The fine structure of penumbral grains

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Master thesis (examensarbete, 10p) at the Department of Astronomy, su

October 21, 2003

Contents

Abstract

The internal structure and behaviour of sunspot penumbral grains have been investigated at high spatial resolution (0.1") from a data set from the Swedish 1-meter Solar Telescope. From those movies 30 very smaller movies were cut, each following one penumbral grain. The results of these studies are as follows: Most penumbral grains in the middle and inner part of penumbra move toward the umbra. Their structure varies between comet-like, point-like and other complex structures. When they reach the umbra they divide themselves into two or several grains and disappear. The penumbral grains at the penumbra/umbra boundary have shorter life time than those in the middle part. Most penumbral grains in the middle part of the penumbra take comet-like structures. Many penumbral grains look as they have a dark tail or dark core filament. A fraction of penumbral grains are crossed by dark streaks. Some of the penumbral grains start as comet-like or point-like and after a while they get dark tails. When the tails cut off and move to the side, bright tubes appear. A common feature is seen in the penumbra is the structure of the chain. A possible interpretation of the penumbral grain phenomenon is discussed.

1 Introduction

1.1 Sunspots and their penumbra

You can not look at the Sun with the naked eye. But if you use special glasses or when at the sunset the light is dimmed you can see small dark regions. These dark regions are called a sunspots. In 1610, Galileo studied the sunspots with his newly built telescope and since that time the sunspots were studied by many astronomers.
The sunspots are cool regions about 1000 K cooler than the surroundings, and they were believed to be a result of some forces acting in the Sun, in addition to gravity and gas pressure gradient. But G.E. Hale's discovery of the Zeeman effect in a spot spectrum put magnetism into solar physics and astrophysics.

Now, it is well established that a sunspot is a result of the magnetic field.
Observations at low resolution, the sunspots display a smooth pattern without complicated fine structures in the penumbra and the umbra.
At high resolution the fine structure of the penumbra and umbra look very complicated. Note that not all the sunspots have penumbrae.

The penumbra consists of bright and dark filaments. Muller(1973) described from observations that the bright filaments are chains of aligned penumbral grains. They have cometary-like shapes with bright heads at their end close to the umbra. Their average brightness is of order of the mean photospheric intensity. The dark filaments have been described as a coherent background surrounding the bright features.

According to observations done by Beckers & Schröter (1969) at a resolution of order 1" inferred that the magnetic field should be more inclined in the dark filaments than in the bright filaments. Measurements at higher resolution and based on Zeeman splitting of spectral lines revealed fluctuations of the magnetic field strength which were uncorrelated with the changes of the continuum brightness. This was because of difference in height where the magnetic sensitive spectral lines and continuum are formed. Another measurement based on polarimetry showed that the field inclination in dark filaments were 10 degrees larger than in bright filaments, but here they did not find variations in the field strength.

1.2 Penumbral grains and flows

It is natural to assume that penumbral grains are regions of upflow within the penumbra. There are some observational indications of this (Johannesson 1993, Rimmele 1995). If the penumbral grains are such sites, their structure and behaviour would give important clues to the understanding of the mysterious penumbra.
The mechanical effect known in sunspots is the Evershed effect. The Evershed effect is the horizontal outflow in the penumbra of sunspot. This flow is observed in the penumbral photosphere and rather abruptly ceases at the boundary to the undisturbed photosphere. The Evershed effect is related to the variable inclination of the magnetic field at high-resolution spectra. The photospheric Evershed effect is dominated by discrete, dark cloud-like features which move outward in the penumbra. These are visible at the outer boundary of the penumbra (Title 1992).

The largest Evershed effect is found in the dark filaments where the magnetic field is almost horizontal.
The Evershed effect disappears abruptly at the outer penumbral boundary. This is due of the gas flowing along the field lines slightly inclined to the horizontal becomes suddenly transparent to the observed radiation. The Evershed effect has been interpreted as siphon-flow along magnetic flux tubes by Meyer and Schmidt(1968).

1. The siphon flow:

Meyer and Schmidt (1968) proposed that the photospheric and reversed chromospheric Evershed flow due to siphon flows along arched magnetic flux tubes, driven by pressure differences between the footpoints at the same geometric height.
For a higher arched flux tube with one footpoint in the umbra while the other footpoint outside the sunspot in the quiet photosphere, and because of the lower gas pressure at the umbral footpoint (where the magnetic pressure is higher), the flow along the arch will be directed inward toward the umbra. This flow corresponds to the reversed Evershed flow observed at chromospheric height.
For lower arched flux tubes with footpoint in penumbra, where the magnetic field strength is of the order of 1000 G, and connecting to another footpoint with a higher magnetic field strength, the flow will be outward away from the umbra as in the case in the observed photospheric Evershed flow.
Imagine we have many flux tubes which appear from the sunspot, and all those magnetic flux tubes have as their opposite footpoint a magnetic element of field strength 1500 G, then the flow will be outward for low-lying tubes with footpoints in the penumbra (where the field strength is less than 1500 G) and inward for higher-reaching tubes with footpoints in the umbra (where the field strength is greater than 1500 G). The penumbral footpoints could perhaps be identified with penumbral grains.
Meyer and Schmidt's studies were made on the assumption that the shape of the magnetic flux tube is rigid and is unaffected by the siphon-flow.

There is another model of the Evershed effect developed by Schlichenmaier(1999), called for the moving-tube model.
2. The moving-tube model (Schlichenmaier's model):
This model is not related to pressure difference, instead we have a magnetic flux tube which emerges from deep in the penumbra. The tube transports heat to the penumbral photosphere. The tube rises adiabatically, and it bends into the horizontal direction at the point this reaches the photosphere. The high temperature of the upflowing gas in the tube gives rise to a penumbral grain.
When the gas in the tube reaches the optically thin photospheric environment, it cools down and then we get a transparent tube. In this moment the tail of the bright grain gets cut off and the horizontal outflow accelerates to its largest velocity in the outer dark part of the tube.

2 The objective of this work

The aim of this project is to investigate the fine structure of penumbral grains, on which not much work has been done before.
In section 1.2 we assumed that the penumbral grains are the upflows within the penumbra which are visible as small bright regions. Their fine structure could then give information about the mysterious penumbra. The study consists of an investigation of a sunspot movie with much higher spatial resolution than has been done before.
Penumbral grains were looked for and followed. Their behaviour was described with special attention on how the internal structure changed.
Another point of interest was if the filamentary structure within the grains behave independently on the bright feature.
There is no real possibility to make physical interpretations based only on the intensity in the data. But, what we can do is to speculate on the nature of penumbral grains from what we see by the eyes. Remember that during the description of the movies I did not make any speculations. The speculations are done in the discussion and conclusion section.

3 Data and techniques

In order to make an analysis of penumbral grains, I used the data which were taken by Göran B.Scharmer with the Swedish 1-meter Solar Telescope on La Palma on 15 July 2002 (Scharmer et al.2002). Those data have almost twice as high resolution than any data taken before. You can find those data in the directory `/r3_disk2/GORAN-JUL02/jul15/pd`. The data consist of images taken on 15 July 2002 in the G-band, and at 0.1" resolution. The images were recorded and reconstructed with the phase-diversity (PD) technique (Löfdahl 2002). The sunspot group is AR10030.
Those images have been going through many processes and in the end we get files with the suffix 'subv'. The effect of the earth rotation and the oscillations of the Sun and everything which moves faster than the sound were removed. Still, there are some remaining aberrations in the images due to the seeing induced by the Earth's atmosphere. Also, the PD reconstruction and other treatments may leave artificial structures in the data.

Movies were created from the data using the 'TRACE data browser', a program written by Richard Shine in the ANA language. This allows you to select a subfield and a range of image number from which the movie cube is constructed. The time information was extracted from the image files with the 'Inspect' command.
Images number 1000 through 1220 were used for the movie.

In order to investigate the penumbral grains, I made 8 small movies. From those movies I made 30 very smaller movies, each following one penumbral grain. Each movie consists of 220 images. I studied each image separately, tracing the structures and behaviour of penumbral grains. The investigation of these movies went in the following way:
• I started first to describe what I see in the bigger movie in general, how the structure of penumbral grains and dark filaments change.

• In the smaller movies I describe how a single penumbral grain appears and how its structure and behaviour change with time.

4 Table of movies

In the tables below, every first row in a separate frame in each little table is the given part I chose from the data in the directory given in section 3. Below the first row, there are smaller movies. Those movies are from the same part (i.e the file in the first row). I convert those files also to 'fits' and 'gif'. But the converting was not as good as the original files, which were made in 'cube', OBS: All the movies are written below with the address where you find the files in my directory. But in the web page you find all as the following way: `www.solarphysics.kva.se/x-job/ghanjah/namefile.mpg`. E.g., `/home/ghanjah/work_feb17_1.cube` will be in the web page as:
`www.solarphysics.kva.se/x-job/ghanjah/feb17_1.mpg`.

- **Part 1:**

www.solarphysics.kva.se/x-job/ghanjah/feb17_1.mpg	x1=458 x2=636, y1=772 y2=976
www.solarphysics.kva.se/x-job/ghanjah/mars21_11.mpg	x1=485 x2=517, y1=821 y2=874
www.solarphysics.kva.se/x-job/ghanjah/mars21_12.mpg	x1=587 x2=623, y1=812 y2=893
www.solarphysics.kva.se/x-job/ghanjah/feb17_22.mpg	x1=563 x2=588, y1=844 y2=909

- **Part 2:**

www.solarphysics.kva.se/x-job/ghanjah/feb17_2.mpg	x1=200 x2=457, y1=748 y2=974
www.solarphysics.kva.se/x-job/ghanjah/mars25_20.mpg	x1=407 x2=461, y1=757 y2=816
www.solarphysics.kva.se/x-job/ghanjah/mars25_21.mpg	x1=381 x2=445, y1=811 y2=865
www.solarphysics.kva.se/x-job/ghanjah/feb20_23.mpg	x1=351 x2=387, y1=817 y2=872

- **Part 3:**

www.solarphysics.kva.se/x-job/ghanjah/feb17_3.mpg	x1=148 x2=455, y1=594 y2=745
www.solarphysics.kva.se/x-job/ghanjah/feb20_31.mpg	x1=336 x2=386, y1=677 y2=715
www.solarphysics.kva.se/x-job/ghanjah/feb20_32.mpg	x1=377x2=427, y1=599 y2=643
www.solarphysics.kva.se/x-job/ghanjah/feb20_33.mpg	x1=314 x2=358, y1=643 y2=679
www.solarphysics.kva.se/x-job/ghanjah/feb20_34.mpg	x1=31 x2=354, y1=591 y2=657

- **Part 4:**

www.solarphysics.kva.se/x-job/ghanjah/feb17_4.mpg	x1=65 x2=532, y1=479 y2=592
www.solarphysics.kva.se/x-job/ghanjah/feb19_41.mpg	x1=462 x2=562, y1=540 y2=584
www.solarphysics.kva.se/x-job/ghanjah/mars31_40.mpg	x1=381 x2=437, y1=480 y2=511
www.solarphysics.kva.se/x-job/ghanjah/feb21_43.mpg	x1=262 x2=310, y1=539 y2=570

- **Part 5:**

www.solarphysics.kva.se/x-job/ghanjah/feb17_5.cube	x1=68 x2=527, y1=353 y2=476
www.solarphysics.kva.se/x-job/ghanjah/feb22_51.mpg	x1=223 x2=362, y1=400 y2=503
www.solarphysics.kva.se/x-job/ghanjah/feb22_52.mpg	x1=409 x2=459, y1=404 y2=445
www.solarphysics.kva.se/x-job/ghanjah/feb22_53.mpg	x1=395 x2=442, y1=365 y2=421
www.solarphysics.kva.se/x-job/ghanjah/feb22_54.mpg	x1=298 x2=339, y1=347 y2=399
www.solarphysics.kva.se/x-job/ghanjah/feb22_55.mpg	x1=182 x2=231, y1=400 y2=443
www.solarphysics.kva.se/x-job/ghanjah/feb22_56.mpg	x1=116 x2=179, y1=401 y2=458

• **Part 6:**

www.solarphysics.kva.se/x-job/ghanjah/feb17_6.cube	x1=413 x2=625, y1=0 y2=353
www.solarphysics.kva.se/x-job/ghanjah/feb19_61.mpg	x1=417 x2=455, y1=224 y2=277
www.solarphysics.kva.se/x-job/ghanjah/feb24_622.mpg	x1=446 x2=484,y1=274 y2=329
www.solarphysics.kva.se/x-job/ghanjah/feb24_63.mpg	x1=490 x2=536, y1=228 y2=316
www.solarphysics.kva.se/x-job/ghanjah/feb24_644.mpg	x1=487 x2=441,y1=114 y2=171
www.solarphysics.kva.se/x-job/ghanjah/feb25_67.mpg	x1=481 x2=571, y1=9 y2=118

• **Part 7:**

www.solarphysics.kva.se/x-job/ghanjah/feb17_7.mpg	x1=224 x2=412, y1=150 y2=351
www.solarphysics.kva.se/x-job/ghanjah/feb24_71.mpg	x1=235 x2=296, y1=224 y2=269
www.solarphysics.kva.se/x-job/ghanjah/feb24_72.mpg	x1=250 x2=301, y1=283 y2=321
www.solarphysics.kva.se/x-job/ghanjah/feb24_74.mpg	x1=270 x2=317, y1=326 y2=373

• **Part 9:**

www.solarphysics.kva.se/x-job/ghanjah/feb17_9.mpg	x1=2 x2=414, y1=0 y2=193
www.solarphysics.kva.se/x-job/ghanjah/feb25_91.mpg	x1=225 x2=273, y1=128 y2=168
www.solarphysics.kva.se/x-job/ghanjah/feb25_92.mpg	x1=183 x2=227, y1=37 y2=87
www.solarphysics.kva.se/x-job/ghanjah/feb25_95.mpg	x1=69 x2=119, y1=98 y2=152

The second column in the above tables obtains the coordinates (x,y) for the movies.

5 Penumbral grain structure and behaviour

In this section my objective is only to describe what I see without any attempts of explanation.

5.1 Part 1

1.`/home/ghanjah/work_feb17_1.cube`.
In image 14, we see five big granules. One can see that there is a pattern which looks as a wall between those granules and the outer boundary of the penumbra (see image 14 **Figure 2**). As time runs, the plasma which is surrounded by two dark channels move toward the umbra (see the arrow in image 20 **Figure 3**).
One of the five granules bubbles and gets cooler in the middle part (see the arrow in image 60 **Figure 4**). The cooler gas has pressed the hot gas in all directions.We see this effect because the edge of the bubble is still bright when the middle part has cooled.

As time runs, we see clearly how two filaments gathered to one filament which stretched out to the umbra. We see also that inside this filament there is a hairy channel (see 216 **Figure 5**).

SMALL MOVIES OF PART 1:
1:1. `/home/ghanjah/job/mars21_11.cube`:
This movie consists only 122 images and it starts from image 1099 from the data mentioned in section 2.

Figure 1: image 0 in work feb171

Figure 2: image 14 in work feb171

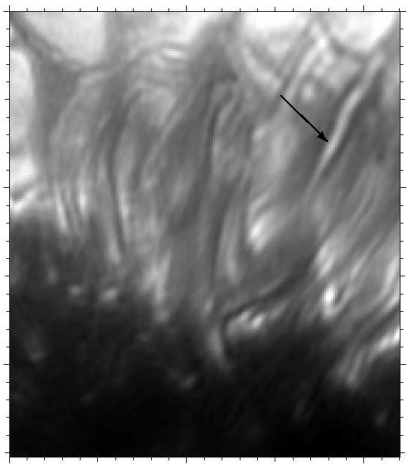

Figure 3: image 20 in work feb171

Figure 4: image 60 in work feb171

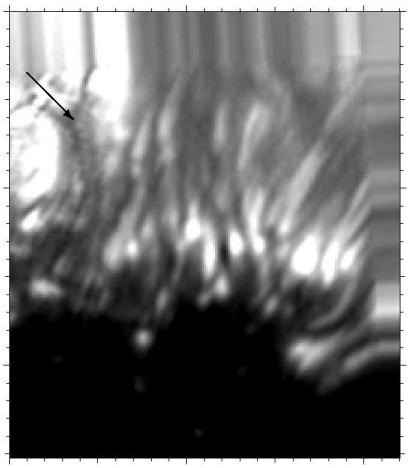

Figure 5: image 216 in work feb171

Take a look at image 0 **Figure 6** and see which part I cut.
In image 0 **Figure 7**, we see a penumbral grain which seems to be under a dark filament.Consider also the weak structures in the dark area. One sees many channels which connect to each other in such a way that one sees that the channels are surrounding weak bright areas (see image 0 **Figure 7**).

As time runs we see that the dark filament which was above the penumbral grain has moved to the left side of the penumbral grain and the grain gets brighter and bigger in image 12 **Figure 8**. Then in image 29 **Figure 9** the grain looked as it divided itself into two penumbral grains. One can see that the wavy dark filaments exist above (above in height) the grains.
The grains disappear under a very thick dark filament (you can see that in image 40 the movie).

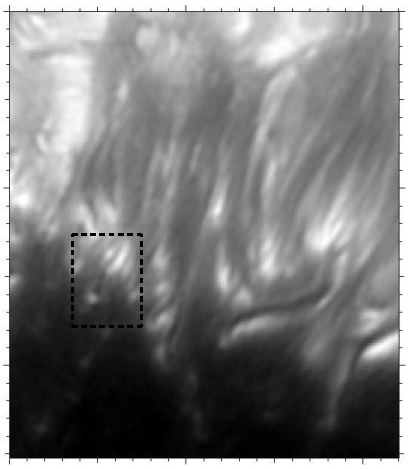

Figure 6: image 99 in work feb171

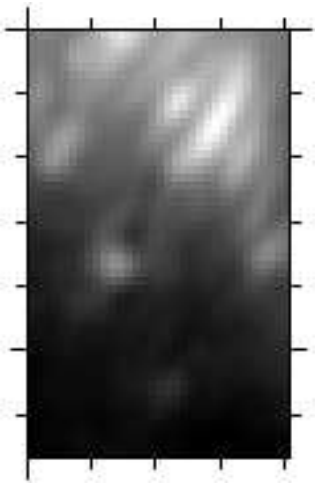

Figure 7: image 0 in job mars2111

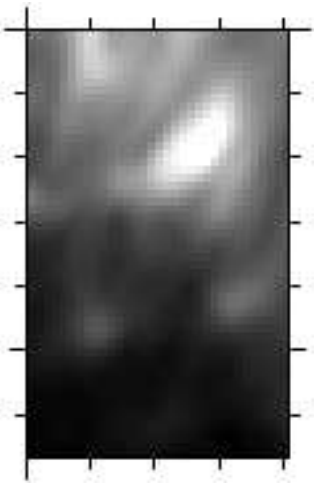

Figure 8: image 12 in job mars2111

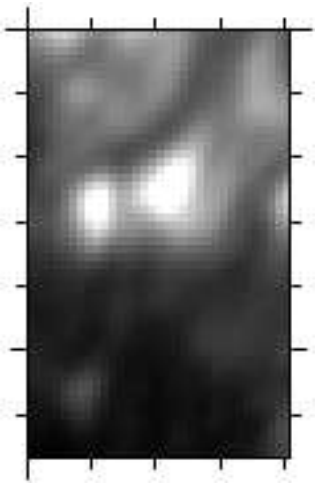

Figure 9: image 29 in job mars2111

1:2./home/ghanjah/job/mars21_12.cube:
Take a look at image 0 **Figure 10** and see which part I cut. In image 0 **Figure 11**, we have three comet-like penumbral grains, they disappeared after a short time without changing their structures. In image 93 **Figure 12**, we see a grain 93a gets bigger and brighter.

After a while the hot plasma looks as it pelts out against the umbra. The grain takes a comet-like structure (see image 103 **Figure 13**). The grain disappears in image 121. From the same place another two comet-like grains are born (see image 180 **Figure 14**). The movie ends here, perhaps they met the same destiny as the other comets.

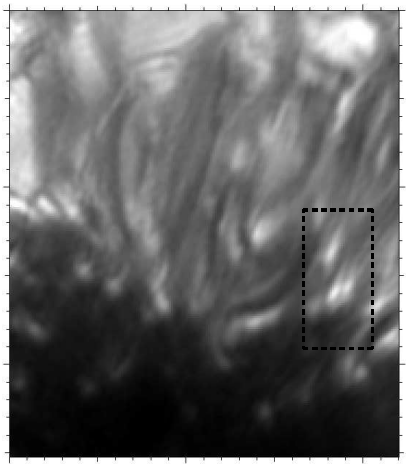

Figure 10: image 0 in work feb171

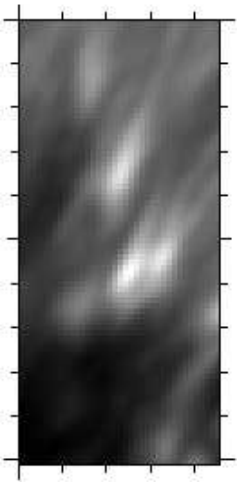

Figure 11: image 0 in job mars2112

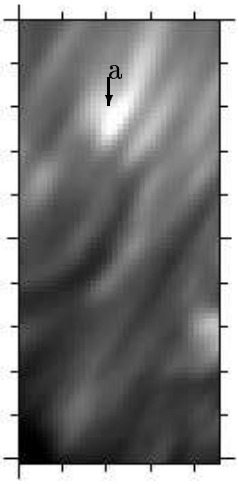

Figure 12: image 93 in job mars2112

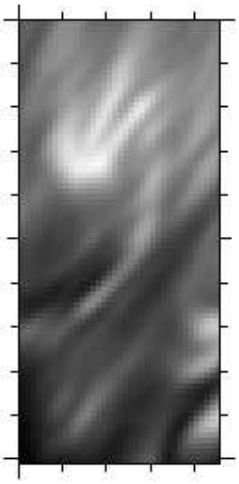

Figure 13: image 103 in job mars2112

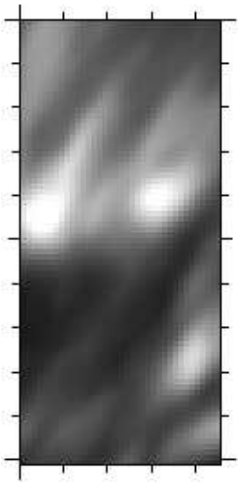

Figure 14: image 180 in job mars2112

1:3./home/ghanjah/job/feb17_22.cube:
Take a look at image 0 **Figure 15** to see which part I cut.
In image number 0 **Figure 16** we see a comet-like penumbral grain. In front of it there is a thick

parabola-like dark filament surrounding the grain.

The grain moves against the umbra and with gets bigger, (see image 49 **Figure 17**) . The thick dark filament on the left side of the grain has straightened itself and seems to move to the right above the grain, (see image 79 **Figure 18**). After a while, the grain gets brighter and it revealed bright tube (see image 121 **Figure 19**).

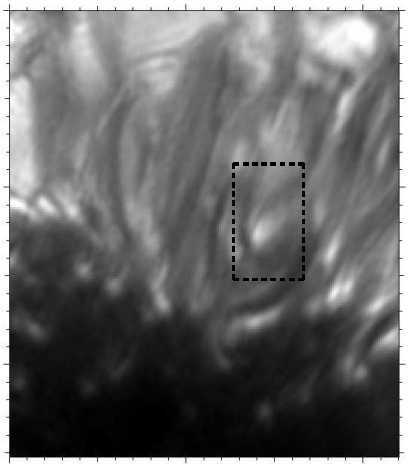

Figure 15: image 0 in work feb171

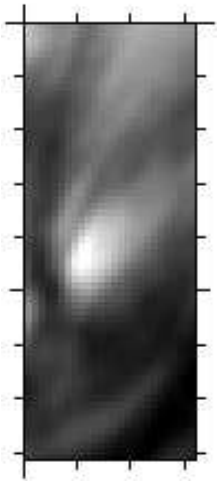

Figure 16: image 0 in job feb1722

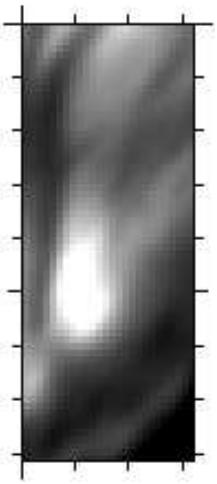

Figure 17: image 49 in job feb1722

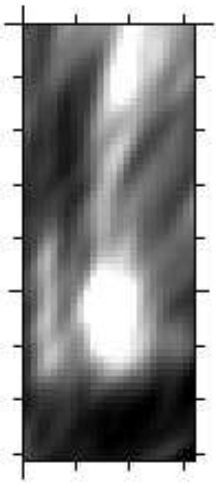

Figure 18: image 79 in job feb1722

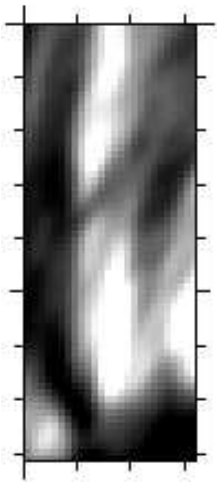

Figure 19: image 121 in job feb1722

5.2 Part2

2.`/home/ghanjah/ana/work_feb17_2.cube`:
In image number 0 **Figure 20** we see a pattern which reminds us of a chain. It seems to be a limit between the granules and the penumbra (see the letter '**a**' in image 0 **figure 20**).
The structures of the dark filaments seem to stem from the dark limits of granules outside the penumbra, (see '**b**' in image 0 **Figure 20**).
A part of the chain is directed against the penumbra and continue to some distance inside it (see '**c**' in image 0 **figure 20**). Chains inside the penumbra and at the limit penumbra/granules get stronger and change to point-like structures, (see '**c**' in image 15 **Figure 21**). Consider a '**plus**'-sign like structure in the same image. The edge of the four sides of the '**plus**'-sign seem to converge. It seems

to be two magnetic loops crossing each other.

In image 86 **Figure 23**, we see a very interesting view, it is magnetic loop (see the box 'l').
In the same image, we see a chain structure in the inner part of penumbra. The chain is more stretched closer to the umbra (see the structure in box '**p**' and compared to the structure in box '**g**'). Take a look at image number 40 **Figure 22** and compare the box '**a**' in that with box '**b**' in image 93 **Figure 24**. The structure inside the boxes are very similar except that in image 40 it is more stretched than in 93. Add also that in image 93 **Figure 24** it is a part of the chain limits the penumbra from the granules.

In image 112 **Figure 25** the chain stretched itself toward the umbra, and part of it shows point-like structures penumbral grains (see '**a**'). The dark filaments continue traveling toward the umbra. When they reach very close they divide themselves into two or more channels. In image 135 **Figure 26**, we can see that there is a similarity between the structures marked with arrows.
There is also a similarity between the structure inside box '**d**' and those inside box '**e**' in image 150 **Figure 27**.

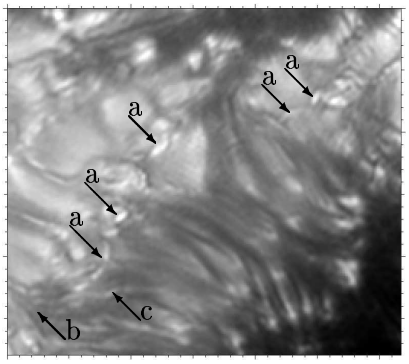

Figure 20: image 0 in work feb172

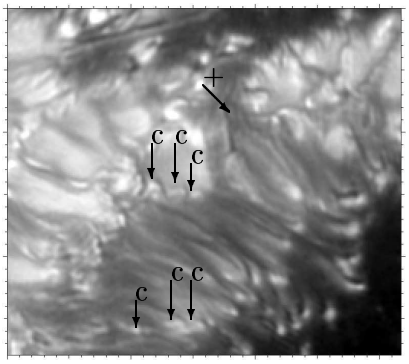

Figure 21: image 15 in work feb172

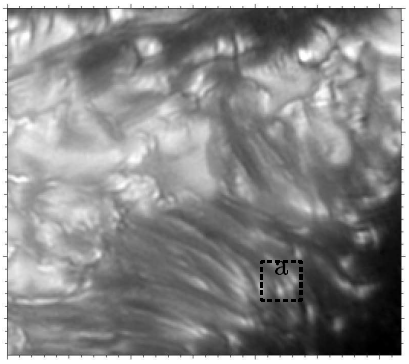

Figure 22: image 40 in work feb172

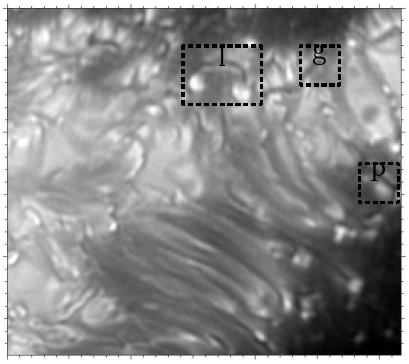

Figure 23: image 86 in work feb172

SMALL MOVIES OF PART2:
2:1./home/ghanjah/job/mars25_20.cube:
Image 0 **Figure 28** shows the small movie I cut).
In image 0 **figure 29**, we see three point-like penumbral grains, they are very close each other.
As the time runs, a dark filament grows from the grains and move toward the umbra, while the other filaments go up. ('up' here means from the perspective of the image). The grains now seem to be

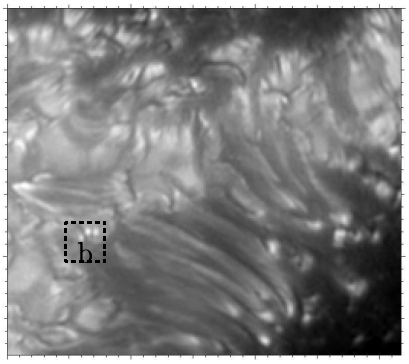

Figure 24: image 93 in work feb172

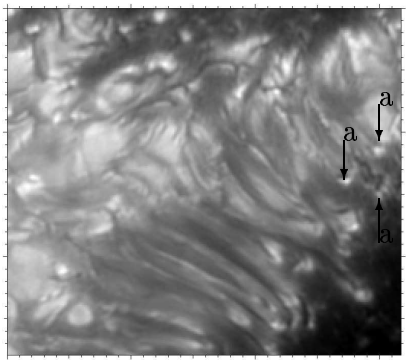

Figure 25: image 112 in work feb172

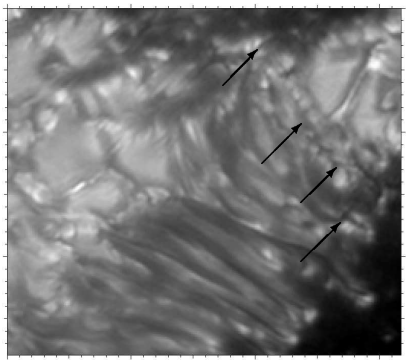

Figure 26: image 135 in work feb172

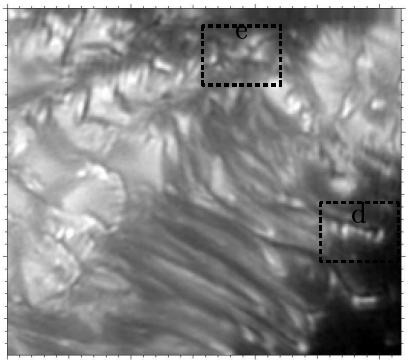

Figure 27: image 150 in work feb172

under a dark filament, (see image 14 **Figure 30**). The dark filament has straightened itself and three other dark short filaments born in the same place. Two of them have point-like grains in their top. The grains move toward the umbra, (see image 68 **Figure 31**). Consider also how the dark filaments in the surrounding are connecting to each other in a complicated way. They look as wavy channels.

In image 74 **Figure 32**, a penumbral grain appears under the dark filament. There are structures which remind us about the dark hairy channels marked with arrows in image 135 **Figure 26**. The grain becomes brighter and moves toward the umbra (see image 132 **Figure 33**). The dark filament divided itself into two short filaments.
In image 150 **Figure 34**, we see that as the grain gets brighter, the parallel dark filament gets darker. Take a look at image 171 **Figure 35** to see what it is left from the structure.

2:2./home/ghanjah/job/mars25_21.cube:
Look on image 0 **Figure 36** to see which part I cut.
In image 0 **Figure 37** there are two penumbral grains. As the time runs, several almost point-like grains appear. After a while they take comet-like structure (see image 24 **Figure 38** These structure changed very fast and became complicated, (see **figure 39, 40, 41, 42 and 43**. Consider the wavy structure in **Figure 43**.

2:3./home/ghanjah/job/feb20_23.cube:
Take a look at image 0 **Figure 44**, to see which part I cut.
In the middle of image 0 **Figure 45**, we have an almost weak dark tube. In both ends of this tube there is a penumbral grain.
The grain on the left side starts to move toward the umbra. As the grain moves it appears a dark

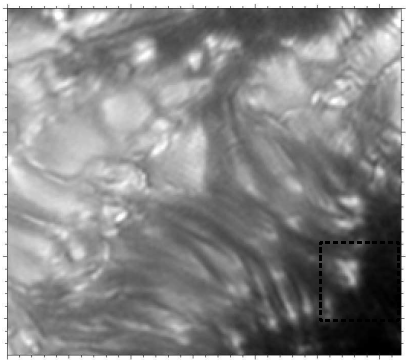

Figure 28: image 0 in work feb172

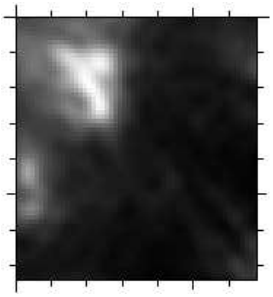

Figure 29: image 0 in job,mars2520

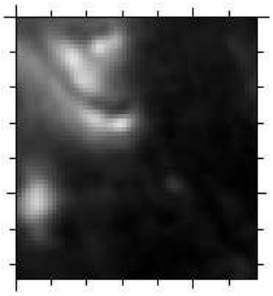

Figure 30: image 14 in job,mars2520

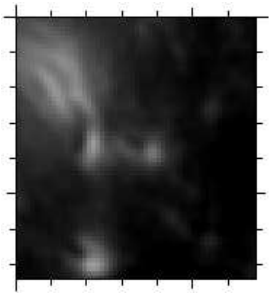

Figure 31: image 68 in job,mars2520

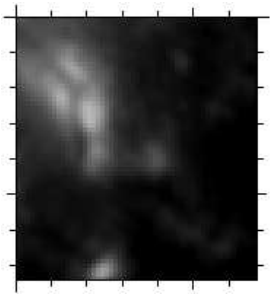

Figure 32: image 74 in job mars2520

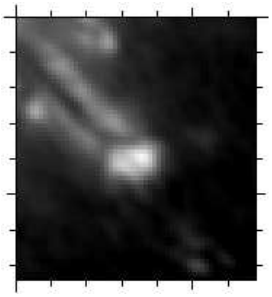

Figure 33: image 132 in job mars2520

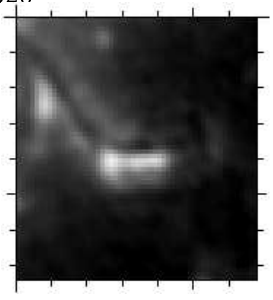

Figure 34: image 150 in job mars2520

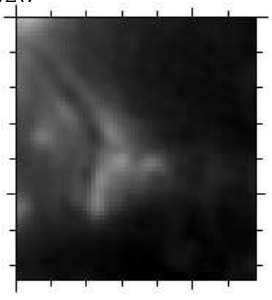

Figure 35: image 171 in job mars2520

filament above it (see image 70 **Figure 47**). The structures of the dark filaments and grains change to wavy structures in image 98 **Figure 48**.
See what happened to the grain in **Figure 49** and **Figure 50**. In image 193 **Figure 51**, a sequence of comet-like grains appears, their structure changes to point-like. there is also an interesting dark

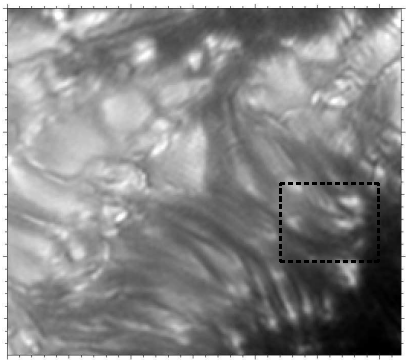

Figure 36: image 0 in work feb172

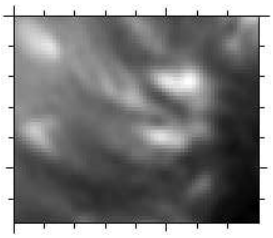

Figure 37: image 0 in jobmars2521

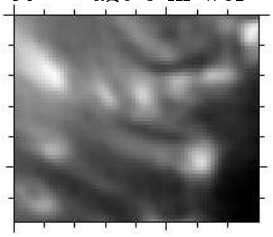

Figure 38: image 24 in job mars2521

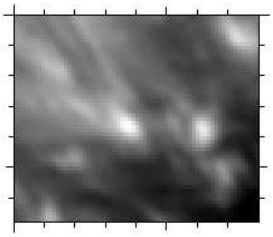

Figure 39: image 53 in job mars2521

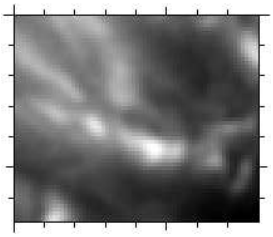

Figure 40: image 76 in job mars2521

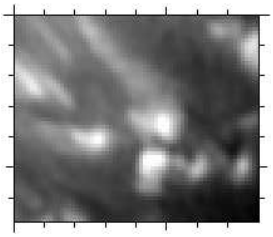

Figure 41: image 93 in job mars2521

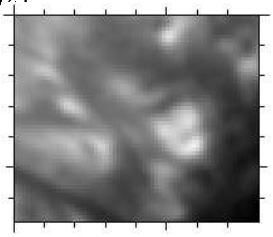

Figure 42: image 115 in job mars2521

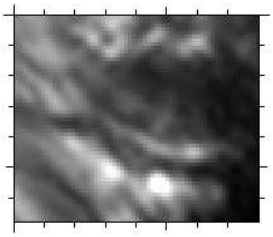

Figure 43: image 208 in job mars2521

structure. From this structure, the dark filaments stretch themselves and connect to other side crossing the bright area, this makes the bright grains look to be stretched. Look at the image 209 to see how the structure changed. The changed structure reminds us about the structure in box '**a**' in image 40 **Figure 22**. In image 218 **Figure 53** we see how the structure has stretched itself much more.

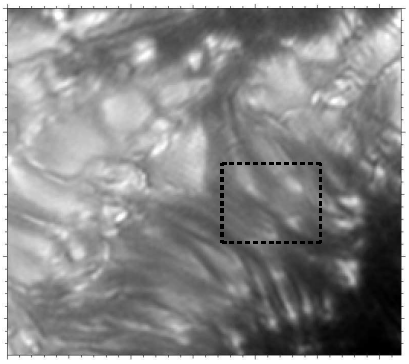

Figure 44: image 0 in workfeb172

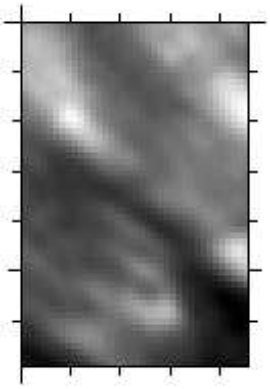

Figure 45: image 0 in jobfeb2023

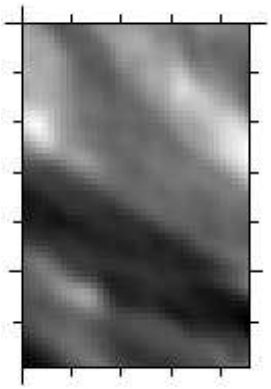

Figure 46: image 35 in jobfeb2023

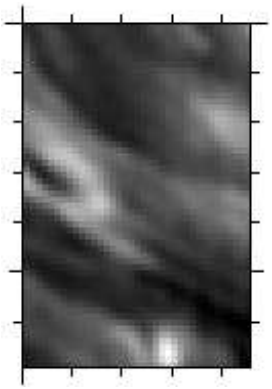

Figure 47: image 70 in jobfeb2023

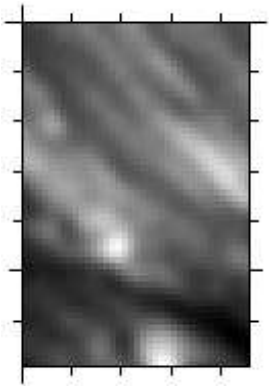

Figure 48: image 98 in jobfeb2023

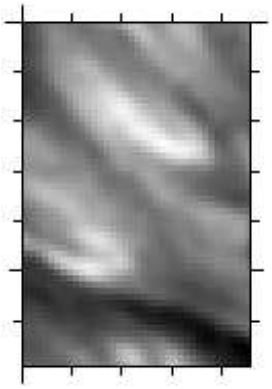

Figure 49: image 124 in job feb2023

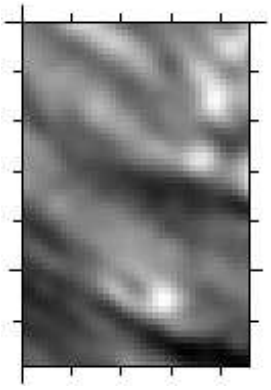

Figure 50: image 154 in job feb2023

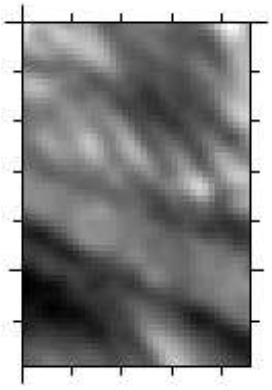

Figure 51: image 193 in job feb2023

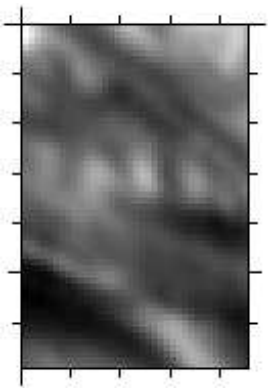

Figure 52: image 209 in job feb2023

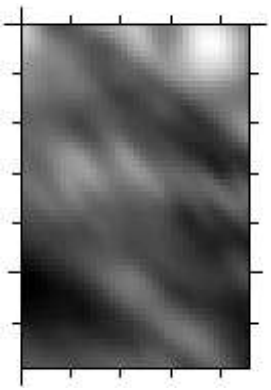

Figure 53: image 218 in job feb2023

5.3 part 3

3./home/ghanjah/ana/work_feb17_3.cube:
Take a long look on image number 0 **figure 54** and then please go farther to image number 27 **figure 55**. The penumbral grains which appear in this image i.e 27, they all have point like structure. Look at **27a**, there are three grains together, with their structures looking similar to those in **27b**.
Let the time run now and see what happened to those penumbral grains in image 35 **Figure 56**. The **27a** grains have not changed noticeably. Neither have **27c**, **27d** and **27e**. But 27b has stretched itself a little bit, see **Figure 56**.

But what about the evolution of penumbral filaments from image 0 to image 35?.
The penumbral filaments have a special connection on the boundary of granules. The penumbral grains are concentrated most at the end of the filaments i.e in the inner boundary of the penumbra. Another thing which is interesting here, is that we see that two parts of the penumbra are separated by a dark area. Those parts are attracted and move toward each other. But as the time runs some filaments start to grow from this dark area.

Now we follow their behavior to image 66 **Figure 57**. The penumbral grain **27c** has moved a little bit against the umbra and divided itself in two channels and disappeared. The grain **27k** became brighter and bigger and started to move in the direction which was almost perpendicular to **27c** and later divided itself to three small point like grains. The grains **27a** have stretched themselves toward two direction (up and down in the image's perspective).The grains **27b** have divided themselves into two channels and become weaker. As the time runs, all those grains become weaker until we reach image 130 **Figure 59**. Here new penumbral grains appear. Let me give names to those grains **130a**, **130b**, **130c**, **130d**, **130e**, **130f** and **130h** (see image 130 **figure 59**).
Now let us see what happened to those grains.
Look at image 150 **figure 60** and see how the structures of those grains change.

What we see is that **130a** became a point-like grain. **130b** became a huge point-like grain and gives impression that it remains besides the dark filament and the brightness from it is hided a little by the dark filament. 130c has moved down (seen from the perspective of the image).All the other grains became weaker but they still have point-like structures. The penumbral filaments changed and became thinner and shorter comparing with image number 0 **Figure 54**. In image 179 and 184 one sees how the filaments from both sides of the dark area are attracted to each other.

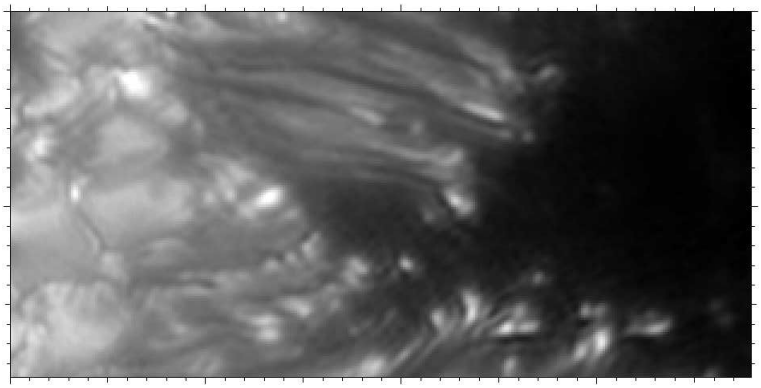

Figure 54: image 0 in work feb173

SMALL MOVIES OF PART 3:

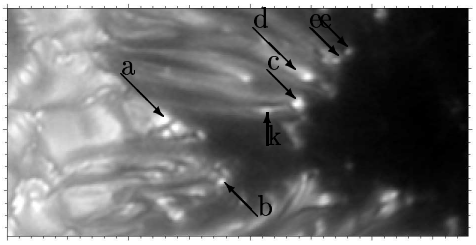

Figure 55: image 27 in work feb173

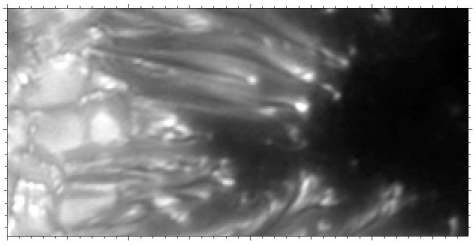

Figure 56: image 35 in work feb173

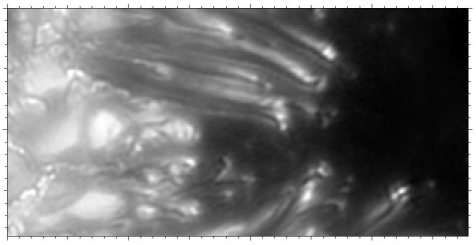

Figure 57: image 66 in work feb173

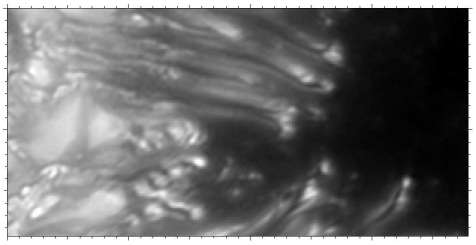

Figure 58: image 76 in work feb173

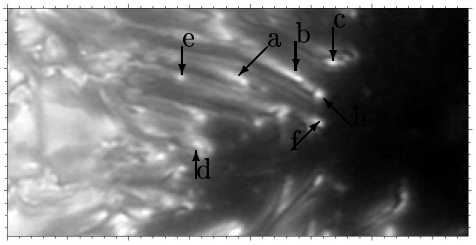

Figure 59: image 130 in work feb173

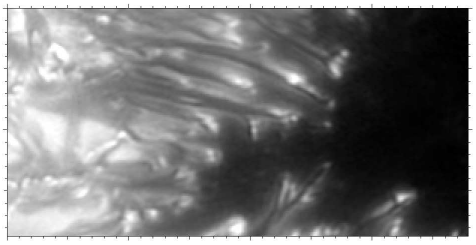

Figure 60: image 150 in work feb173

3:1:`/home/ghanjah/job/feb20_31.cube`:
Take a look at **Figure 61**, to see which part I cut.
We have a bright penumbral filament which seems to be parallel with a dark filament. On the end of this bright filament there are two weak point-like grains (see image 0 in **Figure(62)**). In image 21 **Figure 63** the bright filament has taken a point-like structure and it continues to grow farther against the umbra (see image 76 **Figure 64**). The brightness becomes weaker and decayed. What left is a point-like grain. The grain almost disappeared in image 85 **Figure 65**. Again we get a bright straight filament which almost behaves in the same way as the last one (see image 122 **Figure 66**, 163 **Figure 67**, 176 **Figure 68** and 188 **Figure 69**).

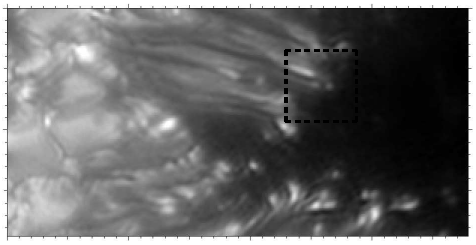

Figure 61: image 0 in work feb173

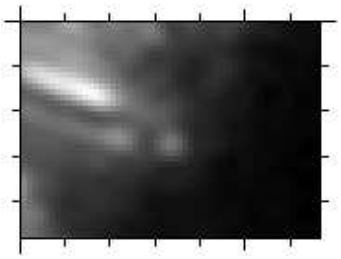

Figure 62: image 0 in job feb2031

3:2./`home/ghanjah/job/feb20_32.cube`:

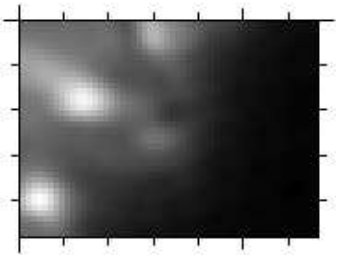

Figure 63: image 21 in job feb2031

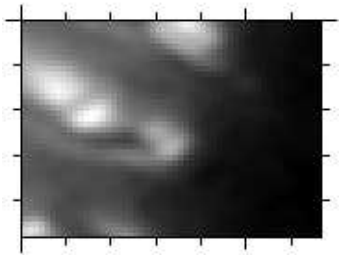

Figure 64: image 76 in job feb2031

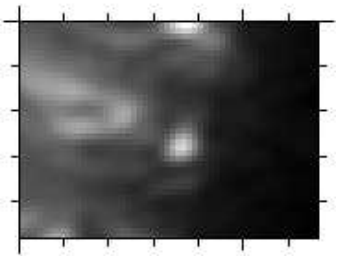

Figure 65: image 85 in job feb2031

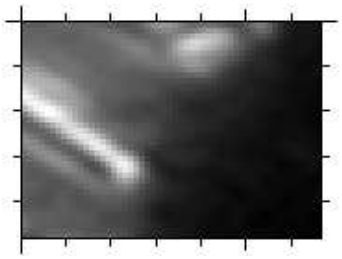

Figure 66: image 122 in job feb2031

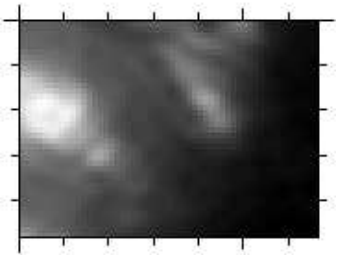

Figure 67: image 163 in job feb2031

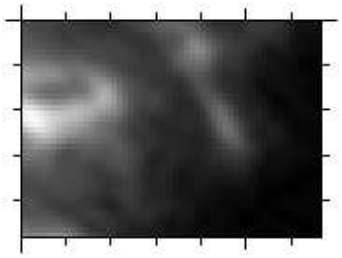

Figure 68: image 176 in job feb2031

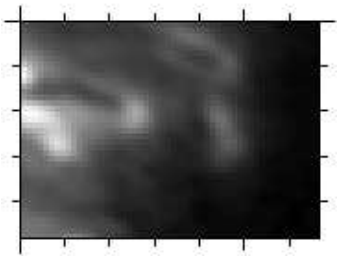

Figure 69: image 188 in job feb2031

In **Figure 70** you can see what part I cut.
In image 0 **Figure 71**, we have a structure which is similar to the structure of the flowers. The grain in the middle of the flowers starts to move against the umbra. There is a dark filament which looks as if it is sticking out of the grain (see image 18 **Figure 72**). The grain starts to take again the structure of the flowers and decays. In image 27 **figure 73**, a little dark filament appears and looks as if it crosses the grain in the middle. But as the time runs it stretches itself and grows, (play the movie and see image 42).

In image 51 **Figure 74**, we see that a point-like grain appears between two small channels. The structure changed and divided into three short channels which grow from the end of the filament (see image number 66 **Figure 75**). The end of the filament then turns back slantingly to the left and forms a part of a toroid-like structure with ring-structures around (see image 125 **Figure 76**). The

rings move perpendicularly to the dark area.
In image number 158 **Figure 77**, the toroid-like filament stretched itself and moves fast toward the umbra. Later in image 205 **Figure 78**, we see a parabola-like structure of a dark filament and several dark streaks crossing it.

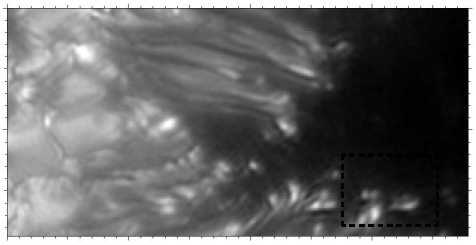

Figure 70: image 0 in work feb173

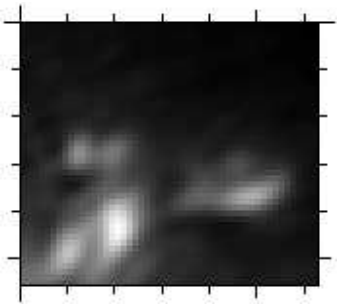

Figure 71: image 0 in job feb2032

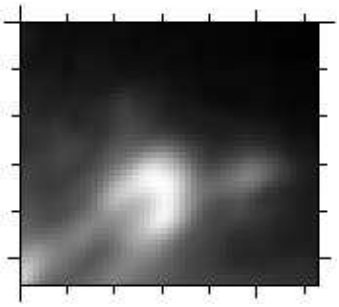

Figure 72: image 18 work feb2032

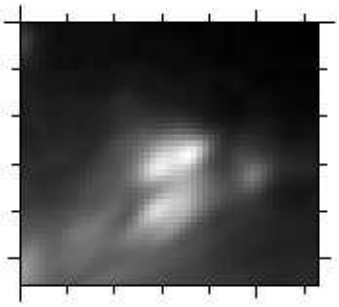

Figure 73: image 27 in job feb2032

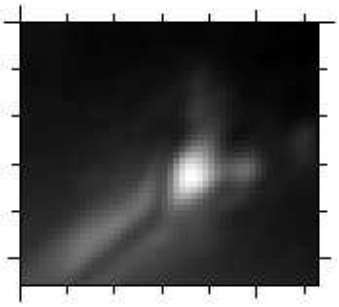

Figure 74: image 51 job feb2032

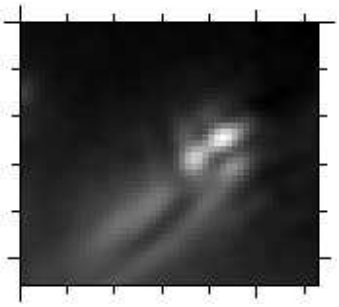

Figure 75: image 66 in job feb2032

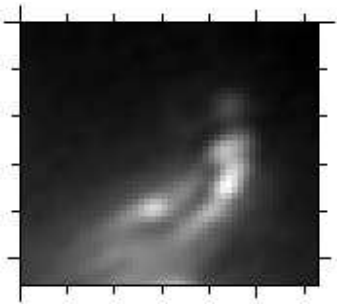

Figure 76: image 125 in job feb2032

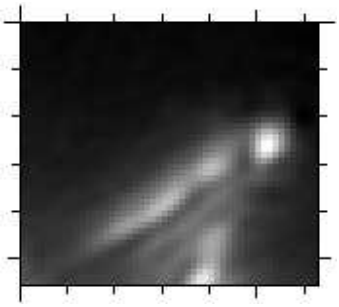

Figure 77: image 158 in small movie job feb2032

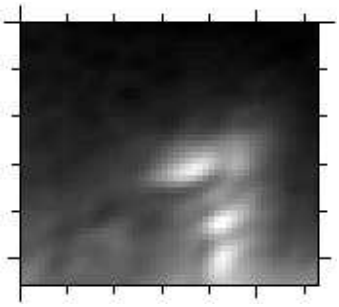

Figure 78: image 205 in small movie job feb2032

3:3./home/ghanjah/job/feb20_33.cube:
In image 0 figure(80), we see a dark filament divides itself into two dark filaments. Between those filaments there is a point-like grain (well actually this grain is closer to one of those filaments). As the time runs the grain moves along one of the two filaments (see image 28 **Figure 81**) and then disappear.

But in image 65 **Figure 82**, two new point-like penumbral grains appear. They take exactly the same direction as the last one, but here it is brighter and bigger, (see image 96 **Figure 83**). The weak grain on the end of the filament starts to move in the opposite direction i.e toward the outer boundary of the penumbra and disappear, while the other grain continues toward the umbra and disappears (see image 113 **Figure 84**).

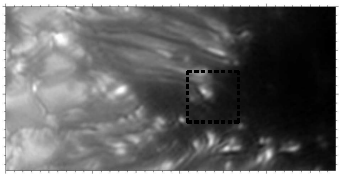

Figure 79: image 0 in work feb173

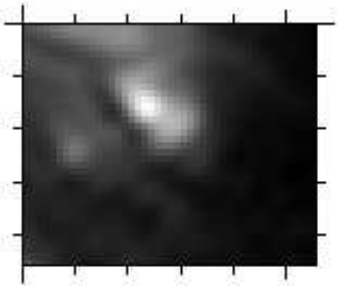

Figure 80: image 0 in job feb2033

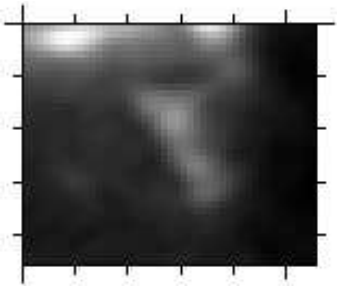

Figure 81: image 28 in job feb2033

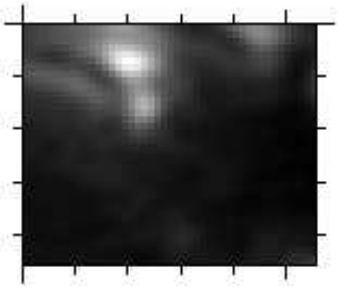

Figure 82: image 65 in job feb2033

3:4./home/ghanjah/job/feb20_34.cube:
(Take look at image 0 **Figure 85** to see which part I cut.
In this movie you see how the bright and the dark filaments grow from the same place. They grow toward three directions, see image 0 figure 86, 163 **Figure 87**, 182 **Figure 88** and 220 **Figure 89**. In image 220 **Figure 89** a dark filament which is perpendicular to the umbra looks as a laying '**M**'.

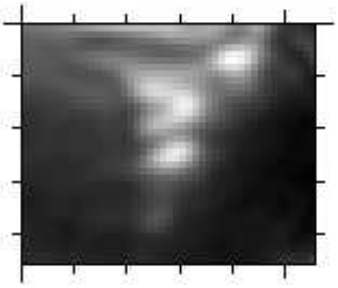

Figure 83: image 96 in job feb2033

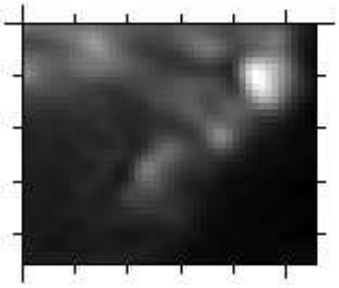

Figure 84: image 113 in job feb2033

There are two other filaments crossing it.

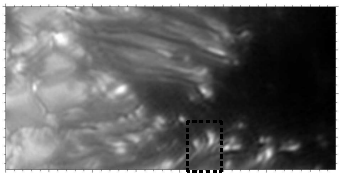

Figure 85: image 0 in work feb173

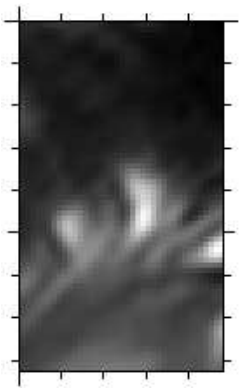

Figure 86: image 0 in job feb2034

5.4 Part 4

`4.\home\ghanjah\work\feb17_4.cube`:
In image number 4 **Figure 91**, we see two dark knots '**a**' and '**b**'. From the knots there are dark filaments which connect them together. There is a weak bright filament which stems from the knot '**a**', and directed toward the umbra. The filament continues into the knot and appears again from the other side (see image 12 **Figure 92**).
The filament seems to have a point-like structure, and it reminds about a chain structure. Between the knots there are stretched penumbral grains, which are directed against the center of the knots, they are similar to loop-like structure.
As the time runs, image 51 **Figure 93** shows a very interesting pattern. It shows a symmetric ring which consists the structure of the chain (see the structure in the box in image 51 **Figure 93**). From the ring, a chain-like filament is sticking out and continues into the penumbra. Close to the ring, there are two other chain structures (see '**a**' and '**b**' in image 51 **Figure 93**).

As the time runs the filaments and their grains at the boundary umbra/penumbra divide themselves into two or more small channels. Many penumbral grains in this part have comet-like structures. In image 61 **Figure 94**, we see that from the knot '**a**' there is a filament which looks as it is switched around another filament which in turn looks as it is sticking out. We see also that there are weak point-like structure everywhere on the left side of the knot.

As the time runs, we see a weak structure which reminds about the chain (see '**n**' in image 109 **Figure 95**). In the same time we see that there is hot plasma while it goes toward the umbra, it turns back toward the opposite direction i.e toward the outer boundary of the penumbra (see '**g**' in

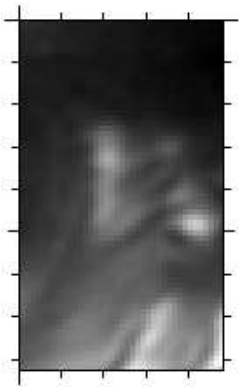

Figure 87: image 163 in job feb2034

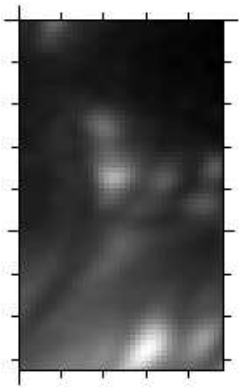

Figure 88: image 182 in job feb2034

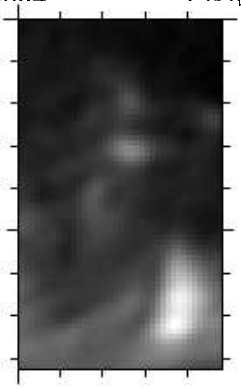

Figure 89: image 220 in small movie job feb2034

image 109 **Figure 95**). If we compare between **g1** and **g2** in image 112 **Figure 96**, we see that there is a similarity between their structures. As the time runs, their structures take the same shape, but in different directions (see image 118 **Figure 97**).

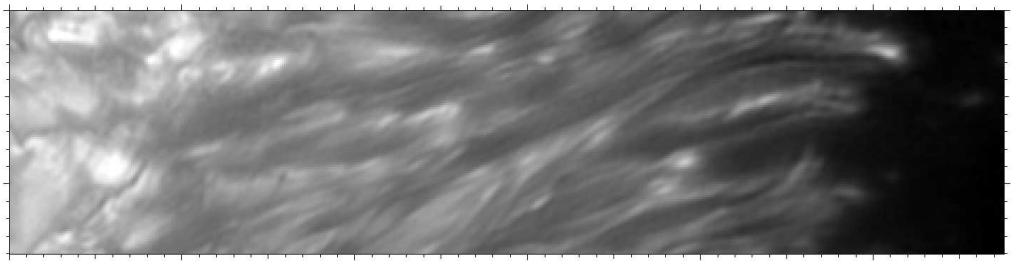

Figure 90: image 0 in work feb174

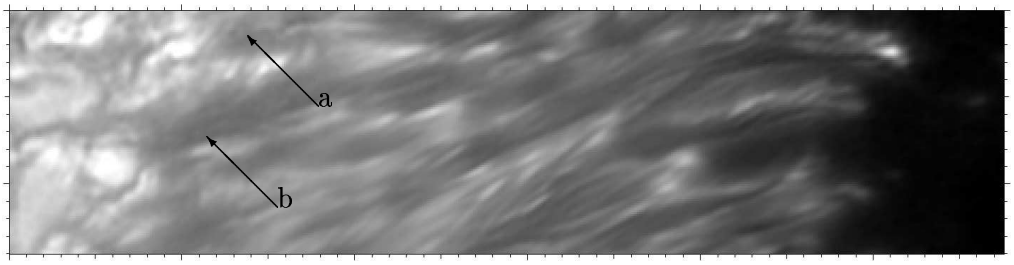

Figure 91: image 4 in work feb174

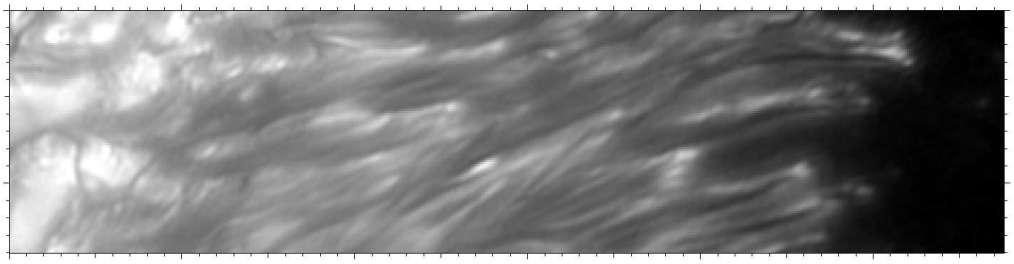

Figure 92: image 12 in work feb174

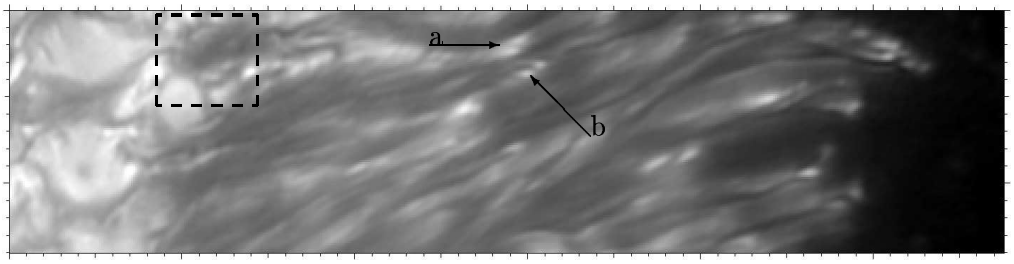

Figure 93: image 51 in work feb174

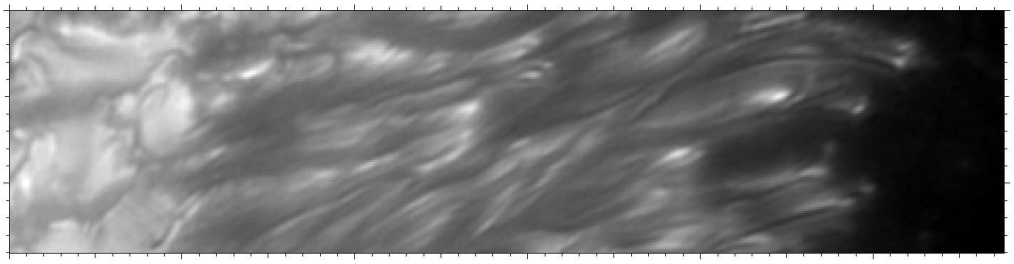

Figure 94: image 61 in work feb174

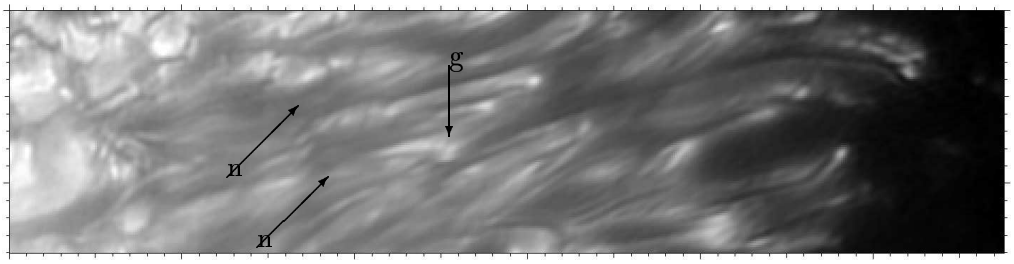

Figure 95: image 109 in work feb174

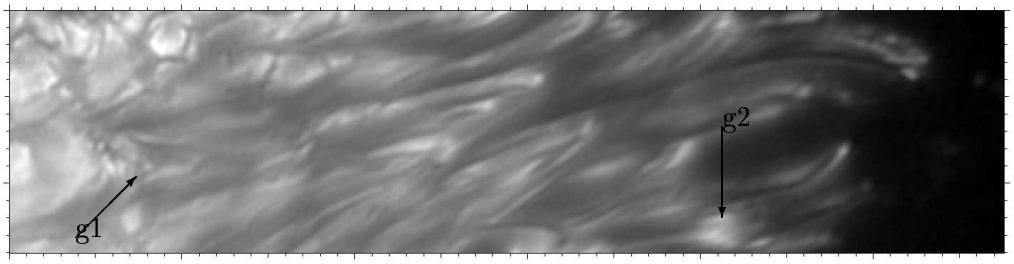

Figure 96: image 112 in work feb174

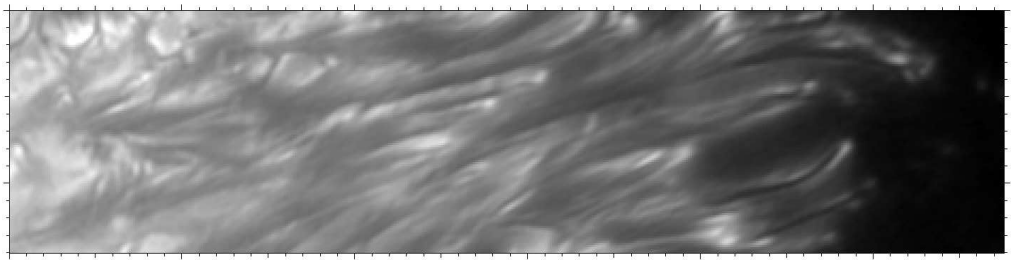

Figure 97: image 118 in work feb174

SMALL MOVIES OF PART 4:

4:1.`/home/ghanjah/job/feb19_41.cube`:
(see which part I cut in image 0 **Figure 98**):
The penumbral grain seems to be at the end of the dark filament in the image 0 **Figure 99**. As the time runs, the structure of the grain changes. It becomes much bigger (see image 36 **Figure 100**). Later on, a huge amount of plasma seems to stream toward the grain and melt together to build up a huge bright area (see image 43 **Figure 101**).
The bright area becomes weaker, but it takes a very interesting structure, this structure reminds us about the chain. When we look farther in the dark area we see the same structure, but it is very weak (see image 80 **Figure 102**).

Later on a plasma looks as it appears under the chain and destroys the structure (see image 126 **Figure 103**). The structure has taken a curvature form and looks as streaks (see image 160 **Figure 104**). At the end of the streaks there is a weak grain which starts to travel in the opposite direction toward the outer boundary of the penumbra (see '**a**' in image 160 **Figure 104** and '**a**' in image 170 **Figure 105**).
The plasma continues to stream against the umbra, and we see also on the other side of the grains there are channels and one sees that the structure of the dark streaks on the grains stem from those channels.
The bright stream behaves as the sea waves (see image 204 **Figure 106**). In image 220 **figure 107**, new sea waves appear and destroy this structure.

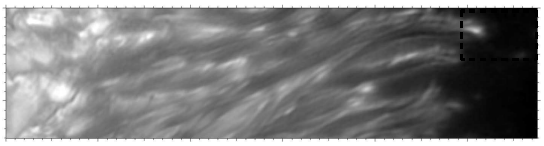

Figure 98: image 0 in work feb174

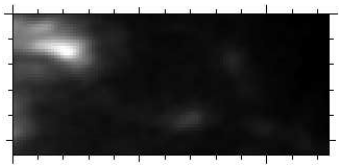

Figure 99: image 0 in job feb1941

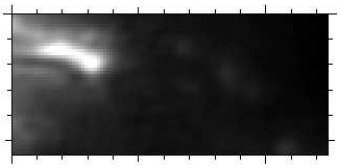

Figure 100: image 36 in job feb1941

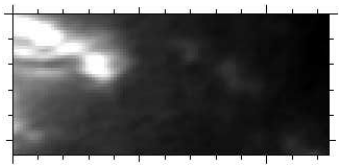

Figure 101: image 43 in job feb1941

4:2.`/home/ghanjah/job/mars31_40.cube`:
This movie consists 133 images and it starts from the data subv 1097 to 1220.
Look at **Figure 108** to see the part I cut.

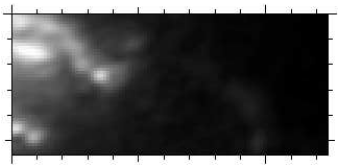

Figure 102: image 80 in job feb1941

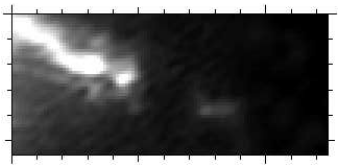

Figure 103: image 126 in job feb1941

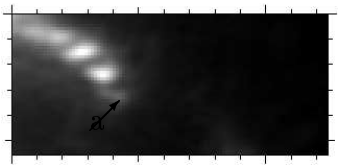

Figure 104: image 160 in job feb1941

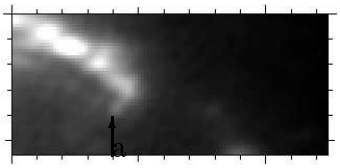

Figure 105: image 170 in job feb1941

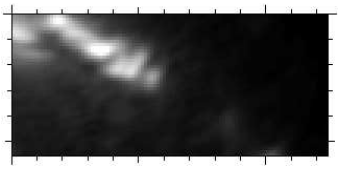

Figure 106: image 204 in job feb1941

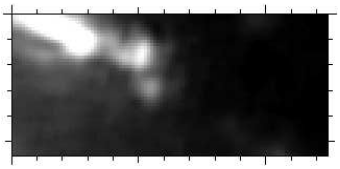

Figure 107: image 220 in job feb1941

In image 0 **Figure 109**, we see several stretched penumbral grains. They are limited by two thick dark filaments. As the time runs, those grains become much brighter and travel toward the umbra. In image 27 **Figure 110**, we see that the dark filaments which cross the grains and look as streaks have a continued part which stretched itself to a long distance.
They become very weak and there appear instead point-like structures, which have shadows on one side (see '**a**' in image 68 **Figure 111**).

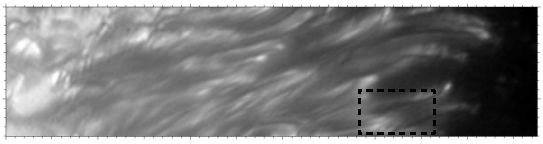

Figure 108: image 97 in work feb174

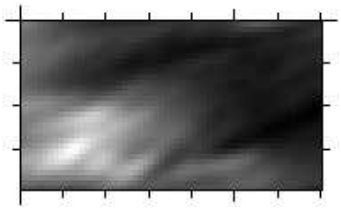

Figure 109: image 0 in job mars3140

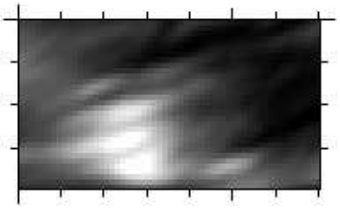

Figure 110: image 27 in job mars3140

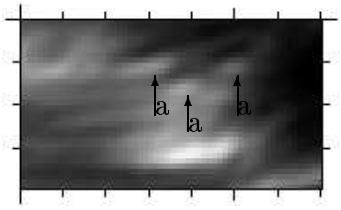

Figure 111: image 68 in job mars3140

4:3./home/ghanjah/job/feb21_43.cube:
Look at image 0 **Figure 112** to see which part I cut.
We see a penumbral grain travels toward the umbra (see image 59 **Figure 114**). The grain disappears in image 137 **Figure 115**. Another penumbral grain appears and moves under the dark

filaments (see image 170 **Figure 116**). The grain disappears in image 208 **Figure 117**.

Figure 112: image 0 in work feb174

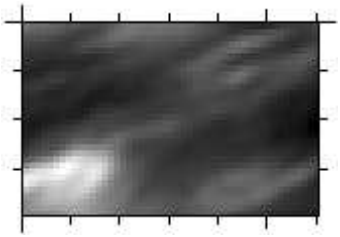

Figure 113: image 0 in job feb2143

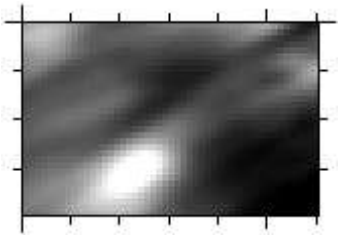

Figure 114: image 59 in job feb2143

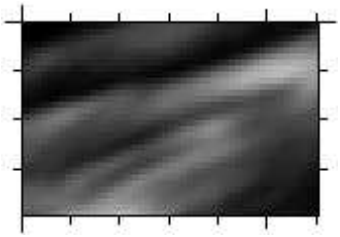

Figure 115: image 137 in job feb2143

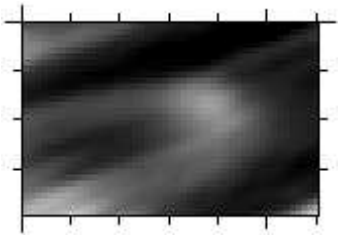

Figure 116: image 170 in job feb2143

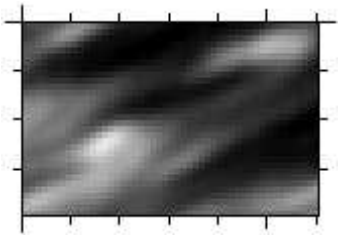

Figure 117: image 208 in job feb2143

5.5 Part 5

`5./home/ghanjah/work/feb17_5.cube`:
We consider the outer boundary of the penumbra. As the time runs we see that a dark cloud goes toward the granules, see how '**a**' in image 45 **Figure 119** and in image 57 **Figure 120** travels against the granules. As the time runs, we see a weak structure which look as a chain (see '**n**' in image 103 **Figure 121**). There is also a filament which stretches from the penumbra into the granules (see '**f**' in image 103 **Figure 121**), we see the filament '**f**' is connected to the dark places on the granules. There is a structure which I call mini-penumbra or an ellipse. On the left side of this ellipse the bright grain goes against the granules, but the filaments on the edge of the ellipse go against the umbra. On the right side we see that the penumbral grains travel against the umbra.

As the time runs, we see that the ellipse stretched itself and became smaller and longer. The penumbral grains move from the edge of the ellipse to the center. We see also the structure of the chain travels toward the center of the ellipse (see '**n**' in image 167 **Figure 122**). You can see what structure is left in image 196 **Figure 123** and image 209 **Figure 124**.

Consider the structure '**h**' in image 167 **Figure 122** and the structure '**h**' in image 209 **Figure 124**. '**h**' in image 209 is what is left from the structure of the chain. The fact is those structures look very similar.

Now look at the penumbral grains close to the umbra i.e those contained in the box in image 209 **Figure 124**. Their structures are reminiscent of the '**h**' in image 167 **Figure 122**. The structure of '**g**' and the structure in the box in image 209 **Figure 124** becomes as those marked with arrows in image 219 **Figure 125**.

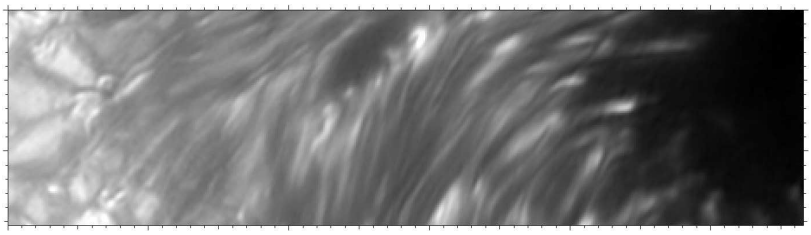

Figure 118: image 0 in work feb175

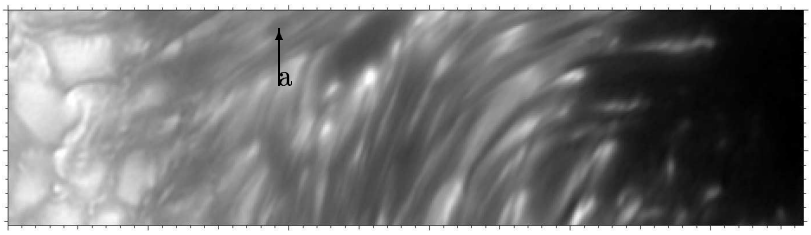

Figure 119: image 45 in work feb175

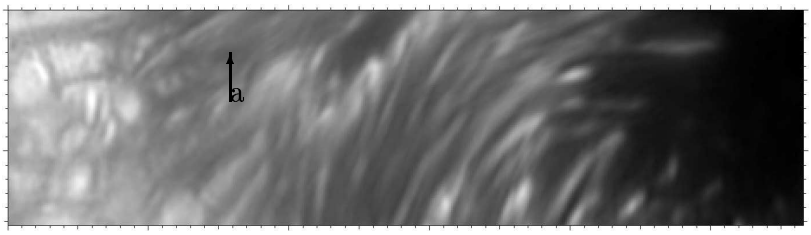

Figure 120: image 57 in work feb175

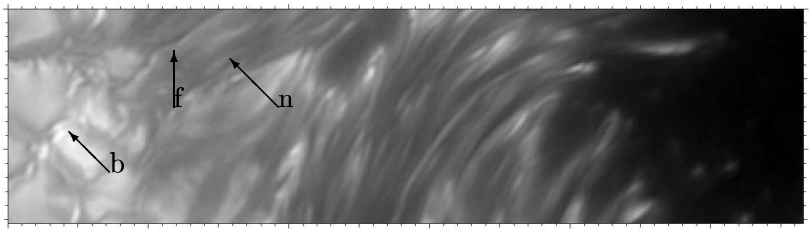

Figure 121: image 103 in work feb175

SMALL MOVIES OF PART 5:

5:1`./home/ghanjah/job/feb22_51.cube`:

Look at image 0 **Figure 126** to see which part I cut.

We see what I called a mini-umbra or an ellipse. The penumbral grains travel against the center of this ellipse, but in general the whole things travel against the umbra. As the time runs, we see a very weak long thin chain, which crosses the miniumbra on both sides of the surrounding (see '**n**' in

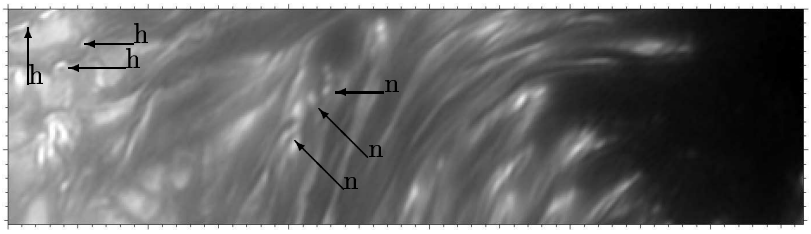

Figure 122: image 167 in work feb175

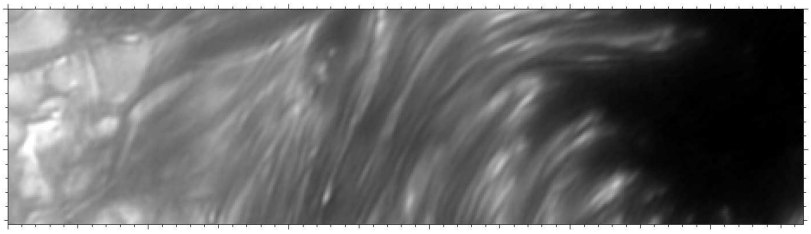

Figure 123: image 196 in work feb175

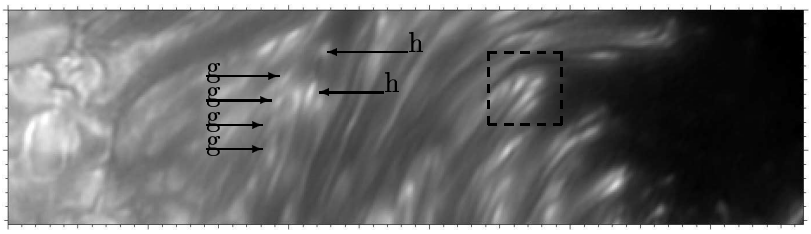

Figure 124: image 209 in work feb175

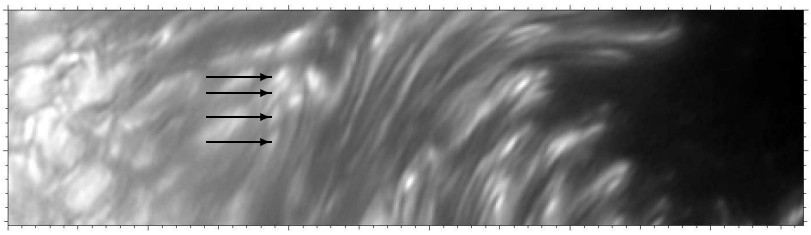

Figure 125: image 219 in work feb175

image 85 **Figure 128**).

As the time runs, there appears a structure inside the miniumbra which is reminiscent of a curved dark channel with many dark hairs which in turn limit a round like structure (see image 144 **Figure 129**). In image 208 **Figure 130** one sees how the filaments from both sides of the miniumbra connect to each other.

5:2.`\home\ghanjah\job\feb22_52.cube`:
Look at image 0 **Figure 131** to see which part I cut.
The penumbral grain is at the boundary umbra/penumbra. As the time runs, the grain becomes thicker and brighter and moves straight to the umbra (see image 51 **Figure 133**). It disappears in image 69 **Figure 134**, but there is another grain which also appears here. This continues to travel

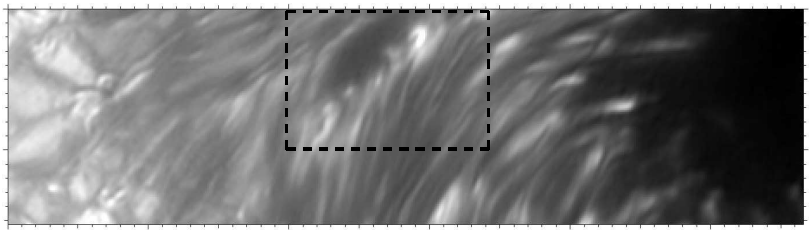

Figure 126: image 0 in work feb175

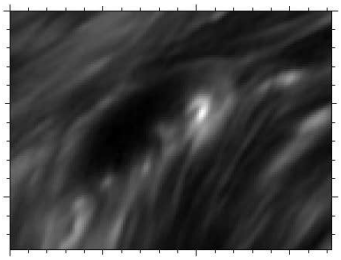

Figure 127: image 0 in job feb2251

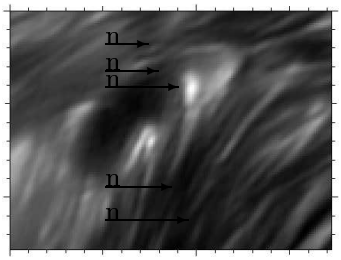

Figure 128: image 85 in job feb2251

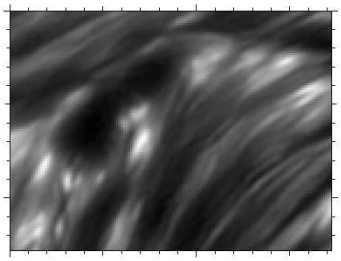

Figure 129: image 144 in job feb2251

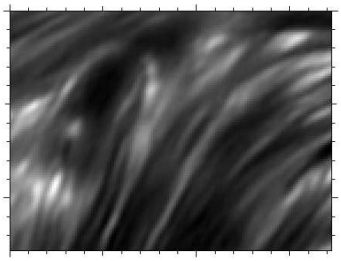

Figure 130: image 208 in job feb2251

up-right toward the umbra and disappeared in image 141.

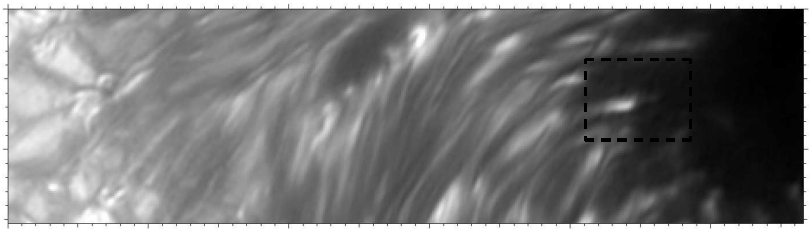

Figure 131: image 0 in work feb175

5:3./home/ghanjah/job/feb22_53.cube:
Take a look at image 0 **Figure 136**, to see which part I cut.
In image 0 **Figure 137** we see a penumbral grain appears and becomes brighter as the time runs. In front of the penumbral grain, we see a very weak chain structure (see image 9 **Figure 138**).
The penumbral grain continues to travel against the umbra and in the same time gets brighter. The chain structure is still seen (see image 19 **Figure 139**). In image 48 **Figure 140** the grain still in the same place.It seems almost fixed. In image 79 **figure 141** the grain has hidden itself under a thick dark filament, and then it travels up and becomes bigger (see image 96 **Figure 142**).

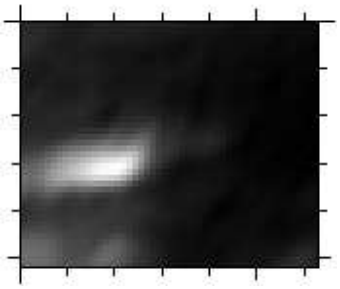

Figure 132: image 0 in job feb2252

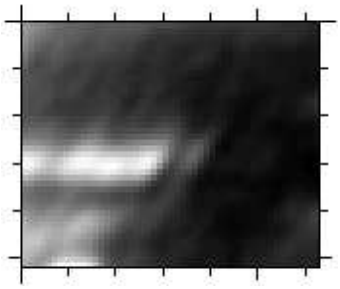

Figure 133: image 51 in job feb2252

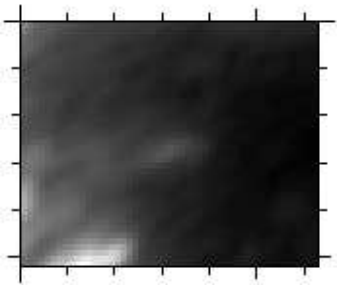

Figure 134: image 69 in job feb2252

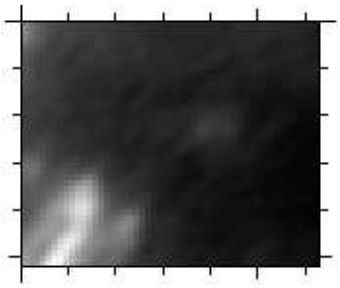

Figure 135: image 104 in job feb2252

Later, the grain disappeared in image 118 **Figure 143**. But we see again from the same place a new penumbral grain which seems to have the same structure (see image 118 **Figure 143**). In image 122 **Figure 144** the grain became almost a bright smooth channel and moved against the umbra. If one looks carefully at image 122 **Figure 144**, one sees a weak filament which crosses the top of the bright grain (see '**a**' in image 122 **figure 144**).

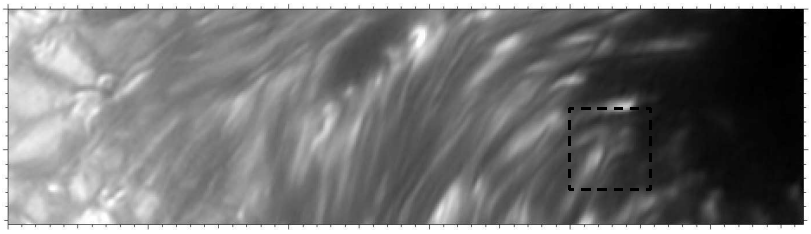

Figure 136: image 0 in work feb175

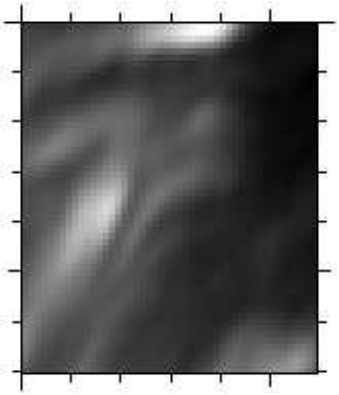

Figure 137: image 0 in job feb2253

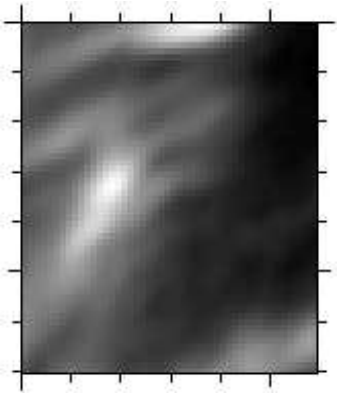

Figure 138: image 9 in job feb2253

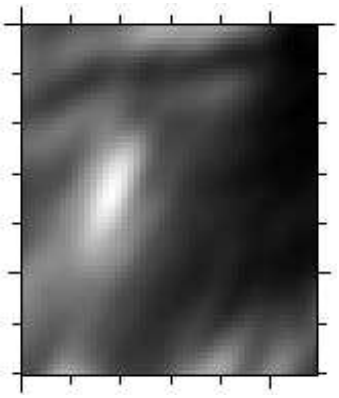

Figure 139: image 19 in job feb2253

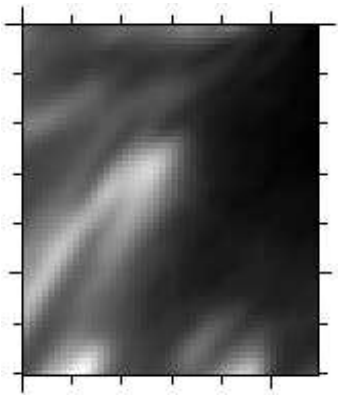

Figure 140: image 48 in job feb2253

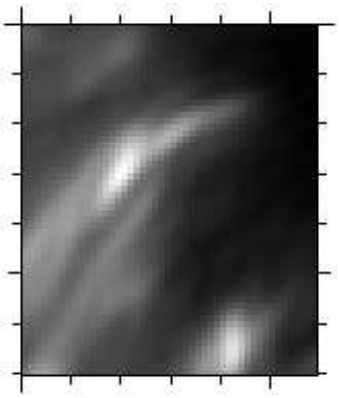

Figure 141: image 79 in job feb2253

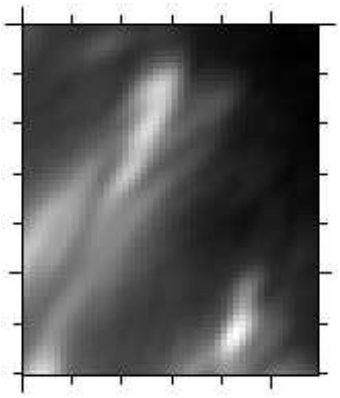

Figure 142: image 96 in job feb2253

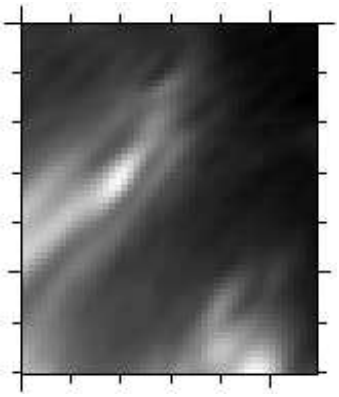

Figure 143: image 118 in job feb2253

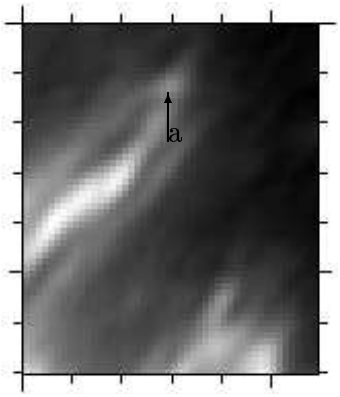

Figure 144: image 122 in job feb2253

5:4.`/home/ghanjah/job/feb22_54.cube`:
Take a look at image 0 **Figure 145** to see which part I cut.
We have a huge bright area. As the time runs, we see three small point-like penumbral grains in this area (see image 14 **Figure 147**). In image 25 **Figure 148** we see a bright structure of a chain. This structure becomes weak after a while.
Later, we see a weak grain (see '**a**' in image 30 **Figure 149**), this grain seems to travel under the dark filament (see image 33 **Figure 150**). See the changing of that structure in image 43. The grain disappeared in image 53.

Later, the grain appears again (see image 56 **Figure 153**). You can see how it changed in the following image sequences: image 58 **Figure 154**, 59 **Figure 155**, 60 **Figure 156**, 67 **figure 157**,

70 **Figure 158**.
In image 97 **Figure 159** one sees how the structure of the grain changed. But in image 103 **Figure 160**, something happened here, the tail of the grain started to swing from the original direction, see the images 106 **Figure 161** and 107 **Figure 162**. In image 125 **Figure 163** one still sees a trace of the swing. This structure looks as loop-like.

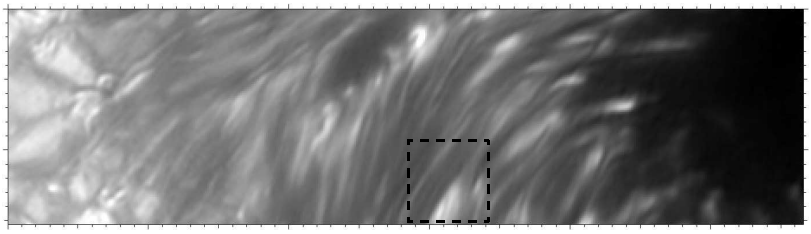

Figure 145: image 0 in work feb175

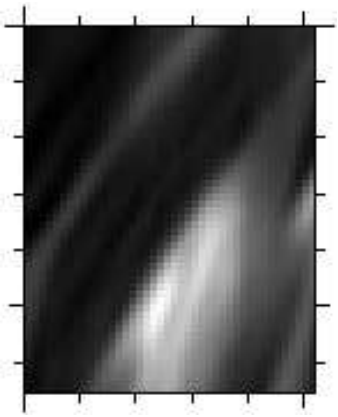

Figure 146: image 0 in job feb2254

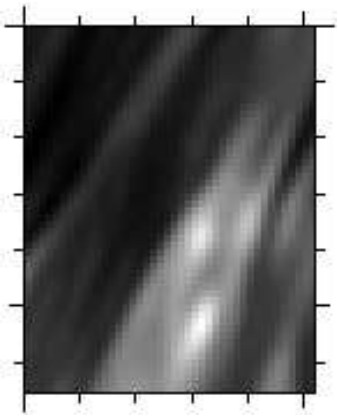

Figure 147: image 14 in job feb2254

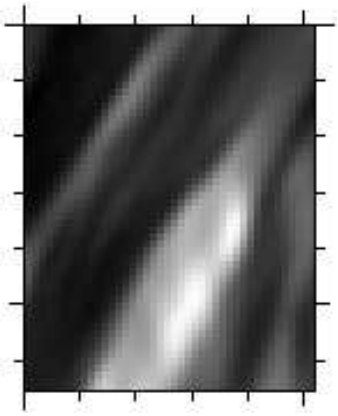

Figure 148: image 25 in job feb2254

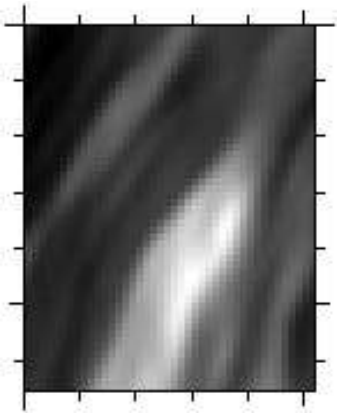

Figure 149: image 30 in job feb2254

5:5./home/ghanjah/job/feb22_55.cube:
Take a look at image 0 **Figure 164** to see which part I cut.
In image 0 **Figure 165**, there are bright and dark filaments. Their structures are smooth and soft. As the time runs, we see a bright filament get brighter. In image 9 **Figure 166** a weak structure appears which reminds us about the structure of the chain.

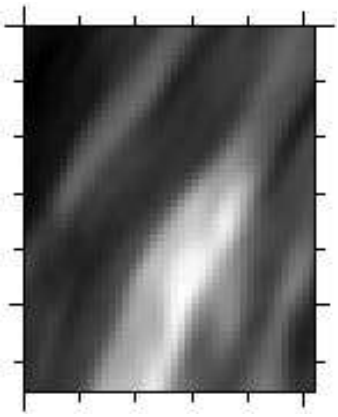

Figure 150: image 33 in job feb2254

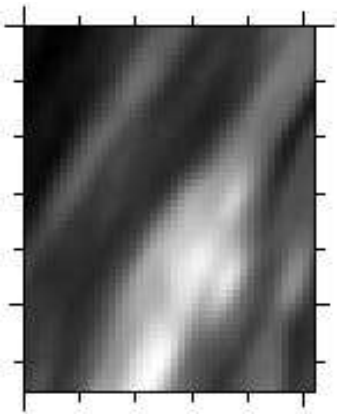

Figure 151: image 36 in job feb2254

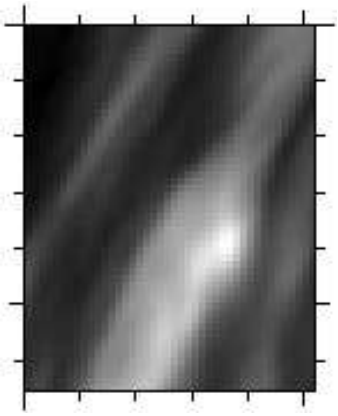

Figure 152: image 40 in job feb2254

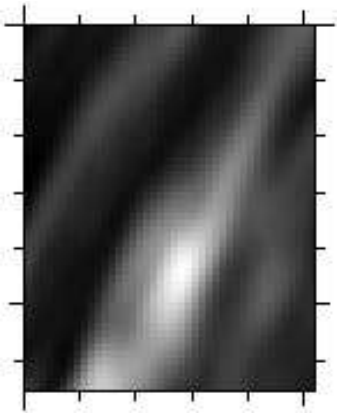

Figure 153: image 56 in job feb2254

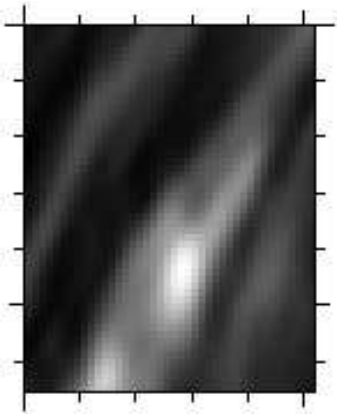

Figure 154: image 58 in job feb2254

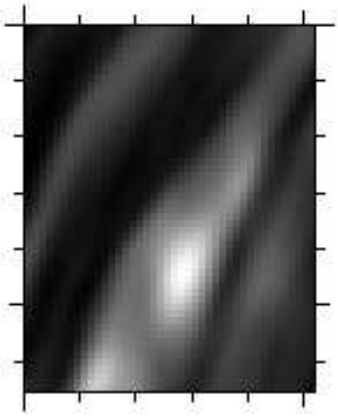

Figure 155: image 59 in job feb2254

In image 10 **Figure 167**, we see a grain which seems to move up (see image 26 **Figure 168**). But in image 32 **Figure 169** we see that the grain disappeared (see '**a**' in image 32 **Figure 169**). From the head of the parable-like structure there is a filament which is sticking out toward the umbra (see '**b**' in image 32 **Figure 169**).This structure is destroyed after a while.

In image 89 **Figure 170**, a structure of a chain appears (see the arrows in image 89 **Figure 170**. We see also a dark little cloud (see '**c**' in image 116 **Figure 171**). This cloud travels against the granules (see '**c**' in image 127 **Figure 172**). In image 183 **Figure 173**, we see a weak dark border. On both sides of this border the grains and the filaments are more clear.

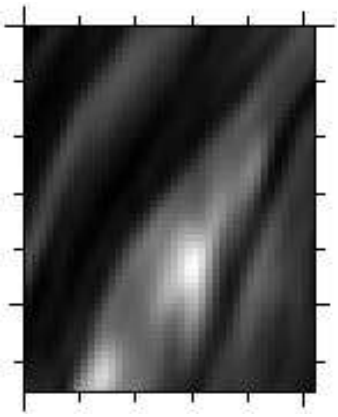

Figure 156: image 60 in job feb2254

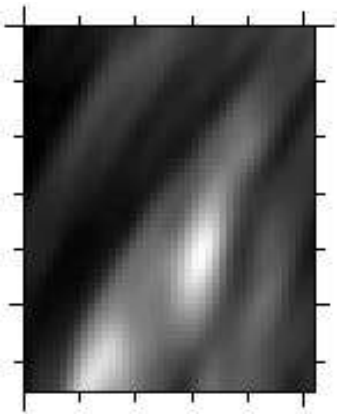

Figure 157: image 67 in job feb2254

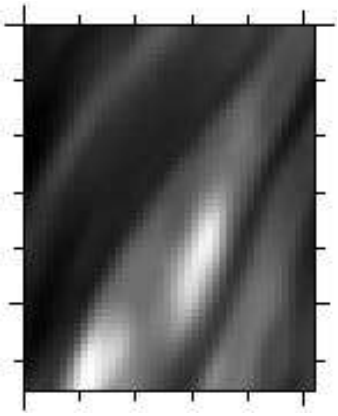

Figure 158: image 70 in job feb2254

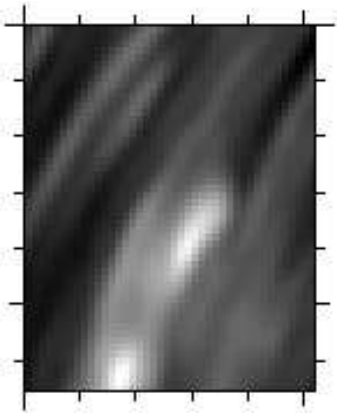

Figure 159: image 97 in job feb2254

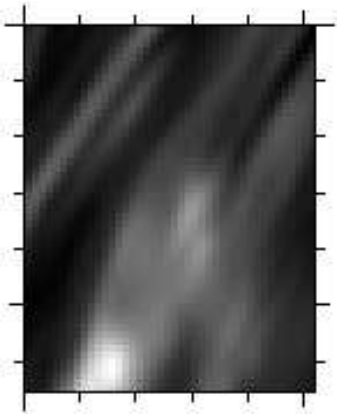

Figure 160: image 103 in job feb2254

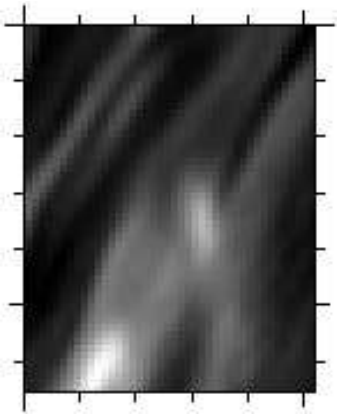

Figure 161: image 106 in job feb2254

5.6 Part 6

6.`/home/ghanjah/work/feb17_6.cube`:
Here, we have different structure of the filaments than in the last studied sections. The filaments are uncombed. One can see that the tails of many filaments are gathered. The places where the filaments start to be gathered to each other show bright areas or penumbral grains which look different from the grains on the umbra/penumbra boundary. We see again a structure which reminds us about the

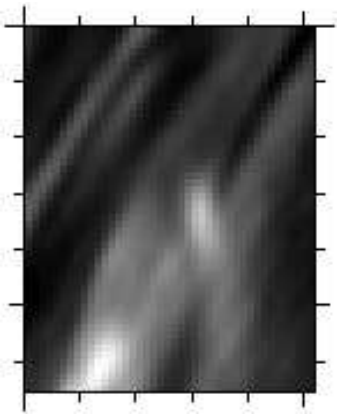

Figure 162: image 107 in job feb2254

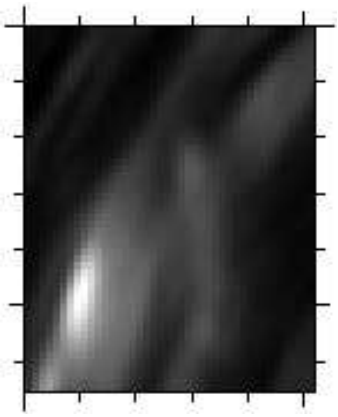

Figure 163: image 125 in job feb2254

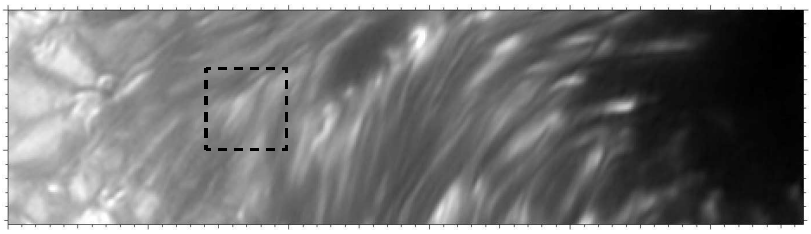

Figure 164: image 0 in work feb175

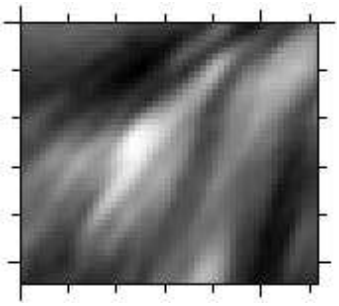

Figure 165: image 0 in job feb2255

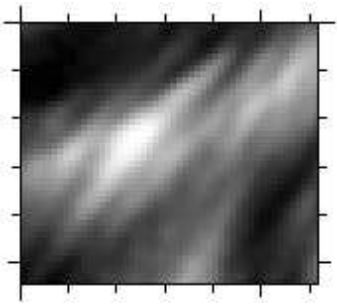

Figure 166: image 9 in job feb2255

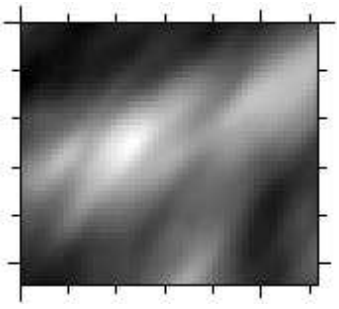

Figure 167: image 10 in job feb2255

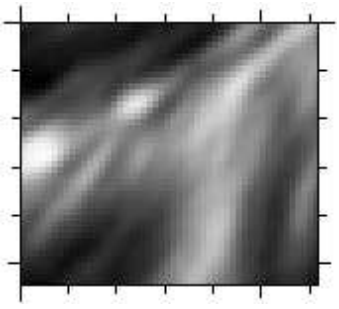

Figure 168: image 26 in job feb2255

chain (see the arrows in image 0 **Figure 174**).

In image 29 **Figure 175**, we see how the structure of the chain stretched itself in a smooth way (see the arrows in image 70 **Figure 176**). In image 84 **Figure 177** the arrows '**a**' show a necklace structure.
Consider also the structure we marked by arrows in **Figure 174**. We see also in the same image that there are structures of dark streaks and if one looks carefully, one sees that the dark streaks stem

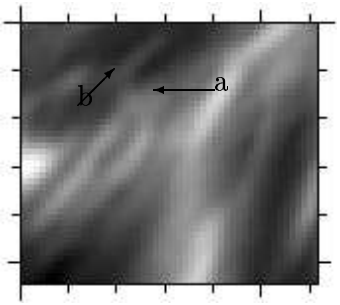

Figure 169: image 32 in job feb2255

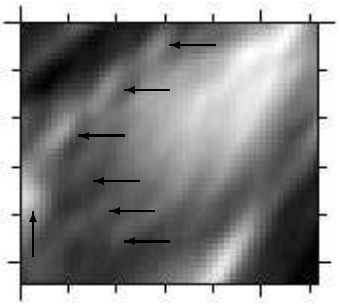

Figure 170: image 89 in job feb2255

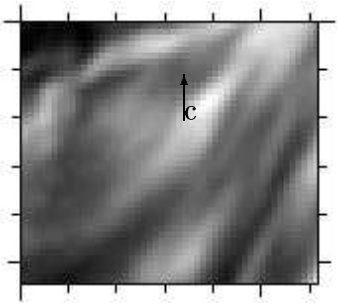

Figure 171: image 116 in job feb2255

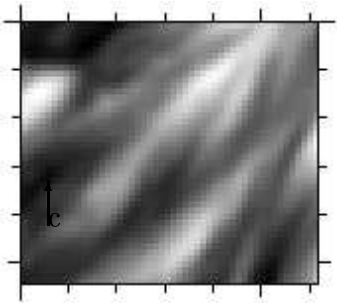

Figure 172: image 127 in job feb2255

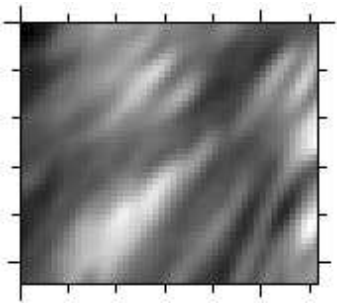

Figure 173: image 183 in job feb2255

from the dark surroundings (see '**t**' in image 84 **Figure 177**).

Let us see what happens to the structure '**a**' we had in image 84 **Figure 177**. They have stretched and twisted themselves, they look as to have spiral structures. This makes the structures of the filaments and penumbral grains look as they have spiral form (see '**a**' in image 105 **Figure 178**). There are also several very dark thick filaments which dominate the area close to the umbra (see image 156 **Figure 179**.

SMALL MOVIES OF PART 6:

6:1`./home/ghanjah/job/feb19_61.cube`:

Look at image 0 **Figure 180**, to see which part I cut.

In image 0 **Figure 181**, we see a penumbral grain, and very thick dark filament at the right side of the grain. The grain moves left-up taking on a comet like structure and becoming brighter (see image 22 **Figure 182**).

The grain becomes bigger (see the image sequences 85 **Figure183**, image 94 **Figure(184)**, image 106 **Figure 185**.

But if one again looks carefully at image 85 **Figure 183,** one can see that there is a very weak structure around the grain. It seems to be the edge of the grain. In image 116 **Figure 186** we see that the thick dark filament on the right side start to cover the grain. In image 136 **Figure 187** the

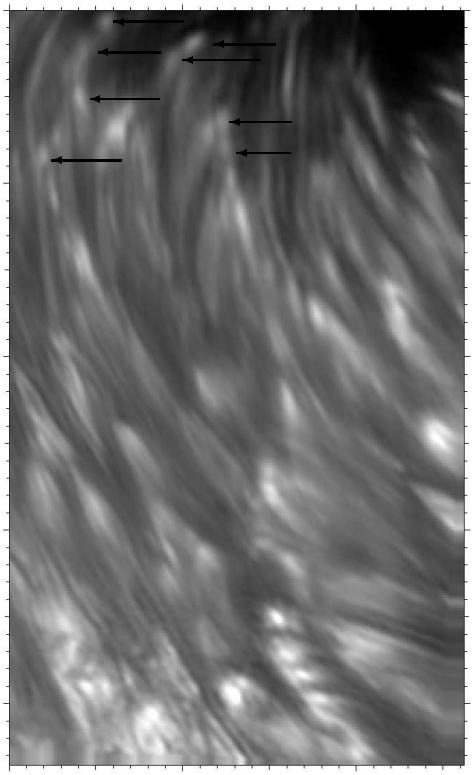

Figure 174: image 0 in work feb176

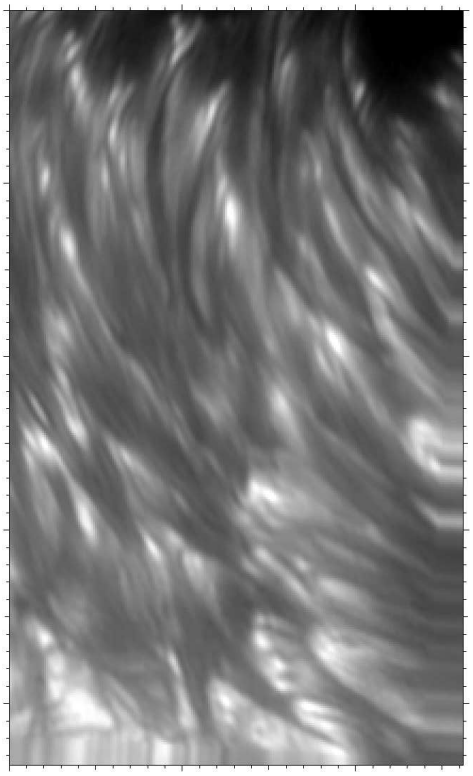

Figure 175: image 29 in work feb176

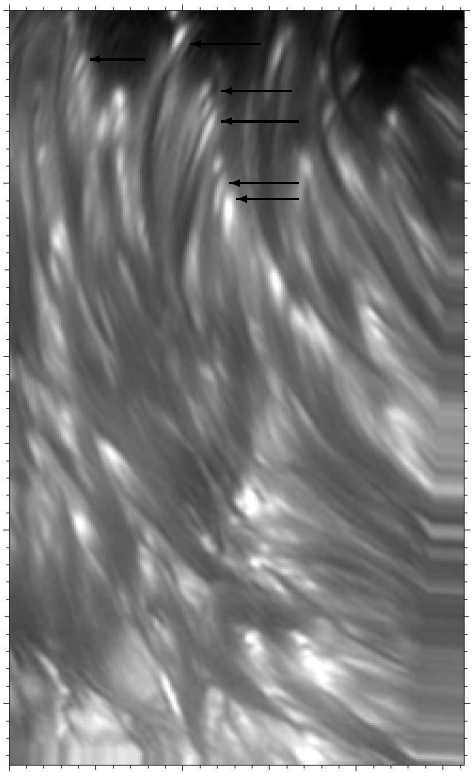

Figure 176: image 70 in work feb176

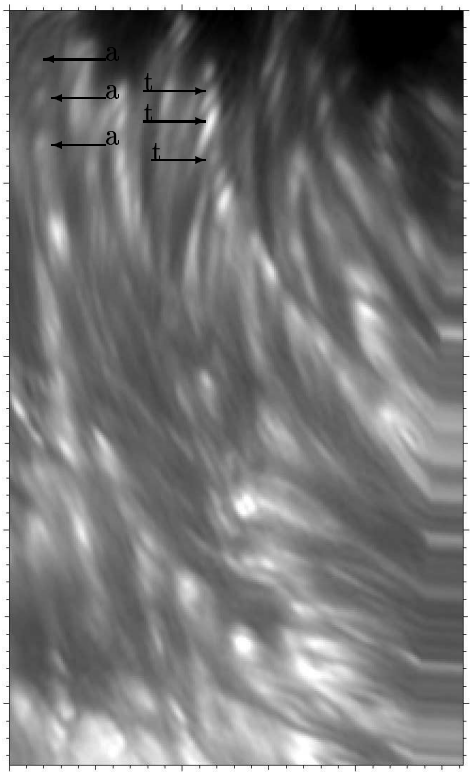

Figure 177: image 84 in work feb176

grain disappeared.

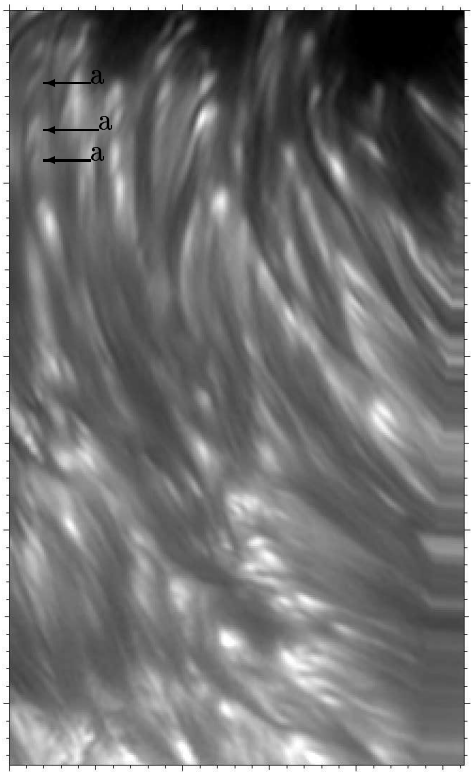

Figure 178: image 105 in work feb176

Figure 179: image 156 in work feb176

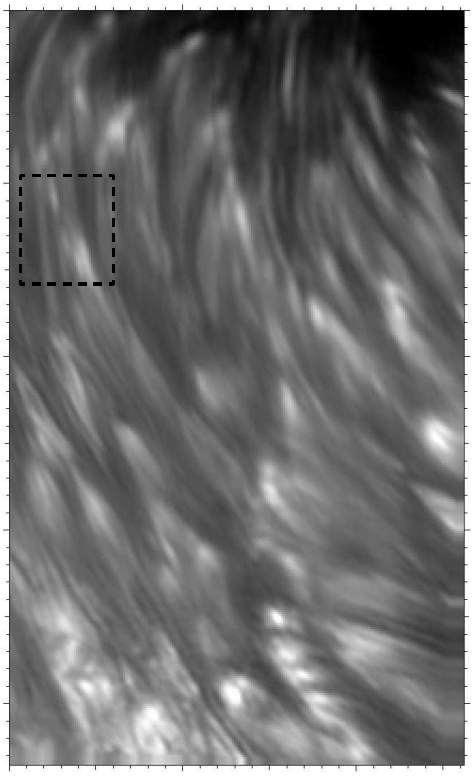

Figure 180: image 0 in work feb176

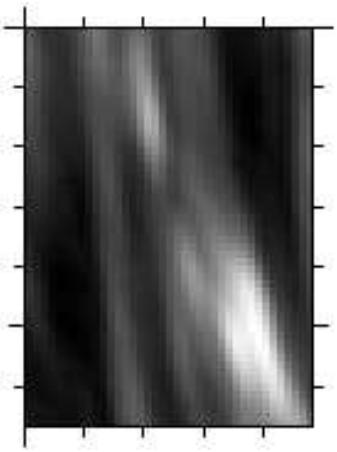

Figure 181: image 0 in job feb1961

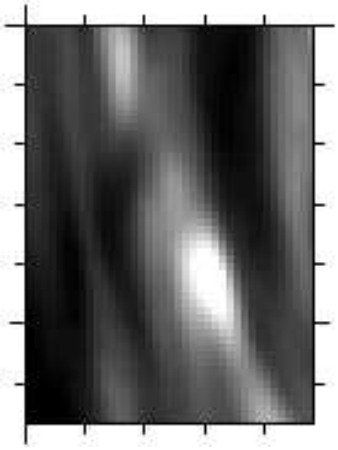

Figure 182: image 22 in job feb1961

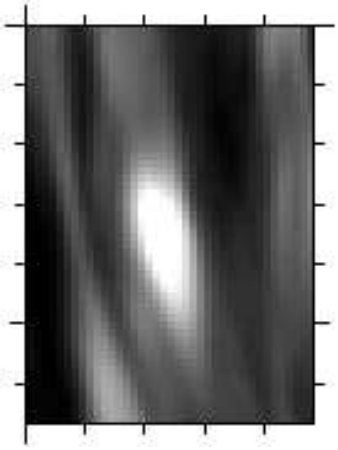

Figure 183: image 85 in job feb1961

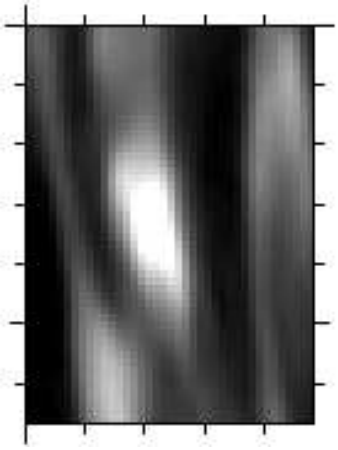

Figure 184: image 94 in job feb1961

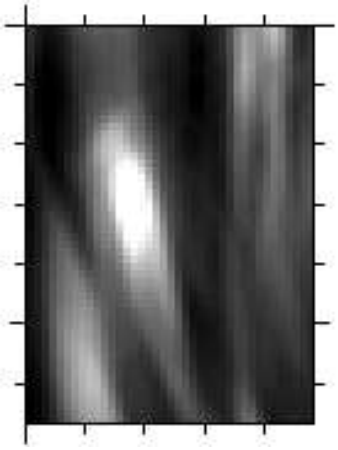

Figure 185: image 106 in job feb1961

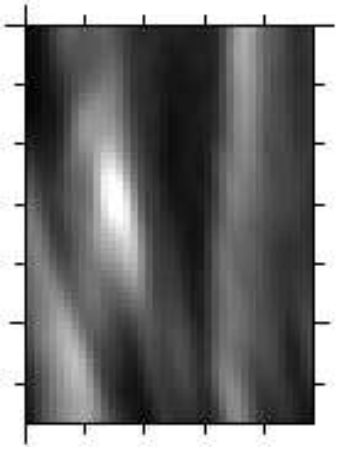

Figure 186: image 116 in job feb1961

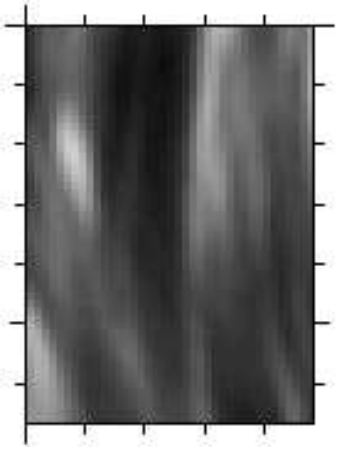

Figure 187: image 136 in job feb1961

6:2./home/ghanjah/job/feb24_622.cube:
In image 0 **Figure 188** you can see which part I cut.
Consider image 0 **Figure 189**, we see a huge penumbral grain, which seems to spread out in the surroundings. The grain becomes weaker and the filaments on the surroundings have taken wavy structures (see image 17 **Figure 190**), the grain disappeared after a while.

As the time runs, a new grain appears. It seems to have a dark tail (see image 40 **Figure 191**). The grain stretches itself and becomes weak (see image 55 **Figure 192**). As the time runs, a plasma

appears under the weak grain and its tail. The plasma makes the grain and its tail to look darker (see image 77 **Figure 193**).
In image 93 **Figure 194** the dark tail moved to the left. On the right side of the tail the plasma looks like a bright channel. One can see very clearly that there are very weak dark filaments which cross the channel. This makes the whole bright channel look like streaks. One can also see that those weak filaments stem from the surroundings.

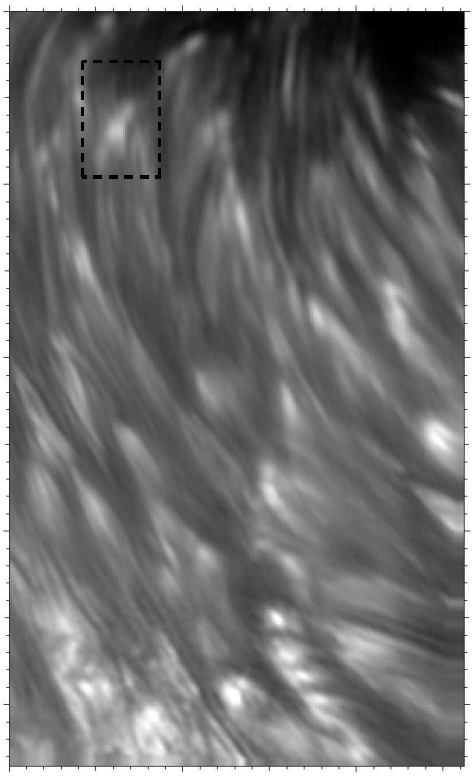

Figure 188: image 0 in work feb176

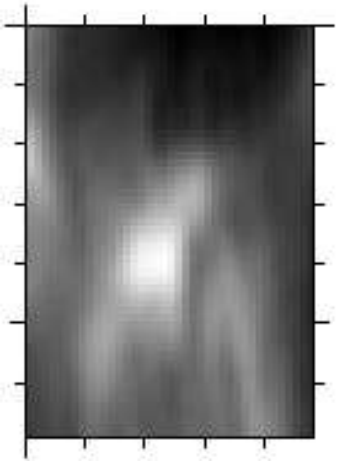

Figure 189: image 0 in job feb24622

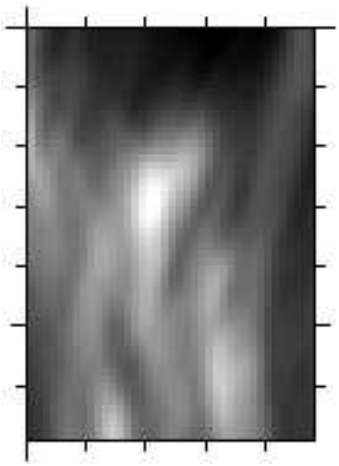

Figure 190: image 17 in job feb24622

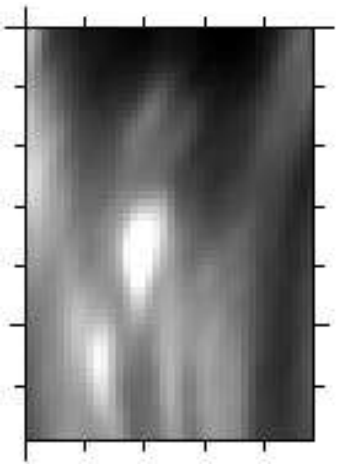

Figure 191: image 40 in job feb24622

6:3./home/ghanjah/job/feb24_63.cube:
Take a look at image 0 figure(195) to see which part I cut.
Here I have taken the structure which I called the chain structure. As the time runs, we see that the grains which look as point-like have smeared themselves (see image 9 **Figure 197**).

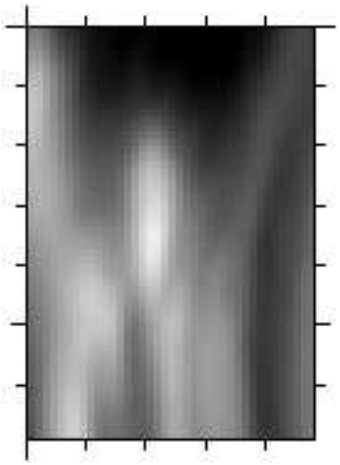

Figure 192: image 55 in job feb24622

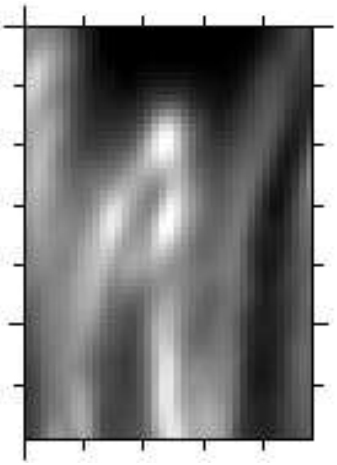

Figure 193: image 77 in job feb24622

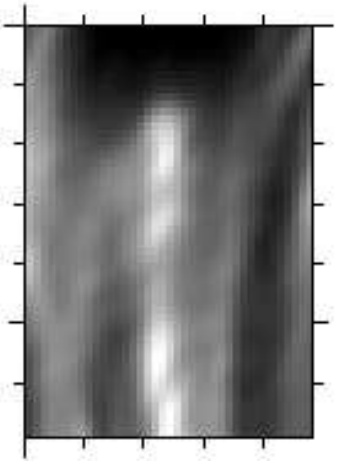

Figure 194: image 93 in job feb24622

We see also very clearly how the dark tiny filament moves very fast (see '**b**' in image 57 **Figure 198** and '**b**' in image 59 **Figure 199**).

As the time runs, we see many dark tiny filaments which look like streaks on the bright areas. If we look closer, we see that they stem from the dark filaments in the surroundings (see image 79 **Figure 200**).
Many streaks disappeared and the weak stretched penumbral grain still survived, but there is a very weak structure of the chain on the middle-left side on image 93 **figure 201**.
Then three weak penumbral grains appeared (see the stretched grains close to each other in image 93 **Figure 201**), and they melt together and build two penumbral grain (see image 120 **Figure 202**). Later, in image 143 **Figure 203** appeared a stream of comet like penumbral grains. Consider the strong dark filament in the dark area, and see what happened to it in image 220 **Figure 204**.

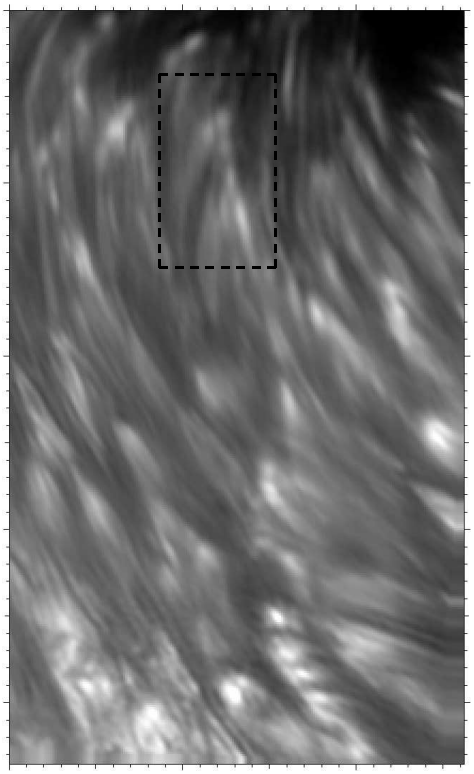

Figure 195: image 0 in work feb176

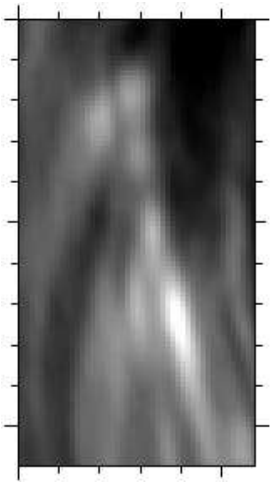

Figure 196: image 0 in job feb2463

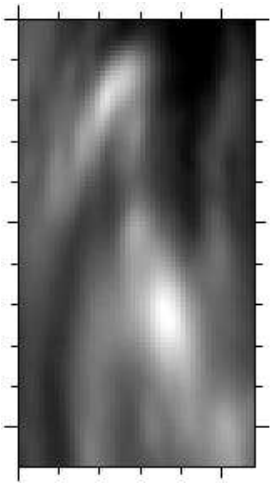

Figure 197: image 9 in job feb2463

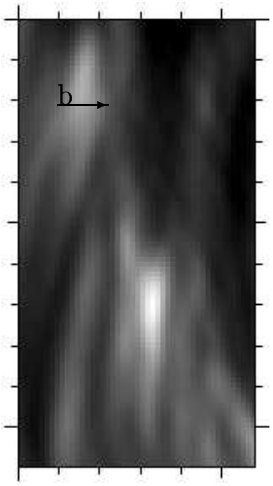

Figure 198: image 57 in job feb2463

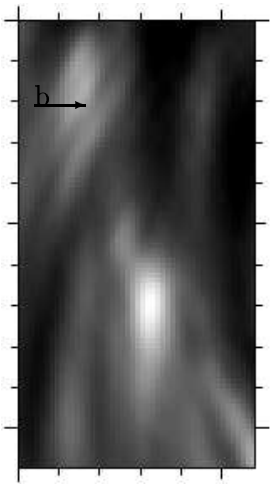

Figure 199: image 59 in job feb2463

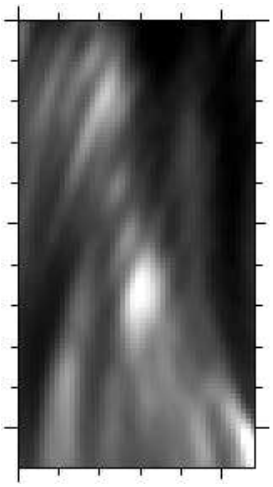

Figure 200: image 79 in job feb2463

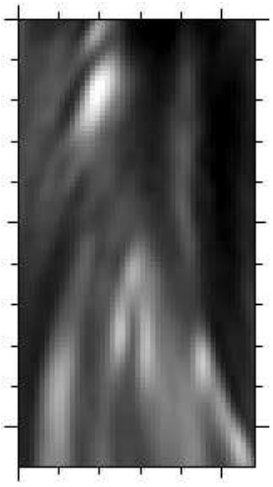

Figure 201: image 93 in job feb2463

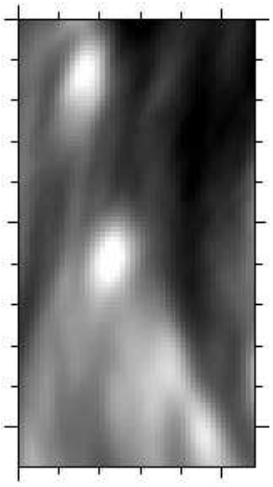

Figure 202: image 120 in job feb2463

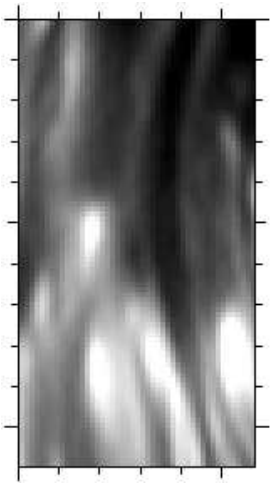

Figure 203: image 143 in job feb2463

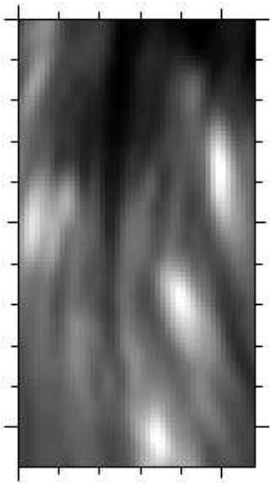

Figure 204: image 220 in job feb2463

6:4.`/home/ghanjah/job/feb24_644.cube`:
Look at image 0 **Figure 205**, to see which part I cut.
We have two penumbral grains in image 0 **Figure 206**. One of them disappeared, and the second moved left-up and became brighter (see image 37 **Figure 207**).
The grain moves and looks as it passes under the dark filament, (see '**a**' in image 41 **Figure 208**). later, the grain seems to move left-up and look like a huge bright point-like (see '**a**' in image 48 **Figure 209**).
As the time runs the grain '**a**' becomes a huge less bright filament (see the '**a**' in image 55 **Figure 210**). The big grain is still bright, (see '**b**' in image 55 **figure 210**). This grain disappeared in image 73 **Figure 211**.

In image 82 **Figure 212**, we see a very bright stretched grain which moves downward (see 105 **Figure 213**). Consider also the two dark filaments surrounding this grain, they look like a stretched ellipse. Those filaments took a wavy structure in image 125 **Figure 214**. In image 136 **Figure 215**, we see one of the filament still exist, and there is a weak tube which seem to be between two attracted filaments.
This structure destroys in image 187 **Figure 216**. In image 203 **Figure 217** we get a bright grain which moves downward. Around the grain there are weak dark point-like structures.

6:5.`/home/ghanjah/job/feb25_67.cube`:
Yoy may look at image 0 **Figure 218**, to see which part I cut:
In image 0 **Figure 219**, we have very complicated structures in the dark filament. We see clearly how the dark filaments have warped themselves and build almost a huge knot.
In image 25 **Figure 220**, we see that from the tails of those knots there are several penumbral grains, which appear and take comet-like structures with tails which connect to each other. The huge knot looks like the tail of the fish.

In image 40 **Figure 221**, we see that the penumbral grains moved and stretched themselves, and got smooth long dark tails i.e filaments. In image 154 **Figure 222**, we see that on the tail of the huge knot there is a dark filament sticking out. There are also weak penumbral grains born from the boundary of this knot.

In image 164 **Figure 223**, we see that the '**a**' and '**b**' filaments are connected together, and the dark filaments '**c**' cross each other and pass almost the filaments '**a**' and '**b**'.

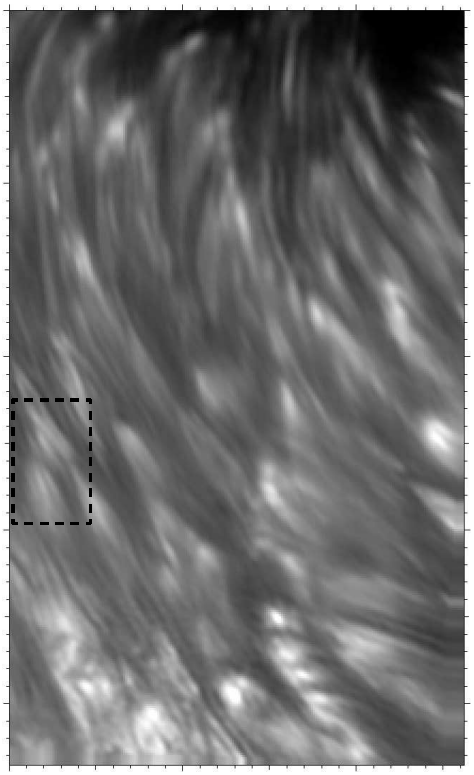

Figure 205: image 0 in work feb176

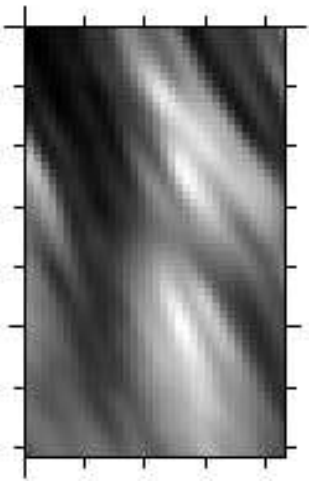

Figure 206: image 0 in job feb24644

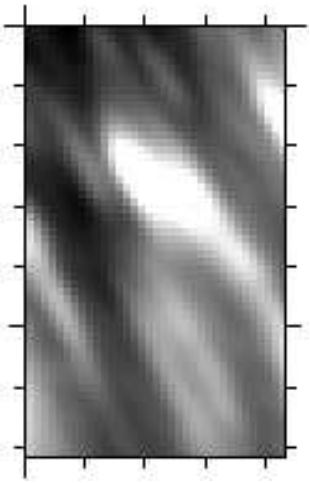

Figure 207: image 37 in job feb24644

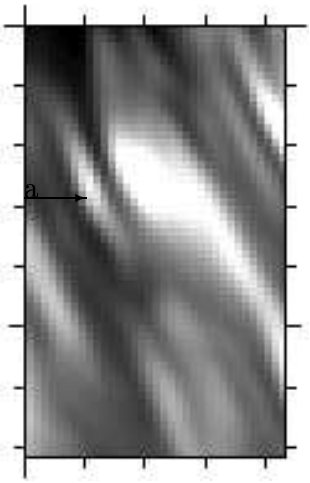

Figure 208: image 41 in job feb24644

In image 177 **Figure 224**, we see how the filaments '**a**' and '**b**' are connected together and have stretched themselves, one sees also another similar structure. There is also a filament which appears from a parabolic structure and continues through the other filaments (see '**d**' in image 177 **Figure 224**). In image 220 we see how the thick dark filaments connect to each other under the fishtail. The penumbral grains took a comet-like structure.

5.7 Part 7

7.`/home/ghanjah/work/feb17_7.cube`:

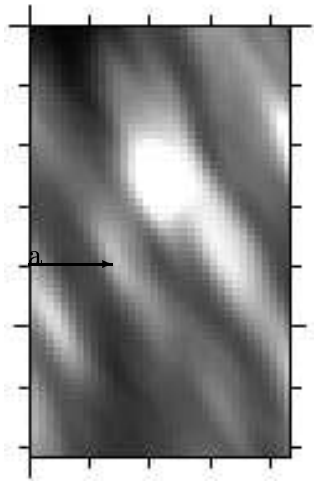

Figure 209: image 48 in job feb24644

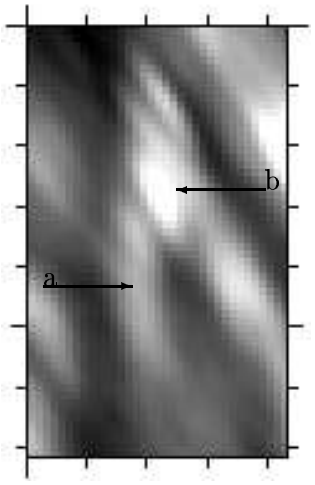

Figure 210: image 55 in job feb24644

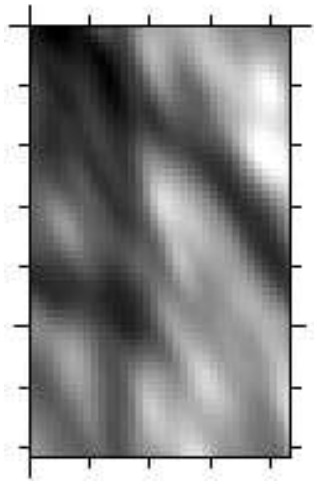

Figure 211: image 73 in job feb24644

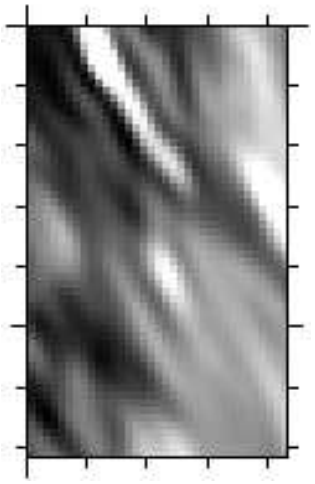

Figure 212: image 82 in job feb24644

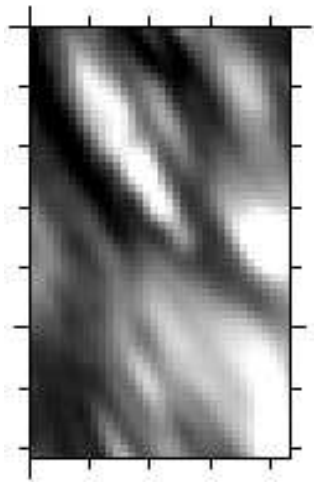

Figure 213: image 105 in job feb24644

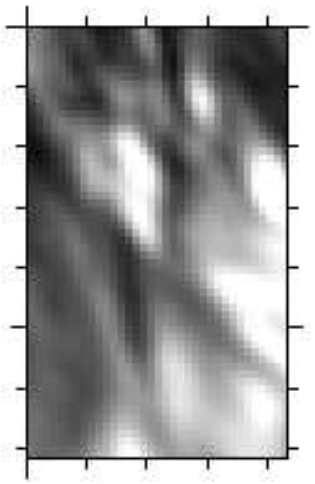

Figure 214: image 125 in job feb24644

Consider the structure limited by the arrows in image 14 **Figure 226**. We have chain structures. Later, we see a point-like structures. Some of them are dark and other are bright. Their structures are connected to each other, and they look as foot-points of a magnetic loop (see the arrows in image 36 **Figure 227**). Close to this we see a loop-like structure (see 'l' in image 36 **Figure 227**). On the right side of the loop-like structure , there are several dark point-like structures which become close

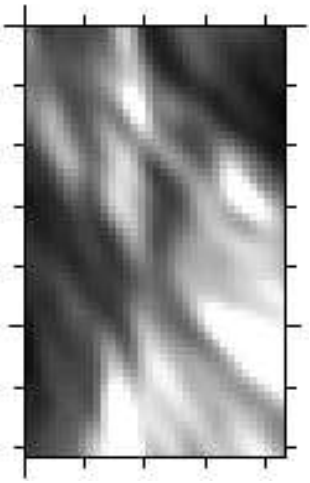

Figure 215: image 136 in job feb24644

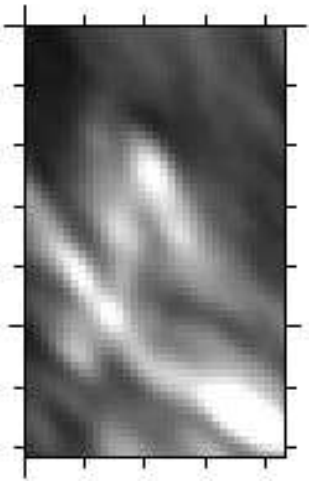

Figure 216: image 187 in job feb24644

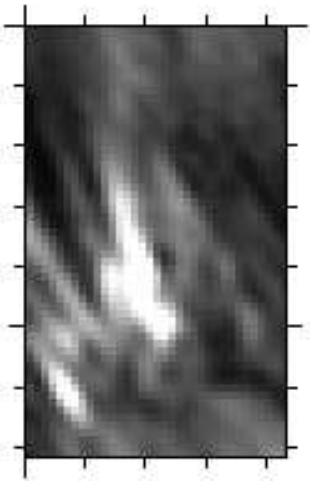

Figure 217: image 203 in job feb24644

each other.
Around the loop-like structure, there appear point-like structures and take a square form (see the arrows in image 63 **Figure 228**).
Close to the knot, the point-like penumbral grains have taken comet-like structures.

The whole area around the knot has connected together in elliptical form (see the arrows in image 95 **Figure 229**). On the right limit there are very tight structures of the weak penumbral grain and the bright and dark filaments. The boundary of the ellipse actually looks like a scar. From the scar one can see that the grains and the filaments stem.
Close to the knot the point-like penumbral grains have stretched themselves (see image 113 **Figure 230**). On the right boundary of the square, some of the grains have stretched themselves (see image 220 **Figure 231**).

SMALL MOVIES OF PART 7:
7:1`./home/ghanjah/job/feb24_71.cube`:
You may take a look at image 0 **Figure 232** to see which part I cut.
In image 0 **Figure 233**, we see a penumbral grain on the boundary of the knot. From the grain we see that there is a point-like grain sticking out (see image 30 **Figure 234** and image 35 **Figure 235**). The grains divided themselves into two comet-like structures (see image 63 **Figure 236**). The comet-like

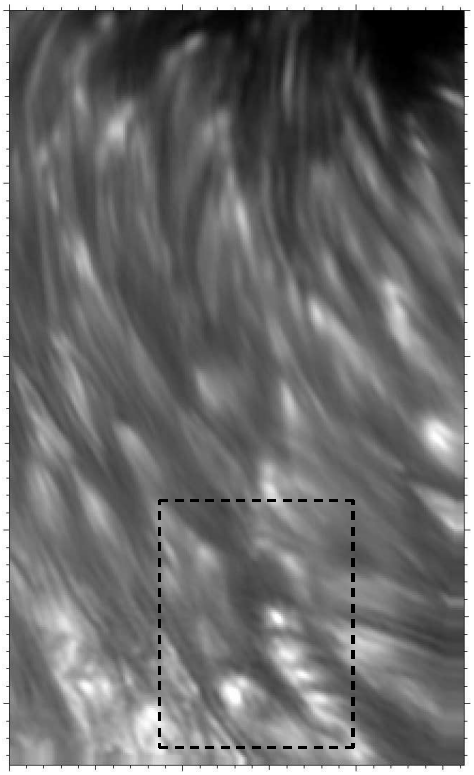

Figure 218: image 0 in work feb176

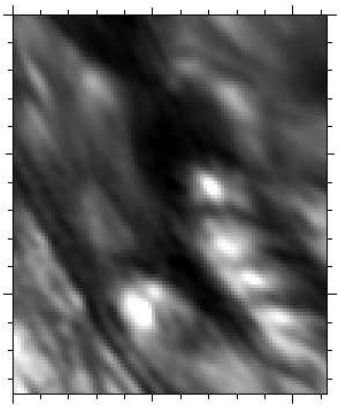

Figure 219: image 0 in job feb2567

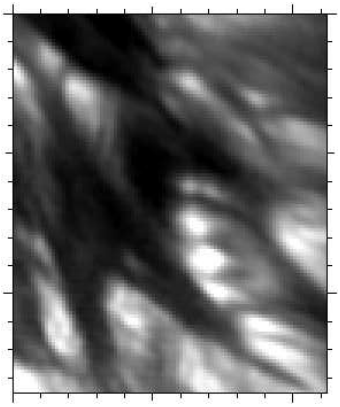

Figure 220: image 25 in job feb2567

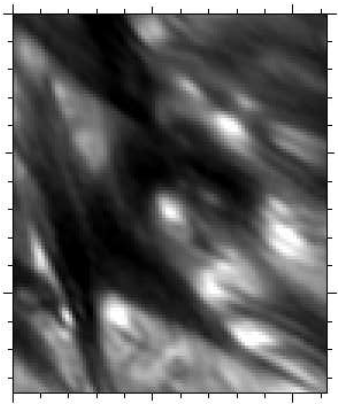

Figure 221: image 40 in job feb2567

structures become a huge point-like grain surrounded by weak dark point-like structures (see image 83 **Figure 237**). From this point-like structures there are dark streaks on the grain. But the streaks seem to be connected to the dark area on the left side of the grains (see image 117 **Figure 238**). In image 128 **Figure 239** on the top next to the stretched grains, we see that there are point-like structures. Then the stretched grains again have taken comet-like structures (see image 143 **Figure 240**).

The comet-like grain disappeared and we get instead an interesting pattern. Two strong dark filaments have attracted again. On their both sides we see point-like structures in such artistic way. One sees also a filament from the right side has crossed the bright area.
In image 203 **Figure 242**, we see that there are dark channels in the whole upper half of the image. On both sides we see how the weak point-like structures have stretched themselves. In image 220 **Figure 243**, we see an almost dark loop-like structure. This structure takes the structure of an

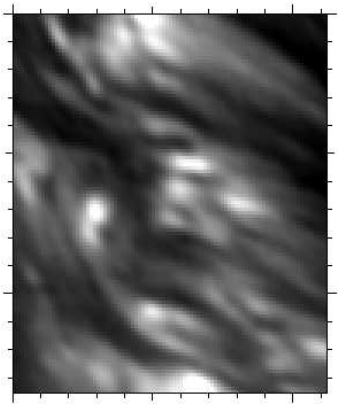

Figure 222: image 154 in job feb2567

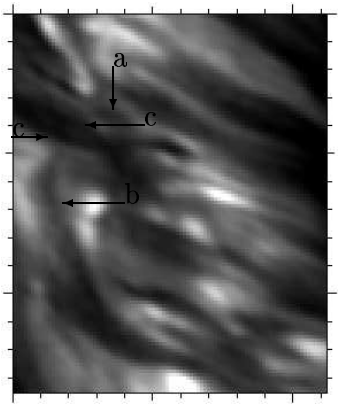

Figure 223: image 164 in job feb2567

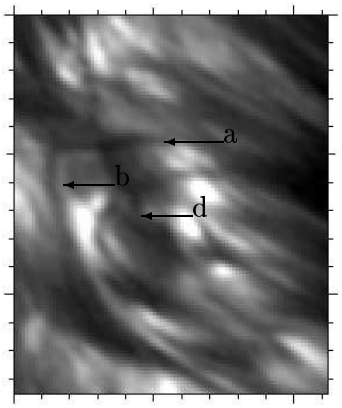

Figure 224: image 177 in job feb2567

Figure 225: image 0 in work feb177

Figure 226: image 14 in work feb177

omega (see the arrows in image 220 **Figure 243**).

7:2./home/ghanjah/job/feb24_72.cube:

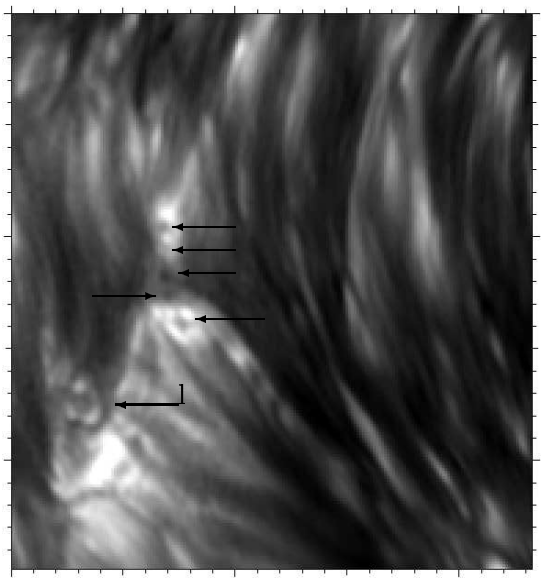

Figure 227: image 36 in work feb177

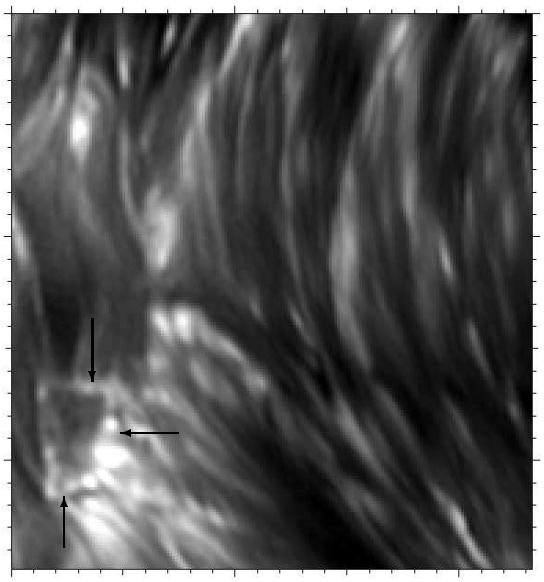

Figure 228: image 63 in work feb177

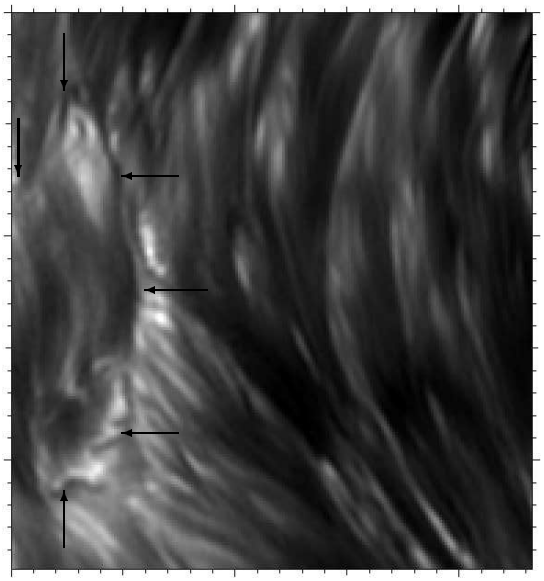

Figure 229: image 95 in work feb177

Figure 230: image 113 in work feb177

In image 0 **Figure 244** you can see which part I cut.
There are two penumbral grains (see image 0 **Figure 245**). They seem to be fixed. They are getting brighter for some time and then less brighter and again brighter (see image 22 **Figure 246**). As the time runs those grains get stretched structures (see image 33 **Figure 247**). The grains disappeared a short time later.
In image 85 **Figure 248**, we see a grain which moves downward (see '**a**' in image 85 **Figure 248** and '**a**' in image 98 **Figure 249**).

Figure 231: image 220 in work feb177

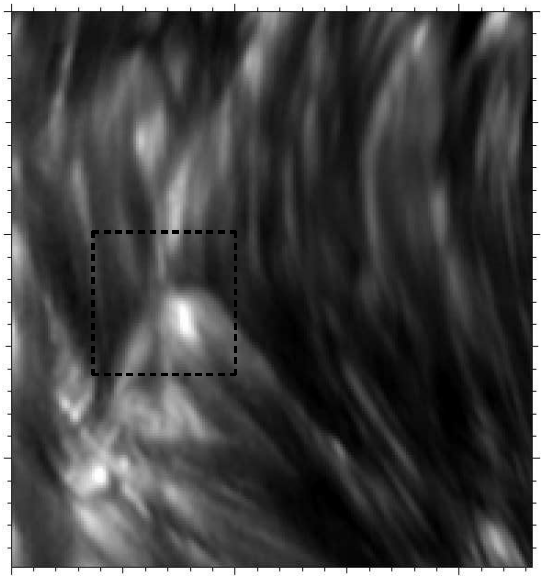

Figure 232: image 0 in work feb177

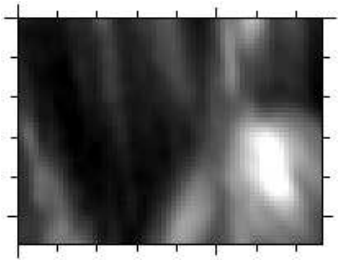

Figure 233: image 0 in job feb2471

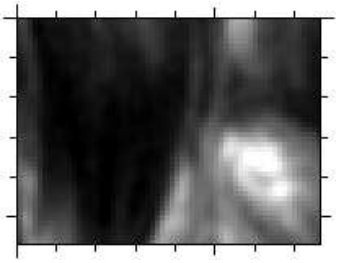

Figure 234: image 30 in work feb2471

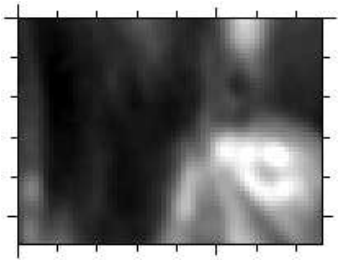

Figure 235: image 35 in job feb2471

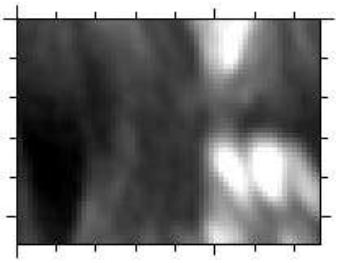

Figure 236: image 63 in work feb2471

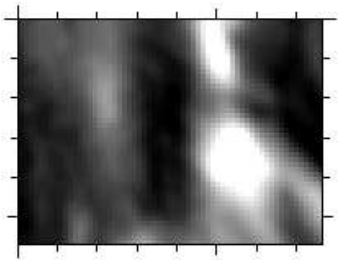

Figure 237: image 83 in job feb2471

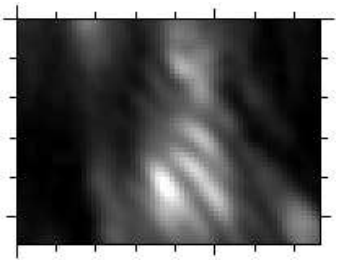

Figure 238: image 117 in work feb2471

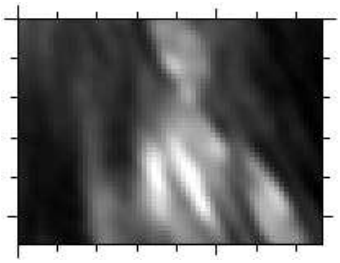

Figure 239: image 128 in job feb2471

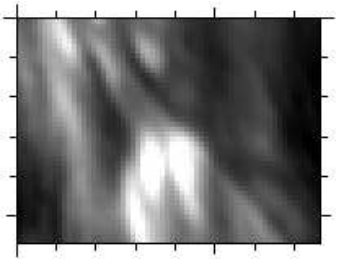

Figure 240: image 143 in work feb2471

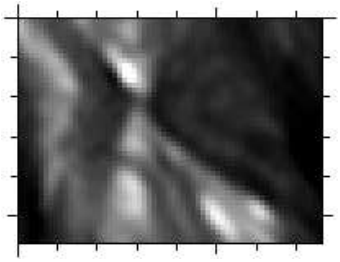

Figure 241: image 167 in job feb2471

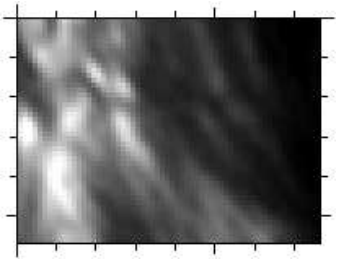

Figure 242: image 203 in work feb2471

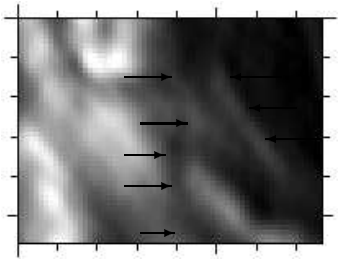

Figure 243: image 220 in job feb2471

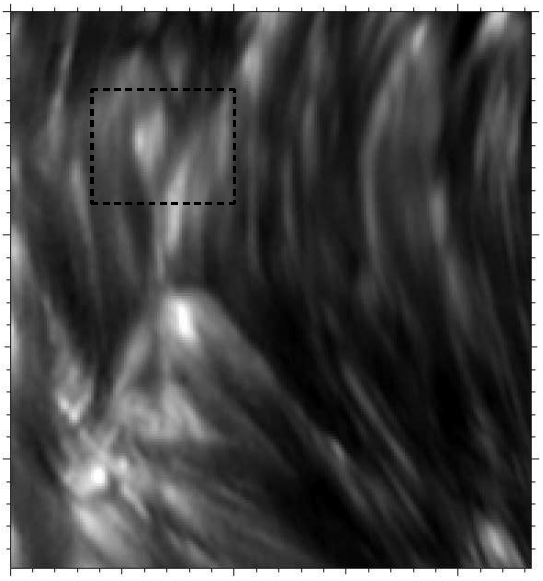

Figure 244: image 0 in work feb177

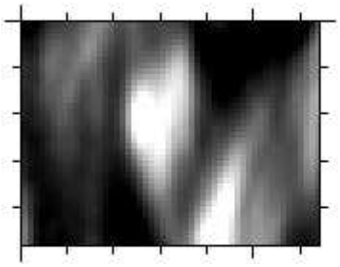

Figure 245: image 0 in job feb2472

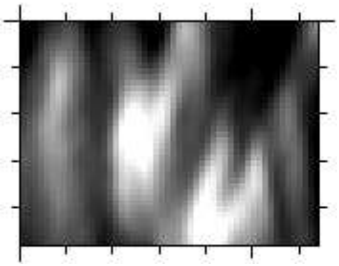

Figure 246: image 22 in job feb2472

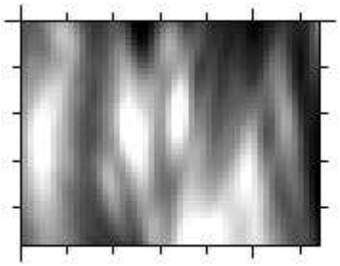

Figure 247: image 33 in job feb2472

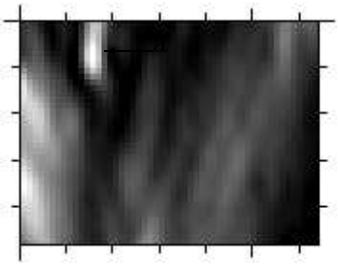

Figure 248: image 85 in job feb2472

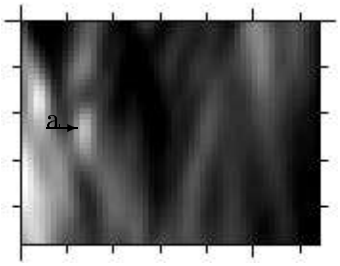

Figure 249: image 98 in job feb2472

7:3./home/ghanjah/job/feb24_74.cube:
Take a look on image 26 **Figure 250**, to see which part I cut.
We see a penumbral grain which seems to have a part of itself hiden by thick dark filaments (see image 0 **Figure 251**). The grain became weaker and disappeared in image 53 **Figure 252**. But there is a new grain appears (see image 114 **Figure 253**). The grain moves left-up and disappears after a while.
As the time runs a new grain appears (see '**a**' in image 180 **Figure 254**). The grain seems to move under the dark filament, and one sees the trace under the dark filament very clearly (see image 184 **Figure 255**). Then the grain moves downward to connect with an another grain (see '**b**' image 184 **Figure 255**). Then, they melt together (see image 192 **Figure 256**).

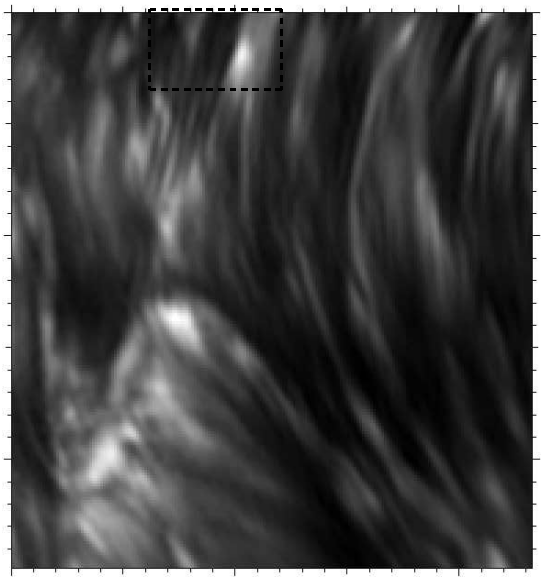

Figure 250: image 26 in work feb177

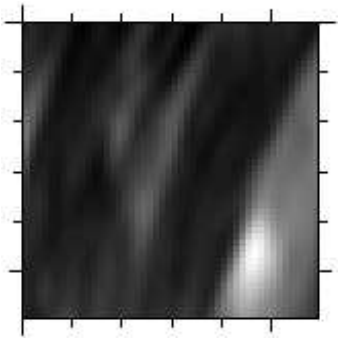

Figure 251: image 0 in job feb2474

5.8 Part 9

9./home/ghanjah/work/feb17_9.cube:
We have a complicated structure in this movie. On the right side on image 0 **Figure 257**, we see that the filaments and the penumbral grains look as they are coming out from the scar. One can also see a loop-like structure close to the huge comet-like grain.
In image 3 **Figure 258** we see dark bow-like structures. Those structures seem to be above the huge grain. The bows move from the right to the left of the huge grain. After a time, the bows almost hid the grain (see image 111 **Figure 260**). The bows have connected to the dark structures on the granules and melted together.

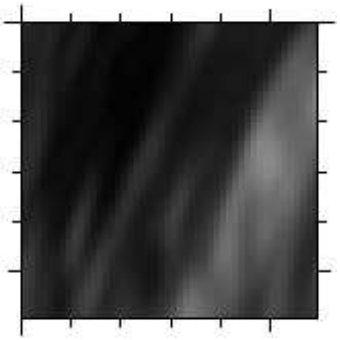

Figure 252: image 53 in job feb2474

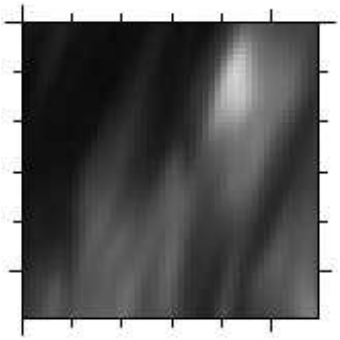

Figure 253: image 114 in job feb2474

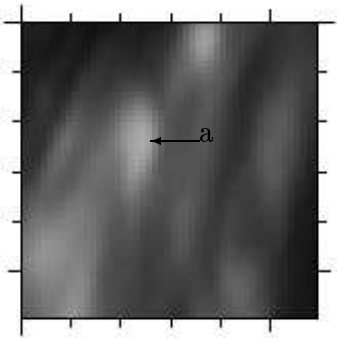

Figure 254: image 180 in work feb2474

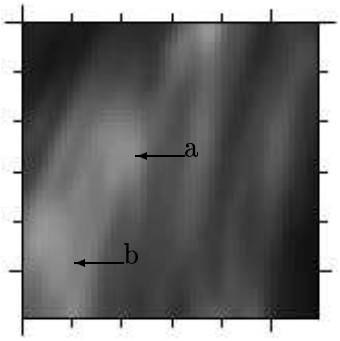

Figure 255: image 184 in job feb2474

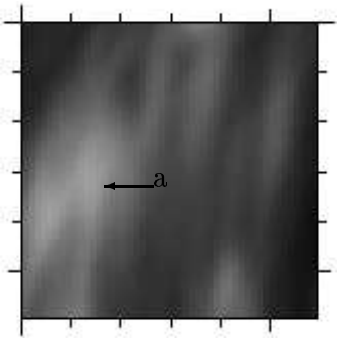

Figure 256: image 192 in job feb2474

In image 87 **Figure 259**, we see a similarity between several structures, which reminds us about the structure of the chain we have seen almost everywhere (see the arrows in image 87 **Figure 259**).
In image 187 **Figure 261**, on the boundary between the granules and the penumbra we see point-like structures (see the places between the weak dark filaments marked with arrows in image 187 **Figure 261**), and the weak dark tiny filaments which is sticking out from one side to connect with another dark channel in the other side (see the arrows in image 187 **Figure 261**). You can see what happened to those structures mentioned above in image 189 **Figure 262**. In image 205 **Figure 263**, we see point-like grains (marked with arrows) changed. They seem to be connected by a dark curvature filament (see the arrows in image 220 **Figure 264**).

SMALL MOVIES OF PART 9:

9:1`./home/ghanjah/job/feb25_91.cube`:
Take a look at image 0 **Figure 265** to see which part I cut.
In image 0 **Figure 266**, we see two small stretched penumbral grains.

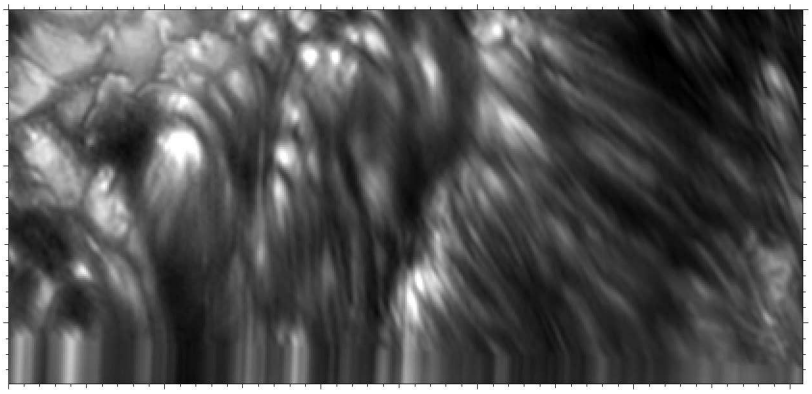

Figure 257: image 0 in work feb179

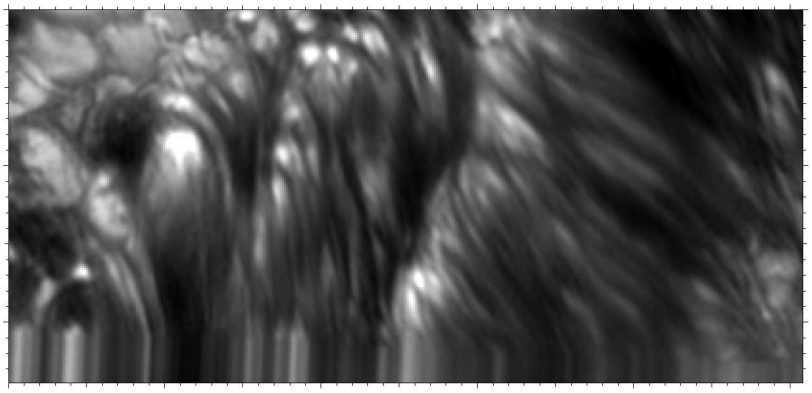

Figure 258: image 3 in work feb179

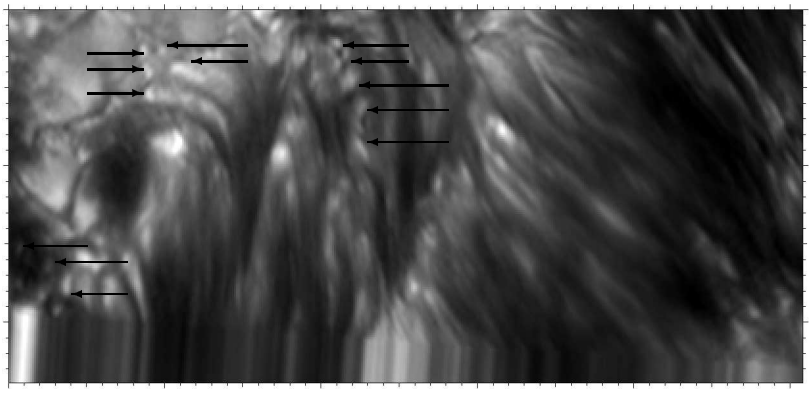

Figure 259: image 87 in work feb179

As the time runs, the grain in image 33 **Figure 267** divided itself to three point-like bright structures. The point-like structures melt together and build one grain (see image 40 **Figure 268**). They disappeared after a while (see image 117 **Figure 269**).

9:2./home/ghanjah/job/feb25_92.cube:
Look at image 0 **Figure 271** to see which part I cut.
In image 0 **Figure 272**, we see three stretched penumbral grains. In image 13 **Figure 273**, they become bigger and get comet-like structures. As the time runs many comet-like grains appear (see image 51 **Figure 274**). In image 110 **Figure 275** the structures look like streaks and one can see that the dark streaks look as they stem from the surrounding dark areas.

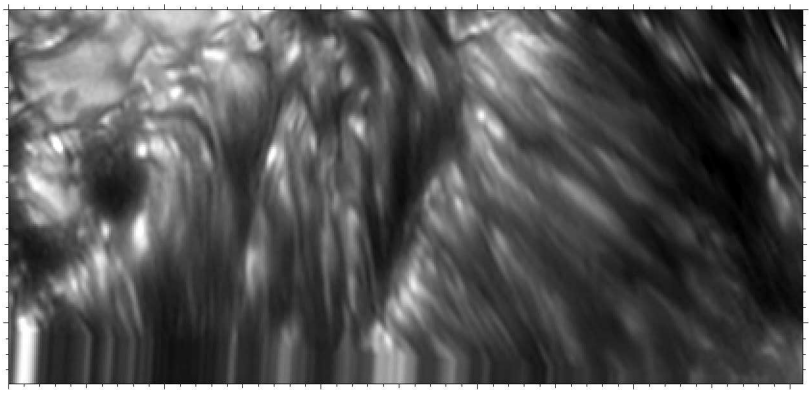

Figure 260: image 111 in work feb179

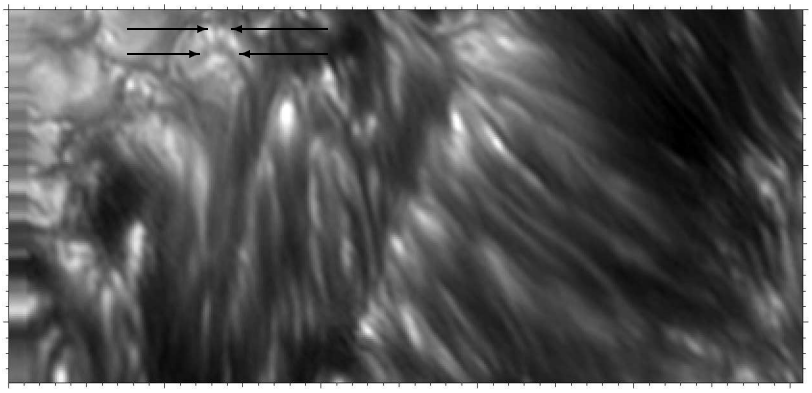

Figure 261: image 187 in work feb179

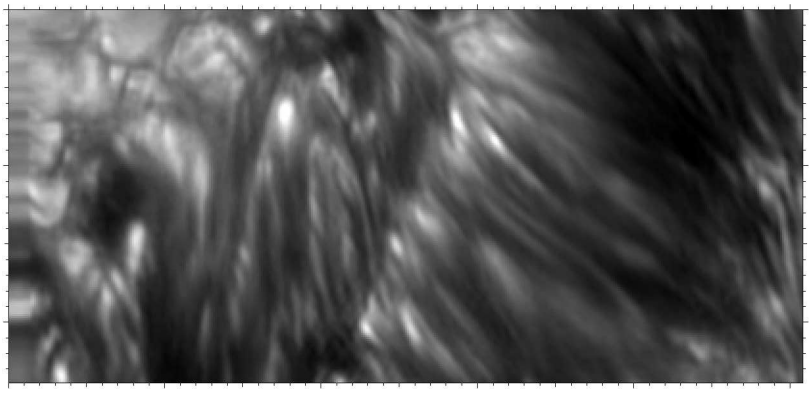

Figure 262: image 189 in work feb179

The streaks make the grain to look as stretched structures (see image 118 figure(276)). You can see how the structures change in image 160 figure(277) and 220 figure(278).

9:3.`\home\ghanjah\job\feb25_95.cube`:
Take a look at image 0 **Figure 279**, to see which part I cut.
In image 0 **Figure 280** we see a huge comet-like penumbral grain. Inside this grain there are several other small point-like grains. If one looks carefully on image 4 **Figure 281**, one can see that the weak point-like structures '**a**' have a weaker corresponding feature '**b**' on the other side of the dark

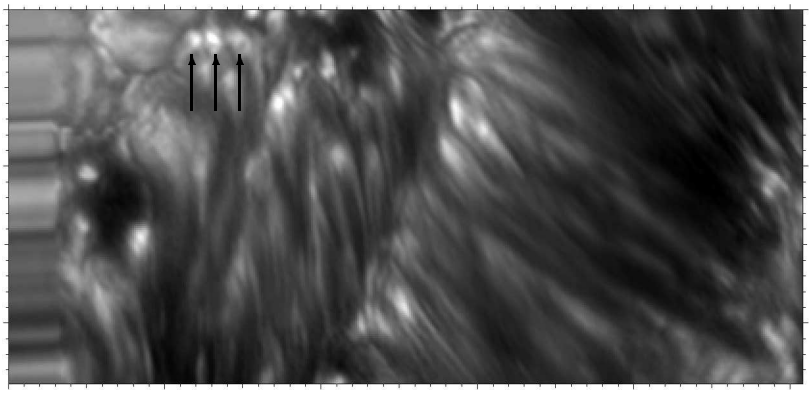

Figure 263: image 205 in work feb179

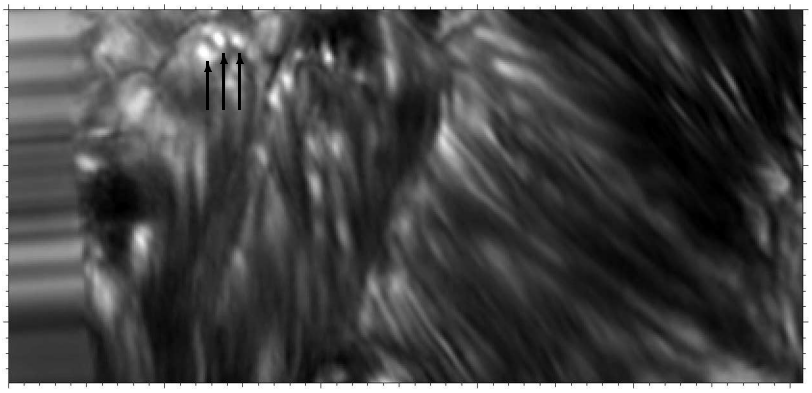

Figure 264: image 220 in work feb179

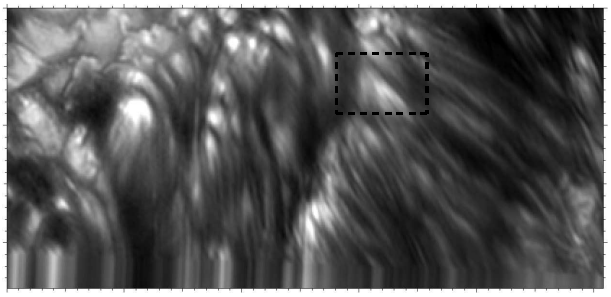

Figure 265: image 0 in work feb179

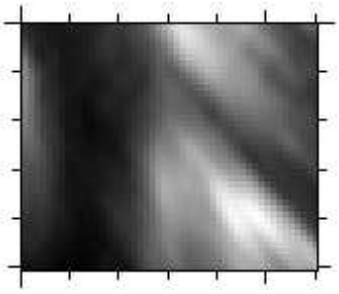

Figure 266: image 0 in job feb2591

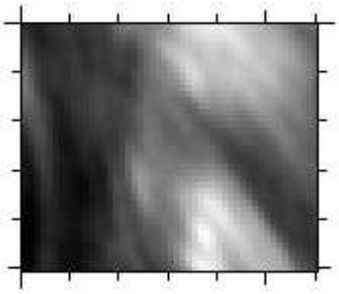

Figure 267: image 33 in job feb2591

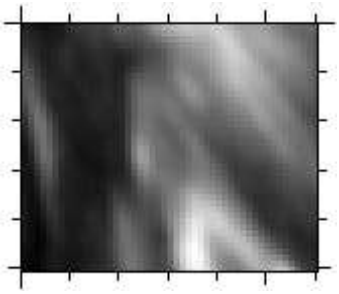

Figure 268: image 40 in job feb2591

bow. The huge bright grain seems to have weak dark filaments going inside it. We see also how the point-like grains '**a**' in image 4 **Figure 281** become more clear in image 6 **Figure 282**.

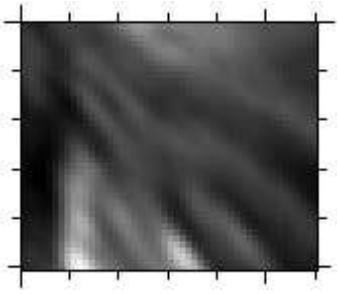

Figure 269: image 177 in job feb2591

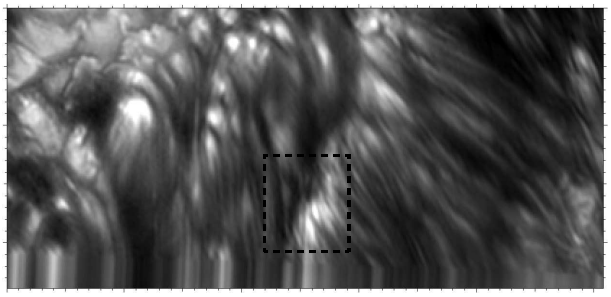

Figure 270: image 0 in work feb179

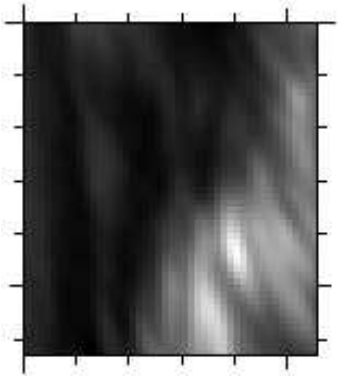

Figure 271: image 0 in job feb2592

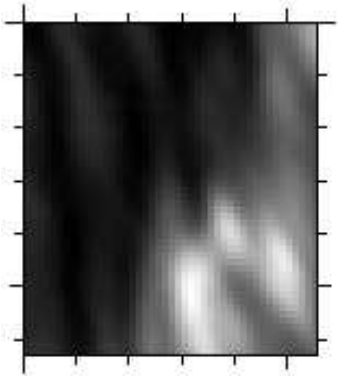

Figure 272: image 13 in job feb2592

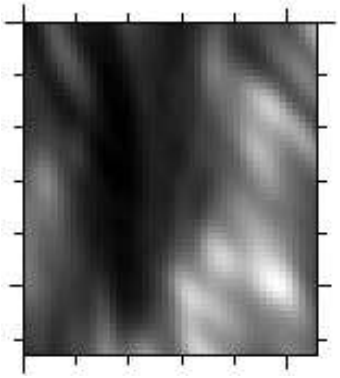

Figure 273: image 51 in job feb2592

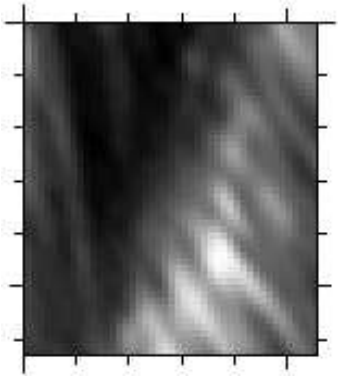

Figure 274: image 110 in job feb2592

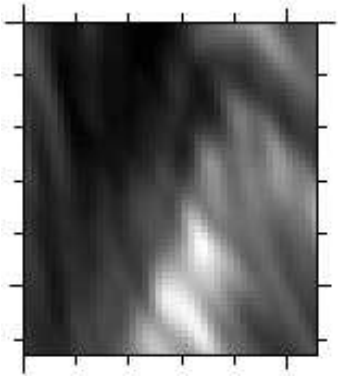

Figure 275: image 118 in job feb2592

We see the dark thick filaments which look as bows move toward the left side of the grain (see image 6 **Figure 282**). We see also that there are many point-like grains inside the huge penumbral grain.
As the time runs, in image 14**Figure 283** the grains above the dark bow have moved (see '**a**' in

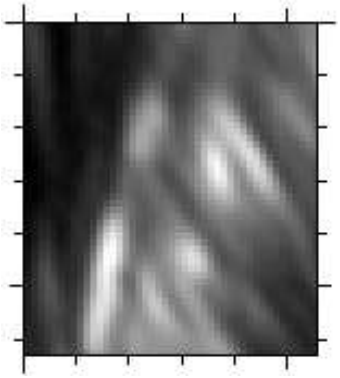

Figure 276: image 160 in job feb2592

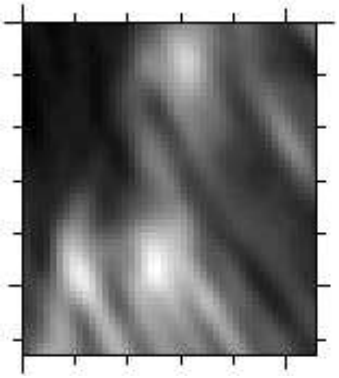

Figure 277: image 220 in job feb2592

image 14 **Figure 283**). The point-like structures on the huge grain stretched themselves. In image 64 **Figure 284**, the bows moved above the huge grain and hid a part of it. They covered the whole grain (see image 157 **Figure 285**).

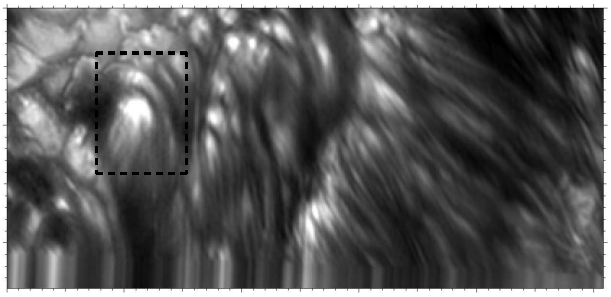

Figure 278: image 0 in work feb179

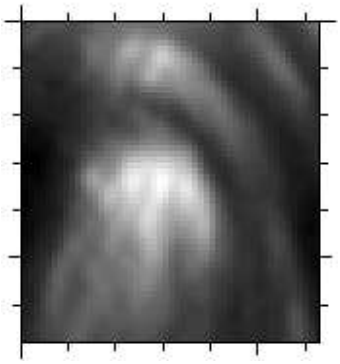

Figure 279: image 0 in job feb2595

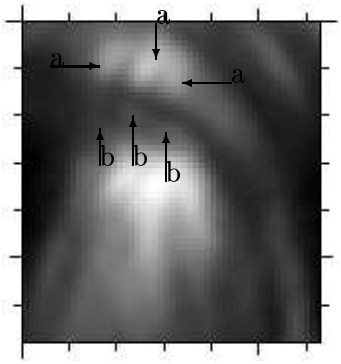

Figure 280: image 4 in job feb2595

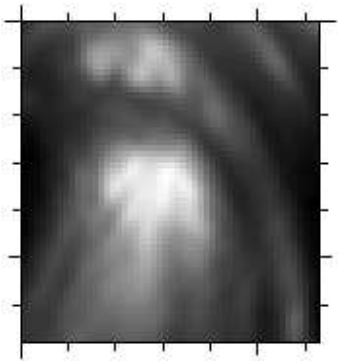

Figure 281: image 6 in job feb2595

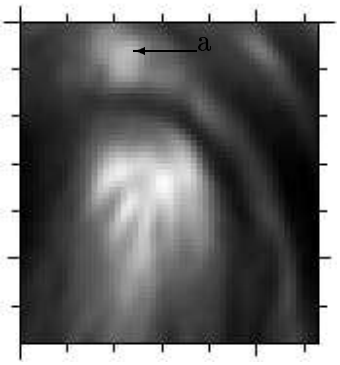

Figure 282: image 14 in job feb2595

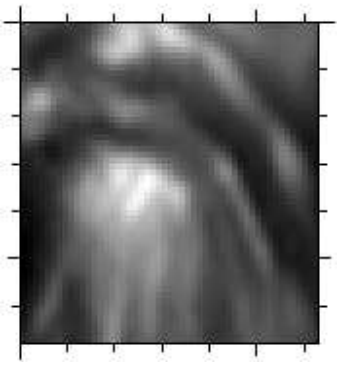

Figure 283: image 64 in job feb2595

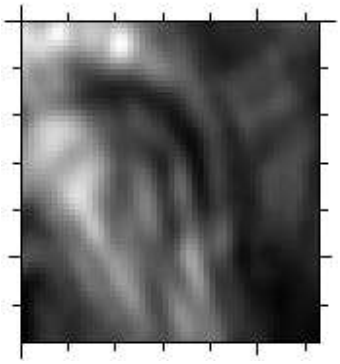

Figure 284: image 157 in job feb2595

6 Other interesting things found

Here I would like to show how the chain structure build:
See the figures 287,288,289,290,291,292,293,294,295,296 and 297.

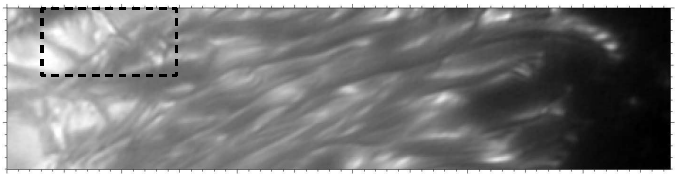

Figure 285: image 160 in work feb174

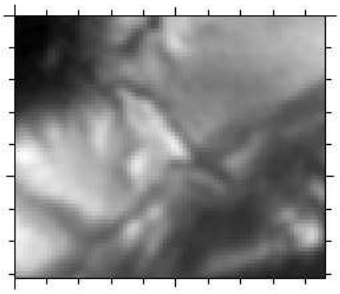

Figure 286: image 0 in job april141

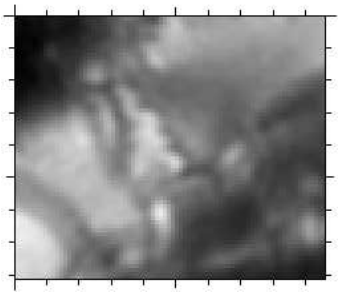

Figure 287: image 6 in job april141

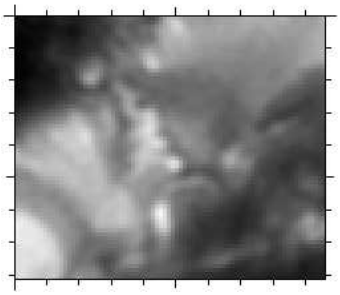

Figure 288: image 7 in job april141

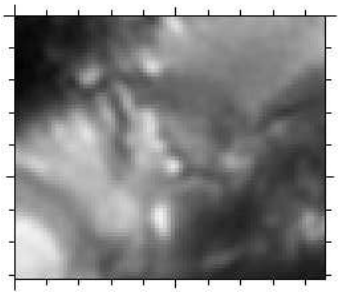

Figure 289: image 8 in job april141

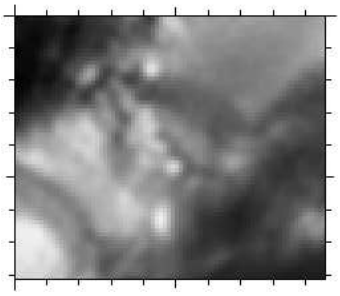

Figure 290: image 9 in job april141

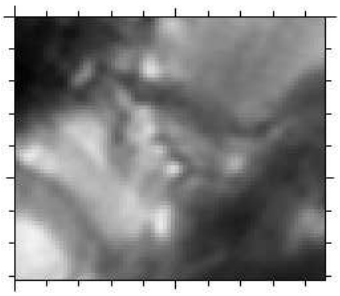

Figure 291: image 10 in job april141

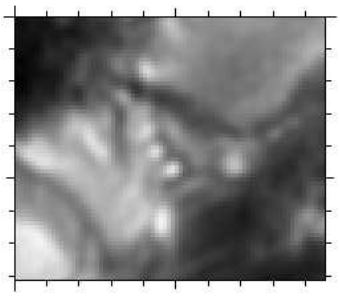

Figure 292: image 11 in job april141

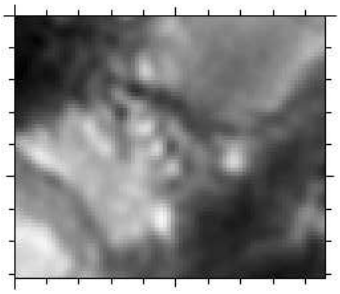

Figure 293: image 12 in job april141

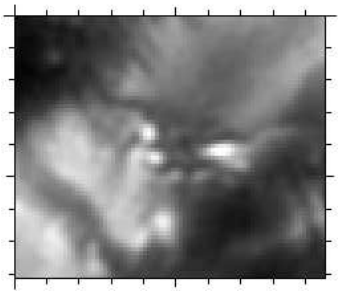

Figure 294: image 17 in job april141

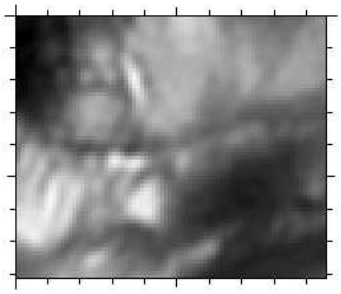

Figure 295: image 48 in job april141

7 The life time of the penumbral grains

I calculated the life time of a fraction of penumbral grains, and divided them in different types. From

Table 1: The life time of different types of penumbral grains

Comet-like (min:sec)	Point at the end of dark filaments (min:sec)	Points under dark filaments (min:sec)	Points parallel with dark filaments (min:sec)	Points on arbitrary places (min:sec)
23:31	7:35	10:30	16:00	10:30
5:19	2:40	15:30	14:33	5:15
21.12	11:5	17:50	10:07	7:07
26:01	5:38	14:28	5:15	6:55
24:04	7:32	5:55	15:55	14:37
32:58	6:18	17:33	13:05	7:43
15:20	11:01	10:23	10:35	26:36
18:22	10:27	14:00	8:38	8:18
23:29	5:38	20:26		
43:28	3:44	11:23		
23:11	22:46			
12:14	16:09			
33:32				
12:18				

the above table, we see that the comet-like penumbral grains live longer than the other types. Most of point-like penumbral grains on the top of dark filaments have short life. The point-like grains under dark filaments live between 10 and 20 minutes. Points parallel with dark filaments are comparable with those on the top of the dark filaments.

8 Discussion and conclusion

• Many point-like penumbral grains seem first to move under dark filaments before they appear bright. When they reach the umbra they get brighter and divide themselves into two or more grains. Example of this:
In part 2, `/home/ghanjah/job/mars25_20.cube`(see image 74 **Figure 32** to image 171 **Figure 35**). In image 74 you can see the dark filaments in turn have smaller hairy channels.

• The penumbral grains at the end of dark filaments i.e. at the penumbra/umbra boundary move inside the umbra and divide themselves into several grains and disappear after short time, example of this you can find in part 3 section 5.3, `/home/ghanjah/job/feb20_33.cube`.

• The penumbral grains in the middle part of the penumbra take comet-like structures without markedly changing, especially in part6. They live longer than those on the umbra/penumbra boundary, see the movie, `/home/ghanjah/job/feb19_61.cube` in part 6.

• The penumbral grains close to the outer boundary of the penumbra change their structures very

fast and they can vary between point-like and comet-like structures, and sometime they have irregular structures, see the movie: `/home/ghanjah/job/feb24_644.cube` .

• The penumbral grains' movement toward the umbra is consistent with the moving-tube model of the Evershed effect. Another aspect of that effect which is obvious is the dark clouds move outward at the outer boundary of the penumbra (the visible photospheric Evershed effect), see `/home/ghanjah/work/feb17_5.cube` (image 45 **Figure 119** and image 57 **Figure 120**).

• A common feature I have seen in the penumbra is the structure of the chain. This structure has a very similar shape to those structures formed by G-band bright points of filigree in the surroundings of the sunspot. The only difference between them is that those inside the penumbra are more stretched comparing to those outside the sunspot, with other word the magnetic field makes the grains to look like as stretched. You find example of this in the movies:
In part 2,`/home/ghanjah/work/feb17_2.cube`(compare the penumbral grain in the box '**a**' in **Figure 22** and box '**b**' in **Figure 24**).
In part 4, `/home/ghanjah/work/feb17_4.cube`(see **g1** and **g2** in image 112 **Figure 96** and compare how their structures became in image118 **Figure 97**).
In part 5,`/home/ghanjah/work/feb17_5.cube`(Compare '**n**' with '**h**' in image 167 **Figure 122** and then compare them also with the box in image 209 **Figure 124**).
In section 6 you can see how the chain builds up.

• Loop-like structures have been found in several places in the penumbra, see the movie `/home/ghanjah/work/feb17_7` image 36 **Figure 227**, 'l' shows a clear loop and the arrows show a chain of loops.

• The chain structures can be foot-points of magnetic loops. If we compare the structure marked with arrows in image 63 **Figure 228** with the structure in section 6 image 48 **Figure 295** we see the similarity between them.

• The dark filaments have darker channels inside them. These in turn have hairy dark channels, see `/home/ghanjah/job/feb17_1.cube`(image 216 **Figure 5**).

• During the analysis we have seen many penumbral grains look as they have dark tails (The dark-cored filaments discovered by Scharmer et al. 2002). Those tails seem to behave independently of the grains. Perhaps the moving-tube model can explain this phenomena. Examples of what I think looks like the moving-tube model:
In part 3, `/home/ghanjah/job/feb20_32.cube` (image 18 **Figure 72**).
In part 6, `/home/ghanjah/job/feb24_622.cube`(image 40 **Figure 191**).
In part 9, `/home/ghanjah/job/feb25_92.cube`(image 220 **Figure 278**).

• Some of the penumbral grains start as comet-like or as point-like and after a while they get dark tails. When the tails cut off and move to the side bright tubes appear. Example of the bright tubes see:
In part 6, `/home/ghanjah/job/feb24_622.cube`(image 93 **Figure 194**).
In part 2, `/home/ghanjah/job/feb17_22.cube`(image 121 **Figure 19**).

• The penumbral grains which look as if they are crossed by dark streaks, but if we look closer, we can see that those dark streaks connect the dark filaments on both sides to each other. Examples of those you can see in the following movies:
In part 4, `/home/ghanjah/job/feb19_41.cube`(image 160 **Figure 104**)
In part 6, `/home/ghanjah/job/feb24_63.cube`(image 59 **Figure 199** and image 79 **Figure 200**).

In part 7, `/home/ghanjah/job/feb24_71.cube`(image 117 **Figure 238**).
In part 9, `/home/ghanjah/job/feb25_92.cube`(image 110 **Figure 275** and image 118 **Figure 276**).

• Most penumbral grains in the inner penumbra move toward the umbra. But there is a small fraction at the outer boundary of the penumbra which move outward. A similar observation has been done before by, e.g., Sobotka et al. (1999).

• The penumbral grains that move toward the umbra often have point-like structures which change very fast at the umbra/penumbra boundary, and they survive short time.

• The fine structure of the penumbral grains varies between point-like, comet-like and some other structures which look like bright tubes, and other complicated structures.

• The penumbral grains do not have the same shape all the time instead they change to other structure and again they change back to the previous shape and so on.

One can speculate too much about the fine structure of penumbral grains. My speculation is that the magnetic field is responsible for their structure in the following way
The hot plasma moves upward against the magnetic field. When the plasma reaches the magnetic field, it gets difficulty to continue upward, but a part of it penetrates between the magnetic field lines, and reaches places with low pressure.
The plasma suffers many obstacles (magnetic field) through its way upward. Part of the plasma succeeds to penetrate the magnetic field and appears at places where the gas becomes transparent and then we get the ability to see it.
The magnetic field have a large filling factor closer to the umbra. This causes the amount of plasma penetrating to be less than the amount in the middle part of penumbra. Perhaps this is the reason that penumbral grains at penumbra/umbra boundary to divide themselves into two or more grains and disappear too fast.

The penumbral grain disappears in two cases, the first is that when the penumbral grain reaches the same temperature as the surrounding, and the second case is that when the penumbral grain reach a space where there is a chance to go toward deeper layer where the transparency vanishes and then we can not see it.
The reason we get structures looking like streaks is that the dark filaments sometimes connect each other from the side way and when the plasma appears it looks as the plasma divides itself, but the case is that we see the brightness in places we do not have a large magnetic field and where the gas becomes transparent.
The internal structure of penumbral grains changes depending on where they are on the penumbra. It depends also on the thickness of the penumbra. Sometime the structure of the dark filaments behave independently from the bright grains, especially on the umbra/penumbra boundary.

Acknowledgments
Thanks:
Mats Löfdahl for all times you spent helping me with ANA, computer problems and learning me Latex. Luc Rouppe van der Voort for learning me how to create movies. My supervisor Dan Kiselman for following the development of my work and helping me when I needed. Pete Dettori for helping me with computer problems.
The Swedish 1-m Solar Telescope is operated on the island of La Palma by the Institute for Solar Physics of the Royal Swedish Academy of Sciences in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canaries.

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