Statistical Study of Chromospheric Anemone Jets Observed with Hinode/SOT and Chromospheric Reconnection

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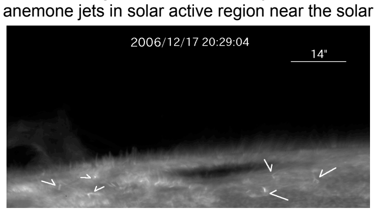
Ca II H broad band filter images taken with Hinode/SOT

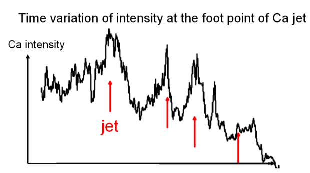
ABSTARCT: Solar Optical Telescope (SOT) aboard **Hinode discovered numerous tiny jets in the chromosphere outside sunspots** with Ca II H broad band filter. Typical chromospheric jets have cusp structure at their footpints, similar to the shape of X-ray anemone jets observed with Yohkoh soft X-ray telescope in the 1990s, although the size of chromospheric jet is about 1/100 that of X-ray jet. We think that **chromospheric jets are small scale version of solar X-ray anemone jets**, and may be called chromospheric anemone jets or simply Ca jets. We examined chromospheric jets in solar active region near the solar limb. We studied chromospheric jets statistically and found following characteristics. Typical **length of chromospheric jets is 1000-3000 km, width is 100-300 km, cusp size is 1000 km, lifetime is 100-300 s** and **velocity is 10-20 km/s**. The velocity of the jets is comparable to the local Alfven speed in the low chromosphere and their structures are similar to those of X-ray anemone jets, so it is suggested that **chromospheric jets are produced by magnetic reconnection** between small bipole (tiny emerging flux ?) and pre-existing (locally uniform) magnetic field in the low chromosphere. Furthermore, we examined the relation between the velocity and length of jets, which shows that chromospheric jets do not show balistic motion but are **accelerated by slow shock**. as shown by numerical simulations of spicules.

1. Introduction

The solar chromosphere is known to be very dynamic (e.g., Bray and Loughhead 1974; Zirin 1988). However, recent Hinode observations revealed that it is even more dynamic than previously thought. Ubiquitous jets and ubiquitous reconnection were discovered in the solar atmosphere as conjectured by Parker (1988): for example, many polar jets (Cirtain et al. 2007), chromospheric anemone jets (Shibata et al. 2007; Nishizuka et al. 2008), penumbral micro-jets (Katsukawa et al. 2007) and maybe spicules (De Pontieu et al. 2007). We determined jets with footpoint brightening as chromospheric anemone jets in this poster. To reveal the origin of chromospheric jets, we performed statistical study of chromospheric anemone jets in solar active region near the solar limb.



Chromospheric Jets (Shibata et al. 2007, Science)

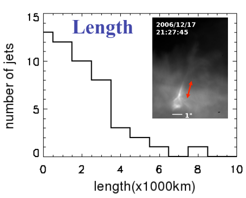


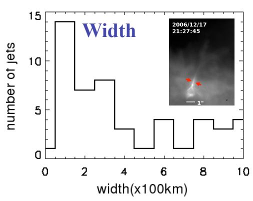
Time (total 5hours)

2. Observation & Statistical Analysis

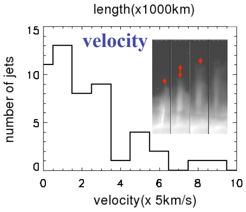
We analyzed a Ca II H broadband filter image of chromospheric jets taken with Solar Optical Telescope (SOT) on board Hinode from 20:00:00 UT to 21:00:00 UT on 2006 Dec 17. We detected 150 jet-like events and selected ~100 events for chromospheric anemone jets.

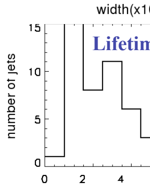
Statistical Study of Chromospheric Jet (Length, Width, Velocity and Duration)





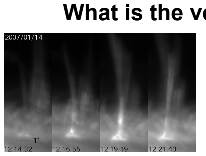
•**Length**: from top of the cusp structure to that of jet
•**Width**: at middle of jet



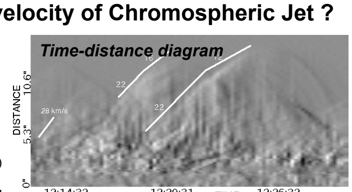


- Typical size of ubiquitous jets (anemone jets) in the solar chromosphere : width ~ 100 - 300 km, length ~ 500 - 2000 km, velocity ~ 5 – 20 km/s, lifetime ~ 100 – 200 sec

What is the velocity of Chromospheric Jet ?



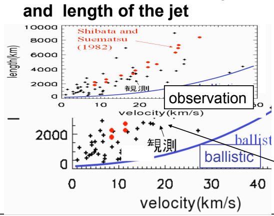
2007 Jan 14 jet (Shibata et al. 2007)

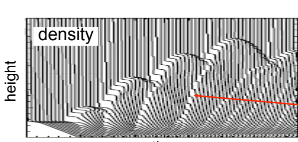


Jet Velocity
= 10~20 km/s
~ **Alfvén velocity** in the low chromosphere or photosphere

⇒consistent with reconnection model

Relation between velocity and length of the jet



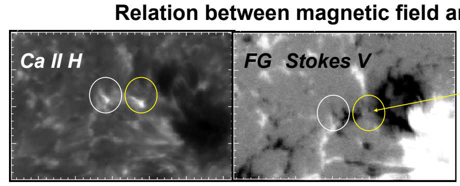


1D MHD simulation Saitoh, Kudoh, Shibata (2001) ApJ

cf) rebound shock Model (Sterling)

L∝V² /g ∝ V (g ∝ V)
Hansteen et al. 2006

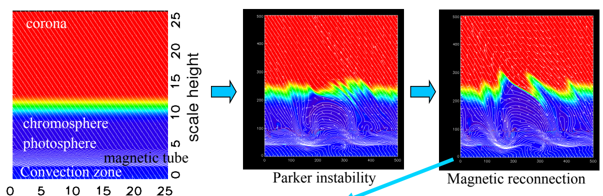
Relation between magnetic field and jets

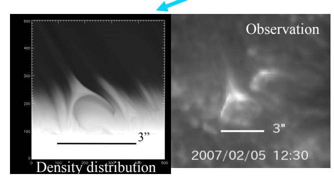


Bipole or mixed polarity region (taken with Hinode/SOT)

Magnetic reconnection seems to occur between **small bipole (tiny emerging flux ?)** and **pre-existing** (locally uniform) **magnetic field** in the low chromosphere.

2-dim Magnetohydrodynamic Simulation of jets





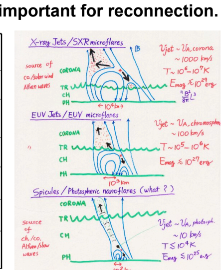
Resistive MHD simulation
HLLD (Miyoshi and Kusano 2005)

β~3 (horizontal flux sheet),
β~0.01 (inner corona)

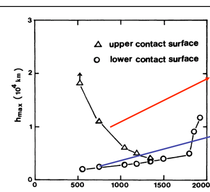
3.Summary

Statistical study shows that Typical **length of chromospheric jets is 1000-3000 km, width is 100-300 km, cusp size is 1000 km, lifetime is 100-300 s** and **velocity is 10-20 km/s**. This results suggest that the jet may be accelerated by slow mode shock (or Alfven wave) generated by reconnection. Furthermore, **reconnection rate in the chromosphere can be estimated 0.02-0.1 (see Table below).** This means that fast reconnection occurs in the chromosphere. In fact, our MHD simulation assuming anomalous resistivity can also reproduce chromospheric jet well. These results may indicate **evidence of fast reconnection in the chromosphere**, **suggesting that not only microscopic but also macroscopic physics are important for reconnection.**

"flares"	Size (L)	Lifetime (t)	Alfven time (t_A)	t/t_A	Mass ejection
?	< 200 km	< 300 sec	< 20 sec	~ 10~20?	Spicules ?
nanoflares	~200 km	200-1000sec	20 sec	~10~50	Chromospheric jets (anemone, penumbral)
Microflares	10^3 -10^4 km	100-1000sec	1-10 sec	~100	jet/surge
Impulsive flares	(1-3) x 10^4 km	10 min – 1 hr	10-30 sec	~60-100	X-ray plasmoid/ Spray
Long duration (LDE) flares	(3-10)x 10^4 km	1-10 hr	30-100 sec	~100-300	X-ray plasmoid/ prom. eruption
Giant arcades	10^5 -10^6 km	10 hr – 2 days	100-1000 sec	~100-300	CME/prom. eruption



Summary of "Reconnection" observation with Hinode



Shibata, Suematsu, Nishikawa, Kitai (1982)

If the jet is ejected at 10 km/s withballisticmotion, maximum height of the jet would be

$$h_{jet} \approx v^2/(2g) \approx 2\times10^7 \left(\frac{v}{10km/s}\right)^2 cm$$

$$\approx 200km \approx 0.3"$$

So the jet cannot reach height greater than 200km !

This suggests that the jet may be accelerated by slow mode shock (or Alfven wave) generated by reconnection

Chromospheric jets are **not** a **ballistic** motion, but **accelerated by slow shocks which propagated through chromosphere**