CLASP2 data levels user guide

Content:

1. Acknowledgement statement

All publications and presentations using CLASP2 data must include the following acknowledgement statement:

CLASP2 is an international partnership between NASA/MSFC, NAOJ, JAXA, IAC, and IAS; additional partners include ASCR, IRSOL, LMSAL, and the University of Oslo. The CLASP2 research was funded by ISAS/JAXA as a Small Mission-of-Opportunity Program, by JSPS KAKENHI Grant numbers JP25220703 and 16H03963, 2015 ISAS Grant for Promoting International Mission Collaboration, 2016 NAOJ Grant for Development Collaboration, NASA Award 16-HTIDS16_2-0027, and Spanish participation through ERC Advanced Grant agreement 742265; and French hardware participation was funded by CNES funds CLASP2-13616A and 13617A.

2. Pointing

CLASP2 flew on 11 April 2019 and pointed at three different positions on the Sun: at disk center for about 15 seconds for polarization calibration, at a plage position for about 2 min 26 sec, and near the limb for the rest of the flight. Figure 1 shows the three pointings overplotted on an AIA 304 image during that time. The IDL code to get the coordinates is described in Section 4.

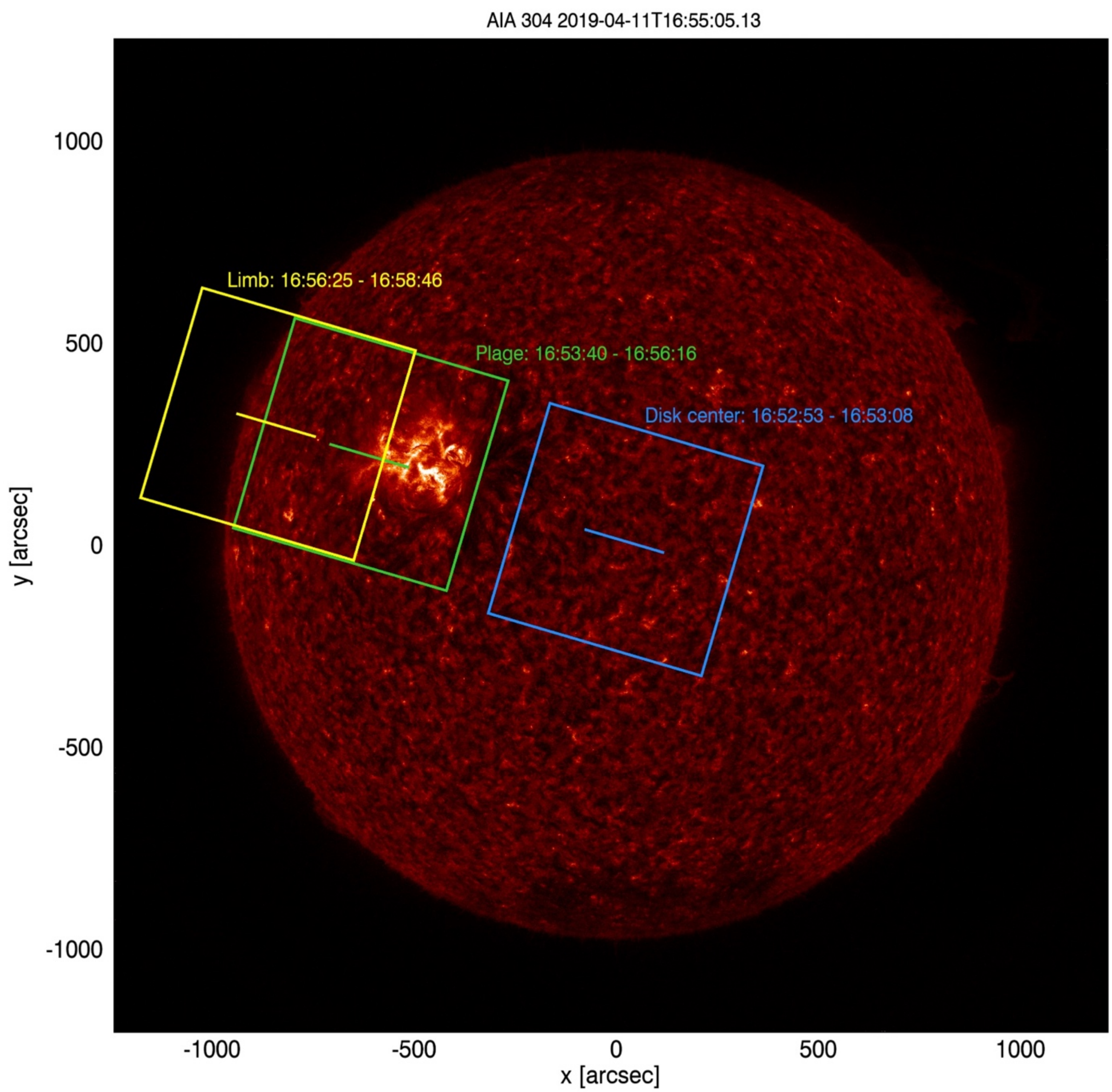


Figure 1: The CLASP2 pointings at disk center, plage, and near the limb.

2.1 IRIS co-observation data

The IRIS co-observation data for CLASP2 can be found at: https://iris.lmsal.com/search/
OBSID: 3683603440

Note that there is also context data available at different times. Search for “CLASP-2” in the “DESC” box.

3. Description and graphical examples of data levels

CLASP2 observed in the wavelength region around Mg II h & k. The data was taken with three cameras, two cameras for spectropolarimetry (SP1 and SP2) and one slitjaw camera (SJ). Table 1 shows the data levels for each camera, the ones shaded in green are available through the VSO.

	SJ	SP1	SP2	SP (SP1 and SP2 combined)
Level-0	X	X	X	-
Level-0.5	X	X	X	-
Level-1	X	X	X	X

Table 1: Data levels for each camera (green = available through the VSO)

3.1 Brief description of data levels available through the VSO (“which data do I want?”)

Spectropolarimetric data:

Level-0.5: highest cadence data (200 ms), basic correction steps applied, no demodulation, no co-registration, no coordinate information.

You probably want this data if... you do not care about polarimetry or coordinates and need the highest possible cadence for the intensities.

Level-1: lower cadence data (3.2 s), all correction steps applied, demodulated, co-registered, coordinate information.

You probably want this data if... you want Stokes parameters and/or coordinates.

Slitjaw data:

Level-1: 600 ms cadence, all correction steps applied.

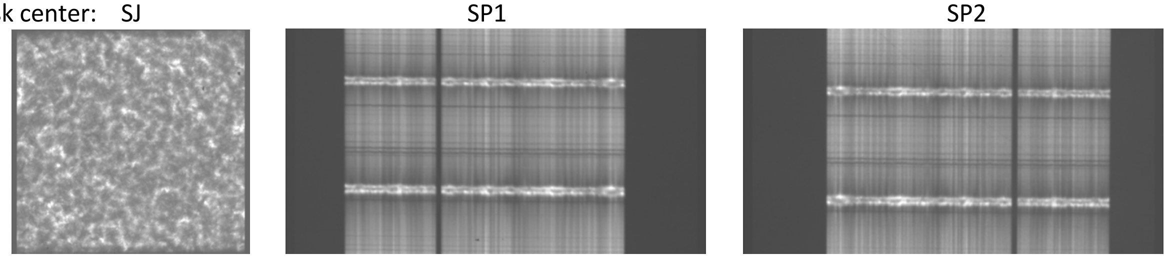
3.2 Lower data levels for all cameras

Level-0:

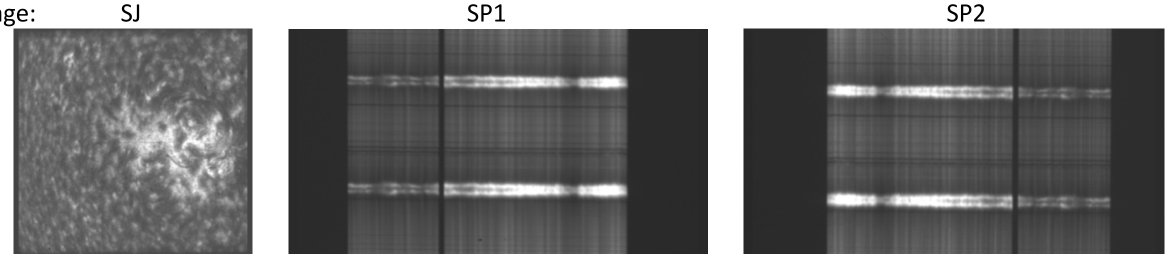
- SJ: 600 ms cadence
- SP1/SP2: 200 ms cadence
- unit: DN
- data in primary FITS HDU
- raw data
- timestamp correction
- adding information to the FITS headers:
    - TARGET: “Dark”, “Moving”, “SunCenter”, “Plage”, “Limb”
    - TELESCOP, INSTRUME, WAVELNTH, etc.

Graphical examples of the data:

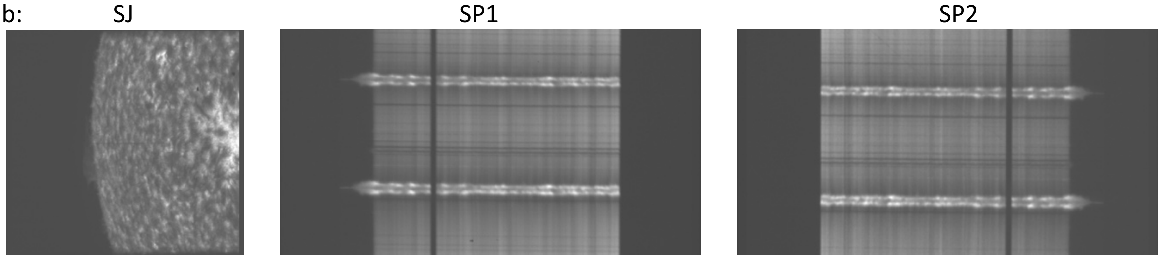
Disk center: SJ SP1 SP2



Plage: SJ SP1 SP2



Limb: SJ SP1 SP2



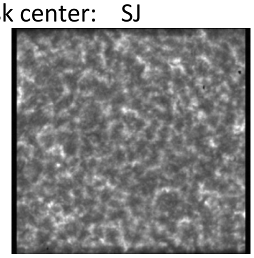
Note: The vertical black line in the SP1/SP2 data is caused by dust obscuring the slit.

Level-0.5:

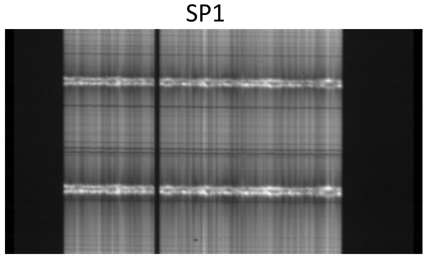
- SJ: 600 ms cadence
- SP1/SP2: 200 ms cadence
- unit: electrons
- data in primary FITS HDU
- correction for:
  - bias
  - dark
  - gain
  - frame transfer image smear
- darks and exposures during slew discarded (TARGET = “Dark” or “Moving”)
- manually selected images discarded

Graphical examples of the data:

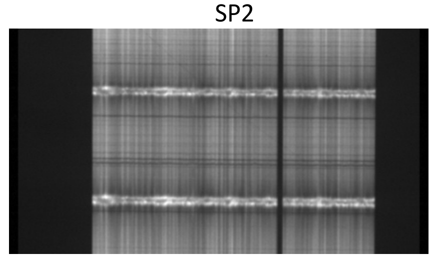
Disk center: SJ



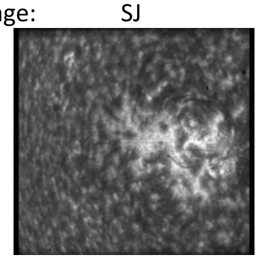
SP1



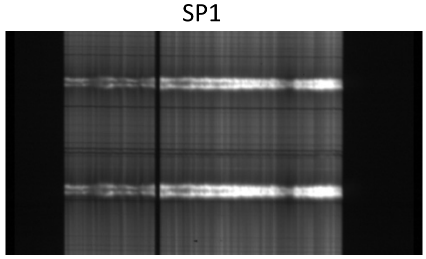
SP2



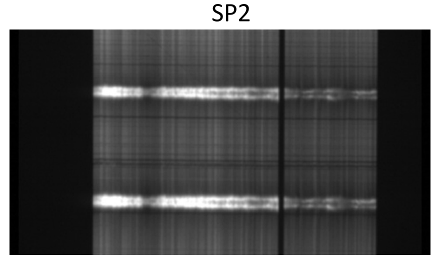
Plage: SJ



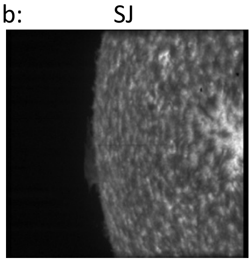
SP1



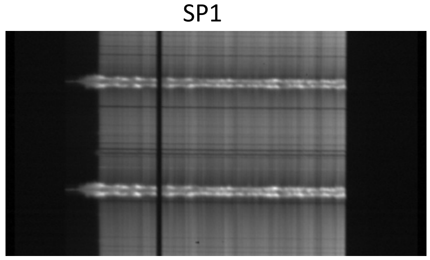
SP2



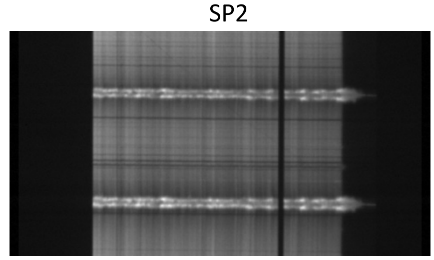
Limb: SJ



SP1



SP2



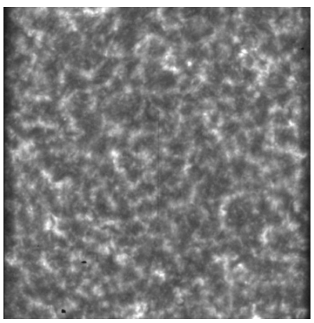
3.3 Higher data levels for slitjaw data

Level-1:

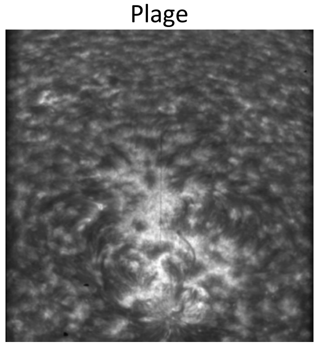
- 600 ms cadence
- unit: electrons
- data in primary FITS HDU
- flatfield correction
- cutting off non-active pixel regions
- image rotation (90° CW) and horizontal flip
- cross-correlation with AIA 304 data to add coordinates to the FITS headers

Graphical examples of the data:

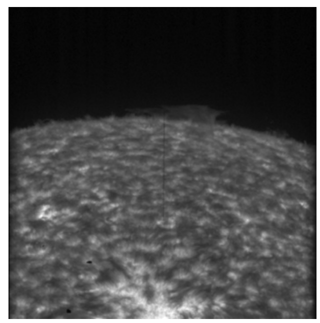
Disk center



Plage



Limb



3.4 Higher data levels for spectropolarimetric data

Level-1:

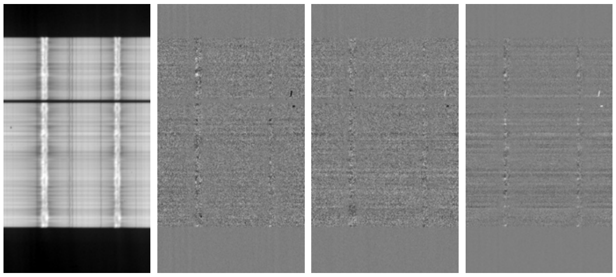
- 3.2 s cadence
- unit: electrons
- Stokes I/Q/U/V in FITS extension 1/2/3/4
- polarization demodulation
- cutting off non-active pixel regions
- SP1: image rotation (90° CW)
- SP2: image rotation (90° CCW) and horizontal flip
- affine transformation:
    - shift (co-registration, slit drift compensation)
    - rotation (wavelength axis parallel to x-axis, slit axis parallel to y-axis)
- combining SP1 and SP2 to SP
    - compensation for (slightly) different SP2 spatial scale
    - process of combining SP1 and SP2 is described below

Graphical examples of the data:

Disk center:

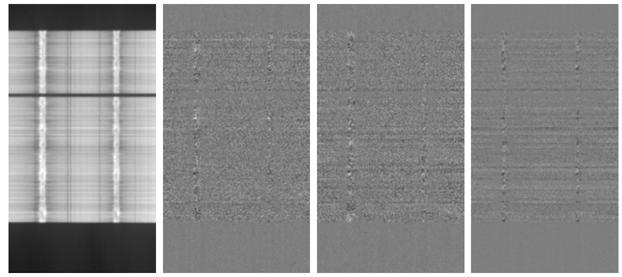
SP1

I Q U V



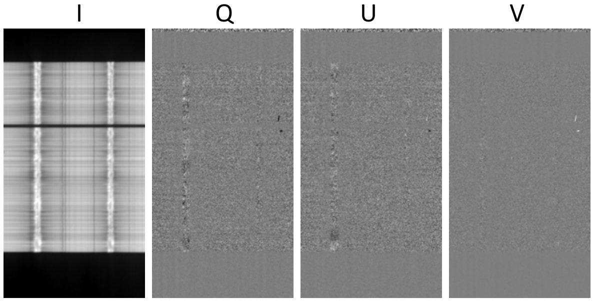
SP2

I Q U V



SP (SP1 and SP2 combined)

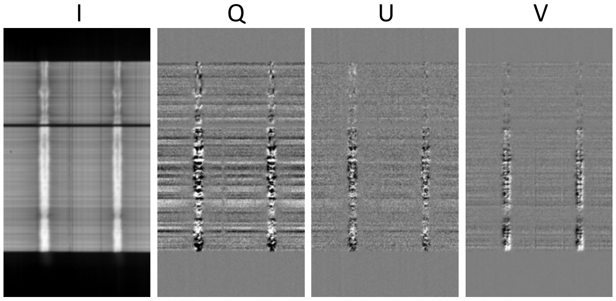
I Q U V



Plage:

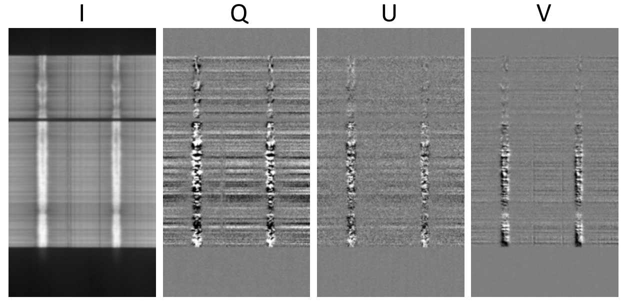
SP1

I Q U V



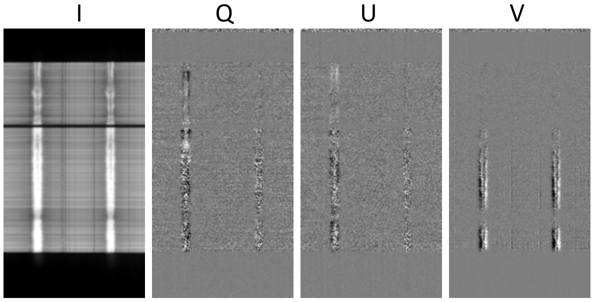
SP2

I Q U V



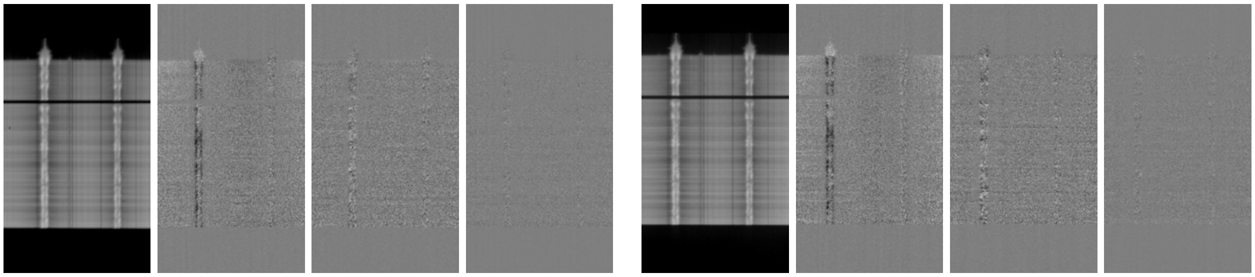
SP (SP1 and SP2 combined)

I Q U V



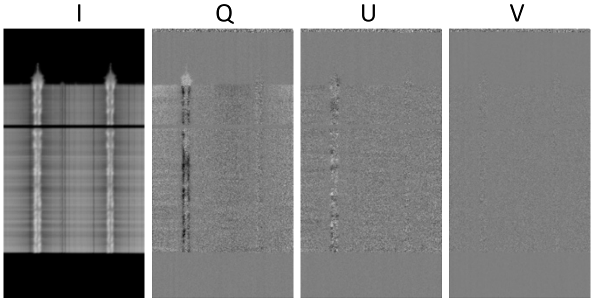
Limb: SP1 SP2

I Q U V I Q U V



SP (SP1 and SP2 combined)

I Q U V



How SP1 and SP2 are combined (description is for Stokes Q, same for Stokes U and V):

1. Derive the fractional polarization at each spatial and wavelength pixel at each PMU rotation in each channel:

$$q_{\mathrm{SP1}} = \frac{K_1 Q(x,\lambda,t)}{K_1 I(x,\lambda,t)} = \frac{Q_{\mathrm{SP1}}(x,\lambda,t)}{I_{\mathrm{SP1}}(x,\lambda,t)} \qquad q_{\mathrm{SP2}} = \frac{K_2 Q(x,\lambda,t)}{K_2 I(x,\lambda,t)} = \frac{Q_{\mathrm{SP2}}(x,\lambda,t)}{I_{\mathrm{SP2}}(x,\lambda,t)}$$

   where *t* is the PMU rotation number and K_1 and K_2 are the throughputs in SP1 and SP2
2. Take the average of the fractional polarization between the two channels:
   $q_{\mathrm{SP}} = (q_{\mathrm{SP1}}(x,\lambda,t) + q_{\mathrm{SP2}}(x,\lambda,t))/2$

   Note: the averaged quantity q_{SP} is the fractional polarization without any uncertainty in throughput. This process also cancels out I → Q/U crosstalk.

   $q_{\mathrm{SP}} = \left(\frac{K_1 Q(x,\lambda,t)}{K_1 I(x,\lambda,t)} + \frac{K_2 Q(x,\lambda,t)}{K_2 I(x,\lambda,t)}\right)/2 = \frac{Q(x,\lambda,t)}{I(x,\lambda,t)}$
3. Multiply the averaged fractional polarization with the sum of the SP1 & SP2 intensities:
   $Q_{\mathrm{SP}}(x,\lambda,t) = q_{\mathrm{SP}}(x,\lambda,t) \cdot (I_{\mathrm{SP1}}(x,\lambda,t) + I_{\mathrm{SP2}}(x,\lambda,t)) = q_{\mathrm{SP}}(x,\lambda,t) \cdot I_{\mathrm{SP}}(x,\lambda,t)$
4. The final outputs are: $I_{\mathrm{SP}}(x,\lambda,t)$, $Q_{\mathrm{SP}}(x,\lambda,t)$, $U_{\mathrm{SP}}(x,\lambda,t)$, $V_{\mathrm{SP}}(x,\lambda,t)$
   Advantage of this procedure: $I_{\mathrm{SP}}(x,\lambda,t)$ directly provides the total number of e^- collected by the two channels.

4. IDL software

Note: all of the software described below requires the SolarSoft environment ("sswidl"). Everything from Section 4.2 on requires the instrument package "CLASP2" in SolarSoft.

4.1 Getting data from the VSO with vso_search and vso_get

CLASP2 data is available in zip files that contain all data levels for each instrument. Searching for and downloading the slitjaw data for example could be done with the following syntax:

```
IDL> clasp2_files = VSO_SEARCH('2019-apr-11 00:01','2019-apr-11 23:59', \
                               SOURCE='CLASP2', PROVIDER='MSFC', INSTRUMENT='SJ')
IDL> getfiles = VSO_GET(clasp2_files, FILENAMES=filenames)
```

Valid entries for "INSTRUMENT" are "SJ", "SP1", "SP2", "SP", and "ALL". The variable "filenames" will contain the full path to the downloaded files.

4.2 Reading data with read_clasp2

Similar to read_sdo and mreadfits, the CLASP2 package contains a routine "read_clasp2.pro":

```
IDL> READ_CLASP2, files, index, data

files:   String array of CLASP2 files, for example from FILE_SEARCH.
         *Must* be only files of one type, i.e. only SJ, SP1, SP2,
         or combined SP files. Only exception is SP1 and SP2 data,
         which can be mixed because they have the same dimensions.
         Note: the input files list will be modified when either
         of the /LIMB_ONLY or /DC_ONLY keywords are set.
index:   The FITS file headers in a structure. For SP1/SP2/SP Level-1
         or Level-2 files, this routine will merge the information
         from the primary HDU and the extension HDU, so that all
         information is available in one structure.
data:    For SP1/SP2/SP: the data in a 4D array
         [x,y,time,Stokes parameters (0=I, 1=Q, 2=U, 3=V)].
         For SJ: the data in a 3D array [x,y,time].
         This is optional, can be omitted with the /NODATA keyword.
```

Optional Keywords:

```
/LIMB_ONLY    - Only read in limb pointing data from the list of files.
/PLAGE_ONLY   - Only read in plage pointing data from the list of files.
/DC_ONLY      - Only read in disk center pointing data from the list of files.
/NODATA       - Do not read in data, only the index.
/SILENT       - Suppress all of the (M)READFITS messages.
```

4.3 Getting CLASP2 coordinates

```
IDL> coords = CLASP2_GET_COORDINATES( path_to_file )
```

```
path_to_file:  path to a CLASP2 SJ/SP1/SP2/SP Level-1 or Level-2 file
```

Output:

```
coords:    - If the input file is an SP1/SP2/SP file:

              structure containing wavelength, xcoord, and ycoord (all 1-D)

           - If the input file is an SJ file:

              structure containing xcoord and ycoord (both 2-D)
```

Optional Keywords:

```
/VERBOSE:  Show plots indicating the slit (SP1/SP2/SP) or the 2-D FOV (SJ)
           on a circle representing the Sun.
```