Digitized photographic plate photometry with VaST software

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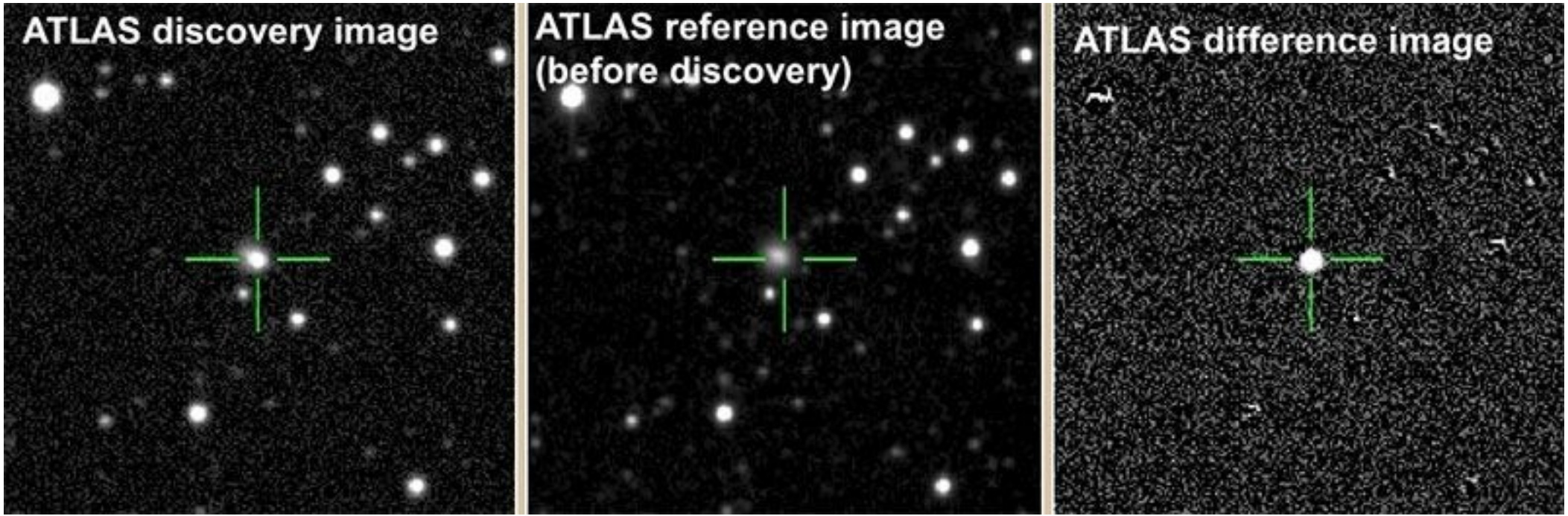
How to find a variable star?

One way is image subtraction...

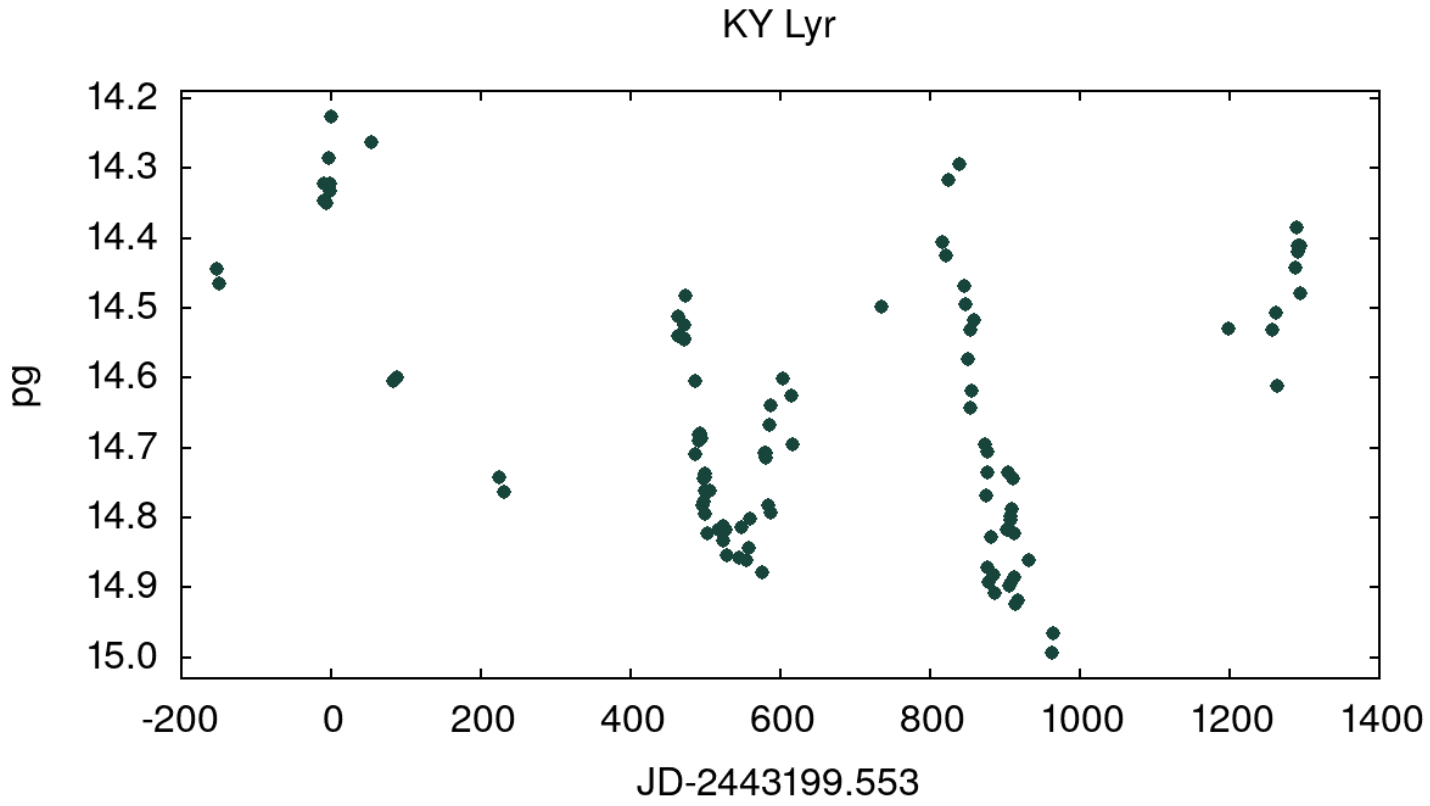


Example of image subtraction: discovery images of AT2018cow by the ATLAS survey

How to find a variable star?

Construct lightcurves of all sources, find which stand out:

- **smooth**
- high scatter
- periodic



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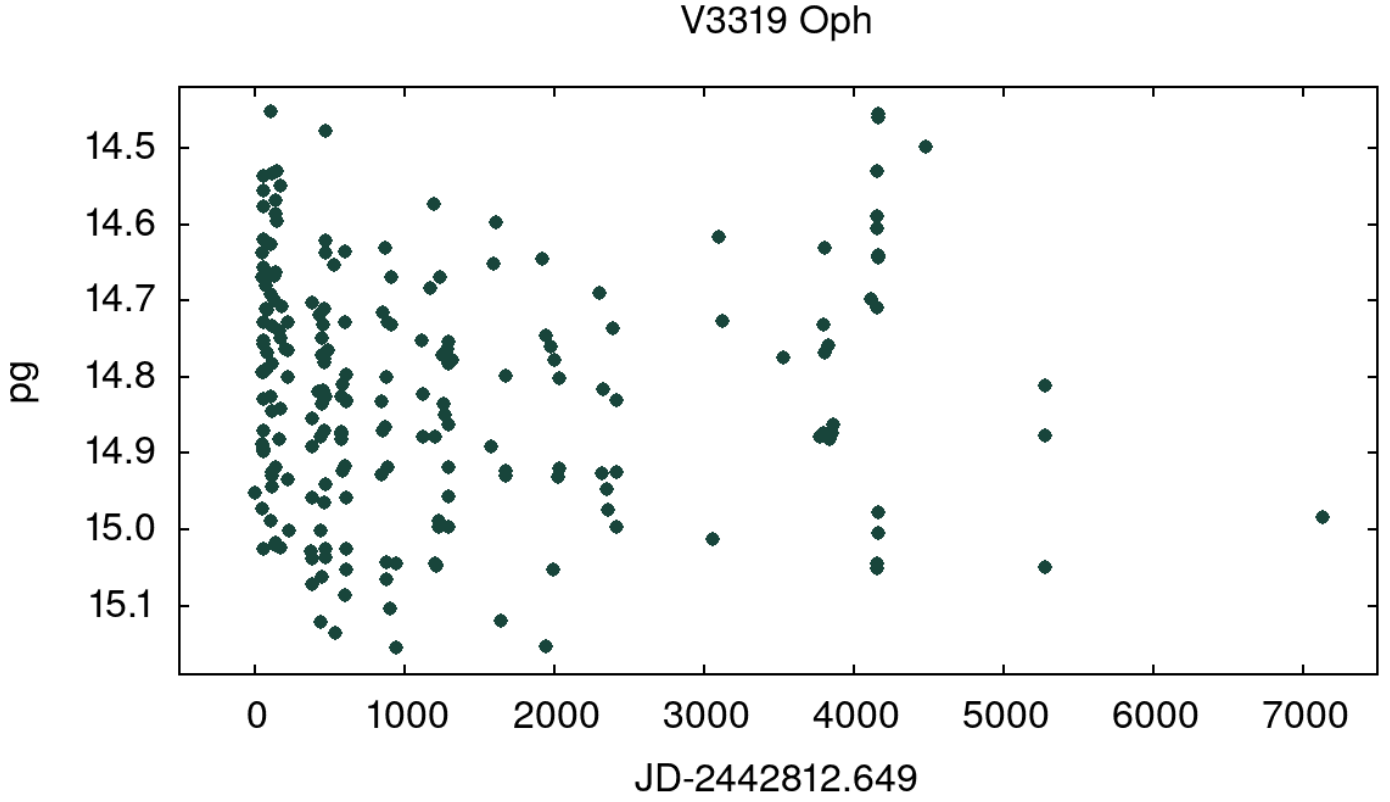

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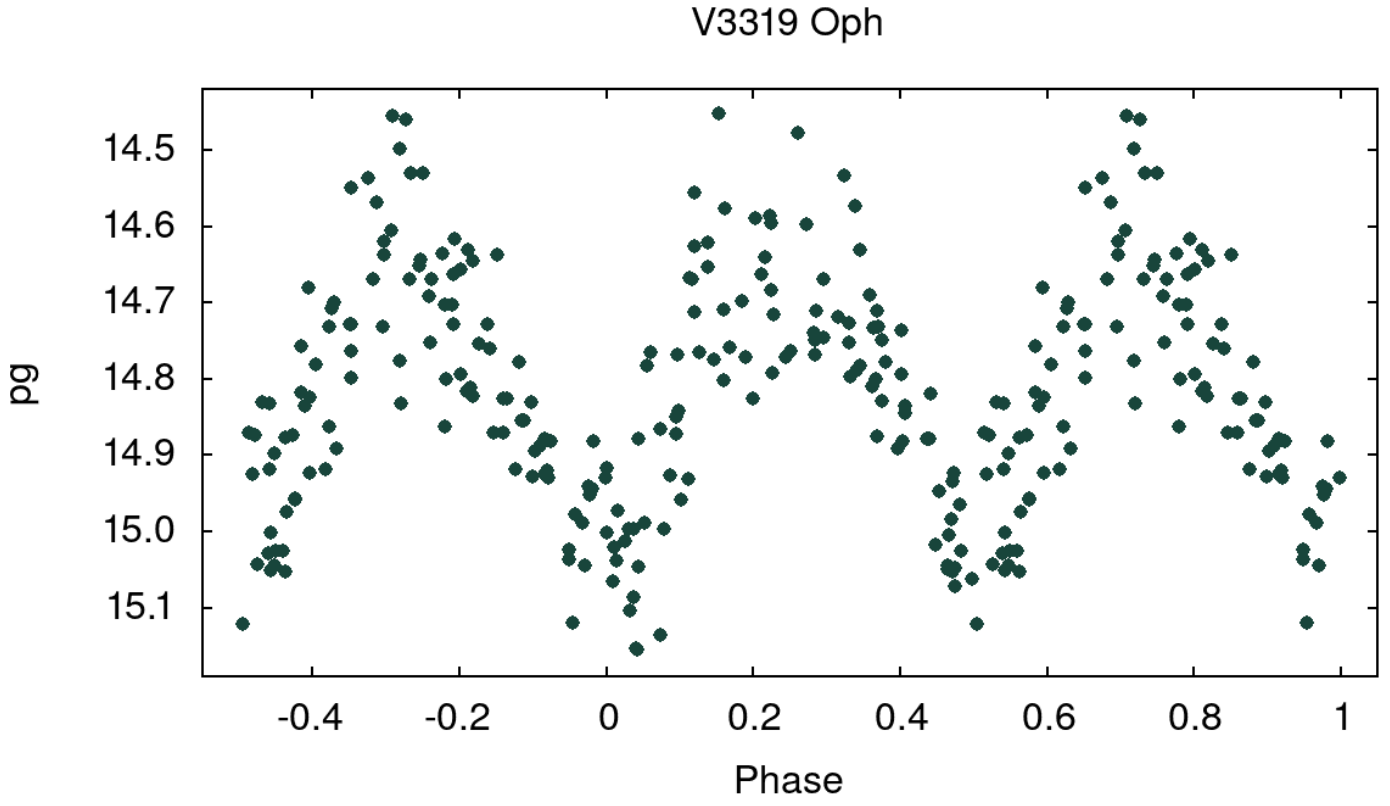


Variability Search Toolkit (VaST)

Original design goals

- Find variable sources in a series of sky images
- Support photgraphic and CCD images
- Can be used interactively or as pipeline
- Modest hardware requirements = lots of big images

Open source - comments and contributions welcome!
https://github.com/kirxkirx/vast
http://scan.sai.msu.ru/vast/

VaST workflow

Input: FITS images with obs. date/time (plate cutouts)

- Source detection/aperture photometry with SExtractor
- Triangle matching -> star matching -> lightcurves
- Plate-solve reference image with Astrometry.net code
- Fix astrometry - TPV/SIP problem
- Match to external catalogs: UCAC5 (μ), APASS B, PS1
- Magnitude scale calibration
- Local astrometric corrections

Result: calibrated lightcurves + source ID

TPV vs SIP convention problem

Two alternative FITS header conventions to approximate distortions with polynomials

- **SIP** supported by Astrometry.net code
- **TPV** supported by SExtractor & Co

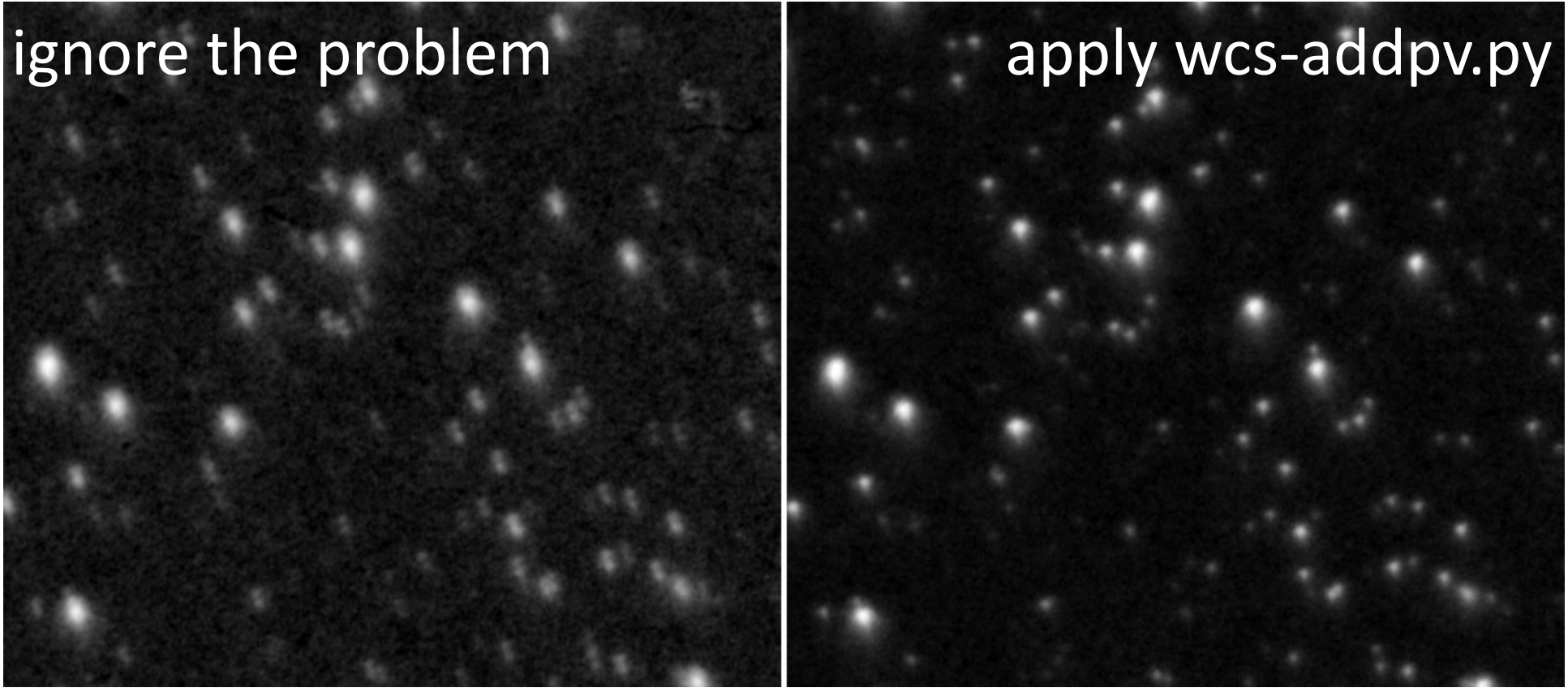
Ignore? There are bigger issues with astrometry...

Workaround 1: fix (R.A.,Dec.) in SExtractor catalog with xy2sky from WCStools

Workaround 2: wcs-addpv.py by Evert Rol
https://github.com/evertrol/sippv

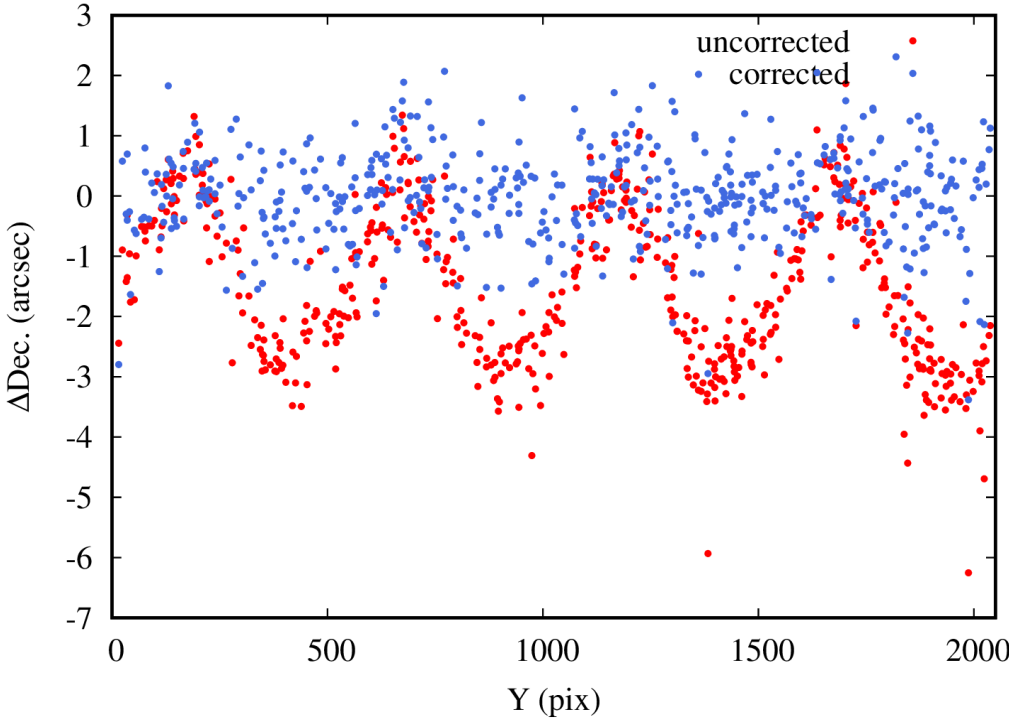
TPV vs SIP: illustration

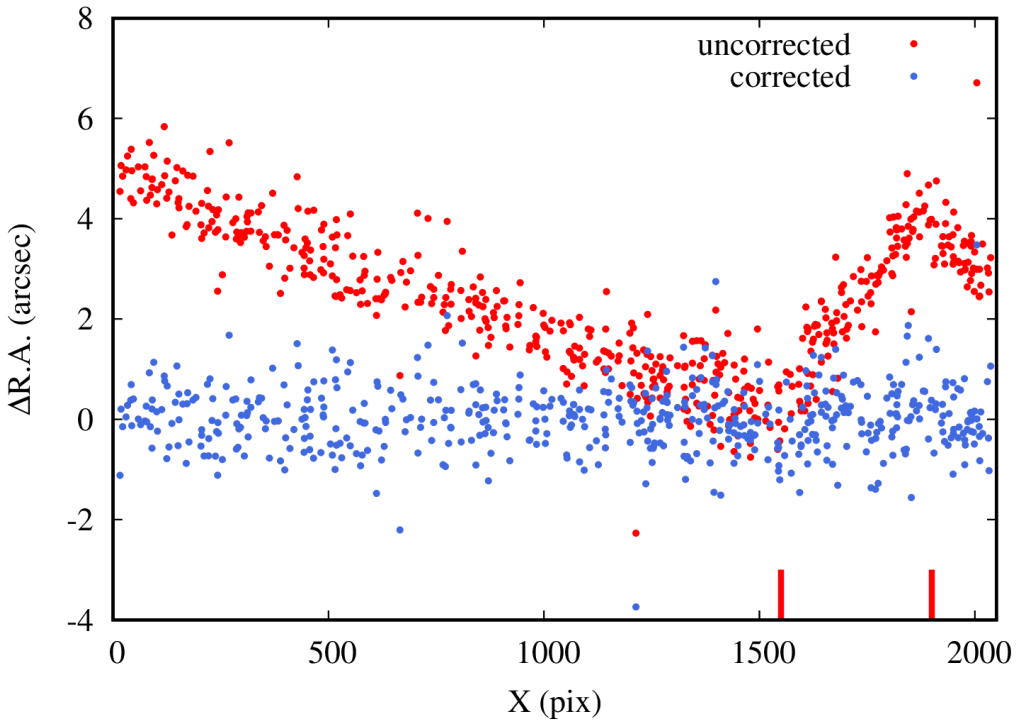
Cutouts from 10 plates median-stacked with SWarp



Flatbed scanner vs. astrometry

The “hacksaw” pattern and stitches

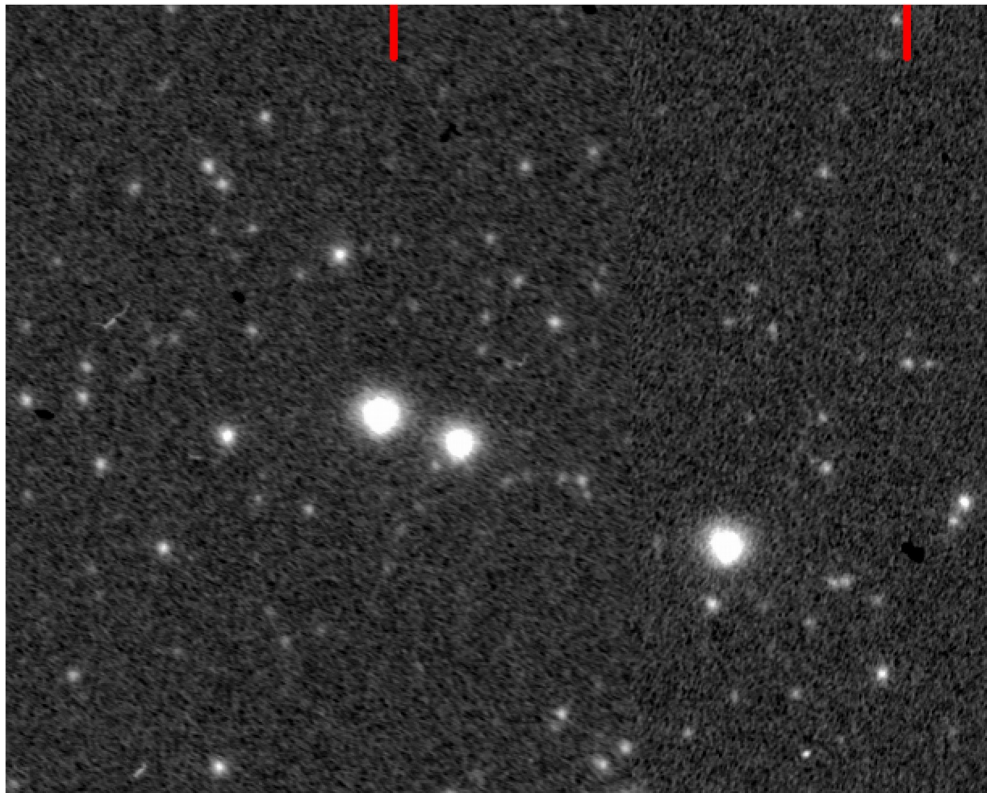


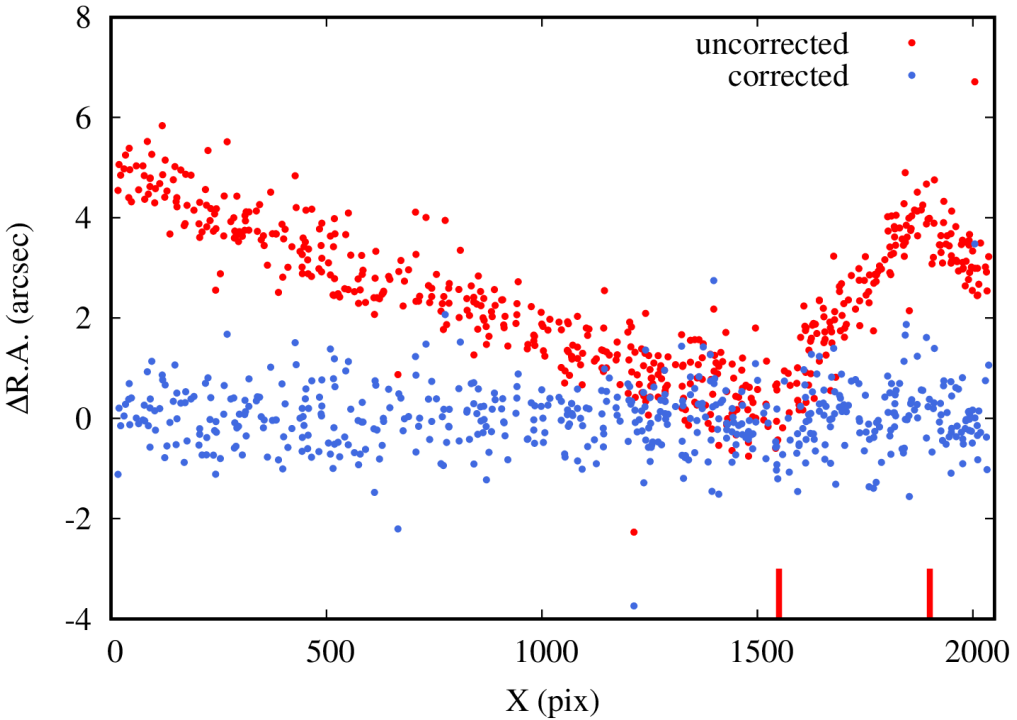


Mitigated with local corrections, no hope for science, just ID

Flatbed scanner vs. astrometry

The stitch is hard to see (its in the marked area)





Magnitude calibration

We use the fitting relation suggested for DSS by

Bacher, Kimeswenger & Teutsch (2005 MNRAS, 362, 542)

$$m_{\mathrm{ref}} = \frac{1}{a_1} \times \log_{10}\left(10^{\frac{(m_{\mathrm{inst}}-a_3)}{a_0}} - 1\right) + a_2$$

$$m_{\mathrm{ref}} = a_0 \times \log_{10}\left(10^{a_1 \times (m_{\mathrm{inst}}-a_2)} + 1\right) + a_3$$

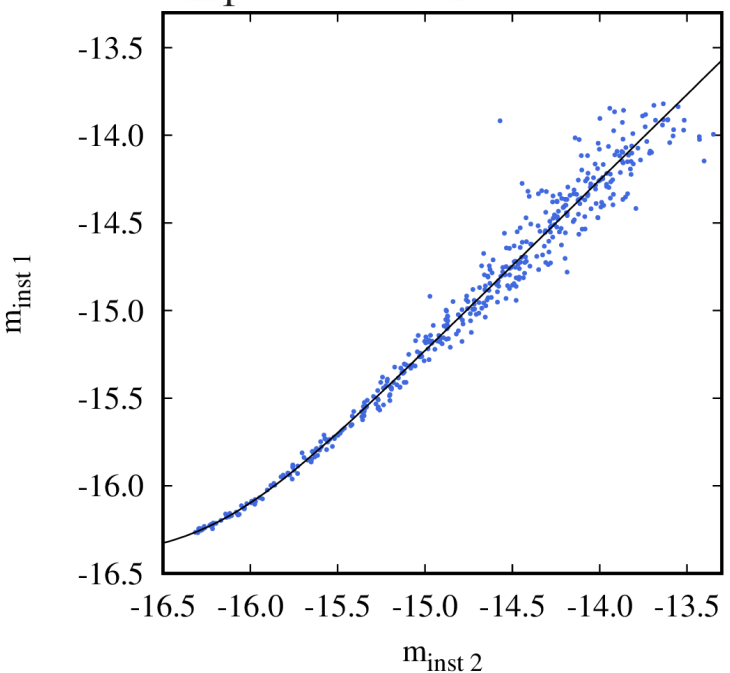
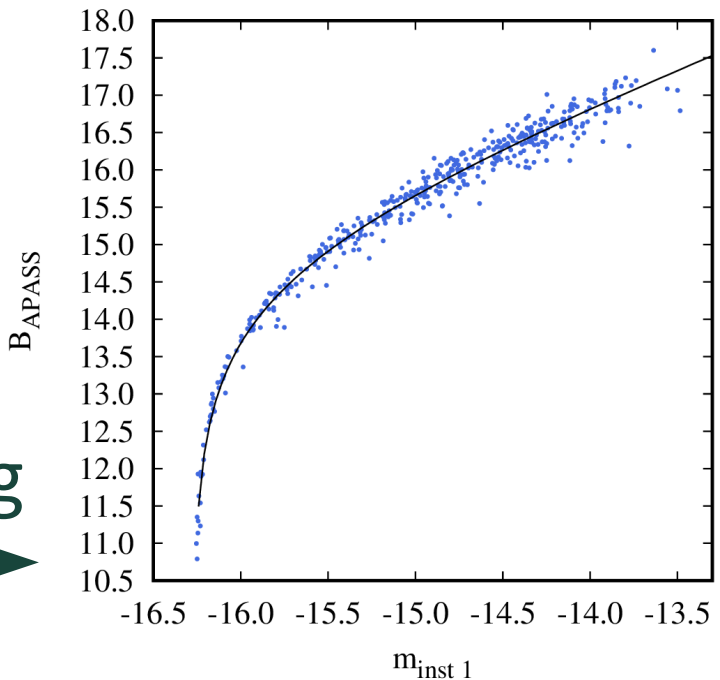


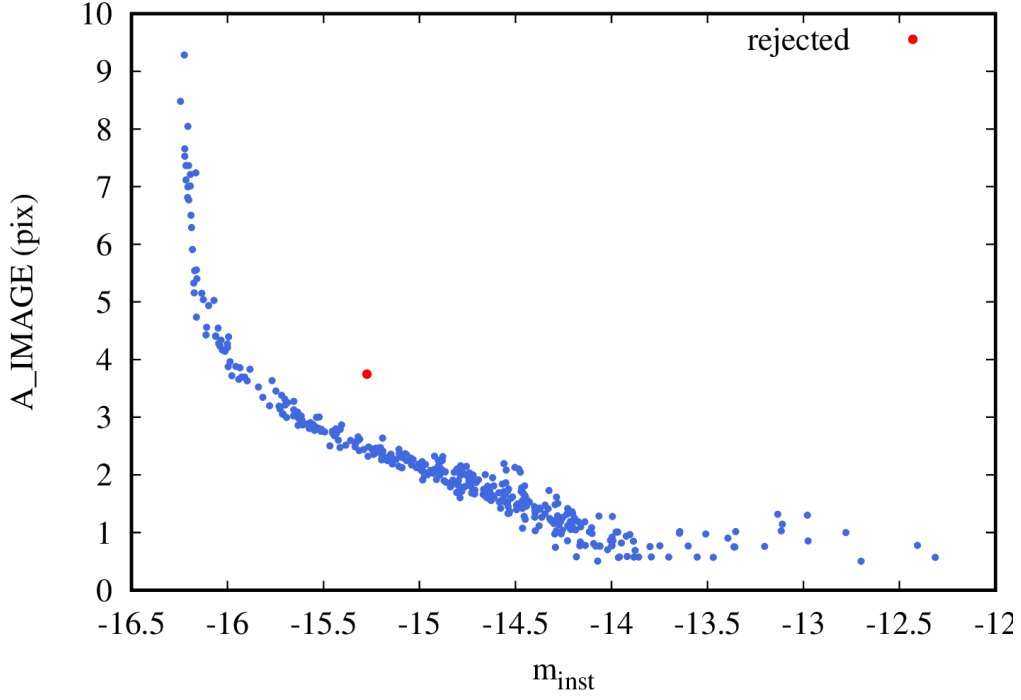
plate-to-plate

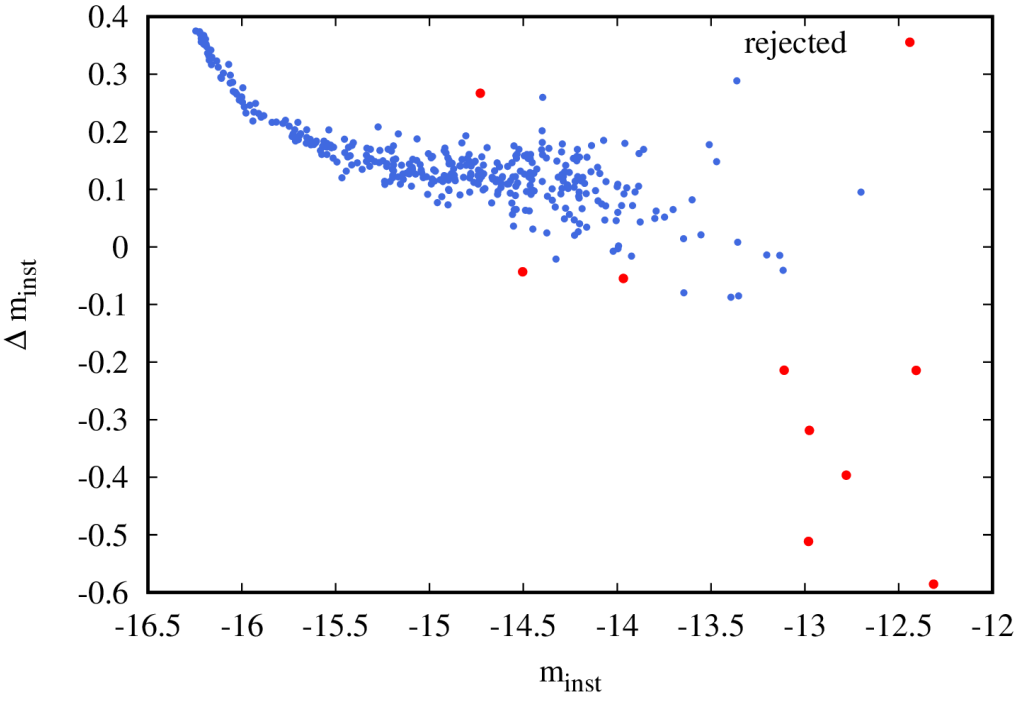
plate-to-catalog



Filtering SExtractor detections

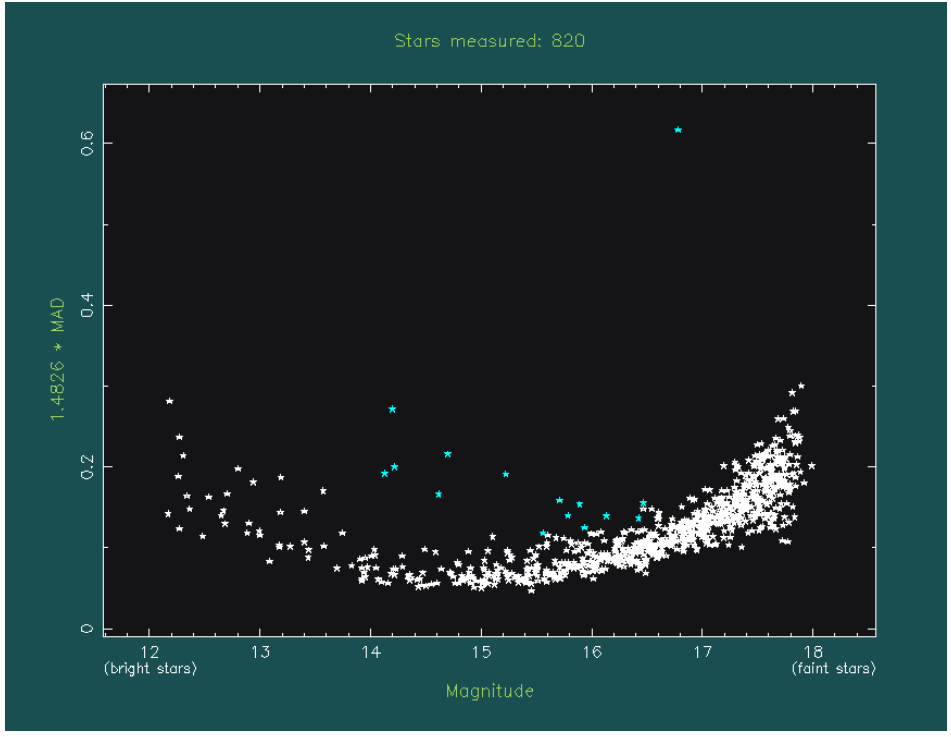
To remove blended and extended sources (that will have bad photometry) reject outliers in mag-size curve

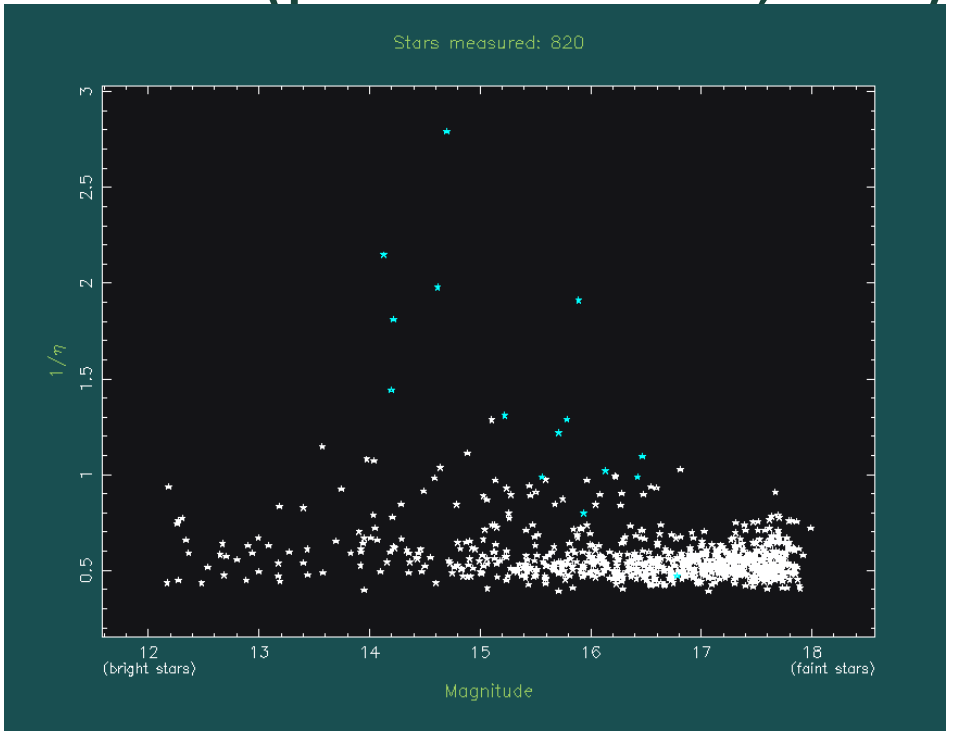




VaST -> lightcurves of all sources

The lightcurves may be (non)interactively earched for variability using “variability index”-mag. plots or processed with external software like VARTools (period search, etc.)





VaST testing

- Automated testing
- VMs with various Linux & FreeBSD versions
- Profiling with Valrind
- Memory debugging: Valgrind & AdressSanitizer

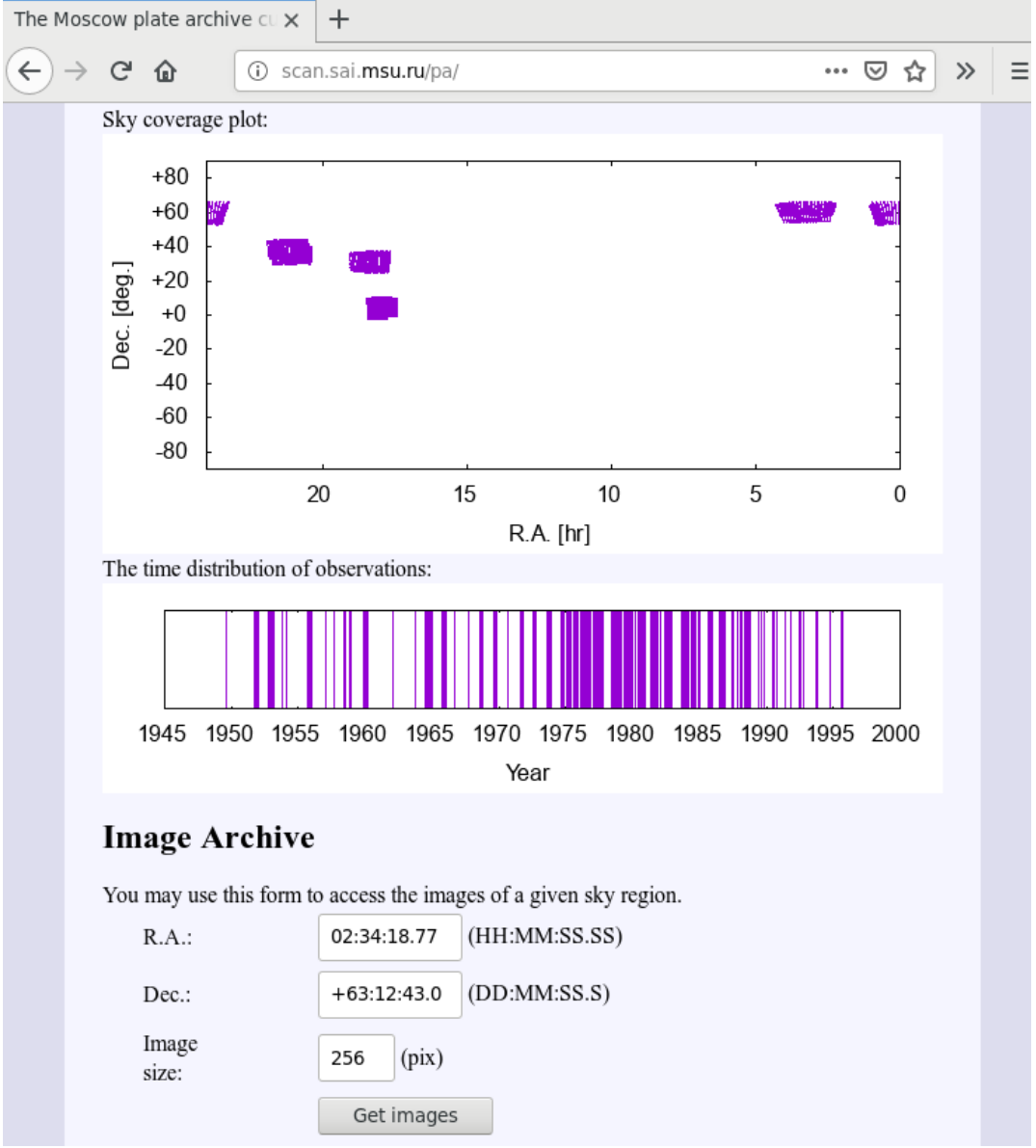


Image access

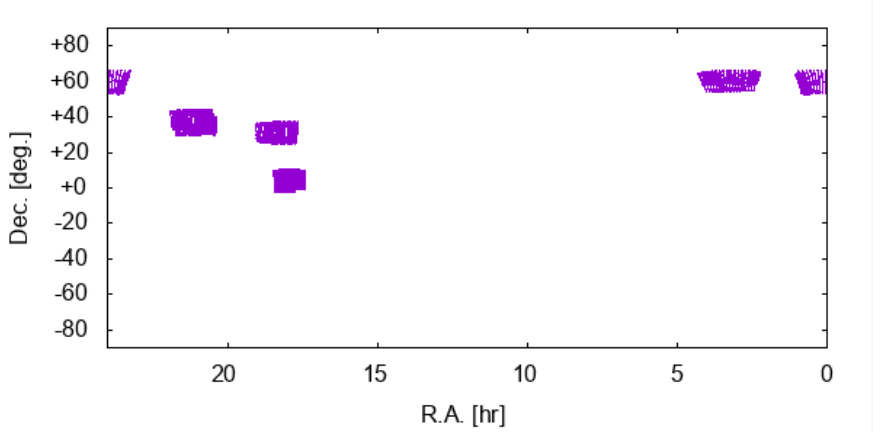
We are testing web interface providing cutouts from Moscow “A” series plates:

- 40cm astrograph
- 10x10 deg, 30x30cm plates
- limit B<17
- five fields digitized so far
- 169 to 413 plates/field

The Moscow plate archive cu

scan.sai.msu.ru/pa/

Sky coverage plot:



The time distribution of observations:

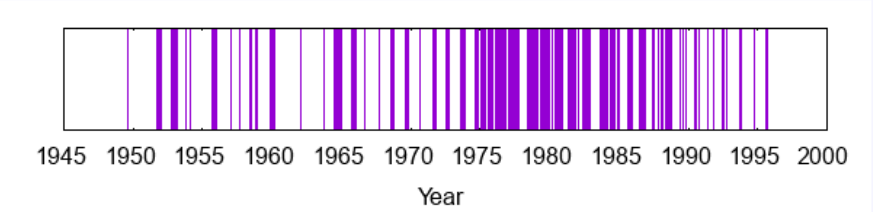


Image Archive

You may use this form to access the images of a given sky region.

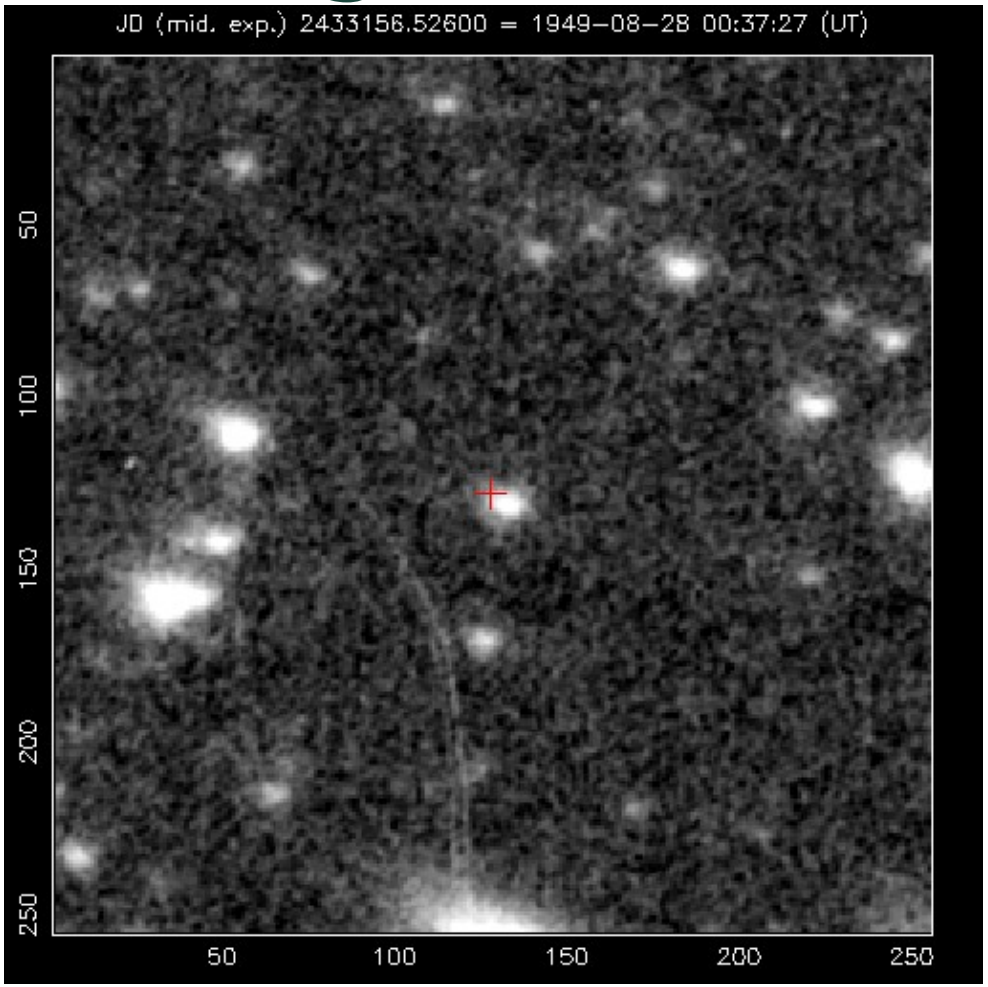
R.A.: 02:34:18.77 (HH:MM:SS.SS)

Dec.: +63:12:43.0 (DD:MM:SS.S)

Image size: 256 (pix)

Get images

Image access



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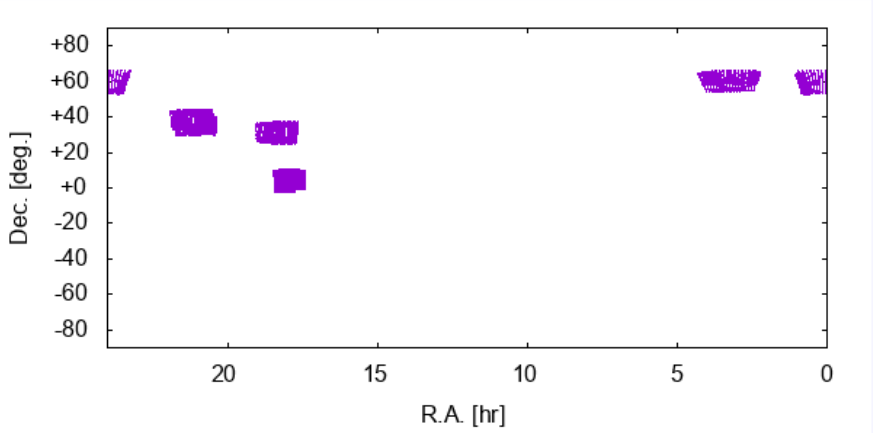

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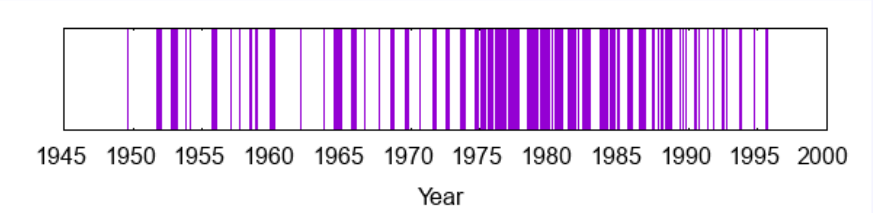

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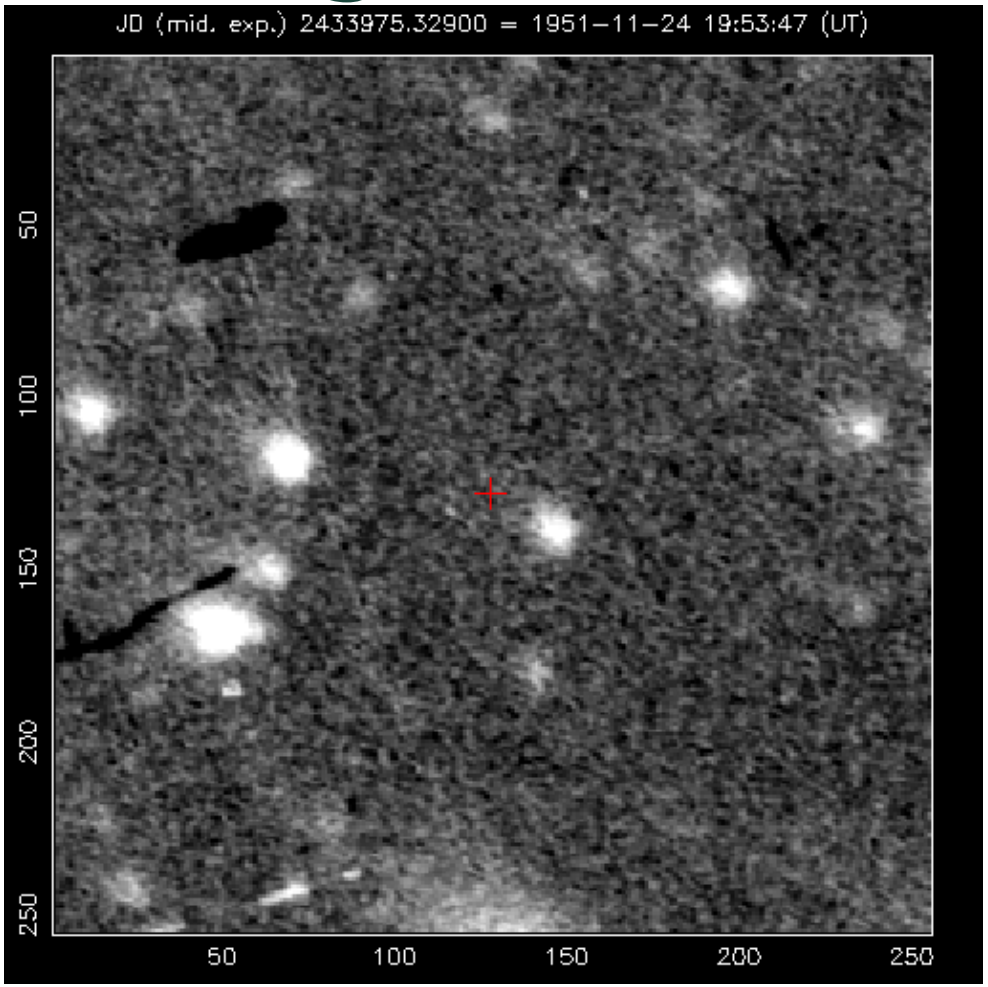

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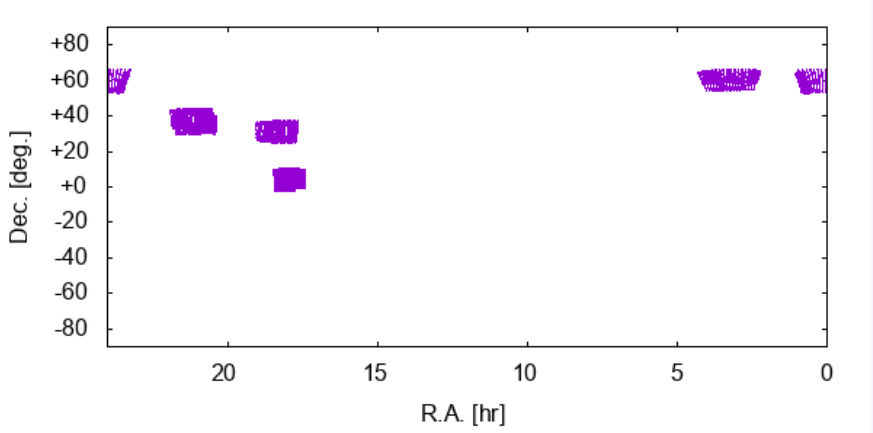

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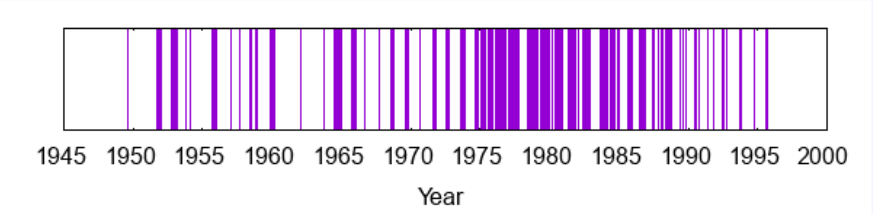

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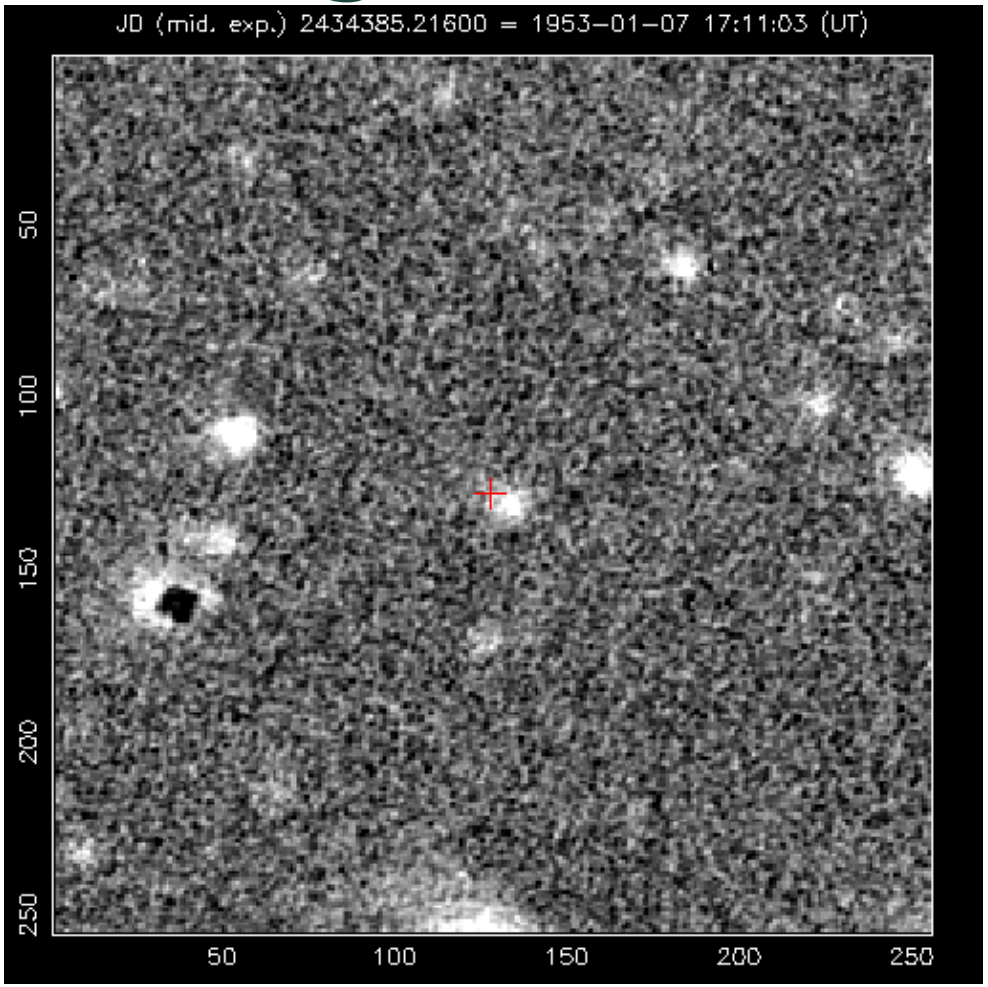
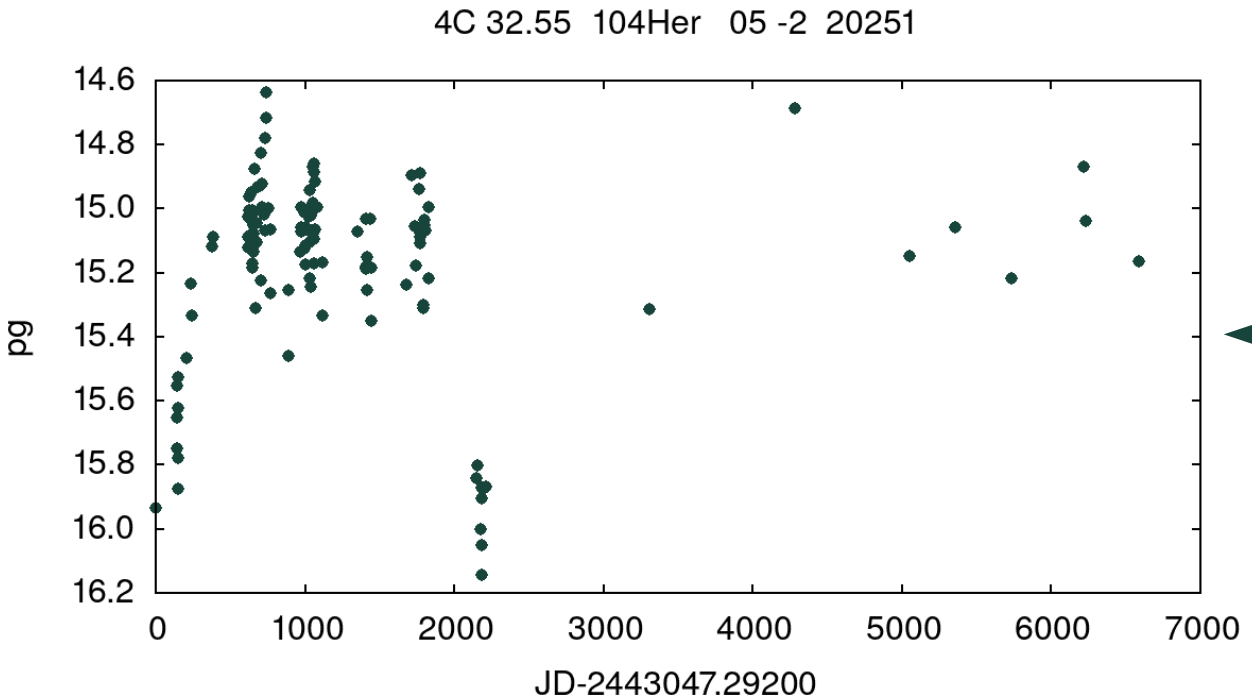


Photometry of known variables

>2000 known variables passed automated scatter/smoothness-based variability selection.
Photometry available at http://scan.sai.msu.ru/pl/



Exotic example:
Radio galaxy
3C 282 = 1833+326

most are eclipsing binaries and red irregular variables

Summary

- VaST is an open code that constructs lightcurves from a series of photographic (or CCD) images
- Can be used interactively or as a pipeline
- We use it for variable star studies with digitized Moscow collection plates
- Test access to the images of five 10x10 deg fields and photometry of ~2000 known variables, see http://scan.sai.msu.ru/pa/