DARK ENERGY SURVEY

The Dark Energy Survey Y6A1 Production Overview

Robert Gruendl

NCSA/University of Illinois

Outline

- A Brief Introduction to the Dark Energy Survey
- Overview of the Main Pipelines
- Y6A1 Data Products

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Dark Energy Survey

Probe origin of Cosmic Acceleration:

Distance vs. redshift

Growth of Structure

- Two multicolor surveys:

300 M galaxies over 5000 sq deg

grizY to 24th mag

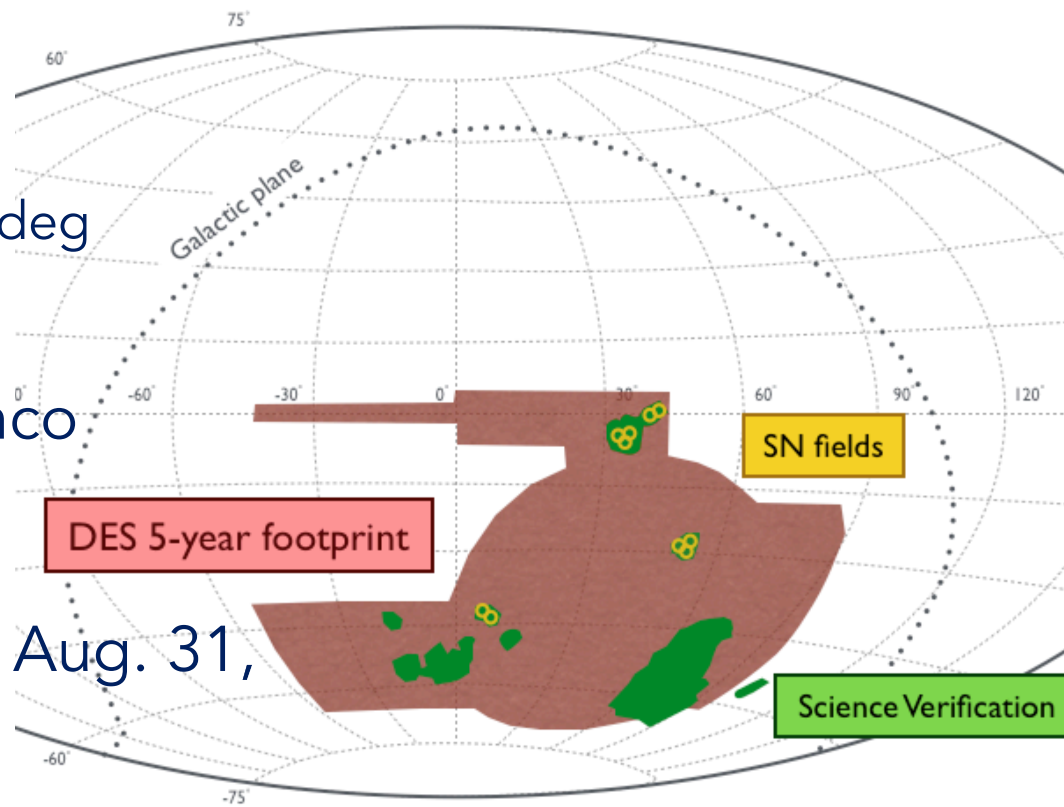
3500 supernovae (30 sq deg)

New camera for CTIO Blanco telescope

Facility instrument

- Five-year Survey started Aug. 31, 2013

525 nights (Sept.-Feb.)



Dark Energy Survey

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DES Collaboration

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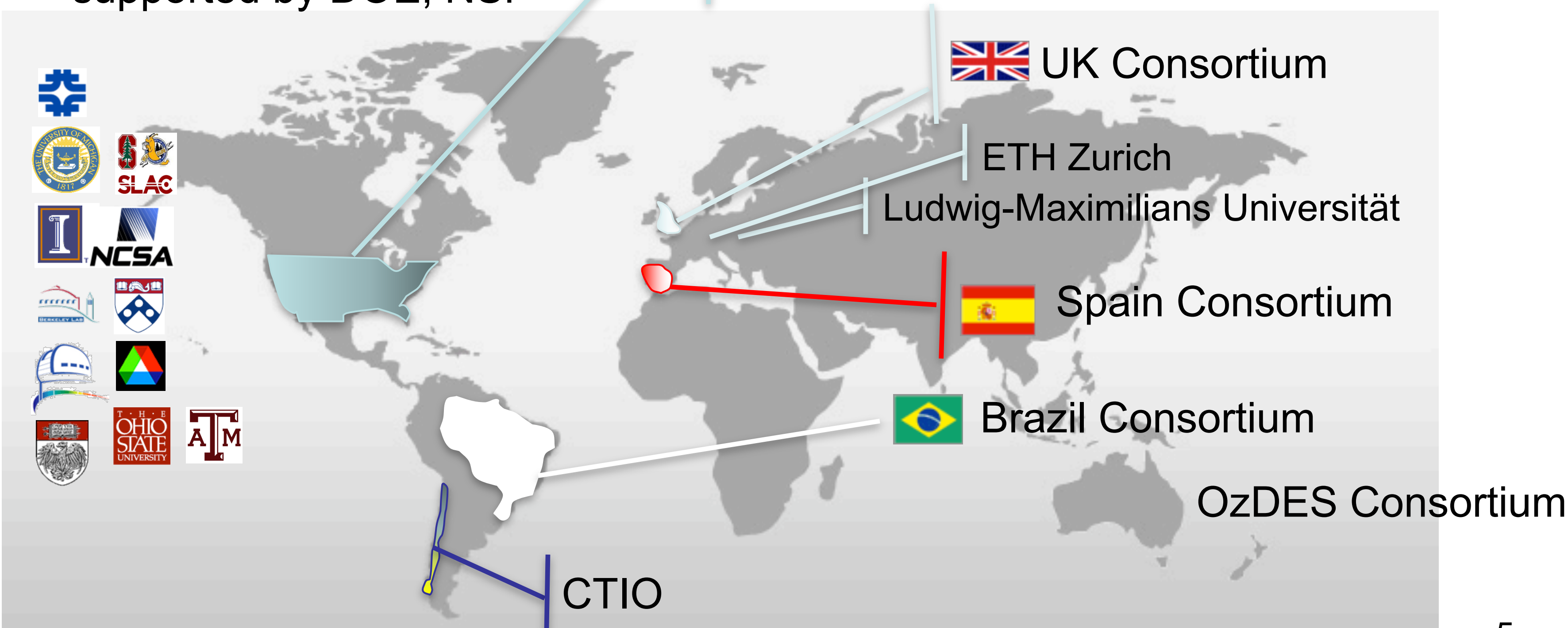
- 400 to 600 collaborators
- 12 Science Working Groups
- 25 institutions, including 9 US universities
- Operations + maintenance supported by DOE, NSF

Fermilab, UIUC/NCSA, University of Chicago, LBNL, NOAO, University of Michigan, University of Pennsylvania, Argonne National Laboratory, Ohio State University, Santa-Cruz/SLAC/Stanford Consortium, Texas A&M



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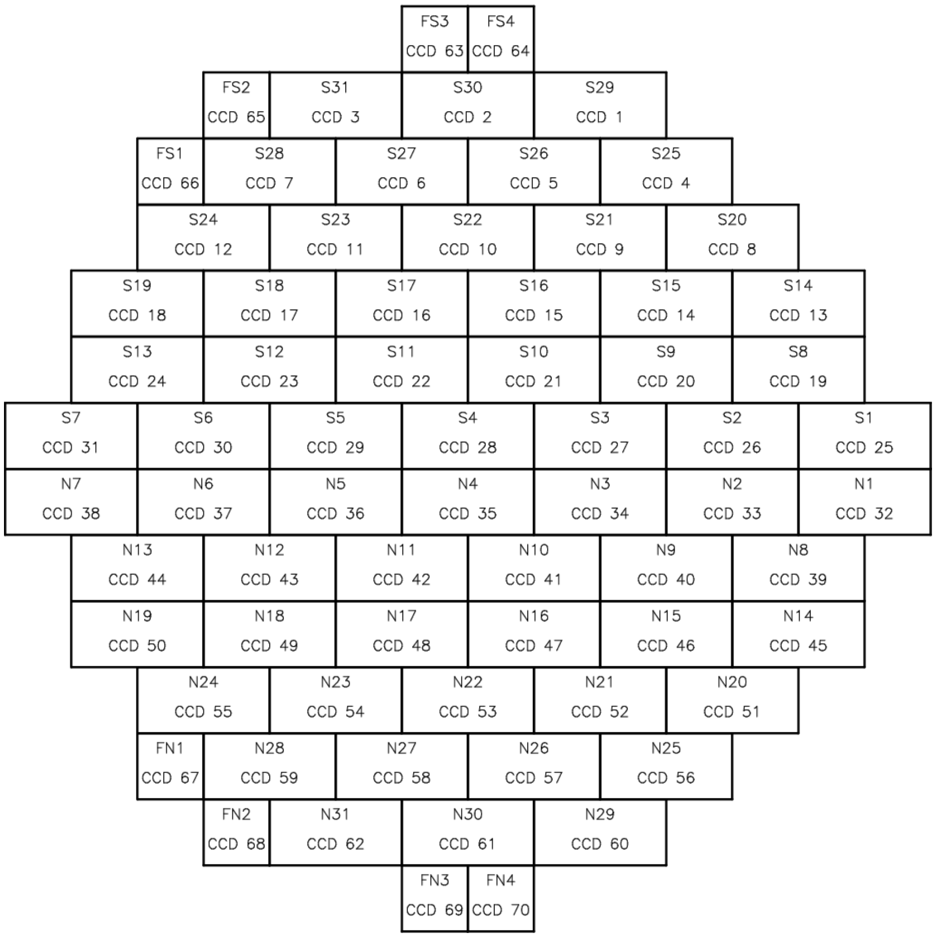
DECam



- 62 Science CCDs (2-amplifiers)
- 8 focus and guide CCDs
  - FS[1-4],FN[1-4]

- CCD 31[S7]
  - Gain for Amp A unstable
  - No linearity correction

- CCD 61[N30]
  - became non-linear during

- CCD 2 [S30]
  - Became un-usable Nov 2013 (mid Y1)
  - Revived Nov 2017 (mid Y4)

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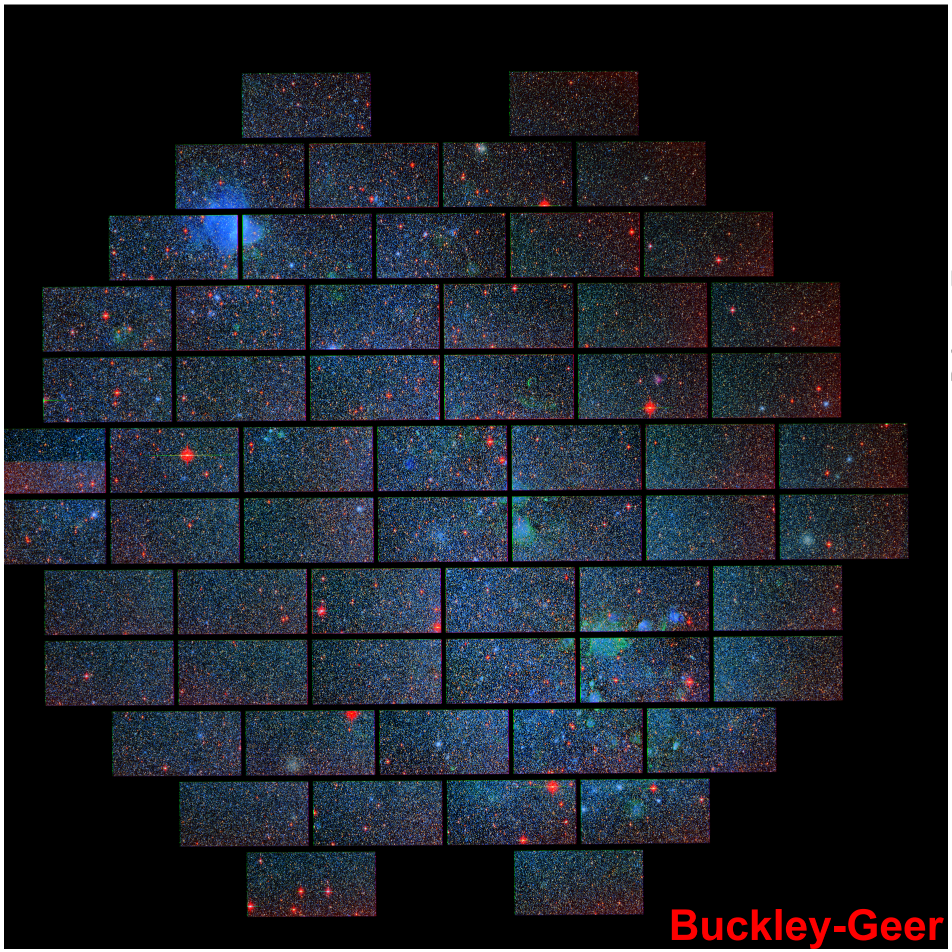
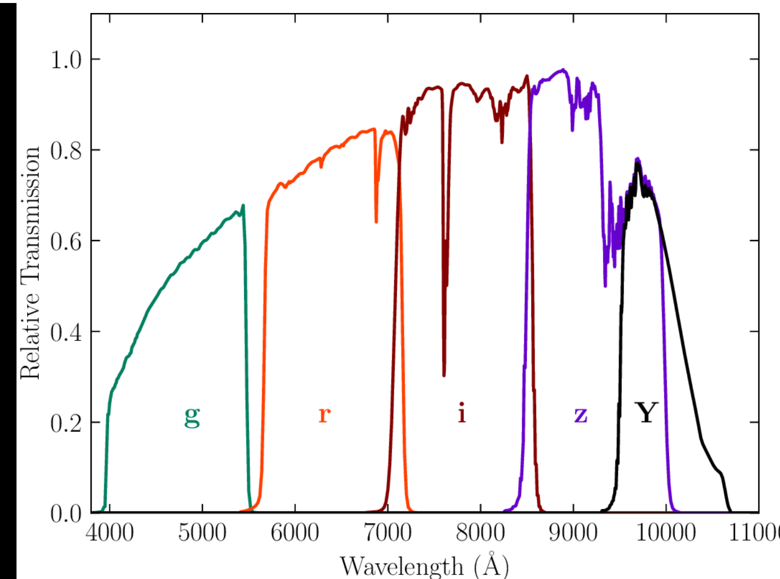
DECam





- Survey used 5 filters
- Each area was observed 10x
- ~~525 nights over 5 years~~
- 575 nights over 6 years

What do I mean by a pipeline?

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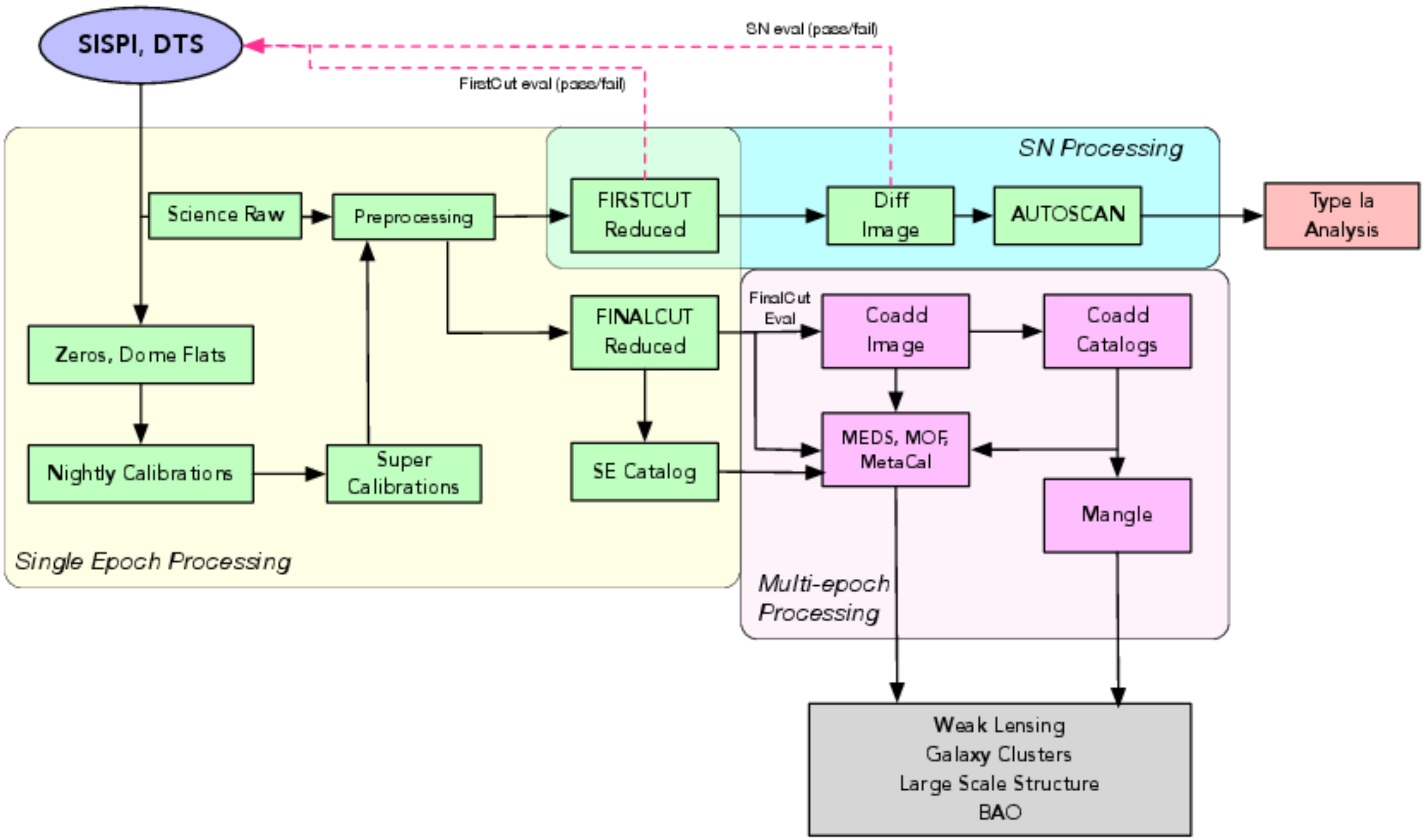
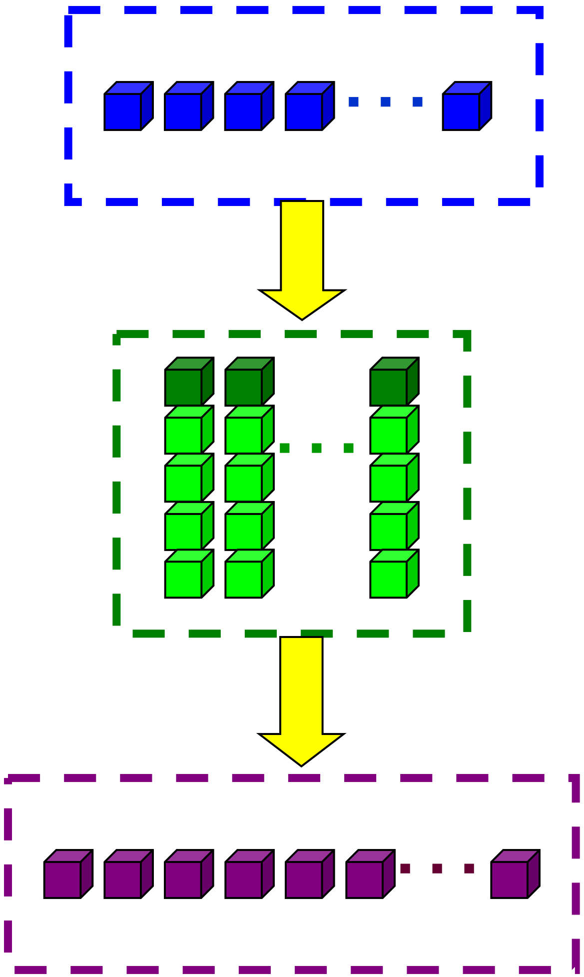
Current DES pipelines



Organized Workflow



Crosstalk Block: X pipeline jobs

Modules in pipeline: Crosstalk

CreateCor Block: Y pipeline jobs

Modules in pipeline: mkbiascor, mkflatcor

Note: mkflatcor is repeated for each band

Detrend Block: Z pipeline jobs (Z >> Y)

Modules in pipeline: imcorrect

Precursor Pipelines (Calibrations)

Calibration (per observing epoch):

- Supercal → bias/flat/BPM
  - Combines 100+ bias/flat observations

- Astrometric WCS/distortion model

- SkyTemplate → principle component analysis of background/scattered light/fringe

- Star Flat → 2nd order flat field correction derived through stellar photometry in heavily dithered set of observations

Major Pipelines (single-epoch)

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Pipelines that operate on a per-exposure basis

FIRSTCUT: (runs nightly)

- Quality Assessment
- preliminary reduction and assessment of data within 24h for feeback to mountaintop (observers/*obstac*)
- In later years this used the previous version of FINALCUT with most recent set of supercals.

FINALCUT: (runs as a campaign)

- **Science-Ready survey products**
- **Careful attention to generate and use best calibrations**
- **Results form data releases to DES collaboration and eventually the astronomical community**

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Major Pipelines (multi-epoch)

Combined products (i.e. many exposure)

COADD:

- **Combined images (for increased depth)**
- **Basic detection and source catalogs**
- **Overall survey coverage and systematics maps**

MOF/SOF/ngmix/photo-z (afterburners)

- Multi-band/multi-object fitting
  - MOF: joint fit of an object and its neighbors
  - SOF: single object fit (neighbors are masked)
- Ngmix: shear measurements for weak-lensing
- Photo-z: BPZ (using MOF/SOF catalogs)

Detrending in the DES SE pipelines

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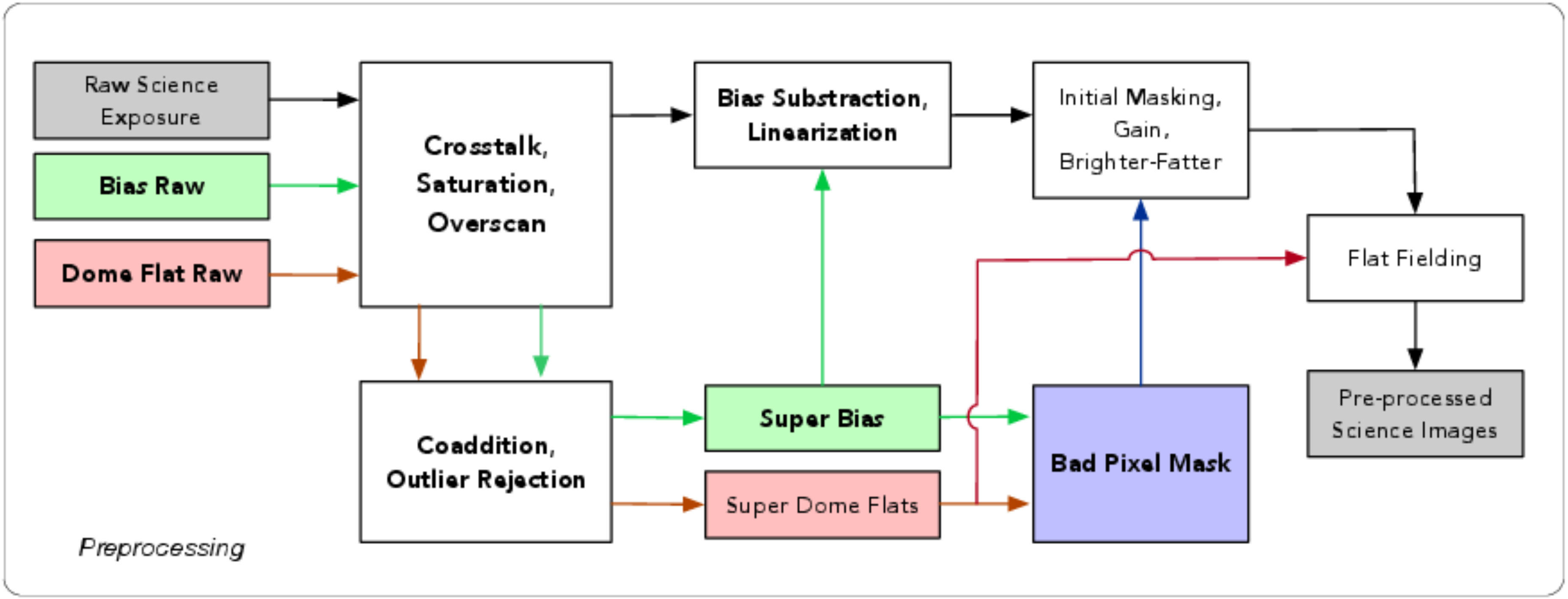
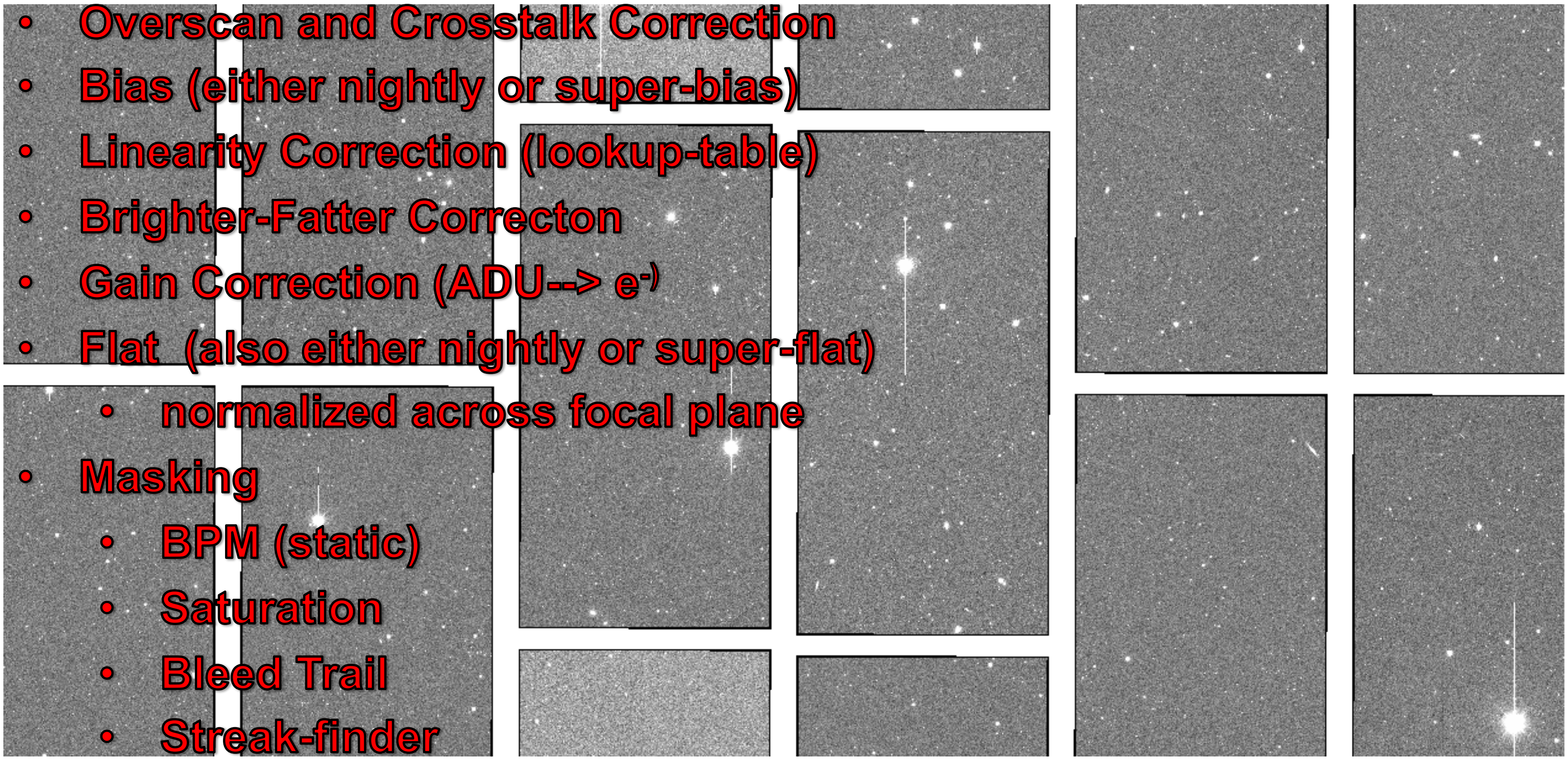


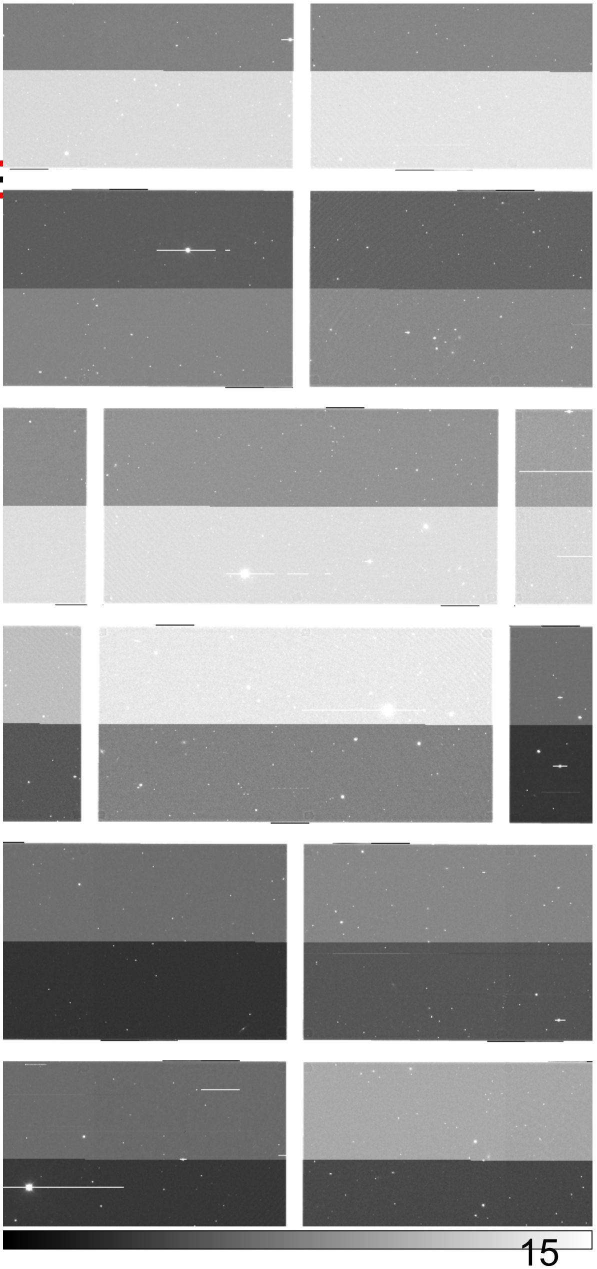
Detrend



- Overscan and Crosstalk Correction
- Bias (either nightly or super-bias)
- Linearity Correction (lookup-table)
- Brighter-Fatter Correcton
- Gain Correction (ADU--> e^{-})
- Flat (also either nightly or super-flat)
  - normalized across focal plane
- Masking
  - BPM (static)
  - Saturation
  - Bleed Trail
  - Streak-finder

DECam (raw)

Raw Exposure from the telescope



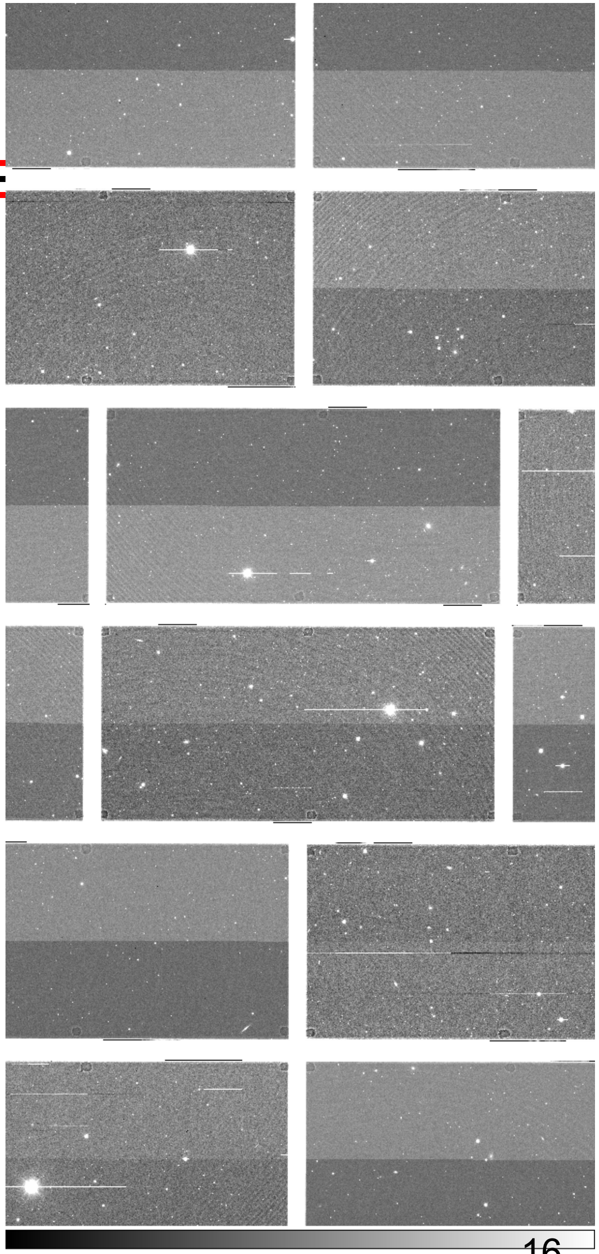
Crosstalk & Overscan

Remove overscan:

- Currently uses line-by-line average with outlier rejection
- Functional fitting and splines would require knowledge of bias jumps for backplanes containing focus chips

Crosstalk:

- Crosstalk removal (mostly inter-ccd) but has a non-linear behavior and super-saturated sources cannot be corrected.



Detrend

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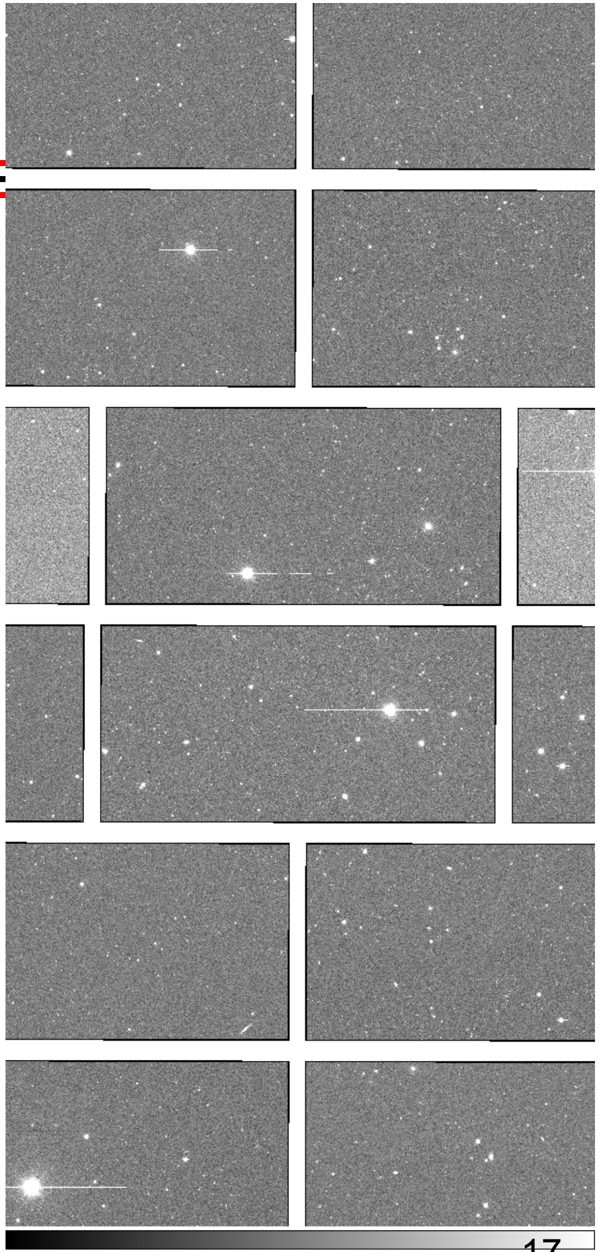
- Bias (either nightly or super-bias)
- Linearity Correction
- Gain Correction (**added for Y3**)
- Brighter Fatter (**Y3A1 and later**)
- Flat (super-flat)
    - Y3A1 switched to normalization across focal plane to enable full focal plane sky subtraction (not shown in figure)
- Apply Bad Pixel Mask (static)
- Mask simple artifacts
    - Saturated pixels
    - Y5 lightbulb (on ccd 46)
    - Y6 CTI (ccd 41, amp B)



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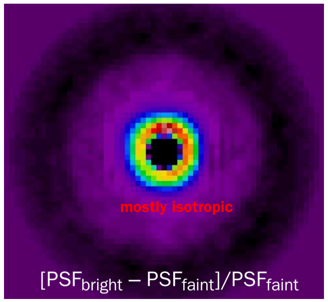
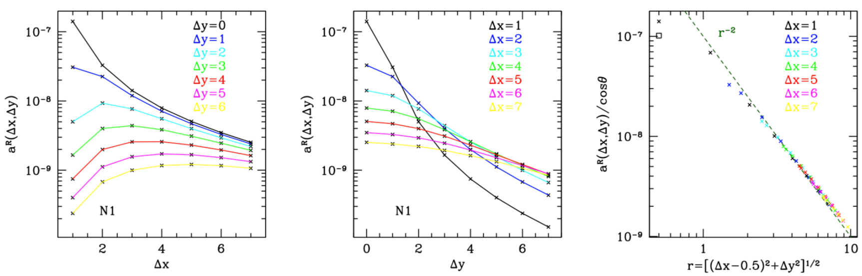
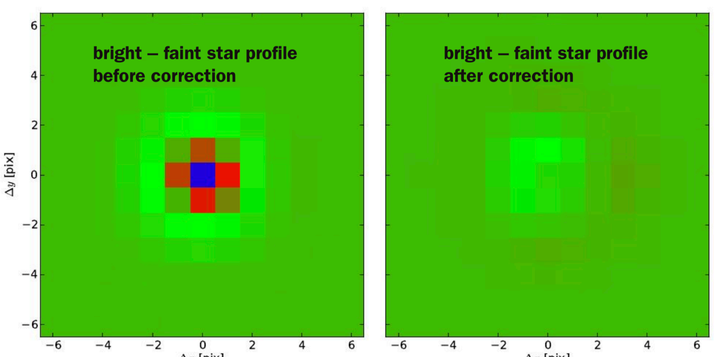
Brighter - Fatter







Gruen, Bernstein, Jarvis

- Can be thought of as pixels with lots of charge being stretched
- **Or:** As charge accumulates in a pixel subsequent photo-electrons are driven into neighboring pixels
- **Upshot is that the PSF depends on source brightness.**
- Either need a PSF model that varies with brightness or a correction.
- DES applies a correction based on covariance statistics from flat-field

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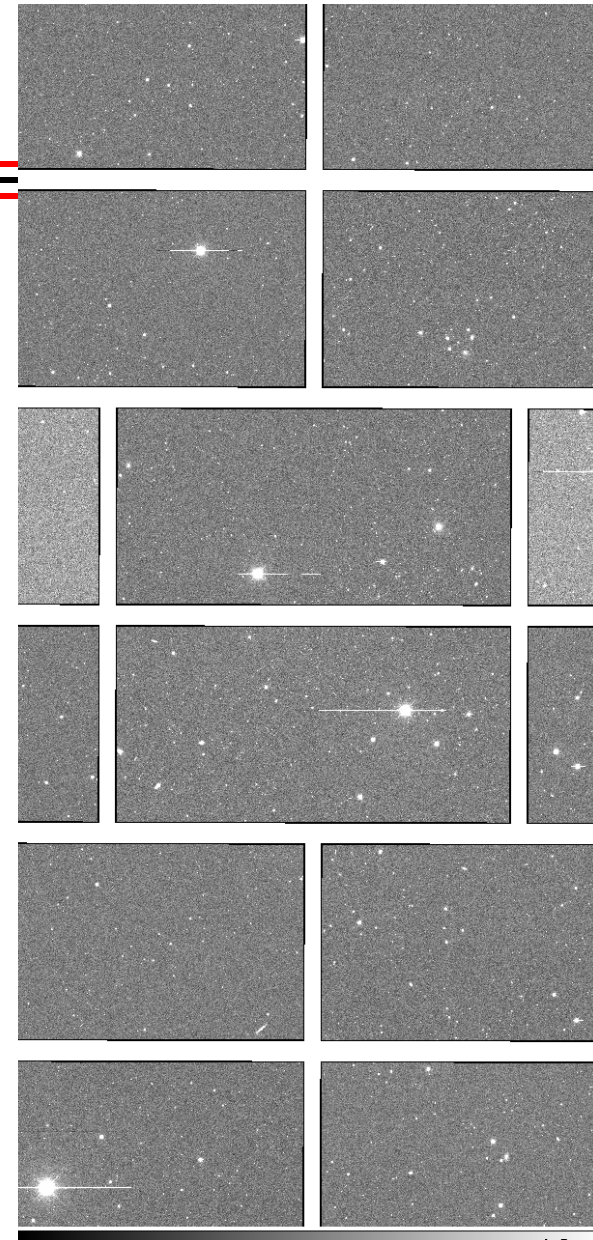
Astrometry



<u>Up through Y3A1:</u>
Used UCAC-4 along with a single predetermined distortion correction → 250 mas RMS

<u>Starting with the Y4 (campaign):</u>
Switched to GAIA-DR2 for a reference → 70 mas RMS
Add per epoch distortion estimates (from star-flats) → 25-50 mas RMS

Astrometric Distortion

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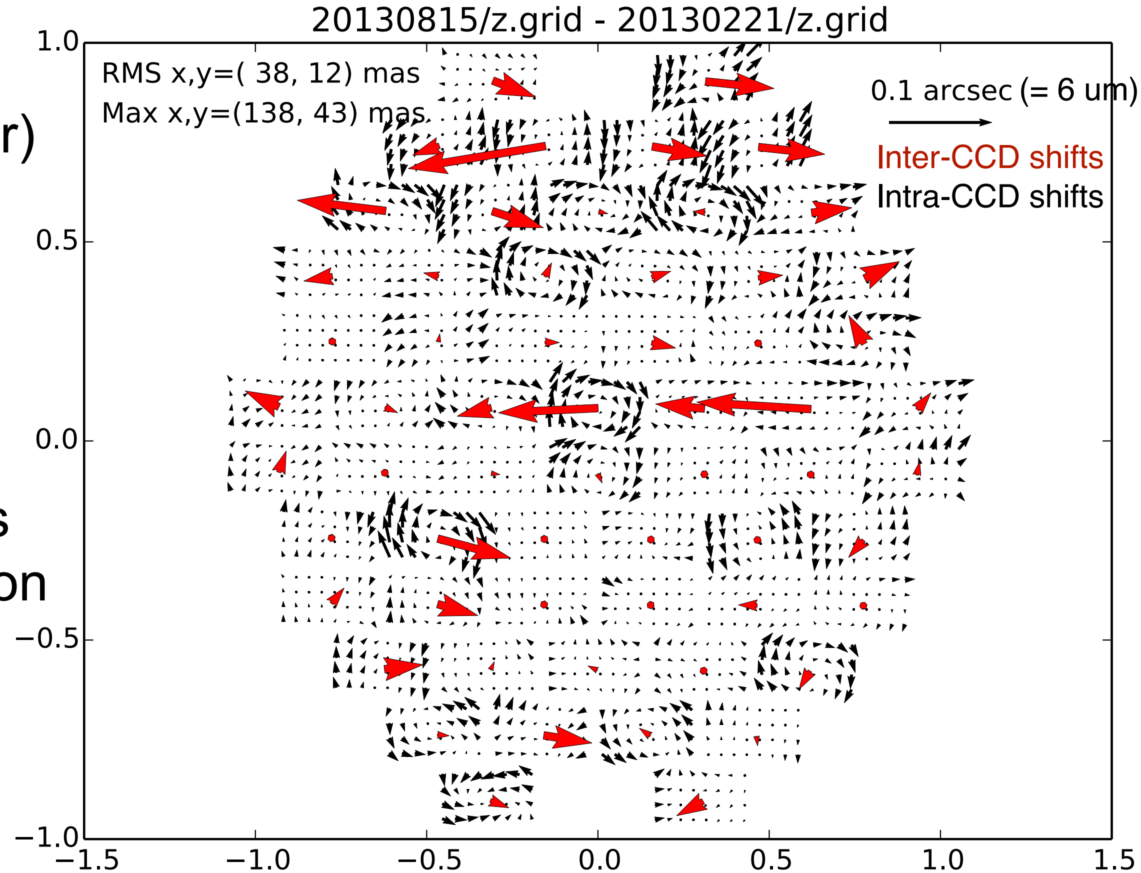
Y1:

- Showed both a band dependence (i.e. per filter)
-
- And identified temporal changes in astrometric distortion pattern

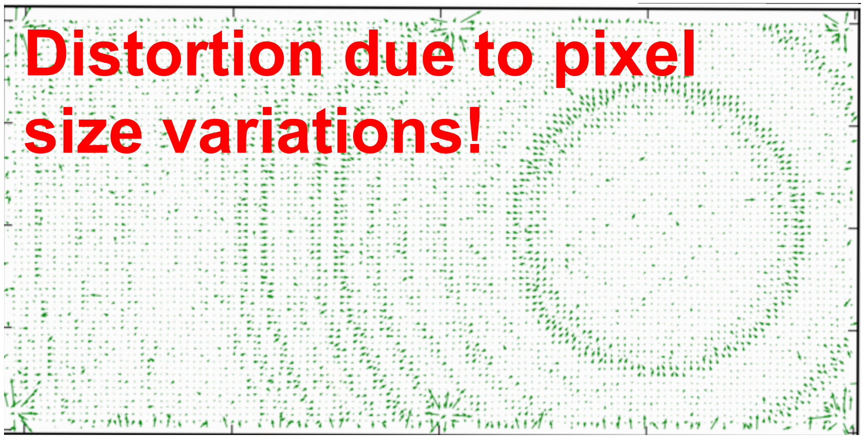
- Traced to actual changes in CCD location/orientation when camera warm-up occurs



(from G. Bernstein)

Astrometry (longer term)

Current (Y6) incorporates systematic shifts due to tree-rings and then goes further and can now estimate an atmospheric component (can reach a floor of 5-10 mas)



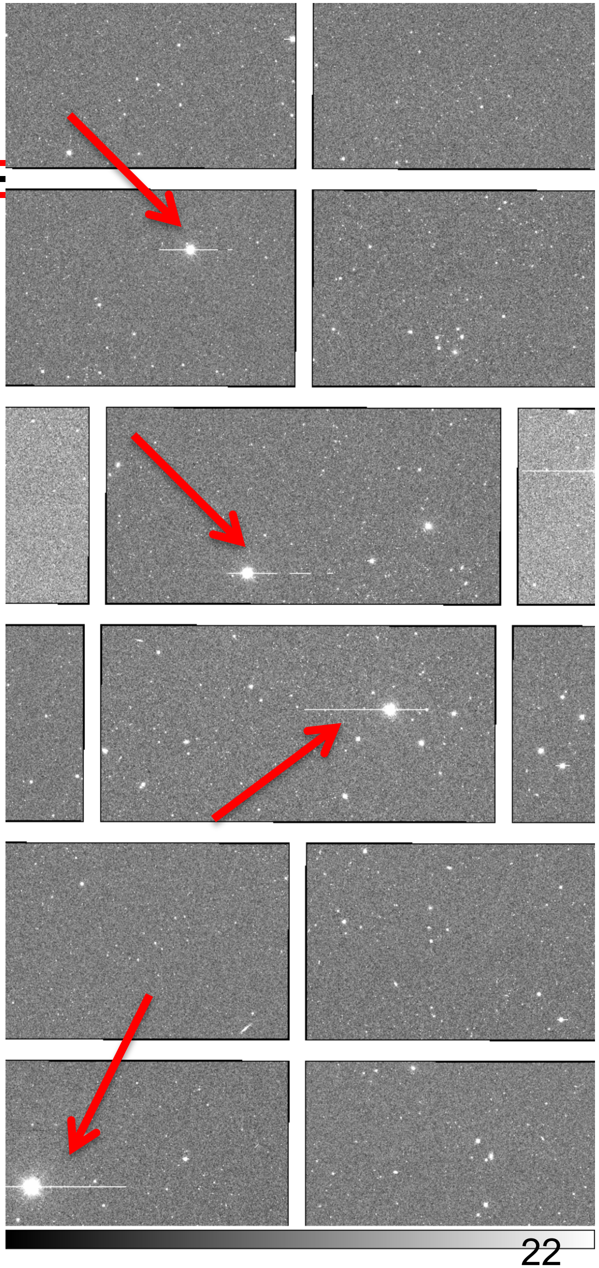
(From G. Bernstein)

Bleed

Bleed trail identification by searching for extended structures stemming from saturated islands.

After detection

- Mask dilation in the cross-trail direction to better remove strong bleeds.
- Search for edge-bleed conditions for trails that intercept the read registers.



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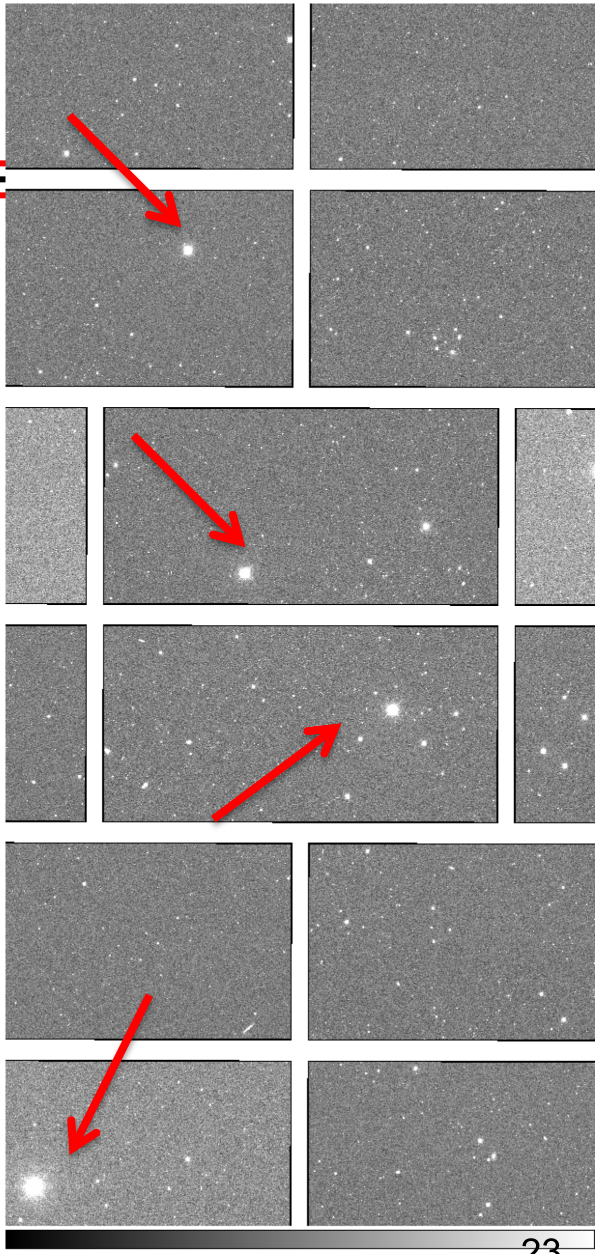
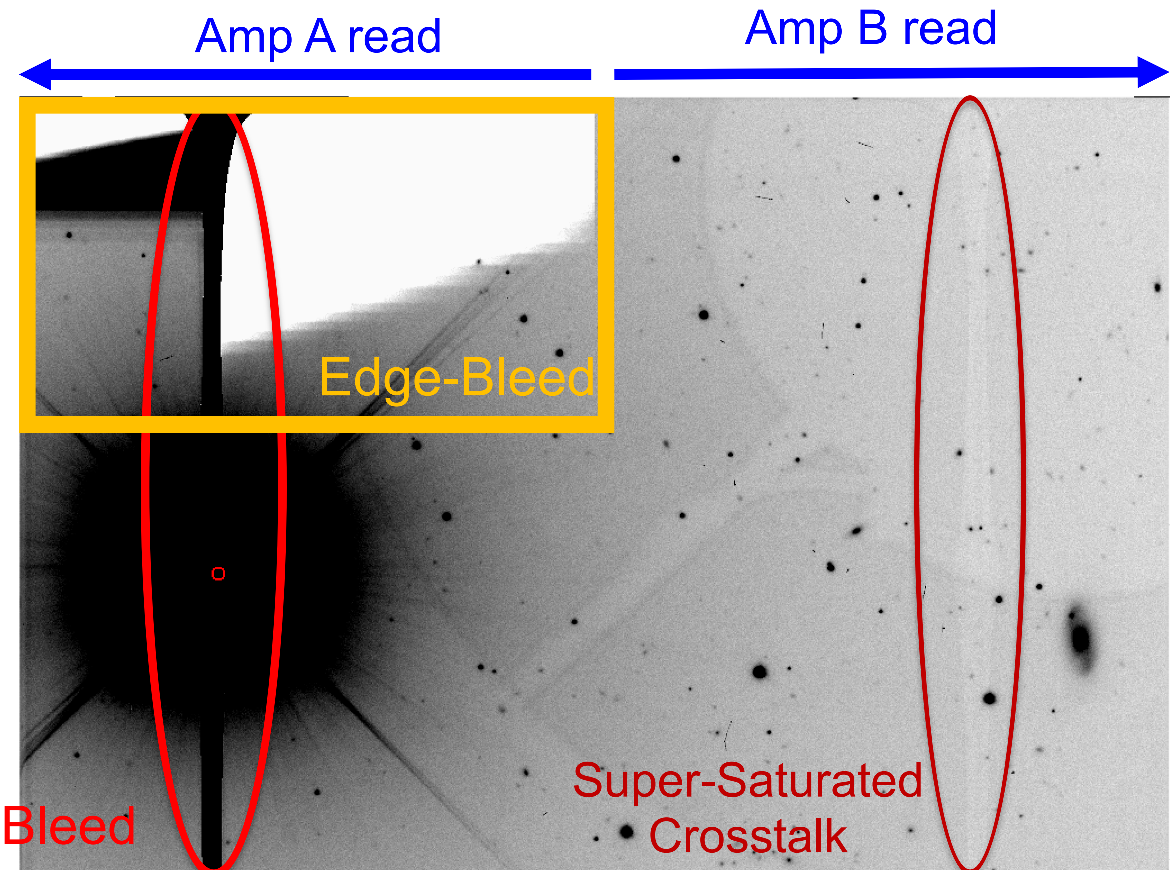


Edge-Bleed

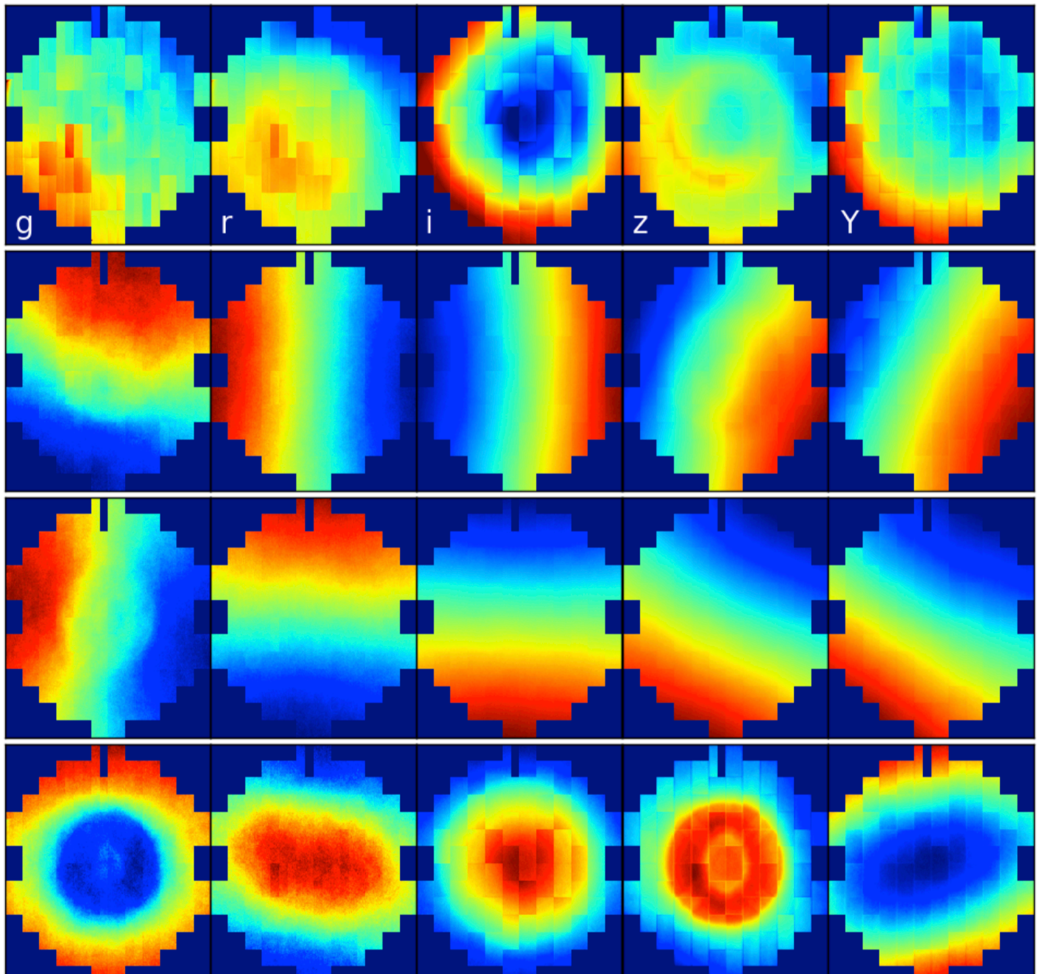


Occurs when a strong bleed reaches the read registers (and accumulates)

Amplifier sees a residual effect until the number of rows read is sufficient to clear "memory" off large accumulated charge.

Bleed masking code searches for and attempts to flag appropriately. However this is dependent on being able to make a background estimate so can fail.

Sky Subtraction



Bernstein

Background and diffuse scattered light are estimated by considering a stack of 100's of exposures with objects masked and then decomposed into a set of Principal Components.

For DECam 4 components have been found to be sufficient to encompass most features/variations.

Fits are made using heavily binned templates and then

Sky Subtraction (Fringing)

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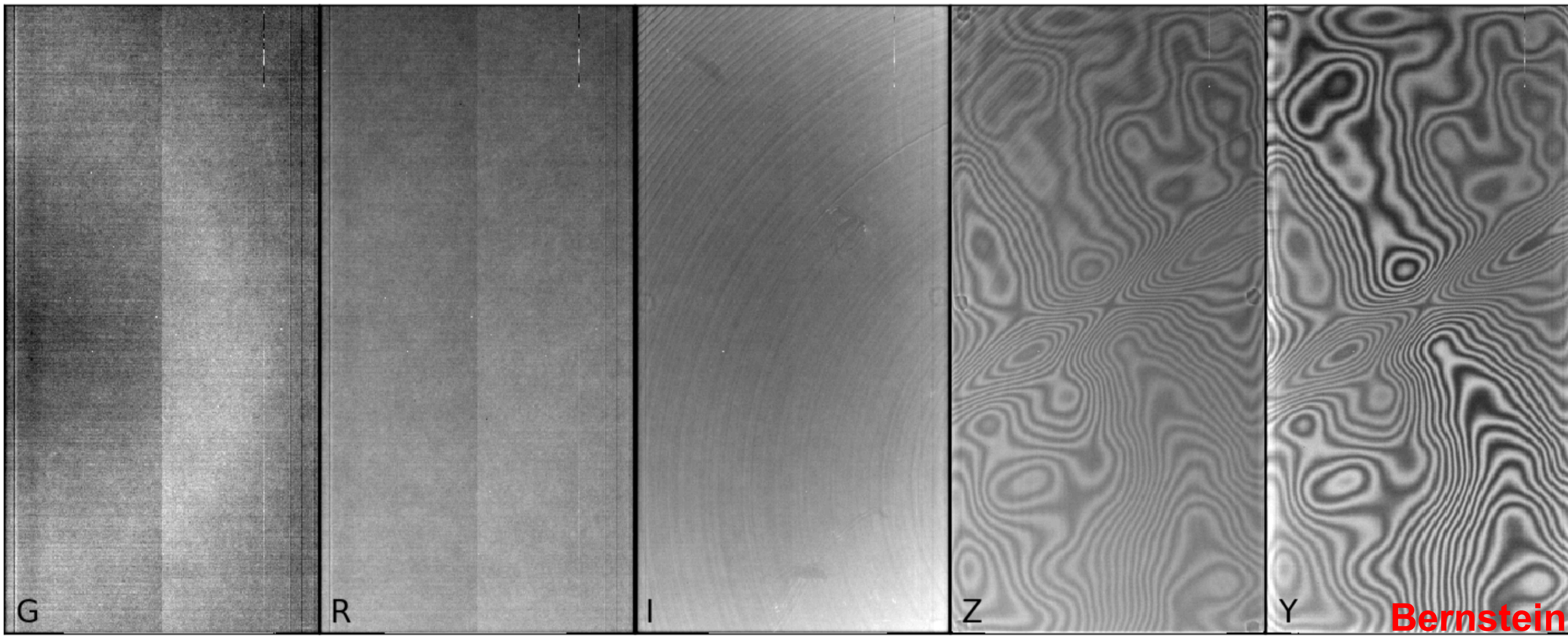
As part of this process fringing (at z- and Y-bands) is detected within one (typically the first) component and removed when subtraction occurs.



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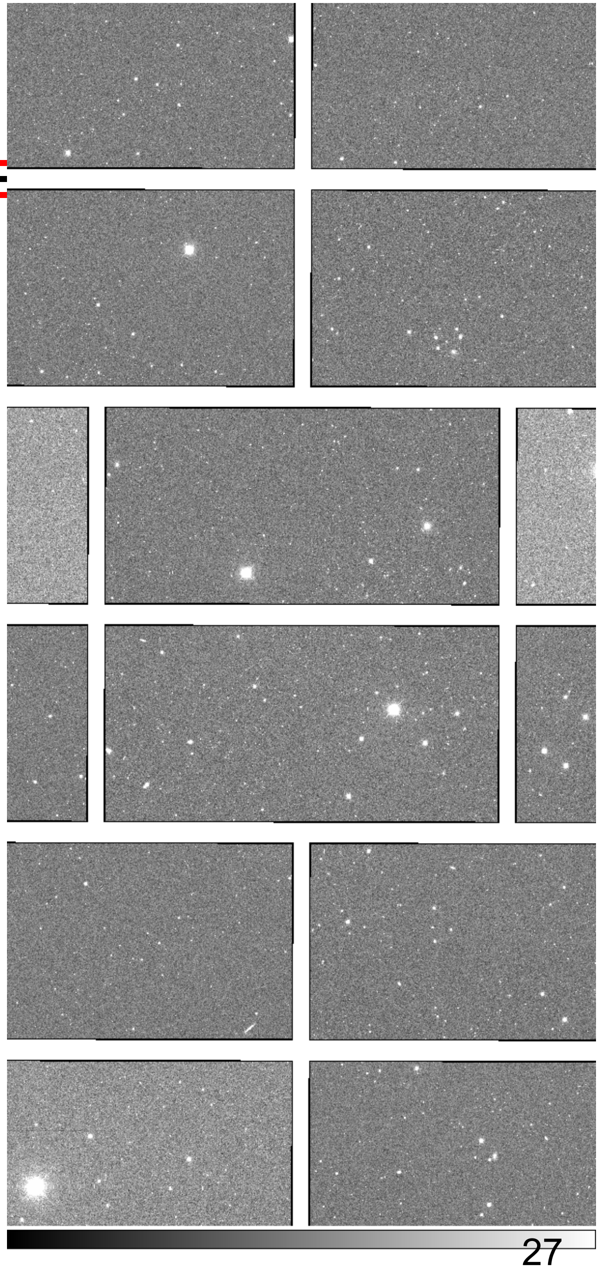
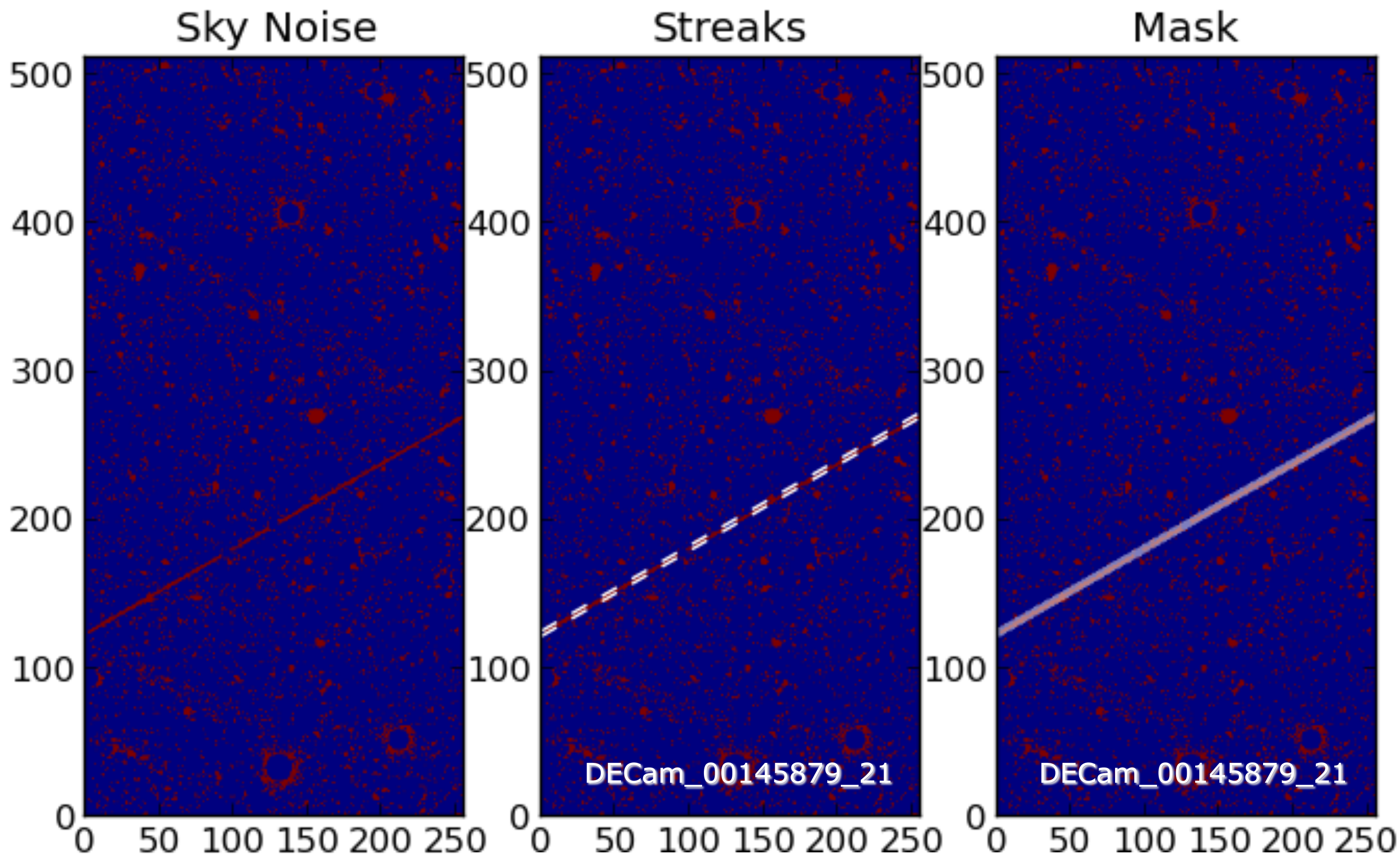
CR-reject & streak finder

- Early CR-rejection used neural net identification (only partially effective).
- SV: Single-Image CR-rejection was via gradient (better)
- Implemented LSST-stack CR-rejection algorithm within DESDM pipelines.
- Within measurement and COADD algorithms pixels affected by CR's are given weight=0
- Streak finder deployed in Y1 uses identification via Hough transform



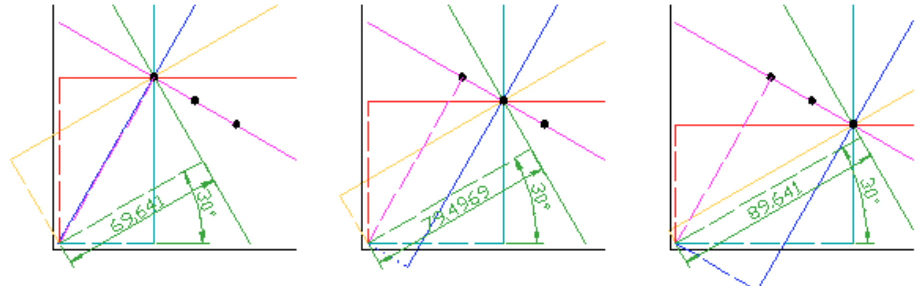
Detection and Masking of Streaks



Hough Transform

(Eli Rykoff's pyhough http://github.com/erykoff/pyhough)

- Iterate through each pixel of the thresholded image and count how many pixels lie at each possible angle
- Create a 2D histogram in "Hough-space" where lines accumulate as localized over-densities
- Has to ignore the special case where of streaks aligned along the read-direction (i.e. the y-direction) to prevent false positives from bleed trails

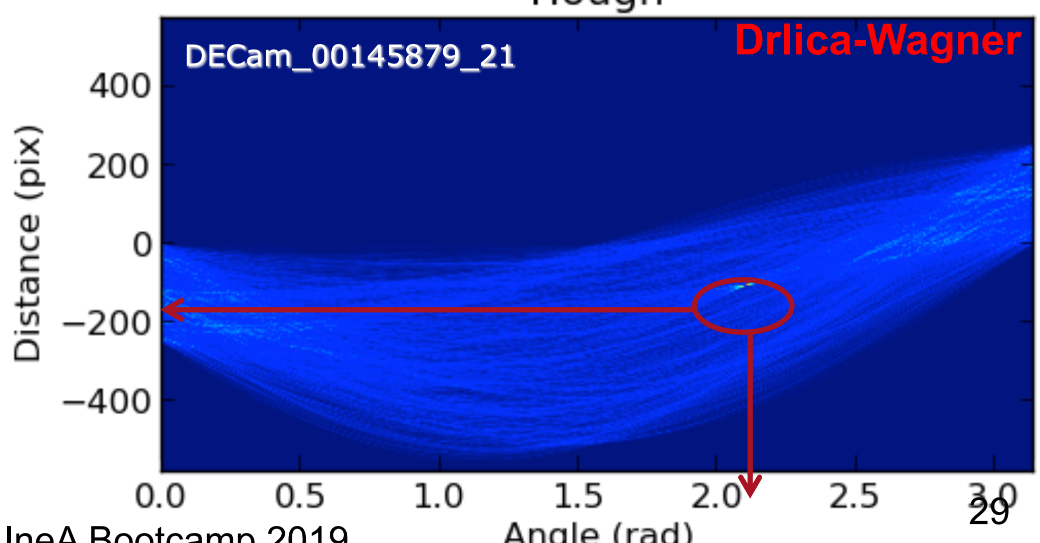


Angle	Dist.
0	40
30	69.6
60	81.2
90	70
120	40.6
150	0.4

Angle	Dist.
0	57.1
30	79.5
60	80.5
90	60
120	23.4
150	−19.5

Angle	Dist.
0	74.6
30	89.6
60	80.6
90	50
120	6.0
150	−39.6

Hough



Streak Connector

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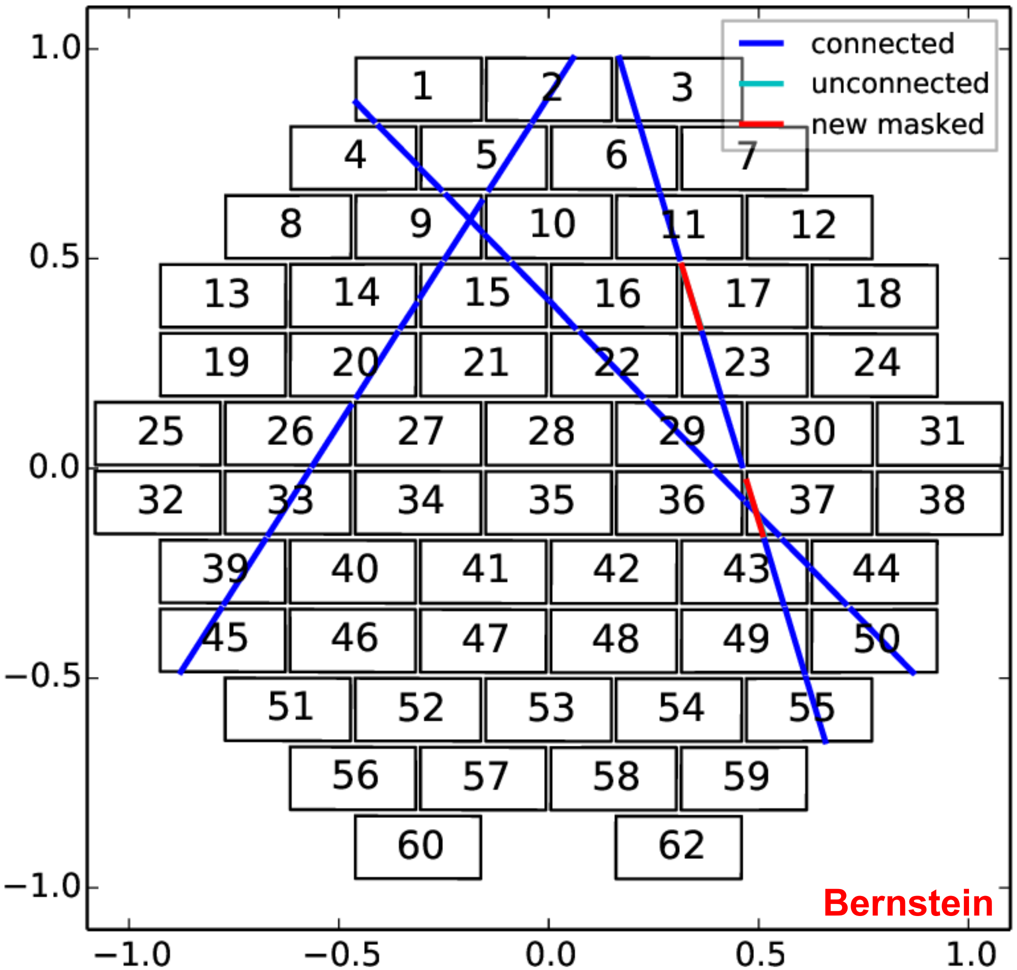

Streak detection algorithm is augmented by considering all streaks found across an exposure.

Interpolates/extrapolates mask to cover missed streaks on adjacent CCDs.

Single Epoch Cataloging

- PSF modeling through AstrOmatic PSFex
- Single Epoch model fitting using SExtractor provides single-epoch catalogs
- Currently, investigating use of PIFF to provide an alternative PSF model (compatible with MOF/SOF/shear afterburners)
- **Forward Global Calibration Module ~1 mmag rms**

Exposure Based Assessment

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FIRSTCUT → determine whether each exposure meets basic survey requirements/standards (should observing team reobserve).
FINACUT → determine whether each exposure meets basic requirements to be included in COADD

Primary decision based on the effective exposure time:

$$T_{eff} = (0.9\,k / FWHM)^2 \;(Bkgd_{dark} / Bkgd)\; (10^{-2\,cloud / 2.5})$$

$$= F_{eff} \times B_{eff} \times C_{eff}$$

Cutoffs for both survey (FIRSTCUT) and normal COADD (FINALCUT) are:

T_{eff} > 0.3 (riz-bands), > 0.2 (gY-band)

Further cuts can be placed based on individual components or other QA (e.g. astrometry, PSF, background, scattered light) to form input TAG for COADD or other analysis.

Y6A1 FINALCUT Campaign

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- DES survey (SV-Y6)
- DES SNe survey exposures (SV-Y5)
- Miscellaneous exposures
  - COSMOS (DES and community)
  - Alhambra Deep-2 and 8 fields (DES supplemental)
  - Community SNe exposures
  - DES-GW & ICECUBE follow-up exposures

Where:

- PSF/seeing < 2.0”
- Extinction (atmospheric) < 4.0 mag
- No known problems (e.g. telescope moving)

Total of 131,602 exposures:

- Processed O(2,000) exposures/day (many months)

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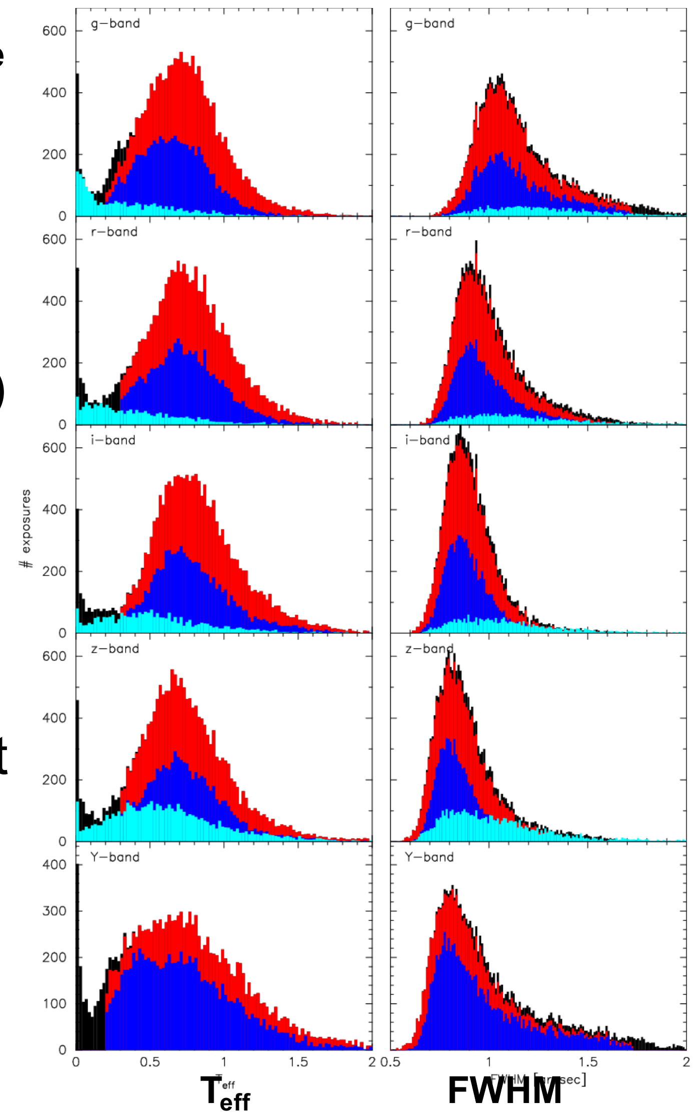
Y6A1 FINALCUT Campaign

All processable
Y6A1
Y3A2
supernova

Basic results:

- Total of 131,602 exposures
- 87,647 total survey
- 78,364 “accepted” survey (→Y6A1_COADD)
- 12,421 supernova field exposures
- 31,534 miscellaneous
  - photom-std, deep fields, related programs

- T_{eff} distribution has remained nearly constant from Y3A2→Y6A1
- Median FWHM < 1.0” except at g-band



COADD Pipeline

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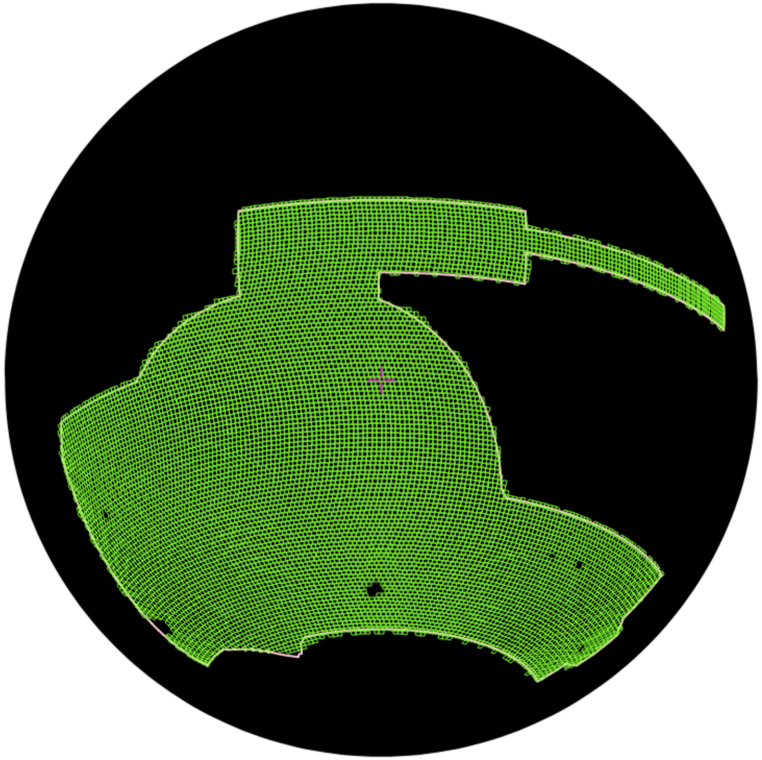
Operates on a per-tile basis:

Tiles are defined as:

- 10,000 x 10,000 (0.263”/pix)
- 43.8’ x 43.8’
- 0.53 sq deg / tile

Tiles overlap by 1’ with neighbors

- 0.485 sq deg unique area / tile



COAD Pipeline

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- Collect:
  - object catalogs from exposures that overlap a tile
  - images where QA met basic survey standards
  - photometric calibration (zero points) for input images.
- Astrometric Refinement
  - Simultaneous fit for all bands (SCAMP)
  - Apply WCS offsets and mask all known artifacts (weight→0)
- COADD
  - SWarp/combine (wgt-average per band) →coadd images
  - Make second version with background subtraction turned off
- Detection Image
  - Combine r + i + z band COADDs → “detection image”
- PSF model for each COADD image
- Catalog
  - Sextractor: flux, shape, position measurements based on “detection image”
- Systematics
  - Use Mangle to obtain depth and other systematics per location
- Produce MEDs: (snapshots from single-epoch for each object)

Coverage Check Prior to COADD

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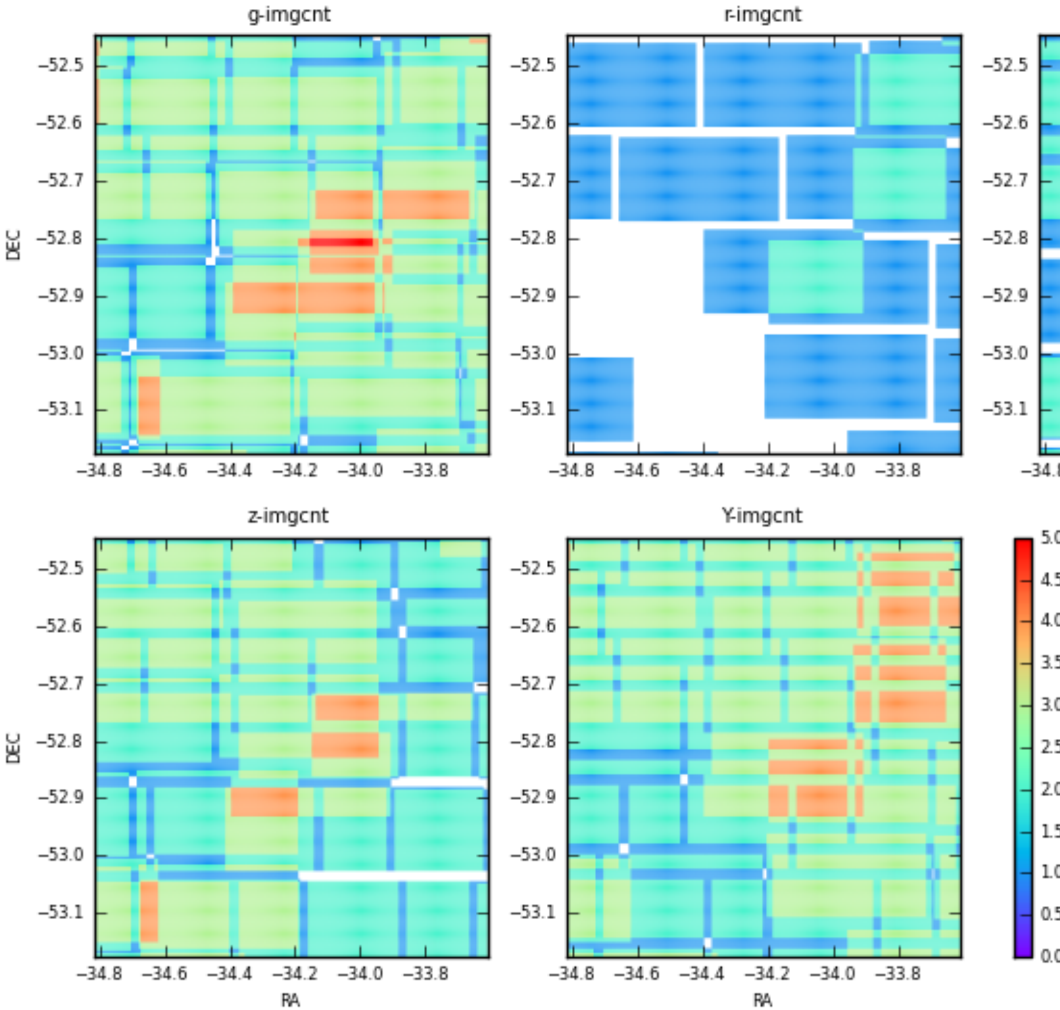

Tool developed to predict the detailed coverage/depth per band for each tile operates on an input tag.

Y6A1 COADD Footprint (Y1-Y6)

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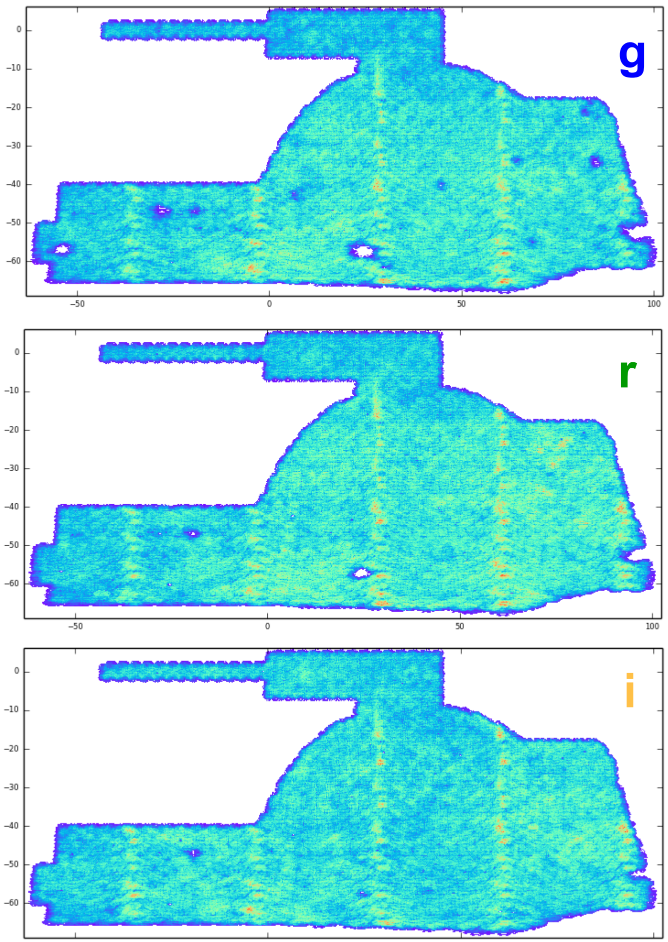

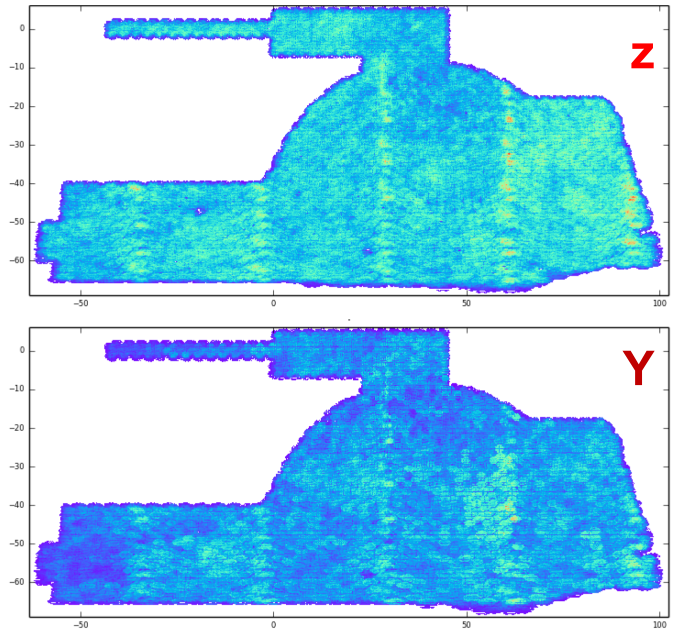

- 78,364 exposososures
- contribute to 10,167 Tiles
- where *grizY*-bands >30% coverage at depth=3

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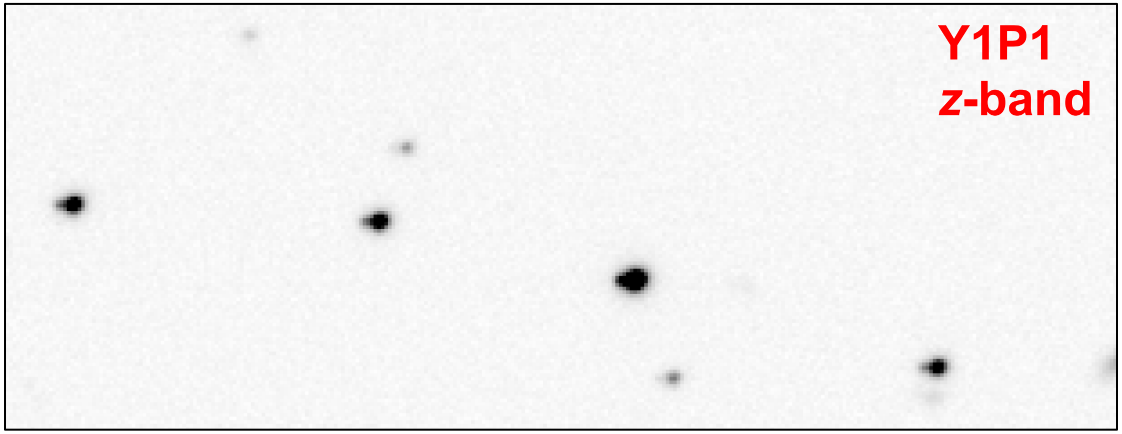
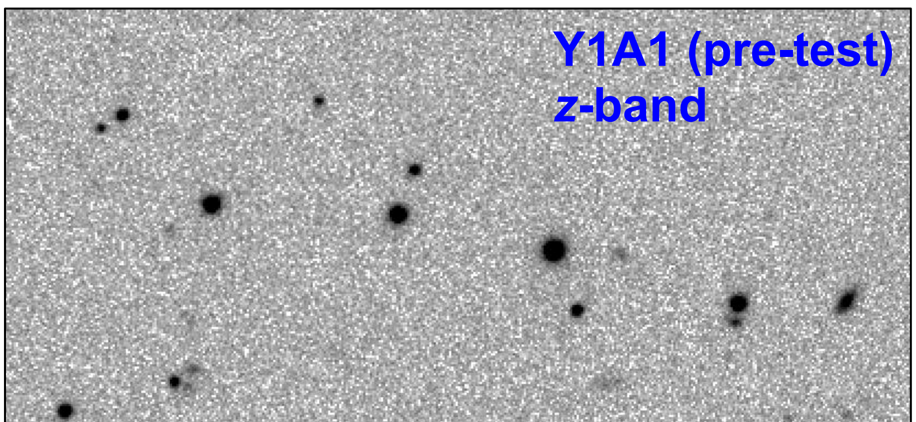
Astrometric Refinement for COADD





Photometric Calibration

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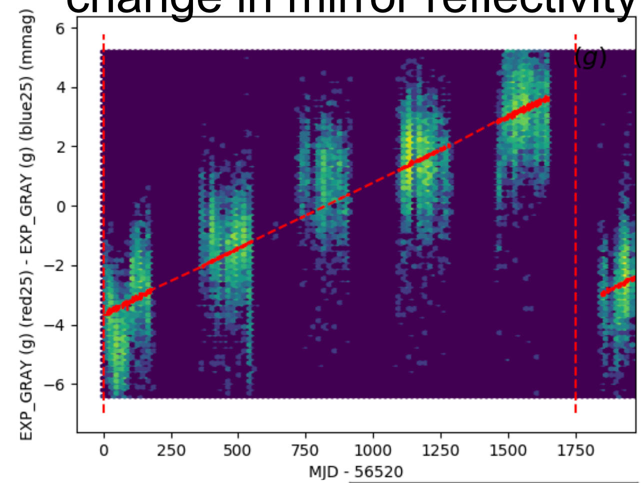
Final crucial ingredient photometric calibration!

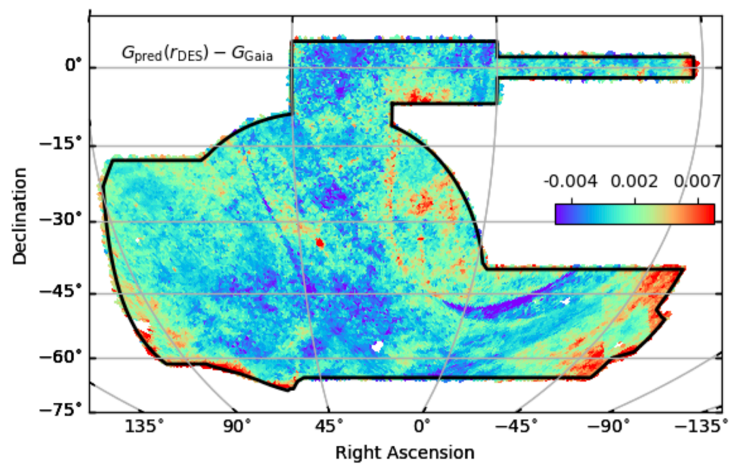
- Y1: GCM → 2-3 percent
  - Based on tertiary standards
- Y3 later: FGCM → sub-percent accuracy
  - Telescope + atmosphere
  - Bootstrap to non-photometric nights

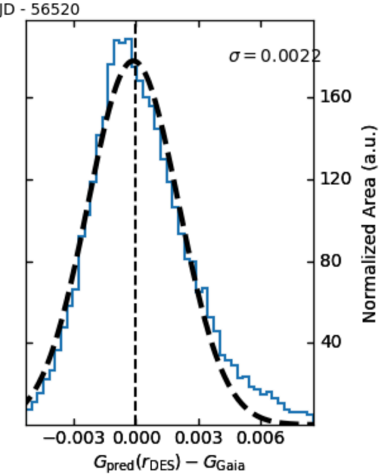
change in mirror reflectivity



Current FGCM calibration encompasses Y1-Y6 for all survey and SN exposures with good quality assessments.

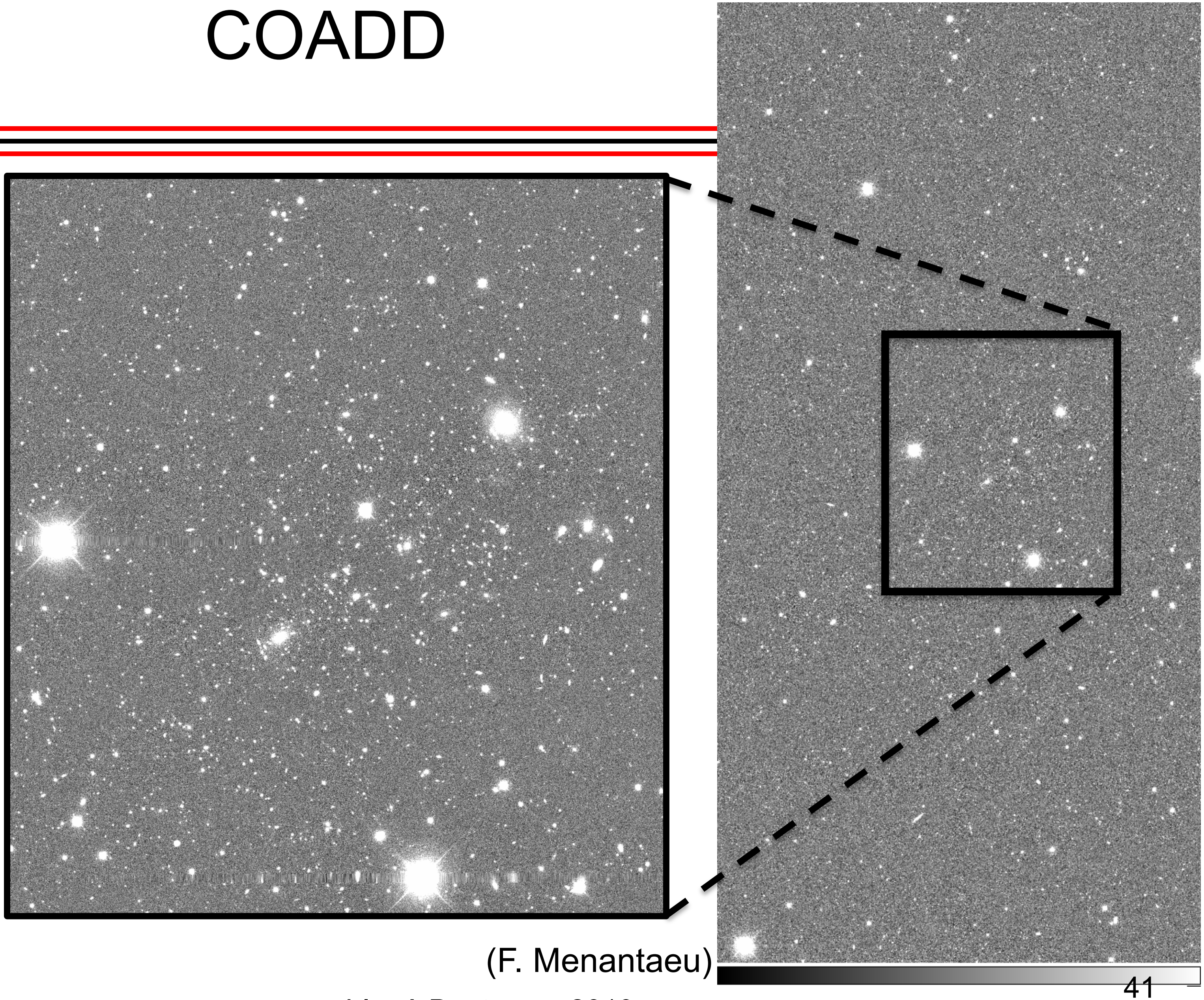
All other exposures (note this includes both miscellaneous and “special” data (e.g. u-band) will eventually be calibrated through a bootstrap from tertiary standards by PGCM.





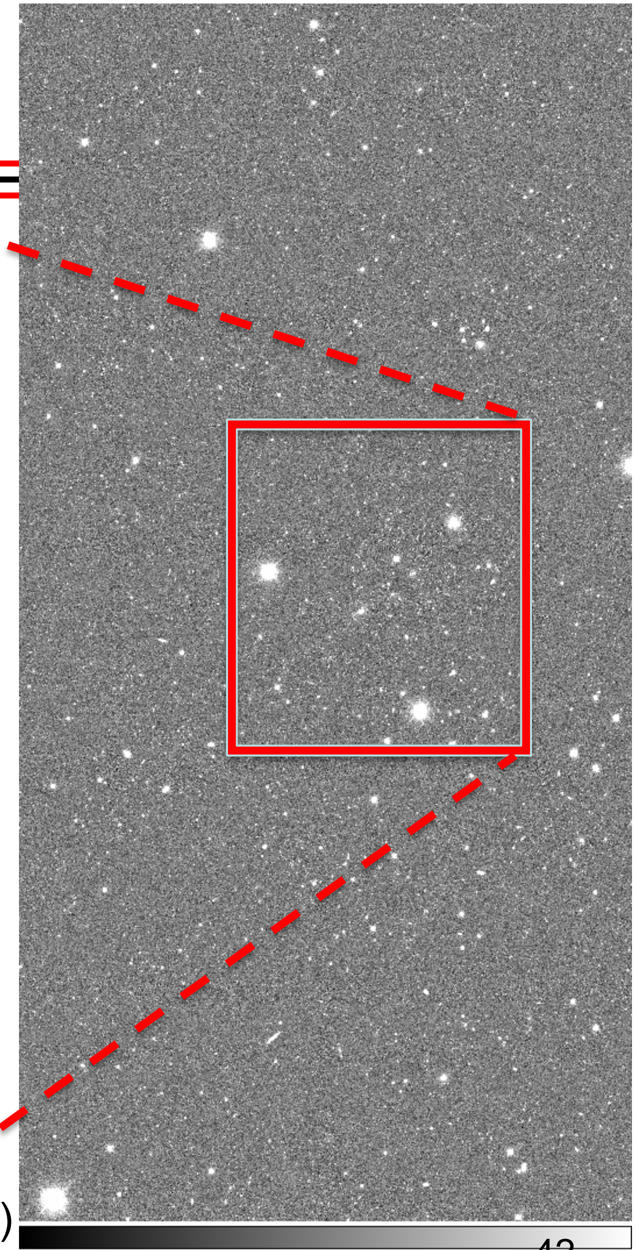
Rykoff & Burke

COADD



(F. Menantaeu)

COADD



(F. Menantaeu)

COADD Products: Mangle

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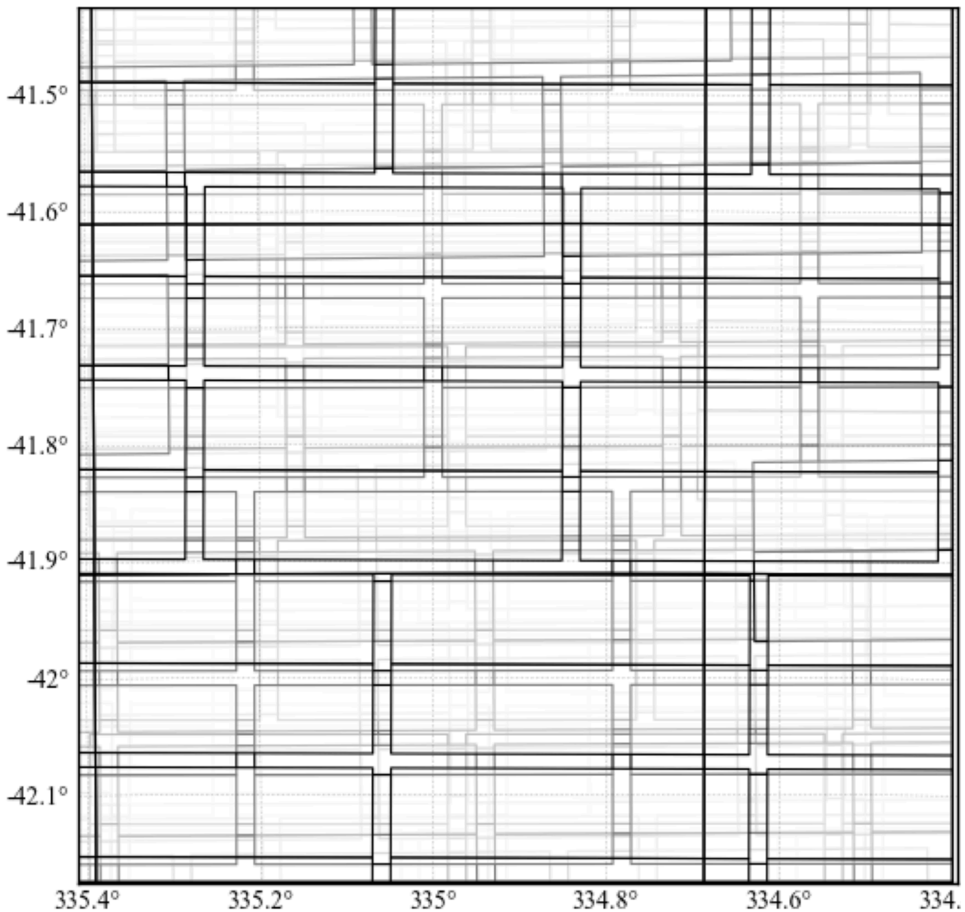


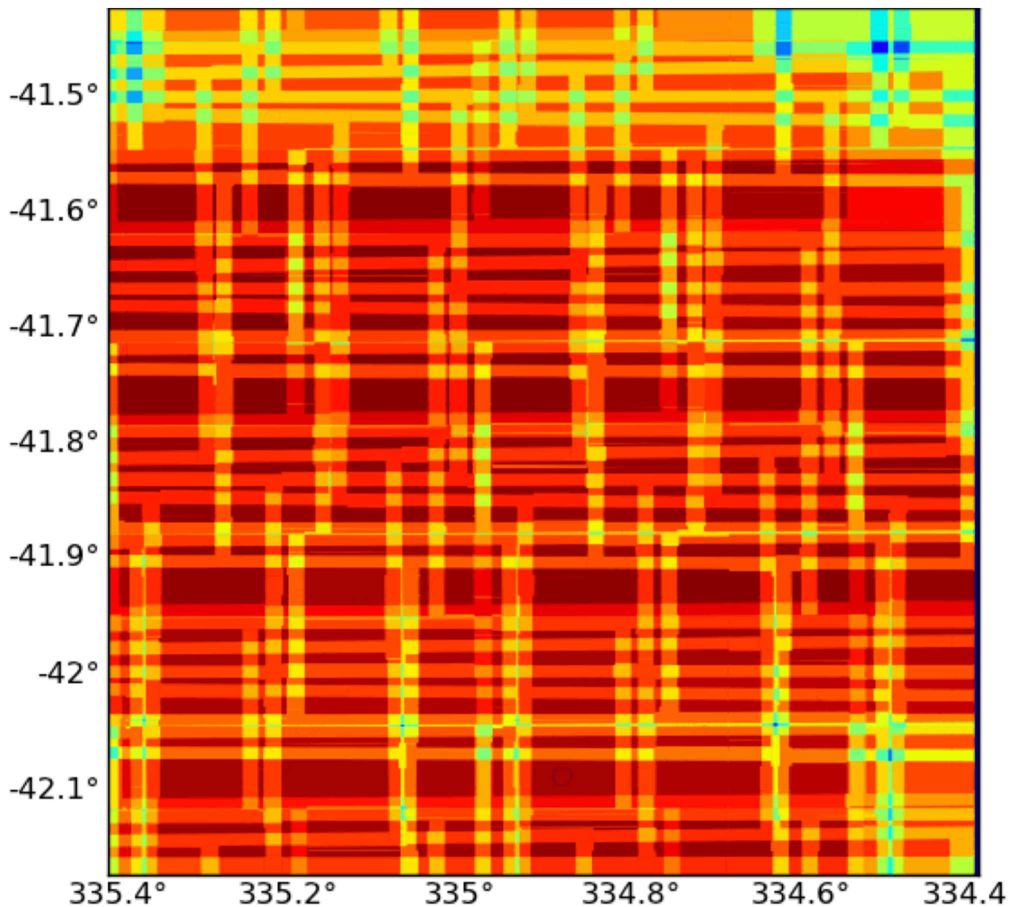
Swanson, Benoit-Levy

Goal is to keep track of data systematics across the survey. Within a COADD such items are linked back to the constituent observations (images) that were combined

Step 1: Render each amplifier's footprint as a polygon.

COADD Products: Mangle

DARK ENERGY SURVEY

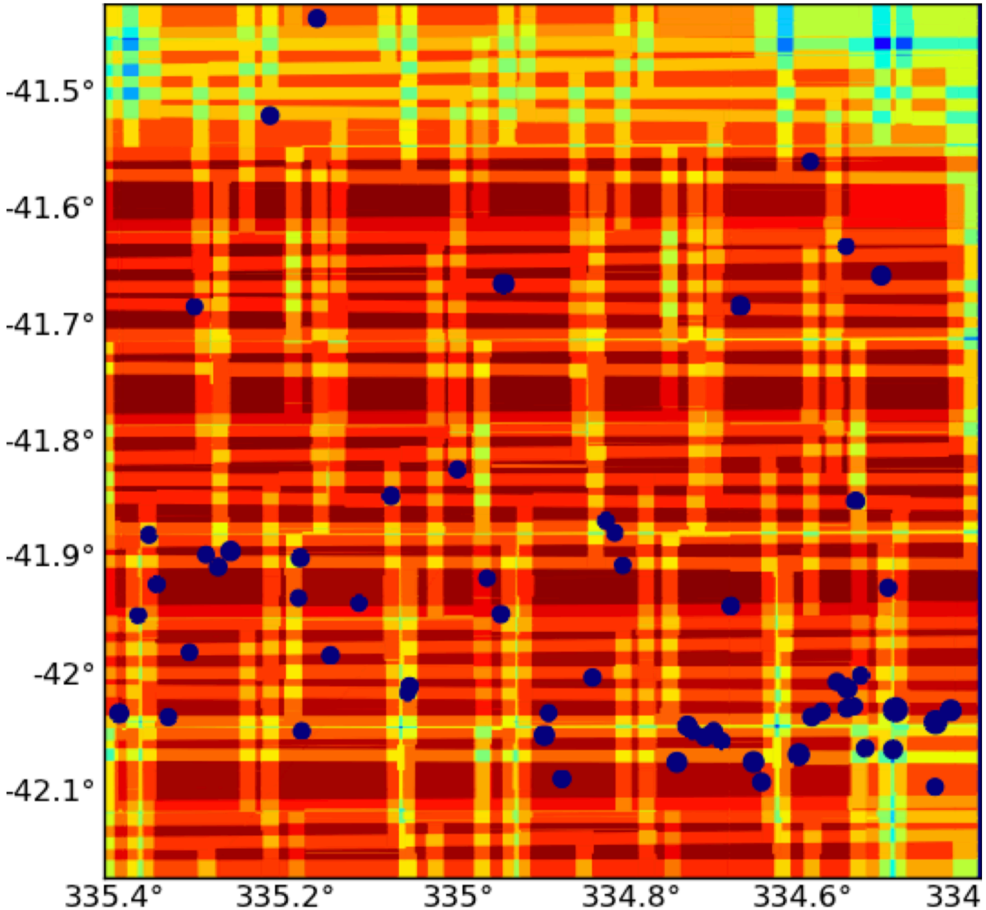


Swanson, Benoit-Levy

Step 2:

Find intersection of all polygons to define polygonal area with a common set of observations.

COADD Products: Mangle

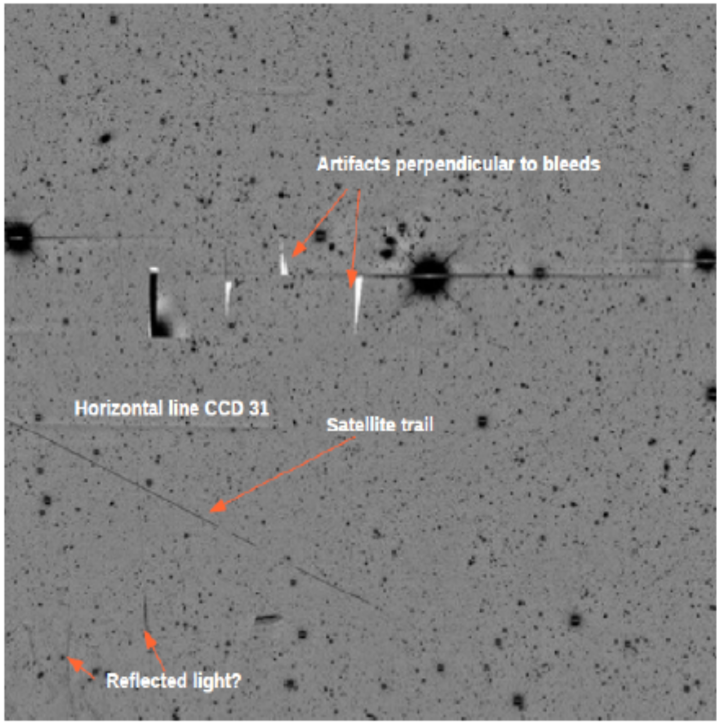


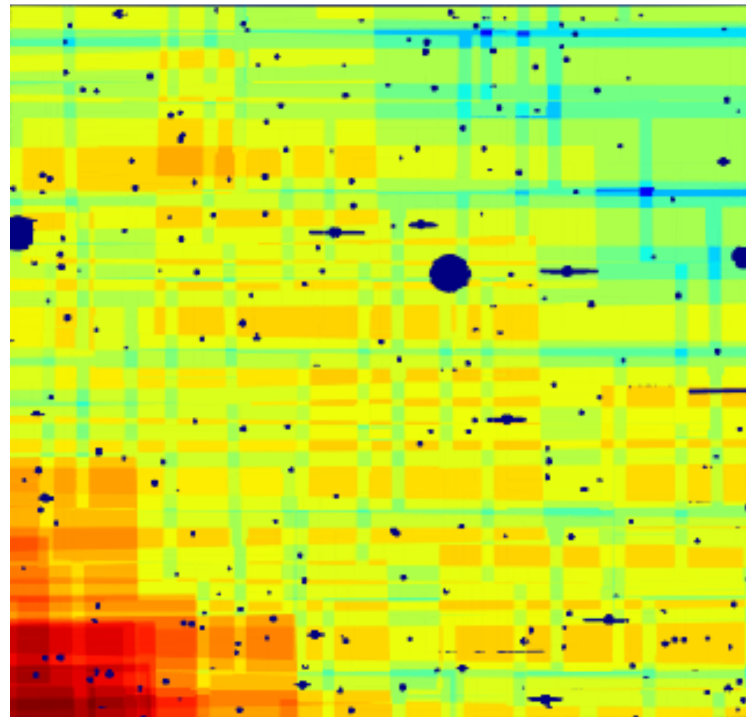
Swanson, Benoit-Levy

Step 3:

Remove areas that are systematically biased or masked (e.g. bright stars)

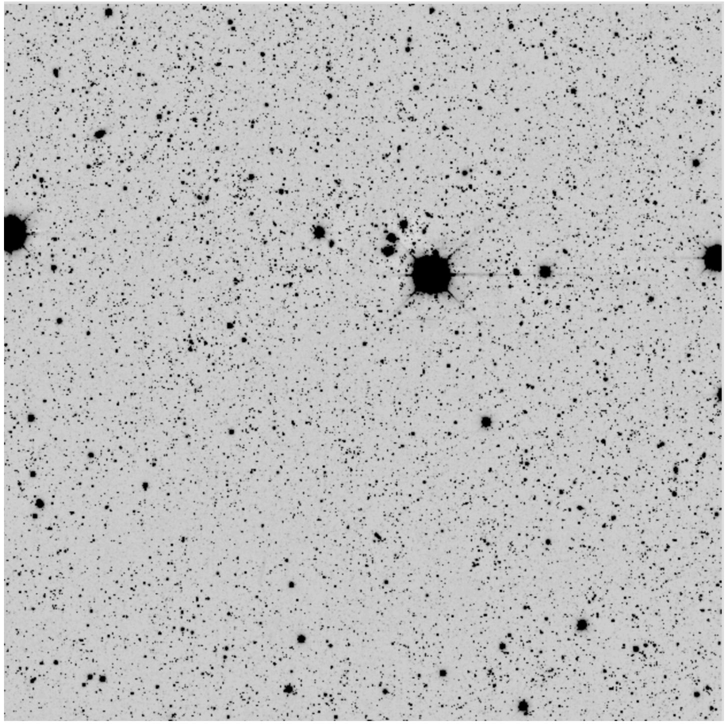
COADD Products: Mangle

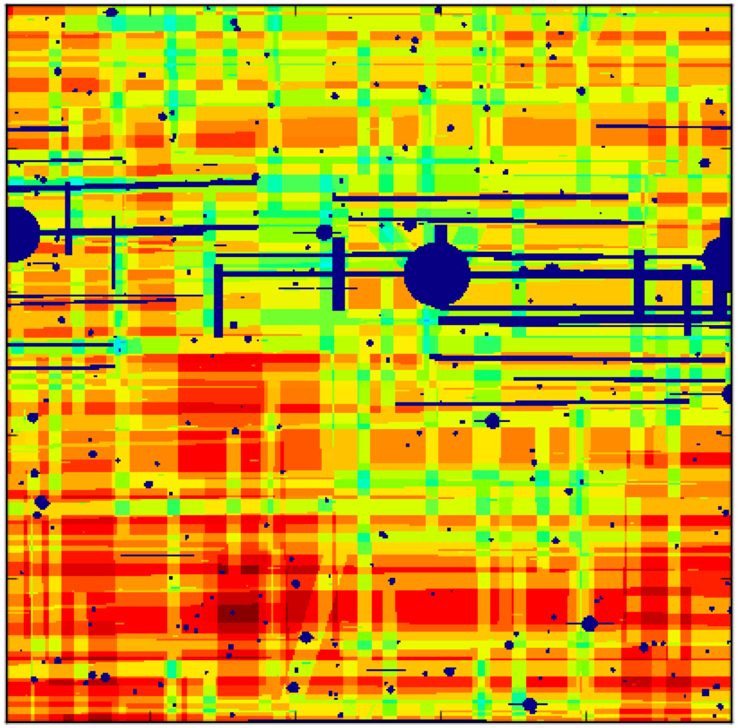




Example from Y1 (note unmasked edgebleeds)

COADD Products: Mangle





Same tile from Y6

COAD Products: DeepFields

DARK ENERGY SURVEY

COADD Products: DeepFields

COAD Products: DeepFields

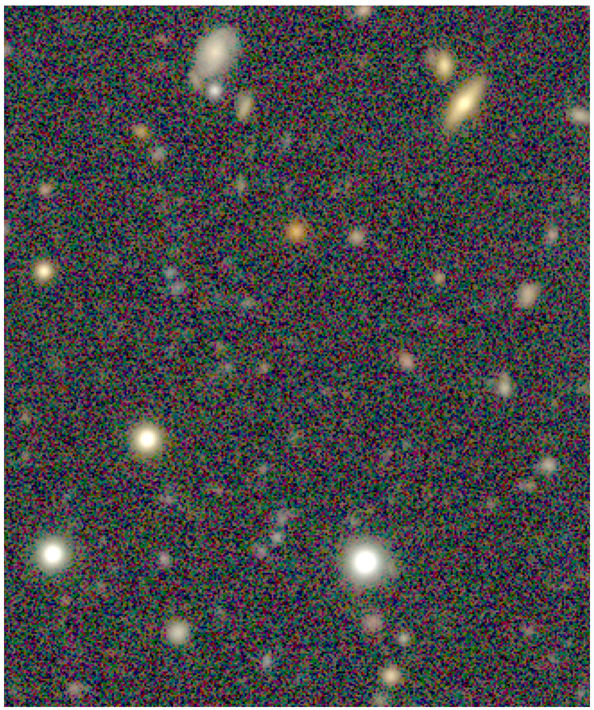
COAD Products: DeepFields

COAD Products: DeepFields

COADD Products: DeepFields

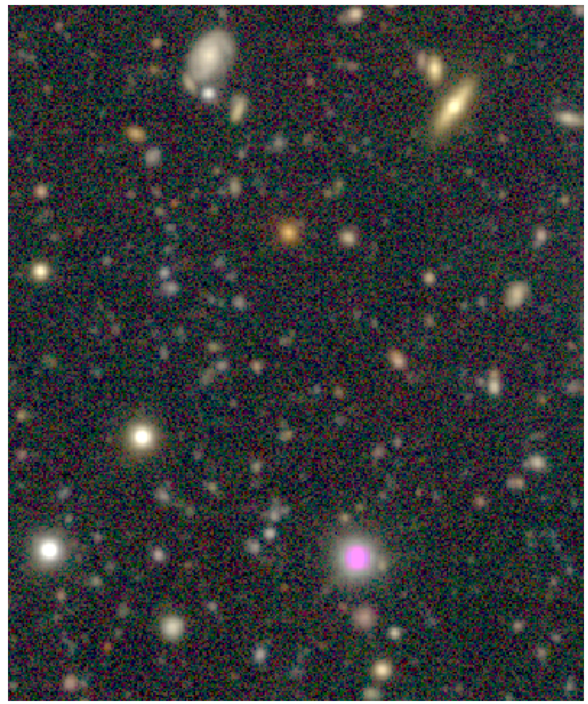
DARK ENERGY SURVEY

Y6A1 (survey depth)



~10 x SE depth
~1 x coadd depth

Y3A2 COADD_TRUTH



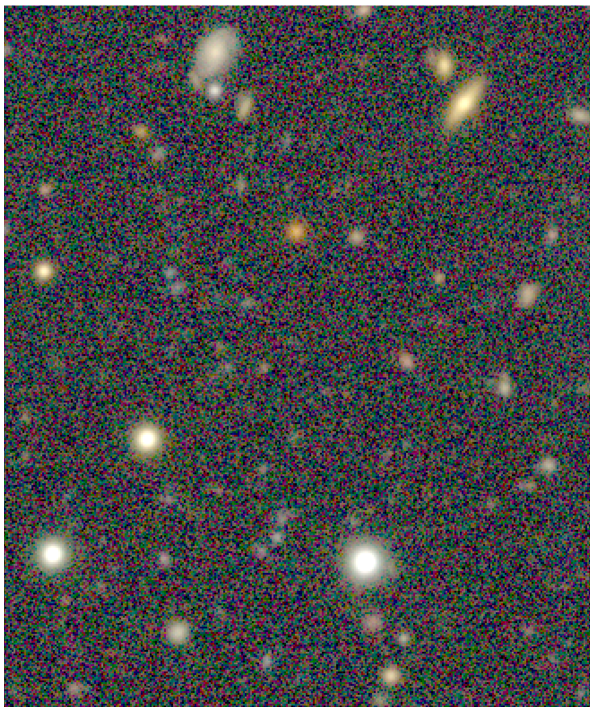
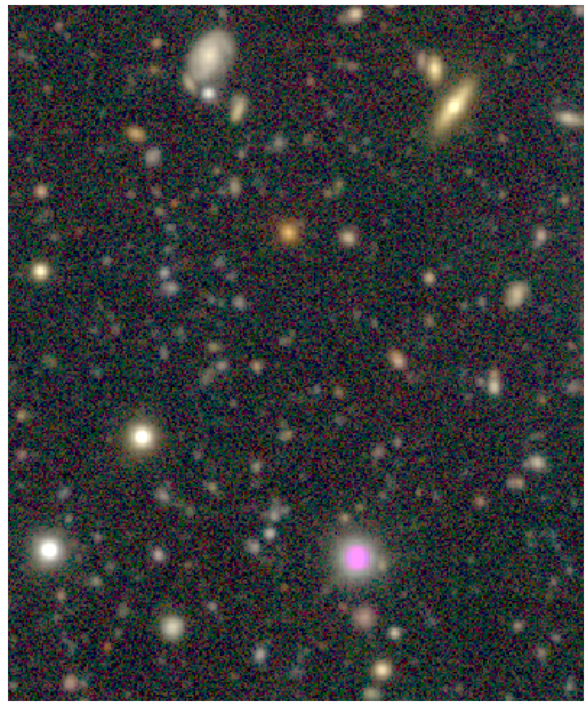
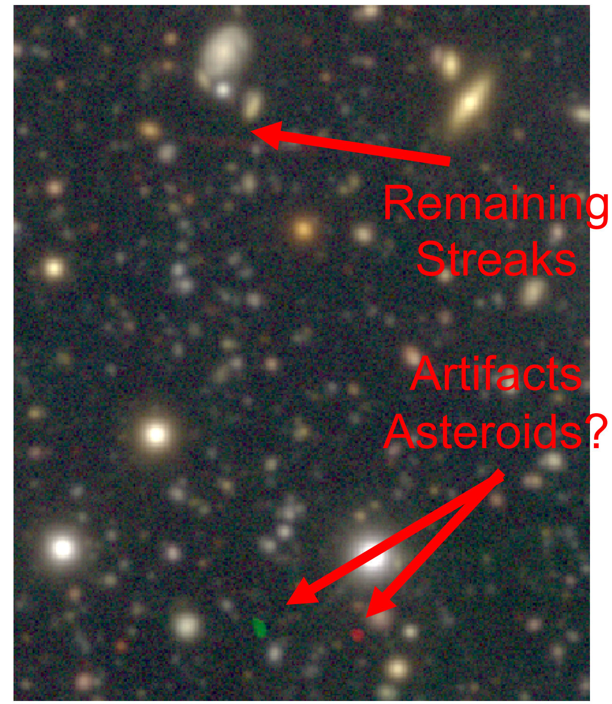
O(80-100) x SE depth
10 x coadd depth

Y3A2 DEEPEST

O(3000) x SE depth
~300 x coadd depth

DARK ENERGY SURVEY

Why you might yet

Y6A1 (survey depth)	Y3A2 COADD_TRUTH	Y3A2 DEEPEST
		
~10 x SE depth ~1 x coadd depth	O(80-100) x SE depth 10 x coadd depth	O(3000) x SE depth ~300 x coadd depth

Why you might yet see a Y6A2 COADD

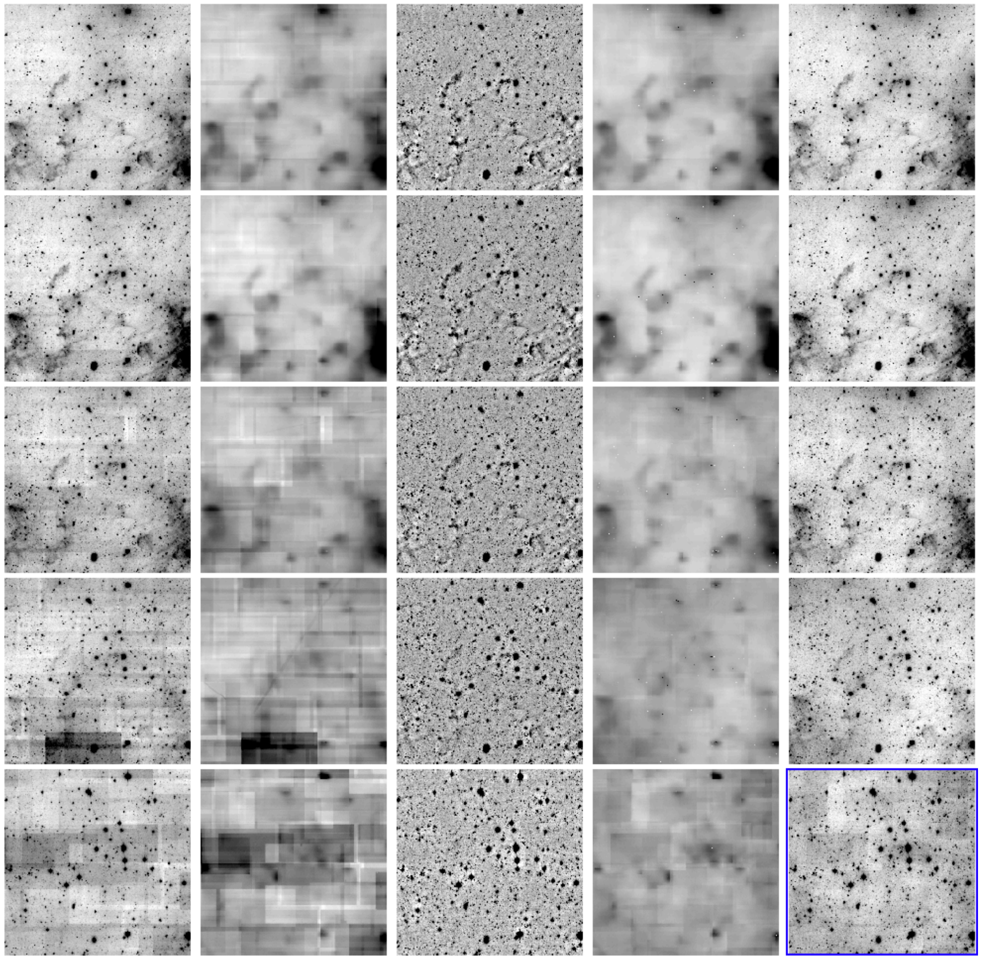
DARK ENERGY SURVEY

SWarp background subtraction ON

SWarp background subtraction OFF

Why you might yet see a Y6A2 COADD

DARK ENERGY SURVEY



Currently catalogs use **ON**

- This tends to misestimate background near bright extended sources (galaxies, clusters, cirrus)

Switching to **OFF**

- Imprints residual single-epoch background which has sharp discontinuities!

New algorithm (in progress)

- Attempts to find the middle-ground by solving for and remove the remaining single-epoch background prior to COADD

How to Access the Data

FIN

Unspoken Thoughts

COAD Products: DeepFields

DARK ENERGY SURVEY

COAD Products: DeepFields

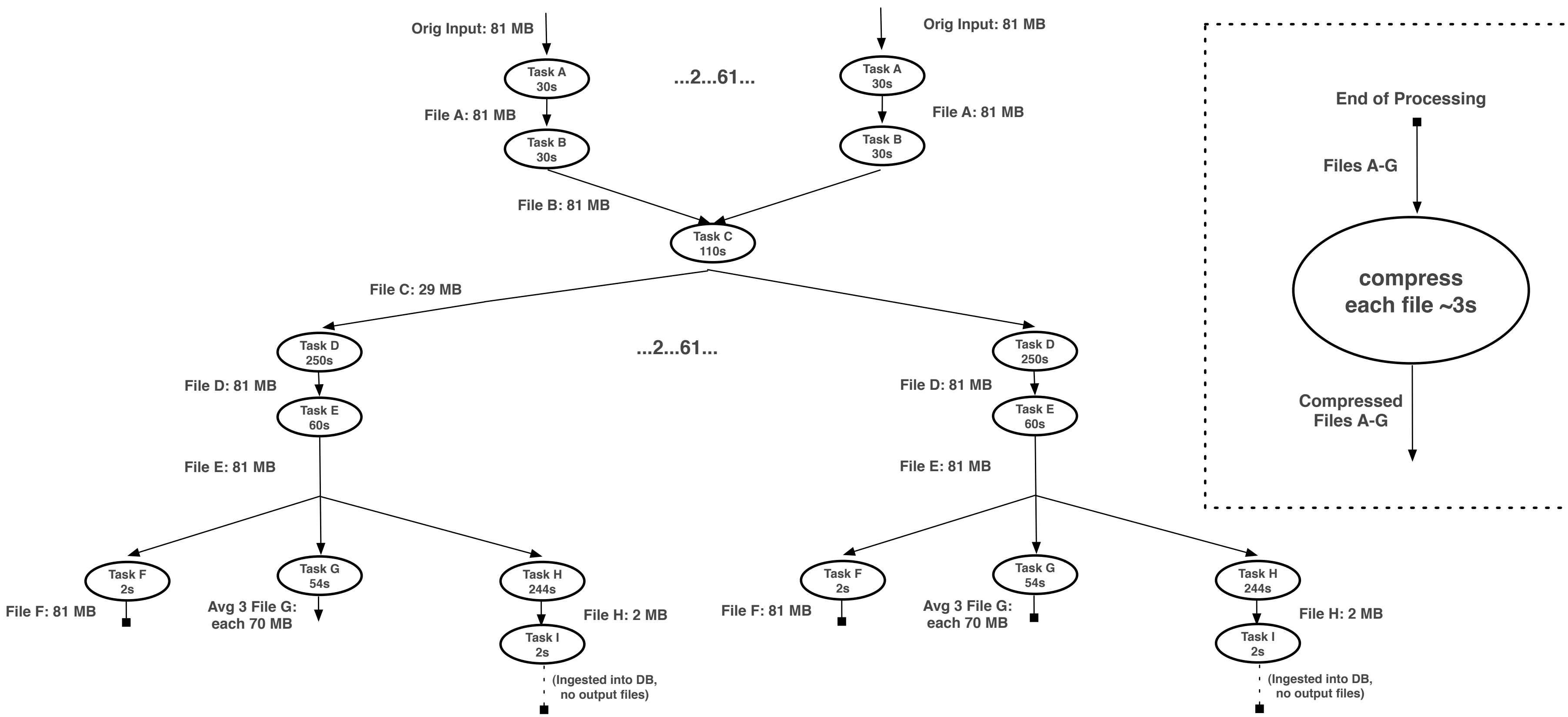
COAD Products: DeepFields

Example for Execution Paths

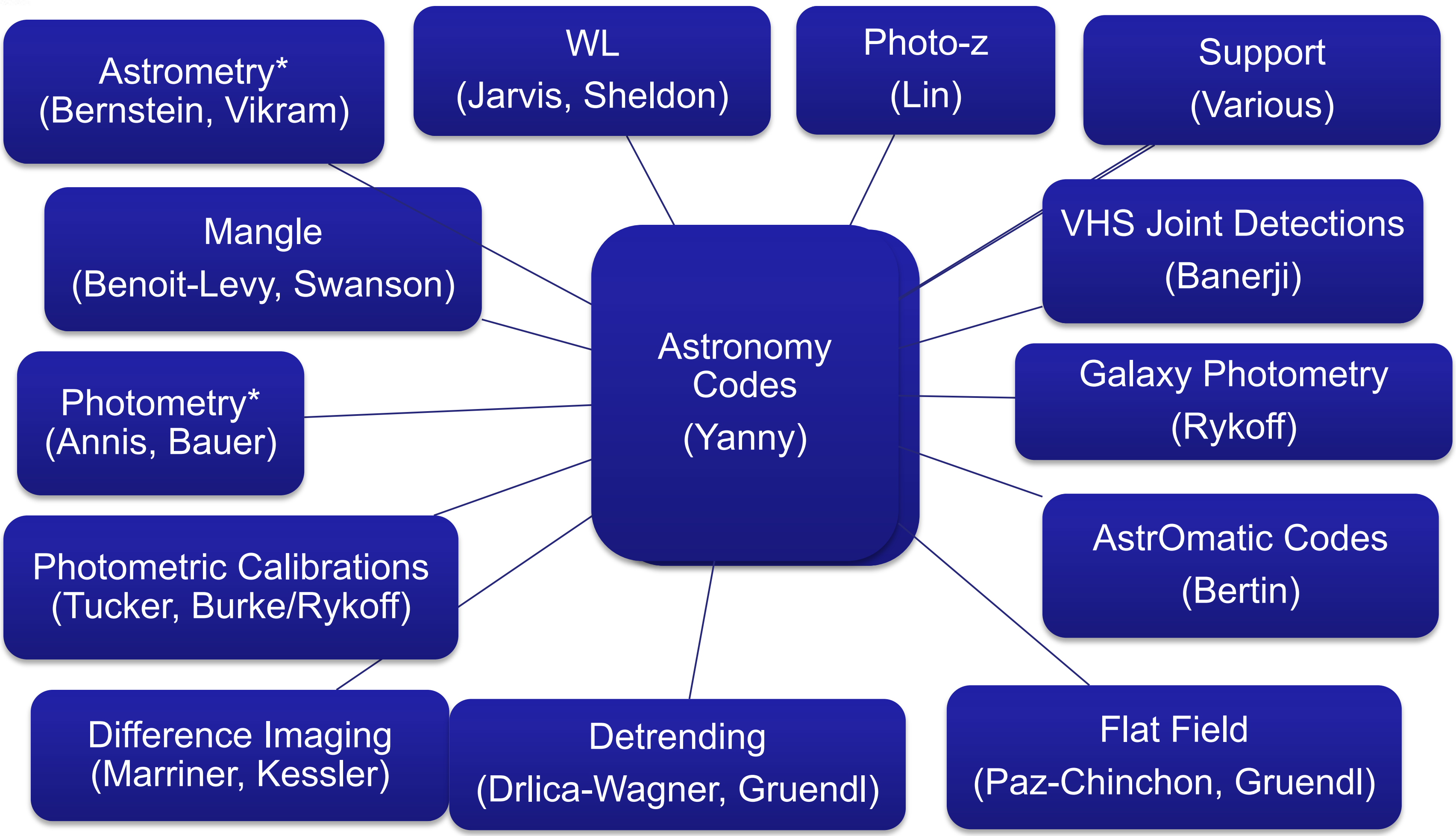
DARK ENERGY

FinalSE Pipeline

All numbers are estimates with some more accurate than others
Codes use less than 2G memory (Most less than 1G)
Extra calibration files not illustrated ~18G total
Misc smaller output files not illustrated
62 pieces almost independent trivially-parallel pipelines (exception task C)

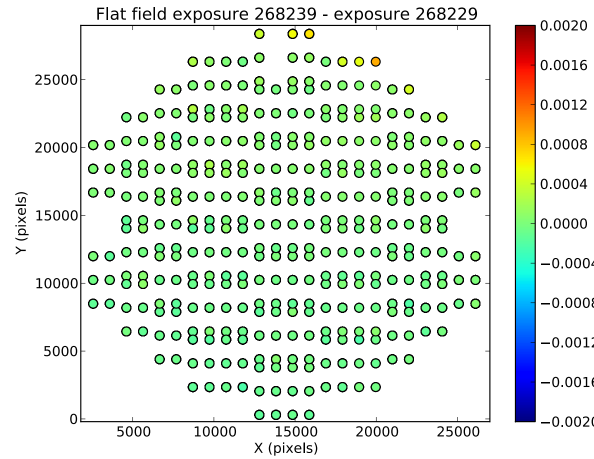


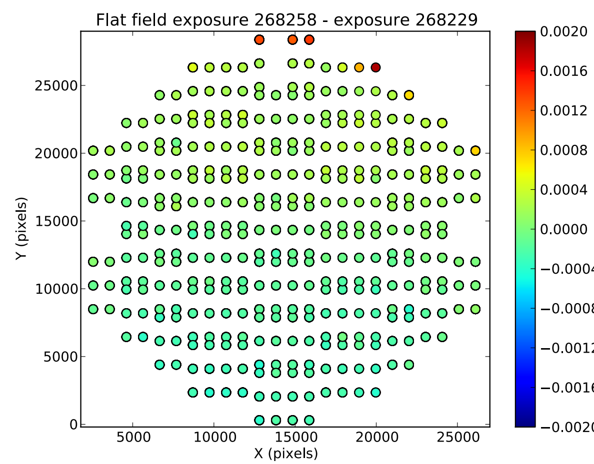
Distributed Development



Intentional Dome Misalignment: ~2 mmag effect

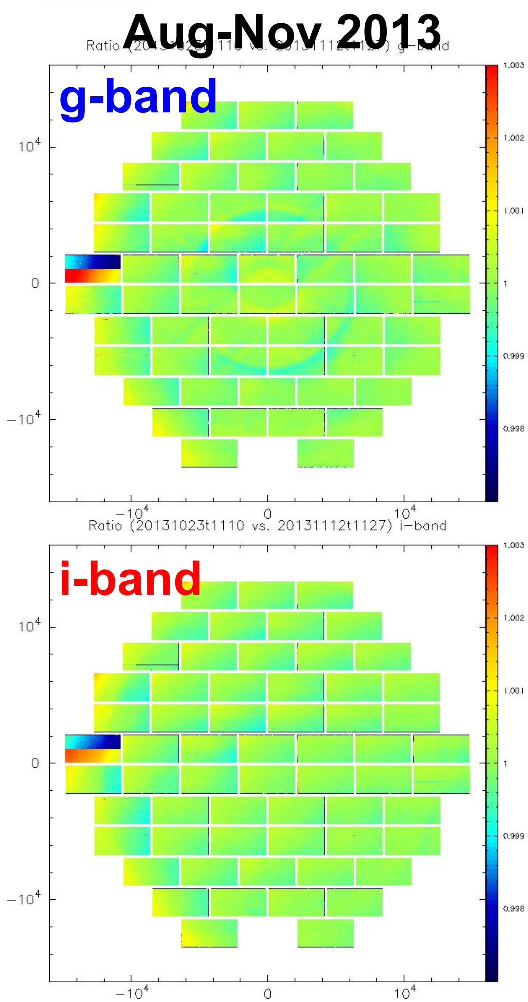
DARK ENERGY SURVEY





Experiment by
G. Bernstein and
D. James

Flat Field Monitor



± 0.5%

Loss of CCD#2
+
Degrading output of blue Lamps
+
Identified projector lamp misalignment