Chirality of the Magnetic Field in Solar Filaments

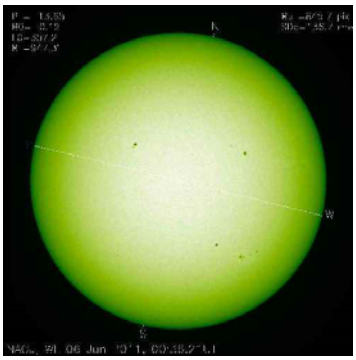
1. Observation of the magnetic field in filaments at Mitaka
2. Statistical study of the magnetic field in filaments (Hanaoka & Sakurai, ApJ in press)

Y. Hanaoka and T. Sakurai

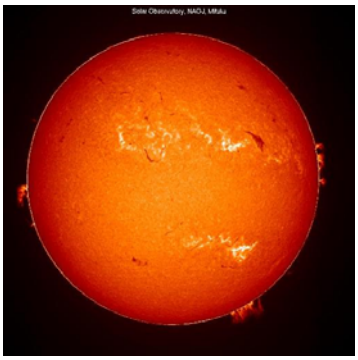
National Astronomical Observatory of Japan

1. Observation of filaments at Mitaka
Magnetic field of prominences/ filaments

- Magnetic field supports the mass of prominences/ filaments, and also causes eruptions
- To measure the magnetic field in prominences/ filaments has been difficult
  - Zeeman polarization is very weak
- Recently it became possible to measure the magnetic field in prominences/ filaments based on the polarimetric observations of the He I 10830 Å line



White-light image of the Sun

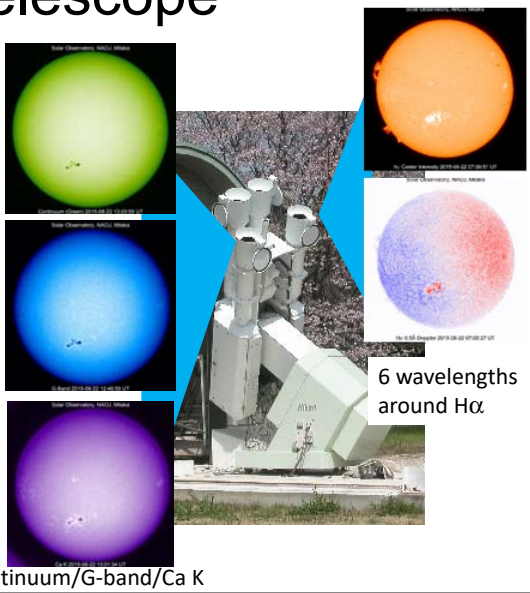


Hα image of the Sun

1. Observation of filaments at Mitaka

Solar Flare Telescope

- The Solar Group of NAOJ is operating some small solar telescopes including the Solar Flare Telescope (Sakurai+1995) at Mitaka for synoptic solar observations
- Currently we are conducting some kinds of imaging observations as well as infrared spectropolarimetry to measure magnetic field



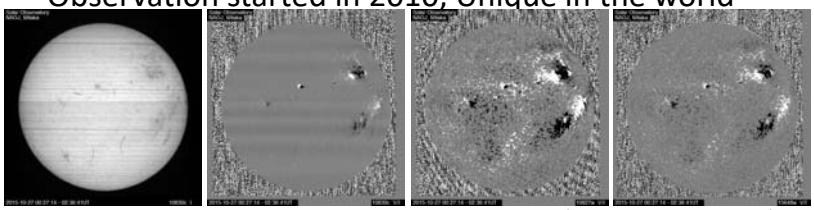
6 wavelengths around Hα

Continuum/G-band/Ca K

1. Observation of filaments at Mitaka

Infrared spectropolarimeter of the Solar Flare Telescope

- Full-Sun, full-Stokes spectropolarimeter for near-IR (Sakurai+2017 in prep)
  - Two wavelength windows, He I 10830/Si I 10827, Fe I 15648/15653
  - Both the chromospheric and photospheric magnetic field
- Observation started in 2010, Unique in the world



He I 10830 I | He I 10830 V/I | Si I 10827 V/I | Fe I 15648 V/I

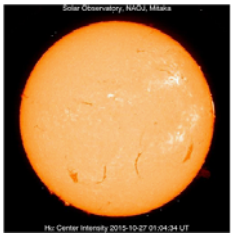
Zeeman polarization signals corresponding to the positive and negative magnetic polarities

In addition to the surface magnetic field, the spectropolarimeter can measure the magnetic field of filaments

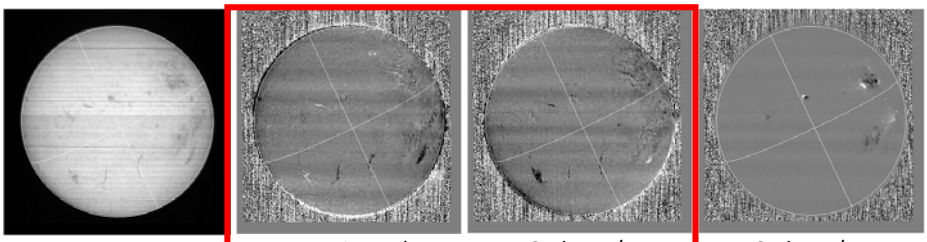
1. Observation of filaments at Mitaka

Filaments on the Stokes Maps

- He I 10830 is absorbed by filaments
- Filaments are remarkably seen in linear polarization images



He I 10830 Stokes maps (red component)



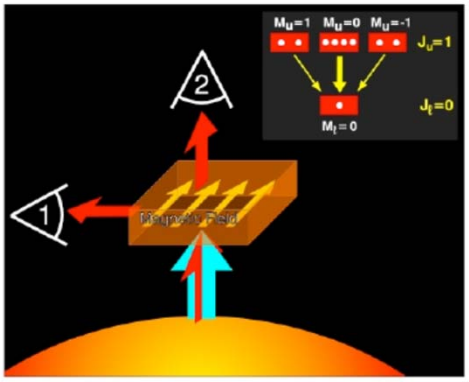
Stokes I | Stokes Q/I | Stokes U/I | Stokes V/I

Linear Polarization Signals

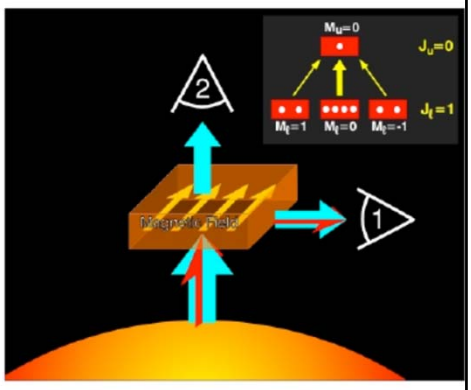
1. Observation of filaments at Mitaka

Why do the filaments show linear polarization?

- Atomic level polarization in the He 10830 line



Red (main) component
Polarization of the transmitted light:
parallel to the magnetic field



Blue component
Polarization of the transmitted light:
perpendicular to the magnetic field

(Trujillo Bueno+2002,2007)

1. Observation of filaments at Mitaka

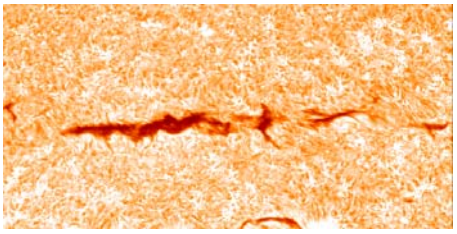
Measurement of the magnetic field in prominences/filaments

- It was revealed that filaments produce remarkable linear polarizations of the He I 1083.0 nm line due to the magnetic field
- The mechanism of the generation of the polarization by the magnetic field was understood
- Now magnetic field in filaments can be deduced based on the polarimetric observations of the He I 1083.0 nm line

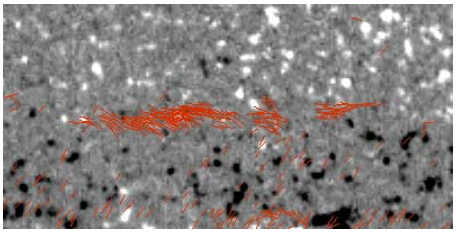
1. Observation of filaments at Mitaka

Polarization Signals seen in Filaments

- Our observation show the orientation of the linear polarization, namely the magnetic field direction
  - 180-degree ambiguity remains
- Hα fine structures in filaments are basically parallel to the magnetic field



Hα image taken with the SFT

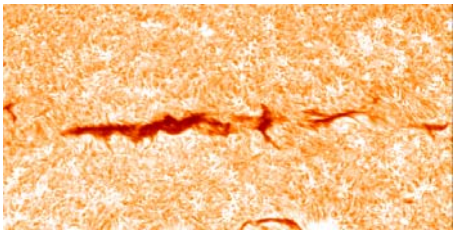


Linear polarization signals > 0.1 %
Background: Si I 10827 Stokes V/I

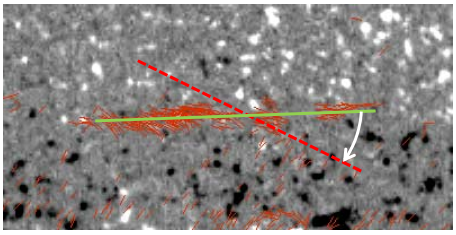
1. Observation of filaments at Mitaka

Polarization Signals seen in Filaments

- Orientations of the polarization signals in a filament (and Hα fine structures) are aligned on the whole
  - We can define the average orientation of the polarization as well as the filament axis
- The magnetic field direction deviates from the axis of the filaments by a certain angle
  - Sheared magnetic field



Hα image taken with the SFT



Linear polarization signals > 0.1 %
Background: Si I 10827 Stokes V/I

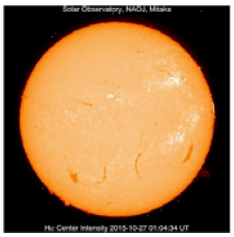
2. Statistical Study of the Magnetic field in filaments

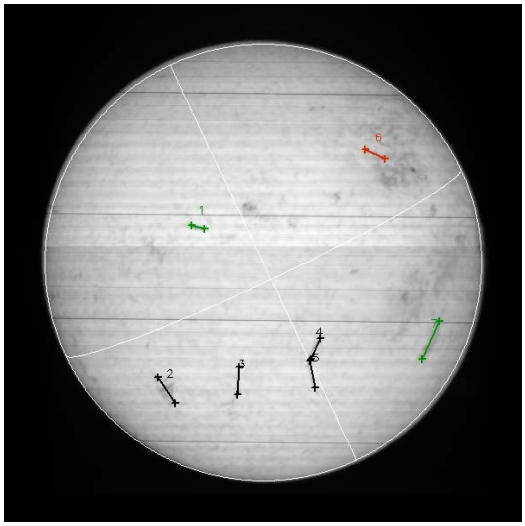
- In our observations, polarization signals of the filaments are measured every day
- Our data is suitable for the systematic study of the magnetic field of the filament on the disk
- We carried out the statistical study of the orientation of the linear polarization in filaments seen in the He I 10830 line
- 438 samples are picked from 6 year observation (2010-2016)

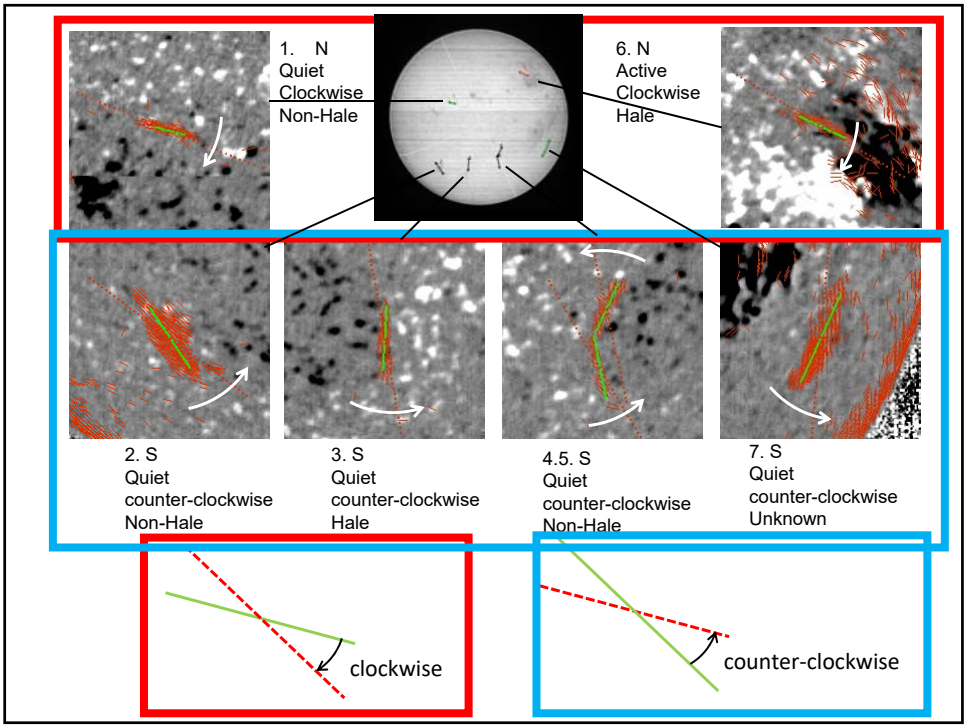
2. Statistical Study of the Magnetic field in filaments

Example of the systematic property: 2015 Oct 27

- 6(7) filaments are picked for the study
- 1/2/3/4/5/7 in quiet region
- 6 near an active region





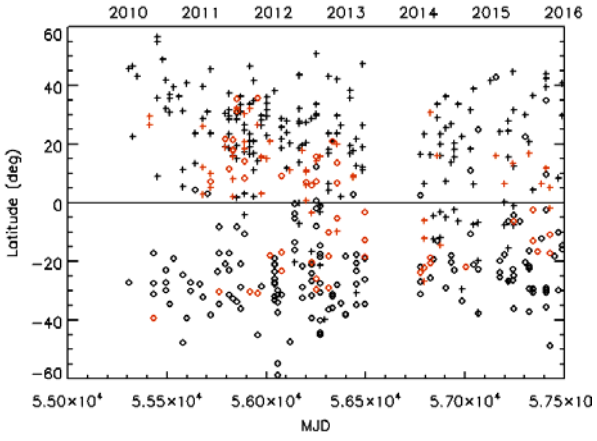


- All the filaments in the northern (southern) hemisphere show the clockwise (counter-clockwise) deviation of the polarization orientation with respect to the filament axis
- We studied the deviation angle of the average polarization direction from the filament axis (chirality) for the 438 samples

2. Statistical Study of the Magnetic field in filaments

Results: Time dependence of the deviation direction

- "butterfly diagram"
  - High-latitude not covered
- Active period of cycle 24 is covered
- Hemispheric pattern of the chirality is clear
- No remarkable dependence on the cycle phase

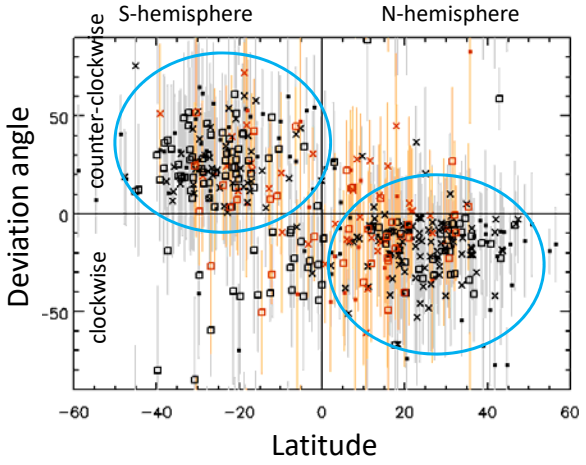


+: clockwise ◇: counter-clockwise
black: quiet region red: active region

2. Magnetic field in solar filaments

Results: Distribution of the deviation angle

- Relation between latitude and deviation angle
  - black: quiet region red: active region
- Hemispheric pattern is clearly seen, regardless of the latitude
  - normal/reverse deviation :
  - quiet area 88%/12%
  - active area 73%/27%



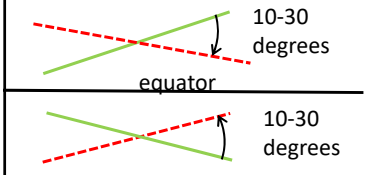
x : N-polarity preceding (S Hale)
□ : S-polarity preceding (N Hale)
● : unknown

2. Statistical Study of the Magnetic field in filaments

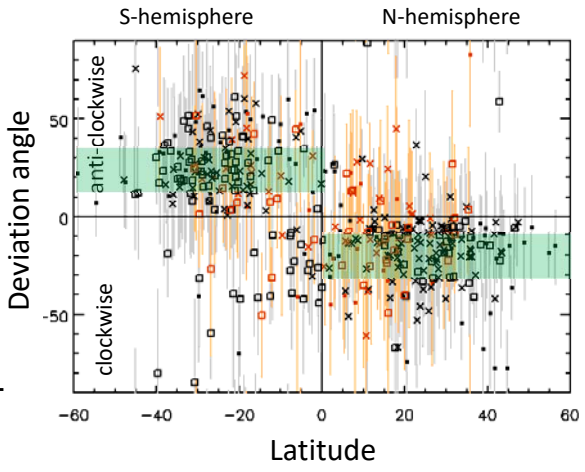
Results: Distribution of the deviation angle

- There is a preferable deviation angle, 10-30 degrees
  - The magnetic field direction deviates equatorward for 10-30 degrees
- Strong shear was confirmed

Northern hemisphere: clockwise



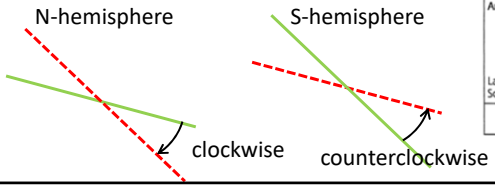
Southern hemisphere: counter-clockwise

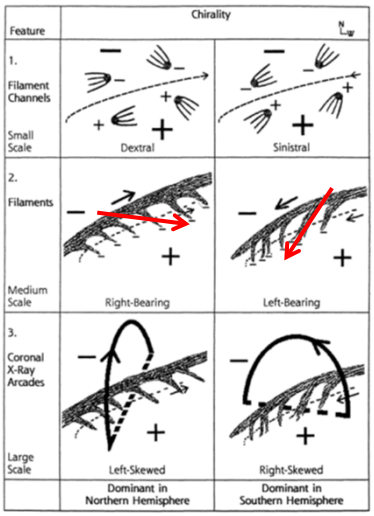


2. Statistical Study of the Magnetic field in filaments

Hemispheric pattern of the chirality has been often discussed

- Various types of hemispheric patterns are reviewed by Martin
- Filaments were analyzed morphologically, and our result is consistent with the former analysis (Martin+ 1994,Pevtsov+ 2003, Bernasconi+ 2005, Yeates+ 2007, Ouyang+ 2017 ...)
- The magnetic field of the prominences are known to be consistent with the result of the morphological studies (Bommier and Leroy 1998)
- Our study for the first time showed the hemispheric pattern by the direct measurement of the magnetic field in filaments



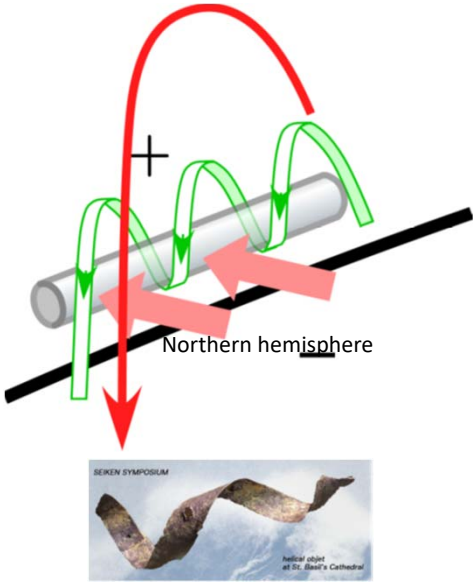


Martin 1998

2. Statistical Study of the Magnetic field in filaments

Plausible model

- Filament in a flux rope
  - Filament material is located at the bottom of the flux rope
- Magnetic field of the flux rope: left (right)-handed screw in the northern (southern) hemisphere
- Probably governed by the global dynamo action



2. Statistical Study of the Magnetic field in filaments

Chiral Structures

- Whirls in the Hα superpenumbra around sunspot
- Majority of sunspot whirls corresponds to left (right)-handed screw in the northern (southern) hemisphere

solar cyclus	1903-13	1913-23	1923-33	1933-44		total	positive spirals
spots with vortices	12	65	40	24		141	

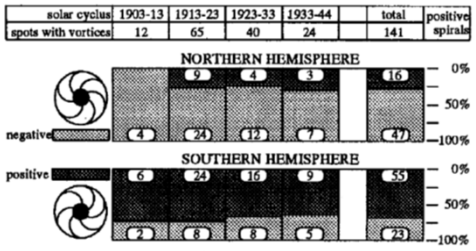
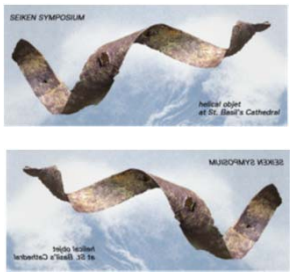


Figure 2. Distribution of the whirl's direction around sunspots (after Richardson 1941). The numbers in the fields show the number of spots observed. On the left-hand side the typical direction of the whirl is demonstrated for each hemisphere.



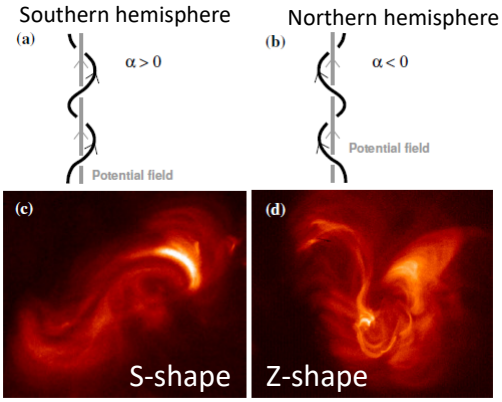
Richardson 1941/ Peter 1996

2. Statistical Study of the Magnetic field in filaments

Chiral Structures

- In general, sigmoid structures in active region corona show left (right)-handed screw in the northern (southern) hemisphere

Mackay & Yeates 2012

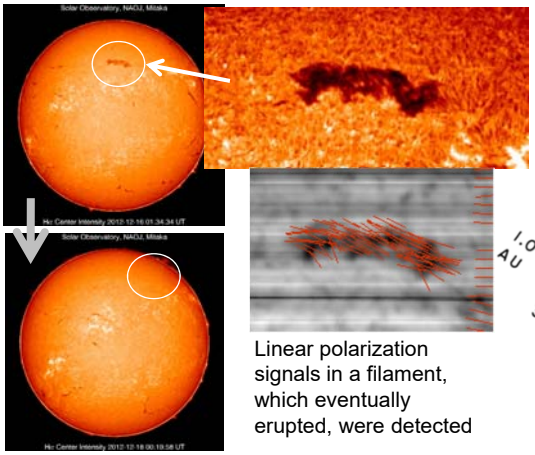


- The flux rope model of filaments are consistent with other chiral structures

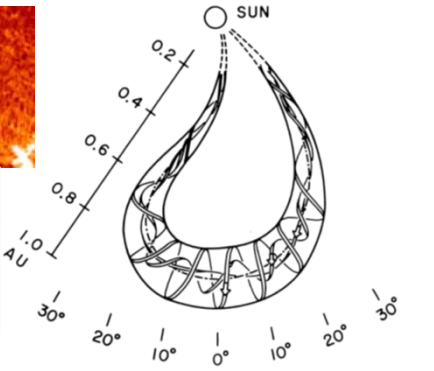
2. Statistical Study of the Magnetic field in filaments

Implication to the Space Weather

- Flux Rope Erupts as a part of a Coronal Mass Ejection
- He 10830 polarization shows the magnetic field in a CME flux rope before eruption



Linear polarization signals in a filament, which eventually erupted, were detected



CME flux rope (Marubashi)

Concluding Remarks

- Our results based on the observations of the filaments
  - Confirm the hemispheric pattern of the magnetic field in filaments with the direct measurements
  - Are considered to be consistent with other chiral patterns seen in the solar atmosphere
- We would like to extend the period of investigation beyond the coming solar minimum
- Our daily, synoptic observation of the chromospheric magnetic field has importance in terms of the space weather