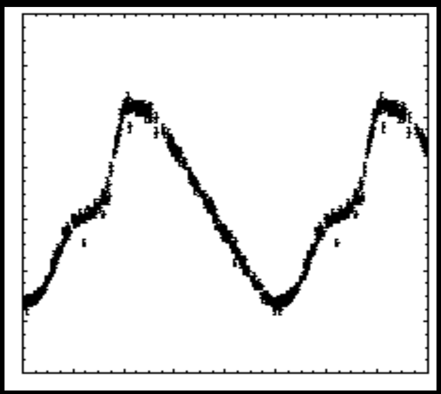
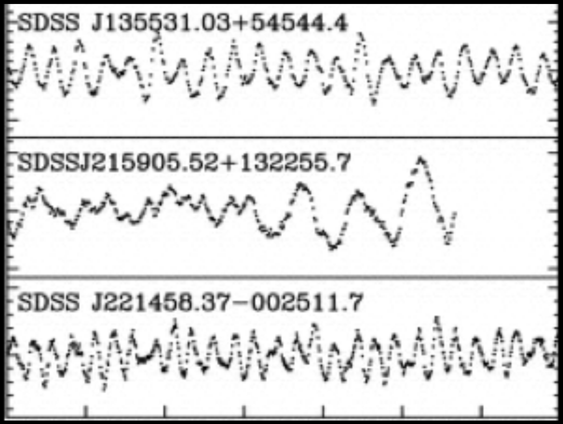
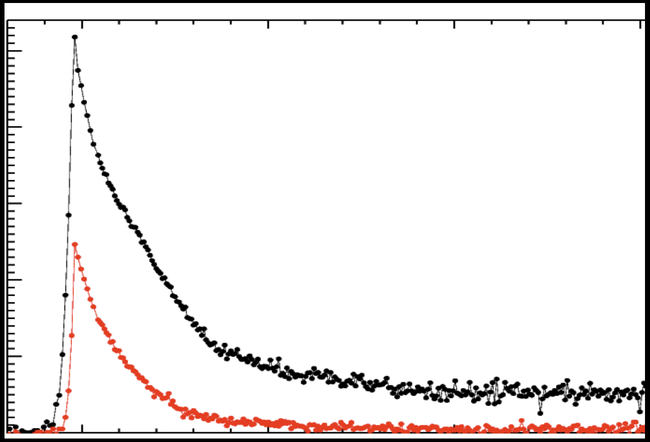
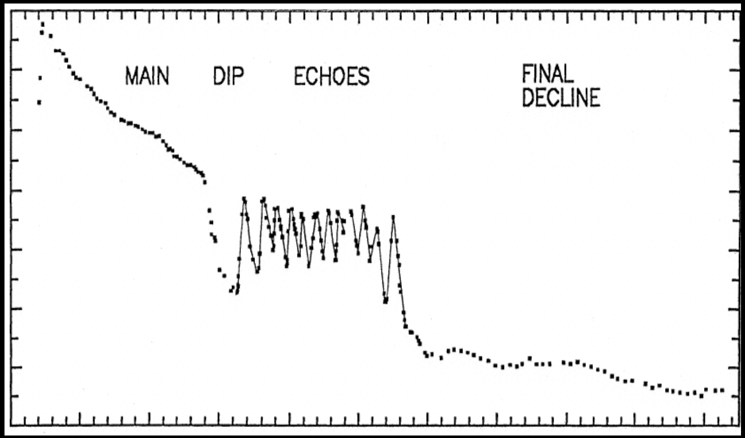
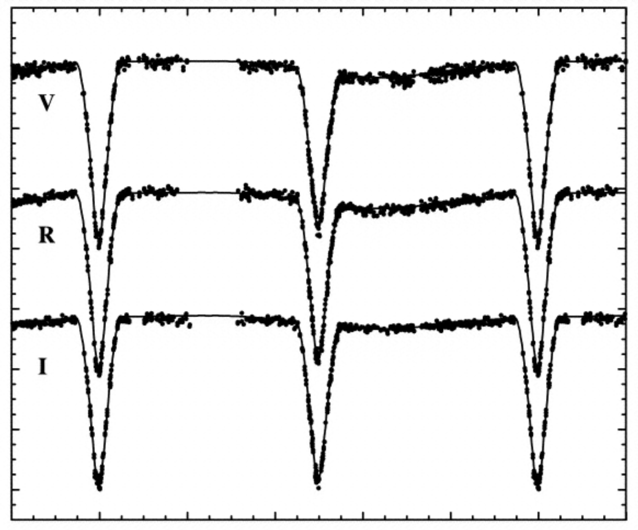
Coordinating TMT and LSST to Maximize Time Domain Science on Variable Stars











TMT Science Forum June 24, 2015 Paula Szkody, UW

Time Domain Science

1. Transient
   - single event
   - repeating events on random timescales
2. Periodic
   - orbital variations
   - rotation
   - pulsations

Known Variables:

Eclipsing: **Algol** — B8-M (hrs-days) | **ß Lyr** — B8-G3 | **W Uma** — F0-K0 (hrs) | ~~(microlensing)~~

Eruptive:

single

- ~~SNII 15-20 mag (yrs)~~
- flare 1-6 mag (<hr) K-M

binary

- WD: ~~SNI -20mag (yrs)~~
  - N -10mag (1000s yrs)
  - DN - 2-7 mag (weeks)
  - NL - erratic
- Symbiotic: 3mag (erratic)
- XRB: HMXRB, LMXRB
- ~~γ-ray Bursters~~
- RS CVn: F,G+KIV, spots

Pulsating:

short P

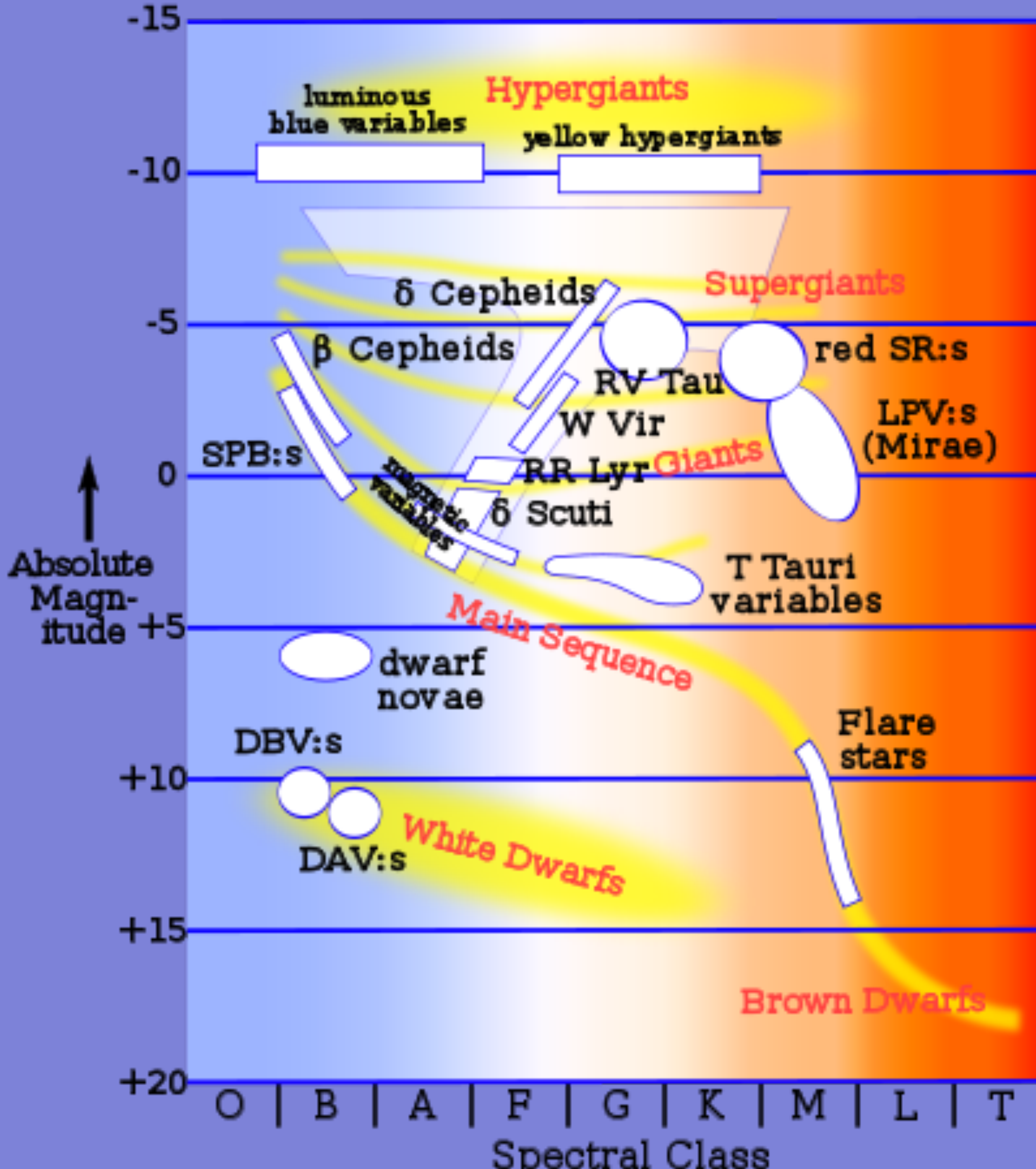
- Cepheids:F-K, 1-50d, 1.5mag
- RR Lyr: A-F, 0.5 day, 1 mag
- δ Scuti: A-F, hrs, 0.02 mag

long P

- Mira:M, yrs, 1-5mag
- S-R: K, M

odd

- ß Ceph: B, 0.5d
- ZZ Ceti: WD, min



-15
-10
-5
0
+5
+10
+15
+20
Absolute Magn-itude
Hypergiants
luminous blue variables
yellow hypergiants
Supergiants
δ Cepheids
β Cepheids
red SR:s
RV Tau
W Vir
LPV:s (Mirae)
SPB:s
RR Lyr
Giants
magnetic variables
δ Scuti
T Tauri variables
Main Sequence
dwarf novae
DBV:s
Flare stars
DAV:s
White Dwarfs
Brown Dwarfs
O
B
A
F
G
K
M
L
T
Spectral Class

Time Domain Science

1. Transient

- single event (SN, GRB, **Novae**)
- repeating events on random timescales
  (flare stars, **dwarf novae**, novalikes, symbiotics)

2. Periodic

- orbital variations (**eclipsing binaries, interacting binaries**)
- rotation (RS CVn, **accreting magnetic WDs**)
- pulsations (**Cepheids, RR Lyrae, ZZ Cet**, Mira)

To classify a variable correctly, we need:

- **amplitude of variation**
- **color of variation**
- **timescale of variation (periodic or not)**
- **shape of variation**
- **spectrum**

L
S
S
T

TMT

What future surveys need to enable good science for variable stars:

- a cadence that produces a recognizable light curve
- sufficient colors to aid in classification
- rapid/smart classification to ensure followup as needed
- spectral followup to confirm classification and provide basic parameters

Cadence Matters

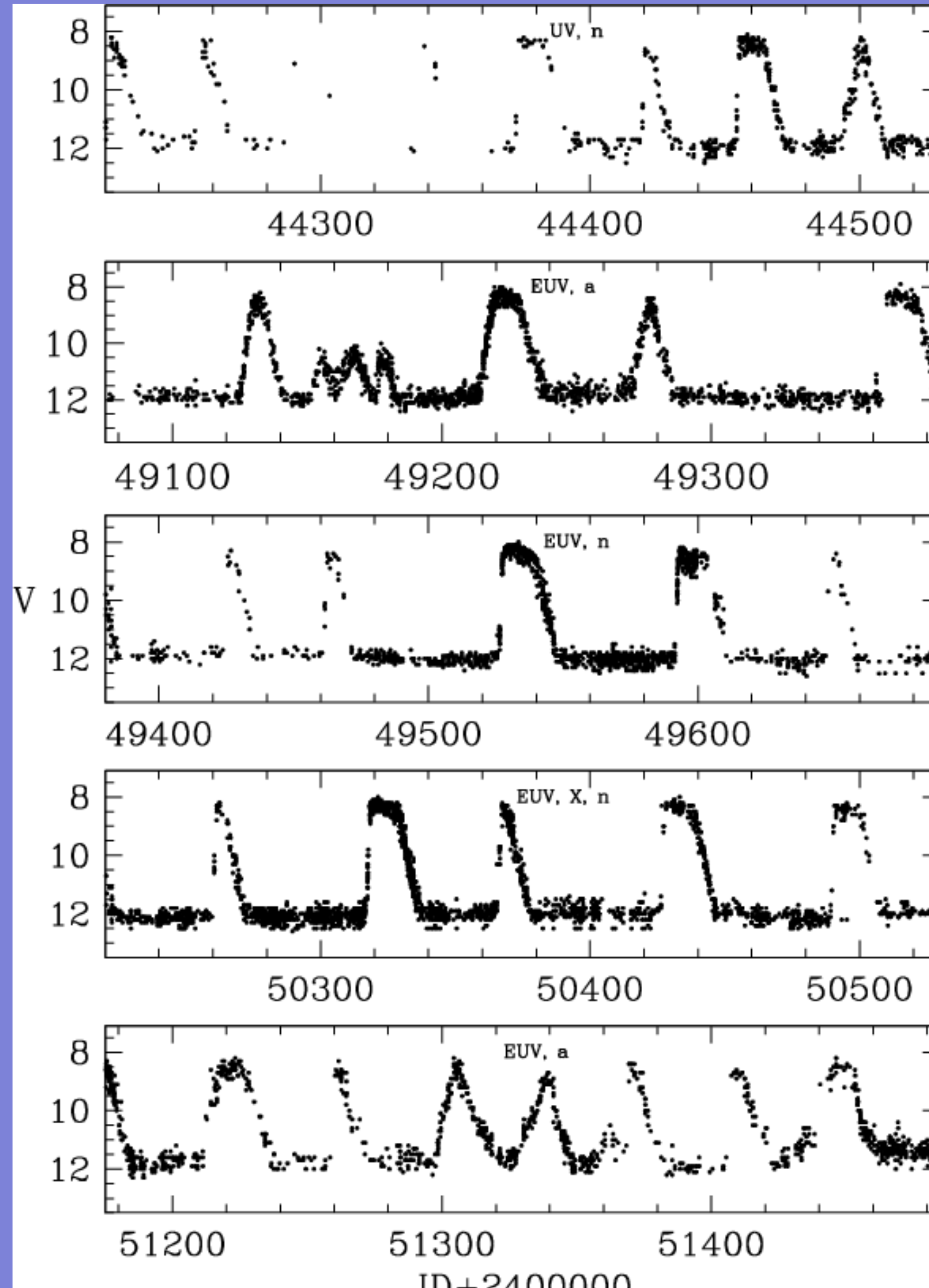
Example: Dwarf novae

Repeated disk instability

AAVSO

outbursts of SS Cygni

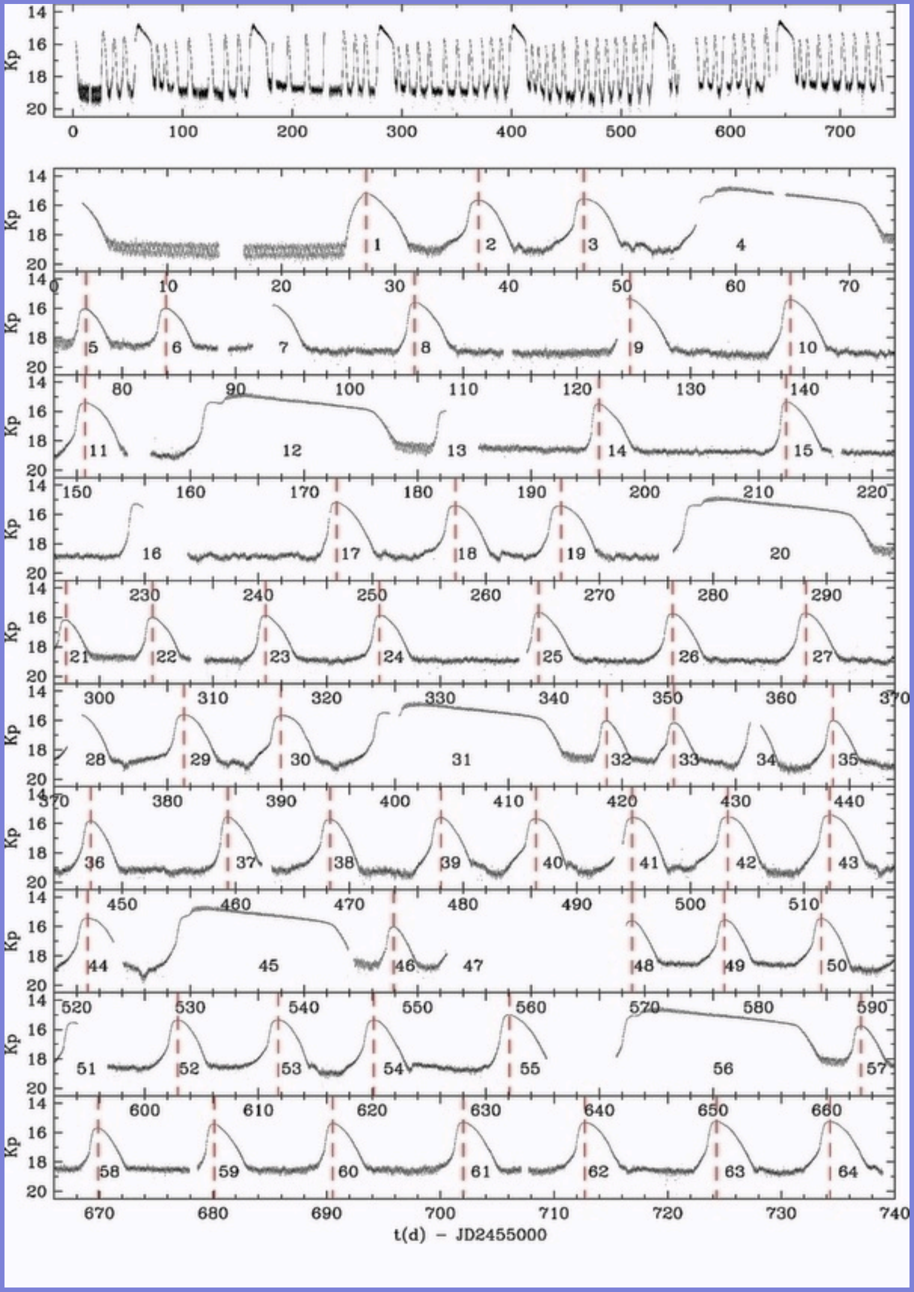
High $\dot{M}$,
outburst ~1/month

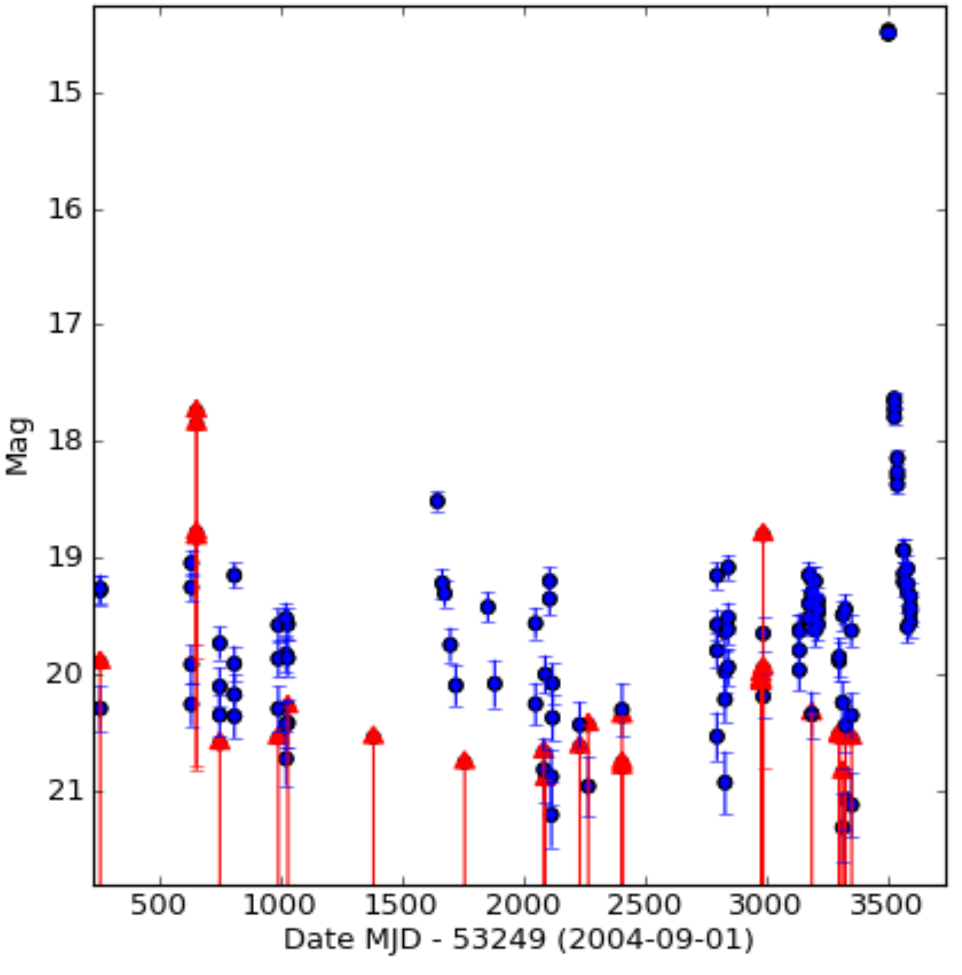


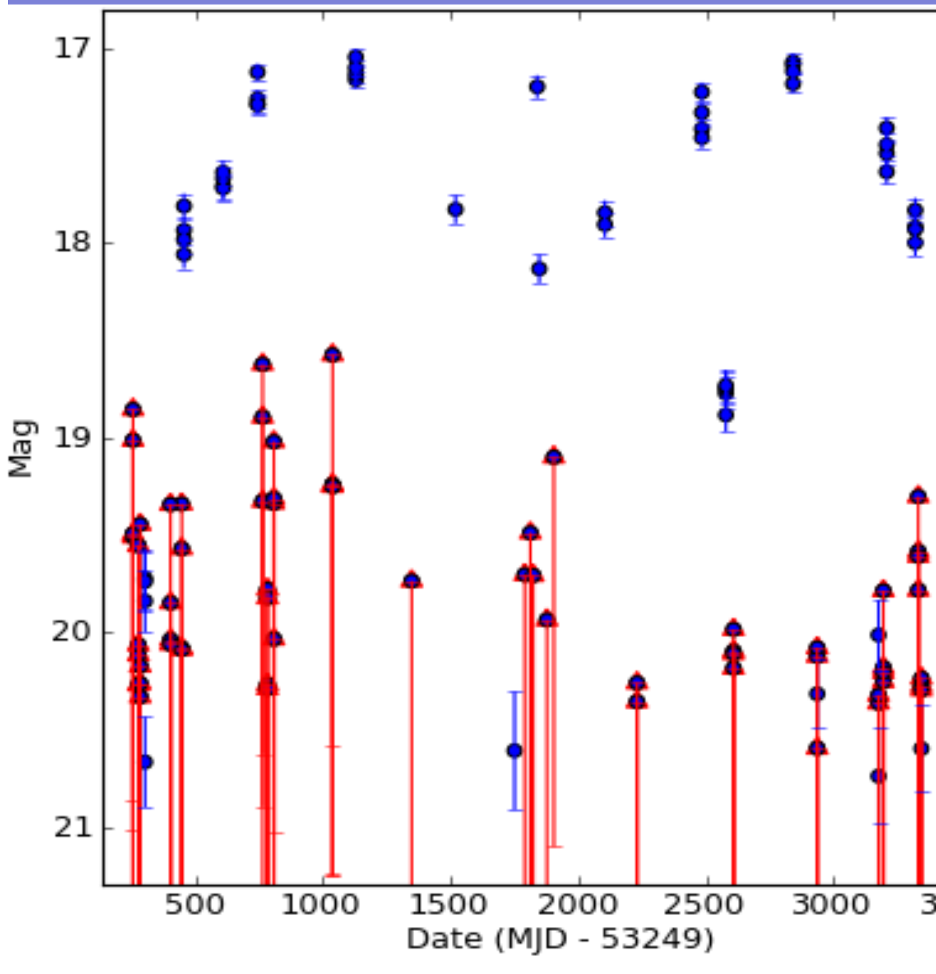
Kepler cadence

V344 Lyr

Cannizzo et al. 2012, ApJ, 747,117



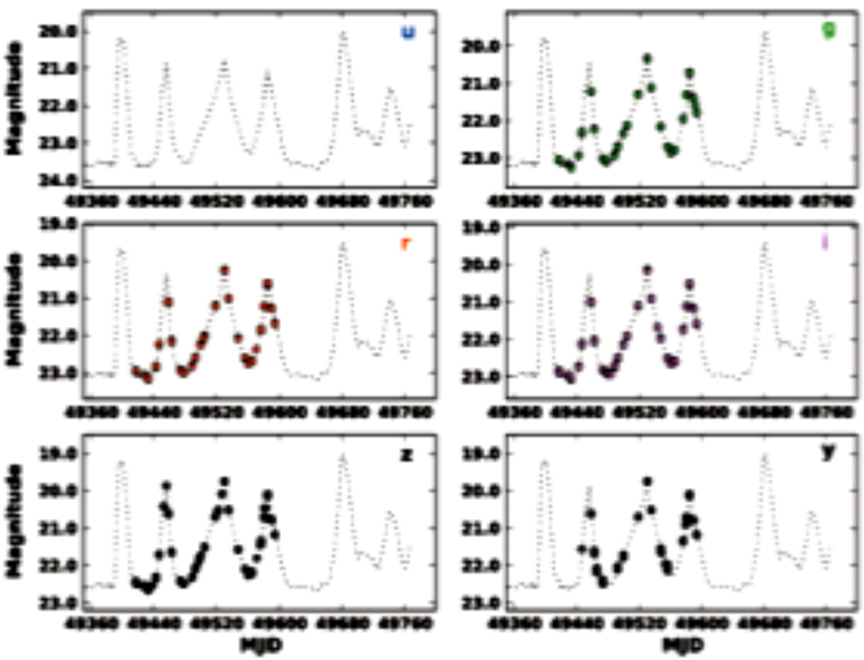


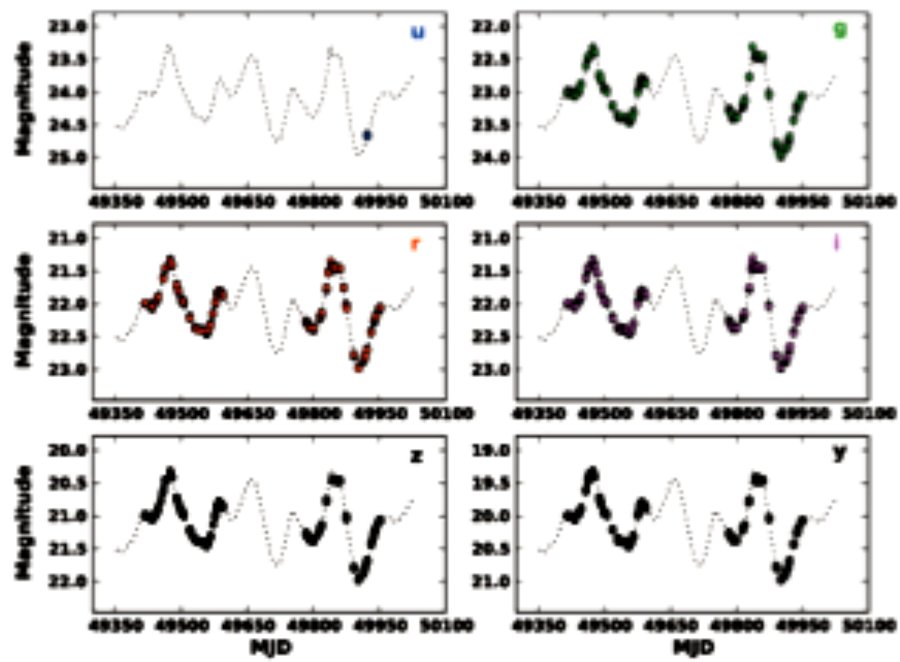


CRTS cadence

Will we be able to identify the variables correctly?

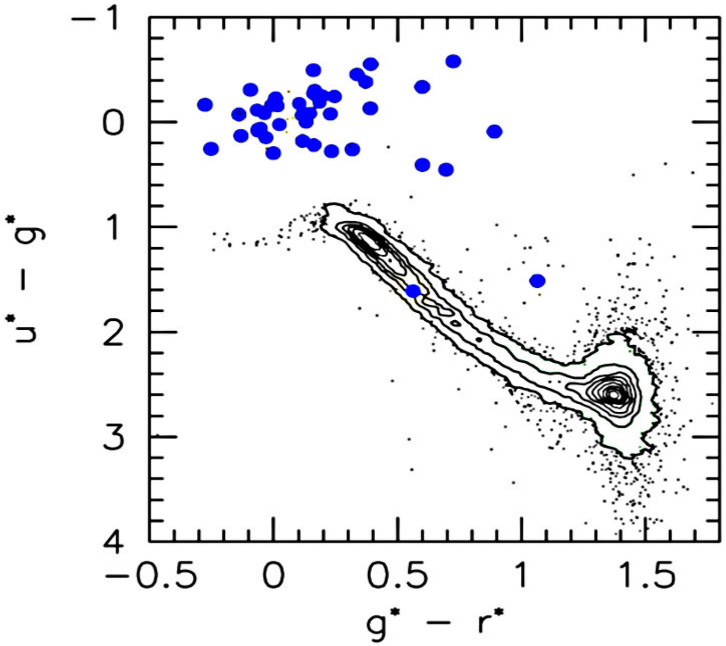
90% of RR Lyrae periods recovered to g=24 in 2 yrs

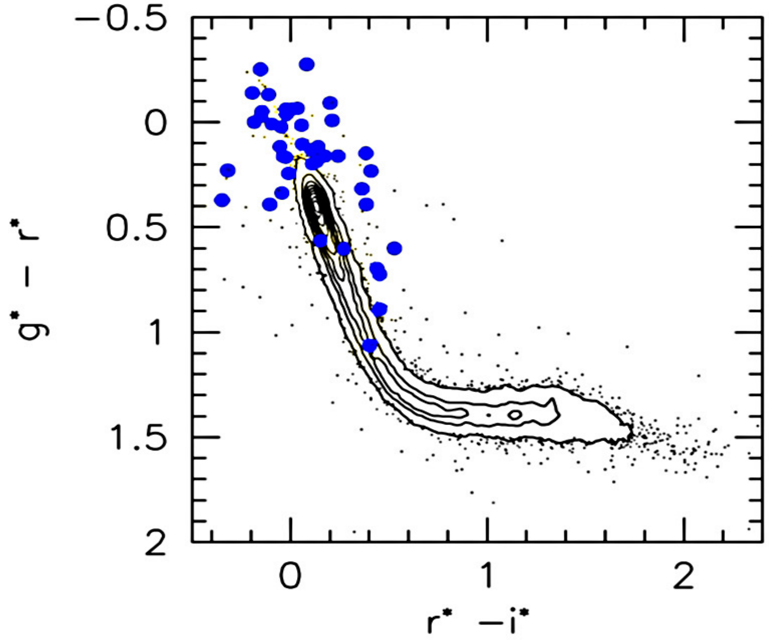


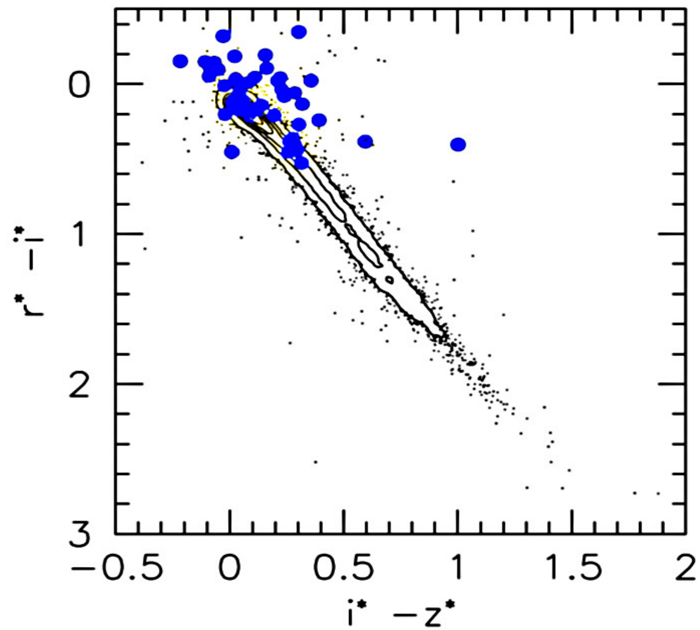


Dwarf nova SS Cyg at g=22 mag sampled for one year

Semi-reg Z UMa at g=23 sampled for 2 yrs





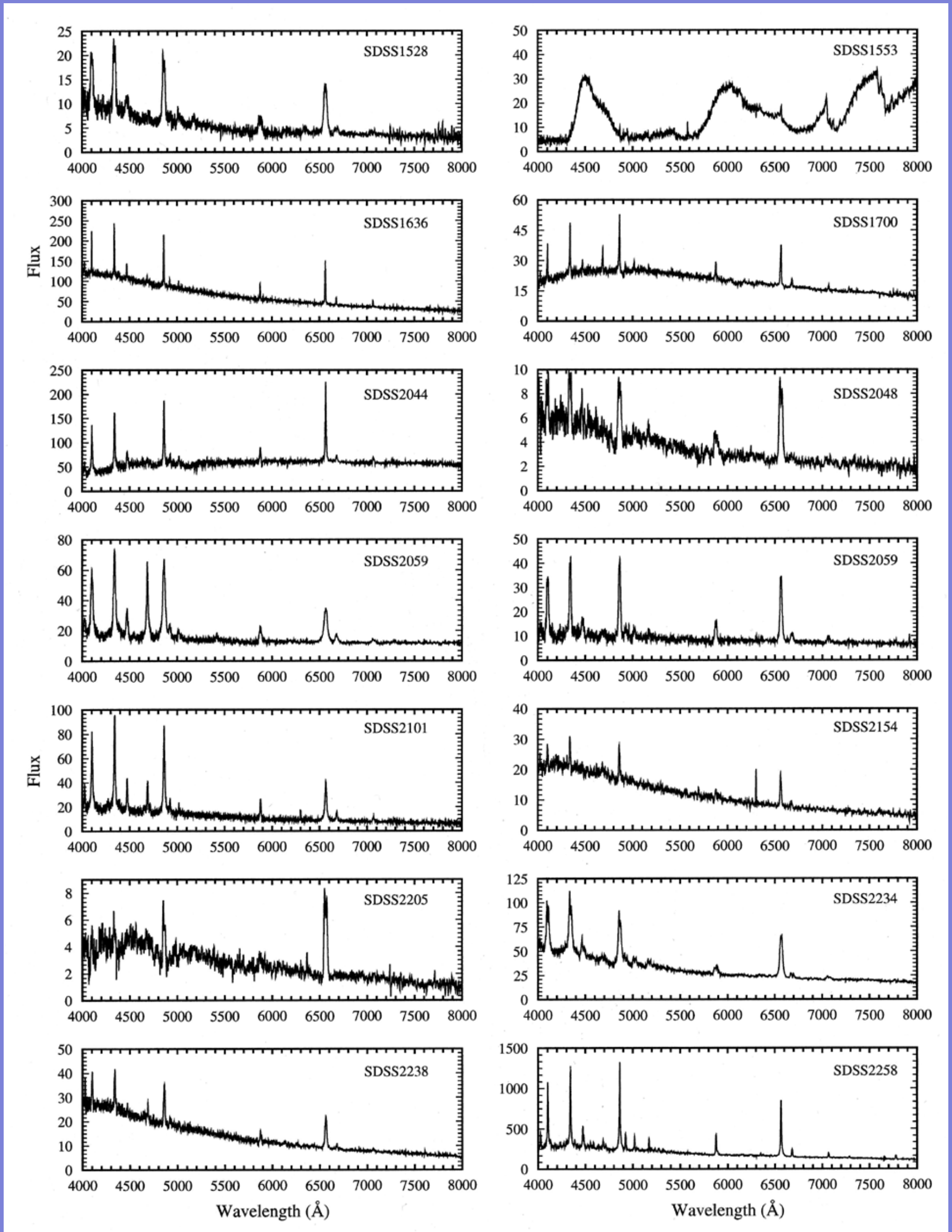


Color Matters

What we learned from SDSS:

Color range too wide to find objects -- need color plus variability to find true populations

Typical CV spectra in SDSS



What we learned from SDSS:

Need a lot of followup spectra!

CVs in SDSS
Szkody et al. 2002-2011, AJ.

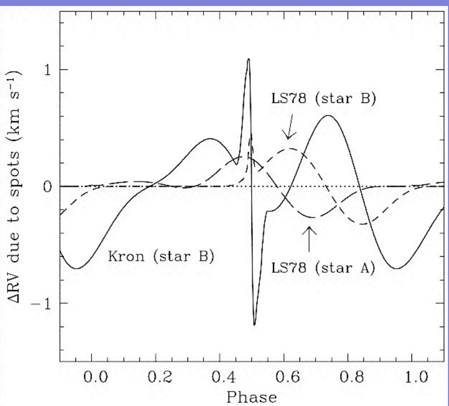
Prime Advantages of TMT

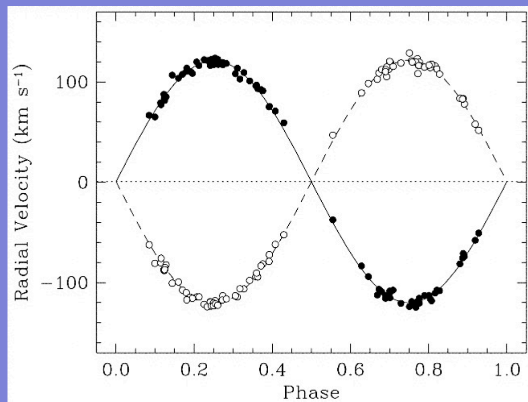
- Spectra of 24-25 mag objects (nearby faint sources plus brighter extragalactic)
- Time series for faint short P, low amp variables

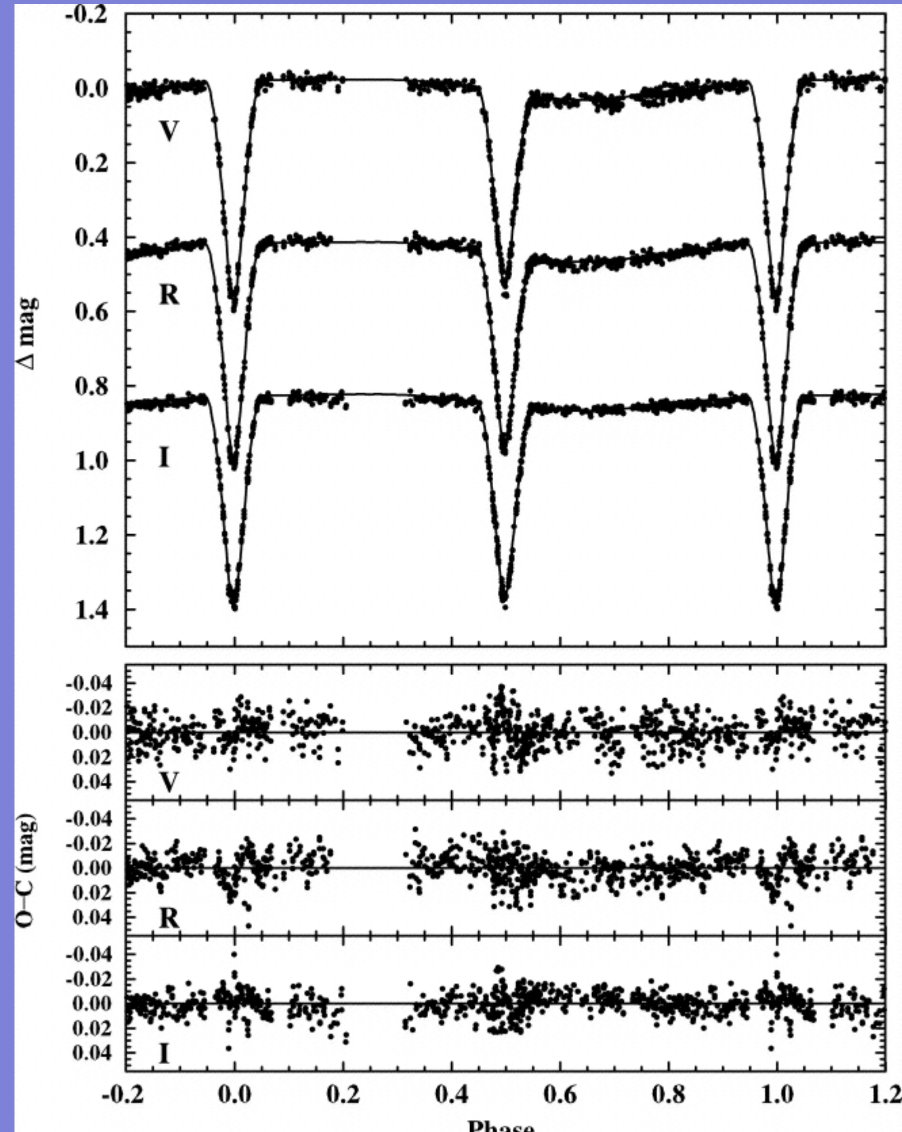
Current focus: low mass binaries: YY Gem

dM+dM

Torres & Ribas (2002)







Parameter	Value
Mass ($M_\odot$)	0.5992 ± 0.0047
Radius ($R_\odot$)	0.6191 ± 0.0057
$\log g$ (cgs)	4.6317 ± 0.0083
$\bar{\rho}$ (g cm^{-3})	3.56 ± 0.10
$v \sin i$ (km s^{-1})[a]	37 ± 2
$v_{sync} \sin i$ (km s^{-1})[b]	38.5 ± 0.4
T_{eff} (K)	3820 ± 100
$L/L_\odot$[c]	0.0733 ± 0.0015
M_{bol} (mag)[c,d]	7.569 ± 0.020
M_V (mag)[e]	8.950 ± 0.029

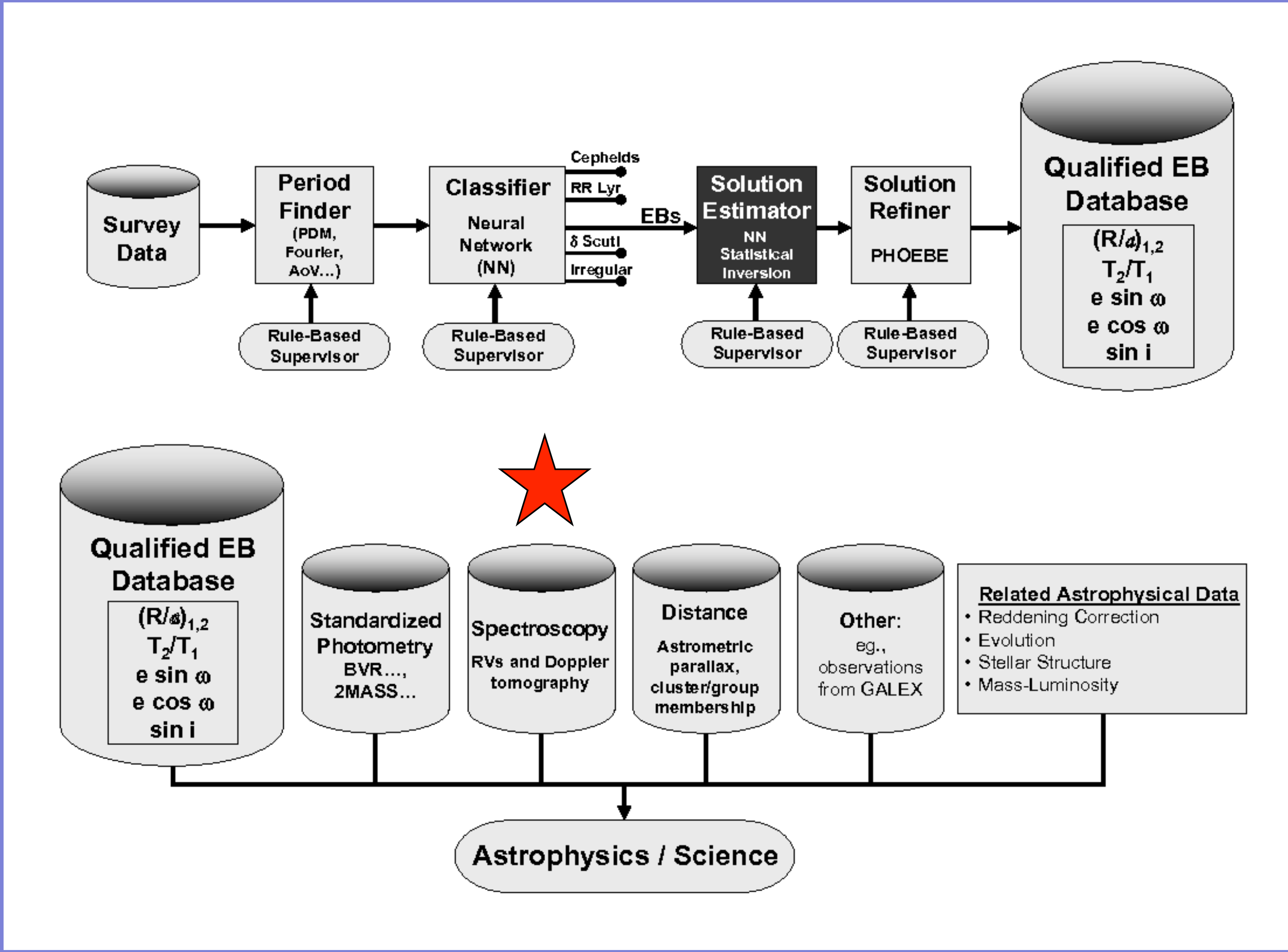
P = 0.814282212(1) d

activity level affects solutions

Current State of EBs and the Future:

- LSST will find 16 million EBs with ~1.6 million suitable for modeling)
- Too many EBs, and too few astronomers!

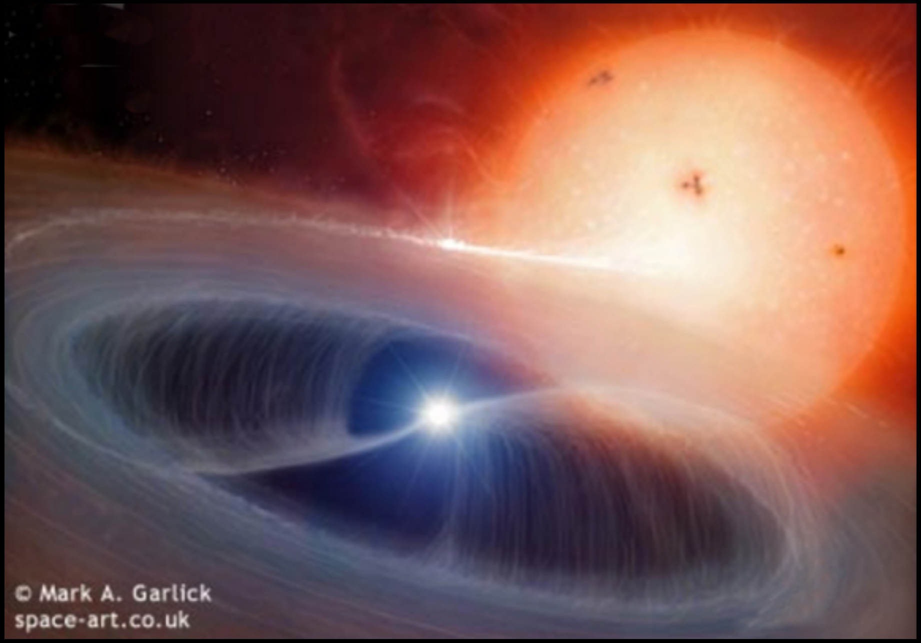
EBAI - eclipsing binary artificial intelligence- Prša et al. 2009



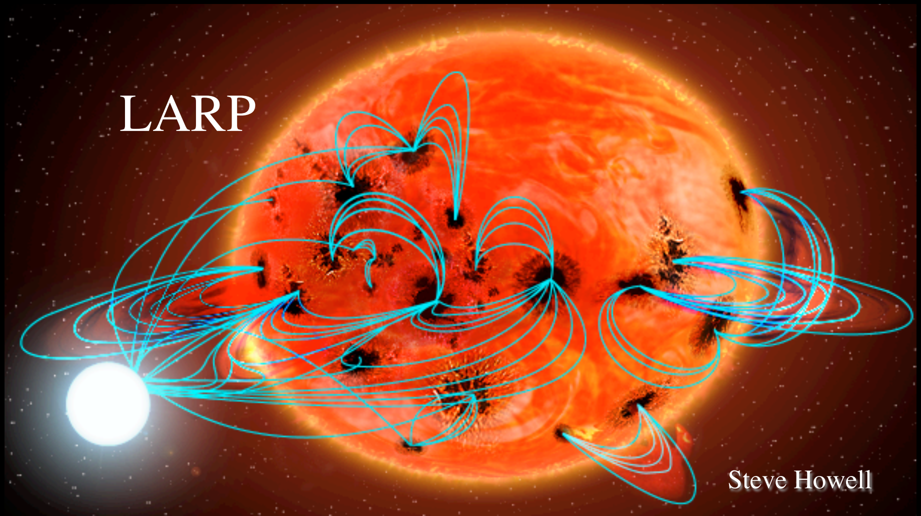
Interactive Binaries

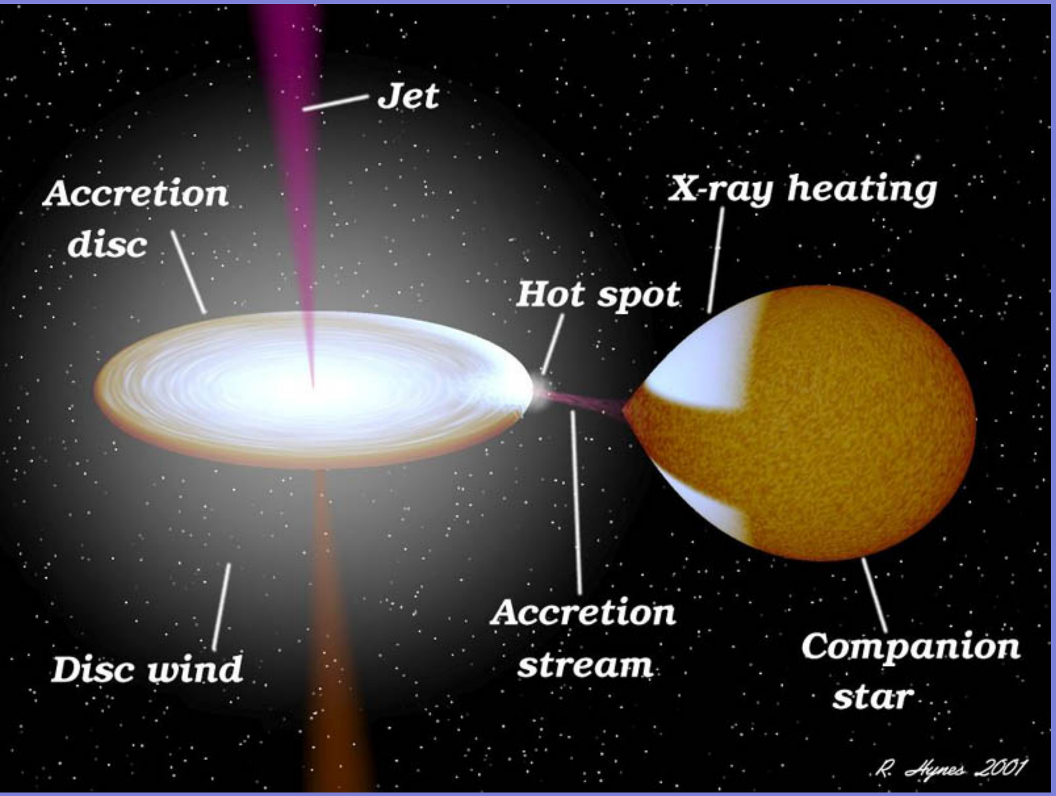
CV types

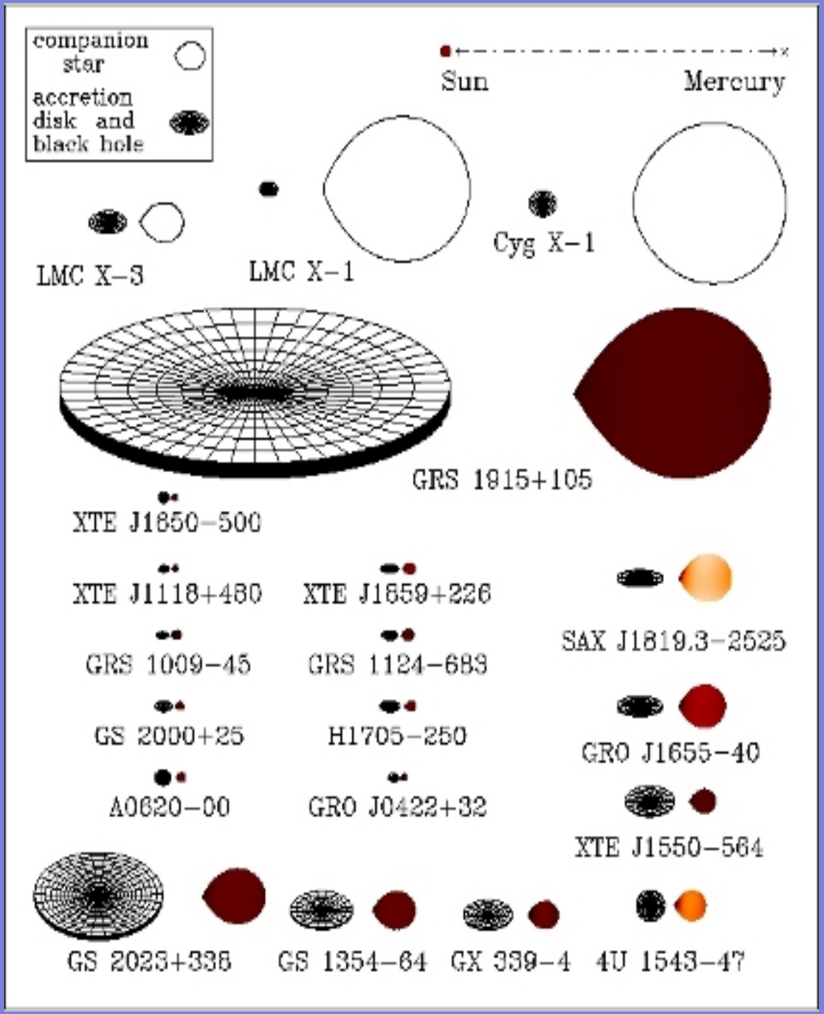
WD primary



Intermediate Polar







X-ray Binaries

Neutron star or
BH primary

Summary of Variability and timescales for Interacting Binaries

Variability	Typical Timescale	Amplitude (mag)
Flickering	sec – min	tenths
WD pulsation	4–10 min	0.01–0.1
AM CVn orbital period	10–65 min	0.1–1
WD spin (intermediate polars)	20–60 min	0.02–0.4
CV orbital period	10 min–10hrs	0.1–4
Accretion Disks	2–12 hrs	0.4
AM CVn Outbursts	1–5 days	2–5
Dwarf novae Outbursts	4 days–30 yrs	2–8
Symbiotic Outbursts	weeks–months	1–3
Symbiotic orbital period	months–yrs	0.1–2
Novalike High-Low states	days–years	2–5
Recurrent Novae	10–20 yrs	6–11
Novae	1000–10,000 yrs	7–15

Novae (TNR):

- brightest CVs (-6 to -10) so can probe MW and other galaxies
- decline time (0.01-1 mag/day), shape give info on d, WD mass, composition
- slow novae fainter, show FeII and found in bulge
- fast novae have massive WDs; He,N, O, Ne, Mg; occur in disk

Correct nova rates are needed to understand Galactic chemical evolution and star formation history

Past surveys have limited time sampling

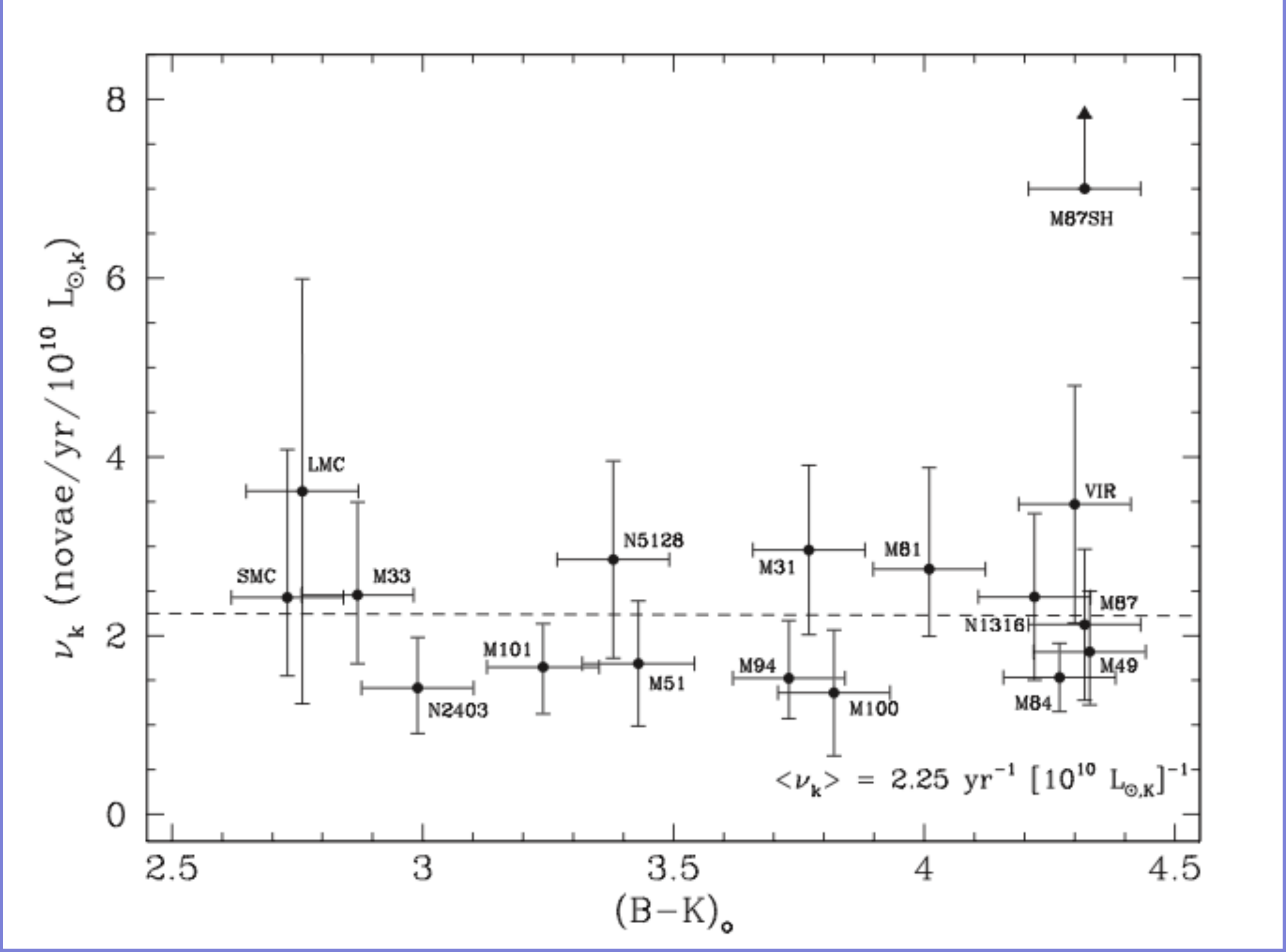
Recurrent novae may be underestimated by 10 X

Kasliwal, Shafter papers

Novae in Other Galaxies

Luminosity-Specific Nova Rates

from Shafter et al (2014)

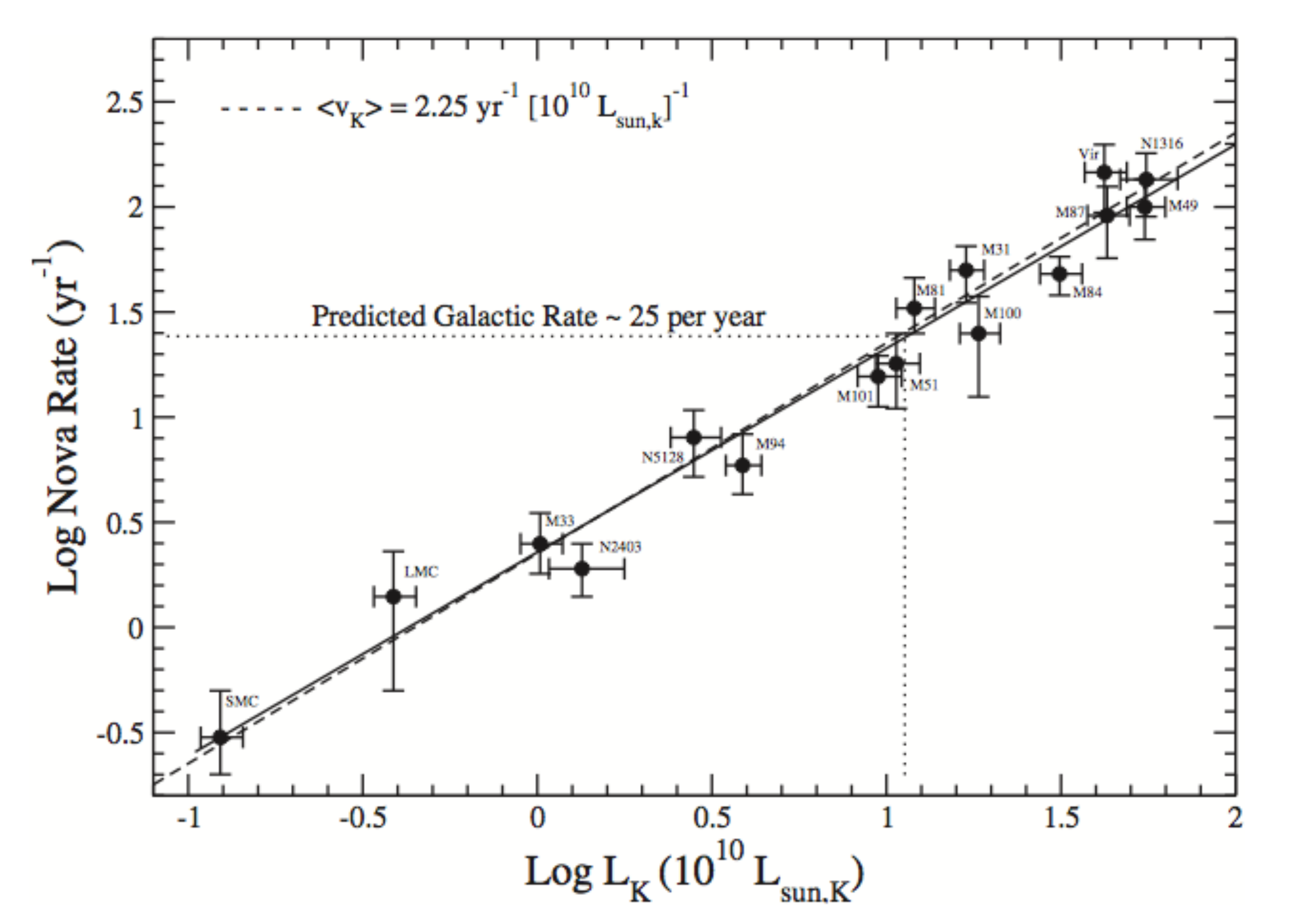


Rates for about a dozen galaxies don’t vary much with Hubble type

Novae in other Galaxies

Nova Rates vs Galaxy *K*-band Luminosity

Rates vary with mass

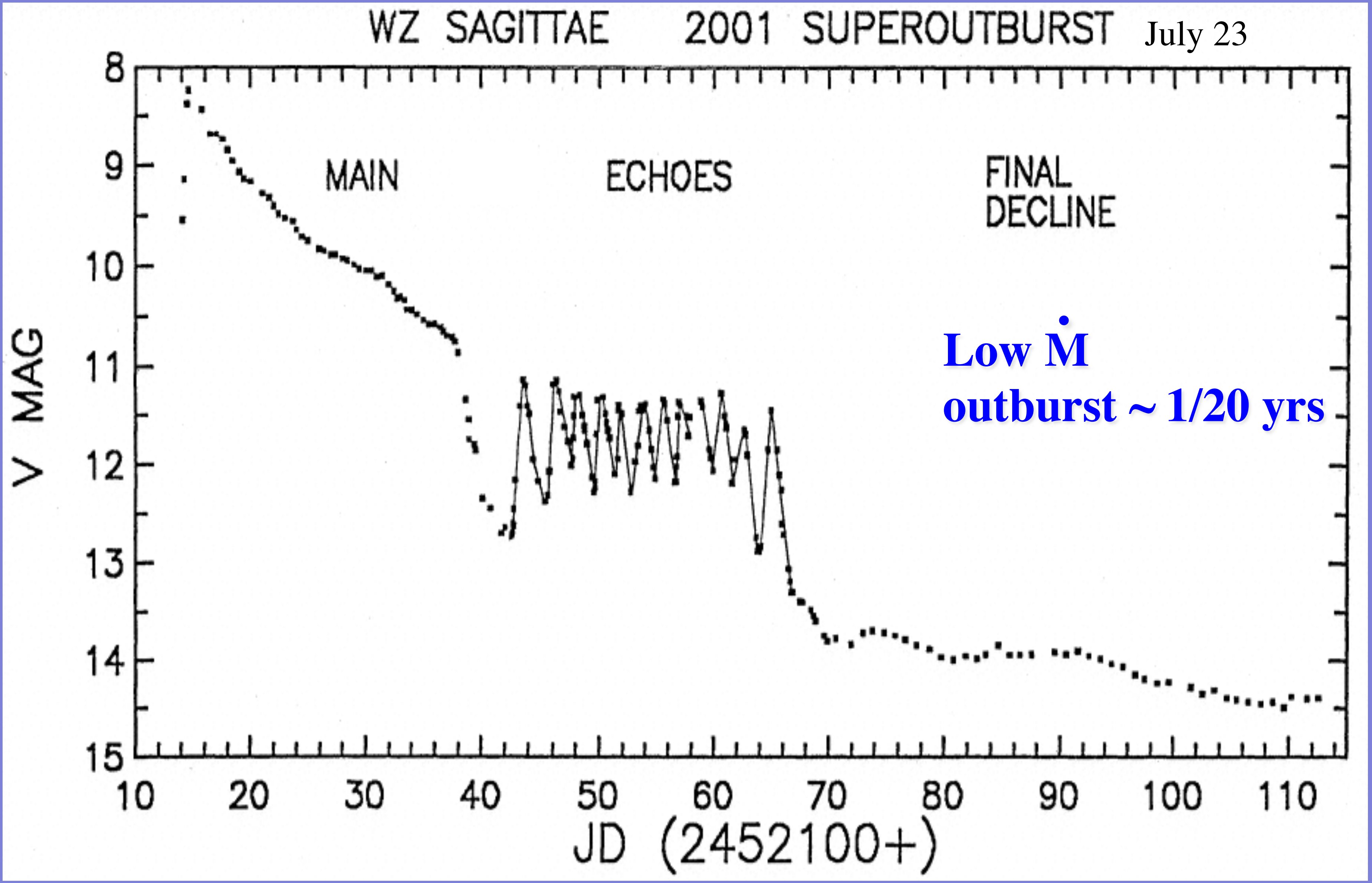


Future possibilities (LSST):

- will detect novae out to Virgo
- useful light curves will be obtained
- precursor star can be observed

TMT followup – FeII; He/N;O,Ne,Mg novae

Followup of Dwarf Novae Outbursts

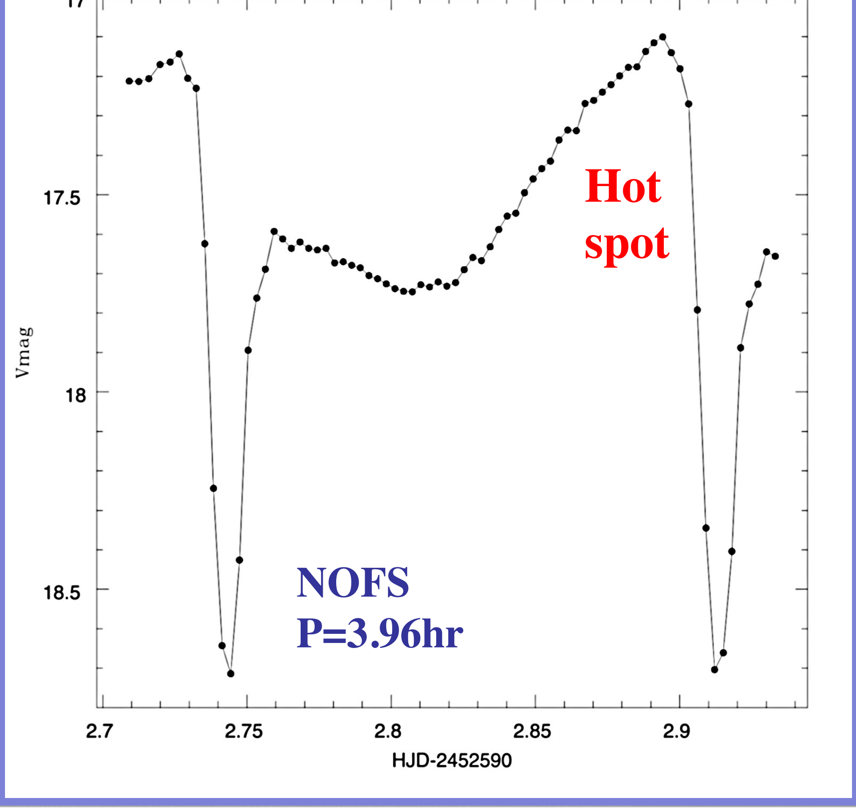


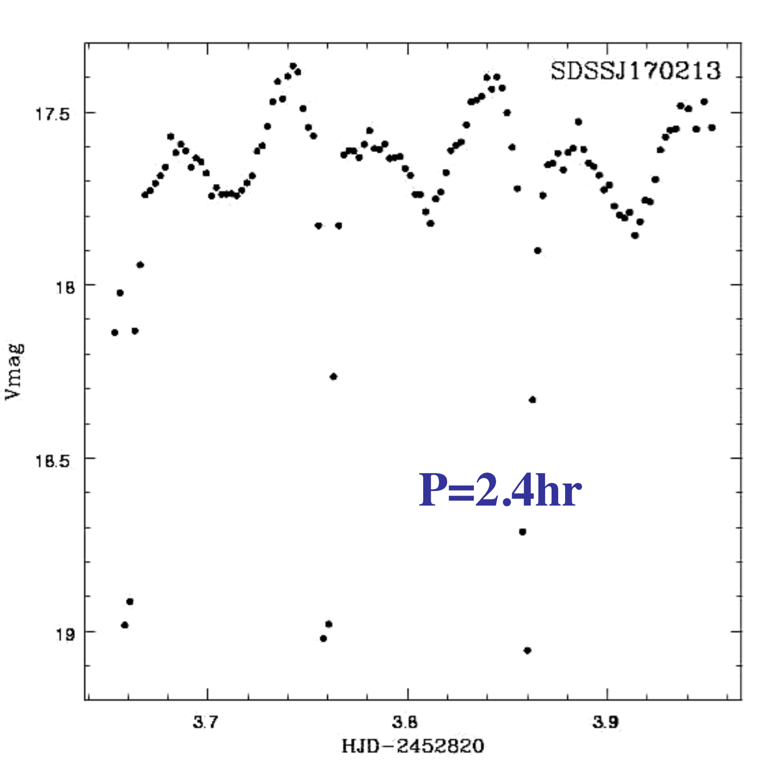
Followup of DN Orbital variations

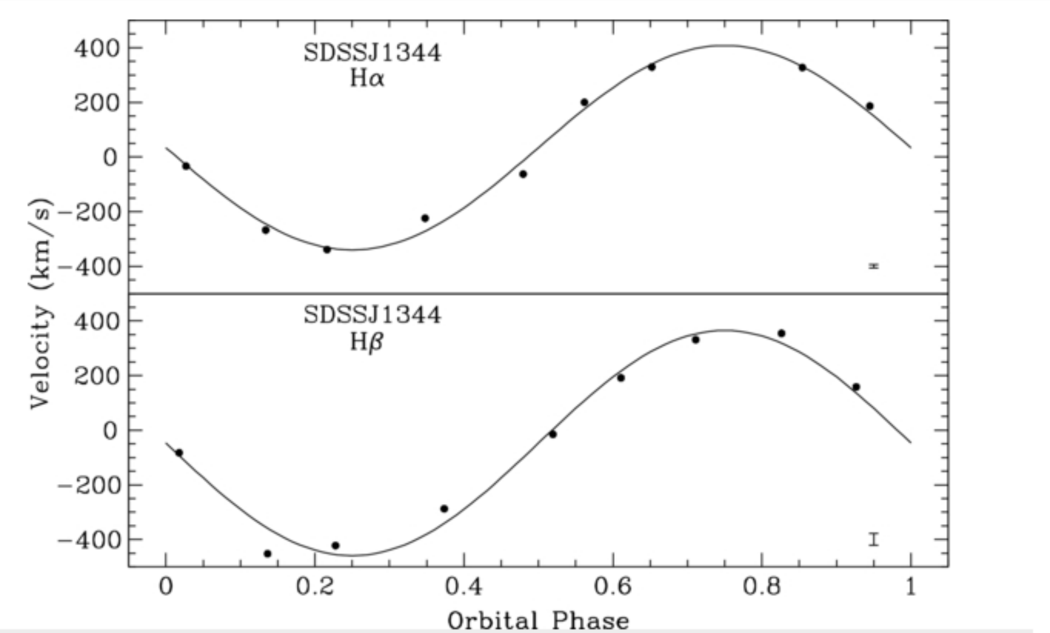
- Eclipsing systems enable photometric model
- Can detect eclipse of disk, hot spot, WD
- Can parameterize accretion area in magnetic systems
- P_{orb} (1.2-10 hrs) allows population, evolution study

Requires high time resolution (eclipses are typically 15 min duration) -> big telescope

~30% of disk systems show orbital variations (spot); 100% of polars (amplitudes of 0.1-4 mags)



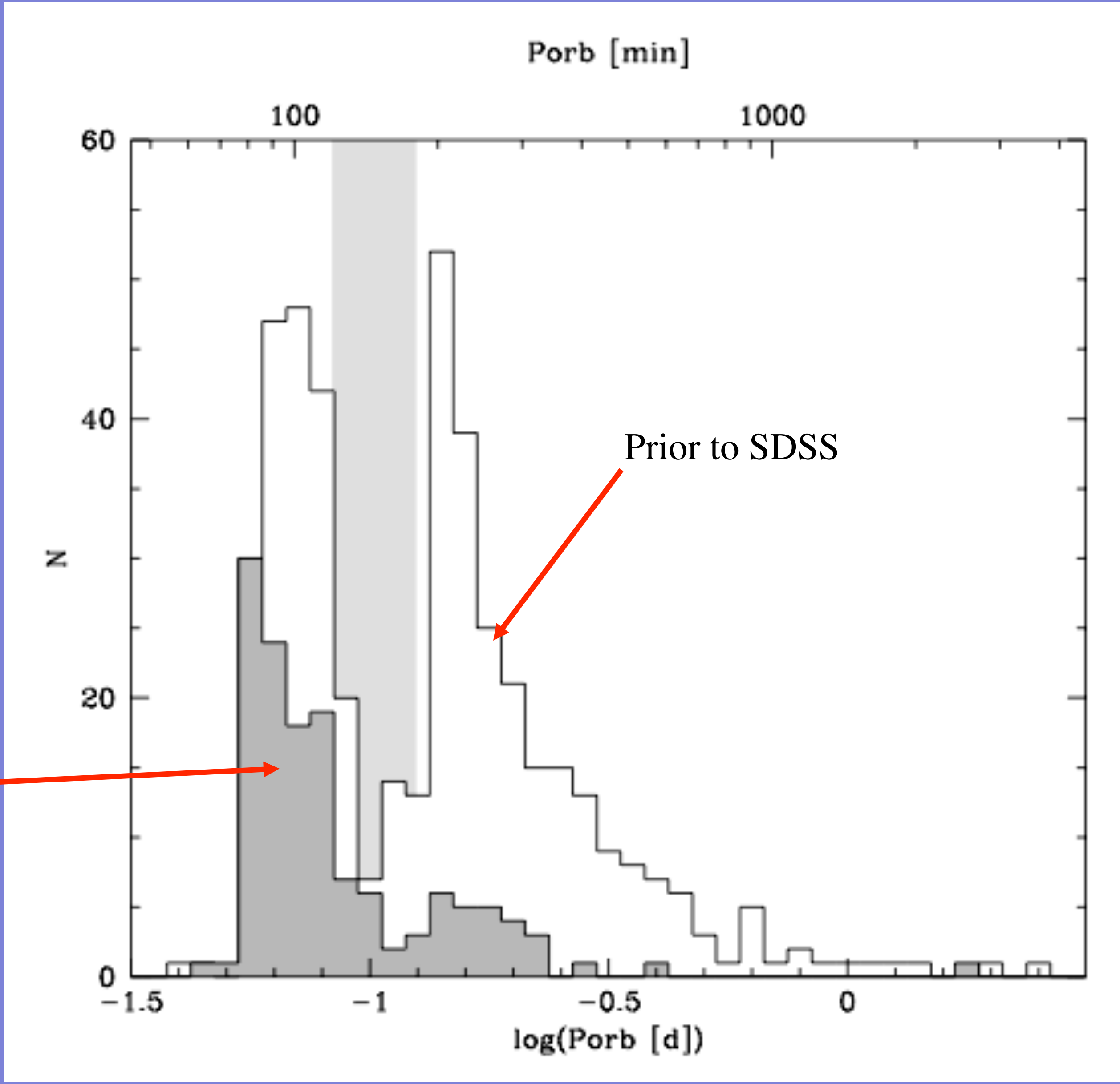




Photometry – Eclipsing systems

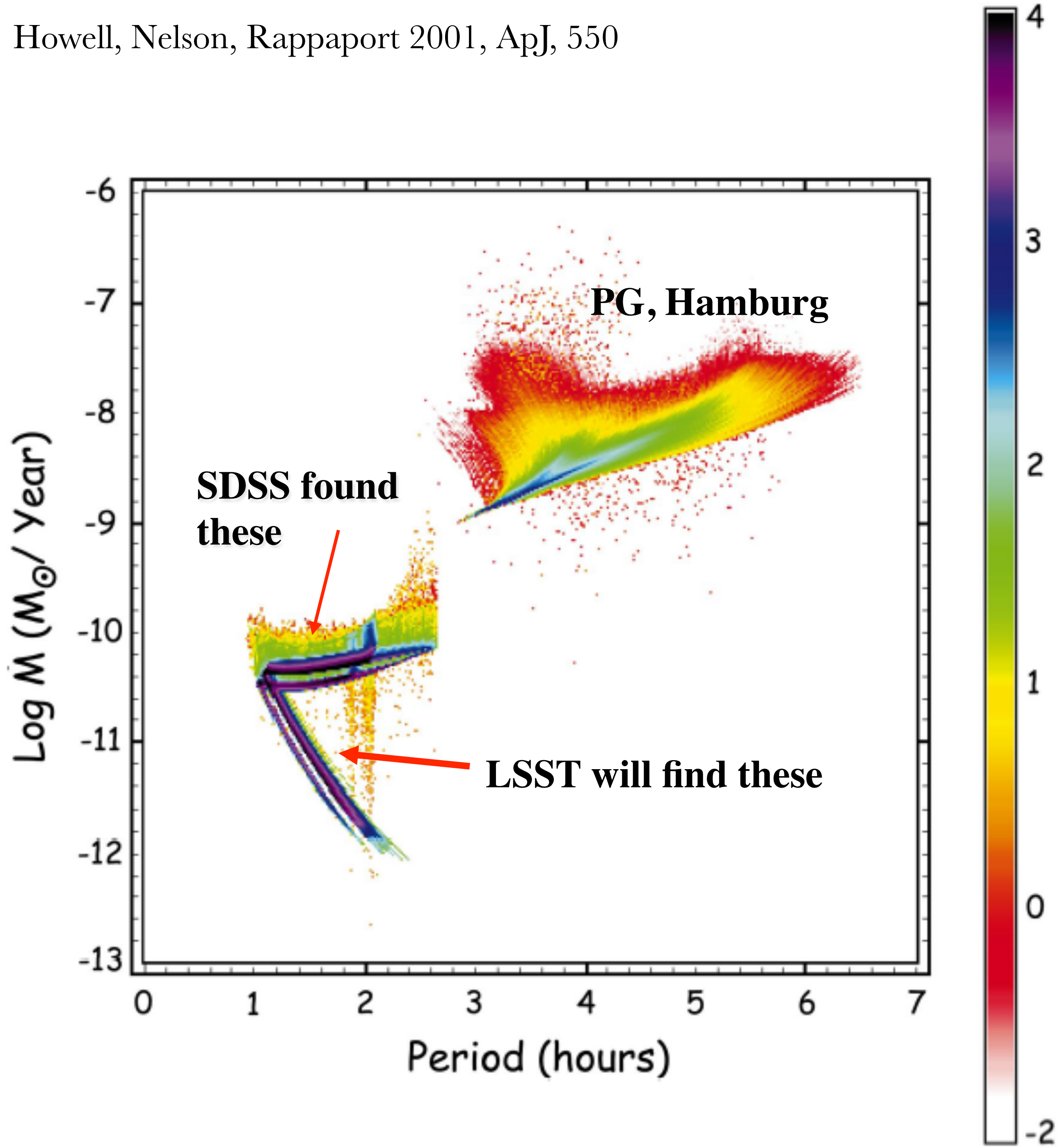
Spectra – RV curve

Science from Orbital variations



Gansicke et al. 2009

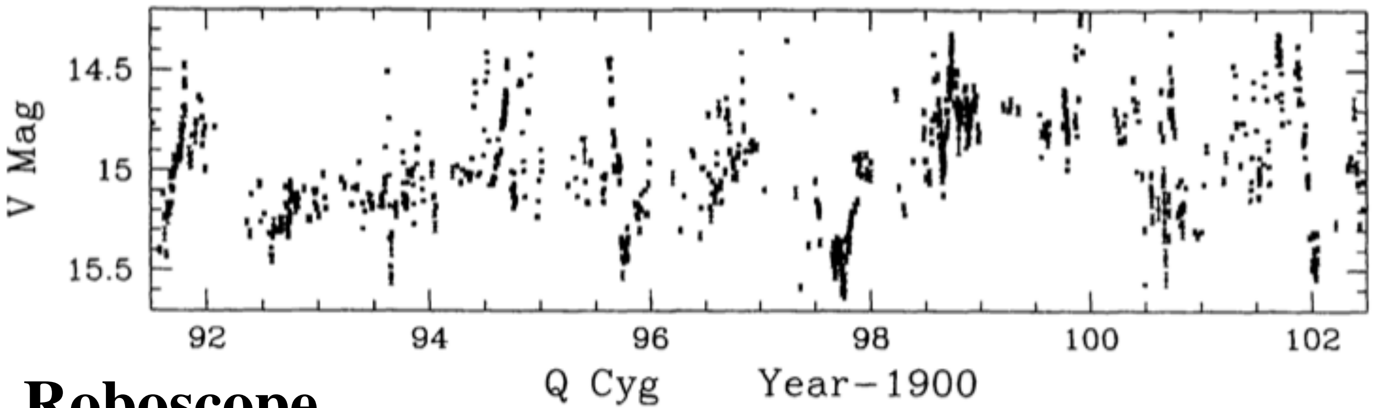
Howell, Nelson, Rappaport 2001, ApJ, 550



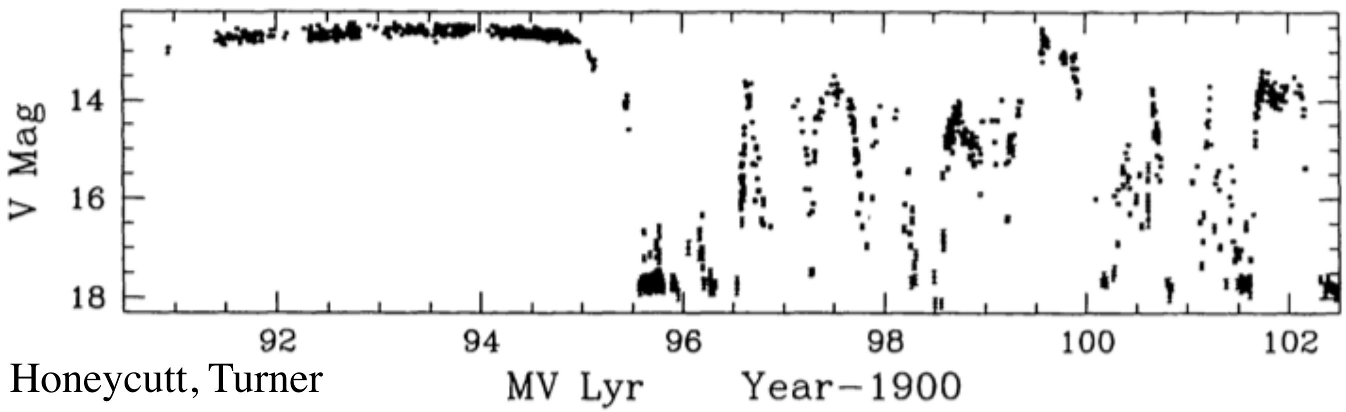
Log number of CVs

Need numbers to understand evolution

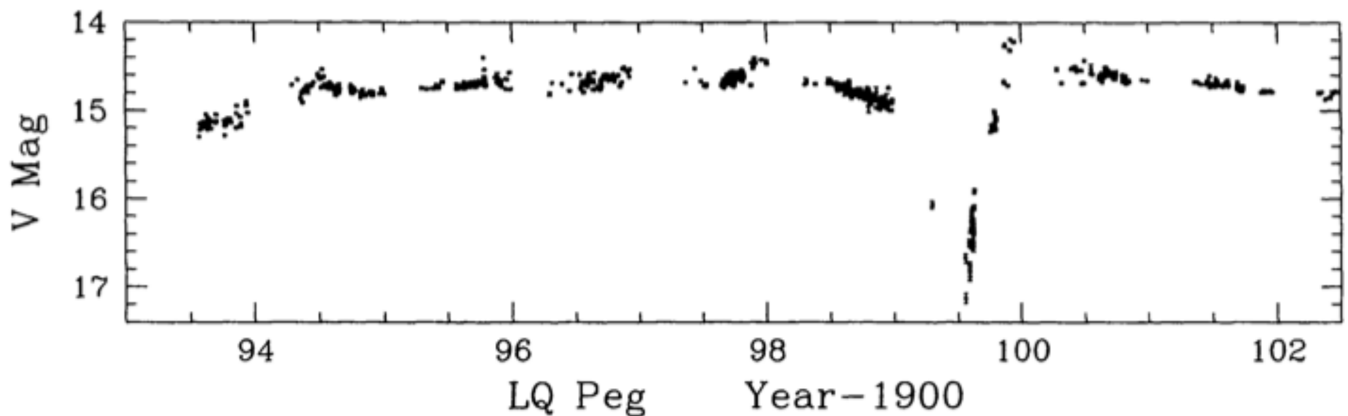
Long term variability



Roboscope

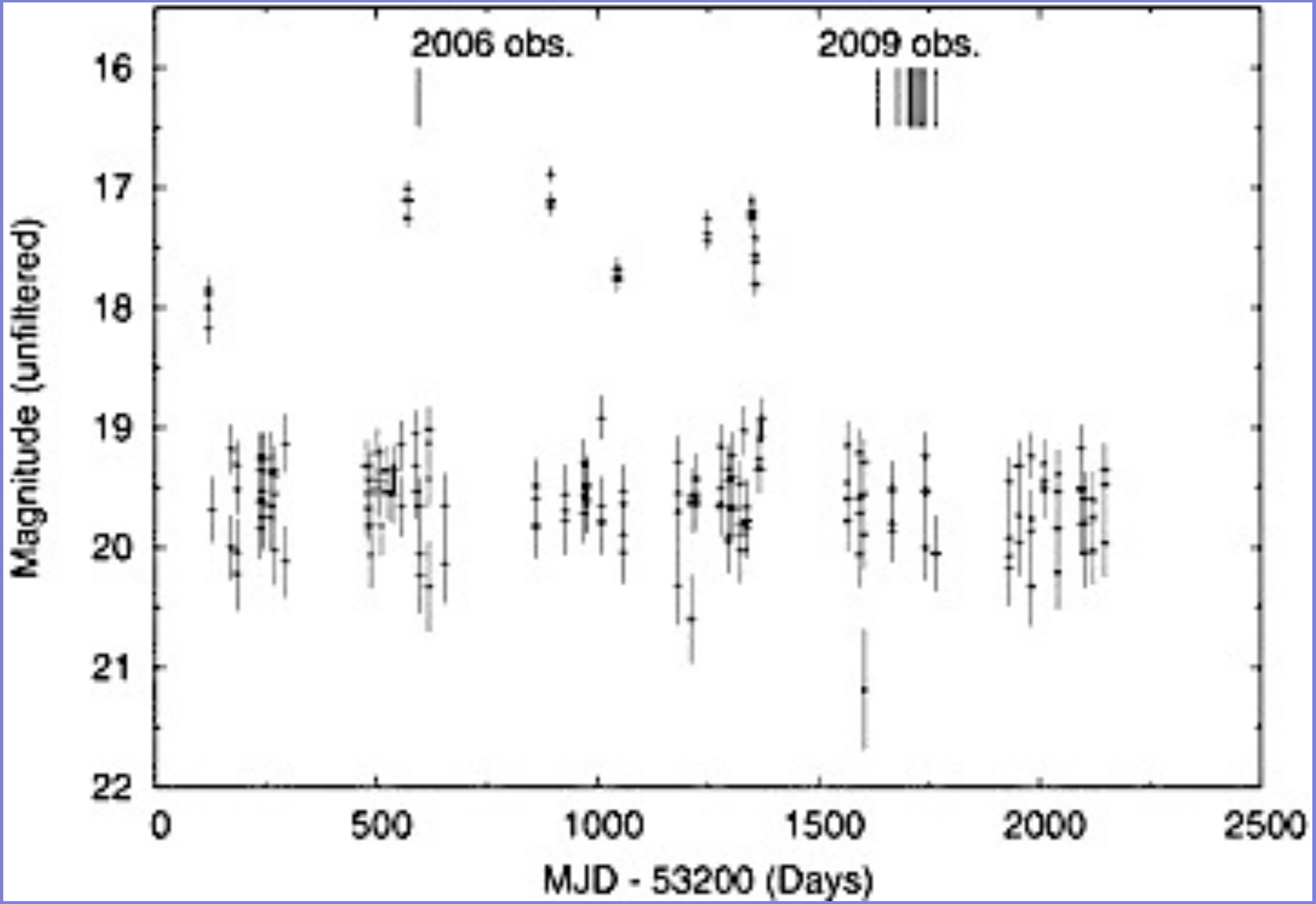


Honeycutt, Turner & Adams 2003



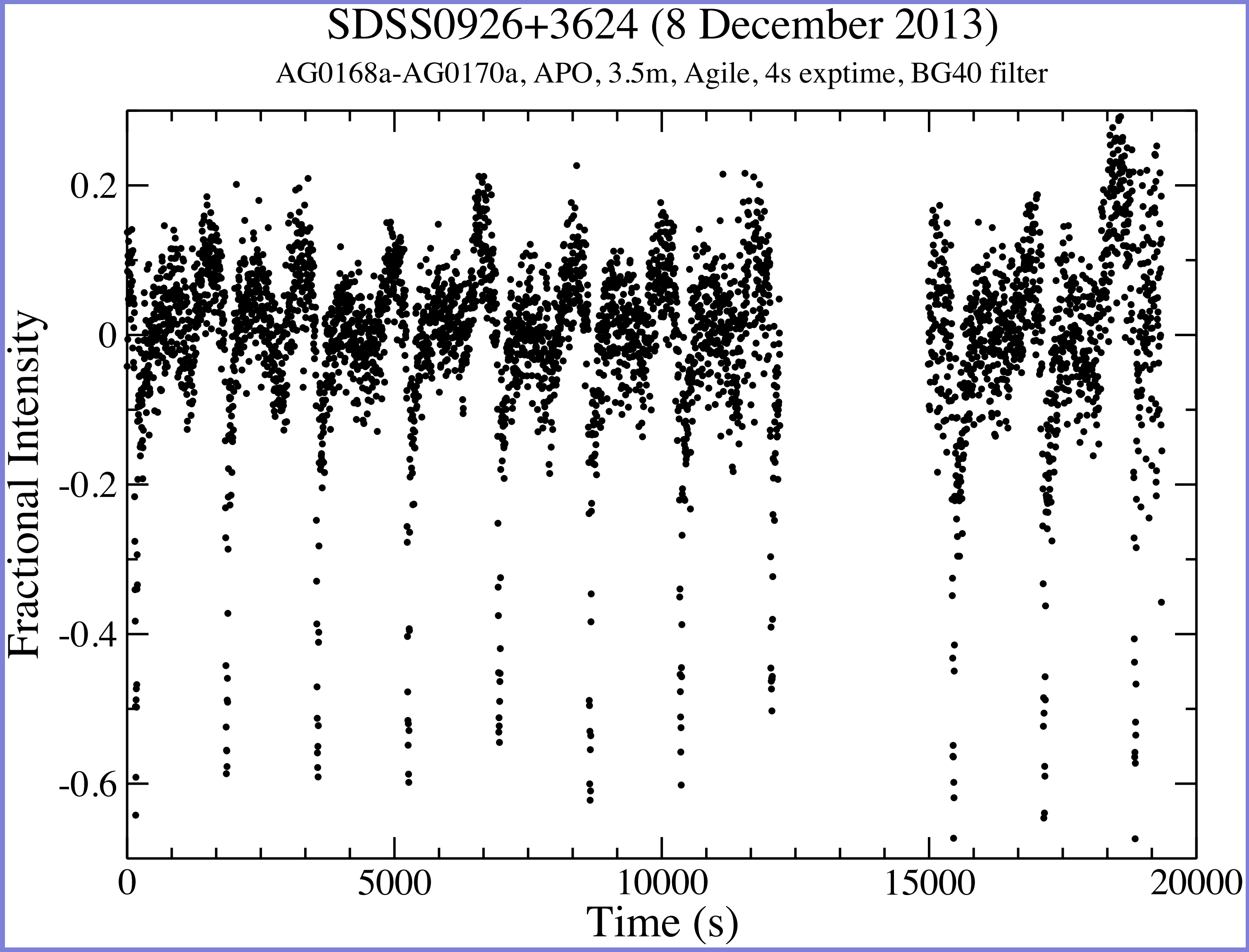
See stars at low states!

CRTS data on AM CVn SDSS0926+36



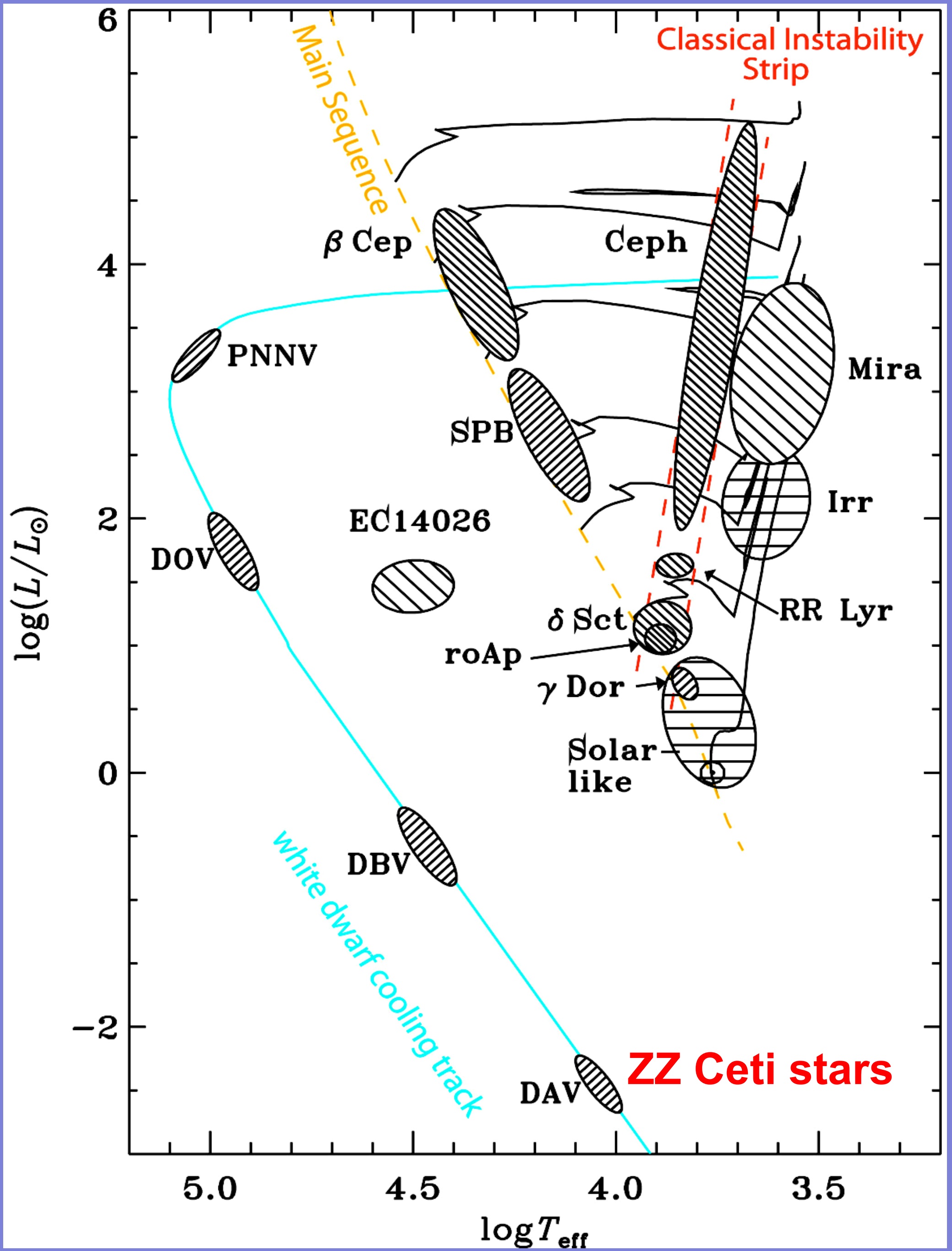
Rapid timescale photometric followup

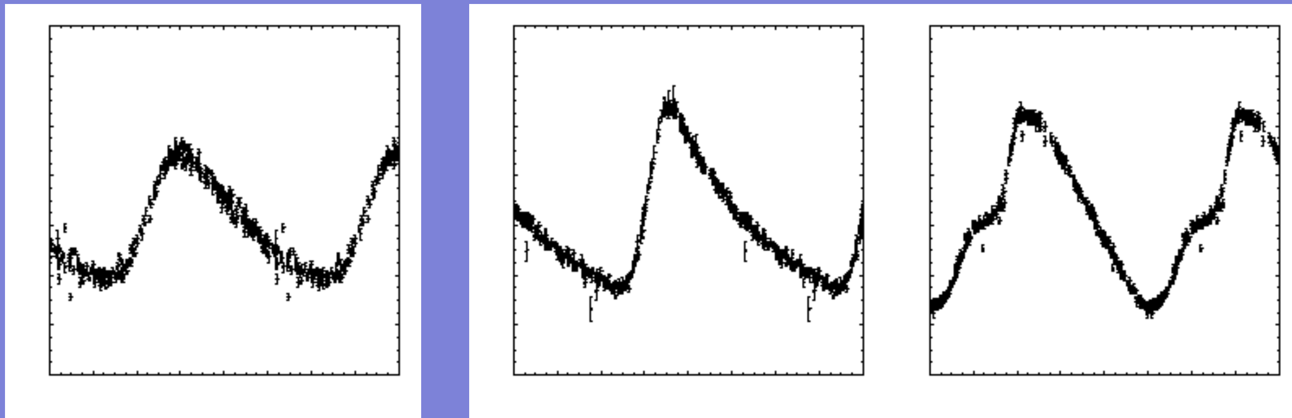
Eclipsing AM CVn P=28 min, eclipse=1 min



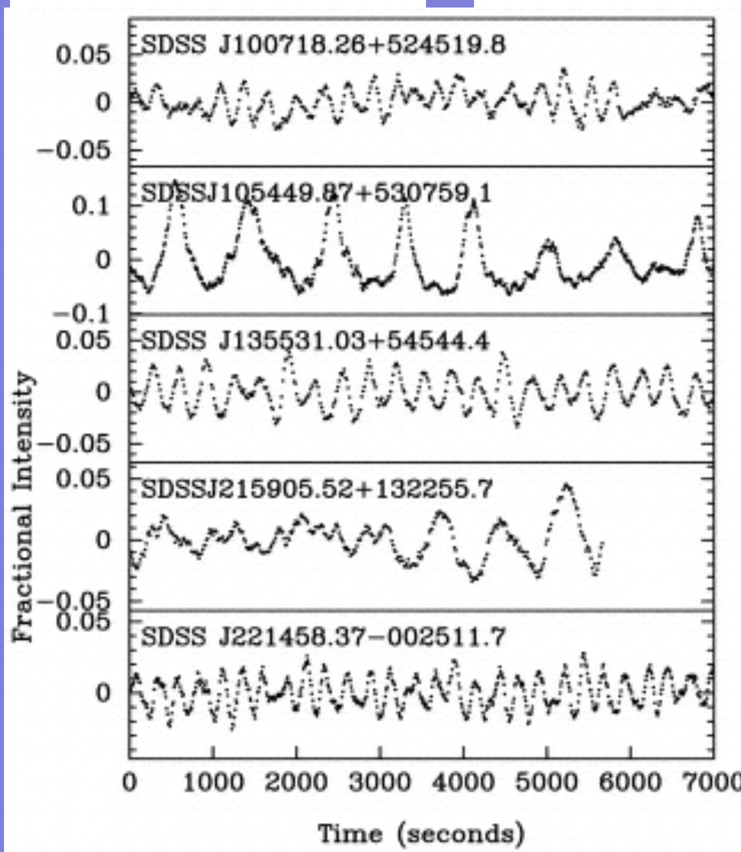
Pulsating stars:
Asteroseismology

- Pulsations $\Rightarrow$ Only systematic way to **study the stellar interior**
- Pulsations are observed in stars **all over the HR diagram**

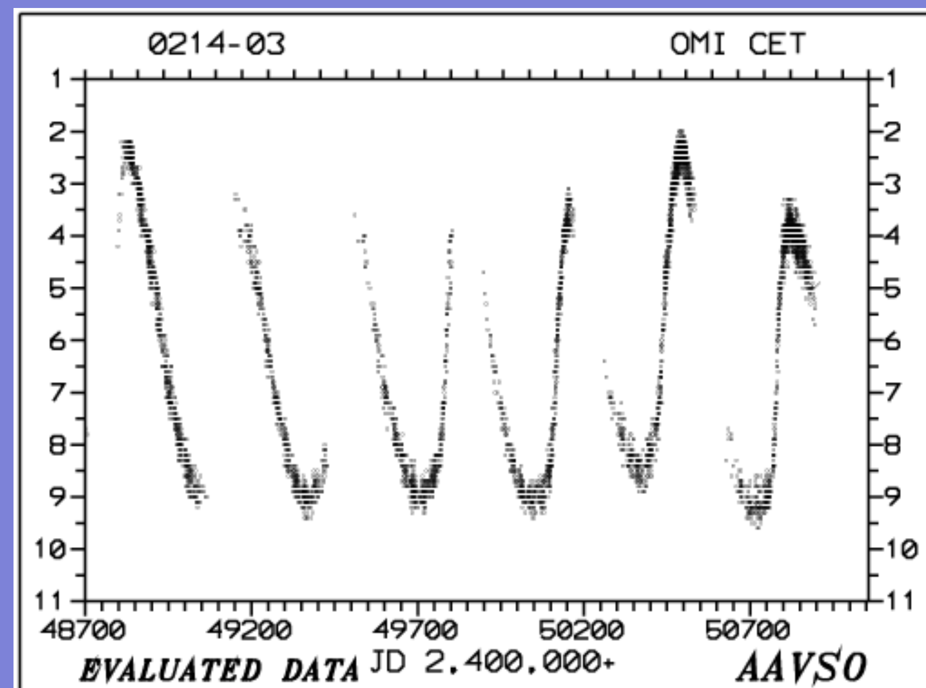




MACHO cepheids
P~2-60 days



ZZ Ceti pulsating WDs
P~ mins



Mira - pulsating RG
Period ~ 11 months

Science for Pulsators

- Cepheids, RR Lyr and LPV can be used to get distances (Type Ia SN, nearby galaxies)
- RR Lyr are tracers of galactic structure:info on metallicity, evolution of globular clusters and nearby galaxies

WD Followup for Pulsations, Spins

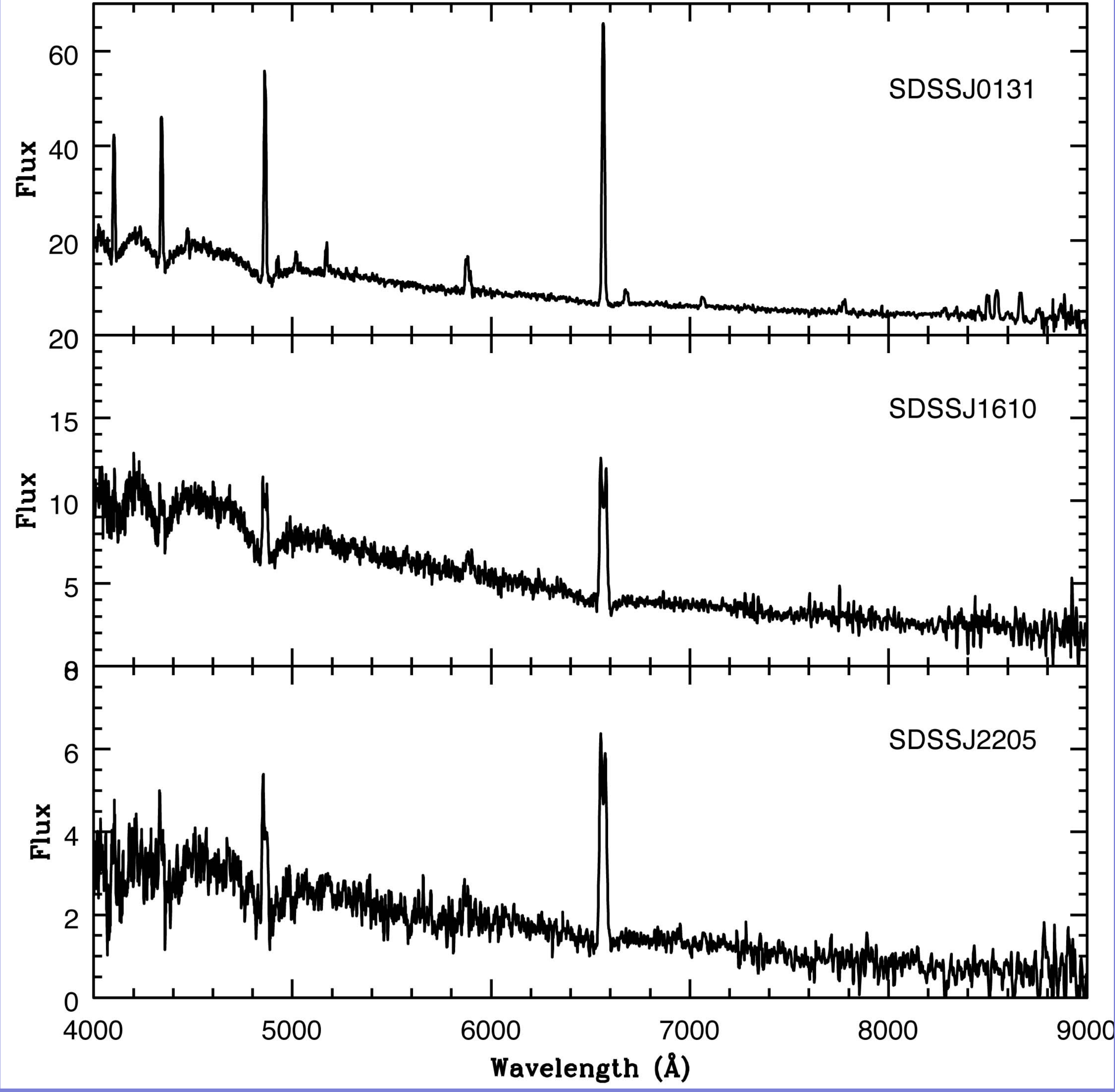
Pulsations

- 18 White Dwarfs in Instability Strip
- Periods about 2-10 min
- Amplitudes < 0.1 mag
- Gives info about WD interior

Spins

- Magnetic White Dwarfs in Binaries
- Periods 10 - 60 min (IP), hrs (polars)
- Amplitudes 0.01-0.5 mag
- Gives info on magnetic field

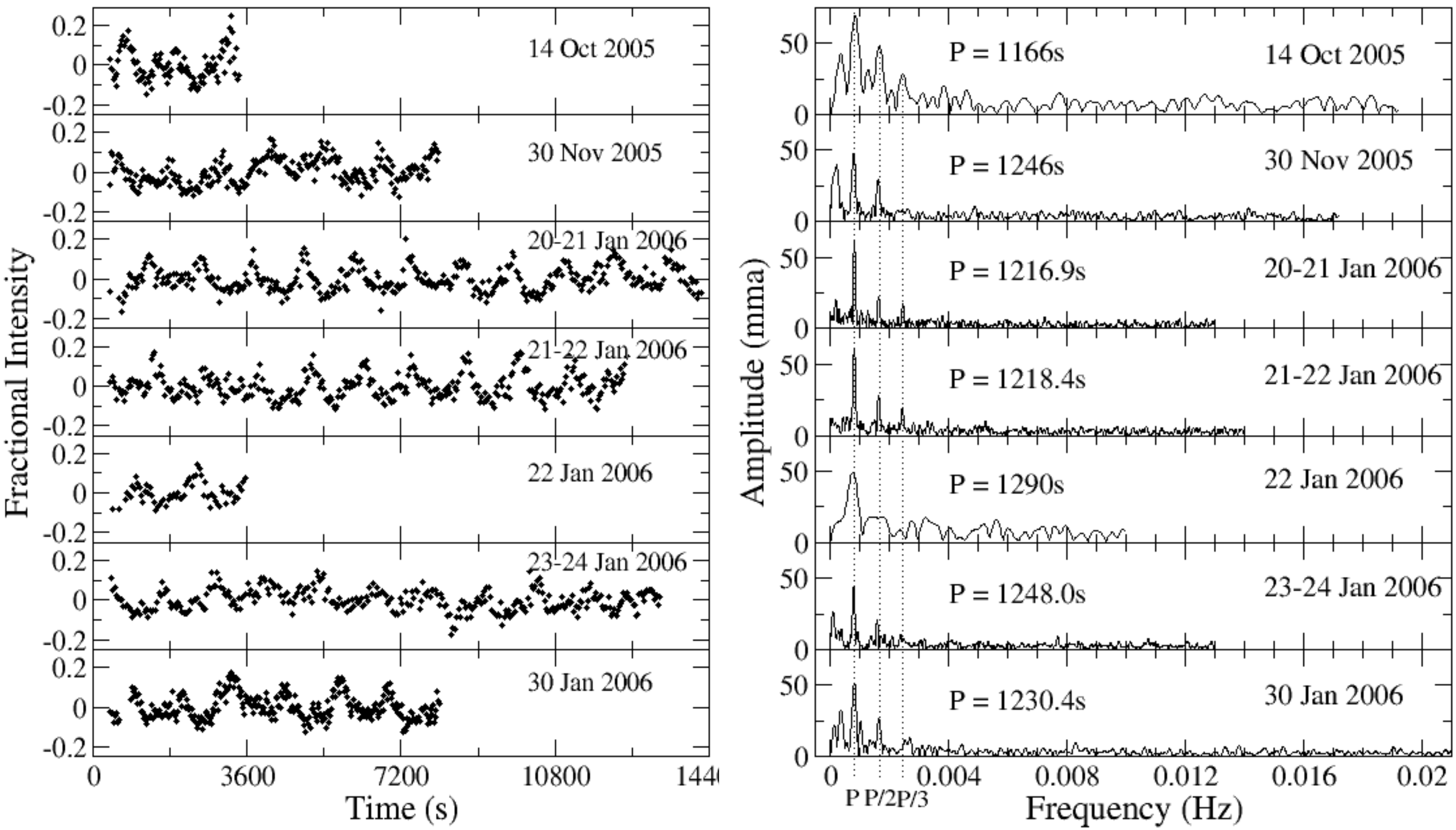
optical signature of pulsating, accreting WDs : find from colors, spectra



Rapid Photometry of Pulsations

Light curves of accreting pulsator SDSS0745+45

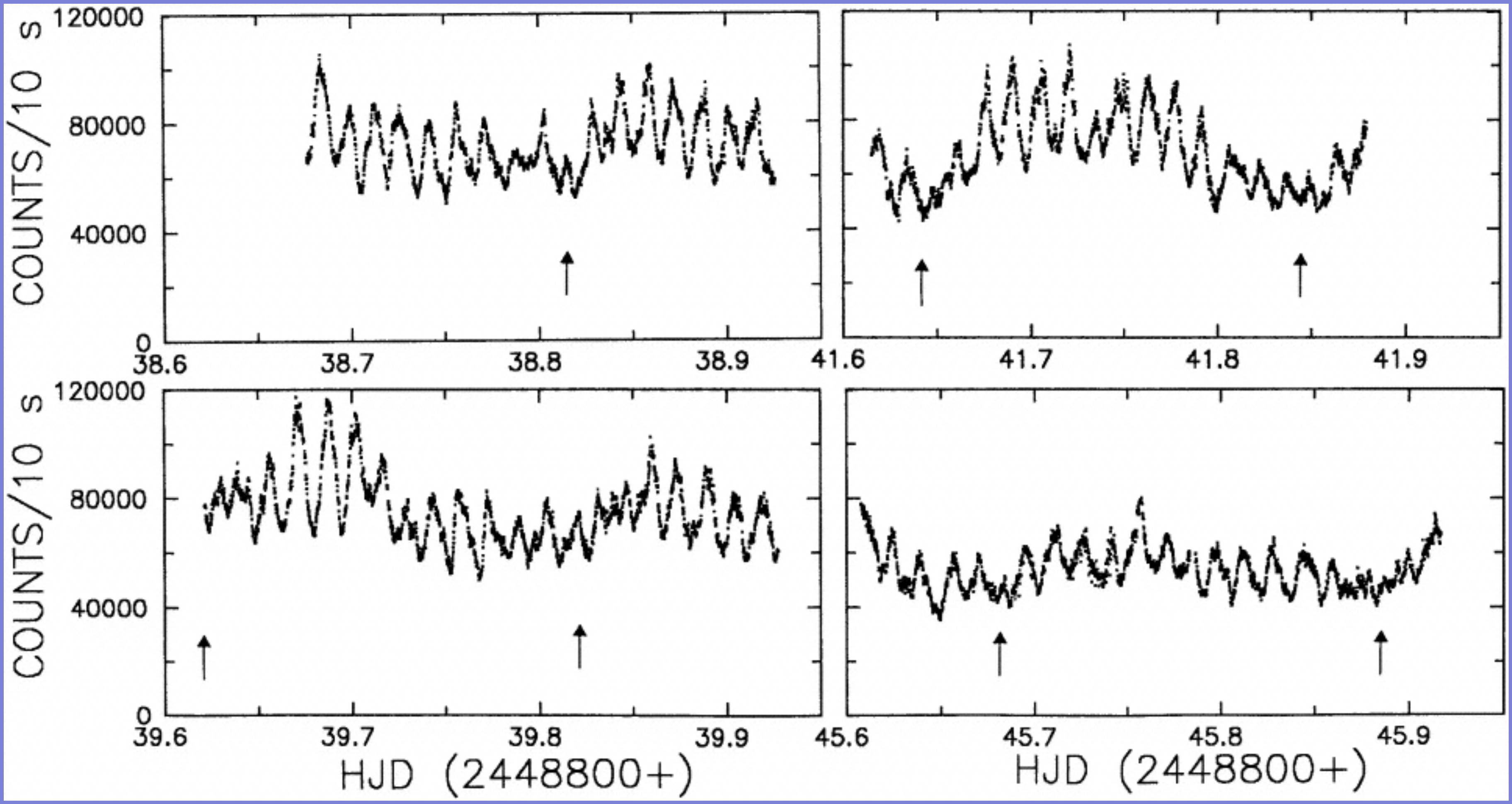
Fourier transforms



Rapid Photometry of WD Spin

FO Aqr Patterson et al. 1998 PASP

P_{spin}= 21 min



Summary for Maximizing Science Return from TMT/LSST:

- Fast TOO with low res spectra to identify variables
- Slower science followup with medium res spectra to obtain period, composition, radial velocities,etc
- Slower science followup with fast-readout CCD to resolve rapid timescale phenomena