Kink instability of jets in the solar atmosphere

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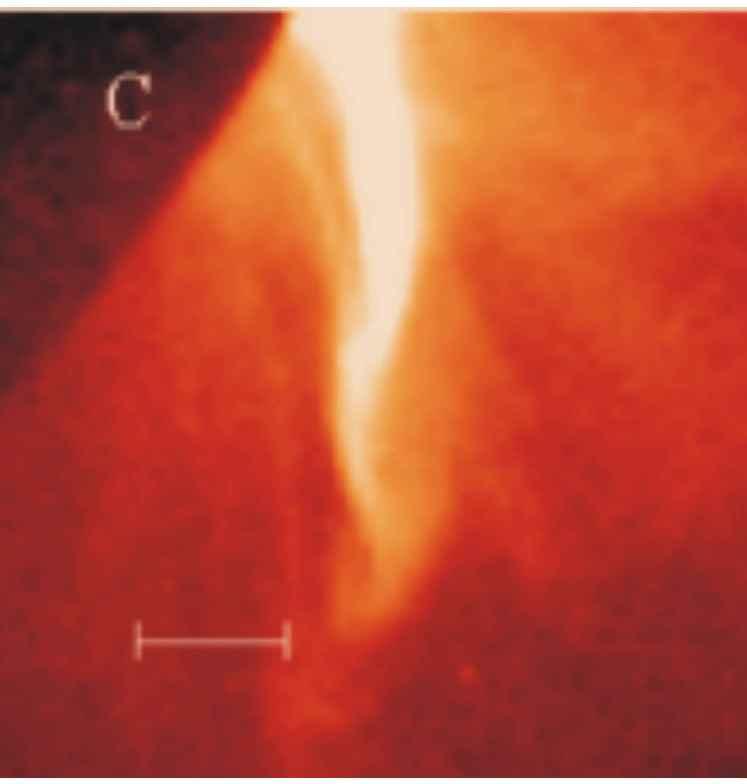
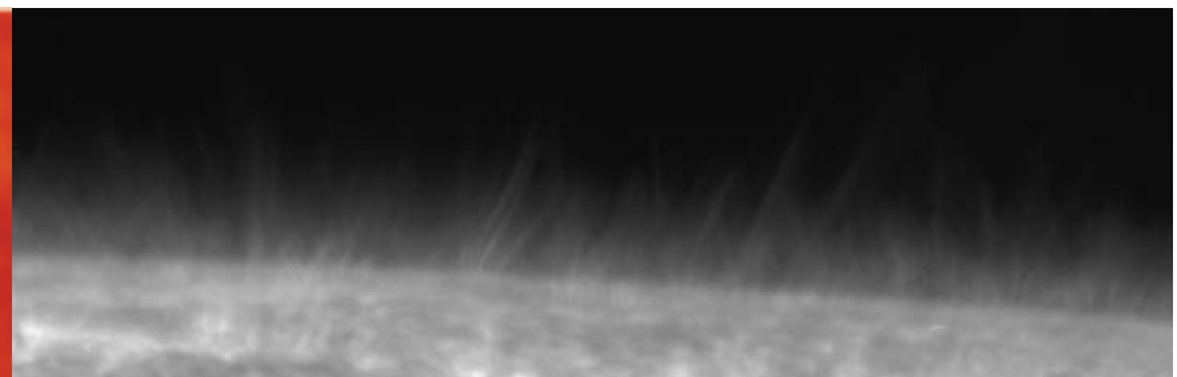
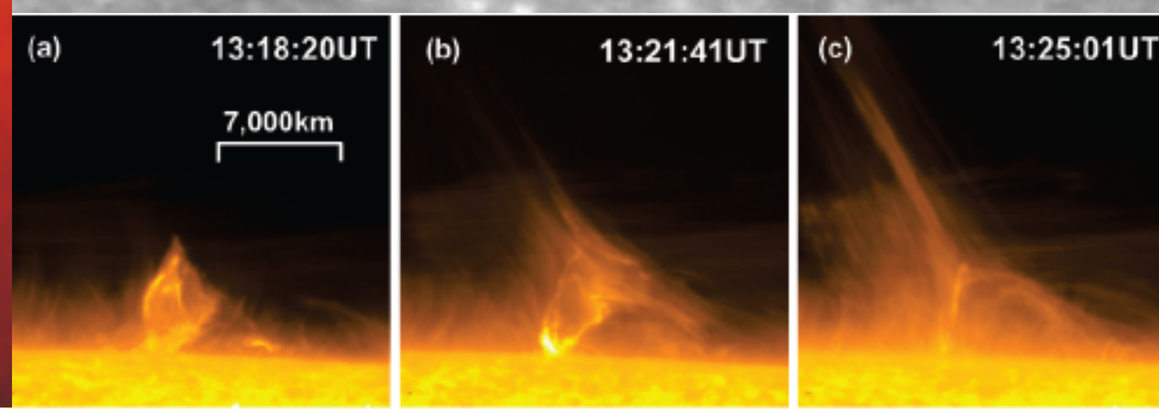
Observations show various kinds of jets in the solar atmosphere:

- spicules (type I) - 20-25 km/s (Beckers 1968)
- macro spicules - 100-150 km/s (Pike and Mason 1998)
- type II spicules/RBEs/RREs - 50-100 km/s (De Pontieu et al. 2007, Rouppe van der Voort et al. 2009)
- Hα surges - 50-200 km/s (Canfield et al. 1996)
- X-ray jets - 200-600 km/s (Shibata et al. 1992, Moore et al. 2013)
- chromospheric anemone jets - 10-20 km/s (Shibata et al. 2007)

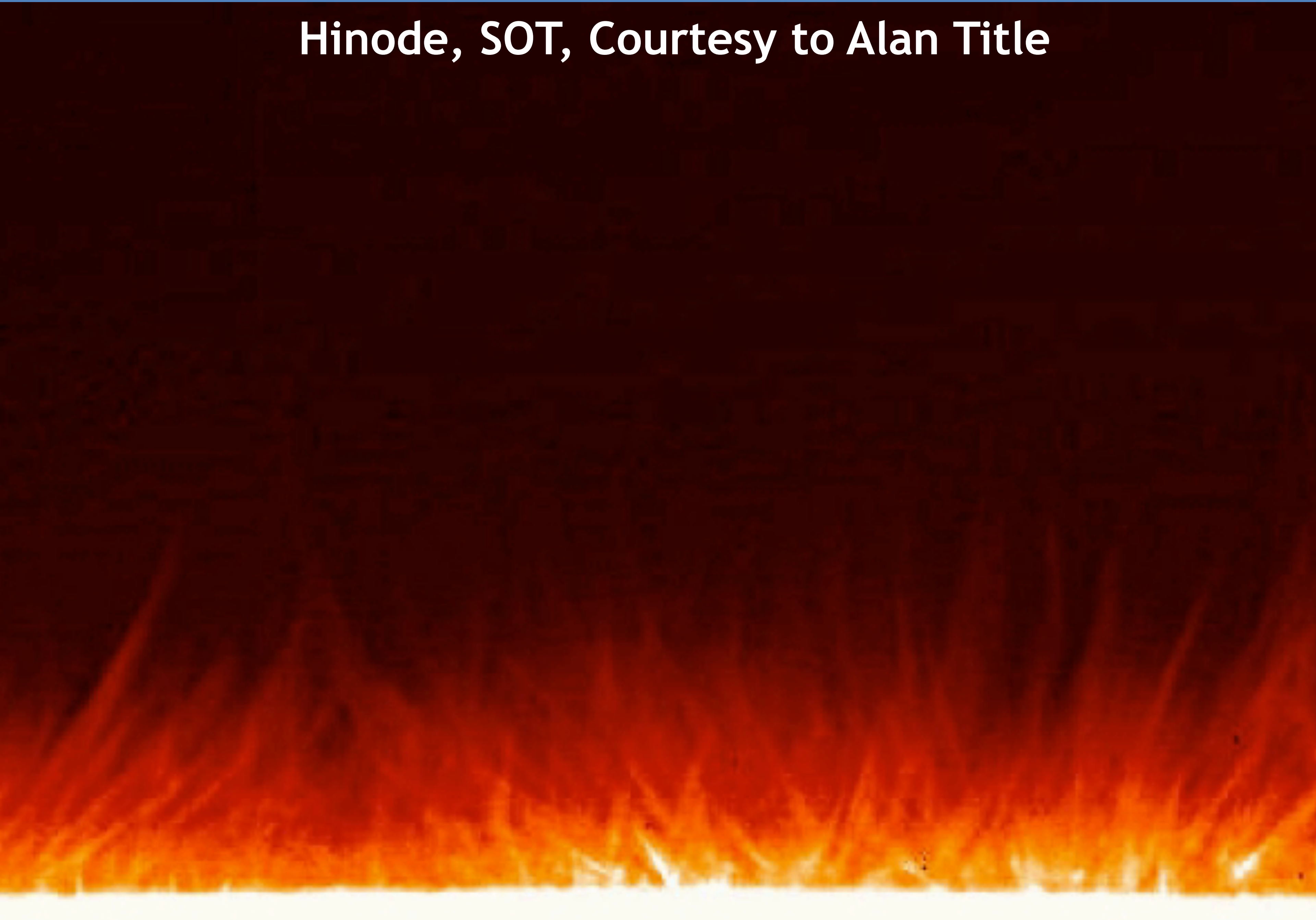






Transverse motion of spicules

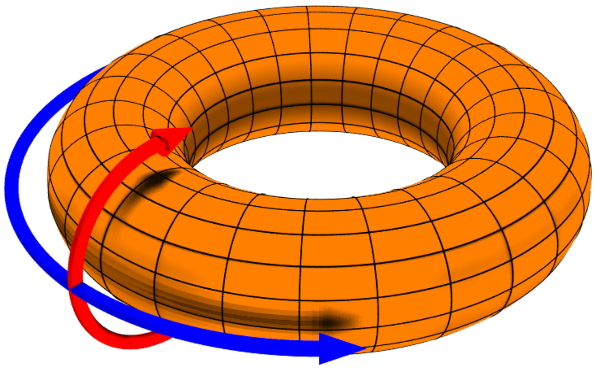
Hinode, SOT, Courtesy to Alan Title



Twisted magnetic flux tubes: magnetic kink instability

Tokamaks: Kruskal-Shafranov criterion

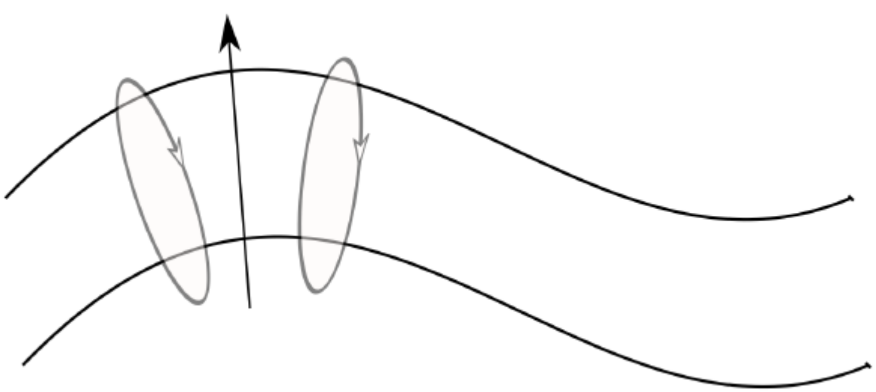
$$\frac{LB_\phi}{aB_z} > 2\pi$$



Coronal loops: Hood and Priest 1979

$$\frac{LB_\phi}{aB_z} > 2.5\pi$$

Straight twisted tubes:

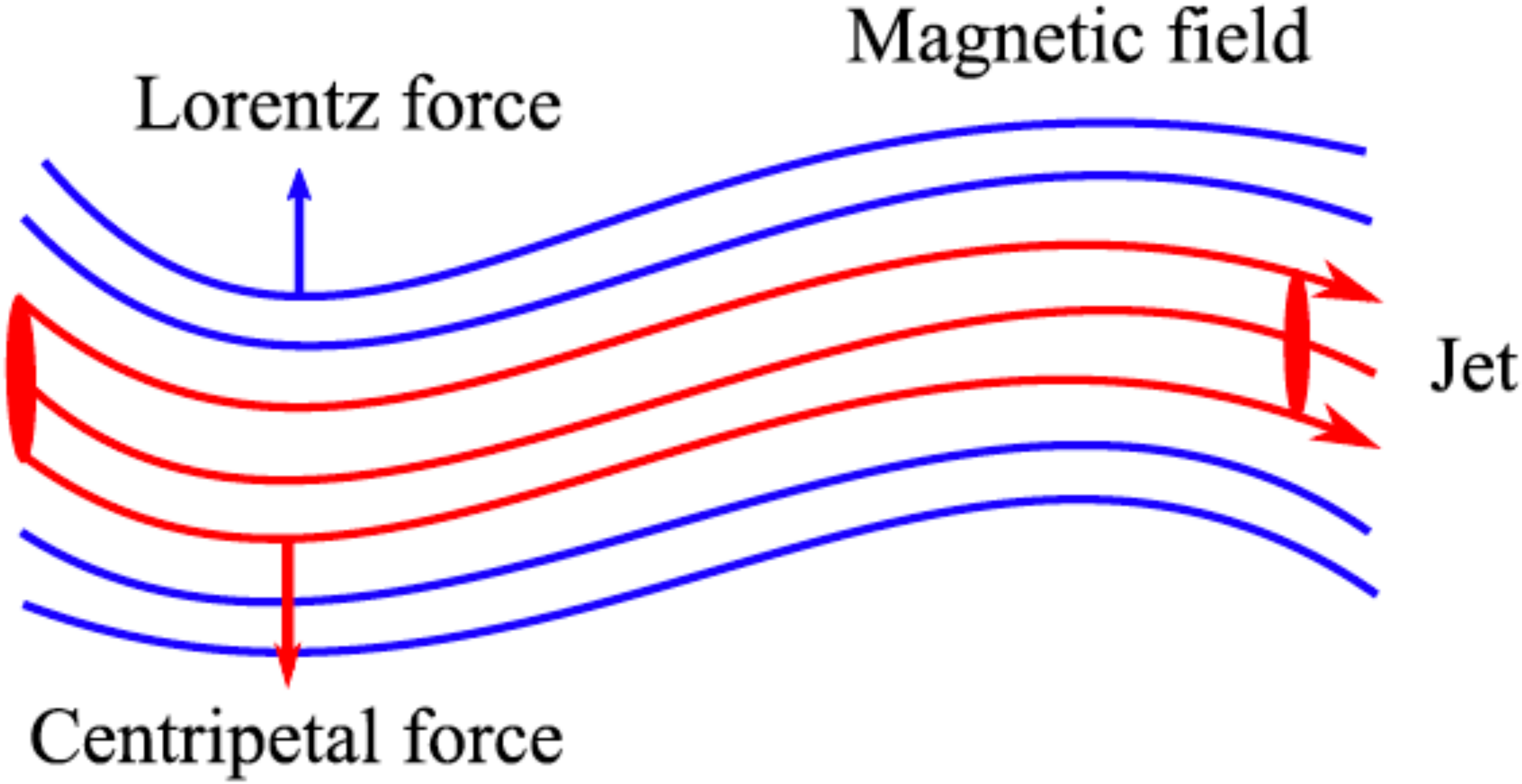


$$B_\phi > 2B_z$$

Dungey and Loughhead, 1954

Jets: dynamic kink instability

Hydrodynamic homogeneous jets are always unstable to the kink instability due to the centripetal force.



The instability is stabilised by the magnetic field if $V_A > 0.5\,U$

Zaqarashvili, 2020

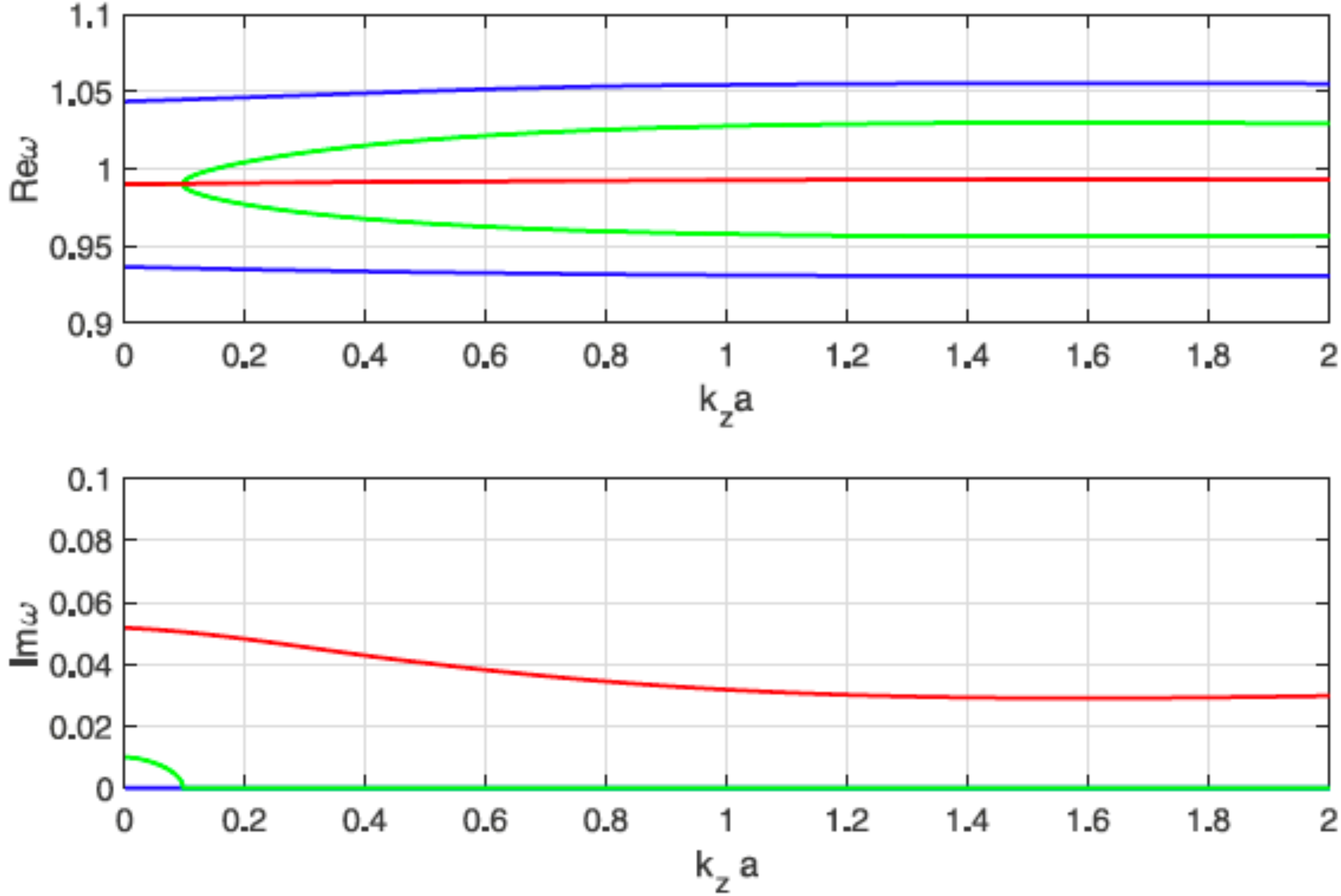
Dense homogeneous jets

Blue: $V_A = 0.8\,U$

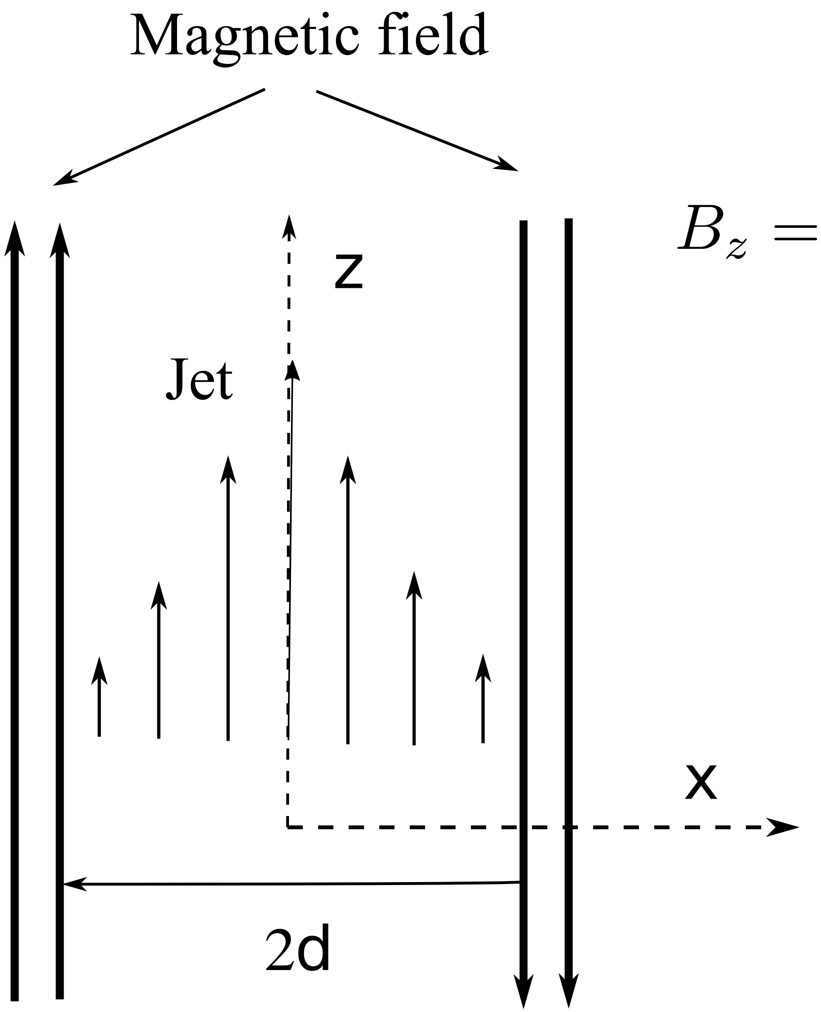
Green: $V_A = 0.7\,U$

Red: $V_A = 0.6\,U$

$\rho_0/\rho_e = 100$



Zaqarashvili 2020



$$| B_z | = const, \; V = 0 \text{ for } | x | > d$$

$$B_z = 0, \; V = V_0 \left(1 - \alpha \frac{| x |}{d}\right) \text{ for } | x | < d$$

$$\alpha = 1$$

inhomogeneous jet

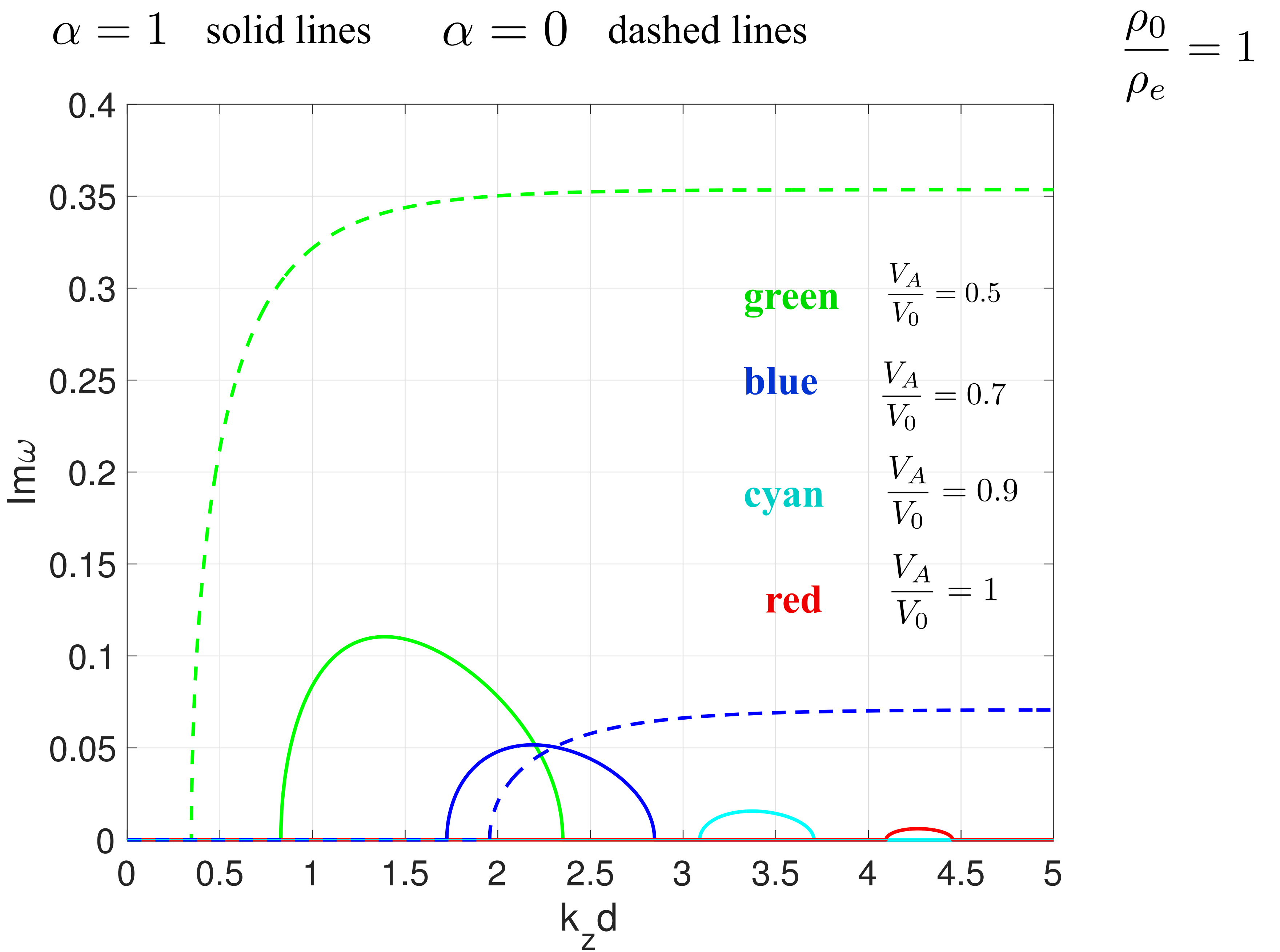
$$\alpha = 0$$

homogeneous jet

solutions inside the jets in terms of hyperbolic functions:

$\cosh$

$\sinh$

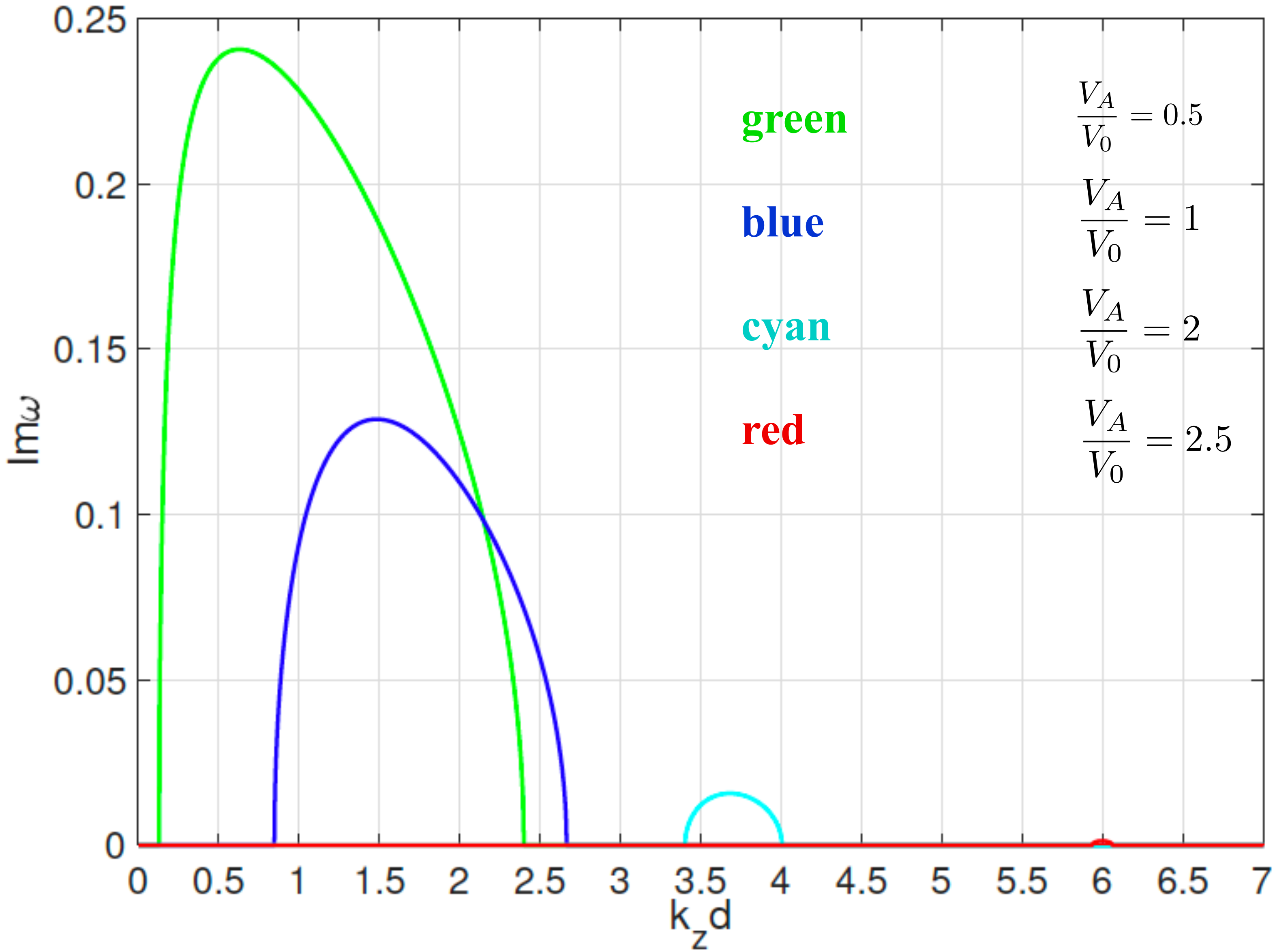


$\alpha = 1$ solid lines
$\alpha = 0$ dashed lines
$\frac{\rho_0}{\rho_e} = 1$
green $\frac{V_A}{V_0} = 0.5$
blue $\frac{V_A}{V_0} = 0.7$
cyan $\frac{V_A}{V_0} = 0.9$
red $\frac{V_A}{V_0} = 1$
Imω
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
$k_z d$

Dense jets

$\alpha = 1$

$\frac{\rho_0}{\rho_e} = 10$



Type I and II spicules

Beckers (1972)
temperature: 10-20 MK
electron density: 10^{10}-10^{11} cm^{-3}

Type I spicules
length: 5-9 Mm, diameter: 400-1500 km,
speed: 20-30 km/s
life time: 5-15 min

Type II spicules (De Pontieu et al. 2007)
length: 3-5 Mm, diameter: < 200 km,
speed: 50-150 km/s
life time: 10-150 s

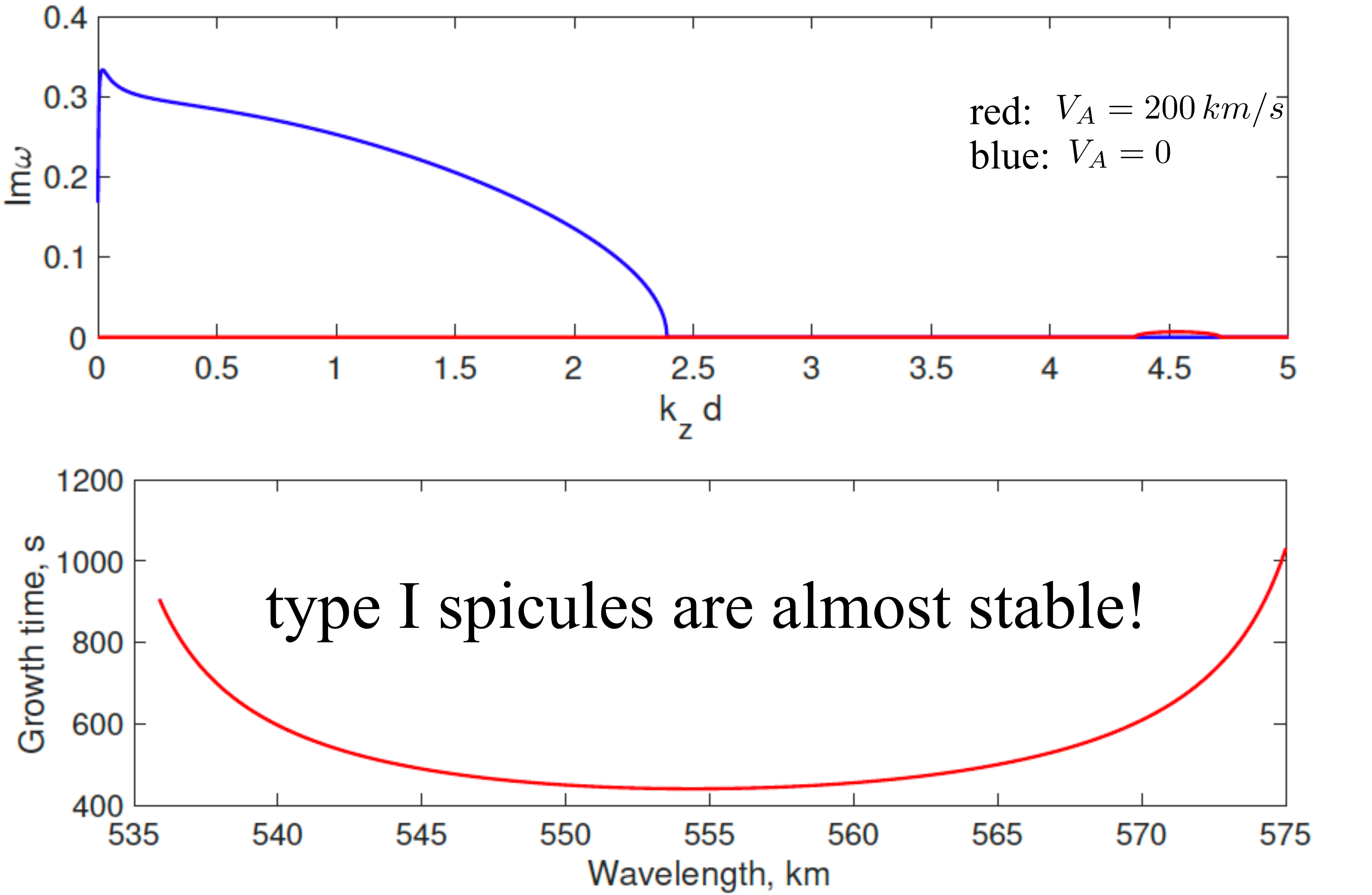
What causes the short life time of type II spicules?

Rapid heating to transition region temperatures (Pereira et al. 2014)?

KHI related heating in PIP (Kuridze et al. 2016)?

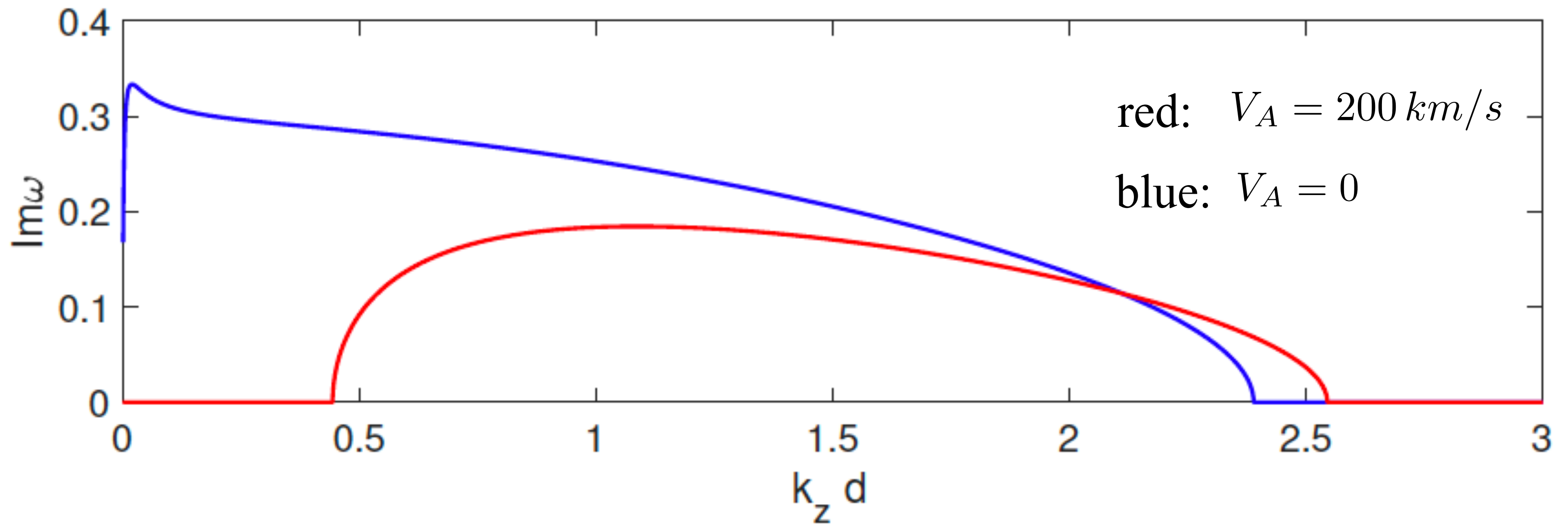
Solutions for type I spicules

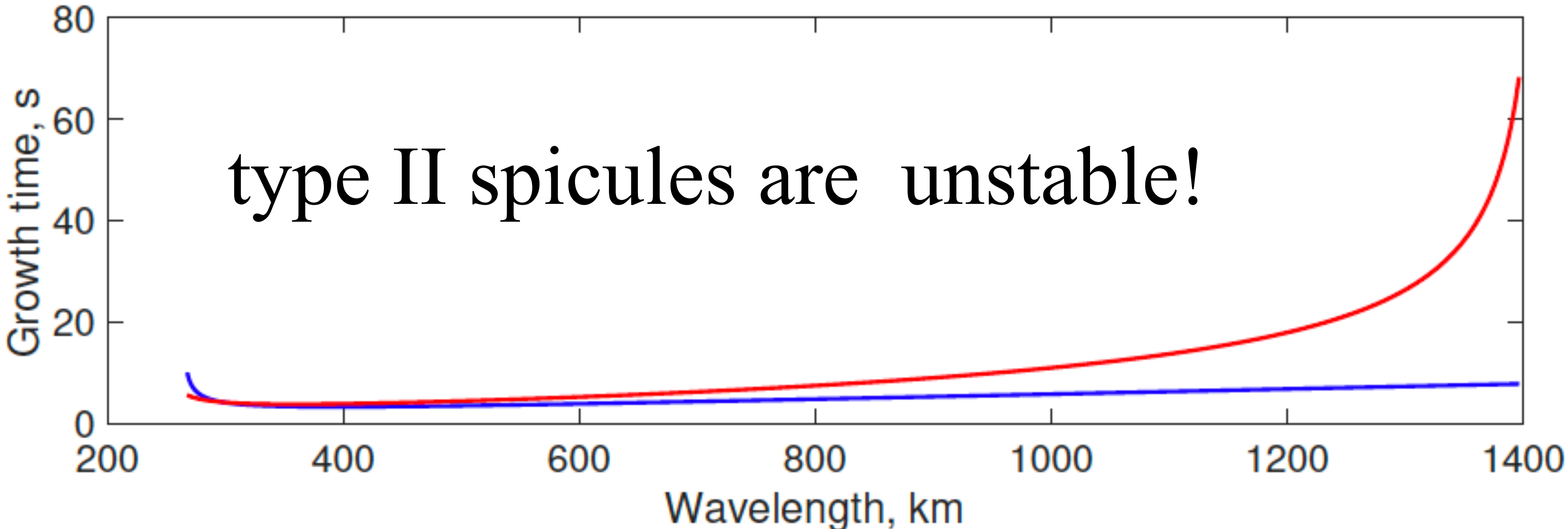
$\rho_0/\rho_e = 100 \qquad \alpha = 1 \qquad V_0 = 30\,km/s \qquad d = 400\,km$



Solutions for type II spicules

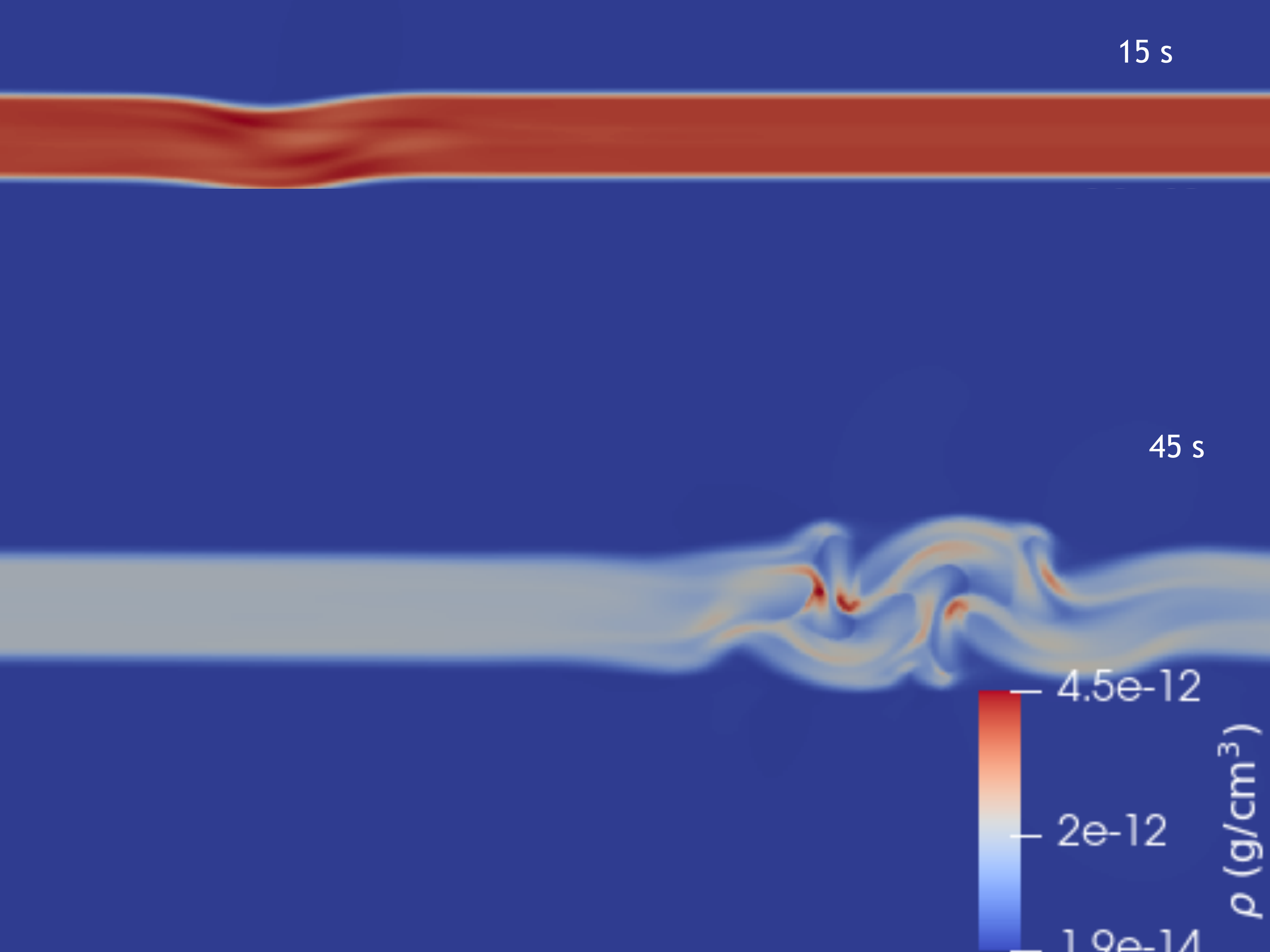
$\rho_0/\rho_e = 100 \quad \alpha = 1 \quad V_0 = 100\,km/s \quad d = 100\,km$





Numerical simulation for type II spicules

Width: 200 km
Velocity at the jet centre: 100 km/s
Magnetic field: 10 G
Density ratio: 40


15 s
45 s
4.5e-12
2e-12
1.9e-14
ρ (g/cm³)

Conclusions

Triangular jets are unstable to antisymmetric kink instability depending on Alfven Mach number and the density ratio.

Jets with $\rho_0/\rho_e = 1$ are unstable in super Alfvenic regime.

Denser jets are unstable also in sub Alfvenic regime.

The dynamic kink instability may destroy jets in short time in super Alfvenic flows.

The growth time of kink instability in type I spicule conditions is 6-15 min, while in type II spicule conditions is 5-60 s.

The kink instability may lead to the observed short life time of type II spicules.