# PTFIDE and Forced Photometry

Frank Masci & the iPTF Collaboration

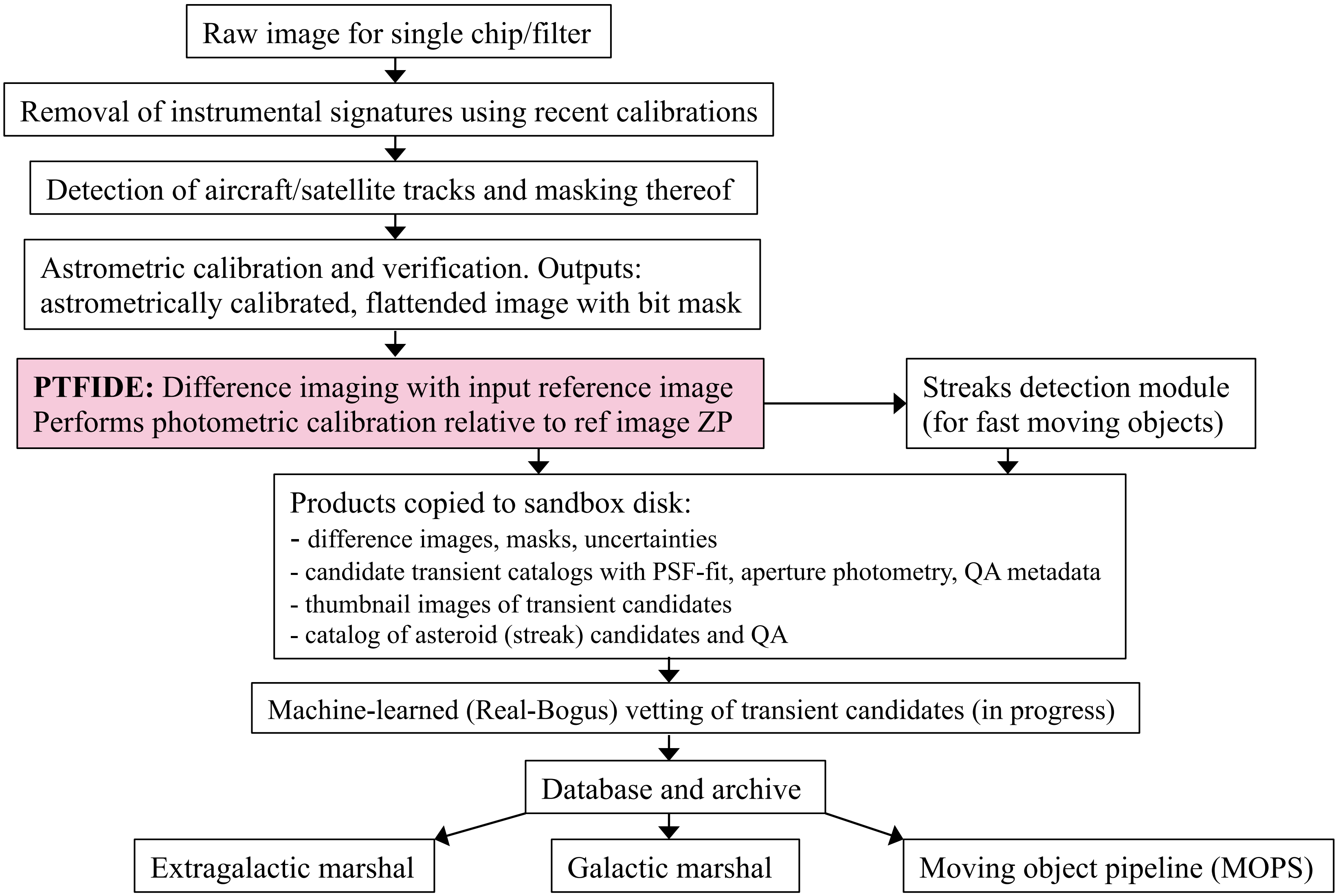
iPTF workshop, August 2014

# Goals

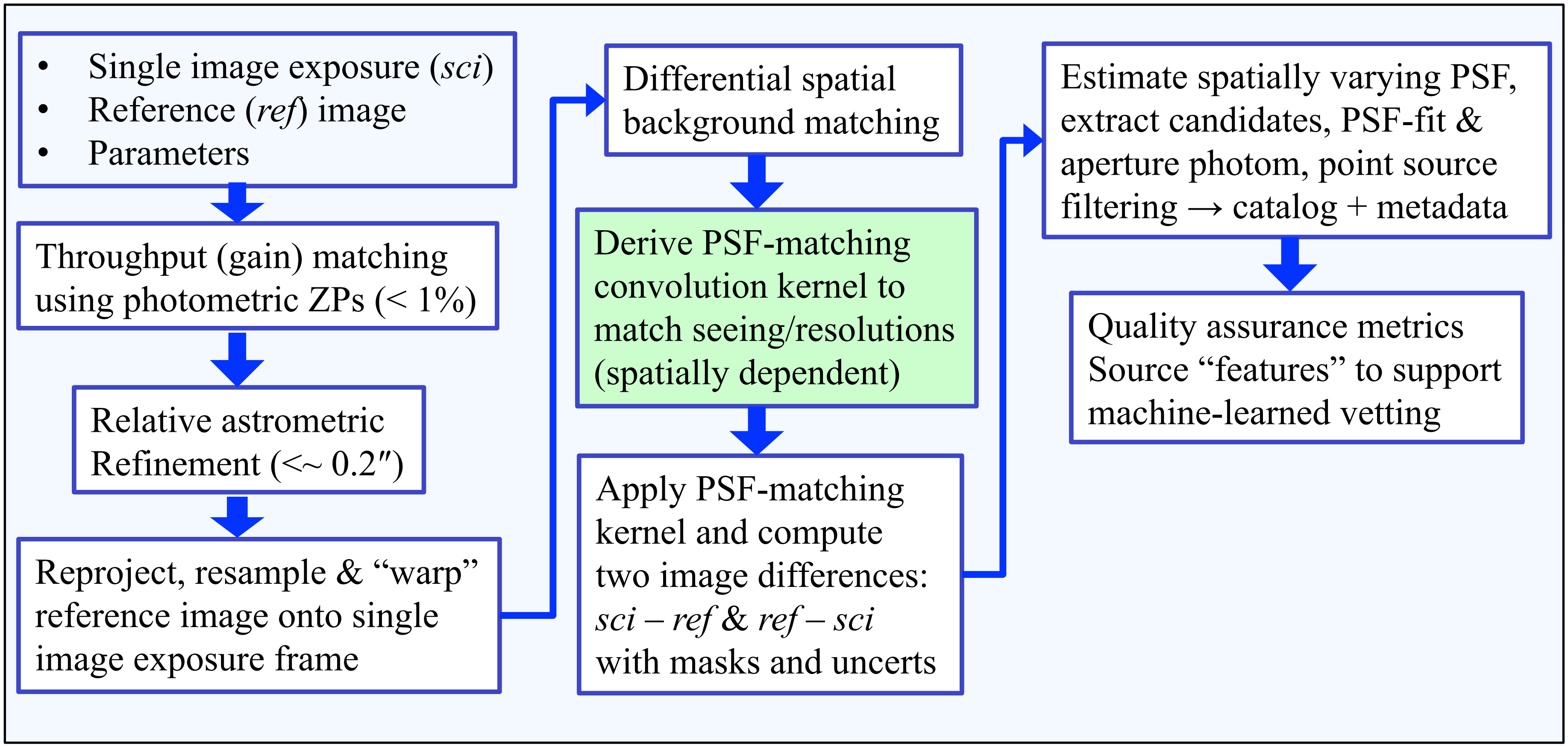
- **PTFIDE:** Image Differencing and Extraction engine for iPTF, ZTF and the future
- **Difference imaging**: discover transients by suppressing everything that's static in space and time
- Given the complexity and heterogeneity of the iPTF survey, we wanted a tool that:
  - is **flexible:** robust to instrumental artifacts, adaptable to all seeing, little tuning
  - could operate in a **range of environments:** high source density, complex backgrounds and emission
  - could probe a **large discovery space:** pulsating & eruptive variables, eclipsing binaries, SNe, asteroids
  - **maximizes** the reliability of candidates to streamline vetting process downstream
  - is **photometrically accurate:** to obtain reasonably accurate "first look" light curves
  - had **preprocessing steps** customized for the iPTF instrument/detector system
- Existing off-the-shelf methods and tools (as of ~2 years ago) were not flexible or generic enough

# The “real-time” operations pipeline at IPAC/Caltech

PTFIDE has been running in the real-time (nightly) pipeline for > 1 year. Can also execute offline for archival research



# PTFIDE processing flow




http://web.ipac.caltech.edu/staff/fmasci/home/miscscience/ptfide-v4.0.pdf

# PSF-matching step

- In general, an observed image *I* (exposure) can be modeled as a reference image *R* and convolution kernel *K*:

$$I_{ij} = \left[ K_{lm} \otimes R_{ij} \right] + dB + \varepsilon_{ij}$$

- PSF-matching entails finding an optimum convolution kernel *K* by minimizing some cost function:

$$C = \sum_{i,j} \left[ I_{ij} - \left( K_{lm} \otimes R_{ij} \right) - dB \right]^2$$

- **Traditional method (until about 2008, but still in use today):**

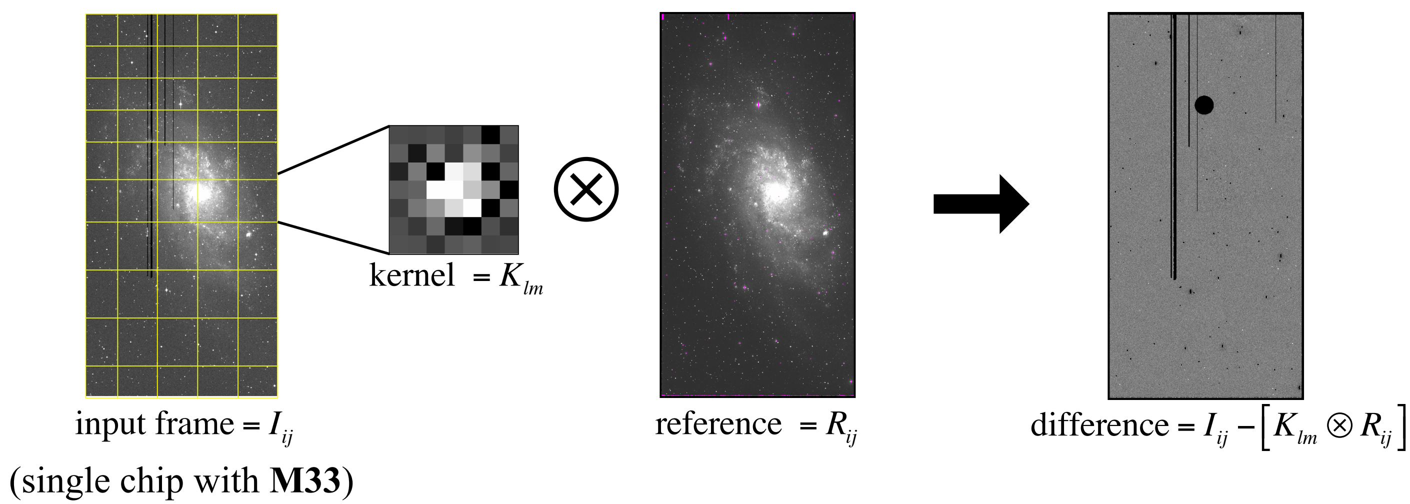
  Decompose *K* into a sum of Gaussian basis functions × by polynomials (e.g., Alard & Lupton, 1998; Alard 2000). The coefficients are then fit for. Too many parameters, not generic, and hard to tune!

# PSF-matching in PTFIDE

- Instead, PTFIDE solves for each of the individual kernel pixel values $K_{lm}$ (= 7 × 7 parameters) directly using a linear least squares minimization of the cost function:

$$C = \sum_{i,j} \left[ I_{ij} - \left( K_{lm} \otimes R_{ij} \right) - dB \right]^2$$

  - similar to method proposed by Bramich (2008)
  - more flexible, $K$ can take on more general shape, and also compensate for bad astrometry
  - since PSF is spatially dependent, we grid images into 5 × 10 overlapping squares, then solve for $K$ in each

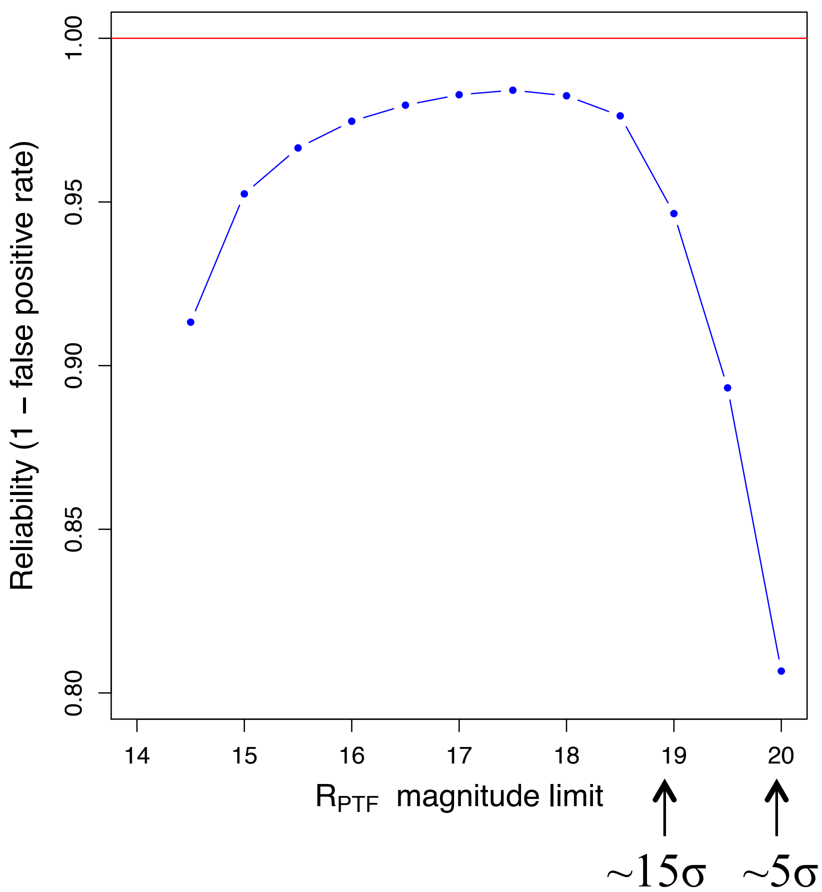


# Candidate transient photometry

- Performed using PSF-fitting
- Provides better photometric accuracy to faint fluxes
- Provides diagnostics to distinguish point sources from glitches (false-positives) in diff. images
  - maximizes reliability of difference-image extractions since most transients are point sources
- Above assumes accurate PSF-estimation (over chip) and image registration prior to differencing
- Aperture photometry and source-shape metrics are also generated

# Performance: real vs. bogus (reliability)

- with no real-bogus vetting yet in place, explored reliability of raw extractions using a simulation
- took 350 real, moderately dense *R*-band frames, derived spatially-varying PSFs, then simulated point source transients with random positions and fluxes
- executed PTFIDE to create diff images and extract candidates with **fixed** threshold (S/N = 4) and filter params.

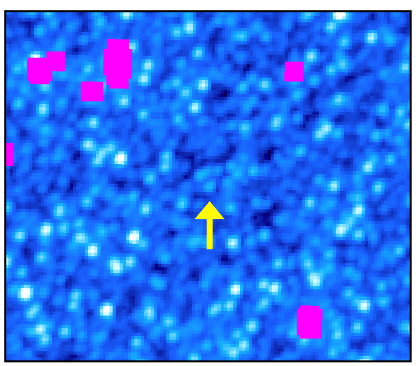



$$R = \frac{\#\text{ matched to truth } (< R_{mag})}{\#\text{ total extracted } (< R_{mag})}$$

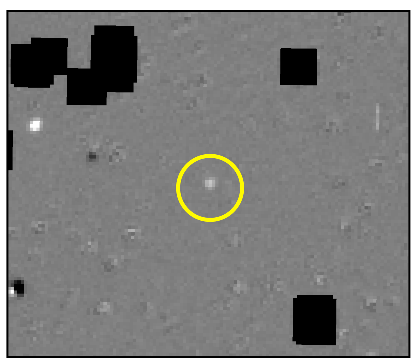
# From difference-images to light curves

- Recall PTFIDE uses a fixed detection threshold (S/N ~ 3) to aid **discovery only**
- Bonus: input frames are all gain-matched to a common photometric ZP (the reference image)

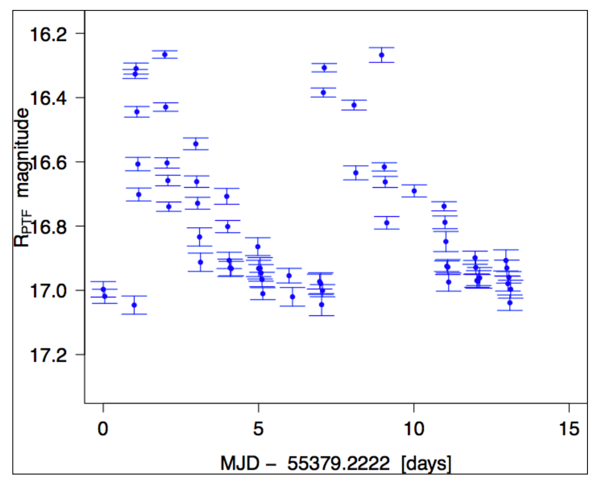
- Can generate quick-look light curves for candidates of interest using forced PSF-photometry at fixed sky position through stack of difference images with no threshold
  - ➢ enables unbiased measurements down to low S/N
  - ➢ obtain tighter upper limits and better S/N by combining light-curve data
  - ➢ implemented as a separate pipeline at Caltech that can be run offline
  - ➢ supported numerous projects (e.g., Seméli and Ariel's SNe Ia project; RCBs and Novae in M31)



galactic bulge field
~ 2.2 arcmin

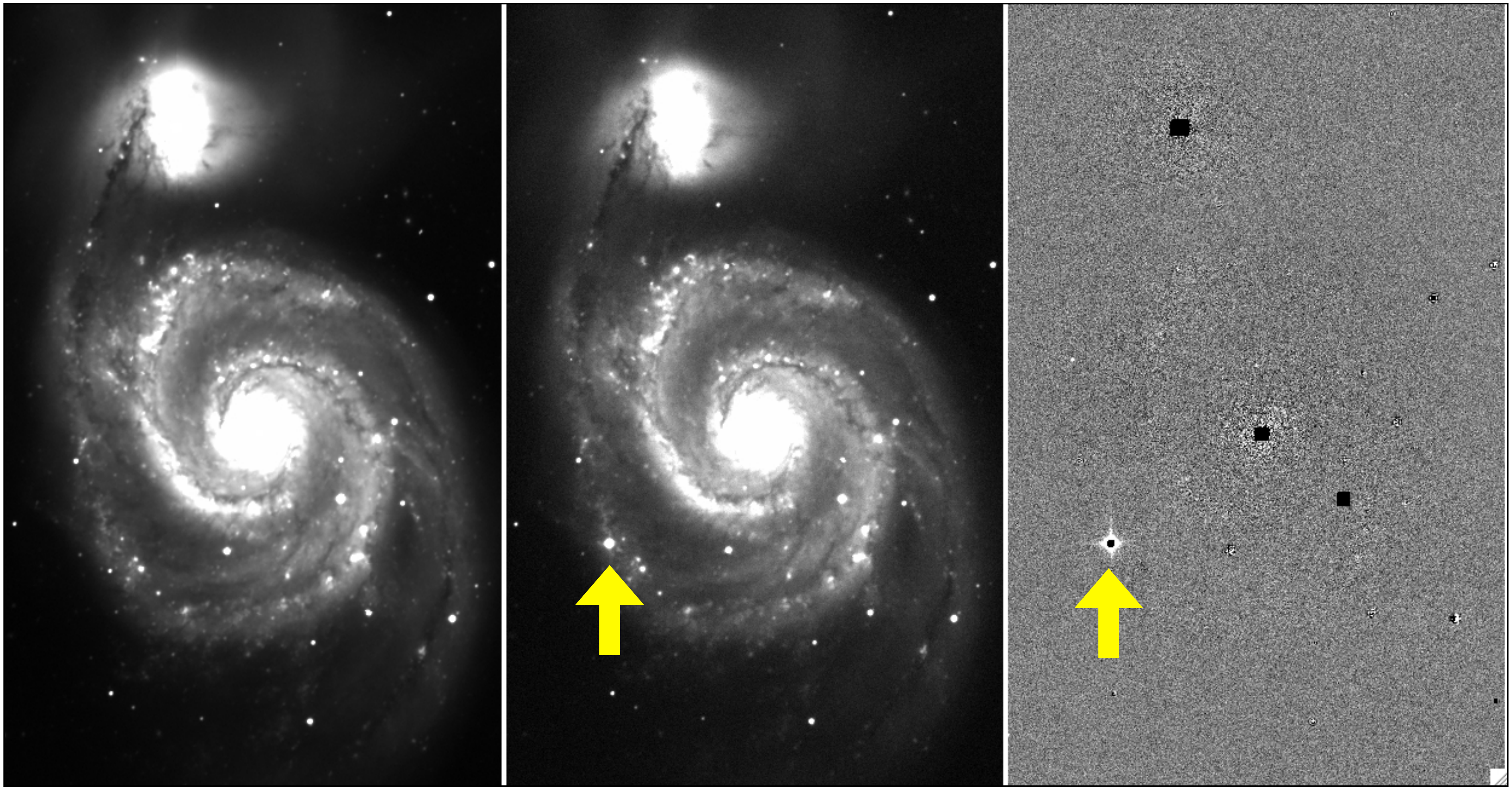


difference image




Cepheid variable (?)

# SN 2011dh (PTF11eon) in Messier 51



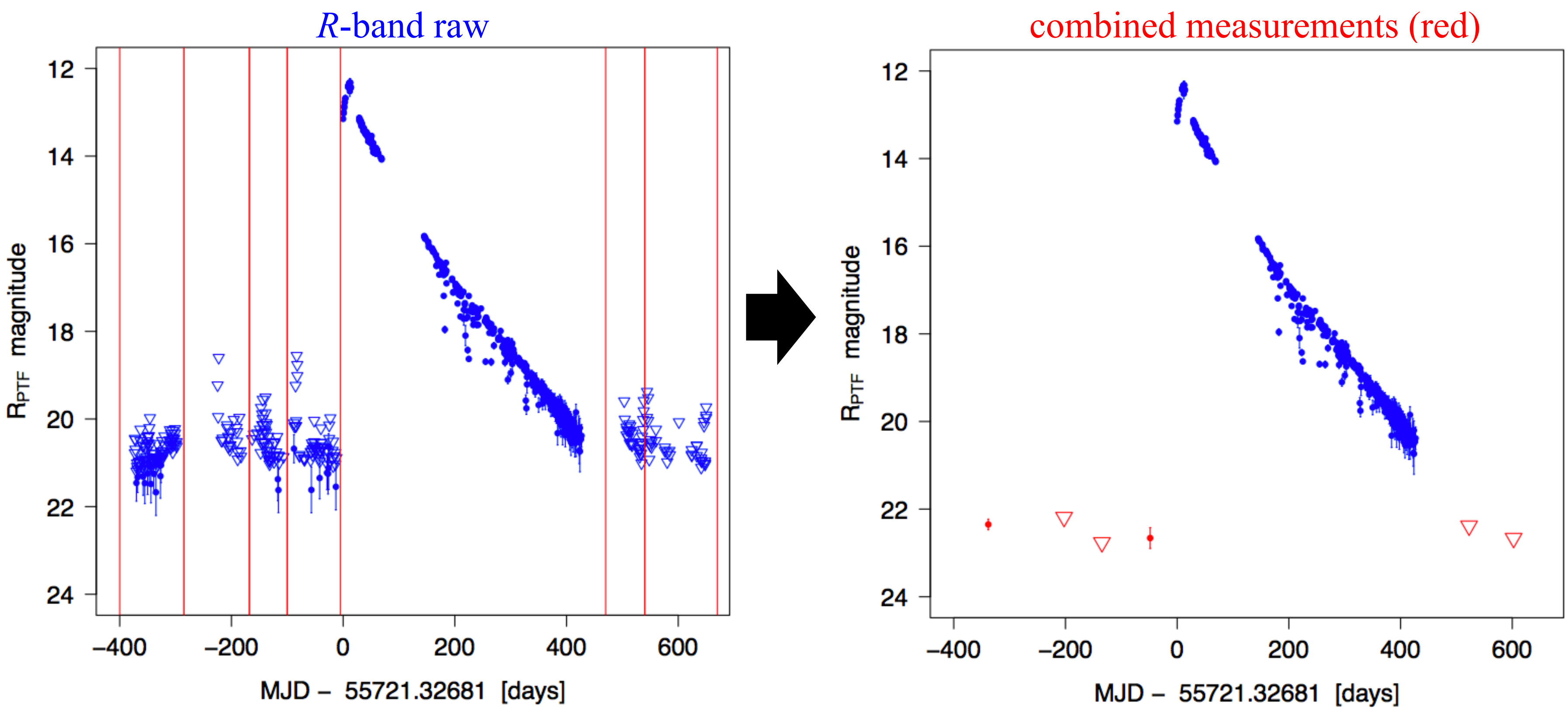
Reference image = co-add of 20 *R* exposures (pre-outburst)

*R* exposure on June 19, 2011 Type IIb supernova ~ $10^9 L_\odot$

Difference image: exposure - reference

# SN 2011dh *R*-band light-curve from windowed-averaging

Combine difference-image photometry (weighted averaging) within windows to improve S/N and obtain tighter upper limits on non-detections => method is faster than co-adding images!

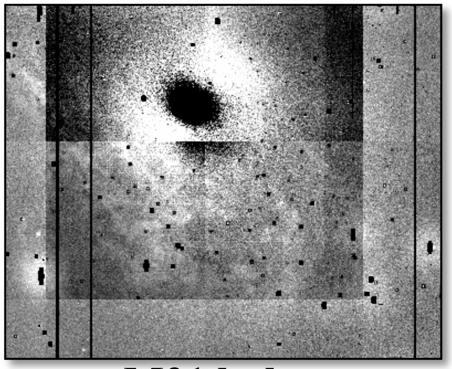


# Improvements for PTFIDE

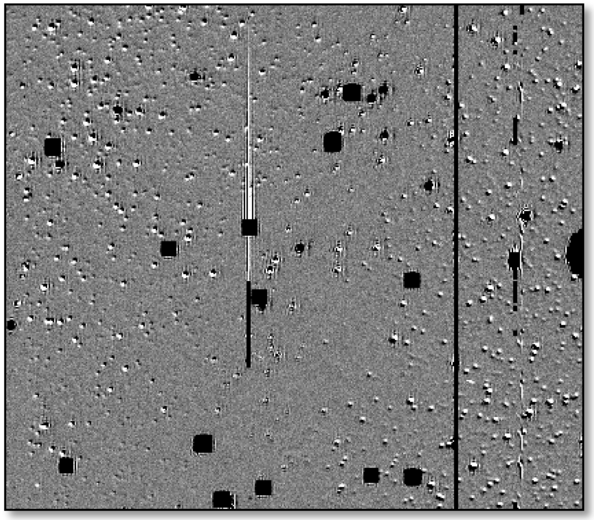
- Difference images are not always “pristine”. At the mercy of accurate astrometric and distortion calibration upstream, and relative photometric (throughput) matching with reference image
- Too many false positives will strain Real-Bogus vetting (human and machine)

- PSF-matching can be challenged in very confused fields (e.g., galactic plane)
  - ➢ can be mitigated using smoothness/regularization constraints when deriving matching kernel
  - ➢ updates are in progress

**e.g. BAD differences:**



**M31 bulge**



**Galactic plane field**

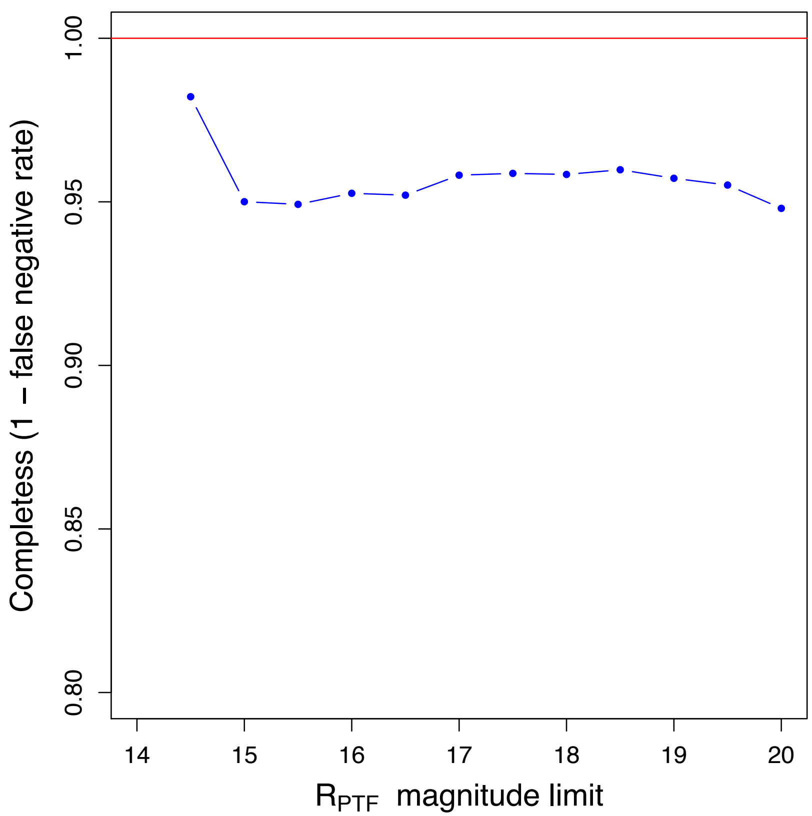
# Summary

- The transient-discovery engine PTFIDE is now running in near real-time at IPAC/Caltech to support (at least) asteroid discovery
- Plan to use for real-time discovery of all transients in the near future
- Also equipped with a forced photometry (post-processing) pipeline to obtain accurate light-curves for candidates of interest
- Vetting (real-bogus) infrastructure is currently in progress (training phase)
- Validation and testing continues. It can only get better…

# Back up slides

# Performance: completeness

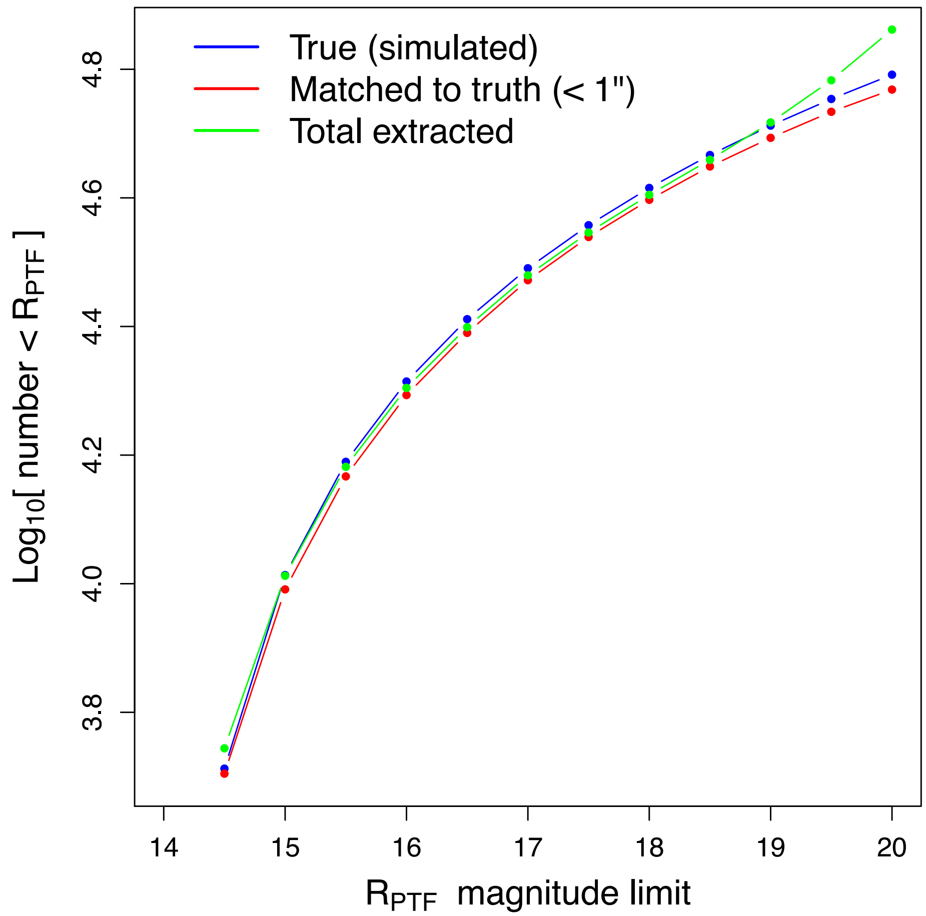
- took ~350 real, moderately dense *R*-band frames, derived spatially-varying PSFs, then simulated point source transients with random positions and fluxes.
- executed PTFIDE to create diff images and extract candidates with **fixed** threshold (S/N = 4) and filter params.




$$C = \frac{\#\,\text{matched to truth}\ (<R)}{\#\,\text{total truth}\ (<R)}$$

# Performance: #extractions vs "truth"

- took ~350 real, moderately dense *R*-band frames, derived spatially-varying PSFs, then simulated point source transients with random positions and fluxes.
- executed PTFIDE to create diff images and extract candidates with **fixed** threshold (S/N = 4) and filter params.

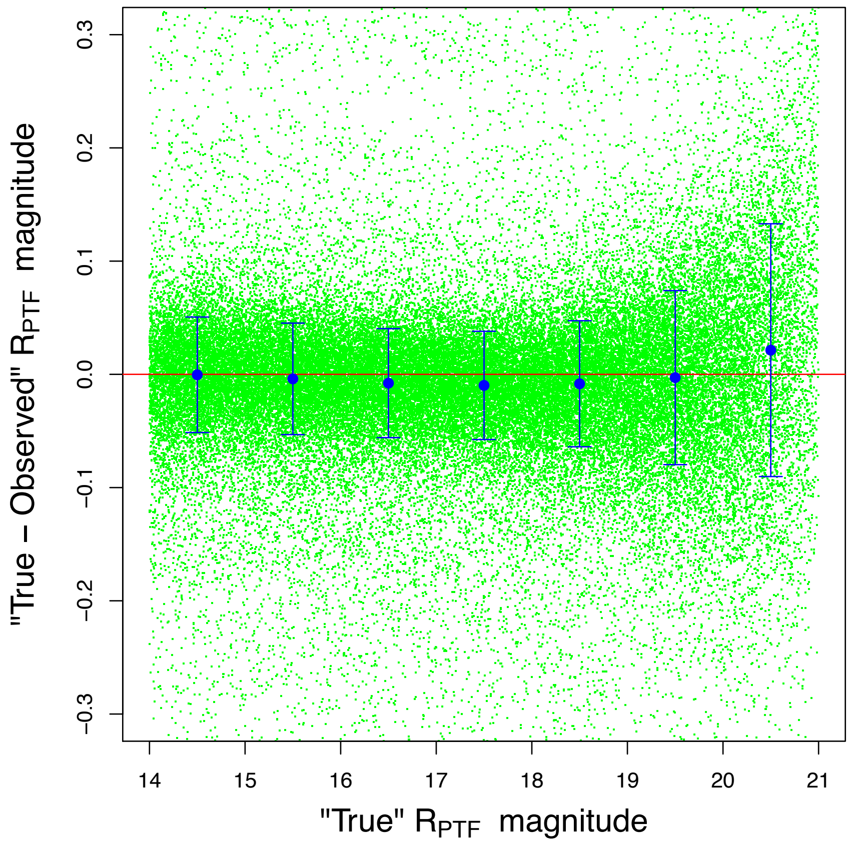



$$R = \frac{\#\,\text{matched to truth}\ (<R)}{\#\,\text{total extracted}\ (<R)}$$

$$C = \frac{\#\,\text{matched to truth}\ (<R)}{\#\,\text{total truth}\ (<R)}$$

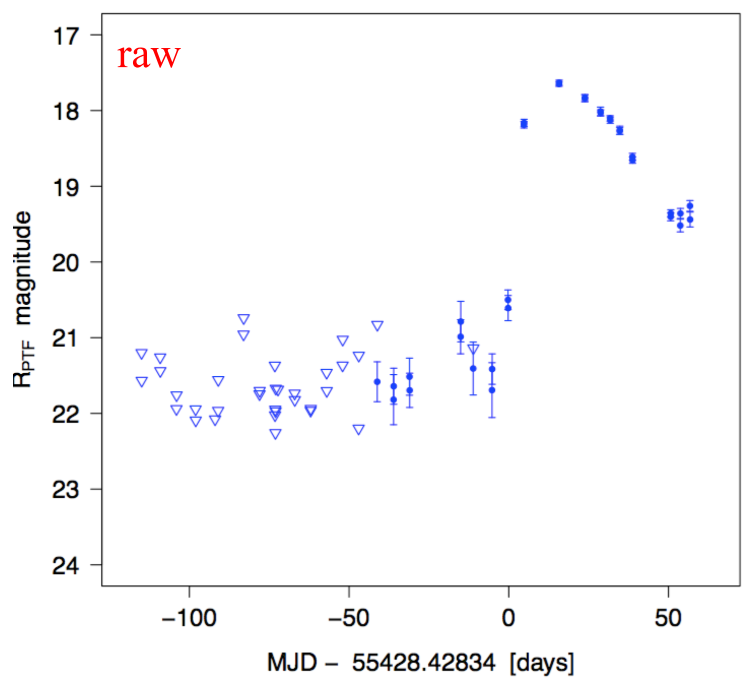
# Performance of PSF-fit (AC) photometry

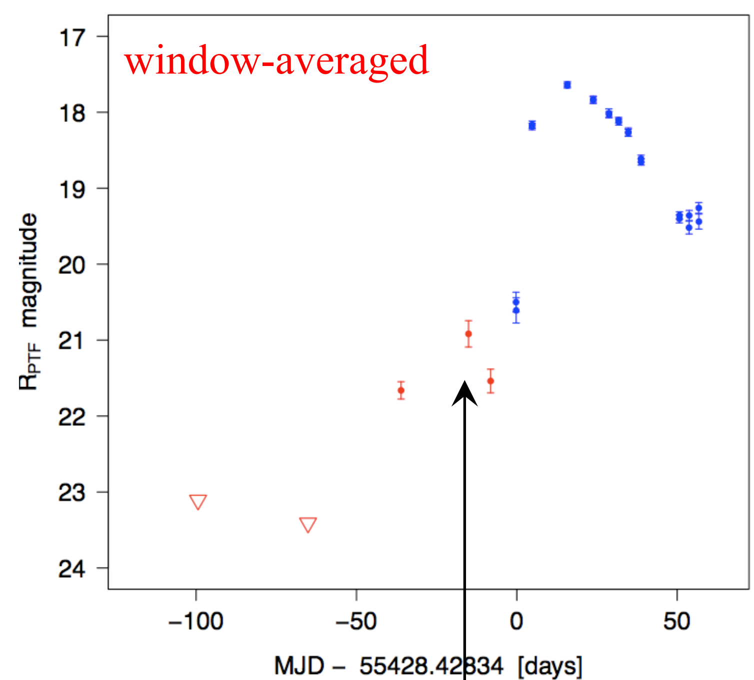
- took ~350 real, moderately dense *R*-band frames, derived spatially-varying PSFs, then simulated point source transients with random positions and fluxes.
- then executed PTFIDE to create diff images and extract candidates.
- difference image (AC) fluxes consistent with truth.

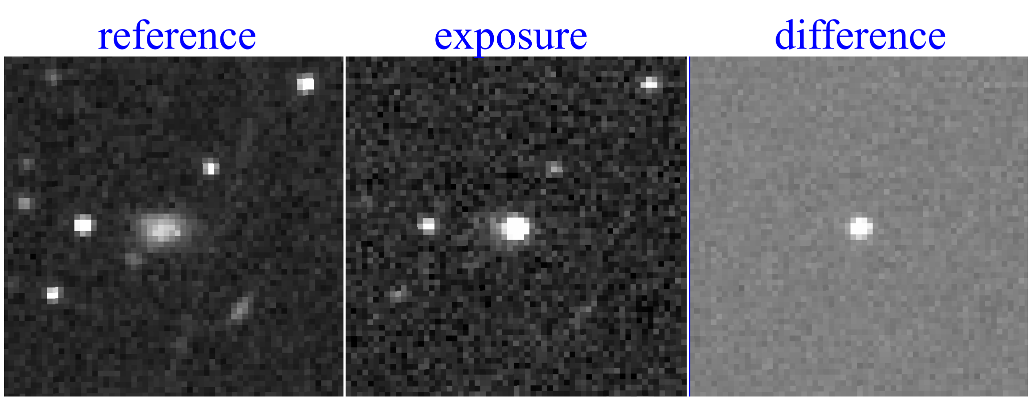


# SN 2010mc (PTF10tel)

Type IIn supernova in unknown galaxy at ~ 153 Mpc



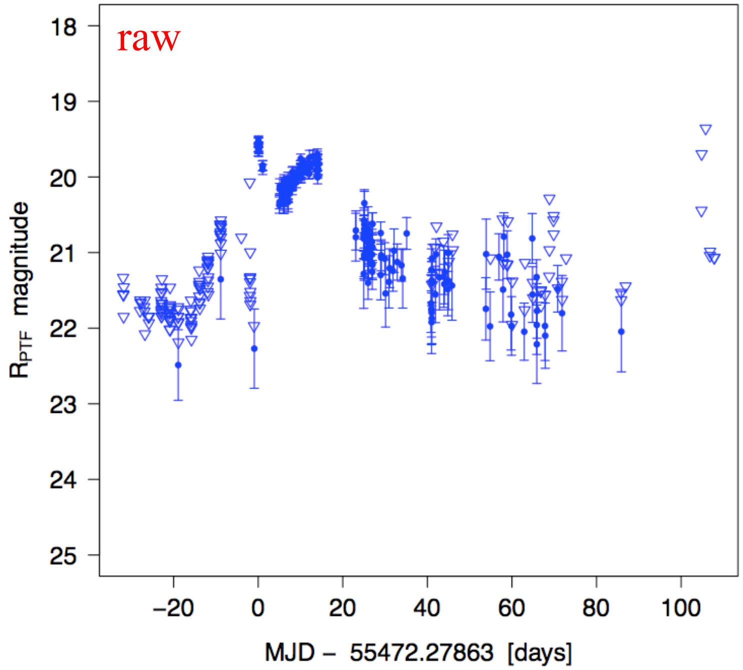



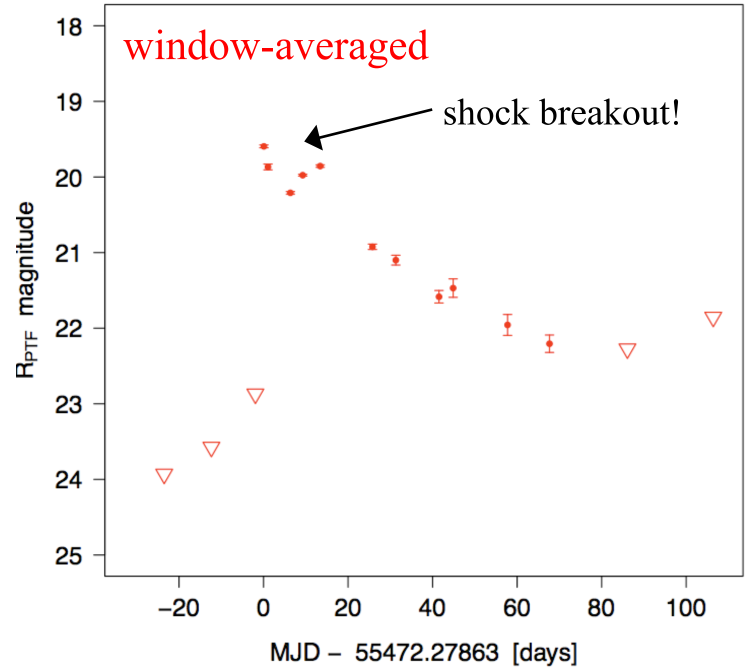



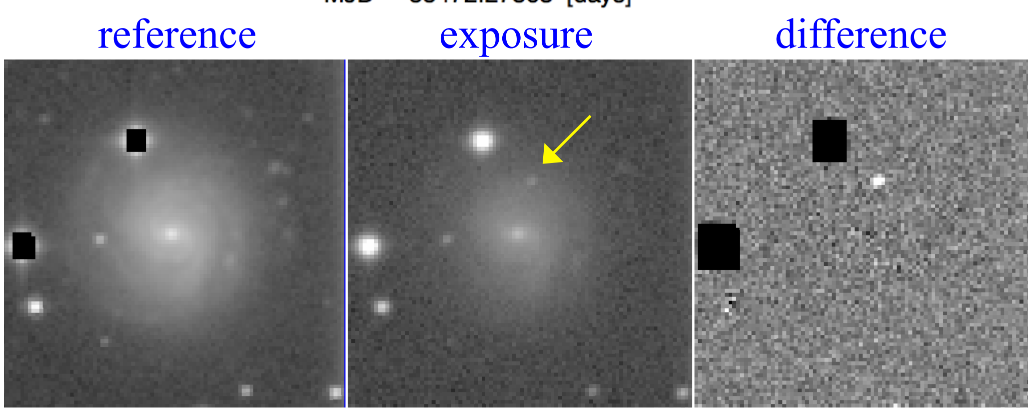

Outburst 40 days before explosion:
Ofek et al. (2013), Nature, 494, 65

# SN PTF10xfh

Type Ic supernova in NGC 717 at ~ 65 Mpc (Yi Cao, private communication)



# SN PTF13ai
# (or PSN J12541585+0926259)

- Type Ia Supernova in galaxy PGC 43884 (~197 Mpc); discovered Feb 5, 2013
- One of the first to be discovered for iPTF