Accurate photometry with digitized photographic plates of the Moscow collection

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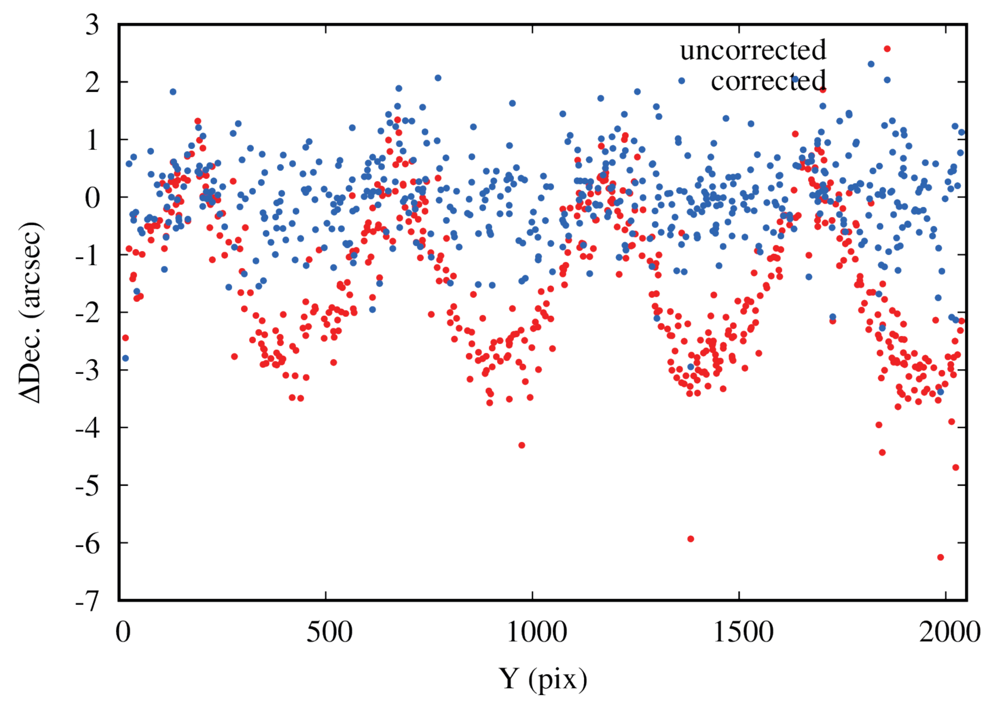
Abstract

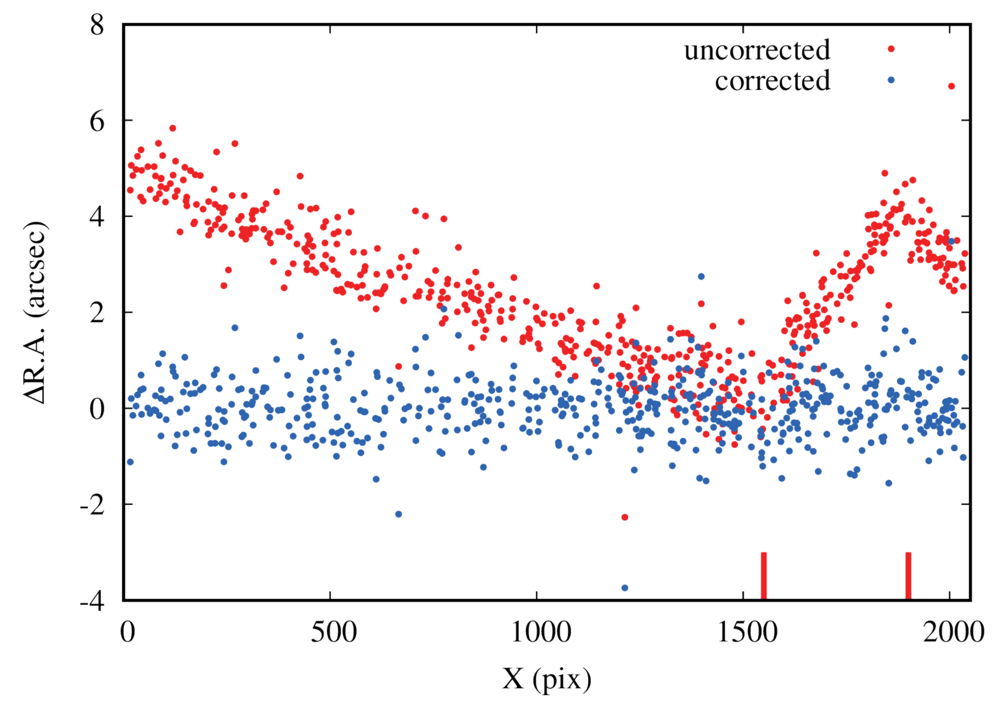
Photographic plate archives contain a wealth of information about positions and brightness celestial objects had decades ago. Plate digitization is necessary to make this information accessible, but extracting it is a technical challenge.
We develop algorithms used to extract photometry with accuracy ~0.1m in the magnitude range 13<B<17 from photographic images obtained in 1940-90s with the 40cm Sternberg institute's astrograph (30x30cm plate size, 10x10deg field of view) and digitized using a flatbed scanner. The extracted photographic lightcurves are used to identify thousands of new high-amplitude (>0.3m) variable stars. The algorithms are implemented in the free software VaST.

Astrometry

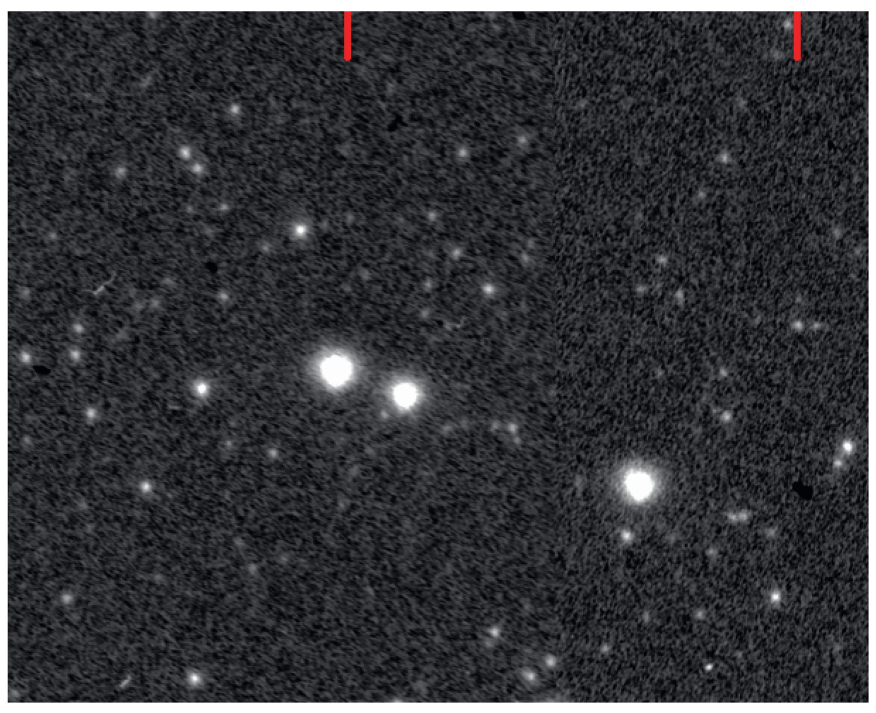
Flatbed scanners introduce systematic errors in source position. After computing with `Astrometry.net` an approximate plate solution, for each detected source we use nearby UCAC4 stars to correct the source position. The resulting accuracy of <1" is sufficient to match the imaged sources to USNO-B1.0 (as the plates go deeper than UCAC4).



The "hacksaw" pattern in astrometric deviations along the Y axis is introduced by the uneven motion of the scanning ruler.



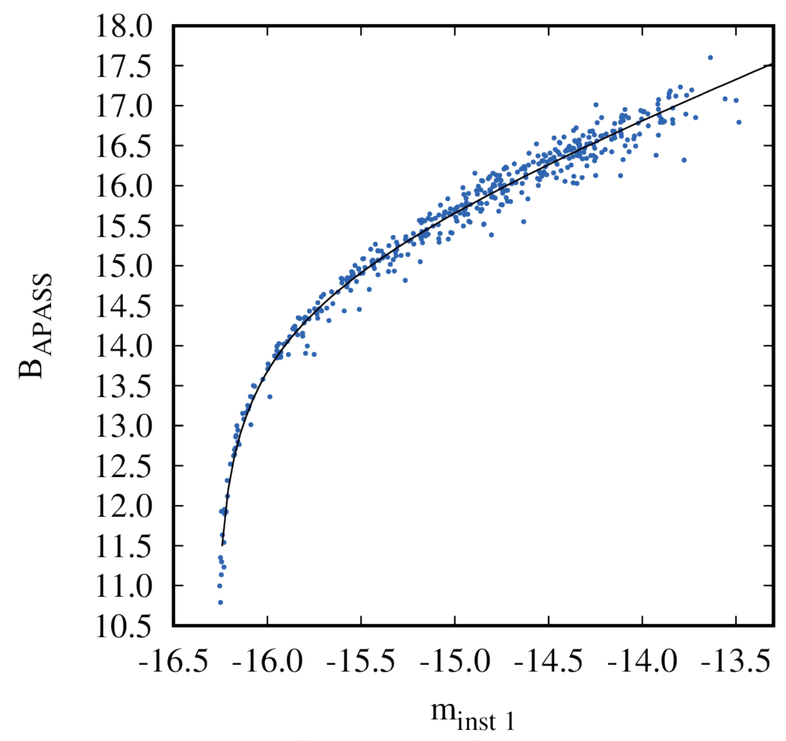
As the 30cm photographic plate is wider than the scanning ruler, the resulting image has a "stitch" between the areas covered at the two passes of the scanning ruler. The stitch area is indicated by the two red bars.



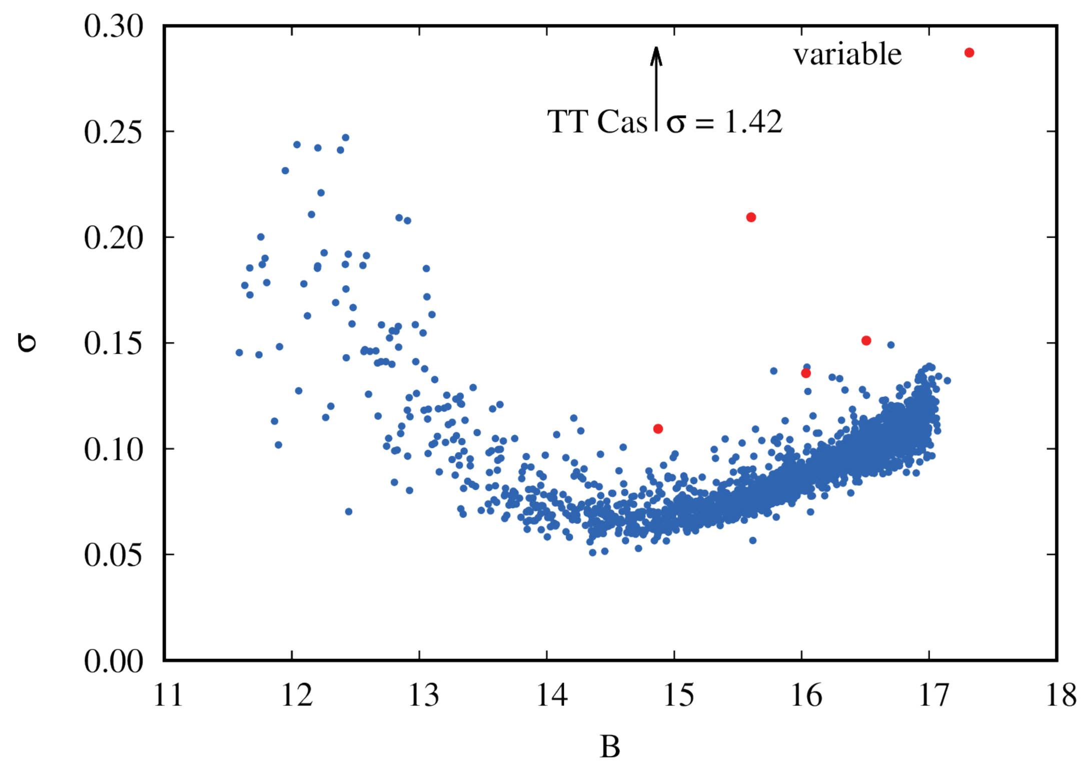
The "stitch" between the two passes of the scanning ruler is barely visible on the image, but introduces considerable deviations in source positions. The two red bars mark the same area as the bars on the astrometric deviations plot to the left.

Photometry

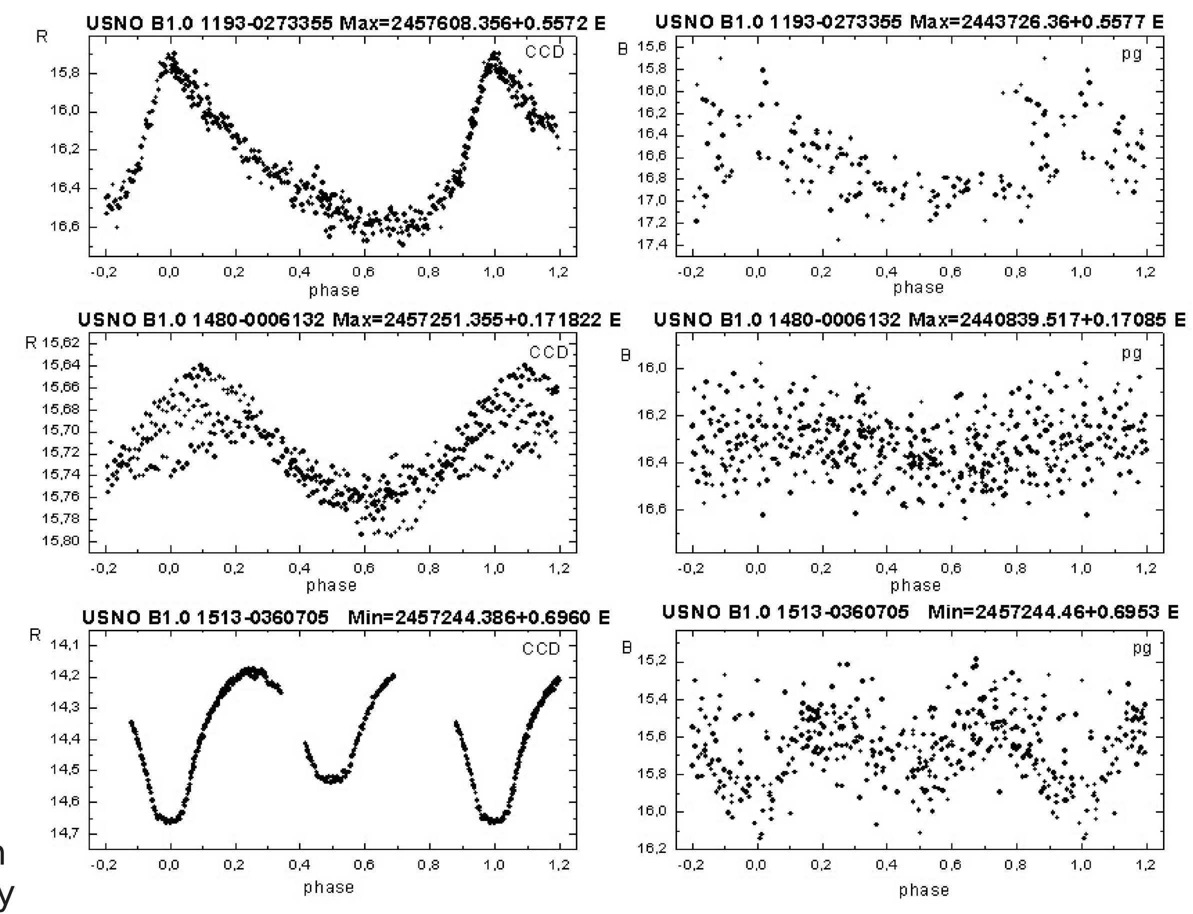
We rely on `SExtractor` to perform source detection and photometry using a fixed circular aperture. The photographic density is a non-linear function of the number of incoming photons. We use the function suggested by Bacher et al. (2005, MNRAS, 362, 542) to approximate the relation between the instrumental photographic magnitude measured in a circular aperture and the APASS B magnitude (as the plates are blue-sensitive). The plate images are split into overlapping 1.2x1.2deg subfields that are processed independently.



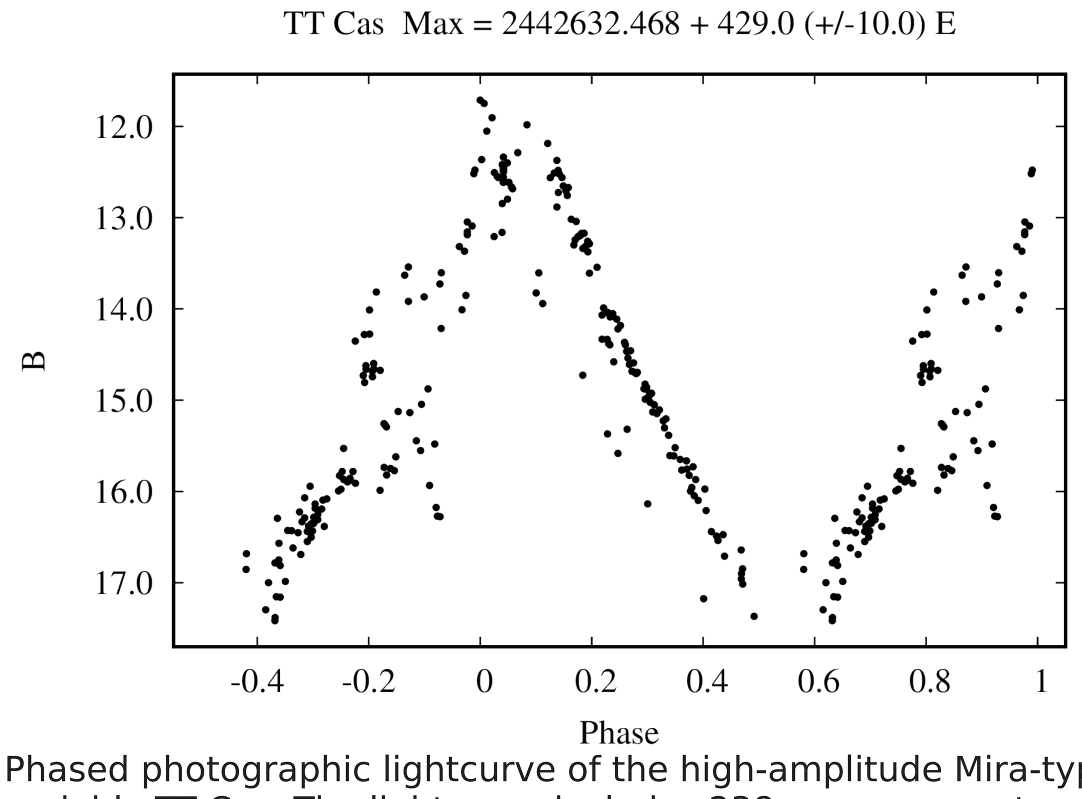
APASS B magnitude as a function of the measured instrumental photographic magnitude.



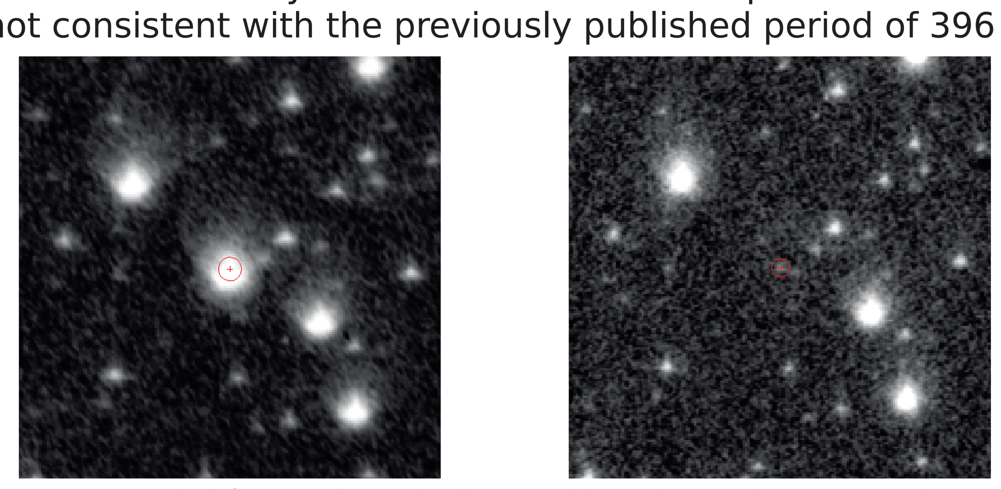
The magnitude vs. standard deviation (σ) plot highlighting variable objects as the ones having lightcurve scatter larger than most stars of similar brightness in this field. The highest accuracy relative photometry (σ~0.08m) is reached for sources in the magnitude range 14<B<15. Photometric accuracy for the brighter stars is deteriorated as they spill over the fixed-radius aperture.



Low-amplitude variables suspected from period search results in photographic data (right) and confirmed by our CCD photometry (left).



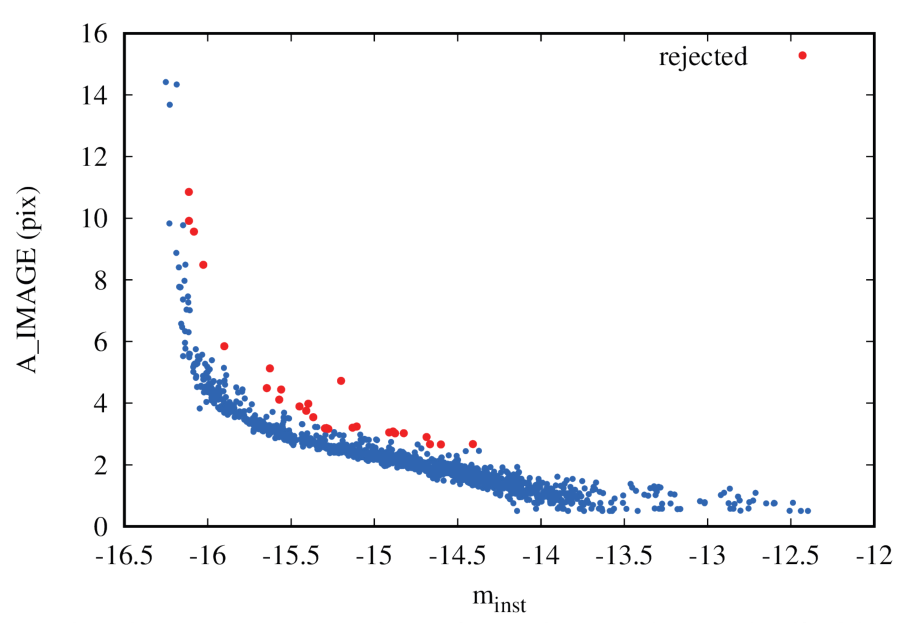
Phased photographic lightcurve of the high-amplitude Mira-type variable TT Cas. The lightcurve includes 238 measurements obtained over a 25-year interval. The derived period of 429+/-10d is not consistent with the previously published period of 396 days.

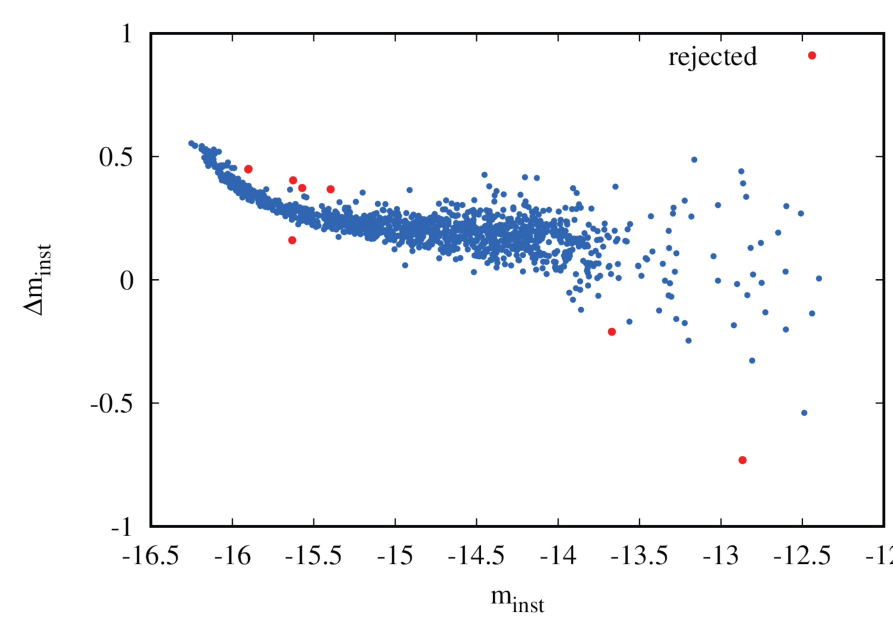


Mira-type variable TT Cas (indicated by the red marker) imaged with the 40cm astrograph at maximum on 1975-08-07 (B=11.7) and minimum on 1971-08-24 (B=17.4).

Filtering

The brightness of blended stars cannot be accurately measured with aperture photometry. We use two types of plots to identify and remove them. Blended stars appear as outliers in "magnitude vs. source size" and "magnitude vs. magnitude difference between two concentric apertures" plots.





Magnitude vs. source size along its major axis (left) and magnitude vs. difference between the magnitudes measured in two concentric circular apertures (right). One aperture is 30% larger than the other. The identified blended objects are marked in red. This blend rejection procedure is applied automatically to each image.

The VaST code is available at
http://scan.sai.msu.ru/vast/