

HUBBLE LAW

$$V = H_0 D$$

AGE $t = \frac{D}{V} = \frac{1}{H_0}$

$$\frac{\text{Mpc}}{\text{km/s}}$$

$$H_0 = 70 \text{ km/s/Mpc}$$

$$1 \text{ Mpc} = 3.1 \times 10^{19} \text{ kms}$$

$$1 \text{ yr} = 3.1 \times 10^7 \text{ secs}$$

$$t = \frac{1}{H_0} = \frac{3.1 \times 10^{19}}{70 \times 3.1 \times 10^7} =$$
$$= \underline{14 \text{ BILLION YEARS}}$$

HUBBLE: $H_0 \sim 500 \text{ km/s/Mpc}$

$\rightarrow t \sim 2 \text{ BILLION YEARS}$

$\rightarrow$ STEADY STATE UNIVERSE

GALAXIES WITH ACTIVE NUCLEI

- SEYFERT GALAXIES
- RADIO GALAXIES
- QUASARS

PROBABLY RELATED

- CENTRAL MASSIVE
BLACK HOLE ?
- DIFFERENT EVOLUTIONARY
STAGES ?

SEYFERT GALAXIES

DISCOVERED OPTICALLY :

SPIRAL GALAXIES WITH BRIGHT
STAR-LIKE NUCLEUS

TYPE 1 : BROAD EMISSION LINES

TYPE 2 : SHARP EMISSION LINES

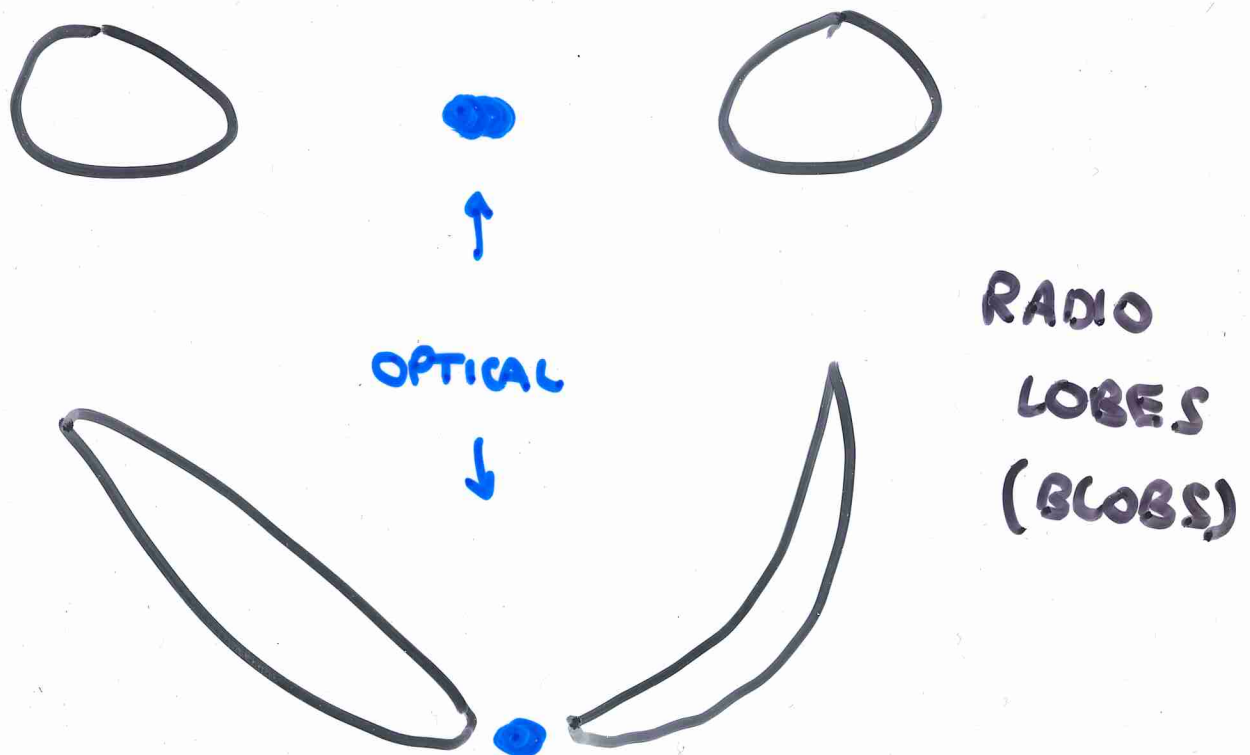
APART FROM NUCLEUS, SG's
ARE NORMAL

RADIO GALAXIES

DISCOVERED BY RADIO ASTRONOMERS

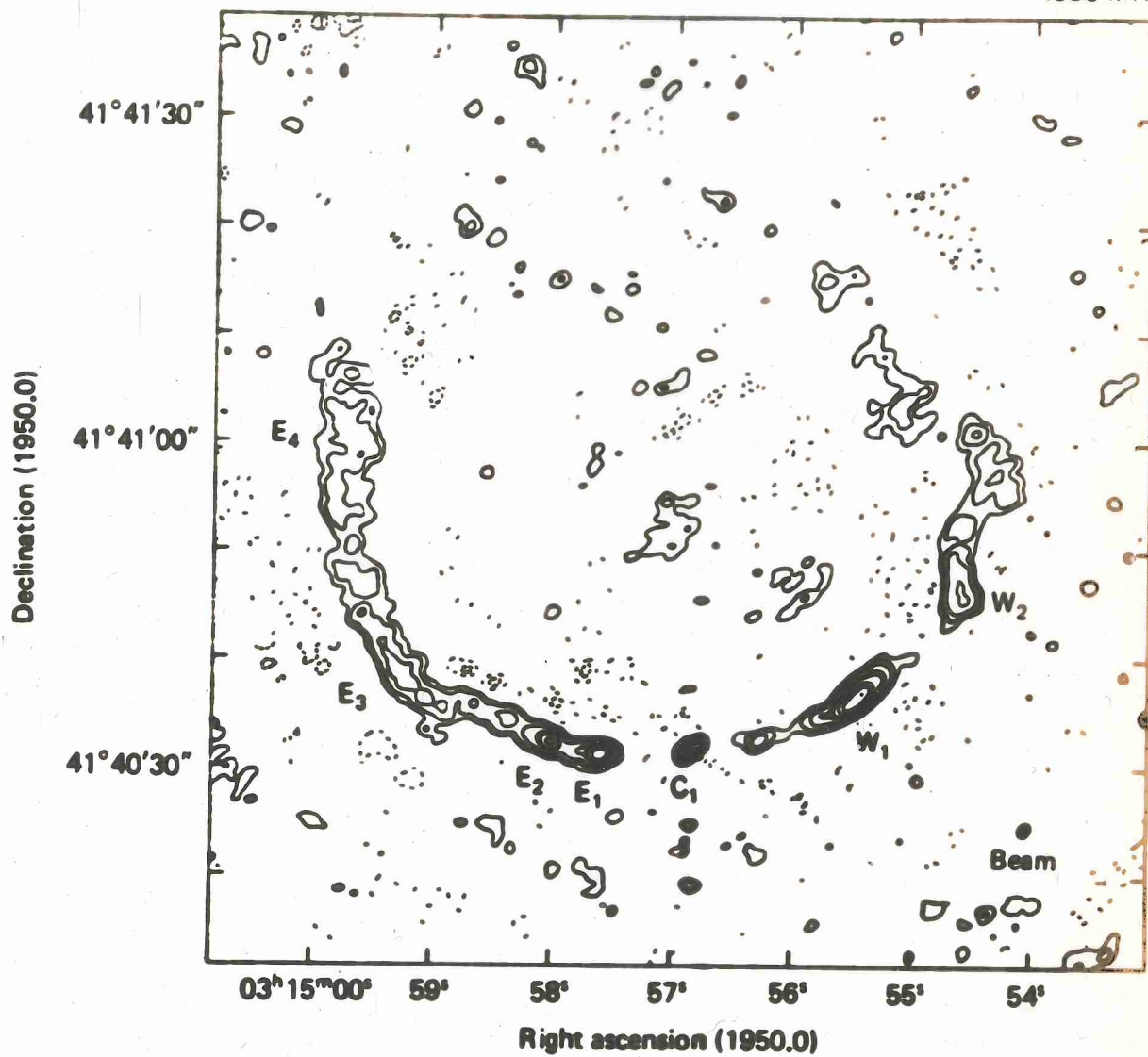
[CYGNUS A, PERSEUS A, ...]

OPTICAL IMAGES, OFTEN FAINT +
FUZZY, AND RADIO IMAGES DIFFER
GREATLY



0314 + 416

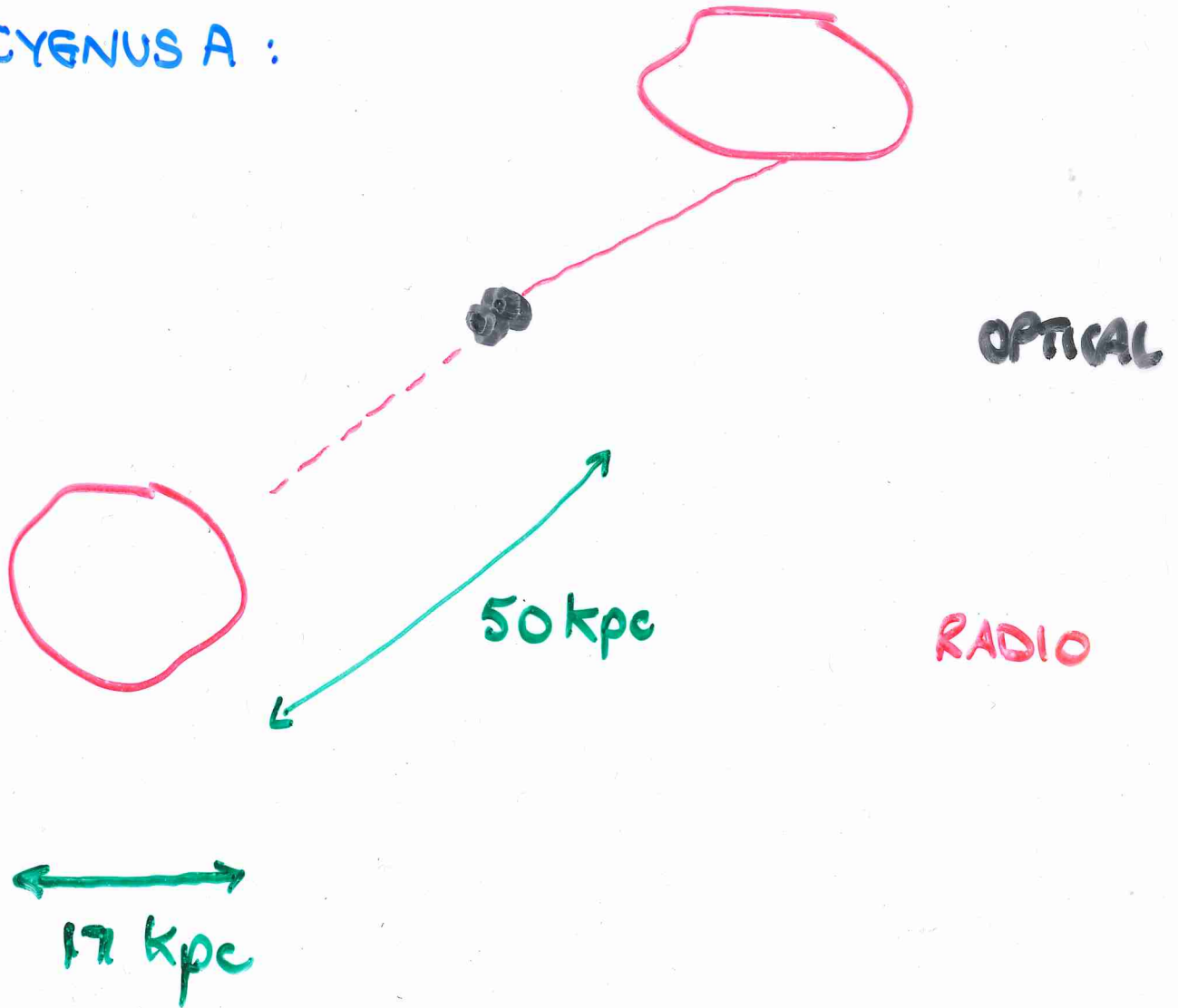
4886 MHz



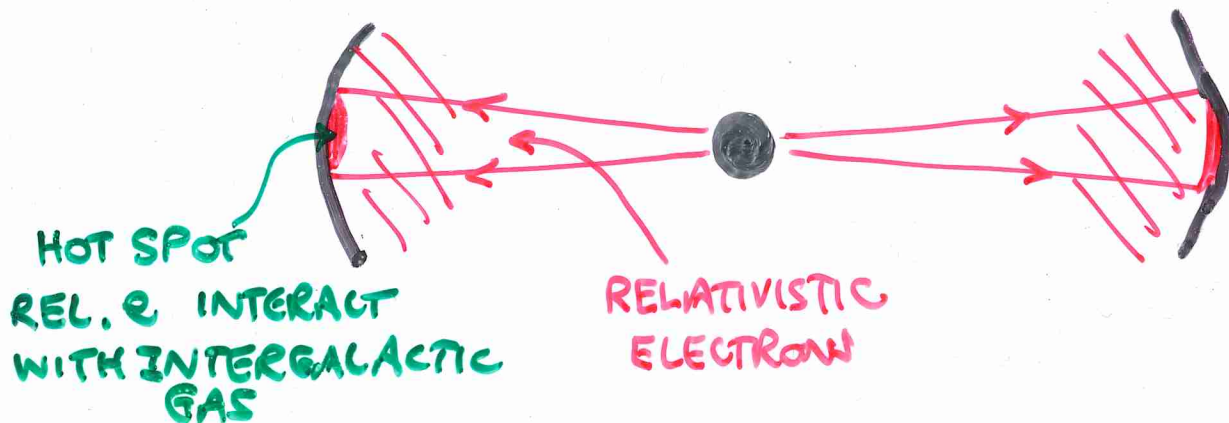
A RADIO GALAXY

Seeds Fig 18:1, 2, 3 4, 5, 6, 7

CYGNUS A :



DOUBLE - EXHAUST MODEL (FIG 14-3)



QUASARS

QUASI-STELLAR RADIO SOURCE, ALSO
RADIO-QUIET SOURCES

DISCOVERED WHEN INTENSE RADIO
SOURCES IDENTIFIED WITH STAR-LIKE
OBJECTS

- LUNAR OCCULTATION OF 3C273
→ 1ST OPTICAL IDENTIFICATION
- SPECTRUM OF 3C273 $\Rightarrow$ BALMER
LINES RED-SHIFTED BY 15% OF
SPEED OF LIGHT, THEN 3C48
BY 48%, NOW 95+% FOR
SOME QSOs.

1000's NOW IDENTIFIED ACROSS A
RANGE OF REDSHIFTS

RECALL!

RESOLVING POWER

$$"RP" \propto \frac{\lambda}{D}$$

RADIO TELESCOPE

$\lambda \sim$ LONG

$D \sim$ MODEST for SINGLE DISH

$\therefore RP \sim$ poor

BUT COMBINE DS WITH
SEPARATION OF S

$$\rightarrow RP \propto \frac{\lambda}{S}$$

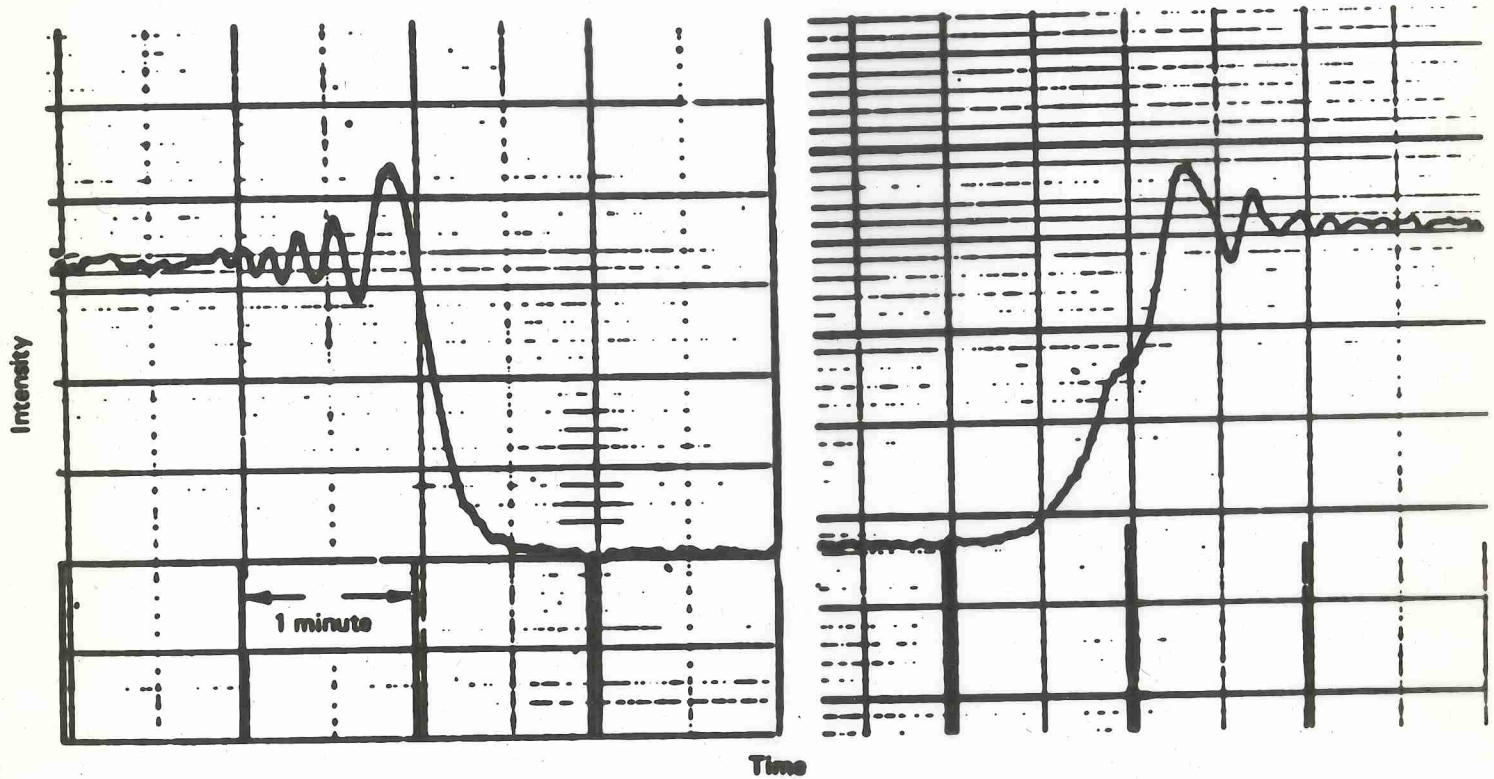
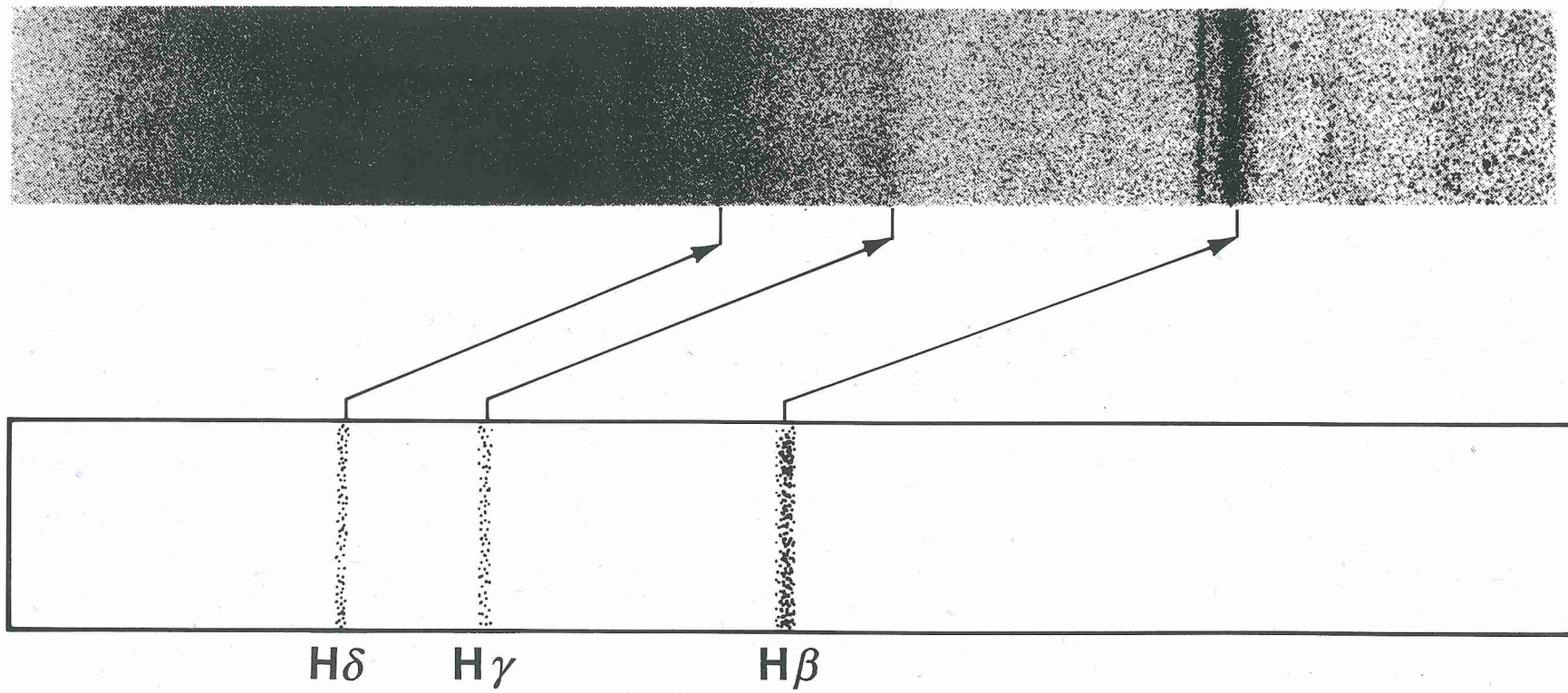


Figure 29.2 Lunar occultations of 3C273 observed in 1962. Analyses of these diffraction patterns allowed Hazard and his colleagues to make precise determinations of the quasar's structure and coordinates (C. Hazard, University of Pittsburgh, and *Nature*).



Red shift in spectrum of 3C273

Seeds: Horizons, 1995 ed., Fig. 14-10b; Foundations of Astronomy, 1994 ed., Fig. 17-16b

ARE REDSHIFTS OF QSO's COSMOLOGICAL ?

- QSO IMAGES IN GOOD SEEING OR WITH HST REVEAL FAINT FUZZ ($\equiv$ GALAXY)

SPECTRUM SHOWS THAT
EXPECTED OF A GALAXY AT SAME
REDSHIFT

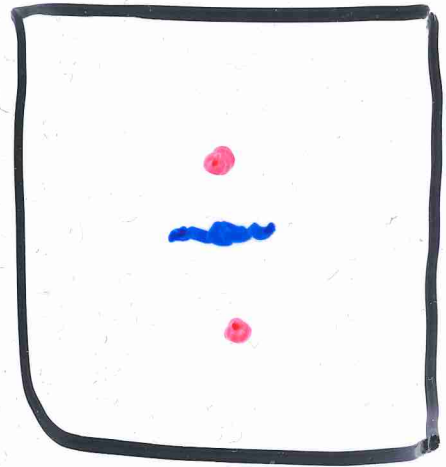
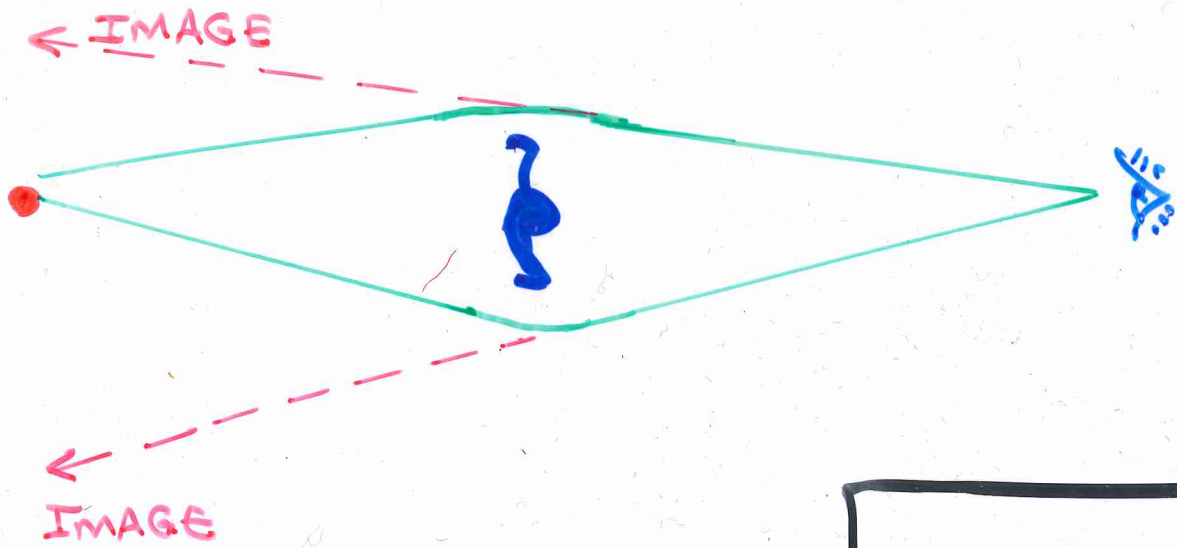
- SOME QSOs LOCATED IN
CLUSTER OF GALAXIES

SPECTRA OF GALAXIES $\rightarrow$

REDSHIFT $\approx$ REDSHIFT OF QSO

- SN DETECTED IN HOST
GALAXY (UNIQUE CASE SO FAR)

• GRAVITATIONAL LENSES

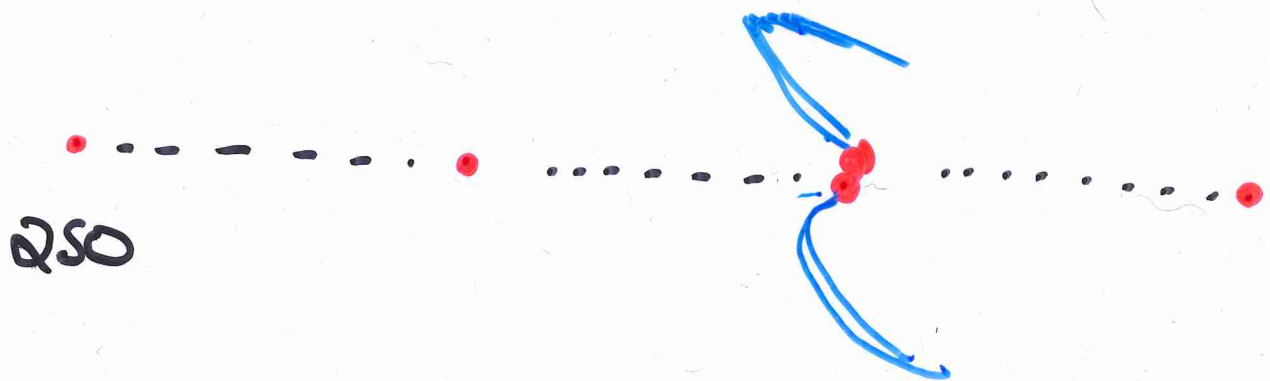


REDSHIFT OF GALAXY
≪ REDSHIFT OF
QSO

LENSING SHOWS QSO BEHIND
GALAXY

COUNTER-ARGUMENTS ?

- A FEW ALIGNMENTS OF GALAXY + QSOs



QSOs ALIGNED WITH GALAXY

GALAXY NEARBY

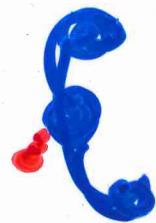
QSOs 'EJECTED' from GALAXY ?

'CHANCE' SAY CRITICS

- BRIDGES BETWEEN QSO AND GALAXY ?

'POOR QUALITY PICTURE'

SAY CRITICS



SUPERLUMINAL EXPANSION

(Seeds
p373)

- RADIO OBSERVATIONS show 'blobs' (electron clouds) apparently moving out from QSO at

$$v > c$$

Example: 3C273 : 0".008 per year

$$z = 0.16 \rightarrow d = 960 \text{ Mpc}$$

$$v_{\text{blob}} \approx 3.8 \text{ pc/yr}$$

$$\approx 12 \text{ light years/year}$$

"IMPOSSIBLE"

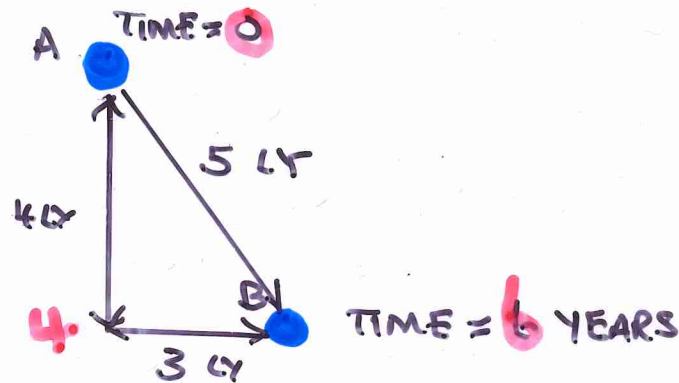
QUASAR IS A LOCAL

OBJECT : $d \ll 960 \text{ Mpc}$?

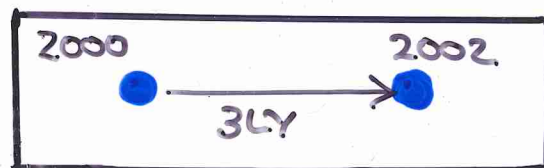
ALTERNATIVE MODEL : RELATIVISTIC JET FROM QUASAR AT ITS COSMOLOGICAL DISTANCE



$$\text{SPEED OF BLOB} = \frac{5}{6}c$$



- FIRST SNAPSHOT (A) IN 2000
- 2ND SNAPSHOT (B) IN 2002, 6 yrs later but 4 ly closer
- APPARENT VELOCITY IS 3 LY IN 2 YEARS



OR

$$v = \frac{3}{2}c = 1.5c$$

WHAT IS THE ENERGY SOURCE / CENTRAL ENGINE?

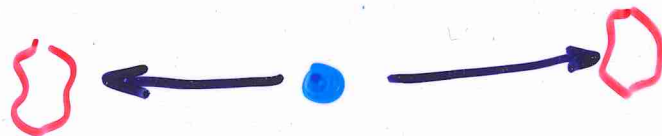
PROPERTIES

1. ENERGY OUTPUT - COLOSSAL!

$$L \sim 10^{12} L_{\odot} \text{ (typical)}$$

for ? years

2. OUTPUT LARGELY AS HIGH SPEED
ELECTRONS IN BEAMS



3. SOURCE IS SMALL

RAPID VARIATIONS $\rightarrow$ SMALL
SIZE (one-few light days)

4. SOURCE IS IN NUCLEUS OF A GALAXY

5. QUASARS ARE YOUNG
(COSMOLOGICALLY SPEAKING)
EVOLVE! NUMBER VARIES WITH z

THE CENTRAL ENGINE ?

- DENSE STAR CLUSTER?

$\sim 10'' \text{ } \times \text{ s/pc}^3 \sim 10^5 \text{ DENSITY}$
IN OUR NUCLEUS

→ COLLISIONS FREQUENT

→ DISRUPTION OF STARS

→ TRIGGERING OF SNe?

→ SUPERMASSIVE STARS
($10^6 M_{\odot}$?)

→ FLARES ?

→ SUPER SN ?

→ GIANT PULSAR?

- RADICAL IDEAS

— MATTER + ANTIMATTER

— WHITE HOLES

AND ALONG COMES

HST

CENTRAL ENGINE shown

to be so small only

a SUPERMASSIVE BLACK HOLE
fits observations

3. BLACK HOLE

$m \sim 10^8 m_{\odot}$ fed at
rate of $\sim 1 m_{\odot}/yr$

surrounded by an ACCRETION DISK

① HOW IS BH FED?

- MASS LOSS (WINDS) from STARS
- TIDAL DISRUPTION OF STARS
- INFALL OF PROTOGALACTIC GAS

HOW ARE ELECTRON JETS
PRODUCED?

HOW ARE BH'S RELATED TO
EVOLUTION OF GALAXIES

- PASSING PHASE? QSO's VS REDSHIFT
- OUR GALACTIC NUCLEUS

SUPERMASSIVE BLACKHOLES IN CENTER OF GALAXIES

= COMMON & CORRELATED
WITH GALAXY MASS [WHY?]

GALAXY COLLISIONS

- GALAXIES WITH TWO BHs
- GALAXIES WITHOUT BHs

UNIFIED MODEL

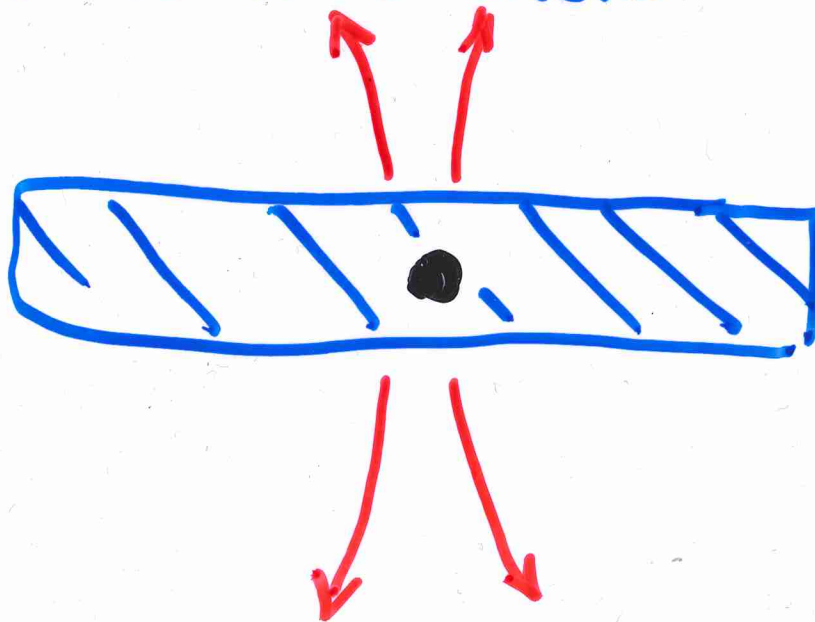
EVOLUTION WITH TIME

QSO $\rightarrow$ RADIO GALAXY

$\rightarrow$ SEYFERT $\rightarrow$ MILKY WAY

VIEWING ANGLE W.R.T.
ACCRETION DISK


TYPE 2
SEYFERT
(NARROW
LINES)




TYPE 1 SEYFERT
(BROAD LINES)