

Alfvén Wave Based Mechanism of Polar Coronal Jets

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Coronal Polar Jets: Main Features

- The length of the jet is much larger than the width
- Jets are highly collimated in the direction of the eruptive flow
- The average observed outflow velocity is ~ 200 km/s
 - The speed of the jet is assumed to be the velocity of the intensity front.

References: Shibata et al/ PASJ, 1992; Shimojo et al. PASJ, 1996; Culhane et al. PASJ, 2007; Savcheva et al. PASJ, 2007; Cirtain et al. 2007; Kamio et al. PASJ, 2007; Moreno-Insertis et al. 2008; Koutchmy et al. 2008,

Coronal Polar Jets: Observations/Models

- Fine structure and their motion strongly support an X-ray jet model based on magnetic reconnection (first suggested by Shibata et al. 1992)
 - 2D simulation by Yokoyama and Shibata (1995, 1996),
 $V_{\text{Model}} \sim V_a \gg V_{\text{Observed}}$
- It was proposed that X-ray jets are evaporation flows subsequent to the magnetic reconnection.
Question: what happened to the reconnection outflow? If it is a part of the evaporation flow picture, why it is not detectable?
This model cannot explain helical structure or Alfvénic (or wave-kind) motions
- 3D configuration picture needs to be considered (References: Patsourakos et al. 2008, Zaqarashvili and Skhirtladze, 2008; Fillippov et al. 2009)
 - Pariat et al. 2009 model reproduces helical structure (massive, non-linear AW driven, high-speed jets)
 $V_{\text{Model}} \sim V_a \gg V_{\text{Observed}}$

References: Shibata et al. 1992; Shimojo M. et al. PASJ, 2007; Savcheva et al., ApJL, 2009

Coronal Polar Jets: Observations/Models

(continued)

- Model of Reconnection Outflow Jets Including Thermal Conduction

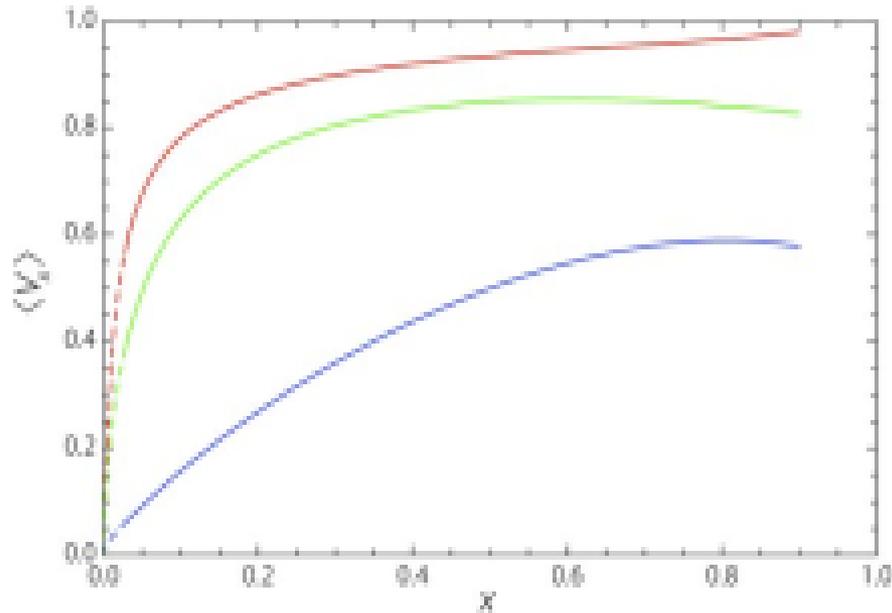


Figure 7a. from Seaton and Forbes, ApJ 701, 2009.

- Red curve: outflow speed without thermal conduction ($\lambda = 0$)
- Green Curve: modest amount of conduction (small λ)
- Blue curve: very high conduction
- λ ratio: energy loss due to the therm. Conduction to the energy input by Poynting flux in the current layer; In the model: $0 \leq \lambda \leq 1$
- $x = [0,1]$ interval is the half length of the current layer

Alfvén Wave Based Polar Coronal Jet Physics

- Consider a magnetic field aligned flow with a cross-field velocity shear

$$\vec{V}_0 = (S_y y, 0, 0)$$

- the physical picture similar to the plasma outflow in the expanding polar coronal holes.
- Our main focus is a temporal interface during which the Alfvén wave transitions from almost zero cross-shear flow to the expanding solar corona region.

Reference: Kaghshvili, 2007; Kaghshvili et al. 2009; Hollweg and Kaghshvili, 2012; kaghshvili, 2012

Flow-shear Driven Waves: Initial Conditions

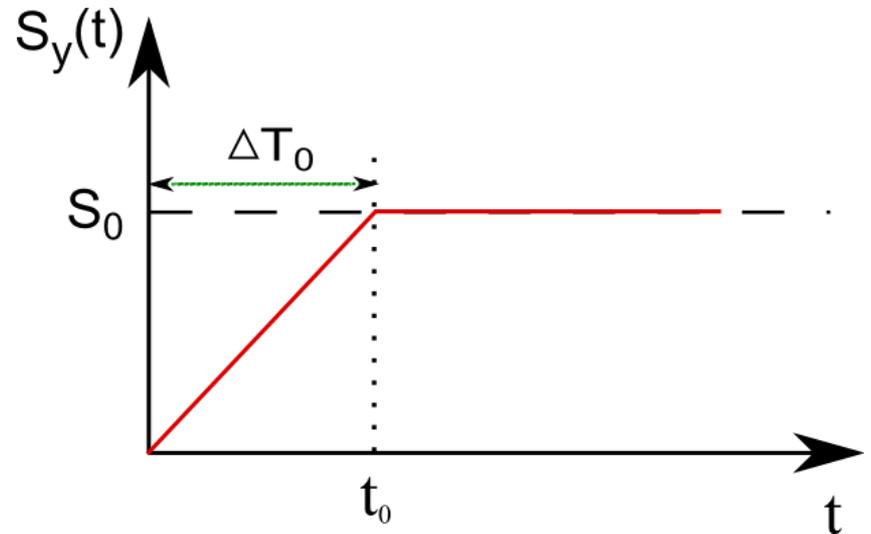
Background Plasma:

- $\rho_0 = \text{const.}$ & $P_0 = c_s^2 \rho_0 = \text{const.}$
- $\vec{B}_0 = (B_0, 0, 0)$, where $B_0 = \text{const.}$

Old Work(s): velocity shear present at $t=0$:

$$\vec{V}_0 = (V_0, 0, 0), \text{ where } V_0 = S_y y \text{ and } S_y = \text{const.}$$

$$\vec{V}_0 = (V_0, 0, 0), \text{ where } V_0 = S_y(t)y$$



Case I. $\Delta T_0 = 2.4$ Alfvén Period (slow ramp)

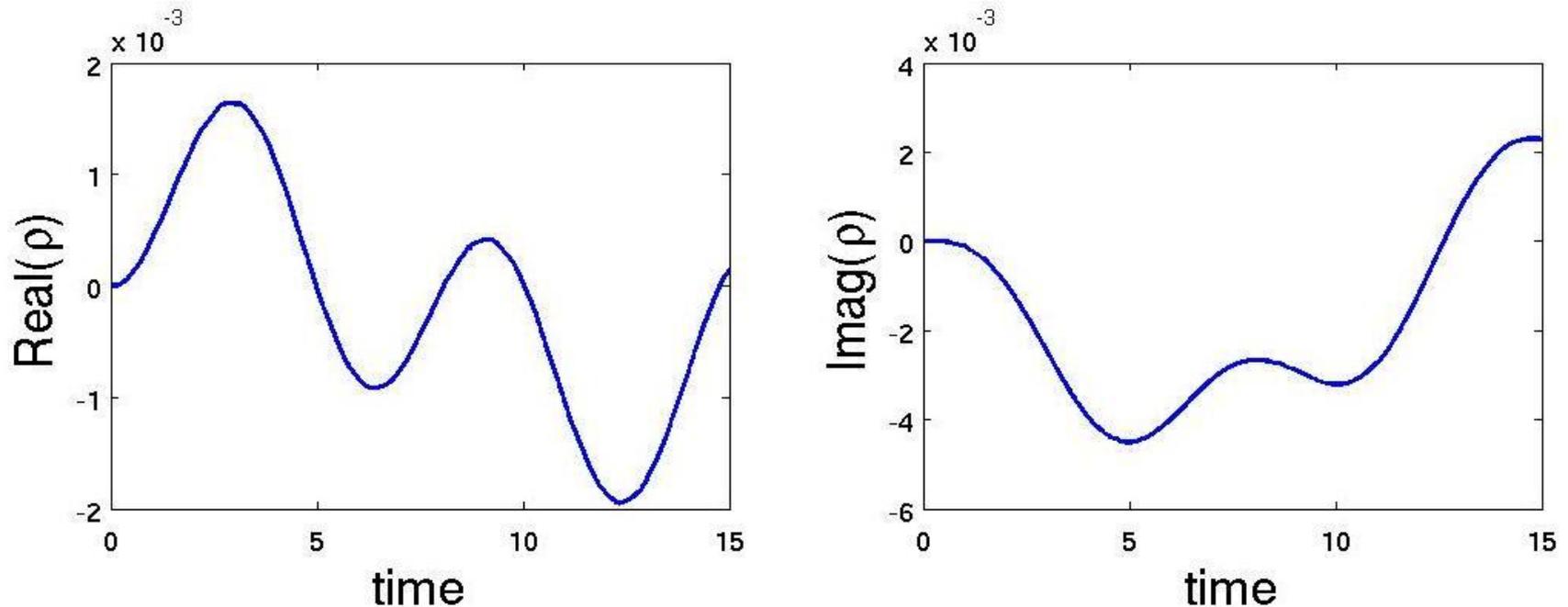


FIGURE: Real and imaginary parts of the normalized density fluctuations.

- Very weak compressions
- Mixed propagating and standing waves

Case II. $\Delta T_0 = 0.16$ Alfvén Period (medium ramp)

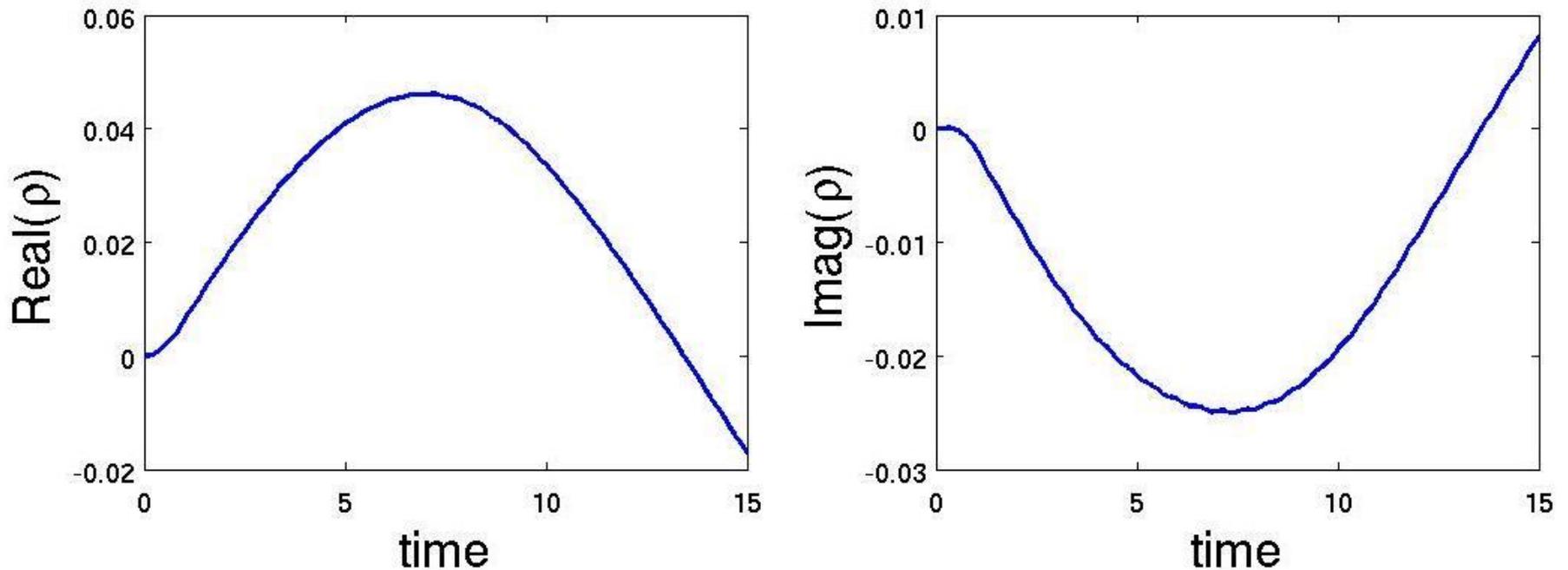


FIGURE: Real and imaginary parts of the normalized density fluctuations.

- Possibly detectable compressions
- Mixed propagating and standing waves

Case III. $\Delta T_0 \approx 0.0002$ Alfvén Period (fast time ramp)

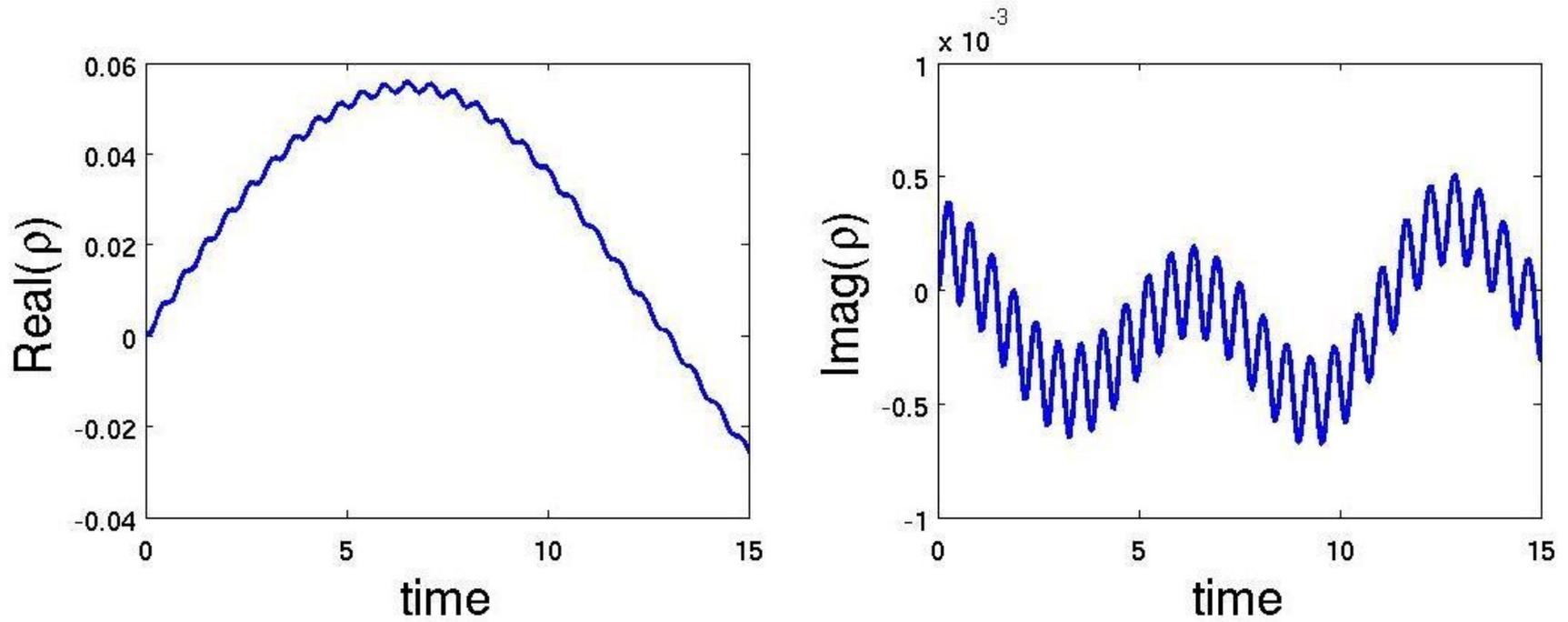


FIGURE: Real and imaginary parts of the normalized density fluctuations.

- Possibly Observable compressions
- Mainly standing waves

Flow-shear Driven Waves

$$\frac{\rho(t)}{\rho_0} = \sum \exp(\pm i \omega_a t) + \exp(\pm i \omega_s t) + \exp(\pm i \omega_f t)$$

Reference: Kaghshvili, 2007; Kaghshvili et al. 2009; Hollweg and Kaghshvili, 2012; kaghshvili, 2012

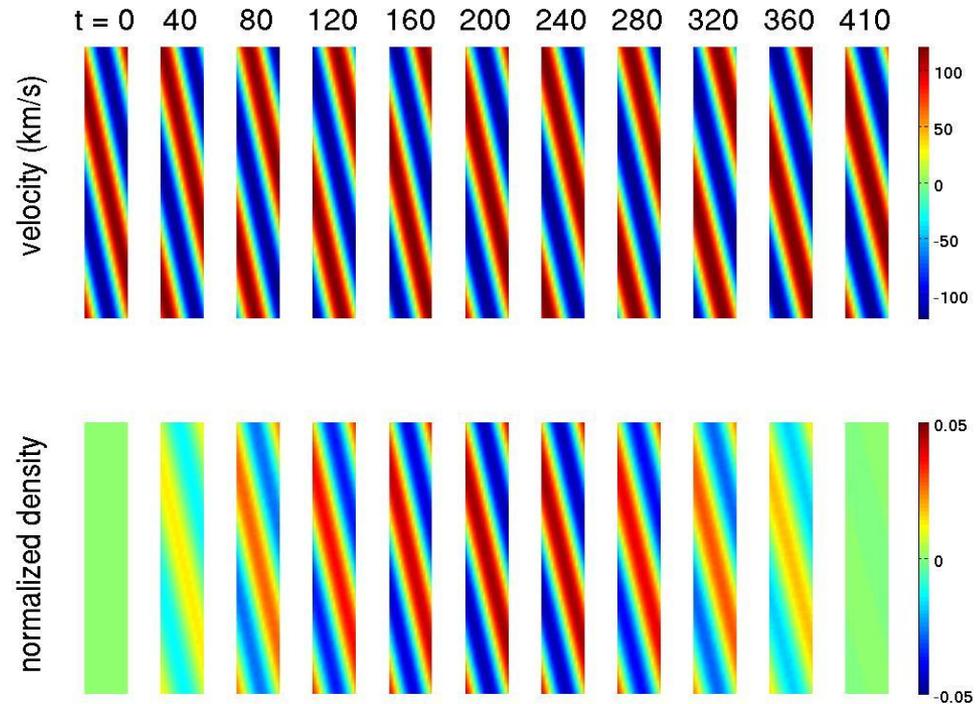


FIGURE 2. Evolution of the driver- and flow-shear driven-waveforms in time, The upper panel shows the time evolution of the spatial dependence of the intensity of one of the transverse Alfvén wave component, $v_y(t)$ (Units are in $km\ s^{-1}$. Time is in seconds.) The lower panel shows the evolution of the density fluctuations. The quantity plotted in each snapshot is the normalized density ($\equiv \rho(t)/\rho_0$). As expected for fast time ramp case, driven density fluctuations are mainly standing slow magnetosonic waves.

Why flow inhomogeneity can be more important than other inhomogeneities in the solar corona? especially in the polar coronal holes?

There are a few basic arguments why the velocity inhomogeneity might play more crucial role in the interplay of different modes in the coronal holes than say inhomogeneities in the magnetic field or density:

- I. in the low-beta, magnetically dominated corona no strong gradients in $|\mathbf{B}|$ are expected, and
- II. if there are strong local gradients in the background density, coronagraph observations should have been able to detect them.

Summary

Alfvén wave based mechanism of Polar Coronal Jets can explain:

- Appearance of the intensity enhancements in the corona
- explain the observed helical structure of the jets,
- explain $v_{\text{Observed}} \ll v_a$ velocity of the jets
- Produced intensity enhancement is subject to strong cooling,
(i.e. it can produce the downward motion in the intensity images as plasma material cools.)

Note that the mechanism that launches the Alfvén wave from below is not specified. Of course, it can be the reconnection (in this case, $v_{\text{Observed}} \ll v_a$ problem still needs to be explained) or it can be just a simple process of the Alfvén wave propagating along the open field line.