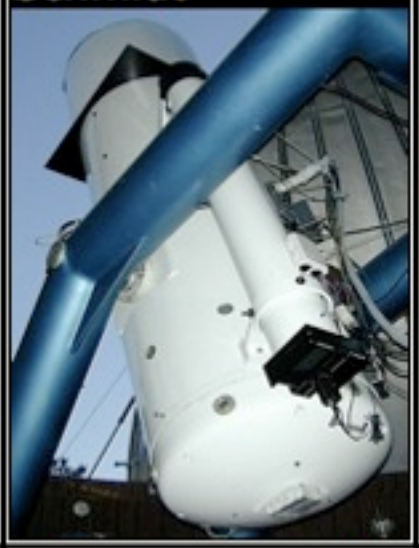
Catalina Real-Time Transient Survey (CRTS)

S. G. Djorgovski, **A. Drake,** A. Mahabal, C. Donalek, R. Williams, M. Graham (CIT), E. Beshore, S. Larson, et al. (UA/LPL), and numerous collaborators world-wide

The Eventful Universe
NOAO, March 2010

Catalina Real-Time Transient Survey

CRTS uses the data from all three Catalina NEO surveys, with a coverage of up to 2,500 deg^2 / night, and the total area coverage of ~ 30,000 deg^2

	MLS The Mt. Lemmon Survey 1.5m Cass	CSS Catalina Sky Survey 0.7m Schmidt	SSS Siding Springs Survey 0.5m Schmidt
			
Survey region (deg)	+/- 5 deg ecliptic	-25 < Dec < +70	-80 < Dec < -25
Field of View (square deg)	1.2	8.1	4.2
Mag limit (V)	21.5	19.5	19.0

We are processing the Catalina data streams in real time to look for astrophysical transients

http://crts.caltech.edu

An open optical transient survey

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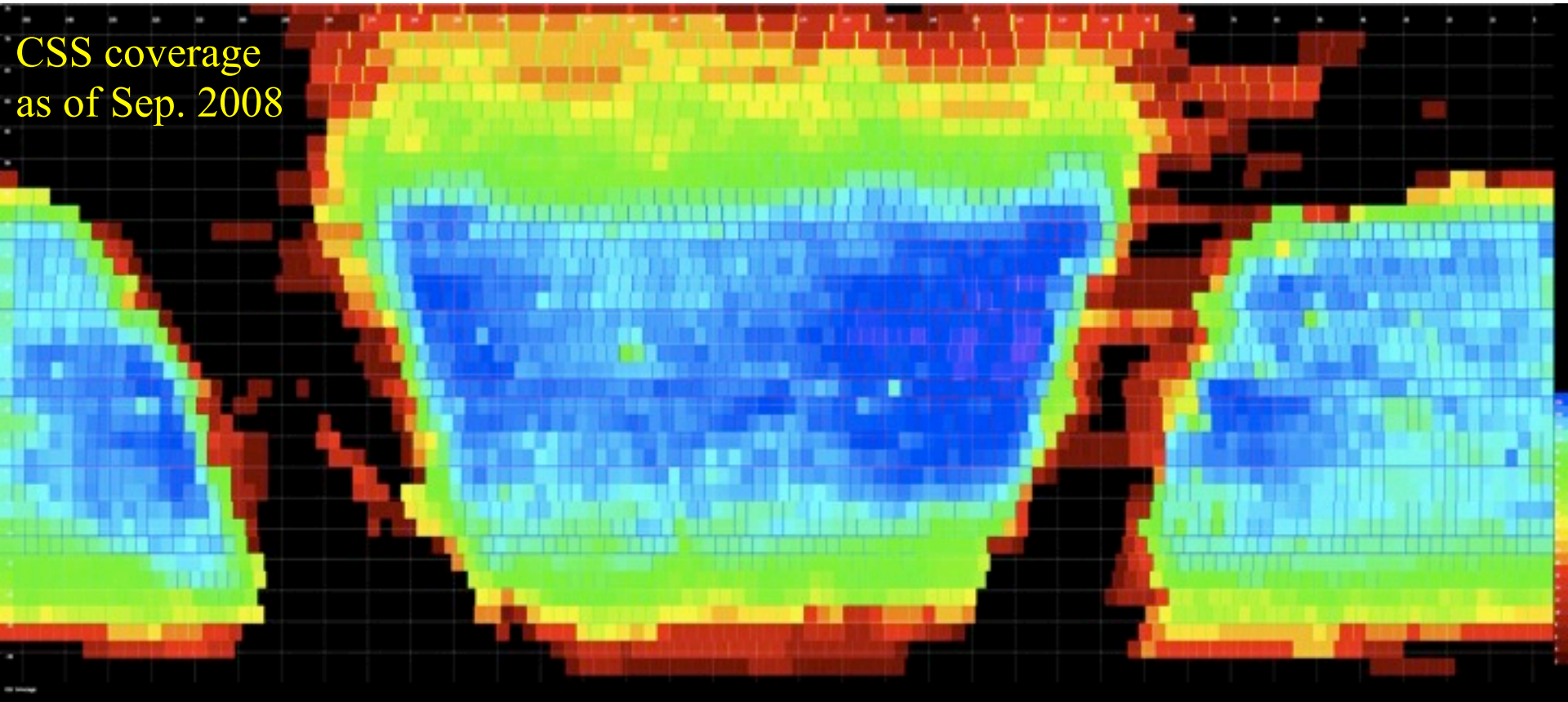
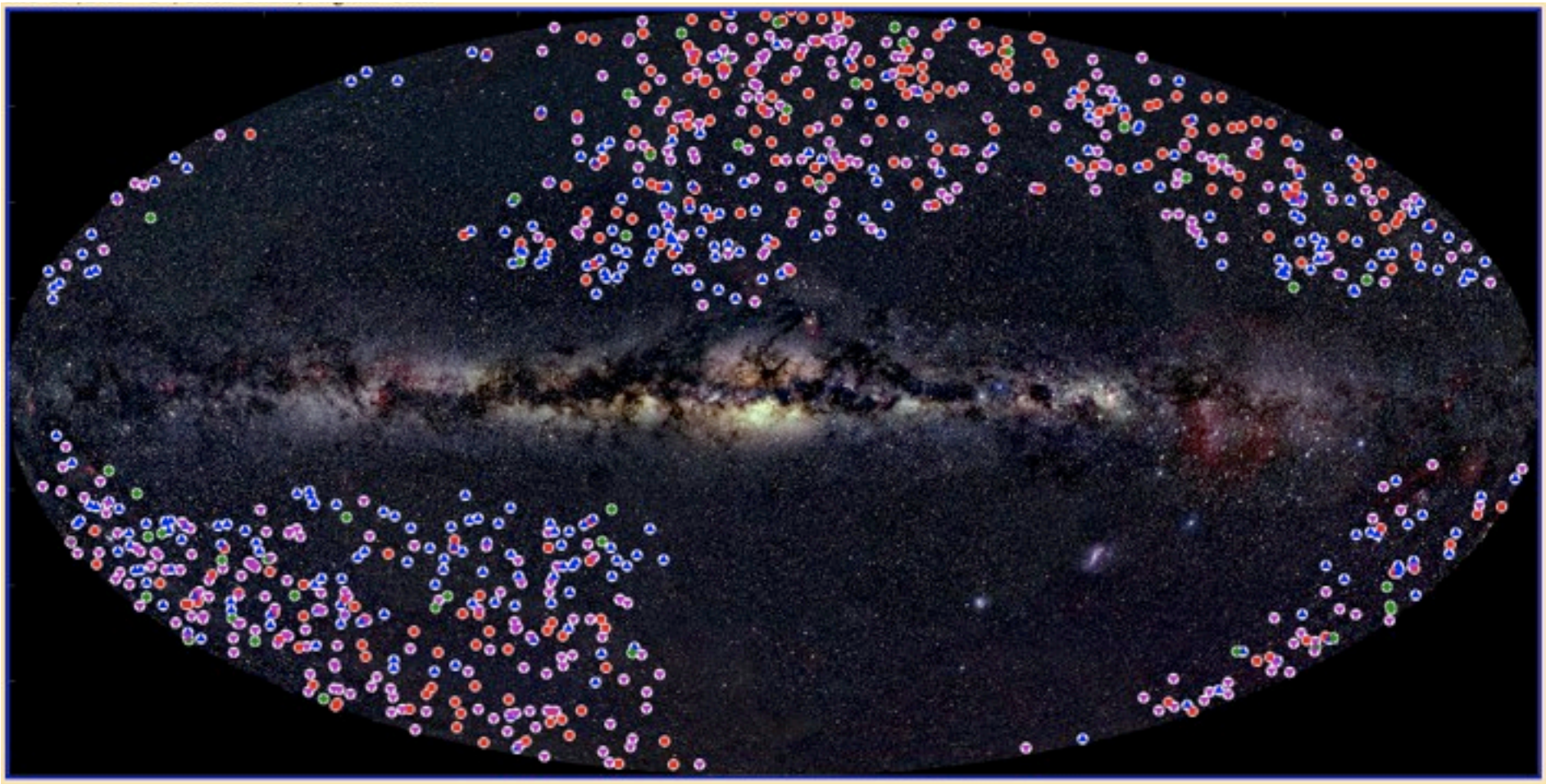


CRTS Coverage Map (CSS only)

As of the early 2010, over 1200 unique transients discovered

Red = SN, Blue = CV, Green = Blazar, Magenta = Other



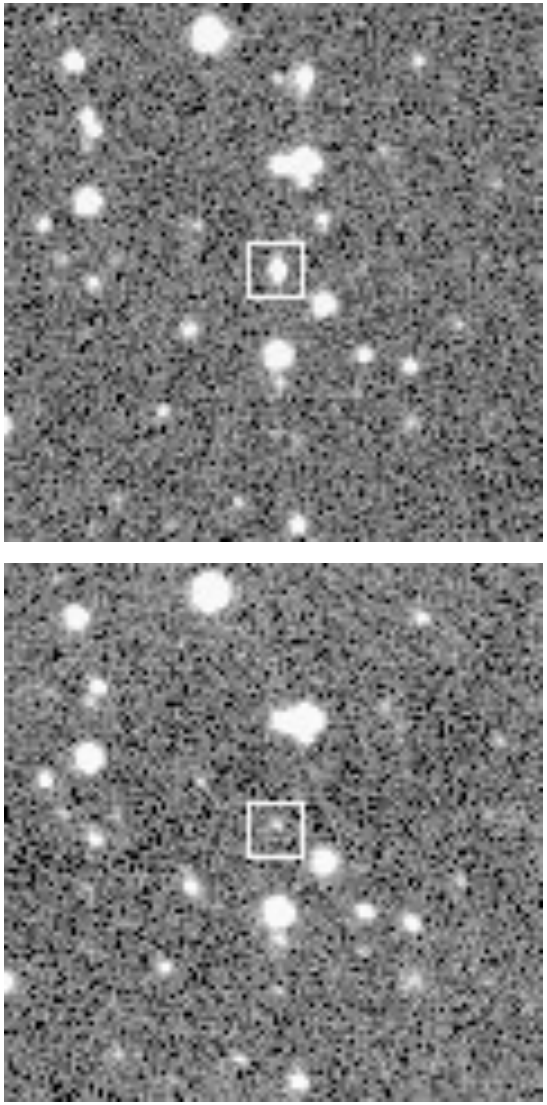
- Discovery rate ~ 1 transient per 10^6 sources detected per epoch
- Amplitude threshold deliberately set high, but can be lowered

Some Good Things About CRTS

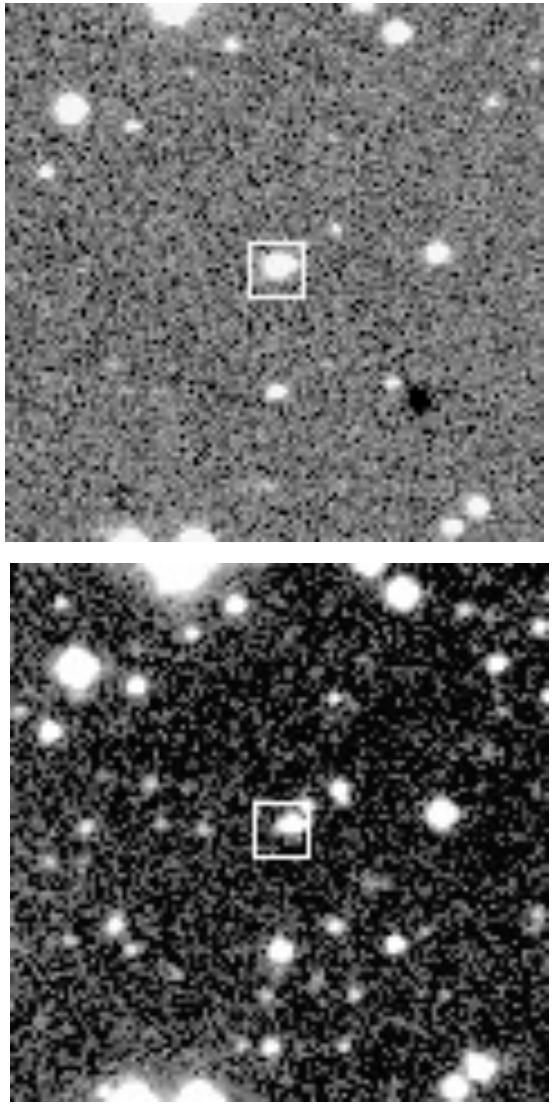
- Real-time processing, detection, and publishing of transients
  - Builds on the work started in the PQ survey (science & technology)
- Added value for the data from the Catalina NEO surveys
  - Focus on astrophysical transients, ***a systematic exploration of the time domain***, and the computational infrastructure
- It is ***a fully open survey***: all data are made public instantly, with no proprietary period at all
  - Benefits the entire community
  - Maximizes the follow-up and the resulting science
  - A new "open data" sociology – the shifting focus from the ownership of data to the ownership of expertise
- Public outreach via the Google's Sky, MSR's WorldWide Telescope, and "Citizen Science"
- Supported by the NSF, NASA, and private gifts

Examples of CRTS Transients

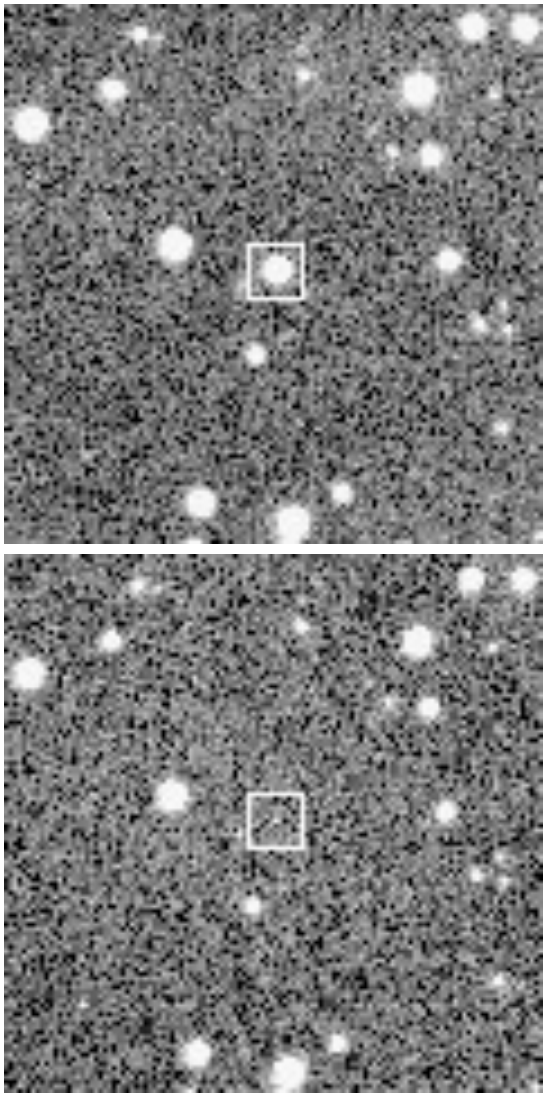
CSS090429:135125-075714
Probable flare star



CSS090429:101546+033311
Probable dwarf nova

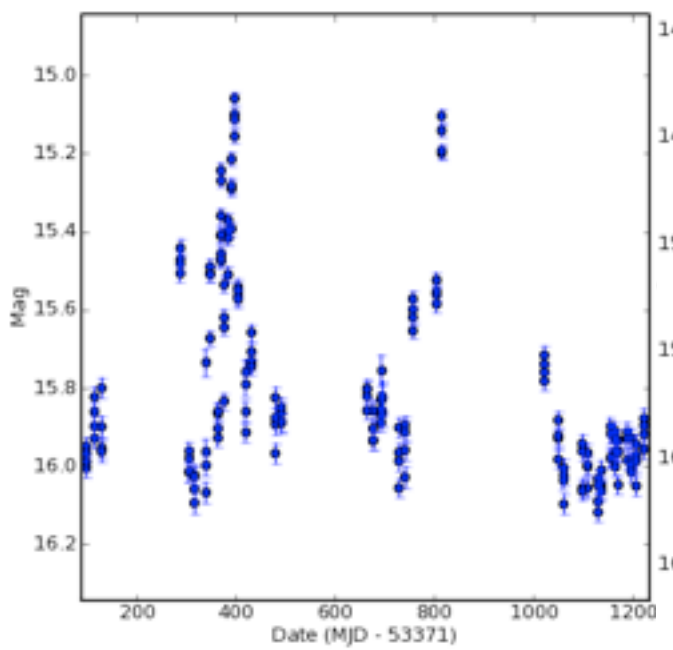


CSS090426:074240+544425
Blazar, 2EG J0744+5438

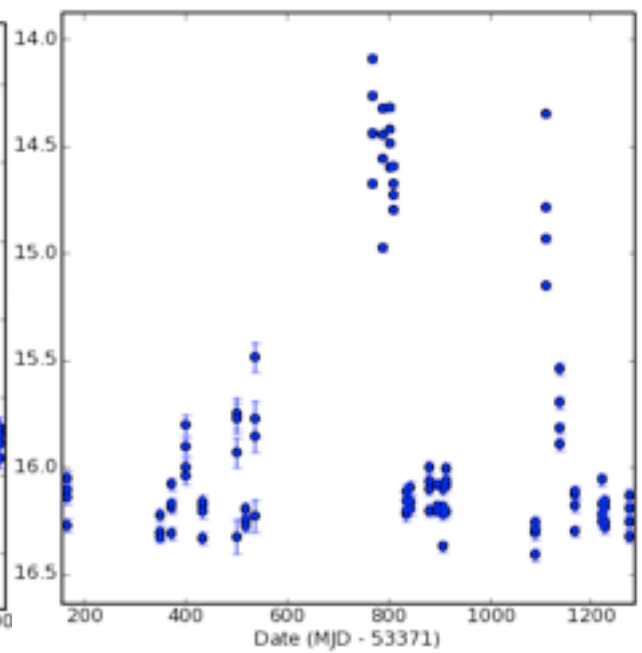


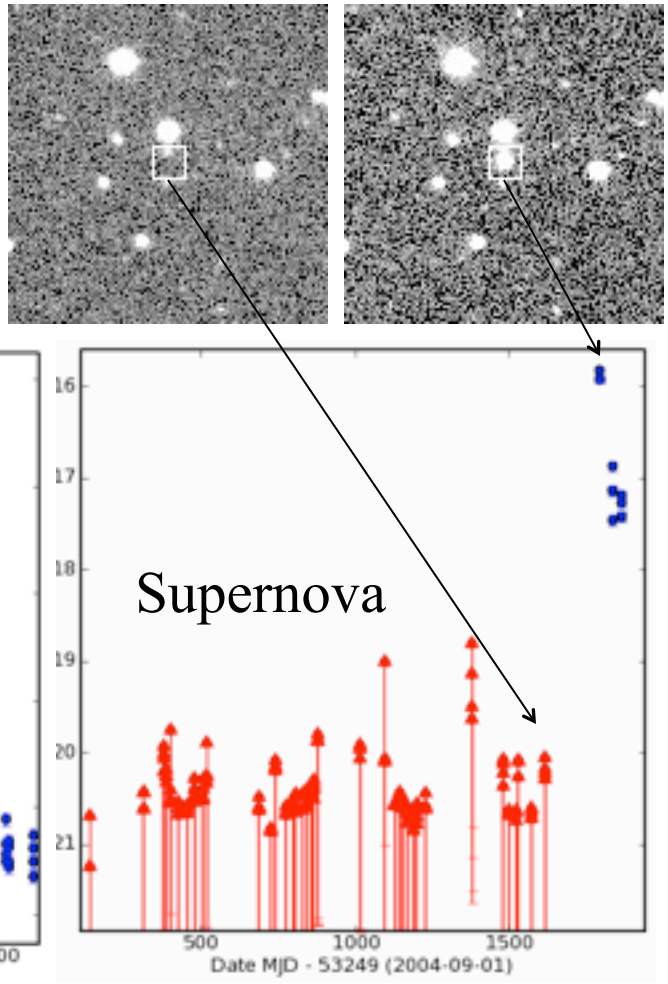
Sample Light Curves

Blazar PKS0823+033



CV 111545+425822





The plan is to produce light curves for every detected source in the survey (> 10^8 sources), make them publicly available, and mine that data set. Light curves are generated on demand for transient sources, blazars, etc.

Real Time Event Publishing via *VOEvents* and *SkyAlert* (The successor of VOEventNet)

http://skyalert.org

From the CRTS stream.
Catalina Real-time Transient Survey
Position is 115.98635,21.1753 ± 0.0012
This portfolio initiated 2009-11-11 08:35:18

See context in WorldWideTelescope

CRTS
911111210394136030
2009-11-11T11:34:58

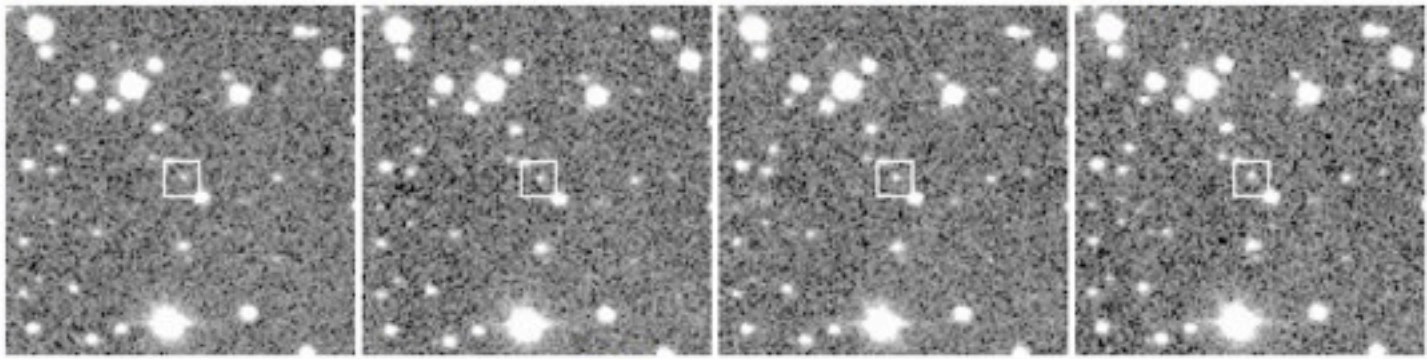
CRTSCircular
911111210394136030-2009-
2009-11-11T16:26:29

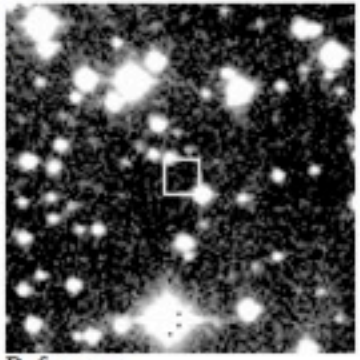
SDSS
observation
2009-11-11T16:35:19

CatalogArchives
observation
2009-11-11T16:35:26

CRTS (Catalina) Event identifier is 911111210394136030 or CSS091111:074357+211031

2455146.986330 | 2455146.975340 | 2455146.978970 | 2455146.982620





Reference

Finding Chart	Click here
Past CRTS images	Click here
Other images	Click here
Lightcurve	Click here
SDSS cutout	Click here
Position	(115.98635,21.1753)
Time	2009-11-11T11:34:58 (MJD 55146.4826157)
Magnitude	18.559700
Magnitude	18.673201

PI: R. Williams

SkyAlert: Links to the Archival Data

From the CRTS stream.
Catalina Real-time Transient Survey
Position is 115.98635,21.1753 ± 0.0012
This portfolio initiated 2009-11-11 08:35:18

CRTS
911111210394136030
2009-11-11T11:34:58

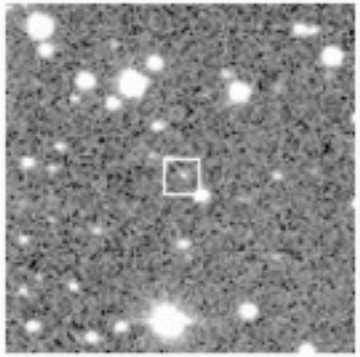
CRTSCircular
911111210394136030-2009-
2009-11-11T16:26:29

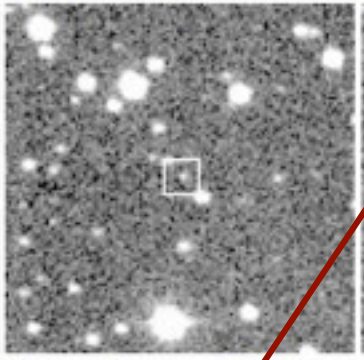
SDSS
observation
2009-11-11T16:35:19

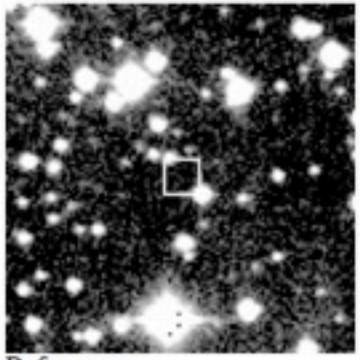
CatalogArchives
observation
2009-11-11T16:35:26

CRTS (Catalina) Event identifier is 911111210394136030

2455146.986330 | 2455146.975340 | 24551



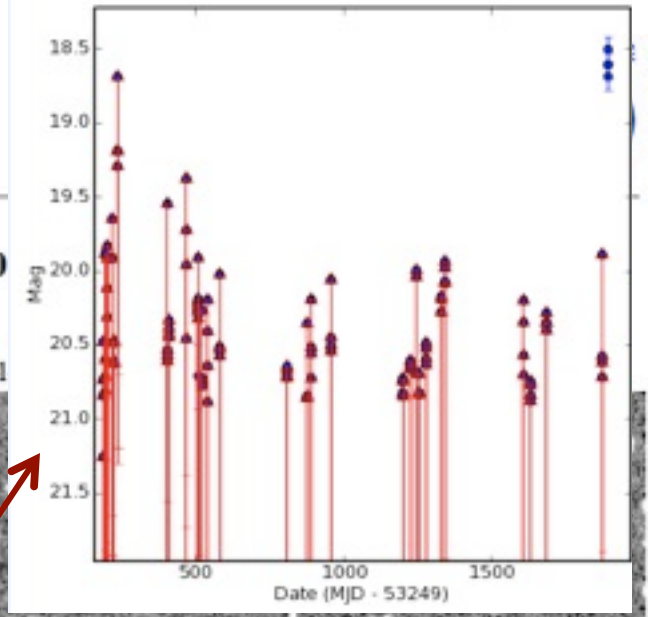




Reference

Finding Chart	Click here
Past CRTS images	Click here
Other images	Click here
Lightcurve	Click here
SDSS cutout	Click here
Position	(115.98635,2
Time	2009-11-11T1
Magnitude	18.559700
Magnitude	18.673201

Click on the points for associated images
Values for object: 911111210394136030
Date: 1897.47998 (2009-11-11)
Mag: 18.687151
Error: 0.091546
Red points upper limits
Blue points measurements



Including the VO DataScope, etc.

CRTS events in *WorldWide Telescope*

Annotated Table of Transients

All Catalina Real-time Transient Survey Optical Transients

Last updated at 11/22/2009 03:57:41

Show entries sorted by RA

http://nesssi.cacr.caltech.edu/catalina/Allns.html

Show entries sorted by Last update

Info about the table

CSS ID	RA (J2000)	Dec (J2000)	Date	Mag	CSS images	SDSS	Others	Followed	Last	LC	Classification
CSS091121:221159+263906	332.99697	26.65153	20091121	18.33	911211261084134848	no	34848	no	2009-11-21	34848	SN/Blazar mag 21
CSS091121:013728+253450	24.36768	25.58061	20091121	17.78	911211260084103595	no	03595	no	2009-11-21	03595	SN/CV
CSS091121:032627+070744	51.61364	7.12902	20091121	16.68	911211070194124436	no	24436	no	2009-11-21	24436	CV mag 21
CSS091121:033232+020439	53.13295	2.07747	20091121	16.93	911211010194134434	no	34434	no	2009-11-21	34434	CV mag 20
CSS091121:085600-051945	133.99922	-5.32906	20091121	18.17	911210040484107252	no	07252	no	2009-11-21	07252	SN CFHT mag 22 gal
CSS091120:100525+511639	151.35223	51.27742	20091120	18.80	911201520354108835	yes	08835	no	2009-11-20	08835	SN SDSS mag 21,9 gal
CSS091120:082908+482639	127.28503	48.44423	20091120	15.69	911201490314109371	yes	09371	no	2009-11-20	09371	CV/SN SDSS mag 21,6 gal?
CSS091120:004417+411854	11.07004	41.31494	20091120	17.00	911201400044145995	yes	45995	no	2009-11-20	45995	Nova M31 2009-11d
CSS091120:001019+410455	2.58044	41.08191	20091120	16.69	911201400014137919	no	37919	no	2009-11-20	37919	CV mag 20,0
CSS091120:000945+402928	2.43941	40.49111	20091120	17.85	911201400014122995	no	22995	no	2009-11-20	22995	SN/CV
CSS091120:231103+202620	347.76298	20.43877	20091120	19.34	911201211174111923	yes	11923	no	2009-11-20	11923	SN SDSS mag 21,3 gal
CSS091120:055510-041030	88.79123	-4.17498	20091120	14.13	911200040324150271	no	50271	no	2009-11-20	50271	HPM HL_4 mag 13,9
CSS091119:104915+210545	162.31058	21.09579	20091119	19.22	911191210554118814	yes	18814	no	2009-11-19	18814	AGN? SDSS mag 20,5
CSS091119:001627+222610	4.11070	22.43613	20091119	17.48	911191210024141794	no	41794	no	2009-11-19	41794	SN DSS mag 18,6
CSS091119:213938-023913	324.90657	-2.65352	20091119	16.56	911190011164102559	no	02559	no	2009-11-19	02559	CV mag 19,8
CSS091118:100110+291138	150.29247	29.19375	20091118	15.72	911181290484113217	yes	13217	no	2009-11-18	13217	Blazar mag 17,6 CRATES_J100110+291130
CSS091118:054301-164011	85.75538	-16.66983	20091118	15.06	911180150304104379	no	04379	no	2009-11-18	04379	CV mag 18,8
CSS091118:053542-113717	83.92422	-11.62134	20091118	15.99	911180120304152609	no	52609	no	2009-11-18	52609	CV mag 19,6
CSS091117:211110-213729	317.78973	-21.62473	20091117	16.32	911170211074120836	no	20836	no	2009-11-17	20836	Var RRLyr_126093,1135 mag 17,0
CSS091117:005036-202111	12.64904	-20.35305	20091117	19.07	911170210054133098	no	33098	no	2009-11-17	33098	Ast?
CSS091117:002501-204312	6.25451	-20.72012	20091117	19.08	911170210034128706	no	28706	no	2009-11-17	28706	SN/Ast SDSS mag 22,1 z=0,054
CSS091117:021921-184239	34.83822	-18.71077	20091117	17.97	911170180124117023	yes	17023	no	2009-11-17	17023	Blazar PKS_0217-189 mag 18,6
CSS091117:221901-145635	334.75442	-14.94304	20091117	19.07	911170151164131837	no	31837	no	2009-11-17	31837	AGN?
CSS091117:030116-033429	45.31612	-3.57461	20091117	19.34	911170040174132508	no	32508	no	2009-11-17	32508	Blazar mag 21 CRATES_J030114-033423
CSS091116:072002+523421	110.00676	52.57255	20091116	18.30	911161520254139263	no	39263	no	2009-11-16	39263	CV mag 21
CSS091116:080454+370751	121.22584	37.13093	20091116	17.87	911161380354109438	yes	09438	no	2009-11-16	09438	SN? SDSS mag >22
CSS091116:080428+363104	121.11848	36.51784	20091116	18.94	911161350364152378	yes	52378	no	2009-11-16	52378	CV? mag 22,4
CSS091116:232551-014024	351.46440	-1.67327	20091116	15.92	911160011254116087	no	16087	no	2009-11-16	16087	CV mag 18,3

Selected transients and follow-up also published in ATel and CBET

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Present Time: 23 Nov 2009; 6:41 UT

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Transients
SGRs
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Optical Transients from CRTS

ATel #2266; *A.J. Drake, S.G. Djorgovski, M.J. Graham, A.A. Mahabal, R. Williams (Caltech); M. Catelan (PUC); E.C. Beshore, S.M. Larson, A. Boattini, A. Gibbs, A. Grauer, R. Hill, R. Kowalski (LPL/UA); E. Christensen (Gemini Observatory);*
on 26 Oct 2009; 22:16 UT
Distributed as an Instant Email Notice (Request for Observations)
Password Certification: Andrew J. Drake (ajd@cacr.caltech.edu)

Subjects: Request for Observations, Cataclysmic Variables, Novae, Supernovae, Transients

We report the following transient sources discovered by the Catalina Real-time Transient Survey (CRTS) between 2009-09-24 and 2009-10-24 UT.

ID	Disc. Date	RA	Dec	Disc. Mag	Type
CSS091024:231936+071839	2009-10-24	23:19:36.25	07:18:39.0	19.5	SN
CSS091023:030259-144902	2009-10-23	03:02:59.01	-14:49:02.0	16.4	SN?
CSS091023:033948-111325	2009-10-23	03:39:47.78	-11:13:25.0	18.7	SN
CSS091020:221124-091244	2009-10-20	22:11:23.59	-09:12:44.0	18.2	SN
CSS091018:091109+195945	2009-10-18	09:11:09.20	19:59:45.0	19.1	SN
CSS091016:160146+323457	2009-10-16	16:01:45.52	32:34:57.0	19.2	SN
CSS091016:004842-055119	2009-10-16	00:48:41.34	-05:51:19.0	19.4	SN
CSS090929:173609+491749	2009-09-29	17:36:09.13	49:17:49.0	18.1	SN
CSS090929:172039+183802	2009-09-29	17:20:38.67	18:38:02.0	18.1	SN
CSS090927:232926+040036	2009-09-27	23:29:25.83	04:00:36.0	18.4	SN
CSS090925:001259+144121	2009-09-25	00:12:59.46	14:41:21.0	18.8	SN
CSS091024:050124+203818	2009-10-24	05:01:24.13	20:38:18.0	16.0	CV
CSS091023:044806-104134	2009-10-23	04:48:05.82	-10:41:34.0	16.4	CV
CSS091022:090516+120451	2009-10-22	09:05:16.05	12:04:51.0	17.7	CV
CSS091021:025613-103359	2009-10-21	02:56:12.87	-10:33:59.0	15.1	CV
CSS091019:220450+054852	2009-10-19	22:04:49.75	05:48:52.0	15.4	CV
CSS091017:210206+025834	2009-10-17	21:02:05.69	02:58:34.0	16.0	CV
CSS091017:081210+040352	2009-10-17	08:12:10.22	04:03:52.0	18.7	CV
CSS091016:010550+190317	2009-10-16	01:05:50.30	19:03:17.0	16.3	CV
CSS091009:010412-031341	2009-10-09	01:04:11.61	-03:13:41.0	17.2	CV
CSS090930:165003+435616	2009-09-30	16:50:02.78	43:56:16.0	18.4	CV
CSS090929:232716+413149	2009-09-29	23:27:16.25	41:31:49.0	15.9	CV
CSS090929:172039+183802	2009-09-29	17:20:38.67	18:38:02.0	16.2	CV
CSS090929:173150+150258	2009-09-29	17:31:50.13	15:02:58.0	18.5	CV
CSS090929:172734+130513	2009-09-29	17:27:33.67	13:05:13.0	17.3	CV
CSS090928:032812+280631	2009-09-28	03:28:11.85	28:06:31.0	16.3	CV
CSS090925:004807+264621	2009-09-25	00:48:07.21	26:46:21.0	18.6	CV
CSS090924:210651+110250	2009-09-24	21:06:50.56	11:02:50.0	16.1	CV

Three additional supernovae were discovered and confirmed during this period and eight known CVs were detected in outburst. Numerous other transient and highly variable sources were discovered and are posted at http://nesssi.cacr.caltech.edu/catalina/Allns.html

Electronic Telegram No. 2023

Central Bureau for Astronomical Telegrams
INTERNATIONAL ASTRONOMICAL UNION
M.S. 18, Smithsonian Astrophysical Observatory, Cambridge, MA 02138, U.S.A.
IAUSUBS@CFA.HARVARD.EDU or FAX 617-495-7231 (subscriptions)
CBAT@CFA.HARVARD.EDU (science)
URL http://www.cfa.harvard.edu/iau/cbat.html

SUPERNOVAE 2009lf AND 2009lg

Further to CBET 1996, A. J. Drake, S. G. Djorgovski, A. Mahabal, M. J. Graham and R. Williams, California Institute of Technology; M. Catelan, Pontificia Universidad Catolica de Chile; E. C. Beshore and S. M. Larson, Lunar and Planetary Laboratory, University of Arizona; and E. Christensen, Gemini Observatory, report the CRTS discovery of two apparent supernovae in unfiltered Catalina Sky Survey (CSS) images:

SN	2009 UT	R.A. (2000.0)	Decl.	Mag.	Offset
2009lf	Nov. 6.25	2 01 39.61	+15 19 58.1	18.5	16".7 W, 5".4 N
2009lg	Nov. 10.15	23 38 49.93	+28 15 54.2	18.0	4".3 E, 20".2 S

Additional magnitudes for 2009lf: Oct. 14.35 UT, [19.8 (CSS); Nov. 8.23, g = 18.1, r = 18.1, i = 17.9 (Palomar 1.52-m reflector); Nov. 16.06, 18.2 (S. Howerton, Arkansas City, KS, U.S.A., remotely using the 0.3-m LB-0003 telescope near Rodeo, NM, U.S.A.). Additional magnitudes for 2009lg: Oct. 27.16, [20.2 (CSS); Nov. 16.14, 17.3 (Howerton, remotely using the 0.3-m GRAS-1 telescope located near Mayhill, NM, U.S.A.).

NOTE: These 'Central Bureau Electronic Telegrams' are sometimes superseded by text appearing later in the printed IAU Circulars.

2009 November 17 (CBET 2023) Daniel W. E. Green

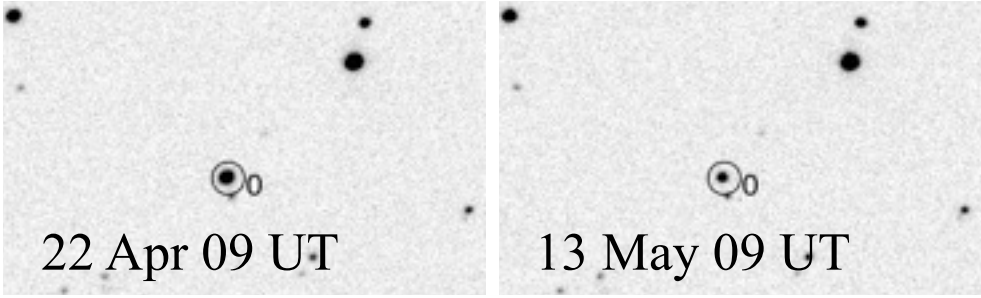
Many also picked up by VSNET

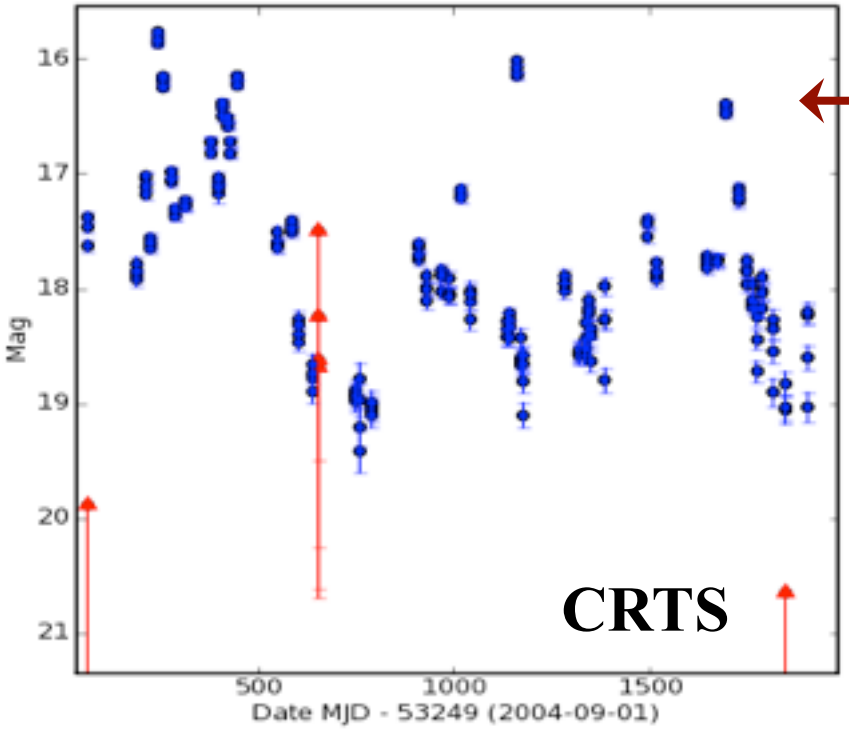
Follow-Up Observations:

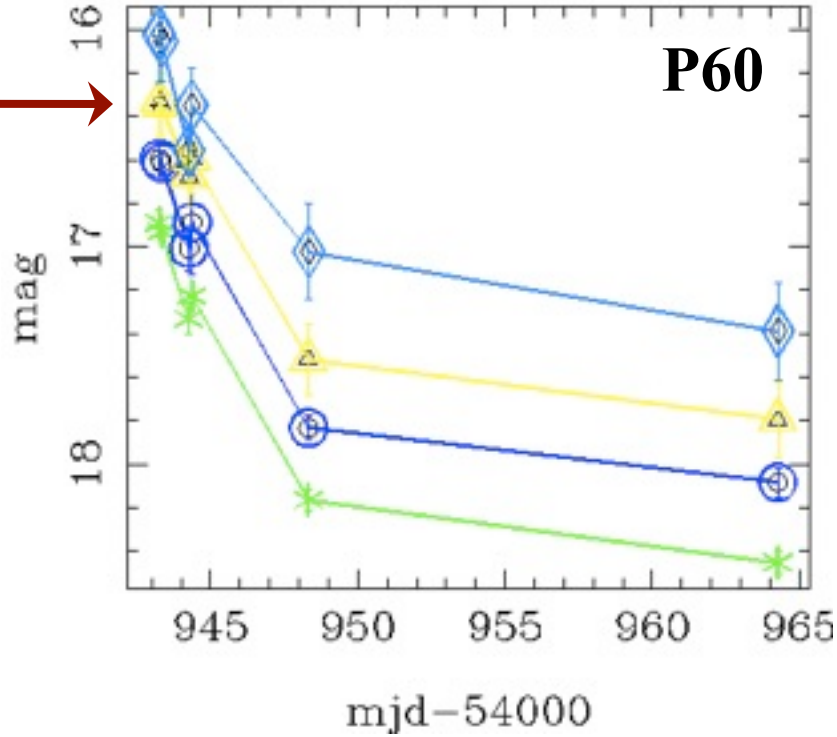
Lead: A. Mahabal

- Photometry (P60, NMSU, DAO, HTN, India, soon Mexico)
- Spectroscopy (Gemini N+S, Keck, P200, SMARTS, IGO, MDM)

CSS090421:174806+340401
A blazar, also monitored at OVRO in radio







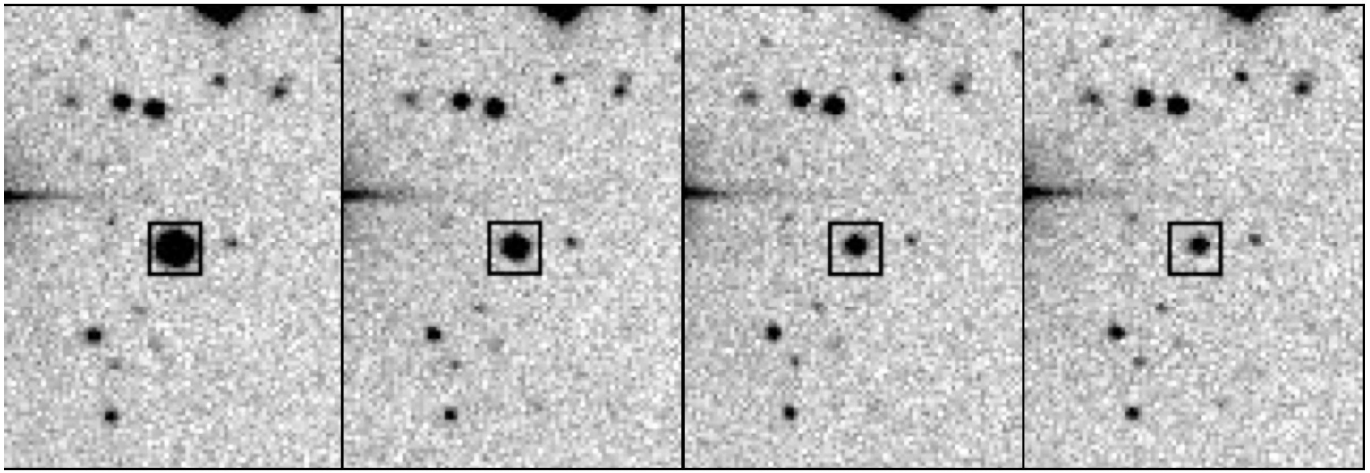
Some Results from CRTS

To date: Over 1200 confirmed, unique transients discovered (some are detected repeatedly), including:

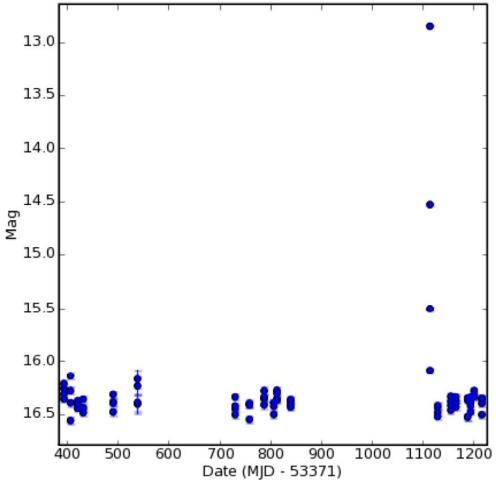
- Over 300 SNe, including some ultraluminous ones
- Over 300 CVs, ~ 75% previously unknown, some novae
- Over 50 blazars, many previously unknown
- About 50 flaring UV Ceti stars (CRTS has a 10 min time cadence)
- Many other, high-amplitude variable stars, etc.; ***many unknown***

Fast transient (a flare star), CSS080118:112149–131310

4 individual exposures, separated by 10 min

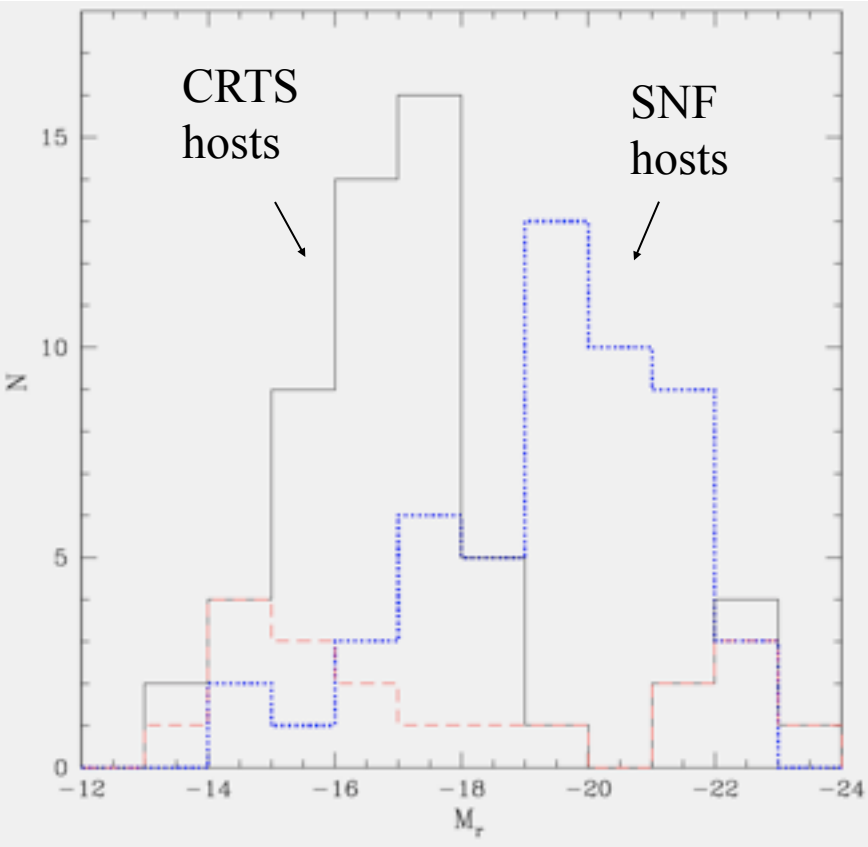


Light curve

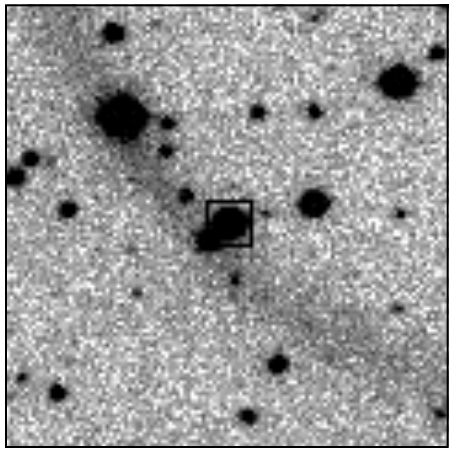


CRTS Supernova Discoveries

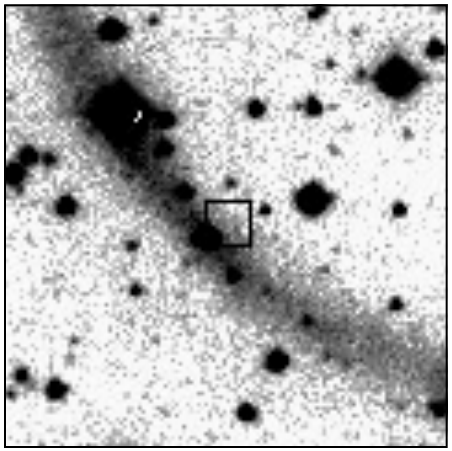
- More SNe published in 2009 than any other survey
- Extremely luminous and possible pair-production SNe (e.g., SN 2007bi, 2008fz, 2009jh)
- Extremely long time-scale SNe, e.g., 2008iy
- SNe associated with very faint host galaxies



Discovery



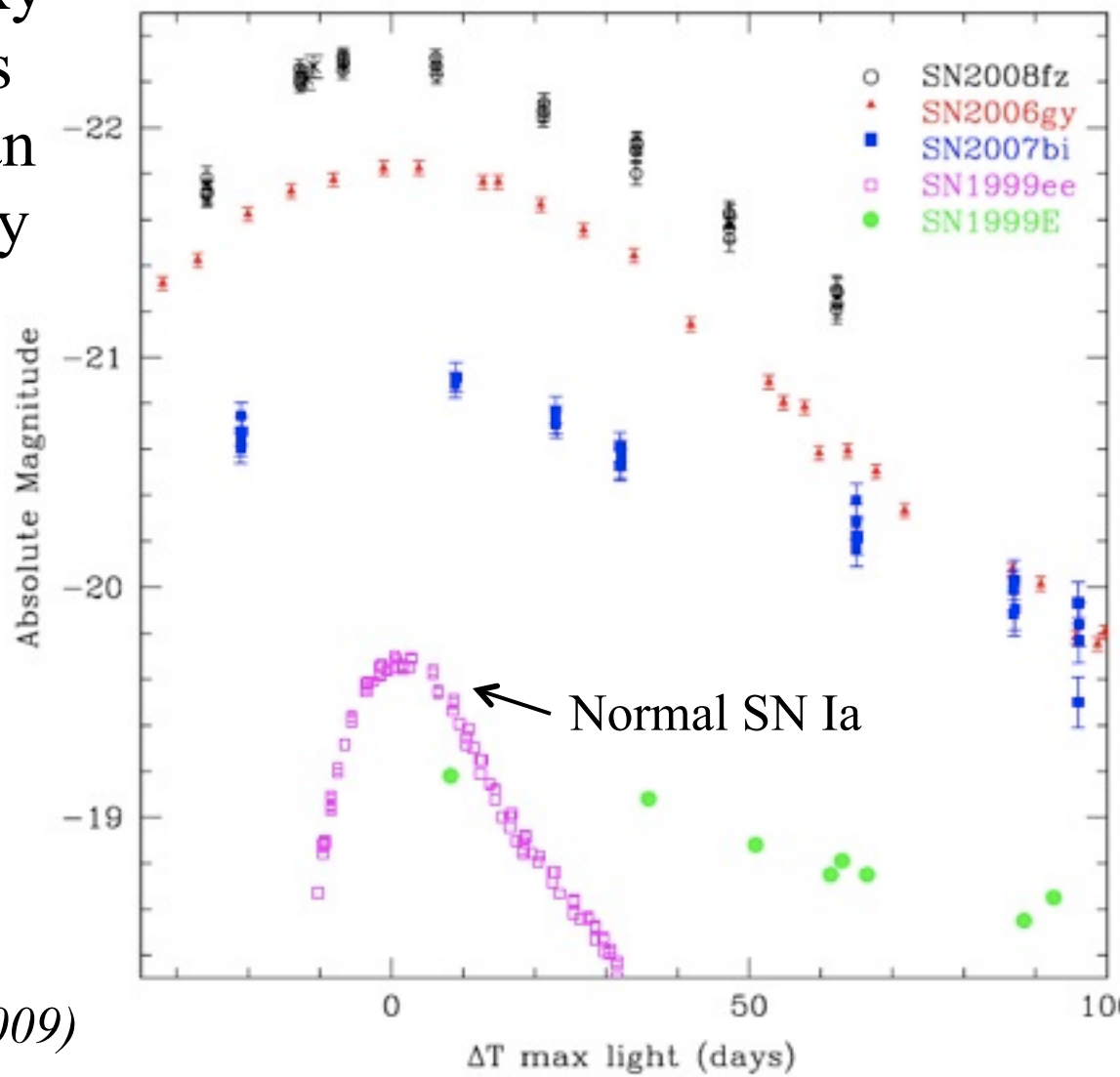
Baseline



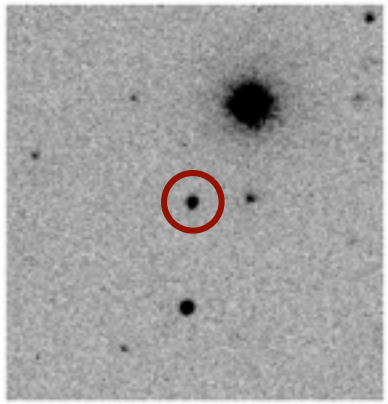
CSS 071218:120153-185822 = SN 2007sr: Ia in the Antennae merger

2008fz: The Most Luminous Supernova?

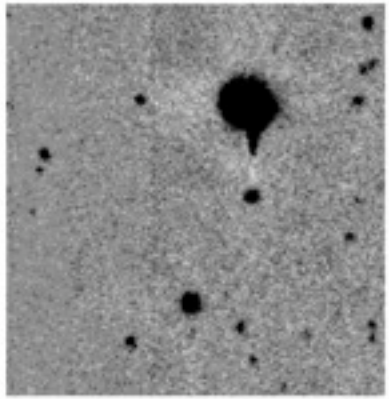
- Brightest type IIn known (5 times brighter than the Milky Way)
- Host galaxy > 50 times fainter than Milky Way



Discovery



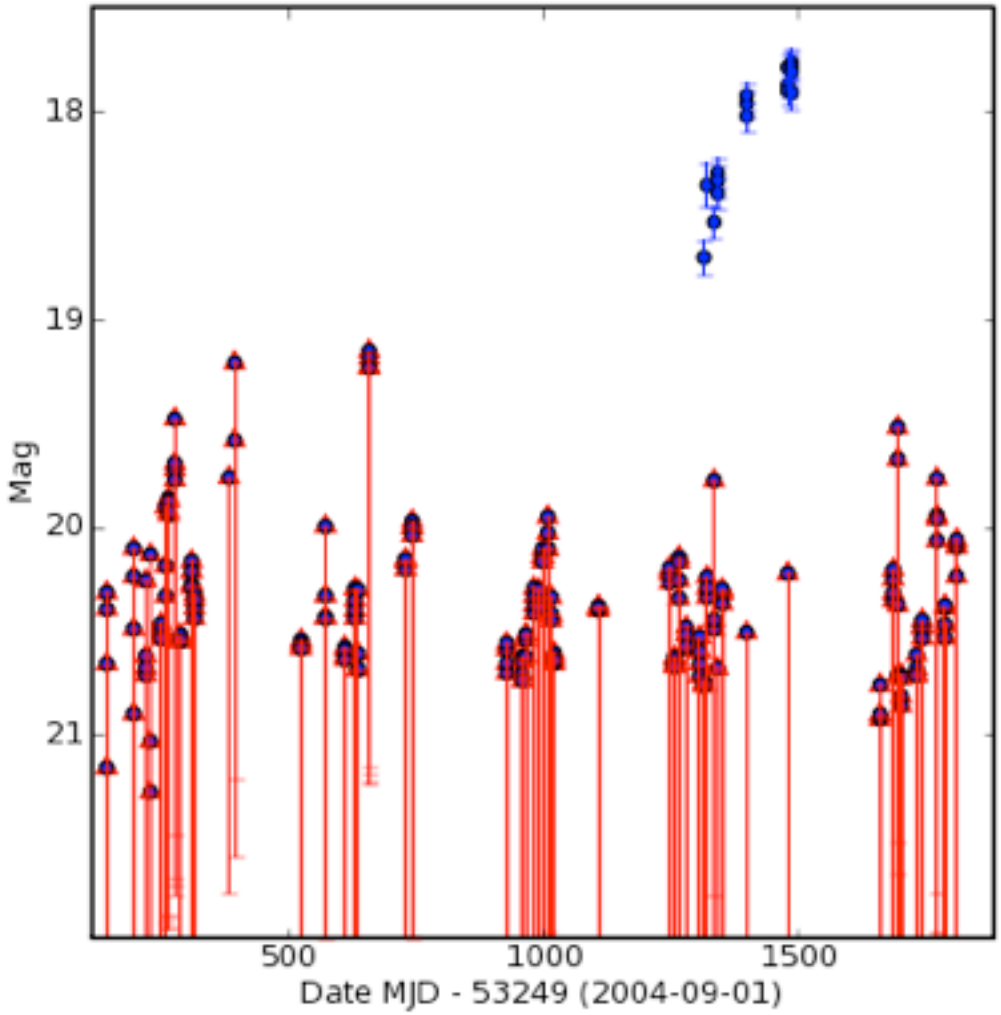
Comparison

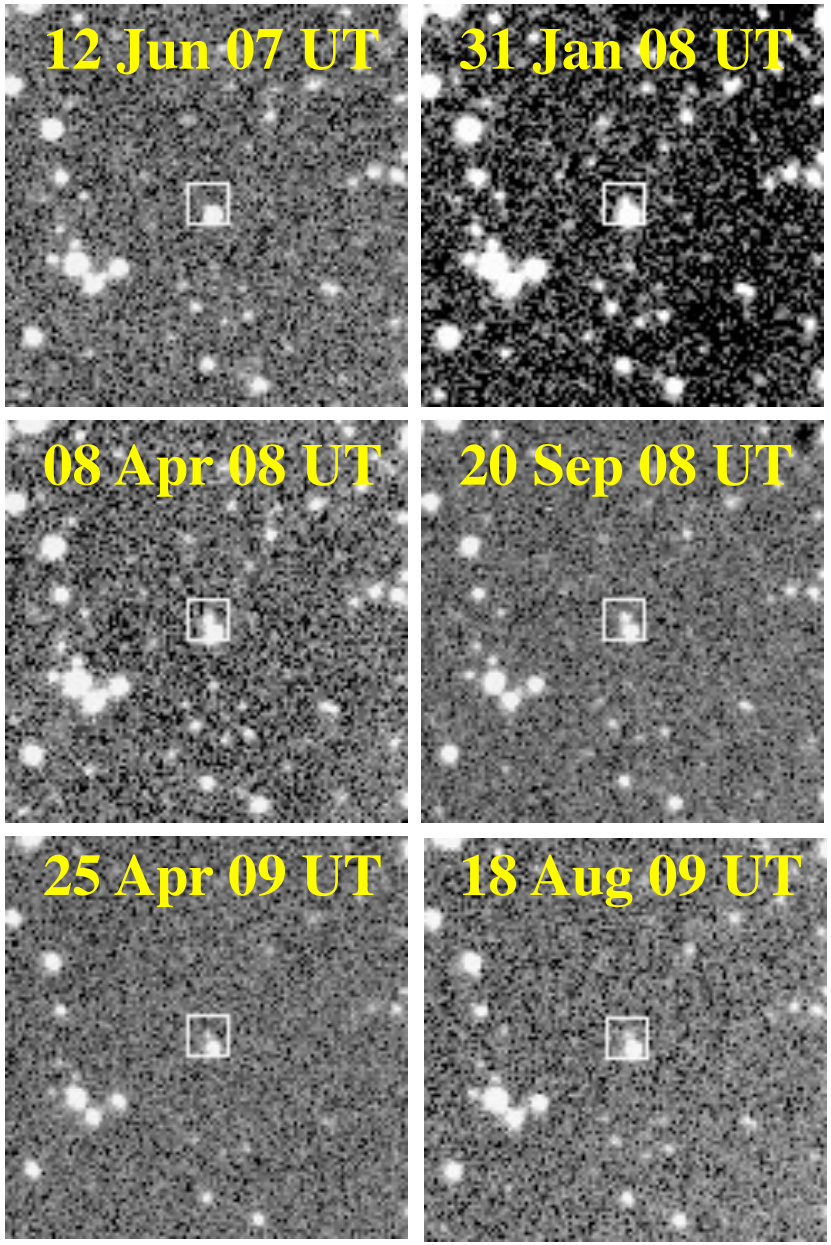


(Drake et al. 2009)

The Unusual SN 2008iy = CSS080928:160837+041627

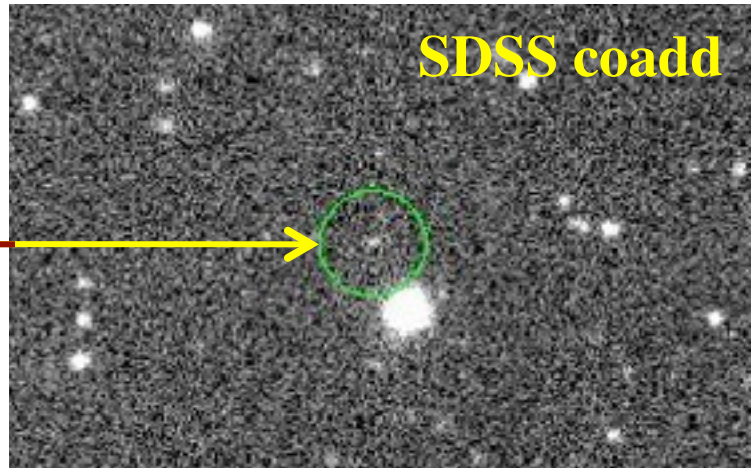
Longest-lasting type IIn at z = 0.041 (Catelan et al., CBET 1780): it took **> 400 days** to reach the peak!



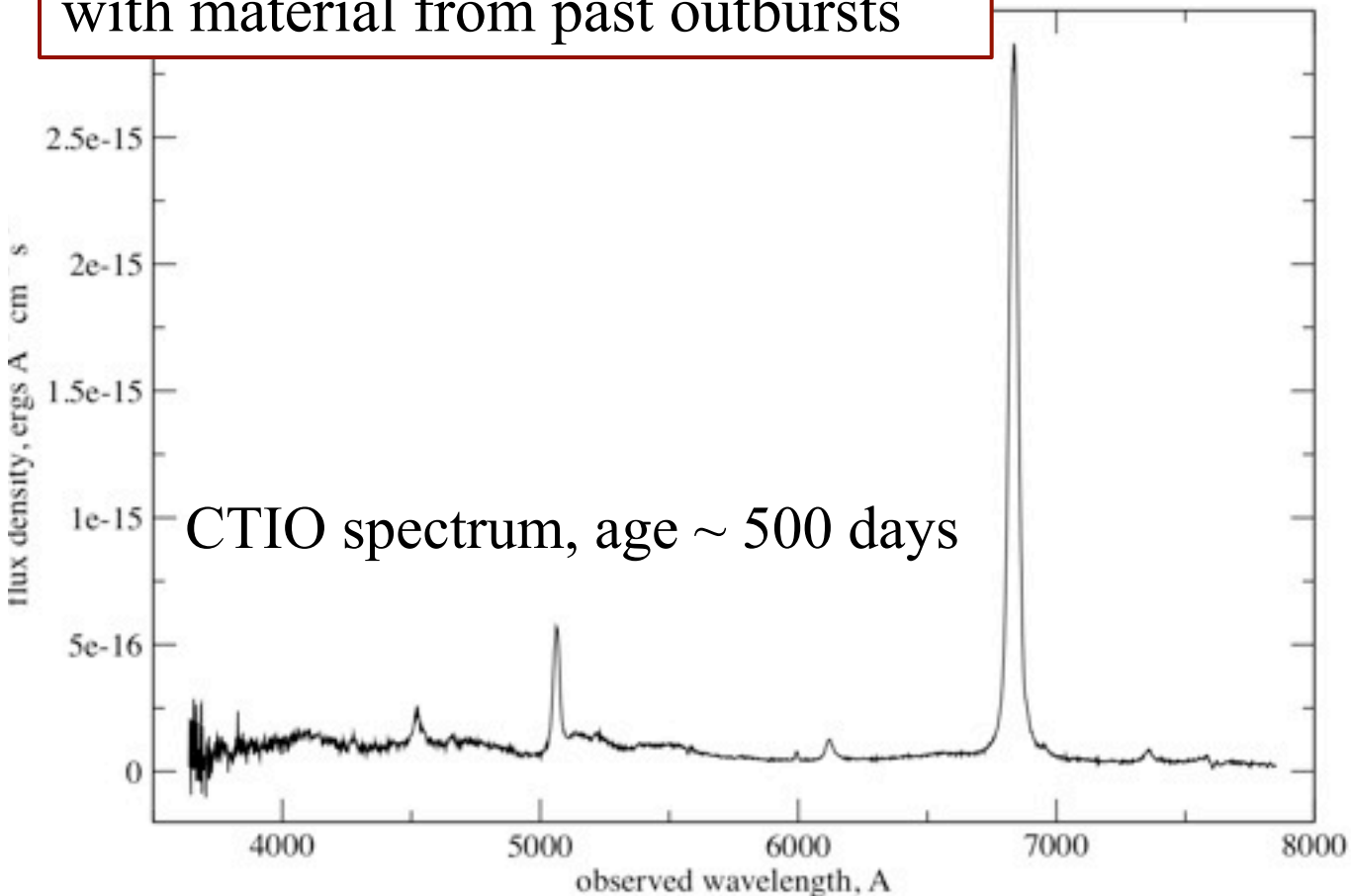


The Slow SN 2008iy

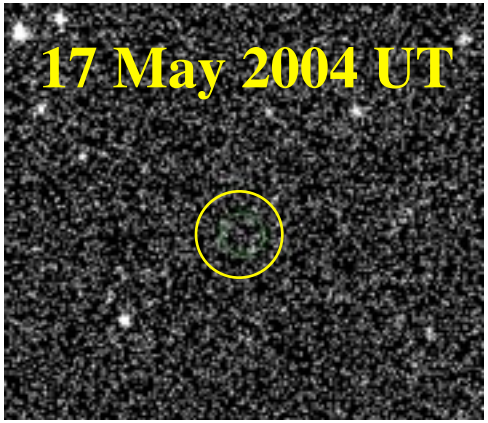
Host galaxy > ***500 times fainter*** than the Milky Way (~ 23 mag, M ≈ −13)

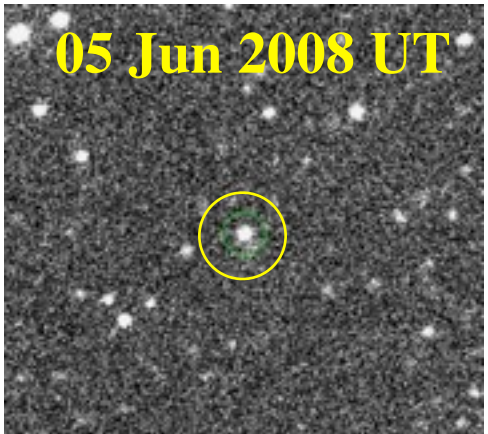


Possibly from a LBV (~ η Carinae) progenitor: expanding SN interacts with material from past outbursts



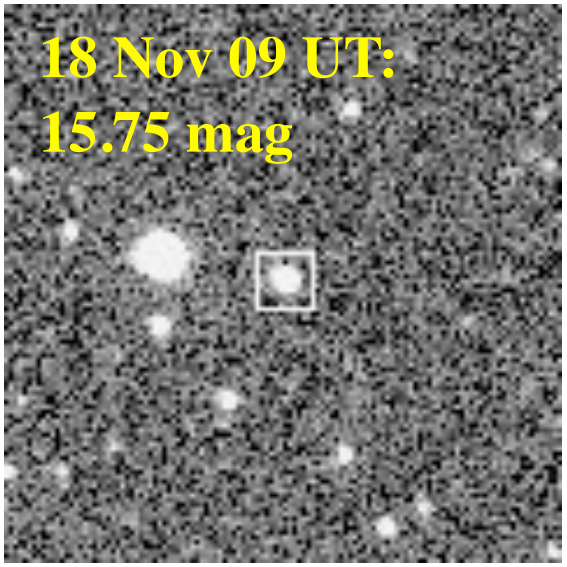
GALEX NUV:

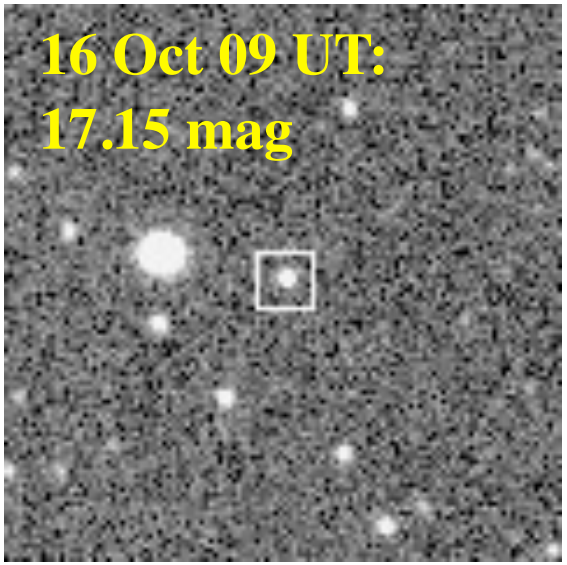


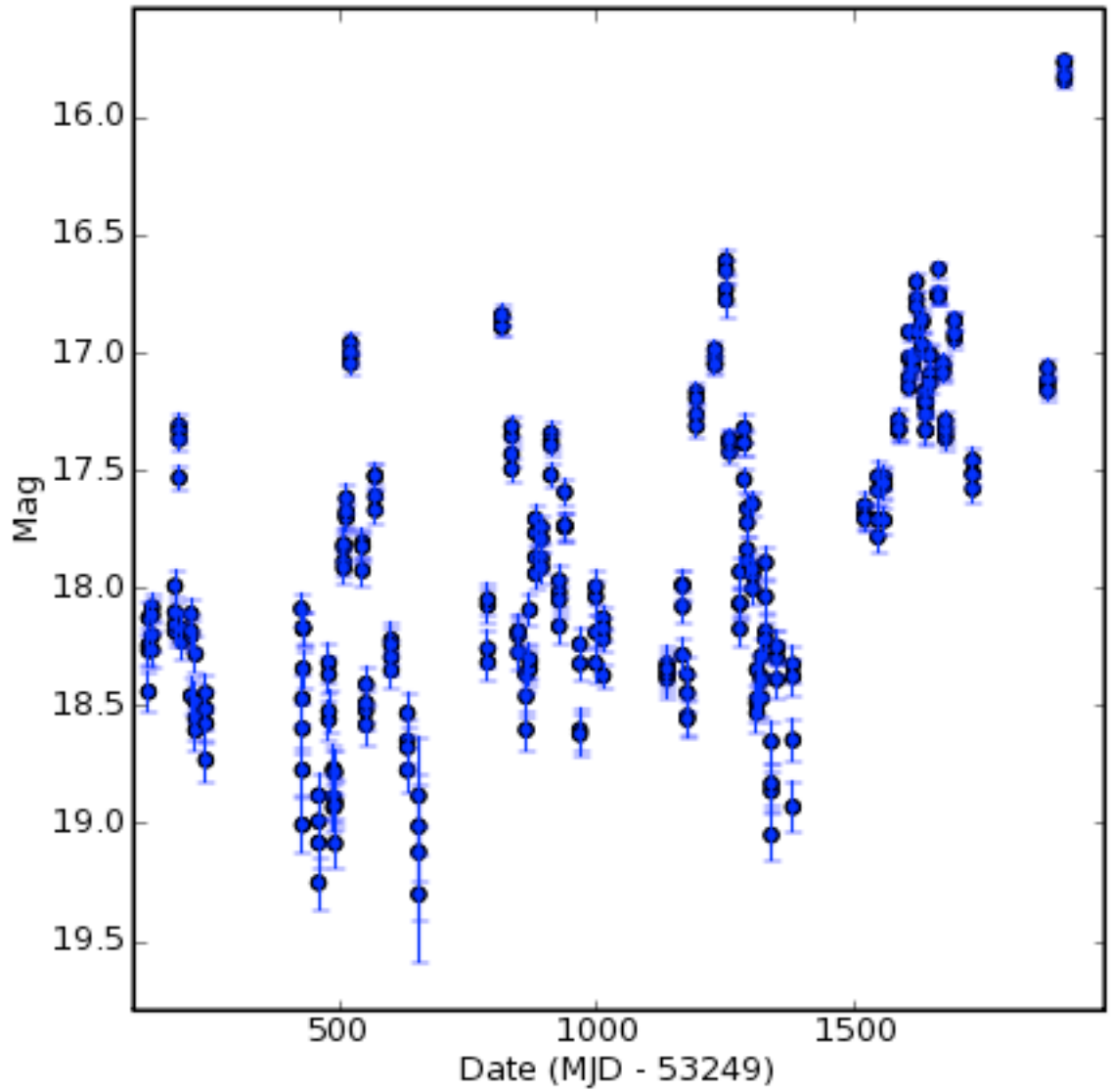


Blazar Flares: A Recent Example

CRATES J100110+291130 = CSS091118:100110+291130

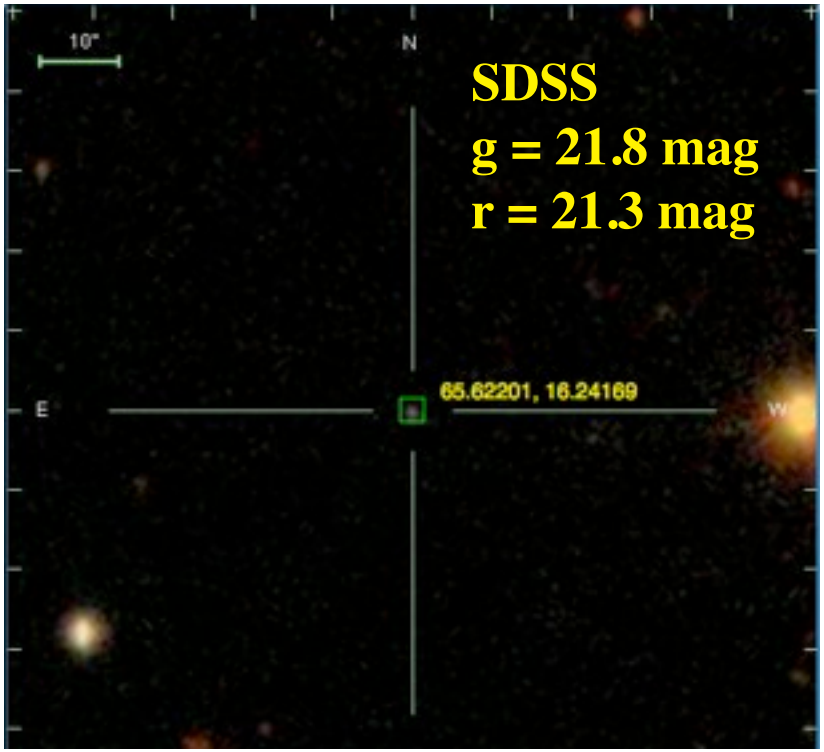


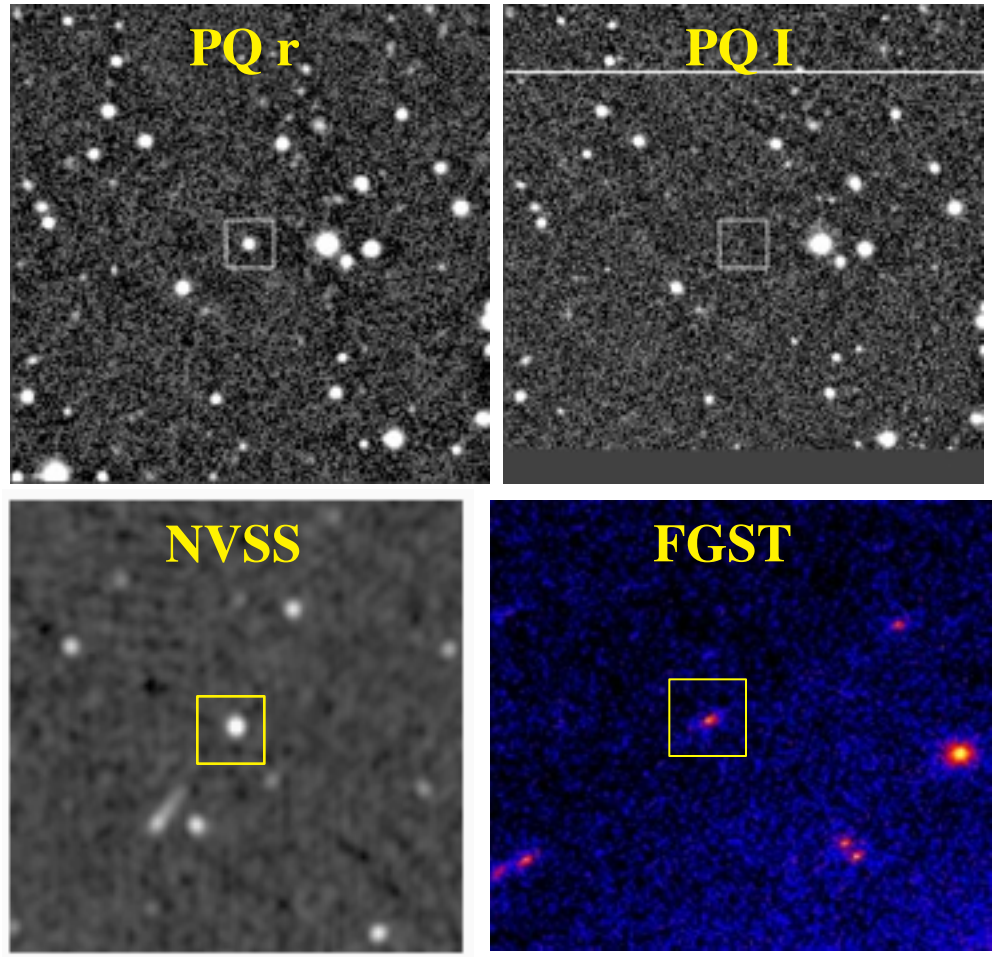




Blazar Flares: Mining the Archival Data

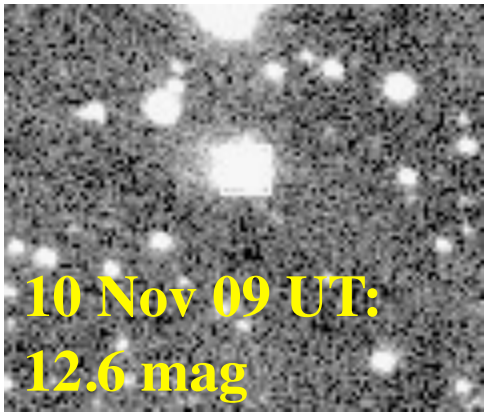
NVSS J012612+113009 =
CSS091110:012612+113016

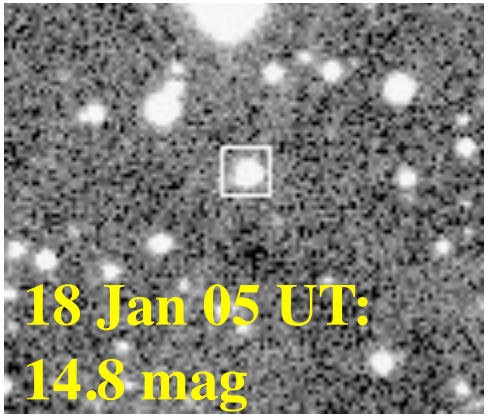


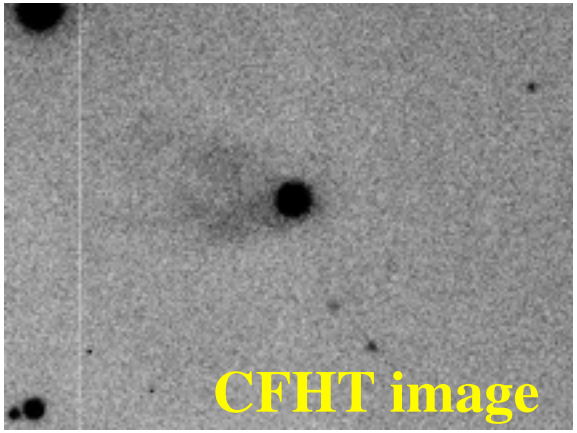


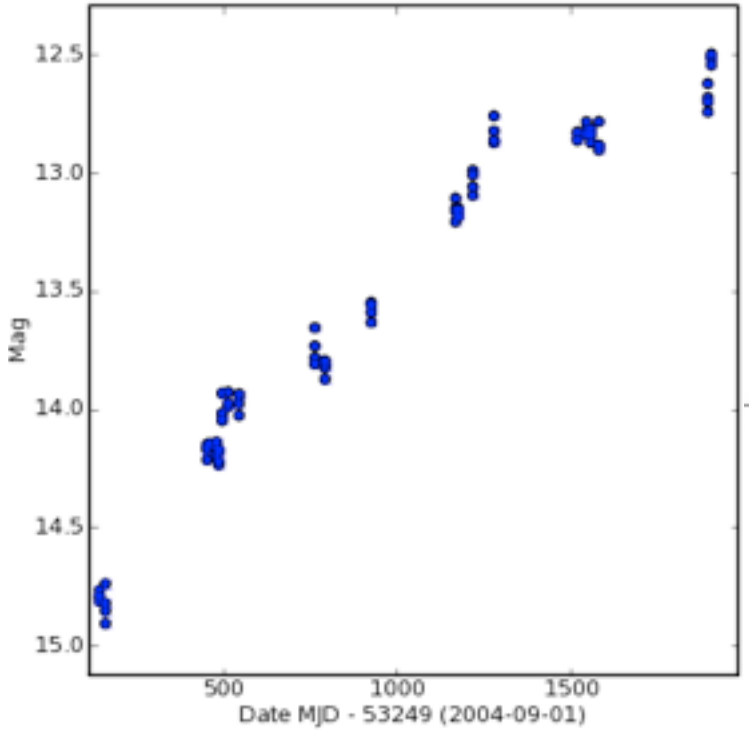
- Correlating blazar light curves from the visible, radio, and γ-rays, in order to constrain physical models
- Real-time correlated blazar flare discovery with CRTS+FGST

Discovery of a New FU Ori Object



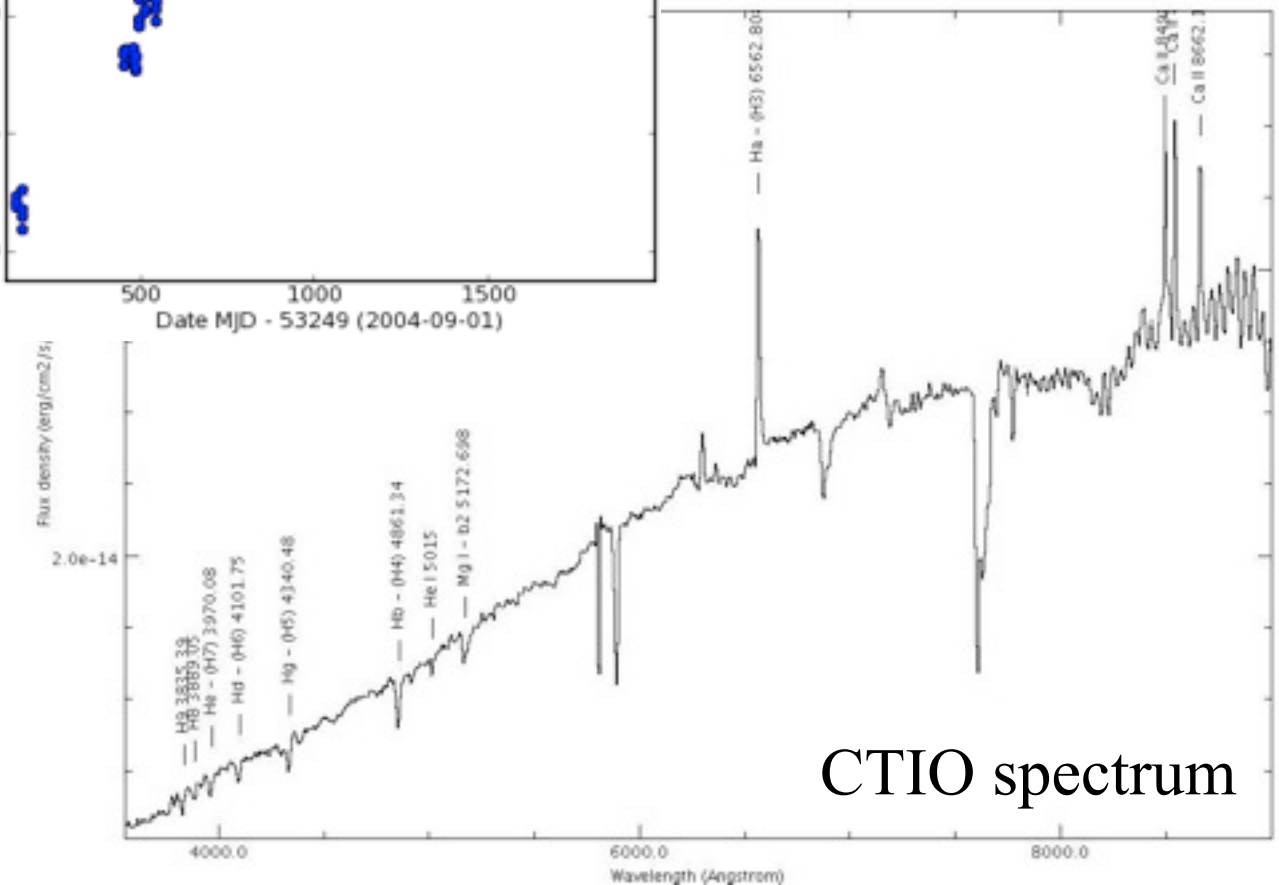






IRAS 06068–0641 =
CSS091110:060919–064155

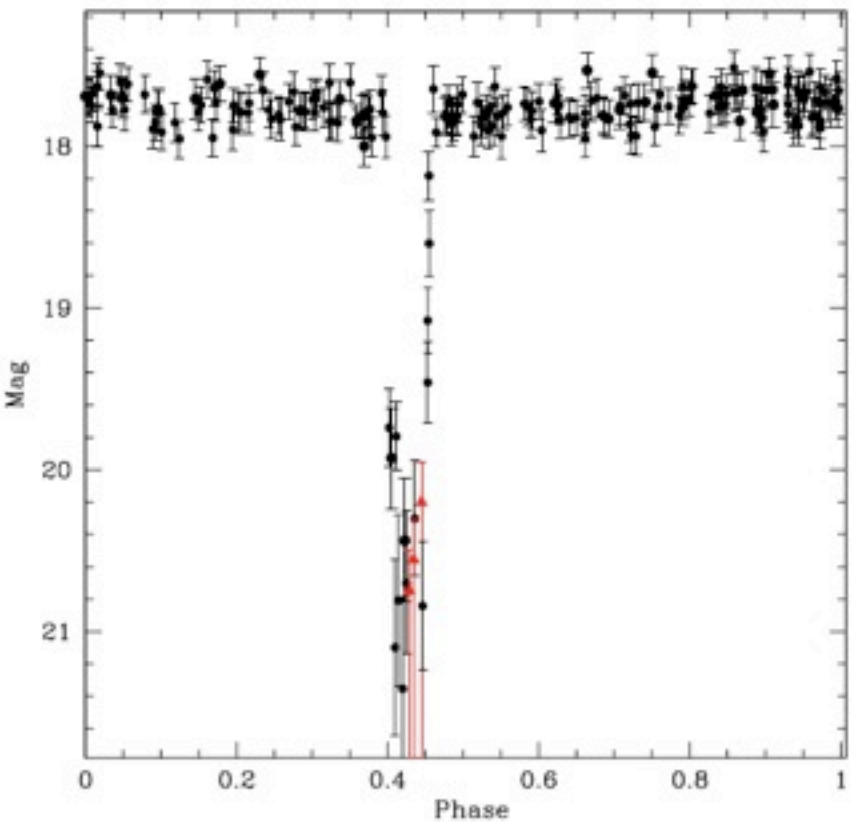
Wils et al. ATel 2307

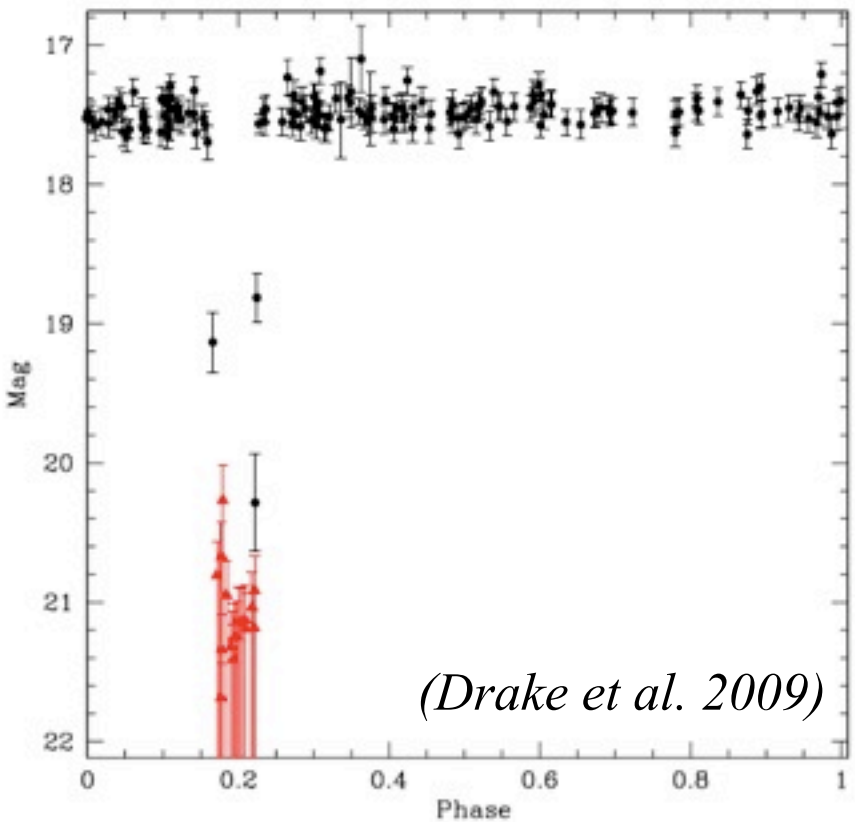


CTIO spectrum

Eclipsing White Dwarfs: Planets?

- Color-selected sample of WD candidates from CRTS + SDSS
- Light curves from CRTS: looking for eclipses
- Companion radii as low as a few Earth radii
- Some could be ~ Earth-size planets; or late-M/brown dwarfs; IR spectroscopy will tell

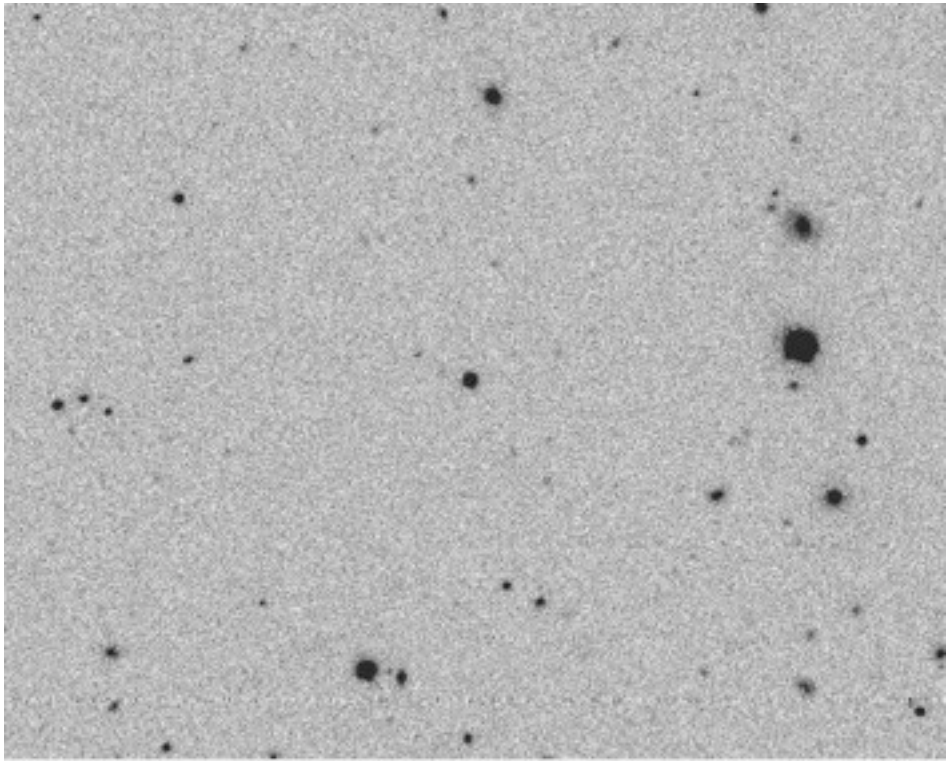




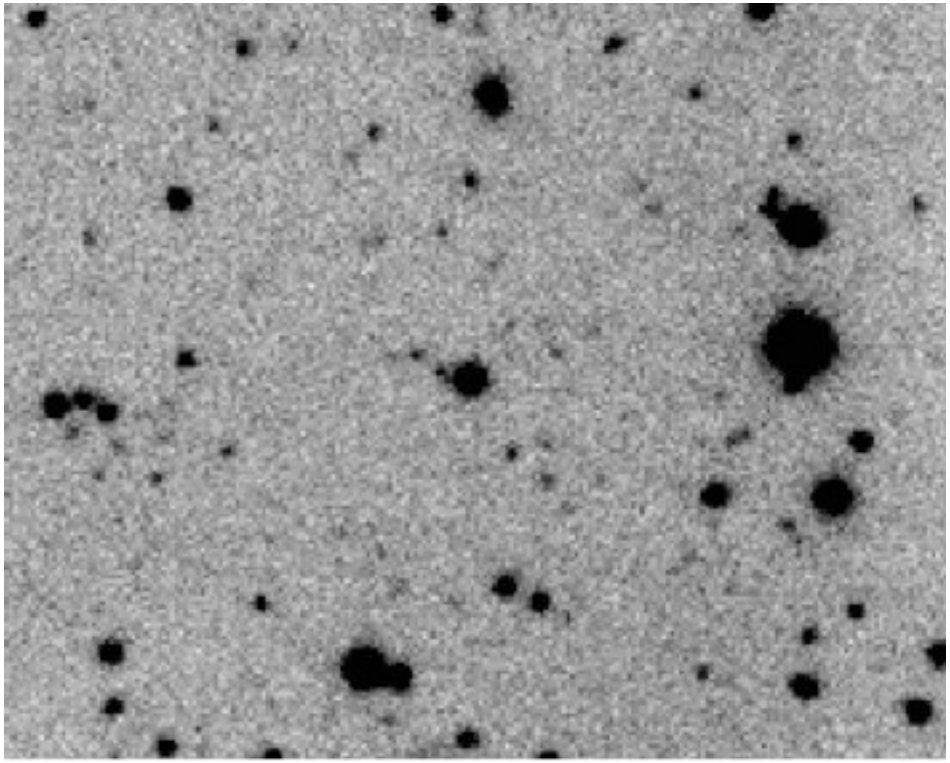
(Drake et al. 2009)

Coadded Images From MLS (1.5m)

SDSS



CRTS

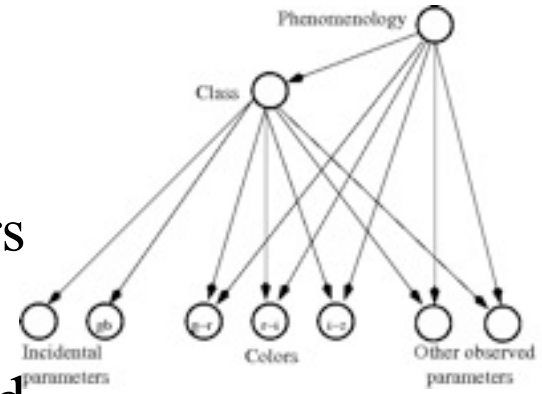


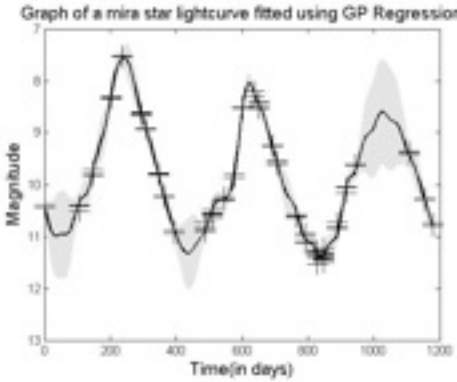
Combining the data from CRTS and PQ (DeepSky), we will have a reference sky coverage of ~ 3π sterad to the depth of $r > 23$ mag, and the light curves (detections or upper limits) for all detected sources

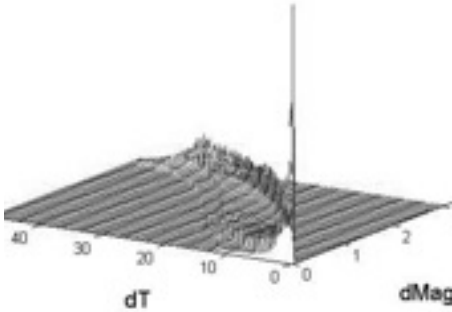
Automated Classification of Transients

A critical and growing need for synoptic sky surveys

- Efforts started with the PQ survey, now continuing with CRTS and soon PTF
  - Collaboration with CS experts: M. Turmon, B. Moghaddam (JPL), D. Heckerman (MSR), others
- Exploring Bayesian Nets, Gaussian Process Regression; also using Neural Nets for selected tasks; Markov Logic Chains, MAB, etc.
- A key importance of the contextual information: e.g., presence of the possible host galaxies, Gal. latitude, past light curve…
  - Very hard to encode in the traditional ML methods
  - Harvesting human pattern recognition through the "citizen science" projects







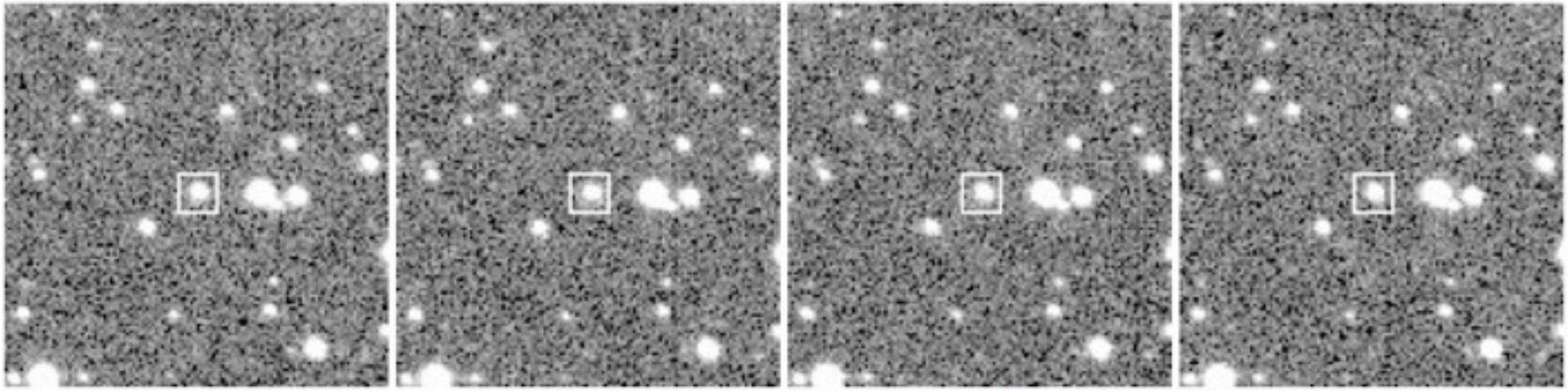
Crowdsourcing / Citizen Science

Harvesting the human pattern recognition skills

CRTS (Catalina) Event 6824.

Logged in as djorgovski

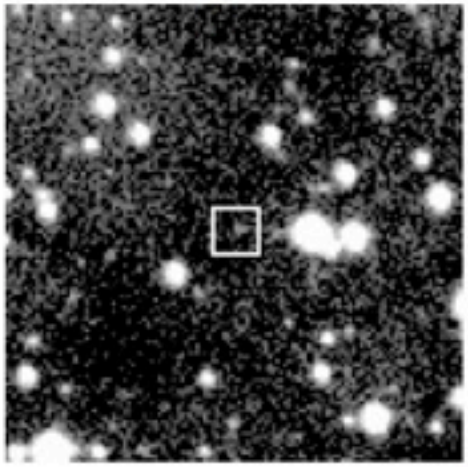
New images



First we would like to understand if the set of images that you see represents a real astronomical object, such as a star getting much brighter, or if it is an artifact or other man-made cause that is nothing to do with what is really happening in the deep sky.

Does this look like a real star field? Is it Real or is it Artifact?

Reference Image



- ☐ Do you see a source in middle of the central box for each of the new images? ...more
- ☐ Has it moved from the reference position? ...more
- ☐ Is there a host galaxy? ...more
- ☐ Is there a bright star in the image? ...more
- ☐ Does this image look strange in some other way besides those above? ...more
- ☐ Is it a crowded field? ...more
- ☐ Do you think there is a true transient detection here? ...more

Click to submit results: submit result

Summary

- CRTS is producing a steady stream of transients, including blazars, SNe, CVs, etc.
  - All events are published in real time, with no proprietary period
  - All data (images, catalogs, lightcurves) will be made public
  - Time baselines from 10 min to several years
  - CSS+MLS+SSS coverage up to ~ 2500 deg^2 daily, 4 exposures per field, ~ 30,000 deg^2 total, hundreds of epochs
- ***We can follow up only a modest fraction***; this is a problem which will plague all synoptic sky surveys for a while
- Numerous scientific projects are under way
  - Blazar science is largely driven by the *Fermi* opportunities
  - SN science: peculiar SN types, the puzzle of the faint hosts
- A strong outreach component ("citizen science", WWT)
- A major effort on automated classification of transients