AWAIC: A WISE Astronomical Image Co-adder

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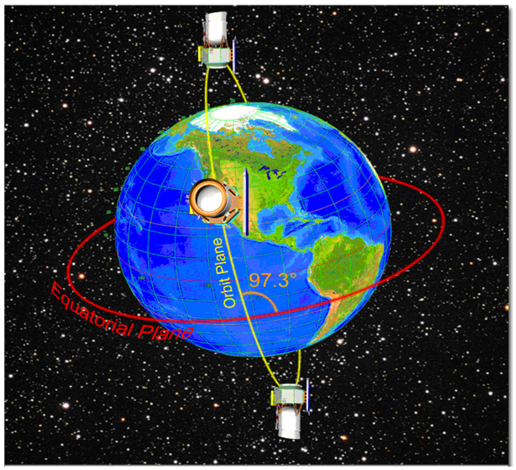
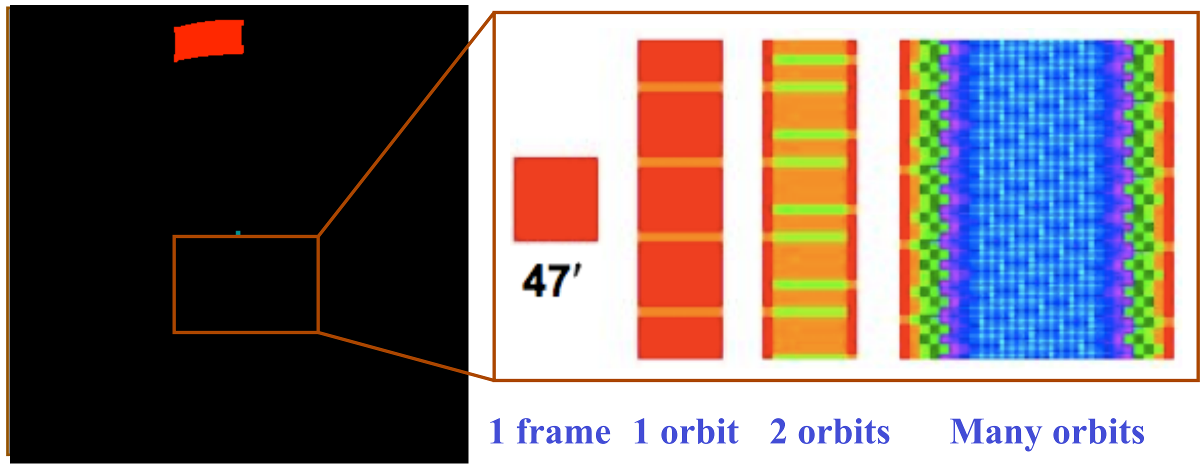
WISE: A Simple Mission Design





- The **W**ide-field **I**nfrared **S**urvey **E**xplorer: all-sky survey at 3.3, 4.7, 12 & 23 μm with ~ $10^3 \times$ more sensitivity than previous surveys
- 523 km, circular, polar orbit
- One month of checkout
- 6 months of survey ops

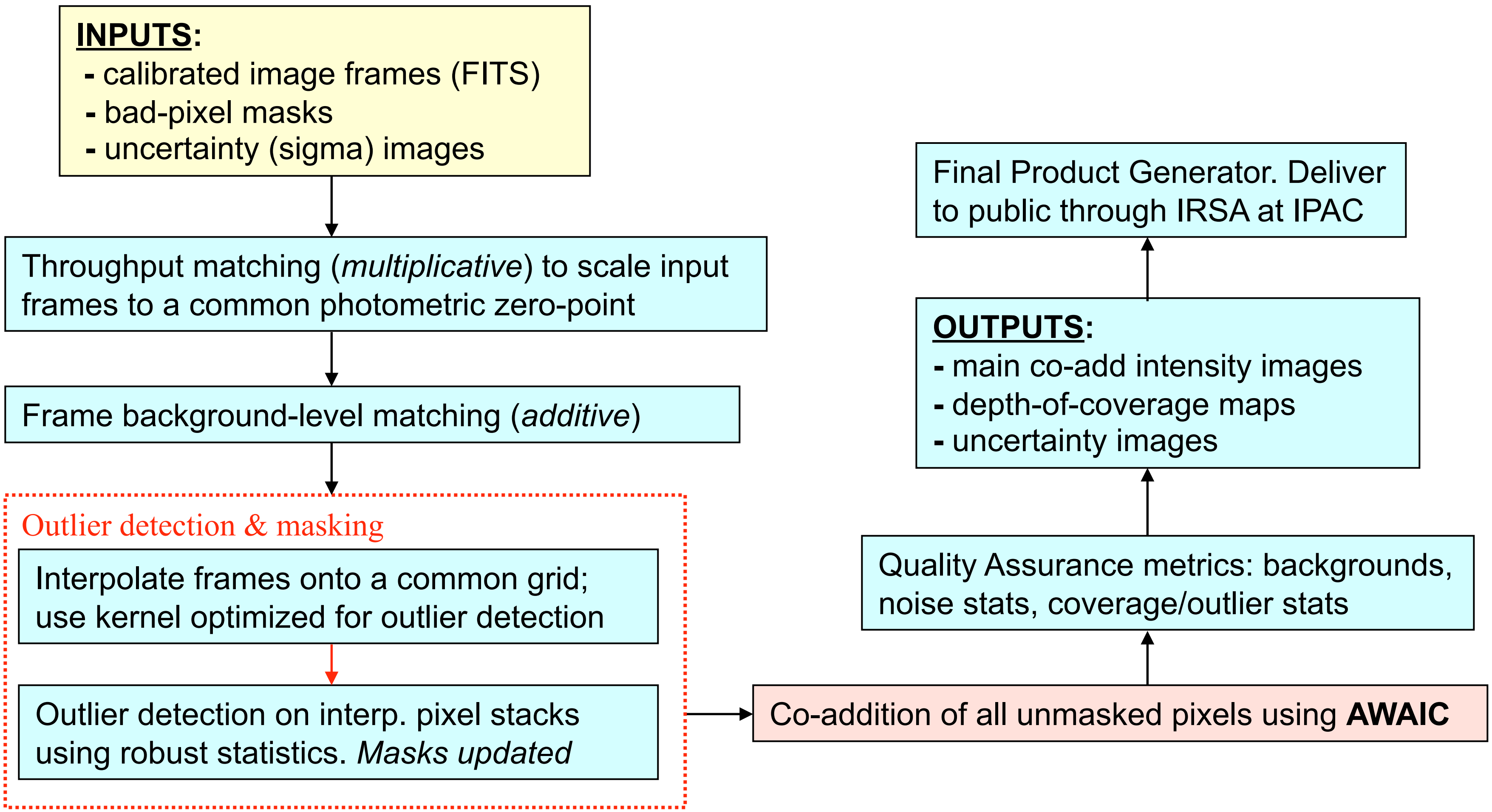
- Scan mirror "freezes" orbital motion ⇒ efficient mapping
  - 8.8-s exposure per frame
  - 10% frame to frame overlap (in-scan)
  - 90% orbit to orbit overlap (cross-scan)
- Expect to achieve a median of 8 exposures/position on the ecliptic equator, > 1000 exposures at poles
- Requirement is to have >95% of sky with ≥4 frame exposures
- Scheduled for launch at 6:00 am on November 1st 2009!

WISE Products

WISE will deliver to the scientific community:

- A digital Image Atlas containing ~220,000 co-adds of the survey frame exposures covering the whole sky in 4 mid-IR bands
- Ancillary co-add products: depth-of-coverage maps and uncertainty maps
- Atlas Image tiles are $\approx 1.5° \times 1.5°$ re-sampled at 1.375″/pixel
- A Source Catalog of $\approx 5 \times 10^8$ objects merged across all 4 bands to photometric S/N = 5. All sources will be astrometrically and photometrically calibrated

Co-addition Pipeline Overview



Background-level Matching

- Instrumental transients lead to varying background levels between frames
- **Goal:** obtain seamless (or smooth) transitions between frames across overlaps
- **Simple method:** fit a “robust” plane to each frame, subtract to equalize frames, then add back a common plane or level to all frames computed from a median over all the fits

No matching With matching

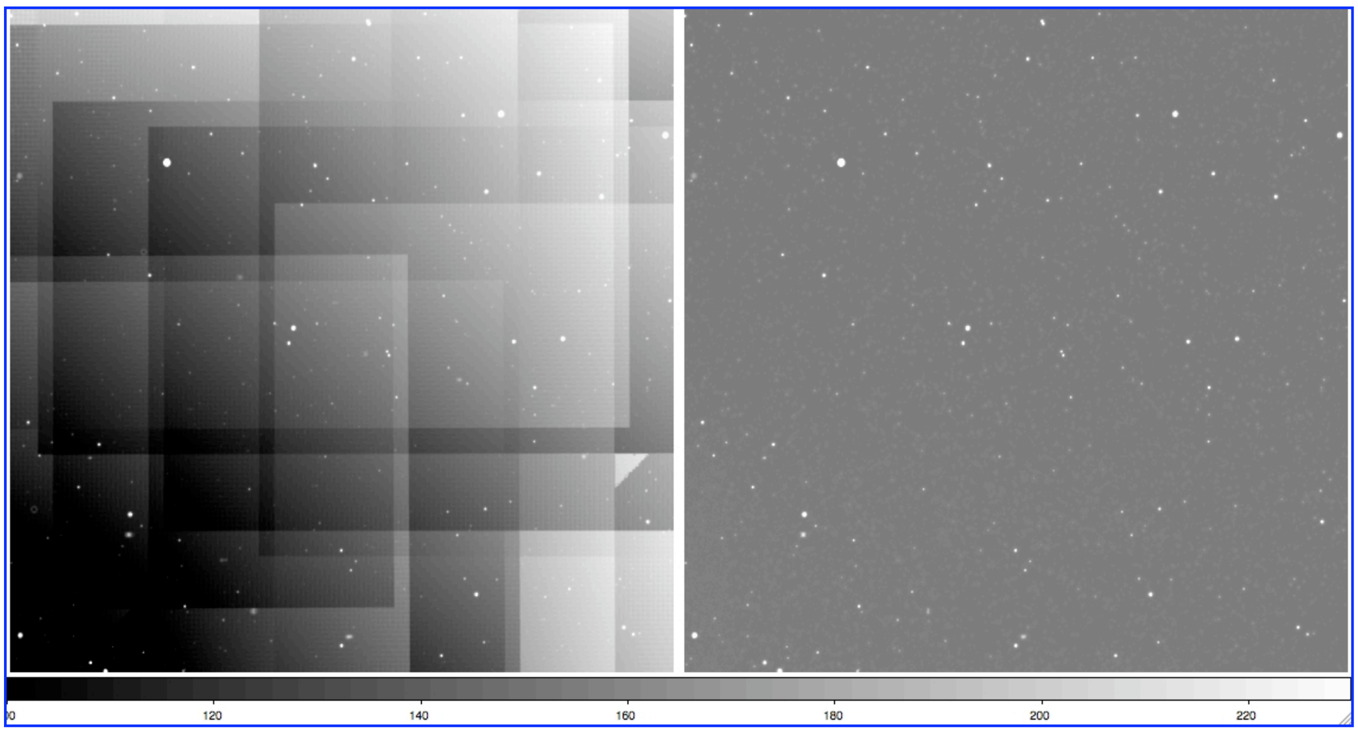
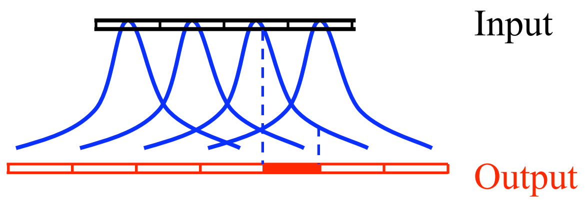


Image Co-addition in AWAIC

- **Goal:** want to optimally combine all measurements into a *faithful* representation of the sky
- AWAIC uses the detector's **P**oint **R**esponse **F**unction (PRF) as the interpolation kernel
- **PRF** = *Point Spread Function* (*PSF*) ⊗ *pixel response*
  - each pixel collects light from its vicinity with an efficiency described by the PRF

- Flux in a co-add pixel *j* is estimated using PRF and inverse-variance weighted averaging:



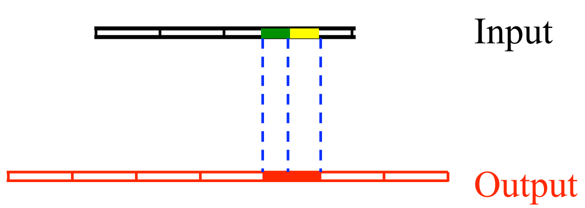
$$f_j = \frac{\sum_i \frac{r_{ij}}{\sigma_i^2} D_i}{\sum_i \frac{r_{ij}}{\sigma_i^2}}$$

D_i: Input detector (pixel) measurements

r_{ij}: PRF (volume normalized to unity)

σ_i^2: Variance from propagated noise model (optional)

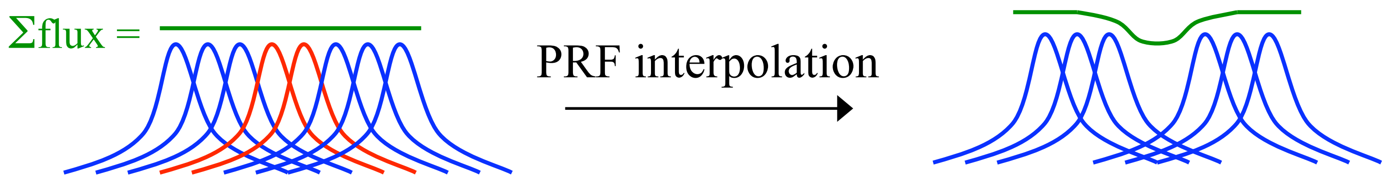
- For comparison, the popular overlap-area weighted interpolation method (e.g., *Montage*, *MOPEX*, *drizzle*…):



$$f_j = \frac{\sum_i \frac{a_{ij}}{\sigma_i^2} D_i}{\sum_i \frac{a_{ij}}{\sigma_i^2}}$$

Why PRF as Interpolation Kernel?

- Reduces impact of masked pixels if the data are well sampled (even close to critical). Leads to effectively non-zero coverage at the bad pixel locations on co-add due to overlapping PRF tails:



- Defines a linear matched filter optimized for point source detection
  - High frequency noise is smoothed out without affecting point source signals ⇒ peak S/N maximized
  - Process is effectively a cross-correlation of a point source template (the PRF) with input data
  - This will benefit processing at the WSDC since a source catalog is one of its release products

- The big one: allows for resolution enhancement (HiRes): PRF can be "deconvolved" - more later
  - Not in WISE automated pipeline. Implemented to support offline research

Other Features in AWAIC

- Allows for a spatially varying PRF. Usually non-isoplanatic over the focal plane for large detector arrays

- Ancillary products (for both simple co-addition and HiRes'ing):
  - Uncertainties in co-add pixel fluxes: from input prior model or *a posteriori* from repeatability
  - depth-of-coverage maps and images of outlier locations
  - Quality Assurance metrics on depth-of-coverage; sky-backgrounds; outliers; χ^2 tests to validate uncerts

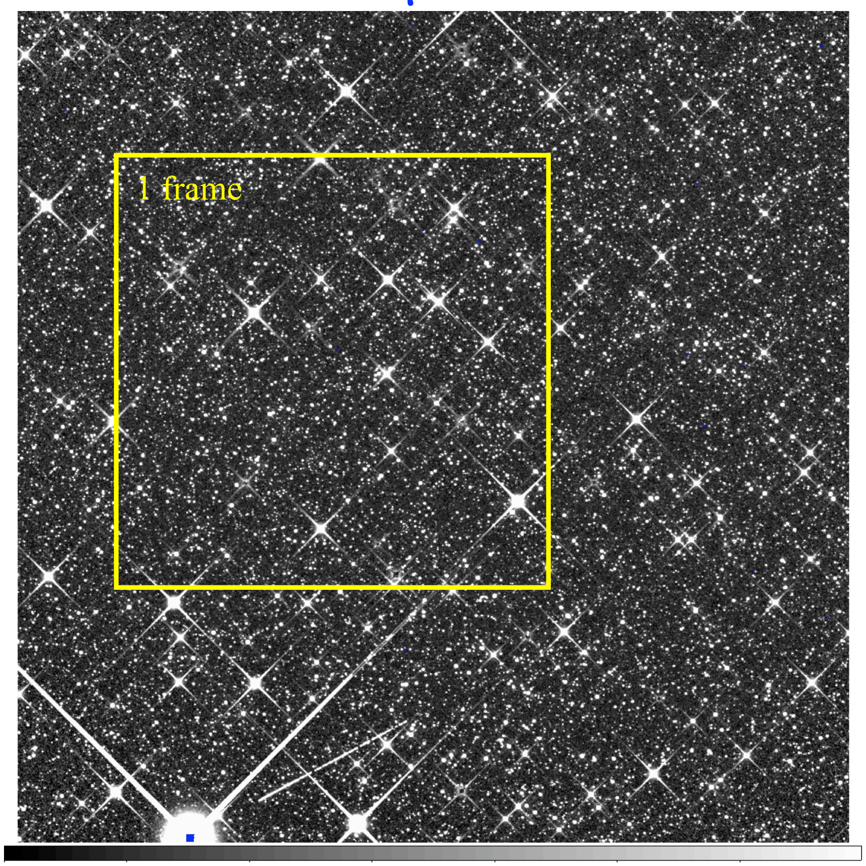
- Supports:
  - FITS standard;
  - WCS standards with distortion;
  - five commonly used projections: TAN, SIN, ZEA, STG, ARC implemented in a fast re-projection library

- Generic enough for use on any astronomical image data: exercised extensively on *Spitzer* and *HST* data

Example of WISE Atlas Images

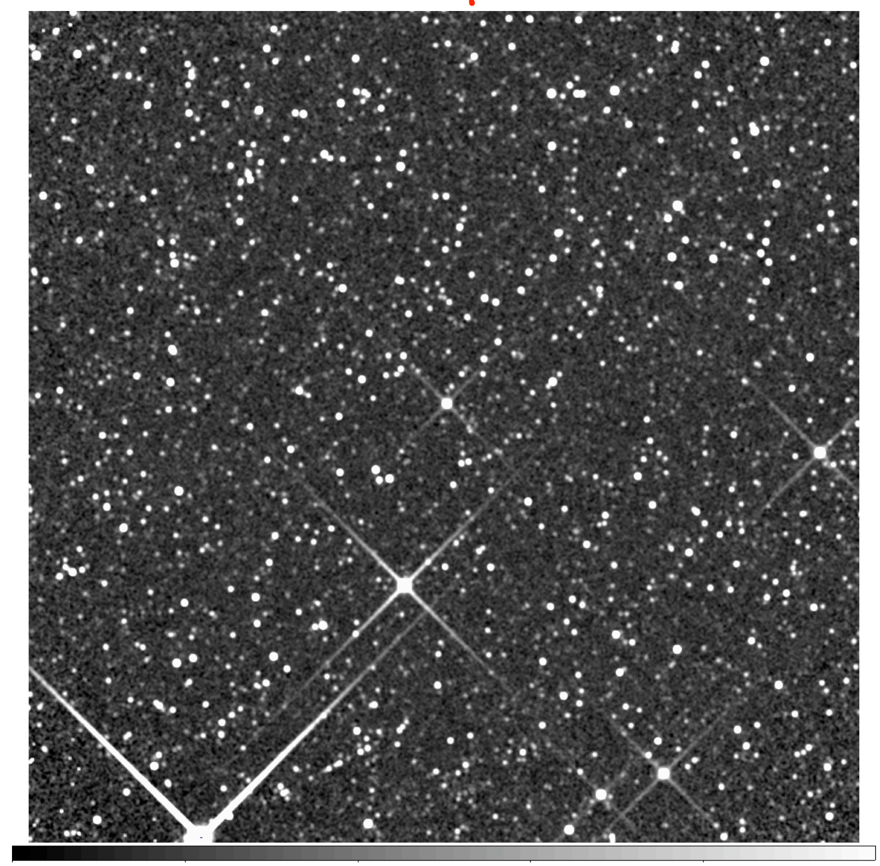
- Simulated frames provided by Ned Wright (P.I.): used seed sources from 2MASS catalog
- Mid-ecliptic latitude field (β ≈ +30°) - example of what WISE *may* see

3.3 μm



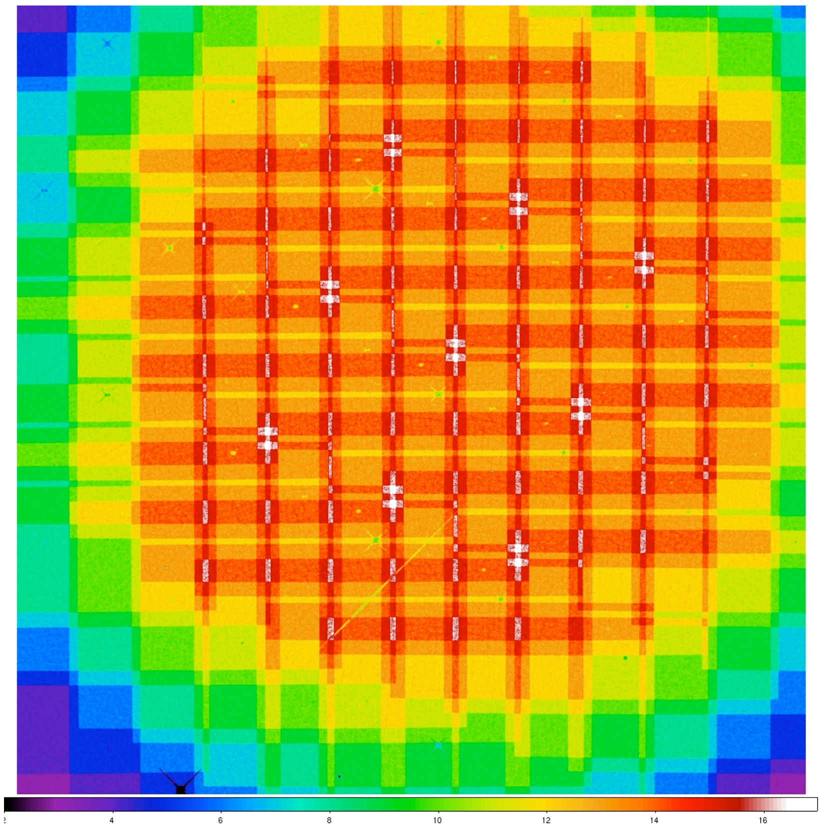
1.56°

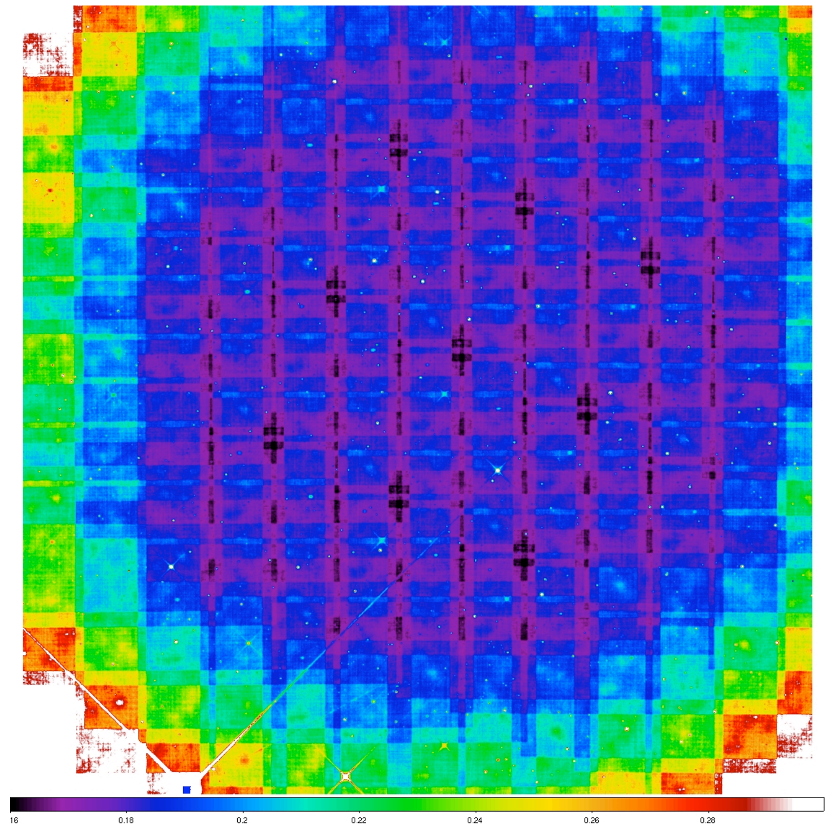
23 μm



Depth-of-coverage and σ maps

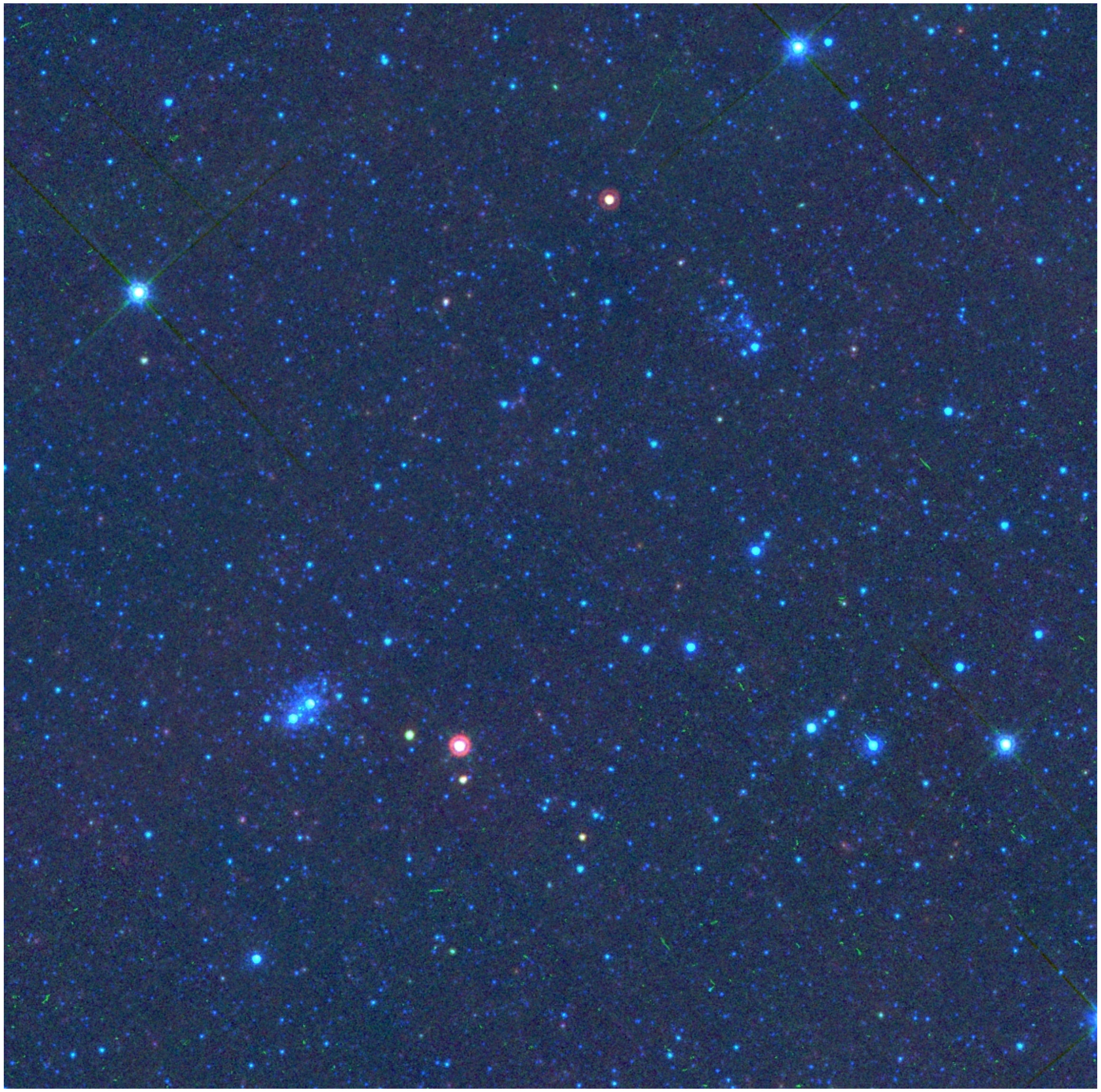
- Depth-of-coverage map: effective number of repeats from all *unmasked* pixels at each location
- σ-map: 1-sigma uncertainty for each pixel propagated from a noise model





$$\sigma \propto \frac{1}{\sqrt{\text{coverage}}}$$

South Ecliptic Pole (near LMC)



WISE "Touchstone field"
Combines AWAIC mosaics in *Spitzer* bands:
4.5μm (blue)
8μm (green)
24μm (red)

⇒ Proxy for WISE bands 2, 3, 4

~ 20′ ~ 1/5 of WISE Atlas Image

HiRes: Maximum Correlation Method (MCM)

- Originally implemented for IRAS ~ 22 years ago. Now extended and made more generic.

- Earlier we discussed combining images to create a co-add, **MCM** asks the reverse:
  - what model of the sky propagates through the measurement process to yield the observations within measurement error?

- Measurement process is a filtering operation performed by the instrument's Point Response Function (PRF):

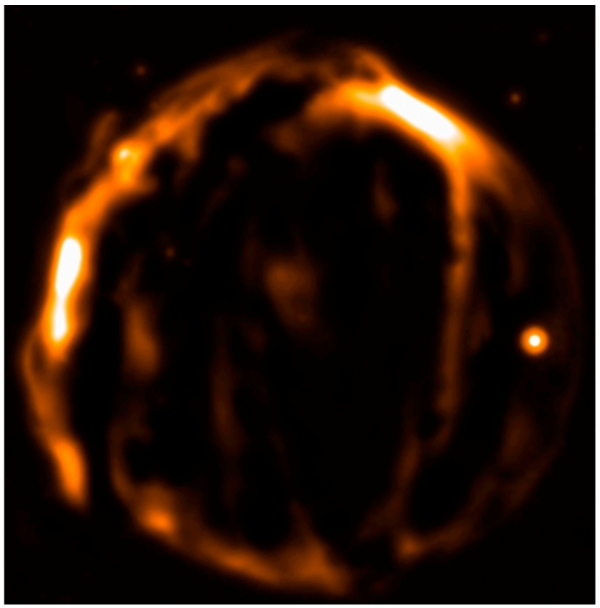
$$\underset{?}{Sky\ "truth"} \otimes \underbrace{PSF \otimes \Pi}_{PRF} \otimes sampling \rightarrow measurements$$

- MCM starts with a "maximally correlated" image - a flat model image and modifies (or de-correlates) it to the extent necessary to make it reproduce the measurements. The model is iteratively refined.

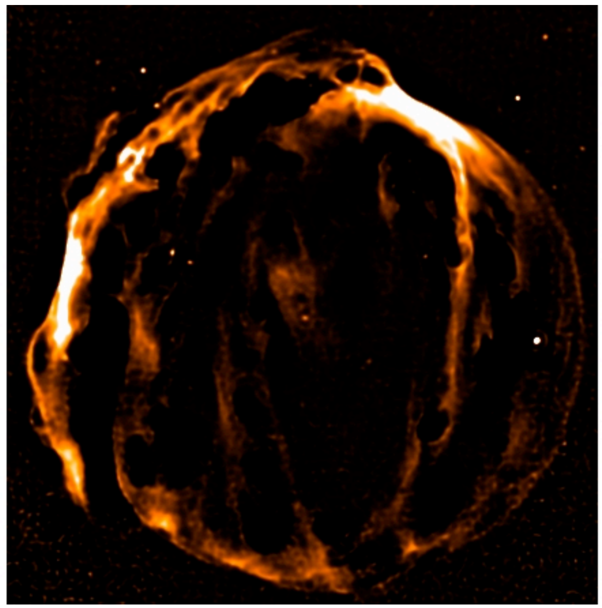
- Includes:
  - a ringing suppression algorithm (minimize leakage of power into low-frequency side-lobes);
  - allows for spatially varying PRFs over focal plane;
  - uncertainty estimation;
  - diagnostic variance images for outliers and assessing convergence

Tycho's Supernova Remnant

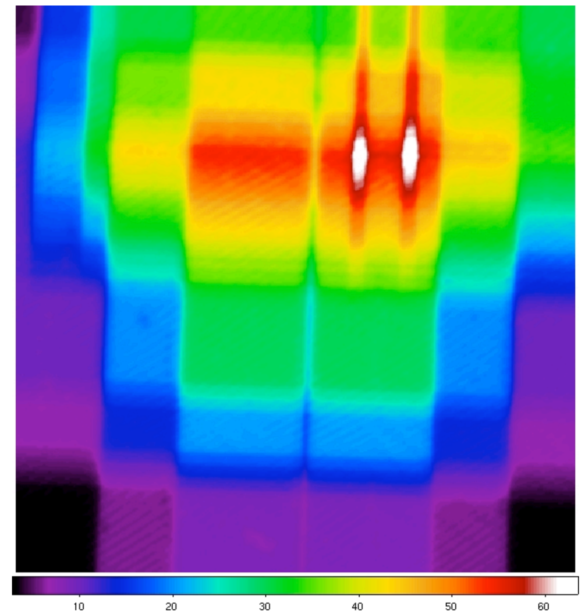
Spitzer-MIPS 24 μm



Co-add (1st MCM iteration)



HiRes: 40 MCM iterations



5 65

depth-of-coverage map

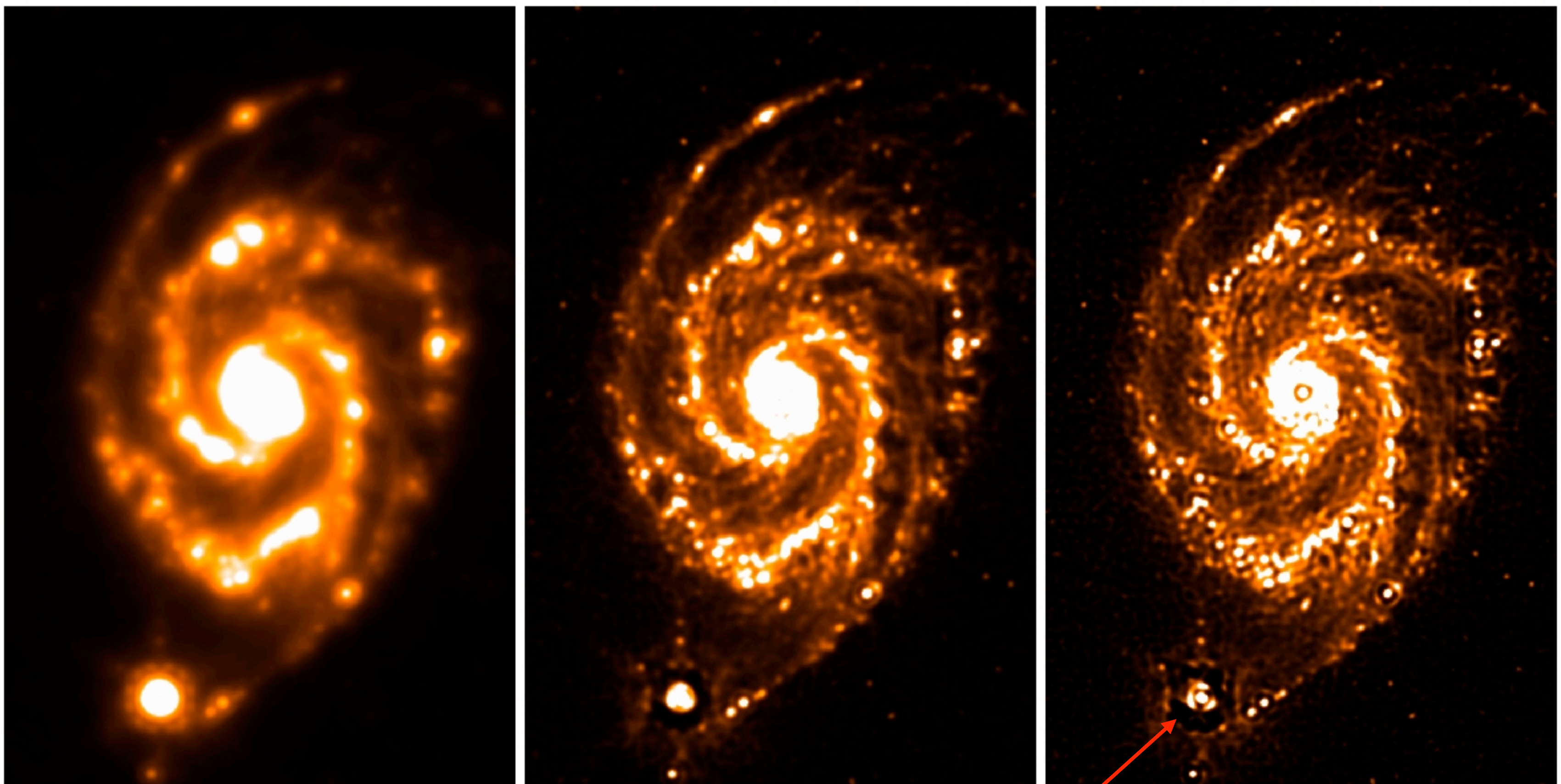
FWHM of effective PRF: went from ~5.8″ (native) to ~1.9″

⇒ ×3 gain in resolution per axis

M51 or NGC 5194/95

"Whirlpool Galaxy"

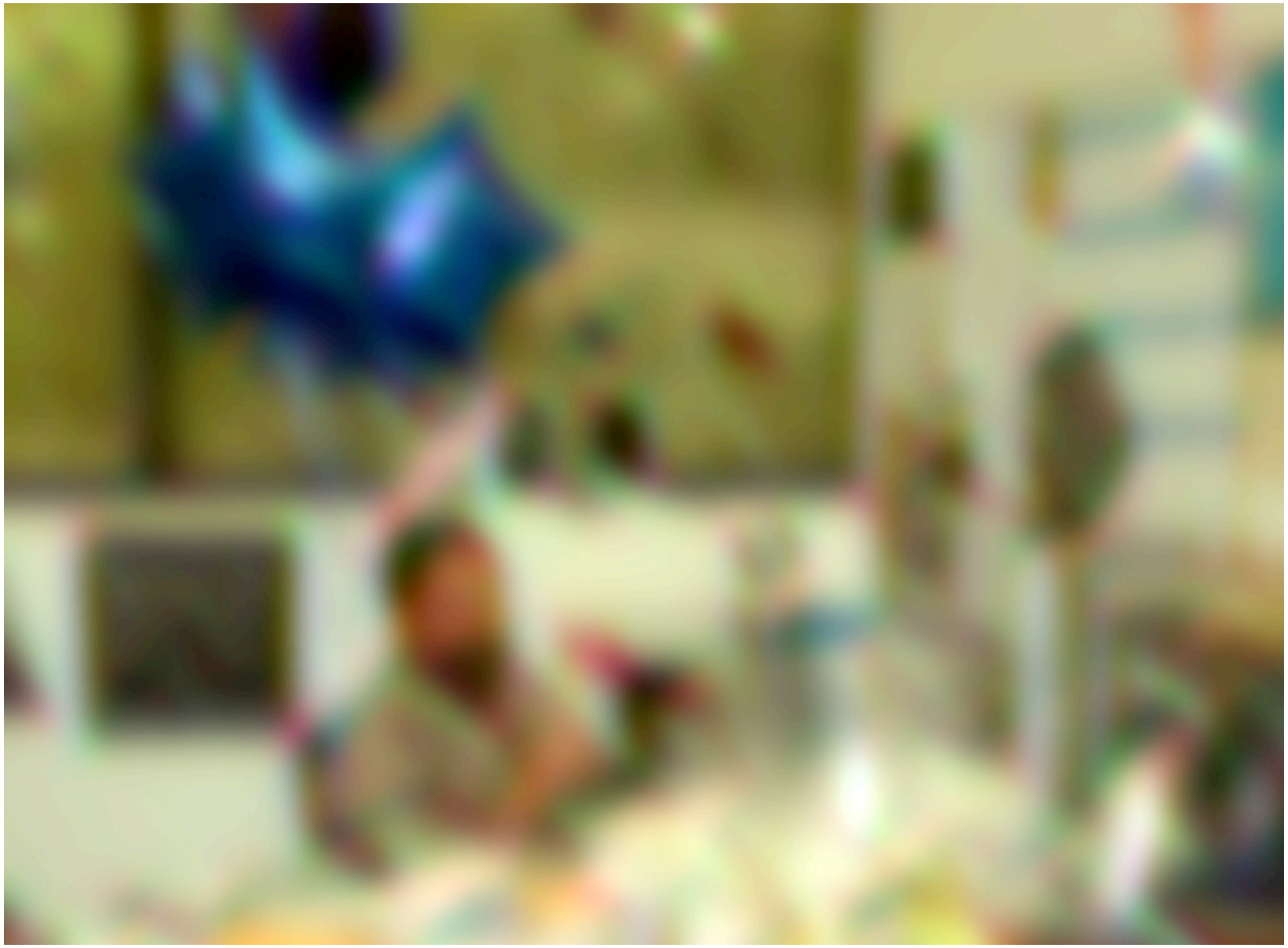
Spitzer-MIPS 24 μm



Co-add (1st iteration) | HiRes: 10 iterations | HiRes: 40 iterations

profile saturated!

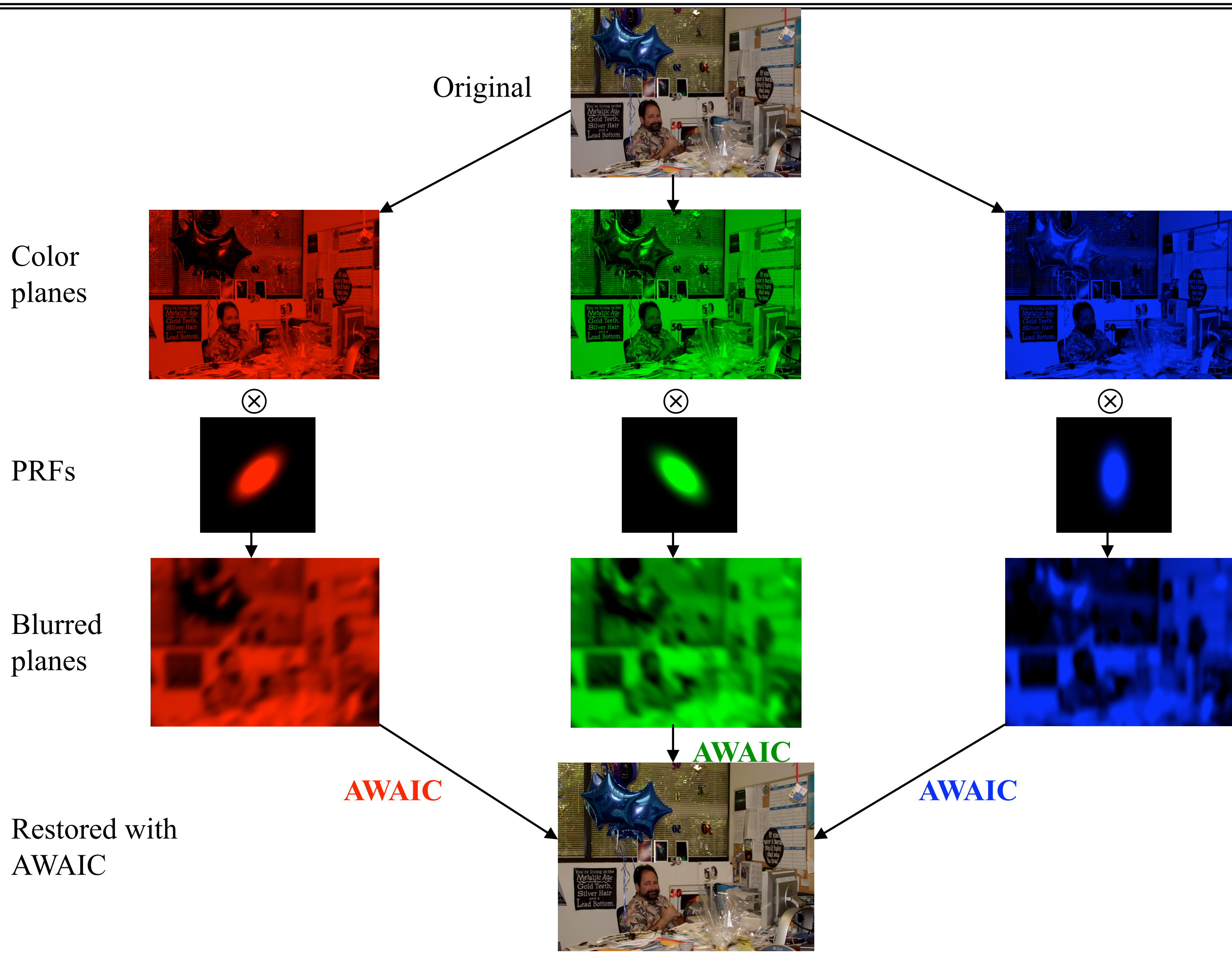
Digital Photo Experiment
(blurred original)



Digital Photo Experiment
“AWAIC’end”

Digital Photo Experiment (Original)

Digital Photo Experiment



Summary and Future Plans

- Described co-addition framework for WISE with extension to resolution enhancement
  - provides a generic tool for use on any image data that conforms with FITS/WCS standards
  - co-add products are <u>optimized for source detection</u>
  - bonus over previous co-adders: HiRes'ing with flux uncertainties and QA metrics for validation thereof

- Currently, AWAIC is a suite of modules implemented in ANSI C and wrapped into a Perl script
  - runs under Linux in WISE processing environment. Plan to make portable for community.

- Extend to handle time dependent PSFs (e.g., adapted to seeing) - time domain applications, e.g., LSST

- Research in progress: performance of MCM on confusion limited observations. How far below the native confusion limit can we go and reliably detect sources?

- More examples, papers, and an explanation of algorithms can be found at:
  http://web.ipac.caltech.edu/staff/fmasci/home/wise/awaic.html