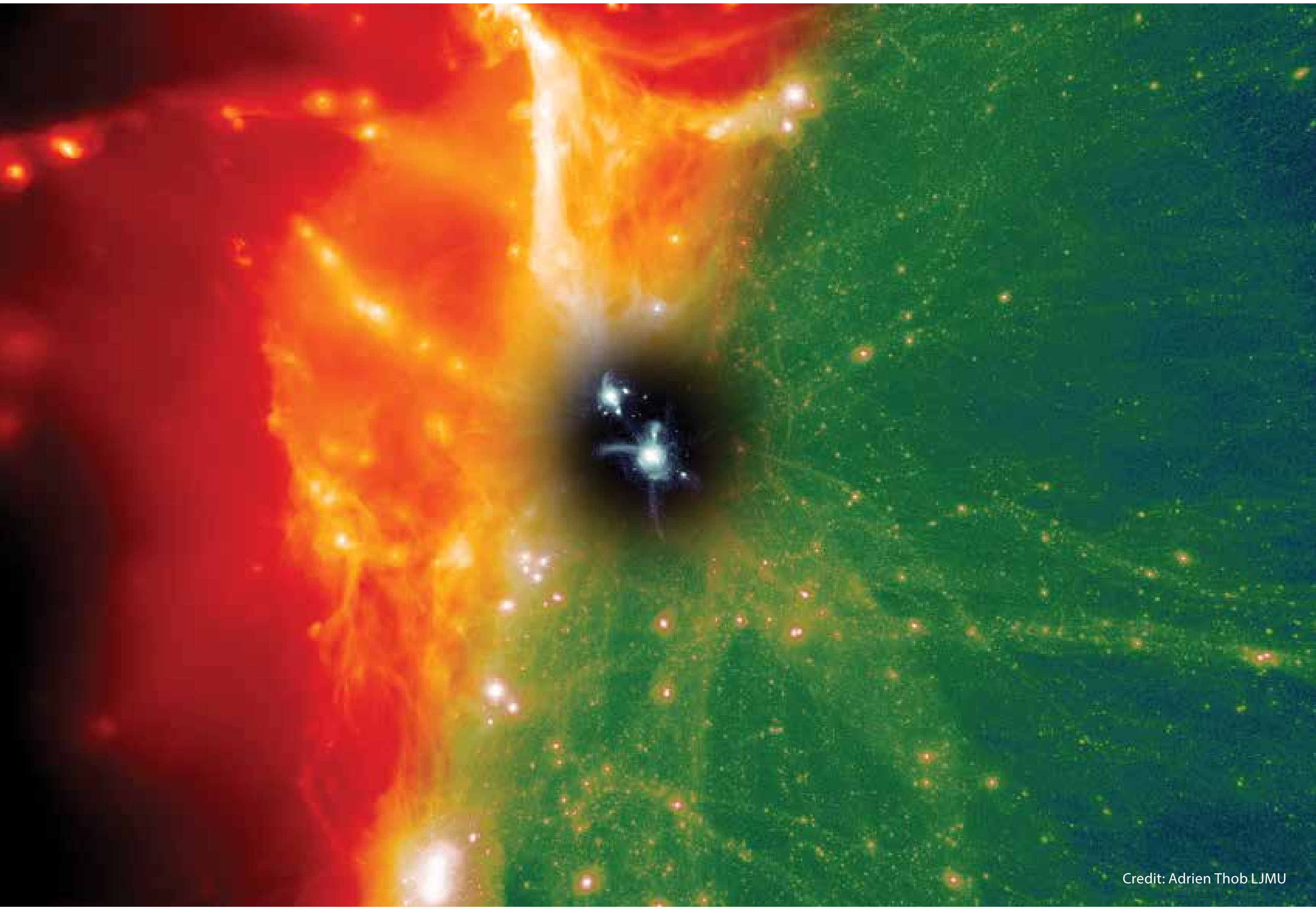
University of Victoria

ARC 2017 NEWSLETTER

ASTRONOMY RESEARCH CENTRE



Credit: Adrien Thob LJMU

Distributions of gas (left), dark matter (right), and stars (centre) in a region of the universe resembling the Local Group, simulated at high resolution as part of the APOSTLE project.

(See article on page 6).

In this issue:

Director's Message 2
ARC members 3
Thirty Metre Telescope 4
RAVEN 5
Cosmology – APOSTLE 6
Gemini Planet Imager 7
Planetary science 8
Radio Astronomy – PAF 9
Stellar Astrophysics 10
TRIUMF 11
Outreach 12
CULT 12

Astronomy Research Centre | Email: sciarc@uvic.ca

Director's message

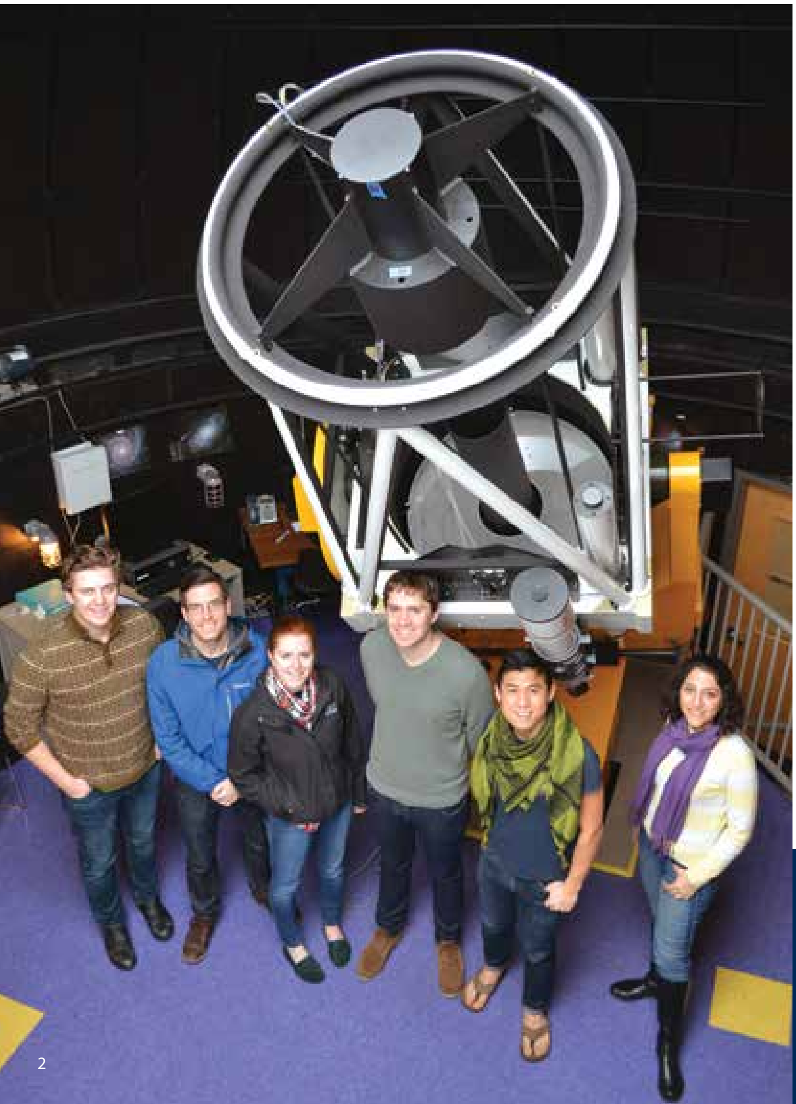
The Astronomy Research Centre (ARC) was initiated in April 2015, through funding from the UVic Vice President Research and Dean of Science offices. In its first year, the ARC hosted a workshop on second-generation instrumentation for the Thirty Metre Telescope (TMT) and cohosted a meeting of the multi-object adaptive optics science demonstrator RAVEN. The TMT workshop brought together scientists and engineers from academia, government, and industries across Canada, as well as students and postdoctoral researchers, while the RAVEN meeting included the science and engineering teams from both Victoria and Japan. The ARC also developed a new web profile, which aims to collect and provide links to the wide variety of astronomical research that is carried out in and near Victoria, BC.

In 2016, the ARC focused on several major funding requests, including taking the lead on a Canada Foundations for Innovation (CFI) request for instrumentation development for the Maunakea Spectroscopic Explorer (MSE). The MSE is an international collaboration led by Canada and France, with five additional partner countries, to renew the highly successful CFHT 3.6-m telescope with an 11.5-m telescope and multi-object dedicated spectroscopic facility. Such a facility has been recognized as a top priority in Europe, the US, and Australia, and was ranked highly in the Canadian 2015 Mid-term Review. The ARC-led CFI proposal includes prototype work packages for a high-throughput, fiber-fed, blue-arm spectrograph. This prototype would be unique given the number of objects that could be observed simultaneously, and the richness of the spectral features that would be available for a number of science cases in galactic and stellar astronomy. This collaboration includes significant contributions from across Canada in both optical components and software survey system development, including from Laval, UBC, Saint Mary's U, UWaterloo, YorkU, UWO, UToronto, Fibertech Optica Inc., ABB Inc., INO, and NRC-Herzberg.

ARC Director and UVic faculty member Kim Venn and graduate student Masen Lamb working at the adaptive optics bench at the NRC-Herzberg.

The ARC is also leading an effort to build a new student training program in technological developments for uses in Canadian observatories. In a proposal to the NSERC CREATE industrial stream program, we have outlined a program that would increase student opportunities in government and industrial labs related to detector and focal plane technologies, and other advances in optics and photonics, fostering relationships between academic and industrial research. Members of the ARC are already involved in leading edge developments in astronomical instrumentation, and connecting students with industrial partners increases opportunities for hands-on learning experience and industrial professional practices.

Finally, the ARC plays a supporting role in other UVic programs, particularly its diverse outreach efforts. ARC members lead the UVic Observatory open houses, Department of Physics & Astronomy public outreach program, and support the Committee for Upgrading the Learning Telescopes. ARC has recently contributed to a graduate-student led effort for new astrophotography equipment to be used for the first UVic astronomy calendar in 2017. In this first newsletter, we report on a number of recent research activities carried out by ARC members. On behalf of the ARC Program Management Team, we look forward to supporting and sharing the creative and exciting astronomical research that is carried out here in the coming years.



Student volunteers in front of the UVic 32" telescope.
From left to right: Nic Annau, Micheal Pearson, Kristi Webb, Matthew Wine, Mike Chen & Azi Fattahi Savadjani.

ARC member list

FACULTY

Name	Research Area
Justin Albert	Physics
Arif Babul	Astronomy
Jens Bornemann	Engineering
Colin Bradley	Engineering
Sara Ellison	Astronomy
Colin Goldblatt	Planetary
Falk Herwig	Astronomy
Julio Navarro	Astronomy
Poman So	Engineering
Geoff Steeves	Physics
Kim Venn	Astronomy
Jon Willis	Astronomy

EMERITUS FACULTY

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Christian Marois	Astronomy, Engineering, NRC-Herzberg
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Chris Ruiz	Nuclear Physics, TRIUMF
David Schade	Astronomy, NRC-Herzberg
Luc Simard	Astronomy, NRC-Herzber
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Name	Research Area
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Name	Research Area
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Pavel Denisenkov	Astronomy
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Russ Robb	Astronomy
Eric Steinbring	Astronomy, NRC-Herzberg
Karun Thanjavur	Astronomy
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Stephenson Yang	Astronomy

POSTDOCTORAL RESEARCHERS

Name	Research Group
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Benoit Côté	Stars, Galaxies
Samantha Lawler	Planetary, NRC-Herzberg
Cameron Yozin	Cosmology
Joel Roediger	Galaxies, NRC-Herzberg

STUDENTS

Name	Research Group
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Connor Bottrell	Galaxies
Michael Chen	Star formation
Ondrea Clarkson	Stars
Austin Davis	Stars
Zachary Draper	Planetary
Nick Fantin	Galaxies
Azadeh Fattahi Savadjani	Cosmological simulations
Logan Francis	Star formation
Benjamin Gerard	Planetary, Adaptive optics
Maan Hani	Galaxies
Clare Higgs	Stellar populations, Galaxies
Farbod Jahandar	Stars, Stellar populations
Jared Keown	Star Formation
Collin Kielty	Stars, Stellar populations
Masen Lamb	Stellar populations, Adaptive optics
Sébastien Lavoie	Galaxies
Nick Loewen	Cosmological simulations
Steven Mairs	Star formation
Kyle Oman	Cosmology
Douglas Rennehan	Cosmological simulations
Alireza Seyfallahi	Engineering
Christian Ritter	Stars
Cory Shankman	Planetary
Chelsea Spengler	Galaxies
Mojtaba Taheri Nieh	Stellar populations, Adaptive optics
Thorold Tronrud	Cosmological simulations
Paolo Turri	Stellar populations, Adaptive optics

Next Generation Science:
The Thirty Meter Telescope

Rendering of the Thirty Metre Telescope atop Maunakea. Hawaii is the best location for the TMT, which has been designed to incorporate advanced adaptive optics systems throughout the telescope and instruments.
Credit: National Astronomical Observatory of Japan (NAOJ) TMT-J Project Office.

The Thirty Meter Telescope (TMT) International Observatory is a partnership between China, India, Japan, Canada, the University of California and the California Institute of Technology to build a next-generation 30-m telescope with integrated adaptive optics systems and cutting-edge science instruments. It represents a gain of almost 200 times in sensitivity over existing large telescopes. The science cases span the full cosmic timeline from the first luminous objects in the Universe to our own Solar System. The scientific excitement of TMT has been captured in a recent version of its Detailed Science Case document, a collaborative effort of nearly 200 scientists from across the partnership with many Canadians playing key roles.

The preferred site for TMT remains Maunakea on the Big Island of Hawai'i. A new contested case hearing is under way to determine whether or not a new construction permit will be issued. In light of the proceedings in Hawai'i, the TMT Board decided to explore a number of alternative sites for TMT, identifying Observatorio del Roque de los Muchachos (ORM) on La Palma in the Canary Islands, Spain as the primary alternative to Hawai'i. The Canadian community was very active in this process with country-wide consultations by a Canadian Astronomical Society appointed committee that included ARC faculty member Prof. Sara Ellison and ARC adjunct members Dr. John Hutchings and Dr. Luc Simard. The next step will be to examine instrumentation and operational choices that would maximize the scientific productivity of TMT on ORM.

Work on the two main Canadian deliverables namely the innovative Calotte dome enclosure and the Narrow-Field InfraRed Adaptive Optics System (NFIRAOS) is progressing very well. Dynamic Structures will complete the final design phase to reduce the size and improve the speed of the enclosure, effectively shielding the telescope and instruments from temperature variations, unbalanced wind forces, snow, and ice. The NFIRAOS team is in the final design phase in close collaboration with a number of industrial partners. NFIRAOS is built-upon a powerful type of adaptive optics corrections known as Multi-Conjugate Adaptive Optics (MCAO). The Herzberg NFIRAOS Optical Simulator (HeNOS) is being used to test various optical components and correction algorithms with the involvement of UVic graduate students Paolo Turri and Masen Lamb. A new type of wavefront sensor called a Pyramid Sensor is being integrated into HeNOS, to increase the sensitivity of NFIRAOS to the light from natural guide stars and improve the quality of its optical corrections.

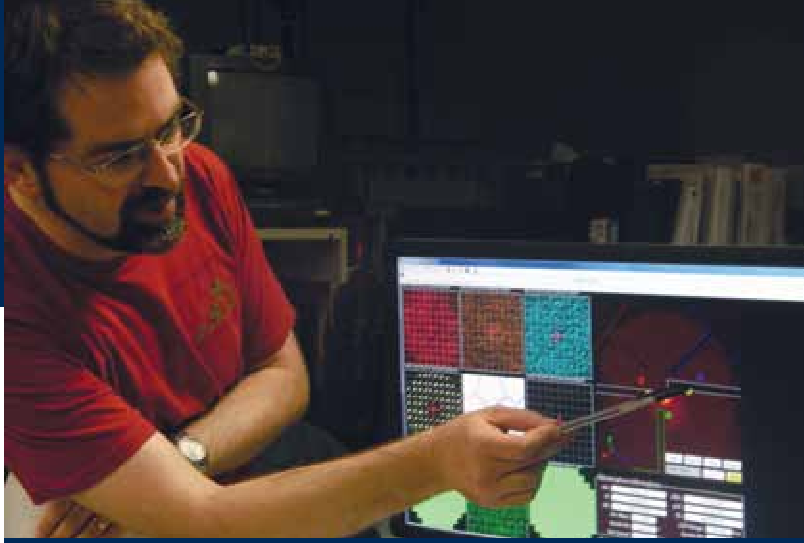
Science instruments have also gone through significant milestones. The team for the InfraRed Imaging Spectrometer (IRIS), a nearly diffraction-limited imager and integral field spectrograph, successfully passed its Preliminary Design Review. The Canadian contribution to IRIS (with ARC adjunct members Drs. David Andersen, Jean-Pierre Veran and Luc Simard) is a sophisticated set of robotic arms able to deploy wavefront sensor probes in the focal plane of NFIRAOS to collect tip-tilt-focus measurements from natural guide stars. The NFIRAOS Science Calibration Unit (NSCU) is starting a Canadian collaboration between the University of Toronto and industrial partners with ARC adjunct member Dr. Alan McConnachie serving as Project Scientist.

A "Future TMT Leaders" workshop took place in Hilo in December 2016 (see photo below). Workshop participants were students and postdocs from across the entire TMT partnership. Presentations were from TMT staff on science, project management, systems engineering, software, instrumentation development, and outreach. Activities included developing instrument concept from science cases and requirements in under one hour! The future of TMT looks very bright knowing that such a creative, dynamic and enthusiastic group of young scientists and engineers will make up its user community!

Written by: L. Simard

Group photo of the attendees and select organizers of the Future TMT Leaders workshop in Hilo, Hawaii. Participants include ARC graduate student members Paolo Turri and Mojtaba Taheri Nieh, and former UVic undergraduate student Deborah Lockhorst (now a graduate student at the University of Toronto).
Credit: Austin Barnes

Adaptive Optics:
RAVEN, An Adaptive Optics Demonstrator & Innovator



ARC Adjunct member Dave Andersen pointing to the graphical interface of one of the two science arms of the RAVEN multi-object adaptive optics science demonstrator. Photo taken during RAVEN commissioning at the Subaru Telescope in May 2014.

Credit: ARC associate member Celia Blain.

Advancements in the field of Adaptive Optics (AO) are crucial to the design and success of the next generation of large telescopes. The University of Victoria AO Lab was involved in the design, and construction of the next generation AO demonstrator, RAVEN. Founded in 2010, the RAVEN project is a collaboration across institutions, including UVic, the National Astronomical Observatory of Japan (NAOJ), NRC Herzberg and Tohoku University. RAVEN was built entirely in house by UVic's AO Lab, headed by ARC member Prof. Colin Bradley of the Mechanical Engineering Department, ARC adjunct members Dr. David Anderson and Dr. Jean-Pierre Veran at the NRC Herzberg, and a long list of past and present post-docs, graduate, and undergraduate students, including current UVic mechanical engineering post-doc Dr. Celia Blain.

One of the first of its kind, RAVEN is a Multi-Object AO (MOAO) demonstrator that performs corrections within a 2-arcminute field of regard, encapsulating two, 4-arcsecond squared field of views in order to image and study two science objects at a time. Differing from classical AO, RAVEN utilizes one laser guide star (LGS) and three natural guide stars (NGS) in order to determine corrections to the distorted wavefront associated with two science targets. It determines the distortion correction through multiple wavefront sensors and applies the correction via two deformable mirrors, one for each object. RAVEN also differs from another emerging AO technology, multi-conjugate adaptive optics (MCAO), in that it performs object-specific corrections within the field of regard, while neglecting the surrounding sky, while MCAO systems correct a larger field of view, one which includes, but is not limited to, the science object.

RAVEN saw first light in early 2014 atop Maunakea when it was used at the 8-metre Subaru Telescope with the Infrared Camera and Spectrograph (IRCS). IRCS provides diffraction-limited images in the range from 2-5 microns when fed by an AO system, as well as providing spectroscopy with grisms and a cross-dispersed echelle. Much of the design and implication of RAVEN was driven by the science cases put forth by members of the RAVEN team, including UVic ARC director, Prof. Kim Venn and UVic graduate student Masen Lamb. Prof. Venn and her collaborators wanted to study low metallicity stars in the Galactic Bulge, which led to the need for RAVEN to operate at high zenith angles. This affected the design of many of the optical components, including the crucial deformable mirrors.

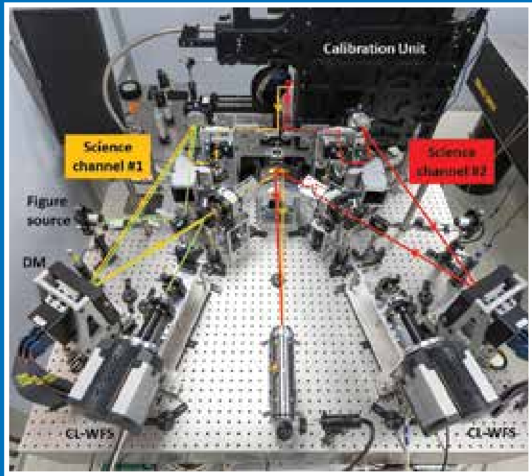
The first science results from RAVEN were presented at the 2014 Society of Photographic Instrumentation Engineers (SPIE) Conference in Montreal. Olivier Lardière presented impressive initial observations of Saturn using three of its moons as NGSs to resolve detailed imaging of the rings. The RAVEN team was able to reduce the turbulent seeing from 0.35 arcseconds without correction, to 0.1 arcseconds with MOAO correction, a task made more difficult by the movement of the NGS asterism resulting from the orbital motion of the moons. Shortly thereafter, a study to probe the central regions of the nearby elliptical galaxy Maffei 1 was published by ARC associate Dr. Tim Davidge of NRC Herzberg. Masen Lamb and Prof. Venn have also published the results of their study into low metallicity stars in the Galactic Bulge and the early stages of the formation of the Galaxy.

RAVEN has acted as a demonstrative and innovative instrument with a lasting legacy. ARC is committed to supporting the development of this capability at UVic for the next generation of large telescopes, especially the Thirty Metre Telescope.

Written by: S. Monty
Edited by: C. Blain & K. Venn

For a complete list of the many people involved and publications pertaining to Raven please visit: **www.web.uvic.ca/~ravenmoa**

The primarily Canadian-Japanese RAVEN team during first light commissioning at the Subaru Telescope, May 2014. *Credit: RAVEN team.*



Raven has two science pick-off arms and three natural guide star wavefront sensors MOAO-correction is applied and the objects are remapped onto the Subaru Telescope's Infrared Camera and Spectrograph slit. *Credit: RAVEN team.*

The APOSTLE simulations:
A Local Universe laboratory

Dark matter (top-left corner) and stellar component (bottom-right) in a region of the universe resembling the Local Group, simulated at high resolution as part of the APOSTLE project. Luminous and dark matter distribution show a dramatic difference in the Local Group. *Credit: Dr. Till Sawala.*

Cosmology probes the very fundamentals of the creation, history and evolution of the Universe. Conceived in the 1990s, the Lambda-Cold Dark Matter (LCDM) theory is now the "standard model" of cosmology. Its predictions regarding the formation of structure in the Universe across a wide range of scales and epochs, from the very early Universe to the present, have been borne out of both state-of-the-art observational surveys and computer simulations. Where these two methods disagree is in observations of the Local Group (LG) of galaxies—comprised of the Milky Way, the Andromeda galaxy, and more than 50 nearby dwarf galaxies. For instance, LCDM predicts a multitude of relatively small dark matter clumps should be orbiting the Milky Way, each in principle able to host a galaxy. Yet the Milky Way has only a handful of galaxies surrounding it; where are its "missing satellites"? Are there less clumps than the theory predicts, or is the process of galaxy formation only able to proceed in some special subset of the clumps?

These and other unresolved puzzles have prompted UVic Professor and ARC faculty member Dr. Julio Navarro and his collaborators, including UVic graduate students Azadeh Fattahi and Kyle Oman and international collaborators in the UK and Finland, to undertake A Project On Simulating The Local Environment (APOSTLE), begun in 2013. They have selected 12 regions from a low-resolution simulation of a large volume of the Universe—each chosen to resemble the LG in terms of total mass, distance separating two galaxies analogous to the Milky Way and Andromeda, and the kinematics of the same pair. Each region was then simulated at high resolution, tracing the evolution of up to 20 million particles from a time before the formation of the first stars to the present day, using the cutting-edge hydrodynamic simulation software and galaxy formation physics developed for the EAGLE project. The end result is a richly detailed picture of the two giant galaxies, complete with their spiral disks, stellar halos and streams, and orbiting satellite galaxies, and their broader environment out to a distance of 2 Mpc.

The first important result to emerge from the simulations was the recovery of the stellar mass function of LG galaxies: the number of galaxies as a function of mass in the Local Volume. Prior to the APOSTLE simulations, the LCDM model had failed to predict the observed abundance of galaxies within the LG. The EAGLE model, a product of the EAGLE cosmological simulations, was calibrated to reproduce the stellar mass function for massive galaxies, but there was no guarantee that the same physical assumptions would yield a realistic population of dwarf galaxies when the code was used for much higher resolutions simulations. The APOSTLE team has now demonstrated that the combination of LG-like initial conditions and a properly motivated and calibrated model of galaxy formation physics prevents many dark matter clumps from forming galaxies and reproduces the right number of LG galaxies, thus resolving the puzzle of the "missing satellites".

Since the publication of this initial result, many more researchers from around the world have taken an interest in analyzing the APOSTLE data. There are now more than 40 completed and ongoing projects in the collaboration on a wide range of topics, from the nature and properties of dark matter to the stellar populations of the Milky Way and its satellites, from the large-scale local distribution of intergalactic gas to how the masses of the smallest galaxies are measured. As the APOSTLE team continues to examine the results of these remarkable simulations, the LCDM model will be put to the test, answering existing questions and raising new ones.

Written by: K. Oman & S. Monty

For more information on the APOSTLE collaboration and relevant publications please visit: **blogs.helsinki.fi/sawala/the-apostle-collaboration/**

Cosmology group discussing APOSTLE galaxy simulations. From left, Azi Fattahi, Thor Thonud, Prof. Julio Navarro, and Kyle Oman.

From Giants to Dust, Exploring planetary systems with the **Gemini Planet Imager**

The search for exoplanets (planets in orbit around other stars) is one of the hottest fields in astronomy. Exploring the diversity of planets in the universe, and searching for another planet like the Earth, captures our imagination. Studies of debris disks (the remnants of collisionally-evolving disks of asteroids and comets around young stars) go hand-in-hand with understanding how planetary systems form and evolve. ARC adjunct members, Drs. Brenda Matthews and Christian Marois, along with their collaborators and students, are actively participating in the largest and deepest direct-imaging search for exoplanets and debris disks. This is with the Gemini Planet Imager (GPI, PI Dr. Bruce Macintosh, Stanford University), a $25M USD instrument in operation at the Gemini South observatory in Chile. GPI achieves two orders of magnitude better contrast than previous instruments, which is necessary to resolve exoplanets in close orbits from their host stars. GPI is helping to revolutionize the field of exoplanet imaging.

GPI development began in 2000, with some of the work being completed at NRC-Herzberg. It uses an advanced adaptive optics system to correct the errors induced by the Earth's atmosphere, a coronagraph to block the light from the host star to allow the dim light of exoplanets and debris disks to be detected, and an integral field spectrograph to acquire low resolution near-infrared spectra of an exoplanet atmosphere. The instrument also features a polarimeter to detect light being scattered in debris disks, and map the disk geometry and composition. Dr. Christian Marois was also deeply involved in the polychromatic performance analysis that guided the instrument's optical design, and he invented two of GPI's main observing strategies, some of the new data processing and calibration techniques.

GPI's extensive campaign ("GPIES") now searches for exoplanets and debris disks around 600 young and nearby stars. As of early 2017, more than 300 stars have been studied. Results have included several dozen images of debris disks and the first discovery of a new exoplanet, known as 51 Eri b. This new planet is unique in that it is the least massive planet discovered by direct imaging, its mass being twice that of Jupiter. Orbiting a young, relatively massive, hot star in the Beta Pictoris star group, 51 Eri b is the first exoplanet found to have a strong detection of methane gas in its atmosphere.

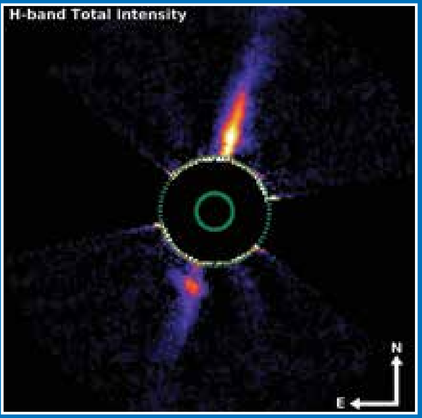
UVic graduate students and postdoctoral researchers have been actively involved in the GPIES campaign. PhD student Benjamin Gerard is implementing a new and powerful post-processing method to boost GPI performance at very small separations. Mara Johnson-Groh looked for ways to better optimize stellar subtraction algorithms as part of her MSc thesis, and PhD student Zachary Draper has developed an innovative data extraction algorithm to minimize noise propagation. Zachary Draper is also searching for debris disks with GPI to characterize their properties and relationships to their host stars. NRC-Herzberg Plaskett Fellow and ARC associate member Dr. Samantha Lawler is also searching for "invisible planets" in GPI images of debris disks. The GPI campaign is scheduled to end in 2018, when the instrument will be shipped back to the NRC-Herzberg for extensive upgrades. Benjamin Gerard is already developing a new focal plane wavefront sensing scheme for the instrument as part of his PhD thesis. Once completed in early 2020, the instrument will be installed at the other Gemini Observatory (Gemini North, in Hawaii), where it will be the most powerful instrument for direct-imaging of exoplanets in the northern hemisphere.

This team is also working in partnership with the UVic Adaptive Optics lab in the Department of Mechnical Engineering, lead by ARC faculty member Prof. Colin Bradley and postdoctoral researcher Dr. Célia Blain. They are developing a specialized thermal imaging coronagraphic camera for the Gemini South telescope, to directly image rocky Earth-like planets located inside the habitable zone (a region around stars where liquid water may be found on the surface of a planet) of the stars Alpha Centauri A & B, our closest neighbors. Dr. Célia Blain is leading the opto-mechanical design work, and UVic co-op student Spencer Bialek has contributed developing the science case. When installed on the Thirty Meter Telescope, this instrument will be capable of surveying the 10 nearest stars for habitable, rocky planets, and detecting biomarkers such as water vapor, methane, ozone, and CO2. This camera could also play a pivotal role in our quest to find an "Earth 2.0" in orbit around one of the Sun's closest stellar neighbours.

Written by: C. Marois & B. Matthews
Edited by: K. Venn & S. Monty

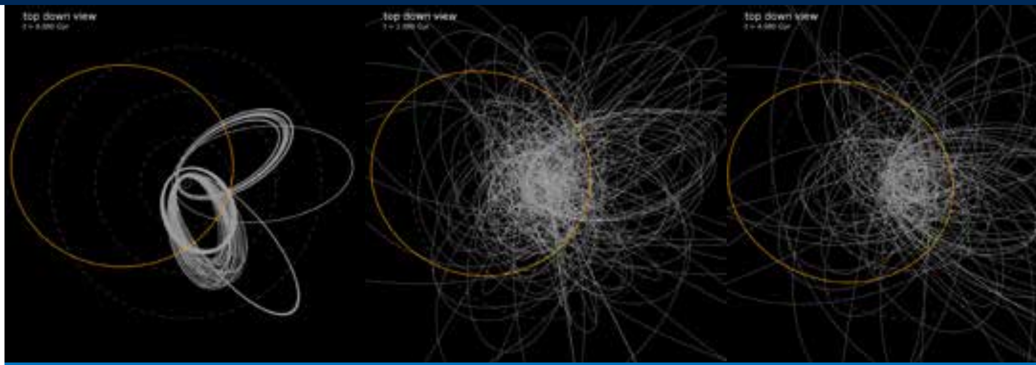
UVic graduate student Benjamin Gerard at the Gemini South Observatory.

ARC adjunct member Dr. Christian Marois preparing to work with the Gemini Planet Finder at the Gemini South Telescope.



The debris disk around HD 111520 in the near infrared H-band (1.6 microns) using GPI. The coronograph blocks the light from the bright host star (central circular region). The dim light from the circumstellar disk is seen edge-on, but with an unusual asymmetry. The northern extension of the disk is about twice as bright as the southern extension. Using total intensity and polarized light, in combination with multiple infrared bands, the dust size and composition can be characterized. *Credit: GPIES team & Zachary Draper, University of Victoria.*

Planetary Science: **The Search for Planet Nine**



Results from the work UVic graduate student Cory Shankman and colleagues. The orange ellipse marks the orbit of the proposed distant massive planet, and the light-gray ellipses show the orbits (with extra clones for uncertainties) of the six a > 250 AU KBOs. At the start of the simulation, all of the KBO orbits are clustered in physical space. As the simulation progresses, the orbits shear out and cover all angles. The proposed extra planet does not sculpt a confined alignment of orbits, even with the alignment present in the starting conditions. *Credit: Cory Shankman & the OSSOS collaboration*

One of the hottest topics in Solar System studies right now is what people are calling "Planet Nine". A hard to explain clustering in the orbits of the most distant Kuiper Belt objects (KBOs) has led many to invoke an as yet unseen planet for the solution. Hard to explain orbits have a storied history in Solar System studies, with extra planets having been invoked to explain a variety of phenomena to some degree of success. The peculiar orbit of Uranus led to the successful prediction of Neptune, but the peculiar orbit of Mercury found its solution not with the companion planet Vulcan, but in General Relativity. Right now the hunt is on to either find a new planet in the distant Solar System, or else to explain the source of the apparent clustering of the most distant KBOs.

The current wave of interest in an additional planet in the Solar System came from the new detections of distant KBOs. We now know of nearly 20 KBOs with semi-major axes, beyond 150 astronomical units (AU), with a handful of these beyond 250 AU and that the known KBOs with a beyond 150 AU have a clustering of pericentre angles of their orbits. This clustering should be randomized and shear out over time due to interactions with the giant planets, in particular Neptune, leading researchers to suggest that a planet could possibly maintain this confinement. In January of 2016, researchers noticed that the KBOs with a larger than 250 AU all group in physical space, and then demonstrated that a massive planet (10 times the Earth's mass) on a very distant orbit (750 AU) could provide a mechanism to maintain the confined orientation of KBOs in physical space. This launched a flurry of research activity with over 25 papers in 2016.

ARC members from UVic and NRC-Herzberg led several studies on the implications of such a planet on the known KBOs. One study, led by Plaskett Fellow and ARC associate member Dr. Samantha Lawler (with contributions from UVic PhD Candidate Cory Shankman, ARC adjunct faculty member Dr. JJ Kavelaars, and former ARC member Dr. Michelle Bannister) simulated the effects an additional planet would have on the formation of the Kuiper Belt and its observability today. They found that the additional planet would cause distant KBOs to be placed on highly inclined orbits and produce a large population of KBOs that have their closest approach to the Sun pulled out to distances of 50 AU or more. This study also examined the observability using the Canada-France Ecliptic Plane Survey, which was not sensitive to KBOs at the large distances where the planet would reshape the Kuiper Belt, and so was unable to provide an observational test of the extra planet hypothesis. This study did however provide robust predictions for future surveys.

In another study led by UVic PhD candidate Cory Shankman, the simulated behaviour of these KBOs in the presence of the proposed planet was examined over a timespan of billions of years. This study showed that an extra planet does not produce the clustering of orbits seen in the known KBOs, and that the planet would produce a massive reservoir of undetected high inclination KBOs. Both of these studies received wide attention, with interviews and mentions in articles by Scientific American, Science Magazine, Cantech Letter, and NPR.

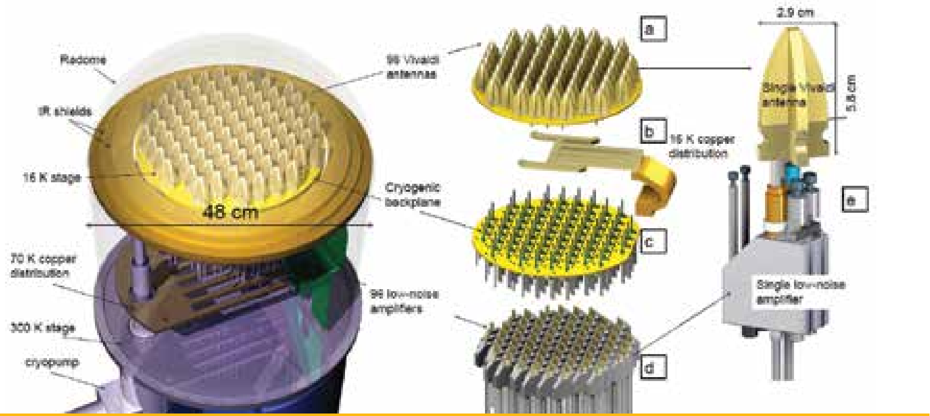
The search for an explanation to the peculiar apparent clustering of the most distant KBOs continues. Future KBO detections will reveal if the clustering is real or if it results from small numbers of detections and complicated biases. The Outer Solar System Origins Survey (OSSOS), a Canada-France Hawaii Telescope Legacy Project being led by Dr. JJ Kavelaars and Dr. Michele Bannister, is on track to discover hundreds of new KBOs, possibly shedding light on the clustering of the most distant KBOs.

Written by: C. Shankman & S. Lawler

For more information on the OSSOS survey please visit: **www.ossos-survey.org**

OSSOS Collaboration meeting in Beaune, France.
Credit: Michele Bannister & the OSSOS collaboration.

Radio Astronomy: **Phased-Array Feeds & The Future of Instrumentation**



Left panel: A phased array feed receiver. A cryopump cools the 96 copper antennas and low noise amplifiers from room temperature to 16 K. A dewar and composite radome maintain an extremely high vacuum. Incoming radiant heat is reduced through the radome with many layers of infrared shielding and concentric metal shields. *Image courtesy of R. Wierzbicki.*

Right panel: Antenna and amplifier assembly. The elements that are cooled to 16 K include (a) the metal antenna array, (b) the copper distribution system, (c) the backplane for thermal distribution and mechanical integrity, (d) and the low noise amplifier array. Details on a single bullet-style element with RF connector, axial release mechanism, and low noise amplifier body are shown in (e). *Image courtesy of R. Wierzbicki.*

The next generation of astronomical telescopes will require unprecedented levels of sensitivity and efficiency to answer fundamental astrophysical questions about subjects ranging from dark matter and the nature of gravity, to the origins of magnetic fields in space and the first stars. Radio astronomy offers a chance to investigate these questions in a different light, sampling the electromagnetic spectrum from wavelengths of tens of meters to well into the submillimeter regime. Responsible for discoveries ranging from of the cosmic microwave background in the 1960's, to the more recent discovery of an extrasolar planetary system forming about a distant young star (ALMA Partnership et al., 2015); much of the progress that's been made in the area of radio astronomy is owed to the technological development of the associated instruments.

From the beginnings of radio astronomy, detecting farther and fainter sources has pushed antenna and receiver technology to extreme limits. As a result, innovative research being done today at NRC Herzberg both in Victoria and in Penticton, has helped the most advanced radio telescope to date, the Atacama Large Millimetre Array (ALMA), "see" with the Band 3 receiver, and is contributing key technology to the ambitious Square Kilometre Array (SKA) project.

Two of the greatest challenges historically for radio astronomy are: the field of view of the telescopes and the sensitivity of the telescopes. The quest to improve and increase both these quantities has spanned more than 60 years. Ever-larger reflectors have increased the field of view and the steady progress in low-noise cryogenic amplifiers research has improved system sensitivity, however, both improvements have been technologically and cost limited. With regards to sensitivity, technology has now progressed such that the internally generated noise is now fast approaching the quantum limit and as such reducing receiver noise temperatures will do little more to increase performance and sensitivity.

With regards to increasing the field of view of radio telescopes, by combining radio dishes in groups of as many as 66, as is currently in use by ALMA, interferometry may be exploited to effectively simulate one giant dish. The next generation radio telescope, the SKA, also makes use of interferometry, combining many different elements to create a collecting area spanning one square kilometre. Imaging with this impressive telescope, effectively creating a "radio camera", is one of the key technologies being investigated by ARC member, Dr. Lisa Locke at the NRC Herzberg and ARC faculty member, Prof. Jens Bornemann.

Dr. Locke's research involves investigating phased-array feeds (PAF) in order to increase the number of focal plane elements and produce more synthesized beams on the sky. PAFs could allow for faster mapping speeds and therefore less time required to image extended sources or to complete large surveys of the sky, including surveys of transient, time sensitive, objects. Phased-array elements are packed tightly as electromagnetically, physically and economically as possible allowing for full Nyquist sampling of the imaged area in one observation, instantaneously, maximizing the survey speed. Older technology such as multi-beam feed horns, which can increase the field of view by a factor equal to the number of horns, suffer from large apertures that create a non-uniform image necessitating costly interleaved pointings. In contrast, PAFs require only one imaging pass, reducing the imaging time by an order of magnitude. This is a result of the primary contribution of PAFs, a fully Nyquist sampled field of view, where the Nyquist sampling rate is the ideal rate to recover as much information as possible from the signal.

Today, PAFs are not only being investigated for the future of astronomy, in the SKA and perhaps other collaborations, but also in the current generation of telescopes, as the technology could be worked into existing instruments. In addition to the research being done at NRC-Herzberg and UVic, institutes within the United States, Netherlands and Australia are also investigating the power of PAFs. The promise of PAFs to improve radio astronomy is real and could lead to significant discoveries using both the current, and next generation of telescopes.

Written by: S. Monty & L. Locke

For more information on the SKA telescope & PAFs please visit: **www.skatelescope.ca**

Dr. Lisa Locke sets up a near-field antenna measurement in the millimetre-wave lab at NRC Herzberg. The device under test is a commercial 2-18 GHz dual linear Vivaldi antenna.

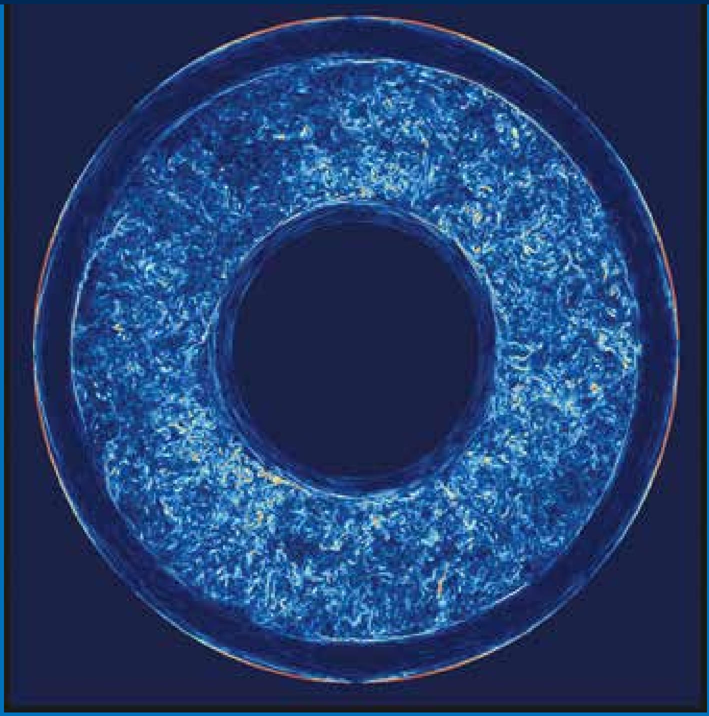
Computational Stellar Astrophysics: **Hydrodynamics and Nucleosynthesis of Stars**

The computational stellar astrophysics group investigates how stars evolve, how the elements are made at various times in the universe, and how the different nuclear astrophysics sources contribute to the chemical enrichment of the Universe. Research topics range from the hydrodynamics of convection in stars and the interaction of convection with nuclear burning, to the origin of the elements in stars and stellar explosions, as well as in interacting binary stars, such as merging white dwarf stars and nova.

Among the highlights of the group's recent research are results from the accreting white dwarf program and in the area of stellar hydrodynamics. Group members investigate exotic nucleosynthesis processes in order to explain unresolved questions in nuclear astrophysics, such as nucleosynthesis in rapidly accreting white dwarfs, or convective-reactive nucleosynthesis in massive stars. Such nuclear astrophysics simulation predictions are then tested and embedded in chemical evolution models of dwarf galaxies and the Milky Way. One of the goals is to provide reliable yields of nuclear production for a wide range of sources that can be used to study the chemical evolution of galaxies.

The research in stellar hydrodynamics was initially focused on low-mass stars, but more recently open problems in massive stars have been approached. Dr. Sam Jones and the group report on the highest-resolution 3-dimensional 4π simulations of the oxygen-burning convective shell in a star with an initial mass of 25 solar masses. A series of medium-resolution runs allowed the determination of scaling relations to be used for building more advanced models of convection. Based on high-resolution simulations a model for mixing at convective boundaries was calibrated that can now be directly applied in global long-term stellar evolution simulation. This will improve the predictive power of stellar models, as well as the understanding of how the elements form in stars.

The group has been involved in investigations of nuclear burning on top of white dwarfs, both in binaries and single stars, for many years now. The latest result of this research program are new stellar evolution simulations lead by ARC associate member Dr. Pavel Denissenkov that follow the evolution of rapidly accreting white dwarfs through many He-shell flashes for the first time. These flashes have been suspected to cause further troubles to the single-degenerate evolutionary scenario to form supernova of type Ia. The new simulations show that despite accretion in the stable H-burning regime He-shell flashes in these objects prevent the mass of the white dwarf to grow sufficiently within the available time to ever explode as a white dwarf supernova. Instead, our models predict that such rapidly accreting white dwarfs may produce neutron-capture elements in the intermediate neutron density regime. The possible importance of this so-called "i-process" for galactic chemical evolution is presently investigated. Preliminary estimates suggest that the newly discovered i-process in rapidly accreting white dwarfs may be as important as the well–studied low-mass giant stars for some elements.



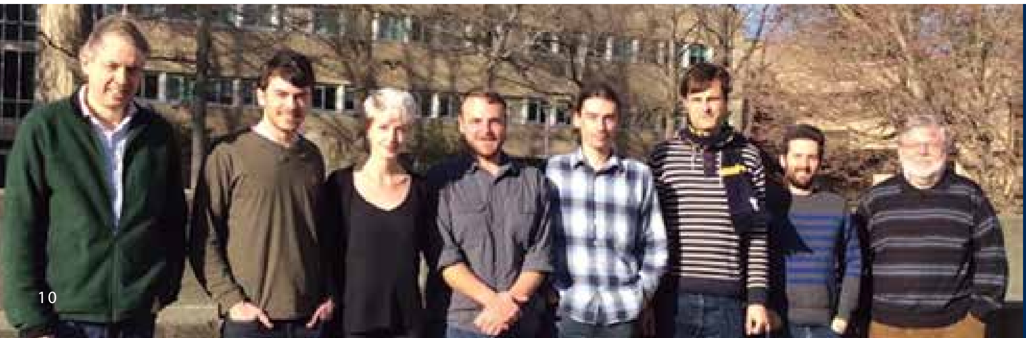
A volume rendering of the vorticity of an oxygen-shell convection zone. From the outside is the domain boundary, a stable layer, the convectively unstable region, a rather thin stable region below the turbulent convection zone and the inert core can be distinguished. *Image with permission from Dr. Sam Jones.*

This research is based on designing, performing and analyzing computer simulations, including the necessary software tools. The research group takes advantage of the computational resources provided by WestGrid and Compute Canada. UVic Professor and ARC faculty member Prof. Falk Herwig is significantly involved with CANFAR. The group is an active node and founding member of the international NuGrid collaboration. The research program is supported by and integrated with the NSF Physics Frontier Center Joint Institute for Nuclear Astrophysics – Center for the Evolution of the Elements (JINA-CEE). A long-term collaboration with the Laboratory for Computational Science and Engineering at the University of Minnesota provides the context for the work on large-scale computer simulations that aim to understand dynamic mixing processes in stars.

Written by Prof. Falk Herwig, with input from Dr. Pavel Denisenkov, Dr. Robert Andrassy, Dr. Benoit Côté, Christian Ritter, Austin Davis, and Ondrea Clarkson.

Edited by K. Venn & S. Monty

For more information, see
CSA : **http://csa.phys.uvic.ca** NuGRID: **http://www.nugridstars.org**



Members of the computational stellar astrophysics group, from left to right, Prof. Falk Herwig, Adam Paul, Ondrea Clarkson, Austin Davis, Dr. Robert Andrassy, Christian Ritter, Dr. Benoit Côté, and Dr. Pavel Denisenkov.

Nuclear Astrophysics
and DRAGON

Drawing from theoretical and computational astronomy and theoretical and experimental nuclear physics, nuclear astrophysics is a multidisciplinary field exploring the very building blocks of our universe. Through probing the inner workings of stars, via experimentation and simulation, nuclear astrophysics aims to answer questions regarding the origin and evolution of the chemical elements. Responsible for synthesizing and populating the universe with all the elements heavier than hydrogen and helium, with the exception of lithium, the processes involved in stellar nucleosynthesis and eventual death are active areas of research at TRIUMF: Canada's national laboratory for particle and nuclear physics and accelerator-based science.

TRIUMF's Nuclear Astrophysics Group is comprised of a large group of dedicated scientists and post-doctoral fellows. Included are ARC adjunct members, Dr. Chris Ruiz and Dr. Iris Dillmann and ARC associate Dr. Barry Davids. Amongst their many projects the DRAGON recoil mass spectrometer allows for the direct study of the nuclear reactions occurring in stars and their explosions. Installed in 2000 and operational since 2001, the DRAGON (Detector of Recoils And Gammas Of Nuclear reactions) facility, led by Dr. Ruiz since 2007, works in tandem with ISAC-I (Isotope Separator and Accelerator) facility to study nuclear reactions fuelled by the ISAC-generated rare-isotope beams. More specifically, DRAGON studies radiative proton- and alpha- capture reactions by sending the ion beam through a chamber filled with hydrogen or helium. The types of reactions were chosen specifically because of their relevance to stellar phenomena including novae, supernovae and x-ray bursts.

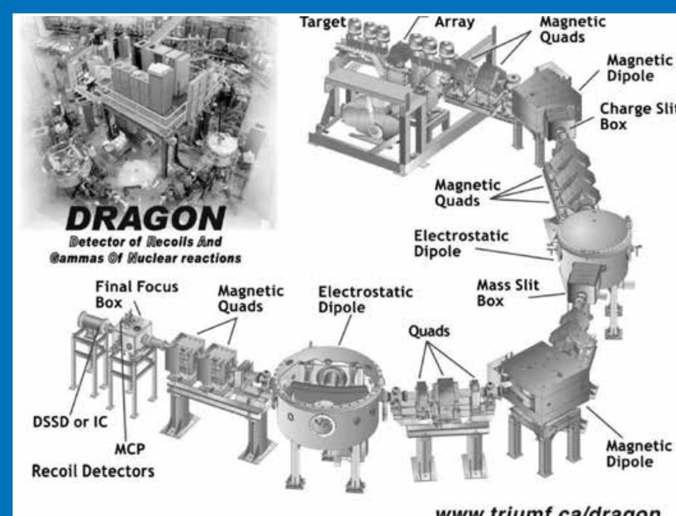
Filtering and separating reaction products from the incoming beam is done using magnetic and electric dipole devices. DRAGON typically has a very high separation capability, where it can reject one trillion beam particles for each reaction product it detects. DRAGON has contributed to processes ranging from the production and destruction of oxygen-16, an element associated with the latter helium-burning era of a stars life, to the abundance and production of fluorine-18, an element associated with cataclysmic thermonuclear blasts in white dwarf binary systems known as classical novae.

Exploring the many facets of nuclear astrophysics, through the use of world class experimental facilities, ARC member scientists at TRIUMF, have had an inside look at the processes that produce the fundamental building blocks of our universe. The DRAGON facility allows nuclear astrophysicists to study the inner workings of stars inside a lab. Involving many people, fostering an excellent environment for collaboration across disciplines and institutions, projects like DRAGON are not only instrumental in furthering the field of nuclear astrophysics, but also a perfect example of the goals behind the formation of the ARC. In the coming years, ARC is excited to support the research being conducted by the scientists and collaborators of the TRIUMF Astrophysics Group.

Written by: S. Monty
Edited by: C. Ruiz & Iris Dillman

For more information on the nuclear astrophysics group at TRIUMF and the DRAGON facility, please visit: **www.astro.triumf.ca**

ARC associate member Dr. Chris Ruiz and TRIUMF engineer Peter Machule contemplating DRAGON(s).



Located in the ISAC facility at TRIUMF in Vancouver, British Columbia, DRAGON is an apparatus designed to measure the rates of nuclear reactions important in astrophysics. Of particular interest are the reactions that made the elements around us; the nucleosynthesis reactions, which occur in the explosive environments of novae, supernovae and x-ray bursters.

Outreach:
The UVic Observatory

Student volunteers in front of the UVic 32″ telescope.

The UVic Observatory has a history of active public outreach and community engagement initiatives spearheaded mainly by the senior astronomy lab instructor, Russ Robb (now retired). The tradition of the Wednesday night open house at the observatory was established by him and continues actively even after his retirement in 2015, following 32 years of service. In 2015-2016, Steve Mairs, a UVic doctoral scholar in astrophysics assumed the responsibility of astronomy public outreach for the department. Along with maintaining a level of superb commitment to all the ongoing outreach work, Steve also developed several new educational initiatives. In July 2016, ARC associate Dr. Karun Thanjavur accepted the position of senior astronomy lab instructor in the department.

The Wednesday night open house continues to form the centerpiece of the outreach efforts at the UVic observatory. Every Wednesday night, rain or shine, the new observatory, located on the fifth floor of the Bob Wright building is open to the general public. The open house events are run by three undergraduate students hired for the year on a work-study program through the department. In addition, several undergraduate volunteers also participate and help out just for their love of astronomy and public education.

On clear summer nights, well over fifty people, local residents and out of province visitors alike, pass through the Open House. More surprisingly, even on a dismal winter nights, cold and rainy, we have ten or fifteen visitors, who join us just to talk about astronomy. There is a large range in ages and diversity in backgrounds of the people who attend the Open House, but the central love of astronomy draws us all together.

We also host on average one or two observatory tours each week for special groups, such as Girl Guides or Cubs, school groups, science camps, etc. In 2017, we plan to extend these outreach events with more school visits, e.g., organizing a mini-star party at a school using a few of the portable Celestron 8″ telescopes and introductory astrophotography sessions.

cosmology, we have also initiated closer ties with the ongoing VICTA (Vancouver Island Cosmic Ray Telescope Array) outreach initiative led by Dr. Lyle Robertson in the UVic Physics department. Detectors for the muon showers from cosmic ray events will be installed in the UVic Observatory in the Bob Wright building, in order to complement the one already in operation in the department. The UVic Observatory is an excellent teaching, research and outreach facility on our campus.

Written by: K. Thanjavur

For more information please visit: **www.uvic.ca/research/centres/arc/outreach/astronomy-open-house**

A calendar of events such as viewings of eclipses and planetary transits can be found on the UVic Observatory Facebook page.

CULT: Committee for Upgrading the Learning Telescopes

The CULT is an association of 15 students, both graduate and undergraduate, seeking to develop and enhance the capabilities of the UVic telescopes. The committee is passionate about observational astronomy and driven to develop their skills in areas such as astrophotography, instrumentation, scientific project development, and public outreach.

Inaugurated in 2015 by UVic graduate students Steve Mairs and Sébastien Lavoie, the group seeks to motivate young scientists to turn their gaze to the stars by refurbishing older telescopes and developing practical systems that aid in scientific observations. With more than twenty functional telescopes on campus including the 20″ Climenhaga Observatory, the 32″ UVic Observatory, and a large helio-stat, the CULT has no shortage of work and no lack of vision.

Several projects are underway including building and installing rain sensors on the largest observatory, designing a guidance system for the 32″ telescope, stabalising the helio-stat for high quality data collection, cleaning and restoring telescopes built nearly 30 years ago, and developing software to automate nightly observations of interesting stellar systems such as binaries or exoplanet candidates.

Recently, the CULT has also assisted in acquiring a research grade spectrograph for the UVic observatory. This new device would allow students to pursue publishable thesis projects on campus. The CULT has been engaged in bringing staff at UVic together with staff at the NRC Herzberg to discuss the technical challenges such as how to properly fibre feed the instrument and how to design the data collection pipeline.

Another exciting project led by UVic students Levente Buzas, Mojtaba Taheri, Kali Salmas, and Nic Annau is the University of Victoria's first astronomy calendar that will be released at the end of 2017. This industrious team, supported in part by funding through the ARC, has put together a suite of equipment to capture high-calibre photos of astronomical objects taken near Victoria, BC.

The CULT is always open to suggestions for projects. If you'd like to be involved, or you would like to know more, contact Steve Mairs at **smairs@uvic.ca**.