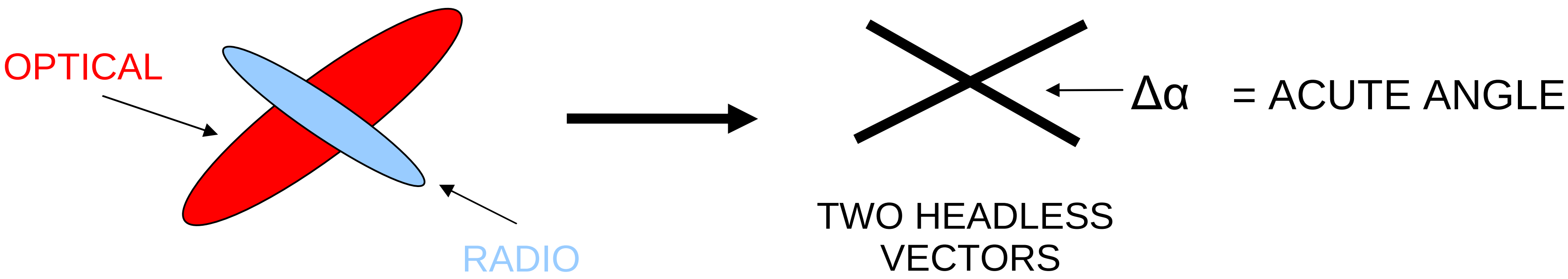
A dichotomy in radio jet orientations in elliptical galaxies

Weak radio jets know about the overall shape of their host galaxies but stronger jets do not!

(Battye & Browne astro-ph:0902.1637; MNRAS submitted)
University of Manchester, Jodrell Bank Centre for Astrophysics

OBJECTIVES

- DOES THE SHAPE OF A RADIO SOURCE KNOW ABOUT THE SHAPE OF ITS HOST GALAXY?



- PREVIOUS STUDES ~ 100 OBJECTS (VALTONEN 1983, BIRKINSHAW & DAVIES 1985, SANSOM et al 1987, CONDON et al 1991)

  - MAINLY GIANT RADIO ELLIPTICALS
  - WEAK BIAS TOWARD Δα = 90
  - RADIO EMISSION ASSOCIATED WITH JETS

- ROLE OF BLACK HOLE & JETS IN GALAXY FORMATION ?

- CONCENTRATE ON ELLIPTICAL GALAXIES – LOW OPTICAL ACTIVITY

SDSS & FIRST

OPTICAL : *SDSS* DR6

(YORK et al 2000,
ADELMAN-MCCARTHY et al 2008)

- ~ 2.9 x 10^8 OBJECTS IN *ugriz*
- ~ 1.3 x 10^6 SPECTRA
- PHOTOMETRIC CALIBRATION ~ 1%

RADIO : *FIRST*

(BECKER et al 1995)

- VLA B-ARRAY @ 1.4GHz
- 5 arcsec RESOLUTION
- ~ 10^6 RADIO SOURCES

BOTH COVER THE SAME ~10000 deg^2 IN THE NORTHERN SKY

OUR SELECTION

SDSS/FIRST MATCH IN THE *SDSS* ARCHIVE (~ 240000 OBJECTS)

OPTICAL : r < 18, b/a < 0.8

RADIO : S > 1 mJy, b/a < 0.8, a > 2 arcsec

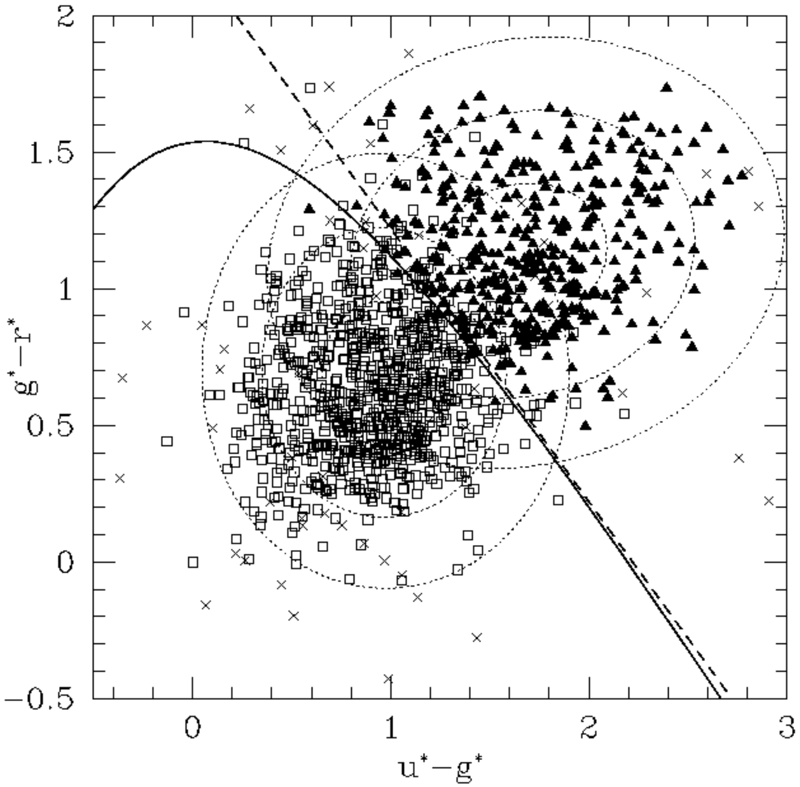
→ 14302 GALAXIES WITH z ~ 0.1

3-4 % OF *SDSS*
20-30% OF *FIRST*

COLOUR & CONCENTRATION

(STRATEVA ET AL 2001)

COLOUR



u – r = 2.22 SEPARATES BLUE AND RED GALAXIES

CONCENTRATION

SDSS COMPUTE :

R_{50} & R_{90}
FOR PETROSIAN INTENSITY PROFILE

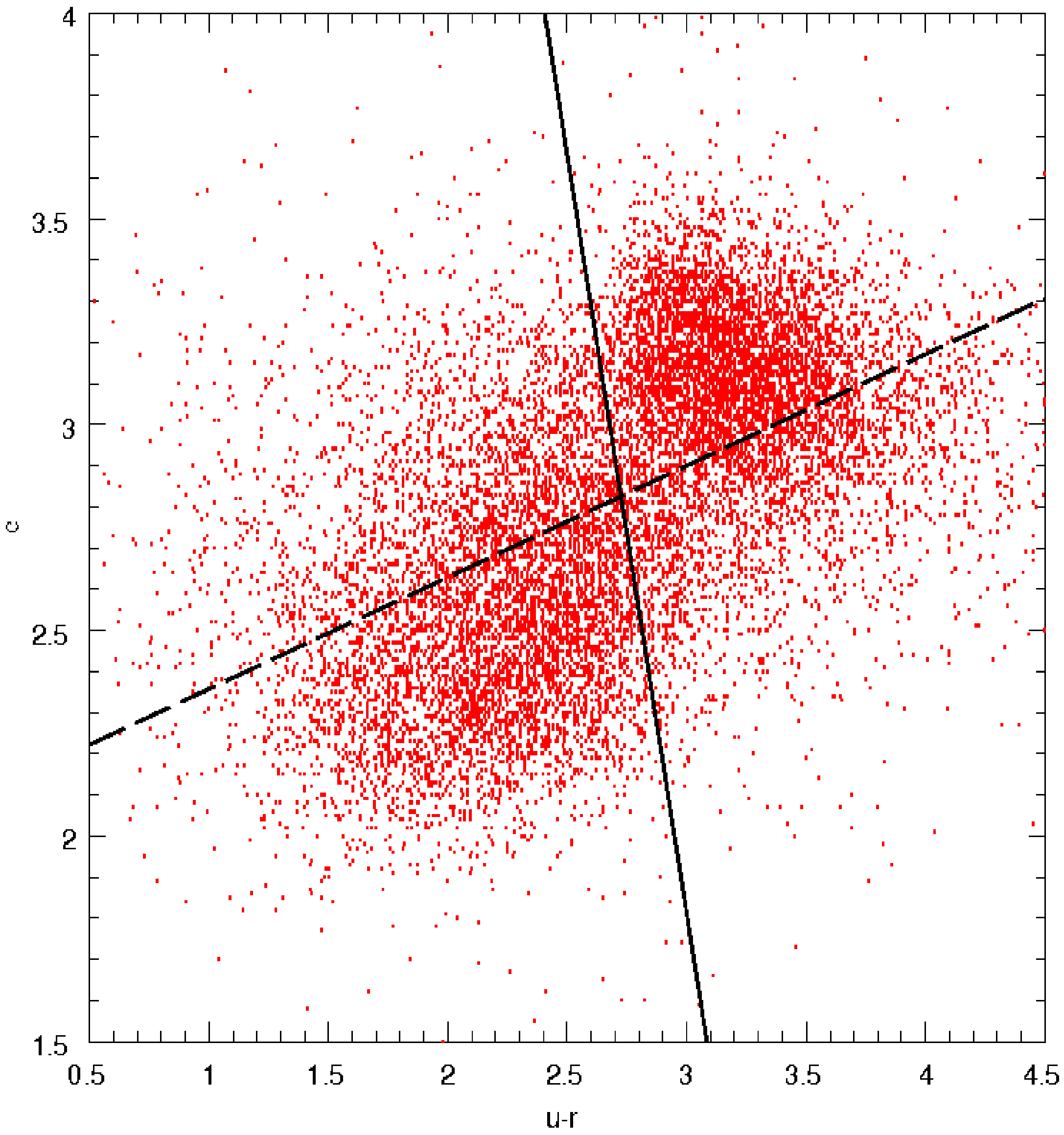
DEFINE :

$c = R_{90} / R_{50}$

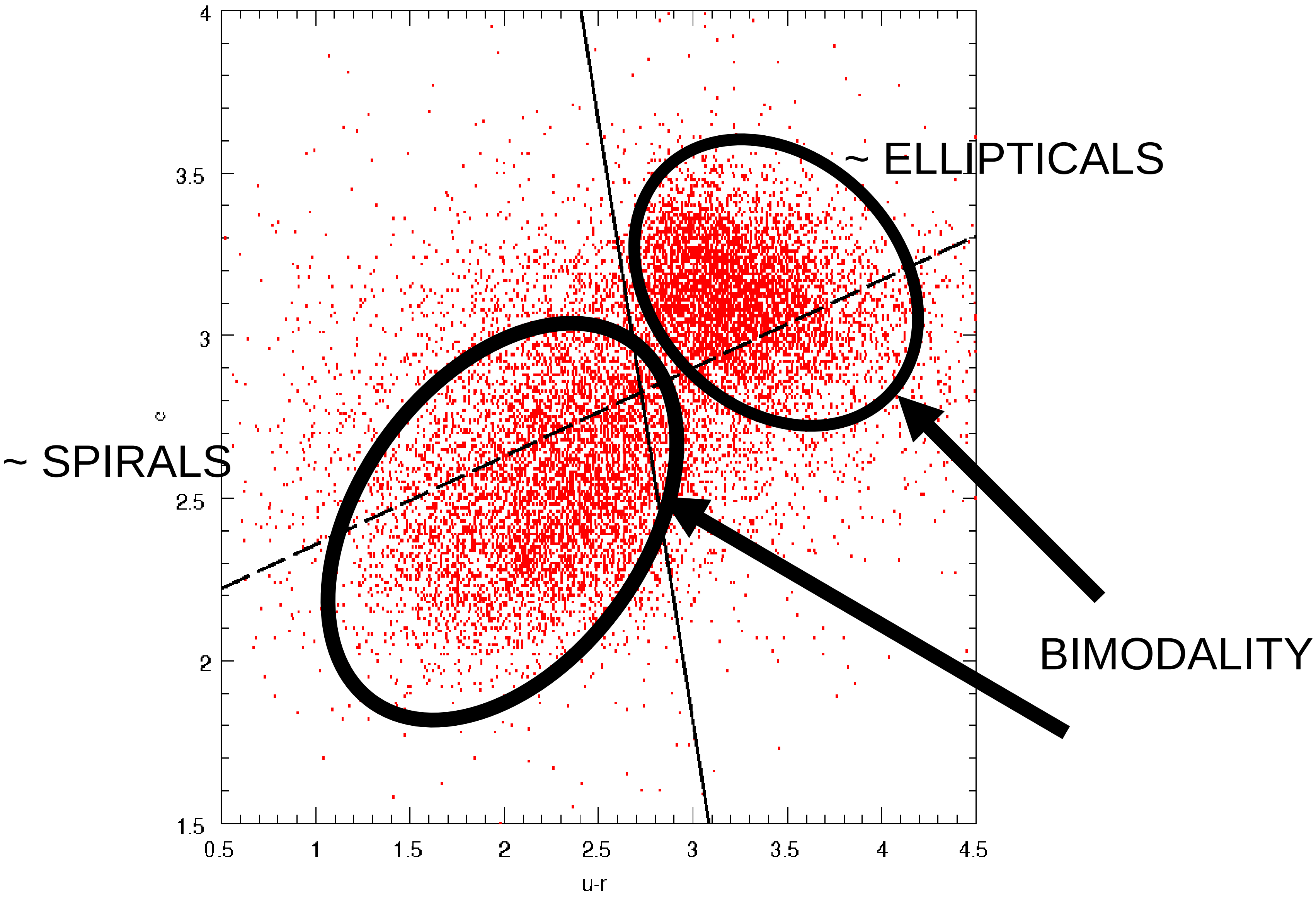
C LARGE – DE-VAUCOULEURS PROFILE
- ELLIPTICAL GALAXY

C SMALL – EXPONENTIAL PROFILE
- SPIRAL GALAXY

COLOUR - CONCENTRATION



COLOUR - CONCENTRATION



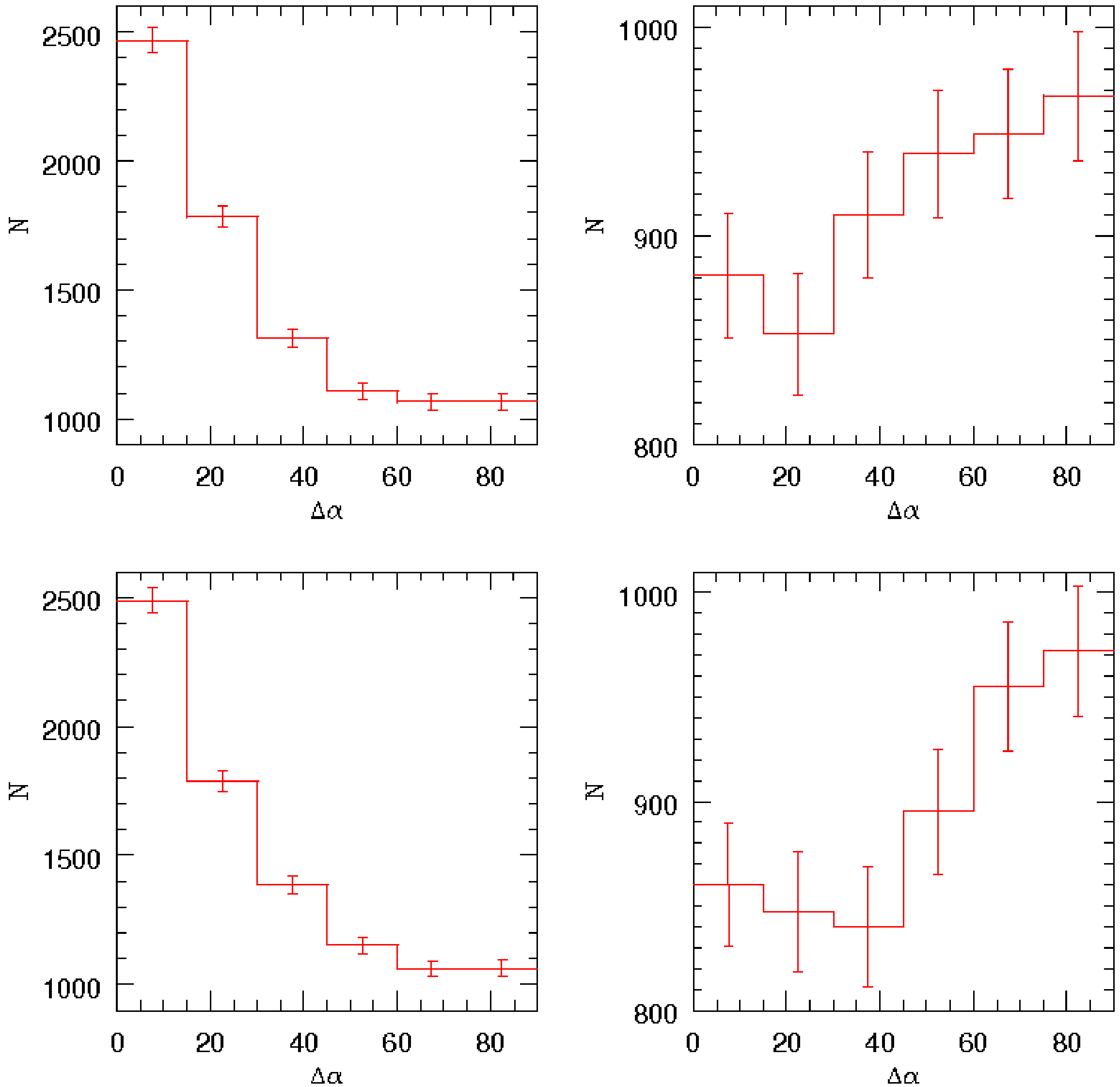
SPLIT ON CONCENTRATION & COLOUR

c < 3

c > 3

u-r < 3

u-r > 3

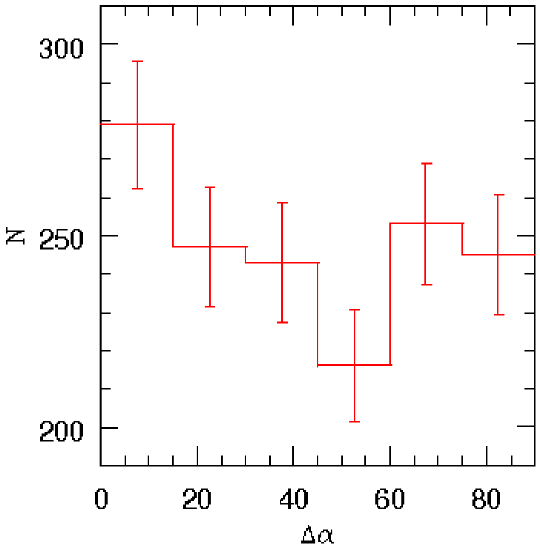


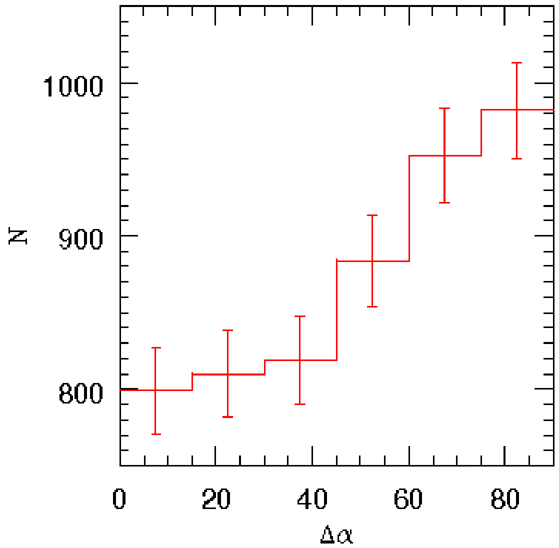
CUTS OPTIMIZED TO GIVE LARGEST χ^2

USING C_2 TO MAKE THE SPLIT

($C_2 = 0.965C - 0.262(U - R)$)

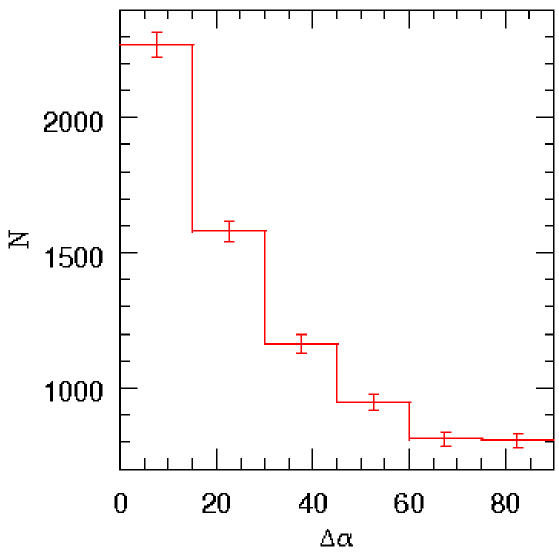
$C_2 > 3.5$
& $b/a < 0.6$

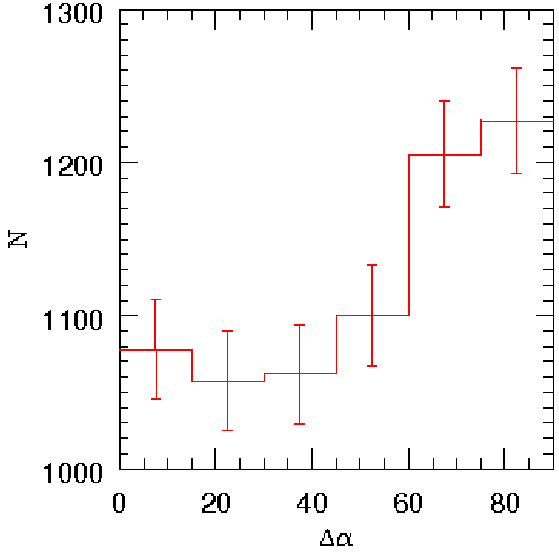




$C_2 > 3.5$
& $b/a > 0.6$

$C_2 < 3.5$





$C_2 > 3.5$

A LITTLE SURPRISING ?

- RADIO EMISSION FROM JETS AND LOBES
  - EXPECTED TO BE CORRELATED WITH SPIN AXIS OF CENTRAL BLACK HOLE ~ THE CENTRAL PARSEC

- OPTICAL FROM STARS – VERY FEW ARE OPTICAL AGN

- PROJECTION EFFECTS UNLESS OBLATE SPHEROIDS

- THIS WOULD SUGGEST
  - THAT THE OUTER REGIONS OF A GOOD FRACTION ELLIPTICALS “KNOW” ABOUT THE CENTRAL PARSEC

  - AND A GOOD FRACTION ARE OBLATE

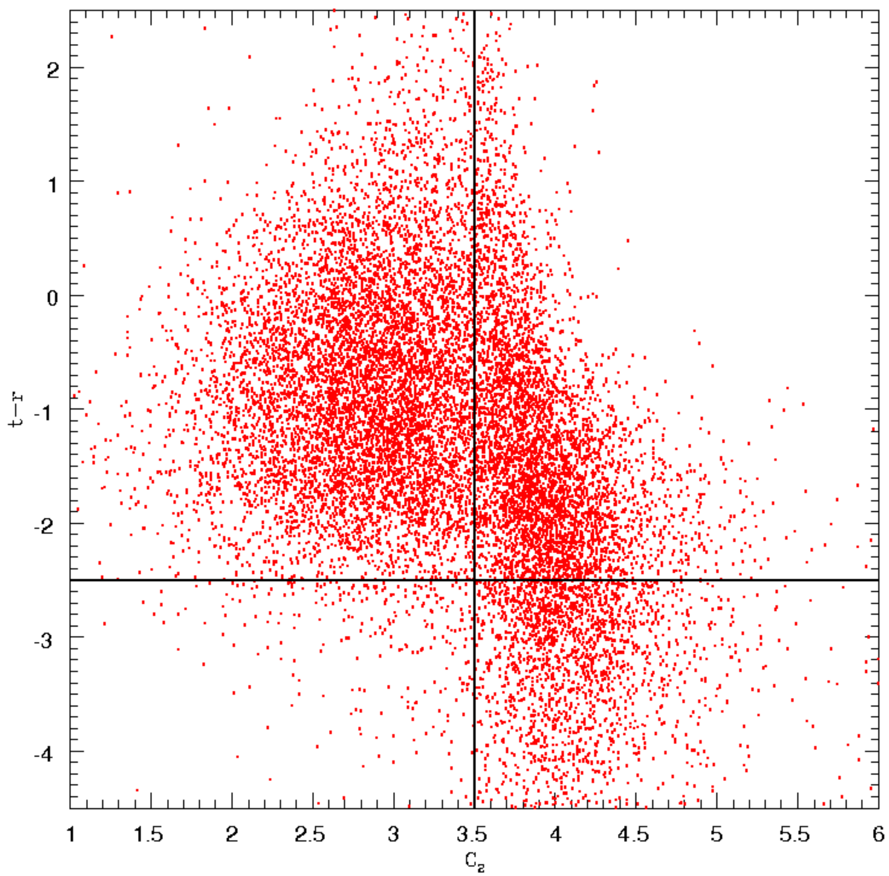
(CONFIRMED BY PADILLA & STRAUSS ANALYSIS OF ELLIPTICAL SHAPES)

“RADIO LOUD/QUIET”

DEFINE RADIO MAGNITUDE : $t = -2.5 \log_{10} [S_{int} / 3631 \text{ Jy}]$

RADIO QUIET

RADIO LOUD



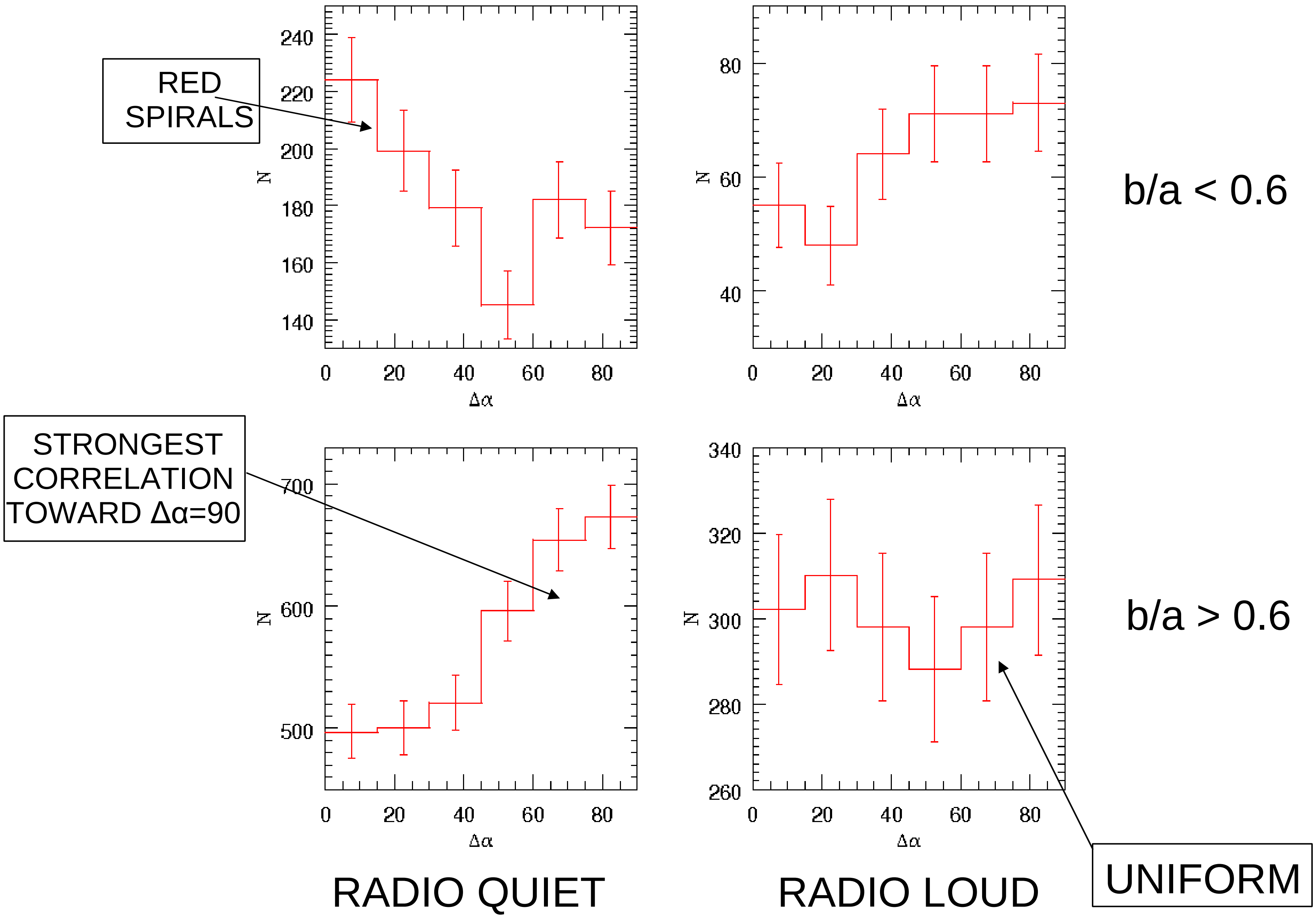
SPIRALS ELLIPTICALS

“RADIO QUIET”
$t - r > -2.5$

“RADIO LOUD”
$t - r < -2.5$

NOT THE STANDARD DEFINITION
-- NOT WRT AGN LIGHT
-- NOT FR1/FR2

SPLITS ON RADIO LOUD/QUIET AND AXIAL RATIO



A SURPRISING DICHOTOMY!

- SIGNIFICANT MINOR AXIS ALIGNMENTS ARE ONLY PRESENT AMONGST THE RADIO QUIETER POPULATION
  - ALIGNMENTS IMPLY OBLATE GALAXIES AND JETS EMERGE ALONG THE MINOR AXIS
  - SPECULATE THAT GALAXY SHAPE IN THE QUIETER OBJECTS IS FIXED BY ROTATION AND THAT JETS EMERGE ALONG THE STELLAR ROTATION AXIS.
  - IMPLIES THAT CENTRAL ACCRETION DISK/BH SYSTEM IS ALIGNED WITH STELLAR ROTATION AXIS

TWO VARIETIES OF ELLIPTICAL GALAXIES

- RADIO QUIET

  - MINOR AND MAJOR AXES OF RADIO AND OPTICAL ARE CORRELATED

  THIS REQUIRES : NEGLIGIBLE PROJECTION EFFECTS
  THE OUTER REGIONS “CONNECTED” TO INNER

  → ARE THEY OBLATE & ROTATIONALLY SUPPORTED ?

- RADIO LOUD

  - APPARENTLY UNIFORM DISTRIBUTION OF POSITION ANGLE DIFFERENCES

  WHAT WE WERE EXPECTING DUE TO LACK OF ROTATION SUPPORT ?

  RELATE TO : DECOUPLED CORES, ENVIRONMENT, TRIAXIALITY ?

ANOTHER DICHOTOMY IN ELLIPTICALS

(KORMENDY, FISHER, CORNELL & BENDER 2008; MUCH PREVIOUS WORK)

GIANT ELLIPTICALS

- HAVE CORES
- SLOWLY ROTATING
- ANISOTROPIC, TRIXIAL
- BOXY ISOPHOTES
- STRONG RADIO SOURCES

NORMAL & DWARF ELLIPTICALS

- CORELESS
- RAPIDLY ROTATING
- ISOTROPIC & OBLATE
- DISKY-DISTORTED ISOPHOTES
- WEAK RADIO SOURCES

IS THIS THE SAME SPLIT THAT WE HAVE ESTABLISHED ?

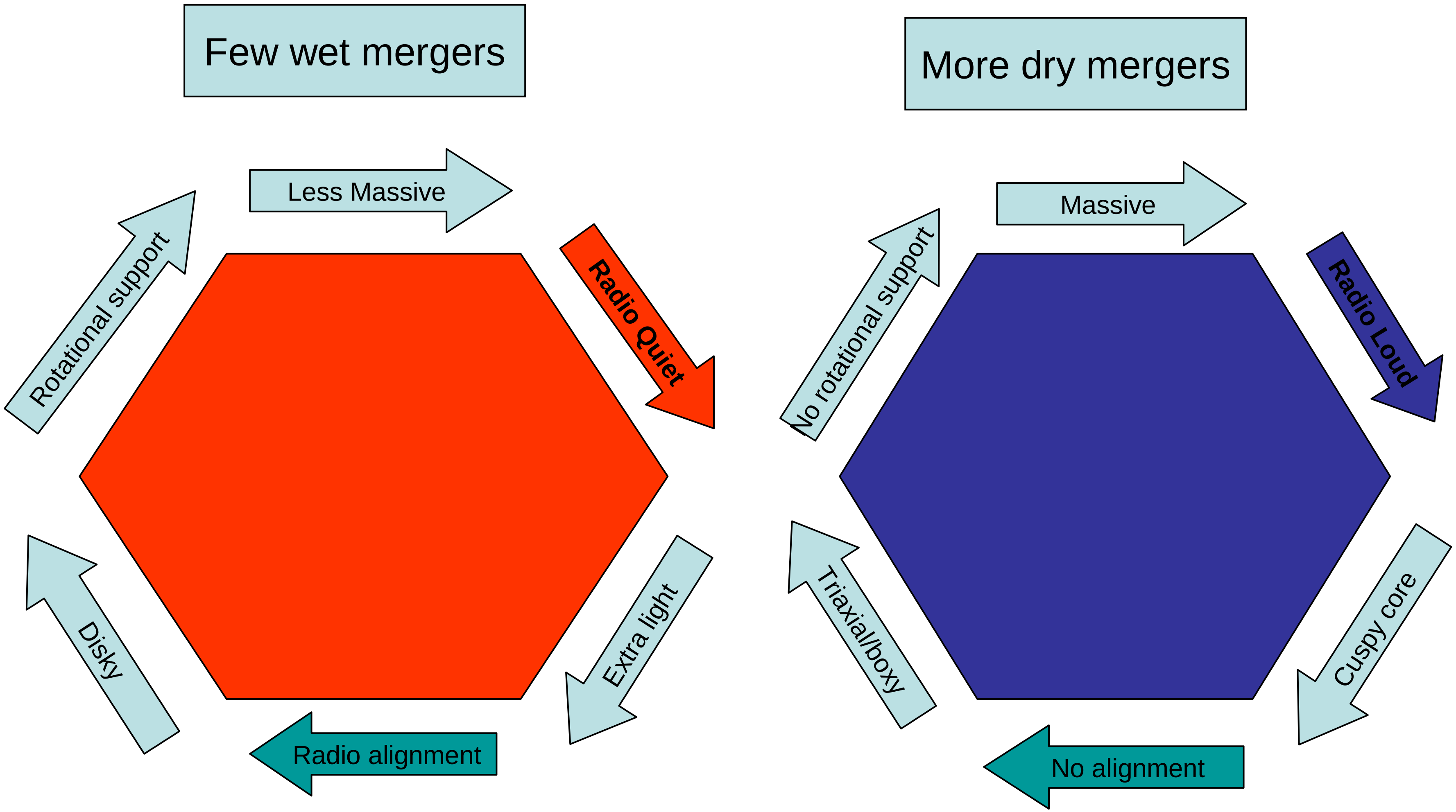
RADIO LOUD POPULATION ?

- UNIFORM DISTRIBUTION
- NOT ROTATIONALLY SUPPORTED

RADIO QUIET POPULATION ?

- MAJOR AND MINOR AXES ARE CORRELATED
- ROTATIONALLY SUPPORTED

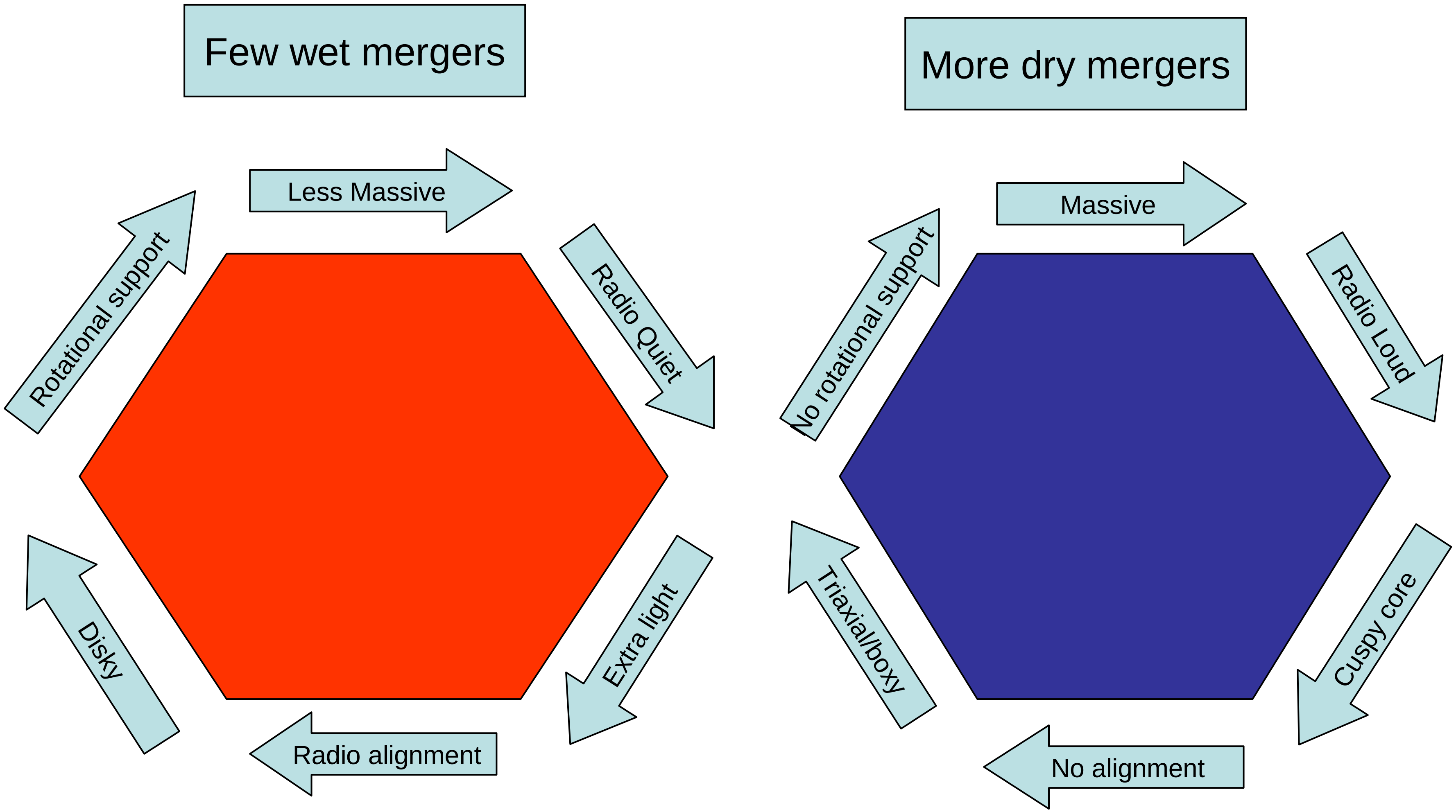
The E-E dichotomy



SUMMARY

- USING *SDSS* AND *FIRST* WE FIND A HIGHLY STATISTICALLY SIGNIFICANT BIAS FOR MINOR AXIS ALIGNMENT IN ELLIPTICALS
- THE ALIGNMENT IS ONLY THERE FOR THE RADIO QUIETER OBJECTS
- RESULT ADDS SUPPORT TO THE IDEA THAT THERE ARE TWO TYPES OF ELLIPTICALS

The E-E dichotomy



SUMMARY OF PHOTOMETRIC SPLITS

- $C_2 < 3.5$ CAN BE USED TO SELECT SPIRALS
- SPIRAL GALAXIES HAVE

  - RADIO AND OPTICAL ISOPHOTES ALIGNED
  - ORIGIN OF RADIO IS STAR-FORMATION
  - VERY STRONG RESULT

- $C_2 > 3.5$ & $b/a > 0.6$ CAN BE USED TO SELECT ELLIPTICALS
- ELLIPTICAL GALAXIES HAVE

  - RADIO AND OPTICAL ISOPHOTES ARE ANTI-ALIGNED
  - ORIGIN OF RADIO IS NUCLEAR BLACK HOLE AND JET
  - LESS STRONG RESULT, BUT STILL SIGNIFICANT

- TWO CLASSES OF ELLIPTICALS : RADIO QUIETER/LOUDER

  - RADIO LOUD HAVE A UNIFORM DISTRIBUTION

NOT THE STANDARD LOUD/QUIET DEFINITION

- WE USE RATIO OF RADIO FLUX DENSITY TO TOTAL OPTICAL LIGHT RATHER THAN JUST THE AGN LIGHT

- N.B. NEARLY ALL OUR RADIO SOURCES ARE IN FR1 LUMINOSITY RANGE

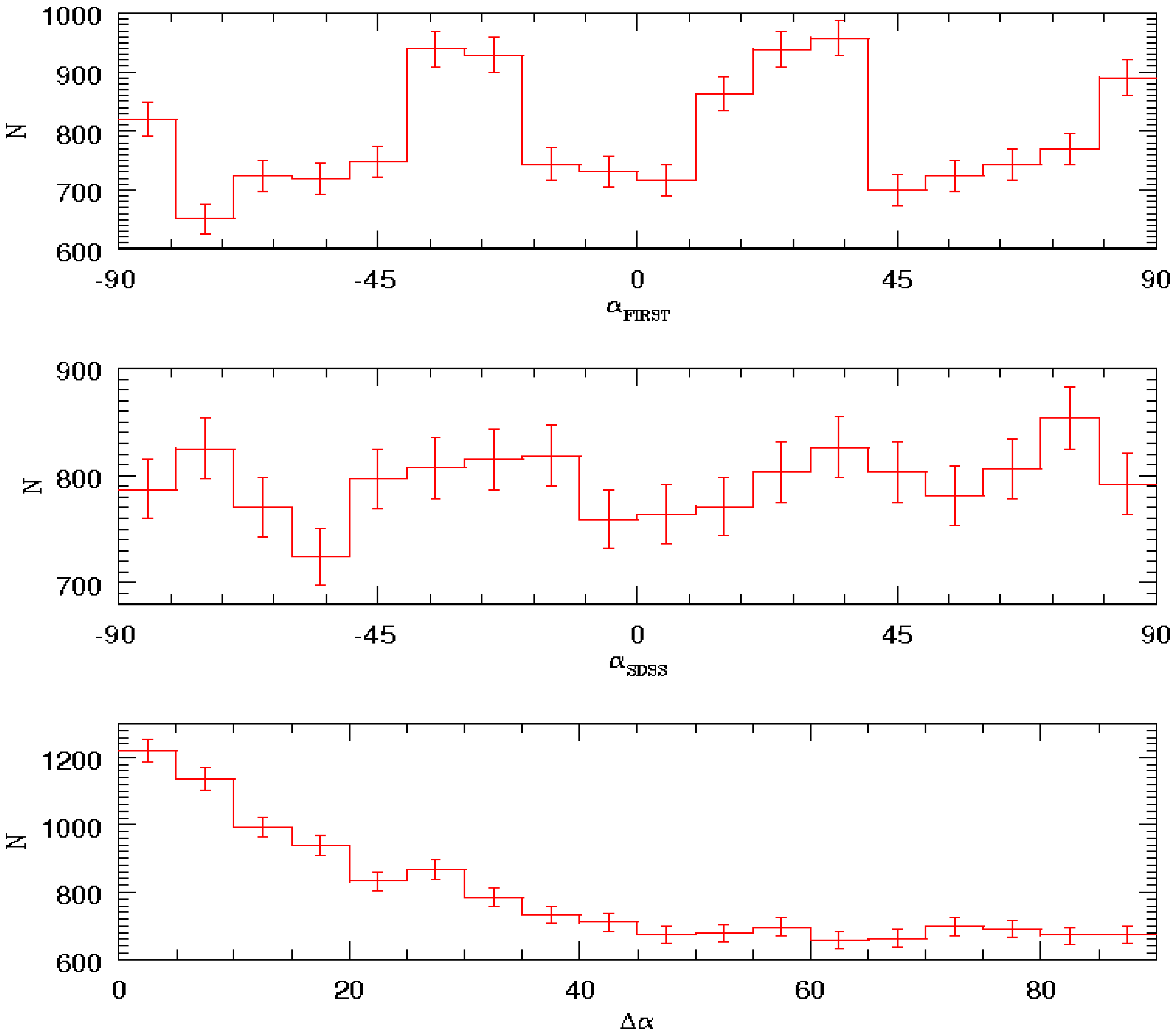
- t - r ~ -7 IS THE FR1/FR2 TRANSITION FOR L_* GALAXIES

FIRST LOOK RESULTS

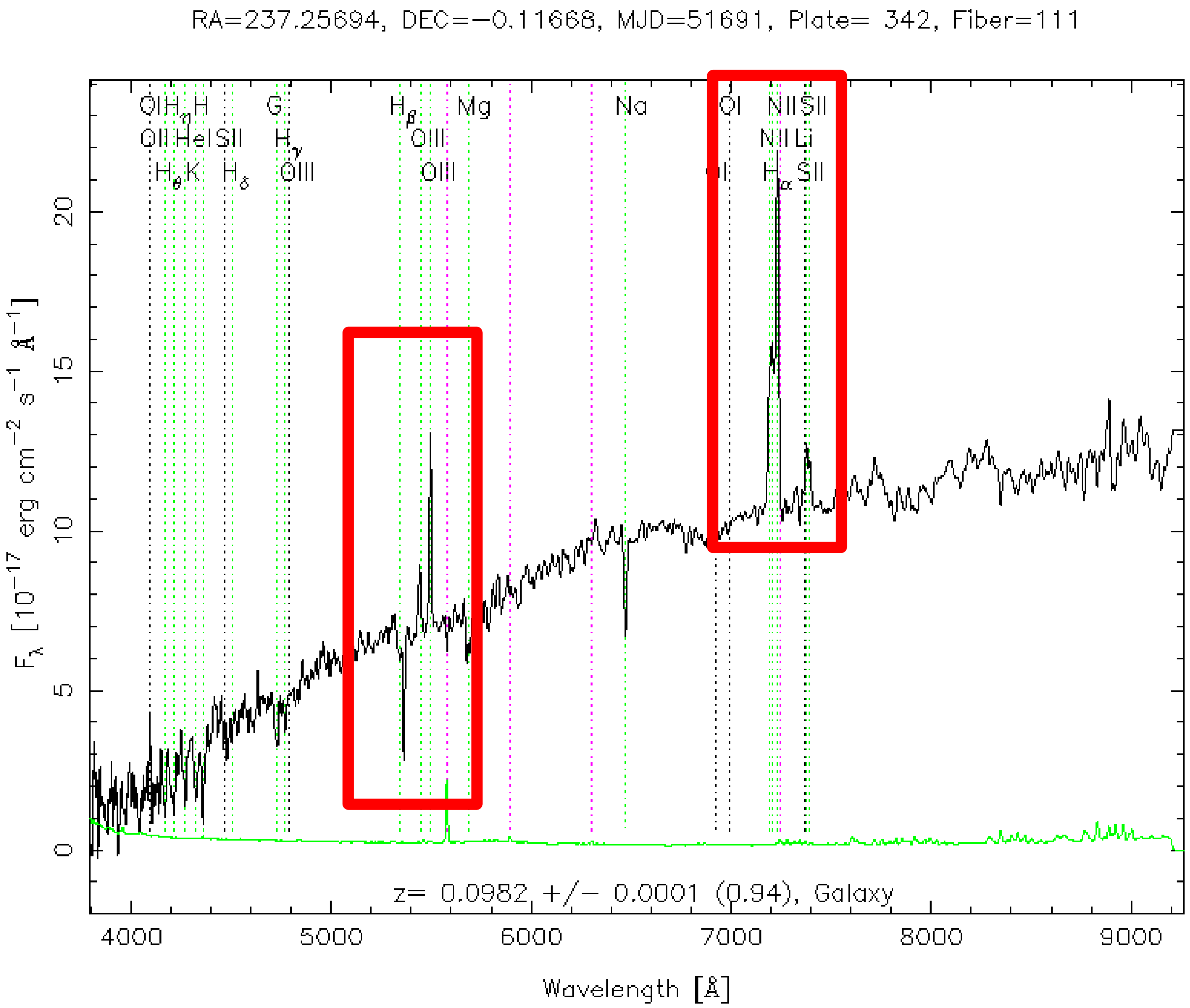
FIRST ALONE

SDSS ALONE

DIFF ($\Delta\alpha$)

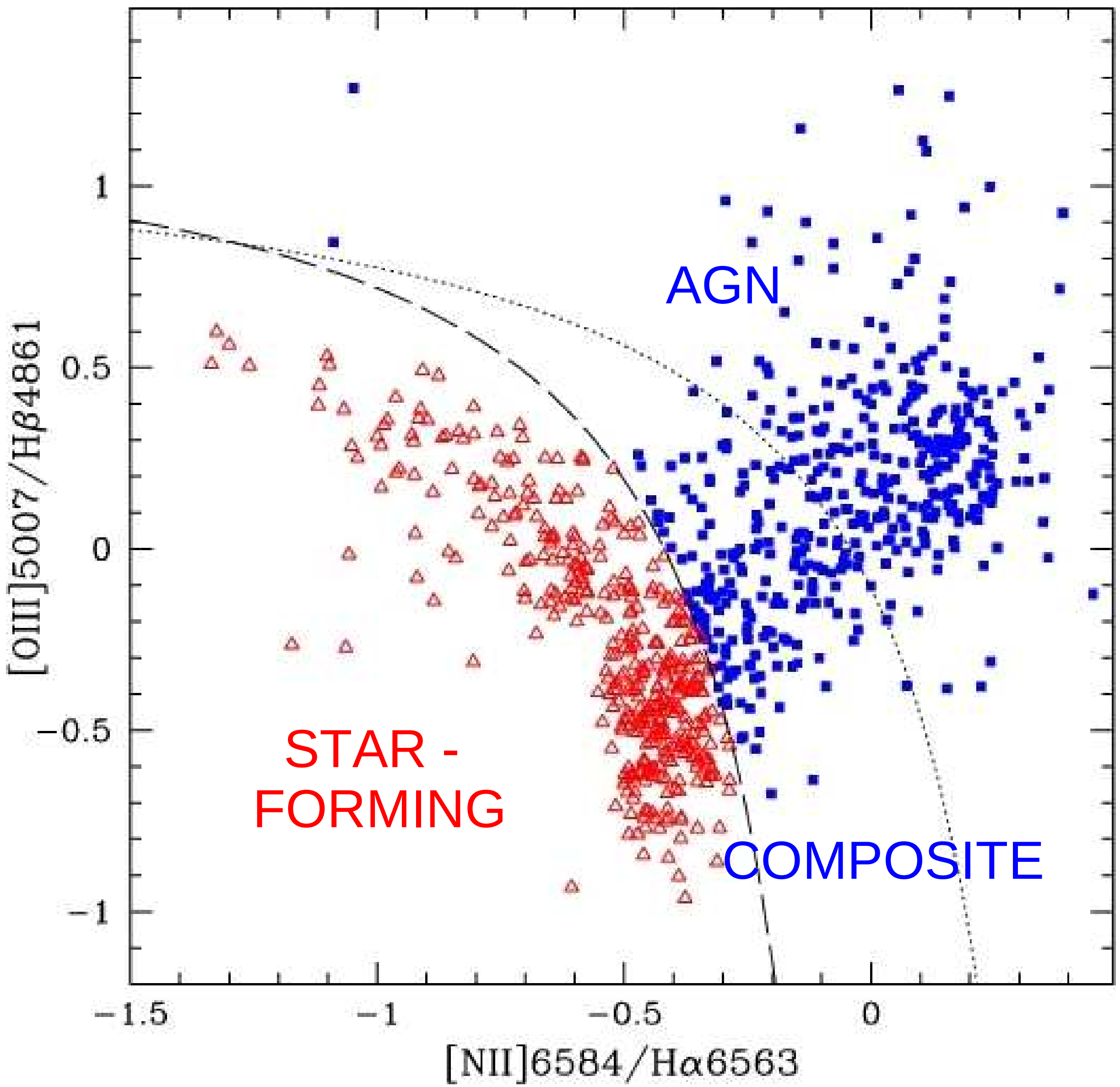


SDSS SPECTRA



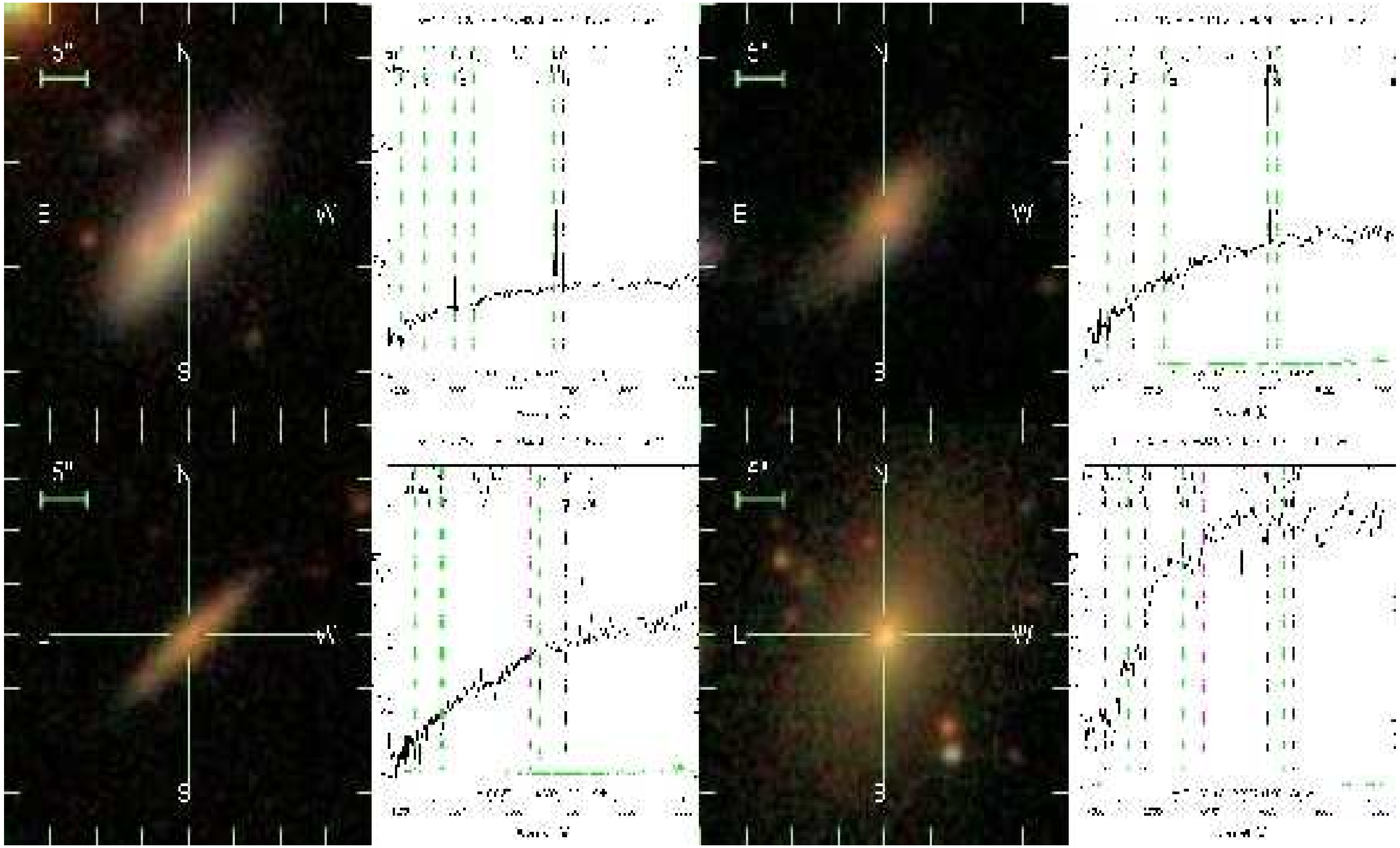
6053 / 14302 HAVE SPECTRA

BALDWIN-PHILLIPS-TERLOVICH (BPT) DIAGRAM



SPECTRAL CLASSIFICATION

STAR-FORMING COMPOSITE



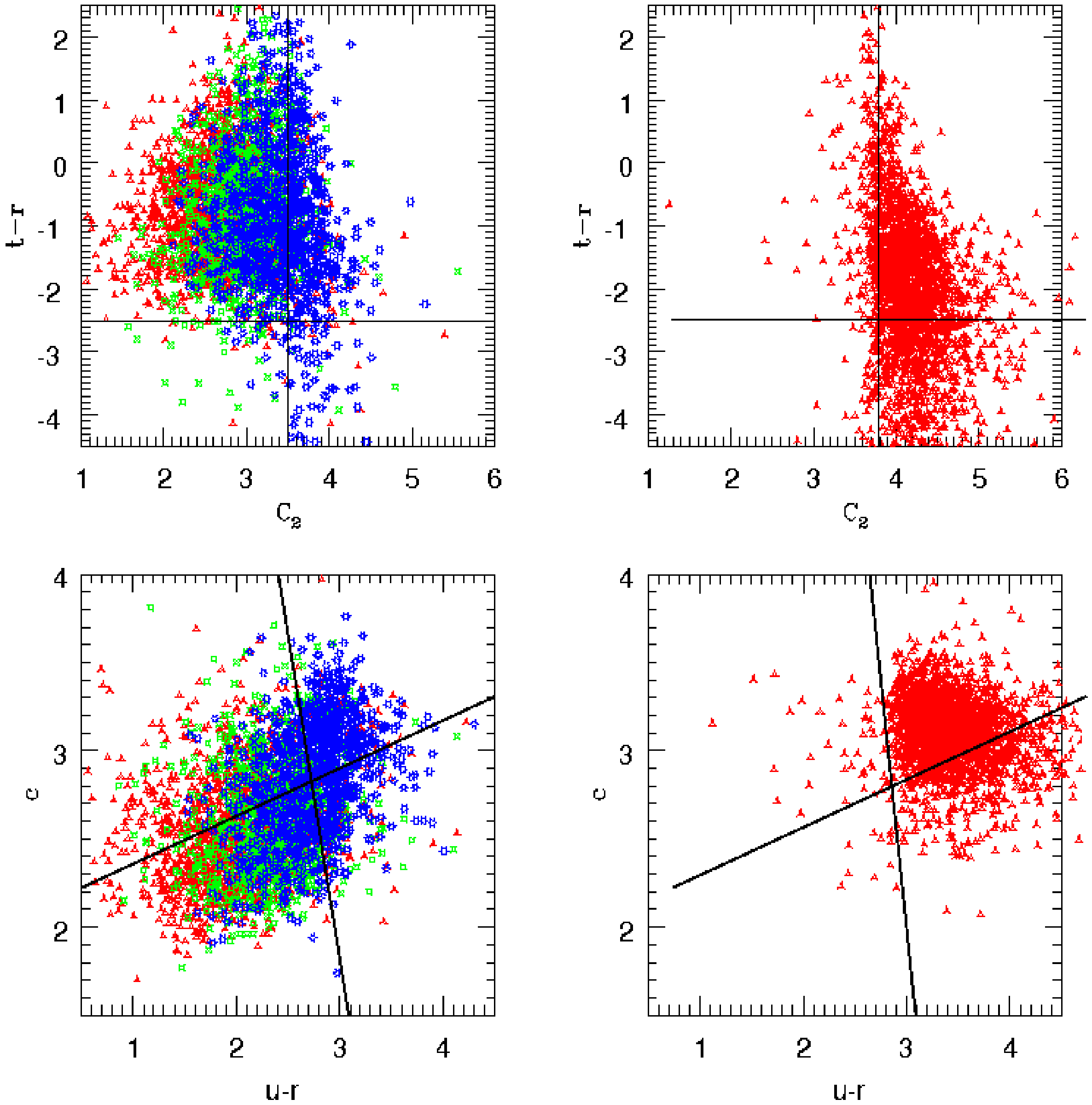
ACTIVE GALATIC NUCLEUS (AGN) UNCLASSIFIED (PASSIVE ELLIPTICAL)

CORRESPONDENCE TO PHOTOMETRIC SPLITS

STAR FORMING

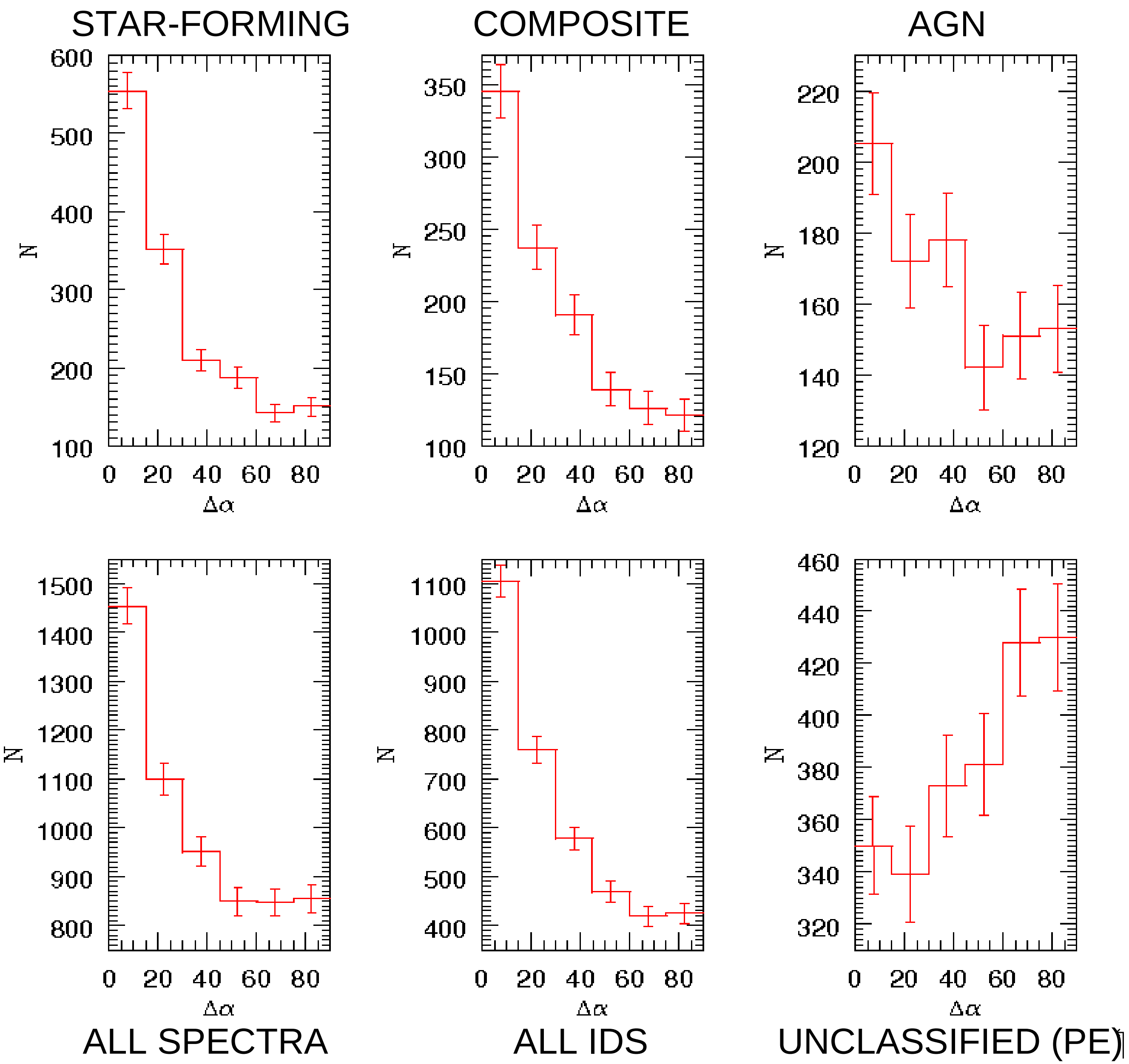
COMPOSITE

AGN



PASSIVE E

SPLIT USING SPECTRAL IDS



DERIVED QUANTITIES

Kauffmann et al 2003, Brinchmann et al 2004

- STELLAR AGE, $t_{stellar}$

  - FROM 4000 A^{O} BREAK

- STELLAR MASS, $M_{stellar}$

  - z-BAND M/L

- STAR-FORMATION RATE (SFR)

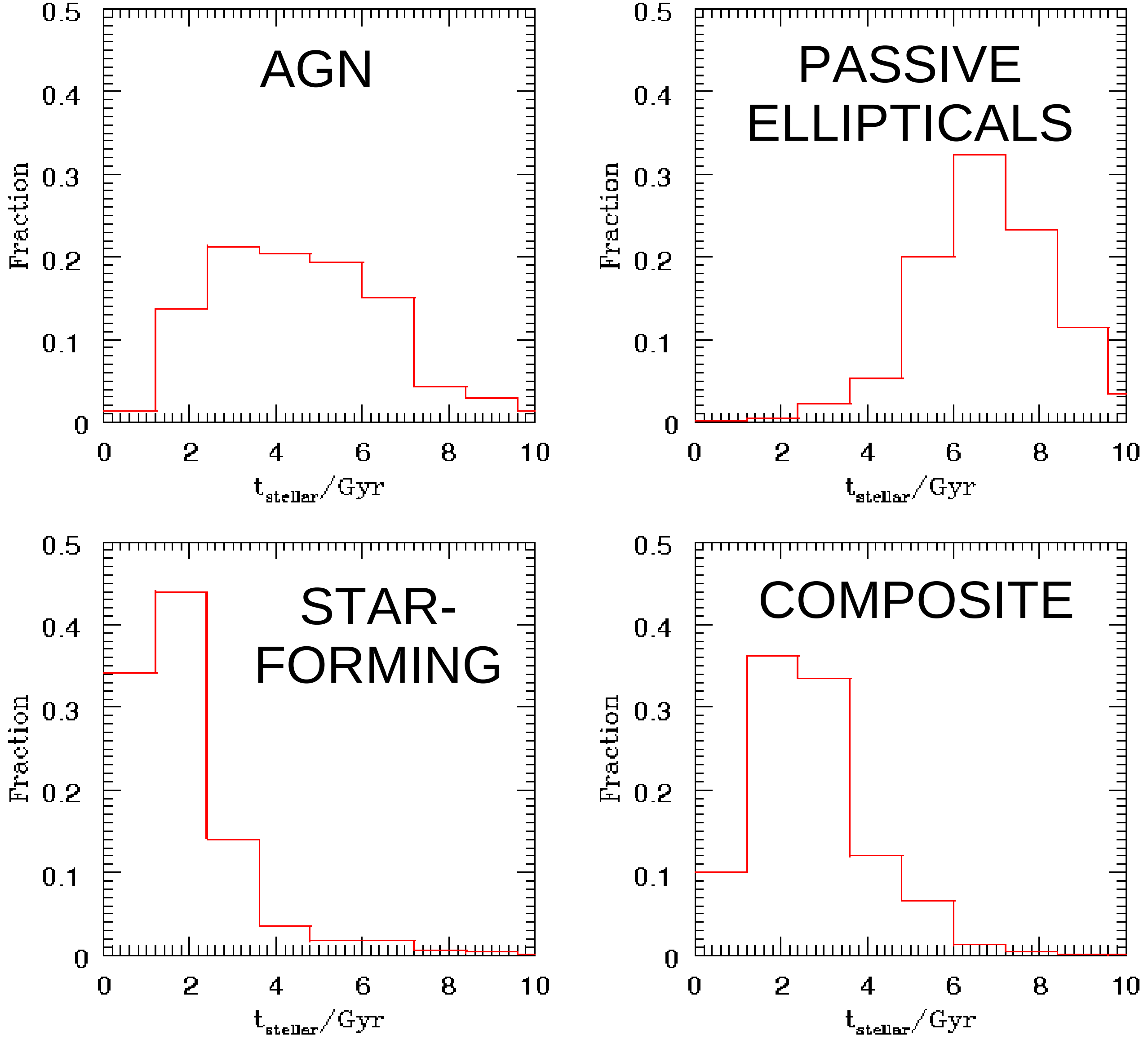
  - RANGE OF LINE RATIOS

- CHARACTERISTIC AGE

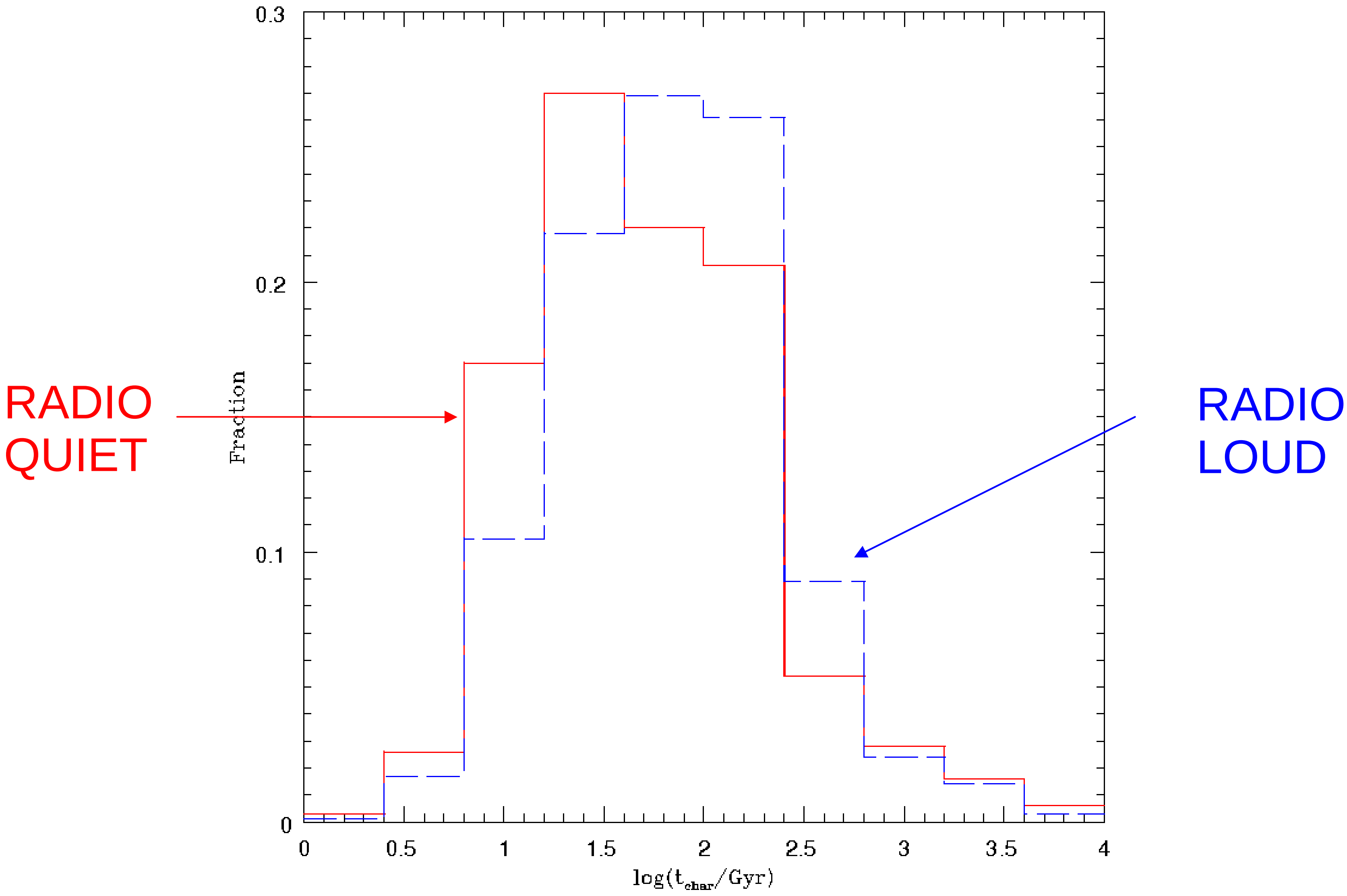
  - $t_{char} = M_{stellar}$ / SFR

COMPUTED BY MPA FOR SDSS DR4

STELLAR AGE


AGN
PASSIVE ELLIPTICALS
STAR-FORMING
COMPOSITE
Fraction
$t_{stellar}$/Gyr
0
0.1
0.2
0.3
0.4
0.5
0
2
4
6
8
10

PROPERTIES OF PASSIVE ELLIPTICALS



RADIO LOUD AND RADIO QUIET ELLIPTICAL ALMOST IDENTICAL

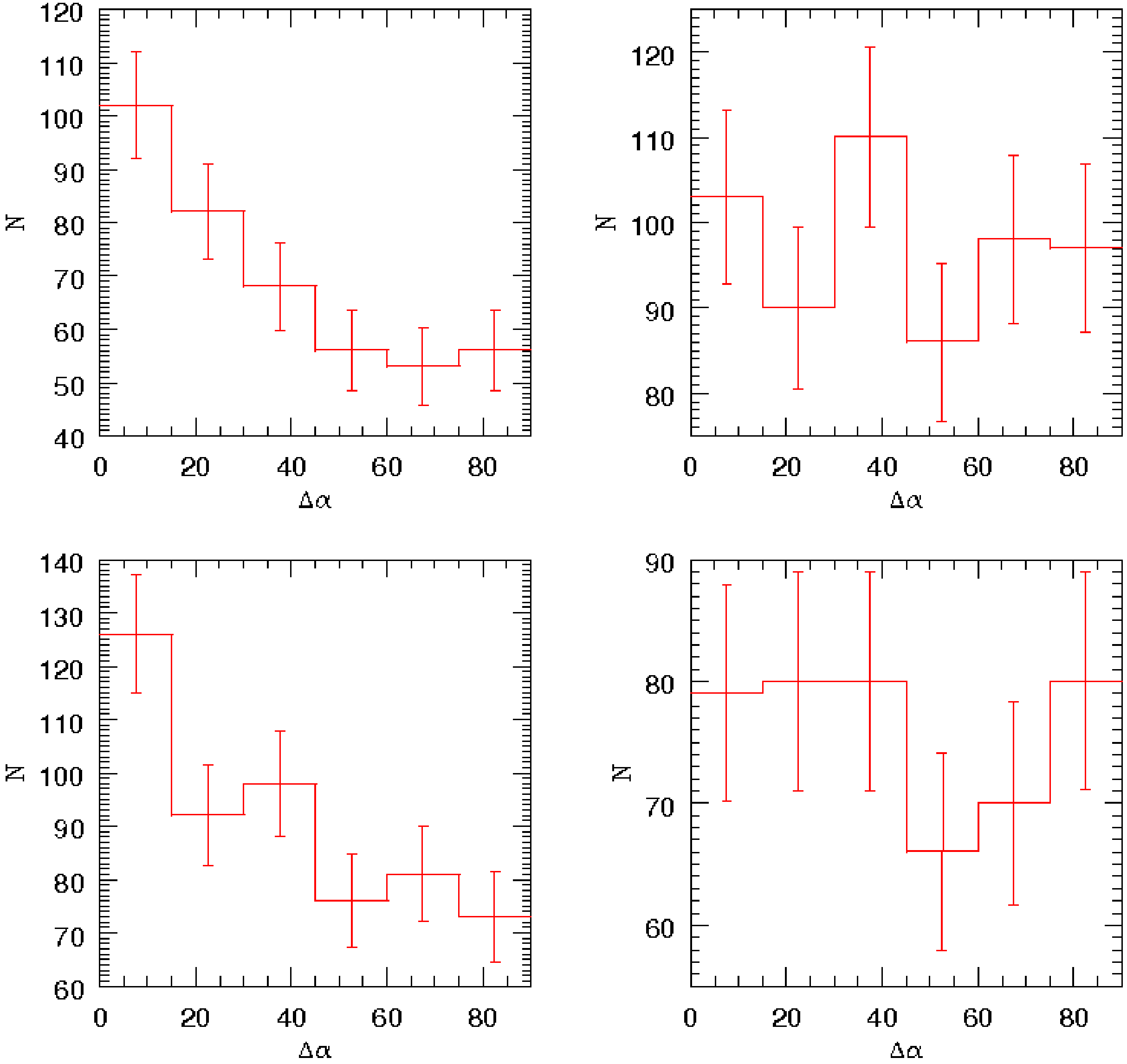
SPLIT OF AGN POPULATION

b/a < 0.6

b/a > 0.6

$C_2 < 3.5$

$C_2 > 3.5$



PHYSICAL PROPERTIES OF AGN

IMAGES :
- SPIRALS

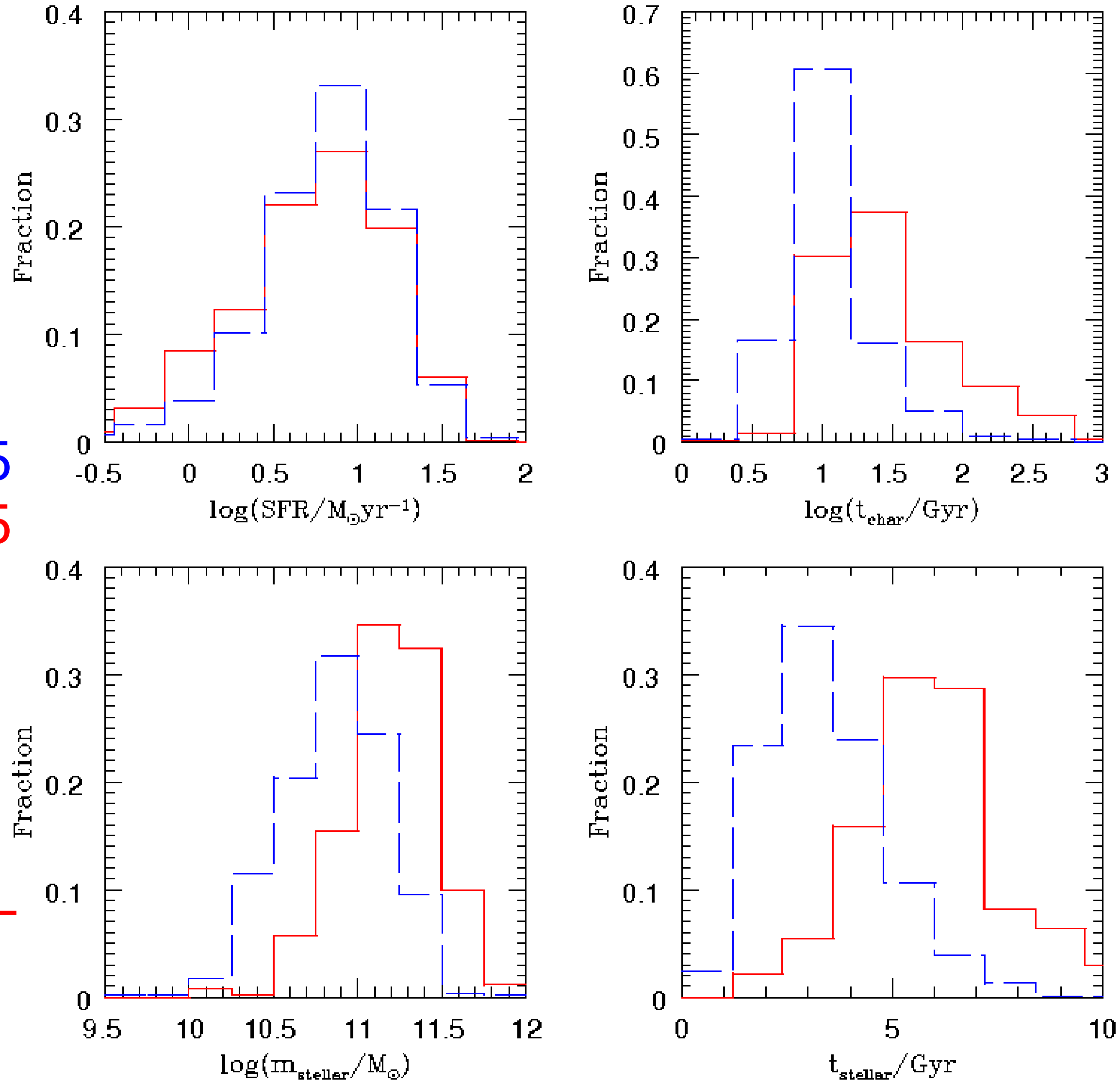
↑

-- = $C_2 < 3.5$

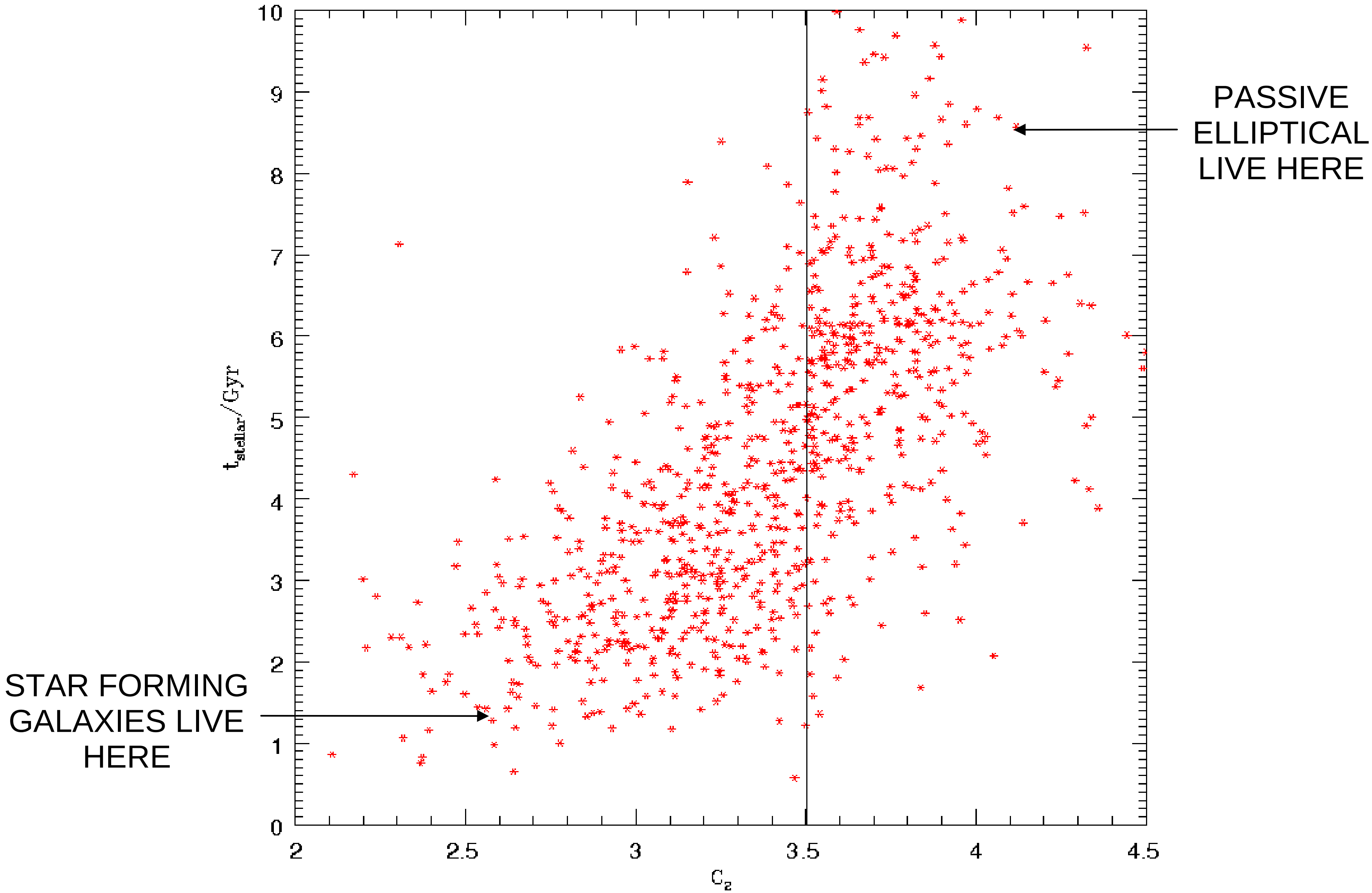
-- = $C_2 > 3.5$

↓

IMAGES :
ELLIPTICAL

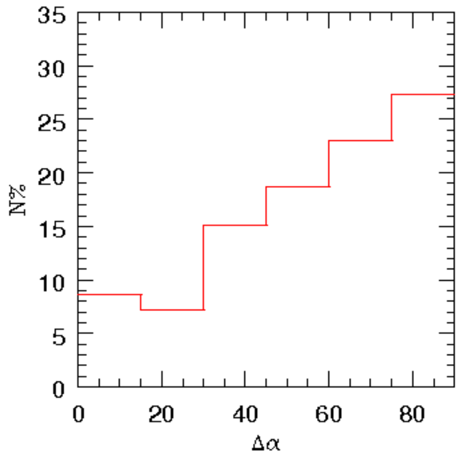


STELLAR AGE VERSUS C_2 FOR AGN

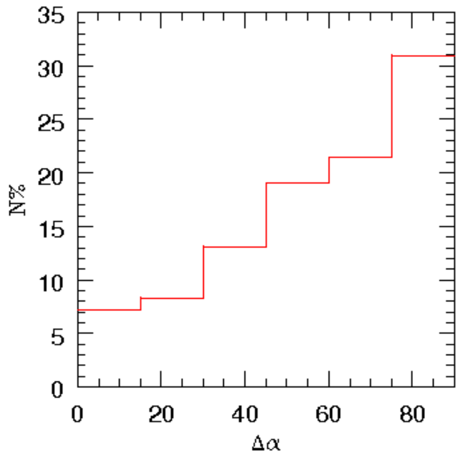


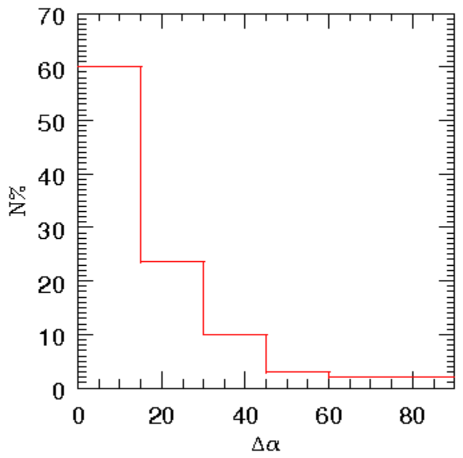
WHAT IS THE INTRINSIC DISPERSION ?

$C_2 > 3.5$, b/a >0.6

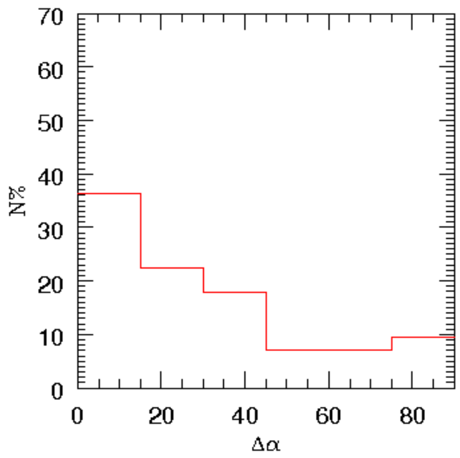


$C_2 > 3.5$, b/a > 0.7





$C_2 < 3.5$, b/a < 0.5



$C_2 < 3.5$, b/a >0.6

ASSUME MEASUREMENT ERROR SAME AS BELOW FOR A GIVEN b/a & IGNORE PROJECTION EFFECTS

< FOR b/a>0.6

< FOR b/a>0.7

→ - INCREASING WITH b/a

CONSISTENT WITH MEASUREMENT NOISE INCREASING WITH b/a

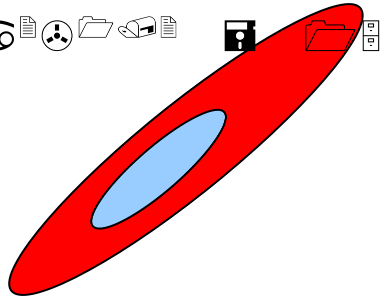
< FOR b/a<0.5

→ - AN UPPER LIMIT ON INTRINSIC DISPERSION

R < 15 & S > 5mJy TO REDUCE NOISE IN PA DETERMINATION

CONCLUSIONS

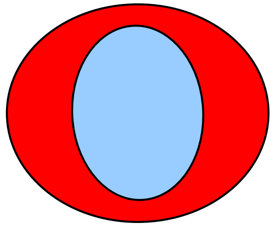
STAR FORMING SPIRALS



SNe DUE TO MASSIVE STAR FORMATION

“RADIO QUIET” ELLIPTICALS

FOR b/a >0.6



FOR b/a >0.7

NUCLEAR JET ACTIVITY

“RADIO LOUD” ELLIPTICALS

- UNIFORM DISTRIBUTION
- ALMOST IDENTICAL TO “QUIET”
- DECOUPLED CORE ?
- ENVIRONMENT ? TRIAXIAL ?

ACTIVE GALACTIC NUCLEI

SPIRALS :

- SAME AS STAR-FORMING

ELLIPTICALS :

- UNIFORM DISTRIBUTION

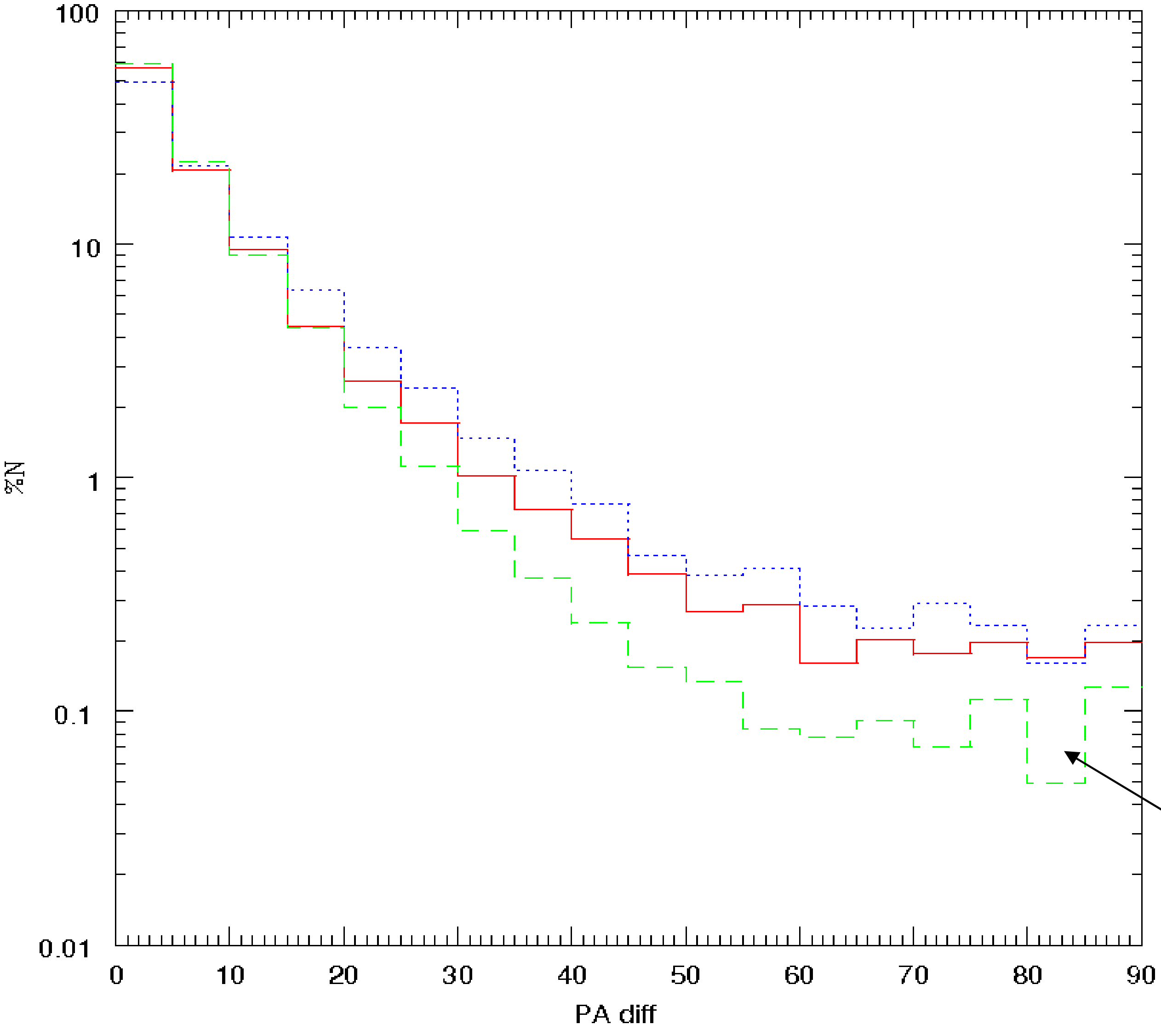
RADIO AND OPTICAL ORIENTATION OF GALAXIES

RICHARD BATTYE
JBCA
UNIVERSITY OF MANCHESTER

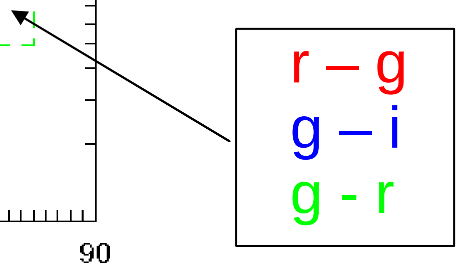
IN COLLABORATION WITH IAN BROWNE

arXiV:0902.1632, submitted to MNRAS

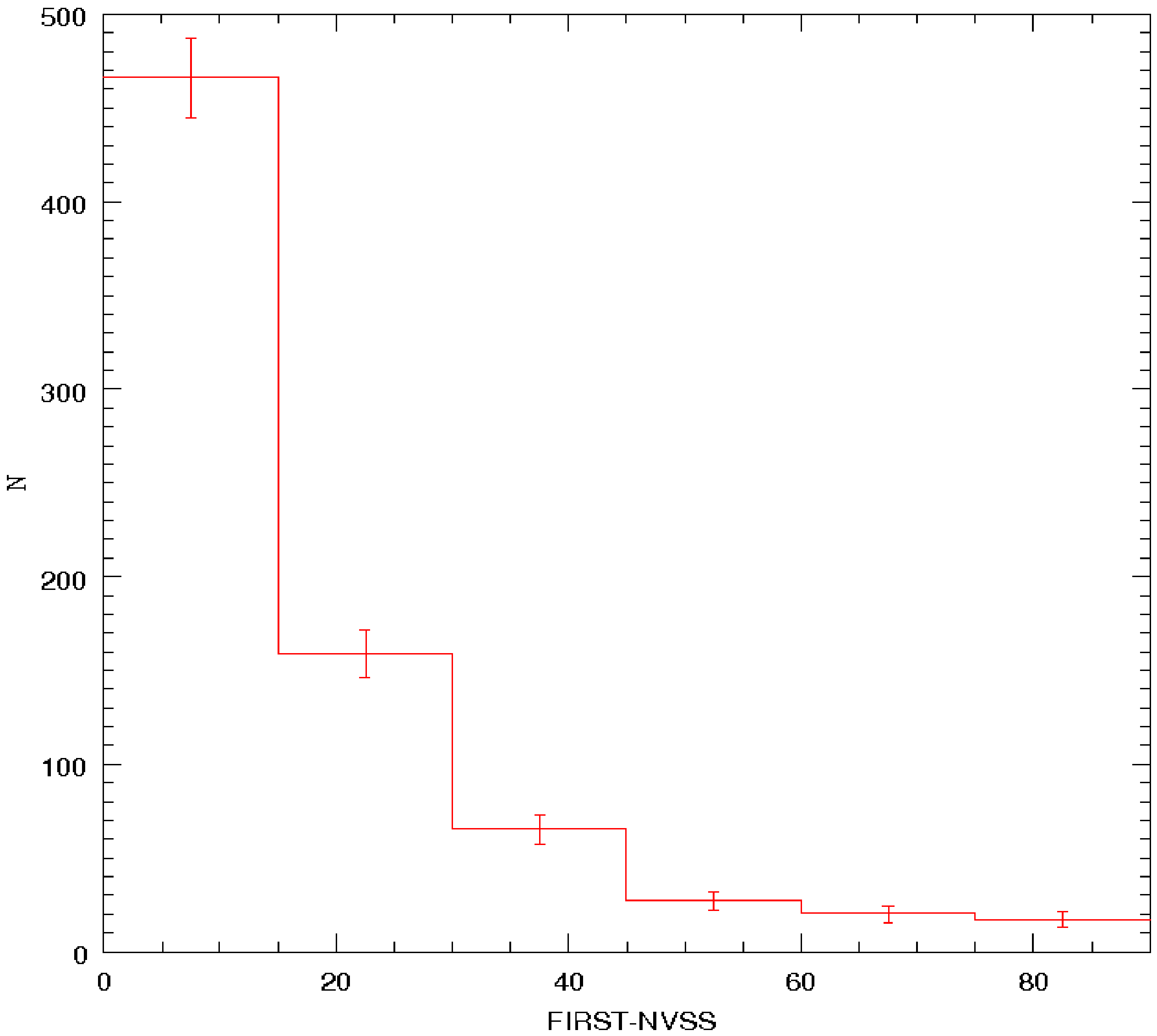
ACCURACY OF POSITION ANGLES : OPTICAL



COMPARISON OF POSITION ANGLES MEASURED IN SDSS BANDS



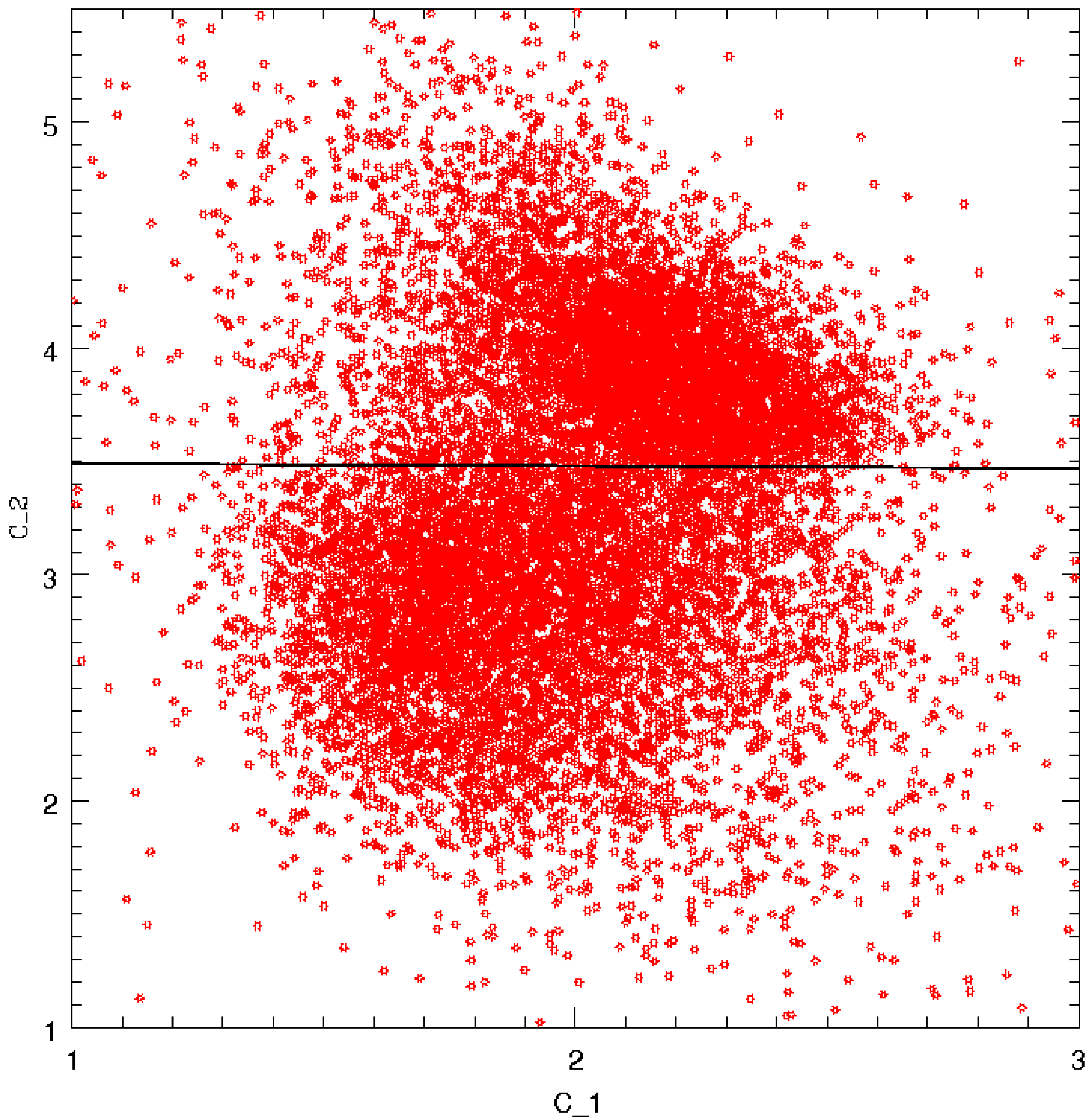
ACCURACY OF POSITION ANGLES : RADIO



754 FIRST SOURCES ARE WITHIN 15 ARCSEC OF NVSS SOURCES

THEIR POSITION ANGLES AGREE WELL !

PRINCIPAL COMPONENT ANALYSIS



$C_1 = 0.965c - 0.262(u\text{-}r)$ $C_2 = 0.262c + 0.965(u\text{-}r)$

COLOUR - CONCENTRATION