First Detection of Radial and Azimuthal Oscillations in Halo CMEs

Harim Lee, Y.-J. Moon, Valery M. Nakariakov

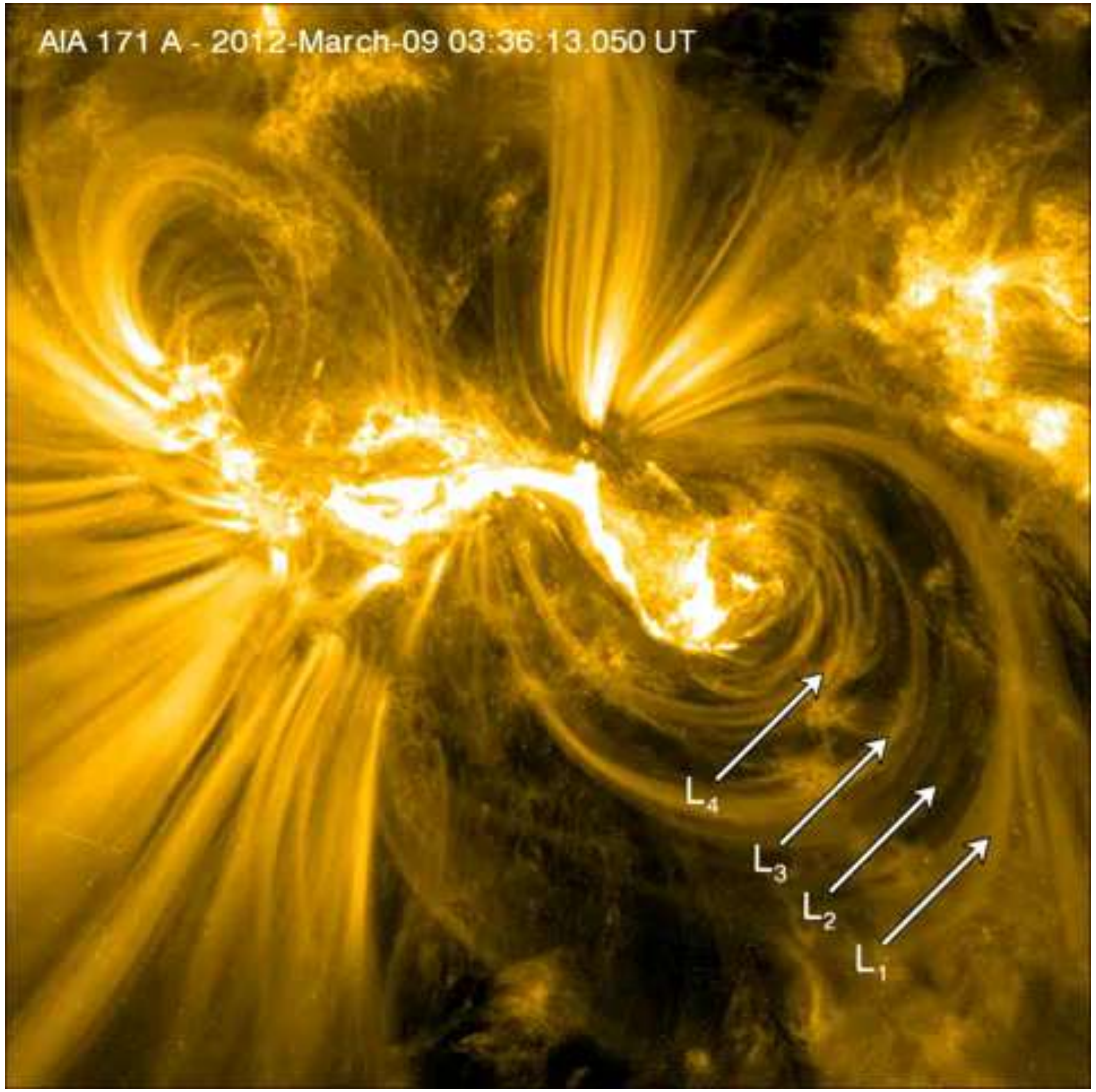
School of Space Research, Kyung Hee University

harim@khu.ac.kr / Lee et al., ApJL, 803, 2015

Introduction

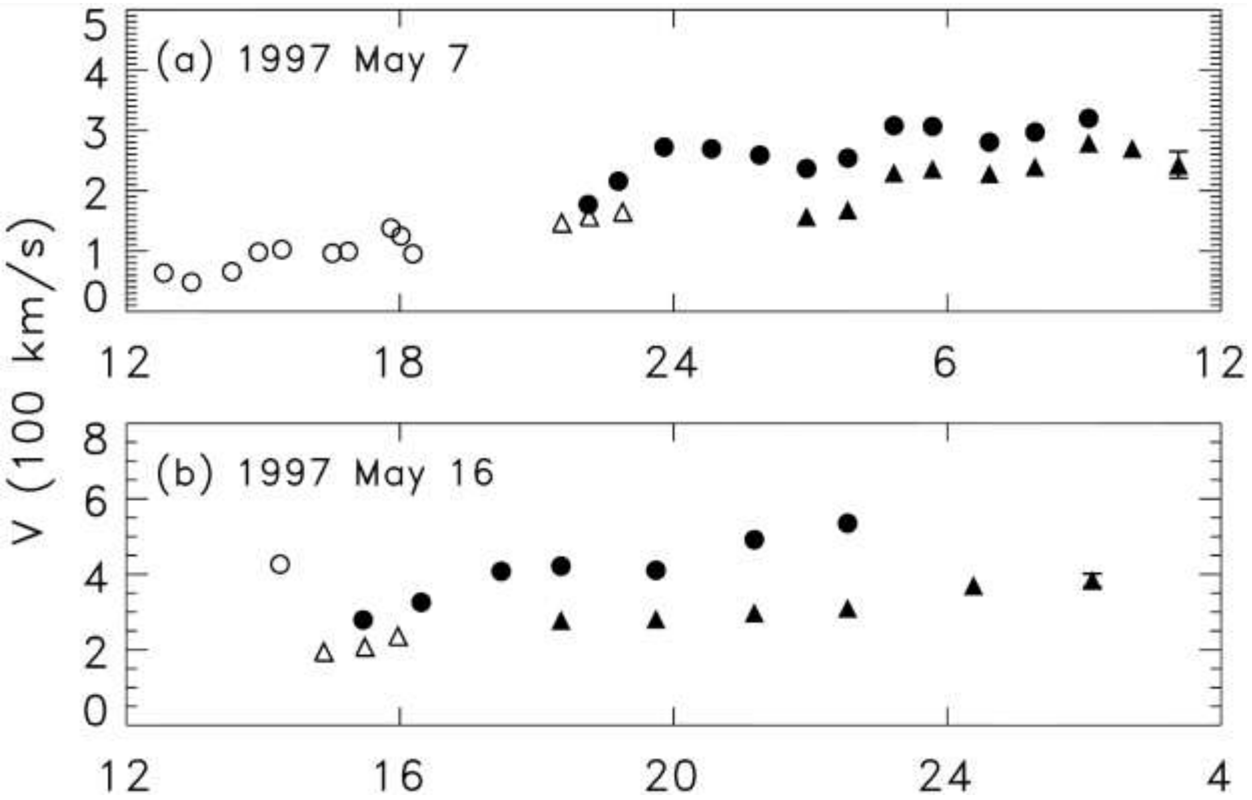
- There have been many observations on the oscillations of **prominence/filaments** [Oliver & Ballester 2002; Lin et al. 2007; Tripathi et al. 2009] and **coronal loops** [Aschwanden et al. 2003; Nakariakov & Verwichte 2005; Ruderman & Erdelyi 2009; Terradas 2009].

- The interest in MHD oscillations is connected with **MHD seismology** - diagnostics of plasma parameters and physical processes operating in the plasma by means of MHD oscillations.

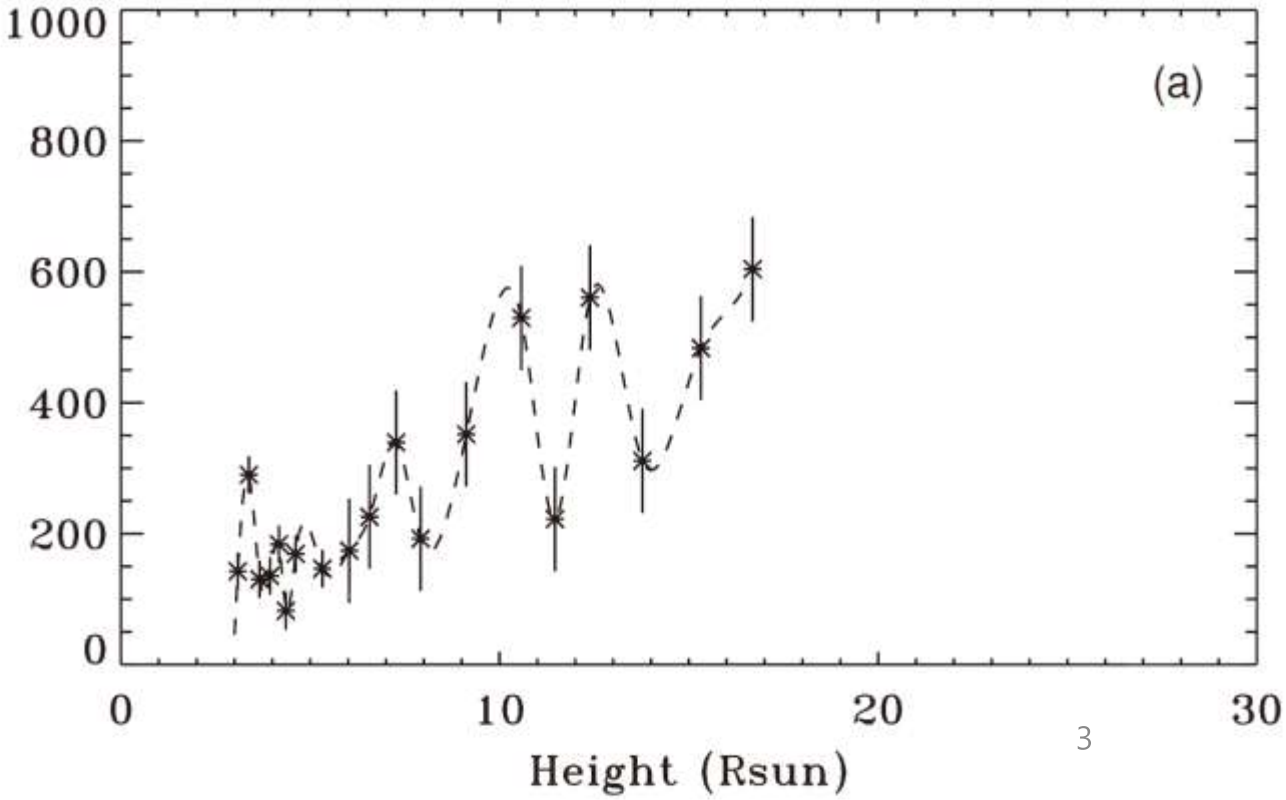


Introduction

- Krall et al. [2001] found that the projected velocities varied with the period of about 4 - 6 hours for 11 CME events.

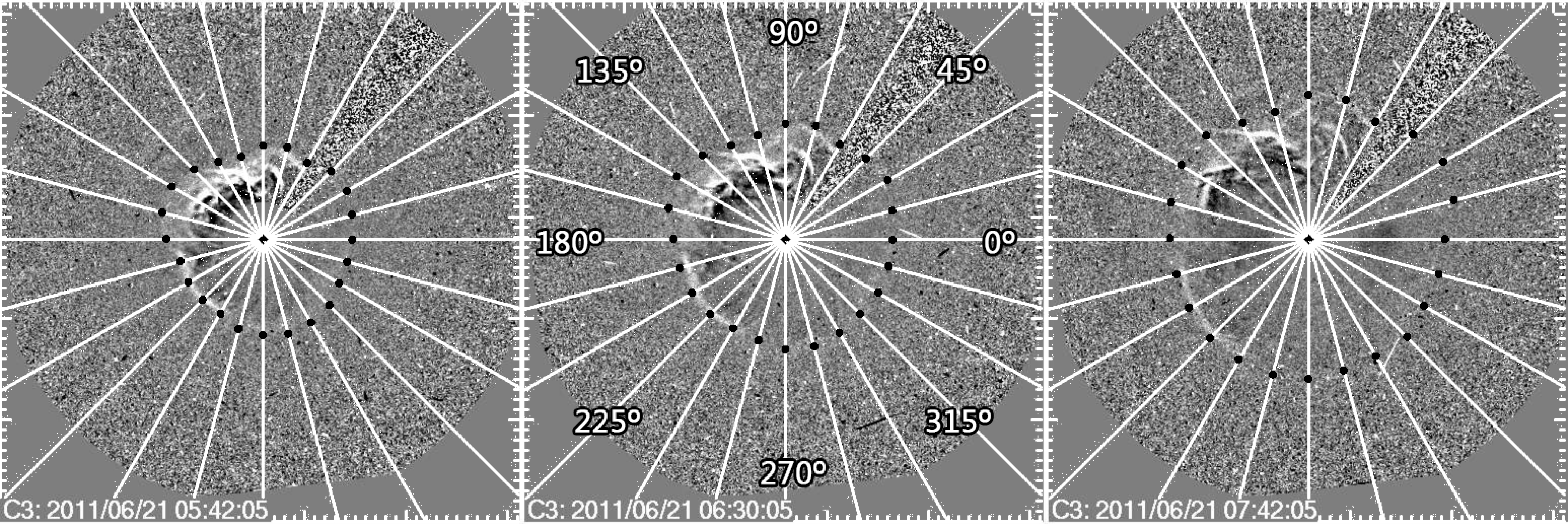


- Shanmugaraju et al. [2010] found that the periods of quasi-periodic oscillations range between 48 and 240 minutes for 15 CME events.



Data

- We consider well-observed 9 HCMEs by LASCO from 2011 February to June.



➢ The running difference images of the propagation of the HCME (5:42-07:42 UT) on 2011 June 21. The radial white lines (every 15°) show the given direction and black dots show the measured front edge of the HCME.

Spherical harmonics

: Laplace's equation in spherical coordinates

$$\nabla^2 f = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial f}{\partial r}\right) + \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta \frac{\partial f}{\partial \theta}\right) + \frac{1}{r^2 \sin^2\theta}\frac{\partial^2 f}{\partial \varphi^2} = 0$$

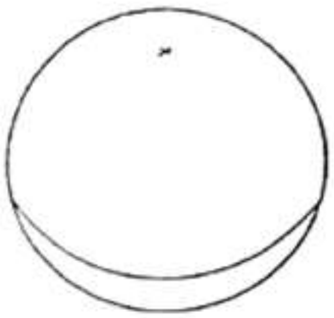
$$r^2 \nabla^2 Y_\ell^m(\theta,\varphi) = -\ell(\ell+1) Y_\ell^m(\theta,\varphi)$$

Is called spherical harmonic function of degree ℓ and order m

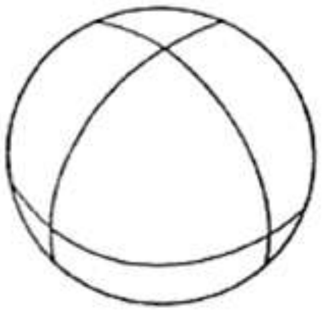
ℓ : degree, the total number of node circles on the sphere

m : longitudinal order, the number of node circles through the poles

ℓ=1, m=0

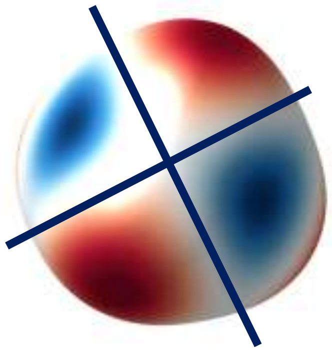


ℓ =3, m =2

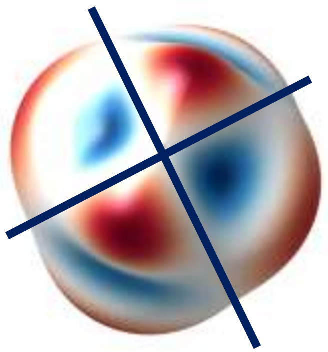


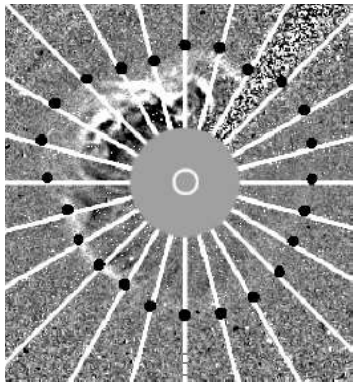
ℓ=10, m=5

ℓ =3, m =2

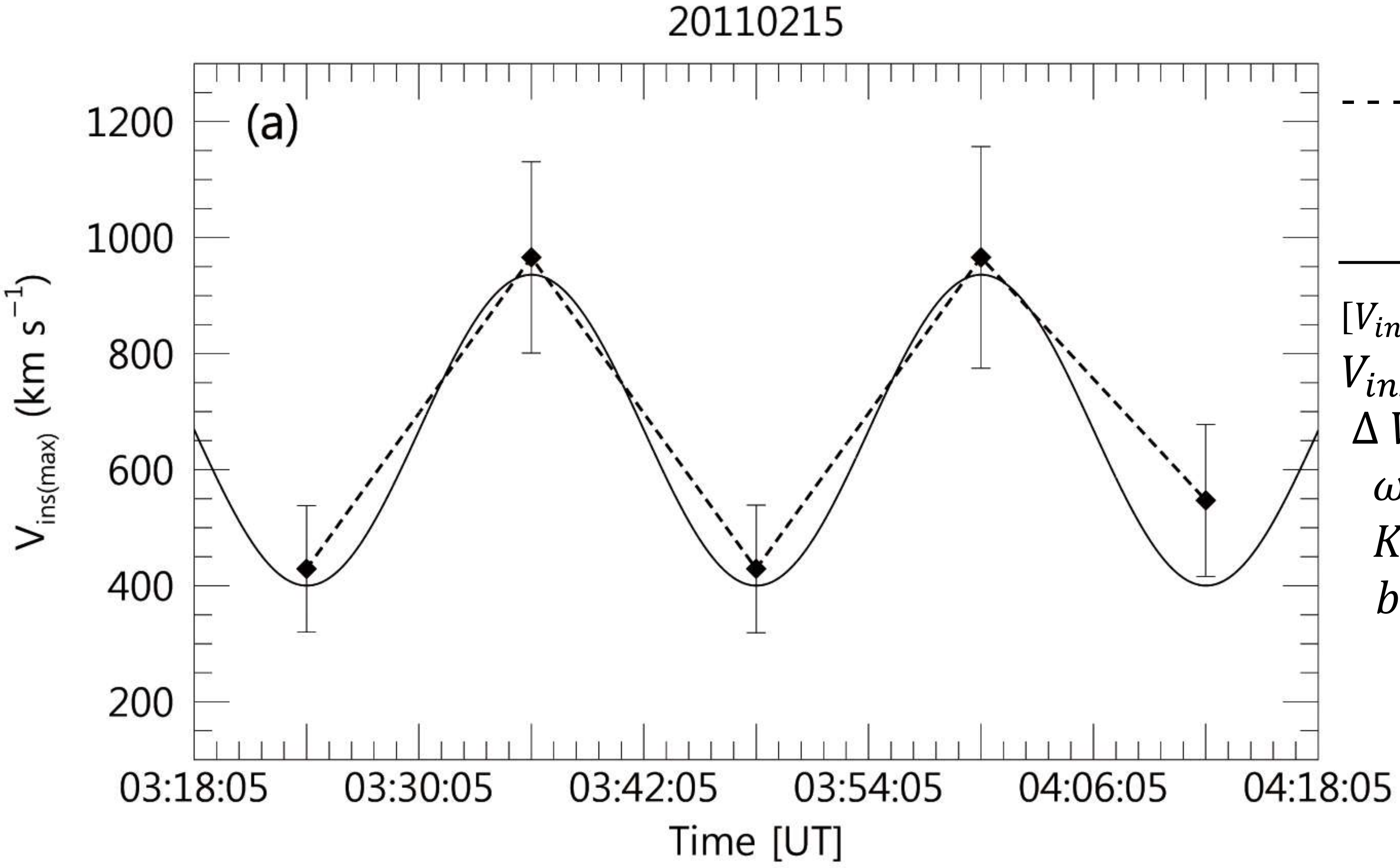


ℓ=5, m=2





Results



- - - - **Maximum amplitude**

—— **Harmonic function**

$[V_{ins} = \Delta V sin(\omega(t-K)) + b]$

V_{ins} : instantaneous speed

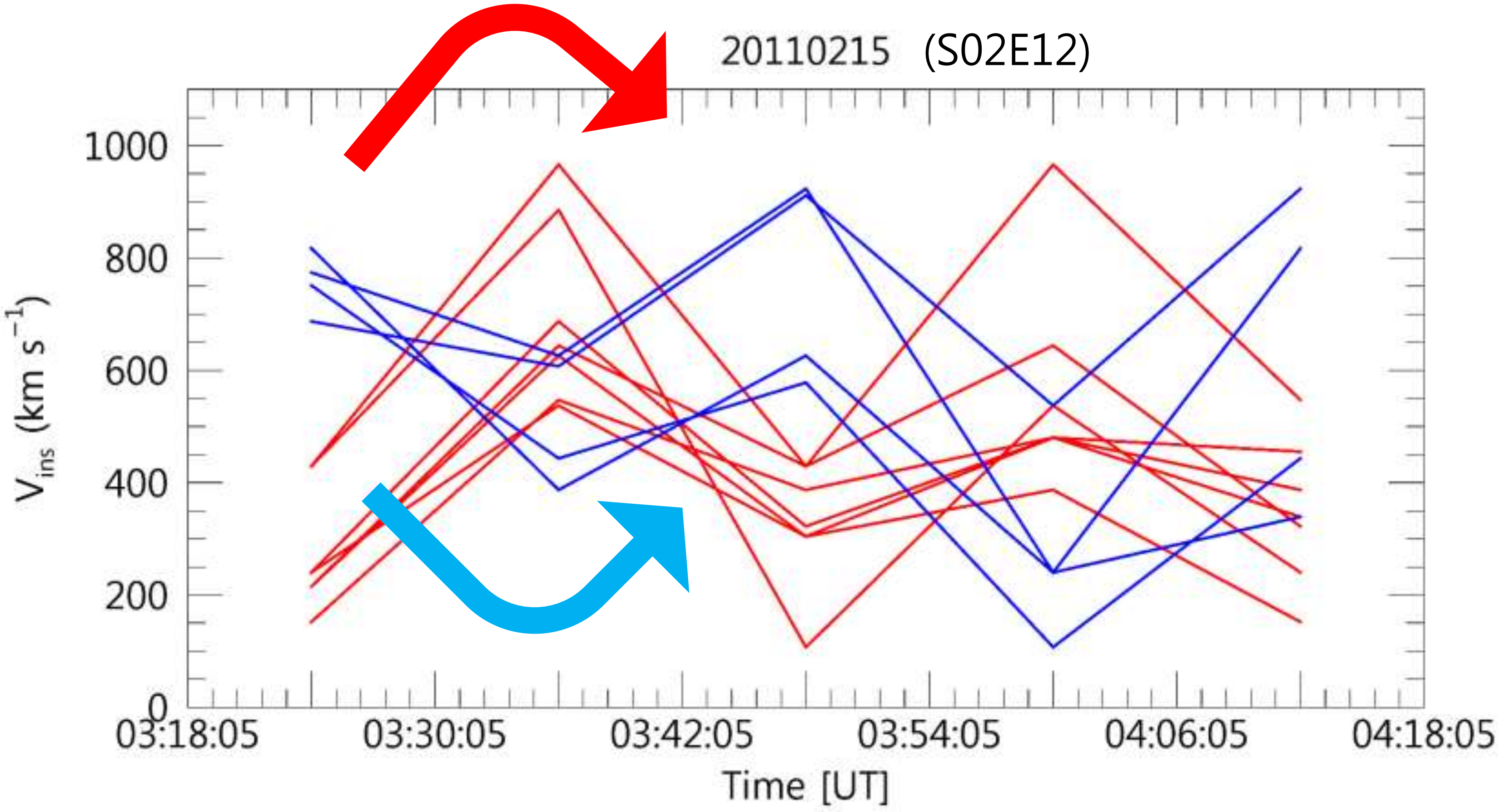
ΔV : speed amplitude

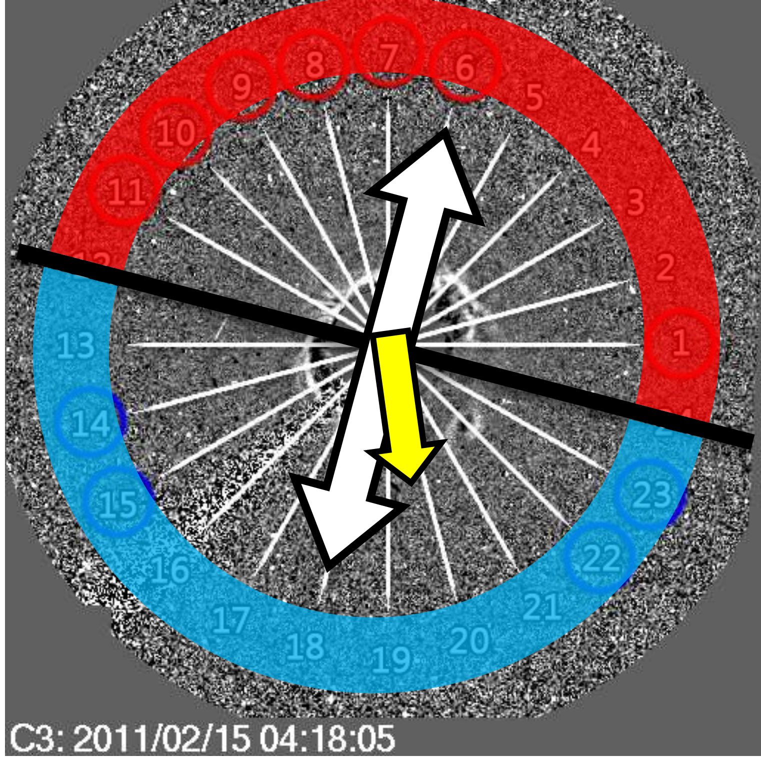
ω : cyclic frequency

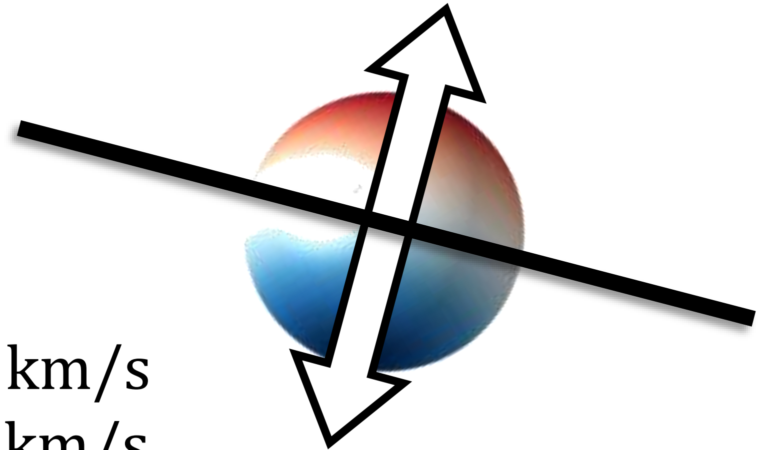
K : phase

b : mean value

Results (wave mode : m=1)

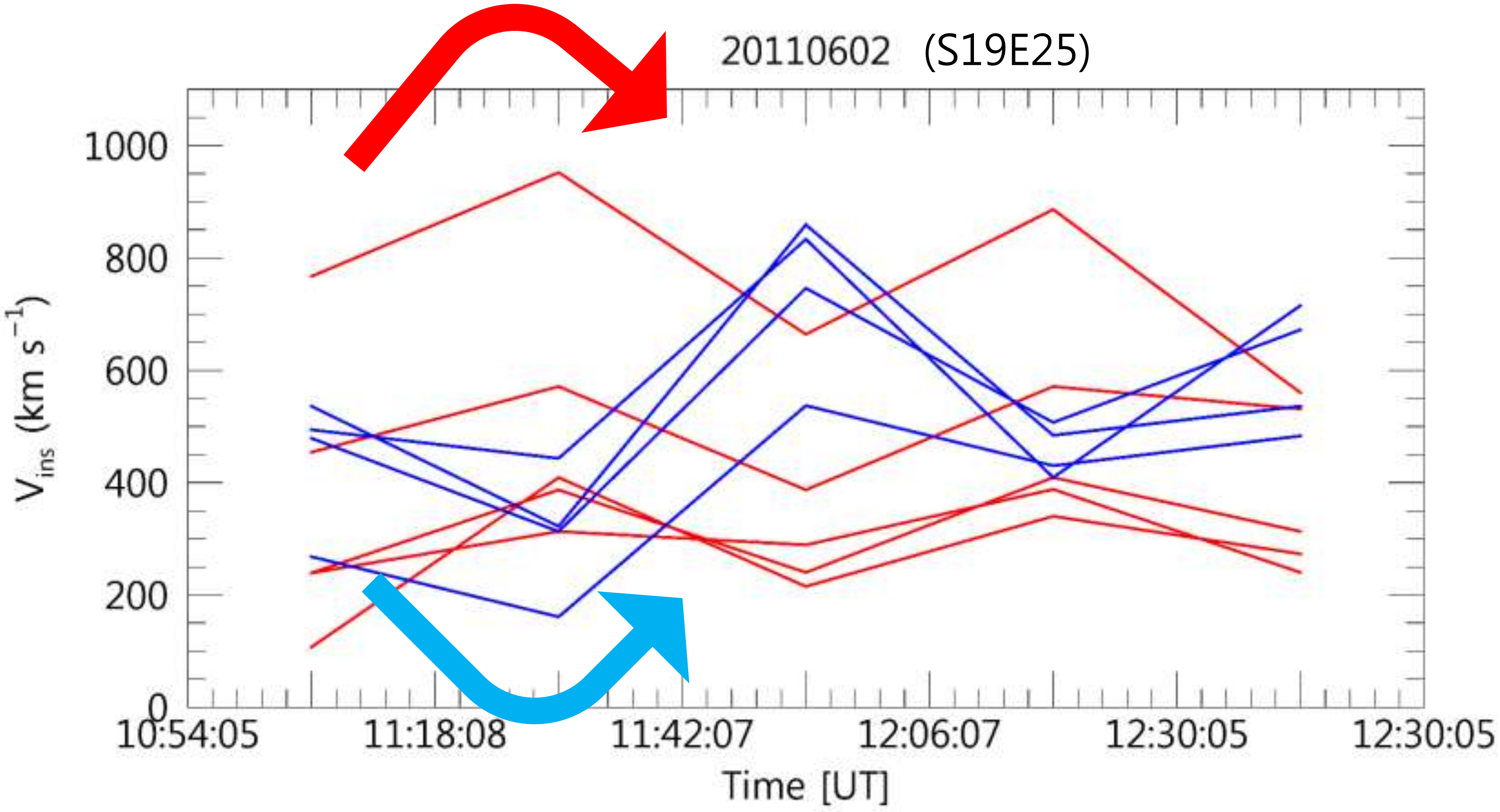


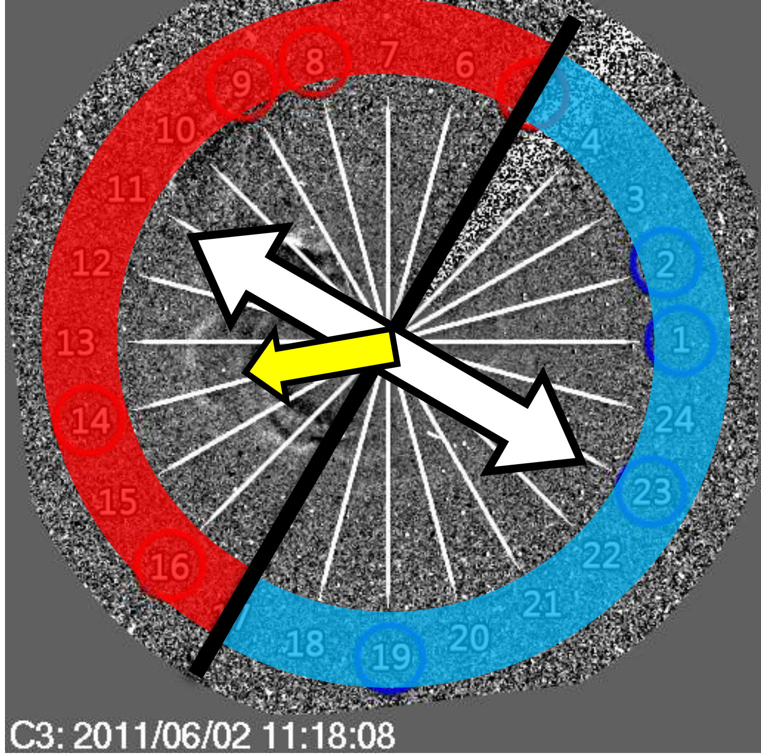


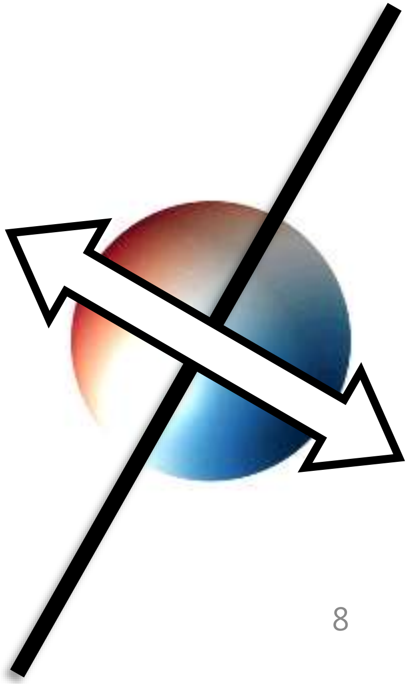


- ✓ Oscillation direction (arrow) : 75°
- ✓ Oscillation period : 24 mins
- ✓ Speed amplitude : 400 km/s
- ✓ Projection speed : 800 km/s

Results (wave mode : m=1)

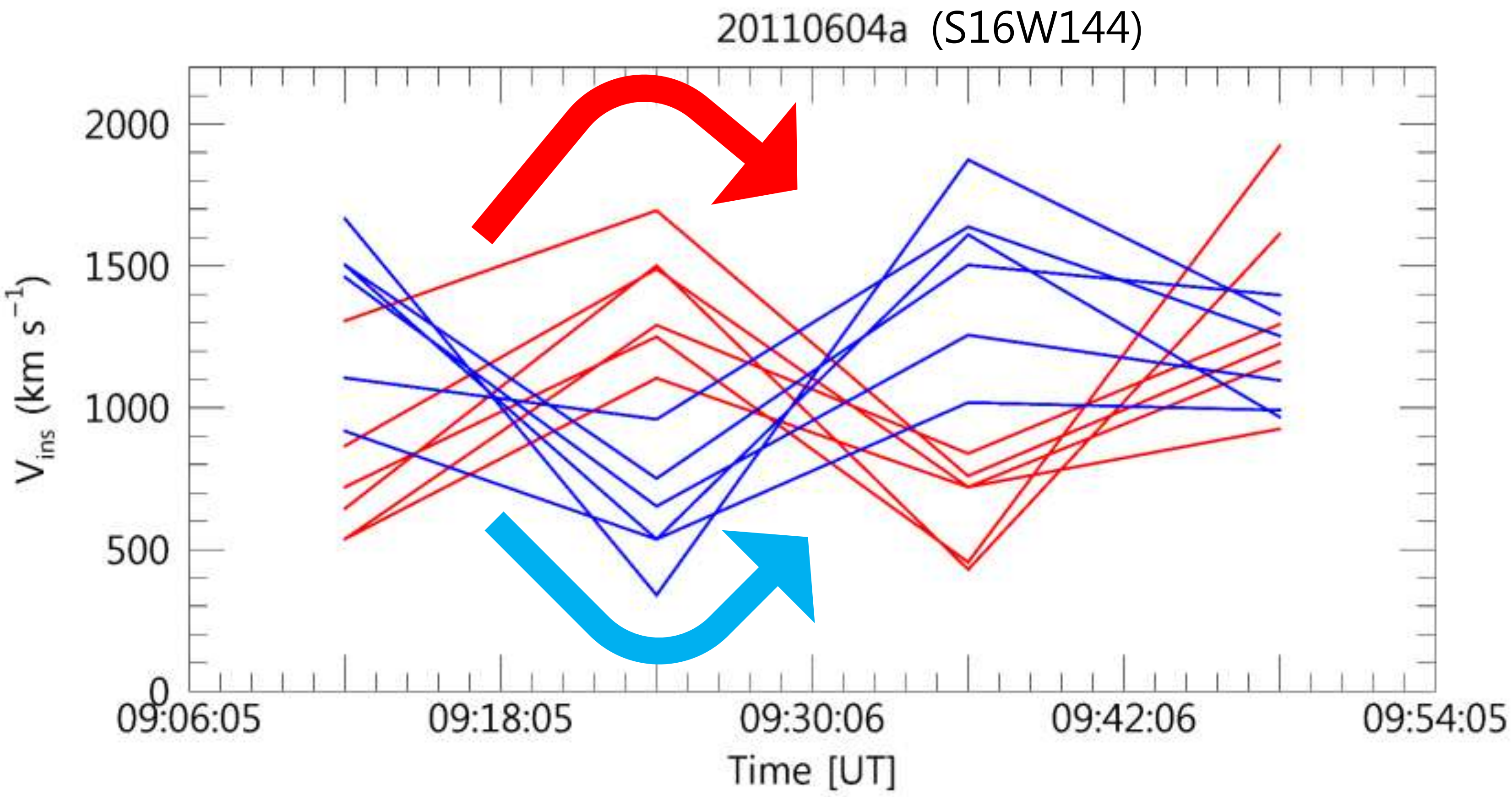


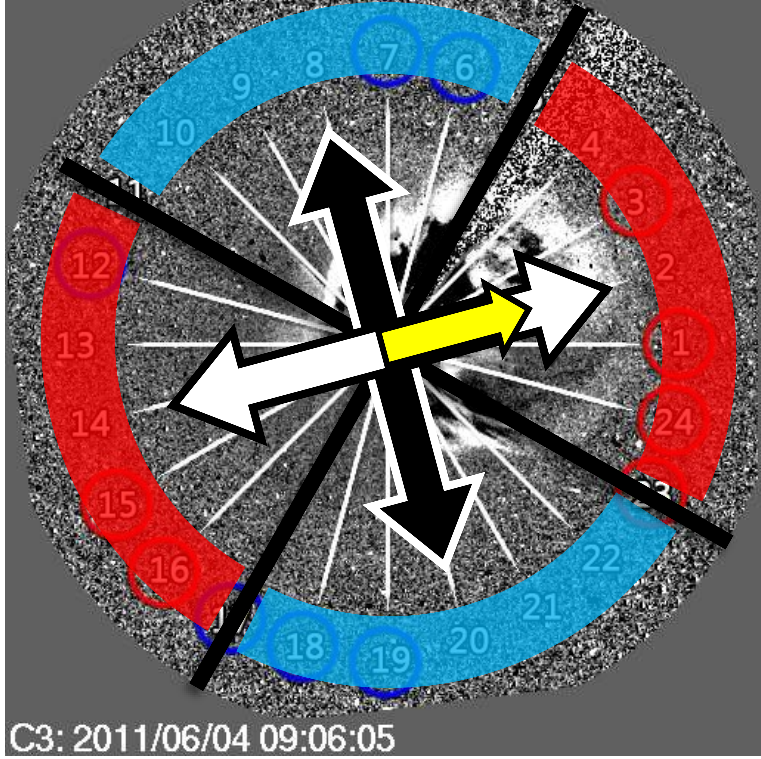


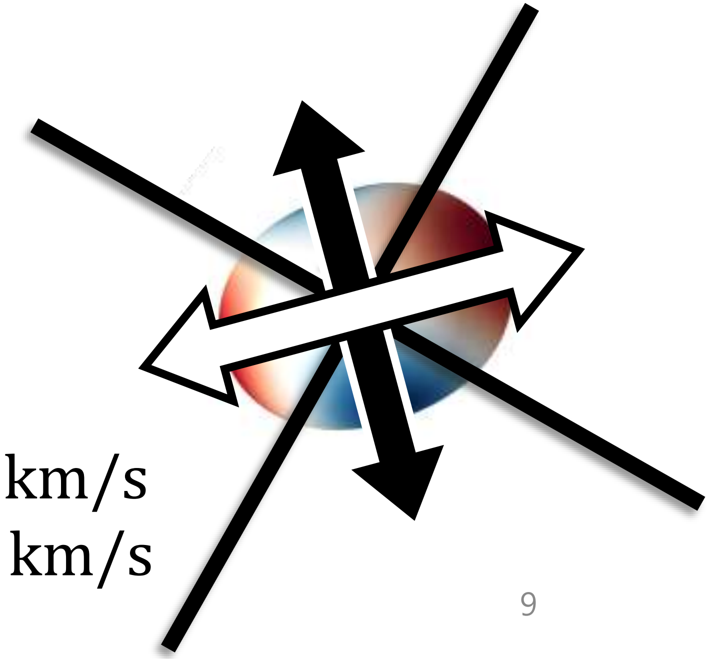


- ✓ Oscillation direction (arrow) : 135°
- ✓ Oscillation period : 48 mins
- ✓ Speed amplitude : 300 km/s
- ✓ Projection speed : 800 km/s

Results (wave mode : m=2)

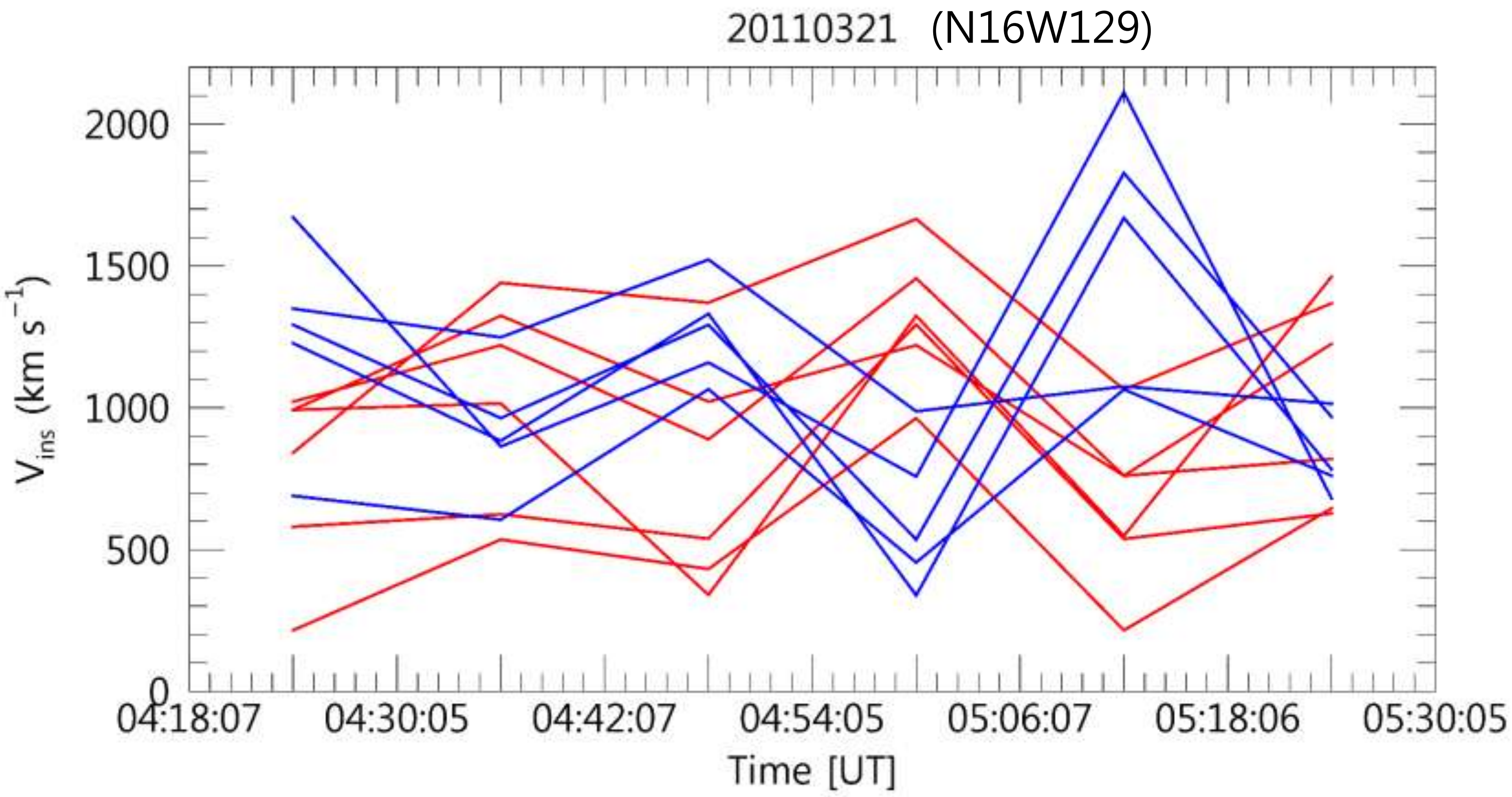


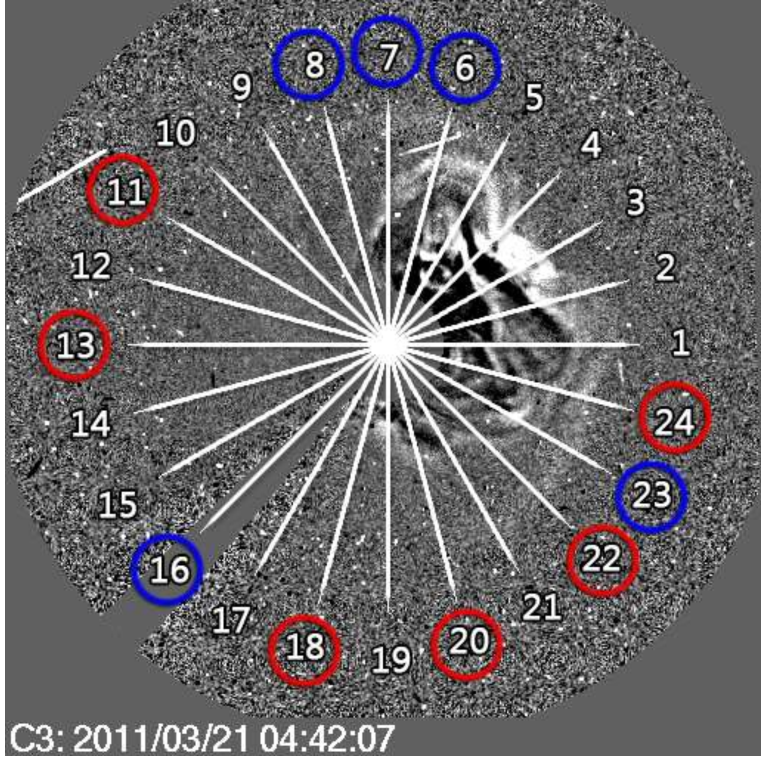




- ✓ Oscillation direction : 15°, 105°
- ✓ Oscillation period : 24 mins
- ✓ Speed amplitude : 800 km/s
- ✓ Projection speed : 1500 km/s

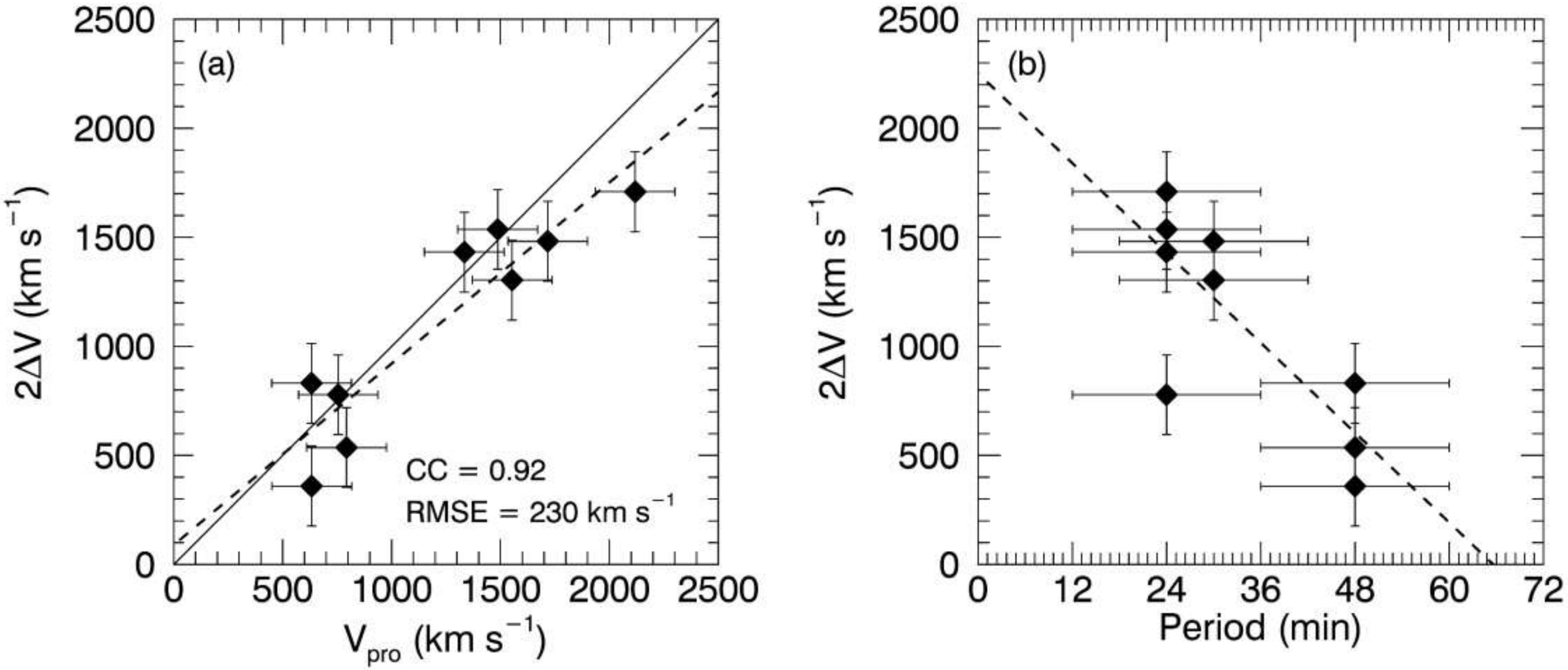
Results (complex wave pattern)





- ✓ Oscillation direction : 30°, 90°
- ✓ Oscillation period : 24 mins
- ✓ Speed amplitude : 700 km/s
- ✓ Projection speed : 1300 km/s

Results

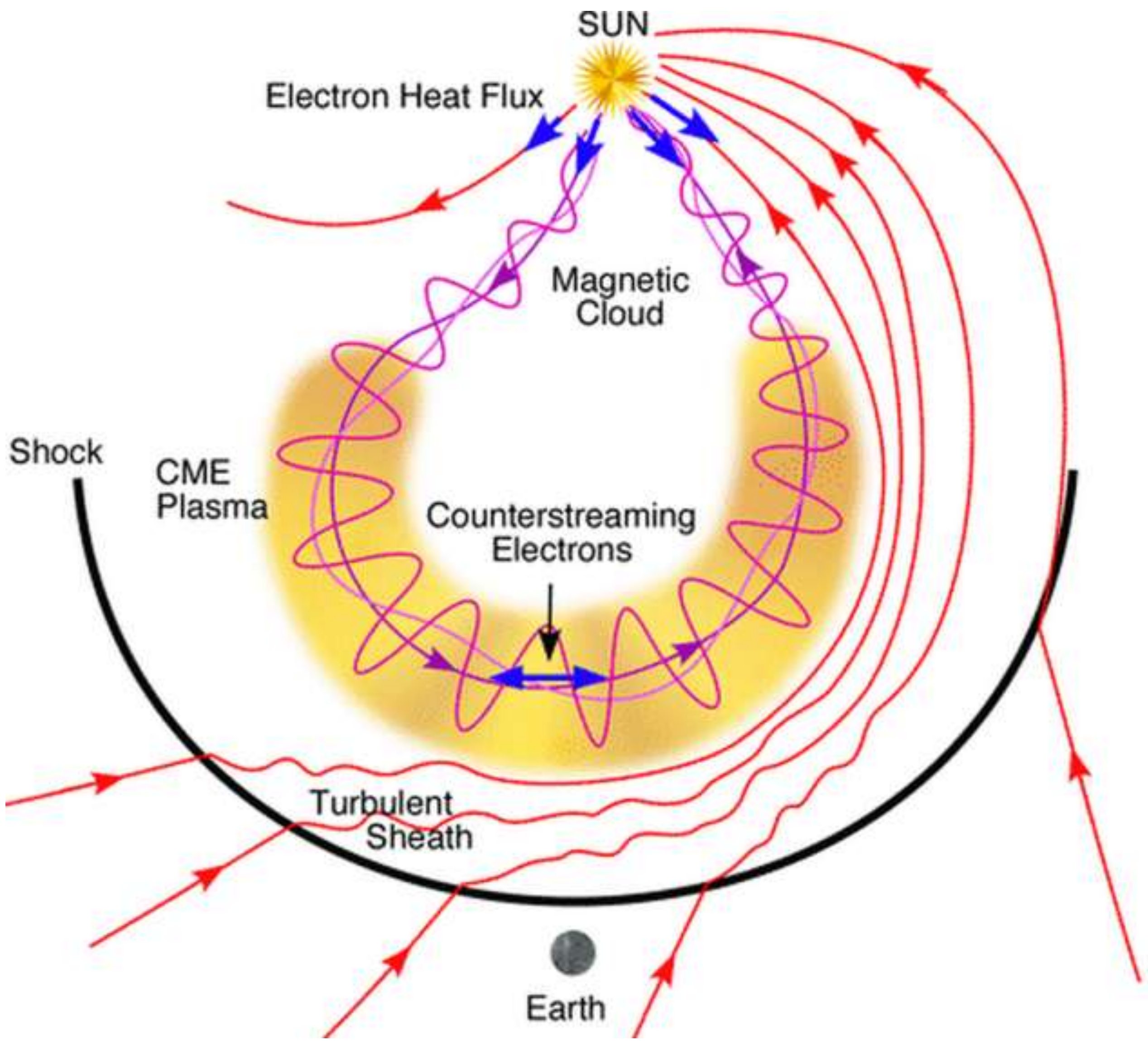


- Correlation between (a) the observed maximum projected speed (V_{pro}) and the oscillation amplitude ($2\Delta V$). (b) the oscillation period and amplitude.

Discussions

- One interpretation is connected with the natural oscillations of the plasmoid displaced from its equilibrium.

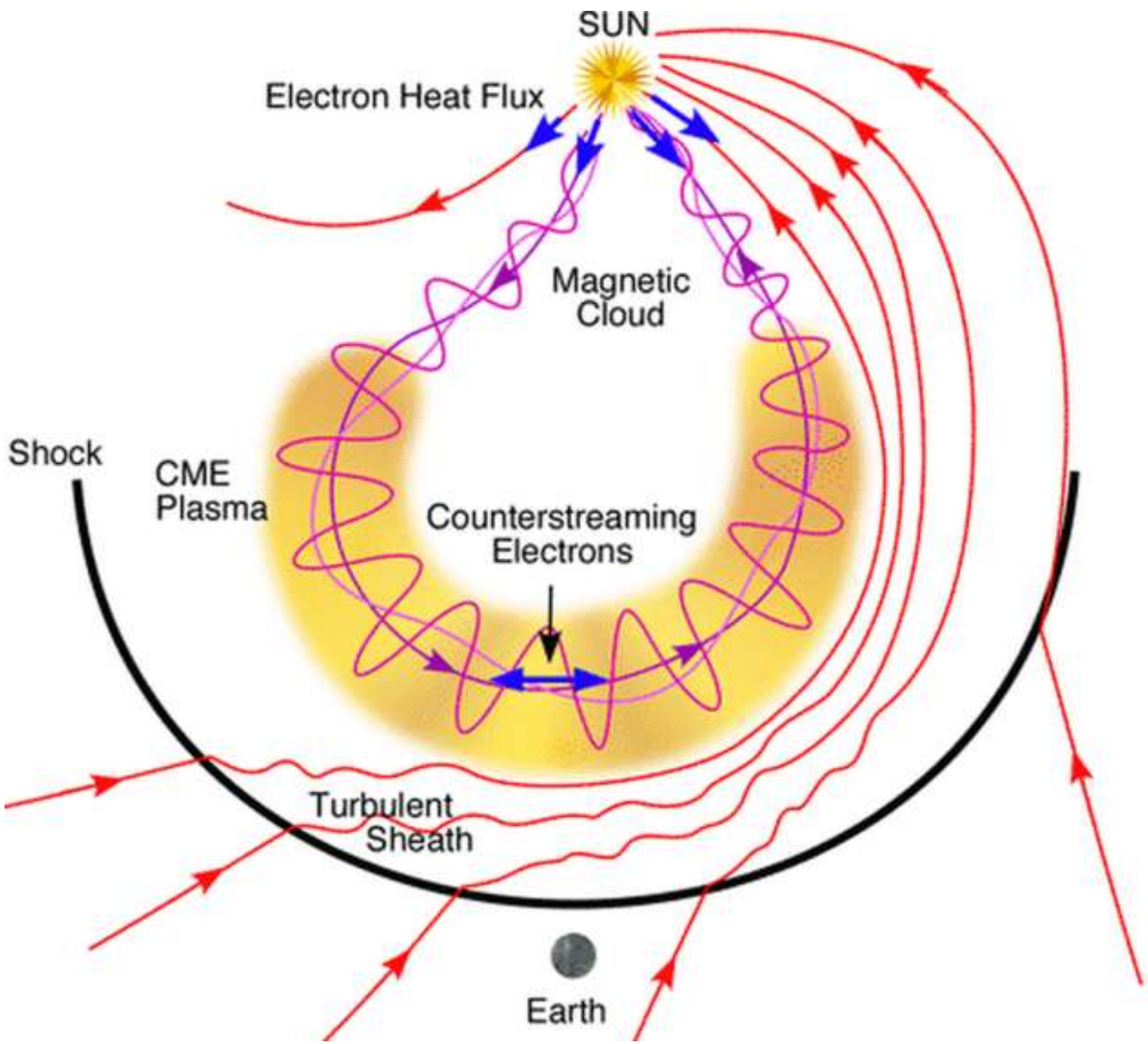
- In particular, estimations performed by Cargill et al. [1994] and Filippov et al. [2001] showed that a curved magnetic rope could perform oscillations with a period up to several tens of minutes.



Discussions

- These models accounted for the restoring force caused by the perturbations of the magnetic field and also the aerodynamic drag force.

- These results would be consistent with the observed coincidence of the m=1 oscillation polarization with the direction along the HCME position angle.

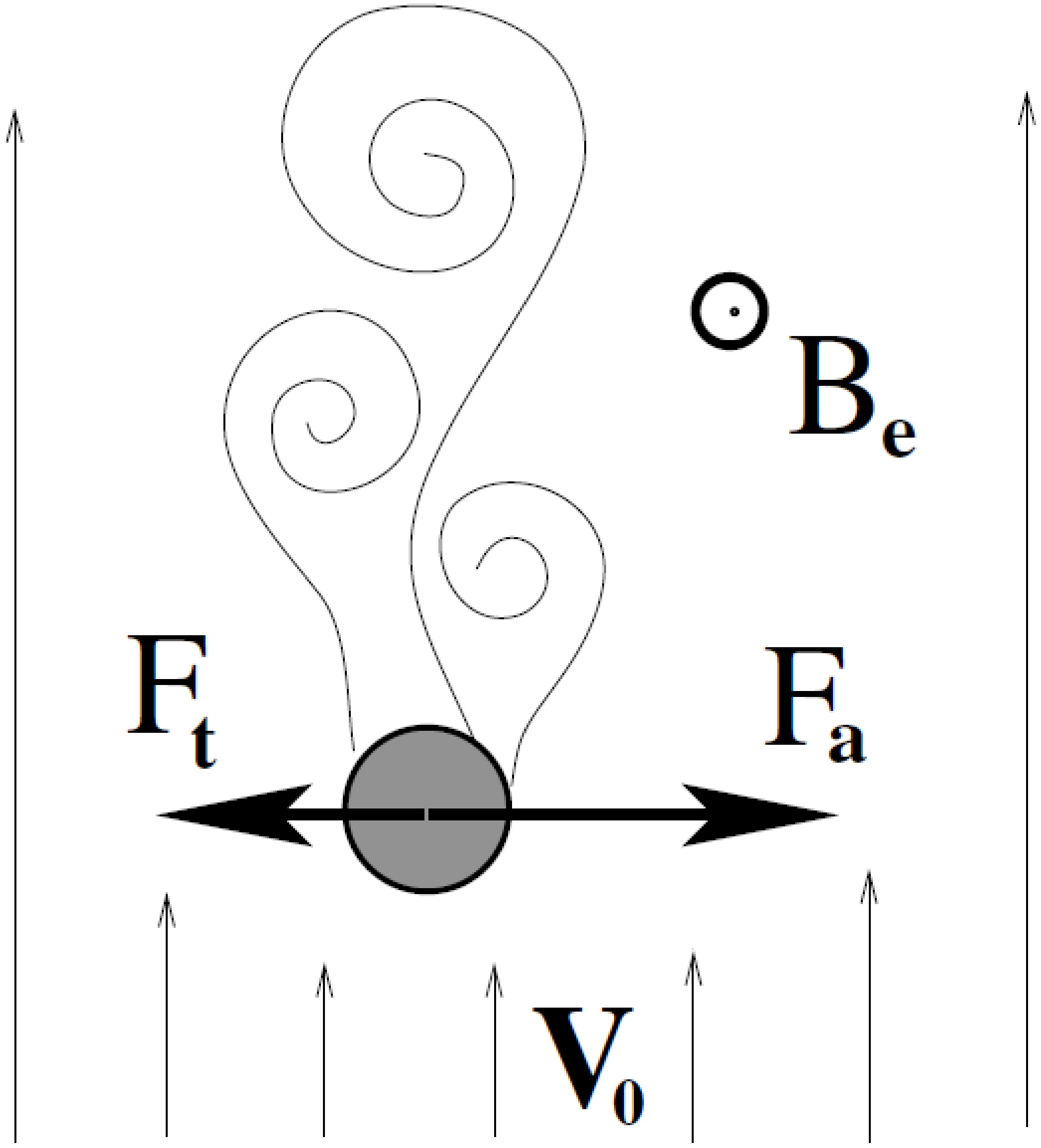


Discussions

- Another possibility is connected with the typical zigzagging trajectory of an emerging body, connected with shedding of vortices.

- This mechanism belongs to the class of self-oscillations that appear because of the nonlinear conversion of DC energy (e.g. of the steady flow) in AC energy (e.g. the transverse oscillatory motion).

- B_e : external magnetic field
  F : MHD force



Nakariakov et al. [2009]

Summary

- We present the first observational detection of radial and azimuthal oscillations in full HCMEs.

- The oscillations in seven events are found to be associated with distinct azimuthal wave modes with the azimuthal wave number m=1 for six events and m=2 for one event.

- We find that the development of all these HCMEs is accompanied with quasi-periodic variations of the instantaneous radial velocity with the periods ranging from 24 to 48 minutes.

Summary

- The amplitudes of the instant speed variations reach about a half of the projected speeds. The amplitudes are found to anti-correlate with the periods and correlate with the HCME speed, indicating the nonlinear nature of the process.

- The polarization of the oscillations in these seven HCMEs is broadly consistent with those of their position angles with the mean difference of 43 degrees.

- The oscillations may be connected with natural oscillations of the plasmoids around a dynamical equilibrium, or self-oscillatory processes, e.g. the periodic shedding of Alfvenic vortices.