Extragalactic Radio Sources

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I. Why are radio sources cosmological? eg why is 2d brightest radio source in the sky at $z = .07$ while second brightest optical object is at $z = 10^{-17}$ (moon) or $\gtrsim 10^{-4}$ (Sirius)?

Luminosity Function $n(P)$ = no of sources per unit volume with intrinsic power = P (per unit P). Then relative number of sources in $d\ln z$ in a survey with limiting flux S is

$$\frac{dN}{d\ln z} = \frac{d\,Vol}{d\ln z}\int_{P_{min}}^{\infty} n(P)\,dP = \frac{4\pi c^3}{H_0^3} z^3\,\Phi(P_{min})$$

where $P_{min} = 4\pi S_{min}\frac{z^2c^2}{H_0^2}$. Suppose $n \propto P^{\beta}$ so $\Phi \propto P^{1+\beta}$

Then $\frac{dN}{d\ln z} \propto z^3 * \left(\frac{z^2c^2}{H_0^2}\right)^{1+\beta} \propto z^{5+2\beta}$.

$\therefore$ if $\beta < -2.5$ most sources at small z

$\beta > -2.5$ " " " large z ($\gtrsim 1$)

in fact $\beta \gtrsim -2.5$ so $\frac{dN}{d\ln z} \simeq$ const. which means many sources are at large z, but also many at small z so doing cosmology without optical data (z) is difficult.

II Suppose we try any ways. Crudest approach is to determine $\frac{dN}{dS}$ regardless of optical type or data.

For Euclidean space $N(S) = \int_0^{\infty} n(P)\,Vol(P,S)\,dP$

$$= \int_0^{\infty} n(P)\cdot\frac{4}{3}\pi\left(\frac{P}{4\pi S}\right)^{3/2} dP = \frac{(4\pi)^{-1/2}}{3} S^{-3/2}\int n(P)\,P^{3/2}\,dP$$

In General Relativity (Weinberg S., Gravitation & Cosmology p. 457)

$$N(S) = \frac{(4\pi)^{-1/2}}{3} S^{-3/2}\int n\left\{1 - \frac{3}{2}(\alpha+1)\left(\frac{PH_0^2}{S}\right)^{1/2} + F(q, H_0) + O(S)^{-2}\right\}$$

α is spectral index

We could (in principle) try to ~~define~~ determine q, H_0 from N(

if we could estimate $n(P)$ locally.

Problems: 1) we need $\int n(P) P^{3/2,\, 4/2,\, 5/2 \ldots} dP$

but since $n \,\tilde{\propto}\, P^{-5/2}$ integrals don't converge ie we need precise knowledge of $n(P)$ for large P.

2) note $S^{3/2} N(S)$ (or $S^{5/2} \frac{dN}{dS}$) should decrease with decreasing S, since $1+\alpha > 0$

observed.

Ryle, M. <u>Ann Rev. of Astron. + Astrophys.</u> Vol 6 1968.

See also Willis et al. IAU Symposium 74 "Radio Astronomy & Cosmology" one of these days

COUNTS OF RADIO SOURCES 257

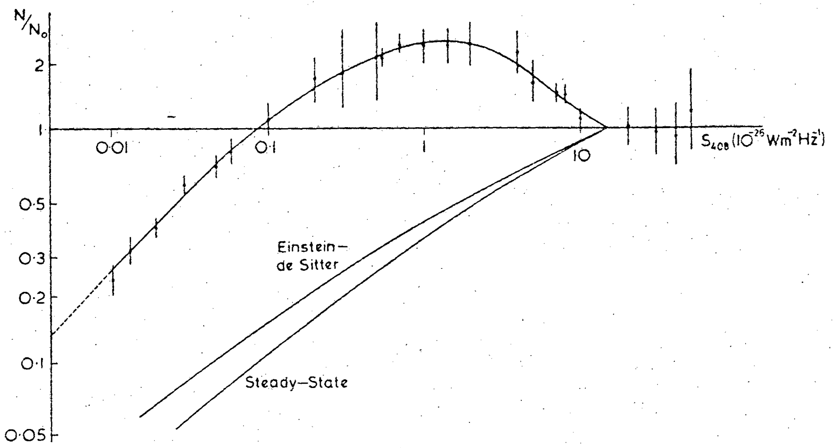


FIG. 3. The source counts presented as a curve of log (N/N_0) against log S, where N_0 is the number of sources per steradian which would be observed with a flux density greater than S in a static Euclidean universe. The corresponding curves for steady-state and source-conserving Einstein-de Sitter cosmologies are also shown.

Curve rises, then drops. Cannot be explained by fiddling with H_0, q.

Either: There were more sources in past, or brighter ones (Evolution!) or we live in a local (?) hole. Drop at very low S necessary to explain finite sky Temperature – due both to geometrical effects & limit on rate of evolution for $z > 3-4$.

Current controversy: if you include only identified Radio Galaxies evolution disappears (because RG's can only be identified for small z) So if Quasars are non-Cosmological (z?) case is much weaker although most of the sources contributing to source counts seem to be galaxies.

See Schmidt, M. 1973, ApJ <u>176</u> 273, 289, 303

III Surrendering Cosmology, study sources for Themselves (Physics!)

Morphology: "standard" source is big double like Cyg A

Two high brightness regions symmetric about galaxy (or QSS) with low brightness Tails pointing back toward center. In center often (always?) a compact source ($\theta \ll 1''$)

Typical size of extended components $\simeq$ 200-500 kpc with $\frac{d}{D} \simeq 10^{-1-2}$, cores perhaps 10pc. In a few cases core is resolved by VLBI into double with same orientation as extented part.

Extended components have spectral index $\alpha \simeq 0.7$ (.5 – 1.2) with Tails somewhat steeper, often show high polarization ($\gtrsim 10\%$)
Compact $\alpha \simeq 0.0$, lower polarization (few percent)

Because these big doubles showed up often in surveys they were considered typical & the rest atypical, eg. in 3CR
(c.f. Macdonald et al MNRAS $\underline{138}$ 259
MacKay $\underline{145}$ 31
Elsmore & Mackay $\underline{146}$ 361)

of 219 sources 56 % "basically" double
92% "complex"
31 % unresolved
4 % "Core-Halo"

In fact percentages are dependent on source power and a flux limited survey picks out high power sources
From Perola & Gavazzi (preprint)

for P (W Hz^{-1}) > 10^{25}		< 10^{25}	
60%	are D $\underline{\text{II}}$ (classical doubles)	30%	D $\underline{\text{II}}$
~ 10%	D $\underline{\text{I}}$	15	D I
10%	Complex	15	Cx
20%	small (< 16 kpc)	40%	"small"

Note There is some bias toward finding D II sources because the are easily recognizable

Identifications: in 3CR
110 R. Galaxies ^{12} Ngal
52 QSS
37 ?
73 no ID

In fact QSS's over represented because they can be seen at much greater distances. Probably most of no ID and ? are RG's so (in some sense) only ~20% of sources are QSO's

From Schmidt only a few percent of QSO's are strong radio sources (say $P > 10^{26}$), which is also true of bright galaxies. Also physical characteristics (size, power, morphology) are similar, so it may be that the property of being a Quasar & being a radio source are essentially unrelated. (For extended sources)

For core sources this is not true, QSS's have brighter cores than RG's, hence most flat spectrum compact sources are QSO's

"Most" RG's are very bright ellipticals with $M_v \simeq -23.4$ (Sandage) but in fact there is a distribution among all brightnesses with Probability of being a radio source $\propto (L_{opt})^{1.5}$. This, folded with galaxy optical luminosity function $\left(\frac{dN_g}{dL_{opt}}\right) \propto L^{-1} e^{-L/L_*}$ ($L_* \simeq -21.2$ produces a function of radio galaxies $\frac{dN_r}{dL_{opt}} \sim L^{+.5} e^{-L/L_*}$ that peaks at the right place.

Originally very many "special" properties were thought correlated with radio behavior

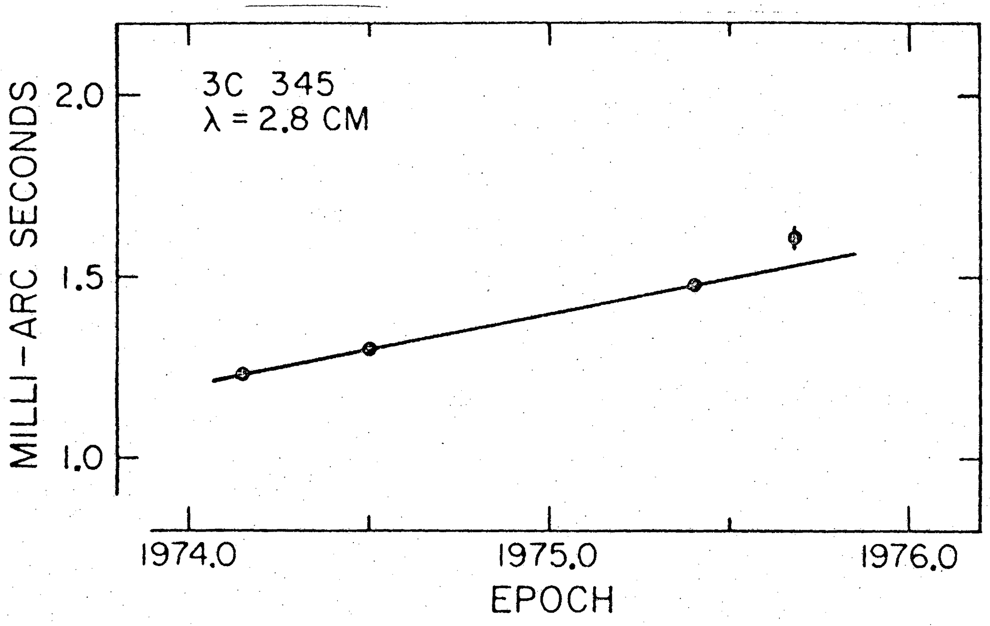
emission line nuclei
peculiar structure
cluster membership

Most of These are qite dubious however. There is a bias Toward finding queer objects. Also There were statistical fluctuations in original small samples which led people astray

IV Special problems

Superluminal velocities: eg. 3C 345 Cohen et al ApJ L <u>206</u> L1 at $z = .595$ shows $V_{sep} \approx 8c$. about 4 such cases

maybe - redshift not cosmological
- christmas Trees (or searchlights)
- relativistic effects (Rees, <u>Nature</u> <u>211</u> 468)



Tailed sources: see Jaffe & Perola A & A 26 423
Scott & Pacholczyk Ap J 203, 313

appear only in (super) clusters of galaxies

First model involved particles "streaming" but This is not probable

Ryle & Windram MNRAS 138,

2d involved "normal" RG moving through cluster medium.

Miley et al
Nature 237, 269

characteristics: tail (blobby)
steepening spectral index
high polarization

Various models for physics, none very convincing,

why only in clusters?

a) high density medium (probably not True because LF is same in non-clusters

b) movement of galaxy through medium,
gives clue to ejection velocity