The Optical Transient Sky:

Arne Rau (Caltech)

History: Optical Transients and Variables

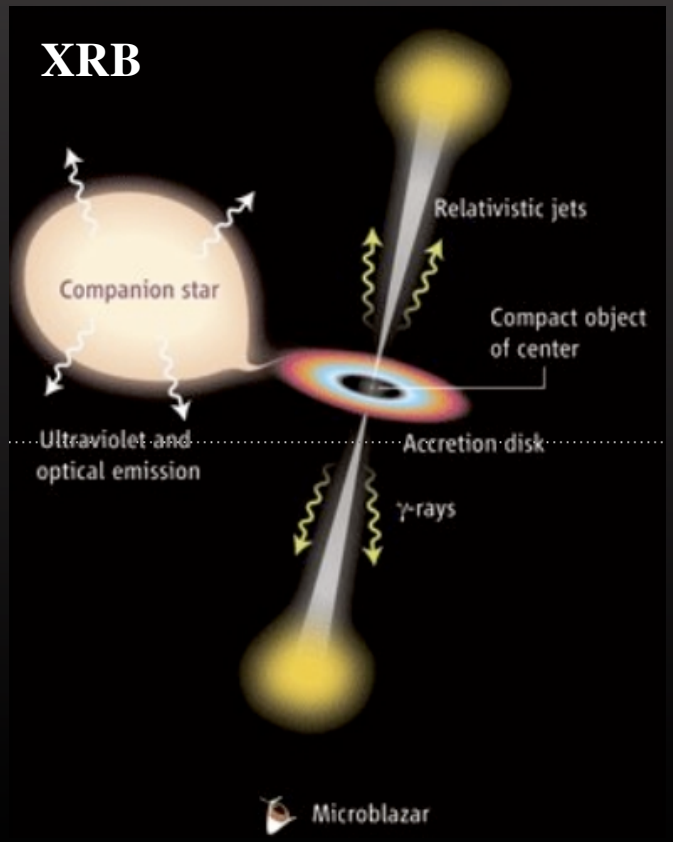
- until mid 20th century, transients and variables were major focus of astronomy
- discovery of Supernovae, Planets, Comets, Novae
- distance to M31 using Cepheids

1054 A.D. / Crab

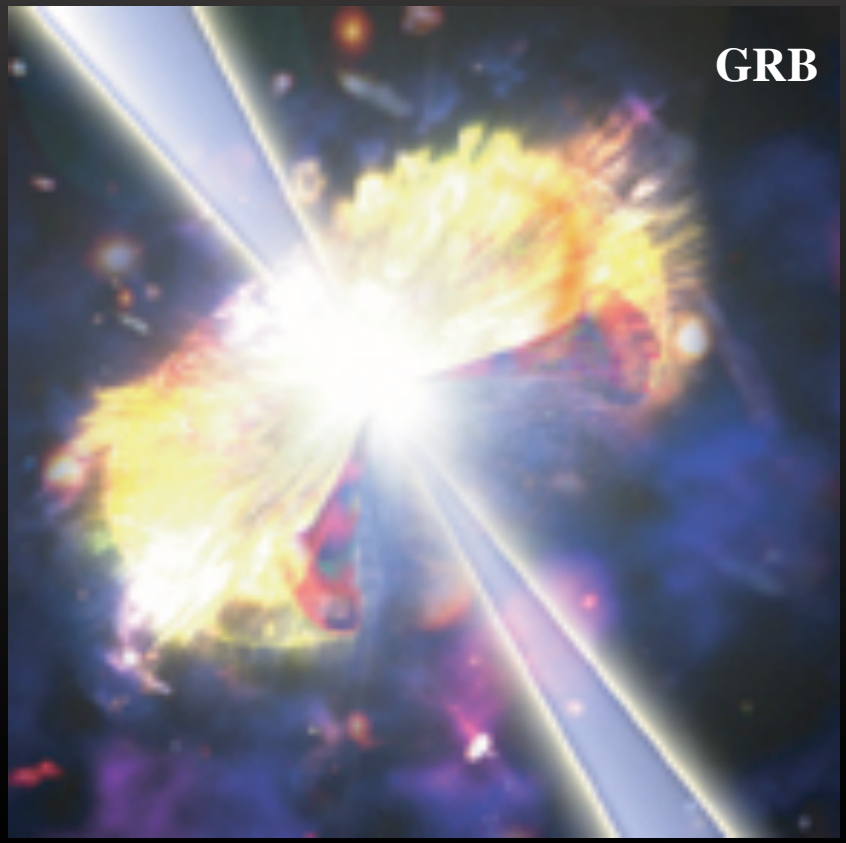
M31 (Roberts 1899)

Recent History - Shift to other wavelengths

- Discoveries outside the optical (e.g., Pulsars, X-ray Binaries, Gamma-ray Bursts)
- Radio, X-ray and Gamma-ray sky scant is of sources



(Mirabel et al.)



(NASA/GLAST)

The Optical Zoo - Known Knowns, Known Unknowns and Unknown Unknowns

Known Knowns:

Eruptive:	SNe, Novae, Dwarf Novae, Luminous Blue Variables, AM CVn, AGN
Pulsating:	Cepheids, RR Lyr, Delta Scuti, Mira
Magnetically-driven:	UV Ceti, RS CVn, CU Virginis
Geometric:	Microlensing, wide binaries, planetary transits

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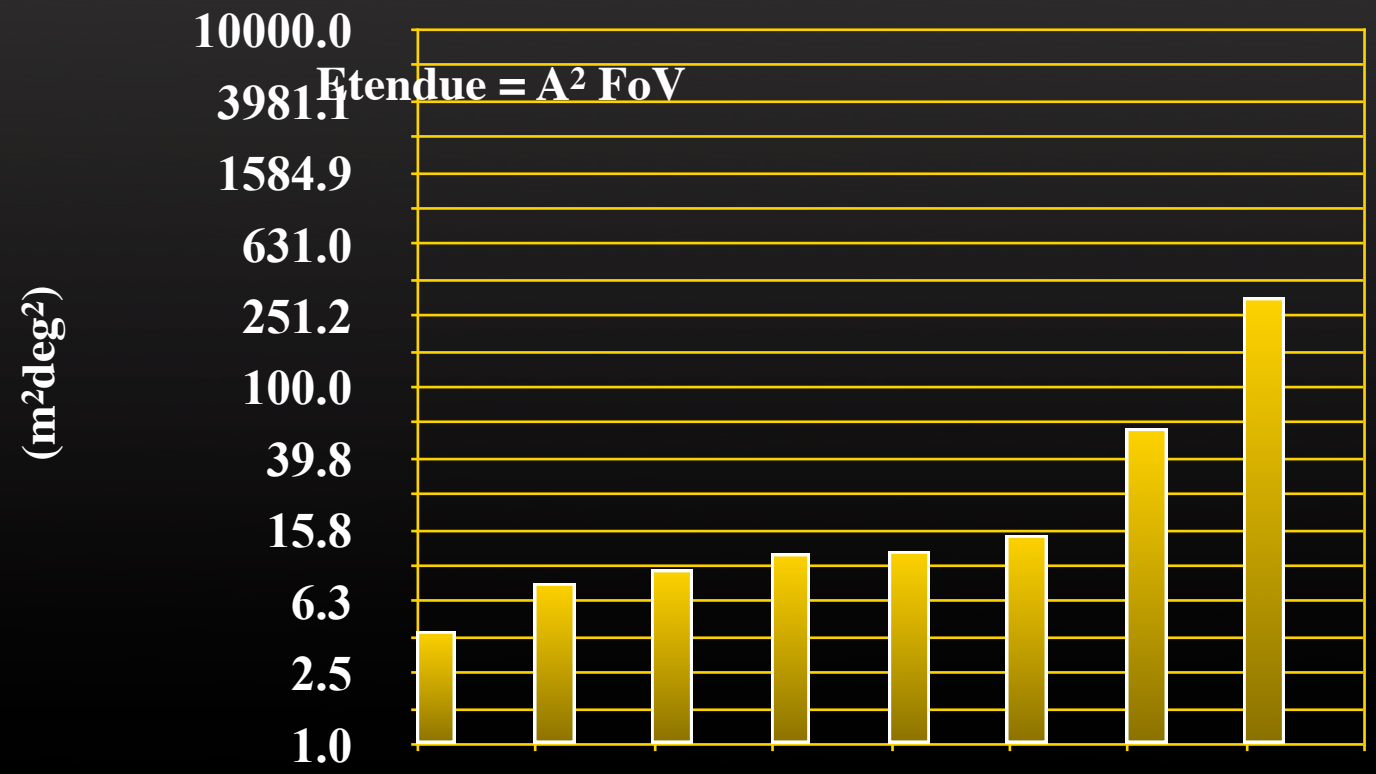
Unknown Unknowns:

?, ?, ?, …

A New Dawn

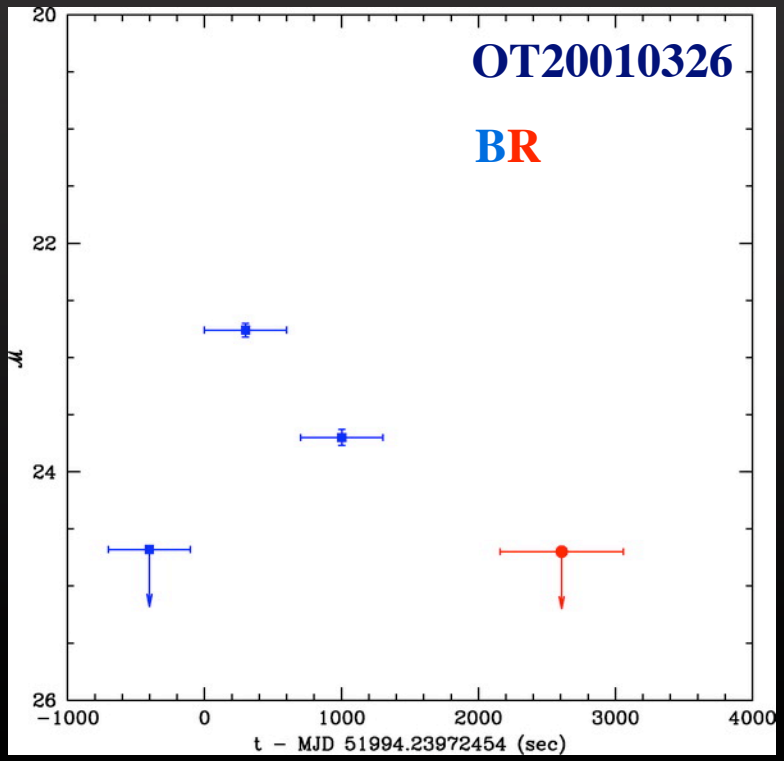
- survey renaissance due to technological advances (sensors, computing, storage, network)
- SkyMapper (2007), Pan-STARRS1 (2007), VISTA (2007), LSST (2013)
- **BUT:** require renaissance in transient/variable selection

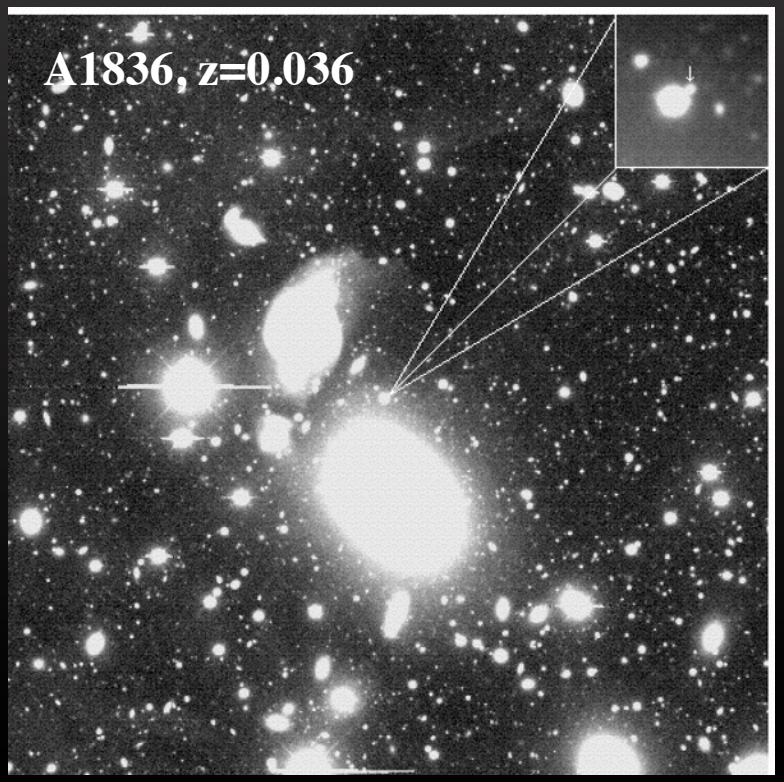


The Deep Lens Survey Transient Search

(Becker et al. 2004, ApJ)

- high Galactic latitude survey at CTIO/Blanco and NOAO/Mayall from 1999-2005
- repeated 600-900s exposures in BVRz'
- 2 unidentified fast transients





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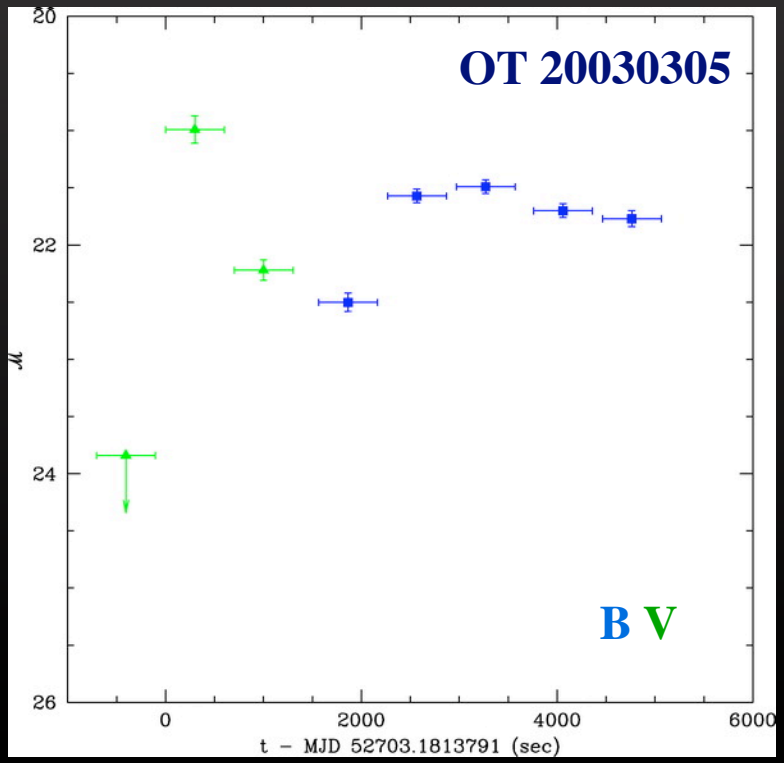


- counterpart at R=24.6, z'=21.4
- inconsistent with PSF (χ^2=11.3/3)
- extra-galactic?

Appreciation of Rates

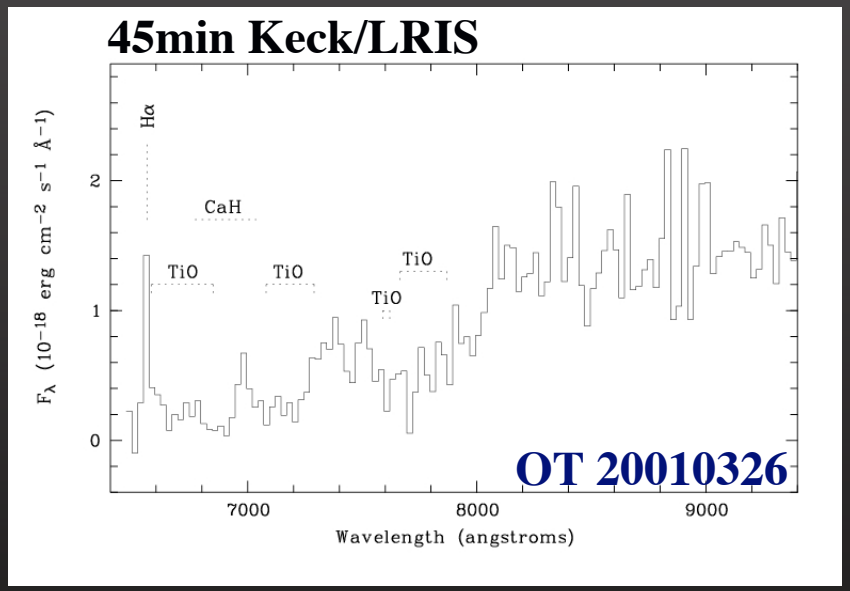
- if both extra-galactic, than staggering annual rate of 10^8 events per year (3 per second)

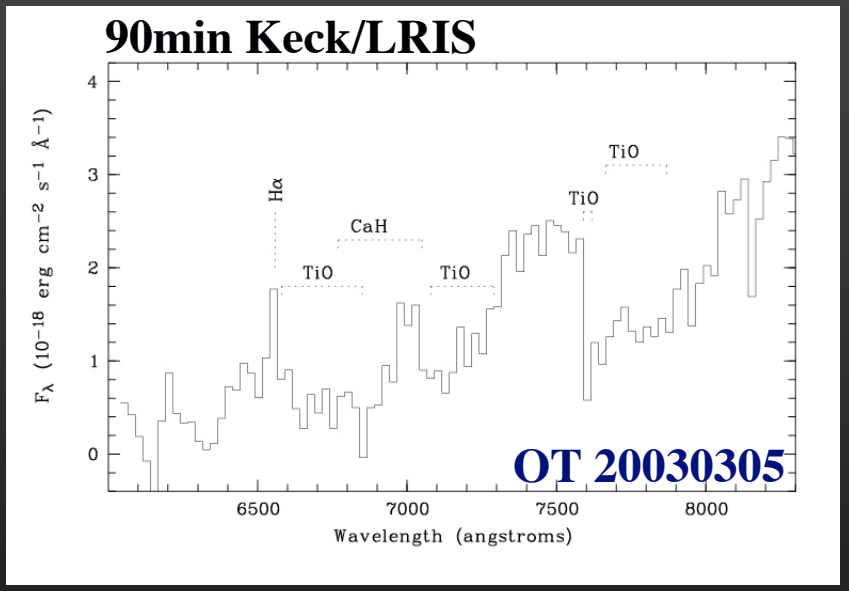
(z=0 rates, Kulkarni & AR 2006)

Type	Rate (Gpc^{-3} yr^{-1})	Reference
Long-soft GRBs...	~30	Guetta et al. 2005
Core-collapse SNe...	$\sim 5 \times 10^4$	Cappellaro et al. 1999
Short-hard GRBs...	$10–10^5$	Nakar et al. 2005
Novae...	$\sim 10^8$	See below

Unusual kind of Novae? But bright as SN and fading much faster!

Spectroscopic Identification





(Kulkarni & AR 2006, ApJ)

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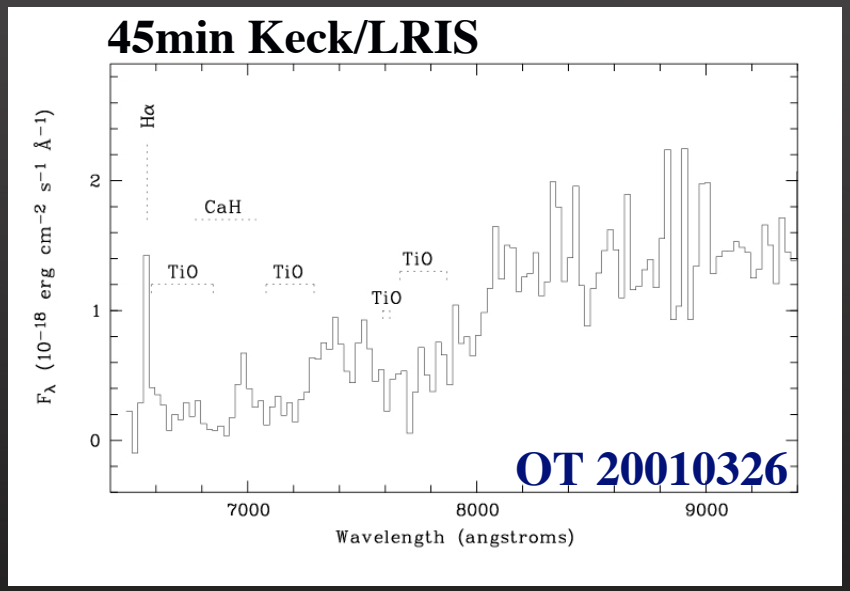

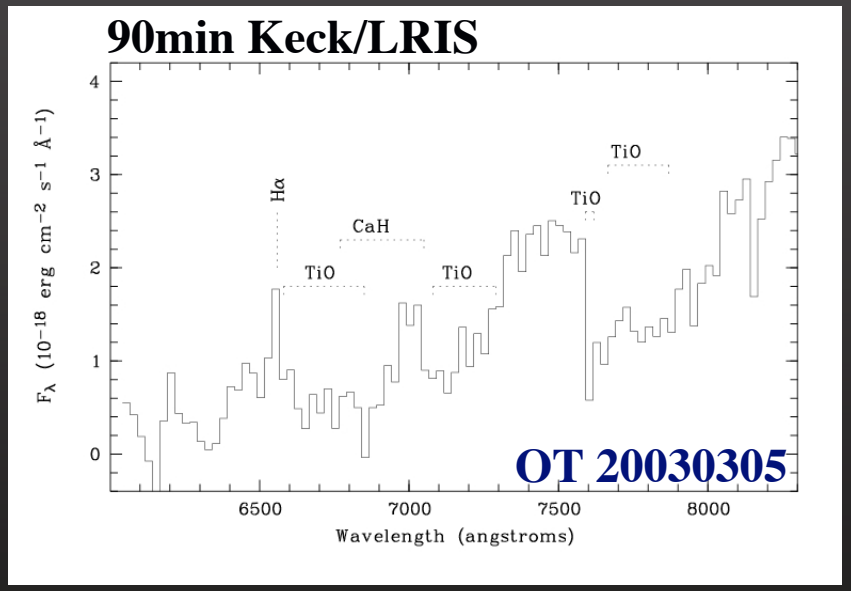

(Kulkarni & AR 2006, ApJ)

DLS transients = Flares from Galactic M dwarfs

- Similar to solar flares, but on larger scales (1/5th of the circumsphere)
- heating and acceleration of plasma in magnetic reconnection
- high Galactic latitude suggests detached binary (RS CVn)

Lesson Learned I

- flare stars with rate as high as 10^8 events per year
- outnumber genuine sources by (at least) factor of 100
- old friends: false GRB afterglows (Greiner & Motch 1995; Gizis 2000),
  Catalina transient in Lynx (Djorgovski et al. 2004),
  CFHT fast transient (Price 2005)

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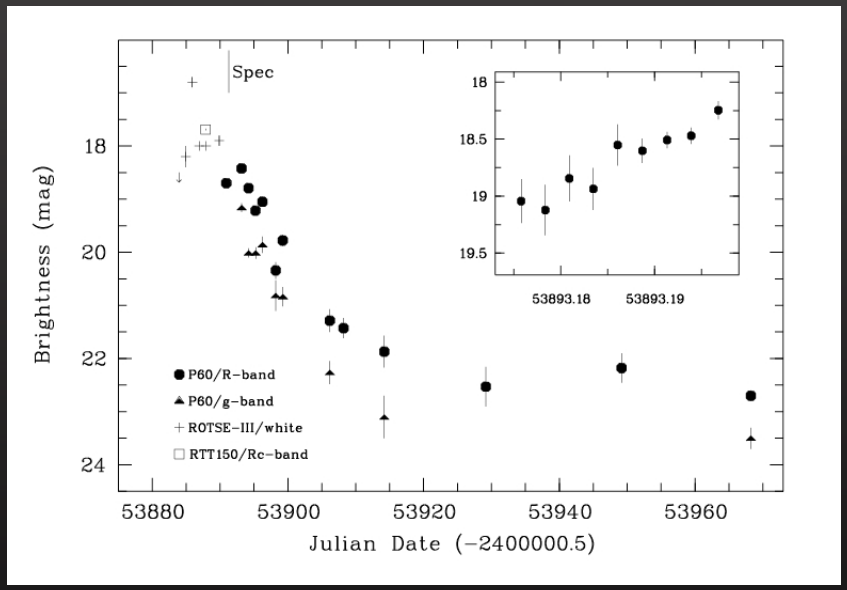
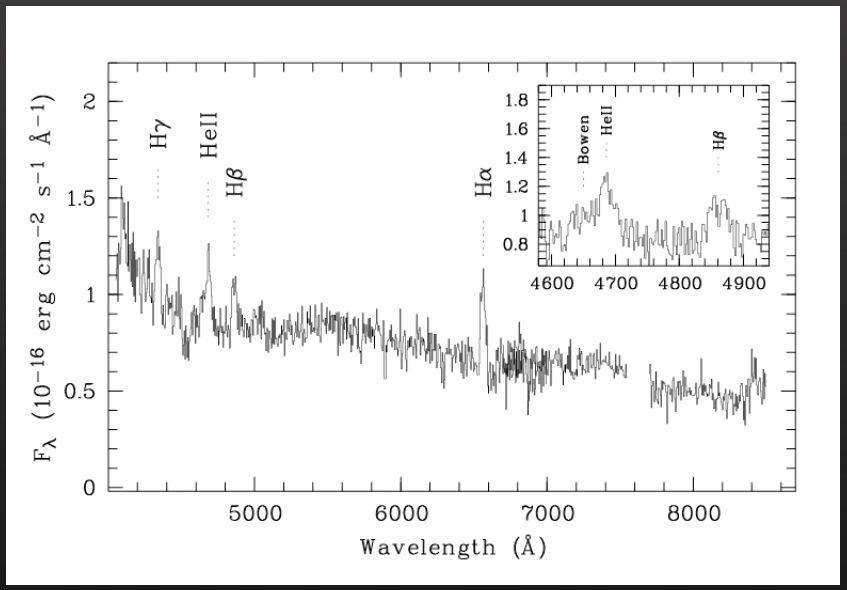
How to penetrate the Flare Star Fog

- extent may be gaseous nebula after multiple flares or asterism
- location close to galaxy must not mean association
- make use of UV colors
- judicious choice of direction (high Galactic latitude) and
  filter (not too blue)
- pre-search for dM with deep K-band imaging

ROTSE Transient J160213.1-021311.7

- in ROTSE-III sky patrol fields in May 2006 (Rykoff et al. 2006)
- no known counterpart (DSS, 2MASS)





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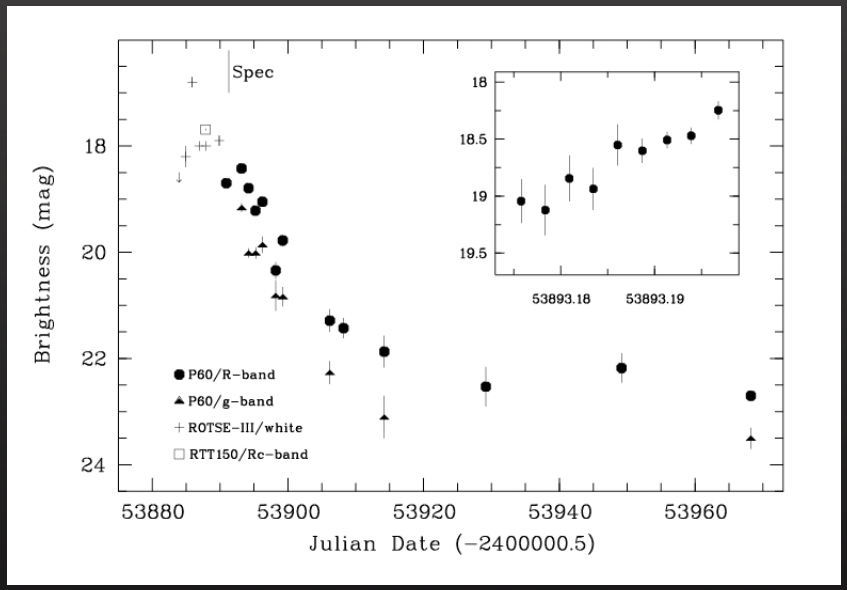
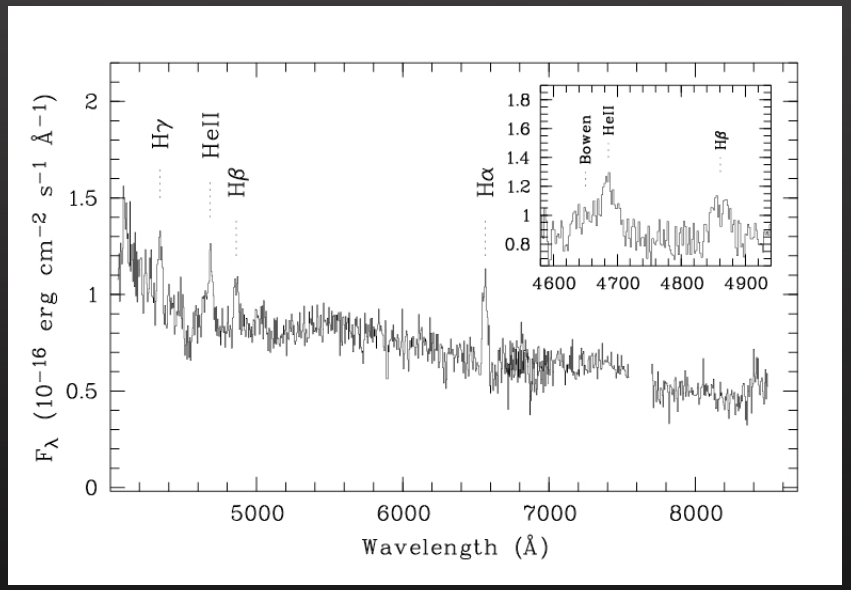


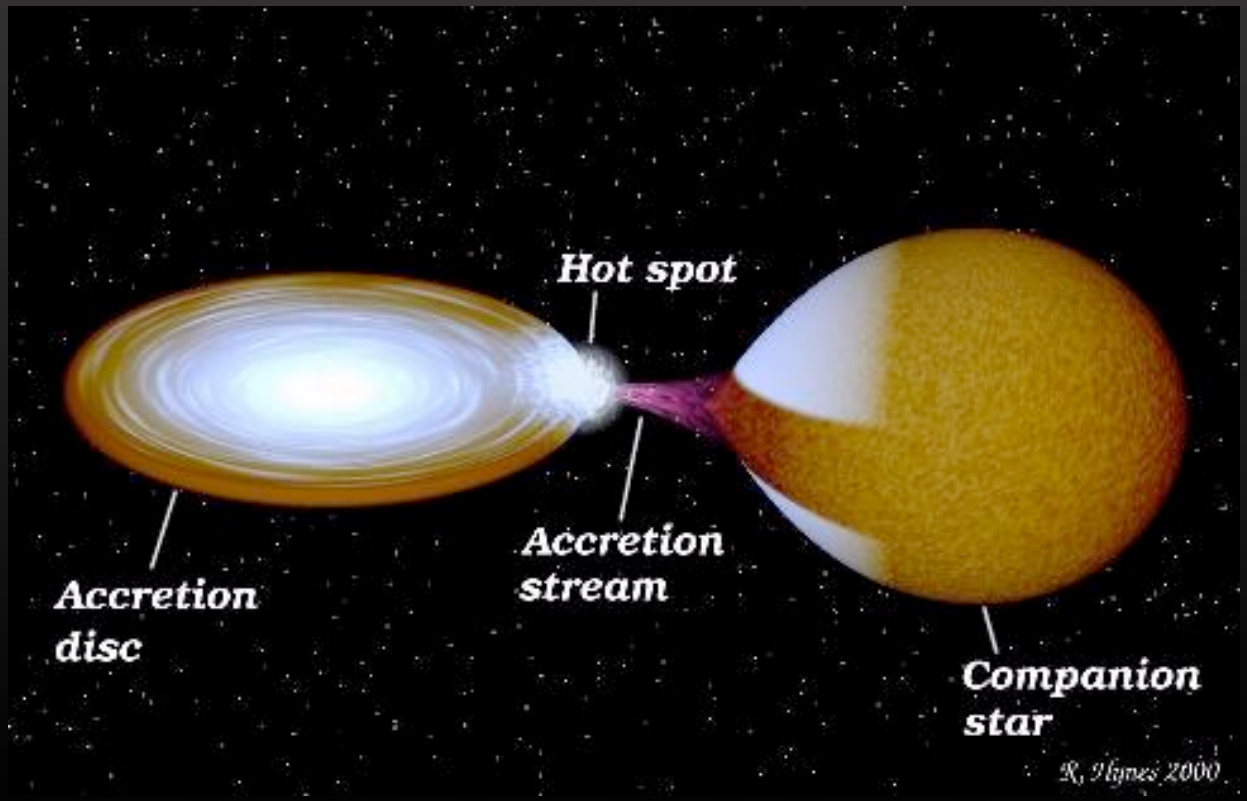


(AR et al. 2007a, ApJ)

Superoutburst from Dwarf Nova

Interlude: Dwarf Novae

- cataclysmic variable, consisting of close binary (WD + X)
- outbursts caused by sudden viscosity changes in the accretion disk
- typical amplitudes of 2-8mag in SU Uma type DNe



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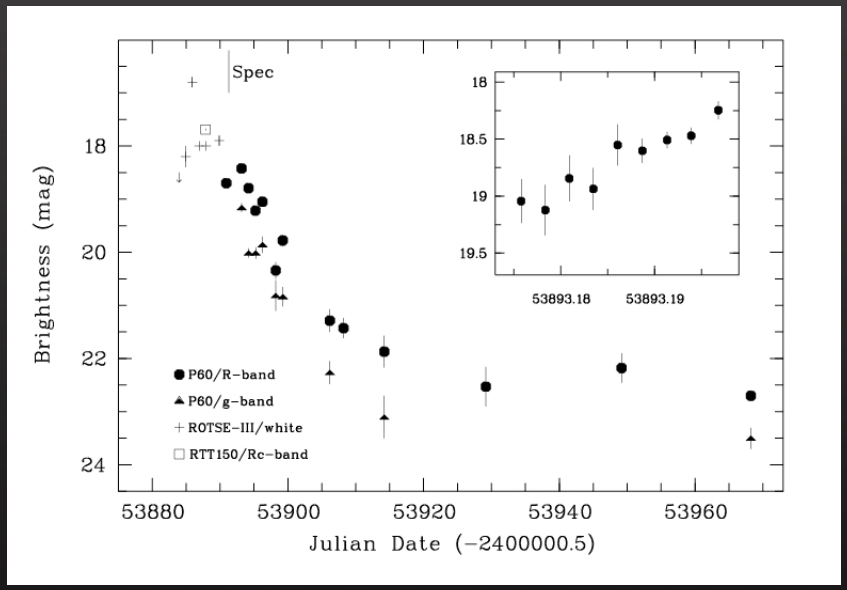

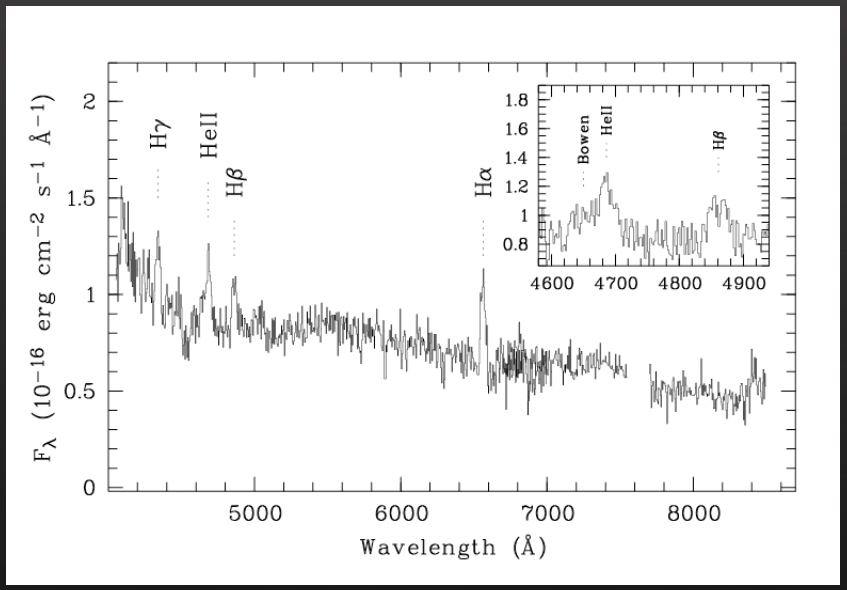

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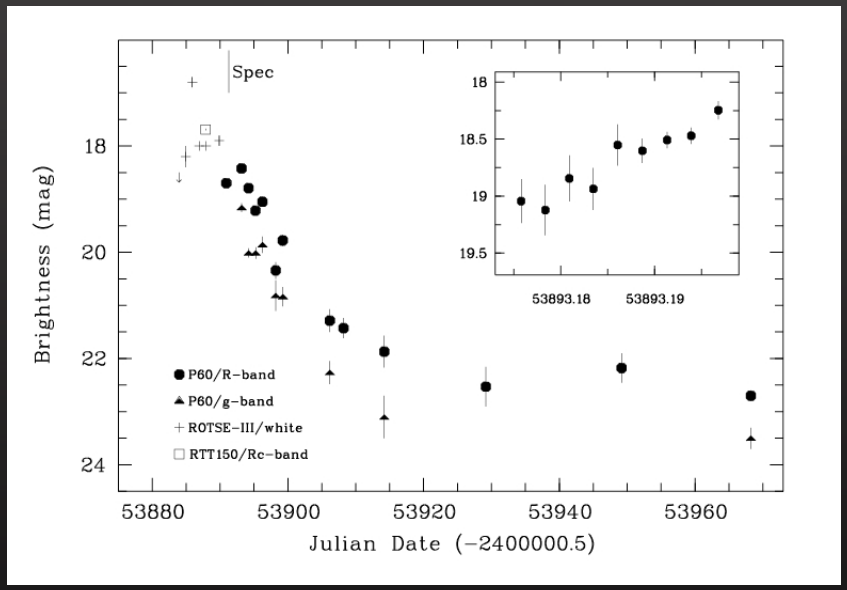
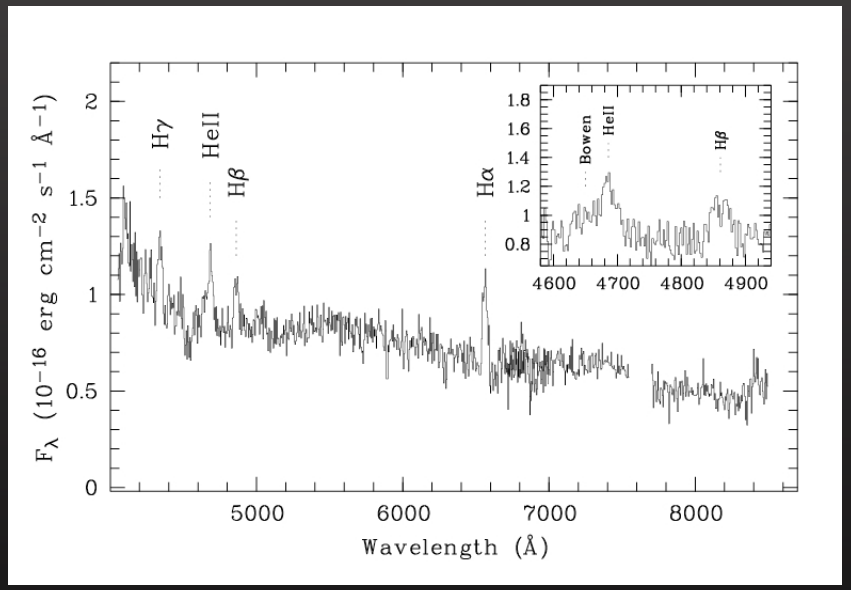




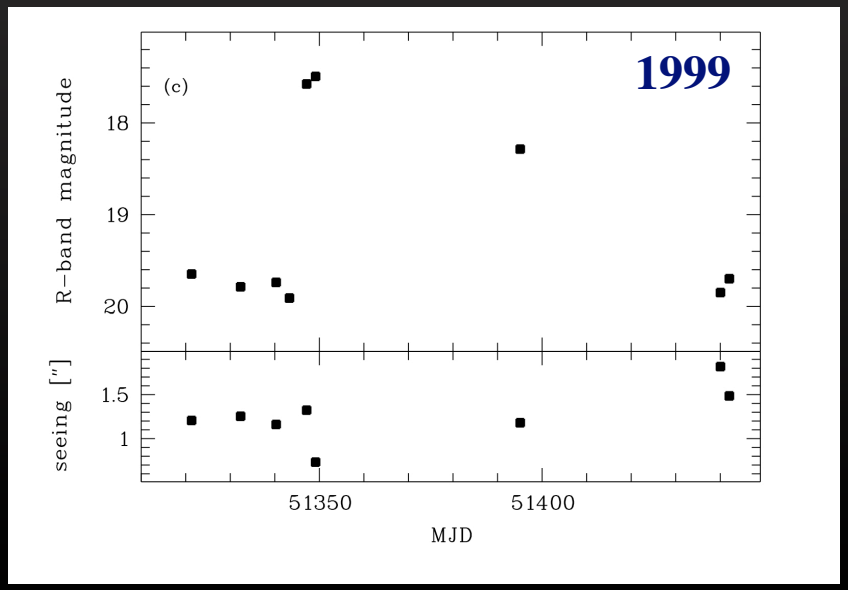
(AR et al. 2007a, ApJ)

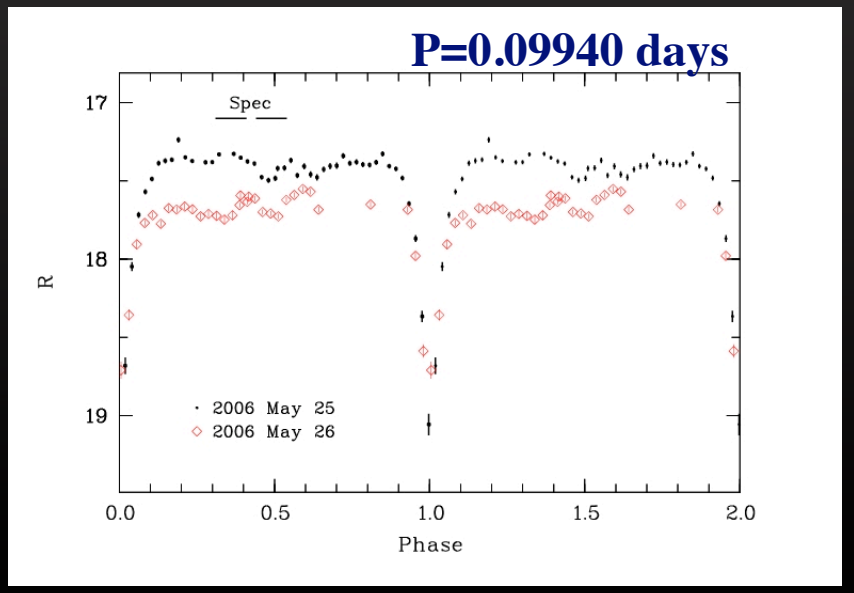
Superoutburst from Dwarf Nova

- Hα FWHM = 2000km/s
- double peaked lines indicate disk system
- color suggests cold disk with low mass transfer

WFI Transient J161953.3+031909

- in ESO/MPG 2.2m WFI Orphan Afterglow Search (AR et al. 2006, A&A)
- faint ROSAT source
- LRIS spectrum in 2006: with high inclination disk DN in quiescence (low mass accretion rate)
- uncanny coincidence of orbital period and observing schedule





(AR et al. 2007a, ApJ)

Lesson Learned II

- 3 more recent DNe (Var Leo, SN15207 and Var Vul 05)
- DNe with faint quiescence can mimic new transients
- N_{DN} (# of DNe) & N_{SO} (# of superoutburst in all-sky snapshot) for $R_{amp}<23$, $R_{quies}<25$, $M_{R,WD}=12$, 1yr cycle, 10days plateau

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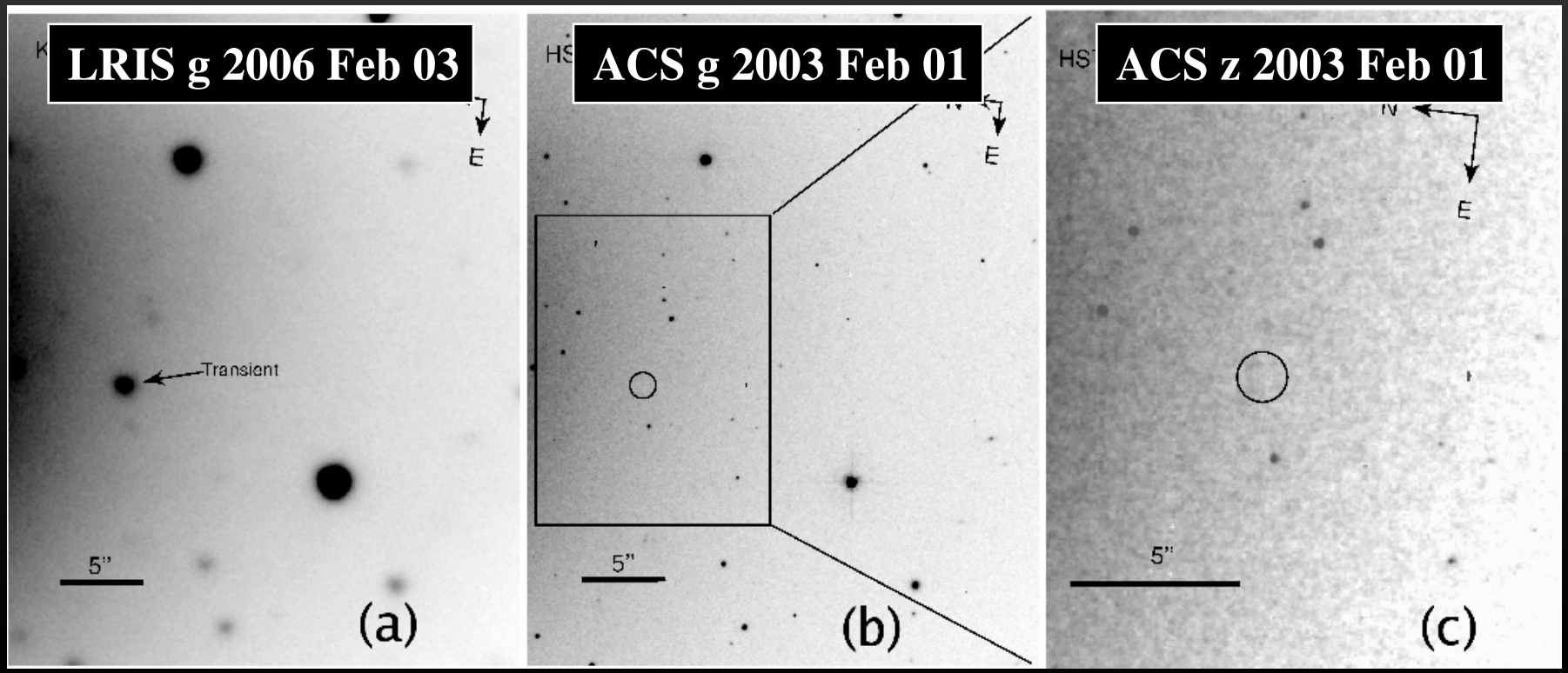
Table 5: Dwarf novae number counts and outburst rates.

Galactic latitude	N_{DN}[1]		N_{SO}[2]	
	$\rho = 3 \times 10^{-5}\,\mathrm{pc}^{-3}$	$\rho = 10^{-3}\,\mathrm{pc}^{-3}$	$\rho = 3 \times 10^{-5}\,\mathrm{pc}^{-3}$	$\rho = 10^{-3}\,\mathrm{pc}^{-3}$
$\lvert b\rvert < 10°$	$\sim 1 \times 10^3$	$\sim 4 \times 10^4$	~ 32	$\sim 1 \times 10^3$
$10° < \lvert b\rvert < 45°$	$\sim 6 \times 10^2$	$\sim 2 \times 10^4$	~ 16	$\sim 5 \times 10^2$
$\lvert b\rvert > 45°$	$\sim 1 \times 10^2$	$\sim 5 \times 10^3$	~ 4	$\sim 1 \times 10^2$

- 4×10^4 events per year, comparable to CC SNe

A new Discovery - M85OT2006-1

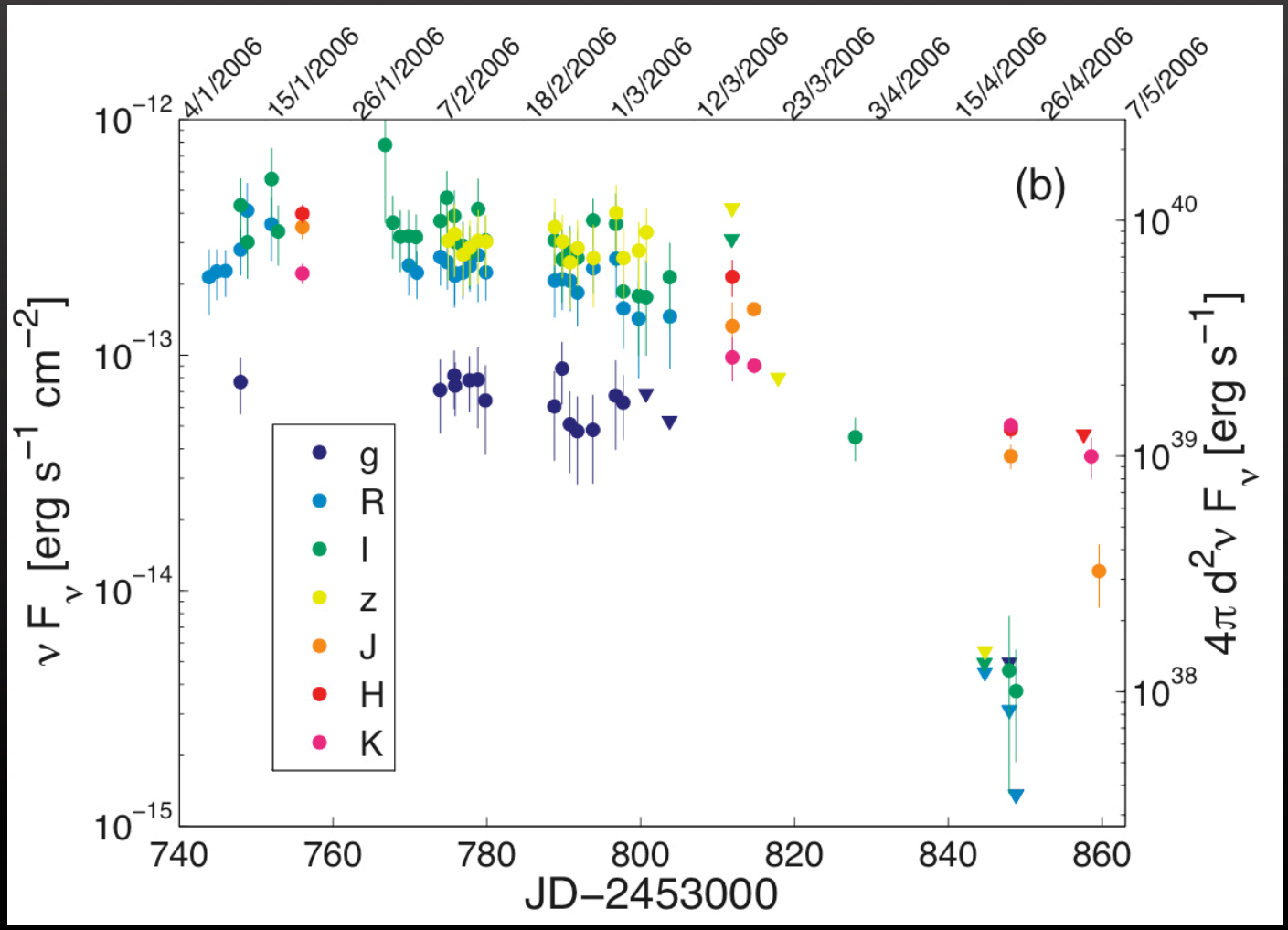
- Lick Observatory Supernovae Search, Jan 07 2006 at 19.3mag
- 2.3kpc from center of M85
- precursor F475W > -4.3 and F850LP > -6.4
- peak V=-13



(Kulkarni et al. 2007, Nature)

Temporal Evolution

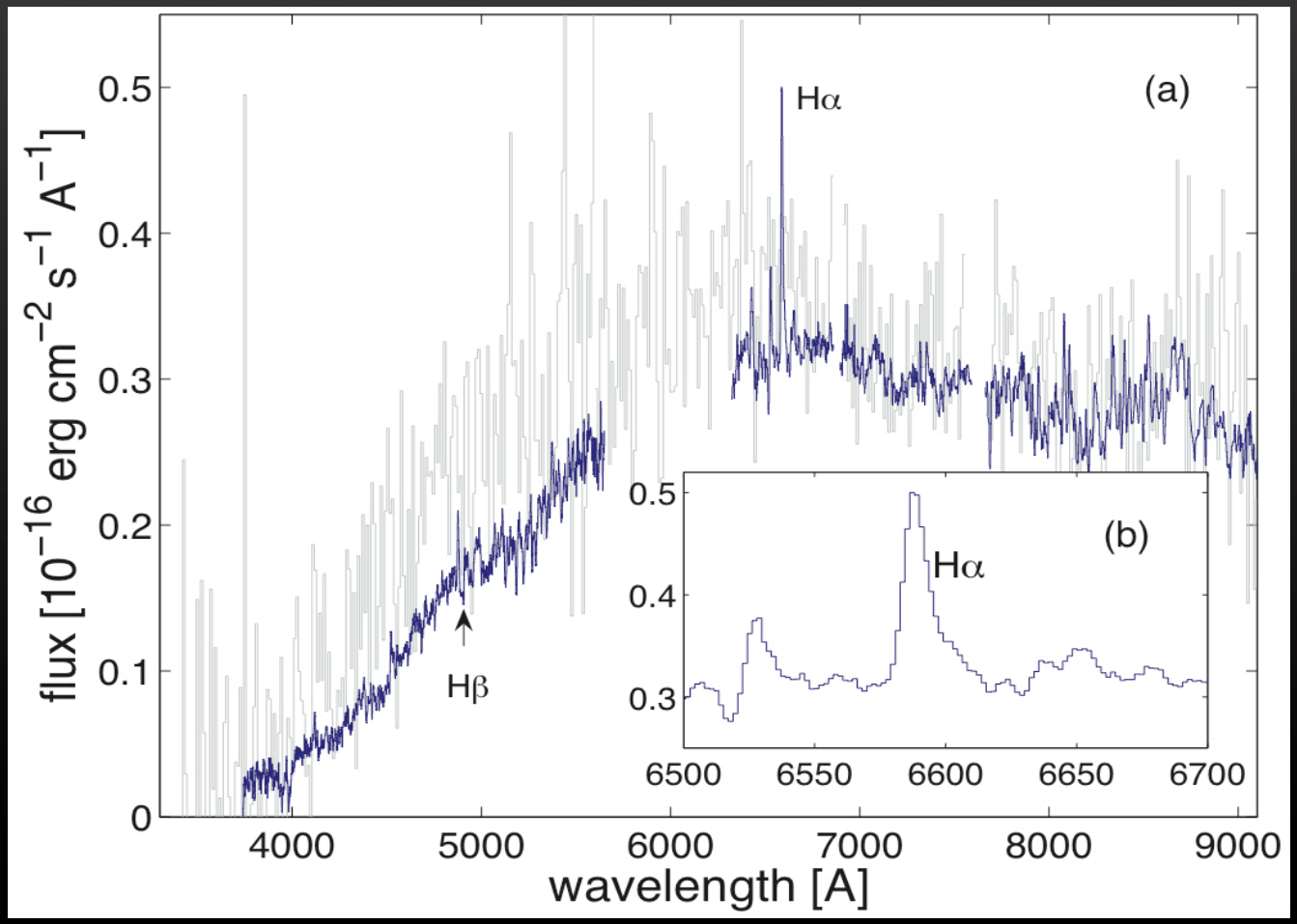
- data from: P60, P200, Keck, Magellan, UKIRT
- strong red-ward evolution



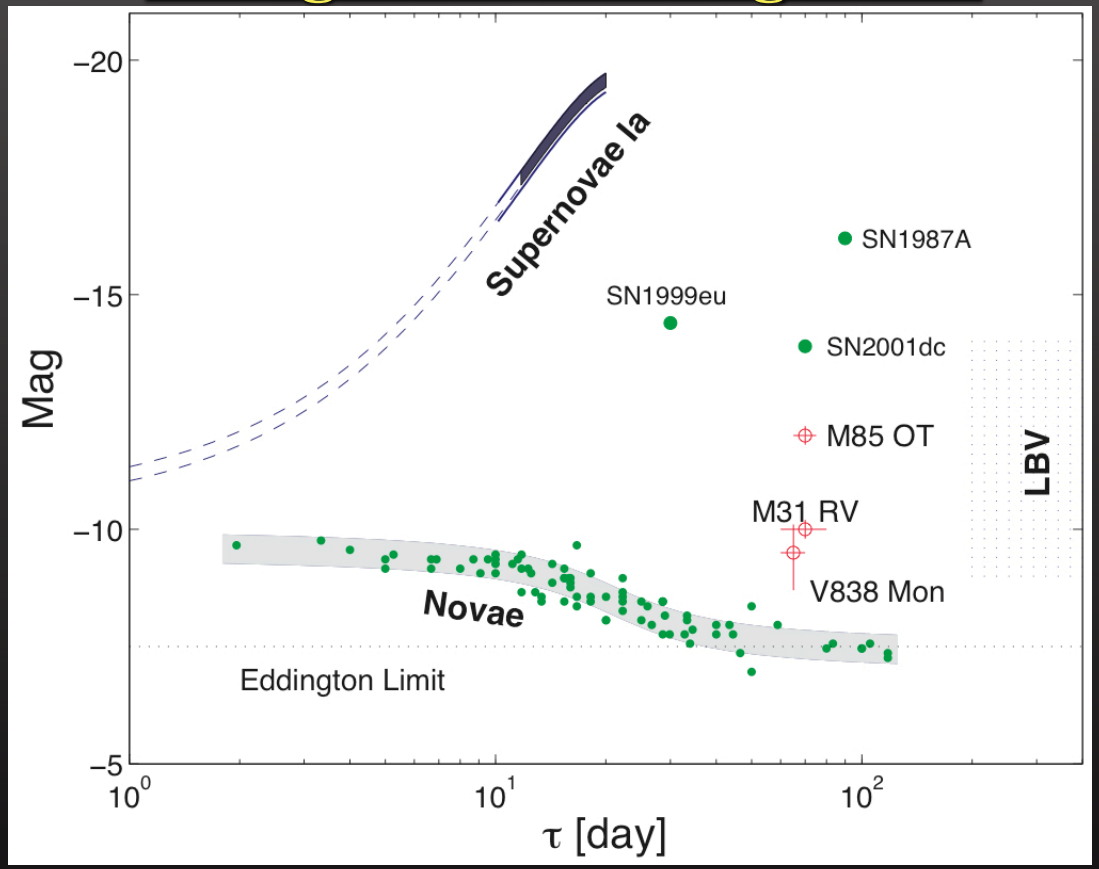
(Kulkarni et al. 2007, Nature)

Optical Spectroscopy

- P200/DBSP (Jan 08) and Keck/LRIS (Feb 24)
- Hα and Hβ at M85 distance of 15Mpc, FWHM= 350±140 km/s
- numerous unidentified lines (λλ4115,6428,6527,8079,8106)
- $T_{BB} \sim 4600$ K
- $A_R < 1$mag



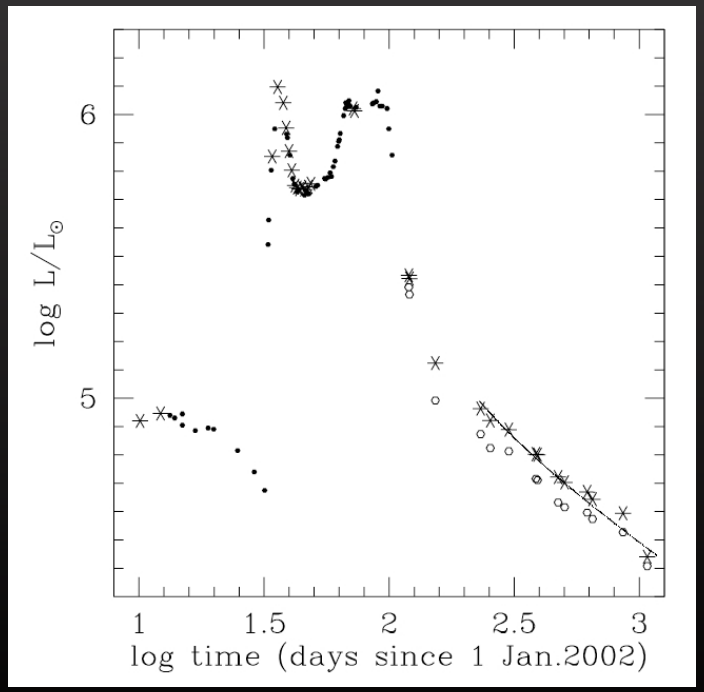
Energetics and Progenitor



- $L_p \sim 5 \times 10^6\ L_\odot$, $E_{ph} \sim 7 \times 10^{46}$ erg
- HST limit excludes LBVs, no ongoing star formation)
- 100x larger than Eddington luminosity (for $M \sim M_\odot$)
- $R_{BB} = [L_p/4\pi\sigma_B T^4_{eff}]^{1/2} \sim 17(T_{eff}/4600K)^{-2}$ AU
- A stellar merger ? (Soker & Tylenda 2003)

Known Analogs

- M31RV (Rich et al. 1989) in bulge of M31
- V4332 Sgr (Martini et al. 1999) in Milky Way
- V838 Mon (Brown et al. 2002) in Milky Way B-star cluster

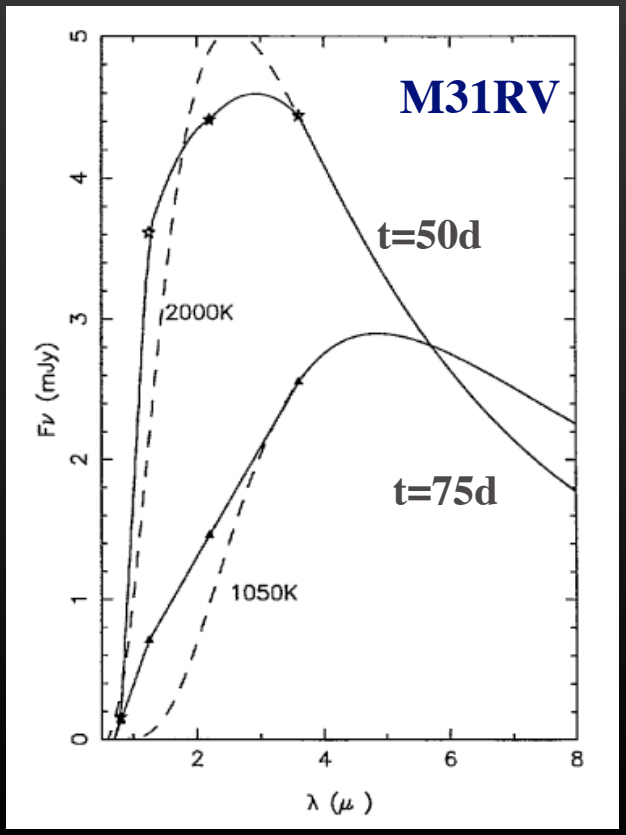


(Tylenda et al. 2005)

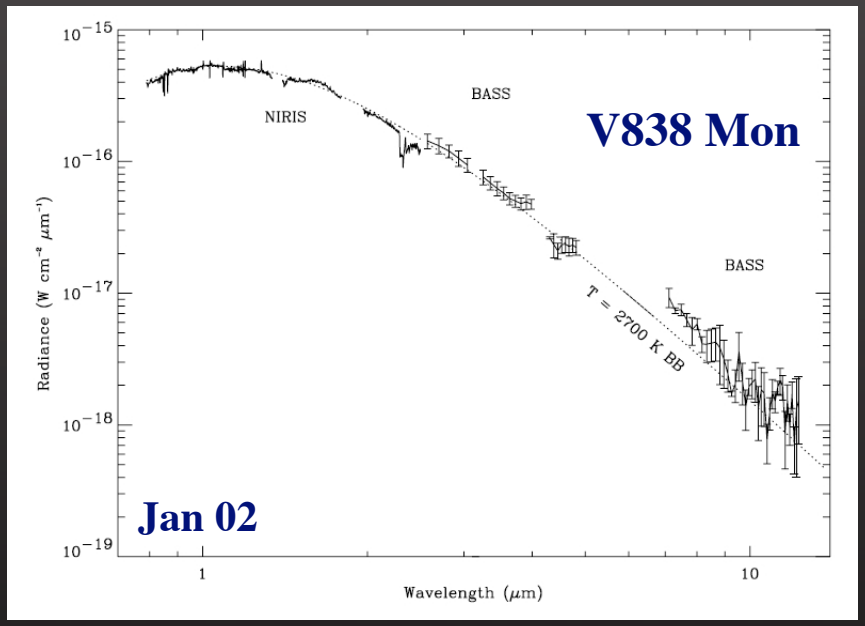
The Mid-Infrared Evolution

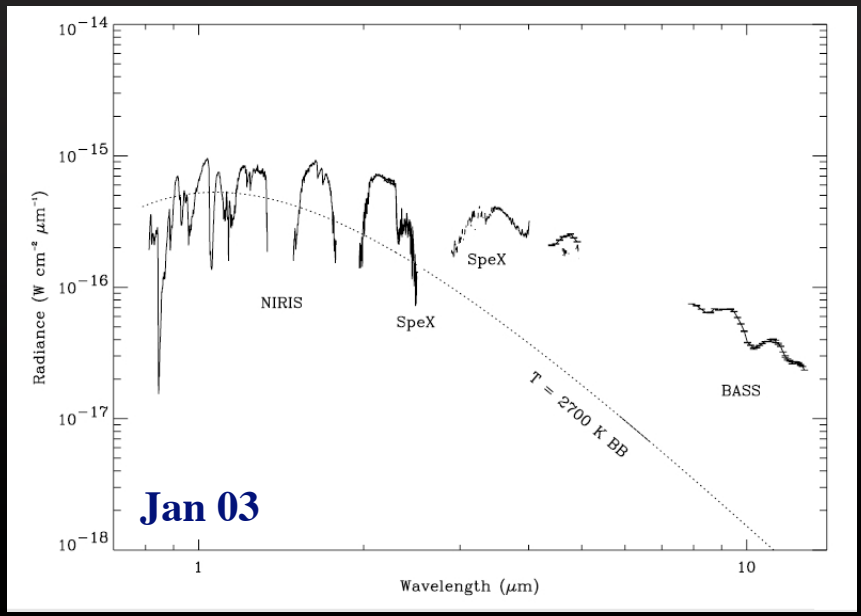
(Lynch et al. 2004)

- strong IR excess after few months
- newly formed dust?



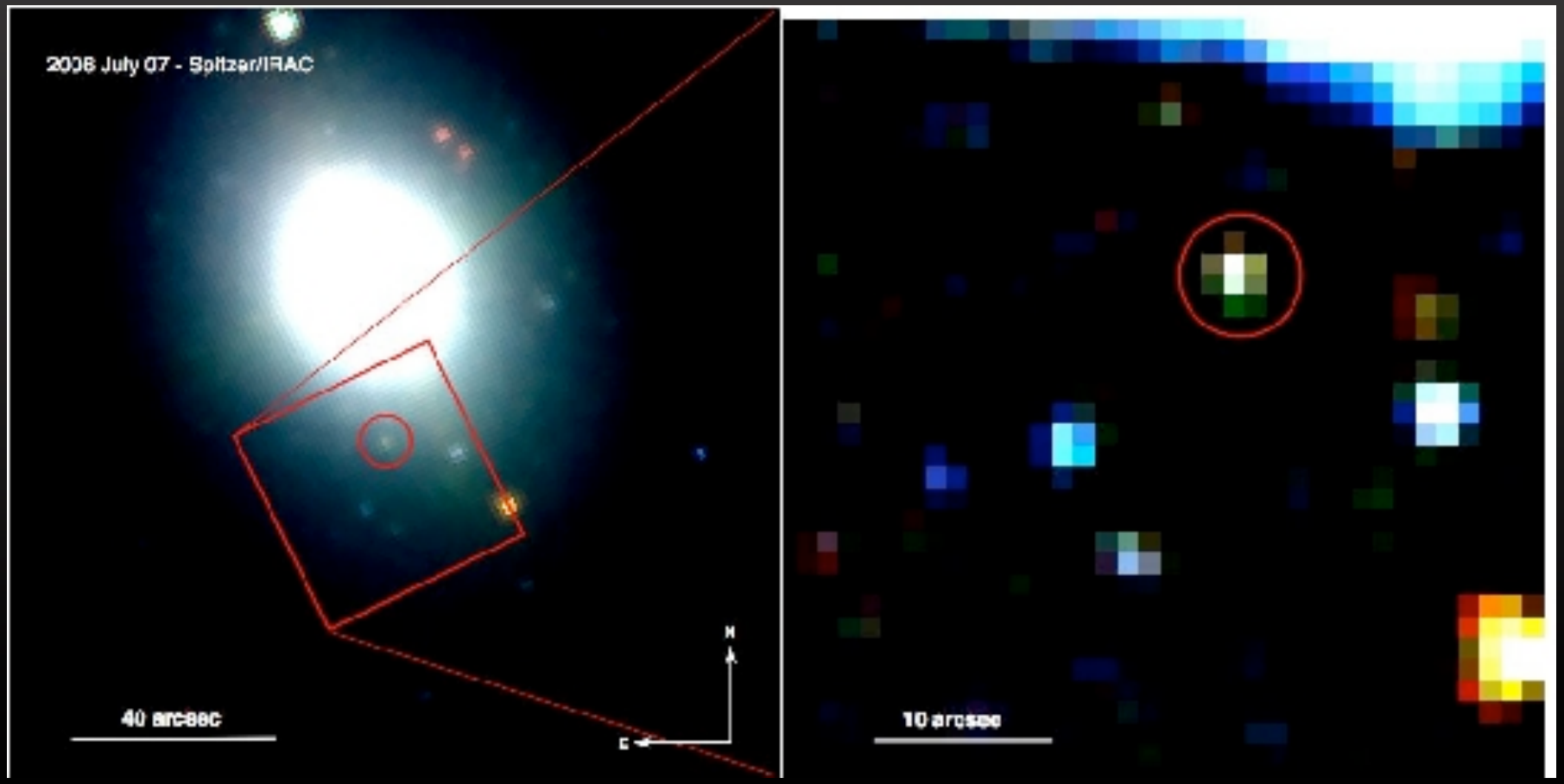
(Mould et al.. 1990)





Spitzer near and mid-IR of M85OT2006-1

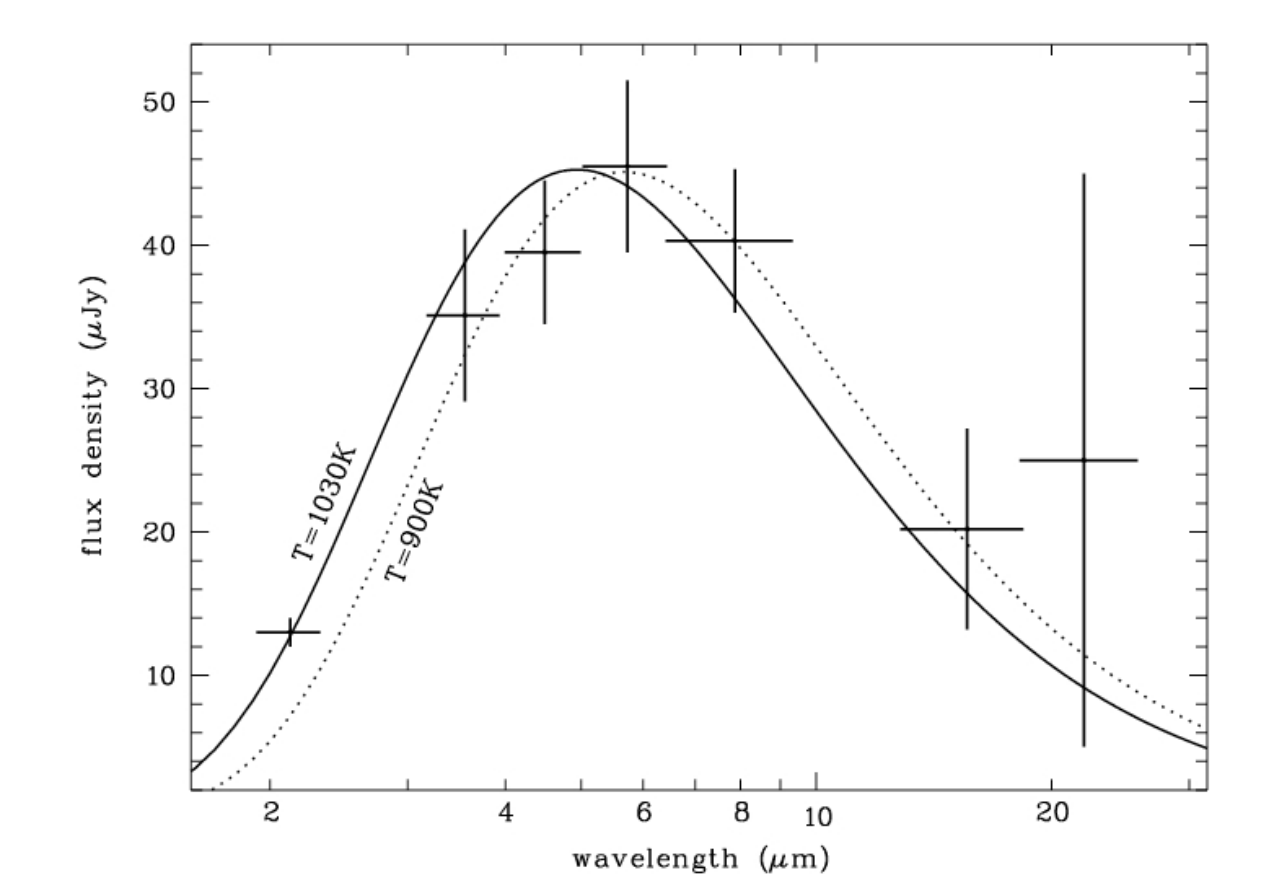
- 3000s in IRAC (3.6-8 μm) and IRS peak-up (15.8 & 22 μm)
- July 2006 , t ~ 180days
- $F_{IRAC} \sim 40$ μJy



(AR et al 2007b)

Spectral Energy Distribution

2.1-22 μm	T_{eff}=1030 ± 50 K	χ^2/dof=3.3/5
3.6-22 μm	$T_{eff}=900^{+140}_{-100}$ K	χ^2/dof=0.9/4



Energetics

Table 2: Inferred black body parameters.

Source	$L_{\rm peak}$ [$\times 10^5\,L_\odot$]	$T_{\rm eff,peak}$ [$\times 10^3$ K]	$R_{\rm peak}$ [$\times 10^3\,R_\odot$]	$L_{\rm late}$[a] [$\times 10^5\,L_\odot$]	$T_{\rm eff,late}$ [$\times 10^3$ K]	$R_{\rm late}$ [$\times 10^3\,R_\odot$]	$R_{\rm late}/t$ [km s^{-1}]
M85 OT2006-1[b]	~ 50	~ 4.6	~ 3.6	$2.9^{+0.4}_{-0.5}$	0.95 ± 0.15	20^{+6}_{-4}	870^{+260}_{-180}
M31 RV[c]	~ 8	~ 4	~ 2	~ 0.6	~ 1	~ 8	~ 920

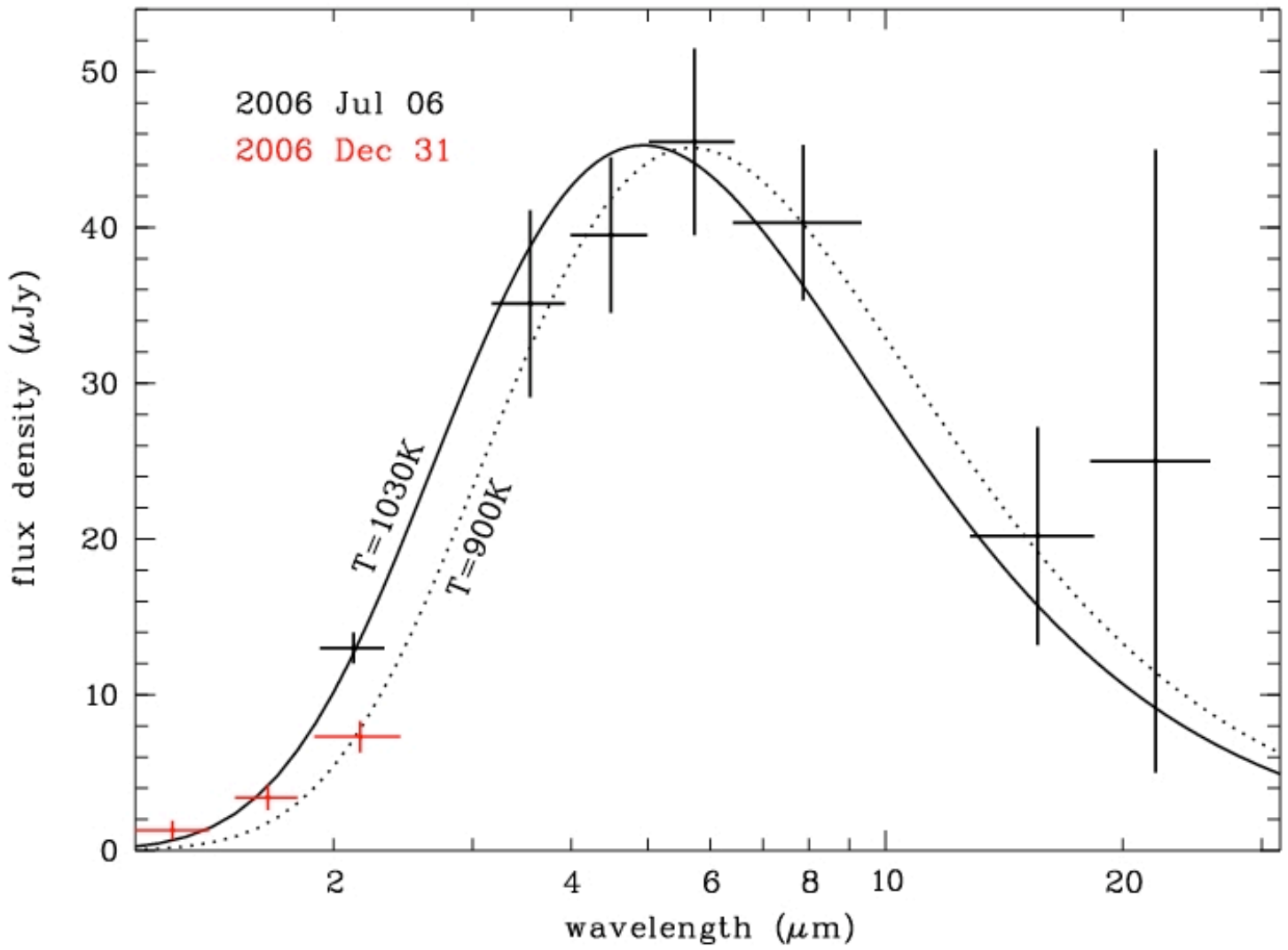
[a] at $t \sim 180$ days for M85 OT2006-1 and $t \sim 70$ days for M31 RV

[b] peak values from (Kulkarni et al 2006). Late time values this paper

[c] peak luminosity from (Rich et al.1989). Remaining values from (Mould et al. 1990)

- **velocity from black body >> FWHM(Hα) ~ 350 km/s (Feb 24)**
- **a-spherical explosion? long lasting activity? different components?**
- **V838 Mon : slower evolution (late time collaps)**

Energetics

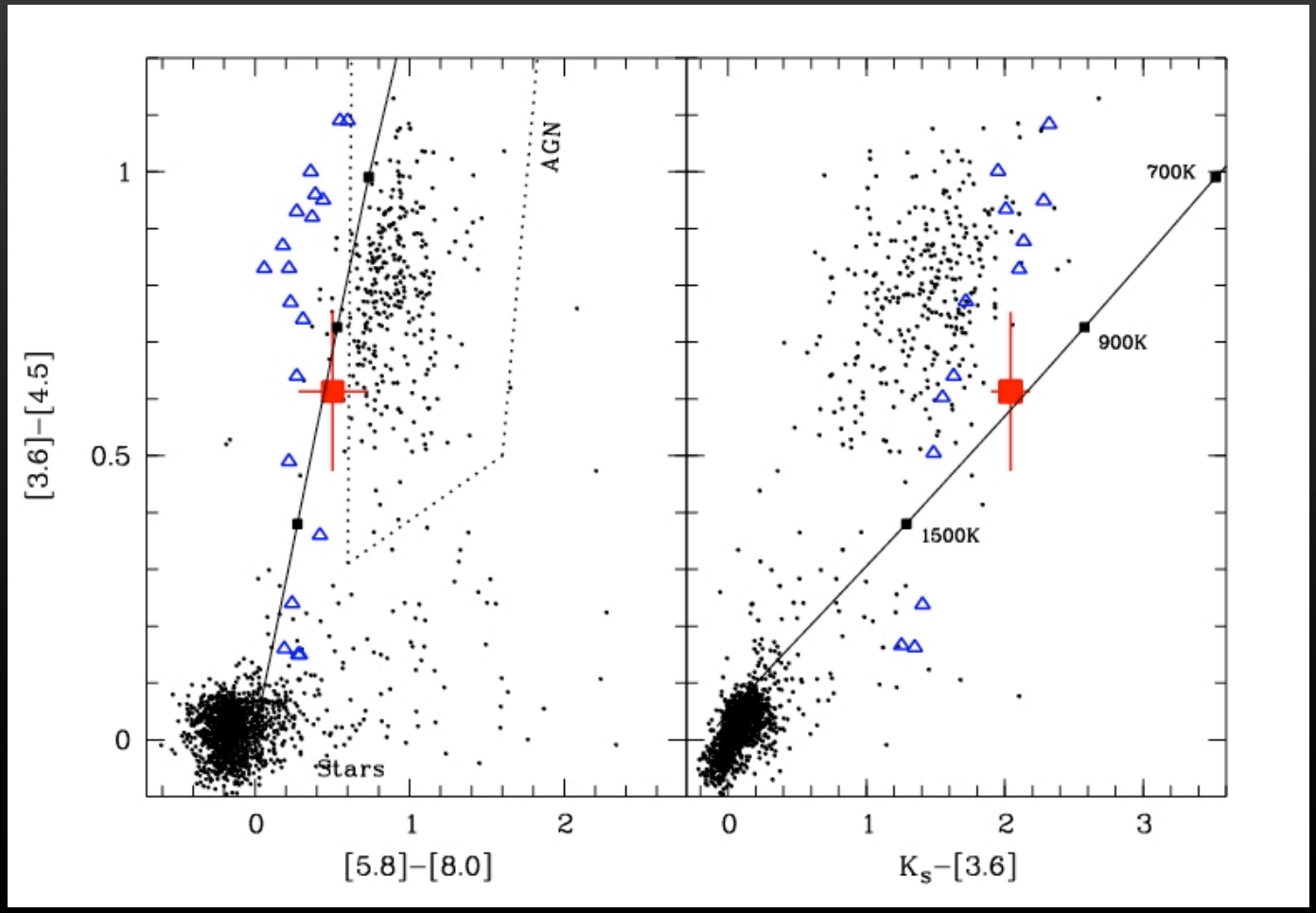


- vel
- a-s
- V8

nts?

Lesson Learned III

- event rate ~ 12 per year to 20 Mpc (Kulkarni et al 2007, Soker & Tylenda 2006)
- search in IR: duration longer than in optical
- e.g. 1-10 new events in SINGS or with Akari (ASTRO-F)



Summary

New Surveys will detect millions of transient and variables per year.

The known/unknown unknowns will be diluted in the fog of known knowns.

Event	Rate
Long-soft GRBs	30 (Gpc^{-3} yr^{-1})
Core-Collapse SNe	$5x10^4$ (Gpc^{-3} yr^{-1})
Short-hard GRBs	$10\text{-}10^5$ (Gpc^{-3} yr^{-1})
Novae	10^8 (Gpc^{-3} yr^{-1})
Flare Stars	10^8 (R<23 per yr)
Dwarf Novae Superoutburst	$4x10^4$ (R<23 per yr)
Luminous Red Novae	12 (per yr)

Hi

- ul

Hi

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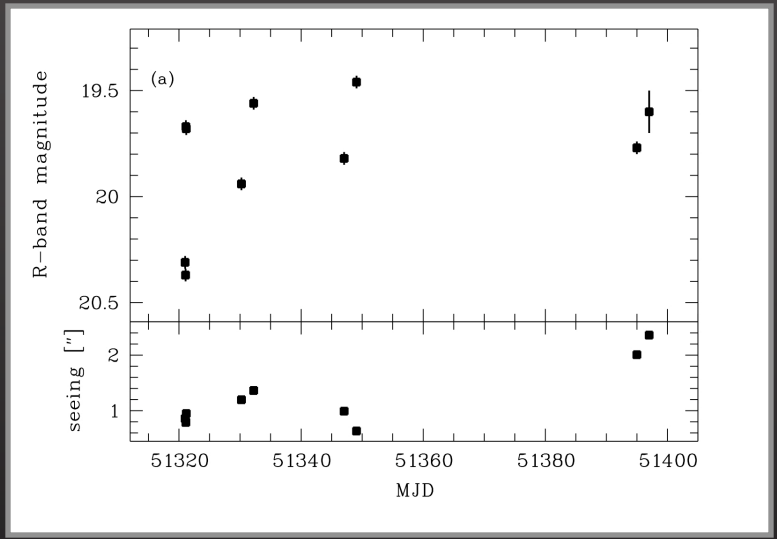
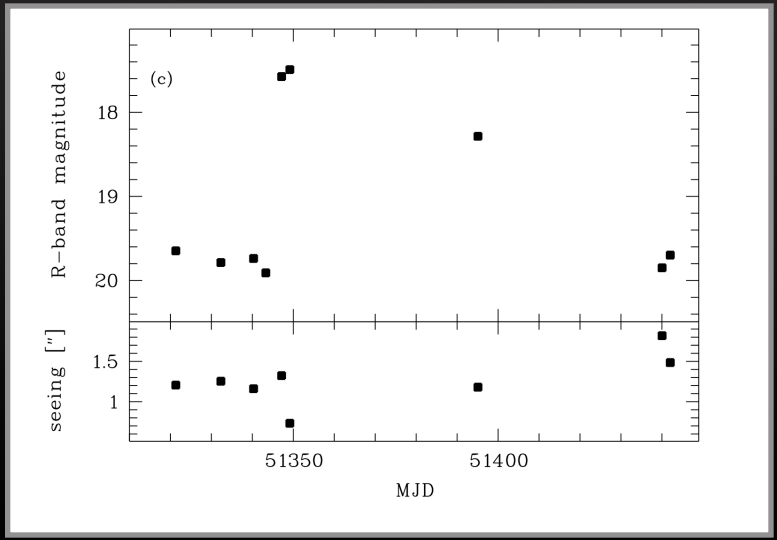
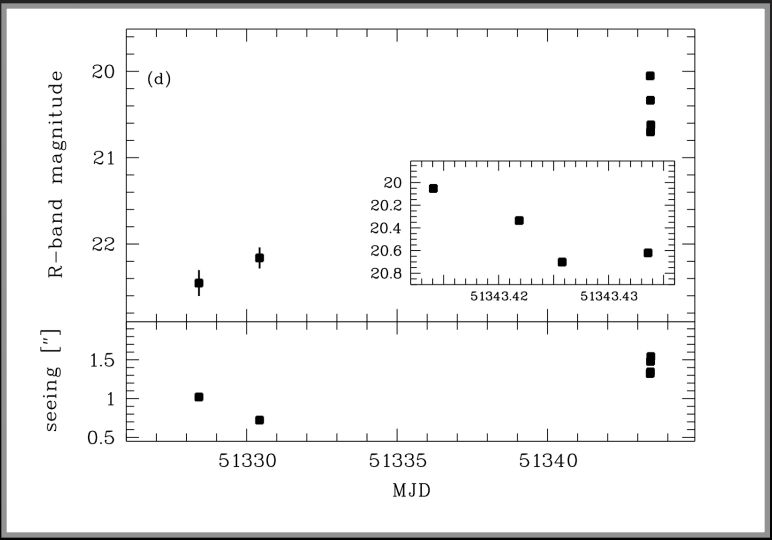
Reduction and Transient Search



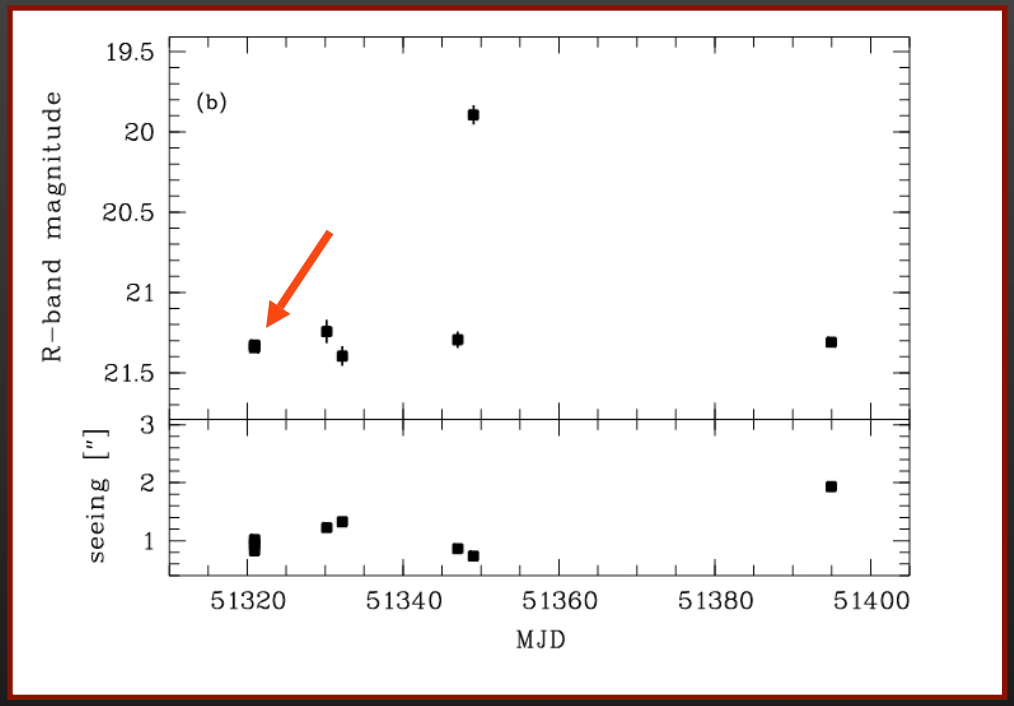
Transient Search:

- **differential photometry ($\Delta R > 0.75$ mag)**
- **12000 candidates**
  $\Rightarrow$ 4 transient sources in >2 obs.

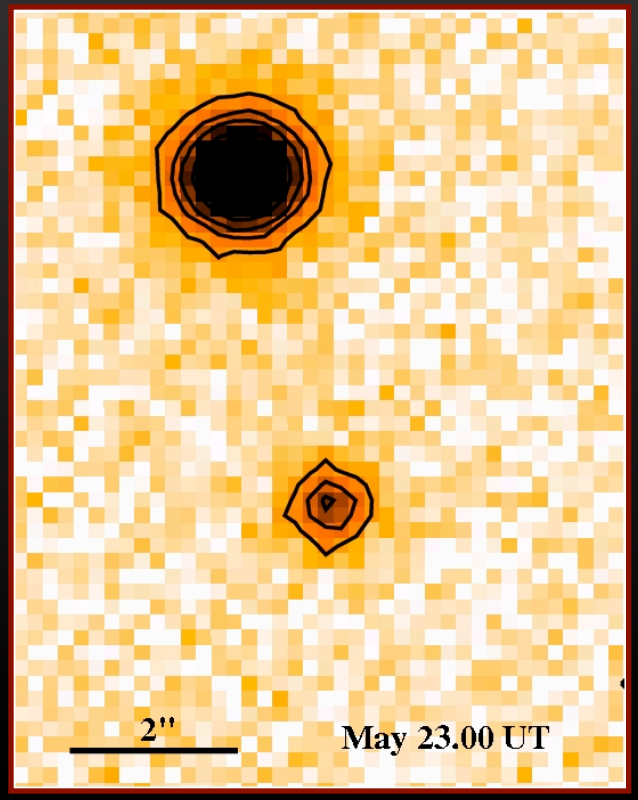




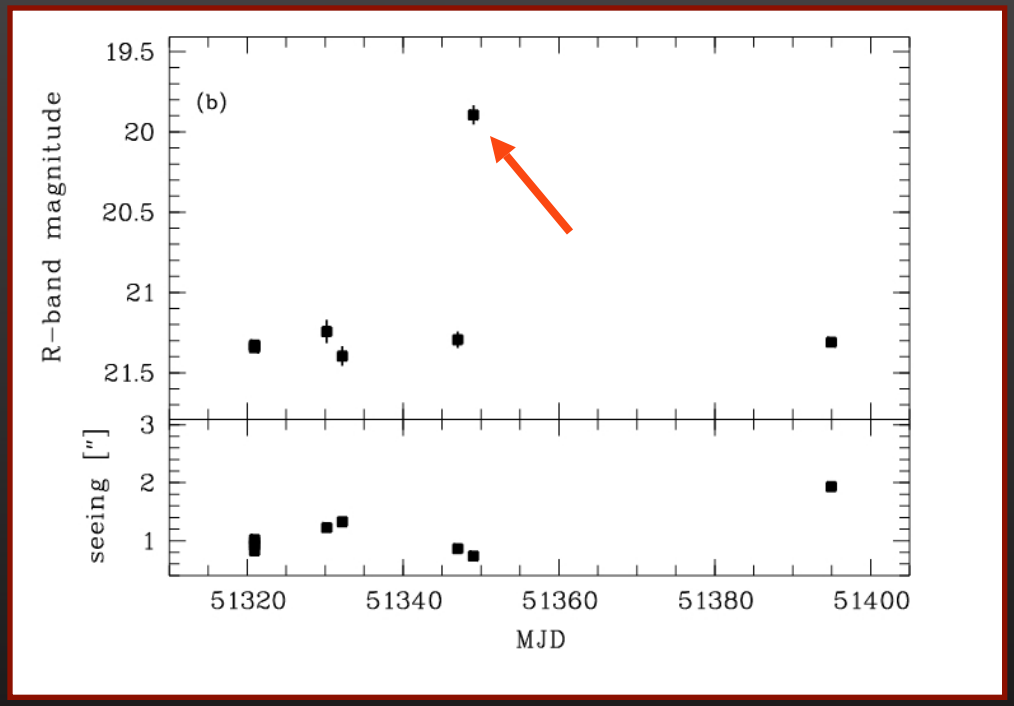
Transient #4: origin unknown



- ΔR~1.5 mag in 2 days
- flare star, supernova, afterglow, asteroid ?
- not associated with a triggered burst



Transient #4: origin unknown



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