CAASTRO

ARC CENTRE OF EXCELLENCE
FOR ALL-SKY ASTROPHYSICS

Reader's Digest

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Publication stories about CAASTRO research

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Cover image from McKinley et al. (MNRAS, 2013)

These stories were written by the leading CAASTRO affiliated author in collaboration with CAASTRO Education & Outreach Coordinator **Dr Wiebke Ebeling**.

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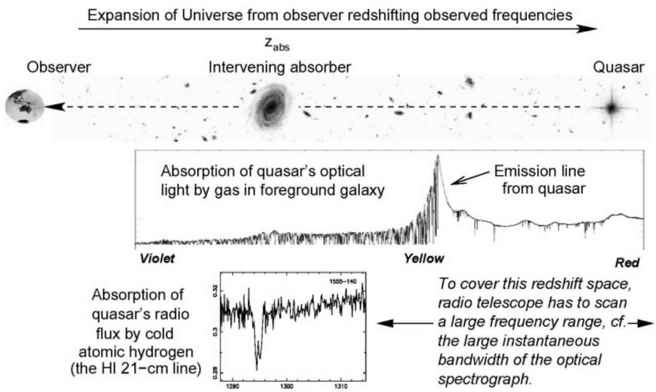
Unprecedented number of gas-rich galaxies along single sightline

Absorption of the 21-cm spin-flip transition of hydrogen (HI) by galaxies intervening the lines-of-sight to high redshift radio sources (quasars) can provide important insight into star formation rates and galaxy evolution at a time when chemical abundances were markedly different to the present day. Although there are currently 12,000 strong intervening HI absorbers known, detected through the ultra-violet Lyman-alpha transition redshifted into the optical band at $z > 1.7$, only 40 of these systems have been detected in 21-cm absorption. While Ly-α traces all of the neutral gas, 21-cm traces the cool, star-forming component, and so is of particular importance in determining the star formation history of the Universe.



The authors had previously shown that the traditional selection of the optically identified absorbers biases against the intervening galaxies which contain the most dust, required to protect the cool phase of the atomic and molecular gas against the harsh UV environment. Searches for this material must therefore be radio biased. However, given that redshifts are usually obtained from good optical spectra means that we do not have a frequency at which to tune the radio receiver.

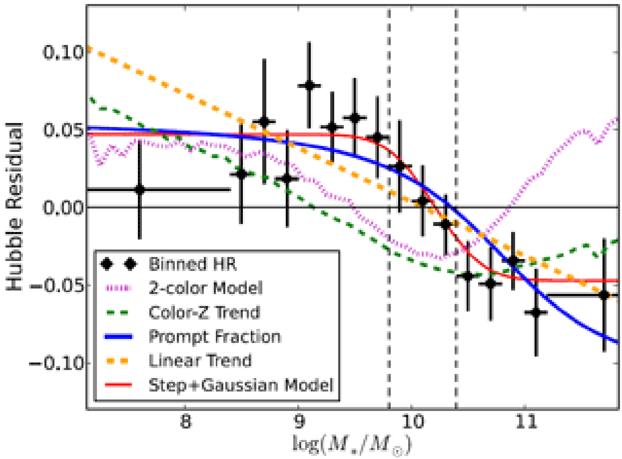
In their recent publication, the authors have therefore embarked upon a program of spectral scans, with the Green Bank Telescope (GBT), towards optically faint, but radio bright, objects in the search for any intervening galaxies responsible for the obscuration of the optical light from the background quasar. From the first of these, the extremely red (V - K = 10.26) MG J0414+0534, they have so far detected four gas-rich intervening systems, in addition to the previously known 21-cm absorption in the quasar host galaxy at z = 2.64. This is an unprecedented number of galaxies detected along a single sight-line and could have profound implications for how the Universe is populated by objects invisible to even the largest optical telescopes. Although equipped with wide-band spectrometers, the GBT is a single dish, susceptible to severe radio frequency interference (RFI). The Australian Square Kilometre Array Pathfinder, ASKAP, however, while equipped with a similarly wide instantaneous band-width, will have the further advantages of being an interferometer in an RFI quiet environment, thus being ideal in determining whether such a high occurrence of intervening galaxies is common.

Publication:

A. Tanna, **S. J. Curran**, M. T. Whiting, J. K. Webb, C. Bignell in the Astrophysical Journal Letters 772 (2013): "*A fourth HI 21-cm absorption system in the sight-line of MG J0414+0534: a record for intervening absorbers*"

Supernova brightness shows correlation with host galaxy mass

More than a decade after the discovery of the accelerating expansion of the universe, Type Ia supernovae (SNe Ia) remain the best standard candles for cosmology. However, recent studies have indicated that the standardised brightness of SNe Ia may have a residual dependence on their host galaxy environment. In a pair of papers from the Nearby Supernova Factory (SNfactory) led by CAASTRO researcher Dr Michael Childress (Australian National University), the authors derive precision estimates of SN Ia host galaxy properties and show that SNe Ia show a sharp transition in their standardised brightness when going from low mass to high mass host galaxies.



SNe Ia are used to measure distances by comparing their observed brightness to the brightness predicted for their observed light curve shape and colour. Dr Childress and the SNfactory team computed the light curve properties for a sample of 115 new SNe Ia from SNfactory, and derived the mass, metallicity, and star-formation rates for their host galaxies. Combining these data with three other major surveys to form a sample of over 600 SNe Ia, the team found that SNe

Ia in low mass galaxies were too faint while those in high mass galaxies were too bright. Such a large sample of SNe allowed the team to inspect the structure of the luminosity trend with host galaxy mass and to find a difference of 0.10 magnitudes that undergoes a sharp transition at a galaxy mass scale of about 10^{10} solar masses.

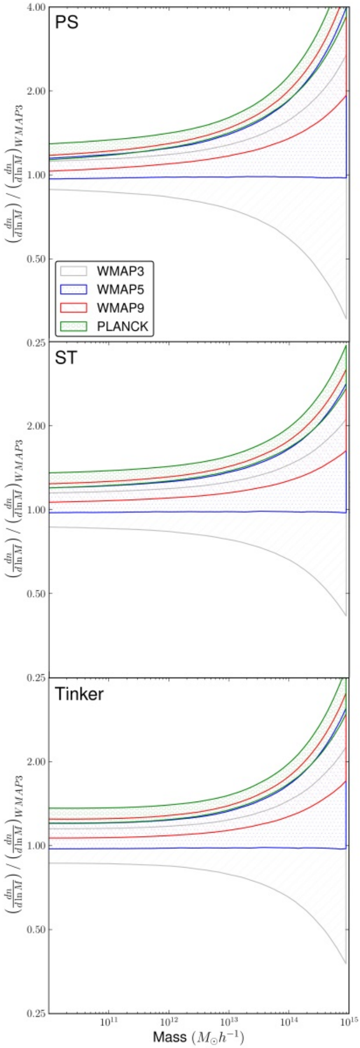
While previous work interpreted this SN Ia "host bias" as likely arising from metallicity effects, the SNfactory analysis inspected all physical properties which evolve along the galaxy mass sequence. Age, metallicity, and dust were all compared to the luminosity-mass trend, and the authors found SN Ia age showed the most consistency with the data. The authors also uncovered a tentative trend of SN Ia colour with host galaxy metallicity. These results illustrate the importance of studying SN Ia environments to fully quantify the environmental impact on SN Ia properties.

<u>Publication:</u>

M. J. Childress, G. Aldering, P. Antilogus, C. Aragon, S. Bailey, C. Baltay, S. Bongard, C. Buton, A. Canto, F. Cellier-Holzem, N. Chotard, Y. Copin, H. K. Fakhouri, E. Gangler, J. Guy, E. Y. Hsiao, M. Kerschhaggl, A. G. Kim, M. Kowalski, S. Loken, P. Nugent, K. Paech, R. Pain, E. Pecontal, R. Pereira, S. Perlmutter, D. Rabinowitz, M. Rigault, K. Runge, R. Scalzo, G. Smadja, C. Tao, R. C. Thomas, B. A. Weaver, C. Wu in the Astrophysical Journal 770 (2013): "*Host Galaxies of Type Ia Supernovae from the Nearby Supernova Factory*" and "*Host Galaxy Properties and Hubble Residuals of Type Ia Supernovae from the Nearby Supernova Factory*"

How well do we know the Halo Mass Function?

The halo mass function describes the abundance of collapsed dark matter objects of a given mass and can be used in observational tests to constrain cosmological parameters, as well as in theoretical models to predict galaxy clustering and even basic galaxy properties.



In their recent paper, CAASTRO PhD student Steven Murray (University of Western Australia), and his supervisors CAASTRO Associate Investigator Prof Chris Power and Dr Aaron Robotham present the halo mass function for the recently released Planck1 cosmology and compare it to predictions from previous WMAP results, focusing on the inherent uncertainty.

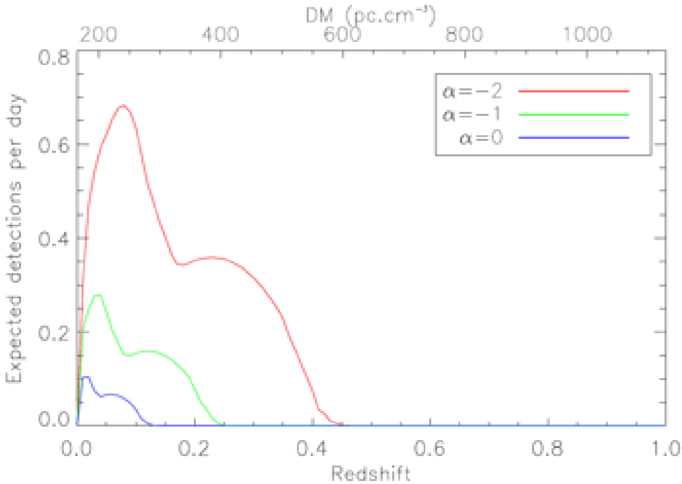
They conclude that the predicted mass function for PLANCK1 is consistent with previous results within the quoted uncertainties of the cosmologies. They also derive a rule-of-thumb measurement of uncertainty in the halo mass function for each cosmological data-set considered, which is important for robust model-testing with observed data. Finally they show that for the tightly constrained parameters of PLANCK1, the uncertainty due to choice of parameterisation of the mass function is similar to the cosmological uncertainty, which encourages the effort to provide more accurate theoretical mass functions for precision cosmology.

Publication:

S. G. Murray, C. Power, A. S. G. Robotham in the Monthly Notices of the Royal Astronomical Society Letters 434 (2013): "*How well do we know the Halo Mass Function?*"

Detection of several Fast Radio Bursts per month predicted

Fast Radio Bursts (FRBs) are bursts of radiation observed at radio frequencies that last only a few milliseconds. The physical mechanisms for generating FRBs are unclear, but there are a lot of intriguing suggestions. What is clear is that these are very energetic events, and their short durations suggest these are the hallmark of extreme events in the Universe; collapses, explosions, collisions involving compact objects.



The frequency-dependence of the pulse arrival time suggests that FRBs are extragalactic, prompting a flurry of theoretical discussion about the potential sources of these highly-energetic events. After the discovery of four FRBs with the Parkes radio telescope by an international team (including CAASTRO members Prof Matthew Bailes, Dr Ramesh Bhat, Andrew Jameson, Prof Michael Kramer, and Dr Willem van Straten), Curtin University's Dr Cath Trott, Prof Steven Tingay and Dr Randall Wayth published a paper predicting the rate of FRB detections expected for the new Murchison Widefield Array radio telescope (MWA). The MWA's low radio frequencies and large number of small antennas allows it to monitor a huge fraction of the sky all the time. This is where its main advantage lies, and it is likely to be an excellent instrument to survey the Universe for FRBs, with the expectation of several events per month. Crucially, because it is an array of antennas (and not a single dish), it has the ability to localise any detections on the sky. This will allow it to make the key link between the burst of radiation, and a particular galaxy in the Universe, providing information about its origin. This attribute is not possible with a single dish such as Parkes, which sees many galaxies at any one time.

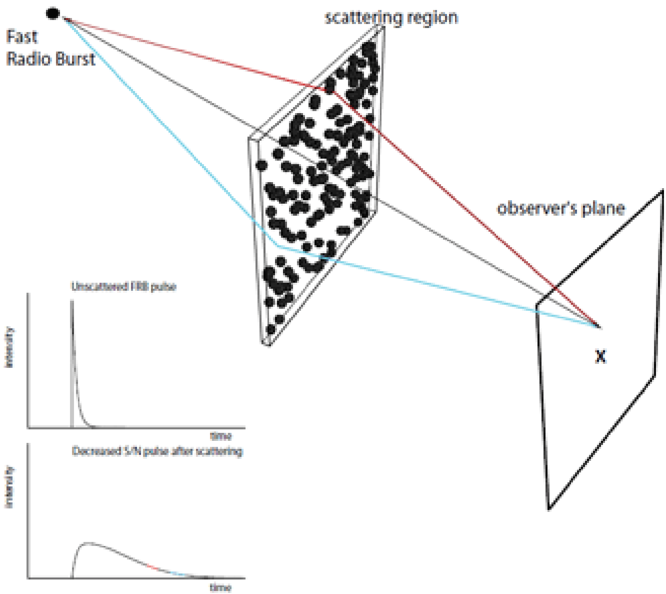
Success of the MWA in its first few months of observing to discover these bursts will provide the first census of this new and exciting population. Conversely, failure of the MWA to detect the expected number will place strong constraints on the underlying source population, informing our knowledge of the progenitors of these energetic events.

Publication:

C. M. Trott, S. J. Tingay, R. B. Wayth in the Astrophysical Journal Letters 776 (2013): “*Prospects for the Detection of Fast Radio Bursts with the Murchison Widefield Array*”

Probing turbulence in the Inter-Galactic Medium

The mean number density of baryons in intergalactic space is a low 2 x 10^{-7} cm^{-3} – roughly equivalent to an office cubicle that contains only six protons! Yet CAASTRO Associate Investigator Dr Jean-Pierre Macquart and his colleague Dr Kevin Koay at Curtin University have found that, even at such low densities, the cumulative effect of this matter over large intergalactic distances is enough to alter the properties of radio waves that propagate through it. If the Inter-Galactic Medium (IGM) is stirred up by the jets of active galaxies, winds from massive stars and supernovae, or shocks along void walls, the medium will be turbulent. Density fluctuations associated with this turbulence scatter the emission from an impulsive radio signals so that its radiation becomes smeared out in time.



The effect of temporal smearing appears to have already been seen in some radio transients at cosmological distances. If so, it may be providing the first glimpse of the turbulent structure of the IGM. In their recent publication, the researchers generalise the theory of scattering to cosmological contexts and provide the theoretical framework for reverse-engineering the turbulent structure of the IGM using scattering measurements. They also estimated the approximate magnitude of scattering effects associated with the various components of the IGM, including the contribution from the diffuse IGM itself, intervening galaxies, and intra-cluster gas. They calculated that, in most cases, the amount of temporal smearing expected at 300MHz is typically ~1ms – sufficiently small that the detectability of the recently-discovered Fast Radio Bursts (Lorimer et al. 2007; Thornton et al. 2013) would not be impaired at wavelengths comparable to a metre and are therefore potentially within the scope of low-frequency widefield arrays such as the MWA and LOFAR.

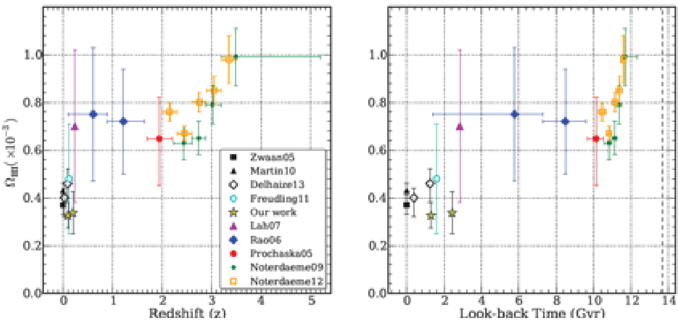
Dr Macquart and Dr Koay also examined the redshift dependence of the temporal smearing caused by Inter-Galactic turbulence and show that its properties are readily distinguishable from scattering in the host galaxy in which the transient event occurred. Thus, with the detection of more Fast Radio Bursts in the future, it ought to be possible to chart the evolution of turbulence in the IGM and clearly distinguish it from the effects of scattering in their host galaxies.

Publication:

J. - P. Macquart and J. - Y. Koay in the Astrophysical Journal 776 (2013): "*Temporal smearing of transient radio sources by the Inter-Galactic Medium*"

Stacking of hydrogen signals to study density over cosmic time

Neutral atomic hydrogen (HI), a fundamental ingredient in a galaxy, is key to our understanding of galaxy formation and evolution. Large optical surveys with ground- and space-based telescopes have allowed us to assess the physical properties of many millions galaxies, focusing on stellar components and leading to a clear history of star formation in galaxies over cosmic time. In contrast though, gas components – especially HI – beyond the local Universe ($z > 0.2$) have been poorly constrained because existing radio telescopes are not sensitive enough to directly detect weak HI signals from individual galaxies.



While waiting for SKA precursor telescopes to come online, CAASTRO PhD student Jonghwan Rhee, his supervisor Prof Frank Briggs (Australian National University), and colleagues used an HI spectral stacking technique with 21-cm emission data from the Westerbork Synthesis Radio Telescope (WSRT) in the Netherlands to overcome the current limitations. The technique required galaxy positions and redshifts (obtained from CNOC2 optical redshift survey) and performed a cross-correlation between 21-cm observation data and optical spectroscopic data. The researchers extracted HI emission lines from radio spectral data cubes taken from radio observations, based on positions and redshifts that were known from optical photometric and spectroscopic observations. They then co-added the extracted HI spectra of multiple galaxies to measure the average HI signal and converted this into HI mass and finally cosmic HI mass density (Ω_{HI}).

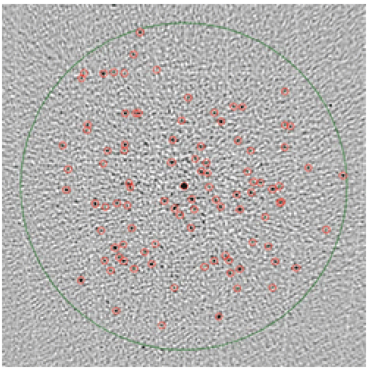
In their recent publication, the team reports the most reliable measurements beyond the local universe yet using this stacking technique and the highest signal-to-noise measurement of Ω_{HI} at intermediate redshifts. Their Ω_{HI} at $z \sim 0.1$ and 0.2 was consistent with results at $z = 0$ based on large scale 21-cm surveys, as well as other measurements at $z < 0.2$, and Ω_{HI} at $z < 0.5$ (based on 21-cm emission line observations) was consistent with no evolution in the neutral hydrogen gas density over the last ~ 4 Gyr.

Publication:

J. Rhee, M. A. Zwaan, F. H. Briggs, J. N. Chengalur, P. Lah, T. Oosterloo, T. van der Hulst in the Monthly Notices of the Royal Astronomical Society 435 (2013): "*Neutral hydrogen (HI) gas evolution in field galaxies at z ~ 0.1 and 0.2*"

Making cosmic movies with the Murchison Widefield Array

While telescopes have been capable of capturing a single "picture" of the sky for quite some time, the high demand for the use of world-class facilities and historically limited fields of view on offer meant that repeat observations of the same areas of sky were sparse. Next-generation widefield instruments, such as the Murchison Widefield Array (MWA), break down this paradigm and achieve many repeat observations of the same piece of sky with less competition. By taking multiple images of the sky, they can effectively make cosmic movies of the Universe. Each single image (equivalent to the frames of a movie) captures time-domain information about that region of the sky and allows for the detection of new types of objects that might only be observable for a short time, for example explosions.



In a recent study by CAASTRO researchers and their colleagues of the international MWA consortium, observations were obtained from the (by now decommissioned) MWA 32-tile prototype telescope (MWA-32T) at 154 MHz. Operating at such low radio frequencies (80 to 300 MHz), the Southern hemisphere sky is poorly explored in the image domain, and therefore offers discovery of sources and subsequent physical processes potentially unique in this regime.

The researchers' recent publication explored the variability of a sample of 105 low frequency radio sources within the MWA-32T's field of view. Fifty-one images were obtained in 2010 and 2011 that covered a field of view of 1430 deg^2

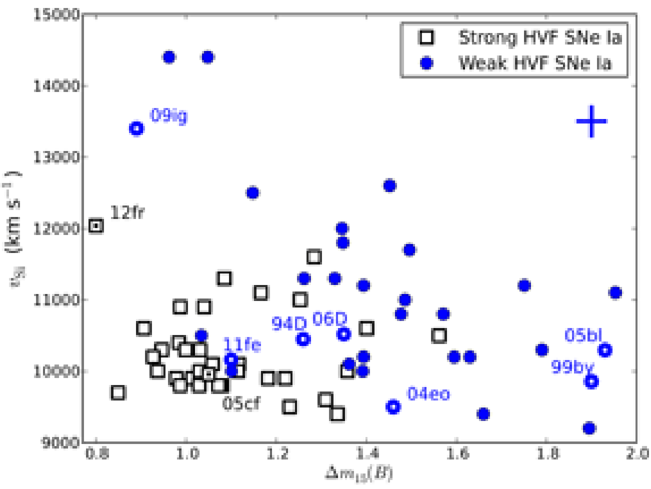
centred on the bright radio galaxy Hydra A. They identified four bright candidate variable radio sources that displayed low levels of short timescale variability (26 minutes), likely caused by simplifications in the calibration strategy or ionospheric effects. On the timescale of one year though, two sources showed significant variability, attributed to either refractive scintillation or intrinsic variability. No radio transients were found, but the team could place upper limits on the occurrence of such sources. Surveys are currently underway with the 128-tile MWA system to probe this dynamic parameter space further.

Publication:

M. E. Bell, T. Murphy, D. L. Kaplan, P. Hancock, B. M. Gaensler, J. Banyer, K. Bannister, C. Trott, N. Hurley-Walker, R. B. Wayth, J. - P. Macquart, W. Arcus, D. Barnes, G. Bernardi, J. D. Bowman, F. Briggs, J. D. Bunton, R. J. Cappallo, B. E. Corey, A. Deshpande, L. deSouza, D. Emrich, R. Goeke, L. J. Greenhill, B. J. Hazelton, D. Herne, J. N. Hewitt, M. Johnston-Hollitt, J. C. Kasper, B. B. Kincaid, R. Koenig, E. Kratzenberg, C. J. Lonsdale, M. J. Lynch, S. R. McWhirter, D. A. Mitchell, M. F. Morales, E. Morgan, D. Oberoi, S. M. Ord, J. Pathikulangara, T. Prabu, R. A. Remillard, A. E. E. Rogers, A. Roshi, J. E. Salah, R. J. Sault, N. Udaya Shankar, K. S. Srivani, J. Stevens, R. Subrahmanyan, S. J. Tingay, M. Waterson, R. L. Webster, A. R. Whitney, A. Williams, C. L. Williams, J. S. B. Wyithe in the Monthly Notices of the Royal Astronomical Society 438 (2013): "*A survey for transients and variables with the Murchison Widefield Array 32-tile prototype at 154 MHz*"

High-Velocity Features connected to supernova explosion physics

Type Ia supernovae (SNe Ia) are believed to result from the explosion of a carbon-oxygen white dwarf, induced by interaction with a binary companion. Spectroscopy of SNe Ia offers clues to the explosion properties from the composition and velocities of the SN ejecta imprinted in spectroscopic absorption features. A new study by CAASTRO researchers Dr Michael Childress and Prof Brian Schmidt (Australian National University), with Berkeley colleagues Prof Alex Filippenko and Dr Mo Ganeshalingam, examines spectroscopic features with anomalously high velocities which provide important clues to the nature of SN Ia explosions.



SNe Ia synthesise new material through rapid nuclear fusion, generate tremendous energy, and eject this material at thousands of kilometres per second. The spectrum of a SN shortly after the explosion, when the ejecta are hot and dense, is essentially a blackbody spectrum dominated by absorption features produced by material at the edge of this optically thick zone (the photosphere). These lines typically manifest at the same velocity, corresponding to the edge of the photosphere, which gradually proceeds inwards to lower velocities as the ejecta expand and cool.

Early spectra of some SNe Ia, however, have exhibited some features with exceptionally high velocities 5,000 to 10,000 km/s faster than the photospheric velocity. Since the origin of these high velocity features (HVFs) remains a mystery, the present study searched for correlations with other SN behaviour to provide clues to the HVF origin. The research team found a strong correlation of HVF strength with the decline rate of SN Ia lightcurves, such that HVFs are stronger in the more luminous slow-declining SNe Ia and weaker in the fainter fast-declining SNe Ia. Surprisingly, they also discovered that SNe Ia with high photospheric velocities lack distinct HVFs.

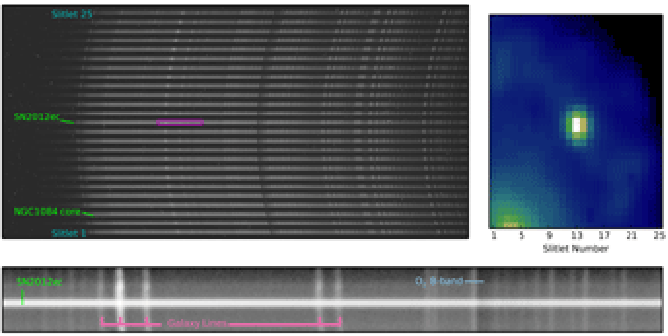
These results show for the first time a distinct connection between the SN Ia explosion physics and the presence of high velocity features in the SN spectrum: faint fast-declining SNe Ia have low photospheric velocities and no HVFs; luminous slow-declining SNe Ia tend to have either high photospheric velocities or distinct HVFs, but not both. These trends provide an important new observational constraint on the nature of SNe Ia which will inform future models of the progenitor mechanism.

<u>Publication:</u>

M. J. Childress, A. V. Filippenko, M. Ganeshalingam, B. P. Schmidt in the Monthly Notices of the Royal Astronomical Society 437 (2014): "*High-velocity features in Type Ia supernova spectra*"

New spectrograph data pipeline yields high quality results

Integral field spectroscopy provides a remarkable observational window into the most complex astrophysical objects. By obtaining spectra at multiple contiguous positions, the spatially resolved structure of star-formation and chemical enrichment can be revealed for complex systems such as galaxies and gaseous nebulae. The Wide Field Spectrograph (WiFeS) on the Australian National University (ANU) 2.3m telescope is one of the world's most sensitive integral field spectrographs and the workhorse for many Australian spectroscopic efforts including supernova classification, exoplanet characterisation, stellar structure measurements, and galaxy emission line mapping. A paper led by CAASTRO researcher Dr Michael Childress (Australian National University) presents a new data reduction pipeline PyWiFeS which enables rapid and scriptable data reduction for WiFeS.



WiFeS "slices" a 25" x 38" field of view into 25 1"-wide "slitlets" by means of a fanned segmented mirror. Light in each slitlet is dispersed in the same manner as a longslit spectrograph, but ultimately yields a data volume 25 times that of a standard longslit spectrograph. Calibrating this volume of data is a challenging task, but one well suited to recursive software techniques such as PyWiFeS that accomplishes end-to-end processing of WiFeS data with minimal user interaction by utilising an abstract metadata format and a carefully constructed data reduction script.

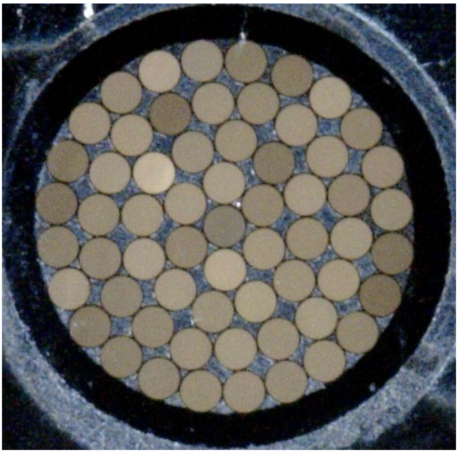
PyWiFeS also marks the implementation of several new innovative data processing routines which provide optimal data quality. These include scattered light corrections for flat-field calibrations, a WiFeS-tailored implementation of Laplacian kernel cosmic ray rejection, and a global detector wavelength solution based on an optical model of the instrument. The research team around Dr Childress made sure that PyWiFeS can be easily scripted to facilitate rapid data reduction, and the ANU supernova group, for instance, use it to classify and process new supernova data in under one minute from completion of detector readout.

Publication:

M. J. Childress, F. P. A. Vogt, J. Nielsen, R. G. Sharp in Astrophysics & Space Science 349 (2014): "*PyWiFeS: a rapid data reduction pipeline for the Wide Field Spectrograph (WiFeS)*"

Lab tests confirm excellent imaging properties of hexabundles

We are now moving into an era where multi-object wide-field galaxy surveys, which traditionally use single fibres to observe many targets simultaneously, can exploit compact integral field units in place of single fibres. Current multi-object integral field instruments, such as SAMI, have driven the development of new imaging fibre bundles (hexabundles) for multi-object spectrographs. The technology underpinning hexabundles was developed at the University of Sydney, by fusing optical fibres using a complex glass fibre processing facility.



However, optical fibres can be the source of loss in an instrument if not handled correctly. Focal ratio degradation (FRD) is such a loss in all fibres because it causes the light to come out of the fibre with a larger light cone than it went in. If this cone is larger than the acceptance cone of the spectrograph, then the throughput of the system will be reduced. A unique aspect of the hexabundle development was that the fibres could be fused in such a way as to remove the FRD seen in previous devices.

In a recent paper, CAASTRO member Dr Julia Bryant and co-workers have characterised the performance of hexabundles to assess the FRD and throughput for a range of input light cones (f-ratios) typically used in astronomy. This work proves that at low f-ratios, typical of fibre instruments, the FRD in hexabundles is as good as that in a single fibre of the same fibre type.

Another unique feature of the hexabundle design is that the cladding on the fibres is etched from 10 microns thickness down to between 1 to 8 microns. If the cladding on a fibre is too thin, then it will no longer sufficiently guide light, leading to losses into adjacent fibres, or "cross-talk". The researchers found that cladding thicknesses as thin as 2 microns still gave a level of cross-talk that is negligible compared to the effects of atmospheric seeing in an observation. This means that by reducing the cladding thickness, hexabundles can be made with a higher fraction of the face being fibre cores that accept light, and less being cladding that does not accept light. This higher fill-fraction is unique to these devices and further increases the throughput of the system.

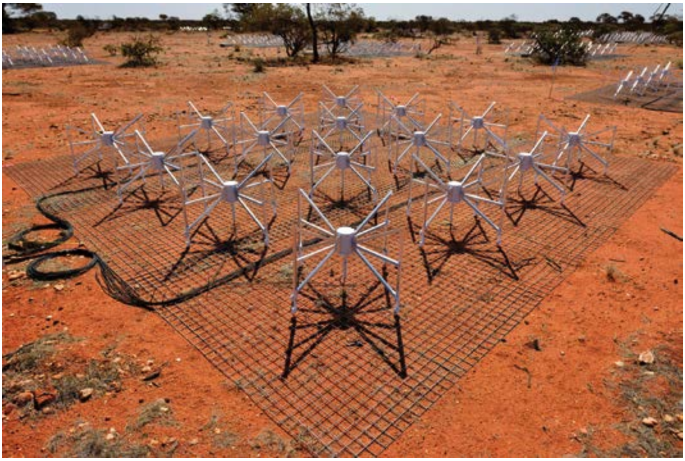
The performance results they have presented can be used to set a limit on the f-ratio of a system based on the maximum loss allowable for a planned instrument. These results confirm that hexabundles are a successful alternative for fibre imaging devices for multi-object spectroscopy on wide-field telescopes and have prompted further development of hexabundle designs with hexagonal packing and square cores.

Publication:

J. J. Bryant, J. Bland-Hawthorn, L. M. R. Fogarty, J. S. Lawrence, S. M. Croom in the Monthly Notices of the Royal Astronomical Society 438 (2014): "*Focal ratio degradation in lightly-fused hexabundles*"

Science with the Murchison Widefield Array

Low frequency radio waves give us a unique window on the Universe. New technological advances mean that we can build sensitive wide-field telescopes that can explore this regime in detail for the first time. One of the instruments designed to do this is the Murchison Widefield Array, the first telescope in the Southern Hemisphere that will be able to explore the low-frequency astronomical sky between 80 and 300 MHz.



CAASTRO scientists (including Dr Tara Murphy, Dr Randall Wayth and many Chief Investigators) and their colleagues plan to investigate four main science areas with the MWA. They will conduct a search for redshifted 21-cm emission from the Epoch of Reionisation: the period in which the first radiating objects in the Universe formed. To do this, the MWA will look back in time to about a hundred million years ago, when all the gas in the Universe transformed from a neutral state to an ionized state. Another focus will be time variable phenomena: looking for objects that change rapidly on human timescales. Transient and variable behaviour is a sign that extreme physics is occurring, for example we could discover black holes in the process of forming.

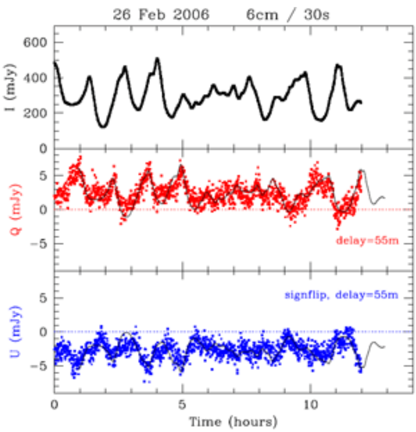
The MWA will also do a massive survey of the whole Southern Sky, studying a range of Galactic and extragalactic phenomena such as supernova remnants and massive radio galaxies. Finally, astronomers will do a detailed study of our own Sun, and the space weather in our solar system. This paper describes all of these key science goals in detail, outlining the great discovery potential of this exciting new telescope.

<u>Publication:</u>

J. D. Bowman, I. Cairns, D. L. Kaplan, **T. Murphy**, D. Oberoi, L. Staveley-Smith, W. Arcus, D. G. Barnes, G. Bernardi, F. H. Briggs, S. Brown, J. D. Bunton, A. J. Burgasser, R. J. Cappallo, S. Chatterjee, B. E. Corey, A. Coster, A. Deshpande, L. deSouza, D. Emrich, P. Erickson, R. F. Goeke, B. M. Gaensler, L. J. Greenhill, L. Harvey-Smith, B. J. Hazelton, D. Herne, J. N. Hewitt, M. Johnston-Hollitt, J. C. Kasper, B. B. Kincaid, R. Koenig, E. Kratzenberg, C. J. Lonsdale, M. J. Lynch, L. D. Matthews, S. R. McWhirter, D. A. Mitchell, M. F. Morales, E. H. Morgan, S. M. Ord, J. Pathikulangara, P. Thiagaraj, R. A. Remillard, T. Robishaw, A. E. E. Rogers, A. A. Roshi, J. E. Salah, R. J. Sault, N. U. Shankar, K. S. Srivani, J. B. Stevens, R. Subrahmanyan, S. J. Tingay, R. B. Wayth, M. Waterson, R. L. Webster, A. R. Whitney, A. J. Williams, C. L. Williams, J. S. B. Wyithe in the Publications of the Astronomical Society of Australia 30 (2013): “*Science with the Murchison Widefield Array*”

Obituary for fallen scintillator J1819+3845

The garden-variety z = 0.54 quasar J1819+3845 was once celebrated as the fastest varying radio quasar in the sky. Its flux density sometimes tripled over the course of twenty minutes! This object was the poster-child for the phenomenon of radio intra-day variability. The timescale of the quasar's variations changed according to an annual cycle, attributed to the fact that the Earth's orbital velocity changed direction with respect to the interstellar medium responsible for the scintillations. Its annual cycle demonstrated means of proving that the variations that had been observed in a number of other intra-day variable quasars were also unambiguously due to scintillation. Thus J1819 was pivotal in proving that radio quasar intra-day variability is caused primarily by interstellar scintillation, and that the brightness temperatures inferred from the variations under the assumption they were intrinsic were fictitious.



But somewhere between 2006 and early 2007 the scintillations stopped, and J1818+3845 flatlined. Why? One possible explanation is that the source suddenly expanded and became too large to exhibit interstellar scintillation. However, this would have required the source to have expanded at an apparent speed of at least 40 times the speed of light, an untenable hypothesis given that VLBI observations showed that the source remained unresolved.

In their 2013 publication, ASTRON's Prof Ger de Bruyn and CAASTRO member Dr Jean-Pierre Macquart (Curtin University) could prove that the cessation of scintillations was due to the fact that the scattering cloud that previously sat along the line of sight to the quasar had moved away. They also examined the polarisation variations in J1819, which often look identical to the unpolarised variations, but lags them by up to 100 minutes. This suggested that the polarisation structure in the source was offset from the unpolarised emission, and comparison of VLBI polarisation images with the scintillation variations enabled the researchers to determine the distance to the scattering cloud responsible for J1819's once-magnificent variability to be an astounding 1.5 +/- 0.5 parsec. This turbulent cloud is one of the closest objects to Earth outside the solar system!

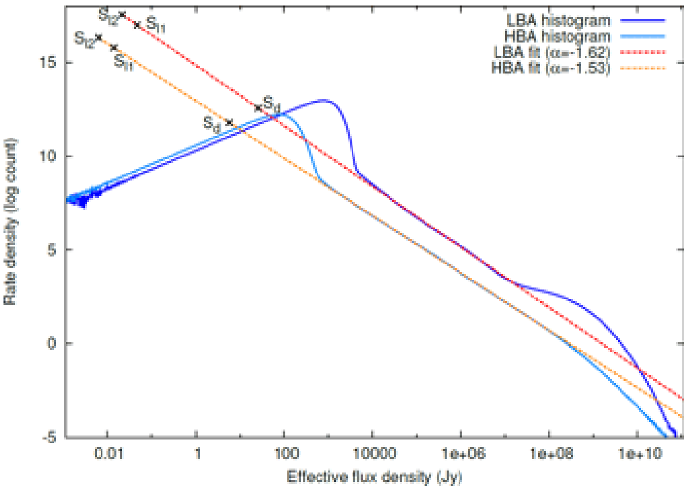
Armed with this distance, they estimated some of the physical properties of the cloud. Its ~ 100 cm^{-3} density is remarkably large for an object embedded in the ionised interstellar medium, and it has a physical extent of >100 Astronomical Units, so this cloud should subtend at least 50" on the sky. Furthermore, if the cloud is in pressure balance with its magnetic field, one expects the cloud to increment the rotation measure in the sky near J1819 by at least 2 rad m^{-2}. Given the direction in which the cloud is moving on the sky, Prof de Bruyn and Dr Macquart conducted a preliminary search for variations in other sources near J1819 but found nothing remarkable. They also searched for this RM structure in the cloud, but found no definitive evidence for its signature in RM synthesis cubes.

Publication:

A. G. de Bruyn and **J. - P. Macquart** in Astronomy & Astrophysics (accepted): "*The intra-hour variable quasar J1819+3845: 13-year evolution, jet polarization structure and interstellar scattering screen properties*"

Do Earth-based transmitters affect our cosmological observation?

CAASTRO researchers Dr André Offringa (Australian National University) and Dr Martin Bell (University of Sydney) and their international colleagues used the Low-Frequency Array (LOFAR) radio telescope in The Netherlands to analyse the effect of terrestrial transmitters on an observation. They assumed that sources of interference are uniformly distributed over the Earth's surface. If this model is correct, a telescope would see many distant sources that have a faint effect and a few strong sources close to the telescope. Having mathematically derived what effect the number of sources and the curvature of the Earth have on the power level of the interference, the researchers show that the actually observed interference follows such a model very well.



While modern interference-detection algorithms can remove most interference caused by terrestrial (and orbiting) transmitters, it is hard to identify interference by distant transmitters with a very low effect. There are so many of such transmitters that they might actually disturb some of the deepest observations, such as the Epoch of Reionisation. The

LOFAR and Murchison Widefield Array (MWA) telescopes collect many nights of data to detect this cosmological event.

To estimate the contribution of distant sources on such observations, the model for close-by transmitters was further extrapolated to distant transmitters. As their recent publication reveals, it appears that, in theory, these distant transmitters could severely limit deep observations. In fact, they show that some of the observations that have already been successful should have been limited by interference, which is obviously incorrect. This can be explained by assuming transmitter signals are not received coherently by the telescope: their combined power does not add up linearly because each transmitter has different properties. This suggests that, after all, it should be possible to make very deep observations of the sky without being limited by interference.

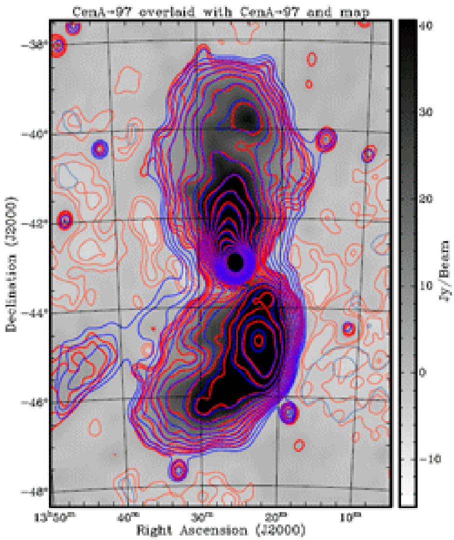
<u>**Publication:**</u>

A. R. Offringa, A. G. de Bruyn, S. Zaroubi, L. V. E. Koopmans, S. J. Wijnholds, F. B. Abdalla, W. N. Brouw, B. Ciardi, I. T. Iliev, G. J. A. Harker, G. Mellema, G. Bernardi, P. Zarka, A. Ghosh, A. Alexov, J. Anderson, A. Asgekar, I. M. Avruch, R. Beck, M. E. Bell, M. R. Bell, M. J. Bentum, P. Best, L. Bîrzan, F. Breitling, J. Broderick, M. Brüggen, H. R. Butcher, F. de Gasperin, E. de Geus, M. de Vos, S. Duscha, J. Eislöffel, R. A. Fallows, C. Ferrari, W. Frieswijk, M. A. Garrett, J. Grießmeier, T. E. Hassall, A. Horneffer, M. Iacobelli, E. Juette, A. Karastergiou, W. Klijn, V. I. Kondratiev, M. Kuniyoshi, G. Kuper, J. van Leeuwen, M. Loose, P. Maat, G. Macario, G. Mann, J. P. McKean, H. Meulman, M. J. Norden, E. Orru, H. Paas, M. Pandey-Pommier, R. Pizzo, A. G. Polatidis, D. Rafferty, W. Reich, R. van Nieuwpoort, H. Röttgering, A. M. M. Scaife, J. Sluman, O. Smirnov, C. Sobey, M. Tagger, Y. Tang, C. Tasse, S. ter Veen, C. Toribio, R. Vermeulen, C. Vocks, R. J. van Weeren, M. W. Wise, O. Wucknitz in the Monthly Notices of the Royal Astronomical Society 435 (2013): "*The brightness and spatial distributions of terrestrial radio sources*"

Low-frequency images of our nearest neighbouring radio galaxy

When the Murchison Widefield Array (MWA) in Western Australia looks up at the sky, it sees thousands of distant galaxies that emit radio waves with tremendous intensity. Most of these objects appear as unresolved points in the radio maps produced; however, some are large and extended, allowing scientists, such as CAASTRO PhD student Ben McKinley (Australian National University) and colleagues, to examine their complex structure in intricate detail.

The closest radio galaxy to Earth is Centaurus A, at a distance of about 12 million lightyears. Its proximity and intrinsic size mean that its giant radio lobes extend an angular distance across the sky equal to that of 14 full Moons placed side-by-side. Counter-intuitively, this has made studies of Centaurus A difficult with traditional radio telescopes, as it requires many pointings to image the entire source.



The wide field of view of the MWA allows observers to fit Centaurus A into a single “snapshot” though, and this is precisely what the MWA team did in a recent publication in order to study the properties of this radio galaxy at low frequencies. The widefield images at 118 MHz produced by the researchers were compared to previously published images at higher radio frequencies with some interesting results.

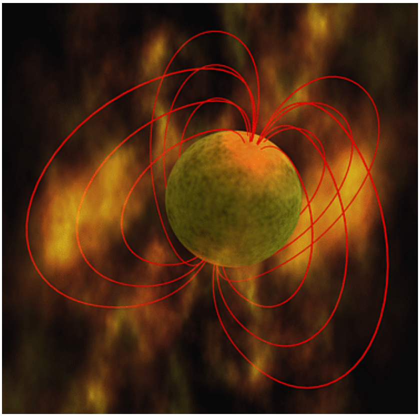
They found tentative evidence for the existence of a new structure in the southern giant lobe of Centaurus A that had previously only been detected in linear polarisation measurements. This was made possible by the low operating frequency of the MWA and the high image quality close to the bright core of Centaurus A. The team also examined the shape of the radio spectrum of the lobes and its variation across their spatial extent. The results support the widely held view that Centaurus A is a "restarting" radio galaxy, with a central active galactic nucleus that has stopped and restarted its activity several times in its 80-million-year history.

Publication:

B. McKinley, F. Briggs, B. M. Gaensler, I. J. Feain, G. Bernardi, R. B. Wayth, M. Johnston-Hollitt, A. R. Offringa, W. Arcus, D. G. Barnes, J. D. Bowman, J. D. Bunton, R. J. Cappallo, B. E. Corey, A. Deshpande, L. deSouza, D. Emrich, R. Goeke, L. J. Greenhill, B. J. Hazelton, D. Herne, J. N. Hewitt, D. L. Kaplan, J. C. Kasper, B. B. Kincaid, R. Koenig, E. Kratzenberg, C. J. Lonsdale, M. J. Lynch, S. R. McWhirter, D. A. Mitchell, M. F. Morales, E. Morgan, D. Oberoi, S. M. Ord, J. Pathikulangara, T. Prabu, R. A. Remillard, A. E. E. Rogers, A. Roshi, J. E. Salah, R. J. Sault, N. Udaya Shankar, K. S. Srivani, J. Stevens, R. Subrahmanyan, S. J. Tingay, M. Waterson, R. L. Webster, A. R. Whitney, A. Williams, C. L. Williams, J. S. B. Wyithe in the Monthly Notices of the Royal Astronomical Society 436 (2013): "*The giant lobes of Centaurus A observed at 118 MHz with the Murchison Widefield Array*"

Magnetised spinning neutron star at heart of brightest explosion

Gamma-Ray Bursts (GRBs) are by far the most luminous events in the cosmos we are aware of. These stellar explosions emit the amount of energy the whole Milky Way galaxy releases in ten years, and they do so in a few tens of a second. To the question which engine is able to produce these spectacular explosions, the astronomy community has long identified two possible scenarios, and as often the case when extreme physics is involved, compact objects are the usual suspects.



One scenario is the fall (or accretion) of material onto a black hole of a few solar masses, the other invokes a class of neutron stars known as "magnetars". If some (if not all) GRBs had their origin in this highly magnetised and fast spinning neutron stars, we would have a simple solution to a long standing issue – which an international research team tested in a recent publication, co-authored by CAASTRO member Dr Davide Burlon (University of Sydney). Around one in six GRBs show emission prior to the main explosion, sometimes recurring in a few episodes – a phenomenon known as "precursor" emission. A consistent fraction of GRBs also shows a peculiar behaviour in the light-curve of the afterglow in the days following the main explosion. The presence of an accreting magnetar consistently gives a natural explanation for all these features.

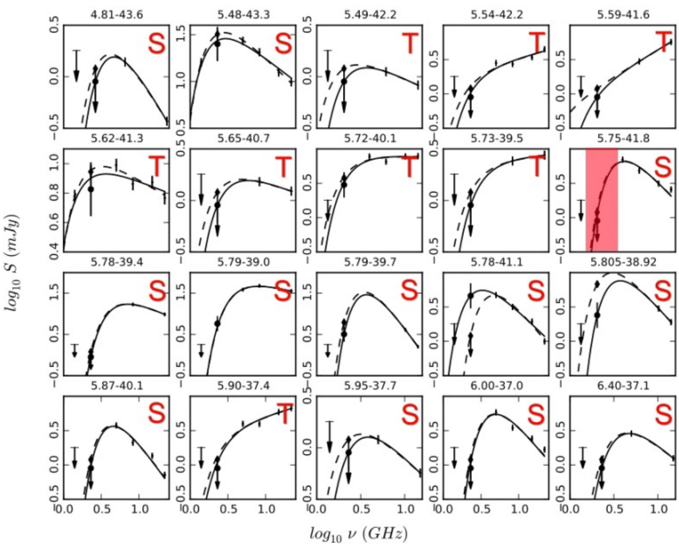
Using this method of fitting the light-curve of the X-ray afterglow with the aforementioned model the researchers propose that also a very famous explosion, known as GRB 130427A, could be due to an accreting magnetar. This GRB is per se a standard-long GRB, with the exception of being very close – in astrophysical terms – to Earth, allowing an unprecedented campaign of follow-up with several telescopes. This makes it possible for scientists all over the world to test their models with high-quality data across the whole electromagnetic spectrum.

Publication:

M. G. Bernardini, S. Campana, G. Ghisellini, P. D'Avanzo, G. Calderone, S. Covino, G. Cusumano, G. Ghirlanda, V. La Parola, A. Maselli, A. Melandri R. Salvaterra, **D. Burlon**, V. D'Elia, D. Fugazza, B. Sbarufatti, S. D. Vergani, G. Tagliaferri in the Monthly Notices of the Royal Astronomical Society 439 (2014): "*A magnetar powering the ordinary monster GRB 130427A?*"

Uncovering the hidden underbelly of a starburst galaxy

In a recent publication, a team of astronomers from Curtin University, with CAASTRO co-authors Dr Emil Lenc (University of Sydney) and Prof Steven Tingay (Curtin University), have used radio observations spanning 21 years to uncover the processes driving intense star formation in the nuclear regions of the starburst galaxy NGC 253. The nuclear region is obscured by gas and dust when observed at optical wavelengths but is revealed at radio wavelengths. Utilising the Australian Long Baseline Array (LBA), the highest-resolution instrument in the southern hemisphere, Curtin PhD student Hayden Rampadarath and colleagues were able to detect and resolve individual compact sources in NGC 253.



By combining the LBA results with previously published observations at higher radio frequencies the team modelled the spectra of 20 sources to measure the line-of-sight ionised gas content. Foreground ionised gas causes a drop-off in source intensity at lower frequencies. Spectral modelling also enabled source categorisation. Supernova remnants, relics left behind after massive stars end their lives with a bang, have spectra dominated by synchrotron emission so their brightness decreases steeply with frequency. Whereas HII regions – clouds of hot gas in which star formation has recently taken place – have spectra dominated by thermal emission so their brightness is flat or increases with frequency.

Additionally, using improved modelling of radio supernovae, the team were able to place limits on both the supernova rate and star formation rate within the nuclear region of the galaxy. The results, which suggest a supernova rate of less than one every five years and a star formation rate of less than 4.9 solar-masses per year, are consistent with studies utilising very different techniques. Furthermore, they point to the possible existence of a small population of undetected supernova remnants and suggest a low rate of radio supernovae production in NGC 253.

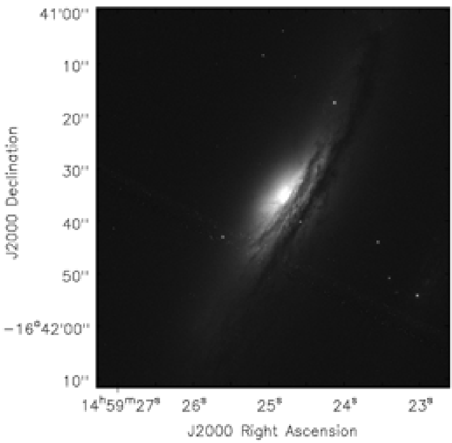
<u>Publication:</u>

H. Rampadarath, J. S. Morgan, **E. Lenc**, S. J. Tingay in the Astronomical Journal 147 (2014): "*Multi-epoch Very Long Baseline Interferometric Observations of the Nuclear Starburst Region of NGC 253: Improved Modeling of the Supernova and Star formation Rates*"

“The Dish” detects star fuel reservoirs around radio monsters

The HI Parkes All-Sky Survey (HIPASS) was completed over a decade ago and still represents the most comprehensive census of the atomic hydrogen (HI) content of our local Universe. The 21-cm signal of hydrogen can be picked up by radio telescopes with relative ease from local galaxies and is used to map out the speed at which they are spinning and to trace the fuel available for future star formation.

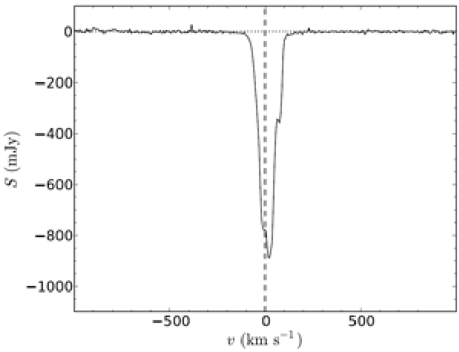
In their recent paper, our University of Sydney based researchers Dr James Allison (now at CSIRO) and Prof Elaine Sadler, together with their previous third year project student Alex Meekin, have used HIPASS data to search for cold clumps of hydrogen in galaxies that host the most radio-bright supermassive black holes. These clouds of hydrogen pass in front of the radio-emitting plasma and absorb some of the radiation, manifesting as a silhouette in the radio signal.



Using a robust technique developed by the FLASH (First Large Absorption Survey in HI) team at the University of Sydney, they carried out a survey of over two hundred radio galaxies. In four of these, they detected hydrogen absorption, all of which are amongst the most radio bright and which are known to have lots of cold material in the form of dust and molecular gas.

In one galaxy, hydrogen absorption was found for the first time – its silhouette in the radio signal indicating that the hydrogen is located in an obscuring disc that is of similar orientation to the edge-on disc of stars seen in the optical images. As has been noted in previous such surveys, these detections seem to be dominated by those radio sources that are small and powerful, concentrating their radio emission behind the hydrogen gas.

Importantly, these results indicate that imminent early-science surveys with the Australian Square Kilometre Array Pathfinder (ASKAP) will be able to detect strong hydrogen absorption in such galaxies at much earlier times in the history of the Universe**.**



<u>Publication:</u>

J. R. Allison, E. M. Sadler, A. M. Meekin in the Monthly Notices of the Royal Astronomical Society 440 (2014): "*A search for associated HI absorption in nearby galaxies using HIPASS*"

Mystery burst from unusual pulsar or dying black hole in Galaxy

Over the past few years, astronomers have been intrigued by a growing number of detections of very unusual bursts of radio waves of unknown origin. There are now six confirmed observations of these so-called "Fast Radio Bursts" (FRBs). These bursts are very bright and only last a few milliseconds. What makes them unusual is that each burst has only been detected once; they are unlike normal pulsars that emit repeated bursts of radio waves with clockwork precision. In addition, they are not associated with any known stars, galaxies or quasars.

A variety of explanations has been put forward to explain this strange phenomenon. FRBs may be the result of black holes or neutron stars annihilating one another. Or they could come from bizarre magnetic fields rearranging themselves near supernovae or highly magnetised stars. Another possibility is that they are from a rare type of pulsar. It is also thought that they may not even come from space but rather are produced by a strange weather phenomenon on Earth.

The main reason that we cannot identify their cause is that we have no measure of how far away they are. They could be anywhere from millions of light years to just tens of kiloparsecs distance. A detailed analysis of the signals suggests that the radio waves from the bursts traverse dense clouds of electrons before reaching our telescopes.

In a recent paper, CAASTRO members Dr Keith Bannister (CSIRO) and Dr Greg Madsen (University of Cambridge) have taken one step closer towards understanding FRBs. They analysed one burst that was observed at a low elevation above the horizon of the Galactic plane, near the Galactic plane. Using spectra from optical telescopes, they measured the amount of interstellar electrons in the direction of the burst and concluded that there is a 90% chance that the FRB resides inside our Galaxy. Its proximity rules out some of the explanations listed above. The researchers found that the only two viable interpretations are that this burst was either given off by an unusual pulsar or by an annihilating black hole in the Galaxy.

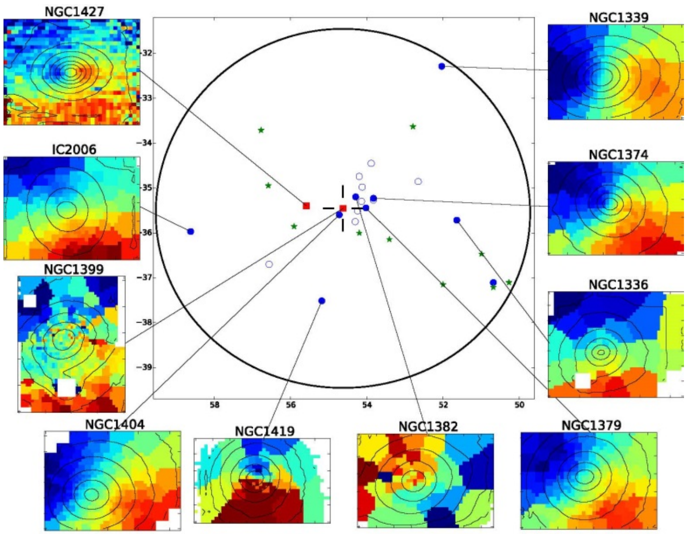
There currently are a number of vigorous, ongoing observational programs designed to find more FRBs for which we may be able to constrain the distance.

Publication:

K. W. Bannister and **G. J. Madsen** in the Monthly Notices of the Royal Astronomical Society 440 (2014): "*A Galactic Origin for the Fast Radio Burst FRB010621*"

Majority of galaxies in Fornax Cluster are fast rotating disks

Since the time of Edwin Hubble, astronomers have been classifying galaxies into different types based on their appearance, and this approach has taught us much about how galaxies formed and have evolved. However, this approach has significant limitations because we cannot observe the true, three-dimensional shape of a galaxy, only a two-dimensional projection from an arbitrary viewing angle. For example, we cannot reliably tell the difference between a spheroidal galaxy and a disk galaxy seen face-on. This degeneracy can be broken by studying the motions of the stars within a galaxy – the stellar kinematics – and accurately classifying galaxies as either slow rotators (spheroidal systems with mainly disordered stellar kinematics) or fast rotators (disk-like systems with ordered rotation).



CAASTRO researcher Dr Nicholas Scott (University of Sydney), along with CAASTRO Partner Investigator Prof Roger Davies (University of Oxford) and a team of international astronomers, used the Wide Field Spectrograph on the Australian National University 2.3m telescope to study the stellar kinematics of galaxies in the nearby Fornax cluster. The team found that the majority of galaxies in the cluster are disk-like fast rotators or spiral galaxies, with slow rotators making up only 7% of the total population.

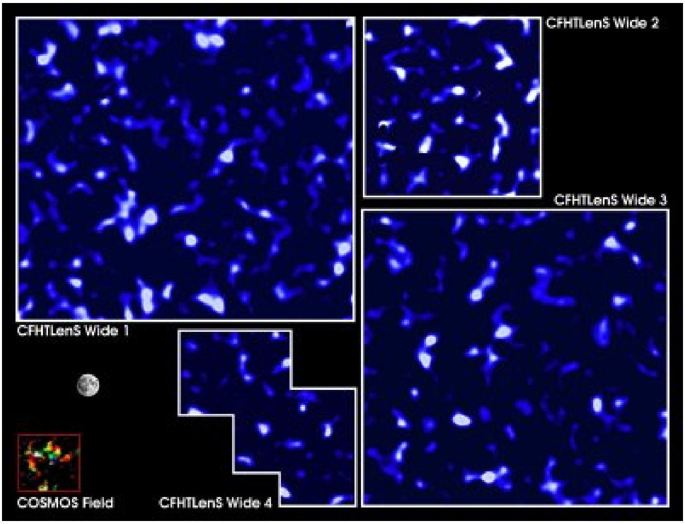
Combining their result with complementary studies of galaxies in other clusters, they found that slow rotators mainly reside in the dense cores of galaxy clusters. By controlling for other galaxy parameters, such as mass, they concluded that migration due to dynamical friction cannot be solely responsible for the over-representation of slow rotators in the centres of clusters but that a more complex mechanism is required. The researchers suggest that slow rotators either preferentially form in the centre of clusters – so they do not need to migrate – or they merge into the cluster as a central group galaxy – so the relevant mass for dynamical friction is the group mass, not the galaxy stellar mass.

Publication:

N. Scott, R. L. Davies, R. C. W. Houghton, M. Cappellari, A. W. Graham, K. A. Pimbblet in the Monthly Notices of the Royal Astronomical Society 441 (2014): “*Distribution of Slow and Fast Rotators in the Fornax Cluster*”

The known unknowns of dark matter annihilation

One of cosmology's most persistent mysteries is that of the nature of dark matter – the invisible matter that holds galaxies together. The leading theory is that dark matter is made of an as-yet undiscovered fundamental particle, with the strange property that it is its own antiparticle. That means that pairs of dark matter particles can annihilate, leaving behind radiation or high-energy particles that we can potentially detect. Searches for this radiation in nearby galaxies and in the centre of our own galaxy make up a major part of the effort to finally identify dark matter.



While gamma ray telescopes and cosmic ray detectors search for the products of dark matter annihilation in the local Universe, CAASTRO Affiliate Dr Katherine Mack (University of Melbourne) considered how dark matter annihilation could affect the formation of the first stars and galaxies in the Universe in her recent publication.

She asked the question, "When is dark matter annihilation at its peak?"

In the early Universe, dark matter begins to come together via gravity to form "halos" – quasi-spherical clumps in which galaxies and clusters form. The annihilation rate depends on the square of the halo density so a high-density halo has a much higher rate of annihilation than a low-density halo. Over time, more halos form and become denser while, at the same time, the Universe expands and gets less dense.

The question then becomes, "Is the annihilation rate higher at early times when the Universe is denser, or at late times when halos are more common and denser?"

The answer, according to Dr Mack's research, depends on the unknown properties of the dark matter halos. She shows that we need to understand the formation of dark matter halos better before we can accurately predict their effects on early stars and galaxies. Using halo parameters drawn from the literature, she found that uncertainties up to factors of 10,000 exist for the annihilation rate during the time of the first star formation. These uncertainties include the density distribution within the halos and the size of the smallest halos that form. They also make it hard to say when the "smooth" component of the annihilation, from dark matter distributed diffusely in the Universe, is overtaken by the "clumpy" component from individual halos.

Publication:

K. J. Mack in the Monthly Notices of the Royal Astronomical Society 439 (2014): "*Known Unknown of Dark Matter Annihilation over Cosmic Time*"