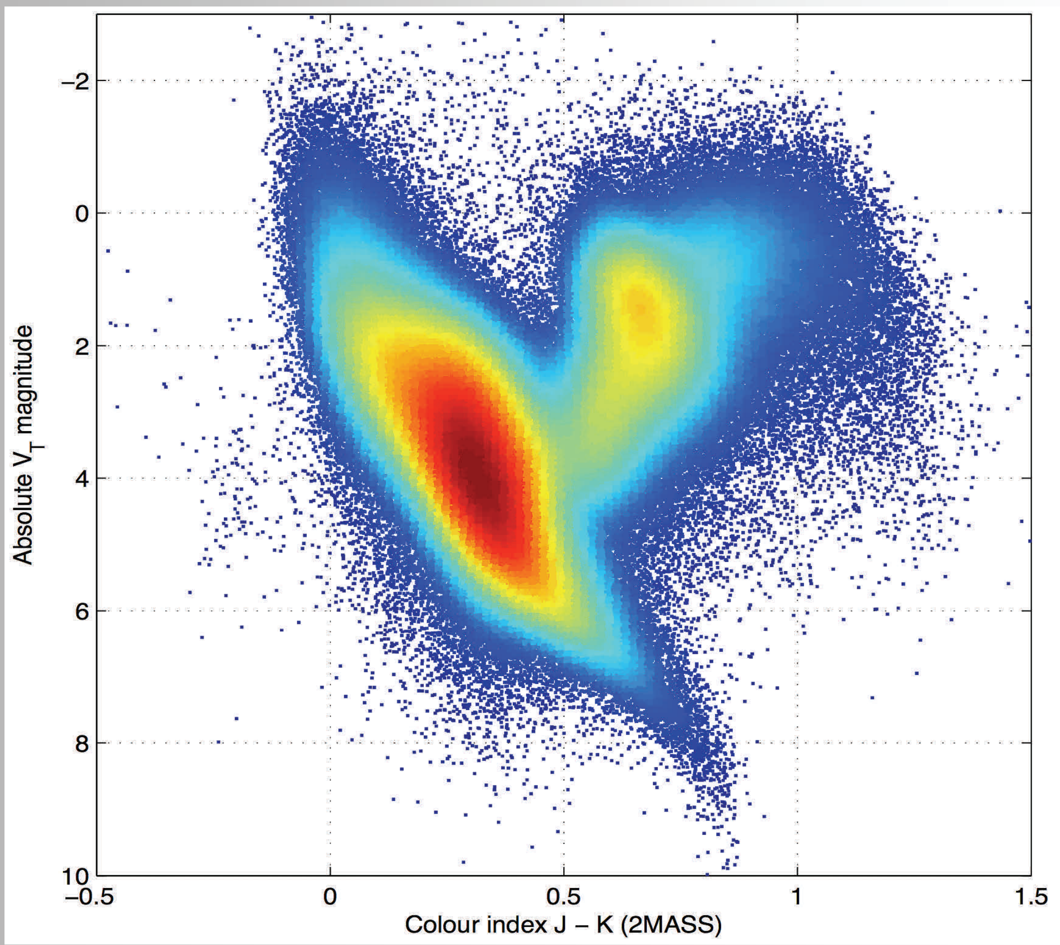
BAV MAGAZINE SPECTROSCOPY



OF THE GERMAN ORGANIZATION & WORKING GROUP VARIABLE STARS BAV

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MUNSTERDAMM 90
12169 BERLIN

ISSUE No. 02 12/2017 ISSN 2566-5103

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Imprint
The BAV MAGAZINE SPECTROSCOPY appears half-yearly from June 2017. Responsibilty for publication: German Working Group for Variable Stars e.V. (BAV), Munsterdamm 90, 12169 Berlin

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Cover picture: EESA/GAIA/IDT/FL/DPCE/AGIS

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EDITORIAL

From the stars we basically receive only their electromagnetic radiation of different wavelengths, and we "see" essentially only the surface of the radiating bodies. By evaluating the light, we obtain information about:

- the direction of the radiation (positions and movement of the stars)
- the quantity of the radiation (brightness)
- the quality of the radiation (color, spectrum, polarization)

For amateurs, only the narrow band of visible light is easily accessible. In this spectral region, however, both the brightness (photometry) and the spectra of the objects can be examined. Today's amateur astronomy, with its instrumental and computer-assisted equipment, enjoys observation possibilities that were reserved exclusively for professional astronomers until a few years ago.

Thanks to the development of CCD technology, the types of observational perspectives have become much more varied. For example, in the area of variable star observation, there are many new possibilities in addition to already existing approaches.

Professional variable star research employs techniques and observation methods to study the physics and atmospheres of the stars in a holistic manner, considering all aspects and occurrences. Thus, this means that the collected radiation must be understood as a complex storage medium of the physical processes on and in the observed star.

This is appropriate for the intensity of the light, as well as for its spectral composition. The linking of brightness measurements and spectroscopy, a matter of course in professional astronomy, reflects this connection.

Along with brightness changes that occur in variable stars (which can occur quite frequently) variable changes in the state of the stars also can take place and often are revealed in the corresponding spectrum.

Ernst Pollmann

Disks and Kitchen Sinks (Part II)

by Prof. Dr. Steve Shore, University of Pisa

You'll see (more or less) solid body rotation from the planet that varies as the angle to the line of sight so goes through zero at the center of the disk. In contrast, at the limb, you'll see a jump - a decrease - between the innermost part of the ring and the limb of Saturn. That's what I'll be talking about with the angular momentum barrier, you have to slow the orbiting material down to accommodate the rotation rate of the planet.

1.3 Back to the gas

The shock is very important. Not only does the gas compress and heat on passing through this zone, it also slows down relative to its upstream value. That is the real clue: if the gas is slowed and deviated inward, it can start filling in the region toward the companion. This is an accretion disk in a nutshell. The heating is derived from dissipation of kinetic energy and because we're astronomers, the universe is a big empty volume into which the excess thermal energy radiates. So at the first you have a mechanism for dissipating energy of motion. But to get the material to accrete, to actually flow inward instead of just expanding to fill the region around the star, requires additional dissipation.

Here you can think of a sink or bathtub. The density is constant. When you open a drain, the water above it falls inward. But you know this isn't just a plug of uid, it initiates a ow that causes an inward drift and spin-up of the water as it nears the drain. Water, like all normal fluids, has an internal friction, viscosity, that causes sheared (differentially moving) parts of the fluid to drag on each other just as the atmosphere does on a satellite.

The greater the velocity difference across some distance, the greater the shear. Note that this isn't along the direction of circulation, it's across it - there has to be a distortion (a flux *de cisaillementor flusso di taglio* or Scherströmung, I hope that covers things linguistically, it's hellish to find the correspondence for some of these terms in fuid mechanics). Put another way, there has to be a viscocity in the system on all scales. Having two layers moving at different rotational frequencies is the way this is produced. Now for dry water (my favorite phrase from Feyman) there's no such coupling but wetting is evidence that this isn't true for real liquids, no matter how low the internal friction is. Keplerian disks are perfectly stable because, if we can somehow ignore this viscosity, because they can't sufficiently drag to drift on reasonable timescales.

Disks and Kitchen Sinks, Steve Shore

1.4 Establishing the structure and what you see

But I said *if sufficiently inviscid*. What if you increase, somehow, the viscosity above what you'd expect just from the gas kinetics - the collisions between the individual ions and atoms? Since the fluid is possibly turbulent, there are motions on scales larger than the collision distances between the particles, at macroscopic scales of the disk. This couples much more gas on shorter timescales than is possible from the so-called molecular viscosity alone and can also operate at supersonic velocities. Thus, if some cause can be found to render the disk turbulent, you have the problem solved.

The extra viscosity, arising from motion within the disk, renders the medium sufficiently viscous (think "gooey"like a supersonic molasses) to cause an inward drift by increased orbital kinetic energy loss. Keplerian motion alone isn't sufficient, under normal conditions, to generate turbulence by excess shear alone, that's what I mean by stability, but if there is some way of doing it the effect is dramatic. The turbulent motions coupe the gas to far greater distances and transfer angular momentum at the same time as energy since for gravitational motion the two are directly linked. Thus, losing kinetic energy forces the matter to drift inward, increasing the shear and producing an increased dissipation.

How this works, and what it means for spectroscopic and photometric signatures, is also easy to understand by continuing the molasses analogy. A moment's reflection on physics is in order. The work done on an elastic medium by stressing it is the product

(Work) = (stress, or applied distorting force) x (strain or deformation).

The rate at which work is done is the heating, the emission by which that energy is ultimately lost radiatively is the *cooling*, and in steady state these balance. The *shear*, the rate at which the strain varies with time, depends on the distance, it's larger for the inner parts of the disk. Then, using the elastic principle that the applied force is proportional to the shear and the viscosity (which is the coupling), if the shear is the Keplerian orbital frequency ω_K, the rate of "internal frictional" energy generation is

$$L = \text{Luminosity per unit mass} \sim h\omega_K^2 \sim h(GM/r^3)$$

where M is the mass of the accreting object, *h* is the viscosity (for our case just a number), and r is the distance in the disk. This energy must then be transferred vertically through the disk to ist surface at each ring (annulus). The temperature will, therefore, be higher in the inner portion where the dissipation is greater and where the mater comes into contact with the stellar surface.

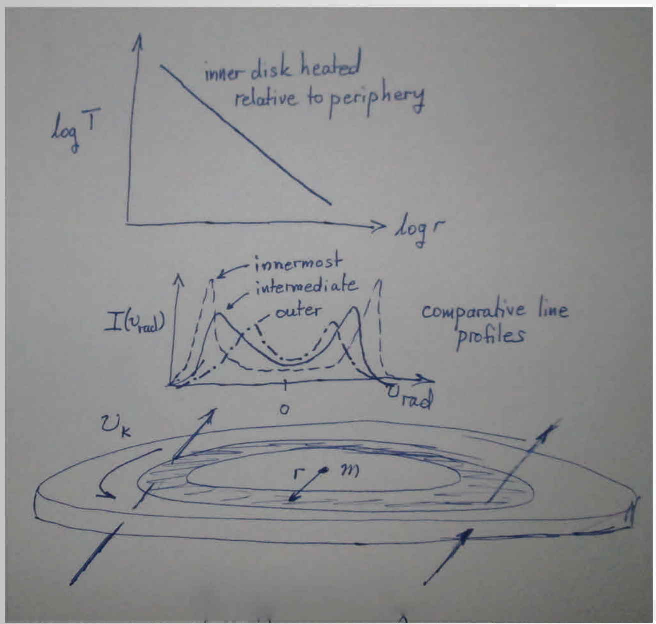

Fig. 4: The run of temperature through the viscous disk with sample line profiles coming from different transitions weighted toward different annuli depending on the temperature and density.

There's your clue. The amount of available energy to radiate is the change in the gravitational energy with time,

$$L \sim (GM/r)\ M$$

and this balances the energy loss rate. Thus, the rate of mass accretion, M is set by the energy losses so the higher the luminosity through viscosity the greater the rate of mass inflow. If the central object is a normal star, the energy isn't much, the disk will not be bright, and the amount of mass transferred will be rather low. The effect is to build up a thick region around of star that is comparatively cold and dominated by th light from the central star. For cataclysmics, instead, the amount of heating is substantially grater than the luminosity supplied by the central star and the depth of the gravitational "well" into which the disk gas is falling is much deeper (the radius of a WD is less than 1% that of the main sequence stars of the same mass so the energy is a factor of a few hundred higher) and the temperature produced in the disk will suffice to emit UV and XR. This is what you see spectroscopically. The inner regions of cataclysmics are dominated by high ionization, especially He II 4686, 5411 Å while the He I lines also arise from parts of the disk. More to the point, the gas isn't uniform density through the disk nor is the surface brightness.

For He II, it's heavily biased toward the inner parts where the Keplerian velocity is highest so the profile comes close to that of a ring. There are two peaks at roughly the (inclination projected) orbital velocity projected along the line of sight and the line has two peaks at roughly the mean velocity of the zone in which the emitter is present. The total luminosity is given by the sum of the disk and final shock contribution (the standing impact radius at which the disk hits the star) and is the same as we just found for M.

1.4.1 A side remark about observable disks

This is not the same as you see in systems like β Pic or others with so-called *debris disks* that are the remnants of star formation and not viscous. But it has a lot in common with a current picture of the disks in the Be and related stars. In those, mater is shoved out into the circumstellar environment by some (still poorly specified) process, such as a hiccup or belch or pulsation, and then drifts outward by viscosity creating an outward directed torque in the same way the matter is forced to flow inward by the outward transfer of its angular momentum. In the Be and B[e] stars, you see low ionization double profiles because the gas is sufficiently warm, or excited, to produce emission and the disks are rotating so you see the same double lines. The difference is that the peaks are farther out.

1.5 Stability

This viscous action is local in the sense of being confined to annuli. The turbulent viscosity, however it's generated, can't couple more than a small radial part of the disk together. So locally the vertical structure of the disk depends on the rate of energy generation and how the vertical forces of central gravity and pressure gradient from the midplane balance in light of the local heating. The inner part of the disk may puff up from the high temperature, as we see in β Lyr and some of its cousins such as W Ser, or it may start to flow away from the midplane in - yes, really - a wind. This swirling outflow is confined around the vertical direction to the inner disk and seems to be the source for the jets seen coming from T Tau stars and other protostellar objects.

Now small changes in the mass accretion rate change the heating locally, thereby disrupting the vertical balance; the higher or lower fluxes from the midplane cause the upper layers to expand or contract. If this sounds like a pulsating variable star you've got it. On expansion, the opacity may increase from expansion-driven cooling and the temperature gradient has to increase more. On the contrary, if the opacity decreases the expansion is damped. So since this depends on the temperature, it's different at each radius. Disks, on other words, show multiple periods biased toward those zones that are thermally unstable at some mass accretion rate.

This is the basic mechanism of dwarf novae. The details depend on the binary, how the mass is transferred, the precise turbulence mechanism, and the role of the hot spot (see Brian Warner's book on Cataclysmic Variables or, for the more stout-hearted, the text Accretion Power in Astrophysics by Frank, King, and Raine; both are from Cambridge and, I think, still in print). The outbursts of SS Cyg and U Gem are the prototypical examples of this instability. We don;t know if jets, or collimated outflows, are launched during these episodes, that requires spectroscopic monitoring (and even Alpy 600 provides the required resolution). Some of this has already been achieved by the ARAS group, some of the most important work lies ahead with looking at changes - correlations - in time between different species.

This is why I keep beating on the point that the understanding of these structures, be they disks or winds, requires observing different lines at as close to the same time as possible. What one line traces ma be invisible to another and vice versa.

1.6 Flickering and other non-periodic - but nearly – oscillations

A photometric phenomenon also serves to inspire spectroscopic monitoring. Disks flicker. Discovered in the XRs from compact systems, and also seen in the optical spectrum of some systems such as Sco X-1, photometry shows what almost looks like noise, fluctuations on a vast range of timescales ranging from milliseconds to days.

Taking these as frequencies (the time interval being the sampling time), you can obtain the amplitude of the individual frequency components and wit that get the power spectrum, the way the fluctuations are apportioned in time. When XRs were analyzed from some of the early detections, such as Cyg X-2 and related systems, a broad feature was discovered in the spectrum (you can think of this as a spectral line) that centered on a frequency but also shifted around in time between bounds.

The breadth indicates that the frequency isn't stable in a strict sense and the phenomenon is called *quasi-periodic oscillations or QPOs*. Think of it as organized flickering. One source that shows this is an old friend of many of you, MWC 560 = V694 Mon.

Symbiotic stars show this too, and the lower frequency variations of the emission lines could in part reflect conditions in a disk (or its innermost region - the boundary layer - where it slows down rapidly to the rotational speed of the underlying star). Changes in the brightness of the disk in a binary will clearly affect the environment, but it is more important to use different tracers of the disk to understand if the line profile changes (which will be fast) come from the disk or the surrounding.

Disks and Kitchen Sinks, Steve Shore

Changes in the wind structure in symbiotics can mimic features of the accretion disk but occur on longer timescales and can be seen to vary progressively with time and distance from the central star. But little is known about the spectroscopic variations on short timescale (less than days) for almost al gainers. While some systems show the variations only photometrically because nobody's bothered to follow them spectroscopically, others show clear variations on multiple timescales and in key parts of the line that distinguish between outflow and accretion.

2 Coda

It's best to stop here, I'm sure you're kinda tired if you've followed this through, but I hope this discussion gives you a start on how to think about both what to observe and how it reveals the underlying processes in your celestial friends. I'll continue the next set with some observational examples to illustrate the different kinds of analyses you can do. For now, a moment of reflection. Three years ago, V1369 Cen went into outburst. Three and a half years ago, we entered this new territory together. I want to tale this opportunity to thank you all, sincerely, for the friendship and interest you show and your continuing labors and thoughts. May the new year be one of exciting observations, new ideas and understanding, and most of all serenity for you and yours under that star-filled sky, "*that great o'er hanging firmament, that majestical roof fretted with golden fires*" (Shakespeare, Hamlet, II.2), that unites us.

Spektroskopie von Sternenlicht

Wissenschaftliche Prüfungsarbeit (Auszug)
am Institut für Physik der Johannes Gutenberg-Universität Mainz
von Taylan Demirel

1 Einleitung

Die wissenschaftliche Prüfungsarbeit, die hier aufgrund ihres Umfanges nur auszugsweise wiedergegeben werden kann, verfolgte die Zielsetzung, eine Methode zu finden, mit der das Thema Sternspektroskopie relativ einfach in den Schulunterricht integriert werden kann. Es wurde genauer untersucht, inwieweit die bereits in vielen Einrichtungen vorhandenen Spektrometer und Teleskope dazu geeignet sind, beispielhaft Spektralklassensequenzen selbst aufzunehmen und auszuwerten.

Zu diesem Zweck wurde mit zwei verschiedenen Spektralapparaten, einem USB-Spektrometer und einem DADOS-Spektrographen, Spektren von hellen Sternen aufgenommen und ausgewertet, welche die sieben Hauptklassen repräsentieren.

2 Licht, ein „ kosmischer Bote“

In der fachspezifischen Literatur, die sich mit der Spektralanalyse des Lichts beschäftigt, trifft man auf die Bezeichnung des „kosmischen Boten". Diese Bezeichnung bringt einen wesentlichen Sachverhalt auf den Punkt: Licht trägt zahlreiche Informationen in sich und transportiert diese über weite Strecken hinweg. Nahezu unser gesamtes Wissen über das Universum haben wir auf diese Weise erhalten. Die entferntest beobachtete Galaxis, (MACS0647-JD), befindet sich 13.3 Milliarden Lichtjahre von uns entfernt und wurde 2012 mit dem Weltraumteleskop Hubble und dem Infrarot-Weltraumteleskop Spitzer entdeckt.

Viel weiß man über diese Galaxie nicht, da Hubble keine spektroskopischen Aufnahmen ermöglichte. Warum ist die Erfassung eines Spektrums notwendig? Um die Informationen, die das Licht transportiert, umfassend nutzen zu können, muss dieses zunächst in sein Spektrum zerlegt und anschließend analysiert werden. Durch diesen Prozess können zahlreiche Erkenntnisse gewonnen werden. So zum Beispiel welche chemischen Stoffe in der Atmosphäre eines Objekts vorhanden sind oder welche Temperatur auf der Oberfläche vorherrscht. Damit lernt man gleichzeitig, wie „alt" die Galaxie bzw. der jeweilige Stern ist. Um zu verstehen, was ein Spektrum ist und wie man seine „Botschaft"deutet, ist ein Grundverständnis im Gebiet der Quantenphysik notwendig.

3 Woraus besteht Licht?

Isaac Newton (1642-1726) führte in den 1660er Jahren Experimente durch, welche bewiesen, dass sich das uns bekannte weiße Licht aus verschiedenen Farben zusammensetzt. Er ließ weißes Licht durch ein Prisma treten. Der entstehende Effekt ist uns allen aus dem Alltag geläufig: Das Licht tritt in Regenbogenfarben hinter dem Prisma wieder heraus. Zunächst war unklar, ob der austretende Regenbogen der Eigenschaft des Prismas oder der des Lichts zuzuschreiben war.

Als Newton dann das austretende rote Licht ein zweites Mal durch ein weiteres Prisma treten ließ und diesmal nur rotes Licht wieder heraustrat, war bewiesen, dass die Farben eine Eigenschaft des weißen Lichts sind. Die sichtbaren Regenbogenfarben sind jedoch nur ein kleiner Ausschnitt des gesamten Spektrums des Lichts.

4 Das elektromagnetische Spektrum

Newton machte die Annahme, dass sich Licht aus winzigen Teilchen zusammensetzt. Andere Wissenschaftler, wie Christiaan Huygens (1629-1695), hatten die Vermutung, dass Licht eine Welle ist. Es entstand die wohl kontroverseste Debatte in der Geschichte der Physik. Ist Licht eine Welle oder besteht es aus Teilchen? 1802 fand diese Debatte ein vorzeitiges Ende. Mit dem Young´schen Experiment stand vorerst fest: Licht ist eine Welle. Bis 1905 Albert Einstein diese einfache Erklärung widerlegte, indem er zeigte, dass der Lichtelektrische Effekt durch einen Energiestrom stattfindet, welcher Lichtquanten (Photonen) der Energie $E = h * \nu$ transportiert *(h = Planckkonstante* $6.33*10^{34}$*Js,* ν *= Frequenz).* Weitere Experimente folgten. Schließlich stellte 1923 Louis De Broglie (1892-1987) seine Theorie über die Welleneigenschaft von Teilchen vor.

Das Ergebnis der Debatte, dass elektromagnetische Strahlung nicht kontinuierlich, sondern gequantelt ausgestrahlt wird, war damals umwälzend. Vereinfacht kann man sich eine kleinstmögliche „Portion" an Strahlung vorstellen, welche den Namen „Photon" erhielt. Im „Zoo" der Elementarteilchen wird das Photon den Bosonen zugeordnet. Photonen sind Lichtteilchen ohne räumliche Ausdehnung.

Sie können wie makroskopische Objekte nachgewiesen werden, wie ein Fußball, den man gegen eine Wand schießt. Die verwirrende und sogleich revolutionäre Entdeckung im 20. Jahrhunderts war es, dass diesem Teilchen eine Frequenz, Wellenlänge und Energie zugeschrieben werden kann. Diese drei Eigenschaften sind im Grunde wellenspezifisch. Somit weist Licht neben dem Teilchencharakter einen Wellencharakter auf. Dieser Sachverhalt wird in der Literatur oft unter dem Begriff „Welle-Teilchen Dualismus"zusammengefasst.

Der technische Standard unserer heutigen Welt wäre ohne die Nutzung beider Eigenschaften nicht erreicht worden. So wäre der gesamte Telekommunikationsbereich, wie Radio, TV, Mobiltelefonie etc., ohne die Nutzung des Wellencharakters des Lichts nicht möglich. Energiesparlampen, Computer, CCD-Kameras, etc. und auch die Spektroskopie bedienen sich hingegen des Teilchencharakters.

Erhöht man die Wellenlänge des weißen Lichts von 10^{-6} m auf 10^{-4} m, gelangt man in den Bereich der Infrarotstrahlung (Abb. 1). Diese ist für das menschliche Auge nicht mehr sichtbar, obschon Menschen selbst im Infrarotbereich strahlen. Erhöht man die Wellenlänge auf 10^{-3} m, kommt man in den Bereich der Mikrowellen und bei einer Wellenlänge von 10^{3} m erreicht man den Bereich der Radiowellen.

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Langwellen, die von manchen Radiosendern ausgestrahlt werden können, weisen eine Wellenlänge von bis zu 100 km auf. Verringert man hingegen die Wellenlänge aus dem Bereich des optischen Fensters heraus, gelangt man in den Bereich der UV/Röntgen- und Gammastrahlung. Bei allen genannten Strahlungsbereichen handelt es sich weiterhin um Licht. Genauer gesagt um elektromagnetische Strahlung mit Teilchencharakter. Der einzige Unterschied zwischen all diesen Strahlungsbereichen ist die Größenordnung der Wellenlänge. Da Wellenlänge λ, Frequenz ν, Lichtgeschwindigkeit C und Energie E über

$$E = h * \nu = h * C/\lambda$$

miteinander verknüpft sind, führt eine Variation eines dieser drei Parameter immer zu einer Änderung aller drei Parameter.

Die Erdatmosphäre transmittiert diese Strahlung nur bedingt, was essenziell für die Entstehung und Erhaltung organischen Lebens auf der Erde ist. So wird zum Beispiel Röntgen-Strahlung in der äußeren Ionosphäre vollständig absorbiert. Auch UV-Strahlung wird hier zum größten Teil aufgehalten. Aus dem Weltall erreichen hauptsächlich zwei Wellenlängenbereiche unsere Erdoberfläche: Zum einen, das optische Fenster im Wellenlängenbereich von 650 nm bis 1100 nm und zum anderen, das Radiofenster im Wellenlängenbereich zwischen 1 mm bis 18 m. Hinzu kommen noch schmale Durchlässigkeitsstreifen im Infrarotbereich (Abb.1). Mit einem Teleskop wird Licht betrachtet, welches mit der Materie von Objekten aus dem All in Wechselwirkung getreten und durch das optische Fenster von der Erdoberfläche aus beobachtbar ist. Damit das Licht aus dem Weltall analysiert werden kann, muss es in die Bestandteile seines Spektrums zerlegt werden. Im Folgenden werden die Apparate und Methoden für diese Zerlegung des Lichts näher erläutert.

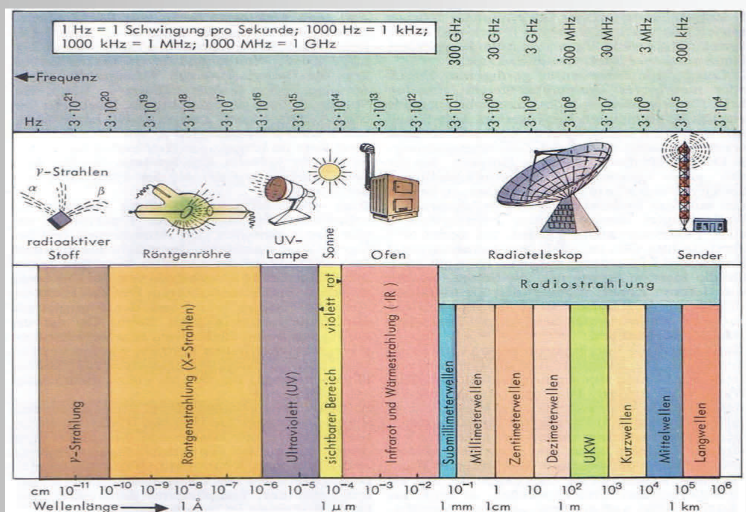

Abb. 1: Absorption der Strahlung aus dem Kosmos (Deutsch. Taschenbuch Verlag 1990, München].

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5 Wie Licht in seine Komponenten zerlegt wird

Spektren werden durch zwei unterschiedliche Methoden erzeugt. Zum einen kann ein Prisma, zum anderen ein Beugungsgitter verwendet werden.

5.1 Das Prisma

Wenn weißes Licht durch ein Prisma hindurch tritt, fächert dieses das Licht in ein buntes Farbband auf, wobei die Ablenkung des Lichts mit der Wellenlänge sinkt. Der entstandene Regenbogen wird in der Fachsprache als Spektrum bezeichnet. Physikalisch beruht die Entstehung des Spektrums auf der Dispersion, der Abhängigkeit des Brechungsindex von der Wellenlänge. Physiker wie Isaac Newton, Joseph von Fraunhofer, Robert Bunsen und Edward Pickering haben durch diesen Apparat ihre Spektren erhalten. Heutzutage finden Prismen in der Astrospektroskopie seltener Verwendung.

5.2 Das Beugungsgitter

Die Erzeugung und Auffächerung eines Gitterspektrums beruht auf der Beugung und Interferenz, wobei die Ablenkung des Lichtes mit der Wellenlänge wächst. Joseph von Fraunhofer erfand das erste Beugungsgitter, mit welchem er Spektren betrachtete. Zunächst ordnete er 260 feine Fäden parallel und eng zueinander an. Später stellte er Glasgitter her, in welche er 3600 Linien ritzte. Heutzutage haben die kostengünstigeren Gitter das Prisma weitestgehend abgelöst.

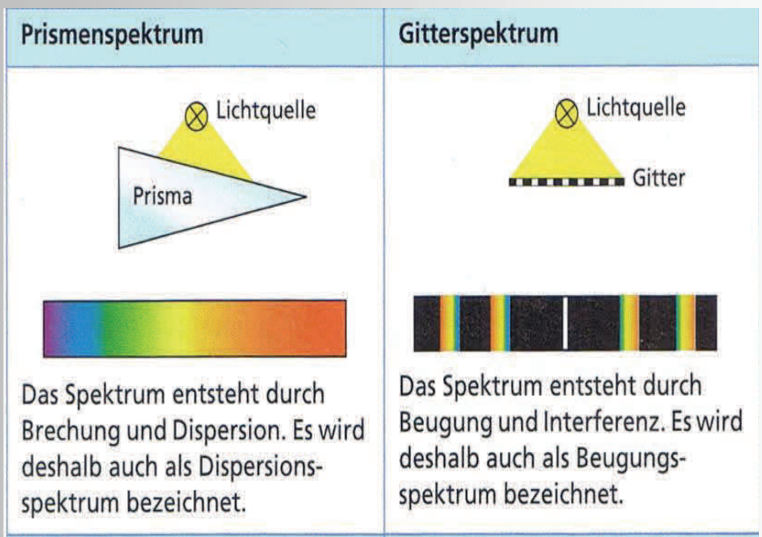

Abb. 2: Entstehung eines Spektrums mit Hilfe eines Prismas (links) und eines Beugungsgitters (rechts)
[aus: D. Hoche et al., DUDEN, Basiswissen Schule, Physik Abitur, Mannheim: Bibliographisches Institut , 2007]

Diese erzeugten Spektren unterscheiden sich in der Reihenfolge ihrer Farben und der Breite der jeweiligen Spektralbereiche (Abb. 3). Beim Prisma wird die Farbe Rot schwach und Blau stark abgelenkt. Beim Gitter ist dies umgekehrt. Ein wesentlicher Vorteil für die Nutzung im Amateurbereich ist die Tatsache, dass der Beugungswinkel, der durch das Gitter entsteht, proportional zur Wellenlänge ist. Beim Prisma sind die Wellenlängenbereiche auf nicht lineare Weise gedehnt. Eine Normierung der Spektren am Rechner lässt sich leichter durchführen, wenn, wie es bei dem Gitter der Fall ist, ein linearer Zusammenhang gbesteht.

6 Einführung in die Spektroskopie

Der Prozess der Spektrengewinnung und der anschließenden Auswertung wird Spektroskopie genannt. Das zu analysierende Licht kann dabei aus den verschiedensten Lichtquellen stammen. Es spielt dabei keine Rolle, ob es sich um eine Straßenlaterne vor der Haustür oder um ein fern gelegenes Objekt im Universum handelt, dessen Licht mittels eines Teleskops gesammelt wird. Das einzig entscheidende Kriterium ist eine ausreichende Menge an Photonen. In Abb. 3 ist ein Beispielspektrum eines Planeten dargestellt.

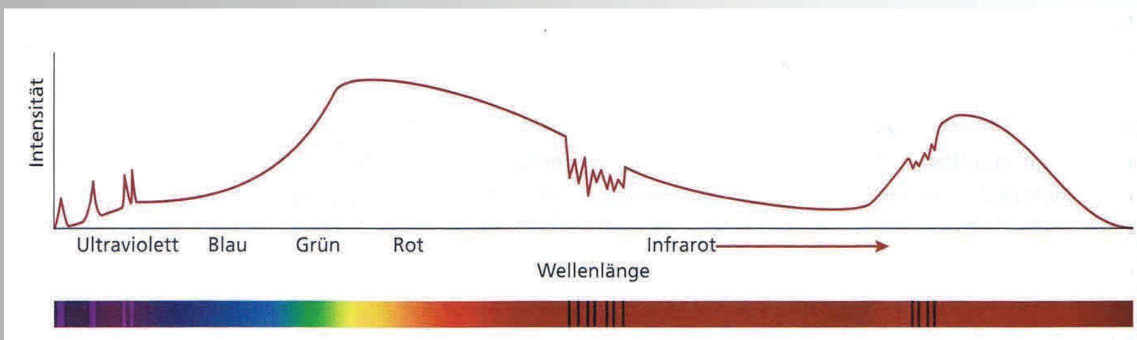

Abb. 3: Darstellung eines schematischen Spektrum als Intensitätskurve (oben) und als synthetisches Spektrum (unten) (aus: J. Benett et al., Astronomie, Eine kosmische Perspektive, Pearson Verlag, 2010)

Zunächst werden Spektralstreifen über verschiedene Instrumente gewonnen. Zu Anfangszeiten der Spektroskopie konnten nur die offensichtlichen Unterschiede dieser Spektralstreifen, z.B. die Position und Stärke der Absorptionslinien, miteinander verglichen werden. Heutzutage werden diese mit entsprechenden rechnergestützten Hilfsmittel ausgelesen und als Graphen dargestellt. Die Graphen können nach abschließender Bearbeitung wiederum als synthetisches Spektrum dargestellt werden (Abb. 3). Auf der vertikalen Achse wird üblicherweise die Anzahl der Photonen, multipliziert mit der Energie eines jeweiligen Photons, aufgetragen. Die entstehende Kurve stellt also als Funktion der Wellenlänge dar, welche Lichtenergie vorhanden ist.

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6.1 Kontinuierliche Spektren

Eine heiße Lichtquelle erzeugt, wenn man das ausgesendete Licht in sein Spektrum zerlegt, einen Regenbogen ohne Unterbrechungen, welches vom langwelligen Infrarot bis zum kurzwelligen Ultraviolett reicht. Für ein total absorbierendes Objekt folgt der Intensitätsverlauf des Planck´schen Strahlungsgesetzes (siehe Abschnitt: „Der ideale schwarze Strahler“). Die Lichtquelle kann ein heißer, fester Körper, wie zum Beispiel ein Glühdraht oder eine Flüssigkeit bzw. Gas unter hohem Druck sein. Da keine Unterbrechung des Spektrums vorhanden ist, wird diese Erscheinungsform als kontinuierliches Spektrum bezeichnet.

6.2 Emissionslinienspektren

Emissionslinienspektren entstehen durch Gase mit geringer Dichte, welche zu charakteristischen Wellenlängen angeregt werden. Das entstehende Spektrum zeigt keinen kontinuierlichen Bereich, sondern einzelne helle Linien, die sich vor einem dunklen Hintergrund abheben. Welche Linien dabei, mit welcher Intensität, zum Leuchten angeregt werden, hängt von der Zusammensetzung und Temperatur des Gases ab. In der Astronomie kann man dieses Phänomen bei Gasnebeln beobachten, die durch UV-Strahlung benachbarter Sterne zum Leuchten angeregt werden. Auch im Spektrum der Sonnenchromosphäre, die durch das Strahlungsfeld der Photosphäre angeregt wird, trifft man diese an.

6.3 Absorptionslinienspektren

Liegt eine „dünne“ Gaswolke zwischen einer heißen, dichten Lichtquelle und einem Spektralapparat, erscheint das kontinuierliche Spektrum mit Unterbrechungen bei bestimmten Wellenlängen. Dabei handelt es sich um die gleichen Wellenlängenbereiche, die vom dünnen Gas als Emissionslinienspektrum emittiert werden könnten. Mit Vorhandensein der heißen Lichtquelle erscheinen nun, anstelle der Emissionslinien, dunkle Linien im kontinuierlichen Spektrum. Das dünne Gas, „klaut" sozusagen bestimmte Wellenlängen aus dem kontinuierlichen Spektrum. Voraussetzung hierfür ist, dass die dünne, äußere Gaswolke kühler als die heiße, dichte Lichtquelle ist.

Für die Spektroskopie nimmt die Balmerserie (nach dem Schweizer Mathematiker und Physiker Johann Jakob Balmer, 1825-1898) eine außerordentliche Rolle ein, da das abgestrahlte Licht hier zwischen 410,1 nm - 656,3 nm liegt und so auch fotografisch festgehalten werden kann. Aus diesem Grund werden die einzelnen Übergänge explizit aufgelistet:

Hα bei $\lambda = 656{,}3$ nm; Hβ bei $\lambda = 486{,}1$ nm; Hγ bei $\lambda = 434{,}1$ nm; Hδ bei $\lambda = 410{,}2$ nm; Hε bei $\lambda = 397{,}0$ nm; H8 bei $\lambda = 388{,}9$ nm, usw.

6.4 Die chemischen Abdrücke eines Linienspektrums

Ebenso wie Wasserstoff ganz bestimmte Energiewerte absorbiert und emittiert, kann jedes chemische Element durch charakteristische Photonen identifiziert werden. Analysiert man nun ein Spektrum, kann man aufgrund der Erscheinung des vorhandenen Musters auf die Anwesenheit bestimmter Elemente schließen.

Im Grunde gleicht ein solches Muster dem eines Barcodes, welches auf jedem Produkt im Supermarkt vorhanden ist. Der Laser an der Kasse kann jedes Muster in Sekundenschnelle auslesen und dieses individuell zuordnen. Die Zusammensetzung eines fernen Objekts lässt zudem Schlüsse auf die vorherrschende Oberflächentemperatur zu.

Bei heißen Sternen sind meist mehrfach geladene Ionen vorhanden. Bei kühleren Sternen trifft man meist Moleküle an, da die zusammengesetzten Atome nur dort ihre Verbindungen aufrechterhalten können. Moleküle haben zudem ein ganz charakteristisches Spektrum (Abb. 4), da Moleküle aus zusammengesetzten Atomen bestehen, verfügen sie, neben den Übergangen der Elektronen zwischen den Energieniveaus, über weitere Möglichkeiten Photonen zu absorbieren und zu emittieren: Die Verbindungen können rotieren und schwingen. Emittiert oder absorbiert es dabei ein Photon, wirkt sich dies auf die Rotationsgeschwindigkeit oder die Schwingungsfrequenz aus.

Diese Vorgänge weisen jedoch in der Regel wesentlich kleinere Energiebeträge als die der Elektronenübergänge auf. Das Erscheinungsbild von Molekülen ist dementsprechend ein dichtes Linienmuster, so dass man von Molekülbanden spricht. Diese sind meist im Infrarotbereich des Spektrums anzutreffen. Aus diesem Grund und aufgrund der Rotverschiebung entfernter Objekte, sind Infrarotteleskope unerlässlich für die Erforschung des Inter- und des extrastellaren Raums.

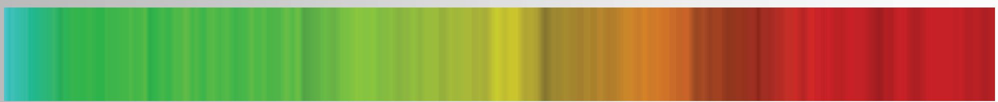

Abb. 4: Eigene Aufnahme und synthetisches Spektrum des Sterns Beteigeuze mit Molekülbanden. Es sind viele, eng beieinander liegende Absorptionslinien, die sich zu Banden zusammenfassen, im Wellenlängenbereich der Farbe Rot zu erkennen. Dieses charakteristische Merkmal lässt Schlüsse über die Oberflächentemperatur des jeweiligen Objekts zu. (Aufgenommen:14.03.2014; Belichtungszeit: 1 sec; Spektrograph: Dados).

Der Beitrag wird fortgesetzt.

The outburst activity of the symbiotic binary AG Draconis

by Rudolf Gális[1], Jaroslav Merc[1] & Laurits Leedjärv[2]

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(2) Tartu Observatory, Observatooriumi 1, Tõravere, 61602 Tartumaa, Estonia

AG Dra is one of the best studied symbiotic systems, thanks to its relatively high brightness and high Galactic latitude favorable for observations. The system undergoes characteristic symbiotic activity with alternating quiescent and active stages. During quiescence, the mean magnitude of AG Dra is 11.4, 11.1 and 9.8 mag in U, B and V filter, respectively.

The amplitude of the brightness variations decreasing with wavelength, from 1.3 mag in the filter U to 0.4 mag in the filter V. The active stages consist of several outbursts of about 1–1.4 mag in the V/visual band and up to 2.3 and 3.6 mag in the B and U bands, respectively. Major outbursts occur in intervals of 12–15 yr (in 1936, 1951, 1966, 1980, 1994 and 2006), and are usually followed by minor-scale outbursts in intervals of about 1 yr (Hric et al. 2014).

Using UV and X-ray observations, González-Riestra et al. (1999) showed that there are two types of outbursts: cool and hot ones. In our recent paper (Leedjärv et al. 2016) we demonstrated that the outbursts of AG Dra can be clearly distinguished also according to behavior of the prominent emission lines in optical spectra.

After seven years of flat quiescence following the 2006-08 major outbursts, in the late spring of 2015, AG Dra begun rising again in brightness toward what appeared to be a new minor outburst (Fig. 1). The recent outburst activity of AG Dra was definitely confirmed by a more prominent outburst in April 2016.

The photometric observations suggest that these outbursts are of the hot type. Such behaviour is quite unusual, because the major outbursts in the beginning of active stages are usually cool. Moreover, the spectroscopic observations suggest that the minor outburst of AG Dra in April 2016 demonstrates the behaviour of both hot and cool outbursts. Is it a new type of outburst or some kind of transition between (or combination of) the hot and cool outbursts?

Another interesting question is the next evolution of activity of the symbiotic binary AG Dra. According to our detailed period analysis of photometric and spectroscopic observations we know that the median of the time interval between outbursts is around 365 days.

The symbiotic binary AG Draconis; Galis et al.

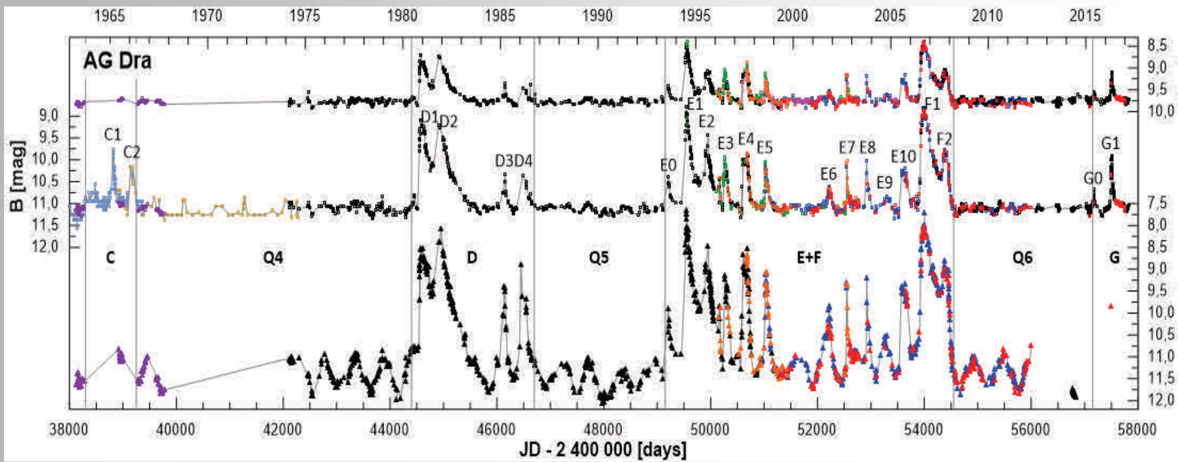


Fig. 1:: UBV LCs from the period 1963–2016 with marked active stages (C, D, E + F and G) and quiescent ones (Q4, Q5 and Q6). Particular outbursts are assigned as C1, C2, D1 – D5, E0 – E10, F1, F2 and G0, G1. The thin curves show spline fits to the data points.

It is worth noting that these time intervals vary from 300–400 d without an apparent long-term trend. Nevertheless, can we expect the major cool or minor hot outburst during the late spring of 2017? Or maybe none of them and AG Dra will return to quiescence as we have already detected such behavior during the weak activity stage 1963–66. In any case, AG Dra clearly demonstrates the importance of long-term monitoring of symbiotic stars in order to disentangle the nature and mechanisms of their active stages and outbursts.

According the aforementioned, we kindly ask the ARAS observers for spectroscopic monitoring of AG Dra in the coming period. The spectroscopic observations with a cadence of 5-10 days will be sufficient to monitor AG Dra during ongoing quiescent stage.

Daily monitoring is highly desirable during next potential outbursts, which will be announced by the special alert based on photometric observations of this interesting symbiotic binary. Further spectroscopic monitoring of this interesting symbiotic binary is still desirable to study the orbital modulation of the spectral characteristics and thus the morphology of its circumbinary envelope.

References:

González-Riestra R., Viotti R., Iijima T., Greiner J., 1999, A&A 347, 478
Hric, L., Gális, R., Leedjärv, L., Burmeister, M., Kundra, E., 2014, MNRAS 443, 1103
Leedjärv, L., Gális, R., Hric, L., Merc, J., Burmeister, M., 2016, MNRAS 456, 2558

My new home built echelle spectrograph

by Tim Lester, Ontario, Canada

I have just acquired my first "real" spectrum with my new home built echelle spectrograph. The instrument is not fiber coupled but is rigidly built. The completed spectrograph will have additional cross bracing from the camera down to the guiding assembly to aleviate flexure at the camera to lens coupling. I will also be making a heated foam enclosure with the aim of controling its temperature to better than 1° C for the one to two hours of exposure for a single object. Here is a picture of it mounted on the telescope.

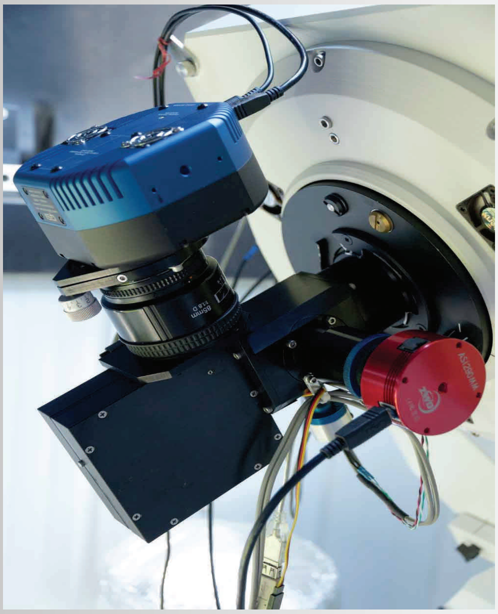


Fig. 1: The new home built echelle spectrograph mounted on the telescope

The spectrograph was designed specifically for my home built 310mm DK cassegrain. It has a built in reducer to convert the telescopes f9.8 focus to f6.6.A reflective aluminum coating with a 23um x 75um aperture applied to a 1mm thick glass plate serves as the slit and guiding mirror. The 75 um slit width still gives enough separation between orders out to 8000 A.

The collimator is an Edmunds 100mm focal length spherical mirror. this places an image of the telescope entrance pupil near a perforated folding mirror. The cassegrain secondary blocks the center of the entrance pupil any way so no light is lost due to the perforation. For a mirror of this size and f/ratio The spherical aberration is smaller than the diffraction limit. A mirror collimator has the advantage of not producing any additional chromatic aberration. The perforated flat mirror was made by diamond drilling a Thorlabs quartz mirror.

Home built echelle spectrograph,Tim Lester

The grating is a Thorlabs echelle with 63 degree blaze and 79 lpmm. The blaze angle actually turned out to be 61.5 degrees. It is twisted to a gamma angle of 7 degrees (14 degrees between incident and reflected) so the spectral lines are slanted at about 22 degrees. The cross disperser is an F2 prism and the camera is an 85mm f1.8 Nikon lens. The detector can by tilted in the cross dispersion direction to try and maintain focus at the blue end.

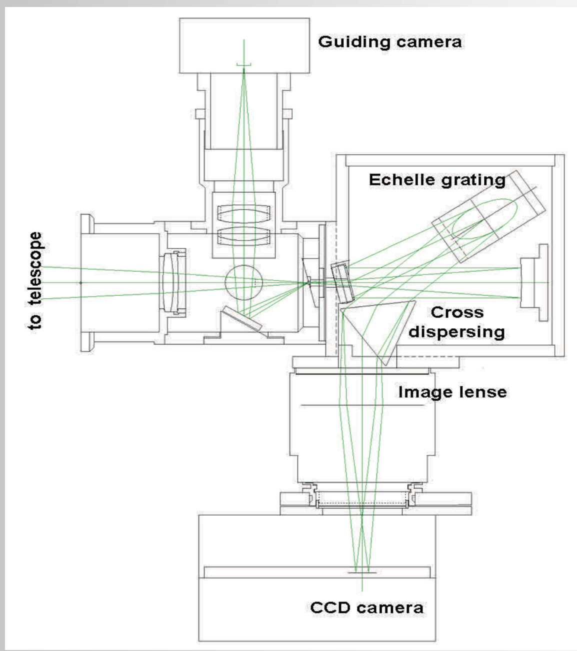


Fig. 2: Drawing of the internals.
The slit housing is rotated 90 degrees from its true orientation in this view.

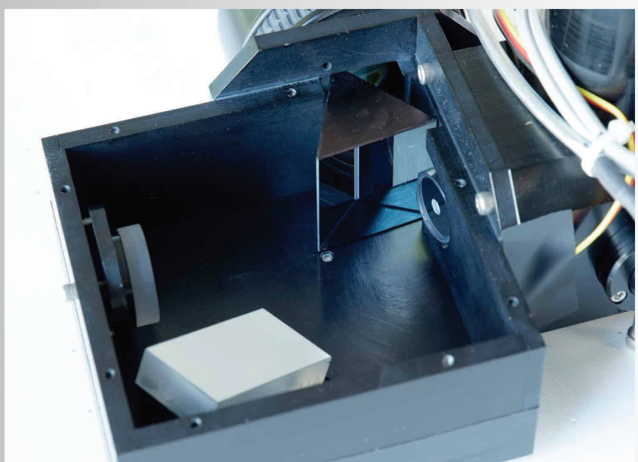


Fig. 3: A photograph of the inside

Initial results are encouraging. Here is a plot of resoltion versus wavelength determined from the FWHM of the spectral lines of the Relco calibration lamp.

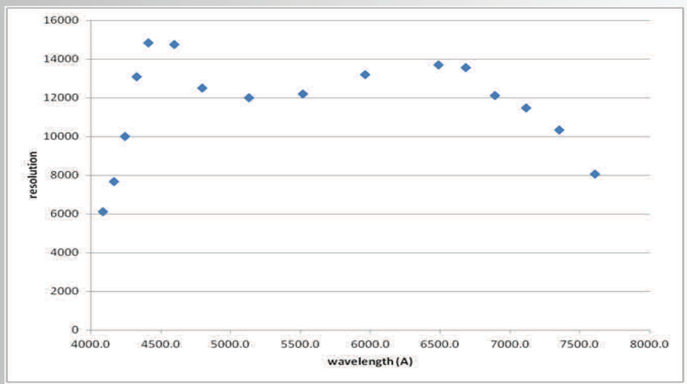
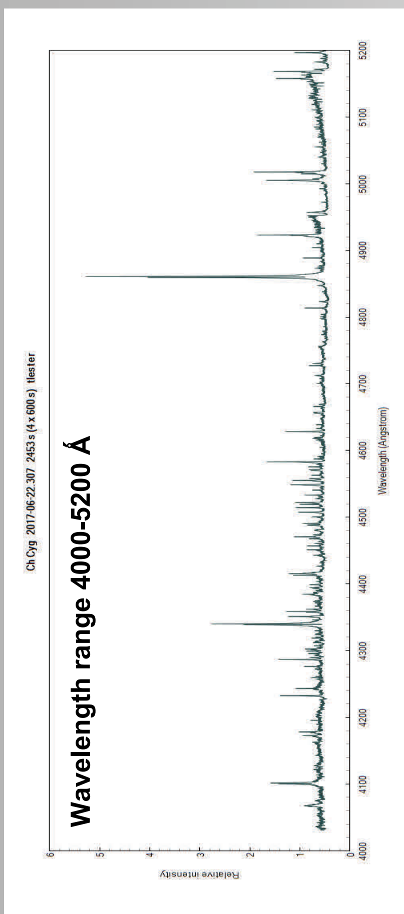
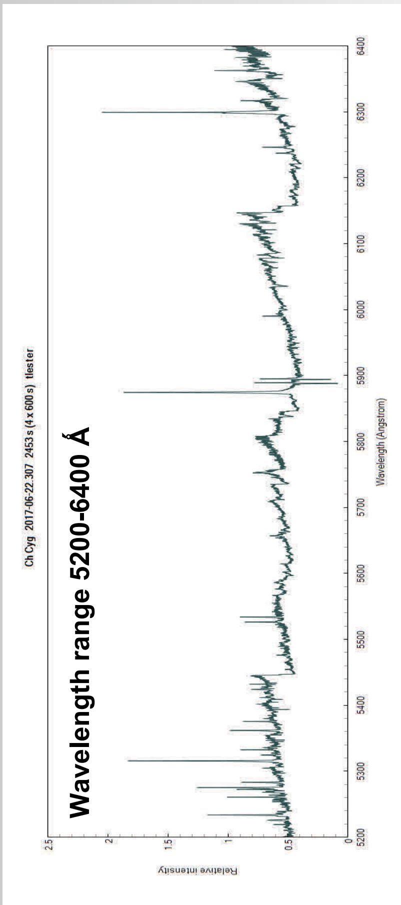
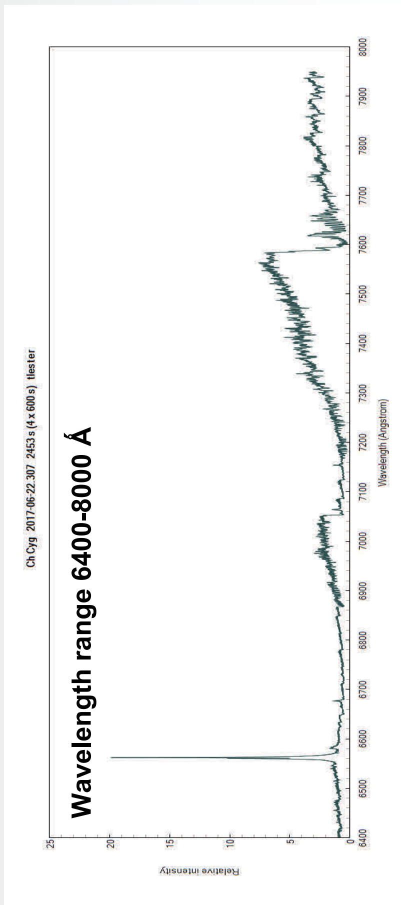


Fig. 4: Plot of resolution versus wavelength

Finnally here three plots of my first stellar trial - the symbiothic variable Ch Cyg.







3D printed UVEX spectrograph

by Christian Buil, Castanet-Observatory, France

Here I want to introduce a 3D printed version of the UVEX spectrograph (**U**lta-**V**iolet-**Ex**plorer) as a Czerny-Turner design (https://de. Wikipedia.org/ monochromator) with the following actual optical definition (Fig.1):

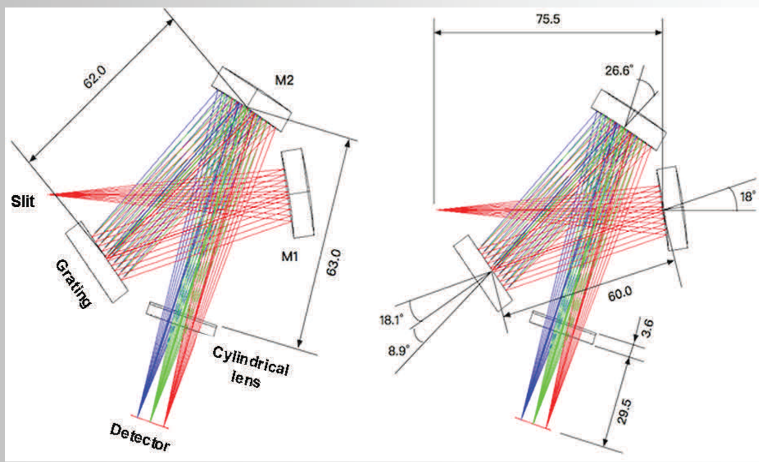


Fig. 1: Schematic description of the beam paths of the spectrograph

UVEX is a low cost and light spectrograph (300 grams without the camera, 670 grams with an Atik414EX camera). In this stage is not a guiding system integrated and no slit as well (!). The spectrograph is designed to be operated only on small telescopes (apochromatic refractors, small Newton telescopes). Fig.2 shows the first 3D printing prototype (a more optimized version is coming, thanks Pierre Thierry and Franck Vaissiere for help).

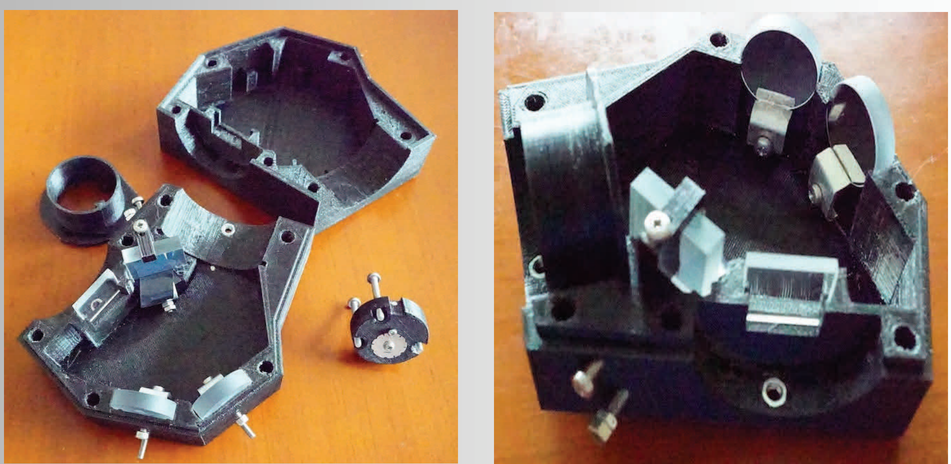


Fig. 2: View of the first 3D printing prototype

3D UVEX spectrograph, Christian Buil

Fig. 3: The first light on a Kepler 200 mm f/5 telescope
(no CMOS camera has been used but a ASI1600MM cooled model).

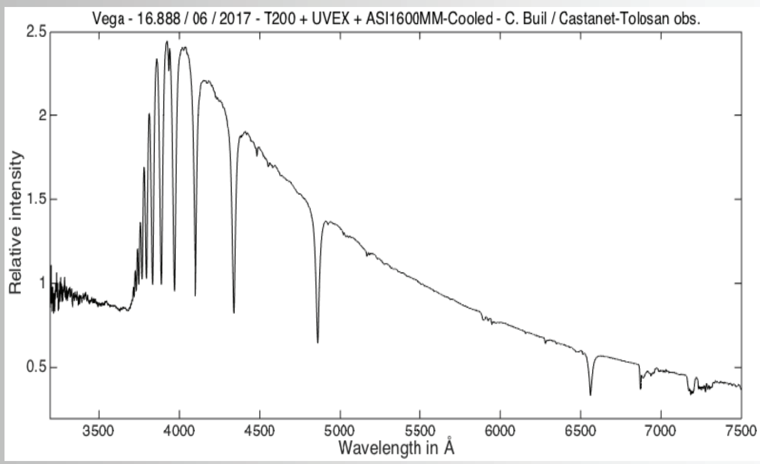


Fig. 4: A first Vega spectrum for orientation of the grating
to capture the entire visible spectrum on the large ASI1600MM sensor.

The great advantage of the system is the high degree of achromaticity, which allows to capture a correct spectrum over a very broad spectral range (R = 700 approximately). It is also possible to orient the grating to optimize the observation of ultraviolet (the primary goal!). Nothing else is changed in the spectrograph (it is also possible to obtain a good spectrum of the infrared part with the same definition).

3D UVEX spectrograph, Christian Buil

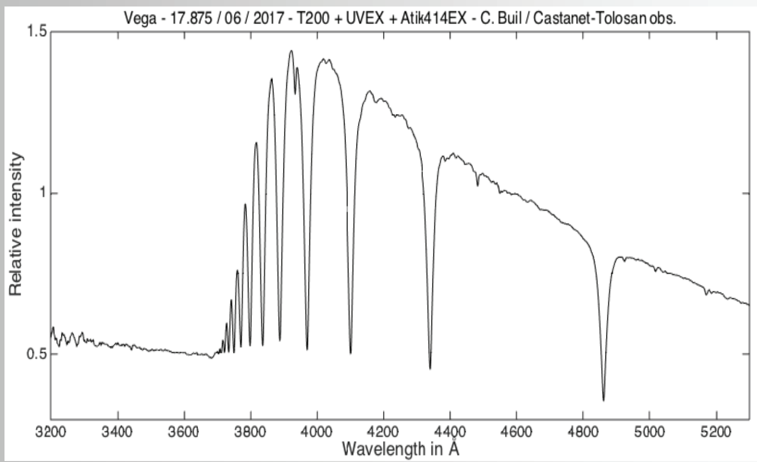


Fig. 4: A first UV spectrum of Vega

A significant signal had been detected down to 3200 A with the Atik414EX/460EX camera. The spectrum has been taken at allocation near a city center. The "lines" observed near 3200-3300 A are the stratospheric ozone (O3), the so-called Huggins band. It is the proof of a real signal detection, not a noise.

Another representative example is shown in Fig. 5. It demonstrates the wide spectral range in a spectrum of β Lyrae (Fig.5 left). Noticable here is the high S/N ratio close to the ultraviolet part (Fig. 5 right).

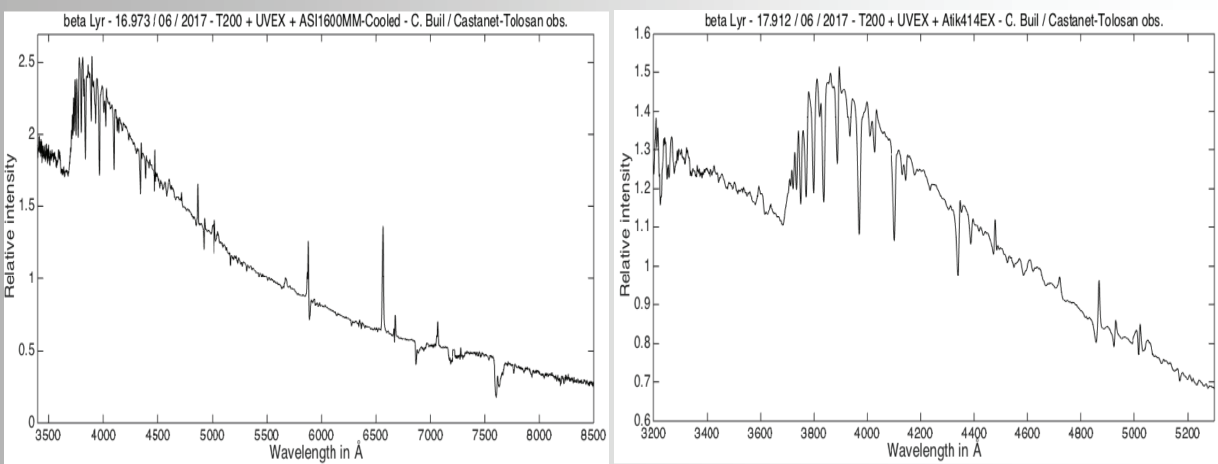


Fig. 5 : A first UV spectrum of β Lyr

3D UVEX spectrograph, Christian Buil

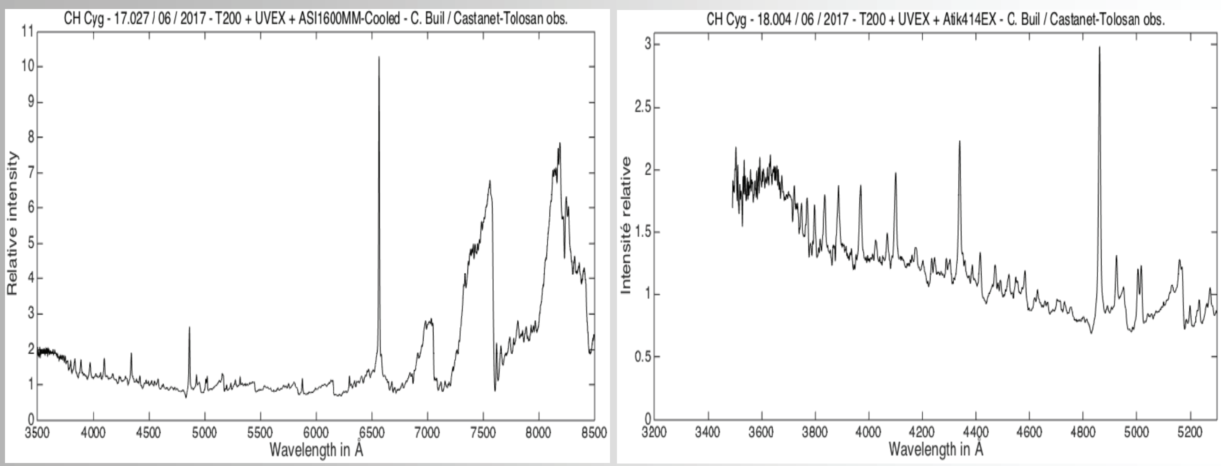


Fig. 6 : The symbiothic variable star CH Cyg

A further example shows the spectrum of the symbiotic variable star CH Cyg in Fig. 6. The wide spectral range is shown in Fig. 6 left. Noticable also here is the high S/N ratio close to the ultraviolet range (Fig. 6 right). In that example, the absence of a slit under the light-polluted city sky a real problem. But under effective more better conditions the result would be more correct also here in the UV range. UVEX is a modest spectrograph for the discovery and exploration of the ultraviolet spectral area. It enables scientific studies within regions, which has been rarely explored by amateurs. The comparison of UVEX to a conventional spectrograph of the same spectral area is shown in spectra of the Be star γ Cas and γ Cyg in Fig.7.

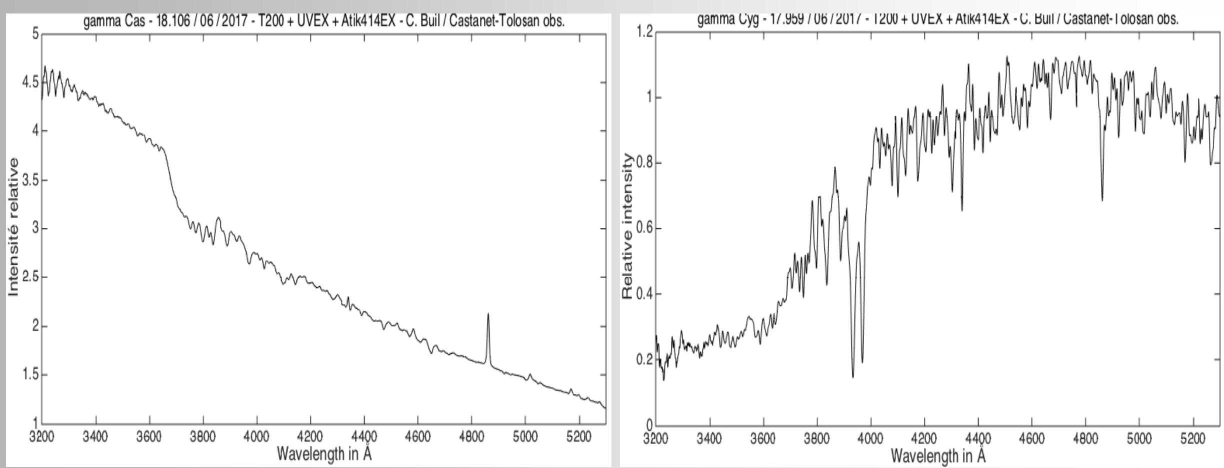


Fig. 7: left: the Be star γ Cas taken with UVEX (note: Huggins band near 3200 A); right: spectrum of γ Cyg taken with a conventional spectrograph

A time series of BV photometry and Hα emission Fluxes of the eclipsing binary VV Cep

by E. Pollmann, W. Vollmann, Ph. Bennett

Introduction

The VV Cep binary is a red supergiant of mass 15–20 M solar masses, with a hot, presumably mainsequence, early B-type companion of comparable mass. The two stars are sufficiently well separated that Roche lobe mass transfer does not occur at present, and given the high orbital eccentricity (e = 0.346, Wright 1977), probably has not occurred over the evolutionary history of the system. (The orbits of binaries undergoing Roche lobe mass transfer rapidly circularize). In the ultraviolet (UV), the hot companion appears embedded in a region of circumstellar gas, as inferred from the veiled appearance of the UV spectrum (the spectrum of the naked B-star is never seen).

The gas around the companion is probably a result of wind accretion from the massive wind of the M supergiant. In VV Cep, Hα emission is especially prominent, with peak fluxes of ~10-30 times that of the (M star) continuum.

This Hα emission exhibits radial velocity behaviour opposite to that of the M supergiant, implying a source near the hot companion (Wright 1977). Eventhough this emission declines sharply for higher Balmer lines, at times Balmer emission remains visible from levels up to n ~ 16. Balmer continuum emission is often observed at wavelengths shortward of 3700 °A, and at times, is strong enough to dominate this part of the UV spectrum (Bennett & Bauer 2015). In the UV, lines of Fe II also ap- pear strongly in emission, and are probably pumped by Lyman-α and Lyman-β emission (Bennett & Bauer 2015).

The great width of these Fe II emission lines (with wings out to ~300 km s^{-1}) suggests the line-forming region is in Keplerian rotation around the B star companion, as these velocities are far larger than any other observed in the circumstellar environment of VV Cep. Although the source of the companion's emission spectrum is usually attributed to „accretion" of circumstellar gas from the M star onto the hot star, it is likely that the emission luminosity comes not from the release of gravitational energy, but from recombination of circumstellar hydrogen photoionized by the B star's Lyman continuum.

The Hα emission is variable on both short timescales and longer timescales of several years. The slow variability in Hα flux appears to correlate with the orbital separation of the two stars, with larger emission flux seen when the companion is near periastron (Bennett, private communication).

Observations

VV Cep is a 5th magnitude system of variable visual brightness, with V magnitudes ranging from 4.9–5.4. Due to its high declination (+64°), VV Cep is circumpolar and well-suited for year-round observations at northern mid-latitude sites. In preparation for the VV Cep international campaign, contemporaneous observations of B and V band DSLR photometry. and Hα emission equivalent width (EW) have been obtained over the past eight years.

The V band photometry was obtained by W. Vollmann (DSLR, AAVSO+BAV), B. Hassforther (DSLR, BAV-Germany) and G. Samolyk (CCD, AAVSO data base). W. Vollmann and G. Samolyk also obtained B photometry, concurrent with the DSLR V observations. However because of the lower DSLR pixel sensitivity in Vollmann's B photometry, these data are inevitably not as precise, nor as accurate, as the V photometry. Vollmann used the Johnson B brightness of the reference stars, but did not transform to the Johnson B system, and that process resulted in an offset in the derived B magnitudes compared to Samolyk's more accurate Johnson B magnitudes.

Data reduction was per- formed using MaxIm-DL 3.06 (Diffraction Limited, Sehgal Corporation) for Pollmann's data, while data from other amateur observers were reduced with software packages de- veloped for amateur spectrographs, such as SpcAudace3, Audela4, VSpec5, and IRIS36.

The Hα EW study used 86 spectra, obtained by members of the ARAS spectroscopy group between July 2004 and October 2016, at times with simultaneous V band photometry. These Hα spectra were obtained with 0.2m to 0.4m telescopes with a long-slit (in most cases) and echelle spectrographs with resolutions of R = 1000–22000. All spectra included the 6400–6700°A region, with a S/N of _100 for the continuum near 6600°A.

Spectral line parameters were measured with the spectral classification software package MK32. The EWs reported here included the entire Hα emission profile (including both red and blue components) from 6550–6571Ǻ. Since the Hα emission originates from a different source (the B-type companion) than the optical continuum of the M supergiant, the EWs calculated relative to the M stars (variable) continuum were corrected for this variability in order to provide a reliable estimate of total Hα emission flux. This correc- tion was done by scaling the previously calculated Hα EWs by a factor of $10^{-0.4\Delta V}$, where $\Delta V = V - V$ and V is the mean magnitude of the out-of-eclipse V time series.

Results

Here we present the data and analyses.
Figures 1, 2, and 3 show the time series of the V and B data, and the Hα emission fluxes (Hα emission EWs, corrected for continuum variability). These observations are from July 2004 to October 2016 (JD 2455500 to 2458000), or from orbital phases of 0.625-0.961, measured from mid-eclipse. Figure 4 compares VV Cep Hα emission fluxes to simultaneous V band photometry from July 2004 to October 2016 (JD 2455500–2458000).

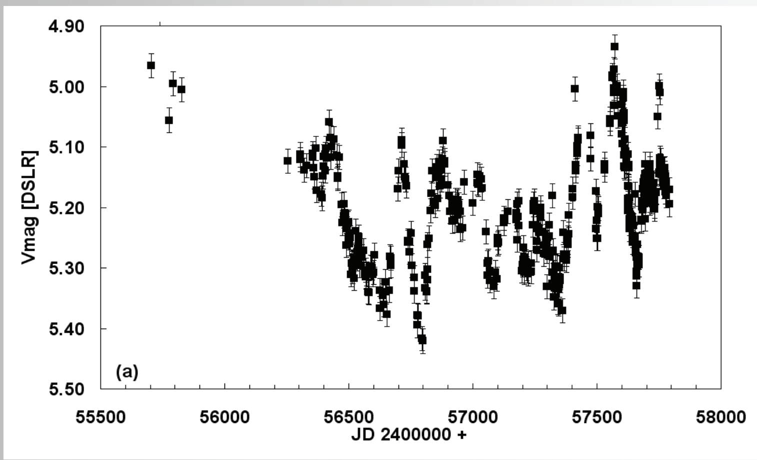


Fig. 1: VV Cep DSLR V magnitudes: July 2004 to October 2016.

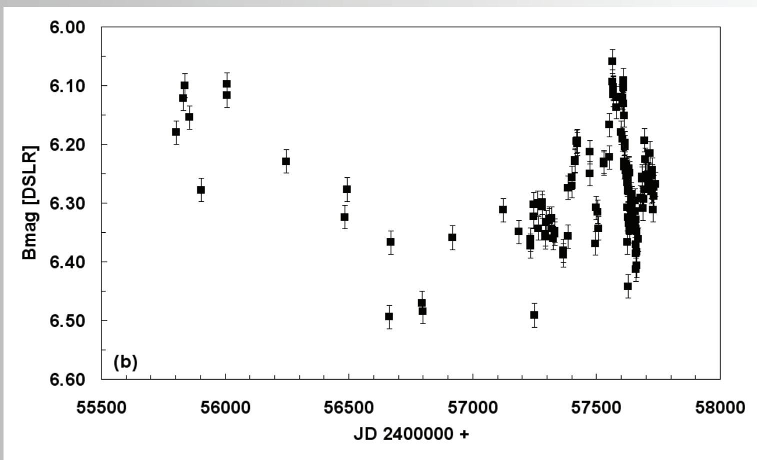


Fig. 2: VV Cep B magnitudes: July 2004 to October 2016.

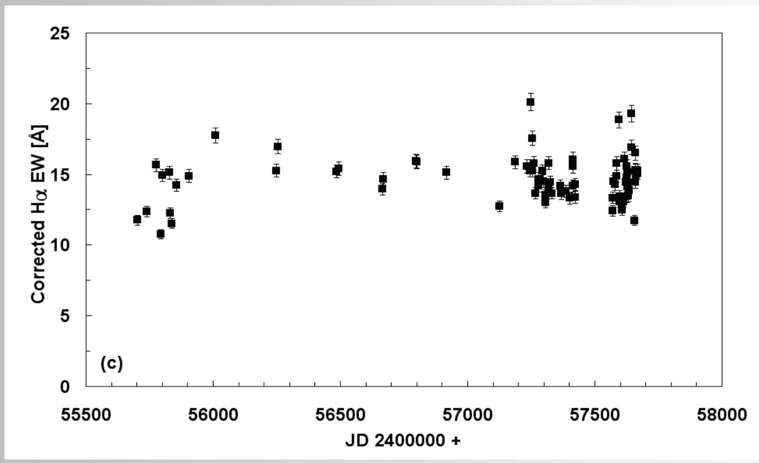


Fig. 3: VV Cep Hα emission fluxes: July 2004 to October 2016

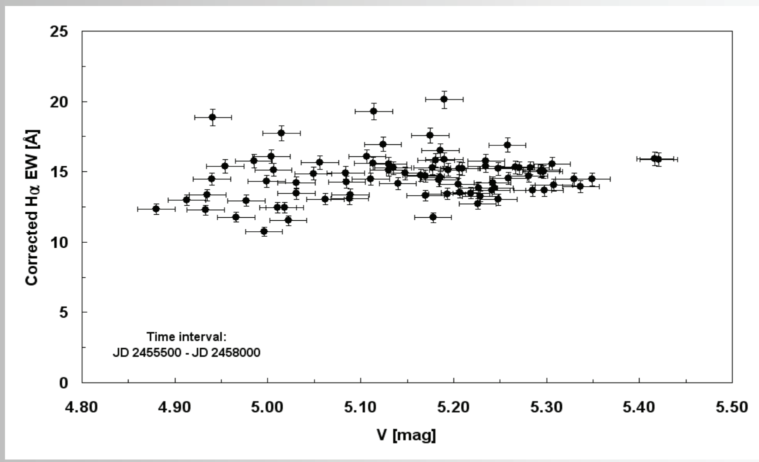


Fig. 4: VV Cep Hα emission fluxes versus DSLR V magnitude

Figure 5 shows the power spectrum of the V photometry of VV Cep obtained using the Period04 code (Lenz & Breger 2005). The strongest peaks in the power spectrum of the V photometry are near 145 and 656 days. The first period lies close to the 150 day period first proposed by Hayasaka et al. (1971) and is almost certainly real. The second period is about one-half of the time spanned by the vast majority (406 out of 412 points) of the photometry, and may be an artifact resulting from long-term variations over this period.

Figure 6 shows the corresponding phase diagram of the V photometry produced by program AVE (Barber'a 1998), of Figure 1, phased with a 145.5 day period. Many other periods have been reported in the literature over the years: e.g., periods of 60, 110, 114,116, and 280 days (Graczyk et al. 1999; Saito et al. 1980; McCook et al. 1978; Baldinelli et al. 1979; Pfeiffer et al. 1989), and it apparent from Figure 5 that there is significant power at other frequencies with periods longer than about 30 days, and especially longer than 100 days. This behaviour suggests the short-term variability is somewhat irregular in nature, and probably has a substantial stochastic component. Indeed, the plot of the V variability, phased to a period of 145.5 days (Figure 6), shows a substantial fraction of this variability remains unexplained by this regular short-period oscillation.

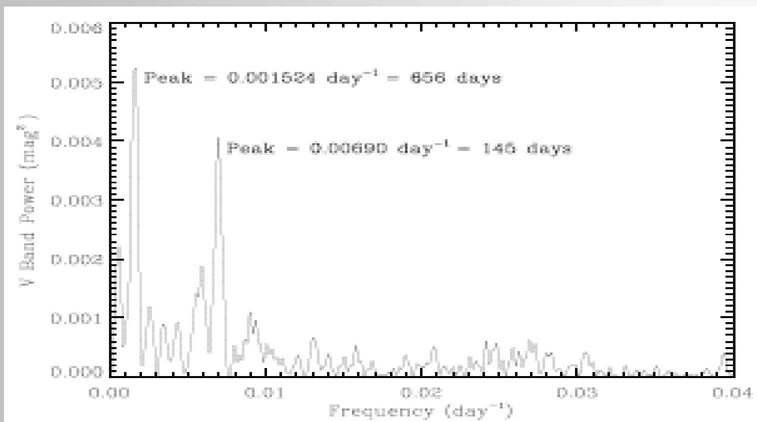


Fig.5: Power spectrum of V band photometry of VV Cep. The peak of 656 days may be an artifact due to the finite length of the time series; the second prominent peak at 145 days is probably real and due to intrinsic pulsation of the M supergiant.

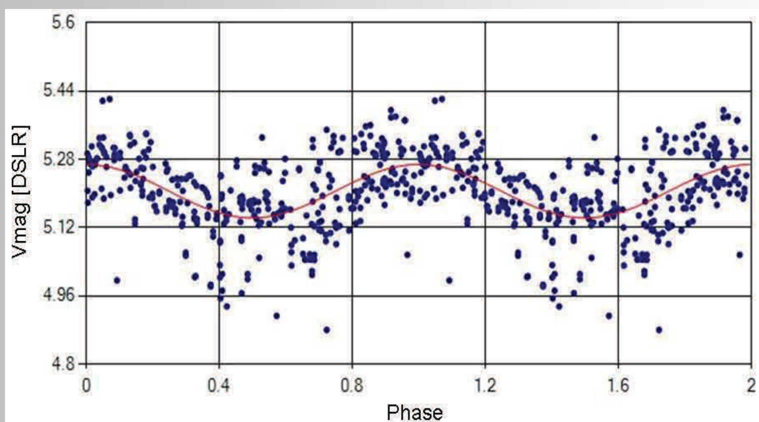


Fig. 6: AVE phase diagram of the V photometry of Figure 1, with a fitted period of 145.5 ± 1.2

Conclusions

The observations presented here span the period from JD 2455500 to 2458000, corresponding to orbital phases 0.625-0.961. The amplitude of the photometric variability is $\Delta V \approx 0.4$-0.5 mag, whereas the amplitude of the total eclipse of the B star is only is $\Delta V \approx 0.15$ mag. The period and photometric amplitude of the variability is quite similar to that resulting from irregular pulsation in other, single late-type supergiants. We confirm the peak power of this pulsation lies near a period of 145 days. A second, longer period of 656 days may be an artifact arising from the finite length of the time series. All of this strongly suggests that the photometric variability observed for VV Cep is intrinsic, and due to irregular pulsation of the M star. The source of the variability of Hα, originating from an accretion region around the hot companion, remains unclear and the time sampling of these Hα observations are too sparse to permit a meaningful period analysis.

Acknowledgements

We are grateful to Sara and Carl Sawicki (Alpine, Texas, USA) for their helpful improvements and suggestions in language. We are grateful to the observers of the ARAS spectroscopy group for contributing Hα spectra of VV Cep. We wish to thank Bela Hassforther (Deutsche Arbeitsgemeinschaft Veränderliche Sterne, BAV) for supplying additional V photometry. Finally, we acknowledge, with thanks, the use of variable star observations contributed to the AAVSO International Database by Gerard Samolyk.

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