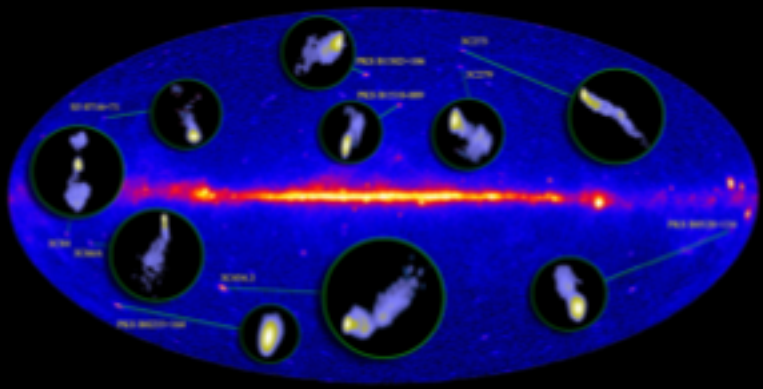
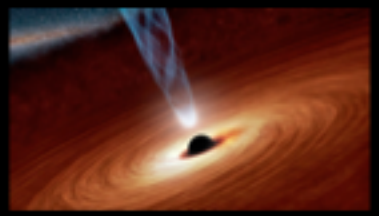
Systematics of Jets from AGN:

Prajval Shastri

Indian Institute of Astrophysics, Bangalore





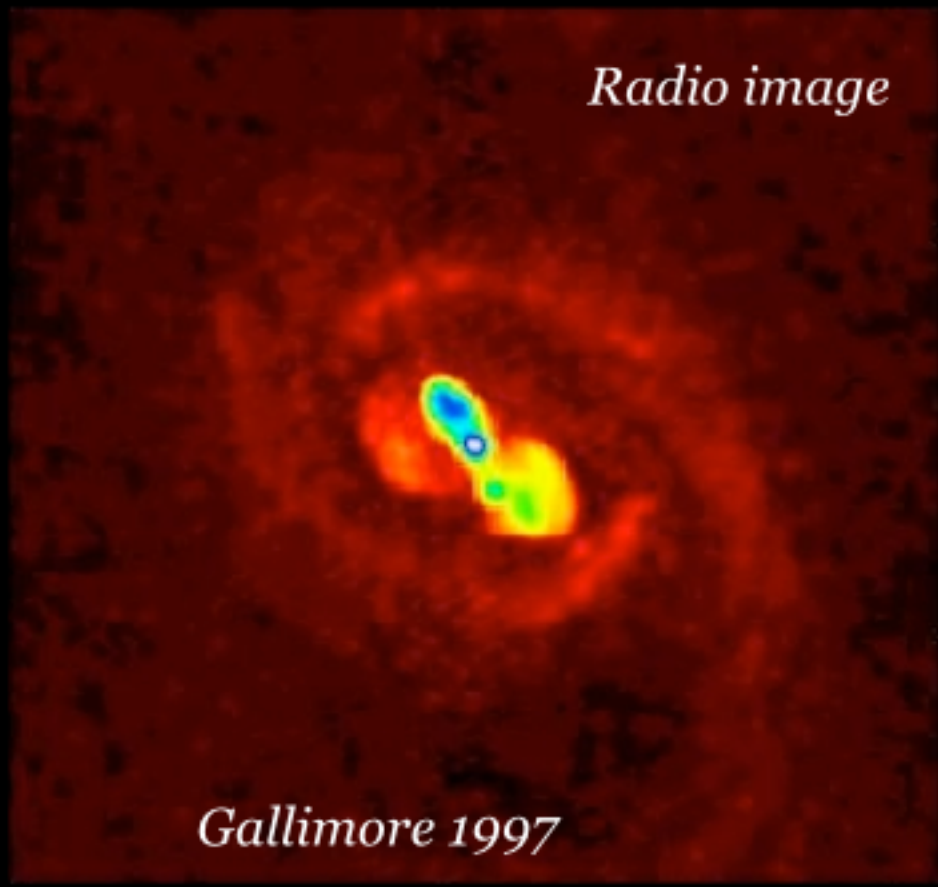
Collaborators:

Estrella Jimenez Gomez

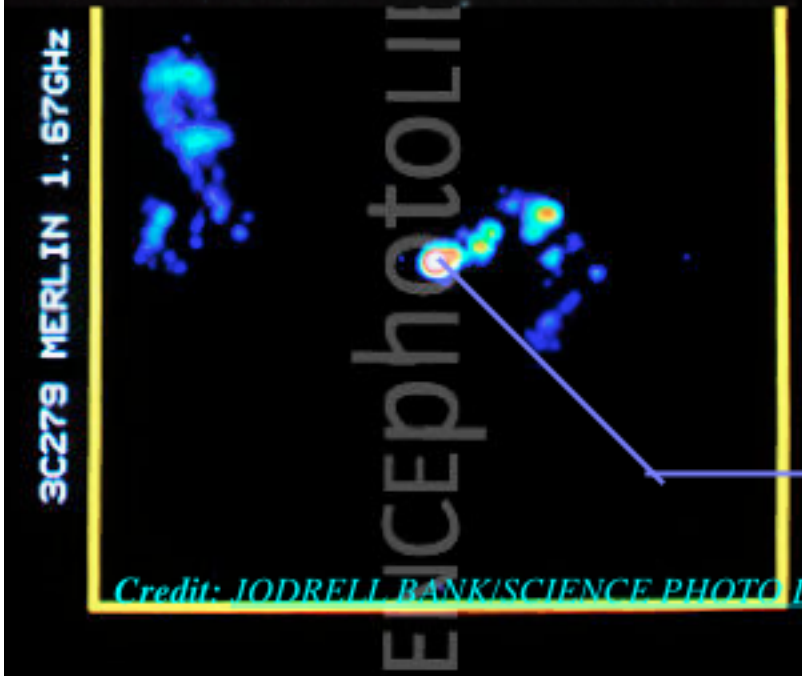
Maitrayee Gupta

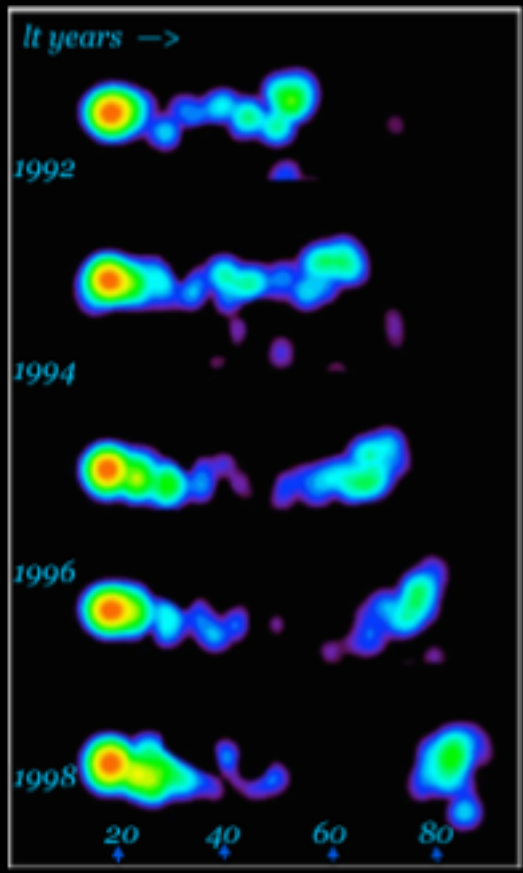
Greg Madejski

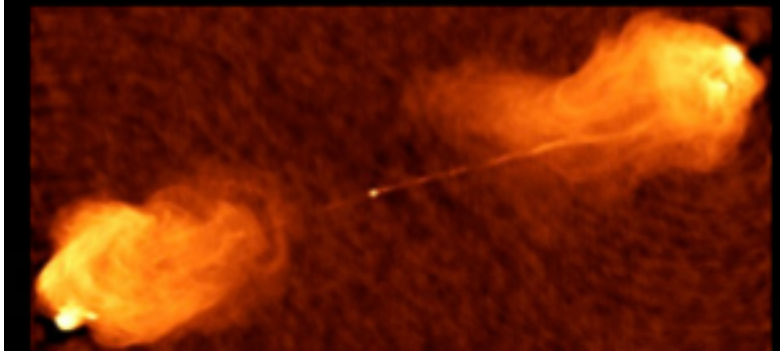
As far as we can tell all accreting supermassive black holes produce bipolar synchrotron-emitting jets
Majority cases: jets confined to within the host galaxy scale ~kpc: Radio "quiet" AGNs



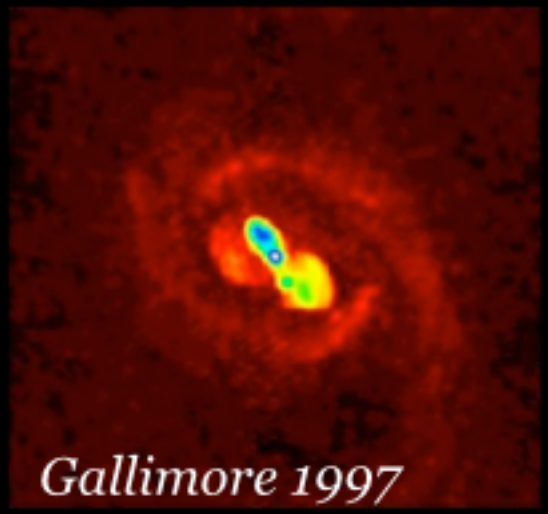
A minority produce high kinetic power bulk-relativistic jets:
scale ~ 100s of kpc - 1Mpc
Radio "Loud":
Doppler beamed when directed close to the line-of-sight







low kinetic power jets



Gallimore 1997

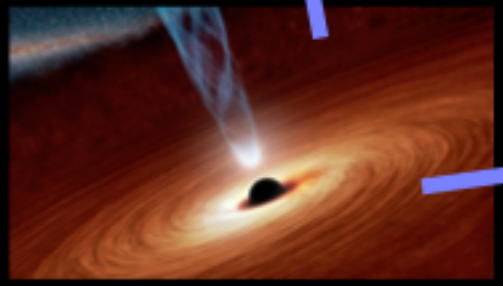
- *mildly relativistic jets?* Yes
- *In spiral galaxy hosts?* maybe
- *Black hole not spinning?* NO

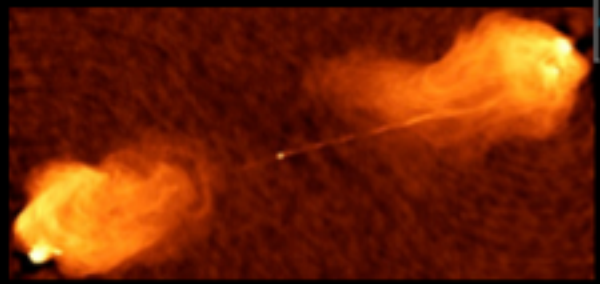
"Radio-quiet"

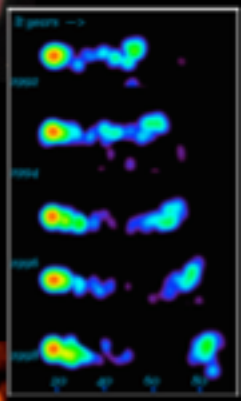
"Radio-loud"

high kinetic power bulk-relativistic jets

- *Highly relativistic jets?* Yes
- *In elliptical galaxy hosts?* Maybe
- *Black hole spinning?* YES



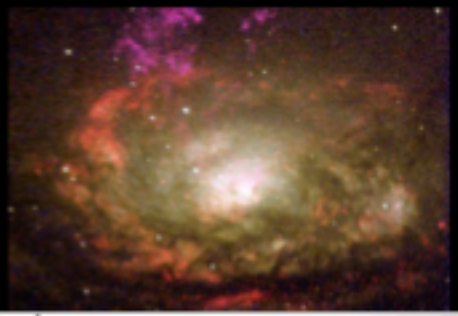




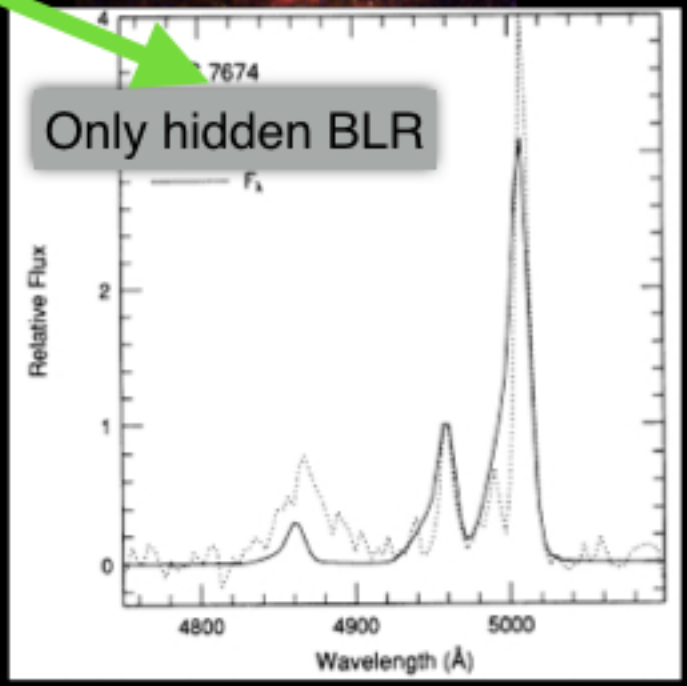
Among the low kinetic=power jet (i.e. "radio-quiet") AGNs, the absence of a BLR has often been explained by the presence of an obscuring toroidal matter of gas and dust around the accreting supermassive black hole

Seyfert Galaxies

Type 2

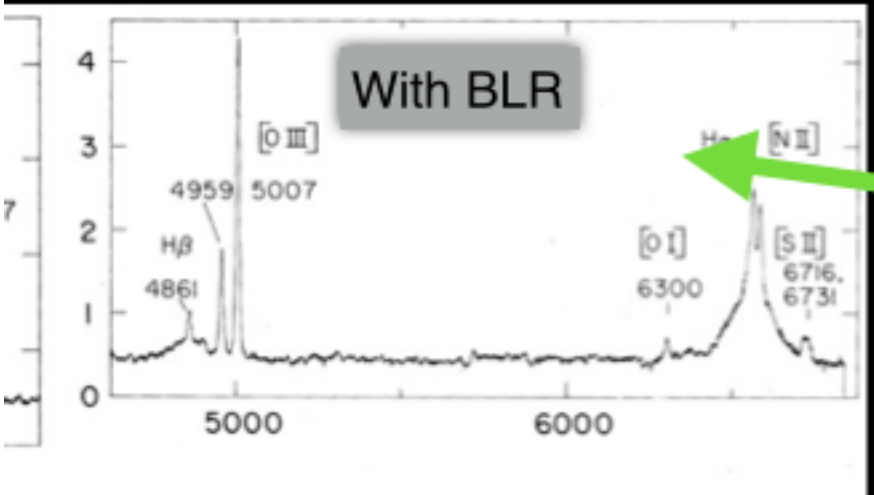


Only hidden BLR



Type 1

With BLR



Unified models don't assert that just any old (famous) Seyfert 1 is to be identified with any old Seyfert 2

- Antonucci 2001

Intrinsically similar Sy1 and Sy2s:

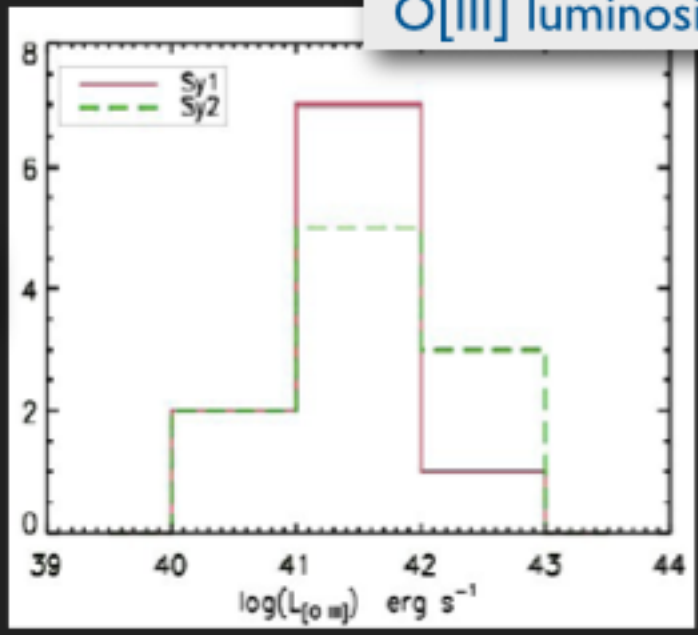
Seyfert 1s & Seyfert 2s: (~ 10 each)

Radio quiet, low B luminosity in face-on spiral hosts

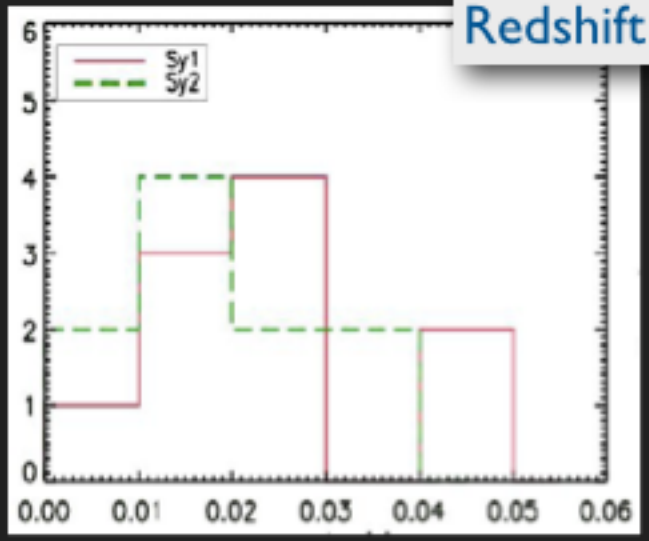
with matched distributions of :

- *[OIII] luminosities (proxy for AGN power)*
- *Redshifts*
- *Hubble type of host galaxy*
- *Stellar & bulge luminosity of the host galaxy*

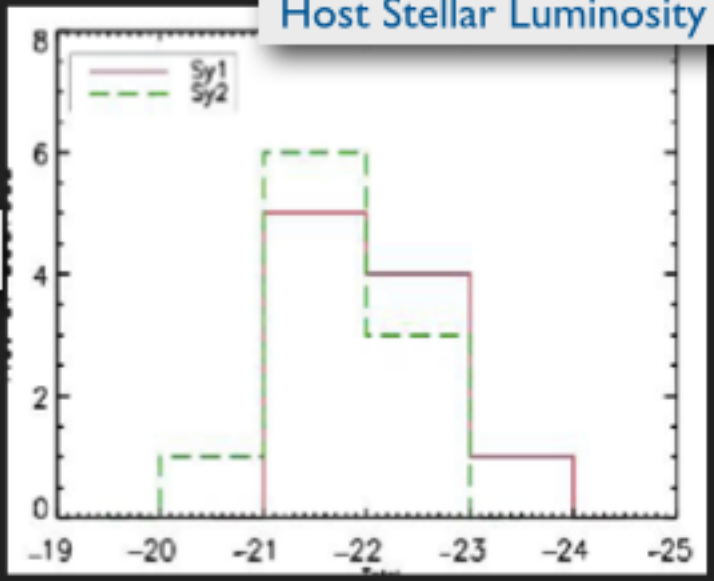
O[III] luminosity



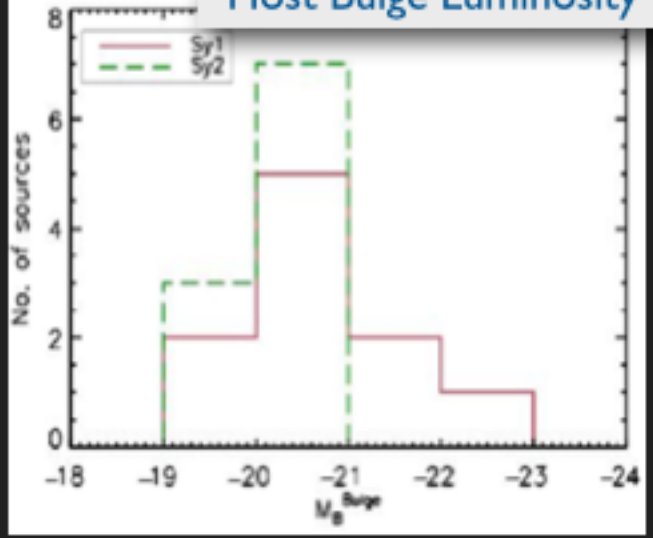
Redshift



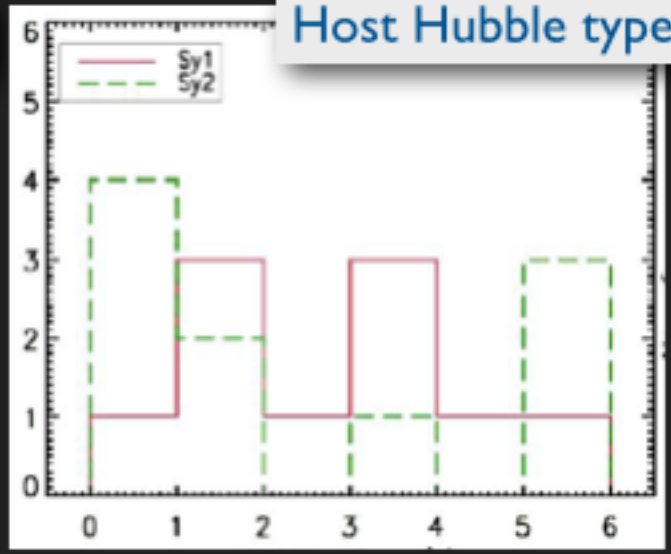
Host Stellar Luminosity

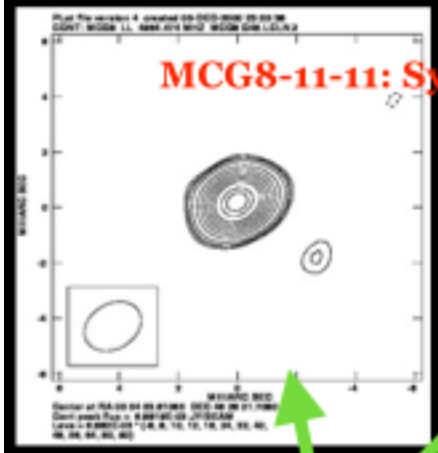


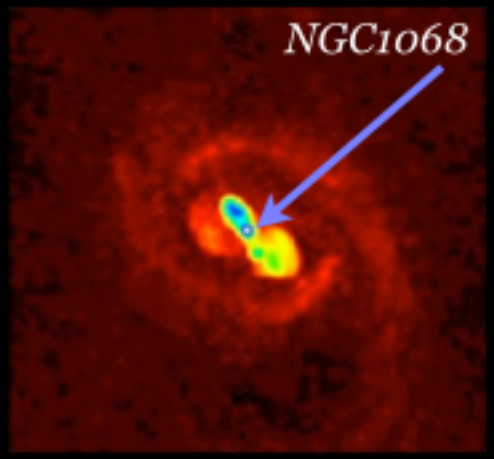
Host Bulge Luminosity



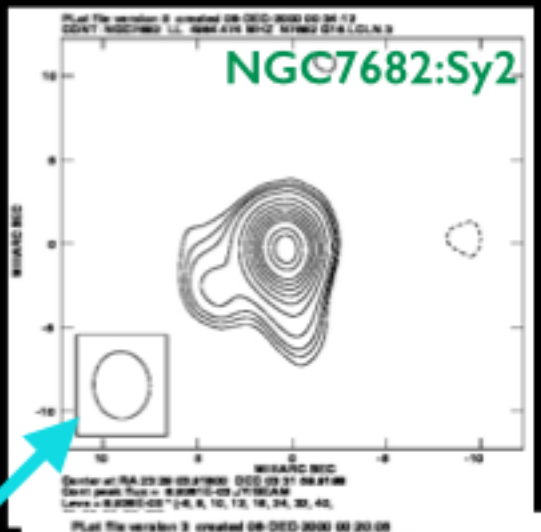
Host Hubble type

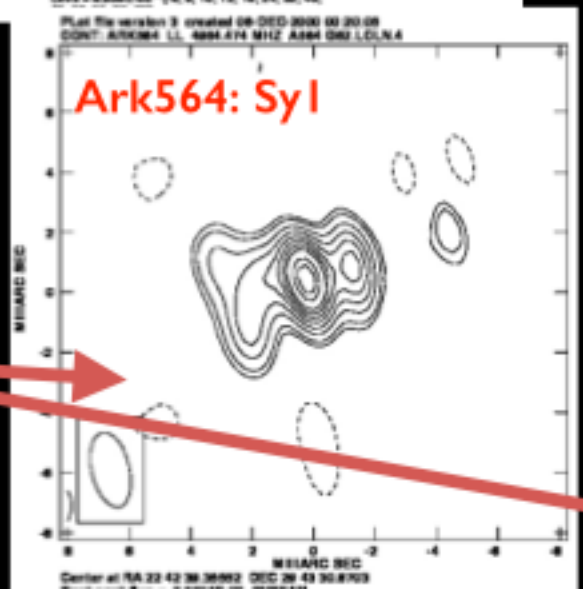


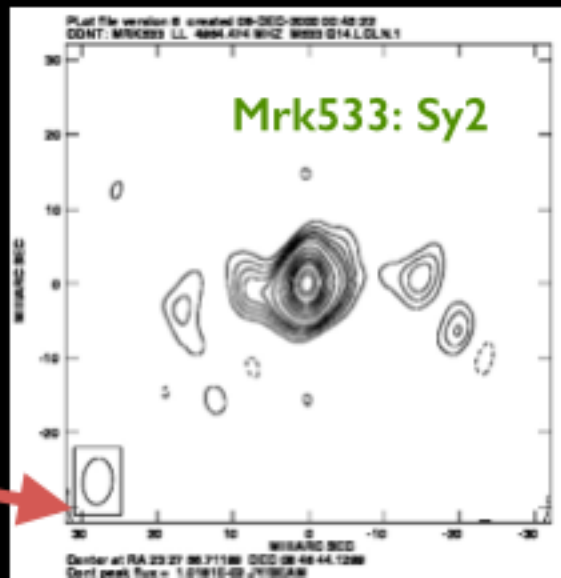




Gallimore 1997





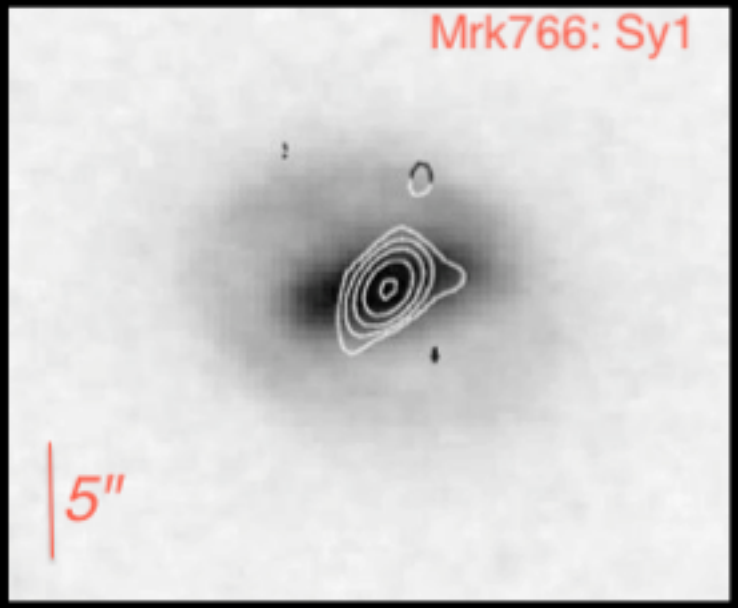


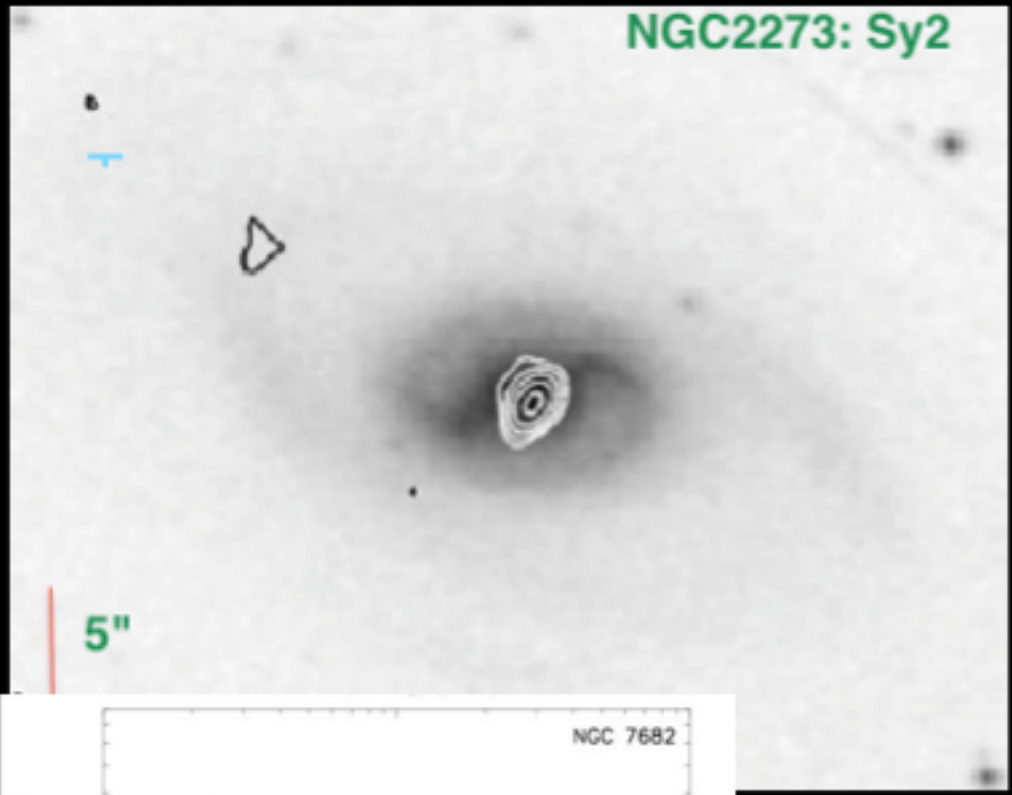
Parsec-scale radio structures are similar in Seyfert 1s & Seyfert 2s: Both kinds show unresolved, "core-jet" and "linear" structures.

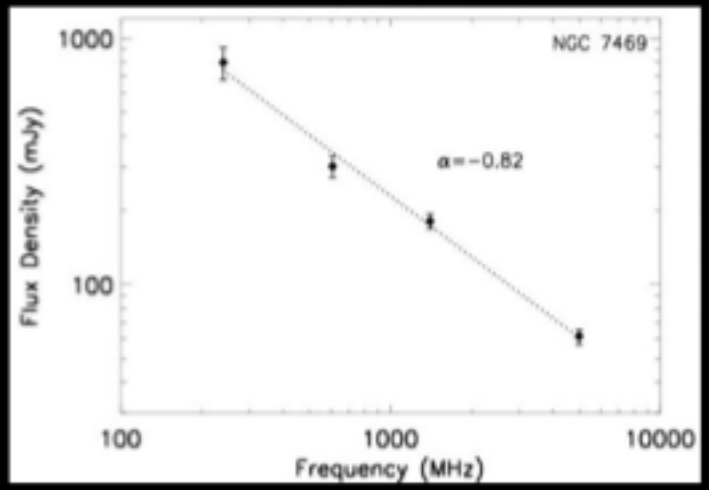
Lal Shastri Gabuzda 2011

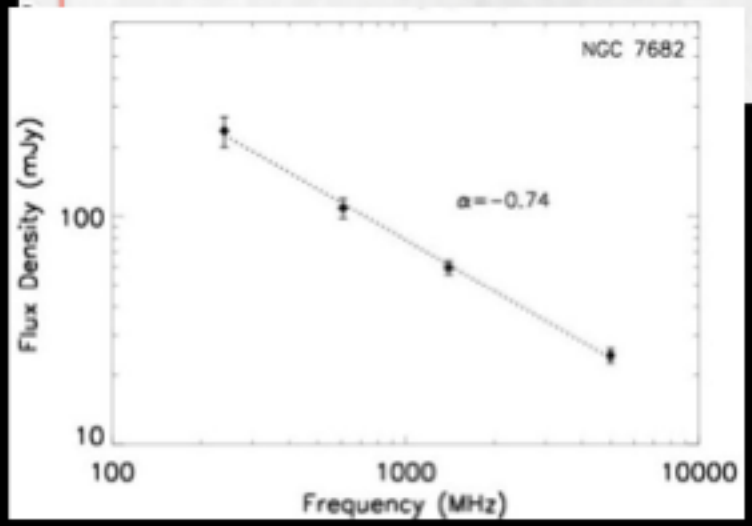
Low radio-frequency emission is primarily from the nucleus and the luminosity and spectral indices are similar in the two types of Seyferts

GMRT 610MHz images

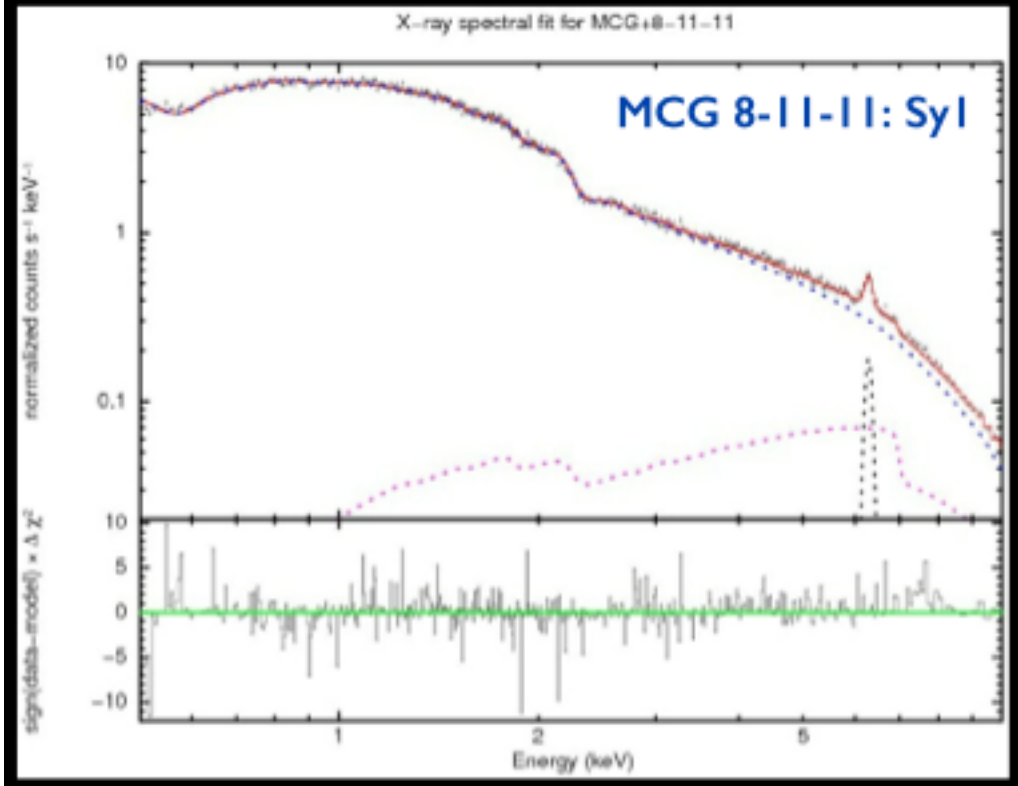


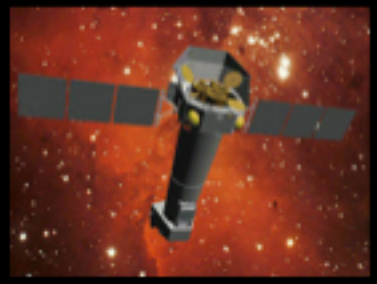




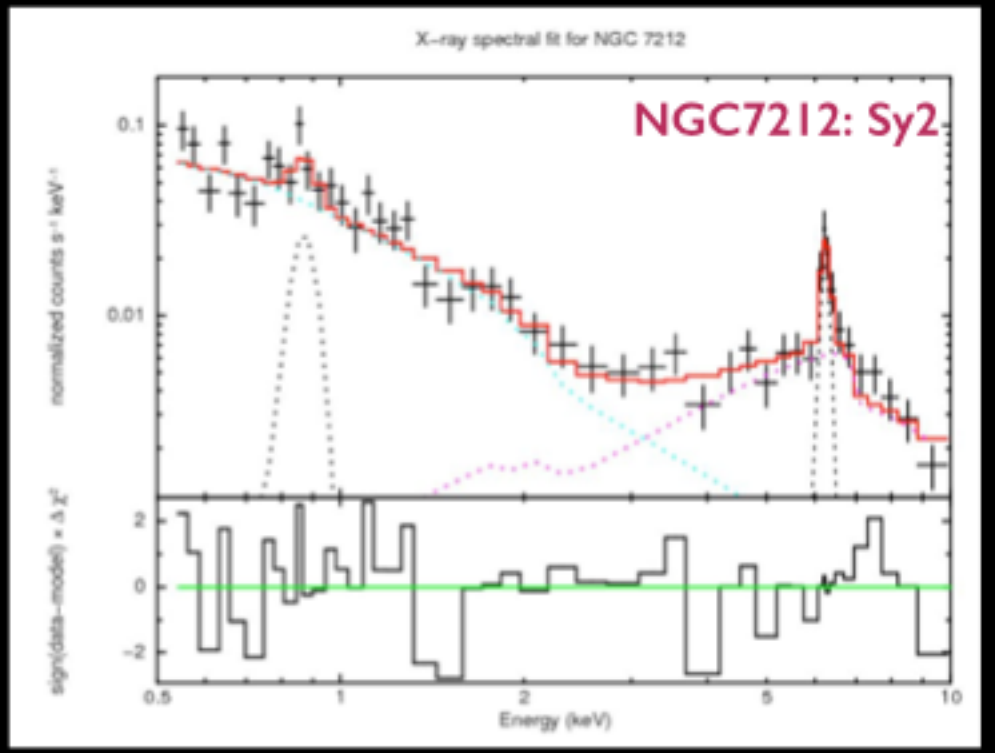


Singh, Shastri Ishwara Chandra & Athreya 2013





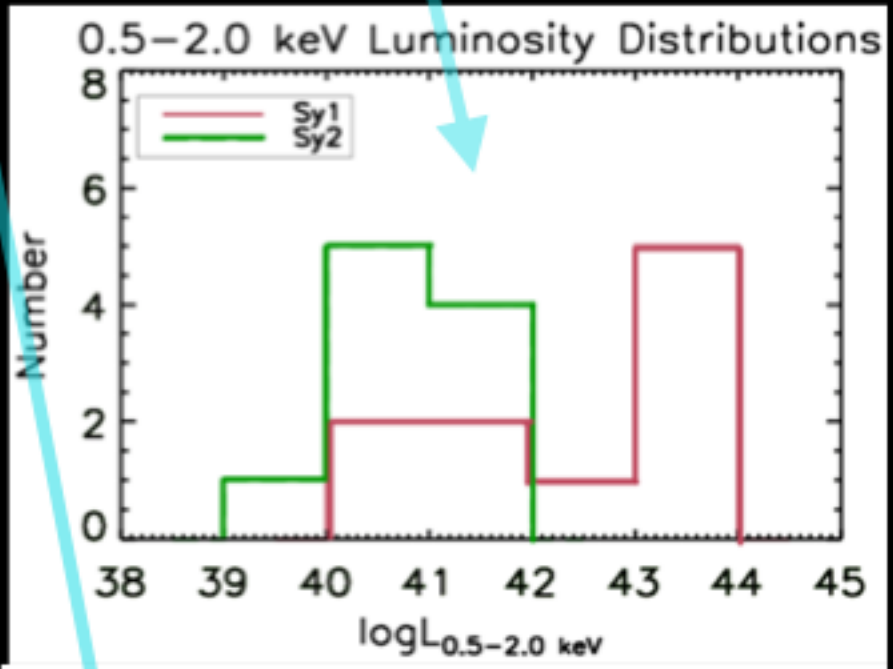
- *Archival XMM-Newton data*

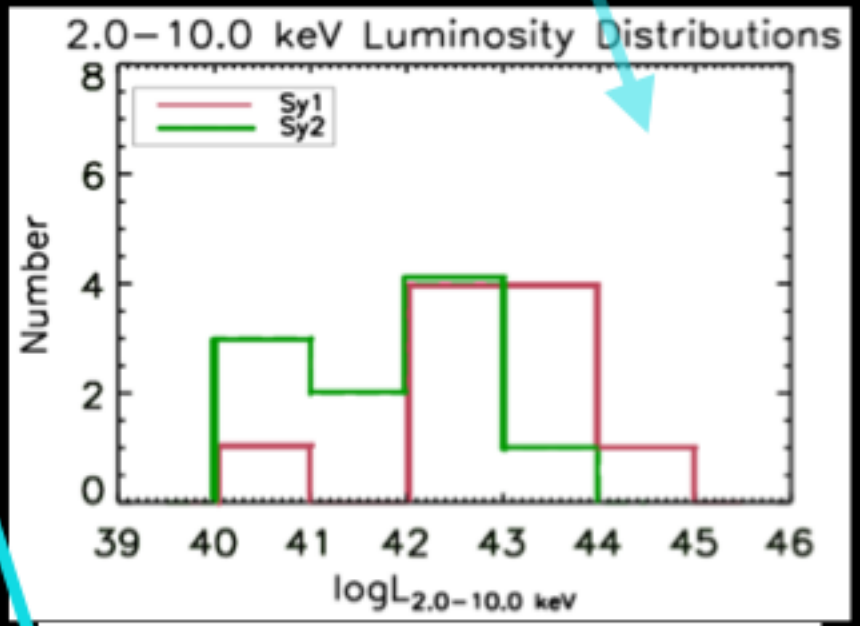


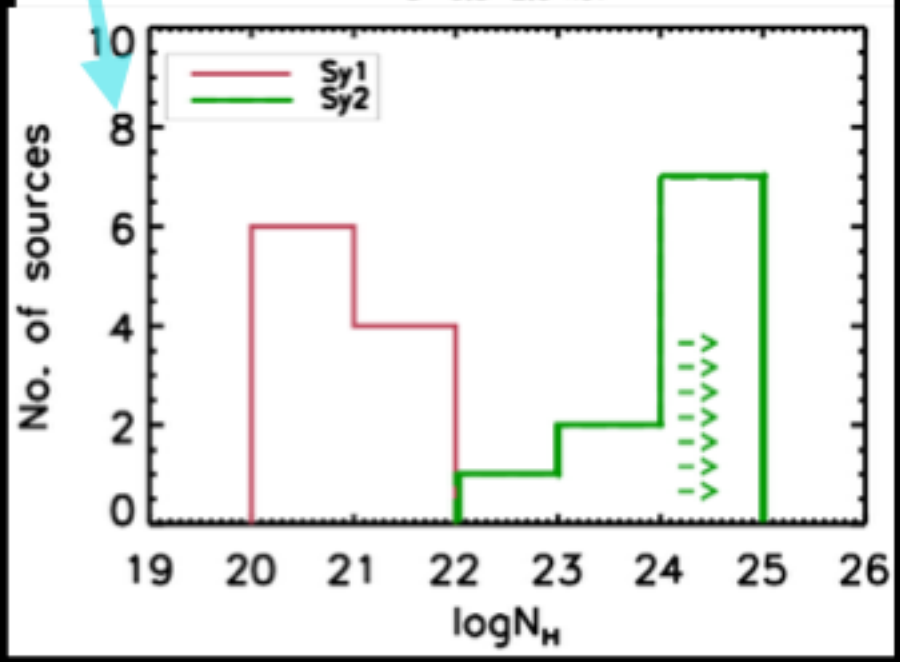
The X-ray spectra of the two Seyfert types systematically differ in the expected way:

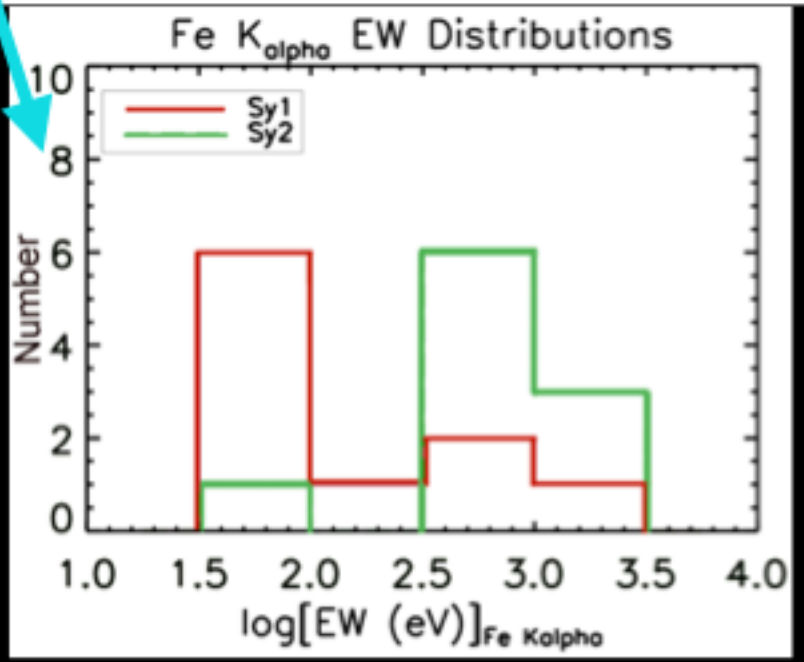
Singh, Shastri & Risaliti 2011

Significantly lower soft X-ray luminosities, less significantly lower hard X-ray luminosities, far higher absorbing columns and Fe Kα equivalent widths in Sy2s compared to Sy1s

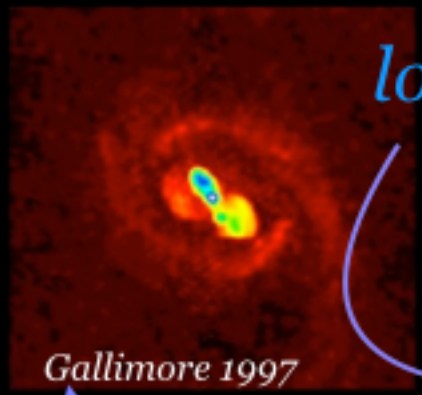








Singh, Shastri & Risaliti 2011


Gallimore 1997

low kinetic power jets

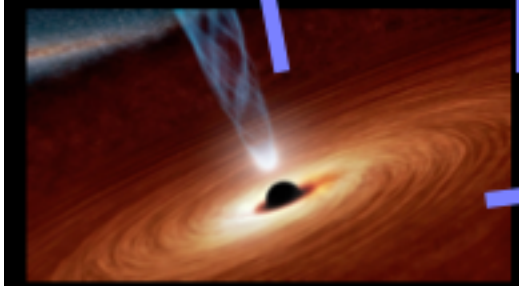
- *mildly relativistic jets?* Yes
- *In spiral galaxy hosts?* Maybe
- *Black hole not spinning?* NO

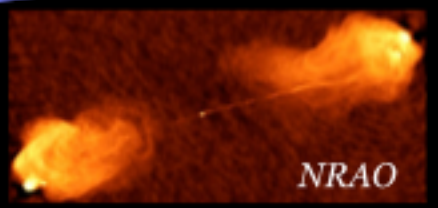
absence of BLR =>
obscuring toroidal matter

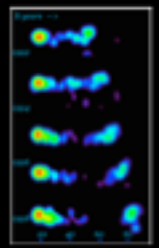
also applies to the high kinetic power bulk-relativistic jets that are FRIIs

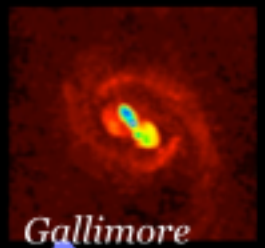

CSIRO

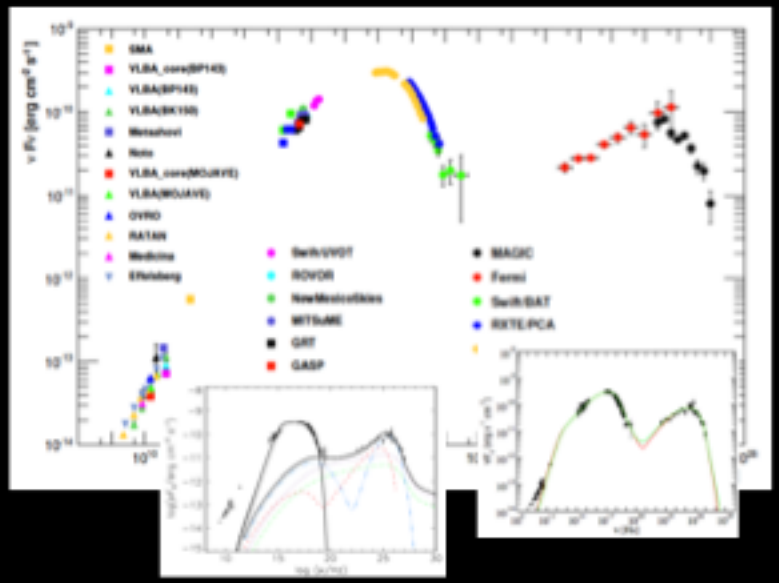
- *Highly relativistic jets?* Yes
- *In elliptical galaxy hosts?* Maybe
- *Black hole spinning?* YES




NRAO




Gallimore

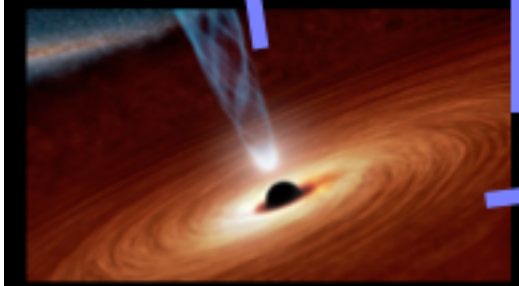


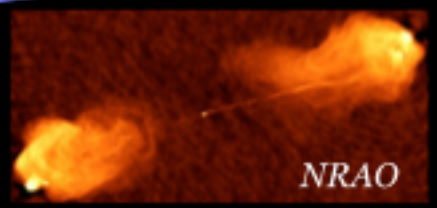
Doppler-beamed bulk-relativistic jets:

absence of BLR cannot be explained by obcuring toroidal matter being edge-on


CSIRO

- *Highly relativistic jets? Yes*
- *In elliptical galaxy hosts? Maybe*
- *Black hole spinning? YES*

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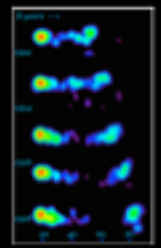

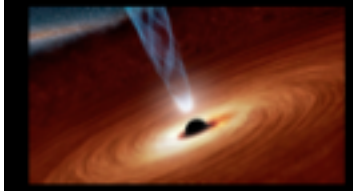

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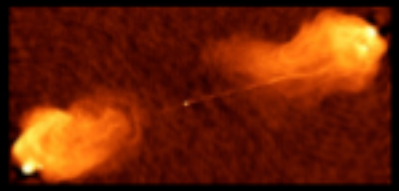
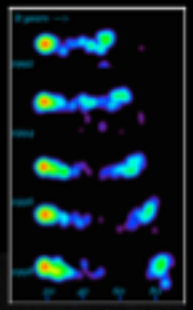
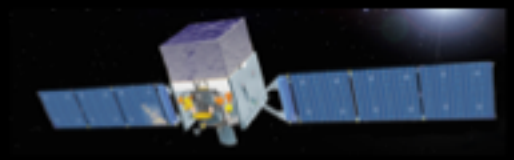
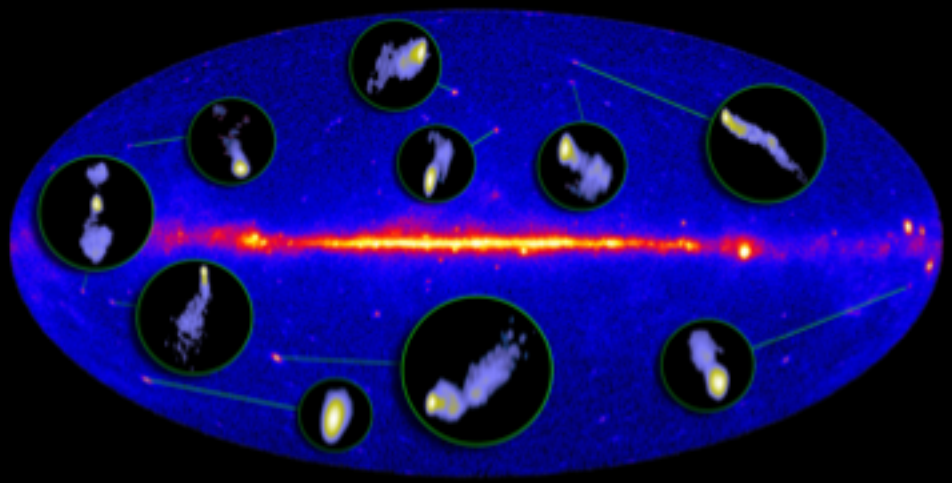


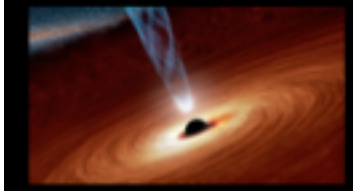


systematics of the highly Doppler beamed high-kinetic power jets:

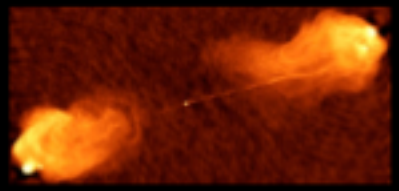


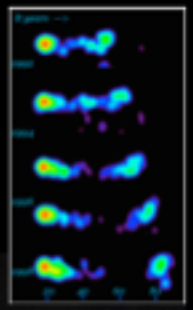


Credit: NASA/DOE/Fermi LAT Collaboration & NRAO/AUI/MOJAVE Team/M. Kadler

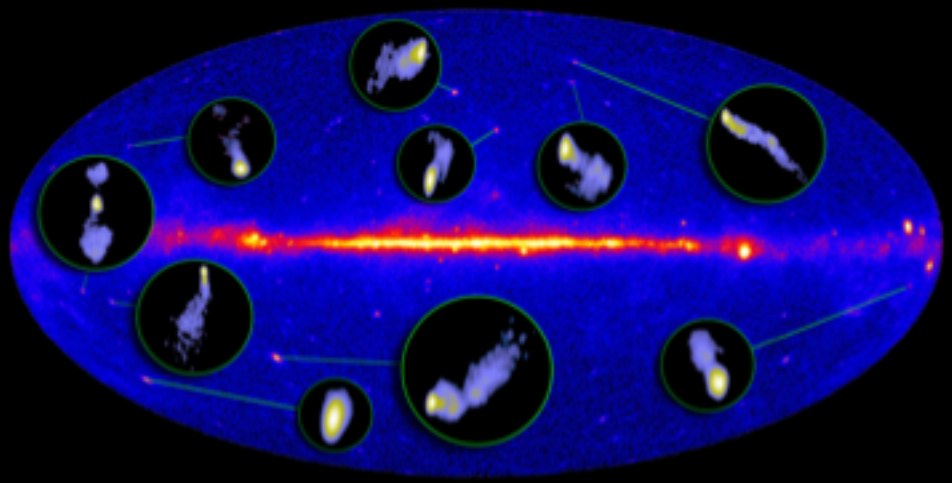


- *Highly relativistic jets?* Yes
- *In elliptical galaxy hosts?* Maybe
- *Black hole spinning?* YES



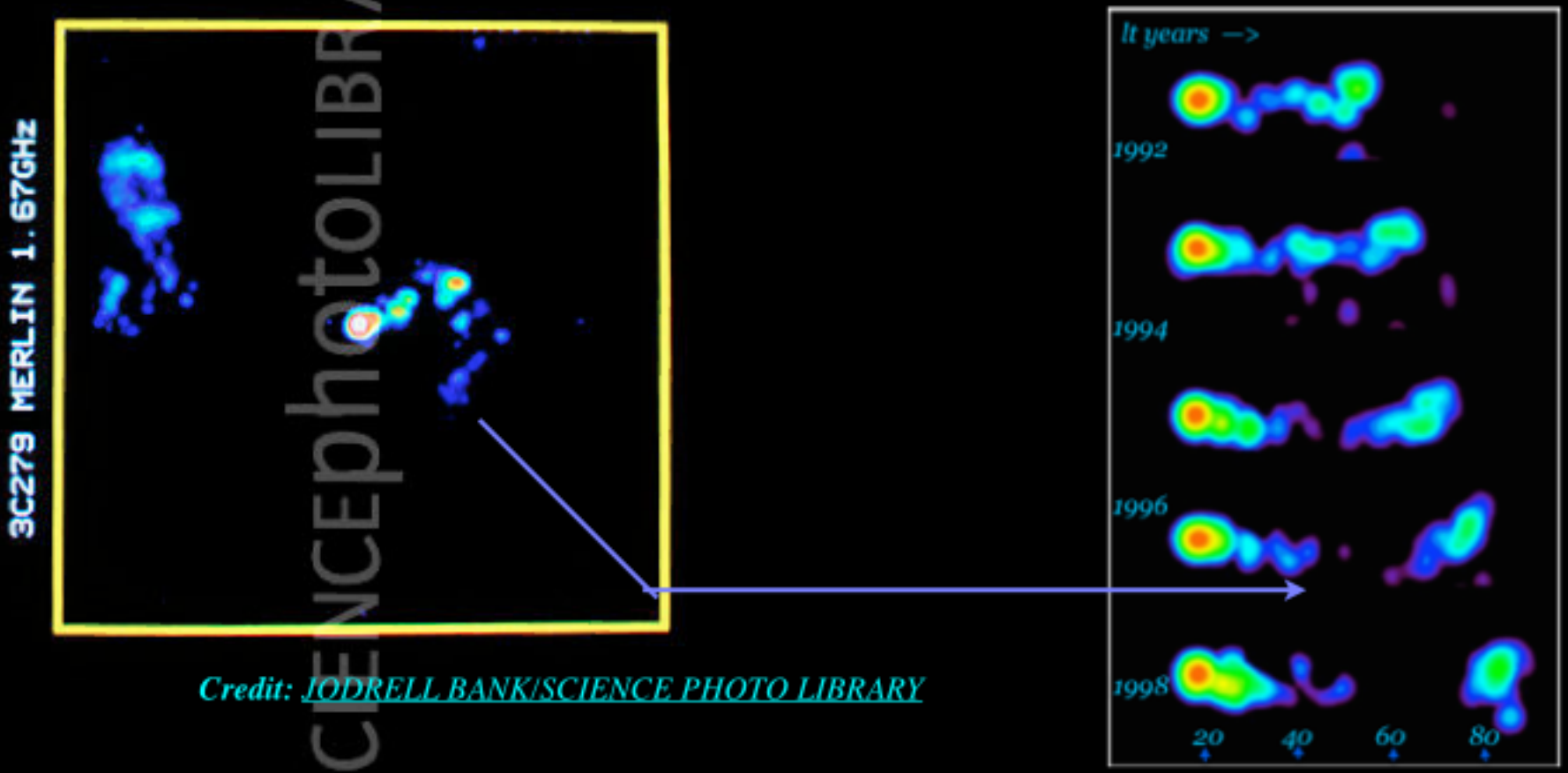


Work in Progress:
Prelude to:
following Bev Footsteps



Credit: NASA/DOE/Fermi LAT Collaboration & NRAO/AUI/MOJAVE Team/M. Kadler

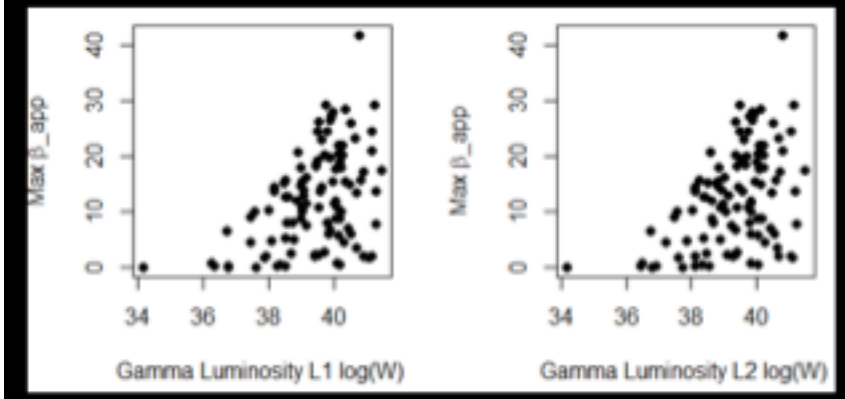
$\beta_{apparent}$; proper motion speed of the moving component

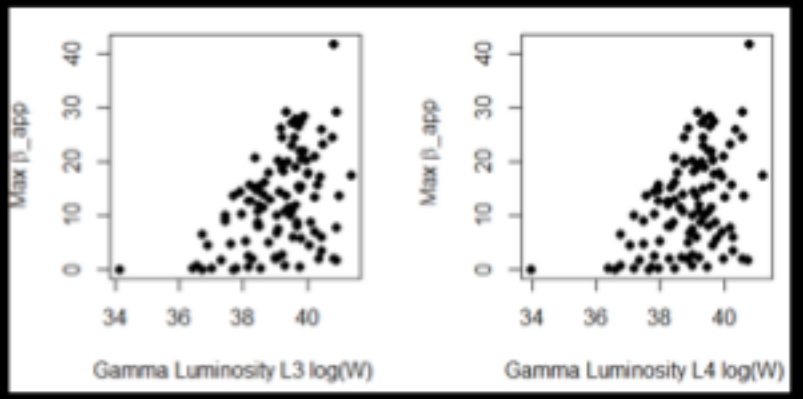


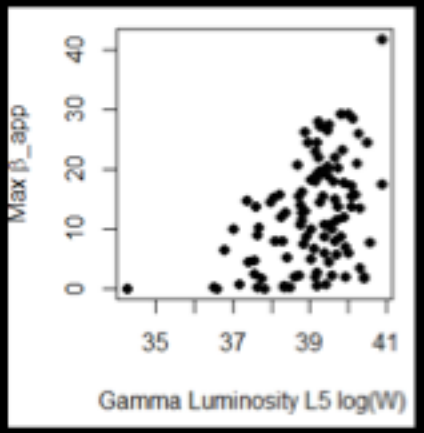
Credit: JODRELL BANK/SCIENCE PHOTO LIBRARY

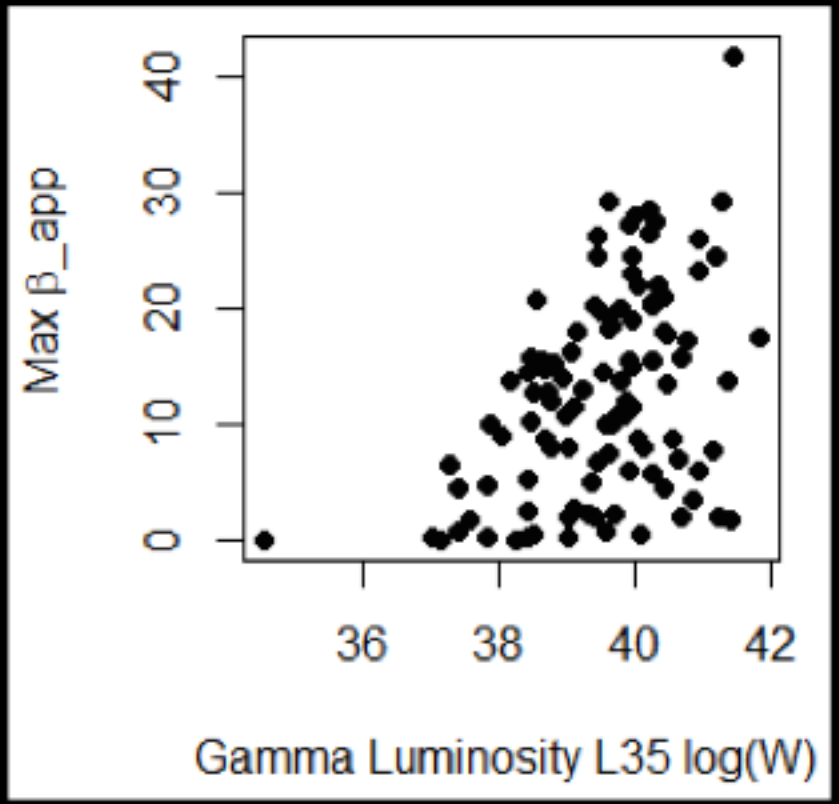
maximum $\beta_{apparent}$ - Gamma ray Luminosity:

different energy bands









1: 100-300MeV

2: 300-1000MeV

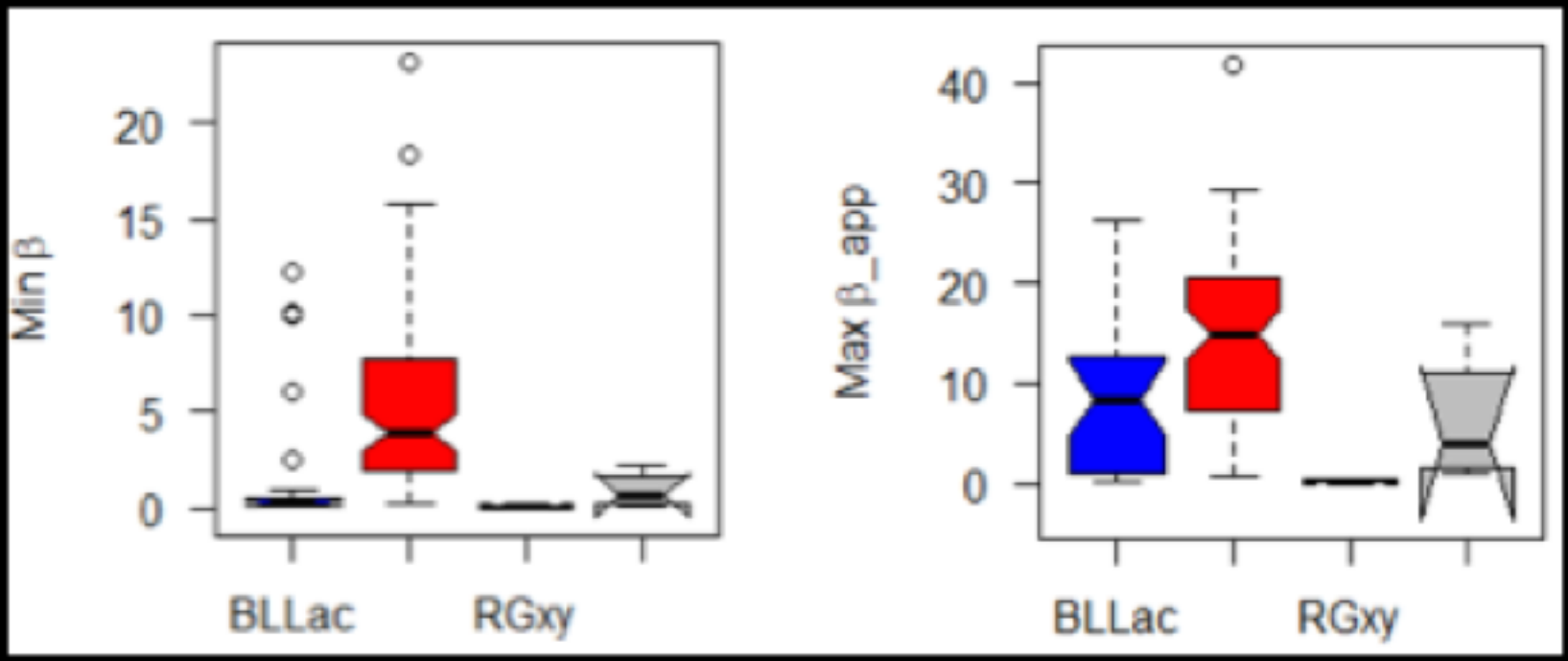
3: 1-3GeV

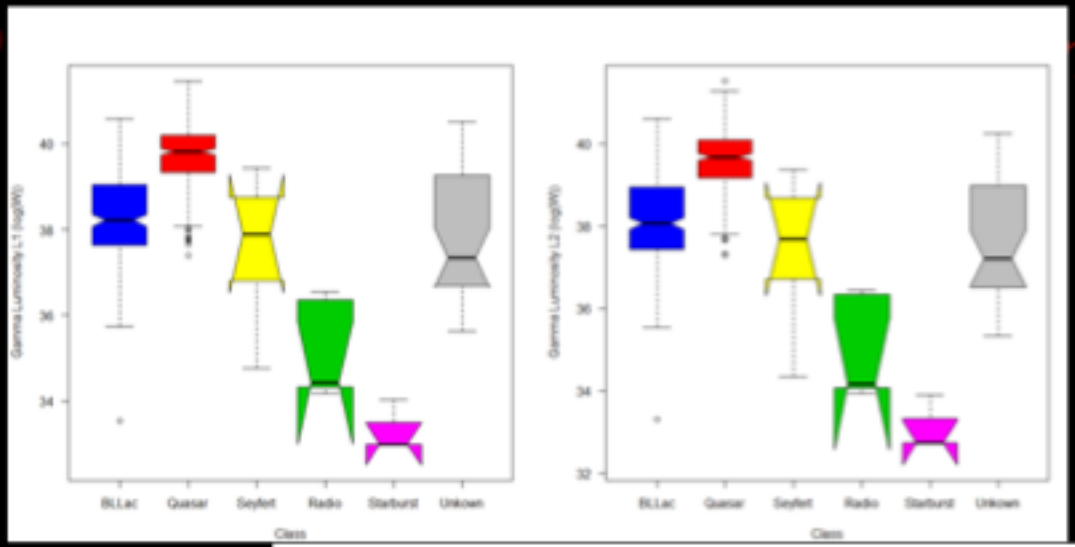
4: 3-100GeV

5: 100-1000GeV

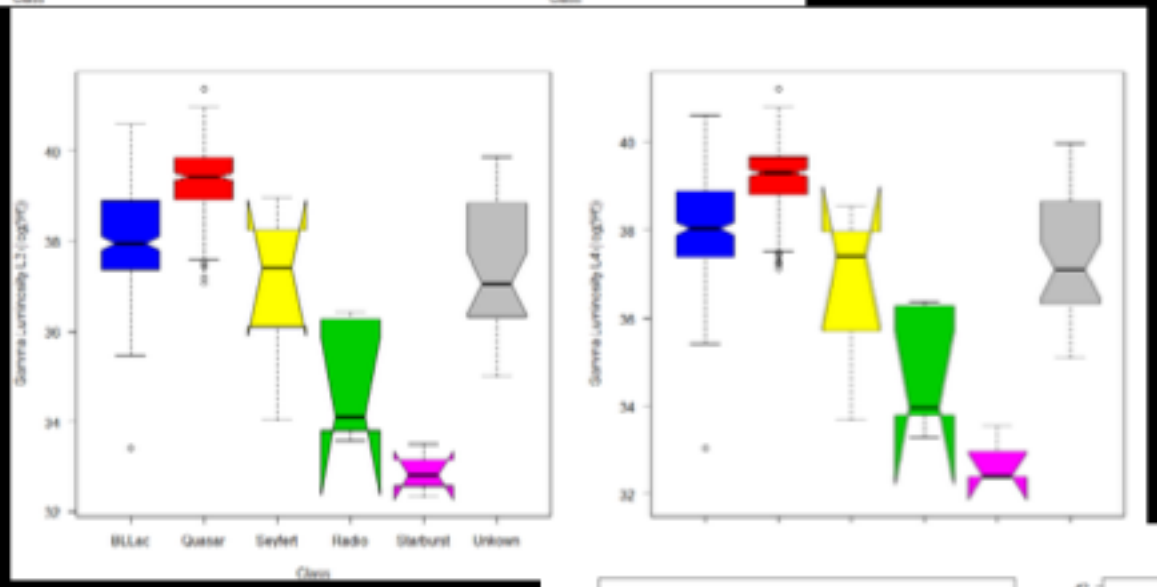
35: 1-1000GeV

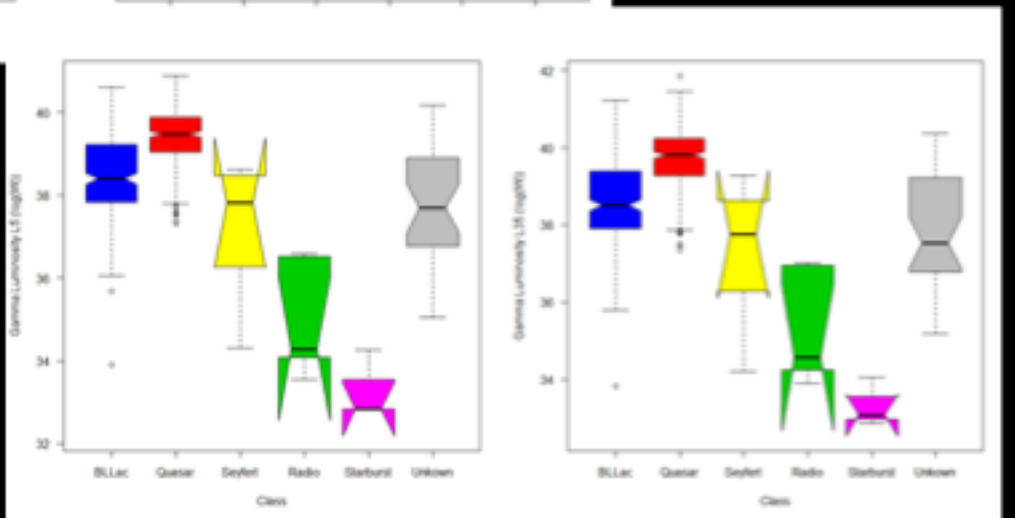
$\beta_{apparent}$: AGNs with and w/o BLR:





Gamma-ray Luminosity

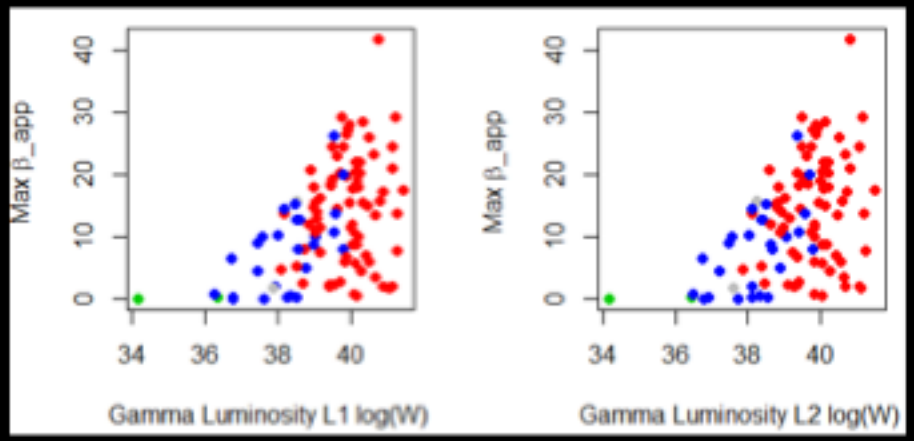


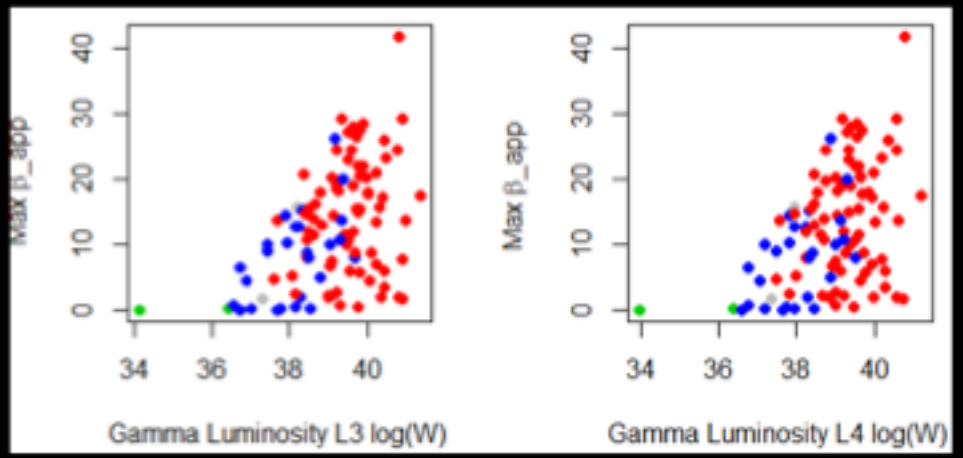


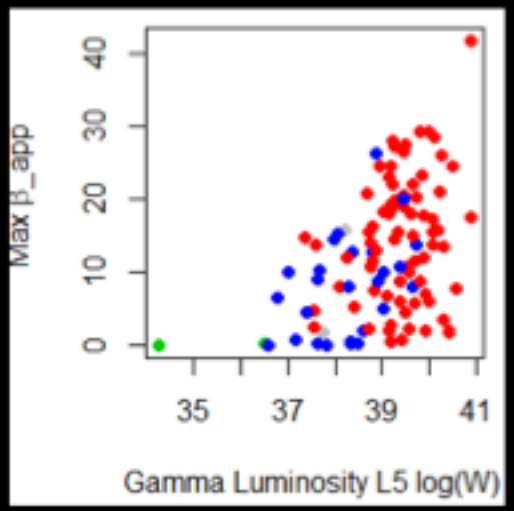
BLLac

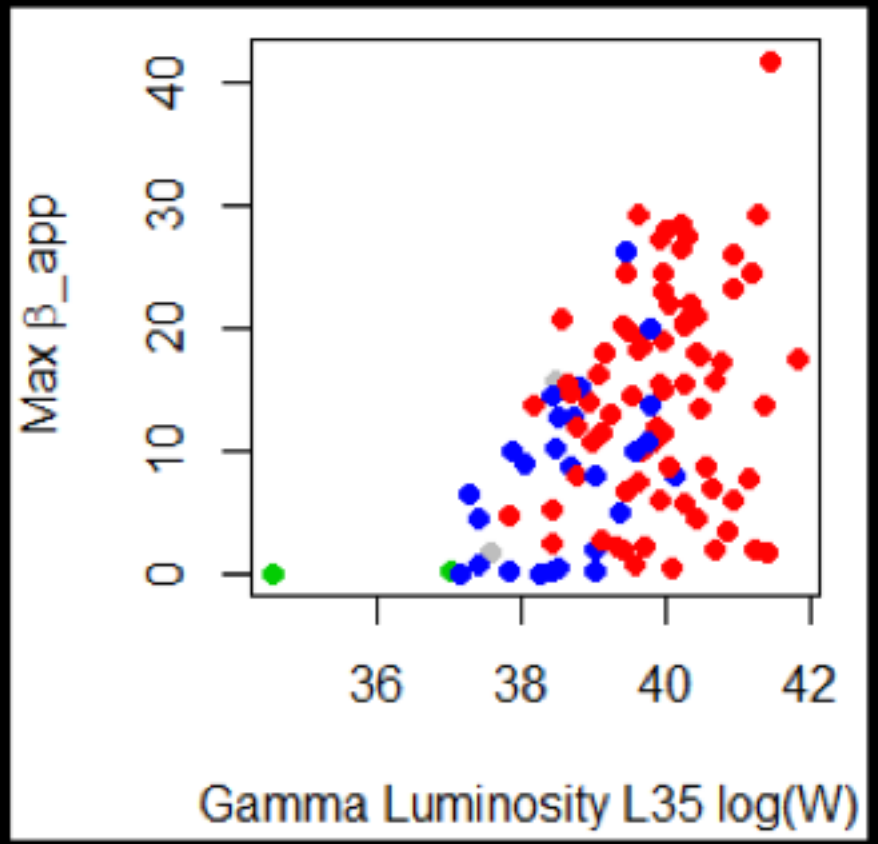
Quasar

The systematic trend appears to be due to the systematic difference between BLLacs and Quasars rather than a quantitative trend









1: 100-300MeV

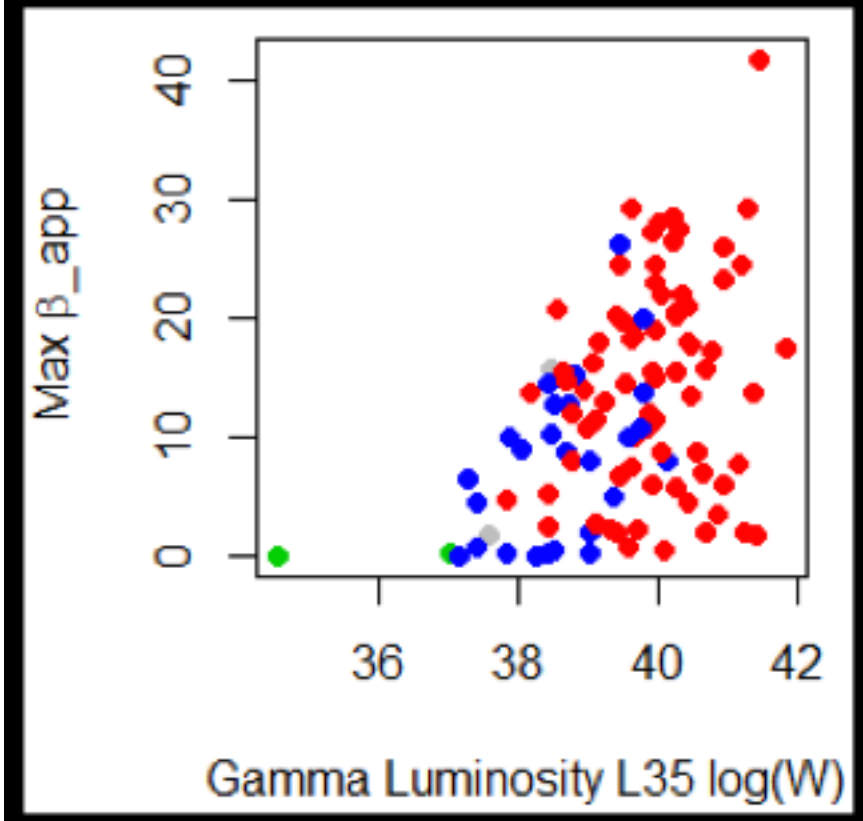
2: 300-1000MeV

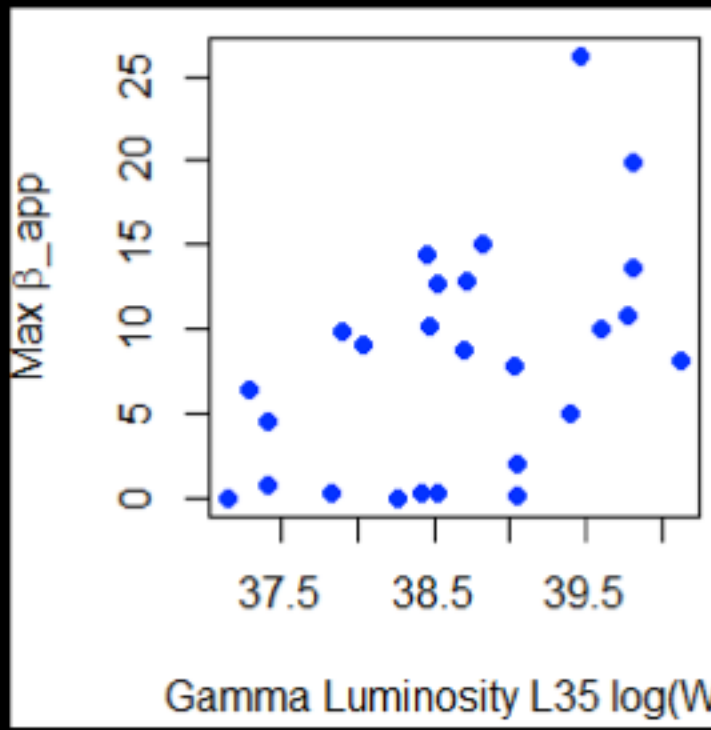
3: 1-3GeV

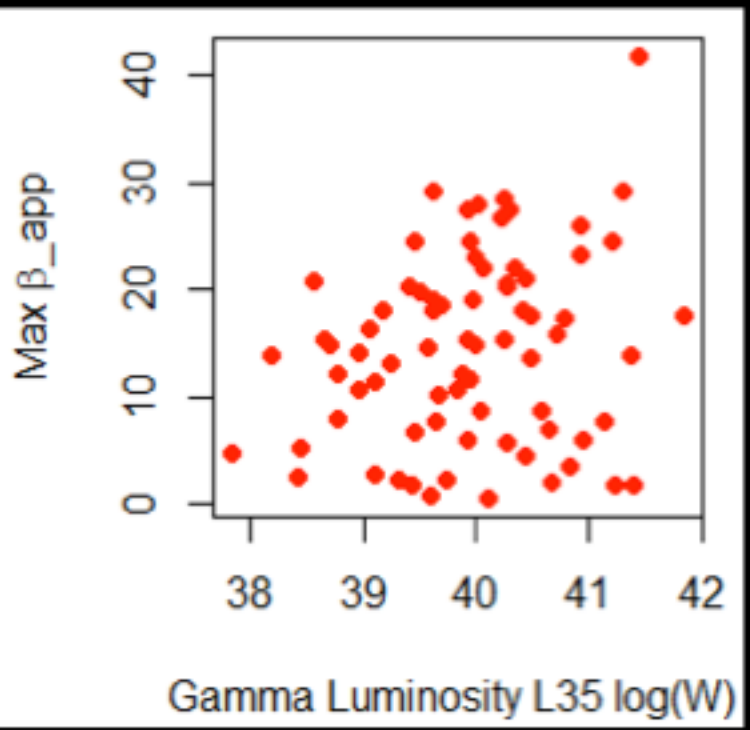
4: 3-100GeV

5: 100-1000GeV

35: 1-1000GeV

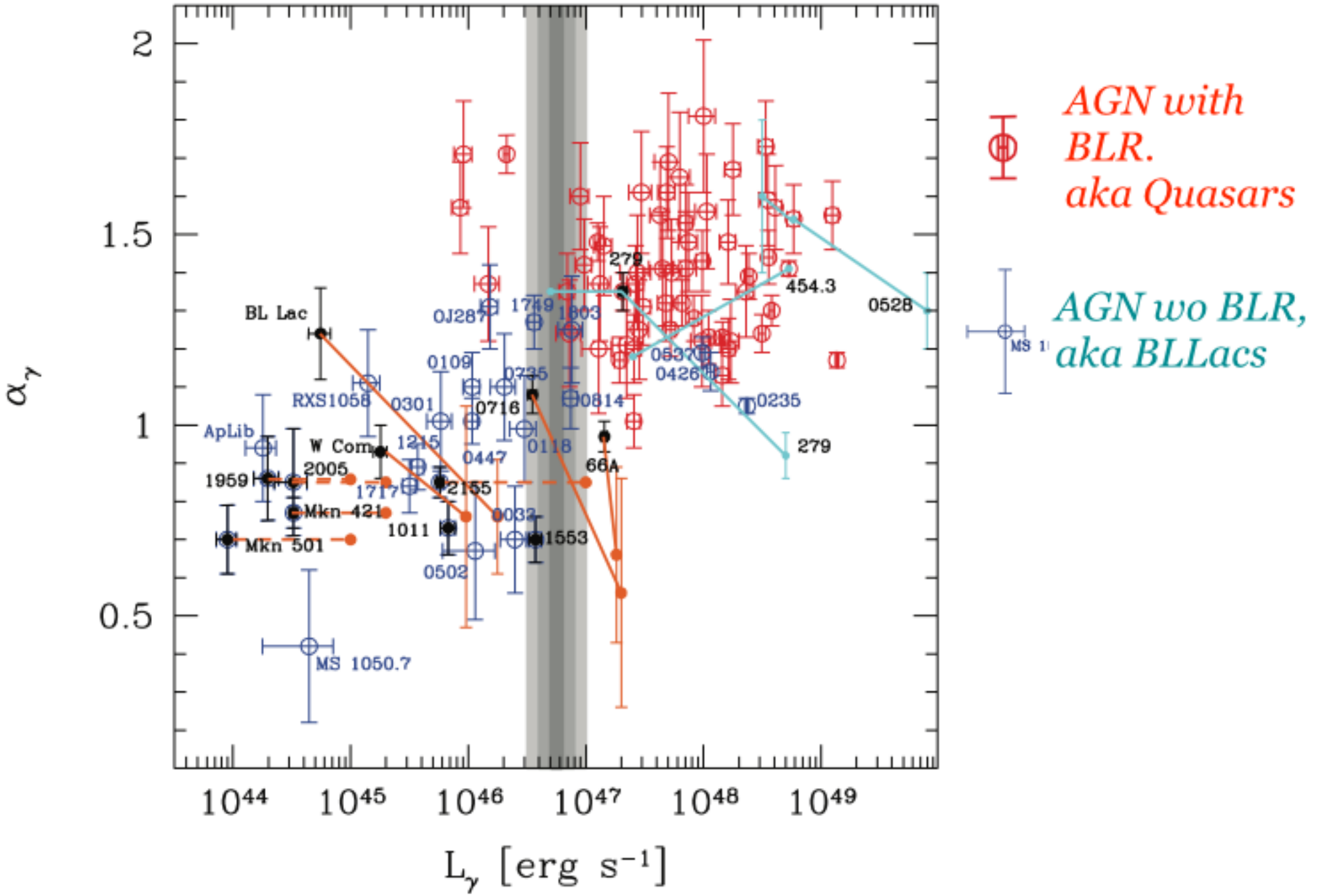

Max β_app
0
10
20
30
40
36
38
40
42
Gamma Luminosity L35 log(W)


Max β_app
0
5
10
15
20
25
37.5
38.5
39.5
Gamma Luminosity L35 log(W)

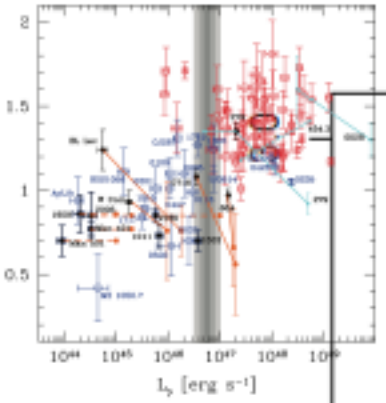

Max β_app
0
10
20
30
40
38
39
40
41
42
Gamma Luminosity L35 log(W)

Ghisellini Marschi Tavecchio 2009: Found with early Fermi data:

"clean separation of BLs and Qsrs in alfa-lum plane but continuity"



"clean separation": YES; BUT, "continuity"??



BLLac

Quasar

2.5

2.0

1.5

34

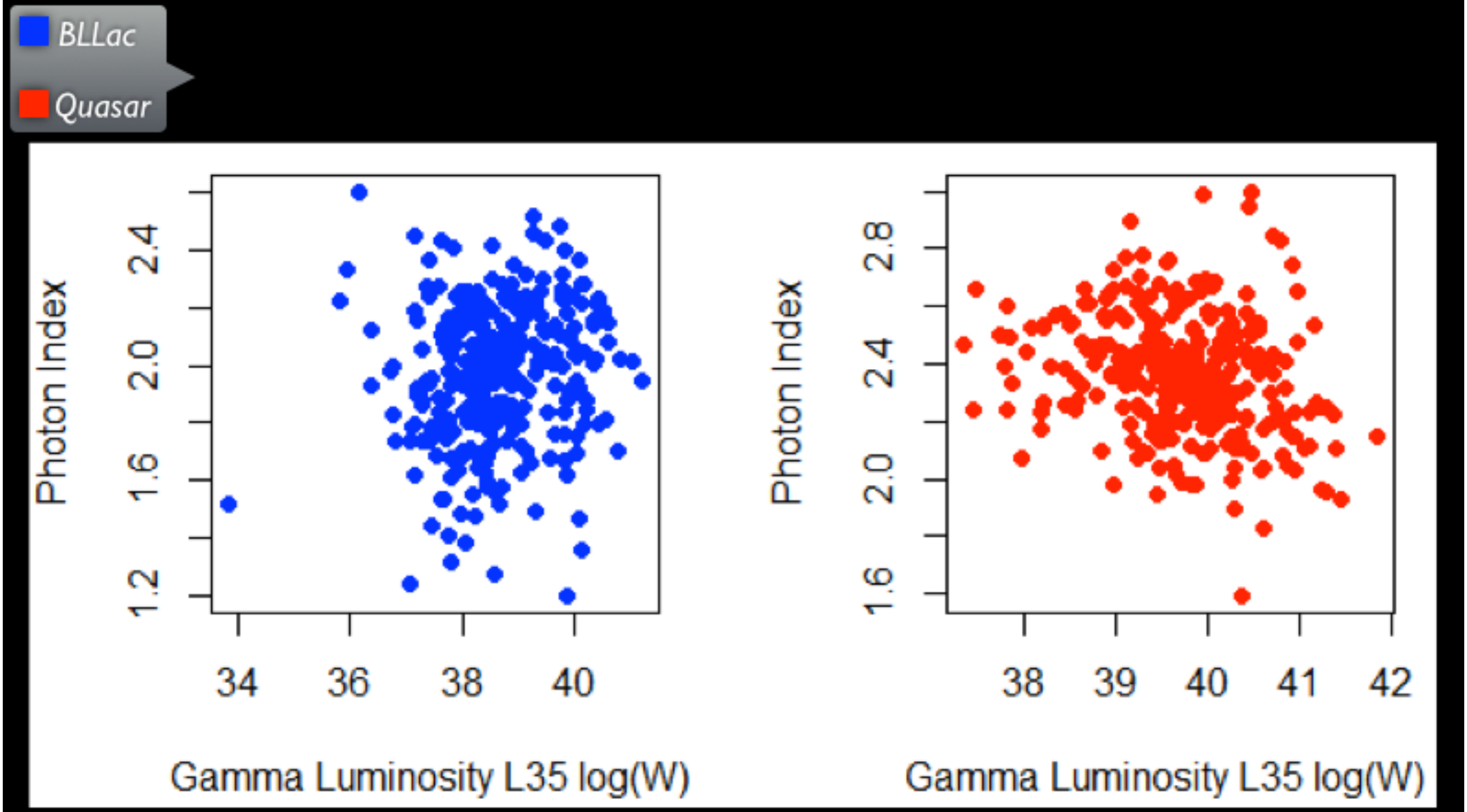
36

38

40

42

Gamma Luminosity L35 log(W)


BLLac
Quasar
Photon Index
1.2
1.6
2.0
2.4
34
36
38
40
Gamma Luminosity L35 log(W)
Photon Index
1.6
2.0
2.4
2.8
38
39
40
41
42
Gamma Luminosity L35 log(W)

Ghisellini+09:

Blazar divide: division in accretion rate:

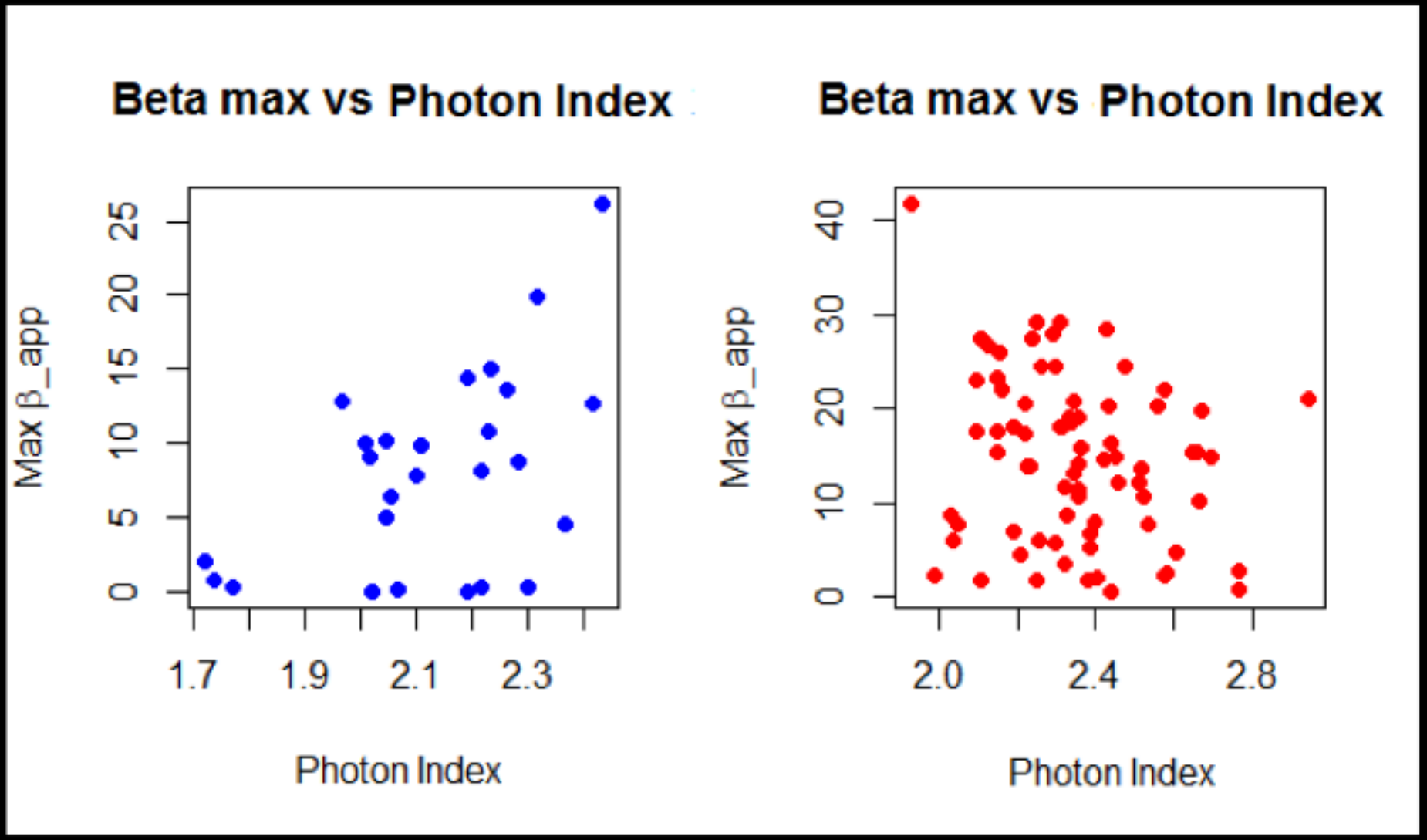
**Lower accretion rate, radiatively inefficient*

weaker ionizing flux (therefore weaker BLR)

**jets cool less (because medium is photo starved), therefore spectra harder*

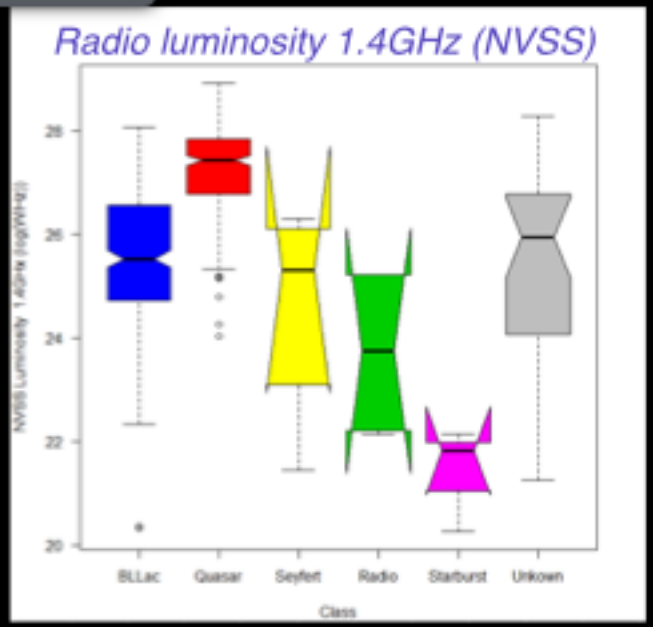
BLLac

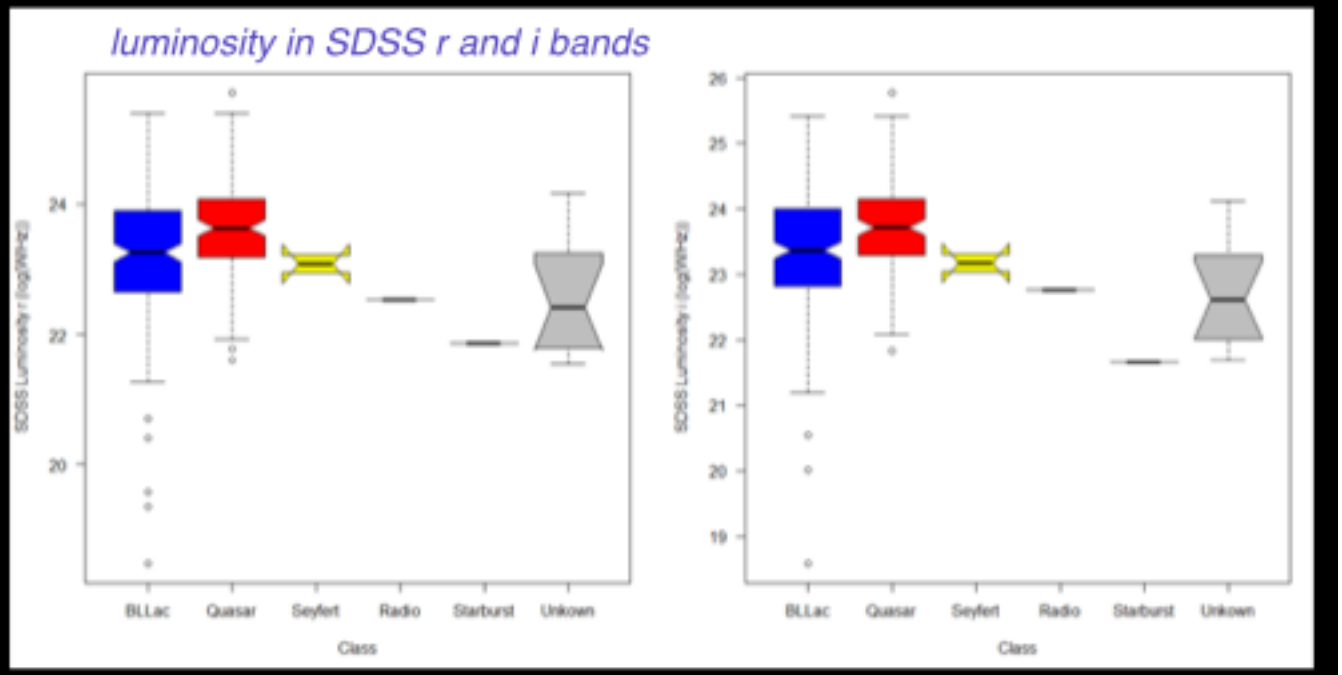
Quasar

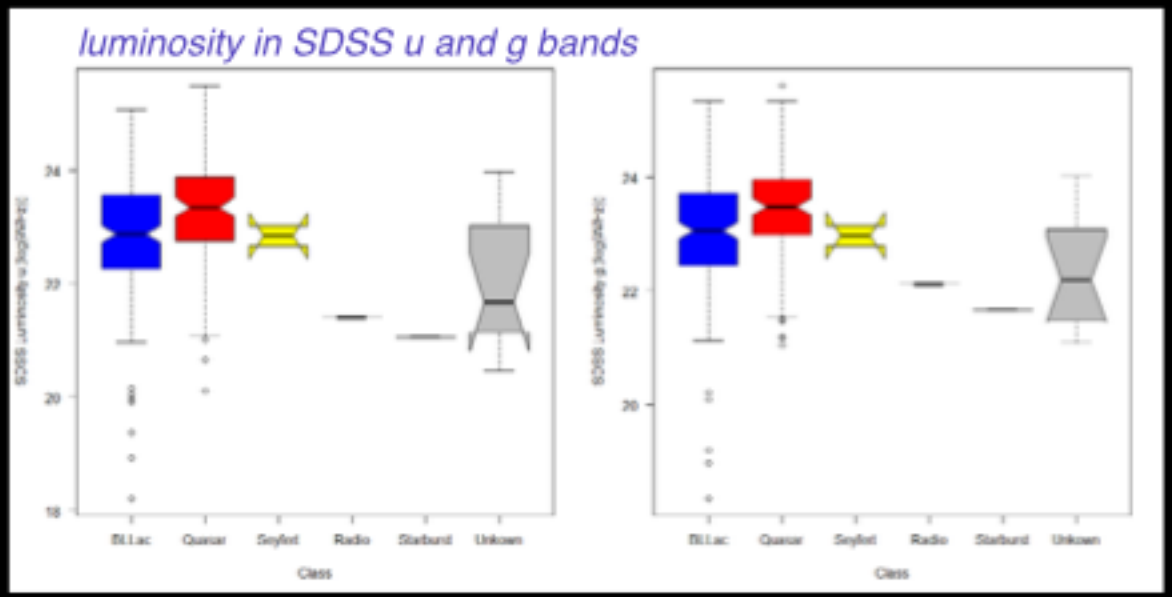


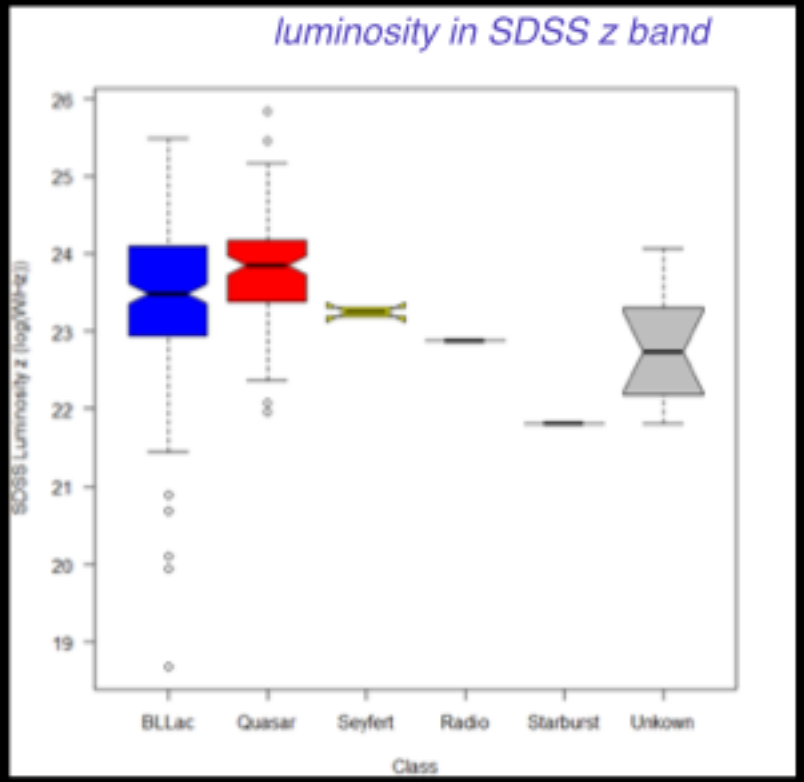
BLLac

Quasar

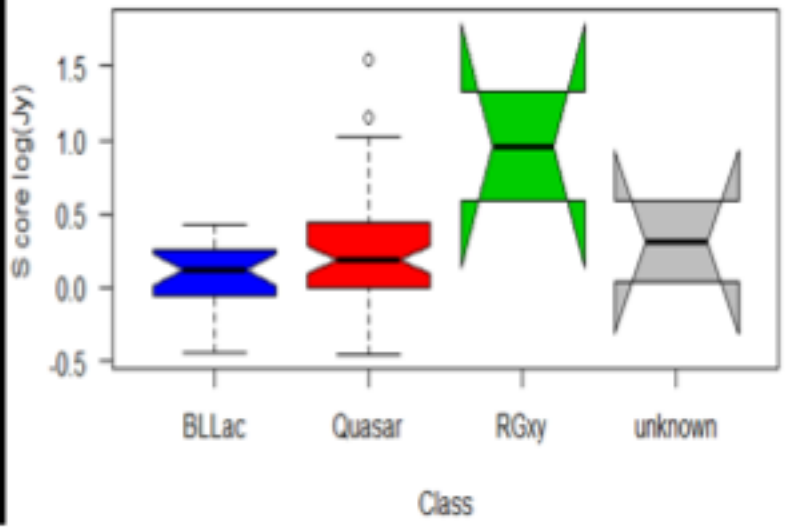




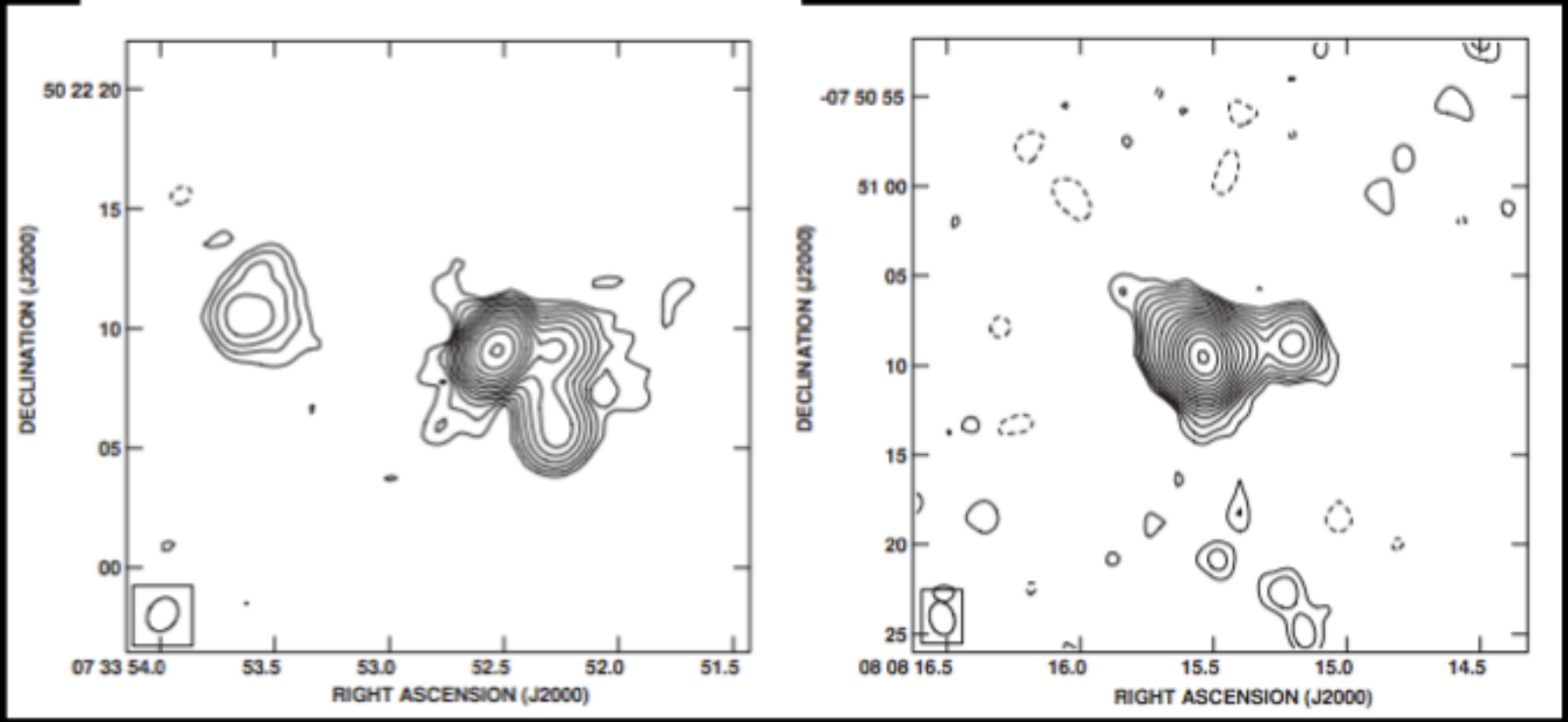




Core Radio Luminosity



MOJAVE: Kharb+ 2010

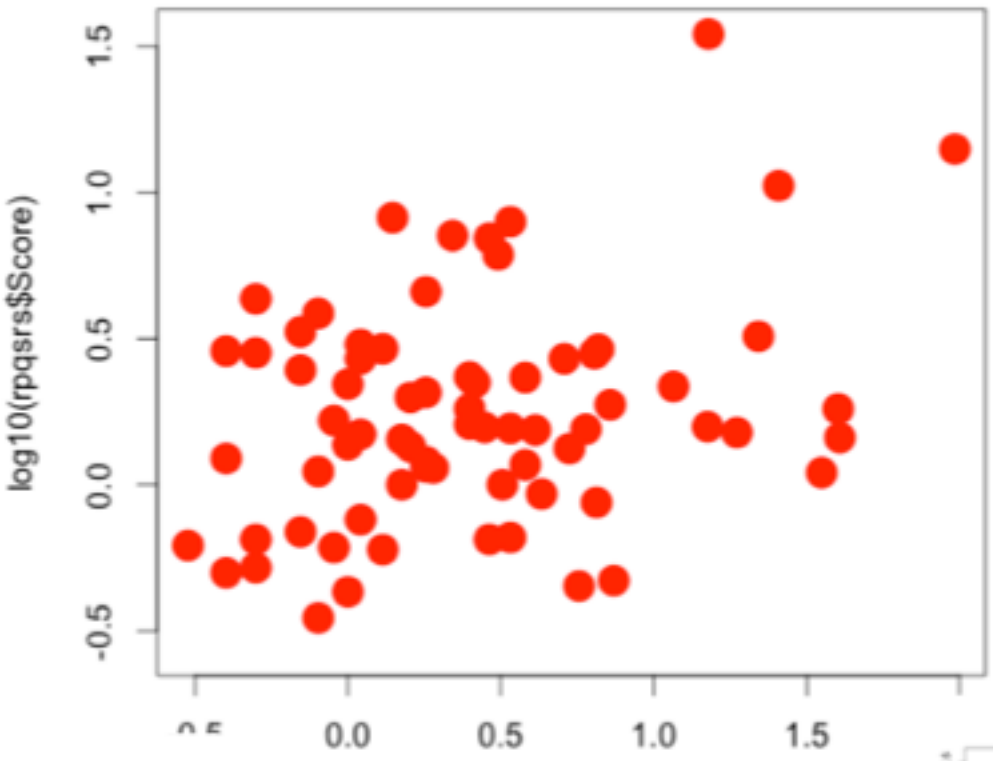


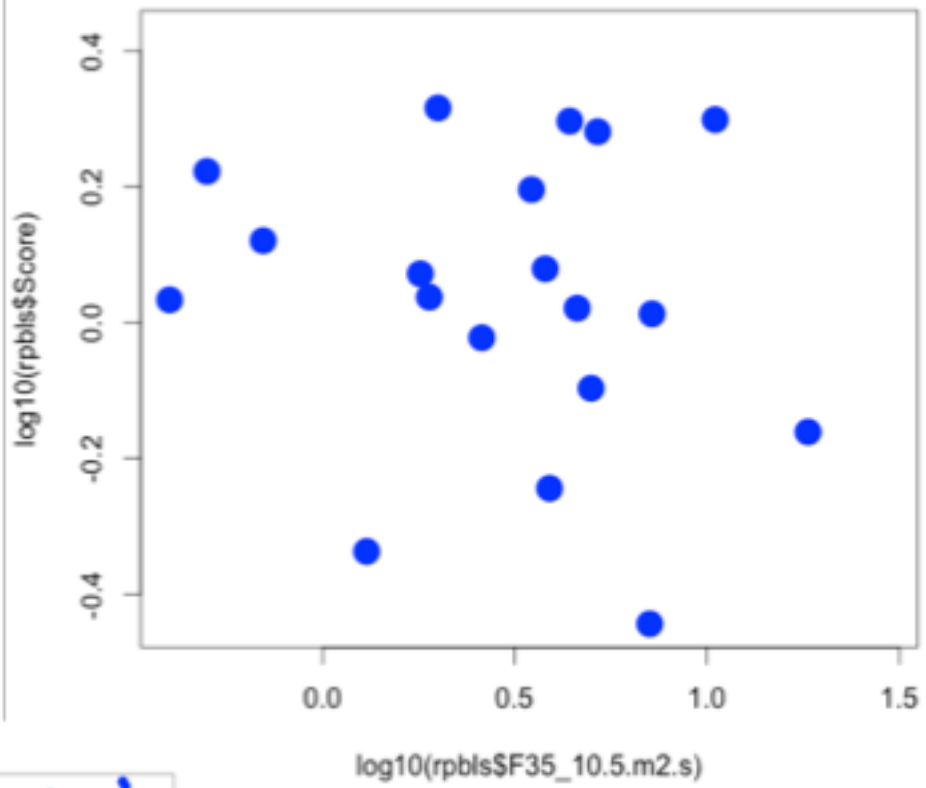
BLLac

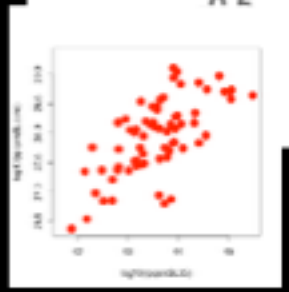
Quasar

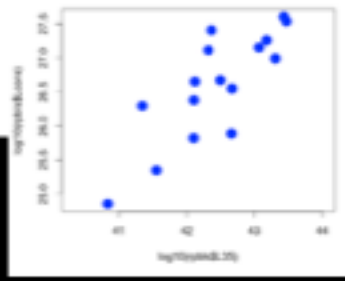
Kharb+10: MOJAVE

Core radio flux density - Gamma flux

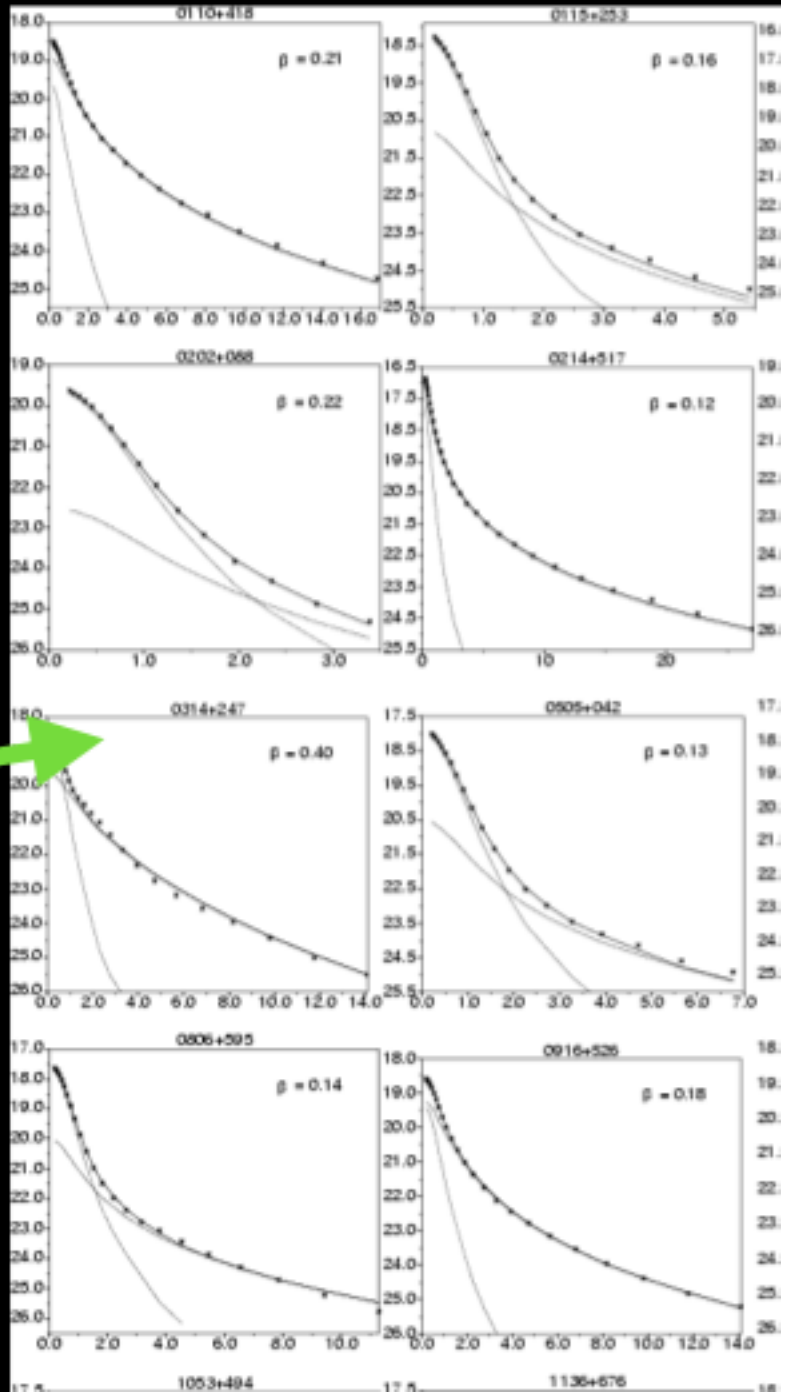






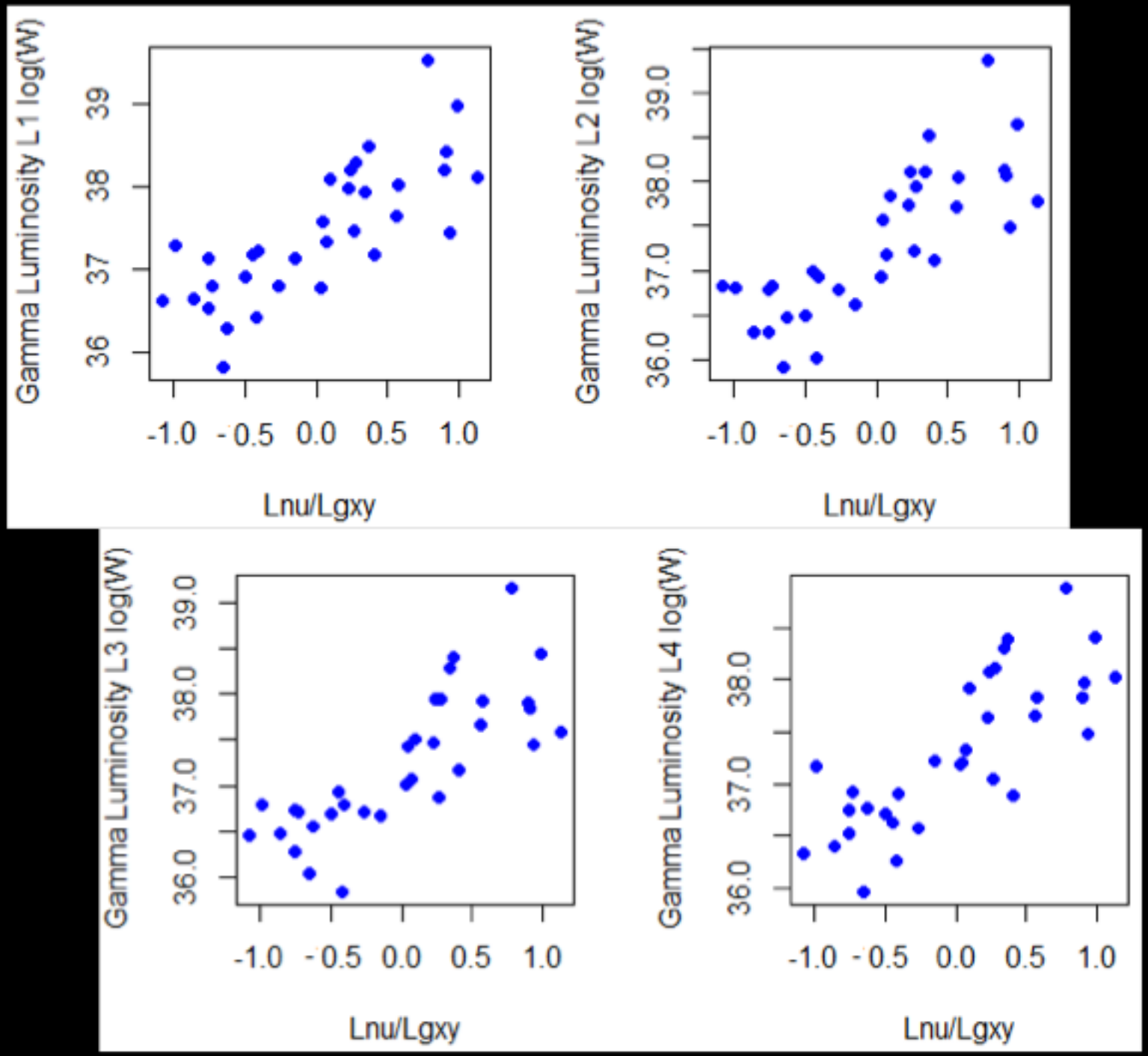


Nilsson+ 2003



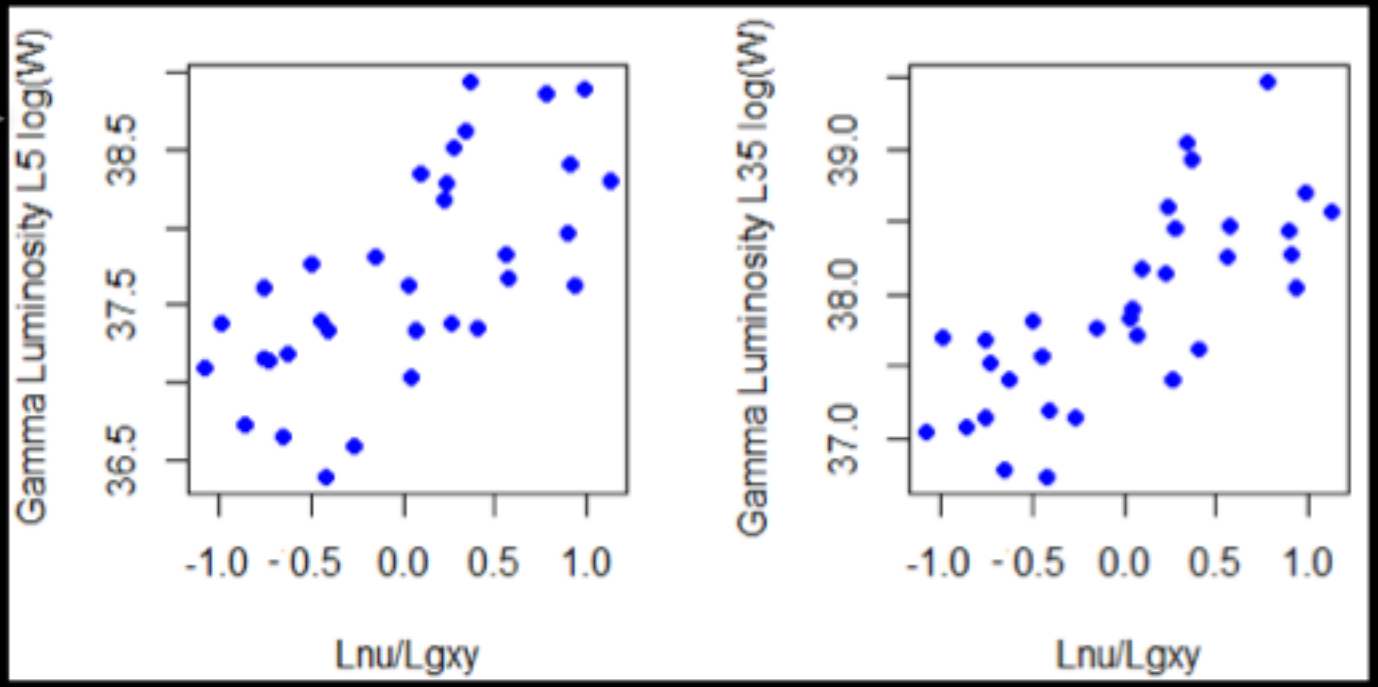
variation with Nuclear to Host Galaxy Ratio (Optical)

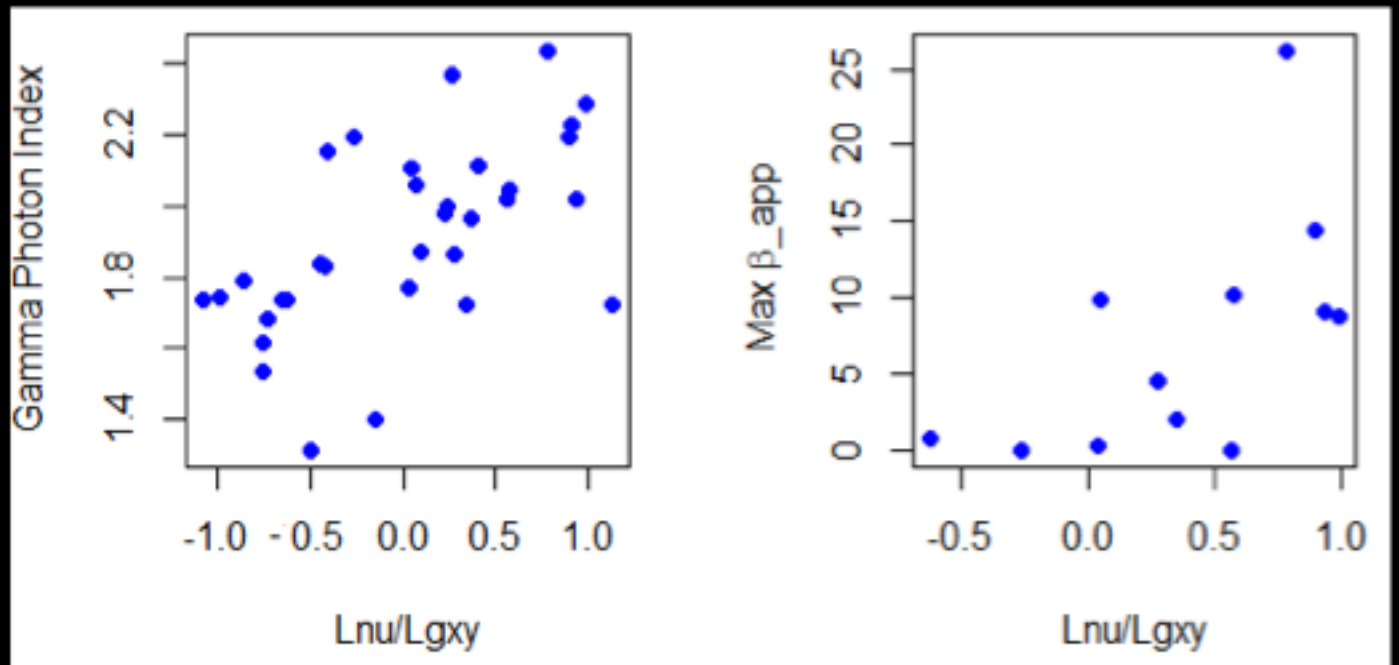
BLLac



variation with Nuclear to Host Galaxy Ratio (Optical)

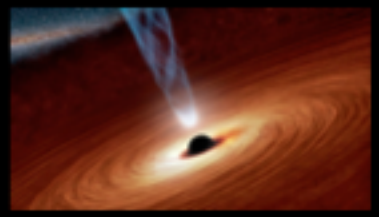
BLLac





SUMMARY

- *In Seyfert galaxies, multi-wavelength data are consistent with predictions of ubiquitous obscuring toroidal matter surrounding the accreting SMBH*
- *In highly Doppler-beamed high kinetic power AGN ("Blazars") the data are qualitatively consistent with the idea that BL Lac jets are launched in a relatively photon-starved environment*
- *Current data suggest that the blazar-divide is a dichotomy*
- *Explanations for the divide have to be consistent both with the data for the unbeamed AGN and for the AGN w/ low-kinetic power jets, aka RQ AGNs*
- *Quantitative modelling, and exploring whether the divide is reflects the Fanaroff-Riley divide requires a robust proxy for orientation and accounting for Malmquist bias, and selection effects*
- *Optical nuclear/host galaxy ratio may be an alternative proxy for orientation of the axisymmetric system wrt line of sight*



Future: Bev Footsteps

Thank you!