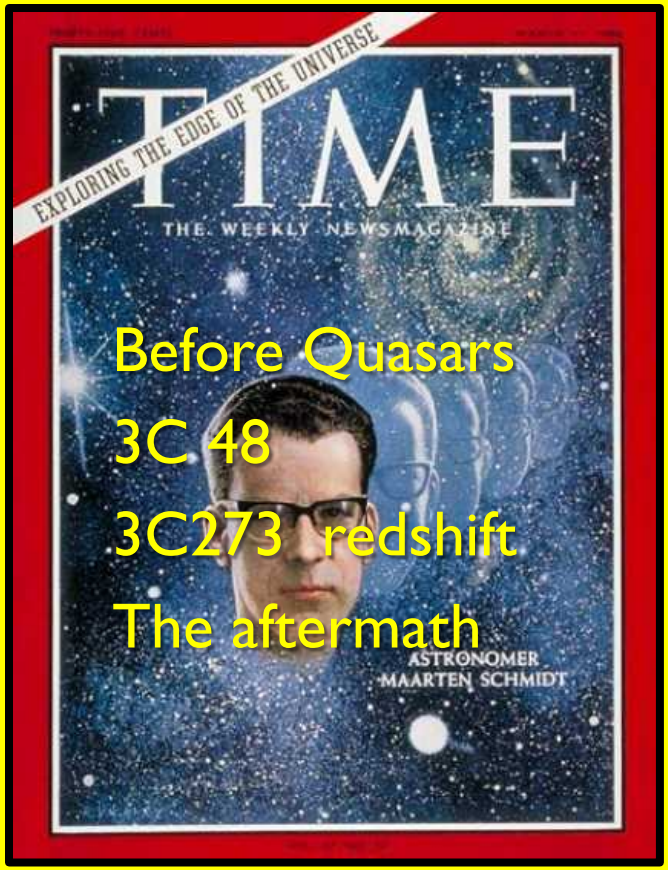
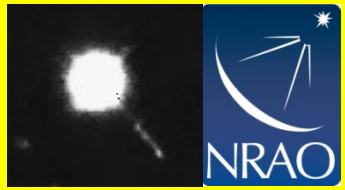
50 Years of Quasars

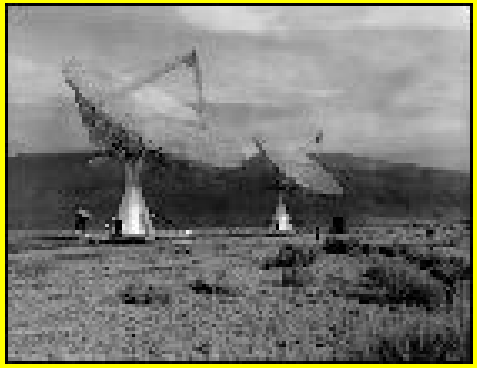
Ken Kellermann
NRAO



3C 48, the first radio star



- Accurate position measured at OVRO
- 1960 Tom Matthews and John Bolton identify 3C 48 with a stellar object
  - Greenstein, Munch, Sandage obtain 200" spectra
  - Lots of unidentified emission and absorption lines
  - Alan Sandage presents late AAS paper (Dec 29, 1960),
  - Records of 107th AAS meeting lost
    - "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*



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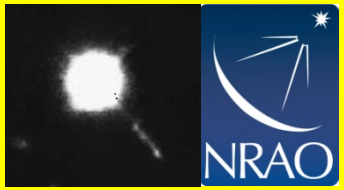
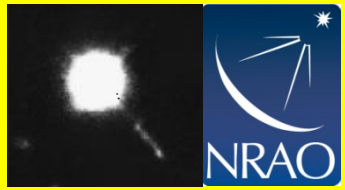


- First radio star
  - Unresolved radio and optically (< 1 arcsec)
  - Peculiar spectrum (Strange emission lines, UV/Blue continuum excess)
  - Variable
- *The Radio Star 3C 48," Greenstein, ApJ (accepted)*
  - Stellar remains of SN
  - Spectrum: highly ionized rare earth elements
  - No mention of redshift in abstract
  - *"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"*
- *Matthews and Sandage*
  - *"No plausable combination of red-shfited emission lines"*

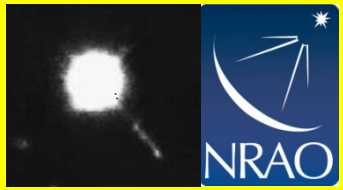
3C 48 Revisited



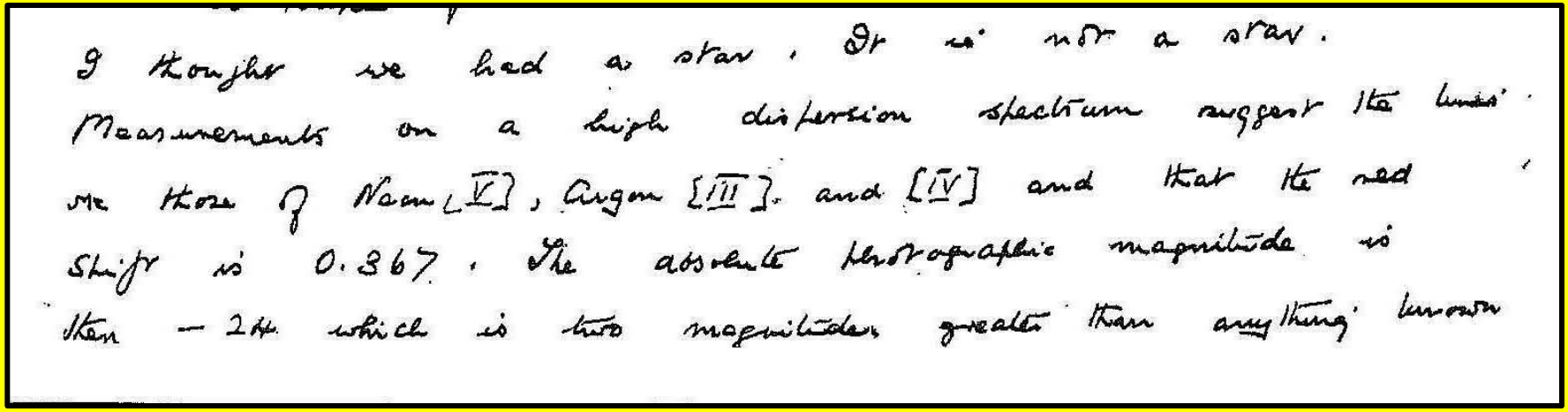
The best fit I could find for the one broad line and one narrow line which Jesse [Greenstein] had measured were with Mg II λ2798 and [Ne V] λ3426, and a ***redshift of 0.37.***

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

3C 48 Is it or isn't it a star?



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

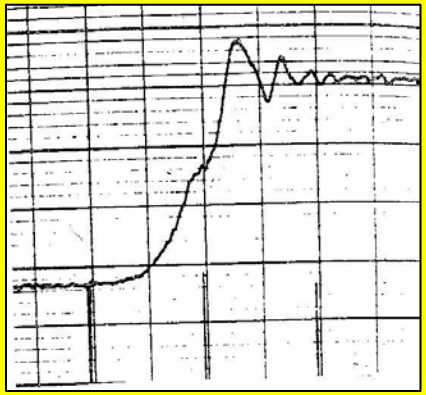
"It is not a star. Measurements on a high dispersion spectrum suggest the lines are those of Neon [V], Argon [III], and [IV] and that ***the redshift is 0.367****. The absolute photographic magnitude is -24 which is* ***two orders of magnitude*** *greater than anything known.*

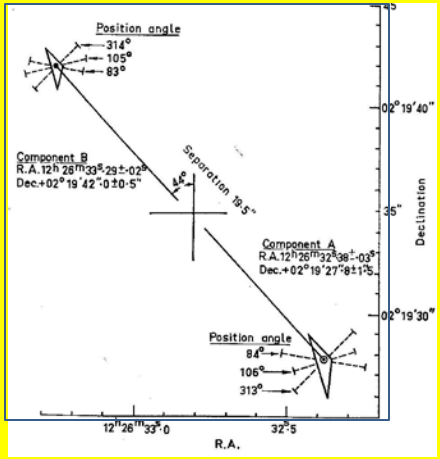
But, on Dec 19, 1960, influenced by Greenstein and Bowen, Bolton writes *"It's most likely a star"*

3C 273 redshift

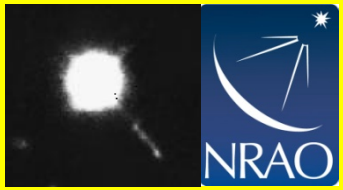
March, August, Oct1962

Parkes Occultation led by Cyril Hazard

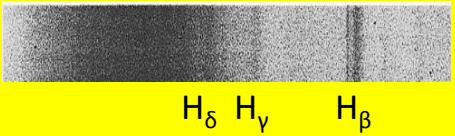




3C 273 as a distant galaxy

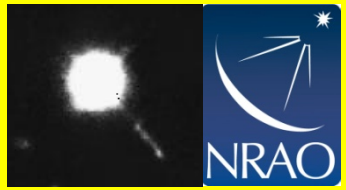


- August, 1962: John Bolton sends position to Pasadena
- Radio position coincides with 13 mag star and jet
- Dec 27-30 Schmidt takes 200" spectra
- Feb 5,1963, Schmidt identifies HI Balmer lines

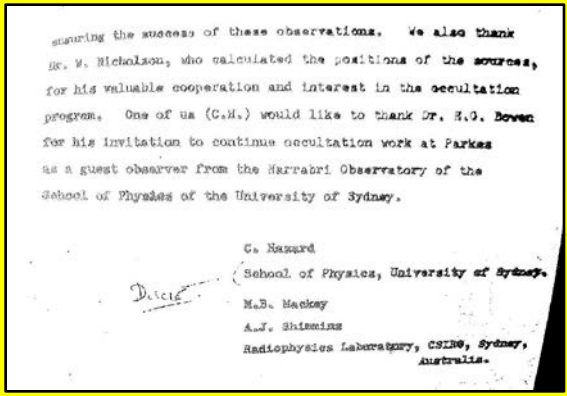


  - $H_\beta, H_\gamma, H_\delta, H_\varepsilon$ ⟹ z = 0.158 M = -27 MgII (λ2798)
  - Oke recognizes H_α in 3C 273 NIR
  - Greenstein and Schmidt recognize Mg II in 3C 48 (z=0.37)

Nature, Vol. 197

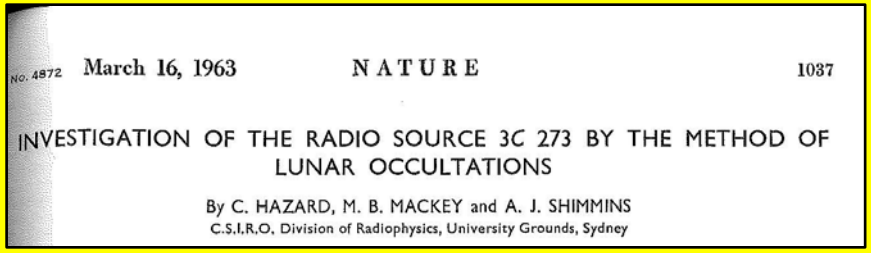


- Hazard, Mackey, Shimmins - 3C 273 occultation
  - CSIRO / Univ. of Sydney controversy
- Schmidt - ID with "star-like object" z =0.16
  - *"The nuclear region would be about 100 times brighter optically than the luminous galaxies which have been identified so far."*
- Oke: Spectrophotometry,
  - Continuum spectrum
  - H_α (λ7600)
- Greenstein & Mathews: 3C 48, Mg II, z = 0.37
  - Greenstein withdraws his 3C 48 paper
  - Matthews & Sandage
    - note in proof - "3C48 *as a galaxy*"



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. H.C. Bowen
for his invitation to continue occultation work at Parkes
as a guest observer from the Harrabri 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.



No. 4872 March 16, 1963 NATURE 1037

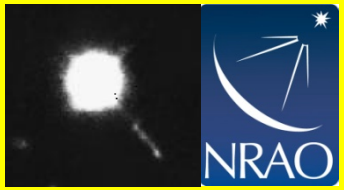
INVESTIGATION OF THE RADIO SOURCE 3C 273 BY THE METHOD OF LUNAR OCCULTATIONS

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

Competition to find highest z's

- 1963: **3C 273 (z=0.16),** Schmidt
- 1963: **3C 48 (z=0.37),** *Greenstein and Matthews*
- 1964: **3C 47 (z = 0.42),** *Schmidt and Matthews*
- 1964: **3C 147 (z = 0.54),** *Schmidt and Matthews*
- 1965: **CTA 102 (1.04)** *Schmidt*
- 1965: **3C 9 (z = 2),** *Schmidt*
- 1973: **OH471 (z= 3.40),** *Carswell and Strittmatter*
- 1982: **2200-330 (z= 3.78),** *Peterson et al.*
- 2007: **J2329-0201 (z=6.12),** *Willott et al.*
- 2011: **ULAS J1120+0641 (z = 7.1)** *Bolton et al.*
- Cosmology? SMBH's
  - Relativistic astrophysics and Texas Symposia
  - Role in galaxy formation

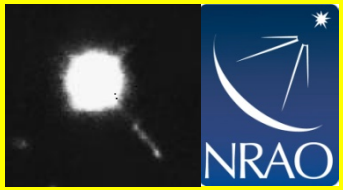
Naming Quasars



So far, the clumsily long name 'quasi-stellar radio sources' is used to describe these objects ..... For convenience, the abbreviated form 'quasar' will be used throughout this paper.

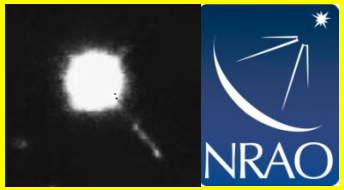
— *Hong-Yee Chiu, Physics Today, May, 1964*

What is a Quasar?



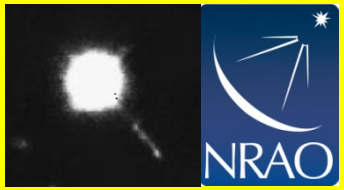
We use the term "quasar" for the class of objects of starlike appearance (or those containing a dominant starlike component) that exhibit redshifts much larger than those of ordinary stars in the Galaxy. QSOs are quasars selected on the basis of purely optical criteria, while QSSs are quasars selected on both the optical and radio criteria - *Maarten Schmidt, 1970*.

ApJ conceeds



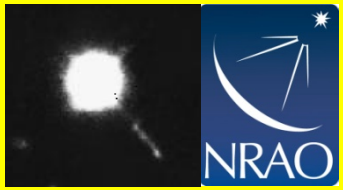
The Astrophysical journal has till now not recognized the term "quasar"; and it regrets that it must now concede: Dr. Schmidt feels that, with his precise definition, the term can no longer be ignored. – *S. Chandrasekhar*

Summary



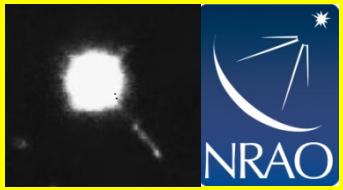
- For more than three decades nature of radio sources controversial
- Non cosmological redshifts,: Arp, Burbidge, Hoyle, Terrell
- Strong competition to find highest redshifts for cosmology
- Quasars have had little impact to classical cosmology (H_o, q_o)
- Quasars and AGN now a fundamental part of astrophysics: SMBHs
- Sociological Impact
  - Caltech and Carnegie
  - CSIRO Radiophysics and the University of Sydney
  - Non cosmological reshifts

Acknowledgements



Tom Matthews, Jesse Greenstein, Allan Sandage
John Bolton, Marshall Cohen, Maarten Schmidt,
Ron Ekers, Miller Goss, Jasper Wall

Issues and Questions

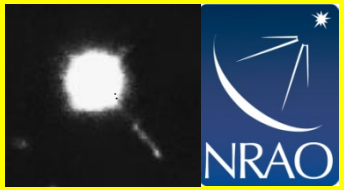


- Why was 3C 273 not identified earlier?
  - Known double? Too big? Position error?
  - Position was known in 1961 to ± 6 arcsec
  - Why did Schmidt observe the wrong galaxy
- Who identified 3C 273?
  - Bolton, Matthews?
- Why did it take 6 weeks to recognize the 3C 273 redshift?
- Why was 3C 48 redshift not accepted 2 years earlier?

Discovery of Quasars (who gets credited?)

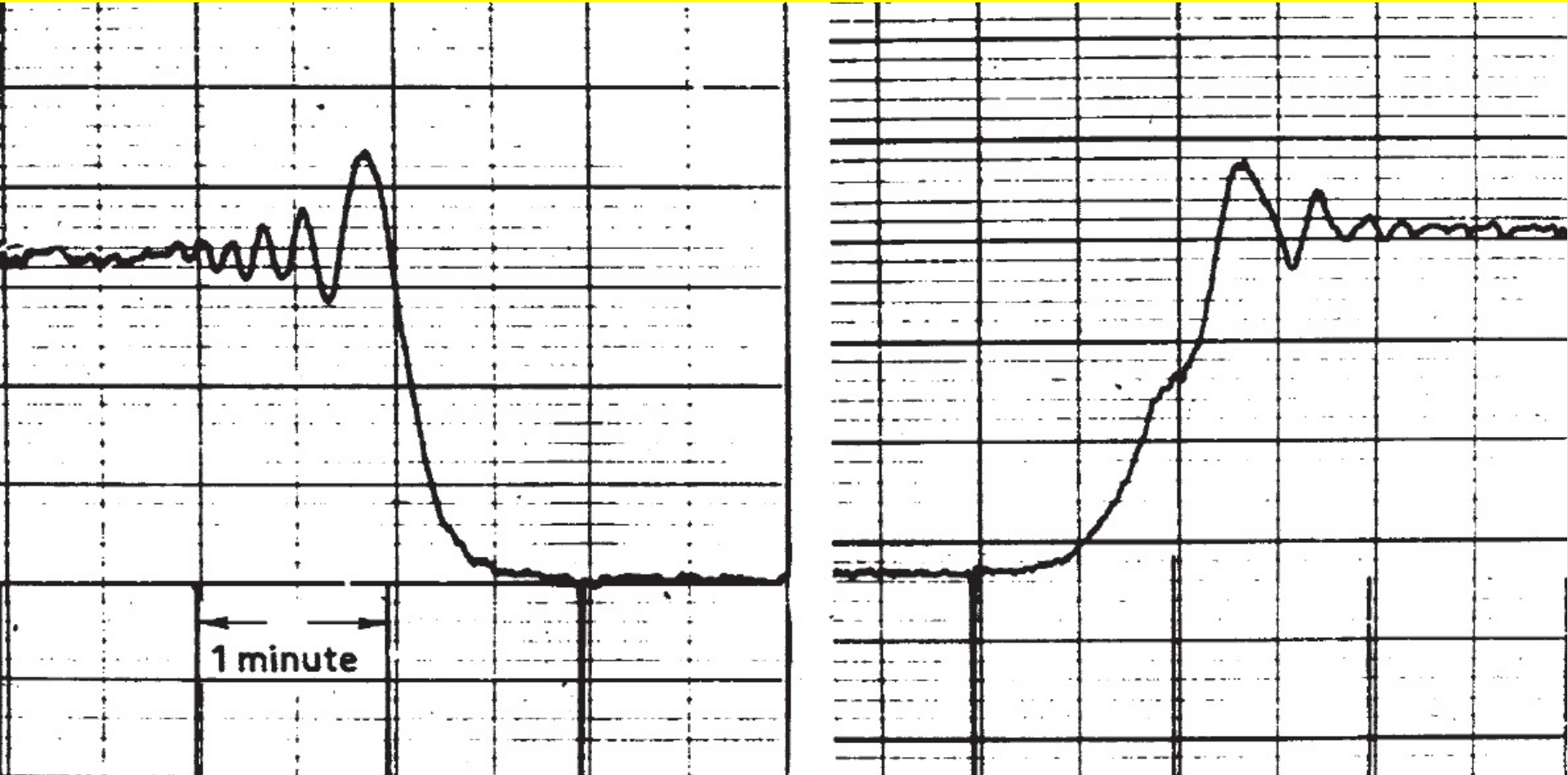
Date	
1960	Tom Mathews identifies 3C48 with a stellar object Spectrum has a possible z=0.36 but not accepted (variability, line fit) Misinterpreted as a peculiar galactic star
1962	Cyril Hazard observes multiple lunar occultations of 3C273 at **Parkes** Core jet structure and position determined
Jan 1963	13mag star identified with 3C273 using position and structure Bolton, Hazard and Mathews all involved in the now obvious identification
Mar 1963	Schmidt observes spectrum and identifies lines with z=0.158
Mar 1963	Greenstein and Mathews now reinterpreted 3C48 as a z=0.36 Quasar Sandage has already measured variability
1963	Variability implies small volume and luminosity implies gravitational energy Requires a black hole potential
Dec 1963	First Texas Symposium on Relativistic Astrophysics, Named Quasars but name not in general use for many years

CSIRO's
Parkes Radio Telescope – 1961

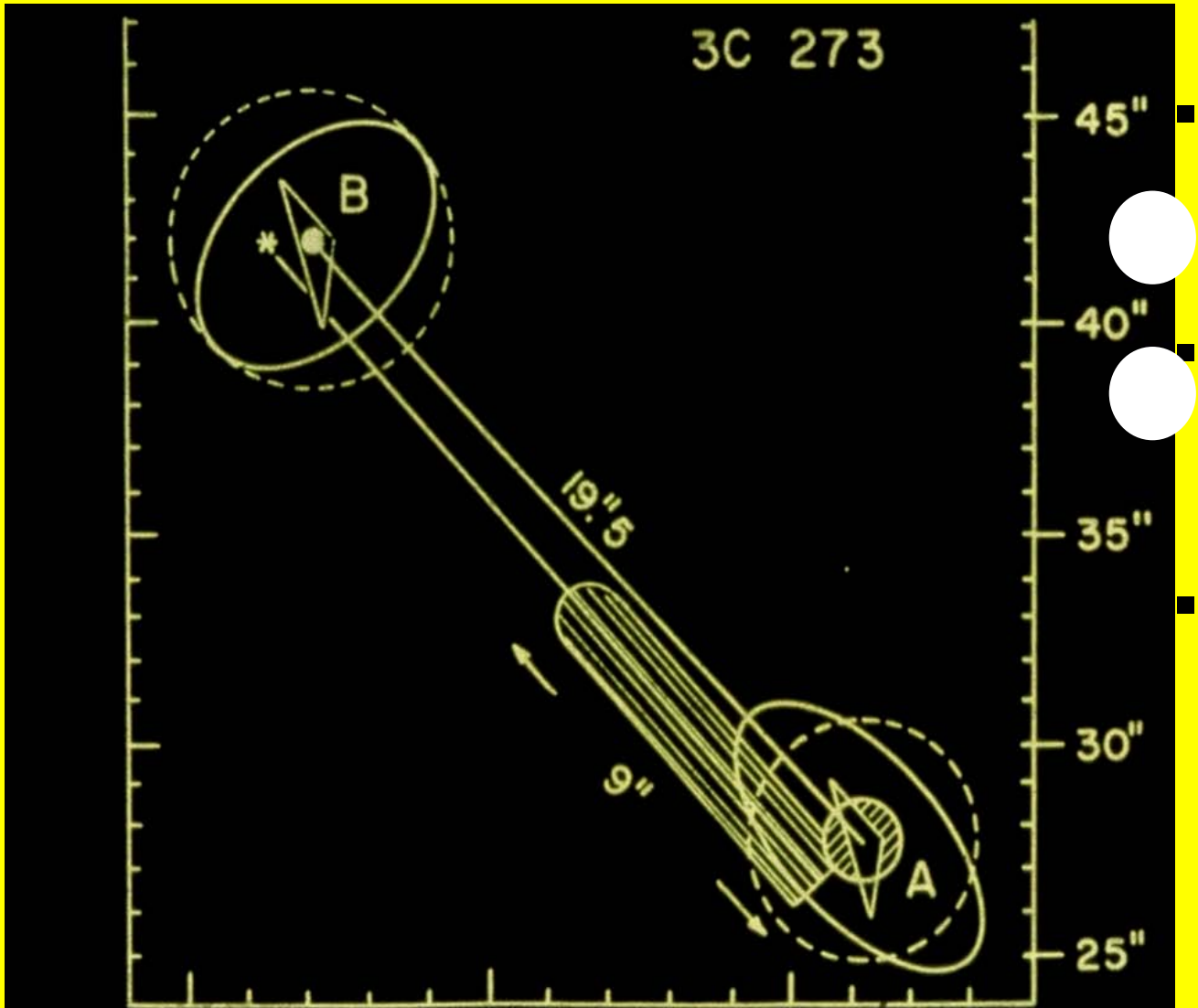


3C273 Occultation
Parkes, Aug 5 1962, 410MHz

- *Hazard, Nature 197, p1037, 1963*



3C273
Parkes Occultation

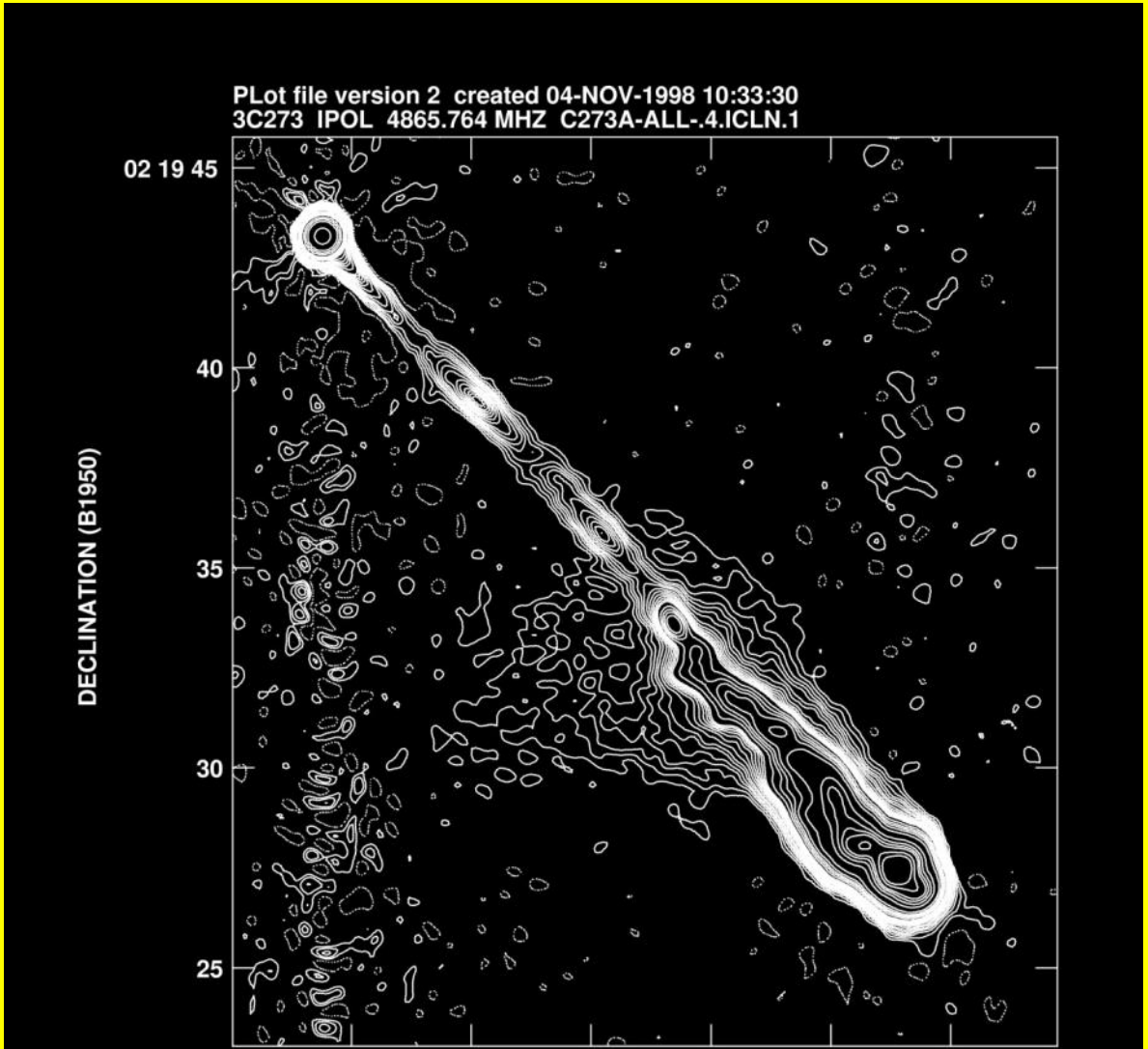


- Striking difference in radio spectra
- Component A

  $S = \upsilon^{-0.9}$
- Component B

  $S = \upsilon^{0.0}$

3C273
VLA 5GHz



3C273
Optical HST

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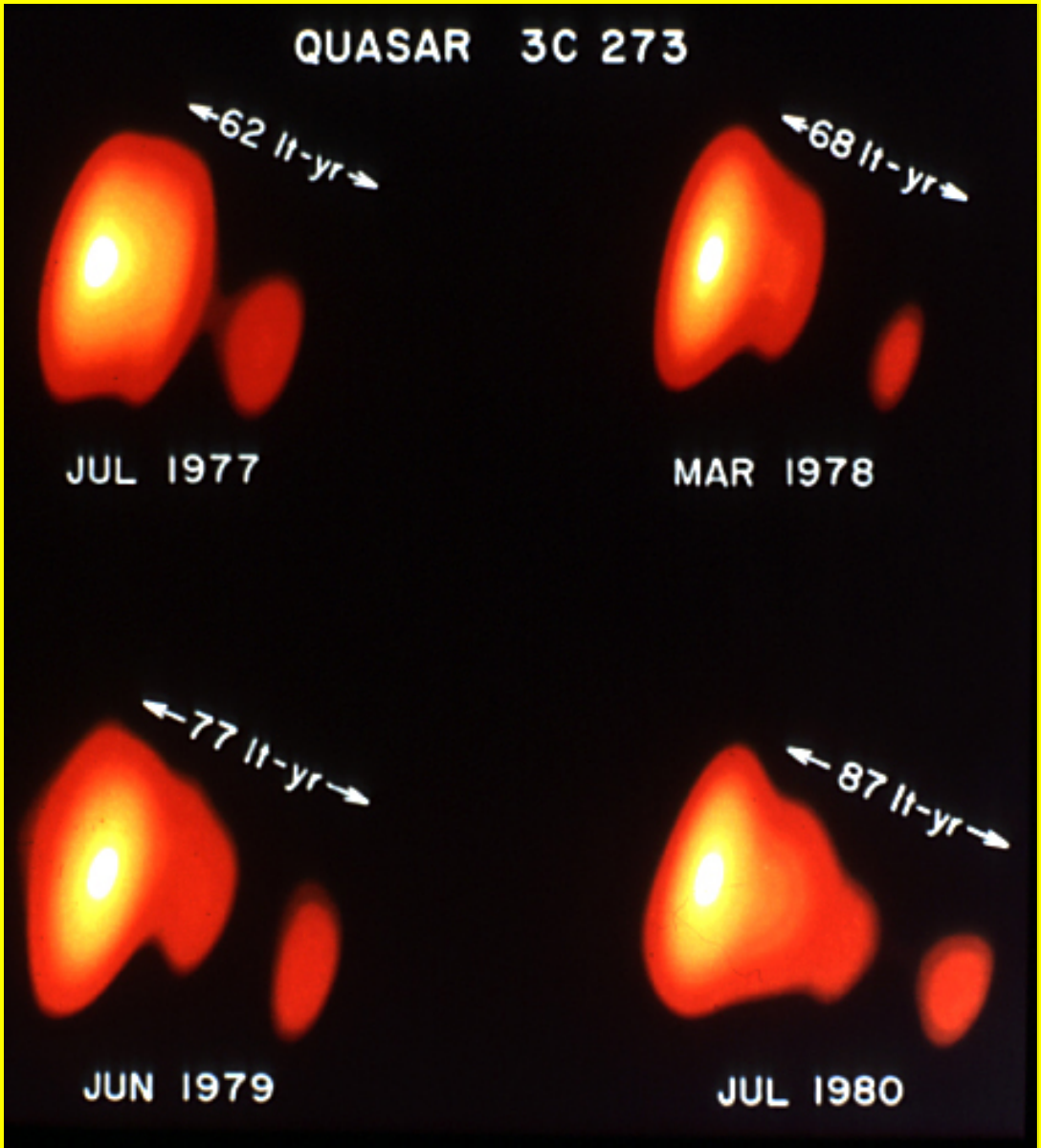
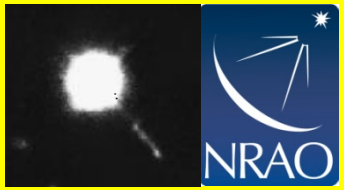
3C273 expansion



Black Holes

Black Holes



- Chandrasekhar (1931) – *paper rejected by ApJ*
  - "A star of large mass cannot pass into the white dwarf stage, one is left speculating on other possibilities"
- Eddington – *the authority*
  - "a star would have to go on radiating and radiating, and contracting and contracting….I think there should be a law of nature to stop matter behaving in this absurd way"
- Oppenheimer (1939) – *exercise in abstraction*
  - "the star closes itself off from any communication…only its gravitational field persists"

Nobel Prize 1983
Subrahmanyan Chandrasekhar

- for his theoretical studies of the physical processes of importance to the structure and evolution of the stars
  - White dwarfs, neutron stars, relativistic effects…
  - For the heaviest stars having a mass in excess of 2-3 Solar masses, the force of gravity becomes so strong that the matter simply disappears in the form of a *so-called black hole*.