UCoMP Data User's Guide Dec 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 on GitHub at: https://github.com/NCAR/ucomp-pipeline

The current data release is based on December 2023 with the 1.0 pipeline version. As for version 1.0, we plan to fix the FITS file extension formats and names, but future reprocessing will change metadata and FITS pixel 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 with a polarimeter and narrow-band tunable Lyot filter capable of spectro-polarimetric imaging of coronal emission lines in the visible and near-IR portions of the solar spectrum above the limb. The UCoMP is an upgrade of the CoMP instrument. It has a broader wavelength range (530 - 1083 nm) than CoMP (1074 - 1083 nm), increasing the number of emission lines observed to enhance the plasma diagnostic capabilities, a larger field-of-view (+/- 2 Rsun) compared to CoMP (+/- 1.3 Rsun), and higher spatial resolution (6 arcseconds) compared to CoMP (9 arcseconds).

Level 1 (L1) UCoMP data comprises Stokes I, Q, U, and V images taken at several selected wavelengths across the coronal emission lines of FeXIV 530.3 nm, FeX 637.4 nm, ArXI 691.8, FeXV 706.2 nm, FeXI 789.4, FeXIII 1074.7 and 1079.8 nm and the chromospheric emission lines of HI 656.3 and HeI 1083 nm. Each Level 1 fits image contains extension arrays of size 1280 x 1024 x 4, which are the number of pixels in the x and y directions respectively, and the 4 Stokes images I, Q, U and V. The number of wavelengths observed across the line is designated in the filename. For example, the file, '20220831.201003.ucomp.1074.l1.p3.fts' contains 3 points across the emission line as indicated by '.p3.' in the filename.

From the L1 data, Level 2 (L2) quantities can be derived, including

1) the Doppler shift and line width from the line profile in intensity
2) the azimuth of the magnetic field from the ratio of Stokes U to Stokes Q
3) the line-of-sight (LOS) magnetic field from the Stokes V signal
4) the plane-of-sky (POS) magnetic field from the phase speed of MHD waves in the time series of Doppler images
5) the density of coronal plasma from the intensity ratio of the 1074.7 and 1079.8 nm lines of FeXIII

UCoMP began collecting commissioning data in July 2021.

Wave regions available in 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	2.2	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

Processed Data

Development of the UCoMP Data processing pipeline is ongoing and documented in Github. Data processed with version 1.0 of the pipeline significantly changed FITS extension formats and filenames. Data users with older copies are encouraged to re-download data with the newer processing versions. As of version 1.0 the pipeline team does not expect any major changes to the filenames or FITS extension formats, so we expect that software tools designed to work with

1.0 data products should continue to work without changes in future versions.   The pipeline team is aware of and has documented in github issues multiple noise sources in the data; as we address these in future releases, we expect FITS pixel and metadata values will change. We encourage users to periodically refresh their data to get the best possible data processing.

Data location and avaiablity

Quick look and FITS data can be found from the MLSO webpage calendar at: https://mlso.hao.ucar.edu/mlso_data_calendar.php?&calinst=ucomp. Quick-look images are available in movies and pngs from the webpage. Tarballs and zip files of a days Level 1, Level 2, and quicklook data can also 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 now.

Processing levels

UCoMP data is computed and 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 reduce storage and traffic on the mountain but otherwise contain raw camera reads. Level 1 data (L1) in which known instrumental effects are removed, and the raw data is converted into Stokes IQUV vectors. Level 2 data (L2) are derived data products that compute physical properties from the Wavelnght and Stokes

Level 2 (L2) Data Products

L2 data products come from either individual L1 (files) observations or ensembles (mean and median) of the data taken over an entire observing program (typically 2-3 hours of data).

All L2 data files will contain FITS extensions associated with products derived from Stokes I, and pixel-by-pixel Gaussian fits of the multiple wavelength tunings process an emission line.

For the lines with strong polarization signals (1074 and 1079), extra FITS extensions related to data products derived from the QUV stokes vectors will be computed.

The Fits exentsion include:

Intensity derived polariation products::

- "Center wavelength intensity": "L1 intensity at center tuning wavelength"
- "Enhanced intensity": "unsharp mask of center wavelength intensity"
- "Peak Intensity": "peak value of Gaussian fit"
- "LOS Velocity": "Doppler velocity derived from Gaussian fit"
- "Line Width": "FWHM from Gaussian fit"

fv: Summary of 20220831.173529.ucomp.637.l2.fts in C:/data/newL2/

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

Polarization drived data products (1074/1079 only)

- "Weighted average I": "sum of I at center 3 wavelengths / 2"
- "Weighted average Q" (Q/I in the quicklook png files): "sum of Q at center 3 wavelengths / 2"
- "Weighted average U" (U/I in the quicklook png files): "sum of U at center 3 wavelengths / 2"
- "Weighted average L" (Log(L/I) in the quicklook png files):

$$L = \sqrt{(Weighted\ average\ Q)^2 + (Weighted\ average\ U)^2}$$

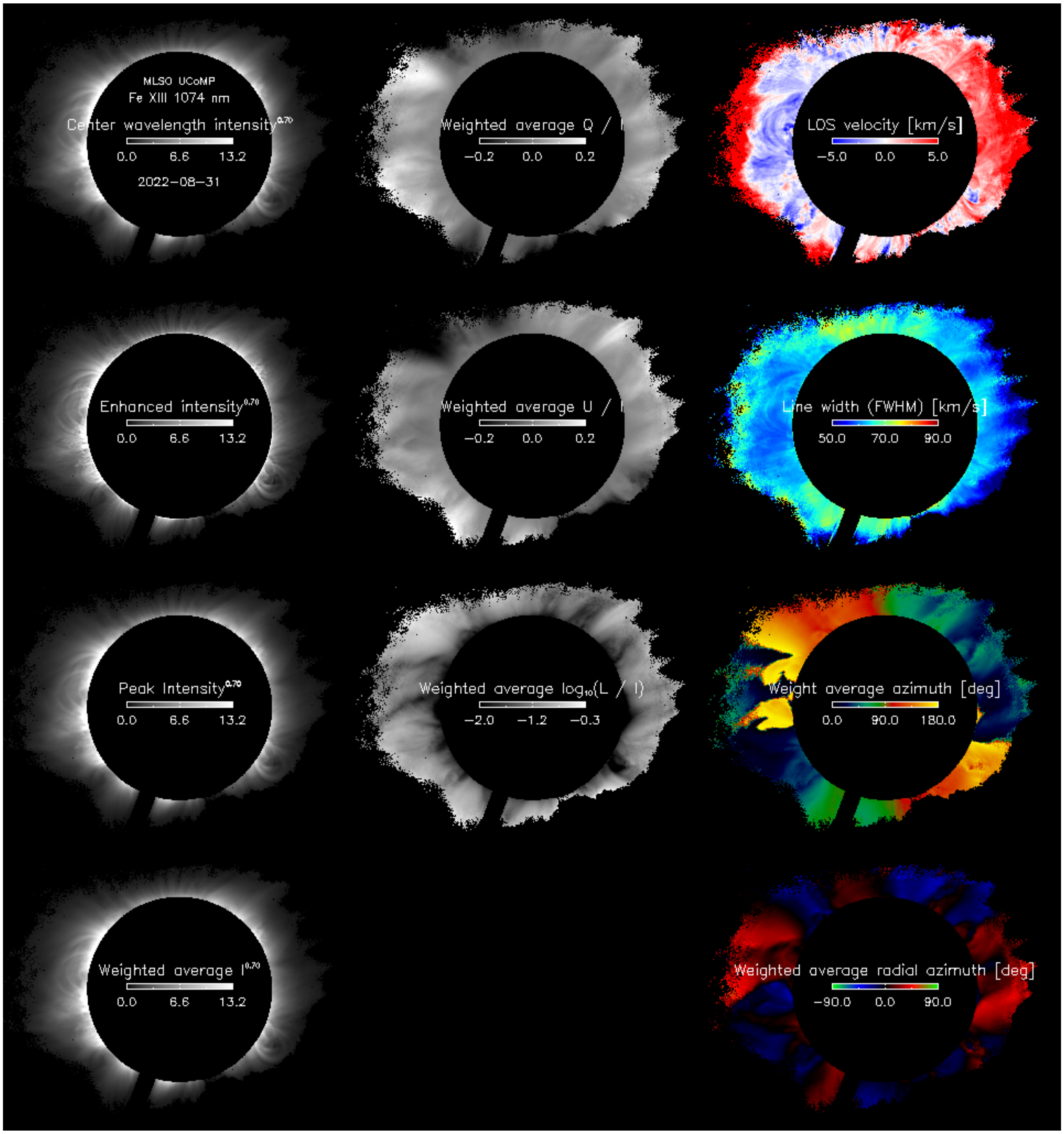
- "Azimuth": $0.5 * atan(\frac{Weighted\ average\ U}{Weighted\ average\ Q})$
- "Radial Azimuth": "azimuth with respect to the radial direction"

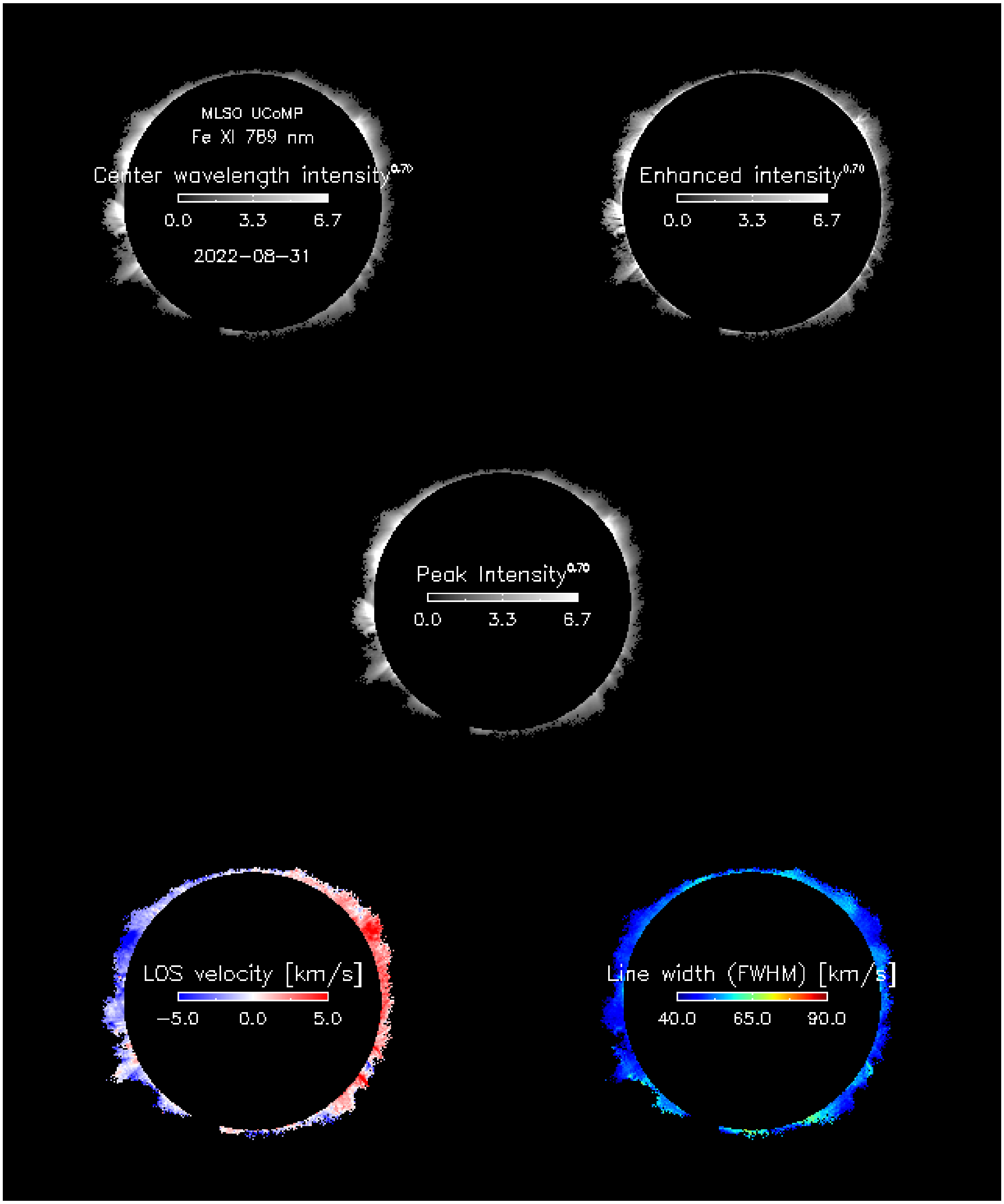
fv: Summary of 20220831.175123.ucomp.1074.l2.fts in C:/data/newL2/

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	Weighted average I	Image	1280 X 1024	Header Image Table
7	Weighted average Q	Image	1280 X 1024	Header Image Table
8	Weighted average U	Image	1280 X 1024	Header Image Table
9	Weighted average L	Image	1280 X 1024	Header Image Table
10	Azimuth	Image	1280 X 1024	Header Image Table
11	Radial azimuth	Image	1280 X 1024	Header Image Table

Data examples: 20220831 1074 waves median and 789 synoptic median quick looks. Showing examples of the intensity and polarization product(1074) and the intensity only products in (789).


MLSO UCoMP
Fe XIII 1074 nm
Center wavelength intensity^0.70
0.0 6.6 13.2
2022-08-31
Weighted average Q / I
−0.2 0.0 0.2
LOS velocity [km/s]
−5.0 0.0 5.0
Enhanced intensity^0.70
0.0 6.6 13.2
Weighted average U / I
−0.2 0.0 0.2
Line width (FWHM) [km/s]
50.0 70.0 90.0
Peak Intensity^0.70
0.0 6.6 13.2
Weighted average log10(L / I)
−2.0 −1.2 −0.3
Weight average azimuth [deg]
0.0 90.0 180.0
Weighted average I^0.70
0.0 6.6 13.2
Weighted average radial azimuth [deg]
−90.0 0.0 90.0


MLSO UCoMP
Fe XI 789 nm
Center wavelength intensity0.70
0.0 3.3 6.7
2022-08-31
Enhanced intensity0.70
0.0 3.3 6.7
Peak Intensity0.70
0.0 3.3 6.7
LOS velocity [km/s]
−5.0 0.0 5.0
Line width (FWHM) [km/s]
40.0 65.0 90.0

L2 Filenames:

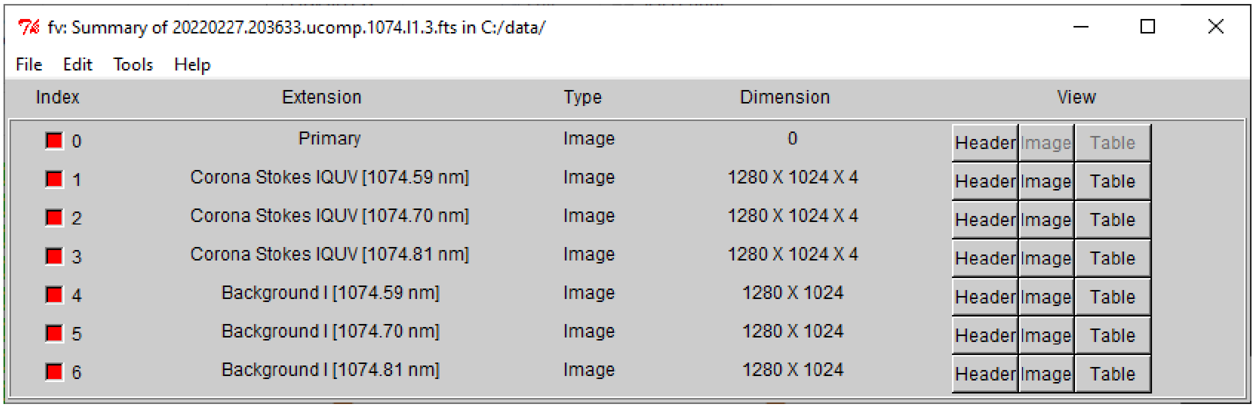
L2 files derived from a single L1 file are named:
YYYYMMDD.HHMMSS.ucomp.WAVE.l2.fts
L2 files based on an ensemble of mutiple files taken during a program are named:
YYYYMMDD.ucomp.WAVE.l2.PROGRAM.GROUPING.fts
Where
YYYY=4 digit year
MM = zero-padded 2-digit month
DD = zero-padded 2-digit day of the month 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, all commissioning data is either waves or synoptic
GROUPING = Mean or Median defines how a single pixel value is calculated across all the FITS frames in that program.

Examples:
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

Level 1 (L1) Data Products

L1 Data processing removes known instrumental issues, subtracts the continuum, combines the cameras, and demodulates the raw polarizations to Stokes IQUV. A single L1 FITS file will be created for each L0 science/coronal file that is complete and passes a very basic quality check, intending to promote as many L0 files as possible to L1. (This excludes files that contain flats, darks, polarization calibrations, or files with incomplete metadata). After the individual L1 files are created, the pipeline creates ensemble L1 data by combining individual L1 files via per-pixel mean and median combinations.

Below is an example L1 data file containing three tunings (1074.59, 1074.70, and 1074.8) across the 1074.7 Iron 13 emission line.



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

The L1 data processing software performs the following steps:

1) sum over the repeated data
2) dark correction, which corrects dark and offset signals in the detector
3) other corrections, including hot pixel correction, linearity correction, etc.
4) flat field correction, which corrects for gain variations in the detector
5) photometric calibration, which converts to units of ppm of the solar disk intensity
6) polarimetric calibration, which converts the 4 polarization states to Stokes I, Q, U, and V
7) image translation to put the occulting disk at the center of the image
8) image rotation to put solar north up
9) beam combining to subtract the background channel from the corona+background channel

The L1 images are translated so that the center of the occulter is in the center of the array. Since the solar disk is blocked by the occulter, the exact position of the solar disk is not known.

The intensity units are 10^{-6} of the solar disk intensity (parts per million or ppm).

The L1 data products are stored in FITS files. One L1 file is computed for each L0 file. A fits viewer listing of the contents of an L1 file from one observation using the fv fits viewer is shown below.

The data is stored as a 3-D array indexed x-pixels by y-pixels, with the third dimension containing Stokes I, Q, U, V, with one extension for each tuning of the Lyot filter. The last extension contains the background averaged over all of the tunings. The background level has been removed from the non-background extensions.

The primary header in extension 0 holds the metadata about the observation, and the extension headers contain metadata about the corresponding extensions. Examples of the primary and extension headers are given in Appendix A and B, respectively.

Level 0 (L0, Raw) Data

The UCoMP L0 data is organized as multiple extension fits files, with each extension containing a 2x4x1280x1024 image array. The first dimension of the array identifies the camera, the second identifies the polarization modulation, and the 3rd and 4th dimensions identify the image columns and rows.

UCoMP is a two-channel instrument with one channel/camera tuned to receive the ONBAND coronal emission line (defined in the WAVELNG keyword) and the other camera receiving photons from a nearby region of the wavelength spectrum. To correct for systematic noise in the instrument well, formatted observing programs will swap the role of the two cameras back and forth. In any single extension, the camera receiving ONBAND light will be specified with the ONBAND keyword. The two options are RCAM (reflected beam camera) and TCAM (transmitted beam camera).

The UCoMP polarization modulator contains two electrically tuneable Ferroelectric liquid-crystal (FLC) polarizers driven to 4 states (++,+-,--,+-). These FLC devices have a highly chromatic wavelength response to how much of each IQUV vector gets transmitted in each state. This means the L0 modulation images cannot be assumed to be I,Q,U or V states but instead a mix of all 4. To retrieve the Stokes vectors from the raw modulations, the L1 pipeline applies a demodulation matrix (measured in special engineering modes).

The L1 pipeline will process any L0 science file that meets the following criteria.

-It is a science/coronal file and contains extensions with extra shutters, polarizers, or diffusers in the beam. These rejected files will become darks, flats, or polarization calibration files if they meet other requirements.

-The file contains FITS extensions with at least 3 wavelength tunings across the emission line observed (ONBAND) in both cameras.

-Time time gaps between adjacent extensions of more than 10 seconds

-All wavelength tunings are

file that meets the

The instrument software does not impose any requirements on the flavors of LYOT filter tunings found in FITS to allow for special engineering runs. TheThe L1 pip file this allows for special ; but in order to be processed by the L1 pipeline an L0 file must contain teh follow.

To save storage and bandwidth off the mountain, the L0 observing code can co-add up to 16 like images.

up to 16

As such

These states give FLCS polarizaer is a seris of FLeC has a chromatic wavelneght response

the nearby continuum emission

At any point one of the 2 cameras is acting as the ONBAND camera receives coronal emission from the commanded wavelength; while the other camera receives continuum emission

The LYOT filter is re-tuned between each FITS extension to shift the wavelength

Each extension relates to a different lyot filter tuning to either shift the wavelength of the filter or swap the roles of the two cameras.   At a minimum, an L0 file should have six FITS extensions representing = 3 wavelength tunings across the emission line * 2 repeats of these tunings with both cameras taking turns imaging the onband emission line and the continuum background. Depending on the science case, an L0 file may contain more points across the emission line (typically 5 or 7) or multiple repeats of a tuning flavor for deeper observations.

Data within each extension includes at least 8 camera reads to collect to 4 raw polarization states across the 2 cameras. To save bandwidth of the mountain, typically observing programs co-add 16 (or 14 for the waves program) like raw polarization frames together in each of these extensions. Given a more typical total of 2 cameras * 4 polarization * 16 co-adds, 128 camera reads per fits extension.

The units of the L0 data are Data Number or DN. For the Owl cameras, there are approximately 4 electrons per DN.

TH

Catalog and GBU files:

Two additional files are found in the process directory for each day. The first is the catalog file that lists each of the L0 files taken that day and the characteristics of that file. An additional file is the GBU (Good, Bad, Ugly - traditionally) file that lists all of the L1 files created for that day and an estimate of whether that file is Good or Bad. This is useful for users to avoid questionable data. A GBU file is created for every day. If no data was taken that day, the GBU file will be empty.

All level 2 data products are computed using only the ‘Good’ L1 data files.

L2 Primary headers:
SIMPLE =   T / image conforms to FITS standard
BITPIX =   -32 / bits per data value
NAXIS   =   0 / number of axes
EXTEND =   T / file may contain extensions
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= '2022-08-31T19:59:59.02' / [UT] date/time when obs started
DATE-END= '2022-08-31T20:00:27.02' / [UT] date/time when obs ended
FILTER = '1074   '   / [nm] prefilter wavelength region identifier
OBJECT = 'SUN   '   /
COMMENT --- World Coordinate System (WCS) info ---
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)
CRVAL1 =   0.00 / [arcsec] occulter X sun center
CRUNIT1 = 'arcsec '   / unit of CRVAL1
CRPIX2 =   512.5 / [pixel] occulter Y center (index origin=1)
CRVAL2 =   0.00 / [arcsec] occulter Y sun center
CRUNIT2 = 'arcsec '   / unit of CRVAL2
COMMENT --- Ephemeris info ---
COMMENT Ephemeris calculations done by sun.pro
SOLAR_P0=   20.989 / [deg] solar P angle applied (image has N up)
SOLAR_B0=   7.185 / [deg] solar B-Angle
SECANT_Z=   1.215072 / secant of the Zenith Distance
SID_TIME=   0.78261 / [day fraction] GMST sidereal time
CAR_ROT =   2261 / Carrington Rotation Number
JUL_DATE=   2459823.333321760 / [days] Julian date
RSUN_OBS=   950.72 / [arcsec] solar radius using ref radius 959.63"
R_SUN   =   322.93 / [pixel] solar radius
COMMENT --- Level 1 processing info ---
LEVEL   = 'L2   '   / level 2 calibrated
DOI   = 'https://doi.org/10.26024/g8p7-wy42' / Digital Object Identifier
DATE_DP = '2023-11-07T00:37:44' / [UT] L1 processing date/time
DPSWID = '0.5.1-dev [2b873b19*]' / L1 processing software (2023-11-06) [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
BUNIT   = '1.0E-06 B/Bsun'   / brightness with respect to solar disk
COMMENT --- Quality metrics ---
VCROSSTK=   1.56188 / Stokes V crosstalk metric
MED_BKG =   12.893 / [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 =                  113 / number of non-linear pixels in onband RCAM
NUMNL1O =                  256 / number of non-linear pixels in onband TCAM
NUMNL0C =                   13 / number of non-linear pixels in bkg RCAM
NUMNL1C =                   67 / number of non-linear pixels in bkg TCAM
```

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
```

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= '27'                 / 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  =                2.070 / [nm] Tuning offset for Lyot filter
LCVRELX =                0.300 / [ms] Delay after LCVR turning before data
FILTFWHM=                0.138 / [nm] Lyot FWHM
CONTOFF =              1.25625 / [nm] continuum offset
D_LAMBDA=               0.1100 / [nm] wavelength spacing
OCCLTR-X=               60.070 / Occulter X position
```

OCCLTR-Y=   3.570 / Occulter Y position
O1FOCUS =   60.230 / O1 focus position
COMMENT --- Temperatures ---
T_RACK =   26.399 / [C] Computer Rack Temp
T_LCVR1 =   34.566 / [C] Lyot LCVR1 Temp
T_LCVR2 =   34.491 / [C] Lyot LCVR2 Temp
T_LCVR3 =   34.571 / [C] Lyot LCVR3 Temp
T_LNB1 =   34.567 / [C] LiNb1 Temp
T_MOD   =   31.868 / [C] Modulator Temp
T_LNB2 =   34.496 / [C] LiNb2 Temp
T_LCVR4 =   34.500 / [C] Lyot LCVR4 Temp
T_LCVR5 =   34.391 / [C] Lyot LCVR5 Temp
T_BASE =   31.362 / [C] Instrument Baseplate Temp
TU_RACK =   26.844 / [C] Computer Rack Temp Unfiltered
TU_LCVR1=   34.568 / [C] Lyot LCVR1 Temp Unfiltered
TU_LCVR2=   34.490 / [C] Lyot LCVR2 Temp Unfiltered
TU_LCVR3=   34.573 / [C] Lyot LCVR3 Temp Unfiltered
TU_LNB1 =   34.569 / [C] LiNb1 Temp Unfiltered
TU_MOD =   31.815 / [C] Modulator Temp Unfiltered
TU_LNB2 =   34.503 / [C] LiNb2 Temp Unfiltered
TU_LCVR4=   34.516 / [C] Lyot LCVR4 Temp Unfiltered
TU_LCVR5=   34.434 / [C] Lyot LCVR5 Temp Unfiltered
TU_BASE =   31.380 / [C] Instrument Baseplate Temp Unfiltered
T_C0ARR =   5.055 / [C] Camera 0 Sensor array temp
T_C0PCB =   37.500 / [C] Camera 0 PCB board temp
T_C1ARR =   5.025 / [C] Camera 1 Sensor array temp
T_C1PCB =   37.500 / [C] Camera 1 PCB board temp
COMMENT --- SGS info ---
SGSSCINT=   4.19350 / [arcsec] SGS scintillation seeing estimate
SGSDIMV =   8.46933 / [V] SGS Dim Mean
SGSDIMS =   0.01849 / [V] SGS Dim Std
SGSSUMV =   8.46767 / [V] SGS Sum Mean
SGSSUMS =   0.01408 / [V] SGS Sum Std
SGSRAV =   0.00094 / [V] SGS RA Mean
SGSRAS =   0.02628 / [V] SGS RA Std
SGSDECV =   0.00000 / [V] SGS DEC Mean
SGSDECS =   0.02378 / [V] SGS DEC Std
SGSLOOP =   1.00000 / SGS Loop Fraction
SGSRAZR =   -14.08333 / [V] SGS RA zero point
SGSDECZR=   25.50000 / [V] SGS DEC zero point
COMMENT --- Weather info ---
WNDSPD =   6.000 / [mph] wind speed
WNDDIR =   355.000 / [deg] wind direction
COMMENT --- Occulter centering info ---
COMMENT X/YOFFSET define position w.r.t. distortion corrected L0 images
XOFFSET0=   -2.126 / [pixels] RCAM occulter x-offset from CRPIX1
YOFFSET0=   -0.991 / [pixels] RCAM occulter y-offset from CRPIX2
RADIUS0 =   333.332 / [pixels] RCAM occulter radius
FITCHI0 =   0.010498 / [pixels] chi-squared for RCAM center fit
XOFFSET1=   -3.099 / [pixels] TCAM occulter x-offset from CRPIX1
YOFFSET1=   -2.133 / [pixels] TCAM occulter y-offset from CRPIX2

```
RADIUS1 =             333.508 / [pixels] TCAM occulter radius
FITCHI1 =           0.013232 / [pixels] chi-squared for TCAM center fit
POST_ANG=             159.777 / [deg] post angle CCW from north
RADIUS  =             333.420 / [pixels] occulter average radius
IMAGESCL=            2.939181 / [arcsec/pixels] image scale for this file
RCAMECC =              0.0240 / occulter eccentricity in RCAM
TCAMECC =              0.0321 / 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
```

Archive/delete text below this line

UCoMP FITS data is processed and saved at three levels. Level 0 (L0) data are the lowest level raw data files recorded at the telescope; once created, we will not edit these files.

Level 1 (L1) files remove the known instrumental effects and demodulate the L0 files to produce IQUV stoke vector arrays. Level 2 (L2) processing combines multiple IQUV arrays to create derived data products such as Radial velocity, line width, and radial polarization maps around the sun.

Level 0 (L0) is the raw data collected at the telescope and saved by the observing program. The UCoMP team has no plans to publish the L0 data, but it can be made available on request. Level 1 (L1) processing removes known instrumental issues (flats, darks, polarization corrections, etc) as some co-adding of like frames within observation programs. The results of the L1 pipeline produce 1 calibrated IQUV FITS file for each suitable L0 file. It also makes ensemble L1 files based on the excellent median and mean L0 data during the day. Level 2 (L2)processing combines the Stokes polarization states to produce observables like LOS velocity, Radial Polarization, and Line Width. The L2 pipeline has these data products for all suitable L1 data files and ensemble collections (mean and median) processing for the whole day.

Glossary of Header values:

(Dynamics File) L2 file focused on dynamics products;produced for a single L1 fits file identified with a filename with the pattern: YYYYMMDD.HHMMSS.ucomp.[wavelength].l2.dynamics.fts

i_1 = Red L1 I image

i_2 = Line center L1 I image

i_3 = Blue L1 I image

$linespacing = Line\ Center\ Wavelength - Red\ Wavelength$

Peak intensity: Gaussian fit of the intensity across the wavelengths available in an L1 file. $exp(LOS\ Doppler\ Velocity^2 / line\ width^2)$

Enhanced peak intensity: Unsharpened mask of the Peak Intensity

LOS doppler velocity: Line of sight doppler velocity as measuring across the wavelengths available in the L1 file. Equation:

$doppler = line\ width^2 / (4 * linespacing) * (alog(i_1/i_2) - alog(i_3/i_2))$

Line width: Gaussian fit to the line width as measured across the wavelengths available in the L1 file. Equation: $Line\ width = \sqrt{-2 * (linespacing)^2 / (alog(i_1/i_2) + alog(i_3/i_2))}$

(Polarization) L2 file focused on polarization products; produced for a single L1 fits file identified with a filename with the pattern: YYYYMMDD.HHMMSS.ucomp.[wavelength].l2.polarization.fts

Integrated intensity: The average value of the L1 I values across the available wavelengths

$(i_1 + i_2 + i_3)/3$

Enhanced integrated intensity: Unsharpened mask of the Integrated I.

Integrated Q: The average value of the L1 Q values across the available wavelengths.

$$(Q_1 + Q_2 + Q_3)/3$$

Integrated U: The averaged value of the L1 U values across the available wavelengths.

$$(U_1 + U_2 + U_3)/3$$

Integrated L: v

Azimuth: $0.5 * atan(Average\ Q,\ Average\ U)\ *!radeg$

Radial Azimuth: $azimuth - theta + 90$

L2 Mean and Median Ensemble Files

The pipeline produces Mean and Median daily ensemble L2 results for each program (i.e., synoptic and waves). This most basic of these ensembles files combines the IQUV stoke vector images for each wavelength plus a continuum (background) I. This is a daily L1 file.

fv: Summary of 20220227.ucomp.1074.waves_1074_1hour.mean.fts in C:/data/

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

This combined ensemble data is used to produce the L2 Polarization and Dynamics data products similar to what is done with the individual fits files.

The pipeline also produces

were computed using all of the data collected in a day. One mean image and one median image are computed at each of the wavelength regions, at all of the number of tunings that were used in a day. Also, standard deviation (sigma) images were computed corresponding to the mean and median images. No effort was made to co-align the coronal images so the sigma images are probably dominated by the evolution and drift of the corona throughout the day. The mean, median, and sigma image fits files contain those quantities for each Stokes parameter and tuning.

Also, in the Mean and Median folder are the so-called “quick_invert” files for the 1074 nm, 3 tuning data. The listing of the contents of a quick invert file from the fits viewer fv is shown below.

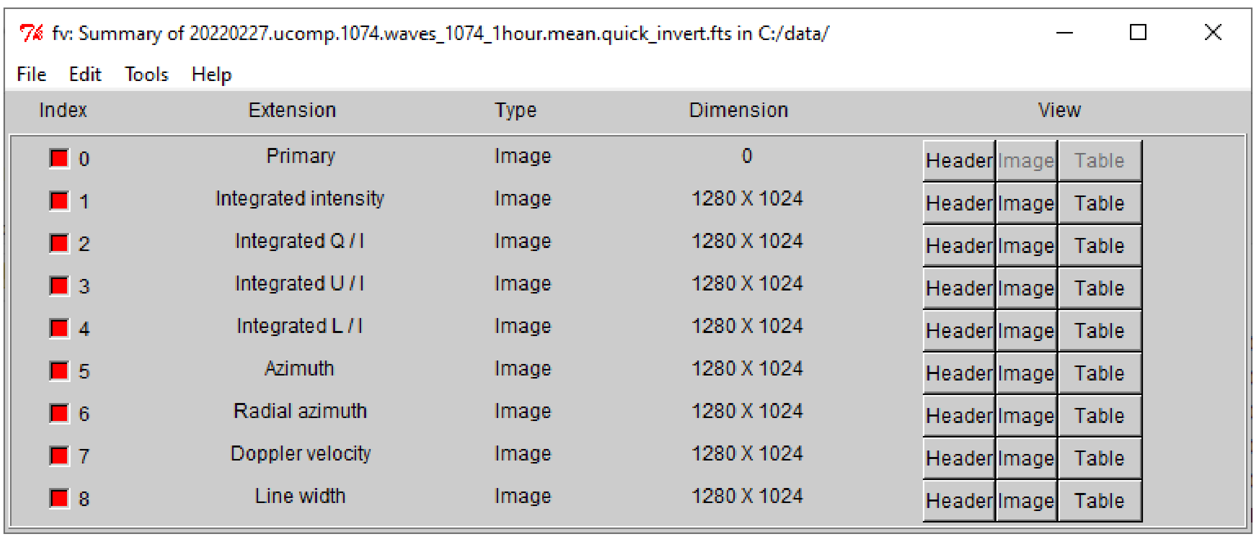
The average quantities (I, Q, and U) were computed by taking the sum of the quantity over the 3 wavelength tunings and dividing by 2. Integrated L is the total linear polarization defined as:

$$L = (Q^2 + U^2)^{½.}$$

The azimuth is the POS direction of the magnetic field computes as:

$$\text{Azimuth} = 0.5 \text{ atan}(U/Q)$$

and is measured in solar coordinates, CCW from horizontal. The Radial Azimuth is the Azimuth measured CCW from the local radial. The units for Azimuth and Radial Azimuth are degrees, while the units are ppm for the other quantities. The Azimuth, Radial Azimuth, Doppler Velocity, and Line Width are computed with the analytic Gaussian solution described in the L2 Dynamics files described above.



fv: Summary of 20220227.ucomp.1074.waves_1074_1hour.mean.quick_invert.fts in C:/data/

File Edit Tools Help

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header Image Table
1	Integrated intensity	Image	1280 X 1024	Header Image Table
2	Integrated Q / I	Image	1280 X 1024	Header Image Table
3	Integrated U / I	Image	1280 X 1024	Header Image Table
4	Integrated L / I	Image	1280 X 1024	Header Image Table
5	Azimuth	Image	1280 X 1024	Header Image Table
6	Radial azimuth	Image	1280 X 1024	Header Image Table
7	Doppler velocity	Image	1280 X 1024	Header Image Table
8	Line width	Image	1280 X 1024	Header Image Table

L2 Polarization Files

The so-called polarization files are stored in the level2/Polarization directory for a given day. There is one polarization file for each of the ‘Good’ L1 files. An example header of a polarization file is shown below.

Like the quick invert file, the integrated quantities (I, Q, and U) were computed by taking the sum of the quantity over the 3 wavelength tunings and dividing by 2. Integrated L, Azimuth, and Radial Azimuth are computed as described in the quick invert section above.

[Synotic | Waves] (Median or Mean files)

The pipeline does combines all high quality L1 files with mean and median processing

Each daily observing program typically Synoptic (deep observation of all available wavelengths) and Waves (30 second cadence observations of 1074) receives a mean and median

One set of Mean and Median quick look

One set of Program Median or Mean files will be produced for each emission line and observing program run during that day. Typically this will include a synoptic program observing most or all of the UCoMP emission lines and a waves program observing only 1074 at a high cadence.

Within each emission line/program file, there will be X FITS extensions, one for each of the wavelength tunings made across the emission line (X typically =3 and sometimes 5). Each extension will contain a 4x1280x1024 array with the daily mean or median of the I,Q,U,V values measured in that wavelength tuning for the specified emission line/observing program.

Fits headers will be named:

[PROGRAM NAME] Stokes IQUV, wavelength[nm]

Such that a 1074 Waves program with tunings at 1074.59,1074.70,1074.81 will have extensions names:

Waves Stokes IQUV, wavelength 1074.59

Waves Stokes IQUV, wavelength 1074.70

Waves Stokes IQUV, wavelength 1074.81

(Quick invert)

Using the PROGRAM Median (and/or??) Mean files, the following quantities are computed.

PROGRAM Average I: Average of the I signal across all the wavelengths in a Daily file.

PROGRAM Peak Intensity: Gaussian fit to the intensity values in the Program file.

PROGRAM Average Q/PROGRAM Average I Average across the wavelengths of the Program Q/Average Average across the wavelengths of the Program I

PROGRAM Average U/PROGRAM Average I Average across the wavelengths of the Program Q/Average Average across the wavelengths of the Program U

PROGRAM Average L/PROGRAM Average I L (see dynamics section for description) computed from PROGRAM file instead of single L1 file / PROGRAM Average I

PROGRAM Azimuth Azimute (see polarization section for description) computed form the PROGRAM instead of a single L1 file.

PROGRAM Radial Azimuth Radial Azimute (see polarization section for description) computed from the PROGRAM instead of a single L1 file.

PROGRAM LOS Doppler Velocity LOS velocity (see polarization section for description) computed from the PROGRAM instead of a single L1 file.

PROGRAM Line Widith Line width (see polarization section for description) computed from the PROGRAM instead of a single L1 file.

PROGRAM Uncorrected LOS Doppler Velocity ???

Appendix A, Level 1 Primary Header Example

```
SIMPLE  =                    T /image conforms to FITS standard
BITPIX  =                   16 /bits per data value
NAXIS   =                    0 /number of axes
EXTEND  =                    T /file may contain extensions
BZERO   =                32768
BSCALE  =                    1
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'              / TODO calculate software id.
DATE-OBS= '2022-05-11T19:45:45.36' / UTC Date time when obs was started
OBJECT  = 'SUN'                / Corona and Chromosphere
LEVEL   = 'L1      '           / Level 1
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= '27'                 / Unique ID of the current occulter
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
OBSERVER= 'Berkey'
OBS_ID  = '1074_03wave_2beam_16sums_4rep_BOTH' / Name of current observation
OBS_IDAU= ''                   / Author of the observing program
OBS_IDDA= ' Wed Feb 16 13:55:59 2022' / Edit date of the observing program
OBS_IDVE= '2d069f93becbc0fcab4a416df2d4ee4e' / [Md5 hash] Observation ver
OBS_PLAN= 'all_wavelength_coronal.cbk' / Name of Current program
OBS_PLAU= 'BERKEY'             / Author of the program
OBS_PLDA= ''                   / Edit date of the observing plan
OBS_PLVE= 'da77e06e185c691c24815a8d0a248995' / [Md5 hash] Program ver
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
GAIN    = 'high'               / Camera gain setting
SAVEALL =                    F / [TF] Save all frames instead of summing
T_COMPS =                    T / [TF] Lyot turning temperature compensation on
WAVOFF  =                2.030 / [nm] Tuning offset for Lyot filter
LCVRELX =                0.250 / [ms] Delay after LCVR turning before data
FILTER  = '1074'               / [nm] Prefilter identifier
OCCLTR-X=               59.900 / Occulter X position
OCCLTR-Y=                3.400 / Occulter Y position
```

```
O1FOCUSE=              60.230 / O1 focus position
T_RACK  =              22.830 / [C] Computer Rack Temp
T_LCVR1 =              34.560 / [C] Lyot LCVR1 Temp
T_LCVR2 =              34.500 / [C] Lyot LCVR2 Temp
T_LCVR3 =              34.575 / [C] Lyot LCVR3 Temp
T_LNB1  =              34.562 / [C] LiNb1 Temp
T_MOD   =              32.353 / [C] Modulator Temp
T_LNB2  =              34.471 / [C] LiNb2 Temp
T_LCVR4 =              34.446 / [C] Lyot LCVR4 Temp
T_LCVR5 =              34.215 / [C] Lyot LCVR5 Temp
T_BASE  =              30.999 / [C] Instrument Baseplate Temp
TU_RACK =              23.205 / [C] Computer Rack Temp Unfiltered
TU_LCVR1=              34.564 / [C] Lyot LCVR1 Temp Unfiltered
TU_LCVR2=              34.498 / [C] Lyot LCVR2 Temp Unfiltered
TU_LCVR3=              34.572 / [C] Lyot LCVR3 Temp Unfiltered
TU_LNB1 =              34.560 / [C] LiNb1 Temp Unfiltered
TU_MOD  =              32.289 / [C] Modulator Temp Unfiltered
TU_LNB2 =              34.472 / [C] LiNb2 Temp Unfiltered
TU_LCVR4=              34.451 / [C] Lyot LCVR4 Temp Unfiltered
TU_LCVR5=              34.241 / [C] Lyot LCVR5 Temp Unfiltered
TU_BASE =              31.083 / [C] Instrument Baseplate Temp Unfiltered
T_C0ARR =               4.803 / [C] Camera 0 Sensor array temp
T_C0PCB =              27.500 / [C] Camera 0 PCB board temp
T_C1ARR =               7.267 / [C] Camera 1 Sensor array temp
T_C1PCB =              26.500 / [C] Camera 1 PCB board temp
WNDSPD  =              10.000 / [MPH] Wind Speed
WNDDIR  =              86.000 / [DEG] Wind Direction
SGSDIMV =             8.48500 / [V] SGS Dim Mean
SGSDIMS =           0.0124300 / [V] SGS Dim Std
SGSSUMV =             8.48400 / [V] SGS Sum Mean
SGSSUMS =          0.00809000 / [V] SGS Sum Std
SGSRAV  =        -0.000190000 / [V] SGS RA Mean
SGSRAS  =           0.0169000 / [V] SGS RA Std
SGSDECV =         2.00000E-05 / [V] SGS DEC Mean
SGSDECS =           0.0172400 / [V] SGS DEC Std
SGSSCINT=             2.81300 / [arcsec] SGS scintillation seeing estimate
SGSLOOP =             1.00000 / SGS Loop Fraction
SGSRAZR =            -33.3000 / [V] SGS RA zero point
SGSDECZR=             39.7000 / [V] SGS DEC zero point
VCROSSTK=            0.442601 / Stokes V Crosstalk Metric
NUM_WAVE=                   3 / Number of Wavelengths
NUMSUM  =                  16 / Number of camera reads summed together
NREPEAT =                   4 / Number of repeats of wavelength scans
NUM_BEAM=                   2 / Number of beams
FLATBEF = '20220511.182757.36.ucomp.1074.l0.fts' / Name of flat field file befor
FLATAFT = '        '          / Name of flat field file after
FLTWTBEF=             1.00000 / Weight of flat field file before
```

```
FLTWTAFT=           0.00000 / Weight of flat field file after
JUL_DATE=     2459711.32344 / [days] Julian Date
SOLAR_P =          -21.8092 / [deg] Solar P-Angle
SOLAR_B =          -3.04417 / [deg] Solar B-Angle
SECANT_Z=           1.21343 / Secant of the Zenith Distance
RSUN    =           950.196 / [arcsec] Solar Radius
OPAL_RAD=           14.8000 / [ppm] Opal Radiance
CDELT1  =           2.93907 / [arcsec/pixel] Image Scale at Focal Plane
XOFFSET0=          -8.60862 / [px] Occulter X-Offset 0
YOFFSET0=          -9.07658 / [px] Occulter Y-Offest 0
ORADIUS0=           333.009 / [px] Occulter Radius 0
FITCHI0 =           1.13229 / [px] Chi-squared for image 0 center fit
XOFFSET1=          -10.3050 / [px] Occulter X-Offset 1
YOFFSET1=          -10.9159 / [px] Occulter Y-Offest 1
ORADIUS1=           333.857 / [px] Occulter Radius 1
FITCHI1 =           1.10490 / [px] Chi-squared for image 1 center fit
MED_BACK=           16.6982 / [ppm] Median of Background
ORADIUS =           333.433 / [px] Occulter Average Radius
POST_ANG=           202.455 / [deg] Post angle CCW from north
LIN_CRCT= 'no      '          / Linearity Corrected?
END
```

Appendix B, Level 1 Extension Header Example

```
XTENSION= 'IMAGE   '          /extension type
BITPIX  =                 -32 /bits per data value
NAXIS   =                   3 /number of axes
NAXIS1  =                1280 /
NAXIS2  =                1024 /
NAXIS3  =                   4 /
PCOUNT  =                   0 /
GCOUNT  =                   1 /
EXTNAME = 'sci [1074.59 nm]'   /
O1FOCUS =              60.230 / O1 focus position
DATATYPE= 'sci'               / [sci/cal/dark/flat] Science or Calibration
DATE-BEG= '2022-05-11T19:48:10.21' / Date time of the beginning of data for this
OBJECT  = 'SUN'               / Emission Line Corona
WAVELNG =             1074.59 / [nm] WAVELENGTH OF OBS
O1ND    = 'out'               / [out/in/mid] Manual O1ND filter in beam
EXPTIME =              80.000 / [ms] Exposure time
FRAMERT =              10.691 / [Hz] Frequency of images
SEQNUM  =                  23 / Position number in the Observation
OCCLTR  = 'in'                / [in/out/mid] Occulter Position in beam
CALOPTIC= 'out'               / Polarizer and retarder in or out of the beam
COVER   = 'out'               / [out/in/mid] O1 Lens cover
DIFFUSR = 'out'               / [out/in/mid] Diffuser
DARKSHUT= 'out'               / Dark shutter in or out of the beam
POLANGLE=            -110.210 / [deg] angle of rotation of cal polarizer
RETANGLE=             -86.940 / [deg] angle of rotation of cal retarder
END
```

o gaussian the

For most of 2022 we ran two observing programs, a synoptic data program which collected about 2.5 minutes of data across 3 wavelength tunings for each emission line. And a waves program which collected about 1 hour of 30 seconds cadence 3 wavelength tuning 1074 data. The biggest difference between the synoptic and saves 1074 observations is in the synoptic data we co-add 8x more images producing a higher SNR data product.

For each of the individual good L1 observations the pipeline produces 2 L2 FITS files, one collecting Dynamics products and the other Polarization products.

For the ensemble files the pipeline produces all the products created for the individual L1 files plus some ensemble specific FITS files. These includes both a L1 like ensemble file containing the IQUV and background/continuum images for each of the 3 wavelength tunings; plus a COMP like quick_invert file that contains quantities similar to what is found in both the dynamics and polarization files.

Along with these FITS files some quicklook data is produced to aid in the inspection of images. Every product within the FITS files get a quicklook PNG file, and these PNGS are combined together into MP4 movies to show qualitative changes of these quantities over the course of the day. When data is available temperature maps are also produced combining median ensemble center wavelength I stokes polariztiong.