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空间物理
SPACE PHYSICS

A new method to diagnose the shock waves in the solar atmosphere

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1. Background

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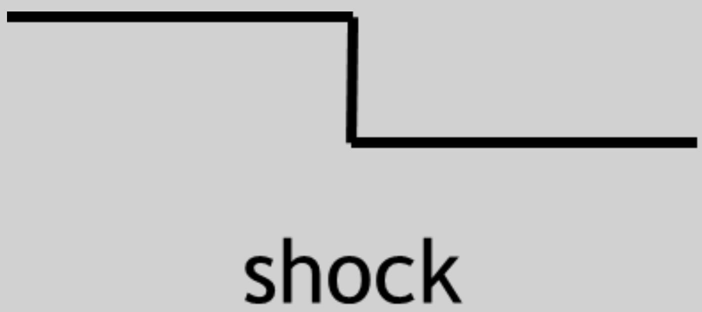
Shocks in the lower solar atmosphere

Shocks are often observed in the lower solar atmosphere (e.g. in the sunspots). [e.g. Rouppe van der Voort et al., 2003; Tian et al., 2014 …]



An important source of the shocks: **compressible waves**

The waves (such as slow mode wave) likely to steepen and evolve into shocks when they propagate upward.

A case of shock waves

From Tian et al. (2014)

Location: sunspot
Spectral line: Si IV & Mg II
Period: 3 min

Line core jump from blue-side to red-side

Shock is important

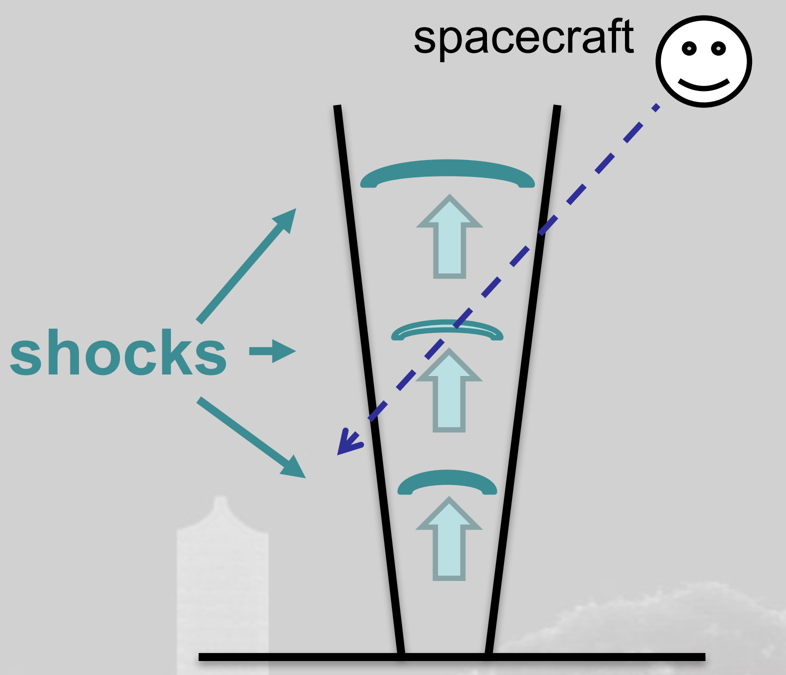
Shock play an important role in the evolution of solar atmosphere:

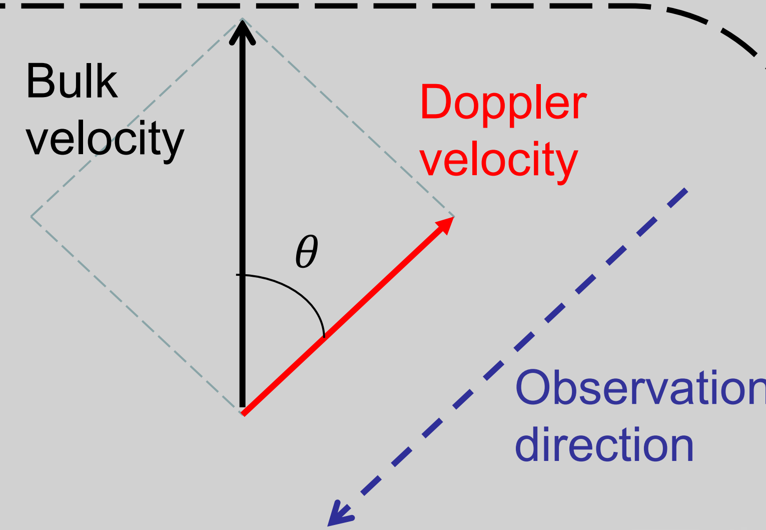
1. Shocks heat the atmosphere [see Hollweg, 1982]
2. Shocks drive the jets such as spicules [Hansteen et al. 2006]
3. Shock waves act as probes of solar atmosphere [Lites,1992]

It is important to know the parameters of shocks such as propagating speed and bulk velocities in upstream and downstream. For example, we need the parameters when we want to evaluate the energy flux carried by the shock waves.

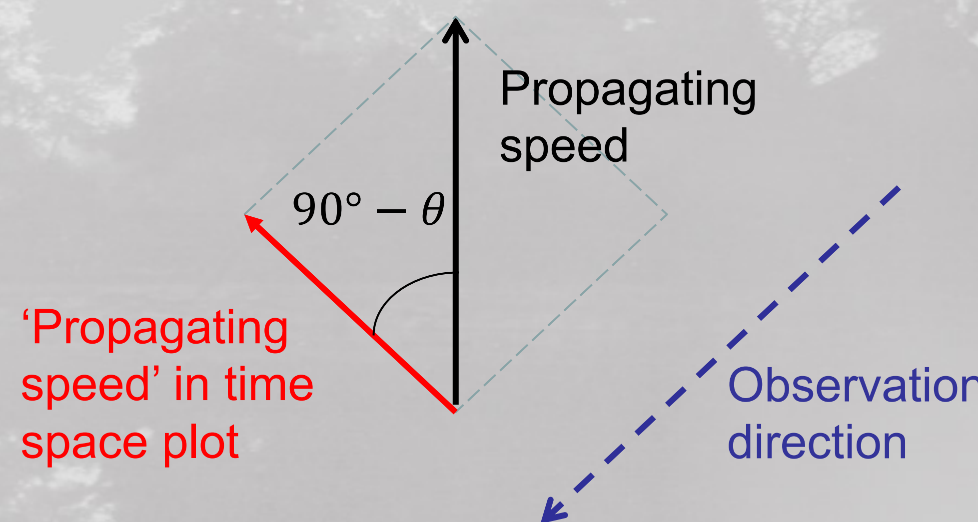
However, it is difficult to derive the parameters from the observation data.

It is difficult to know the parameters of shocks





θ – The angle between the observation direction and the propagating direction



Since θ is unknown, it is difficult to derive the values of bulk velocity and propagating speed from the observation data.

Goal

Finding out a viable method to diagnose the parameters of the observed shocks.

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Our method

Observation direction

To know the parameters like propagating speed, we should know the angle $\boldsymbol{\theta}$ firstly.

$$\rho_1(v_1 - v_p) = \rho_2(v_2 - v_p),$$

+

$$I \sim \rho^2,$$

+

$$v1 = -D1\cos\theta \,, v2 = -D2\cos\theta$$

⇩

$$\sqrt{I_1}(D_1 + v_\alpha) = \sqrt{I_2}(D_2 + v_\alpha).$$

Time-space plot → v_β + v_α

⇩

$$\theta = \arctan(v_\beta / v_\alpha).$$

$$v_p = \sqrt{v_\alpha^2 + v_\beta^2},$$
$$v_1 = D_1/\cos\theta,$$
$$v_2 = D_2/\cos\theta.$$

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How to test the method?

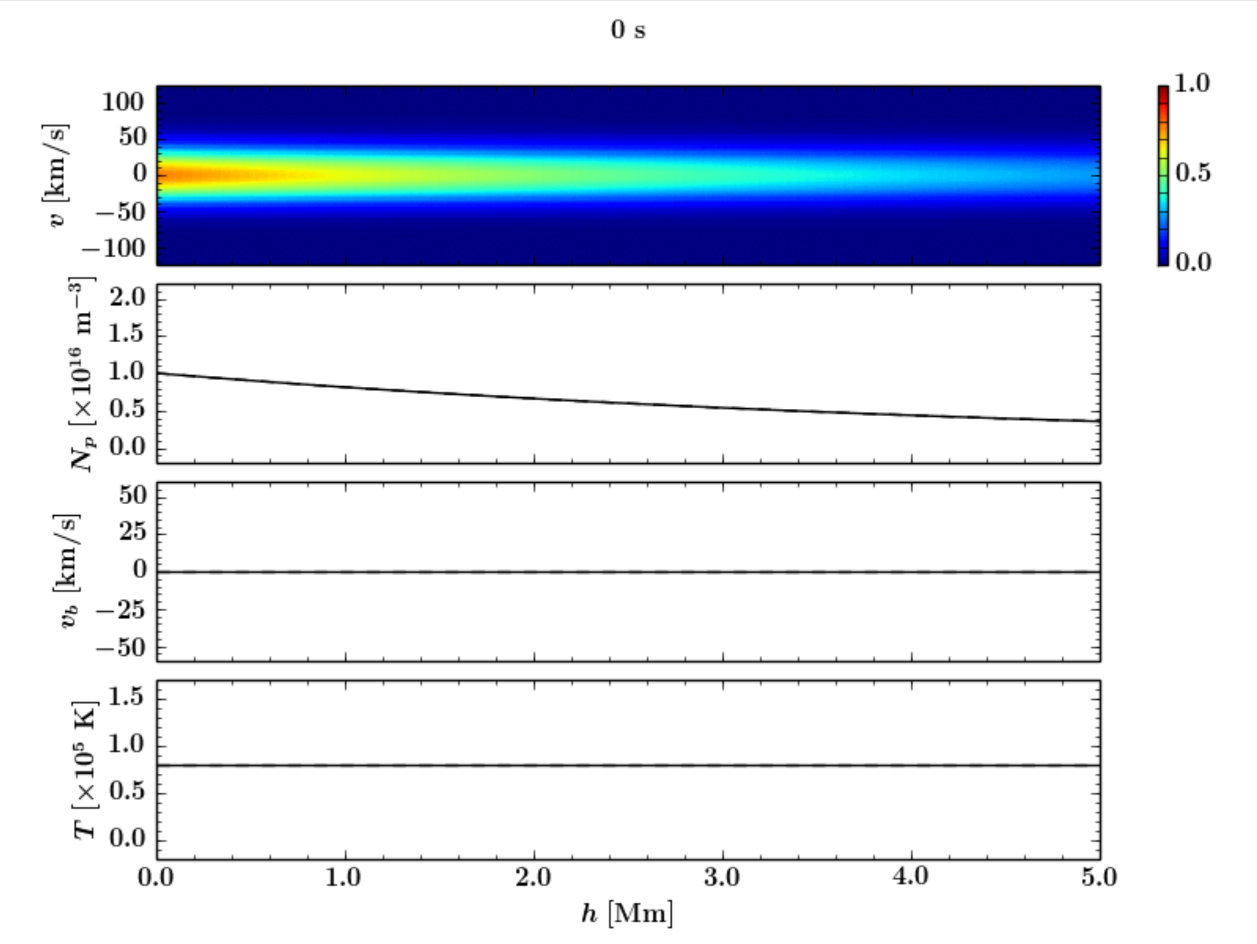
Step 1: Simulating the evolution of shock waves

Step 2: Synthesizing the spectrum of ions with the simulation data

Step 3: Deriving the parameters of the shock waves from the spectrum with our method

Step 4: Comparing the parameters derived by us with the real parameters

Simulation results of shocks



Governing equation:
Boltzmann equation

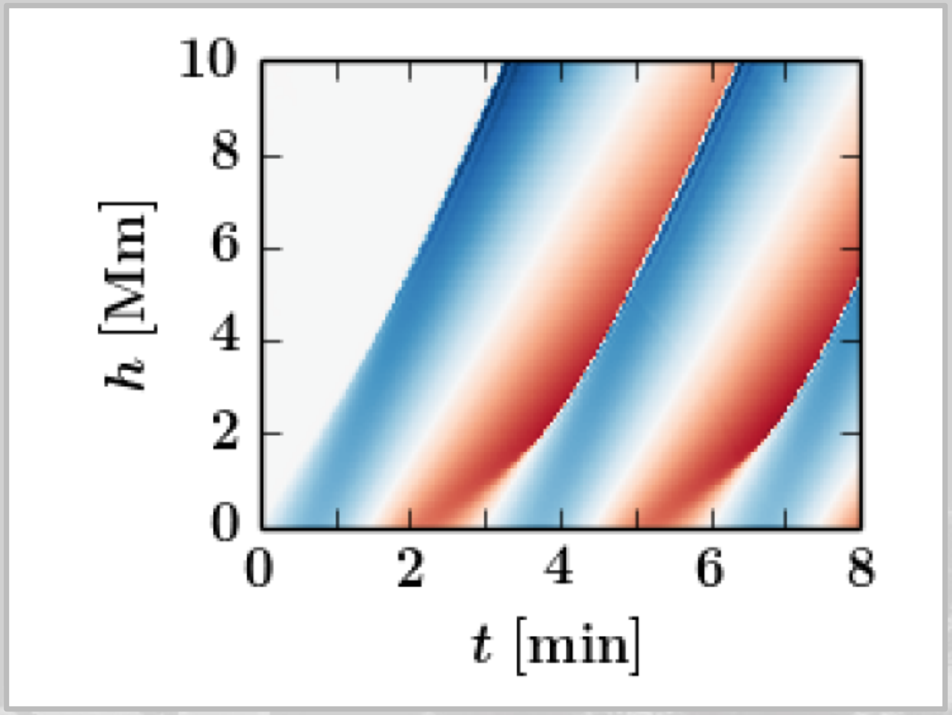
Dashed lines: values at 0 s
Solid lines: values at t

The width of shock surface is about 3 network grids

We change the plasma parameters at the lower boundary periodically to generate acoustic waves. The acoustic waves evolve into shocks when they propagate upward.

Parameters of shocks

Time-space plot



Parameters at h = 3 Mm

Propagating speed of shocks:
vp = 45 km/s.
Not far from the local sound speed.

Near the shock surface:
v1 = -20 km/s, v2 = 14 km/s

Synthesize spectrum

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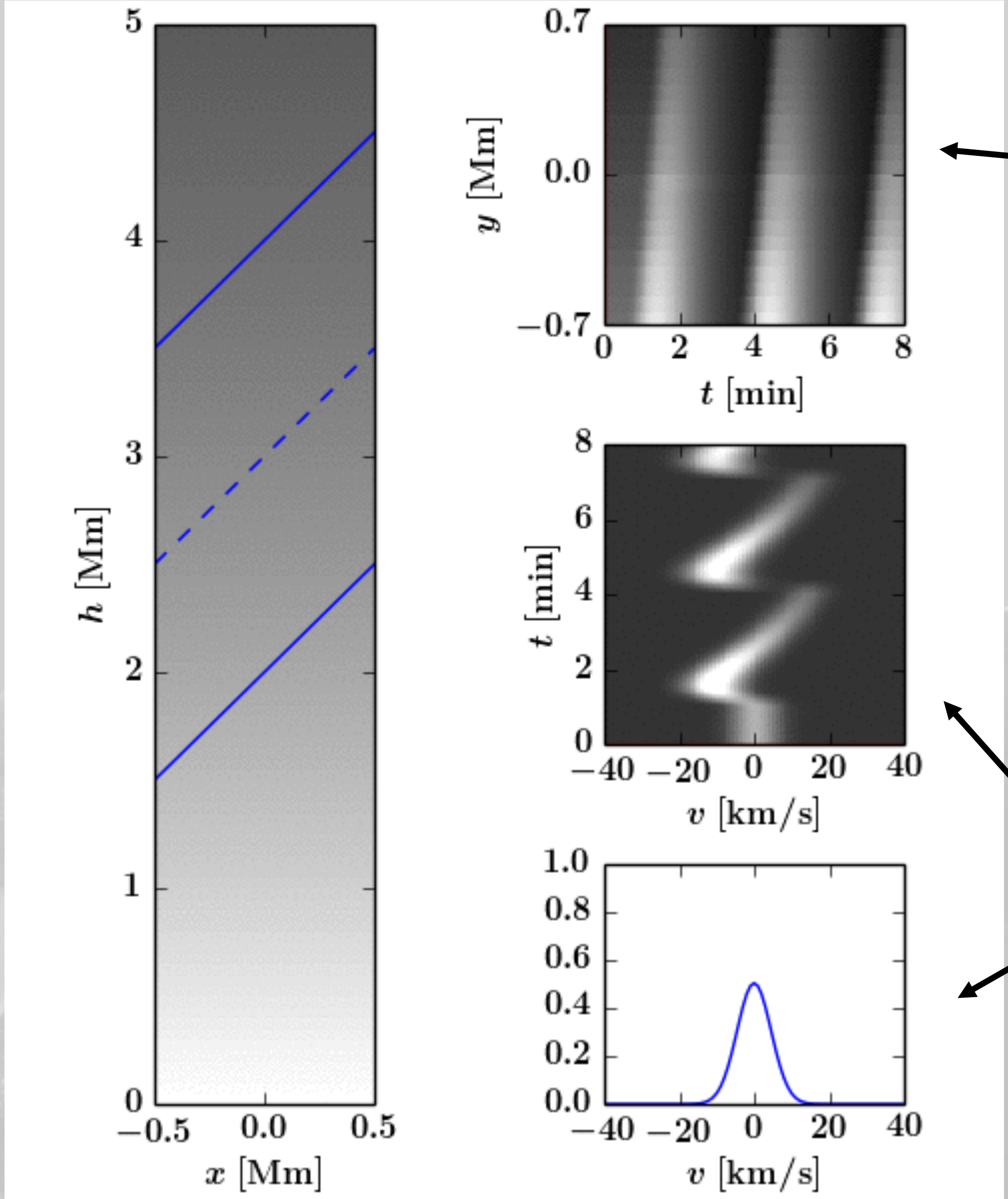
Flux tube

Assumption:
The flux tube is observed by a spacecraft along the dashed line.

The angle between the observation direction and the propagating direction is $\theta = \pi/4$



Time space plot

Z pattern can be found in the spectral profile

Spectral profile

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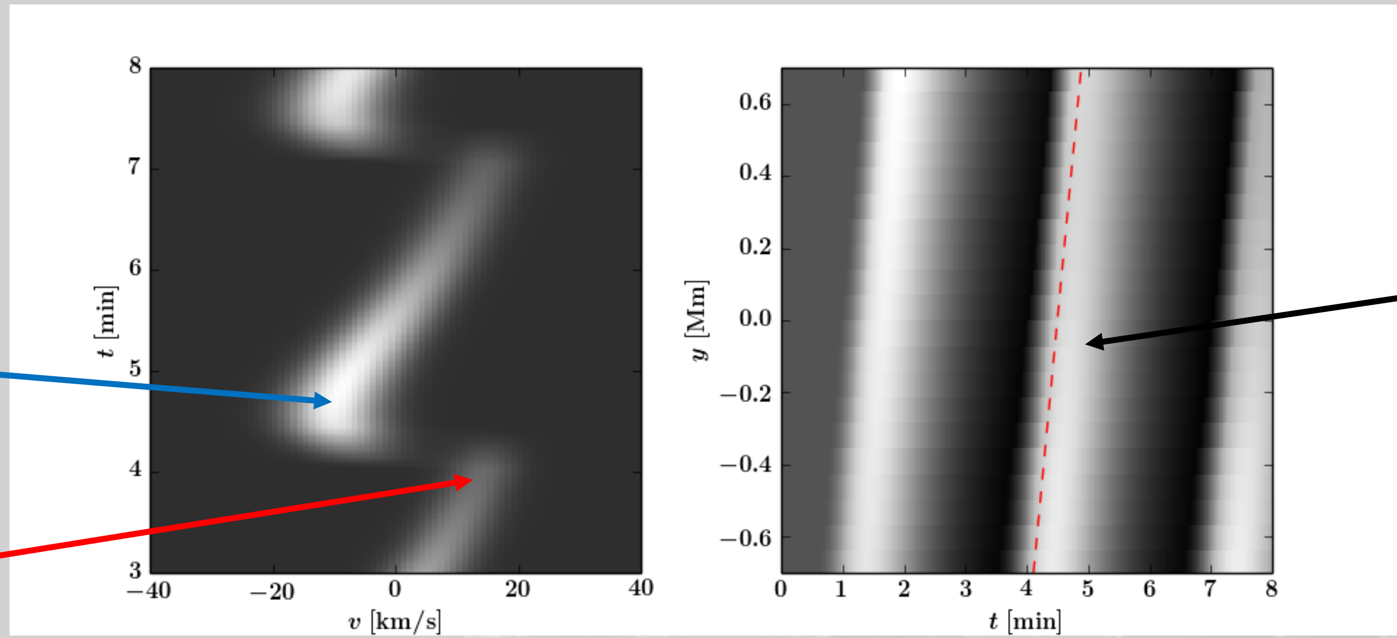
Derive parameters from the spectrum



$D2$ = 10.3 km/s

$D1$ = 13.7 km/s

$v_\beta = 30\ \mathrm{km/s}$

$$\sqrt{I_1}(D_1 + v_\alpha) = \sqrt{I_2}(D_2 + v_\alpha).$$

$$\theta = \arctan(v_\beta / v_\alpha).$$

$$\begin{aligned} v_p &= \sqrt{v_\alpha^2 + v_\beta^2}, \\ v_1 &= D_1/\cos\theta, \\ v_2 &= D_2/\cos\theta. \end{aligned}$$

$\theta = 44°$

$v_p = 44\ \mathrm{km/s}$

$v_1 = -20\ \mathrm{km/s}$

$v_2 = 15\ \mathrm{km/s}$

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Compare the results

	v_p	θ	v_1	v_2
Real values	45 km/s	45º	-20 km/s	14 km/s
Derived from spectrum	44 km/s	44º	-20 km/s	15 km/s

The parameters derived from the spectrum with the method presented by us fit the real parameters well.

The model used to test our method is too simple, we should test our method with a more complicate model.

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Conclusions

1. We present a method to estimate the parameters of the shocks observed in the lower atmosphere.

2. The method is tested with the help of numerical simulation, and good results are obtained in the test.

3. We suggest that the method presented by us may be a viable method.

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Thank you for your participation!