NOVA
NEWSLETTER OF THE VANCOUVER CENTRE RASC
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Five Education Events Already

by Leigh Cummings

2016 has started off with a bang for the education co-chairs. Two of these were at Science World, one was at an elementary school in Surrey, and two with Girl Guide troops in the Tri-Cities area.

On Tuesday, January 19th, Jeremy van den Driesen, Karl Miller, Ron Jerome and I spent most of the day at Science World for their "High School Days" event. We had students and teachers visit from all over the Lower Mainland and as far away as Nakusp. Karl, Ron and Jeremy were continually busy handing out Star Wheels and giving instruction on how to use them. They were also very engaged talking to people and giving away educational material from our table. Although the weather would not co-operate and allow us to set up a solar telescope outside, I did set up my 90mm Vixen indoors so kids could look at one of Science World's animal displays up close. It still amazes me how many kids have their very first look through a telescope at events we participate in. In all, there were over 500 students and teachers from six different high schools in attendance. As usual, we were made most welcome by Samara (Sam) Marriott and her staff at Science World.

Elise Harrington speaking to the Hammond Girl Guides

On Friday, January 29th, Jeremy, Terry McComas and I spent a most enjoyable afternoon at Goldstone Park Elementary School in south Surrey. We were the guests of two grade 3 classes and one class of mixed grade 2 and 3 students. When we arrived at the school, the teachers were at-

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MARCH 10 — SFU
Levon Pogosian of SFU: From Static to Expanding to Accelerating: The past 100 years and the next 20. Room C9002.

APRIL 14 — SFU
Dr. Kyro Masui of UBC: Fast radio bursts: flashes from outside the Galaxy. Room SWH10081.

MAY 7 — SFU
NO REGULAR MEETING IN MAY. Instead, join us for Astronomy Day at SFU on Saturday, May 7. See Meetup for details.

Members' Gallery

M13 by Howard Trottier

This is the 2nd image from the Trottier Observatory. The magnitude 16.5 galaxy IC 4167 is visible near the upper right corner (distance around 500 million light-years). Amazingly, this image is only three hours total integration!

The telescope is a 0.7-m aperture PlaneWave CDK700, and the camera is a 16 Megapixel Finger Lakes PL16803, with an external filter wheel and TrueBalance filters from Astrodon. The raw frames were shot in unbinned red, green, and blue filters (no luminance), but the final image was downsampled by a factor of two, with a final image scale of about 0.8"/pixel. Image processing was done using CCDInspector, PixInsight, and Photoshop.

President's Message

by Suzanna Nagy

Our biggest event of the year is fast approaching – International Astronomy Day.

Although the rest of the world will be celebrating the event on Saturday, May 14, your Vancouver Centre will be celebrating a week early in order to participate in SFU's annual Science Rendezvous. Last's year attendance for the joint International Astronomy Day and Science Rendezvous event was estimated at 8,000 people.

Please note on your calendar Saturday, May 7 and we hope that you will join us at SFU Burnaby Campus that day to participate in the fun family activities, lectures, solar observing, and displays.

In addition, we are pleased to announce that your Vancouver Centre (with sponsorship from SFU) has arranged for Dr. Ray Villard of NASA's Hubble Space Telescope Program to attend our International Astronomy Day event. Dr. Villard will be

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About RASC

The RASC Vancouver Centre meets at 7:30 PM on the second Thursday of every month at SFU's Burnaby campus (see map on page 4). Guests are always welcome. In addition, the Centre has an observing site where star parties are regularly scheduled.

Membership is currently $78.00 per year ($45.00 for persons under 21 years of age; family memberships also available) and can be obtained online, at a meeting, or by writing to the Treasurer at the address below. Annual membership includes the invaluable Observer's Handbook, six issues of the RASC Journal, and, of course, access to all of the club events and projects.

For more information regarding the Centre and its activities, please contact our P.R. Director.

NOVA, the newsletter of the Vancouver Centre, RASC, is published on odd-numbered months. Opinions expressed herein are not necessarily those of the Vancouver Centre.

Material on any aspect of astronomy should be e-mailed to the editor or mailed to the address below.

Remember, you are always welcome to attend meetings of Council, held on the first Thursday of every month at 7:30pm in the Trottier Studio in the Chemistry wing of the Shrum Science Centre at SFU. Please contact a council member for directions.

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At Large Howard Trottier

Library

The centre has a large library of books, magazines and old NOVAs for your enjoyment. Please take advantage of this club service and visit often to check out the new purchases. Suggestions for future library acquisitions are appreciated.

On the Internet

http://rasc-vancouver.com or
http://www.rasc.ca/vancouver
http://astronomy.meetup.com/131/
http://www.facebook.com/RASC.Van
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Map to Meeting Site

Our SFU meeting site for March is in room C9002 in the Chemistry wing of the Shrum Science Centre. Make your way to the southwest corner of the Academic Quadrange and follow the adjacent hallway south. The theatre is the second room on your right.

The April meeting is in SWH10081.

Pay parking is available at several locations located around campus (indicated as "P" on the map).

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giving two lectures on Saturday, May 7: 2 pm for the children and 7:30 pm for the adults and public at large. The title of his lecture will be "25 years of Hubble" and his presentation is expected to be very informative as well as full of amazing Hubble photos gathered over the last 25 years. Both lectures are free and open to all to attend.

Please keep an eye on our website as well as meetup.com for full particulars of all activities and lectures planned for Saturday, May 7 in celebration of International Astronomy Day and Science Rendezvous. ✸

For Sale

Aventura 8" Dobsonian telescope with setting circles, alti-gauge finder, and two speed viewer. Brand new, never used except for initial set-up. Purchased for $700. Asking $600 obo. Contact Bruce at linuxer@telus.net

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tending a lunch hour meeting, so we went to the school office (no we weren't sent!) to check in and introduce ourselves to one of the office staff. The lady chuckled and informed me that she had overheard some of the children talking about how three "Astronauts" were coming to their class and she thought we should be forewarned that we had a high bar to jump over. Unfortunately, the weather was overcast during the afternoon, so we prepared to spend our time with the kids in the library. I gave a PowerPoint presentation on what can be found in the night sky which kept me very busy answering some challenging questions from some very enthusiastic young minds. They were so well behaved and showed such great interest that my presentation used up most of our available time. Fortunately Jeremy and Terry had kept busy instructing the teachers in the use of our Star Wheels. The teachers thought it would be best if we left the Star Wheels with them so they could give them out and teach the kids how to use them at their next available class. This enabled Terry and Jeremy to spend the time we had left showing the kids how to look through the telescopes we had brought. We had to be satisfied looking at subjects out the window as well as viewing posters that Jeremy had taped up on the walls of the library. Our contact for this event was one of the grade 3 teachers, Joanne Johnson, who, along with her husband, has become a regular at our monthly meetings. They are very enthusiastic star gazers which explains why she loves to teach astronomy to her students as well. We have been invited back when the weather permits to try to have a viewing day or night at their school. We look forward to the chance. We also were presented with a lovely handmade thank you card signed by all the students and teachers. The students' attention to detail in their drawings of the planets impressed our council when I passed their card

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A Tale of Four Planets

by Bill Burnyeat

Two cities move over—this is a tale of four planets. The planets are a mixed bunch. Not gas or rock, nor death-dealing atmospheres separates them into classes. Instead, a state of being ferrets them into neat boxes, and herein lies the real interest. The tangible and alleged Sun-orbiting bodies are: Neptune, a discovered and current planet; Vulcan, a planet that does not exist; Pluto, a planet, then not a planet; and finally Planet Nine, a maybe planet some hope to fetch from a dark hiding place. Planet Nine must not be confused with *Plan Nine from Outer Space* which is a movie featuring Bela Lugosi.

Heat and light reach out into space; not from a self-luminous body but from an oddly emotional reaction to the delisting of Pluto as a planet. It seems many are unable to grasp that knowledge evolves. Childhood planet rhymes must be reinforced, ratified and constant assurance must be supplied that the solar system does not resemble Bambi losing its mother. I suppose the notion that Pluto must be returned to planethood derives from the idea supplied by television that when something we don't want takes place, at the last moment it will be averted.

Is there any sense or pattern to our infatuation with new planets? The

Clyde Tombaugh, discoverer of Pluto

historical method may serve. It is something most readers are familiar with and allows a string of disparate entries to be shaped into a final pattern, although it must be remembered at all times that the pattern is something we make and is not an object in nature.

We begin at the observatory of William Herschel, in the southwest of England, and the year is 1781. Herschel turned the glass to the heavens where he was conducting a methodical survey of the stars. As each star came to the meridian, he recorded its brightness, if double or single, and made estimates of colour and if a nebula lurked nearby. All this was recorded carefully and each star then added to a list. In March of that year, he was examining a star-like object in Gemini when he noticed it looked larger and then smaller upon changing magnifications. Stars do not become much larger at higher powers so Herschel suspected he was watching a comet. When the body's orbit was calculated it was clear the solar system was not limited to six planets and this was number seven.

The new planet came to be called Uranus. From the start it was a problem planet. It seemed to be moving just slightly at odds with its predicted path. Over the next 40 years the newcomer was inspected but it kept speeding up, then very oddly it began to slow down.

Figure 1 shows the problem. The

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Upcoming Events

March
19 – Night Quest at Pacific Spirit Regional Park

19-22 – RASC General Assembly in London

May
7 – Astronomy Day at SFU

July
30 - Aug 7 – Mt. Kobau Star Party

August
27 - Sep 4 – Merritt Star Quest

December
8 – AGM

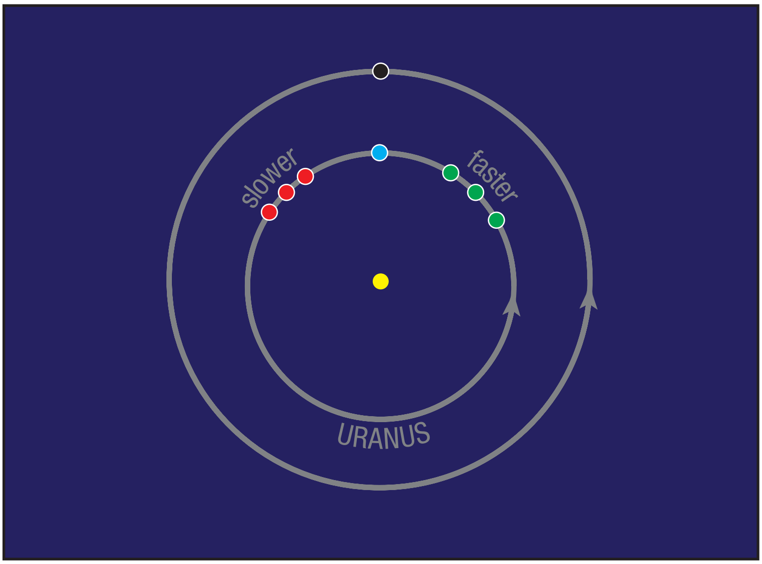

Figure 1: The effect on the motion of Uranus by a then-unknown Neptune

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yellow dot at the centre is our Sun while the first circle moving outwards represents the orbit of Uranus. The coloured dots on the circle are the positions of Uranus in time. Locating a planet on its orbital path is made possible by Newtonian mechanics, yet a plotting of Uranus shows it goes too fast in positions indicated by the green dots and too slowly in the case of the red dots. As if that were not enough fuss, for a short time it goes at just the right speed represented by the lone blue dot. The problem sorts itself out in a way that was one of the intellectual feats of the 19th Century. Consider the outer orbit. Suppose we put an unknown planet, represented by the black dot, in this orbit. Suppose Uranus is orbiting in a counter-clockwise motion around the grey line. The unknown planet pulls on it with a force proportional to mass and the distance between the two objects. As Uranus comes around in the green the black dot pulls on it and the planet experiences an extra pull and speeds up. Since the unknown planet is in a more distant orbit it moves more slowly and Uranus passes by at the blue dot. Then as Uranus hurries away (red dots) the planet in the outer orbit now retards its progress and it moves too slowly. The situation at the blue dot shows no apparent problem, even though the pull is greater since the line of disruption is to pull Uranus radially away from us. The position of Uranus, or any other body on the celestial sphere, is a motion at right angles to the surface of the sphere. Motions going directly away or coming like a bullet right at us were not measurable before the technique of radial velocities was adapted from the spectroscope.

One thing was certain. In the blue dot position there must have been a straight line connecting the inner solar system, Uranus, and the unknown planet. Since the position of the newcomer was known at one instant in the past it was worked out where the new planet would be currently and the position published. All that remained was to point the telescope to the place and discover the new planet. This took place in 1846.

The location of the new planet having been worked out, it needed someone to point the telescope and discover it. But observational routines at both Greenwich in England and the US Naval observatory in

Washington D.C. acted to prevent any unplanned activity to interfere with routine measurements and the compilation of mundane data.

On the continent, where the observatories were not as yet overwhelmed with a petty bureaucracy, two observers, Johann Galle and Heinrich Louis d'Arrest, were given permission to use the 9-inch Fraunhofer refractor of the Berlin Observatory. On September 23, 1846 they turned the great telescope to RA 22h 46m; declination -13° 24' and, Galle at the eyepiece, called out descriptions of the stars he could see while d'Arrest checked off each star in the field against a star chart he held in his lap. Only a few had been checked when Galle described a star of the eighth magnitude at RA 22h 53m 25.8 sec. D'Arrest exclaimed, "That star is not on the map!"

It was planet number eight. The newcomer was called Neptune.

Now the odd thing is, later that century, the same trick was attempted a second time. It involved an unknown planet this time not at the edge but at the very centre of the solar system. For the inner planet Mercury had long been the subject of wonder since it too exhibited an extra motion that was not accounted for by mechanics. Since Neptune solved the problem of the motion of Uranus, could it be that an inner planet, one closer to the Sun than Mercury, was causing that world to wobble out of position? The new planet was called Vulcan, after the God of fire, an appropriate name for a place that would be rather on the hot side of things. The hunt for an inner planet just beside the Sun was difficult due to solar glare. An opportunity arose after the introduction of photography to spot Vulcan when the Sun's light was subdued in a solar eclipse. Telescopes with cameras were set in the path of totality in the hope of spotting a point of light near the Sun that was not a background star.

It was a puzzle but Vulcan failed to show up. In eclipses in the late 1800s, the field around the Sun was both observed visually and photographed but no one could find even the faintest star-like trace of an interior planet.

The planet seekers had been fooled this time by a factor they could not have anticipated. Today we would say it was "funny" physics, or the assumptions of the dynamics of the time failed to describe objects moving with high speed. The theory of relativity straightened out the Mercury problem and, once it was accepted, Vulcan disappeared. It was simply no longer needed.

At about the same time at the Lowell Observatory in Arizona, teams of astronomers were hunting for a trans-Neptune planet. Again it was the wobble in Neptune's orbit that seemed to point to another body outside, a Ninth Planet. In the 1920s, a youthful Clyde Tombaugh was taken on to work on finding number nine. He examined thousands of plates of the sky until, in March of 1930, he found a ninth planet.

The New York Times, in the edition of Friday March 14, 1930, reported that "there are, be it known, nine instead of a mere eight worlds" in the solar system. The new planet is at least as big as the Earth and "possibility larger than Jupiter" the paper reports. The implication is that nine is better than eight and, right from the start, Pluto's size is exaggerated due to the lack of data about the object. In fact, Pluto seems to be only 2/3 the size of the Moon. No matter.

It seems with Pluto, a special status for a planet had grown up, and singled it out. The distance, alleged mysterious nature of the body, and its forming a boundary to our solar system all seemed to captivate the imagination easily captivated by trifles.

In a telephone conversation with Tombaugh, he told me the planet fanciers had taken to calling him up and asking his "acknowledgment" of planets they had discovered often with the unaided eye. Some of these may have been bright planets, others cannot even be identified with any real perception. The new planet might live in the caller's garage and only come out at night. I tried to make light of these erstwhile explorers of the cosmos but Tombaugh would have none of it. I think he saw these people as the cutting edge of a kind of irrationalism that is both incredibly self-indulgent and pointlessly imitative of projects they read about and think they can duplicate without any sane context for their activities. They are encouraged in this by the widespread belief, generated by consumerism, that skills and talents can be purchased and deployed without work or thought.

His notoriety had become a magnet for just the kind of people he would not want to attract and after

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our talk I felt a mixture of compassion and sorrow for the old man. But I see Tombaugh as a sort of Canary in the coal mine, drawing out the consequences of a culture where there is a platform for all—no matter how little they have to say.

And now, another chapter is opening in the quest for the Ninth Planet. In 2006, Pluto was taken off the list of planets but it seems we need to have it back: or, some substitute.

Caltech researchers have found evidence of a giant planet tracing a highly elongated orbit in the distant solar system. The object, which the researchers have nicknamed Planet Nine, has a mass about 10 times that of Earth and orbits about 20 times farther from the Sun on average than does Neptune (which orbits the Sun at an average distance of 2.8 billion miles). In fact, it would take this new planet between 10,000 and 20,000 years to make just one full orbit around the Sun.

The researchers, Konstantin Batygin (rhymes with Batty-on-Gin) and Mike Brown (unimaginatively Anglo), discovered the planet's existence through mathematical modelling and computer simulations but have not yet observed the object.

"This would be a real ninth planet," says Brown, the Richard and Barbara Rosenberg Professor of Planetary Astronomy. "There have only been two true planets discovered since ancient times, and this would be a third. It's a pretty substantial chunk of our solar system that's still out there to be found, which is pretty exciting."

Brown, well known for the significant role he played in the demotion of Pluto from a planet to a dwarf planet, adds, "All those people who are mad that Pluto is no longer a planet can be thrilled to know that there is a real planet out there still to be found. Now we can go and find this planet and make the solar system have nine planets once again."

This is what used to be called playing to the gallery: where the cheap seats are to be had. Notice the large size attributed to Planet Nine, just like the Times article on Pluto.

Brown notes that the putative ninth planet—at 5,000 times the mass of Pluto—is sufficiently large that there should be no debate about whether it is a true planet. Unlike the class of smaller objects now known as dwarf planets, Planet Nine gravitationally dominates its neighbourhood of the solar system. In fact, it dominates a region larger than any of the other known planets—a fact that Brown says makes it "the most planet-y of the planets in the whole solar system."

Great. But what about the evidence? Batygin and Brown noticed that several distant Kuiper Belt objects have orbits that are inclined to the ecliptic at the same angle. There seems to be some sort of preferential orbital pattern amongst these dim and remote small bodies.

"It's almost like having six hands on a clock all moving at different rates, and when you happen to look up, they're all in exactly the same place," says Brown. The odds of having that happen are something like 1 in 100, he says. But on top of that, the orbits of the six objects are also all tilted in the same way—pointing about 30° downward in the same direction relative to the plane of the eight known planets. The probability of that happening is about 0.007%. "Basically it shouldn't happen randomly," Brown says. "So we thought something else must be shaping these orbits."

In a nutshell, the pair suppose an unknown massive planet, Planet Nine, shepherds the small Kuiper belt worlds in a way similar to the effect Neptune has on Pluto. The two world's orbits cross at two points but they never collide because of a resonance effect that keeps order in the relative locations of the two bodies.

The Planet Nine contenders suppose that the giant unknown planet perturbs many of the small outer solar system objects, like Sedna, discovered by Brown in 2003, and others, and the orbital characteristics of these small objects show enough similarity to support this contention.

However, forces causing objects to line up with our pre-existing expectation that they must be random are not hard to point to. The small satellite galaxies of M31 orbit in a disk and not randomly as was the initial supposition. Some planetary nebula seem to have a preference in the orientation of their poles to the galactic plane.

Batygin and Brown may be right, but certainty is not achieved as long as there are other unknown, but at least imaginable, causes for the orbits of these bodies. We simply don't know if some subtle force, a small factor but powerful in effect given

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around at our last meeting.

On Tuesday February 16th we found ourselves once again at Science World for High School Days. Ron couldn't make it this time, however Karl, Jeremy and myself did quite well. Unfortunately, the weather was a real tease for most of the day. Karl set up his solar scope outside on the roof patio for a couple of hours. He told me it was a matter of stealing a peak at the Sun through the occasional sucker hole in the clouds. Even when cloudy, it remained quite bright which just added to the frustration. Jeremy and I kept busy talking to teachers and students and demonstrating star wheels and discussing astronomy in general. We also gave away some posters to schools as well as a calendar to each school. Sam had supplied us with a big screen TV to show short films on but my laptop and/or CD decided to act up. Sam called Science World's tech support and, with his help, we soldiered on. We certainly get to meet a lot of school students and their teachers at these events, which are lots of fun. Sam has invited us back for the next High School Day events in April and May. (There isn't an event in March). We have also been invited to another SWEET (Science World Extravagant Evening for Teens) event.

I want to add, at this time, that this is now our third event of Science World's that we have attended. We have been very warmly welcomed by Sam and Katherine (Kat) Hamill and all the rest of the staff at Science World. At this last event, Sam gifted RASC–Vancouver with a copy of "THE RED BULLETIN" featuring articles about the Red Bull Stratos program. It had been autographed by Joe Kittinger, Art Thompson and Mike Todd on pages featuring their photos. Joe Kittinger is most recently known as the *capsule communicator* directing Filix Baumgartner on his record-breaking 39-kilometre freefall from Earth's stratosphere, exceeding Kittinger's earlier freefall in 1960. Art Thompson is the engineer who designed the capsule that took Baumgartner into the stratosphere. Mike Todd is the ever important *life support engineer*. He was responsible for the pressure suit and supporting hardware and software to bring Baumgartner back alive. All three of these gentlemen have very interesting histories that warrant further reading. Our copy will be in the hands of our librarian, William Fearon, for safe keeping.

On Thursday, February 18th, Karl Miller and I gave a presentation at the 1st Eagle Mountain Girl Guides meeting at Scott Creek Middle School in Coquitlam. Guide leaders Angie Skidmore and Leah Questroo were most accommodating to us and helped us make the most use of the space we had available. I gave a PowerPoint presentation aimed at earning the girls their Astronomy Badge. The girls were very attentive and had some challenging questions for me. Again, the weather forced us to set up our telescopes indoors and view some posters that we brought. I found the young ladies were very delightful and lots of fun was had by them and Karl and myself. Angie assured me they had earned their Astronomy Badges and the girls thanked us with a box of Girl Guide Cookies. Sorry members, the cookies did not survive our council meeting.

On Saturday March 5th, Elise Harrington, Kyle Dally and I attended an invitation to hold an astronomy session at Camp Kanaka in Maple Ridge during a Girl Guide camp weekend. The girls at the camp represented five different groups: 2nd Port Hammond Sparks ages 5-6 (leaders Stephanie, & Sandra), 3rd Port Hammond Brownies ages 7-8 (leaders Barb, Eleah & Christina), 1st Port Hammond Guides ages

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the amplification of a huge amount of time, is acting in the absence of Planet Nine to produce the results we see.

So, will Planet Nine be another Neptune or another Vulcan? I'm not taking any bets but will only point out that the ninth planet does not have to exist just because we want it to be there.

As a sort of footnote, our anxiety to have more planets took a little backward step recently with an audit of the planets discovered by the Kepler Space Telescope. It found about half the new planets were either little stars or oscillations of a star itself masquerading as planets. The existence of so many false positives is now an issue in the planet hunting community. Still, even subtracting half leaves a residue of many hundreds of planets still remaining. ✸

Spectroscopy at SFU's Trottier Observatory

by Howard Trottier

Astronomical spectroscopy has been practiced by small numbers of amateurs for decades, generally using home-made equipment of limited resolution and sensitivity. We may now be at the threshold of a new era of amateur spectroscopy, thanks to commercially-available equipment that can produce measurements of professional quality, at prices that are comparable to higher-end astronomical imaging cameras.

This situation is reminiscent of the revolution in amateur astrophotography that began about twenty years ago, when CCD cameras first became widely available to hobbyists, opening up vast new realms of possibilities. Today's amateur spectroscopists can make scientific measurements of astounding variety and precision. Along with investigations for personal education and reward, amateurs can also contribute to research collaborations with professionals.

Equipping the Trottier Observatory at SFU with a high-resolution spectrograph was a key part of the earliest plans for development of the facility. We quickly settled on acquiring an "echelle" spectrograph made by a French company called Shelyak, which manufactures a wide range of devices of varying cost and capability. We took delivery of their top-of-the line spectrograph, called the eShel, in late June of 2015, only two months after the observatory opened!

In this article I'll give only a very brief survey of what makes this spectrograph special, along with a very small sampling of the results that have been ob-

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9-11 (leaders Natalie & Danielle), 1st Port Hammond Pathfinders ages 12-14 (leader Brittany Harris), and 1st Port Hammond Rangers ages 15-17 (leader Kathleen). There were also a few other leaders such as their QM staff Sabrina & Monica, First Aider/treasurer Coleen, and organizers Lorraine & Vanessa. Prior to our visit, we had been very kindly invited to have dinner with the girls, so we scheduled our talks for the afternoon and, following dinner, we had hoped to set up our telescopes and do some evening viewing with them (weather permitting, of course). For the talk portion of our day, I was lucky to have Elise Harrington volunteer to give a talk centring on Planetary Geology, her area of study. I thought she gave a superb presentation which seemed very well received. As a side-topic, she talked to them about her educational history and how she had changed her direction several times before finding her true passion. This really struck home with the older girls and maybe will help a few handle the stress of future decisions. Kyle volunteered his time helping out with demonstrations, setting up, and pretty well anything else I asked of him. I gave my usual talk about finding things in the night sky, which is aimed at helping the girls acquire their Astronomy Badge. Following our talks, Elise and I compared notes and we both felt that the girls were not only super well behaved, but also reading well above their grade level based on the questions they asked and the answers they gave to our questions. I was assured by one of the leaders that they all earned their Astronomy Badges. After the talks, while we all sat indoors enjoying our dinner together, the sky continued to become more and more overcast and, unfortunately, put a damper on our viewing plans. So after we finished dinner, the three of us put on clinics with the leaders and older girls to instruct them how to assemble star wheels and use them, so they could teach the younger ones on Sunday. After our star wheel instruction, we packed up our equipment. Kyle and Elise headed home while I sat around a campfire listening to the girls having a sing-a-long. Elise, Kyle and I thought the entire visit at Kanaka Camp was very rewarding. My thanks to them both for helping to make it such a success. I gave the leaders our centre's card and encouraged them to follow us on Meetup in hopes that their troops can join us at one of our future star parties. Our thanks to all the leaders and girls of the troops at Camp Kanaka for a very enjoyable afternoon and evening. ✸

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tained to date. A comprehensive report, which includes an overview of the design principles of echelle spectrometers, can be freely downloaded from:

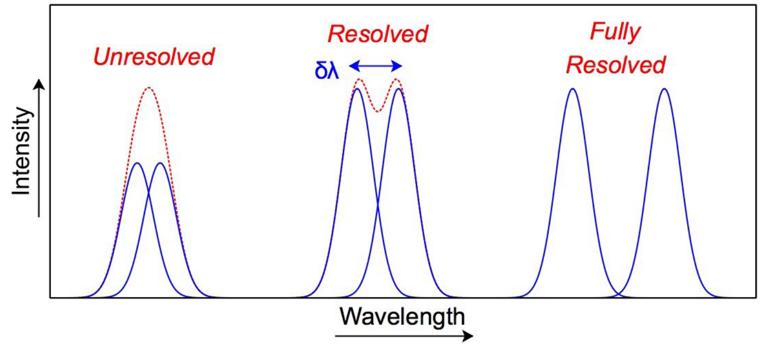
https://www.sfu.ca/science/trottierobservatory/observatory.html

After the spectrograph arrived, I spent about six weeks learning how to install and calibrate it, and how to use the (free!) data acquisition and analysis software packages. Then, from late summer through early winter, I spent a good deal of time taking data for a wide range of astrophysical objects, and figuring out how to squeeze as much quantitative information as I could from the results.

In addition to measuring the spectra of a few star types, including Vega and the Sun (via the Moon), and closely comparing the results with data from other observatories, I obtained results for the following: the Ring Nebula's emission spectrum; the radial velocities of the stars in two spectroscopic binaries; the rotational speeds of several stars; the properties of several circumstellar disks; the spectra of stars with fast winds; and, perhaps most exciting of all, a set of extraordinarily precise measurements of the (relative) recessional velocities of some carefully selected stars, which very clearly demonstrates that we can use the eShel to detect a few hot-Jupiter exoplanets!

All of these measurements can be done with relative ease (that is, after learning how to use the equipment and software!). High-quality data for bright stars can be collected in minutes, and within about an hour for stars down to about sixth or seventh magnitude; this is very different from acquiring high-quality astronomical images, which require many nights of telescope time. And, unlike astronomical image processing, which demands *many* hours of effort, with lots of trial-and-error, to obtain the best possible final image, the processing of spectroscopic data requires relatively little time and intervention by the user, once the initial setup for a particular spectrometer/telescope combination has been made.

Echelle spectrometers are advantageous compared to other designs because of their high resolution. Spectral resolution is characterized by the smallest possible wavelength interval $\delta\lambda$ between two neighbouring spectral features that can be individually identified, as illustrated below for two emission lines.



Resolution is usually quoted in terms of a fractional measure R that is defined by

$$R = \frac{\lambda}{\delta\lambda}$$

The eShel has a resolution R of about 10,000, meaning that it can distinguish between spectral features separated by about as little as 5,000 Angstroms/10,000 or 0.5Å, at a typical wavelength of optical light. By way of comparison, the highest-resolution professional echelles have R above 100,000.

The eShel layout when in use at the observatory is shown below. The spectrograph is remarkably compact, and sits on top of a small dolly that is wheeled into the dome area to collect data. A light-weight acquisition/guiding unit is attached to the periscope. The acquisition unit houses a plane mirror with a small hole: the mirror deflects almost all of the incoming starlight to a guide camera mounted on the side of the unit, while a fibre optic cable mounted be-

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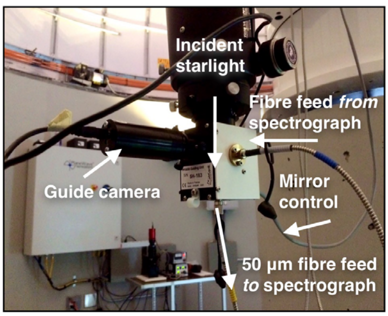
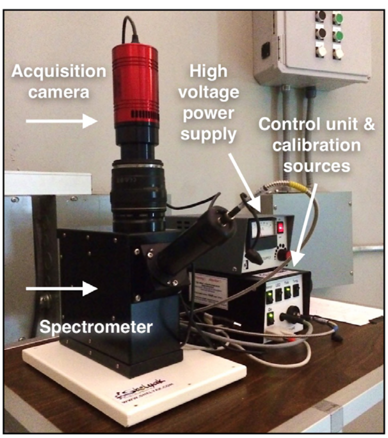
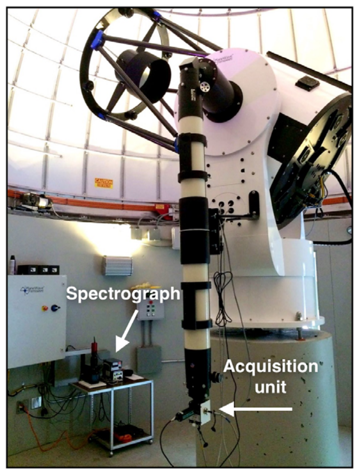
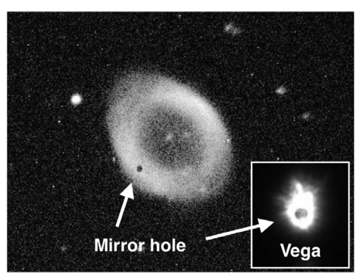
hind the hole in the mirror feeds light to the spectrometer.

The spectrograph is positioned beside the telescope control panel, where the ends of the acquisition unit's fibre optic and control cables come up through the floor, and are attached to the spectrometer and its control unit. The spectrometer's diffraction grating disperses the light (similar to the rainbow of colours reflected from a compact disk), and a CCD camera mounted on the unit images the resulting spectrum. USB cables connect the equipment to the control room computer. The spectrograph has calibration sources, and the light that they produce when activated is fed to the acquisition unit at the telescope through a separate fibre optic cable. A flip mirror in the acquisition unit redirects the calibration light to the pickup fibre: this ensures that the calibration is done with light that follows the same optical path to the spectrometer as the starlight.





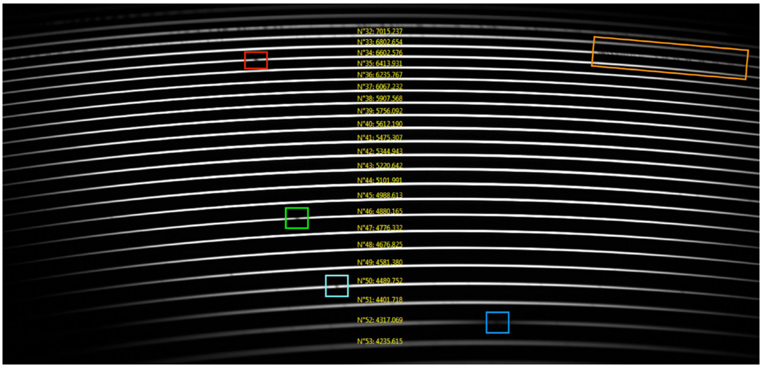




The fibre optic cable that transmits the incoming starlight is only 50 microns in diameter! The small size is necessary for the high resolution, but limits the sensitivity of the spectrometer. The above images of the Ring Nebula and Vega (the latter on a night of poor seeing!) were taken through the guide camera, and show the tiny region occupied by the hole in the mirror. This illustrates why this unit is suited to stellar spectroscopy, but not so much to extended sources (though brighter nebulae can be measured). These images also demonstrate the importance of auto-guiding, to keep the target starlight on the hole!

An acquisition image of the spectrum of Vega obtained with our eShel is shown at the top of the following page. Echelle spectra take the form of a set of narrow bands stacked one on-top of the other, with each band corresponding to the output from one order of the diffraction grating. In the case of the eShel, some 25 orders cover the entire optical band (the bands have no colour in this image because our camera is monochrome). The yellow text on the image identifies the central wavelength in each of the displayed orders. Since Vega is so bright, this image is the result of less than three minutes of total exposure!

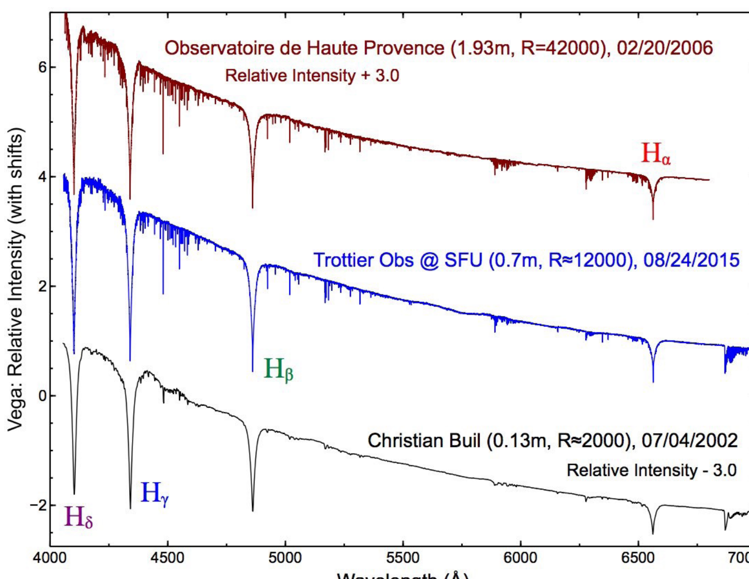
Some of the absorption lines that stand out here are identified with coloured boxes. On the left side of the image, running from top to bottom: the Hydrogen-alpha line at 6562Å (red box); the Hydrogen-beta line at 4861Å (green); and a Magnesium line at 4481Å (cyan). On the right side, again from top to bottom, there is a very dense set of absorption lines due to



oxygen molecules in our own atmosphere, running from about 6850-7000Å (orange box), and the Hydrogen-gamma line at 4340Å (blue).

To turn an image like this into a graph of intensity versus wavelength requires calibration of the spectrometer/camera system, which I won't go into here. Suffice it to note that calibration is needed for three reasons: to map the geometry of the echelle rungs; to map the pixel position at which light reaches the imaging CCD to the corresponding wavelength; and to correct for the non-uniform response of the spectrometer/camera to light of different wavelengths.

The figure below plots my fully calibrated spectrum for Vega, along with two other measurements that provide instructive comparisons. The upper plot is from a professional observatory in France, Observatoire de Haute Provence, taken with an echelle spectrometer called ELODIE (now decommissioned), with a resolution about 5X times larger than the eShel. The lower plot shows data taken by one of the world's leading "amateurs," Christian Buil, using a spectrometer with a resolution about 5X smaller than the eShel (http://www.astrosurf.com/buil/us/vatlas/vatlas.htm). To more clearly compare the three plots, I've shifted the other plots vertically relative to mine. Notice the four labelled optical



Balmer lines.

To illustrate the many quantitative studies that have already been made with our eShel, I'll give just one example: measuring the orbital velocities of spectroscopic binary star systems.

Spectroscopic binaries come in two broadly-defined varieties. In one type, the spectral lines of only one star are visible, and these are called single-lined spectroscopic binaries. When the lines of both stars are visible, you've got a double-lined binary.

I measured the spectra of two double-lined binaries, one of which was Mizar A, a very well-known example (Mizar A and B constitute a visual binary, and both stars are spectroscopic binaries, with the two stars in Mizar A separated by less than 0.01"). The stars in Mizar A are of about the same spectral type, A2V, and I compare my spectrum for Mizar A with a unary star of the same class in the two

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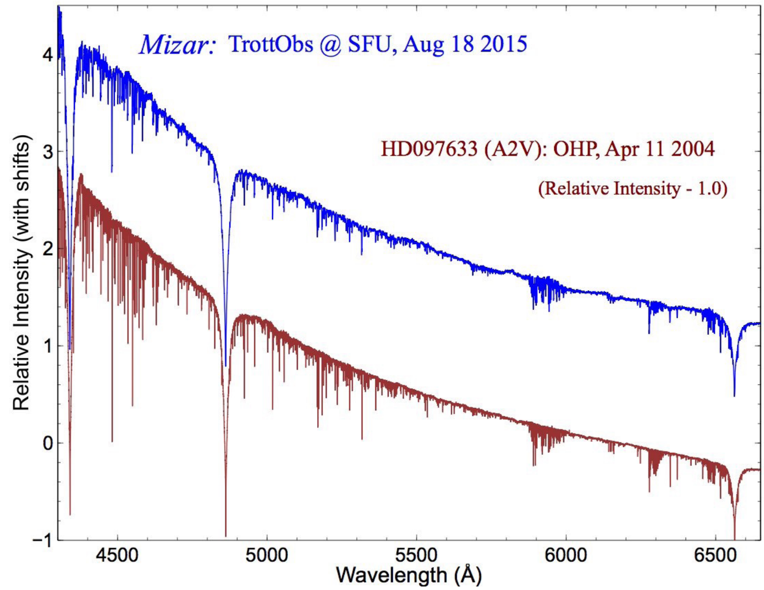
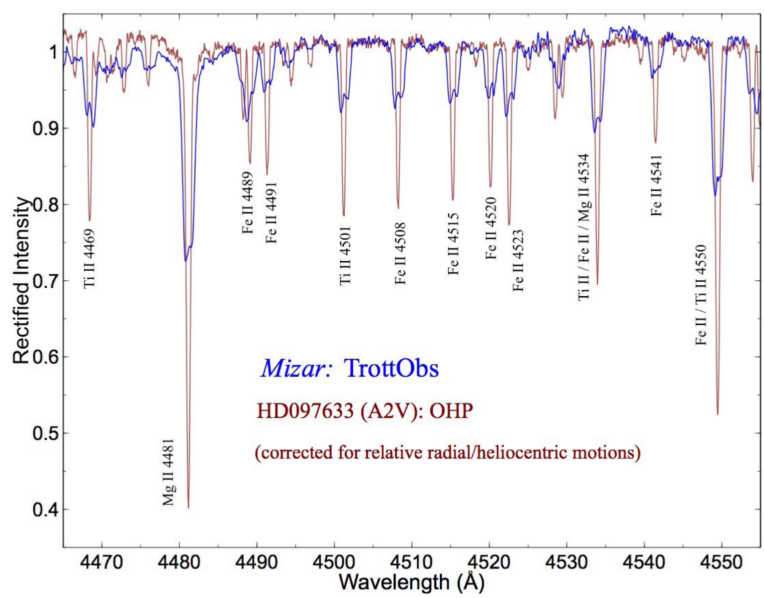
plots on the right.

The second plot zooms into a region in the blue-green part of the spectrum with a rich set of absorption lines. The double dips clearly reveal the presence of the two stars. The radial velocities v_r are inferred from the wavelengths of the dips, using the formula $\Delta\lambda = \lambda * v_r / c$. The results are consistent with the velocities being equal in magnitude (as expected in this case), at about ±30 km/sec on that night, to be compared with the known maximum radial velocities of just under 70 km/sec.

The other spectroscopic binary that I studied, 57 Cygni, has a very short orbital period of 2.85 days (compared to 20.5 days in the case of Mizar A), and the results of my measurements, taken on three nights spread out over a week, clearly tracked the known radial velocity curve for that system.

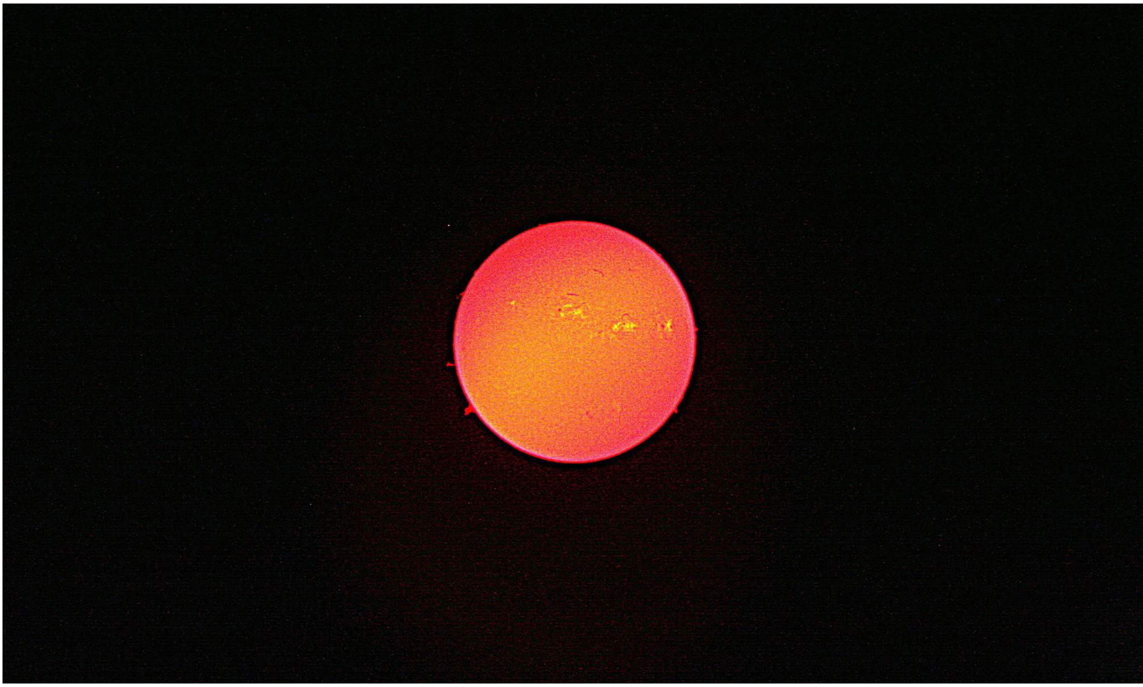
In conclusion, this article gives just a tiny taste of what has already been done with our spectrograph, and of the possibilities for future projects. The report cited at the beginning of the article gives a comprehensive review of the equipment, and of the first set of results that have been obtained, including some background on the design principles of an echelle spectrograph, an overview of the data collection procedures, and details on the mathematical methods used to extract a wealth of quantitative results.





One last note! We recently took delivery of a second spectrograph, also made by Shelyak (the LISA): it has lower resolution but higher sensitivity than the eShel, and will provide us with complementary capabilities, notably the ability to take spectra of faint extended objects and measure quantities like galactic redshifts and rotation curves! I hope to install and test the new unit once the current rainy season passes ;). ✸

Members' Gallery



H-Alpha Sun by Karl Miller
Taken in 2010 using a 60mm Lunt solar telescope.

King Tide by Elena Popovici
The effects of moon on tides. On January 15, with the Moon at perigee, and only a few days from new moon and less that two week from the Earth passing perihelion, the tide inundated the False Creek seawall (left). For comparison, a typical high tide on February 21st, with the Moon almost full but at aphelion (right).