Variable stars review

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1 Pulsating variable stars

Pulsating variables are stars that show periodic expansion and contraction of their surface layers. Pulsations may be radial or non-radial. A radially pulsating star remains spherical in shape, while a star experiencing non-radial pulsations may deviate from a sphere periodically. The following types of pulsating variables may be distinguished by the pulsation period, the mass and evolutionary status of the star, and the characteristics of their pulsations.

1.1 Cepheids and cepheid-like

1.1.1 Type I Cepheids (α Cephei)

Cepheids are variable supergiant stars with similar temperatures to the Sun. They are radial pulsators with maximum velocity of approach (of the moving surface of the star) near light maximum and bluest colour (recall that $L = 4\pi R^2 T^4$).

As noted above, Cepheids have similar temperatures to the Sun (something like 5000 to 7000K; spectral types from early F to K) and range in luminosity from about $500L_\odot$ to about $30000L_\odot$ which makes them detectable at great distances. Their periods are typically from about 1 to 50 days.

For individual stars, light amplitude variations are typically 0.5 to 2 magnitudes (again making them relatively easy to detect), and they have velocity amplitudes ~ 30 – 60 km/s. The next figure show δ Cephei itself, as an example.

1.1.2 Type II Cepheids

These low-mass stars pulsate with periods typically between 1 and 50 days. Like all Cepheid variables, Type IIs exhibit a relationship between the star's luminosity and pulsation period Type II Cepheids are population II stars and are thus old, typically metal-poor, and low mass objects.

W Virginis -type Cepheids are intrinsically less luminous by 1.5 - 2 magnitudes than the Type I Classical Cepheids and have typical periods of 12 - 30 days. As they are older stars than Type Is their spectra are characterised by having lower metallicities. Type II light curves show a characteristic bump on the decline side and they have an amplitude range of 0.3 - 1.2 magnitudes.

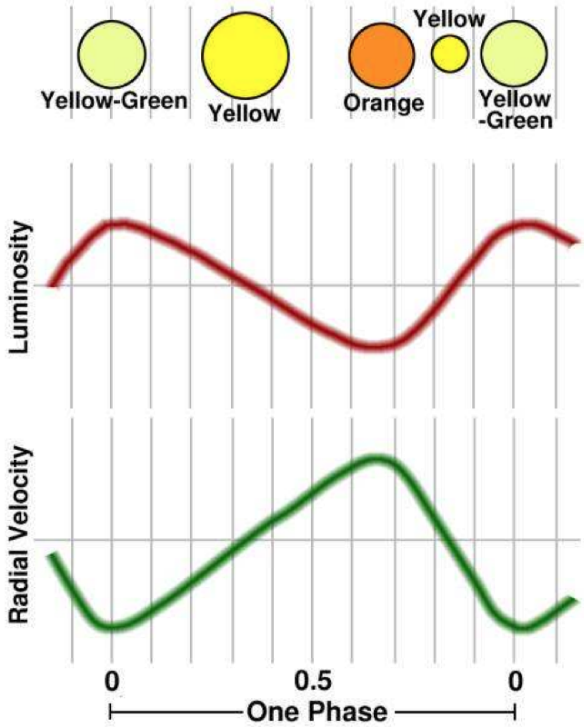

Figure 1: Schematic of luminosity, colour and velocity variations for a classical Cepheid pulsator – a radial, fundamental mode pulsator.

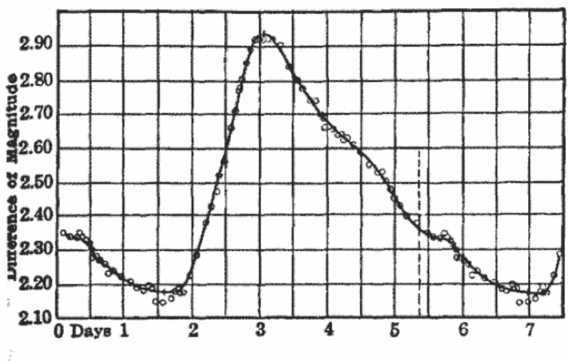

Figure 2: δ Cepheid light-curve.

1.1.3 RR Lyrae stars

These are short-period (.05 to 1.2 days), pulsating, white giant stars, usually of spectral class A. They are older and less massive than Cepheids. The amplitude of variation of RR Lyrae stars is generally from 0.3 to 2 magnitudes.The average absolute magnitude of an RR Lyrae is about 0.75, only 40 or 50 times brighter than our Sun.

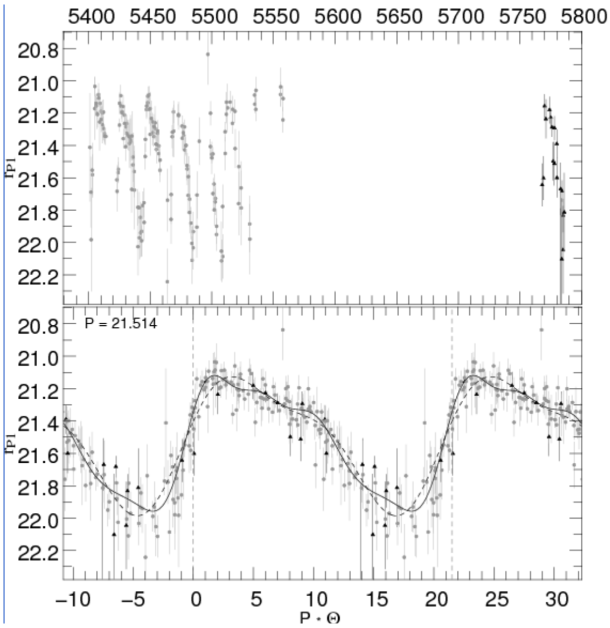

Figure 3: δ Type II Cepheid light-curve.

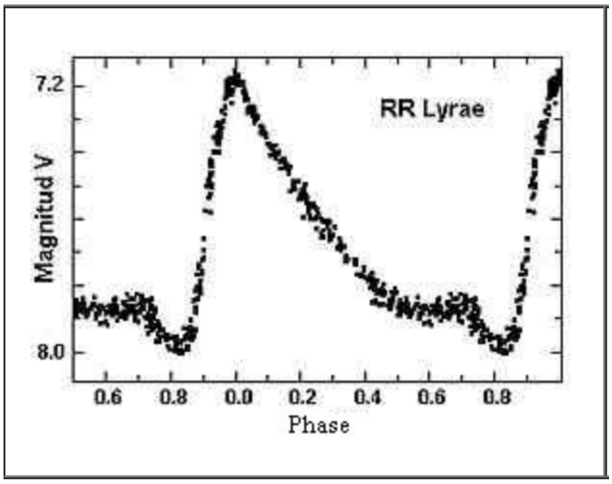

Figure 4: RR-Lyrae light-curve.

1.1.4 Delta Scuti variables

A Delta Scuti variable (sometimes termed dwarf cepheid) is a variable star which exhibits variations in its luminosity due to both radial and non-radial pulsations of the star's surface. They are pulsating variables of spectral types A to early F with luminosity classes V to III. They pulsate in radial and nonradial p (and possibly also g) modes with periods between about 30 minutes to 8 hours and photometric amplitudes less than 1 magnitude. After white dwarfs, they are the second most abundant pulsating variables in our Galaxy. Delta Scuti stars obey a period-luminosity-color relationship (PLCR). Since the pulsation "constant" Q does not change very much over the whole lower instability strip and since it is reasonable to assume that stars with similar temperature have similar overtones excited, the existence of a PLCR is not surprising.

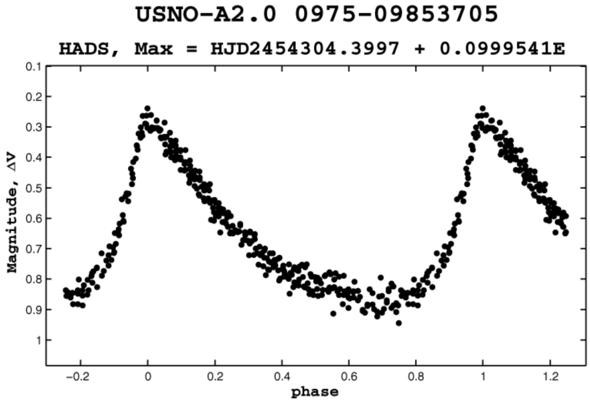

Figure 5: Delta Scuti light-curve

1.1.5 SX Phoenicis variables

These stars exhibit a short period pulsation behavior that varies on time scales of 0.03-0.08 days (0.7-1.9 hours). They have spectral classifications in the range A2-F5 and vary in magnitude by up to 0.7. Compared to the Sun, these stars have a lower metallicity, which means they have a reduced abundance of elements other than hydrogen and helium. They also have relatively high space velocity and low luminosities for stars of their stellar classification. These properties distinguish the SX Phoenicis variables from their cousins, the Delta Scuti variables. The latter have longer periods, strong metallicity and large amplitudes.

1.2 Long period and semi regular

Long Period Variables (LPVs) are pulsating red giants or supergiants with periods ranging from 30-1000 days. They are usually of spectral type M, R, C or N. There are two subclasses; Mira and Semiregular.

1.2.1 Mira

These periodic red giant variables vary with periods ranging from 80 to 1000 days and visual light variations of more than 2.5 magnitudes.

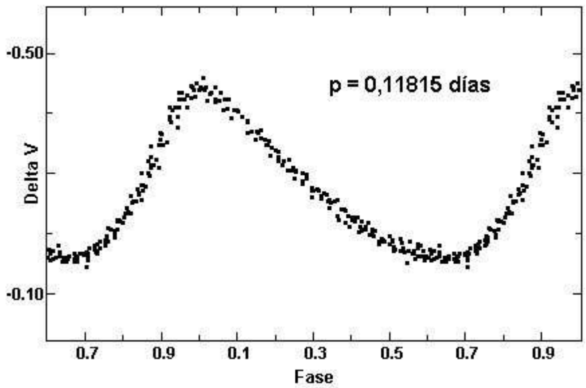

Figure 6: SX Phoenicis light-curve

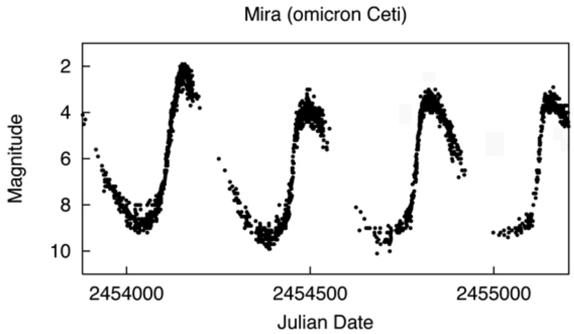

Figure 7: Mira light-curve.

1.2.2 Semiregular

These are giants and supergiants showing appreciable periodicity accompanied by intervals of semiregular or irregular light variation. Their periods range from 30 to 1000 days, generally with amplitude variations of less than 2.5 magnitudes.

1.2.3 Slow irregular variables

These stars, which include the majority of red giants, are pulsating variables. As the name implies, these stars show luminosity changes with either no periodicity or with a very slight periodicity.

1.3 Rapidly oscillating Ap variables

Rapidly oscillating Ap stars (roAp stars) are a subtype of the Ap star class that exhibit short-timescale rapid photometric or radial velocity variations. They are hydrogen core-burning stars of mass $M \sim 2M_{\odot}$ which have global dipole magnetic fields with effective

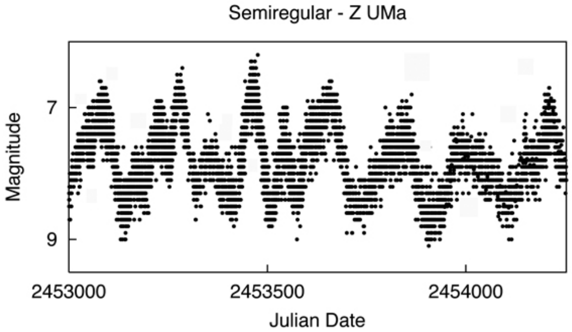

Figure 8: Semiregular star light-curve.

strengths of a few hundred to a few thousand gausses and which pulsate in high-overtone, low-degree, nonradial p-modes with periods in the range 4-15 min.

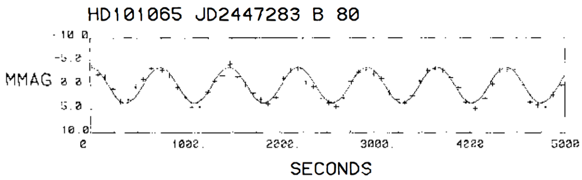

Figure 9: Rapidly oscillating Ap star light-curve

1.4 Other

1.4.1 Alpha Cygni variables

Alpha Cygni variables are variable stars which exhibit non-radial pulsations, meaning that some portions of the stellar surface are contracting at the same time others parts expand. They are supergiant stars of spectral types B or A. Variations in brightness on the order of 0.1 magnitudes are associated with the radial pulsations, which often seem irregular, due to beating of multiple pulsation periods. The pulsations typically have periods of several days to several weeks.

1.4.2 RV Tauri stars

These are yellow supergiants having a characteristic light variation with alternating deep and shallow minima. Their periods, defined as the interval between two deep minima, range from 30 to 150 days. The light variation may be as much as 3 magnitudes. Some of these stars show long-term cyclic variations from hundreds to thousands of days. Generally, the spectral class ranges from G to K.

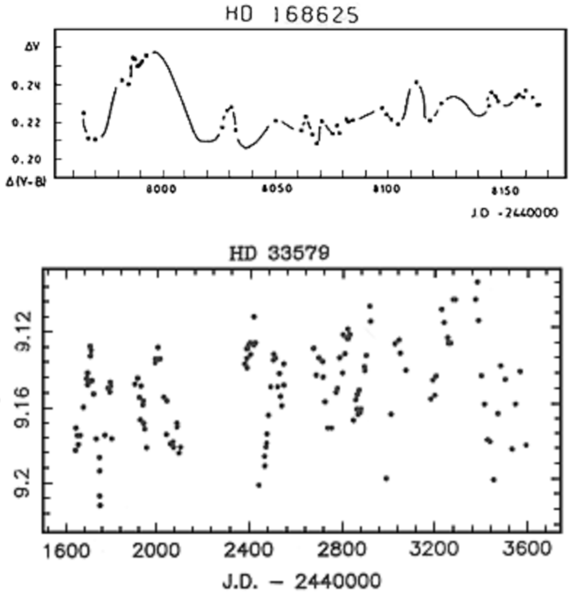

Figure 10: Alpha Cygni light-curves

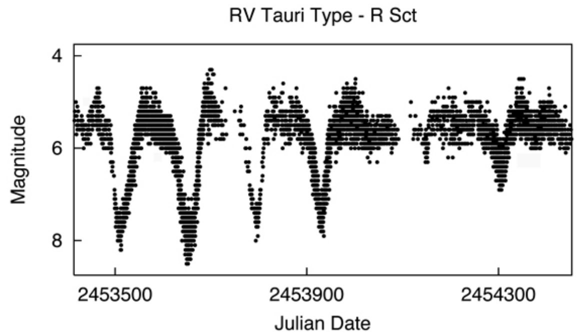

Figure 11: RV Tauri star light-curve.

1.5 Gamma Doradus variables

Gamma Doradus variables are variable stars which display variations in luminosity due to non-radial pulsations of their surface. The stars are typically young, early F or late A type main sequence stars, and typical brightness fluctuations are 0.1 magnitudes with periods on the order of one day.

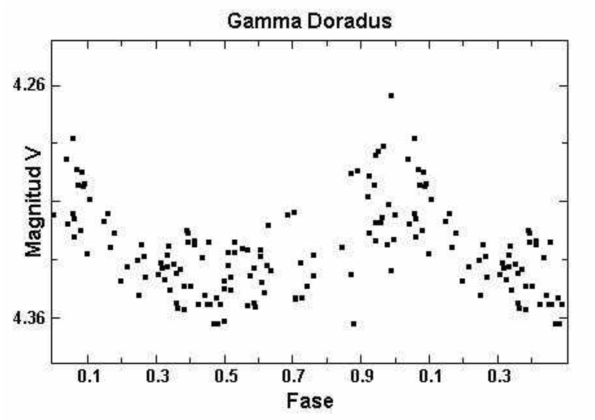

Figure 12: Gamma Doradus light-curve

2 Eruptive variables

Eruptive variables are stars varying in brightness because of violent processes and flares occurring in their chromospheres and coronae. The light changes are usually accompanied by shell events or mass outflow in the form of stellar winds of variable intensity and/or by interaction with the surrounding interstellar medium.

2.1 Cataclysmic or explosive variables

Cataclysmic variables as the name implies, are stars which have occasional violent outbursts caused by thermonuclear processes either in their surface layers or deep within their interiors. The majority of these variables are close binary systems, their components having strong mutual influence on the evolution of each star. It is often observed that the hot dwarf component of the system is surrounded by an accretion disk formed by matter lost by the other, cooler, and more extended component.

2.1.1 Supernovae

These massive stars show sudden, dramatic, and final magnitude increases of 20 magnitudes or more, as a result of a catastrophic stellar explosion.

2.1.2 Novae

These close binary systems consist of an accreting white dwarf as a primary and a low-mass main sequence star (a little cooler than the Sun) as the secondary star. Explosive nuclear burning of the surface of the white dwarf, from accumulated material from the secondary, causes the system to brighten 7 to 16 magnitudes in a matter of 1 to several hundred days. After the outburst, the star fades slowly to the initial brightness over several years or decades. Near maximum brightness, the spectrum is generally similar to that of A or F giant stars.

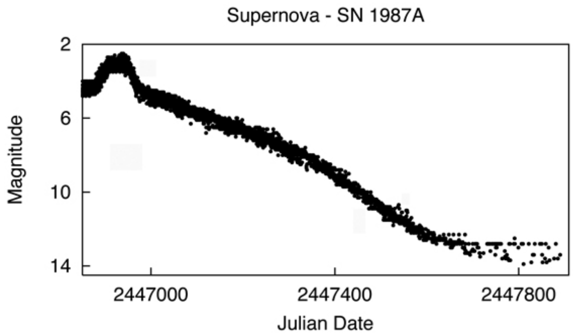

Figure 13: Supernovae light-curve.

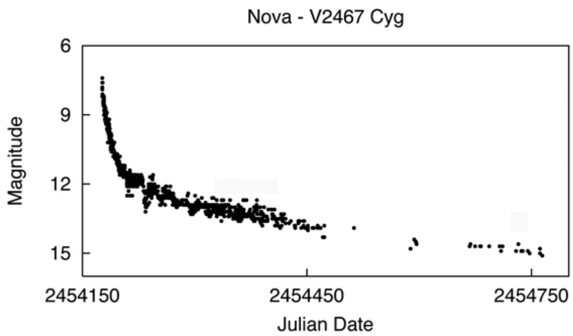

Figure 14: Nova light-curve.

2.1.3 Recurrent Novae

These objects are similar to novae, but have two or more slightly smaller-amplitude outbursts during their recorded history.

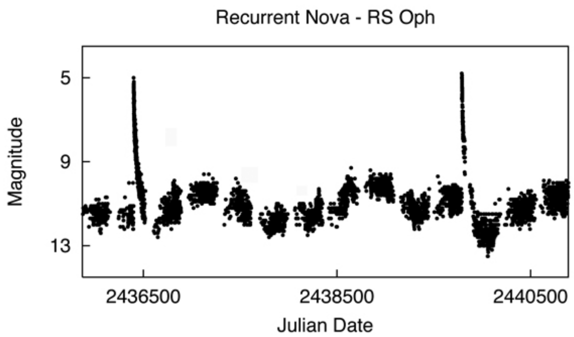

Figure 15: Recurrent nova light-curve.

2.1.4 Dwarf Novae

These are close binary systems made up of a red dwarf–a little cooler than our Sun, a white dwarf, and an accretion disk surrounding the white dwarf. The brightening by 2 to 6 magnitudes is due to instability in the disk which forces the disk material to drain down (accrete) onto the white dwarf. There are three main subclasses of dwarf novae; U Gem, Z Cam, and SU UMa stars.

- U Geminorum

  After intervals of quiescence at minimum light, they suddenly brighten. Depending on the star, the eruptions occur at intervals of 30 to 500 days and last generally 5 to 20 days.

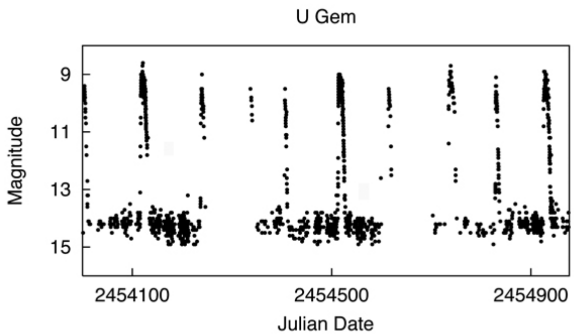

Figure 16: U Geminorum light-curve.

- Z Camelopardalis

  These stars are physically similar to U Gem stars. They show cyclic variations, interrupted by intervals of constant brightness called “standstills”. These standstills last the equivalent of several cycles, with the star “stuck” at the brightness approximately one-third of the way from maximum to minimum.

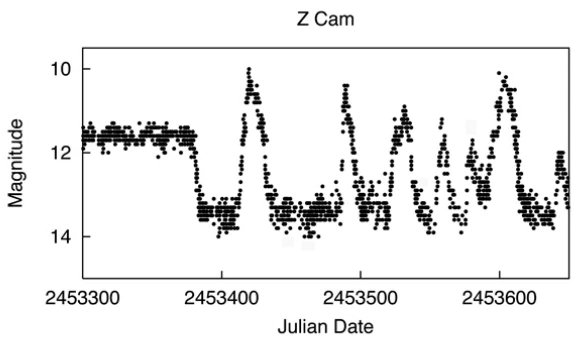

Figure 17: Z Camelopardalis light-curve.

- SU Ursae Majoris

  Also physically similar to U Gem stars, these systems have two distinct kinds of outbursts: one is faint, frequent, and short, with a duration of 1 to 2 days; the other ("superoutburst") is bright, less frequent, and long, with a duration of 10 to 20 days. During superoutbursts, small periodic modulations ("superhumps") appear.

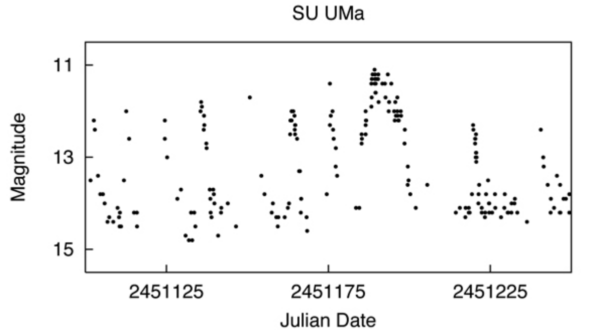

Figure 18: SU Ursae Majoris light-curve.

2.1.5 Symbiotic stars

These close binary systems consist of a red giant and a hot blue star, both embedded in nebulosity. They show semi-periodic, nova-like outbursts, up to three magnitudes in amplitude.

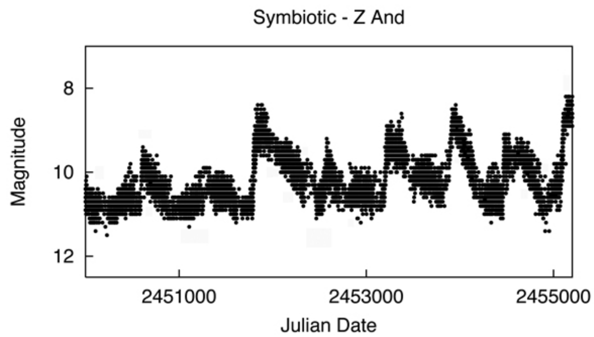

Figure 19: Symbiotic star light-curve.

2.2 Giants and supergiants

2.2.1 R Coronae Borealis

These rare, luminous, hydrogen-poor, carbon-rich, supergiants spend most of their time at maximum light, occasionally fading as much as nine magnitudes at irregular intervals.

They then slowly recover to their maximum brightness after a few months to a year. Members of this group have F to K and R spectral types.

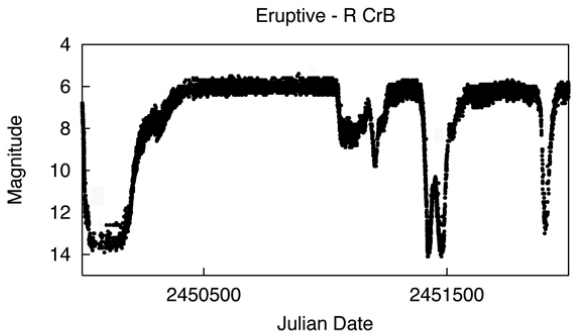

Figure 20: R Coronae Borealis star light-curve.

2.2.2 Luminous blue

Luminous blue variables (LBVs) are massive evolved stars that show unpredictable and sometimes dramatic variations in both their spectra and their brightness. They are very luminous, unstable, hot supergiant which suffers irregular eruptions. They are extraordinarily rare with just 20 objects listed in the General Catalogue of Variable Stars as SDor. The LBVs are stars of high intrinsic luminosity. The "classical" examples, including most of the well-studied LBVs, have absolute bolometric magnitudes brighter than -9.5, corresponding to luminosities of the order of $10^6 L_{\odot}$.

Photometric variations in LBVs are observed with a wide range of amplitudes and times scales:

- Giant eruptions of $\geqslant$ 2 mag in M_v refer to sudden ejections of unusually large amounts of mass and a probable increase in bolometric luminosity. The time scales for these giants eruptions are of course very uncertain, but because we see so few, hundreds to thousands of years are reasonable estimates of the frequencies of these events.
- Eruptions of 1-2 mag are often observed on time scales of 10-40 years.
- Smaller oscillations of about half a magnitude are often observed on time scales of months to a few years, on top of the longer-term normal eruptions.
- Microvariations of $\leqslant$ 0.1 mag have been also described.

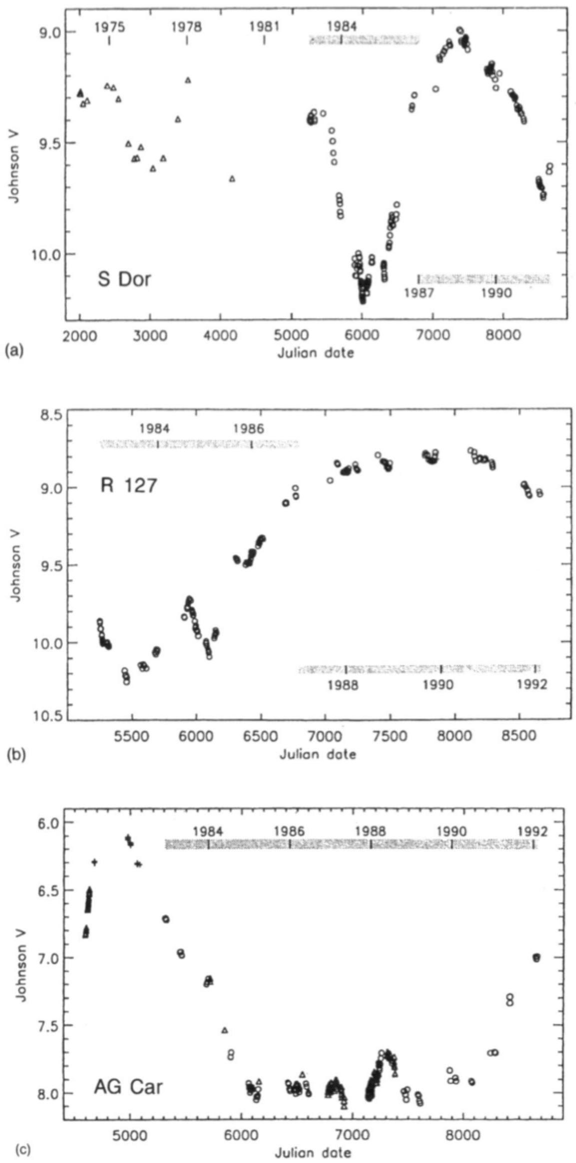

Figure 21: Recent light-curves for (a) S For, (b) R 127, and (c) AG Car.

3 Eclipsing Binaries stars

These are binary systems of stars with an orbital plane lying near the line-of-sight of the observer. The components periodically eclipse one another, causing a decrease in the apparent brightness of the system as seen by the observer. The period of the eclipse, which coincides with the orbital period of the system, can range from minutes to years.

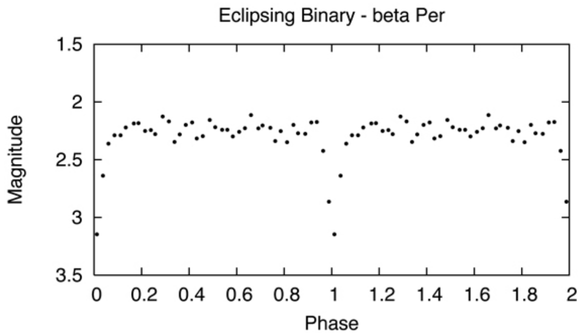

Figure 22: Eclipsing binary star light-curve.

3.1 Algol variable stars

Algol variables or Algol-type binaries are a class of eclipsing binary stars where the orbital plane of the stars are coincident with the line of sight from Earth. When the cooler component passes in front of the hotter one, part of the latter's light is blocked, and the total brightness of the binary, as viewed from Earth, temporarily decreases.

The period, or time span between two primary minima, is very regular, being determined by the revolution period of the binary, the time it takes for the two components to once orbit around each other. Most Algol variables are quite close binaries, and therefore their periods are short, typically a few days. The shortest known period is 0.1167 days ($\sim 2:48$ hours, HW Virginis); the longest is 9892 days (27 years, epsilon Aurigae).

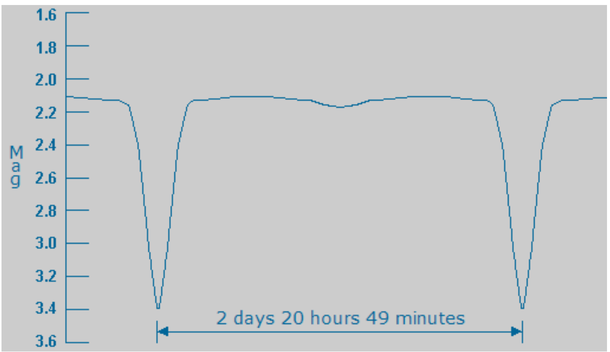

Figure 23: Algol variable star light-curve.

3.2 Beta Lyrae variable

Beta Lyrae variables are a class of close binary stars. Their total brightness is variable because the two component stars orbit each other, and in this orbit one component periodically passes in front of the other one, thereby blocking its light. The two component stars of Beta Lyrae systems are quite heavy (several solar masses each) and extended (giants or supergiants). They are so close, that their shapes are heavily distorted by mutual gravitation forces: the stars have ellipsoidal shapes, and there are extensive mass flows from one component to the other.

The light curves of beta Lyrae variables are quite smooth: eclipses start and end so gradually that the exact moments are impossible to tell. This is because the flow of mass between the components is so large that it envelopes the whole system in a common atmosphere. The amplitude of the brightness variations is in most cases less than one magnitude; the largest amplitude known is 2.3 magnitudes (V480 Lyrae).

The period of the brightness variations is very regular. It is determined by the revolution period of the binary, the time it takes for the two components to once orbit around each other. These periods are short, typically one or a few days. The shortest known period is 0.29 days (QY Hydrae); the longest is 198.5 days (W Crucis). In beta Lyrae systems with periods longer than 100 days one of the components generally is a supergiant.

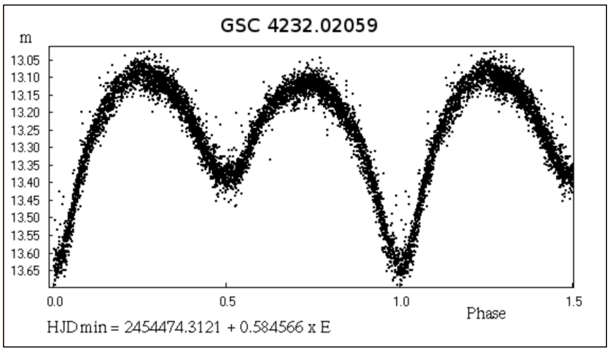

Figure 24: Beta Lyrae variable light-curve.

3.3 W Ursae Majoris variable

A W Ursae Majoris variable is a type of eclipsing binary variable star. These stars are close binaries of spectral types F, G, or K that share a common envelope of material and are thus in contact with one another. They are termed contact binaries because the two stars touch and transfer mass and energy through the connecting neck.

The class is divided into two subclasses: A-type and W-type. A-type W UMa binaries are composed of two stars both hotter than the Sun, having spectral types A or F, and periods of 0.4 to 0.8 day. The W-types have cooler spectral types of G or K and shorter periods of 0.22 to 0.4 day.

Their light curves differ from those of classical eclipsing binaries, undergoing a constant ellipsoidal variation rather than discrete eclipses. This is because the stars are gravitationally distorted by one another, and thus the projected area of the stars is constantly changing. The depths of the brightness minima are usually equal because both stars have nearly equal surface temperatures.

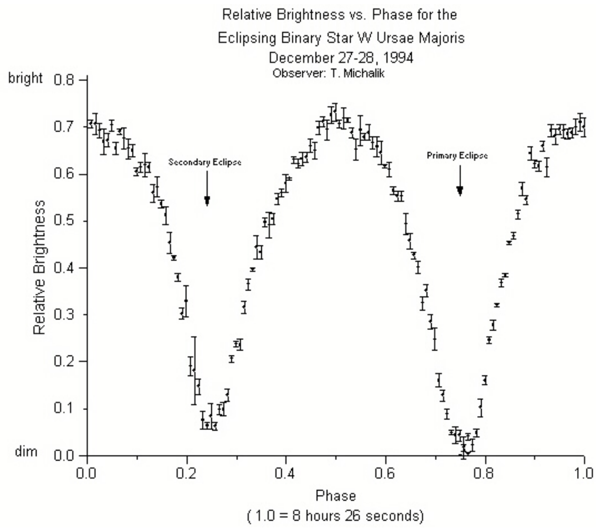

Figure 25: W Ursae Majoris variable light-curve.

4 Rotating variables

Stars with sizeable sunspots may show significant variations in brightness as they rotate, and brighter areas of the surface are brought into view. Bright spots also occur at the magnetic poles of magnetic stars. Stars with ellipsoidal shapes may also show changes in brightness as they present varying areas of their surfaces to the observer.

4.1 Alpha2 Canum Venaticorum Type

Alpha2 Canum Venaticorum variables are main-sequence stars. They have strong magnetic fields that vary, along with brightness, in a period of about 0.5-160 days. The amplitudes of the brightness changes are usually around 0.1-1 magnitudes.

4.2 Rotating Ellipsoidal Binary Variables

Rotating ellipsoidal binary variables are close binary systems with ellipsoidal components, which change combined brightnesses with periods equal to those of orbital motion because of the change in which part of the stars is being seen by an observer. The components do not eclipse each other.

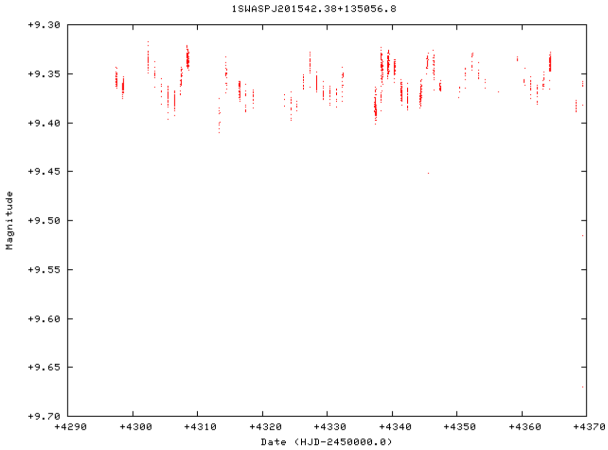

Figure 26: Alpha2 Canum Venaticorum light-curve.

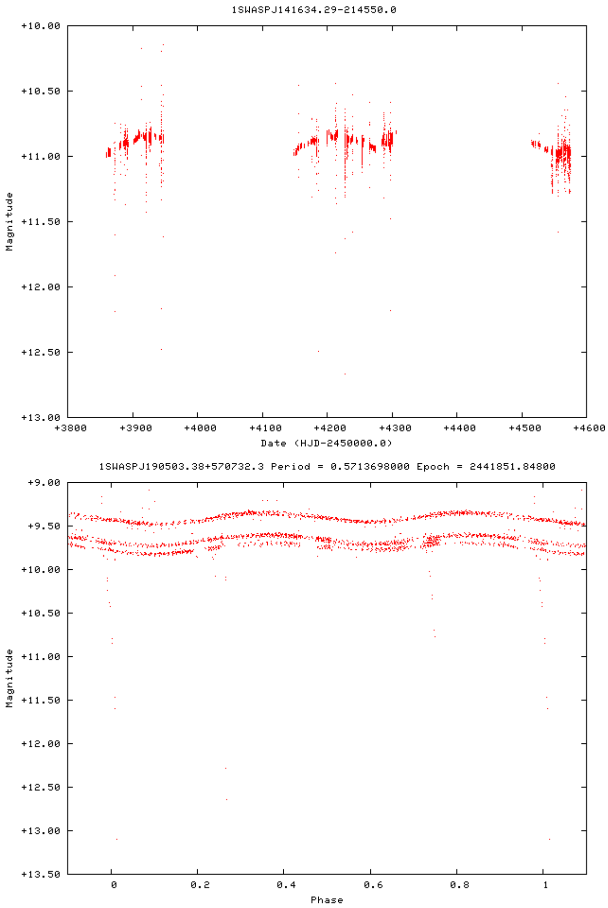

Figure 27: Rotating ellipsoidal binary variable light-curves.