The Rise of Multibeam Astronomy

Lister Staveley-Smith, ICRAR
Outline

- Single beam v. multibeam
  - Survey speed and sensitivity
- History of the Multibeam
  - Galileo and Canares
- Innovations, discoveries and science
  - HIPASS and legacy
- The present and future
  - ASKAP and Parkes as an SKA Pathfinder
Parkes single-beam HI spectra – c.1980’s
Sensitivity comparison

Relative Speed

- Parkes
- Lovell
- Effelsberg
- Arecibo

Sensitivity Speed
Are multiple beams useful?

- Highly optimized single pixel feeds will always outperform multibeam arrays (R. Fisher et al. circa 1995)
- Correlation expensive
Why multibeam?

– A journey from one of the world’s least-sensitive large single-dish telescopes to the world’s fastest
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- A journey from one of the world’s least-sensitive large single-dish telescopes to the world’s fastest
Sensitivity v. survey speed

- Time taken to reach a given sensitivity:

\[ \tau = \left( \frac{A}{T} \right)^{-2} \propto D^{-4} \]
Sensitivity v. survey speed

- Time taken to survey an area of sky to a given sensitivity

  - Ekers & Rots (1979):
    \[ \tau \propto n_{RX}^{-1} \]

  - Staveley-Smith et al. (1996) – multibeam concept paper:
    \[ \tau \propto (N_b A_t N_a \Delta \nu)^{-1} \]

  - ASKAP (Johnston et al. 2007); SKA (Schilizzi et al. 2007):
    \[ \tau = \left( \frac{A}{T} \right)^{-2} \Omega^{-1} \]
We need a new focus cabin!

The Galileo connection

Galileo with non-deployable X-band antenna

100 b/s
The transition to a multiple feed cluster

Trevor Bird (feeds)

Warwick Wilson (correlator & project leader)

Mal Sinclair (receiver)
NASA/Canares chip

- Cheap, fast correlator ASIC
- 64 MHz (14,000 km/s); suitable for Disney’s crouching giants
How do you tile the sky with 13 beams?
On-the-fly mapping: a better way to cover the sky

Mike Kesteven
Innovation – hardware and operational

• Unprecedented number of beams
  – First cm-wave multibeam spectroscopic receiver

• Excellent $T_{\text{sys}}$ and Efficiency
  – 21K/60% efficiency bettered most existing single pixel receivers

• Reasonable bandwidth
  – 300 MHz enabled pulsar survey sensitivity

• Fast/stable calibration noise diode
  – 100 Hz cal avoided interference problems
  – Stable over ~decade

• On-the-fly mapping
  – Allowed fast and redundant and robust coverage of sky

• Realtime data reduction and data archiving
  – Quality control and data security
A few technology spin-offs from the Parkes multibeam project

- LBA correlator capacity
- Areccibo multibeam
- Lovell multibeam
- TCS/on-the-fly mapping
- SEST correlator
- First PSR 1 GHz correlator
- Methanol multibeam
A Parkes HI data cube

- Galactic Emission
- HI Recombination Line @ $V \sim 4600$ km/s
- $V \sim 5000$ km/s
- $V \sim -1200$ km/s
- NGC 6744
- ESO 141-G042
- R.A.
- Decl.
Extragalactic multibeam surveys (1997-2002)

• Instrument, Calibration and Survey
  – Staveley-Smith et al (1996); Barnes et al. (2001)

• Discoveries
  – Leading Arm (Putman et al. 1998)
  – Tidal debris around galaxies (Ryder et al. 2001, Kilborn et al. 2000)

• Surveys
  – HIPASS bright galaxies (Koribalski et al. 2004)
  – HOPCAT (Doyle et al. 2005)
  – ZOA (Henning et al. 2000; Donley et al.; Staveley-Smith et al. 1998)
  – Gas around nearby galaxies (Pisano et al.)

• Cosmology
  – HI mass function (Zwaan et al. 2003, 2005)
  – Clustering, Tully-Fisher (Meyer et al. 2007, 2008)
THE 1000 BRIGHTEST HIPASS GALAXIES: H I PROPERTIES


The HIPASS catalogue – I. Data presentation

The HIPASS catalogue – II. Completeness, reliability and parameter accuracy


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Technology, science and software partnership
HIPASS data server – a legacy

Downloads

Multibeam astronomy beyond HIPASS: ASKAP/SKA

Phased Array Feed @ PKS 12-m
ASKAP/Wallaby simulated lightcone

500k galaxies

Alan R. Duffy\textsuperscript{1}, Martin J. Meyer\textsuperscript{1}, Lister Staveley-Smith\textsuperscript{1}, Max Bernyk\textsuperscript{2}, Darren J. Croton\textsuperscript{2}, Baerbel Koribalski\textsuperscript{3}, Stefan Westerlund\textsuperscript{1}
Gas Evolution: GMRT stack at $z=0.24$

Lah et al. (2007)

$$M_{HI} = (2.26 \pm 0.90) \times 10^9 M_\odot$$

$$0.36 \pm 0.14 M^*$$
A stacked HI signal at $z=0.1$ with Parkes (GAMA9 field; Delhaize)
An intensity map of hydrogen 21-cm emission at redshift $z \approx 0.8$

Tzu-Ching Chang$^{1,2}$, Ue-Li Pen$^2$, Kevin Bandura$^3$ & Jeffrey B. Peterson$^3$

Figure 2 | The cross-correlation between the DEEP2 density field and GBT H\textsc{i} brightness temperature. Crosses, measured cross-correlation
Parkes@60: possible upgrade path?
HIPSR: new unified Pks backend

- 16x2 beams
- 400 MHz bandwidth
- 8192 channels
- 20 Tflops Tesla GPU compute power
HIPSR first light: 2011 Oct 6
Summary

• **PKS@40 paved way for multibeam astronomy**
  - high survey speed for HI and pulsars
  - pipeline data reduction
  - large collaborations
  - ASKAP

• **PKS@50 will pave the way for SKA techniques**
  - intermediate redshift galaxy stacking
  - intermediate redshift intensity mapping
  - RFI excision