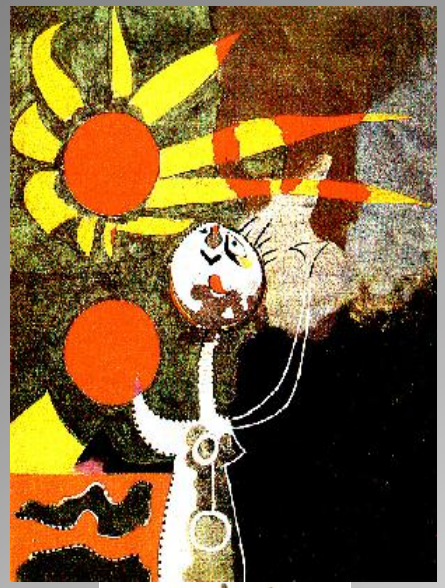
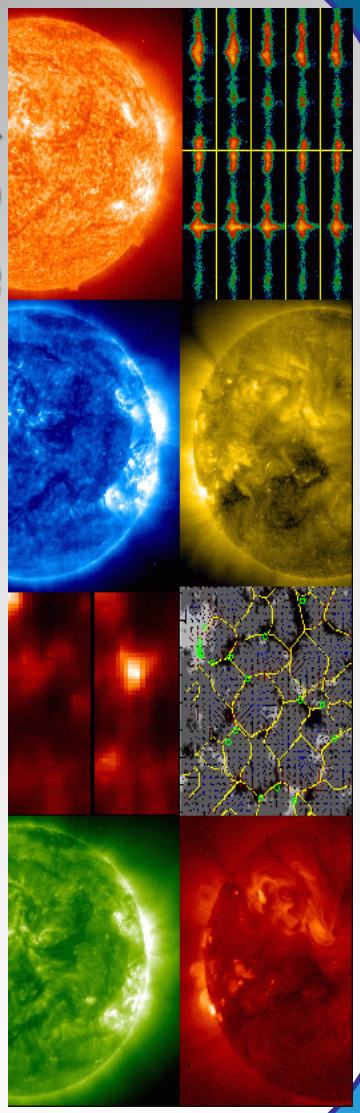


Solar & Space Plasma Physics

Spectroscopic Observations & Modelling of Flows, Jets & MHD Waves in the Solar Atmosphere







Speaker: B.N. Dwivedi

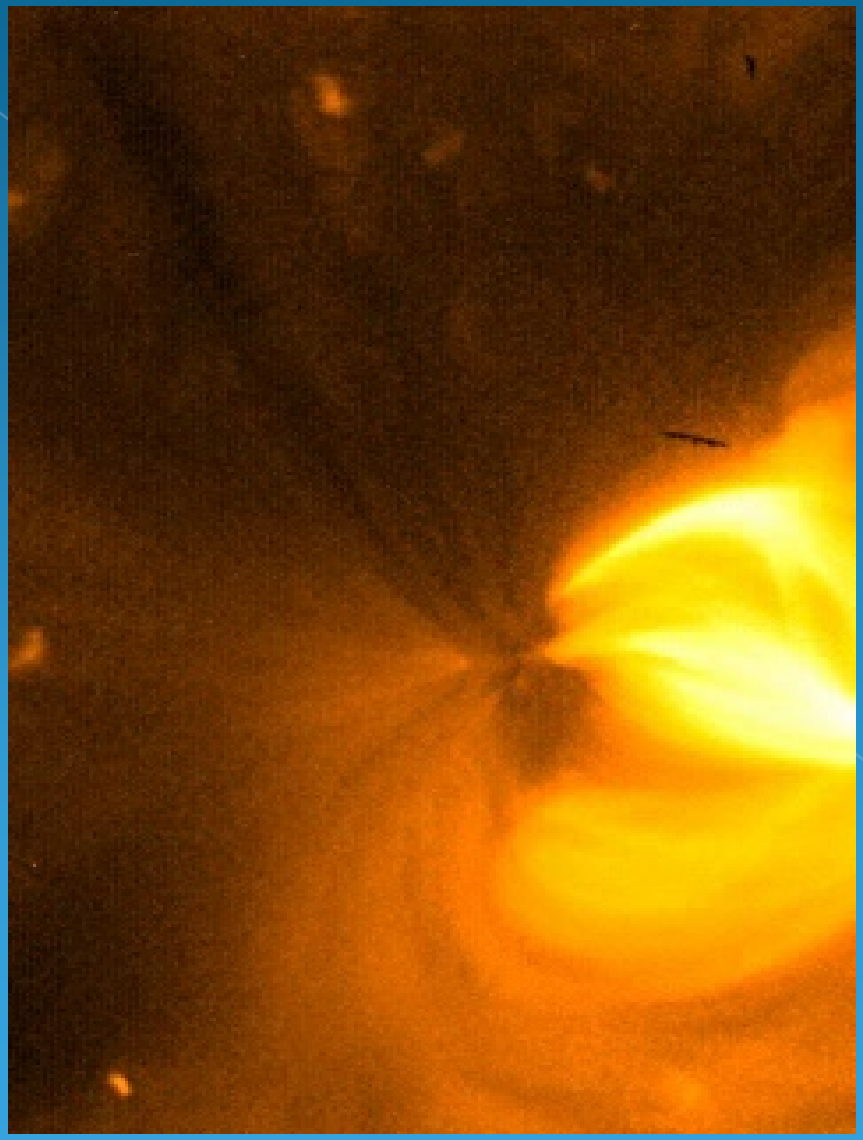
Contributors

A.K. Srivastava & B.N. Dwivedi

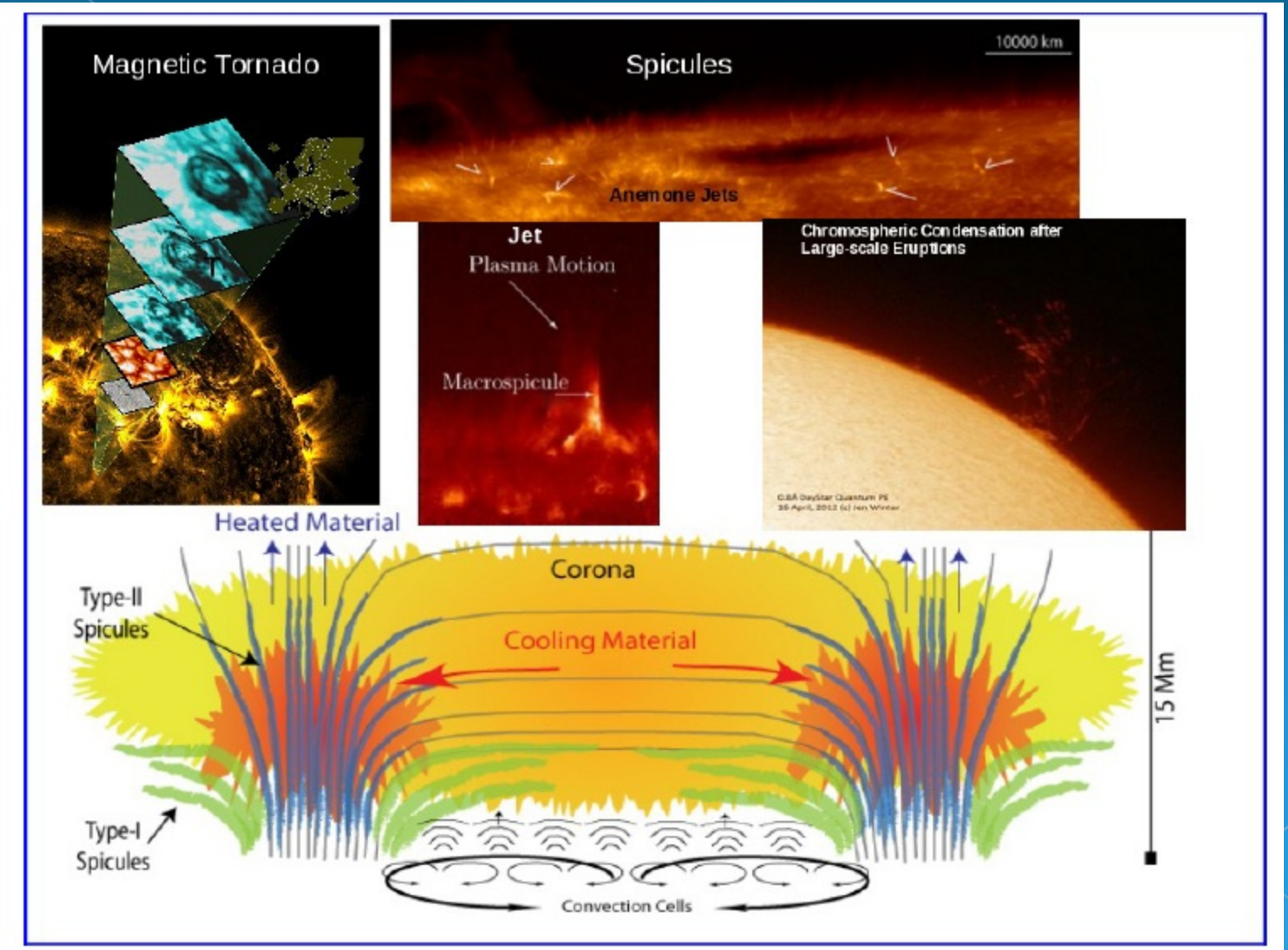
Department of Physics
Indian Institute of Technology (BHU)
Varanasi -221005, India

Collaborators: P. Jelinek, K. Murawski, P. Konkol, P. Kayshap, A. Mohan

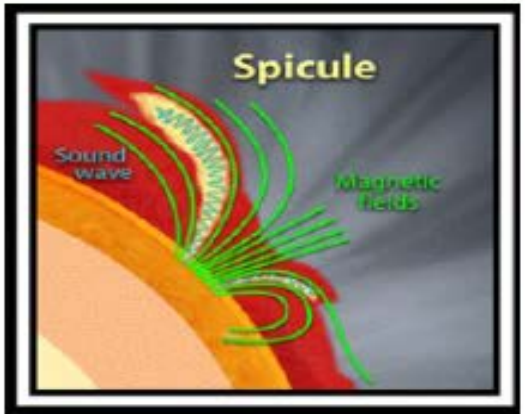
Plasma flows, originated in the lower solar atmosphere, contribute to the formation of nascent solar wind



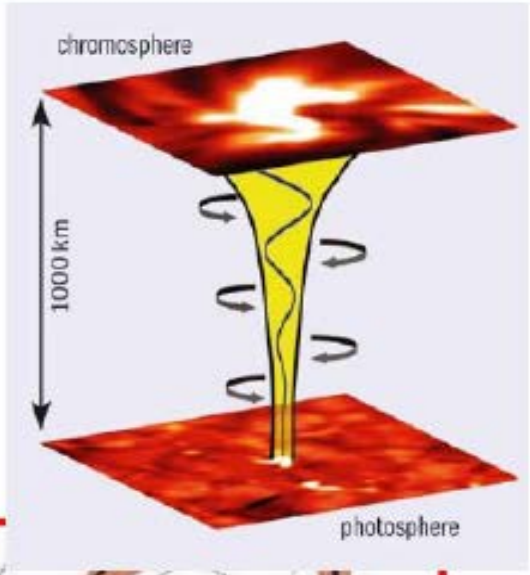
Jets at Diverse Spatio-temporal Scales: The candidate to transport mass & energy in the solar atmosphere

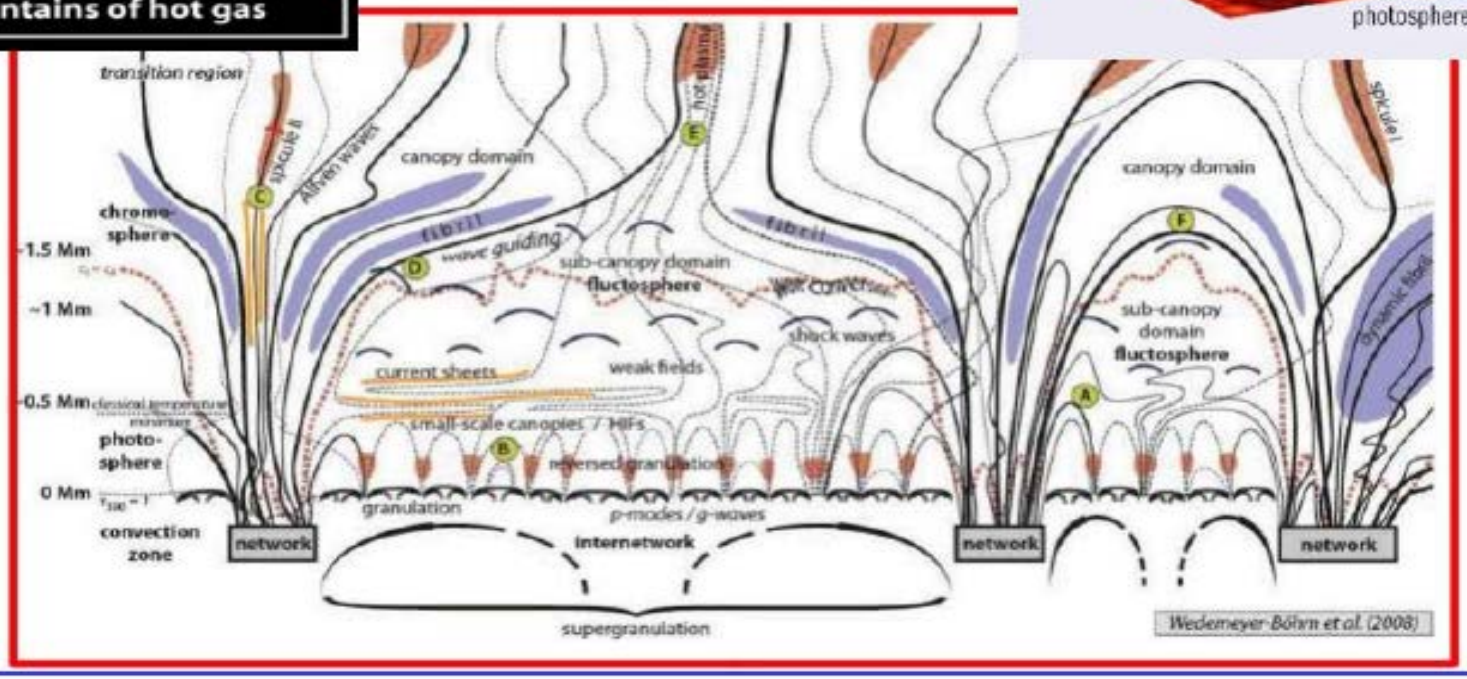


Possible Drivers: MHD Waves or Reconnection not yet fully known !



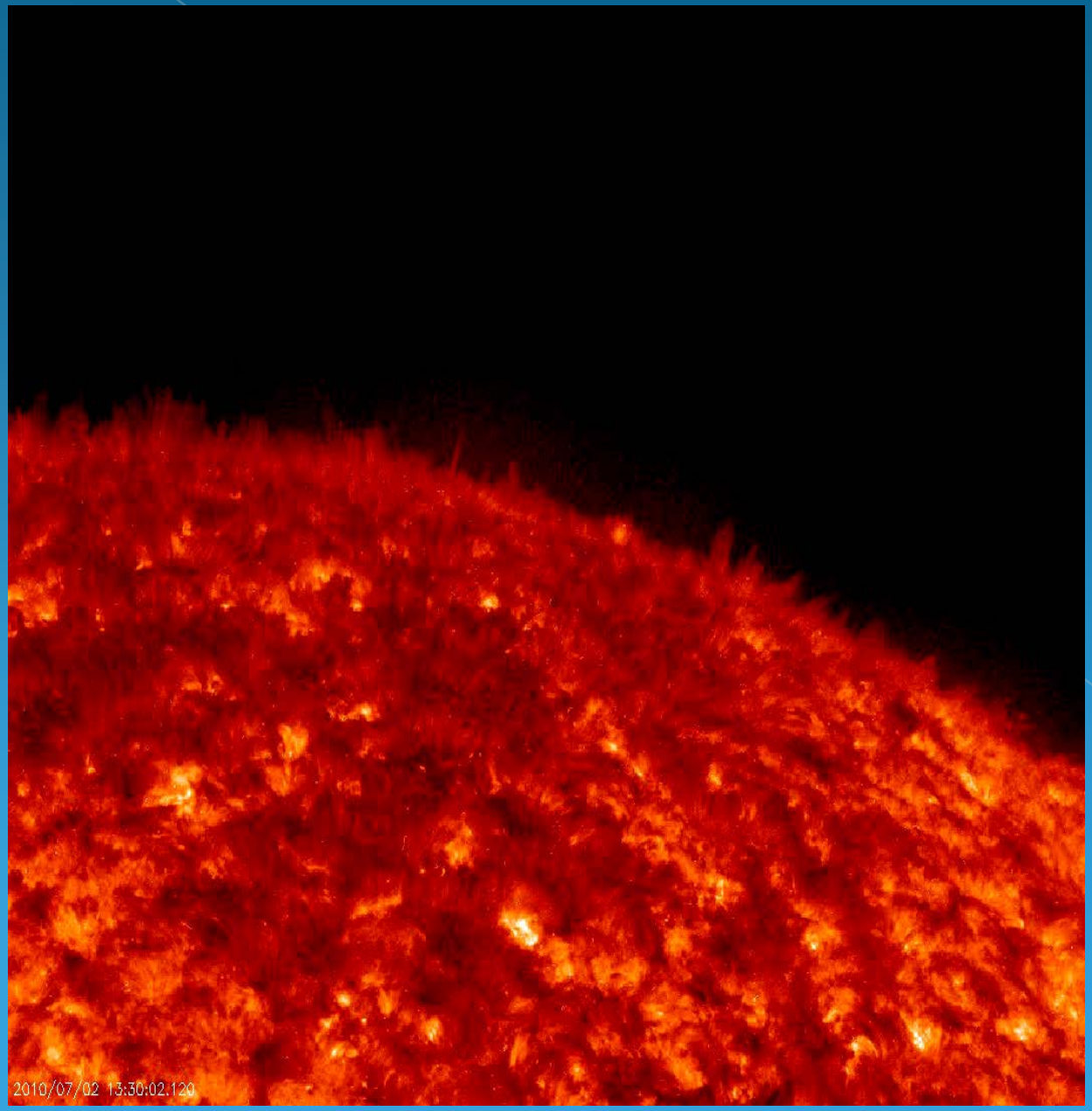
Magnetic "portals" release sound waves and fountains of hot gas





Spicules, Macrospicules & Cool Jets

In Abundant Measure -- Filling the Solar Atmosphere



Spicules

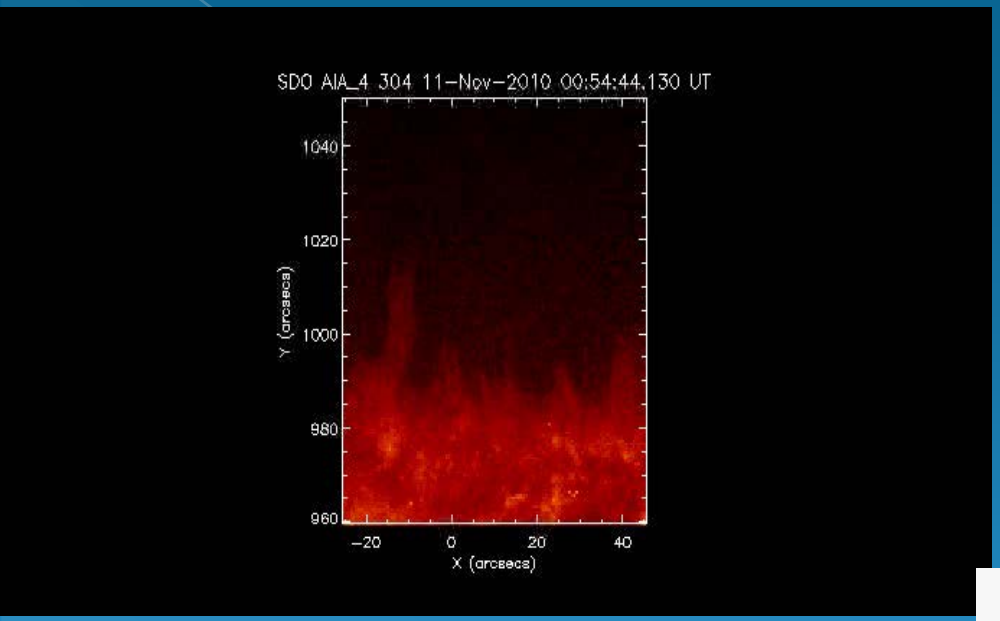
Length: 7 - 13 Mm;
Width: 0.5 - 1.5 Mm;
Life-time: 1 - 10 Minutes;
Terminal Speed: 20 - 25 km s^{-1};
Temperature: 5000-15000 K;
Density: ~ 3 x 10^{-13} kg m^{-3}

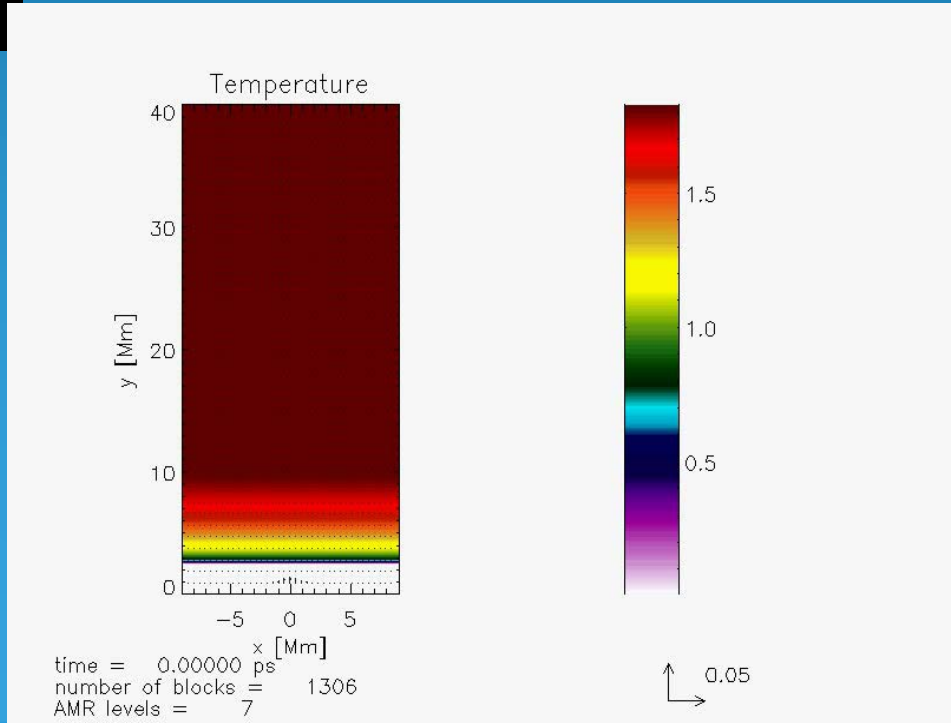
Macrospicules

Length: 7 - 45 Mm;
Life-time: 3 - 45 Minutes; &
Terminal Speed: ~ 50 km s^{-1}

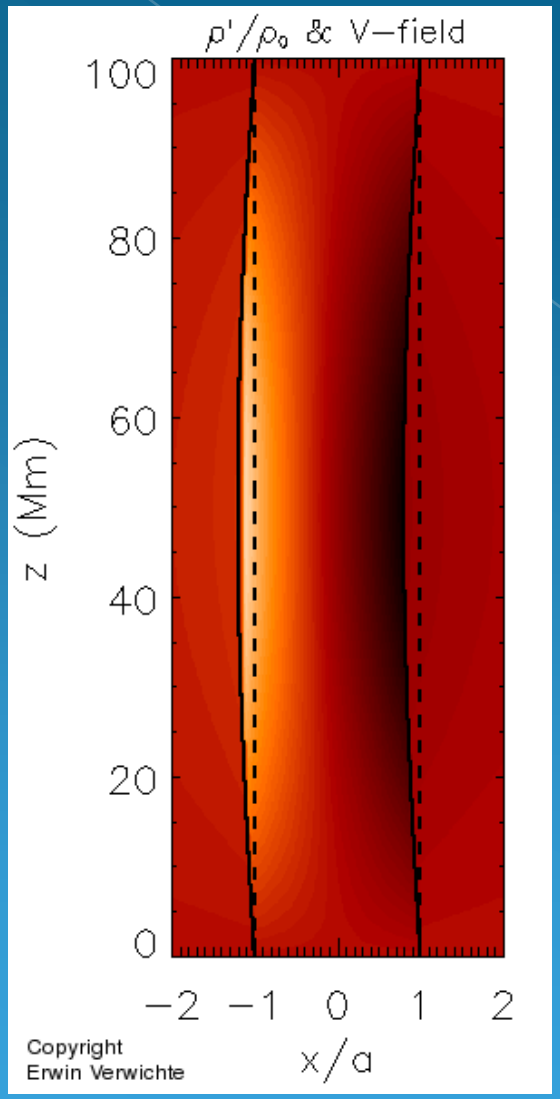
Drivers: Instability & Reconnection !

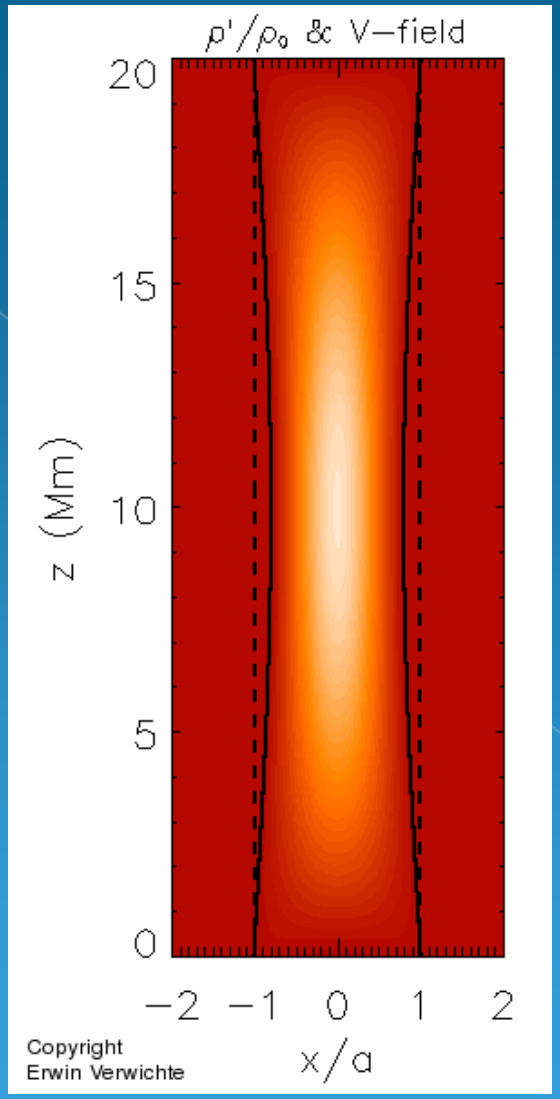
See Poster by Kayshap, Srivastava, Dwivedi, Tripathi

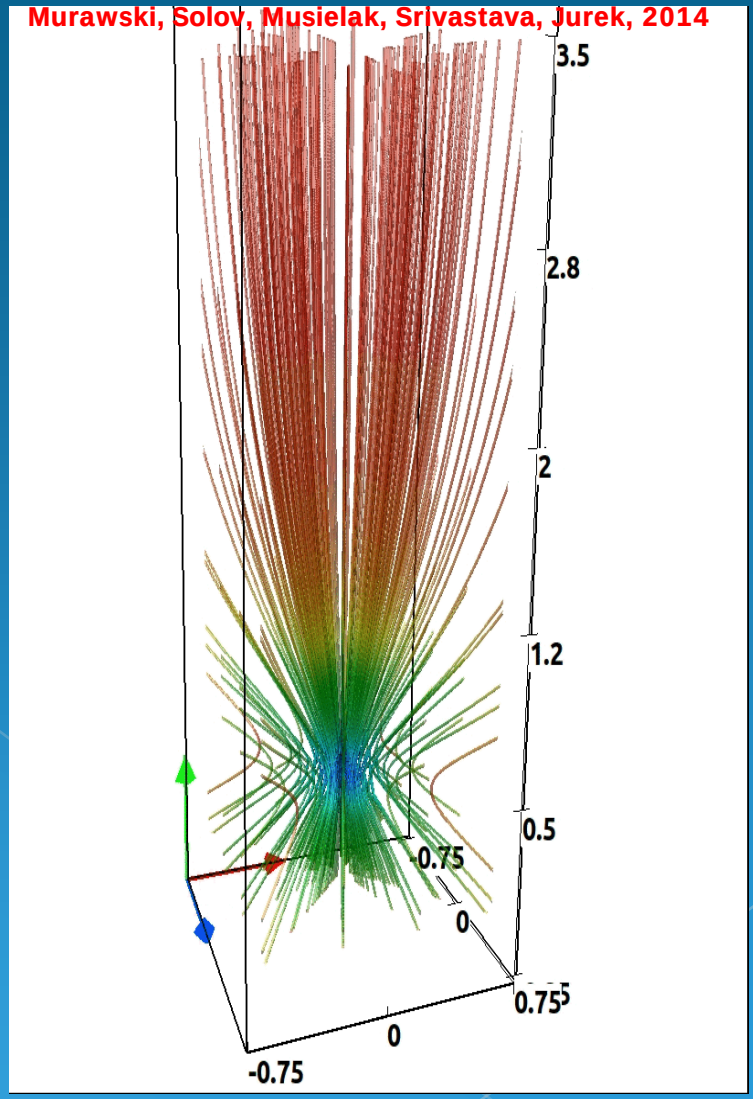




MHD Wave Modes: Identified in Thin Flowing Structures

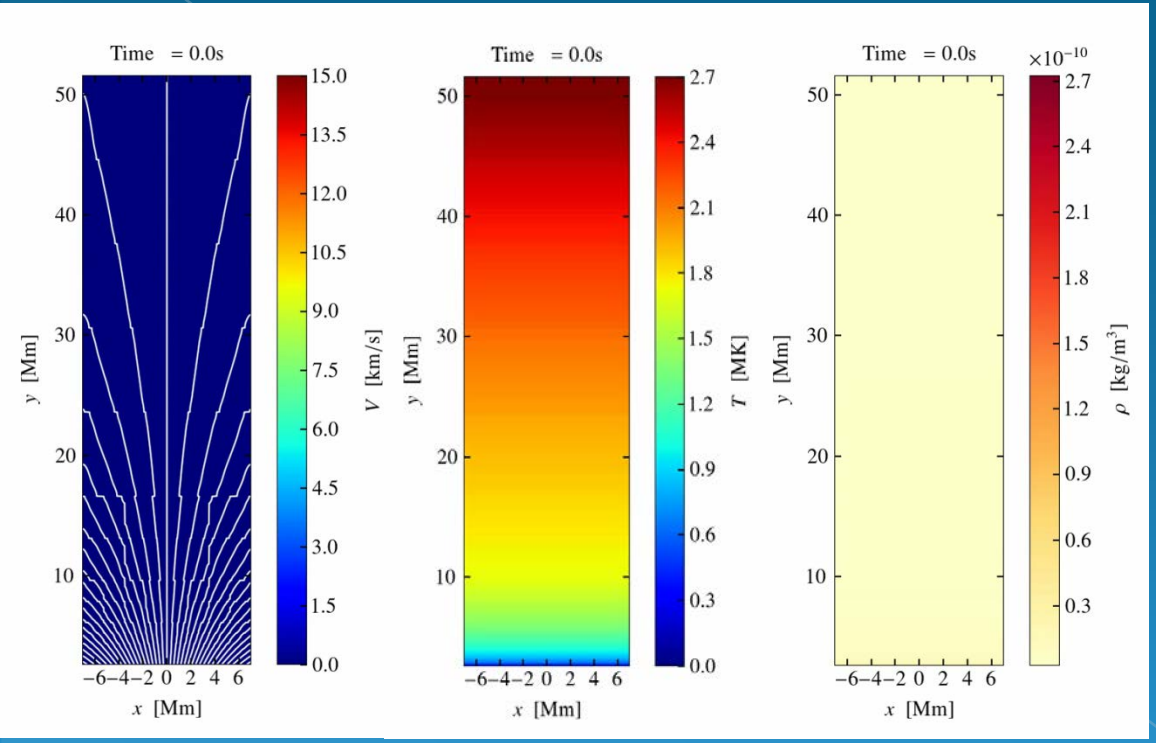






Apart from Fast Magnetoacoustic (kink and sausage) & Torsional Alfvén Waves, the coupled slow magnetoacoustic waves can also be excited.

[1] Plasma Flows in Loop Arches: Response to Heating at Footpoints



Governing MHD Equations

$$\frac{\partial \varrho}{\partial t} + \nabla \cdot (\varrho \boldsymbol{V}) = 0,$$

$$\varrho \frac{\partial \boldsymbol{V}}{\partial t} + \varrho (\boldsymbol{V} \cdot \nabla) \boldsymbol{V} = -\nabla p + \frac{1}{\mu} (\nabla \times \boldsymbol{B}) \times \boldsymbol{B} + \varrho \boldsymbol{g},$$

$$\frac{\partial p}{\partial t} + \nabla \cdot (p \boldsymbol{V}) = (1 - \gamma) p \nabla \cdot \boldsymbol{V},$$

$$\frac{\partial \boldsymbol{B}}{\partial t} = \nabla \times (\boldsymbol{V} \times \boldsymbol{B}), \quad \nabla \cdot \boldsymbol{B} = 0.$$

Initial Magnetic Field Conditions

$$(\nabla \times \boldsymbol{B}_e) \times \boldsymbol{B}_e = \boldsymbol{0}.$$

$$\boldsymbol{B}_e = \nabla \times (A \hat{\boldsymbol{z}}).$$

$$A(x, y) = S \frac{x - a}{(x - a)^2 + (y - b)^2},$$

Initial Plasma Conditions

$$-\nabla p_e + \varrho_e \mathbf{g} = \mathbf{0}.$$

$$p_e(y) = p_0 \exp\left[-\int_{y_r}^{y} \frac{dy'}{\Lambda(y')} \right], \qquad \varrho_e(y) = \frac{p_e(y)}{g \Lambda(y)},$$

$$\Lambda(y) = \frac{k_B T_e(y)}{mg}$$

PERTURBATIONS DURING HEATING

$$\varrho(x, y, t) = \varrho_e(y)\left[1 + A_\varrho f(x, y) g(t)\right],$$
$$p(x, y, t) = p_e(y)\left[1 + A_p f(x, y) g(t)\right],$$

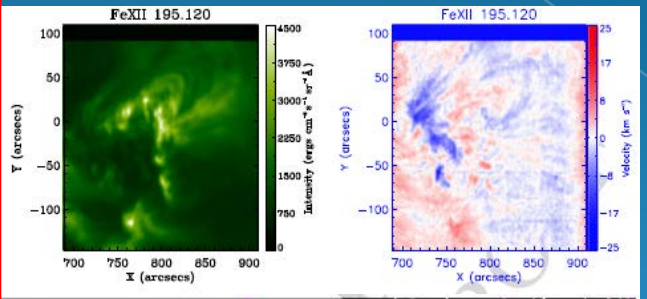
$$f(x, y) = \exp\left[-\frac{(x - x_0)^2}{w_x^2} - \frac{(y - y_0)^2}{w_y^2} \right]$$

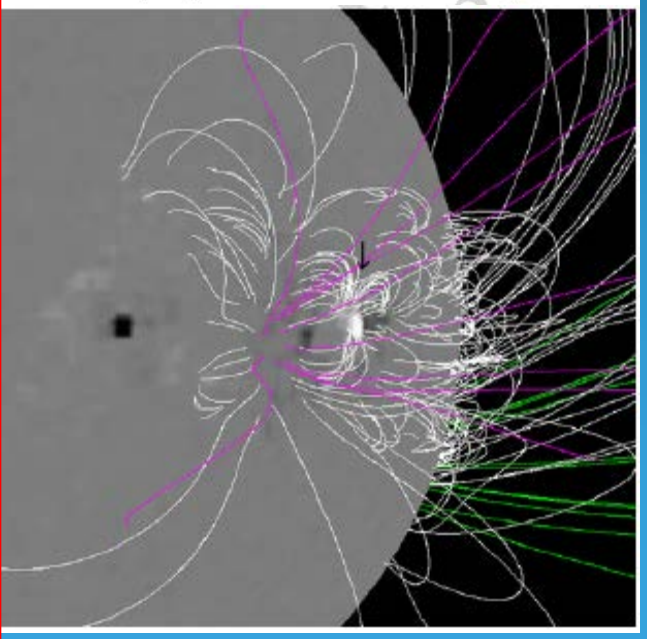
$$g(t) = -\left[\exp\left(-\frac{t}{\tau} \right) - 1 \right].$$

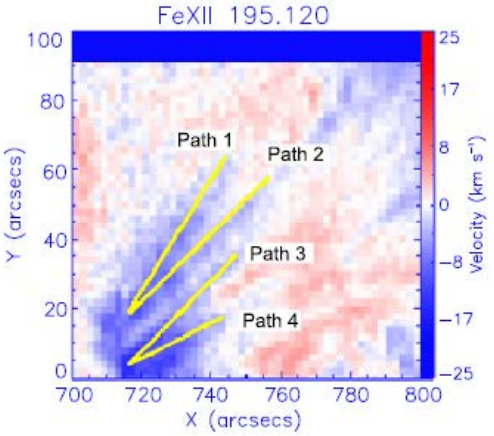
Srivastava, Konkol, Murawski, Dwivedi, Mohan: *Solar Physics* (2014)

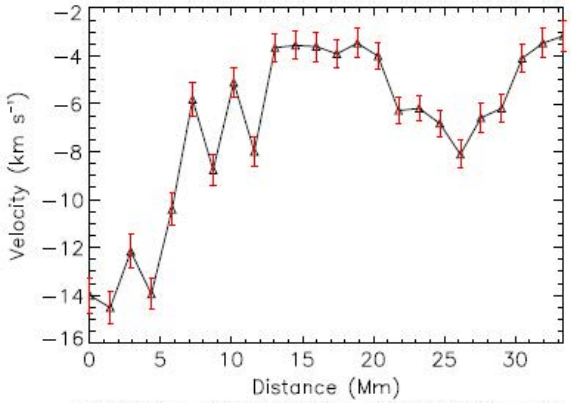
Observations supported by Model

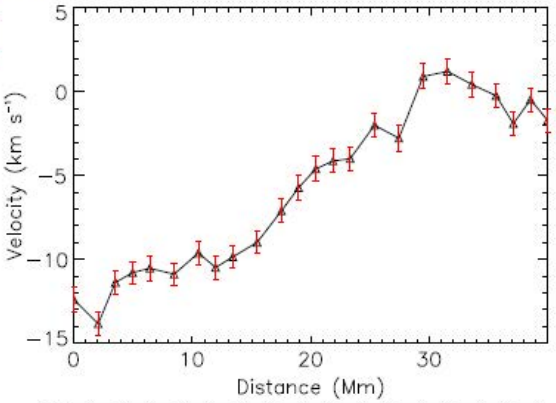
AR 10940; 05 February 2007

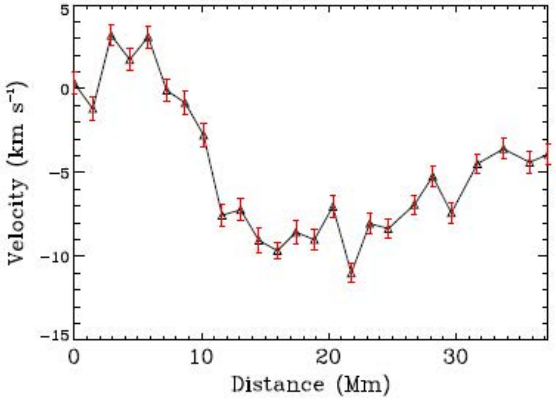


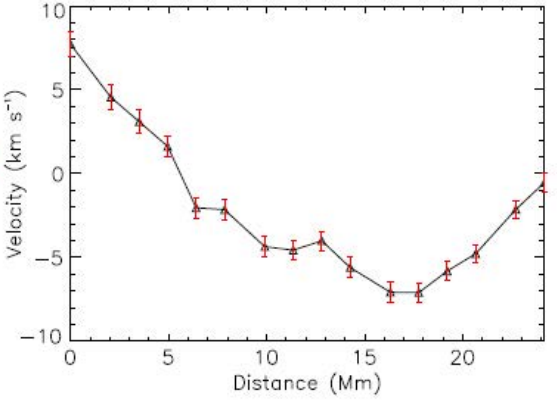




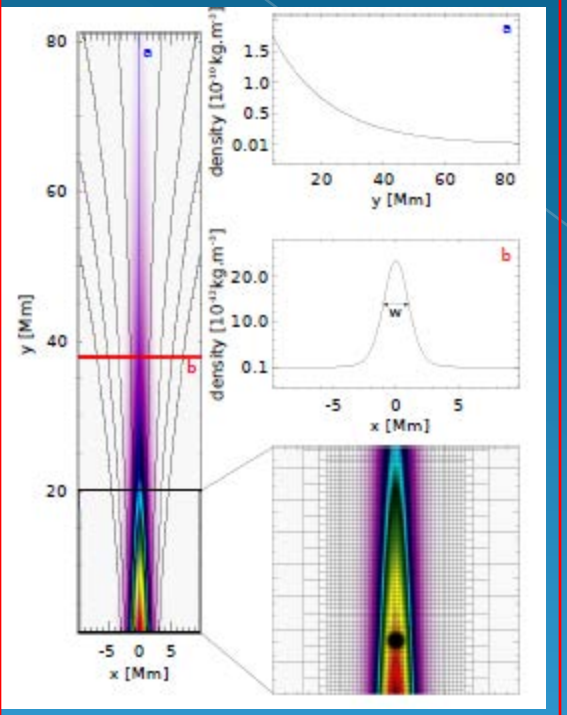


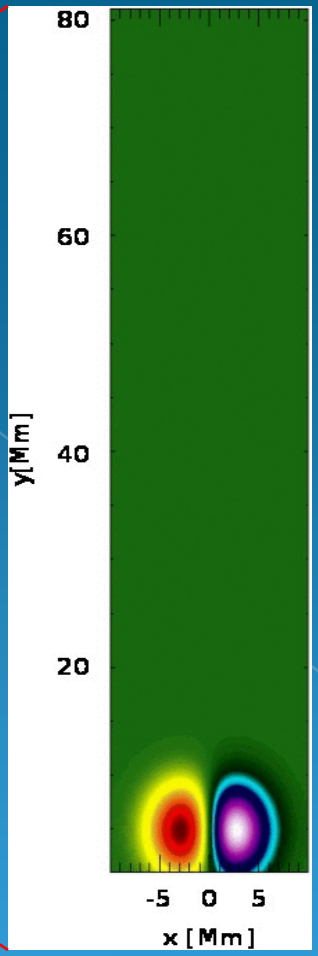






[2] Alfvén Waves Along Coronal Jet: Impulsive Trigger by Coronal Reconnection





Governing MHD Equations

$$\frac{D\varrho}{Dt} = -\varrho \nabla v,$$

$$\varrho \frac{Dv}{Dt} = -\nabla p + j \times B + \varrho g,$$

$$\frac{DB}{Dt} = (B \cdot \nabla) v,$$

$$\frac{De}{Dt} = -\gamma e \nabla \cdot v,$$

$$\nabla \cdot B = 0.$$

PERTURBATIONS DURING RECONNECTION

$$V_z(x, y, t = 0) = -A_0 \cdot \frac{x}{\lambda} \cdot \exp\left[-\frac{x^2 + (y - L_p)^2}{\lambda^2}\right]$$

Alfven Wave Equation

$$\frac{\partial^2 V_z(x,y,t)}{\partial t^2} = c_A^2(x,y) \frac{\partial^2 V_z(x,y,t)}{\partial s^2},$$

Harris Current Sheet

$$B = \nabla \times A.$$

$$A_z = -B_0 w_{cs} \ln\left\{\left|\cosh\left(\frac{x}{w_{cs}}\right)\right|\right\} \exp\left(-\frac{y}{\lambda}\right).$$

$$B_x(x,y) = B_0 \frac{w_{cs}}{\lambda} \ln\left[\cosh\left(\frac{x}{w_{cs}}\right)\right] \exp\left(-\frac{y}{\lambda}\right),$$

$$B_y(x,y) = B_0 \tanh\left(\frac{x}{w_{cs}}\right) \exp\left(-\frac{y}{\lambda}\right).$$

$$\varrho(x,y) = \left\{\frac{B_0^2}{\mu_0 g \lambda}\left\{1 + \ln\left[\cosh\left(\frac{x}{w_{cs}}\right)\right]\right\} \operatorname{sech}^2\left(\frac{x}{w_{cs}}\right) + \varrho_0\right\} \cdot \exp\left(-2\frac{y}{\lambda}\right),$$

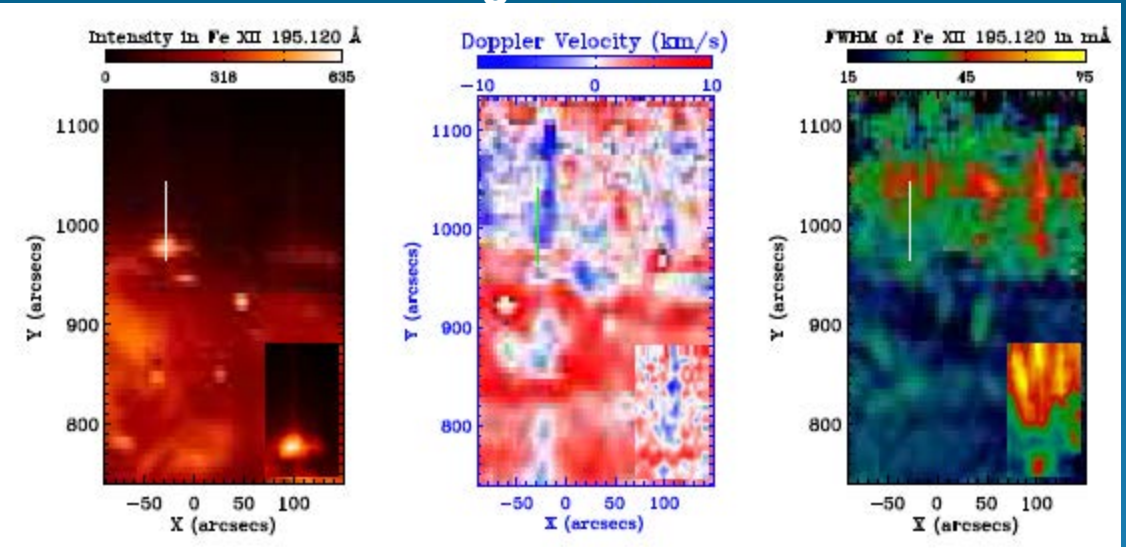
$$p(x,y) = \left\{\frac{B_0^2}{2\mu_0} \operatorname{sech}^2\left(\frac{x}{w_{cs}}\right) + \frac{B_0^2 w_{cs}^2}{2\mu_0 \lambda^2} \ln^2\left[\cosh\left(\frac{x}{w_{cs}}\right)\right] + \frac{\varrho_0 g \lambda}{2}\right\} \cdot \exp\left(-2\frac{y}{\lambda}\right) + p_0.$$

Initial Plasma Conditions

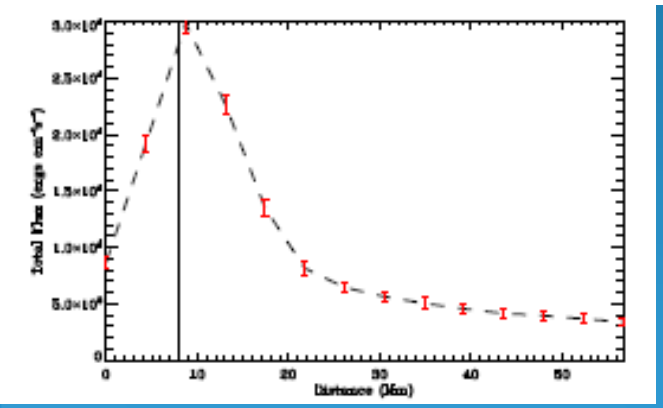
$$-\nabla p + j \times B + \varrho g = 0.$$

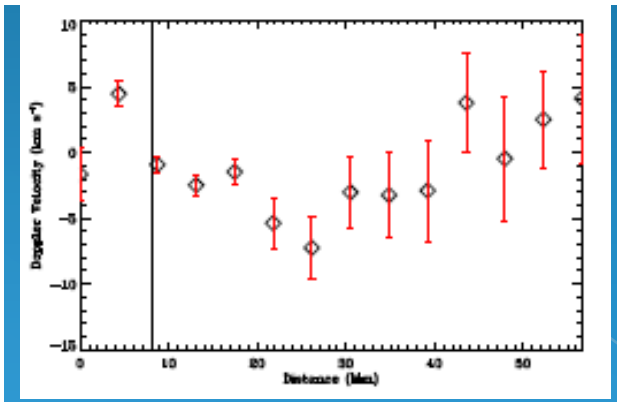
Jelinek, Srivastava, Murawski, Kayshap, Dwivedi: *A&A* (2014) submitted

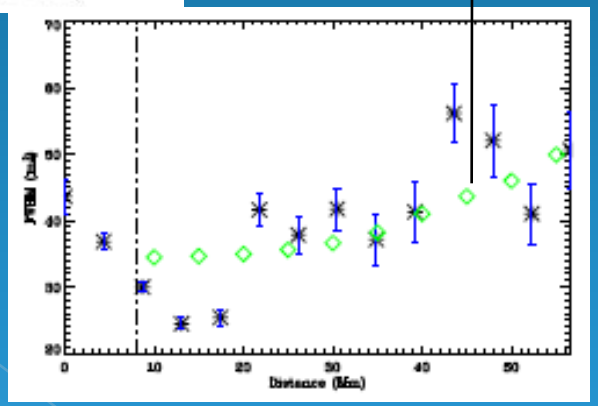
Match with observational signature of Alfvén waves in coronal jet

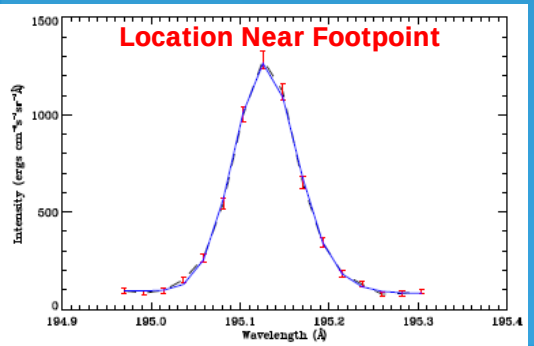


Green Diamonds: Synthetic Line Width derived by Spatio-temporily averaged Vz

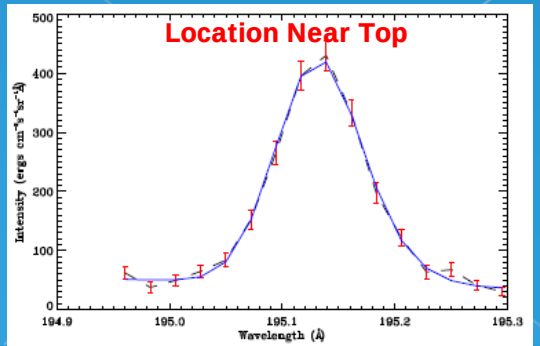






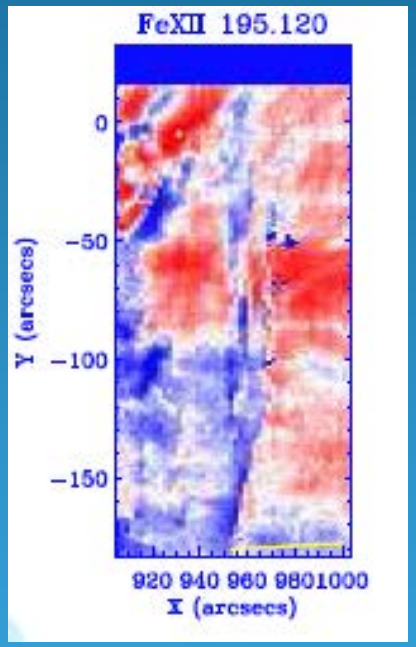


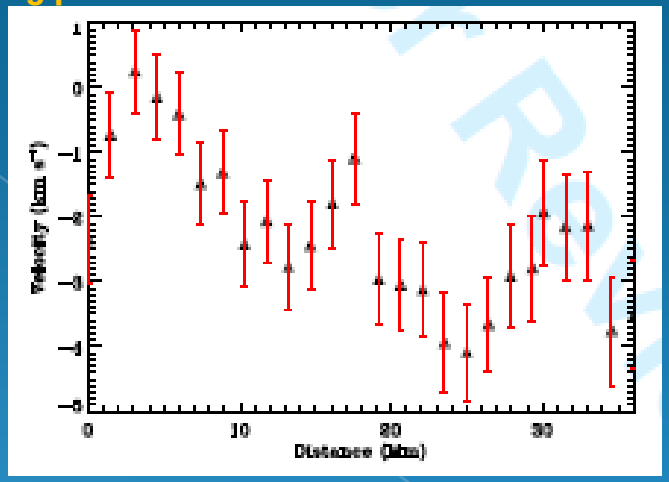
Example of Gaussian Fit

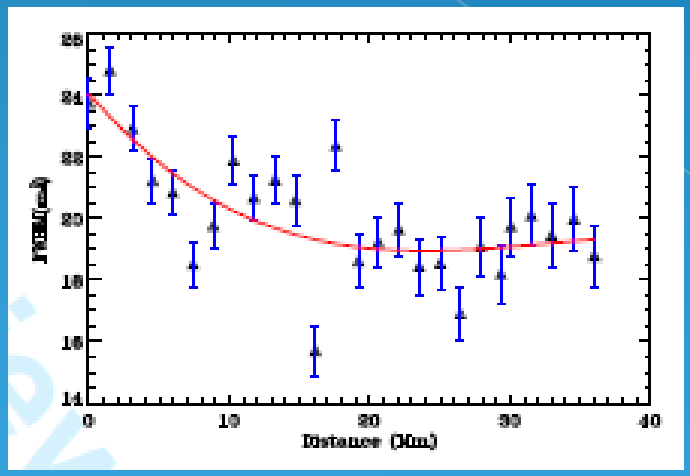


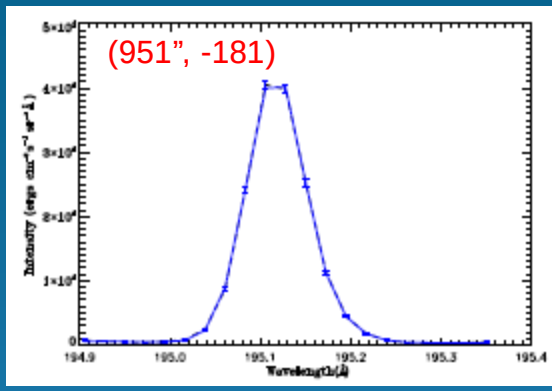
[3] Signature of Dissipative Alfvén Waves in Equatorial Corona

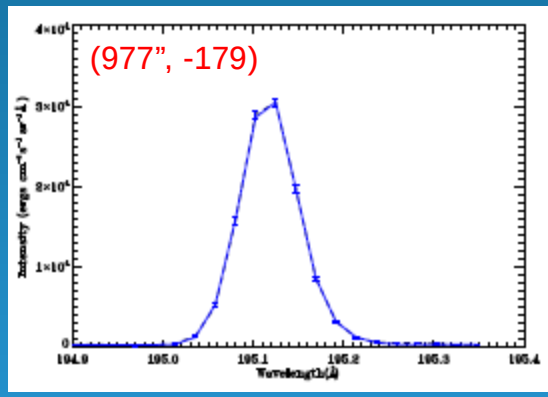
Yellow strip passes through outflowing region in the equatorial corona where outflow speed increases with height while FWHM of Fe XII 195 line decreases up to 20 Mm height. This region is associated with the lower part of denser coronal loop --- The signature of Alfvén wave dissipation in this localized funnel , providing energy to outflowing plasma.

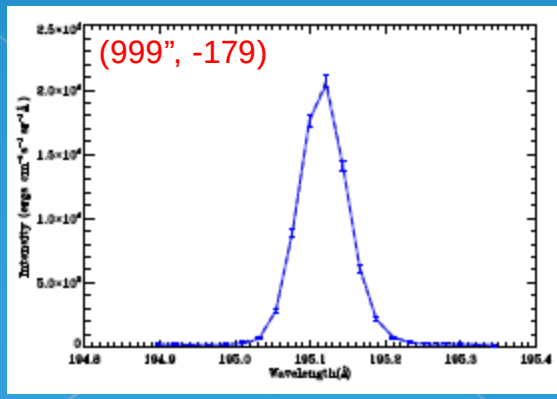






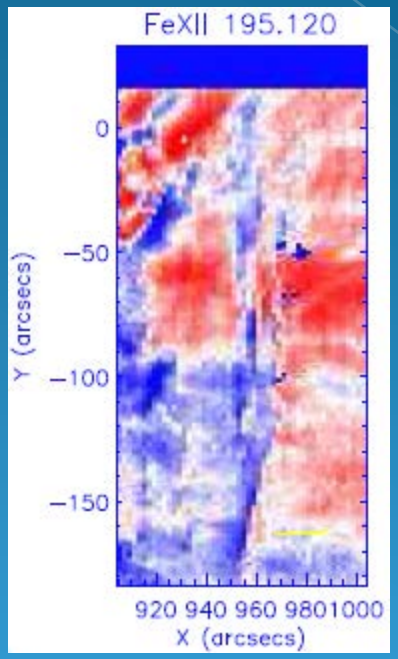


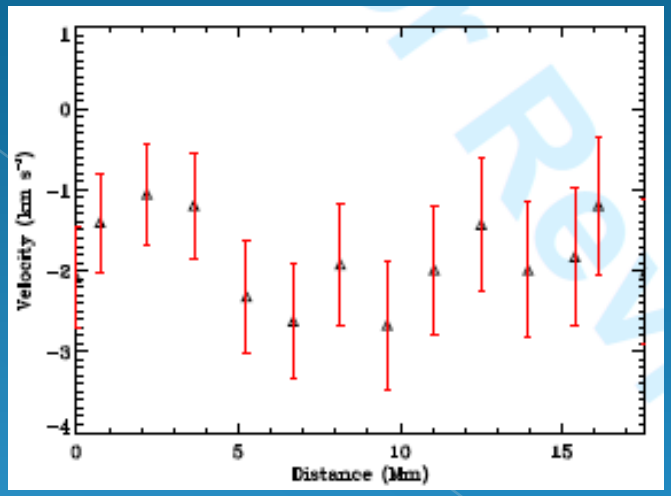


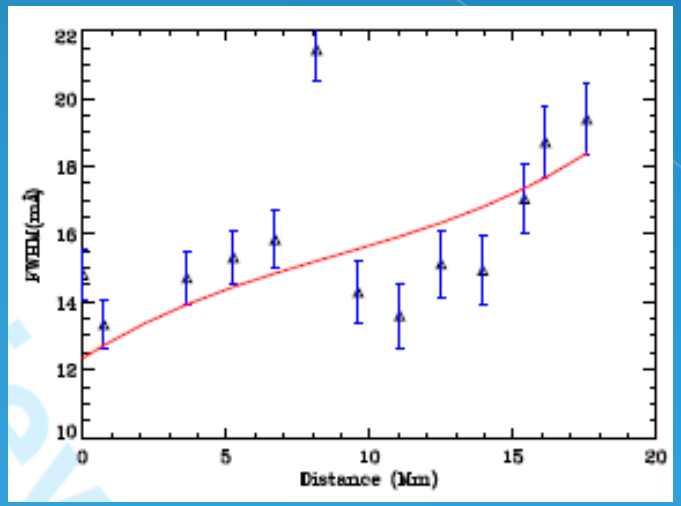


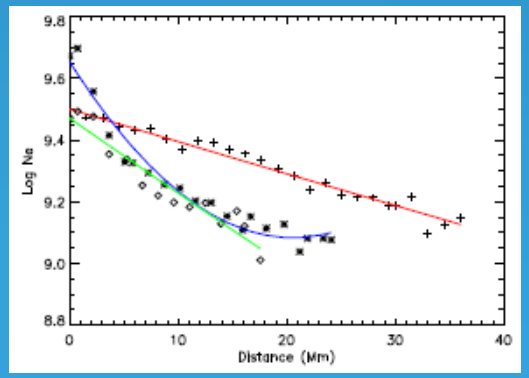
Dwivedi, Srivastava, Mohan: *PASJ* (2014) in press

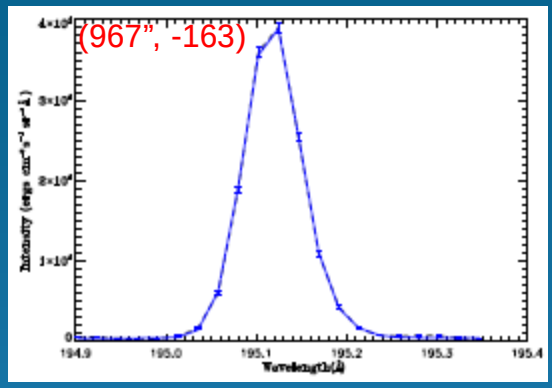
Yellow strip this time passes through a weakly outflowing region in equatorial corona which is less intense and the likely region sandwiched between two tubes with lesser density. This is weakly outflowing region. On the contrary, FWHM of Fe XII 195 line increases up to 20 Mm height in this region. This may be the signature of Alfvén wave growth in localized region. It should be noted that density falls very quickly with height in this region compared to the previous tube, which causes the growth of Alfvén waves.

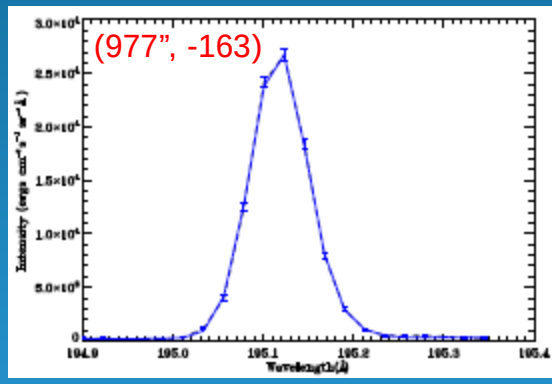


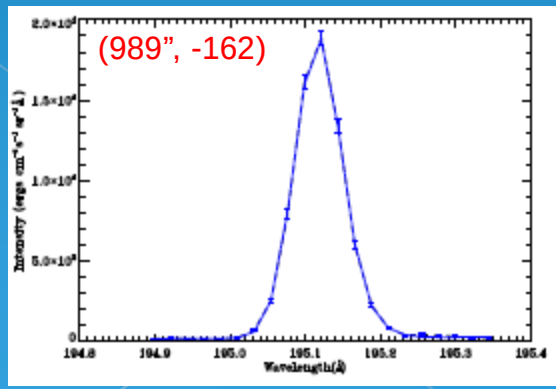












Dwivedi, Srivastava, Mohan: *PASJ* (2014) in press

Conclusions

[1] The plasma flows occur in large-scale coronal funnels driven by localized heating. (example 1)

[2] Plasma motions can occur in large-scale coronal jets by ponder-motive forces during non-linear evolution of impulsive Alfvén waves. (example 2)

[3] In localized coronal funnels, the Alfvén wave can provide energy to increase the outflow speed. (example 3)

[4] In general, waves & plasma flows are able to transport the energy for localized coronal heating, as well as mass, contributing to the formation of the nascent solar wind.

THANK YOU