Polarimeter to Unify the Corona and Heliosphere

Science Operations Center Development

Dan Seaton, Craig DeForest, Marcus Hughes
Chris Lowder, Ritesh Patel, Jillian Redfern, Matthew West

Southwest Research Institute

Second PUNCH Science Meeting 4
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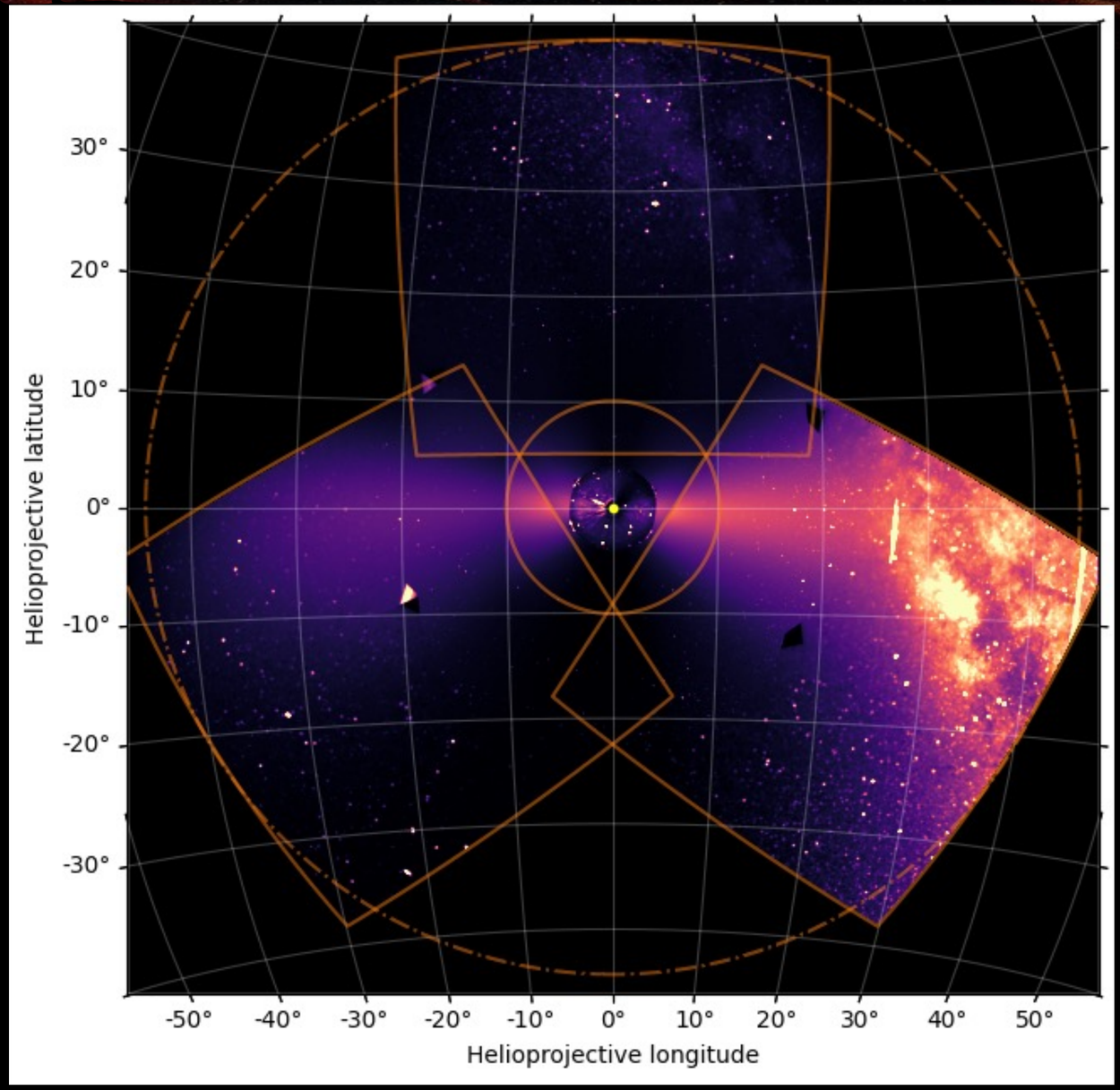
Polarimeter to Unify the Corona and Heliosphere

Data Processing for PUNCH

Many Observations to Make One Data Product

- PUNCH observes continuously at 4-min. cadence
- NFI covers 5.4–32 $R_\odot$
- WFI covers 20–180 $R_\odot$, 3 separate segments
- PUNCH produces 3 full mosaics per orbit, from 6-180 $R_\odot$



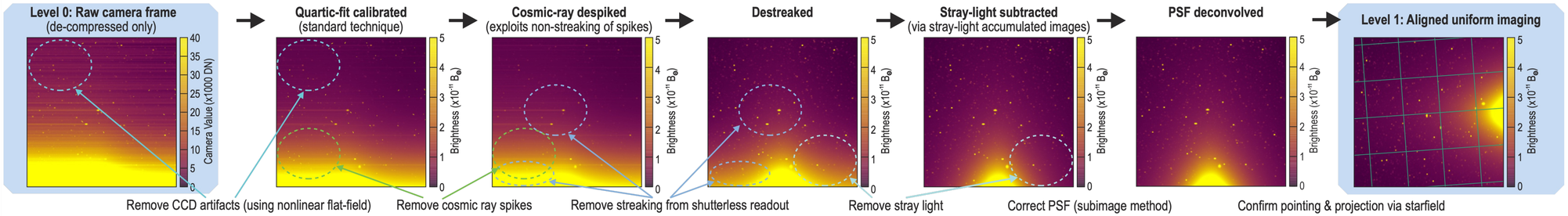
PUNCH Science Data Pipeline and Products

For effective data analysis by the PUNCH team and the broader community, PUNCH produces (A-C) and disseminates (D) calibrated, simple-to-use data products and analysis tools.

L3 Products Levels 2 & 3 Level 1

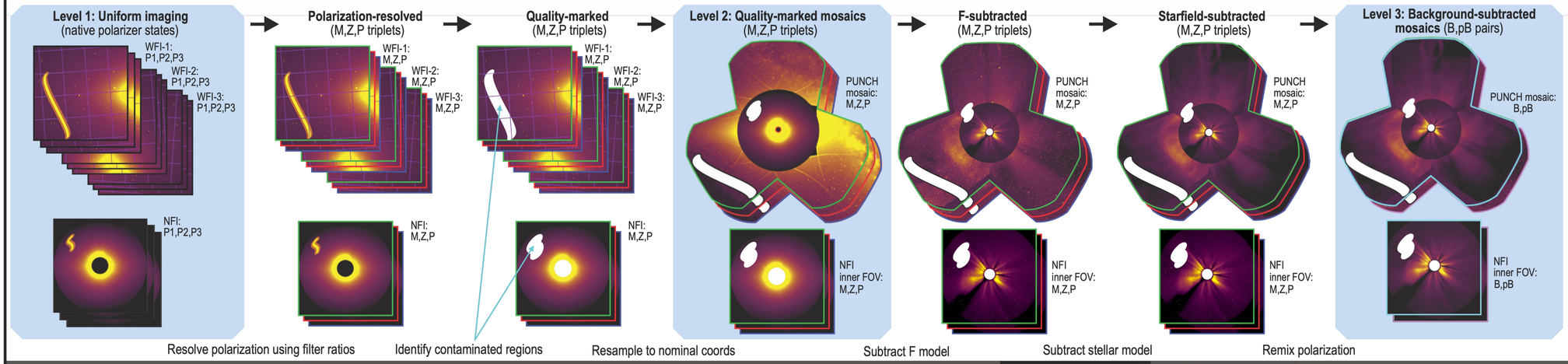
A. Level 0 → Level 1 Pipeline

Level 1 images are photometrically calibrated, precisely aligned images with instrumental artifacts corrected. To demonstrate PUNCH data reduction, we degraded and then processed data from STEREO/HI1 to show the PUNCH L1 processing. For clarity, all visual effects are 10-40x stronger here than in actual PUNCH images. These processing steps are the same for both WFI and NFI.



B. Level 1 → Level 3 Pipeline

The L1 to L2 stage maps polarization to M,Z,P triplet polarizer brightnesses, then generates full PUNCH mosaics. Clear exposures (not shown) skip the (M,Z,P) step. The L2 to L3 stage removes background F corona (fixed in heliospheric coordinates) and starfield (fixed in celestial coordinates), then generates B and pB products. Nearly all frames have no contamination.



C. Level 3 Data Products

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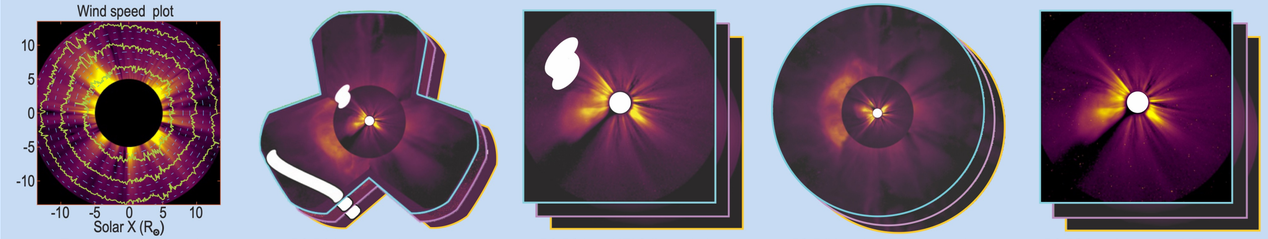
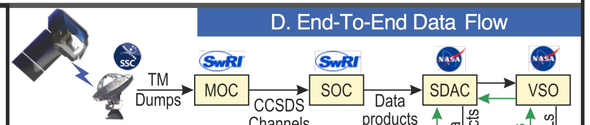


Legend

- Data Product
- Polarized Images:
  - M (–60°)
  - Z (0°)
  - P (+60°)
  - B
  - pB
  - Clear

D. End-To-End Data Flow



PUNCH data are downlinked and transferred to the MOC, reduced (Panels A-C) at the SOC, then mirrored to SDAC for archiving & dissemination. SOC software written in Python and publicly accessible via SunPy/Github.

Code/Tool/Doc Repository (main at SwRI; mirror at SDAC)

- PUNCH Science Team
- Science Community
- General Public

SOC pipeline workflow orchestrated by Prefect. Data & metadata flow managed with NDCube.

PREFECT

Original figures and layout from PUNCH CSR

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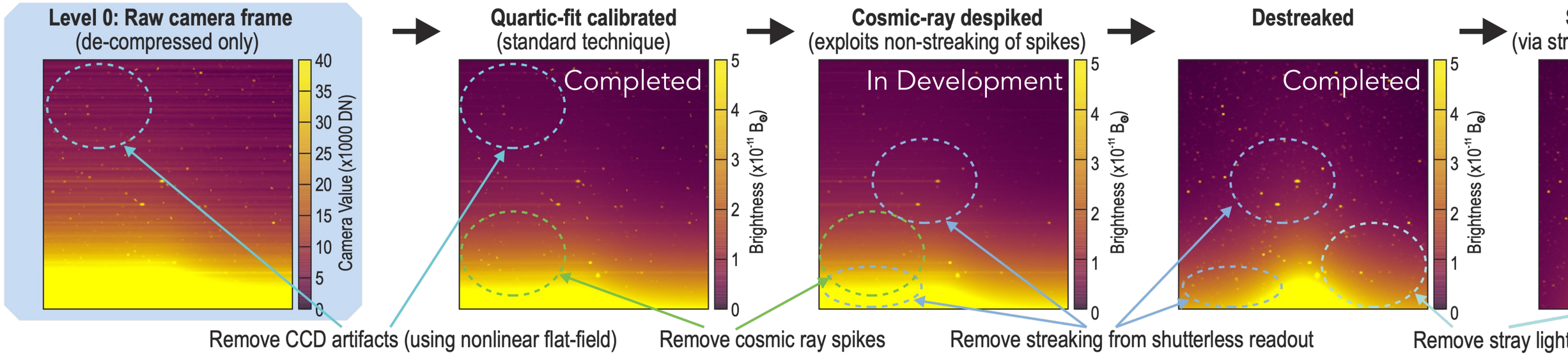

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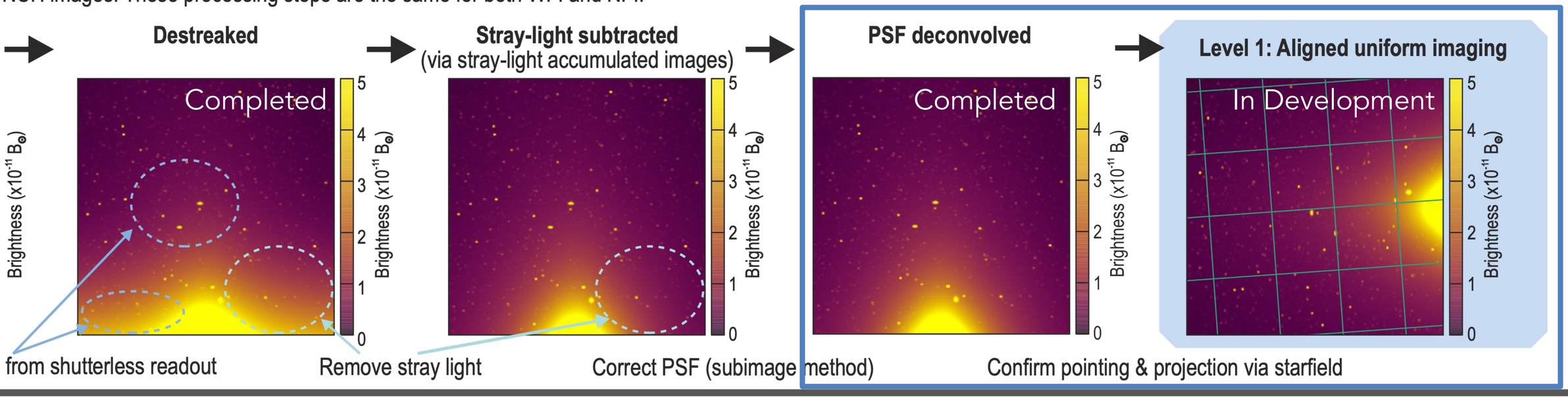

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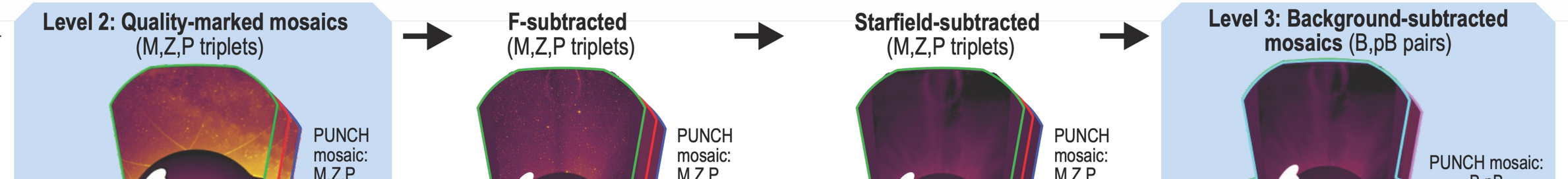
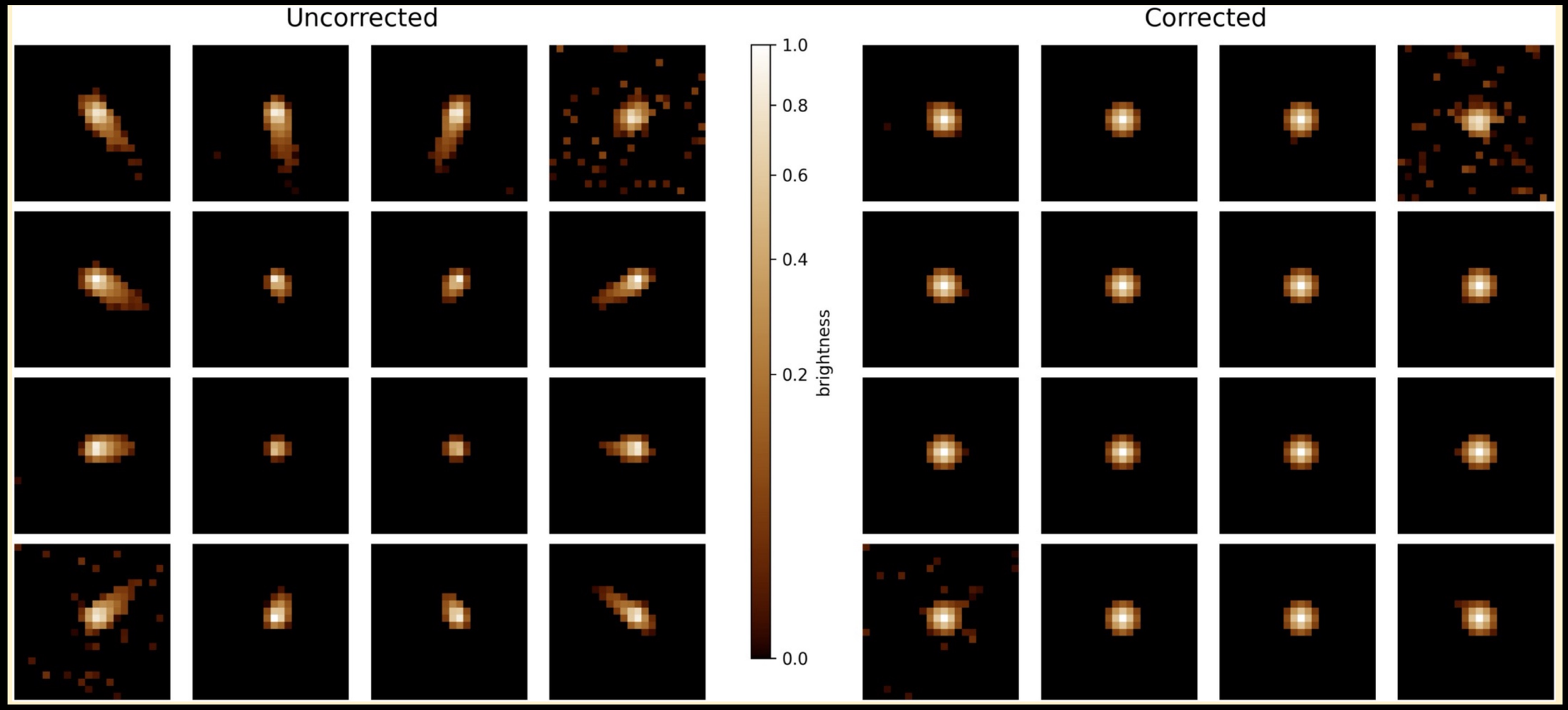
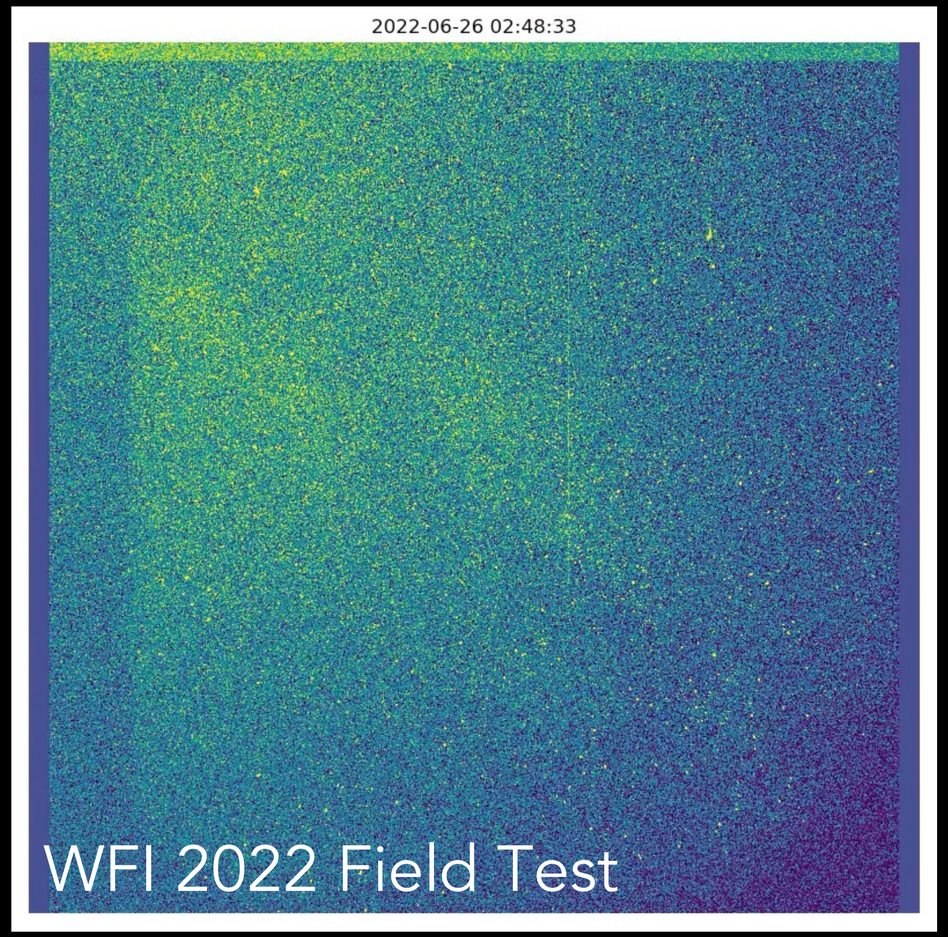


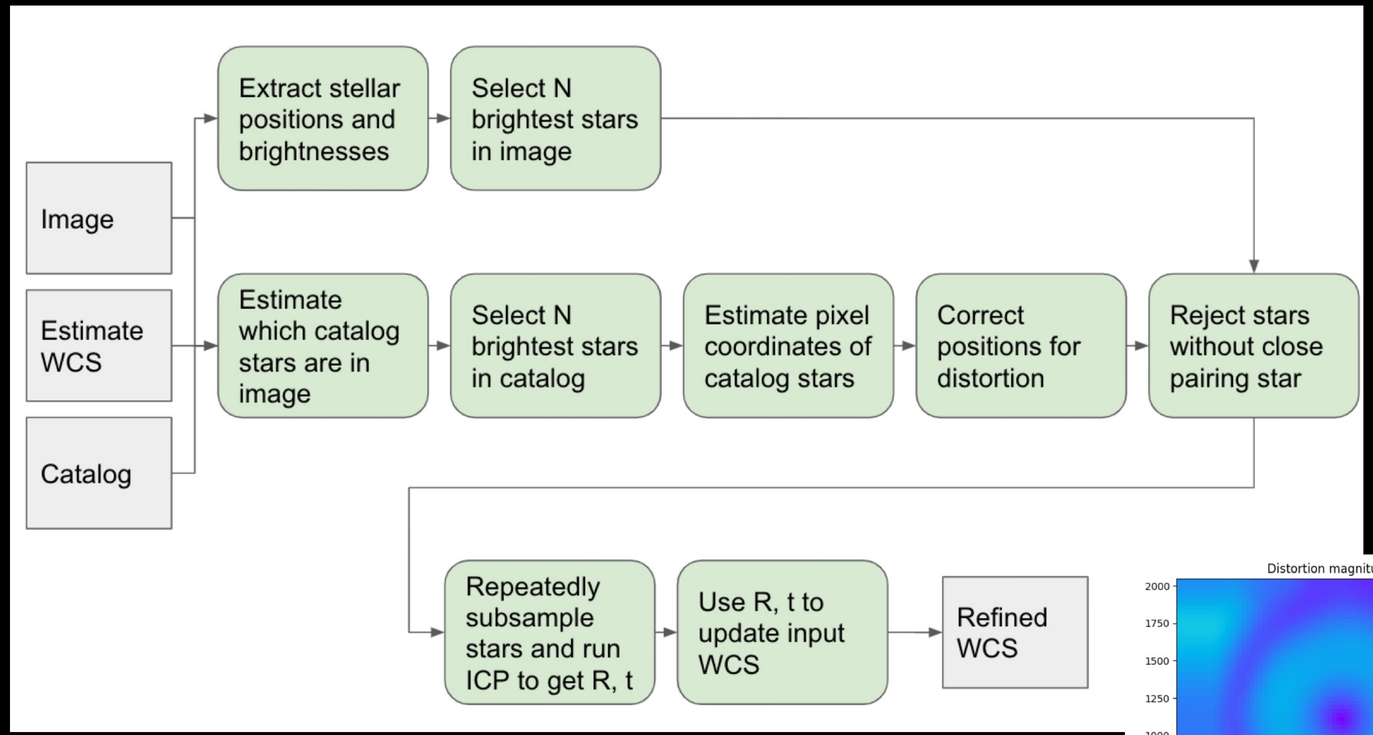
Community Package: RegularizePSF

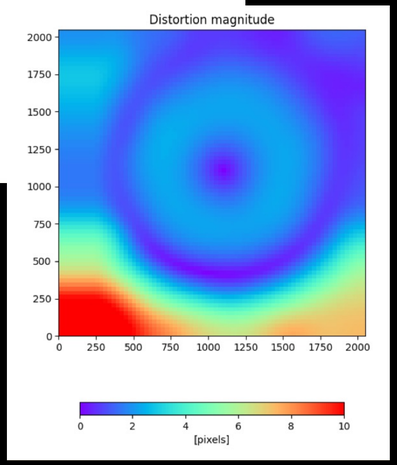


See Marcus Hughes's Poster on Supporting Packages

Community Package: refineWCS







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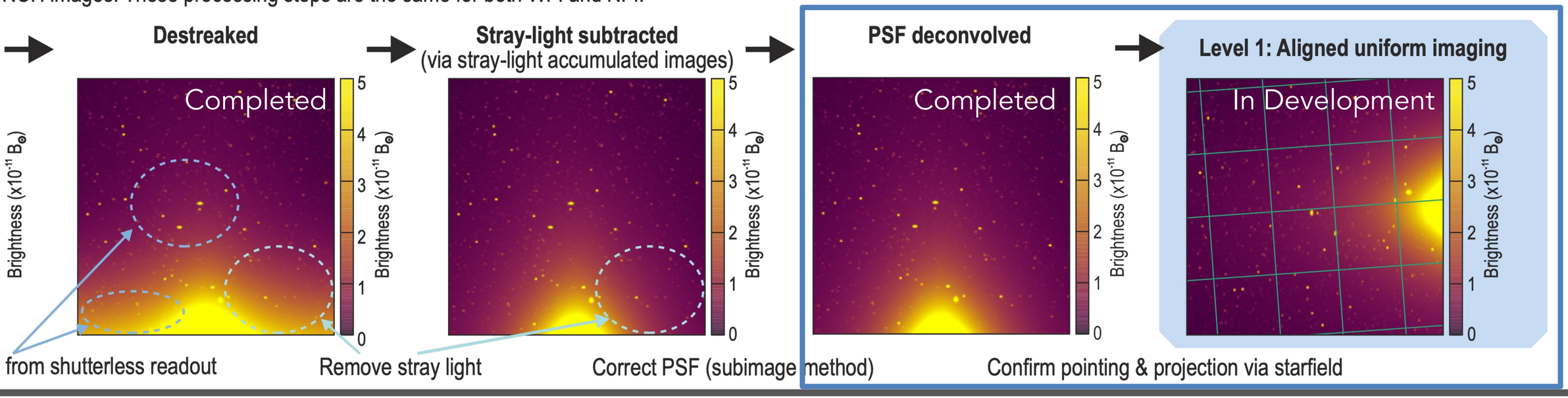

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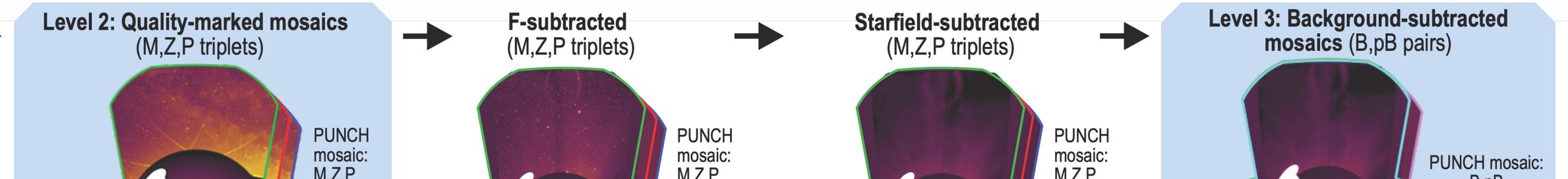

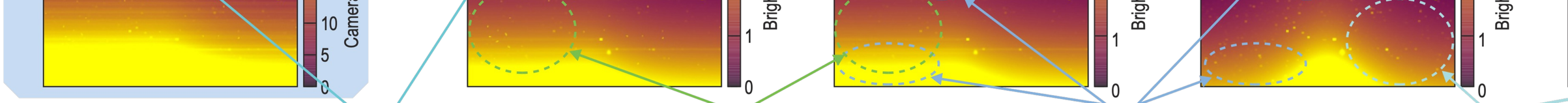

Remove CCD artifacts (using nonlinear flat-field)

Remove cosmic ray spikes

Remove streaking from shutterless readout

Remove stray l

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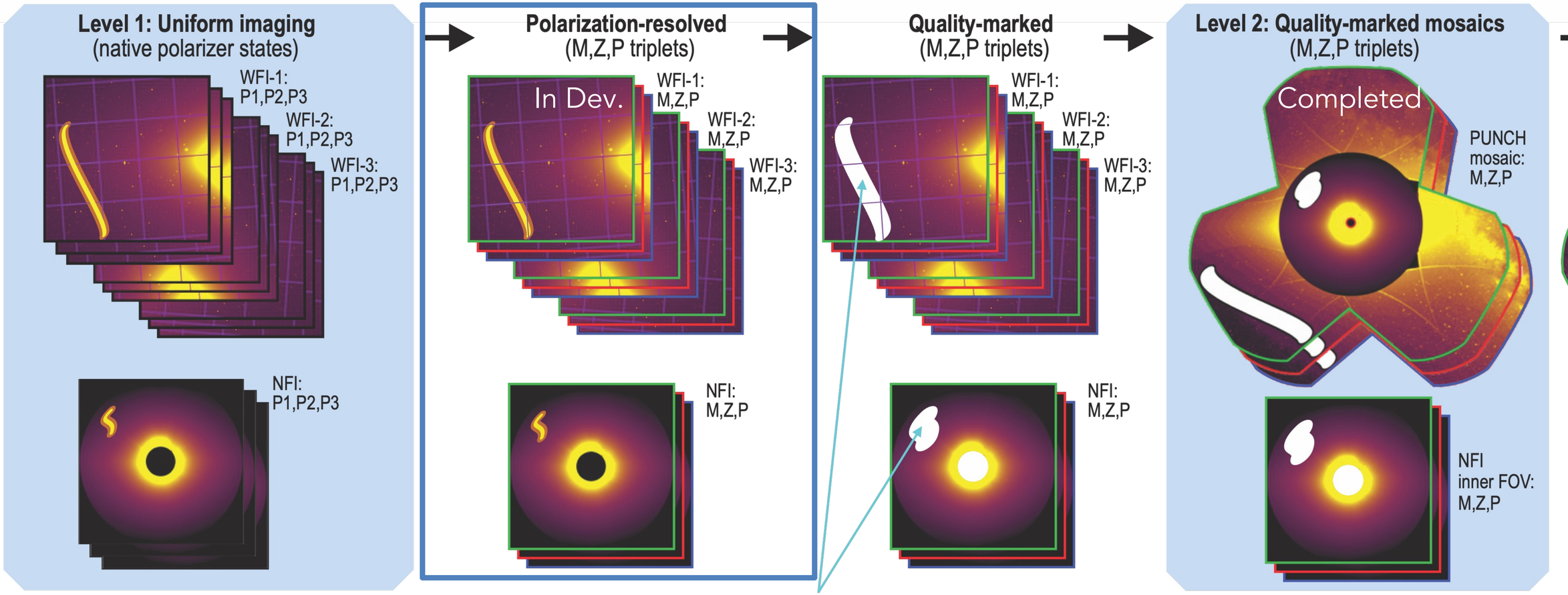

Resolve polarization using filter ratios

Identify contaminated regions

Resample to nominal coords

Subtract F m

C. Level 3 Data Products

PUNCH Data Products are polarized and clear photometric images suitable for analysis in common existing scientific envi
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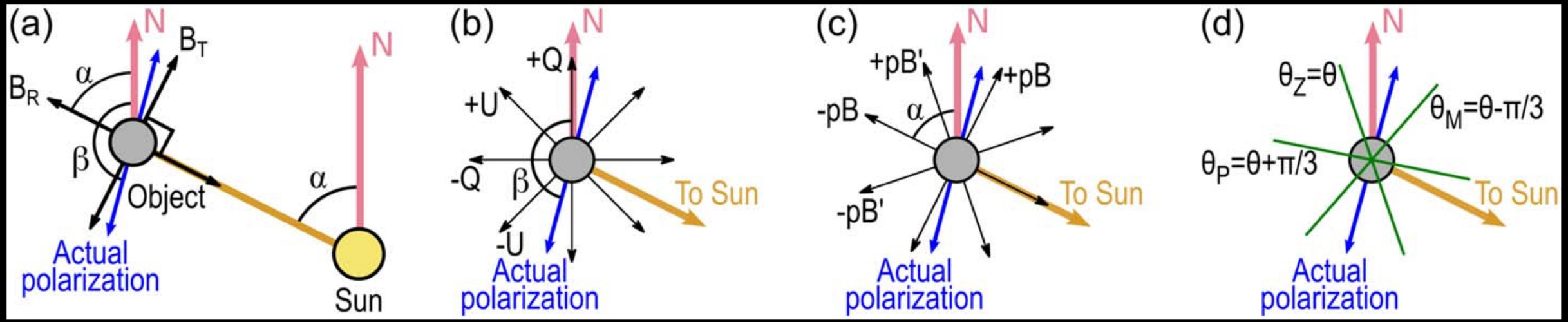
Community Package: SolPolPy

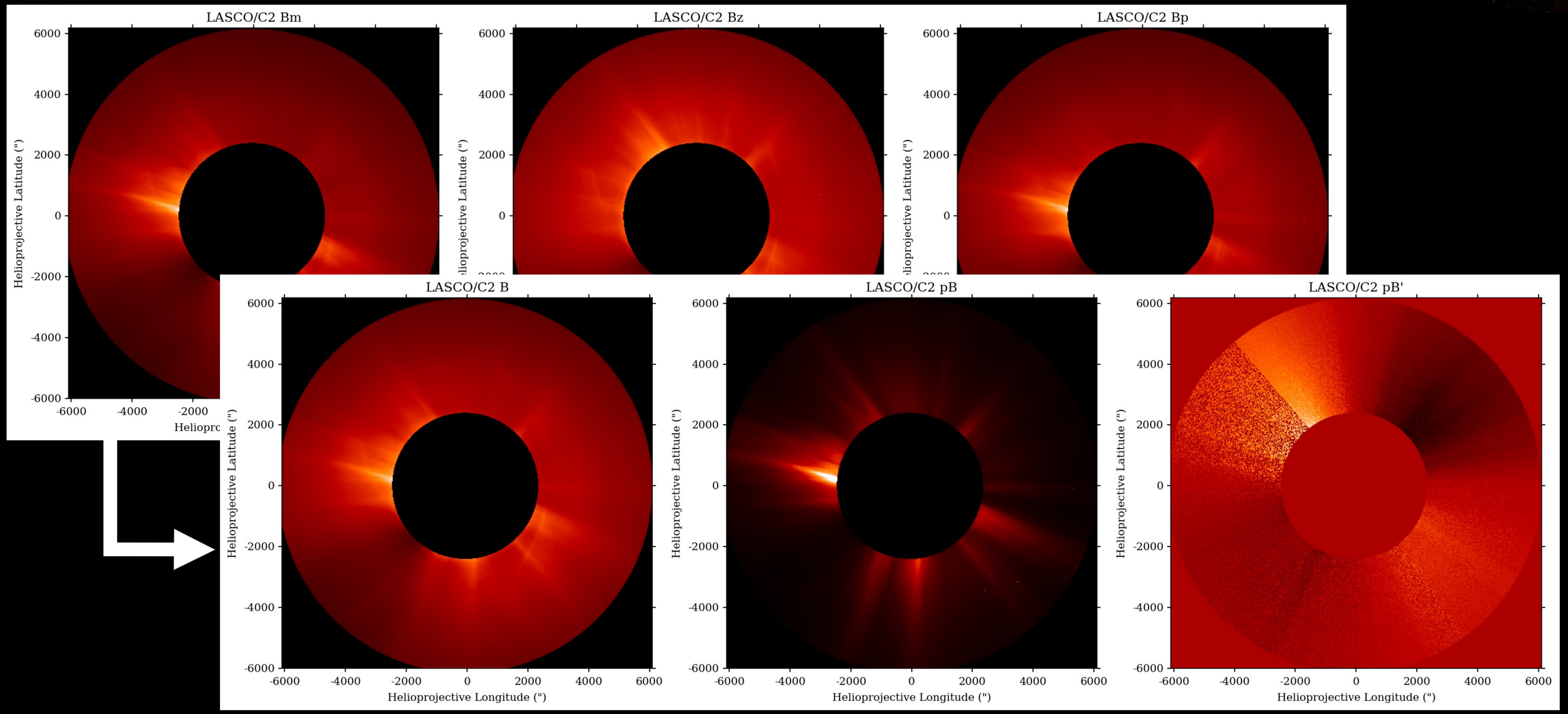
SolPolPy converts from arbitrary polarization measurements to common bases.



Radial/Tangential | Stokes | B/pB | MZP

See Ritesh Patel's Poster on Polarization Tools

Community Package: SolPolPy



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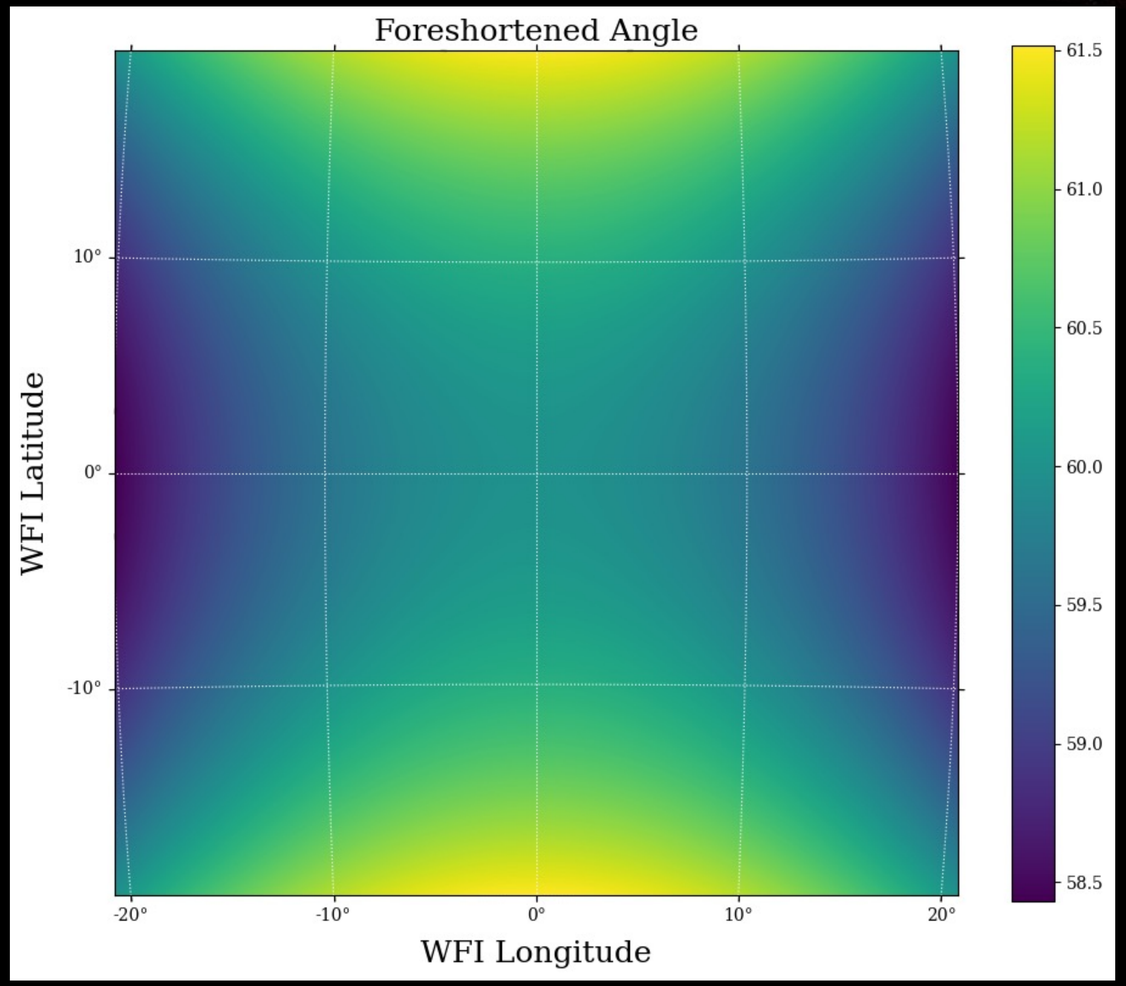
“IMAX Problem”

- WFI field of view is so large that sampled polarization angle varies across field of view



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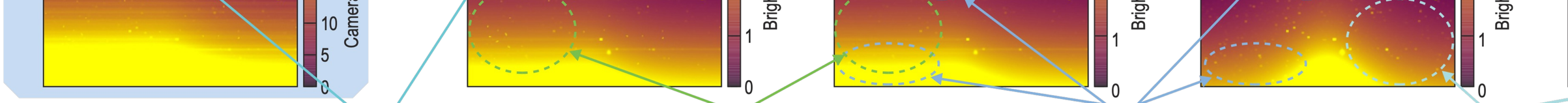

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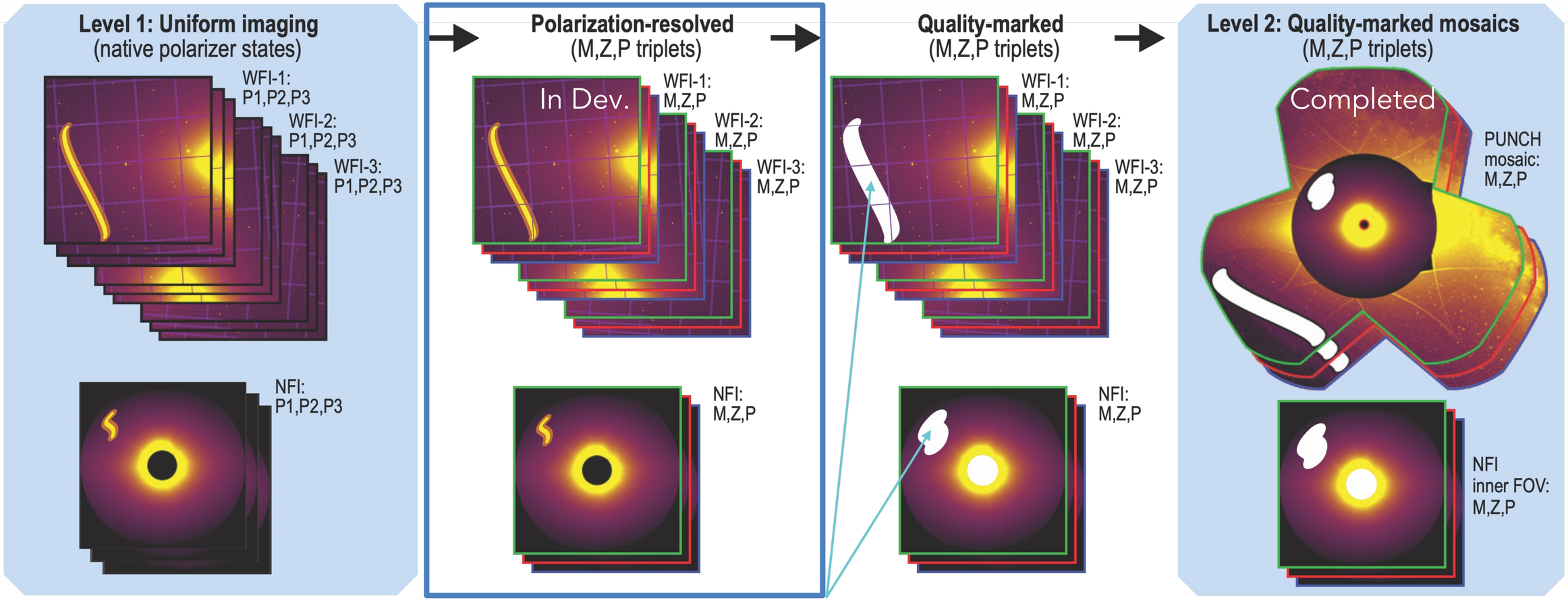

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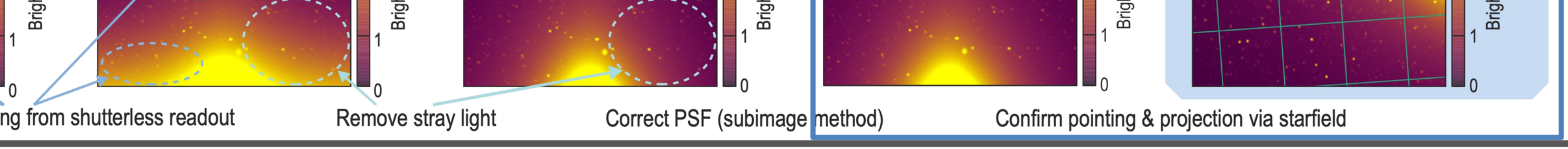

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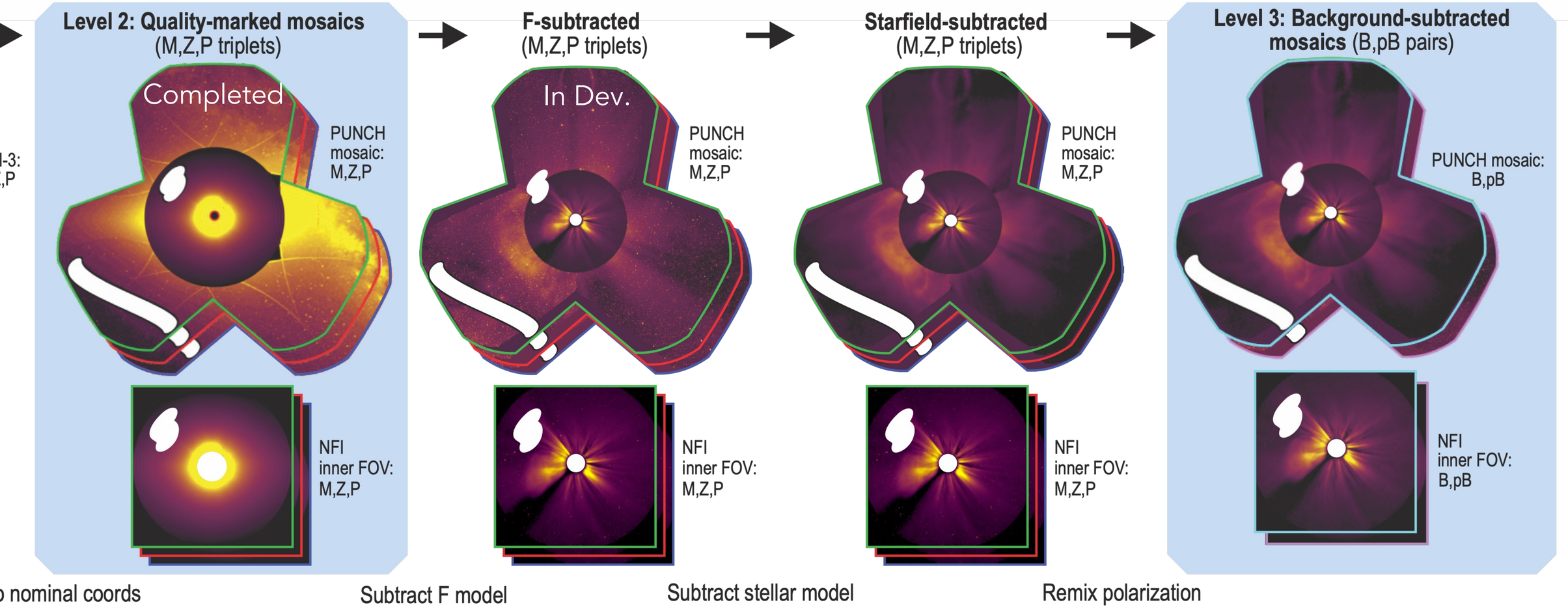

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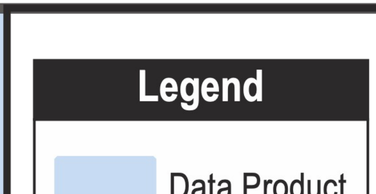
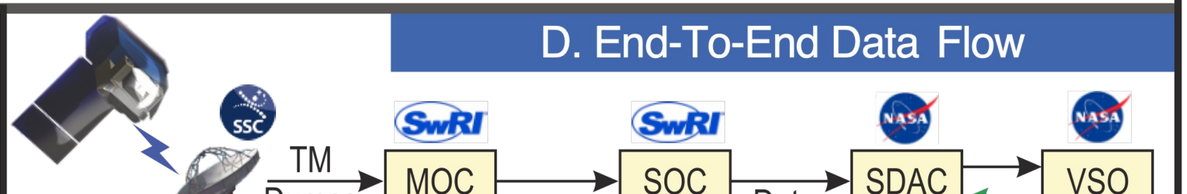




Polarimeter to Unify the Corona and Heliosphere

Data Pipeline, Analysis Tools, and Products

Data Processing: PUNCHPipe & PUNCHBowl

***PUNCHPipe* handles SOC workflow**

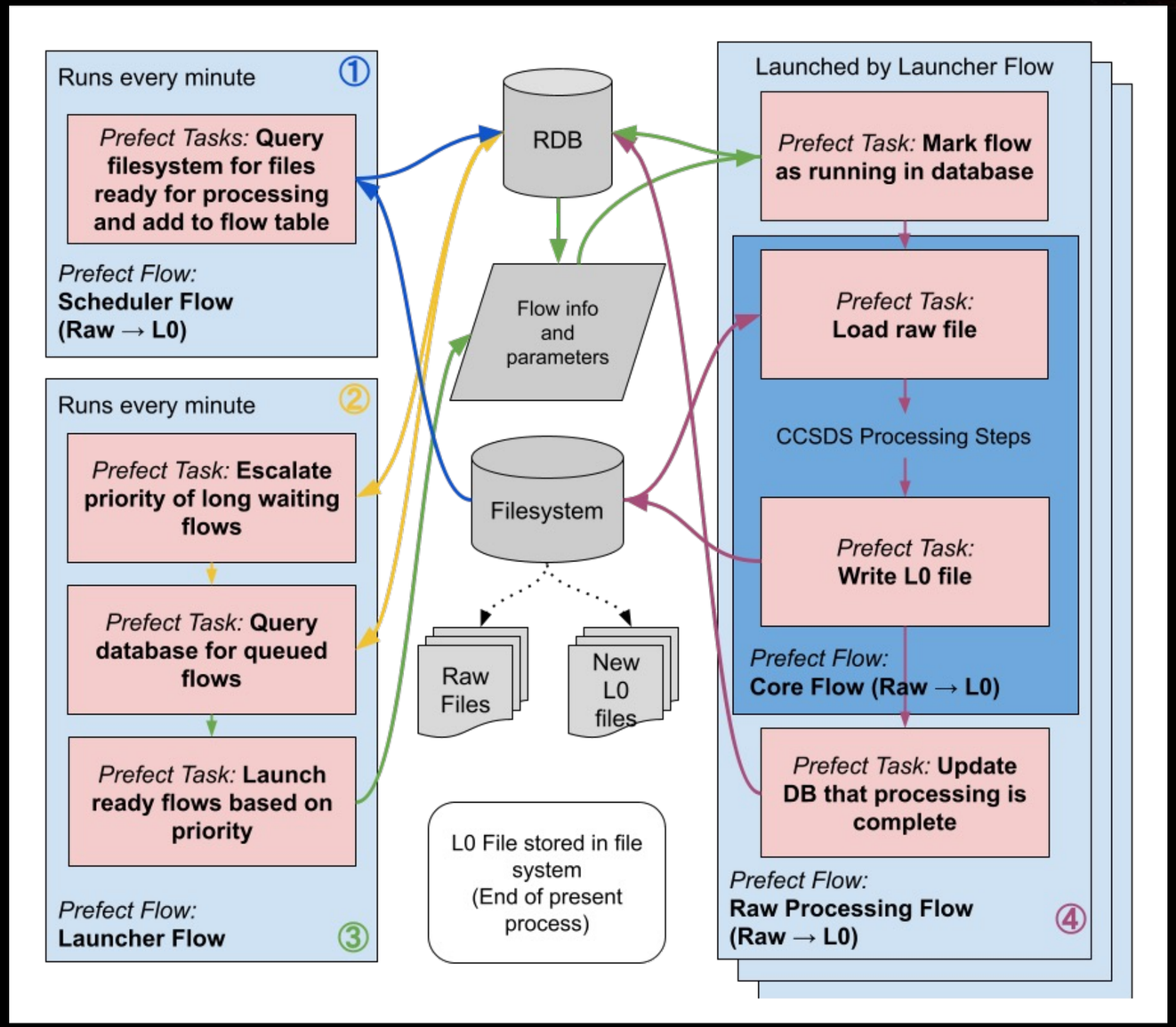
4 Key Flow Types:

1. Scheduler
2. Launcher
3. Core - *PUNCHBowl*
4. Process

Two Key Databases

1. Science Reduction Database (RDB)
2. Archive Database (ADB)

PREFECT



Data Processing: PUNCHPipe & PUNCHBowl

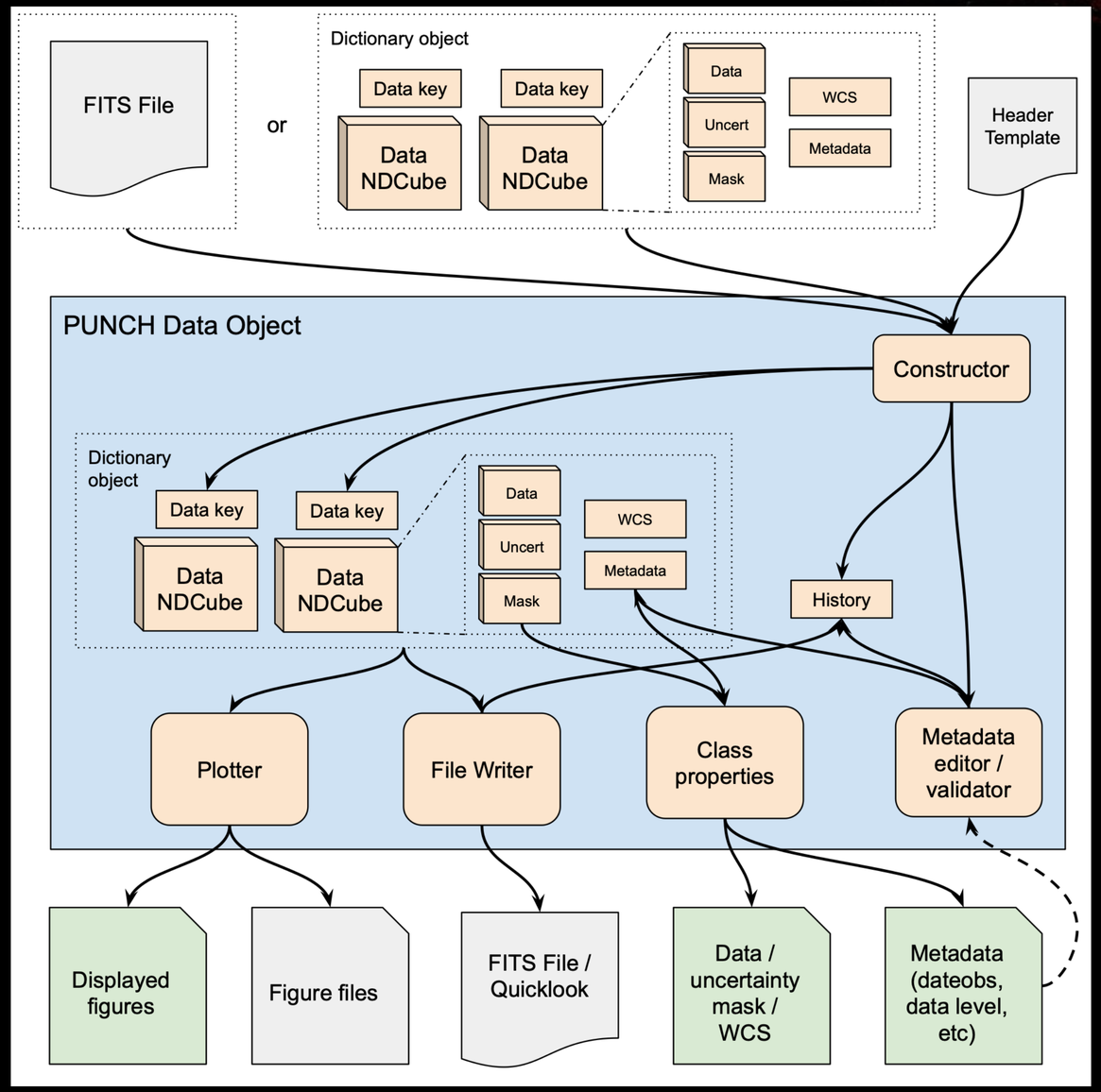
***PUNCHBowl* is the science code**

Python code used for:

- Generating custom data
- Polarization analysis
- Simulating data from models

Data handler:

- Seamlessly work with data and metadata
- Create data files, images, etc.



Data Product Strategy

Data Products leverage best practices and good examples

- Transparent & self-describing metadata
- Fully standards (FITS 4.0) compliant
- Uses FITS's multidimensional data capabilities to represent polarization, uncertainty, etc.

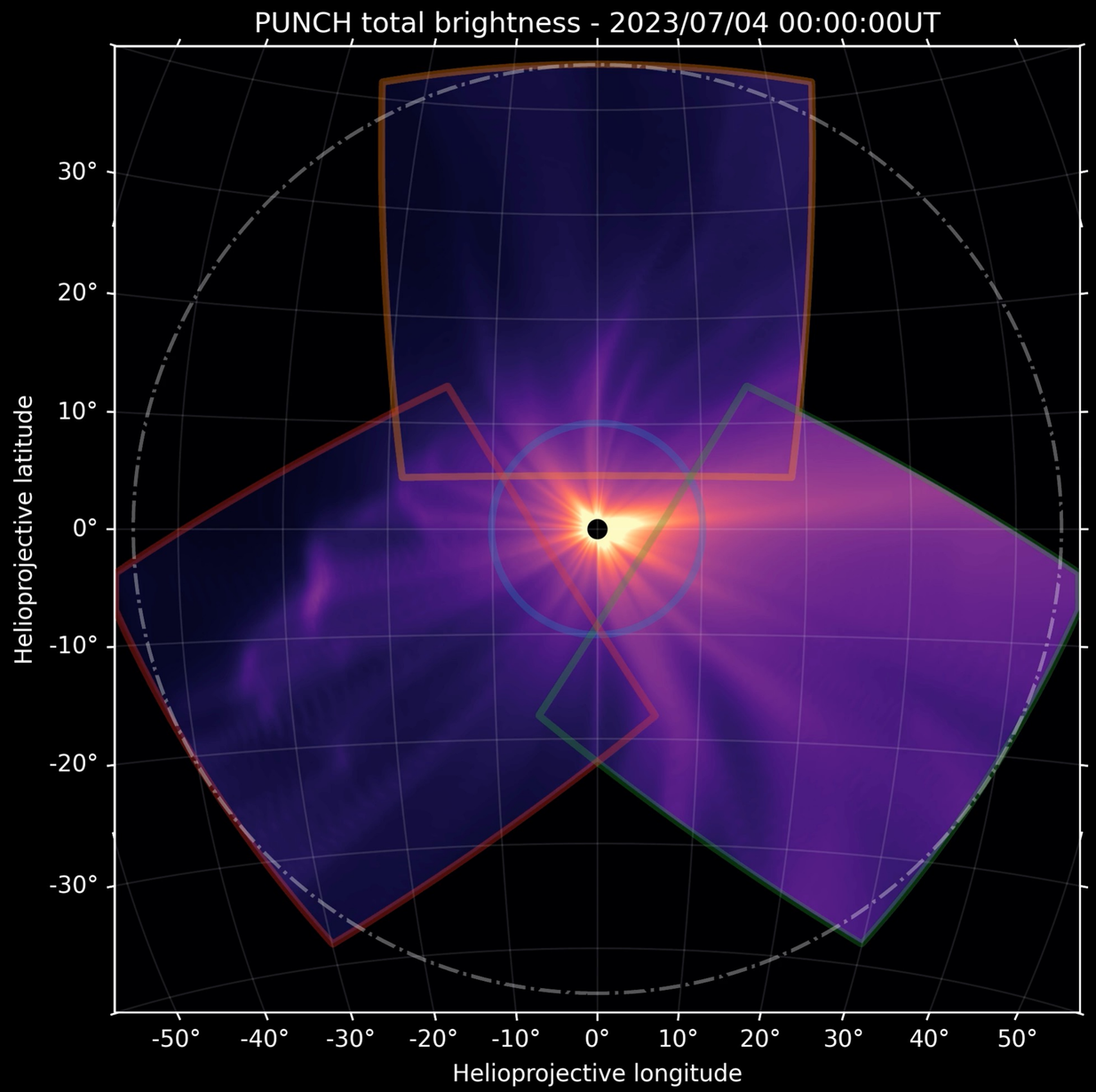
```
COMMENT ----- FITS Required ------------------------------------------------------
SIMPLE  = T                     / conforms to FITS Standard
BITPIX  = 16                    / number of bits per pixel
NAXIS   = 3                     / number of axes
NAXIS1  = 2048                  / length of the first axis
NAXIS2  = 2048                  / length of the second axis
NAXIS3  = 5                     / length of the third axis
LONGSTRN= 'OGIP 1.0'            / the OGIP long string convention may be used
COMMENT ----- Documentation, Contact, and Collection Metadata ------------------
DOI     = 'https://doi.org/TBD'  / data reference DOI
PROJECT = 'PUNCH'               /
TITLE   = 'PUNCH Level-1 WFI-1 Clear Image'
KEYVOCAB= 'Unified Astronomy Thesaurus Keywords'
KEYWORDS= 'Solar Corona (1483), Solar K Corona (2042), Solar F Corona (1991), &'
CONTINUE  'Solar Coronal Streamers (1486), Solar Coronal Plumes (2039), Solar &'
CONTINUE  'Wind (1534), Fast Solar Wind (1872), Slow Solar Wind (1873), Solar &'
CONTINUE  'Coronal Mass Ejection (310), Heliosphere (711), Polarimetry (1278)'
LICENSE = 'Creative Commons Attribution 4.0 International | CC BY 4.0'
COMMENT  PUNCH Level-1 data, Calibrated instrumental units in camera coordinates
COMMENT  Documentation is available on the PUNCH website:
COMMENT  https://punch.spaceops.swri.org and via the DOI referenced above (TBD)
COMMENT ----- File Type and Provenance ----------------------------------------
FILENAME= 'PUNCH_L1_P11_20220204134800_0.fits' / name of file
LEVEL   = 1                     / product Level
OBSTYPE = 'unpolarized NFI image' / plain text observation
TYPECODE= 'P1'                  / observation product type code
L0PARENT= 'PUNCH_L0_P11_20220204134800_0.fits' / name of parent file
PIPEVRSN= '1.2.3'               / PUNCHPipe software version number
FILE_RAW= 'PUNCH_L0_P11_20220204134800_0.fits' / raw telemetry filename
ORIGIN  = 'SwRI'                / institution responsible for creating the file
COMMENT ----- Temporal Information -------------------------------------------
TIMESYS = 'UTC'                 / principal time system
DATE-BEG= '2022-02-03T00:00:36.72' / UTC time observation
DATE-OBS= '2022-02-03T00:00:36.73' / UTC reference time at observatory
DATE-END= '2022-02-03T00:00:36.73' / UTC time of observation end at observatory
DATE    = '2022-02-03T00:09:11.29' / UTC file generation date and time
COMMENT ----- Instrument and Spacecraft State ---------------------------------
WAVELNTH= 530                   / [nm] average peak response
WAVEUNIT= 'nanometer'           / unit of observation measurement
FILTER  = 'Clear'               / name of filter for observations
OBS-MODE= 'Unpolarized'         / image Mode (Unpolarized, Polar_M, _Z, or _P)
POLAR   = 60                    / [deg] polarizer angle or fill value for clear
INSTRUME= 'WFI'                 / instrument name
TELESCOP= 'PUNCH-1'             / satellite name
OBJECT  = 'Heliosphere white light' / object observed
```

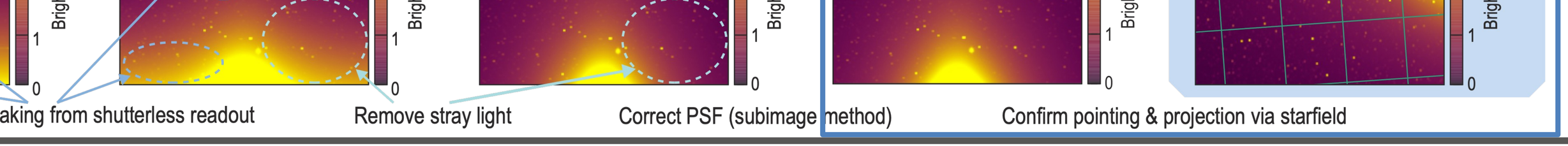
Sample Products Are Ready

GAMERA Model-derived Data Products are now available

- Level-3 Mosaics (B/pB)
- Level-2 QuickPUNCH Space Weather Products (Unpolarized)
- Get FITS files here: http://tinyurl.com/PUNCH4Data

Data processing by Chris Lowder





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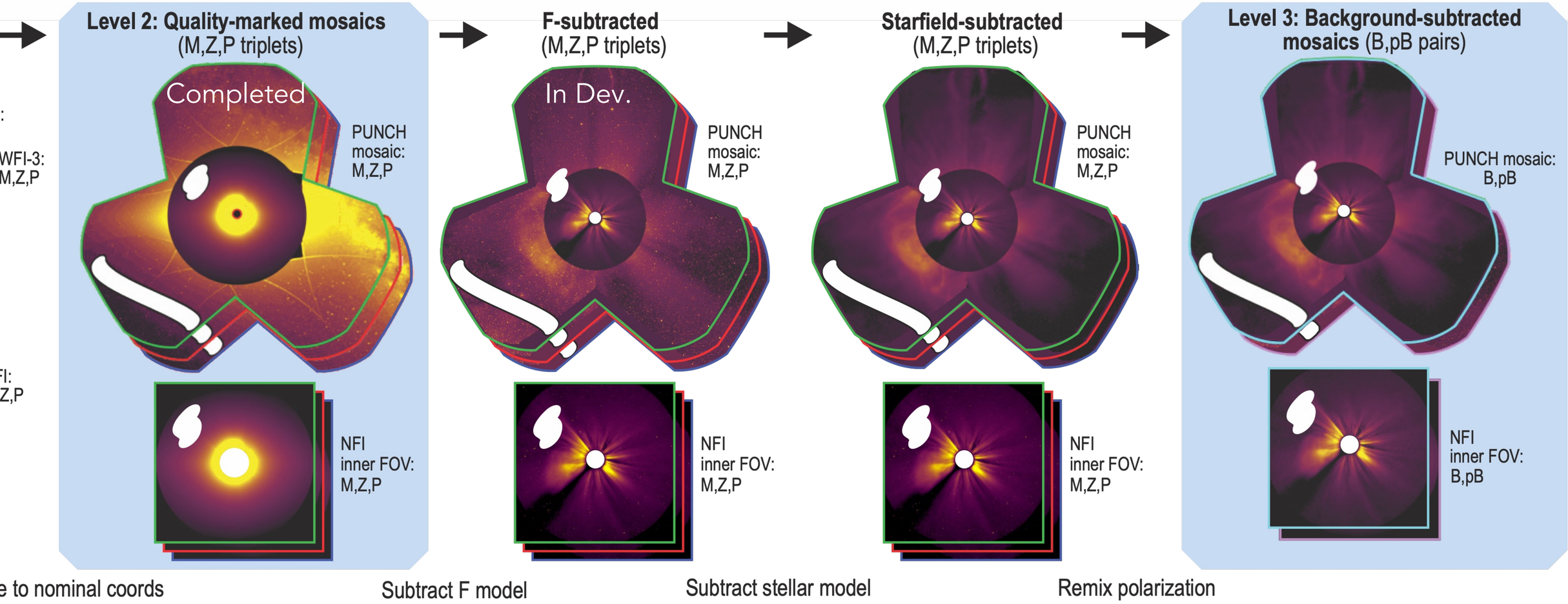

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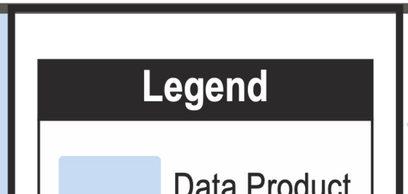

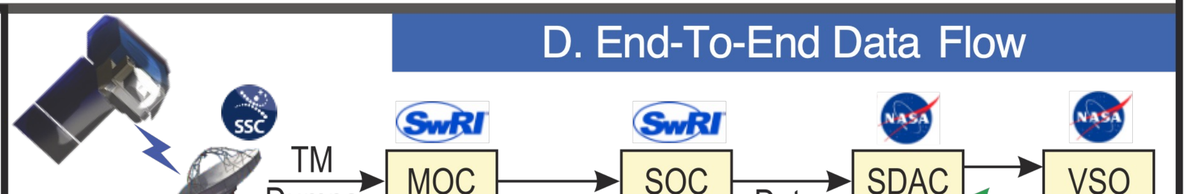

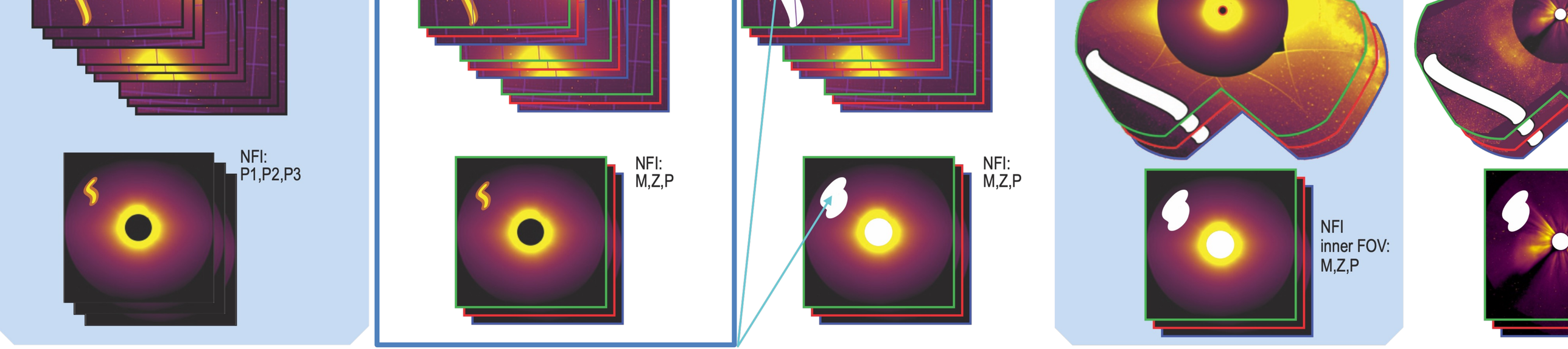

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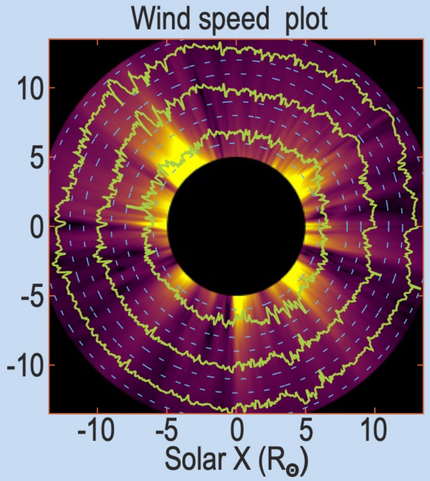
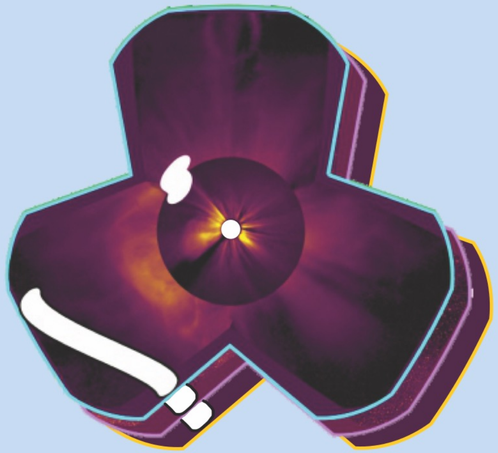
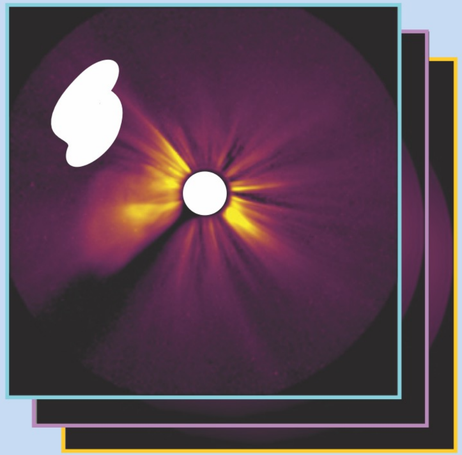


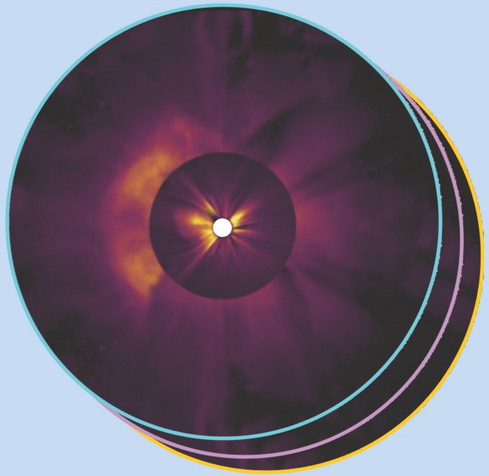
Extracted wind speed product (4k × 4k)



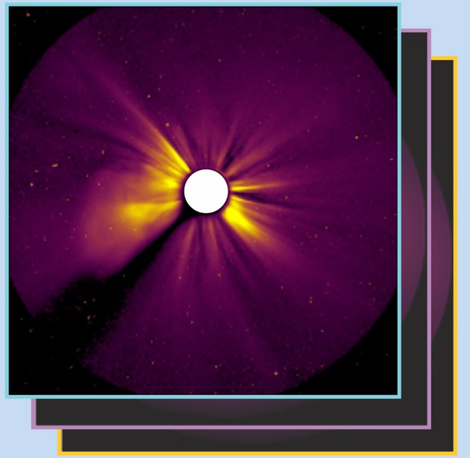
B/pB/clear mosaics every 4 minutes (4k × 4k)



B/pB/clear NFI full-resolution images every 4 minutes (2k × 2k)



B/pB/clear low-noise mosaics every 32 minutes (4k × 4k)



B/pB/clear low-noise NFI images every 24 minutes (2k × 2k)

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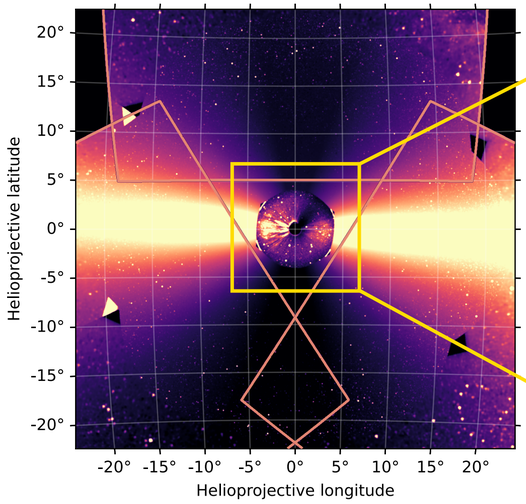
Polarimeter to Unify the Corona and Heliosphere

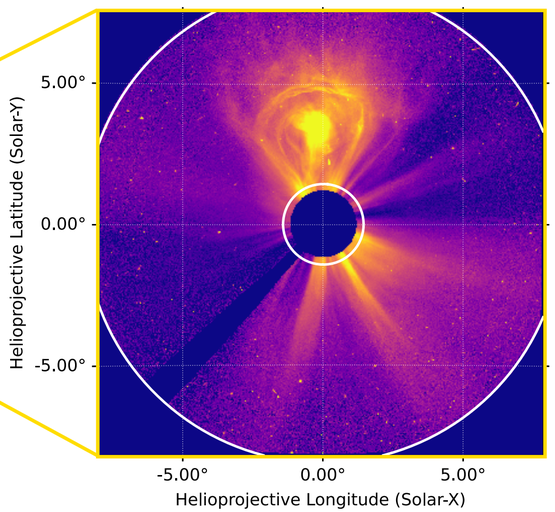
Space Weather Applications

QuickPUNCH Space Weather Products

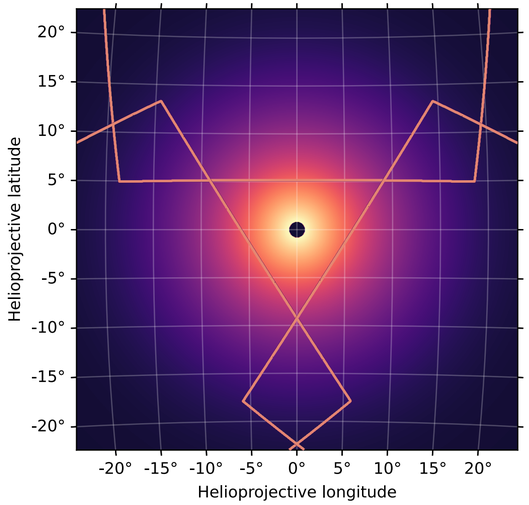
Planned QuickPUNCH Low-Latency Data Products



Low-Latency WFI Mosaics
5–80 $R_\odot$
Every 4 Minutes
1024×1024 pixels
~3 arcmin resolution



Low-Latency NFI Images
5.4–32 $R_\odot$
Every 4 Minutes
1024×1024 pixels
~1 arcmin resolution



WFI & NFI F-Corona Background
Every 12 Hours
Derived from preceding 1 month of data

Dedicated Python software generates running difference & F-corona-subtracted images on the fly.

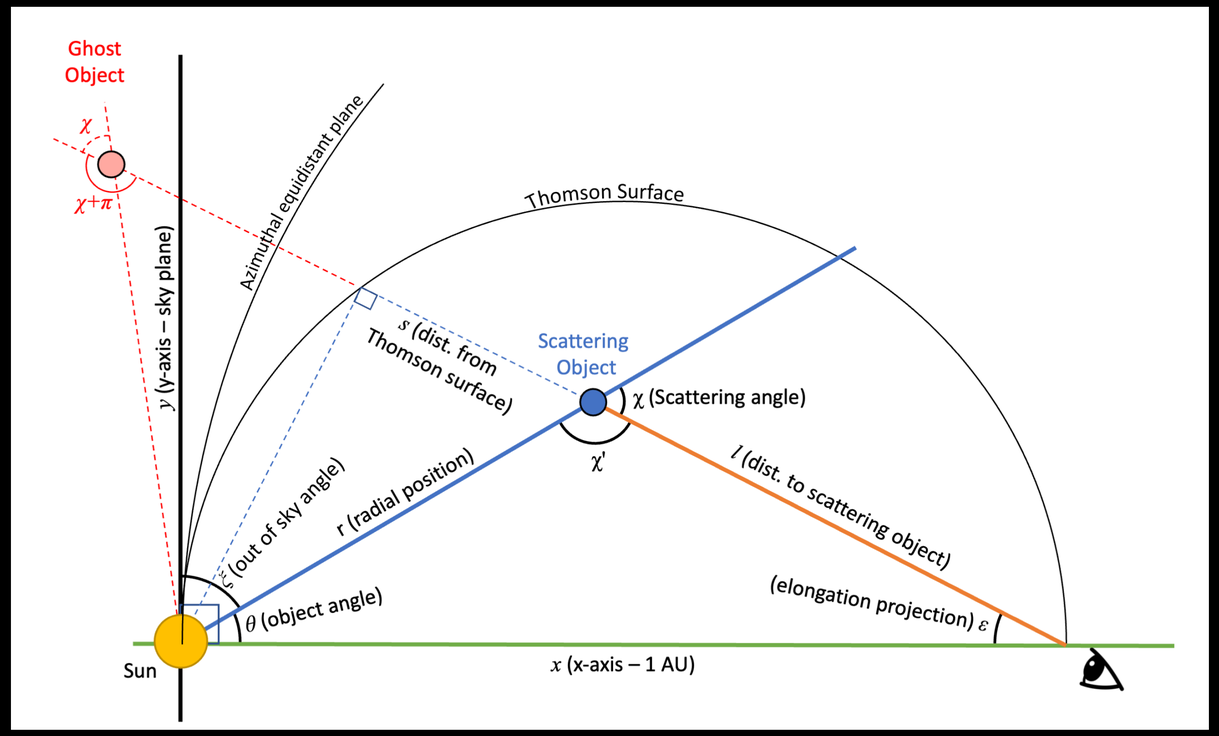
Analysis products are FITS format. Quicklook in JPEG & Helioviewer-compatible JPEG2000.

Data available via PUNCH website as soon as generated.

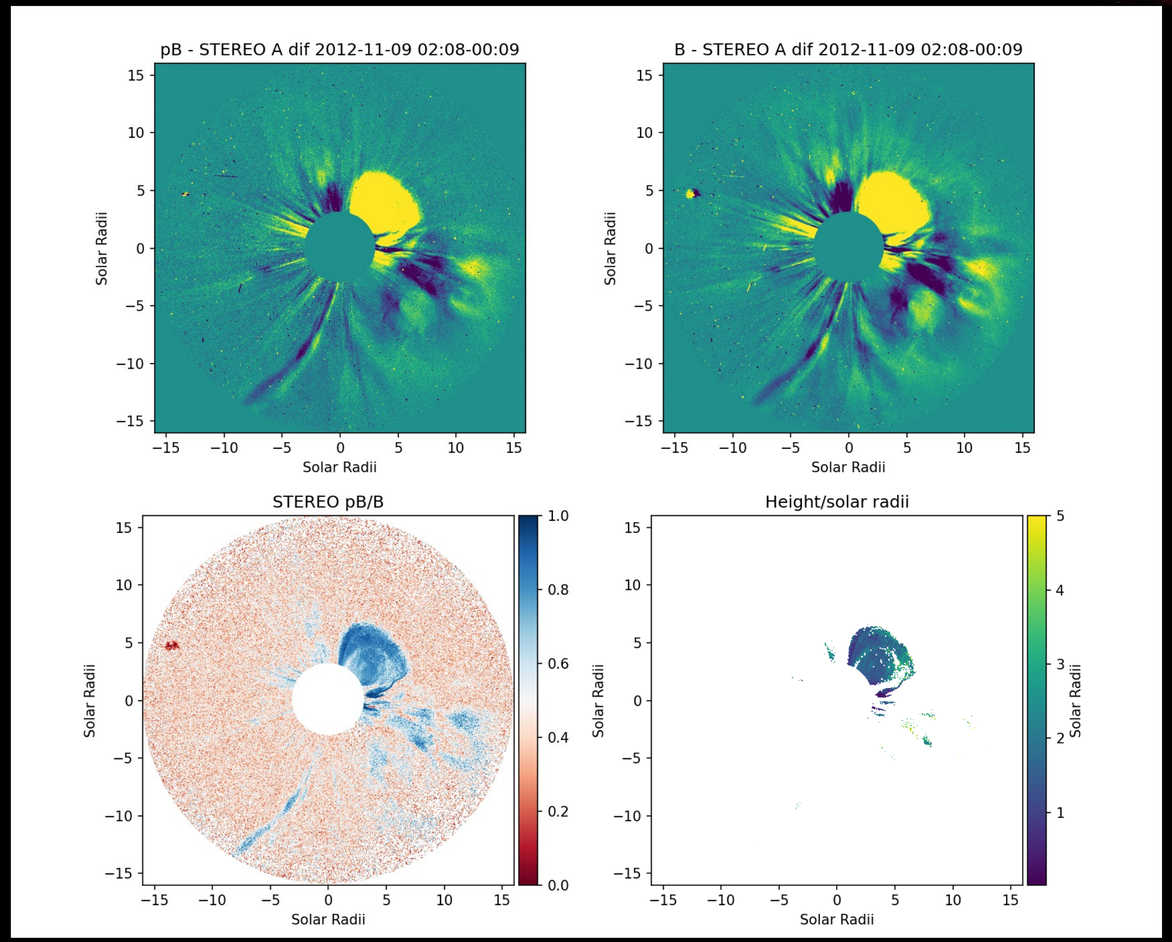
See Don Schmit's Talk on QuickPUNCH

Tracking CMEs with Polarization Observations

Can estimate line-of-sight distance to CMEs using the polarization ratio.



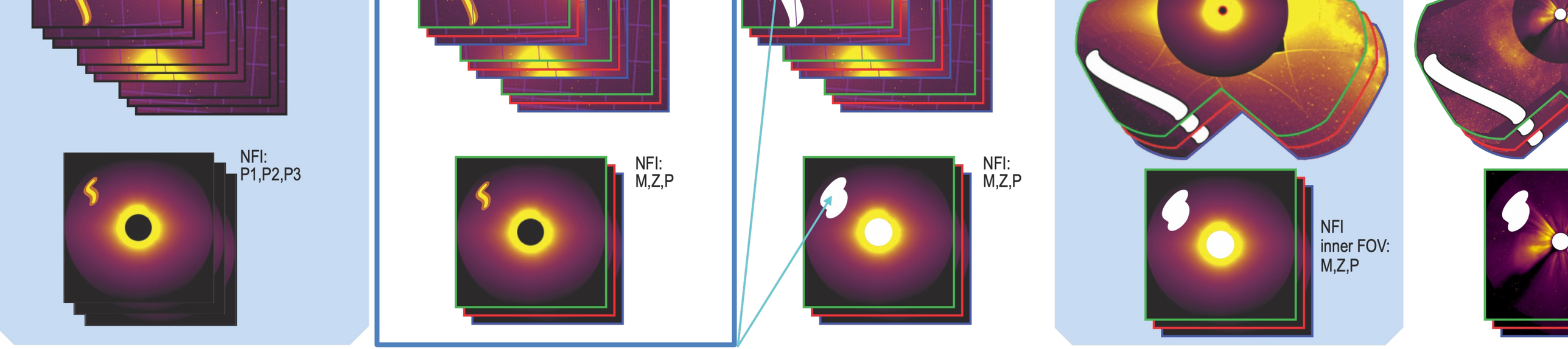
Sun – Scattering object geometry.



See Matt West's poster on CME tracking with polarization

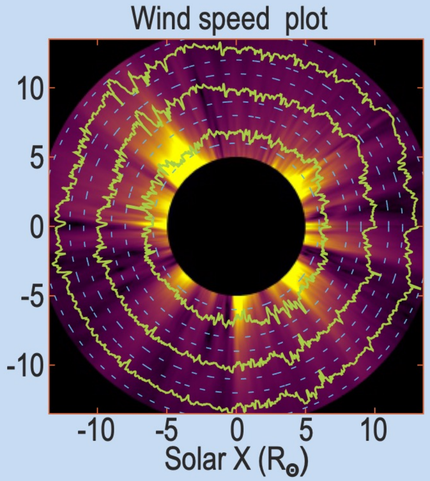
Polarimeter to Unify the Corona and Heliosphere

What's Next?

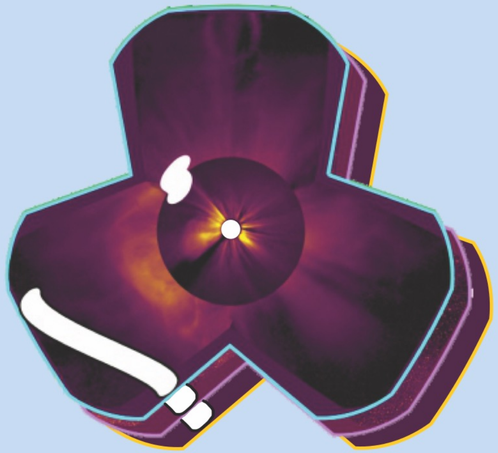


C. Level 3 Data Products

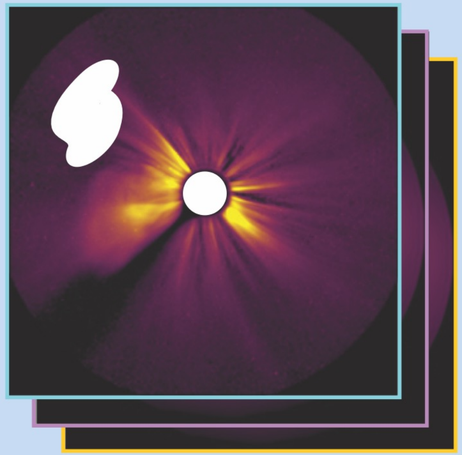
PUNCH Data Products are polarized and clear photometric images suitable for analysis in common existing scientific environments and with PUNCH-specific tools distributed by the project. Primary science products are shown.



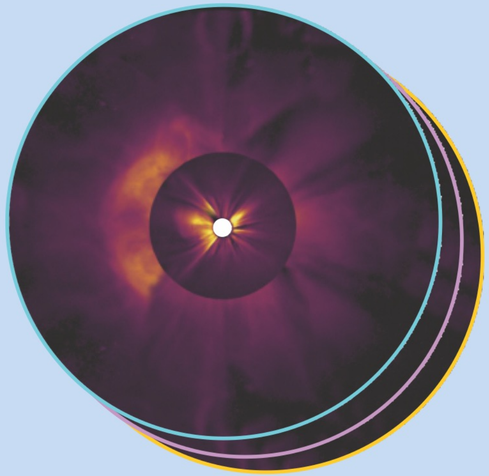
Extracted wind speed product (4k × 4k)



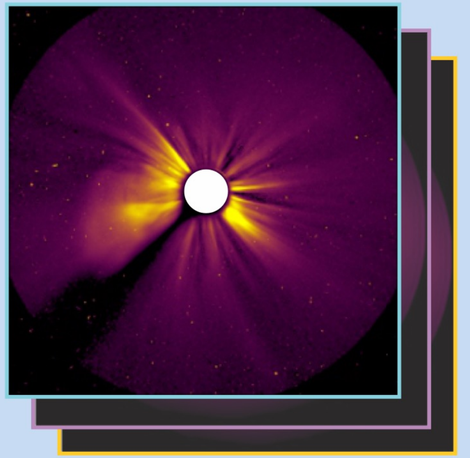
B/pB/clear mosaics every 4 minutes (4k × 4k)



B/pB/clear NFI full-resolution images every 4 minutes (2k × 2k)



B/pB/clear low-noise mosaics every 32 minutes (4k × 4k)



B/pB/clear low-noise NFI images every 24 minutes (2k × 2k)

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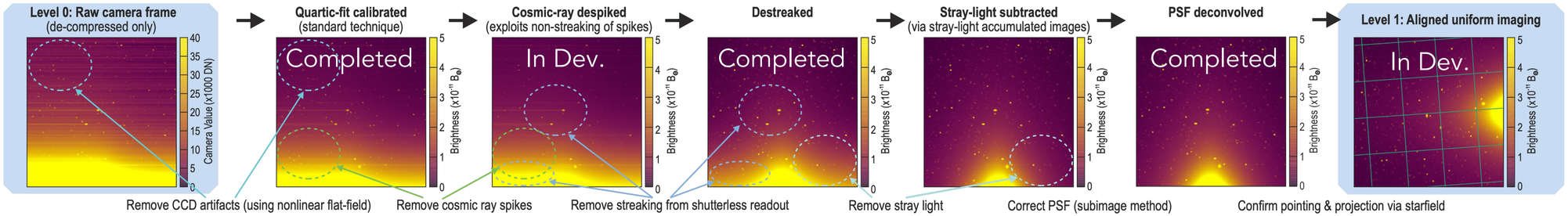
PUNCH Science Data Pipeline and Products

For effective data analysis by the PUNCH team and the broader community, PUNCH produces (A-C) and disseminates (D) calibrated, simple-to-use data products and analysis tools.

L3 Products Levels 2 & 3 Level 1

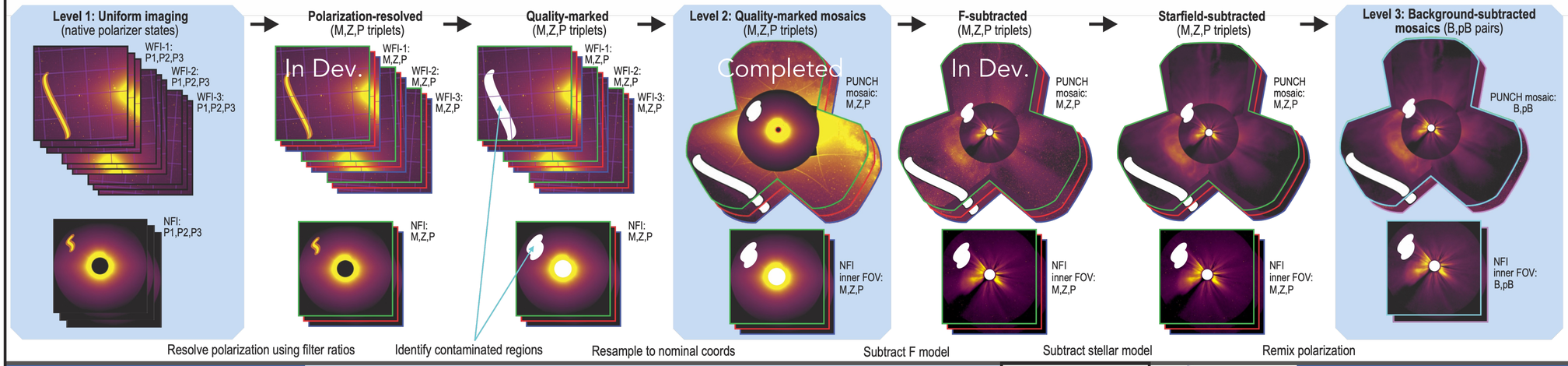
A. Level 0 → Level 1 Pipeline

Level 1 images are photometrically calibrated, precisely aligned images with instrumental artifacts corrected. To demonstrate PUNCH data reduction, we degraded and then processed data from STEREO/HI1 to show the PUNCH L1 processing. For clarity, all visual effects are 10-40x stronger here than in actual PUNCH images. These processing steps are the same for both WFI and NFI.



B. Level 1 → Level 3 Pipeline

The L1 to L2 stage maps polarization to M,Z,P triplet polarizer brightnesses, then generates full PUNCH mosaics. Clear exposures (not shown) skip the (M,Z,P) step. The L2 to L3 stage removes background F corona (fixed in heliospheric coordinates) and starfield (fixed in celestial coordinates), then generates B and pB products. Nearly all frames have no contamination.



C. Level 3 Data Products

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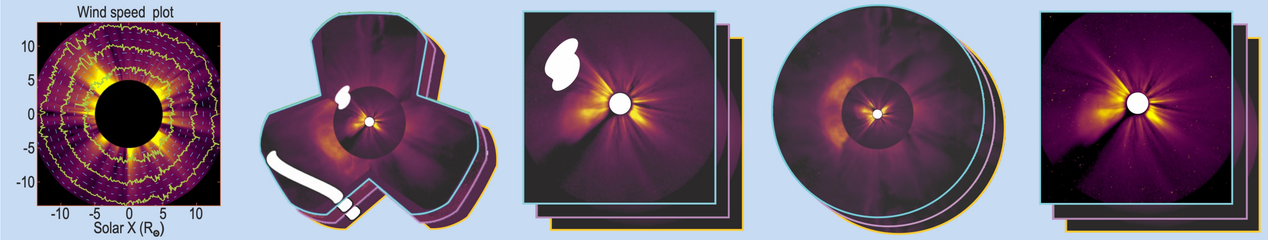
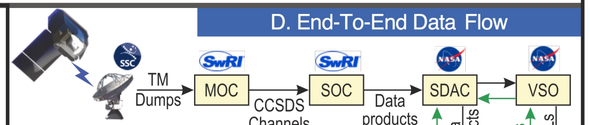


Legend

- Data Product
- Polarized Images:
  - M (–60°)
  - Z (0°)
  - P (+60°)
  - B
  - pB
  - Clear

D. End-To-End Data Flow



PUNCH data are downlinked and transferred to the MOC, reduced (Panels A-C) at the SOC, then mirrored to SDAC for archiving & dissemination. SOC software written in Python and publicly accessible via SunPy/Github.

Code/Tool/Doc Repository (main at SwRI; mirror at SDAC)

- PUNCH Science Team
- Science Community
- General Public

SOC pipeline workflow orchestrated by Prefect. Data & metadata flow managed with NDCube.

PREFECT

Original figures and layout from PUNCH CSR

Next up

- Finish data product definitions
- Develop more synthetic data: SimPUNCH
- Deploy data server and test product-archive interfaces
- Complete CCSDS-to-Level-0 algorithms
- Adding functionality to SolPolPy to support other measurements/instruments
- Continue work on tools to generate calibration data based on lab/field observations
- Developing polarization-based CME tracking tools

Summary

- Data pipeline is running in test environment, key steps implemented
- Key community tools are available (or soon will be)
- SOC has made important progress on polarization and applications
- **Synthetic Data Available Now: http://tinyurl.com/PUNCH4Data**

Other SOC-related presentations and posters:

- **Marcus Hughes:** Community Software Packages (poster)
- **Ritesh Patel:** Polarization Tools (poster)
- **Matt West:** Tracking CMEs with Polarization (poster)
- **Don Schmit (NOAA NCEI):** NOAA's QuickPUNCH Project (talk)

Polarimeter to Unify the Corona and Heliosphere

We want to work with you!

Get in touch!

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daniel.seaton@swri.org

Modeling, Polarization, SpWx Applications:
matthew.west@swri.org