```
file: instruction.txt = hands-on demo SDO alignment
init: Feb 16 2020  Rob Rutten  Deil
last: Apr 24 2021  Rob Rutten  Deil
note: # = comment
todo: tasks A-C below
site: parallel versions .txt, .html, .pdf (latter two with active links) at
```

https://robrutten.nl/rrweb/sdo-demo/dircontent.html

(or Google "rob rutten webstek" > "Recipes for IDL" > SDO)

```
Introduction
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This instruction was written for a hands-on session at a planned
Solarnet school on solar space- and groundbased co-analysis at MSSL in
March 2020.  The school got covid-shifted to an on-line version in
January 2021.  Meanwhile I webposted this material for users not at
the school.

The tasks are:

  A Beforehand
    - set up my IDL, SSW, JSOC registration etc
    - download required data files

  B SDO cross-alignment
    - demo how to get and cross-align SDO cutout sequences
    - inspect alignments for the 2019-11-11 Mercury transit

  C SST-SDO co-alignment
    - demo how to inspect SST/CRISP data my way
    - demo how to get and co-align corresponding SDO cutout sequences

I welcome error logs, suggestions, improvements, and also science
discussions of what is seen or not seen in the co-aligned SST-SDO
data.  You are welcome to contact me (R.J.Rutten@uu.nl), especially if
you meet problems.  Skype may serve to share laptop screens; I am
robertjellerutten there but need prior email warning to switch on.

For the showex inspections below it may be better to run IDL not
remotely but in your local computer (maybe per remote license).


A.  Beforehand (prior to the school)
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1. Get my SDO manual at:
```

https://robrutten.nl/Recipes_IDL.html

2. Do step 0 of the manual: get my rjrlib, install, add to IDL search path. Renew if a newer date is given in the func line at the top of the manual.

3. You must also have SSW including gen, sdo (maybe also vobs, iris, optical). Also David Fanning's coyotelib (see manual). And add IDL search priorities (see manual). And be registered at JSOC (see manual).

4. Download and unzip needed SST data (3G):
   https://robrutten.nl/rrweb/sdo-demo/2014-06-24/sst.zip

   and also the small file:
   https://robrutten.nl/rrweb/sdo-demo/2014-06-24/align_sdo_sst.idl

5. Optional data for further inspections (16M, 10M, 3.5G):
   https://robrutten.nl/rrweb/sdo-demo/2019-11-11/ingress.zip

   https://robrutten.nl/rrweb/sdo-demo/2019-11-11/egress.zip

   https://robrutten.nl/rrweb/sdo-demo/2014-06-24/sst2rotsdo.zip

6. Quick IDL check:

```
cd .../2014-06-24/sst
IDL> showex,'wb.6563.corrected.aligned_cut.icube'   # granulation movie
```

B. Get and cross-align SDO for the recent Mercury transit

```
mkdir 2019-11-11/midpoint
go there, start IDL/SSW.

     IDL> sdo_getdata_rr,'2019.11.11_15:18',5,-13,70,xsize=60,ysize=50,$
          /addfires,name='xxx',email='yyy@zzz'
```

use straight-up single quotes (do not copy-paste the curvy latex quotes in the pdf version of this instruction). Your name xxx and email address yyy@zzz must be registered at JOC.

it should start ordering data at JSOC. Normally there will be waits to avoid JSOC-forbidden parallel ordering and also waits for data downloads if the orders are not yet completed. Completion then generates 8 JSOC emails (I taught Google to shunt them to spam). However, if the same data were ordered earlier JSOC recognizes duplication and links to the already completed files. The program then warns that the order sizes seem too small - this is fine, no waits and no emails to you. The program

then downloads and starts processing, flashing many aia_prep.pro messages that you can ignore. It should end with "===== sdo_getdata_rr done" and the time it took.

at home (fast download) with my laptop the whole run takes about 25 min incuding the waits (only 16 min for a duplicate request).

I show output graphs in appendices A and B of my recent https://robrutten.nl/rrweb/rjr-pubs/2020LingAstRep...1R.pdf henceforth LAR-1, especially in figures 70-75 (last pdf pages) and their captions. The "fire detector" defined in the caption of fig. 69 is now part of the pipeline and is called by the /addfires option above.

I found the (X,Y) location above with:

```
IDL> sdo_featurelocator,'2019.11.11_15:23','continuum'
```

and pulling out Mercury and clicking on it. Try this. (SSW needs to know your email address, see manual.)

When done inspect the cross-alignments (in your midpoint dir):

```
IDL> showex,/allsdo,sdodirs=['center/cubes','center/cubesxal']
```

which loads non-aligned and aligned disk center cubes. They are all synchronised to the 12s-cadence 171 timings and follow solar rotation for the cutout center (also largely undoing the 1 px sawtooth jumps of the JSOC cutouts). Blink between pairs of each sequence.

Zoom in to Mercury by pulling out small areas (if this doesn't work anymore then you ran out of limited IDL LUNs and must restart IDL). Keep in mind that Mercury's shape gets deformed by temporal interpolation to the 171 timings (EUV 12s cadence, UV 24s, HMI 45s). Worse for HMI which uses 3 exposures to construct continuum and magnetogram images.

Also zoom in to field edges to observe the limbward increasing 1600-1700 offsets shown and explained in appendix A of LAR-1.

If you have interest in chromospheric and coronal heating then blink the cubesxal/aiafire and aia193 sequences (iwA=17, iwB=19). The ubiquitous grey patches in aiafire are heated chromosphere (with similar patterns in reversed Halpha intensity and ALMA), the white aiafire spots underlie "coronal bright points" in aia193. The diffuse aia193 background around these appears to be partly set by the chromosphere, partly leftovers from previous fires. The smallest fires are "Solar Orbiter campfires". Zoom in by drawing a small box around them and blink these cutouts. Also wavs 12-17 in search of magnetic causes. Return to the full-field display underneath with the "quit this" button.

The cross-alignments are done in a sequence of SDO channel pairs with the resulting spline-fitted corrections shown as ps plots in dir driftscenter. Inspect these. Explanation under LAR-1 figure 75. The check-xal plot is the final check, comparing two at the ends of pairwise chains and so showing combined errors. Should remain within 1 px (AIA 0.6 arcsec).

Inspect the small target cutouts with:

```
IDL> showex,/allsdo,sdodirs='target/cubes'
```

```
# sliding the time to it=16 has Mercury on a "fire" as reference
# hitting the sqrt button may improve greyscale
```

I did the same as above for the Mercury ingress and egress with:

```
IDL> sdo_getdata_rr,'2019.11.11_12:39',20,-936,52.5,xsize=100,ysize=50
IDL> sdo_getdata_rr,'2019.11.11_17:54',13,940,89.7,xsize=100,ysize=50
```

You find the resulting results under
https://robrutten.nl/rrweb/sdo-demo/2019-11-11/dircontent.html

For comparison pull over the zips and inspect target/cubes as above.

C. Get SDO for SST/CRISP data and co-align

This practical uses a brief segment from a high-quality 75-min SST/CRISP data set pointing at very quiet Sun under a disk-center coronal hole. The observations were done in June 2014 by Tiago Pereira and are property of the Institutt for Teoretisk Astrofysikk at Oslo. If you want to use them further you should obtain permission from Luc Rouppe van der Voort <l.r.van.der.voort@astro.uio.no> as well as the full-duration data.

These data are in
https://robrutten.nl/rrweb/sdo-demo/2014-06-24/sst.zip

which you should have and unzipped. Go to dir sst and list.

The three sst/CRISP sequences ("crispex" 6563, 8542, 6302) resulted from the usual CRISPRED pipeline: MOMFBD, undoing of the time-dependent SST field rotation, and co-alignment putting 6563 and 6302 on 8542. (I think Luc did this.)

I cut out a 10-minute-only segment to gain download and processing speed in this demo. The seeing improved during the observation as evident in sst/rmsplot.ps showing photospheric contrast rms along the full 75-min duration. I initially selected it=218-270 for 10 min of consistently very good seeing, but in December 2020 I switched to it=60-112 because this less good segment contains some coyly-called "Solar Orbiter campfires", the topic of my LAR-1 based on SDO data; this dataset adds higher-resolution SST data.

C-1 Inspect the SST data

```
(from dir .../2014-06-24)
cd sst
IDL> showex,/full
```

This assoc-opens 51 parallel movies. My laptop needs 5s for greyscale setup and then opens three screens.

Shift the stream A wavelength slider to iw=6 (wide band 6563) and appreciate the overall quality by sliding the time slider (topmost). During this segment the seeing varied from mostly good to sometimes excellent ("good to excellent" at the SST is "excellent to superb" at other telescopes). Zoom in to (pull out) some small magnetic network patch and see how the "flower" morphs with time just as in MURaM and Bifrost simulations. Hit "quit this" on top to return to the full-field display.

The overall seeing was better than in the two SST data sets of Rutten++ 2019A\&A...632A..96R
https://robrutten.nl/rrweb/rjr-pubs/2019AAp...632A..96R.pdf
which made much use of "Strous" scatter contour plots as the one now on your screen. Its format is explained in Section 2 and demoed in Fig. 5 of that article. You may mimic that here by moving the stream A slider to iw=10 (Halpha-0.8 AA), stream B to iw=18 (Halpha+0.8 AA). Hit blink. The mountain summit represents all grey internetwork. The downward mountain ridge represents RREs, tne wider leftward ridge more numerous RBEs, the small upper-right ridge the rather scarce magnetic bright points. This separation of different features is more informative than the overall Pearson correlation coefficient in the lower-left corner.

Now move B to iw=15 (+0.2 AA), blink and cursor-increment the time-delay slider slowly to the right while inspecting the scatter diagram per blink. The contour mountain tilts down from no dark-dark correlation at simultaneous sampling to an extended left-down promontory of darkest-darkest correlations around delta_t = 20 (4 minutes, the cadence is 11.5s). The blink shows matches between RBEs and subsequent core fibrils. Hit dt=0 to jump back to simultaneous showing without correlation (perpendicular dashed moment curves). You see similar time-averaged downtilt when hitting the mean(t) button. Even clearer at Ha+0.4 (iw_B=16). These correlations are evidence that dark downdrafting Halpha core fibrils tend to follow on repeating dark RBEs (spicules-II). We might well have added these better-seeing data to our article.

These data also have CaII 8542 and so repeat the quiet-sun dual-line analysis of Cauzzi++ 2009A\&A...503..577C
https://robrutten.nl/rrweb/rjr-pubs/2009AAp...503..577C.pdf

>

which used lower-quality DST/IBIS data. A major result there was that Halpha core width and CaII 8452 core minimum intensity both sample temperature, clearest in temporal averages. In that article Kevin Reardon cleverly defined ways to measure these quantities isolating chromospheric cores. My program mwseq2special.pro implements them. It is slow by fitting profiles per pixel per timestep, so I ran it for you and added the results into the sst directory you now have. They are the first six A and B "xxx_kr" "wavelengths" of the showex display. You can check the reported "bright-bright" Halpha-width and CaII 8542 minimum intensity correlations by selecting these (iwA=1, iwB=4), inspect the scatter plot while blinking and time-sliding, and then check their temporal average correlation by hitting mean(t). In the blinking image display you may study how they come about - which features make them. For example, iw=4 versus iw=10 shows that RBEs are hot (bright in Halpha width). In mean(t) its good bright-dark correlation survives, showing that most hot Halpha features here were recurrent spicules-II.

There is more to see but let's add corresponding SDO data.

C-2 Get and co-align SDO

Reread my SDO manual. First now is Step 1: find where and when. The SST turret logs provide pointing data but imprecise.

```
     cd sst
     IDL> sst_findlocation,$
        'wb.6563.corrected.aligned_cut.icube',$
        '2014.06.24','tseries.6563_cut.sav',$
        x_sst,y_sst,angle_sst,px_sst
```

```
which puts SST precisely on SDO in (slow) "Metcalf" iterations
(I have green light from LMSAL to use "Metcalving" as verb).
I got:
   itsample_sst = 22 as best SST seeing moment
   after rotation excellent blinks between mucked SST and HMI granulation
   result: (X,Y) = -114.9 -112.3  angle_stx = 62.02  px_stx = 0.0567
           at it=0 (specify in getting SDO): (X,Y) = -115.5 -112.3
Copy your results in your log file for insertion below.

What SDO timing is needed?
     cd sst (or you are still there)
     IDL> restore,'tseries.6563_cut.sav'
     IDL> help,time       ; nt=53
     IDL> print,time[0]   ; 08:38:43.402
     IDL> print,time[52]  ; 08:48:38.956  # 10 minutes duration (my cutout)

Now Step 2: get co-aligned SDO now knowing (X,Y) and timing return
     to top directory = 2014-06-24, mkdir sdo, go there
     IDL> sdo_getdata_rr,'2014.06.24_08:37',12,-115.5,-112.3,/addfires
     In my laptop this took 31 min.
     The check-xal plot was good (explanation under last figure LAR-1).

Now Step 3: co-align SST and SDO.  I suggest sst2rotsdo output mode
in which the SST data are co-aligned with the SDO data after
rotating the latter to the large SST field angle.  This maximizes
the field within figures (no awkward grey triangles as for (X,Y)
orientation) and undoes the drifts of the SST guiding (which tracks
features near field center going their own erratic way).  The SDO
data strictly follow standard differential rotation, but with a
0.1-AIA-px wobble left from the JSOC full-px im_patch cutting.
This I also remove by separating it from the slower drift (two
spline fits in the resulting align plot opening on your screen).
This rotation-following output mode is best suited to temporal
averaging, Fourier or wavelet frequency analysis, time-averaged
scatter analysis etc., by undoing both AIA wobble and SST drift.

Step 3 is done by running sdo_stx_align.pro which is a complex
program needing an elaborate choice of input parameters.  I
collected my choices in IDL main align_sdo_sst.idl in:
 https://robrutten.nl/rrweb/sdo-demo/2014-06-24/dircontent.html


Inspect these choices, adapt the path specified at its top to your
directory, and run it with
  .r align_sdo_sst.idl
on your IDL command line.  It skips the slow Metcalving because this
was done already by sst_findlocation.pro, by entering its results
above.  For setting show=1 you get intermediate showex inspections
of "forward" = SDO on SST and "reverse" = SST on SDO results, first
```

for the best-seeing image pair, later for the final cubefiles of the two alignment channels (usually both continuum but your choice). In each showex hit "quit this" to continue the program. It finally transforms and writes all co-aligned data into dir sst2rotsdo, first SDO, then SST.

In my laptop this program took 9 min for these relatively small files. The initial check blink was good thanks to sst_findlocation.pro (otherwise Metcalving is needed). The two showex blinkers with the mucked align-images were good. The driftplot showed a drift in y of 5 SST px (10x smaller than AIA px!) from the SST tracker plus 1-px SDO leftover wobble; both were spline-fitted and removed. The final showex sequence blinkers showed good forward and reverse alignments (slide the time slider for check blinking at different times).

If this co-alignment fails for you or takes to long you can instead use my results (5.4G) in:
https://robrutten.nl/rrweb/sdo-demo/2014-06-24/sst2rotsdo.zip

C-3 Time for science

Step 4: inspection of the co-aligned data.

```
cd 2014-06-24
IDL> showex,/full,montydirs='sst2rotsdo',spectdirs='sst'
```

This assoc-opens 64 parallel movies; in my laptop the greyscale setup takes 10s. The spectdirs serve to add Halpha and 8542 wavelength labels and for Dopplergram mode.

First blink iwA=1 and iwB=63 (last) = magnetograms to check SDO-SST alignment and admire quality difference. Zoom in and check that it=22 is best.

Select the 304x131 ("aia3013", iw=5) fire detector (the next "aiafire" is nearly the same due to lack of activity above the greyscale threshold and shows only few pixels above the whiten-fire threshold). At mid-sequence showex startup there is a "Solar Orbiter campfire" within the coronal hole. Check it out in 171 and 193. Shift the time slider to find some more and wonder whether they come in pairs. Blink with the Halpha and 8542 samplings to search for cause or effect underneath, also at time delays. Let me know when you find such! (I call them "St. Elmo's fires", just as coyly, for being harmless little electric flames.)

Compare RBEs and RREs in the blue and red wings of Halpha and 8542.

Blink Halpha Doppler at iwA=30 ("black=blue") against Halpha core width (iwB=17) and identify heating spicules-II versus subsequent cooling return fibrils. Can you identify tips of spicules-II in hotter AIAs as in 2016ApJ...820..124H?

The upper-left quadrant samples internetwork that is unusually non-veiled by Halpha fibrils in this very quiet area so that you can actually discern reversed granulation (cut it out, blink iwA=24 and iwB=60). Try to identify acoustic grains in 8542 ("K2V Carlsson-Stein shocks") and study time-delay Halpha response. What are the thin swirling Halpha iw=30 Doppler strands there? Are there granular swirls (iw=7)? Any swirls or swirl heating in AIA?

All yours! This rich multi-diagnostic display is the motivation to precisely co-align ground- and spacebased data sets. Adding IRIS would be yet better but that day had no SST-IRIS co-pointing.

Showex also offers an option (upper-left pull-down menu) to show periodograms per pixel for <UK> wave types. I aim to add running differences, unsharp masking, line-core integration, and more <sometime>.

D Write your article

Naturally I offer recipes:
https://robrutten.nl/Recipes_latex.html

https://robrutten.nl/Recipes_publications.html

You might acknowledge me, but if you ask me as co-author the warning is that I first make you redo every figure and then muck with every comma.

Acknowledgements

Gherardo Valori diagnosed and solved various problems.
SDO is the most important facility of solar physics but only rarely mentioned in acknowledgments specifying lesser instruments with mandatory (often irritating) formulations. Likewise, Alan Title and Phil Scherrer should be the most acknowledged solar physicists whereas lesser facilities may even require coauthorship.
Harry Warren, Neil Sheeley and Peter Young gave key suggestions during my start of this pipeline. Since then I enjoy frequent help from Arthur Amezcua, Greg Slater, John Serafin, Marc DeRosa, Mark Cheung, Phil Scherrer, Sam Freeland. Various users reported deficiencies.