THE ROAD TO QUASARS

Ken Kellermann
National Radio Astronomy Observatory

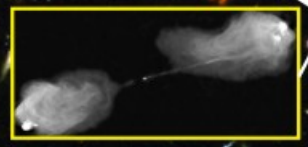
1949

1937

1933

1959

1954

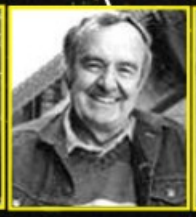


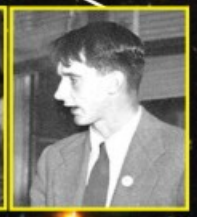
1960

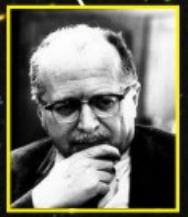
1963

1962

1961





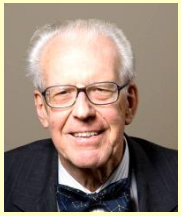


NRAO

Associated Universities, Inc.

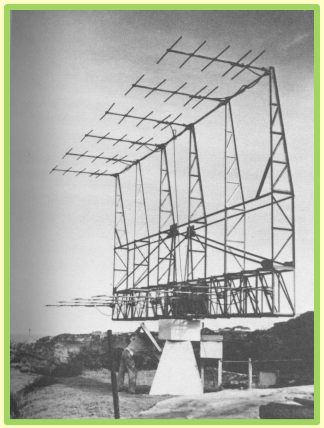
NSF

Before quasars

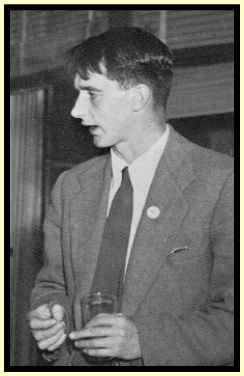
Pre-1949: All radio sources are Galactic stars

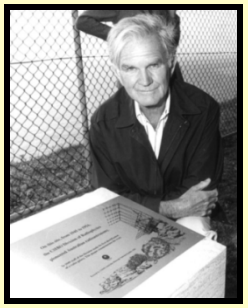
1949 : The first radio galaxies?

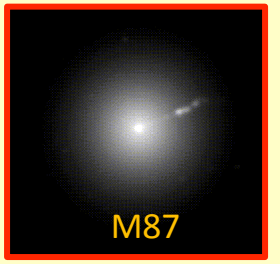


"Positions of Three Discrete Sources of Galactic Radio-Frequency Radiation"

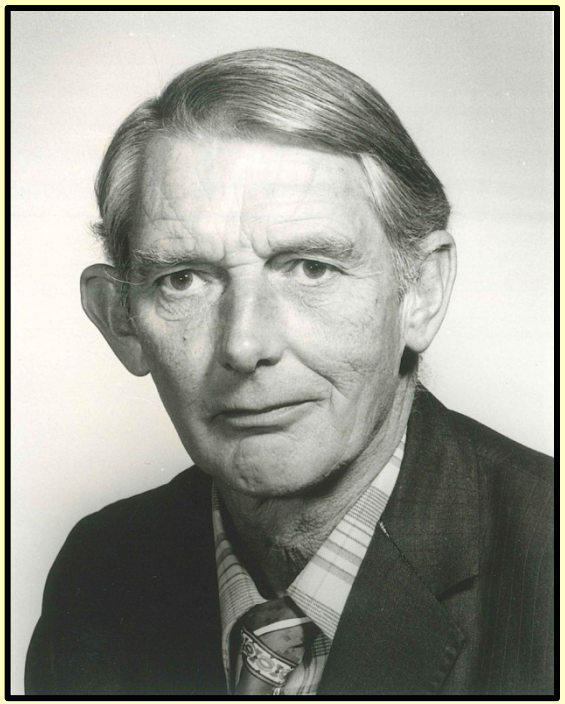
Bolton, Stanley, and Slee, Nature 164, 101

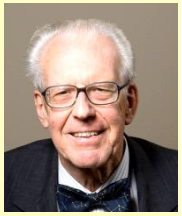




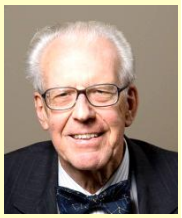
"NGC 5128 and NGC 4486 (M87) have not been resolved into stars, so there is little direct evidence that they are true galaxies. If the identification of the radio sources are accepted, it would indicate that they are [within our own Galaxy]."



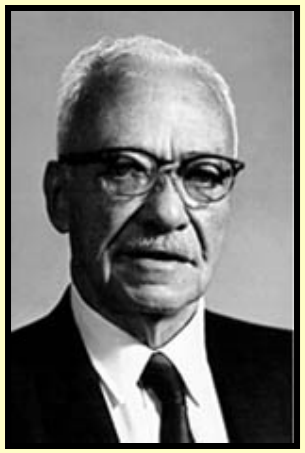
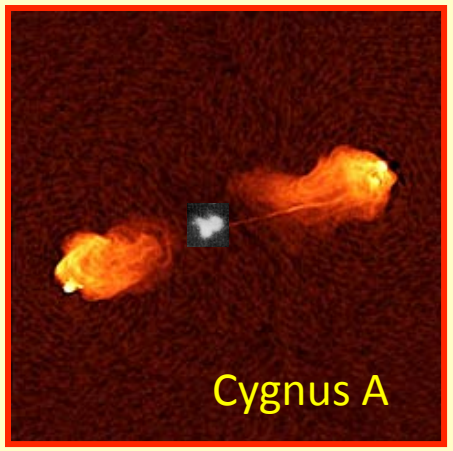


"I knew it (M87) was extragalactic; but that meant that the radio luminosity would be orders of magnitude greater than the Galaxy, and I was afraid this might deter a referee."

Radio Galaxies

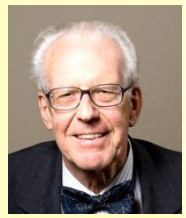



- 1954: Cygnus A (z=0.06) (*Baade and Minkowski, ApJ 119, 206*)

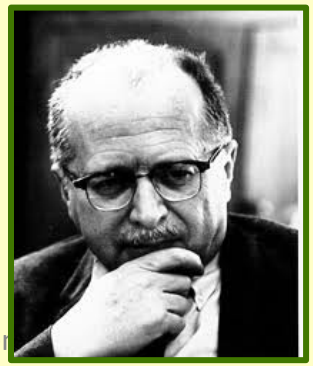




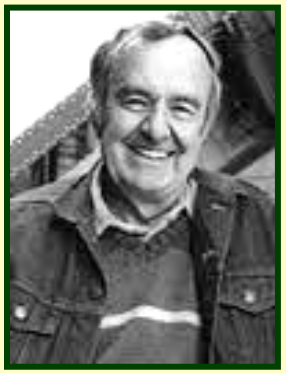
- Starting in 1960 OVRO started to produce accurate positions
  - 1960: Many radio galaxies identified with brightest cluster galaxy
  - 3C 295 identified with faint mag 20 galaxy
    - Minkowski measures redshift as z =0.46
  - All |b| > 10 deg radio sources are galaxies (radio galaxies)
  - Smallest sources expected to be most distant

3C 48: "The first radio star"

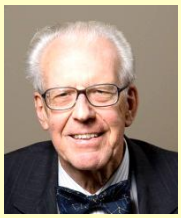


- Tom Matthews and John Bolton obtain accurate OVRO position and identify 3C48 with a stellar object
- Greenstein, Munch, Sandage obtain 200" spectra
  - Lots of unidentified lines
  - Allan Sandage presents late AAS paper (Dec 29, 1960),
- "Remote possibility that it may be a distant galaxy of stars. But there is general agreement … that it is a relatively nearby star." *S&T, 21, 148*
- Records of 107th AAS meeting lost



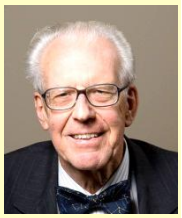


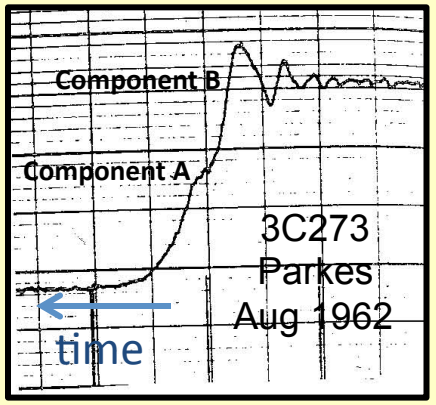
3C 48, the first radio star



- First radio star
  - Unresolved radio and optically (< 1 arcsec)
  - Peculiar spectrum (emission lines, UV/Blue continuum excess)
  - Variable
- "The Radio Star 3C 48," Greenstein, accepted by ApJ
  - Stellar remains of a SN
  - Spectrum: highly ionized rare earth elements
  - *"Except for Δ = 0.367 no shift explains the strongest lines of any single ionization. The case for a large red shift is definitely not proven" "Not an extragalactic nebula"*
- Two other (3C 196, 3C 286) radio stars discovered
- Matthews and Sandage
  - *"No plausable combination of red-shifted emission lines"*

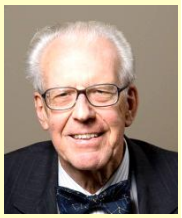
3C 273 as a distant galaxy

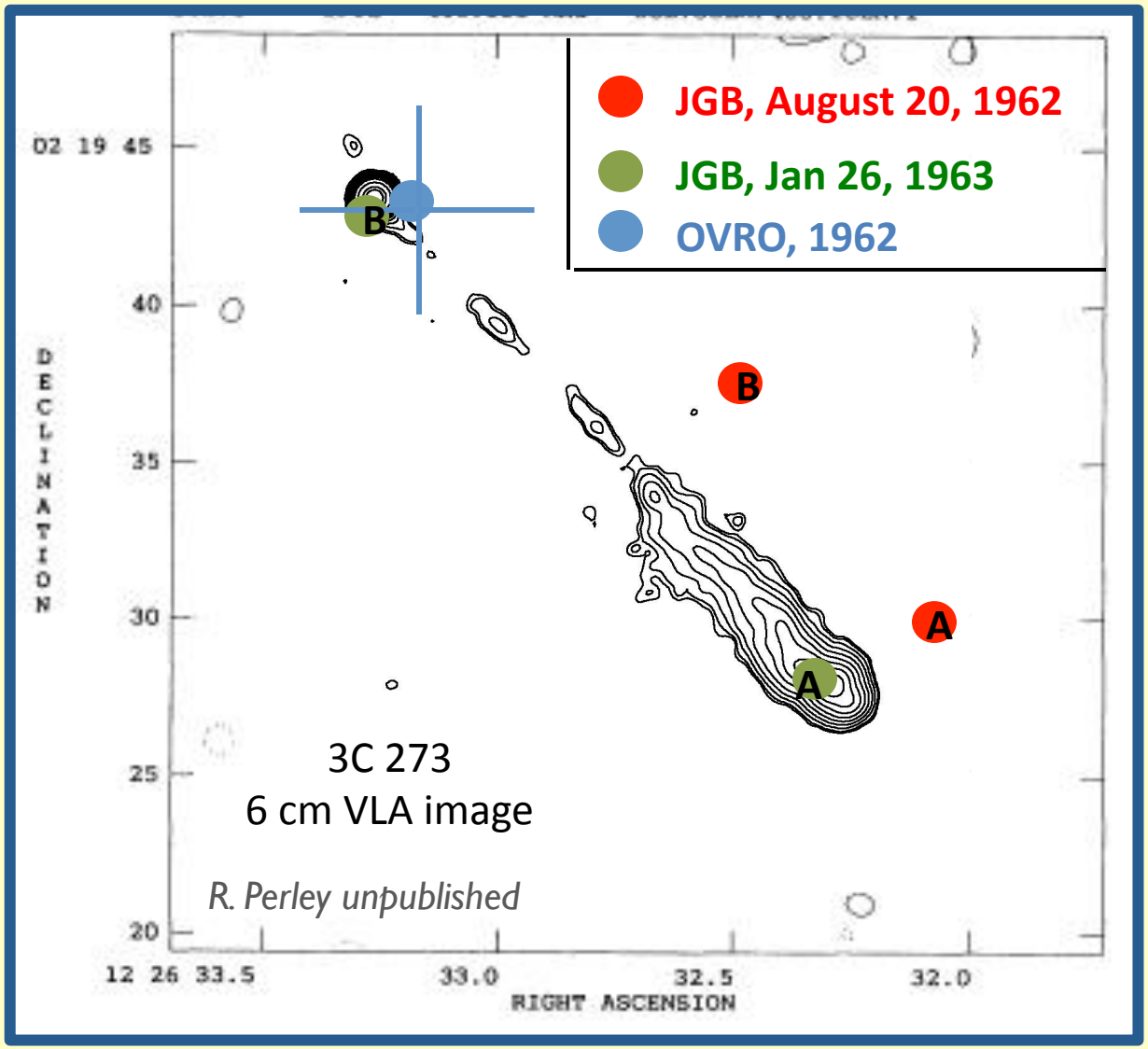




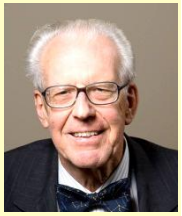
- May, August, October1962 occultations of 3C 273
- August 20, 1962: Bolton sends position to Schmidt
- Dec 27-30: Maarten Schmidt takes 200" spectra
- Jan 1963: Bolton sends Schmidt correct position

3C 273 Positions

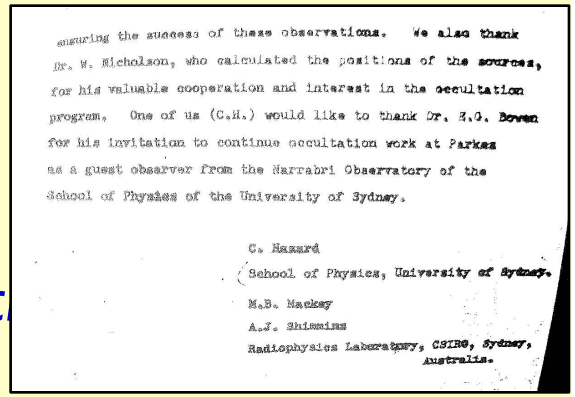




Nature, Vol. 197



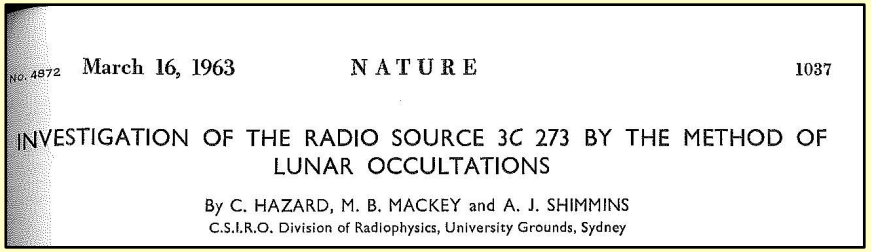
- Hazard, Mackey, Shimmins - 3C 273 occultation
  - CSIRO / Univ. of Sydney controversy
- Schmidt - ID with "star-like object" z =0.16
  - *"The nuclear region would be about 100 times brighter optically than the luminous galaxies whic have been identified so far."*



ensuring the success of these observations. We also thank Dr. W. Nicholson, who calculated the positions of the sources, for his valuable cooperation and interest in the occultation program. One of us (C.H.) would like to thank Dr. E.G. Bowen for his invitation to continue occultation work at Parkes as a guest observer from the Narrabri Observatory of the School of Physics of the University of Sydney.

C. Hazard
School of Physics, University of Sydney.
M.B. Mackey
A.J. Shimmins
Radiophysics Laboratory, CSIRO, Sydney, Australia.

- Oke: P hotoelectric IR scanner,
  - Continuum spectrum
  - H_α (λ 6563) observed at λ7560



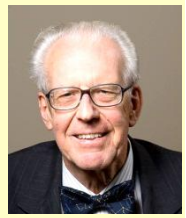
No. 4872 March 16, 1963 NATURE 1037

INVESTIGATION OF THE RADIO SOURCE 3C 273 BY THE METHOD OF LUNAR OCCULTATIONS

By C. HAZARD, M. B. MACKEY and A. J. SHIMMINS
C.S.I.R.O. Division of Radiophysics, University Grounds, Sydney

- Greenstein & Mathews: 3C 48, Mg II, z = 0.37
  - Greenstein withdraws his 3C 48 paper
- Matthews & Sandage (ApJ, submitted Dec 8, 1962)
  - Optical Identification of 3C48, 3C196, 3C286 with stellar objects
  - Section added in proof - *"3C48 as a Galaxy"*

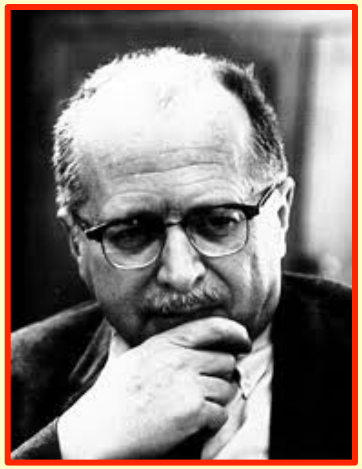
3C 48 Revisited



The best fit I could find for the one broad line and one narrow line which Jesse [Greenstein] had measured were with Mg II λ2798 and [Ne V] λ3426, and a redshift of 0.37.

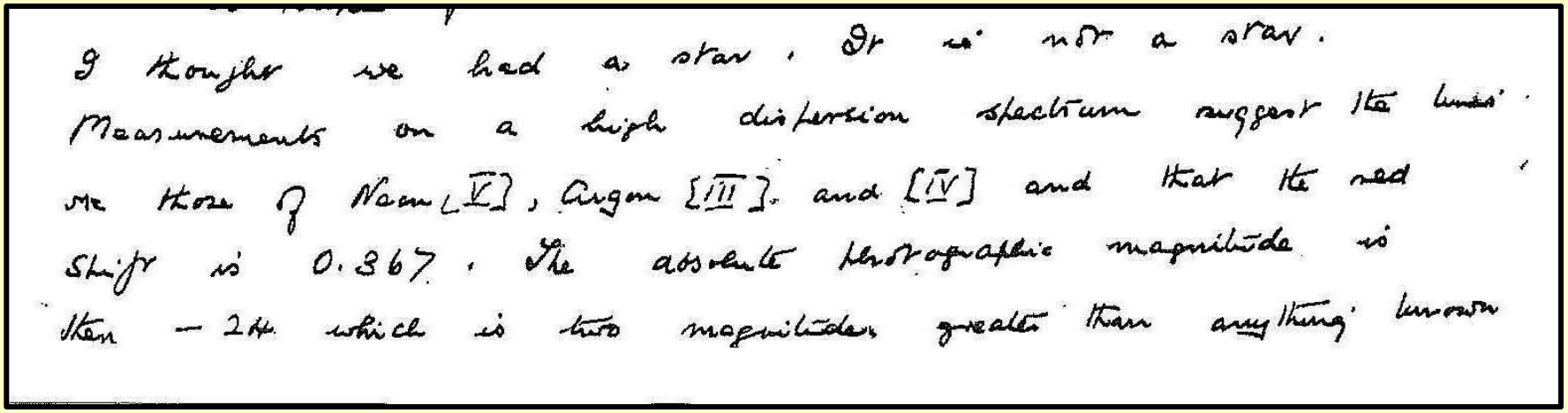
1989 John Bolton, *Radiophysics in Exile*
Publ. Astron. Soc. Australia, 8, 381 (1990)

"Bolton's account is a fabrication. I resent having my contributions to astronomy 40 years ago erased or credited to others." *1994, Jesse Greenstein*



3C 48: Galactic or extragalactic?

Nov 16, 1960: John Bolton writes to Joe Pawsey

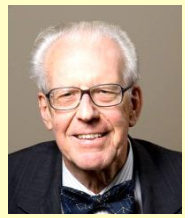


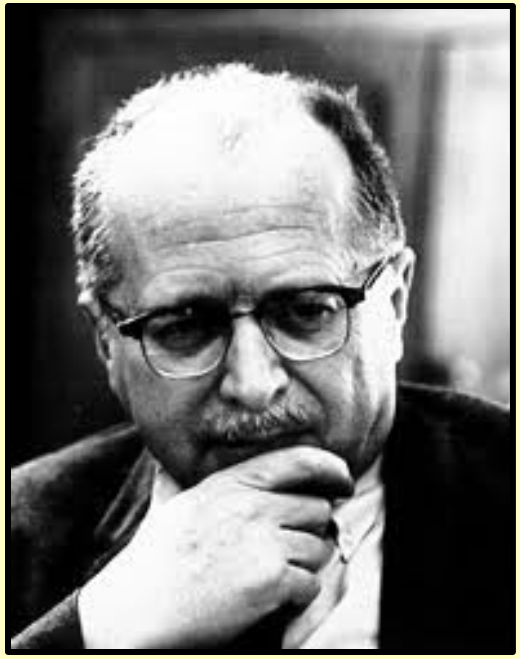
I thought we had a star. Or is not a star.
Measurements on a high dispersion spectrum suggest the lines
are those of Neon [V], Argon [III] and [IV] and that the red
shift is 0.367. The absolute photographic magnitude is
then −24 which is two magnitudes greater than anything known

*"It is not a star. Measurements on a high dispersion spectrum suggest the lines are those of Neon [V], Argon [III], and [IV] and that **the redshift is 0.367**. The absolute photographic magnitude is -24 which is **two magnitudes** greater than anything known.*

But, on Dec 19, 1960, influenced by Greenstein and Bowen, Bolton writes *"It's most likely a star"*

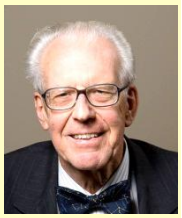
3C 48: reflections





"I had a reputation for being a radical and was afraid to go out on a limb with such an extreme idea." *JLG Jan 6, 1995*

Quasi-stellar Galaxies



THE ASTROPHYSICAL JOURNAL

VOLUME 141 MAY 15, 1965 NUMBER 4

THE EXISTENCE OF A MAJOR NEW CONSTITUENT OF THE UNIVERSE: THE QUASI-STELLAR GALAXIES

ALLAN SANDAGE

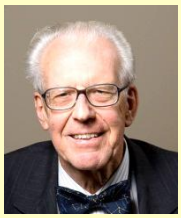
Mount Wilson and Palomar Observatories
Carnegie Institution of Washington, California Institute of Technology

Received May 15, 1965

ABSTRACT

Photometric, number count, and spectrographic evidence is presented to show that most of the blue, starlike objects fainter than $m_{pg} = 16^m$ found in color surveys of high-latitude fields are extragalactic and represent an entirely new class of objects Members of the class called here quasi-stellar galaxies (QSG) resemble the quasi-stellar radio sources (QSS) in many optical properties, but they are radio-quiet. The QSG brighter than $m_{pg} = 19^m$ are 10^3 times more numerous per square degree than the QSS that are brighter than 9 flux units. The surface density of QSG is about 4 objects per square degree to $m_{pg} = 19^m$.

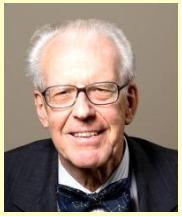
Rebutal



Sandage's statistics challenged by Tom Kinman (Lick) and Roger Lynds (KPNO). BSOs are BSOs.

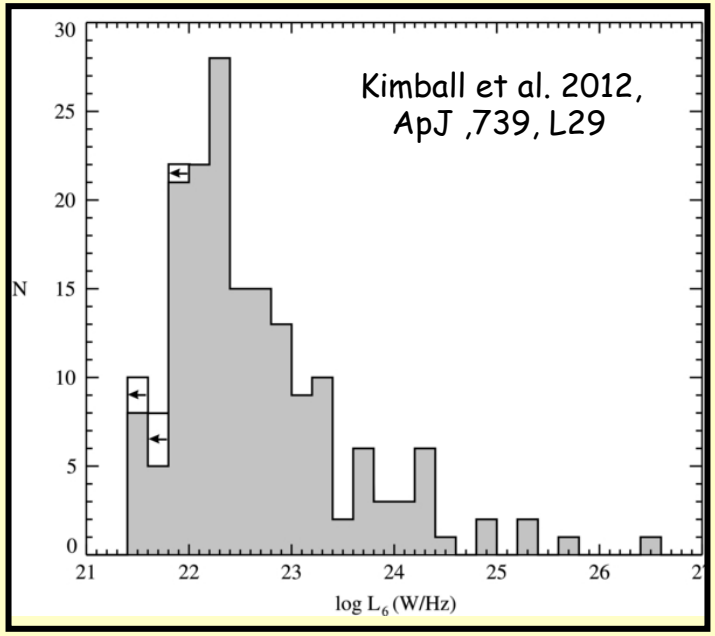
"All of the five quasi-stellar galaxies described individually by Sandage (1965) evidently belong to the subclass of compact galaxies … previously discovered … by the present writer." Fritz *Zwicky 1963*

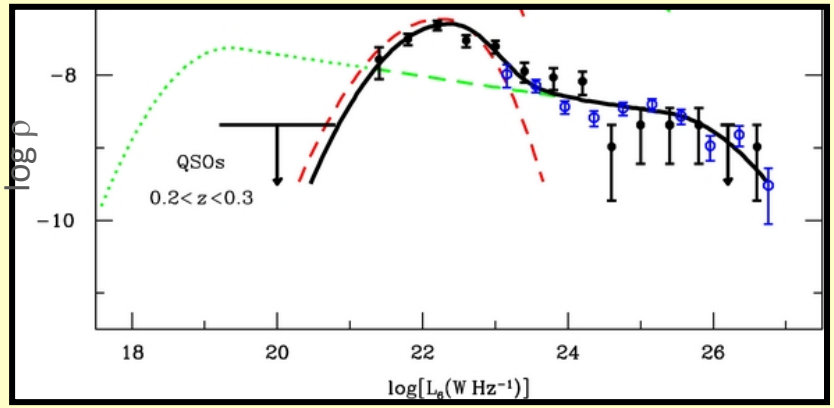
VLA Observations of SDSS QSOs



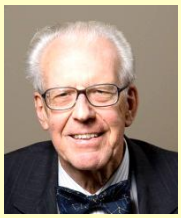
- 179 SDSS QSOs
- $5<\nu<7$ *GHz*
- $14<i<19$
- $0.2<z<0.3$; Mi < - 23
- $\tau \sim 30$ *min*
- $\sigma \sim 6$ μJy

Radio emission from RQ QSOs due to SF in host galaxy



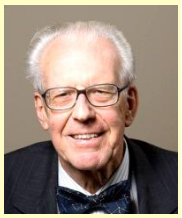


Summary

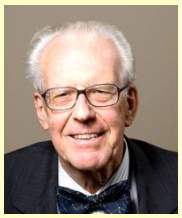


- Schmidt observed 3C273 because it was occulted. But the accurate position was not available until after Schmidt recognized the peculiar nature of the "star"
- Occultation observations unrelated to the quest for high redshifts.
- Large 3C 273 redshift determination possible because it was small
- 3C48 (3C 286, 3C 196) played no role in the recognition of quasars
- 3C 273 and 3C 48 spectra led to z ~2, but quasars have had little impact to classical cosmology (H_o, q_o) – no standard candle
- Quasars and AGN now a fundamental part of astrophysics - SMBHs
- Sociological impact to astronomy and astronomers over past 50 years
  - Conferences
  - Caltech and Carnegie
  - CSIRO Radiophysics and the University of Sydney
  - Non cosmological redshifts: very contentious: e.g., Arp, Burbidge, Hoyle

Questions and Issues

- What took so long?
  - Strong radio source; bright optically (13 mag)
  - Stellar counterparts already accepted since 1960
  - OVRO positions determined in 1961 to $\pm$ 6 arcsec
  - Why was the wrong galaxy misidentified in 1962?
  - Position error? Typo? Communication?
- Why was 3C 48 redshift not accepted in 1961?
  - Too luminous? Too small. Too variable.
  - Too conservative
  - Why was a 3 to 4 Angstrom dispersion a problem?
- Why did it take Maarten 6 weeks to recognize the H Balmer series?

Acknowledgements

Tom Matthews, Jesse Greenstein, Allan Sandage
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Cyril Hazard, Ron Ekers, Miller Goss, Jasper Wall