A Survey of Current Amateur Spectroscopic Activities, Capabilities and Tools

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Abstract

Over the past several years, the amateur astronomy community has become increasingly interested in spectroscopy. Although a growing number of amateurs are doing very advanced work, the majority of our community isn't familiar with the field, the tools, or how to get started. In this paper, we'll briefly review the history of amateur astronomical spectroscopy and the state of the art today. This paper will enumerate the various tools that are available and provide an overview of the scientific and outreach opportunities that exist in the field.

1. Introduction

Amateur astronomers have been capturing spectroscopic data with their telescopes for at least twenty years. (Gavin, 2006) These early adopters pioneered new techniques and established the fact that small telescopes operated by non-professionals are capable of capturing useful scientific data. These amateurs often ended up designing and manufacturing their equipment themselves. Once the sole domain of professionals and very advanced amateurs, the equipment and knowledge necessary are now widely available and accessible to the broad amateur community.

As the amateur community has become more skilled and experienced, exciting new opportunities have opened up allowing it to do real science. Professional researchers, who have long valued the photometric data amateurs have provided, have now begun to use spectral data from the amateur community.

This paper presents some of the spectroscopic tools and methods that are used today on small telescopes. The author's experience has been that there are a large number of amateurs who if they only knew what was possible, would enthusiastically embrace this new discipline. This paper is an effort to reach the widest possible audience, providing them with a broad overview of what's possible.

2. Early History

In about 1995, amateurs gained a simple way to capture astronomical spectra when Rainbow Optics introduced the Star Spectroscope, a 200 line/mm grating in a standard 1.25" filter cell.. (di Cicco, CCD Astronomy, 1995) Over the next ten years, a small number of amateurs experimented in spectroscopy.

It wasn't until almost ten years later that a small European community of amateurs developed the tools and techniques that have made the field so accessible to newcomers. At that time, a more economical (USD $179) 100 line/mm grating that was optimized for amateur telescopes and cameras was designed by Robin Leadbeater and manufactured by Patton Hawksley (Figure 1) At about that time, the first software (VSpec) was developed that allowed amateurs to process their data on a PC.

Figure 1. The Patton Hawksley Star Analyser 100 line/mm grating ($179) screws directly into a camera nosepiece or filter wheel.

3. Spectrometers without slits

These initial slit-less gratings first used by the amateur community are easy to use. They are still generally recommended for newcomers to the field of spectroscopy. They can be mounted on the nosepiece of almost any mono or color CCD or DSLR. Inexpensive spacers may be necessary to adjust the grating to sensor distance. It's easy to determine the optimal mounting for a grating by plugging a few numbers (like telescope focal length, grating lines/mm, seeing, etc.) into an on-line calculator. (http://www.patonhawksley.co.uk/calculator)

An inexpensive slit-less grating is easier to setup and use than more complicated devices described later in this paper. With a slit-less grating, the entire field of view is available for pointing and guiding. These devices are easy to calibrate. And, the data provided by is generally easier to interpret because usually the entire broad band of visible wavelengths, from the blue to the red is visible.

For an amateur who wants to learn the basics of spectroscopy and capture interesting scientific data, a slit-less grating allows the easiest and most economical learning curve. There are a large number of interesting targets available. (The rule of thumb is that a 100 line/mm astronomical grating reduces the limiting magnitude of your equipment by five to six magnitudes.)

4. Examples of Low Resolution, Slit-less Spectra

With a simple 100 line/mm grating, and a moderate 6 -10” SCT or APO refractor, amateurs can capture a wide range of scientific data. Using an astronomical video camera on a 20cm Newtonian, for example, Torsten Hansen captured spectra for each of the OBAFGKM star types in a series of spectra in Figure 2.

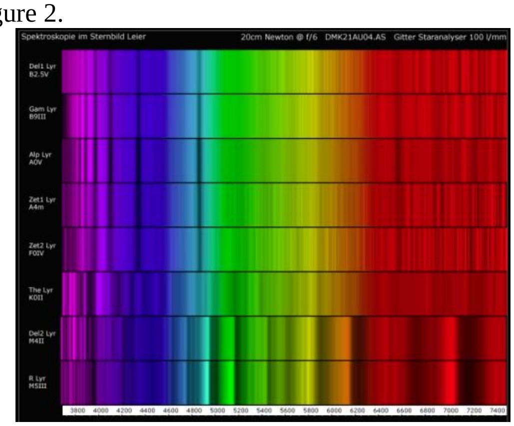

Figure 2. The OBAFGKM series captured with a video camera and 20cm Newtonian. (Torsten Hansen)

Although this dataset wouldn’t be of interest to a modern researcher, spectra like this allow amateurs as well as students in high school or Astro 101 classes to reproduce some of the research which forms the basis of our fundamental understanding of the stars. These spectra can easily be converted into Planck curves.

In Figure 3, the broadened Carbon emission lines of a Wolf-Rayet star were captured by Janet Simpson with just a DSLR and its 85 mm lens. Exposure time was just thirty seconds with a grating mounted on the nosepiece of her DSLR. (Figure 4)

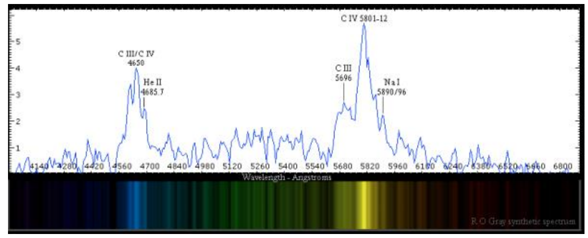

Figure 3. Broadened Carbon emission lines of WR 140. (Janet Simpson, 30 second DSLR with grating)

Figure 4. A 100 line/mm grating mounted using a thread adapter on the lens cap threads of a DSLR in an objective grating configuration.

One limitation of a slit-less device is that the target has to be relatively compact visually rather than an extended object like a large planet. However, even with that limitation, it’s possible to capture the spectra of any comet that is somewhat condensed in appearance. Using a Star Analyser 100 grating and just an 80mm refractor and DSLR, Vikrant Agnihotri captured the Swan bands of Comet ISON. (Figure 5)

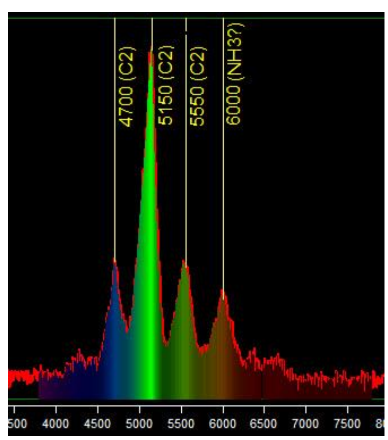

Figure 5. The Carbon Swan bands of Comet ISON are clearly visible. (Angihotri. 80 mm refractor, Star Analyser grating, Canon 1100D)

5. Supernovae

Bright supernovae make excellent targets for a slit-less grating. Classification of supernovae is frequently done using a low resolution, non-slit device. For example, Gialuca Masi of Rome, Italy, has had several of his SN classifications appear in CBET bulletins. Masi uses his 100 line/mm grating on a C14 that he operates remotely. Supernova identification is done using well-known features that are unique to each type. (Figure 6)

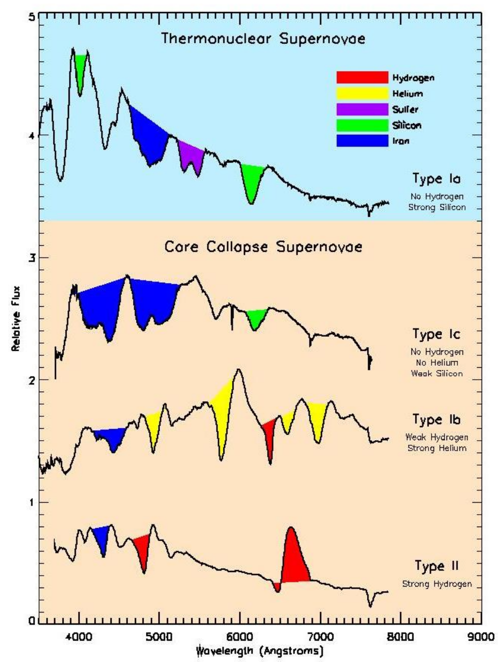

Figure 6. Identification of Supernova type can be done with spectra from a simple grating by detecting features that are unique each type. (Kasen)

Although Masi is using a 100 line/mm grating in his remote telescope, Patton Hawksley recently released low-profile, 200 line/mm grating which is more often the best fit for mounting in the tight confines of a filter wheel mounted close to the sensor.

One advantage amateur observers have is that they can do time studies that professionals using large instruments can't get telescope time to perform.

Figure 7 shows work done by Mark Bunnell using a 100 mm refractor to capture SN2014J repeatedly over a period of one month. Like Masi, his spectra allowed him to use the Si absorption line to identify the outburst as a Type Ia supernova. Bunnell also measured the blue shift due to the radial velocity of the expanding SN. His one-month time study clearly shows gradual migration of the Si line back toward the longer wavelengths as the radial velocity of the expanding shell decreases over time.

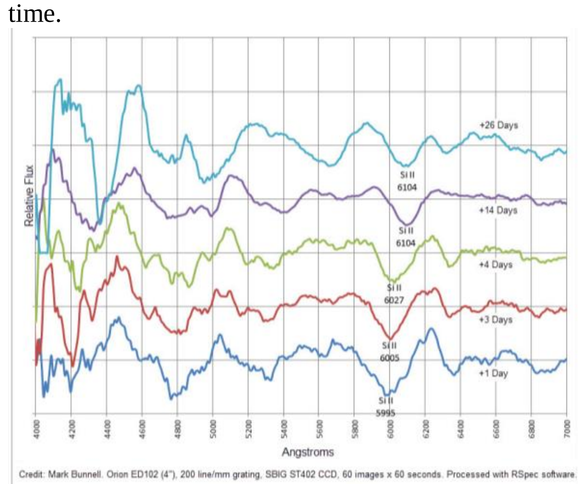

Figure 7. The spectra of SN2014J captured during the first 30 days after detection. The Si feature identifies it as a Type Ia. This Doppler-shifted feature migrates toward longer wavelengths as the eruption proceeds. 102 mm refractor and 200 line/mm grating (Bunnell, Agnihotri)

6. Cosmological Red Shift of a Quasar

Figure 8 shows spectrum of quasar 3C 273 captured by Astronomy 101 students at San Mateo Community College (http://collegeofsanmateo.edu/astronomy/studentprojects.asp) using just a 140 mm f/7 refractor with ST-10 CCD. Their data clearly shows the red shift due to cosmological expansion of this object that is 2 billion light years away.

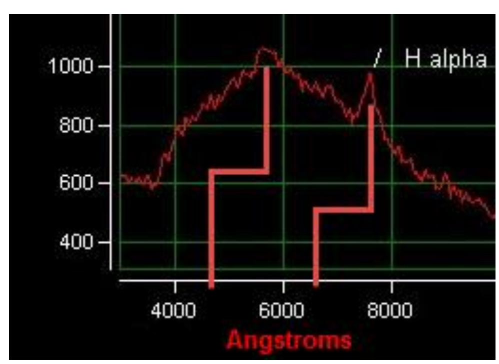

Figure 8. Cosmological red shift of QSO 3C 273 captured by Astronomy 101 students. (San Mateo CC, 140 mm refractor and Star Analyser grating.)

As noted earlier, most of these spectra (other than Masi's determination of SN type) don't contain data that will likely to be of research value to professionals or advanced amateurs. The reason for including these spectra in this paper is to demonstrate that with only modest equipment and an inexpensive grating, it's possible to capture interesting scientific data. The skills necessary are not advanced and are easily learned. Capturing these low resolution spectra is a great place to start spectroscopy. One learns not only the how to process the data, but to understand the nature of spectra and how to interpret them.

7. Outreach Opportunities

Live video spectroscopy of bright stars like Vega is possible even from relatively well-lit locations like a parking lot or high school football field. Setup is simple: just a 6" refractor or 8" SCT, grating, and astronomical video camera (like a ZWO, Mallincam, or Imaging Source).

Whether you teach in a classroom or do informal sidewalk outreach, a 10 frame/second colorful live video spectrum (Figure 9) of an overhead star that's 25 light years away always generates a lot of interest. If you're a teacher, you might also want to preview the fifth Cosmos episode on spectroscopy with your students before the outside viewing.

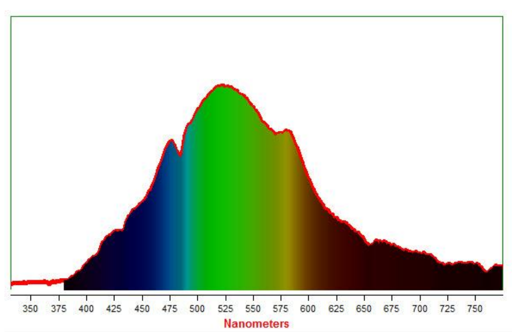

Figure 9. Screen capture of a sidewalk astronomy session with a live, 10 frame/second video spectra of Vega, clearly showing the Hydrogen Balmer series. (8" SCT, in light polluted Seattle, WA, just 3 miles from the Pikes Place Market downtown.) (www.rspec-astro.com)

8. Spectrometers with Slits

Slit-less gratings are low resolution devices. Adding a slit to a spectrometer creates an instrument with additional capacity, including being capable of considerably higher – often sub-Angstrom – resolution. This allows for more science to be done. Using a slit spectrometer is usually more difficult than using a simple grating. For example, image acquisition and guiding on a ~25 micron or smaller slit is more difficult than what most amateurs are accustomed to.

Some amateurs -- including some SAS members – have successfully built their own slit spectrometers. It can be a big project and it can be difficult to build a device that performs as well as devices that have been designed and fabricated by experts, and fine-tuned by years of customer feedback. Most amateurs purchase a commercial spectrometer.

It's beyond the scope of this paper to discuss the details of the commercial slit spectrometers that are available, other than to give a general overview of the best-known devices. As would be expected, different devices have different capabilities to serve different needs. You should confer carefully with your vendor and experts in the field when selecting a device. There are many important factors that need to be optimized, including being sure that the spectrometer, telescope and the camera work well together.

The most well-known spectrometers used by amateurs are from Shelyak in France. The company's owner, Olivier Thizy, is an experienced member of the amateur community. His well-respected product line covers a wide range of devices with differing capacities. The LHIRES III Littrow device ($4,725) is quite popular and considered a standard in the amateur community. Shelyak recently released a less expensive device: the Alpy 600, which can be used without a slit too. The base model is about $850. Additional optional modules for guiding and calibration add approximately $1,700.

Several years ago, author Ken Harrison developed a DIY kit, the Spectra-L200, which is also quite popular. The L200 has recently been commercialized and is now for sale fully assembled for about $1,880.

9. Software

A variety of software tools are available for processing spectra. Although professionals often use a software package named IRAF, this software is not in general use by amateur spectroscopers, due to its complexity. Amateurs use these programs:

- VSpec
- RSpec
- IRIS
- SPCAudAce
- BASS

Reviewing these programs is beyond the scope of this paper.

10. Organizations

Amateur astronomical spectroscopy was pioneered by a small group of dedicated amateurs (mostly in Europe) who designed instruments, wrote software, cultivated professional contacts, and developed many of the techniques and methodologies that are used by amateurs world-wide today. The modern amateur spectroscopy community owes a big debt to these early adopters for the enormous contributions they've made to the state of the art.

Some of these amateurs (many in France) formed an informal volunteer group, the "Astronomical Ring for Access to Spectroscopy (ARAS). The purpose of ARAS is to actively promote astronomical spectroscopy within the amateur community. They coordinate and provide resources for many different spectral campaigns, tending towards cataclysmics. Campaigns exist to study Be stars, AZ Cas, CVs and symbiotics, RR Lyrae, micro quasars and others. Most of their campaigns have a least one professional astronomer behind them. The many activities of ARAS are cataloged on their site: http://www.astrosurf.com/aras.

Another group that actively promotes pro-am collaboration is the Convento group in Germany: http://www.stsci.de/convento.

The AAVSO has taken some initial steps into the field of spectroscopy, including adding a forum section dedicated to spectroscopy: http://www.aavso.org/forums/variable-star-observing/spectroscopy. Their road map is currently evolving.

The Astronomical Spectroscopy Group working with Variable Stars South (VSS) is creating new database which will be named the International Database for Amateur Spectroscopy (IDAS). IDAS will allow submission of spectra for any object (not just campaign objects). IDAS will be a fully searchable (including using Aladin/Simbad) database for amateur spectra at every level, beginner through experienced user, whatever the type of spectroscope (gratings/ slit etc.).

11. Example Pro-am Campaign: Be Stars

Be stars are non-supergiant B-type stars that have shown specific emission line in their spectra. Their spectra can be quite interesting as their Hydrogen alpha line can transition from an absorption to an emission feature. (Figure 10) in very short time-frames.

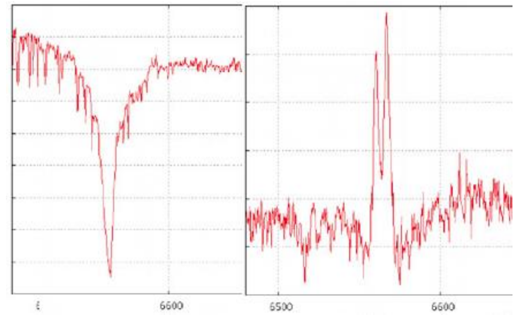

Figure 10 QR Vul before and after the outburst discovery shows the dramatic change of the Hydrogen alpha line from an absorption to an emission feature. (Thizy, Buil, Desnoux)

Be stars are easy targets for small instruments, with 300 stars up to magnitude 8 in the Northern hemisphere. Their spectra evolve on different timescales (from days to years), periodically or with episodic outbursts.

The mechanism that causes these stars to eject material and create a circumstellar disk is unknown at the current time. (Carciofi, 2010) Long-term observations of outbursts are required to better understand the phenomenon. This is where amateurs can (and do!) contribute.

The Be star spectra study is organized by the Paris Professional Observatory (Coralie Neiner) It uses the BeSS database to archive spectra from both professional campaigns and amateur observations.

The Be Star Spectra (BeSS) database (http://basebe.obspm.fr/basebe) is a searchable database of almost 100,000 Be star spectra, including almost 1,000 different Be stars. It is maintained at the LESIA laboratory of the Observatoire de Paris-Meudon. BeSS accepts submissions of spectra in 1D profile FITS format (tables, not images). Files must contain certain FITS header information to be accepted.

Of key importance in any database is maintaining quality control and standards. All submissions to BeSS are reviewed by an experienced team of administrators before being accepted. Quality control includes comparisons with other spectra of the same stars, check on telluric lines for calibration accuracy, etc.

The ARAS site also provides their own searchable front end to the BeSS database as well as coordination resources at http://arasbeam.free.fr/?lang=en. (ARAS also maintains their own database for non-Be stars at http://www.astrosurf.com/aras/Aras_DataBase/DataBase.htm)

Be stars are also easy to find. There are more than 100 at mag 6 or brighter. The community of Be star observers is very active and welcomes newcomers.

12. Example Pro-am Campaign: Nova Del 2013 (V339 Del)

The recent Nova Del 2013 campaign is a good example of the way that ARAS serves the astronomical community. In July of 2013, a group of astronomers from all over the world met in Pisa, Italy, to plan what they would do when the next bright galactic nova went off. It was a small group but included a representative of ARAS (Francois Teyssier) who was asked to attend in order to provide insight into how the amateur community might contribute. The goal of the meeting was to decide, based on observations and theory, what needed to be done to insure the maximum coverage and information, and what theoretical problems remained to be resolved because of incomplete and/or improperly collected data. The result of this meeting was a general plan of action, involving gamma-rays/Fermi-LAT, XRs/Chandra-Swift, optical, UV/HST-STIS, IR, radio, and theory. The meeting turned out to be amazingly well-timed because, exactly one month later, V339 Del erupted and the group had the whole plan ready for action (including target of opportunity time on HST.)

More than three dozen amateurs contributed more than a thousand spectra to the campaign. On a daily basis for three months, they uploaded their data to the ARAS site where it was screened for quality and then posted for public viewing at http://www.astrosurf.com/aras/novae/Nova2013Del.html. Currently, the campaign continues at Mag V ~12. Several publications by professional astronomers are under preparation, using ARAS data. ARAS surveys continues on recent novae, for instance Nova Cen 2013 or Nova Cyg 2014.

Steve Shore, a professional astronomer, provided on-going feedback and suggestions on what data was needed. He also periodically sent the group information notes discussing their data, explaining its context and significance, and sharing his initial interpretation of their results These notes helped keep the group motivated and provided them with the background to understand what they were observing. The amateurs on the team were getting tutored by a professional, in almost real-time, about the data they were capturing! Shore's active communication with the team no doubt contributed to the success of the campaign.

Shore says, "This almost continuous data stream on a daily basis is unprecedented. The spectra that the amateur community collected are revolutionary. The archive is better, more uniform, and more reliable than anything that's ever been available -- McLaughlin included." He continued, "The study of ANY time dependent phenomena (let alone on time-scales less than a year) is a new area but not what large telescope time will be used for. Ever. I'm really excited to see the amateur community becoming more spectroscopically oriented. In the same way that the amateur community's photometric data has been valued by professional community, so too but to even a greater extent, will their spectroscopic data be important in future research, both mine and that of other professional researchers. The size and geographic distribution of the amateur community gives them the ability to collect data that otherwise would be lost..."

Shore points out that the wide distribution of amateur observers around the world meant that changes on very short time scales could be observed. This is a key strength that the amateur community brings to pro-am work. However, as Figure 11 shows, the vast majority of known pro-am amateur spectroscopers are in Europe. There is a big opportunity for observers in North American to fill the gap by contributing to pro-am campaigns that study similarly fast changing phenomena.

Figure 11. The distribution of all known amateur pro-am US and European participants in pro-am spectroscopy programs shows little North American participation. (Thizy)

Figure 12 shows Nova Del 2013 over a period of nine days during its fireball and optically thick stage (Thizy, 85 mm refractor, Alpy). The changes in the Hydrogen Balmer lines that are characteristic of the early phases of this eruption are clearly evident.

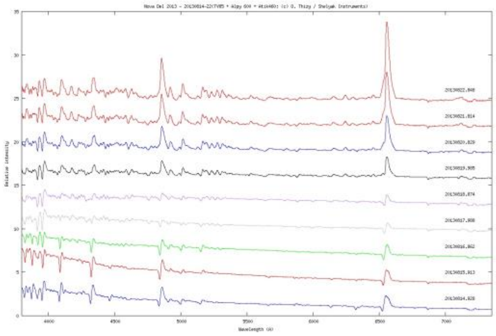

Figure 12. Nova Del 2013 over a period of nine days shows the growing Hydrogen Balmer lines. (Thizy, 85 mm refractor, Alpy)

Wiethoff et al. (2014) at the University of Minnesota captured more than 100 spectra of the same nova with a C14 and just a 100 line/mm grating. They also were able to identify the major phases of the nova evolution, including:

- the fireball and optically thick phase;
- recombination;
- the appearance of Fe II (5187 and 5316 Å);
- the O I emissions at 7773 and 8446 Å (the latter results from Lyman-Beta pumping);
- the appearance of O III (5007 Å) that signals the transition to the nebular phase.

Their data (Figure 13) from the early phase compares favorably with Thizy's (Figure 12), detecting the same major changes in Hydrogen and Iron. Of course their grating produced lower resolution spectra, so finer details are not visible.

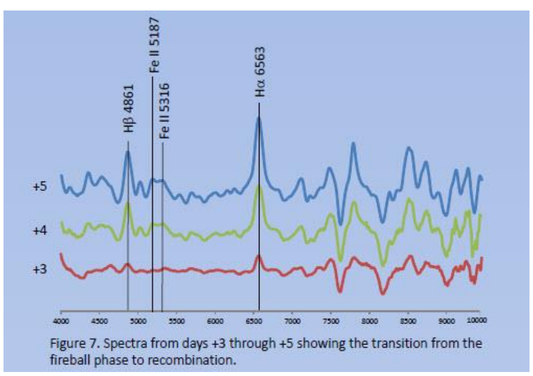

Figure 13. Nova Del 2013 over days +3 to +5 showing the transition from the fireball stage to recombination. (Wiethoff *et al*, C14 and Star Analyser-100 grating.)

13. Conclusion

We've seen that there are many, many interesting spectroscopy projects available to the amateur with modest equipment. The major obstacle keeping more amateurs from participating in this aspect of astronomy is a general lack of information about what's possible and how to accomplish it. Organizations like ARAS, AAVSO as well as attendees to the SAS 2014 Conference, can all have a big impact in educating our peers so that they are aware of the thrilling and relatively easy field of spectroscopy.

Researcher Steve Shore is enthusiastic about the results he's seen from amateurs. He says, "I would love to see pro-am projects become a new way of doing REAL science. It's a way to get those who have never considered they could understand physical science into the fold and move amateur astronomy into the realm of real science. There are far too few 1-2 meter class telescopes left in the world. But, there are a lot of bright objects that have lots to tell us about very general phenomena. I'm thinking of some magnificent studies of helium and Balmer line variability on short timescales in Cepheids and RR Lyr stars (for shocks and nonlinear dissipative processes), flare star and T Tau monitoring (more on the limit), bright systems like Algol and active binaries of the RS CVn type, all of which can be done by amateurs with modest resolutions."

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