

Real-time Variability Studies with the NOAO Mosaic Imagers

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(NOAO/CTIO)

w/ experience from

**SuperMacho Team + High-z SN Team
+ NOAO Data Products Program**

Example Time Domain NOAO Survey Projects

- Real-time detection of transients in the “DLS” = Deep Lens Survey
 - Transients available in near real time on web @ <http://dls.bell-labs.com>
- Microlensing, SNe, & Moving Objects
 - Kuiper Belt survey at NOAO (KP+CT), 2001-2004
 - “[SuperMacho](#)” survey at NOAO/CTIO, 2001-2005
 - “[ESSENCE](#)” SN survey at NOAO/CTIO, 2002-2006
- All rely on rapid analysis of data from NOAO 8Kx8K Mosaic imagers

The Hard Stuff = Software!

- Real-time reduction AND analysis of LARGE and CONTINUOUS data flows
- Automated discrimination and classification
- Detection efficiency calibration (rates)
- DB structures optimized for time-domain
- Wide Area Networking/Data Dissemination
- “System-wide” coordinated follow-up

Science Drivers

- DARK MATTER: SuperMacho
- DARK ENERGY: ESSENCE

Common Requirements

- Detect and follow faint transients with variability on timescales of days
 - Detection of faint transients on complicated backgrounds
 - Area+Depth: Need wide field + ~4m aperture
 - Sampling: between nightly and weekly
- Rapid transient detection for alerts and planning of follow-up observations
 - Ability to process >20 GB/night in near real time
 - Detections matched against catalogs: new object?
 - Transient alerts <12 hours after observations for follow-up on large telescopes

Additional Strategies

- Provide self-contained follow-up
 - SM: survey produces single-band light curves sampled every 2 nights
 - SN: survey produces VRI light curves and colors sampled every 4 nights
- Provide rapid public access
 - No proprietary period on data from either project
- RESULTS
 - TAC approved
 - 150 nights over 5 years on CTIO Blanco 4m
 - Starting Oct 2001 (SM) and Oct 2002 (SN)

SM+SN Data Acquisition



- Mosaic camera + Arcon controller
 - 8 x 2048x4096 SITe CCDs
 - Each CCD read from 2 amplifiers
 - 20s to 200s exposures, 100s read time
- “mosocs” control script
 - List of observations, exptimes, filters, etc.
 - Guider control (acquisition of guide star)
 - Sends setup request to telescope, guider, & instrument as soon as shutter closes, overhead minimized
- Result: ~20-30 GB/night



The SM+SN Pipeline

Armin Rest

- UW + NOAO + LLNL collaboration
- Built on MACHO + High-z + DLS experience
- Mixture of C programs, IRAF, Perl, and Python
- Modular Components
 - Smallest unit: “action”, ex: find stars
 - Larger unit: “stage”, ex: align images
- Experience feeds the “NOAO Mosaic Pipeline”
- Three major sections
 - Data Reduction & Data Quality Assessment
 - Transient Detection
 - Data Products

Data Reduction and DQA

- Removal of instrumental signature
 - Crosstalk correction
 - Distortion (WCS mapping) using UCAC1 catalog to achieve $<0.1''$ RMS in LMC (SuperMacho)
 - Bias & Flat Field in parallel, amp by amp
- Detailed propagation of noise arrays
- *Real-time Data Quality Assessment*
 - *Automated analysis of instrumental (e.g., noise), telescope (e.g., focus), and environmental (e.g., transparency) conditions*
 - *Real-time feedback to observer; the sooner problems are detected, the sooner they can be fixed!*

Transient Detection & Analysis

- Difference imaging technique
 - Alard-Lupton PSF-matching algorithm
 - Poisson limit detection in moderately crowded fields
- Absolute photometry “stage” also available
 - MACHO project style analysis
- False positive suppression
 - Use pre-subtraction DoPHOT PSF on difference image to look for new objects (eliminates most CRs)
 - Analyze positive/negative pixels to reject ringing residuals at faint levels

High-z SN Experience

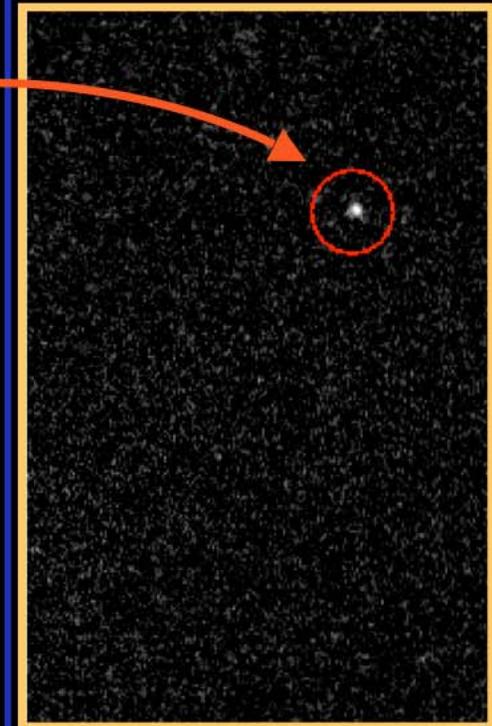
Epoch 1



Epoch 2 (3 weeks later)



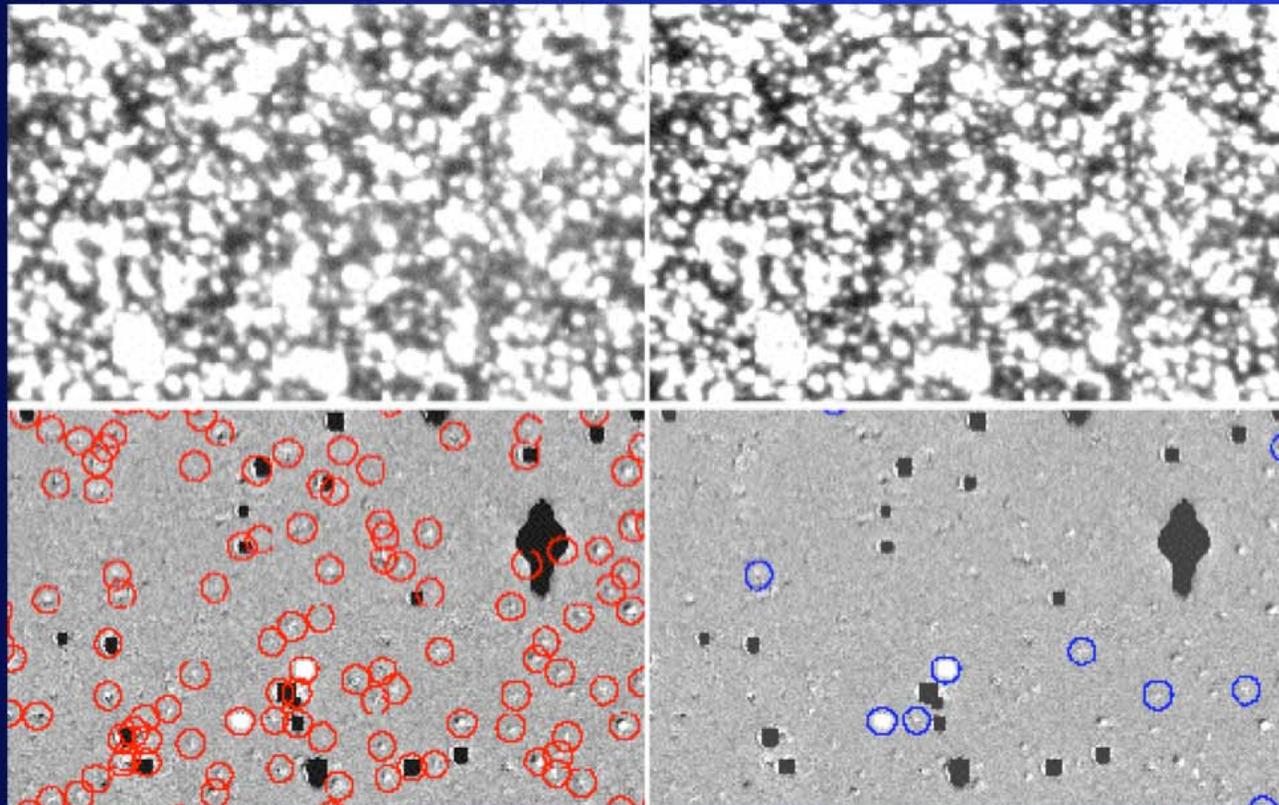
Epoch 2 - Epoch 1



(High-z Supernova Team)

False Positive Filtering

- Life is not always perfect, but not bad...
Example near *center* of LMC bar



Database

Rafael Hiriart

- Using PostgreSQL: fast, relational, open-source
- Combined Operations and Science DB
- Operations
 - Observations, processing, and templates used
- Transient analysis
 - Detections in any given observation
 - “Detection” based, not “object” based
 - Detections to Objects: clustering algorithms
- Additional tables
 - Classification (SN, variable star, moving object)
 - Spectroscopic information (IDs, etc.)
 - Relations to external DBs (previously known variables)

Object Classification

Andy Becker

- Organic Neural Net + “Diff Sniff”

The screenshot displays the following components:

- Image Grid:** A 2x3 grid of images. The top row shows a 'Template' image (2001-11-15 06:46:7.624), an 'Image' (2001-11-17 06:57:54.978), and a 'Difference' image (2001-11-17 06:57:54.978). The bottom row shows the same 'Template' image, a second 'Image' (2001-11-22 06:46:6.800), and a second 'Difference' image (2001-11-22 06:46:6.800). File names are listed below each image.
- DoPhot Profile:** Two sections, one for each image pair, showing a central peak and a 'chi^2' value of 100.
- Kernel Profile:** Two sections, one for each image pair, showing a central peak and a 'chi^2' value of 10.
- Star List:** A table of 13 stars with RA and DEC coordinates. The star at RA = 05:20:52.172, DEC = -68:25:51.71 is highlighted.
- Classification Legend:** A list of object types with checkboxes: (A)steroid, (B)ad Object, (C)osmic Ray, (I)gnore, (K)nown Variable, (M)icrolensing, (S)uperNova, (U)nclassified, (V)ariable Star.
- Parameter Table:** A table of object parameters at the bottom.
- Buttons:** 'Search', 'View LightCurve', 'Quit', 'Next', and 'Prev' buttons are visible.

Xpos	Ypos	M	dM	type	class	sky	FWHM1	FWHM2	FWHM
827.37	664.13	14.861	0.024	0x0001	0.00	14.5	3.19	2.94	3.07
angle	extended	flag	Nsat	Nbad	M_ap	dM_ap	N_TOT	N_POS	N_NEG
-29.3	-7.5	0x000000	0	0	0.000	0	81	67	0
N_MASK	POSFLUX	NEGFLUX							
0	9135	0							

Object Review on Web

- “Web sniffing” for remote users

[Return To Main Page](#)

Candidate smca_4.sm031123_4.fd_cand3711

RA : 05:00:21.805

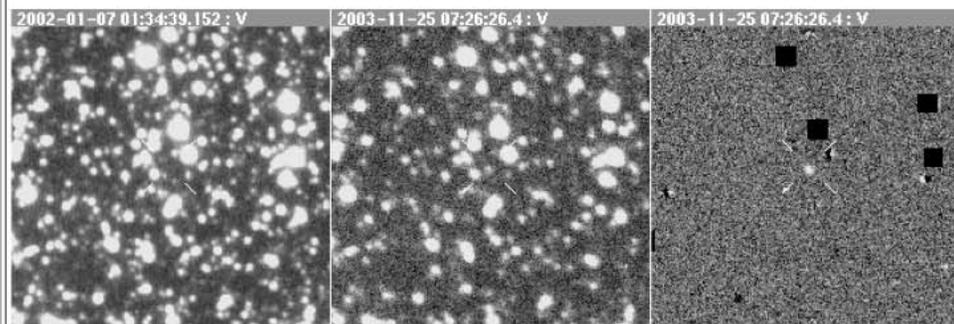
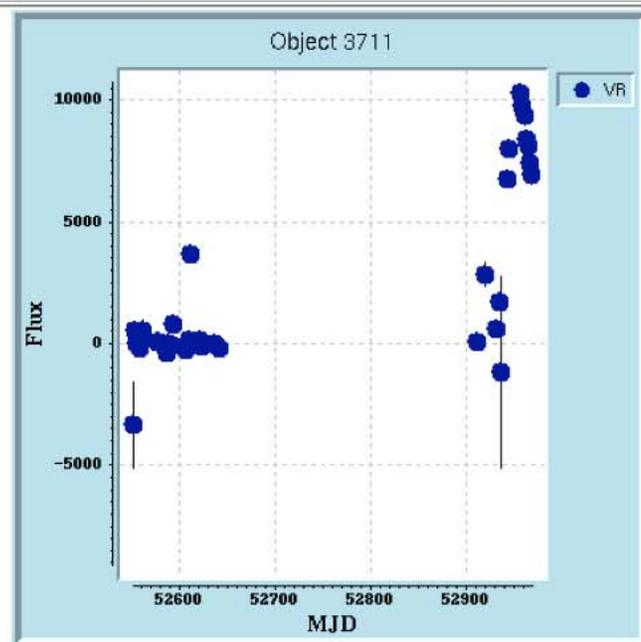
DEC : -67:41:25.07

[Texttable lightcurve](#)

[Search MACHO](#)

[Finding Chart \(PDF\)](#)

[Finding Chart \(FITS\)](#)



Classify as Variable

Level-1 Alert! (Microlensing)

Reference : http://darkstar.astro.washington.edu/~smsn/lev0_sm031123_sm020107/4/smca_4.sm031123_4.fd.html#smca_4.sm031123_4.fd_cand3711

[Return To Main Page](#)

Hardware

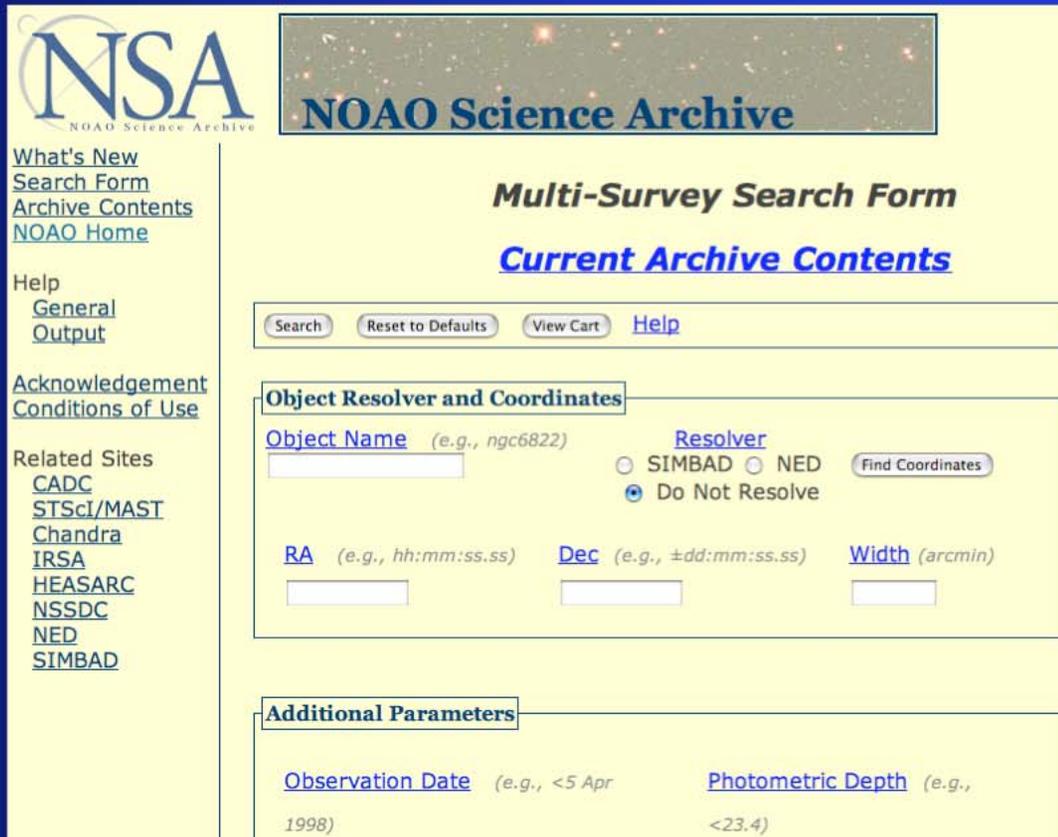
- Computers
 - Linux PCs running RedHat 7.x
 - 10 x dual 1.2Ghz Athlon CPU processing cluster
 - 2 x dual 2.8Ghz Intel CPU storage servers
 - Use Condor to manage cluster processing
- Storage
 - 4 TB IDE RAID array for transient detection system
 - +2-4TB/yr IDE RAID for review and online storage
- Infrastructure
 - 155Mbps link from Tololo to La Serena
 - 1Gbps link between all components in La Serena
 - 10Mbps link to U.S. (additional bandwidth planned)

Data Products

- Transient announcements
 - Email list (bidirectional!) & IAU Circulars
 - Finder charts, “postage stamps”
- Images
 - No proprietary period
 - Raw & Reduced (flat fielded) data
- Additional products
 - SM: deep astrometric catalog of LMC
 - SM: Obtained B & I images > stellar population studies
 - SN: Variable stars, AGN, etc.
 - SN: Add B, z, JHK for additional studies

Public Access: NOAO Science Archive

- Data flows into the NOAO Science Archive
<http://archive.noao.edu/nsa>
- >10Mbps
- FedExNet



The screenshot shows the NOAO Science Archive website. At the top left is the NSA logo with the text "NOAO Science Archive". To its right is a header image of a star field with the text "NOAO Science Archive". Below the logo are links for "What's New", "Search Form", "Archive Contents", and "NOAO Home". There is also a "Help" section with "General" and "Output" links, and an "Acknowledgement" section with "Conditions of Use". A "Related Sites" section lists "CADDC", "STScI/MAST", "Chandra", "IRSA", "HEASARC", "NSSDC", "NED", and "SIMBAD". The main content area is titled "Multi-Survey Search Form" and "Current Archive Contents". It features a search bar with "Search", "Reset to Defaults", "View Cart", and "Help" buttons. Below this is the "Object Resolver and Coordinates" section, which includes an "Object Name" field (with example "ngc6822"), a "Resolver" section with radio buttons for "SIMBAD", "NED", and "Do Not Resolve" (which is selected), and a "Find Coordinates" button. There are also fields for "RA" (with example "hh:mm:ss.ss"), "Dec" (with example "±dd:mm:ss.ss"), and "Width" (with example "arcmin"). At the bottom is the "Additional Parameters" section, which includes "Observation Date" (with example "<5 Apr 1998") and "Photometric Depth" (with example "<23.4").