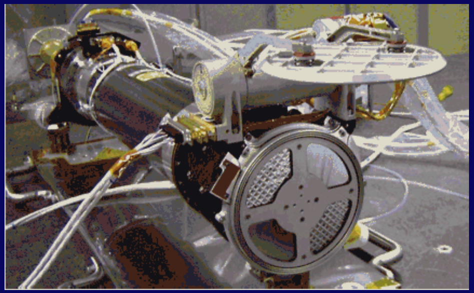
EUVI



Data Analysis Tools: How to determine the 3D Geometry of Coronal Loops

Markus J. Aschwanden
Jean-Pierre Wuelser, Jim Lemen, & Nariaki Nitta
(LMSAL)

SECCHI Consortium Meeting
STEREO Science Working Group 21, 22-26 Mar 2010, Dublin, Ireland

Goto to he EUVI website at LMSAL :

http://secchi.lmsal.com/EUVI/

EUVI Instrument Documentations

SECCHI chapter of STEREO book (Howard et al. 2007, Space Science Reviews)
EUVI: The STEREO-SECCHI extreme ultraviolet imager (Wuelser et al. 2004, SPIE Vol. 5171, p.111-122)
EUVI (on STEREO-SECCHI) Instrument Overview
SECCHI EUVI: Calibration Status and Software Notes
Notes on Data Analysis: EUVI

EUVI Images

First-light Images, STEREO-A, 4 wavelengths (2006-Dec-04)
First-light Images, STEREO-B, 4 wavelengths (2006-Dec-12)
Full resolution 171 A, STEREO-A (2006-Dec-04)
Full resolution 171 A, STEREO-B (2006-Dec-12)

EUVI Movies

MOVIE DIRECTORY : 2007 Jan-Apr (early mission phase with spacecraft separation <5 deg)
MOVIE DIRECTORY : 2007 Apr-Sept (weekly anaglyph movies, spacecraft separation 5-30 deg)
MOVIE DIRECTORY : 2007 Sept - 2008 Sep (weekly two-panel movies, SC separation 30-50 deg)
FLARE MOVIE DIRECTORY : 2007 Jan - 2008 (Movies of flare events, see EUVI event catalog)
FLARE MOVIE DIRECTORY : 2007 - 2008 (two-panel movies of flare events, see EUVI event catalog)

EUVI Event Catalog

Comprehensive EUVI Event Catalog Compilation [285 events]
Comprehensive EUVI Event Catalog List (one-line list format)
EUVI Event Quicklook Plots with GOES and EUV Lightcurves
CME Event Lists: SOHO/LASCO - CACTUS - SEEDS

EUVI Software

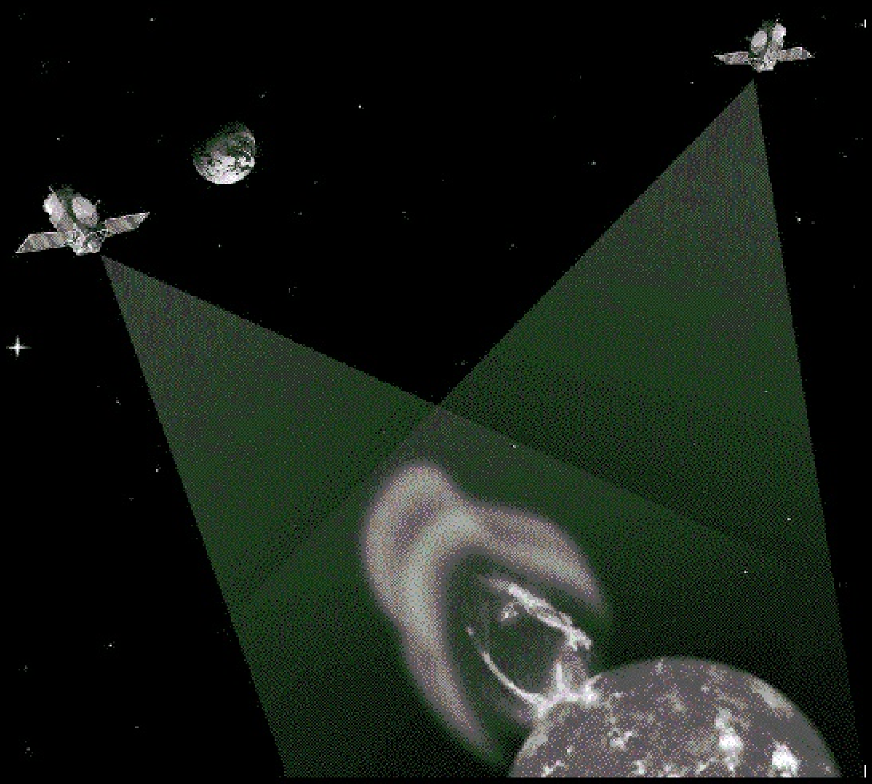
EUVI Data Analysis Software+Tutorials (IDL)
SSW SolarSoftWare, (STEREO IDL software)
SECCHI Wiki (Data Processing+Analysis Info)

http://secchi.lmsal.com/EUVI/index_soft.html

http://secc…e/home.html MARKUS J. ASCHWANDEN Yahoo! News (917) Apple (159) Amazon eBay

STEREO Science - LMSAL Group

URL = "http://secchi.lmsal.com/Science/index_soft.html"



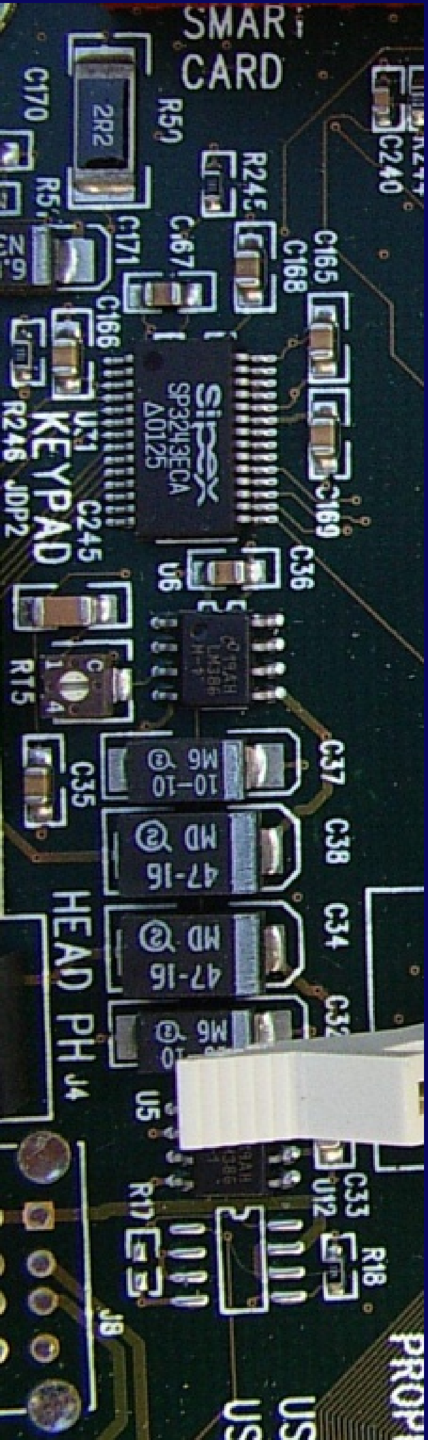
SECCHI/EUVI Software

Tutorials for EUVI Data Analysis Software: $/SSW/package/mjastereo/idl/ : HTML

List of IDL Procedures in SSW package $/SSW/package/mjastereo/idl/ : HTML

SECCHI/EUVI Software Approach at LMSAL : HTML

Contact website author: aschwanden@lmsal.com



EUVI Data Analysis Software: IDL Procedures
$/SSW/package/mjastereo/idl

(1) EUVI Data Analysis :

- EUVI_COALIGN.PRO
- EUVI_CONTOUR.PRO
- EUVI_CORR.PRO
- EUVI_CORRPLOT.PRO
- EUVI_DISPLAY.PRO
- EUVI_EVOL.PRO
- EUVI_FILES.PRO
- EUVI_FOV.PRO
- EUVI_GOES.PRO
- EUVI_GOES_READ.PRO
- EUVI_LOOPFILE.PRO
- EUVI_ORTHOGONAL.PRO
- EUVI_PROJECTION.PRO
- EUVI_PROJECTION3.PRO
- EUVI_SPLINE.PRO
- EUVI_STEREO.PRO
- EUVI_STEREO_HEIGHT.PRO
- EUVI_STEREO_OFFSET.PRO
- EUVI_STEREO_ROT.PRO
- EUVI_STEREOPAIR.PRO
- EUVI_SUMMARY.PRO

(2) Stereoscopy Simulation Tools :

- STEREO_GUIDE.PRO
- STEREO_LOOP.PRO
- STEREO_SIMUL.PRO

(3) Loop Geometry Tools :

- LOOP_COORD_PARA.PRO
- LOOP_COORD_PARA0.PRO
- LOOP_FILLING.PRO
- LOOP_INTERPOL.PRO
- LOOP_PARA_COORD.PRO
- LOOP_POWELL.PRO
- LOOP_SMOOTH.PRO
- LOOP_TEST.PRO
- LOOP_TEST2.PRO

(4) Coordinate transformations :

- COORD_ADDINDEX.PRO
- COORD_CART_HELIO.PRO
- COORD_HELIO_CART.PRO
- COORD_HELIO_SPHERE.PRO
- COORD_SPHERE.PRO
- COORD_TEST.PRO
- HELIO_LOOPCOORD.PRO
- HELIO_LOOPCOORD2.PRO
- HELIO_POWELL.PRO
- HELIO_TRANS.PRO
- HELIO_TRANS2.PRO

(5) Auxiliary Routines :

- ARRAY_CURVE_ALIGN.PRO
- PARABOL_MAX.PRO ($SSW/gen/idl/util/)

Tutorials for EUVI Data Analysis Software

Set your environment variable in your IDL startup file to: setenv SSW_INSTR "stereo secchi sbrowser"
Including these packages automatically also includes the path: $/SSW/package/mjastereo/idl/
which is needed for the EUVI data analsyis software described in the following.
On the following tutorials pages you can just click and copy the lines that contain IDL commands (orange color)
and drag them into your IDL window to execute them.

You need also access to the SECCHI database, which you have available at SECCHI centers (e.g., NRL, GSFC, LMSAL, ...), or alternatively you may download SECCHI data onto your local machine (e.g. through the STEREO science center at http://stereo-ssc.nascom.nasa.gov/data.shtml or trough the Virtual Solar Observatory VSO). The SECCHI archive is described in http://sohowww.nascom.nasa.gov/solarsoft/stereo/secchi/doc/scctree.txt (you can also get there through http://secchi.nrl.navy.mil/ , click on "SECCHI wiki" (lower left), then "4. Data Processing and Analysis" and then "Description of SECCHI Data Archive" (under SECCHI Data Management)). In the following example, the level-0 SECCHI data are available in the globally defined data directory DATADIR='$secchi/lz/L0/' (e.g., pointing to DATADIR='net/kokuten/archive/stereo/lz/L0' at LMSAL).

Tutorials for STEREO/EUVI Tasks with One Spacecraft

- (a) Plot EUVI data + GOES curve
- (b) Get EUVI summary
- (c) Get EUVI data filenames
- (d) Display EUVI image sequences
- (e) Extract EUVI Subimages in a Selected Field-of-View
- (f) Plot EUVI Image Time Sequence + GOES curve

Tutorials for STEREO/EUVI Tasks with Two Spacecraft

- (a2) Coalignment of a stereoscopic EUVI image pair
- (b2) Testing and Perfecting the Coalignment
- (c2) Stereoscopic 3D reconstruction of a curvi-linear feature
- (d2) Overlay of 3D coordinates on image or contourplot
- (e2) Cartesian Projections of 3D coordinates of curvi-linear features
- (f2) Projections of 3D coordinates in Arbitrary Direction
- (g2) Orthogonal Projections of Loops in Loop-Plane System
- (h2) Stereoscopic Height Measurement of Point-like Features

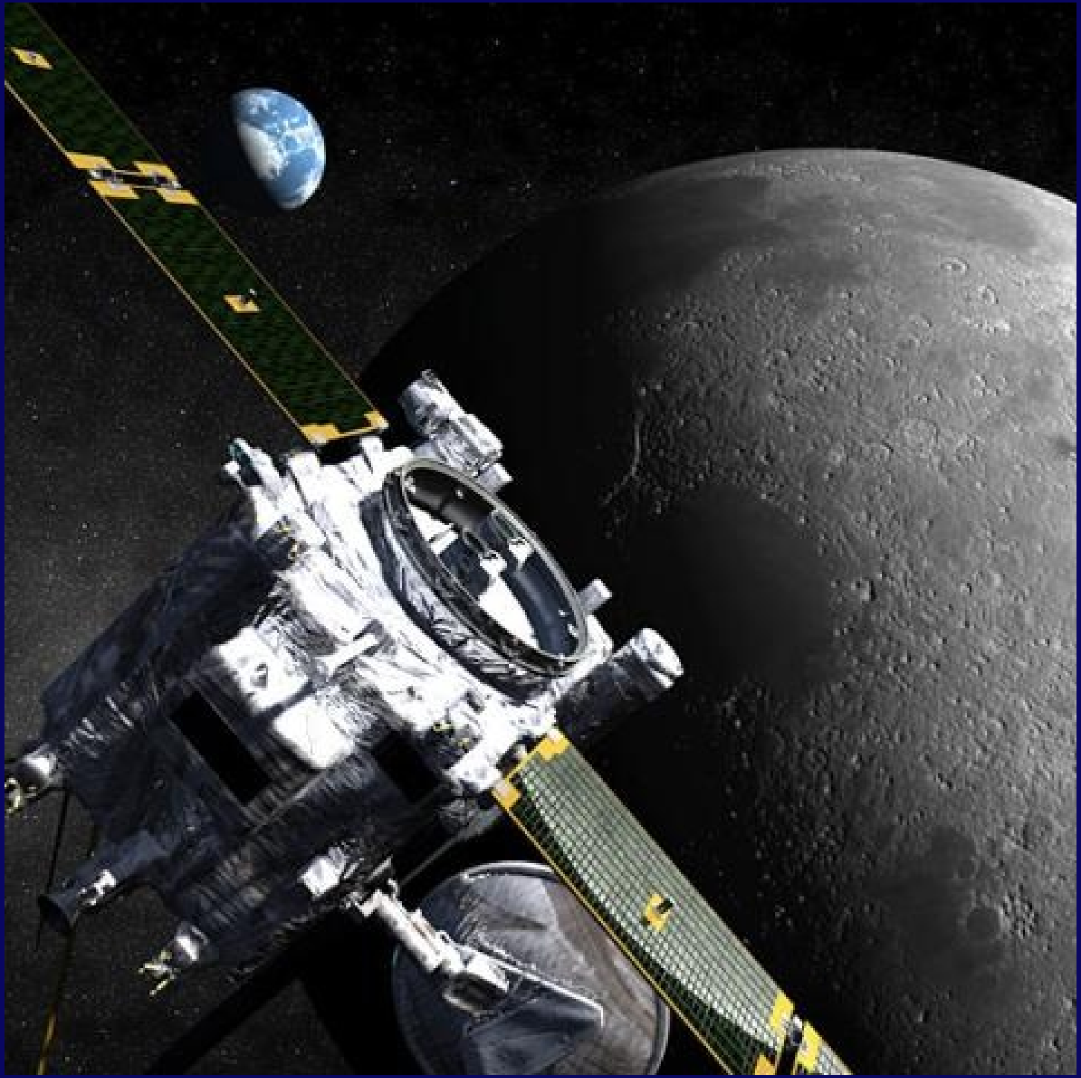
Datafiles and IDL demo used in these EUVI Tutorials

- loop_A.dat --> 3D loop coordinates of 30 loops traced on 2007-May-09, EUVI 171 A"
- loop_A2.dat --> 3D loop coordinates of 30 loops traced on 2007-May-09, EUVI 171 A, interpolated with 8 times higher resolution than in loop_A.dat"
- loop_A.sav --> IDL save file of images and parameters associated with output in loop_A.dat "
- 070509_D_trace.dat --> 3D loop coordinates of 100 loops traced on 2007-May-09, EUVI 171, 195, 284 A"
- moss_A.dat --> 3D loop coordinates of 30 moss sources traced on 2007-May-09, EUVI 171 A"
- euvi_demo.pro --> IDL procedure to run all demonstration examples shown in this tutorial"

Publications with Applications

- Aschwanden,M.J., Wuelser,J.P., Nitta,N., and Lemen,J. 2008, ApJ 679, 827-842
  First 3D reconstruction of coronal loops with the STEREO A+B spacecraft: I. Geometry
  URL="http://www.lmsal.com/~aschwand/eprints/2008_stereo.pdf"

Basic EUVI tools for images from 1 spacecraft



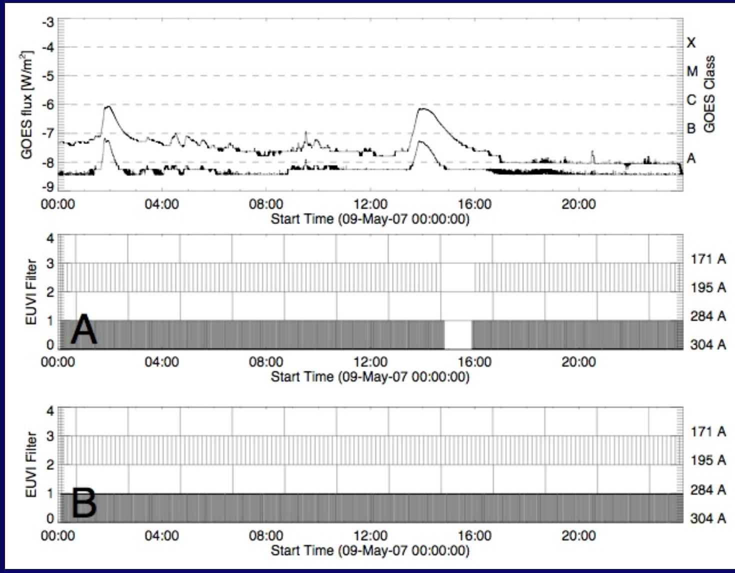
(a) Plot EUVI data + GOES light curve

To start data analysis with EUVI data we like to see a catalog of EUVI data in a graphic display over some time interval, if possible along with a GOES light curve, which shows us the activity level of the Sun in soft X-rays, from which we can gather the times of flares and CMEs.

Let us check if EUVI observed on Dec 13, 2006 and whether there was a GOES flare.
The commands for this example in IDL are:

```
IDL>
date ='20070509' ;'YYYYMMDD' date of observation
tstart ='000000' ;'HHMMSS' start time interval for image selection
tend ='240000' ;'HHMMSS' end time interval for image selection
type ='img' ;'img','cal', 'seq'
instr ='euvi' ;instrument
dir ='~/work/' ;local working directory
euvi_goes,date,tstart,tend,type,instr,dir
```

The plot shows two small flares of about C1 GOES class around 2:00 UT and 14:00 UT. EUVI was observing all day, with a small data gap around 15-16 UT in spacecraft A[head] (middle panel), while spacecraft B[ehind] was observing continuously (lower panel). Every vertical mark in the lower two EUVI displays indicates the time of an image taken, with the wavelengths indicated on the right hand side.
The program EUVI_GOES.PRO produced also a postscript file of the graph and you should find in your current work directory with the filename="goes070509.ps".



(b) Get EUVI Summary

Let us get a summary of EUVI datafiles. The IDL procedure EUVI_SUMMARY reads the EUVI summary file (generated by the SECCHI software) and extracts an observation summary (filenames, times, filter, wavelength, exposure time, image size, etc.) according to the selected observing time interval specified by DATE, TSTART, TEND, INSTR, SPACECRAFT, TYPE and returns a structure DATASUM and string array DATAFILES. Beacon data are included in the summary.

Let us check the EUVI datafiles of spacecraft A on May 9, 2007, 20-21 UT hours.
The commands for this example in IDL are:

```
IDL>
datadir='$secchi/lz/L0/' ;disk or data archive
date ='20070509' ;'YYYYMMDD' date of observation
tstart ='200000' ;'HHMMSS' start time interval for image selection
tend ='210000' ;'HHMMSS' end time interval for image selection
type ='img' ;'img','cal', 'seq'
instr ='euvi' ;instrument
sc ='a' ;spacecraft "a" or 'b'
euvi_summary,datadir,date,tstart,tend,type,instr,sc,datasum,datafiles
```

The output on the screen looks like this:

```
{ 20070509_200028_n4euA.fts 2007/05/09 20:00:28 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200105_n4euA.fts 2007/05/09 20:01:05 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200120_n4euA.fts 2007/05/09 20:01:20 EUVI      4.00000    2048     2048 S1       195.000 Norm      1613 SSR1 ON None ICER5         0 A img}
{ 20070509_200120_n7euA.fts 2007/05/09 20:01:20 EUVI      4.00000     512      512 S1       195.000 Norm      1613 SW ON None ICER10         0 A img}
{ 20070509_200143_n4euA.fts 2007/05/09 20:01:43 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200220_n4euA.fts 2007/05/09 20:02:20 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200258_n4euA.fts 2007/05/09 20:02:58 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200335_n4euA.fts 2007/05/09 20:03:35 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200413_n4euA.fts 2007/05/09 20:04:13 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200450_n4euA.fts 2007/05/09 20:04:49 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200528_n4euA.fts 2007/05/09 20:05:28 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200605_n4euA.fts 2007/05/09 20:06:05 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200643_n4euA.fts 2007/05/09 20:06:43 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200720_n4euA.fts 2007/05/09 20:07:20 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200758_n4euA.fts 2007/05/09 20:07:58 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200835_n4euA.fts 2007/05/09 20:08:35 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
{ 20070509_200913_n4euA.fts 2007/05/09 20:09:13 EUVI      2.00000    2048     2048 S1       304.000 Norm      1619 SSR1 ON None ICER5         0 A img}
```

The output is the structure DATASUM and the string array DATAFILES.

(c) Get EUVI Data Filenames

In order to download data we need first to get the filenames. It is often convenient to select by a time interval, which can be done with the IDL procedure EUVI_FILES. This routine finds the filenames of EUVI image data on the disk DATADIR that correspond to the time range specified by OBSDATE, TSTART, TEND, from spacecraft SC=A or B, in wavelength filter WAVE. The array of selected filenames is output in array DATAFILES. Beacon data are excluded in this data selection.

Let us get the EUVI data filenames of spacecraft A on May 9, 2007, in the wavelength of 171 A. The IDL commands for this example are:

```
IDL>
datadir='$secchi/lz/L0/' ;disk or data archive
date ='20070509' ;'YYYYMMDD' date of observation
tstart ='000000' ;'HHMMSS' start time interval for image selection
tend ='240000' ;'HHMMSS' end time interval for image selection
sc ='a' ;spacecraft "a" or 'b'
wave ='171' ;wavelength '171','195','284', or '304' (Angstrom)
nfilemax =100 ;maximum number of files (optional)
expmax =10. ;maximum exposure time in seconds (optional)
euvi_files, datadir,date,tstart,tend,sc,wave,datafiles,nfilemax,expmax
```

The output on the screen looks like this:

```
 0 --> 20070509_000600_n4euA.fts | 2007/05/09 00:06:00 | EUVI |  4.0| 2048 | 2048 |  S1 |  171 |
 1 --> 20070509_004045_n4euA.fts | 2007/05/09 00:40:45 | EUVI |  4.0| 2048 | 2048 |  S1 |  171 |
 2 --> 20070509_024045_n4euA.fts | 2007/05/09 02:40:45 | EUVI |  4.0| 2048 | 2048 |  S1 |  171 |
 3 --> 20070509_044045_n4euA.fts | 2007/05/09 04:40:45 | EUVI |  4.0| 2048 | 2048 |  S1 |  171 |
 4 --> 20070509_064045_n4euA.fts | 2007/05/09 06:40:45 | EUVI |  4.0| 2048 | 2048 |  S1 |  171 |
 5 --> 20070509_084045_n4euA.fts | 2007/05/09 08:40:45 | EUVI |  4.0| 2048 | 2048 |  S1 |  171 |
 6 --> 20070509_104045_n4euA.fts | 2007/05/09 10:40:45 | EUVI |  4.0| 2048 | 2048 |  S1 |  171 |
 7 --> 20070509_124045_n4euA.fts | 2007/05/09 12:40:45 | EUVI |  4.0| 2048 | 2048 |  S1 |  171 |
 8 --> 20070509_144045_n4euA.fts | 2007/05/09 14:40:45 | EUVI |  4.0| 2048 | 2048 |  S1 |  171 |
 9 --> 20070509_164045_n4euA.fts | 2007/05/09 16:40:45 | EUVI |  4.0| 2048 | 2048 |  S1 |  171 |
10 --> 20070509_184045_n4euA.fts | 2007/05/09 18:40:45 | EUVI |  4.0| 2048 | 2048 |  S1 |  171 |
11 --> 20070509_204045_n4euA.fts | 2007/05/09 20:40:45 | EUVI |  4.0| 2048 | 2048 |  S1 |  171 |
12 --> 20070509_224045_n4euA.fts | 2007/05/09 22:40:45 | EUVI |  4.0| 2048 | 2048 |  S1 |  171 |
```

The string array DATAFILES contains the names of 13 datafiles:

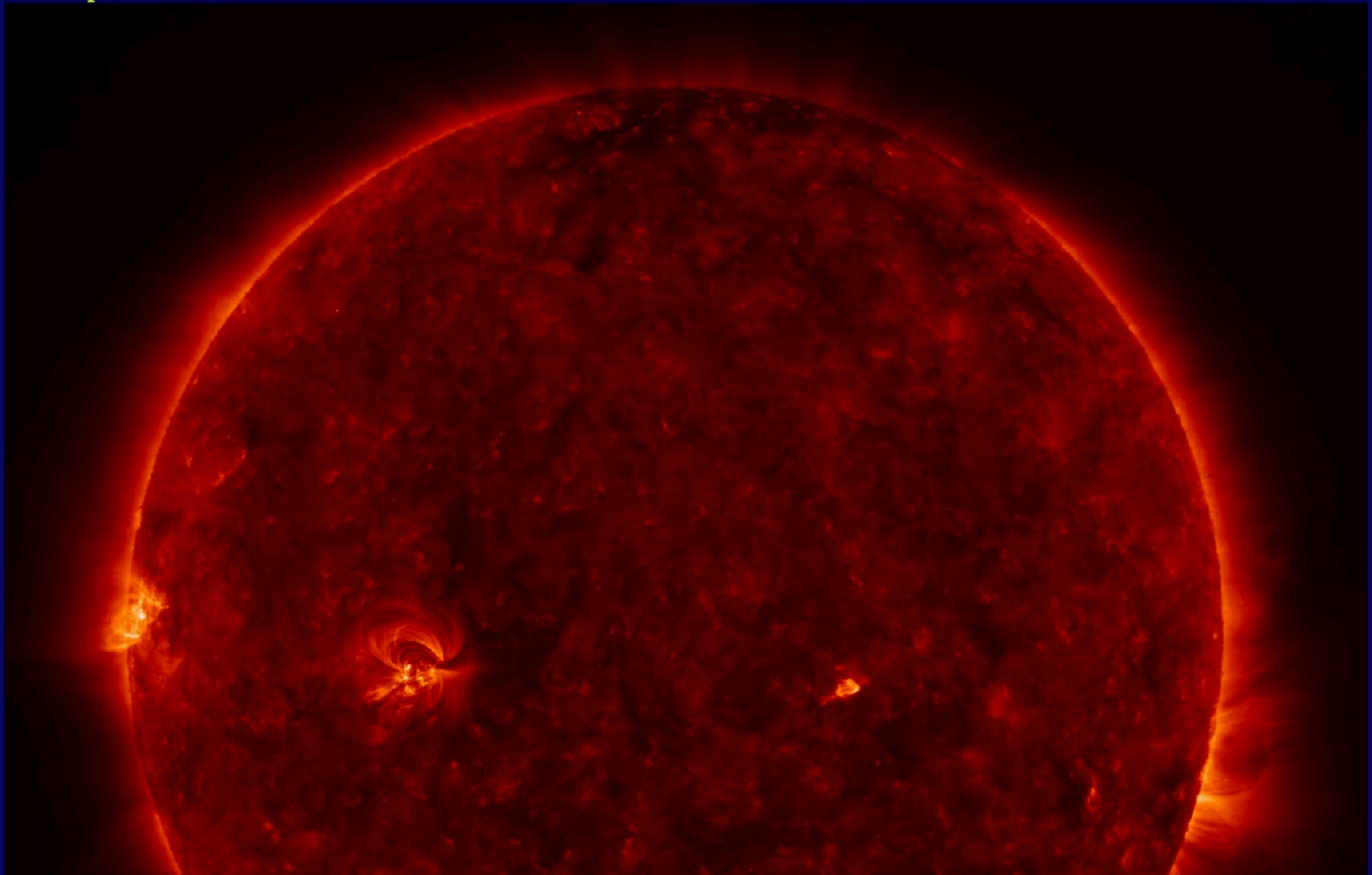
```
help,datafiles
DATAFILES STRING = Array[13]
for i=0,12 do print,i,'-->',datafiles(i)
0 --> 20070509_000600_n4euA.fts
1 --> 20070509_004045_n4euA.fts
2 --> 20070509_024045_n4euA.fts
```

(d) Display EUVI Image Sequences

After we obtained the EUVI data filenames with the previous task (c), we read a sequence of images into an array IMAGES and the corresponding FITS header descriptors into the structure INDEX. We can then display individual images as a sequence stepping in time. In the previous task we obtained a file list DATAFILES with 13 filenames of EUVI images observed with spacecraft A on May 9, 2007. Let us display the 12th datafile at 20:40:45 UT:

```
IDL>
color=0 ;0=automated scaling of min/max, 1=interactive
movie=0 ;0=automated movie play, 1=interactive stepping of images
euvi_display,datafiles(11),color,movie,images,index
```

The output on the screen looks like this:

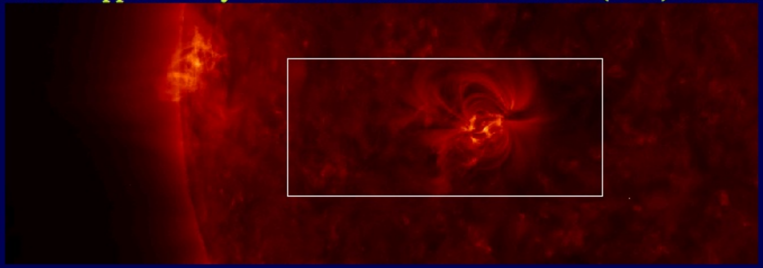


(e) Extract EUVI Subimages in a Selected Field-of-View

In the previous task (d) we downloaded a time sequence of full-size EUVI images, which are stored in the variables IMAGES and INDEX. Now we wish to extract a sequence of subimages within a restricted field-of-view. The procedure EUVI_FOV lets you select a field-of-view (FOV) interactively on the screen and extracts the corresponding sequence of subimages into the array IMAGES_FOV. Pointing offsets up to a maximum misalignment of MISMAX are automatically corrected by cross-correlation of the shifted subimages (by +/- MISMAX pixels in x- and y-direction) at various times compared with the subimage at the first selected time.

```
IDL>
help,images,index
IMAGES DOUBLE = Array[2048, 2048, 13]
INDEX STRUCT = -> SECCHI_HDR_STRUCT Array[13]
color=0 ;0=automated scaling of min/max, 1=interactive
mismax=10 ;10=maximum expected misalignment offset (in units of pixels)
euvi_fov,images,color,fov,images_fov,index,mismax
```

Let us suppose that you clicked the bottom left corner (BLC) and the top right corner (TRC) like this:



Then you can check the image coordinates of your chosen FOV and the resulting datacube of the corresponding subimages:

```
print,fov
512 798 870 954
help,images_fov
IMAGES_FOV DOUBLE = Array[359, 157, 13]
```

which means that you selected the x-range of [i1:i2=512:870] pixels and the y-range of [j1:j2=798:954] pixels. The 4-number array FOV contains these four pixel numbers FOV=[i1,j1,i2,j2], in the same format as the IDL keyword !P.POSITION. So the subarray has images of the size nx=(i2-i1+1)=(870-512+1)=359 and ny=(j2-j1+1)=954-798+1=157. You can play the reduced movie as:

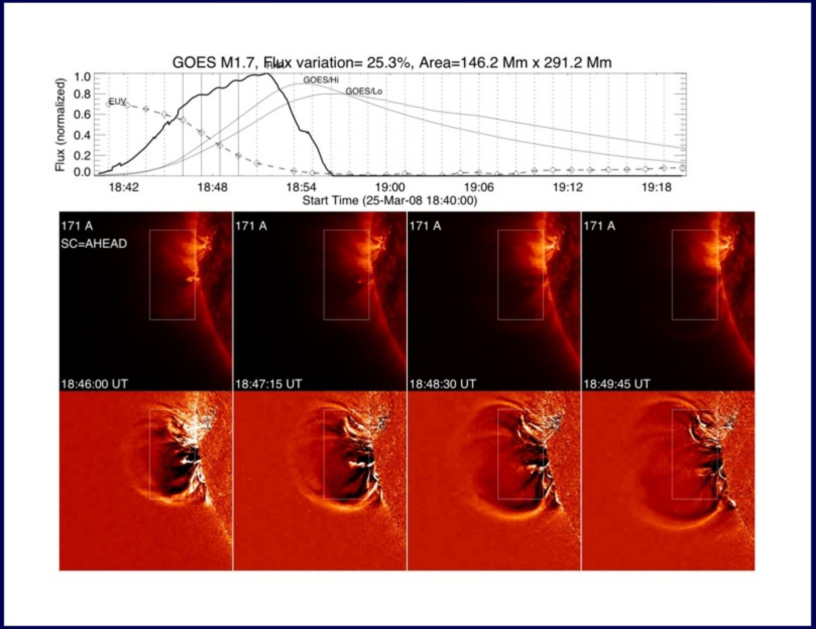
```
window,1,xsize=359,ysize=157
for i=0,12 do begin &tv,bytscl(images_fov(*,*,i)) &wait,1 &endfor
```

(f) Plot EUVI Subimage Time Sequence + GOES Light Curve

For an overview of the evolution of a selected region on the Sun (i.e., an active region) it is convenient to plot a time sequence of EUVI subimages along with the GOES soft X-ray light curve. We can do this taks with the IDL procedure EUVI_EVOL.PRO.

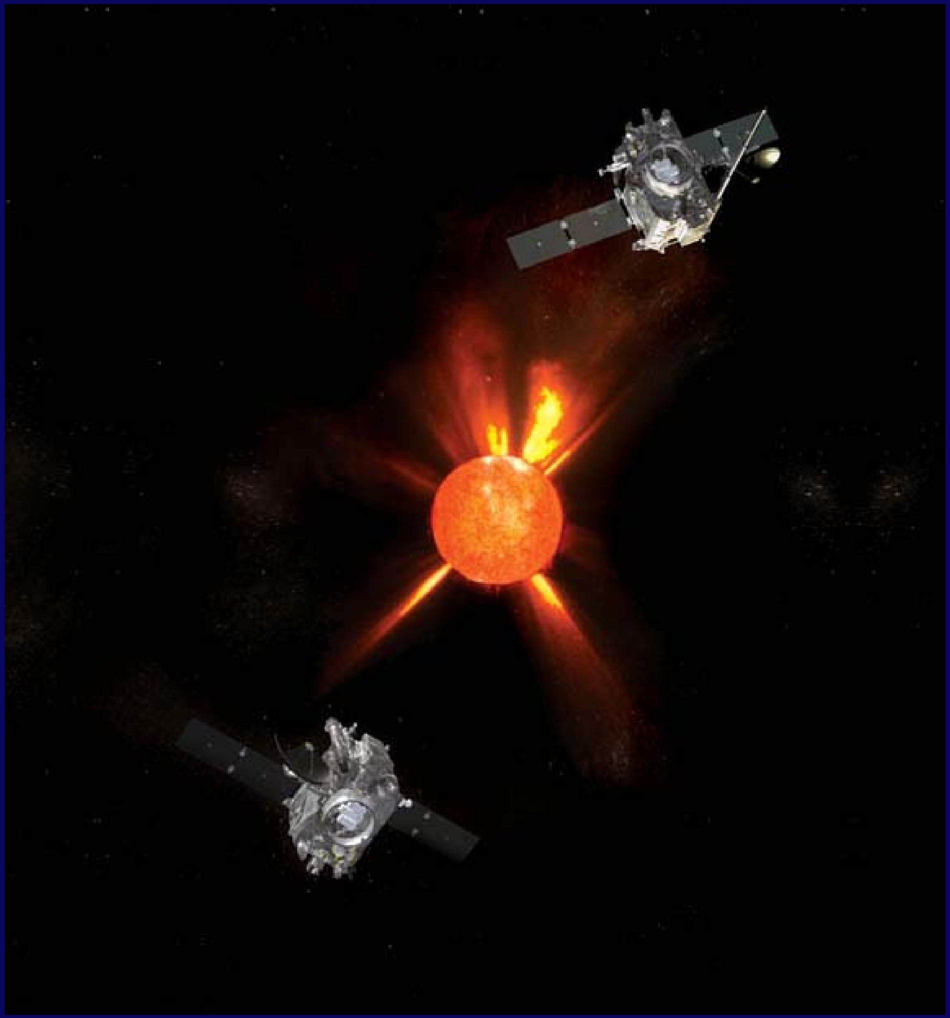
```
IDL>
datadir='$secchi/lz/L0/' ;disk or data archive
date ='20080325' ;'YYYYMMDD' date of observation
tstart ='184000' ;'HHMMSS' start time interval for image selection
tend ='192000' ;'HHMMSS' end time interval for image selection
sc ='a' ;spacecraft "a" or 'b'
wave ='171' ;wavelength '171','195','284', or '304' (Angstroem)
color=0 ;0=automated scaling of dynamic range, 1=interactive
movie=0 ;0=automated movie play, 1=interactive stepping of images
fov=[100,500,600,1100] ;[i1,j1,i2,j2] pixels of field-of-view
mismax =0 ;maximum offset (in pixels) for misalignment correction by cross-correlation
iseq=[4,5,6,7] ;indices of images selected for display (iseq=[-1] for equidistant times)
nmin =3 ;3 or 5 min smoothing of GOES light curve
id =-1 ;ID number of event in EUVI event catalog (id=-1 if not used)
nsme =0 ;(currently unused parameter)
area =[0.5,0.4,0.75,0.9] ;fractional field-of-view area of EUV light curve [x1,y1,x2,y2]
filename=date+'_'+tstart+'_'+wave+'_'+sc+'_' ;filename of plot
dir ='~/work/' ;work directory
euvi_files,datadir,date,tstart,tend,sc,wave,datafiles
euvi_display,datafiles,color,movie,images,index
euvi_fov,images,color,fov,images_fov,index,mismax
euvi_evol,date,tstart,tend,index,images_fov,iseq,sc,wave,nmin,id,nsme,area,pos,dir,filename
```

In this time interval we obtain a sequence 31 images. From these 31 images (with IDL index 0,1,...,30) we choose the subset of ISEQ=[4,5,6,7] for our plot. Let us suppose that you clicked the bottom left corner (BLC) and the top right corner (TRC) of the FOV that encompasses the active region at the south-east limb, say at FOV=[0,500,500,1000]. The resulting plot looks then like this:



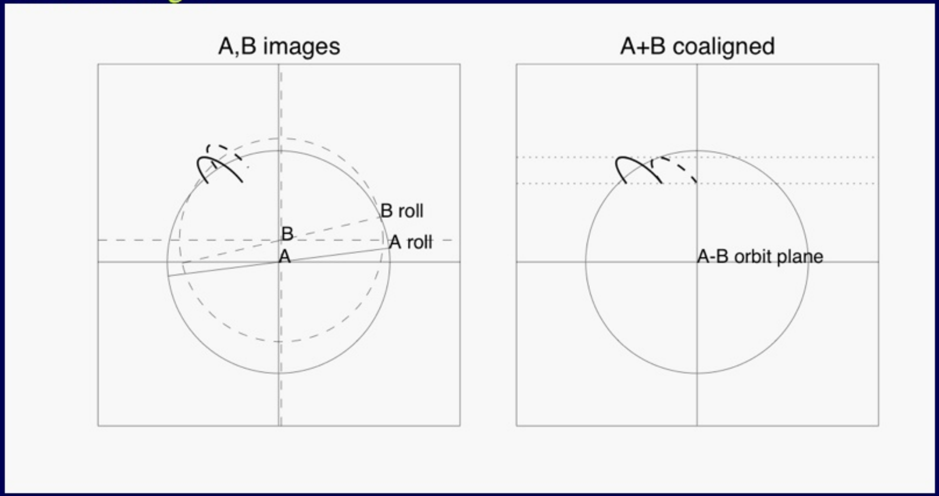
The upper panel shows the GOES soft X-ray light curves (thin solid curves), the time derivative, which is a proxy for the hard X-ray light curve according to the Neupert effect (thick solid curve). The times of the 31 images are marked with vertical dotted lines, and the EUV light curve (averaged over the fractional image area (0.5-0.75 of the x-range and 0.4-0.9 of the y-range) is shown with a dashed curve and diamond symbols. Note the EUV dimming by 25.3% over the selected area with a size of 146 Mm in x-direction and 291 Mm in y-direction (information is given in title of plot). The second panel shows the 4 images (of the chosen sequence numbers ISEQ), and the third panel shows difference plots, which indicate the dynamic changes in the flaring region (white is flux increase, while black denotes flux decreases). Note that the difference images nicely enhance the expanding CME bubble, which is not visible in the original images. You should also find a postscript file of this plot in your directory with the filename: 20080325_184000_171_a_evol_col.ps

EUVI tools for images from 2 spacecraft



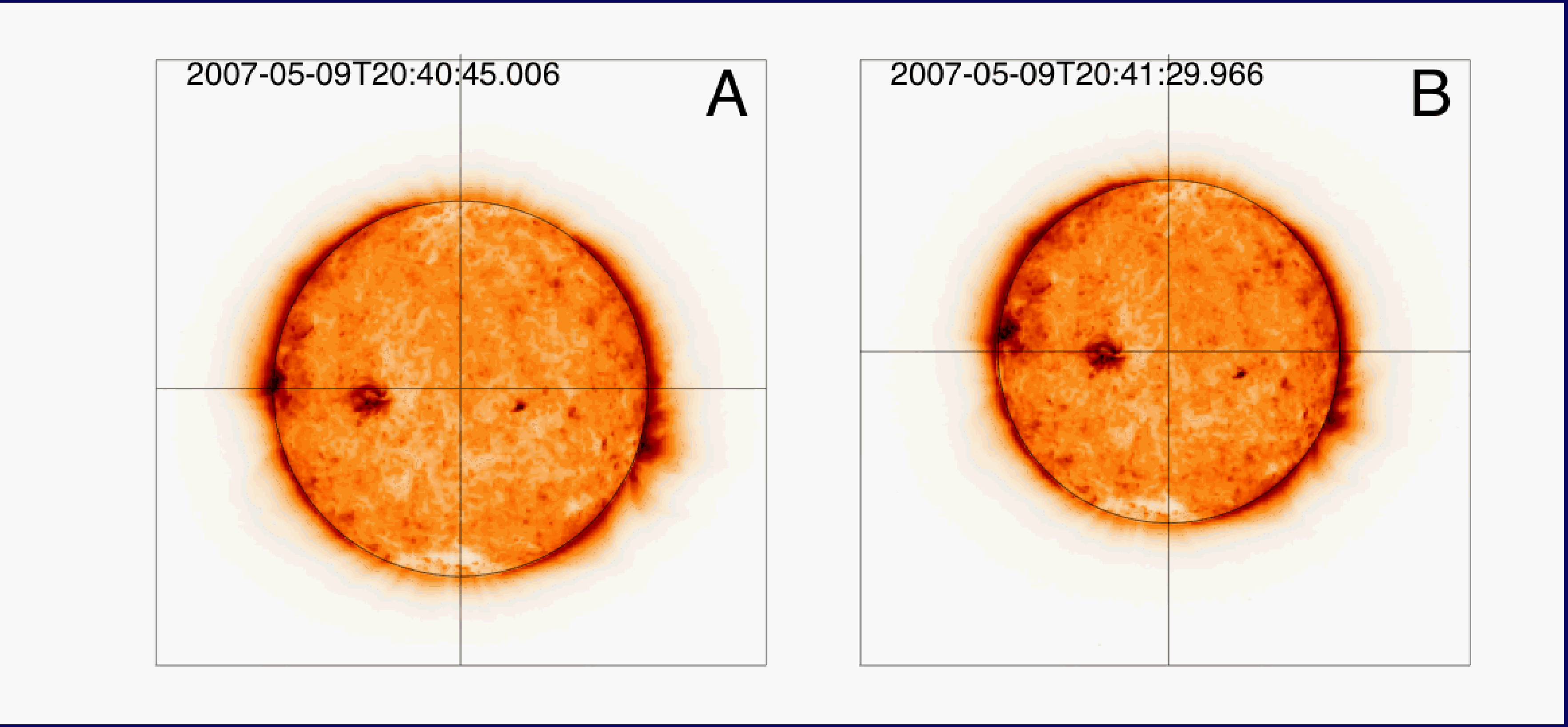
(a2) Coalignment of a Stereoscopic EUVI Image Pair

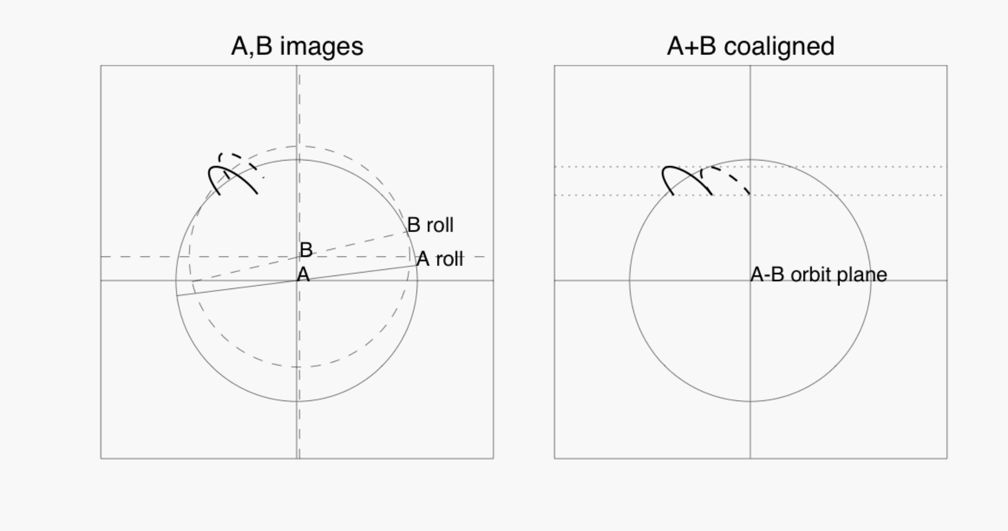
The coalignment between a stereoscopic image pair from spacecraft A and B is accomplished by co-centering, rebinning, and rotating of image B to the same parameters as image A, based on the information given in the FITS header descriptors of the two images.



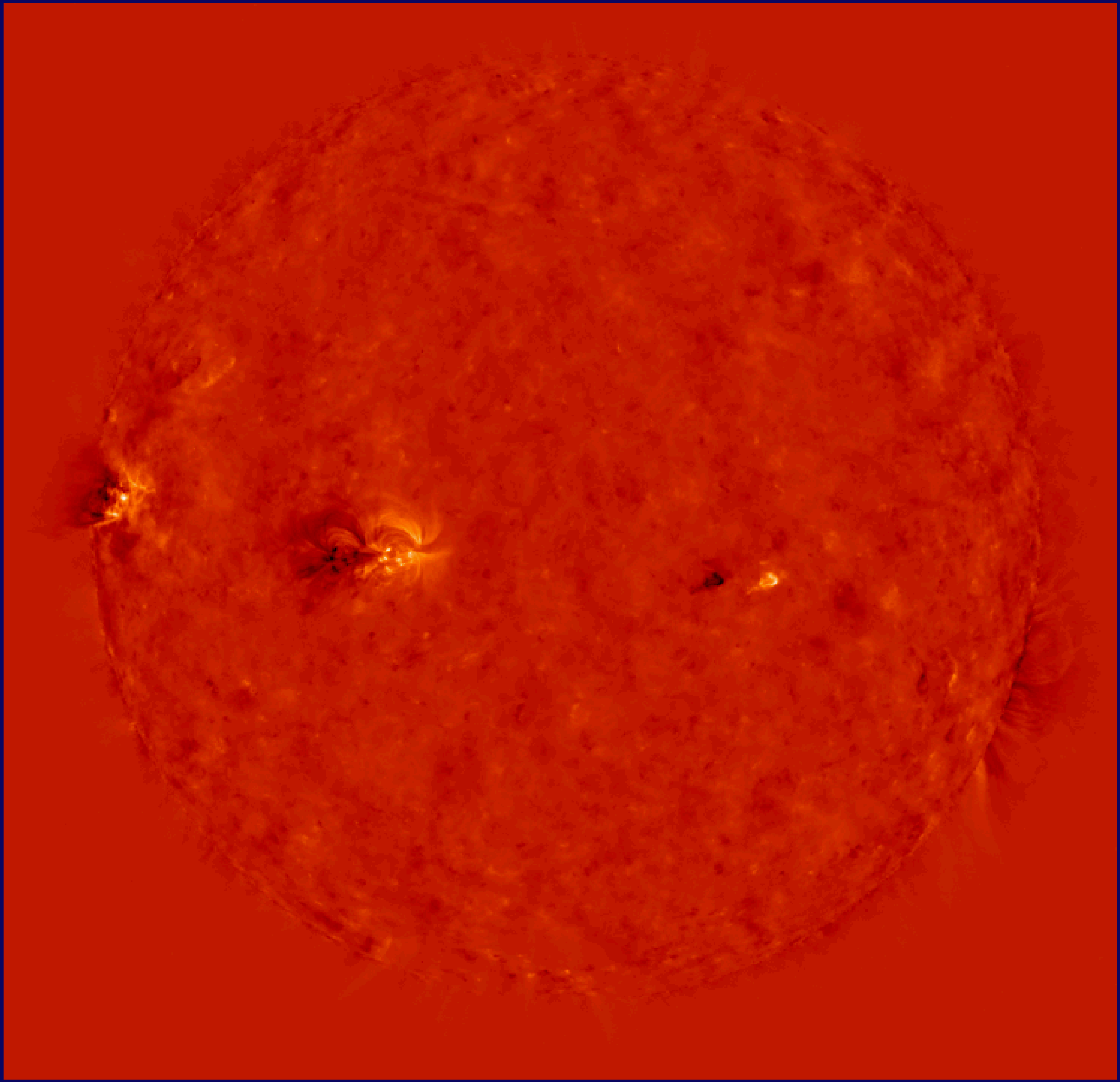
Let us coalign two EUVI images from spacecraft A and B on May 9, 2007, 20:40 UT, in the wavelength of 171 A. The IDL commands for this example:

```
IDL>
datadir='/net/kokuten/archive/stereo/lz/L0/' ;disk or data archive
date ='20070509' ;'YYYYMMDD' date of observation
tstart ='203500' ;'HHMMSS' start time interval for image selection
tend ='204500' ;'HHMMSS' end time interval for image selection
wave ='171' ;wavelength '171','195','284', or '304' (Angstroem)
color=0 ;0=automated scaling of min/max, 1=interactive
movie=0 ;0=automated movie play, 1=interactive stepping of images
euvi_files,datadir,date,tstart,tend,'a',wave,files_a
euvi_files,datadir,date,tstart,tend,'b',wave,files_b
euvi_display,files_a(0),color,movie,image_a,index_a
euvi_display,files_b(0),color,movie,image_b,index_b
euvi_stereopair,files_a,files_b,index_a,index_b,image_pair,para
savefile='loop_A.sav' ;data save file
save,filename=savefile,image_pair,para ;save data
```





- Using FITS header info: (SCCREADFITS.PRO FITSHEAD2WCS.PRO)
- Coaligning to Sun center
- Rebinning to same distance (and pixelsize)
- Rolling into A-B spacecraft plane (for stereoscopy)



Difference of Coaligned STEREO A-B Images:

no gradients at limb visible if perfectly coaligned

(b2) Testing and Perfecting the Coalignment of a Stereoscopic EUVI Image Pair

If you don't trust the coalignment between a stereoscopic image pair from spacecraft A and B, this routine will test how good the coalignment is and produce an improved coaligned image pair.

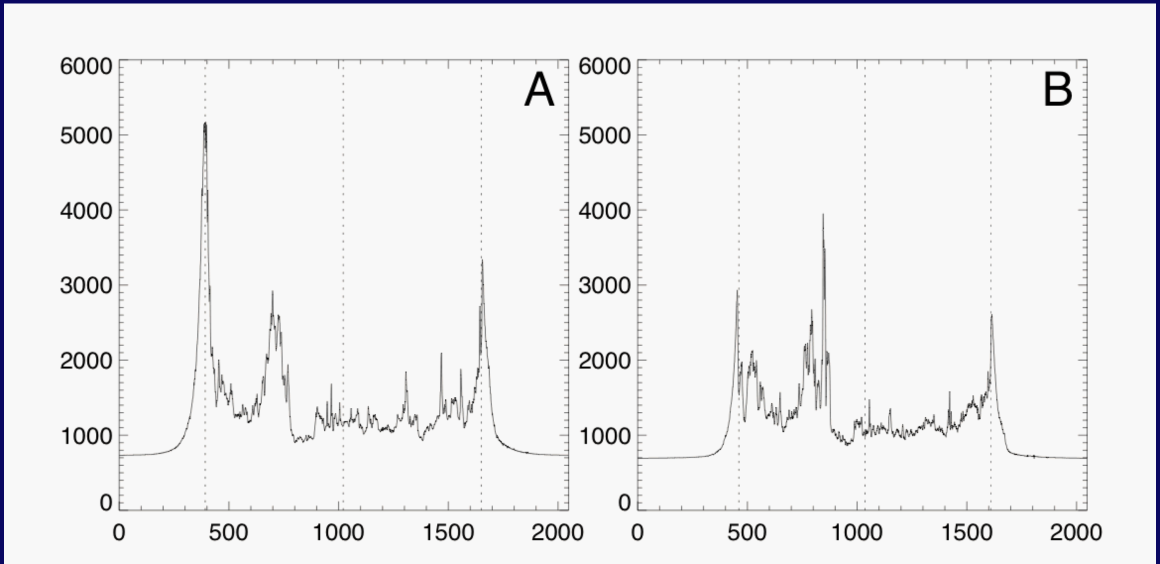
Let us assume you produced already a coaligned EUVI image pair with the routine EUVI_STEREOPAIR.PRO, which stores the coaligned image pair in the array IMAGE_PAIR(2, NX, NY), where the coalignment was done based on the information in the FITS headers of the image. If you call the routine EUVI_COALIGN.PRO, it will will perform an empirical finetuning of the possible imperfect coalignment, based on limb edge detection and correlation of photospheric features. The routine shifts the second image in x-direction and in y-direction and determined the optimum coalignment from the minimum difference at sharp edges at the limb (in N, S, E, and W direction). Then it will rotate the solar disk for a range of roll angles and determine the best relative roll angle from the minimum difference of the images. Each shift is repeated 3 times and the mean and standard deviation of x-offsets, y-offsets, and roll angle is calculated and displayed on the screen and returned in the variables DX, DY, and ROLL in units of pixels and degrees. The better coaligned images are stored in the array COALIGNED_PAIR(2, NX, NY). The algorithm works satisfactorily if the input images are already coaligned within the ranges of the shifts (10 pixels) and roll angles (ROLL_MAX).

Run the steps in tutorial (2a) to obtain a preliminary coalined image pair in IMAGE_PAIR(2, NX, NY) and the parameters in PARA, or restore the data from the savefile.

```
IDL>
savefile='loop_A.sav'
restore,savefile ;restore saved data from step (2a)
roll_max=1.0 ;maximum roll angle range of +/-1 deg for expected roll-angle misalignment
euvi_coalign,image_pair,coaligned_pair,para,roll_max,roll,dx,dy
save,filename=savefile,image_pair,coaligned_pair,para
```

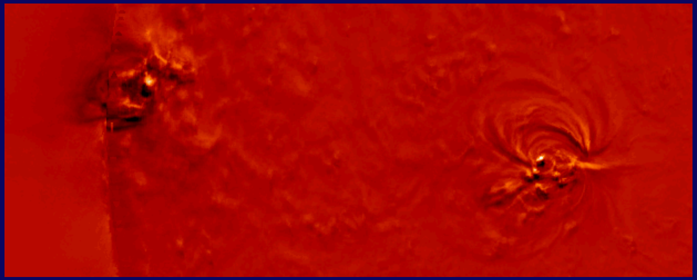
The output is in the variables DX, DY, and ROLL, which give the mean and standard deviation of the offsets. For this example we fine a x-offset of DX=-0.108+/-0.038 pixels, a y-offset of DY=0.241+/-0.199 pixels, and a roll angle offset of ROLL=0.014+/-0.050 deg, so both images are near-perfectly coaligned with subpixel accuracy. Since the coalignment correction is not significant, the pre-coaligned images in IMAGE_PAIR can be used, while the corrected images in IMAGES_COALIGNED should not be used in this case, since they contain somewhat more data noise due to the additional interpolations.

```
help,image_pair,coaligned_pair
IMAGE_PAIR INT = Array[2, 2048, 2048]
COALIGNED_PAIR INT = Array[2, 2048, 2048]
print,dx,dy,roll
DX = [ -0.107665 , 0.0383115 ]
DY = [ 0.241021 , 0.198999 ]
ROLL = [ 0.0140537 , 0.050000 ]
```

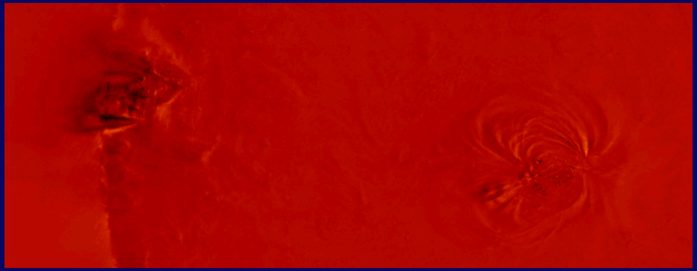


Coalignment testing of offset dx and dy by minimizing flux differences at limb.

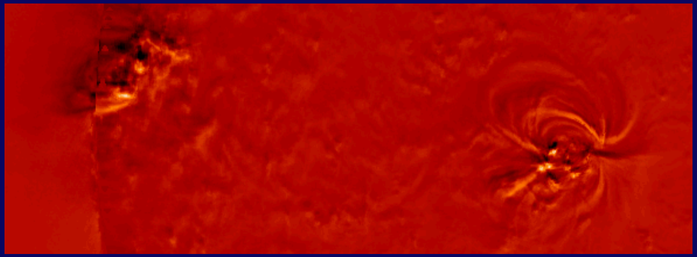
d_roll = $+1.0^0$



d_roll = $+0.0^0$



d_roll = -1.0^0



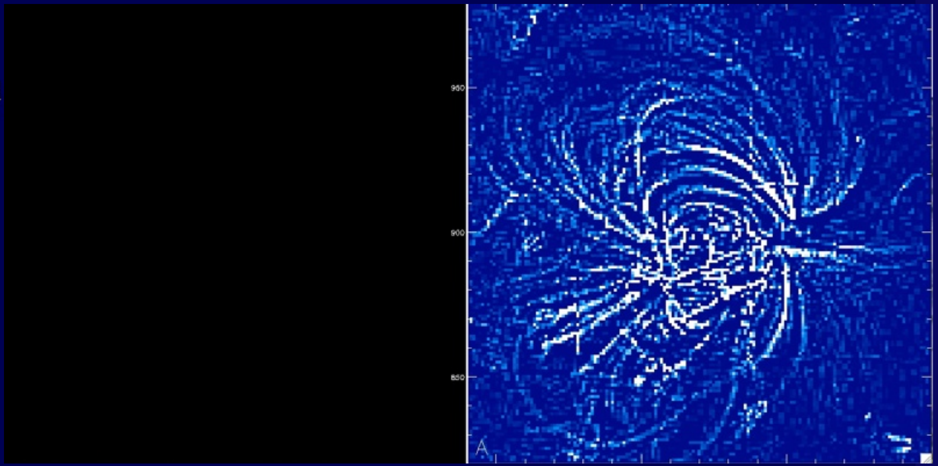
Coalignment testing of roll angle offset by minimizing flux differences in images rotated to same stereoangle by varying relative roll angle. (photospheric features disappear).

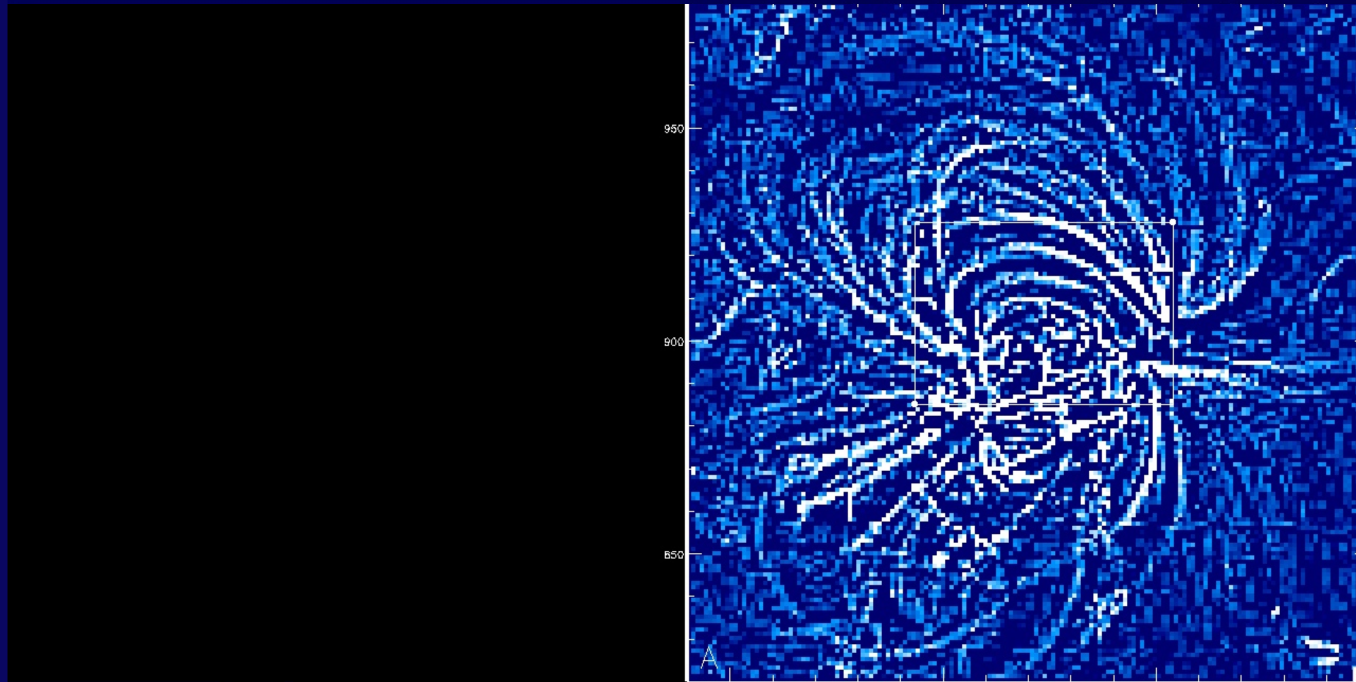
(c2) Stereoscopic 3D reconstruction of a curvi-linear feature

Now we are getting into real stereoscopy, the reconstruction of the 3D geometry of a curvi-linear feature that is visible in a pair or coaligned STEREO images. What we mean with a curvi-linear feature is a one-dimensional structure with arbitrary curvature. It does not neet to be a strictly 1D (and thus unresolved) structure in the mathematical sense, as long as a 1D structure can be uniquely localized in both images, either by an edge or by its cross-sectional centroid. In practice, such curvi-linear futures could be coronal loops or filaments, either directly detectable in the EUV images or in their highpass-filtered versions. The IDL procedure EUVI_STEREO.PRO will use a highpass-filter (defined by the variable NSM=3 [or 5, 7, ...] which defines the smoothing variable of the subtracted smoothed image) to enhance curvi-linear features. The routine then allows a manual input of some spline points of a curve in image A, performs a spline interpolation and transforms its coordinates to image B for an altitude of h=0 and hmax (e.g. = 0.1 solar radii). This visualizes the parallax effect in image B for this height range h=[0,hmax]. The actual coordinates of the loop have then also to be input in image B, usually inside the physical solution range h=[0,hmax]. From the measured offset, the 3D loop coordinates are then computed and stored in the file LOOPFILE. The procedure can be repeated for an arbitrary number of loops, and the 3D coordinates will be appended in the file LOOPFILE. Erroneous entries can also be edited out in the LOOPFILE.

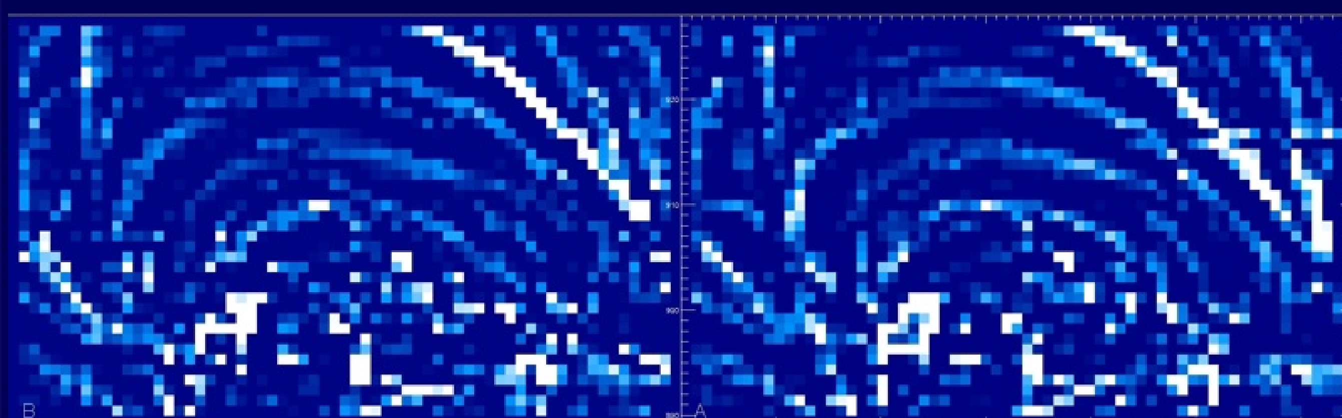
Let us assume you have already done the image coalignment (a2) and tested its accuracy (b2), so that the data in IMAGE_PAIR and PARA can be restored from the savefile.

```
IDL>
savefile='loop_A.sav'
loopfile ='loop_A.dat' ;output filename where 3D coordinates of loops are stored
nsm =3 ;nsm=3, 5, ...., smoothing boxcar for highpass filtering
fov =[640,820,800,980] ;i1,j1,i2,j2 coordinates of field-of-view
poly =2 ;poly=2, degree of polynom for fitting heights h(s)
hmax =0.1 ;e.g. hmax=0.1 or 0.5 solar radii (maximum height range)
filter =1 ;0=no filter, 1=highpass filter
window =0 ;IDL display window
ct =1 ;IDL color table
wave ='171' ;wavelength '171', '195',' 284', '304'
gamma =1. ;slope of color scale
inv =0 ;0=straight color scale, -1=invert IDL color table
restore,savefile ;restore saved data from step (2a)
euvi_stereo,image_pair,para,nsm,fov,poly,hmax,loopfile,filter,window,ct,wave,gamma,inv
```

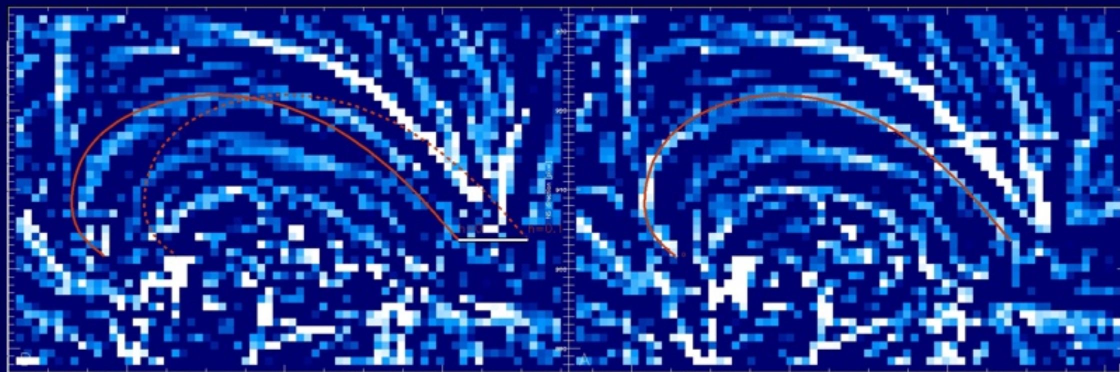




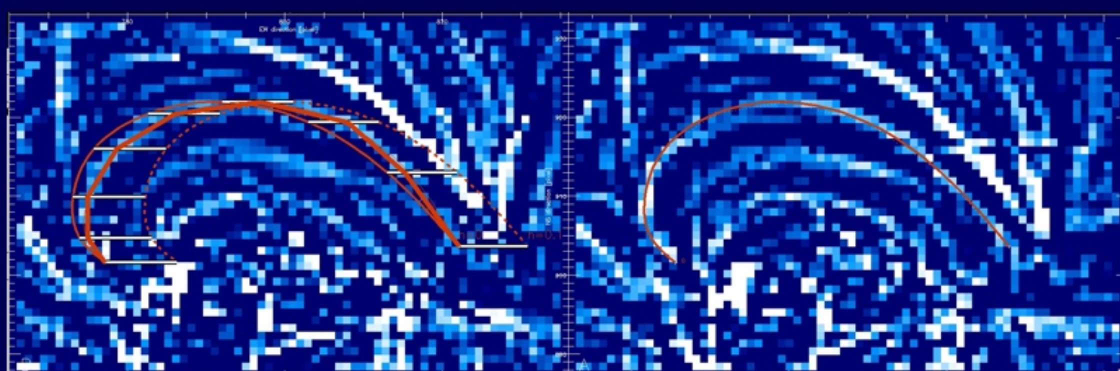
The program prompts you now to narrow down the optimum field-of-view that encompasses an individual loop for stereoscopical triangulation. Click on the bottom-left and top-right corner of the desired enlarged field-of-view.



You selected a snug area around a central loop, which is now displayed enlarged for both the spacecraft A and B image. You are now prompted to click a number of say 5-8 loop positions in image A (right). You end the sequence by clicking onto the empty field above image A.

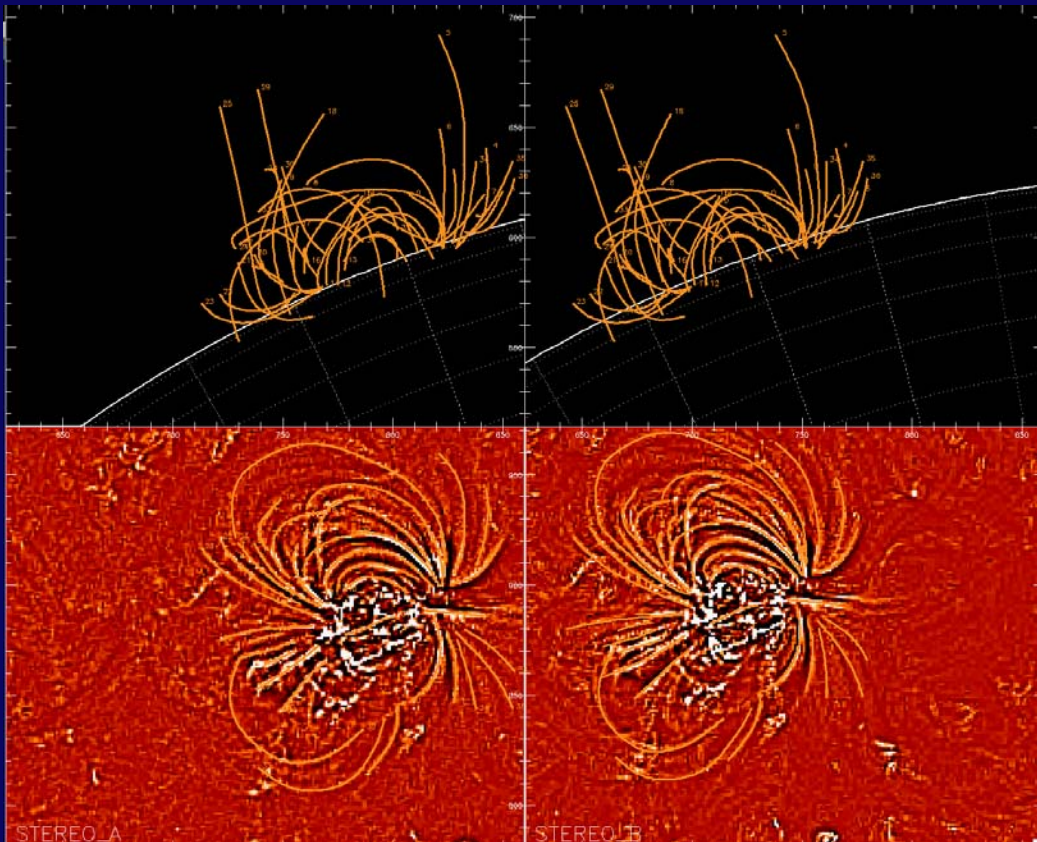


The progam switches now to image B and displays the projected coordinates of the loop (red) at a lower height of h=0 and a maximum height of h=hmax (e.g., 0.1 solar radii). The projected height range of every loop position is high-lighted with a black-white bar and you click the corresponding height position for each loop position in image B.



After finishing all points of a loop you are asked whether you want to save these loop coordinates. If you are happy you answer with yes and the spline point coordinates are stored in the file loop_A.dat, or discarded else. You can now repeat the whole procedure for every loop and should always get an updated display of the previously traced loops. You can interrupt or resume additional tracing of loops ad infinitum. If you have some stored some bad choices of loop coordinates in the file loop_A.dat, you can edit them out manually.

Output: 3D coordinates (x,y,z) of loops:



Coordinates of loop spline points:

0	739.3	897.8	561.4	-0.6	0.5	4.7	5	2	0.63	0.80	0.86
0	730.9	907.0	566.5	7.5	4.9	6.4	5	2	0.63	0.80	0.86
0	716.2	910.4	562.6	10.7	7.0	10.0	5	2	0.63	0.80	0.86
0	710.1	906.6	557.9	9.6	11.5	4.5	5	2	0.63	0.80	0.86
0	708.4	901.1	554.3	7.6	11.0	3.7	5	2	0.63	0.80	0.86
0	710.3	896.0	552.0	4.9	1.8	3.8	5	2	0.63	0.80	0.86

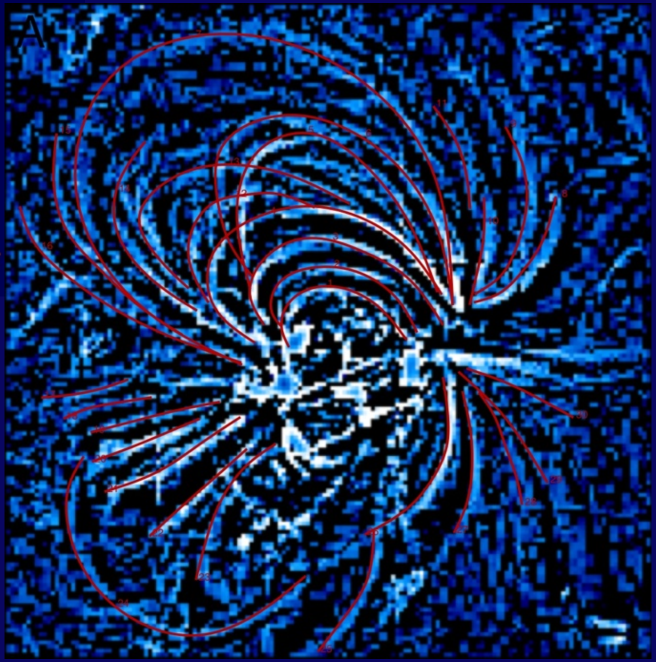
Interpolated loop coordinates:

1	1	-0.447	-0.046	0.892	0.0	0.0
1	2	-0.448	-0.044	0.893	1.3	0.3
1	3	-0.449	-0.043	0.894	2.5	1.2
1	4	-0.450	-0.042	0.895	3.8	2.1
1	5	-0.452	-0.040	0.896	5.0	2.9
1	6	-0.453	-0.039	0.897	6.3	3.8
1	7	-0.454	-0.037	0.898	7.6	4.6
1	8	-0.455	-0.036	0.898	8.8	5.4
1	9	-0.456	-0.035	0.899	10.1	6.2
1	10	-0.458	-0.034	0.900	11.3	6.9
1	11	-0.459	-0.032	0.900	12.6	7.6
1	12	-0.461	-0.031	0.900	13.8	8.2
1	13	-0.462	-0.030	0.901	15.1	8.8
1	14	-0.463	-0.029	0.901	16.3	9.3
1	15	-0.465	-0.029	0.901	17.5	9.7
1	16	-0.467	-0.028	0.900	18.8	10.1
1	17	-0.468	-0.027	0.900	20.0	10.5
1	18	-0.470	-0.027	0.900	21.2	10.8
1	19	-0.472	-0.026	0.899	22.5	11.0
1	20	-0.473	-0.026	0.899	23.7	11.2
1	21	-0.475	-0.025	0.898	24.9	11.4
1	22	-0.477	-0.025	0.897	26.2	11.5
1	23	-0.479	-0.025	0.897	27.4	11.6
1	24	-0.480	-0.025	0.896	28.6	11.6
1	25	-0.482	-0.026	0.895	29.8	11.6
1	26	-0.484	-0.026	0.894	31.0	11.6
1	27	-0.485	-0.026	0.893	32.2	11.5
1	28	-0.487	-0.027	0.892	33.4	11.4
1	29	-0.489	-0.028	0.891	34.5	11.2
1	30	-0.490	-0.029	0.889	35.7	11.0
1	31	-0.491	-0.030	0.888	36.8	10.8
1	32	-0.492	-0.031	0.887	38.0	10.5
1	33	-0.494	-0.032	0.886	39.1	10.3
1	34	-0.494	-0.033	0.885	40.2	9.9
1	35	-0.495	-0.035	0.884	41.3	9.6
1	36	-0.496	-0.036	0.883	42.4	9.2
1	37	-0.496	-0.038	0.882	43.5	8.8
1	38	-0.496	-0.039	0.881	44.6	8.4
1	39	-0.496	-0.041	0.880	45.6	8.0
1	40	-0.496	-0.042	0.880	46.8	7.5
1	41	-0.496	-0.044	0.879	48.0	6.9
1	42	-0.495	-0.046	0.878	49.2	6.3
1	43	-0.494	-0.047	0.878	50.5	5.7
1	44	-0.493	-0.049	0.877	51.7	5.1

(d2) Overlay of 3D Coordinates on Image or Contourplot

After you have done the stereoscopic height measurements of a set of curvilinear features (e.g., loops or filaments) you want to generate an overlay plot of the 3D coordinates on the image. Let us suppose you have stored the coaligned images in the array IMAGE_PAIR(2, NX, NY) in a savefile="loop_A.sav" (see tutorial a2) and the 3D coordinates in the output loopfile="loop_A.dat", you can generate an overlay greyscale/color plot with the following commands (for spacecraft A):

```
IDL>
savefile='loop_A.sav'
restore,savefile ;restore saved data from step (2a)
nsm =3 ;nsm=3, 5, ..., smoothing boxcar for highpass filtering
fov =[640,820,800,980] ;i1,j1,i2,j2 coordinates of field-of-view
hmax =0.1 ;e.g. hmax=0.1 or 0.5 solar radii (maximum height range)
loopfile ='loop_A.dat' ;output filename where 3D coordinates of loops are stored
filter =1 ;0=highpass filter, -1=no filter, linear scale, -2=no filter, logarithmic scale
window =0 ;IDL display window
ct =1 ;IDL color table
sc ='a' ;spacecraft 'a' or 'b'
cont =0 ;0=greyscale plot, 1=contour plot
gamma =0.2 ;slope of color table
inv =0. ;no inversion of color table
euvi_contour,image_pair,para,nsm,fov,hmax,loopfile,filter,window,sc,cont,dcont,ct,gamma,inv
```



If you want a contourplot change to cont=1 and input contour levels (dcont)::

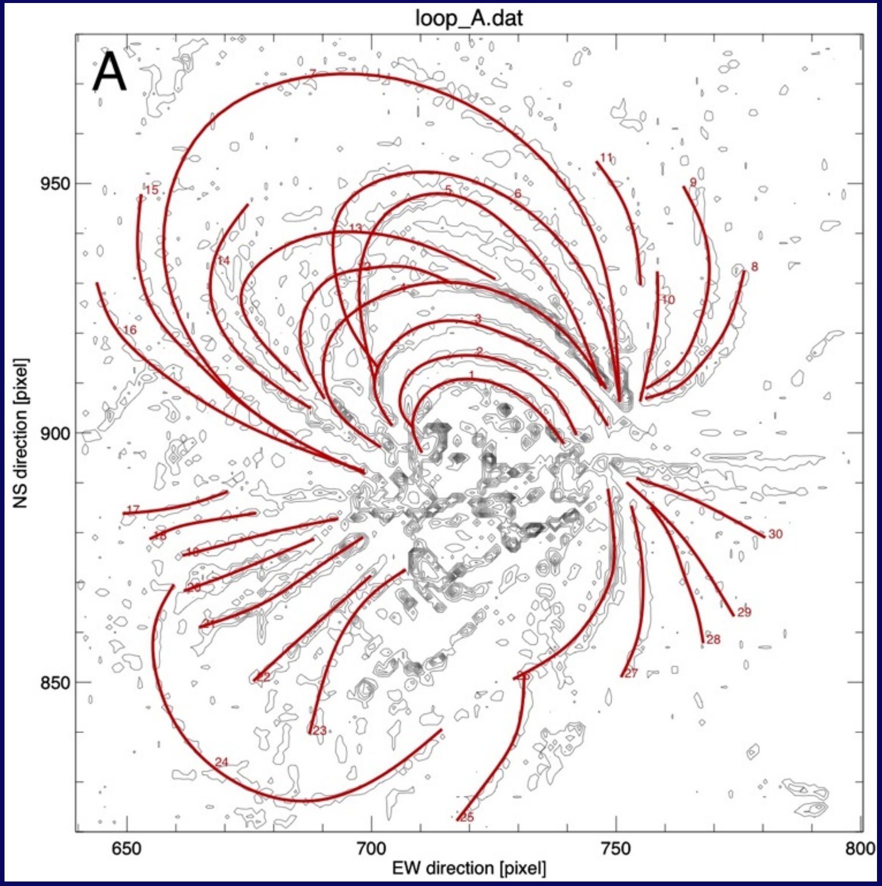
cont =1 ;0=greyscale plot, 1=contour plot

dcont =100. ;lowest (positive) contour level

gamma =1 ;slope of contour levels

euvi_contour,image_pair,para,nsm,fov,hmax,loopfile,filter,window,sc,cont,dcont,ct,gamma,inv

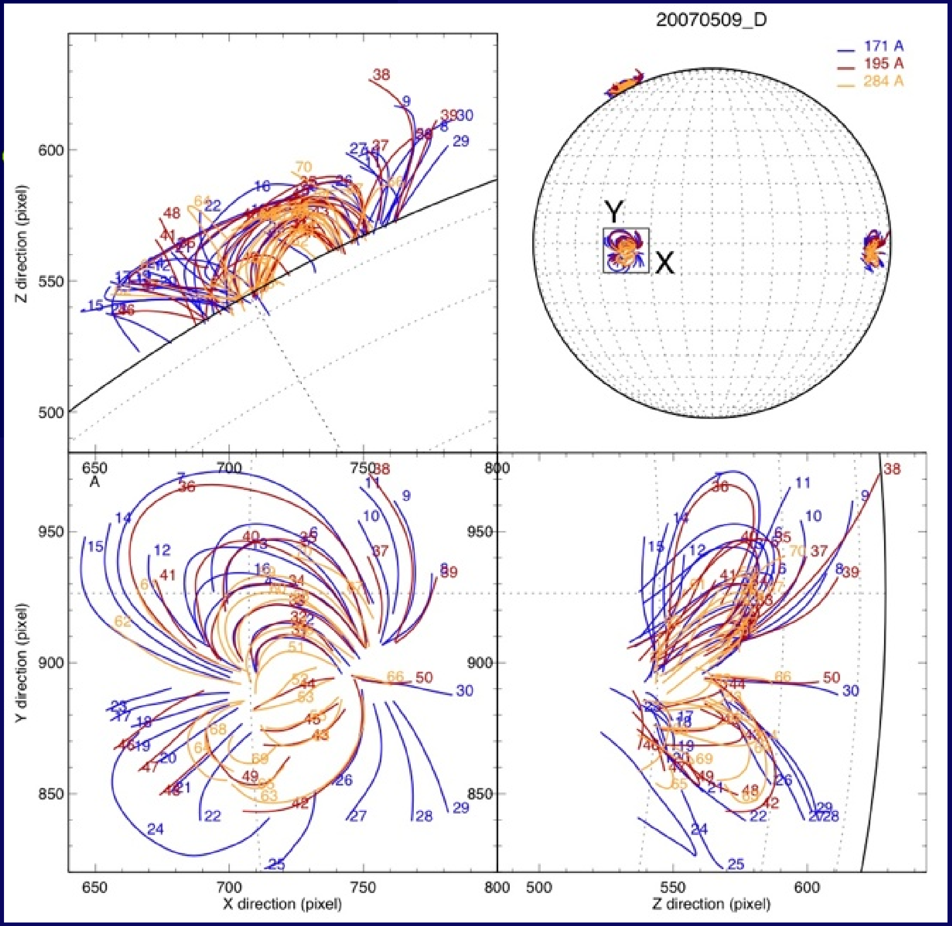
A postscript file of the plot is also generated with the name cont_col.ps



(e2) Cartesian Projection of 3D Coordinates of Curvi-Linear Features

After you have done the stereoscopic height measurements of a set of curvilinear features (e.g., loops or filaments) you may want to visualize the 3D coordinates [x,y,z] of a set of loops in the three orthogonal projections, so in the [x,y], [y,z], and [z,x] planes. Let us suppose you have stored the coaligned images in the array IMAGE_PAIR(2, NX, NY) in a savefile="loop_A.sav" (see tutorial a2) and the 3D coordinates in the output loopfile="070509_D_trace.dat", you can generate a plot with the 3 orthogonal projections with the following commands:

```
IDL>
savefile='loop_A.sav'
loopfile ='070509_D_trace.dat' ;output filename where 3D coordinates
fov =[640,820,800,980] ;i1,j1,i2,j2 coordinates of field-of-view
ct =5 ;IDL color scale
hmax =0.1 ;e.g., hmax=0.1 solar radii (maximum height)
win =0 ;e.g., IDL window nr
restore,savefile ;restore saved data from step (2a)
euvi_projection3,fov,loopfile,para,ct,hmax,win
```

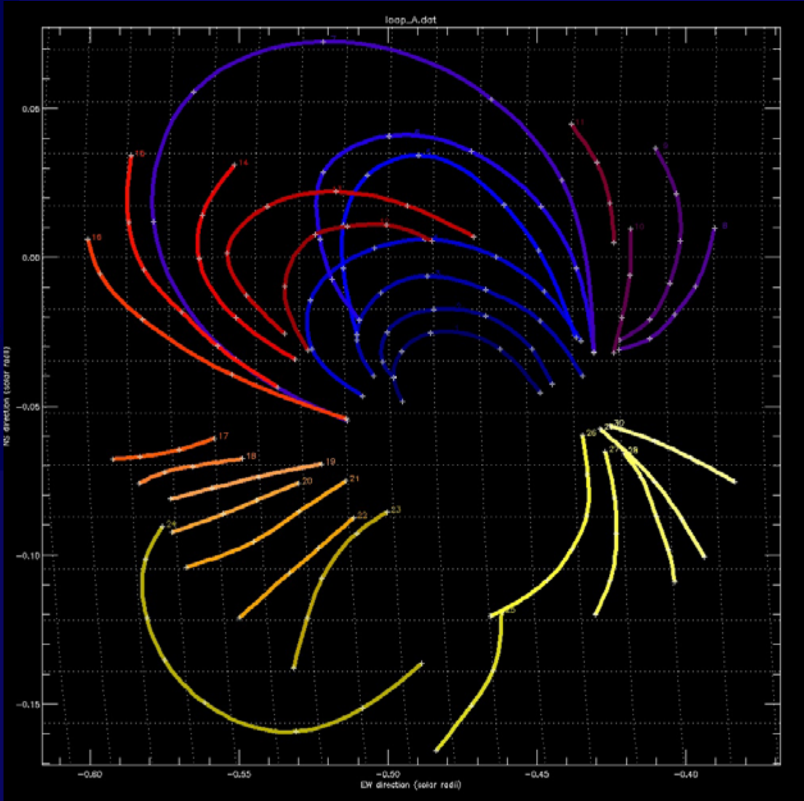


(f2) Projection of 3D Coordinates in Arbitrary Direction

Now we want to project the previously obtained 3D coordinates of a set of curvilinear features (e.g., loops or filaments) into an arbitrary direction. Let us suppose you have saved the 3D coordinates in the output file "loop_A.dat", and the images and its parameters are saved in the savefile "loop_A.sav" (as described in task c2). First we want to show it in the projection along the line-of-sight as observed from spacecraft A, which is the reference direction. It has the Sun center position at a relative heliographic longitude BLONG=0, a relative heliographic latitude BLAT=0., and rotation angle CROTA2=0.

```
IDL>
loopfile ='loop_A.dat' ;output filename where 3D coordinates of loops are stored
savefile='loop_A.sav'
restore,savefile ;restore saved data from step (2a)
crota2 =0. ;rotation angle relative to STEREO-A image (in direction of solar position angle)
blong =0. ;longitude difference relative to STEREO-A image
blat =0. ;latitude difference relative to STEREO-A image
dlat =1. ;spacing of coordinate grid (e.g. 1 deg)
ct =5 ;IDL color scale
h_error =1 ;0=default, 1=with error bars of altitude
hmax =0.1 ;e.g., hmax=0.1 solar radii (maximum height)
window =0 ;IDL window
plotname ='loop_A_proj1' ;plot filename
nops =0 ;produces postscript file (nops=0) or not (nops=-1)
euvi_projection,loopfile,para,crota2,blong,blat,dlat,ct,h_error,hmax,window,plotname,nops
```

The output on the screen will look like the following. The color varies with the loop numeration.



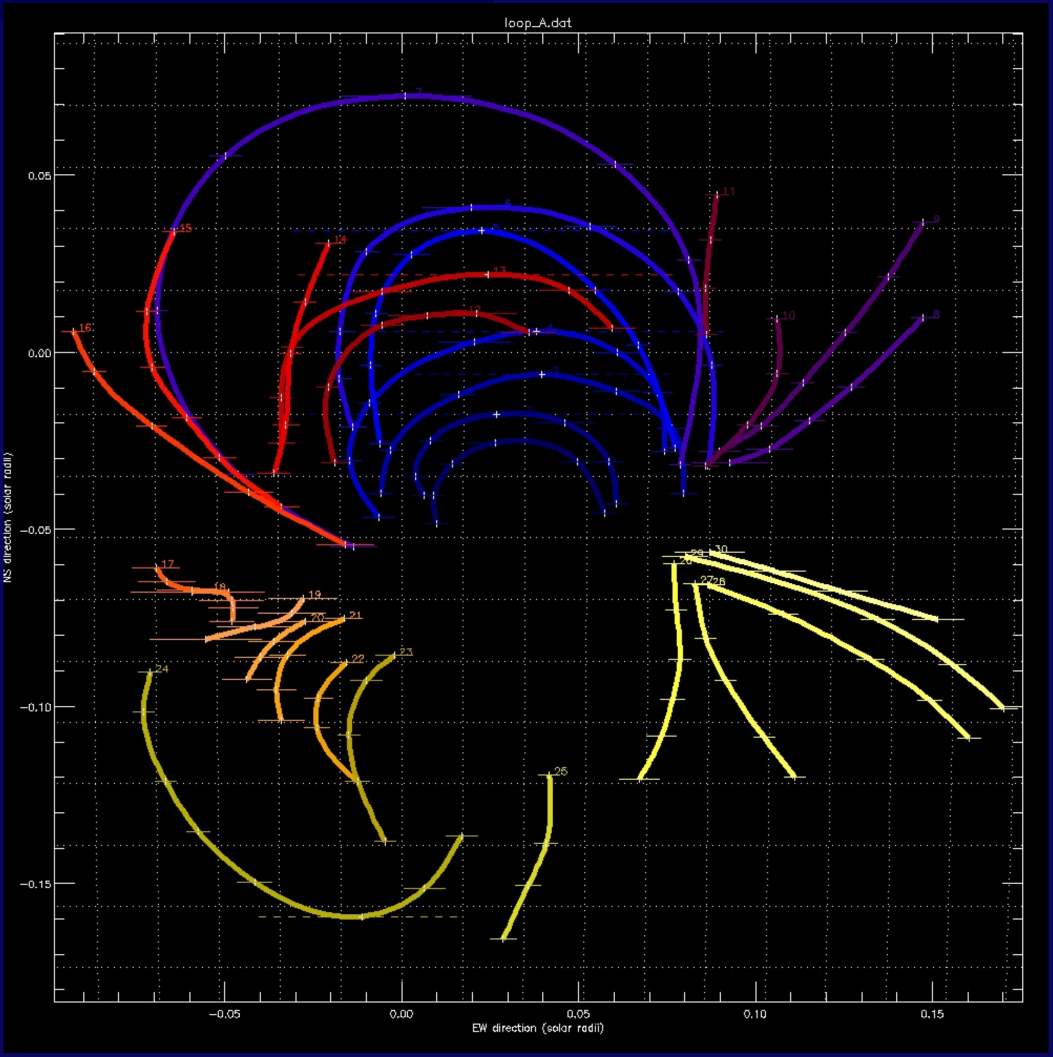
The center of the active region is about 30 deg east of Sun center. So if you want to look straight down in vertical direction, we rotate the 3D coordinates to BLONG=-30:

blong =-30. ;longitude difference relative to STEREO-A image

plotname ='loop_A_proj2' ;plot filename

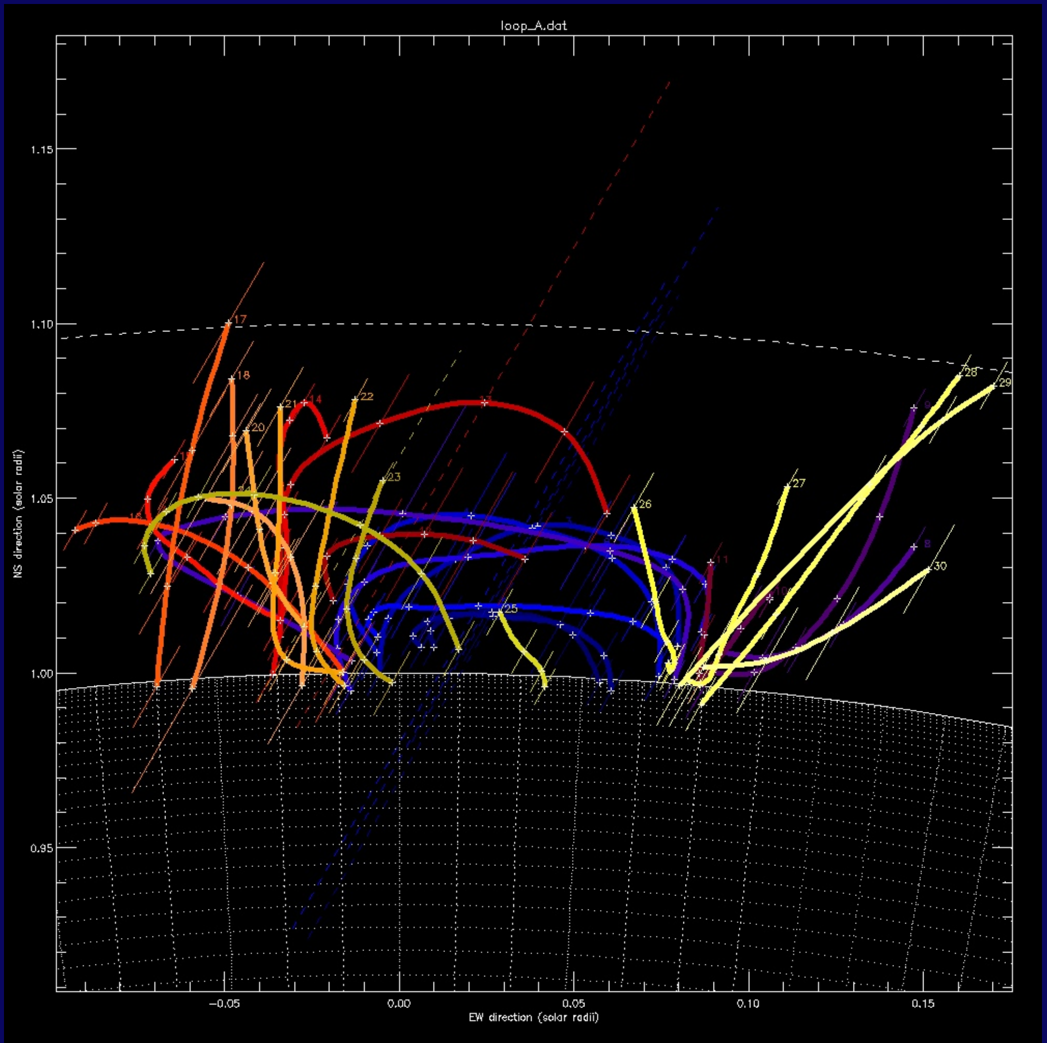
euvi_projection,loopfile,para,crota2,blong,blat,dlat,ct,h_error,hmax

You will find also a postscript file = projection_a_col.ps created.



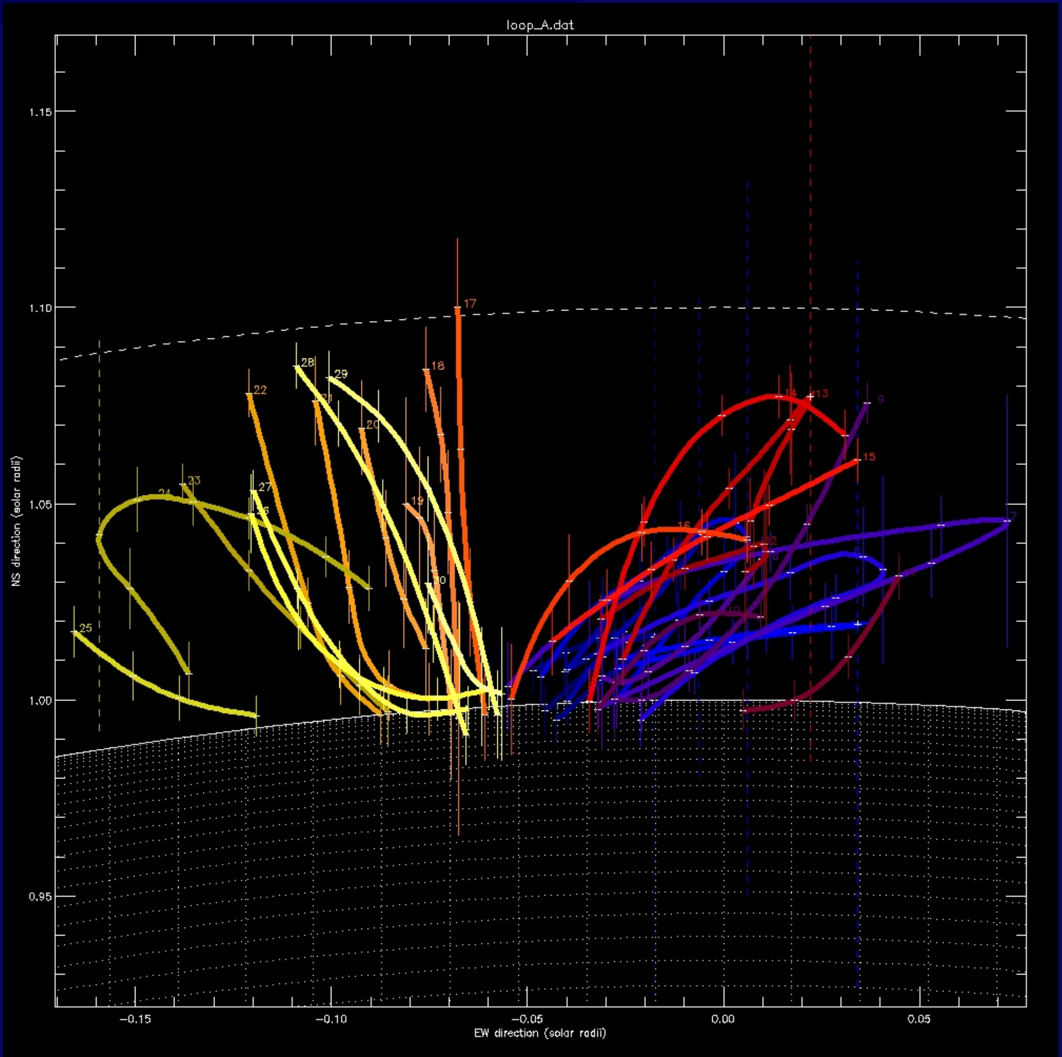
Now we would like to visualize the active region side-on, say looking from a southern viewpoint in northern direction, so that the loops appear above the northern horizon. So we keep the (relative) heliographic longitude BLONG=-30 deg as in the previous image, but rotate the line-of-sight by BLAT=90 deg to the northern position:

```
blong =-30. ;longitude difference relative to STEREO-A image
blat =90. ;latitude difference relative to STEREO-A image
plotname ='loop_A_proj3' ;plot filename
euvi_projection,loopfile,para,crota2,blong,blat,dlat,ct,h_error,hmax
```



As a last view we want to visualize the inclination angles of the loop plane, so we rotate the active region to the East limb by BLONG=+60 deg, and rotate it by a position angle CROTA2=90 to that the horizon looks horizontally.

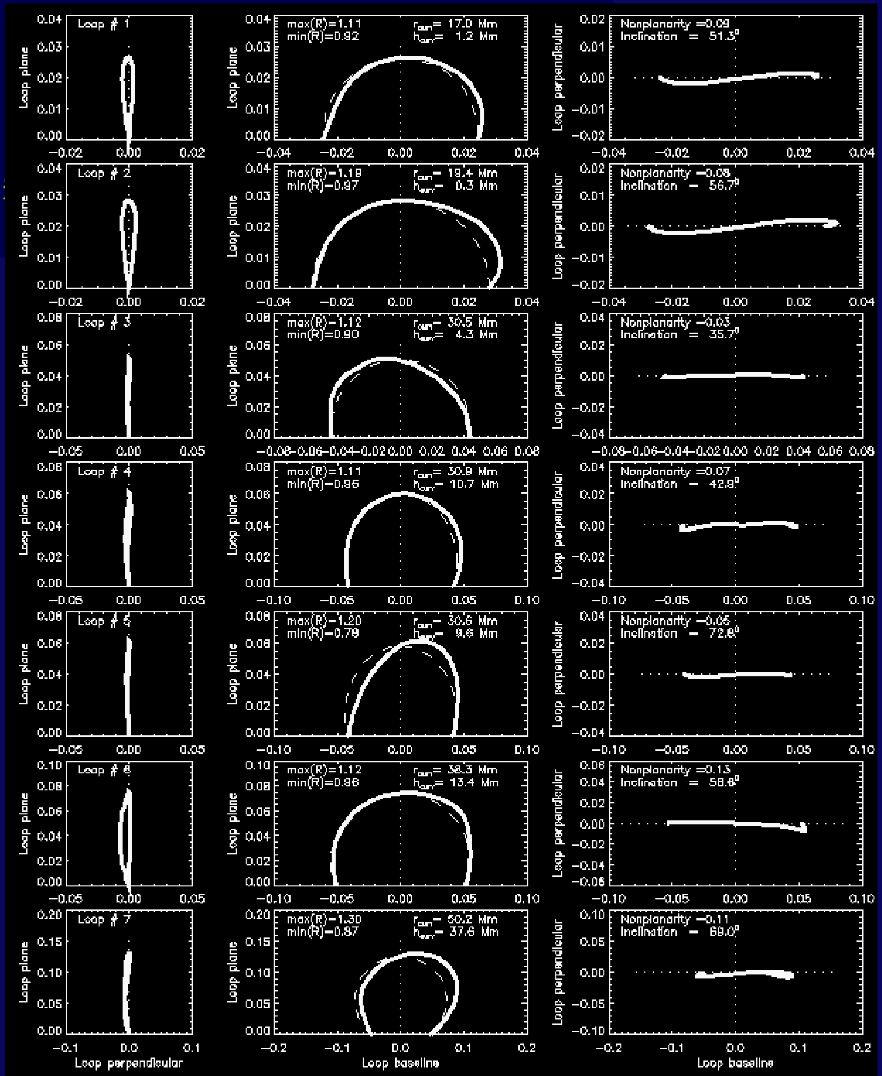
```
blong =+60. ;longitude difference relative to STEREO-A image
blat =0. ;latitude difference relative to STEREO-A image
crota2 =-90. ;relative rotation angle (positive is in anticlock wise direction)
plotname ='loop_A_proj4' ;plot filename
euvi_projection,loopfile,para,crota2,blong,blat,dlat,ct,h_error,hmax
```



(g2) Orthogonal Projections in the Loop-Plane Coordinate System

Sometimes it is useful to study the projections of the 3D coordinates of loops in a cartesian system that is aligned with the loop plane. If the loops are not coplanar, the loop plane has to be defined by 3 points, for which we choose the first and last spline point of the loop (supposedly the footpoints), which define the baseline direction. The loop plane is defined in addition by a 3rd point, for which we choose the loop apex position above the midpoint of the baseline. We need the 3D coordinates from the loop datafile (LOOPFILE) and the image parameters (PARA) from the savefile (SAVEFILE). Let us assume we have the 3D coordinates of 30 loops in the datafile, but select only the first 7 complete loops (LOOPNR=[1,7]):

```
IDL>
loopfile ='loop_A.dat' ;output filename where 3D coordinates of loops are stored
savefile='loop_A.sav'
restore,savefile ;restore saved data from step (2a)
loopnr =[1,7] ;range of loop numbers (loop number 1 corresponds to IDL index 0 :
euvi_orthogonal,loopfile,loopnr,para
```

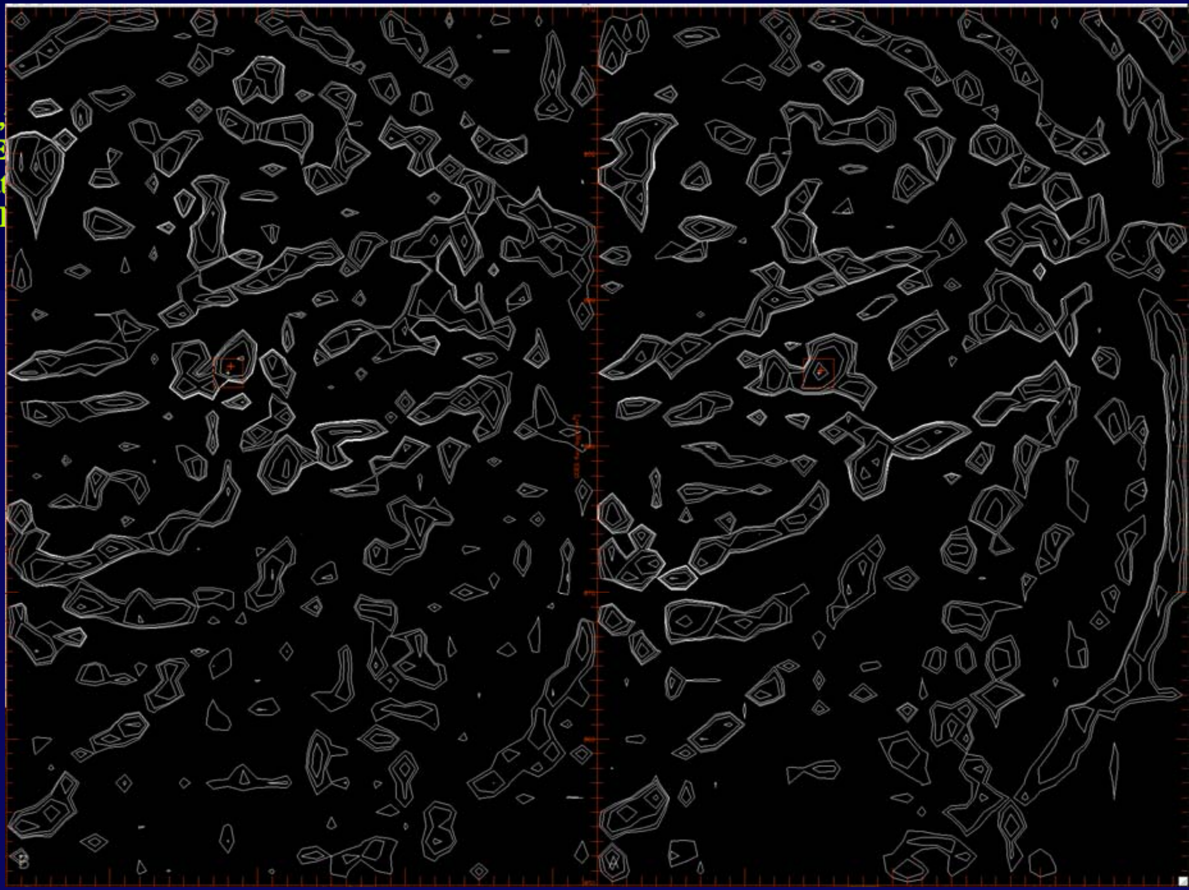


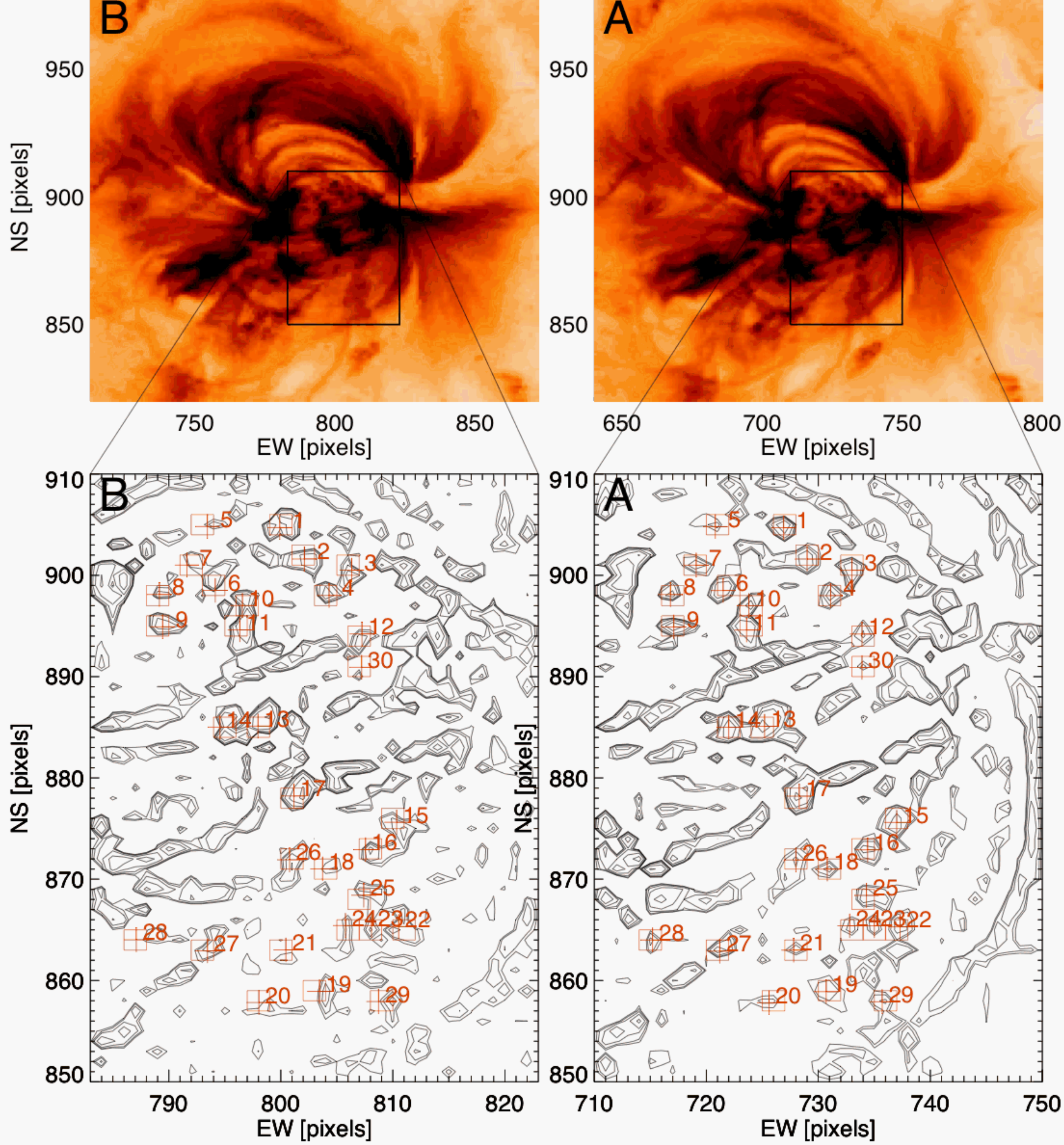
(h2) Stereoscopic Height Measurement of Point-like Features

For point-like features (for instance ``moss'' or small-scale loops of the size of one or a few pixels) that are visible in both the STEREO A and B images), the height can be measured from the stereoscopic parallax. The routine EUVI_CORR.PRO allows the user to click on such a structure in image A and B, and then calculates the stereoscopic height from the centroid determined in a 3x3 pixel neighborhood of the points.

Let us assume the user has produced a coaligned pair of stereoscopic images in array IMAGE_PAIR[2, NX, NY] and the image parameters are in the variable PARA, both stored in the savefile 'loop_A.sav'. We will store the 3D coordinates of the moss feature in the file 'moss_A.dat':

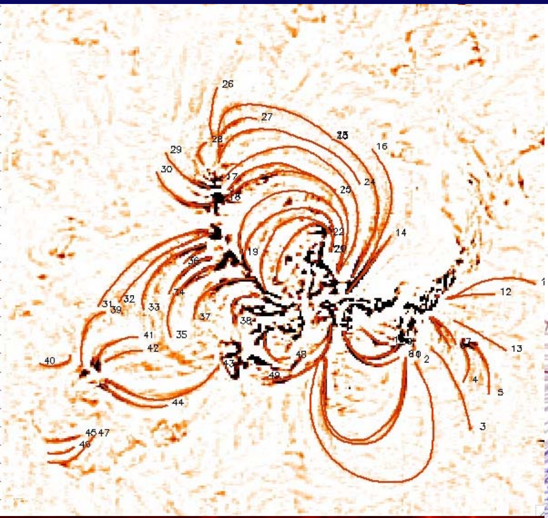
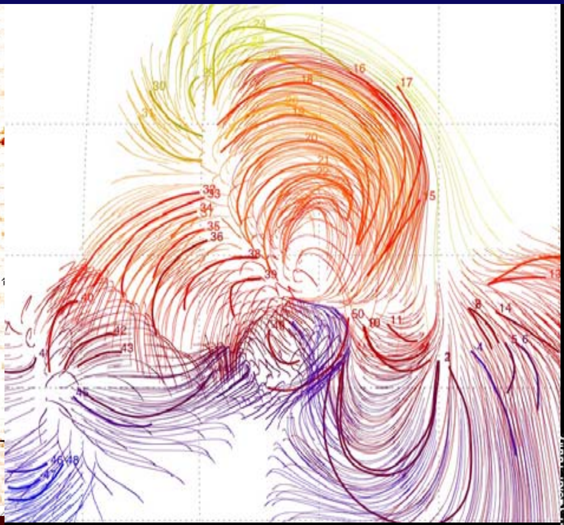
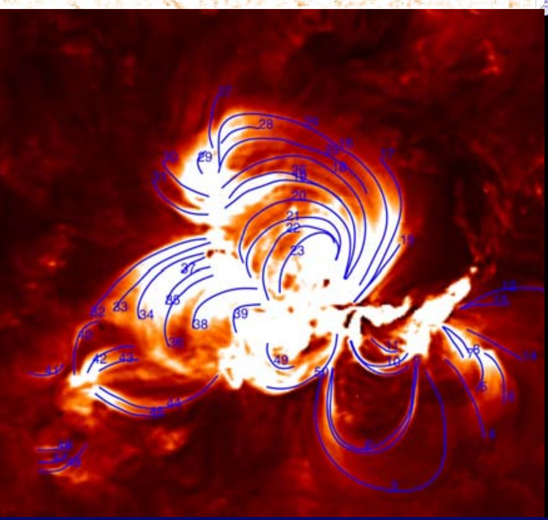
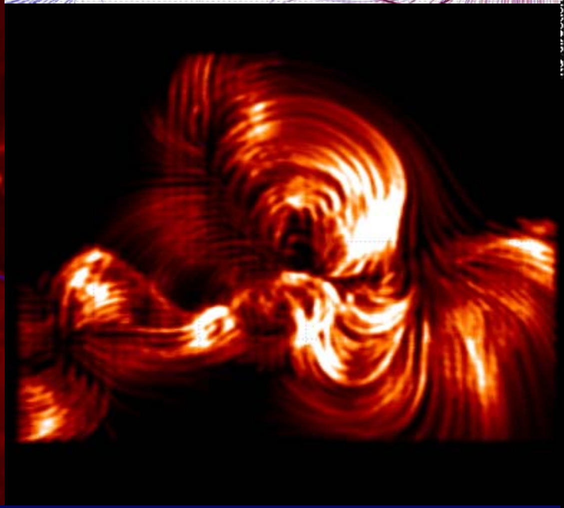
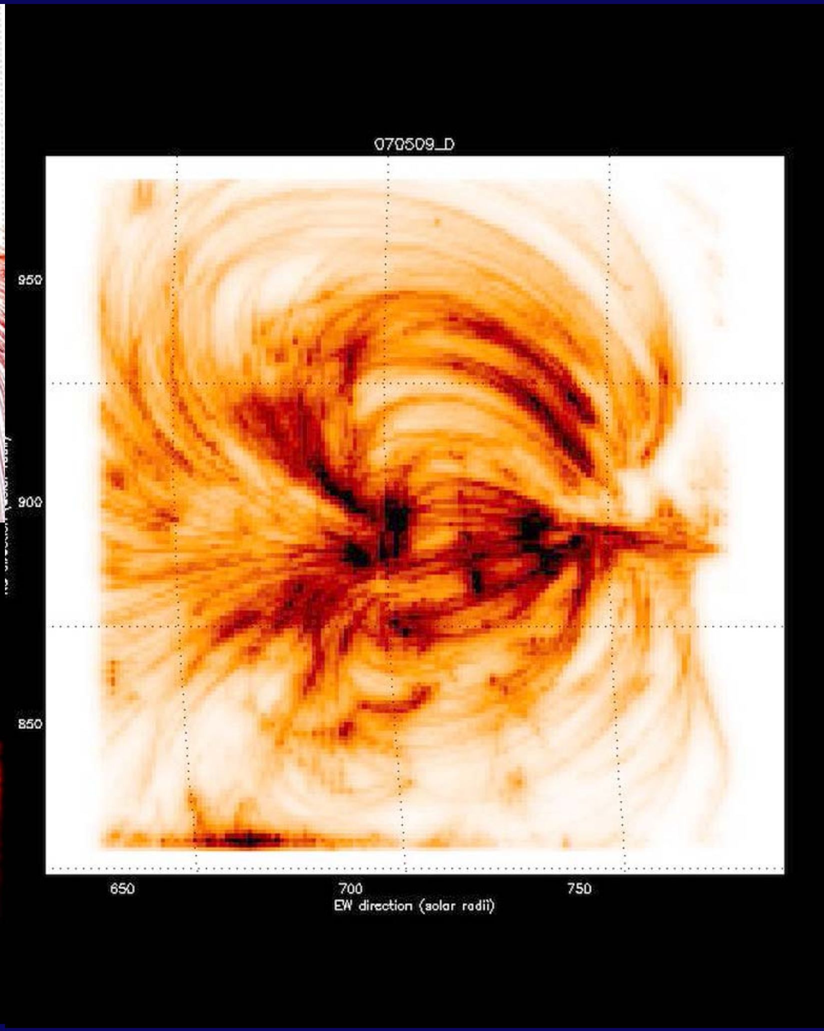
```
IDL>
savefile='loop_A.sav'
restore,savefile ;restore saved data from step (2a)
nsm =3 ;smoothing boxcar for highpass filter
fov_moss=[710,850,750,910] ;field-of-view in pixels [i1,j1,
dcont =5 ;contour level step for logarithmic contours LEVE
mossfile='moss_A.dat' ;output filename where 3D coordinat
ct =3 ;contour level step for logarithmic contours LEVEL=
euvi_corr,image_pair,para,nsm,fov_moss,dcont,mossfile,ct
```





B
A
950
900
850
NS [pixels]
750
800
850
650
700
750
800
EW [pixels]
910
890
880
870
860
790
810
820
710
720
730
740

More EUVI software to come …

CONCLUSIONS:

1) EUVI data analysis tools are online in SSW (package stereo) and available to community.

2) Tutorials how to use EUVI data analysis tools are online on webpage http://secchi.lmsal.com/EUVI/index_soft.html

3) An example of a full analysis using these EUVI tools is documented in publication:

   - Aschwanden,M.J., Wuelser,J.P., Nitta,N., and Lemen,J. 2008, The Astrophysical Journal, URL1="http://www.lmsal.com/~aschwand/eprints/2008_stereo.pdf" First 3D reconstruction of coronal loops with the STEREO A+B spacecraft: I. Geometry

4) Usage of EUVI data analysis tools is encouraged and feedback and bug reports are most welcome.