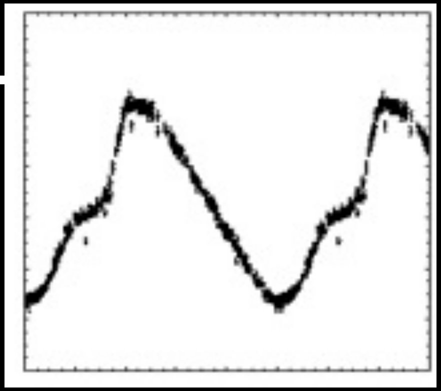
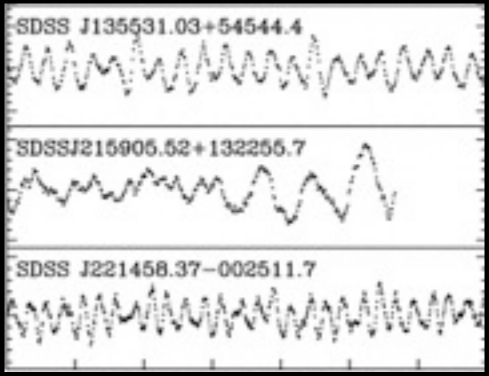
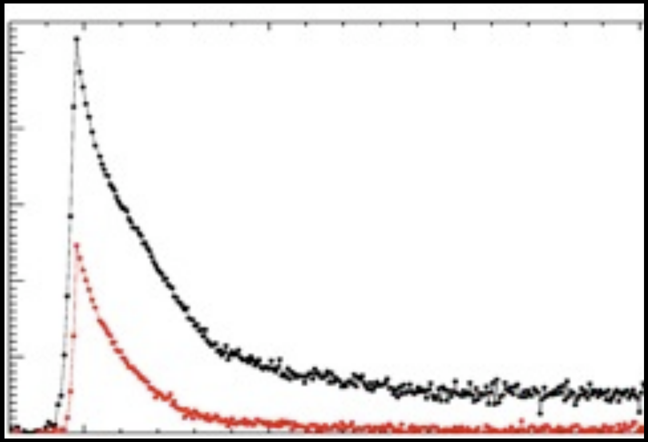
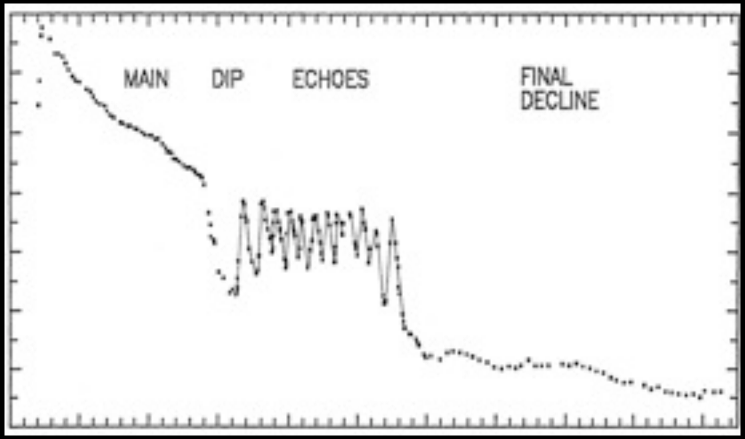
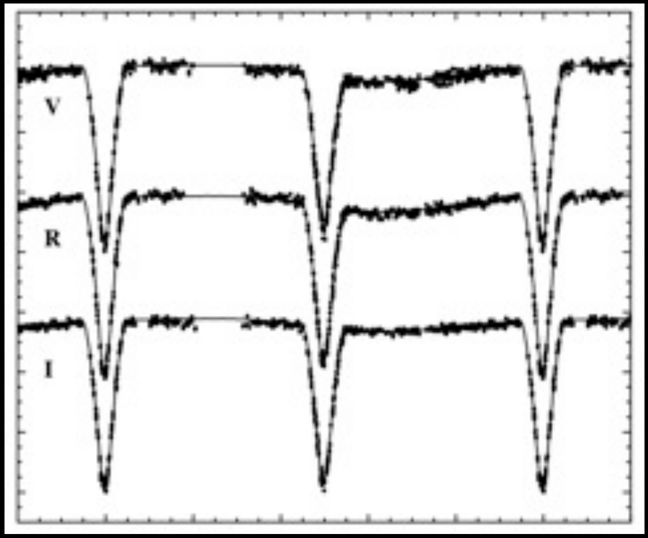
Variable Stars: the Partially Known and the Totally Unknown











The Eventful Universe March 18 Paula Szkody + many

The Partially Known:

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

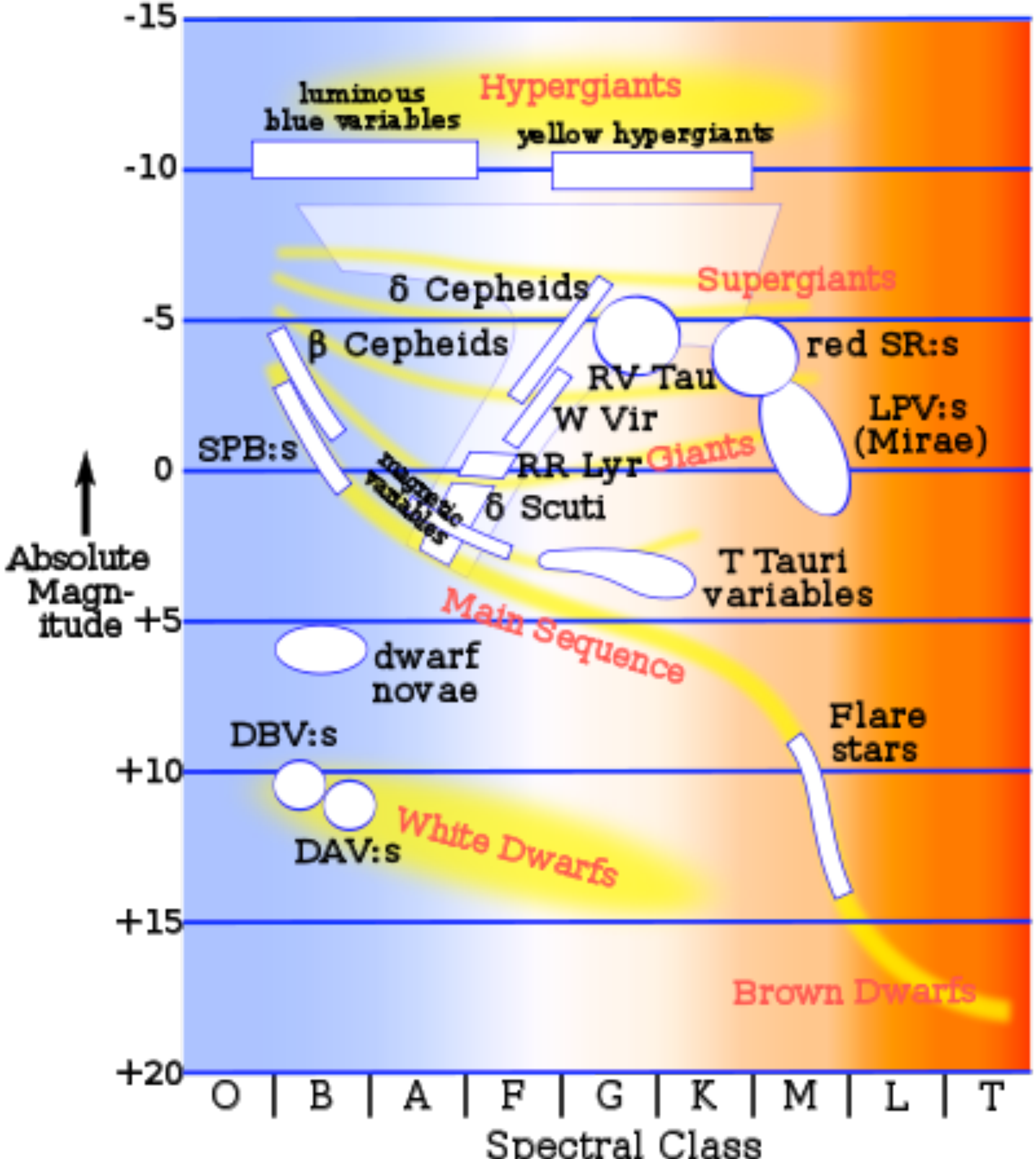
Mira:M, yrs, 1-5mag

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
luminous blue variables
Hypergiants
yellow hypergiants
δ Cepheids
Supergiants
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
White Dwarfs
DAV:s
Brown Dwarfs
O
B
A
F
G
K
M
L
T
Spectral Class

To classify a variable correctly, we need:

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

Primer on Eclipsing Binaries

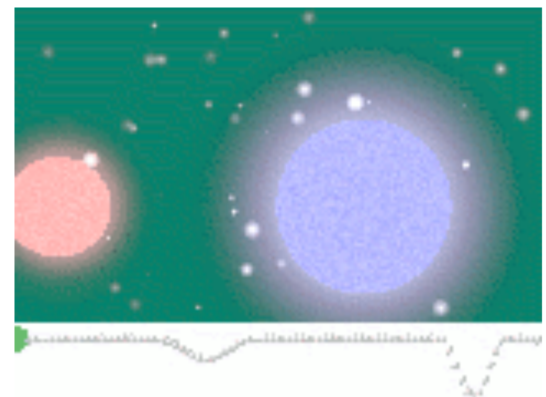
Keivan Stassun

EBs are benchmarks for understanding stellar evolution as they provide fundamental parameters of stars

- Radial velocities
  - Full orbit solution because sin *i* known from light curve
  - Stellar masses

T&R → L&d

R&M → age



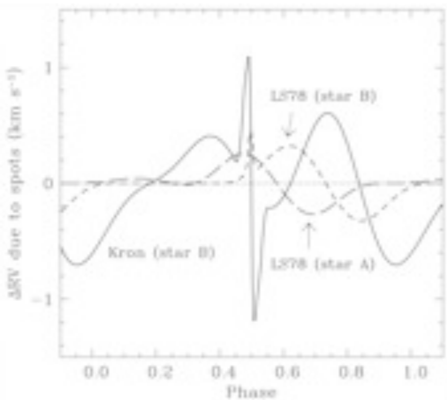
- Multi-band light curves
  - System ephemeris, i
  - Stellar radii and temperatures
  - Spots
- Advantages:
  - Distance independent
  - High accuracy
- Disadvantages:
  - Short periods, fast rotation, tidal interaction, activity
  - Binaries may not be representative of single-star models

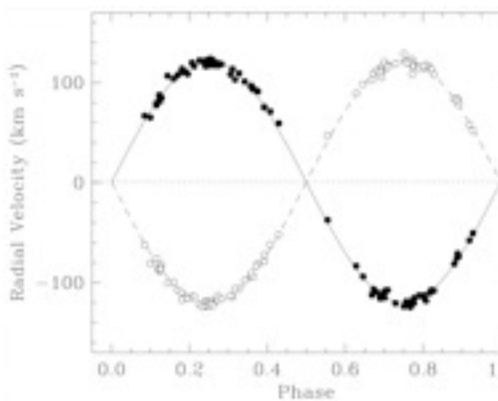
Hipparcos found 0.8% of stars were EBs

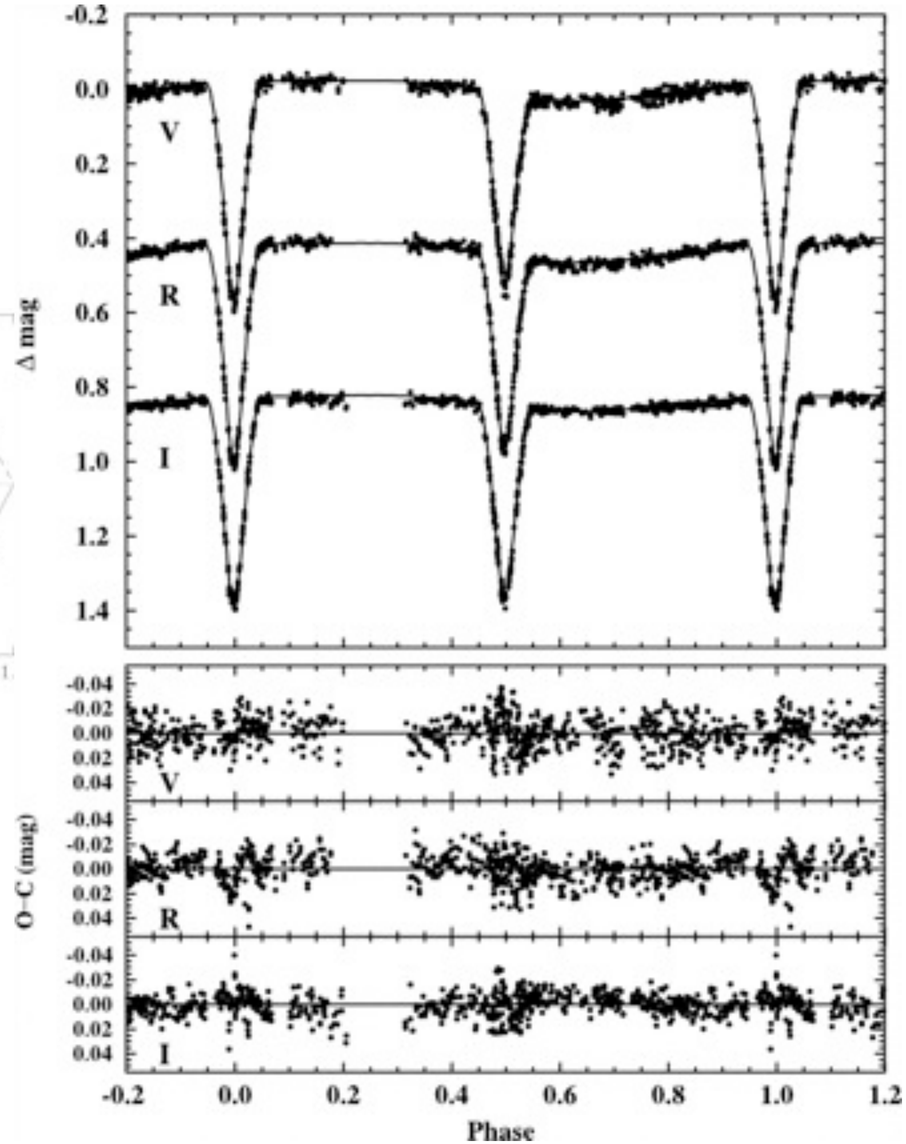
Current focus: low mass binaries: YY Gem

dM+dM

Torres & Ribas (2002)





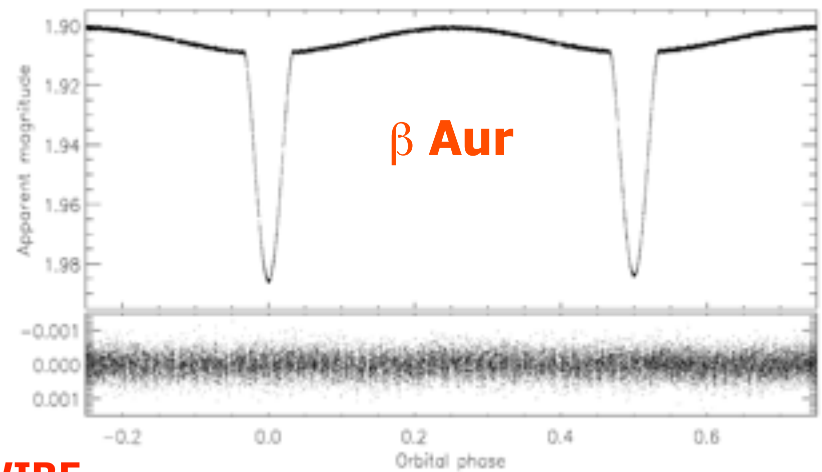


Parameter	Value
Mass ($M_\odot$)	0.5992 ± 0.0047
Radius ($R_\odot$)	0.6191 ± 0.0057
$\log g$ (cgs)	4.6317 ± 0.0083
$\bar{\rho}$ (g cm^{-3})	3.56 ± 0.10
$v \sin i$ (km s^{-1})[a]	37 ± 2
$v_{sync} \sin i$ (km s^{-1})[b]	38.5 ± 0.4
T_{eff} (K)	3820 ± 100
$L/L_\odot$[c]	0.0733 ± 0.0015
M_{bol} (mag)[c,d]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

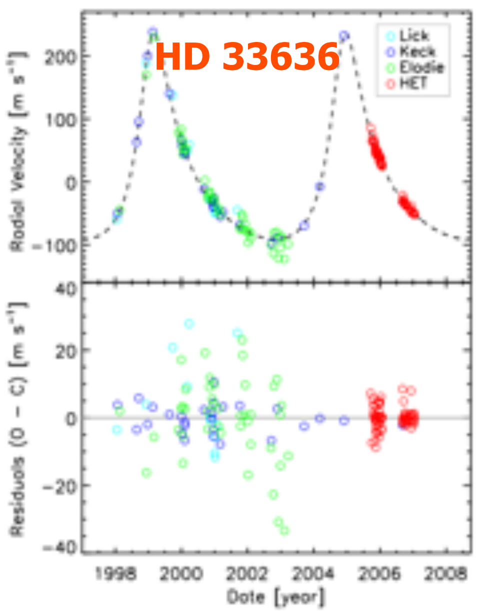
P = 0.814282212(1) d

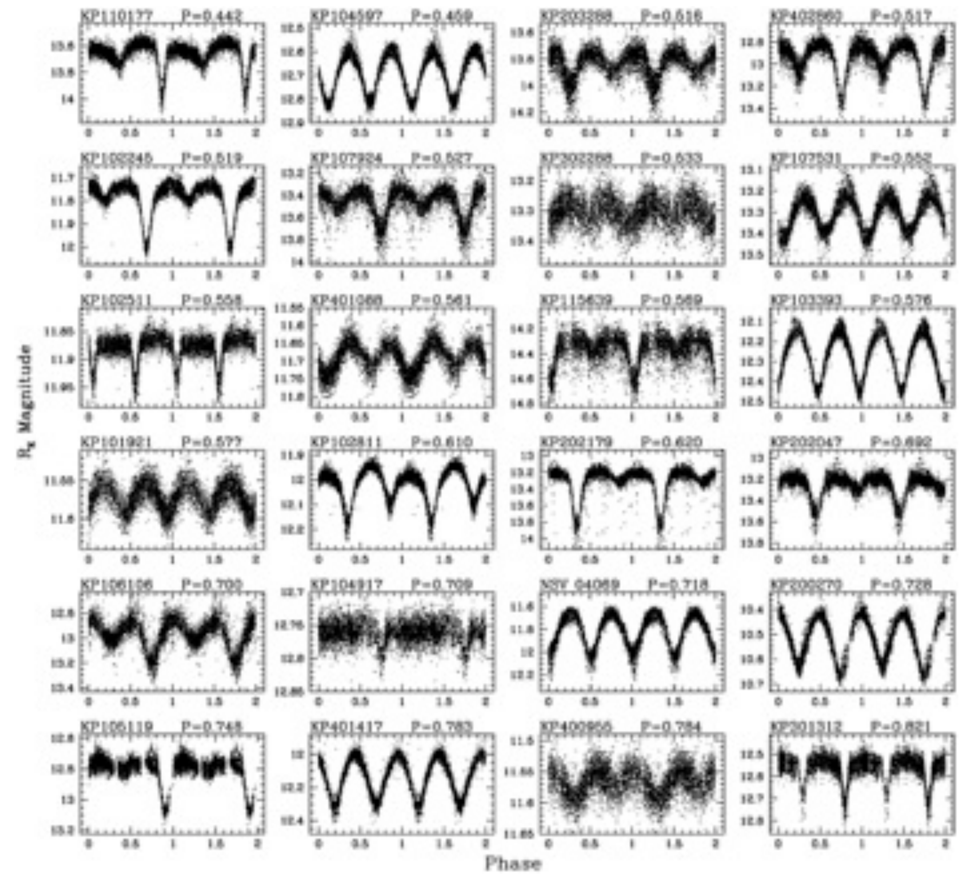
activity level affects solutions

Future Directions:EBs in the Era of Large Surveys



WIRE

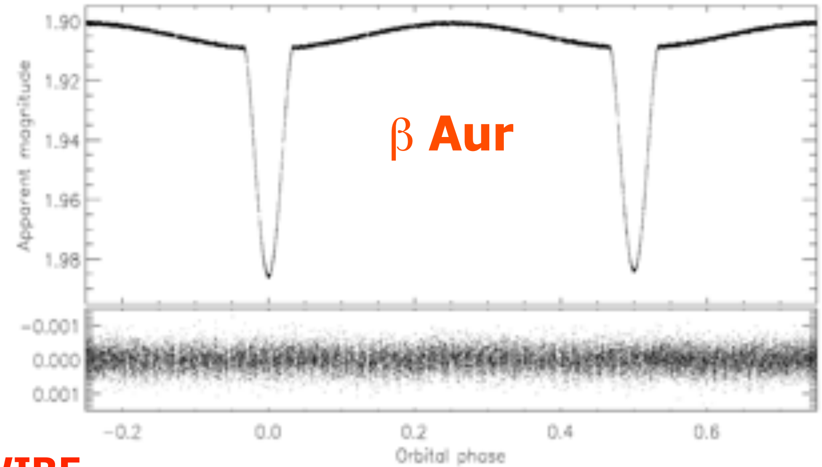




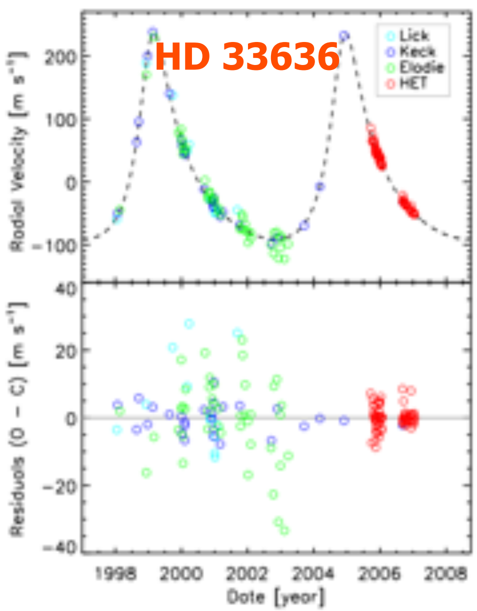
Vanderbilt-Fisk KELT Project

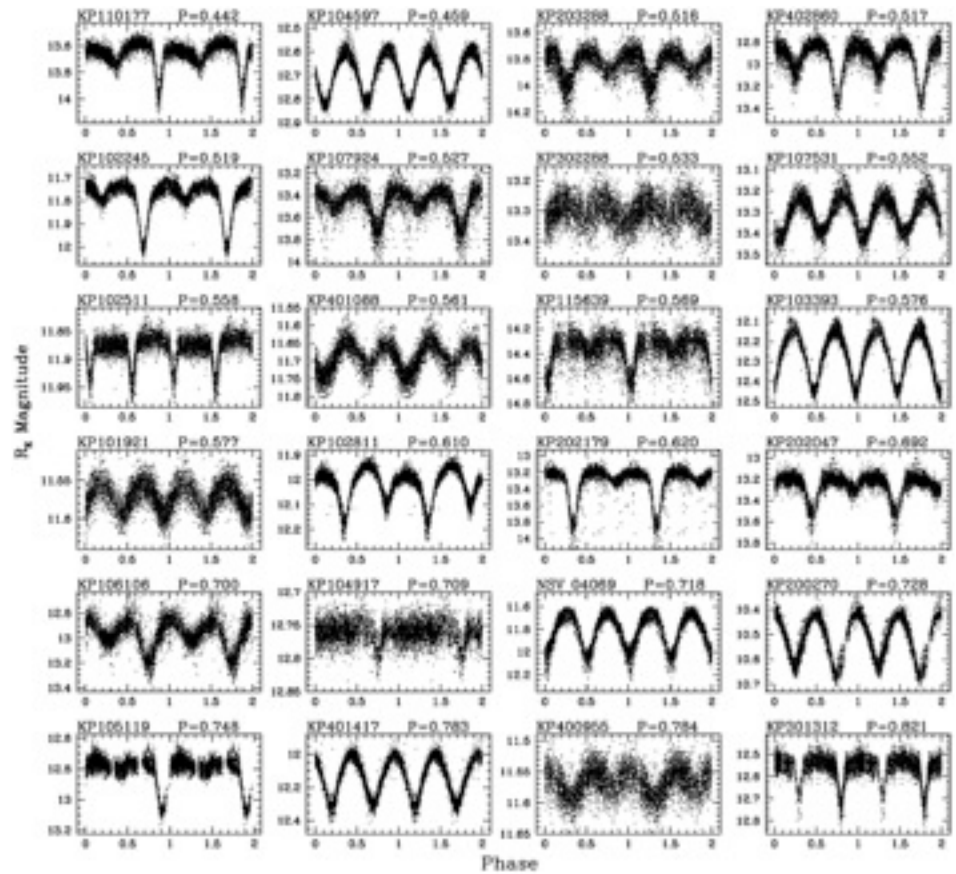
With this level of data precision, systematics in models will be challenged like never before.

Future Directions:EBs in the Era of Large Surveys



WIRE





With this level of data precision, systematics in models will be challenged like never before.

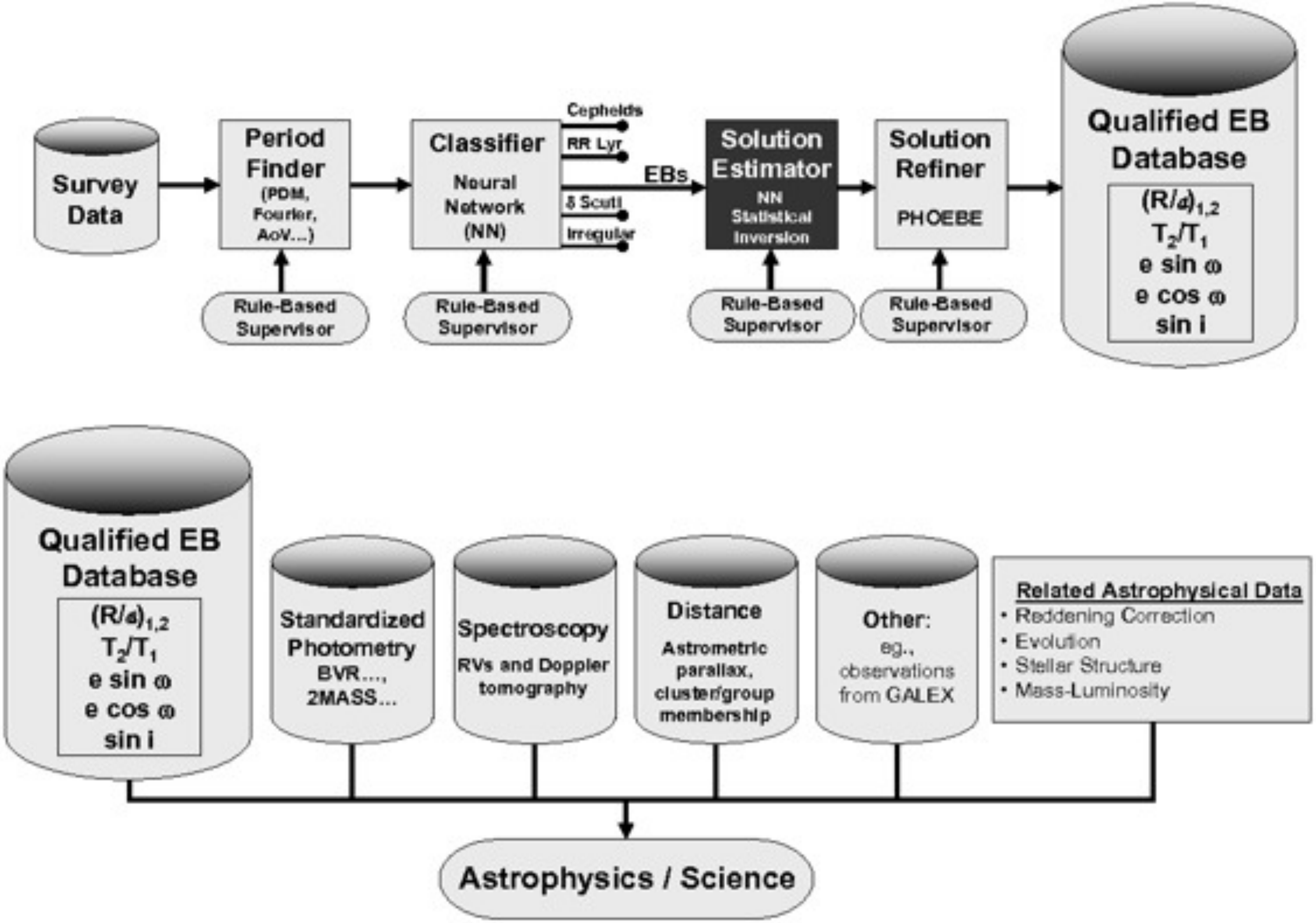
Current State of EBs and the Future:

- Below $1M_{\odot}$ magnetic activity suppresses convection and alters radii/T in rapid rotators so ages off by ~100%

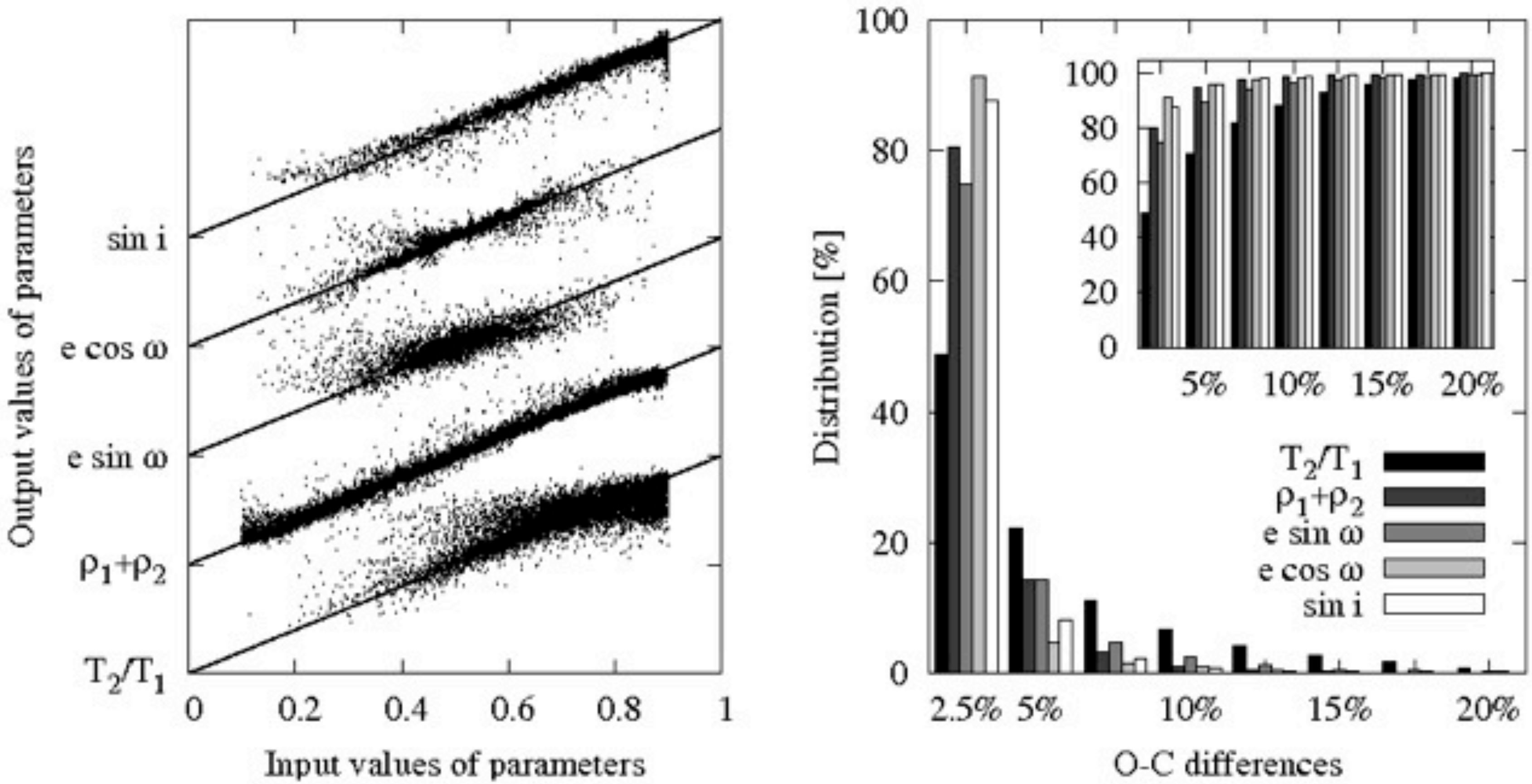
- Upcoming surveys will yield huge numbers and challenge current techniques (LSST will find 16 million EBs with ~1.6 million suitable for modeling)

- Too many EBs, and too few astronomers!

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



Prša et al. (2009)



Results of using neural network on 10,000 LCs

Conclusion:

Statistically significant results should be possible even if reduced in a completely automatic fashion

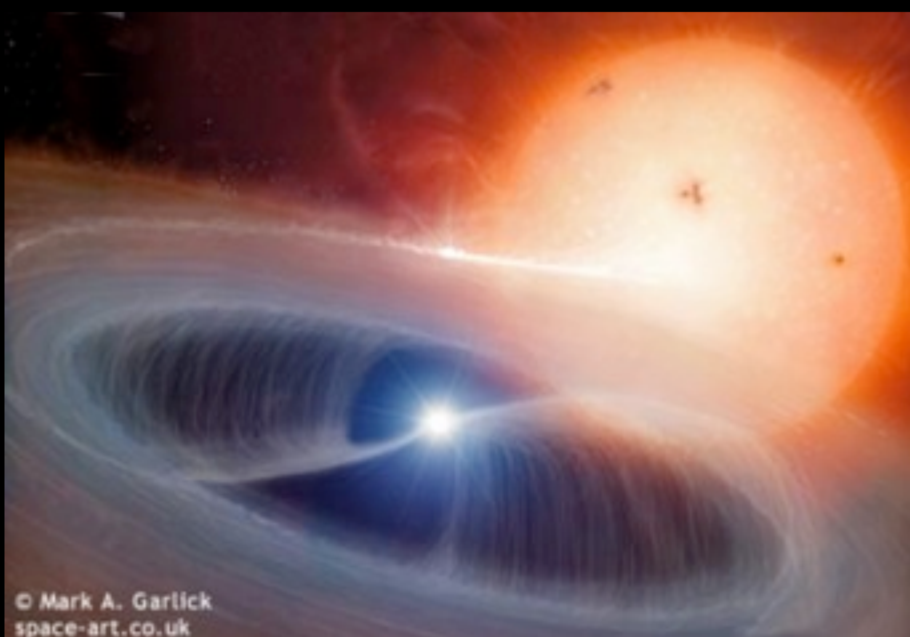
BUT

A dedicated pipeline to cover the discovery, the classification and the steering of the modeling process is needed, with constant revision and development!

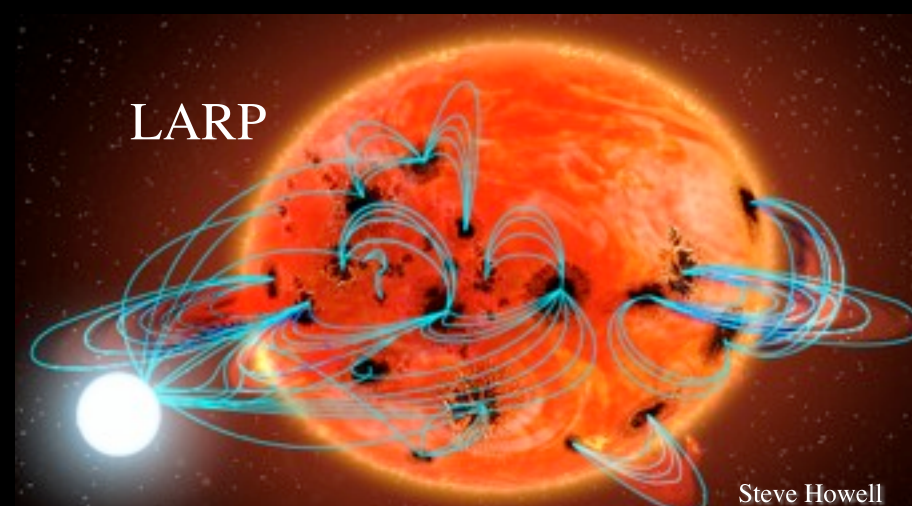
A Primer on Eruptive Variables

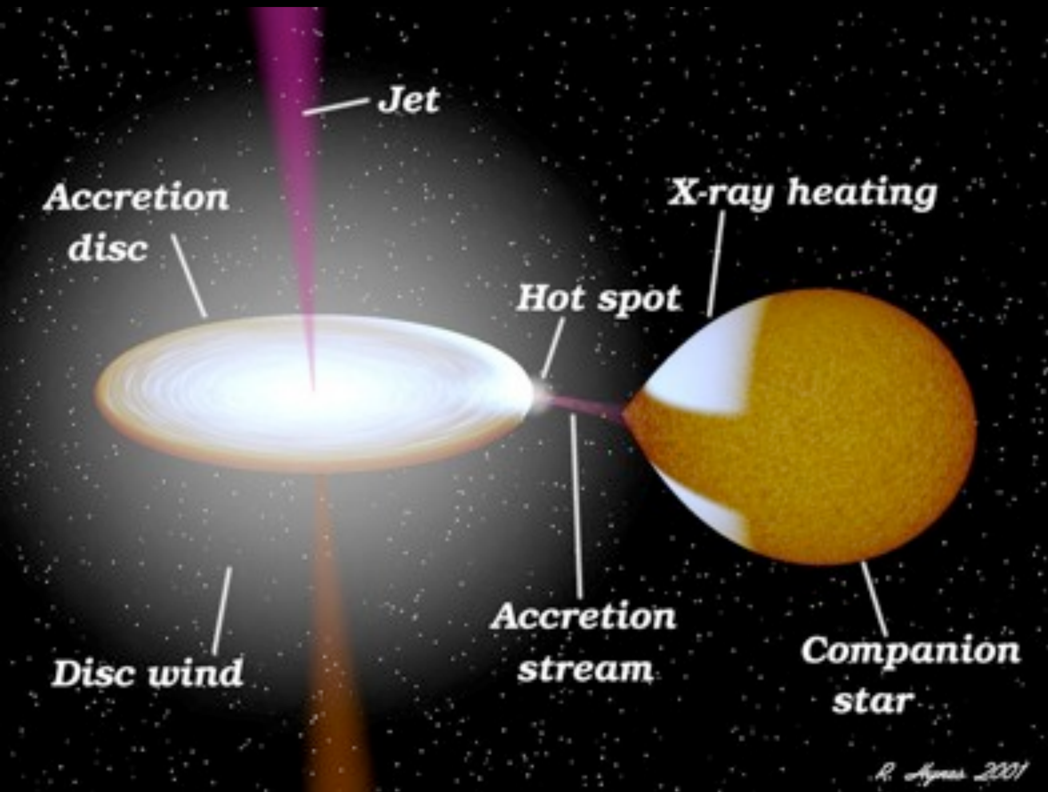
CV types

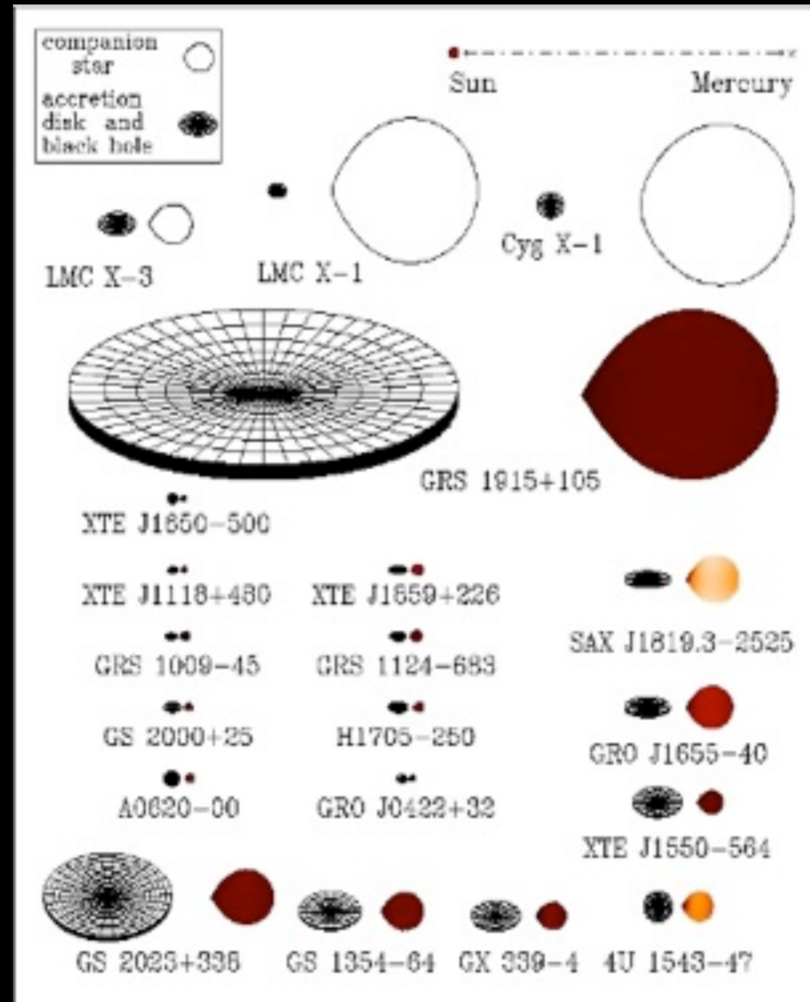
WD primary



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

Science from outbursts:

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; 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

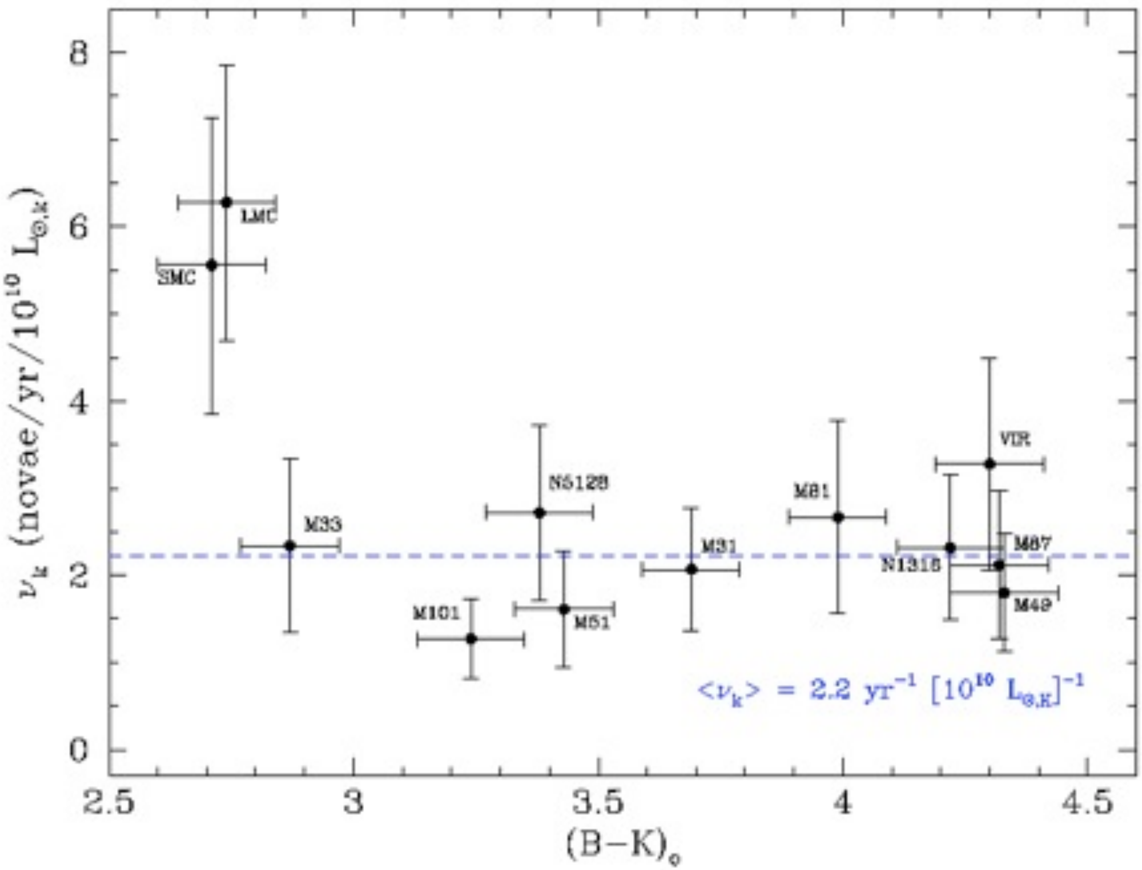
Recurrent novae may be underestimated by 100 X

Mansi Kasliwal et al. 2010 astro-ph

Science from Outbursts

Luminosity-Specific Nova Rates

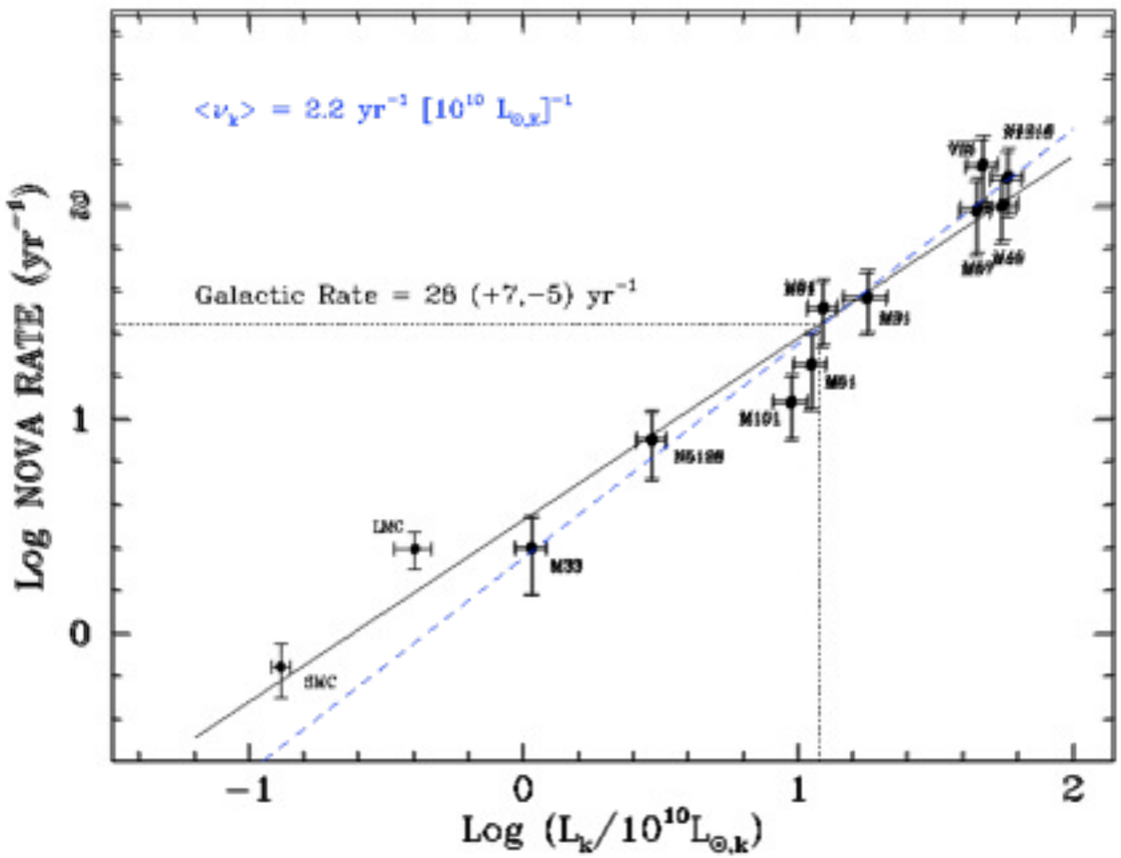
From Williams & Shafter (2004)



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

Science from Outbursts

Nova Rates vs Galaxy *K*-band Luminosity



Future possibilities (LSST):

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

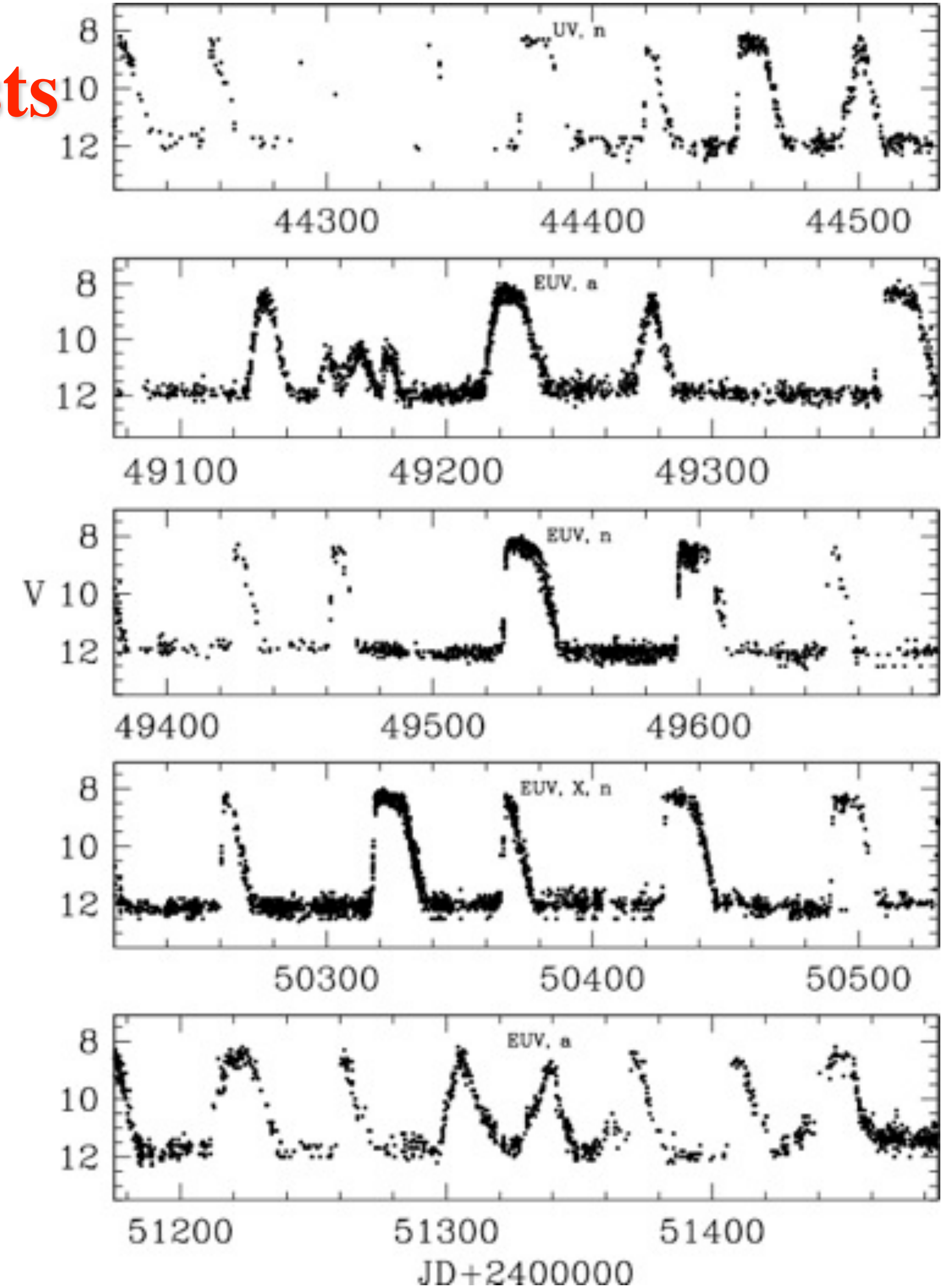
Science from Outbursts

Dwarf novae

Repeated disk instability

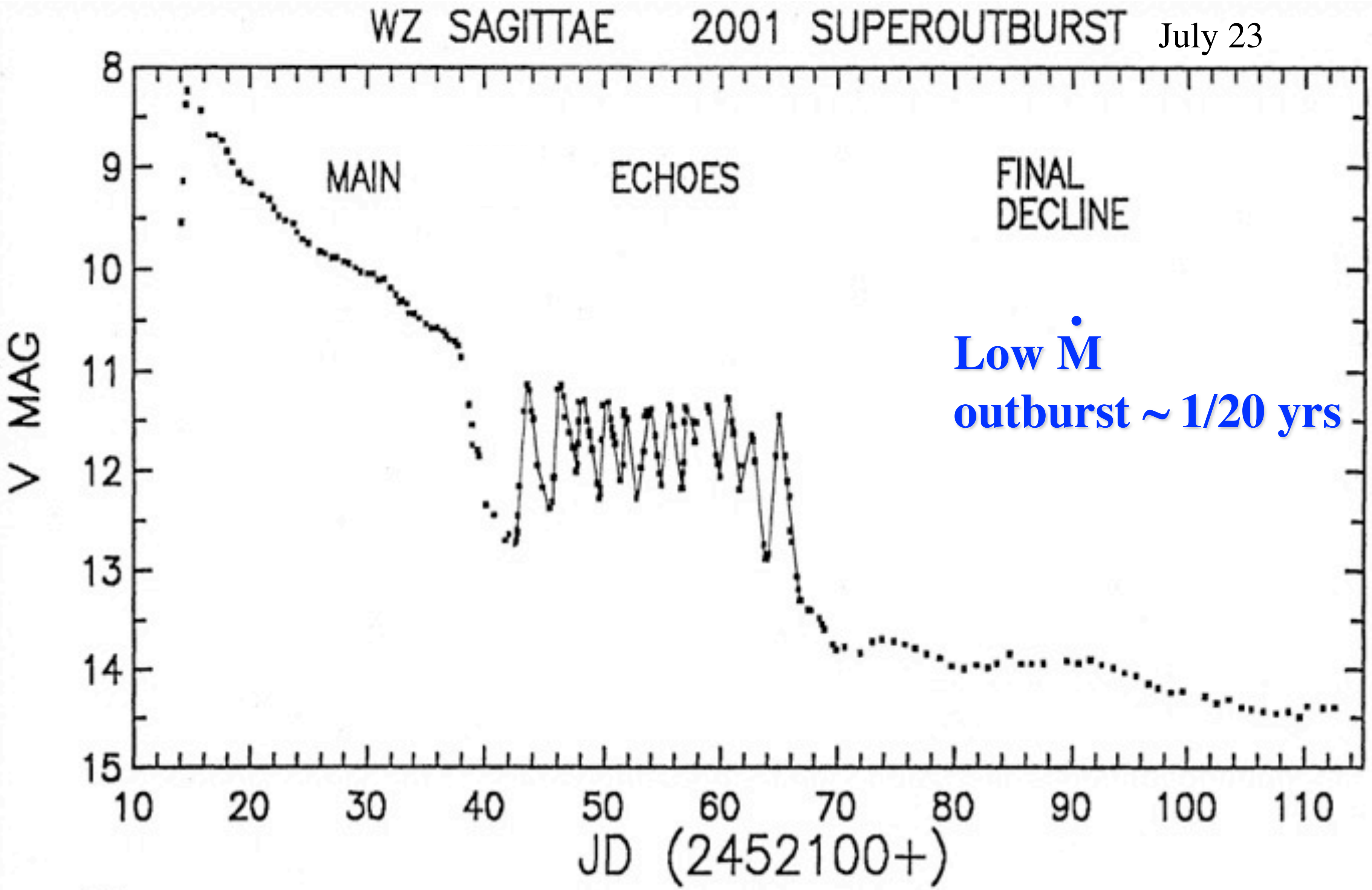
AAVSO

outbursts of SS Cygni



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

Science from Outbursts: Dwarf novae

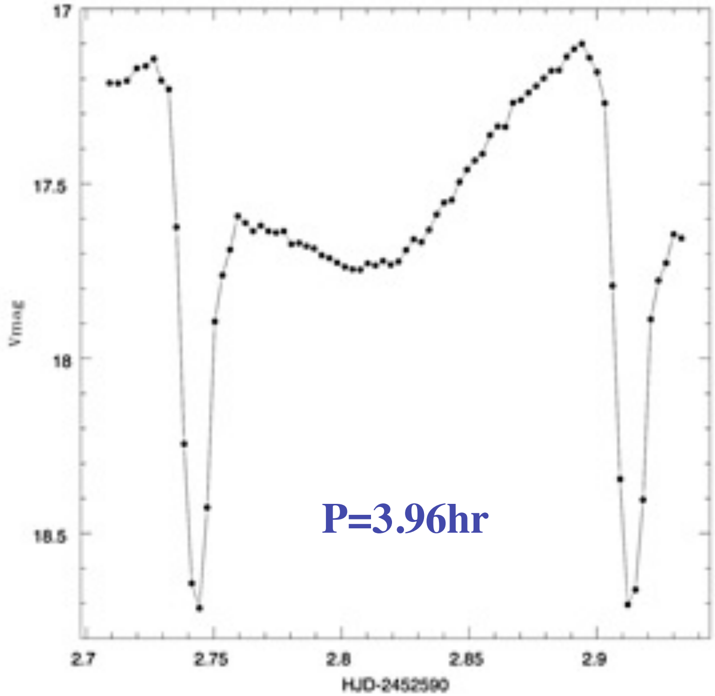


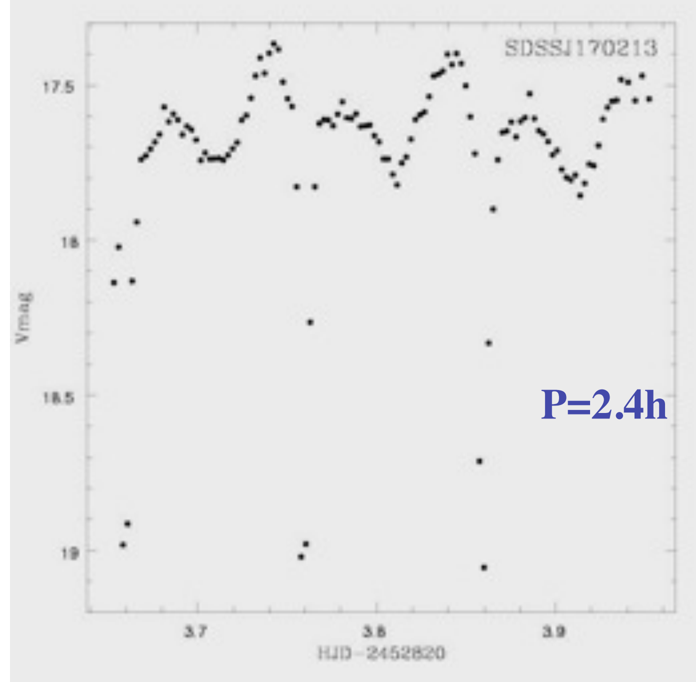
Science from Orbital variations

- 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

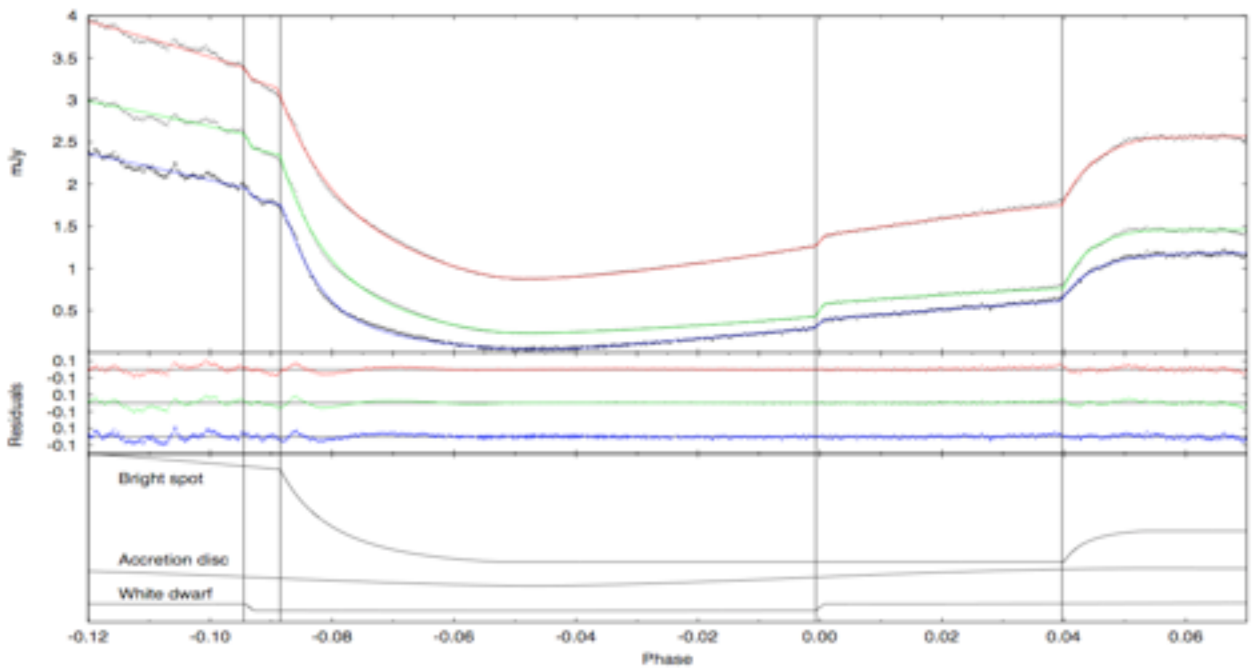
~30% of disk systems show orbital variations (spot); 100% of polars (amplitudes of 0.1-4 mags)





Detailed eclipse coverage of IP Peg

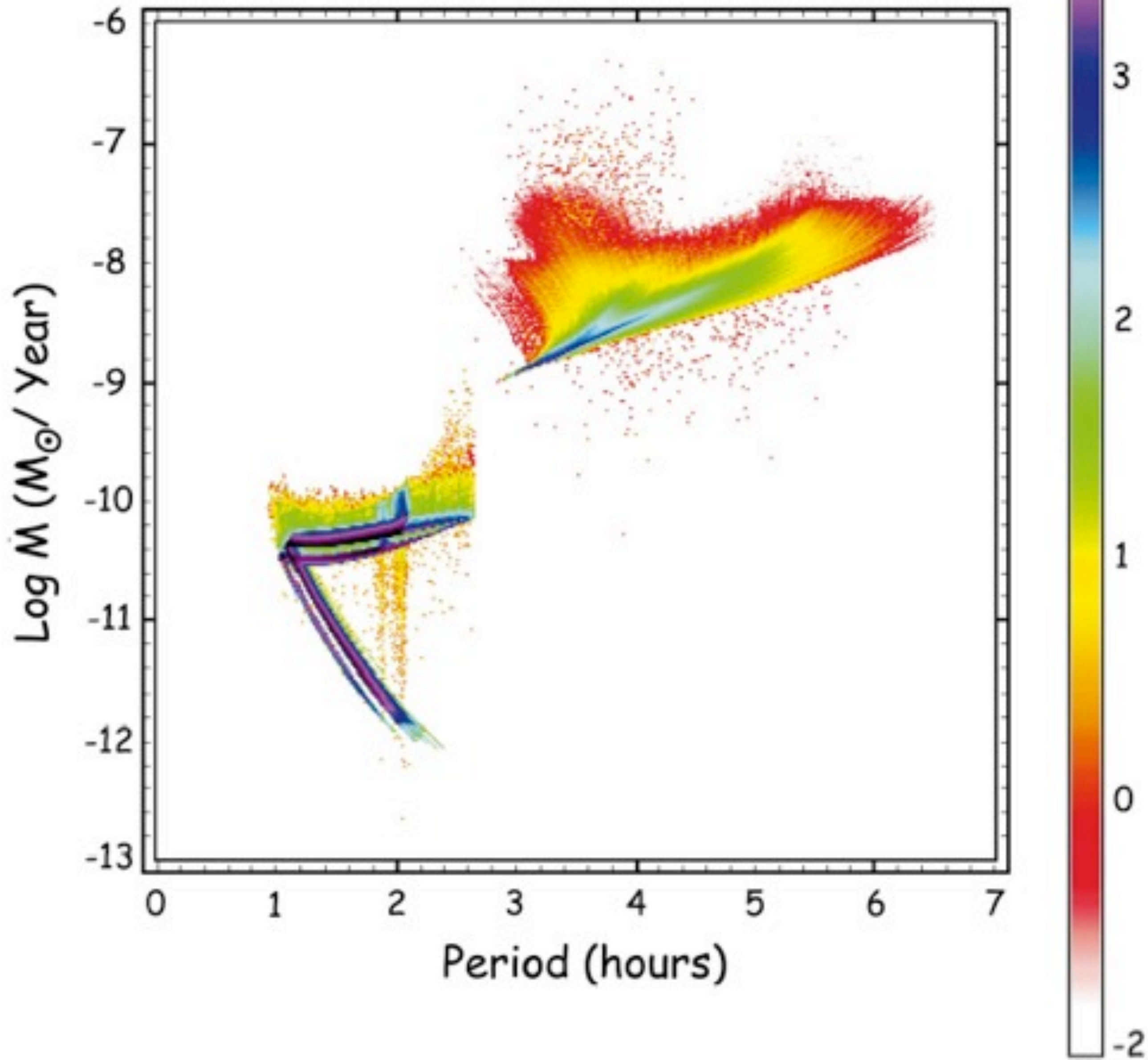
Copperwheat et al. 2010



Science from Orbital variations

A population model

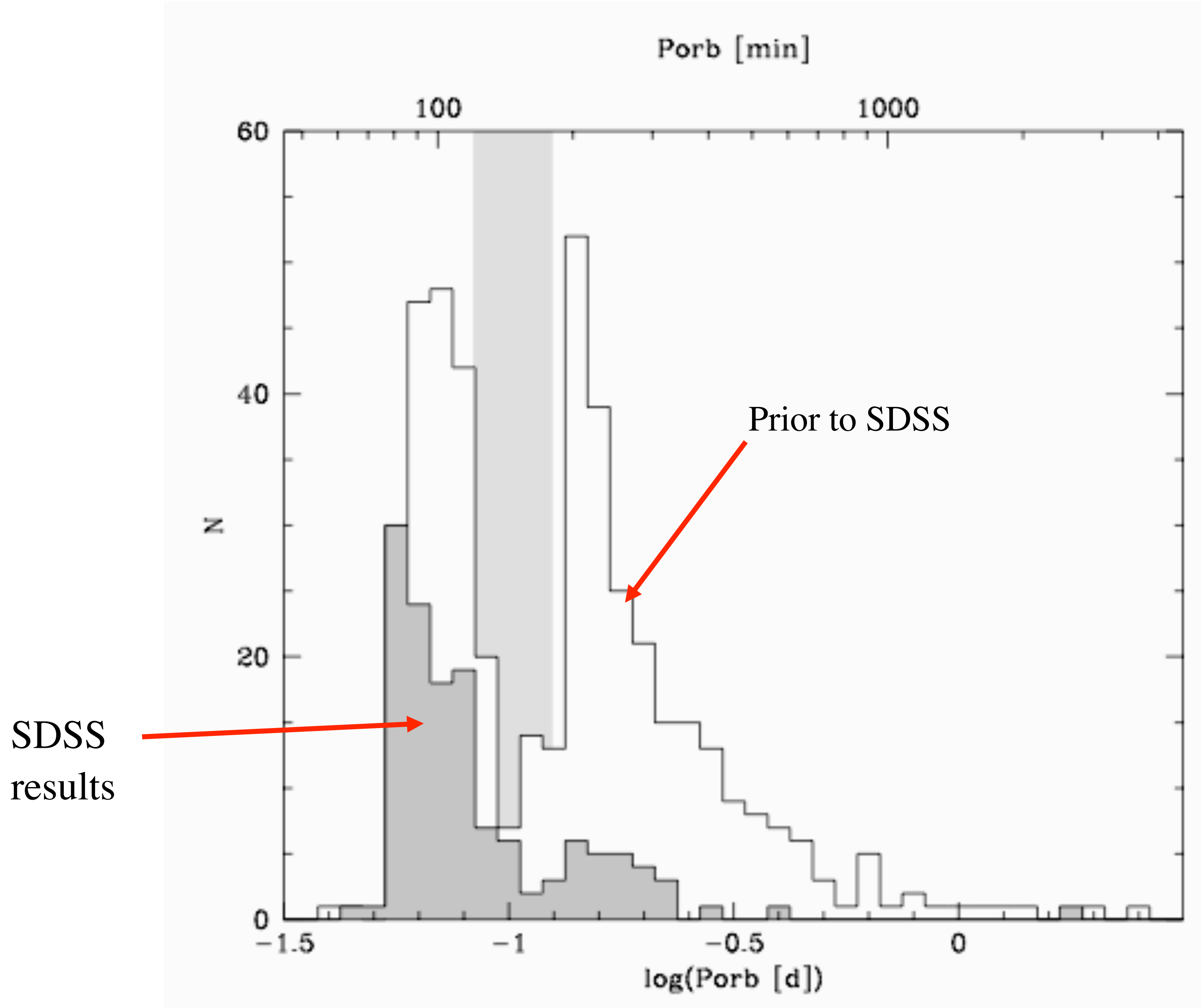
Howell, Nelson, Rappaport 2001, ApJ, 550



Log number of CVs

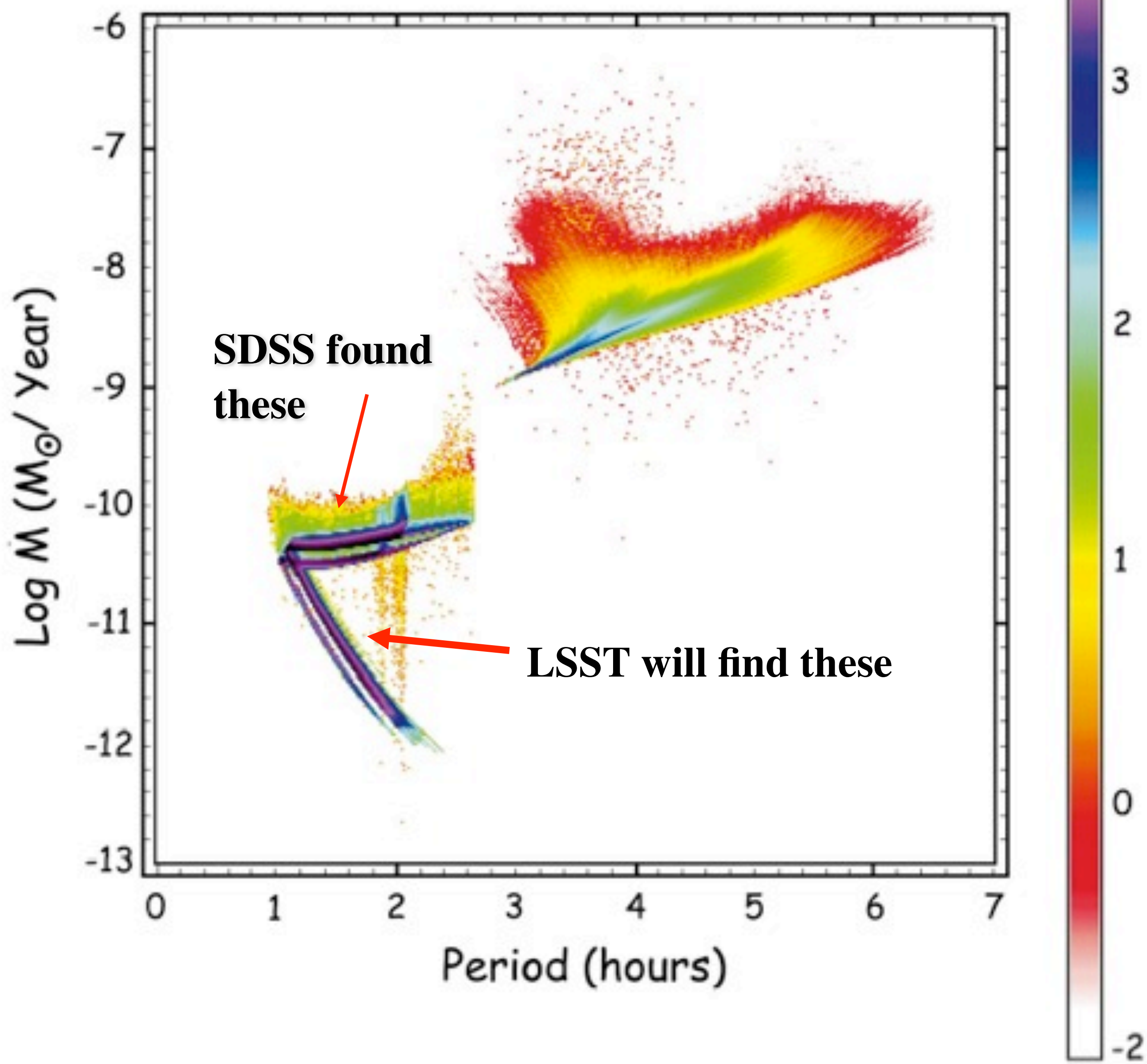
Need numbers to understand evolution!

Science from Orbital variations



Gansicke et al. 2009

Howell, Nelson, Rappaport 2001, ApJ, 550



Log number of CVs

Need numbers to understand evolution

Science from Pulsations, Spins

Pulsations

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

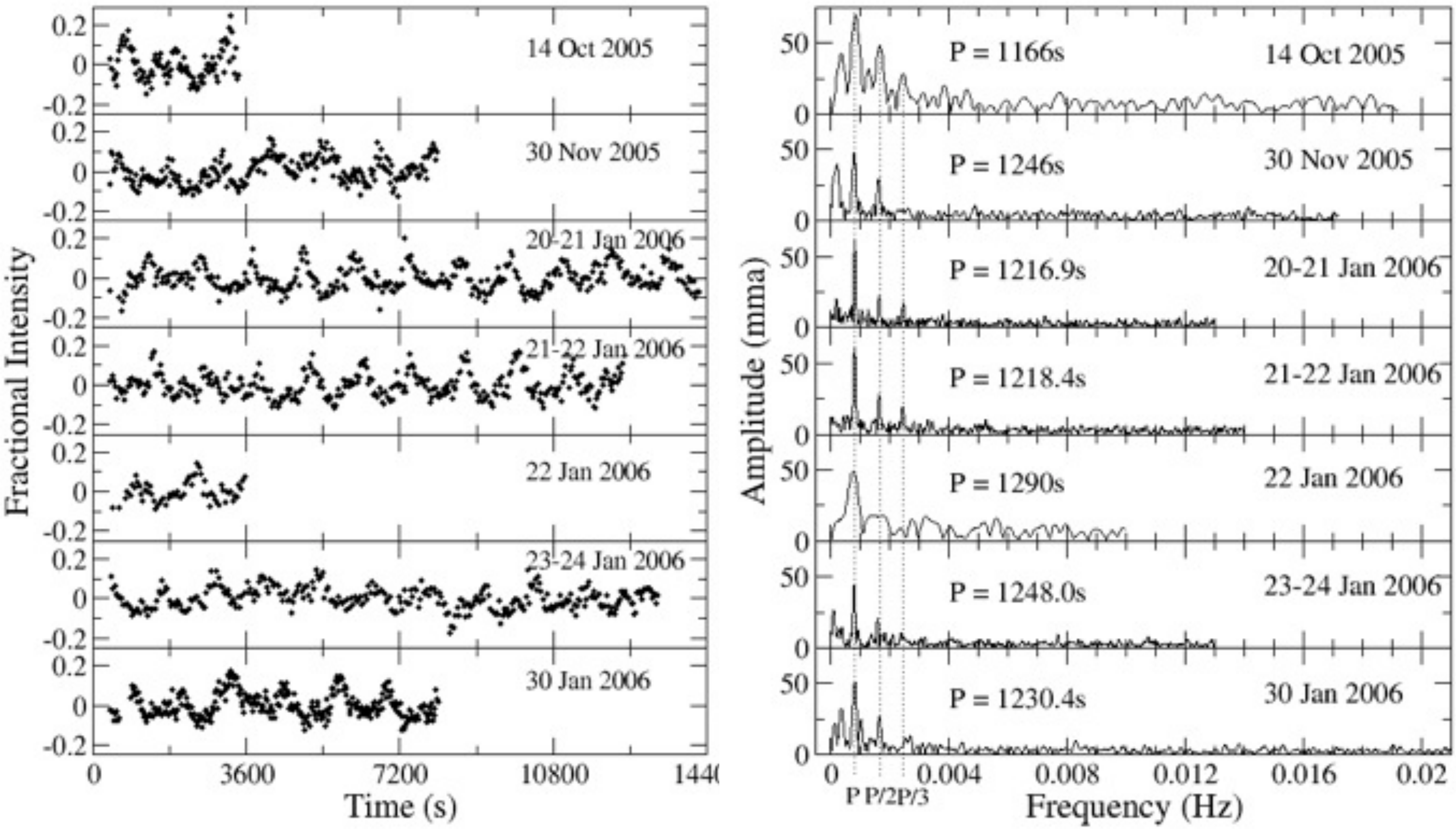
Spins

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

Science from Pulsations, Spins

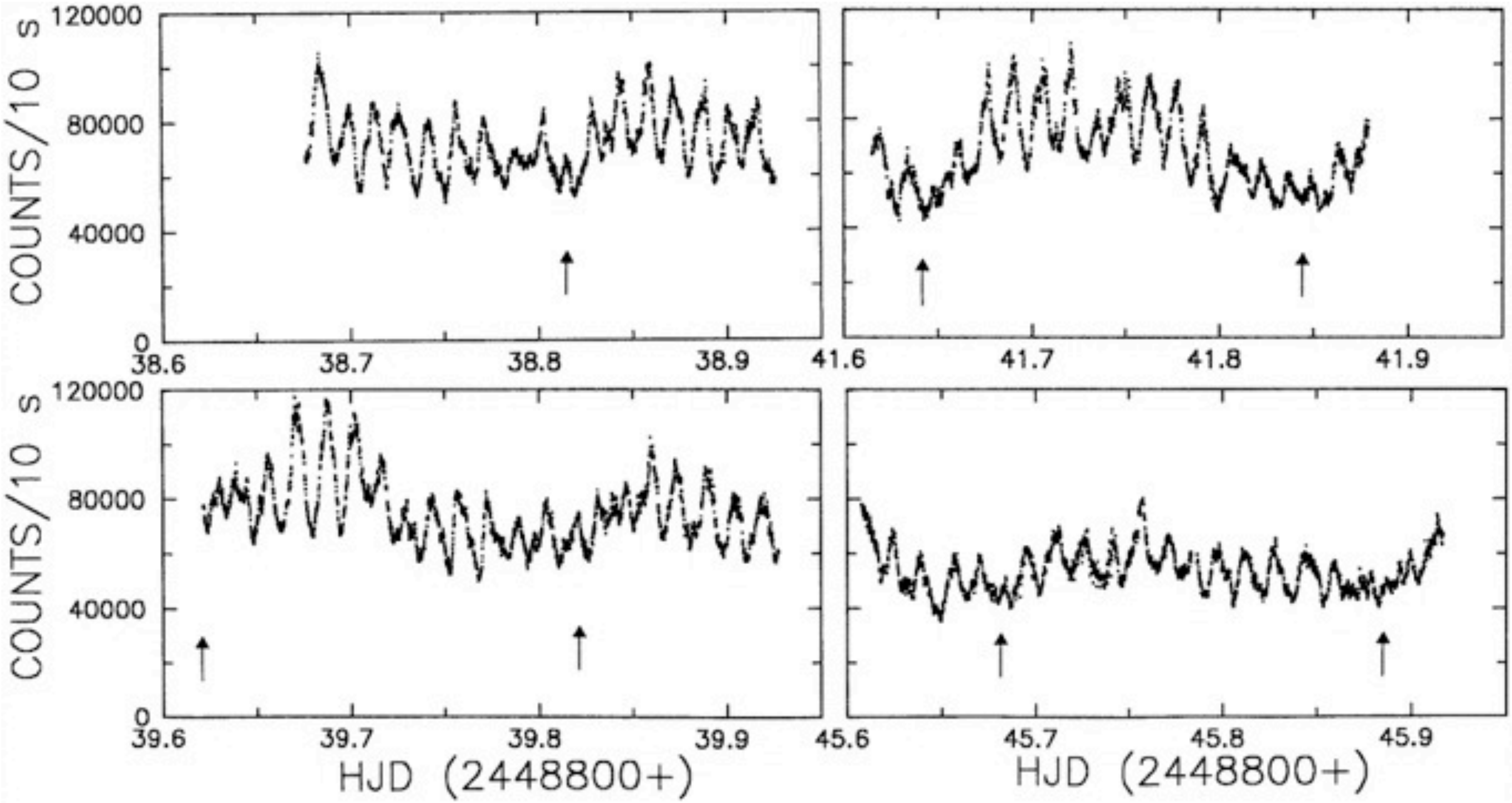
Light curves of accreting pulsator SDSS0745+45

Fourier transforms



Science from Pulsations, Spins

FO Aqr Patterson et al. 1998 PASP **P_{spin}= 21 min**

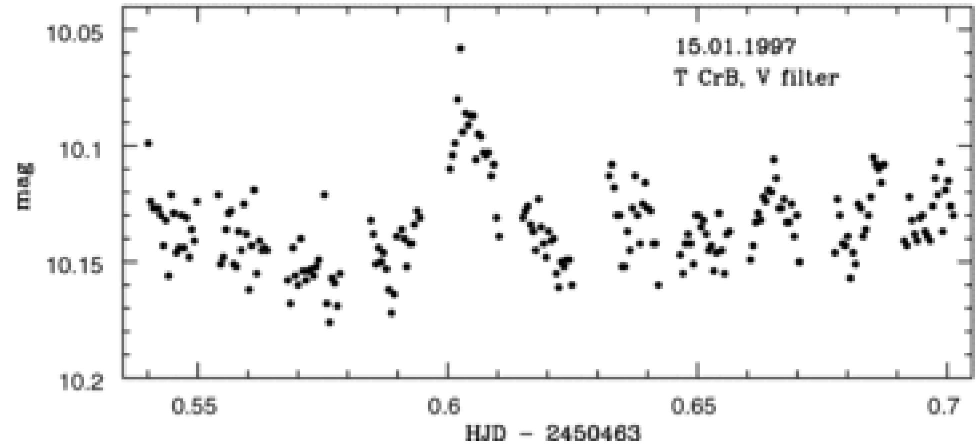


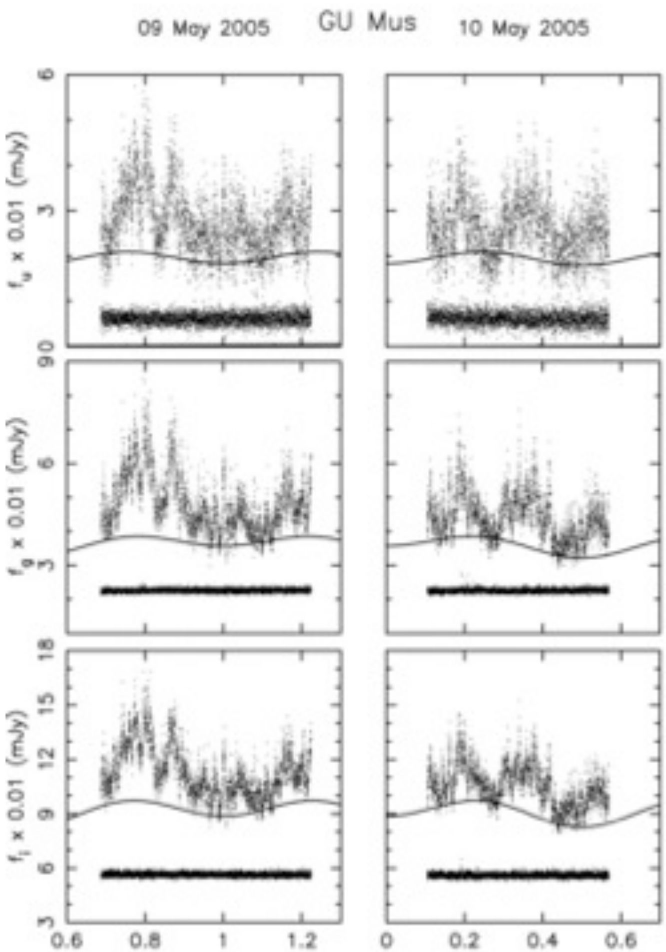
Science from Flickering

- **Signature of active accretion (blobs?)**
- **Timescales of sec (Polars)**
- **Timescales of min (disk)**
- **Origin from spot, column or inner disk**

Science from Flickering

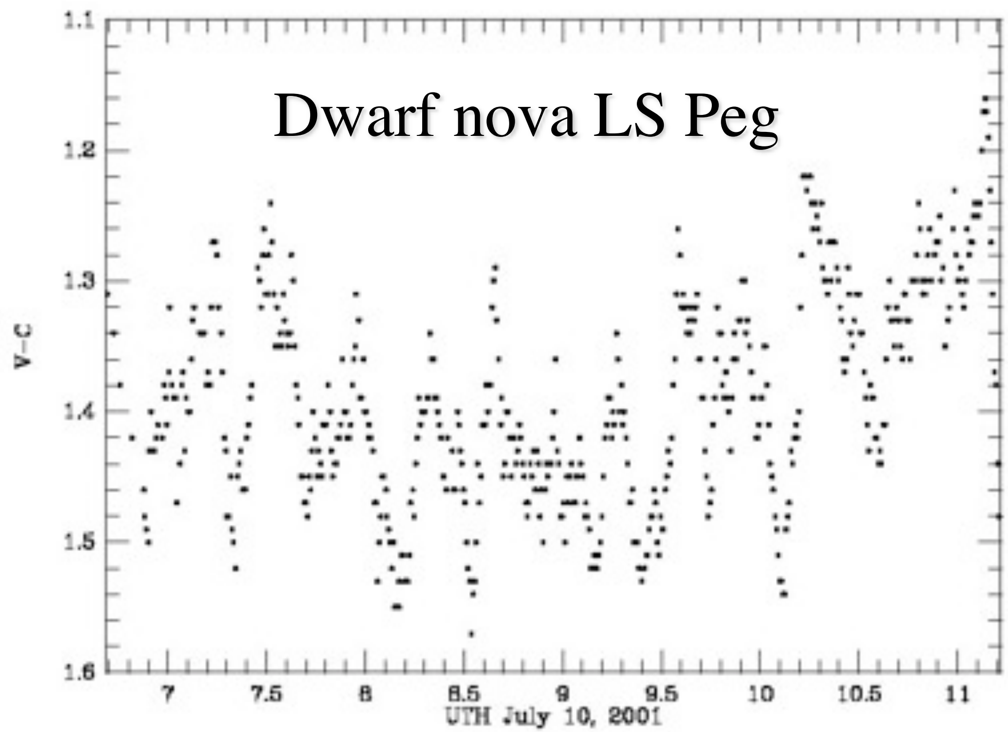
Recurrent nova (Dobratka et al. 2010)





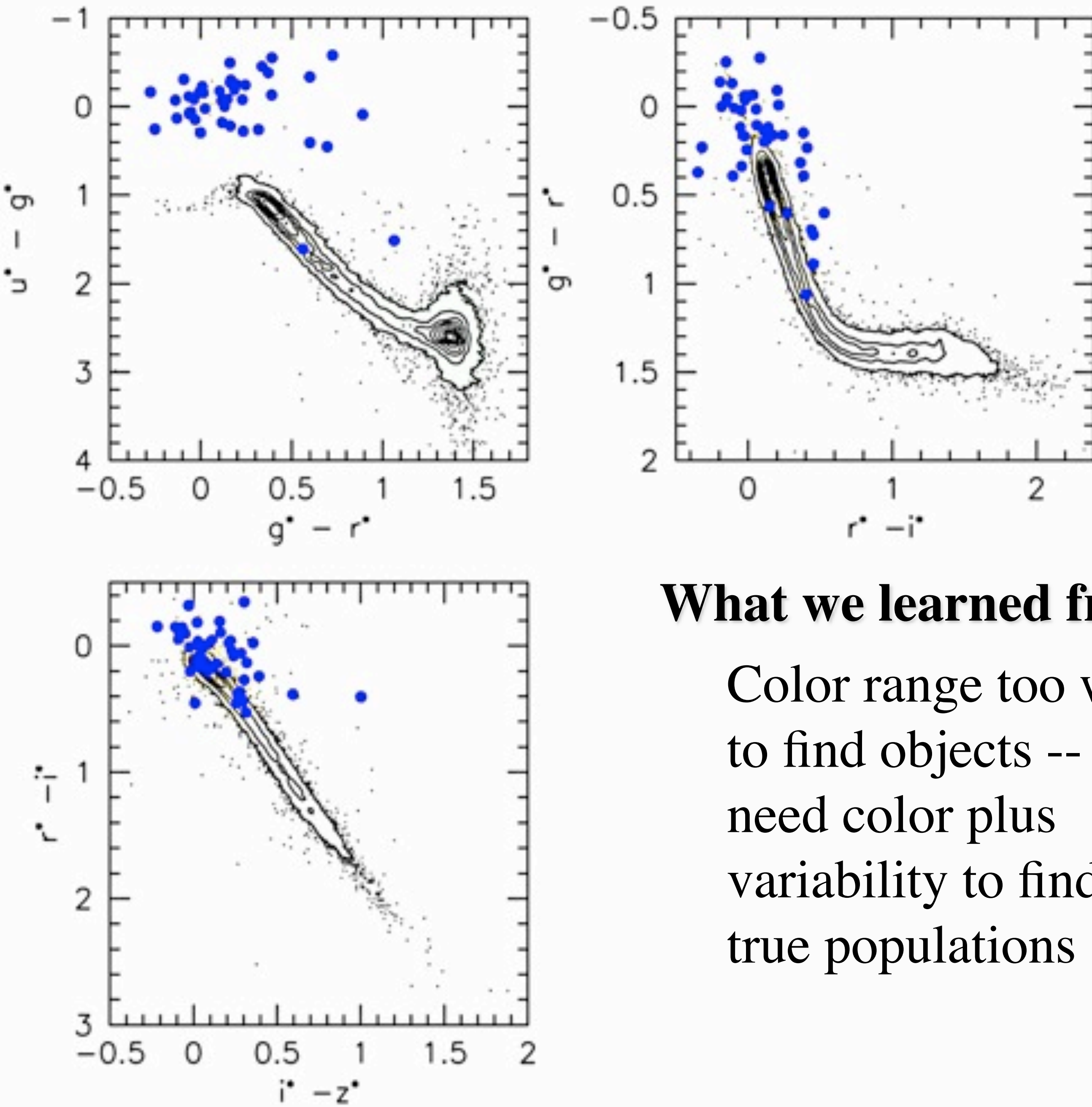
BH X-ray binary
(Shahbaz et al. 2010)

Dwarf nova LS Peg



What we learn from variability in accreting binaries:

- flickering - info on accreting blobs
- pulsations - info on interior of WD, instability strip for accretors
- spin timescale of WD - info on mag field
- orbital variations - info on WD, spot, evolution
- outbursts - info on long term heating, chemical evolution & star formation history

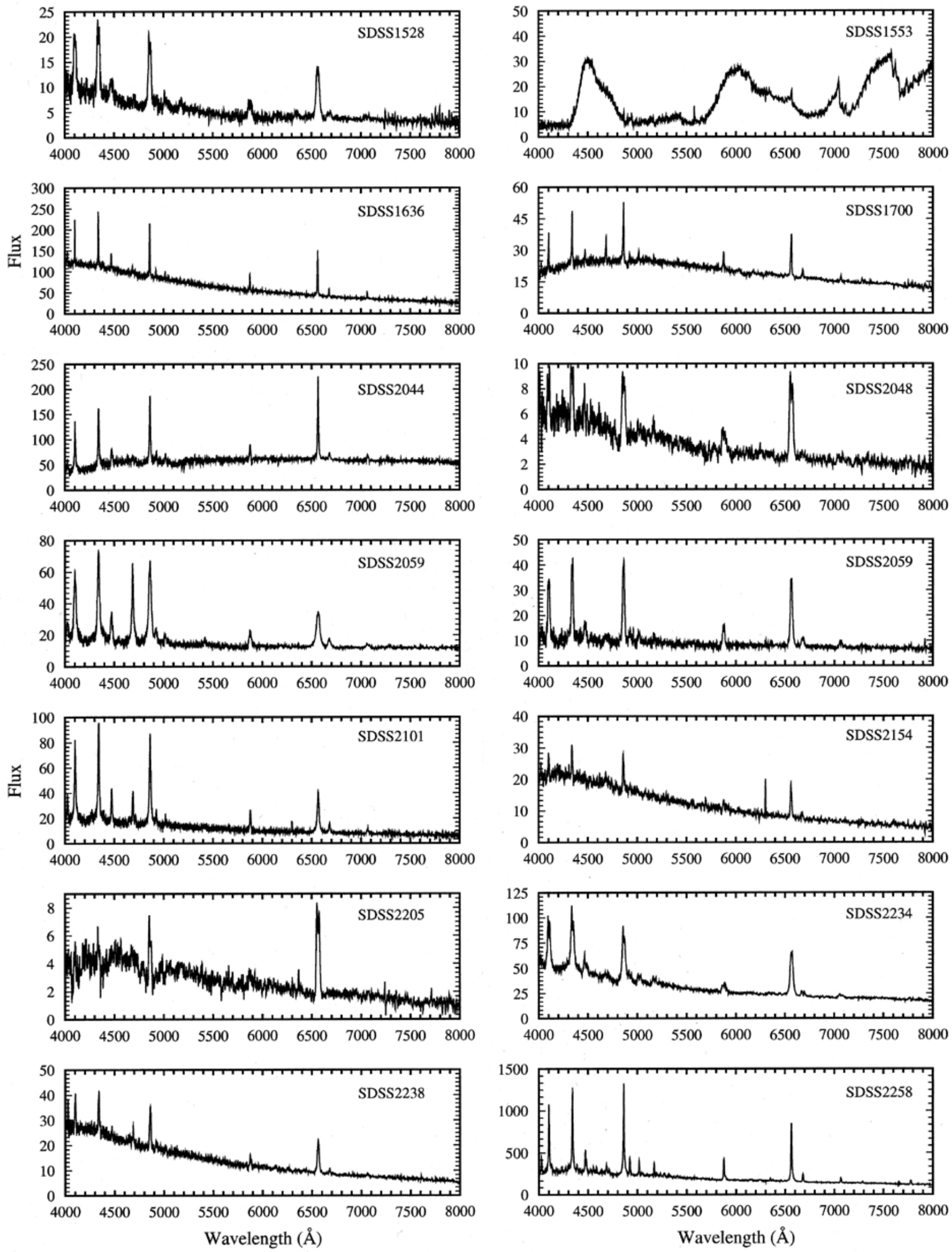


What we learned from SDSS:

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

Typical CV spectra in DR1

CVs in SDSS
Szkody et al. 2002, AJ, 123, 430

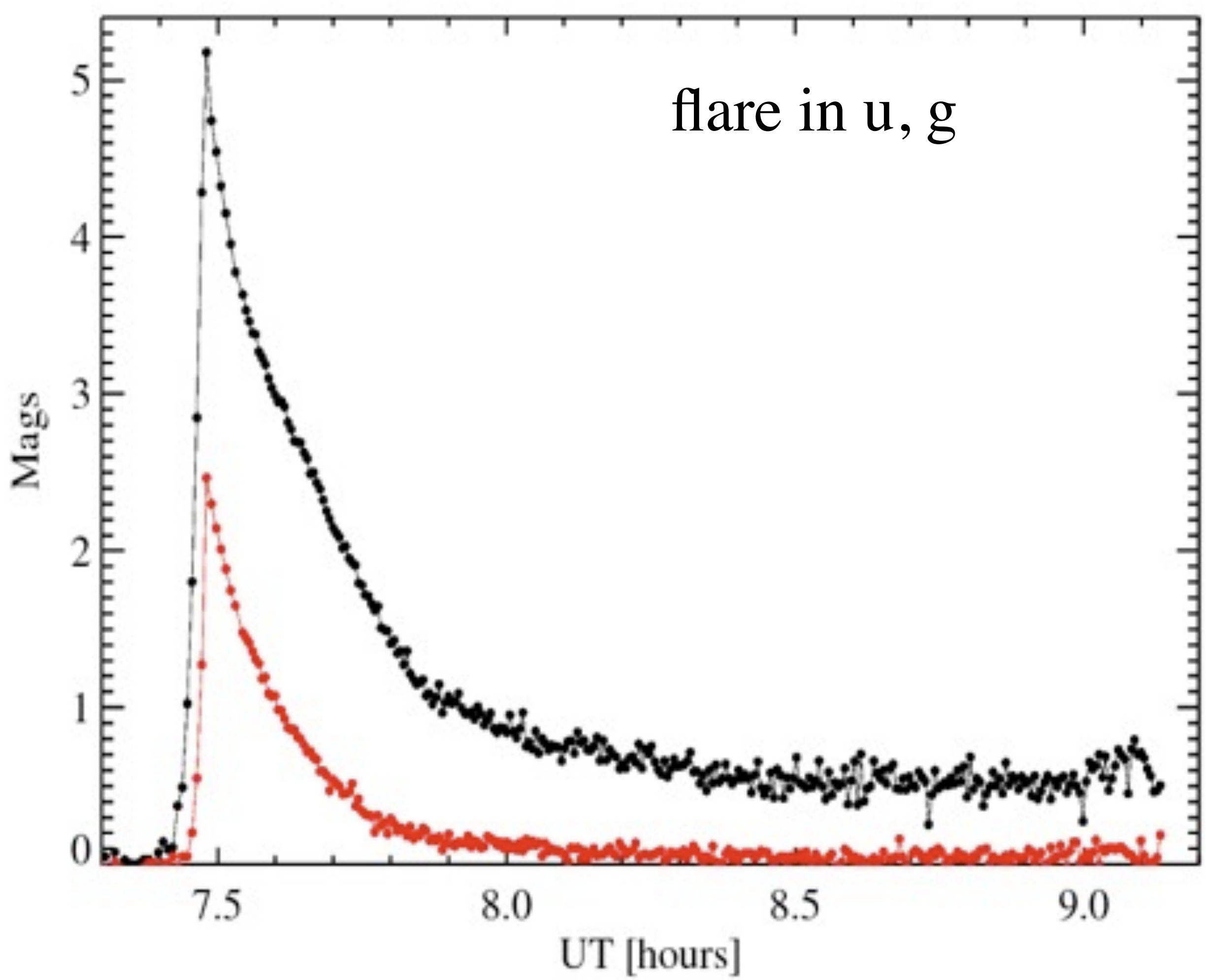


What we learned from SDSS:

Need a lot of followup spectra!

A Primer on Flare Stars by Eric Hilton

fast flare
on EV Lac

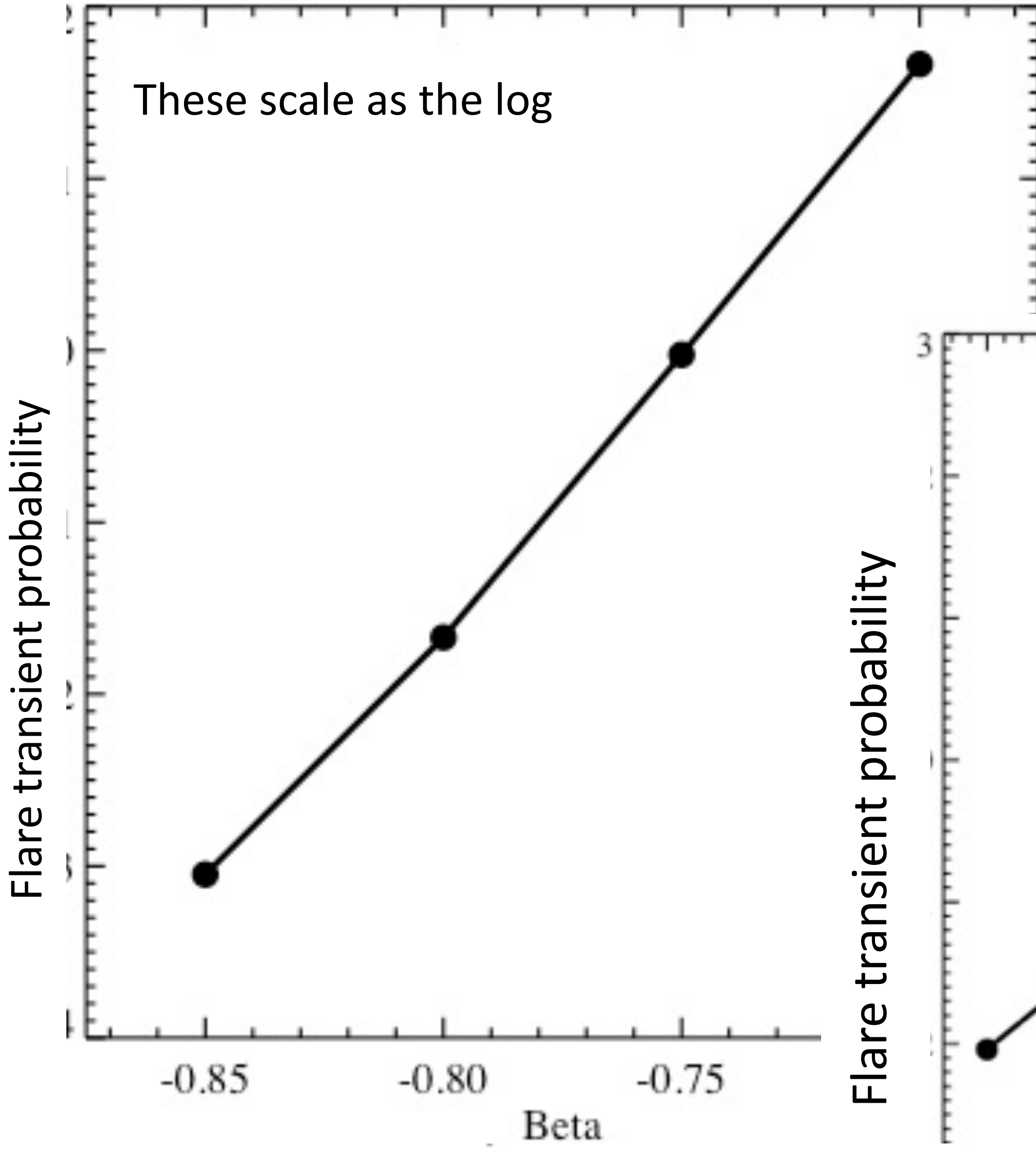


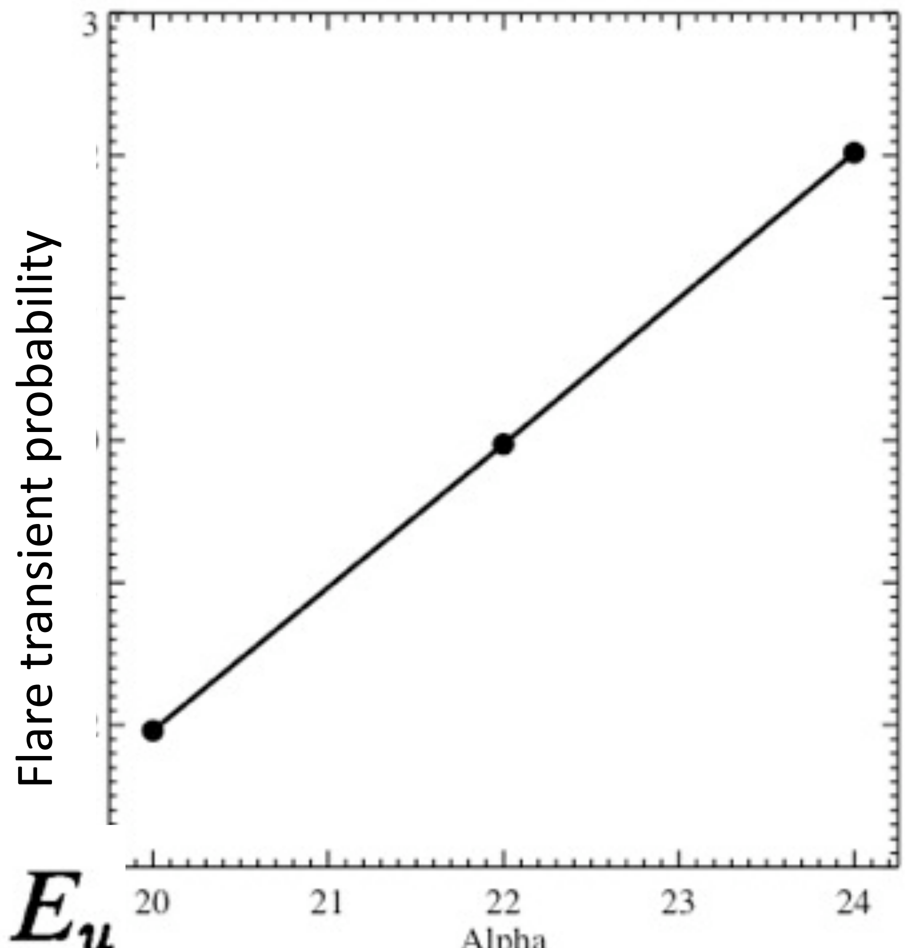
Schmidt et al., in prep.

Science from Flare stars

- low mass stars comprise 70% of stars in Milky Way
- **flare physics** and **planet habitability**, flares may act as a **'fog'** for other transients
- flaring rate depends on flare energy, spectral type, stellar age, line of sight
- model can be used to 'observe' the Galaxy and predict the number of flares seen as optical transients, although several parameters are not yet well-measured.
- hundreds of hours of new observations are measuring flare frequency distributions.

Science from flare stars

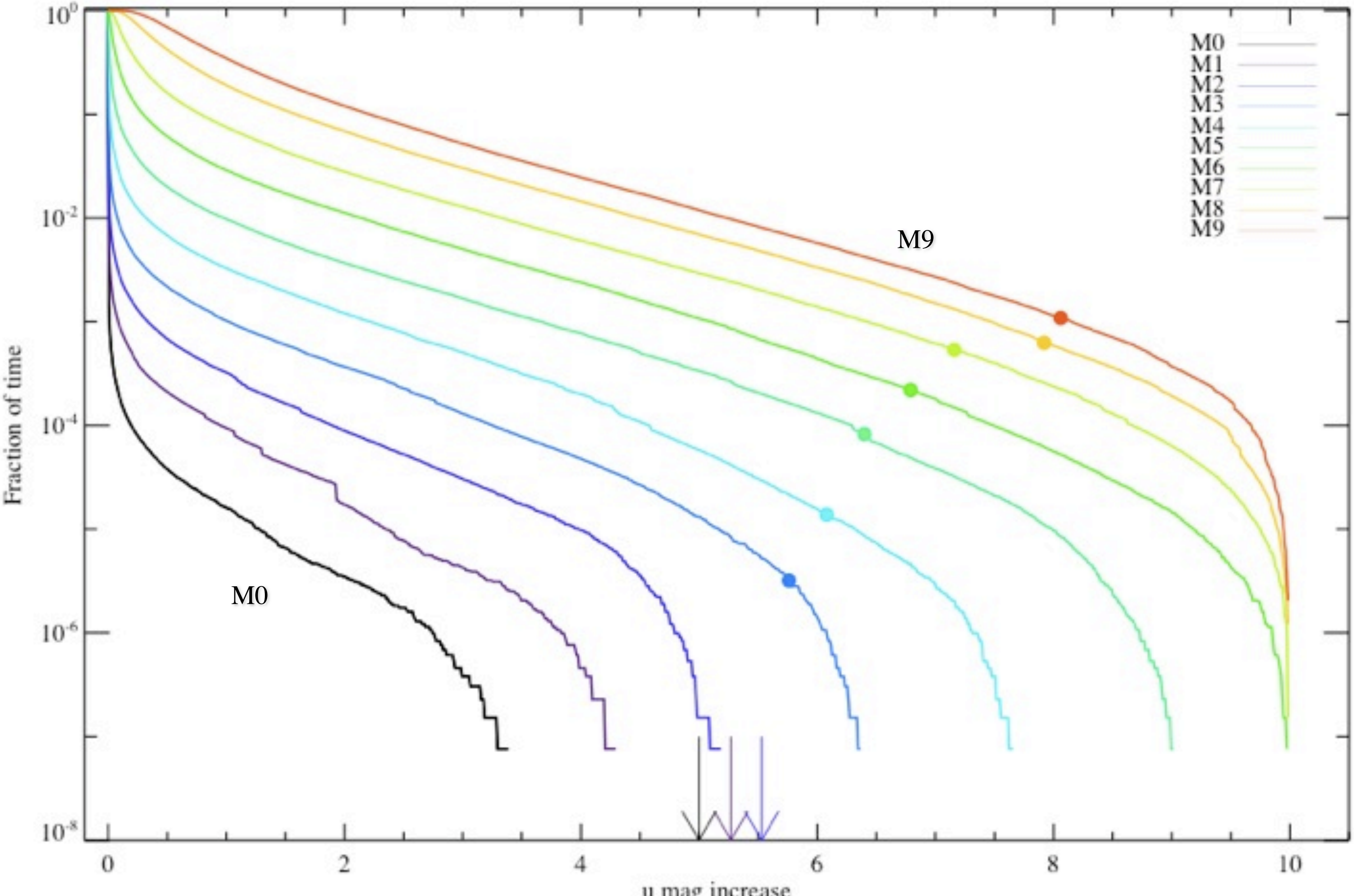




$$\log \nu = \alpha + \beta \log E_u$$

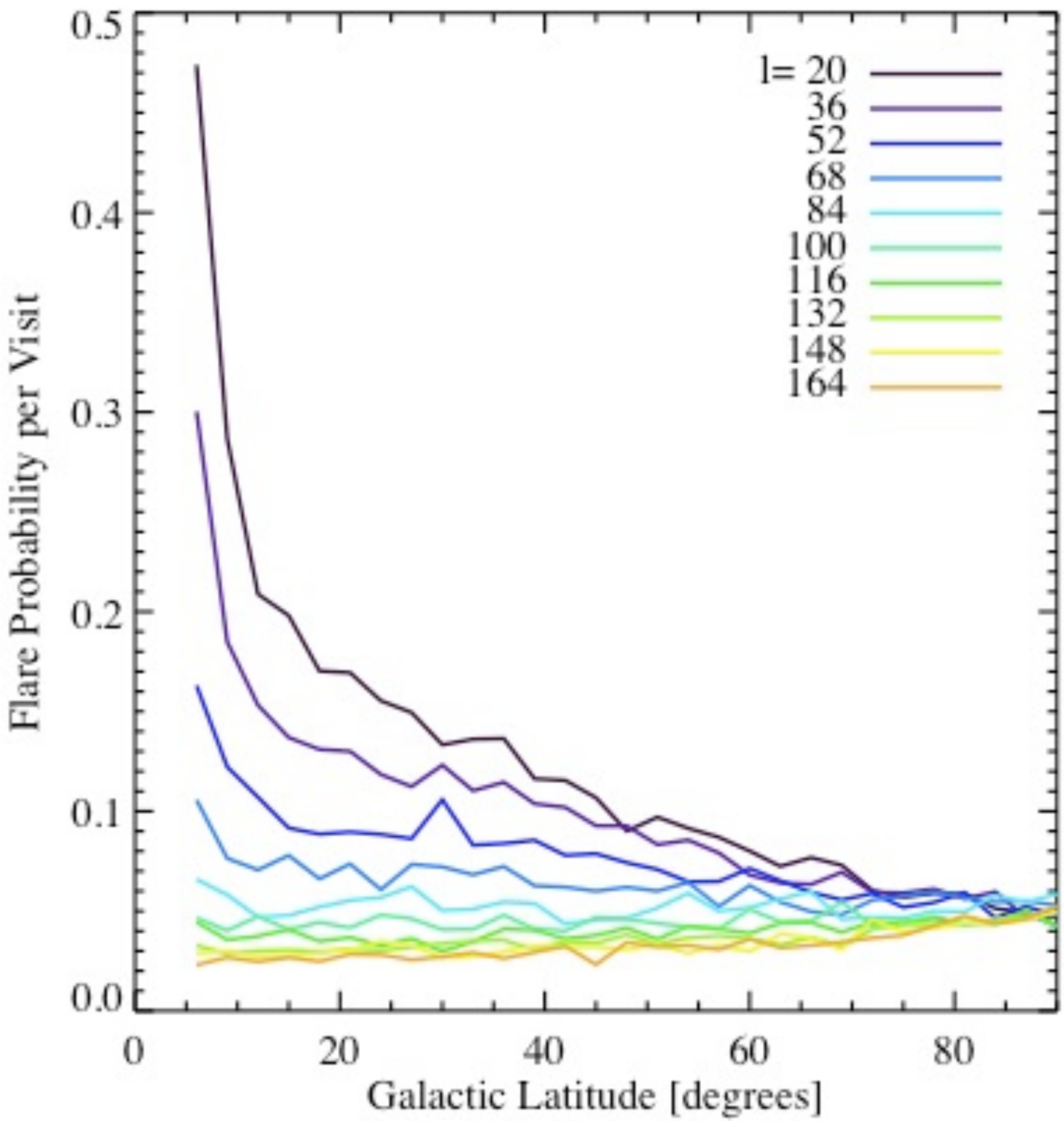
Lacy, Moffett & Evans 1976

Larger flares occur for later types (u-z colors)



Science from Flare stars

More flares at low gal latitude, longitude due to # of stars viewed and age of stars

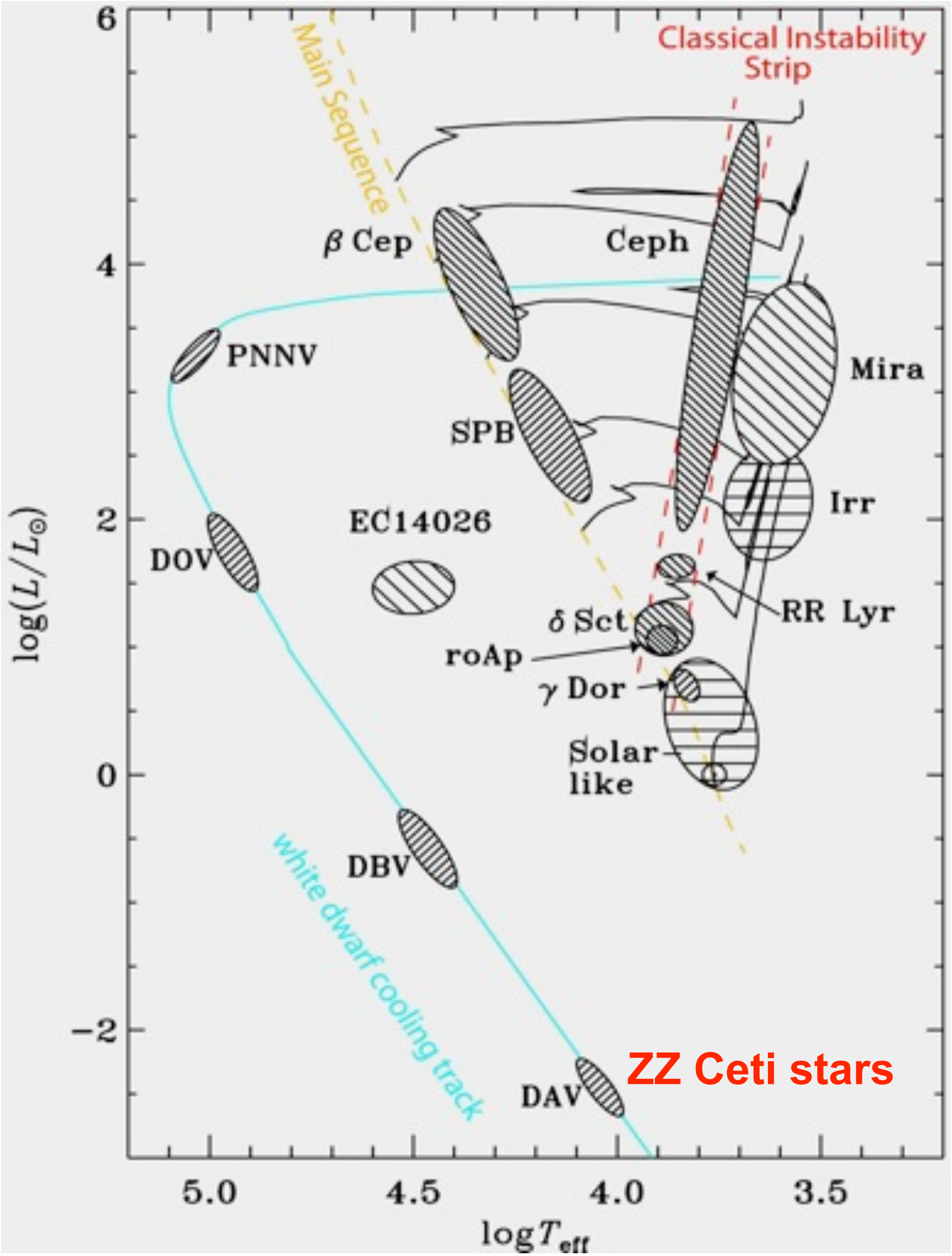


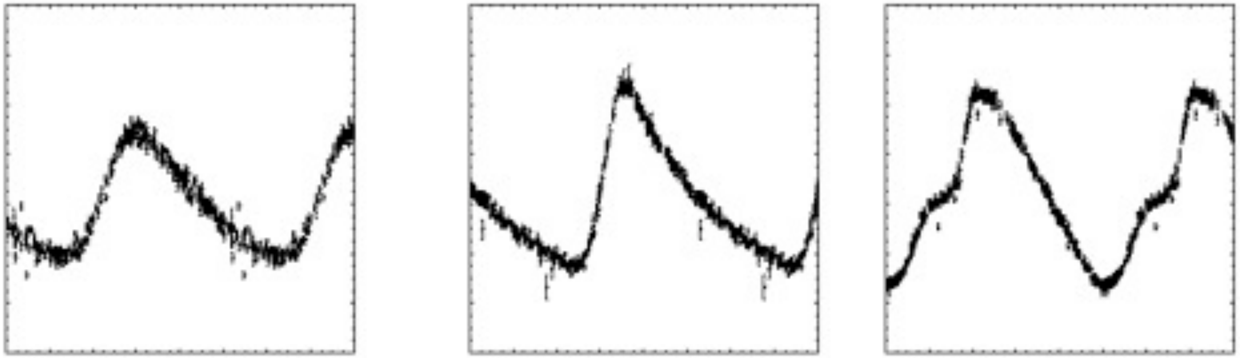
A Primer on Pulsating stars:

Asteroseismology

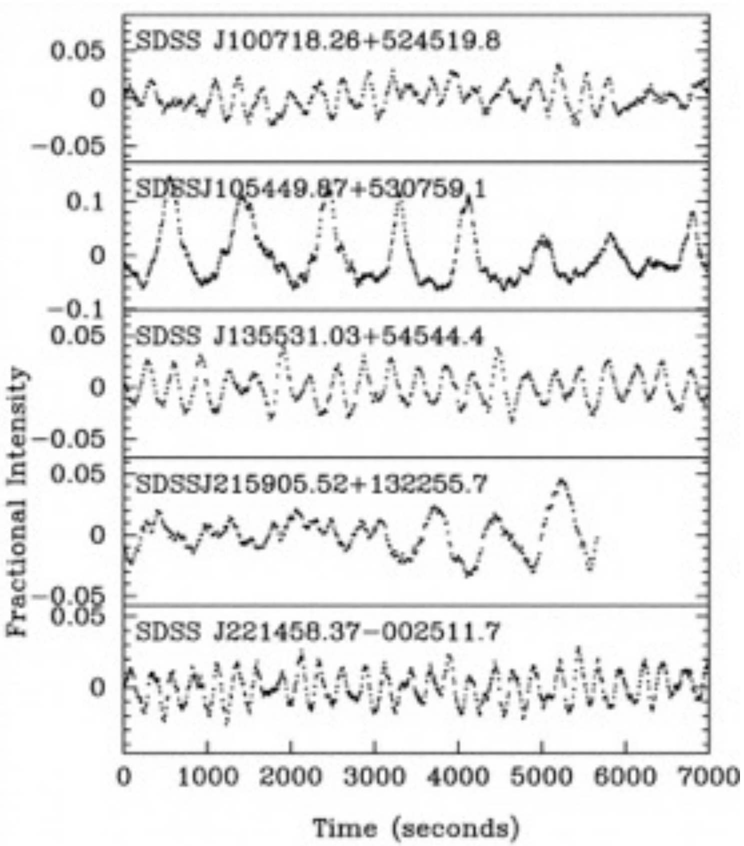
- Pulsations ⇒ Only systematic way to **study the stellar interior**

- Pulsations are observed in stars **all over the HR diagram**

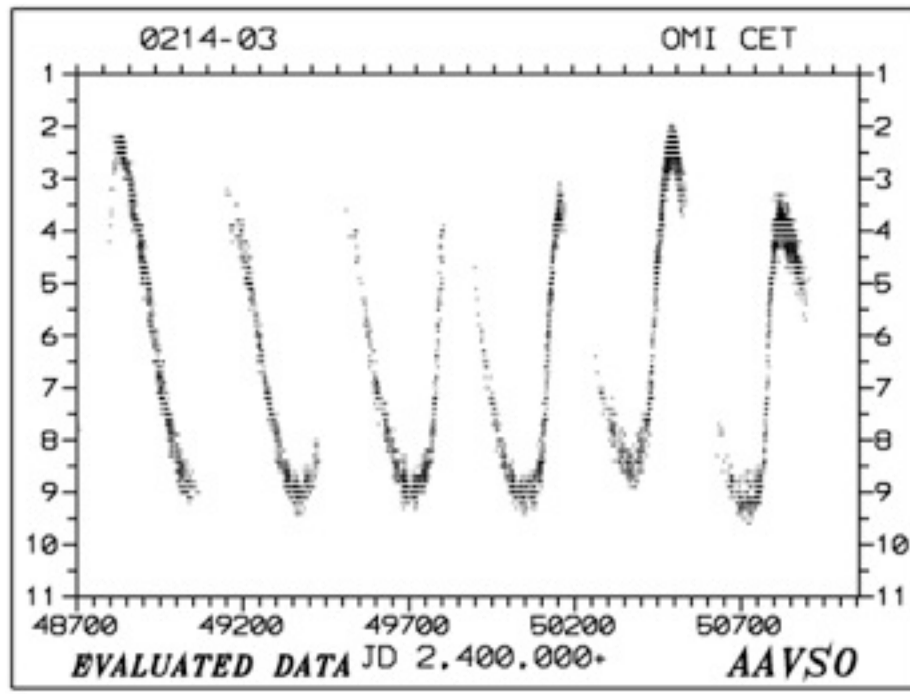




MACHO cepheids
P~2-60 days



ZZ Ceti pulsating WDs
P~ mins

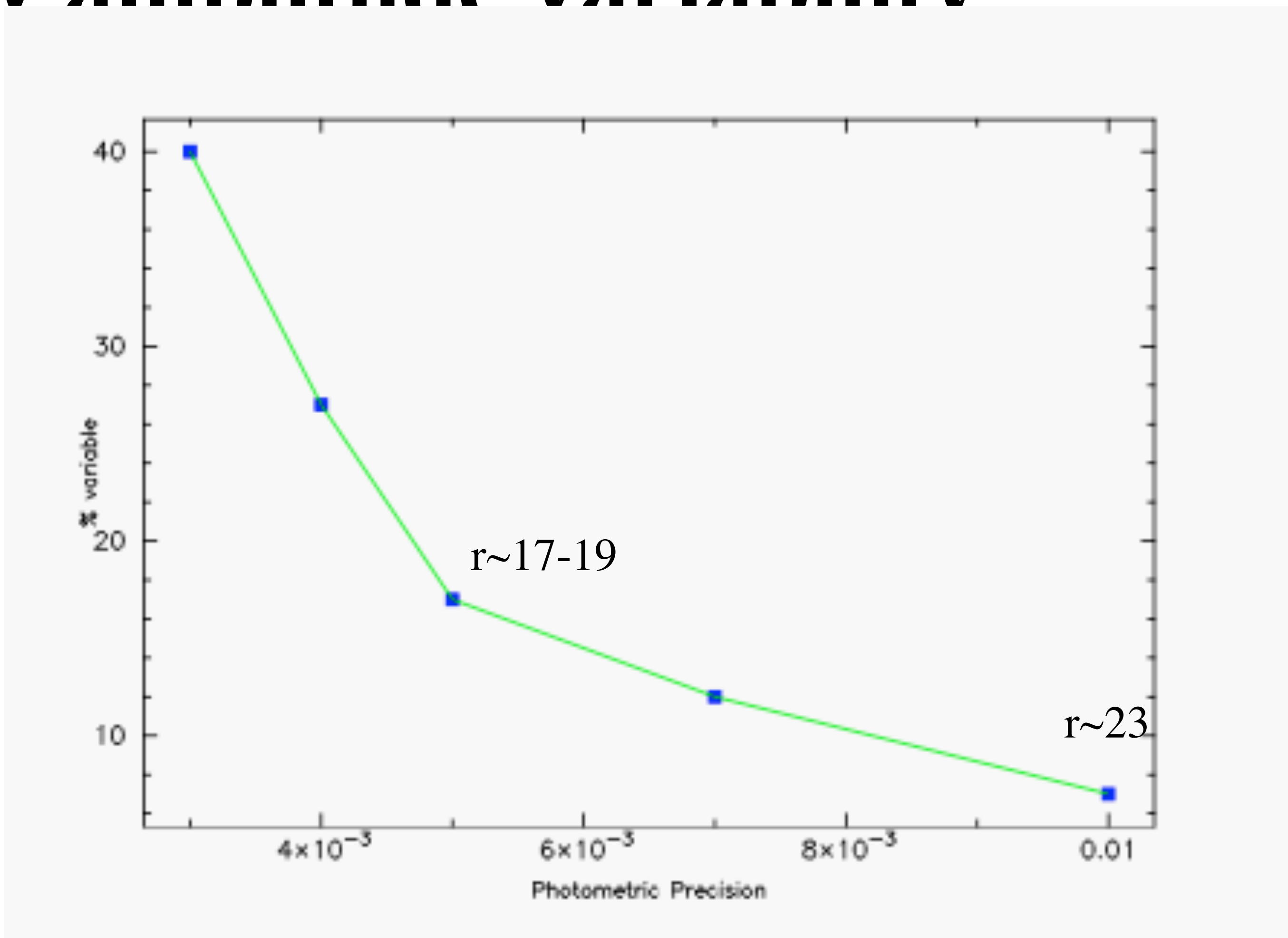


Mira - pulsating RG
Period ~ 11 months

Science for Pulsators

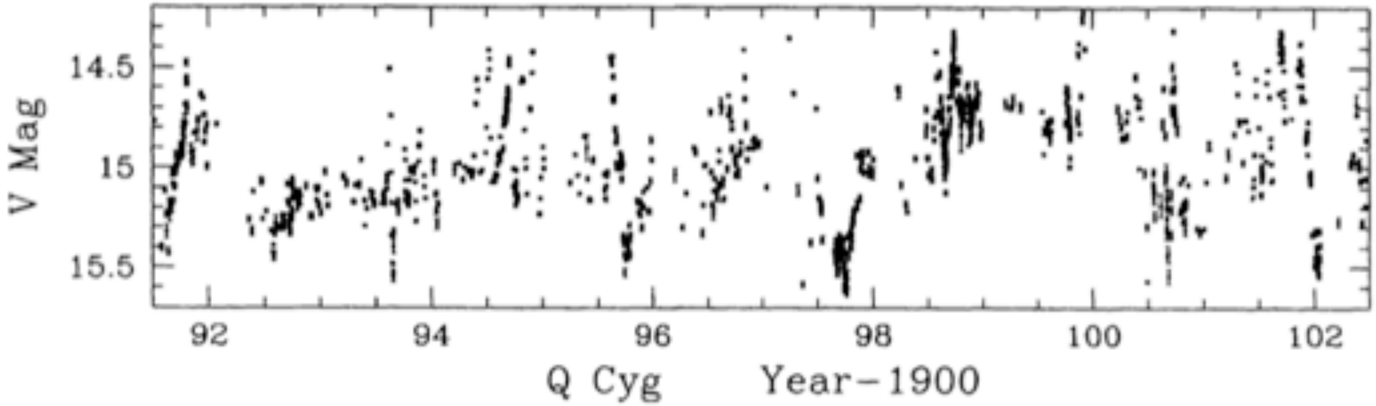
- Cepheids, RR Lyr and LPV can be used to get distances (Type Ia SN, nearby galaxies)
- RR Lyr are tracers of galactic structure:info on metallicity, evolution of globular clusters and nearby galaxies

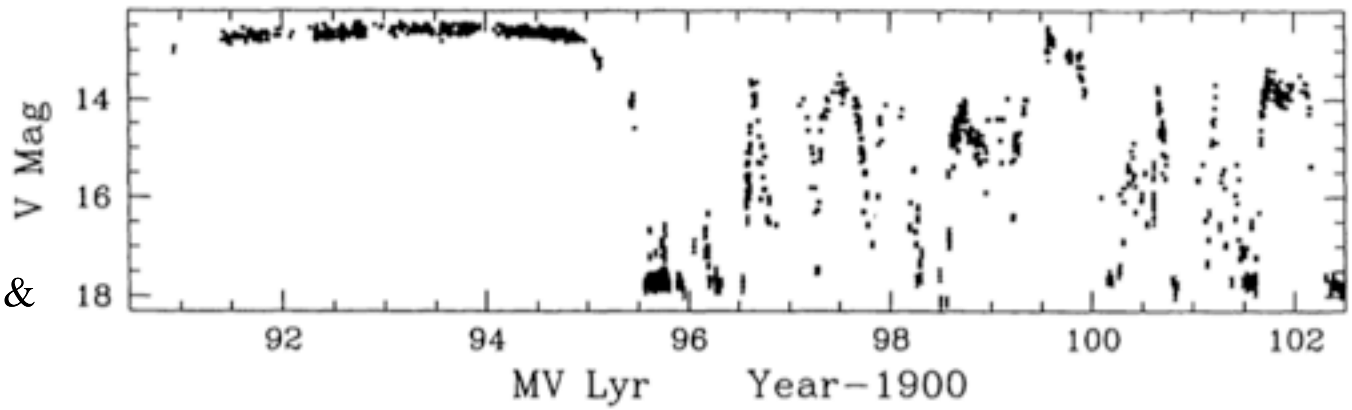
The Totally Unknown:
Low amplitude variability



Howell 2008

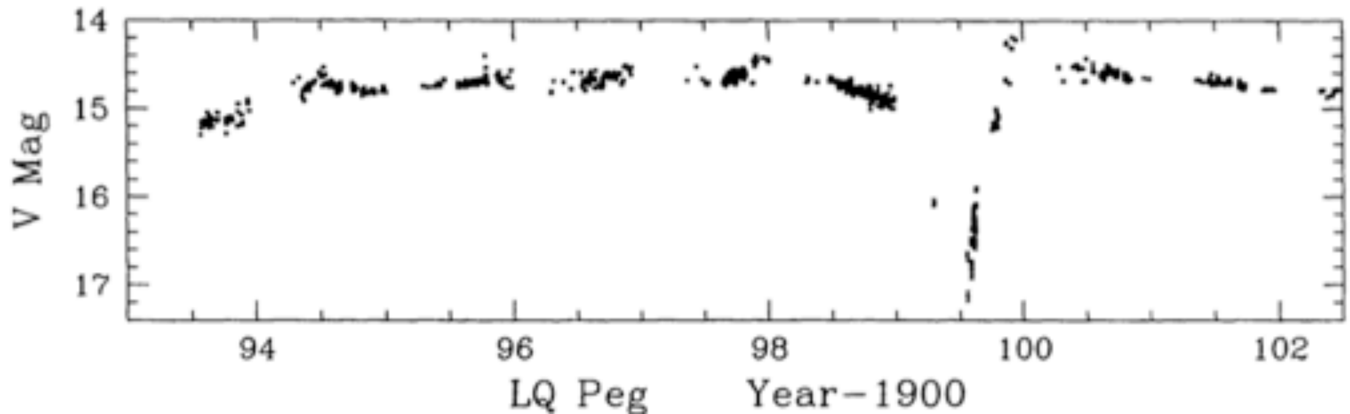
Totally Unknown: Long term variability





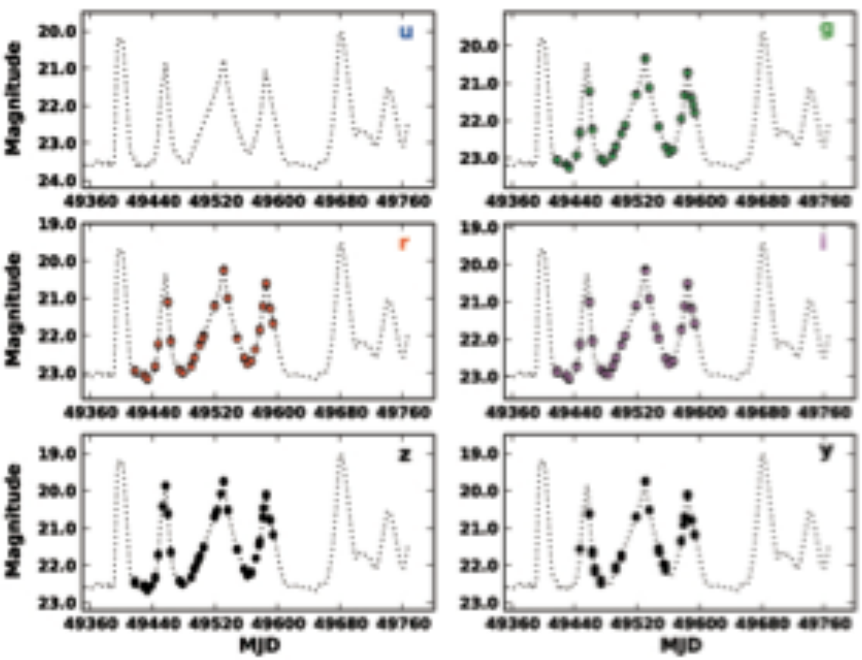
Honeycutt, Turner & Adams 2003

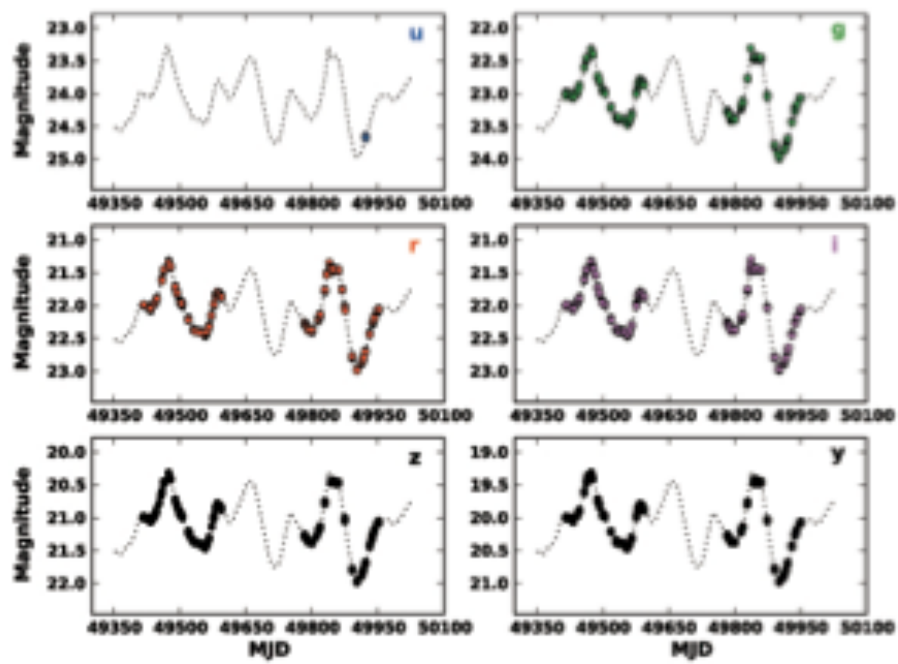
Roboscope



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

Will followup capability be in place when we need it?

- Spectra of 24-25 mag objects
- Time series for short P, low amp variables

My take on 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