Gaia DR2 Photometry

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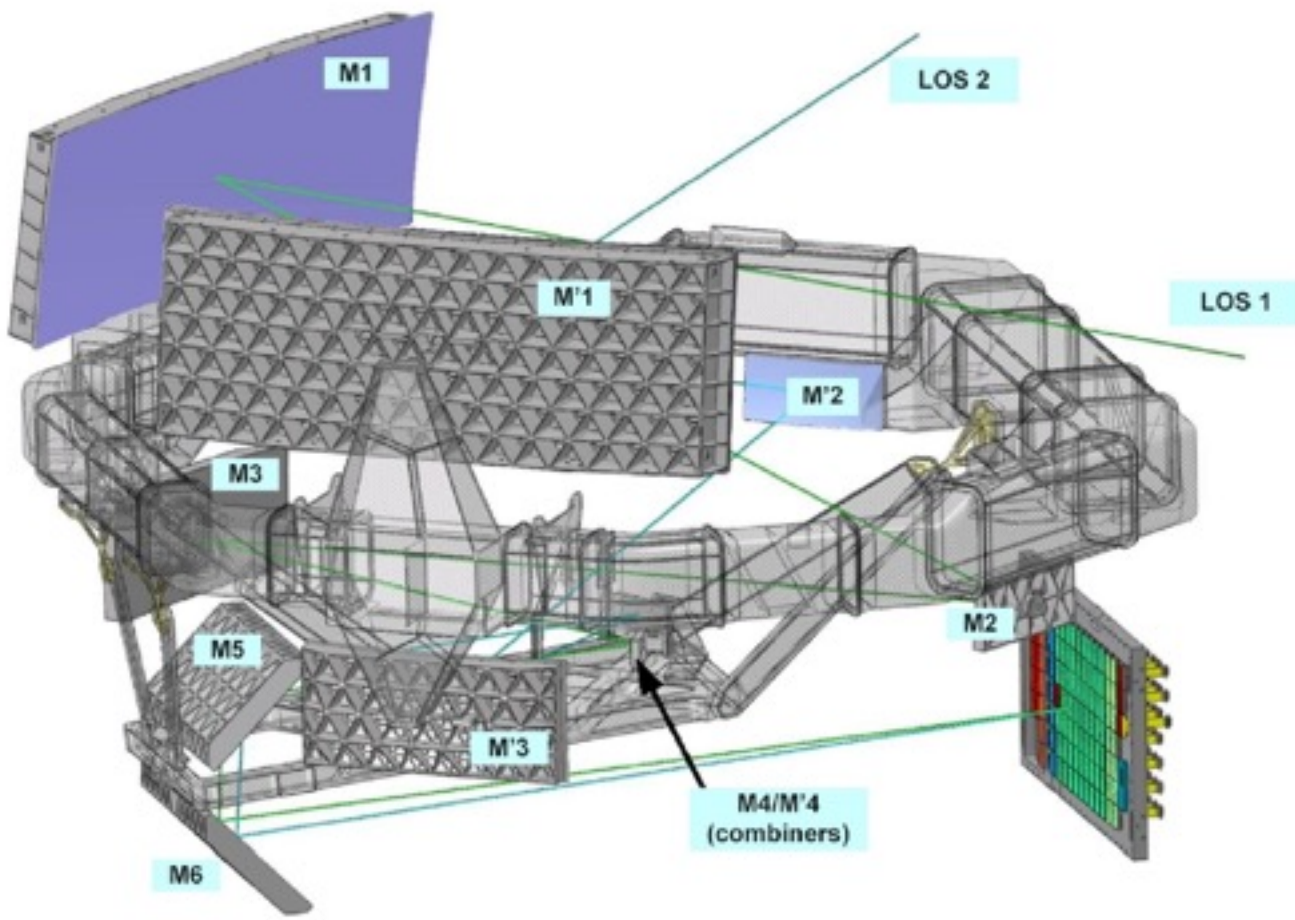
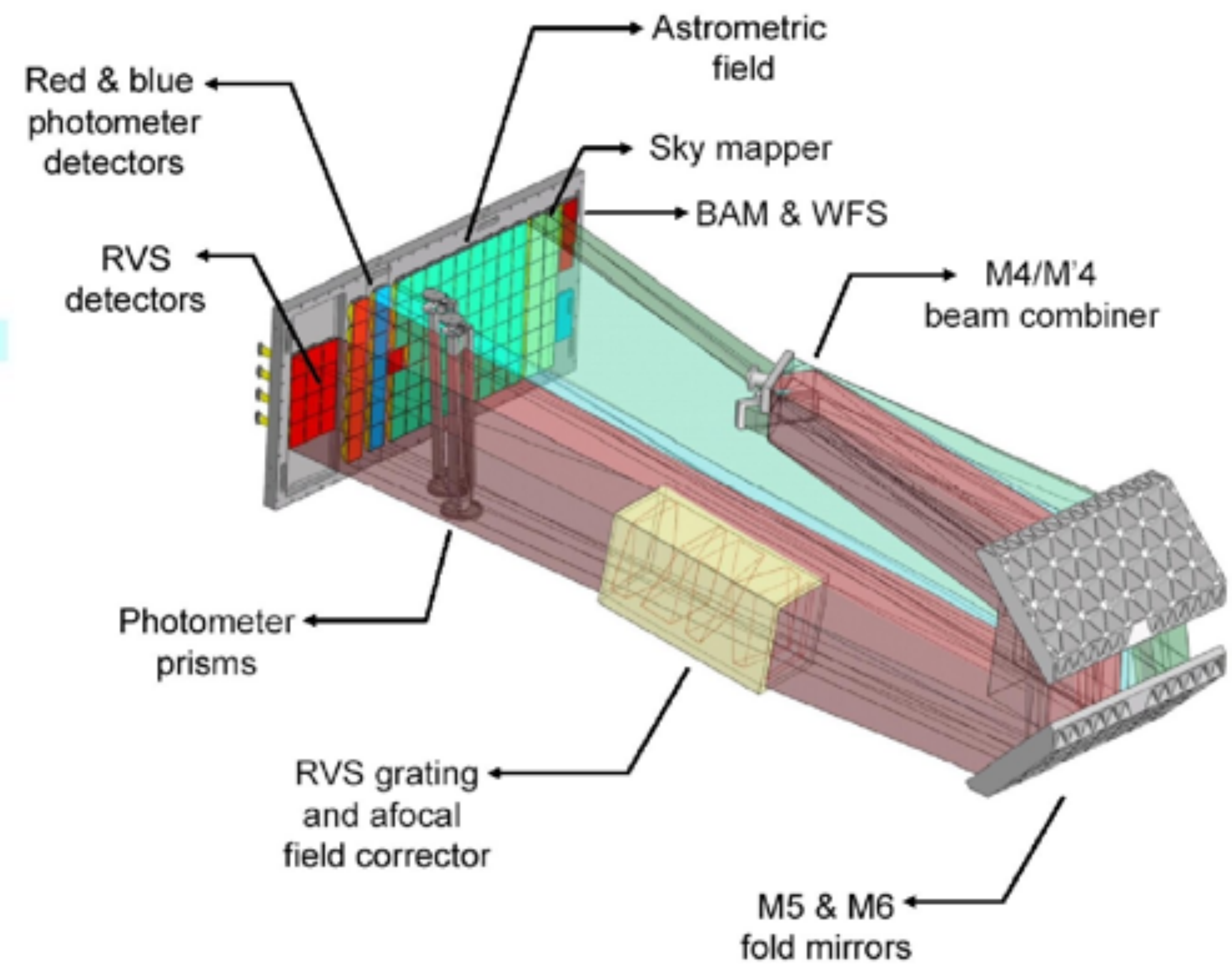
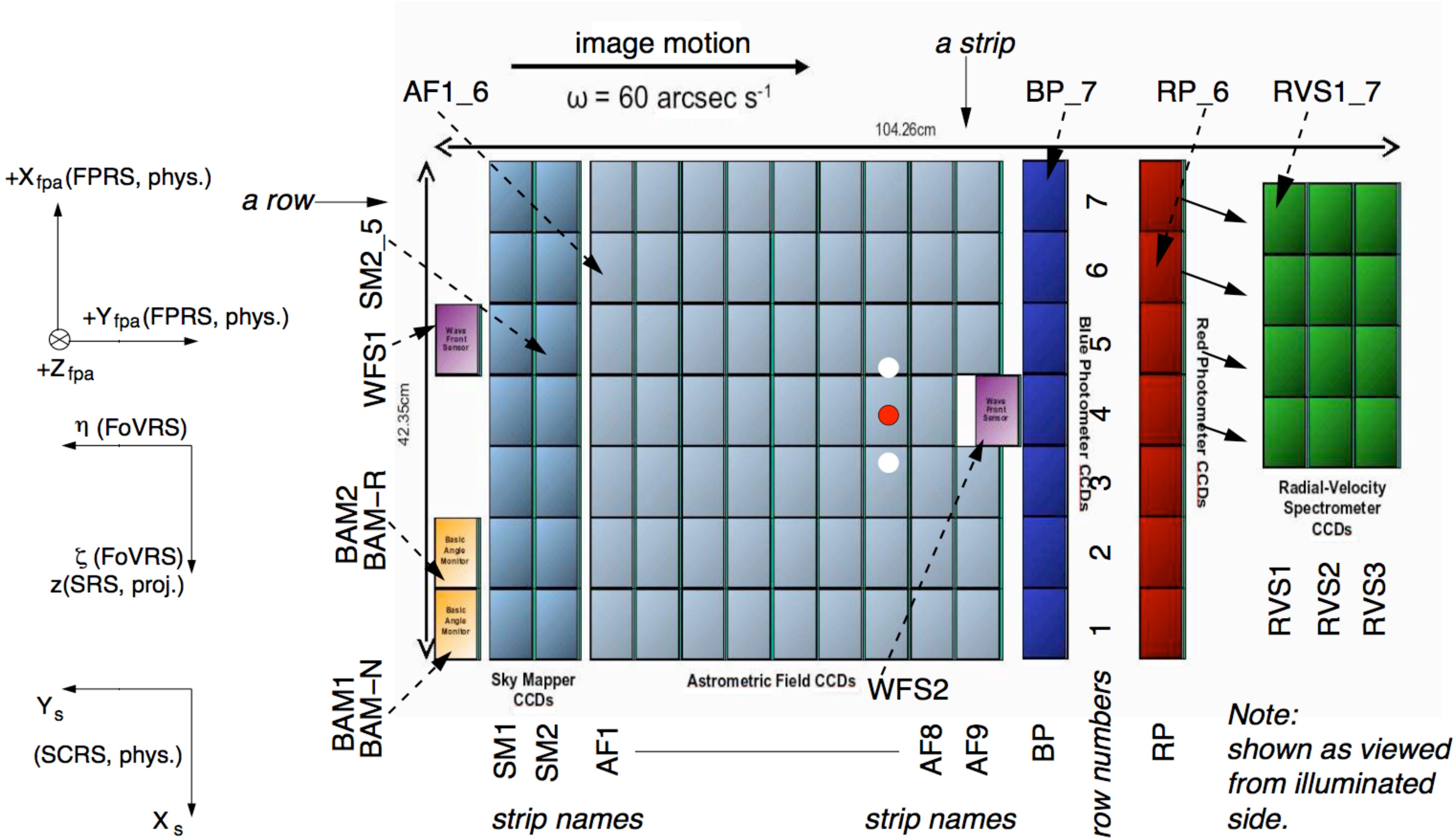
Source of Gaia photometry

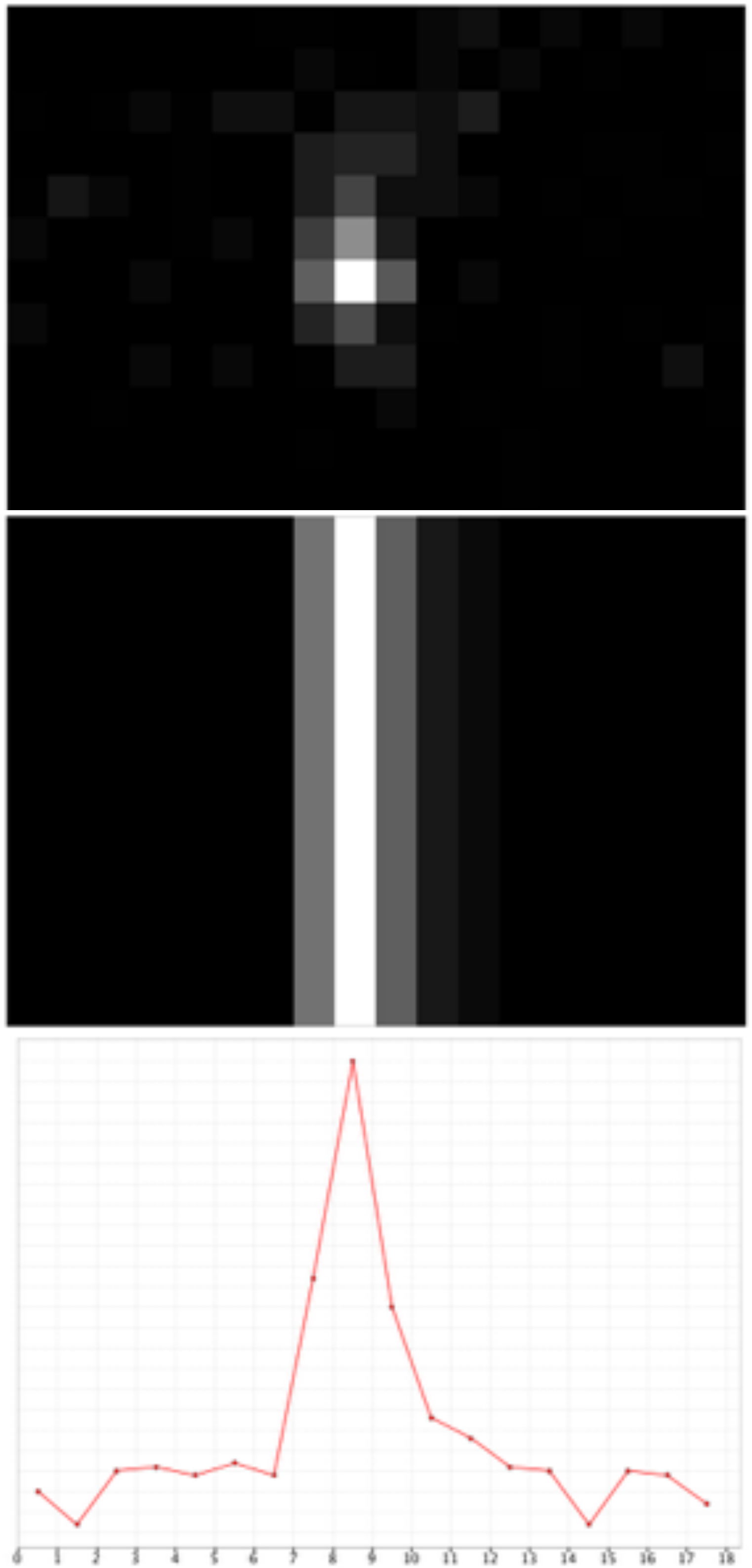




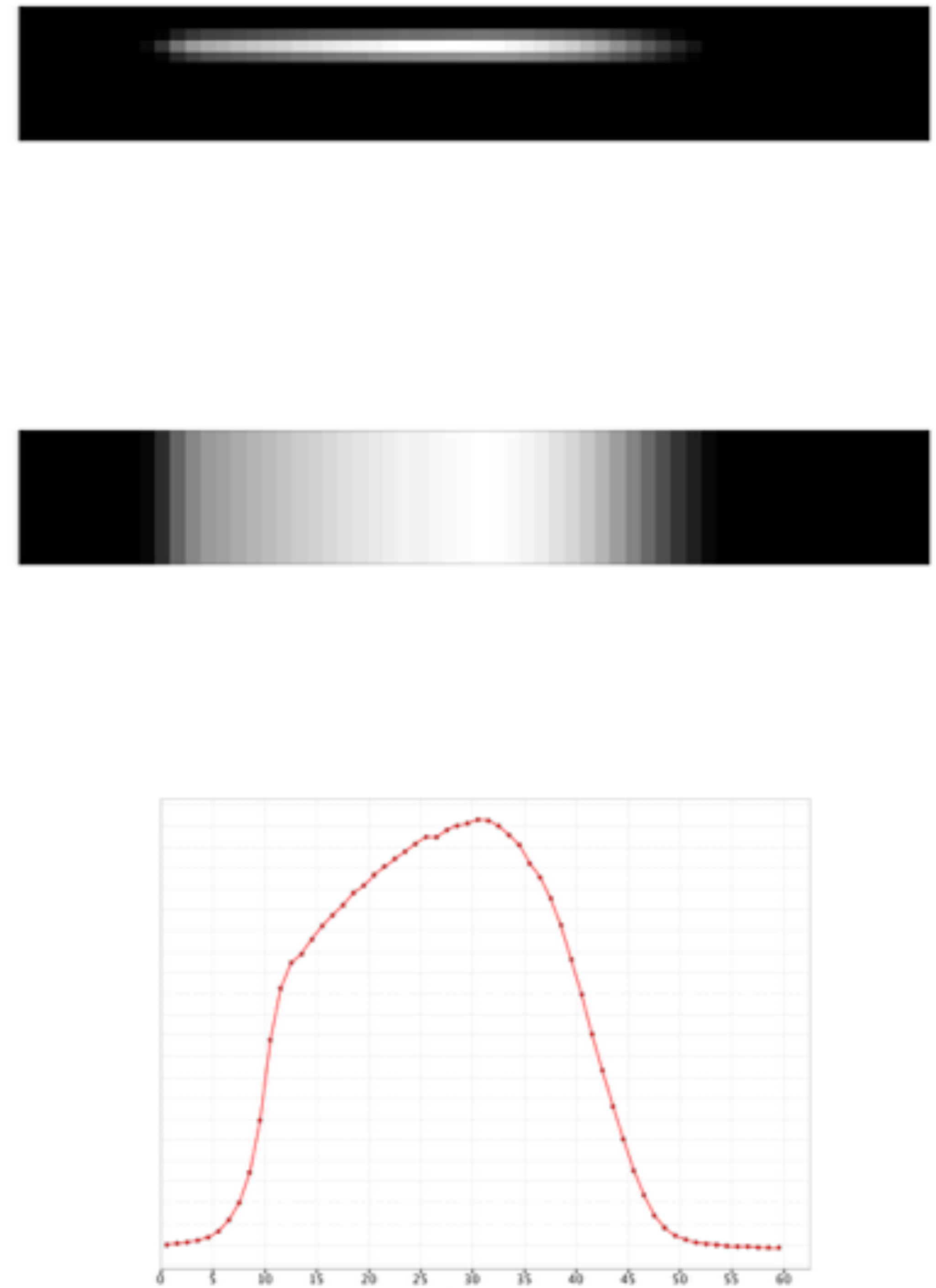
Source of Gaia photometry



AF



BP/RP



Source of Gaia photometry

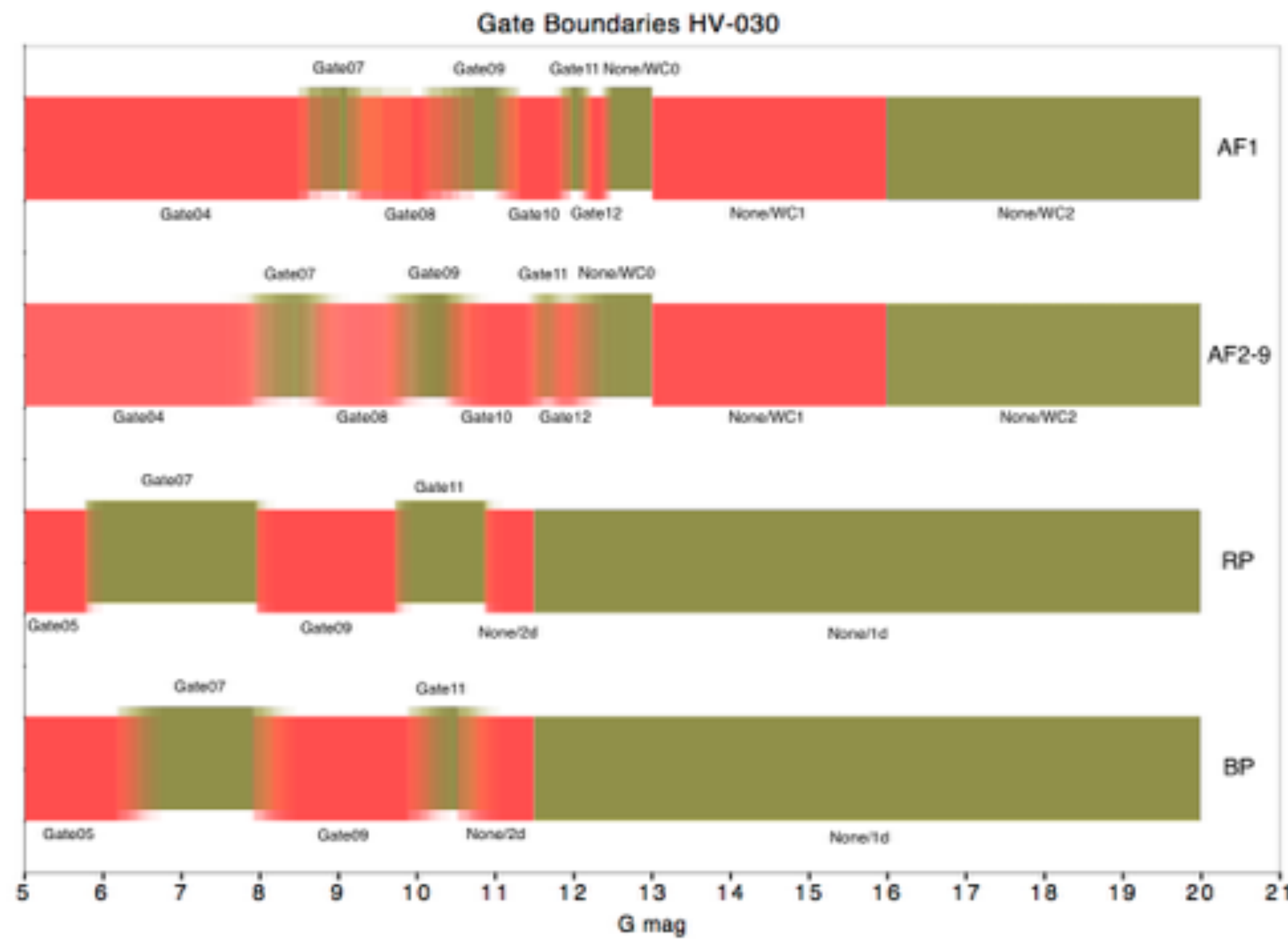
- AF (G-band)
  - Results of Image Parameter Determination
    - LSF/PSF fitting to corrected samples
      - bias, etc.
      - background components (charge release, straylight, astrophysical)

- Integrated BP/RP photometry
  - Results of summing up bias and background-corrected samples

Gating

- Gaia observes with TDI which implies a fixed exposure time
- Gating the CCD allows us to vary this
  - End up with less saturation

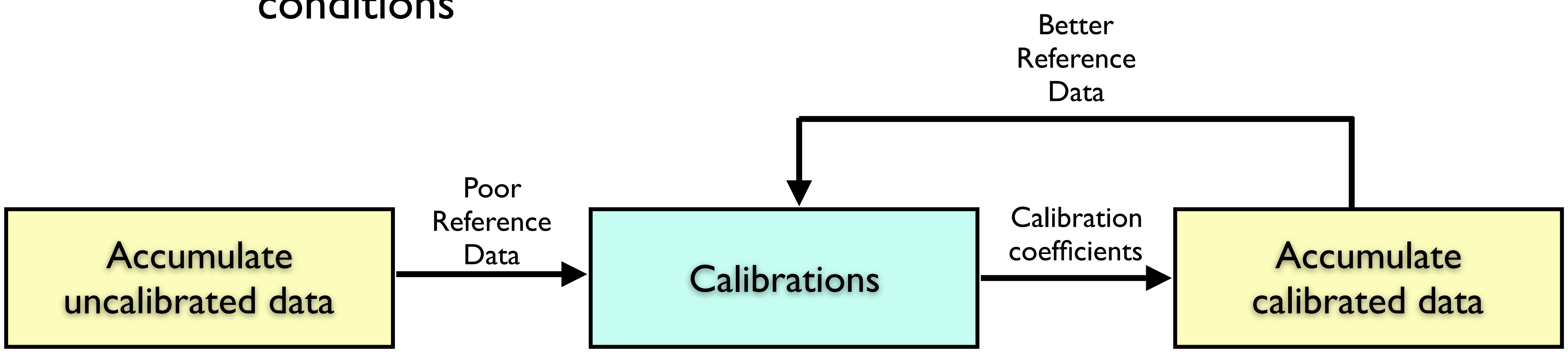
- Gating implies using a different part of the CCD for each gate configuration
  - Each configuration therefore needs a separate calibration



- Limitations of on-board magnitude estimates
  - G<12 accuracy drops to 0.5 mag
  - Saturation masking helps a bit

Basic Principle

- Internal Calibration: self-calibrating system
  - Create first set of reference fluxes from uncalibrated transits (For all sources)
  - Iterate many times between calibrating transits and producing a mean flux for each source
    - Method works since sources are observed under many different conditions



- External calibration
  - Uses ~100 ground-based spectrophotometric standards
  - Done at end of processing chain
    - Flux — zeropoint and passband definition
    - BP/RP Spectra — absolute response

Averaging the fluxes (accumulation)

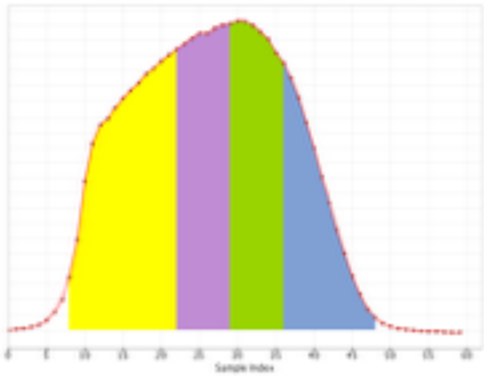
- We work in flux space
  - The errors are more symmetric in flux
    - If you work in magnitudes then you will bias your faint results
  - Although we publish magnitudes, we do not publish magnitude errors
    - The magnitude errors are not symmetric
    - This is also to get the user to think

- Averages are inverse variance weighted
  - This gives the theoretical best result (in the absence of outliers)
  - Used for mean source photometry and FoV transits (light curves)
  - Errors on CCD fluxes are heteroscedastic

- Scatter measure taken into account in error on mean calculation
  - The flux errors at the CCD level are underestimated for AF
    - They do not account for modelling errors
  - This works well for mean source photometry
  - FoV calculation suffers from low number statistics
    - Still much better than errors on CCD-level photometry

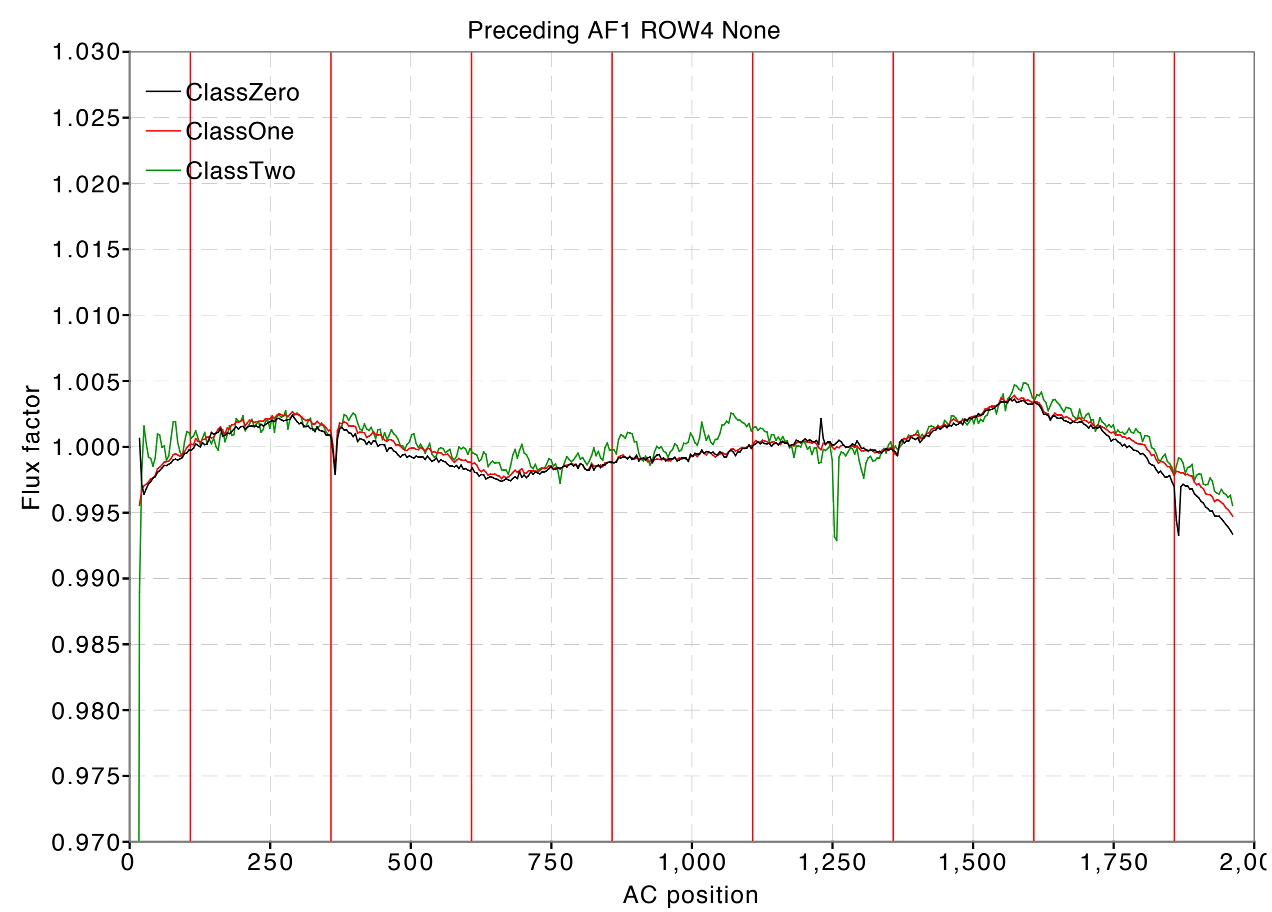
Additional colour information

- Originally (pre-launch tests) used BP-RP as the colour
  - needed 5th order polynomial
  - extrapolating these is very unwise
- Use Spectral Shape Coefficients instead
  - derived from BP/RP spectra
    - geometric and differential dispersion calibrations applied
    - A set of four fluxes extracted from each of BP and RP
    - equivalent to medium band photometry
    - used linearly in calibrations
  - For DR1 and DR2 calibrated exactly like the other fluxes
    - including iteration of the reference fluxes
  - For DR3 we will calibrate the BP/RP spectra and then extract the SSC values
    - no further calibration will be needed of the SSCs



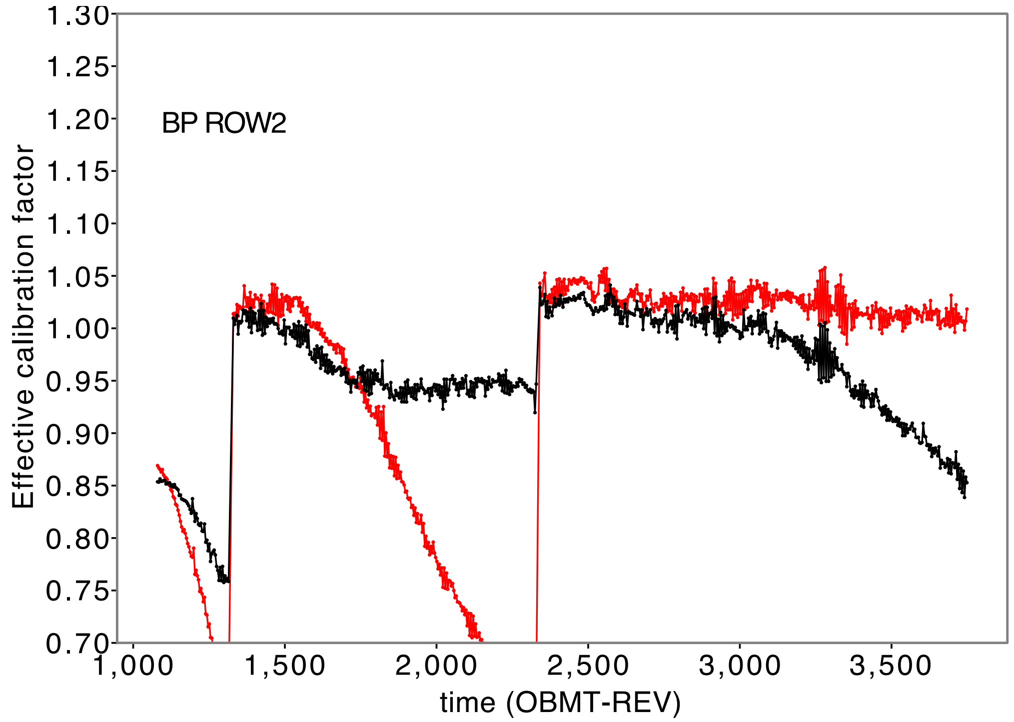
“Planned” Calibrations

- Large and small-scale calibrations are iterated
  - Calibrations split by time ranges, CCD, FoV, gate, window class
  - Large-scale dependencies
    - Position on CCD ⊥ to scan direction (AC position)
    - Colour information
      - Spectral shape coefficients
  - Small-scale dependencies
    - Effectively a 1d flat field
    - No colour terms used



“Unplanned” calibrations TLC

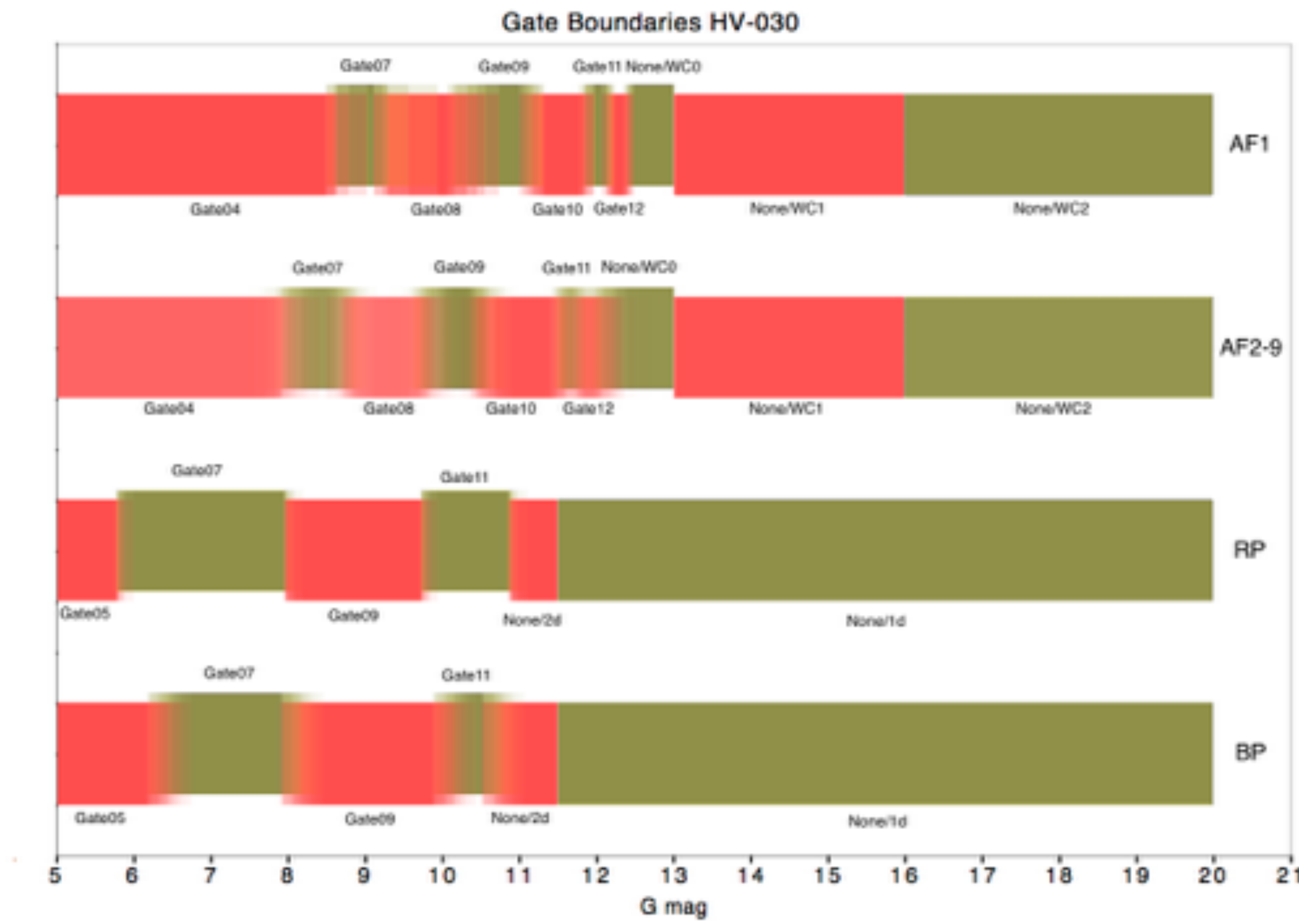
- Time varying contamination
  - throughput changed considerably
  - combined with EPSL
  - translates to a sky position dependency
  - systematic baked into the reference system



- Time Link Calibrations
  - purely differential calibrations
    - assumes source has not changed over time period considered
    - variables are filtered out as outliers

“Unplanned” calibrations GWLC

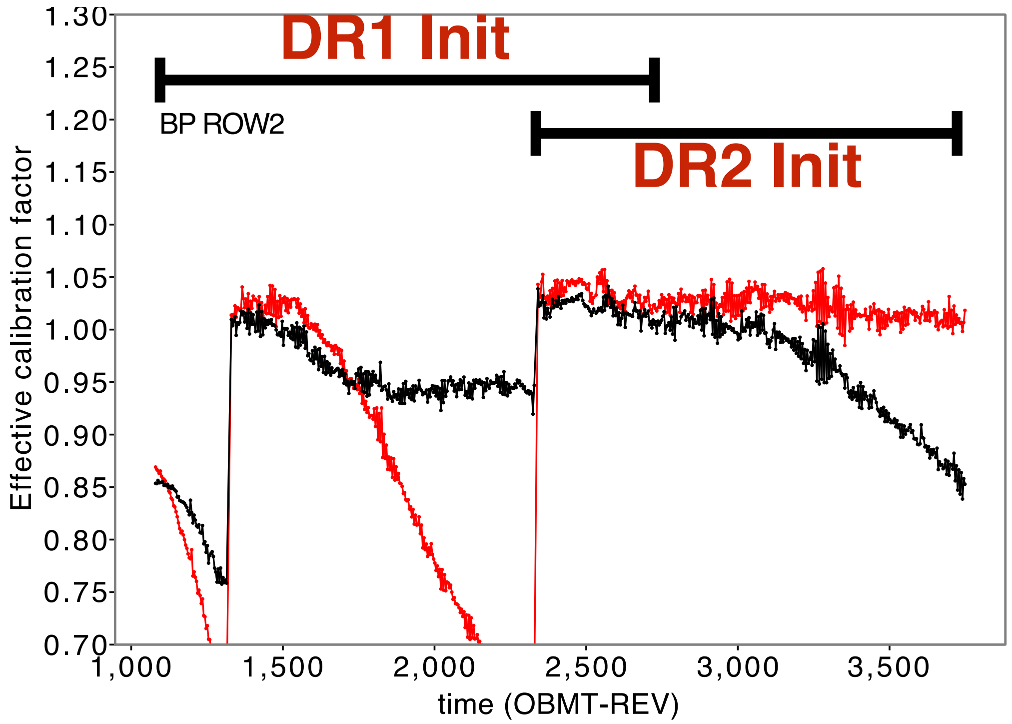
- Gate selection needs a brightness
  - On-board magnitude measure
    - Fainter than G=12
      - unsaturated
      - sum photons
      - accuracy about 1%
    - Brighter than G=12
      - saturated
      - areal estimate
      - accuracy about 50%



- Fainter than G=12 danger of independent photometric systems forming
- Gate Window Class Link Calibration
  - another differential calibration
  - Size of jumps remaining
    - Raw 14 mmag
    - DR1 10 mmag
    - DR2 3 mmag

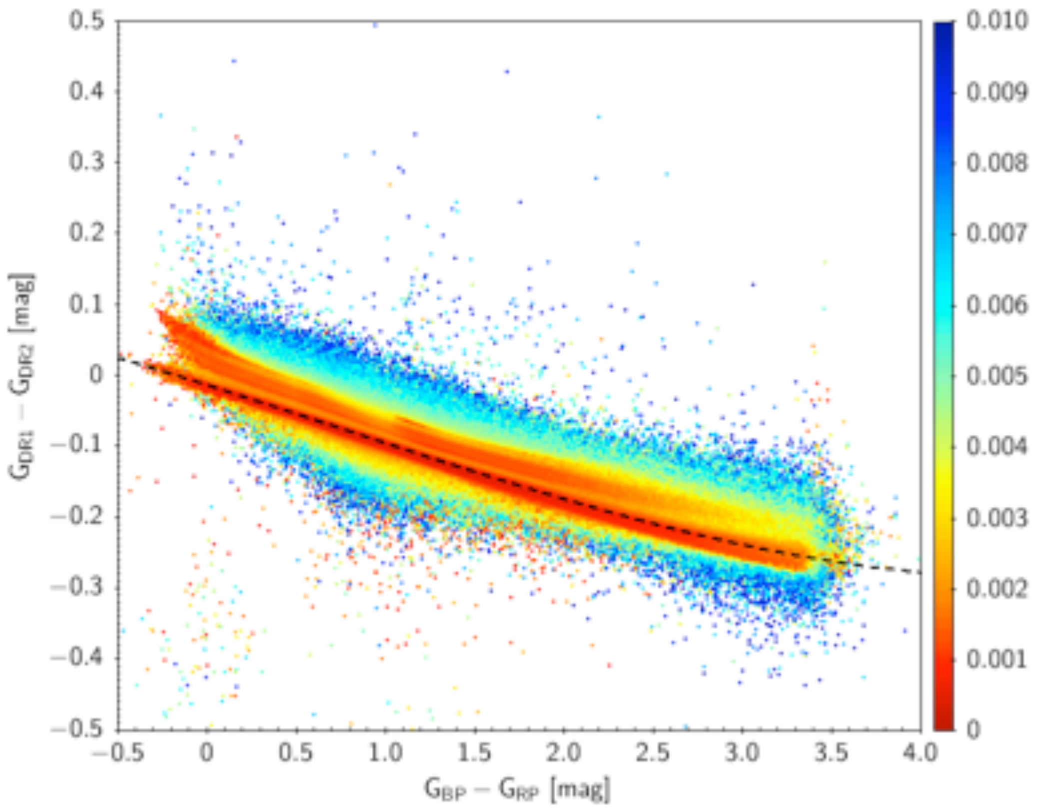
DR1 to DR2 processing differences

- Initialization period different
- DR2 initialization period less contamination
  - effectively a different photometric system
    - significant colour term between the two systems



- Do not use relations derived for DR1 on DR2 photometry
  - Do not use Jordi et al. 2010 (nominal, prelaunch relationships)

- **Use relationships in Evans et al. 2018**

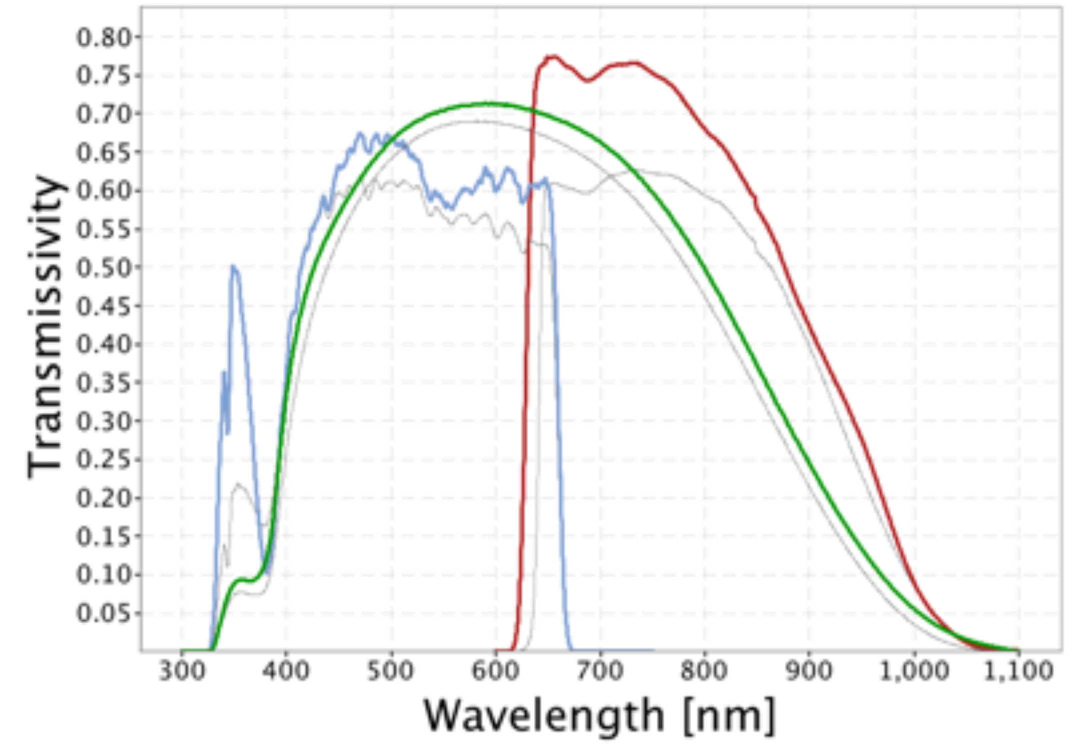


DR1 to DR2 processing differences

- Accumulation improvements
  - Sigma clipping added to remove outliers
  - Sigma is measured from all epochs for a given source and not from individual transits
    - intended to avoid overclipping variables

- Upstream calibrations improved a lot
  - LSF/PSF more sophisticated
  - Handling of saturated pixels better
  - Will be even better in DR3

External Calibration

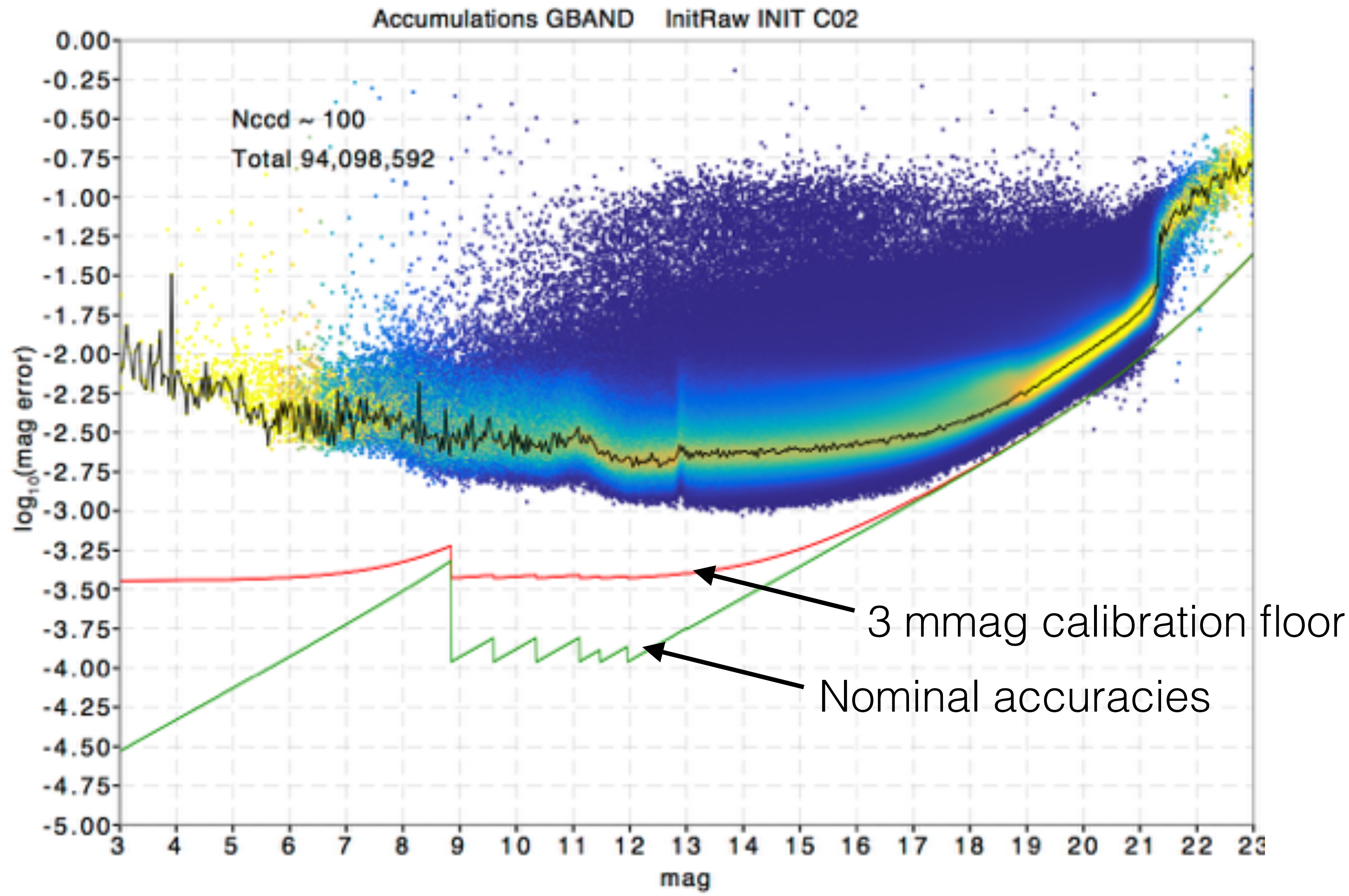


- Determines passband of published photometry
  - not a further calibration of the photometry
  - given the internally calibrated photometry, what passband best represents this

- Magnitude zeropoints also part of external calibration
  - Vega and AB magnitude scale

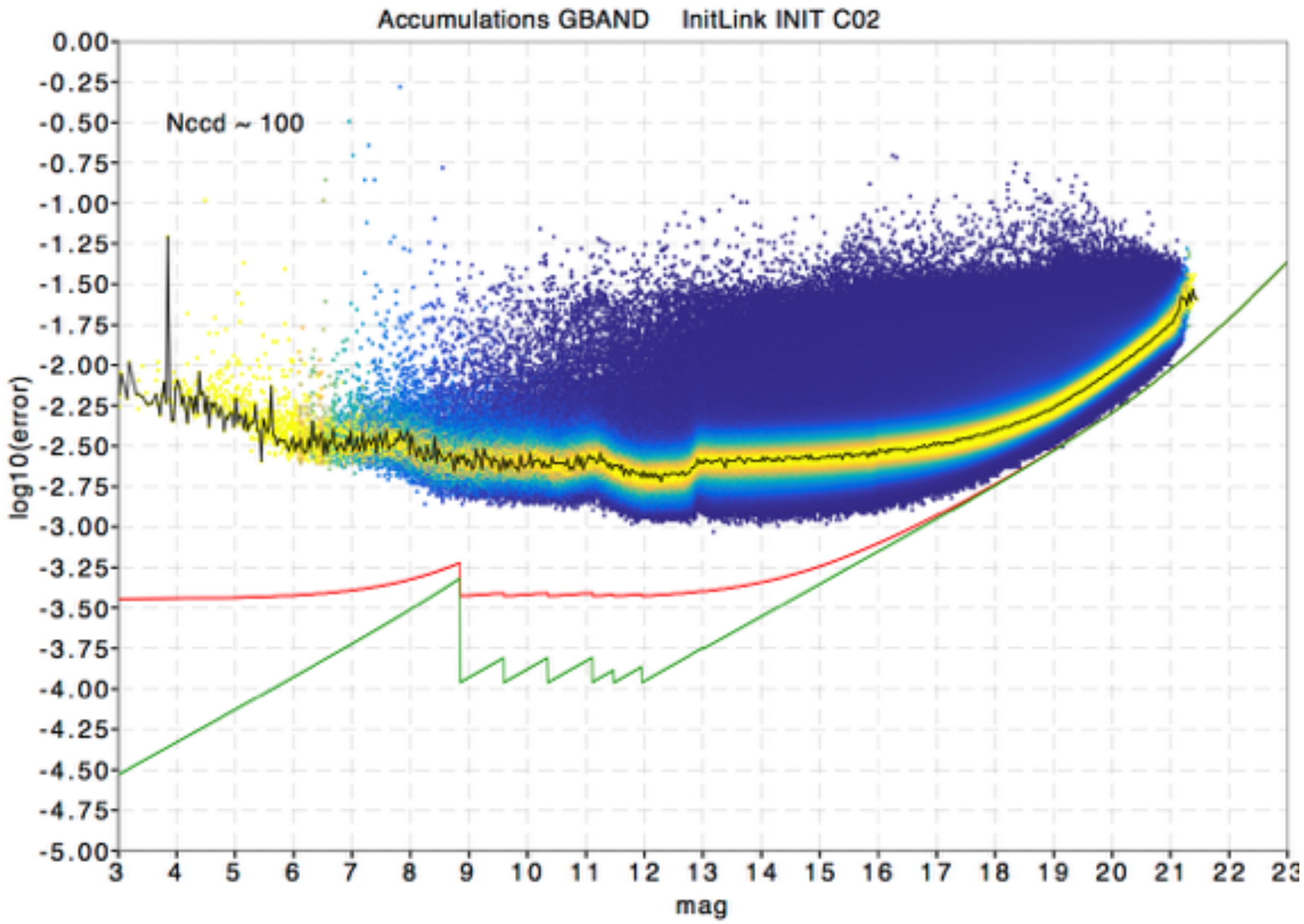
Validations

Error estimates on the mean - G band



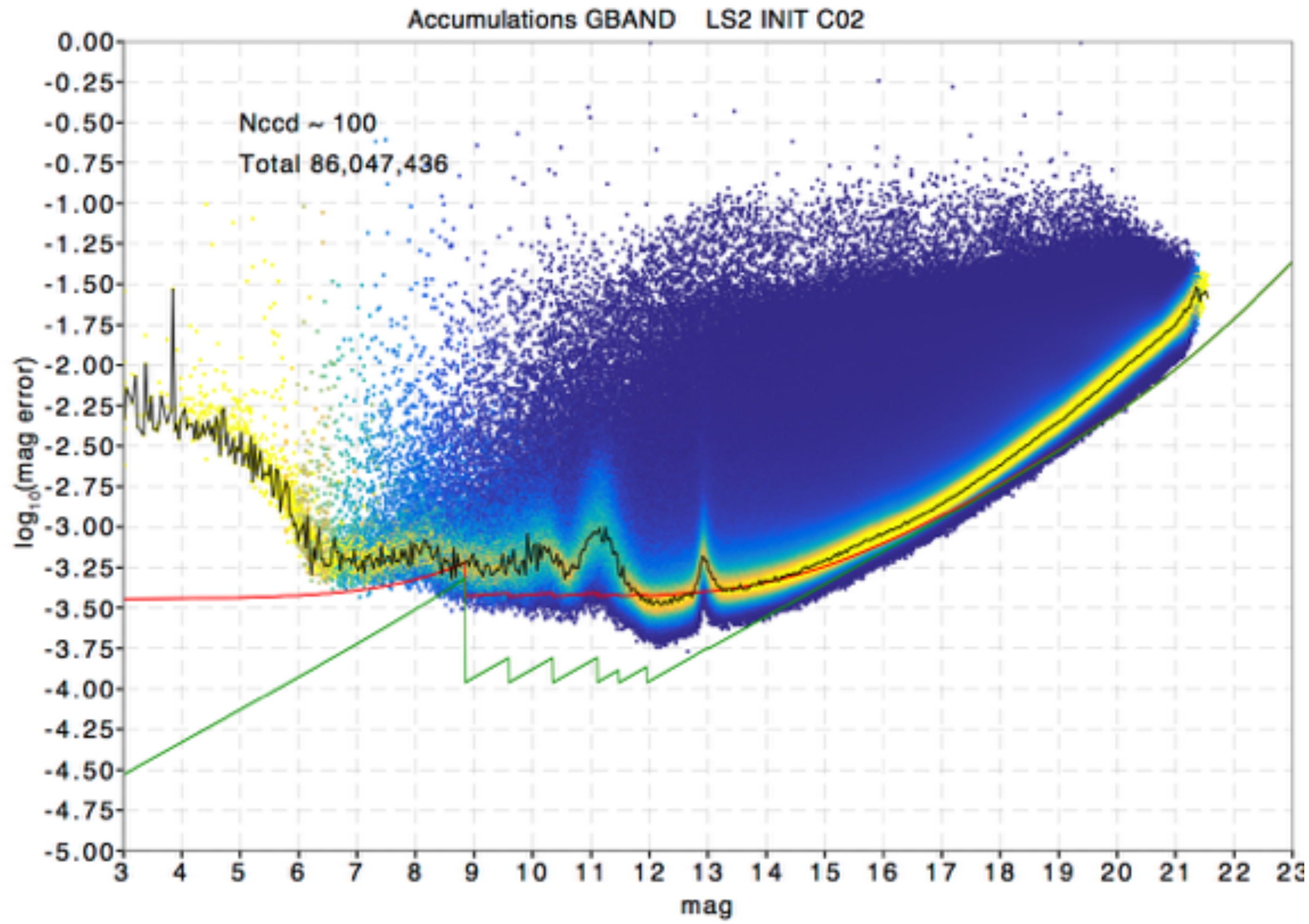
- Limited to sources with about 100 CCD transits
  - Helps with comparison with DR1
  - Probably twice as many transits expected in Gaia DR2
- 3 mmag calibration floor is what we achieved in DR1

Error estimates on the mean - G band



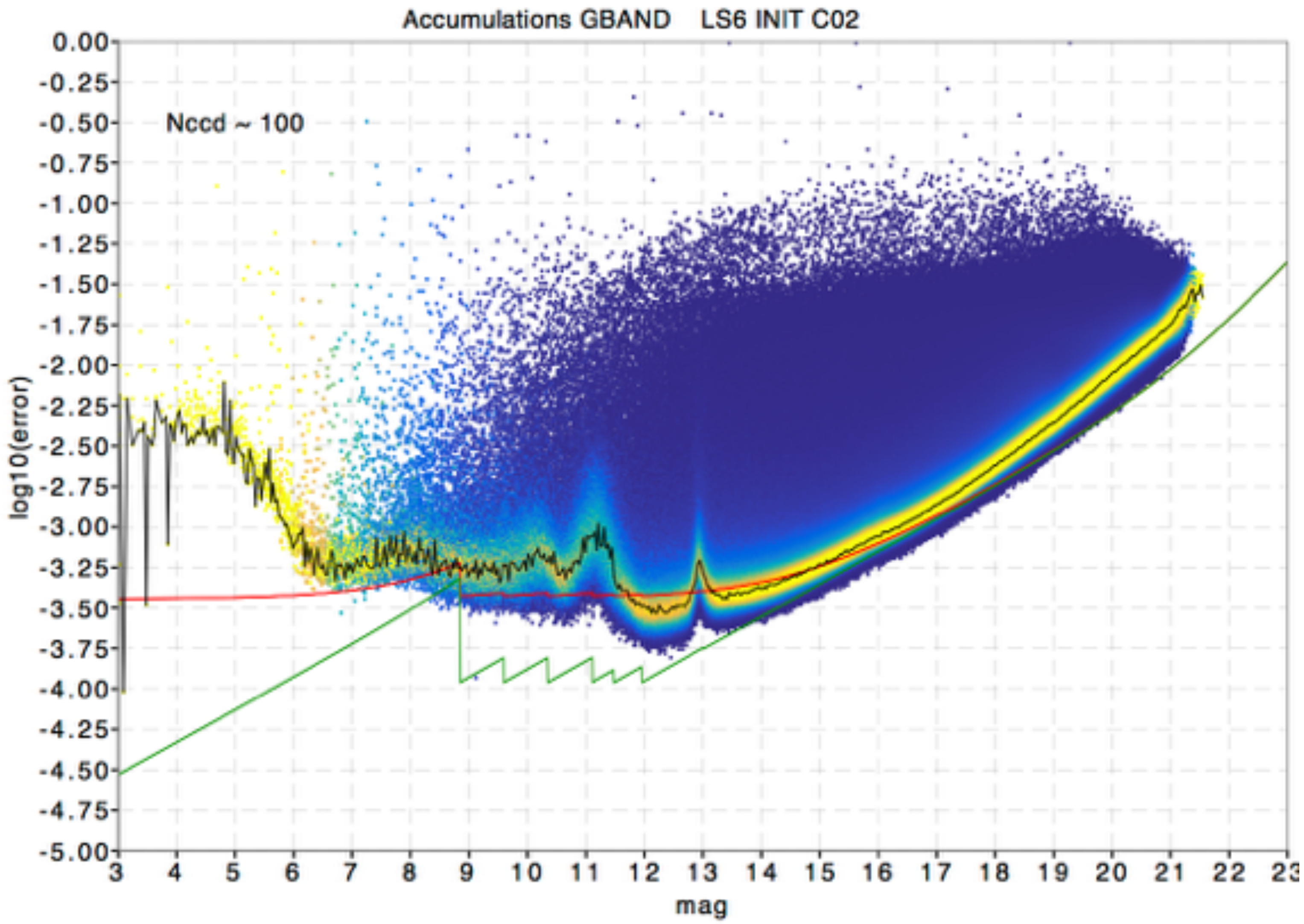
- Not much improvement from Link Calibrations since initialization done using low contamination period

Error estimates on the mean - G band



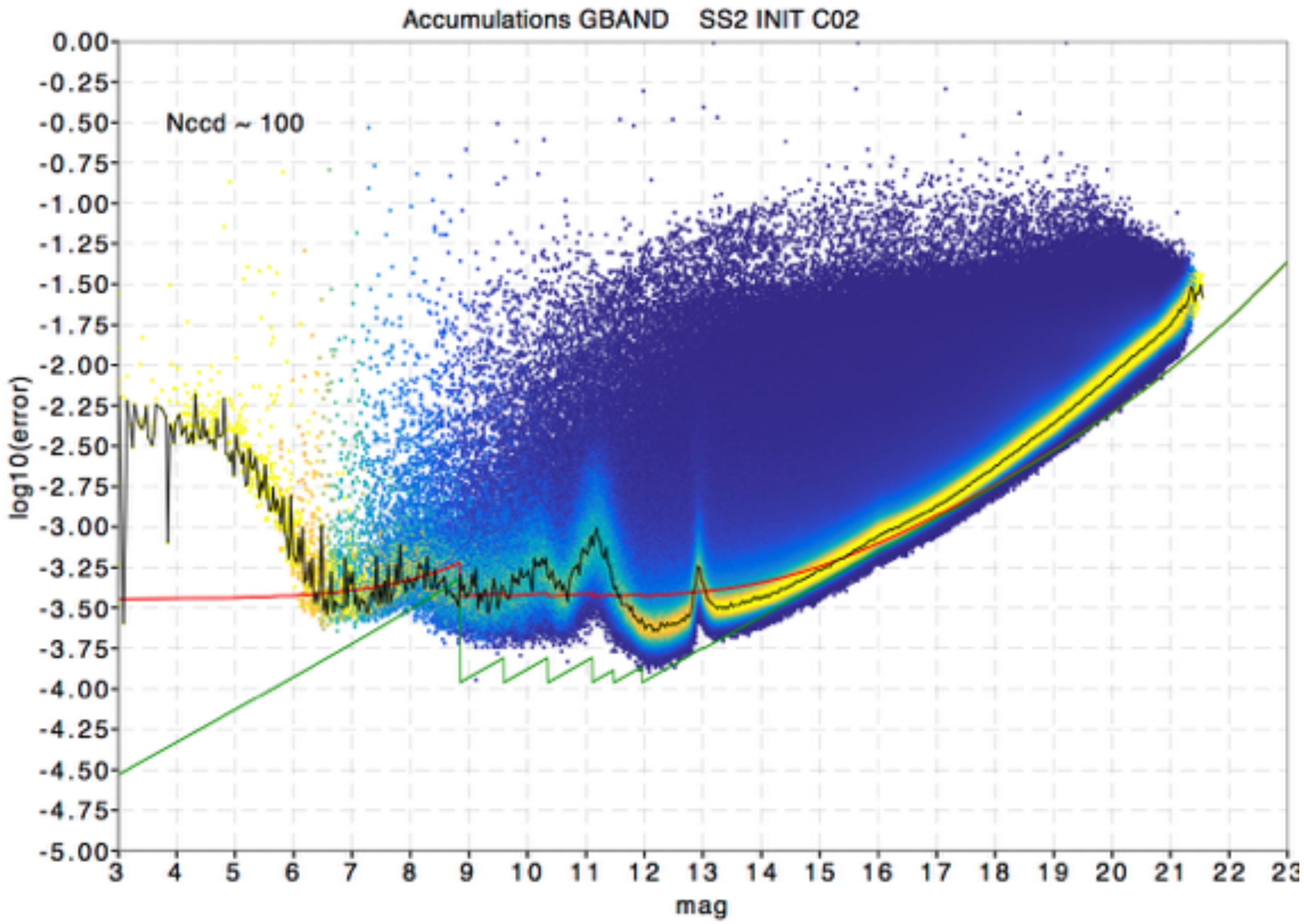
- Big improvement comes from large-scale calibration

Error estimates on the mean - G band



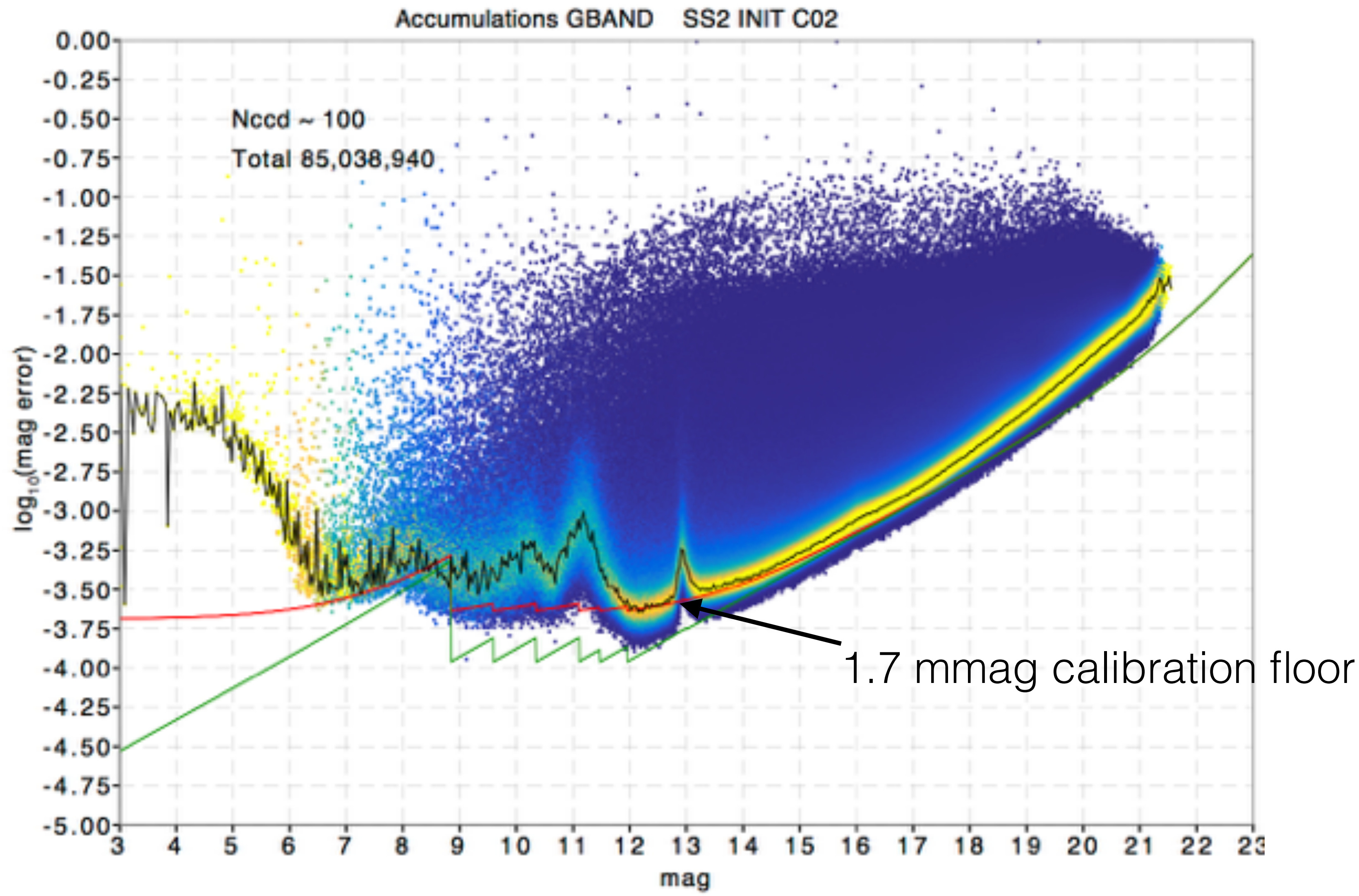
- Further improvement comes with 5 more iterations

Error estimates on the mean - G band



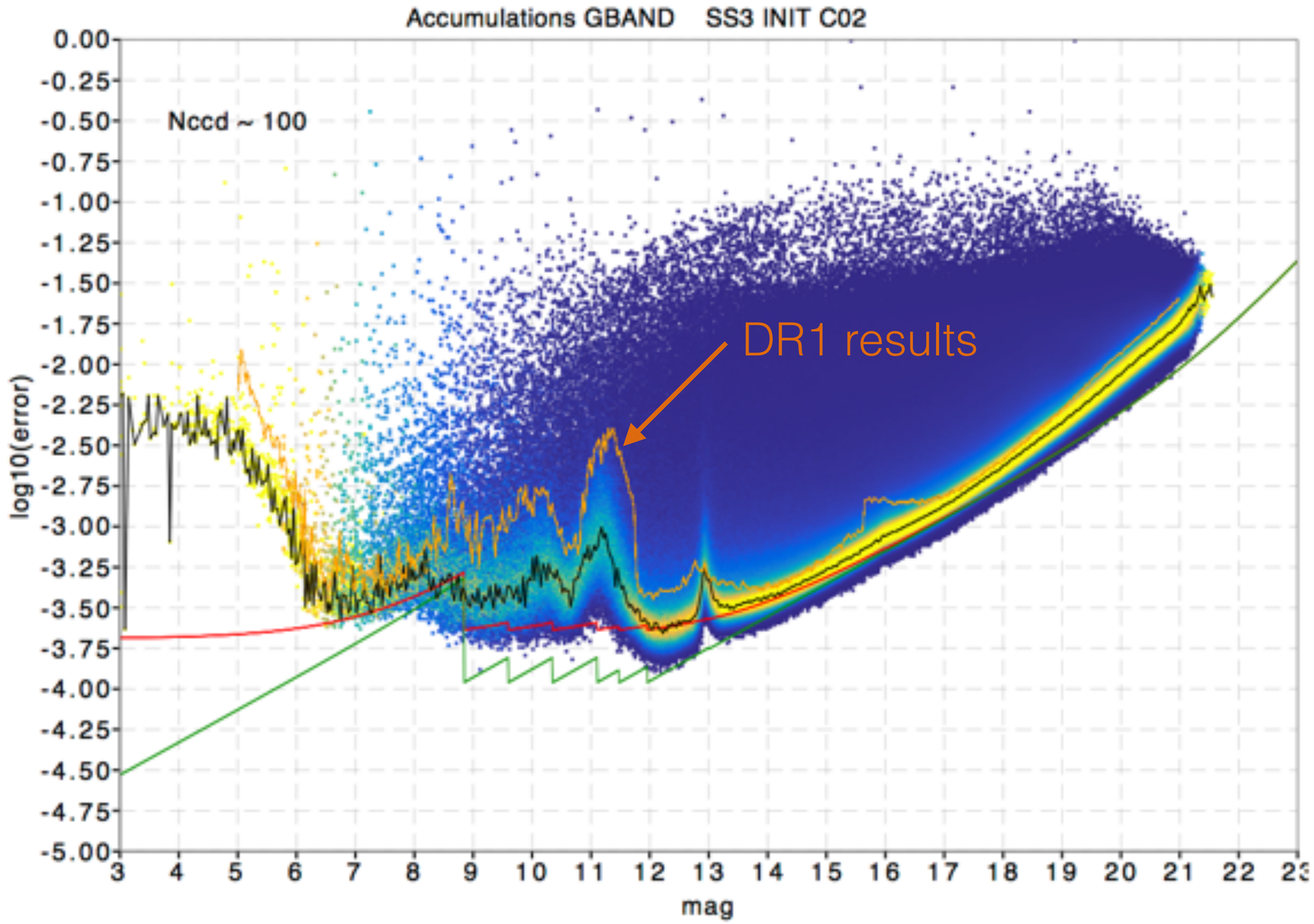
- Small-scale calibrations provide another big improvement

Error estimates on the mean - G band



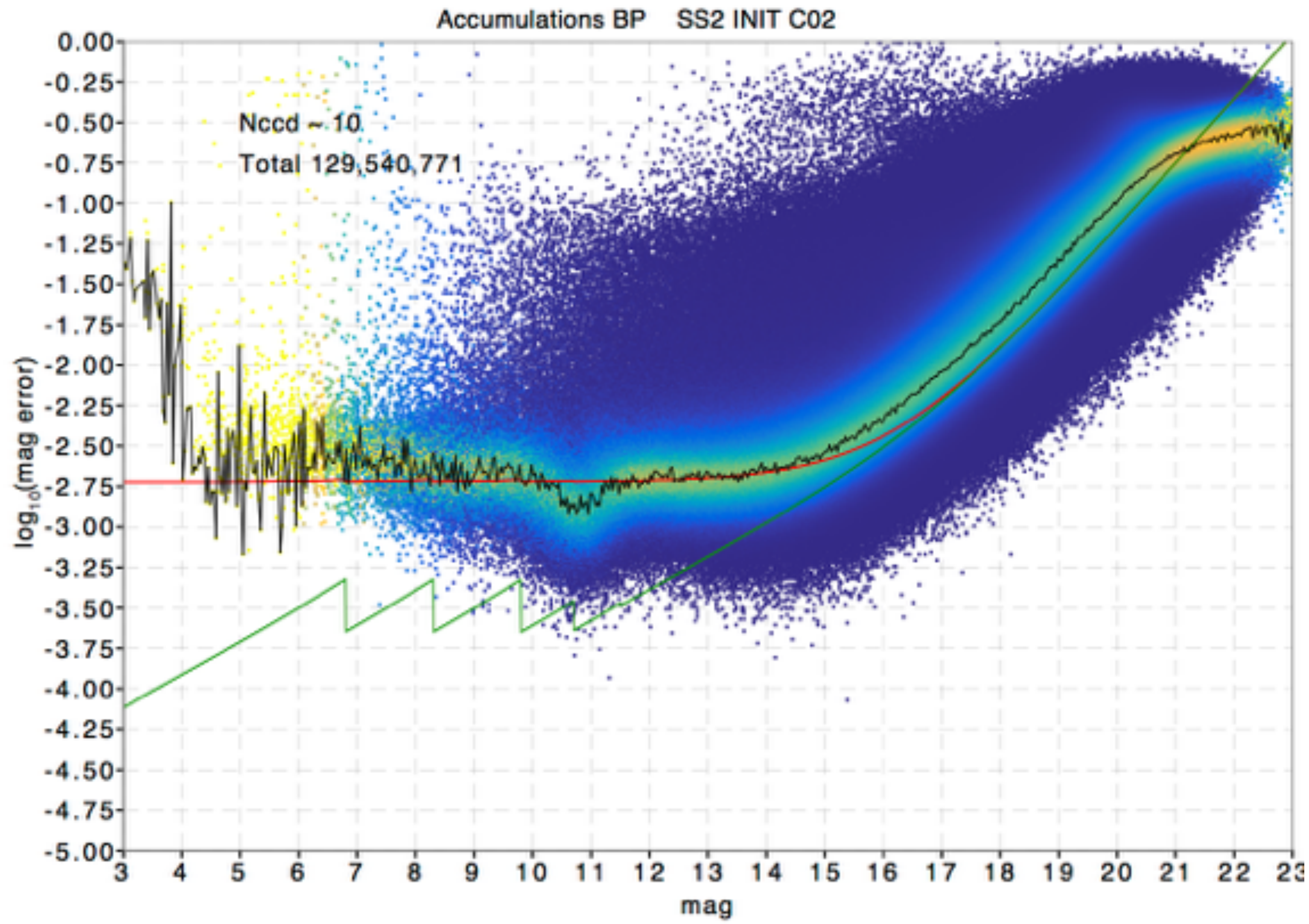
- Calibration floor has been reduced to 1.7 mmag
  - For DR1 it was about 3 mmag for G

Error estimates on the mean - G band



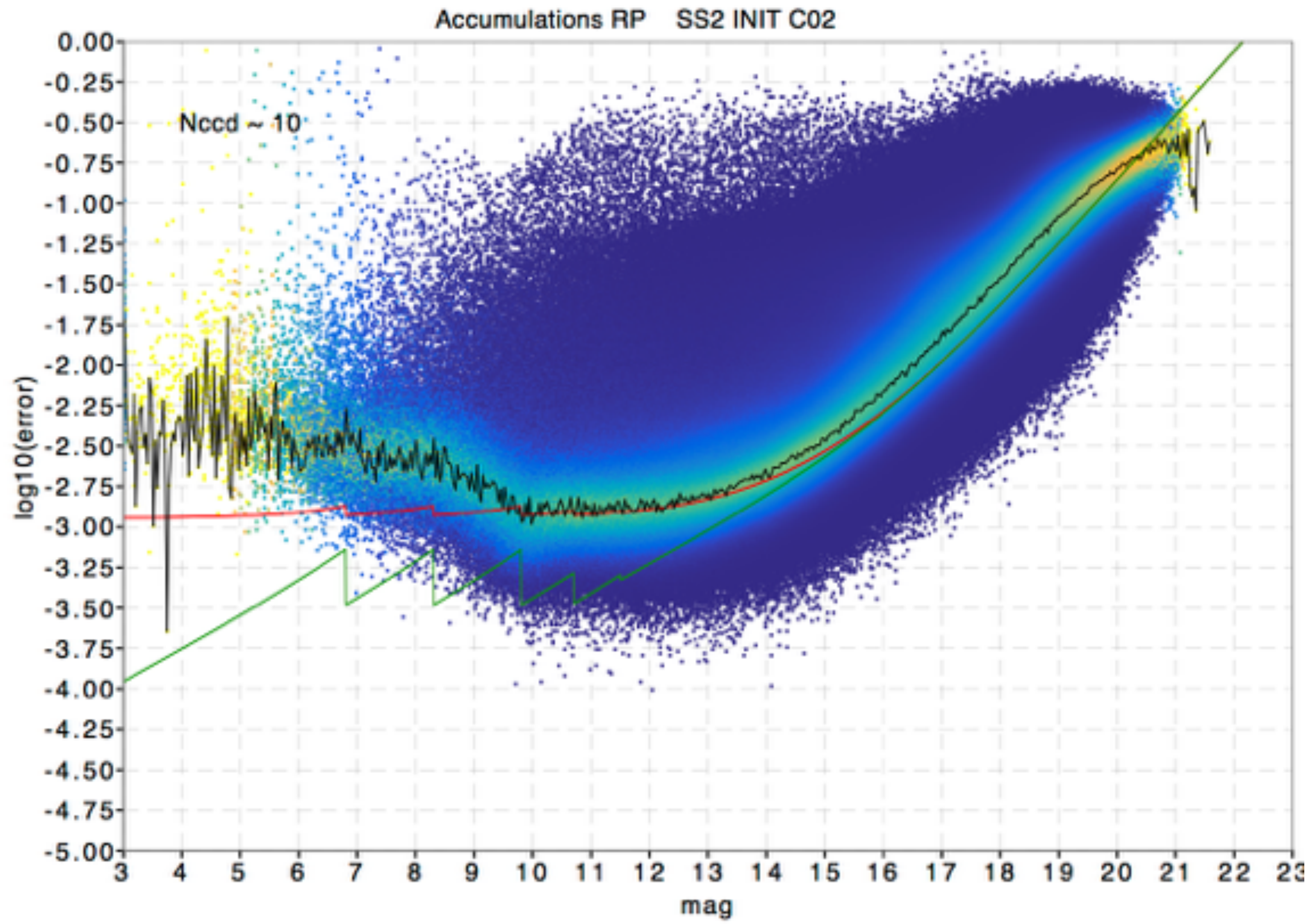
- Better than DR1
  - bumps much reduced
  - saturation handling by IPD improved, but could be better
  - Note in DR2, sources have an average of about 200 CCD transits

Error estimates on the mean - BP



- No LSF fit done here
- Fewer configuration changes
- Less saturation
- Calibration floor 5 mmag

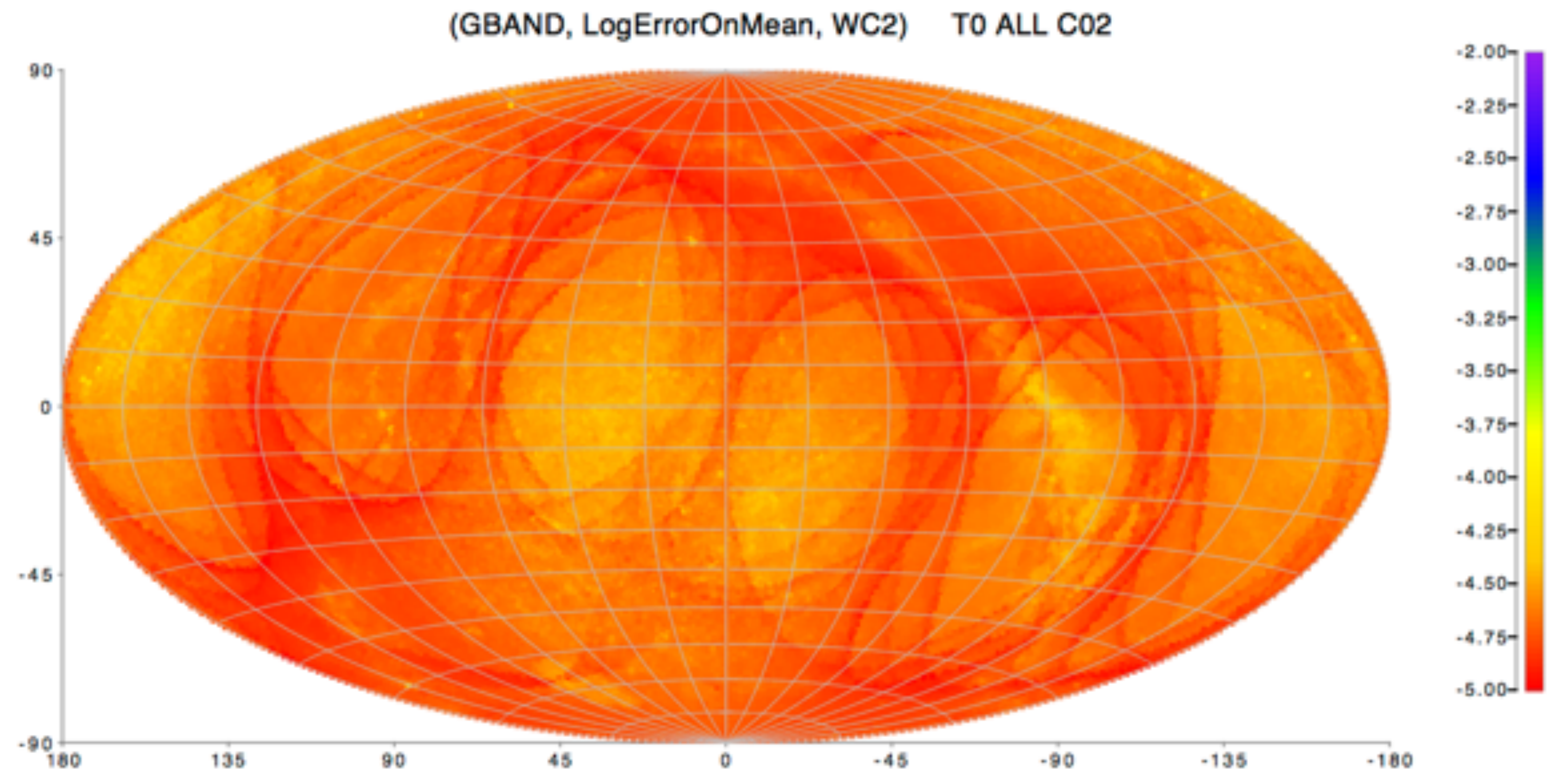
Error estimates on the mean - RP

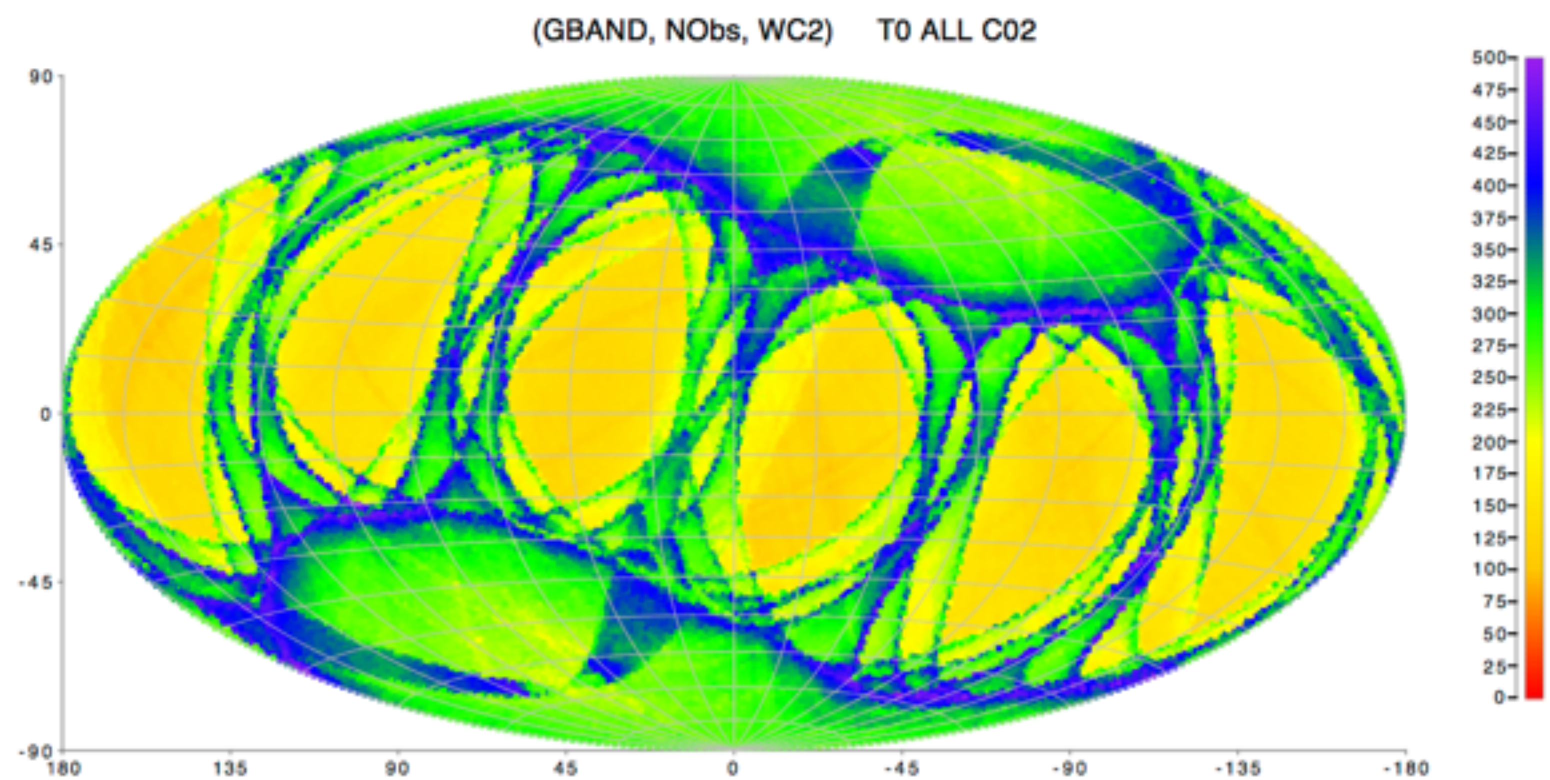


- Calibration floor 3 mmag

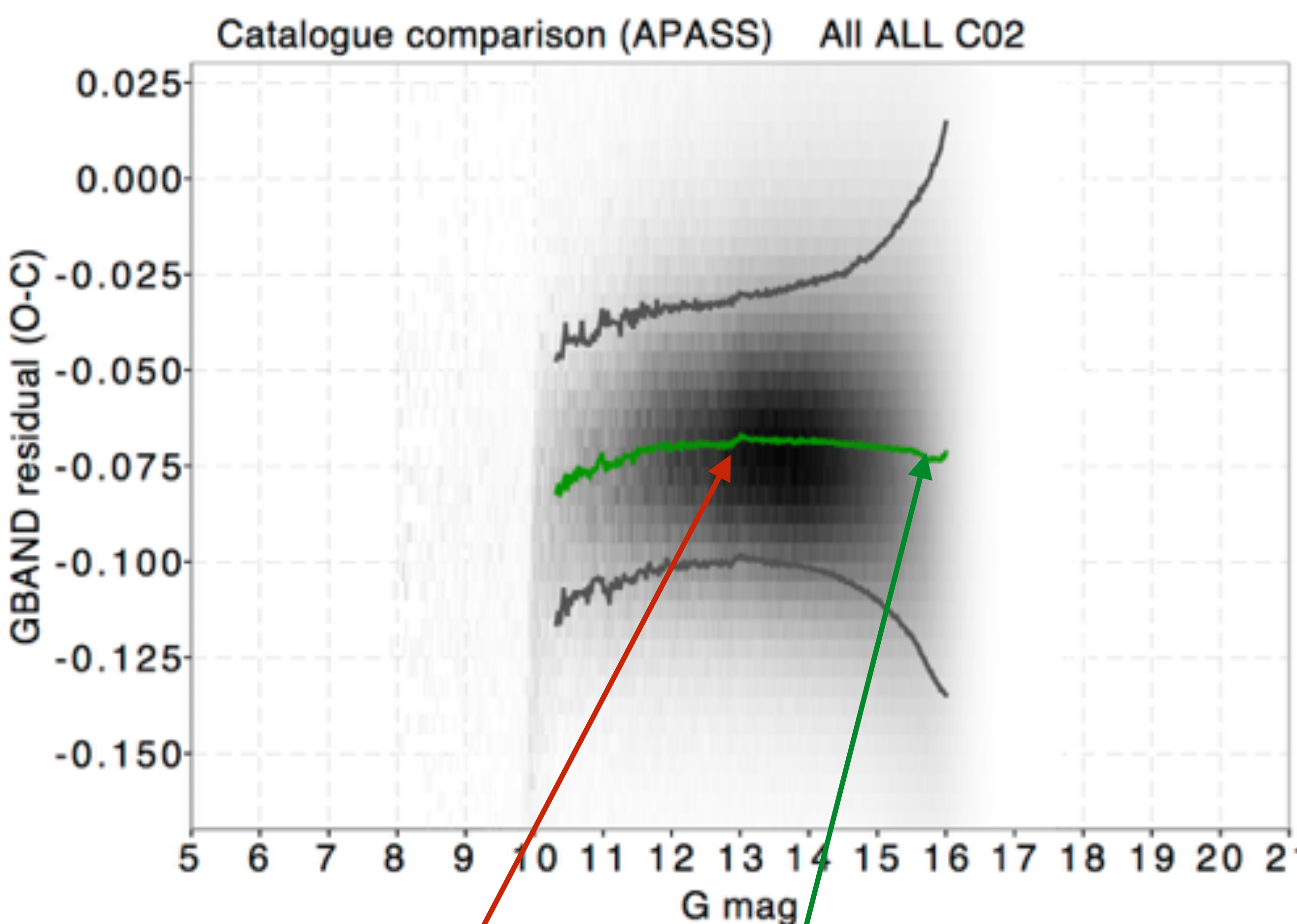
Sky distributions

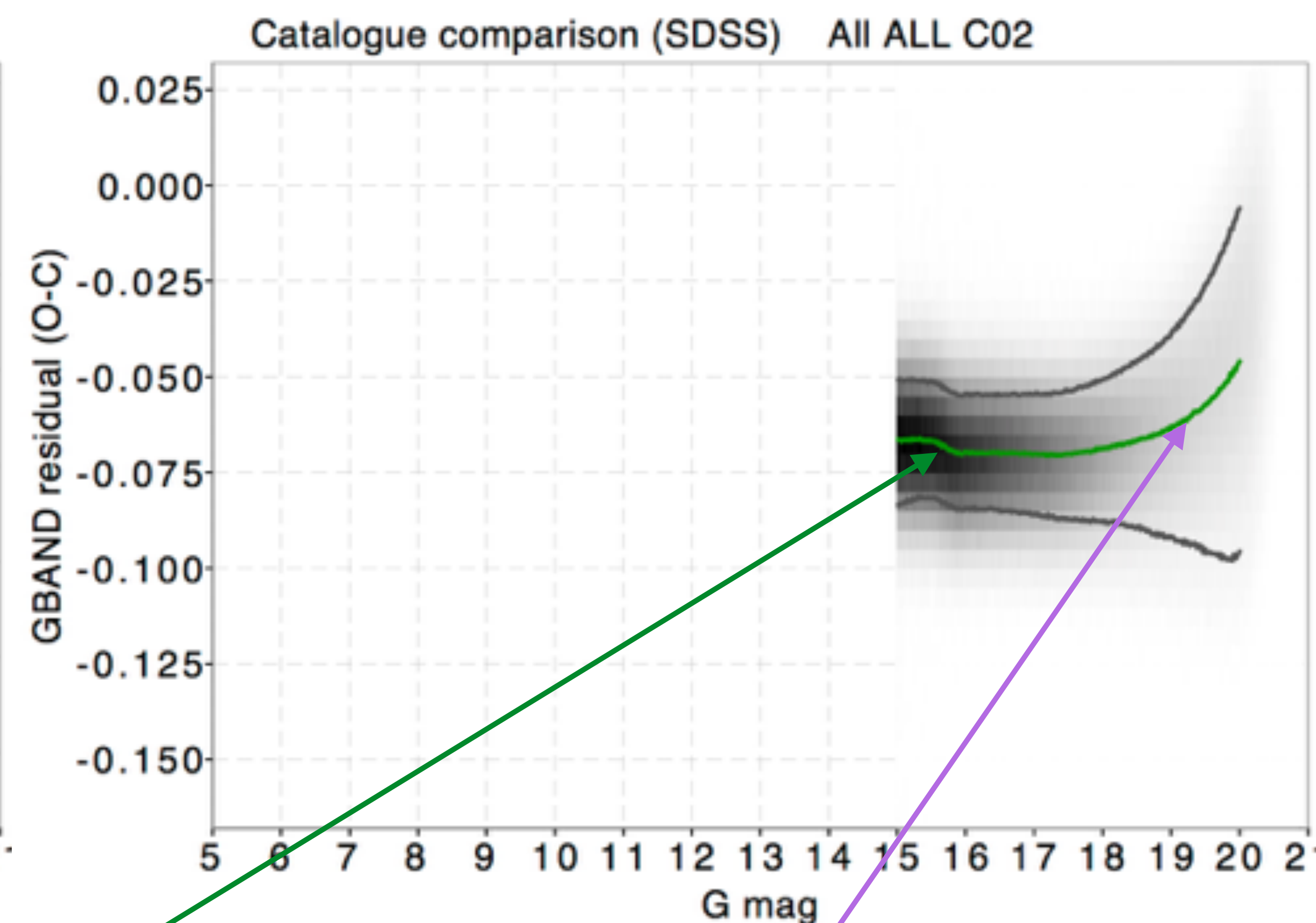
- Better precision when you have more observations
- Worse precision in crowded regions
- Holds for G, BP and RP and all window classes





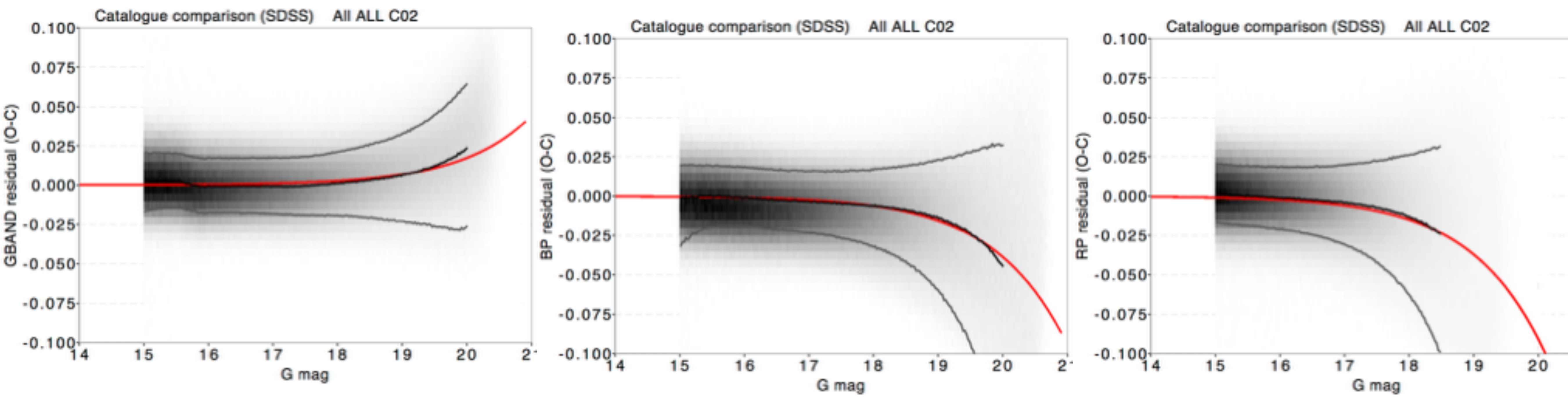
External catalogue comparisons





- G=13, 2-3 mmag step
  - pre-link calibration it is 14 mmag
  - associated with flux loss
- G=16, 3 mmag step
  - DR1 had a 10 mmag step
- Faint end “hockey stick”
  - no magnitude terms in calibrations
  - seen in raw data
  - background issue

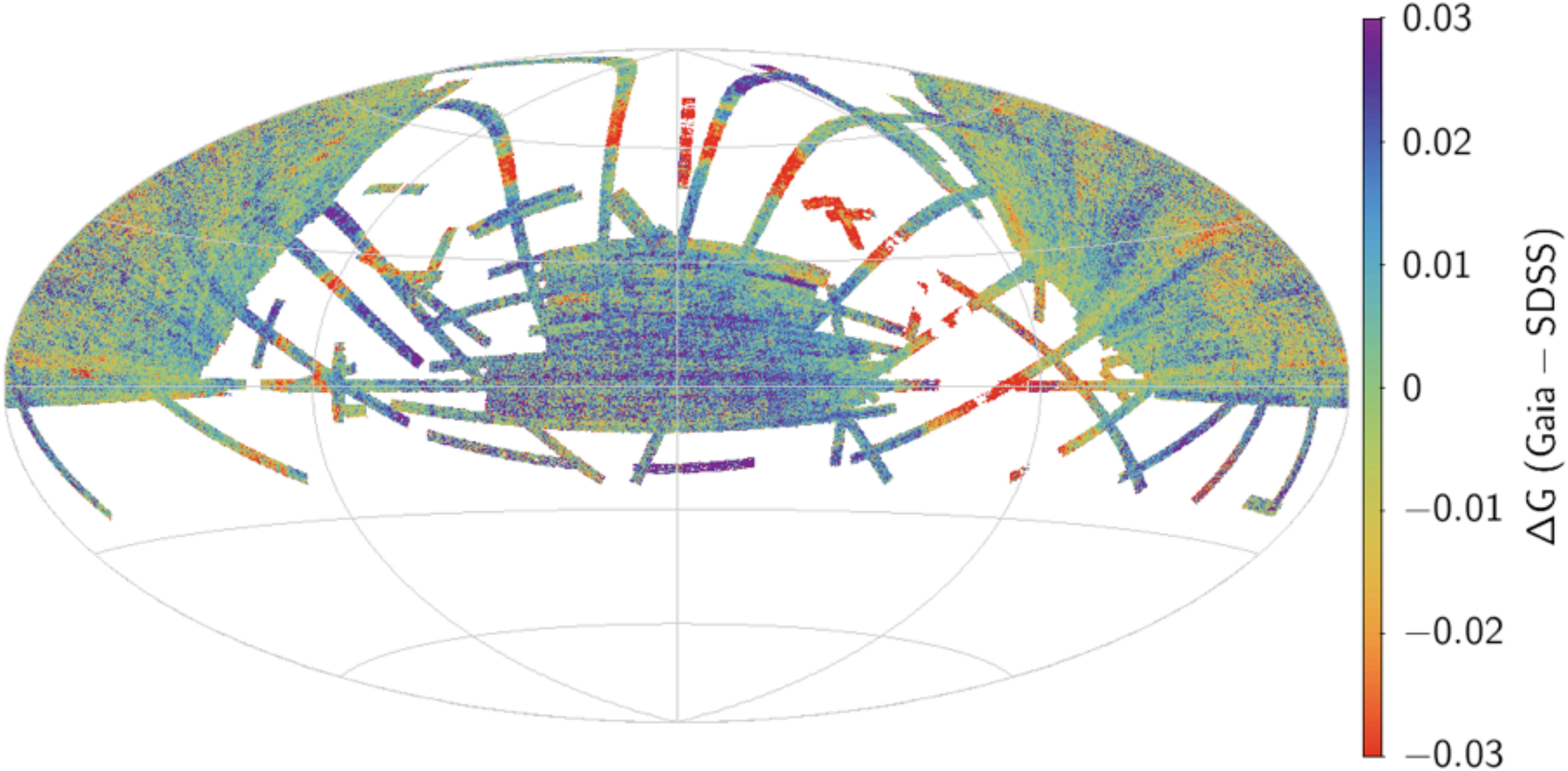
External catalogue comparisons



- Possible flux offsets
  - G -3, BP 5, RP 7
  - Background subtraction problems?

- Do they apply to the whole sky?
  - These comparisons are for sources out of the Galactic plane

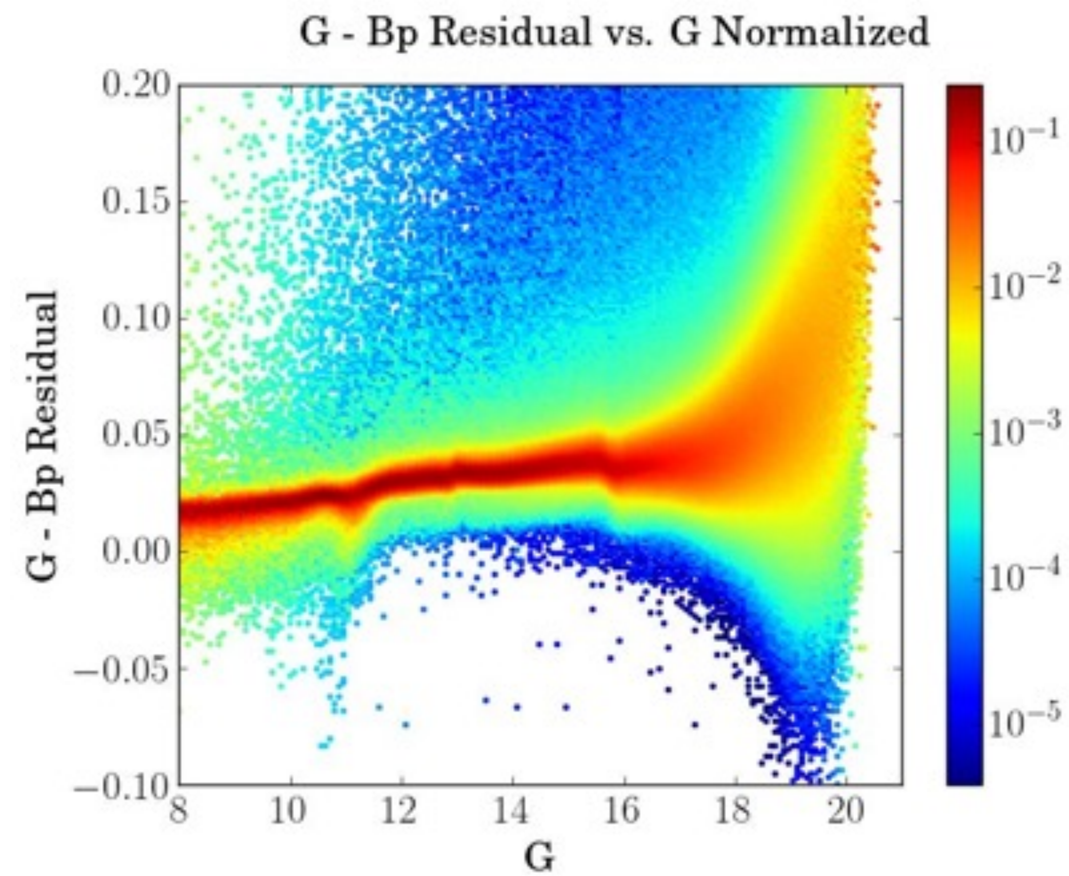
SDSS comparison sky plot



- Mainly SDSS features?

G, BP, RP internal consistency

- Features in consistency plot
  - slope - magnitude term
  - feature at G=11
  - ~3 mmag step at G=13 and 16 (as seen previously)
  - hockey stick feature
- uncertain where features originate
  - systematics at 10—20 mmag level



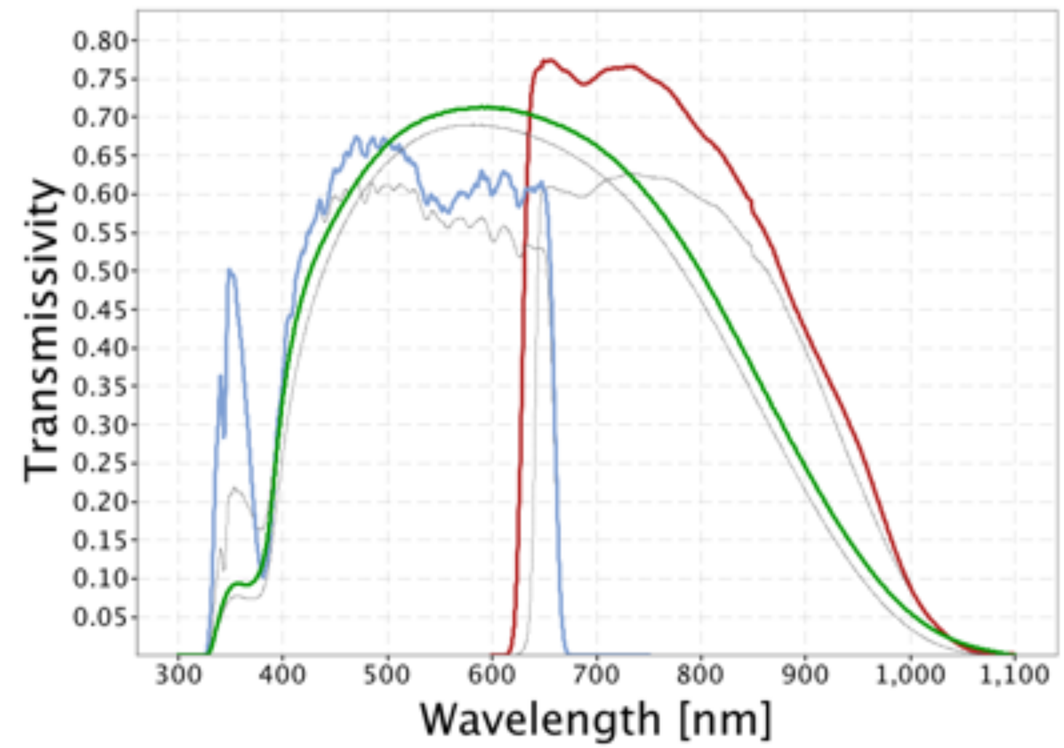
CB's plot from Arenou et al. 2018

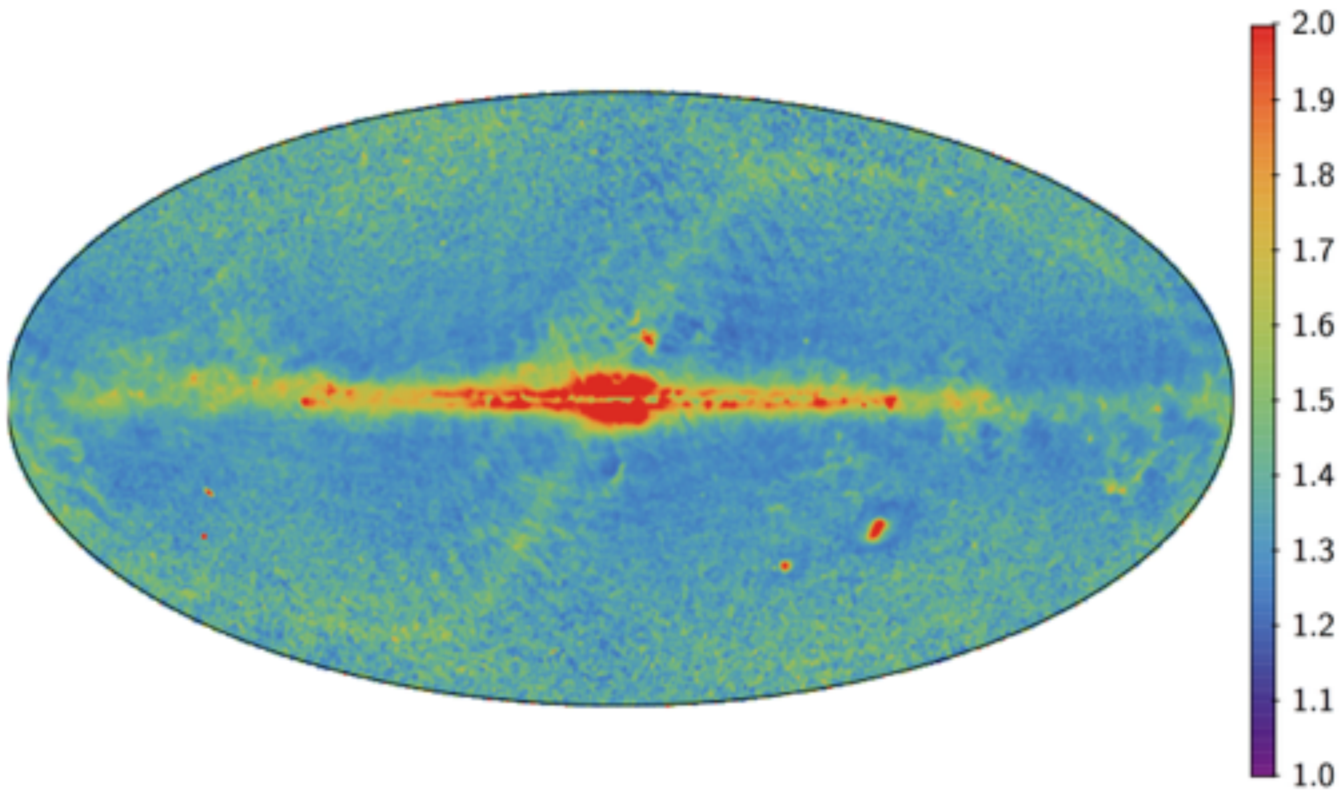
- Magnitude term (G 12–16)
  - G band LSF fitting contributes some
  - Are the CCDs linear?
    - Non-linearities at 1%+ level
  - Serial register CTI (unlikely)

- Feature at G=11
  - not seen in external comparisons for G, BP, RP
  - consequence of analysis?

BP/RP Excess Flux

- Defined simply as $(I_{BP}+I_{RP})/I_G$
  - Should be about 1.0
  - Is in DR2 archive
- High values could indicate BP/RP background problems or crowding issues





- Median BP/RP Excess Flux in Galactic coordinates

Future

DR1 to DR2

Data product	Gaia DR2	Gaia DR1
Total number of sources	1.69 billion	1.14 billion
Position, parallax, proper motion	1.33 billion	0.002 billion
Position only	0.36 billion	1.14 billion
Mean G	1.69 billion	1.14 billion
Mean G_{BP}, G_{RP}	1.38 billion	-
Median v_{rad} at $G_{RVS} < 12 \quad (G \lesssim 13)$	7.2 million	-
Astrophysical parameters at $G < 17$	77–161 million	-
Variable star light curves	551 thousand	3 thousand
Epoch astrometry/photometry for a pre-selected list of asteroids	14 thousand	-

- Exact numbers and more information at https://www.cosmos.esa.int/web/gaia/dr2
- Please read the DR2 papers and the documentation

DR3

- Expected late 2020
- New data type
  - BP/RP mean spectra
    - These will be internally calibrated spectra
    - The external calibration will be in the form of a utility that can convert a SED into the system and resolution of our internally calibrated spectra

- How will the photometry be improved?
  - LSF/PSF calibrations will be considerably improved (G-band)
  - Better background subtraction algorithms used for both AF and BP/RP
  - Accumulation robustness improved
    - RR Lyrae issue
  - More sophisticated processing of BP/RP spectra in crowded regions