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)  
- β Lyr  
  B8-G3  
- W Uma  
  F0-K0 (hrs)  

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  
  β Ceph: B, 0.5d  
  ZZ Ceti: WD, min  

(microlensing)
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

• 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)

\[
P = 0.814282212(1) \text{ d}
\]

activity level affects solutions
Future Directions: EBs in the Era of Large Surveys

With this level of data precision, systematics in models will be challenged like never before.
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With this level of data precision, systematics in models will be challenged like never before.
Current State of EBs and the Future:

• Below 1Mₖ 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)
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

Disk

Polar

CV types

WD primary

Intermediate Polar

LARP

Steve Howell
X-ray Binaries

Neutron star or BH primary
Summary of Variability and timescales for Interacting Binaries

<table>
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<tr>
<th>Variability</th>
<th>Typical Timescale</th>
<th>Amplitude (mag)</th>
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<tr>
<td>Flickering</td>
<td>sec – min</td>
<td>tenths</td>
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<tr>
<td>WD pulsation</td>
<td>4–10 min</td>
<td>0.01–0.1</td>
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<tr>
<td>AM CVn orbital period</td>
<td>10–65 min</td>
<td>0.1–1</td>
</tr>
<tr>
<td>WD spin (intermediate polars)</td>
<td>20–60 min</td>
<td>0.02–0.4</td>
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<tr>
<td>CV orbital period</td>
<td>10 min–10hrs</td>
<td>0.1–4</td>
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<td>Accretion Disks</td>
<td>2–12 hrs</td>
<td>0.4</td>
</tr>
<tr>
<td>AM CVn Outbursts</td>
<td>1–5 days</td>
<td>2–5</td>
</tr>
<tr>
<td>Dwarf novae Outbursts</td>
<td>4 days–30 yrs</td>
<td>2–8</td>
</tr>
<tr>
<td>Symbiotic Outbursts</td>
<td>weeks–months</td>
<td>1–3</td>
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<tr>
<td>Symbiotic orbital period</td>
<td>months–yrs</td>
<td>0.1–2</td>
</tr>
<tr>
<td>Novalike High-Low states</td>
<td>days–years</td>
<td>2–5</td>
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<tr>
<td>Recurrent Novae</td>
<td>10–20 yrs</td>
<td>6–11</td>
</tr>
<tr>
<td>Novae</td>
<td>1000–10,000 yrs</td>
<td>7–15</td>
</tr>
</tbody>
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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
Rates for about a dozen galaxies don’t vary much with Hubble type
Science from Outbursts

Nova Rates vs Galaxy $K$-band Luminosity

\[ \langle \nu \rangle = 2.2 \text{ yr}^{-1} \left[ 10^{10} L_{\odot, k} \right]^{-1} \]

Galactic Rate = 28 (+7,−5) yr$^{-1}$
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 M,
outburst ~1/month
Science from Outbursts: Dwarf novae

Low M outburst ~ 1/20 yrs
Science from Orbital variations

- Eclipsing systems enable photometric model
- Can detect eclipse of disk, hot spot, WD
- Can parameterize accretion area in magnetic systems
- \( P_{\text{orb}} \) (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  

Need numbers to understand evolution!
Science from Orbital variations

Prior to SDSS

SDSS results

Gansicke et al. 2009

Log number of CVs

Need numbers to understand evolution

SDSS found these

LSST will find these
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

$P_{\text{spin}} = 21 \text{ min}$
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)

Dwarf nova LS Peg

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

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.
These scale as the log

\[ \log \nu = \alpha + \beta \log E_u \]

Lacy, Moffett & Evans 1976

Science from flare stars
Larger flares occur for later types (u-z colors)
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

ZZ Ceti stars
Mira - pulsating RG
Period ~ 11 months

MACHO cepheids
P~2-60 days

ZZ Ceti pulsating WDs
P~ mins
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