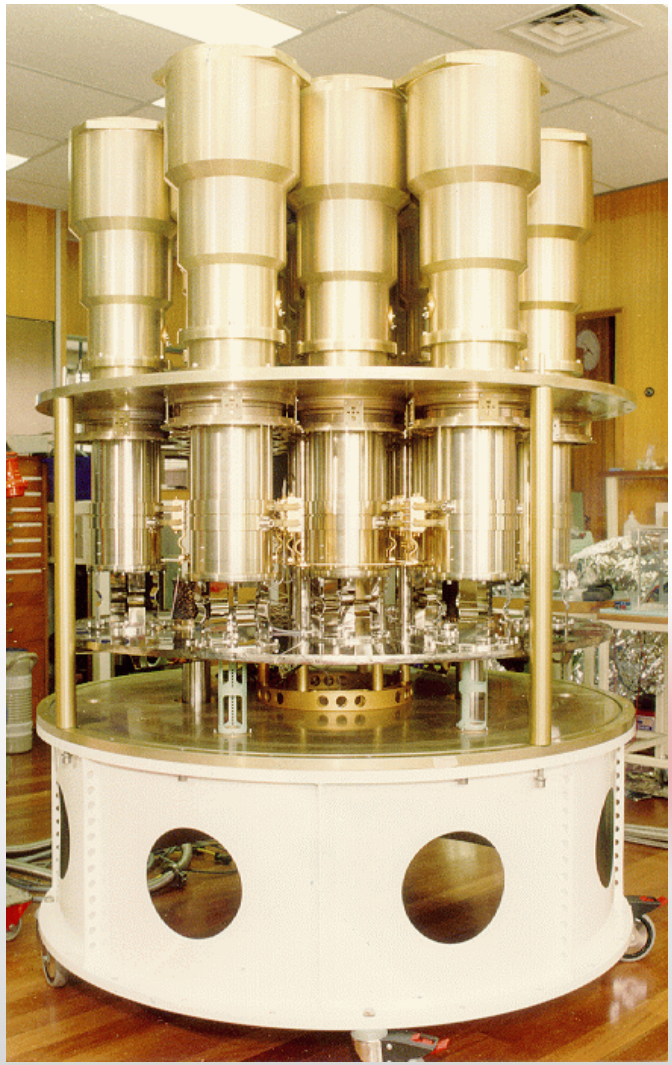


The Rise of Multibeam Astronomy

Lister Staveley-Smith, ICRAR

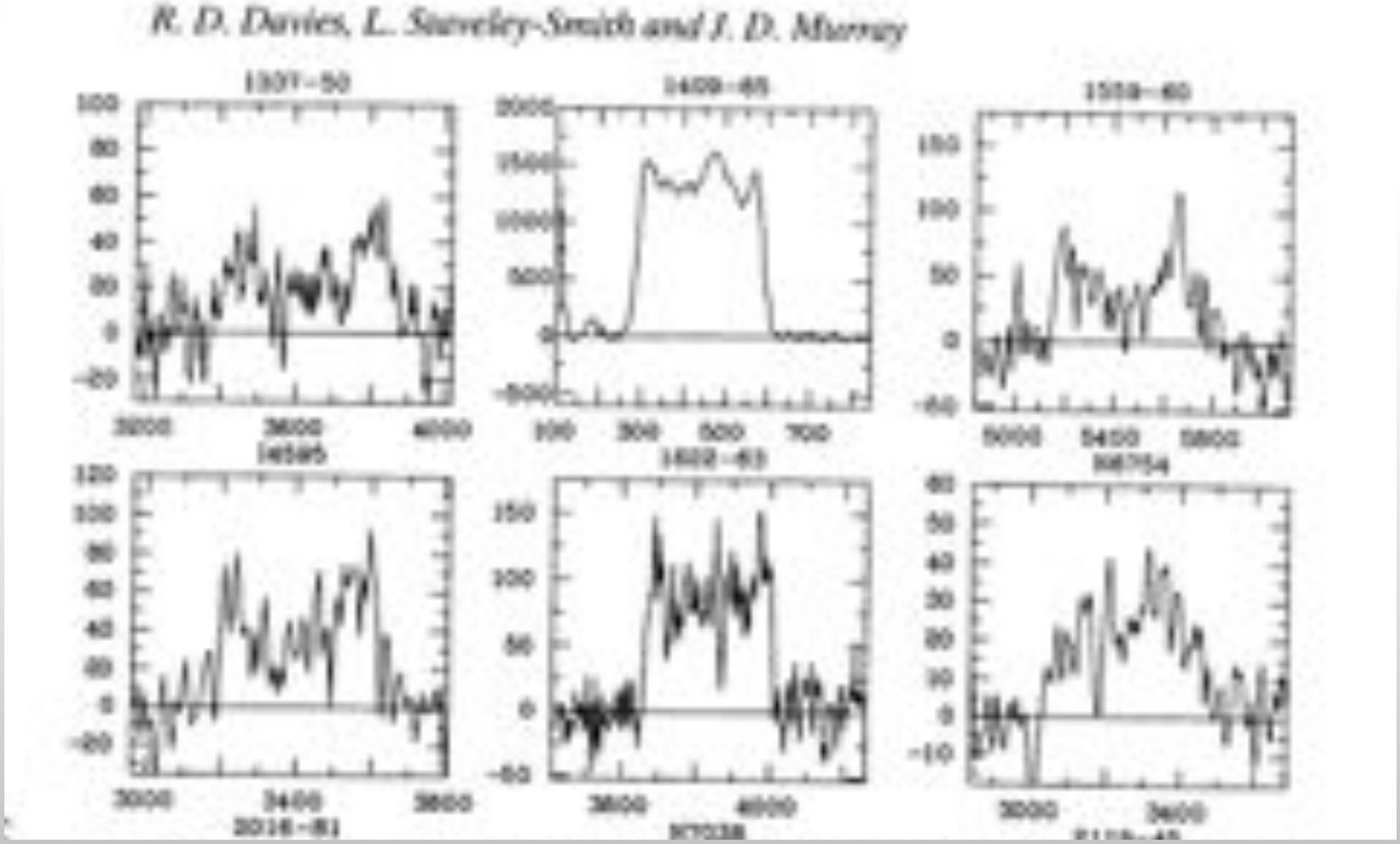
Curtin University

The University of Western Australia

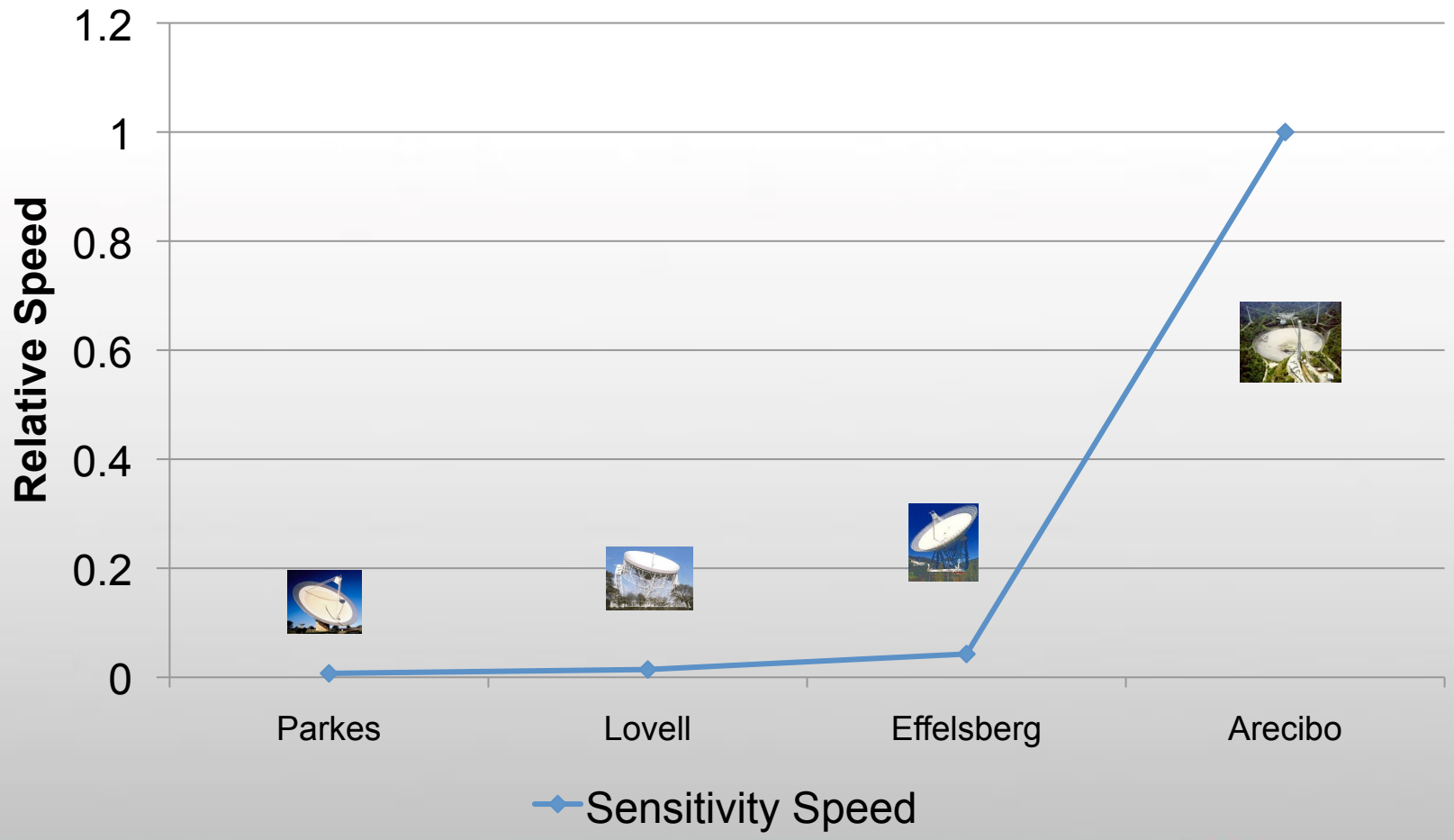
Outline

- **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

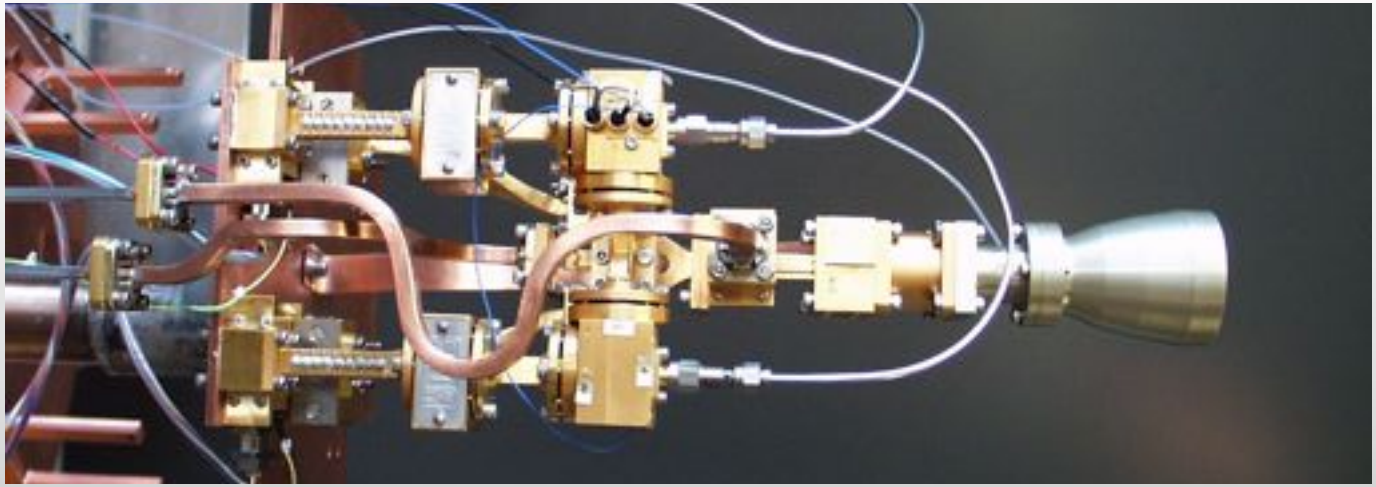


Sensitivity comparison



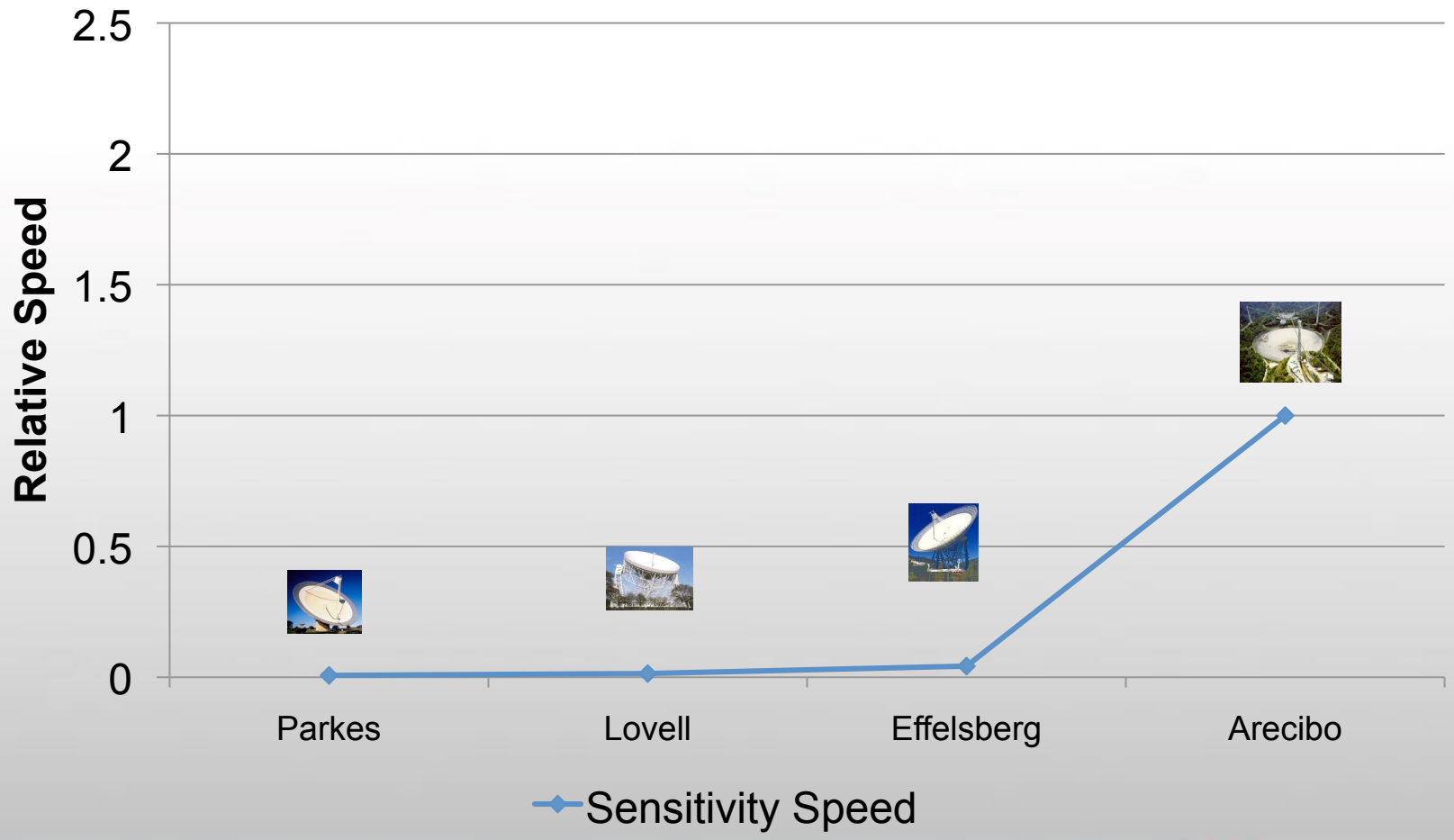
Are multiple beams useful?

- 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



Why multibeam?

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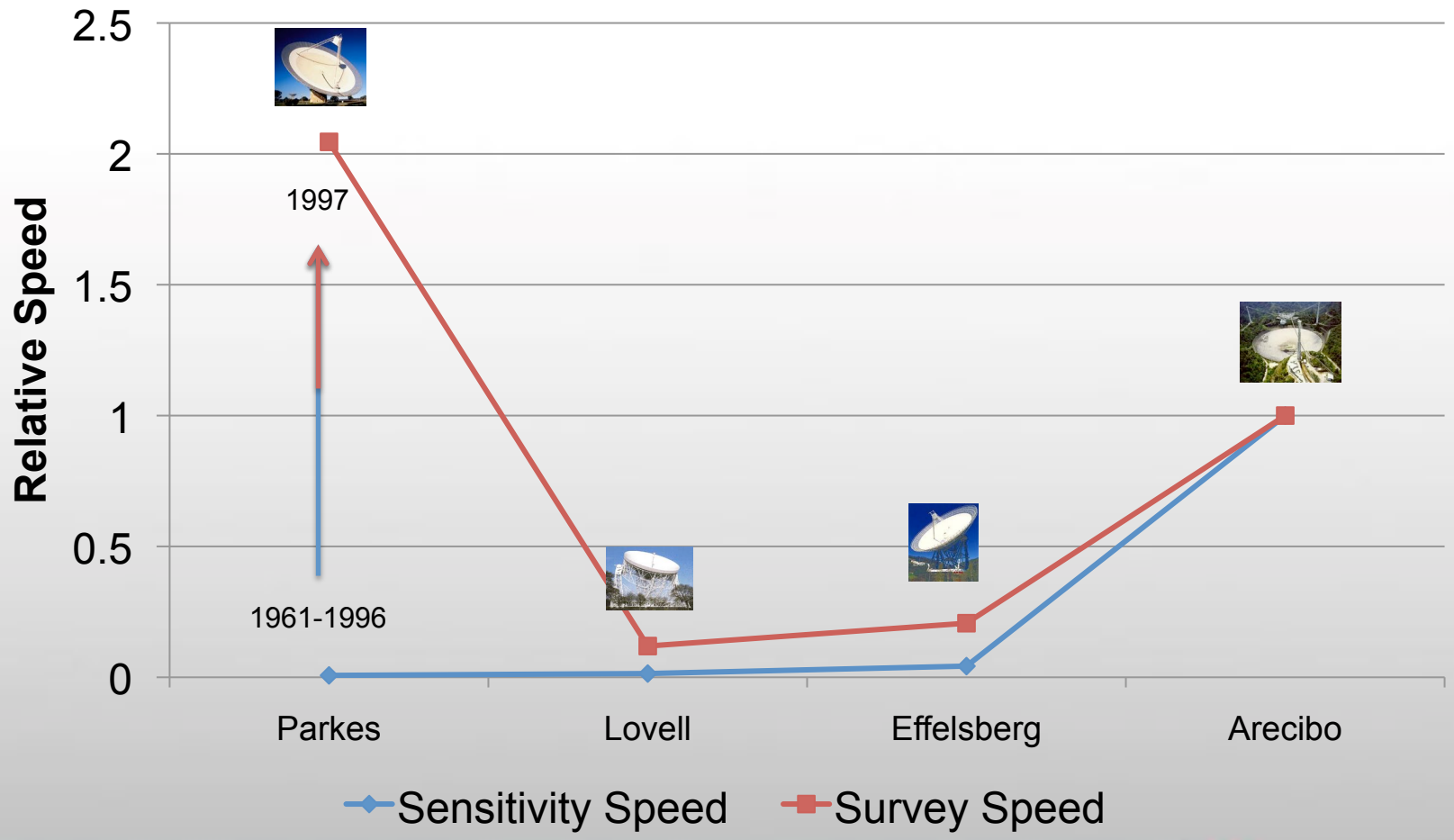


Sensitivity .v. survey speed

- 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 <u>an area of sky</u> to a given sensitivity
  - Ekers & Rots (1979):

$$\tau \propto n_{RX}^{-1}$$

  - Staveley-Smith et al. (1996) – multibeam concept paper:

$$\tau \propto (N_{\mathrm{b}} A_{\mathrm{t}} N_{\mathrm{a}} \Delta\nu)^{-1}$$

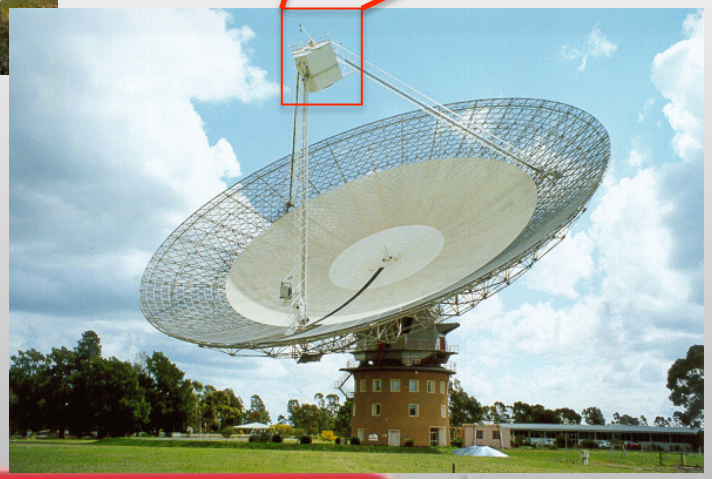
  - ASKAP (Johnston et al. 2007); SKA (Schilizzi et al. 2007):

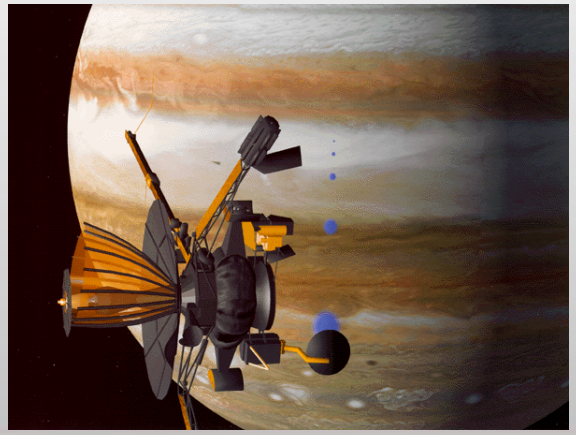
$$\tau = \left(\frac{A}{T}\right)^{-2} \Omega^{-1}$$

We need a new focus cabin!

The Galileo connection

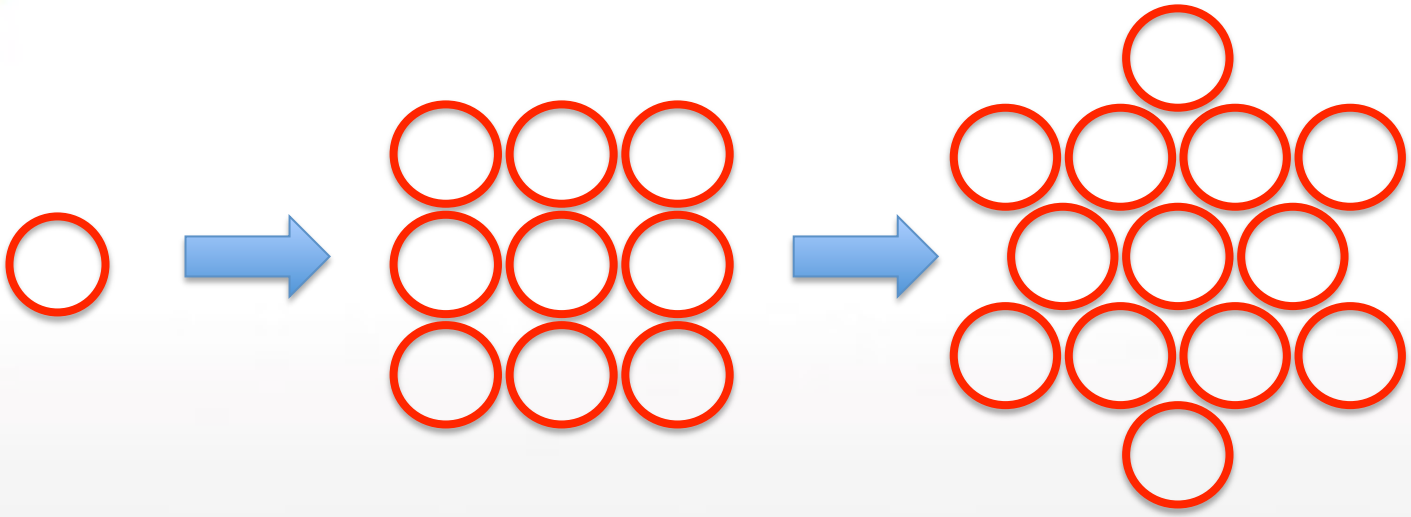
100 b/s



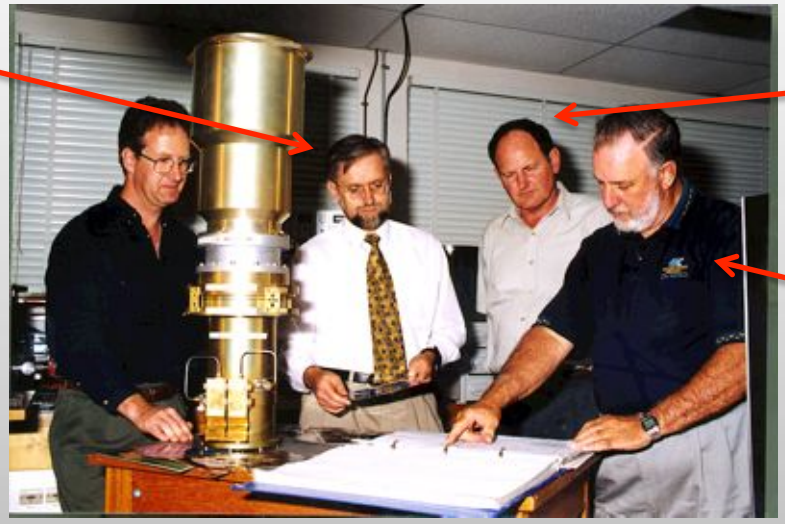


Galileo with non-deployable X-band antenna

The transition to a multiple feed cluster



Trevor Bird
(feeds)



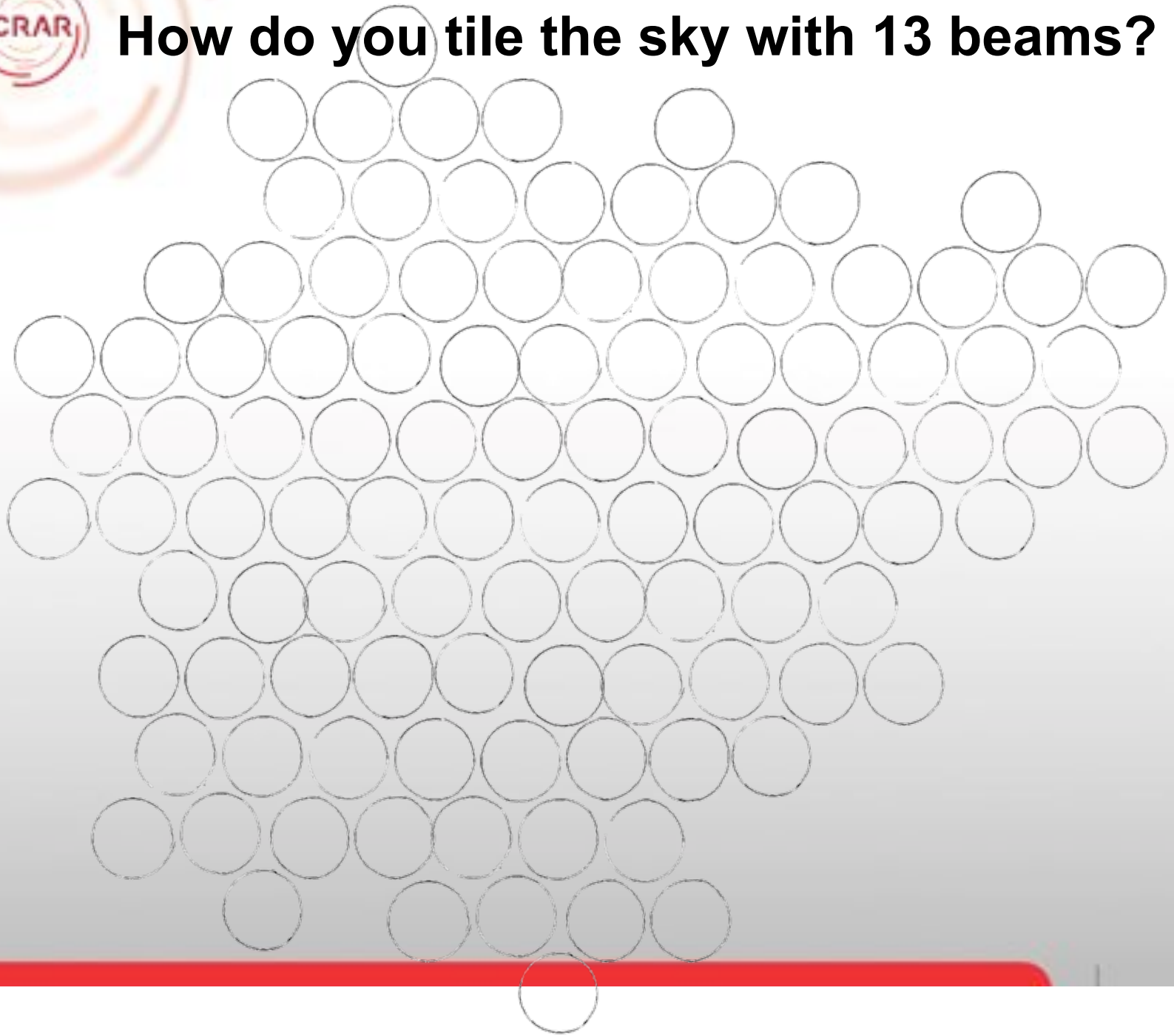
Warwick
Wilson
(correlator &
project leader)

Mal Sinclair
(receiver)

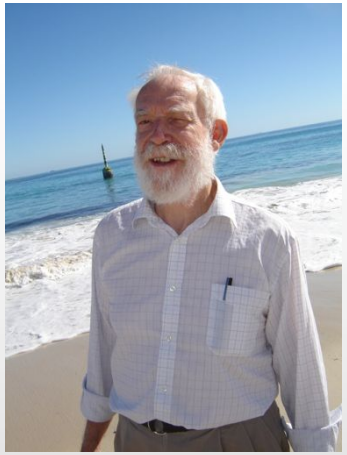
NASA/Canares chip

- Cheap, fast correlator ASIC
- 64 MHz (14,000 km/s); suitable for Disney's crouching giants

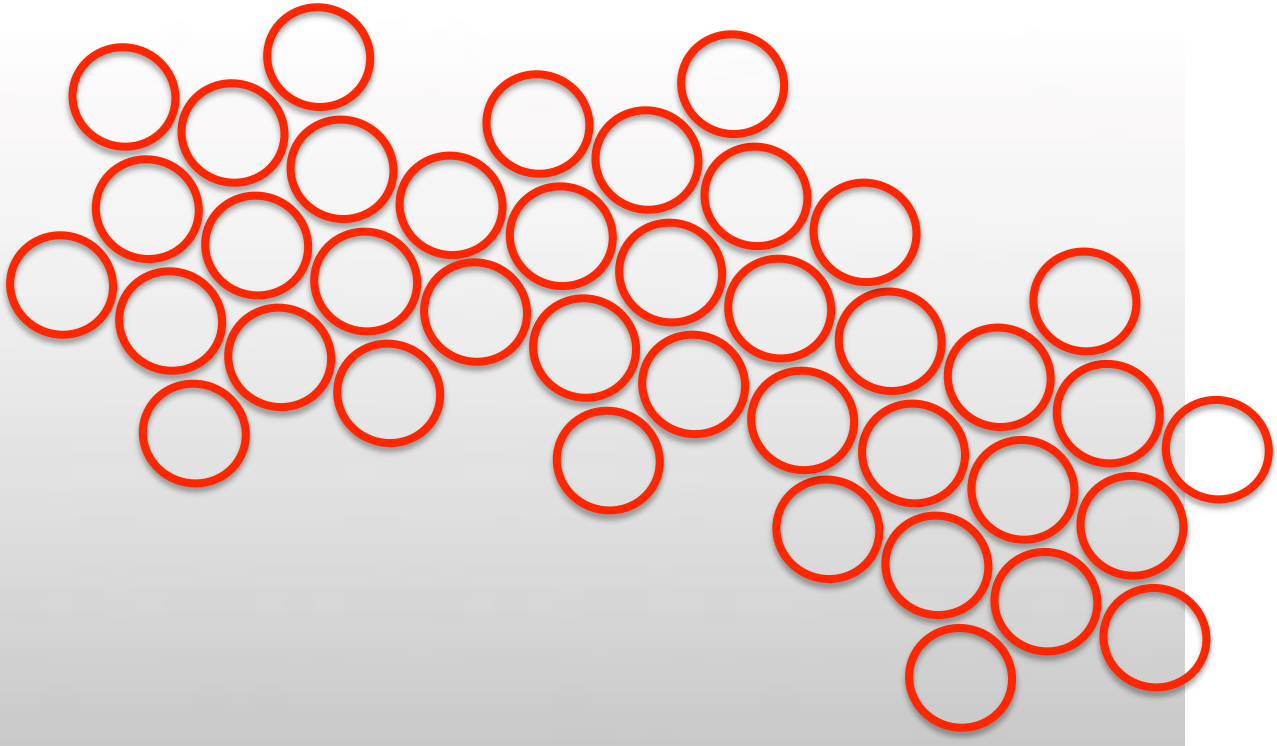
How do you tile the sky with 13 beams?



On-the-fly mapping: a better way to cover the sky



Mike Kesteven



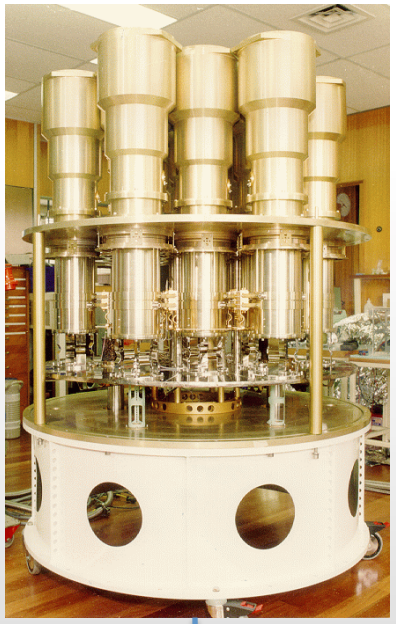
Innovation – hardware and operational

- **Unprecedented number of beams**
  - First cm-wave multibeam spectroscopic receiver
- **Excellent T(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

Arecibo multibeam



Lovell multibeam

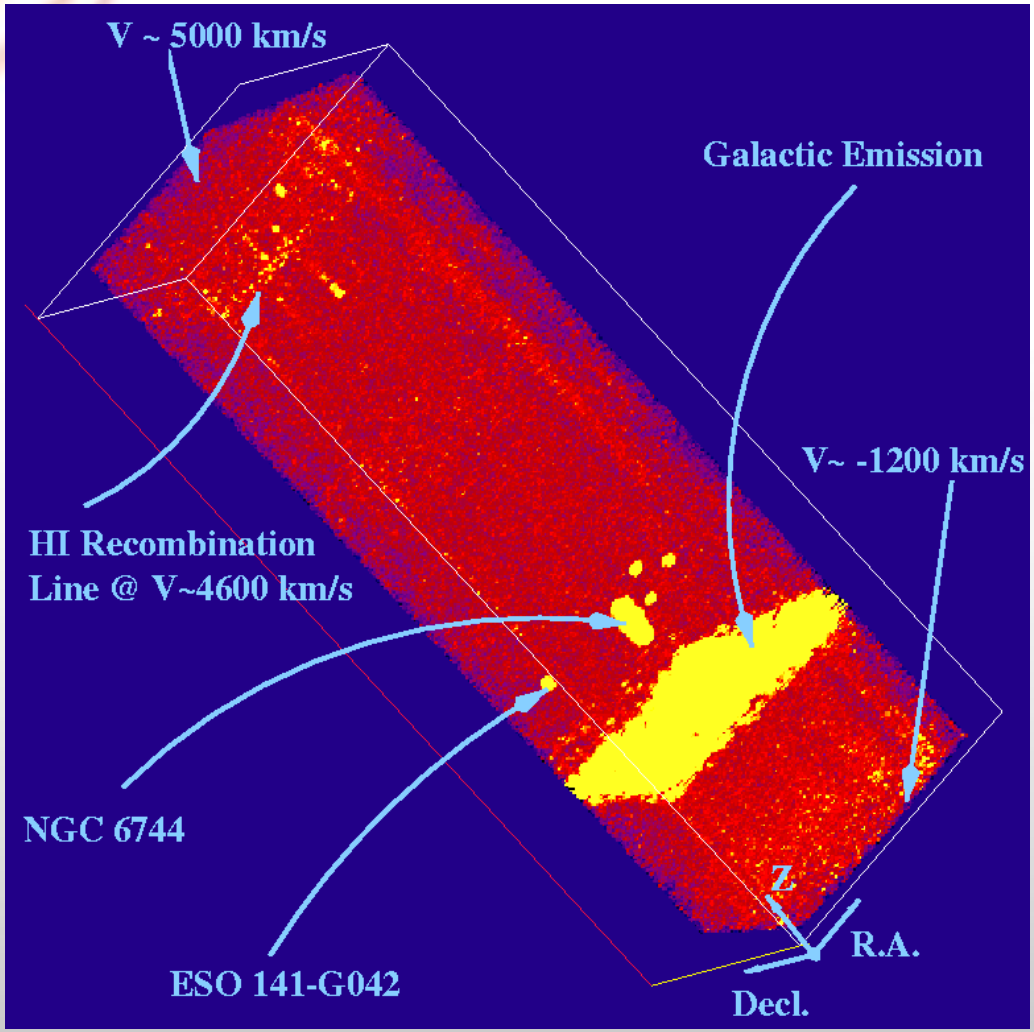
TCS/on-the-fly mapping

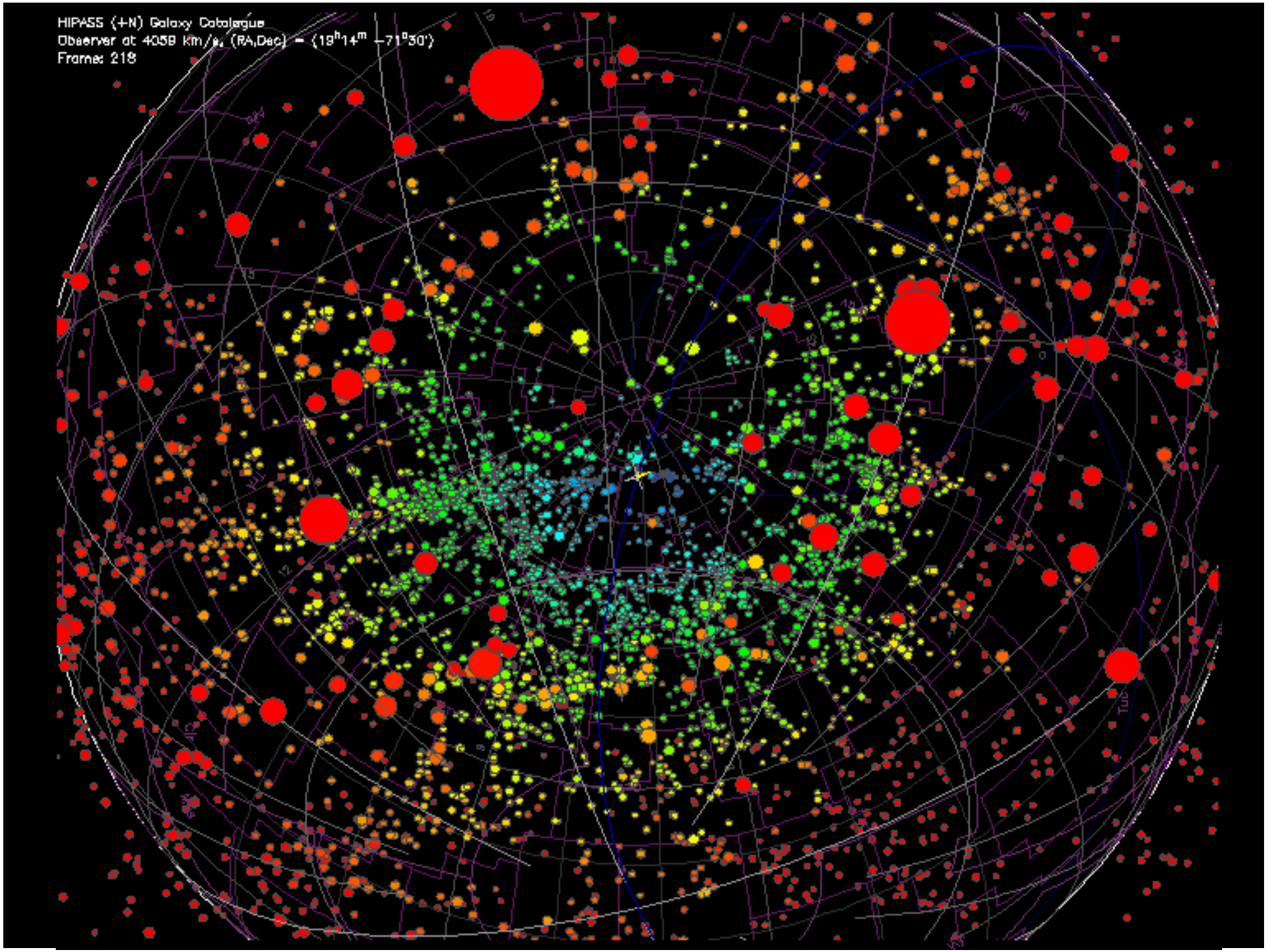
SEST correlator

First PSR 1 GHz correlator

Methanol multibeam

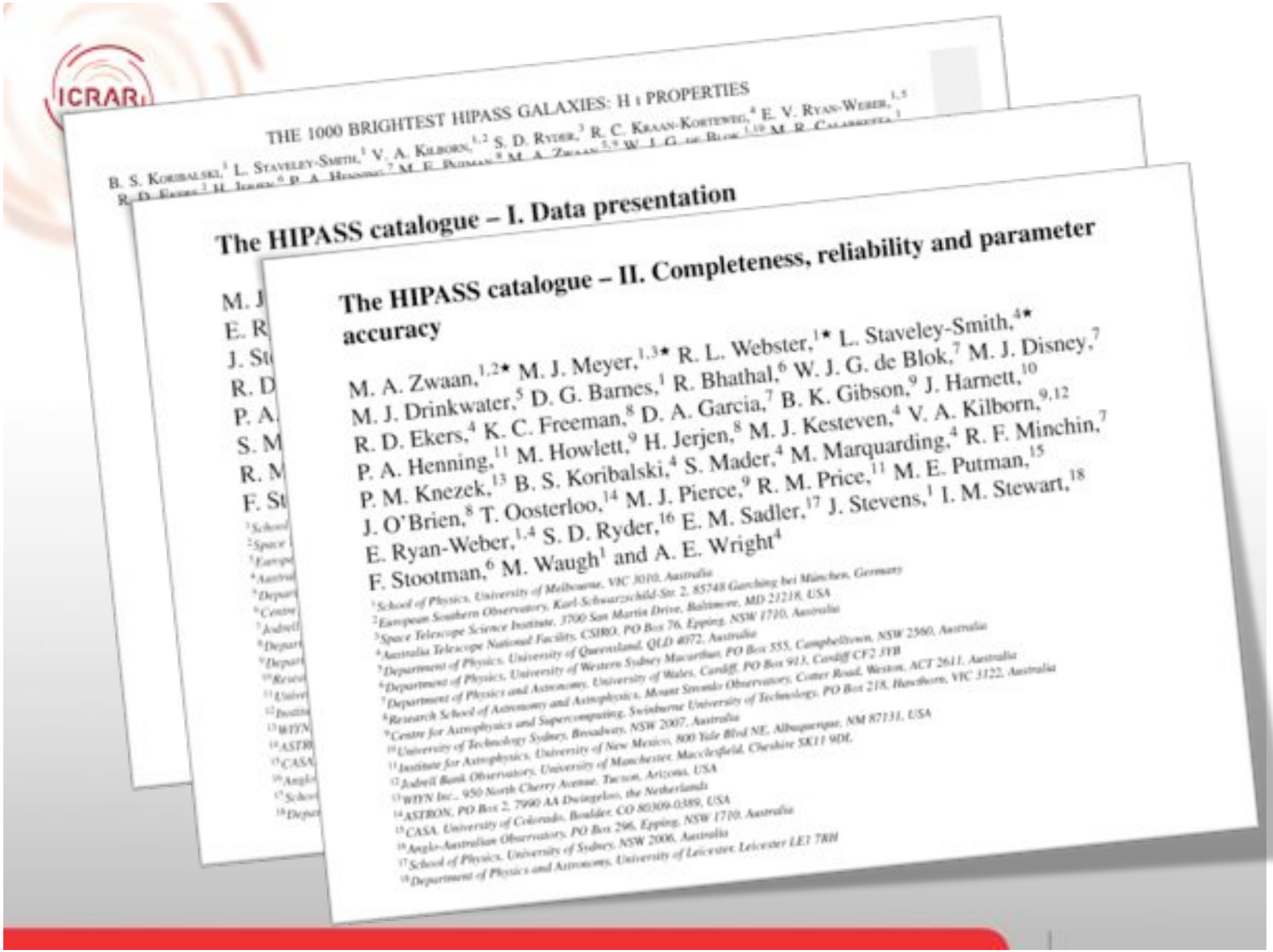
A Parkes HI data cube




HIPASS (+N) Galaxy Catalogue
Observer at 4058 km/s (RA,Dec) = (19h14m −71°30')
Frame: 218

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)
  - HIPASS catalogue (Meyer et al. 2004, Zwaan et al. 2004, Wong et al. 2006)
  - 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

B. S. Koribalski,[1] L. Staveley-Smith,[1] V. A. Kilborn,[1,2] S. D. Ryder,[3] R. C. Kraan-Korteweg,[4] E. V. Ryan-Weber,[1,5]

The HIPASS catalogue – I. Data presentation

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

M. A. Zwaan,[1,2★] M. J. Meyer,[1,3★] R. L. Webster,[1★] L. Staveley-Smith,[4★] M. J. Drinkwater,[5] D. G. Barnes,[1] R. Bhathal,[6] W. J. G. de Blok,[7] M. J. Disney,[7] R. D. Ekers,[4] K. C. Freeman,[8] D. A. Garcia,[7] B. K. Gibson,[9] J. Harnett,[10] P. A. Henning,[11] M. Howlett,[9] H. Jerjen,[8] M. J. Kesteven,[4] V. A. Kilborn,[9,12] P. M. Knezek,[13] B. S. Koribalski,[4] S. Mader,[4] M. Marquarding,[4] R. F. Minchin,[7] J. O'Brien,[8] T. Oosterloo,[14] M. J. Pierce,[9] R. M. Price,[11] M. E. Putman,[15] E. Ryan-Weber,[1,4] S. D. Ryder,[16] E. M. Sadler,[17] J. Stevens,[1] I. M. Stewart,[18] F. Stootman,[6] M. Waugh[1] and A. E. Wright[4]

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[2]*European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany*
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[6]*Department of Physics, University of Western Sydney Macarthur, PO Box 555, Campbelltown, NSW 2560, Australia*
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[8]*Department of Physics and Astronomy, University of Wales, Cotter Road, Weston, ACT 2611, Australia*
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[10]*Centre for Astrophysics and Supercomputing, Swinburne University of Technology, PO Box 218, Hawthorn, VIC 3122, Australia*
[11]*University of Technology Sydney, Broadway, NSW 2007, Australia*
[12]*Institute for Astrophysics, University of New Mexico, 800 Yale Blvd NE, Albuquerque, NM 87131, USA*
[13]*Jodrell Bank Observatory, University of Manchester, Macclesfield, Cheshire SK11 9DL*
[14]*WIYN Inc., 950 North Cherry Avenue, Tucson, Arizona, USA*
[15]*ASTRON, PO Box 2, 7990 AA Dwingeloo, the Netherlands*
[16]*CASA, University of Colorado, Boulder, CO 80309-0389, USA*
[17]*Anglo-Australian Observatory, PO Box 296, Epping, NSW 1710, Australia*
[18]*School of Physics, University of Sydney, NSW 2006, Australia*
[19]*Department of Physics and Astronomy, University of Leicester, Leicester LE1 7RH*

Technology, science and software partnership

AUSTRALIA TELESCOPE NATIONAL FACILITY
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CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

THE UNIVERSITY OF SYDNEY

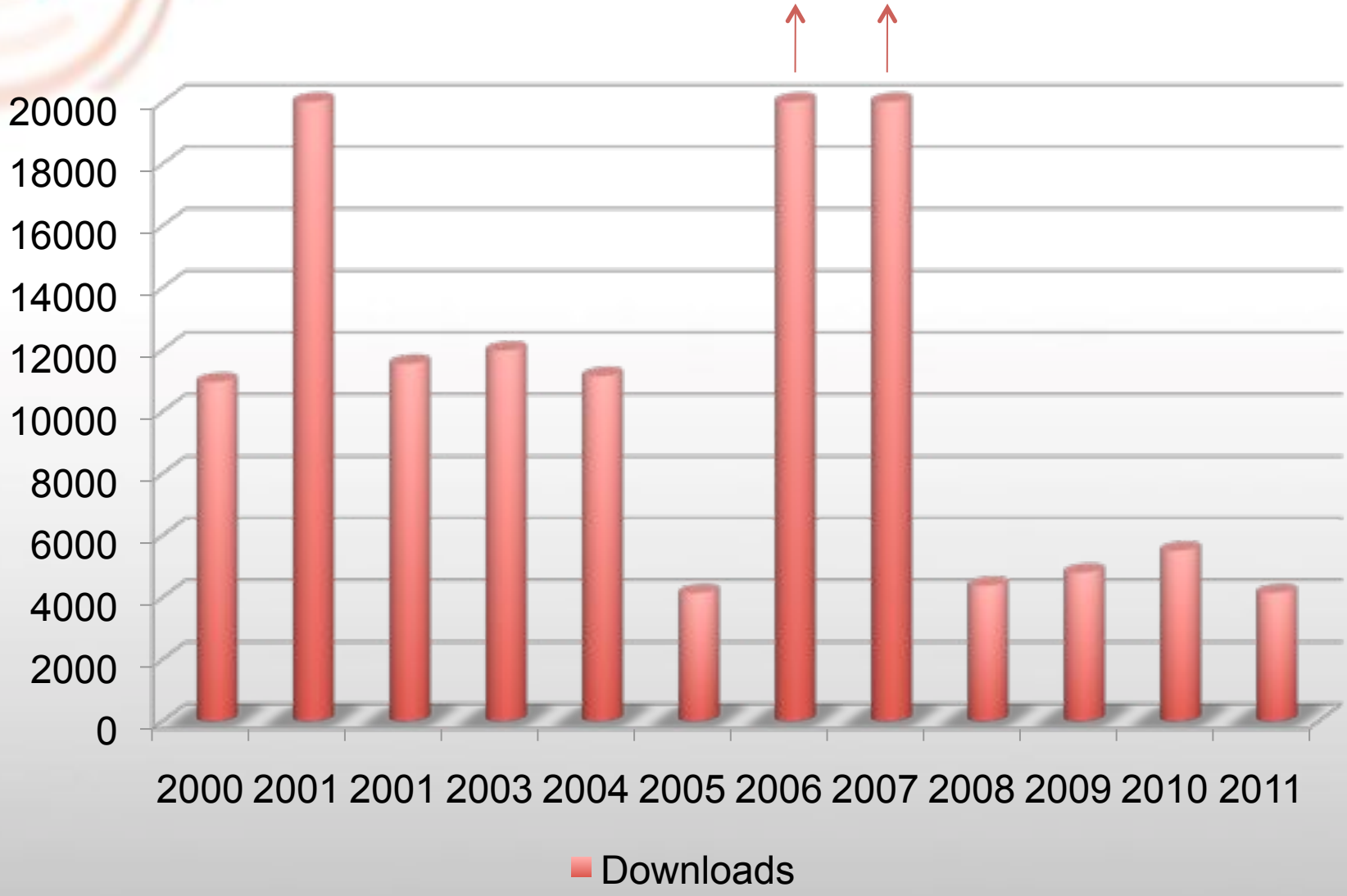
AAO

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

UWS

UNM

HIPASS data server – a legacy

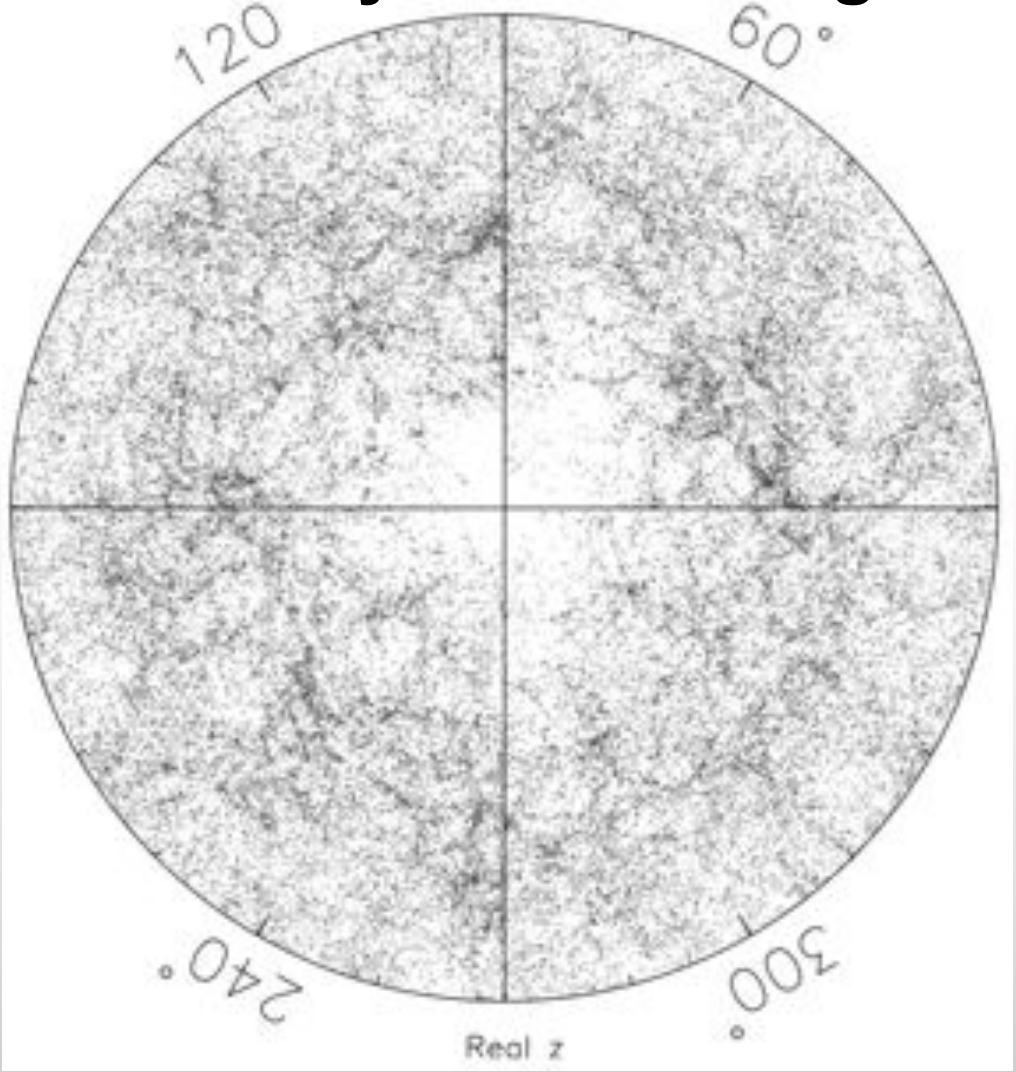


Multibeam astronomy beyond HIPASS: ASKAP/SKA

ASKAP

Phased Array Feed @ PKS 12-m

ASKAP/Wallaby simulated lightcone

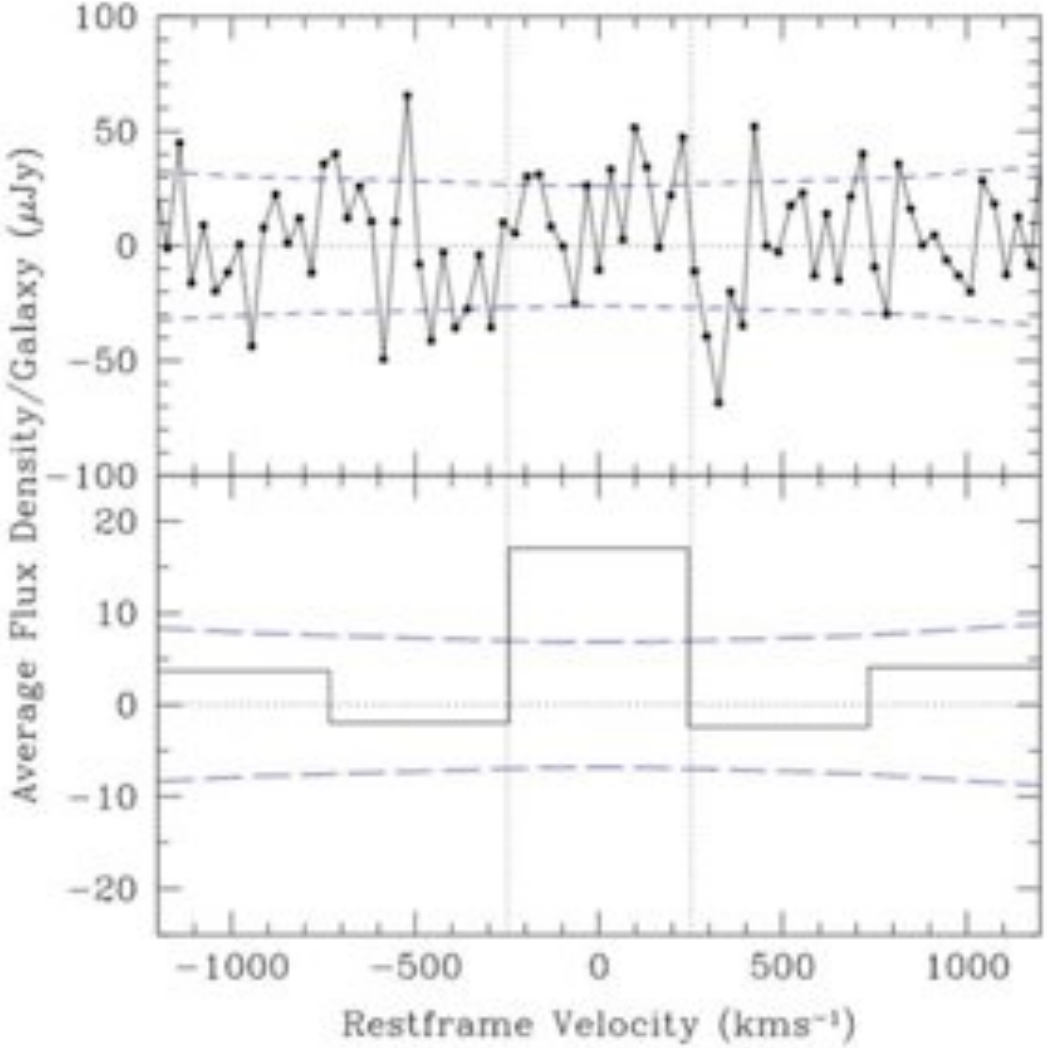


500k galaxies

Alan R. Duffy[1], Martin J. Meyer[1], Lister Staveley-Smith[1],
Max Bernyk[2], Darren J. Croton[2], Baerbel Koribalski[3], Stefan Westerlund[1]

Gas Evolution: GMRT stack at z=0.24

Lah et al. (2007)



neutral hydrogen gas measurement

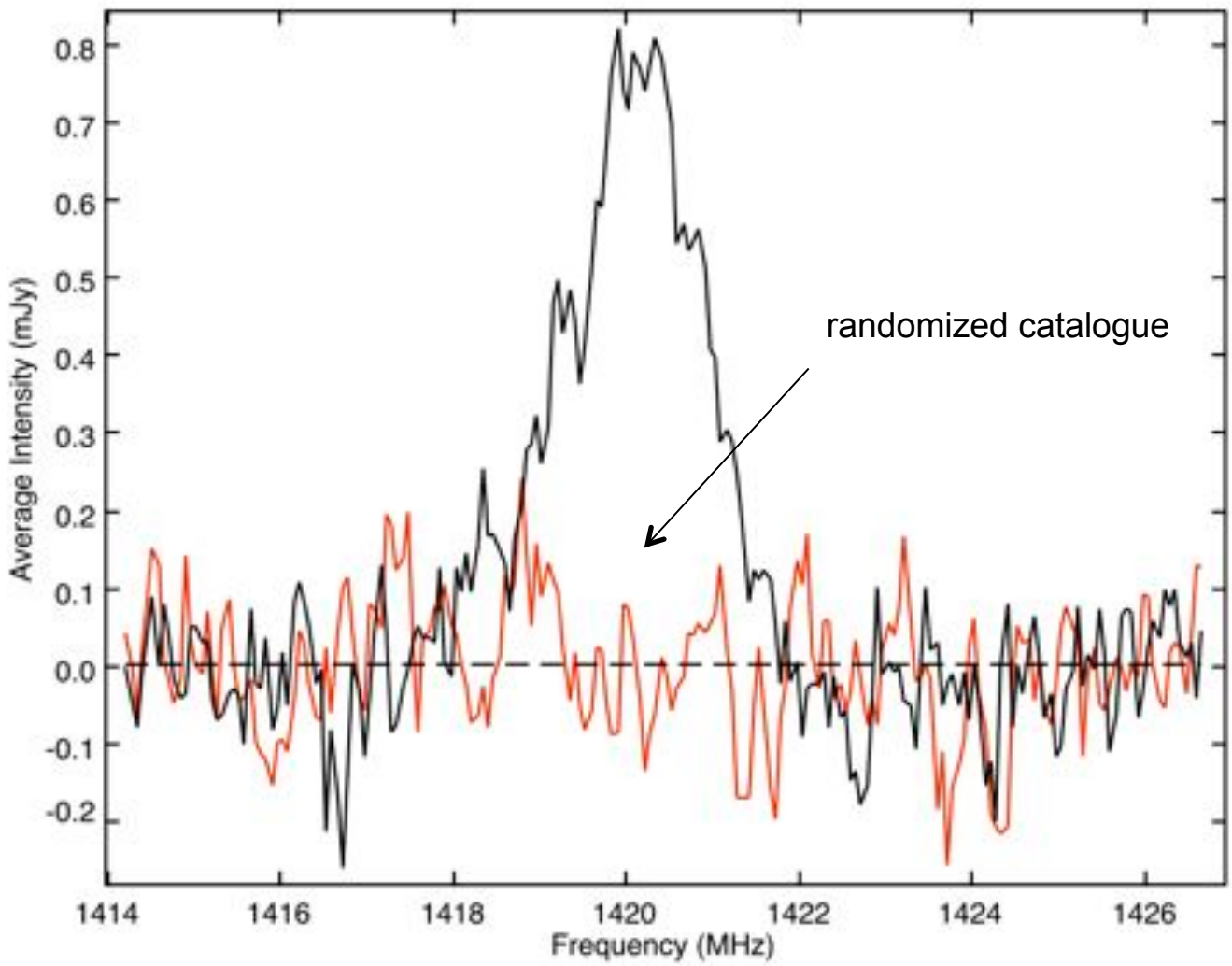
using 121 redshifts

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

$0.36 \pm 0.14 M^*$

A stacked HI signal at z=0.1 with Parkes

(GAMA9 field; Delhaize)



Vol 466 22 July 2010 doi:10.1038/nature09187 nature

LETTERS

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]

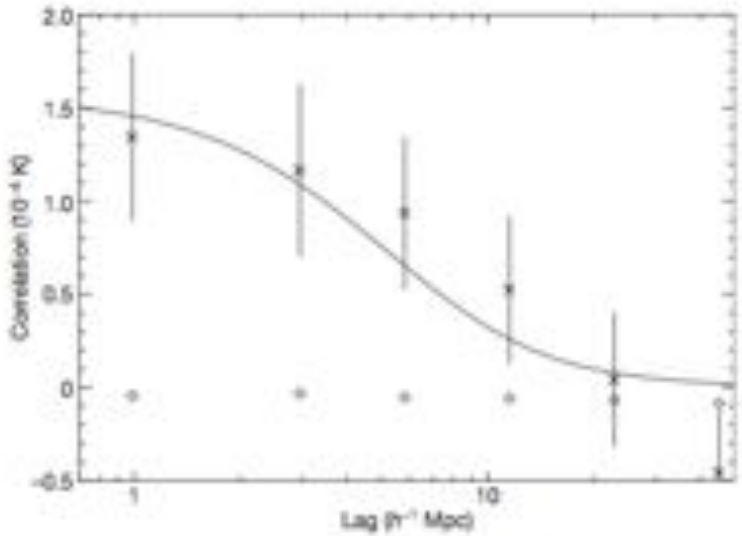
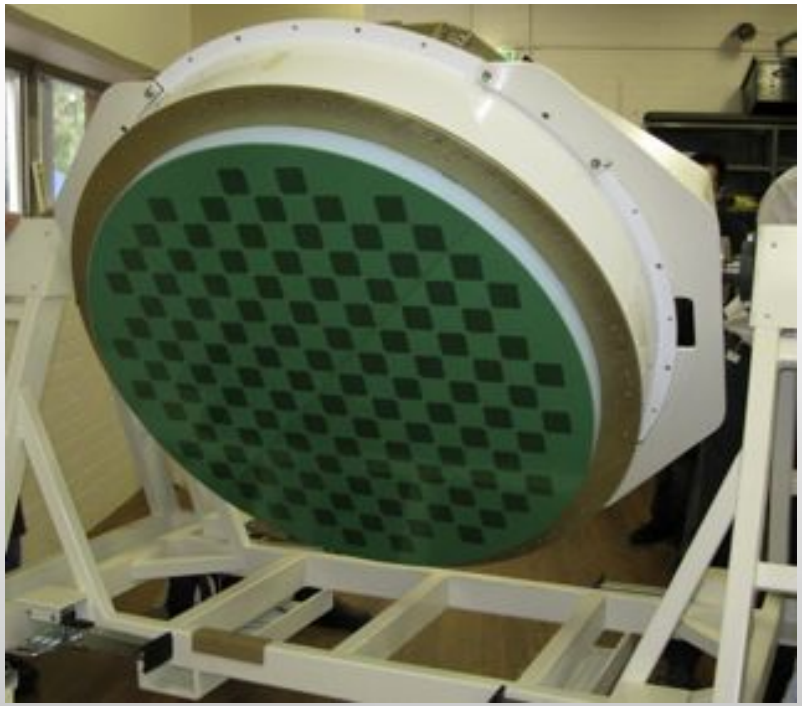


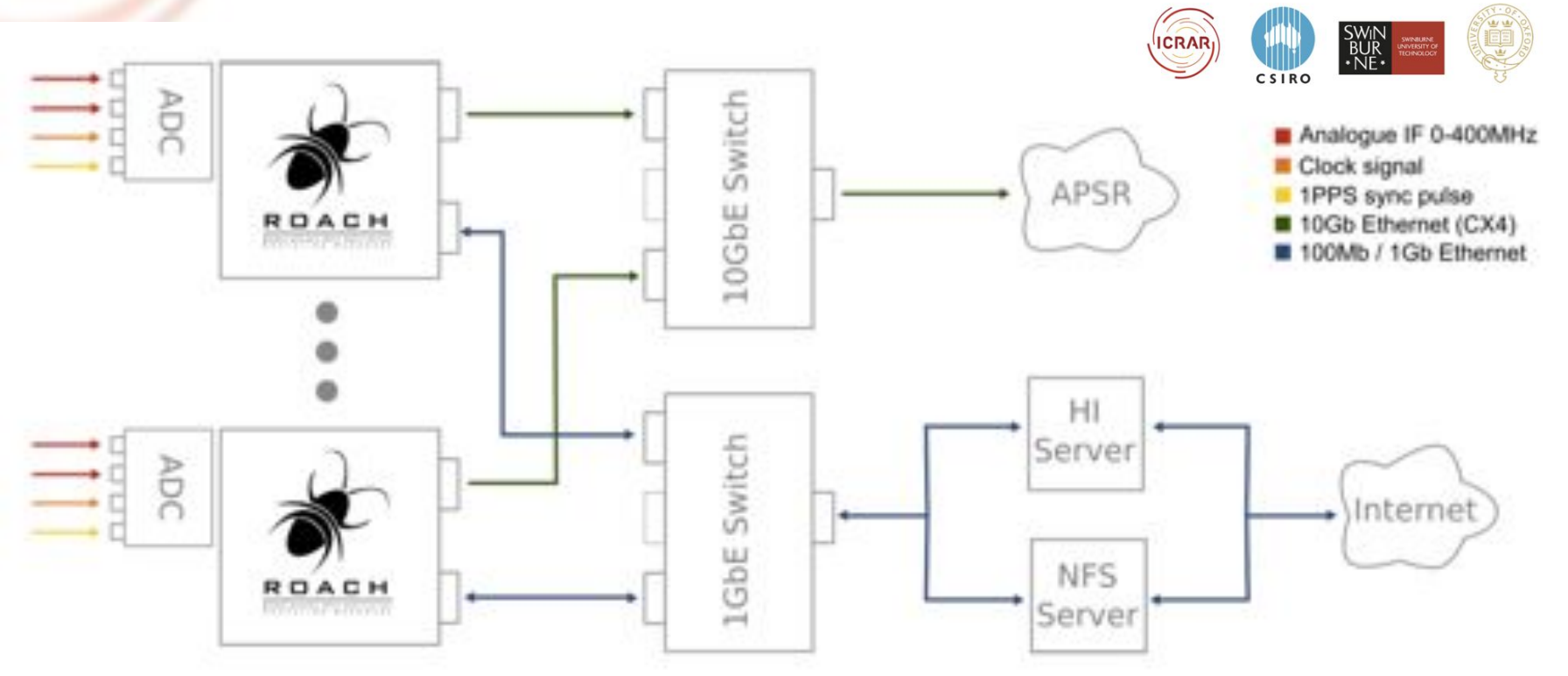
Figure 2 | The cross-correlation between the DEEP2 density field and GBT H I brightness temperature. Crosses, measured cross-correlation

Parkes@60: possible upgrade path?



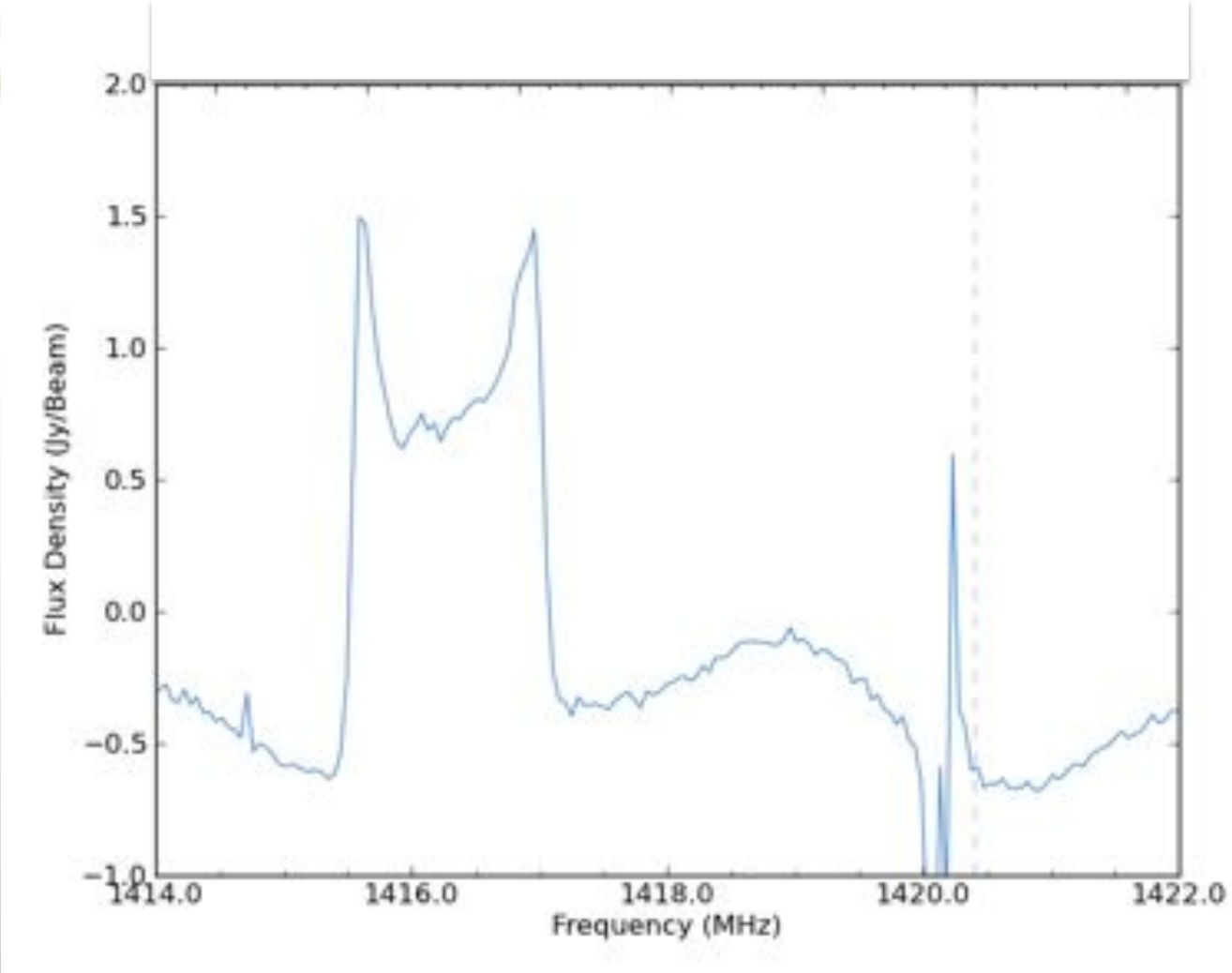
+

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