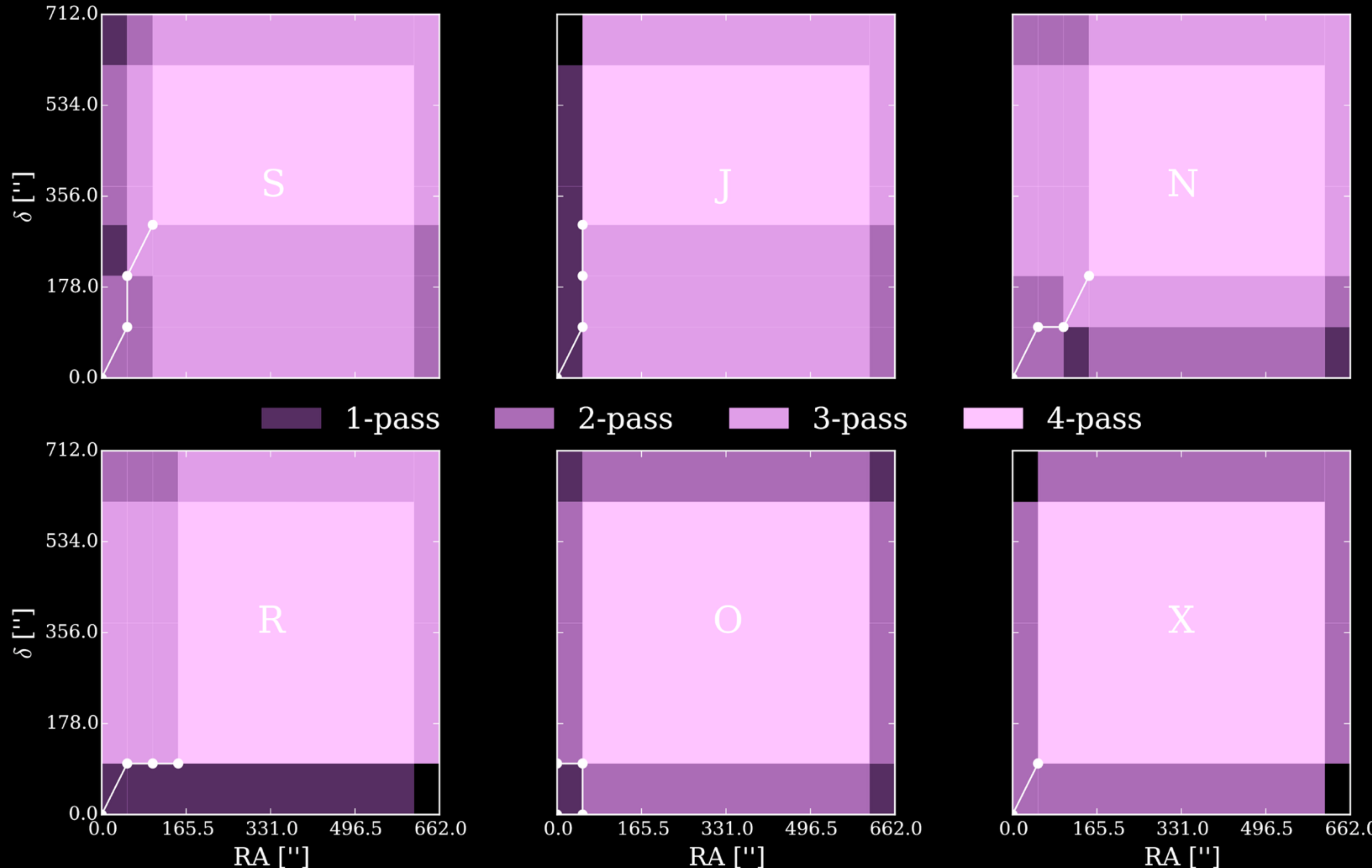


Simulated *Ubercal* with Euclid-like 4-dither patterns

Dida Markovic with Percival, Scodeggio, Ealet, Wachter, Garilli, Guzzo, Scaramella, Maiorano, and Amiaux

arXiv:1606.07061

2016 Euclid Photometric Calibration Workshop, Madrid, 20/09/2016

Portsmouth

Overview

- *motivation: Yannick, Will & Anne*

  R-GC.2.1-12:
  “Within patches of 0.5 deg^2 area distributed over the whole survey, fluctuations in the zero-point of the flux limit shall be smaller than 0.7% rms.”

  - 4% (now 3%) -> 0.7%

- large-scale retrospective *relative* photo self-calibration for clustering: ***Ubercal***

  - Padmanabhan et al. (2008, astro-ph/0703454)

- large-scale retrospective relative spectro-photo self-calibration in space

  - reducing the degrees of freedom in the fitting procedure
  - applying to *spectro-photometry* by integrating over stellar spectra
  - finding an optimal dither pattern with simplified simulations
  - Markovič et al. (2016, arXiv:1606.07061)

Ubercal method

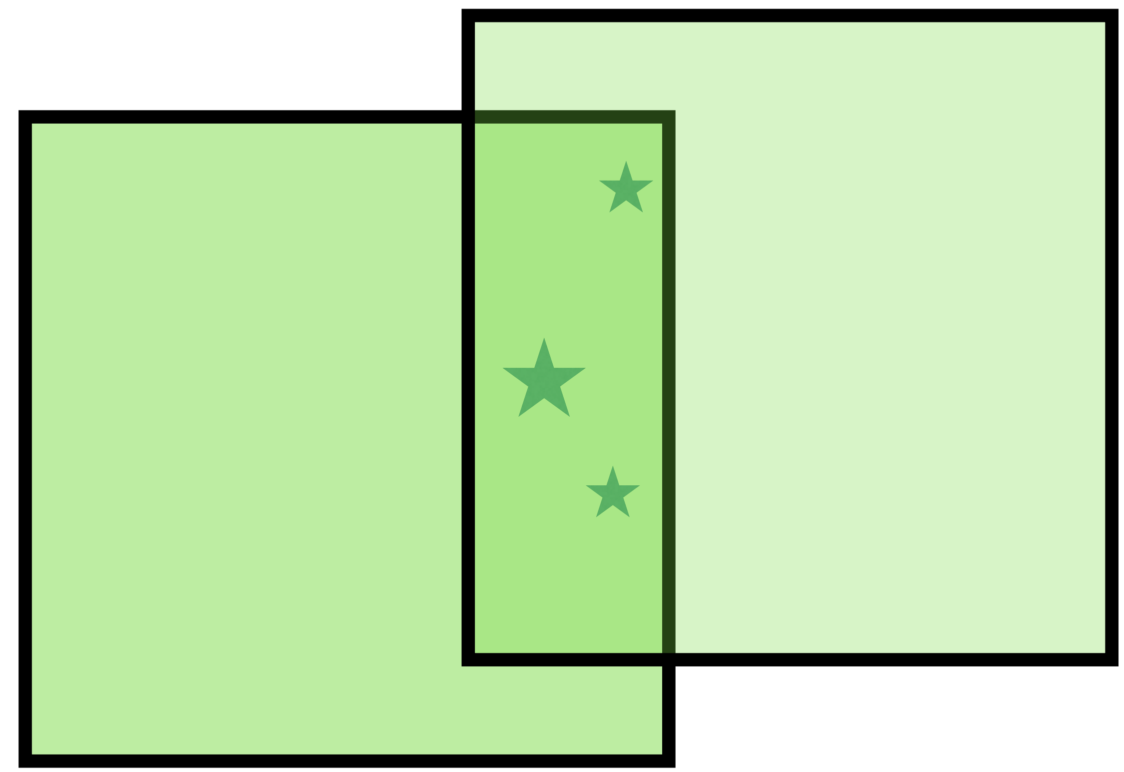
- retrospective relative photometric self-calibration from overlaps of adjacent exps
- defined in Padmanabhan et al., 2008 paper (astro-ph/0703454)
- from photons hitting detector -> energy / area / time / frequency-bin
- absolute / <u>relative</u> calibration
- clustering
    - density **contrast** => need **relative** calibration!

Ubercal method

- main idea:
  find stars in overlaps between exposures and compare ADUs measured for same star in different exposures
- 2 x 3 measurements:
  f_{ADU} of each star in each exposure
- 2 + 3 parameters to fit:
  2 calibrations, 3 stellar fluxes
- if know the true calibration:

$$f = \mathcal{K} f_{\mathrm{ADU}}$$

$$m = m_{\mathrm{ADU}} - 2.5 \log_{10} \mathcal{K}$$



- complicated model for SDSS calibration:

$$-2.5 \log_{10} \mathcal{K} = a(t) - k(t)x + f(i, j; t) + \ldots$$

optical response

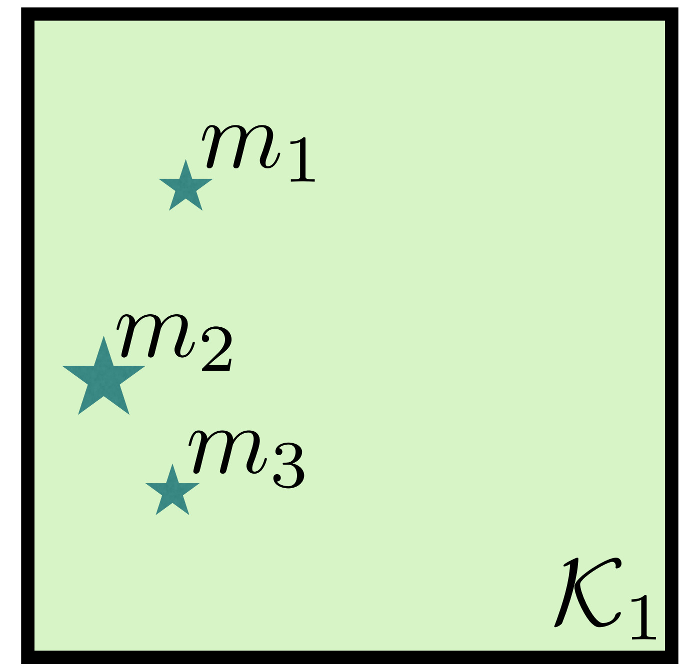
atmospheric extinction

flat field of CCD exposure (i,j)

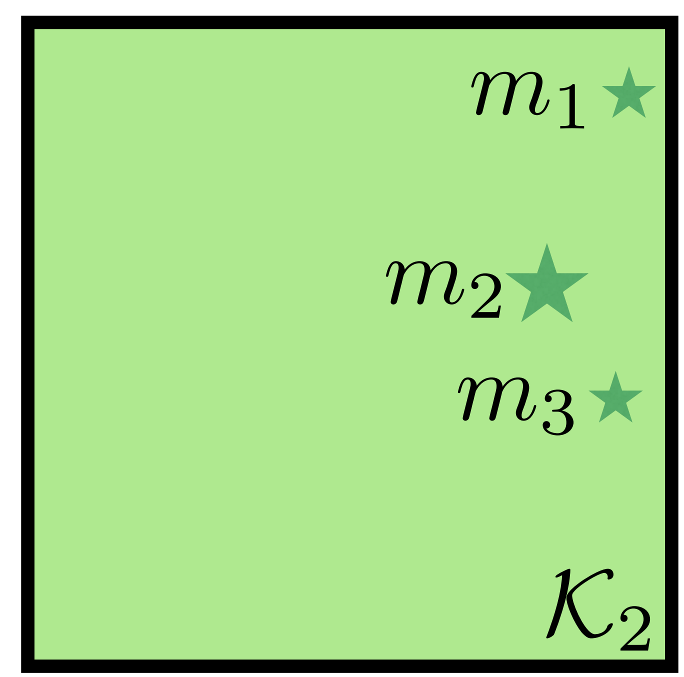
Ubercal method

- minimise scatter of calibration residuals around 0
- multivariate Gaussian likelihood function constructed from:

$$\chi^2(\{\mathcal{K}_j\}) = \sum_i^{n_\star} \sum_{j \in \mathcal{O}(i)} \left[\frac{m_i - m_{j,\mathrm{ADU}} + 2.5 \log_{10} \mathcal{K}_j}{\sigma_j} \right]^2$$



- marginalise out the true magnitudes by setting $\dfrac{d\chi^2}{dm_i} = 0$
- and solve for m_i



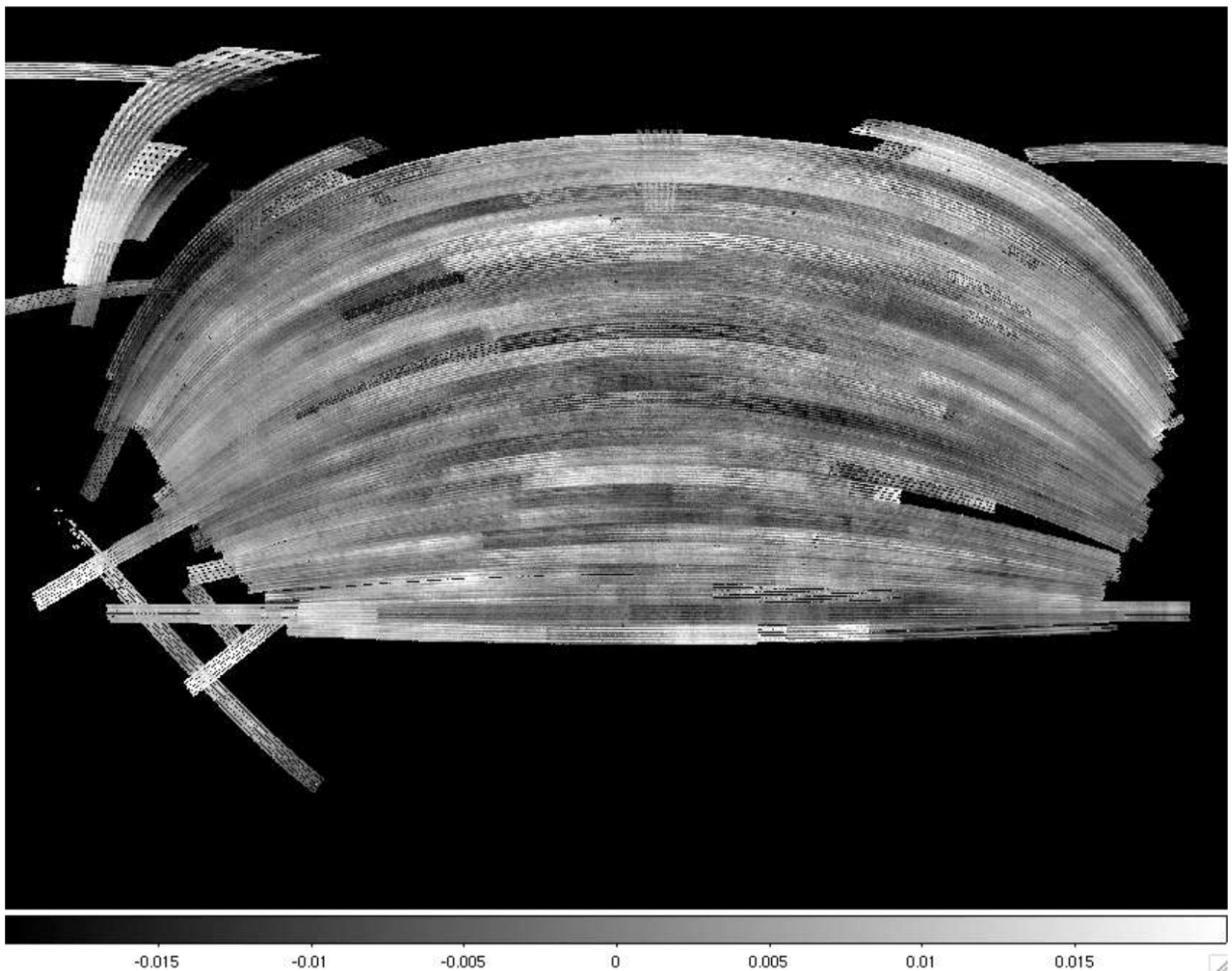
- then can write this as

$$\chi^2(\{\mathcal{K}_j\}) = \sum_i^{n_\star} \sum_{j \in \mathcal{O}(i)} \left[\frac{\overline{m^{\mathrm{c}}}_i - m_j^{\mathrm{c}}}{\sigma_j} \right]^2$$

calibrated magnitude of measured in exposure j of star i

Ubercal method

- Padmanabhan et al. found an improved stability of the flux limit across the survey
- corrected r-band ~1% stability:

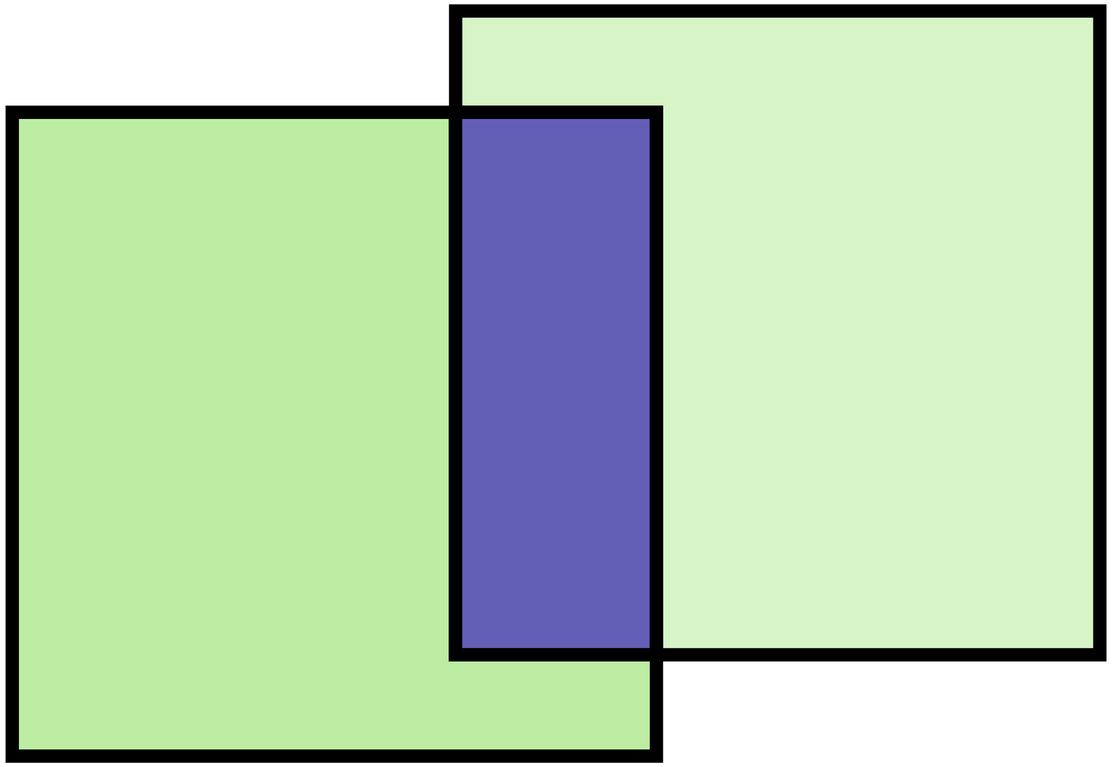


Padmanabhan et al. (2008, astro-ph/0703454)

Ubercal with reduced d.o.f.

- "compress data" by averaging out the individual stars
    - loose flat-field constraints
- compare only the average stellar magnitude of each **overlap tile***:

$$m^{\mathrm{c}}_{il} = \frac{\sum_p m^{\mathrm{c}}_{ilp} w_{pl}}{\sum_p w_{pl}}$$



- with Poissonian optimal weights:

$$w_{pl} = N^{\star}_{pl} \sigma_p^{-2}$$

- for the case of several stellar populations

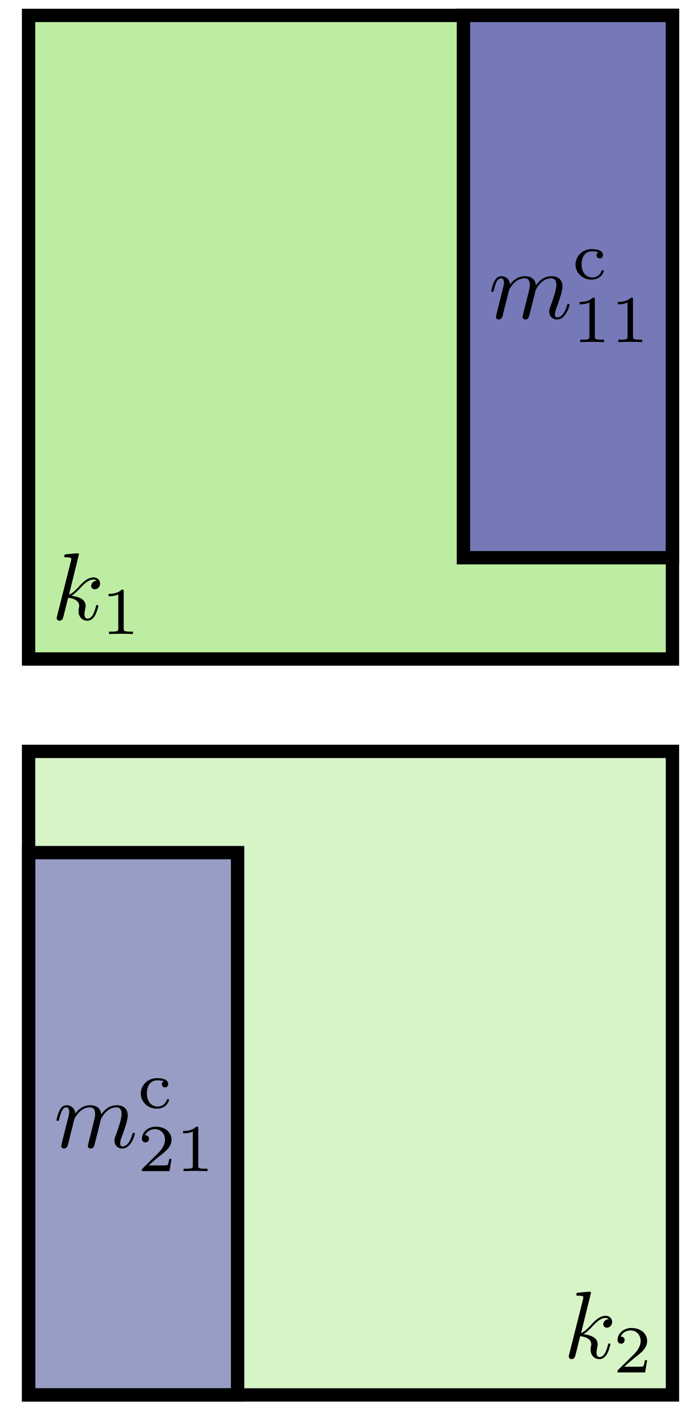
***** contiguous regions observed by same set of exposures

Ubercal with reduced d.o.f.

- again, minimise residual scatter around 0

$$\chi^2_{\mathrm{eff}}(\{k_i\}|m_{li}) = \underbrace{\sum_l^{N_\mathrm{o}}\sum_i^{N_l}\left[\frac{\overline{m^\mathrm{c}}_l - m^\mathrm{c}_{il}}{\sigma^\mathrm{c}_l}\right]^2}_{\text{likelihood part}} + \underbrace{\sum_i^{N_\mathrm{exp}}\left[\frac{k_i}{\sigma^\mathrm{k}}\right]^2}_{\text{prior part}}$$

- equivalent to fitting stars at extremum
- scatter of calibration residuals likely different



A simplified simulation of *Ubercal*

Simulation:

1. create the survey geometry using Mangle (Swanson et al., 2008)
2. generate a set of flux limit offsets
   $m_i \sim N(0, 0.04)$
3. Poisson sample numbers of stars in the overlap tile, given the overlap tile area
4. generate the weighed mean offset from average stellar magnitude expectation and the standard deviation
5. sum exposure and stellar magnitude offsets

Fitting:

6. find minima
7. check improvement in calibration

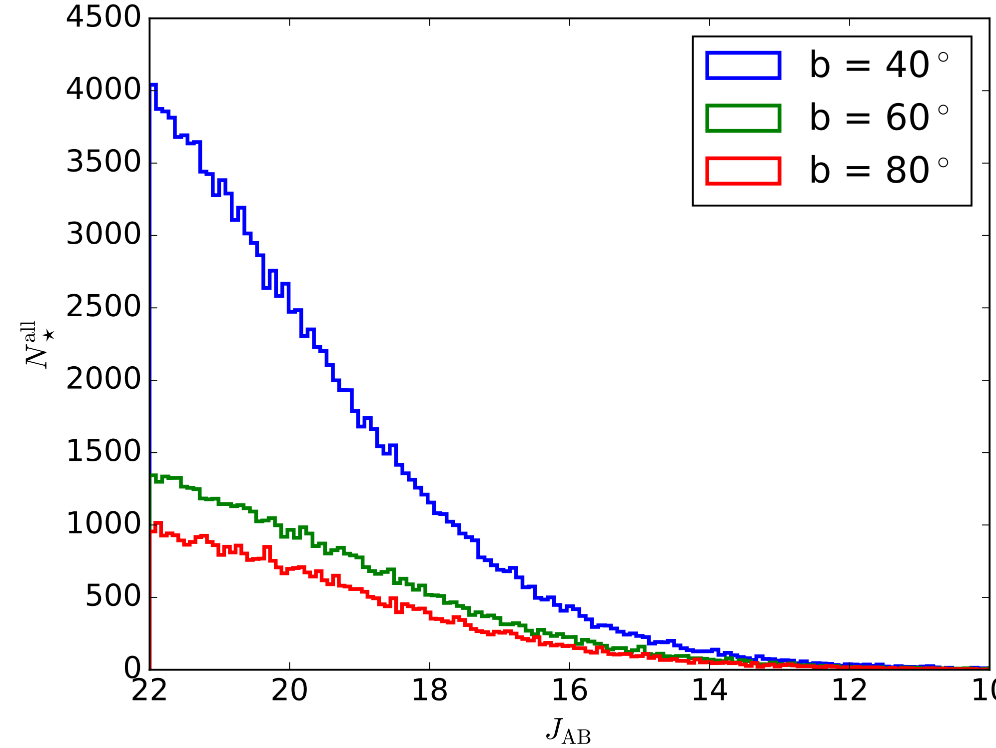
type	mag	rms	stars / deg^2
3	J_{AB}=14	0.00108	31.9
3	J_{AB}=15	0.00168	60.2
3	J_{AB}=16	0.00285	97.5
3	J_{AB}=17	0.00653	156.3
3	J_{AB}=18	0.01372	234.3
3	J_{AB}=19	0.03962	332.1
3	J_{AB}=20	0.07990	428.8

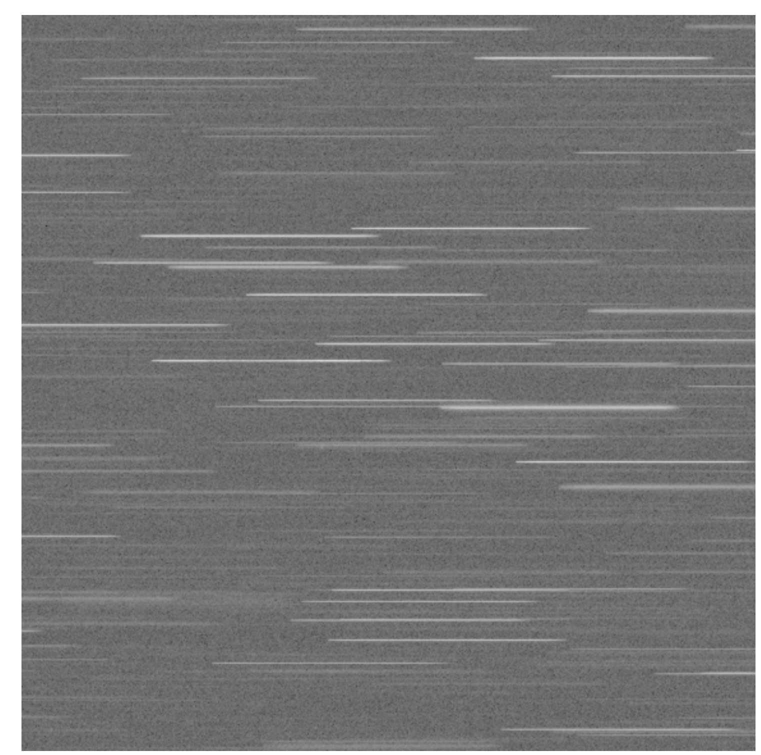
table of stellar properties used

A simplified simulation of *Ubercal*

Stellar properties

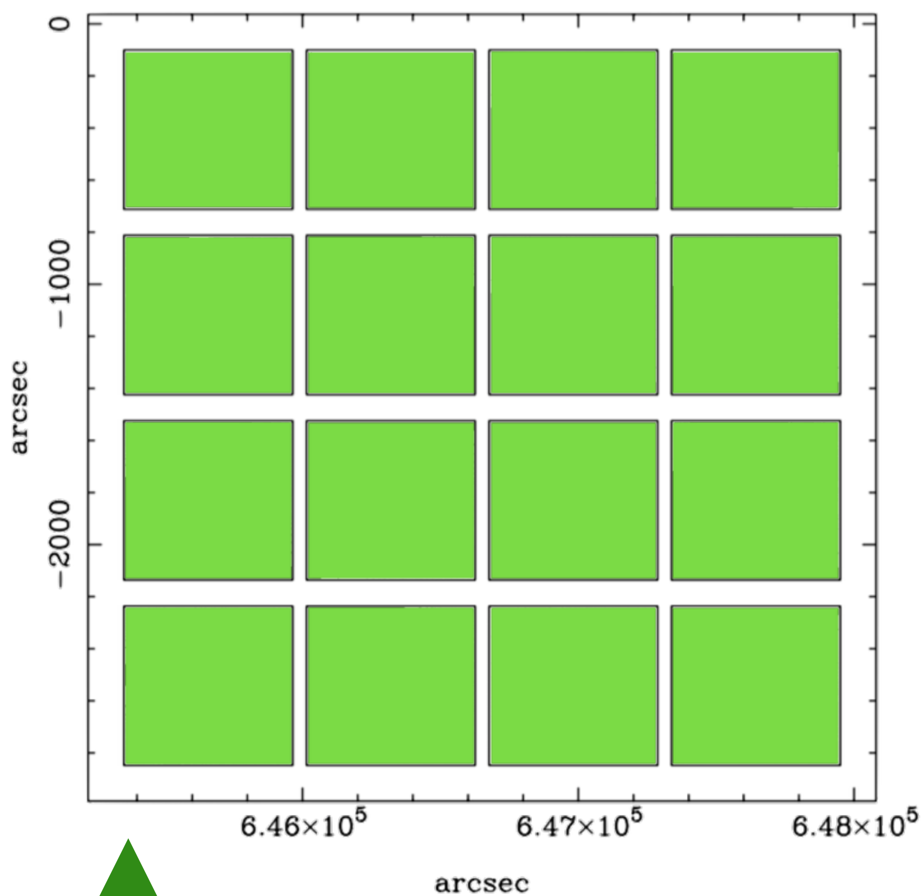
- use Trilegal code to get statistical properties of expected stellar populations
  - agrees with number of stars in VIPERS very well
  - 10 deg² patch at fixed galactic latitude b = 80 deg
- simulate a single exposure using TIPS simulator for NISP:
  - 13,000-14,000 Angstrom range
  - (102 pixels at 9.8 Angstrom/pixel sampling)
- get expected signal scatter for each calibration measurement



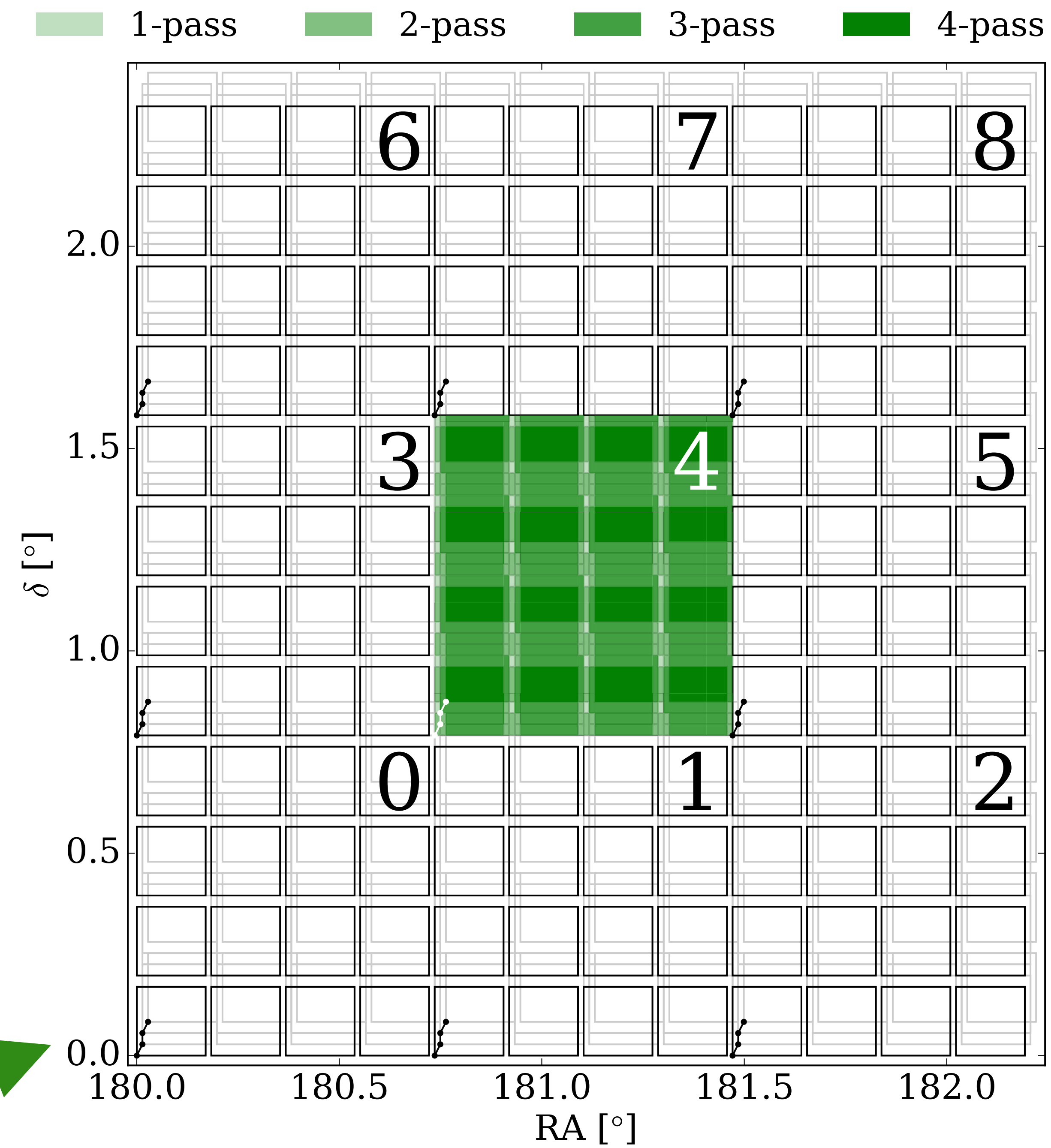


A simplified simulation of *Ubercal*

Survey geometry



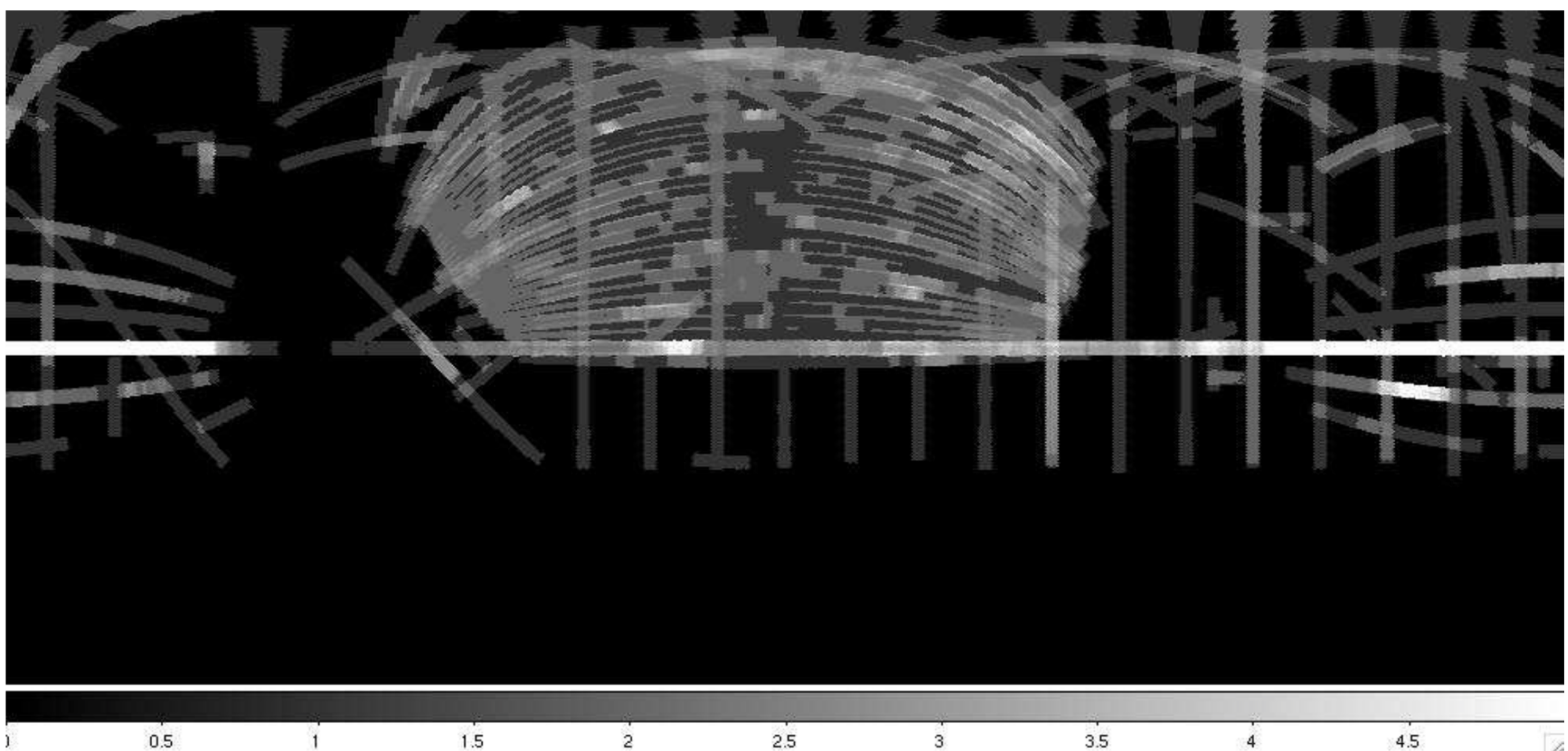
call this one **exposure**
basic unit to calibrate



stitch together surveys of 3x3 dithered pointings
use Mangle (Swanson et al.) to get overlap tiles

Comparing 4-dither patterns

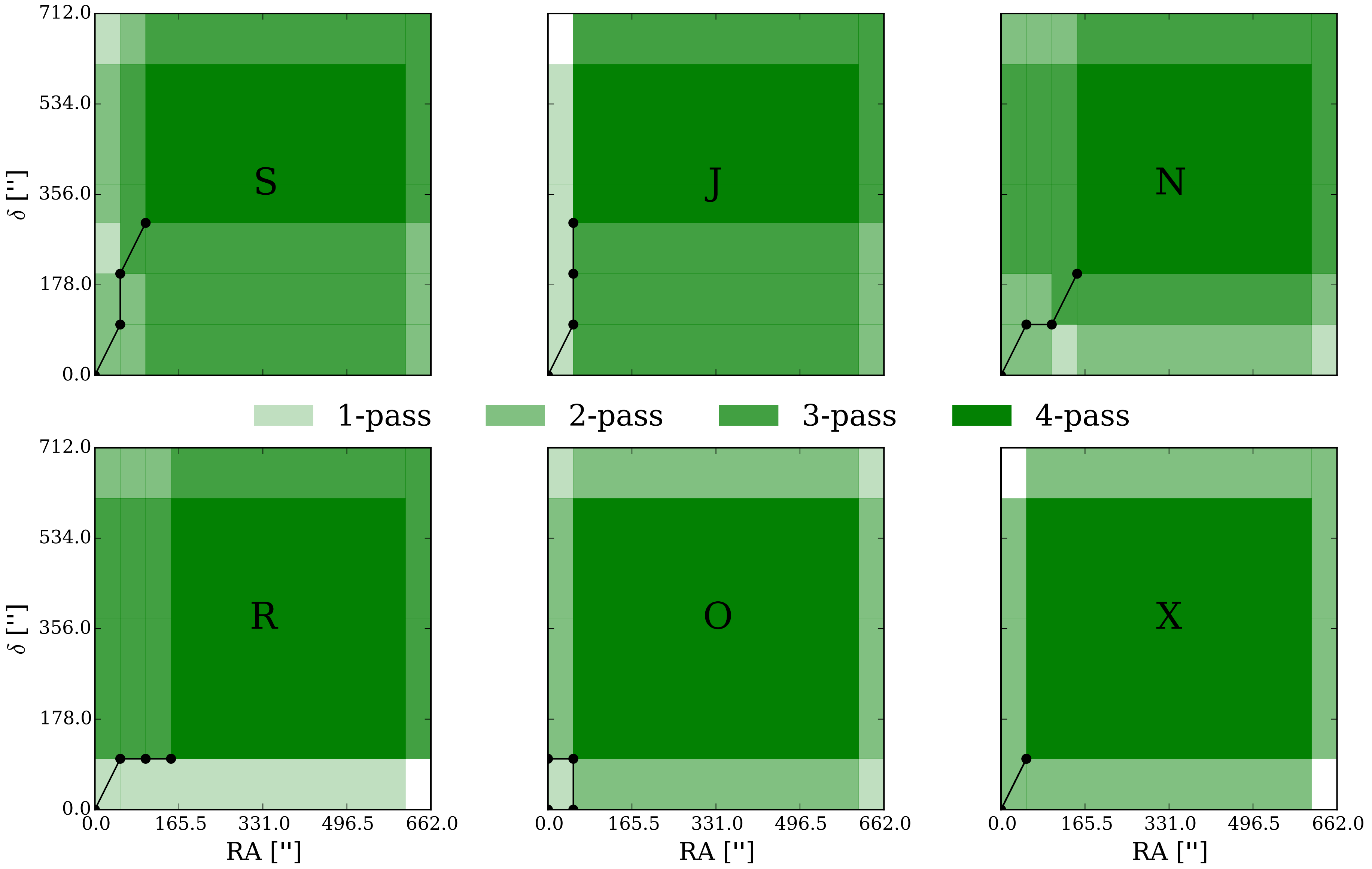
- Padmanabhan et al. found Apache Wheel data (vertical stripes) important for connecting disconnected parts
- without Apache Wheel, up to 30% increase in scatter overall



Padmanabhan et al. (2008, astro-ph/0703454)

Comparing 4-dither patterns

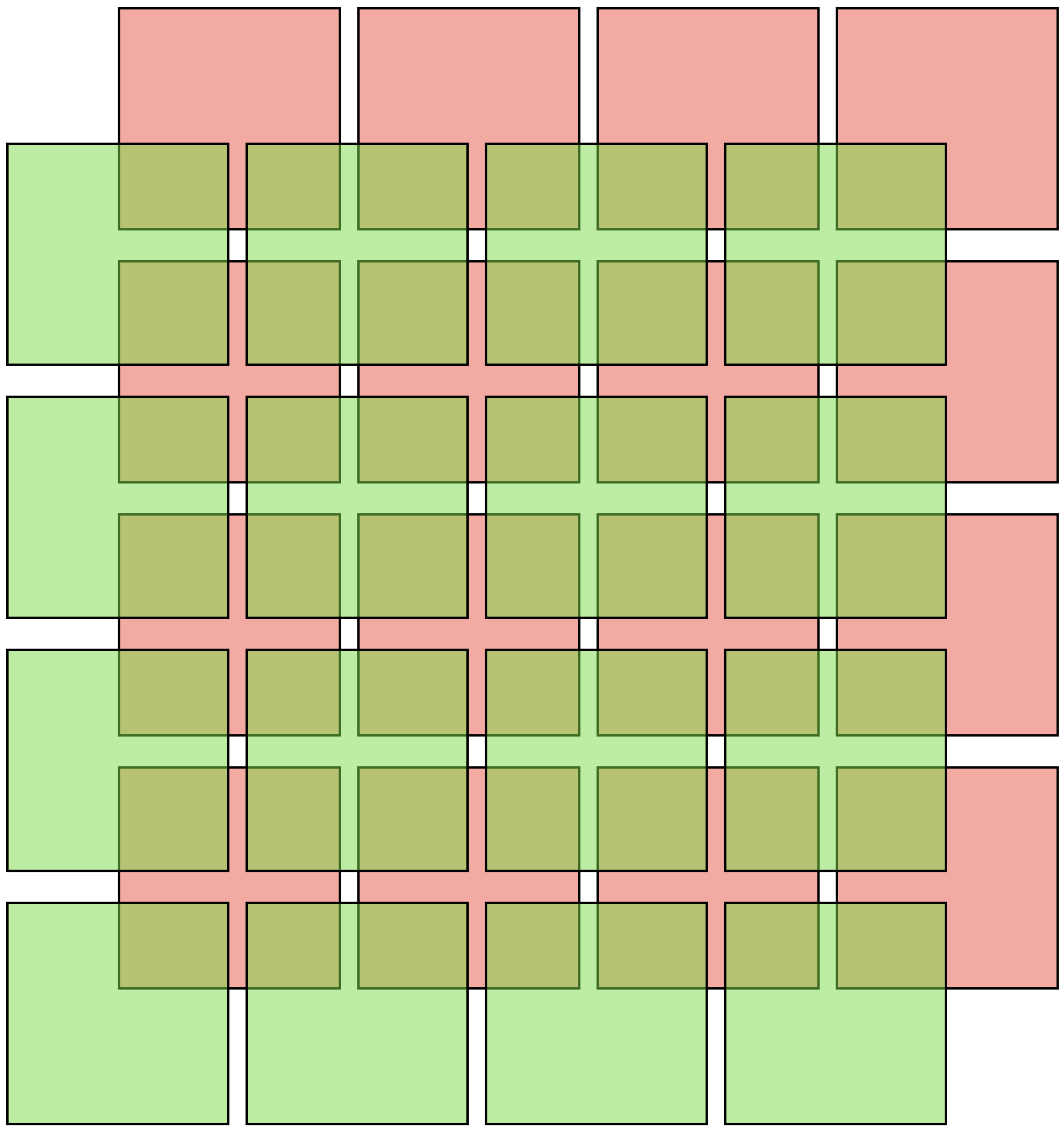
- idealised J-pattern is purely vertical stripes
- wanted to increase connectivity between patches
- without massively increasing the consumables



Markovič et al. (2016, arXiv:1606.07061)

Comparing 4-dither patterns

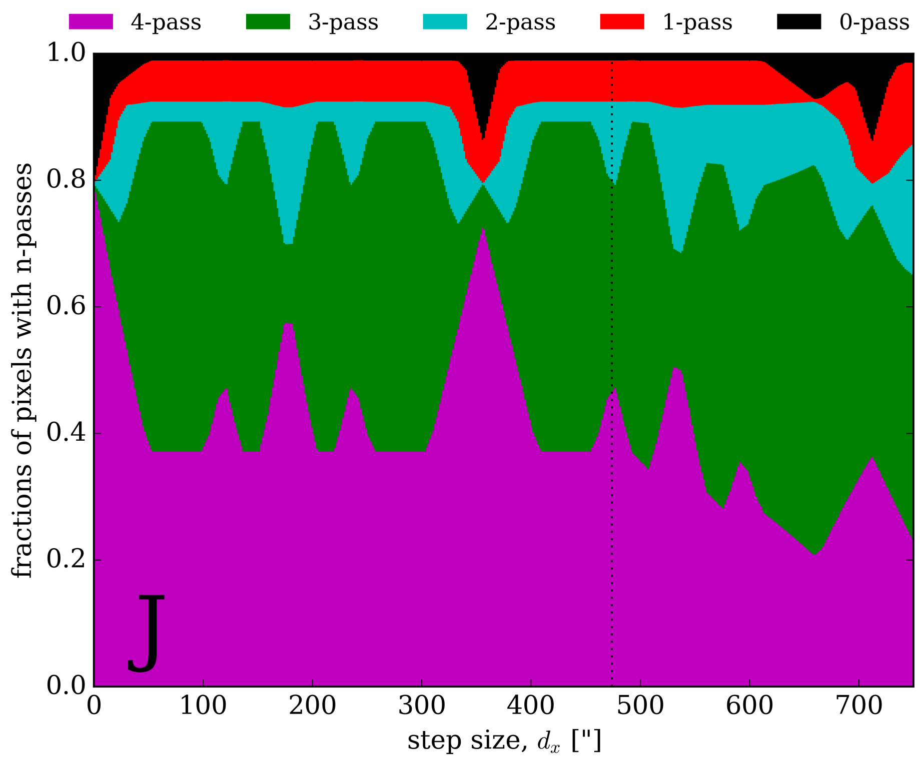
exposure-to-exposure

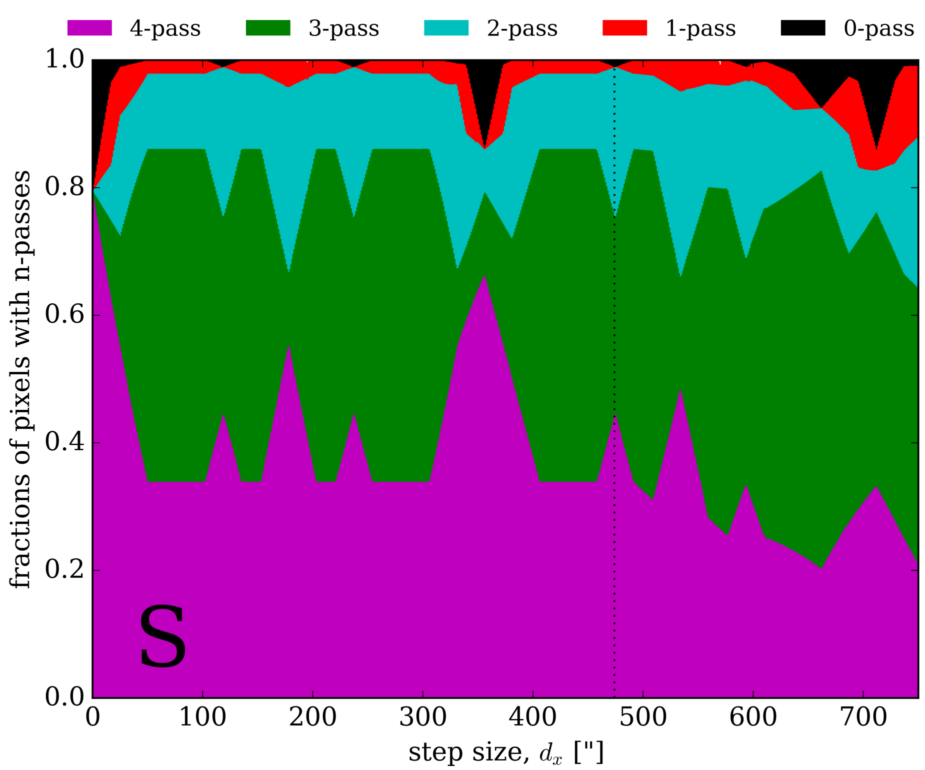


- pure effect of overlaps
- pessimistic: exposure-to-exposure completely random
- optimistic?
  - pixel-to-pixel flat-field **perfectly** constrained otherwise
  - only normalisation of exposure not structure varies with time
- **J**: 0.040% -> 0.013% (q=3.07)
- **S**: 0.040% -> 0.009% (q=4.45)

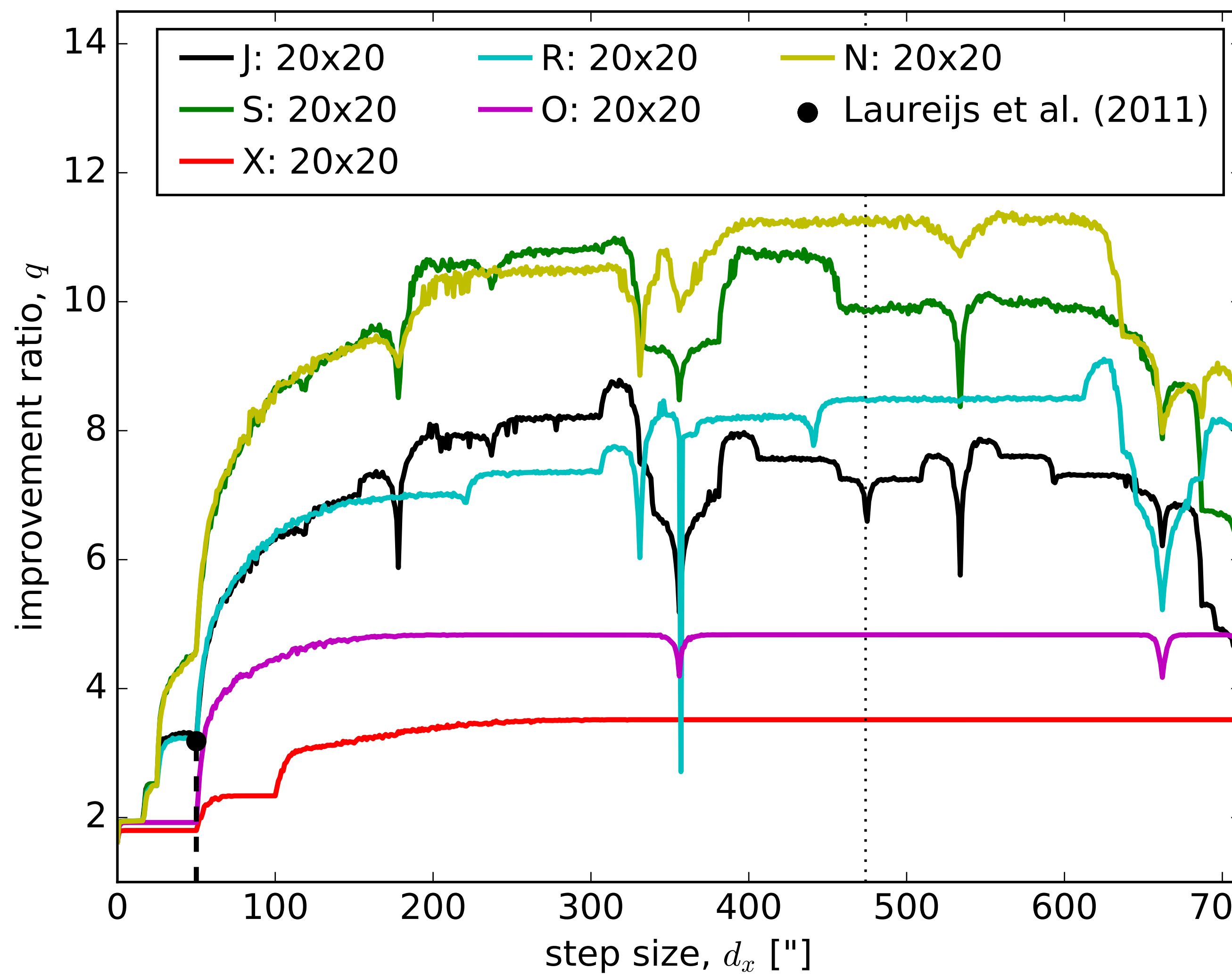
Comparing 4-dither patterns

exposure-to-exposure





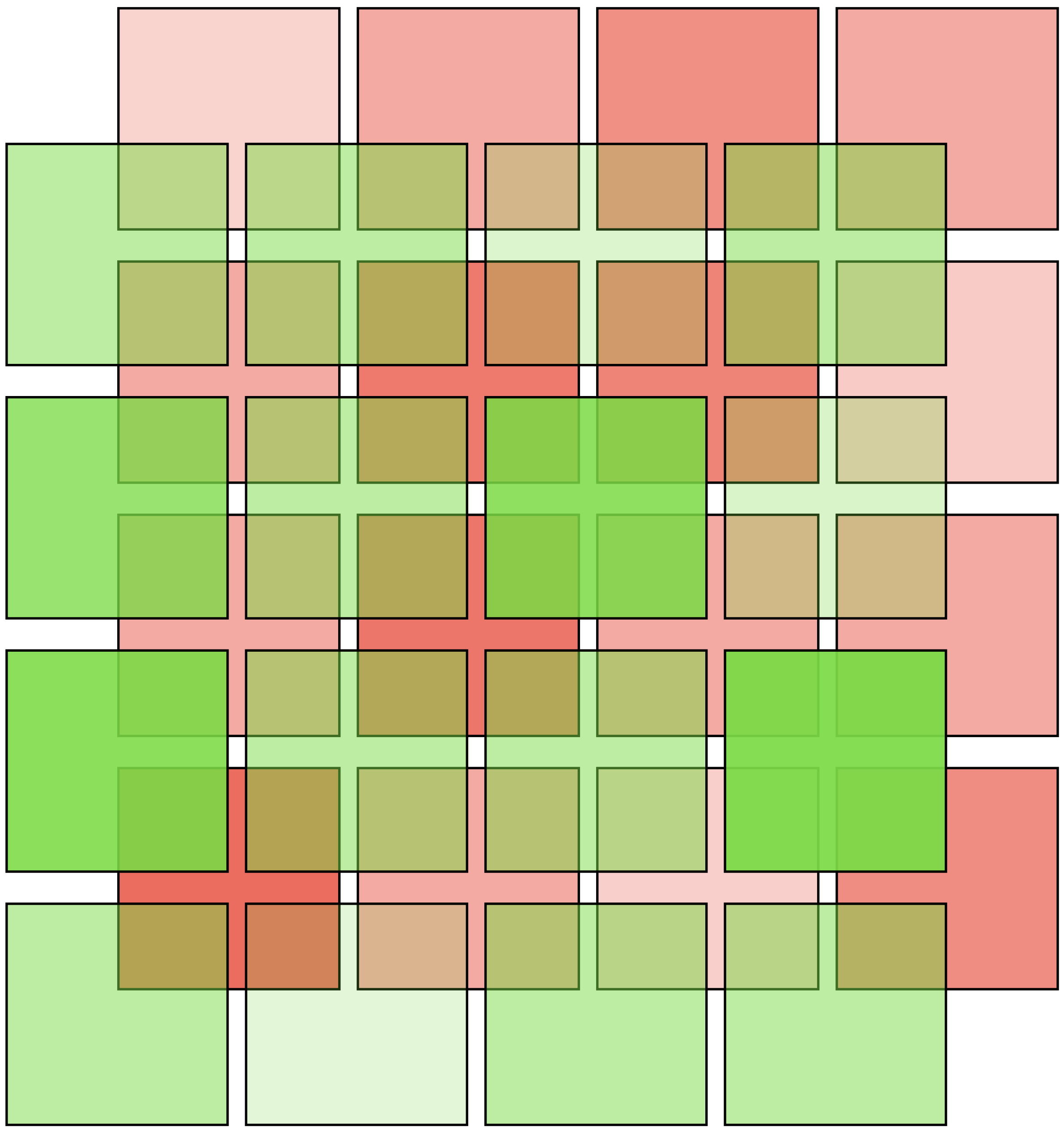
- differ pattern and size
- coverage (left)
- calibration improvement (below)



Markovič et al. (2016, arXiv:1606.07061)

Comparing 4-dither patterns

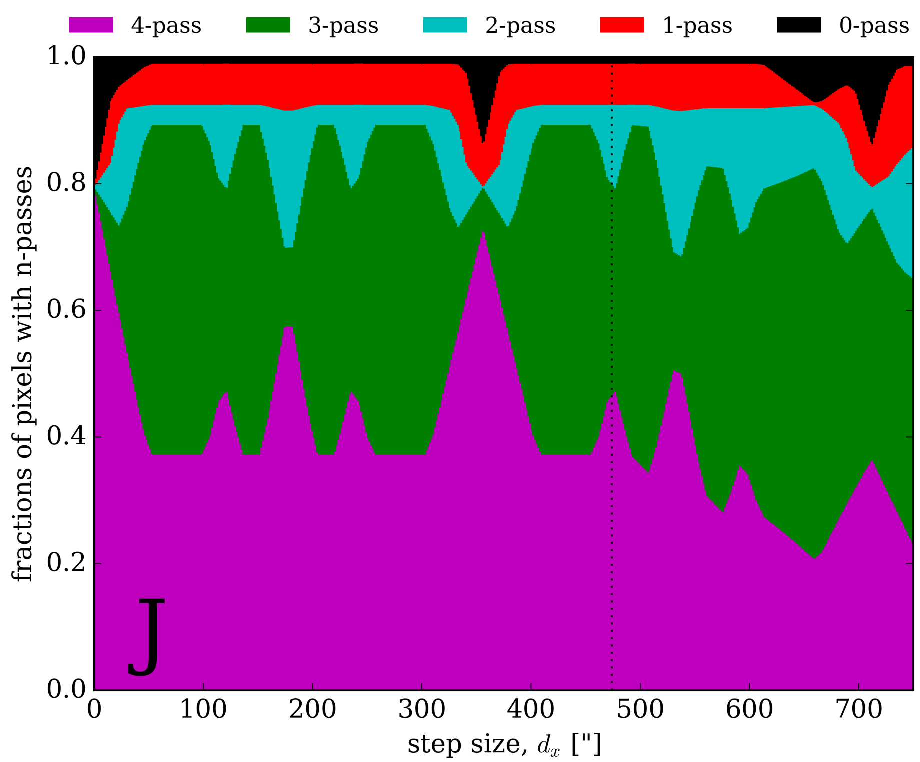
detector-to-detector

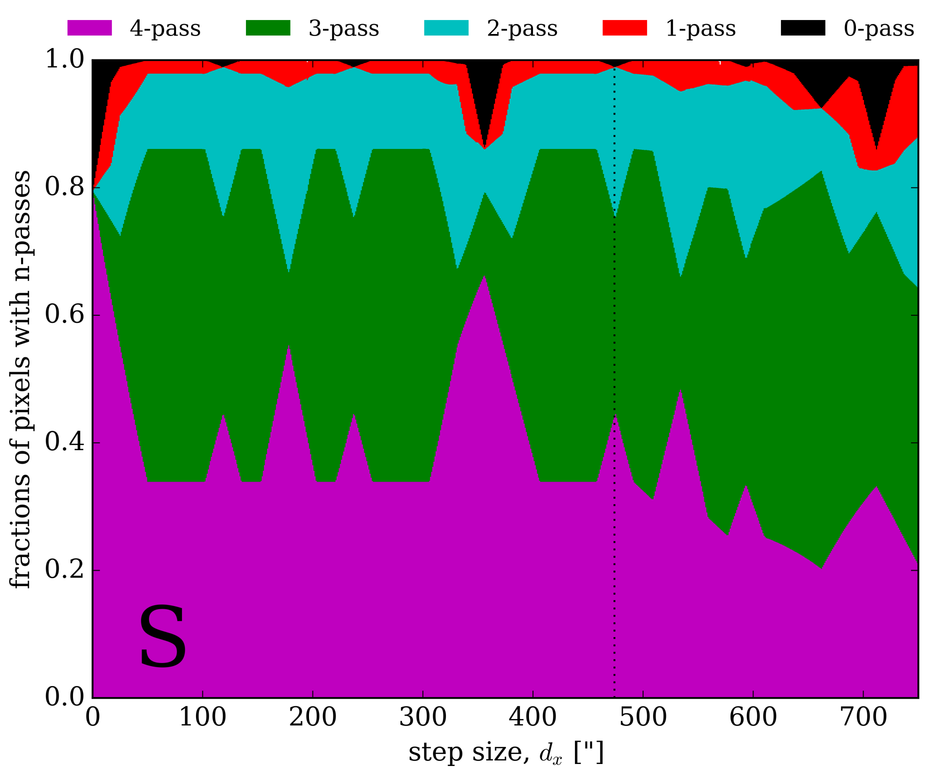


- adds noise
- very pessimistic: detector-to-detector completely random
- optimistic?
  - pixel-to-pixel flat-field **perfectly** constrained otherwise
  - only normalisation of detector not structure varies with time
- **J**: 0.040% -> 0.0162% (q=2.46)
- **S**: 0.040% -> 0.0145% (q=2.76)

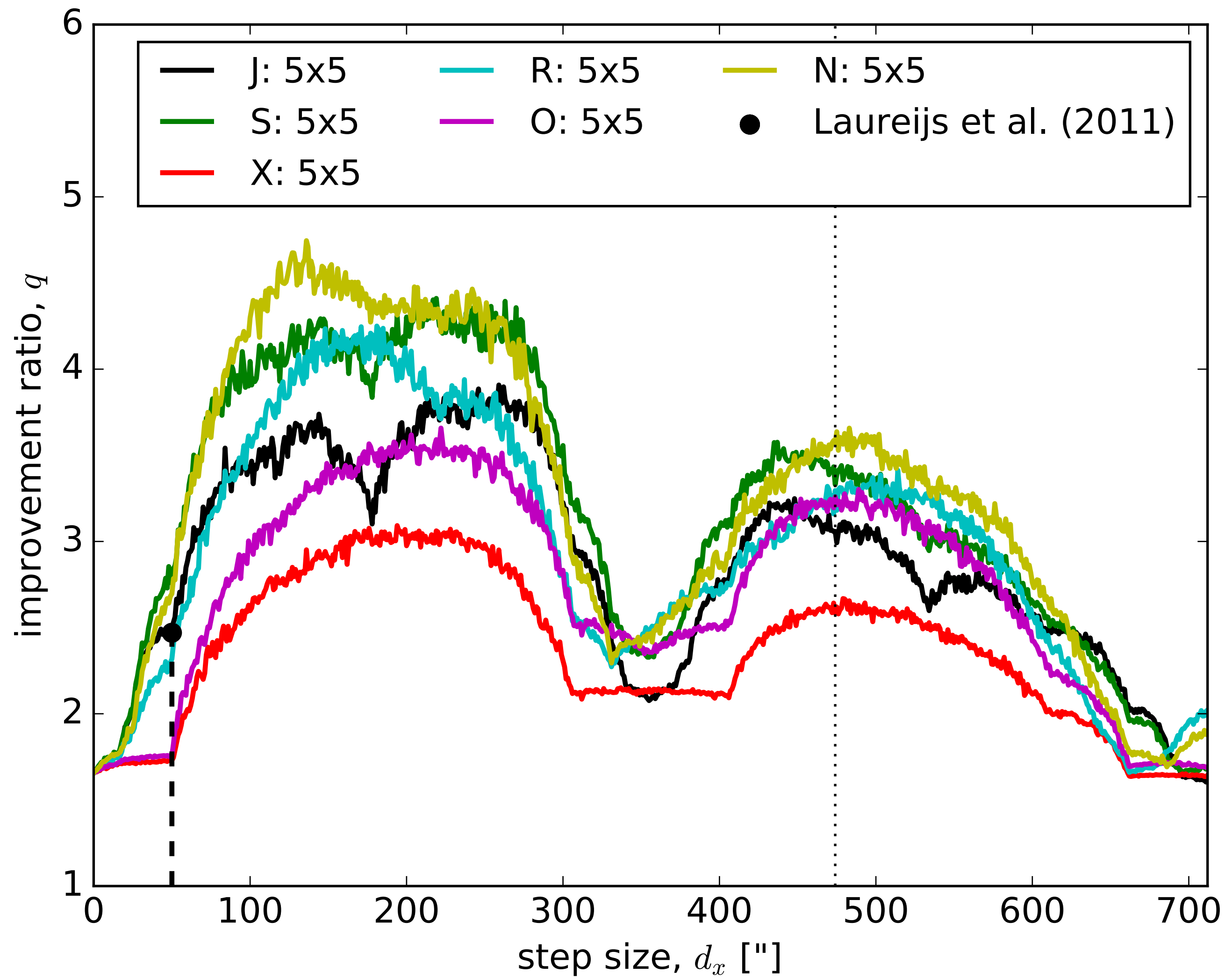
Comparing 4-dither patterns

detector-to-detector





- differ pattern and size
- coverage (left)
- calibration improvement (below)



Markovič et al. (2016, arXiv:1606.07061)

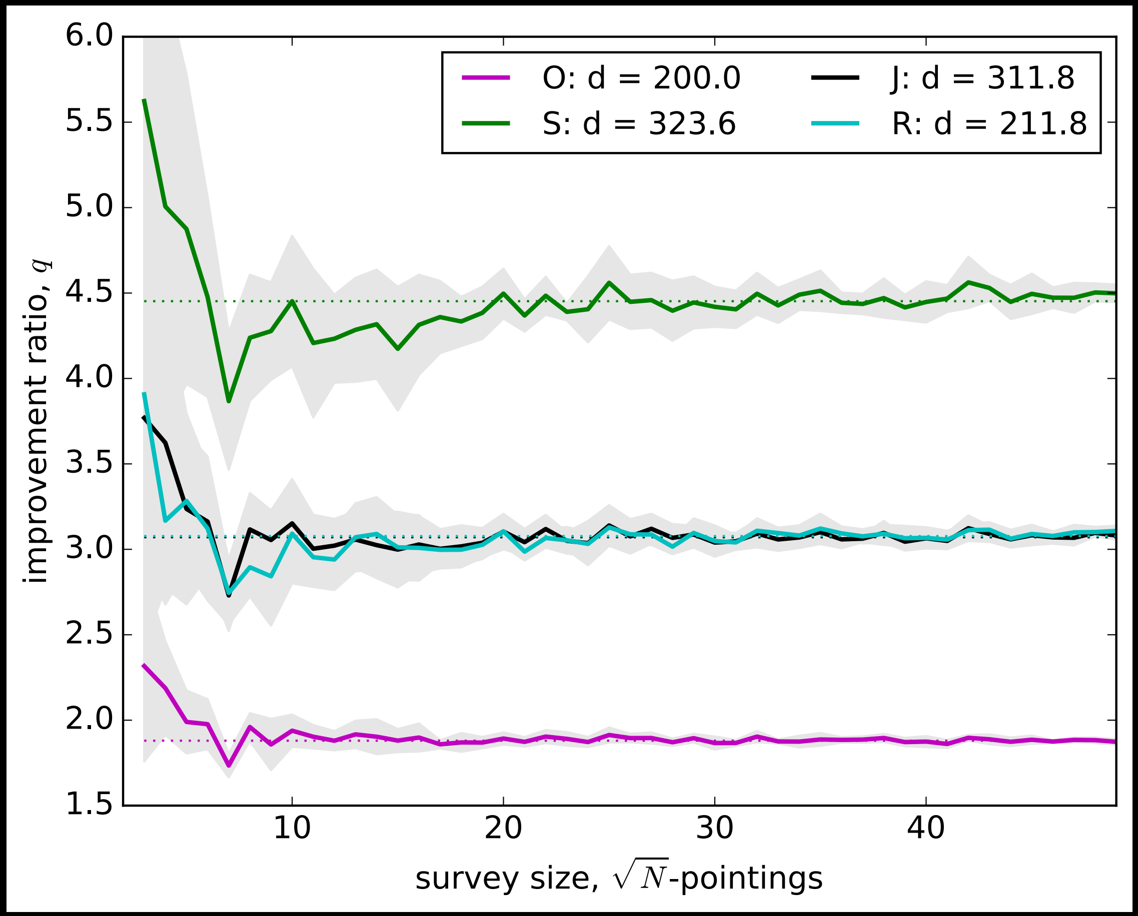
TL;DL

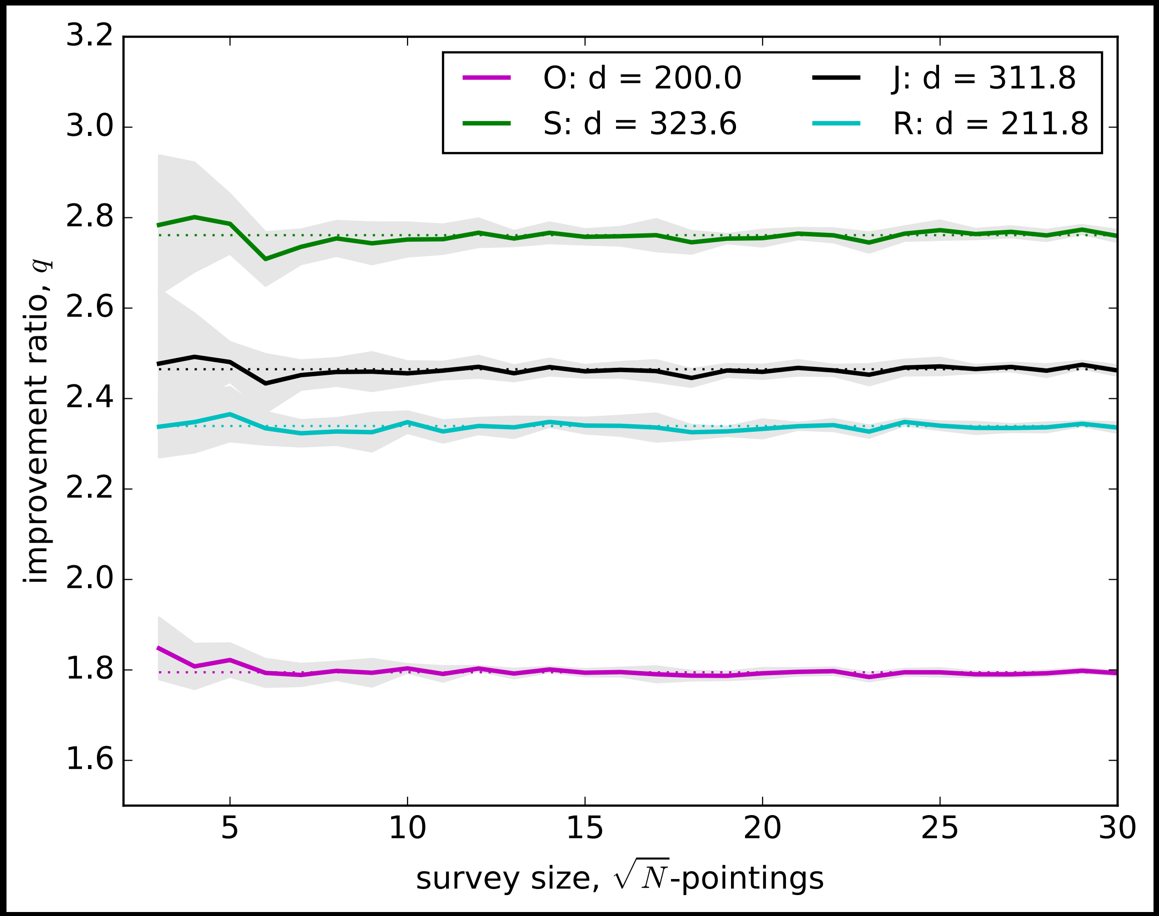
- *Ubercal* = relative photometric self-calibration from overlaps
- simplified by taking optimally weighed means over full overlap tiles
- simulation yielded over a factor of 2 decrease in scatter (depending on strategy)
- minimal modification to dither pattern may be beneficial to *Ubercal*
    - increased horizontal overlap

- Euclid Wiki:
  euclid.roe.ac.uk/projects/gcswg/wiki/Calibration
- code:
  github.com/didamarkovic/ubercal
- paper:
  arXiv:1606.07061

Thank you!

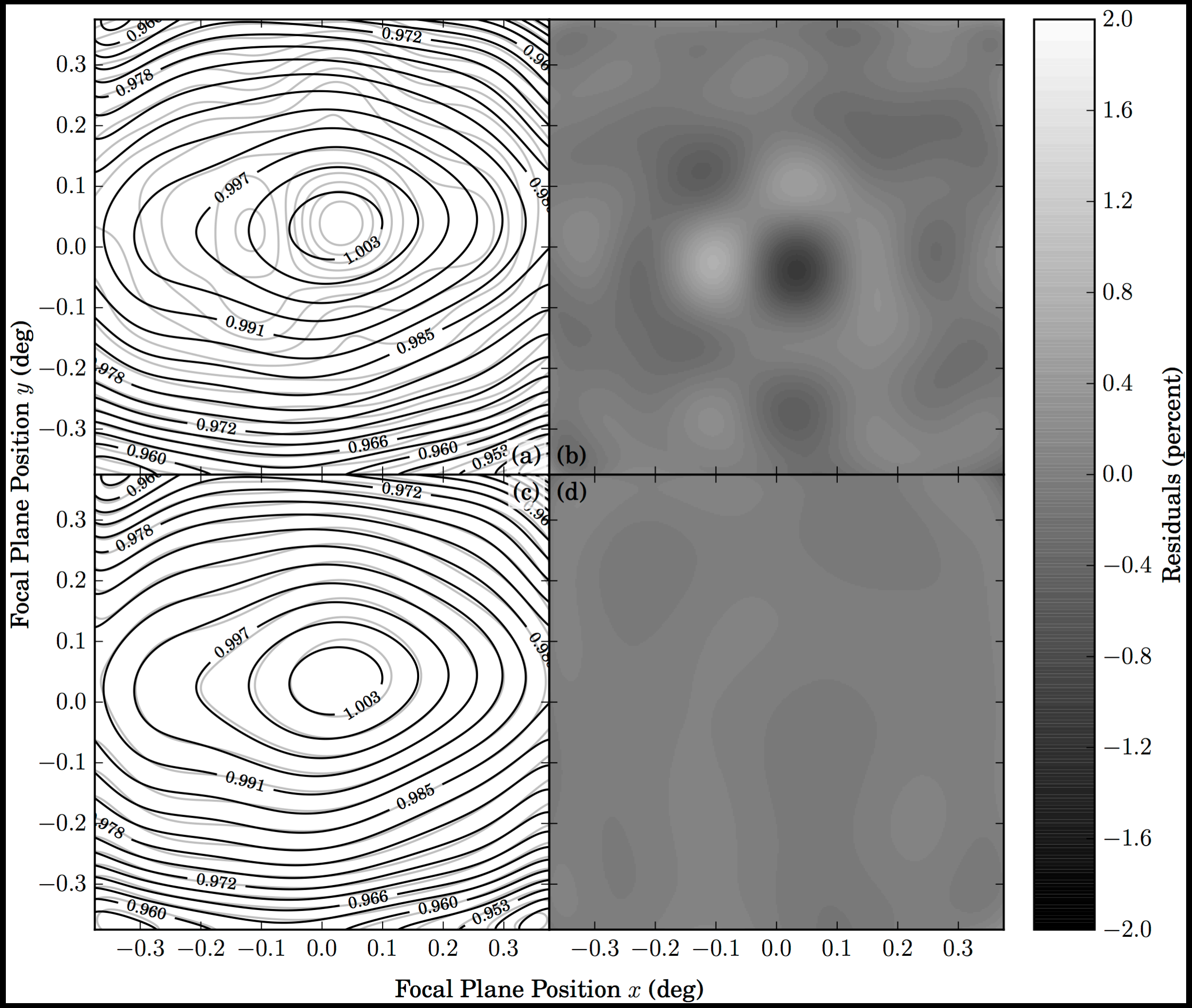
Appendix: convergence





Markovič et al. (2016, arXiv:1606.07061)

Appendix: flat-fields



pat.	# iter.	RMS	Badness	BiB	χ^2
C	26.0	0.2098	0.3373	0.0233	315496.97
QR	13.0	0.2055	0.3388	0.0059	36554.80
J	3459.0	0.2538	0.3340	0.0825	307420.63
S	1447.0	0.2491	0.3364	0.0764	307616.41

Table E1. Results of the Holmes et al. (2012)-like analysis of the S and J patterns. The columns show the number of iterations, the source RMS, the Badness metric, the Best-in-Basis metric and the fit χ^2 for each of the 4 patterns.

Markovič et al. (2016, arXiv:1606.07061)