To: ATNF User Committee
From: Bärbel Koribalski, Lister Staveley-Smith
Subject: **Recent Astrophysics Highlights**
Date: June 1, 2006

Recent Astrophysics Highlights

1. Citation Analysis

A recent citation analysis of radio facilities by Virginia Trimble (University of California, Irvine) and collaborators, and reported at the January AAS meeting and subsequently on p.251 of the January 19, 2006 edition of the journal Nature reports that, amongst radio telescopes worldwide, the Parkes telescope is second only behind the VLA in terms of total citations to papers published in refereed journals (ATCA is third), but that the Parkes telescope leads the world in "impact", defined as the number of citations per paper.

Trimble's study, which is shortly to be published, is based on citations in the years 2002 to 2004 to papers published in the year 2001. In terms of total citations, the order of the top eight is: VLA (3003), Parkes (786), ATCA (523), VLBA (482), Arecibo (366), Merlin (194), Effelsberg (183), and WSRT (181). In terms of citations per paper, the order is Parkes (20.5), VLA (16.5), GBT (13.3), Arecibo (13.1), WSRT (12.8), VLBA (12.6), ATCA (11.2), Jodrell Bank (10.7).

2. Top 10 Science Highlights 2005

According to the journal Science, the top 10 science highlights for the year 2005 were:

- Evolution in Action
- **Planetary Probes** **:** (Australian radio telescopes helped track Huygens)
- Plant development
- **Violent neutron stars** **:** (The outburst in the soft γ-ray repeater or "magnetar" SGR 1806-20)
- Genetics of brain disease
- Earth's differentiation
- Potassium channels
- Climate change
- Systems biology
- ITER – International Thermonuclear Experimental Reactor

In 2004, the double-pulsar system – discovered by Lyne et al. (2004, Science 303, 1153) with the Parkes telescope – made the top 10 science highlights (placed at No. 6).

3. Australia Telescope Large Area Survey (ATLAS)

Analysis of the deep ATCA 1.4 GHz radio continuum observations of the CDFS and ELAIS-S1 fields are now starting to produce results. The typical sensitivity reached by the surveys is about 30 μJy. Norris et al. identified all radio sources in the CDFS field and matched them to infrared sources in the Spitzer Wide-area Infrared Extragalactic Survey (SWIRE, Lonsdale et al. 2003). A paper describing the preliminary catalogue is about to be submitted. In the two fields together ~1700 radio components with SNR > 5 were extracted. The 784 radio components in the CDFS were identified as 726 radio sources, nearly all of which have infrared counterparts. The radio source population in the ELAIS-S1 image is currently being analysed by Middelberg et al., and a paper will be submitted later this year.
Two important results from the current analysis are: (1) The identification of a class of rare infrared-faint radio sources. These are radio sources with flux densities around 1-10 mJy but no infrared counterparts. Norris et al. speculate that these are deeply obscured AGN. (2) The extension of the far-infrared – radio relation to μJy levels. Using stacked radio images at the position of the SWIRE infrared sources they determined the statistical properties of radio sources with flux densities below the image noise, and confirm that the relation holds even at these faint levels.

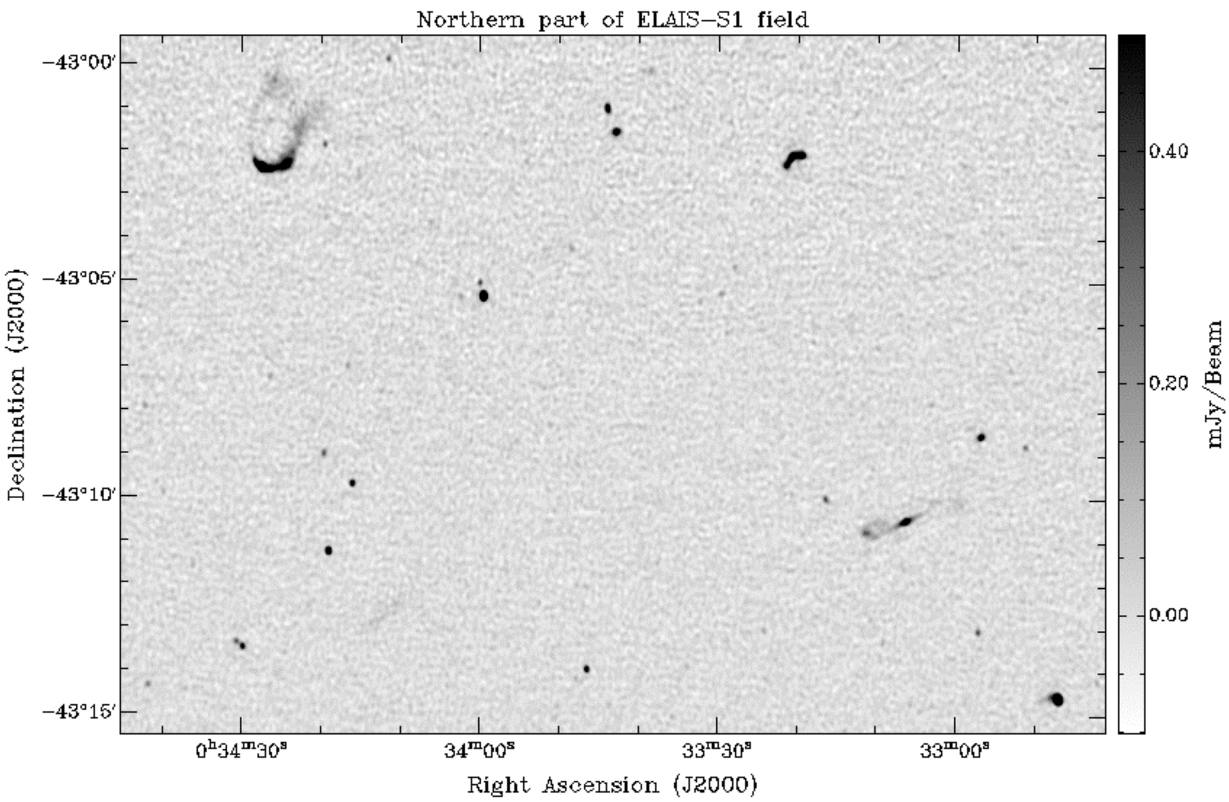

Figure 1: 1.4 GHz radio continuum emission in the northern part of the ELAIS-S1 deep field (Middelberg et al. 2006, in prep.)

4. A Molecular Ring in NGC 7552

Starbursts are regions of enhanced star formation efficiency, where gas is being converted into stars at much higher rates than can be sustained over a Hubble time. Aside from merging and dwarf galaxies, one of the most common sites for starbursts is the central kiloparsec of barred spiral galaxies. Such starbursts appear as bright circumnuclear rings in emission tracers of ionised gas such as hydrogen recombination lines or radio continuum. A nice example in the southern sky is the nearby galaxy NGC 7552, which was recently imaged with the Compact Array in the 3-mm lines of HCN and HCO^+. These lines trace the densest molecular gas and thus provide information on where star formation is still in progress.

As Figure 2 indicates, the dense gas approximately coincides with the ring-like radio continuum structure, reflecting the tight correlation between star formation and HCN emission found by Gao & Solomon in star-forming galaxies. However, in detail, the molecules have more prominent peaks, consistent with a gas pile-up where the bar-like orbits crowd and meet the ring. The molecular kinematics provide good evidence for such orbits. The molecular peaks themselves have a small offset from the radio continuum emission, which is believed to be mostly non-thermal in origin (Forbes et al. 1994). This offset may be related to a time delay between the peaks in the dense gas, which are tied to the pattern speed of the bar, and the locations of recent star formation, which revolve at a different angular velocity.

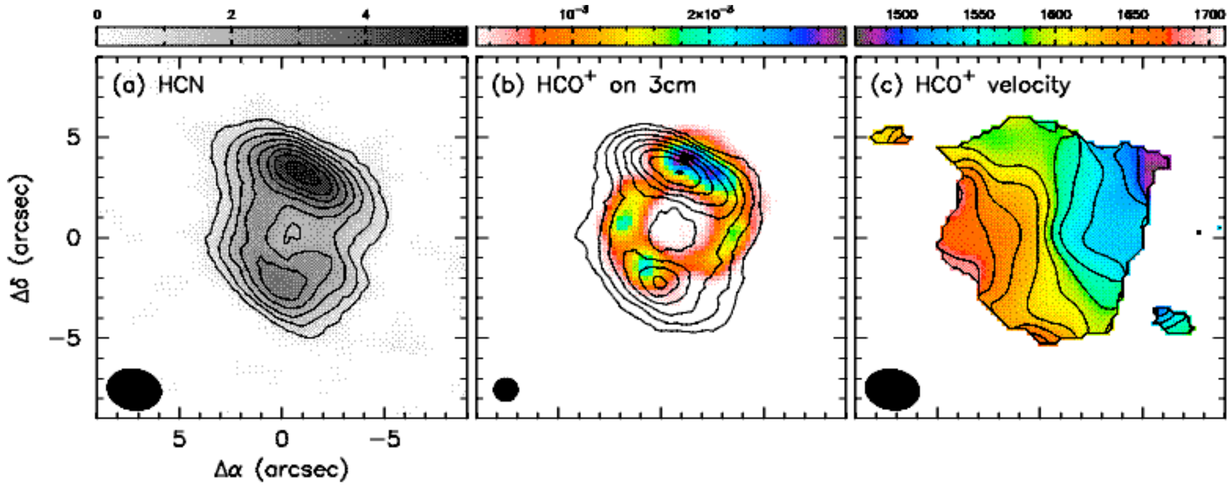

Figure 2: Dense molecular gas in the nuclear region of the starburst galaxy NGC 7552. Left: HCN line emission. Middle: HCO+ line emission (contours) overlaid onto a 3 cm radio continuum image from Forbes et al. (1994). Right: HCO+ velocity field. (Wong, Ryder, Kohno, Dahlem & Buta 2006, in prep.)

The HCO^+/HCN ratio is close to unity, consistent with the lack of Seyfert activity. Any central black hole is probably starved by the inability of gas to flow inwards. Notably, the HCN and HCO^+ peaks do not exactly coincide, even though the two molecules have similar critical densities for excitation. This may be attributable to the dependence of HCO^+ on photochemistry.

5. Galactic All-Sky Survey (GASS) Progress

This ongoing survey of the Milky Way with the Parkes telescope has produced its first major discovery, a massive shell of expanding gas powered by an energy equivalent to 30 supernova explosions. The Galactic All-Sky Survey (GASS) commenced its two-year program of observations at the Parkes telescope last year and, almost immediately, an energetic Galactic supershell (GSH 242-03+37) was found by McClure-Griffiths, Ford, Pisano, Gibson, Staveley-Smith, Calabretta, Dedes & Kalberla 2006, ApJ 638, 196). The radius of the shell is 560 pc. It is believed that fragmentation of such shells may explain the significant population of compact neutral hydrogen clouds recently discovered by the Greenbank telescope.

In another major milestone, the first of two passes of the entire southern sky has recently been completed. An image at a single velocity channel near zero km/s is shown below.

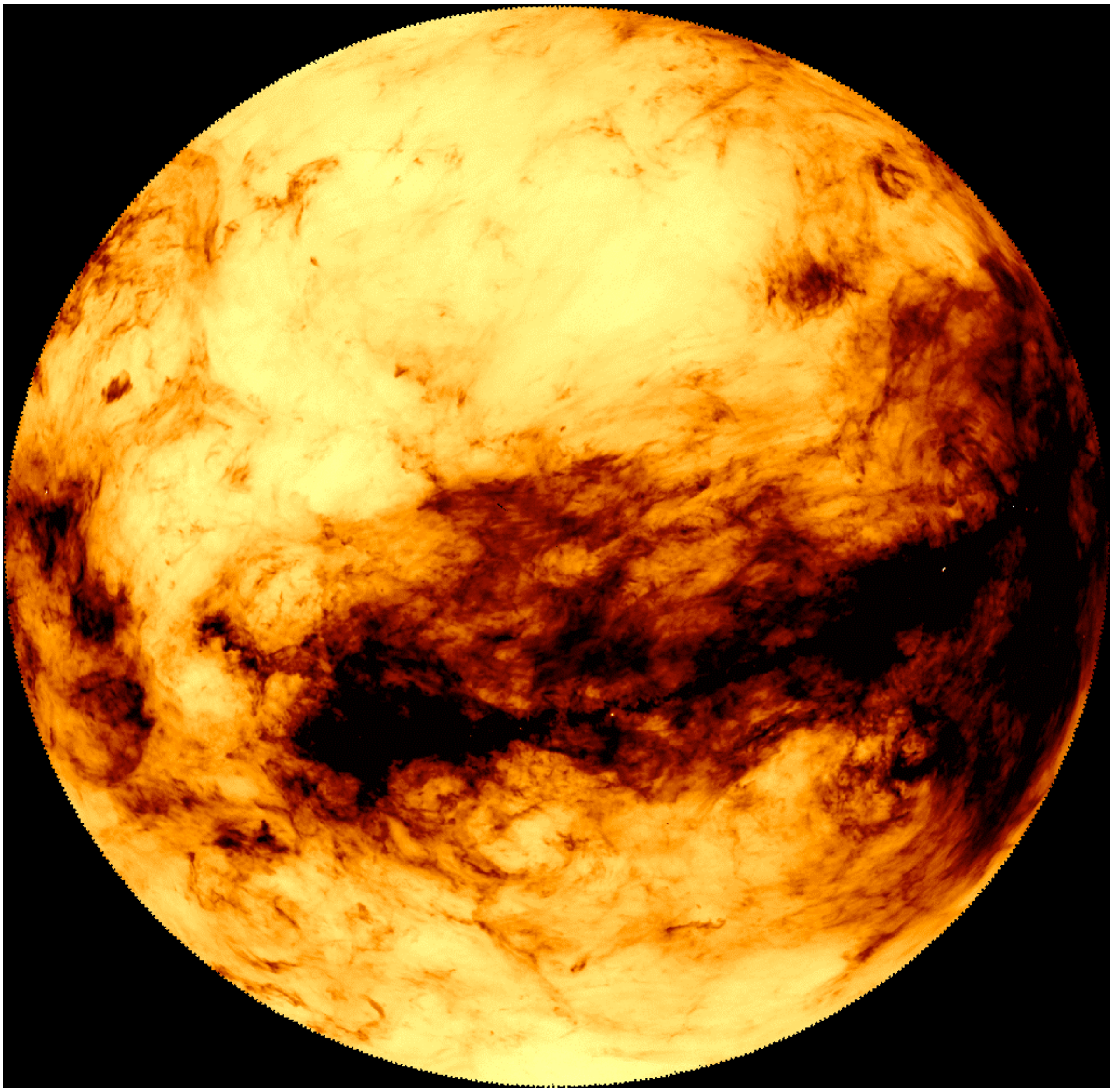

Figure 3: A Parkes GASS image of the complete southern sky near LSR velocity 0 km/s. This image has been formed from one complete pass of Dec scans and 25% of all RA scans (McClure-Griffiths et al.).

6. The Local Volume HI Survey (LVHIS)

The "Local Volume HI Survey" (LVHIS) is a project comprising deep HI line and 20-cm radio continuum observations for all nearby, gas-rich galaxies led by B. Koribalski. The initial sample consists of all galaxies with $v_{LG} < 550$ km/s or Distance < 10 Mpc that are detected in HIPASS. A declination limit of $\delta < -30$ degrees was chosen for the ATCA observations. The aim is to study the HI distribution and kinematics of Local Volume galaxies as well as their star-formation properties on all scales. The project reached its first milestone in March 2006 when all planned observations in the ATCA EW352/367 array were completed. Observations in the ATCA 750-m and 1.5-km arrays are under way. Figure 4 presents a mosaic of mean HI velocity fields for some of the LVHIS galaxies.

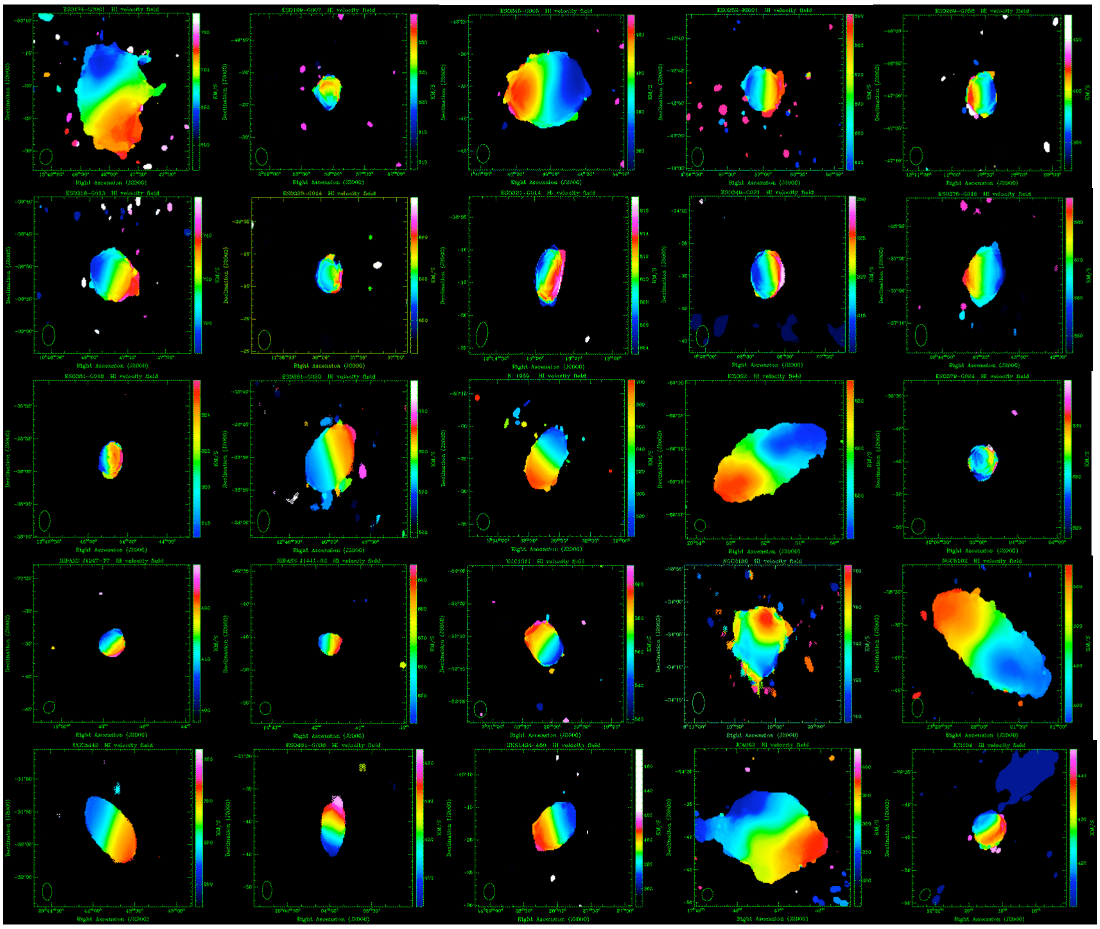

Figure 4: Low-resolution ATCA HI velocity fields for 25 of the LVHIS galaxies. (Koribalski, Staveley-Smith, Ott, de Blok, Jerjen, Karachentsev 2006, in prep.)

7. First Light at Parkes for the Methanol Multibeam Receiver

The new 7-beam Methanol Multibeam (MMB) receiver is being used for two major surveys: for Galactic methanol masers which pinpoint regions containing newly-forming massive stars; and for pulsars which are difficult to see at lower frequencies due to scattering.

The Parkes survey of the Milky Way for methanol masers (Cohen, Caswell et al.) is two orders of magnitude faster than previous systematic surveys using 30-m class dishes. The first science run (10 days in January 2006) yielded 60 new sources, including some which must lie on the far side of the Galaxy (judging from their radial velocities), at a distance of at least 16 kpc. The second run in February proved equally successful. A deeper methanol survey of the Galactic Centre region is being made by piggy-backing onto the pulsar survey and has also yielded its first new masers.

The 6.7 GHz survey for pulsars in the Galactic Plane (Johnston et al.) commenced shortly after the maser survey. Eventually, 6700 individual pointings of the receiver will be made and cover the region from -60 degrees longitude through the Galactic Centre to +45 degrees longitude with a restricted latitude range of ±0.5 degrees. Although 6.7 GHz is a high frequency for pulsar surveys the idea is to find young, distant pulsars obscured in the Galactic murk and missed by lower frequency surveys. A total of about 100 new pulsars are expected.

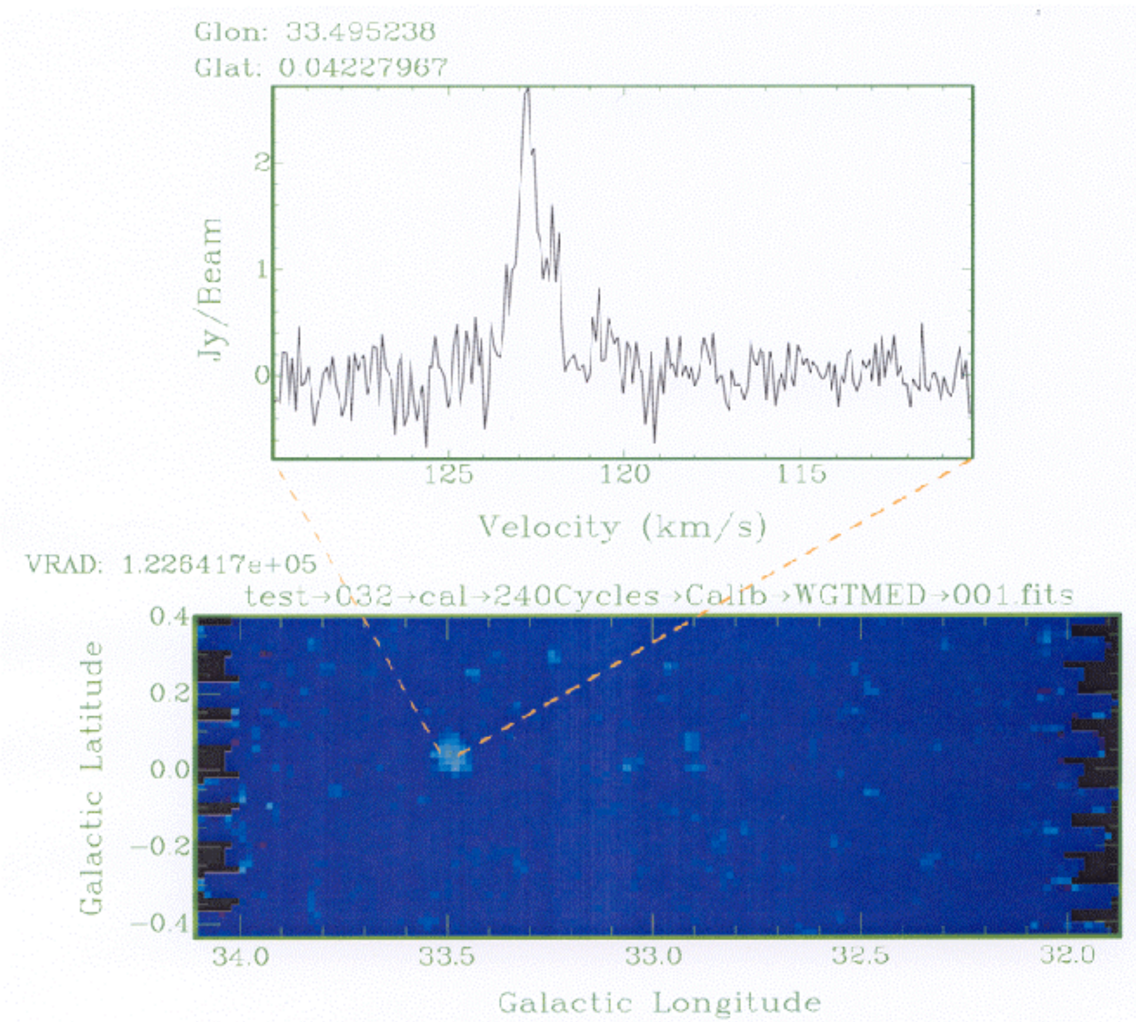

Figure 5: A spectrum (top) and image (bottom) of a new Methanol maser found in the Galactic Plane multibeam methanol survey. This maser has been informally christened James-I in honour of the number of people called James in the observing team.

The successful initial 10 days of observing covered a total of 450 pointings. Tests showed the receiver was performing well with a system equivalent flux density of 60 Jy on all 7 beams over a wide (600 MHz) band.

Data processing on the cluster at Parkes can be achieved in real-time – the survey will eventually collect 8 TB of data.

8. Cleaning up Eta Carina: Detection of Ammonia in the Homunculus

Smith et al. (2006) report the first detection of ammonia in the Homunculus nebula around η Carina, which is also the first detection of emission from a polyatomic molecule in this or any other luminous blue variable (LBV) nebula. Observations of the NH_3 (J,K)=(3,3) inversion transition made with the ATCA reveal emission at locations where infrared H_2 emission had been detected previously, near the strongest dust emission in the core of the Homunculus. We also detect ammonia emission from the so-called "strontium filament" in the equatorial disk. The presence of NH_3 around η Car hints that molecular shells around some Wolf-Rayet stars could have originated in prior LBV eruptions, rather than in cool red supergiant winds or the ambient interstellar medium. Combined with the lack of any CO detection, NH_3 seems to suggest that the Homunculus is nitrogen rich like the ionized ejecta around η Car. It also indicates that the Homunculus is a unique laboratory in which to study unusual molecule and dust chemistry, as well as their rapid formation in a nitrogen-rich environment around a hot star. [abstract from Smith, N., Brooks, K.J., Koribalski, B.S., Bally, J. 2006, ApJ Letter, in press]

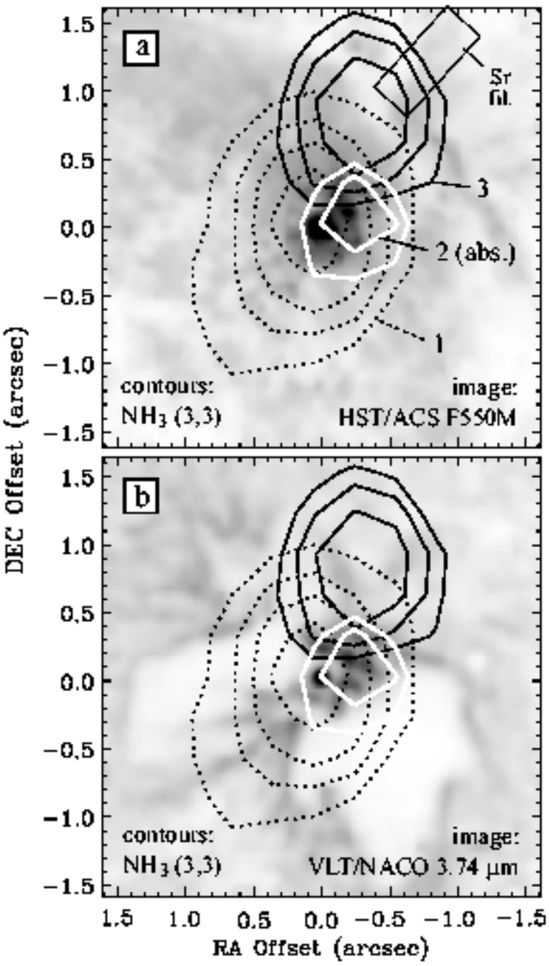

Figure 6: The spatial distribution of ammonia compared to optical and IR emission. NH3 (3,3) contours superimposed on an HST/ACS image in visual continuum light (top; from Smith et al. 2004) and on a 3.74 μm image (bottom; from Chesneau et al. 2005). The approximate extent of the "strontium filament" is indicated with a rectangle in the top image.
(Smith, Brooks, Koribalski, & Bally 2006, ApJ Letters, in press)

9. Pulsars near the Galactic Centre

Just recently, Johnston et al. (2006) discovered two highly dispersed pulsars in the direction of the Galactic Centre made during a survey at 3.1 GHz with the parkes radio telescope. Both PSR J1745-2912 and J1746-2856 have an angular separation from the Galactic Centre of less than 0.3 degrees and dispersion measures in excess of 1100 cm-3pc, placing them in the top 10 pulsars when ranked on this value. The frequency dependence of the scatter-broadening in J1746-2856 is much shallower than expected from simple theory. Johnston et al. suggest that the pulsars are located between 150 and 500 pc from the Galactic Centre on the near side, and are part of the excess population of neutron stars associated with the Centre itself. A second survey made at 8.4 GHz did not detect any pulsars. This implies either that there are not many bright, long-period pulsars at the Galactic Centre or that the scattering is more severe at high frequencies than current models would suggest.

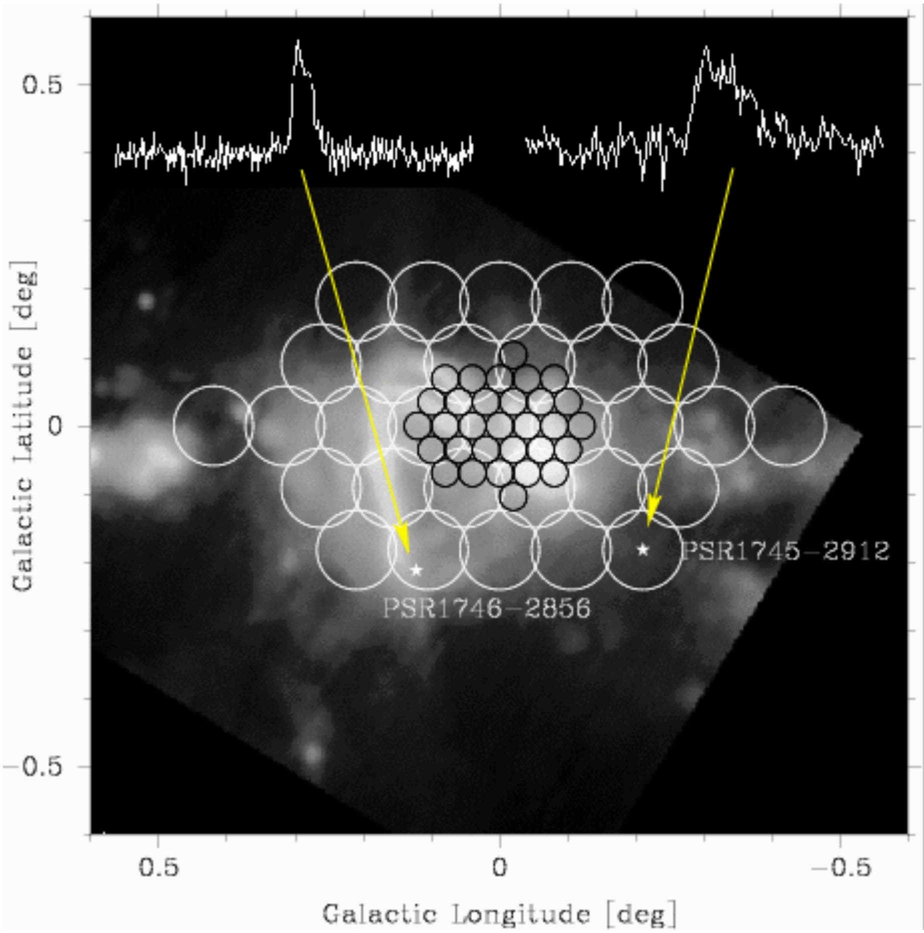

Figure 7: Two pulsars near the Galactic Centre; their pulse profiles and locations are shown. Background image: the Galactic Centre at 10 GHz with as observed with the Effelsberg 100-m telescope. Large circles: Parkes 10cm pointings. Small circles: Parkes 3cm pointings.

(Johnston, Kramer, Lorimer, Lyne, McLaughlan, Klein & Manchester 2006, MNRAS Letters, submitted).

10. A Galactic Centre Ammonia Survey

The Galactic Centre Region (GCR) is the most nearby galaxy core. A large number of very different features are present in the GCR, e.g., the central black hole in Sgr A* and its circumnuclear disc, as well as a variety of massive star forming regions such as Sgr B2 and Sgr B1 which exhibit quite different morphologies and kinematics. The region is furthermore subject to extreme physical conditions such as shear, magnetic fields, and strong tidal forces. For a reliable understanding of the physics involved in galactic cores a large number of direct measurements of parameters such as the density and the temperature of different gas phases is indispensable.

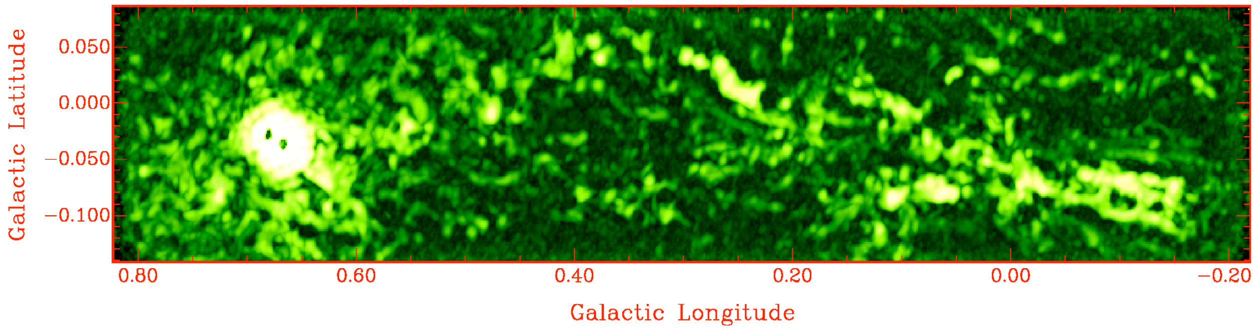

Figure 8: Compact Array ammonia (1, 1) peak intensity map of the Galactic Centre Region (logarithmic representation). The map consists of 840 individual pointings. Sgr A*, the massive central black hole of the Galaxy is located toward the right of the map. The very prominent emission to the left is emitted by Sgr B2. Notable are also the two 'holes' on top of Sgr B2 which exhibit ammonia in absorption (Ott et al.).

Owing to its particular tetrahedral structure, transitions of ammonia can be used as a thermometer for dense molecular gas. This property is the main driver for the wide-field Compact Array ammonia survey toward the Galactic Centre. The first part of the Galactic Centre Region stretching from the central black hole, Sgr A* to the massive star forming region, Sgr B2 has now been observed, covering an area 1° × 0.2°. The observations were made using the ultra-compact H75 array configuration and 840 pointings to cover the large field. Both the metastable ammonia (1, 1) and (2, 2) inversion lines were measured simultaneously. The resulting map, displayed in Figure 9, has a physical resolution of ~1 pc (synthesized beam ~20 arcsec) and is the most detailed, wide-field map of molecular gas toward the GCR to date. Over most of the regions there is a very good correspondence between the ammonia features and the dust distribution.

The ammonia (1, 1) and (2, 2) inversion lines trace a Boltzmann distribution and therefore the temperature of the gas. This rotational temperature can be converted into kinetic temperature by applying radiative transfer models. At high temperatures, however, the ratio of line strengths exhibits only slight variations and, therefore, the (1, 1) and (2, 2) rotational temperature is a tracer for cold gas. Quantitatively, rotational temperatures up to ~30 K correspond well to kinetic temperatures, while higher rotational temperatures indicate a very hot environment.

The full analysis will encompass virial masses of individual clouds, the clump mass-function down to the lowest masses ever determined in the GCR, and more detailed temperature and pressure maps. In addition, a wealth of observations of all wavelengths is available for the Galactic Centre which will be compared with this data in terms of heating / cooling mechanisms and within large velocity gradient radiative transfer models. The data also forms a cornerstone for the comparison with molecular gas properties within the cores of other galaxies (Ott, Henkel, Weiss, & Staveley-Smith, in preparation).

11. RRATs: A New Class of Cosmic Object

Careful examination of data from the Parkes multibeam pulsar survey has revealed 11 radio outbursts. The sources involved in these outbursts have since been monitored, and appear to be characterized by single bursts having durations of less than 30 milliseconds, and a repetition rate of one outburst every few minutes to few hours. The new class of sources, called RRATs for "Rotating Radio Transients", appear to be pulsars with a very high magnetic field (500 million times the strength of the strongest terrestrial magnets), but the results imply that the total Galactic population of these objects significantly exceeds that of normal pulsars (McLaughlin, Lyne, Lorimer, Kramer, Faulkner, Manchester, Cordes, Camilo, Possenti, Stairs, Hobbs, D'Amico, Burgay & O'Brien 2006, Nature 439, 817).

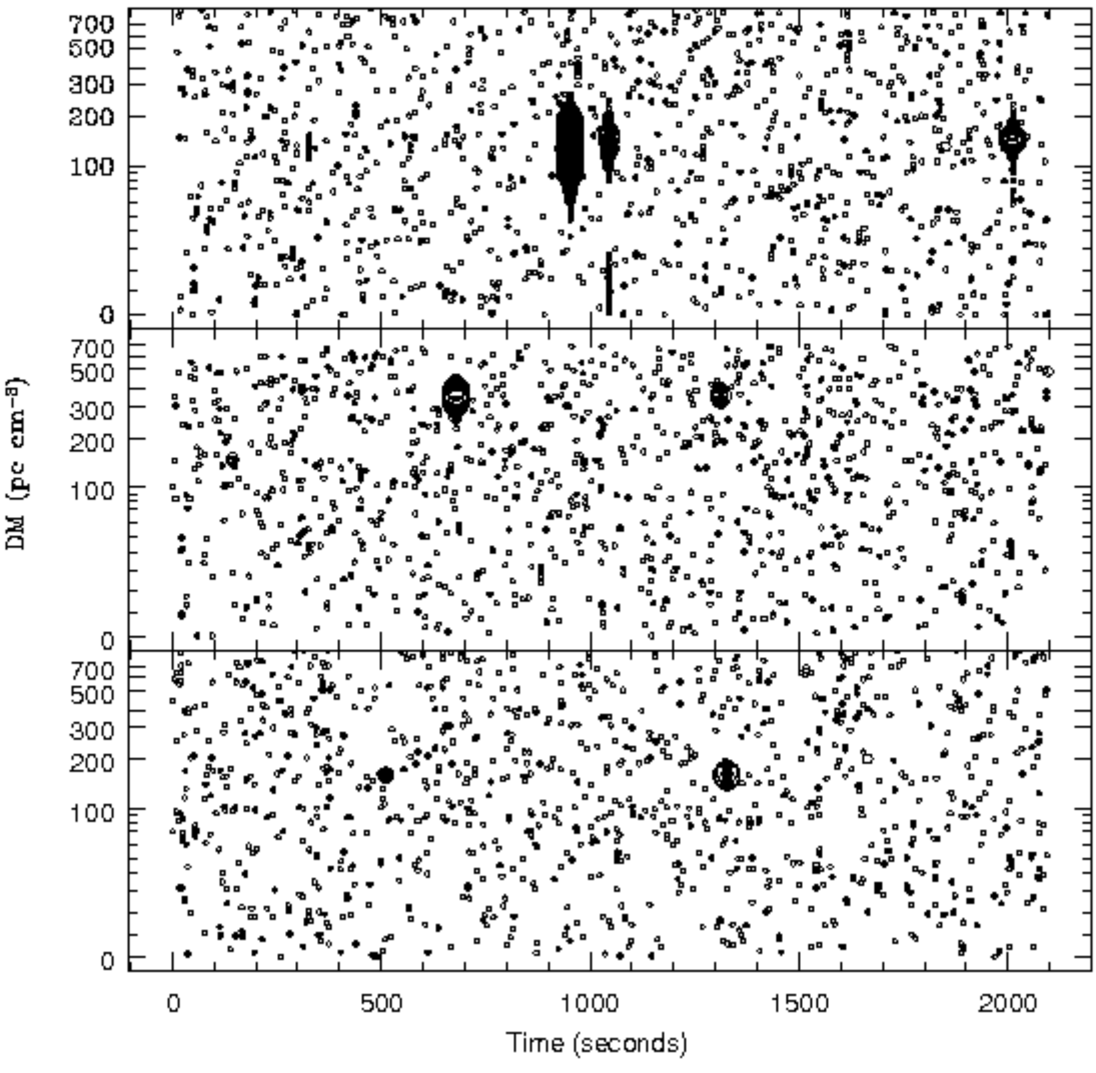

Figure 9: The observational signatures of the new radio transient sources. The original detections of J1317-5759, J1443-60 and J1826-14 (from top to bottom) in the Parkes Multibeam Survey data are shown. See McLaughlin, Lyne, Lorimer, Kramer, Faulkner, Manchester, Cordes, Camilo, Possenti, Stairs, Hobbs, D'Amico, Burgay & O'Brien (2006, Nature 439, 817).

More details on some of the above research, and research reported at previous ATUC meetings, can be found in the 2005 Annual report and at the web address www.atnf.csiro.au/research/highlights/2005.