Overview of Calibration in EXT: EXT-DES Pipelines

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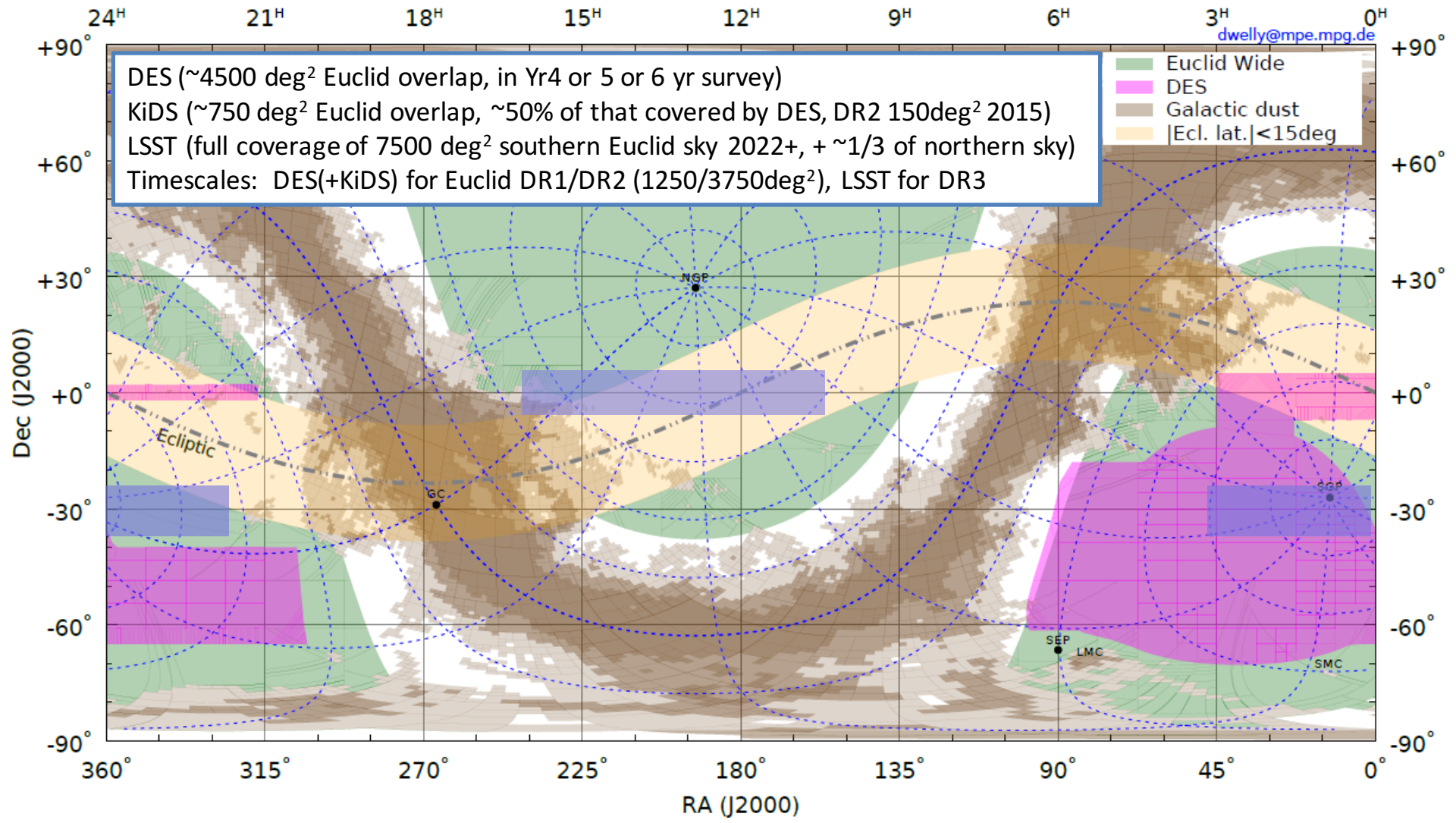
OU EXT Structure

- EXT consists of four PFs
  - Ground based datasets (for photo-z's and stellar colors)
  - Space based datasets (HST, Gaia RP/BP, WISE)
  - Spectroscopic calibration datasets (archival and new)
  - External catalogs (Gaia astrometry, 2MASS, etc)

- Multiple ground based dataset required- each with dedicated OU-EXT team
  - DES- Munich/MPE (see also Mohammad's talk)
  - KiDS- Gröningen (see Gert's talk)
  - CFIS- FR/CA (see Jean-Charles' talk)
  - LSST- FR/US/UK/DE/??+ (TBD)

Story of the Euclid Southern Sky: DES, KiDS, LSST



June 2016 status, courtesy Mohr/Dwelly/Scaramella

Requirements and Task Overview for OU-EXT

Preparation of optical data needed for PSF's and photo-z's

- Quantitative requirements:
  - Photometric zeropoints must be stable over the sky at the 1% level
  - Colors must be stable to 0.2% over scale of Euclid FOV

- Tasks:
  - Detrend, photometrically and astrometrically calibrate single epoch images, ingest them in the EAS
  - Recalibrate astrometry to the VIS sky (which is in turn calibrated to Gaia)
    - This is a "catalog operation" which results in an updated WCS solution for each single epoch image (has implications for our DM and design of EAS)
  - Build a coadd image using all recalibrated, overlapping single epoch images and feed these griz images into MER (perfectly aligned with similar imaging from VIS and NIR)
    - If MER adopts a single epoch simultaneous cataloger then coadds might not be needed

PF1: EXT-DES (and Prototype)

Pipelines for processing and calibrating DES data

- Calibration pipeline
  - produces flat field corrections, bias corrections (crosstalk coefficients, star flat corrections, pixel area corrections)
- Single epoch pipeline
  - detrends, astrometrically calibrates, models PSF and catalogs using PSF corrected model fitting with SExtractor
- Photometric calibration pipeline
  - Determines relative photometric calibration using catalogs from single epoch pipeline
  - Determines absolute photometric calibration using external prior (stellar locus, Gaia)
- Masking and Coadd pipeline
  - Produces PSF homogenized, median combined coadds with PSF corrected model fitting catalogs
  - Uses the coadd model components to identify and mask all transient defects in the single epoch images
  - Produces new version of coadds using inverse variance weighted mean for data validation
- All* pipelines fully Euclidized and can be installed on any SDC
  - No "Legacy Information System" components
  - Same pipelines can be orchestrated within LIS we call CosmoDM

* Masking pipeline prototype being tested in CosmoDM framework now

“Nightly” Calibration Pipeline

- Each afternoon DECam acquires 10 bias frames and 10 dome flat frames for each band

- Biascor produced for each CCD
  - Mean combination of overscan corrected bias frames
  - Weight map encodes inverse variance around mean

- Flatcor in each band produced for each CCD
  - Median combination of modally scaled, overscan and biascor corrected dome flats
  - Weight map encodes combination of Poisson noise + biascor noise

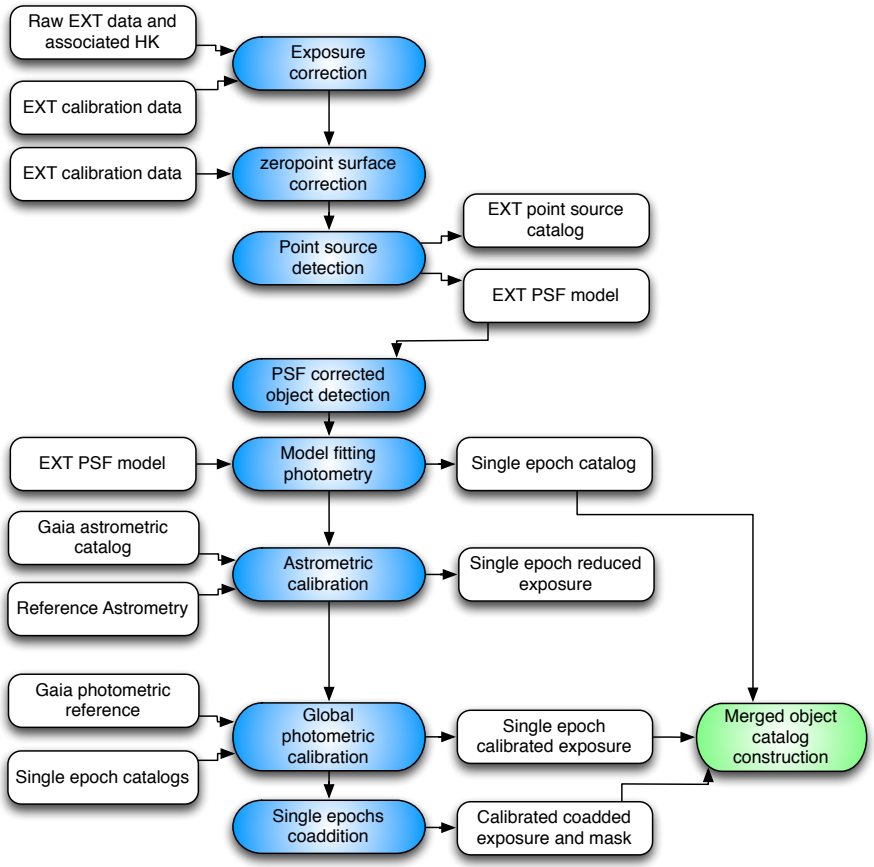
- BPM for each CCD is produced through thresholding of biascor’s and flatcor’s

- Instrument is stable enough that biascor’s and flatcor’s can be produced using *combinations of nights*

- No “sky flats” needed (or desired)

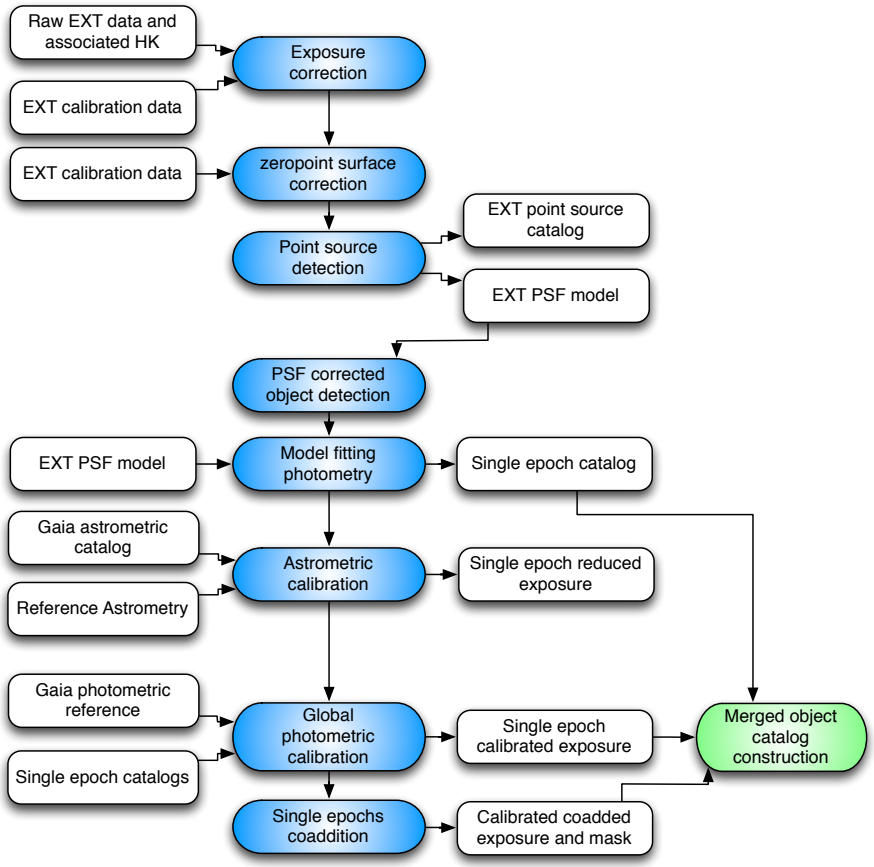
Single Epoch Pipeline (1 of 2)

- DECam exposure X-talk and overscan corrected into 62 CCDs
  - Weight map is Poisson noise
- Corrections applied
  - Biascor and flatcor
  - ZP Flattening corrections
    - Pixel scale correction
    - Starflat correction
- Astrometric correction (SCAMP)
  - Catalog with SExtractor
  - Use overlapping 2MASS cat (Gaia)
    - ~2000 stars w/ 2MASS
  - Use pseudo-catalog (~20000 stars)
  - Solve for 3rd order distorted FP WCS
    - 30 param x 62 CCDs ~ 2000 free P's



Single Epoch Pipeline (2 of 2)

- Model varying PSF (PSFEx)
  - Catalog with Sextractor
  - Fit 2nd order PSF for each CCD
- Model fitting photometry
  - SExtractor 2.x (3.x soon…)
  - PSF model and SE image input
  - PSF corrected model fitting photometry of each image
    - PSF fitting stellar photometry
    - Excellent star-gal separation
    - PSF fitting astrometry
    - Galaxy model (Sersic or B+D)
    - -Model image allows quality check



Photometric Calibration

- Goal is to solve for one number for each photometrically flattened CCD image in the SE dataset
  - SE catalogs output from SE Pipeline are inputs to photometric calibration
  - Can be done for whole survey or for some sky location (i.e. coadd tile)

- (Relative) Photometric calibration
  - Find all overlapping CCDs
  - Use stellar photometry to measure ZP difference and uncertainty
  - (Use direct ZP constraints from Gaia)
  - Put all constraints into giant least squares solver
  - Results allow all CCDs within band to be brought to the same system
    - Assumption is that the filter curves don't vary with position

- Can use stellar locus and 2MASS to determine absolute zeropoints
  - Requires assumption about stellar populations, not adequate for Euclid

Masking and Coaddition

- Build median combine, PSF homogenized coadd tiles in each band and extract PSF corrected catalog
- For all overlapping SE images
  - "Transfer" pristine coadd catalog to SE image with variable PSF
  - Identify/mask all features in image not in model
  - See details in Desai, JM et al. 2016

- Rebuild and catalog coadds using masked images
  - Update astrometry using stacks of overlapping exposures
  - Create inverse variance weighted combine coadds (with or without homogenized PSF)
  - Catalog to determine PSF corrected model fitting photometry (-MODEL image for quality check)

- Same Euclidized pipeline available for MER use (if needed)

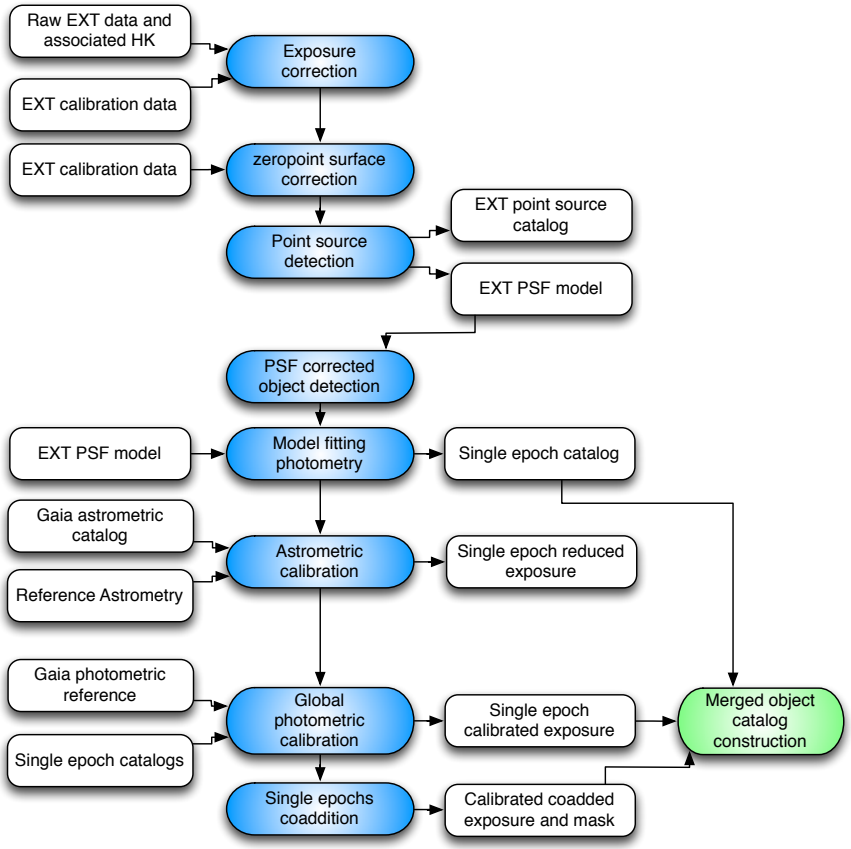
Single Epoch Campaign on DES-Year 1 Dataset with Prototype

- Dataset – 16TB, ~2500 deg^2
  - 25384 science exposures (+flats/biases)
  - 1.6M 2kX4k processed, astrometrically calibrated images w/ PSF models & PSF corrected model fitting photometry
  - 1.9B objects cataloged/ingested
  - Next step: photo-cal & coadd

- Processing Times- EXT prototype
  - ~2 weeks and 300000 core-hours
  - Each exposure takes ~10 min start to finish on single node (32 cores, 64GB RAM)
  - Nites processed typically on ~60 nodes/2k cores simultaneously

See also Hennig, JM+ 2016

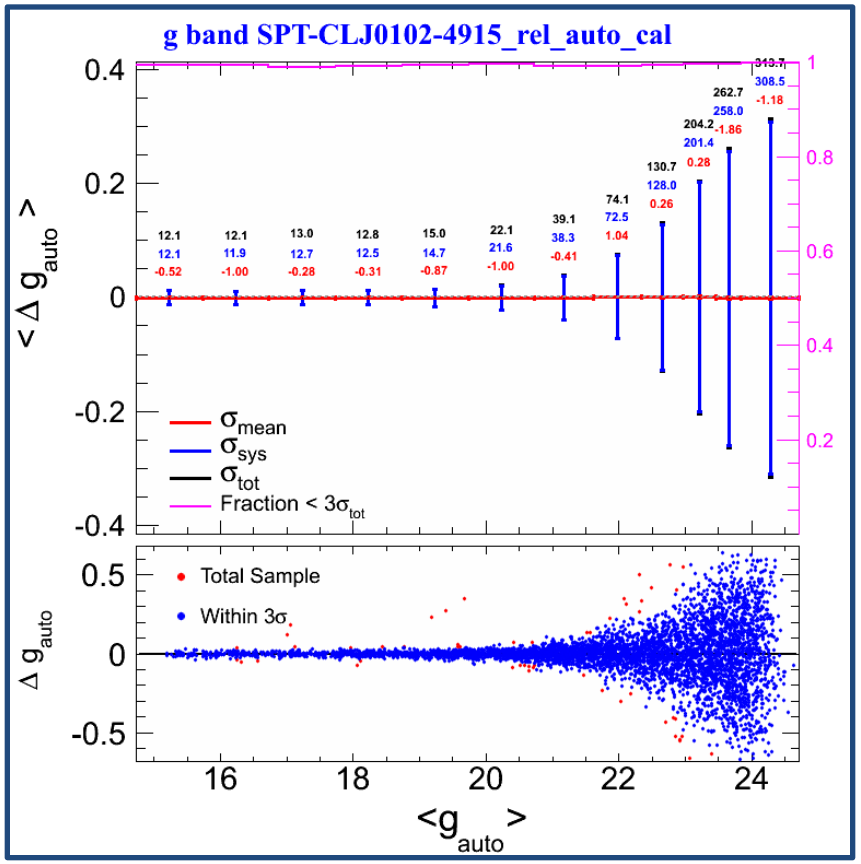
EXT Processing Data Flow

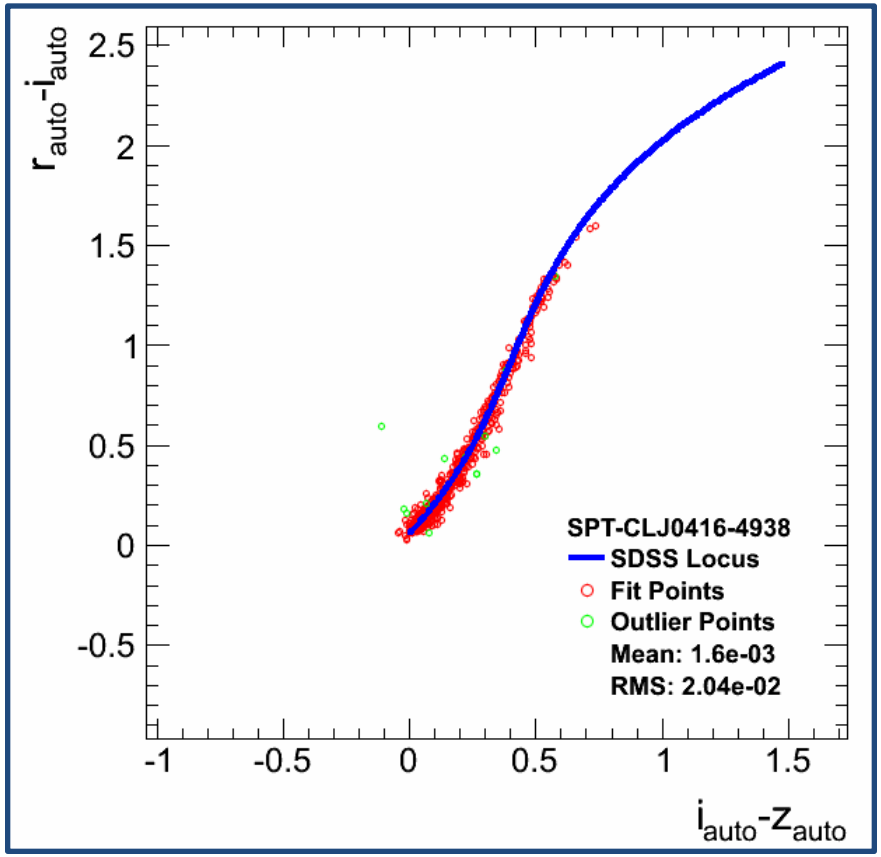


PF1: EXT-DES Prototype Data Quality (1/6)

Repeatability of stellar photometry, Stellar locus scatter

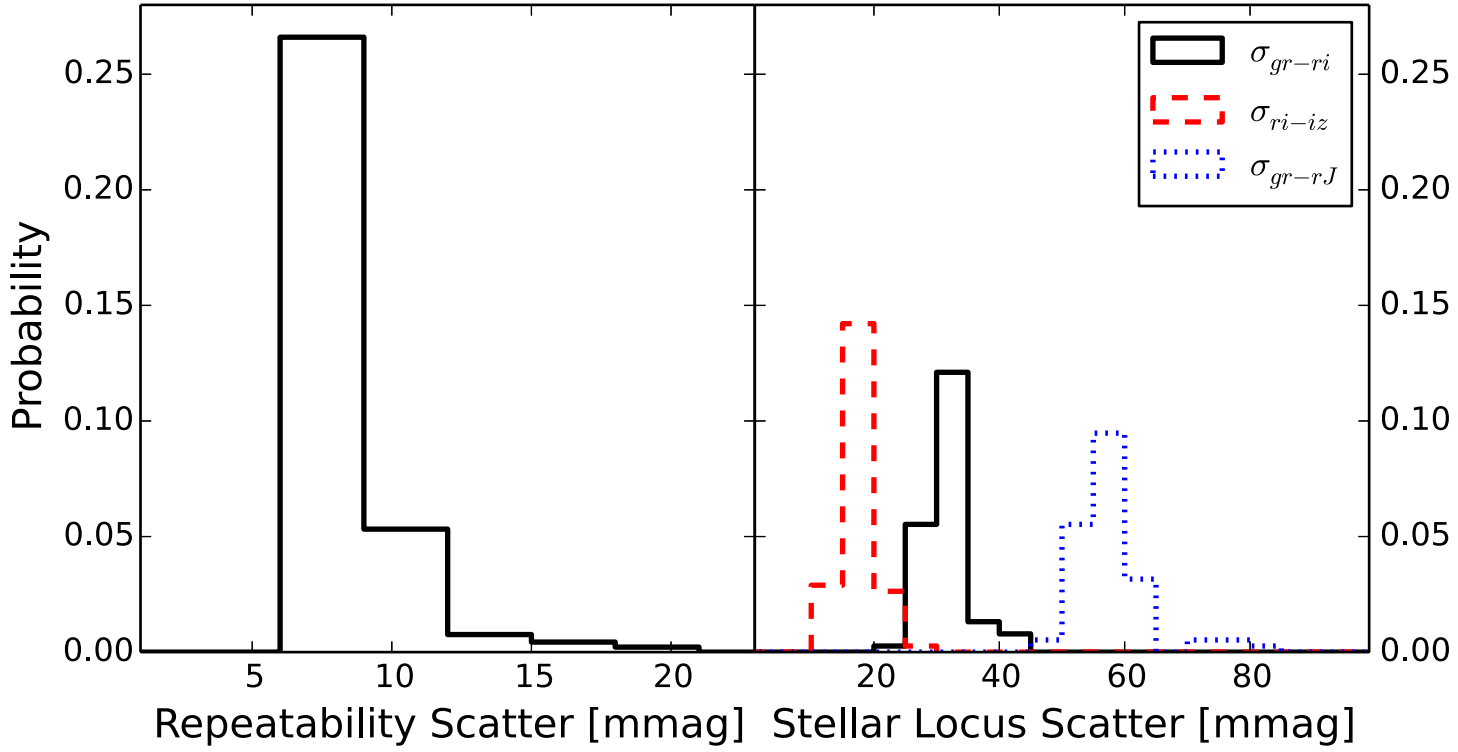
- Typically use mag_psf (PSF fitting magnitudes) in these studies now, but mag_auto can also be used





Repeatability of stellar photometry, Stellar locus scatter

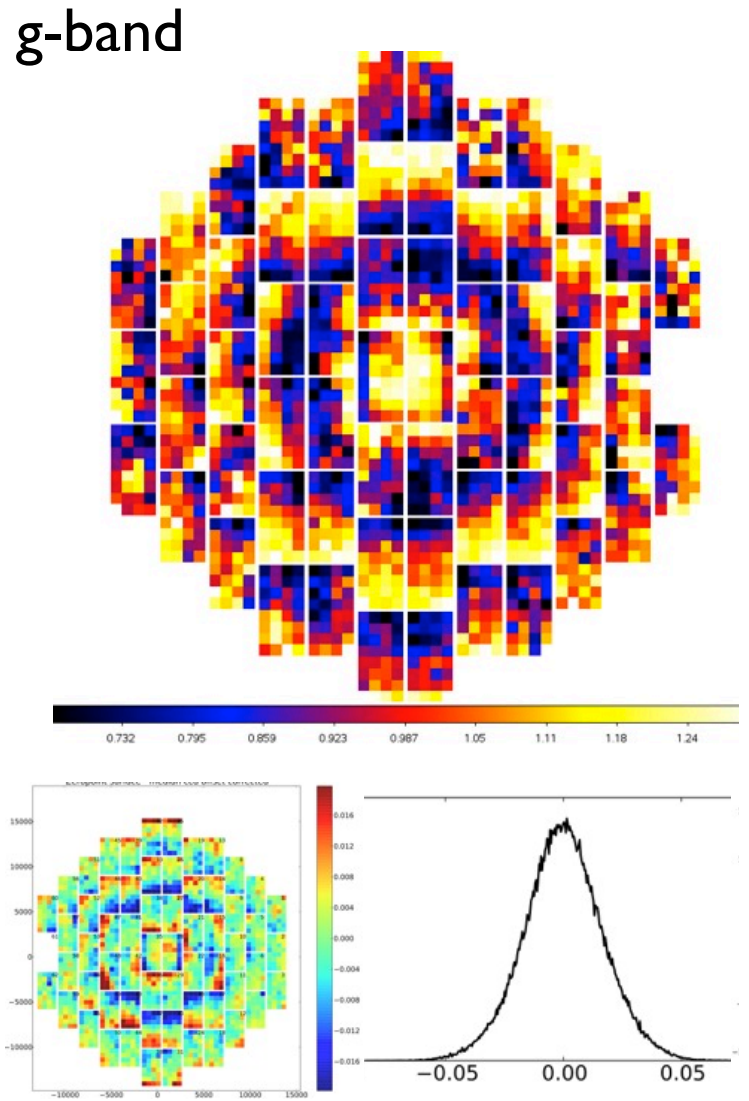
- Ensemble of 74 SV coadd tiles (see Hennig et al 2016, astro-ph/1604.000988)
  - Median repeatability scatter on bright end: griz = 7.6, 7.6, 7.7 and 8.3 mmag
    - Comparison to PS1 (15-20 mmag), CFHTLS (40+ mmag in T0006 processing), DESDM processing (?)
  - Stellar locus median scatter: 17 (gr-ri), 32 (ri-iz) and 57 mmag (gr-rJ)



PF1: EXT-DES Prototype Data Quality (3/6)

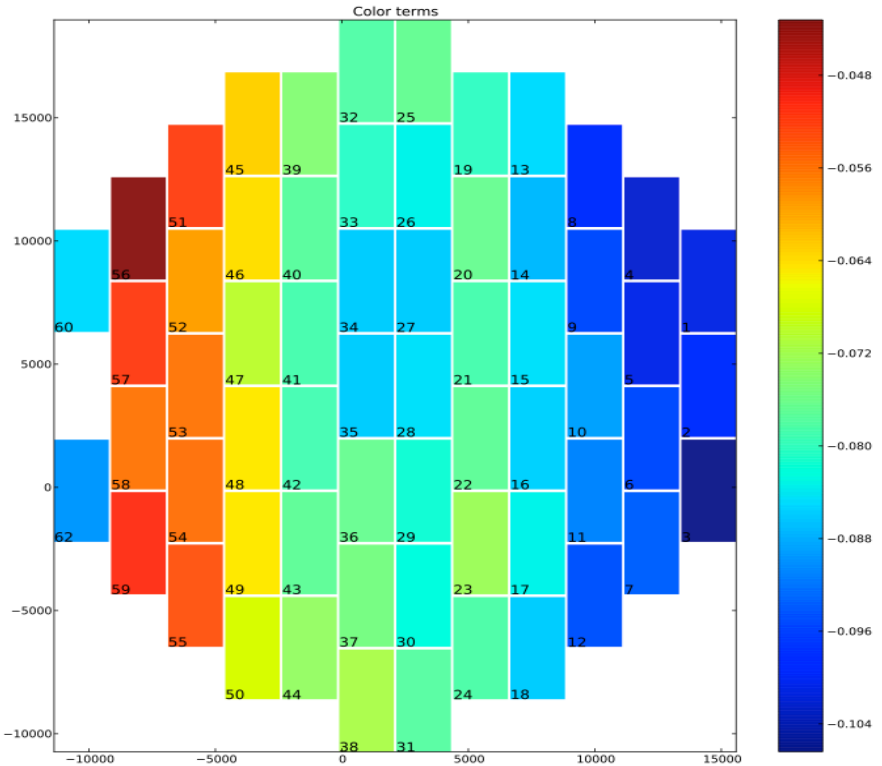
Flattening corrections for DECam

- Apply dome flats- treat each CCD as an independent detector
  - Each CCD treated independently
- Remove errors due to pixel scale variation
  - Use WCS solution to apply correction equal to the fractional deviation of the pixel area from the median pixel area for that CCD (~<1% corrections)
- Apply persistent photometric bias correction
  - Use overlapping photometric exposures from SV examine the typical fractional deviations of stellar photometry from the true value as a function of position within a 6x3 grid within each CCD
  - Typical correction is <1%



Color term variations

- In similar analysis one can examine whether the persistent photometric errors depend on stellar color
- For this z band analysis the coefficients *a* of a color correction, e.g., *a*(r-i)*, vary from -0.05 to -0.11. Given some SED color range of ~1 mag this then introduces systematic photometric errors at the level of ~6%
  - In a coadd built from an overlapping set of 10 exposures the net variation would be reduced to ~2%
- No such thing as "standard" filter set within Euclid context
- Simultaneous cataloging of the single epoch images would allow one to track/correct for this

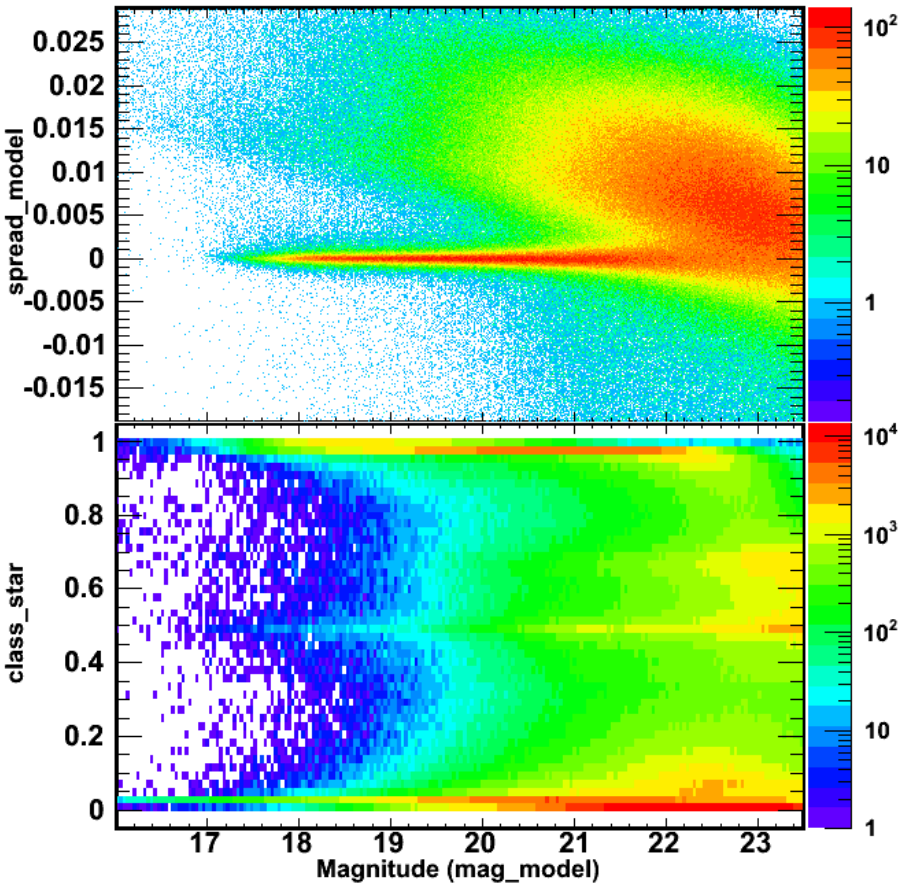


PF1: EXT-DES Prototype Data Quality (5/6)

New tools developed on the way

- Spread_model uses PSF model to separate resolved from unresolved objects
  - Far better performance than class-star

- Mag_detmodel extracts a PSF-corrected radial weighting function from the detection image and then applies it using an appropriate PSF convolution to extract a centrally weighted color
  - 2D version of SDSS C-MODEL
  - Cluster red-sequences using mag_detmodel have noticeably higher contrast than when measured with mag_auto
  - Aperture magnitudes suffer from systematics due to different seeing in each band unless you degrade the data to the same resolution



Desai et al 2012

PF1: EXT-DES Prototype Data Quality (6/6)

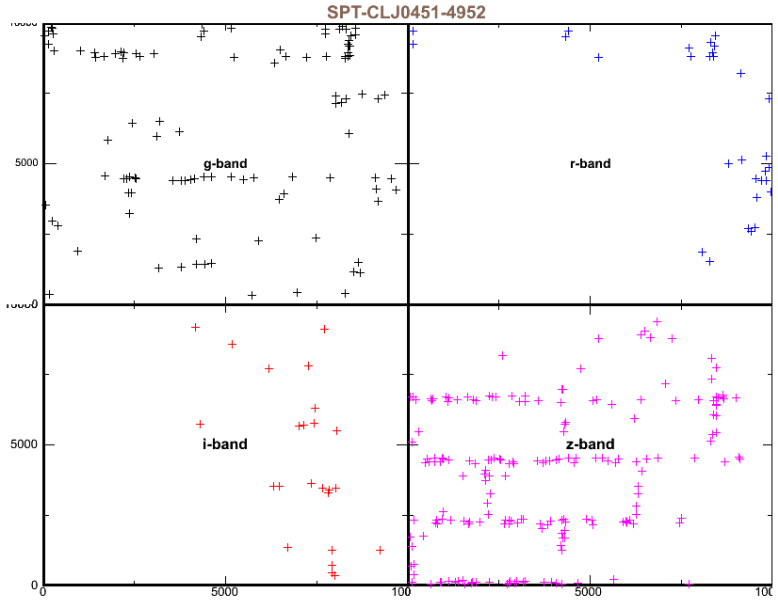
Stacking without homogenizing introduces errors in catalogs

- Here are objects classified as galaxies in DESDM catalogs that are classified as stars in OU-EXT catalogs

- Sharp discontinuities in PSF in non-homogenized data are generic– any PSF corrected quantity will be biased.

- Later it was confirmed that biases in galaxy colors using mag_detmodel were present, and so people were warned NOT to use mag_detmodel

- In the limit of large numbers of exposures with seeing cuts the PSF becomes pseudo-homogeneous



PF1: EXT-DES Pipeline Current Status

Handover of pipelines to SDC-DE underway

- Pipelines are being improved, brought to maturity level 2A ("Euclidized")
  - Data quality+ performance improvements, 2A means: Python/C++ with approved libraries
  - Calibration pipeline
    - Released at maturity level 2A to SDC-DE (+Euclid svn) in Feb 2015 (biascor part) and Sep 2016 (flatcor part)
  - Single epoch pipeline
    - Brought to maturity level 2A, testing and validation ongoing, released in Sep 2016
  - Photometric calibration pipeline
    - Working, partially Euclidized code. Algorithm changes to include Gaia data expected
  - Masking and Coadd pipeline
    - Complete version for coadd production at maturity level 2A in Sep 2016
    - Euclid masking pipeline prototyped 2015, integrated in CosmoDM summer 2016
    - Testing and validation underway on both

Concluding Comments

- EXT-DES end to end systematic noise in PSF fitting stellar photometry on single epoch survey data typically < 1%

- Absolute calibration plan is to use Gaia RP and BP
  - see Mohammad's talk for forecasts of what is possible
  - meanwhile, calibration using stellar locus provides high quality photometry for testing

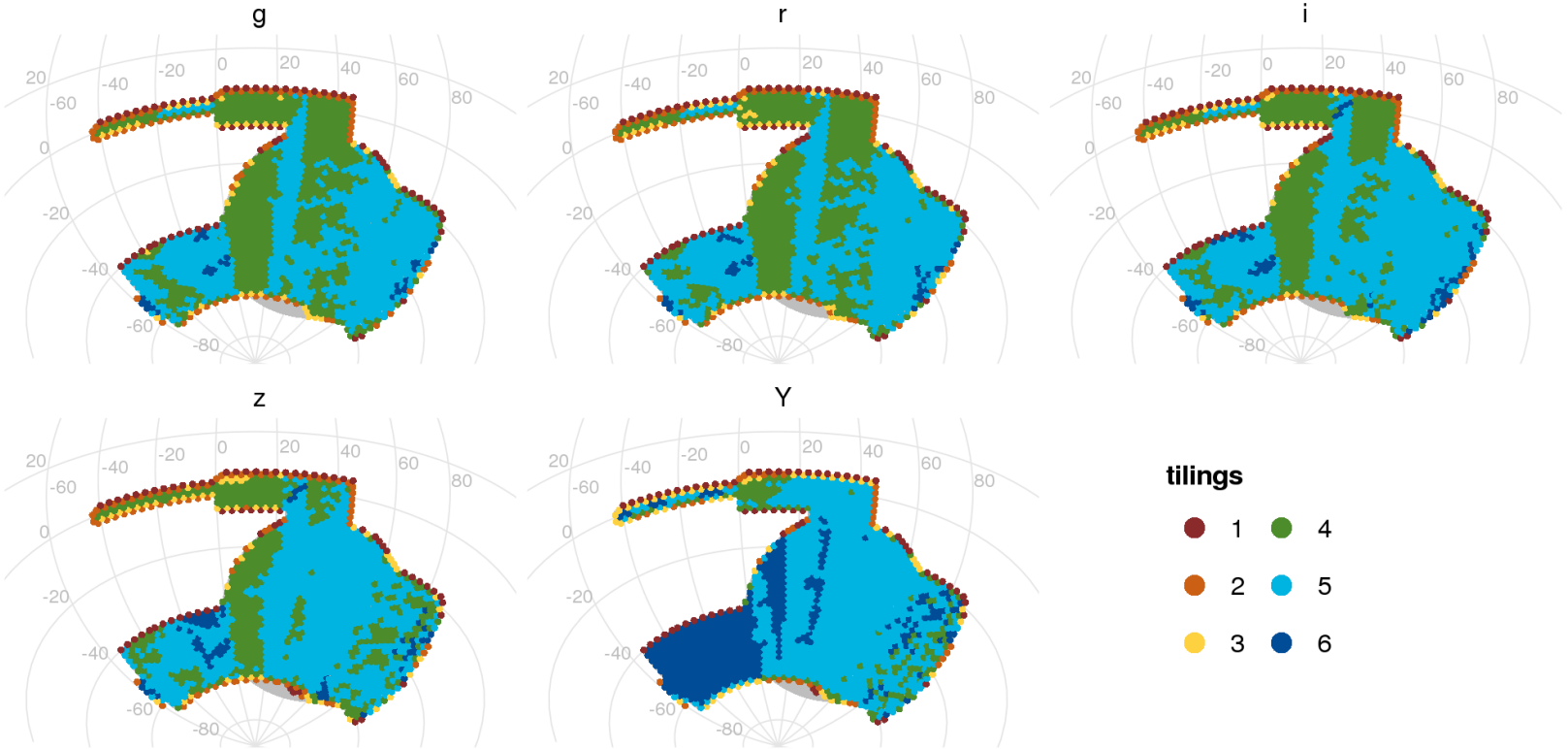
- Single Epoch astrometry calibrated "on the fly" to ~50mas
  - Second pass calibration in stacks of exposures yields <20mas

- For discussion:
  - Color stability at 0.2% level requires position variable filter curve tracking mechanism

DES Data Acquisition Status (1)

Observing through Yr3 completed

- Year 3 has been bad by historic proportions
- Default plan would be to have 6 layers of imaging everywhere

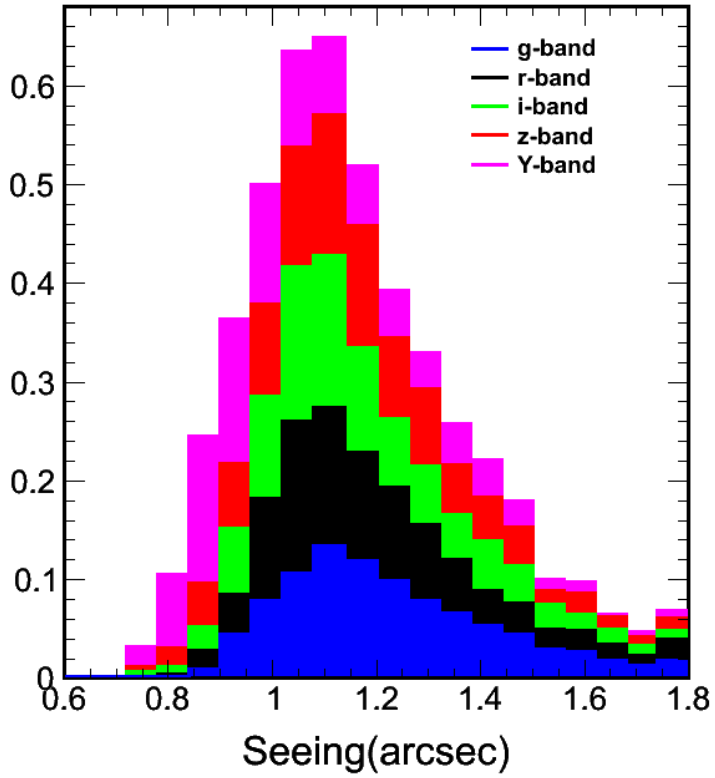


From Eric Neilsen + Josh Frieman

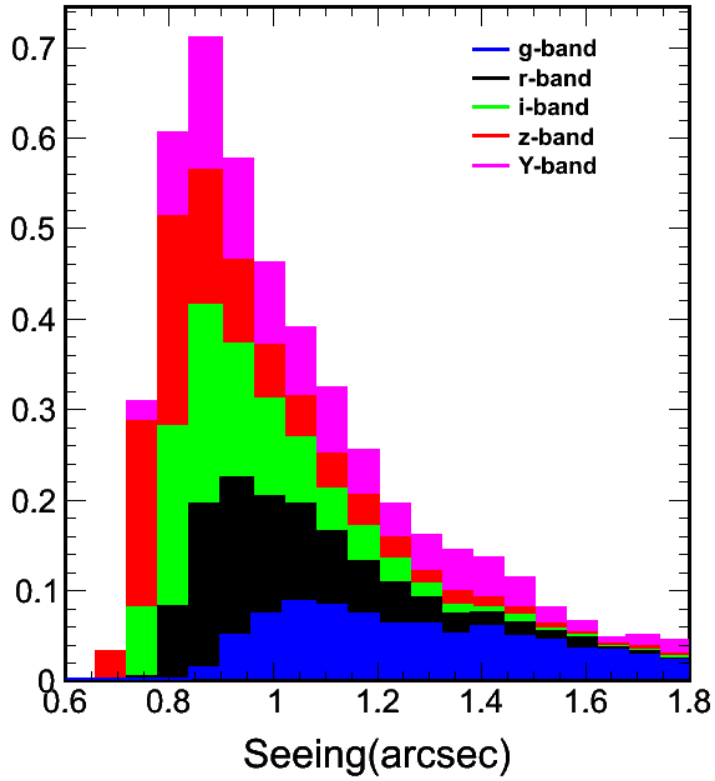
Seeing improvements since SV

- Cooling of the Blanco primary mirror and also of the dome were instituted between SV and Yr1. Modal seeing moved from 1.1” to 0.9” in riz. Same for Yr2

Science Verification



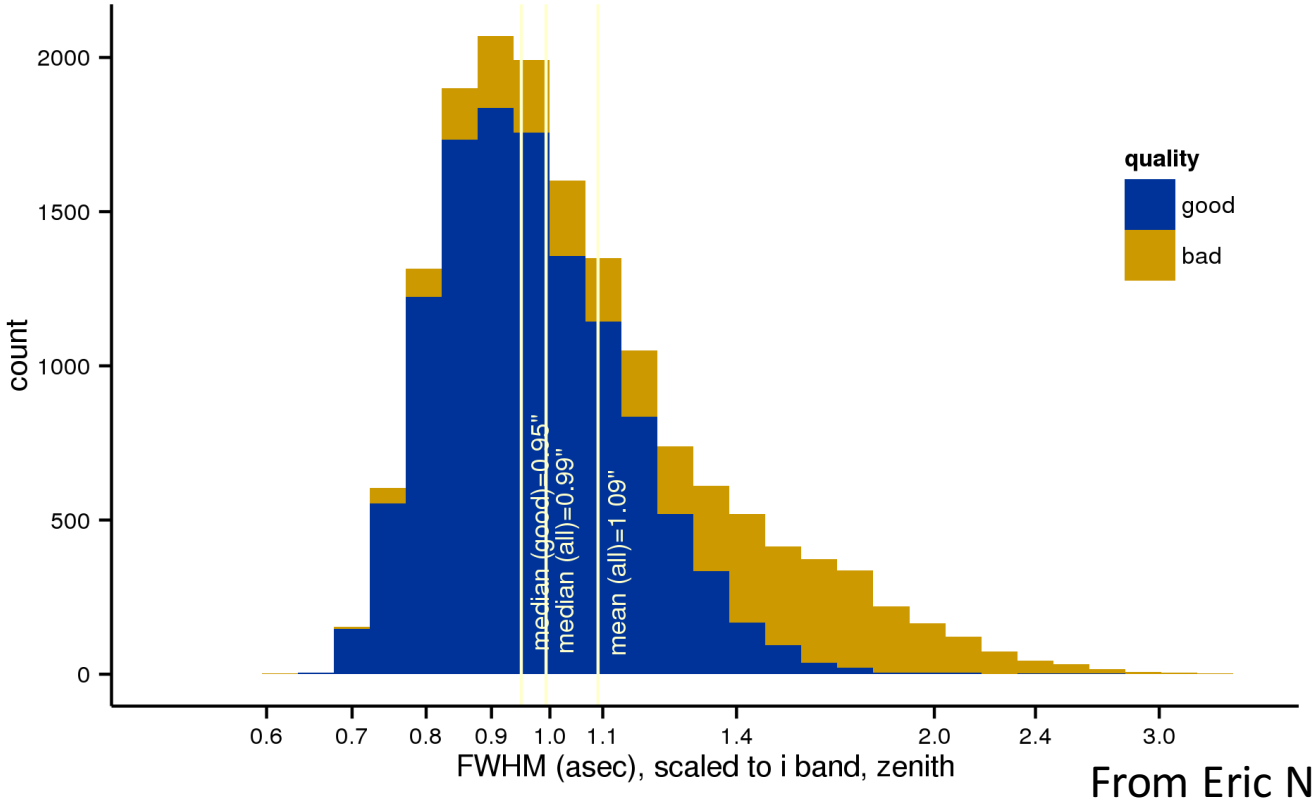
Year 1



DES Data Acquisition Status (3)

Yr 3 seeing has modal value ~0.95”

- Primarily a larger fraction of bad data and less time on sky in Yr3
- Quality of acquired data is in line with quality from Yr 1 and Yr 2

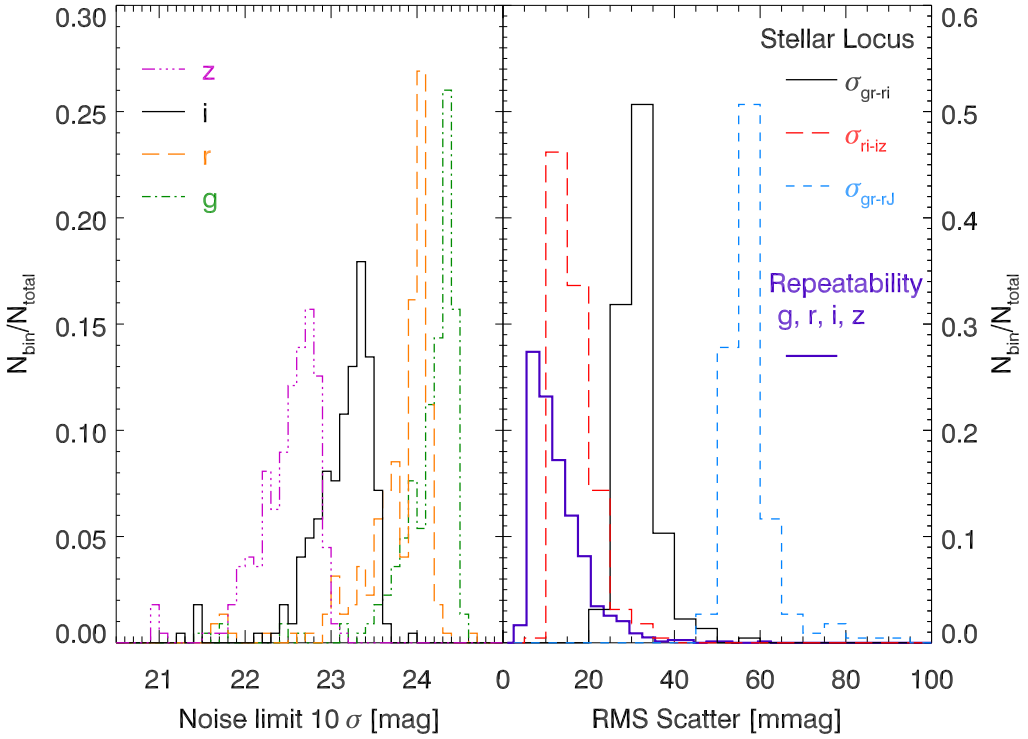


From Eric Neilsen + Josh Freiman

DES Data Acquisition Status (4)

DES-SV depths and photometry scatter

- 10σ photometric noise depths (2 arcsec diam aperture) over ~150 deg² SV
  - griz ~ 24.3, 24.0, 23.2, 22.8
- Repeatability scatter ~10 mmag with tail, stellar locus scatters good (see Desai, JM+ 2012)



Courtesy Holger Israel