ACTIVE NUCLEI IN ELLIPTICAL GALAXIES

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ACTIVE NUCLEI IN
E GAL HAVE A VERY
WIDE RANGE IN LUMINOSITY

$\gtrsim 10^{48}$ ergs s^{-1} BLOs
$\lesssim 10^{39}$ ergs s^{-1} OQ RGs

ARGUMENTS SUPPORTING
NONTHERMAL ORIGIN
FOR SOME OF THE RADIATION

1. POWER DISTRIBUTED OVER
WIDE RANGE IN ν
RATHER THAN IN A NARROW
BAND AROUND SOME $\nu \sim \frac{kT}{h}$

2. HIGH DEGREES OF POLARIZATION ($\gtrsim 30\%$)

3. RAPID, LARGE AMPLITUDE VARIATIONS IN FLUX AND POLARIZATION

$$t_{min} \sim 10^4 \text{ s}$$

$$\Rightarrow U \sim \frac{L}{4\pi R^2 c} \approx \underline{\underline{10^7 \text{ ergs cm}^{-3}}}$$

TOO HOT FOR SCATTERING OFF DUST

e^- SCATTERING REQUIRES UNTENABLE AD HOC SITUATION

MOST PLAUSIBLE NT MECHANISM: SYNCHROTRON

ORDERING OF EMISSION REGION BY B FIELD

⇒ POLARIZATION

ANISOTROPIC B FIELD

⇒ NET RADIATION IS POLARIZED

$$\#(E) \propto E^{-\gamma} \Rightarrow F_\nu \propto \nu^{-\alpha}$$

$\#(E)$ ↓ COSMIC RAYS

$F_\nu \propto \nu^{-\alpha}$ ↓ observed for many sources

$e^{\pm}, p, \bar{p}$ ...

ALL CONTRIBUTE

<u>BUT</u>

$$\frac{dE}{dt} \propto m^{-2}$$

$$t_{LIFE} \propto m^{-4}$$

$\Rightarrow$ PREDOMINANTLY

<u>ELECTRON</u>

<u>SYNCHROTRON</u>

<u>RADIATION</u>

<u>REF.</u> Ginzberg and Syrovatskii 1965 Ann. Rev.

Pacholczyk

OTHER PLAUSIBLE NT MECH

1. COMPTON SCATTERING (e.g. Blumenthal and Gould 1970)

2. COHERENT PLASMA OSCILLATIONS (Colgate and Petschek 1978)

ALL GN ARE
COMPOSITE SYSTEMS
AT VIS-IR λs.

1. NT SOURCE
2. STARLIGHT
3. EMISSION LINES AND GAS CONTINUUM
4. RE-RADIATION BY HEATED DUST

\+ ?

RELATIVE CONTRIBUTIONS OF THESE COMPONENTS DETERMINE OBSERVED CHARACTERISTICS OF A SOURCE

BL LAC OBJECTS
(Miller et al.)

OVVs / HPQs

↑

NT
—
T

RADIO GALAXIES

OQRGs

J. Miller *et al.*

NEBULOSITY AROUND NEARBY BLOs LOOKS LIKE A LATE TYPE * POPULATION WITHOUT ANY TRACE OF SPIRAL STRUCTURE

- FIT WELL BY E GAL

NOT PROVEN ALL BLOs ARE IN E GALs

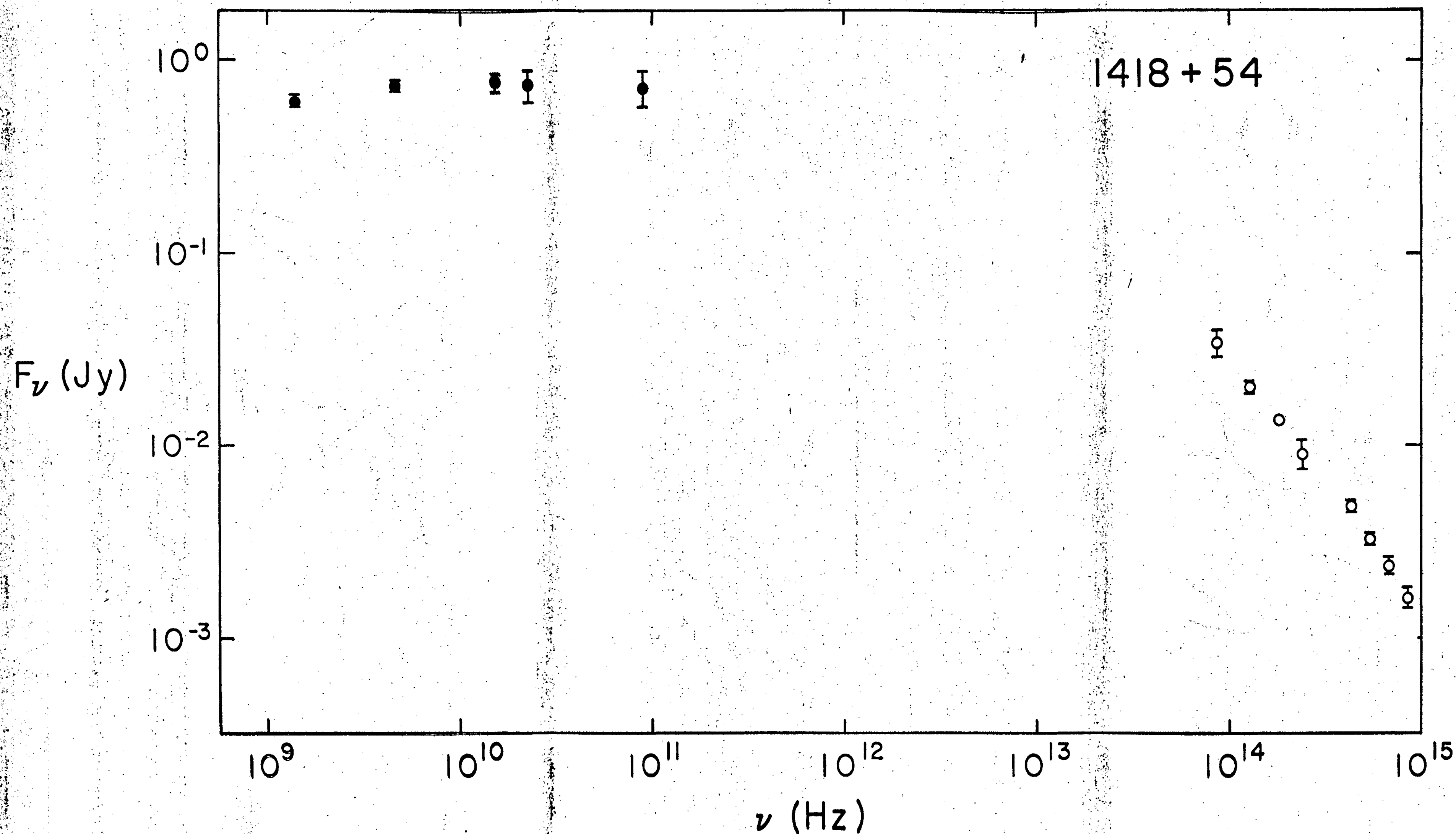
1. NONTHERMAL CONTINUUM WITH MOST OF THE LUMINOSITY RADIATED IN THE INFRARED

2. RAPID VARIABILITY AT RADIO, INFRARED AND VISUAL λS

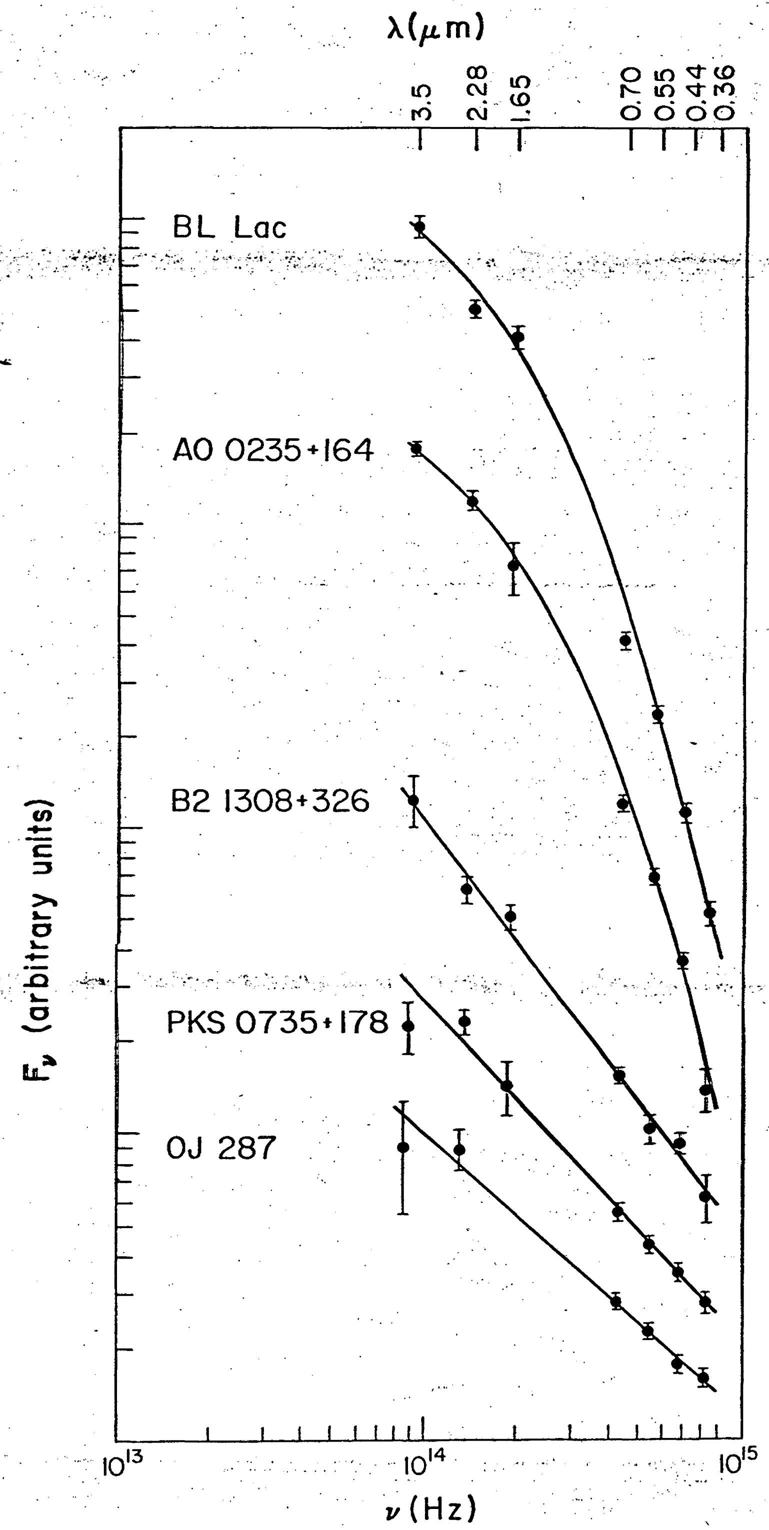
3. STRONG AND RAPIDLY VARYING POLARIZATION

4. NEAR ABSENCE OF LINES

O'Dell et al. (1978)



Puschell (1979)



RADIO PROPERTIES

Weiler and Johnston (1979)

Owen *et al.* (1978)

O'Dell *et al.* (1978)

Condon (1978)

Wardle (1978)

~ FLAT SPECTRA
SELF ABSORBED
AT ~ 3 cm

MOST SHOW STRUCTURE
EXTENDED OVER A
REGION $\gtrsim$ 1 arcsec

$\frac{S_X}{S_{TOT}} \sim 35\%$ AT 6 cm

$3 < R(kpc) < 200$

VISUAL

Δm as much as 5 mag between active and quiescent phases

t_{VAR} generally $\sim$ days - although some people have claimed to have observed substantial changes in flux (0.3 - 1 mag) in less than an hour

Others have suggested possible periodicities in the variations — with T as short as 39.2 min

RADIO

Amplitude of variations typically a factor of 2 or less at cm wavelengths

t_{VAR} $\sim$ weeks for $\nu \gtrsim 10$ GHz

t_{VAR} $\sim$ months for $\nu \sim 1$ GHz

t_{VAR} $\sim$ years for $\nu < 1$ GHz

INFRARED AND VISUAL VARIATIONS ARE IN PHASE

⇒ A COMMON PHYSICAL MECHANISM GIVING RISE TO THE RADIATION IN THESE REGIMES

Puschell (1979)
Rieke et al. (1976)

SOME EVIDENCE FOR ASSOCIATED RADIO ACTIVITY IN THE LARGEST OUTBURSTS

- ESPECIALLY TRUE AT THE HIGHEST RADIO FREQUENCIES

VIZ. mm λ

e.g.
Rieke et al. (1976)
0235+164
Balonek and Dent (1980)
0420-01
Kinman (1974)
Pomphrey et al. (1976)
OJ 287
Puschell et al. (1979)
1308+326

Puschell (1979)

OJ 287

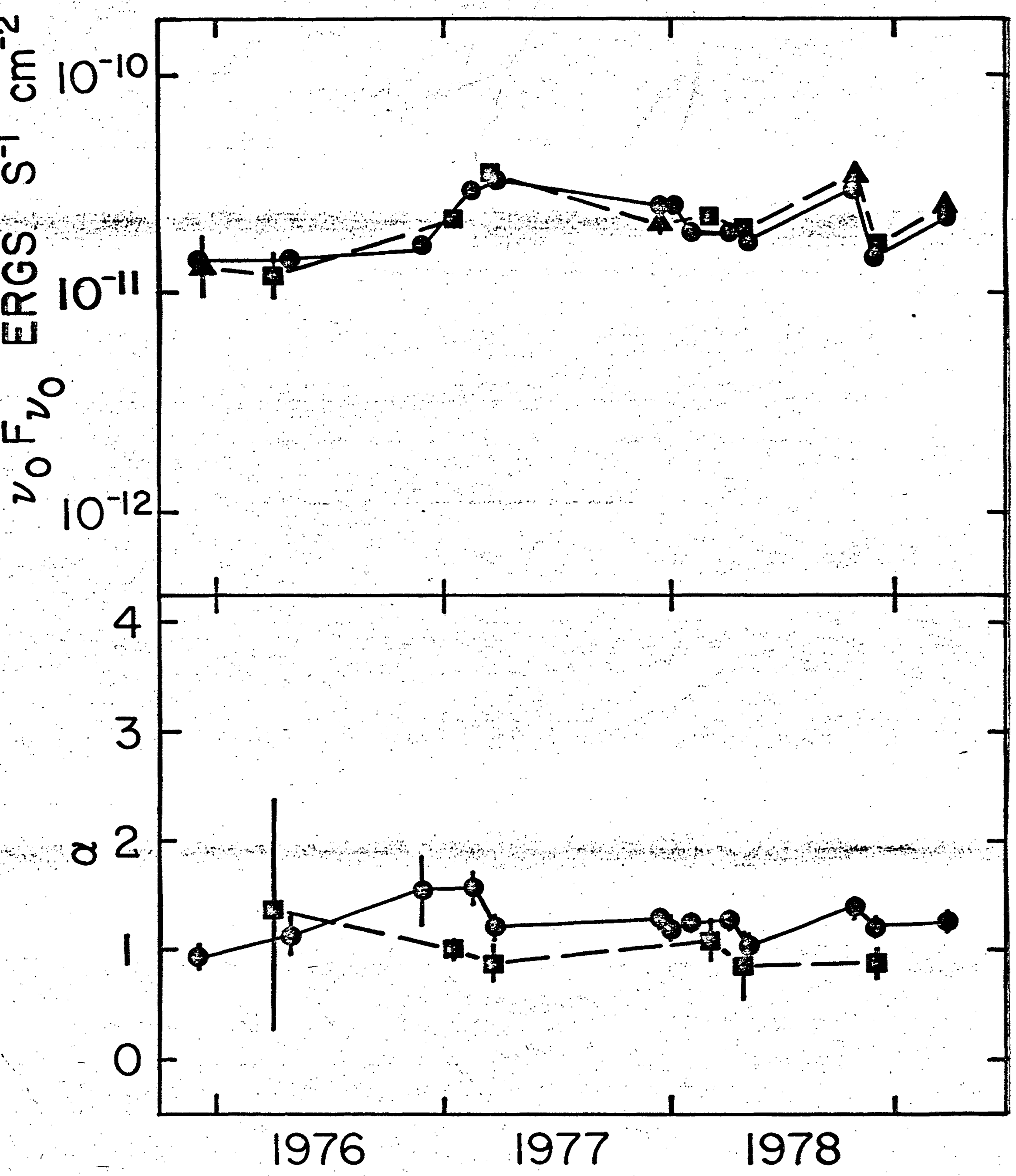


Figure 10

SPECTRAL SHAPE CHANGES OCCUR IN THE VIS-IR DURING THE COURSE OF OUTBURSTS

POSSIBLE CAUSES

1. Increase in the relative contribution of the associated galaxy.

2. Varying extinction along the line of sight

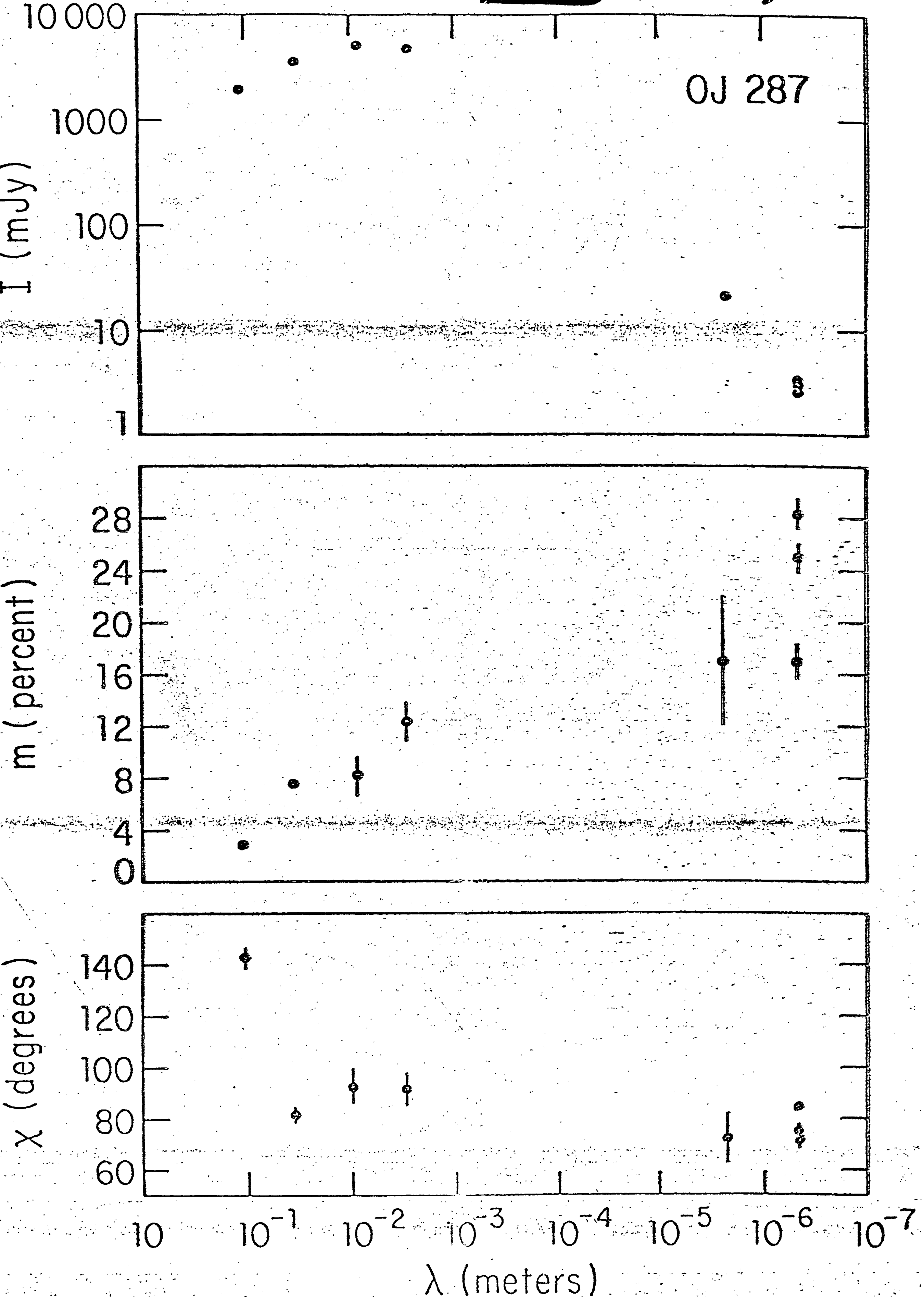
3. Intrinsic variability due to changes in the physical conditions in the emitting region

%P INCREASES WITH
ν FROM mmλ TO
VISUAL λs.

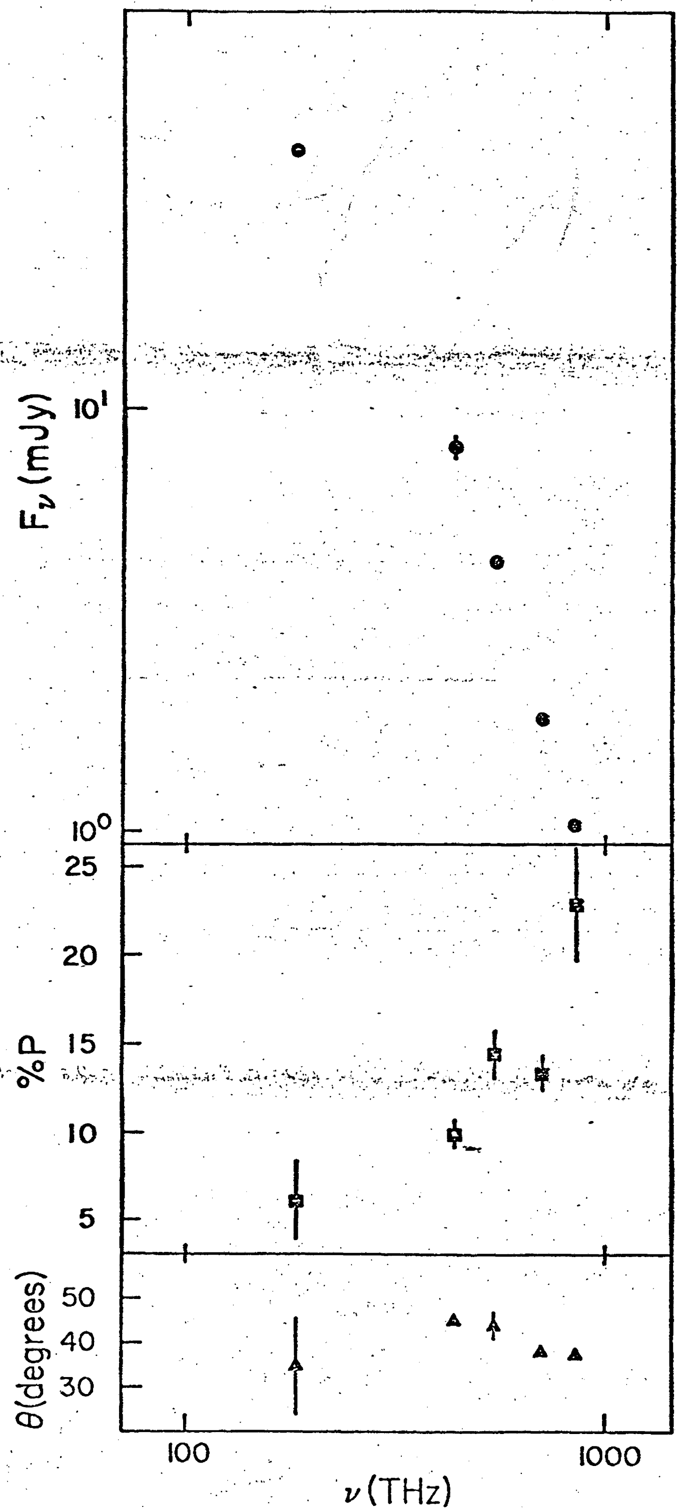
$\Rightarrow$ VIS λ EMITTING REGION
IS MORE ORDERED

%P IN VIS - IR GENERALLY
THE SAME

Rudnick etal. (1978)

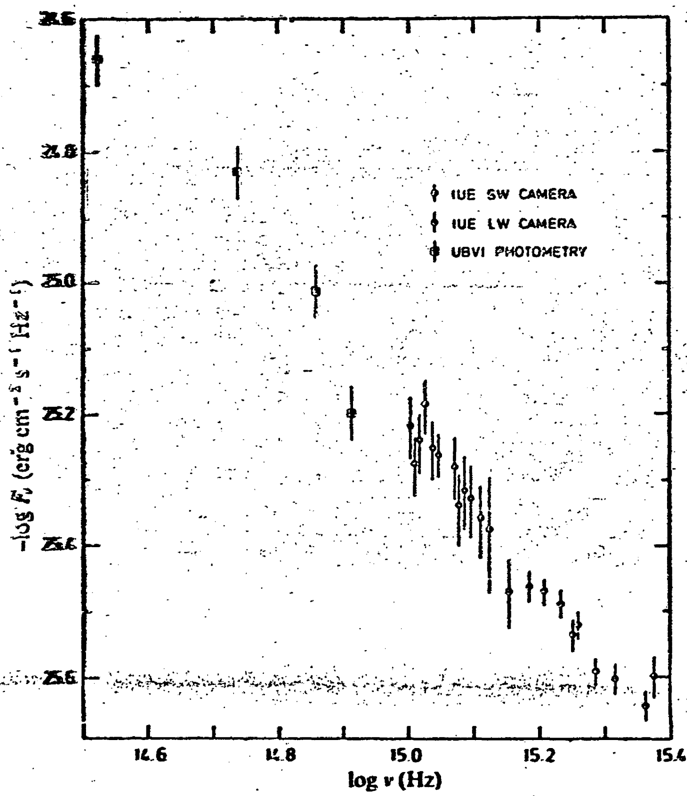


Puschell and Stein (1980)



Boksenberg et al (1978)

Fig. 8 B2 1101+38 continuum fluxes. The IUE data are averaged over 50Å bands. The UBVI photometry are approximately concurrent with the IUE measurements (see Table 1). Errors are estimated only from the 1σ statistical uncertainty in signal. No reddening correction is applied.



$L \sim 10^{48}$ ergs s^{-1}

Rieke et al. (1976)

Puschell et al. (1978)

$t_{VAR}^{min} \sim 2 \times 10^4$ s

Angel et al. (1978)

$\%P \gtrsim 10\%$

EQUATING ct_{VAR} WITH SCHWARZSCHILD RADIUS ⇒ MAXIMUM MASS AT SOURCE CENTER

$$\Rightarrow M \sim 10^{9} - 10^{10} M_{\odot}$$

$$\Rightarrow L_{max} \sim 10^{47-48} \text{ ergs s}^{-1}$$

IF THE RADIATION MECHANISM IS PREDOMINANTLY SYNCHROTRON,

$$\frac{L_c}{L_s} < 1$$

BUT

$$\frac{L_c}{L_s} = \frac{U_{ph}}{U_{mag}} \sim \frac{L/4\pi R^2 c}{B^2/8\pi}$$

$$\Rightarrow B_{Comp} \gtrsim \sqrt{\frac{2L}{R^2 c}}$$

$$\Rightarrow \underline{B \gtrsim 10^4 \text{ G}}$$

L COULD BE ANISOTROPIC

R APP. DECREASED BY [illegible]

$$t_1 \approx \frac{D}{V} - \frac{D}{c} = t_0\left(1 - \frac{V}{c}\right)$$

BUT IF $V \approx c$

$$\left(1 - \frac{V}{c}\right) \sim \frac{1}{2}\left(1 - \frac{V^2}{c^2}\right) = \frac{1}{2}\Gamma^{-2}$$

$$\Rightarrow t_{obs} \sim \frac{\Gamma}{\Gamma^2} t_{rest} = \frac{t_{rest}}{\Gamma}$$

FOR

$\% P \gg 0$

$$\tau_{THOMSON} \ll 1$$

$$\tau_{THOMSON} = \sigma_T \, n \, R$$

$$n \approx \left(\frac{L t_{VAR}}{\gamma m_e c^2 N} \right) \Big/ \frac{4\pi}{3} (c t_{VAR})^3$$

N (a la Blandford and Rees) $\equiv$ # of times $\bar{e}$ re-accel. during t_{VAR}

$$\Rightarrow \quad t_{VAR} \gtrsim 3 \times 10^{-30} \, L^{5/6} \, \nu^{-1/3} \, N^{-2/3}$$

IF $B \approx B_{COMPTON}$, γ at ν_{max}

$\Rightarrow N \sim 100$

$\Rightarrow t_{reaccel} \sim 10^2\,s$

<u>BUT</u>

$n B R \sim 1.5 \times 10^{28}\ G\,cm^{-2}$

as above argument

$\Rightarrow n \sim 10^9\ cm^{-3}$ $(t_{cyc} \sim 0.5\,s)$

Such a high rotation measure would completely de-polarize the source at visual λs.

Suppose the emitting region is moving with bulk Lorentz **$\Gamma \sim 10$**

$$\Rightarrow L \sim 10^{46} \text{ ergs s}^{-1}$$

$$t_{rest} \sim 2 \times 10^{5} \text{ s}$$

$$B_{Comp} \sim 10^{2} \text{ G}$$

$$n \sim 10^{6} \text{ cm}^{-3}$$

$$\Rightarrow nBR \sim 10^{24} \text{ G cm}^{-2}$$

which explains rotations of position angle seen by Rieke et al. (1977) and Moore et al. (1980) **without** invoking re-acceleration and without causing de-polarization.

RELATIVISTIC BULK MOTION OF THE EMITTING REGION RELIEVES CONSTRAINTS ON POLARIZATION AND B_{COMP}

ANISOTROPIC FLOW INVOLVES LESS ENERGY AND IS SUPPORTED BY RADIO MAPS SHOWING EXTENDED LINEAR FEATURES ASSOCIATED WITH RADIO GALAXIES AND QUASARS

⇒ SUPPORT FOR JET MODELS OF BLANDFORD, REES, LOVELACE, ICKE, KÖNIGL, MARSCHER ...

RADIO GALAXIES

≡ DOMINANT RADIO EMISSION COMES FROM EXTENDED RADIO STRUCTURE

ALMOST CERTAINLY RELATED TO THE ACTIVE NUCLEI

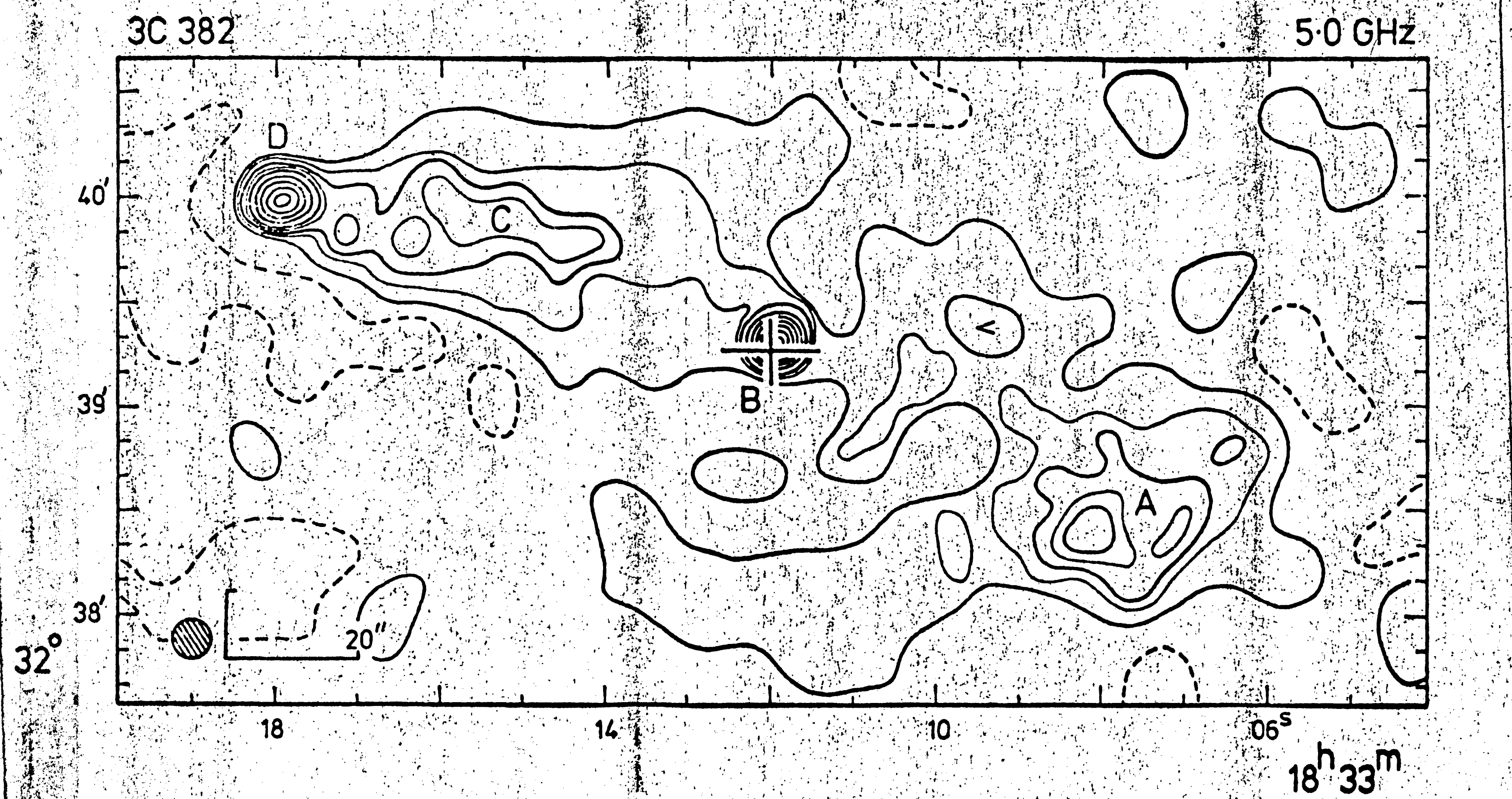
3C 382

D3 galaxy (Matthews, Morgan and Schmidt 1964)

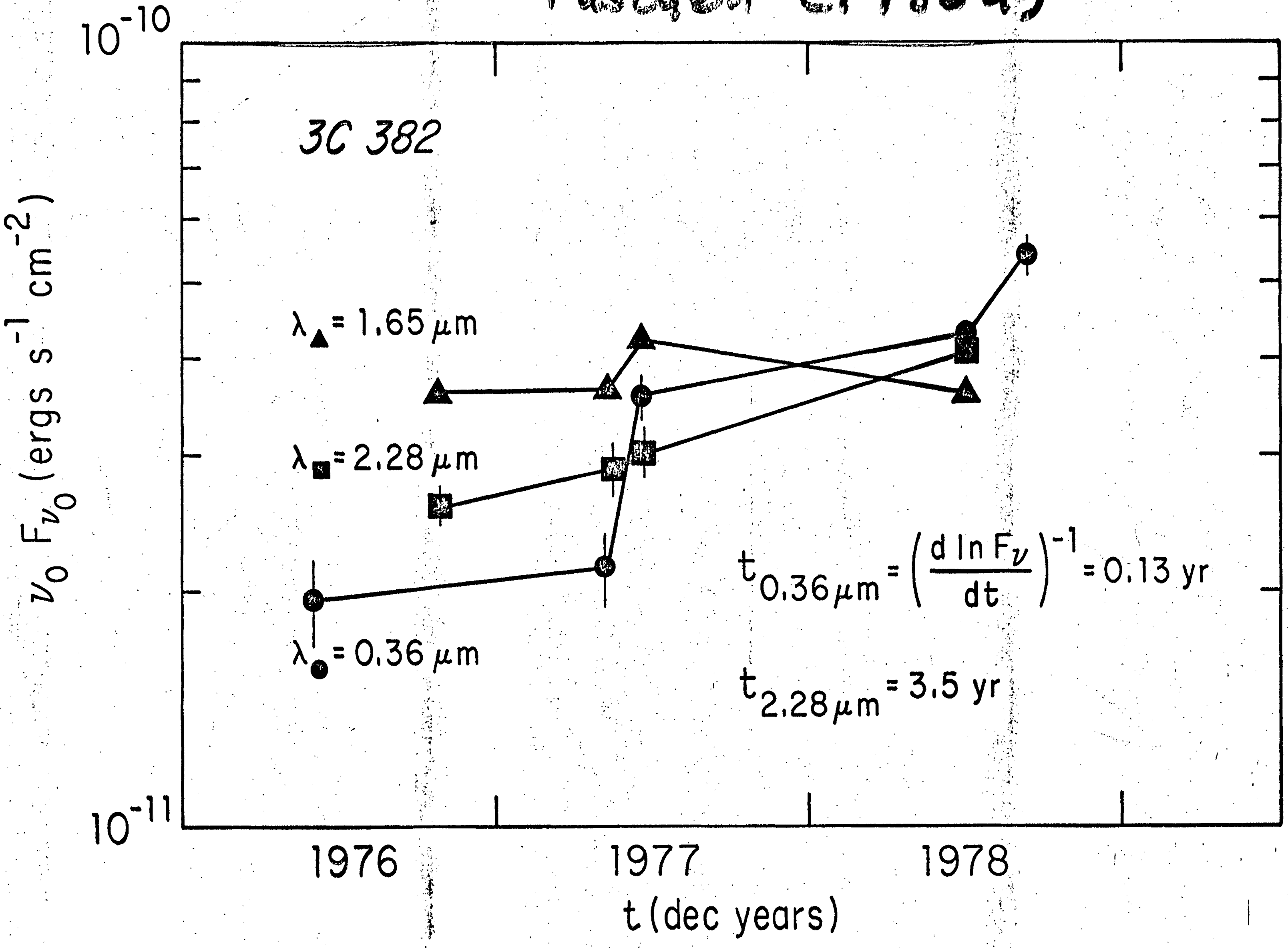
FWHM $\sim$ 25,000 km s^{-1}

$z = 0.0586$

Riley and Branson (1973)



Puschell (1980a)



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$$\epsilon_a \frac{L}{4\pi R^2} \pi r^2 = \epsilon_r \sigma T^4 4\pi r^2$$

$\epsilon \propto \lambda^{-1}$, $\lambda_a \sim 0.3\,\mu m$

$$\Rightarrow T = 20 \left(\frac{L}{R^2}\right)^{1/5}$$

For 3C 382,

$$R \sim c\, t_{VAR}^{2.28\,\mu m} \lesssim 3\times10^{18}\ cm$$

$$L_{UV} \gtrsim 3\times10^{44}\ erg\ s^{-1}$$

$$\Rightarrow T > 700\ K$$

<u>i.e.</u> the dust would re-radiate in the near-IR

OQRGs — radio galaxies showing no evidence of nonthermal optical emission

$N \gtrsim 40$ WITHIN ~500 Mly HAVING COMPACT RADIO CORES WITH 10^{38} ERGS $S^{-1} < L_{RAD} < 10^{40}$ ERGS S^{-1}

MAY BE CONTINUOUS AT LOWER RADIO LUMINOSITY END WITH RADIO QUIET GALACTIC NUCLEI (EKERS 1977)

TEND TO HAVE STRONG [OII] EMISSION ($\lambda = 3727$ Å) WHEREAS Es WITH EXTENDED RADIO SOURCES DO NOT HAVE MORE [OII] EMISSION THAN RQN (O'CONNELL AND DRESSEL 1978)

HI FREQUENTLY DETECTED IN THESE GALAXIES (eg. GALLAGHER et al. 1977)

FLAT RADIO SPECTRA

- VERY COMPACT CORES (*e.g.* SHAFFER AND MARSCHER 1980)
- SOME SHOW EVIDENCE FOR ARCSECOND STRUCTURE (WROBEL AND HEESCHEN 1980)
- KNOWN VARIABLES AT CM AND MM WAVELENGTHS

⇒ MAY BE SIMILAR TO LOW LUM QSOs/BLOs (*e.g.* HEESCHEN 1970)

MAY TEND TO HAVE NONSTELLAR 10 μm EMISSION

PLAUSIBLE ORIGINS FOR 10 μm EMISSION

1. SYNCHROTRON RADIATION
   (a) SAME e^-s AS RADIO
   (b) HIGH FREQUENCY COMPONENT
2. COMPTON SCATTERED RADIATION
3. THERMAL RE-RAD BY DUST
   (a) HEATED BY NT SOURCE
   (b) HEATED BY ANOTHER SOURCE
   e.g. HOT ACCRETION DISK
   OR * FORMING REGION

ALT. 1

(a) SYNCHROTRON MODELS USING $N(E) \propto E^{-1}$ $\Rightarrow F_\nu \propto \nu^0$ PREDICT EXCESSES IN THE NEAR IR REQUIRING ENOUGH DUST EXTINCTION TO YIELD THE 10 μm EMISSION

(b) N4552

$$100\,\text{mJy} \left(\frac{\nu}{90\,\text{GHz}}\right)^{5/2} = 100\,\text{mJy} \left(\frac{\nu}{30\,\text{THz}}\right)^{-2}$$

$$\Rightarrow \nu \approx 10^{12}\ \text{Hz}$$

USE CONDITIONS FOR SSA AND EQUIPARTITION TO SOLVE FOR R AND B

$\Rightarrow \quad R \sim 2.4 \times 10^{15}$ cm ~ 20 Hhr

$B \sim 20$ G

$\Rightarrow$ EASY TO TEST THROUGH OBSERVATIONS AT LONGER λS AND THROUGH MONITORING

ALT. 2 MIGHT WORK IF ENERGY CUTOFFS ARE IN THE RIGHT PLACE - PROBABLY RULED OUT BY OCCAM'S RAZOR

ACT. 3

IS THE PUTATIVE DUST HEATED BY A NT SOURCE?

$L_{UV} \gtrsim L_{IR}$

N 4552

$\Rightarrow L_{UV} \gtrsim 10^{42}$ ergs s^{-1}

$\Rightarrow F_{UV} \sim 4$ mJy

WHICH IS TOO BRIGHT FOR A MINI-BLO

WHAT ABOUT * FORMING REGION?

$$\frac{F(10\mu m)}{F(ff\ rad)} \sim 10$$

(Clebofsky et al 1978)

$\Rightarrow \#_{Ly-c} \gtrsim 3.7 \times 10^{53}$ photons s^{-1}

(based on Rubin 1968)

According to Smith, Biermann and Mezger (1978),

$\#_{Ly-c}^{Milky\ Way} \sim 5 \times 10^{52}$ photons s^{-1}

ACCRETION DISKS ?

$$\beta \frac{GM\dot{m}}{r} \sim 4\pi r^2 \sigma T^4$$

$$r = \frac{2GM}{c^2}$$

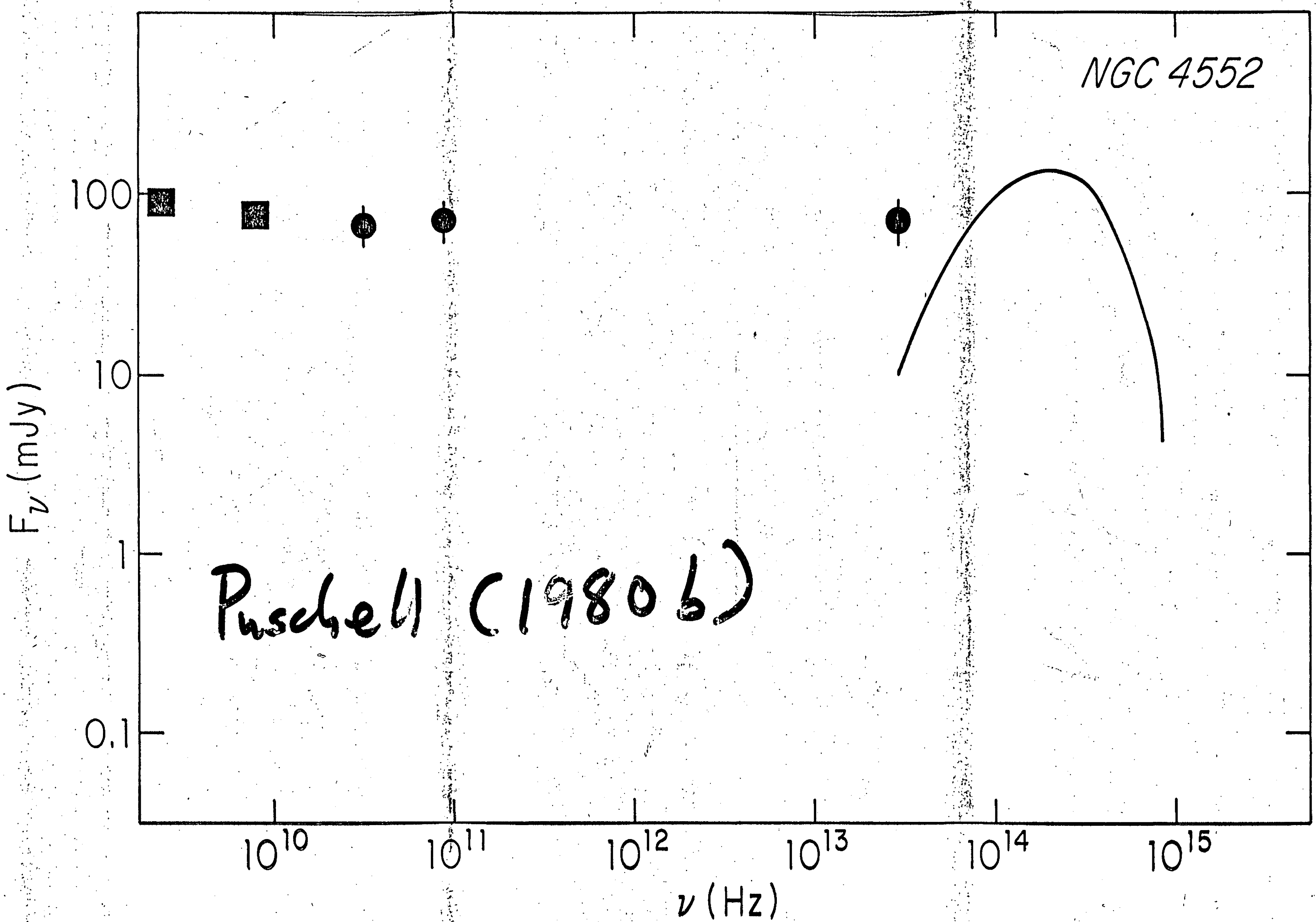
$$\beta \frac{\dot{m}c^2}{2} \sim 4\pi r^2 \sigma T^4$$

<u>IF</u> $M \sim 10^9 M_\odot$

<u>THEN</u> $T \sim 10^4$ K FOLLOWS

FOR $\dot{m} \sim 10^{22}$ gm s^{-1}

$\sim 10^{-4} M_\odot$ yr^{-1}



NGC 4552
100
10
1
0.1
F_ν (mJy)
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
ν (Hz)
Puschell (1980b)

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