Polarimeter to Unify the Corona and Heliosphere

Science Operations Center Development

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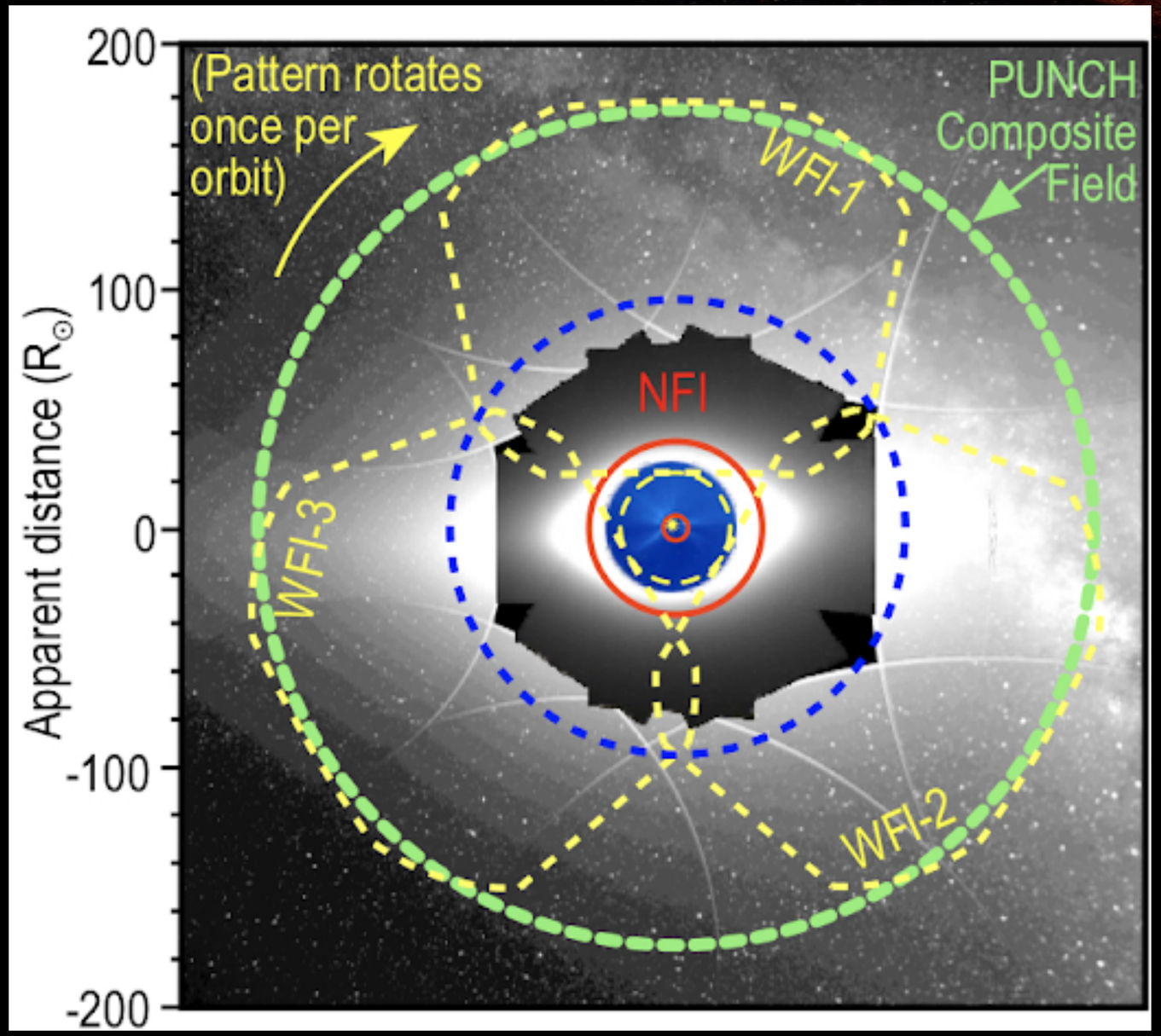
Second PUNCH Science Meeting
August 9 2021

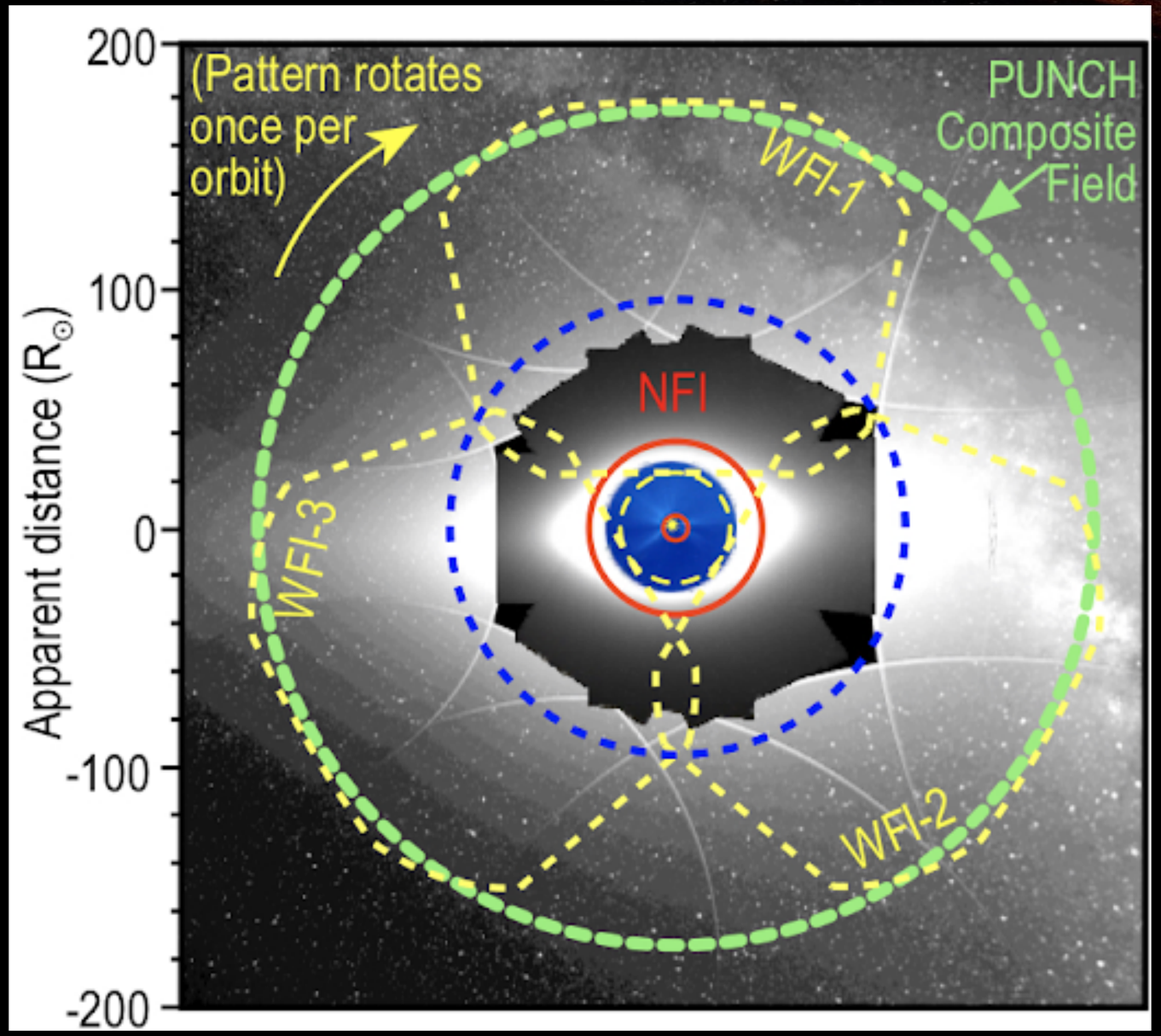
Introduction - Observations

- PUNCH observes continuously at 4-min. cadence
- NFI covers 5.4 $R_\odot$-32 $R_\odot$
- WFI covers 20 $R_\odot$-180 $R_\odot$ in 3 parts (yellow dash trefoil)
- PUNCH produces 3 full mosaics per orbit, from 6-180 $R_\odot$

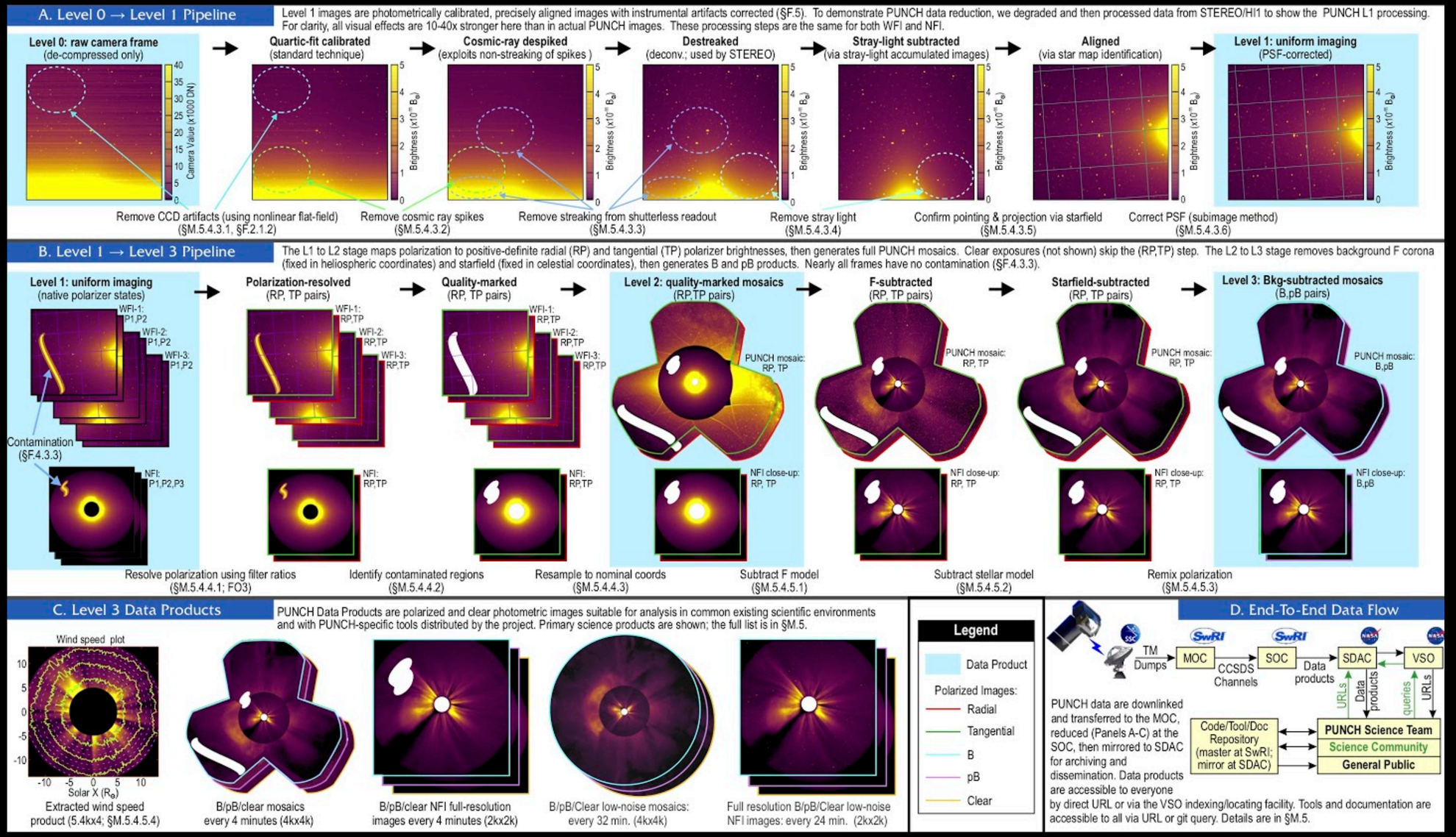


Introduction - Observations

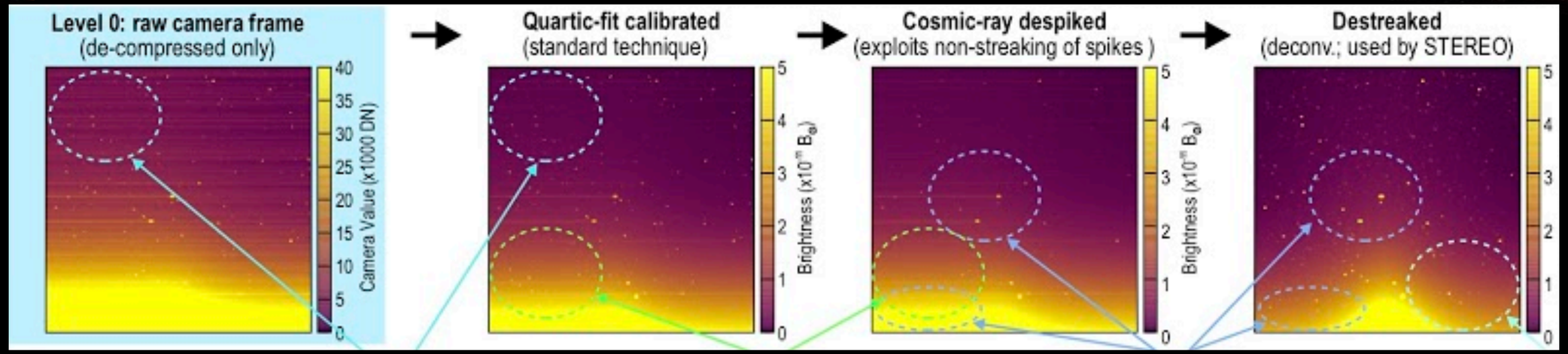
- The PUNCH mission is composed of 4 satellites/instruments:
  - 1×Near-Field Imager
  - 3×Wide-Field Imagers
- PUNCH produces:
  - Individual images at multiple calibration levels
  - Trefoil images
  - Low Noise Composites & Derived Products (e.g., Wind Velocity Maps)
  - Low Latency Space Weather Products
  - Quicklook Products
- Formats: Clear, Polarization States, Brightness & Polarized Brightness Pairs



Data Processing: It's Complicated



Data Processing: Level-0 → Level-1

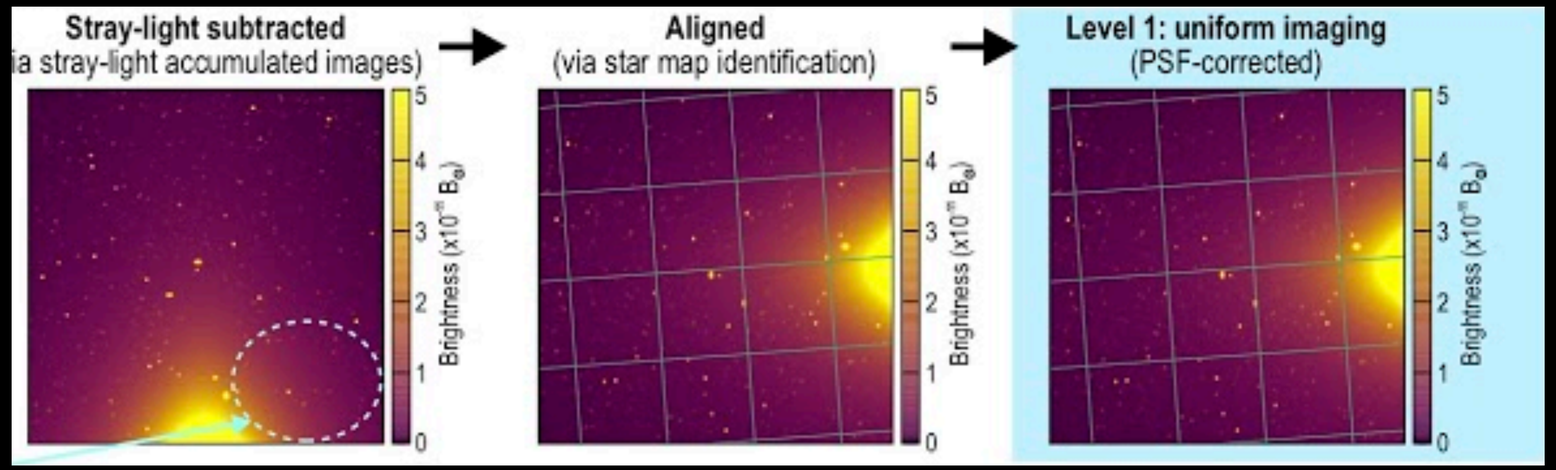


Remove CCD Artifacts

Despike

Destreak

Remove Stray Light

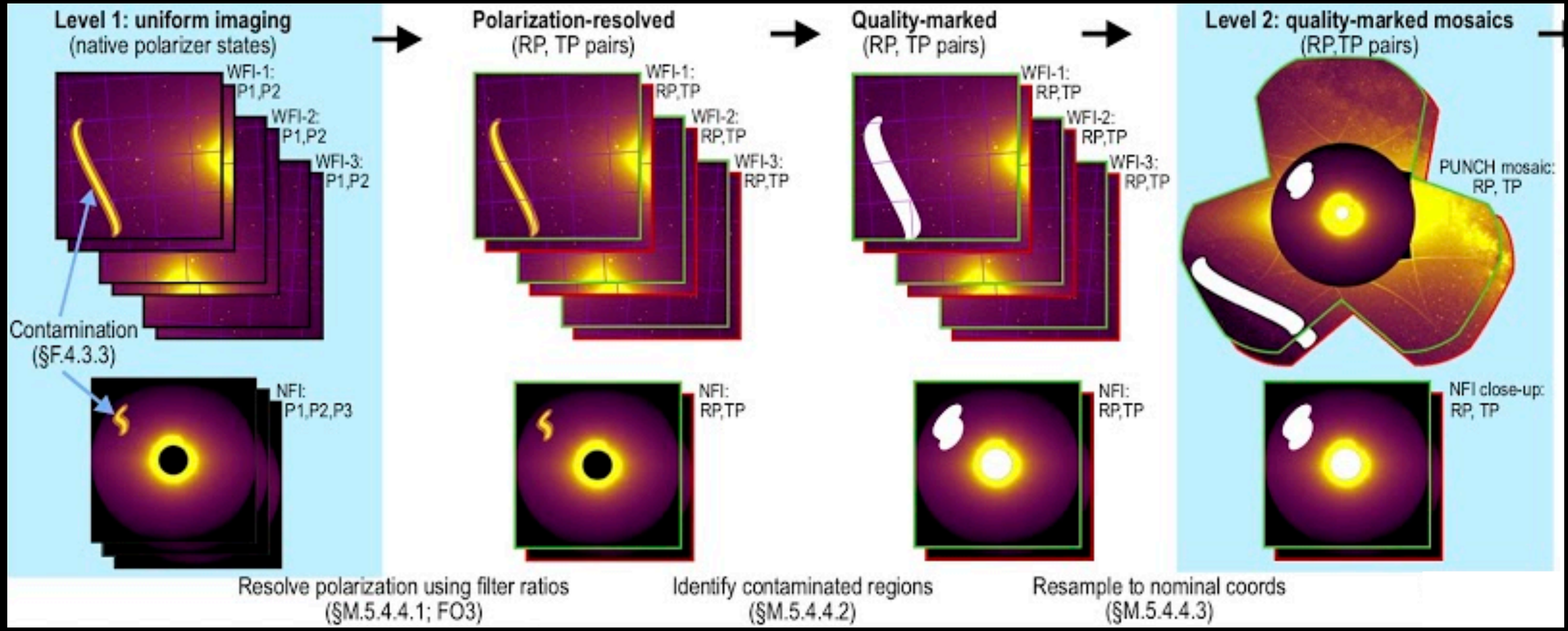


Confirm Pointing
(via star field)

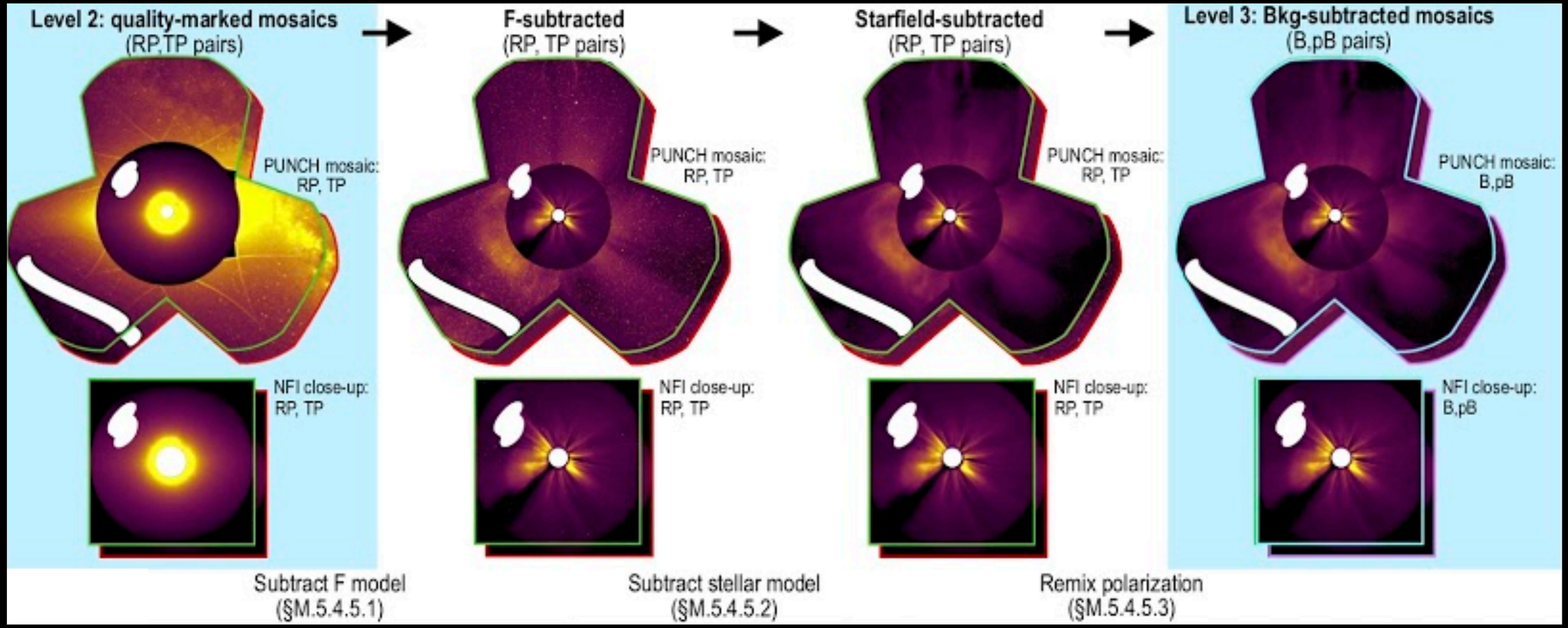
Deconvolve PSF

Fully calibrated,
camera coordinates,
Full image registration
metadata (WCS)

Data Processing: Level-1 → Level-2

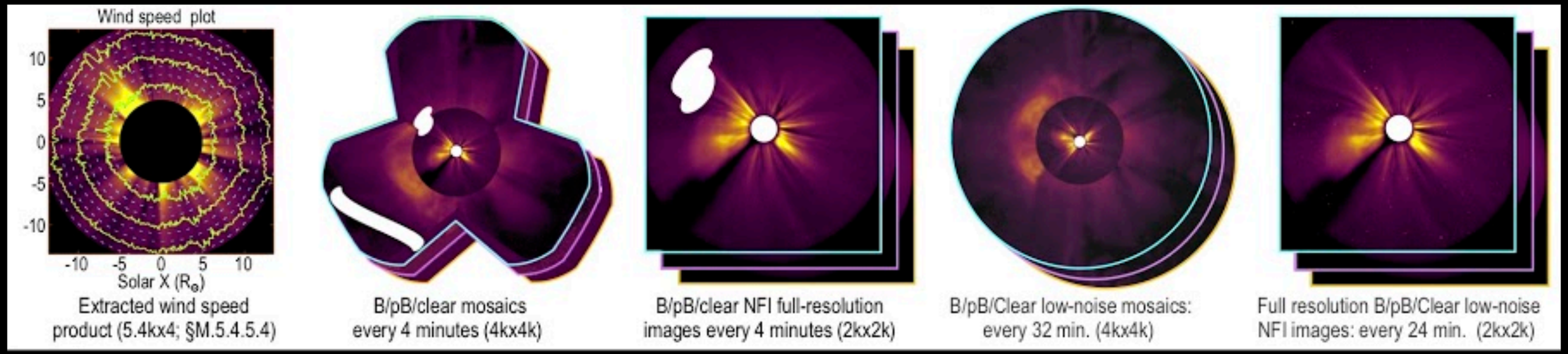


Data Processing: Level-2 → Level-3



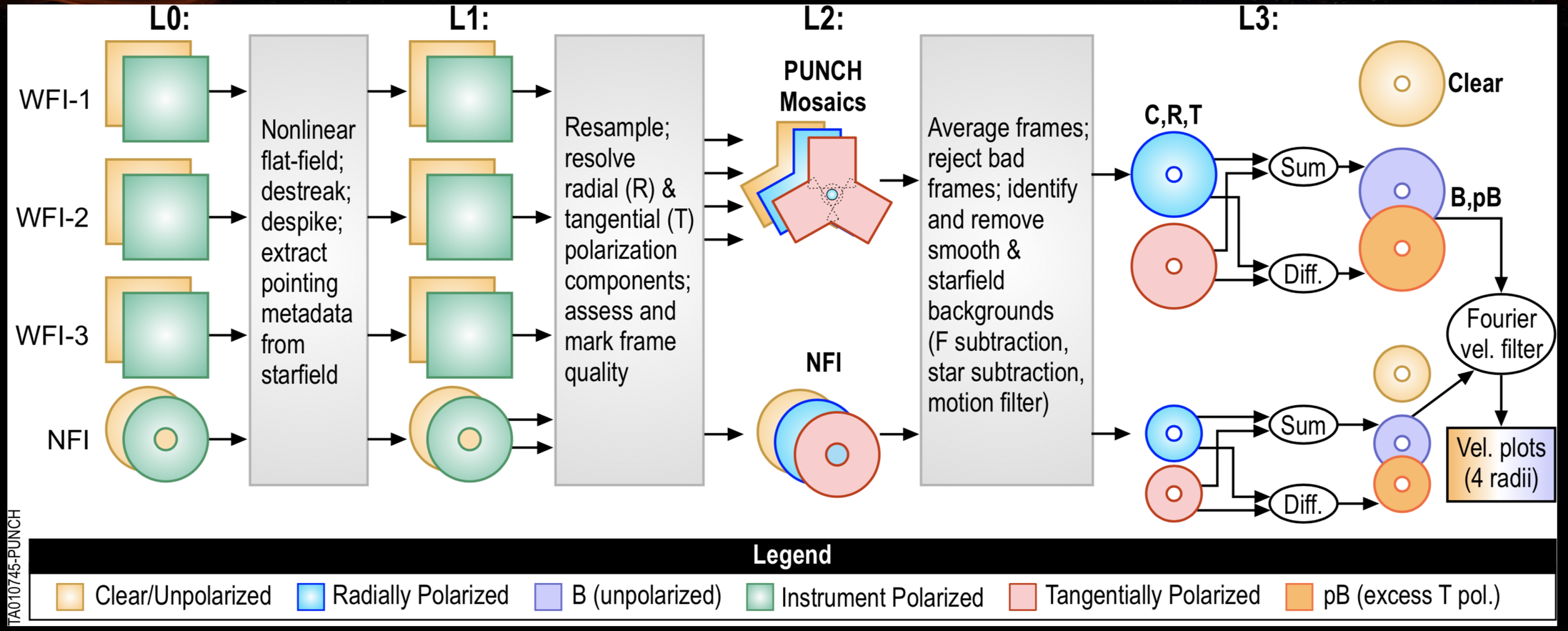
Must also build up F-corona & stellar models

Data Processing: Level-3 Products



Solar Wind Maps | Trefoils | NFI Frames | Low-noise full-field mosaics | Low-noise NFI

Data Processing: Ok, It's Not *That* Complicated

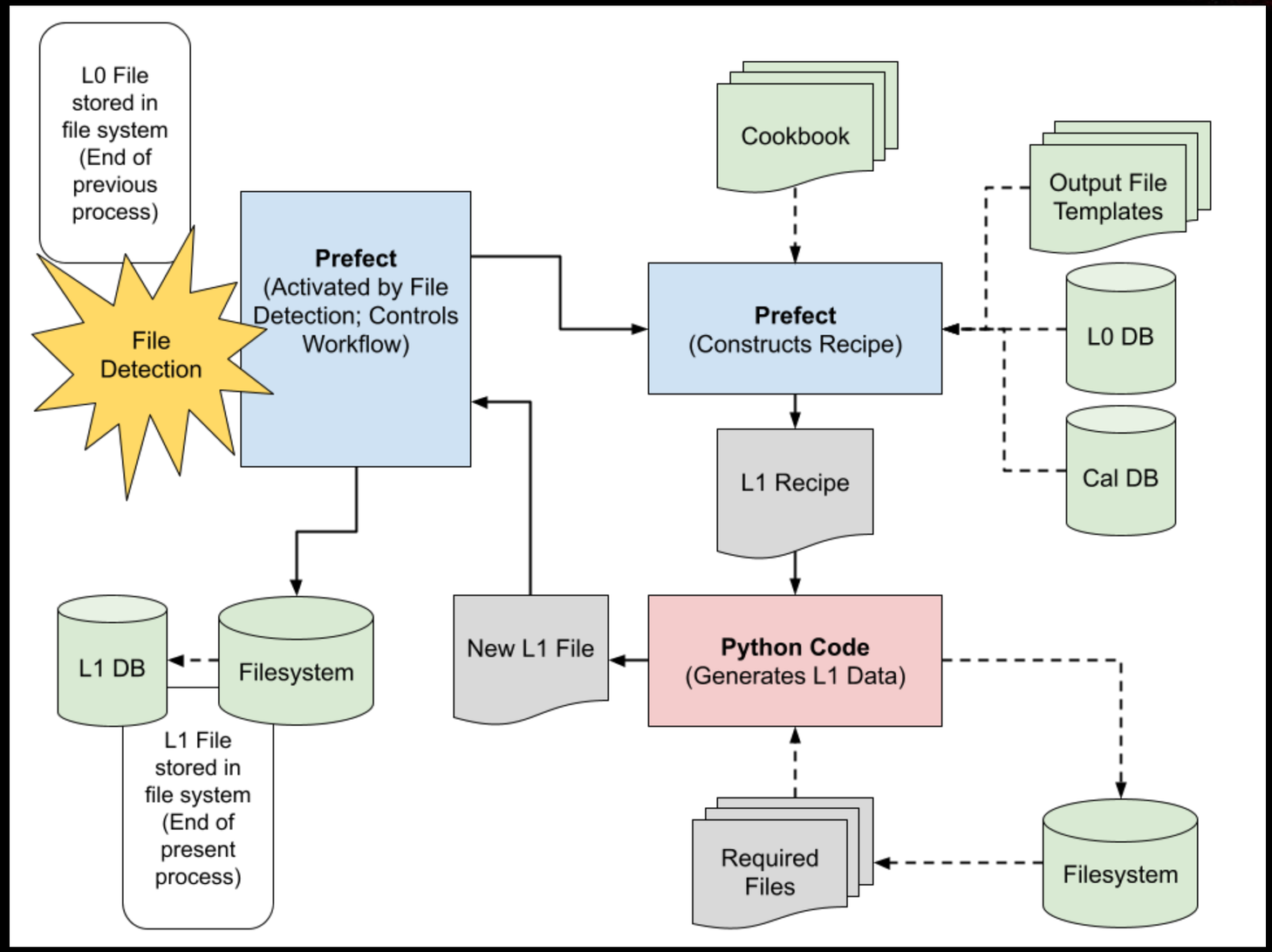


The SOC processes, calibrates, and integrates four independent data streams into single, fully coherent products at Level 3. – This will be performed via a **Data Reduction Pipeline (DRP)**.

SOC Data Flow Architecture

Sample Pipeline Data Flow (L0→L1)

- *Prefect* launches processing runs and manages workflows
- All processing/science code is *Python*, leveraging *SunPy, AstroPy, ndcube, etc.*
- Databases record file processing state & location in file system (*MySQL)*



Product Production Recipes

- **The PUNCH Pipeline segments are invoked by a control segment – *the chef* — which leverages Prefect**
- The control segment carries out workflows, sequences of processing steps — *a recipe* — to generate specific products
- The recipe also instructs the Prefect workflow which parameters, files, and processing steps — *the ingredients* — to use, and in which order
- The control segment selects the appropriate recipe from a library of workflow templates — *the cookbook* — which includes all recipes needed to each possible PUNCH product

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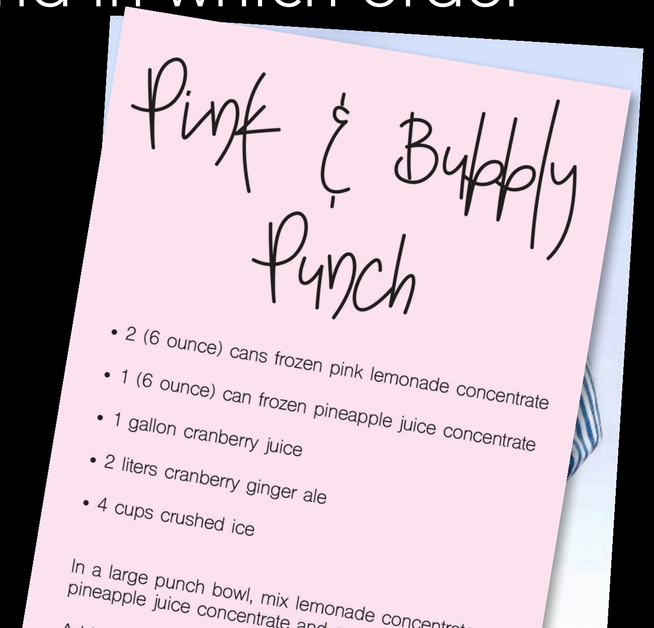

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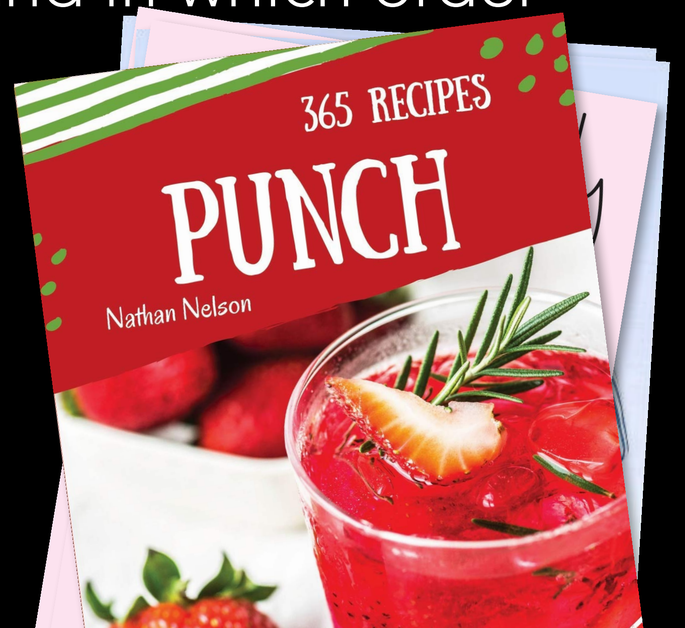

PUNCH Data Product Strategy

- PUNCH leverages Flexible Image Transport System (FITS) for all data & calibration products
- Products are fully FITS 4.0 standards compliant
- Products support open-source community analysis tools in *AstroPy* and *SunPy* Python Packages
- Products follow community best practices (e.g. https://doi.org/10.5281/zenodo.10058, below)

We present an example of best practices for FITS Headers to improve documentation and accessibility of solar physics data distributed as FITS files.

We build on existing norms and standards, including 'Proposed Keywords for SOHO' and the FITS World Coordinate System (WCS) conventions, and include recommendations on the use of FITS features and extensions to help make data stored and distributed in FITS better suited for both present-day usage and for long-term archiving.

Our goals include:

1. *Allow both solar physicists and non-discipline scientists to easily understand what's in a file from an instrument they've never dealt with before*
2. *Allow scientists to quickly determine if the data is useful for their purposes.*
3. *Allow scientists to find where to get documentation on how to use the data.*

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NASA-GSFC (Wyle)
joseph.a.hourcle@nasa.gov

Virtual Solar Observatory
http://virtualsolar.org/

CLEARLY IDENTIFY THE FILE AS FITS, AND PROVIDE A REFERENCE TO THE FITS STANDARDS DOCUMENTATION

PROVIDE AN E-MAIL ADDRESS OR OTHER CONTACT INFORMATION

PROVIDE URLS TO DOCUMENTATION (SEE POSTER #201.27)

PROVIDE THE ORIGINAL FILENAME OR OTHER UNIQUE IDENTIFIER

FULLY SPELL OUT ABBREVIATIONS

```
SIMPLE  =                    T / Conforms to the FITS standard
COMMENT   FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT     and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
COMMENT     http://adsabs.harvard.edu/abs/2001A&A...376..359H
COMMENT   Additional information on FITS available at http://fits.gsfc.nasa.gov/
BITPIX  =                   16 / number of bits per data pixel
NAXIS   =                    2 / number of data axes
NAXIS1  =                 1024 / length of data axis 1
NAXIS2  =                 1024 / length of data axis 2
COMMENT ----------------------------------------------------------------------
COMMENT ---Documentation & Contact Information-------------------------------
COMMENT This is a level-1 SWAP FITS file produced by p2sw_prep v1.1 at the Royal
COMMENT   Observatory of Belgium. If you have difficulty with this file or wish
COMMENT   to make suggestions for improvements, please contact the SWAP
COMMENT   Instrument Team via email at swap_lyra@oma.be.
COMMENT For information on data rights, keyword definitions, citing this data
COMMENT and up-to-date reports on known problems and data quality, see:
COMMENT   http://dx.doi.org/10.5067.example/PROBA2.SWAP.Level1
COMMENT ----------------------------------------------------------------------
COMMENT ---Observation Identification----------------------------------------
FILENAME= 'swap_lv1_20110806_000614.fits' / FITS filename
FILE_TMR= 'swap_0090851269420 9_aa56942a.fits' / SWTMR filename
FILE_RAW= 'BINSWAP20110806000628000037913BPROCESSED' / raw telemetry filename
FILE_TAR= 'BINSWAP_5354_SVA1_2011.08.06T03.26.56.tar' / raw telemetry package
COMMENT ----------------------------------------------------------------------
COMMENT ---Temporal Information----------------------------------------------
DATE    = '2011-08-06T03:37:49' / UTC time of FITS file creation
DATE-OBS= '2011-08-06T00:06:14.708' / UTC time of observation
COMMENT ----------------------------------------------------------------------
COMMENT ---Instrument & Processing Summary-----------------------------------
LEVEL   =                    1 / data processing level
CREATOR = 'P2SW_PREP.PRO v1.1' / FITS creation software
ORIGIN  = 'ROB                 ' / Royal Observatory of Belgium
```

GROUP TOGETHER KEYWORDS THAT DESCRIBE RELATED CONTENT

USE COMMENT CARDS TO SEPARATE GROUPINGS

MARK INSTRUMENT-SPECIFIC (NON-STANDARD) KEYWORDS.

```
COMMENT ----------------------------------------------------------------------
COMMENT ---Spacecraft Location (WCS) and Environment-------------------------
DTPLAR1 =               442.000 / [s] predicted time to prev large angle rotation
DTPLAR2 =              2000.00 / [s] predicted time to next large angle rotation
P2_X0   =   -0.000939076308338 / [deg] s/c yaw
P2_Y0   =      0.136016732901 / [deg] s/c pitch
P2_ROLL =       270.002914893 / [deg] s/c roll
SOLAR_EP=      3.93240510615 / [deg] s/c ecliptic North to solar North angle
HGLT_OBS=      6.09954735628 / [deg] s/c heliographic latitude
HGLN_OBS=   -0.00256070883134 / [deg] s/c heliographic longitude
RSUN_ARC=       946.000717646 / [arcsec] photospheric solar radius
DSUN_OBS=      151753900282. / [m]   s/c distance from Sun
HEEX_OBS=      151753900116. / [m]   s/c Heliocentric Earth Ecliptic X
HEEY_OBS=     -6575934.40209 / [m]   s/c Heliocentric Earth Ecliptic Y
HEEZ_OBS=      2675581.07891 / [m]   s/c Heliocentric Earth Ecliptic Z
GSEX_OBS=     -17950.7202980 / [m]   s/c Geocentric   Solar Ecliptic X
GSEY_OBS=      6575934.40210 / [m]   s/c Geocentric   Solar Ecliptic Y
GSEZ_OBS=      2675581.07891 / [m]   s/c Geocentric   Solar Ecliptic Z
LOS_ALT =      720813.145355 / [m]   s/c LOS altitude (1000000=no atmosphere)
TRAPPROT=              0.00000 / [ct/cm^2/s] AP-8 MAX > 10MeV @ 725km model
TRAPELEC=              0.00000 / [ct/cm^2/s] AE-8 MAX >  1MeV @ 725km model
GEOD_ALT=       721479.056001 / [m]   s/c WGS84 altitude
GEOD_LAT=       5.35086988157 / [deg] s/c sub-point geodetic latitude
GEOD_LON=      -88.2890113983 / [deg] s/c sub-point longitude
CAR_ROT =              2091.00 / Carrington rotation at s/c
COMMENT ----------------------------------------------------------------------
COMMENT ---Temperatures------------------------------------------------------
TEMP1DET=        2.30999100000 / [Celsius] detector temperature (SW HK T CF)
TEMP2DET=        2.23000500000 / [Celsius] detector temperature (SW HK T CF)
TTEMP1  = '2011-08-06T00:05:51.000' / UTC time of detector temp 1st sample
TTEMP2  = '2011-08-06T00:06:21.000' / UTC time of detector temp 2nd sample
TEMPDARK=        2.24678072991 / [Celsius] temperature used in dark subtraction
COMMENT ----------------------------------------------------------------------
```

Data Pipeline & Product Key Principles

Drawn from best practices for scientific data products:

Accessibility: Data/tools are documented & self-describing

Longevity: Data/tools will remain usable after mission ends

Portability: Data/tools work across platforms & analysis environments

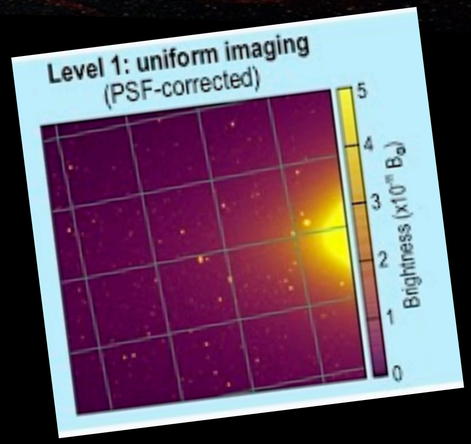
Traceability: Data/tools contain complete records of provenance

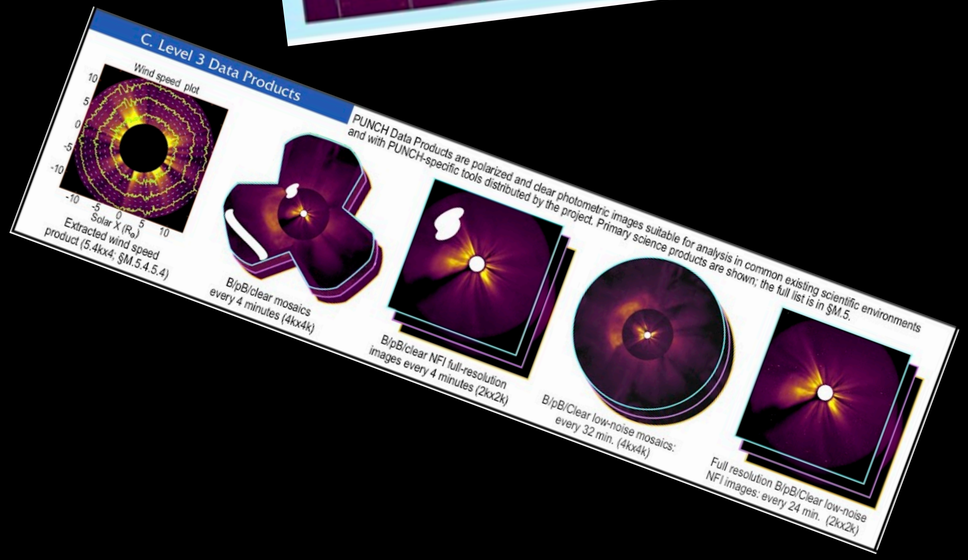
Transparency: Data/tools fully reflect progressive improvements & changes in calibration

Security: SOC must comply with all mission assurance and security requirements/documents

Data Produced by the SOC

- L1 FITS products:
  - 2k×2k single data frame
  - single HDU
  - all polarized and clear data products
- L3 FITS products:
  - 2k×2k NFI Images/velocity maps
  - 4k×4k Trefoil Images
  - 4k×4k Composite Images
  - Secondary HDU used to flag non-standard data
- Low Latency Space Weather Products
- Ancillary Products (e.g. Stray light and F-corona models)
- Data will be released in FITS format (L1 and L3 baseline products). Code will be publicly available in a SunPy-affiliated package for users with special processing needs.





Accessibility of the Data

- *Completely open data policy: everything we make is available to you*
- Primary data repository at NASA SDAC
- Secondary repository maintained at SwRI
- User tools available through SunPy
- Data reduction software, documents and support software available through standard Python package managers & (probably) SunPy
- PUNCH will work with SunPy to ensure standard tools support our data
- **Data will be accessible via the VSO**

The SOC Needs Your Help!!!

- SOC development is ongoing, your sample/model data can help us test our tools to make sure we can give you what you need
- Help us avoid pitfalls of other products/missions: What are your lessons learned from past experience? (e.g., PUNCH analogs like STEREO Cor2 or HI products)
- SOC will be developing sample products and soliciting feedback on usability, format, metadata, etc.
- SOC will distribute preliminary analysis tools as they become available and welcomes feedback on functionality, usability, etc.

Summary

Summary

- SOC is more complex than typical missions
- Architectural and algorithmic development is well underway
- PUNCH leverages FITS for all data & calibration products
- Products support open-source community analysis tools in *AstroPy* and *SunPy* Python Packages
- Products are fully FITS 4.0 standards compliant
- Products and tools follow community best practices
- **The SOC is actively seeking science team involvement!**