Variable Stars: Action in the Sky!

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Outline

- Variable stars: history/introduction
- Types of variable stars
- Methods of observation
- Data mining and analysis
- The power of visual observations
- My current research projects
Why It Matters

Almost all stars (including the sun) are variable at some level

Variable stars provide unique and important information about the nature and evolution of the stars

They are “action in the sky”
Aristotle's Universe

- Earth at the centre, made of "base elements" -- earth, water, air, fire
- Stars were made of "quintessence" which was perfect and unchanging
Variable Stars – Stars that Vary

Below: the light curve (magnitude versus time) of Mira; this may have spurred the Copernican revolution (1596)
Historical Supernovae
Tycho's (1572) and Kepler's (1604) supernovae certainly helped overcome Aristotle's cosmology
The Sun as a Variable Star

- The sun is a ...
- ...pulsating variable star (helioseismology)
- ... flare star
- ... “eclipsing variable star” (left: transit of Venus)
- ... rotating variable star
AAVSO
American Association of Variable Star Observers

- Founded 1911; centennial in 2011
- Most significant organization through which skilled amateurs can contribute to research: “citizen astronomy”
- Website [www.aavso.org](http://www.aavso.org) contains a wealth of data and resources
AAVSO Data Are Used For ...

- Real-time, up-to-date information on unusual stellar activity
- Scheduling and coordinating variable star observing programs
- Simultaneous optical observations of program stars during ground-based or space observing programs
- Correlation of AAVSO optical data with data from other techniques or wavelengths
- Collaborative statistical analysis of stellar behaviour
Types of Variable Stars
or
Why Stars Are Variable
Pulsating Variable Stars expand and contract rhythmically

- Periods range from seconds (white dwarfs) to years (supergiants)
- Period $\rightarrow$ luminosity; the Leavitt Law
- Multiple periods $\rightarrow$ mass and interior structure; asteroseismology
- Period changes $\rightarrow$ rate of evolution; other processes
Why Do Stars Pulsate?

- Most large-amplitude pulsators like Cepheids: due to hydrogen and helium ionization zones, which thermodynamically drive the pulsation – like a car engine.
- Sun and orange and red giants: stochastic excitation of the pulsation by the random convective motions in the outer layers of the star.
Helioseismology

- The sun is pulsating in thousands of low-amplitude non-radial modes, stochastically excited by convection.
- It takes specialized equipment to detect and measure them.

One of thousands of pulsation modes in the sun.
The Leavitt Law for Cepheids
the period-luminosity relation

Henretta Leavitt (1868-1921)
Polaris: An Unusual Cepheid

- Cepheid pulsating variable; period 3.9696 days
- Period slowly increasing; enables us to measure the star's evolution
- Amplitude has decreased to near-zero
- Is it brightening over the centuries?
Pulsation and Mass Loss

Sun-like stars, at the ends of their lives, swell to become red giants, begin to pulsate, eventually become Mira stars. The pulsation drives off the outer half of the star, leaving a planetary nebula and a white dwarf core.
Rotating Variable Stars

- Rotating stars (axis not pointed at us) with non-uniform surfaces; small amplitudes
- Variability period is the rotation period
- (1) Sun-like stars with spots
- (2) “Peculiar A stars” with strong global magnetic fields

NASA
Peculiar/Magnetic A Stars

- Global magnetic fields of up to 20 KGauss!
- Brightness is slightly variable
- Spectra are bizarre and *highly* variable! Why?
- Variability period is rotation period

53 Cam: University of Bonn
Pre-Main Sequence Variables
T Tauri Stars and their Relatives

- Sun-like stars in the last stages of formation
- Star undergoes rotational variability
- Large, irregular variations due to variable accretion from the disc
- Also variability due to absorption by disc
Eclipsing (Binary) Variable Stars

- Period and light curve (plus spectroscopic observations) → mass, radius, luminosity
- Period changes → mass transfer or loss; these can be measured by timing eclipses accurately

Algol: RASC Calgary Centre
Exoplanet Transits

- Transit dims the star by $\leq$ few percent
- Transit light curve $\rightarrow$ period, radius of exoplanet (and mass and density if spectroscopic observations are also available)
- Multicolour light curves $\rightarrow$ atmosphere
Exoplanet Statistics
Erupting (Cataclysmic) Variable Stars

- **Flickering** from hot spot
- **Dwarf nova** outburst from collapse of accretion disc
- **Nova** from runaway thermonuclear fusion on the surface of the white dwarf
- **Supernova** from detonation of the white dwarf if its mass exceeds 1.44 suns

SS Cyg: AAVSO

NASA
Flare Stars

- Sudden release of energy, due to short-circuit of the magnetic field
- Ultimately caused by rotation
- Almost all red dwarfs – the most common stars in the universe – are flare stars
Methods of Observation
Visual Observation

- Simple
- Quick
- ... but prone to some low-amplitude spurious effects
- And accuracy is only 0.15-0.30 mag
- But still useful!

Delta Cephei
Photographic Observation

- Permanent; objective
- Panoramic
- Time exposure possible
- Sensitivity about 0.01; emulsions are very inefficient!
- Accuracy 0.02-0.10 mag, depending ....

Kitt Peak National Observatory
Photoelectric Photometry (PEP)

- Based on photoelectric effect: photomultiplier tube, or photodiode
- Developed around 1910 but amateur PEP blossomed after 1980
- Star-by-star observation
- Accuracy 0.005-0.02 mag
- Especially good for brighter stars

Optec SSP3 photometer
An Example of PEP Research

- Light curves of 5 small-amplitude pulsating red giants, showing short- and long-term variability

- Below: power spectrum, showing short- and long-term periods

Percy, Wilson, and Henry 2001
CCD Photometry
Charge-Coupled Device

- Digital; panoramic
- Co-developed by Canadian, Willard Boyle (Nobel Laureate)
- Sensitivity close to 100%
- Accuracy 0.005-0.02
- Not so good for brighter stars

Smithsonian Astrophysical Observatory
An Example of CCD Research

time series: variable maxima of RR Lyrae stars

AAVSO
Other CCD Photometry Projects
see JAAVSO and www.aavso.org/aavso-print

- Photometric monitoring of various aspects of cataclysmic variables: at quiescence (flickering, pulsation) and in dwarf nova, nova, and supernova eruption
- And short-period pulsators

NASA
Variable Star Data Mining and Analysis

• There are data on the AAVSO website, and many other places, which have not been fully analyzed
• There is a variety of time-series analysis software on the AAVSO website
• Also: useful instructions, tutorials, examples of research papers by amateurs and students
• Personal advice by AAVSO staff and members
Period Analysis

- Light curve: always the best place to start
- Fourier Analysis: determines periods present, and their average amplitudes
- Wavelet Analysis: gives change of period and amplitude with time.
- O-C Analysis: precision analysis of period changes over time
Visual observations of variable stars in modern astrophysics
Long-Term Light Curve of U Mon
AAVSO visual data: numerous, sustained, standardized
20,000 days of observations of U Mon, an RV Tauri star

AAVSO DATA FOR U MON - WWW.AAVSO.ORG

Magnitude

Julian Date

Visual Validated • Visual Prevalidated •

AAVSO
Timing Significant Events:
1. Unpredictable: Fadings of R CrB Stars

- Fadings are caused by ejected, obscuring, carbon-rich dust clouds
- Many (most? all?) RCrB stars are pulsating
- Are the fadings random, or tied to a period e.g. of pulsation?

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Timing Significant Events

2. Semi-Predictable: Maxima of RR Lyrae Stars

- **RR Lyrae**: helium-burning horizontal-branch pulsating (0.3-0.6 day) stars
- Parabolic (O-C) diagrams reveal period changes, presumably due to evolution; can be compared with models
- But some (O-C) diagrams are not parabolic!

GEOS RR Lyrae database
Timing Significant Events
3. Semi-Predictable: Maxima of Cepheid Variables

- Cepheid variables: pulsating (1-100 days) yellow supergiants
- Used for determining distances, and the properties, structure, and evolution of the stars
- Even visual observations can reveal the period, and period change, especially with 200 years of data!
Timing Significant Events

4. Semi-Predictable: Minima of Eclipsing Variables

- Beta Lyrae is perhaps the most bizarre of the thousands of known interacting close binary stars.
- The period change reflects mass transfer and loss.
- Further insight into this star is still needed!

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Period Changes: Systematic and Random

- (O-C) diagrams are not always linear (constant period) or parabolic (constant rate of period change)
- “random walk” (O-C) diagrams reflect random cycle-to-cycle period fluctuations
- These are found in Mira, RV Tauri, and some Cepheid variables

Berdnikov et al. 2007, PASP 119, 82; GY Sge is a classical Cepheid
Period Changes
True Period Changes in Mira Stars

- The curvature of the (O-C) diagram is statistically too large to explain by random fluctuations.
- This may reflect rapid evolution of the Mira star, such as a helium flash.
- Wavelet analysis (left) can show this well.

Templeton 2011 April, AAVSO VSotS
VSTAR Software
Fourier and wavelet analysis of pulsating red giant; other types of time-series analysis

Power versus period versus time for R Dor; www.aavso.org/vstar-overview
Beating Down the Error
Coherent Periods in T Tauri Stars

- T Tauri stars: young, spotted, rotating sun-like stars; coherent rotational variability; period: days; amplitudes small
- AAVSO visual observations, thought to have little value
- Danger: visual observations have small spurious one-year and one-month signals!

Percy, Palaniappan 2006, JAAVSO 35, 290
My Current Research
My Current Research

Studies of pulsating red giants and supergiants, especially their long-term behaviour

Systematic, sustained data from the AAVSO database, spanning many decades

Time-series analysis using the AAVSO VSTAR package

Undergraduate students develop and integrate their science and math skills by doing real science with real data

Results are published in the JAAVSO with students as co-authors; a win-win-win-win situation
The Role of My Students

- Undergrads and outstanding senior HS students
- Enhance math, science, and computing skills
- Are motivated by doing real research, with real (AAVSO) data
- Results presented and published, contributing to science, and providing feedback and motivation to AAVSO observers
Pulsating Red Giants (PRGs) and Supergiants (PRSGs)
The Nature of “Irregular” PRGs
Percy & Terziev 2011
www.aavso.org/ejaavso3911
note the “long secondary period”
V770 Cas Power Spectrum, showing period of about 370 and possibly 3400 days: many “irregular” variables have one or more periods; two pieces of info is better than one, or none!

Frequency = 1/period

3450 days
420 days
365 days (spurious)
Semi-Regular (SR) PRGs
Percy & Tan 2013, www.aavso.org/ejaavso411001
Semi-Regular (SR) PRGs
Percy & Tan 2013, www.aavso.org/ejaavso411001
EP Vel, and many other SRs, pulsate in two modes; very useful! Twice as much info!

Frequency = 1/period
Amplitude Variations in PRGs
RV And power spectrum analysis, showing 171-day period

Frequency = 1/period

165 days
RV And: variation of pulsation amplitude with time; almost all pulsating red giants vary in amplitude; why?
Amplitude Variations in Pulsating Red Supergiants
Percy & Khatu 2013, arxiv.org/abs/1310.6306
S Per: power spectrum analysis, showing 813-day period

Frequency = 1/period
S Per: pulsation amplitude versus time; amplitude varies in this and other pulsating red supergiants; why?
Pulsating Red Supergiants: A Clue

- The detailed power spectrum shows multiple peaks under a Lorentzian envelope.
- This is interpreted as evidence for stochastic oscillations, caused by interplay between convection and pulsation.
- We may be seeing their growth and decay.

Betelgeuse
Image (left); model (right): red supergiants have deep convection zones; huge convective cells; non-uniform!
1. Some pulsating red giants pulsate in both the fundamental and first overtone mode. Do any also pulsate in the second overtone? In progress

2. Do yellow supergiants such as RV Tauri stars and SRd stars vary in pulsation amplitude? Yes!

3. Following on Galileo: if the pulsation amplitude increases, does the pulsation period increase also? It seems to, in many cases
DE Her, Yellow Semi-regular (SRd) Variable
Amplitude as a function of time
Results by Rufina Kim (2014)
Reflections

- Despite decades of dire predictions, visual observation is not dead
- There is a steady stream of research papers, using visual data
- For many applications, including period determination and study of long-term variability, the longer the dataset, the more secure the results
- To reiterate: AAVSO visual observations are numerous, sustained, and standardized
Rewards of Variable Star Observing

- Contributing to science/astronomy – including forefront astronomy; seeing your name in the AAVSO database, or on a paper
- Knowing that your work also contributes to education; being able to share your knowledge and work with others
- Constantly learning about astronomy, variable stars, and observing techniques, from sources such as AAVSO
- Being part of an international community of “kindred spirits”, including those who have gone before us
- Being in touch with the universe
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