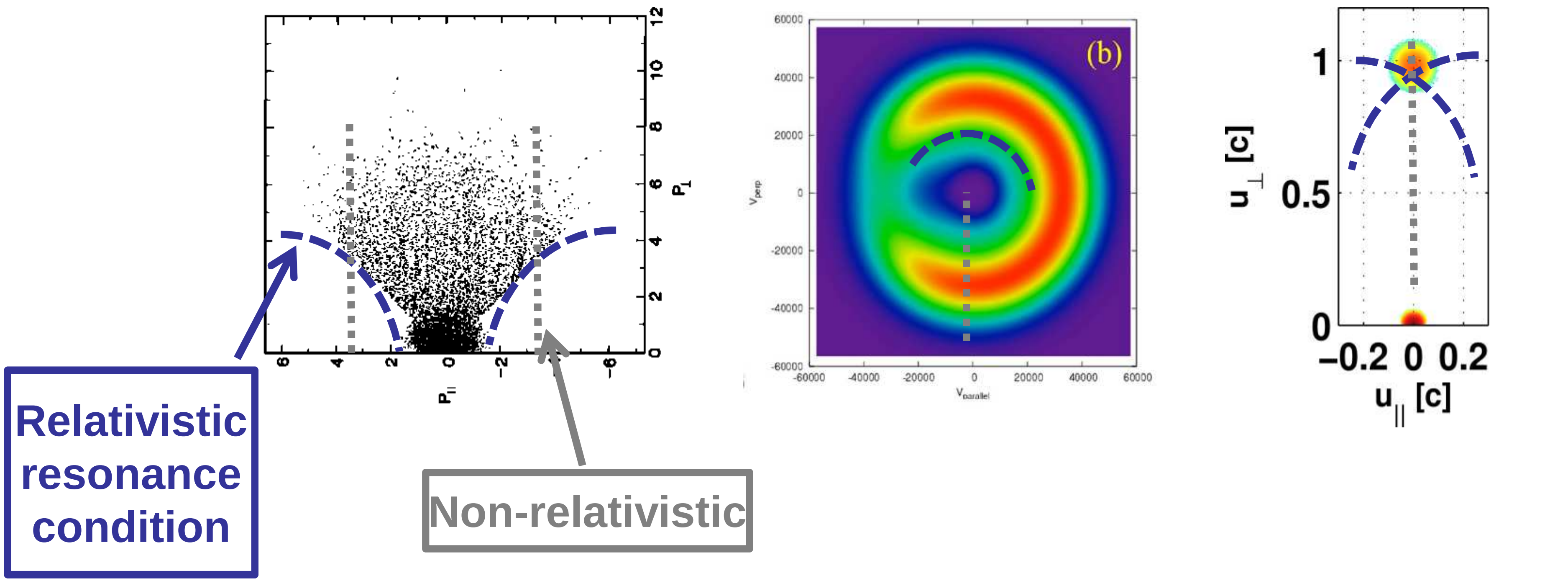
Cyclotron Maser Instability (CMI)

(Wu and Lee, ApJ, 1979)

a) Relativistic resonance condition

$$k_{\parallel}u_{\parallel} - \omega\gamma + n\Omega_c = 0, \quad \gamma = \sqrt{1 + \left(u_{\perp}^2 + u_{\parallel}^2\right)/c^2}$$

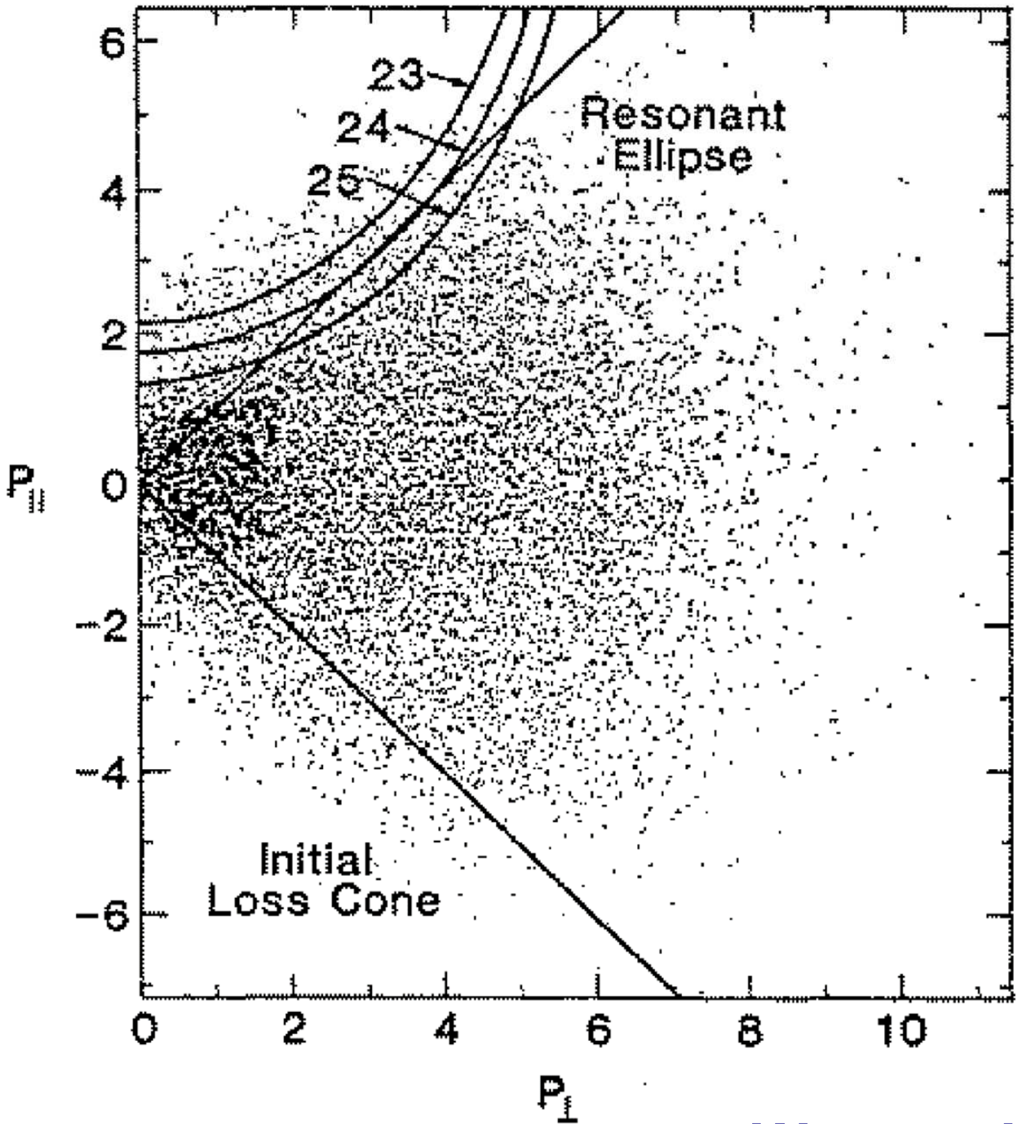
b) Population-inversion distributions:($\dfrac{\partial f}{\partial u_{\perp}} > 0$)

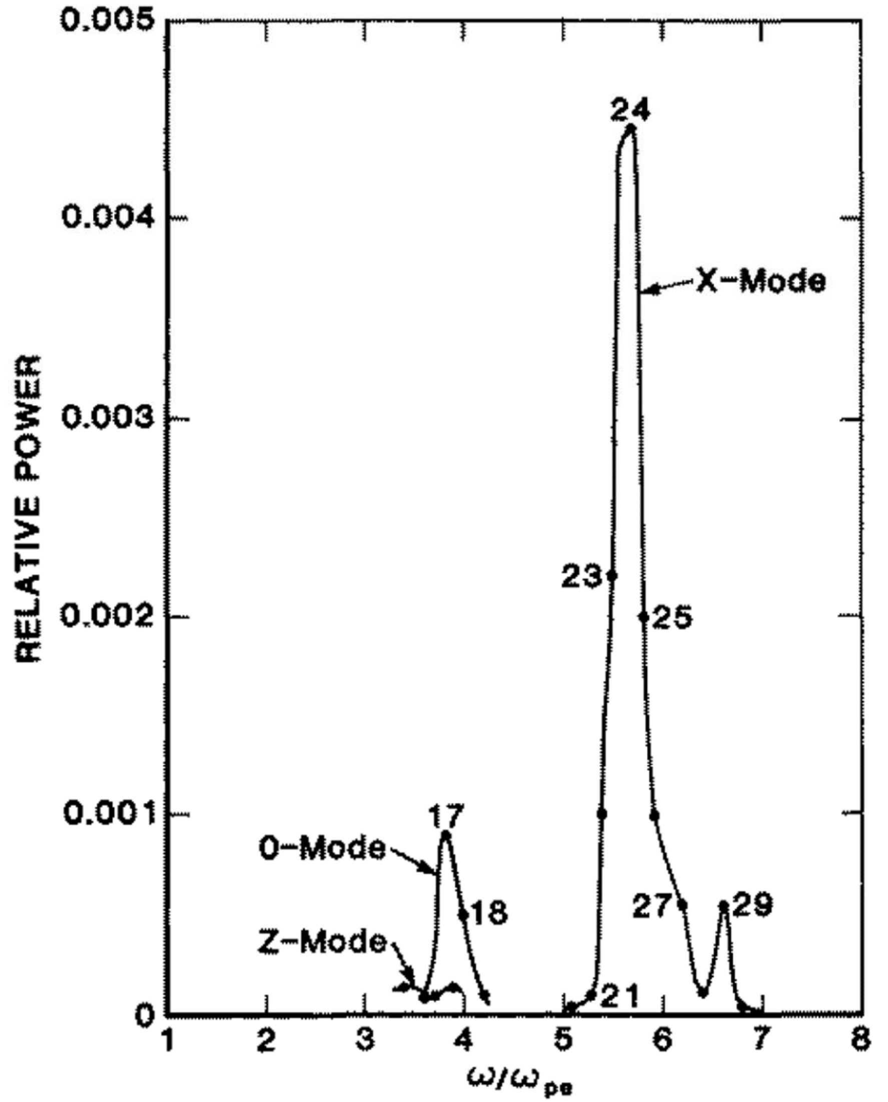


Relativistic resonance condition (ellipse)

$$\left(1+\frac{u^2}{c^2}\right)^{1/2}\omega_r - \Omega_e - N\cos\theta\,\omega_r\frac{u_\parallel}{c} = 0$$

$$\frac{u_\perp^2}{A^2} + \frac{(u_\parallel - u_0)^2}{B^2} = 1$$





Wagner, Lee et al. (Radio Science, 1984)

Radio Emission

1. Sun (1940)

2. Jupiter (1960)
   wave length ≈ 10m, power ≈ 10^{10} W

3. Pulsars (1967)

4. Earth (1974): Auroral Kilometric Radiation (AKR)
   wave length ≈1000m, power ≈ 10^{9} W

5. Saturn, Neptune, Uranus

6. Exoplanet: auroral radio emission from exoplanet can be used to determine the existence and magnitude of magnetic field

(D) Coupling of micro-process to macro-process

(D1) "Resistivity" for magnetic reconnection in a collisionless plasma

(D2) Ion heating in collisionless fast shock

(D1) "Resistivity" in a Collisionless Plasma

H.J. Cai and L.C. Lee (1994, 1997)

Force Balance at Neutral Lines for Electrons and Ions

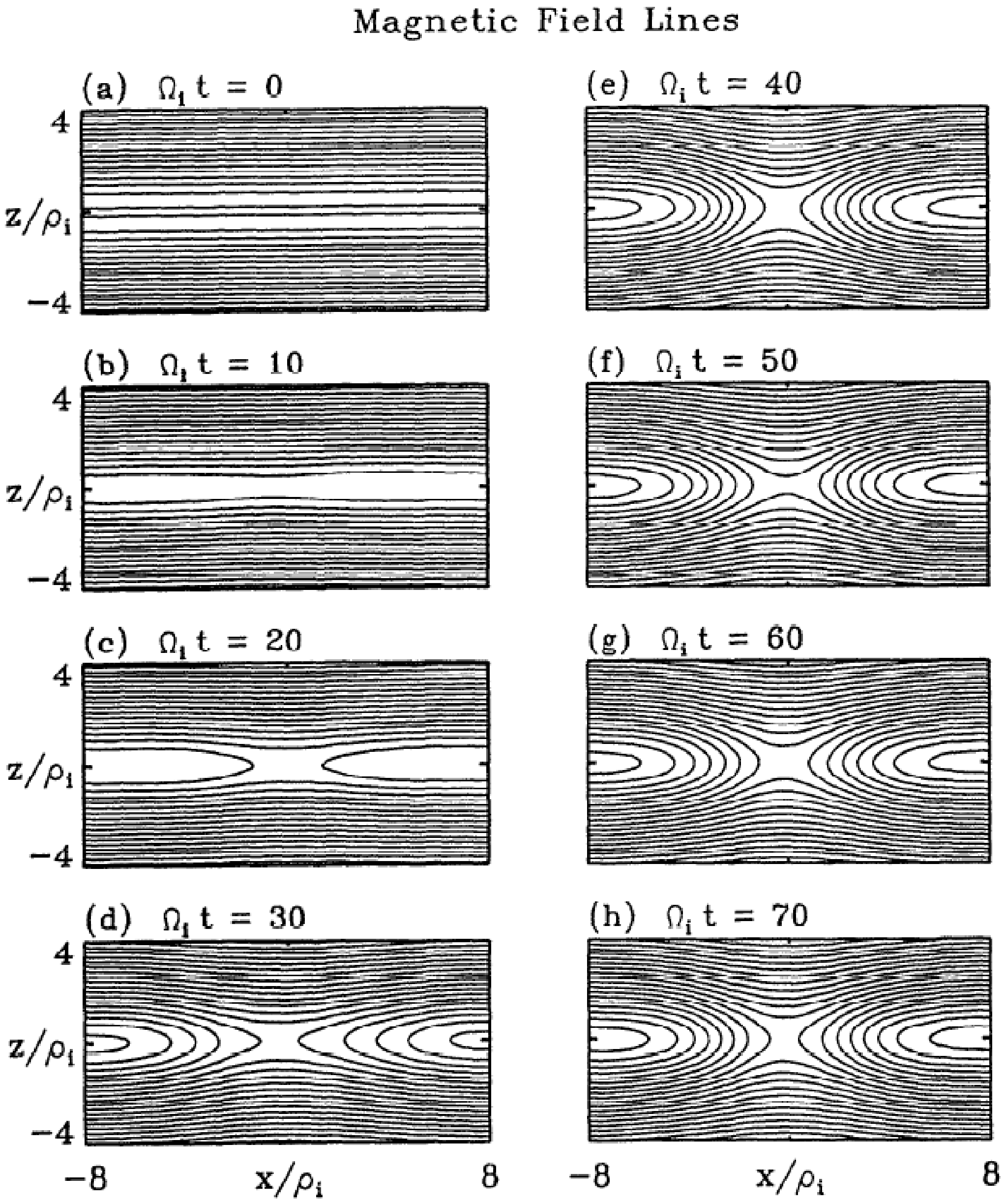
$$-\frac{m_e}{e}\frac{\partial v_y^{(e)}}{\partial t} = E_y + \frac{1}{n_e e}\frac{\partial P_{xy}^{(e)}}{\partial x} + \frac{1}{n_e e}\frac{\partial P_{zy}^{(e)}}{\partial z}$$

$$\frac{m_i}{e}\frac{\partial v_y^{(i)}}{\partial t} = E_y - \frac{1}{n_i e}\frac{\partial P_{xy}^{(i)}}{\partial x} - \frac{1}{n_i e}\frac{\partial P_{zy}^{(i)}}{\partial z}$$

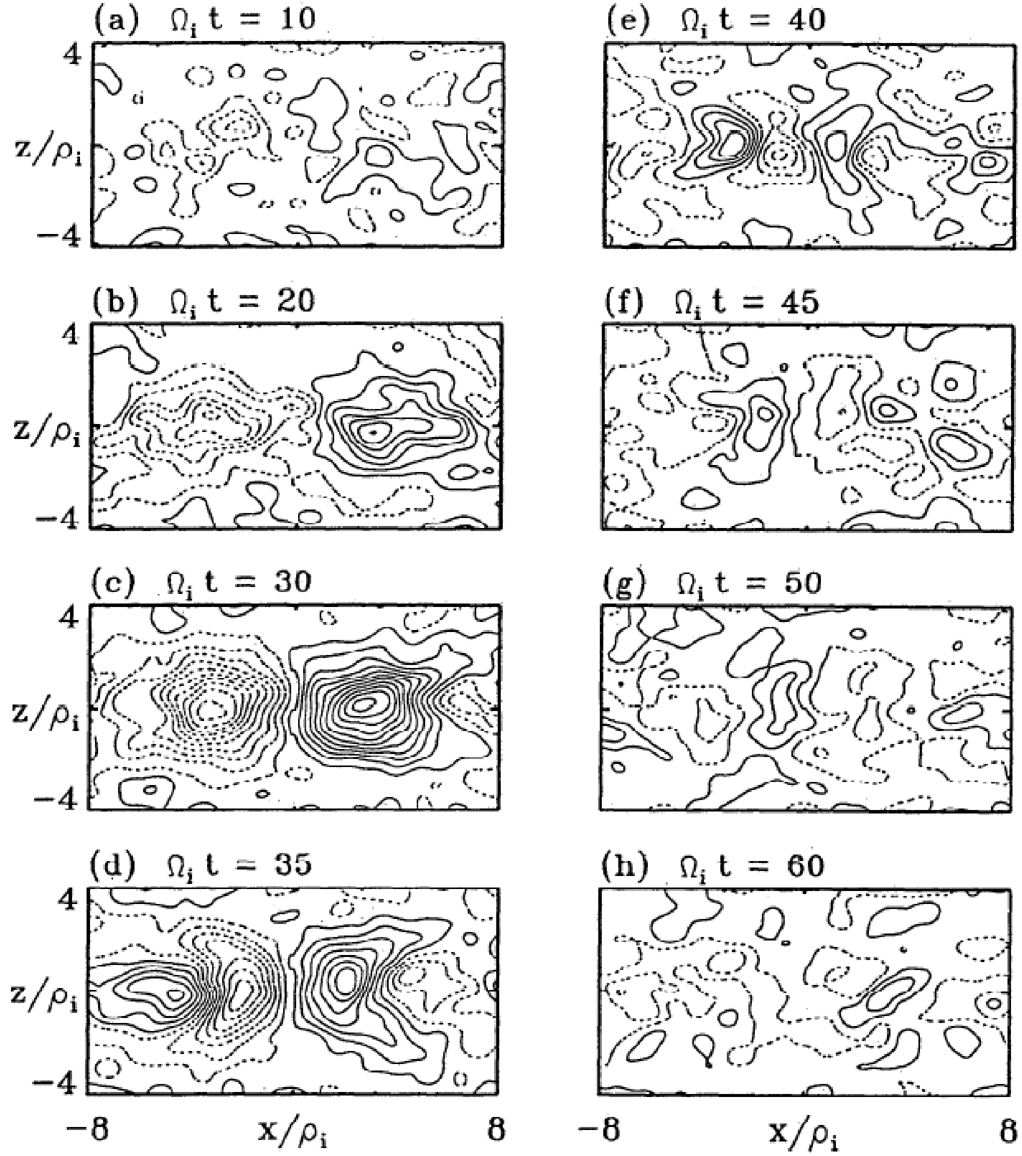
The Generalized Ohm'S Law Near Neutral Line

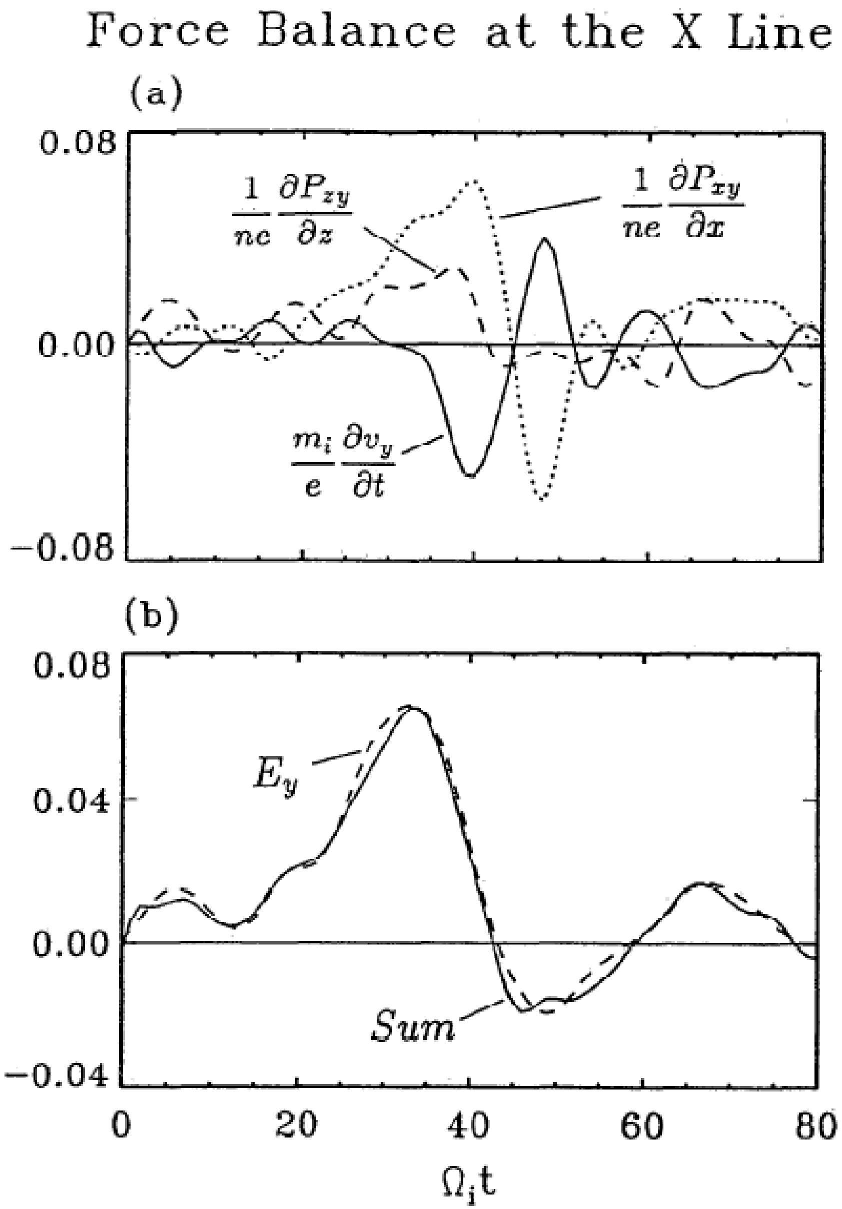
$$E_y = \frac{m_e}{e^2}\frac{\partial (J_y/n)}{\partial t} + \frac{m_e}{m_i}\frac{1}{ne}\left(\frac{\partial P_{xy}^{(i)}}{\partial x} + \frac{\partial P_{zy}^{(i)}}{\partial z}\right) - \frac{1}{ne}\left(\frac{\partial P_{xy}^{(e)}}{\partial x} + \frac{\partial P_{zy}^{(e)}}{\partial z}\right)$$

Off-diagonal terms of pressure tensor are the key to the "anomalous" resistivity for collisionless magnetic reconnection



Off-Diagonal Pressure P_{xy}





$$\frac{m_i}{e}\frac{\partial v_y^{(i)}}{\partial t} = E_y - \frac{1}{n_i e}\frac{\partial P_{xy}^{(i)}}{\partial x} - \frac{1}{n_i e}\frac{\partial P_{zy}^{(i)}}{\partial z}$$

H.J. Cai and L.C. Lee (1994)

"I think your paper marks the breakthrough", by Jim Dungey

Long Roof
Walberswick

28 March 1995

Dear Dr. Cai

Thank you very much for your paper and the pleasing confirmation of my length scale formula.

I think your paper marks the breakthrough. I am not surprised by the dynamo effect, but you clearly have a simulation, that is capable of answering lots of outstanding questions. You have enough particles to compute the pressure tensor and I would like to see them in detail near the X-line, but the first question is how anisotropic does the pressure tensor get? I think a few per cent would be important.

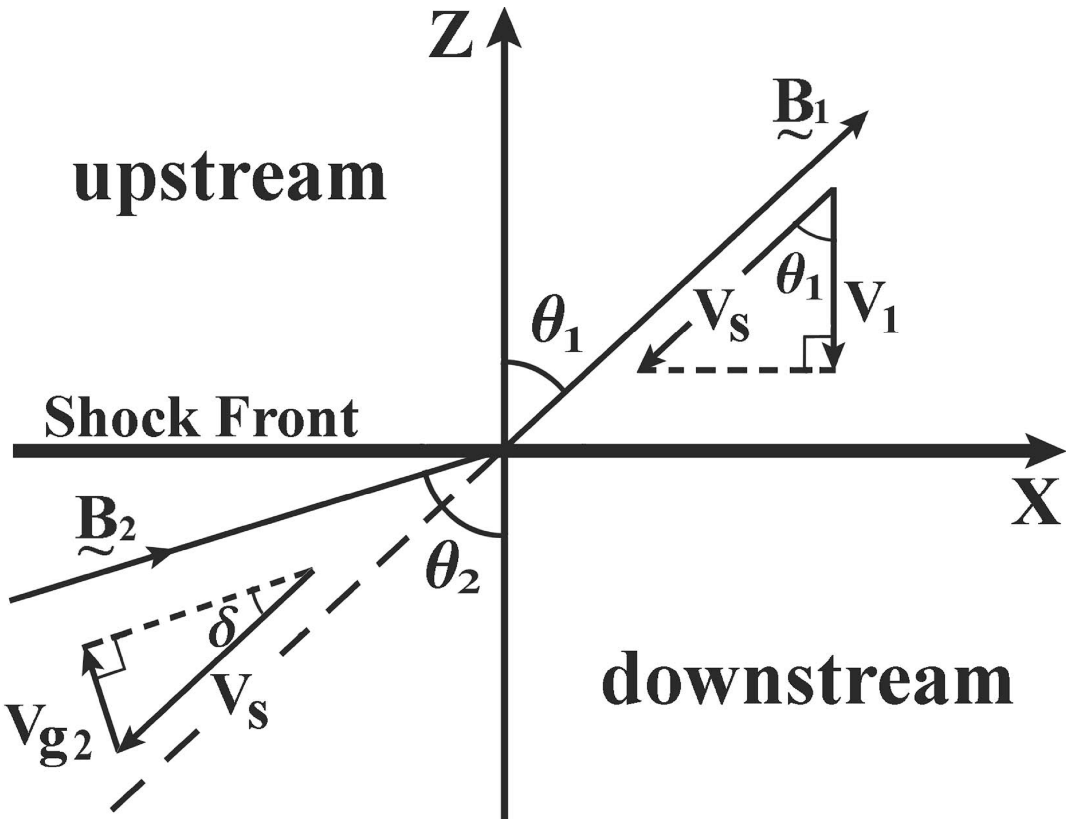
Your mass-ratio scaling is important for the reason you give and I hope this means you are planning to pursue this project. Observations seem to require a variety of scenarios and I expect you haave ideas about varying the initial values.

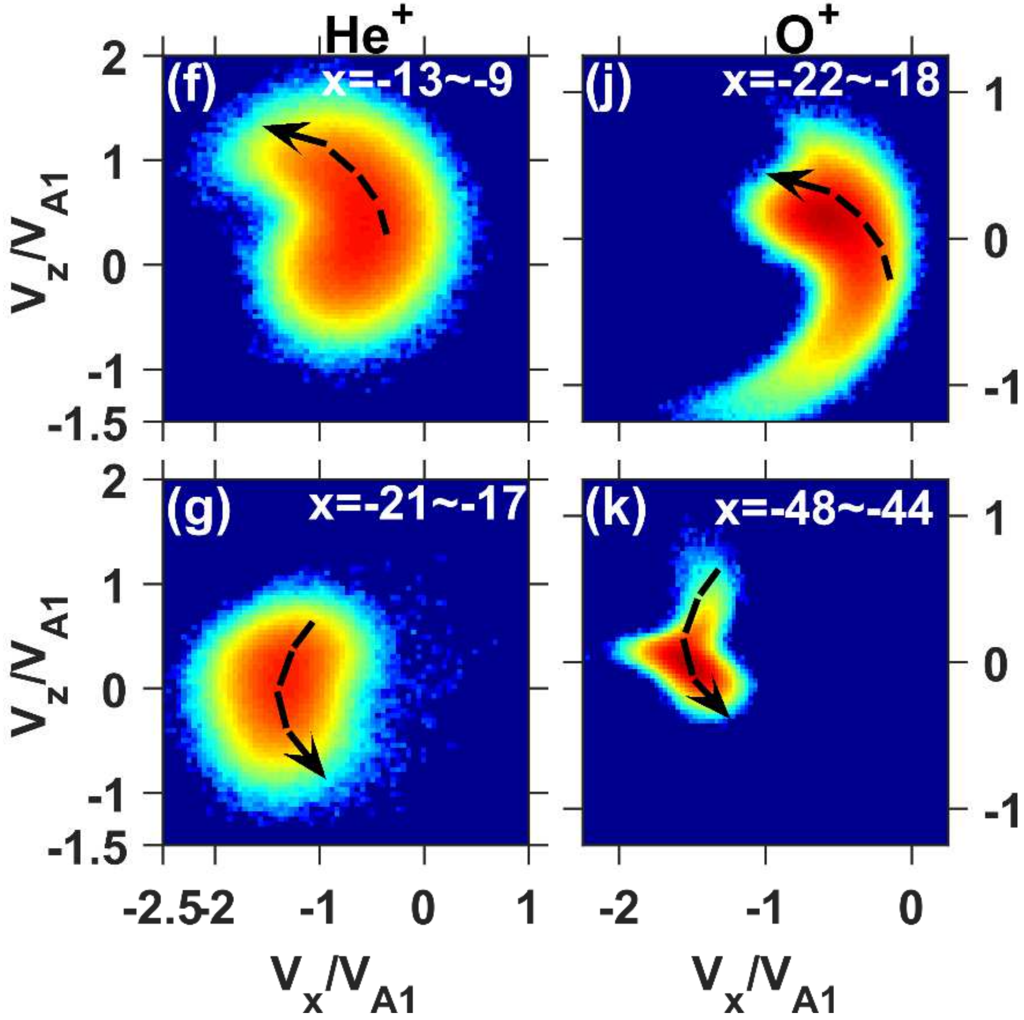
Congratulations on this paper

and keep it up

Jim Dungey

(D2) Ion heating in collisionless fast shock

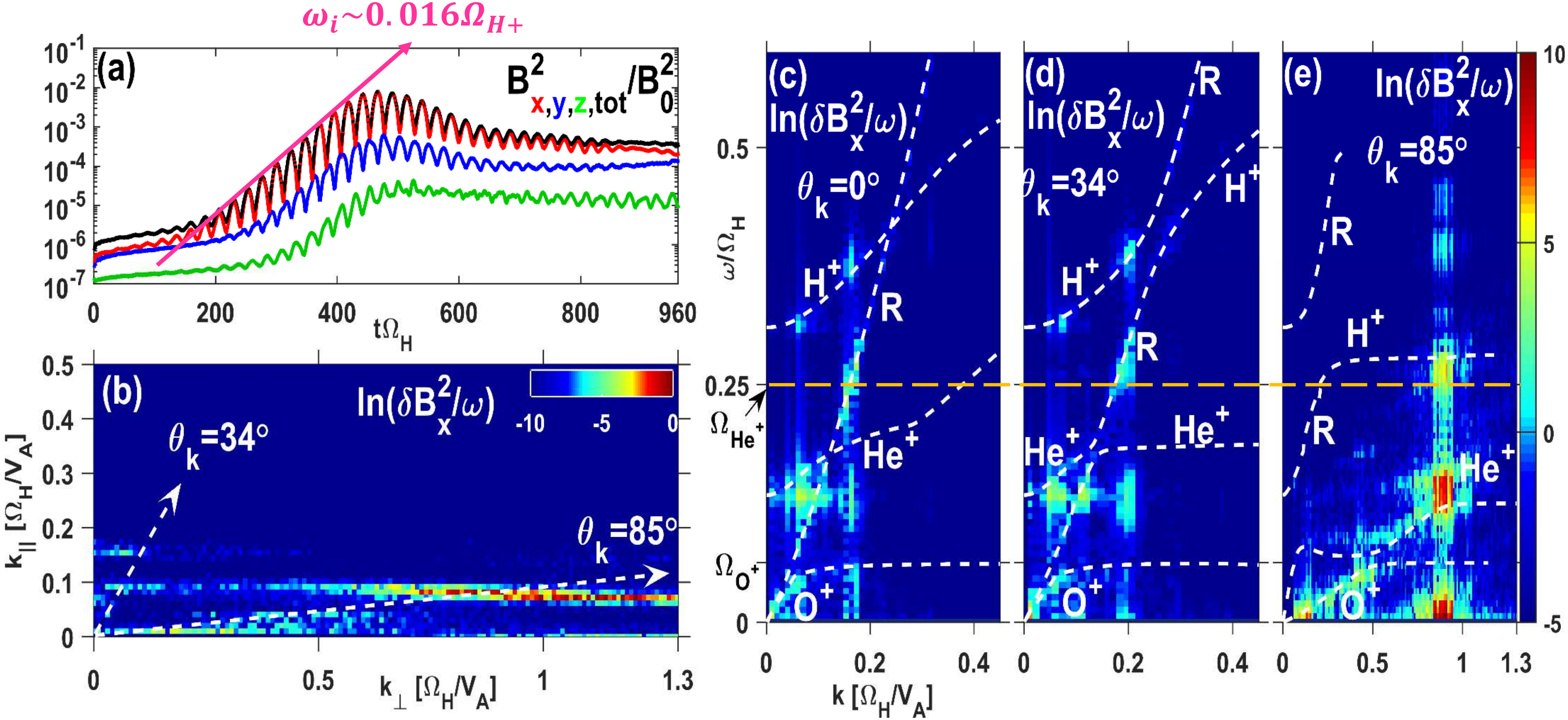


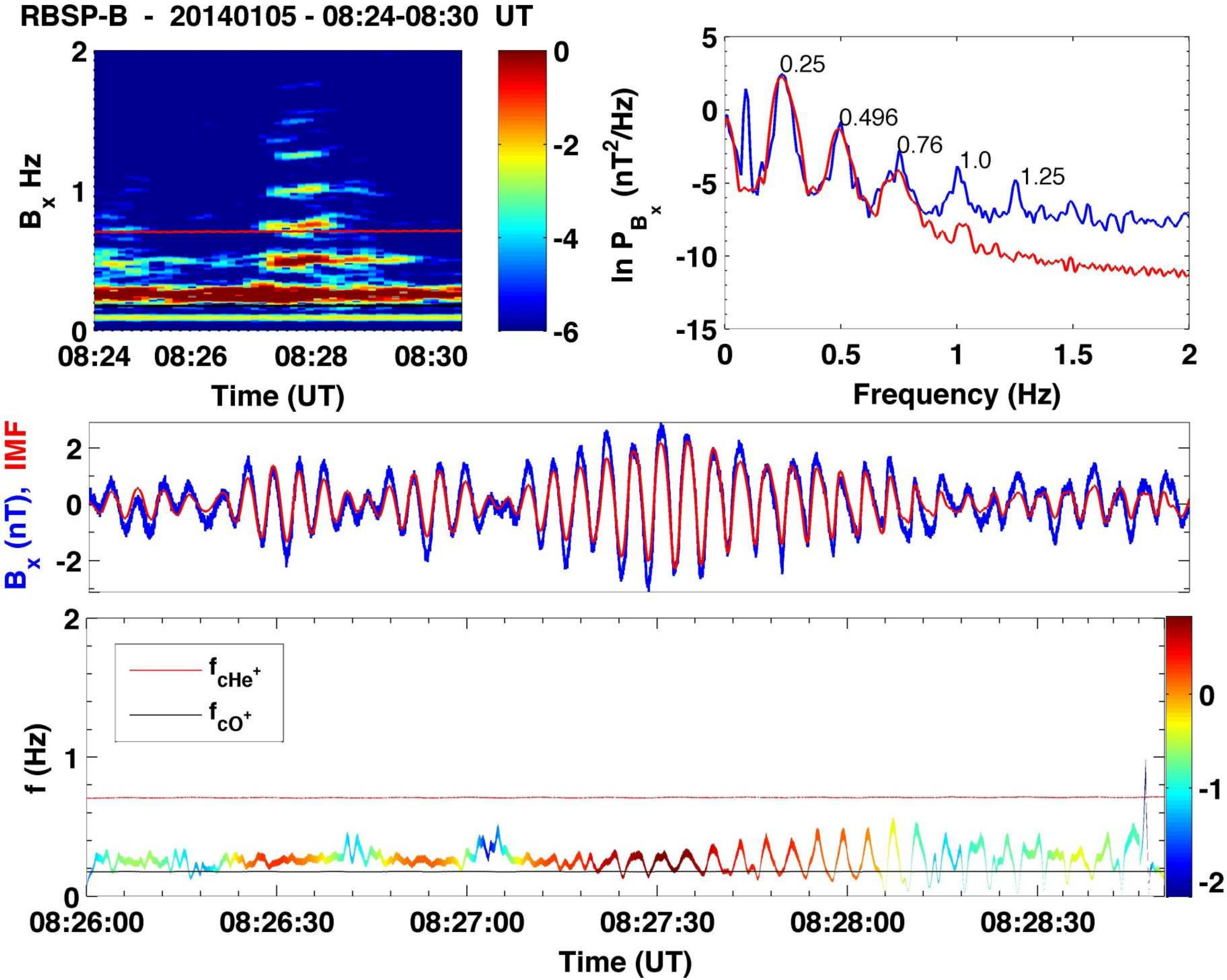


Ion bunch distribution

Lee, Wu, and Hu (1986); Lee and Wu (2000); Lee and Lee (2016)

Helium harmonics generated by oxygen bunch distribution




RBSP-B - 20140105 - 08:24-08:30 UT
B_x Hz
Time (UT)
ln P_{B_x} (nT^2/Hz)
Frequency (Hz)
0.25
0.496
0.76
1.0
1.25
B_x (nT), IMF
f (Hz)
f_{cHe^+}
f_{cO^+}
Time (UT)

Summary

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(D) The micro-scale processes provide electric resistivity for macro-scale magnetic reconnection and ion heating for shocks in collisionless plasma.

Thank You

中央研究院 地球科學所

Institute of Earth Sciences, Academia Sinica