Three Dimensional Visualization of the Solar Corona using Soft X-ray Images taken with Yohkoh/SXT and Hinode/XRT

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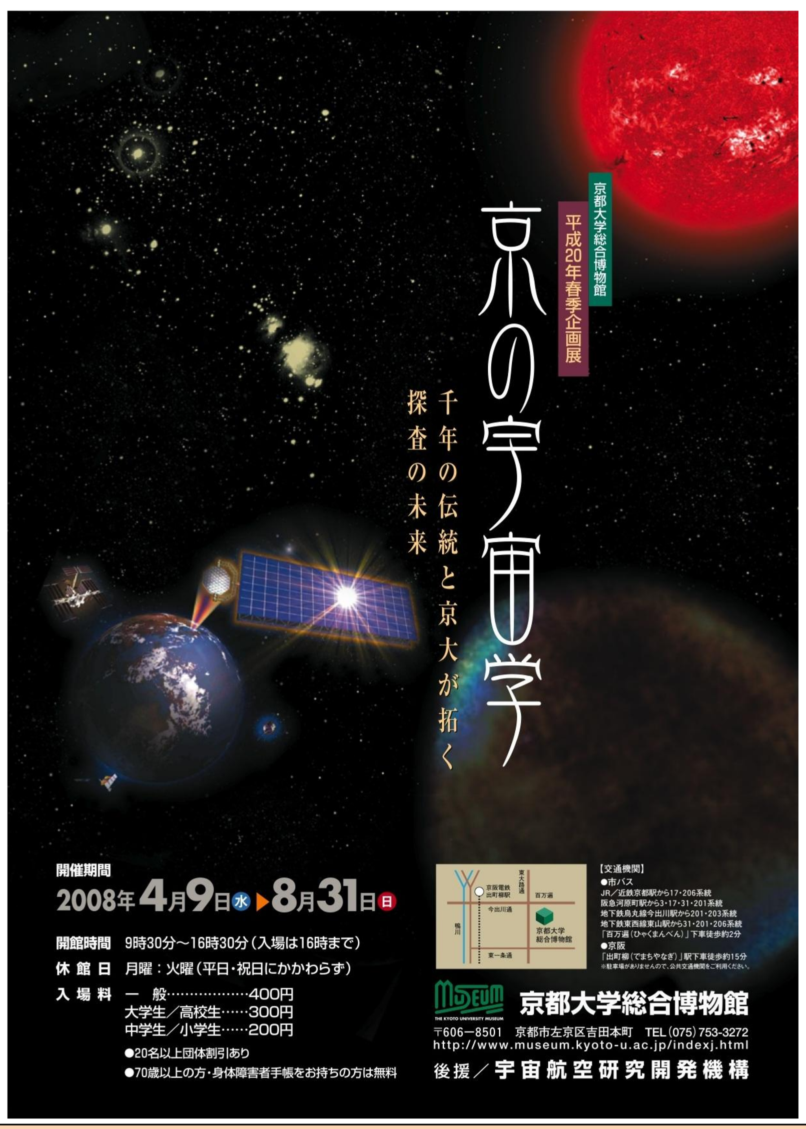
0. Abstract

Recent satellite observations of the Sun with Yohkoh, SOHO, TRACE, RHESSI, STEREO, and Hinode revealed various aspects of the Sun, clarifying what is happening in the outer solar atmosphere, especially in the solar corona. Among them, STEREO has been mapping the three dimensional(3D) structure of the solar corona for the first time using simultaneous observations from two satellites. Since the origin of coronal activity is closely related to 3D configuration of magnetic fields, **observations of the 3D structure of the corona are very important**. Here, we report a new method to map the 3D structure of the corona, using complete soft X-ray images of the Sun taken with Yohkoh/SXT and Hinode/XRT. Our method utilizes two of these images which were taken 7 hours apart, with the assumption that the coronal structure does not change much during this time. This assumption is satisfied for the global coronal structure such as large scale coronal loops in active regions and quiet Sun as well as coronal hole structure. Using this method, **we are trying to make 3D movies of the corona observed by Yohkoh and Hinode**. With this movie, we can see the 3D structure and associated dynamical activity of the Sun more intuitively.

1. Introduction

We had an exhibition about astronomy and space science in Kyoto University Museum during the first half of this year, and we prepared stereoscopic solar movies for this exhibition. **Though these 3D movies were prepared for public to explain about the dynamic solar activity observed with X-ray telescopes, we believe that these movies will also help researchers to understand coronal activity more intuitively**. Actually our method is to make a pseudo-three dimensional movie, whereas STEREO is taking "accurate" stereoscopic images of the Sun. However, **the advantage of our method is we can create a 3D movie using only the data of a single satellite**. In this poster, we introduce this method by using the movie made from Yohkoh's data and make a brief estimation of it's reliability.



2. Preparation of data

First of all, we need the observed center-fixed and axis-fixed images (here, we do not take B-angle into account).

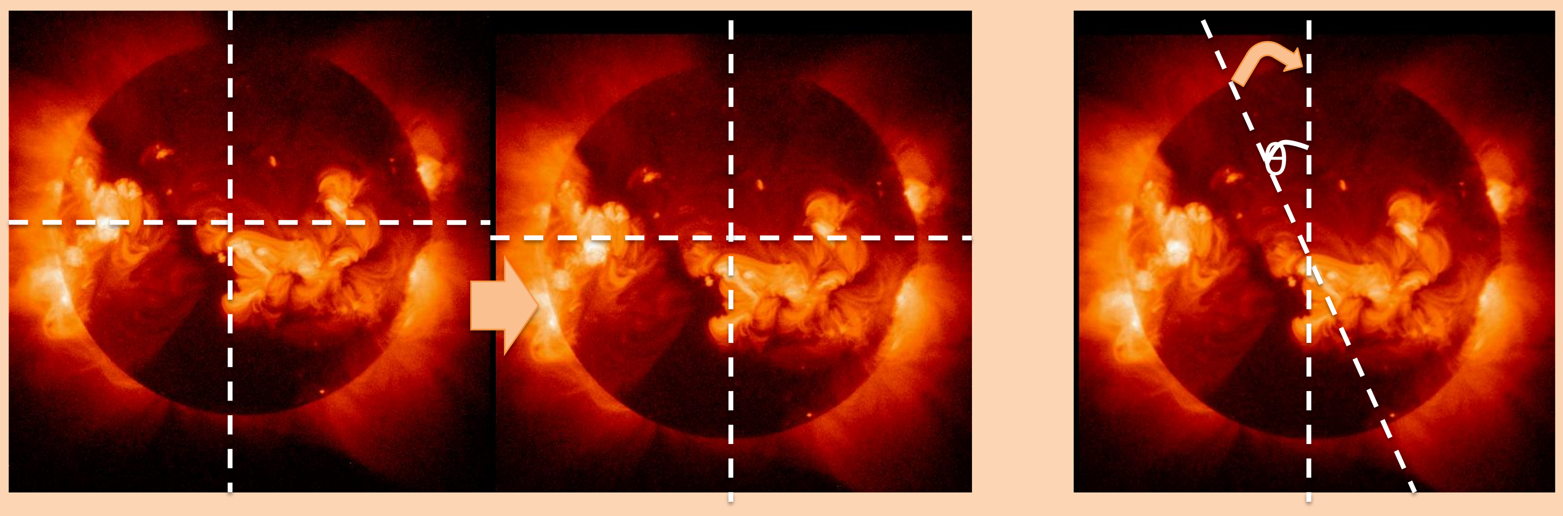
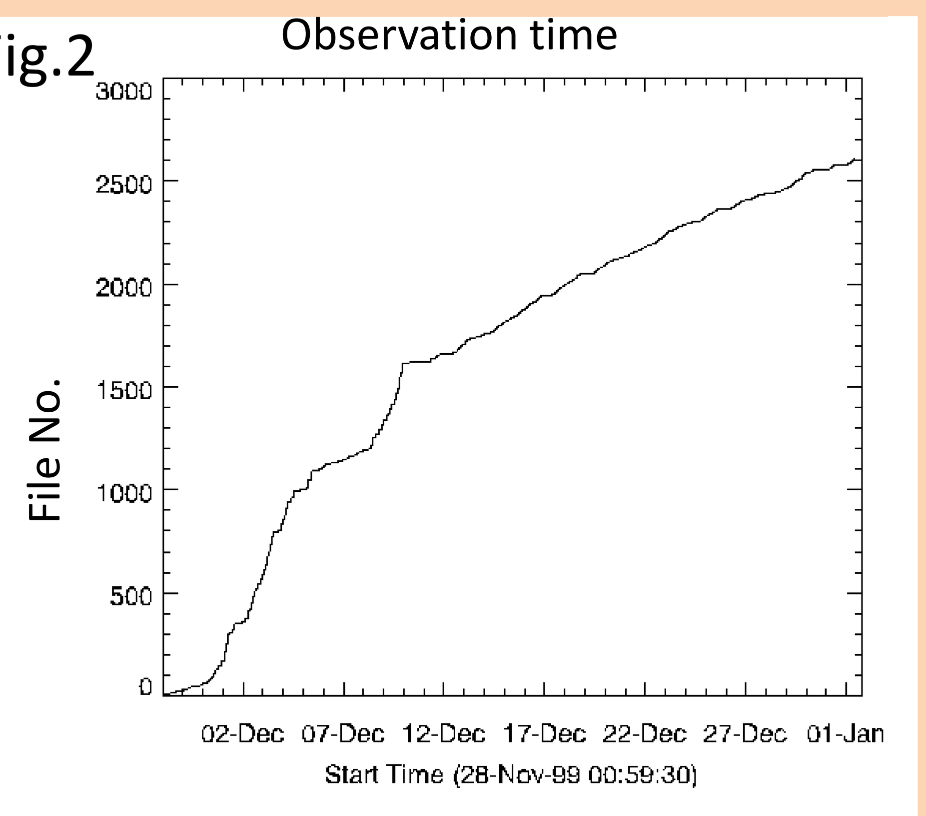


Fig.1 Center correction (left) and axis correction (right). B-angle is not taken into account.

Lining up these images after the corrections, we can make a solar movie. **The difficulty is that these prepared images are not all taken at the same interval**, so the movie will not be smooth.

Fig.2 shows an example of the observation time and the corresponding cumulative distribution of file number. As you can see, time interval depends on the observation date.

Fig.2



Then **we have to select the images,** lining them up at approximately the same interval. Here, we used 30 minutes as the time interval and, selected the data as shown below.

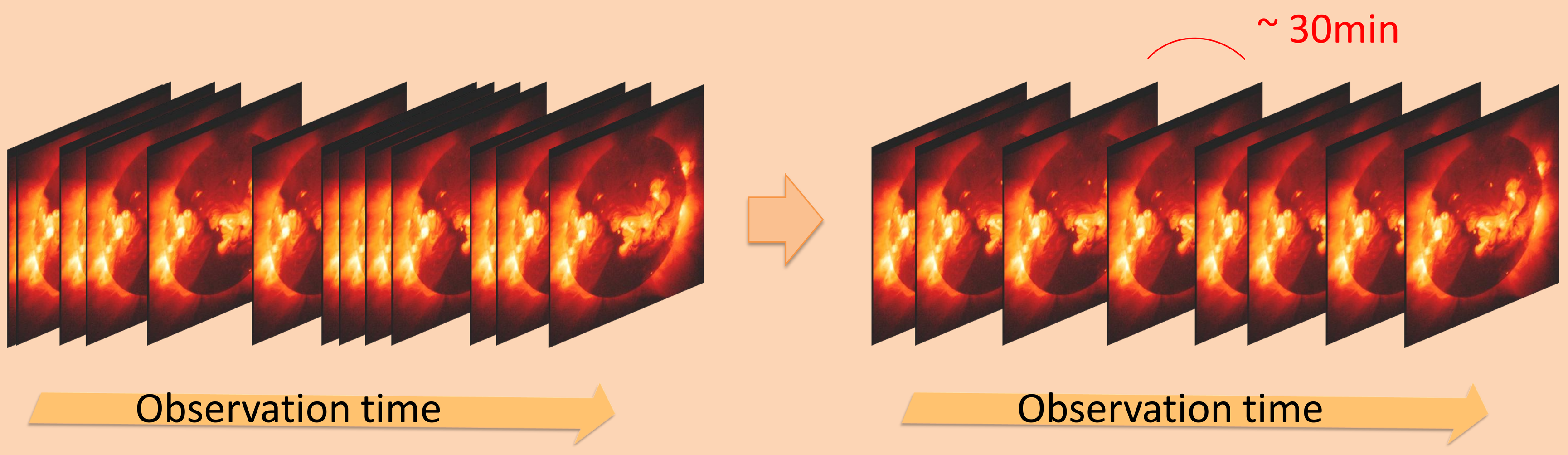


Fig.3 shows an example of the selection. Vertical axis indicates the cumulative file number, and the corresponding observation time is indicated by the horizontal axis. The file number against observation time after selection is shown in Fig.4. In spite of this file selection, the data still has not been smoothly lined up.

Fig.3

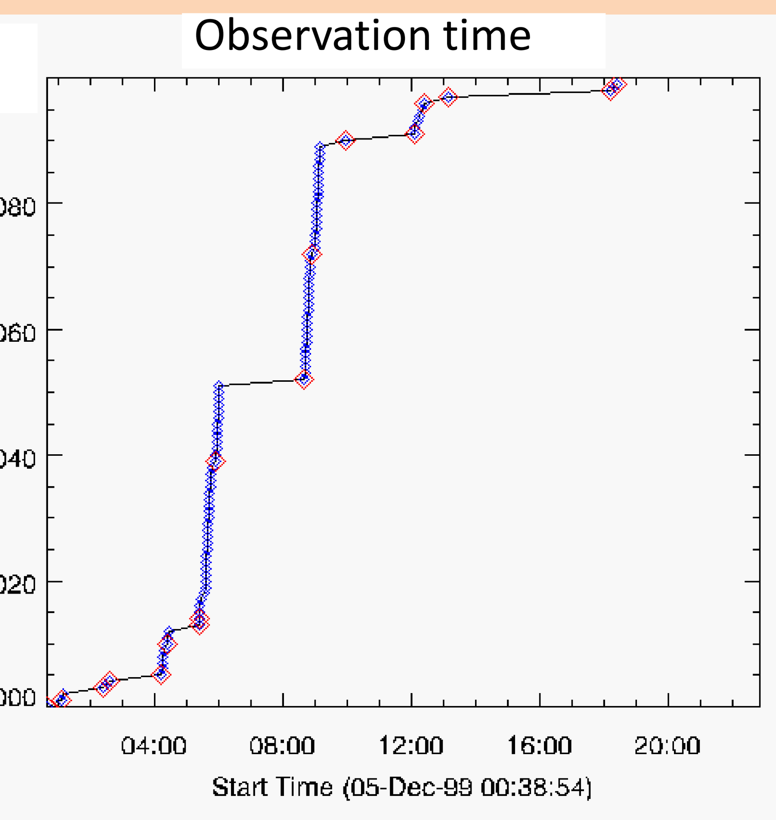
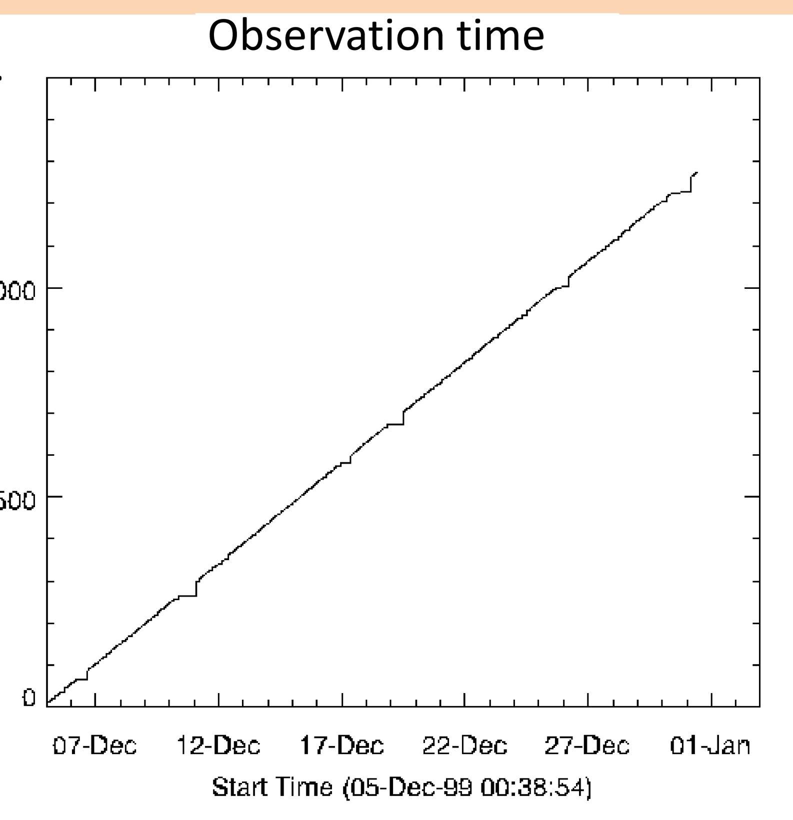
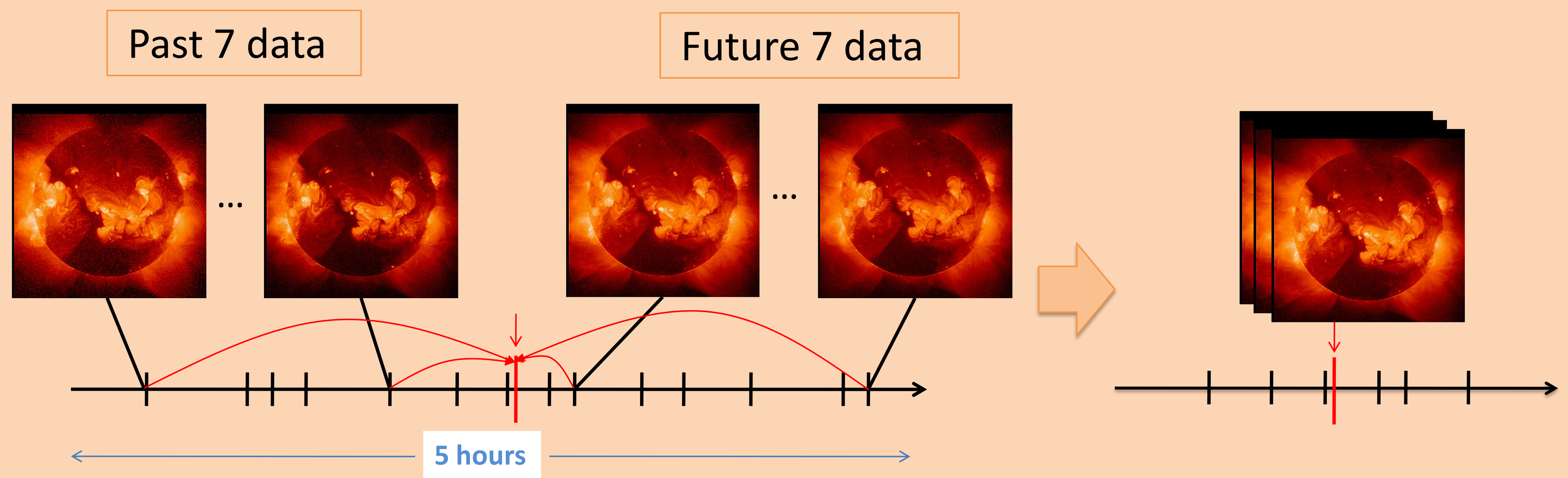


Fig.4



3. Rotating solar images to make images line up at exactly the same interval

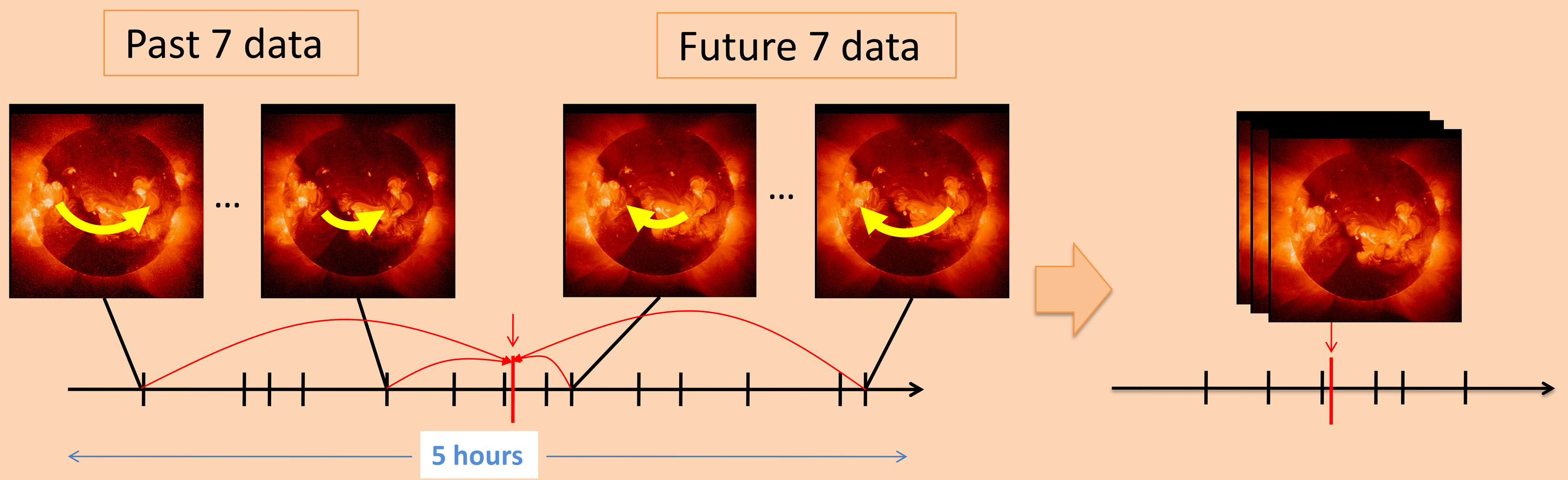
In section 2, we finally could get the images line up in approximately the same interval (here, 30 minutes). These images, however, do not have the exact same interval. **Therefore, for the purpose of interpolation, we utilized 14 images, 7 images before and 7 images after, around the selected images. We merge these 14 images and made the images line up at exactly 30 minute intervals.**



Here, we have to note that these 14 images are taken at different time, and simply merging these different images can be somewhat dangerous (The sun is rotating during observation.)

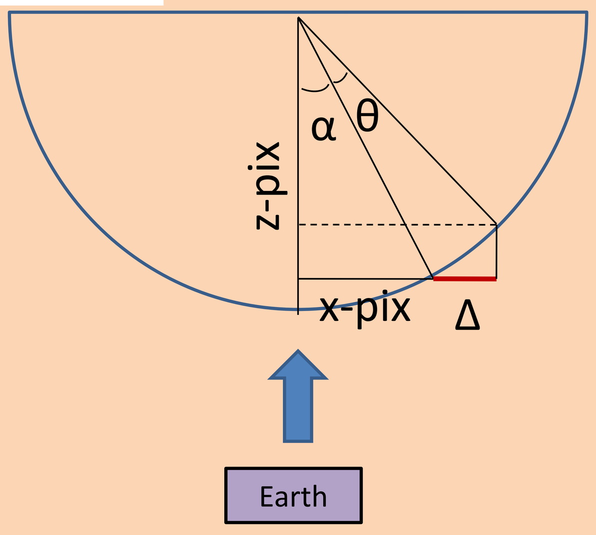
To avoid this inaccuracy, we made two modification.

1. **Rotating the solar image according to how long between the time the image was taken and the time of the image we need to correct.**



To rotate the images, we calculated how many pixels the solar image must be moved to create an image at the correct time (indicated in red line in Fig.5, Δ).

Fig.5



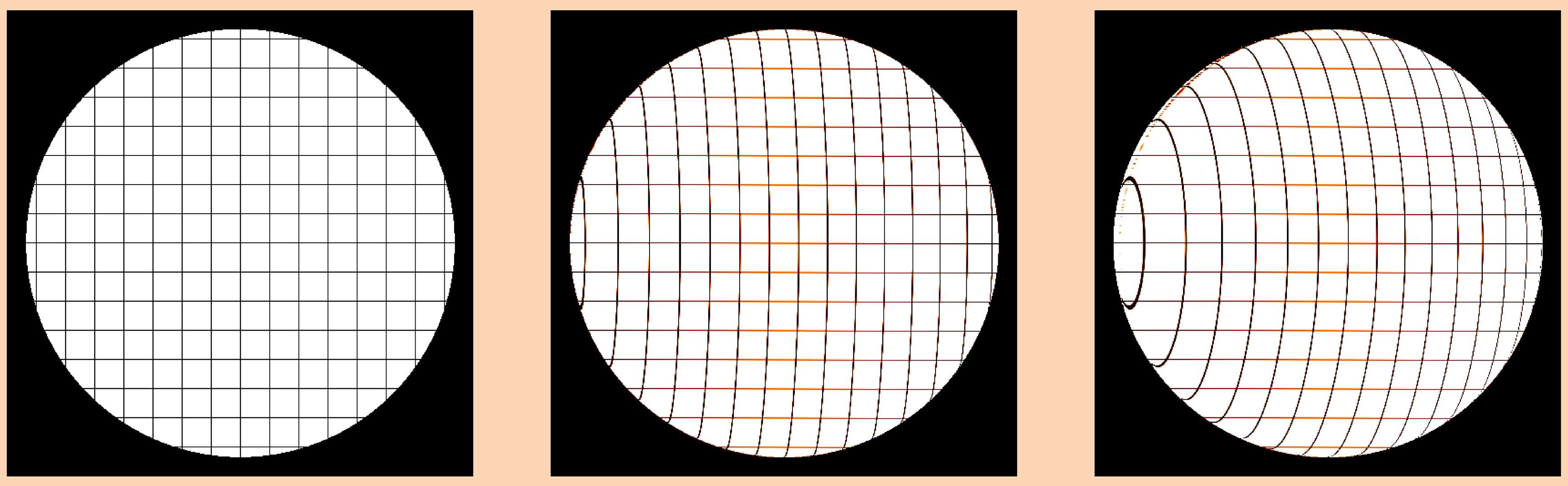
This value Δ can be calculated in the expression below.

$$\Delta = 2\sin\frac{\theta}{2}(x_{pix}\cos\frac{\theta}{2} - z_{pix}\sin\frac{\theta}{2})$$

This time, we utilized the rigid body rotation model rotating in 27.5 days. We can also take the differential rotation of the solar corona into account, and both models seem to have no apparent difference.

In Fig.6, we show how the solar images are rotated using this modification.

Fig.6



0 hour 7 hours 24 hours

2. **Adding a weight, namely utilizing data that is closer to the time we want to make the image more than data that is farther away.**

Fig.7 and Fig.8 are examples of the weight. Here, we estimated the weight according to how long before or after the required time the images were taken. Then we do not have to worry about the inaccuracy that arises from the difference in observation time during taking 14 images.

Fig.7

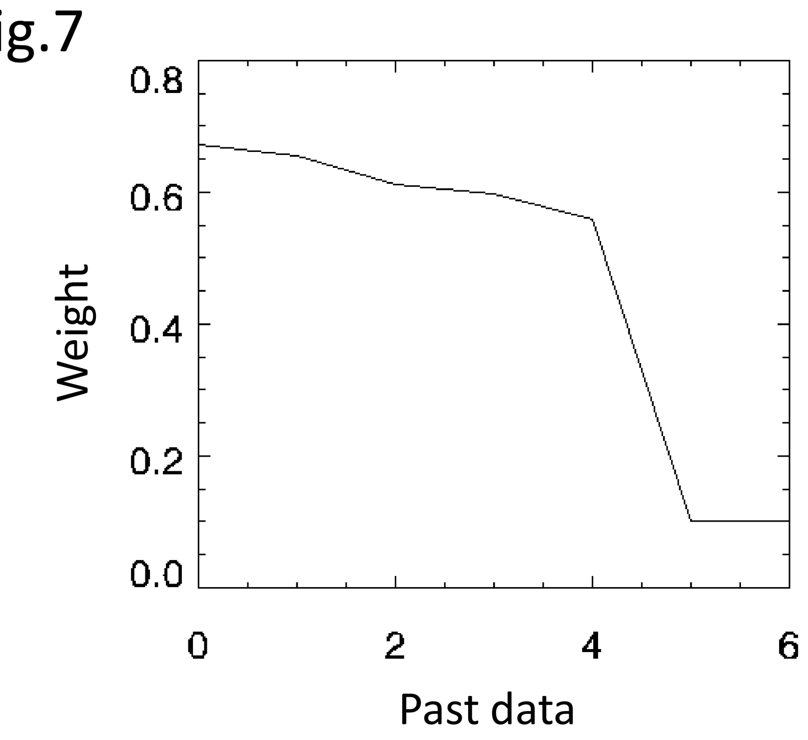
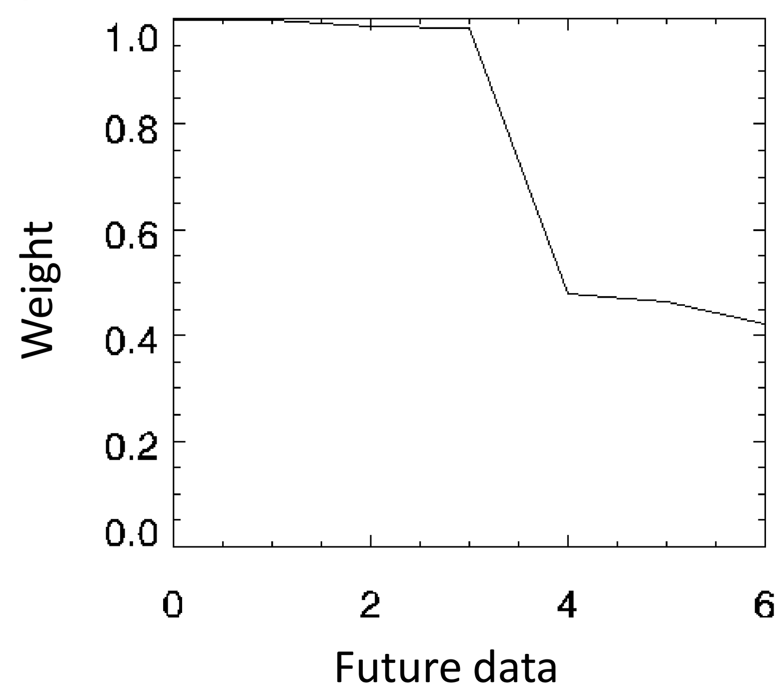
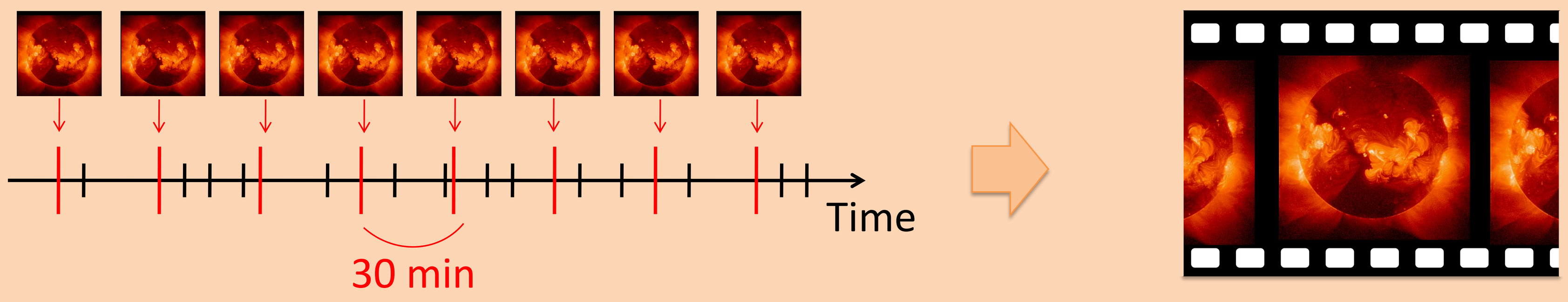
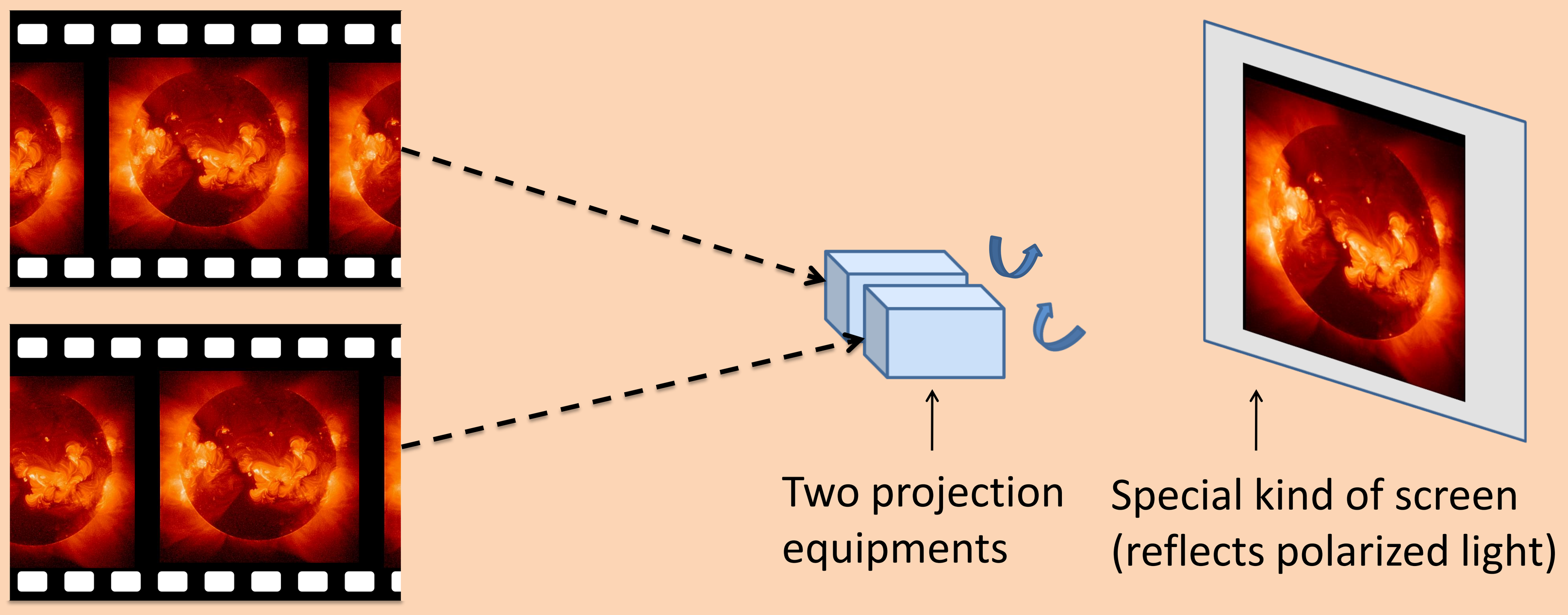


Fig.8



Finally we can get the images lining up at exactly 30 minute intervals, and make a smooth movie. Then showing two movies with a several hour separation can be used in three dimensional visualization system, by using two projectors simultaneously.





4. Three dimensional visualization using the Hinode/XRT data

We also applied this method to Hinode data. Hinode is taking approximately 4 full solar images a day. In Yohkoh's case, we could use 14 images, but this time, we cannot use as many images because there is less data compared with Yohkoh. We utilized only 4 images to make the movie. Hinode has a good spatial resolution and we can see the faint coronal structure in stereoscopic movie we made. Note that this is the first stereoscopic Hinode movies in the world.

5. Summary

Using the method introduced in this poster, we made stereoscopic solar movies, using data taken over 10 years by Yohkoh/SXT, and also made a movie using Hinode images for the first time in the world. In this movie, we can see the faint structure of the solar corona in 3D, and these movies will help not only public people but also researcher to understand the configuration of magnetic field of the solar corona.
In fact, we found more than 100 structures, known as cavities, using these movies.

References

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