CAS HONOURS PROJECT LIST 2023

Properties of different types of stars in strong emitters in the local Universe

Supervisor: Dr Themiya Nanayakkara
Contact: wnanayakkara@swin.edu.au

Project description: Wolf-Rayet (WR) stars (https://astronomy.swin.edu.au/cosmos/w/wolf-rayet+star) are helium burning very hot stars. These stars are generally observed at higher metallicities. However, recent stellar population models suggest that due to effects of binaries, these stars could also be formed at lower metallicities. This may have implications to our understanding of stellar populations in the early Universe. If these types of stars were also prominent at early times, galaxies would produce more high energy photons ionising the gas in and around galaxies. Thus, understanding the properties of WR stars and linking them to galaxy properties is an important step in constraining the contribution of galaxies to the reionisation of the Universe. In this project, you will use data from the MAGPI survey (https://magpisurvey.org/) to explore properties of galaxies that show features of WR stars. By studying the stellar population properties of WR host galaxies and comparing them with the overall galaxy population obtained by MAGPI, this project will make empirical calibrations that can be used to determine how high energy photons are produced in galaxies near and far. You will be able to collaboratively work with the MAGPI team, an Australian led international project and will have the opportunity to contribute to various aspects of ancillary science as well. Previous experience in programming (e.g. python) would be useful for this project.

What cool objects are we missing in the Universe?

Supervisor: Dr Themiya Nanayakkara
Contact: wnanayakkara@swin.edu.au

Project description: We can build up the story on the Universe evolved by studying the nature of different types of galaxies in various cosmic epochs. To do that we need to perform deep observations of the Universe and develop novel methods to identify sources that are not easy to spot. In most cases these faint sources are also extreme sources in the Universe and detecting and studying them is a crucial piece in completing the cosmic puzzle. However, different ways we use to find these sources that are hiding away are not all the same and they can have systemic biases. In this research project you will use a set of recent observations from the MUSE spectrograph of the Very Large Telescope to find if there are systemic differences in the types of objects discovered in the early Universe when different source detection techniques are used. You will be able to collaboratively work with the MAGPI team (https://magpisurvey.org/), an Australian led international project and will have the opportunity to contribute to various aspects of ancillary science as well. Previous experience in programming (e.g. python) would be useful for this project.

Studying the companions of accreting neutron stars and black holes

Supervisor: Dr Simon Stevenson
Contact: spstevenson@swin.edu.au

Project description: Neutron stars and black holes can accrete material from their companion stars, powering X-ray binary phases, and potentially spinning up the compact object, causing it to rotate rapidly. If the neutron star is a pulsar, this may be observed as a binary millisecond pulsar. In low-mass X-ray binaries, the companion star has a mass less than, or equal to the mass of the Sun. The orbit of the binary shrinks over time due to a combination of several processes, including mass lost during the mass transfer phase, energy emitted in the form of gravitational waves, and magnetic braking. The companion star can be potentially inflated by irradiation from the pulsar, or from energy deposited into the star through tides. You will perform detailed binary stellar evolution calculations using the one-dimensional stellar evolution code MESA to study the evolution of the companion star in accreting neutron star and black hole systems. You will compare your models to observed populations, including the binary millisecond pulsars (including black widow and redback binaries), accreting millisecond X-ray pulsars and low-mass X-ray binaries.

Further reading:

- Fragos and McClintock 2015, ApJ 800 17 'THE ORIGIN OF BLACK HOLE SPIN IN GALACTIC LOW-MASS X-RAY BINARIES' https://arxiv.org/abs/1408.2661

Improved modelling of the progenitors of gravitational waves

Supervisor: Dr Simon Stevenson
Contact: spstevenson@swin.edu.au

Project description: Gravitational waves from merging neutron stars and black holes are now regularly being observed. The progenitors of these compact binaries may be massive, isolated binary stars in the Galactic field. In this project you will use the rapid binary population synthesis code COMPAS to study the formation of merging neutron stars and black holes. You will make updates to the model (e.g., incorporating new mass loss rates of red supergiants, or updating the properties of chemically homogeneously evolving stars etc) and investigate the impact of this change on the properties of merging neutron star and black hole binaries. Finally, you will compare your models to the observed gravitational wave population so far (GWTC-3), and make predictions for what will be observed in the upcoming observing run (O4).

Further reading:

- Stevenson et al. 2017, Nature Communications 8, Article number: 14906 (2017) https://arxiv.org/abs/1704.01352

Exploring the realm of transients

Supervisor: Dr Anais Moller
Contact: amoller@swin.edu.au

Project description: Exploding stars and bursts of radiation, called *transients* due to their limited timespan, provide information on the extreme and fundamental physics of the Universe. They create chemical elements, stars and galaxies. In this project we will use the data from one of the large transient surveys in the world, Zwicky Transient Facility, detecting up to 1 million transients per night. We will use Fink broker to explore this data and study properties of different types of transients including supernovae as well as new types of transients. We will study their properties as they evolve over time. In this project you will develop coding, statistics and analysis skills to disentangle unique classes of transients and their properties.

Further reading:

- Fink, a new generation of broker for the LSST community https://ui.adsabs.harvard.edu/abs/2021MNRAS.501.3272M/abstract
- Rapidly evolving transients https://ui.adsabs.harvard.edu/abs/2018MNRAS.481..894P/abstract

Transient classification with Machine Learning

Supervisor: Dr Anais Moller
Contact: amoller@swin.edu.au

Project description: We are entering into a new era for astronomy with optical surveys discovering thousands to millions transients per night. Transients appear suddenly, and then fade over hours and weeks until they are no longer detectable; enriching the Universe with chemical elements and outshining galaxies. This is a great opportunity to observe and understand extreme physical processes in our Universe, but also a big challenge due to the volume and complexity of the data. In this project you will develop and/or adapt machine learning algorithms to select exotic transients in big data. You will work with machine learning algorithms, simulations and data from large optical surveys. Your work will be part of the Fink broker, selected to receive the data from the largest optical survey on Earth for the next decade. If you have some experience with machine learning/coding, want to expand your skills and are interested on exploring exciting transient events in the Universe… this project is for you!

Further reading:

- Fink, a new generation of broker for the LSST community https://ui.adsabs.harvard.edu/abs/2021MNRAS.501.3272M/abstract
- SuperNNova: an open-source framework for Bayesian, Neural Network based supernova classification https://ui.adsabs.harvard.edu/abs/2020MNRAS.491.4277M/abstract

Detecting gravitational waves from core-collapse supernovae

Supervisor: Dr Jade Powell
Contact: jpowell@swin.edu.au

Project description: The first detections of gravitational waves were made during the last few years. The sources of those gravitational waves were binary neutron stars and black holes. Gravitational wave detectors are currently offline to improve their sensitivity for their next observing run. As the detectors become more sensitive, they may begin to detect gravitational waves from other sources. One of those potential sources is a nearby core-collapse supernova. Supernovae are a perfect multi-messenger source as they can be detected electromagnetically and in gravitational waves and neutrinos. A gravitational wave detection may tell us about the mechanism driving the explosion. In this project, you will develop data analysis techniques for the detection and parameter estimation of core-collapse supernovae in data from the LIGO and Virgo gravitational wave detectors.

Testing Einstein with an extreme binary pulsar

Supervisor: Dr. Andrew Cameron
Contact: andrewcameron@swin.edu.au

Project description: When found in binary systems, pulsars (rapidly-rotating, highly-magnetised neutron stars which emit radio pulses as they spin) can prove to be excellent laboratories for testing theories of gravity under extreme conditions. These systems can display a number of relativistic effects over short time scales, which when measured can then be used to test the predictions of different gravitational theories, such as Einstein's General Relativity (GR). This project will involve analysing a specific binary pulsar (PSR J1757-1854) in order to conduct such tests. The student will analyse a large dataset from both the Green Bank Telescope (USA) and the MeerKAT interferometer (South Africa) in order to advance the constraints on GR that this pulsar can provide, directly building on (and also testing the results of) earlier research. Multiple avenues of study are possible here depending on the student's preferences and the time available, including:

- Confirming whether changes in the pulsar's emission profile caused by relativistic effects are continuing as expected from previous studies.
- Improving the precision of relativistic tests which rely on measuring changes in the pulse arrival times.

This project will involve extensive data analysis using custom software. Prior knowledge of programming (e.g. Python) and command-line environments (e.g. Linux) will be useful but not essential, as there will be plenty of opportunity for learning along the way.

Further reading:

- Cameron et al. 2018 (https://arxiv.org/abs/1711.07697)
- Cameron et al. 2022 (https://arxiv.org/abs/2203.15995)

Dark Matter and Massive Galaxies

Supervisor: Dr Tania Barone
Contact: tbarone@swin.edu.au

Project description: What is dark matter and how much of it can be found in galaxies are two open questions that are still puzzling astronomers. We can study dark matter by comparing the total mass of a galaxy with how much mass we can actually see (in stars and gas). But how do we measure what we can't see? For some galaxies, a rare chance alignment with another background galaxy gives us a unique opportunity to measure its gravitational influence, and therefore its total mass. When a massive foreground galaxy happens to perfectly align in front of another background source, the foreground target gravitationally lenses the light from the background galaxy. From this gravitational lensing effect, we can precisely measure its total mass: dark matter and all. We have a growing sample of these rare massive lensing galaxies as part of the ASTRO 3D Galaxy Evolution with Lenses (AGEL) survey. The project will involve comparing the measurements of the stellar mass and the total mass of our lensing galaxies to uncover the dark matter hiding within. We'll predominantly be using Python to study the data. Prior Python experience would be useful but definitely not a requirement, as you'll learn along the way. As part of this project you'll get to be part of a diverse and friendly research team that spans multiple universities and continents!

Axion Dark Matter Detection

Supervisor: Dr Ben McAllister
Contact: bmcallister@swin.edu.au

Project description: The nature of dark matter is one of the biggest mysteries in modern science – it makes up five sixths of the matter in the Universe, and is of unknown composition. It surrounds and passes through the Earth at all times. Axions are a hypothetical particle, and one of the leading candidates for dark matter. Swinburne is building a new axion detector to try and measure small effects induced by dark matter when it passes through the laboratory, and shed light on the mystery. The kind of experiment we are building is called an axion haloscope. The detector is being physically constructed and will be hosted at Swinburne – but work needs to be done on various aspects of the project, from detector characterisation, to control software and data analysis. This project could focus on any of these areas, tailored to fit the skills and interests of the student. There is room for multiple students, and you will be working in a small team with other researchers. You may be working with laboratory equipment, on code to control the experiment, or on a pipeline to acquire and tease through experimental data for hints of new physics.

How Do Exploding Stars Reshape Galaxy Evolution?

Supervisor: A/Prof Deanne Fisher
Contact: dfisher@swin.edu.au

Project description: Supernovae are among the most energetic events in the universe, typically outshining the galaxy they occur in. While very uncommon in our own Milky Way, supernovae happen very often in so-called "star-burst" galaxies that are making new stars at 10-100 times the rate of the Milky Way. In these galaxies, clusters of supernovae explode in the disk, the combined energy and momentum pushes gas up out of the spiral galaxy and into the halo above the disk. This changes the properties of the galaxy, and is considered by most theories to be a linchpin that regulates the growth of galaxies. We view this as faint filaments of gas that extends above star forming galaxies. In this project we will study this gas. The physical properties of the gas directly relate to the physical models of how these large outflows of gas evolve and shape outflows. We will use data from a new Large Program on the Very Large Telescope, an 8 meter telescope in Chile, to study the outflowing gas. The student will be part of an international team that includes astronomers in Europe, USA and Australia. The student will develop skills in python and "datacube" analysis in astronomy. At Swinburne they will work in a team of 4 HDR students and 2 postdocs, along with myself. This is a large program with scope for multiple projects of students.

Further reading:

- Rupke et al 2019 Nature https://arxiv.org/abs/1910.13507
- Galactic Winds Dictating Galaxy Evolution – 20 min Lecture by L. Zscaechner https://www.youtube.com/watch?v=hqpLWgRMdw0
- How Feedback Shapes Galaxy Evolution – 1 hour lecture by Prof Christy Tremonti https://www.youtube.com/watch?v=ODZ_dfe2r7I

Choose Your Own (Data-Intensive Space) Adventure

Supervisor: Prof Christopher Fluke
Contact: cfluke@swin.edu.au

Project description: Advanced Visualisation. Virtual Reality. Artificial Intelligence. Machine Learning. Human-Machine Teaming. Earth Observation. Space Domain Awareness. Space Systems. Augmented Human Performance. Cyber-Human Discovery Systems. Data-Intensive Space Applications. If any combination of these phrases captures your imagination, then this is your opportunity to co-create a customised Honours Project targeting augmented human-machine performance in the era of data-intensive space applications.

Further reading:

- Fluke, C.J., Hegarty, S.E., MacMahon, C.O.-M., 2020, "*Understanding the human in the design of cyber-human discovery systems for data-driven astronomy*", Astronomy & Computing, Vol 33, article id. 100423, see https://ui.adsabs.harvard.edu/abs/2020A%26C....3300423F/abstract

Measuring the non-uniform expansion of space-time!

Supervisor: Prof Chris Blake
Contact: cblake@swin.edu.au

Project description: The standard model of the Universe assumes that space-time expansion is everywhere uniform – the Universe is "homogeneous and isotropic". This basic assumption allows us to solve Einstein's equations of General Relativity and determine how the Universe expands over time. However, the actual Universe is clumpy – full of galaxy clusters, filaments, walls and voids. In this Project, we'll aim to detect the influence of this clumpiness on the expansion of space. First, we'll use a large galaxy redshift survey, which provides a map of cosmic structure across a large volume of the Universe, to divide space into structures with different environments, which may expand differently. Then, we will measure the imprint of the "baryon acoustic oscillation" signal – a standard ruler used to determine cosmic distances – across these different structures. This will allow us to test whether the distance between galaxies on either side of a void, or a cluster, expands differently with time! This Project will allow you to develop research skills such as python coding, statistical analysis, handling large datasets, and reviewing the scientific literature.

Next generation weak lensing cosmology

Supervisor: A/Prof Edward Taylor
Contact: entaylor@swin.edu.au

Project description: Weak gravitational lensing is a central tool for observational cosmology, and now a primary focus for billion dollar projects/missions including VRO-LSST, Euclid and Nancy Grace Roman Space Telescope. With deep imaging over very large areas and systematics now well controlled, conventional lensing is approaching the `shape noise' limit; the statistical limit set by the natural size/shape distribution of distant galaxies. In Gurri et al. (2020, 2021), we have now demonstrated a new approach to precision weak lensing measurements based on resolved spectroscopy that can push well past the shape noise limit. Xu et al. (2022) have shown the potential for applying our analysis to spectroscopy that will be collected as a matter of course by the Euclid and Roman space telescopes, with improvements of a factor of 1.7 for mass clustering, and of 3.65 for the dark energy equation of state relative to conventional approaches. The focus of this project will be a pilot cosmic shear experiment using existing data from two large surveys with the VLT's MUSE integral field spectrograph. The first goal will be just to quantify the limiting precision (the equivalent of shape noise) for our techniques applied to high redshift galaxies to demonstrate proof of concept and inform the design of future experiments. But with ~1500 high-redshift galaxies, we actually have a fighting chance at a detection of the cosmic shear signal. This project will be done in collaboration with Eric Huff at NASA's Jet Propulsion Laboratory and PhD student Vanshika Kansal.

Further reading:

- Gurri P et al., 'The first shear measurements from precision weak lensing', 2020, MNRAS 499, 4591

- DiGiorgio B et al., 'A novel framework for modelling weakly lensing shear using kinematics and imaging at moderate redshift', 2021, ApJ 922, 116
- Xu J et al., 'Kinematic lensing with the Roman Space Telescope', 2022, arXiv:2201.00739
- Muse wide survey: http://muse-vlt.eu/science/muse-wide-survey/
- MAGPI MUSE large program: https://magpisurvey.org/

Connecting galaxies to their larger dark matter halos: the stellar-to-halo mass relation

Supervisor: A/Prof Edward Taylor
Contact: entaylor@swin.edu.au

Project description: We now understand every galaxy to form and reside at the centre of a larger, diffuse halo of dark matter. As far as we know, the properties of dark matter are very simple: no interactions with itself or other matter except through gravity. This makes dark matter easy to model, but very difficult to observe. By contrast, galaxies are easy enough to find and measure, but disentangling the many and varied mechanisms that influence their formation and evolution is a wicked problem. The focus of this project will be to map out the connection between galaxies and their halos by combining dark matter statistics from large cosmological simulations with statistics of the galaxy population in the local universe. The first task will be to derive a new measurement of the number of galaxies in the nearby Universe as a function of their stellar mass. The ultimate goal will be to measure the stellar-to-halo mass relation; that is, how the total mass of stars within a galaxy depends on the mass of its parent dark matter halo (and vice versa). As the conceptual link between the observed galaxy population and the cosmological population of dark matter halos, the stellar-to-halo mass relation represents a crucial interface between observation and theory: especially in how models are calibrated and/or validated. A stretch goal will be to extend this analysis to include recent precision weak lensing results from Gurri et al. (2020, 21), which (surprisingly!) seem to point to a much weaker correlation between stellar and dark matter than suggested from past studies and simulations.

Further reading:

- van Uitert E et al., 'The stellar-to-halo mass relation of GAMA galaxies from 100 deg2 of KiDS weak lensing data' 2016, MNRAS 459, 3251
- Dvornik A et al., 'KiDS+GAMA: The weak lensing calibrated stellar-to-halo mass relation of central and satellite galaxies', 2020, A&A 642, A83
- Gurri P et al., 'Shape noise and dispersion in precision weak lensing', 2021, MNRAS 502, 5612
- Zacharegkas, G et al., 'Dark Energy Survey Year 3 results: galaxy-halo connection from galaxy-galaxy lensing', 2022, MNRAS 509, 3119
- Scholz-Diaz L et al., 'The dark side of galaxy stellar populations - I. The stellar-to-halo mass relation and the velocity dispersion-halo mass relation', 2022, MNRAS 511, 4900

The origin of the present-day galaxy population

Supervisor: Prof Darren Croton
Contact: dcroton@swin.edu.au

Project description: This project will use state-of-the-art galaxy formation simulations and models to understand the birth and early life of the Milky Way and Milky Way-type galaxies. It will focus on the time covering the end of reionisation and cosmic dawn (z~6) until the peak of the first great wave of star formation at cosmic noon (z~2). We will ask: What were the conditions for the birth of the Milky Way like? What environment was the Milky Way born into? Did it grow fast or slow? Was its early life violent or quiet? The project has 5 parts: (1) undertake a literature review of our current understanding of the Milky Way and similar type galaxies; (2) to review the theory of how galaxies form and evolve across cosmic time, with a focus on the relevant physical processes; (3) to construct a model universe with the (existing) SAGE galaxy formation code run on the OzStar supercomputer at Swinburne; (4) using this model, to build a population of Milky Way-type galaxies as seen in the present day; and (5) track these galaxies back in time to their birth at cosmic dawn, and explore the diverse paths such galaxies follow as they evolve across their lives. Additional goals will be to develop a solid understanding of galaxy evolution and cosmology, become familiar with supercomputer simulations and models, and the technical skills required to create and use them for science.

Supermassive black holes in galaxies across cosmic time

Supervisor: Prof Darren Croton
Contact: dcroton@swin.edu.au

Project description: Every galaxy appears to host a supermassive black hole at its centre. Such black holes only make up a tiny fraction of a galaxy's overall mass despite their impressive name. However, in their active phase (AGN), supermassive black holes can release so much energy that they can shut down the production of new stars across the entire galaxy, often permanently. So understanding AGN and how supermassive black holes occupy galaxies is critical to understanding galaxy evolution itself. This project has 5 parts: (1) undertake a literature review of our current understanding supermassive black holes, both theory and observation; (2) to review the theory of how galaxies form and evolve across cosmic time, with a focus on the relevant physical processes; (3) to construct a model universe with the (existing) SAGE galaxy formation code run on the OzStar supercomputer at Swinburne; (4) using this model, measure how black holes populate galaxies across a wide mass range and at different redshifts; and (5) compare these results to observations and make predictions for what telescopes like JWST will see. Additional goals will be to develop a solid understanding of galaxy evolution and cosmology, become familiar with supercomputer simulations and models, and the technical skills required to create and use them for science.

Cosmology with the Hubble Space Telescope

Supervisor: Prof Karl Glazebrook
Contact: kglazebrook@swin.edu.au

Project description: Using the Hubble Space Telescope (HST) we are observing 100 new gravitational lens systems. Of particular interest is to look for 'double source plane lenses' (DSPL) where a single elliptical galaxy magnifies two different galaxies at significantly different redshifts. Every DSPL provides strong constraints on the cosmological parameters via the ratio of angular distance (from lensing) to redshift, however only three DSPLs are known. In this project you will (1) visually inspect all the HST images to make a catalog of DSPL candidates for redshift measurements, (2) participate in Keck observing to get redshifts (timing of follow-up permitting), (3) make simulations of constraints on cosmological models from large DSPL samples - with particular attention to looking at Early Dark Energy models.

Optical Site Testing for Robotic Telescopes

Supervisor: Prof Karl Glazebrook
Contact: kglazebrook@swin.edu.au

Project description: Demand for future optical observing facilities dedicated to survey and fast response trigger follow up is only likely to increase. One such facility is the Gravitational wave Optical Transient Observer (GOTO), a project which is hoped eventually to consist of a pair of instruments, one in La Palma, Canary Islands, and one in Australia. Analysis of meteorological and elevation data from across Australia has revealed potentially the best optical observing site on the continent, in the Hamersley Range in northwest Western Australia. This project involves working with a special a special lightweight telescope and high frame rate camera we have assembled which is designed to be transported to remote sites and measure seeing. Goals:

- Develop improved analysis code and automate based on current software stack and existing on-sky test data.
- Transport telescope to dark sites around Victoria and further around Australia to greatly expand the dataset and externally validate the method, including possibly the Hamersley range if things go well. This would result in a publication demonstrating about seeing measurement and site quality.

This project is most suitable to students who like to get their hands dirty with small telescopes and have a taste for outdoor adventure in science. The project would be in collaboration with Prof. Roberto Abraham and Professor Duncan Galloway of Monash and could lead to commercial applications ('Southern Hemisphere Seeing Monitor').

Further reading:

- Hotan C. E., Tingay S. J., Glazebrook K., 2013, Testing Potential New Sites for Optical Telescopes in Australia, Publications of the Astronomical Society of Australia, 30, e002.

Quantifying morphology in James Webb Space Telescope infrared imaging

Supervisor: Dr Colin Jacobs
Contact: colinjacobs@swin.edu.au

Project description: The James Webb Space Telescope has recently started its observational program and is already having a major impact in the study of galaxy evolution. The JWST's infrared images have revealed snapshots of galaxy structure that were previously inaccessible even to the Hubble Space Telescope, and some of what we see from the Universe's early epochs are surprising, with hints that the shapes we see in the modern universe are forming earlier than we expected. Several tools are available to use to investigate the morphologies of these high-redshift galaxies, including parametric (e.g. GALFIT, Peng et al 2010 - fitting a light model) and non-parametric (making direct measurements from the images - e.g. Conselice 2006). In this project, we will compare the two classes of methods as applied to Webb infrared images and also compare and contrast with previous Hubble space telescope studies from the literature to ask the question, “when and how do modern galaxy shapes appear?” Student will use and/or learn to use the OzSTAR supercomputer, python/Jupyter, and various astronomical codes as well as working directly with data from the James Webb telescope's NIRCam imager. Previous coursework on galaxies and cosmology is required.

Further reading:

- Merlin et al 2022 (https://arxiv.org/abs/2207.11701)
- Jacobs et al 2022 (https://arxiv.org/abs/2208.06516)

Hiding in plain sight? Discovering exoplanets with super-stable spectral lines

Supervisor: Prof Michael Murphy
Contact: mmurphy@swin.edu.au

Project description: Thousands of planets have been discovered around a huge variety of stars by closely monitoring the stars' motions. This "radial velocity" technique of discovering exoplanets relies on the basic idea that the absorption lines in stellar spectra do not shift for other reasons – the Doppler shift induced by the exoplanet motions is presumed to be the dominant factor. But for Earth-like planets orbiting Sun-like stars, this is not true! These stars "jitter" – the stellar photospheres, where the absorption lines are formed, have enormous, mottled cells of plasma which rise and fall, plus magnetic storms, flares and "starspots" just like our Sun, all of which move the spectral lines in seemingly random ways. To discover "Earth twins", we need to avoid, or understand, this jitter. One promising route we've identified is to find "stable lines" that jitter much less. We've found some, quite accidentally, and others have found a few as well. But we think there's more, so many that we could discover new planets in data that's already publicly available! This project is about exploring this idea further, finding all of the most stable lines and discovering planets – possibly some never found before – hiding in the amazing public data from the famous HARPS instrument on the ESO 3.6m telescope in Chile (which has identified by-far the most exoplanets using the radial velocity technique so far).

Further reading:

- Dumusque, X, 2018, A&A, 620, 47, https://arxiv.org/abs/1809.01548