Generation of upward Alfvénic waves by the chromospheric shock waves

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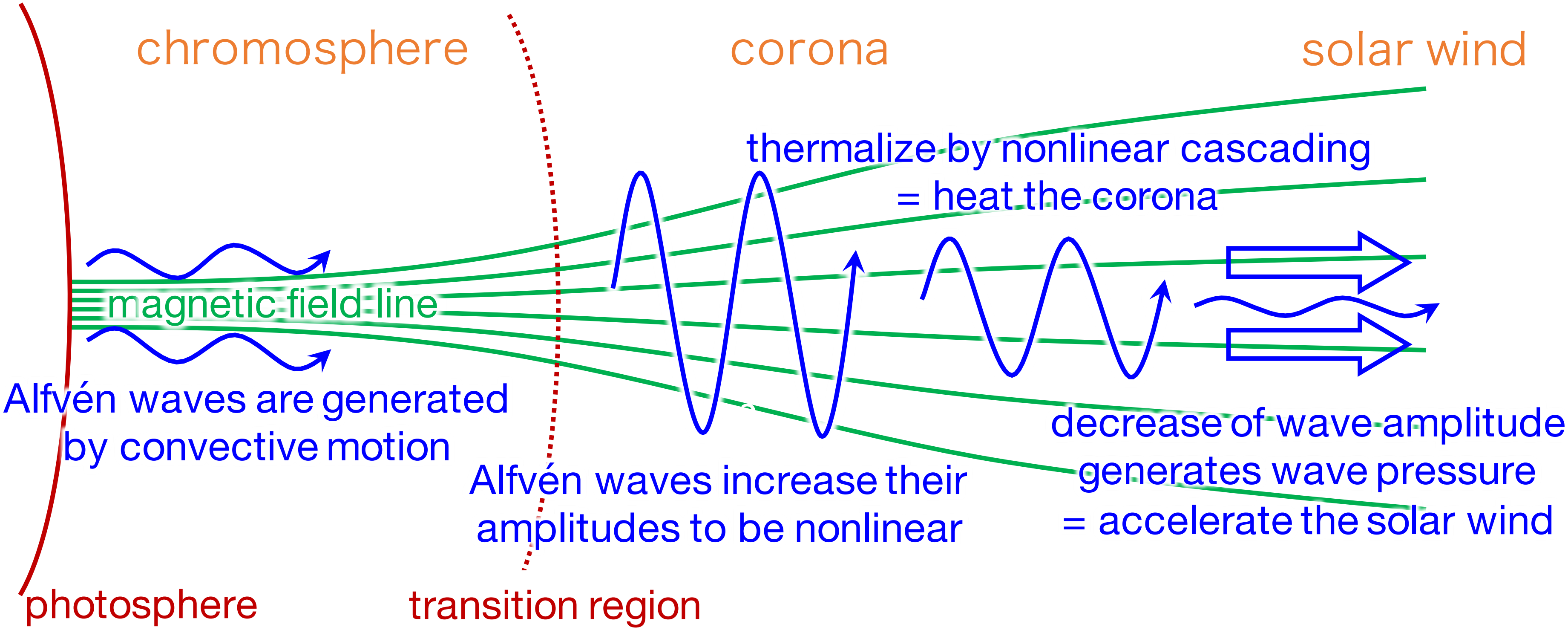
Introduction

standard Alfvén-wave modeling of the corona & wind



chromosphere

corona

solar wind

thermalize by nonlinear cascading
= heat the corona

magnetic field line

Alfvén waves are generated
by convective motion

Alfvén waves increase their
amplitudes to be nonlinear

decrease of wave amplitude
generates wave pressure
= accelerate the solar wind

photosphere

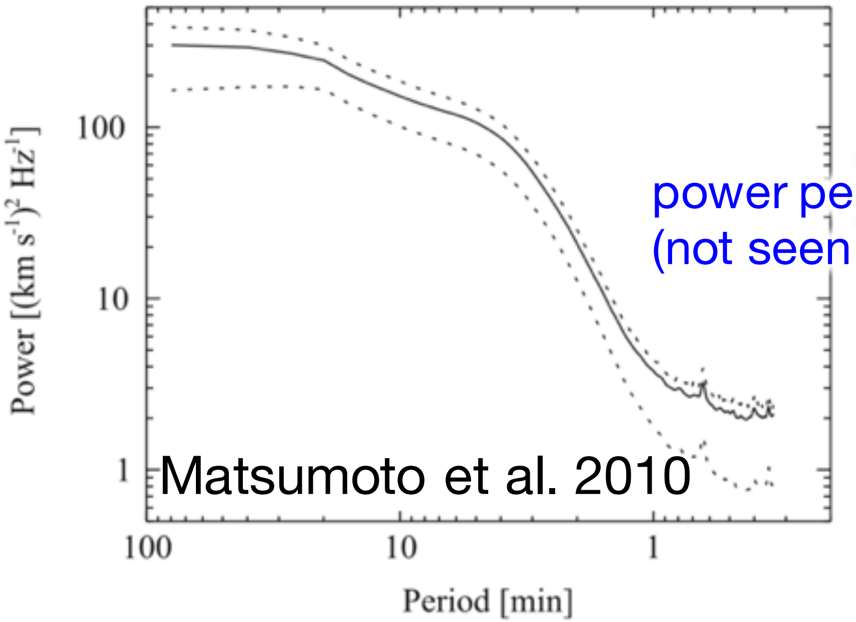
transition region

Introduction

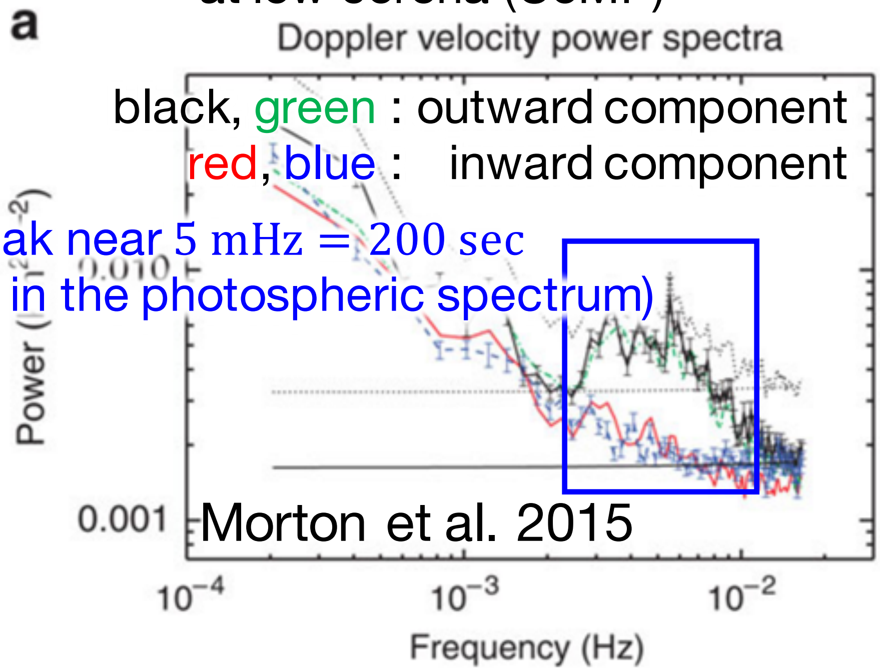
Is the standard understanding correct ?

power spectrum of transverse motion at the photosphere (*Hinode*/SOT)

power spectra of Alfvén waves at low corona (CoMP)



Matsumoto et al. 2010



black, green : outward component
red, blue : inward component

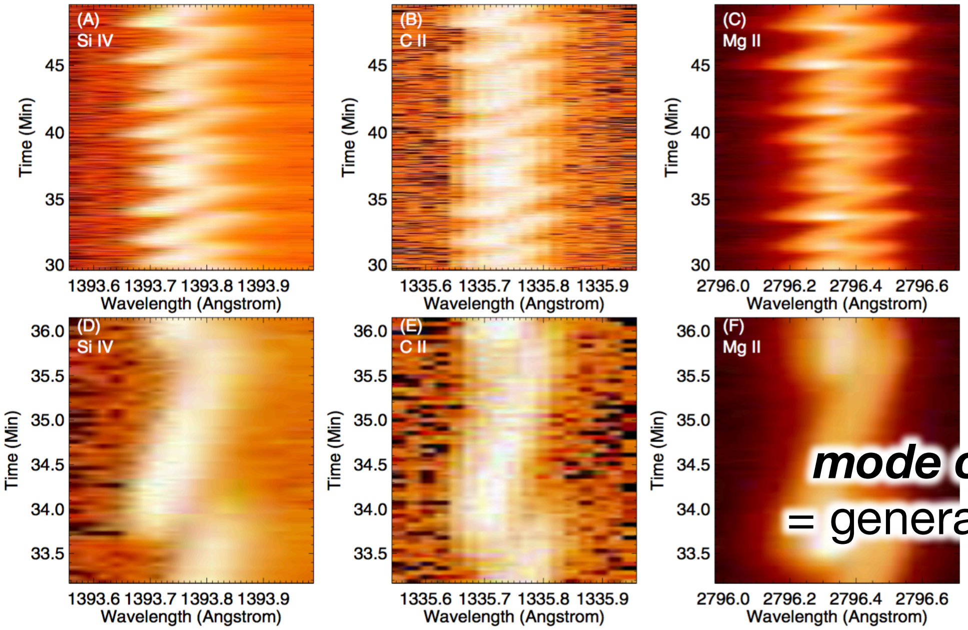
power peak near $5\ \mathrm{mHz} = 200\ \mathrm{sec}$
(not seen in the photospheric spectrum)

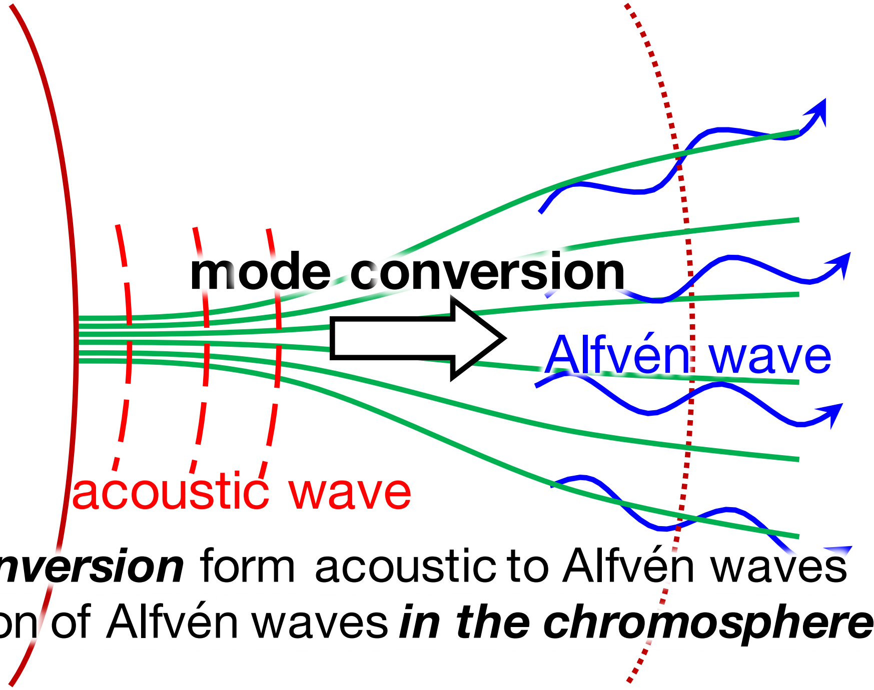
Morton et al. 2015

Introduction

mode-conversion in the chromosphere

shock waves (N-waves) observed
in the chromosphere (Tian et al. 2014)





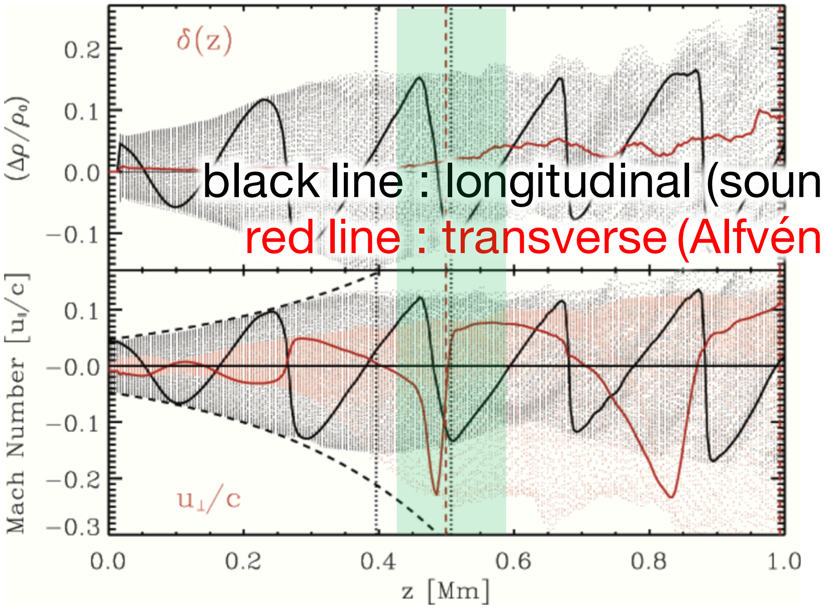
mode conversion form acoustic to Alfvén waves
= generation of Alfvén waves ***in the chromosphere***

Introduction

mode-conversion in the chromosphere

Many previous researches on mode conversion
(Bogdan+03, Cally+06, Khomenko+12, Shelyag+16 etc.)

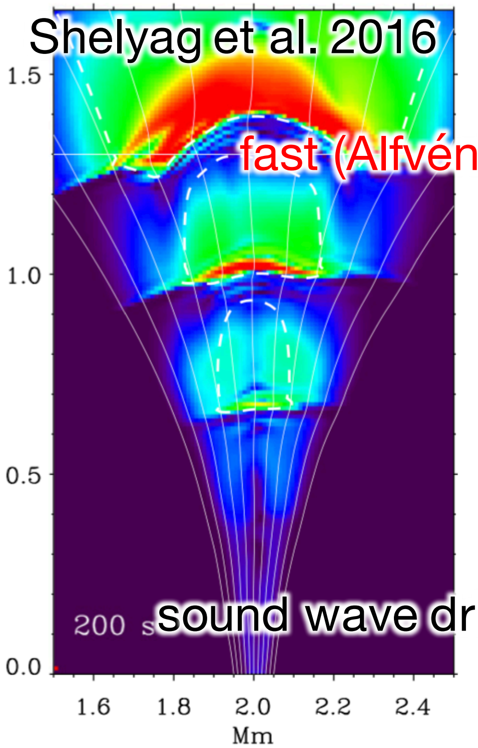
Bogdan et al. 2003 $\beta \sim 1$



black line : longitudinal (sound) wave

red line : transverse (Alfvénic) wave

Shelyag et al. 2016



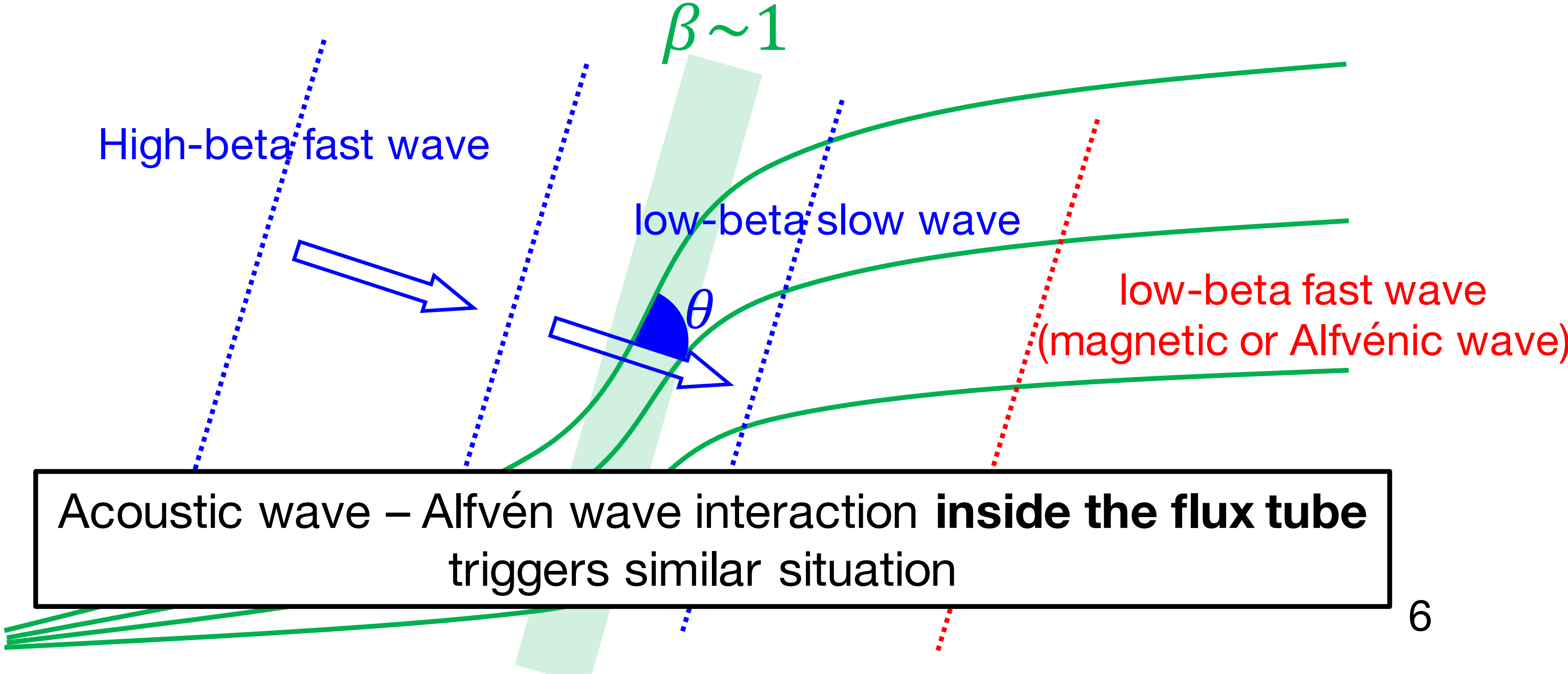
fast (Alfvénic) wave

sound wave driving

Introduction

mode-conversion: elemental process

Critical parameter for mode conversion is the *attacking angle* θ, the angle between the propagation direction & magnetic field



Acoustic wave – Alfvén wave interaction **inside the flux tube** triggers similar situation

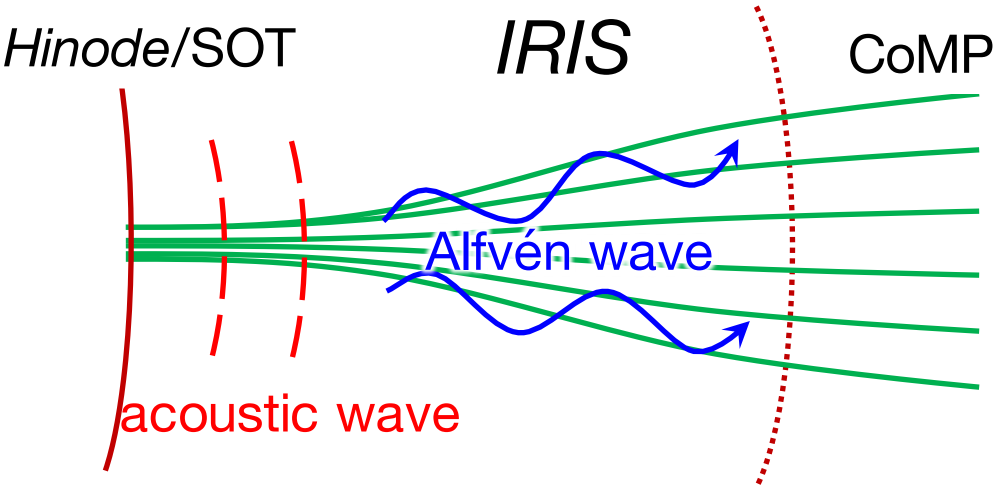
Introduction

motivation of this study

We study the mode conversion process ***inside the flux tube***

all waves propagate along the background flux tube (1D system)

impose both longitudinal & transverse waves at the photosphere



Try to find an evidence of mode conversion ***using IRIS***

Simulation method

Basic equations to be solved

1D *isothermal* MHD equations including gravity & flux tube expansion

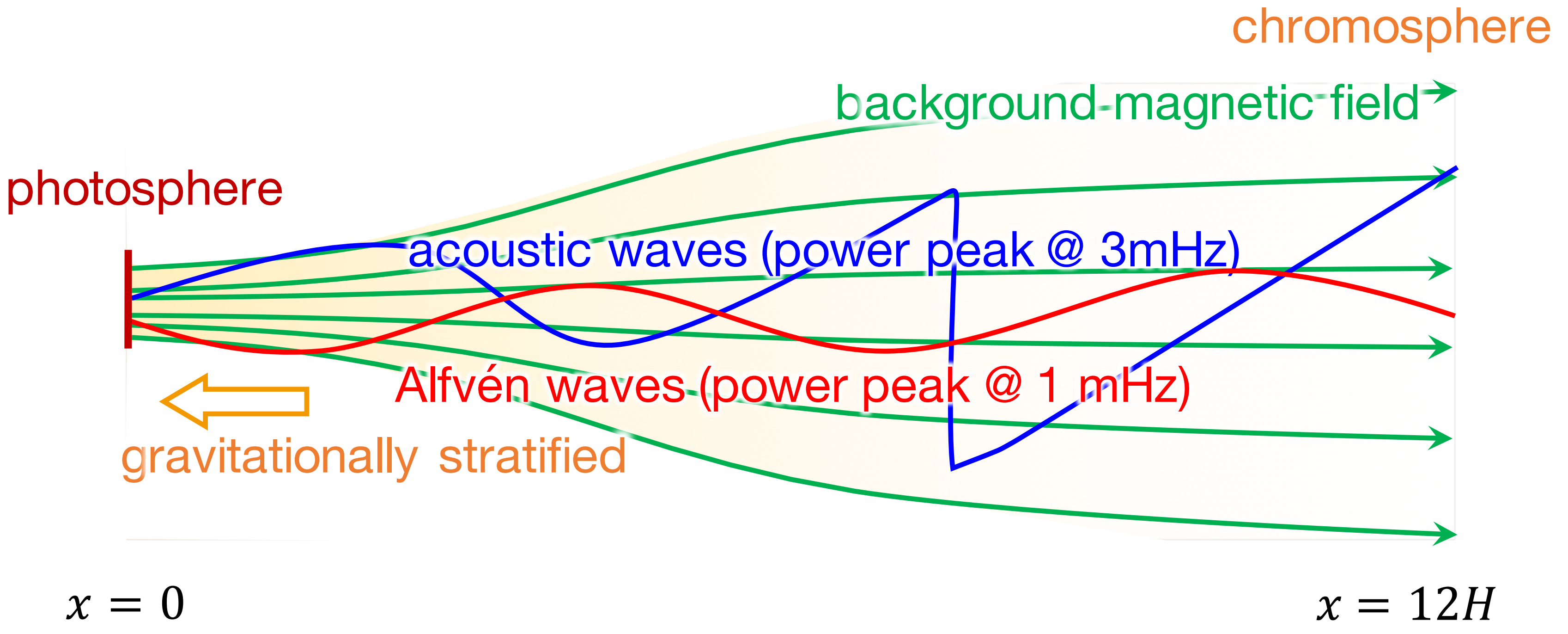
$$\frac{\partial}{\partial t}(\rho A) + \frac{\partial}{\partial x}(\rho v_x A) = 0,$$

We do NOT solve energy equations / radiative transfer to make the physics simple.

$$\frac{\partial}{\partial t}\left(\boldsymbol{B}_\perp \sqrt{A}\right) + \frac{\partial}{\partial x}\left[\left(\boldsymbol{B}_\perp v_x - B_x \boldsymbol{v}_\perp\right)\sqrt{A}\right] = 0,$$

Simulation method

Numerical Setup : overview of simulation



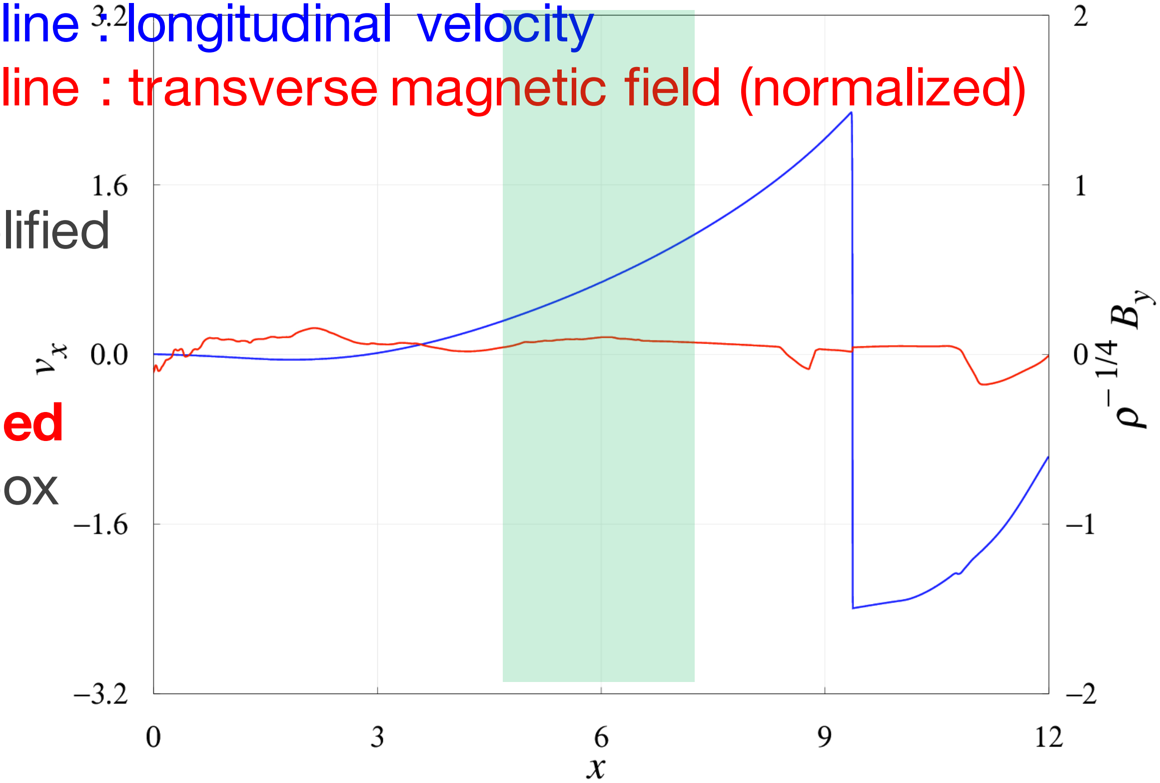
H : density scale height

Simulation result

Numerical Result 1 : case I (uniform flux tube)

Acoustic waves are amplified due to the stratification.

Alfvén waves are **amplified near the center** of the box (~magnetic canopy).



$\beta \approx 1$

blue line : longitudinal velocity

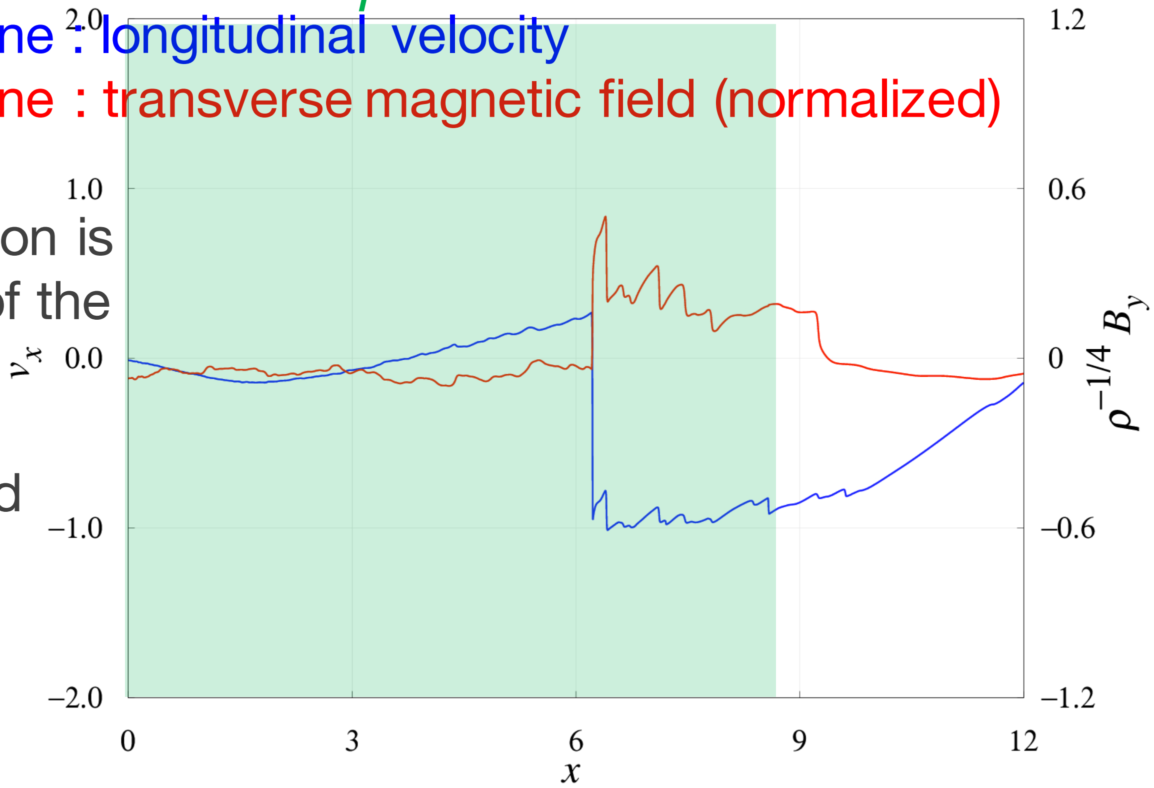
red line : transverse magnetic field (normalized)

Simulation result

Numerical Result 2 : case II (expanding tube)

Acoustic-wave amplification is less significant because of the tube expansion.

Alfvén waves are amplified also in this case.



$\beta \approx 1$

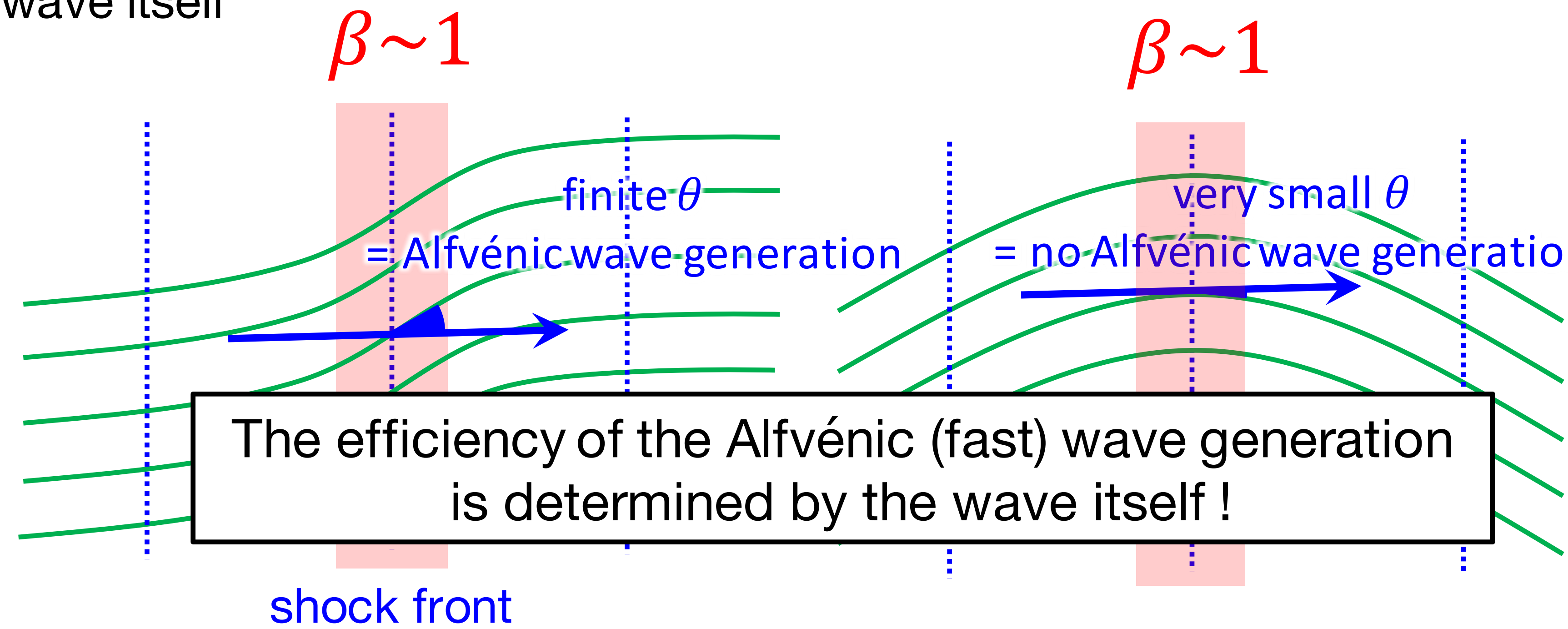
blue line : longitudinal velocity

red line : transverse magnetic field (normalized)

Simulation result

Role of Alfvén wave input

Attacking angle, the critical parameter is determined by Alfvénic (transverse) wave itself



The efficiency of the Alfvénic (fast) wave generation is determined by the wave itself !

Simulation result

amplification of Alfvénic flux (uniform-tube case)

red : without acoustic waves

weak acoustic wave

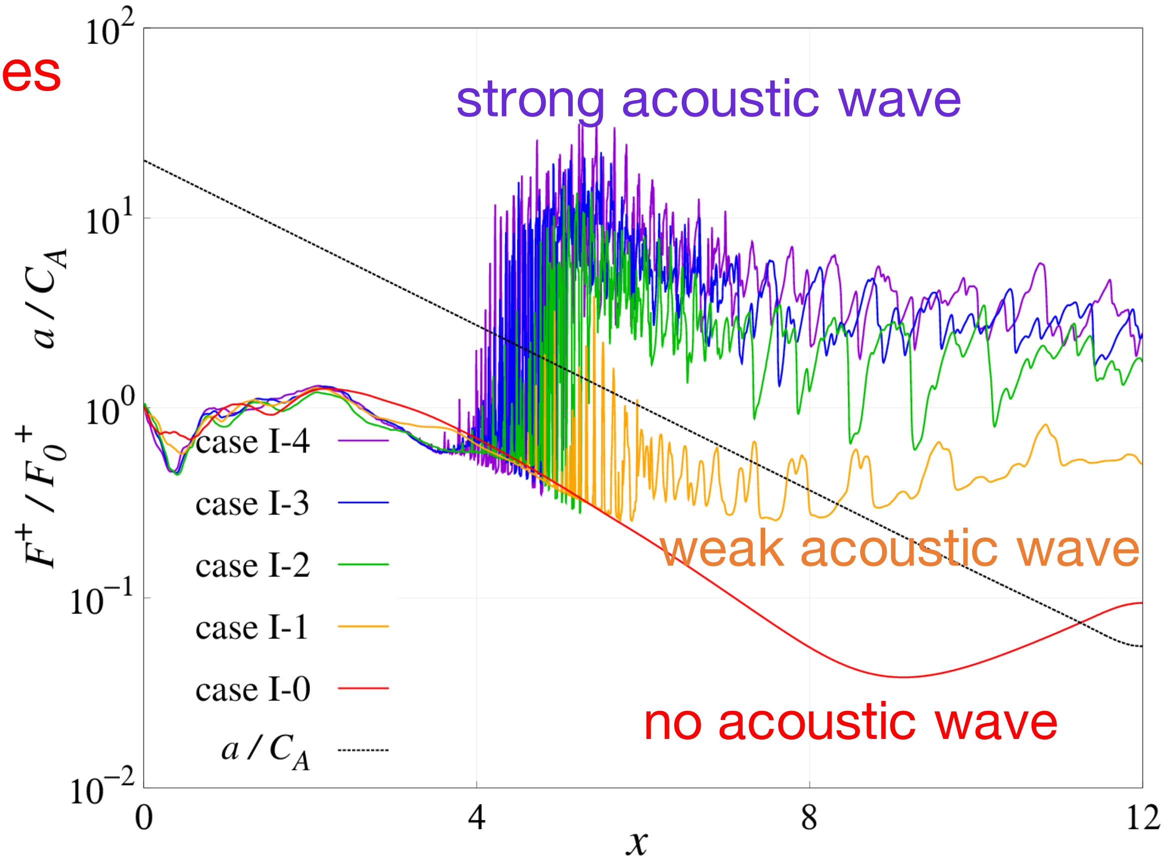
orange

green

blue

violet

strong acoustic wave



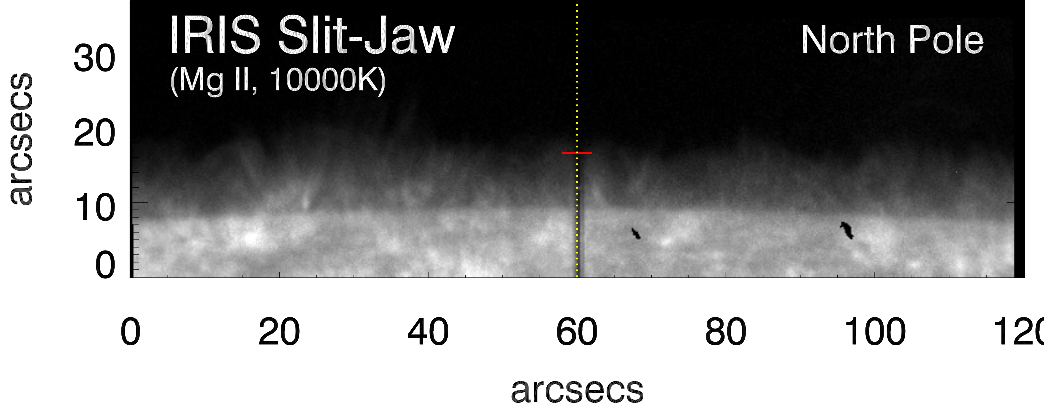
Observation method

Observation by IRIS

observation time:
2014. 4. 4. 00:20UT~01:32UT

cadence: 9 seconds

slit-jaw image with the slit position
(yellow-dotted line)



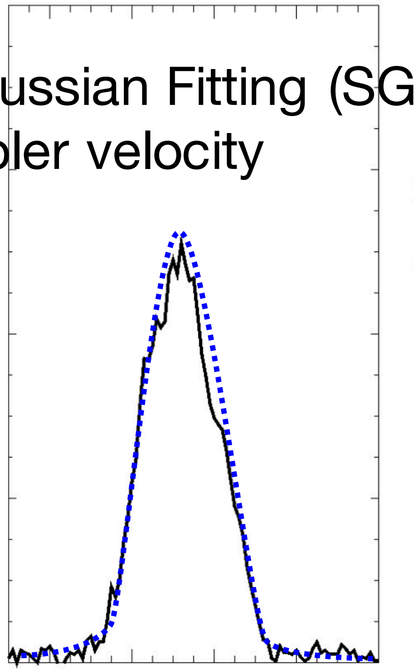
sit-and-stare observation of the northern polar region

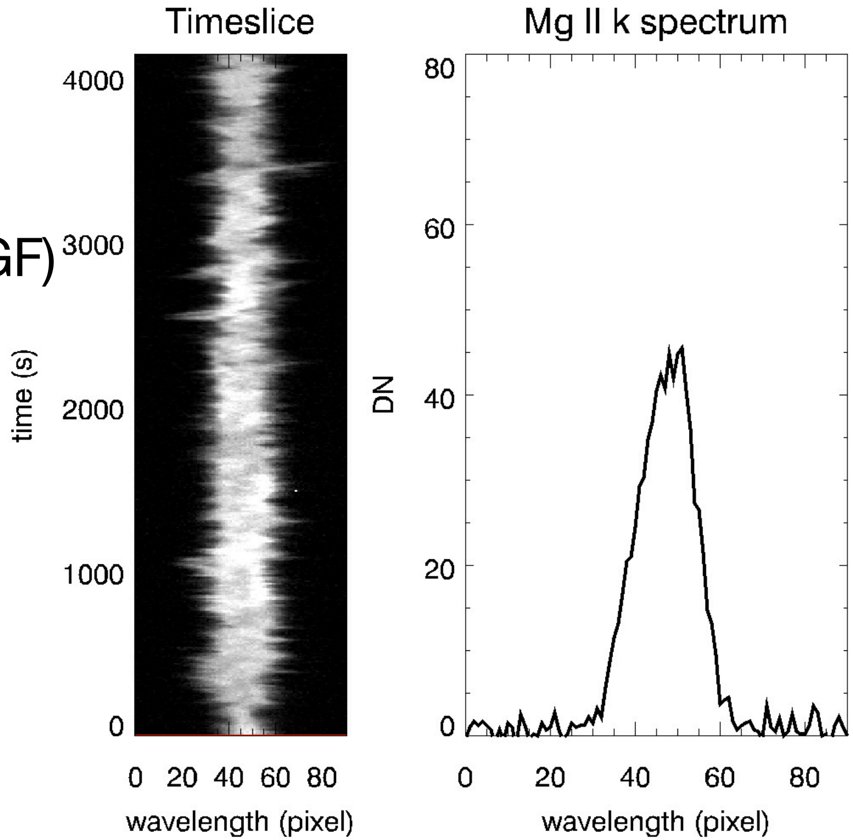
Mg II k line is used for analysis

Observation result

Line profile & timeslice at one pixel

Applied Single Gaussian Fitting (SGF) to derive the Doppler velocity





Result

Observational Result
: comparison with simulation

From top to bottom

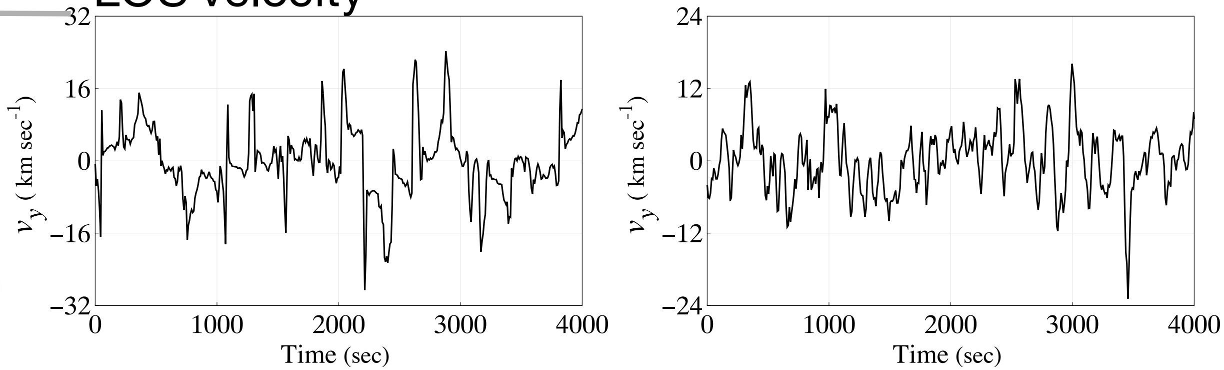
line-of-sight velocity v_y

power spectrum $P(f)$

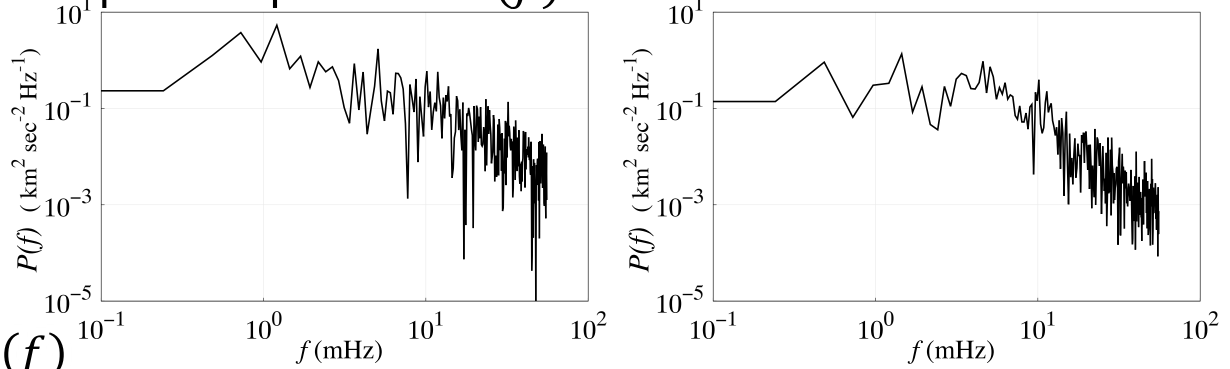
normalized power spectrum $fP(f)$
= representing the
energy-containing scale

simulation observation

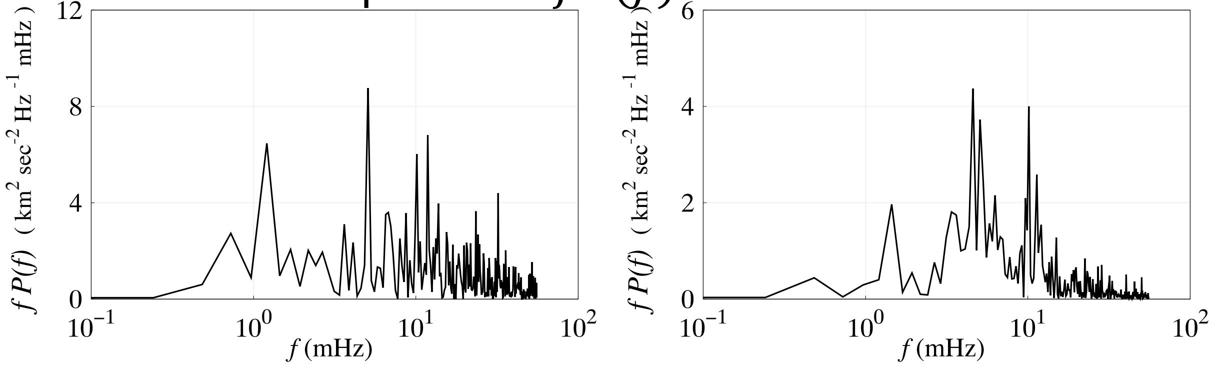
LOS velocity



power spectrum $P(f)$



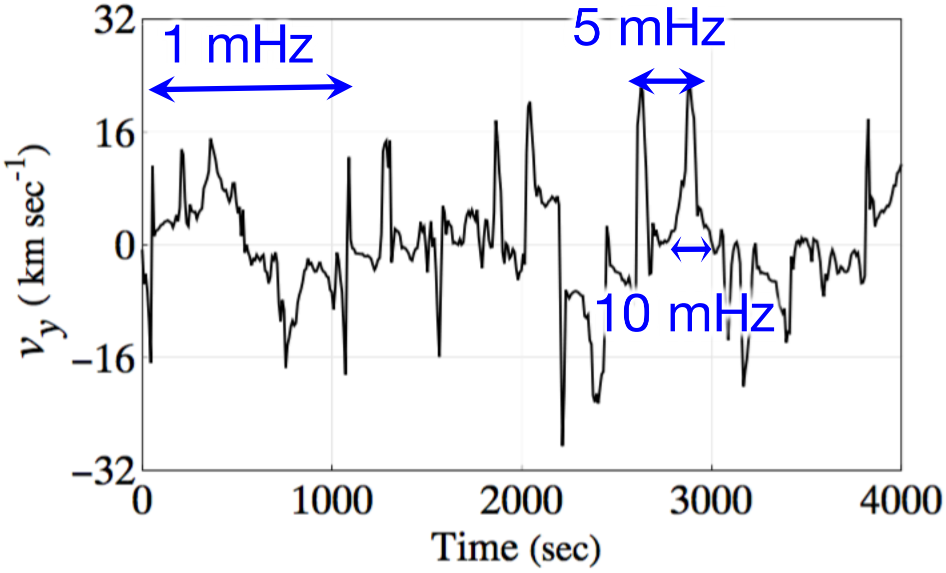
normalized spectrum $fP(f)$



2016/6/23

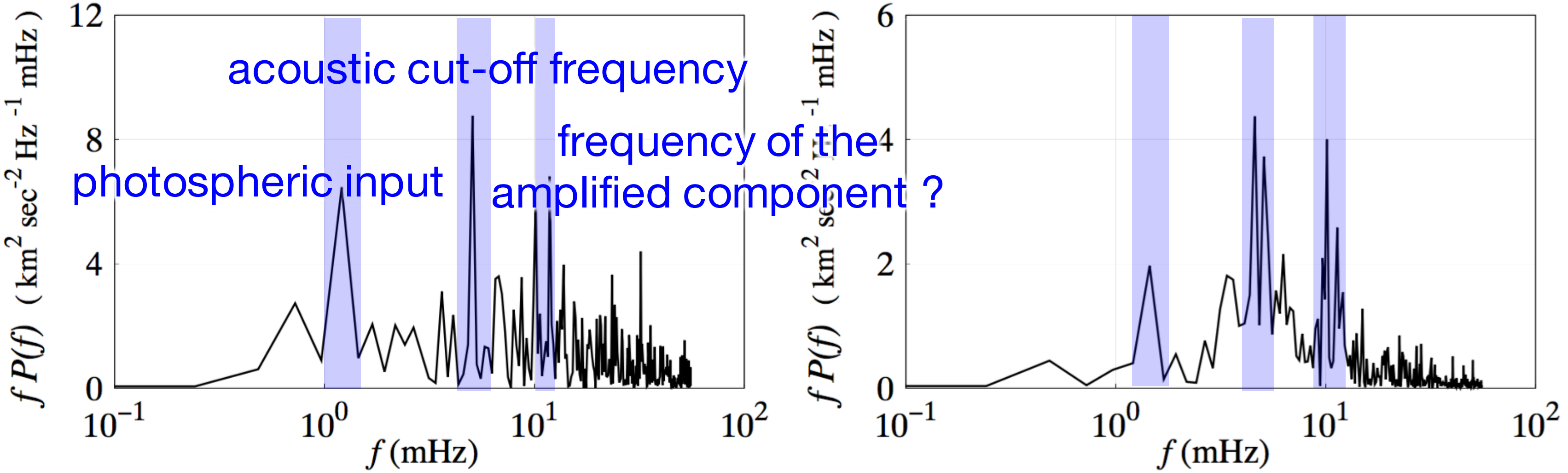
Result

Observational Result : cor



Typical three peaks (1mHz, 5n
simulation and observation

mode conversion occurs under the formation height of Mg II k line



simulation

observation

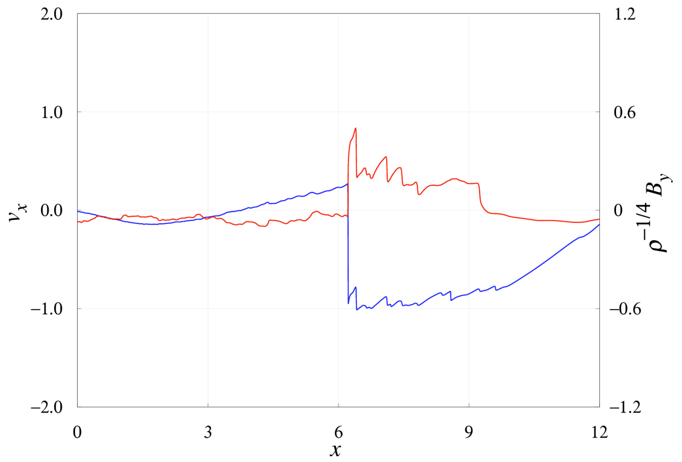
Summary

Using 1D simulation, we have shown intermittent, impulsive Alfvénic-wave generation triggered by acoustic (shock) waves inside the flux tube.

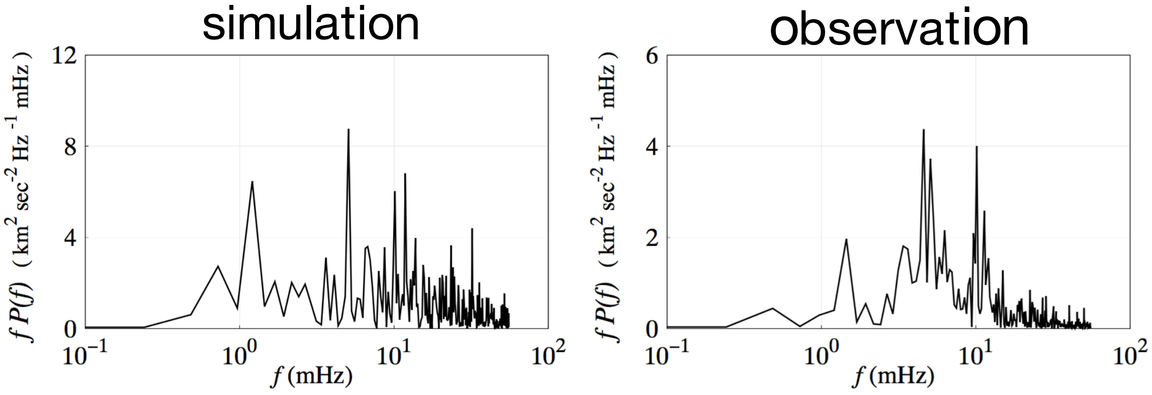
Similarity of the normalized power spectrum (energy-containing scale) shows the mode conversion occurs under the Mg II k formation height.

blue line : longitudinal velocity

red line : transverse magnetic field (normalized)



Normalized power spectrum
of the transverse velocity



simulation

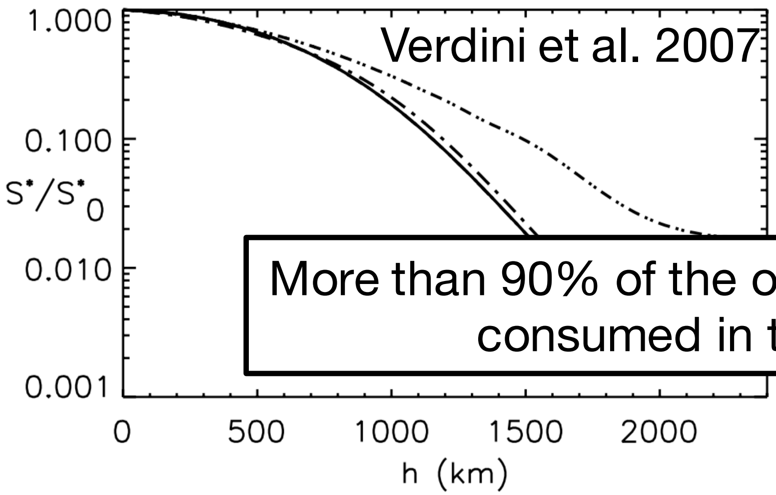
observation

Introduction

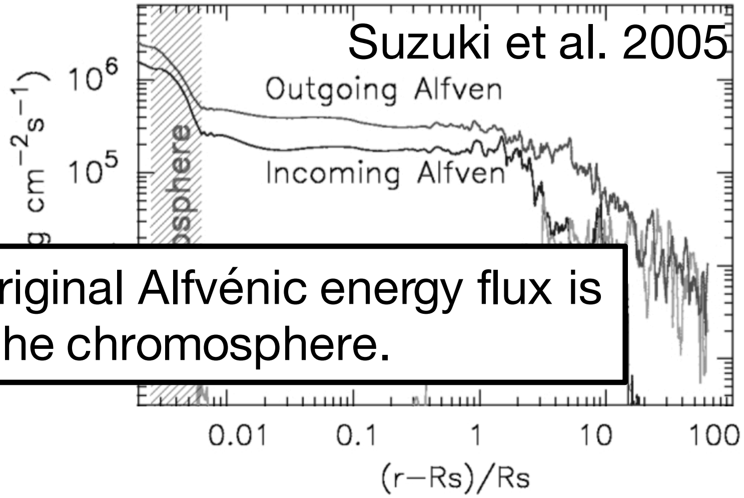
On the role of the chromosphere in coronal heating

The chromosphere was thought to be just a *dissipative medium connecting the wave source & the corona*.

Alfvén-wave energy flux as a function of height (two different models).



Verdini et al. 2007

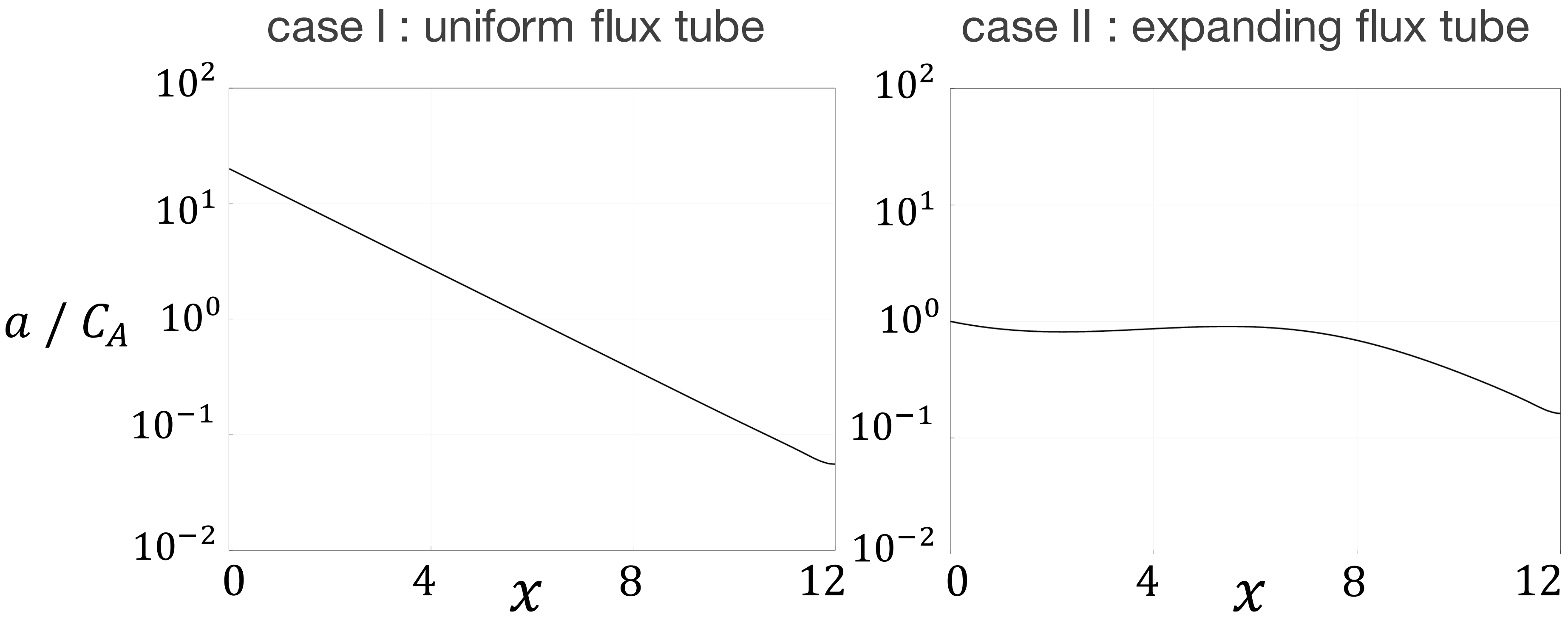


Suzuki et al. 2005

More than 90% of the original Alfvénic energy flux is consumed in the chromosphere.

Method

Numerical Setup : background plasma beta


case I : uniform flux tube

case II : expanding flux tube

Results

Numerical Result : amplification of Alfvénic flux (case I)

Upward energy flux of Alfvén(ic) wave is obtained as below.

$$F^{+} = \frac{1}{T_{\mathrm{sim}}} \int_{0}^{T_{\mathrm{sim}}} \left[\frac{1}{4} \rho \boldsymbol{z}_{+}{}^{2} C_{A} A \right] dt$$

T_{sim} : simulation time (needed for temporal averaging)

$\boldsymbol{z}_{+}$: outward Elsässer variable $\boldsymbol{z}_{+} = \boldsymbol{v}_{\perp} - \boldsymbol{B}_{\perp}/\sqrt{4\pi\rho}$

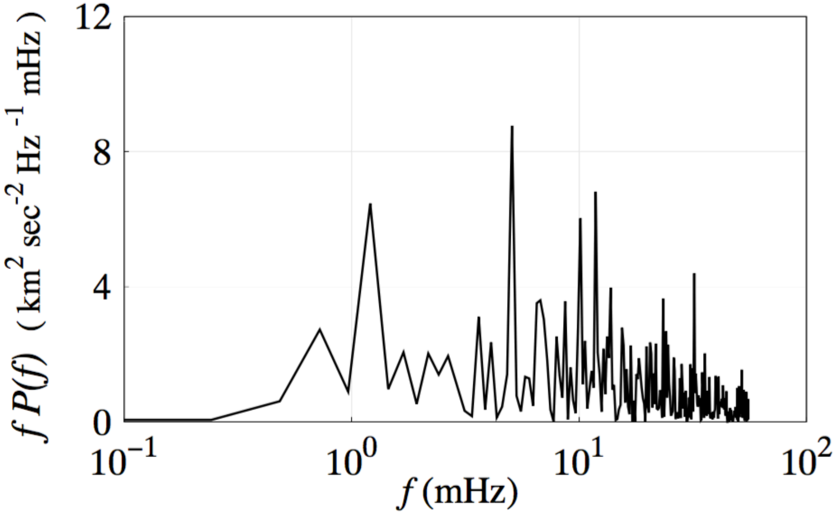
A : cross section of magnetic flux tube

Discussion

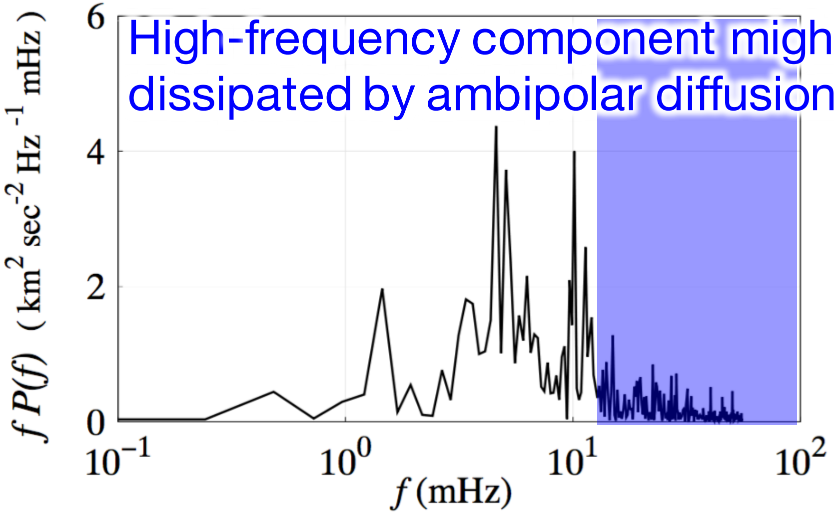
Effect of ambipolar diffusion

Ambipolar diffusion (diffusion caused by neutrals) is recently thought to be Important for high-frequency ($\geq 10\mathrm{mHz}$) Alfvén waves.
(Goodman 2011, Khomenko+ 2012, Shelyag+ 2016)

simulation



observation



High-frequency component might be dissipated by ambipolar diffusion.