Hi-C 2.1 2K Data Level 0.5 Development

1. Purpose

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

Action Summary

- Rotate image by 90 degrees counter clockwise
- Subtract 126 seconds from sounding rocket time stamp
- Determine correct pointing and roll angle with respect to sun center using AIA
- Adjust centers with fine pointing shifts
- Update other FITS header keywords to be more informative

2. Setup

The Level 0 Hi-C "Light" FIT files include file numbers 172 - 249. Frames 142-156 are used for dark calibration. Frame 163 was taken while slewing and is used for locating the mesh to create a flat image.

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. (Contact Sabrina dot Savage at nasa dot gov for the list of IDL programs.) However, the information here provides a reference for how the FITS headers were corrected. (A separate guide, available upon request, describes how the data was processed.)

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 with AIA 171:

Reference AIA 171: 29-May-2018 18:56:57.350 UT.

The closest temporal Hi-C image (after correcting the FITS header time stamp by -126 seconds) was taken at:

Hi-C   172   18:56:56.64 UT
[Level 0 Frame 180; time stamp corrected from 18:59:02:64 UT].

b) Reference Files

The Hi-C reference frame is labeled number 180 in the Level 0 file name set (HiC00180.fit).

The AIA reference files are downloaded as Level 1 FITS.

<u>Testing</u>

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

Hi-C
        HiC00180.fit

AIA
        aia.lev1.171A_2018-05-29T18_56_57.35Z.image_lev1.fits

c) Preparing the Data

Initial actions: read in data, rotate hi-c image to solar orientation (90 deg CCW), and create maps.

<u>Testing</u>

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

<u>Hi-C</u>

Cursory preparation of the Hi-C reference frame for co-alignment:

```
IDL>   mreadfits, 'HiC00180.fit', hindex, hdata
IDL>   index2map_ss, hindex, hdata, hic_map180
IDL>   hic_map180 = rot_map(hic_map180, -90)
```

<u>AIA</u>
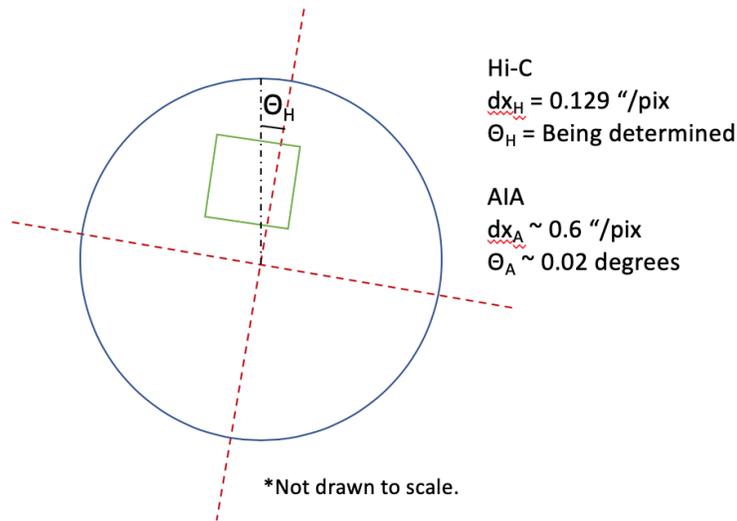
```
IDL>   files = file_search('aia*.fits')
IDL>   mreadfits, files, aindex, adata
IDL>   index2map_ss, aindex, adata, aia_map171
```

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 $dx_H = 0.129$ arcsec/pix.

The Level 1 full Sun AIA images have a roll angle of $\theta_A \sim 0.02°$ and a resolution of ~0.6 arcsec/pix.

Hi-C
dx_H = 0.129 "/pix
Θ_H = Being determined

AIA
dx_A ~ 0.6 "/pix
Θ_A ~ 0.02 degrees

*Not drawn to scale.

b) Extract Hi-C Region from AIA

The following process was iterated until the proper Hi-C roll angle (Θ_H) and center coordinates were determined:

1. Rotate full-Sun AIA by Θ_H. (iterate)
2. Re-grid the rotated AIA image to have the same resolution as Hi-C.
3. Adjust the Hi-C center pixel. (iterate)
3. Extract the Hi-C region from AIA (aia_match) using Hi-C as the reference.

<u>Testing</u>

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

```
IDL>  rotang = hroll - aia_map171.roll_angle
IDL>  raia_map171 = rot_map(aia_map171, rotang,
center=aia_map171.roll_center)
```

*** Answer from iterating: **hroll = 0.985** ***

```
IDL>  hres = 0.129 & ares = aia_map171.dx & frac = ares/hres
IDL>  data_info, aia_map171, /nodata, info=info & asx = info.sx & asy
= info.sy
IDL>  data_info, hic_map180, /nodata, info=info & hsx = info.sx & hsy
= info.sy
```

```
IDL>  graia_map171 = grid_map(raia_map171, asx*frac, asy*frac)
IDL>  gamap = graia_map171 & gamap.dx = hres & gamap.dy = hres
IDL>  hmap = hic_map180 & hmap.dx = hres & hmap.dy = hres
```

```
IDL>  hmap.roll_angle = hroll
IDL>  hmap.xc = hxc & hmap.yc = hyc
```

       *** Answers from iterating: **hxc = -114.39 & hyc = 259.05** ***

```
IDL>  sub_map, gamap, aia_match, ref_map=hmap, /quiet, /preserve
IDL>  my_window, hmap, res=.5, /typ, win=0
IDL>  my_window, sgamap, res=.5, /typ, win=1
IDL>  blink, [0,1]
```

       *** Ignore the lower half of the Hi-C image, below the row of missing pixels. ***
       *** Top half of blinking window should be aligned. ***

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

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 = 0.985°
- **xc** = -114.39 [arcsec from sun-center] -- **Level 0 Frame 8**
- **yc** = 259.05 [arcsec from sun-center] -- **Level 0 Frame 8**
- **rsun** = 946.127 [arcsec]
- **roll_center** = [0,0]
- **image size** = [2152, 2064]

6) Hi-C Co-Alignment

a) Summary

In order to determine the proper pointing information for all of the other Hi-C frames, the rotation drift from this Hi-C frame plus relative offsets to compensate for fine shifts (i.e., jitter) must be incorporated.

b) Determine Rotational Drift

The rotational drift of the region is very small because the image set only spans less than 6 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 "Light" images were taken at the following times:

```
Hi-C   t0     172    18:56:26.210 UT    xc = -114.23  yc ~ 259.2
       tf     172    19:01:52.180 UT    xc = -113.88  yc ~ 259.2
```

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

```
AIA    t0      171     18:56:21.350 UT
       tf      171     19:01:57.350 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_match.

A few points were chosen between the initial and final frames and tracked to determine the drift. **There is less than 3 pixel drift over 326 seconds in the X-direction (~0.00107 arcsec/second)** and about a 0 pixel drift in y, as expected. 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.*)

This drift rate is taken into account in hic21_centers.pro and calculated from the reference frame and center values summarized in Section 5, which is called from hic21_level05.pro.

c) Fine Shifts

The fine shifts are a combination of initial coarse inter-alignment derived by hand (S. Savage) and then combining with fine shifts derived by R. Morton and further refined by P. Chitta.

> *Vector of shifts saved as Calibration/**hic21_fine_shifts.sav**.*

The saved structure contains time, jx, and jy (i.e., jitter x & y). The centers are corrected in hic21_centers.pro (through hic21_level05.pro) via:

```
--> centers.xc = centers.xc + fine_shifts.jx
--> centers.yc = centers.yc + fine_shifts.jy
```


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*.

The program performs the following actions:

- Rotate by 90 degrees CCW.

- Corrects the times.
    - Subtracts 126 seconds from the rocket time stamp.
- Update dx & dy to 0.129 arcsec/pix.
- 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 (AIA co-aligned, rotationally drifted, fine-shifted centers) [arcsec].
    ** 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 $\theta_H = 0.985°$.
    ** [degrees from solar north]
- Fixes exposure keyword units.
    ** (IMG_EXP [ms], EXPTIME [s])
- Adds wavelength, telescope, instrument, level, and updated history information.
- Update the camera file headers with temperatures.

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

Testing

NOTE: To run, you must have the Calibration directory either in the run directory or in one or two levels above the run directory.

>> **00_Hi-C2.1_Flight_Lights/**

```
IDL>  ffiles = file_search('Level_0'+path_sep()+'*.fit')
IDL>  hic21_level05, ffiles
```

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

>> **Level0.5/**

```
IDL>  ffiles05 = file_search('Level_0.5'+path_sep()+'*L0.5*')
IDL>  mreadfits, ffiles05, hindex05, hdata05, /quiet[, 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=.5
```

*** 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. ***