The 6th Solar-B Science meeting@Kyoto Nov 9, 2005

Flare-associated oscillations in coronal multiple loops observed with the Norikura Green-line Imaging System

Hori, K., Ichimoto, K. & Sakurai, T.

National Astronomical Observatory of Japan

SUNRISE@NORIKURA

Observations of Loop Oscillations

(summary from Wang et al. Aschwanden et al.)

A. Standing waves

a) Slow mode (acoustic) oscillations :EUV lines

b) Fast mode (Alfvenic)

Kink mode oscillations :EUV

Sausage mode oscillations :Radio, HXR

B. **Propagating waves** **:EUV, visible light…**

- **MHD waves Þ Possible source of coronal heating and/or acc. of solar wind？**
- **Coronal Seismology : Physical parameters**

e.g. loop length, period, duration → Field strength, density, temperature…

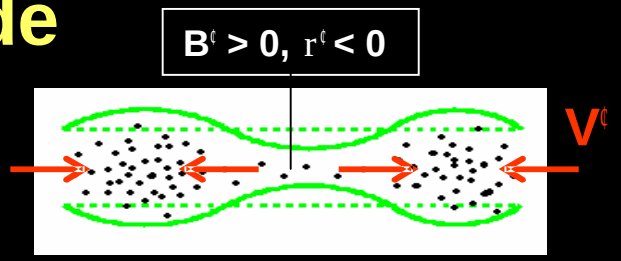
(Uchida 1970, Roberts, Edwin & Benz 1984…)

Interpretation of MHD waves (1)

(summary from Wang et al. Aschwanden et al.)

a) Slow mode

magneto-acoustic

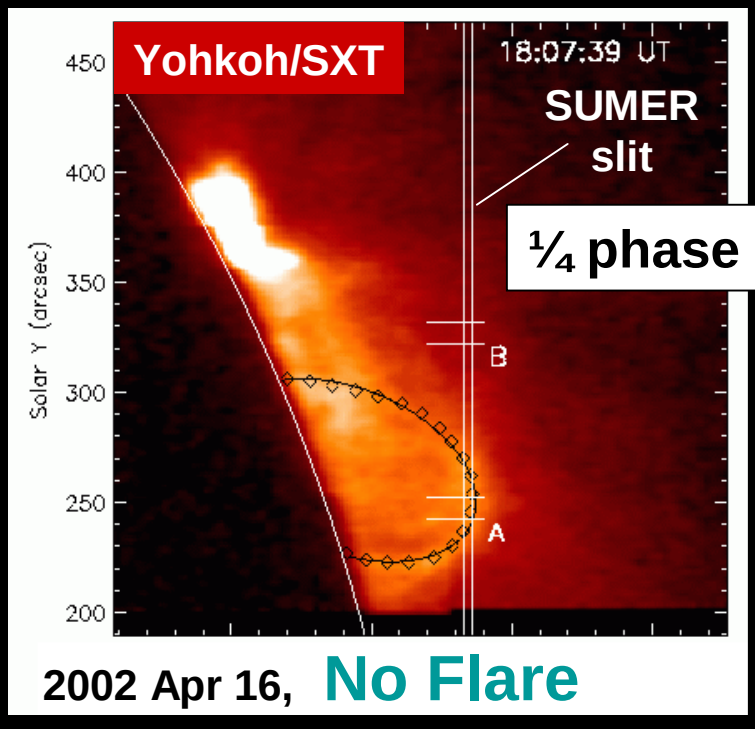


P = 7～70min

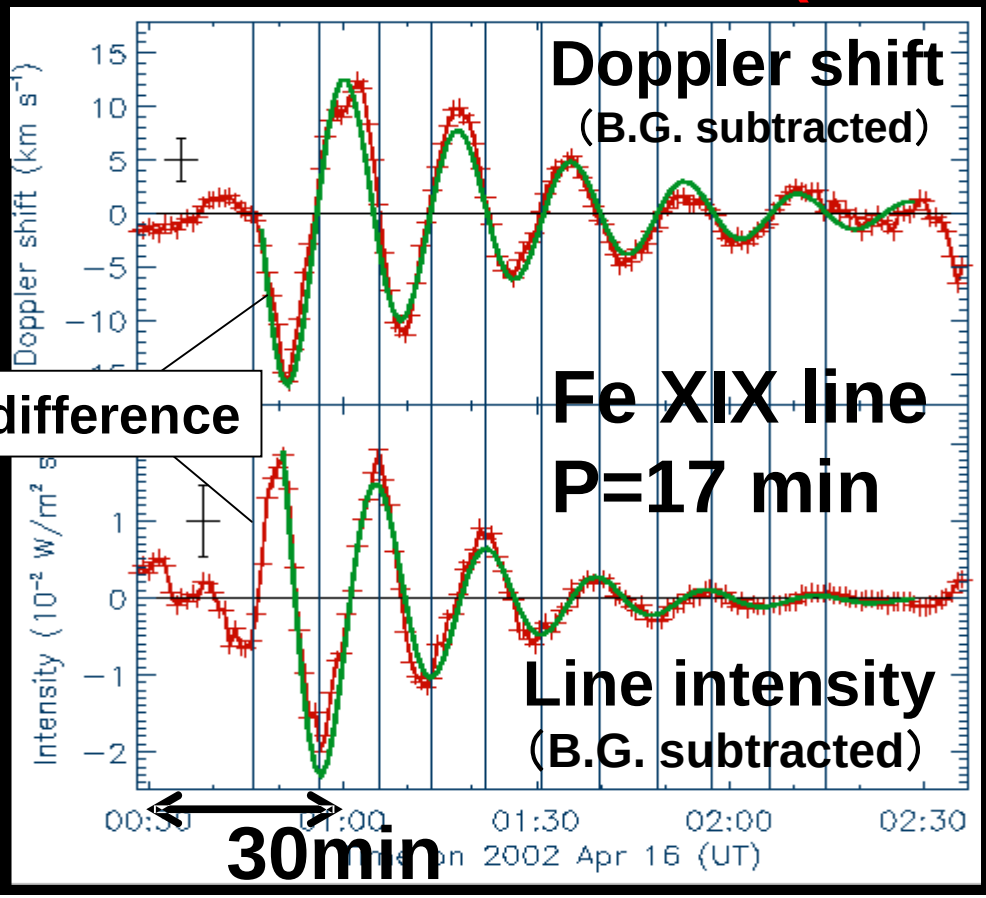
limited to 1D

SOHO/SUMER (6-8MK)

Wang et al. (2002,2003)



2002 Apr 16, No Flare



Interpretation of MHD waves (2)

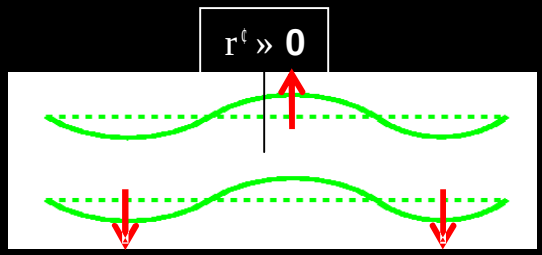
(summary from Wang et al. Aschwanden et al.)

b) Fast mode

KINK

-Asymmetric

-No density variations

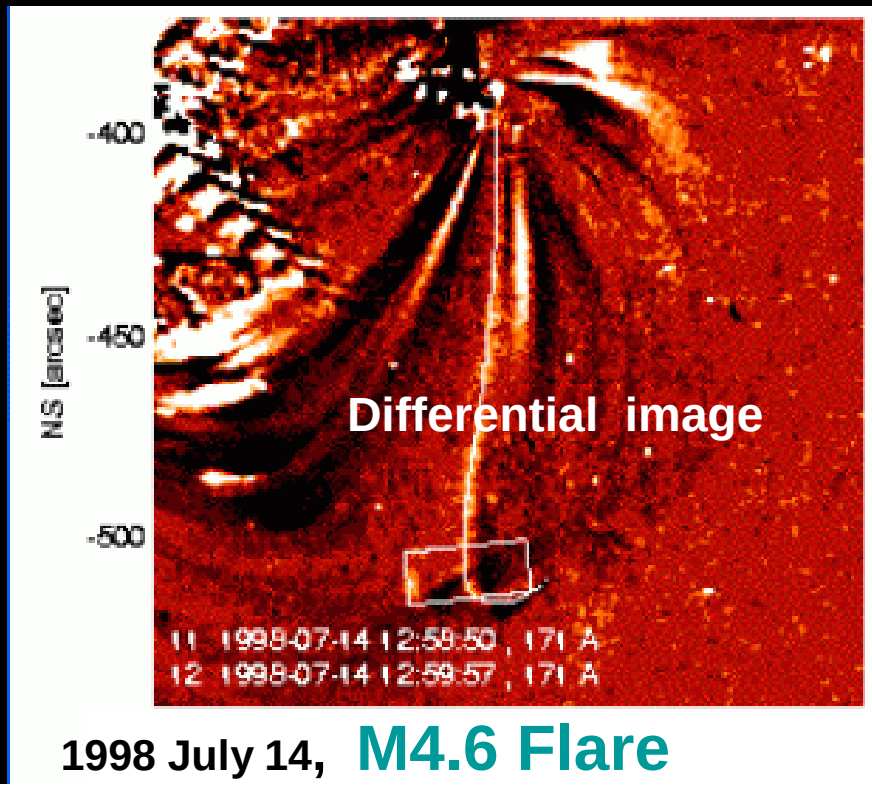


P= 1.4～14min

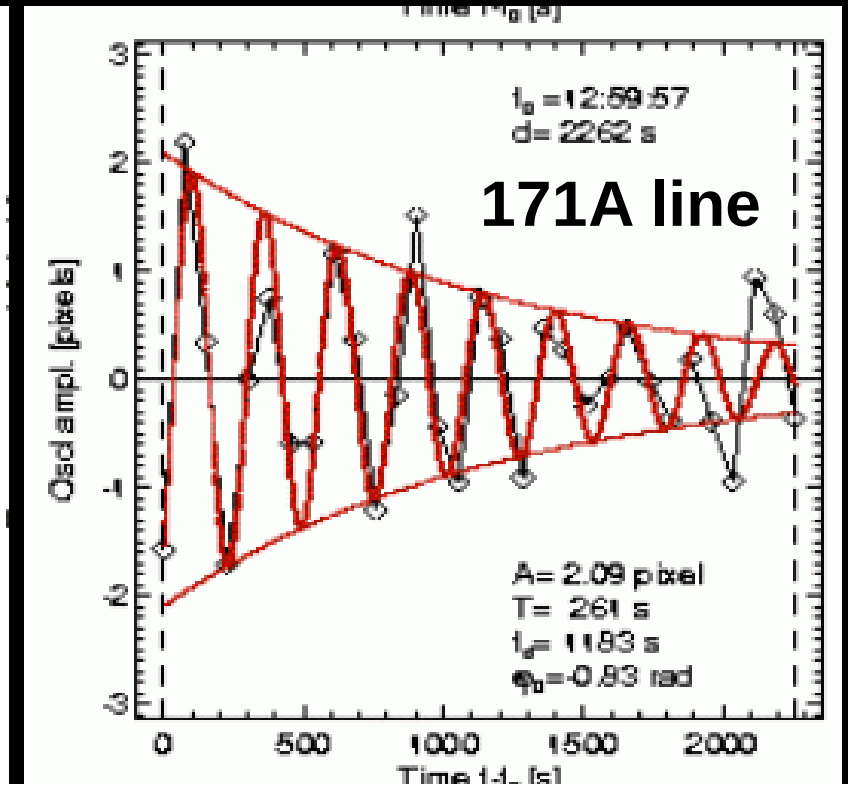
2D but no Doppler Information

TRACE (1.0-2.0MK)

Aschwanden et al. 2002



1998 July 14, **M4.6 Flare**



Coronal Green-line emission

Fe XIV 5303 Å ; 2MK

Center, ±0.45 Å

⇒ 2D Doppler Images

Time resolution ～40sec

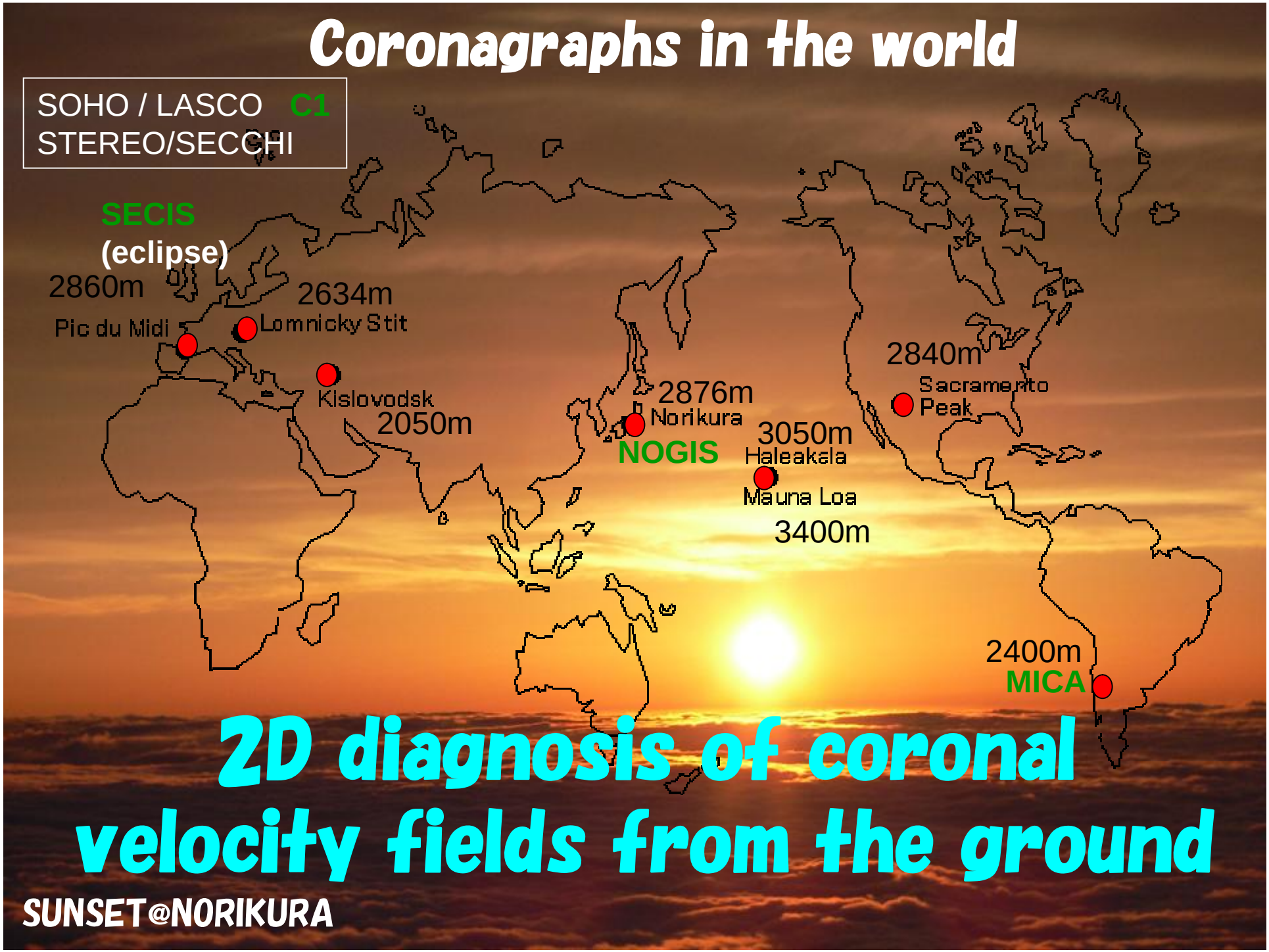
Spatial resolution 1.84”/pix (PFI)

FOV(FFI) 2000 x 2000 pixels

-25km/s～25km/s (Δv ～1km/s)

⇒ X Fast ejection

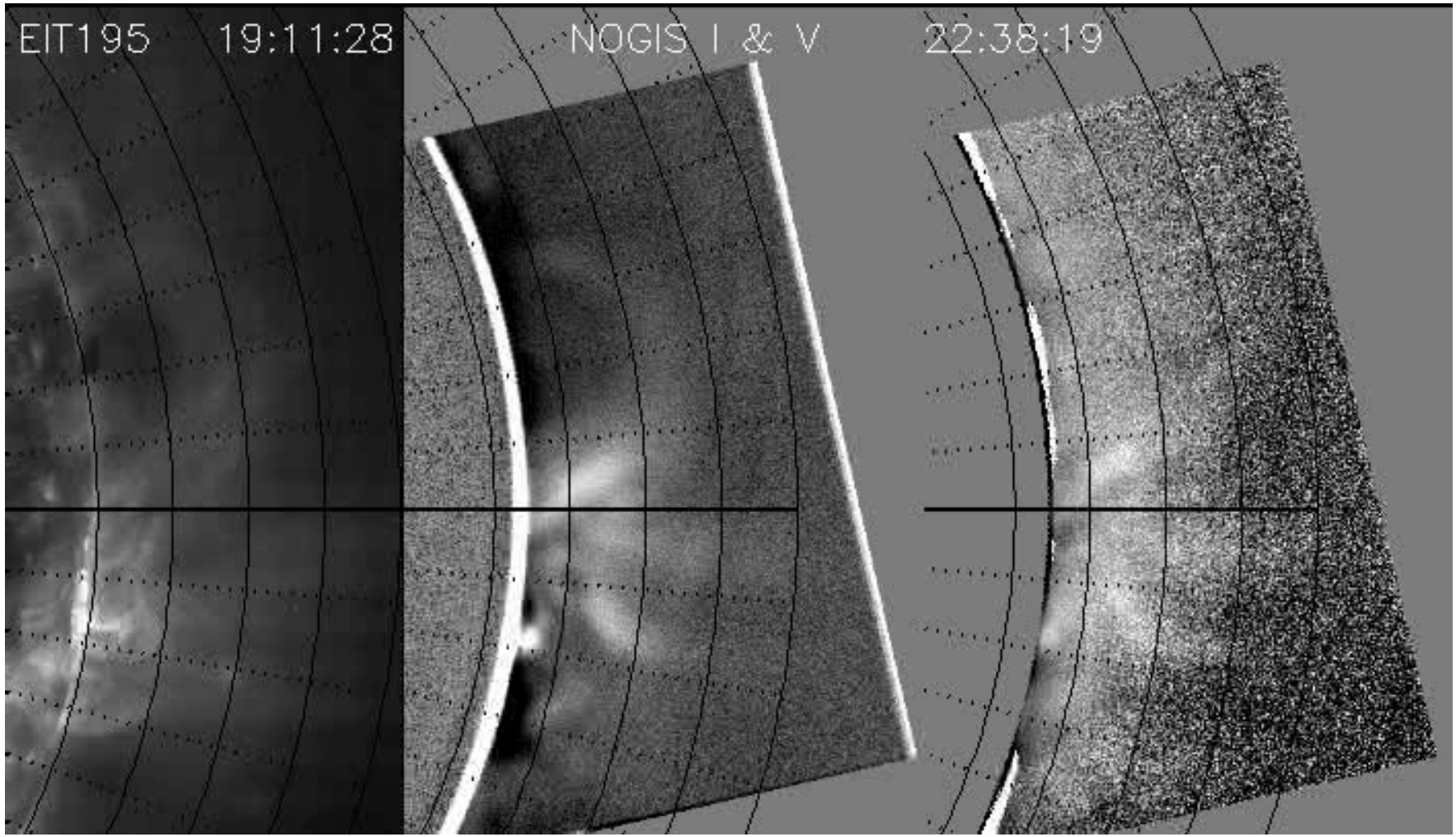
○ waves & flows



MOVIE

2003 Jun 01-02

EIT195 NOGIS (Intensity) NOGIS (Doppler V)



0°

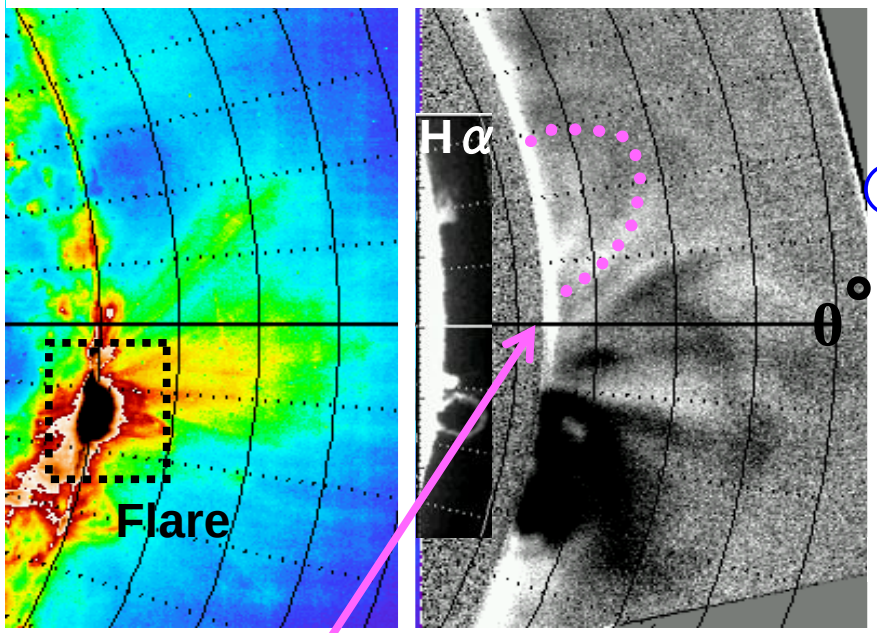
[Center+0.45Å] −[Center-0.45Å]

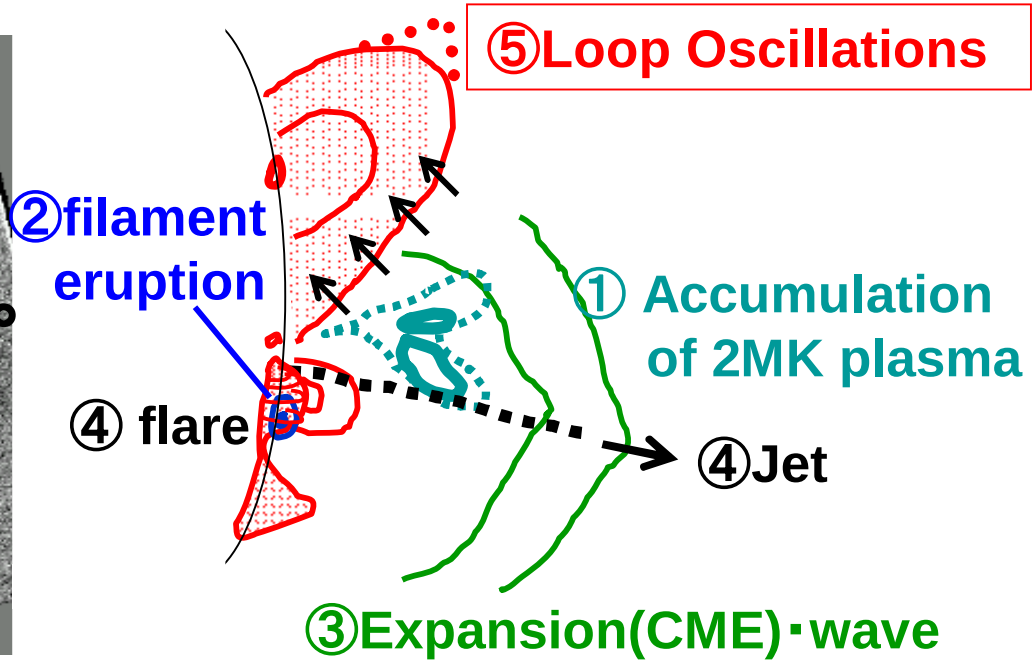
CME Onset and Loop Oscillations

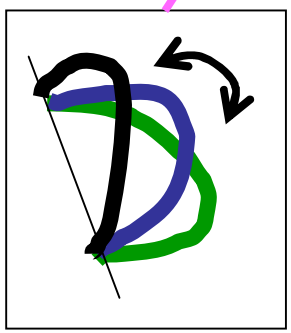
2003 June 2

SOHO/EIT（195Å）NOGIS（5303Å）

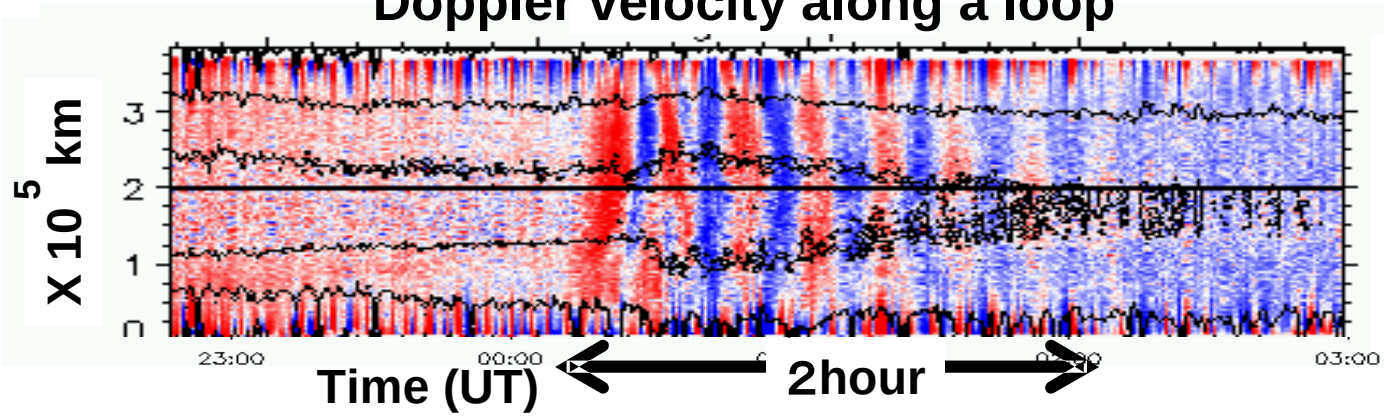
Hori et al. (2005)

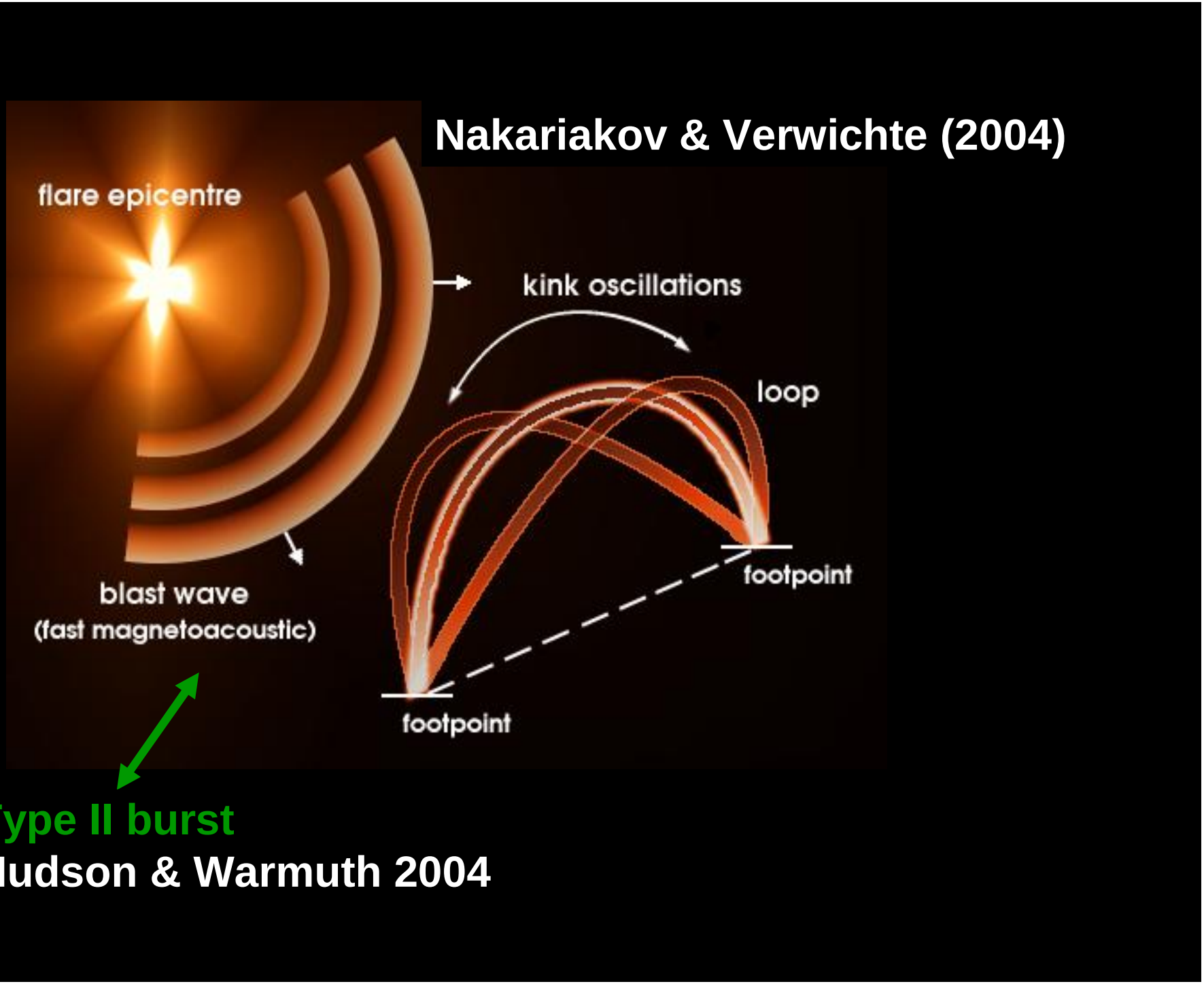




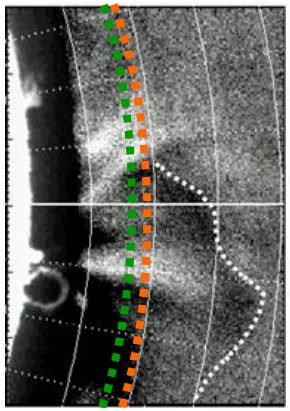


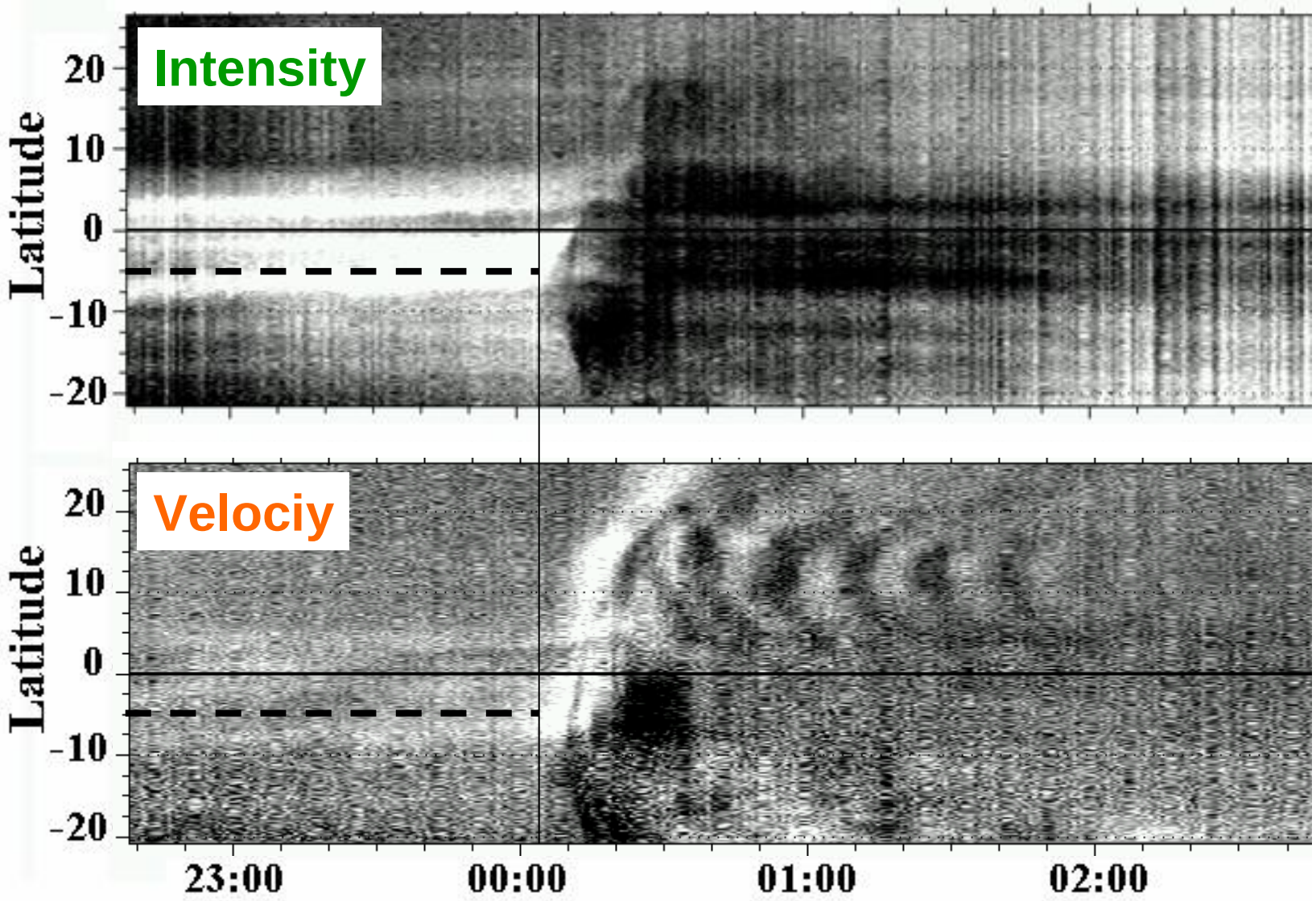
Doppler velocity along a loop



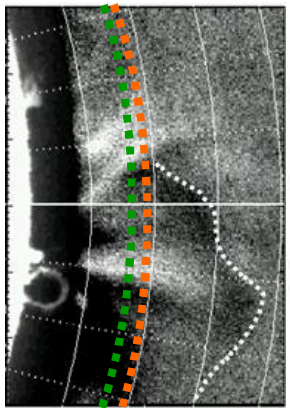


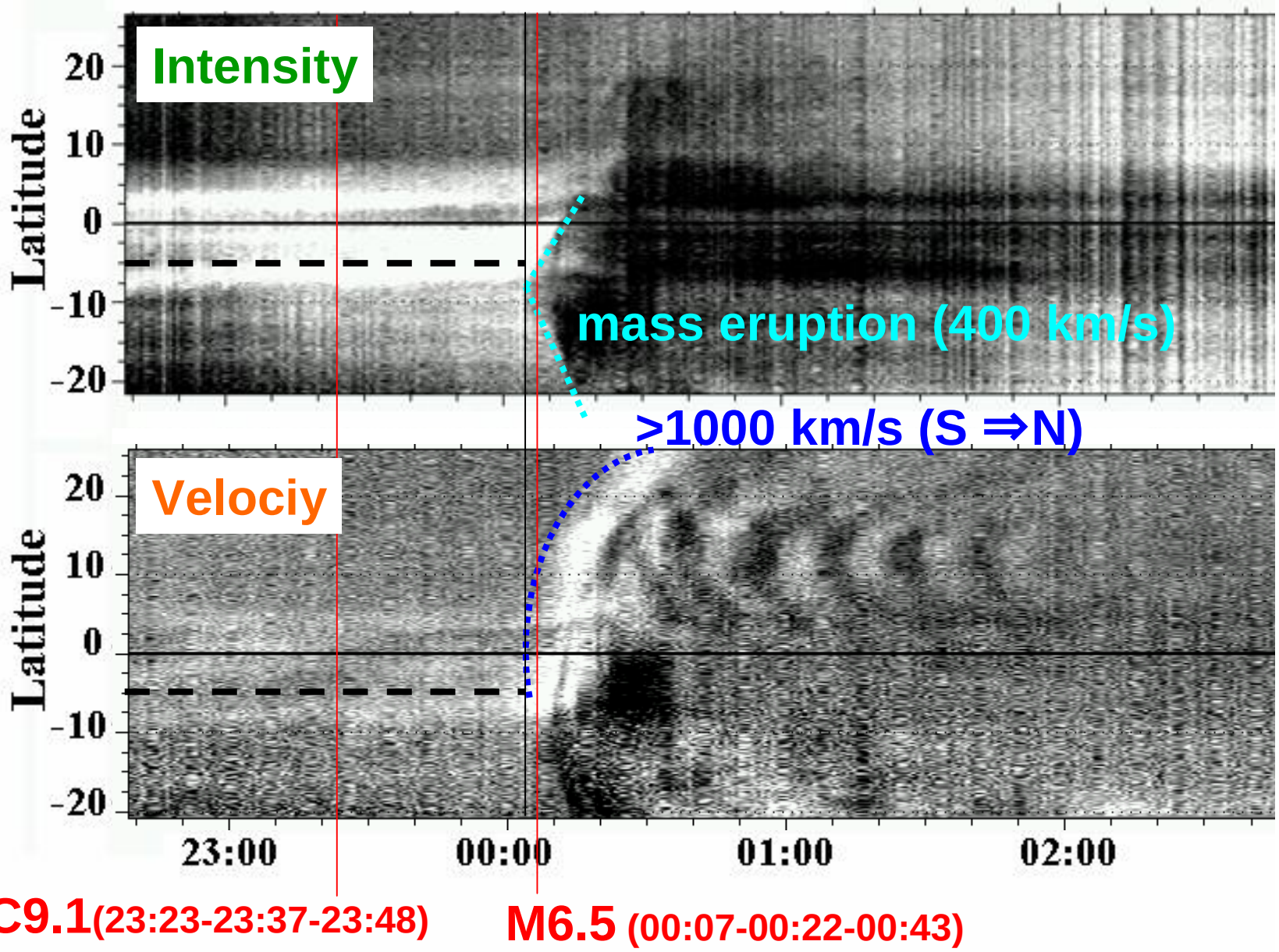
NOGIS time slice along the west limb (at 0.16/0.18Rs)





NOGIS time slice along the west limb (at 0.16/0.18Rs)





C9.1(23:23-23:37-23:48)

M6.5 (00:07-00:22-00:43)

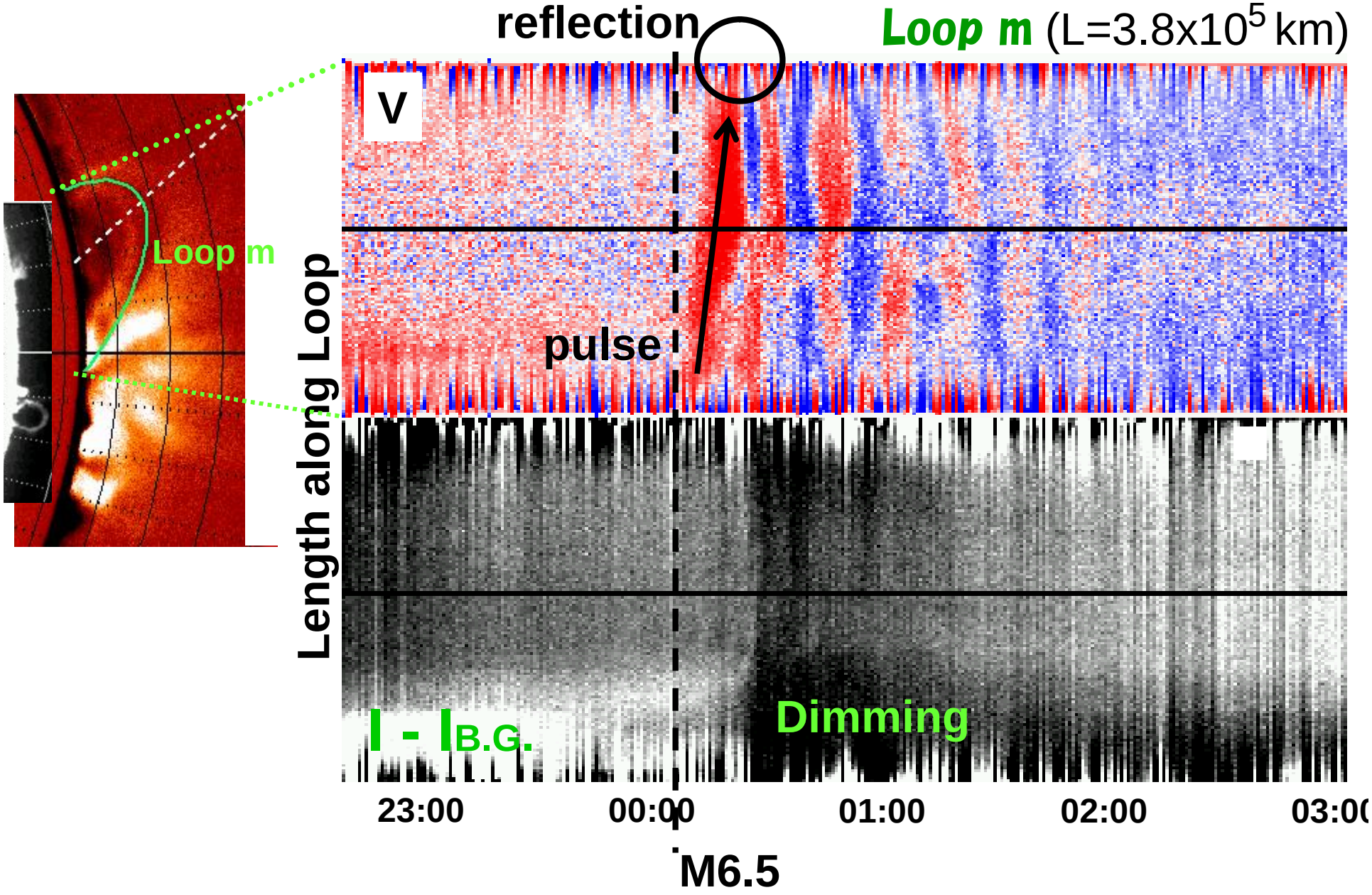
Multiple modes of waves/oscillations

1. ***Separate the individual modes***
   Wavelet analysis

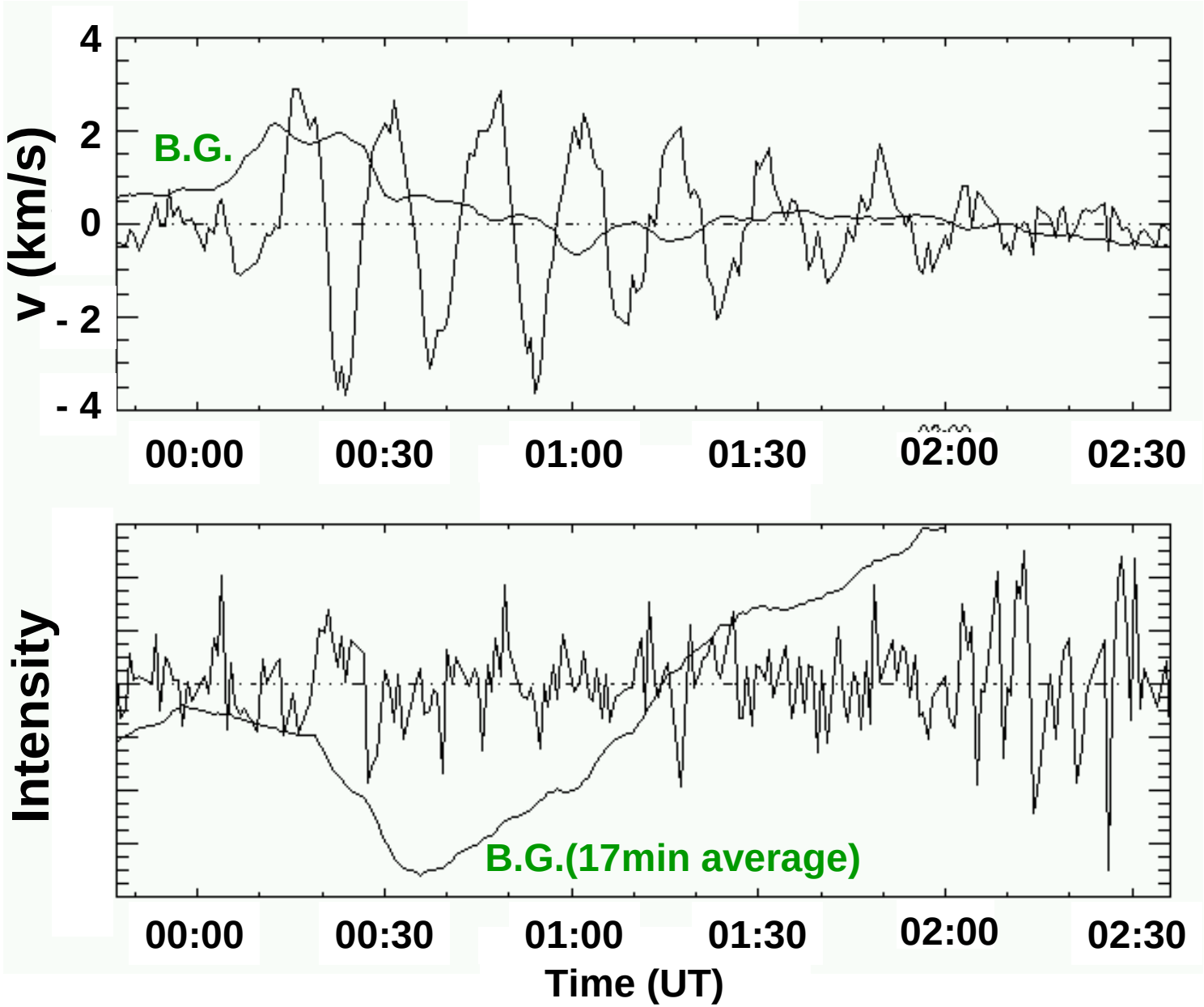
2. ***Physical parameters for each mode***
   ⇒ **Identify the damping mechanism**

3. ***Relation between different modes***
   e.g., energy exchange/transport along/across the loops?

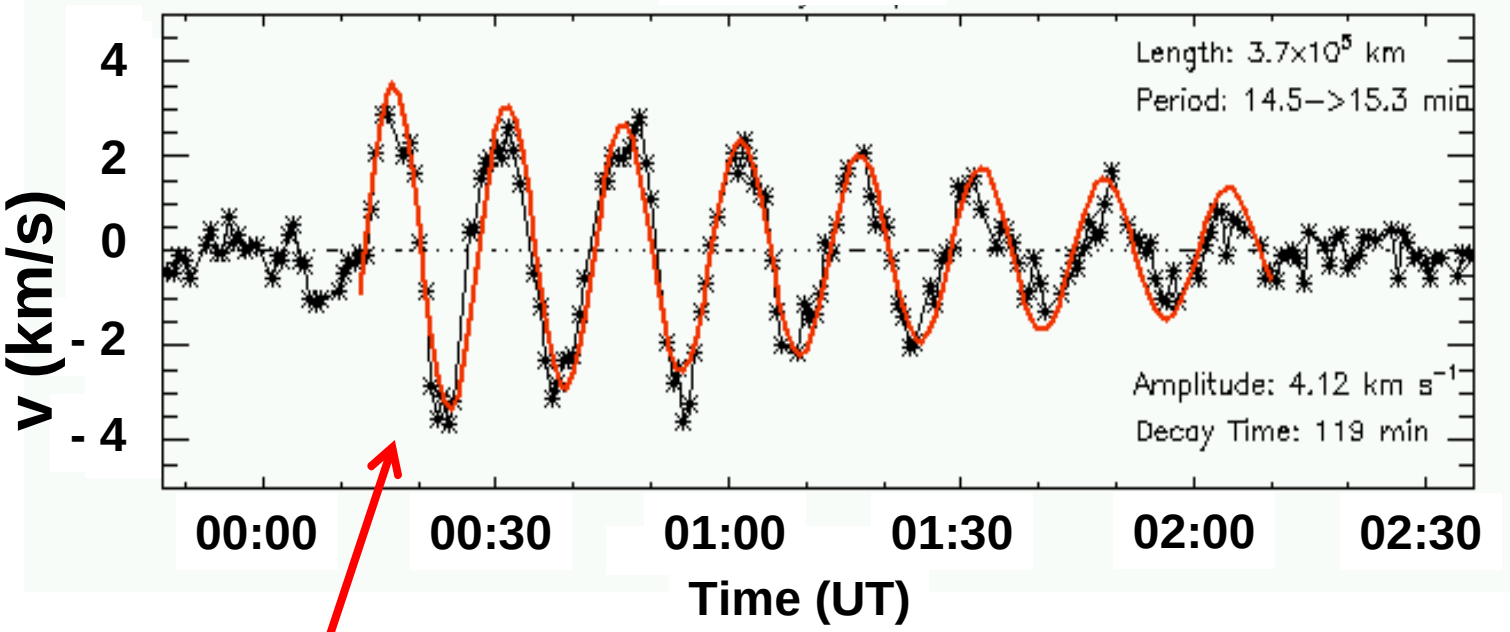
Time slice along a loop



Evolution around the apex



Evolution around the apex



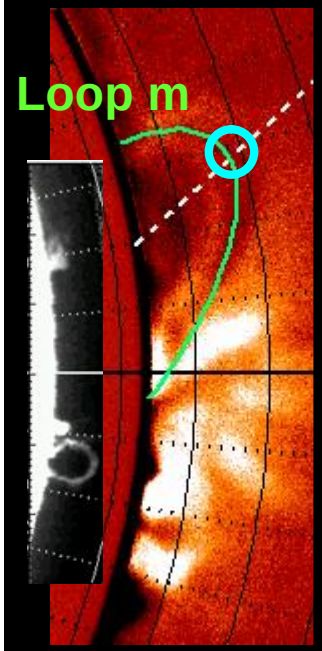
Fitting function

$$v(t) = v_0 \exp\left(-\frac{t}{t}\right) \sin\left(\frac{2p\,t}{P} + j_0\right)$$

$$P = P_0 \left(1 - A \times (t - t_0)\right)$$

Wavelet analysis

Apex of Loop m (L=3.8x10^5 km)



Velocity

km/s

4
0
-4

Wavelet Power Spectrum (contours at 20,40,60,80%)

Period (min)

100
10

95%

95%

τ_{max}

e^{-1}duration of the maximum power

P_{max}

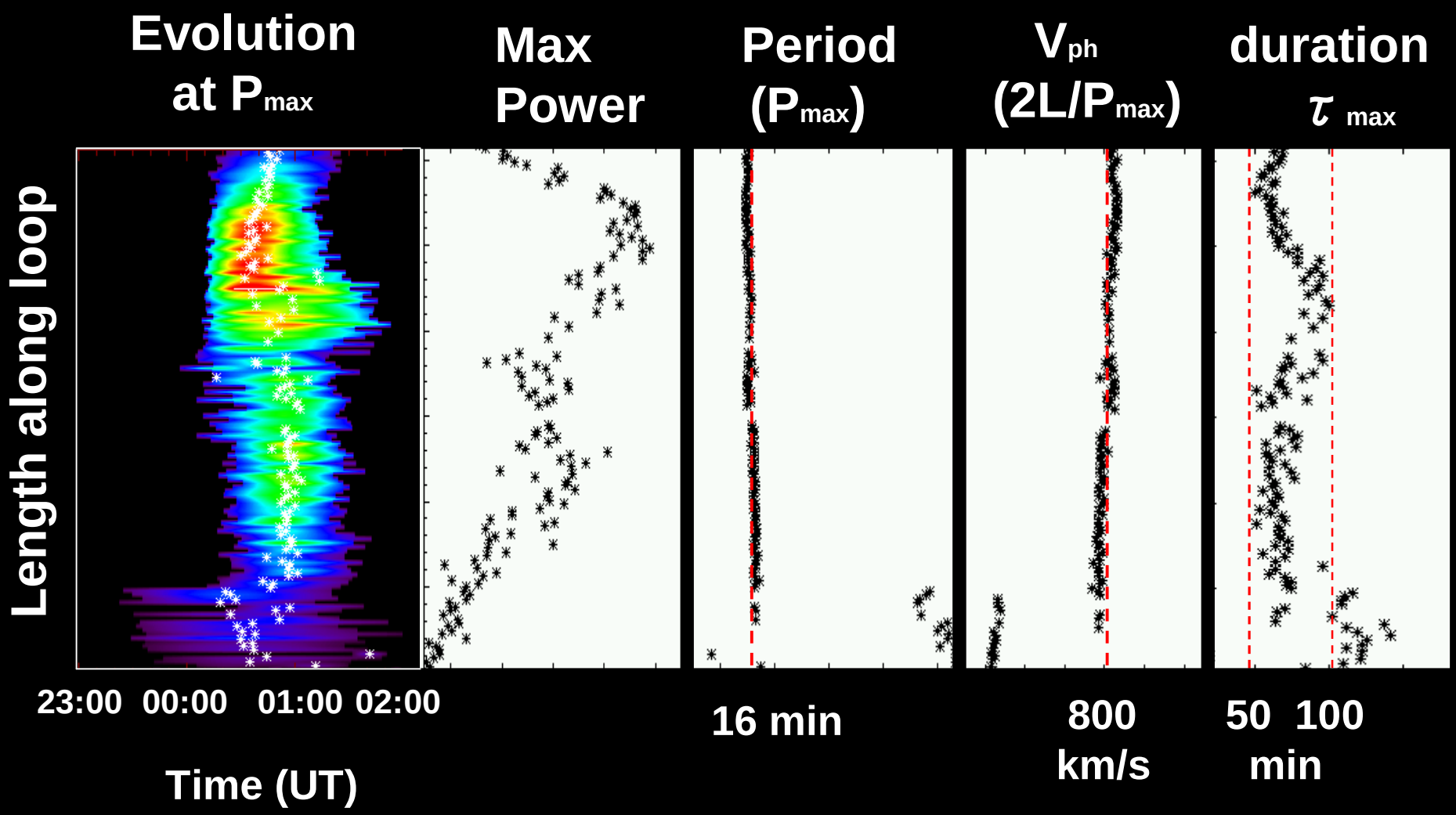
Max Power

23:00
00:00
01:00
02:00
03:00

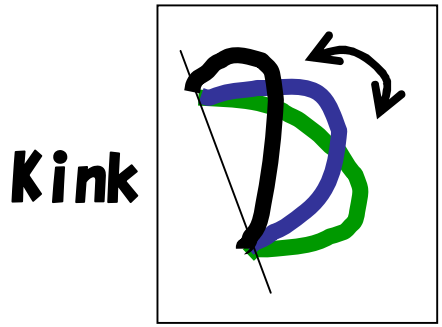
1d Morlet mother wavelet
(Torrence & Compo 1998)

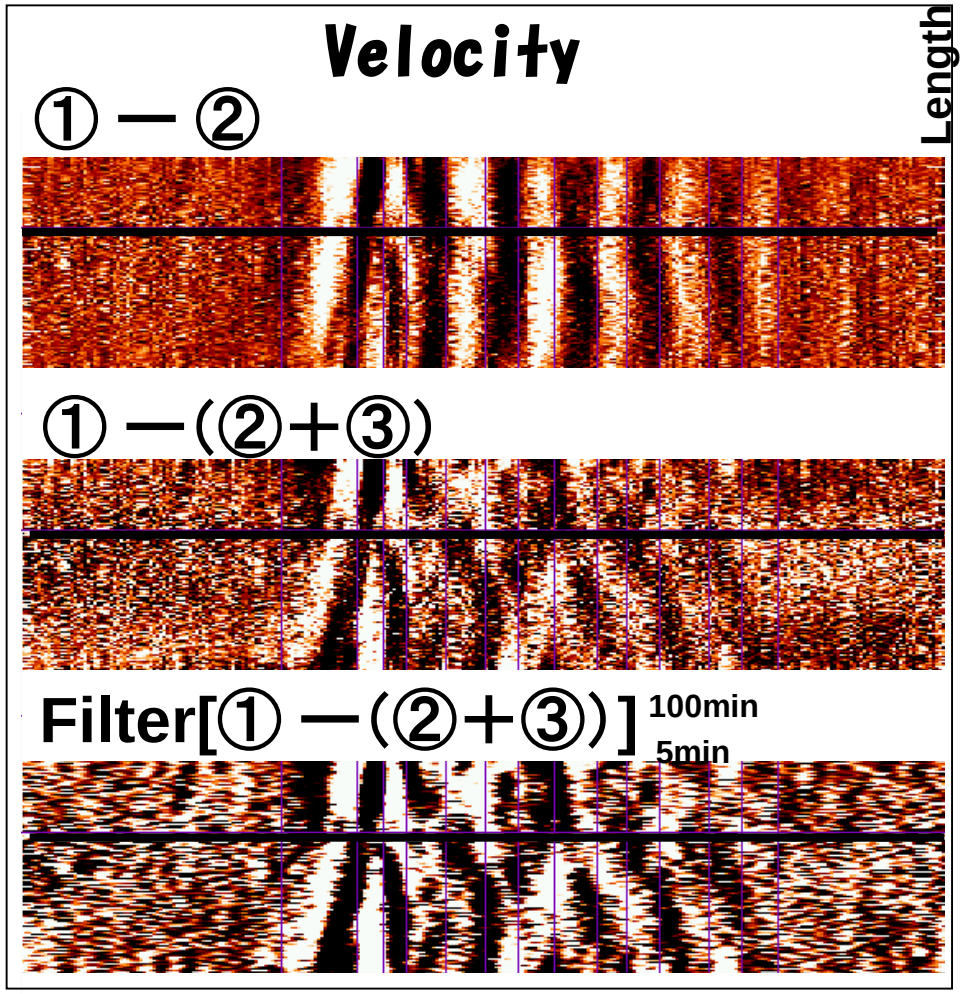
Wavelet analysis

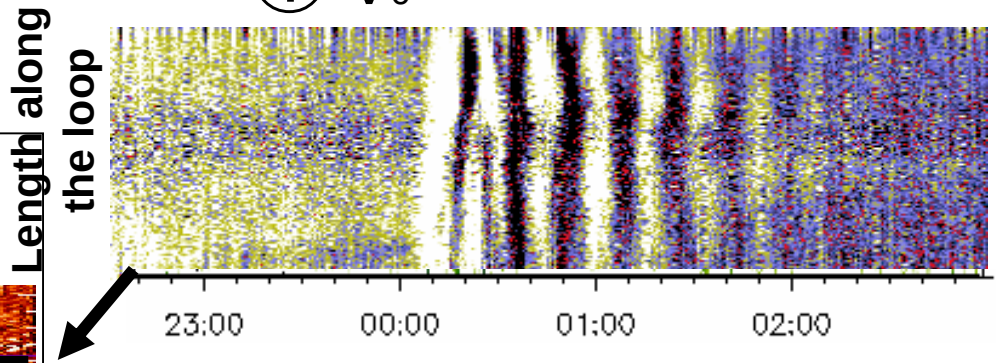
Apex of Loop m (L=3.8x10^5 km)

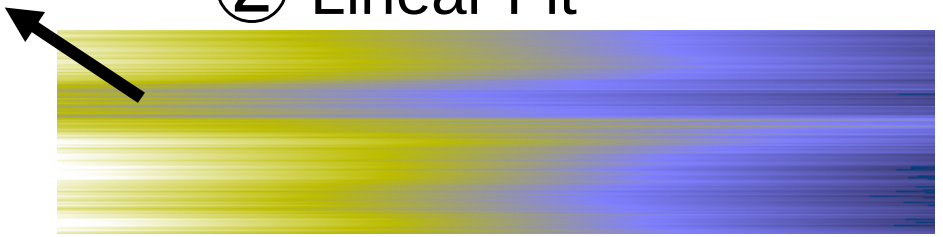


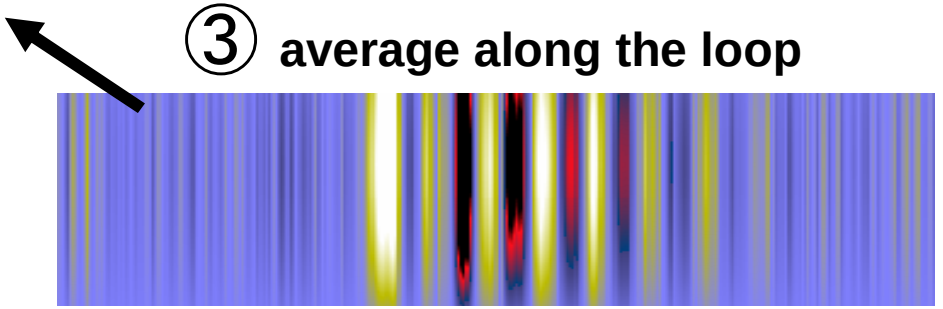
Loop m (L=3.8x10^5 km)



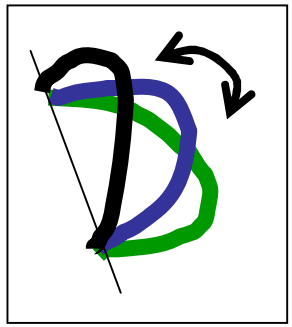




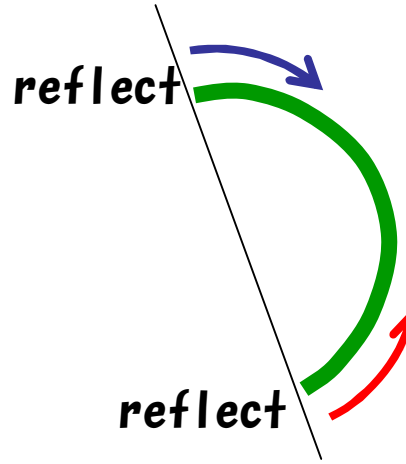




Kink



Plus….

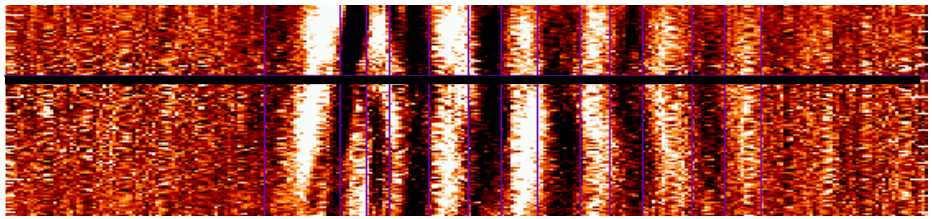


$V_{\parallel} > C_s$

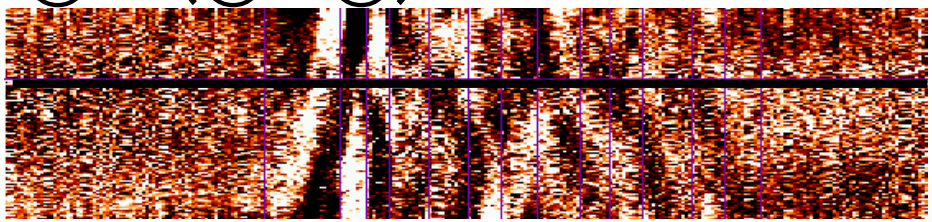
tube speed?

Velocity

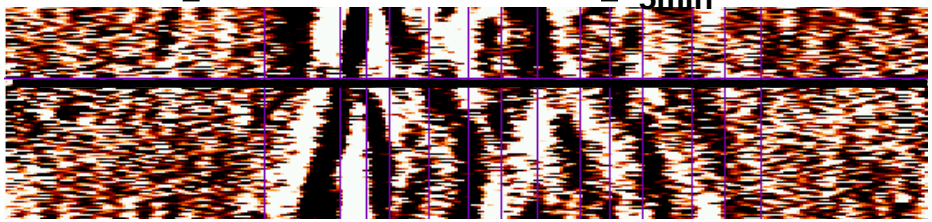
①－②



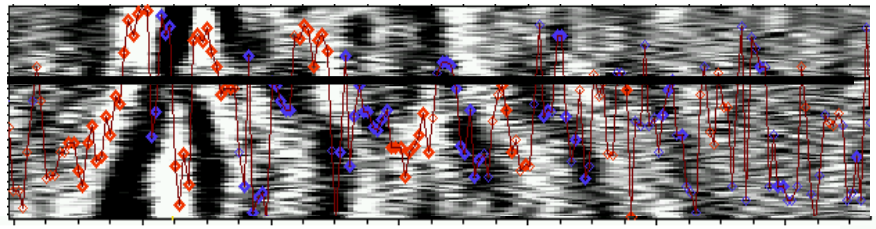
①－(②+③)

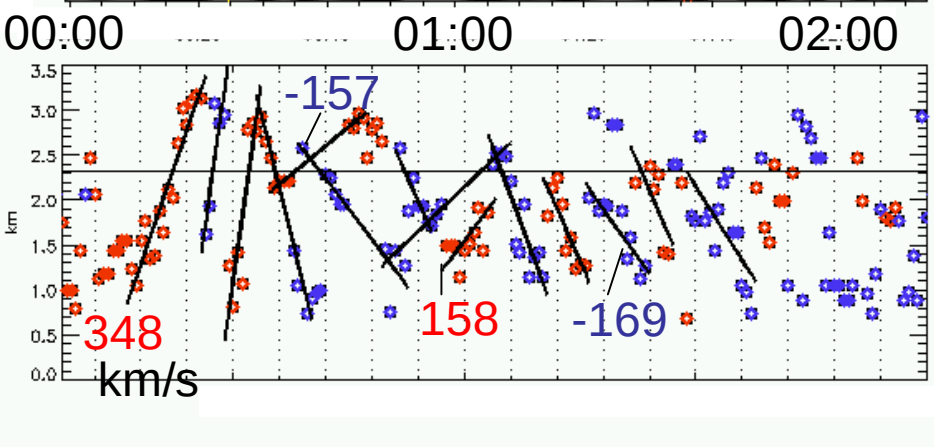


Filter[①－(②+③)] 100min 5min

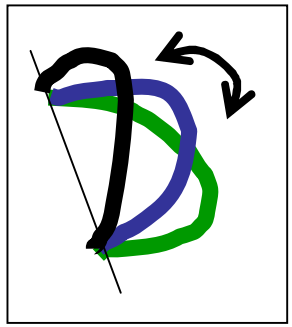


Position of the max |V|



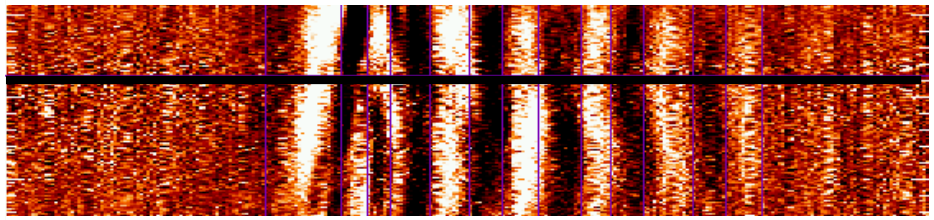


Kink

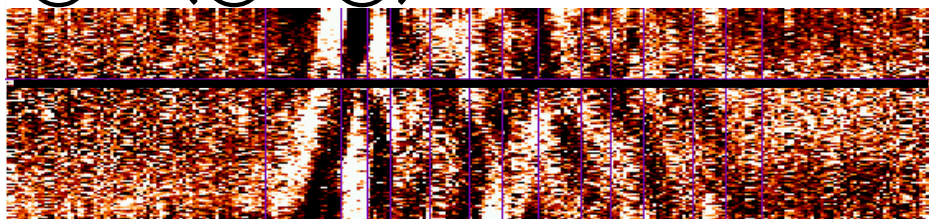


Velocity

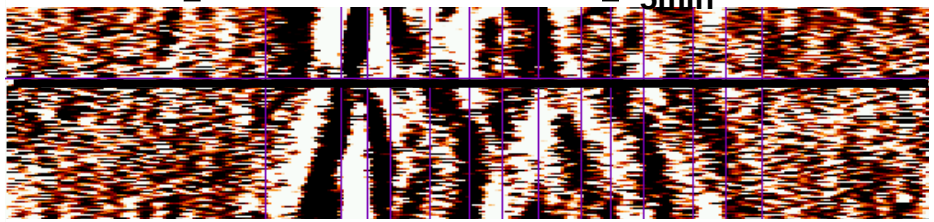
①－②



①－(②+③)

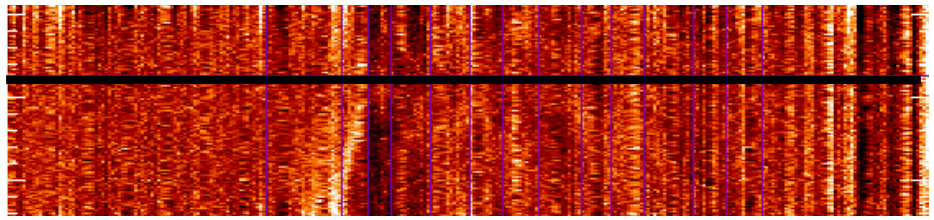


Filter[①－(②+③)] 100min 5min

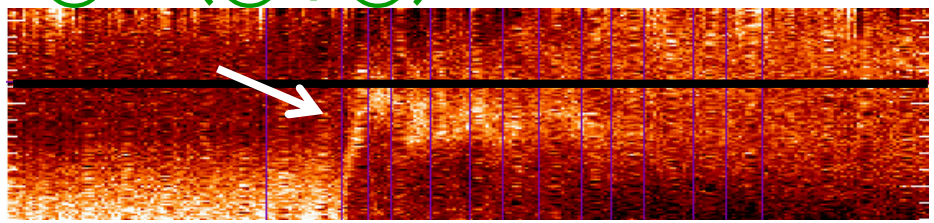


Intensity

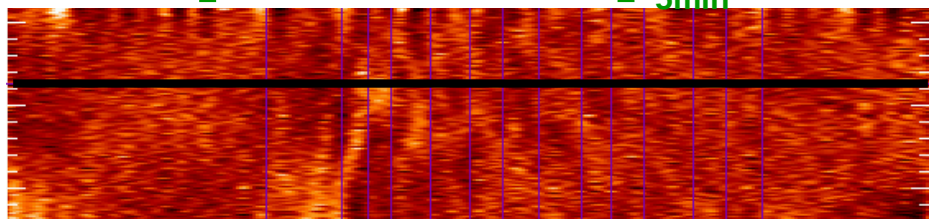
①－②



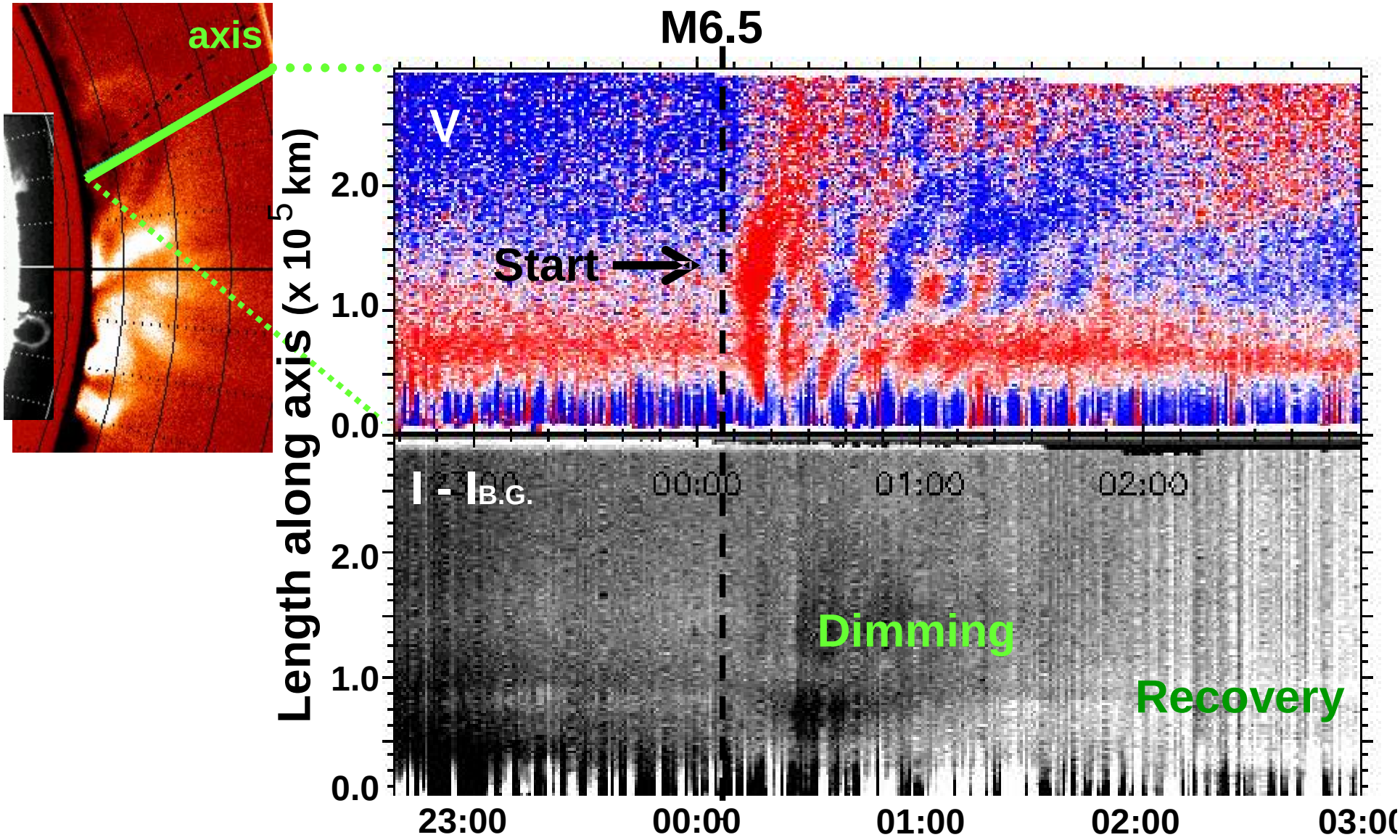
①－(②+③)

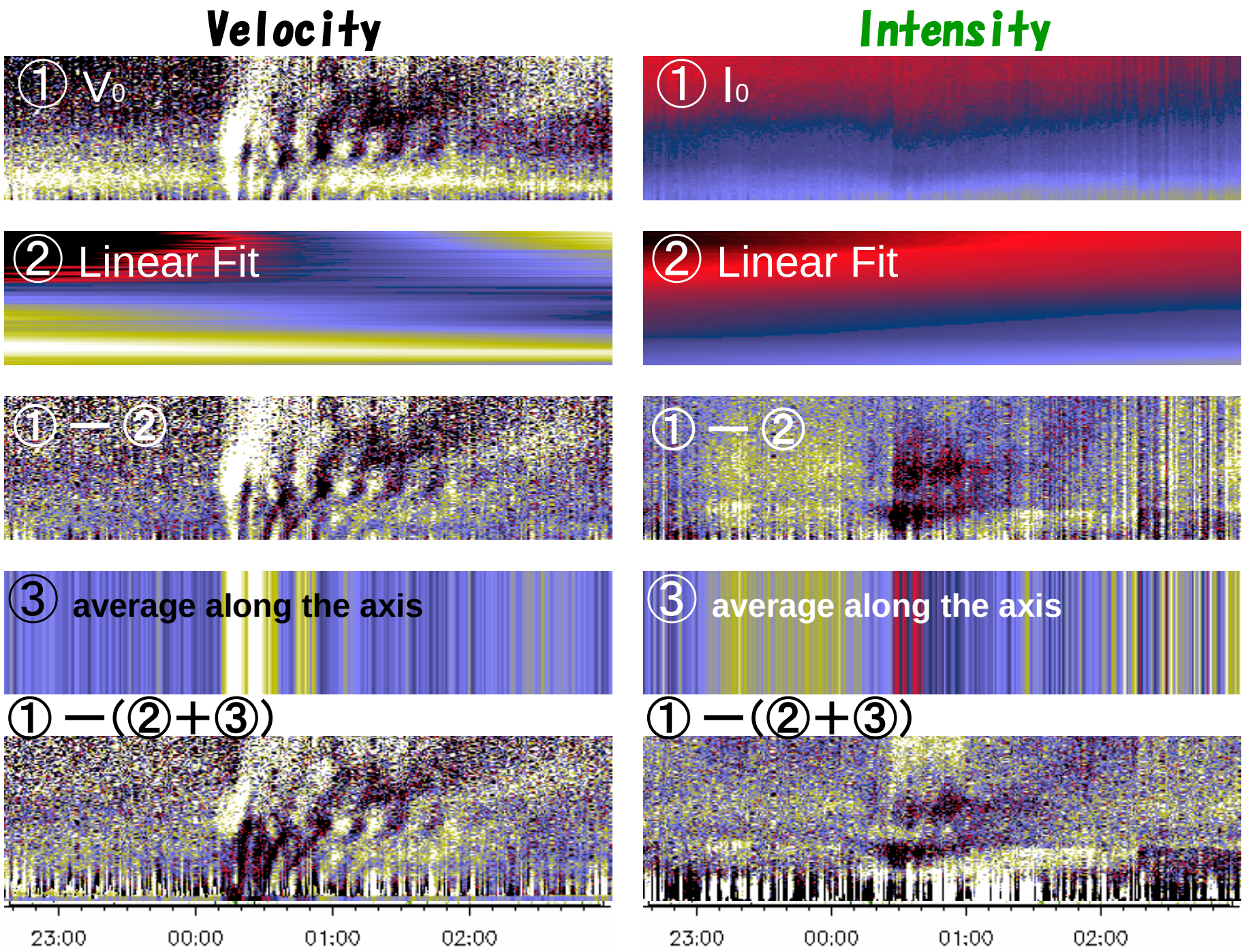


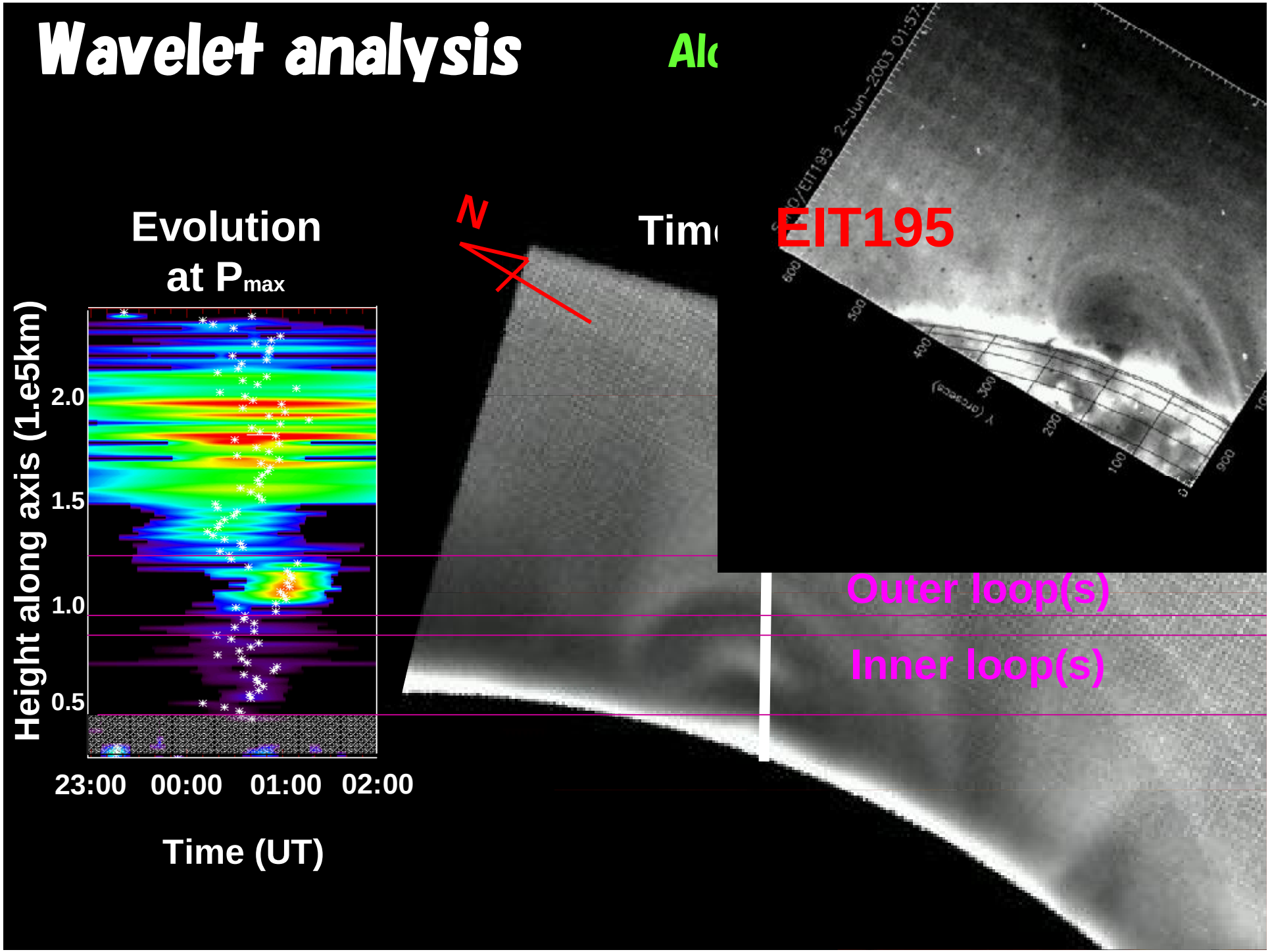
Filter[①－(②+③)] 100min 5min



Time slice along the axis of the oscillations

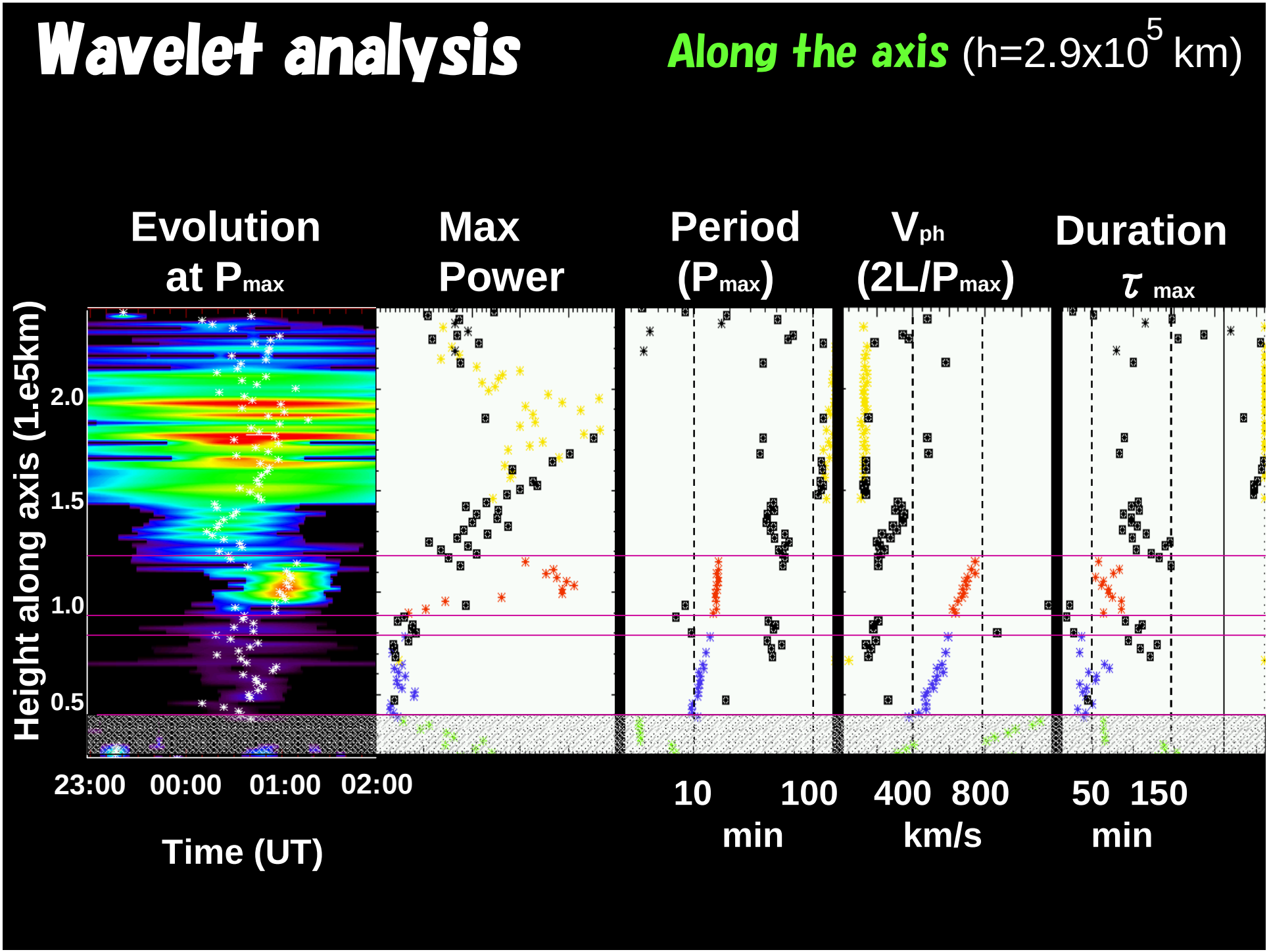




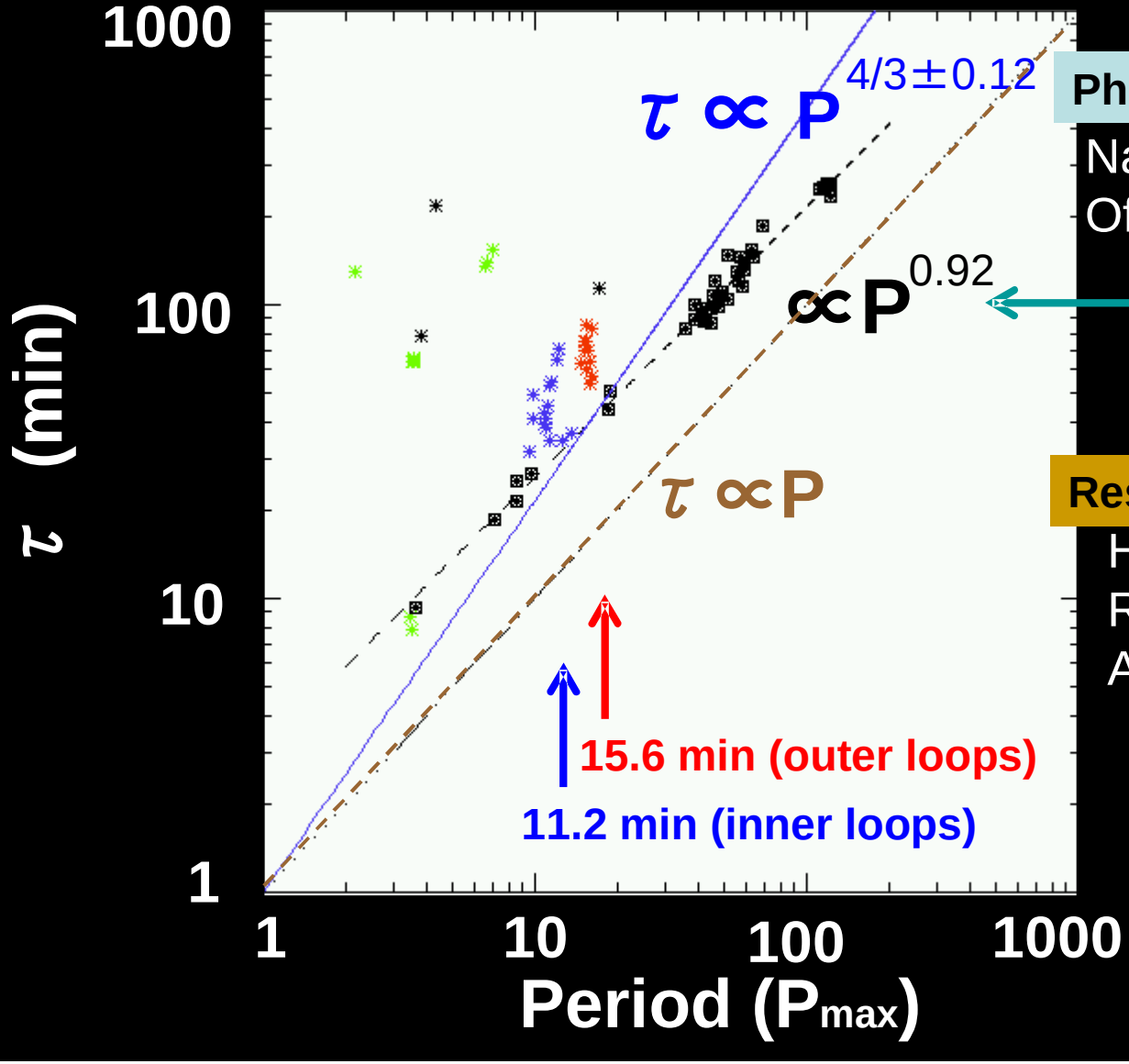


Wavelet analysis

Along the axis (h=2.9x10^5 km)



Wave dumping mechanisms



Phase mixing

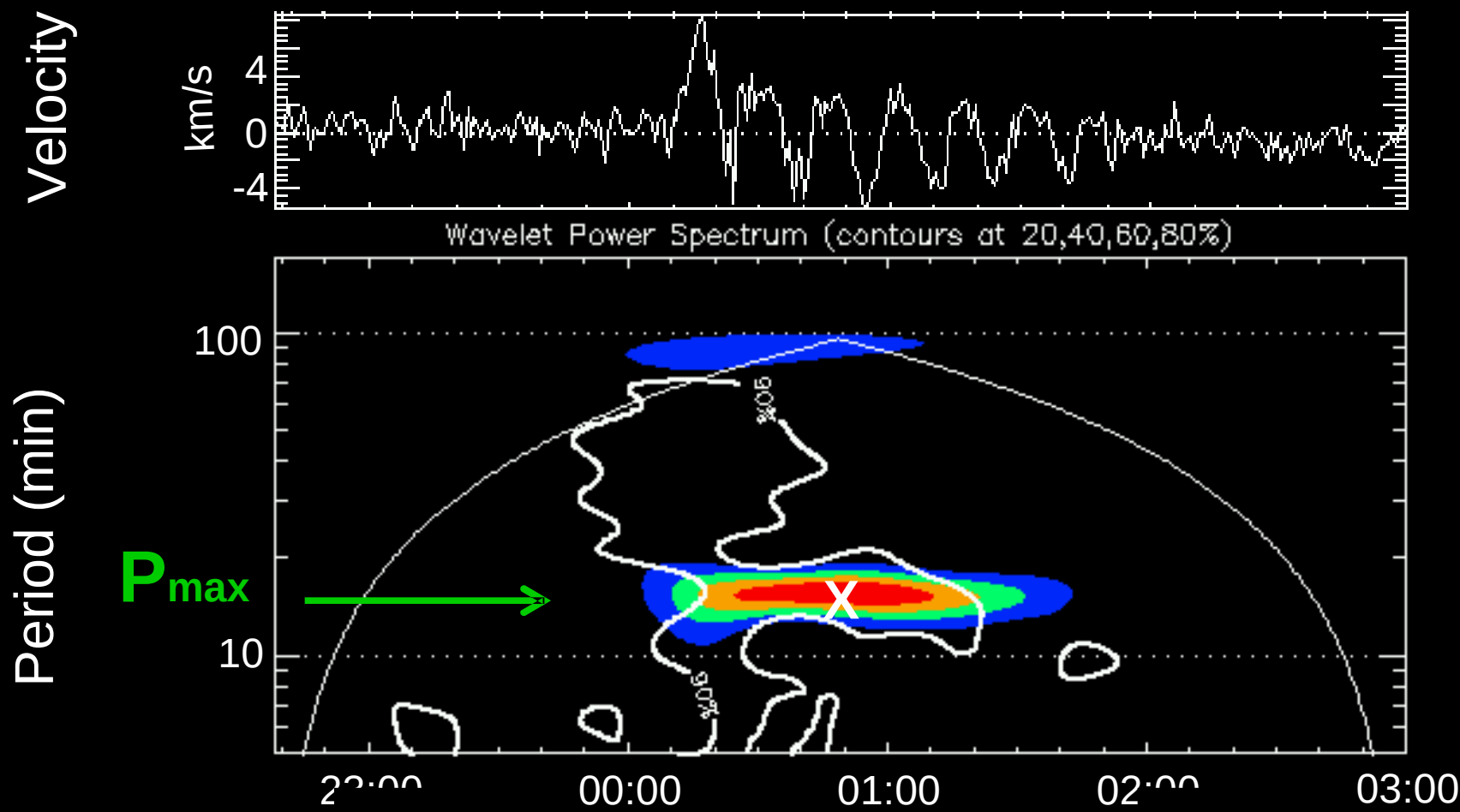
Nakariakov et al. 1999
Ofman & Aschwanden 2002

Outside of the loops?

Resonant absorption

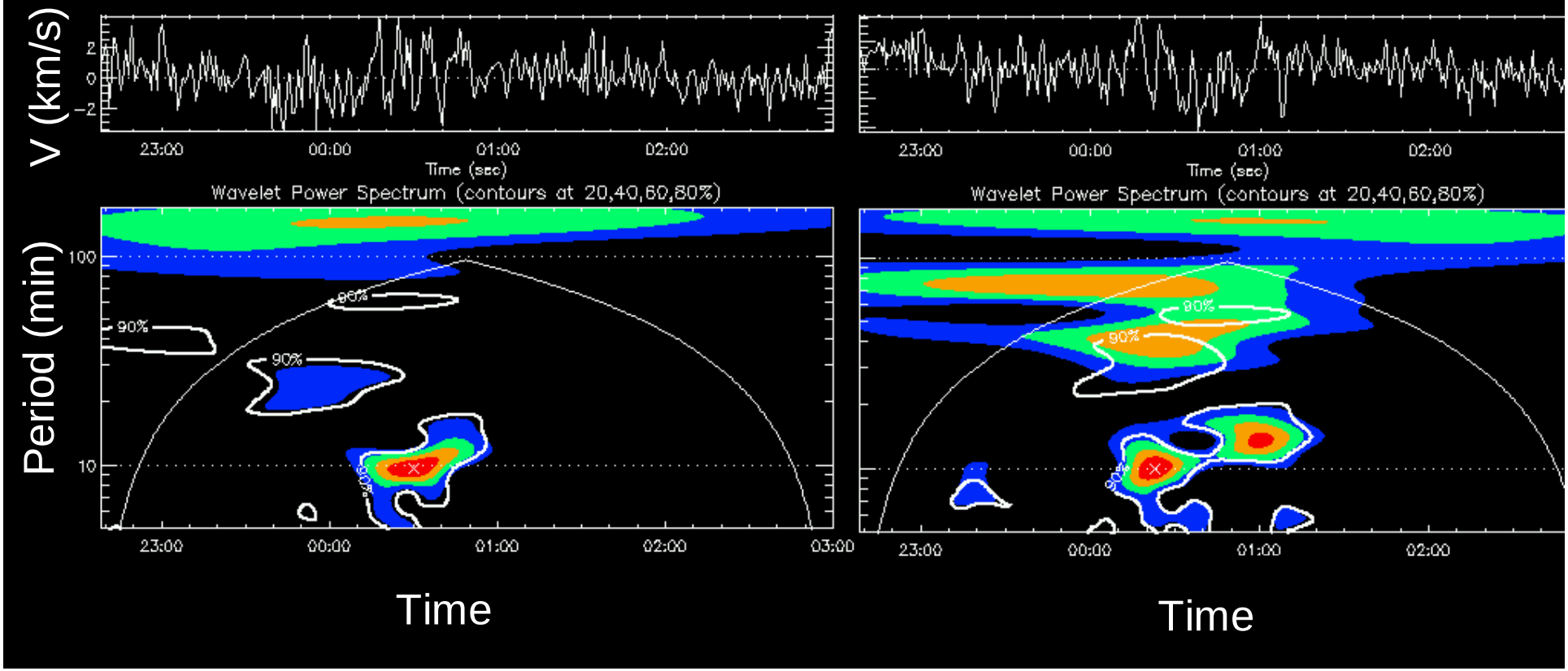
Hollweg 1990
Ruderman & Roberts 2002
Aschwanden et al. 2003

Wavelet analysis



Wavelet analysis

$$dP_{max} / dt \neq 0$$



SUMMARY

We analyzed MHD oscillations in coronal multiple loops observed with NOGIS in the coronal green line (2MK).

○ *Triggered by an impulsive pulse (traveling fast wave)*

○ *Kink + slow mode?*

Doppler velocity was not maximum at the apex of each loop.

The turbulences propagated both transverse and parallel to the loops.

(Intensity oscillations were not seen…)*

○ *Energy propagation toward outer (outside of the) loops?*

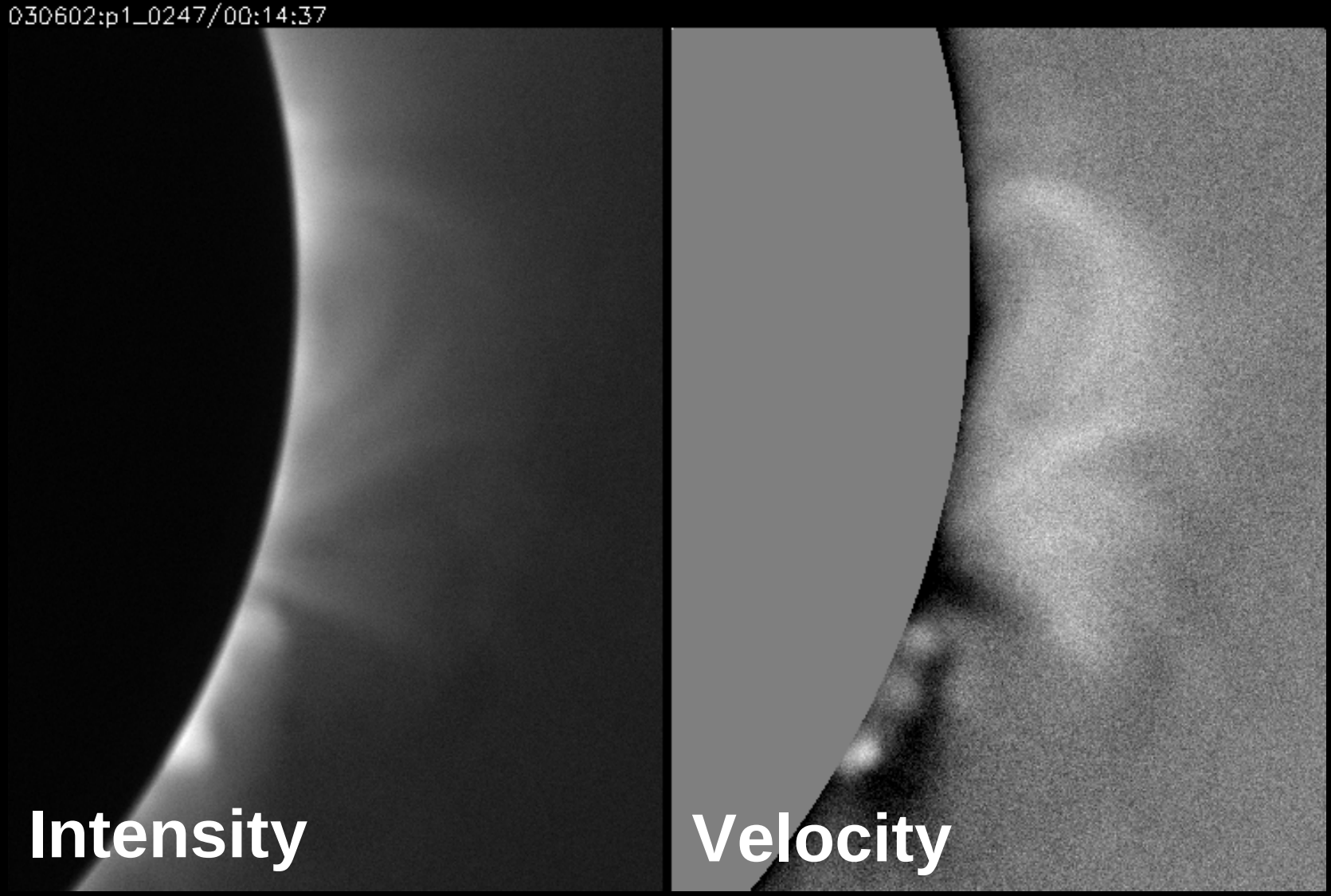
Longer period for outer (less dense) loops (10-16min)

Smooth variations: Fundamental mode for each loop

Collaborative observations with solar-B/EIS in a wide temperature range is crucial to understand the energy exchange (dissipation) process in oscillation/wave phenomena.

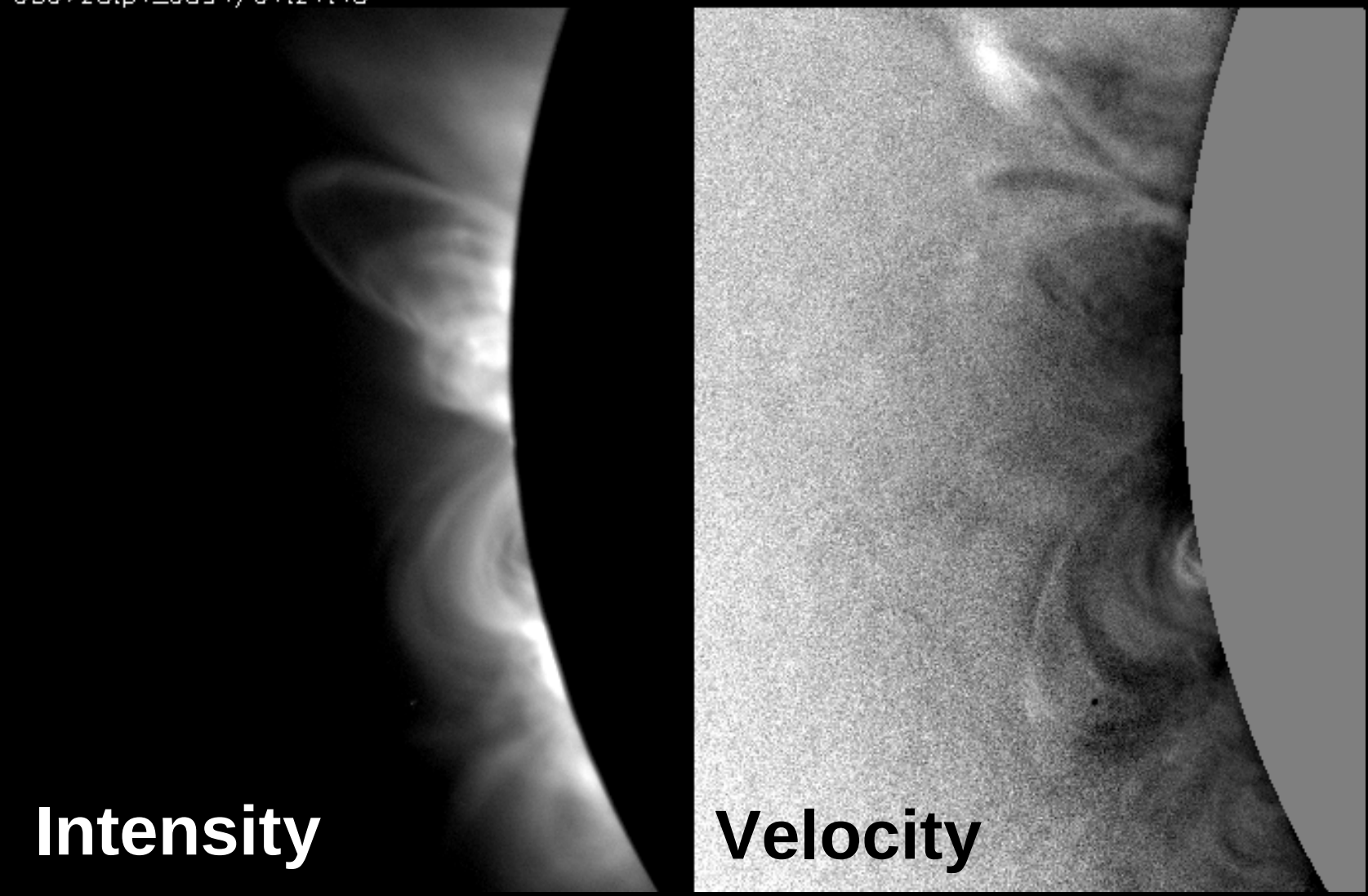
国立天文台 NAOJ National Astronomical Observatory of Japan

NOGIS image (our event)



June 2, 2003

NOGIS best image



July 28, 2005 (P68 Suzuki, I. et al.)