Calibration Peer Review

Instrumental Calibration

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Frame Processing Flow

INPUTS:
- raw "level-0" FITS frame
- default/ground calibrations

Mask initialization and checks
Flag known saturated/bad pixels in processing mask

CAL

Initialize uncertainty using error model

Bias/offset correction using Reference pixels

Rad-hit & "sharp edge" artifact Detection (?) to supplement temporal-stacking method later

Droop/electronic corrections

Dark subtraction ← CAL

Non-linearity correction ← CAL

→ Input for Flatcal PL

Responsivity (flat) correction ← CAL

→ Input for Skycorr PL

Sky-offset correction ← CAL

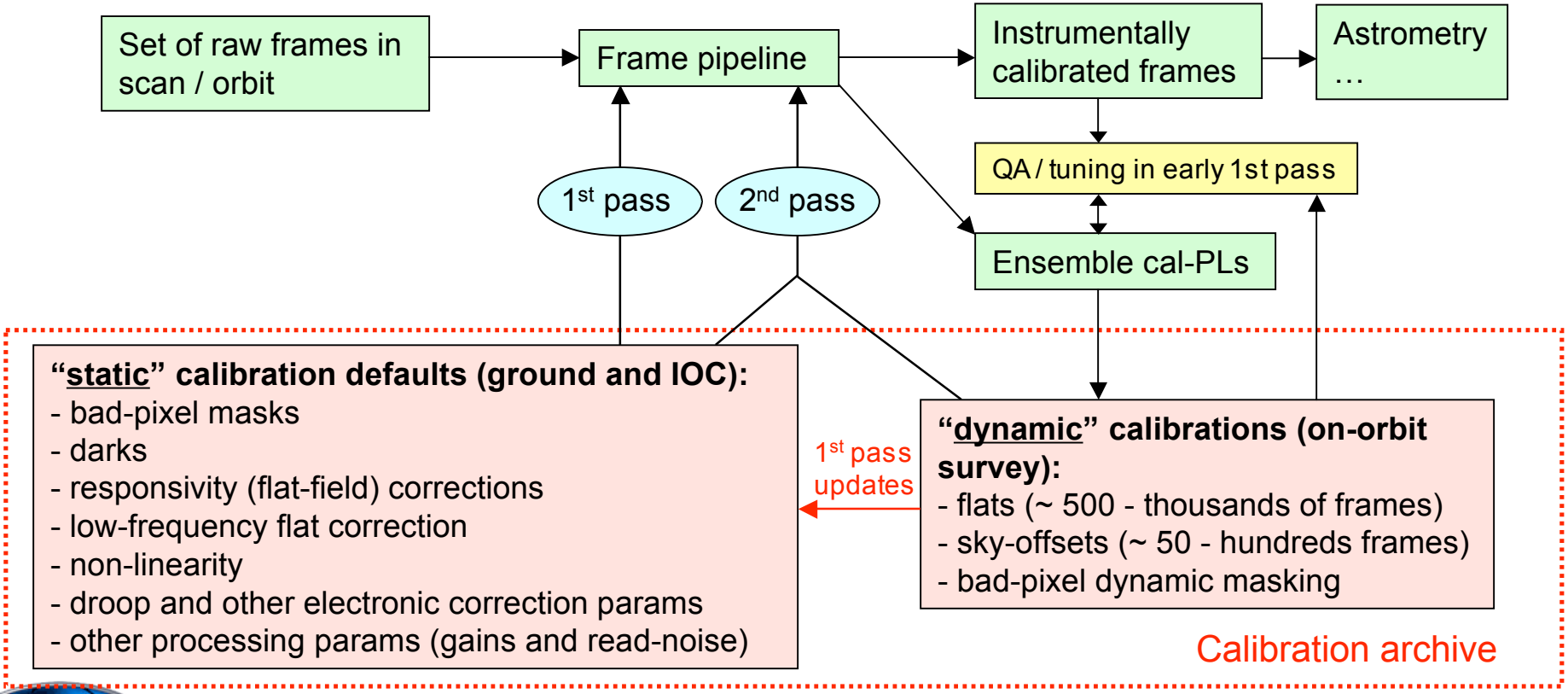
Frame QA metrics/statistics

OUTPUTS:
- instrumentally calibrated FITS frame
- bit-mask storing processing status
- uncertainty image frame
- QA diagnostics

Calibration Flow

Plan is to have 2 processing phases:

- **1st pass:** use ground and updated calibrations from IOC; generate dynamic on-orbit calibrations and optimize windows/parameters (desired accuracy, anneals, SAA passages, stability, transients, bright source avoidance etc..):
  - May apply asynchronously to frame processing on experimental basis, or, if leads to "better" product.
  - May update/supplement "static" defaults with calibrations from dynamic processing (e.g., super-flats, masks).
- **2nd pass (post flight):** expect all frame/scan intervals to be appropriately "calibration matched" prior to reprocessing



Mask Initialization / Updating

- A processing bit-mask is initialized using a mask from ground characterization. This flags pixels with:
  - excessive dark current;
  - excessive read noise;
  - low and high responsivity (dead and hot pixels);
  - reach and stay saturated in their A/D ramps during a nominal exposure;
  - strong inter-pixel capacitance (IPC) - usually the nearest neighbors to hot pixels.

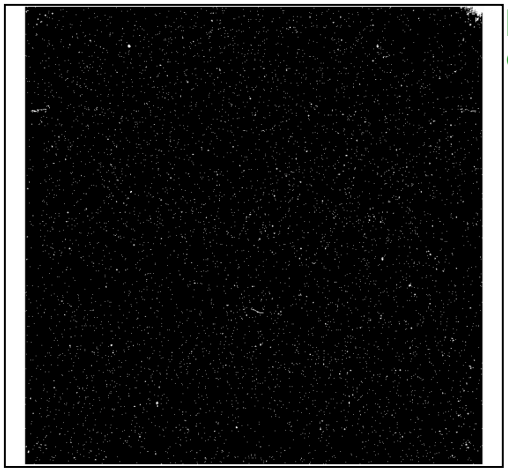
- The mask will also be updated for conditions flagged by on-board DEB processing and recorded in actual down-linked frames: e.g., ramp saturation, broken pixels, DEB -> MUB transfer loses, and overflow.

- Masks are further updated dynamically downstream to record:
  - pixels that cannot be calibrated (e.g., dark subtracted, linearized, flattended…);
  - new (transient) low/high responsive pixels using stacking analyses from the sky-offset estimation step;
  - more “bad” pixels subject to IPC effects and energy leakage from photons hitting dead pixels/regions;

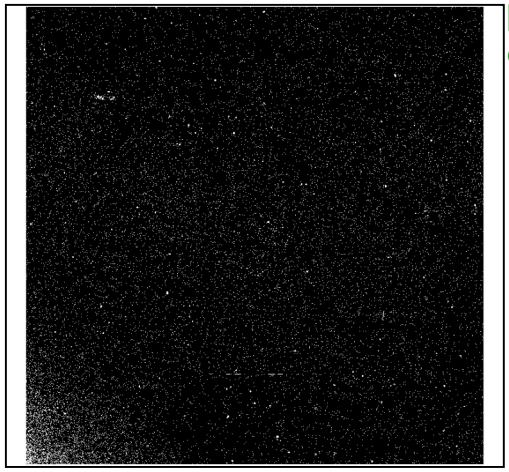
- These frame-pixel status masks will give us flexibility on which pixels to omit from the multi-frame processing stages - e.g, co-addition.

Flight Array Masks

According to the criteria on previous slide, here are bad-pixel masks (white dot => bad pixel) derived from ground characterization of proposed flight arrays:

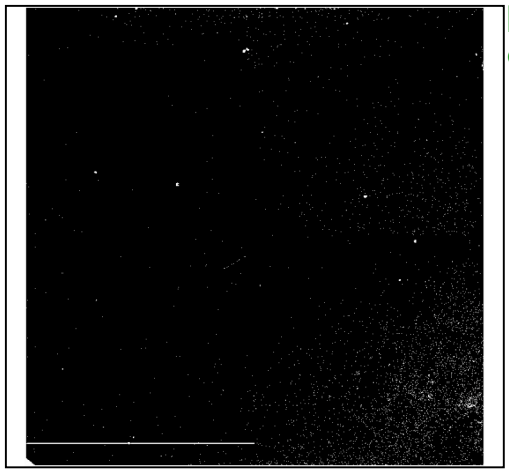


Band 1 (fpa136):
%bad pix = 1.2%



Band 2 (fpa147):
%bad pix = 3.24%

Band 3 (fpa26):
%bad pix = 0.15%



Band 4 (fpa29):
%bad pix = 0.87%

Bias / Offset Subtraction

- The active region of each array is actually 1016 x 1016 pixels. This is surrounded by a 4 pixel-wide border called the "reference pixel region".
- The reference pixels are not connected to the indium layer and do not generate photo-electrons (compare to 'overscan' region of a CCD).
- For bands 1 & 2 (HgCdTe), the reference pixels can be used to remove time-varying DC-offsets across each read-out channel in the active region.
  - This uses a row/column moving averaging algorithm provided by Teledyne. It needs to be further tuned when arrays are connected to flight electronics.
- For bands 3 & 4 (Si:As), it is not yet known how useful the reference pixels will be for removing DC offsets.
  - In testing, an effect known as "banding" was seen where distinct blocks of offsets were seen that started and stopped on clusters of bad pixels.
  - These were not related to offsets represented by the reference pixels.
  - More testing/analysis is needed.

Droop & Electronic Artifacts

- Droop was seen in some of the *Spitzer* arrays (most notably MIPS Si:As).
- Droop manifests itself as an erroneous signal added to the output of a pixel that depends on the total counts on the array.
  - I.e., a global coupling between the readout channels and/or amplifiers exists.
- 2nd order effects were also seen in the *Spitzer* arrays. E.g., where the output from a pixel depends on the total counts from all other pixels in its row or column.
  - This will impact the degree of repeatability in source photometry with location on an array.
- There are plans to search for and characterize droop in all arrays on the ground, and also possibly measure/validate it in flight.
- Other electronic artifacts will also be searched for and characterized:
  - Inter-pixel capacitance (IPC) and crosstalk (including inter-band). Note: IPC will artificially broaden PRFs!
  - Readout-channel dependent patterns and drifts (e.g., “banding” for bands 3 and 4).

Dark Calibration

- Darks and their stability for all bands will be measured on the ground at DRS.

- In flight:
  - Bands 1 & 2: darks can be measured with cover-on during IOC.
  - Bands 3 & 4: predicted to saturate with cover-on since cover is warm.
  - Can estimate average dark current levels (but not on pixel-to-pixel basis) from IOC non-linearity experiment, i.e., from fits to ramp data.
  - Can monitor average (long-term) dark levels and stability from orbit-to-orbit by measuring residuals above the absolute background measured by DIRBE?

- Incorrect dark estimates will impact flat-field estimates (more later).

Sky-offset (illumination) Correction

- Short-term variations in bias and dark structure over an array will not be captured by ground (or long term) calibrations.
- This will leave instrumental residuals and impact source photometry.

- These can be corrected by computing a median of ~50 - 100 consecutive frames within a moving block window, zero-normalizing to the global median, and subtracting this from all frames in that window.
  - At least this number of frames will be needed to reliably filter out sources;
  - A window that's too big may miss short-term instrumental variations;
  - Assumption is that the bias/dark structure is constant over the window span.

- Sky-offset corrections will be computed autonomously by saving intermediate products from the frame pipeline: frames that have been dark subtracted, linearized and flattened.
- This pipeline thread will also dynamically mask and propagate out-of-range pixels (transient low/high responsive pixels) from the stacking statistics.

Non-linearity Correction

- Will first be measured on the ground;
- Then measured/validated in-flight using an experiment in IOC:
- Based on toggling "sample up the ramp" coefficients over several orbits to control frame exposure times, then combining measurements of the same stars and fitting non-linearity curves.
- A question here is: on what scale over an array can the linearity be measured? Will the linearity change appreciably with location, readout-channel?
- We must ensure to sample the full dynamic range in the A/D up to saturation, and watch out for any "hook-like" effects in the linear regime.

Flat-fielding

- Flats will be obtained on the ground, then in-flight during survey operations from observations of the zodiacal background.

From calibration plan:

- Bands 1 & 2: multiple orbits (>~ 25 orbits => thousands of frames) will give flats to an accuracy of 0.2 - 1%. Background here is low!
- Bands 3 & 4: at least one orbit worth (~520 frames) will give flats to accuracy <~0.1%

- Flat-fielding in bands 3 & 4 needs to be more accurate due to high backgrounds, i.e., an erroneous flat => bad background estimate => bad aperture photometry since "larger" (uncertain) background is subtracted.

Flat-fielding error contribution

Example: take band-4 with DIRBE backgrounds of ~ 20.5 - 69.7 MJy/sr from pole to equator:

- ⇒ Within a 50" (~2.5*FWHM) diameter aperture, we expect backgrounds of ~ 945 - 3215 mJy.
- ⇒ Given a required survey 5-σ point source sensitivity of 2.6 mJy, the *B/S* flux ratio is ~363 at a pole, and ~1236 at the equator for sources close to the sensitivity limit.
- ⇒ Given that we measure a total flux '$S + B$' in an aperture, and a background at some other nearby location of $[1 \pm \varepsilon]*B$, the flux estimate will be $S + B - [1 \pm \varepsilon]*B = S \pm \varepsilon B$. Therefore, SNR = $S/(\varepsilon B)$. The fractional error ε is due to the erroneous flat-field alone.
- ⇒ SNR ~ $1 / (363\ \varepsilon)$ at a pole, and SNR ~ $1 / (1236\ \varepsilon)$ at the equator.
- ⇒ To achieve a photometric SNR = 5, we require a flat-field accuracy of $\varepsilon < 0.036\%$ at a pole, and $\varepsilon < 0.016\%$ at the equator.
- ⇒ **Note:** these are very strict upper limits since we have ignored all other error sources in the photometric and instrumental calibration error budget.
- ⇒ Given relatively high backgrounds in bands 3 and 4, there is greater pressure to get the flat-fielding right!

Flat-fielding continued..

- Sky flats will be generated autonomously by saving intermediate products from the frame pipeline: dark subtracted and linearized frames.
  - Ground darks can initially be used, and then iteratively refined until measurements of the same piece of sky over a calibrated frame yield minimal variation, or, are repeatable within *random* measurement error.
- Depending on detector stability, we may also create super-flats by combining frames from many orbits.
- Also, we need to derive "low-frequency" correction maps for the flats.
  - These characterize variations from imperfections when light goes through the entire WISE optical train and is incident from different directions.
  - Can be derived by placing the same star on different portions of an array and measuring relative changes in its brightness. This is a task for IOC.
  - It is expected that these corrections will be made once and applicable throughout the mission.