UCoMP Data User's Guide December 2023

This is a living document. For the most up-to-date definition, please read

https://docs.google.com/document/d/1Lt2b4gx6GR1Wq8z1B0ceQKB0-PBCdGUCmPIKeIOIHQ0/edit

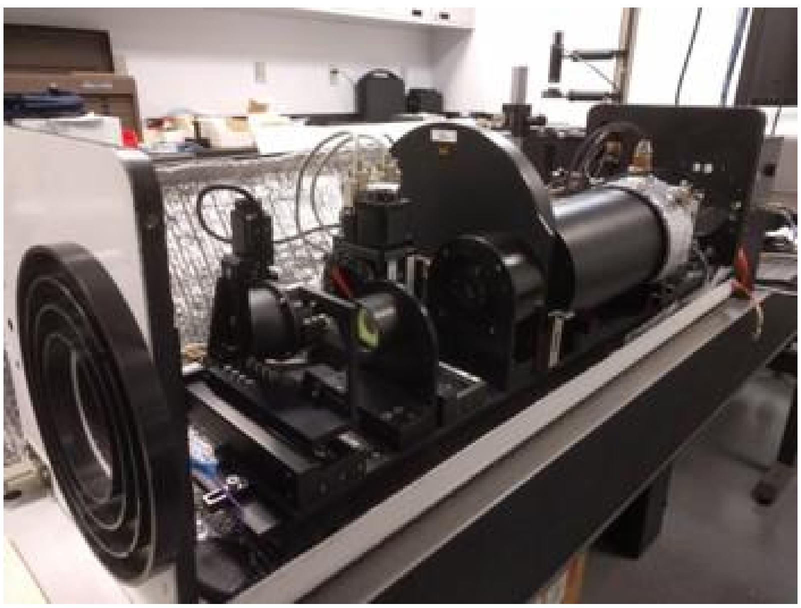
UCoMP Data processing code is on GitHub at: https://github.com/NCAR/ucomp-pipeline

The current data release is December 2023, with the 1.0 pipeline version. In version 1.0, we finalized the FITS file formats and names. However, future reprocessing will change metadata and data values as we address outstanding issues documented in the GitHub issues.

UCoMP Instrument

The Upgraded Coronal Multi-channel Polarimeter (UCoMP) is a 20-cm aperture coronagraph equipped with a polarimeter and a narrow-band tunable Lyot filter. This instrument can perform spectro-polarimetric imaging of coronal emission lines in the visible and near-infrared parts of the solar spectrum over the limb. UCoMP is an improved version of the CoMP instrument. It has a wider wavelength range (530 - 1083 nm), allowing more emission lines to be observed and enhancing plasma diagnostic capabilities. Also, UCoMP has a larger field-of-view (+/- 2 Rsun) compared to CoMP (+/- 1.3 Rsun) and higher spatial resolution (2pixels= 6 arcseconds) compared to CoMP (2 pixels = 9 arcseconds). The UCoMP demonstrates the technology of a large aperture (50 mm) tunable birefringent filter based on Lithium Niobate crystals and is a pathfinder instrument for the Coronal Solar Magnetism Observatory (COSMO).

The spectral resolution of the UCoMP is set by the birefringence of the Lithium Niobate crystals in the birefringent filter. Polarization is encoded into intensity by a modulator consisting of 2 ferro-electric liquid crystals and a fixed waveplate, followed by a polarizer (Tomczyk, Casini, de Wijn and Nelson, 2010). UCoMP captures the full Stokes vectors I, Q, U, V, where I is intensity, Q and U are the two orthogonal linear polarization states, and V is the circular polarization. The polarimeter is calibrated by a polarizer and retarder that can be inserted into the light beam and independently rotated. UCoMP uses two identical cameras to simultaneously capture the emission line and associated continuum intensities.



Above: Picture of the back end of the UCoMP instrument taken in the lab before deployment.

Picture of UCoMP on the spar at MLSO.

Emission lines observed by UCoMP

Wavelength (nm)	Identification	Temperature (MK)	Lyot FWHM (nm)	Time frame
530.30	FeXIV	2.00	0.022	Removed Nov 2022
637.40	FeX	1.07	0.039	Whole mission
670.16	NiXV	2.5	0.044	Added Nov 2022
656.28	HI	0.16	0.042	Removed Nov 2022
691.80	ArXI	2.00	0.048	Removed Nov 2022
706.20	FeXV	2.19	0.051	Whole Mission
761.10	SXII	2.20	0.061	Added Nov 2022
789.40	FeXI	1.26	0.068	Whole Mission
802.41	NiXV	2.5	0.069	Added Nov 2022
991.41	SVIII	0.8	0.069	Added Nov 2022
1074.62	FeXIII	1.66	0.138	Whole Mission
1079.78	FeXIII	1.66	0.141	Whole Mission
1083.00	HeI	0.19	0.142	Remove Nov 2022

Data location and availability

Science FITS data and quicklook images and movies can be found from the MLSO webpage calendar at: https://mlso.hao.ucar.edu/mlso_data_calendar.php?&calinst=ucomp and from the MLSO homepage: https://www2.hao.ucar.edu/mlso. Tarballs of the Level-1 and -2 FITS data and zip files containing the Level-1 and -2 quicklook data can be downloaded from this site. The team anticipates developing an API to download individual L1 or L2 FITS with criteria-based search, but this is not available at this time. Emission line data from the FeX, FeXI, FeXIII and FeXV lines are provided from the MLSO home page. Observations of the FeXIV, ArXI, HI and HeI emission lines are available upon request.

UCoMP collected commissioning data starting in July 2021. The volcanic eruption of Mauna Loa early on Nov 28, 2022, shut down the Mauna Loa site. The last UCoMP observations were obtained on Nov 25, 2022. Major changes were made to the instrument on Nov 10, 2022 to accommodate 4 new emission line filters. Data between Nov 10 and Nov 25, 2022 are still in testing mode and will be released in 2024.

Mauna Loa is expected to reopen for nominal operations in mid-2024. HAO plans to acquire UCoMP and K-Cor observations for the total solar eclipse on April 8, 2024. Eclipse day observations will be made available from the MLSO website:
https://www2.hao.ucar.edu/mlso

UCoMP Data Products

UCoMP data are saved at 3 levels. The Level 0 (L0) data is a pseudo-raw data format produced by the instrument in which like-data frames taken close in time are co-added to increase signal-to-noise and reduce storage and traffic on/off the mountain but otherwise contain raw camera reads. Level 1 data (L1) are geometrically and photometrically calibrated, and demodulated to obtain Stokes I, Q, U, V, and saved in heliographic coordinates. Level 2 data (L2) are science products of physical quantities derived from the L1 data. Details of the various level data products are described below.

UCoMP Data Processing Pipeline

The UCoMP Data processing pipeline continues to be refined and upgraded. The data processed with version 1.0 of the pipeline (current version as of Nov 22, 2023) differ significantly in both the intensity values, FITS extension formats, metadata, and filenames from the beta-test version. The version of the processing software is provided in the FITS primary header in the keyword ‘DPSWID’. For example the current = 1.0.0 [406c5304*]. At this point, the pipeline team doesn't anticipate major changes to these formats in future versions. This means that software tools designed to work with version 1.0 data products should continue to work without any modifications. The pipeline team is aware of multiple noise sources and shortcomings in the data and has documented them as issues in GitHub. The data intensities and metadata values will change as these issues are addressed in future releases. *We recommend users refresh their data periodically to obtain the most accurate data version for their research.*

UCoMP Data processing code is on Public GitHub at:
https://github.com/NCAR/ucomp-pipeline

Level 0 (L0) Data Products

A UCoMP L0 data file is structured as a series of FITS extension files, each comprising a 1280x1024x4x2 image array. The first and second dimensions indicate the image columns and rows, the third dimension indicates the polarization modulation, and the fourth dimension indicates the camera.

UCoMP is a two-channel instrument that uses two identical cameras to capture images of the Sun's corona. One camera is tuned to receive the ONBAND coronal emission line, while the other receives photons from a nearby region of the continuum spectrum. To reduce systematic instrument noise, observing programs will swap the role of the two cameras between ONBAND and continuum. The camera receiving ONBAND light is specified with the ‘ONBAND’ keyword in each image extension header. You can choose between RCAM (Camera 0: reflected beam camera) and TCAM (Camera 1: transmitted beam camera).

Location of the continuum measurement relative to the emission line is shown in the Table below.

Emission Line [nm] (i.e. ONBAND)	Distance of Continuum Measurement from Emission Line [nm]
FeX 637.4	0.351
FeXV 706.2	0.46175
FeXI 789.4	0.6125
FeXIII 1074.7	1.25625
FeXIII 1079.8	1.28025

The UCoMP polarization modulator includes two electrically tunable Ferro-electric liquid-crystal (FLC) polarizers that can be driven to four states (++,+-,--,+-). However, these FLC devices exhibit a highly chromatic wavelength response to the IQUV vector transmitted in each state. As a result, the L0 modulation images observed cannot be assumed to be I, Q, U, or V states individually but rather a mix of all four. To retrieve the Stokes vectors from the raw modulations, the L1 pipeline applies a demodulation matrix that is measured from data collected during a polarimetric calibration. See L1 data processing for more information.

Nominal operations acquire multiple images for each wavelength and polarization state In order to increase signal-to-noise and reduce the amount of data that needs to be transmitted from the Mauna Loa Solar Observatory (MLSO) to the MLSO data center at the High Altitude Observatory (HAO) at NCAR in Boulder, Colorado. Like-images are summed at the telescope to create a L0 image. The number of images summed at the telescope is stored in the 'NUMSUM' FITS keyword in the each FITS extension header. Typically, the value of NUMSUM does not change between extension images within a UCoMP FITS file.

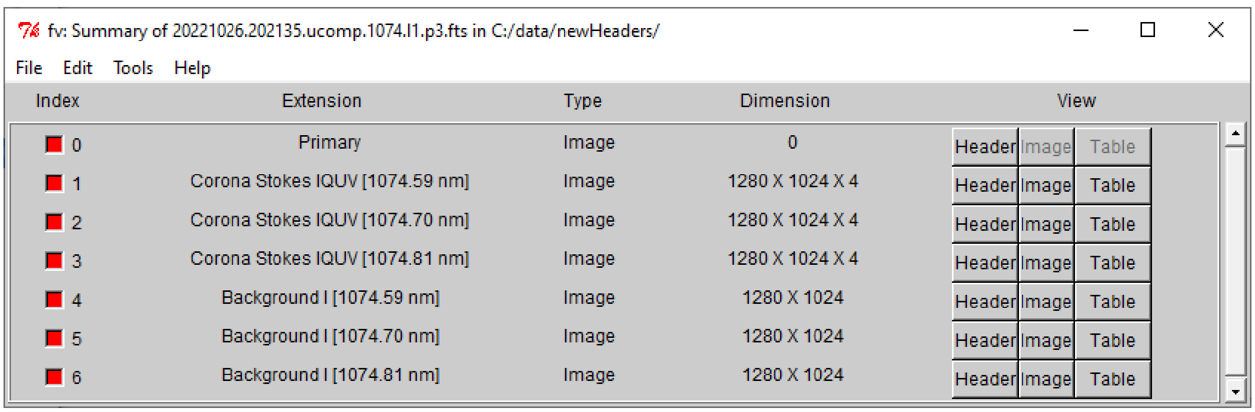
Level 1 (L1) Science Products

The L1 UCoMP science data are in FITS format and consist of images of the Sun's corona and chromosphere at various wavelengths. These wavelengths correspond to the emission lines of FeXIV, FeX, ArXI, FeXV, FeXI, FeXIII, HI, and HeI. Emission line data from the FeX, FeXI, FeXIII and FeXV lines are provided from the MLSO home page. Observations of the FeXIV, ArXI, HI and HeI emission lines are available upon request.

Each FITS image has a primary header and a series of FITS extension image arrays each with its own FITS extension header. The primary header in extension 0 includes metadata about the observation, while the extension headers contain metadata about the corresponding extensions. Examples of the primary and extension headers are provided in the Appendix at the end of this document. Each FITS extension contains an array of size 1280 x 1024 x 4. The image dimensions are 1280 x 1024 and the 4 arrays are the calibrated intensities of Stokes I, Q, U, and V respectively. The intensities are provided in units of ppm of the solar disk brightness (10^{-6} B/Bsun). Each extension contains a specific wavelength at some position in the emission line. A minimum of 3 positions are taken across the emission line. The last extension holds the background level (continuum) averaged over all tunings. As part of L1 processing, the background (continuum) intensity is subtracted from the emission line intensity. More information on the L1 processing is provided in the next section.

The file names indicate the emission line and number of points observed across the line. For instance, the filename '20221026.202135..ucomp.1074.l1.p3.fts' indicates that three wavelength positions were observed across the 1074.7 emission line.

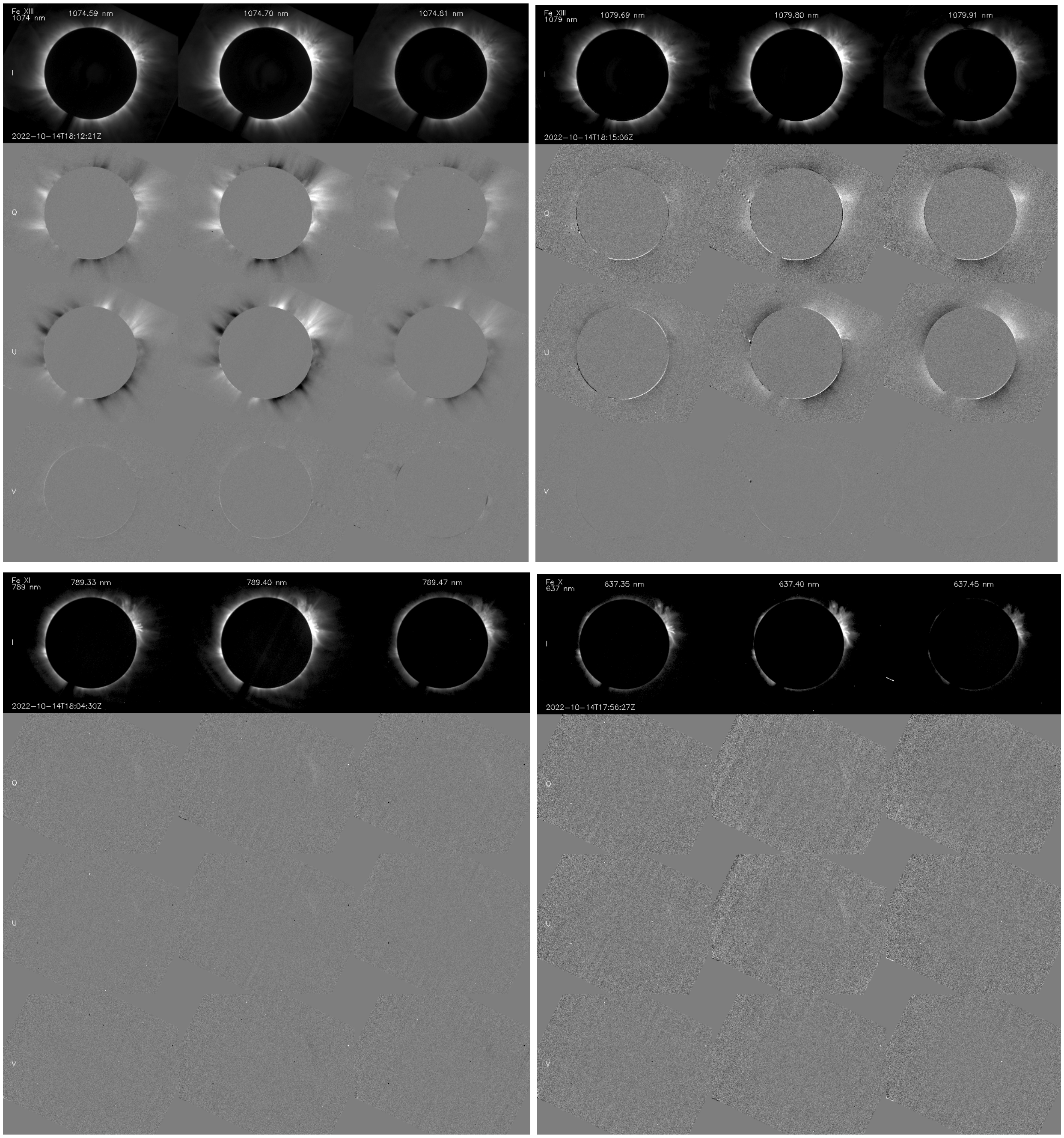
Below is an example L1 data file containing three wavelength tunings (1074.59, 1074.70, and 1074.81 nm) across the 1074.7 FeXIII emission line.


fv: Summary of 20221026.202135.ucomp.1074.l1.p3.fts in C:/data/newHeaders/

File Edit Tools Help

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header Image Table
1	Corona Stokes IQUV [1074.59 nm]	Image	1280 X 1024 X 4	Header Image Table
2	Corona Stokes IQUV [1074.70 nm]	Image	1280 X 1024 X 4	Header Image Table
3	Corona Stokes IQUV [1074.81 nm]	Image	1280 X 1024 X 4	Header Image Table
4	Background I [1074.59 nm]	Image	1280 X 1024	Header Image Table
5	Background I [1074.70 nm]	Image	1280 X 1024	Header Image Table
6	Background I [1074.81 nm]	Image	1280 X 1024	Header Image Table

Examples of Level 1 science data quicklook products on Oct 14, 2022 from various coronal emission lines are shown below. Each 'frame' consists of 12 images along 4 rows and 3 columns. All images display the Stokes vectors along horizontal rows with Stokes I at top, Stokes Q in 2nd row, Stokes U in 3rd row and Stokes V in the bottom row. The images along columns from left to right show the images in the blue wing of the emission line, the line center (center column) and the red wing of the emission line in the right column. The frame of 12 images in the upper left are from the FeXIII 1074.7 nm emission line. Note the polarization signal is strongest in this line. The frame of 12 images in the upper right is from the FeXIII 1079.8 nm emission line. The frame of 12 images in the lower left corner is the FeXI 789.4 emission line and the frame of 12 images in the lower right is the FeX 637.4 nm emission line.Note the lack of polarization signal in the FeXI and FeX lines. These 12-up images have filenames yyyymmdd.hhmmss.ucomp.wave.l1.p3.iquv.all.png; for example, the FeXIII 1074.7 filename is: 20221014.181221.ucomp.1074.l1.p3.iquv.all.png. These images are available in the 'Quicklook' zip download file from the MLSO web page.



Level 1 (L1) Data Processing

The L1 data processing includes dark correcting and flat-fielding the data, removing known instrumental issues (e.g.. camera distortion), subtracting the nearby continuum from the emission line, combining data taken by the two identical UCoMP cameras to reduce seeing-induced polarization, and demodulating the data to derive the Stokes IQUV. The data are also corrected for p-angle. For each L0 science/coronal file, a single L1 FITS file is created, provided it is complete and passes a basic quality check. This is done to promote as many L0 files as possible to L1. Examples of files that are not processed are: files that contain less than 3 wavelength tunings across the emission line (ONBAND) in both cameras; flats; darks; polarization calibrations; or files with incomplete metadata.

A "quality" file is generated to document which L0 files are promoted to L1 science products and which ones are not. This file contains a column of filenames and reasons. *If the reason is 0, an L1 file is created*. If the reason is not 0, the reason(s) is documented.using quality bitmask codes shown below. The quality file is provided in the data download files.

Quality bitmask codes

Code	Description
1	in/out values that are neither in or out
2	check for sequential extensions acquired more than 10.0 secs apart
4	multiple datatypes in a file
8	an extension is identically zero
16	any reported temperatures are identical
32	a temperature is not in the nominal range
64	multiple O1FOCUS values in a file
128	checked for saturated and non-linear pixels in a file
256	some wavelengths that do not match wave region
512	an error occurred in L1 processing

If a L0 file fails for a single reason it will have the code shown above. If it fails for multiple reasons, it will receive a reason value that is the sum of all the failing reasons. For example, if a L0 file fails due to multiple datatypes in a file it will have reason = 4. If it fails because it had sequential extension more than 10.0 secs apart AND it had an out-of-range temperature it would have a quality code reason = 34.

Most L0 files pass quality and are processed to Level 1. The L1 processing steps applied to an L0 image are as follows:

- Average like-images for each camera
- Apply camera linearity correction
- Subtract dark current
- Flat-fielding and conversion to physical units of ppm of solar disk center intensity (photometric calibration)
- Correct camera hot pixels (replaced with neighboring pixels average)
- Apply polarimetric demodulation to derive Stokes I, Q, U, V
- Apply camera distortion correction
- Find center and radius of occulter
- Subtract continuum image
- Apply correction to reduce vertical banding
- Shift images to center of array and rotate images to heliographic coordinates (north up)
- Combine cameras
- Coordinate transformation to put Q and U in solar coordinates
- Correct for sky transmission

Once individual L1 files are created, the pipeline creates average (mean and median) L1 data products by combining individual files.

It is often the case that the Sun is not directly centered under the occulter. Pointing uncertainties, spar flexure, wind, and degrading sky conditions make it difficult to keep the Sun directly under the occulter. It is impossible to determine the precise position of the solar disk since the disk is blocked by the occulter. Therefore, UCOMP images require co-alignment before performing subtraction or comparing with images from other instruments. We are currently evaluating different methods to cross-correlate images over the observing day. A better image alignment will provide more accurate mean and median files and subtraction images and will preserve spatial resolution.

Level 2 (L2) Science Products

L2 science products are obtained from L1 data and provide the following:

1) The line-of-sight (LOS) Doppler velocity, line width, and line peak intensity are determined by fitting a gaussian to the observed intensity line profile.
2) The linear polarization is calculated from Stokes Q and U = sqrt(Q^2 + U^2).
3) The azimuth of the plane-of-sky (POS) magnetic field from the saturated Hanle effect is calculated from Stokes Q and U linear polarization: Azimuth = 0.5 atan(U/Q). The azimuth is measured CCW from horizontal and is subject to a 180-degree ambiguity.
4) The radial azimuth of the plane-of-sky (POS) magnetic field is the azimuth with respect to the radial direction. The radial azimuth of the magnetic field is measured CCW from the local radial direction.

Additional data products that can be derived but are not provided at this time include:

5) The line-of-sight (LOS) magnetic field strength from the Zeeman effect can be found by analyzing the Stokes V signal. Stokes V is a very weak signal. For the Fe XIII 1074.7 line, the LOS field strength is ~ 10^{-4} V/I in units of Gauss and as such is difficult to detect in a 20 cm aperture telescope such as UCoMP.
6) The plane-of-sky (POS) magnetic field is calculated from the phase speed of MHD waves in the time series of Doppler images.
7) The density of coronal plasma can be determined by analyzing the intensity ratio of the 1074.7 and 1079.8 nm lines of FeXIII.

L2 science data are in FITS format. A more complete description of the FITS files and the data products contained in the FITS extension arrays is provided in the next section (Level 2 L2 Data Processing).

Quicklook Images and Movies

The quicklook zip file contains all of the quicklook images and movies available at the top of this page AND it contains some images not displayed on this page: L1 intensity and 2 center line intensity; A single image that displays Stokes I, Q, U, V at each wavelength across the emission line (these have filenames ending in '.iquv.all.png'); A single image that displays the daily average (and median) Stokes I, Q, U, V for each emission line (filenames ending in 'iquv.png');

A single image that displays all of the daily average data products for each emission line (filenames ending in '.l2.all.png').

Level 2 (L2) Data Processing

L2 data products can be generated from either individual L1 observations or the average (mean and median) of data collected over an entire observing program. L1 images must pass a more strict quality control, known as a GBU (good, bad, ugly) test in order to be processed to a L2 science data product. A "gbu" file is provided that includes information about which L1 files are promoted to L2 files and which files fail to pass GBU and the reason for their failure. Like the L1 quality codes, the GBU pass/fail codes are bitmask values. L1 Images with a GBU value of 0 pass GBU quality and are processed to Level 2. L1 Images that fail GBU have a non-zero GBU code (see example below for Fe XIII 1074.7 nm). Like L1 quality codes, if a L1 image fails for multiple reasons, the GBU code will be a sum of the codes for which it failed.

GBU bitmask codes

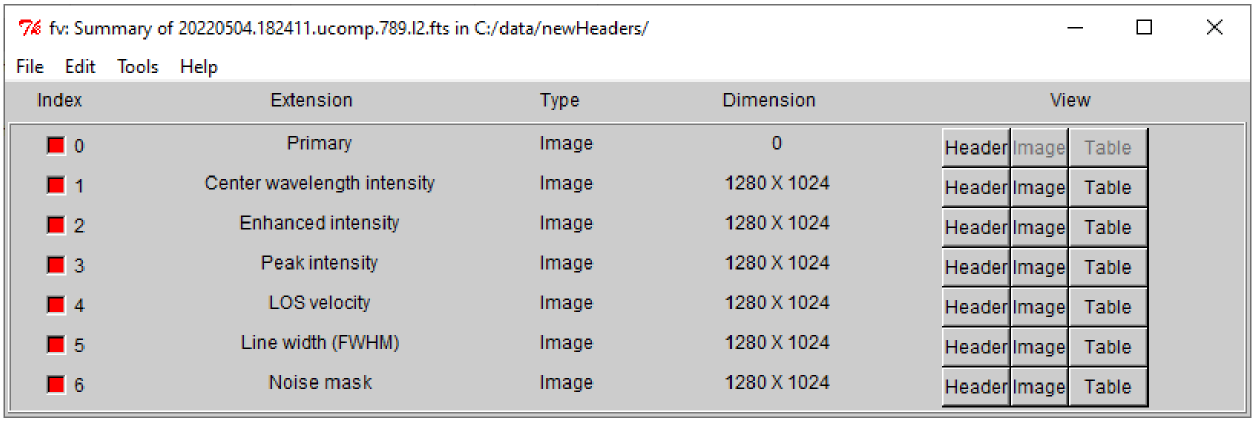
Code	Description for 1074.7 nm (thresholds change with wavelength)
1	spar guide control loop is below threshold (0.99)
2	spar guider intensity below threshold (0.9 * 9.256 * exp(-0.05 * secz))
4	median background is above threshold (30.0)
8	median background is below threshold (5.0)
16	spurious Stokes V signal is above threshold (4.0)
32	the chi-squared of the occulter fit is above threshold (80.0)
64	the difference of the image with the median is above threshold (1.5)

L1 images that pass GBU are processed to Level 2.

L2 data files for all emission lines contain FITS extensions associated with the physical quantities derived from Stokes I and a pixel-by-pixel analytical Gaussian fit to the three-center multiple wavelength tunings across the emission line. The L2 FITS extensions include the following intensity-derived polarization products:

extension 1 = "Center wavelength intensity": L1 intensity at the center tuning wavelength
extension 2 = "Enhanced intensity": unsharp mask of center wavelength intensity
extension 3 = "Gaussian Peak Intensity": peak value of the analytical Gaussian fit
extension 4 = "Line-of-Sight (LOS) Doppler Velocity": derived from the Gaussian fit
extension 5 = "FWHM Line Width": FWHM from the Gaussian fit
extension 6= "Noise Mask". Noise mask displays the pixels in the field-of-view that failed to meet all the signal thresholds for the intensity-derived data products. These noise masking thresholds can be found in the UCoMP GitHub pipeline in the 'wave regions' folder:: https://github.com/NCAR/ucomp-pipeline/tree/master/resource/wave_regions
This folder contains files named ''ucomp.wave.spec.cfg' (e.g. ucomp.1074.spec.cfg) that contain numerous default values including the noise masking thresholds. Future work will replace this mask with noise levels derived from statistical methods.

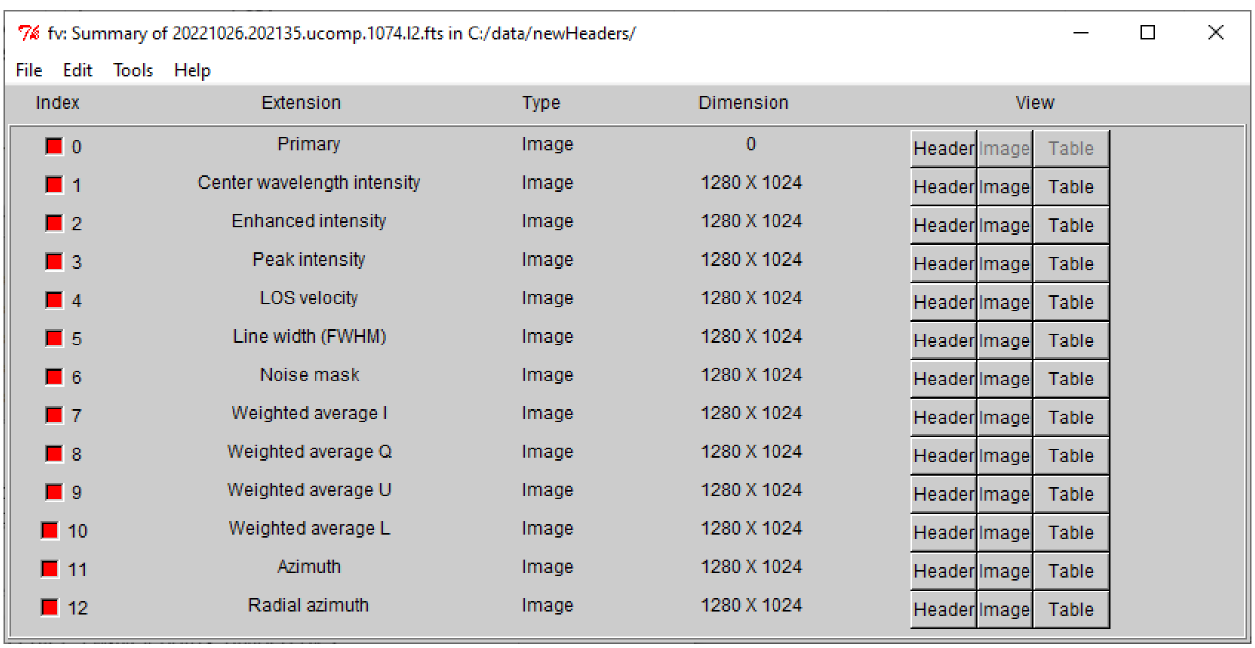
Each extension is a 1280 x 1024 floating point image.


fv: Summary of 20220504.182411.ucomp.789.l2.fts in C:/data/newHeaders/

File Edit Tools Help

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header Image Table
1	Center wavelength intensity	Image	1280 X 1024	Header Image Table
2	Enhanced intensity	Image	1280 X 1024	Header Image Table
3	Peak intensity	Image	1280 X 1024	Header Image Table
4	LOS velocity	Image	1280 X 1024	Header Image Table
5	Line width (FWHM)	Image	1280 X 1024	Header Image Table
6	Noise mask	Image	1280 X 1024	Header Image Table

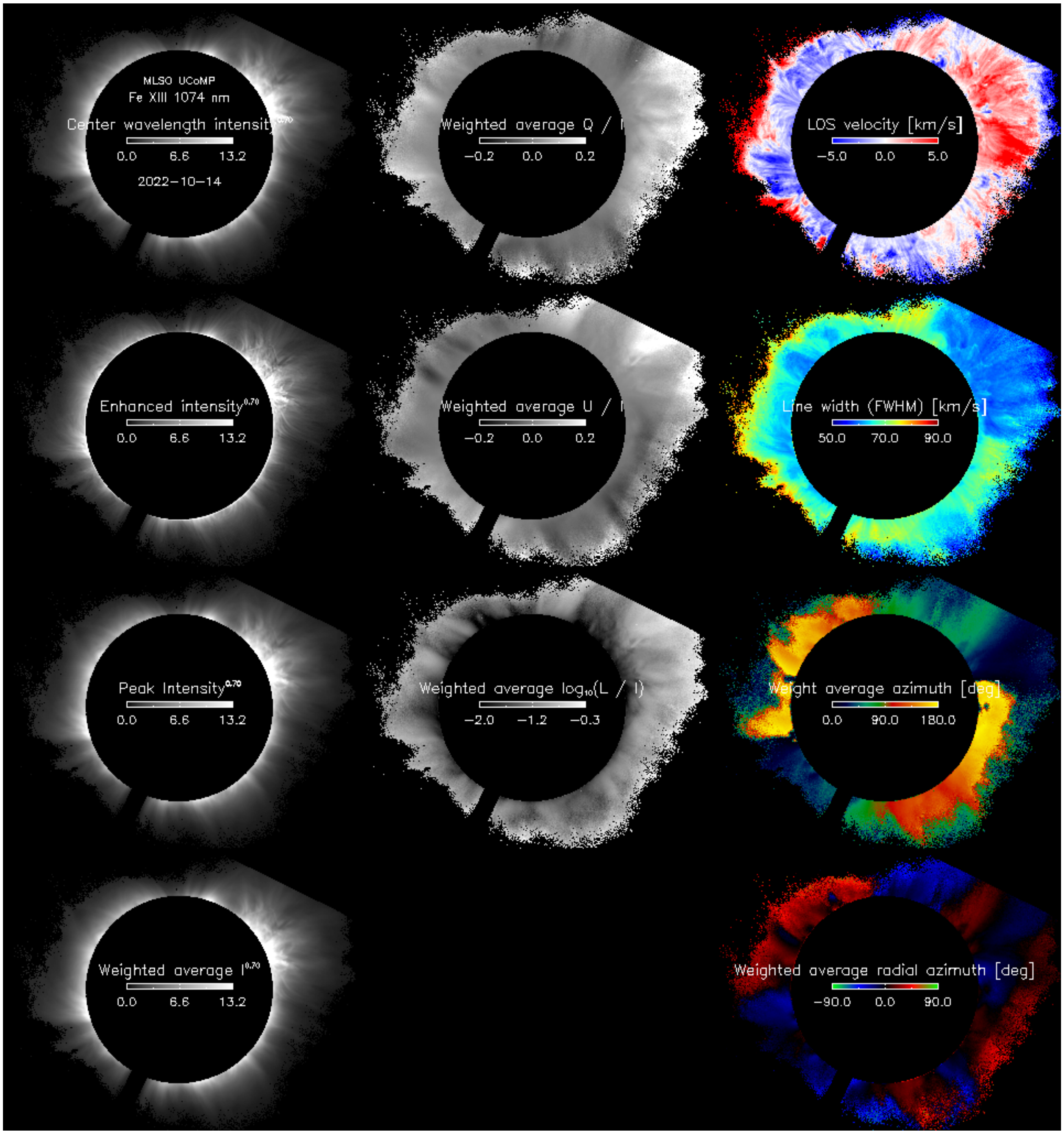
The FeXIII 1074.7 and 1079.8 emission lines exhibit strong polarization signals and, therefore,. polarization products are also provided for these emission lines. The FeXIII L2 data files contain extra FITS extensions with the science products derived from the Q, U, V Stokes vectors.
The following data products are derived from polarization (1074.7 and 1079.8 only) measurements:
extension 7 = "Weighted average I": the sum of I at the center 3 wavelengths divided by 2.
extension 8 = "Weighted average Q": the sum of Q at the center 3 wavelengths, divided by 2.
extension 9 = "Weighted average U": the sum of U at the center 3 wavelengths, divided by 2.
extension 10 = "Weighted average L": linear polarization from U and Q
extension 11 = "Azimuth": the azimuth angle from the ratio of U and Q
extension 12 = "Radial Azimuth": the azimuth angle with respect to the radial direction


fv: Summary of 20221026.202135.ucomp.1074.l2.fts in C:/data/newHeaders/

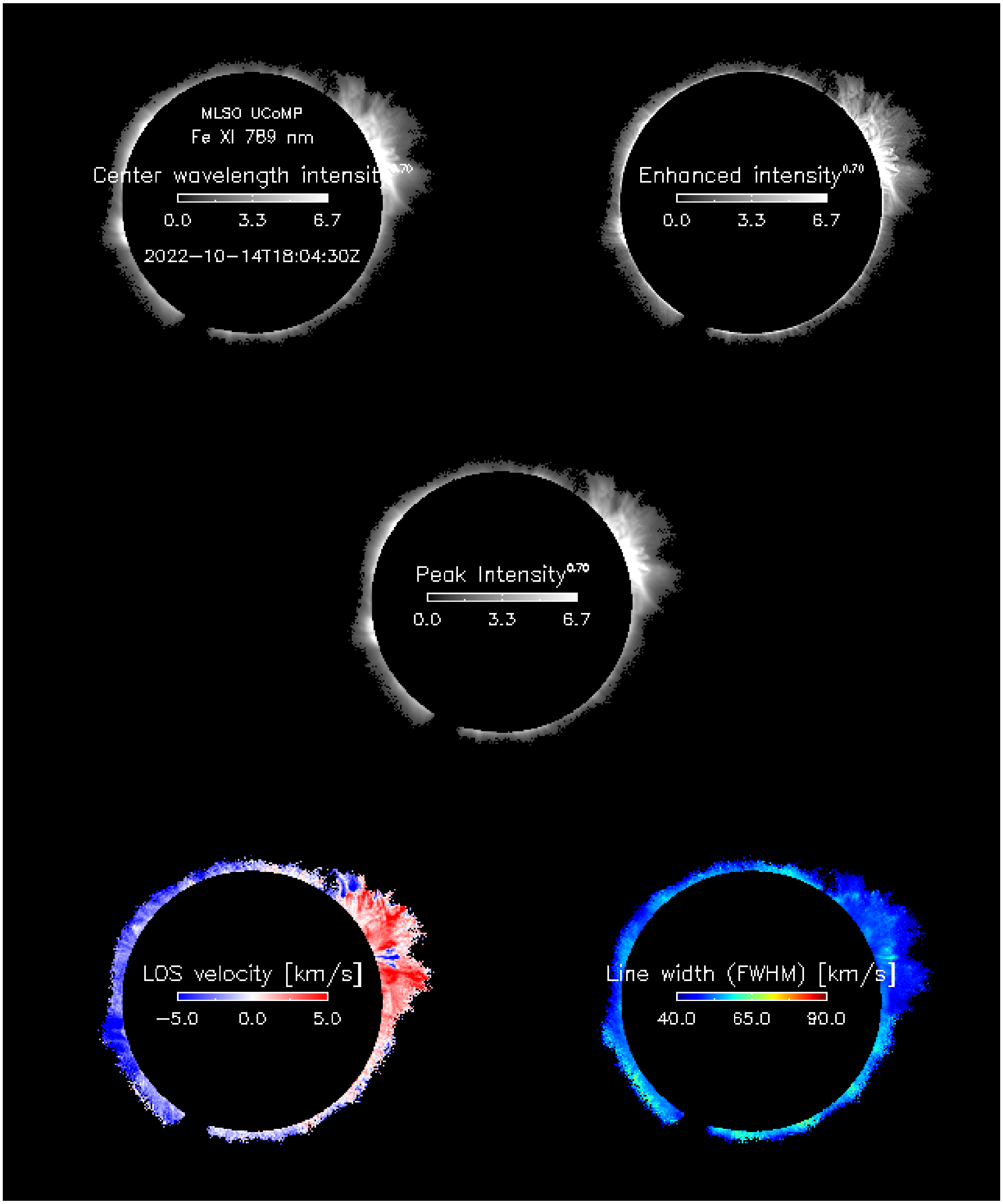
File Edit Tools Help

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header Image Table
1	Center wavelength intensity	Image	1280 X 1024	Header Image Table
2	Enhanced intensity	Image	1280 X 1024	Header Image Table
3	Peak intensity	Image	1280 X 1024	Header Image Table
4	LOS velocity	Image	1280 X 1024	Header Image Table
5	Line width (FWHM)	Image	1280 X 1024	Header Image Table
6	Noise mask	Image	1280 X 1024	Header Image Table
7	Weighted average I	Image	1280 X 1024	Header Image Table
8	Weighted average Q	Image	1280 X 1024	Header Image Table
9	Weighted average U	Image	1280 X 1024	Header Image Table
10	Weighted average L	Image	1280 X 1024	Header Image Table
11	Azimuth	Image	1280 X 1024	Header Image Table
12	Radial azimuth	Image	1280 X 1024	Header Image Table

Example datasets from October 14, 2022 for the FeXIII 1074.7 nm emission line. It shows the eleven L2 data products derived from intensity and polarization images. [Note that for the older CoMP instrument, these products were separated into two FITS files: dynamics (intensity-derived) and polarization files.]



Example datasets from October 14, 2022 for FeXI 789.4 nm emission line. It shows the five L2 data products (intensity-derived science products only)



L2 Filenames:
L2 filenames are based on the source of the data. If the L2 file is derived from a single L1 file, it is named YYYYMMDD.HHMMSS.ucomp.WAVE.l2.fts. On the other hand, if it is created from an average of multiple files taken during a special observing program, it is named
YYYYMMDD.ucomp.WAVE.l2.PROGRAM.GROUPING.fts.
Below is the definition of each component of the filename:
- YYYY: 4-digit year
- MM: Zero-padded 2-digit month
- DD: Zero-padded 2-digit day of the month of the observation in UTC
- HH: Zero-padded 2-digit hours of the observation in UTC
- MM: Zero-padded 2-digit minutes of the observation in UTC
- SS: Zero-padded 2-digit seconds of the observation in UTC
- WAVE: Non-padded integer part of the emission line wavelength in nm
- PROGRAM: Observing program name. For commissioning data, the program is either “waves” or “synoptic” but other programs can be run in future.
- GROUPING: Mean or Median defines how a single pixel value is calculated across all the FITS frames in that program.

Here are some examples of L2 filenames:
- 20220202.215823.ucomp.1074.l2.fts
- 20220202.ucomp.1074.l2.synoptic.mean.fts
- 20220202.ucomp.1074.l2.synoptic.median.fts
- 20220202.ucomp.1074.l2.waves.mean.fts
- 20220202.ucomp.1074.l2.waves.median.fts

Catalog and other ancillary files:
As part of the pipeline, various types of processing logs are generated and provided along with the quicklook ‘zip’ file and the FITS science data ‘tar’ files. This helpful information for the user includes:

- UCoMP user guide (this document)
- catalog listing of all L0 data acquired during the observing day. This contains a comprehensive list of all the L0 files obtained over the observing day. The catalog also summarizes the number of extensions and camera settings for each file.
- Listing of all data acquired by emission line for the observing day.These are separate listings for all the L0 files obtained for each emission line. These files are subsets of the catalog.
- Quality log for each emission line – non zero quality indicates the file failed quality and no L1 image was produced. For more information please see the ‘Level 1 (LI) Data Processing’ section.

- ‘gbu’ log file - a non zero GBU value indicates a L1 file was produced by NOT a L2 file. For more information please see the ‘Level 2 (L2) Data Processing’ section.
- UCoMP data citation text file that contains the UCoMP DOI and data acknowledgment information

Appendix:

Header examples:

Using the following file: 20221026.202135.ucomp.1074.l2.fts With extra documentation at the end of each COMMENT Section.

L2 Primary headers example:

SIMPLE =   T / image conforms to FITS standard
BITPIX =   -32 / bits per data value
NAXIS   =   0 / number of axes
EXTEND =   T / file may contain extensions
L2 data are saved in 32-bit values. It should be noted that primary extensions contain no data so NAXIS=0

COMMENT --- Basic info ---
ORIGIN = 'NCAR/HAO'   / Institution
INSTRUME= 'UCoMP'   / Upgraded Coronal Multichannel Polarimeter
TELESCOP= '20 cm One Shot'   / NSO One Shot telescope
LOCATION= 'MLSO'   / MLSO
OBSSWID = '1.0.6   '   / data collection software ID
DATE-OBS= '2022-10-26T20:21:35.98' / [UT] date/time when obs started
DATE-END= '2022-10-26T20:22:04.05' / [UT] date/time when obs ended
MJD-OBS =   59878.848321760 / [days] modified Julian date
MJD-END =   59878.848657408 / [days] modified Julian date
FILTER = '1074   '   / [nm] prefilter wavelength region identifier
OBJECT = 'SUN   '   /
BUNIT   = '1.0E-06 B/Bsun'   / brightness with respect to solar disk
LEVEL   = 'L2   '   / level 2 calibrated

Most values prompted from the L1 basic info section.

COMMENT --- World Coordinate System (WCS) info ---

```
COMMENT Ephemeris calculations done by sun.pro
WCSNAME = 'helioprojective-cartesian' / World Coordinate System (WCS) name
CDELT1  =               2.944 / [arcsec/pixel] image X increment = platescale
CDELT2  =               2.944 / [arcsec/pixel] image Y increment = platescale
CRPIX1  =               640.5 / [pixel] occulter X center (index origin=1)
CTYPE1  = 'HPLN-TAN'          / helioprojective west angle: solar X
CRVAL1  =                0.00 / [arcsec] occulter X sun center
CUNIT1  = 'arcsec  '          / unit of CRVAL1
CRPIX2  =               512.5 / [pixel] occulter Y center (index origin=1)
CTYPE2  = 'HPLT-TAN'          / helioprojective north angle: solar Y
CRVAL2  =                0.00 / [arcsec] occulter Y sun center
CUNIT2  = 'arcsec  '          / unit of CRVAL2
DSUN_OBS=       148703924816.8 / [m] distance to the Sun from observer
HGLN_OBS=               0.000 / [deg] Stonyhurst heliographic longitude
HGLT_OBS=               4.908 / [deg] Stonyhurst heliographic latitude
PC1_1   =               1.000 / coord transform matrix element (1, 1) WCS std.
PC1_2   =               0.000 / coord transform matrix element (1, 2) WCS std.
PC2_1   =               0.000 / coord transform matrix element (2, 1) WCS std.
PC2_2   =               1.000 / coord transform matrix element (2, 2) WCS std.
```

Keyword values prompted from the L1 WCS header section

COMMENT --- Ephemeris info ---

```
COMMENT Ephemeris calculations done by sun.pro
SOLAR_P0=              25.245 / [deg] solar P angle applied (image has N up)
SOLAR_B0=               4.908 / [deg] solar B-Angle
SECANT_Z=            1.308564 / secant of the Zenith Distance
SID_TIME=             0.95097 / [day fraction] GMST sidereal time
CAR_ROT =                2263 / Carrington Rotation Number
JUL_DATE=   2459879.348321760 / [days] Julian date
RSUN_OBS=              965.40 / [arcsec] solar radius using ref radius 959.63"
R_SUN   =              327.92 / [pixel] solar radius
```

Keyword values prompted from the L1 Ephemeris header section

COMMENT --- Level 1 processing info ---

```
DOI     = 'https://doi.org/10.26024/g8p7-wy42' / Digital Object Identifier
DATE_DP = '2023-11-22T12:05:07' / [UT] L1 processing date/time
DPSWID  = '1.0.0-dev [406c5304*]' / L1 processing software (2023-11-21) [master]
LIN_CRCT=                   F / camera linearity corrected
DEMODV  =                   1 / demod coeffs version [2023-05-15T10:07:04Z]
CONTSUB =                   T / whether the continuum was subtracted
CAMERAS = 'both    '          / cameras used in processing
BOPAL   =               14.80 / [B/Bsun] opal radiance
```

Keyword values prompted from the L1 Level 1 processing header section

COMMENT --- Level 2 processing info ---
DATE_DP2= '2023-11-22T12:56:17' / [UT] L2 processing date/time
DPSWID2 = '1.0.0-dev [406c5304*]' / L2 processing software (2023-11-21) [master]
D_LAMBDA= 0.110 / [nm] wavelength spacing

COMMENT --- Quality metrics ---
VCROSSTK= 1.16518 / Stokes V crosstalk metric
MED_BKG = 9.021 / [ppm] median of line center background annulus
NUMSAT0O= 0 / number of saturated pixels in onband RCAM
NUMSAT1O= 0 / number of saturated pixels in onband TCAM
NUMSAT0C= 0 / number of saturated pixels in bkg RCAM
NUMSAT1C= 0 / number of saturated pixels in bkg TCAM
NUMNL0O = 12 / number of non-linear pixels in onband RCAM
NUMNL1O = 38 / number of non-linear pixels in onband TCAM
NUMNL0C = 10 / number of non-linear pixels in bkg RCAM
NUMNL1C = 34 / number of non-linear pixels in bkg TCAM

Keyword values prompted from the L1 Level 1 quality metrics header section

COMMENT --- Camera info ---
EXPTIME = 80.000 / [ms] Exposure time
FRAMERT = 10.691 / [Hz] Frequency of images
GAIN = 'high' / Camera gain setting
SAVEALL = F / [TF] Save all frames instead of summing
TCAMID = 'Raptor OWL1280 10055' / Unique ID of the TCAM (Camera 1)
RCAMID = 'Raptor OWL1280 10006' / Unique ID of the RCAM (Camera 0)
TCAMLUT = '' / Unique ID of the LUT for TCAM
RCAMLUT = '' / Unique ID of the LUT for RCAM
TCAMNUC = 'Offset + gain corrected' / Camera Correction for TCAM
RCAMNUC = 'Offset + gain corrected' / Camera Correction for RCAM
NFRAME = 48 / total number of image frames in file
REMFRAME= 0 / number of bad frames removed
NUMWAVE = 3 / number of wavelengths
NUMSUM = 14 / number of camera reads summed in an image frame
NREPEAT = 1 / number of repeats of wavelength scans
NUMBEAM = 2 / number of beams
COMMENT Total camera reads in this file = NFRAME * NUMSUM where
COMMENT NFRAME = NUMWAVE * NREPEAT * NUMBEAM * 2(Cameras) * 4(Polarizations)

Keyword values prompted from the L1 Level 1 camera info header section

COMMENT --- Observing info ---
OBS_ID = '1074_03wave_2beam_14sums_1_rep_BOTH' / Name of current observation
OBS_IDAU= '' / Author of the observing program
OBS_IDDA= '' / Edit date of the observing program
OBS_IDVE= 'a9097a357eac9b3d9293f2b535ce0890' / [Md5 hash] Observation ver
OBS_PLAN= 'waves_1074_1hour.cbk' / Name of Current program

```
OBS_PLAU= ''                  / Author of the program
OBS_PLDA= ''                  / Edit date of the observing plan
OBS_PLVE= '466e102210d3660d88b99095afc654fb' / [Md5 hash] Program ver
```

Keyword values prompted from the L1 Observing info header section

COMMENT --- Hardware settings ---

```
DARKID  = 'DARK SHUT 1'        / Dark Shutter ID
O1ID    = 'O1#1'               / Unique ID of objective lens
DIFFSRID= 'S1B'                / Unique ID of diffuser used (change to diffuser
OCCLTRID= '35'                 / Unique ID of the current occulter
FLCVNEG =               -7.000 / [V] Negative FeLC Drive voltage
FLCVPOS =                7.000 / [V] Positive FeLC Drive voltage
POLHOFF =            11021.000 / [counts] Offset in counts for the Cal Pololariz
REDHOFF =             8694.000 / [counts] Offset in counts for the Cal Retarder
T_COMPS =                    T / [TF] Lyot turning temperature compensation on
WAVOFF  =                2.110 / [nm] Tuning offset for Lyot filter
LCVRELX =                0.300 / [s] delay after LCVR tuning before data
FILTFWHM=                0.138 / [nm] Lyot FWHM
CONTOFF =              1.25625 / [nm] continuum offset
COMMENT Continuum can be "red", "blue", or "both": "both" gives equal weight to
COMMENT red and blue sides, "red" samples 90% red contimuum and 10% blue, "blue"
COMMENT samples 90% blue continuum and 10% red; the continuum position is offset
COMMENT from line center by the value of CONTOFF
CONTIN  = 'both    '           / [both/blue/red] location of continuum
OCCLTR-X=               59.820 / Occulter X position
OCCLTR-Y=                3.120 / Occulter Y position
O1FOCUS =               60.230 / O1 focus position
```

Keyword values prompted from the L1 hardware settings header section

COMMENT --- Temperatures ---

```
COMMENT Temperatures used in the Lyot filter calibrations are low-pass
COMMENT filtered and reported in keywords that start with T_. The raw,
COMMENT unfiltered temperature values for recorded temperatures are recorded
COMMENT in keywords that begin with TU_.
T_RACK  =               26.993 / [C] Computer Rack Temp
T_LCVR1 =               34.556 / [C] Lyot LCVR1 Temp
T_LCVR2 =               34.490 / [C] Lyot LCVR2 Temp
T_LCVR3 =               34.567 / [C] Lyot LCVR3 Temp
T_LNB1  =               34.559 / [C] LiNb1 Temp
T_MOD   =               32.816 / [C] Modulator Temp
T_LNB2  =               34.477 / [C] LiNb2 Temp
T_LCVR4 =               34.471 / [C] Lyot LCVR4 Temp
T_LCVR5 =               34.309 / [C] Lyot LCVR5 Temp
T_BASE  =               31.284 / [C] Instrument Baseplate Temp
TU_RACK =               27.706 / [C] Computer Rack Temp Unfiltered
TU_LCVR1=               34.557 / [C] Lyot LCVR1 Temp Unfiltered
TU_LCVR2=               34.487 / [C] Lyot LCVR2 Temp Unfiltered
TU_LCVR3=               34.565 / [C] Lyot LCVR3 Temp Unfiltered
TU_LNB1 =               34.558 / [C] LiNb1 Temp Unfiltered
```

```
TU_MOD  =              32.859 / [C] Modulator Temp Unfiltered
TU_LNB2 =              34.481 / [C] LiNb2 Temp Unfiltered
TU_LCVR4=              34.484 / [C] Lyot LCVR4 Temp Unfiltered
TU_LCVR5=              34.353 / [C] Lyot LCVR5 Temp Unfiltered
TU_BASE =              31.353 / [C] Instrument Baseplate Temp Unfiltered
TU_C0ARR=               4.866 / [C] Camera 0 Sensor array temp Unfiltered
TU_C0PCB=              34.500 / [C] Camera 0 PCB board temp Unfiltered
TU_C1ARR=               4.958 / [C] Camera 1 Sensor array temp Unfiltered
TU_C1PCB=              34.500 / [C] Camera 1 PCB board temp Unfiltered
```

Keyword values prompted from the Level 1temperatures header section

COMMENT --- SGS info ---

```
SGSSCINT=             3.14000 / [arcsec] SGS scintillation seeing estimate
SGSDIMV =             8.81183 / [V] SGS Dim Mean
SGSDIMS =             0.01441 / [V] SGS Dim Std
SGSSUMV =             8.81350 / [V] SGS Sum Mean
SGSSUMS =             0.01003 / [V] SGS Sum Std
SGSRAV  =            -0.00016 / [V] SGS RA Mean
SGSRAS  =             0.01510 / [V] SGS RA Std
SGSDECV =             0.00004 / [V] SGS DEC Mean
SGSDECS =             0.01429 / [V] SGS DEC Std
SGSLOOP =             1.00000 / SGS Loop Fraction
SGSRAZR =           -31.30000 / [V] SGS RA zero point
SGSDECZR=            62.36667 / [V] SGS DEC zero point
```

Keyword values prompted from the Level 1 SGS header section

COMMENT --- Weather info ---

```
WNDSPD  =              13.000 / [mph] wind speed
WNDDIR  =              59.000 / [deg] wind directi
```

Keyword values prompted from the Level 1 Weather header section

COMMENT --- Occulter centering info ---

```
COMMENT X/YOFFSET define position w.r.t. distortion corrected L0 images
XOFFSET0=             -10.701 / [pixels] RCAM occulter x-offset from CRPIX1
YOFFSET0=             -12.808 / [pixels] RCAM occulter y-offset from CRPIX2
RADIUS0 =             341.968 / [pixels] RCAM occulter radius
FITCHI0 =            0.021275 / [pixels] chi-squared for RCAM center fit
XOFFSET1=             -11.773 / [pixels] TCAM occulter x-offset from CRPIX1
YOFFSET1=             -14.114 / [pixels] TCAM occulter y-offset from CRPIX2
RADIUS1 =             342.146 / [pixels] TCAM occulter radius
FITCHI1 =            0.018857 / [pixels] chi-squared for TCAM center fit
POST_ANG=             155.596 / [deg] post angle CCW from north
RADIUS  =             342.057 / [pixels] occulter average radius
IMAGESCL=            2.931982 / [arcsec/pixels] image scale for this file
RCAMECC =              0.0256 / occulter eccentricity in RCAM
```

```
TCAMECC =             0.0100 / occulter eccentricity in TCAM

# Keyword values prompted from the L1 Level 1 Occulter header section

HISTORY
HISTORY Level 1 calibration and processing steps:
HISTORY   - quality check to determine if the file should be processed
HISTORY   - average level 0 data with same onband and wavelength
HISTORY   - apply dark correction
HISTORY   - apply gain correction
HISTORY   - camera corrections such as hot pixel correction
HISTORY   - demodulation
HISTORY   - distortion correction
HISTORY   - find the occulter position and radius
HISTORY   - subtract continuum
HISTORY   - remove hoizontal/vertical bands
HISTORY   - center images using occulter position and rotate to north up
HISTORY   - combine the cameras
HISTORY   - polarimetric correction
HISTORY   - update FITS keywords
END
```

L2 LOS velocity Header example:

```
XTENSION= 'IMAGE   '          / extension type
BITPIX  =                 -32 / bits per data value
NAXIS   =                   2 / number of axes
NAXIS1  =                1280 / [pixels] width
NAXIS2  =                1024 / [pixels] height
PCOUNT  =                   0 /
GCOUNT  =                   1 /
EXTNAME = 'LOS velocity'      / Doppler velocity from Gaussian fit
INHERIT =                   T / inherit primary header
DATATYPE= 'science '          / [sci/cal/dark/flat] science or calibration
OBJECT  = 'SUN'               / Emission Line Corona
RAWFILE = '20221026.202135.98.ucomp.1074.l0.fts' / raw file
FLATDN  =              265.75 / median DN value of the dark-corrected flat used
CAMCORR =                     / correlation between camera images
CAMDIFF =                     / median of absolute difference between camera im
RCAMMED =                     / median value in test annulus in RCAM
TCAMMED =                     / median value in test annulus in TCAM
RSTWVL  =              -5.503 / [km/s] median rest wavelength
RSTMTHD = 'model fit'         / rest wavelength computation method
WAVOFF2 =               1.890 / [nm] offset for center wavelength
SKYTRANS=               0.999 / sky transmission correction normalized to gain
END
```

L1 file Primary FITS HEADER

```
SIMPLE  =                   T / image conforms to FITS standard
```

```
BITPIX  =                  -32 / bits per data value
NAXIS   =                    0 / number of axes
EXTEND  =                    T / file may contain extensions
```

L2 data are saved in 32-bit values. It should be noted that primary extensions contain no data, so NAXIS=0

COMMENT --- Basic info ---

```
ORIGIN  = 'NCAR/HAO'           / Institution
INSTRUME= 'UCoMP'              / Upgraded Coronal Multichannel Polarimeter
TELESCOP= '20 cm One Shot'     / NSO One Shot telescope
LOCATION= 'MLSO'               / MLSO
OBSSWID = '1.0.6   '           / data collection software ID
DATE-OBS= '2022-10-26T20:21:35.98' / [UT] date/time when obs started
DATE-END= '2022-10-26T20:22:04.05' / [UT] date/time when obs ended
MJD-OBS =      59878.848321760 / [days] modified Julian date
MJD-END =      59878.848657408 / [days] modified Julian date
FILTER  = '1074    '           / [nm] prefilter wavelength region identifier
OBJECT  = 'SUN     '           /
BUNIT   = '1.0E-06 B/Bsun'     / brightness with respect to solar disk
LEVEL   = 'L1      '           / level 1 calibrated
```

The Basic info values are created by the observing code at the instrument and are prompted to the L1 and then L2 files. For all data collected before 2024, the OBSSWID was a fixed constant and provided no meaningful information.

COMMENT --- World Coordinate System (WCS) info ---

```
COMMENT Ephemeris calculations done by sun.pro
WCSNAME = 'helioprojective-cartesian' / World Coordinate System (WCS) name
CDELT1  =                2.944 / [arcsec/pixel] image X increment = platescale
CDELT2  =                2.944 / [arcsec/pixel] image Y increment = platescale
CRPIX1  =                640.5 / [pixel] occulter X center (index origin=1)
CTYPE1  = 'HPLN-TAN'           / helioprojective west angle: solar X
CRVAL1  =                 0.00 / [arcsec] occulter X sun center
CUNIT1  = 'arcsec  '           / unit of CRVAL1
CRPIX2  =                512.5 / [pixel] occulter Y center (index origin=1)
CTYPE2  = 'HPLT-TAN'           / helioprojective north angle: solar Y
CRVAL2  =                 0.00 / [arcsec] occulter Y sun center
CUNIT2  = 'arcsec  '           / unit of CRVAL2
DSUN_OBS=       148703924816.8 / [m] distance to the Sun from observer
HGLN_OBS=                0.000 / [deg] Stonyhurst heliographic longitude
HGLT_OBS=                4.908 / [deg] Stonyhurst heliographic latitude
PC1_1   =                1.000 / coord transform matrix element (1, 1) WCS std.
PC1_2   =                0.000 / coord transform matrix element (1, 2) WCS std.
PC2_1   =                0.000 / coord transform matrix element (2, 1) WCS std.
PC2_2   =                1.000 / coord transform matrix element (2, 2) WCS std.
```

Platescale values were derived by analysis of the occulter size in pixels. While the heliographic data is calculated from the ephemeris for Mauna Loa and the date and time of the observation. We continue to refine the derived values for the platescale at each emission line. The reported values may change slightly in future version releases.

COMMENT --- Ephemeris info ---

```
COMMENT Ephemeris calculations done by sun.pro
SOLAR_P0=            25.245 / [deg] solar P angle applied (image has N up)
SOLAR_B0=             4.908 / [deg] solar B-Angle
SECANT_Z=          1.308564 / secant of the Zenith Distance
SID_TIME=           0.95097 / [day fraction] GMST sidereal time
CAR_ROT =              2263 / Carrington Rotation Number
JUL_DATE=    2459879.348321760 / [days] Julian date
RSUN_OBS=            965.40 / [arcsec] solar radius using ref radius 959.63"
R_SUN   =            327.92 / [pixel] solar radius
```

Ephermeris information was derived from IDL sun.pro using the observatory location and time of observations as input.

COMMENT --- Level 1 processing info ---

```
DOI     = 'https://doi.org/10.26024/g8p7-wy42' / Digital Object Identifier
DATE_DP = '2023-11-22T12:05:07' / [UT] L1 processing date/time
DPSWID  = '1.0.0-dev [406c5304*]' / L1 processing software (2023-11-21) [master]
LIN_CRCT=                    F / camera linearity corrected
DEMODV  =                    1 / demod coeffs version [2023-05-15T10:07:04Z]
CONTSUB =                    T / whether the continuum was subtracted
CAMERAS = 'both    '           / cameras used in processing
BOPAL   =             14.80 / [B/Bsun] opal radiance
```

BOPAL is the lab calculated irradiance conversion used to convert camera ADU units to disk center PPM units.

COMMENT --- Quality metrics ---

```
VCROSSTK=           1.16518 / Stokes V crosstalk metric
MED_BKG =             9.021 / [ppm] median of line center background annulus
NUMSAT0O=                 0 / number of saturated pixels in onband RCAM
NUMSAT1O=                 0 / number of saturated pixels in onband TCAM
NUMSAT0C=                 0 / number of saturated pixels in bkg RCAM
NUMSAT1C=                 0 / number of saturated pixels in bkg TCAM
NUMNL0O =                12 / number of non-linear pixels in onband RCAM
NUMNL1O =                38 / number of non-linear pixels in onband TCAM
NUMNL0C =                10 / number of non-linear pixels in bkg RCAM
NUMNL1C =                34 / number of non-linear pixels in bkg TCAM
```

VCROSSTK provides a metric to estimate pointing shake and seeing image motion between frames in the final L2 file. The UCoMP V signal is orders of magnitudes fainter than I and is not measurable by UCoMP except in strong magnetic field regions with long exposure times. Thus, we can assume that V would be effectively zero in most “good” L2 files. However, if there is

motion-induced misalignment between the raw image frames that are combined to produce a L2 file, it can create a spurious signal in the Stoke V. The value of VCROSSTK is used to identify and remove "bad" L2 files that were acquired during bad seeing or bad pointing.

MED_BKG is the average background level in a file and provides a way to track sky brightness and instrument cleanliness. It is also used to separate "good" and "bad" images. L1 files with high MED_BKG or anomalously low MED_BKG are not promoted to the level 2.

COMMENT --- Camera info ---
```
EXPTIME =             80.000 / [ms] Exposure time
FRAMERT =             10.691 / [Hz] Frequency of images
GAIN    = 'high'             / Camera gain setting
SAVEALL =                  F / [TF] Save all frames instead of summing
TCAMID  = 'Raptor OWL1280 10055' / Unique ID of the TCAM (Camera 1)
RCAMID  = 'Raptor OWL1280 10006' / Unique ID of the RCAM (Camera 0)
TCAMLUT = ''                 / Unique ID of the LUT for TCAM
RCAMLUT = ''                 / Unique ID of the LUT for RCAM
TCAMNUC = 'Offset + gain corrected' / Camera Correction for TCAM
RCAMNUC = 'Offset + gain corrected' / Camera Correction for RCAM
NFRAME  =                 48 / total number of image frames in file
REMFRAME=                  0 / number of bad frames removed
NUMWAVE =                  3 / number of wavelengths
NUMSUM  =                 14 / number of camera reads summed in an image frame
NREPEAT =                  1 / number of repeats of wavelength scans
NUMBEAM =                  2 / number of beams
COMMENT Total camera reads in this file = NFRAME * NUMSUM where
COMMENT   NFRAME = NUMWAVE * NREPEAT * NUMBEAM * 2(Cameras) * 4(Polarizations)
```

COMMENT --- Observing info ---
```
OBSERVER= 'Berkey'
OBS_ID  = '1074_03wave_2beam_14sums_1_rep_BOTH' / Name of current observation
OBS_IDAU= ''                 / Author of the observing program
OBS_IDDA= ''                 / Edit date of the observing program
OBS_IDVE= 'a9097a357eac9b3d9293f2b535ce0890' / [Md5 hash] Observation ver
OBS_PLAN= 'waves_1074_1hour.cbk' / Name of Current program
OBS_PLAU= ''                 / Author of the program
OBS_PLDA= ''                 / Edit date of the observing plan
OBS_PLVE= '466e102210d3660d88b99095afc654fb' / [Md5 hash] Program ver
```

OBS_PLAN gives the observing program identifier while the OBS_ID provides the individual script executed to create this L0 FITS file. An MD5 hash of the PLAN and ID files is saved to ensure the exact script can be found. Details of the script can be found on GitHub in https://github.com/NCAR/ucomp-configuration/tree/main/Recipes/previous where the filename is OBS_ID.OBS_IDVE or OBS_PLAN.OBS_PLVE

COMMENT --- Hardware settings ---

```
DARKID  = 'DARK SHUT 1'        / Dark Shutter ID
O1ID    = 'O1#1'               / Unique ID of objective lens
DIFFSRID= 'S1B'                / Unique ID of diffuser used (change to diffuser
OCCLTRID= '35'                 / Unique ID of the current occulter
FLCVNEG =               -7.000 / [V] Negative FeLC Drive voltage
FLCVPOS =                7.000 / [V] Positive FeLC Drive voltage
POLHOFF =            11021.000 / [counts] Offset in counts for the Cal Pololariz
REDHOFF =             8694.000 / [counts] Offset in counts for the Cal Retarder
T_COMPS =                    T / [TF] Lyot turning temperature compensation on
WAVOFF  =                2.110 / [nm] Tuning offset for Lyot filter
LCVRELX =                0.300 / [s] delay after LCVR tuning before data
FILTFWHM=                0.138 / [nm] Lyot FWHM
CONTOFF =              1.25625 / [nm] continuum offset
COMMENT Continuum can be "red", "blue", or "both": "both" gives equal weight to
COMMENT red and blue sides, "red" samples 90% red contimuum and 10% blue, "blue"
COMMENT samples 90% blue continuum and 10% red; the continuum position is offset
COMMENT from line center by the value of CONTOFF
CONTIN  = 'both    '           / [both/blue/red] location of continuum
OCCLTR-X=               59.820 / Occulter X position
OCCLTR-Y=                3.120 / Occulter Y position
O1FOCUS =               60.230 / O1 focus position
```

Hardware ID’s and hardware positions during the acquisition of the observation. Note for coronal science data, the diffuser, calibration polarizer, and calibration retarder are out of the light beam, so the exact position values should not matter.
LCVCRELX defines the time the instrument waits between tuning the LCVR crystals and starting camera integration to allow the crystals to settle.
FILTFWHM tells the Lyot FWHM, which is based on the thickness of crystals in the Lyot filter.
CONTOFF tells where the continuum is with respect to the WAVELNG tuning; this value is set by the thickness of the crystals in the Lyot filter.

COMMENT --- Temperatures ---

```
COMMENT Temperatures used in the Lyot filter calibrations are low-pass
COMMENT filtered and reported in keywords that start with T_. The raw,
COMMENT unfiltered temperature values for recorded temperatures are recorded
COMMENT in keywords that begin with TU_.
T_RACK  =               26.993 / [C] Computer Rack Temp
T_LCVR1 =               34.556 / [C] Lyot LCVR1 Temp
T_LCVR2 =               34.490 / [C] Lyot LCVR2 Temp
T_LCVR3 =               34.567 / [C] Lyot LCVR3 Temp
T_LNB1  =               34.559 / [C] LiNb1 Temp
T_MOD   =               32.816 / [C] Modulator Temp
T_LNB2  =               34.477 / [C] LiNb2 Temp
T_LCVR4 =               34.471 / [C] Lyot LCVR4 Temp
T_LCVR5 =               34.309 / [C] Lyot LCVR5 Temp
T_BASE  =               31.284 / [C] Instrument Baseplate Temp
TU_RACK =               27.706 / [C] Computer Rack Temp Unfiltered
TU_LCVR1=               34.557 / [C] Lyot LCVR1 Temp Unfiltered
```

TU_LCVR2= 34.487 / [C] Lyot LCVR2 Temp Unfiltered
TU_LCVR3= 34.565 / [C] Lyot LCVR3 Temp Unfiltered
TU_LNB1 = 34.558 / [C] LiNb1 Temp Unfiltered
TU_MOD = 32.859 / [C] Modulator Temp Unfiltered
TU_LNB2 = 34.481 / [C] LiNb2 Temp Unfiltered
TU_LCVR4= 34.484 / [C] Lyot LCVR4 Temp Unfiltered
TU_LCVR5= 34.353 / [C] Lyot LCVR5 Temp Unfiltered
TU_BASE = 31.353 / [C] Instrument Baseplate Temp Unfiltered
TU_C0ARR= 4.866 / [C] Camera 0 Sensor array temp Unfiltered
TU_C0PCB= 34.500 / [C] Camera 0 PCB board temp Unfiltered
TU_C1ARR= 4.958 / [C] Camera 1 Sensor array temp Unfiltered
TU_C1PCB= 34.500 / [C] Camera 1 PCB board temp Unfiltered

#The crystals used in UCoMP are bi-refringent and have a strong temperature coefficient. To address this, the filter temperature is actively controlled to 35°C at its center. Additionally, we compensate for small temperature variations by changing the voltages sent to the lyot filter LCVRs in real-time. It is expected that all temperature changes will occur over a relatively long timescale due to the thermal masses involved. Therefore, a low-pass filter is applied to the temperatures to avoid any spurious measurements.

Low-pass temperatures are reported as T_**** while the most recent raw temperature readout for the various subsystems is reported as TU_****. The U denotes that this value is not the low-pass filter output.

COMMENT --- SGS info ---
SGSSCINT= 3.14000 / [arcsec] SGS scintillation seeing estimate
SGSDIMV = 8.81183 / [V] SGS Dim Mean
SGSDIMS = 0.01441 / [V] SGS Dim Std
SGSSUMV = 8.81350 / [V] SGS Sum Mean
SGSSUMS = 0.01003 / [V] SGS Sum Std
SGSRAV = -0.00016 / [V] SGS RA Mean
SGSRAS = 0.01510 / [V] SGS RA Std
SGSDECV = 0.00004 / [V] SGS DEC Mean
SGSDECS = 0.01429 / [V] SGS DEC Std
SGSLOOP = 1.00000 / SGS Loop Fraction
SGSRAZR = -31.30000 / [V] SGS RA zero point
SGSDECZR= 62.36667 / [V] SGS DEC zero point

#Feedback from the guider performance. For best seeing and tracking SGSSCINT, SGSRAV, and SGSDECV should be as close to zero as possible. The SGSDIMV value measures the solar disk intensity and is used during the flat/gain correction to account for differences in air mass between the science file and flat file used for flat-fielding.

COMMENT --- Weather info ---
WNDSPD = 13.000 / [mph] wind speed
WNDDIR = 59.000 / [deg] wind direction

COMMENT --- Occulter centering info ---
COMMENT X/YOFFSET define position w.r.t. distortion corrected L0 images
XOFFSET0= -10.701 / [pixels] RCAM occulter x-offset from CRPIX1
YOFFSET0= -12.808 / [pixels] RCAM occulter y-offset from CRPIX2
RADIUS0 = 341.968 / [pixels] RCAM occulter radius
FITCHI0 = 0.021275 / [pixels] chi-squared for RCAM center fit
XOFFSET1= -11.773 / [pixels] TCAM occulter x-offset from CRPIX1
YOFFSET1= -14.114 / [pixels] TCAM occulter y-offset from CRPIX2
RADIUS1 = 342.146 / [pixels] TCAM occulter radius
FITCHI1 = 0.018857 / [pixels] chi-squared for TCAM center fit
POST_ANG= 155.596 / [deg] post angle CCW from north
RADIUS = 342.057 / [pixels] occulter average radius
IMAGESCL= 2.931982 / [arcsec/pixels] image scale for this file
RCAMECC = 0.0256 / occulter eccentricity in RCAM
TCAMECC = 0.0100 / occulter eccentricity in TCAM

HISTORY
HISTORY Level 1 calibration and processing steps:
HISTORY - quality check to determine if the file should be processed
HISTORY - average level 0 data with same onband and wavelength
HISTORY - apply dark correction
HISTORY - apply gain correction
HISTORY - camera corrections such as hot pixel correction
HISTORY - demodulation
HISTORY - distortion correction
HISTORY - find the occulter position and radius
HISTORY - subtract continuum
HISTORY - remove hoizontal/vertical bands
HISTORY - center images using occulter position and rotate to north up
HISTORY - combine the cameras
HISTORY - polarimetric correction
HISTORY - update FITS keywords
END

L1 file Extension FITS HEADER
XTENSION= 'IMAGE ' / extension type
BITPIX = -32 / bits per data value
NAXIS = 3 / number of axes
NAXIS1 = 1280 / [pixels] width
NAXIS2 = 1024 / [pixels] height
NAXIS3 = 4 / polarization states: I, Q, U, V
PCOUNT = 0 /
GCOUNT = 1 /
EXTNAME = 'Corona Stokes IQUV [1074.70 nm]' /
INHERIT = T / inherit primary header

```
DATATYPE= 'science '          / [sci/cal/dark/flat] science or calibration
OBJECT  = 'SUN'               / Emission Line Corona
WAVELNG =            1074.700 / [nm] Wavelength of observation
RAWFILE = '20221026.202135.98.ucomp.1074.l0.fts' / raw file
RAWEXTS = '3,6     '          / extension(s) used from RAWFILE
RAWDARK1= '20221026.194632.68.ucomp.l0.fts' / raw dark filename used, wt 0.50
DARKEXT1=                   6 / 20221026.ucomp.dark.fts ext used, wt 0.50
RAWDARK2= '20221026.205659.14.ucomp.l0.fts' / raw dark filename used, wt 0.50
DARKEXT2=                   7 / 20221026.ucomp.dark.fts ext used, wt 0.50
FLTFILE1= '20221026.194735.23.ucomp.1074.l0.fts' / name of raw flat file used
FLTEXTS1= '3       '          / 20221026.194735.23.ucomp.1074.l0.fts ext used
MFLTEXT1= '14,17   '          / 20221026.ucomp.1074.flat.fts ext, wt 0.50
FLTFILE2= '20221026.205611.58.ucomp.1074.l0.fts' / name of raw flat file used
FLTEXTS2= '3       '          / 20221026.205611.58.ucomp.1074.l0.fts ext used
MFLTEXT2= '20,23   '          / 20221026.ucomp.1074.flat.fts ext, wt 0.50
FLATDN  =              270.18 / median DN value of the dark-corrected flat used
CAMCORR =                     / correlation between camera images
CAMDIFF =                     / median of absolute difference between camera im
RCAMMED =                     / median value in test annulus in RCAM
TCAMMED =                     / median value in test annulus in TCAM
SKYTRANS=               0.999 / sky transmission correction normalized to gain
END
```

#RAW, FLT and DARK files and extensions document the various L0 files used in the L1 pipeline to calibrate this coronal science file.

#SKYTRANS is the value from the current method used to correct the variability in sky transmission over the observing day due to the change in air mass along the line of sight when viewing near the horizon vs viewing near zenith. The current method is to take the ratio of the Guider intensity value at the time of the science image and divide it by the Guider intensity value at the time of the flat-field image. This is the same method currently used to correct for sky transmission in the MLSO K-Cor coronagraph data. A more sophisticated correction will be implemented for UCoMP data in the future that will take into account the passband of the Guider and the emission wavelength of the various science images since sky transmission is sensitive to wavelength.