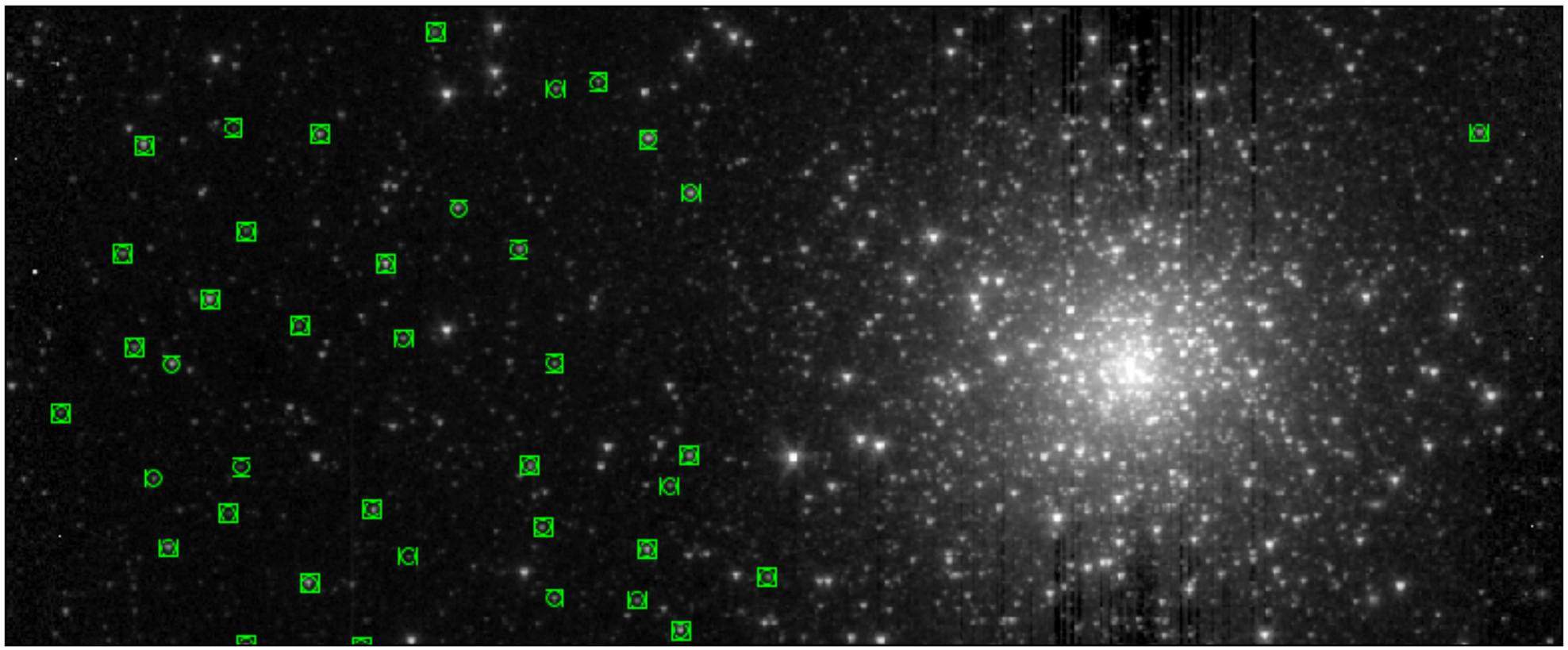
A PSF-fitting Photometry Pipeline for Crowded Under-sampled Fields



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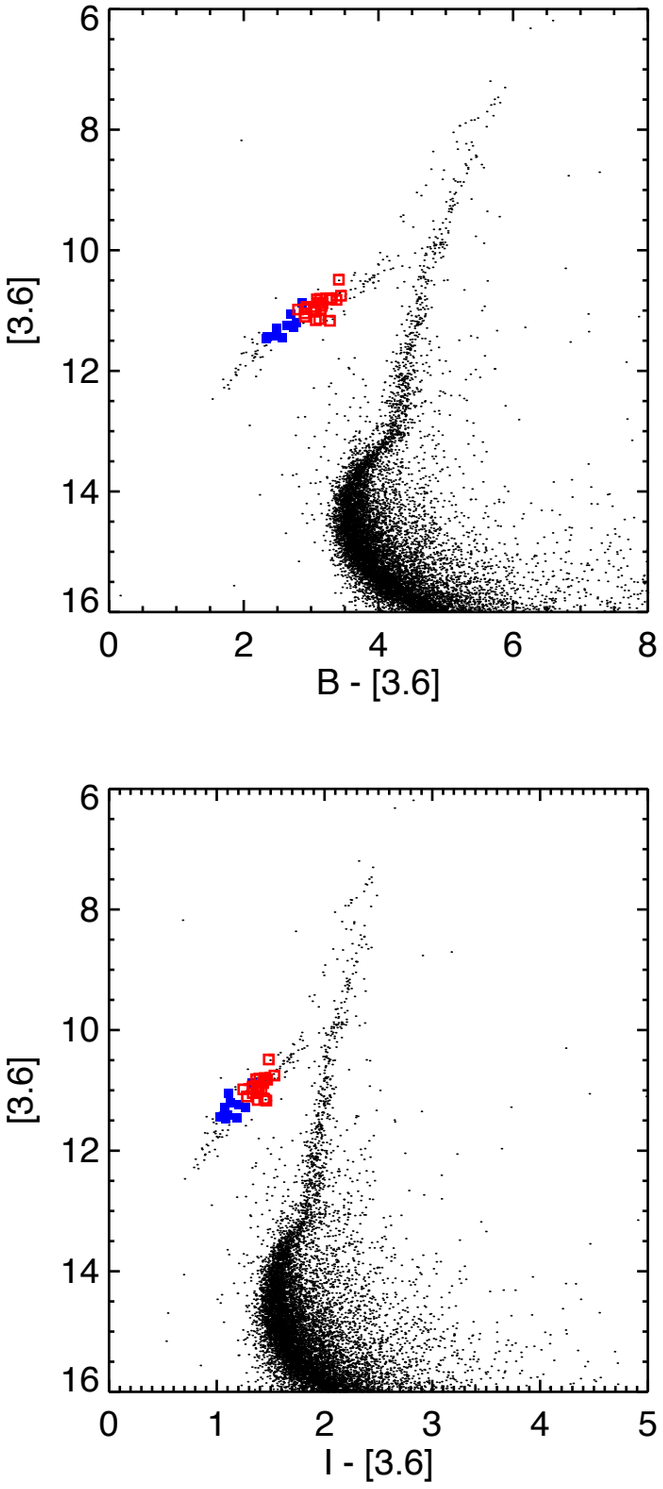
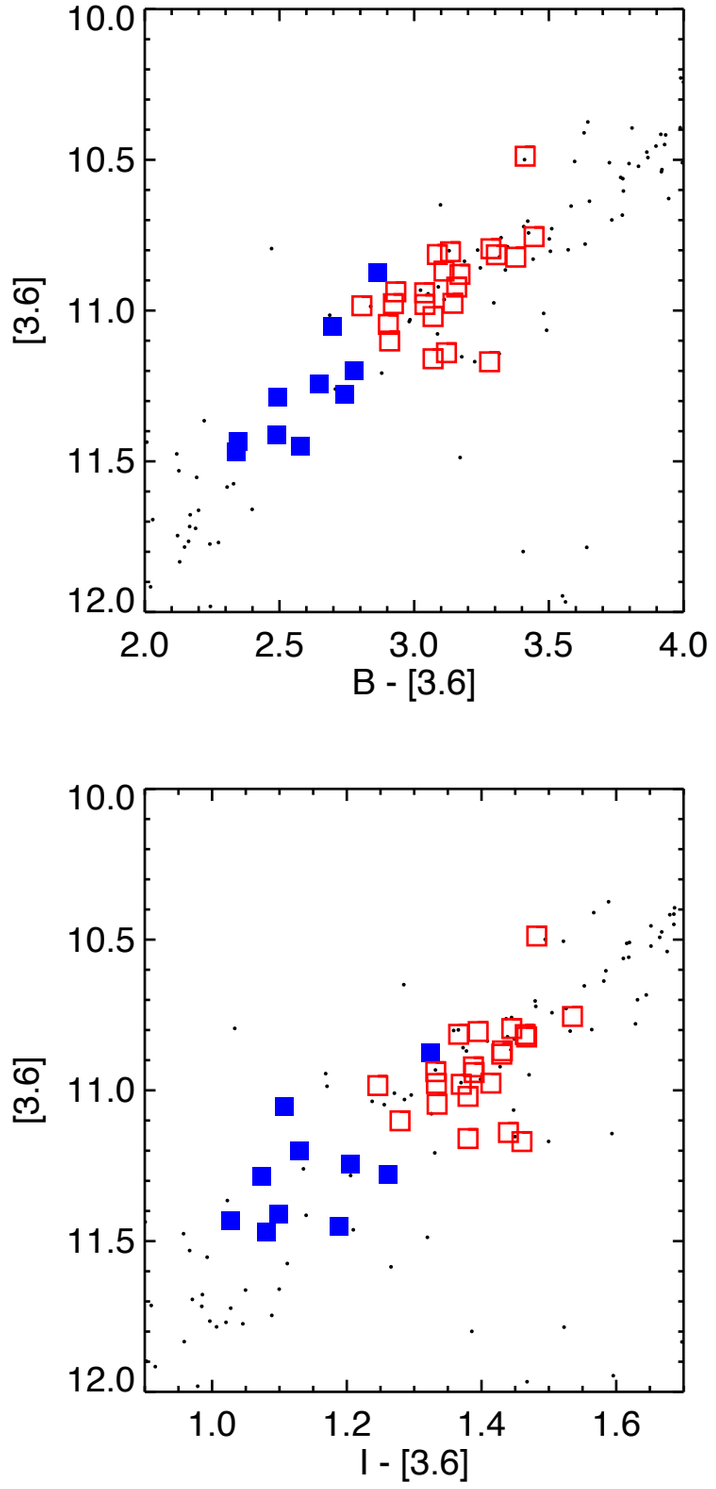
Iowa State University

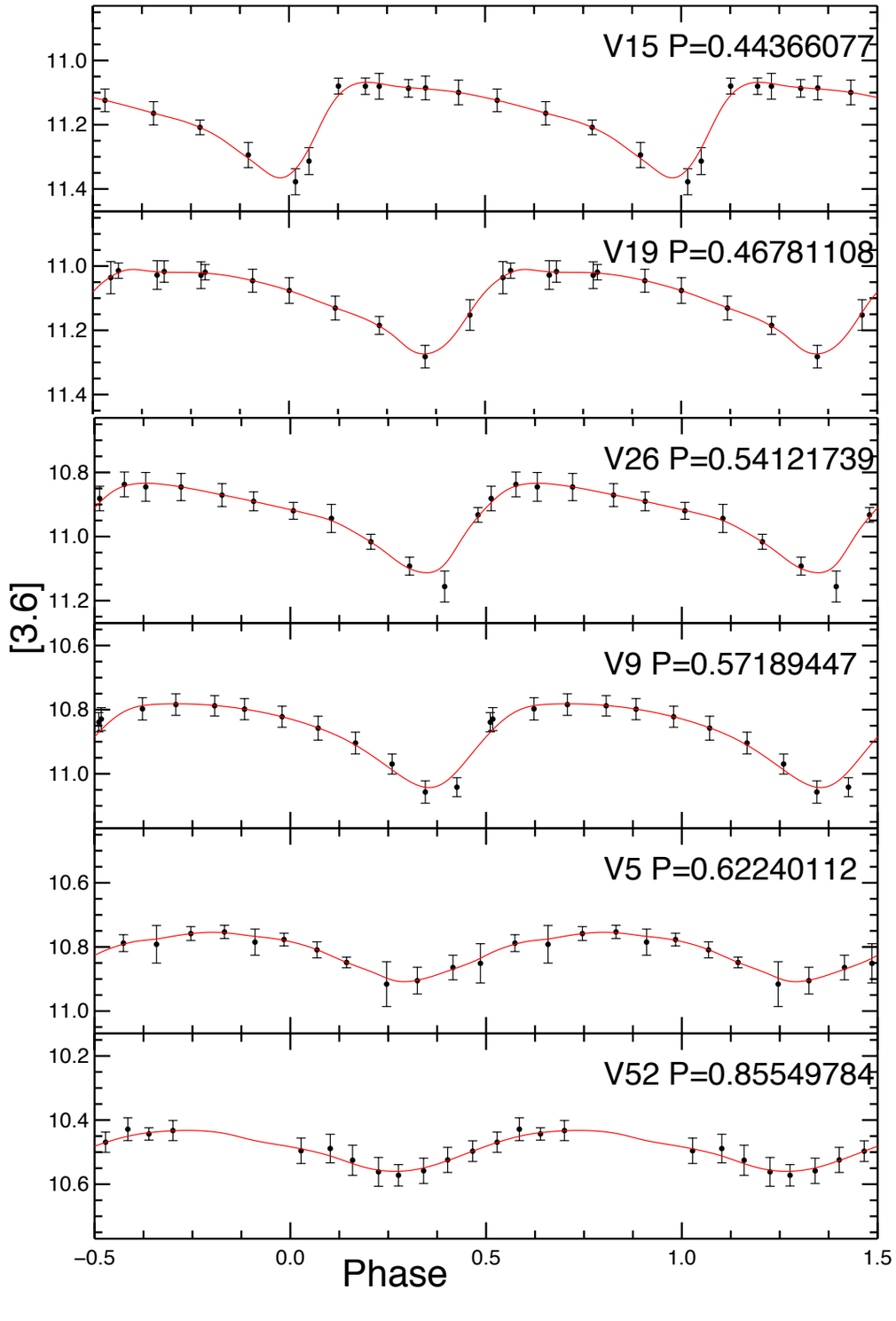
What, and Why

- Developed to extract globular cluster photometry for Spitzer/IRAC "Carnegie RR Lyrae Program" (CRRP): over 900 hours Spitzer observations of RR Lyrae in the MW halo, globular clusters and bulge.
- Individual frame photometry to extract light curves of variables (>12 phase points), plus average magnitudes of cluster stars.
- Based on DAOPHOT, with binding scripts written in Python (plus a few legacy IDL calibration scripts). Strategy similar to one used by Martha for the DUSTiNGS program.
- Challenges similar to JWST observations of Local Group galaxies.

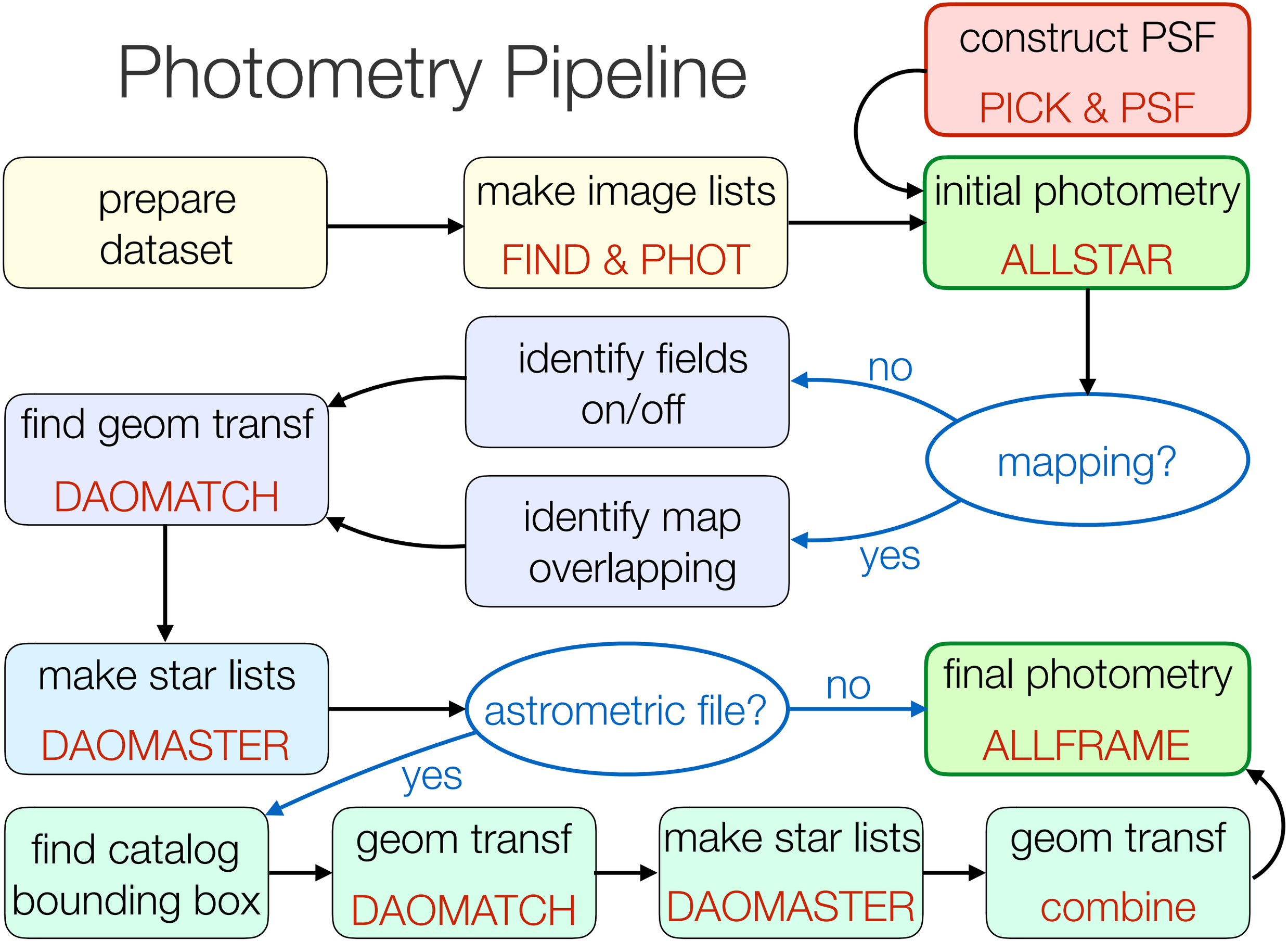
Example: M4 Photometry



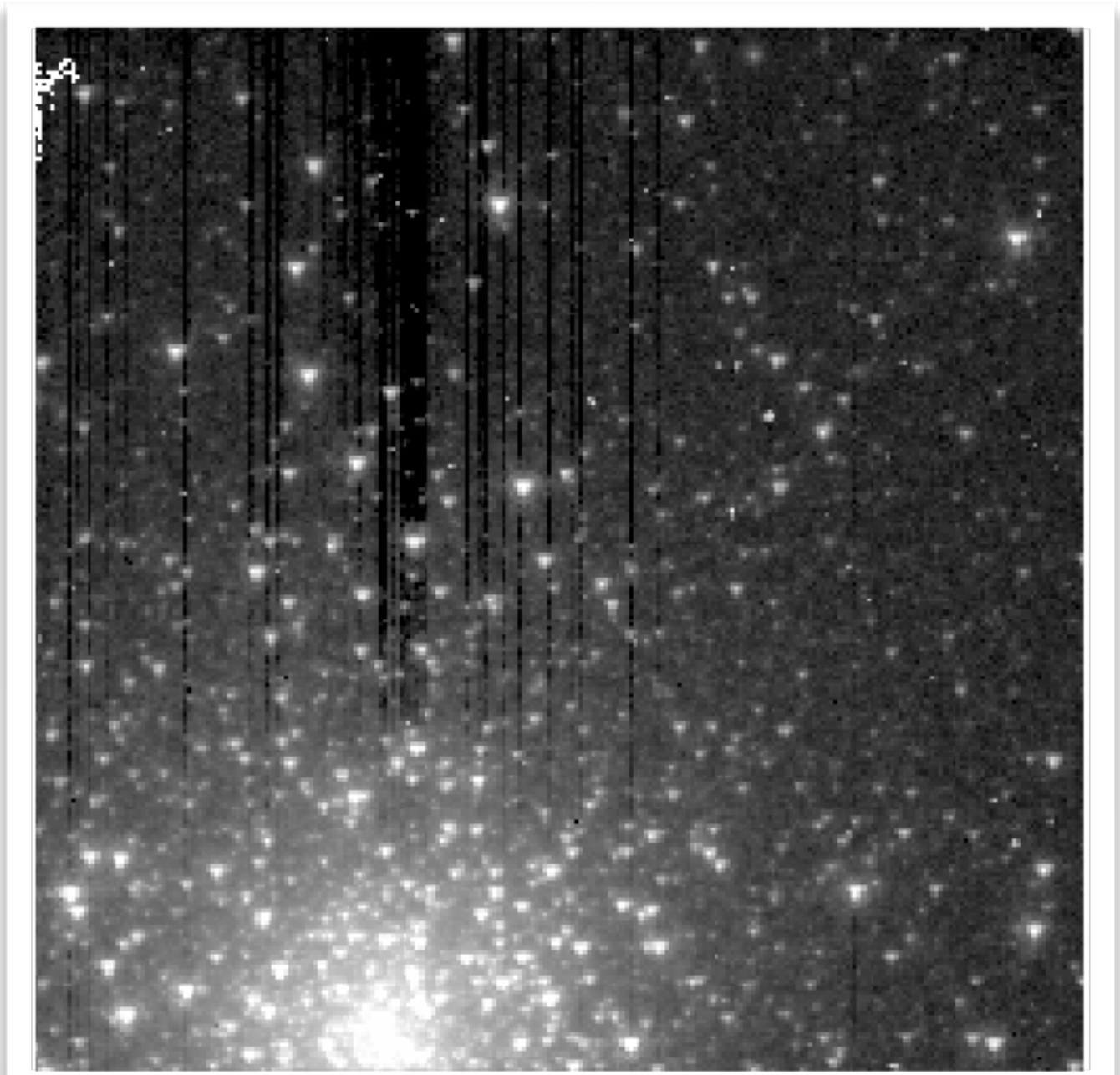


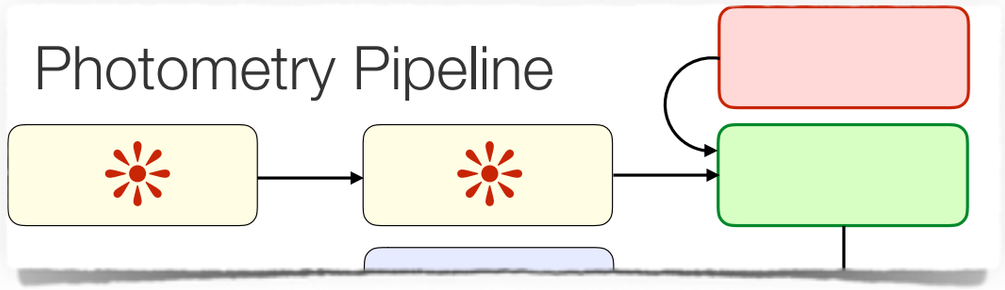


Photometry Pipeline



Pipeline Setup & Initial Source Lists





- Convert all individual frames into photon counts (DN) units.
- Setup DAOPHOT options.
- Make initial source list for each frame separately: FIND & PHOT.
- Photometry at this stage is only used to help source matching across catalogs in following steps.

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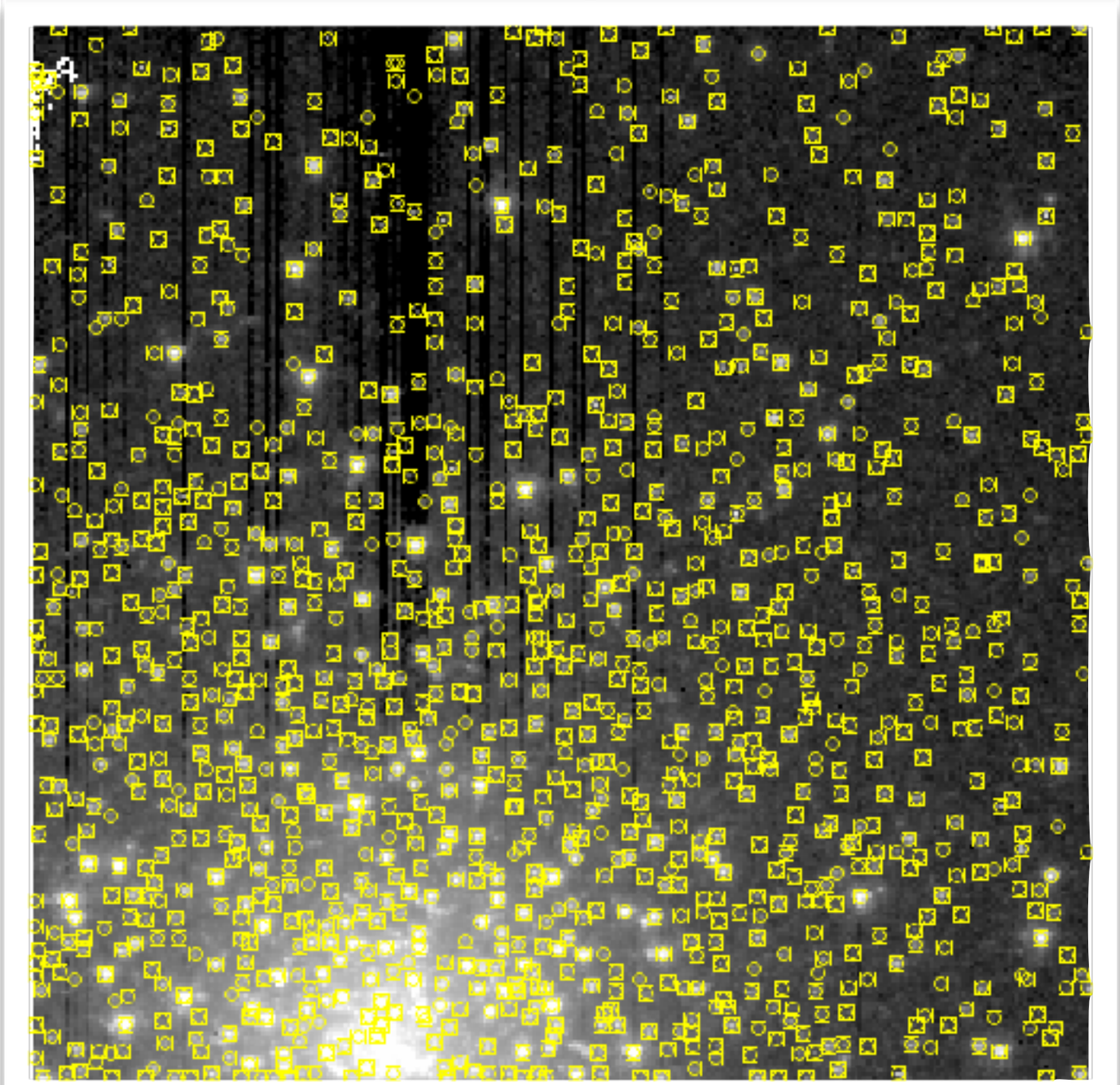

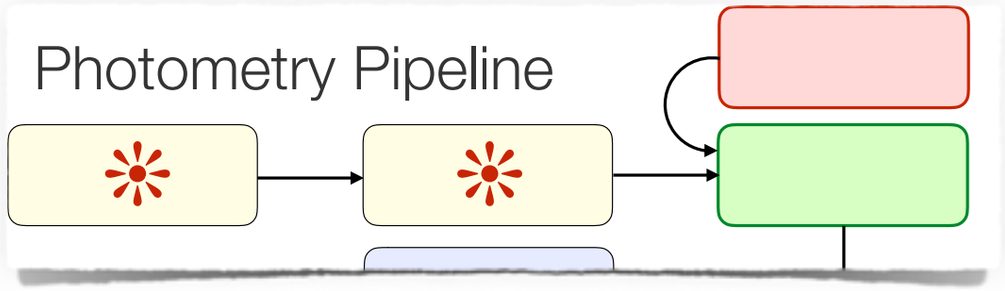

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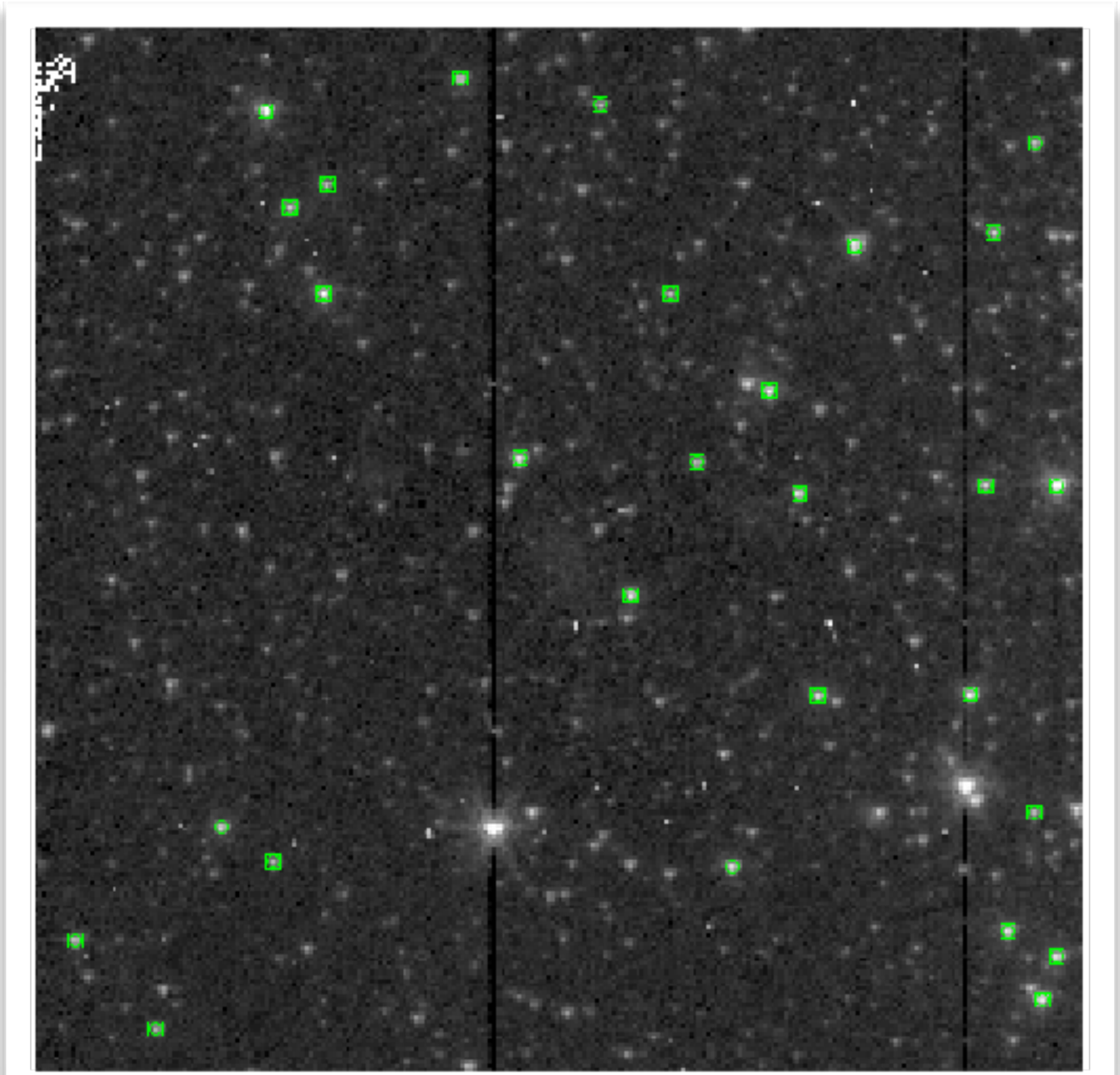
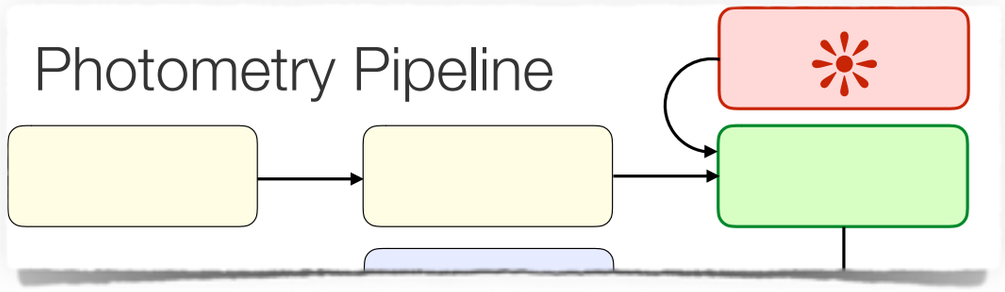
Point Spread Function Characterization





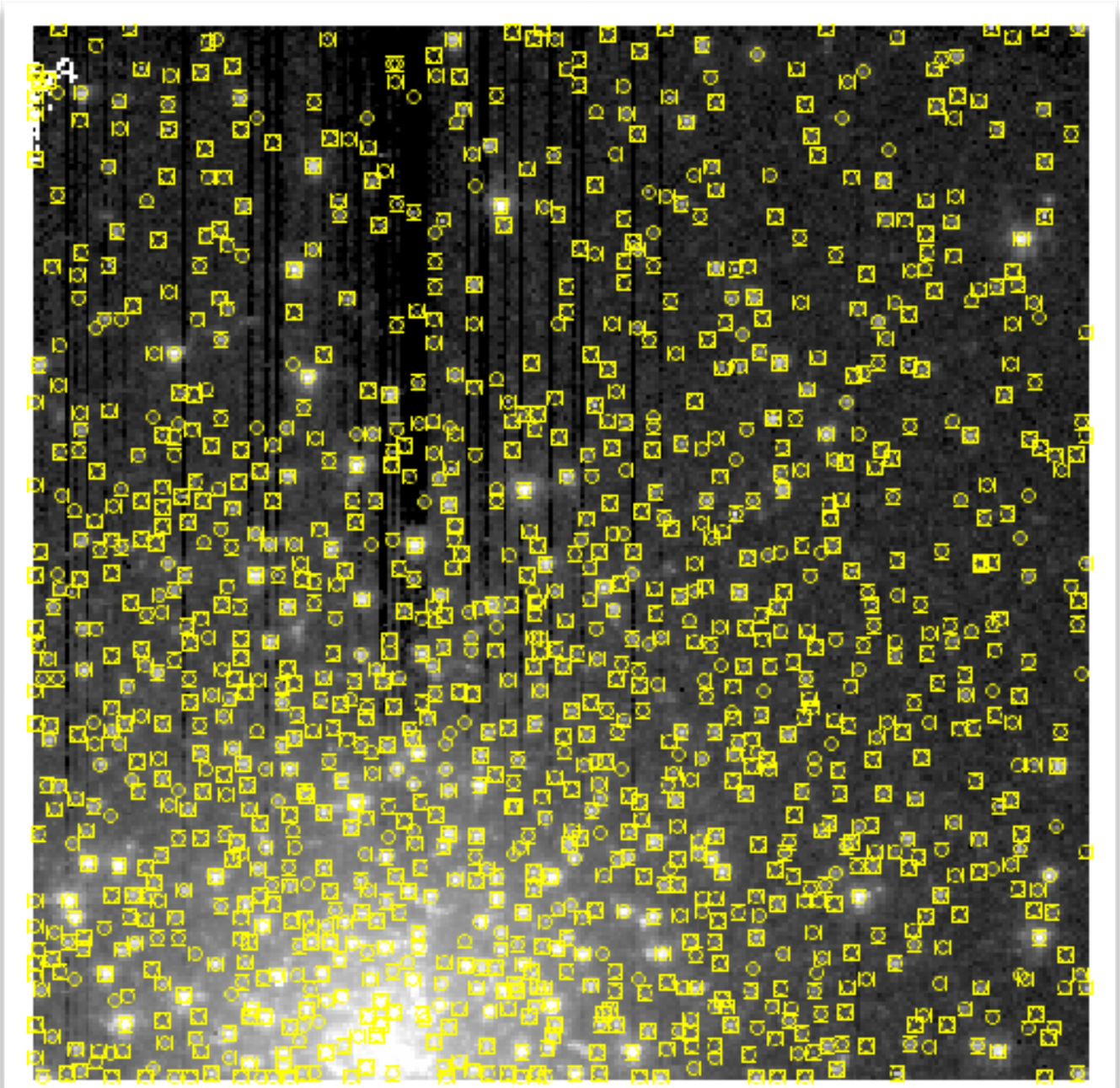
- Make a new analytical PSF: PICK & PSF.
- Chose one of many functional forms: e.g. Moffat ($\beta = 1.5$).

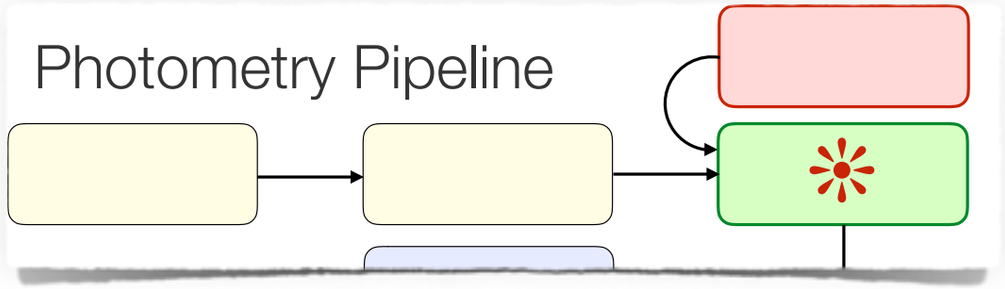
$$\$PSF(z) = \frac{1}{(1+z^2)^{\beta}}$$

$$z^2 = \frac{x^2}{\alpha_x^2} + \frac{y^2}{\alpha_y^2} + \alpha_{xy} xy$$

- Chose order for variation of PSF across frame.
- Use same PSF if stable.

Initial PSF Photometry of All Sources





- Use PSF for photometry of all sources identified, in each frame, in previous step: ALLSTAR.
- Only sources that can be fit by PSF are now retained (initial bad pixels and other artifacts removal).
- Only bright/isolates sources are found at this stage.

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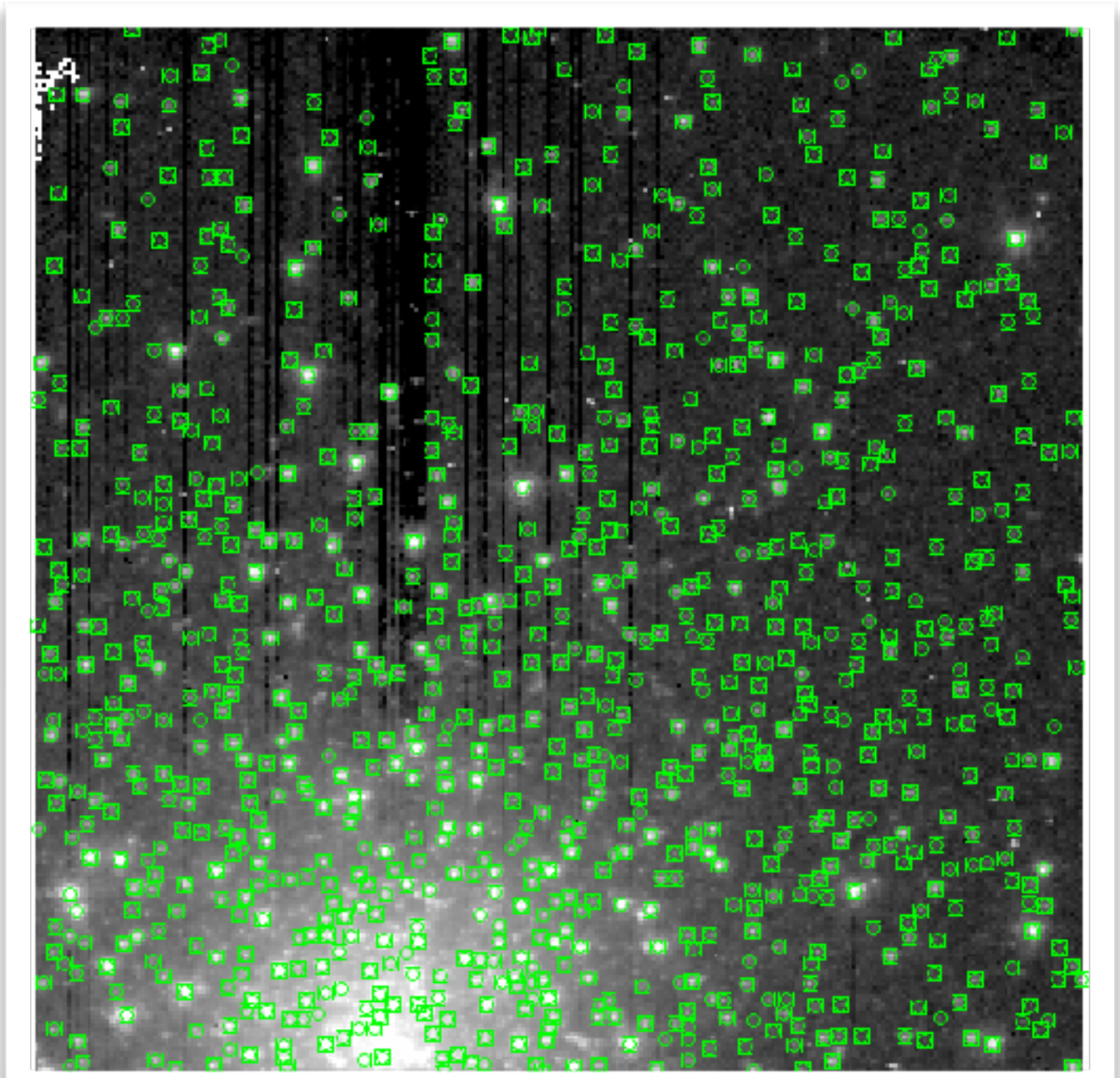

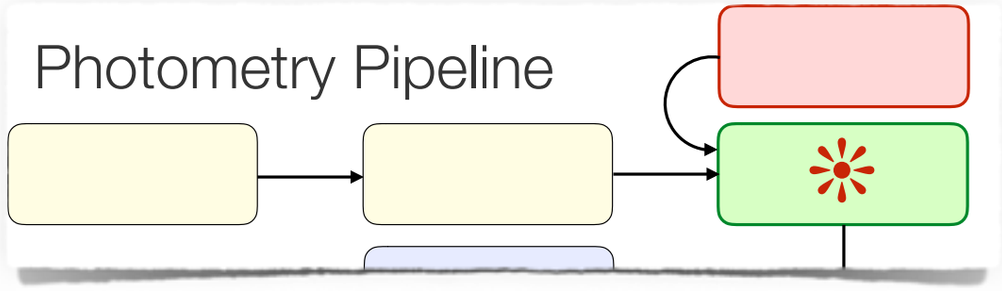

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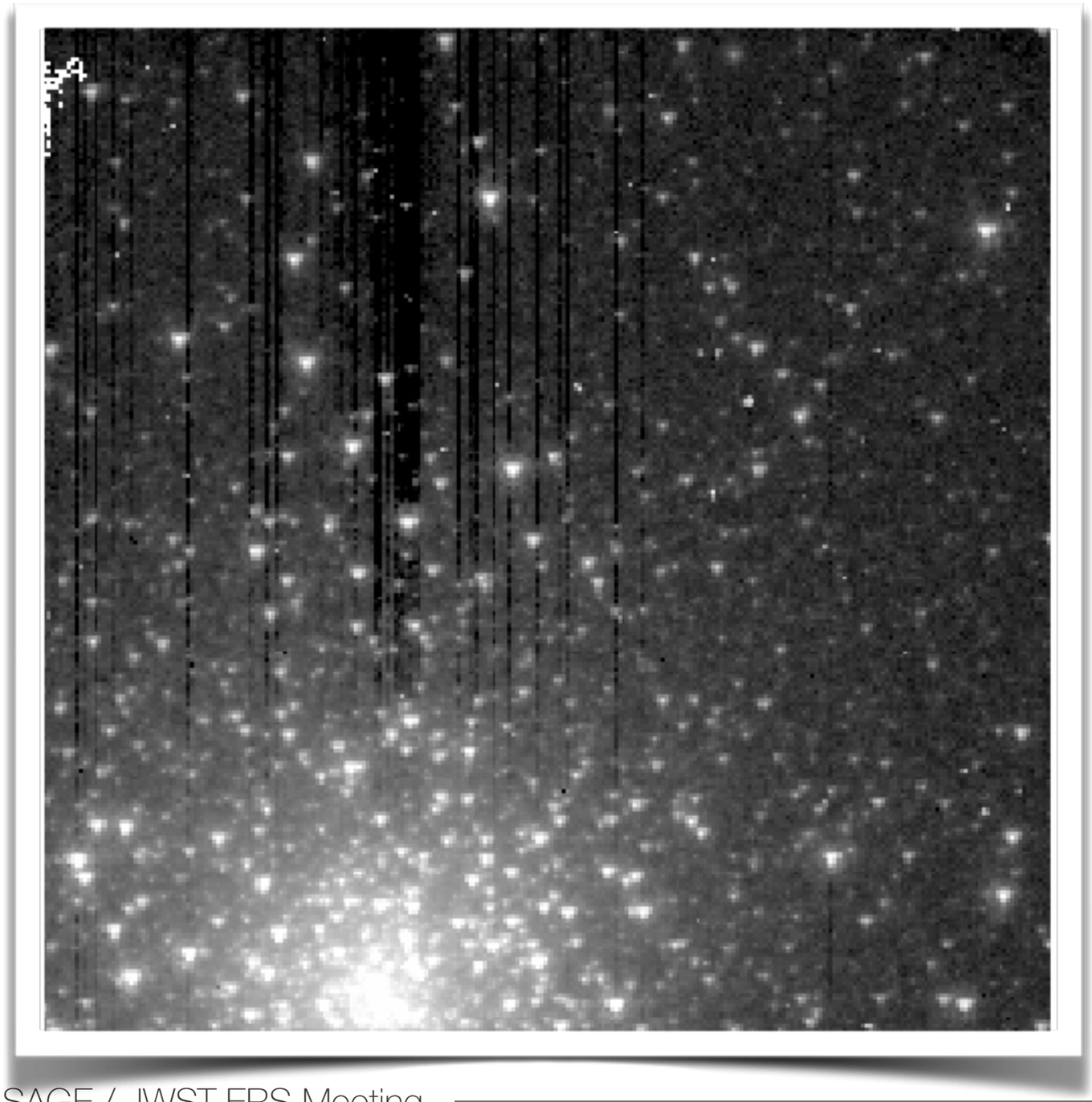

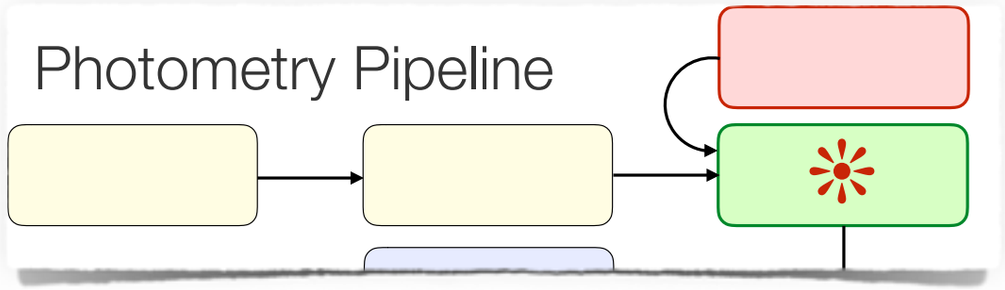

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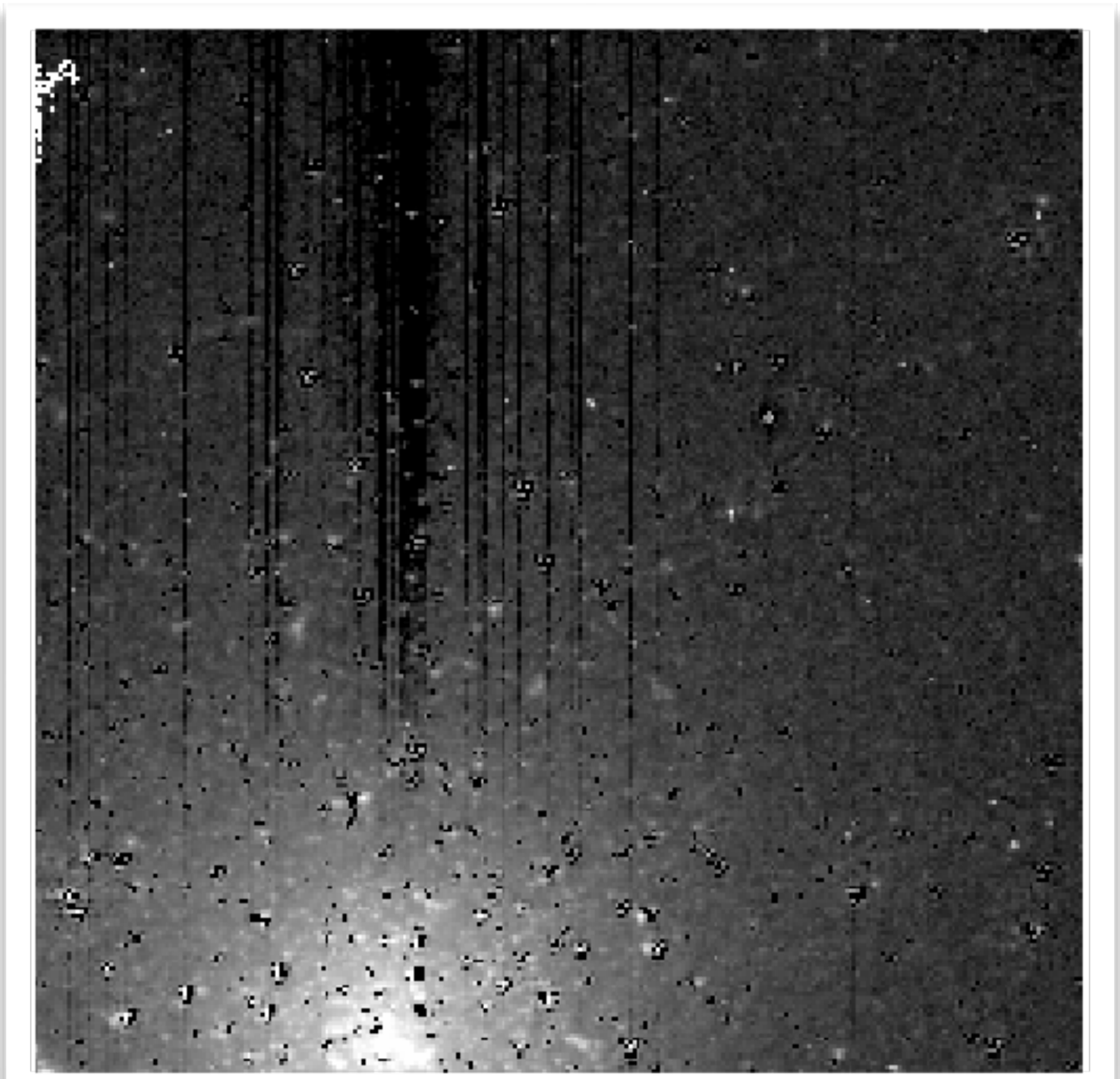

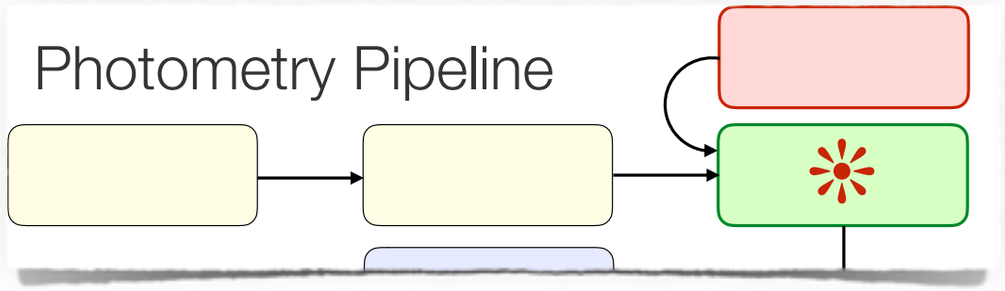

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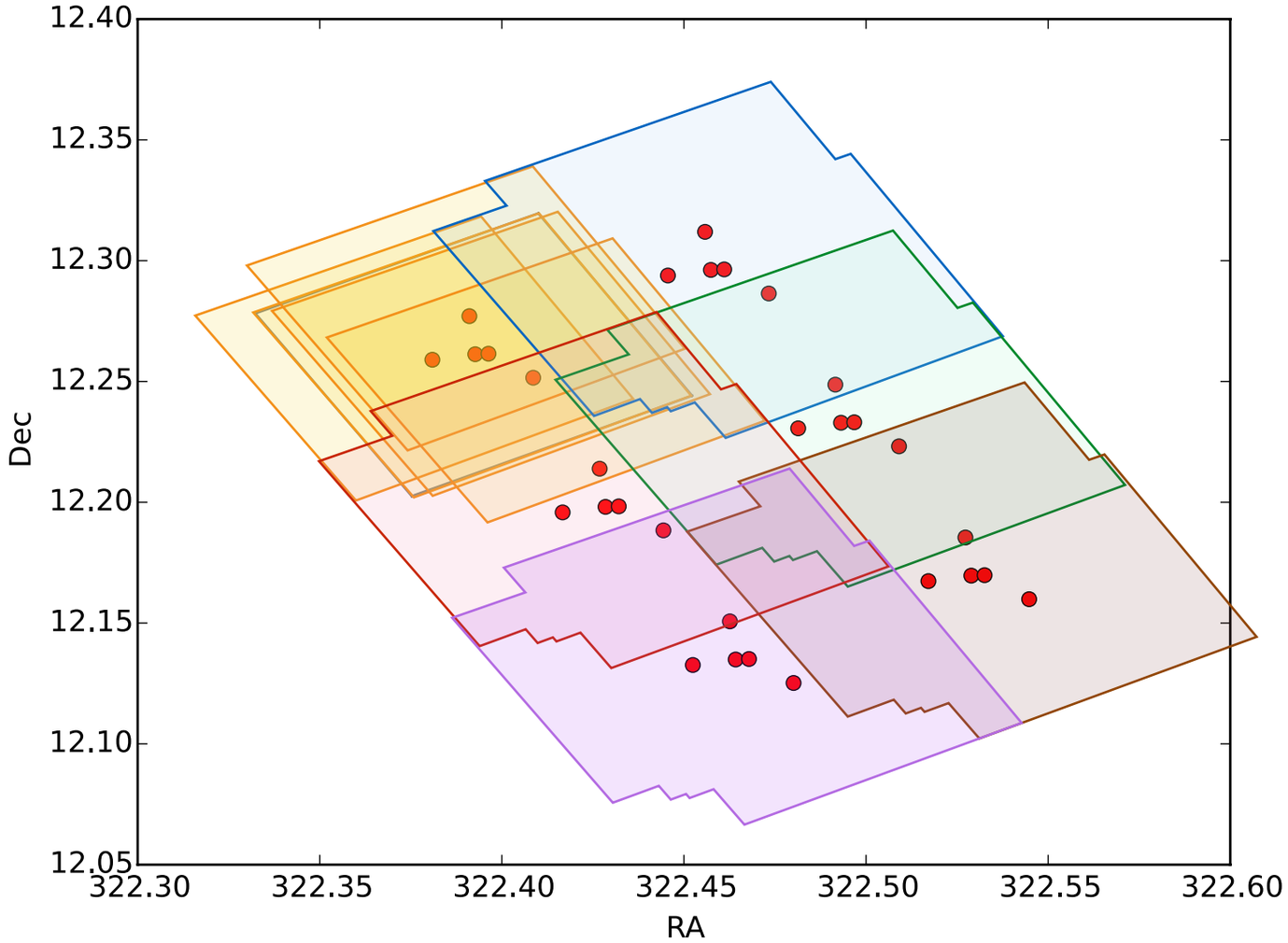
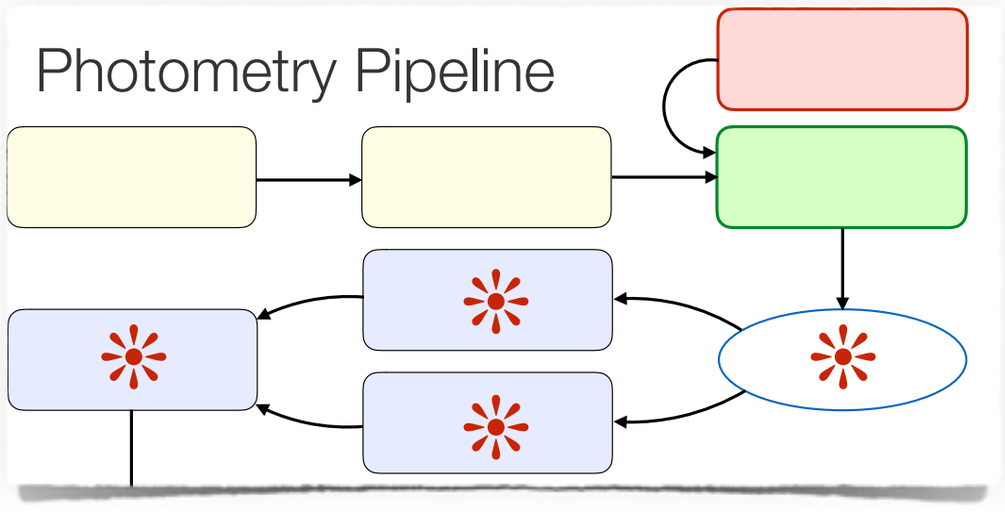
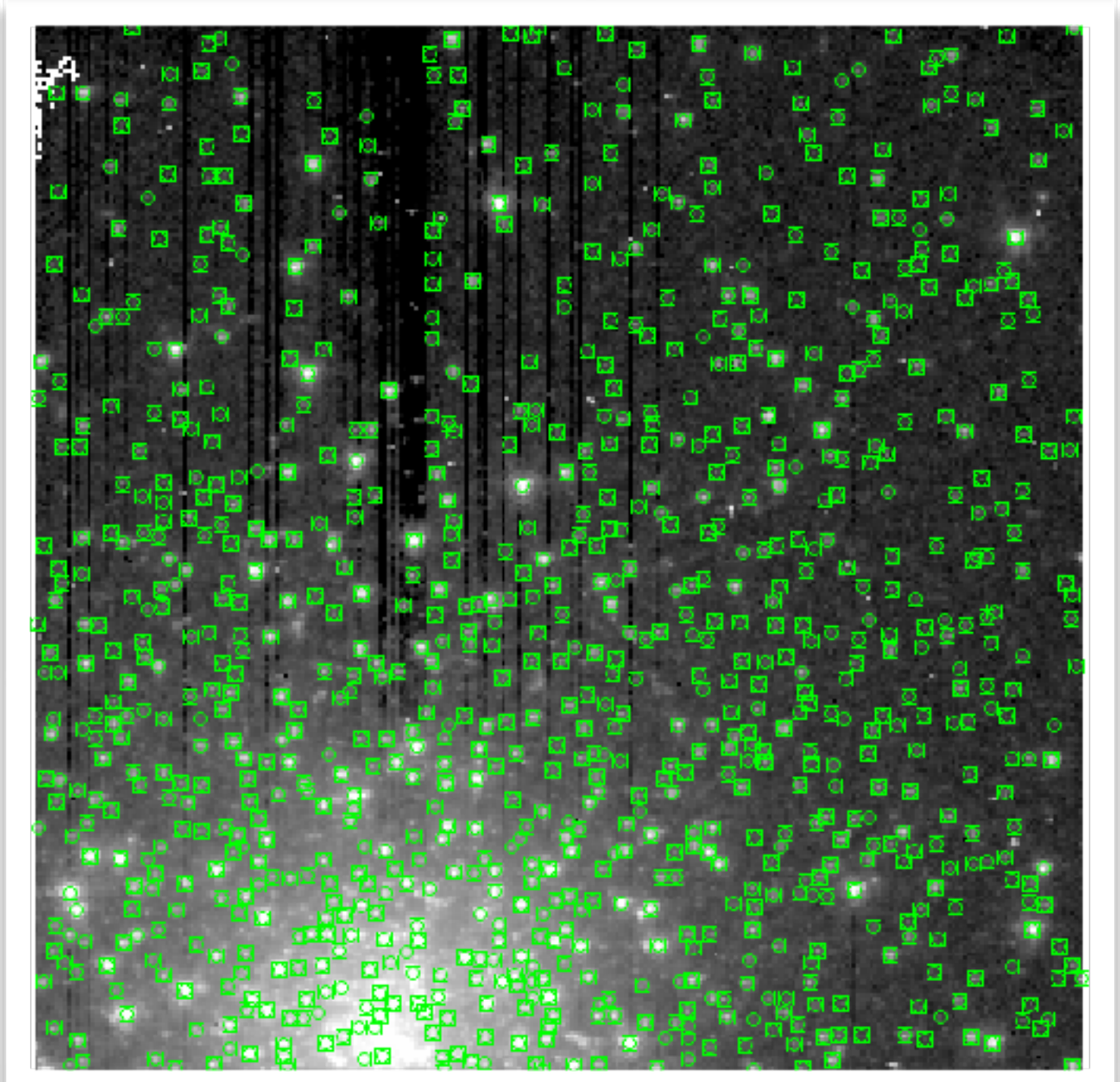
Geometrical Transformation for all Frames

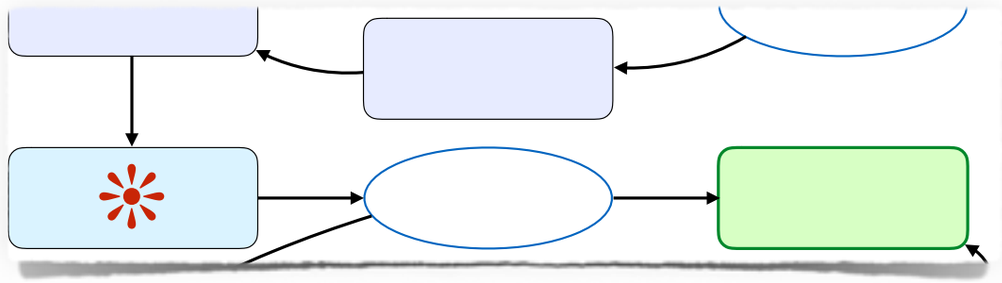




- Identify spatial overlap of individual frames, taking into account dithers, on/off (non contiguous) fields, mapping pattern.
- Find geometrical transformation among all individual (contiguous) frames, based on source matching: DAOMATCH.

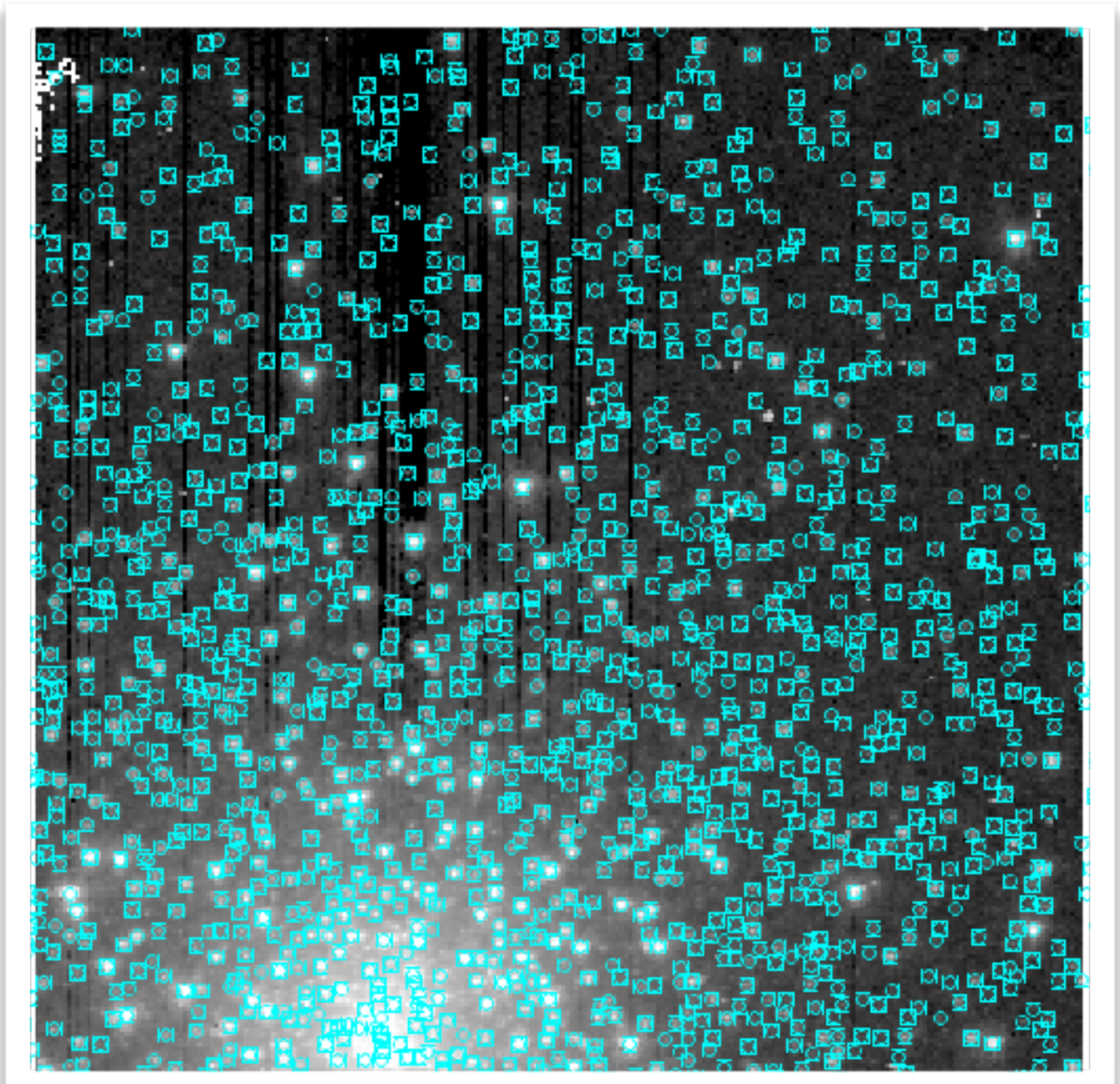
Make Accurate Star Lists for all Fields

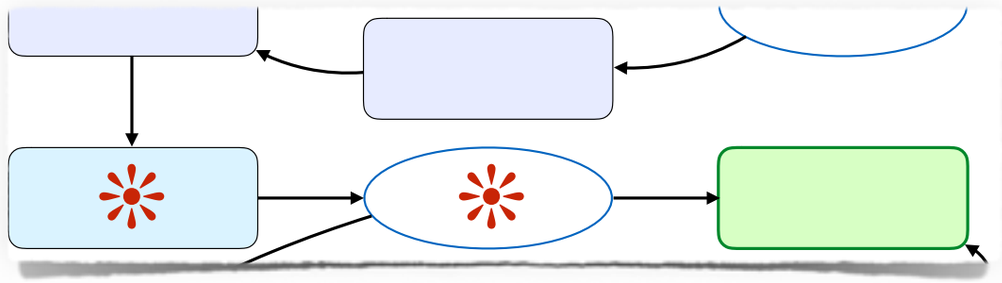




- Refine for each frame the geometric transformations using overlaps.
- Create complete list of sources for each field.
- Uses DAOMASTER.
- This is the final source list unless source list from high resolution images available.

Make Accurate Star Lists for all Fields





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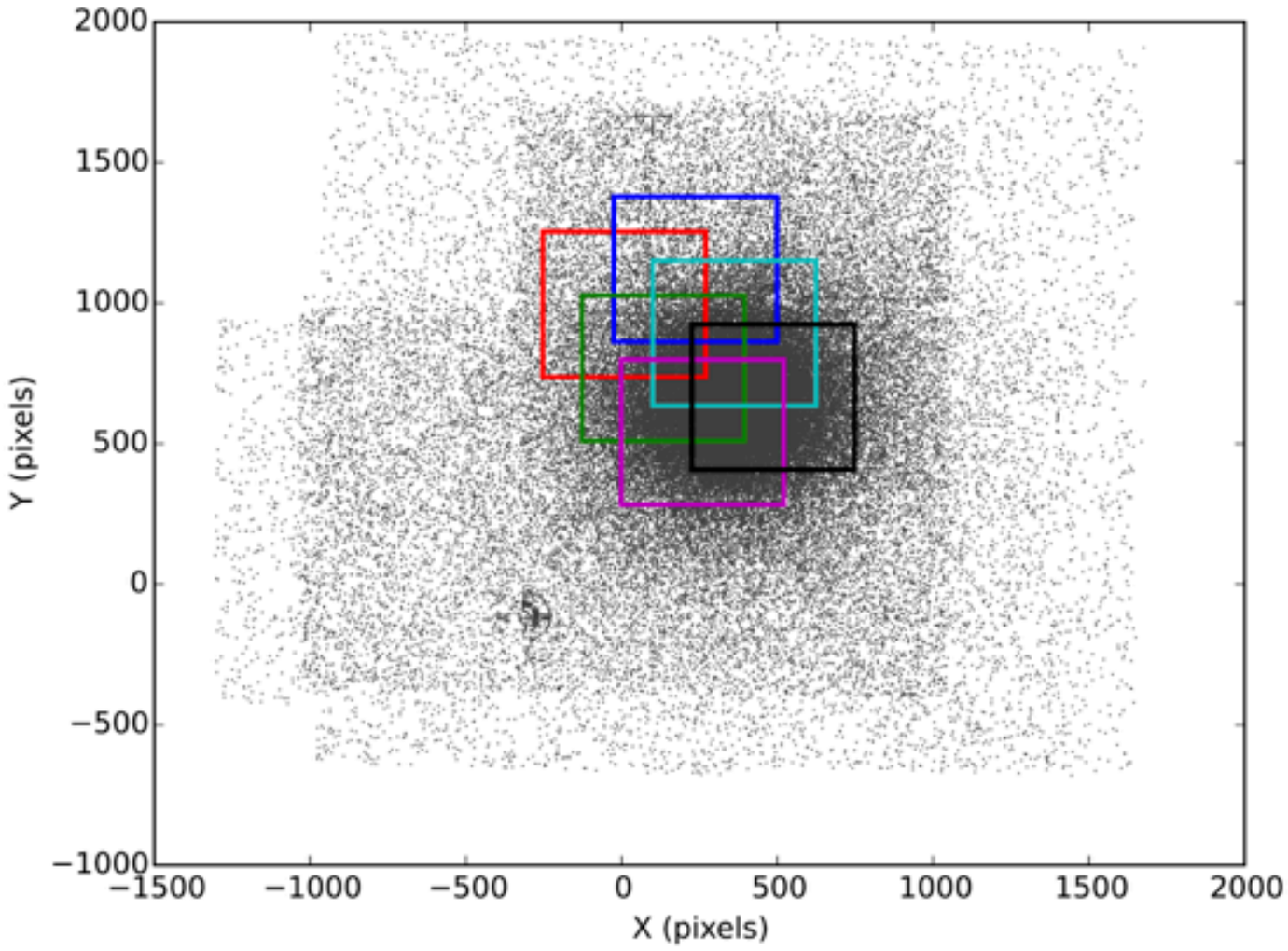
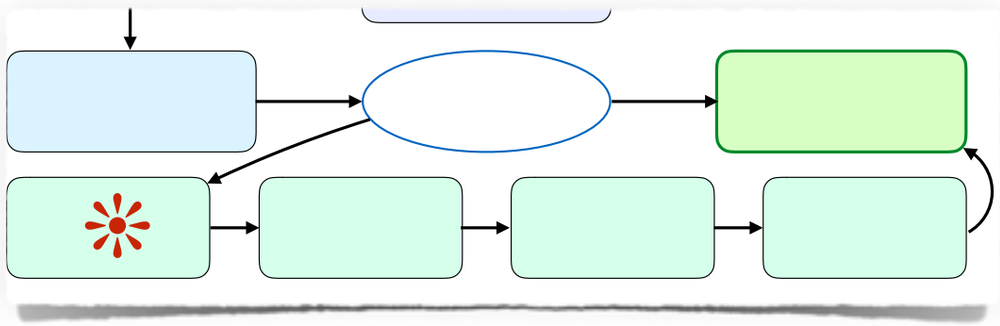
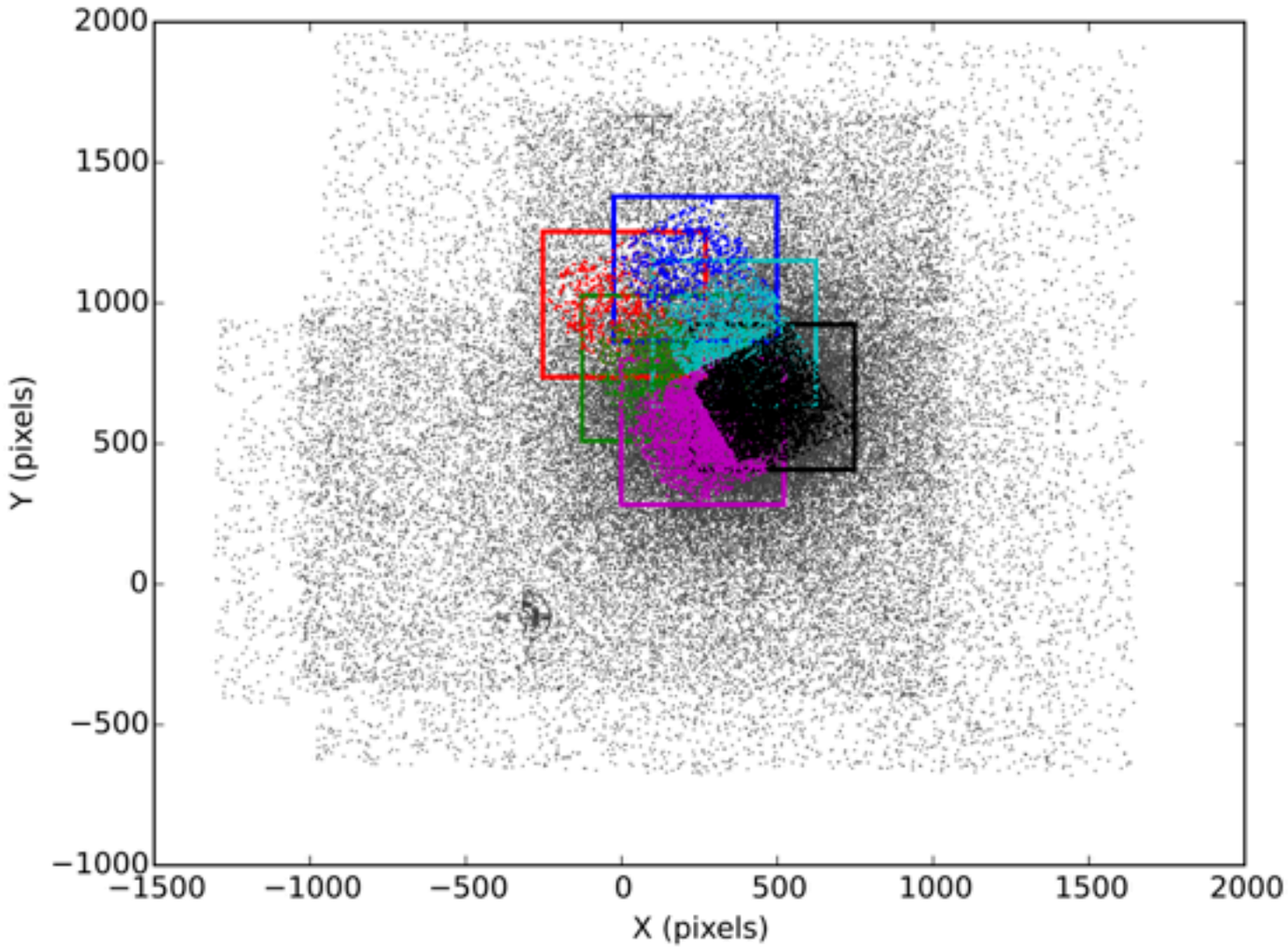
Find Catalog Bounding Box

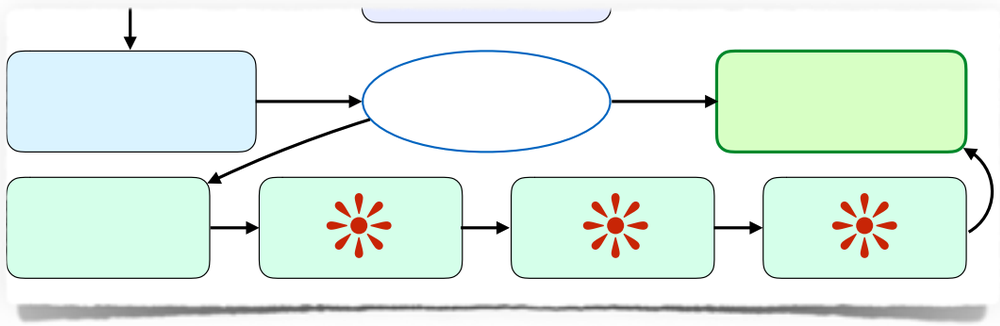




- Find bounding box of fields overlapping with external, high astrometric precision, master catalog.

Create Master Input Source List

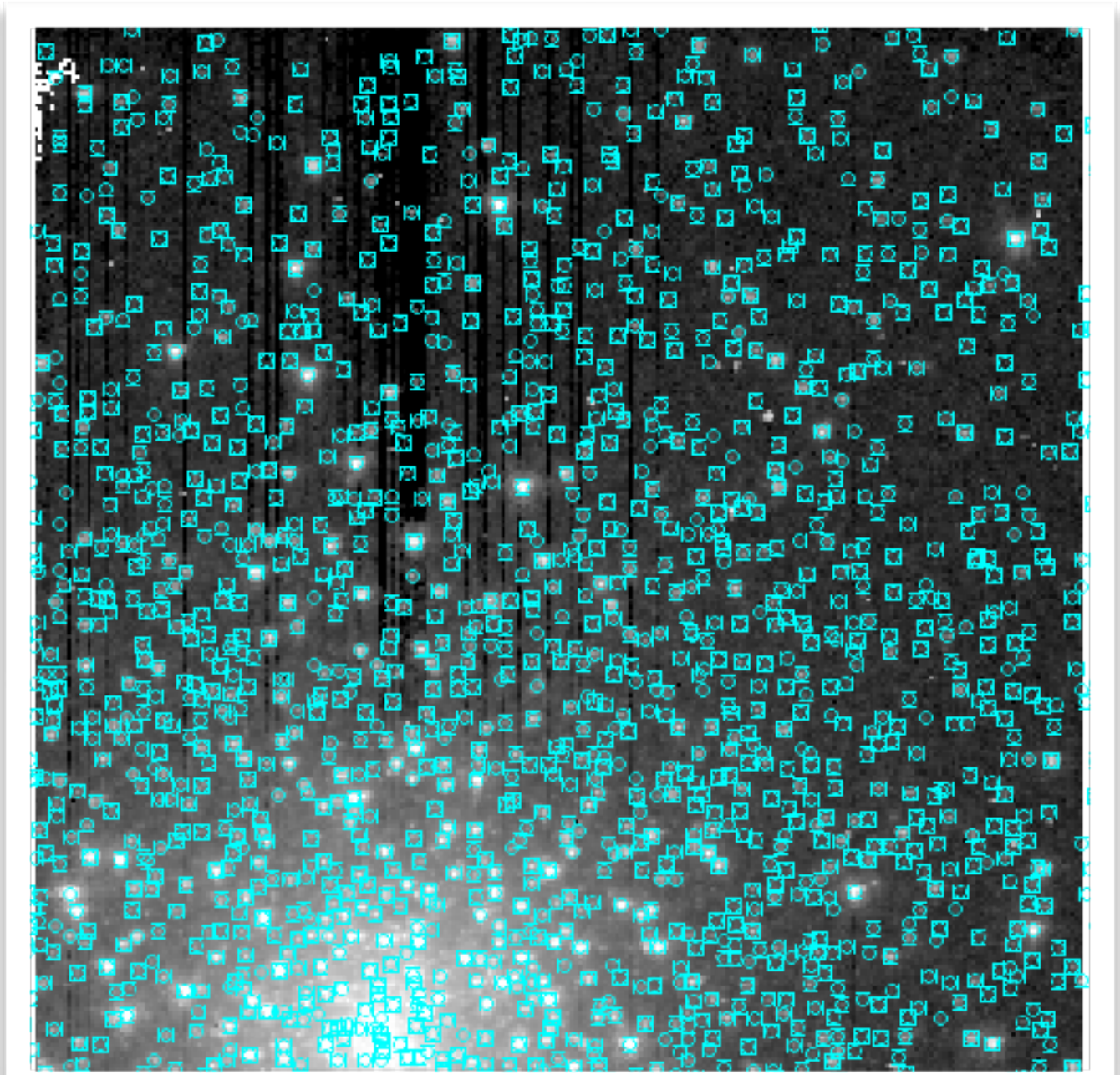


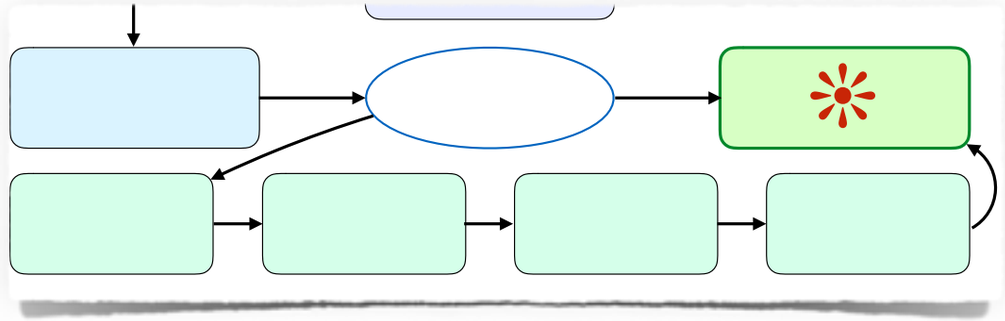


- Find basic geometric transformation among master and individual field catalogs: DAOMATCH.

- Refine geometrical transformation and write final source list with accurate position of each source in each frame: DAOMASTER.
- Combine transformations for all frames: COMBINE.

Measure Final PSF-fitting Photometry





- Run photometry on final matched source list for all frames: ALLFRAME.
- Only sources with good PSF-fitting solution are kept; other rejected.
- Residuals improved by using high precision astrometric catalog.

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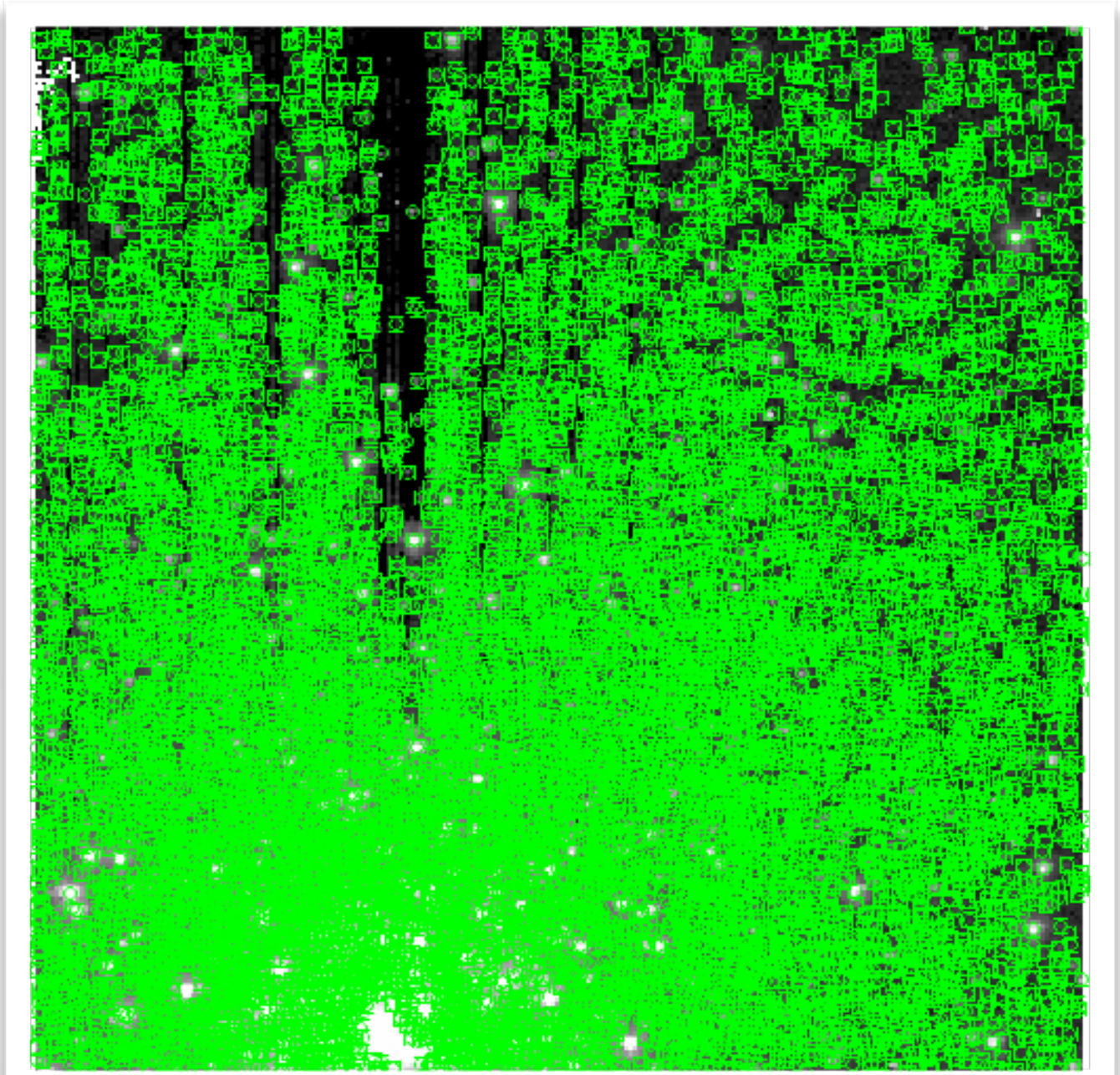

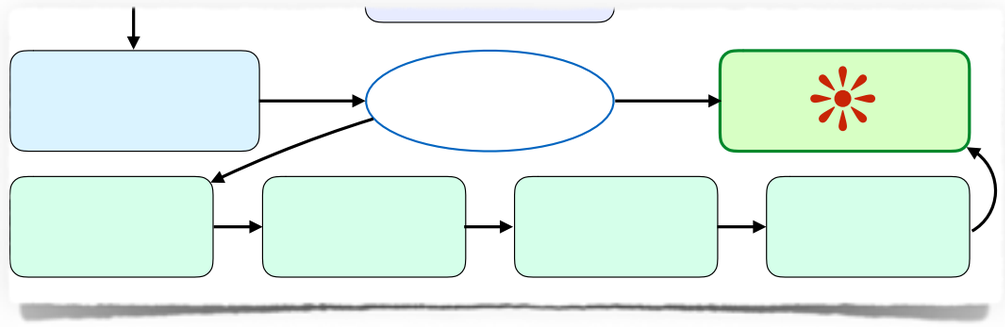

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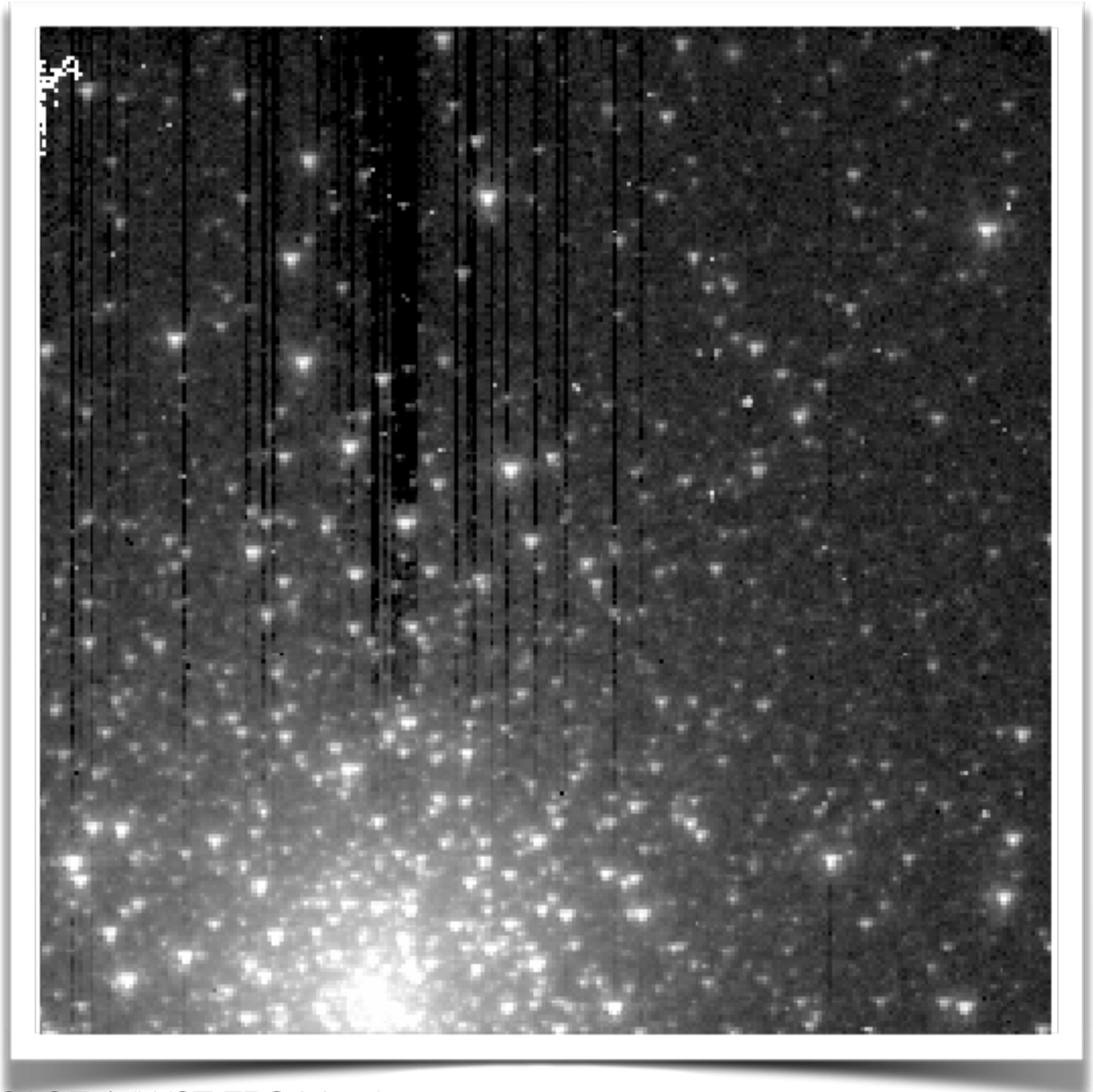

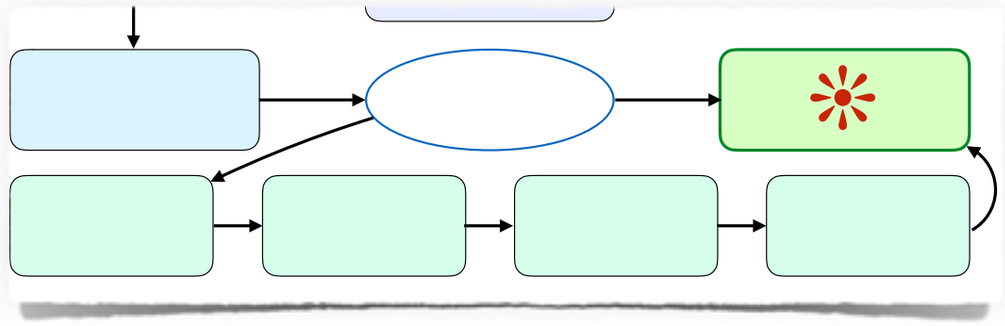

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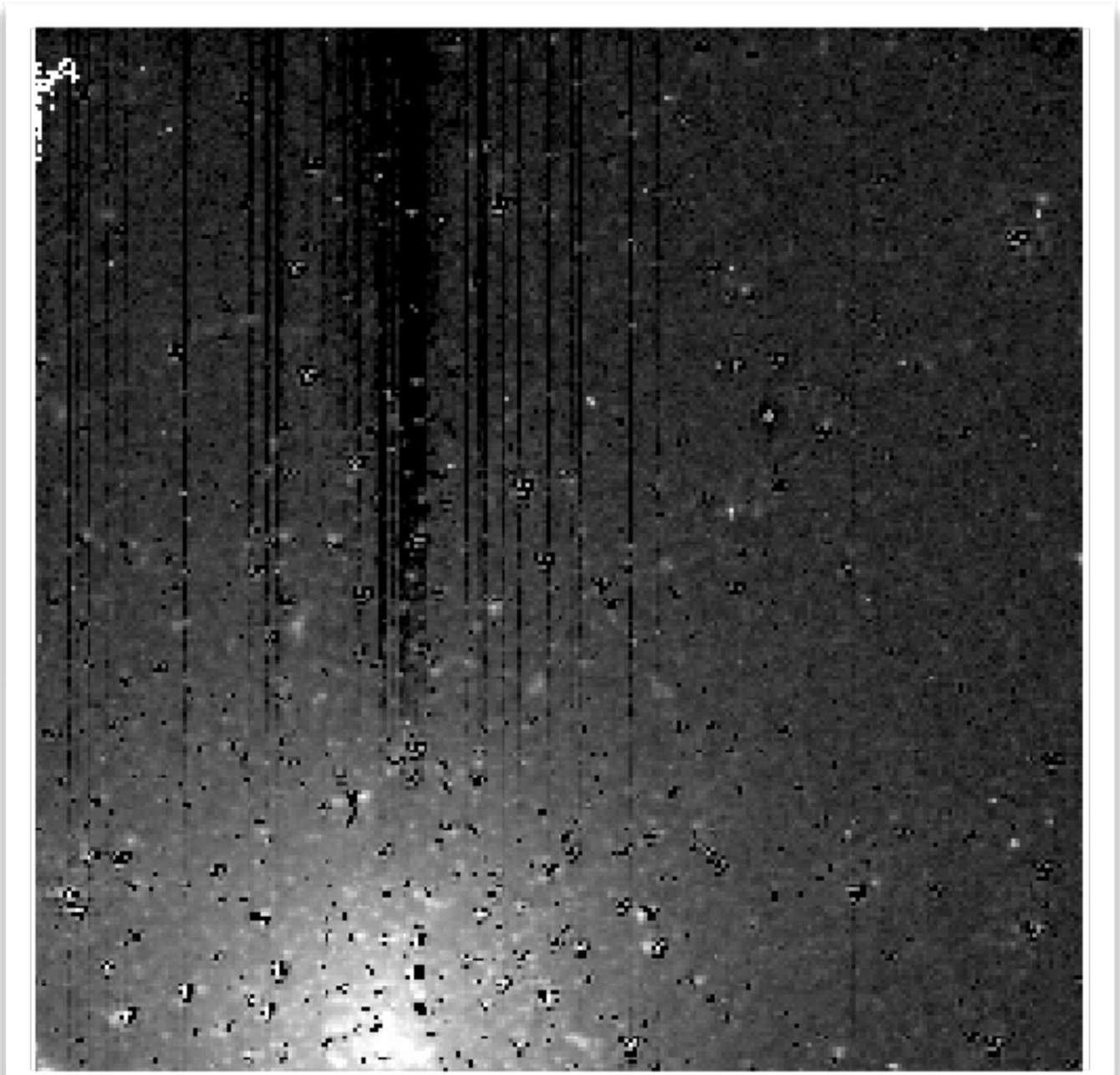

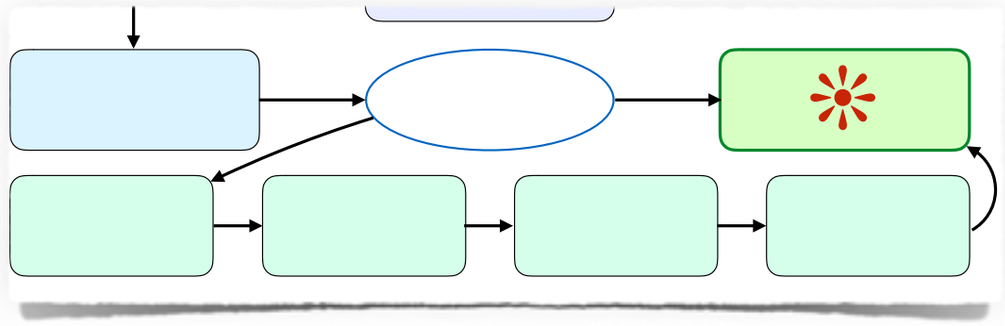

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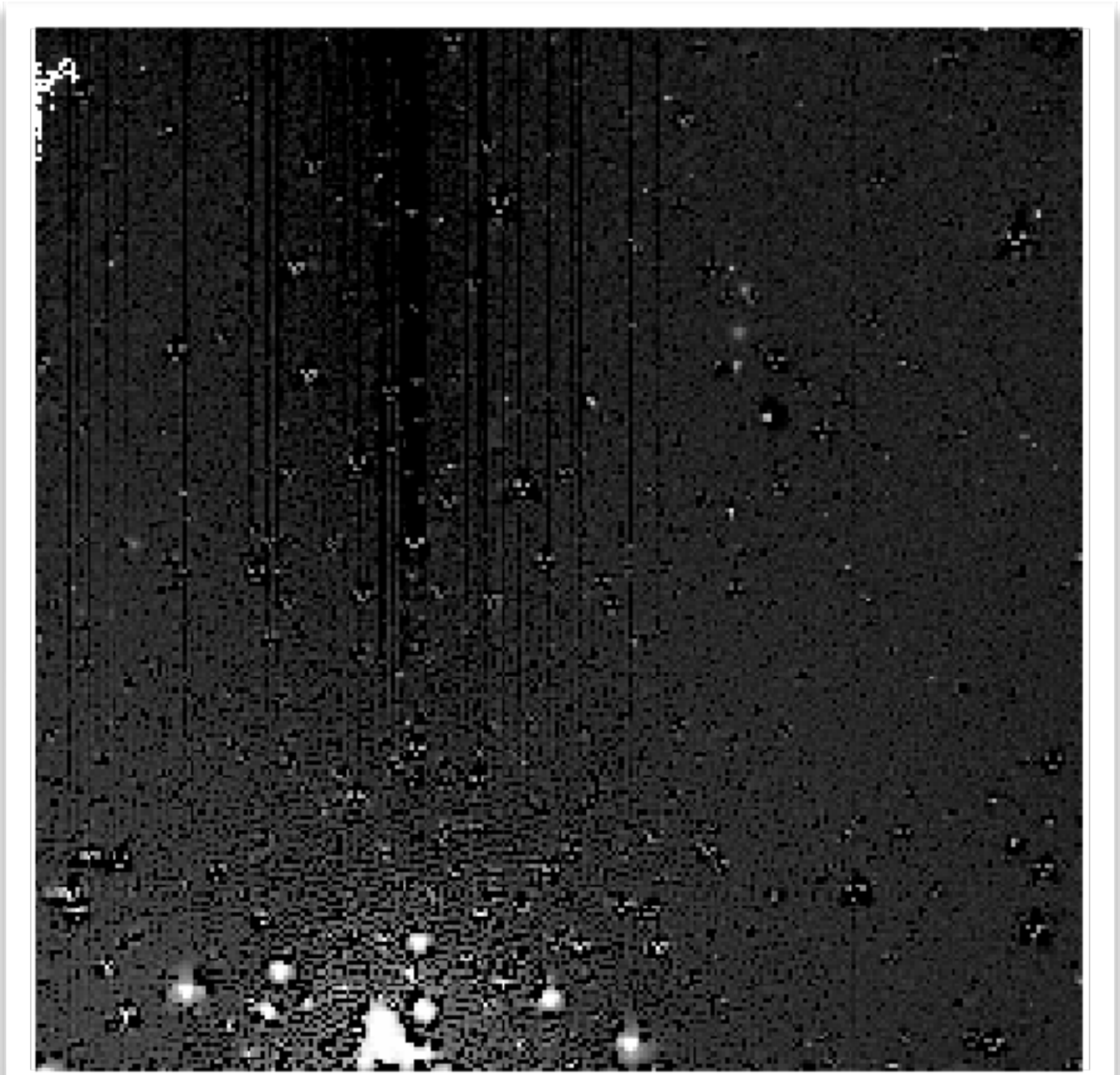

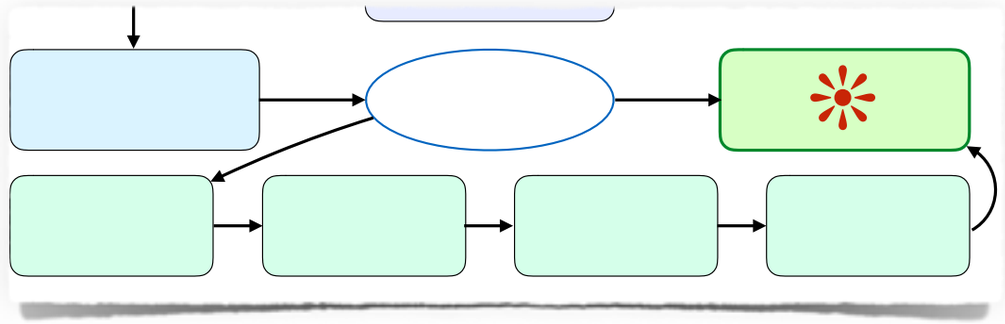

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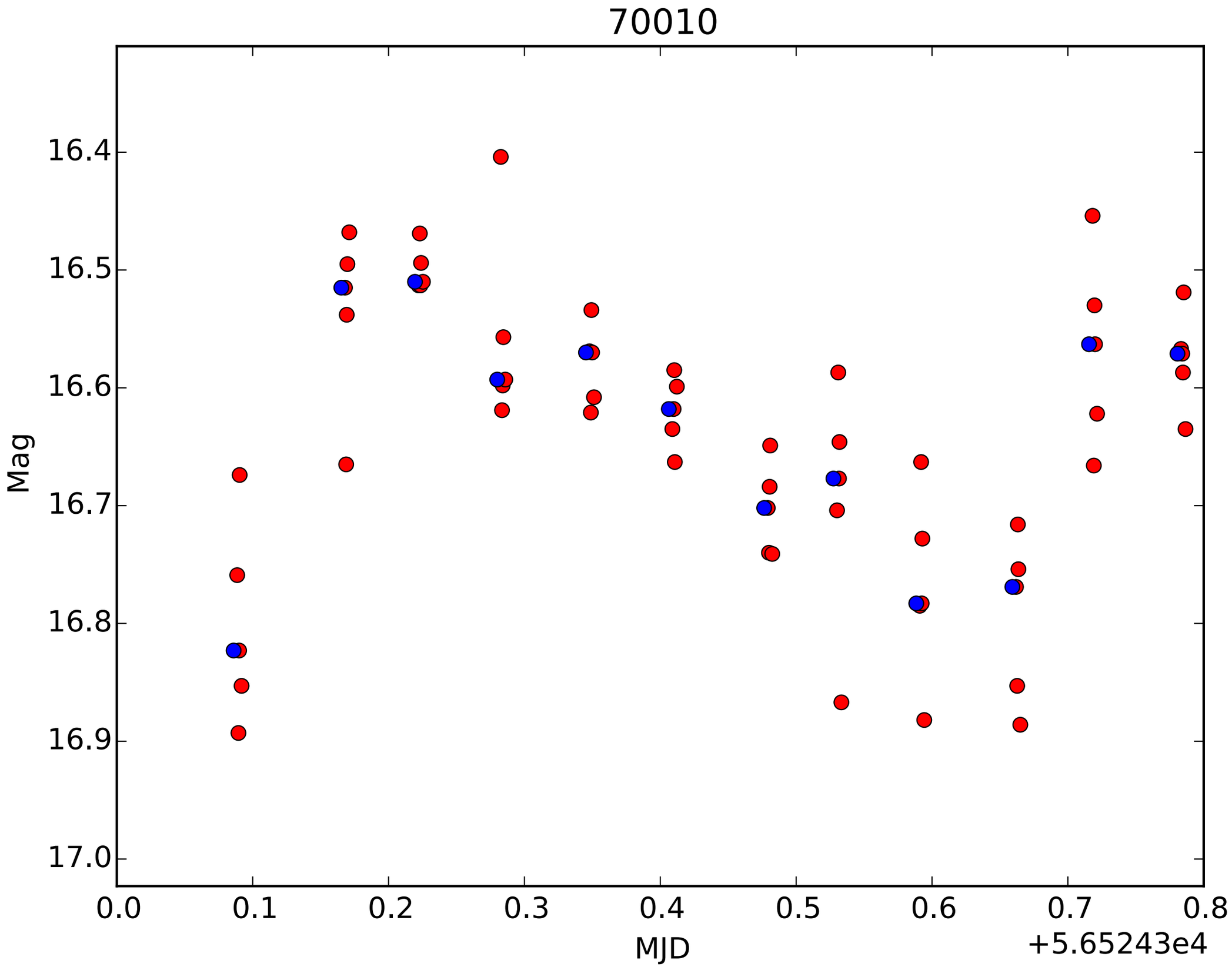
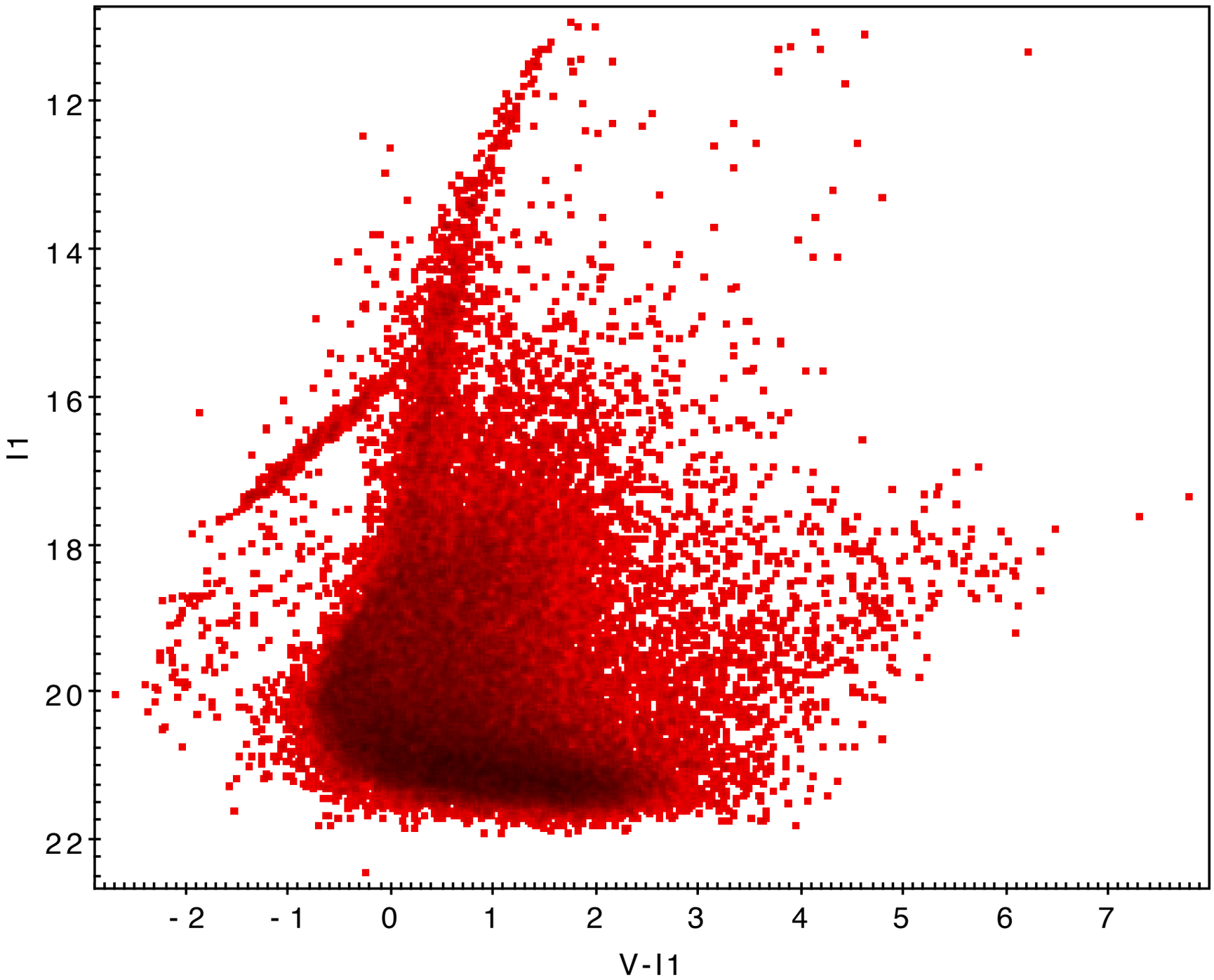
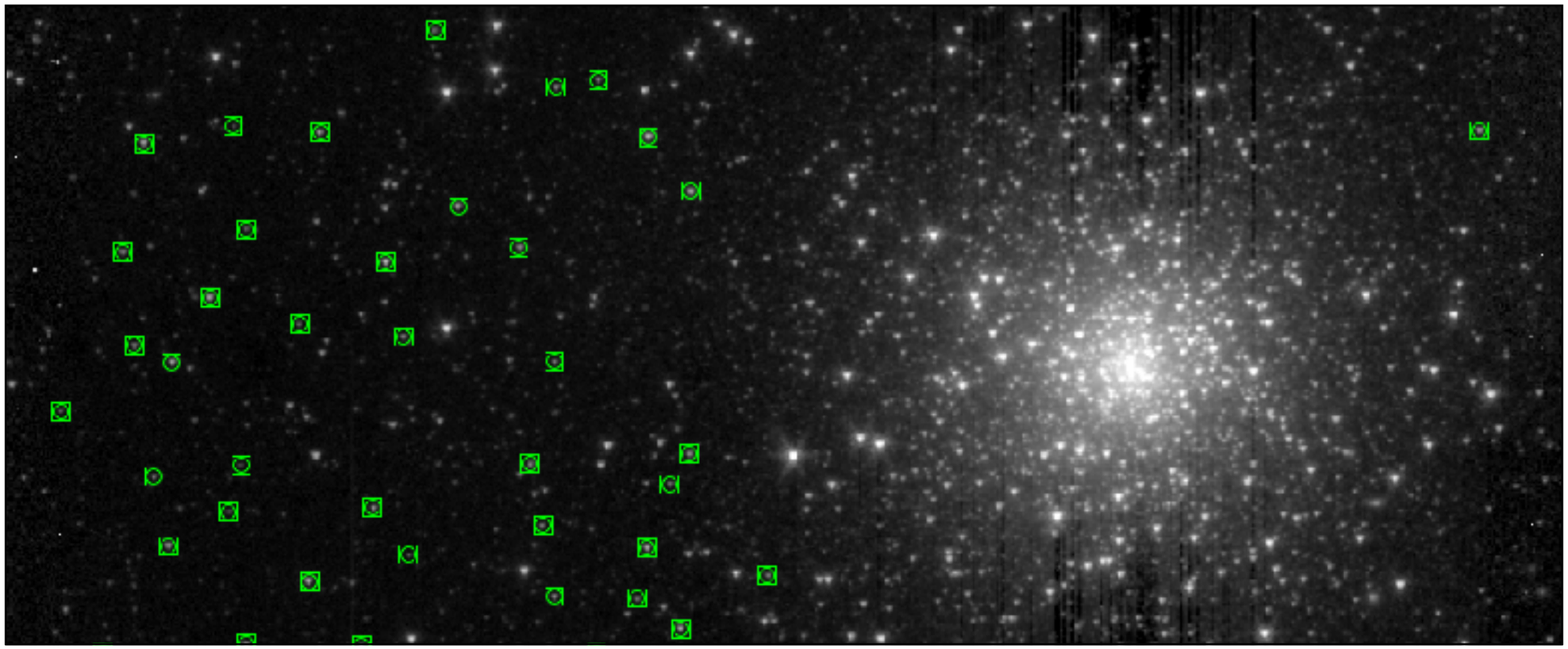

70010
16.4
16.5
16.6
16.7
16.8
16.9
17.0
Mag
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
MJD
+5.65243e4

Using Mosaics for Faint Sources?

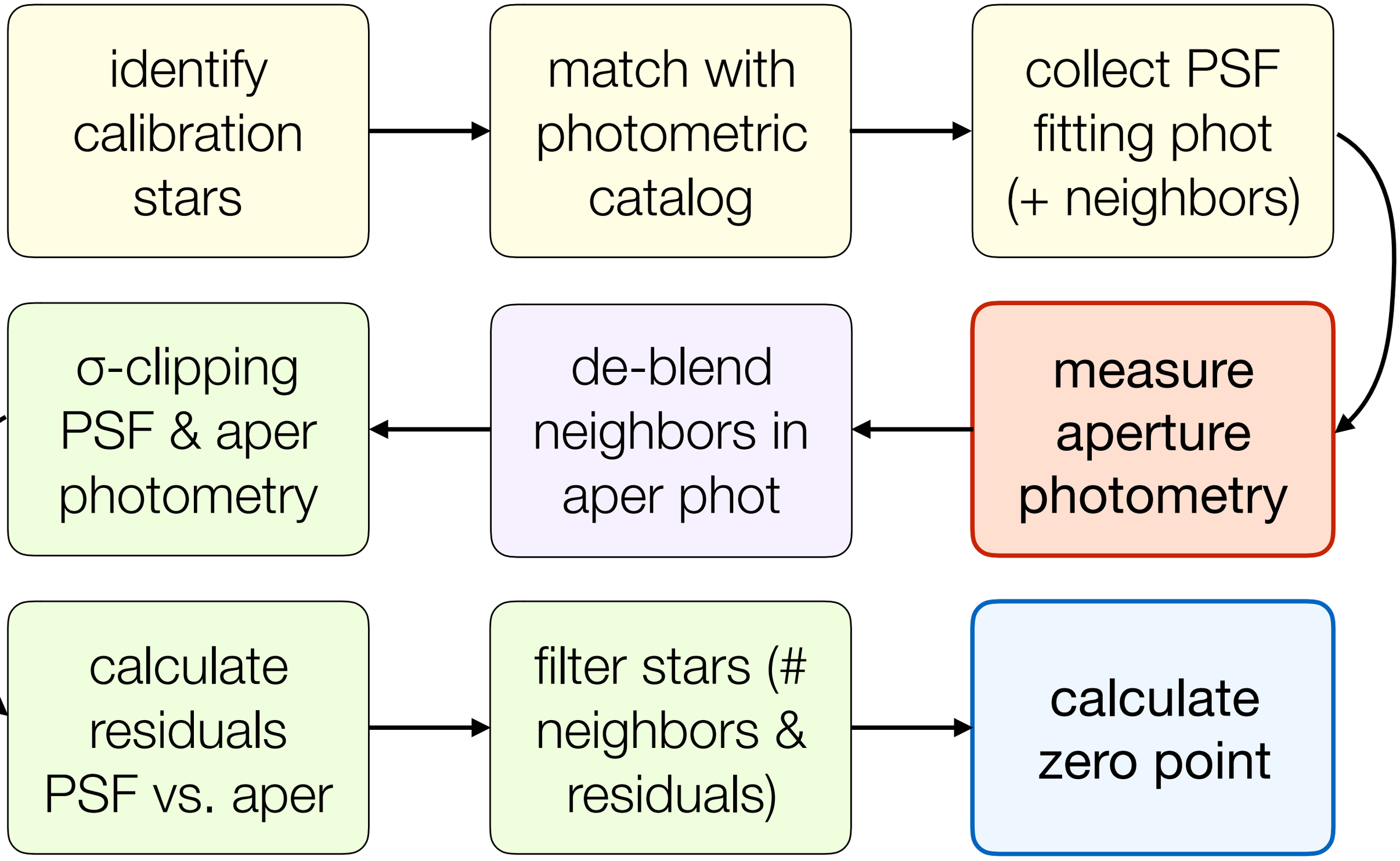


Using Mosaics instead of Single Frames

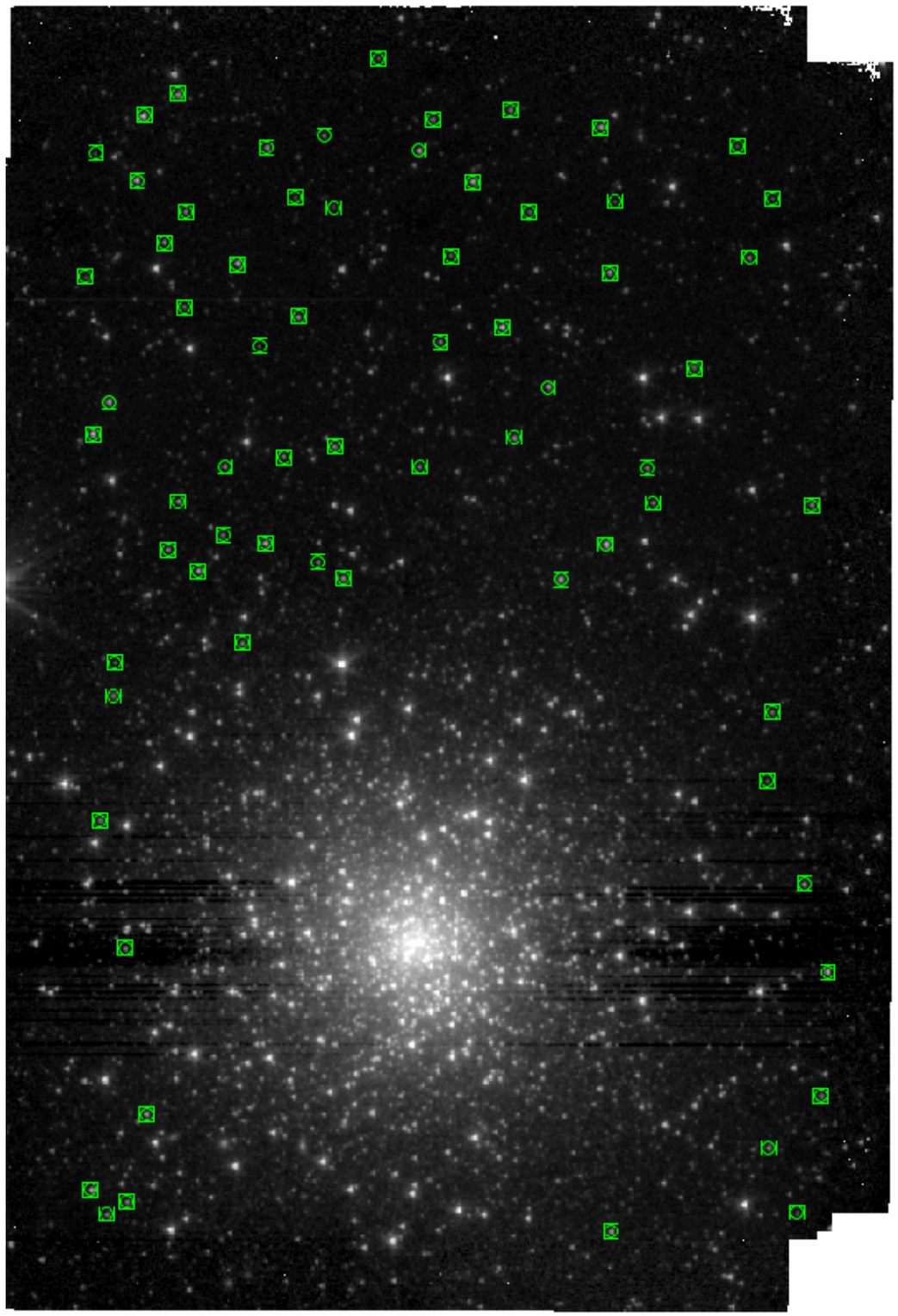


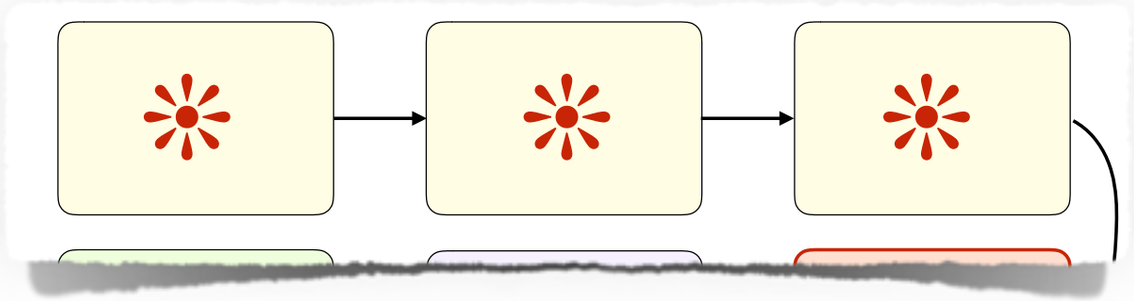
- **Advantages:** better sensitivity (S/N ~ $N^{1/2}$), better sampling (better PSF fitting / source de-blending), better outlier rejection.
- **Disadvantages:** will lose spatial information of PSF variations on detector array, complex PSF if different roll angle, will lose temporal information if frames are taken time apart.

Calibration Pipeline



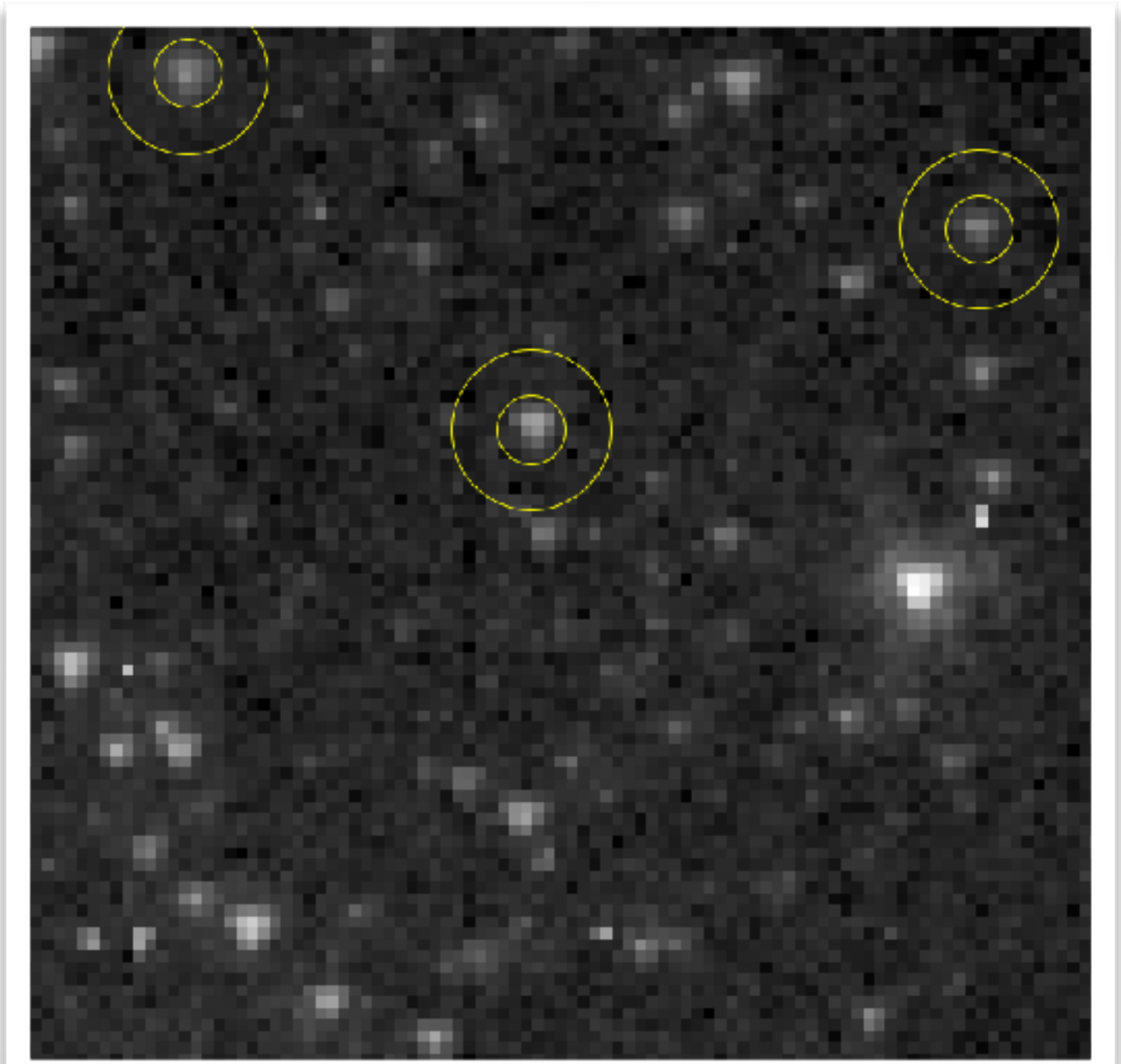
Identify Calibration Stars

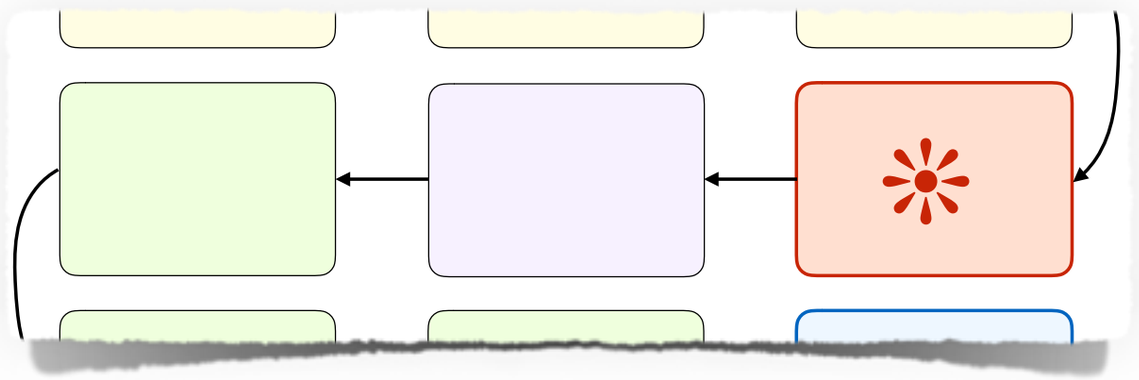




- Identify isolated (minimum number of neighbors) bright stars from mosaic.
- Match calibration stars to PSF-fitting photometry catalog (including neighbors falling within ~2 apertures from center of each star).
- Compile list of PSF photometry for each star and its neighbors.

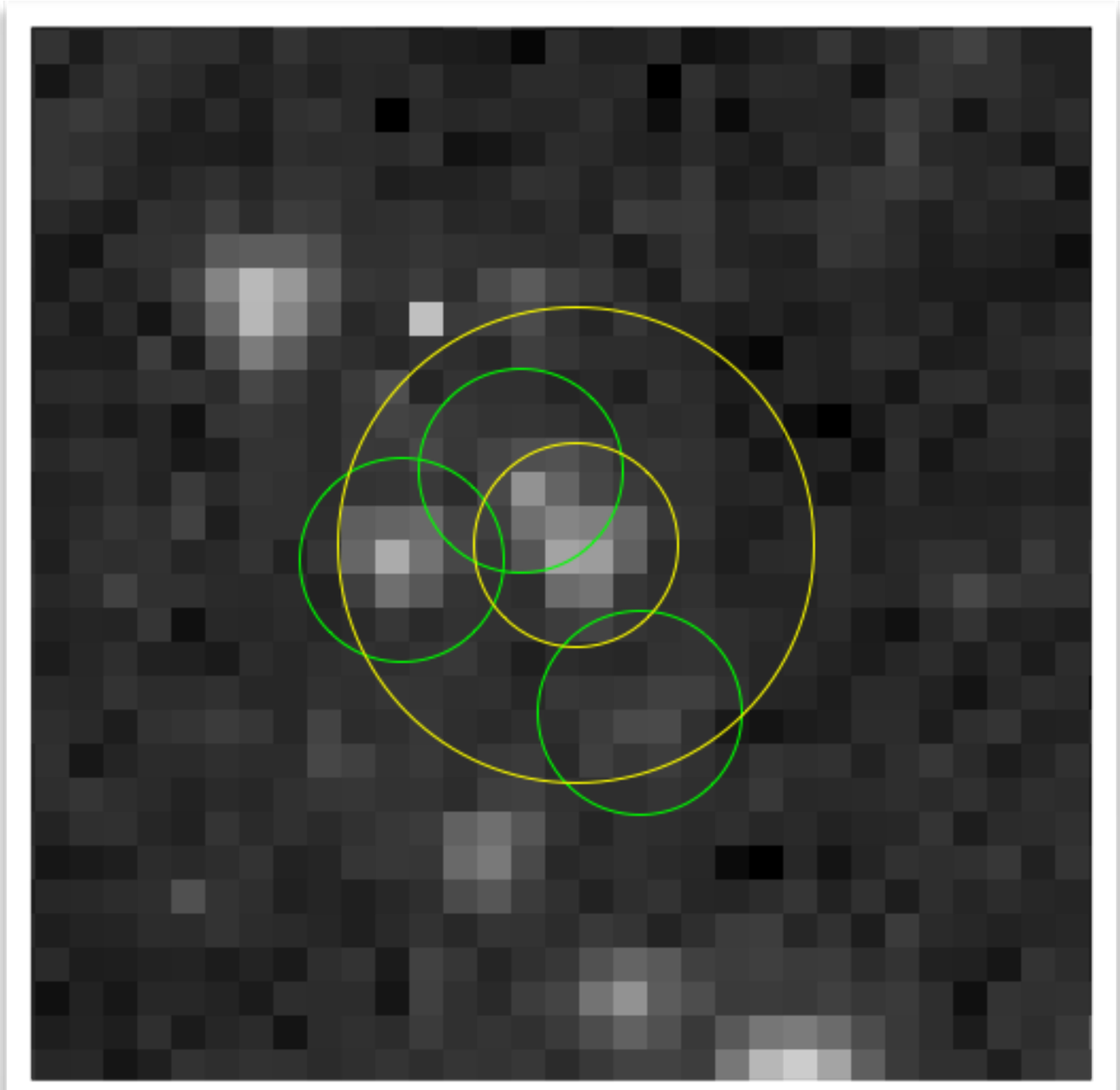
Measure Aperture Photometry

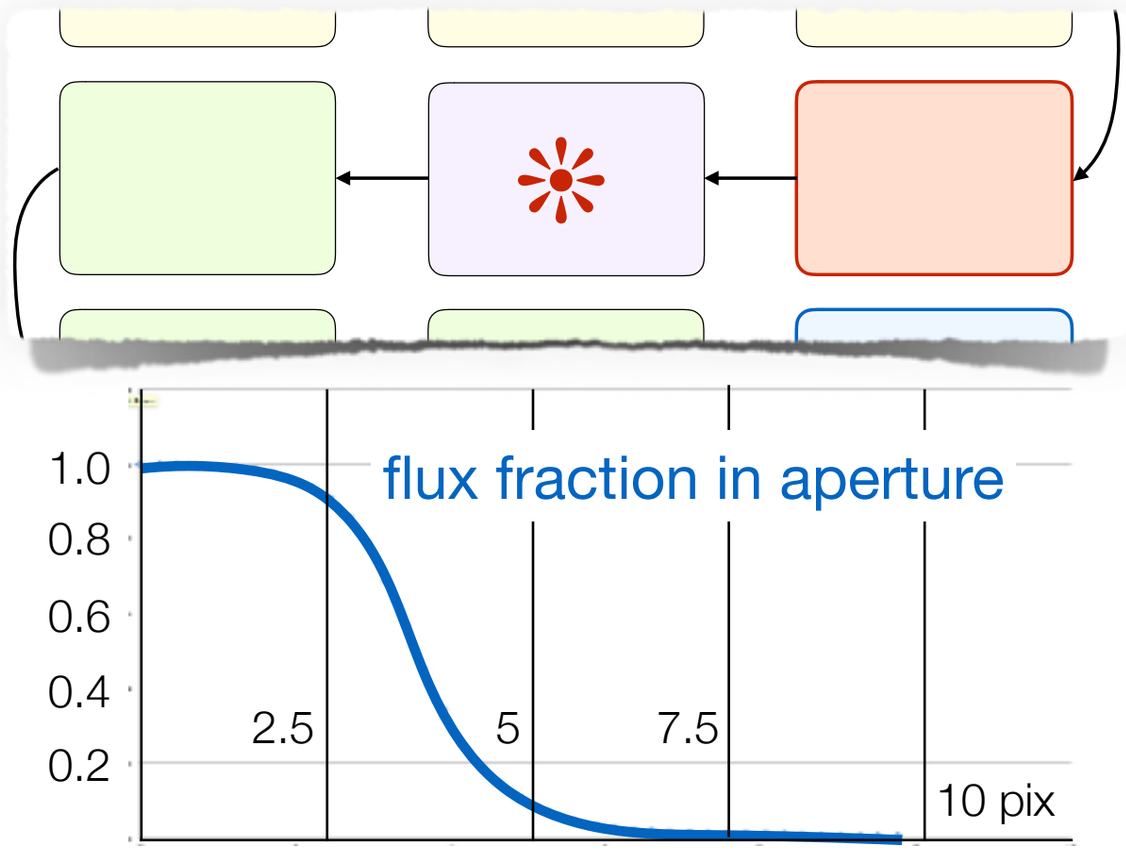




- Perform aperture photometry on individual frames.
- Relies on instrumental absolute calibration and pipeline corrections.
- Apply post-pipeline corrections.

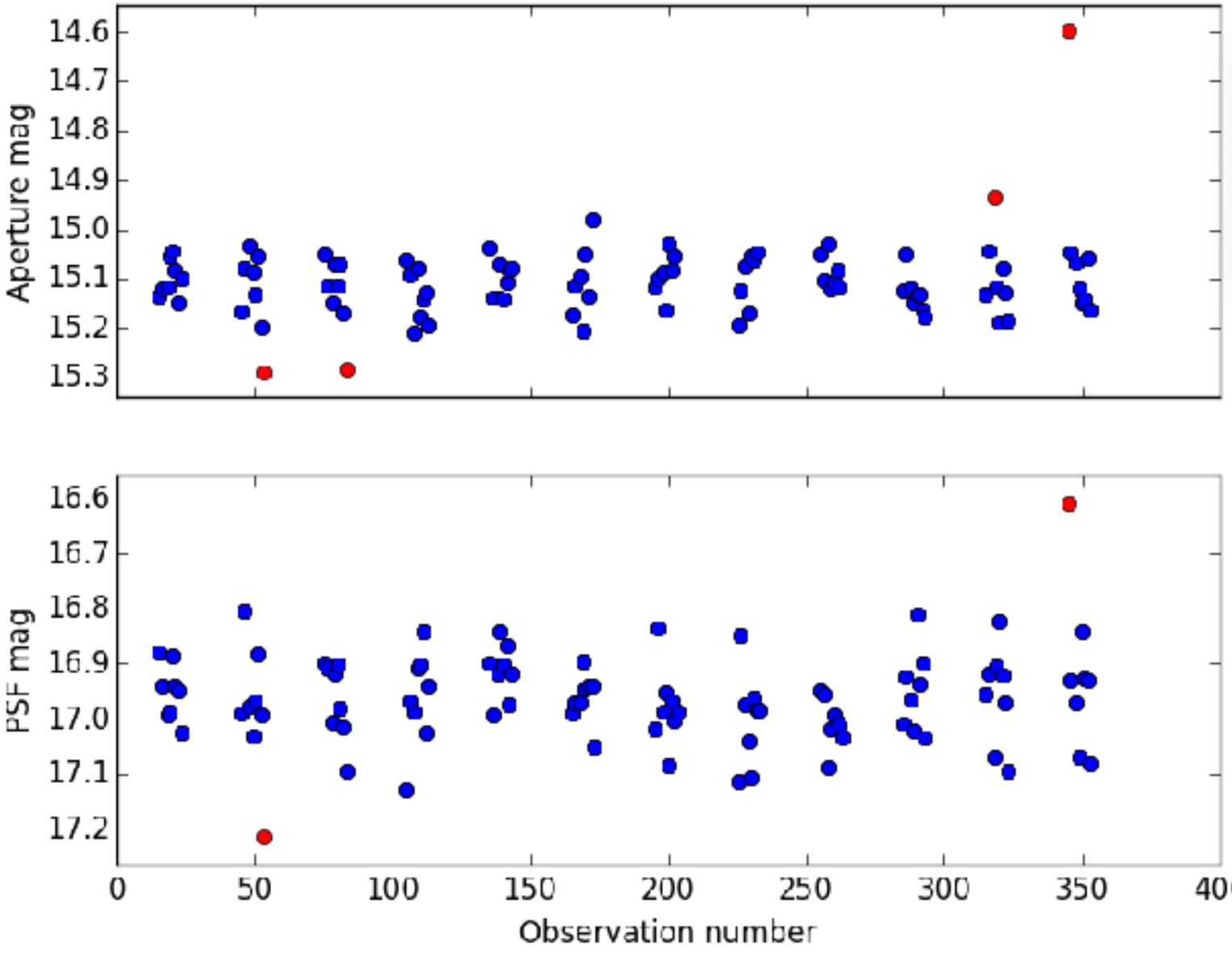
De-blend Calibrator Stars

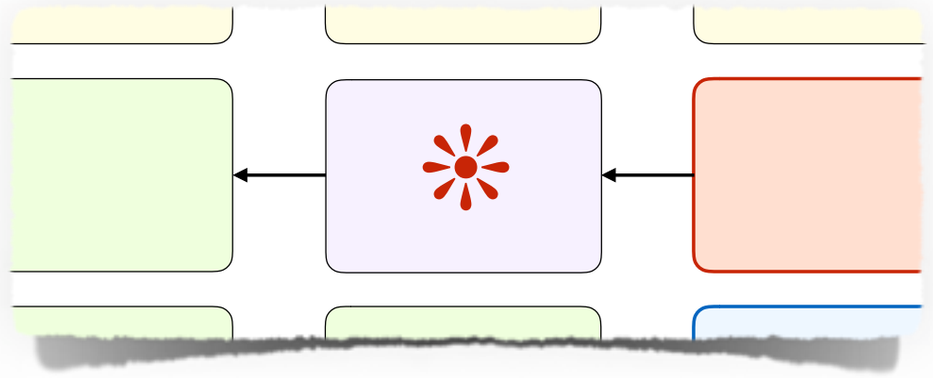




- Use PSF photometry ratio of calibrator star and neighbors too subtract flux fraction of neighbors from aperture.

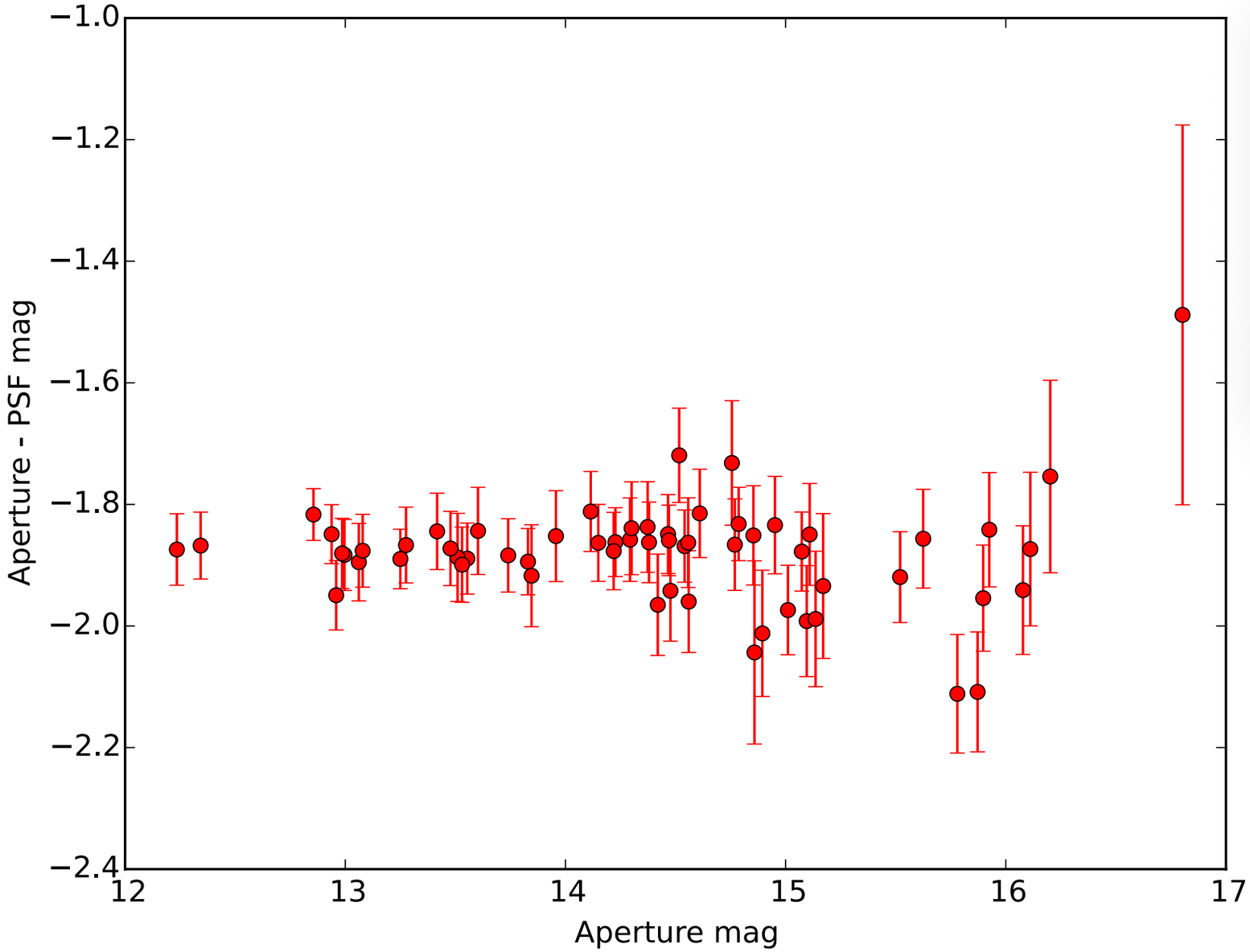
Photometry σ-Clipping

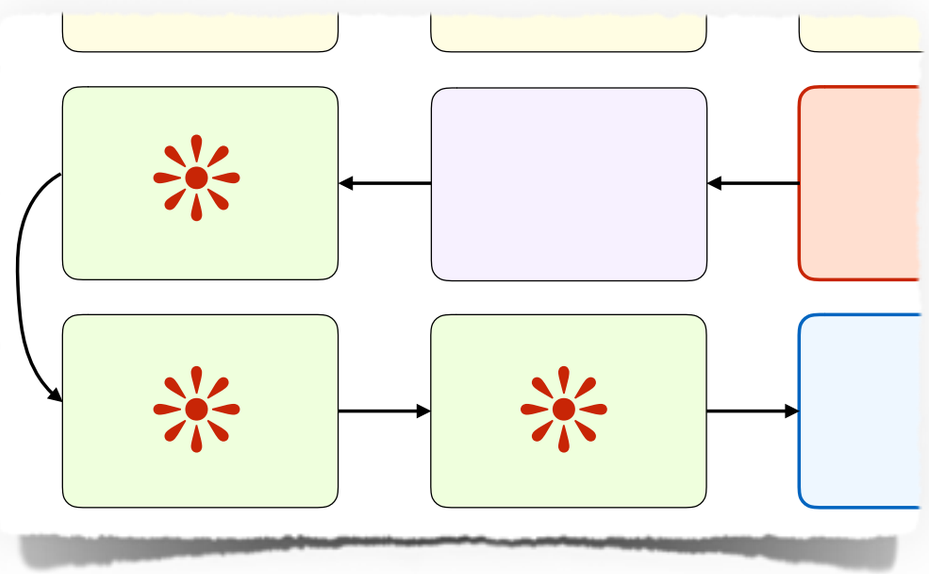




- Remove outliers on both aperture and PSF-fitting photometry.

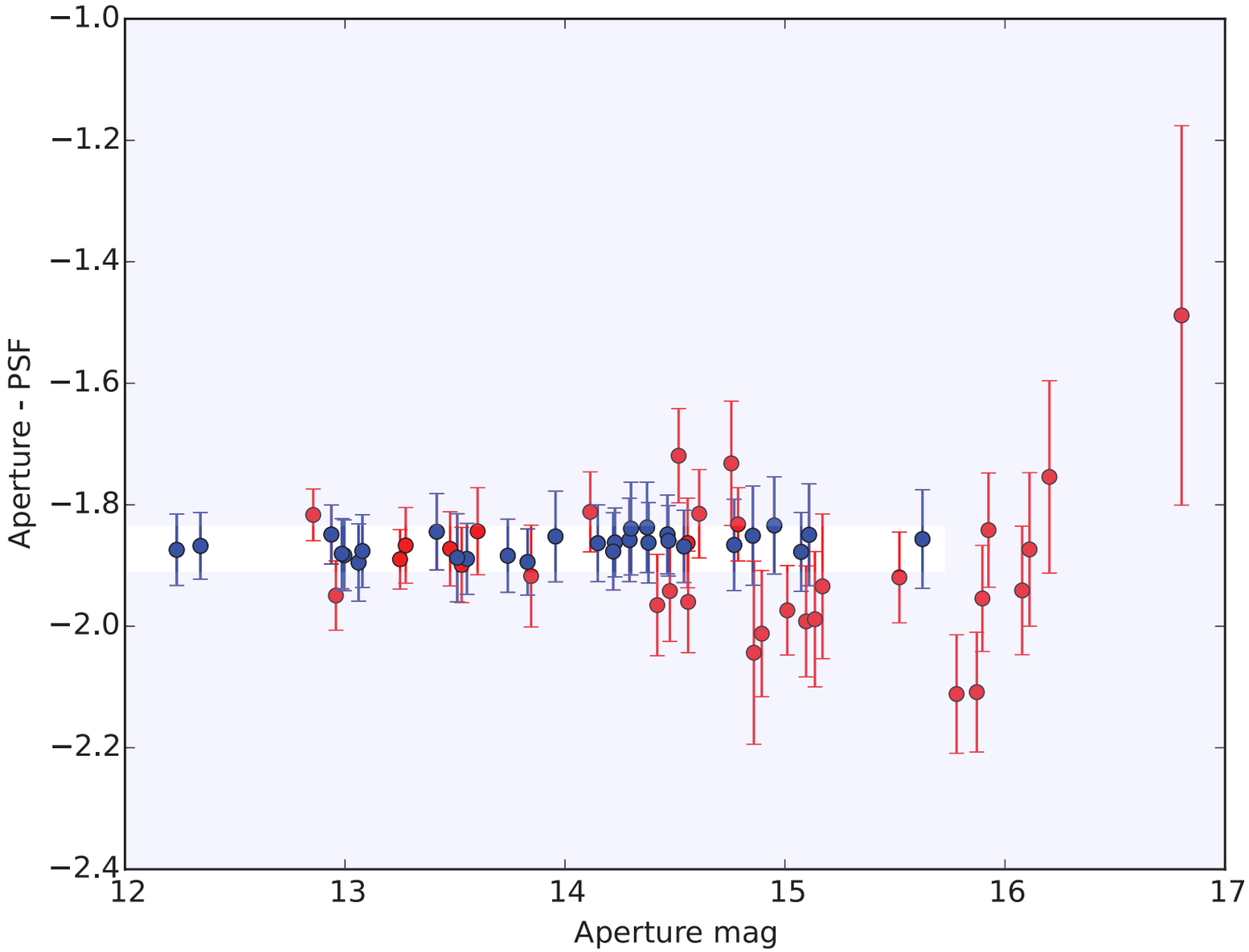
Filtering on Residuals

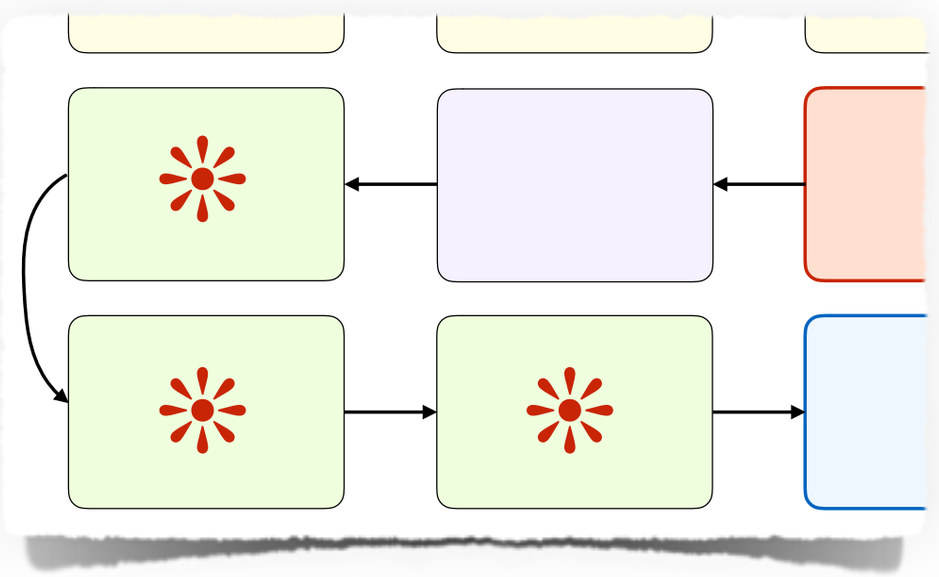




- Calculate residuals between aperture and PSF photometry.
- Remove outliers, (and stars with too many neighbors).

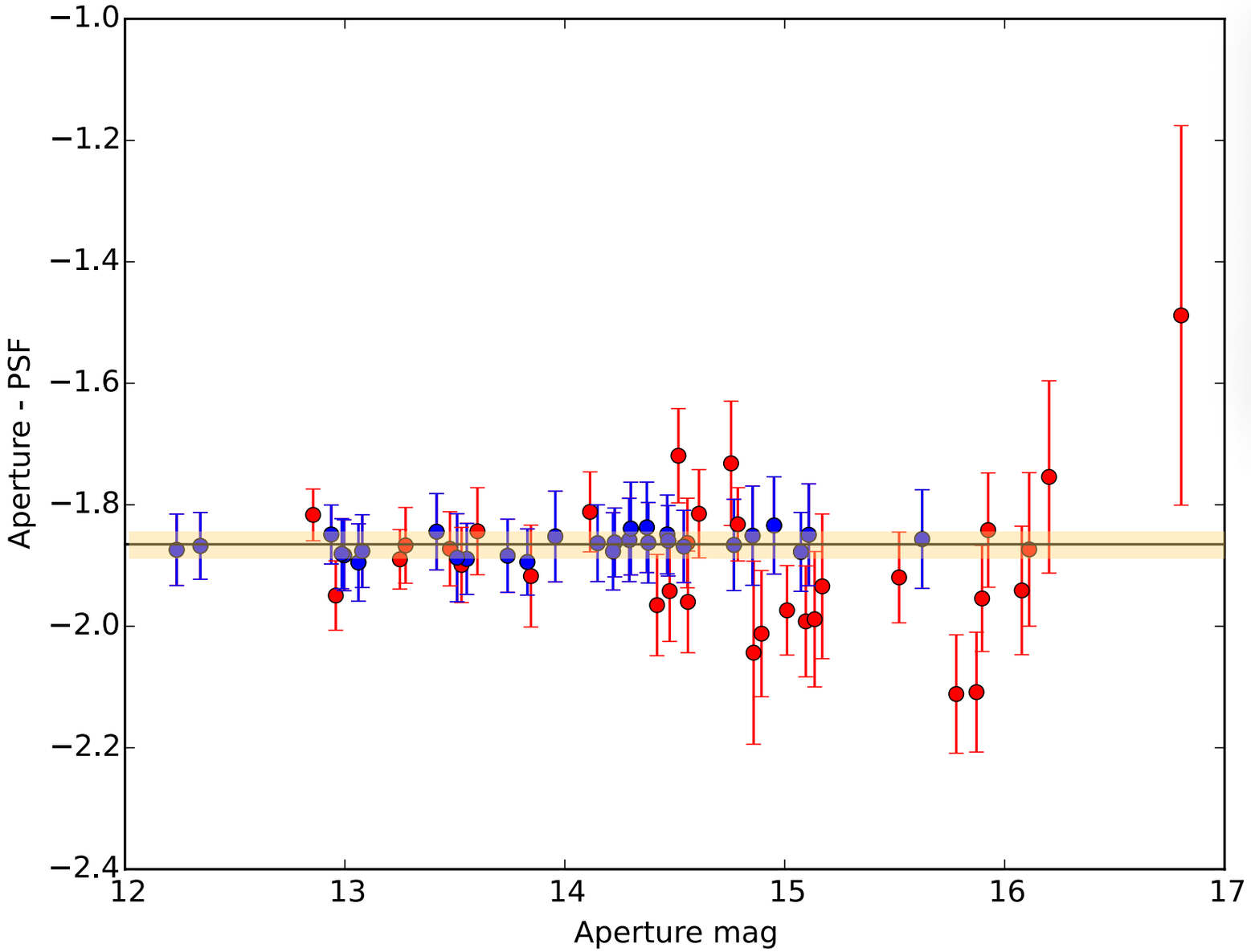
Filtering on Residuals

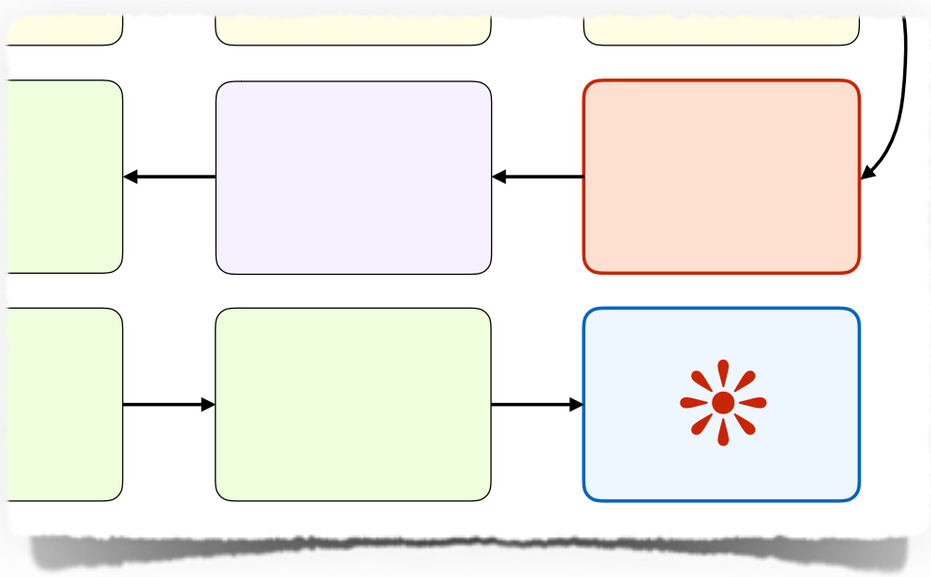




- Calculate residuals between aperture and PSF photometry.
- Remove outliers, (and stars with too many neighbors).

Calculate Zero Point





- Calculate final zero point and uncertainty.

Moving Forward

- Needs to be adapted to specifics of JWST NIRCam/MIRI images.
- Needs to be integrated with JWST tools: how much do we need DAOPHOT, how much can be done natively with JWST pipeline, and JWST post-pipeline tools?
- Alternative software packages: e.g. TPHOT (see M. Di Criscienzo).
- Does the way we plan to do photometry inform the way we propose observations (e.g. availability of HST catalog, mapping/dithering strategy, etc).