

The Parkes Continuum Surveys

A personal view

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The continuum survey epochs

1. 1962 - 1966 408/1410 MHz (original PKS sky survey)
2. 1968 - 1979 2700 MHz (or 2.7 GHz or PKS 11 cm)
3. 1993 - 1996 4.85 GHz (PMN)

The 408/1410 MHz survey

Bolton, Shimmins, Gardner, Mackey, R. Ekers, Day, Price, Milne

Source selection from primary sky scans at 408 MHz, 75 arcmin HPBW (except for +20 to +27, scans at 635 MHz).

Follow-up with 1410-MHz ra/dec scans of candidate sources selected from the chart records $> 3 - 4$ Jy at 408 MHz, down to $0.3 - 0.4$ Jy at 1410 MHz.

All extragalactic sky south of $+27^\circ$ dec, $|b| > 10^\circ$, published in 5 declination zones $+27^\circ$ to $+20^\circ$, $+20^\circ$ to 0° , 0° to -20° , -20° to -60° , -60° to -90° (but not in this - or any - order).

Total of 2133 sources over 7.9 sr

408 MHz: HPBW 75 arcmin; 1410 MHz HPBW 14 arcmin => positions accurate to ~ 1 arcmin. Many sources remeasured at 2650 MHz => positions to 15 arcsec (e.g. Shimmins et al 1966).

Great features of 408/1410 survey

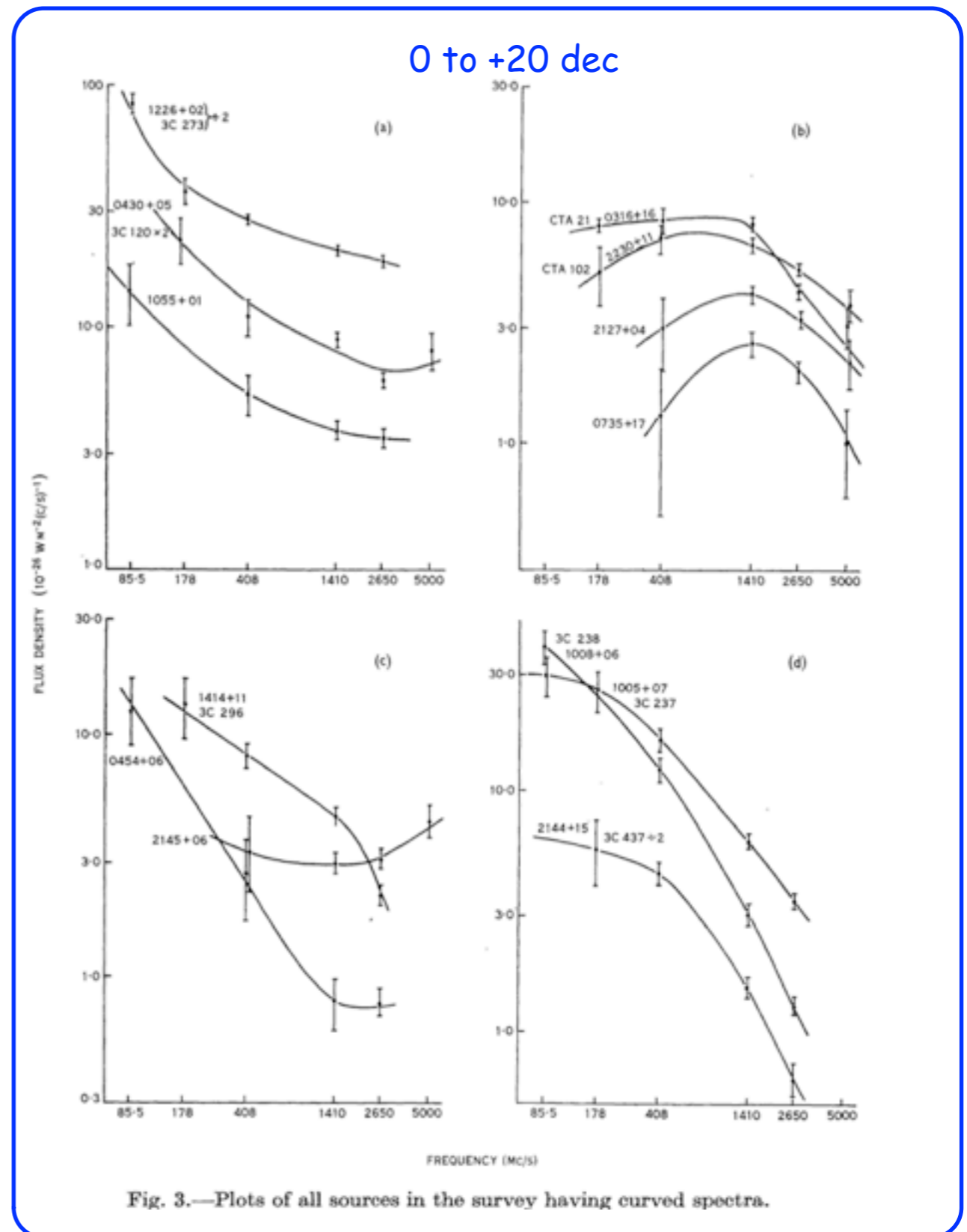
1. The first unbiased filled-aperture survey for extragalactic sources over the southern sky.

There's a complete catalogue of the 2133 sources over 7.9 sr (Jennifer Ekers 1969)

2. The source selection!

The bias introduced by the 1410-MHz selection at >0.3 Jy yielded a much greater proportion of 'flat-spectrum' or curved spectrum sources than a 408-MHz survey.

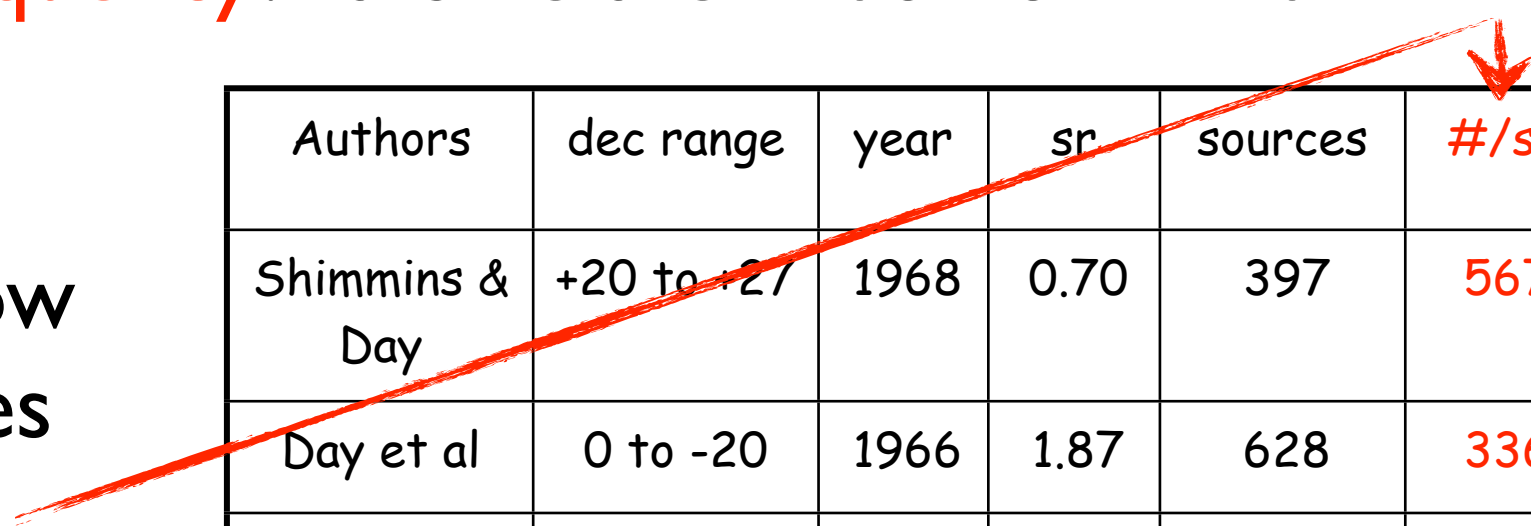
JGB had a hunch that QSO = 'flat-spectrum' = high surface brightness (shown by Kellermann et al. 1962, landmark paper, to be synonymous).



Less than great things, 408/1410 survey

- what is the **survey frequency**? It is neither 408 nor 1410 MHz.

- what is the **survey completeness**? Note how the source density varies from dec zone to zone:



Authors	dec range	year	sr	sources	#/sr
Shimmins & Day	+20 to +27	1968	0.70	397	567
Day et al	0 to -20	1966	1.87	628	336
Shimmins et al	0 to +20	1966	1.88	564	300
Price & Milne	-60 to -90	1965	0.8	247	309
Bolton et al	-20 to -60	1964	2.7	297	110

- because of Galactic emission the completeness is clearly a **function of Galactic latitude as well as dec zone**.

- the **positions** are ± 1 arcmin rms? max? Not always clear.

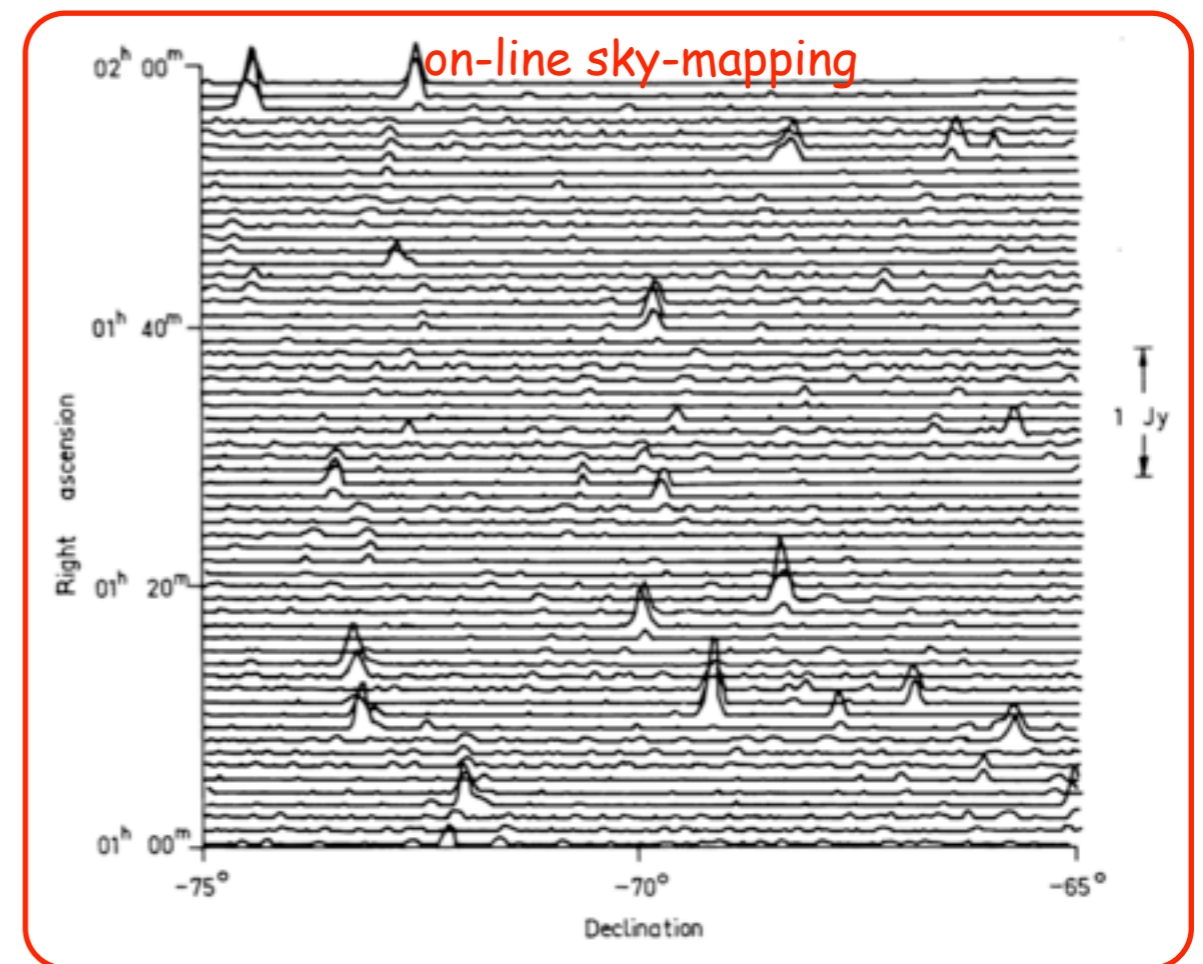
The 2700-MHz (11 cm) survey

1968-1979, Wall, Bolton, Shimmins, Savage, Butler, Wright, Katgert-Merkelijn

Made possible by >> state-of-the-art dual-beam correlating receiver
(Batchelor, Brooks & Cooper 1968)*

Scans with axis of beams perpendicular to direction of scan, so that positive and negative deflections gave source responses for on- and off-axis beams respectively

(After 1972) analysed (PDP9) to give on-line scan map and list; accurate flux densities and positions from repeated ra and dec scans of prelim 'sources'.



All extragalactic sky south of $+25^\circ$ dec, $|b| > 10^\circ$ published in 14 (yes 14) separate sub-surveys, each with a different flux-density limit, G*d help us. Later zones included flux densities at 5 GHz plus IDs. Completeness ranged from 0.10 Jy to 0.6 Jy

Total of about 7000 sources over 7.5 sr

2700-MHz (11 cm) survey - bad things

There is no complete source list or catalogue

With the myriad different zones and completenesses, who can use this survey in anger?

It comes down to those of us who know the secrets, or the real pedants of the literature (for whom I feel sorry).

Who is going to consult 14 papers to figure it out?

Mea culpa.

(There was always something more exciting to do.)

2700-MHz (11 cm) survey - great things

First cm-wavelength survey (arguable[†] on a couple of counts)

No doubt about the survey frequency this time.

First cm-wavelength source count, accurate and well defined because of precision flux densities, distance from confusion limit, and range of survey-zone depths.

Fantastic source selection. Every night brought us spectacular new flat/inverted-spectrum sources. The king was perhaps 2134-004 ('Alpha-Shimmins', as John S was observing that night) -- a previously-uncatalogued source at $S_{2.7} = 7.5 \text{ Jy}^*$ (discovery $s/n \sim 1000$)

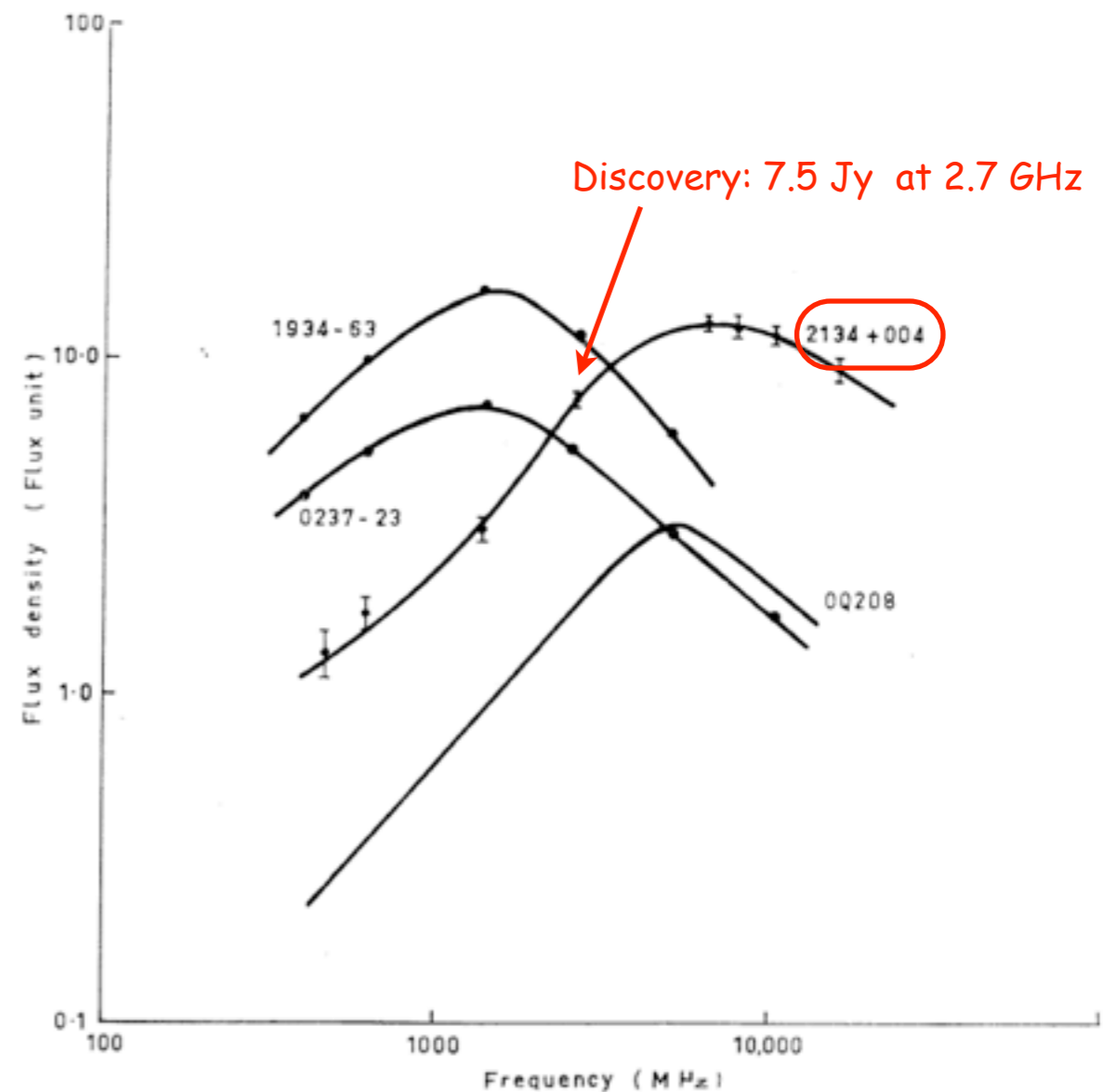


FIG. 2. Spectra of radio sources 2134+004, 1934-63, 0237-23 and 0Q208.

The 4850 MHz PMN (Parkes-MIT-NRAO) survey

Griffith, Wright, Burke, R. Ekers, Hunt, et al.

7-beam MIT/NRAO receiver system on Parkes dish.

Complete over 7.1 sr to 20-70 mJy, published in 4 zones (ApJS 1993-1996).

Total of 54577 sources.

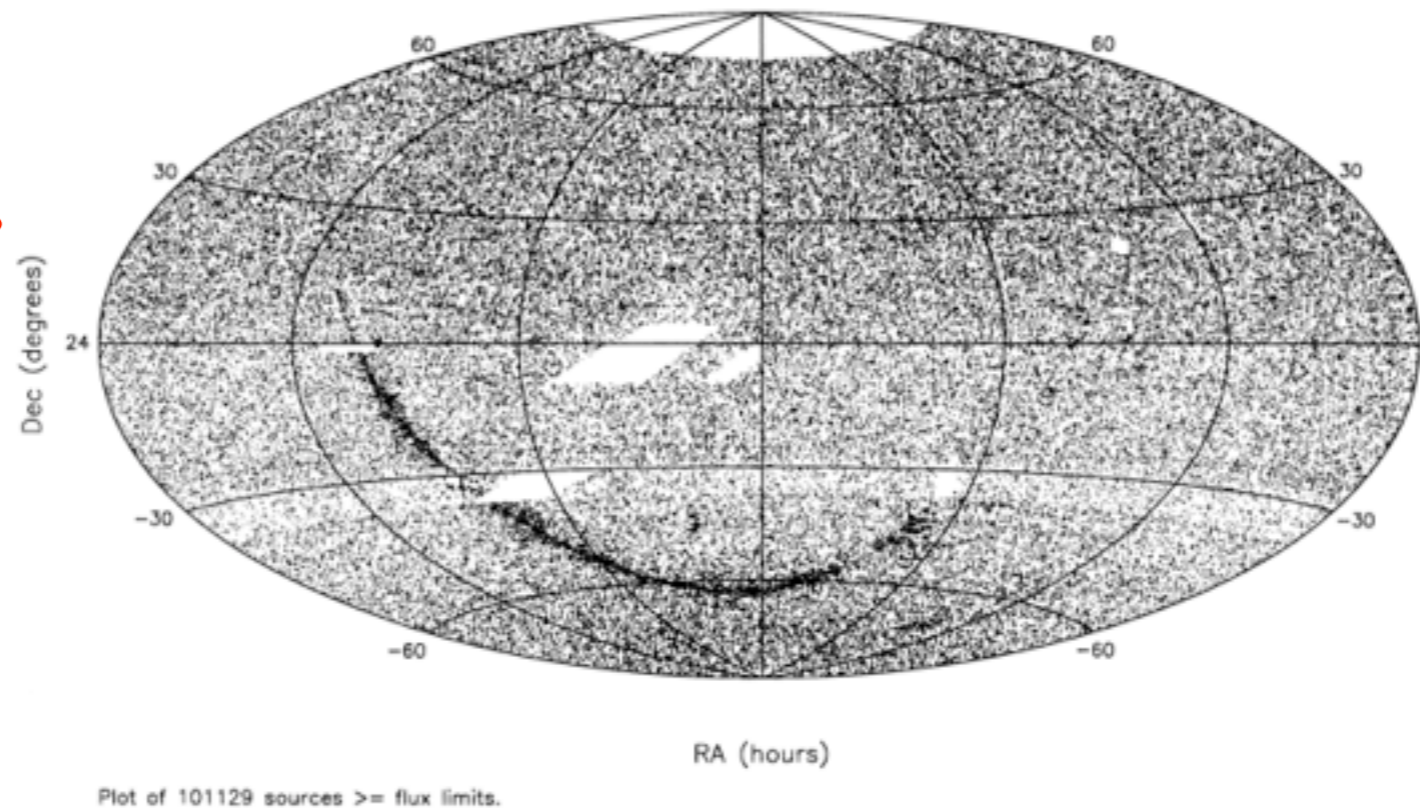
Southern counterpart of 87GB Survey: Condon et al 1989, Gregory et al 1996 (GB6), 0° to +75°, GB 300-foot with MIT/NRAO 7-beam receiver.

The 4850-MHz PMN + 87GB survey

Great features

-deep and ~uniform all-sky coverage, highly accessible catalogues totalling $\sim 10^5$ sources, excellent for obtaining large complete samples of flat-spectrum IDs, gravitational lenses, bright QSOs.

PMN + GB



Bad-luck feature

By 1995-1998 the era of the massive radio survey arrived, with FIRST (Becker et al 1995) and NVSS (Condon et al 1998) providing samples of $\sim 800,000$ and $1,800,000$ sources respectively. Attention shifted. *The days (nights) of the Parkes continuum surveys were over.*

Survey identifications

(without which the surveys were of limited use)

Basically from POSS-1. Initially done via razor-cut (by hand) celluloid overlays, and comparison of POSS1 red and blue plates, to find the blue-stellar-object QSO candidates.

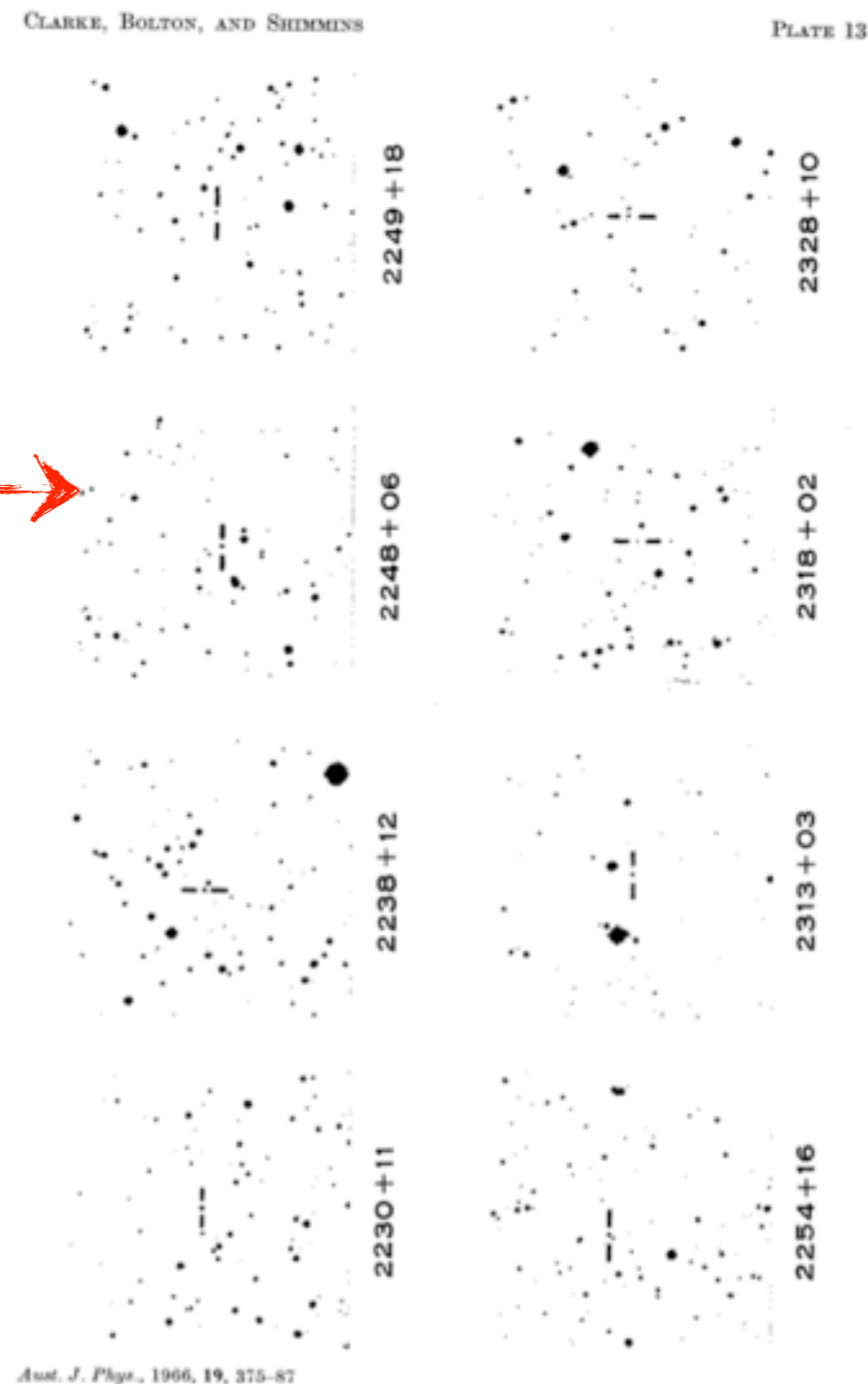
The heroic early efforts were by Margaret Clarke, Jennifer Ekers and Ron Ekers, led of course by John Bolton. Then the rest of us: Katgert-Merkelijn, Savage, JMW, Wright, et al. John Shimmins was always involved, via measuring 'accurate' positions. The results are to be found in AJP, pages and pages of which look like this

Evolution in technique via computerized overlays → copy of Hunstead measuring machine → Bolton dual-camera ("blink") machine.

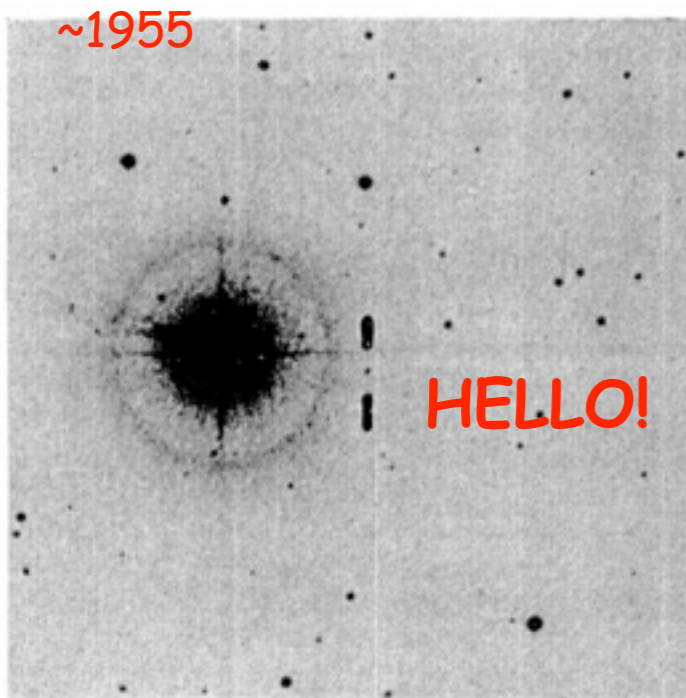
Catalogue positions improved from the initial 1 arcmin ("with this accuracy it is possible to make unique identifications with galaxies as faint as 17m, and, under favourable conditions, even as faint as 18m") to 15 arcsec to 4-5 arcsec

At the 15 arcsec phase, McEwan, Browne and Crowther (1975) showed that the proportion of true IDs we made (considering missed IDs and wrong IDs) was not much better than 50%. This did not worry JGB! He was basically a QSO-hunter. It was amassing numbers for him, and looking for that redshift record.

The rest of us were left to worry about reliabilities, completeness, etc. And we did. (Worry that is.) See later....



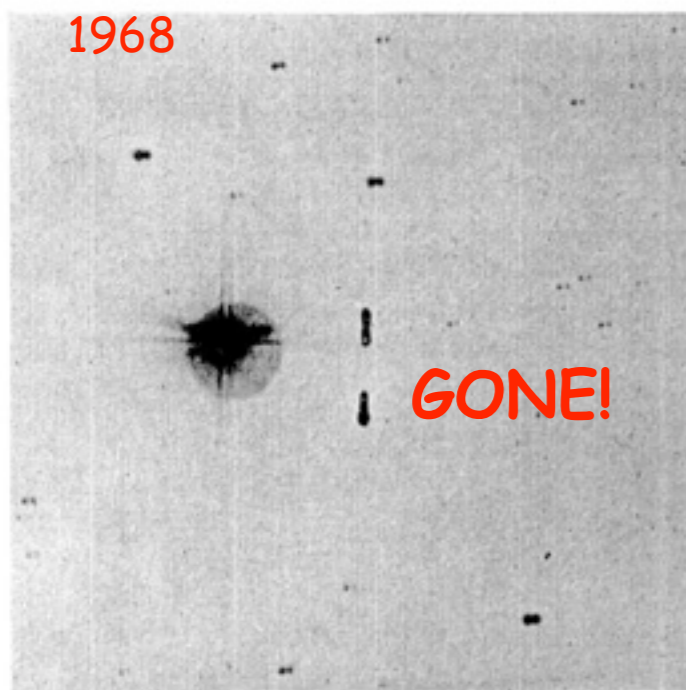
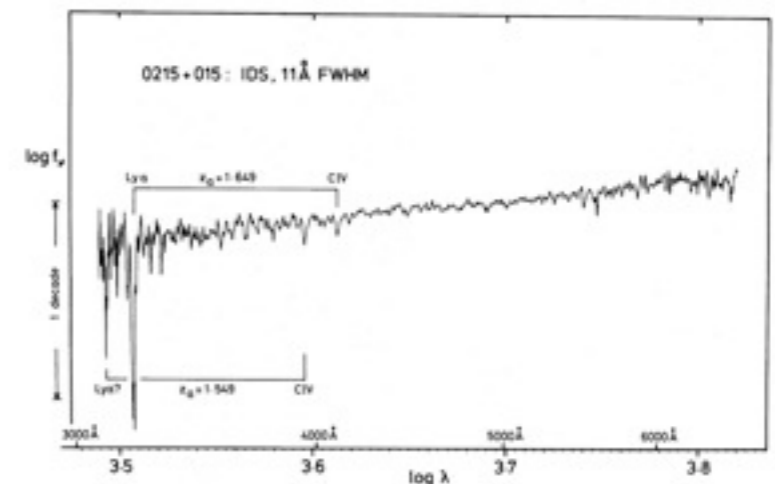
gotta mention my favourite ID- 0215+015 : the comeback kid



0215+015 identified as a blazar by being **NOT THERE** on a 1968 plate (Bolton and Wall 1969).

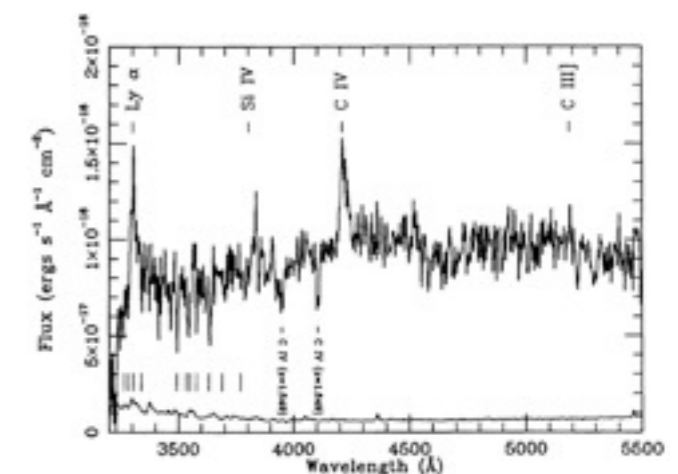
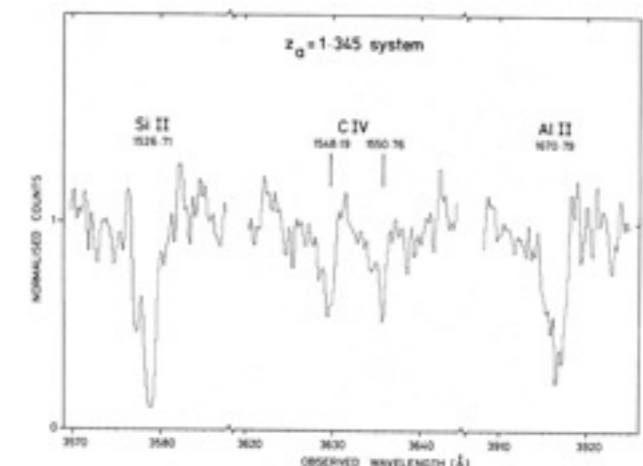
It came back to 15 mag: **211 entries in NED**.

A confirmed BL Lac, perfect **power-law continuum** via low-res optical spectrum.



Metal absorption systems at > 4 redshifts from intervening galaxies (Blades et al 1982).

(Foltz & Chaffee 1987): in 1987 it has **QSO emission lines giving $z=1.715$** , highest redshift for a BL Lac object prior to SDSS.



PKS 0215+015

What's the legacy of the PKS surveys?

1. the **extended southern sources**, so ably mapped by Ron E and many
2. the **flat-spectrum sources**, because of the selection via the 408/1410 survey + the 2.7 GHz surveys:
 - **extreme peakers** like 1934-63, 2134-004 and their physics
 - **complete samples of flat-spectrum sources**, e.g. Wall & Peacock 1985, Savage, Jauncey et al 1988, Drinkwater, Webster et al 1997, Jackson, Shaver et al 2002...(for cosmology studies, to find dusty QSOs, and of course VLBI studies)
3. Southern hemisphere VLBI: **beamers and lensers** (Jauncey et al)
4. **polarization**, Faraday rotation, rotation measures, Galactic structure (Cooper, Price & Cole (Cen A), Gardner and Whiteoak), AND....
5. much of **my personal odyssey is direct from the surveys**, and I finish with four vignettes to show how and what happened:
 - (a) Confusion, P(D)
 - (b) source counts to unified models
 - (c) AGN evolution, redshift cutoff
 - (d) large-scale cosmic structure

(a) Confusion!

Let's start with confusion.

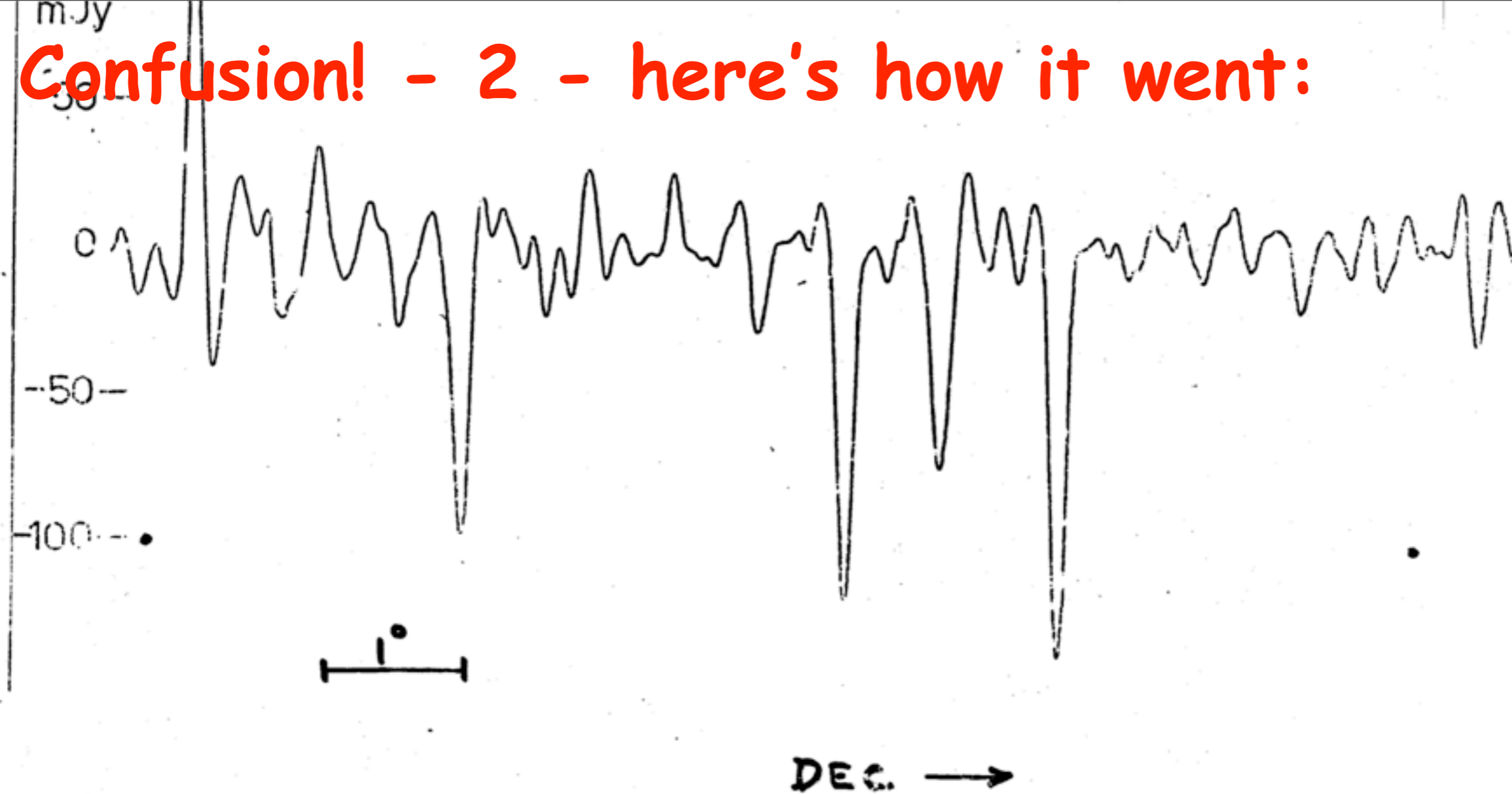
I did some sums in my thesis and discovered how to use a measure of confusion to extend the source counts by at least a factor of 10 deeper than the 'safe' survey limit of ~ 25 beam areas per source.

At the same time, Condon (1974) and Scheuer (1974) worked out the probability of deflection or P(D) method for filled aperture telescopes. (Scheuer's brilliant initial 1957 paper had been for interferometry.)

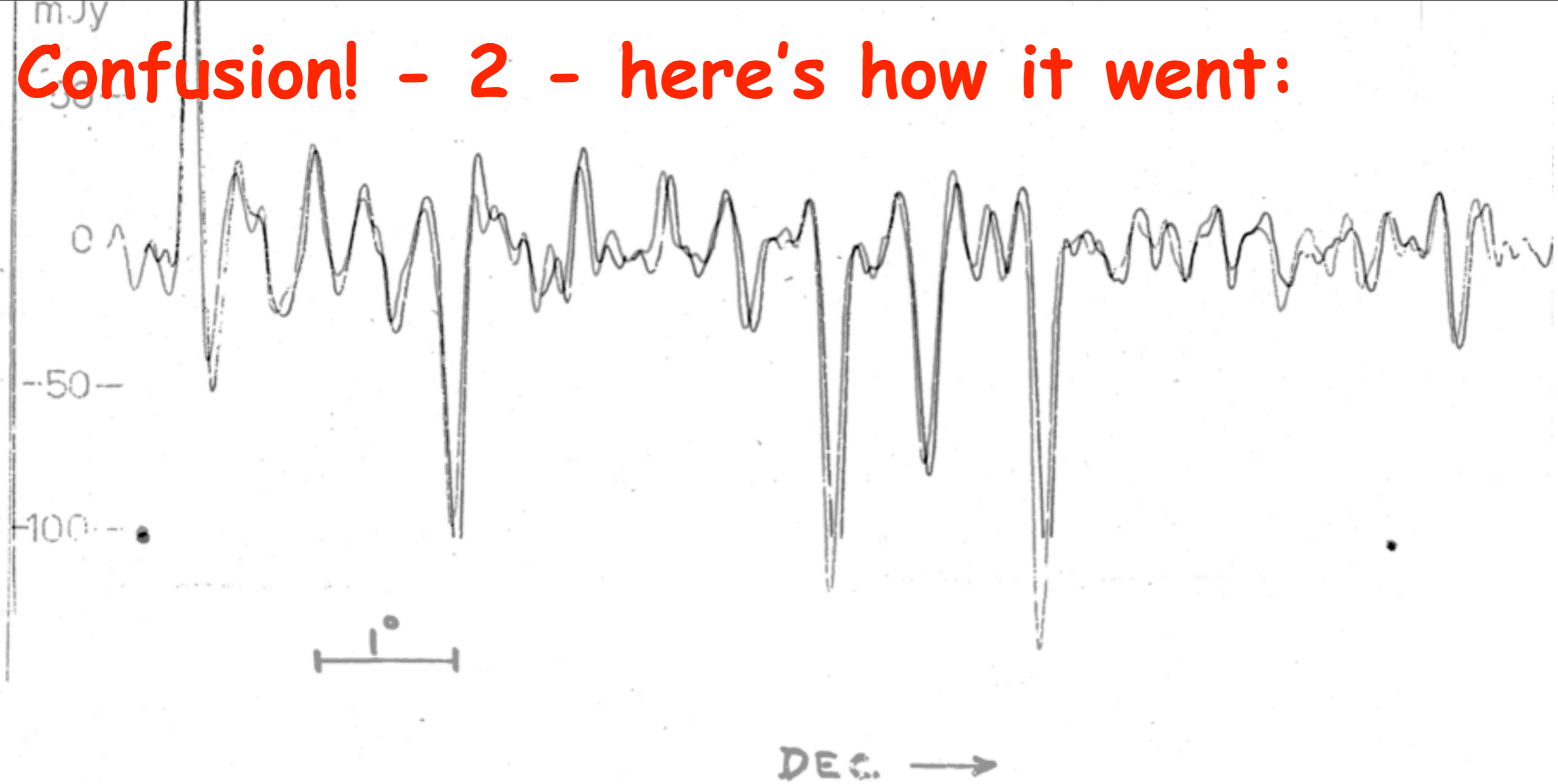
I discovered by accident* how easy it was to integrate to the confusion limit at 2.7 GHz, because of the amazing (at the time) sensitivity of the 2.7-GHz receiver.

Dave Cooke and I decided to do the experiment properly:

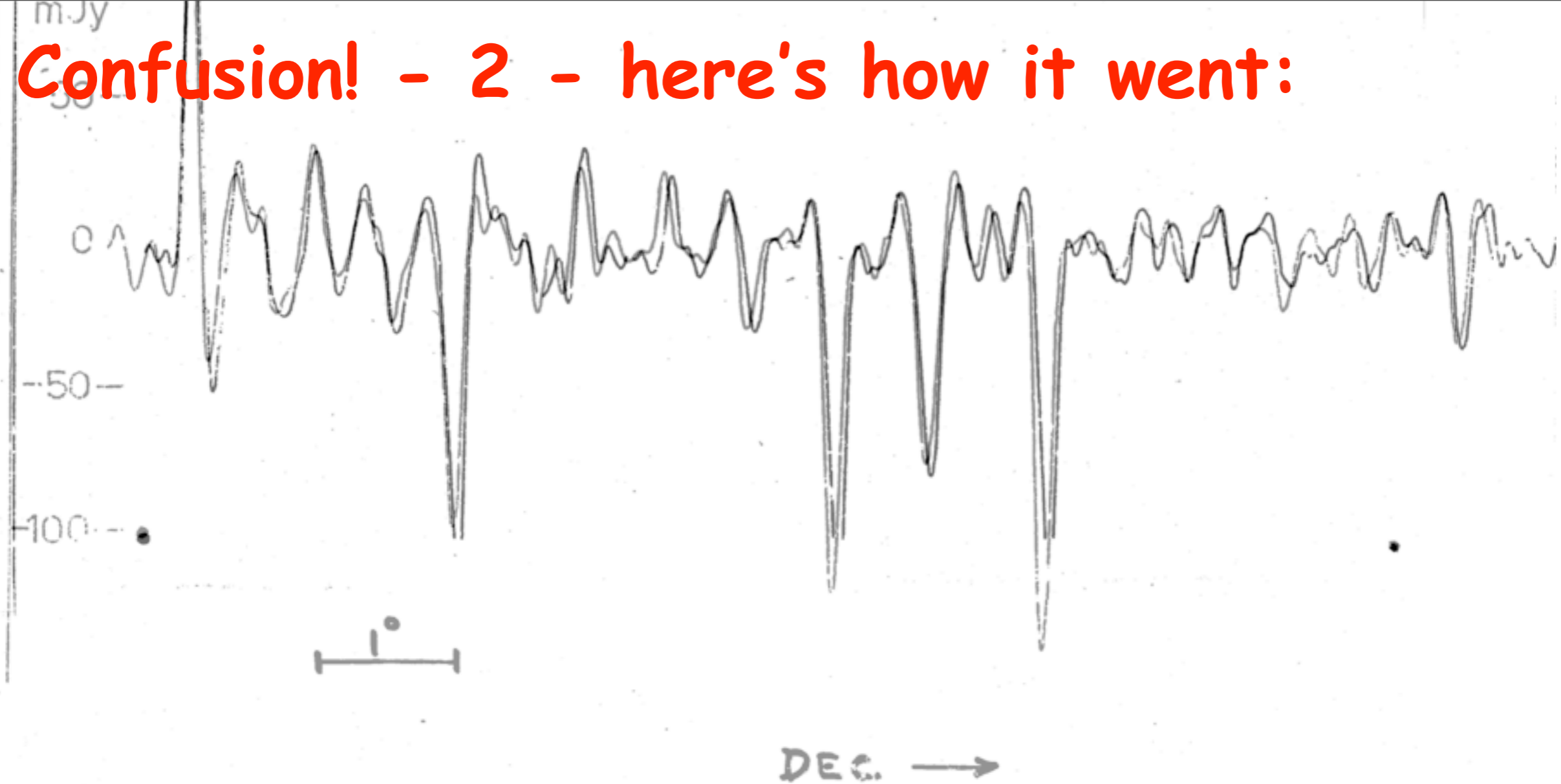
Confusion! - 2 - here's how it went:



Confusion! - 2 - here's how it went:

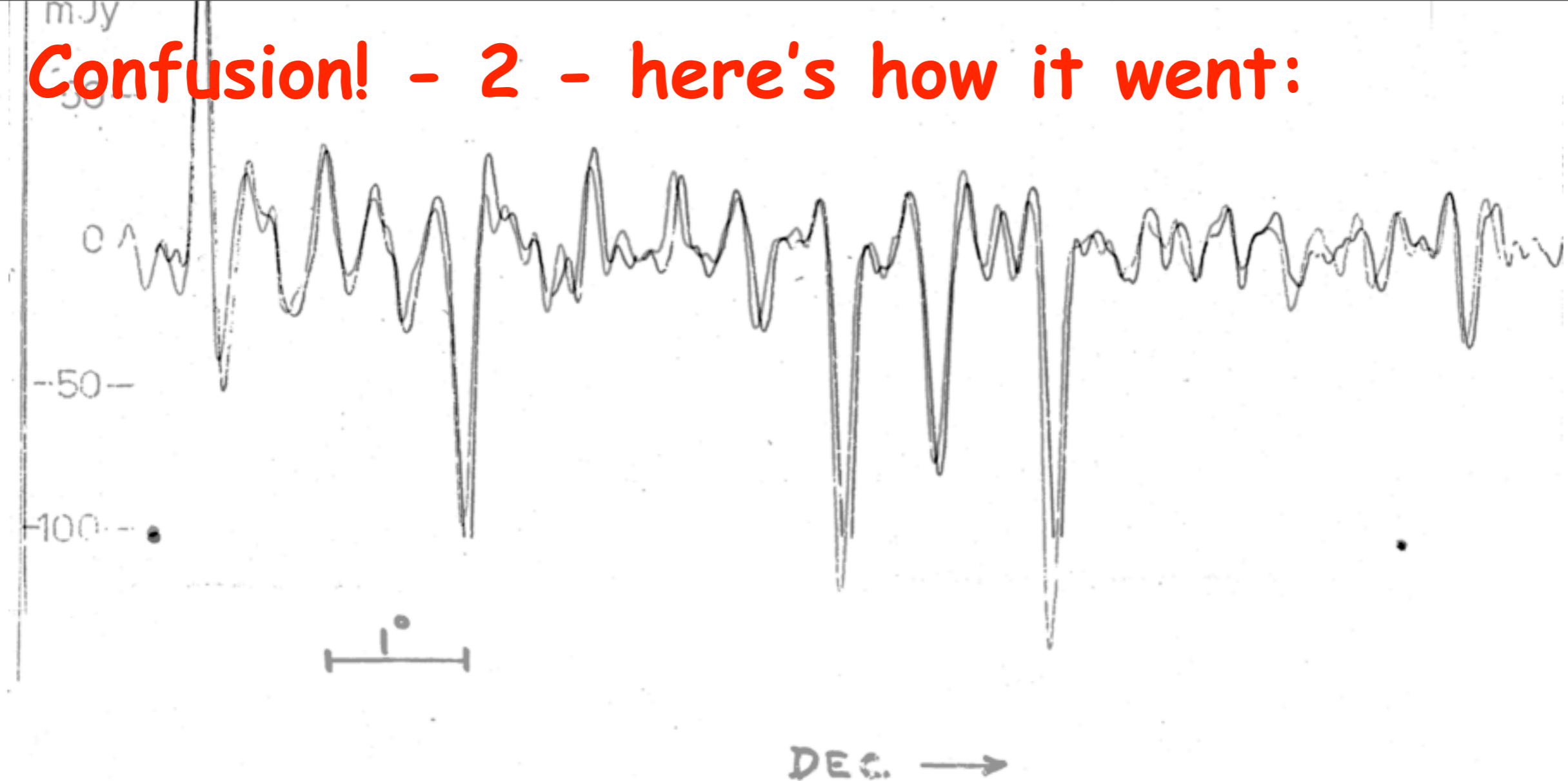


Confusion! - 2 - here's how it went:



A (double) 2.7-GHz sky integration to the confusion limit

Confusion! - 2 - here's how it went:



A (double) 2.7-GHz sky integration to the confusion limit

- NB - dual-beam differencing feed system, HPBW 8'
- only believe sources at level of > 30 beam-areas per source
 - perhaps the 4 largest deflections represent real sources
 - confusion is highly non-Gaussian

Confusion! - 3

Wall & Cooke 1975 (my favourite paper)

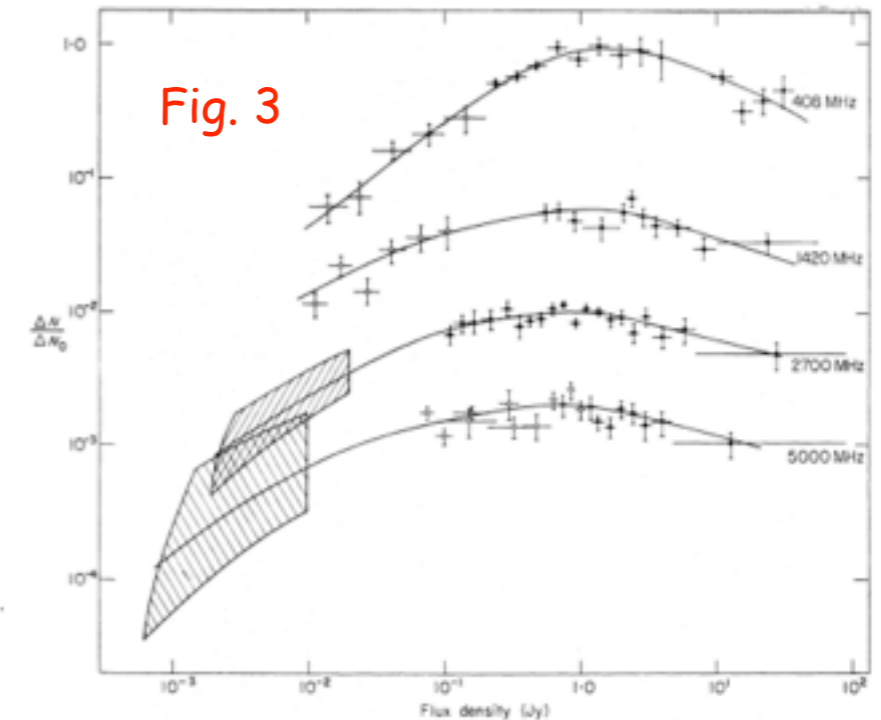
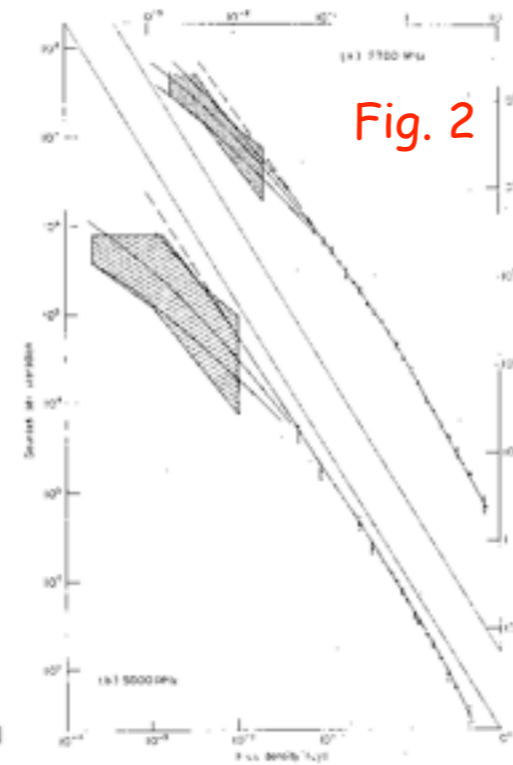
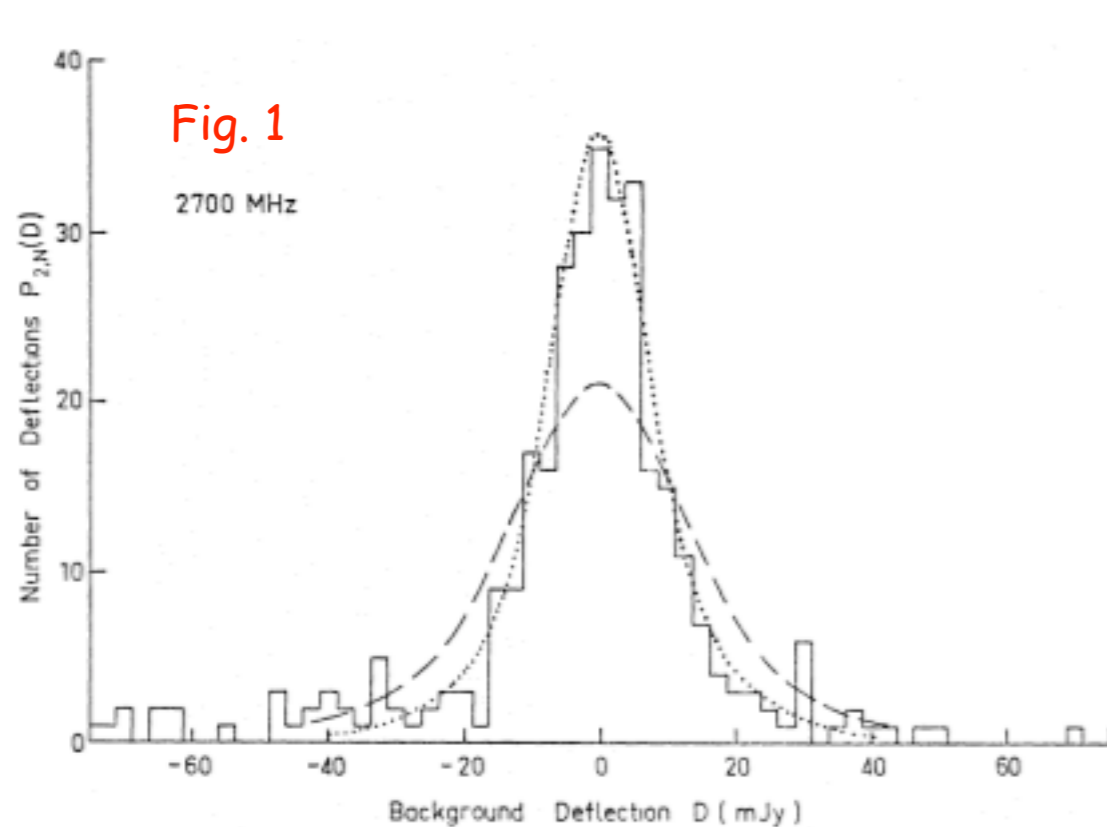
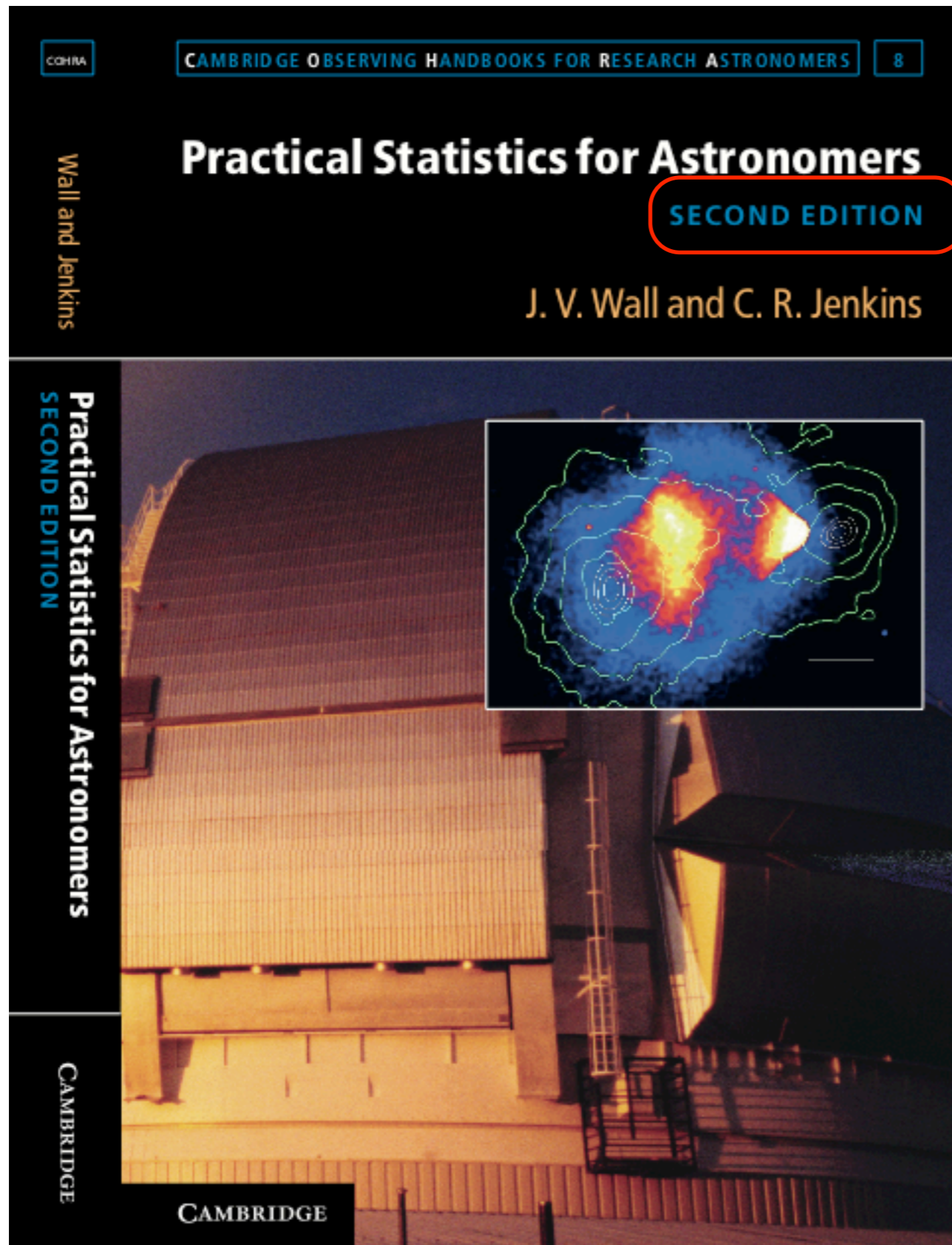


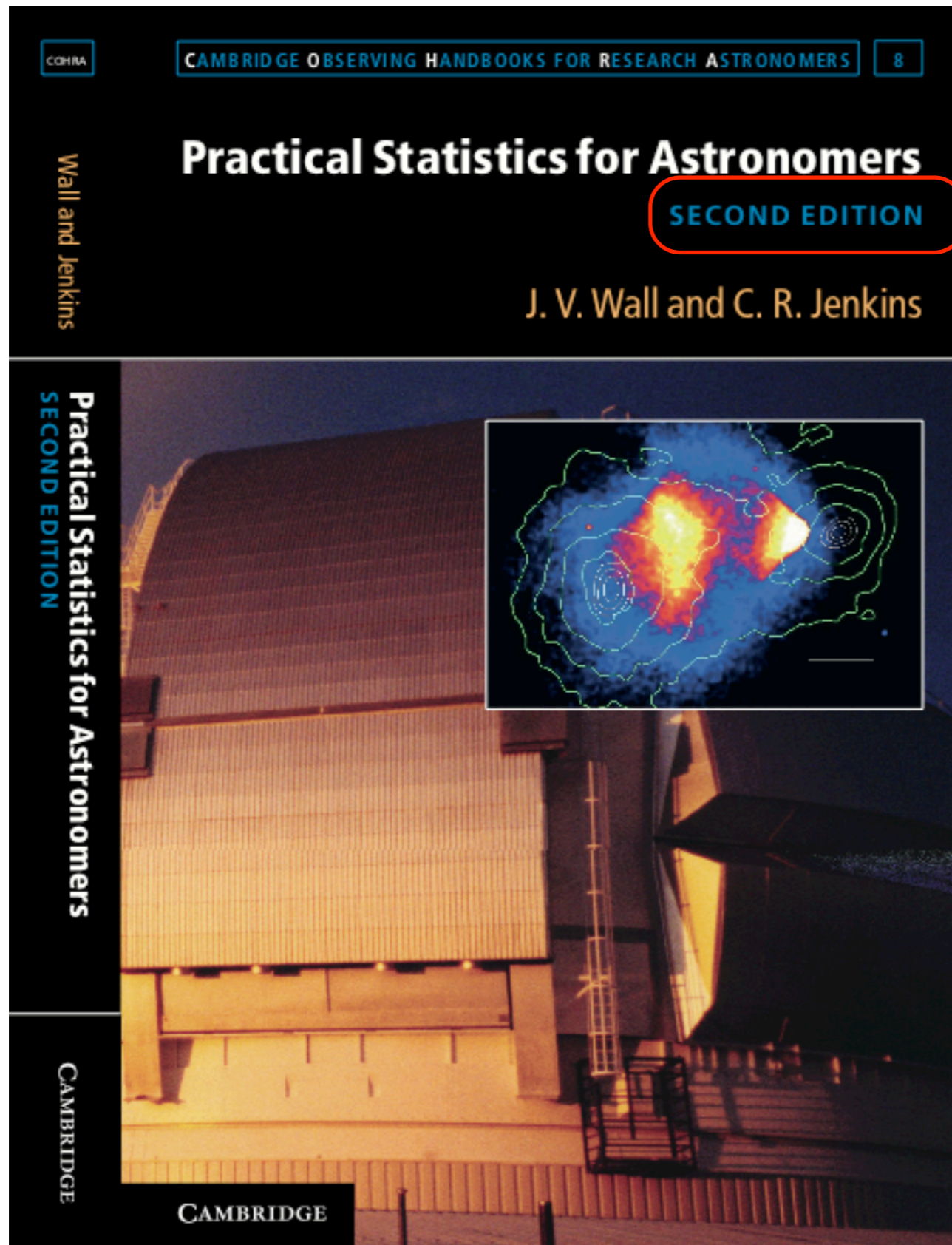
FIG. 8. Differential source counts at four frequencies. The ratio $\Delta N/\Delta N_0$ is the observed number of sources divided by the number in the intensity range which results from the (integral) population law $N_0 = K_0 S^{-1.5}$ (i.e. $\gamma = 2.5$). The lines through the points are

From those scans:

- to compiling a deflection $P(D)$ distribution (Fig. 1)*
- to limits on count slope and normalization via statistical tests, simulations (my first ones!), and crude graphical constructions (Fig. 2) *
- to estimates of differential counts (Fig. 3) down to (almost) mJy levels, ~OK in 1974!
- to a long interest in **statistical / numerical procedures** and what they could do for astronomy →



Second edition in
bookstores February 2012,
expanded and improved



Second edition in
bookstores February 2012,
expanded and improved

Buy this book! (anon)

(b) Counts, evolution, and unity - 1

Source counting was one of our first analyses of the new (1968) 2.7-GHz catalogues.

The counts were different, flatter than at low frequencies (Shimmins et al 1968).

Steady-state is right? **NO, counts do not fit.**

Further, in the 2.7-GHz survey spectral index was shown to depend on flux level (Wall 1972), i.e. **counts of flat-spectrum objects differ from those of steep-spectrum objects.**

Different evolution for flat- and steep-spectrum sources, i.e. QSOs and radio galaxies? **NO!**

(I spent years working on this; but Dunlop (student of my student) & Peacock (my student) showed definitively in 1990 that **the evolutions were ~ the same.**

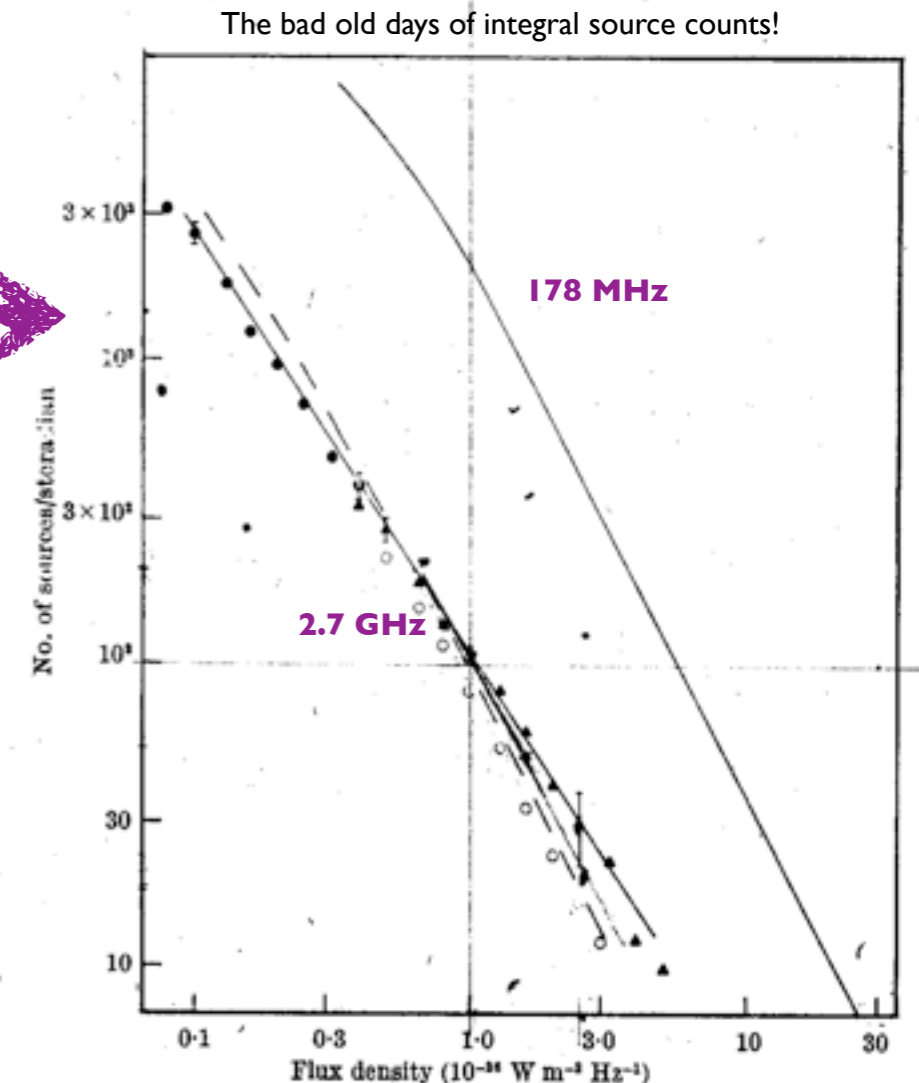


Fig. 1. Cumulative counts of radio sources as a function of flux density. \blacktriangle , 2,700 MHz survey of 0.343 sr; \bullet , 2,700 MHz survey of 0.067 sr; \circ , counts of sources from the Parkes catalogue measured at 2,700 MHz. Solid line to right—counts from 3CR, 4C and Cambridge north polar surveys at 178 MHz after Gower. Dashed line is the expected count at 2,700 MHz obtained by convolving Gower's curve with the spectral index distribution for strong sources at 178 MHz.

Counts, evolution, and unity - 2

Yet, the source counts for flat and steep spectrum objects, i.e. radio QSOs and radio galaxies were very different. (Kellermann & Wall 1987).

And of course very different redshift distributions.

The 'evolution bulge' in the source counts for flat-spectrum objects is shifted to the higher fluxes - that's all. (Ken K told me that from the days of the first cm- λ surveys; the plot shows this clearly.)

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K. I. KELLERMANN AND J. V. WALL

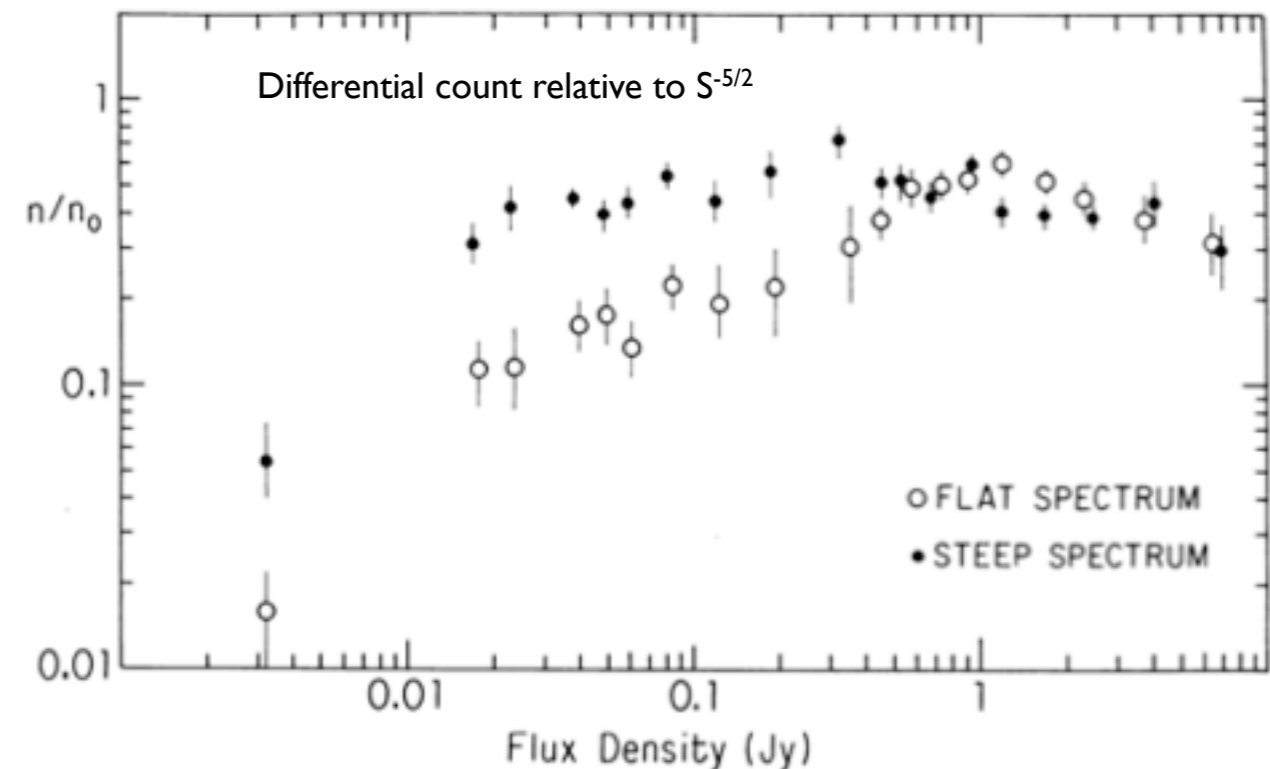


Fig. 6. Differential source counts for flat ($\alpha > -0.5$) and steep ($\alpha < -0.5$) spectrum sources normalized as in Fig. 4. Data are taken from the compilations of Pauliny-Toth *et al.* (1978a) and Condon (1984) and for the point at 3 mJy from Fomalont *et al.* (1984).

So, why would the bulge be shifted to higher fluxes for flat-spectrum QSOs, when their redshifts are generally much higher than the steep-spectrum radio galaxies? They should be fainter? It should be the other way around?

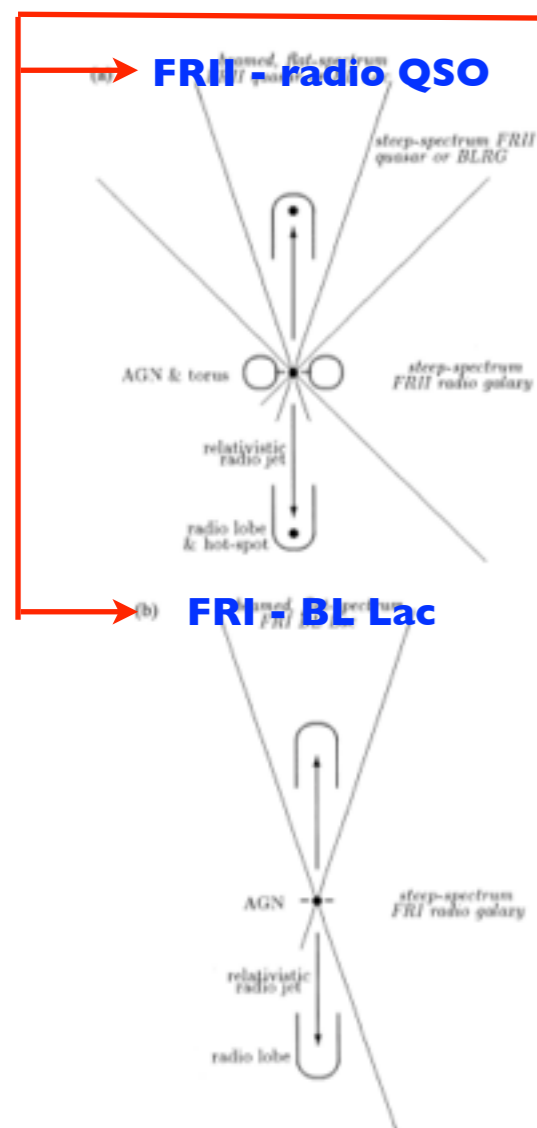
WHAT IS GOING ON?

Counts, evolution, and unity -3

The answer of course - you're there ahead of me - lay in **boosting the apparent flux** with **relativistic beaming**. Radio QSOs are the beamed counterparts of double radio galaxies; we're looking down the pipe, down the lobe axis. The apparent flux boost shoves all the flat-spectrum objects (flat-spectrum because we're looking at boosted core radiation now) to the right in the differential count diagram.

Would the numbers work out? I needed a great student. Enter Carole Jackson.

Dirty details summarized:



1. We assumed a **two-population model**, basically BLLacs as beamed counterparts of FRIIs, and radio QSOs as the beamed FRIIs.
2. We used low-frequency counts and complete low-freq samples to work out details of **space-density/evolution for FRIIs and FRIIs** - using the techniques of the 1980s.

3. We then took large samples of each population, distributed in space according to these evolution models, and **oriented them at random to our line of sight**.

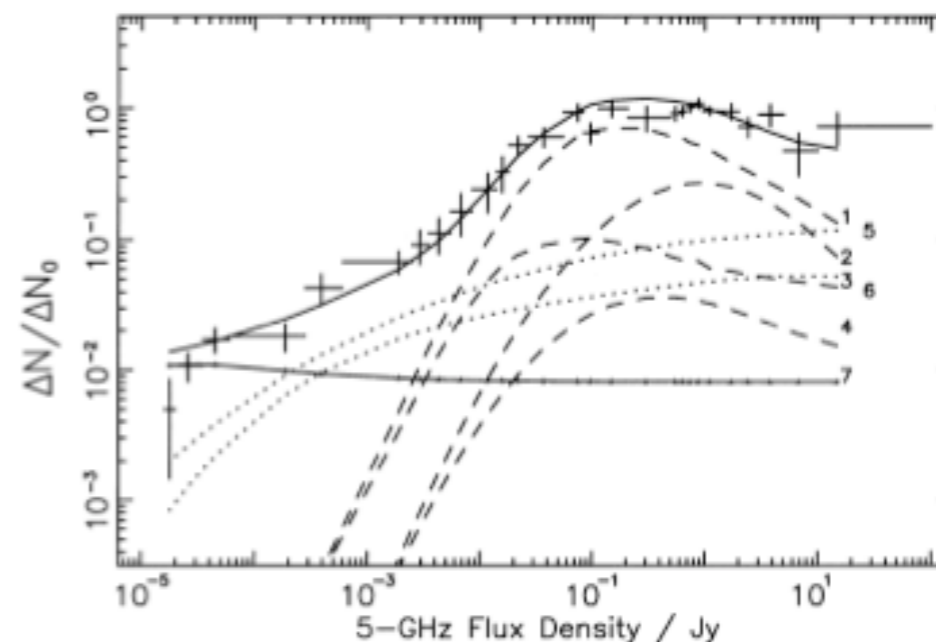
4. We then adjusted beaming parameters for each population to **optimize the fits of the total summed population to the higher-frequency source counts**.

Bottom line: it worked!

Amongst other successes:

1. Source count fits are excellent.
2. Redshift distributions of both flat and steep-spectrum samples are accurately described.
3. Bulk beaming parameters are roughly in accord with individual values found in VLBI measurements.

Wall & Jackson (1997); Jackson & Wall (1999), et seq.



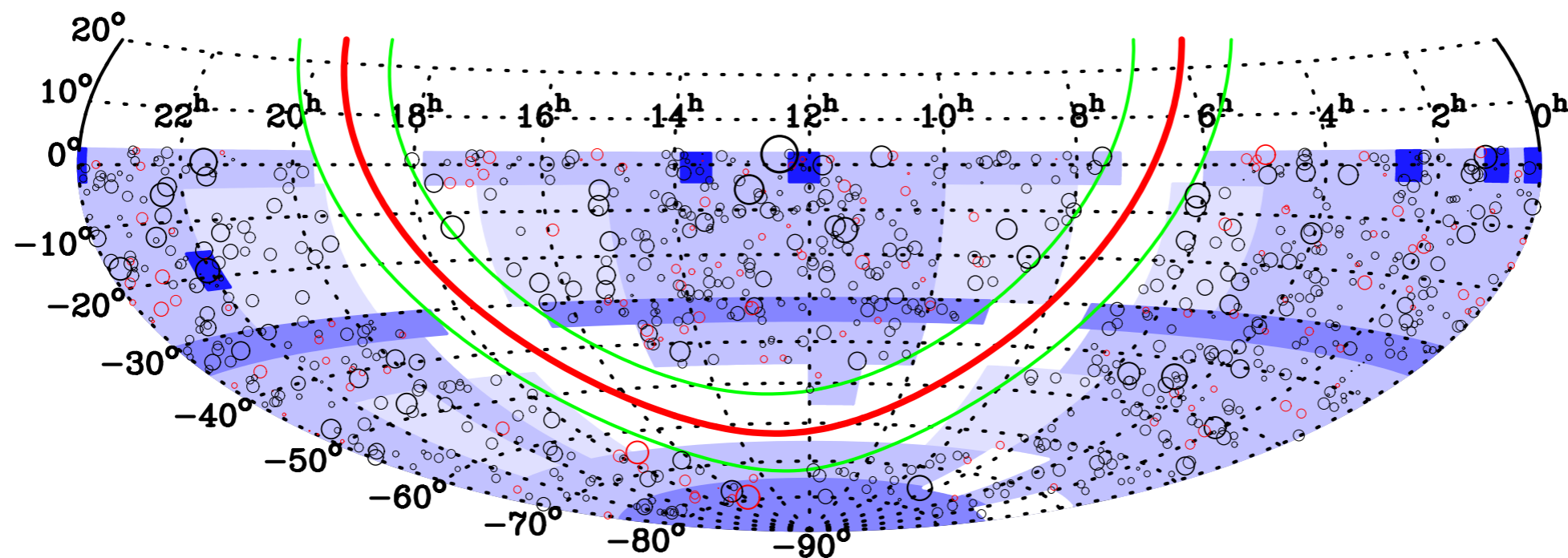
(c) AGN evolution to the edge - the redshift cutoff (1)

Around 1990, Peter Shaver, Ken Kellermann, Carole Jackson and JvW set out to find the most distant QSOs - by deep CCD images/spectra at arcsec positions of flat-spectrum sources

We had some success. but mission creep set in - we realized if we could search a complete sample in this way, we could map radio QSO evolution and search for a redshift cutoff.

From a 6-yr campaign of accurate radio positions, CCD imaging and redshift measurement, we distilled a complete sample of 461 flat-spectrum sources at $\delta \geq -45^\circ$ from the 2.7-GHz surveys for which we were able to identify 460, or 99.8 per cent. The total sample was selected from the regions of the 2.7-GHz survey shown below, with very different completeness levels.

Thus we developed a space-density exploration technique to exploit data at different completeness levels together with variable and individual K-corrections for each source - and we termed it the Single-Object-Survey (SOS) technique, a variant of $1/V_{\max}$ method.



Redshift Cutoff (2)

The results (Shaver et al 1996a,b; Jackson et al 2002; Hook et al 2003; Wall et al 2005; Wall et al 2008):

- (1) a redshift cutoff at $z > 3$ is present at $>3.5\sigma$ level
- (2) the **form of this cutoff is identical** to that found for SDSS optical QSOs and X-ray QSOs (Fig. 1), as well as submm sources.
- (3) **epoch dependence** is similar to that for **star-formation rate** (Lilly-Madau diagram, Fig. 2).
4. New determinations of the cutoff using maximum-likelihood methods show a strong dependence of the cutoff on radio luminosity => **cosmic downsizing** (Fig. 3).

Fig 1 Wall et al 2005

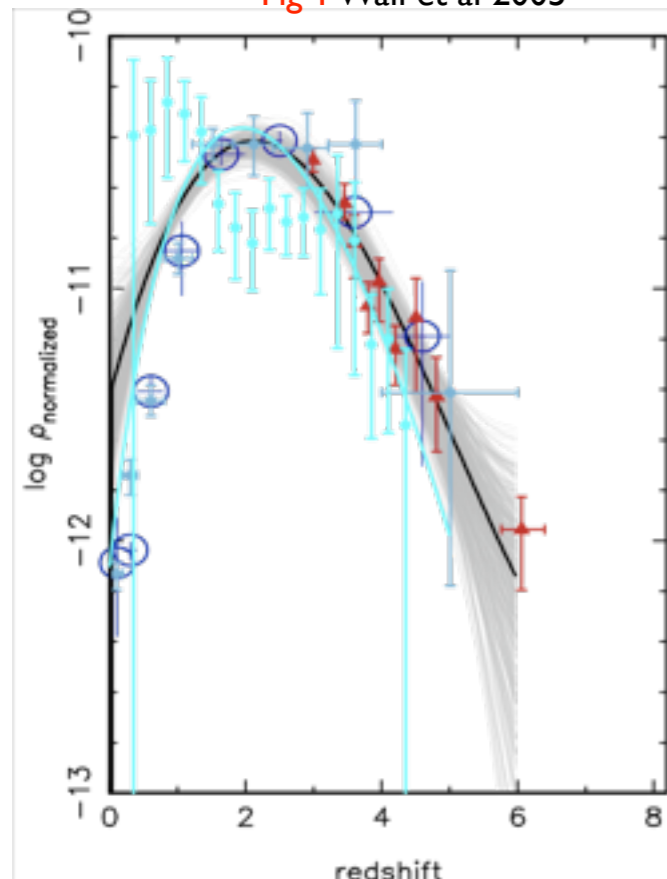


Fig 2 Hopkins 2007

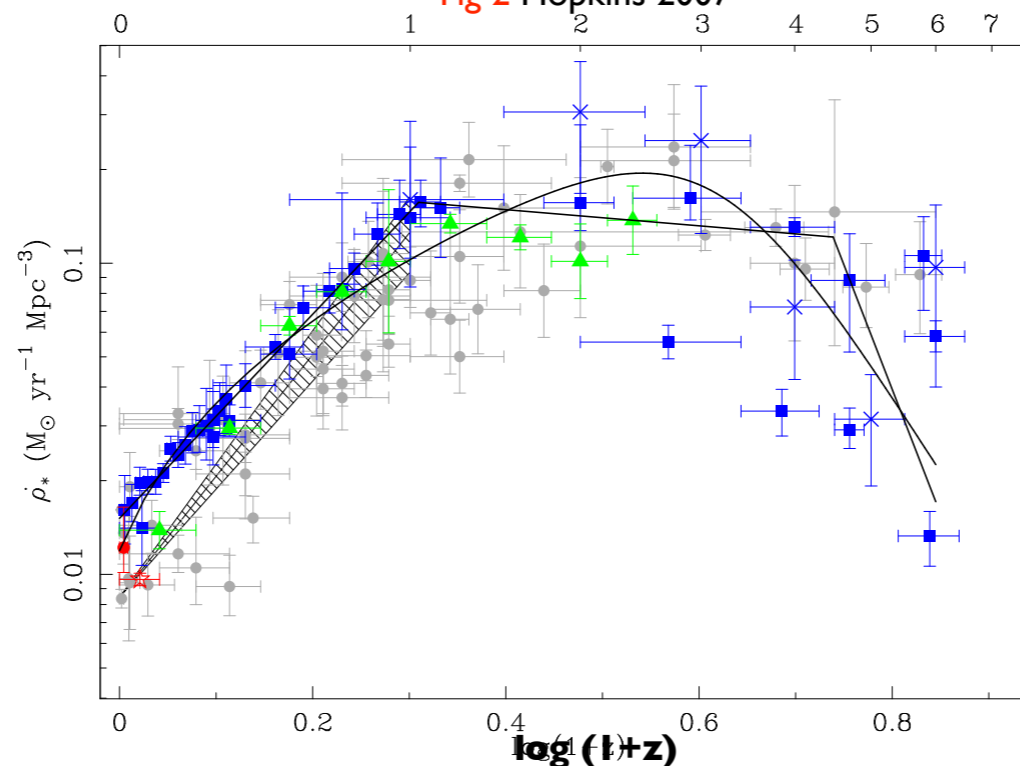
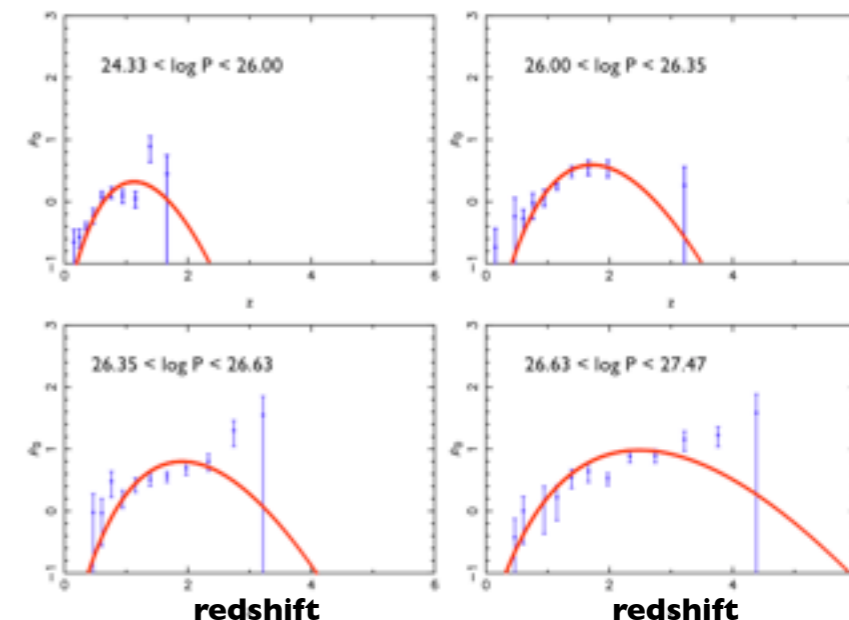


Fig. 3 Wall 2008

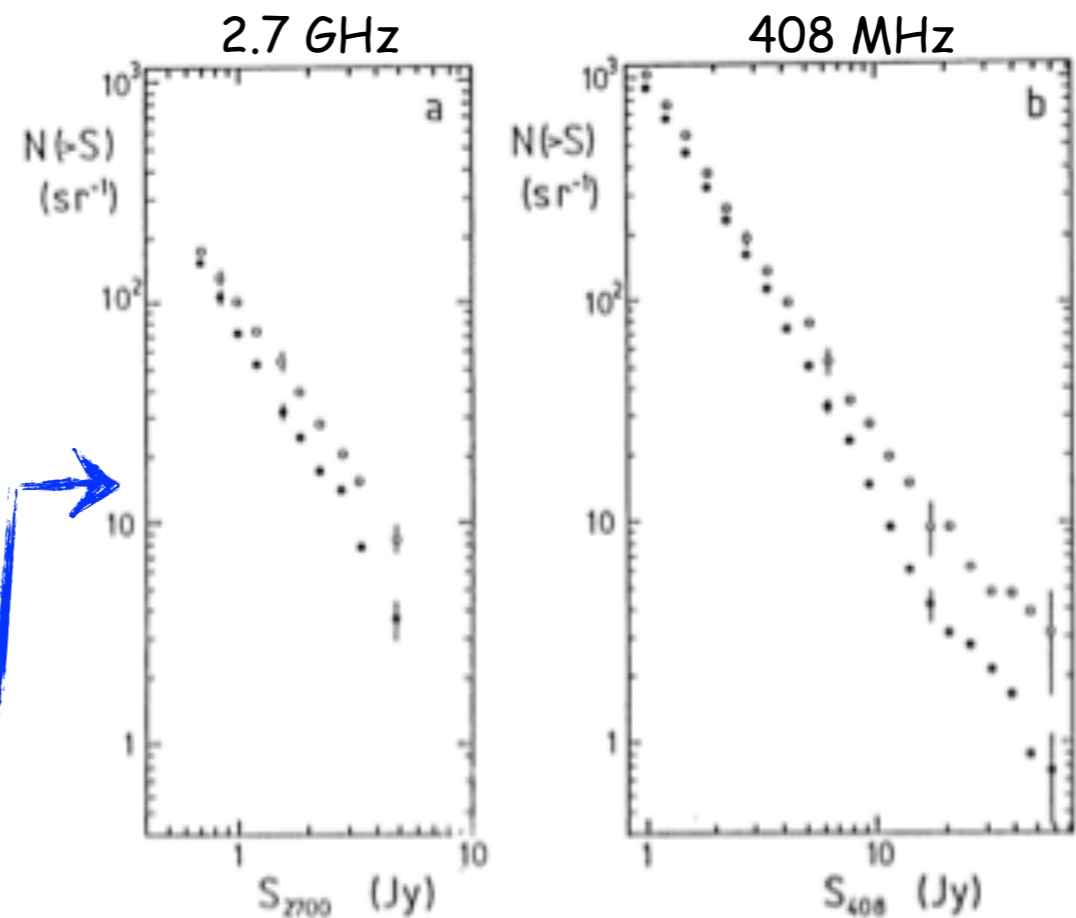


(d) Large-scale structure - 1

AND FINALLY ... how could the relatively shallow PKS continuum surveys possibly say anything about L-S S?

It was like this:

1. For years we had known of **large-scale anomalies in the surveys**, particularly the cm- λ surveys at 2.7 GHz (PKS) and 5 GHz (GB)
2. These were at the tantalizing 3σ level. Couldn't see a pattern - drove us nearly crazy, so we gave up just in time(?)
3. In 1989 Shaver & Pierre (landmark paper) sorted it out. **THE LOCAL SUPERCLUSTER (LSC)** was responsible:



Shaver and Pierre (1989) showed that **source counts were significantly higher (and flatter)** in regions of **low supergalactic latitude**. Our surveys contained many sources within $z < 0.02$ belonging to the LSC

Right : counts from the Molonglo Sky Survey : upper curve $|b_{\text{supergal}}| < 10^\circ$, lower curve, $> 10^\circ$

Left: Part of the anomalies distracting us with the 2.7-GHz survey: upper curve, counts from the first 2 sterad of the survey, slope -1.4; lower curve, counts from the next 5 sterad, slope -1.9. **FIRST 2 sterad were (BY CHANCE!) at low $|b_{\text{supergal}}|$.**

Large-scale structure - 2

So by 1990 I knew that

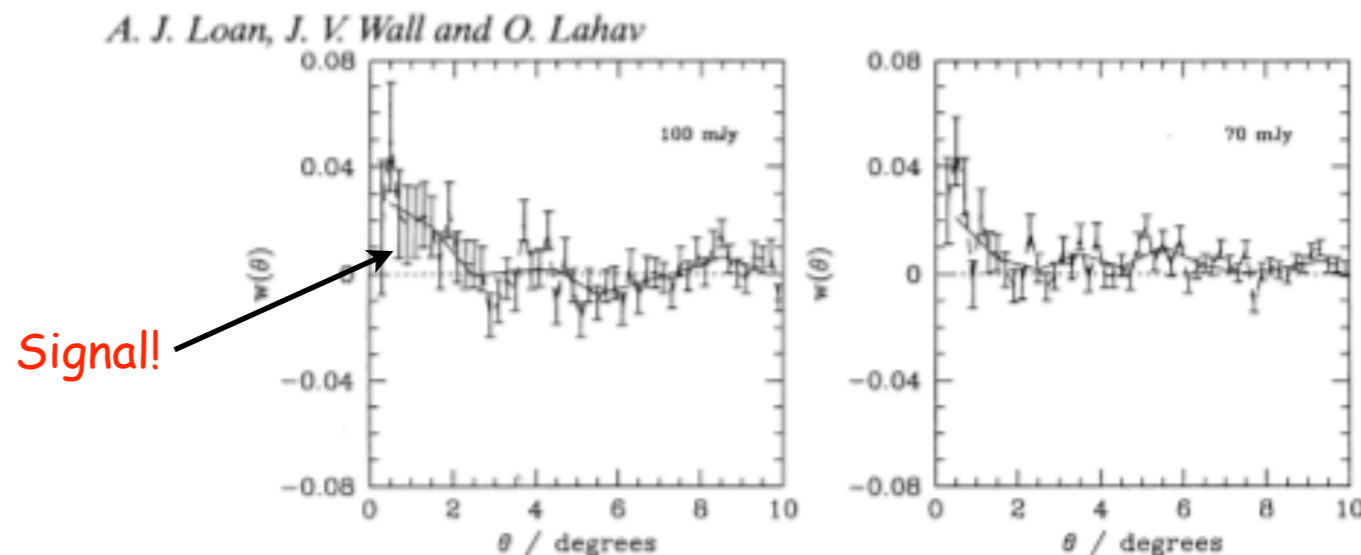
(1) we could see the **Local Supercluster** in shallow radio surveys, and

(2) we could see **clustering in deep radio surveys** (Wall 1990).

The promise of radio surveys for L-SS study was therefore great - **nothing else goes out unobserved to redshifts of 5 and beyond...**

It was just a matter of finding/waiting for the **right** survey.

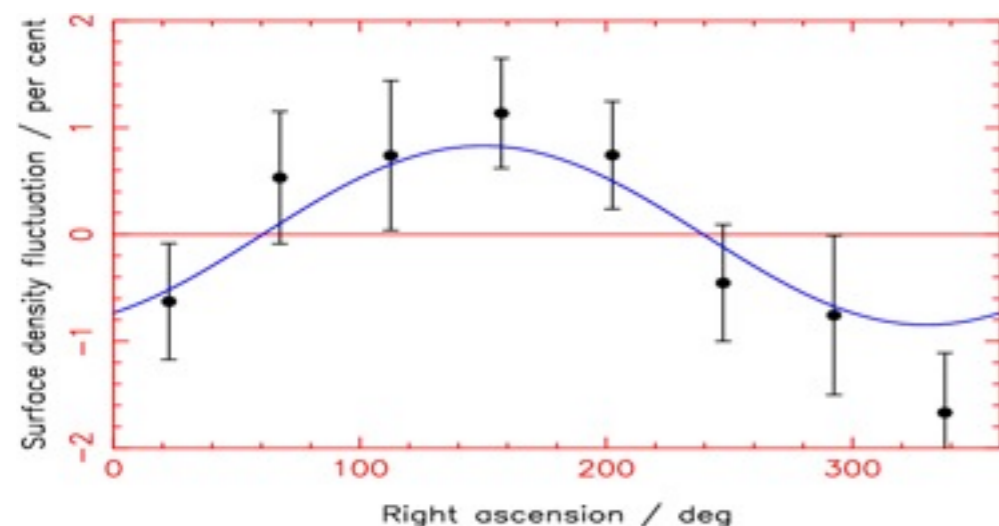
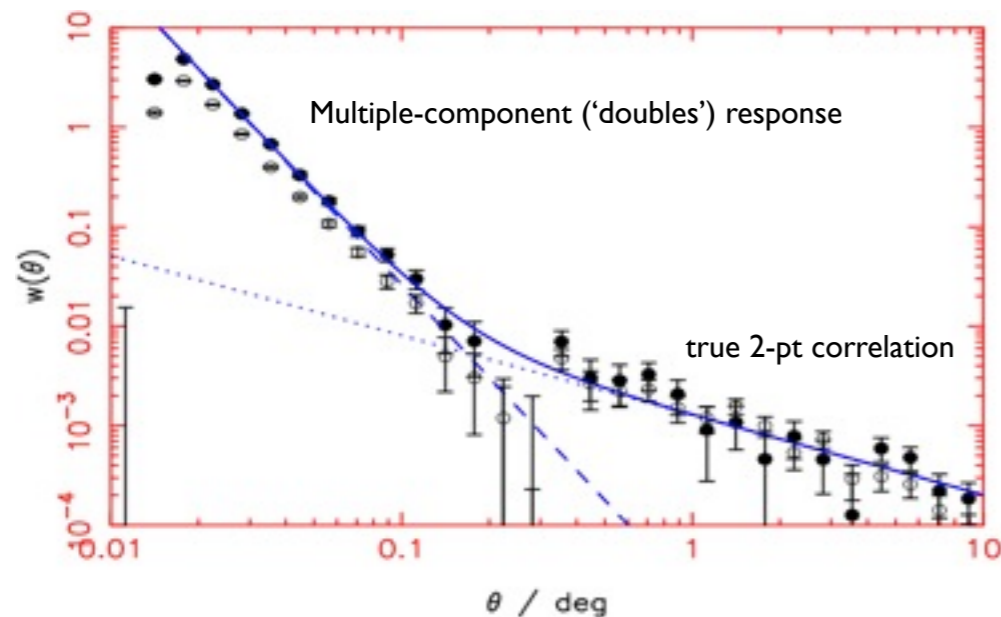
First try in 1996: PMN + 87GB - and **this was not it**.



The 2-point correlation function did show signal (i.e. there is clustering), but low s/n, and our estimate of the radio-galaxy correlation length was too large by a factor of 2. **How innocent we were as to what was really going on.....**

Large-scale structure - 3

We* then struck gold with NVSS:



After understanding/minimizing instrumental effects (no small task - took us a year):

1. a **true measure of the cosmic 2-point correlation function** at last; previous measurements had been contaminated by the multiple-component response.
2. successful measurement of **radio AGN clustering properties** by a) 2-point correl fn, b) counts-in-cells, c) power-spectrum analysis.
3. the **first detection of the cosmic dipole in discrete objects**; agrees in position and direction with that of the CMB.

* **Chris Blake** and JVW: see Blake & Wall 2002a, b, c, d

Epilogue

Large-scale structure has far to go with deep-wide radio surveys - much could still be done from current data with (a) clustering properties as a function of epoch, and (b) with the Integrated Sachs-Wolfe effect. But is it worth it with **magnificent radio/optical surveys on the horizon?**

These will likewise explode the field of unified models and indeed the overall relation between different AGN populations, cosmic evolution and details of the redshift cutoff; **high-frequency surveys** (AT20G etc) will add vastly.

In retrospect **our results to date have barely set up the exploration scaffolding** for it all.

Together with my collaborators, **the second half of my scientific life promises just as much fun as the first 45 years;** it's going to be a great ride.

Thank you!

Thank you very much Carole.

I regret not being present to see
so many good friends.

My very best wishes for the
meeting.

PS I am well, as you can see from
this relatively recent picture.

Control room, 21 July 1969

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