IRIS Technical Note 1
IRIS operations

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1. Instrument Overview

1.1 Summary

IRIS is the Interface Region Imaging Spectrograph small explorer (NASA Small Explorer-SMEX). The IRIS investigation combines advanced numerical modeling with a high resolution, high throughput multi-channel UV imaging spectrograph fed by a 20 cm UV telescope. The main science goal of IRIS is to understand how the solar atmosphere is energized. IRIS will obtain UV spectra and images in two main passbands around 1400Å and 2800Å at high resolution in space (0.33-0.4 arcseconds), time (1s) and spectrally (40 and 80 mÅ respectively) that are focused on the chromosphere and transition region including some coverage in the corona.

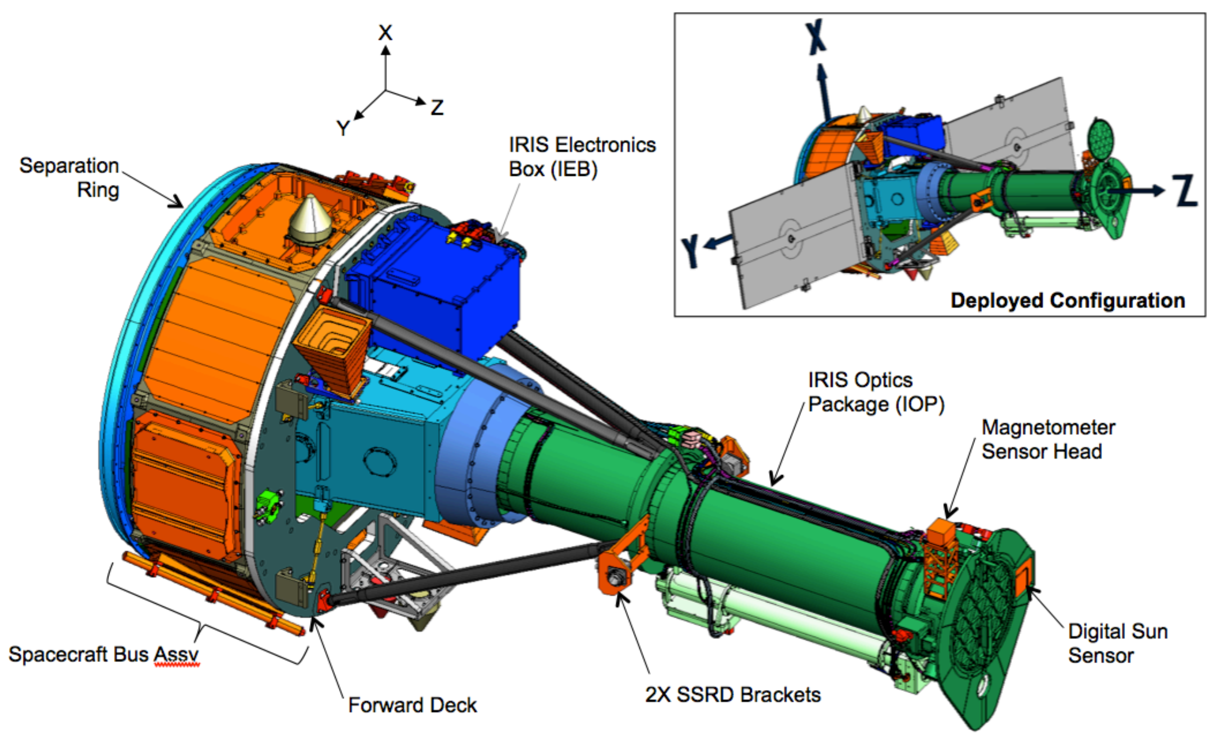

Figure 1: Schematic view of IRIS showing the 20 cm UV telescope, with and without solar panels (for clarity). Light from the Cassegrain telescope (green) is fed into the spectrograph box (light blue).

1.2 Passbands

The IRIS telescope feeds light from two passbands into the spectrograph box:

- far ultraviolet (FUV): 1331.56-1406.79 Å
- near ultraviolet (NUV): 2782.56 - 2833.89 Å

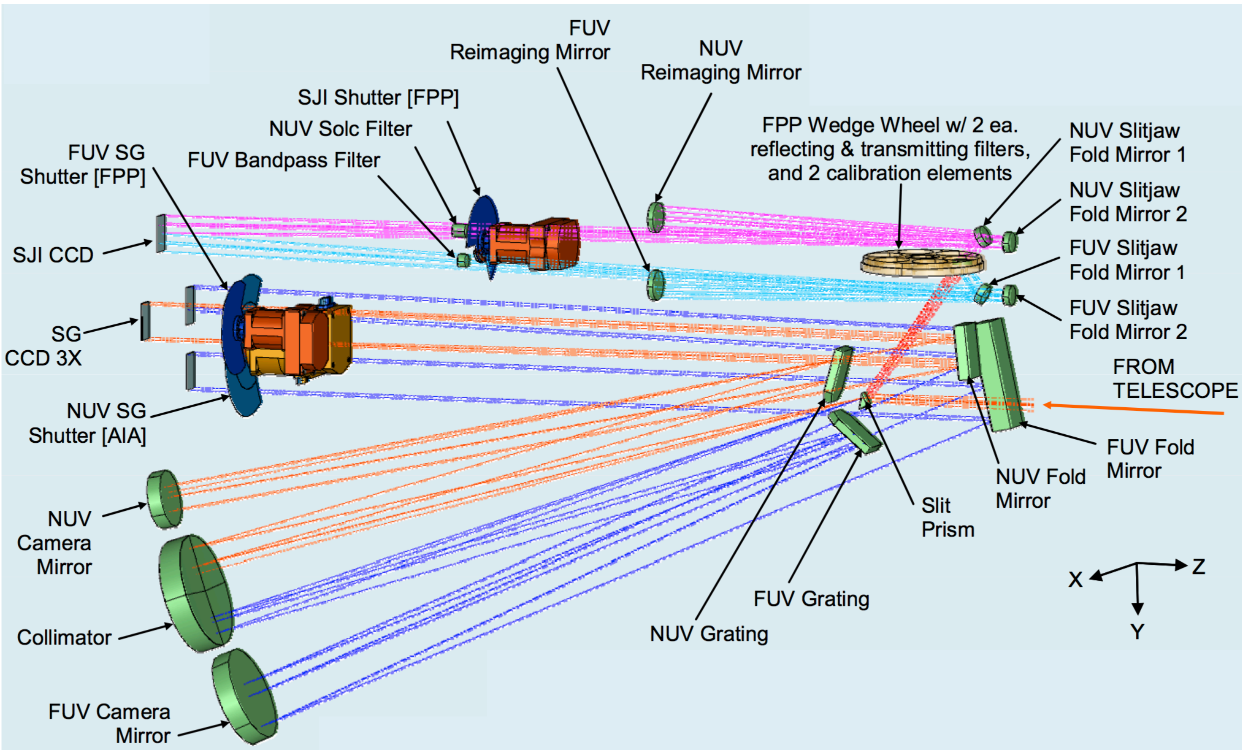

Figure 2: Schematic diagram of path taken by light in the FUV spectrograph (dark blue), NUV spectrograph (orange), FUV slitjaw (light blue) and NUV slitjaw (purple) path.

In the spectrograph, the light follows several paths (Figure 2), either:

- spectrograph (SG): passing through a slit that is 0.33 arcsec wide and 175 arcsec long, onto a grating that is sensitive in both FUV and NUV passbands, then onto 3 CCDs to produce spectra in three passbands (FUV1, FUV2, NUV, Table 1)

- slit-jaw (SJI): reflected off the reflective area around the slit (“slit-jaw”), passing through or reflected off broadband filters on a filterwheel, then onto 1 CCD to produce an image of the scene around the slit (slit-jaw= SJI) in 6 different filters (2 for calibration, 4 for solar images, Table 2)

Exposure times are controlled by 3 different shutters (FUV, NUV and SJI). Light is collected onto 4 CCDs which are read out by 2 cameras (see Section 3 for details) and which cover 3 different spectral bands and the slit-jaw images (Table 1, 2). The IRIS spectral lines cover temperatures from 4,500 K to 10 MK, with the images covering temperatures from 4,500 K to 65,000 K (and possibly 10 MK under flaring conditions).

SG Passband	Wavelength range (Å)	Spectral Dispersion (mÅ)	Spatial range (arcsec)	Spatial pixel size (arcsec)	CCD/ Camera	Shutter	Effective Area (cm^2)
FUV 1	1331.6-1358.4	12.98	175	0.166	1, CEB1	FUV SG	1.3
FUV 2	1380.6-1406.8	12.72	175	0.166	2, CEB1	FUV SG	1.3
NUV	2782.6-2833.9	25.46	175	0.166	3, CEB2	NUV SG	0.18

Table 1: Overview of spectrograph (SG) channels. These are imaged onto 3 identical 1056x2061 pixel^2 CCDs and can all be simultaneously read using two different camera electronics boards (CEB). Ranges, dispersion and effective area are current best estimates based on pre-launch measurements. Spatial range is along the slit. No or little light will fall in the FUV2 wavelength range from 1380.6 to about 1390 Å because of vignetting.

SJI Passband	FW Position - Type	Wavelength (Å)	FWHM bandpass (Å)	Spatial range ($arcsec^2$)	Spatial pixel size (arcsec)	CCD/ Camera	Shutter	Effective Area (cm^2)
Glass	1/2 - T	5000?	2000?	175x175	0.166	4, CEB2	SJI	0.004?
1330	31/32- M	1330	40	175x175	0.166	4, CEB2	SJI	0.46
2796	61/62 - T	2796	4	175x175	0.166	4, CEB2	SJI	0.004
1400	91/92 - M	1400	40	175x175	0.166	4, CEB2	SJI	0.46
2832	121/122 - T	2832	4	175x175	0.166	4, CEB2	SJI	0.004
Broad-band	151/152 - M	1600	400?	175x175	0.166	4, CEB2	SJI	0.46?

Table 2: Overview of slitjaw (SJI) channels. Slitj-jaw passbands are chosen using a filterwheel (FW). The light is imaged onto one 2072x1096 pixel^2 CCD with only one passband exposed/read-out at one time. Read-out is done with same CEB as NUV SG. Ranges, full width half max of passband (FWHM) and effective area are current best estimates based on pre-launch measurements. SJI passband types are either mirrors (M) or transmission filter (T).

1.3 Spatial and spectral resolution, field of view, focus

The spatial scale of the CCD detectors is 1/6 arcseconds, with the spectral scale varying between FUV and NUV (Table 1). IRIS will have an effective spatial resolution between 0.33 (FUV) and 0.4 arcsec (NUV), and an effective spectral resolution of <40 mÅ in FUV and <80mÅ in NUV.

The field of view imaged by IRIS is 175x175 arcsec^2 for the slit-jaw images. To create a raster of spectra of the Sun, the IRIS active secondary mirror is scanned (using PZTs, see section 3.4) in the direction perpendicular to the slit causing different regions of the Sun to be exposed onto the slit. The slit scan range is +-79 arcseconds, so that the maximum field of view of the IRIS rasters is 158x175 arcsec^2 for the SG.

The focus mechanism on the secondary allows a change in telescope focus. The spectrograph focus itself cannot be changed.

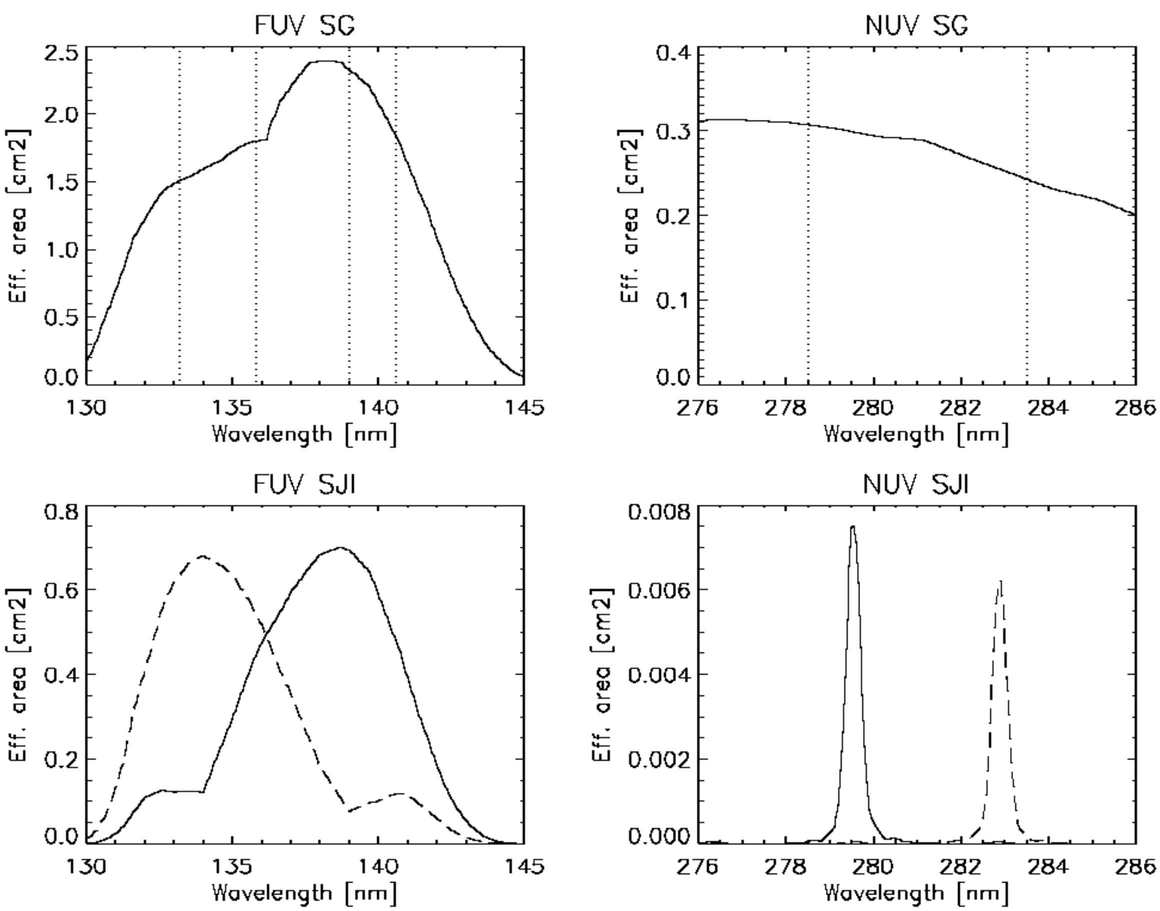

Figure 3: Effective Area of the FUV spectrograph (upper left), NUV spectrograph (upper right), both FUV SJI passbands (bottom left) and both NUV SJI passbands (bottom right).

1.4 Count rates, exposure times

IRIS effective areas are given in Tables 1 and 2 and Figure 3. Table 3 shows predicted count rates for the strongest spectral lines in the FUV and NUV passbands, and the four solar SJI channels (1330,1400, 2796 and 2832Å). IRIS will have thermal coverage from the photosphere (neutral lines, wings of Mg II h/k) through the chromosphere (Mg II h/k) and transition region (C II, Si IV, O IV) into the corona (Fe XII and Fe XXI). The high throughput of the instrument will allow short exposure times that enable measurements of the intensity, Doppler shift (down to 1 km/s) and line width. Deeper exposures will also reveal the full shape of the spectral line profiles (e.g., asymmetries).

The simultaneous slit-jaw images will have broader passbands, so they will contain a mixture of continuum and upper chromospheric (Mg II k) or transition region (C II, Si IV) emission. The upper chromospheric and transition region contributions are estimated to be in excess of 50% of the total emission of the passbands.

Ion Spectrum	λ	Δλ	Log T	Estimated Count Rate (counts/s/line/spatial pixel)			Detector
	Å	mÅ	K	Quiet Sun	Active Region	Flare	
UV Spectra (effective area of 1.8 cm^2 for far-UV, 0.25 cm^2 for Mg passband, continuum is 1 Å) †: Count rates for Mg II wing, h and k are in counts/s/spectral pixel/spatial pixel							
Mg II wing	2820	25	3.7-3.9	3500†	12500†	12500†	3
O I	1356	12.5	3.8	60	165	410	1
Mg II h	2803	25	4.0	1400†	5400†	20000†	3
Mg II k	2796	25	4.0	1800†	7300†	15000†	3
C II	1335	12.5	4.3	670	4300	45000	1
C II	1336	12.5	4.3	920	5700	55000	1
Si IV	1403	12.5	4.8	170	3000	3e6	2
Si IV	1394	12.5	4.8	370	6000	9e6	2
O IV	1401	12.5	5.2	50	230	4e5	2
O IV	1400	12.5	5.2	10	70	1e5	2
Fe XII	1349	12.5	6.2	20	50	500	1
Fe XXI	1354	12.5	7.0	10	40	4e4	1
UV Slit-Jaw Images				**Estimated Count Rate (counts/s/pixel)**			
Effective area 0.003 cm^2 with 4 Å FWHM filter for Mg II; 0.45 cm^2 with 40 Å FWHM for far-UV.							
Mg II wing	2831		3.7-3.9	1800	4100	4100	4
Mg II k	2796		4.0	450	2100	5100	4
C II	1335		4.3	500	1600	16000	4
Si IV	1400		4.8	380	1500	3e5	4

Table 3: Count rates for the strongest spectral lines observed with IRIS for three targets (quiet Sun, active region and flare) as estimated from spectral atlas data. Count rates assume a filling factor of 1/3 (i.e., assuming thin linear structures). Count rates will scale with the actual (unknown) filling factor of the Sun. These estimates are based on outdated effective area calculations (PDR) and need to be changed to reflect latest measurements (see Table 1/2).

2. General Operations Philosophy

2.1 IRIS Orbit

IRIS will be launched in a polar, sun-synchronous orbit with 98 degree inclination and a height of 620x670 km to maximize eclipse-free viewing. The IRIS orbit is similar to that of TRACE and Hinode and allows for 7-8 months of continuous observations per year, with strong atmospheric absorption occurring during the November-February time frame when the Sun is seen by IRIS at heights below ~200 km (FUV) and ~50 km (NUV) above the Earth's surface.

2.2 Data rate and downlink

IRIS data will be downlinked to X-band antennas in Svalbard, Norway (~9 passes/day), Alaska (~6 passes/day) and Wallops (~1-2 passes/day). As a result, IRIS will have a high average data rate of 0.7 Mbit/s, i.e., about 60 Gbits/day. Data (nominally 12 bits/pixel) will be compressed onboard using Rice compression, likely to about 3-4 bits/pixel. Onboard memory is 48 Gbits, allowing storage of more data-intensive observing sequences that can be downlinked later over the course of several orbits.

2.3 Baseline operations

The high datarate, short exposure times, and flexible rastering schemes (Figures 4, 5) will allow rapid scans of small regions on the Sun at very high spatial resolution of order 0.33-0.4 arcseconds. The baseline cadence is 5s for slit-jaw images, and 1s for 6 spectral windows of strong, bright lines.

IRIS rastering of spectra is accomplished through scanning of the active secondary mirror (by driving the PZTs). The flight software allows for (see Figure 4):

- dense rasters: step size of the raster is smaller or equal to the slit width (0.33 arcsec). The smallest possible stepsize is 0.054 arcsec according to current calibration of PZTs.

- sparse rasters: step size of each raster location is larger than the slit width. Stepsize is an integer number of smallest possible stepsize (n x 0.054 arcsec).

- sit-and-stare (fixed slit mode): no rastering.

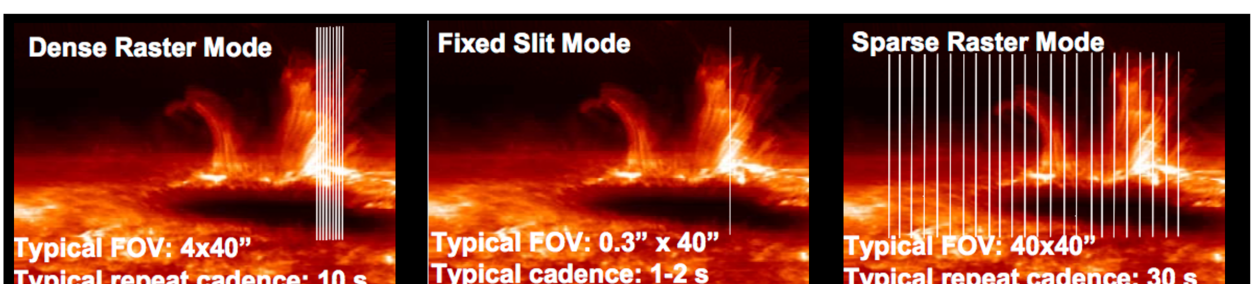

Figure 4: Some example raster modes of IRIS spectra include dense raster, sparse raster and fixed slit ("sit-and-stare") modes, with typical exposure times of order 1s, rasters of of order 4-40 arcsec wide can be obtained within 10-30s. Solar rotation tracking is also available for any of these options.

The sparse raster option will allow rapid scans of much larger areas, which can be used, for example, for flare or CME watch programs.

IRIS will be operated in a manner that is similar to TRACE and Hinode, with observing programs uploaded 5 times per week, and the data made publicly available within a day of the observation.

We will operate IRIS in full coordination with Hinode and SDO. IRIS will function as a microscope to instruments onboard Hinode and SDO, which have a spatial and temporal resolution that is significantly lower than IRIS. For example, IRIS can take a spectral raster across 6 arcsec and context slit-jaw imaging at 0.33 arcsec resolution within the time it take SUMER or EIS to expose one slit position (~20s) at 2 arcsec resolution (Fig. 4).

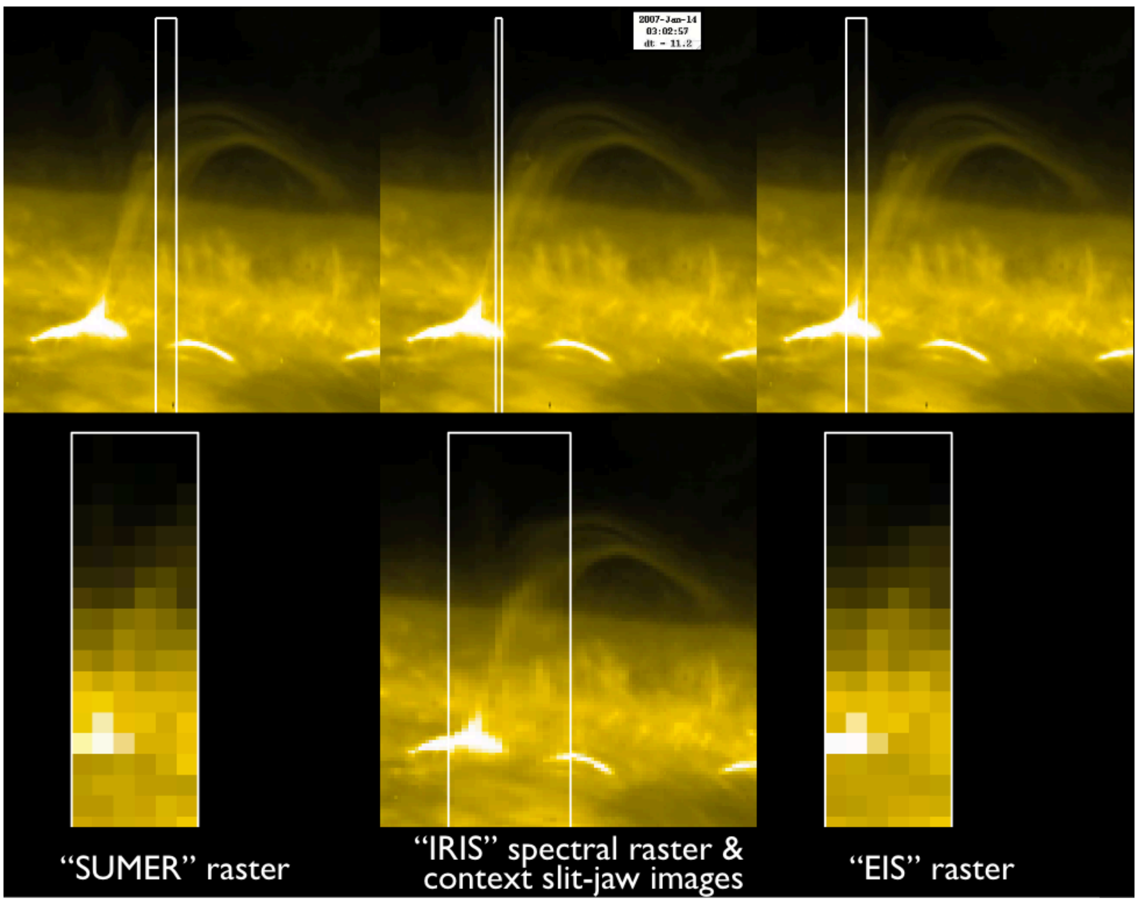

Figure 5: IRIS will allow faster rasters at higher spatial resolution than current instruments. The top row shows an example of a chromospheric image (taken with Hinode) showing a reconnection event, with SUMER, IRIS and EIS slit superimposed. The bottom row shows the observables SUMER, IRIS and EIS would produce given their spatial and temporal resolution. SUMER and EIS take full spectral rasters with 1 arcsecond wide slits at temporal resolutions of order 120-180s. IRIS takes a rapid raster with a 1/3 arcsecond wide slit at a cadence of 20 s and simultaneous slit-jaw images at a cadence of 5 s, and allows a full view of the event at a cadence that captures the dominant dynamics. A movie of this figure is available at http://iris.lmsal.com

To augment the IRIS data, we will have a special focus on coordination with ground-based observations that obtain chromospheric spectral line profiles over a large field of view (using Fabry-Perot interferometers).

Some sample observing sequences are illustrated in Table 4.

Science objective	Observing details Image size / cadence λ Range (FUV+NUV)/cadence	Spectrograph mode Raster stepsize / range Cadence / duration	Dataflow: Rate On-board memory margin Passes that can be missed
Measure energy of longi-tudinal & transverse waves	1335 Å &1400 Å: 384x512/ 20s Mg II k & wing: 384x512/ 20s Spectrograph: 4 Å+2 Å / 1s	*Dense Raster (rotation tracking)* 0.33″ steps / 6.6″x85″ 20 s raster cadence / continuous	*Baseline: 0.7 Mbit/s* 90% (if no passes missed) 1 pass/day for 10 days
Study microflare heating in chromosphere, TR and corona	1335 Å &1400 Å: 512x1024/10s Mg II k & wing: 512x1024/10s Spectrograph: 7 Å+4 Å / 1s	*Dense Raster (rotation tracking)* 0.33″ steps / 5″x171″ 15 s raster cadence / 5 hours	*Transient: 2.7 Mbit/s* 19% (if no passes missed) 2 of 2 passes for 5 hours
Study the formation and impact on transition region of spicules, surges and upflows	1335 Å &1400 Å: 256x512/15s Mg II k & wing: 256x512/15s Spectrograph: 4 Å+2.5 Å / 1s	*Dense Raster (rotation tracking)* 0.33″ steps / 4″x85″ 12 s raster cadence / 10 hours	*Minimum: 0.7 Mbit/s* 90% (if no passes missed) 5 of 5 passes for 10 hours
Study the evolution of promi-nences: motion in legs, re-connection signatures, waves	1335 Å &1400 Å: 384x512/20s Mg II k & wing: 384x512/20s Spectrograph: 8 Å+4 Å / 2s	*Sparse Raster (rotation tracking)* 1″ steps / 18″x85″ 36 s raster cadence / 1 week	*Modified Baseline: 0.7 Mbit/s* 90% (if no passes missed) 1 pass per day
Study flux emergence and flare/CME response	1335 Å: 512x512 / 2.5s Mg II k & wing: 512x512/10s Spectrograph: 8 Å+5 Å / 1s	*Sparse Raster (rotation tracking)* 2″ steps / 24″x85″ 12 s raster cadence / 12 hours	*Modified Transient: 1.5 Mbit/s* 19% (if no passes missed) 3 of 6 passes for 12 hours

Table 4: Sample IRIS observing sequences and modes.

2.4 Operations under roll conditions

The nominal direction of the IRIS slit is parallel with the solar north-south direction (roll angle=0 degrees). However, IRIS is capable of operating with the spacecraft rolled at an angle between -90 and +90 degrees from solar north. This allows for observing programs in which the slit is parallel with the solar limb at any position along the limb (from equator to the poles).

Operations under rolled conditions have two operational impacts that affect their timing and duration:

- reduced downlink datarate, caused by directional X-band antenna no longer pointing "straight down to Earth" for non-zero roll angles. This means that for some stations/seasons significantly shorter downlink passes are available and high datarate operations can only be maintained until the onboard memory is filled.

- certain roll angles are forbidden twice per month (first/last quarter of the Moon) because they can lead to a situation in which neither of IRIS two star trackers is free from Earth and/or Moon (which would result in IRIS going into "safe mode"). At least one star tracker is required to keep IRIS orientation stable. This limitation will be enforced on the ground.

More details of roll condition operations can be found in IRIS Technical Note 5.

3. Sequence control operations

3.1 General procedure

IRIS sequences are observational goals that specify the number, order and cadence of images and spectra to be acquired. The specification is split into three catagories:
1. CCD frame specification
2. Timing and order in which CCD frames are acquired (so-called framelist)
3. An observation program which executes a set of framelists

The IRIS sequencer is controlled by a set of tables that operate the mechanisms, cameras, and the data processing chain to deliver data to the spacecraft. These tables are defined on the ground, checked into a database, uploaded to the spacecraft, and called in the "daily" timeline that is sent up to the spacecraft. The hierarchy of these tables is shown in Table 6 in order of increasing frequency of change.

Acronym	Name of Table	Defines
CRS	Camera Readout Specification	Source, CCD regions, Summing Mode
FDB	Frame Definition Block	CRS, Exposure Time, Compression, Lookup Table
FRM	Frame List	Time, FDB, Repeat Count, PZT Offset (i.e., raster scan), Focus, Slitjaw Bandpass, Cadence
OBS	Observing List	Framelist, Repeat Count, Cadence

Table 6: List of Sequencer Tables that control the sequence of IRIS instrument operations

The CRS and FDB tables contain all information required to "take a picture":

1. CRS table data controls which data is read out from the CCD and sent on to the data compression/high rate interface (DC/HRI) board,

2. The exposure time and light source that are defined in the FDB are used for configuring the shutter,

3. At the time specified by the FRM and OBS the following sequence is started:
   a. the mechanisms are moved (if required/desired): focus position, PZT offsets, filterwheel,
   b. the shutter is opened,
   c. after exposure time, the shutter is closed.

4. Data then is read from the camera and sent to the DC/HRI board,

5. The compression parameters in the FDB are used by the DC/HRI to compress the images before sending them to spacecraft memory.

The flight software ensures that the shutters are not opened until all mechanisms have stopped moving and settled. In addition, the exposures controlled by all three shutters are synchronized so they all end at the same time, followed by the camera readout which then proceeds in parallel for both cameras. The typical sequence of events is illustrated in Figure 6.

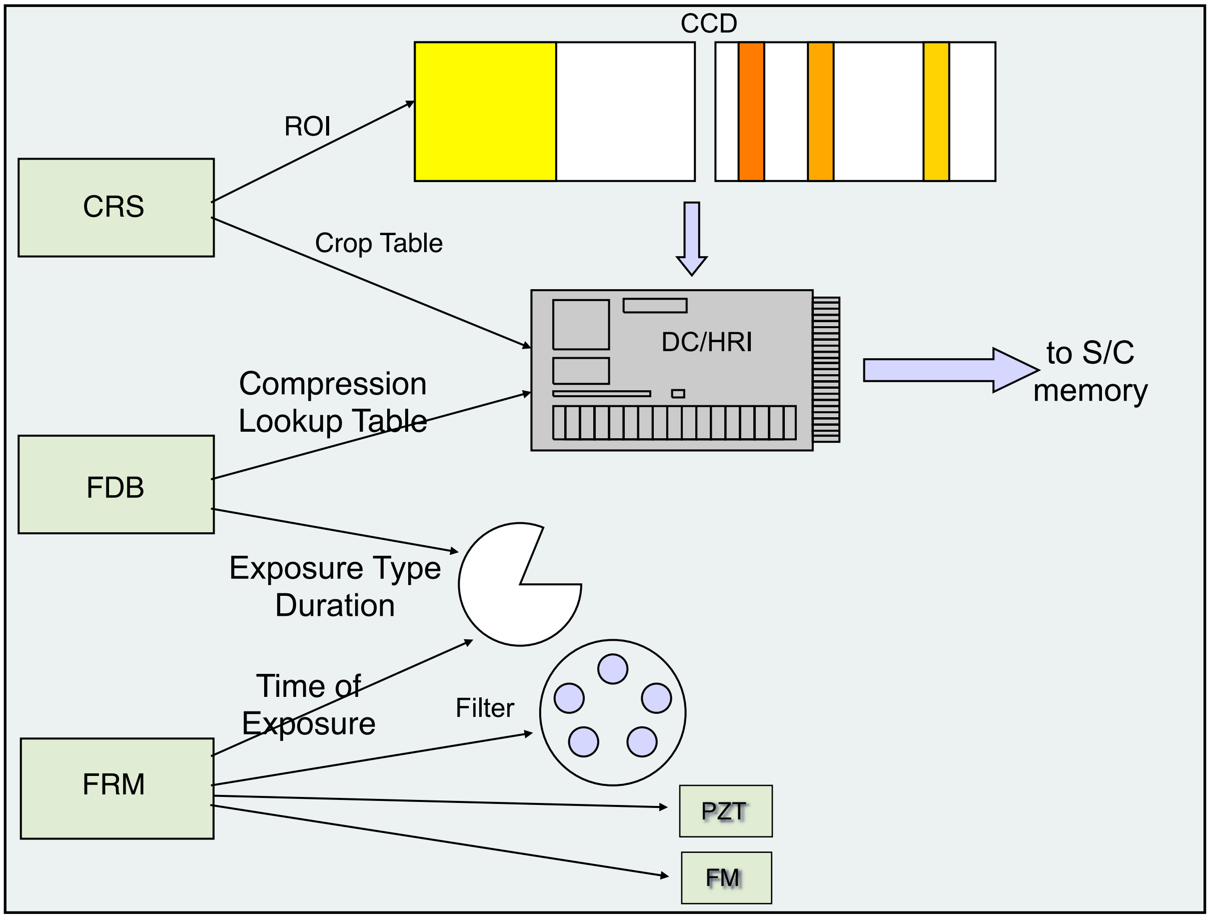

Figure 6: Diagram showing how IRIS images are taken and controlled by CRS, FDB and FRM.

Two flight spare SDO camera electronics boards (CEBs) are used to read the four CCDs. The 4 CCDs are actually configured to operate as 3 camera's, as illustrated in Table 5. Each CEB simultaneously reads out the two CCDs it is attached to, e.g., CEB 1 reads out CCDs 1 and 2 at the same time. All 4 CCDs can be read out at the same time using CEB 1 and CEB 2. The software allows for partial readout, e.g., spectral regions or a subset of the field of view.

Camera ID	Camera Electronics Board (CEB)	Source	Shutter	CCD ID
1	1	FUV SG	Large FUV shutter	1 and 2
2	2	NUV SG	Small NUV shutter	3
3	2	SJI	Small SJI shutter Filterwheel for bandpass	4

Table 5: Three IRIS cameras control the 4 CCDs allowing simultaneous readout of all CCDs.

3.2 Camera Readout Specification

The IRIS wavelength range is dominated by a few select bright lines that will be the focus of most observing programs. This means that the full spectral range of the CCDs will not typically be read-out. This is done to save telemetry and maximize the scientific value of the downlinked data. Instead, a selection of sub-regions will be read out (e.g., Figure 7). These subregions are defined in the Camera Readout Specification (CRS) table, which is defined in Table 8. In what follows, a “rows” is defined as having a specific wavelength and a wide range of spatial locations, whereas columns are defined as having a specific spatial location and a wide range of wavelengths. For example, to cover the full wavelength range, one needs all rows.

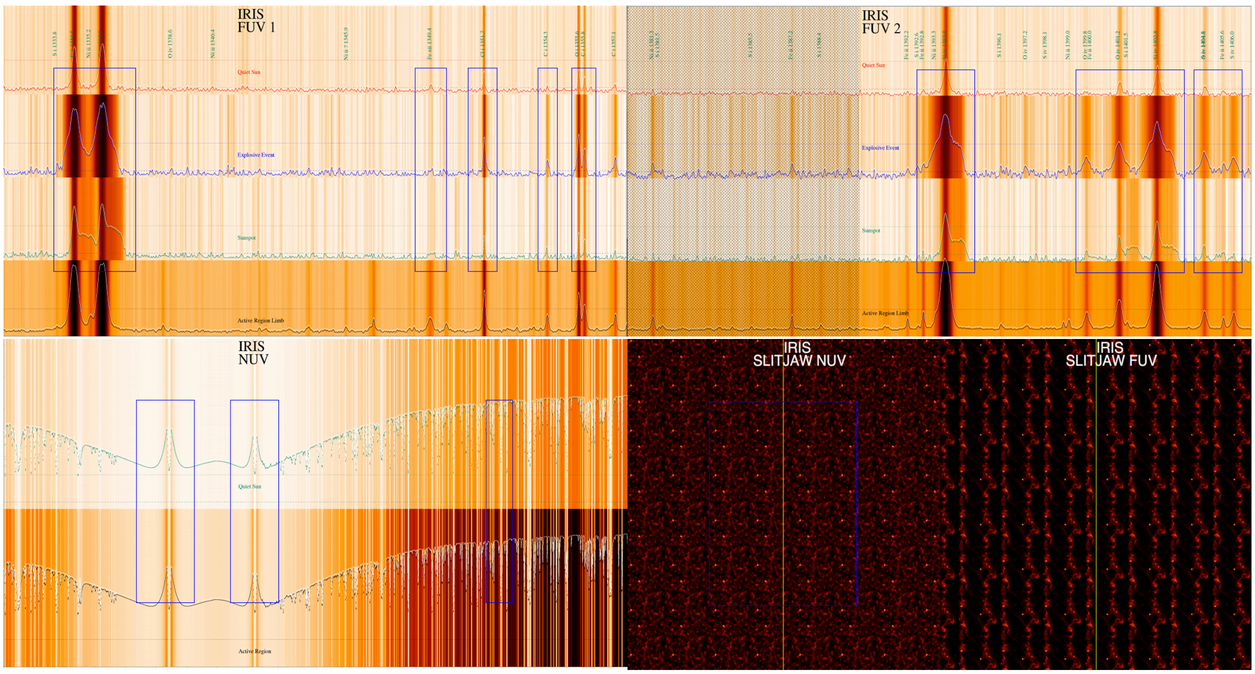

Figure 7: Three examples of the partial readout regions defined by CRS tables, overlaid on spectral atlas data. Top row: CRS for the FUV passband. Bottom left: CRS for the NUV passband. Bottom right: CRS for SJI image (NUV here). This figure does not show overscan rows or baseline stabilization columns.

Subregions are defined by cropping in both the spectral dimension (“rows” in FUV and NUV) and spatial dimension (“columns” in FUV and NUV, and both “columns” and “rows” in SJI). The following requirements on the CRS definitions are applied in the table load tool:

1. the start row and start column must be equal to 1 + a multiple of 4,
2. the end row and end column must be multiples of 4,
3. a maximum of 8 subregions is allowed: 8 in the FUV spectrograph, 6 in the NUV spectrograph and 2 in the SJI,
4. the total number of rows per subregion cannot exceed 2048,
5. the total number of rows selected in all subregions cannot exceed 4096; however if a full detector readout is defined (i.e., one single subregion), all 4144 rows can be read. This mode has been assigned to CRS 1,
6. in the spectral dimension, the data can be summed over 1, 2, 4 or 8 pixels
7. in the spatial dimension, the data can be summed over 1, 2, or 4 pixels
8. if rebinning 4x4, 8x2, the total number of pixels should be a multiple of 256
9. if rebinning 8x4, the total number of pixels should be a multiple of 512, and the number of rows should be a multiple of 8
10. each individual CRS can have a different summing mode

11. when taken at the same time, NUV and SJI need to have the summing mode
12. the allowed range of rows is 1-4144 for FUV, 1-2072 for SJI and 2073-4144 for NUV
13. the allowed range of columns is 5-1092 for all detectors (except for full-frame readout, where it is 1-1096)
14. full-frame readouts can only have 1x1 summing,
15. when summing, more complex rules apply to the CRS start and end row or column. These and other rules are outlined in Appendix A at the end of this document.

Header				
ID	Table Size	Number of sub-regions	Spectral (across rows) Summing Mode	Spatial (across columns) Summing Mode
4 byte integer, 1-4096 allowed	4 byte integer	maximum of 8 allowed	1, 2, 4 or 8 allowed	1, 2 or 4 allowed
Data				
Sub-region ID	Start Row	End Row	Start Column	End Column
4 byte integer, limited to 8	4 byte int, limited to: FUV: 1-4144 NUV: 2073-4144 SJI: 1-2072	4 byte int, limited to: FUV: 1-4144 NUV: 2073-4144 SJI: 1-2072	4 byte integer, limited to: 1-1096	4 byte integer, limited to: 1-1096

Table 8: CCD Readout Specification (CRS) Table with allowed ranges of values.

The camera reads out the CCDs from 4 ports (E, F, G, and H). These ports are located at low row numbers (E, F) and high row values (G, H), see Fig. 8. When charges are read out from the CCD, the charges are shifted from the original row number towards the closest port, with:

- E reads bottom half of FUV1 CCD (or SJI CCD), located closest to the low row and column numbers
- F reads top half of FUV 1 CCD (or SJI CCD), located closest to the low row numbers and high column numbers
- G reads top half of FUV2 CCD (or NUV CCD), located closest to the high row and column numbers
- H reads bottom half of FUV2 CCD (or NUV CCD), located closest to the high row numbers and low column numbers

Because of the camera architecture, when data is read from a subregion in FUV1, a subregion of the same size at a similar row offset from the ports is automatically read out on FUV2. The same occurs for SJI and NUV. This means that the region on FUV1 is reflected onto FUV2 and both the original and the reflected subregion are read out. The data in the reflected subregion is not transmitted to the ground unless it was selected in a CRS. To make matters more complex, original and reflected regions are merged when they are closer than 100 rows to each other. These merged regions are readout regions. Rules 1, 2, 4, 5 are also applied to the readout regions. All of this complexity is handled for the user by the Table Creation tool (see ITN 2).

Each of the CCDs has so-called “over scan rows” (OSR) and “baseline stabilization columns” (BLS), as illustrated in Fig. 8. These rows and columns are not part of the imaging array (and thus will not contain any solar data), but can be used to determine the CCD pedestal.

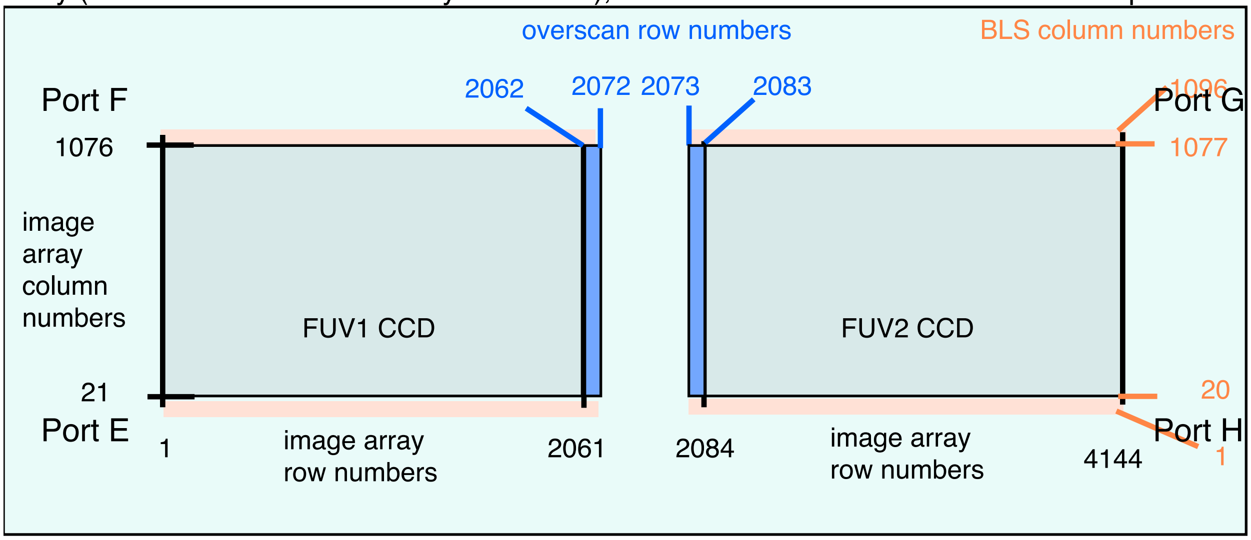

Figure 8: Diagram of FUV CCD array with baseline stabilization columns and overscan rows. Note that wavelength increases towards larger row numbers. NUV and SJI CCDs are similar to this setup with SJI taking the place of FUV1 and NUV that of FUV 2. Four serial registers are used to read out the CCDs, one at each external corner: E (1,1), F (1,1096), H (4144,1), G (4144, 1096).

The imaging array containing solar data is:
- FUV: columns 21-1076, rows 1-2061 (FUV1), rows 2084-4144 (FUV2)
- SJI: columns 21-1076, rows 1-2061
- NUV: columns 21-1076, rows 2084-4144

The overscan rows are:
- FUV: rows 2062-2083
- SJI: rows 2062-2072
- NUV: rows 2073-2083

The baseline stabilization columns are:
- FUV, NUV or SJI: columns 1-20, 1077-1096

The orientation of the detectors is such that (for roll angle = 0 degrees):
- FUV:
  - solar south towards increasing column numbers
  - increasing wavelength for increasing row numbers (row 1 is the shortest wavelength)
- NUV:
  - solar north towards increasing column numbers: **flipped compared to FUV**
  - decreasing wavelength for increasing row numbers (row 1 is longest wavelength): **flipped compared to FUV**
- SJI NUV:
  - solar north towards increasing column numbers: **flipped compared to FUV**
  - solar west towards increasing row numbers
- SJI FUV:
  - solar north towards increasing column numbers: **flipped compared to FUV**
  - solar east towards increasing row numbers: **flipped compared to SJI NUV**

Level 0 data will have the orientation mentioned above. For level 1 data, all images will be oriented to have solar north at the highest column numbers, solar west at the highest row numbers, and the longest wavelength (or solar west) at the highest row numbers.

By default, 36 “full-frame” CRS tables have been defined for FUV, NUV, SJI (table 8b). Only CRS 1 is a **real** full-frame, i.e, all rows and columns of both CCDs are read out (4144x1096). CRS 1 can be used for FUV, where both FUV1 and FUV2 will be read out, and for the SJI-NUV combo, where both NUV and SJI will be read out. Note that if CRS 1 is used for SJI, then the resulting frame automatically includes the NUV CCD as well. Similarly, if CRS 1 is used for NUV, then the resulting frame automatically includes the SJI CCD as well. This is an artefact of how the SJI and NUV are read by the same CEB.

Note though that if you want to expose the SJI *and* the NUV at the same time, they each need their own FDB/CRS.

All other CRS involve either summing, or a selection between NUV or SJI. Such CRSs are, because of hardware limitations, limited to 2048 rows in the readout region. They are thus not “full” frame (since there are 2072 frames in NUV or SJI, and 4144 in FUV), but “almost full” frame. Note that CRS 13-24 are limited to just the NUV CCD (in contrast with CRS 1). The region of interest in the CRSs is the same, irrespective of the summing mode. Similarly, CRS 25-36 only cover the SJI CCD.

CRS 1 is the only CRS that can be used for FUV, NUV or SJI. All other CRSs are specific to the passband.

All of these CRS are available as defaults on the server.

"Full-frame" CRS tables		
CRS-id	**Type**	**Summing (Spat/Spec)**
1	FUV/NUV-SJI	1x1
2	FUV	1x2
3	FUV	1x4
4	FUV	1x8
5	FUV	2x1
6	FUV	2x2
7	FUV	2x4
8	FUV	2x8
9	FUV	4x1
10	FUV	4x2
11	FUV	4x4
12	FUV	4x8
13	**NUV**	**1x1**
14	**NUV**	**1x2**
15	**NUV**	**1x4**
16	**NUV**	**1x8**
17	**NUV**	**2x1**
18	**NUV**	**2x2**
19	**NUV**	**2x4**
20	**NUV**	**2x8**
21	**NUV**	**4x1**
22	**NUV**	**4x2**
23	**NUV**	**4x4**
24	**NUV**	**4x8**
25	*SJI*	*1x1*
26	*SJI*	*1x2*
27	*SJI*	*1x4*
28	*SJI*	*1x8*
29	*SJI*	*2x1*
30	*SJI*	*2x2*
31	*SJI*	*2x4*
32	*SJI*	*2x8*
33	*SJI*	*4x1*
34	*SJI*	*4x2*
35	*SJI*	*4x4*
36	*SJI*	*4x8*
37	*SJI NUV*	*1x1*
38	*SJI NUV*	*2x2*
39	*SJI NUV*	*4x4*
40	*SJi FUV*	*1x1*
41	*SJI FUV*	*2x2*
42	*SJI FUV*	*4x4*

Table 8b: List of "full-frame" CRS tables

3.3 Frame Definition Block

The frame definition block (FDB) specifies the properties of the data acquired from the camera.

The structure of this table is shown in Table 9. The FDB contains a single CRS ID for which the exposure time, exposure type, compression parameters, lookup table ID and maximum exposure time (for AEC, see technical note 6 for details) are given. All exposure times are given in milliseconds (ms).

Header							
ID	Table size						
4 byte integer, 1-4096	4 byte integer						
Data							
CRS ID	Exposure duration	Exposure Type	Compression Parameter N	Compr. Parameter K	Lookup Table ID	Max AEC ex-posure	Min AEC ex-posure
4 byte integer	4 byte integer, in millisecond s (ms)	4 byte int, Light: 1 Dark: 2 LED: 3 Test: 4	4 byte integer, limited to: 6-16	4 byte integer, limited to: 0-7	4 byte integer 1-8	4 byte integer, in ms	4 byte integer, in ms

Table 9: Frame Definition Block (FDB) with allowed ranges of values.

There are four different types of exposures that IRIS can take:
- dark: these are taken for calibration ("dark current") purposes by keeping the shutter closed
- light: this is the nominal observing mode in which the shutters are used to expose the detectors
- LED: in this observing mode light from either an NUV or an FUV LED is projected onto the detector, instead of sun-light. This mode can be used to help calibrate the gain of the cameras
- camera test pattern

IRIS compression is based on Rice compression and a lookup table. See technical note 7 for details of the N and K parameters. We will typically run with N=14. Decreasing numbers of K indicate increasing compression. If N=16 or K=255, then no compression occurs. If lookup table ID is set to 0, then a lookup table is not used. A maximum of 8 lookup tables are allowed onboard at any time. However, up to 16 tables can be loaded into the DCHRI. Information on the HMI and AIA lookup tables can be found at http://sun.stanford.edu/~rock/iris/lookup_tables/

The current list of lookup tables onboard is:

LUT ID	Description	File name at Stanford
0	No LUT applied	N/A
1	Inverse lookup table	inverse.k
2	HMI flight (piecewise linear/square root)	hmi_c3_plin.k
3	AIA flight (square root)	aia_csnr_025.k
4	AIA square root	aia_csnr_050.k
5	AIA square root	aia_csnr_100.k
6	HMI piecewise linear/square root	hmi_c3_5_plin.k
7	HMI piecewise linear/square root	hmi_c4_plin.k
8	HMI piecewise linear/square root	hmi_c4_5_plin.k

A lookup table id of "0" indicates that no lookup table is being used and K may range in value from 0 to 7 (but must be less than N), and N may range in value from 6 to 14.

A non-zero lookup table id requires that N=14 in order to not truncate the data before the lookup table function. K may again be in the range from 0 to 7.

The maximum exposure time set in the FDB determines the exposure time beyond which the AEC algorithm will not increase the exposure time if AEC were operating. If Max exposure time is set to 0, then the AEC algorithm will automatically set it to the default exposure. The maximum exposures that can be taken for any frame are 63.999 seconds.

The minimum exposure time set in the FDB determines the exposure time beyond which the AEC algorithm will not decrease the exposure time if AEC were operating. If Min exposure time is set to 0, then the AEC algorithm will not go below an exposure time equal to to the minimum exposure time set by the global “min exposure time” variable. Exposure times cannot be set to shorter than 20 ms (software limit). In practive, NUV/SJI shutters have a minimum exposure time of 36 ms, and FUV is minimum 112 ms.

3.4 Frame List

The frame list (FRM) specifies a list of frames (or CCD readouts) which are obtained as a unit. At any given relative time (in ms), frames can be taken using the CCDs for the slitjaw, the FUV spectrograph and/or the NUV spectrograph. For each time step, the focus position of the telescope, and the offset of the PZTs can be set. This is illustrated in Table 10. This table can contain contain up to 4096 (?) lines (although the spacecraft buffer for this table type would fill up before that happens), with each line at a different “Time”. The times are relative, in milliseconds, with respect to the initiation of the execution of the frame list.

Header		
ID	Table size	Number of Entries
4 byte integer, 1-4096 allowed	4 byte integer	4 byte integer

Data													
Time	SJI FDB ID	NUV FDB ID	FUV FDB ID	SJI AEC ID	NUV AEC ID	FUV AEC ID	Flush	Inhibit skip	FW pos	Focus pos	PZT A Offset	PZT B Offset	PZT C Offset
4 byte int,ms	4 byte int	4 byte int	4 byte int	4 byte int	4 byte int	4 byte int	2 byte int	2 byte int	4 byte int	4 byte int	4 byte int	4 byte int	4 byte int

Table 10: Frame List (FRM) with allowed ranges of values.

Time/FDB-ID: At each time step (i.e., each line in the FRM), one can specify whether to take an SJI image, an NUV spectrum and/or an FUV spectrum by filling in the FDB ID for each of these three “channels” of images. If the FDB-ID is set to 0, then no “image” is taken for that respective channel. Note that SJI and NUV taken at the same time should have FDBs with the same type of light source (Light/Dark/LED/Test Pattern). If they do not, the light source defined in th SJI frame has priority.

AEC ID: The logic involving the AEC-IDs for each channel (SJI, FUV, NUV) is explained in IRIS Technical Note 6 on AEC operations. If the AEC-ID is set to 0 for a particular channel, then AEC is not operated on that particular channel.

FLUSH: The flush command is executed before exposure and readout. The parameter can take the values 0 (default), 1 and -1:

- If Flush=0, the CCD is not cleared of charges before exposure. This means that any charge left on the CCD either from accumulation of dark current in between exposures, or from a previous exposure is still on the CCD.
- If Flush=1, the CCD is cleared of all charges before exposure.

- If Flush=-1 then the flush command will only be executed if the FLUSH command at the OBS list which is calling this FRM list is set to 1. If the OBS list FLUSH command is set to 0, then no flush will be executed.

INHIBIT SKIP: This parameter controls whether all charges are removed from the CCD during readout. During normal operations, in order for the data in the sub-regions defined in the CRS to be digitized and saved to memory, all charges between the serial registers and the ending row of the sub-region furthest removed from the serial registers need to be clocked (i.e., transferred) to the serial registers. The rows that are not in the CRS are "skipped" (i.e., just clocked to the serial register but the charge is not actually read out or digitized). INHIBIT SKIP controls whether the remaining rows (those beyond the ending row of the last subregion) should be "skipped" (i.e., transferred) or not. It is a bit of unfortunate name and can be translated into "DO NOT CLEAR CHARGE DURING READOUT".

INHIBIT SKIP can take the values 0 (default), 1 and -1:

- If INHIBIT SKIP = 0 then the remaining rows are transferred (i.e., "skipped") during readout. This means that all the charges are removed from the CCD during readout.
- If INHIBIT SKIP=1 the remaining rows are not skipped and while they have been shifted from their original position on the detector, they will remain on the detector. Charges will remain on the detector.
- If INHIBIT SKIP=-1 then the INHIBIT skip command will only be executed if the INHIBIT SKIP command at the OBS list which is calling this FRM list is set to 1. If the OBS list INHIBIT SKIP command is set to 0, then inhibit skip is disabled, i.e., all charges are removed from the detector.

This parameter thus follows the same logic as the FLUSH commands at the OBS and FRM list level.

Note that if a program is run without any flush commands and inhibit skip is set to 1, this means that during readout charges are only shifted until the subfields (associated with the region of interest or ROI) have been shifted to the edge of the CCD. This can leave charges on the CCD (that have been shifted there from the region further away from the read-out locations), but allows for a faster read-out. It can be useful for operations in which fast cadence is preferred, and should be used with care so that remaining charges do not interfere with new exposures. For example, Flush=0 & INHIBIT SKIP=1 could be useful for operations in which exposure times are relatively short so that only a small area of the detector (e.g., the region around the two strong C II lines in the FUV bandpass) receives a significant number of photons leaving the region longward of the CII windows free of charges. This allows the charges of the C II window to be rapidly shifted to the edge of the CCD and read-out without having to shift ALL charges from the whole CCD before taking the next exposure. Note that if no flush command is executed the dark current charges will accumulate between exposure times.

SJI Passband	FW Position - Type	Wavelength (Å)	FWHM bandpass (Å)
Glass	1/2 - T	5000?	2000?
1330	31/32- M	1330	40
2796	61/62 - T	2796	4
1400	91/92 - M	1400	40
2832	121/122 - T	2832	4
Broad-band	151/152 - M	1600	400?
Null (no move)	N/A	N/A	N/A

Table 11: Overview of filterwheel positions for all IRIS slitjaw (SJI) channels. Ranges, full width half max of passband (FWHM) and effective area are current best estimates based on pre-launch measurements. SJI passband types are either mirrors (M) or transmission filter (T).

FW pos: The FilterWheel (FW) position controls the position to which the the filter wheel that contains the various prefilters for the slitjaw channel is rotated. Table 11 lists the current best estimates (pre-launch) of which filter corresponds to which filter-wheel position. A filterwheel position of 9999 corresponds to a “No move” command. Note that a FW position can be changed even if no SJI image is taken at the time.

Focus Pos: The focus of the IRIS telescope can be adjusted by moving the secondary mirror, which is achieved by using the focus motor. The focus position can have allowed values between -200 and 350. In-orbit calibration will be required to determine the most optimal values. Current best estimates (pre-launch) indicate that a focus position of -60 is close to optimal. It is also possible to set the focus position to 9999, which corresponds to a “No move” command. As a policy, we will create FRM tables with “no move” (9999) and set the focus at the timeline software.

PZT (ABC) Offset: The position and orientation of the active secondary mirror of the IRIS telescope is controlled by a set of three piezoelectric transducer (PZT) actuators: A, B and C. These PZTs are oriented relative to one another so that they can be used to change the light feed into the IRIS slit in two directions: H and V, with H perpendicular to the slit and V along the slit. This is illustrated in Figure 9. PZT A, PZT B and PZT C are in datanumbers (DN) and have physically meaningful values between -2048 and 2047. H and V are in arcseconds on the Sun.

The relationship between H and V and the PZT A, B and C is dependent on temperature and will be different after launch. The most up-to-date values pre-launch are as follows:

H = 0.866 * ((B-off)*s3 - (C-off)*s2)

V = ((A-off)*s1 - (B-off)*s2/2 - (C-off)*s3/2)

with s1= 0.0293 arcsec/DN, s2=0.02905 arcsec/DN, s3=0.02905 arcsec/DN.

In addition, we have:

A = off + 2/3 * (V/s1)
B = off - 1/3 * (V/s2) + 1/sqrt(3) * (H/s2)
C = off - 1/3 * (V/s3) - 1/sqrt(3) * (H/s3)

with A, B and C all limited to values between -2048 and 2047. The “off” variable is set to -250 (pre-launch) and ensures that offsets are centered within the available physical range. Note that “off” is set to 0 when calculating PZTA(BC) Step from XStep and Ystep (and vice versa) since those values are multiplied with the frame loop counter and should be the “derivative”.

Note that the table load tool (see Technical Note 2) allows user entry of H and V and calculates PZT A, B and C for the user when creating the tables.

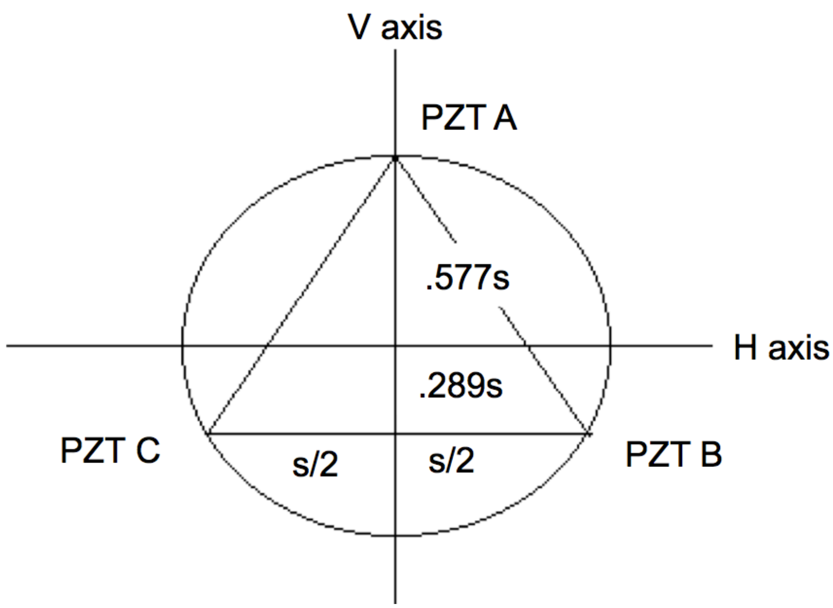

Figure 9: Diagram of the orientation of PZTs A, B and C with respect to the H-axis (perpendicular to the slit) and V-axis (along the slit). The circle represents the active secondary mirror which is controlled by the PZT’s which act as “pistons” to change the orientation of the mirror. To keep the center of the mirror at the same position (i.e., in focus), PZT A + PZT B + PZT C are kept to 0 by the table creator tool.

For rasters (i.e, OBS/FRM lists), the practical range of values for H is +- 65 arcseconds (but see Fig. 9b).

The range of values for V is about +-60 arcseconds (see Fig. 9b). Note that the range of PZT values available to the OBS/FRM lists is -1650 to +1100. Jitter, momentum management, solar rotation tracking and wedge motor offsets are allocated the rest of the available range (+-80 arcseconds).

To ensure that focus is kept, the practical range of H and V is different for various values of H and V. The practical range is a hexagon in H/V space, as shown in Fig. 9b. These limits are maintained by the table creator.

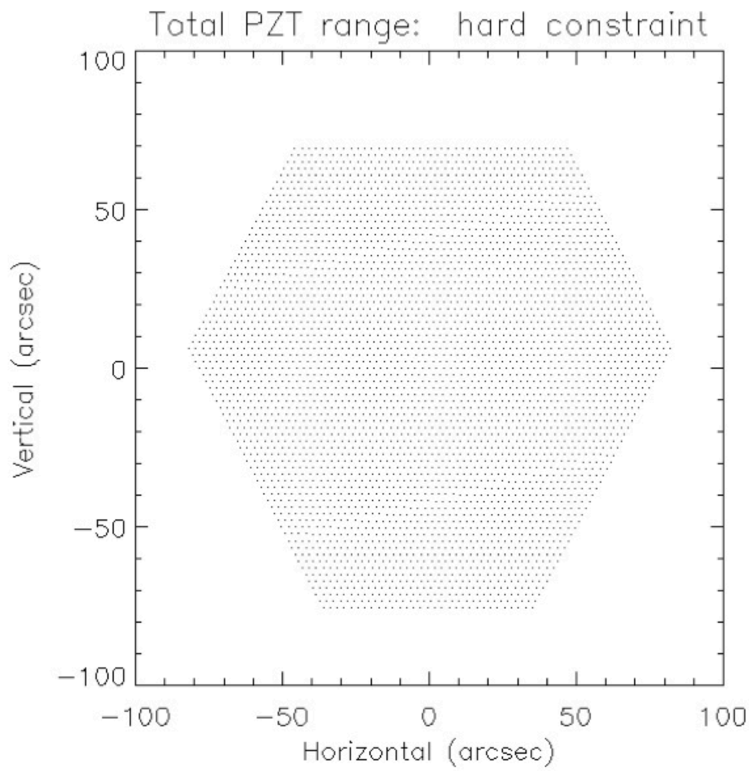

Figure 9b: Practical range of H and V (i.e., PZT ABC) as enforced by the table creator tool.

3.5 Observing List

The observing list (OBS) calls a sequence of frame lists (FRM) and is the work horse in terms of running sequences of spectral rasters and slit-jaw images. While rasters can in principle also be controlled at the FRM list level, the OBS lists are in reality more flexible, as demonstrated below and in section 3.7.

Header

ID	Table size	Relative Time -Tr (start of OBS list)	Number of Entries	Repeat (overall)	Cadence (overall)
4 byte integer, 1-4096 allowed	4 byte integer	4 byte int, ms	4 byte integer	4 byte integer	4 byte int, ms

Data

Rel. Time	FRM ID	Repeat (FRM)	Flush	Inhibit Skip	Tag Number	Cadence (FRM)	PZT A Abs Offset	PZT B Abs Offset	PZT C Abs Offset	PZT A Step	PZT B Step	PZT C Step
4 byte int,ms	4 byte int	4 byte int	2 byte int	2 byte int	12 byte char	4 byte int ms	4 byte int -2048-2047	4 byte int -2048-2047	4 byte int -2048-2047	4 byte int -2048-2047	4 byte int -2048-2047	4 byte int -2048-2047

Table 12: Observing List (OBS) with allowed ranges of values.

HEADER:

- At the top level (HEADER) the **OBS ID number, start time of OBS list, number of entries,** and **overall repeat number and cadence** are defined.

- The start time of the OBS list of relative time Tr is the offset time to start the sequence from the time set at the timeline for OBS start. It is only applied only on the start of the very first repeat of the OBS, i.e., it is a global shift that is not repeated at every repetition of the OBS.

- **Number of entries**: the number of time steps included and called out in the DATA section of the OBS list (with one time step per line in the DATA section).

- **Repeat (overall)** count in the HEADER defines how many times the OBS list is repeated.

- **Cadence (overall)** in the HEADER defines the time it takes to execute the time steps in the DATA section once.

- The total time the OBS list takes is thus **Cadence (overall)** x **Repeat (overall)**.

DATA:
The DATA section of the OBS list contains a variable **number of “entries”**, i.e., (relative) time steps since the start of the OBS list. At each timestep a framelist is executed.

- **Relative Time**: Each line in the DATA section defines what should occur at that **Relative Time** (in ms).

- **FRM ID**: At every time step of the OBS list one can call out one **FRM ID** which is executed at a specific **cadence (FRM)**. This is the time it takes the instrument to execute the FRM ID once.

- **FLUSH**: This parameters controls for the current framelist whether a flush command will be executed (1) or not (0) for any of the frames for which the flush is set to -1 in the FRM. In other words, the OBS list FLUSH command (which can only take values 0 and 1) does not execute a flush command by itself but is passed on to the framelist (FRM). For each frame in the FRM list there is a separate FLUSH command which can take the values 0 (do not perform flush), 1 (perform flush) and -1 (only perform flush if FLUSH command at OBS list is set 1). Note that any frames with FLUSH = 0 or 1 will ignore the OBS list FLUSH command.

- **INHIBIT SKIP**: This parameters controls for the current framelist whether during readout all charges will be removed (0) or whether some charges (beyond the ending row of the last subregion to be read out) will be left on the CCD (1) for any of the frames for which the “inhibit skip” is set to -1 in the FRM. In other words, the OBS list INHIBIT SKIP command (which can only take values 0 and 1) follows the same logic as the FLUSH command: it does not execute an INHIBIT SKIP command by itself but is passed on to the framelist (FRM). For each frame in the FRM list there is a separate INHIBIT SKIP command which can take the values 0 (remove all charges), 1 (do not remove all charges) and -1 (only remove charges if INHIBIT SKIP command at OBS list is set to 0). Note that any frames with INHIBIT SKIP = 0 or 1 will ignore the OBS list INHIBIT SKIP command.

- **Cadence (FRM)**: This **cadence (FRM)** can in principle be set to any number, but if it is lower than the actual time it takes to perform all steps of the FRM ID, the flight software will first execute the FRM ID before accepting the next entry in the OBS list. Any OBS list entries that were called out to occur at relative times before the FRM ID actually finished will be skipped and not executed. To avoid this problem the user should ensure that the cadence and following relative times are long enough. The table load tool assists in this by automatically calculating the minimum time it takes the instrument to execute the FRM, so that skipping can be avoided (in principle).

- **Repeat (FRM):** The FRM ID can be repeated any number of times given by the **repeat (FRM)** number. The relative time of the next entry needs to be equal or larger than **Relative Time of previous entry + repeat (FRM) x cadence (FRM),** otherwise (part of) the next OBS list entry will be skipped. *If Repeat (FRM) = 0 the PZT (ABC) Steps entries are ignored for this FRM.*

- **Tag**: Each time step can be **tagged** with a 12 byte character string that briefly summarizes the type of observation taken at this time step (e.g., “SJI-FNSdense” == slitjaw, Fuv, Nuv, dense raster).

- **PZT**: For each pointing in the FRM, the PZT (ABC) values are calculated by using PZT (ABC) Offset and PZT (ABC) Steps, with:

PZT (ABC) = PZT (ABC) Offset + PZT (ABC) Step x FRM counter + PZT (ABC) Offset_FRM

in which :

- FRM counter is at the OBS level, with 0 for the first execution of the FRM,
- FRM counter is incremented (at the OBS level) by one for every subsequent repeat of the FRM (given by **Repeat (FRM) at OBS list level**)
- PZT (ABC) Offset_FRM is the PZT (ABC) Offset value set in the FRM definition

This means that if **Repeat (FRM) = 0**, then **PZT Step** is ignored

- If PZT (ABC) Offset = 9999, then the formula is changed:
PZT(ABC) = PZT(ABC)_previous + PZT(ABC) Step x(FRM counter+1) +PZT(ABC) Offset_FRM

in which: - PZT (ABC)_previous is the position of the previous timestep (i.e., the sum of the OBS and FRM commanded PZT values)
This allows for execution of a FRM with a pointing that is relative to the previous FRM.
Note that at the start of each OBS list, the PZT values are initialized to 0.

For the special case of PZT (ABC) Offset = 9999 in the very first line of the OBS (this is not actually allowed in flight OBS, but was allowed for test sequences), the PZT_previous is initialized to 0. Following the formula above (for PZT=9999), a step is immediately taken (if PZT (ABC) Step is non-zero).

- **PZT (ABC)**: The PZT variables determine which position on the Sun is being fed into the slit by moving the secondary mirror of the telescope. Note that this is not an “absolute offset on the Sun”, but rather an “offset relative to the mid-point of the range over which the secondary mirror can be moved (+-79 arcsec)”. This latter position is relative to the absolute position on the Sun that is commanded at the timeline level using the wedge motors that offset the guide telescope from the main telescope direction (see section 4).

Note that all PZT (ABC) Offset and Step values can be entered as HV Offsets or Steps in the Table Load Tool, which will automatically transform these into PZT (ABC) Offset or Step values.

3.6 Instrument timing

The "Take Picture" operation of IRIS involves a sequence of events each of which takes a certain amount of time. The timing involved in this sequence sets the minimum (fastest) cadence that IRIS can obtain. In the following we list the timings of various events in the (sequential) order in which they occur when executing an OBS list. The timings are based on pre-launch values. There are three groups of events that are optimized for fastest cadence operations so that they are in part sequential and in part parallel, as illustrated in Figure 10 and explained below.

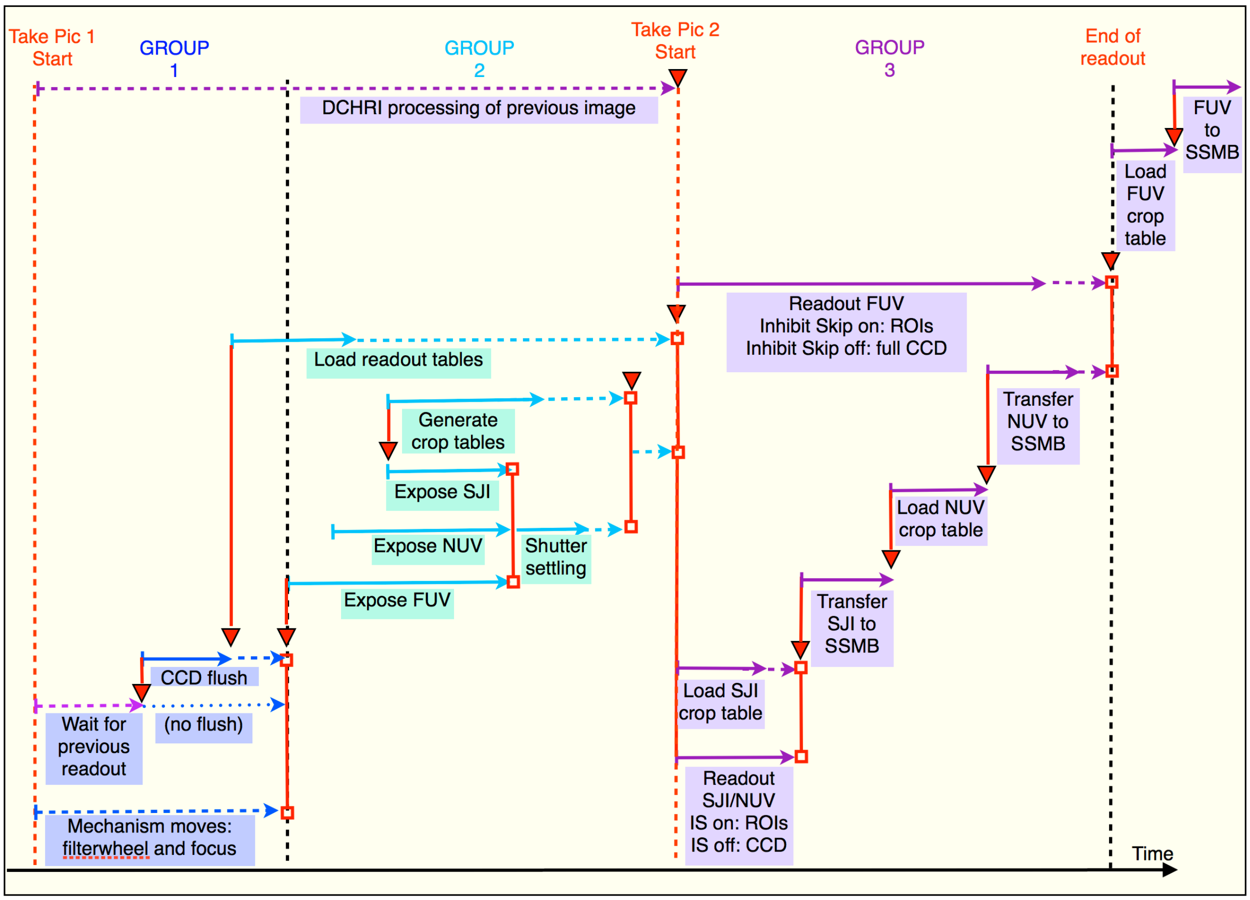

Figure 10: Illustration of sequence of events during "Take Picture" operation.

The sequencer software will take images ("Take Pic Start") at the times set by Tr in the OBS and FRM tables. However, those images will not be obtained if the "Take Pic Start 2" is commanded to occur when operations related to the current image (Group 1 and Group 2) or the previous image (Group 3) are not yet finished. The challenge in building FRM and OBS tables is to choose the cadence that runs the sequencer as fast as possible without trying to run too fast (which would lead to skipped frames). The table creator and associated code attempts to take care of this for the planner.

Group 1 includes mechanism moves, waiting for readout of previous image(s) and CCD flush.

Group 2 starts with the longest exposure time and ends with the start of the readout and/or DCHRI processing of the previous image.

Group 3 includes camera readout and processing of the images in the Data Compression and High Rate Interface to the Solid State Memory Board (SSMB), i.e., the onboard memory. As soon as the readout starts, the mechanism moves could in principle start and a new "Take Picture" sequence can start.

The minimum time between consecutive "Take Picture" events is given by:

Min Cadence = MAX(Δt_Group 1_and_2, Δt _Group 3)

GROUP 1 EVENTS: FW and Focus Mechanisms, CCD Flush command

1. As soon as the "Take Picture" sequence starts, filterwheel rotation can be commanded in parallel with "Waiting for previous Readout" or "Focus mechanism move". Filterwheel rotation between two adjacent positions duration is: Δt = 0.255 s (including settling time). For every additional position, add 0.177s. For example, to move from the 1330Å to the 2832Å passband, the filterwheel moves by 3 positions, so the total time = 0.255+ 2 x 0.177s = 0.60 s. Note that this time delay only occurs if the new position is NOT "Null" and is different from the position during the previous "Take Picture operation".

2. Focus position change occurs in parallel with filterwheel move and/or previous readout+CCD flush. Duration is: Δt= 32 ms per focus step. When moving between both extrema of the focus range, the total time for this activity can be very significant (~20s).

3. Wait for previous readout to finish. This will depend on the duration of the readout of the previous image(s).

4. CCD flush time can only be started when the previous readout is done. Duration is: Δt= 242 ms per CCD + 32 ms overhead to start the flush. The CCD flush action occurs in parallel with the filterwheel rotation (if FLUSH is set).

Group 1 ends when either the FLUSH (or the previous readout if no FLUSH is commanded) is finished and/or when the mechanism moves are done, whichever is the longest.

5. Note that the readout tables need to be loaded before readout. This process starts as soon as the flush is done and the CEB headers are sent to the camera (the latter takes 24 ms). It continues to be executed while the exposures are taken and is thus running in parallel with exposures. The duration for readout tables loading is dependent on the number of readout regions (i.e., merged regions of interest): 52.2 ms (1 region), 97.2 ms (2 reg.), 142.2 (3 reg.), 187.3 (4 reg.), 232.3 (5 reg.), 277.4 (6 reg.), 322.4 (7 reg.), 367.5 ms (8 reg.). If inhibit skip is off, 28.45 ms are added to these load times.

GROUP 2 EVENTS: Exposure time for SJI, FUVS and NUVS, generate crop tables

1. Δt= exposure time set in the FDB that are used by the FRMs in this “Take Picture” command. All exposures are timed such that they end at the same time, so the total time this phase takes is given by the maximum of exposure times. Note that there is some overhead on exposure times to make sure the shutters have settled before readout starts. This is 156 ms for FUV exposures, 82 ms for SJI and 94 ms for NUV. For runs on the brassboard, 90 ms overhead is used for all images. This overhead is added at the end of the exposure times.

2. Crop table generation is started as soon as the shortest exposure has been started. The crop table is used by the DCHRI to determine which data to take and which to “drop”, i.e., to cut out the regions of interest defined by the CRS. This process runs in parallel to the exposures. The duration of this state is: Δt=(C * 137) + (R * 0.05) ms, in which C is the number of crop tables being generated, and R is the total number of rows for all regions. Note that there is significant complexity in this calculation as the crop tables are only generated if they are not already in the buffer of 16 most recently used crop tables. In addition, each NUV/SJI combo is counted as two separate crop tables: one for NUV and one for SJI.

3. There is some additional overhead to this state caused by starting the readout (46 ms) and getting the open/close times for each shutter (32 ms), and generating the Instrument Status Packet (ISP) for NUV (16 ms) or FUV (16 ms).

4. The readout cannot start until the DCHRI has processed the previous image. In principle one could store two images in the Camera Interface (CIF) buffer, but as a policy and to avoid confusion, cadence calculations are done based on the rule that the previous DCHRI processing should be finished before starting a new “Take Pic” sequence.

GROUP 3 EVENTS: Camera Readout and DCHRI processing for SJI, FUVS and NUVS

This process is both parallel and serial in nature. While the camera readout is parallelized, with FUV and NUV/SJI readout occurring simultaneously, there is only one DCHRI and it always processes images sequentially in a specific order: SJI, NUV and FUV. Of course, if a frame does not include all three flavors of images, it will skip those. The DCHRI can start processing the SJI images as soon as those are readout. If the FUV readout is longer than the SJI/NUV readout, the DCHRI processing of SJI and NUV images can run in parallel with FUV readout. If SJI/NUV readout is longest, then the full DCHRI processing waits to start until the SJI is read out.

1. Camera readout: Δt= T_skip + T_read with:
   T_skip = T0 + Trs * Ns with T0 = 0.314 ms, Trs = 0.1 ms and Ns is number of skipped rows (i.e., rows that are not in the ROI)
   T_read = (Tcs + Trs) * Nr with Tcs is the column summed row read time of 0.274 for 1x, 0.178 for 2x and 0.130 for 4x row summing, and Trs is the summer row shift time of 0.1 ms for 1x, 0.2 ms for 2, 0.4 ms for 4x or 0.8 ms for 8x, and Nr is the number of post-summed rows reads.

Note that if inhibit skip is set to 1, Ns is the number of rows not in the ROI as counted from the port to the row furthest to the port. If inhibit skip is set to 0, then Ns is the total number of rows that is not in the ROI.

2. DCHRI processing involves loading of the crop table, compression of the data, and transferring the image data to the spacecraft data interface and memory board. This wait occurs for each image sent from the instrument. Since there is only one DCHRI and it can only run one process at a time these activities need to occur sequentially. This process is started right after the various readouts from the current frame. The duration of the DCHRI transfer is given by: Δt= Npix * CF /869 * 0.01964 ms in which Nx is the pixel counter after cropping and CF is the compression factor which ranges from 0.187 (highly compressable data) to 1.0 (uncompressed data). Fortunately the next frame execution does not have to wait until the DCHRI is finished with these activities. In other words the DCHRI activities can run in parallel with all of the activities of the next frame. If the DCHRI processing of the previous frame is not finished by the time the CCDs have finished exposure, the frame will be skipped. This will likely not occur very often unless full frames are taken. This is because the duration of the DCHRI activities is determined by the high speed of the DCHRI (72 Mbit/s including overhead) and the amount of data that is readout. If full frame are read out for FUV, NUV and half frame for SJI at 16 bits (uncompressed) it would take the DCHRI 1.8 seconds to process all three images. With Rice compression, this would take only half the time, and with a lookup table we expect that data can be compressed down to 4 bits/pixels. This would imply 0.45 seconds for all three full frames. In summary for compressed full frame readout, the DCHRI timing would lead to skipped frames only if the mechanism setup, flush, exposure time and readout time are shorter than 0.45 seconds. This is unlikely to be the case. If the data is uncompressed the DCHRI timing would lead to skipped frames if mechanism setup, flush, exposure time and readout time are shorter than 1.8 seconds.

Timing calculations for OBS and FRM list tables

Given the complex nature of the timing algorithm calculations, it is important to carefully consider the algorithm when building FRM and OBS list tables.

The minimum timing at which FRM and OBS lists can be executed without skipped frames (i.e., relative times or cadence set too fast) depends on the history of the sequencer. For example, a FRM list that does not allow for adequate time to perform filterwheel moves will lead to skipped frames. The duration of the filter wheel move depends on the position of the filterwheel before the FRM is started. This means that when making a FRM list one either has to already know how the FRM list will be used in an OBS (e.g., which FW or Focus position occurs before the FRM, or which set of 16 crop tables will be in the buffer) or make a choice for each of these history options (e.g., make a FRM list for a 3 position FW move, …). The table creator allows for the latter option. It allows the user to set how many FW positions are executed at the beginning of the FRM, how many focus steps, and whether or not the calculation should include the first 16 crop tables already in the buffer, rather than load them.

The most optimal way to deal with this complexity is by making FRM lists that are contain only one line. This way any timing differences because of history can be dealt with at the OBS level, either by changing the Tr (relative time) of the FRM list, or by changing the cadence of the FRM list. This is all done automatically in the table creator tool.

During execution of OBS sequences on the spacecraft using the timeline software, we will automatically “prime” the OBS. This means that we will position the FW and FOCUS so that they are set to the values of the end of the OBS: this guarantees that the cadence calculated for the OBS will be the same for the first iteration and the second (and following) iterations of the OBS sequence.

When executing large filterwheel moves in a FRM list and repeating that FRM list more than once, it is better to put in the large filterwheel move in a separate entry in the OBS list, and then repeating N-1 times following that separate entry. This ensures that the N-1 repeats after the first repeat are not hit by the timing penalty of the large filterwheel move.

When a sequence contains more than 16 different crop tables, extra time will be spent in the crop table loading procedure, which can take several hundred milliseconds. If exposure times are in excess of that, then there is no timing penalty. For high cadence, short exposure runs there can be an issue, and in this case the timing becomes somewhat unpredictable with skipped frames likely. So it is better to limit the crop tables to 16 or less, or make sure enough padding is added to stay above the crop table loading times.

3.7 Lookup Tables and Compression

IRIS data can be compressed onboard in the DCHRI. The compression algorithm is based on RICE compression. Technical note 7 describes in detail the IRIS compression approach and the parameters that can be set, i.e., the n and k RICE compression parameters, and the lookup table(s). These parameters are set in the FDB. A maximum of 16 lookup tables can be onboard.

The lookup table translates the datanumber (DN) of a pixel into another value. The lookup table contains the output values assuming input from 0 to 16383. IRIS will have several relatively straightforward pre-defined lookup tables, such as a table that follows a square root dependence, etc…

Header			
ID	Table size	Length	Row Size
4 byte integer, 1-4096 allowed	4 byte integer	4 byte integer	4 byte integer
Data			
Output (16384 values)			
output 0			
.			
.			
output 16383			

Table 13: Definition of lookup table.

Table 13 describes the format of the lookup table. A maximum of 8 lookup tables are allowed onboard at any time. However, up to 16 tables can be loaded into the DCHRI. Information on the HMI and AIA lookup tables can be found at http://sun.stanford.edu/~rock/iris/lookup_tables/

The current list of lookup tables onboard is:

LUT ID	Description	File name at Stanford
0	No LUT applied	N/A
1	Inverse lookup table	inverse.k
2	HMI flight (piecewise linear/square root)	hmi_c3_plin.k
3	AIA flight (square root)	aia_csnr_025.k
4	AIA square root	aia_csnr_050.k
5	AIA square root	aia_csnr_100.k
6	HMI piecewise linear/square root	hmi_c3_5_plin.k
7	HMI piecewise linear/square root	hmi_c4_plin.k
8	HMI piecewise linear/square root	hmi_c4_5_plin.k

A lookup table id of "0" indicates that no lookup table is being used and K may range in value from 0 to 7 (but must be less than N), and N may range in value from 6 to 14.

A non-zero lookup table id requires that N=14 in order to not truncate the data before the lookup table function. K may again be in the range from 0 to 7.

4. Timeline operations

IRIS operations are controlled by a timeline which contains a list of spacecraft and instrument commands. The timeline can be used by a science planner to perform the following operations:

- point the telescope to a position on (or off) the solar disk. This position is expressed in heliocentric coordinates that are aligned with the solar E-W and S-N directions and expressed in arcseconds, with 0”,0” at disk center, and positive x and y values for respectively solar west and solar north.

- switch on or off solar tracking. When solar rotation tracking is on, the pointing of the telescope is continuously adjusted to compensate for the rotation of the Sun so that the same region on the Sun is kept within the field of view. This is done by using a solar tracking table (see 4.2).

- correct the pointing of the telescope to correct for orbital wobble introduced by thermal flexing between the guide telescope and the main IRIS telescope. This is done by using an orbital wobble table (see 4.3)

- roll the IRIS telescope from its nominal direction which is that the slit is oriented along the S-N direction on the Sun (i.e., the rotation axis of the Sun). This roll is expressed by a roll angle which is allowed to have values between -90 and 90 degrees, with negative values for the top of the slit tilted towards the eastern direction on the Sun (see 4.4). Whenever a roll command is performed the instrument needs to be slewed to disk center. This is enforced by the timeline tool.

- execute (start and stop) a number of previously uploaded OBS lists (see 3). The timeline tool will keep track of which tables are onboard and determine which need to be uploaded.

- execute so-called utim files that contain a set of often used sequences of commands

- set the global automatic exposure control (AEC) parameters (see 4.5)

- determine the times at which the X-band antenna is switched on to perform downlinking of data that has been stored in the onboard memory (which is 47 Gbits large), and at which time it should be switched off (see 4.4). The effective downlink rate is 12.2 Mbit/s during a downlink pass.

- ISS (image stabilization system) loop on (to remove jitter) or off. This is a feedback loop between guide telescope signals and the active secondary mirror that removes any spacecraft jitter and stabilizes the pointing to the required accuracy to allow for high-resolution imaging spectroscopy.

The timeline will be made using the timeline tool, which is based on the TRACE timeline tool. Timelines will be uploaded to IRIS on Monday, Tuesday, Wednesday, Thursday and Friday.
The Monday through Thursday timelines will cover a planning period of 1 full day. For example, the Monday timeline will cover a time from 4h UTC Tuesday to 4h UTC Wednesday.
The Friday timeline will cover a time period from 4h UTC Saturday to 4h UTC Tuesday.

In the following we describe the various types of commands that can be included in the timelines.

4.1 Pointing

The solar pointing of IRIS is determined by a combination of:

- the wedge motors that offset the guide telescope from the main IRIS telescope
- the three PZT's (A, B and C) that control the active secondary mirror

The PZT positions are set by:

- PZT Offset at OBS list level (set at table level)
- PZT Step at OBS list level (set at table level)
- PZT Offset at FRM list level (set at table level)
- PZT values set in Solar Tracking Table (set at timeline level)
- PZT values set in Orbital Wobble Table (set at timeline level)
- the guide telescope which sends error signals to maintain stable fine-pointing

The wedge motors allow for variable offsets between the guide telescope and the main telescope. This has the effect of feeding light from a different part of the Sun into the slit and slitjaw. Because of the way in which these motors are set up, the pointing occurs along a polar coordinate system: IRIS can be pointed to any of 240 azimuths on a set of 120 concentric circles that are centered on a location that is close (within 1 arcminute) of disk center (see Figure 11). The timeline tool allows for accurate conversion between solar x,y coordinates and wedge positions.
Note that at disk center, the wedge positions have a granularity in the radial direction of 15.7 arcseconds with a smaller granularity (subarcsecond) in the azimuthal direction. At the limb the granularity is of order 25 arcseconds in the azimuthal direction and 10 arcseconds in the radial direction. More details can be found in IRIS Technical Note 18.

If the planner wanted to point IRIS to a specific location (e.g., a small plage region) for a raster that does not cover a large spatial range in the direction perpendicular to the slit, it is clear that the granularity in the wedge motor positions may not allow fine pointing down to the last 5-10 arcseconds. The timeline tool resolves this problem by accepting the planner's input values for solar x and y, and automatically calculating the closest wedge motor position, the offset in x and y from the PZTs to obtain the final pointing, and the PZT values in the solar rotation tracing table (SRT) required to perform solar rotation tracking (if desired, see 4.2). The PZT commands at the OBS and FRM list level cannot be used for this purpose since they are general tables that should not be tailored on a day-to-day basis for timeline/absolute pointing purposes.

IRIS can be rolled to any angle between -90 and +90 degrees from solar north. The start and stop times and roll angle are set by the timeline. Under rolled conditions the wedge positions are modified from what is shown in Figure 11 and Technical Note 18: the timeline software automatically translates the desired solar x and y coordinates into corrected wedge positions and PZT values.

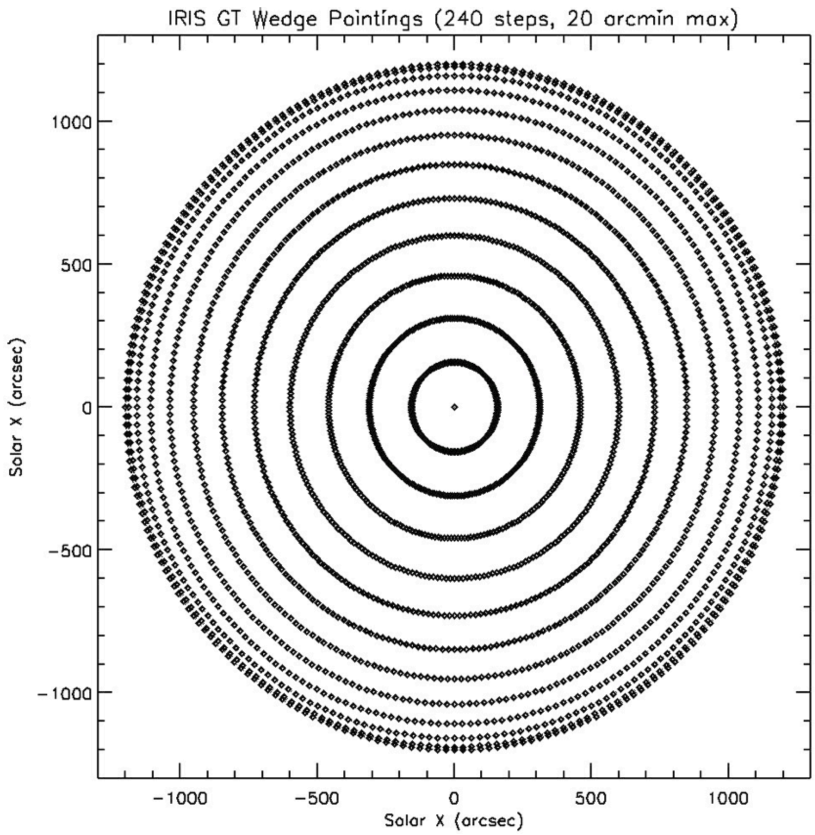

Figure 11: Wedge positions shown as a function of solar x and y (arcsec). For clarity, this figure only shows all positions in azimuth on every 10th radial circle.

4.2 Solar Tracking Table

The planner can define in the timeline whether the region that is being observed with the OBS list should be tracked to compensate for solar rotation or not. This is implemented by starting solar rotation tracking and referring to a solar rotation tracking table ID. The solar tracking table definition is shown in Table 14. It consists of a PZT offsets as a function of time. During IRIS operations, to calculate the PZT offsets caused by rotation tracking, the onboard software will perform linear interpolation between the times given in the solar tracking table.

Header			
ID	Table size	Number of Entries	
4 byte integer, 1-4096 allowed	4 byte integer	4 byte integer	
Data			
Time (seconds, 8 byte ?)	Offset PZT A (4 byte integer)	Offset PZT B (4 byte integer)	Offset PZT C (4 byte integer)
Time-1 (TAI seconds)	Offset A 1	Offset B 1	Offset C 1
Time-2 (TAI seconds)	Offset A 2	Offset B 2	Offset C 2
…	…	…	...
Time-N (TAI seconds)	Offset A N	Offset B N	Offset C N

Table 14: Definition of solar rotation tracking table.

As mentioned before, the solar tracking table can also be used to perform fine-scale pointing on a scale that is not feasible with the wedge motors. Six different tracking tables can be onboard at any time. If the current time is later than the last entry of the table, the last value of the table is used. The solar rotation tracking table is automatically calculated by the timeline software, and placed on the server for uploading when doing a final “submit”.

4.3 Orbital Wobble Table

The thermal cycling of the IRIS instrument and spacecraft as IRIS completes an orbit around the Earth can lead to small deformations and flexing of various structures in the instrument and spacecraft. This can lead to slight pointing differences between the boresight of the guide telescope and that of the main telescope. The pointing differences slowly change with time as the orbital conditions change the illumination of the spacecraft by Earth and the Sun. This can lead to “orbital wobble” which would lead to a slow but significant drifting of the solar image across the slit. To compensate for this wobble, the planner can invoke an “orbital wobble table” which specifies the PZT A, B and C offsets needed to compensate for the wobble so that the desired region stays centered in the field of view.

The wobble table is defined in Table 15. The timings in the wobble table are relative to the time of ascending node that is provided in the timeline tool. The planner sets the appropriate wobble table ID in the timeline software (=0 means no wobble table used). In addition, the timeline sends up the time of the ascending node during the time period covered by the timeline. There can be up to 3 orbital wobble tables onboard at any one time. The actual PZT offset caused by the wobble table are calculated by linear interpolation between successive entries of the orbital wobble table.

Header			
ID	Table size	Number of Entries	
4 byte integer, 1-4096 allowed	4 byte integer	4 byte integer	
Data			
Time (milliseconds, 4 byte integer) since last ascending node	Offset PZT A (4 byte integer)	Offset PZT B (4 byte integer)	Offset PZT C (4 byte integer)
Relative Time-1 (milliseconds)	Offset A 1	Offset B 1	Offset C 1
Relative Time-2 (milliseconds)	Offset A 2	Offset B 2	Offset C 2
…	…	…	...
Relative Time-N (milliseconds)	Offset A N	Offset B N	Offset C N

Table 15: Definition of orbital wobble table.

4.4 Roll conditions and Data downlink

The nominal orientation of the IRIS slit (roll angle=0) is S-N on the Sun, i.e., aligned with the solar rotation axis. This orientation can be changed by rolling the spacecraft about the direction spacecraft-sun center by angles between -90 and +90 degrees. The sign convention is such that the top end of the slit is oriented towards the east (on the Sun) for negative values of the roll angle. Changing the roll angle is done in the timeline by entering a roll command and an associated roll angle.

After a non-zero roll angle is commanded, the translation from solar x and y to wedge motor positions and PZT offsets that are set at the timeline level (wobble table, solar rotation tracking table) is automatically performed by the timeline software (i.e., the planner does not need to do so manually). However, the PZT offsets that are set in the OBS and FRM lists are NOT transformed and thus are left unchanged, since those are meant to be in the direction perpendicular to the slit and along the slit, not relative to the solar x and y direction.

The X-band antenna is located on the “bottom” side of the spacecraft which is typically pointed towards Earth. The boresight of the X-band antenna is oriented along the solar south direction if the spacecraft is not rolled. This means that for typical passes in the northern hemisphere (Svalbard, Alaska, Wallops) the X-band is pointed towards Earth. When the spacecraft is rolled this is not necessarily the case any more, which leads to lower power received on the ground, and thus reduced contact time and reduced total downlinked data volume during the average pass. In other words, running under roll conditions for extended periods of time means that the onboard memory (47 Gbit is available for science data) will fill up faster than under no-roll conditions. The planner needs to take this into account when planning rolled conditions, which is feasible using the timeline tool which allows the planner to choose the best trade-off between roll and downlink volume.

The planner needs to include commands in the timeline to “start X-band transmission” and “stop X-band transmission”. The times for these events will be automatically populated in the timeline tool which will ingest the exact timing of positive link margin (i.e., received power at ground station is sufficient to perform downlinks) from input files from the LM Flight Dynamics Team, with the actual pass/antenna combination determined by files from the Mission Operations Center (MOC) at NASA Ames which is responsible for scheduling of downlink passes.

When the planner chooses to roll the spacecraft and introduces a non-zero roll angle, the link margin calculations are automatically adjusted to take into account the shorter contact times because of the non-optimal direction of the X-band antenna.

Because of the pecularities of the X-band transmission pattern there are certain periods during the year where non-zero roll conditions are actually beneficial in terms of total downlink volume. These periods depend on the station and season and will be available to planners through graphical input files. This is illustrated in ITN 5.

IRIS attitude is controlled by two star trackers at opposite ends of the spacecraft. During two periods around first and last quarter of the Moon there are certain roll angles for which Earth is in one star tracker and the Moon is in the other star tracker. When that occurs the star tracker CCDs are saturated and attitude control is no longer possible which would lead IRIS to go into a safe mode. To avoid this there are certain roll angles that are forbidden for certain times of the month. This will be available to planners through graphical input files and imposed by the timeline tool.

Operations under roll conditions are described in more detail in IRIS Technical Note 5.

4.5 AEC operations

The exposure time for IRIS slitjaw images and spectra is usually set by the FDB. However, it is also possible to have IRIS perform Automatic Exposure Control (AEC), i.e., change the exposure time of slitjaw images or spectra dynamically based on the number of overexposed pixels in a given (chosen in the FRM list) slitjaw image. The AEC philosophy and detailed operations are outlined in IRIS Technical Note 6. Most of the AEC operations are set at the FRM and FDB level. However, there are six global flags or parameters that are set in the timeline. These are listed in table 16.

Name	Acr	Description
Flare Flag	FF	Controls whether IRIS goes into special “flare AEC” mode (FF=1), or not (FF=0). If FF=1, SJI images control exposure time of spectra
AEC Flag	AF	Controls whether the AEC software in the camera electronics will be used to change exposure times (AF=1) or not (AF=0)
AEC Lapse Time	ALT	If last SJI (that drives AEC for both SJIs and spectra) was taken more than ALT seconds ago, the exposure time is set back to what is set in the frame definition block (FDB), i.e., it reverts back to the original exposure time.
Event Flag	EF	Keeps track of whether a flaring “event” has occurred (EF=1) or not (EF=0). Normally this is calculated from the chosen SJI images, but can also be set by the planner (e.g., for testing purposes)
Event Lapse Time	ELT	After this time period (in seconds), the event flag is set back to 0 by the software.
Event Enable Mask	EEM	Sets which AEC table will be used to determine whether an event occurs. 16 bit variable (one bit per possible AEC table) allows IRIS to use many different SJI filter images, a single SJI filter, or no SJI for event calculation

Table 16: Global flags or parameters that control AEC operations

Use of these parameters and flags is outlined in Technical Note 6. The EF is typically calculated and set automatically by the AEC algorithm that is part of the instrument software, and keeps track of whether an actual flare is occurring or not. This EF will be set to 1 by the onboard software when the computed AEC exposure times drop below a specified threshold exposure time. This threshold exposure time is set in the AEC tables (see Technical Note 6). After EF was set to 1, the instrument software sets EF=0 after a flare condition has not been satisfied for the time specified by ELT.

These global parameters determine the AEC boolean logic. AEC operations are driven by the onboard software which for every SJI image taken onboard calculates whether the event flag (EF) should be set to 1 or not. This will be based on criteria set by the AEC table that is set for the particular image taken. If the particular AEC table is not selected in the Event Enable Mask (EEM, see Technical Note 6), then the event flag will not be set to 1 even when the AEC criteria for an event are met (i.e., the exposure time is below the threshold). Table 17 describes what the onboard software will do for various combinations of parameters.

AF	FF	EF	SJI-AEC ID[1]	Action
0	0 or 1	0 or 1	0 or ≠0	AEC does NOT operate on either SJI or spectra
1	0	0 or 1	≠0	AEC operates on SJI, but not on spectra AEC ignores EF, since FF=0 (EF only determines whether AEC works on spectra if FF=1) Spectra are taken at fixed exposure time set in FDB
1	1	0	≠0	AEC operates on SJI, but not on spectra (EF=0). Spectra are taken at fixed exposure time set in FDB
1	1	1	≠0	AEC operates on SJI AEC operates on NUV spectra if NUVS-AEC ID=SJI-AEC ID (set in framelist)[2] AEC operates on FUV spectra if FUVS-AEC ID=SJI-AEC ID (set in framelist)[2]

Table 17: AEC Boolean Table
[1]: set in the framelist table
[2]: only if an SJI image with that SJI-AEC ID was taken during this observing list, and if it was taken within ALT seconds of current image.

The panner will control these global settings, and can also upload specific AEC tables into certain slots. A total of 16 slots are available, 4 for each type of SJI images. This is detailed in ITN 6.

5. Upload consideration and onboard limitations

As outlined in the above, IRIS operations are driven by parameters set in a variety of tables. There are several limitations on how many of these different tables can be held in the onboard memory. These are listed in Table 18.

Table 18: Table of IRIS table properties

Table Buffer Name		SW Up date	ID	Max Table Entries	Approx. Table Size (Bytes)	Buffer Size (Bytes)	Upload Frequency
Sequencer Tables	Frame List Table		0	100	72 – 2304	30000	50 – 200 bytes / day
	Frame Definition Block Table		1	200	44	10420	~5 K bytes / week
	CCD Readout Spec Table		2	200	184	38420	~500 bytes / month
	Observing List Table	Static	3	100	16 – 128	8000	~100 bytes / month
	Solar Rotation Tracking Table	Static	4	6	1600	9600	monthly
	Orbital Wobble Table	Static	5	3	1600	4800	monthly
	Automatic Exposure Control Table	Static	11	16	60	1108	monthly
CEB Ops	CCD Control Table	Dynamic	6	10	60 – 100	500	Infrequently
	CCD Waveform Table	Dynamic	7	1	280	320	Fixed Table
DC / HRI	Crop Table	Dynamic	8	12	32800	393716	4 times / year
	Lookup Table	Static	9	8	32780	262324	Infrequently
Other Tables	Diagnostic Configuration Table		10	5	780	3980	780 / month
	GT Axis Mapping Table		12	1	44	68	Once during S/C I&T
	Script Table		13	16	8352	133780	Infrequently

When working on the timeline, the planner will have access to a graphical user interface (GUI) to a "Load Size Calculator" which will flag how close the current timeline is to filling up the buffers, and whether to perform a new load.

Appendix A: Table Rules

Rule	FUV1	FUV2	NUV	SJI	CRS	Read-out	FDB	FRM	OBS	HW Rule	Seq Rule	Policy Block	Warn-ing	Auto-fix
CRS # regions: FUV 8, NUV 6, SJI 2	X	X	X		X						X			
CRS # regions: SJI 1, and it must be entirely on the NUV or FUV half of the SJI CCD				X	X							X		
SJI region must include the slit				X	X							X		X
Total pixels readout must be multiple of 16	X	X	X	X		X					X			
2048 rows max per region	X	X	X	X	X	X					X			
Startcol and Endcol must be between 5 and 1092; first/last 4 cannot be used	X	X	X	X	X	X					X			
region may not include pixels from more than 1 ccd (all rows < 2073, or all rows > 2072).	X	X	X	X	X						X			
NUV/SJI combo: CRSes must use same summing spec			X	X				X			X			
If startrow < 2073, then (startrow - 1) MOD (4*rowsum) must equal 0	X			X	X	X					X			X
If startrow >= 2073, then (4145 - startrow) MOD (4*rowsum) must equal 0		X	X		X	X					X			X
If endrow < 2073, then endrow MOD (4*rowsum) must equal 0	X			X	X	X					X			X
If endrow >= 2073, then (4144 - endrow) MOD (4*rowsum) must equal 0		X	X		X	X					X			X
If startcol < 549, then (startcol - 5) MOD (4*colsum) must equal 0	X	X	X	X	X	X					X			X
If startcol >=549, then (1093 - startcol) MOD (4*colsum) must equal 0	X	X	X	X	X	X					X			X
If endcol < 549, then (endcol - 4) MOD (4*colsum) must equal 0	X	X	X	X	X	X					X			X
If endcol >= 549, then (1092 - endcol) MOD (4*colsum) must equal 0	X	X	X	X	X	X					X			X
Endrow > startrow & endcol > startcol	X	X	X	X	X						X			

Rule	FUV1	FUV2	NUV	SJI	CRS	Read-out	FDB	FRM	OBS	HW Rule	Seq Rule	Policy Block	Warn-ing	Auto-fix
If (rowsum * colsum) = 16, the total pixels readout (num_readout_rows*1088*2) MOD 256 = 0	X	X	X	X		X					X			
If (rowsum * colsum) = 32, the total pixels readout (num_readout_rows*1088*2) MOD 512 = 0	X	X	X	X		X					X			
Overlapping regions are not allowed	X	X	X	X	X							X		
Due to extra 4 pixel region, the max # of readout rows (counting both CCD1+2) is 4095, if rowsumming=1 and no data on port E. Otherwise the max readout rows is 4096.	X	X	X	X	X	X					X			
(4 * rowsum) number of last rows rows cannot be in a selected region (FUV: when no data in port E; NUV: always except full frame)		X	X		X						X			
Full frame readouts ARE allowed but ONLY with 1x1 summing. These CRS region are allowed to violate all of the conflicting rules above. The full readout is rows 1-4144 (IE both halves of FUV together, or NUV+SJI; we will use 1 CRS for both unlike most others saved with a FUV/NUV/SJI tag).	X	X	X	X	X	X					X			
Compression: If LUT ID = 0, K may be 0-7 and N 6-14, but K must be less than N. If LUT ID != 0, N = 14, K 0-7. For uncompressed, both N and K must have uncompressed as their selection.	X	X	X	X			X				X			
Minimum exposure time is 20ms; max is 63999ms							X			X				X
Users should not allow AEC to lengthen exposures, set maxExposure = desired exposure							X						X	
Flight focus mechanism hard limits are: -275 to +349	X	X	X	X				X		X				
The first frame in an OBS containing a SJI image must define a FW (no 'nomove' / 9999)				X					X			X		
FW position must match what region the SJI is on.								X	X				X	

Rule	FUV1	FUV2	NUV	SJI	CRS	Read-out	FDB	FRM	OBS	HW Rule	Seq Rule	Policy Block	Warn-ing	Auto-fix
Exposure type: warn user if not the same for NUV/SJI (the FSW will use the SJI if they differ)								X				X		
Warn if vertical extents of selected FUV/NUV/SJI do not correspond			X	X				X					X	
If full frame (an FDB with CRS 1) selected for either of SJI/NUV, the other must be unused in that FRM row.			X	X				X				X		
Warn of skipped frame possibility if -1 set for either Flush or Inhibit Skip and user assumed the ‘fast’ settings (flush off, I-S on)								X					X	
First row of an OBS cannot have ‘undefined/no move’ (=9999) for X/Y/PZT offsets									X		X			
PZT offsets must be in allowable range. ‘Allowable range’ depends on thermal characteristics know postlaunch, as well as policy decisions on PZT margin left for jitter correction. Because position involves FRM + OBS, we only block if OBS is out of bounds. FRM level check assumes OBS values of ‘centered’ and warns if those would go out of range.								X	X	X			X	

Explanation of columns:

FUV1 and 2 are the lower and higher wavelength halves of the FUV, or ‘left’ and ‘right’ sides as viewed in the TableCreator tool. Some rules apply separately to the two halves, although the tool has the user draw them on the same canvas.

NUV, SJI apply to their respective CRS regions, or possibly to which NUV/SJI are chosen for higher level sequencer tables.

FDB, FRM, OBS are checked at those levels.

CRS: rule applies to the regions in a CRS (FUV, SJI, or NUV considered alone).

Readout: rule applies to the readout region (formed by the mirroring of the CRS from FUV 1+2, or the SJI+NUV, then merging regions with gaps of fewer than 100 rows between them. Note that a rule can apply to both CRS and readout regions, and that some of these can be enforced at CRS creation (FUV) while others must be checked at the FRM (as that is where the SJI+NUV pairing is determined.)

HW rule: comes from hardware limitations.

Sequencer rule: comes from constraints on flight software.

Policy rule: outlaws something that is technically legal for IRIS to do, but will never have any science value and is thus disallowed.

Warning: similar to 'policy rule' but has some very small number of cases where breaking the rule makes sense. Only users who are very familiar with IRIS should ignore these.

Autofix: a rule where a table will be 'adjusted' for the user on save, instead of telling the user to fix the problem. Example is the 'drawing' of CRS, to save the user frustration the table creator will 'snap' the points to the nearest pixel coordinates satisfying all the modular arithmetic rules.

For the 5 above rule categories (which are mutually exclusive, except Autofix), the table creator will forbid saving of a table if it violates a HW, Sequencer, or Policy rule. Submission and conversion requests will also be rejected. For Warning rules, the user will be advised to change but will be given the option to save without changes. Autofix will apply the needed changes to the user's table before save/submit. Of course, if multiple rules are violated the 'hard block' rules take precedence.