PHOTOMETRYPIPELINE

An Automated Pipeline for Calibrated Photometry

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Motivation for an Agnostic Pipeline

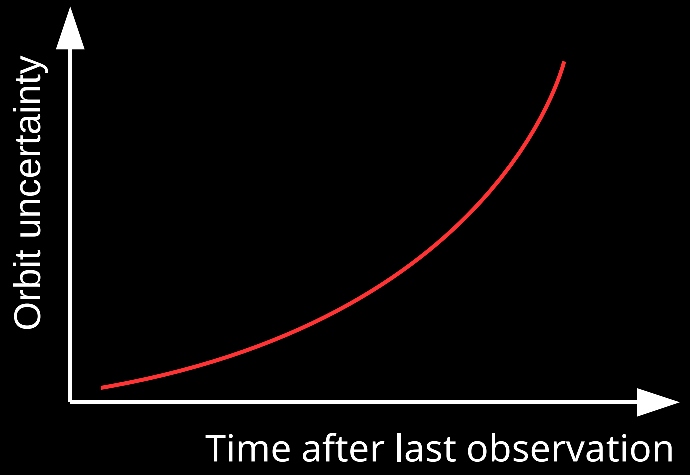
- Large number of small telescopes
- Observers are left to themselves with analysis
  - Image calibration is tough
  - Low motivation to analyze imperfect data

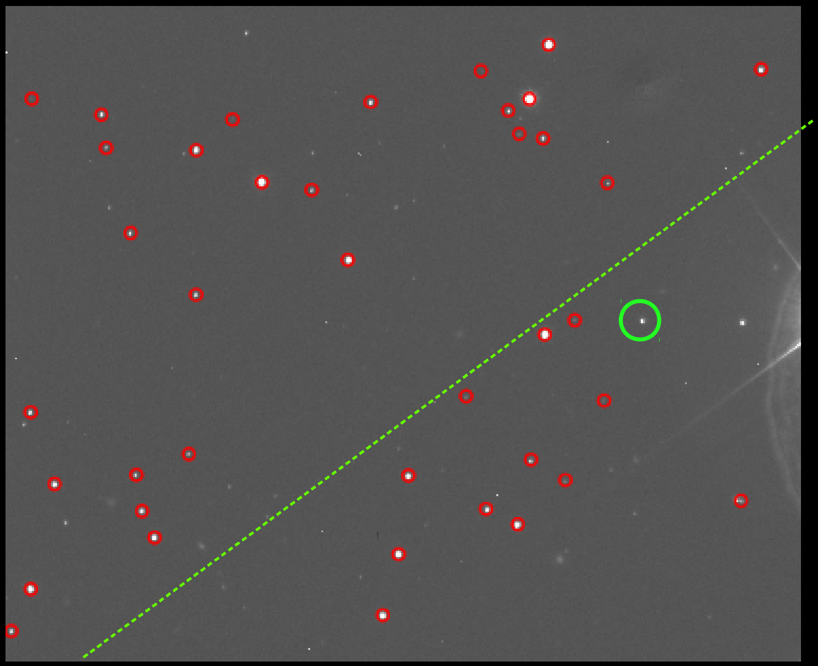
More Motivation

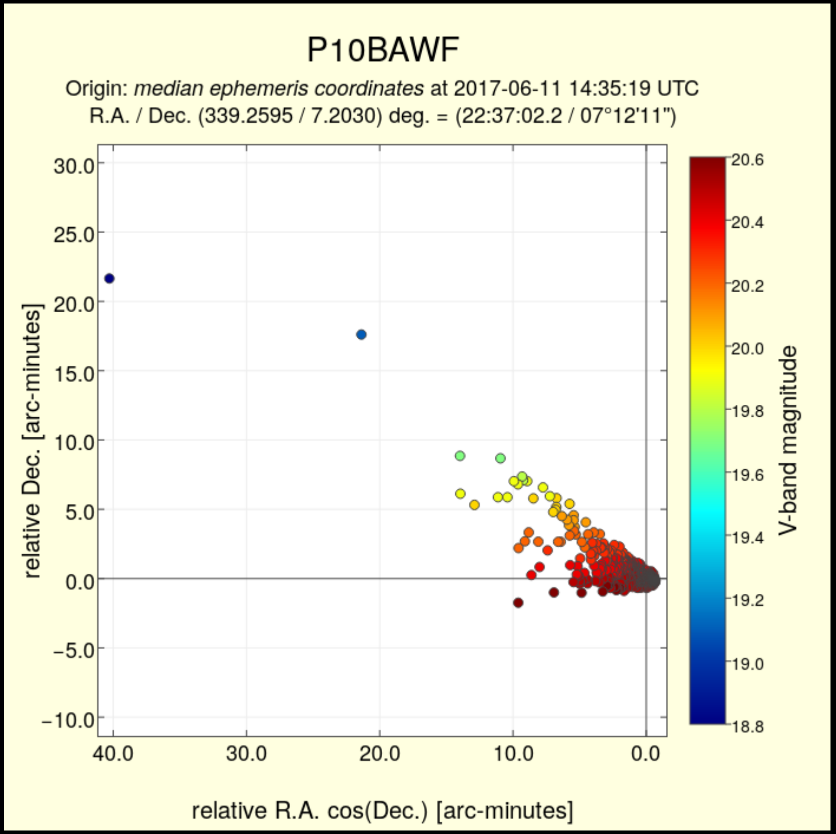
- The Mission Accessible Near-Earth Asteroid Survey (MANOS, PI: Moskovitz, Lowell Obs.)
- Asteroid characterization survey using photometric and spectroscopic observations
- 6 optical telescopes for asteroid imaging

Asteroid Observations

- Astrometry:
  - improve asteroid orbits

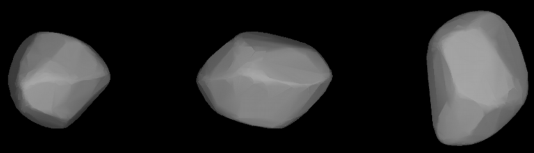


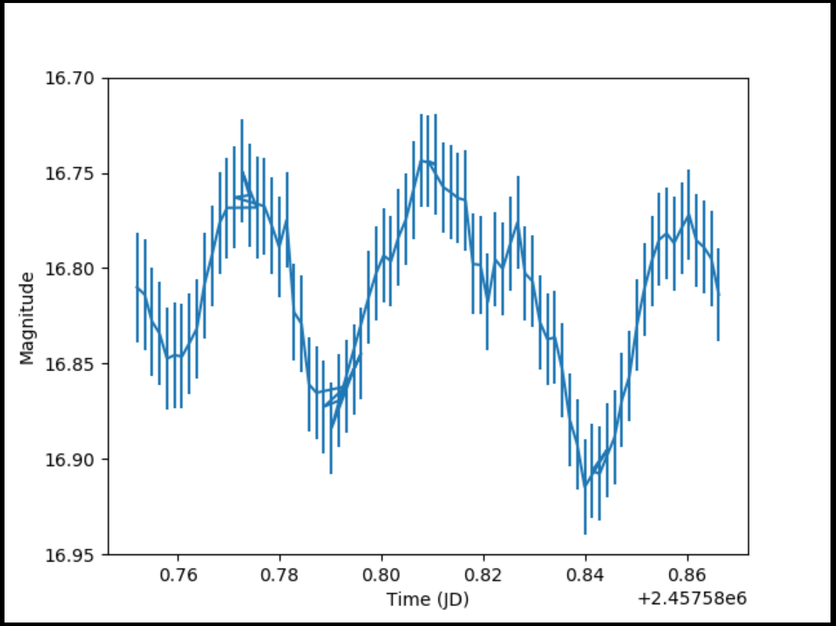




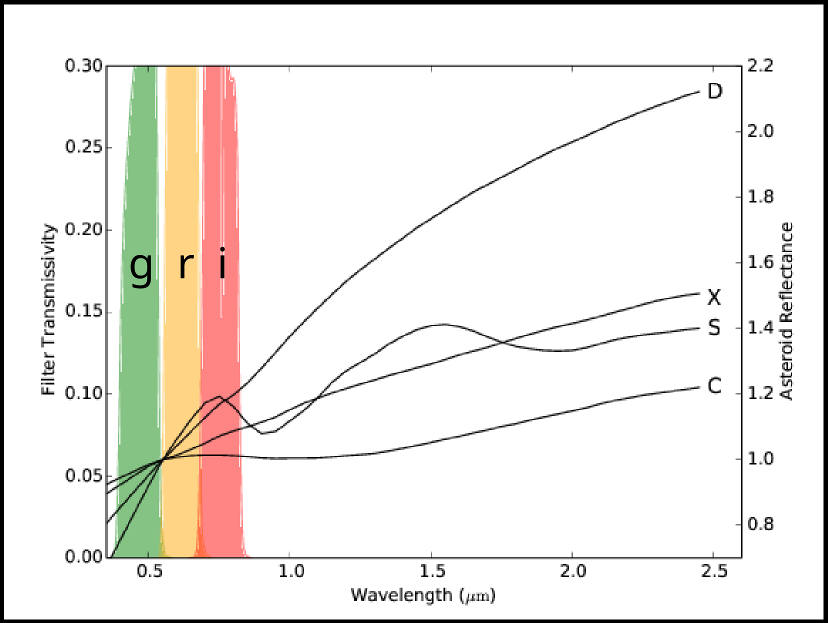
Asteroid Observations

- Photometry:
  - Shape information through lightcurves





  - Compositional information through colors



The Photometry Pipeline

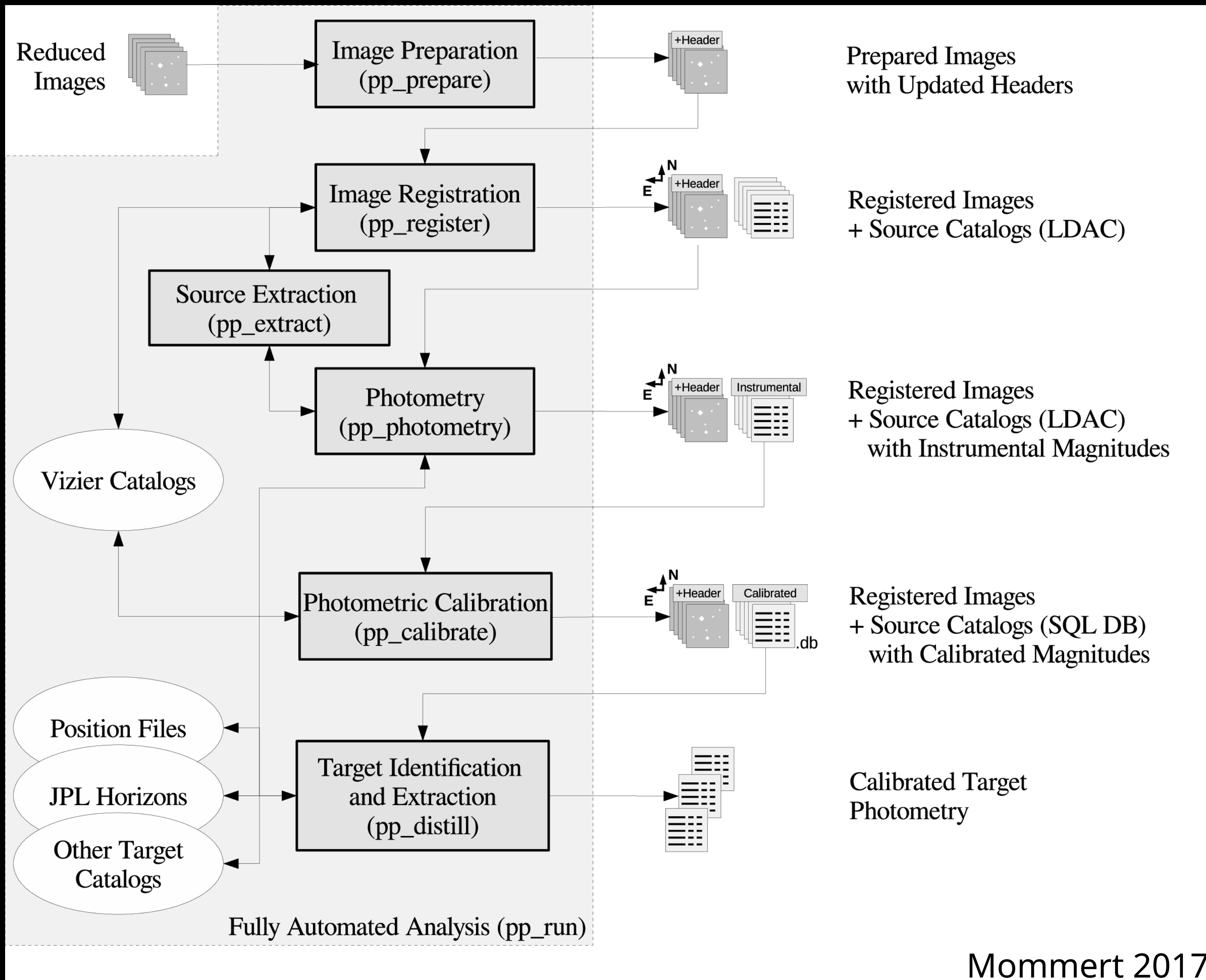
- Requirements:
  - single pipeline for all observatories
  - Easy to use
  - >90% success rate on reasonable data
  - Goals:
    - Photometry: ~0.05 mag
    - Astrometry: ~0.3 arcsec

PP – The Photometry Pipeline

- Automated astrometric and photometric calibration of imaging data
- Extraction of aperture photometry for point sources: stars, quasars, asteroids, satellites
- Currently ~20 telescopes implemented (0.5 m – 6.5 m apertures)
- Coded in Python, uses Source Extractor and SCAMP

- Available on github: github.com/mommermi/photometrypipeline
- Published in Astronomy and Computing: Mommert 2017, A&C, 18, 47

PP - Overview



Reduced Images
Image Preparation (pp_prepare)
+Header
Prepared Images with Updated Headers
Image Registration (pp_register)
N
E
+Header
Registered Images + Source Catalogs (LDAC)
Source Extraction (pp_extract)
Photometry (pp_photometry)
N
E
+Header
Instrumental
Registered Images + Source Catalogs (LDAC) with Instrumental Magnitudes
Vizier Catalogs
Photometric Calibration (pp_calibrate)
N
E
+Header
Calibrated
.db
Registered Images + Source Catalogs (SQL DB) with Calibrated Magnitudes
Position Files
JPL Horizons
Other Target Catalogs
Target Identification and Extraction (pp_distill)
Calibrated Target Photometry
Fully Automated Analysis (pp_run)
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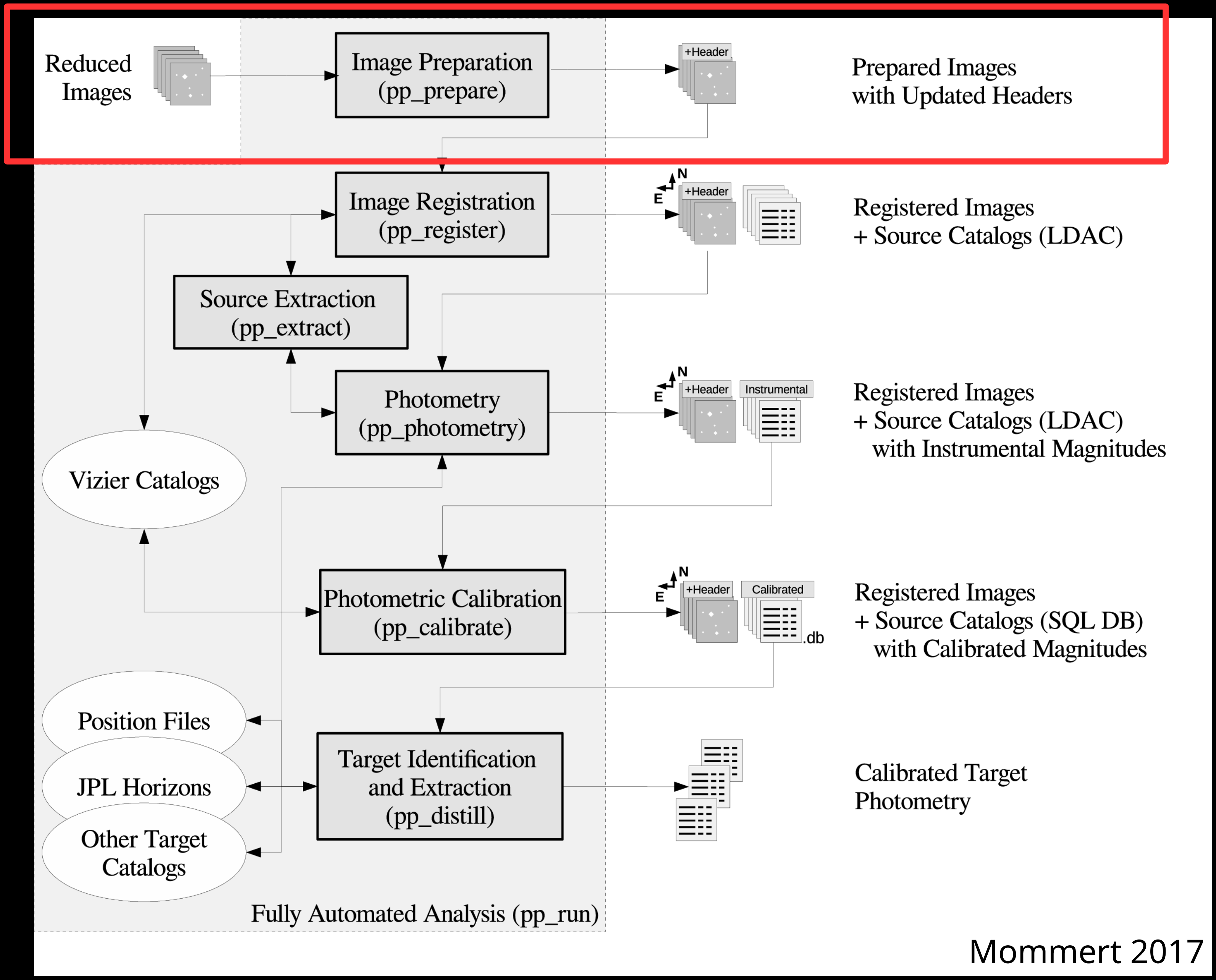
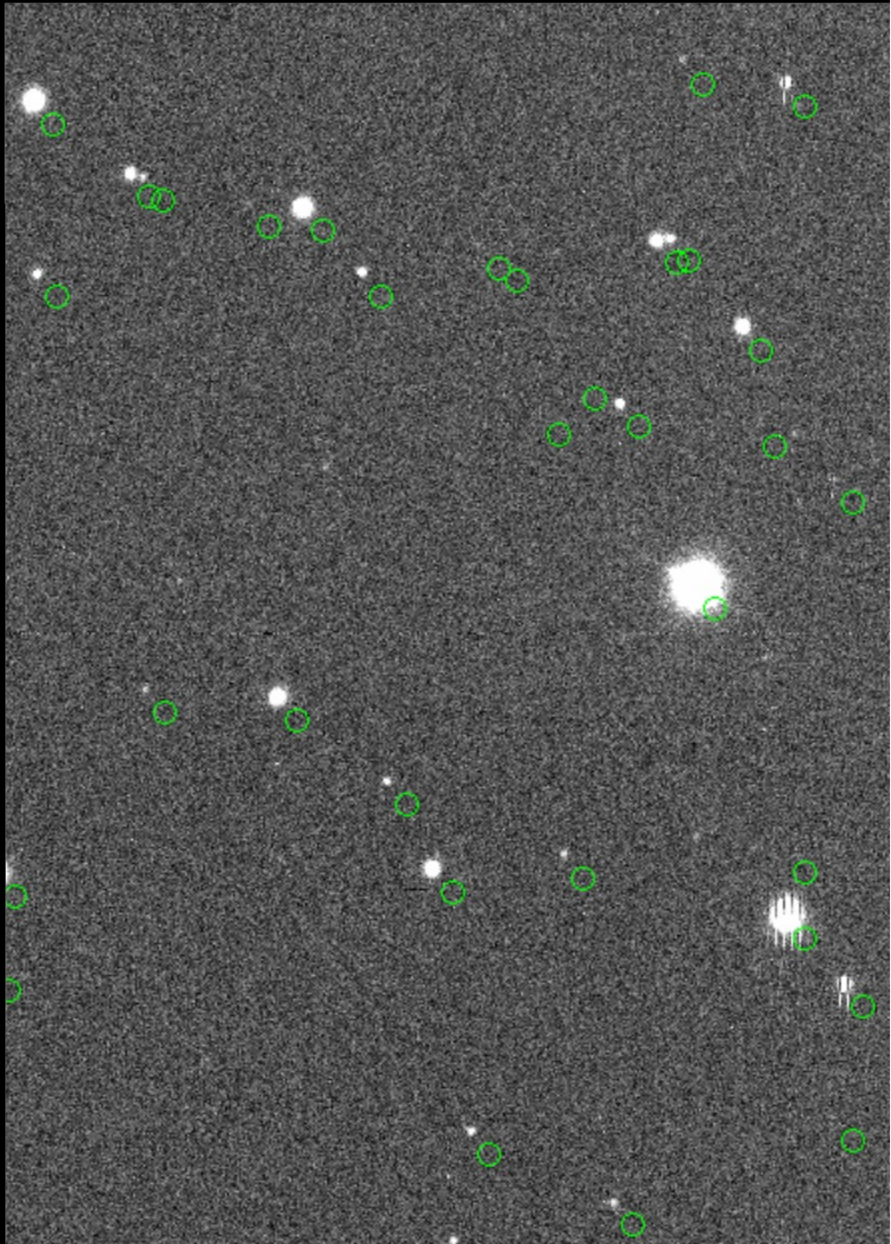
Preparing Data



Preparing Data - Problems

- FITS Header keywords are not standardized:
  was it 'DATE', 'DATE-OBS', or 'OBS_DATE'... ?
- WCS information in the header (if available) are generally unreliable
- Every telescope is different...



Preparing Data - Solution

- Telescope setup file
- Translate telescope-specific FITS header keywords
- Add useful information to the header
- Telescope-specific setup of registration and calibration
- Implant 0-th order WCS solution

telescopes.py:

```
# VATT, VATT4k
vatt4k_param = {
    'telescope_instrument' : 'VATT/VATT4k', # telescope/instrument name
    'telescope_keyword'    : 'VATT4K',      # telescope/instrument keyword
    'observatory_code'     : '290',         # MPC observatory code
    'secpix'               : (0.1875, 0.1875), # pixel size (arcsec)
                                               # before binning

    # image orientation preferences
    'flipx'                : True,
    'flipy'                : False,
    'rotate'               : 0,

    # instrument-specific FITS header keywords
    'binning'              : ('CCDBIN1', 'CCDBIN2'), # binning in x/y
    'extent'               : ('NAXIS1', 'NAXIS2'),   # N_pixels in x/y
    'ra'                   : 'RA',  # telescope pointing, RA
    'dec'                  : 'DEC', # telescope pointin, Dec
    'radec_separator'      : ':',   # RA/Dec hms separator, use 'XXX'
                                    # if already in degrees
    'date_keyword'         : 'DATE-OBS|TIME-OBS', # obs date/time
                                                  # keyword; use
                                                  # 'date|time' if
                                                  # separate
    'obsmidtime_jd'        : 'MIDTIMJD', # obs midtime jd keyword
                                         # (usually provided by
                                         # pp_prepare
    'object'               : 'OBJECT',  # object name keyword
    'filter'               : 'FILTER',  # filter keyword
    'filter_translations'  : {'TOP 2 BOT 1': 'V', 'TOP 3 BOT 1': 'R',
                              'TOP 4 BOT 1': 'I', 'TOP 5 BOT 1': 'B'},
                             # filtername translation dictionary
    'exptime'              : 'EXPTIME', # exposure time keyword (s)
    'airmass'              : 'AIRMASS', # airmass keyword


    # source extractor settings
    'source_minarea'       : 12, # default sextractor source minimum N_pixels
    'source_snr': 3, # default sextractor source snr for registration
    'aprad_default'        : 5, # default aperture radius in px
    'aprad_range'          : [2, 10], # [minimum, maximum] aperture radius (px)
    'sex-config-file'      : rootpath+'/setup/vatt4k.sex',
    'mask_file'            : {},
    #                        mask files as a function of x,y binning

    # registration settings (Scamp)
    'scamp-config-file'    : rootpath+'/setup/vatt4k.scamp',
    'reg_max_mag'          : 19,
    'reg_search_radius'    : 0.5, # deg
    'source_tolerance': 'high',

    # default catalog settings
    'astrometry_catalogs'  : ['GAIA'],
    'photometry_catalogs'  : ['SDSS-R9', 'APASS9', 'PANSTARRS', '2MASS']
}
```

Image Registration

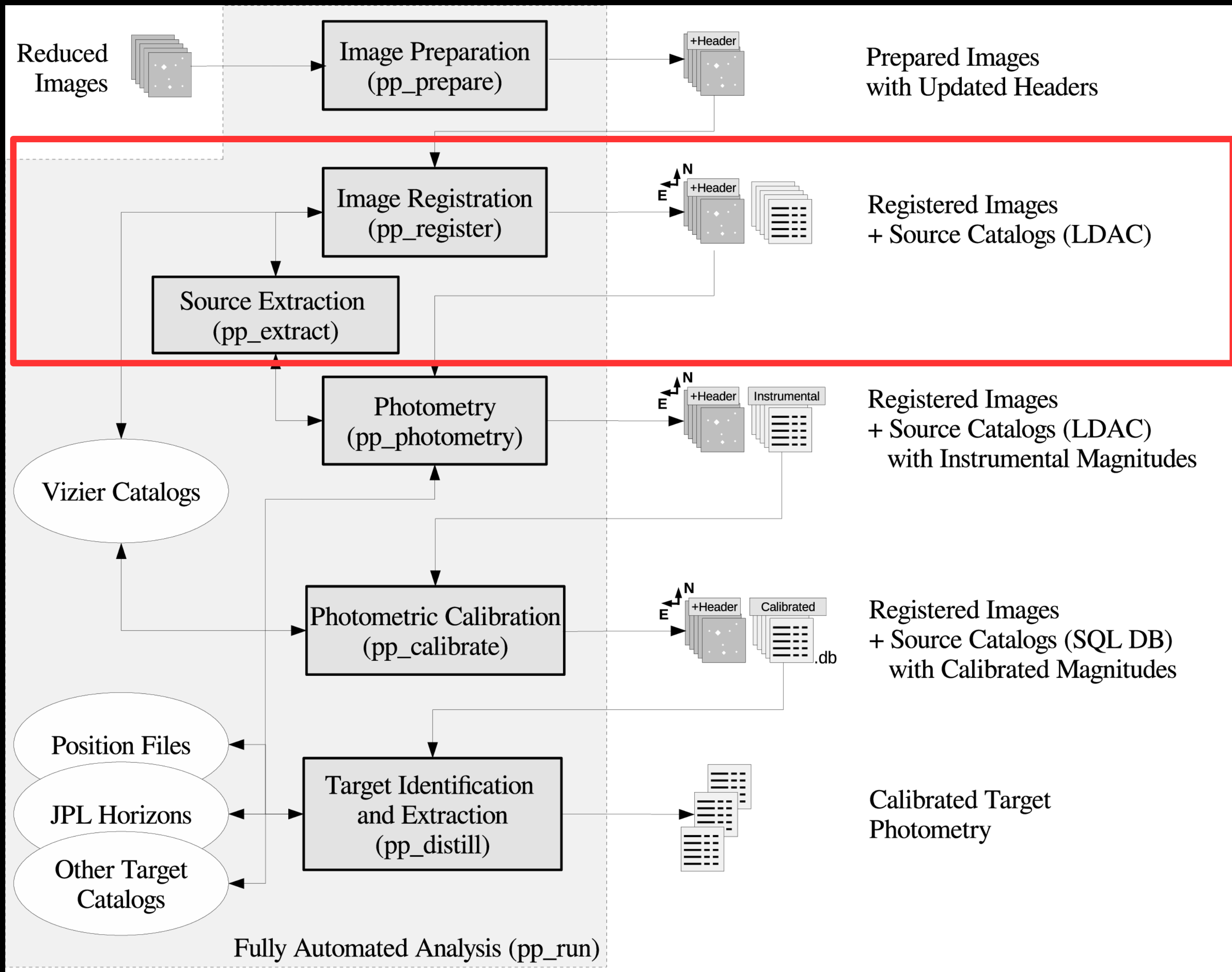


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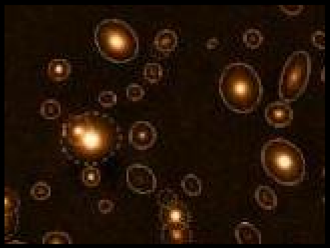
Image Registration

- Registration through matching of sources in image with catalog stars
- Use Source Extractor and SCAMP, both of which are well-tested and highly customizable

SExtractor



- Run in a threaded Python environment
- Used for:
  - Building source catalogs
  - Aperture photometry

Image Registration with SCAMP

- SCAMP taps a number of Vizier catalogs
- PP uses its own catalog interface:
  - Allows use of GAIA DR1, Pan-STARRS
  - Enables proper motion corrections
  - Enables filtering (e.g., mag upper limits)

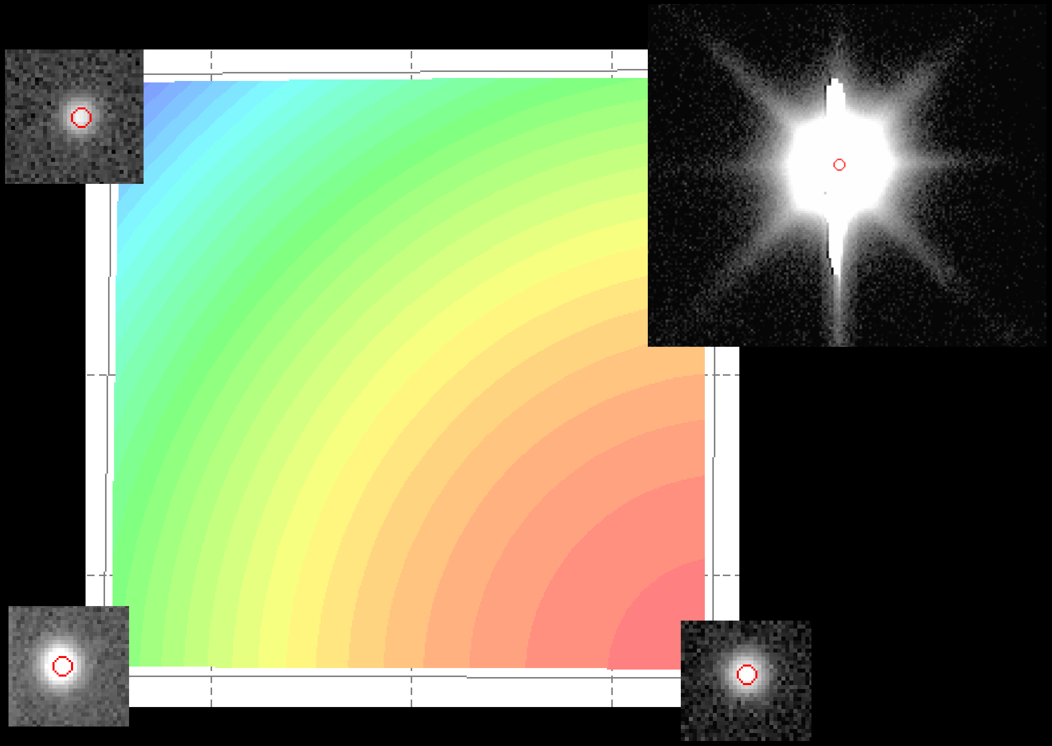
PP

Image Registration Results

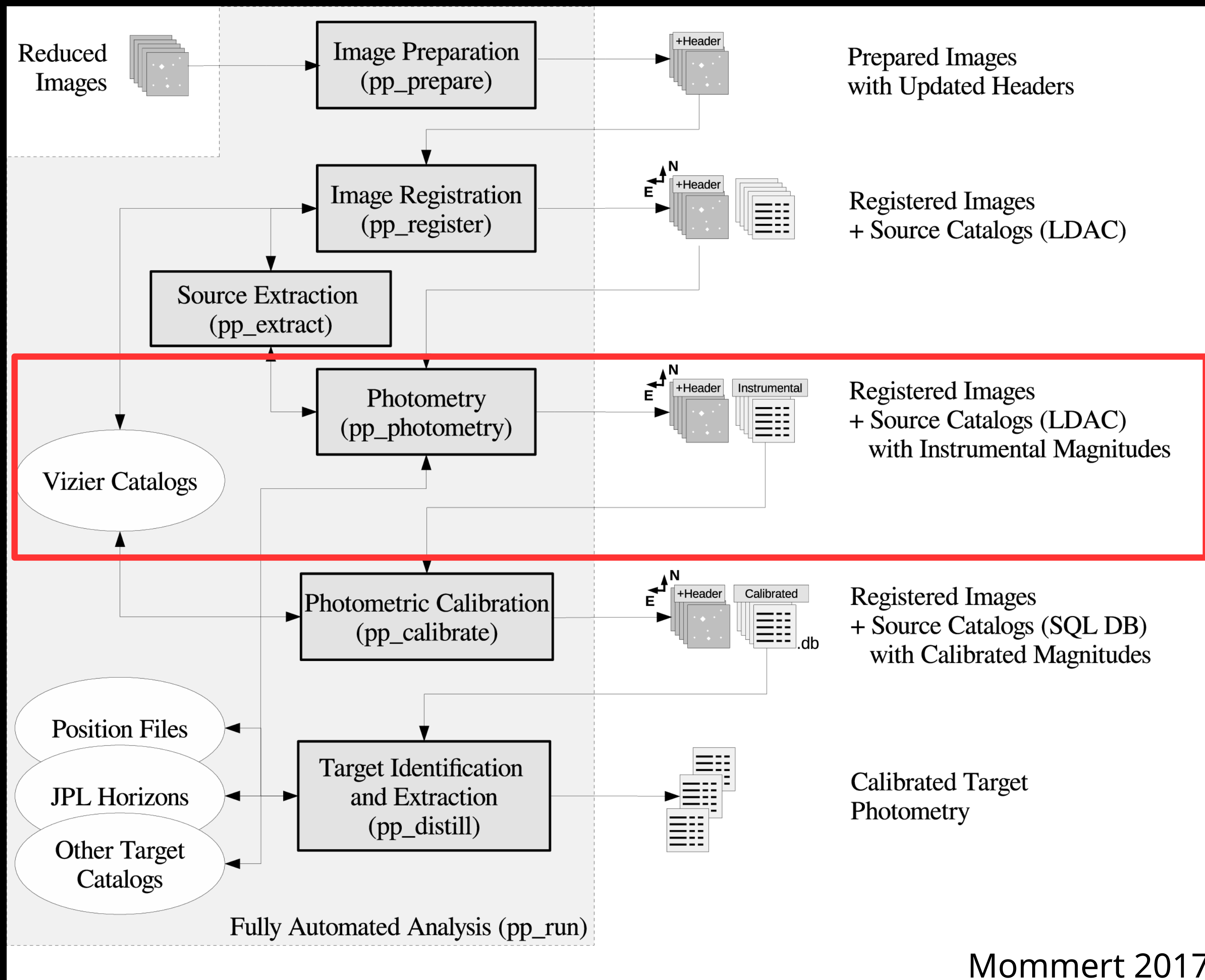
- Default astrometry catalog: Gaia DR1
- Typical astrometry uncertainties: 0.2 arcsec (for 1.0 arcsec pixel scale, using Gaia DR1)
- Distortions are properly taken into account

KMTNET-S

- 1 chip = 1 sq. deg
- 4% variation in pixel scale across field

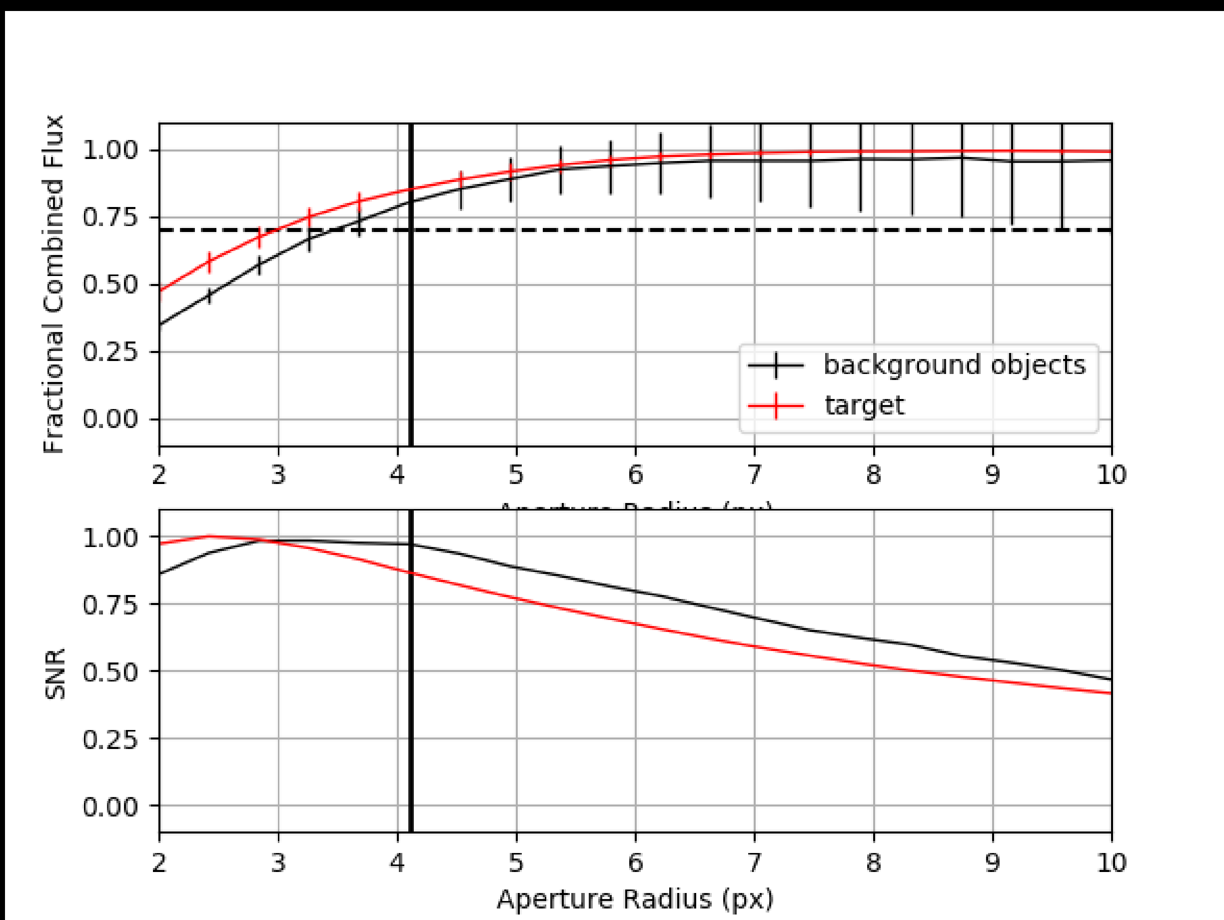


Aperture Photometry



Aperture Photometry with Source Extractor

- Find optimum aperture size in curve-of-growth analysis

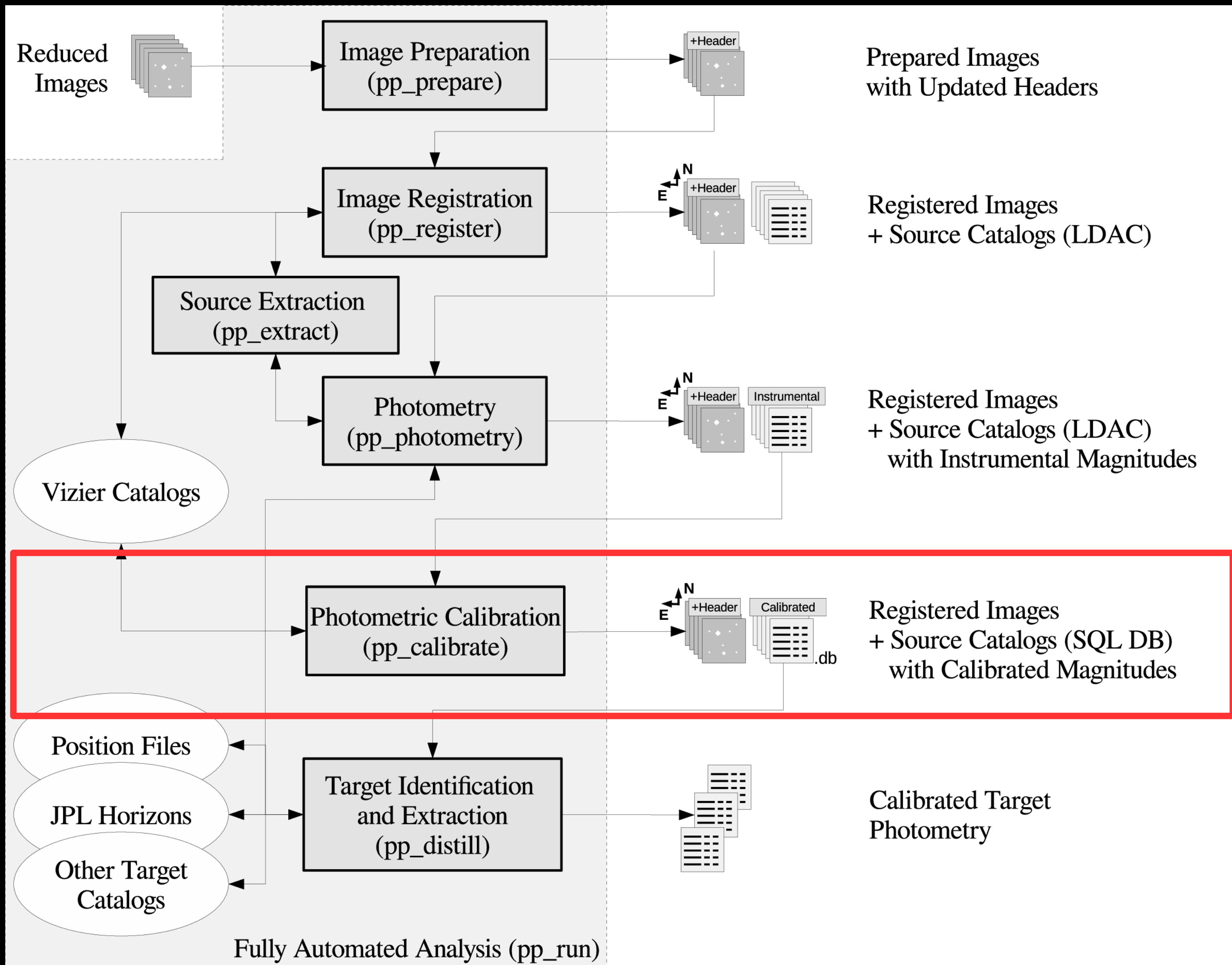


$Flux_{stars} > 0.7 \max(Flux_{stars})$

$Flux_{target} > 0.7 \max(Flux_{target})$

$|Flux_{stars} - Flux_{target}| < 0.05\ |Flux_{stars}|$

Photometric Calibration



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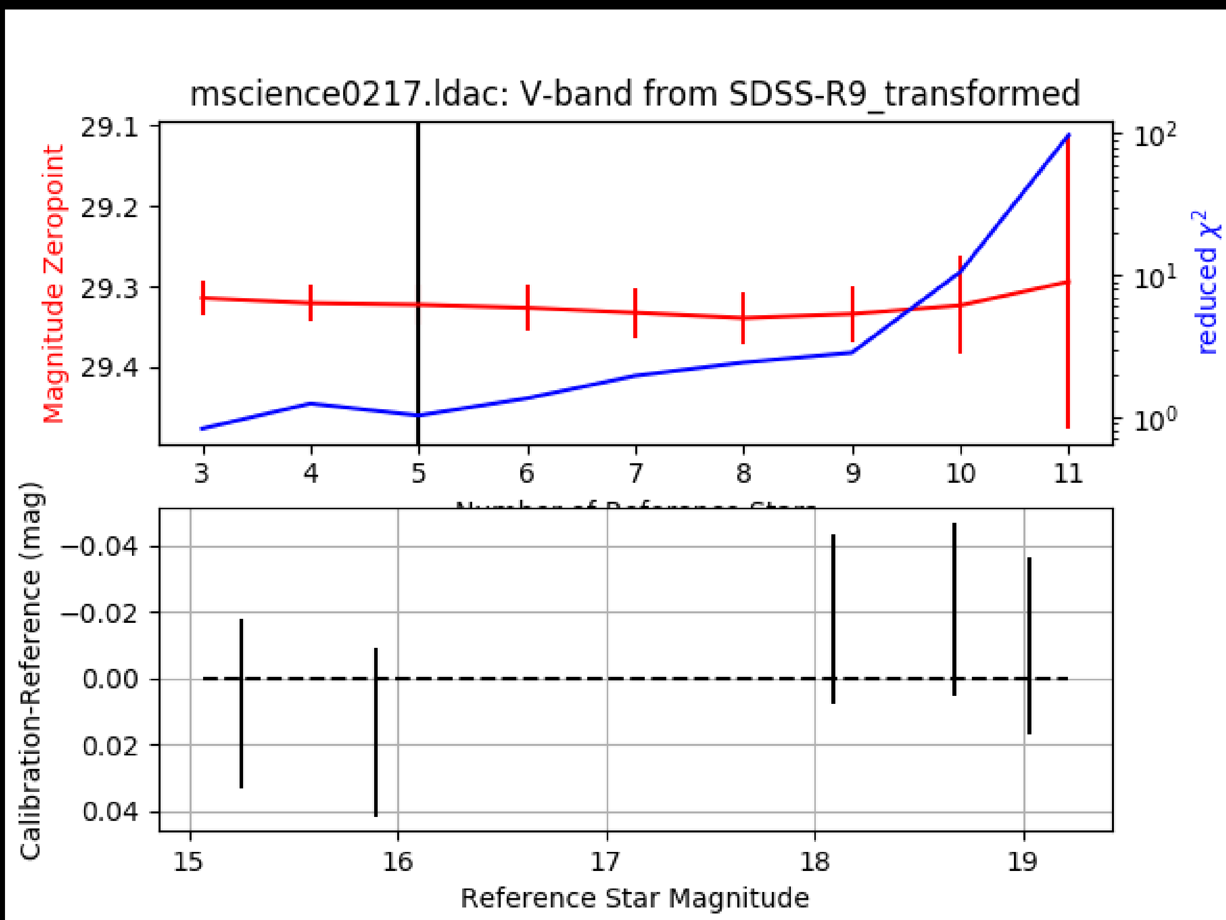
Photometric Calibration

- Photometric Calibration using field stars
- Available catalogs: SDSS, Pan-STARRS, APASS9, 2MASS
- Available photometric bands: u, B, g, V, r, (R), i, (I), y, z, (Z), J, H, K
- Photometric band transformations:
  - SDSS → Johnson (Chonis & Gaskell 2008)
  - 2MASS → UKIRT (Hodgkin et al. 2009)
  - SDSS – Pan-STARRS – Johnson soon available (Auge et al., in progress)

Photometric Calibration - How

- Weighted Chi² fitting combined with an iterative sigma-rejection



Default strategy:

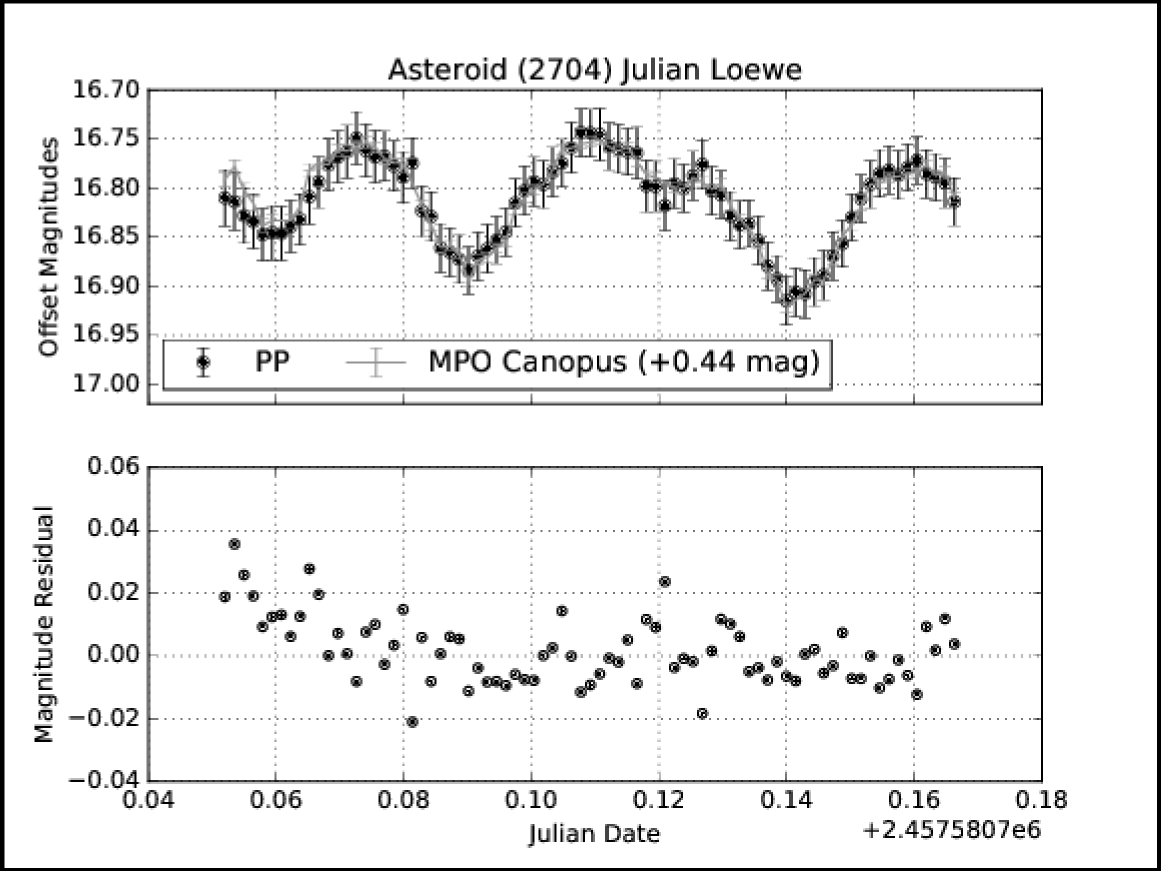
- Reject reference stars with extraordinary colors
- keep at least 50% of all available reference stars

Magnitude zeropoint in this example:

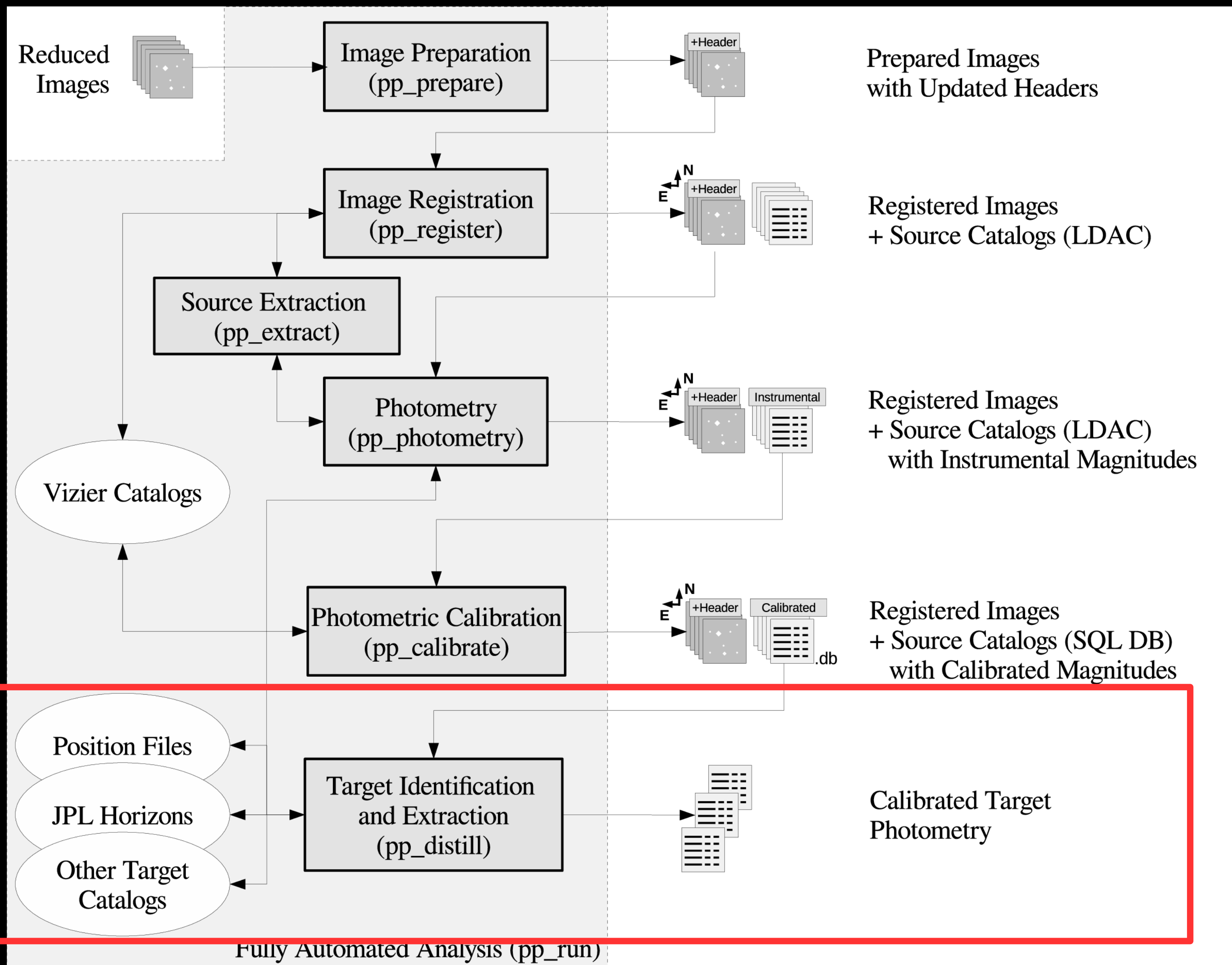
M_{zp} = 29.32+-0.03 mag

Photometric Calibration - Results

- Typical magnitude zeropoint accuracy of 0.03 mag



Target Extraction



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Target Extraction

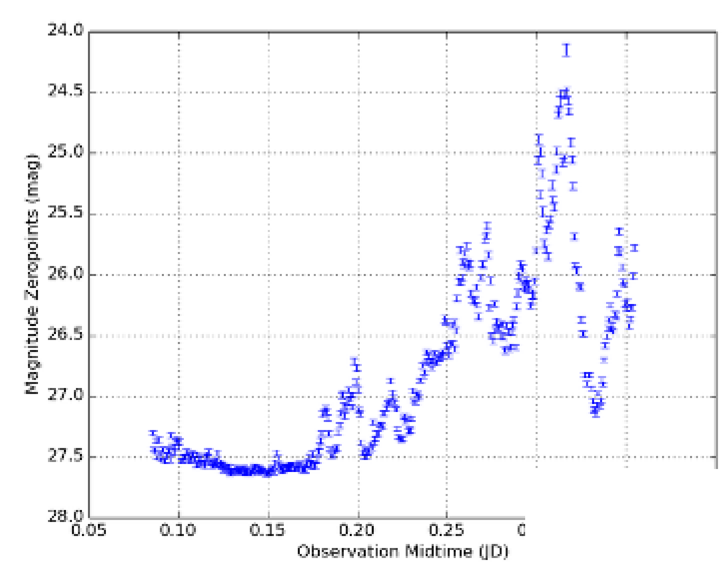
- Set of fixed positions
- Manually selected positions as function of time
- Moving target name
- Serendipitously observed variable stars
- Serendipitously observed asteroids
- TBD: Simbad query
- ...

Diagnostics

- PP produces comprehensive diagnostic output

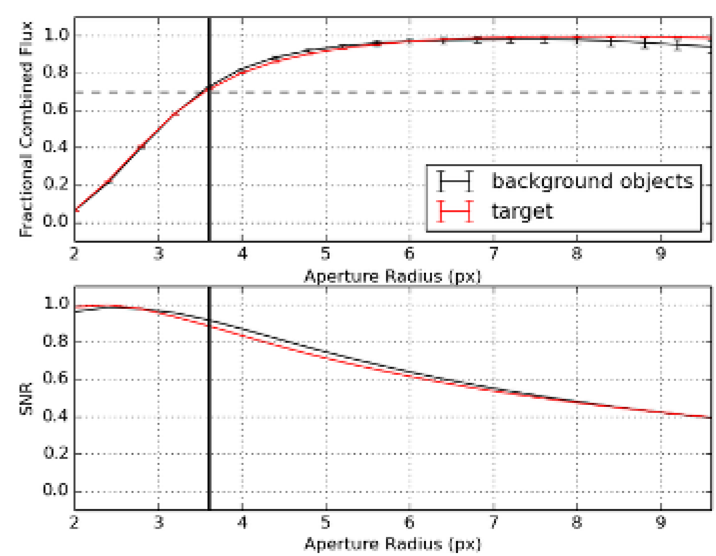
Photometric Calibration - Catalog Match

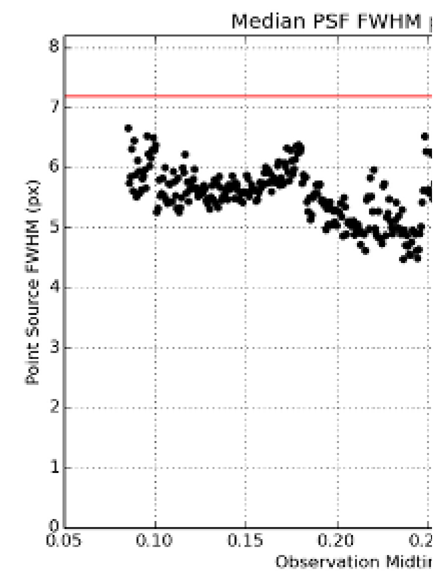
atch image data with SDSS-R9_transformed (6242 sources downloaded, 777 transformed to V (V

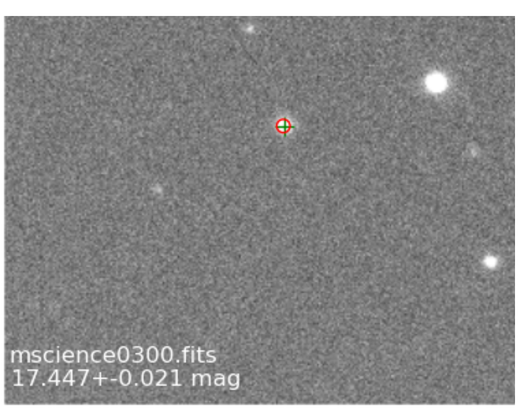


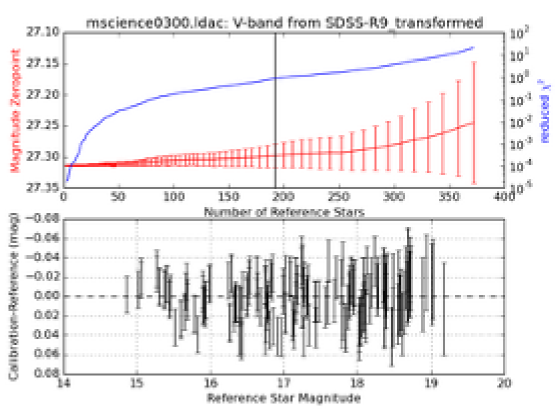
Photometric Calibration - Aperture Size

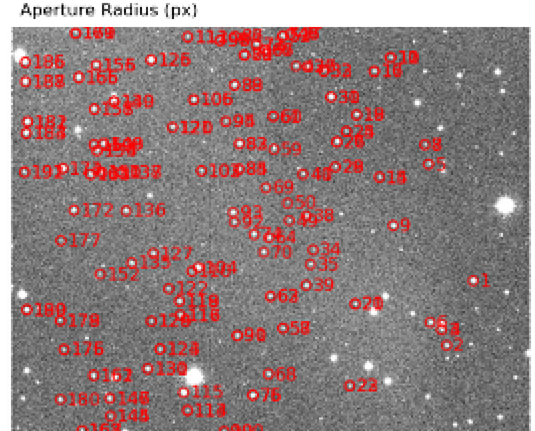
optimum aperture radius derived as 3.60 (px) through curve-of-growth analysis based on 20 frames with target and 20 frames with background detections











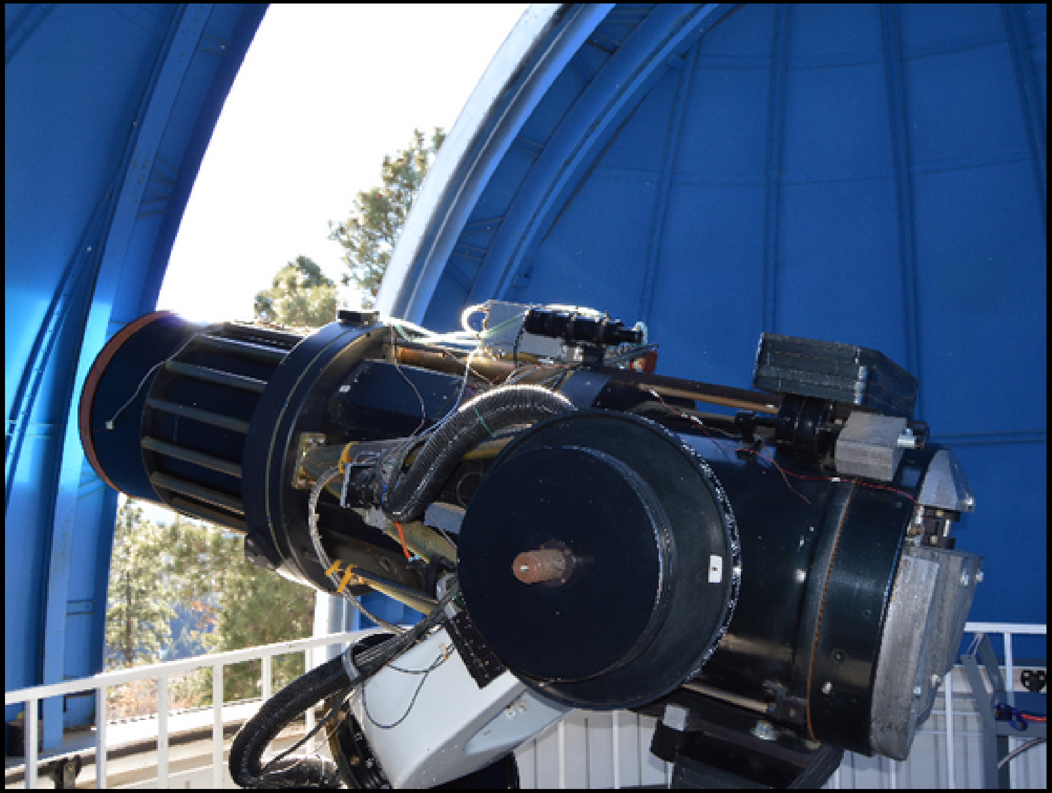
92	J081238.32+010208.2	123.1596
93	J081238.42+010222.7	123.1601
94	J081239.05+010436.3	123.1627
95	J081239.05+010436.3	123.1627
96	J081239.51+010634.9	123.1646
97	J081239.51+010634.9	123.1646
98	J081239.51+010634.9	123.1646
99	J081239.55+005701.6	123.1648
100	J081239.56+005701.5	123.1648
101	J081240.80+010704.9	123.1700
102	J081241.50+010324.4	123.1729

Future Developments

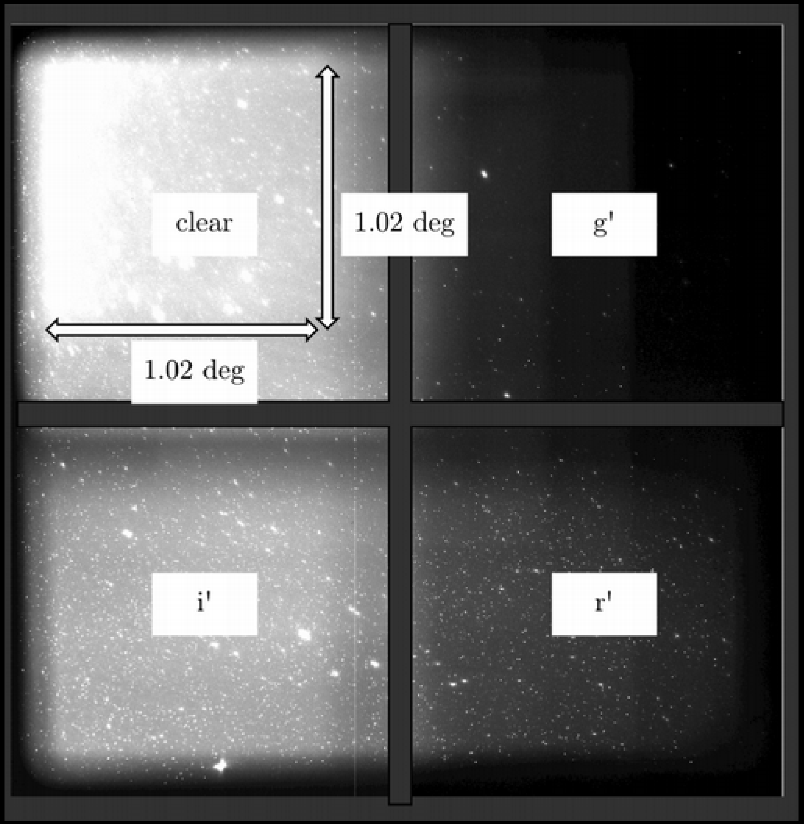
= some cool ideas...

Flagstaff Robotic Survey Telescope

- PP will provide near-realtime analysis of imaging data at the Flagstaff Robotic Survey Telescope



0.6m Schmidt + 4k CCD

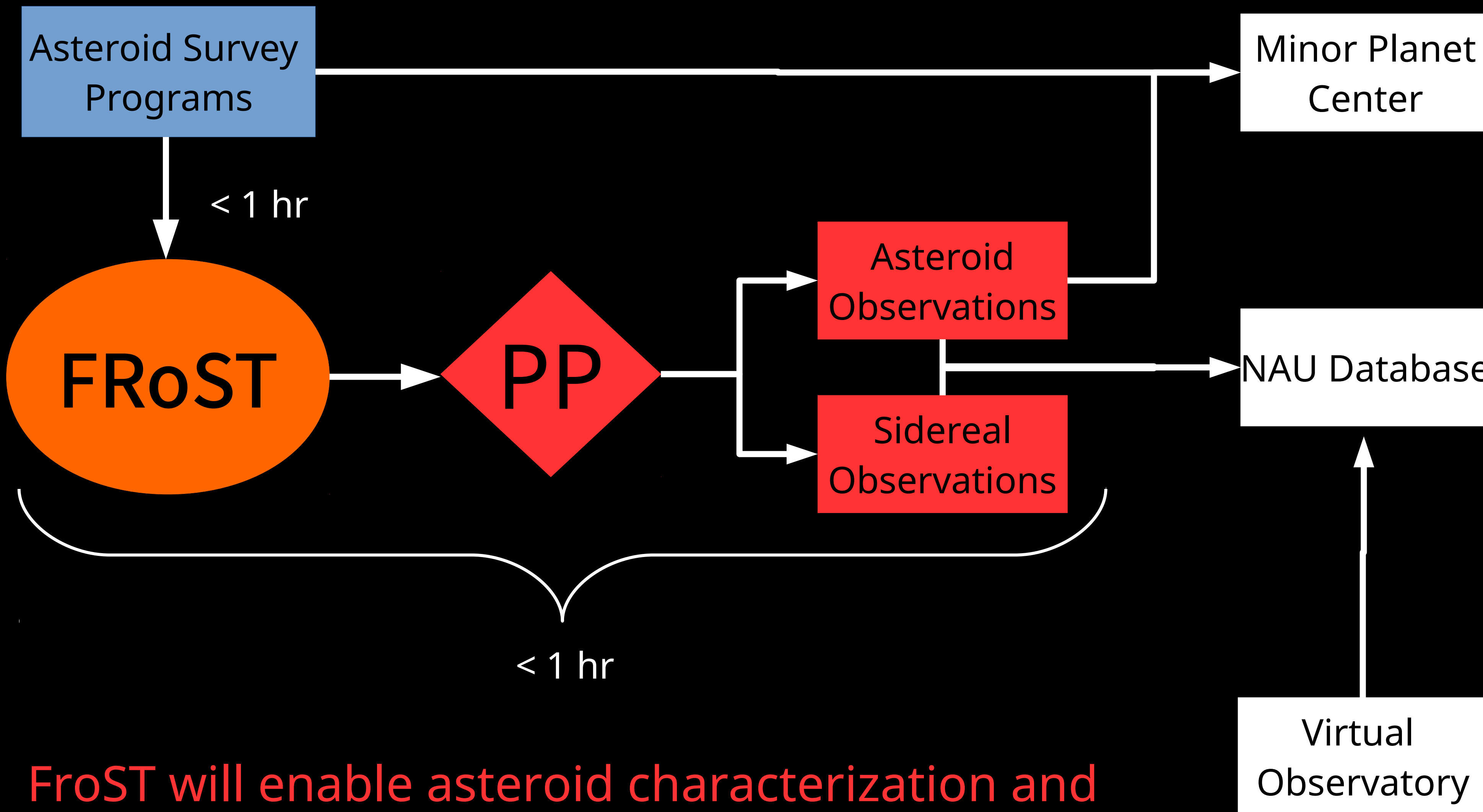


FRoST and Asteroids

- Rapid Response: FRoST can observe asteroids discovered only a few hours (minutes?) ago
- Astrometry: follow-up to improve orbits; accuracy better than 0.3 arcsec (2.8 arcsec/px); 3 sigma detection limit: V ~ 21
- Spectrophotometry: rough taxonomic classifications for asteroids with V < 18
- Lightcurves: (partial) lightcurves for V < 19

FRoST is able to recover and characterize a large fraction of all newly discovered Near-Earth Asteroids (… before LSST comes online)

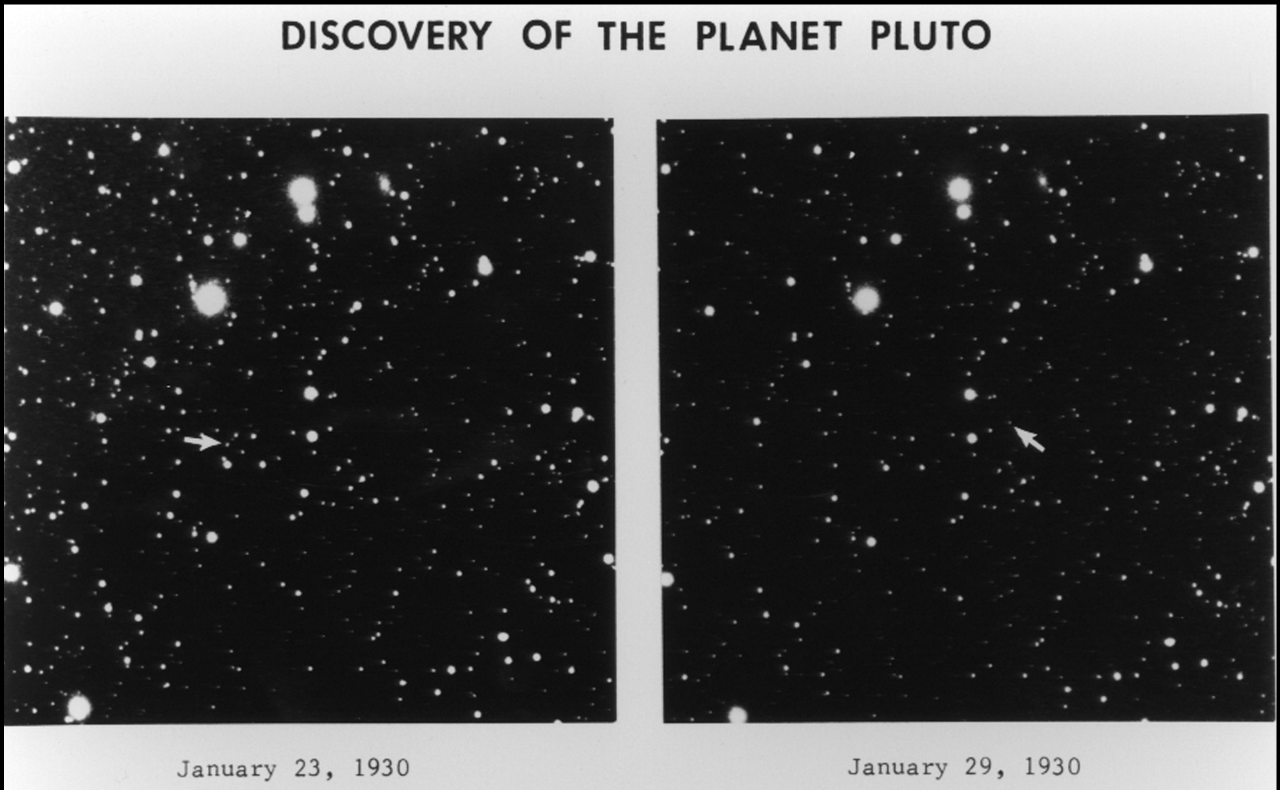
FRoST and PP



FroST will enable asteroid characterization and follow-up only hours after discovery!

Archival Data:

- Application to archival data:
  - public observatory archives (e.g., NOAO)
  - Lowell photographic plates

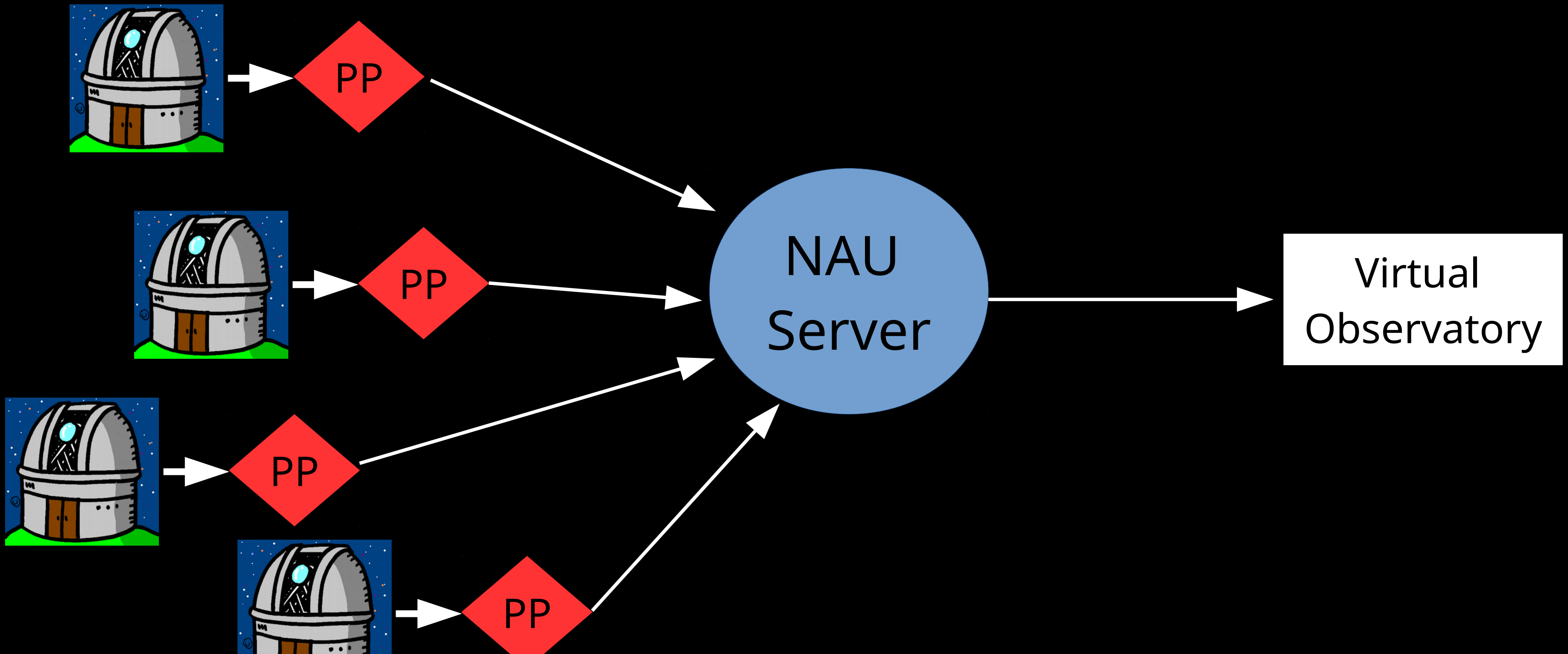


Why?

- Long-term variability of stars
- Who-knows-what

“NSA Pipeline”

- “Pipeline NSA”: PP users (voluntarily) donate their observations: primary target + field stars
- Goal is the development of a large catalog stellar and Solar System observations



Summary

- PP is an agnostic pipeline providing astrometry and photometry of point sources
- Highly customizable, can be run fully automatic
- Lots of use cases

Give it a try:

github.com/mommermi/photometrypipeline