CAASTRO
ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

THE UNIVERSITY OF SYDNEY

AGN with the Parkes-Tidbinbilla Interferometer

Working with Bruce Slee, 1988-95

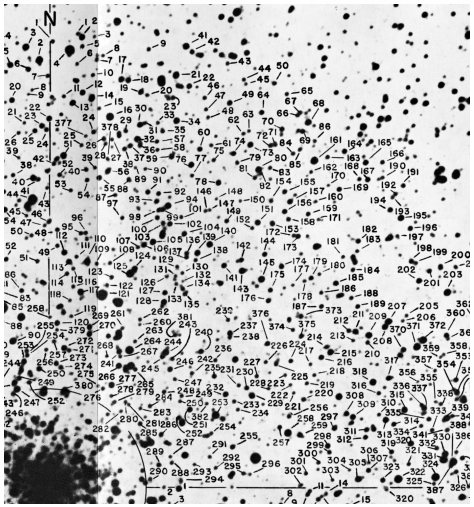
Elaine Sadler
University of Sydney / CAASTRO

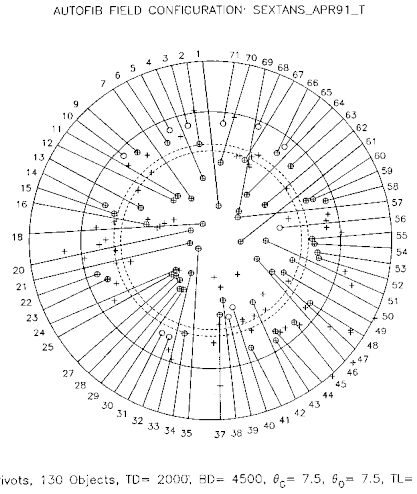
17 August 2016

Sydney, 1988

Where I was in 1988…

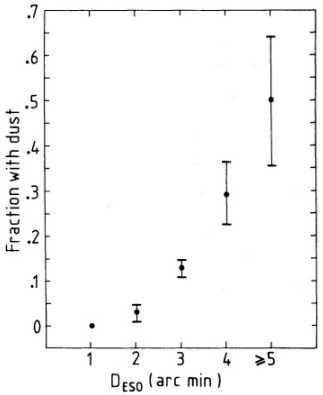
- Just arrived back in Australia from the USA
- Staff astronomer at the AAO in Sydney
- Early days of multi-object spectroscopy
- Working on galaxy dynamics, and a new (large) project on kinematics and metal abundances of stars in the Galactic bulge
- But still interested in radio astronomy…



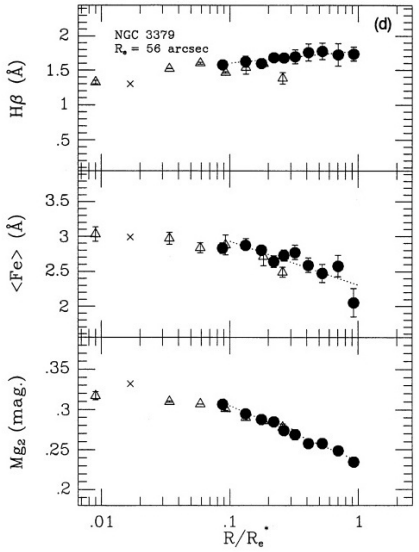


Elliptical galaxies - optical

E. M. Sadler and O. E. Gerhard



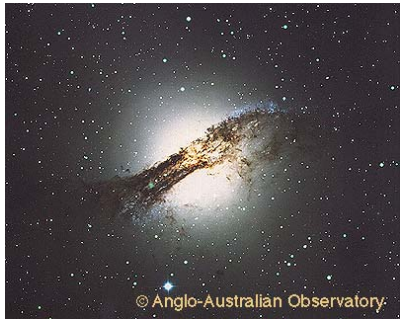
Line-strength gradients in elliptical galaxies 669



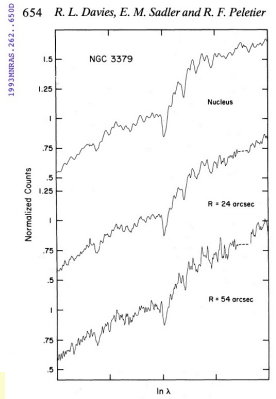
Elliptical galaxies had a violent past, and formed by successive mergers of smaller galaxies

[Sadler & Gerhard 1985] >50% of nearby ellipticals contain "dust-lanes" of debris from smaller galaxies captured in the past.

[Davies, Sadler & Peletier 1993] Spectroscopic measurements "support the hypothesis that *giant ellipticals form by… mergers*, and that the line-strength gradients originate in their lower-mass progenitors which formed predominantly by stellar collapse".

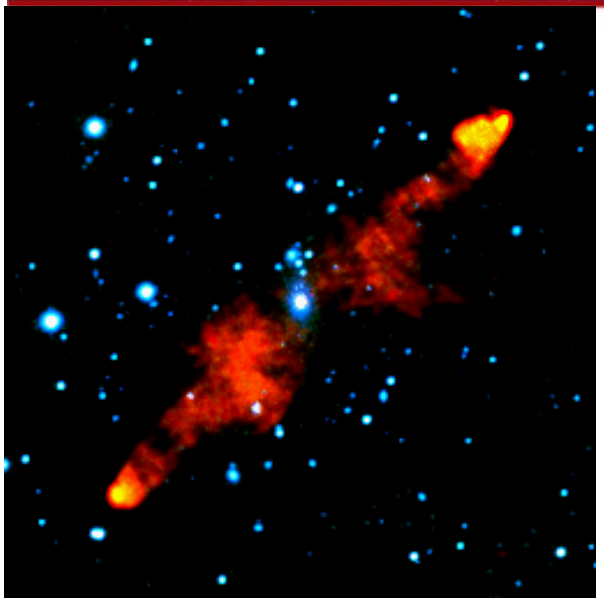


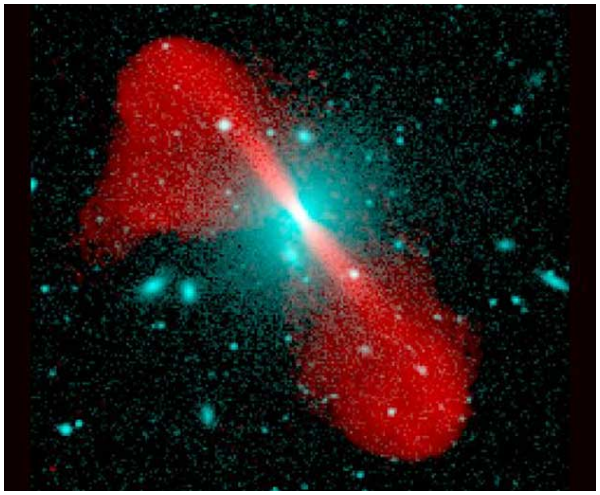
654 R. L. Davies, E. M. Sadler and R. F. Peletier



Stellar populations are **old** - why did these galaxies stop forming stars billions of years ago?

Elliptical galaxies – radio



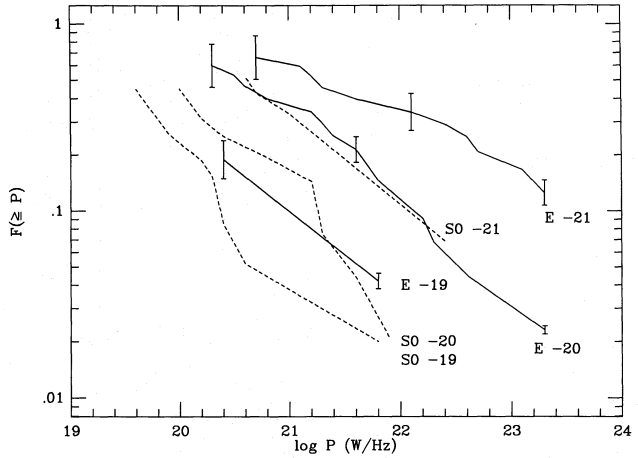


Some galaxies are enormously energetic sources of radio waves, and are so luminous that they can be seen to huge cosmic distances.

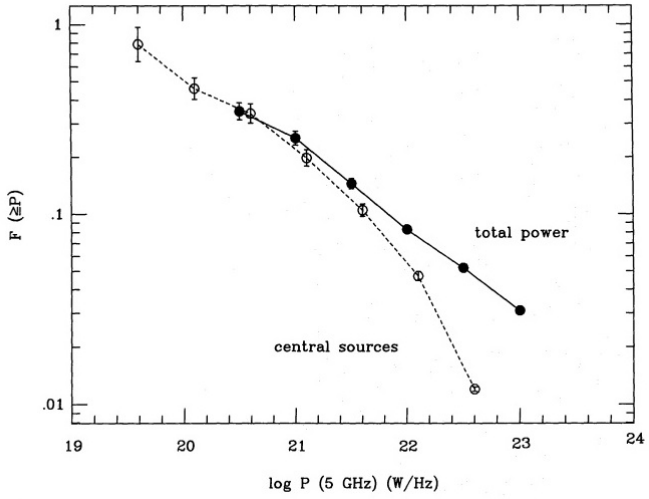
Two questions from my PhD thesis:

- **Why are most of the powerful radio sources found in giant elliptical galaxies, rather than in spiral galaxies or dwarfs?**
- **Since elliptical galaxies appear to be a very homogeneous class in their optical properties, why are some of them radio sources while others are not?**

Elliptical galaxies – radio



E. M. Sadler, C. R. Jenkins and C. G. Kotanyi



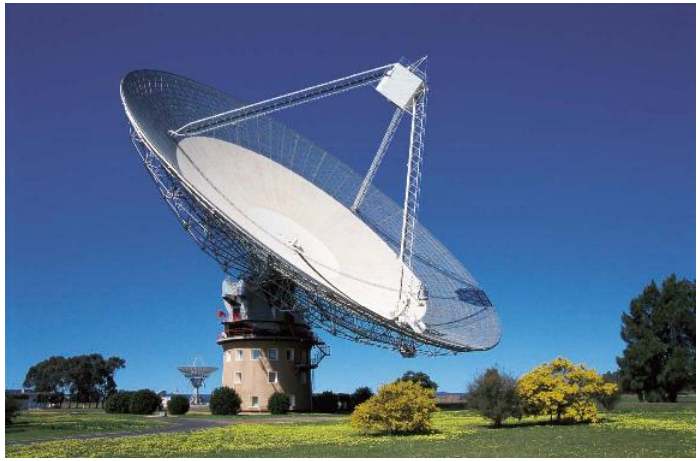
Almost all bright elliptical galaxies are radio continuum sources at some level - this is not a rare or exotic phenomenon

[Sadler, Jenkins & Kotanyi 1989] For sensitive observations, the radio detection rate of the most massive nearby elliptical galaxies is close to 100%.

The radio sources in nearby E/S0 galaxies become increasingly *core-dominated* at lower radio luminosity – i.e. most of the radio emission is coming from the central few kpc.

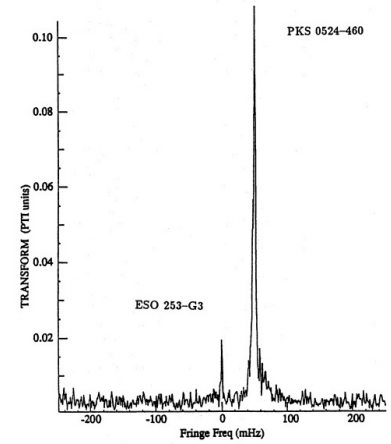
What physical process powers these low-luminosity radio sources?

The Parkes-Tidbinbilla Interferometer



Parkes 64m dish

Microwave link



Tidbinbilla 70m dish

Operated 1986-98

- World's longest real-time radio interferometer
- Single 275km baseline
- Original aim – ATCA calibrators

(Norris & Kesteven 2013)

Observing modes:

Frequency 1.7, 2.3, 8.4 GHz

Resolution 0.13, 0.09, 0.03 arcsec

PTI observations 1988-91

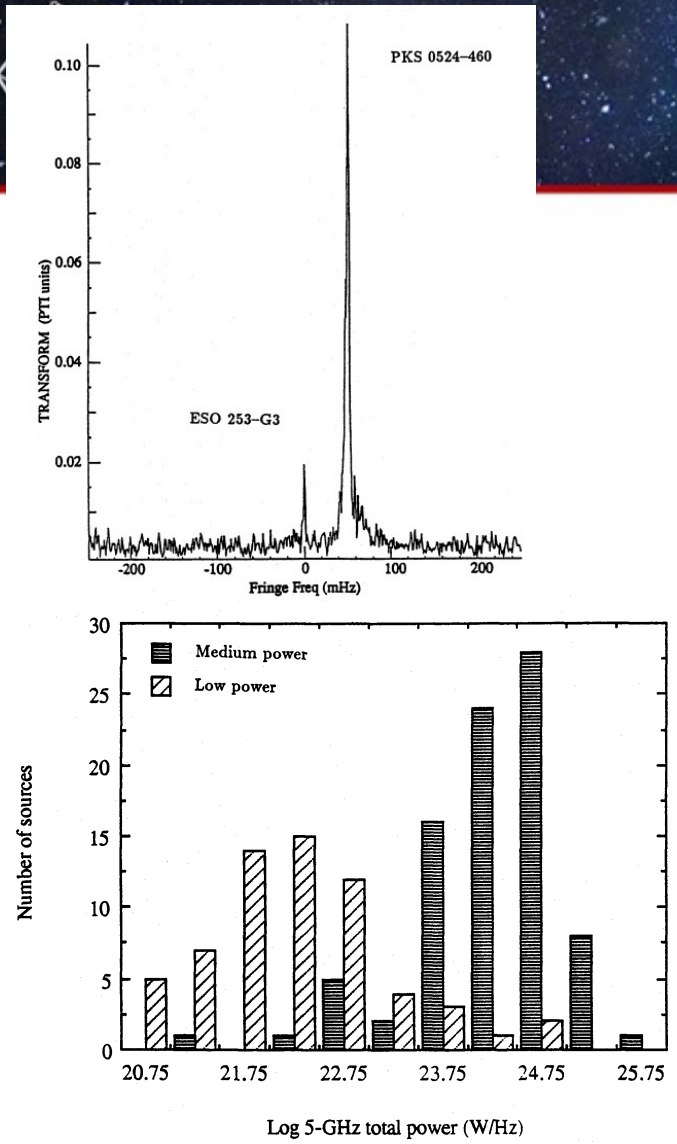


Figure 1. Histogram of total 5-GHz radio power for elliptical and S0 galaxies in samples A (low power) and B (medium power).

(with Bruce Slee, Ron Ekers and John Reynolds)

Observed:

- 67 nearby E/S0 galaxies with 'low-luminosity' radio emission (10^{20} – 10^{23} W/Hz at 5 GHz)
- 91 more powerful radio galaxies (10^{22} – 10^{26} W/Hz at 5 GHz)

PTI observations at two frequencies, 2.7 and 8.4 GHz

(Slee et al. 1994)

Publications

1994MNRAS.269..928S

Mon. Not. R. Astron. Soc. **269,** 928–946 (1994)

Parsec-scale radio cores in early-type galaxies

O. B. Slee,[1] Elaine M. Sadler,[2,3] J. E. Reynolds[1] and R. D. Ekers[1]
[1] *Australia Telescope National Facility, CSIRO, PO Box 76, Epping, NSW 2121, Australia*
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[3] *School of Physics, University of Sydney, NSW 2006, Australia*

Accepted 1994 March 18. Received 1994 March 16; in original form 1993 October 1

1995MNRAS.276.1373S

Mon. Not. R. Astron. Soc. **276,** 1373–1381 (1995)

Parsec-scale radio cores in spiral galaxies

Elaine M. Sadler,[1] O. B. Slee,[2] J. E. Reynolds[2] and A. L. Roy[1, 2]
[1] *School of Physics, University of Sydney, NSW 2006, Australia*
[2] *Australia Telescope National Facility, CSIRO, PO Box 76, Epping, NSW 2121, Australia*

Accepted 1995 May 19. Received 1995 May 18; in original form 1995 March 6

What we found…

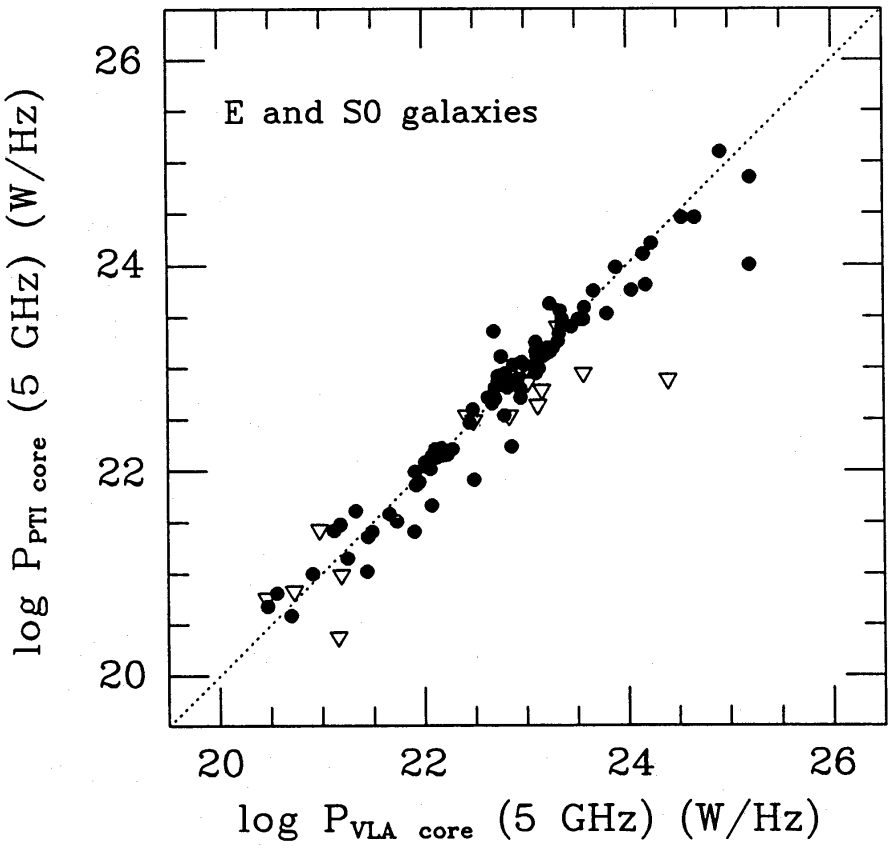
Slee, Sadler, Ekers & Reynolds 1994

ABSTRACT

We find compact (< 0.03 arcsec) radio-continuum cores in about 70 per cent of radio-emitting elliptical and S0 galaxies over a wide range in total radio power (10^{21}–10^{26} W Hz^{-1} at 5 GHz). The cores usually have a flat or rising spectrum between 2.3 and 8.4 GHz, with a median spectral index of $+0.3$. Even at low luminosities, the radio emission from most elliptical galaxies appears to be powered by a parsec-scale 'engine' like those in classical radio galaxies and quasars. The core and total radio power are related ($P_{\rm core} \propto P_{\rm total}^{0.7}$ on average), and the parsec-scale cores of radio galaxies are typically one hundred times more powerful than those in 'normal' giant elliptical galaxies.

i.e. Most low-luminosity radio sources in nearby E/S0 galaxies are powered by black holes in the same way as the 'central engines' of the most powerful radio galaxies!

PTI results…



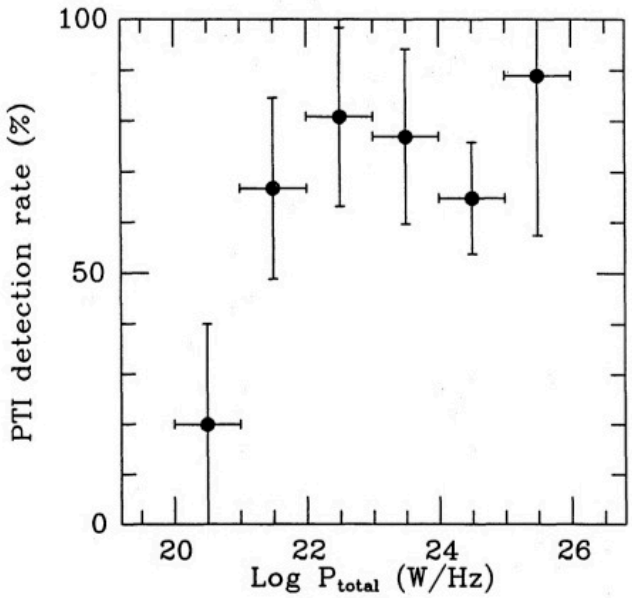
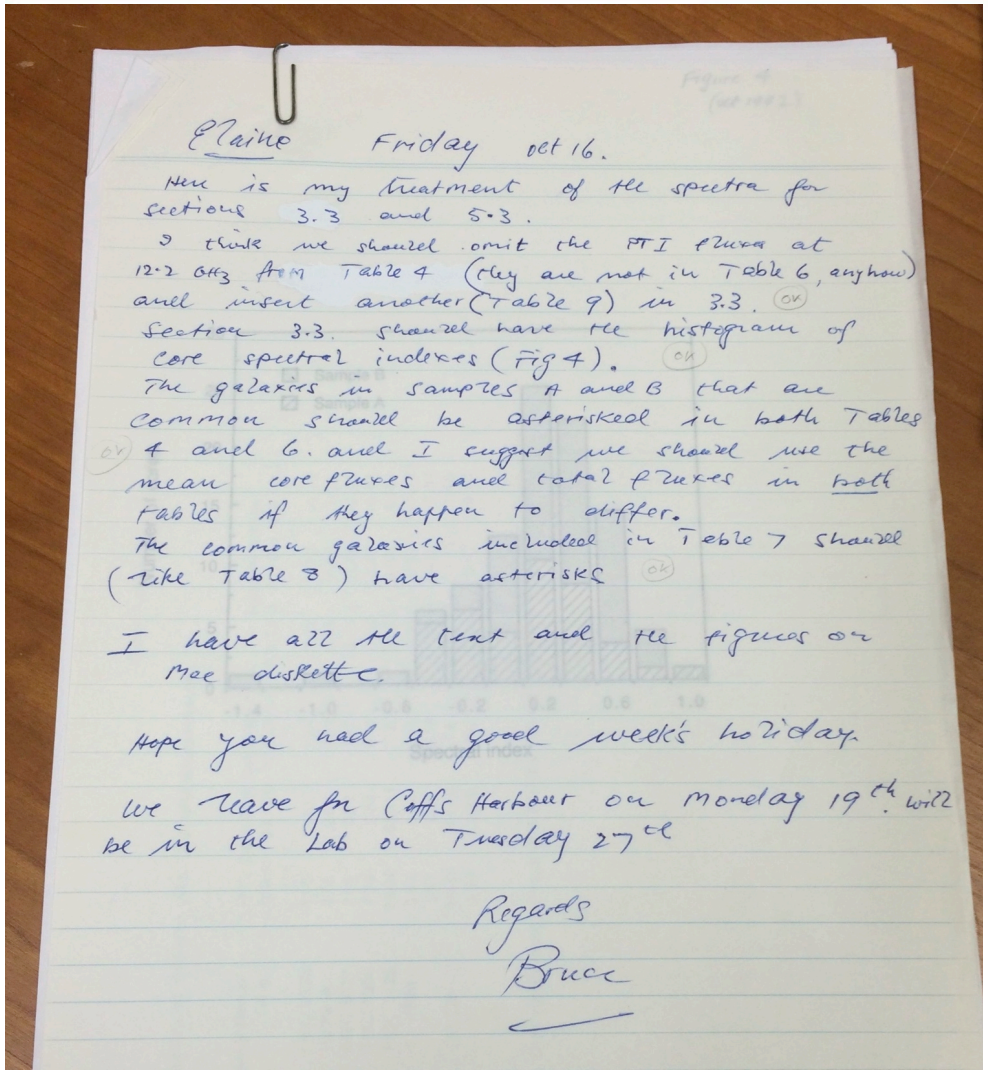


Figure 3. Detection of PTI cores as a function of total radio power at 5 GHz. Since only five galaxies with $P_{total} < 10^{21}$ W Hz^{-1} were observed, the low detection rate in the leftmost bin may not be significant.

Writing the papers…



Elaine Friday Oct 16.

Here is my treatment of the spectra for sections 3.3 and 5.3.

I think we should omit the MTI fluxes at 12.2 GHz from Table 4 (they are not in Table 6, anyhow) and insert another (Table 9) in 3.3.

Section 3.3 should have the histogram of core spectral indexes (Fig 4).

The galaxies in samples A and B that are common should be asterisked in both Tables 4 and 6. and I suggest we should use the mean core fluxes and total fluxes in both Tables if they happen to differ.

The common galaxies included in Table 7 should (like Table 8) have asterisks

I have all the text and the figures on Mac diskette.

Hope you had a good week's holiday.

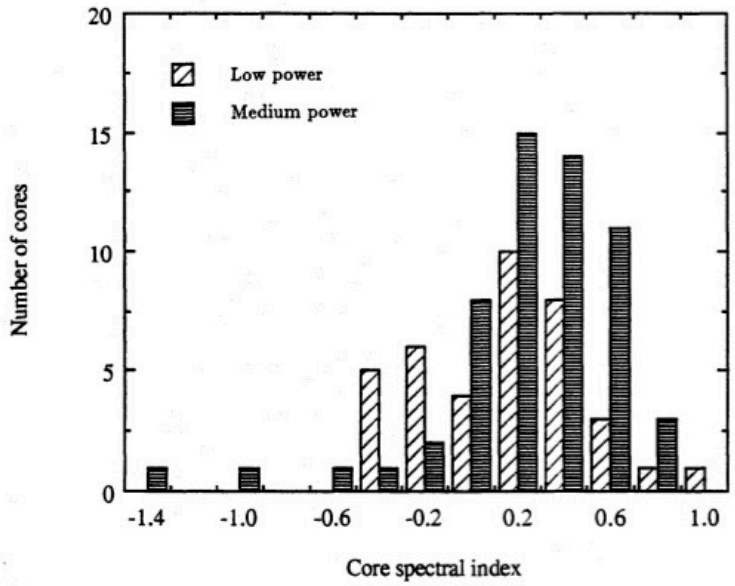
We leave for Coffs Harbour on Monday 19th. will be in the Lab on Tuesday 27th

Regards

Bruce

Bruce would leave me detailed notes about what needed doing next - this one is from October 1992.

Interpreting the radio spectra



Most PTI cores have flat or rising radio spectra

(Slee et al. 1994)

What produces the observed radio spectra?

Main contenders are:

Synchrotron self-absorption:

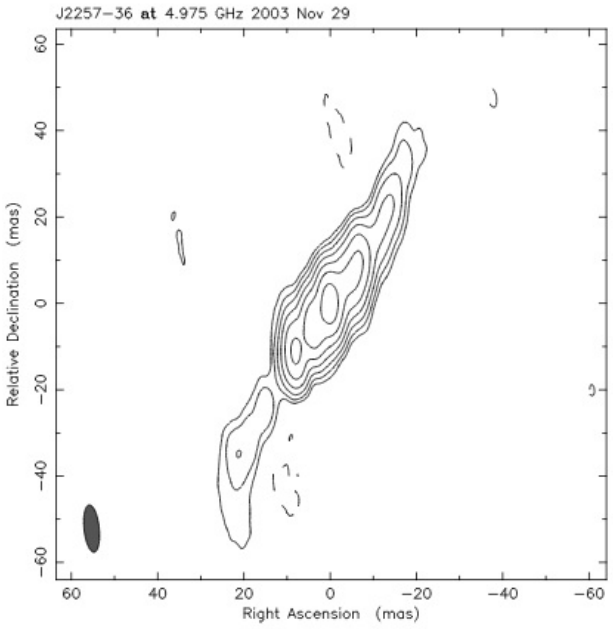
For a typical low-power source with turnover frequency above 5 GHz, require either strong magnetic fields (~0.1 G) or far from equipartition. In either case, cores must be < 1 mas in size

Free-free absorption

Know that ionized gas in generally present – would need ~ 10^4 solar masses of ionized gas within ~4 pc of the centre. Need more detailed spectral coverage over a wide frequency range.

Still an open question over 20 years later!
(see Joe Callingham's talk)

Interpreting the radio spectra



Nearby low-power radio AGN, IC 1459

(Tingay et al. 2015)

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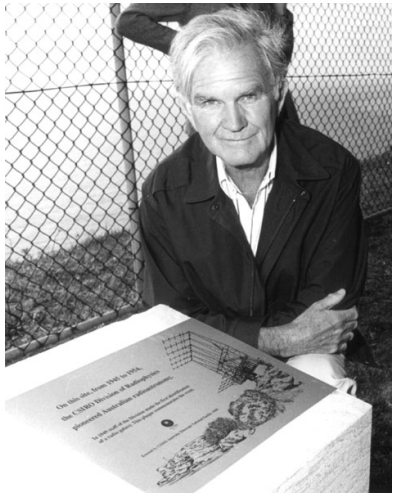
Conclusions



- It was enjoyable (and inspirational) to work on this project with Bruce
- *Our paper (Slee et al. 1994) helped to bring AGN into mainstream studies of galaxy evolution, and remains well-cited today*
- The PTI, as a single baseline radio interferometer, was extremely successful – with 24 journal papers published (including 3 in Nature)

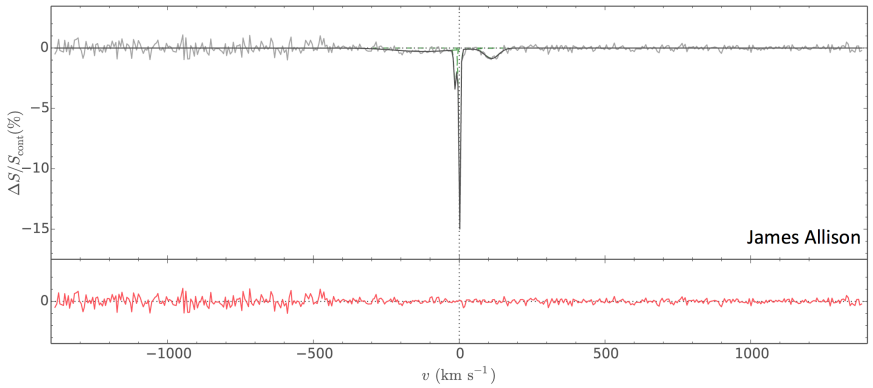
"A next-generation single- baseline instrument could be built using ASKAP and the Parkes antenna equipped with a phased-array feed... Such an instrument would be a powerful resource for identifying which populations of galaxies contained AGN." (Norris & Kesteven 2013 PASA)

Future: Spectral-line VLBI?

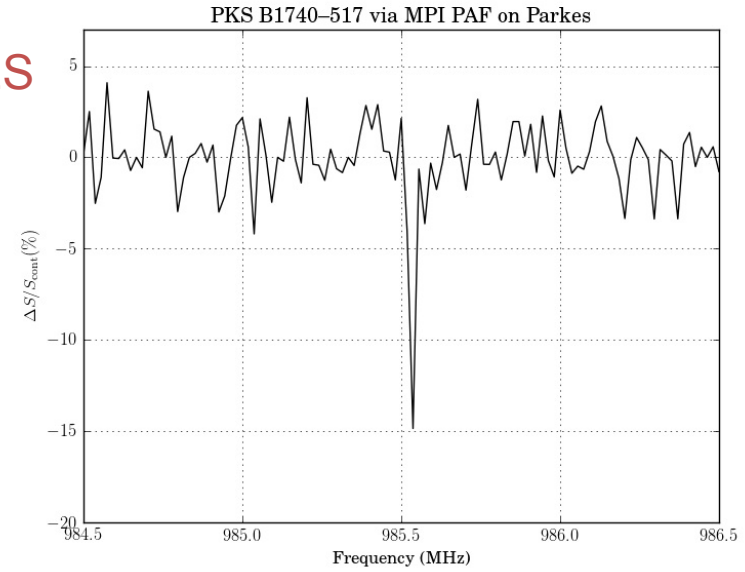
A phased-array feed (PAF) at Parkes operating down to 700 MHz opens up exciting possibilities for **spectral-line VLBI on a PKS-ASKAP baseline**. Spatial resolution would be ~25 mas (0.025 arcsec) at 850 MHz, corresponding to ~180 parsec in an absorbing galaxy at z=0.7.

HI absorption at z = 0.44 in PKS 1740-517

ASKAP



PARKES



Presented at June 2016 ASKAP meeting