The Hubble Catalog of Variables (HCV)

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on behalf of the HCV team

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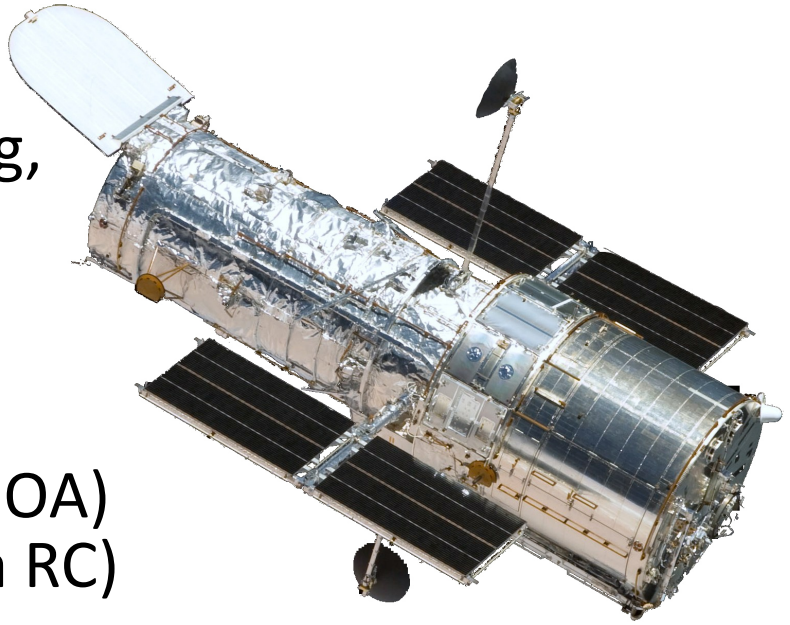
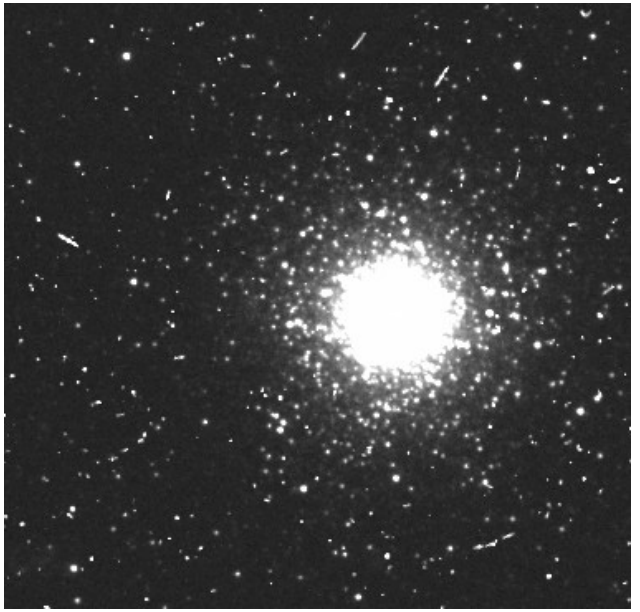


HST is good for deep imaging

- PSF FWHM ~0.1”
- Wide FoV (compared to ground-based AO)
- Low sky background

Individual stars in nearby galaxies!

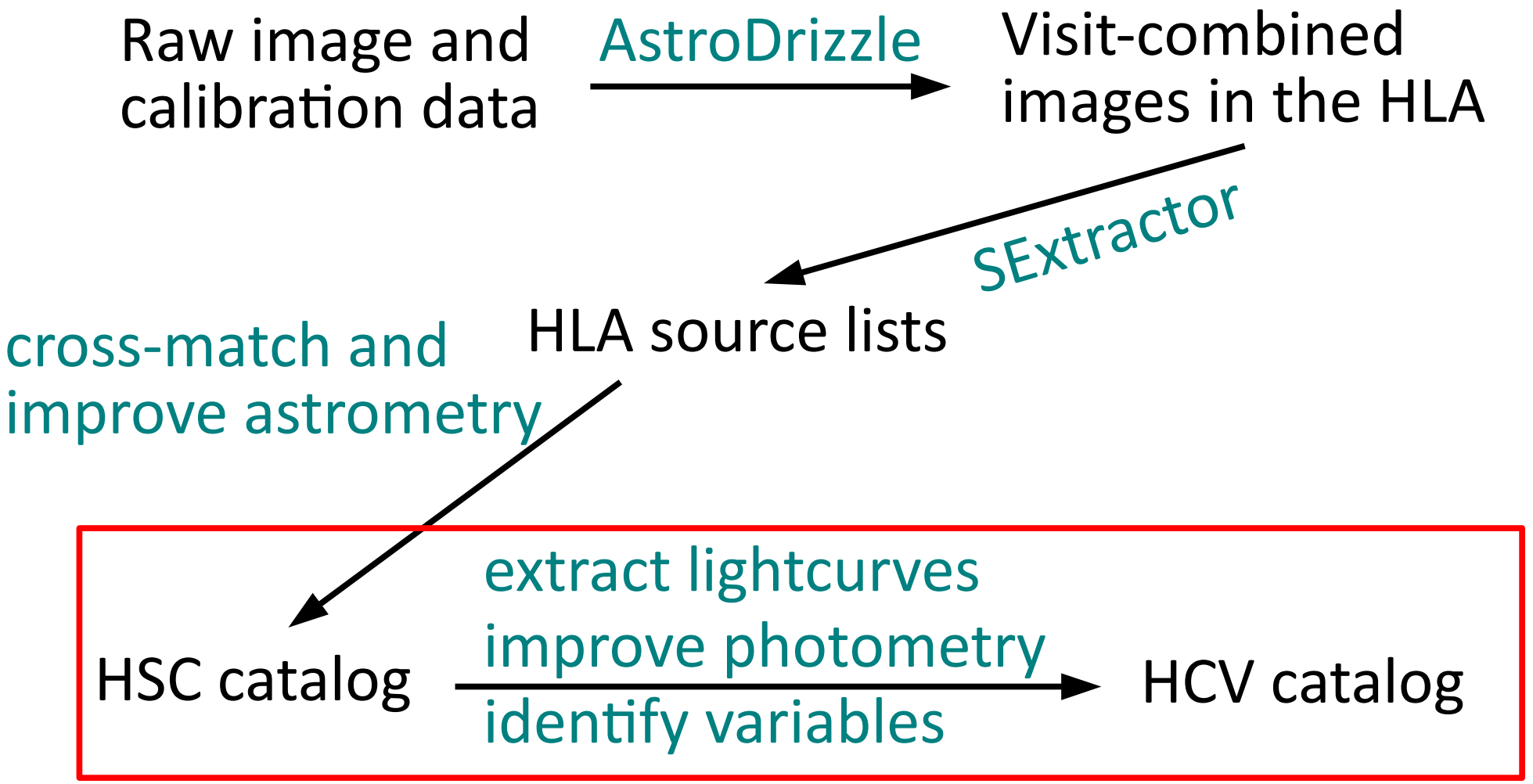


GC in M31: stacked vs single exposure

Complications specific to HST

- High CR background
- Bad absolute astrometry (GSC)
- HST-specific software

HST archive


Raw image and calibration data
AstroDrizzle
Visit-combined images in the HLA
SExtractor
HLA source lists
cross-match and improve astrometry
HSC catalog
extract lightcurves
improve photometry
identify variables
HCV catalog

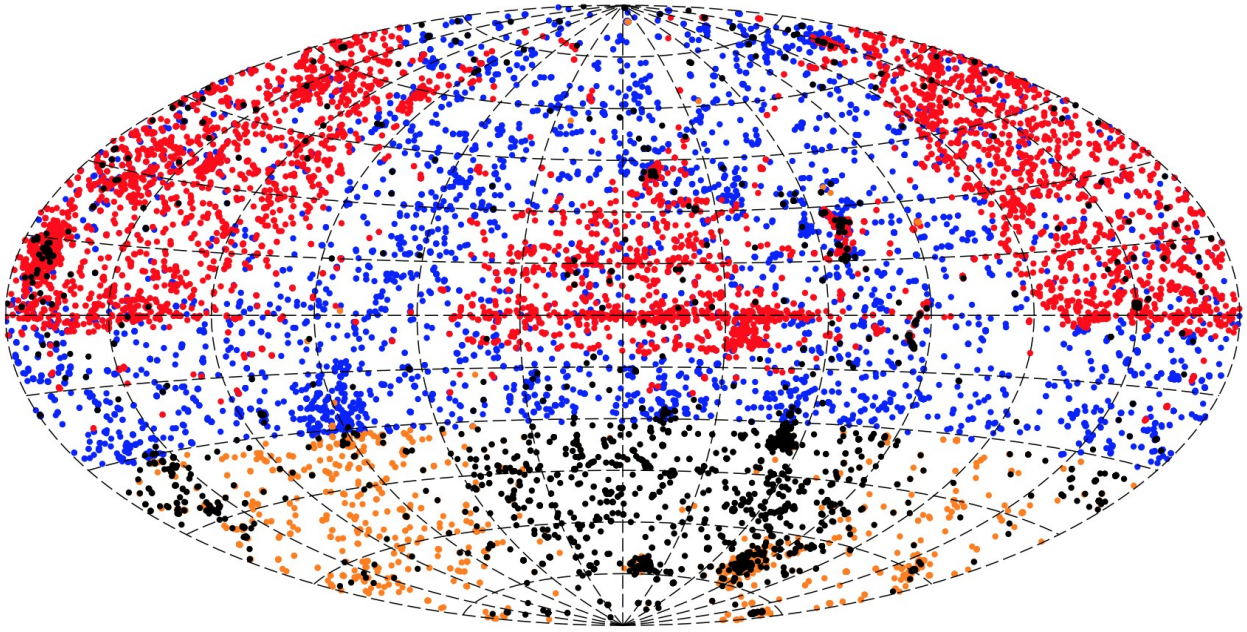
The Hubble Source Catalog (HSC)

Whitmore et al. (2016), Budavari & Lubow (2012)

- $\sim 10^7$ objects across ~0.1% of the sky
- Instruments: WFC3, ACS, WFPC2
- Photometry accurate at a few % level
- Absolute astrometry accurate to 0.1”

HSC sky coverage

- Pan–STARRS 42%
- SDSS 39%
- 2MASS 10%
- None 9%



The Hubble Catalog of Variables (HCV)

A few fields were visited by HST more than once

Some were specifically monitored in search of Cepheids, RR Lyrae, SNe

Objective: define a set of algorithms that will detect and validate a candidate variable source within the HSC, producing the HCV

- The HCV will include variable objects (Galactic & extragalactic) in the magnitude range not easily accessible to ground-based telescopes
- The HCV will be available in 2018

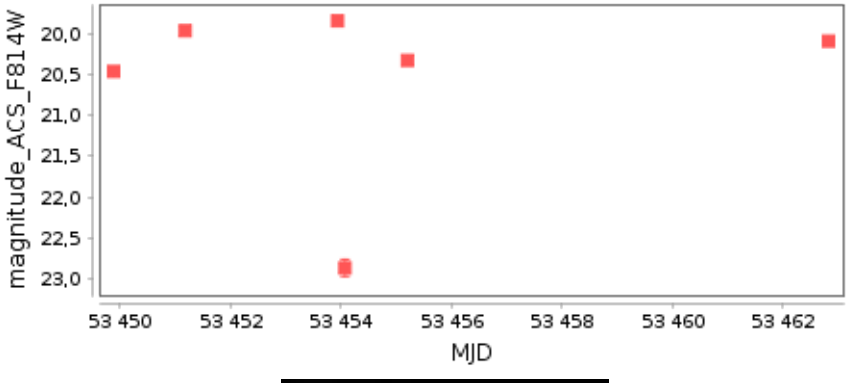
Variability detection problem

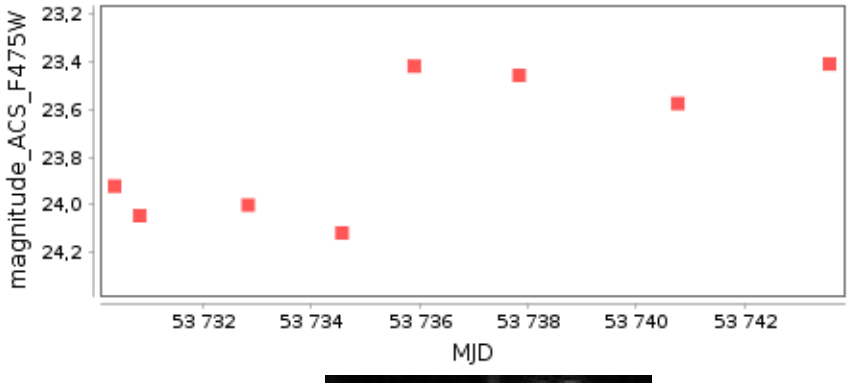
We don't really know measurement errors

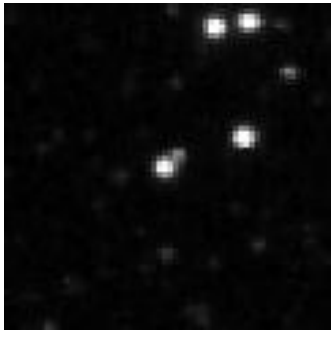
1) Underestimated errorbars (flatfielding, CTE...)

2) Outlier measurements (CR, frame edge, bad images...)

3) All measurements of a particular source may be corrupted (blending, saturation, misplaced aperture)





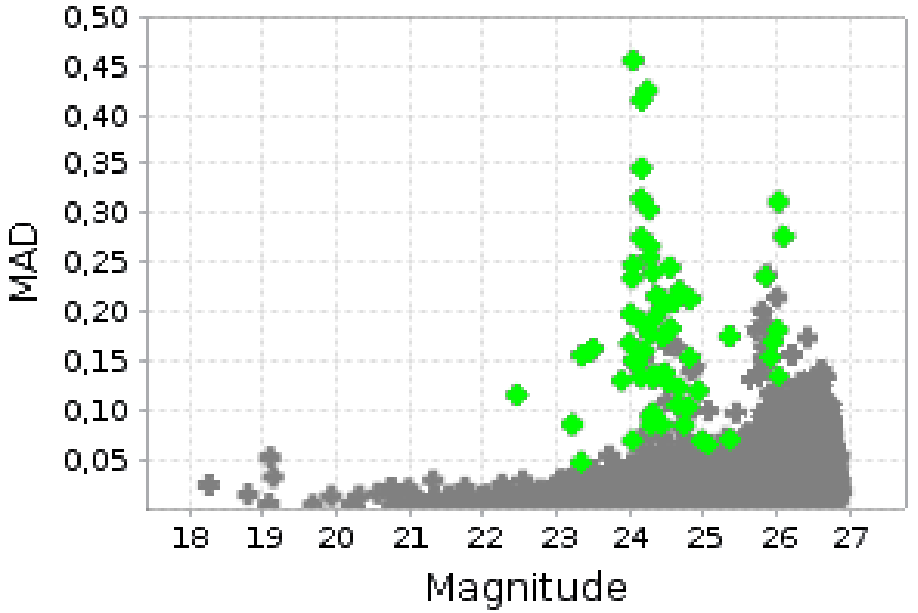


Proposed solutions

1) Assume the majority of stars are not variable

2) Robust variability-detection statistic

$$\mathrm{MAD} = \mathrm{median}(\ |X_i - \mathrm{median}(X)|\ )$$



3) Bad image rejection + Local ZP correction + Quality flags characterizing object's profile and position stability + visual inspection

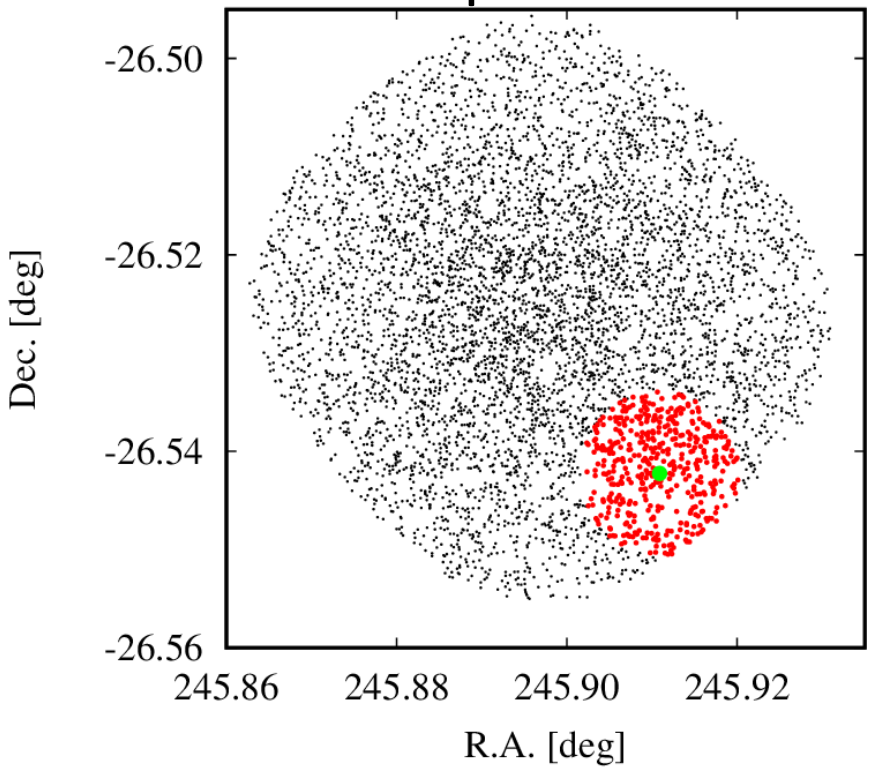
The 24 variability indices tested

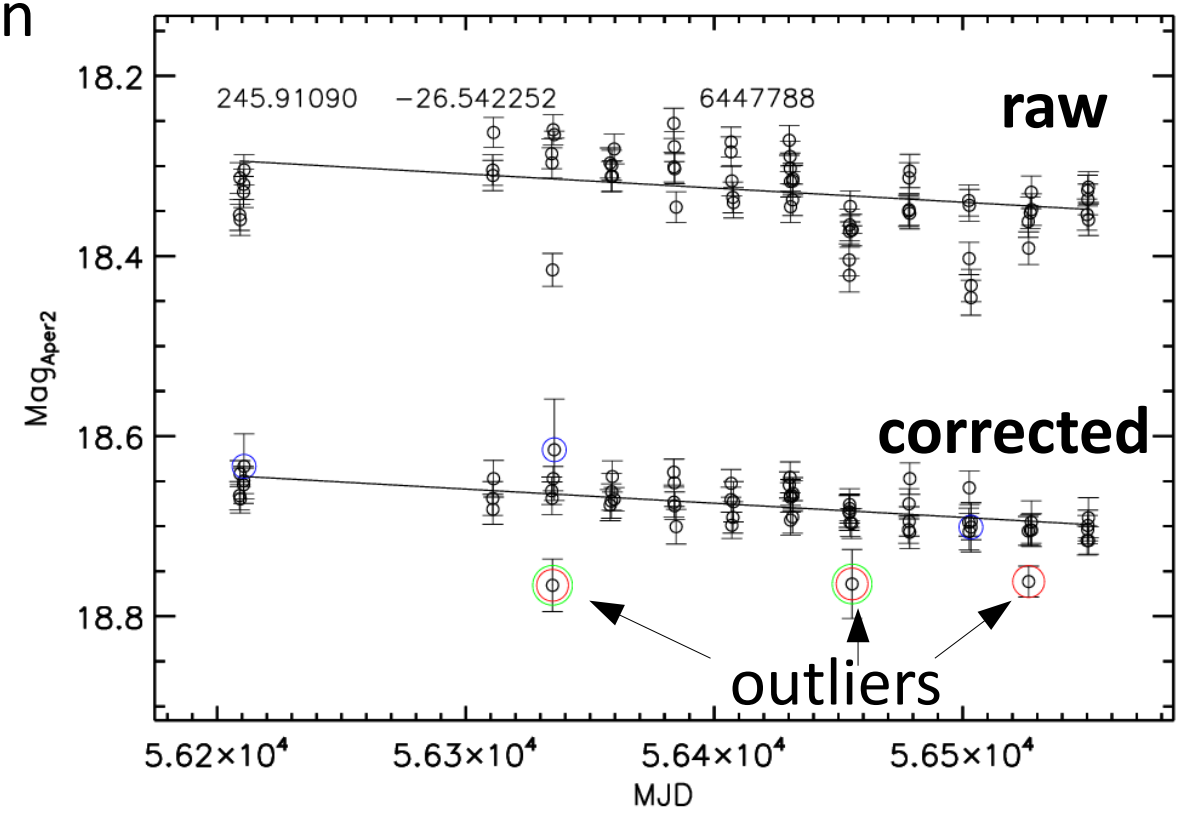
Sokolovsky et al. (2017)

Index	Errors	Order	Time	Reference
		Scatter-based indices		
weighted standard deviation – σ	✓			Kolesnikova et al. (2008)
clipped σ – $\sigma_{\rm clip}$				Kolesnikova et al. (2008)
median abs. deviation – MAD				Zhang et al. (2016)
interquartile range – IQR				Sokolovsky et al. (2017)
reduced χ^2 statistic – $\chi^2_{\rm red}$	✓			de Diego (2010)
robust median statistic – RoMS	✓			Rose & Hintz (2007)
norm. excess variance – $\sigma^2_{\rm NXS}$	✓			Nandra et al. (1997)
norm. peak-to-peak amp. – v	✓			Sokolovsky et al. (2009)
		Correlation-based indices		
autocorrelation – l_1		✓		Kim et al. (2011)
inv. von Neumann ratio – $1/\eta$		✓		Shin, Sekora & Byun (2009)
Welch-Stetson index – $I_{\rm WS}$	✓	✓	✓	Welch & Stetson (1993)
flux-independent index – $I_{\rm fi}$	✓	✓	✓	Ferreira Lopes et al. (2015)
Stetson's J index	✓	✓	✓	Stetson (1996)
time-weighted Stetson's $J_{\rm time}$	✓	✓	✓	Fruth et al. (2012)
clipped Stetson's $J_{\rm clip}$	✓	✓	✓	Sokolovsky et al. (2017)
Stetson's L index	✓	✓	✓	Stetson (1996)
time-weighted Stetson's $L_{\rm time}$	✓	✓	✓	Fruth et al. (2012)
clipped Stetson's $L_{\rm clip}$	✓	✓	✓	Sokolovsky et al. (2017)
S_B statistic	✓	✓		Figuera Jaimes et al. (2013)
excursions – E_x	✓	✓	✓	Parks et al. (2014)
excess Abbe value – $\mathscr{E}_{\mathscr{A}}$		✓	✓	Mowlavi (2014)
		Shape indices		
Stetson's K index	✓			Stetson (1996)
kurtosis				Friedrich, Koenig & Wicenec (1997)
skewness				Friedrich, Koenig & Wicenec (1997)

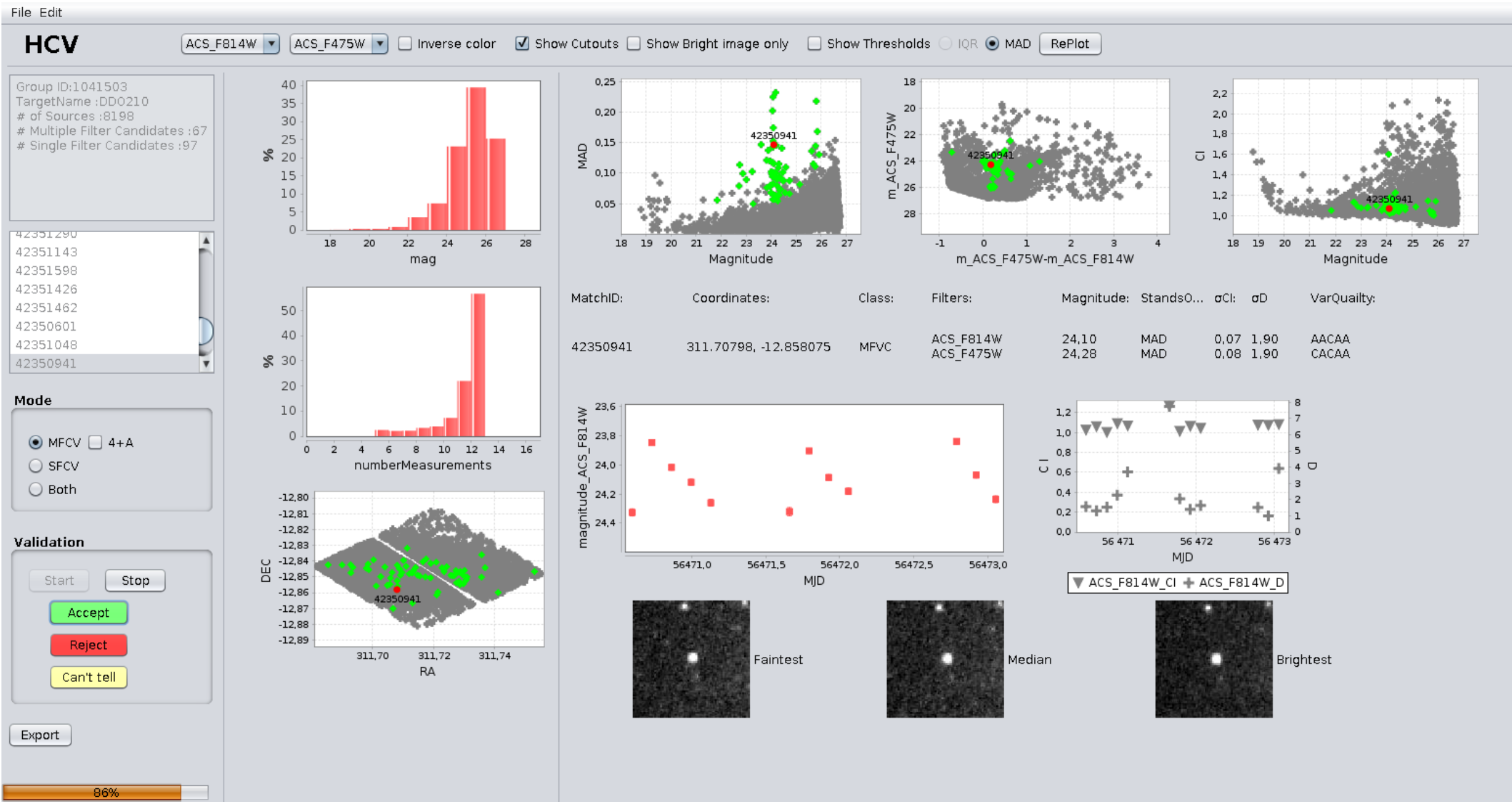
Local ZP correction and outliers

Local zero-point correction





Visual inspection interface

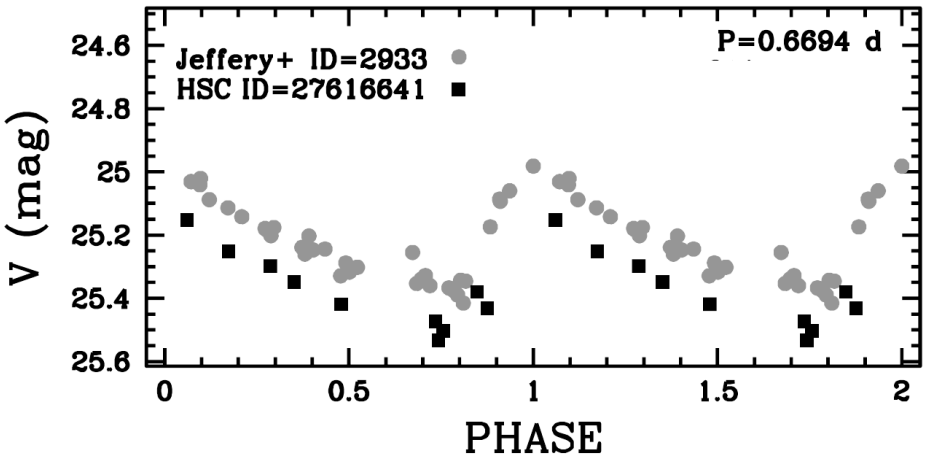


Current status

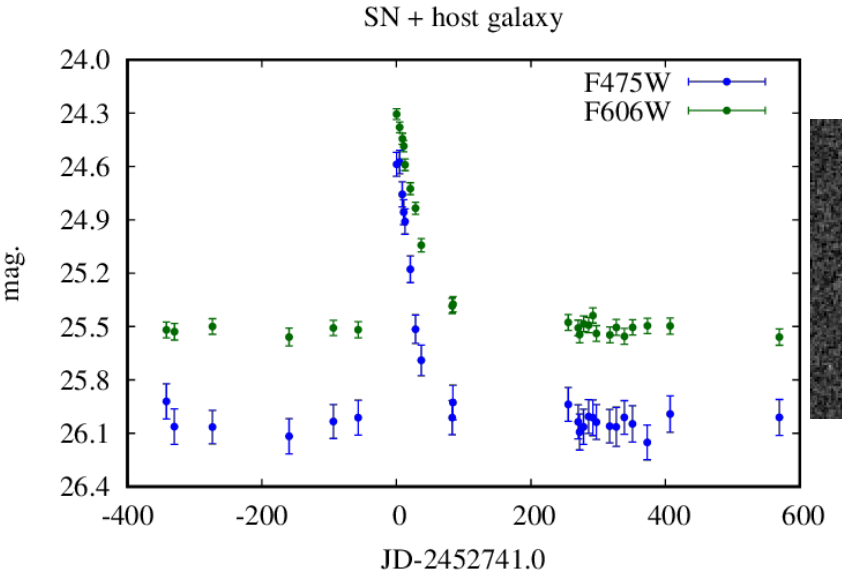
Test run: **N>5**, **MAD>5σ** and χ^2_{red}**>3** *in two filters*

Among ~**700 000** sources that have multi-filter data: ~**2000** automatically-selected multi-filter variability candidates, **70%** of which pass visual inspection

known RR Lyr in M31



new SNIIL(?) in the field of NGC3314



Conclusions

- HCV - catalog of variable objects derived from HSC
- to be released next year
- Very heterogeneous due to the nature of the dataset
- Very deep; venture into poorly explored region of variability parameter space
- HCV data pre-processing and variability detection techniques are applicable to other variability surveys

and...

Related posters

- *"Variability of massive stars in the Virgo Cluster galaxy NGC 4535 with the Hubble Space Telescope"*
  Z. T. Spetsieri
- *"Near-infrared Variable Candidates in the CANDELS/UDS, COSMOS and GOODS-South Fields from the Hubble Source Catalog"*
  M. Yang
- *"Machine learning search for variable stars"*
  I. Pashchenko
- *"Accurate photometry with digitized photographic plates of the Moscow collection"*
  K. Sokolovsky

Indices are compared on F-score

$$C = \frac{\text{Number of selected variables}}{\text{Total number of confirmed variables}}$$

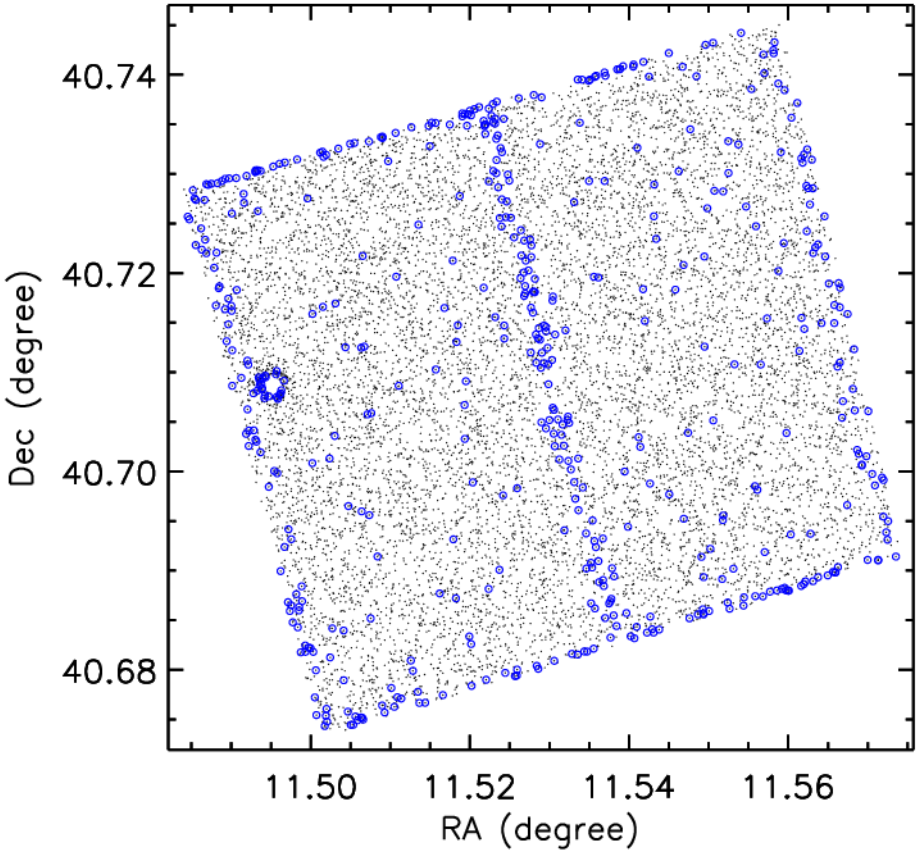
$$P = \frac{\text{Number of selected variables}}{\text{Total number of selected candidates}}$$

$$F = 2(C \times P)/(C + P)$$

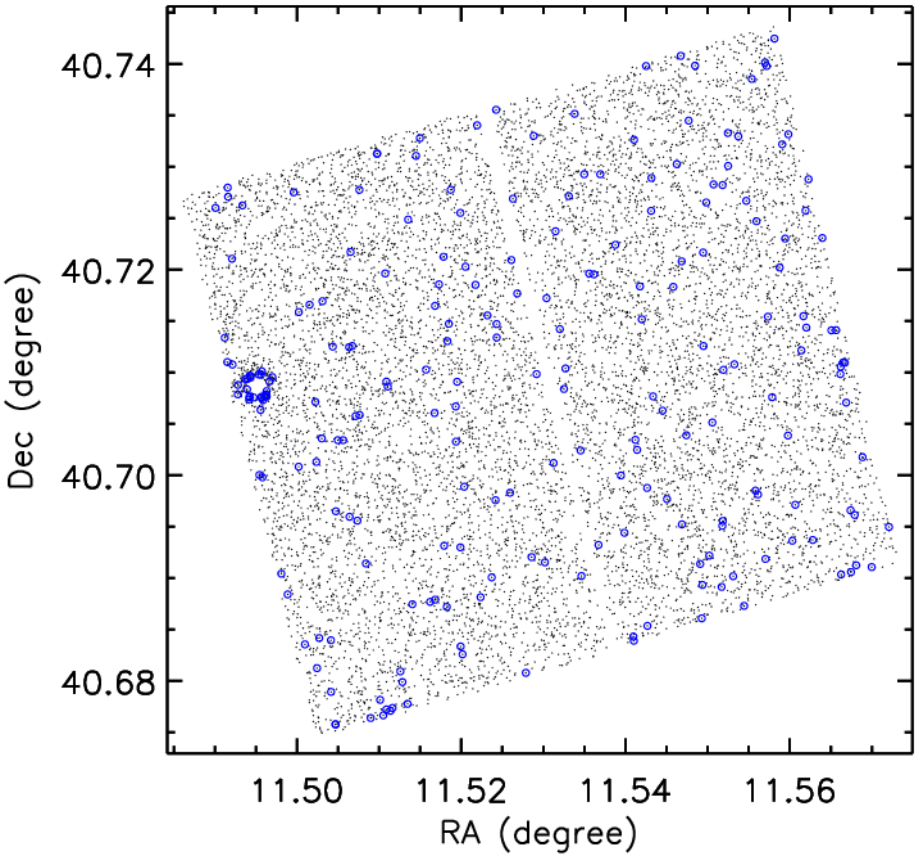
See https://en.wikipedia.org/wiki/F1_score

The edge effect

Before cleaning



After cleaning



Bad group example

Misaligned images and uncleaned CRs compromise photometry