Hi-C 4K Data Level 0.5 Development

1. Purpose

To provide a properly-oriented raw level dataset with correct FITS header information.

Action Summary

- Transpose image
- Subtract 92 seconds from sounding rocket time stamp
- Determine correct pointing with respect to sun center using AIA data
- Determine correct roll angle with respect to sun center using AIA data
- Update other FITS header keywords to be more informative

Updates to version 3 Level 0.5 development

- The time stamp was originally corrected based on the .idx time stamp. This was determined to be an incorrect time stamp, and should have instead been read from the original FITS headers. This was corrected in versions 2 and 3 of the Hi-C data.

- Two center rows were found to be missing from the output of the CCD. Version 3 of the data has this issue corrected. The center coordinates had to be adjusted based on this fix, as well as the time stamp adjustment   since a different Hi-C reference image had to be used.

- Fine alignment shifts were applied.

2. Setup

The Level 0 Hi-C files have been down-selected to only include file numbers 25 - 61. Frames 21, 22, and 23 are not useful to the community at large due to re-pointing and focus. In addition, they were not used by Craig DeForest in determining Hi-C co-alignment offsets. *Note that there is not a frame labeled 24 nor 51.

In order to run the programs listed within this document, you will need to include all of Hi-C IDL programs under your IDL tree. In other words, you will need to perform an ssw_upgrade and include "HIC" as an instrument variable in your particular shell login script (or use ssw_instr).

** Testing statements throughout the document refer to the files and directory structure made available through the MSFC Sol1 Hi-C directory. **

3. Gathering Appropriate Reference Data

a) Alignment Reference File Time Options

The Hi-C file to sort out alignment was chosen based on a common reference times between AIA and XRT to allow for redundancy checks. XRT has the smallest data set out of the three instruments; therefore, it is used as the time constraint. The first XRT image for the rocket flight was taken at:

XRT   Ti-poly   18:53:32.653 UT.

The closest temporal Hi-C image (after correcting the FITS header time stamp by -92 seconds) was taken at:

Hi-C   193   18:53:33.270 UT.

The closest temporal AIA images for four wavelengths are:

AIA   193   18:53:31 UT
       131   18:53:33 UT
        94   18:53:38 UT
       171   18:53:36 UT.

b) Reference Files

The Hi-C reference frame is labeled number 40 in the Level 0 file name set (HiC00040.fit and hic00040.idx).

The AIA reference files are downloaded as Level 1 FITS. These files are flat-fielded, but **not** calibrated or co-aligned.

Testing

>> Level0.5_Development/**1_Alignment_Setup**/

```
Hi-C
     HiC00040.fit
     hic00040.idx

AIA
     aia.lev1.193A_2012-07-11T18-53-31.84Z.image_lev1.fits
     aia.lev1.131A_2012-07-11T18-53-33.62Z.image_lev1.fits
     aia.lev1.94A_2012-07-11T18-53-38.12Z.image_lev1.fits
     aia.lev1.171A_2012-07-11T18-53-36.34Z.image_lev1.fits
```

c) Preparing the Data

Initial actions on the Hi-C reference frame are to transpose and correct the time stamp by -92 seconds to 18:53:33.270 UT.

For the AIA files, run aia_prep. This serves to shift the image sun centers to [0,0] in the images and unrolls the data to 0 degrees.

Turn into maps.

Testing

>> Level0.5_Development/**1_Alignment_Setup**/

Hi-C

Cursory preparation of the Hi-C reference frame to make it usable:

```
IDL>  hic_level05, 'HiC00040.fit', 'hic00040.idx'
IDL>  mreadfits, 'HiC_L0.5_18.53.33.27.fit', hindex, hdata
```

   *** Note that this is not a proper Level 0.5 file. ***

```
IDL>  index2map_ss, hindex, hdata, hic_map40
```

AIA

```
IDL>  files = file_search('aia*.fits')
IDL>  aia_prep, files, -1, aindex, adata
IDL>  index2map_ss, aindex, adata, aia_maps
```

```
-aia_maps131 = aia_maps[0]
-aia_maps171 = aia_maps[1]
-aia_maps193 = aia_maps[2]
- aia_maps94 = aia_maps[3]
```
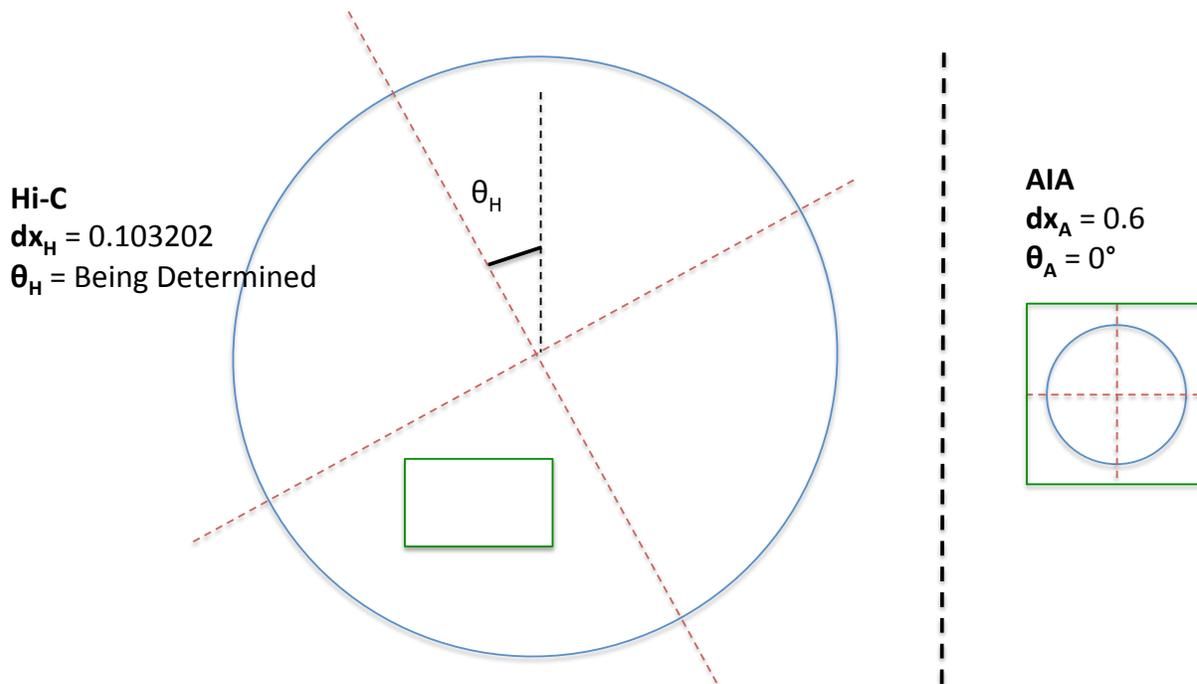
*The prepped AIA maps have been saved as Level0.5_Development/ 1_Alignment_Setup/**aia_maps.sav**.*

4) Co-align Hi-C and AIA 193 Reference Files

a) Initial Setup

The Hi-C images are an extracted region of unknown pointing rolled by an unknown number of degrees (θ_H). The Hi-C resolution is dx_H = 0.103202 arcsec/pix.

The prepped full Sun AIA images have a roll angle of $\theta_A = 0°$ and a resolution of 0.6 arcsec/pix.

Hi-C
dx_H = 0.103202
θ_H = Being Determined

θ_H

AIA
dx_A = 0.6
θ_A = 0°

*Extraction areas not necessarily drawn to scale or in exact relative position.

Testing

Due to similarity in wavelength with Hi-C, focus on AIA 193.
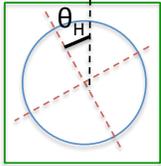
>> Level0.5_Development/**2_Alignment**/

```
IDL>  restore, 'hic_map40.sav', /v
IDL>  restore, 'aia_maps.sav', /v
IDL>  aia_map193 = aia_maps[2]
```
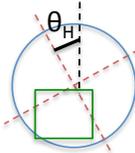
b) Extract Hi-C Region from AIA

In order to make proper comparisons between the Hi-C and AIA data, the AIA data needs to be re-gridded to have Hi-C resolution, which would make the AIA image size unmanageable. Therefore, a sub-region of the AIA is used for this process. The following process was iterated until the proper Hi-C roll angle (θ_H) and field of view were determined:

1. Rotate full-Sun AIA by θ_H.
2. Extract a sub-region larger than the Hi-C field of view (aia_ext1_small).
3. Re-grid this AIA sub-region to have the same resolution as Hi-C.
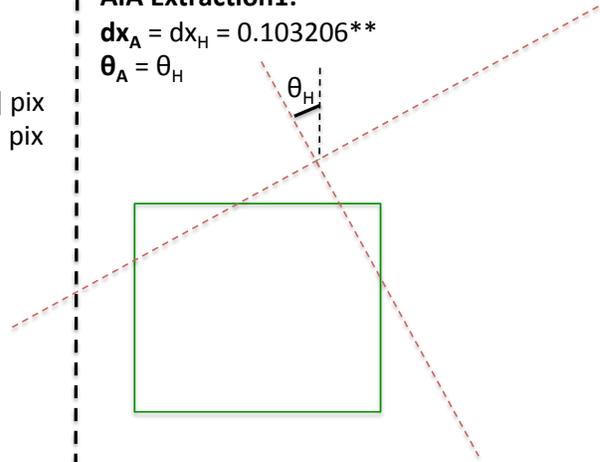4. Extract the Hi-C region from AIA (aia_ext2)

[ROT_MAP_SS]**
AIA
dx_A = 0.6
$\theta_A = \theta_H$ (Varying
      until correct)

[SUB_MAP_SS]**
AIA Extraction1:
dx_A = 0.6
$\theta_A = \theta_H$
xrange1 = [1360, 2300] pix
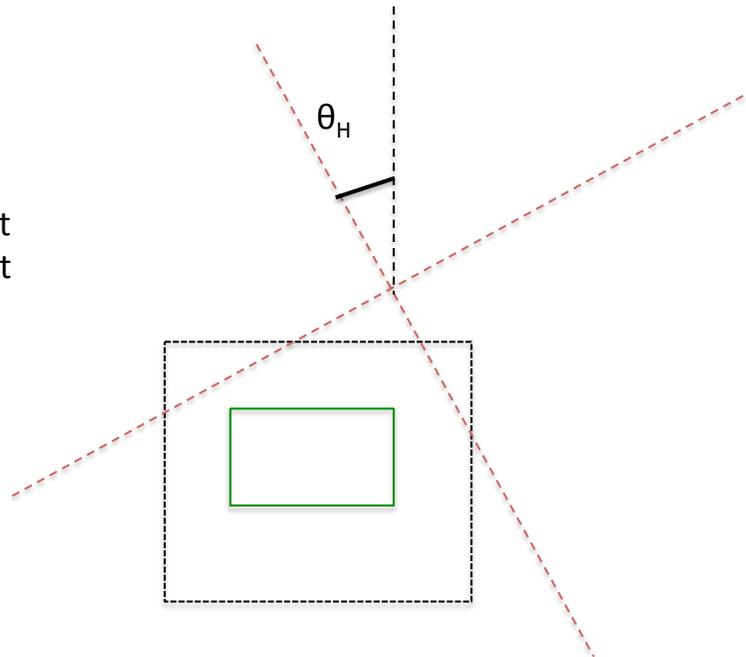**yrange1** = [880, 1680] pix

[GRID_MAP_SS]**
AIA Extraction1:
$dx_A = dx_H = 0.103206$**
$\theta_A = \theta_H$

*Extraction areas not necessarily drawn to scale or in exact relative position.
**This ends up being 'rounded' to 0.103199 with grid_map... no effect on overall results.

[SUB_MAP_SS]**
AIA Extraction2:
$dx_A = dx_H = 0.103202$
$\theta_A = \theta_H$
xrange2 = varied until correct
yrange2 = varied until correct
image size = [4096, 4096]

*Extraction areas not necessarily drawn to scale or in exact relative position.

<u>Testing</u>

>> Level0.5_Development/**2_Alignment**/

```
IDL>  raia_map193 = rot_map_ss(aia_map193, hroll)
```

*** Answer from iterating: hroll = -1.81969° ***

```
IDL>  xrange1 = [1360, 2300] & yrange1 = [880, 1680]
IDL>  sub_map_ss, raia_map193, aia_ext1_small, xrange=xrange1,
yrange=yrange1, /pix
```

*Result saved as Level0.5_Development/2_Alignment/**aia_ext1_small.sav**.*

```
IDL>  data_info, /nodata, /quiet, aia_ext1_small, info=info
IDL>  sx = info.sx & sy = info.sy

IDL>  dxA = 0.6 & dxH = 0.103206
IDL>  aia_ext1 = grid_map(aia_ext1_small, sx*dxA/dxH, sy*dxA/dxH)
```

*Result saved as Level0.5_Development/2_Alignment/**aia_ext1.sav**.*

```
IDL>  sub_map_ss, aia_ext1, aia_ext2, xrange=xrange2, yrange2=yrange2,
/pix
```

*** Answer from iterating: xrange2 = [366, 4461]
                             yrange2 = [157, 4254]
***

*Result saved as Level0.5_Development/2_Alignment/**aia_ext2v3.sav**.*

```
IDL>  my_window, hic_map40, /over, gam=.4, res=.25, w=0
IDL>  my_window, aia_ext2, /over, gam=.4, res=.25, w=2
IDL>  blink, [0,2]
```

*** Blinking windows should now be lined up. ***

5) Alignment Results

The Hi-C parameters are set to those of the known values for the aligned, extracted AIA field of view determined from Section 4 above (aia_ext2). The results are:

- θ_H = -1.81969°
        ** This is the roll angle listed for the very first Hi-C 4k image (frame 21, unused in this set). **
- **xc** = -163.678 [arcsec from sun-center]
- **yc** = -473.090 [arcsec from sun-center]
- **rsun** = 943.321 [arcsec]

** This may be off by 4 arcsec for all AIA images; non-critical. **
- **roll_center** = [0,0]
- **image size** = [4096, 4096]

6) Hi-C Co-Alignment

a) Initial offsets

In order to determine the proper pointing information for all of the other Hi-C frames, their relative offsets must be incorporated. Craig DeForest used a cross-correlation algorithm to determine these offsets for two portions of the data: prior to & following the rocket re-pointing between frames originally labeled 50 and 52 (frame 51 does not exist.) The offsets provided are in pixel units and were not applied to the frames originally labeled 21, 22, or 23; those frames have already been omitted from the final set.

Testing

>> Level0.5_Development/**2_Alignment/**

```
IDL>  restore, 'offsets4k.sav', /v
```

- offsets4k -> {file_num, offx, offy}

** The variable file_num ranges from 25 - 61 (skips 51) to line up with original file labels. **

b) Re-pointing offset

The offset between frames 50 and 52 during re-pointing were determined to be [69., 39.8] arcsec.

- Image52 : xc = xc + 69.   [arcsec]
- Image52 : yc = yc + 39.8 [arcsec]

The initial offsets were then adjust after the re-pointing in order to have all of the Hi-C images have proper relative offsets to the first image.

For quick reference, the following integer arrays depict the file numbers corresponding to the offset indices:

f: [25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, | 52, 53, 54, 55, 56, 57, 58, 59, 60, 61]
i: [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, | 26, 27, 28, 29, 30, 31, 32, 33, 34, 35]

Testing

>> Level0.5_Development/**2_Alignment**/

```
IDL>  offsets4k_ss = offsets4k

IDL>  offsets4k_ss[26:35].offx = offsets4k_ss[26:35].offx + 69./dxH $
+ offsets4k_ss[25].offx
IDL>  offsets4k_ss[26:35].offy = offsets4k_ss[26:35].offy + 39.8/dxH $
+ offsets4k_ss[25].offy
```

*Result saved as Level0.5_Development/2_Alignment/**offsets4k_ss.sav**.*

c) Absolute Co-Aligned Pointings

Now the offsets between all images in the Hi-C set can be applied to the solar reference pointings. The Hi-C reference image is original file number 40, which corresponds to offset index 15 (see reference arrays above). Because the correct pointing information was determined for Hi-C file 40 (offset index 15), the offsets must be adjusted based on the reference image:

- New_offsets => offsetsXY - offsetsXY[15]

These offsets can now be fully applied to the solar reference pointings. ** However, these adjusted pointings create a co-aligned Hi-C image set that does not allow for active region drift across the disk. **

Testing

>> Level0.5_Development/**2_Alignment**/

```
IDL>  offsets4k_ss40 = offsets4k_ss

IDL>  offsets4k_ss40.offx = offsets4k_ss40.offx - $
offsets4k_ss[15].offx
IDL>  offsets4k_ss40.offy = offsets4k_ss40.offy - $
offsets4k_ss[15].offy
```

*Result saved as Level0.5_Development/2_Alignment/**offsets4k_ss40.sav**.*

The offsets were further refined by Caroline Alexander by co-aligning the previous Level 1.5 version of the data. These shifts have the rotational drift removed; therefore, the 0.0027 arcsec/sec drift in X determined in the next section are added to determine the properly-shifted coordinates. (*Only the X-coordinate is adjusted for drift due to the small roll angle and short observing period.*)

They were also shifted based on the 0th image. Because the Hi-C coordinate alignment is based on image 15, this was also adjusted.

- shiftsX_adj = shiftsX - shiftsX[15] ; [pixel units]
- shiftsX_adj = shiftsX_adj + (driftx/dxH)*time-difference-from-image15
- shiftsY_adj = shiftsY - shiftsY[15]
- jitter4k_adj = {jitterx:shiftsX_adj, jittery:shiftsY_adj}

*Result saved as Level0.5_Development/2_Alignment/**jitter4k_adj.sav**.*

```
IDL>  restore, 'aia_ext2v3.sav'; (See Section 4.b.)
IDL>  xc40 = aia_ext2.xc & yc40 = aia_ext2.yc

IDL>  delvarx, hic_acents
IDL>  for i=0,35 do hic_acents = merge_stcs(hic_acents, {xc:xc40 +
offsets4k_ss40[i].offx*dxH + jitter4k_adj[i].jitterx*dxH, yc:yc40 +
offsets4k_ss40[i].offy*dxH + jitter4k_adj[i].jittery*dxH})
```

*Result saved as Level0.5_Development/2_Alignment/**hic_acentsv3.sav**.*

d) Apply Rotational Drift

The rotational drift of the region is very small because the image set only spans less than 4 minutes. However to be thorough, we will calculate and incorporate it into the pointing information. To do so, we get the precise drift rate from the corresponding AIA image set. The initial and final Hi-C 4kx4k images were taken at the following times:

Hi-C	t0	193	18:52:09.750 UT
	tf	193	18:55:30.150 UT

The AIA 193 images encompassing the Hi-C data set are taken from the following times:

AIA	t0	193	18:51:44 UT
	tf	193	18:55:19 UT

The AIA extractions corresponding to the Hi-C field of view were created in the same way as described in Section 4 to create aia_ext2 (prepped, un-rolled, extracted, re-scaled, extracted).

A few points were chosen between the initial and final frames and tracked to determine the drift. There is about a 1 pixels drift over 216 seconds in the X-direction (~0.0027 arcsec/second) and about a 0 pixel drift in y, as expected. (An AIA image from 18:00:07.840 was also used to confirm this amount of drift over an even longer time period.) The Hi-C co-aligned pointings were then adjusted to allow for this small amount of drift in the X-direction. (*Only the X-coordinate is adjusted for drift due to the small roll angle and short observing period.*)

Testing

>> Level0.5_Development/**2_Alignment/Drift/**

The downloaded, pre-processed AIA FITS files used to determine the drift are
save as Level0.5_Development/2_Alignment/Drift/:

```
aia.lev1.193A_2012-07-11T18-00-07.84Z.image_lev1.fits
aia.lev1.193A_2012-07-11T18-51-43.84Z.image_lev1.fits
aia.lev1.193A_2012-07-11T18-55-19.84Z.image_lev1.fits
```

```
IDL>  driftx = 0.0027 ;arcsec/sec
```

*Result saved as Level0.5_Development/2_Alignment/Drift/**driftx.sav**.*

>> Level0.5_Development/**2_Alignment**/

```
IDL>   restore, 'hic_timesv3.sav'
IDL>   restore, 'hic_acentsv3.sav'

IDL>   htimes_sec = conv_time(hic_times)
IDL>   hdtimes_sec = htimes_sec - htimes_sec[15]

IDL>   delvarx, hic_cents
IDL>    for i=0,35 do hic_cents = merge_stcs(hic_cents,
{xc:hic_acents[i].xc + driftx*hdtimes_sec[i], yc:hic_acents[i].yc})
```

*Result saved as Level0.5_Development/2_Alignment/**hic_centsv3.sav***

7. Converting to Level 0.5

Now that we have all of the proper header information to reference the Hi-C images to
their proper field of views on the Sun, we can use hic_level05.pro to properly apply it to
all of the images and update the FITS headers ***in a way that is consistent with the***
AIA FITS headers.

Note: *** *This program will only work on frames 25 - 61 (not 21 - 23).* ***

The program performs the following actions:

- Transposes the data.
- Corrects the times.
    - Subtracts 92 seconds from the rocket time stamp (from original FITS
      header, *not* .idx file).
- Changes CRVALs to drifted, AIA co-aligned centers.
    ** Sun-center reference pixel position [0,0]. [pix]
- Changes CRPIXs to where sun-center is relative to the image's center pixel.
    ** i.e., CRPIX1 = (image_sx/2.) - xc/dx$_A$ [pix]
- Adds XCEN, YCEN.
    ** Image center pixel position from CRVAL (sun-center). [arcsec]
    ** The centers, from hic_centsv3, are manually added to the hic_level05

program rather than needing to read in an extra file.
- Changes roll to θ_H = -1.81969°.
    ** [degrees from solar north]
- Adds throughput values from the Level 0 .idx files.
- Fixes exposure keyword units.
        ** (IMG_EXP [ms], EXPTIME [s])
- Adds wavelength, telescope, instrument, level, and updated history information.

The output files are named in the following format: HiC_L0.5_[time_stamp].fit
    - To avoid confusing with previously numbered file names.

<u>Testing</u>

>> **Level0/**

```
IDL>  ffiles = file_search('*.fit')
```

    - Index files (.idx), which must be in the same directory as the FITS, are located automatically.

```
IDL>  hic_level05, ffiles[, savedir='../Level0.5']
```

    *Results have been saved as **Level0.5/*.fit**.*

>> **Level0.5/**

```
IDL>  ffiles05 = file_search('*L0.5*')
IDL>  mreadfits, ffiles05, hindex05, hdata05[, head=head]
      - head will be the last file's FITS header

IDL>  index2map_ss, hindex05, hdata05, hic_l05_map
[IDL>  my_stepper, hic_l05_map, /over, gam=.4, res=.25]
```

    *** *Note that these images are not aligned to one another; however, the pointing information is correct in the headers and in the index and map structures.* ***