The DECam Plane Survey

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LBL

DECam Community Science Workshop
May 21, 2018
The DECam Plane Survey

- DECam survey of southern Galactic plane
- grizY filters
- $\delta < -30^\circ$, $|b| < 4^\circ$ ($5^\circ > l > -120^\circ$)
- roughly main-sequence turn-off at 8.5 kpc through $E(B-V) = 1.5$
- 23.7, 22.8, 22.3, 21.9, 21.0 mag in grizY in single exposures
- 3 epochs per filter, observed on adjacent nights
Source Density

The image shows a map of source density with coordinates in $b$ (°) and $l$ (°). The map displays variations in density across different regions of the sky, with darker areas indicating higher source densities. The map covers a range of $b$ from $-8$ to $8$ and $l$ from $-120$ to $-60$. The data points suggest a non-uniform distribution of sources across the celestial sphere.
Source Density

20 billion detections of 2 billion objects
The Legacy Survey Viewer

Browse the southern Galactic plane as seen by DECaPS in Dustin Lang’s viewer

Things to do:

- Dust and protostars
- White dwarfs
- Clusters
- Nebulosity
- Crowding
- Bright stars
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http://decaps.legacysurvey.org
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Pipeline

- Concept: find and fit sources to steadily improve model of image
  - repeat source finding on residual images to find fainter, blended sources
  - Same idea as DAOPHOT, DOPHOT, DOLPHOT.

- Steps:
  1. Sky subtraction
  2. Source detection
  3. Position, flux, and sky determination
  4. PSF determination
  5. Repeat
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Steps:
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5. Repeat
Photometric Calibration

- We wish to place all of the DECam observations onto a common magnitude scale, removing the effect of sensitivity variations between
  - the system throughput from night to night
  - the opacity of the atmosphere (from night to night)
  - different regions of the DECam focal plane
- We achieve this by adopting a simple model for the system throughput over the course of the survey
- We constrain the model using repeat observations of the same stars
Photometric Calibration Flat Field

- Flat fields show $\sim 5$ mmag corrections
- True effect is presumably largely chromatic
- Pupil ghost
- Tree rings
- PSF-fitting-related artifacts
- Unstable S7 amplifier
- mounting board in $Y$

$\mu : -1.7$  $\sigma : 8.2$
Photometric Calibration Flat Field

- Flat fields show $\sim 5$ mmag corrections
- True effect is presumably largely chromatic
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$\mu : -1.3$  $\sigma : 4.4$
Photometric Calibration Flat Field

- Flat fields show \( \sim 5 \) mmag corrections
- True effect is presumably largely chromatic
- Pupil ghost
- Tree rings
- PSF-fitting-related artifacts
- Unstable S7 amplifier
- mounting board in \( Y \)
Photometric Calibration Flat Field

- Flat fields show ~ 5 mmag corrections
- True effect is presumably largely chromatic
- Pupil ghost
- Tree rings
- PSF-fitting-related artifacts
- Unstable S7 amplifier
- mounting board in $Y$

$\mu : 0.0 \quad \sigma : 3.6$
Photometric Calibration Flat Field

- Flat fields show $\sim 5$ mmag corrections
- True effect is presumably largely chromatic
- Pupil ghost
- Tree rings
- PSF-fitting-related artifacts
- Unstable S7 amplifier
- mounting board in $Y$

$\mu : 0.6 \quad \sigma : 7.4$
So... did all of that work?
Open Cluster NGC 2660

Very narrow sequence! Secondary binary sequence visible?
Open Cluster NGC 2660

Very narrow sequence! Secondary binary sequence visible?

Eddie Schlafly (LBL)
CMDs

$(236°, -14°)$
CMDs

(240°, 0°)
CMDs

(299°, 0°)
CMDs

$(0^\circ, 0^\circ)$
CMDs

![ CMDs Graph ]

PS1

Eddie Schlafly (LBL) DECaPS May 21, 2018 12 / 14
CMDs

DECaPS

$CMDs$

$i - z$

$DECaPS$
Median colors of stars
Conclusions

- DECam Plane Survey finished
  - 23.7, 22.8, 22.3, 21.9, 21.0 mag in grizY in single exposures
  - $\delta < -30^\circ$, $|b| < 4^\circ$ ($5^\circ > l > -120^\circ$)
  - 2 billion stars
  - Extension to $4^\circ < |b| < 10^\circ$ ongoing

- Dust related projects:
  - 3D dust map within 8 kpc
  - Extinction curve map in concert with APOGEE-II

- Data publicly available at http://decaps.skymaps.info
  - images
  - single-epoch catalogs
  - merged catalogs
Sky Subtraction

- Improve sky relative to best model so far
- Sky determination should give zero if the model is perfect
- Needs to be fast
- We just take the median in $20 \times 20$ pixel regions
- This should change depending on seeing!
Source Detection

- Convolve image with PSF
- > 5σ peaks are candidate sources
- Candidate sources passing blending criteria added to source list
Source Detection

- Convolve image with PSF
- $> 5\sigma$ peaks are candidate sources
- Candidate sources passing blending criteria added to source list
- $S_I/S_M > 2B$ or $(S_I/S_M > B) \& (I/M > B)$
  
  $I$ residual image
  $M$ model image
  $S_I$ signal-to-noise of residual image
  $S_M$ signal-to-noise of model
  $B$ blending threshold
Position, flux, and sky determination

- Everything is a point source—life is easy!
- Sky and fluxes are completely linear
- Positions can be linearized via first derivative
- Plug into large sparse linear algebra code
- LSQR, conjugate-gradient type solver, Stanford Systems Optimization Laboratory
- We fit up to 30k stars per $1024 \times 1024$ pixel region, for $\sim 100k$ simultaneous parameters
PSF determination

- Start with best model so far
- Get model for image from linear least squares fit
- Subtract neighbors around each star from model
- Use newly isolated stars to model PSF
- (though we probably should be thinking about an EM solution...)

![PSF plot]

Eddie Schlafly (LBL)  
DECaPS  
May 21, 2018  
18 / 14
DECaPS PSF model

- start with “ideal-seeing” PSF models
- find parameters of spatially-varying Moffat that convolve with ideal-seeing PSF to match neighbor-subtracted PSFs
- pixel-by-pixel spatially varying model of PSF core (9 × 9 pixel)
- Need to do better!
  - “analytic” model tends to be dominated by core and fail in the wings (∼ 2″ from center)
  - “aperture correction” is the dominant source of photometric calibration error
  - diffraction spikes don’t quite match
  - lots of structure in PSF wings!
  - variations in PSF with color and brightness
Ideal-seeing PSFs

- average PSFs over large numbers of bright stars on very good seeing nights
- Extend 255 pixels from PSF center
- Deconvolved with good-seeing Moffat
- Modeled as sum of Moffats and diffraction spikes
- → noise-free, ideal-seeing PSF
- needs improvement? ideal-seeing PSFs often dominate in the wings
Nebulosity

- How should one deal with ...
Nebulosity

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Nebulosity

- How should one deal with nebulosity?
- No good techniques I know of!
- Only 0.1% of footprint affected
- Mask and apply stronger blending & sharpness cuts in these regions
Nebulosity

- How should one mask nebulosity?
- Simple approaches (variance in sky estimates on different scales) break down around bright stars and in crowded regions
- Neural network trained on $\sim 5,000$ hand-classified $512 \times 512$ pixel images
- Ultimately did an excellent job flagging nebulous regions
- This image: 100% nebulous ✓
Photometric Calibration

- We calibrate each detection with a zero point $Z$ so that
  \[ m = m_{\text{inst}} + Z \]
- We take $Z = a - kx + f$, with
  - $a$: system zeropoint (one parameter per night)
  - $k$: atmospheric opacity (one parameter [whole survey!])
  - $x$: airmass of observation
  - $f$: flat field (10,000 parameters)
- We then solve for the parameters of this model for $Z$, to minimize
  \[ \chi^2 = \sum_o \sum_i \frac{(m_{o,i} - \overline{m_o})^2}{\sigma_{o,i}^2} \]
- Note: 10,000 parameters, constrained using hundreds of millions of observations
- Same technique as Padmanabhan et al. (2008) for the SDSS
Photometric Calibration Nightly QA

- 5 mmag precision in any given exposure
- 1% rms residuals, correlated with wings of PSF
- poor “aperture correction”; c.f. \(\sim 3\) mmag in PS1
- we should have enough information to get this right!
Mosaicing scheme

- Don’t want to fit $4096 \times 2048$ pixel images simultaneously
- Cut into $1024 \times 1024$ pixel blocks (primary plus 50 pix overlap)
- Add stars from primary regions of other blocks to model for this block, fixing their fluxes.
- Really should have done sky subtraction, source detection, and PSF fitting steps on full image, and just introduced a mosaicing scheme for the least-squares fit.