

High energy emission component and population of gamma-ray emitting radio galaxies

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Radio galaxies established as a gamma-ray source
thought to be a parent population of blazars
more numerous than blazars

Open Questions for GeV-loud radio galaxies ...

Luminosity Function (LF) ?

Contribution to Extragalactic gamma-ray bkgd ?

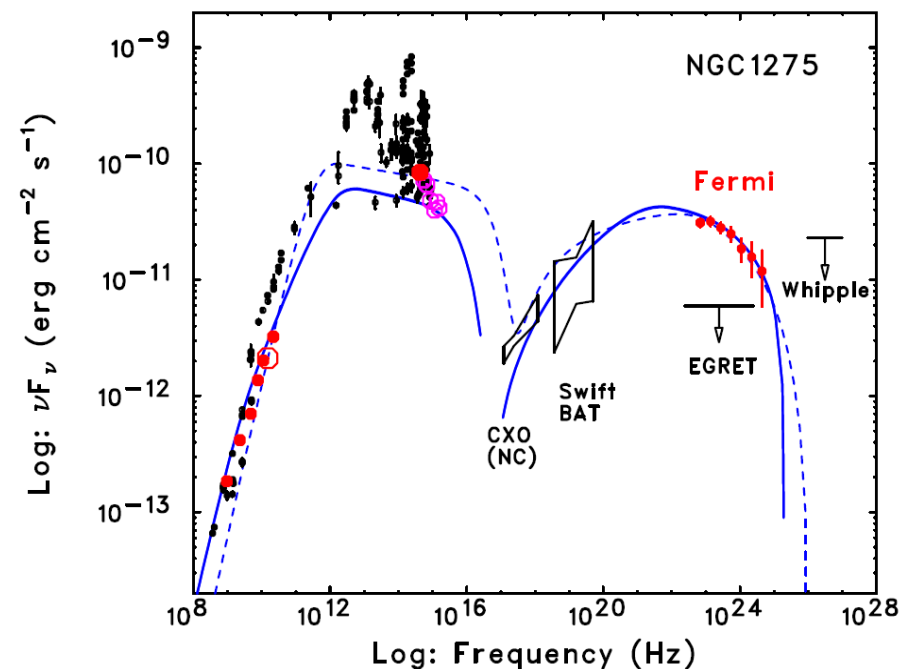
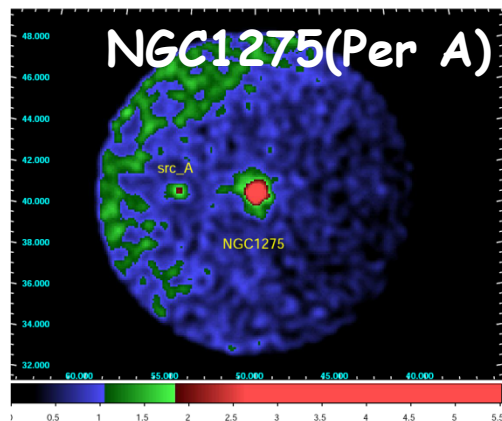
How about SED is from X-ray to gamma-ray ?

Population ?

FR-I rich ? FR-II rich ?

GeV-loud vs GeV-quiet ?

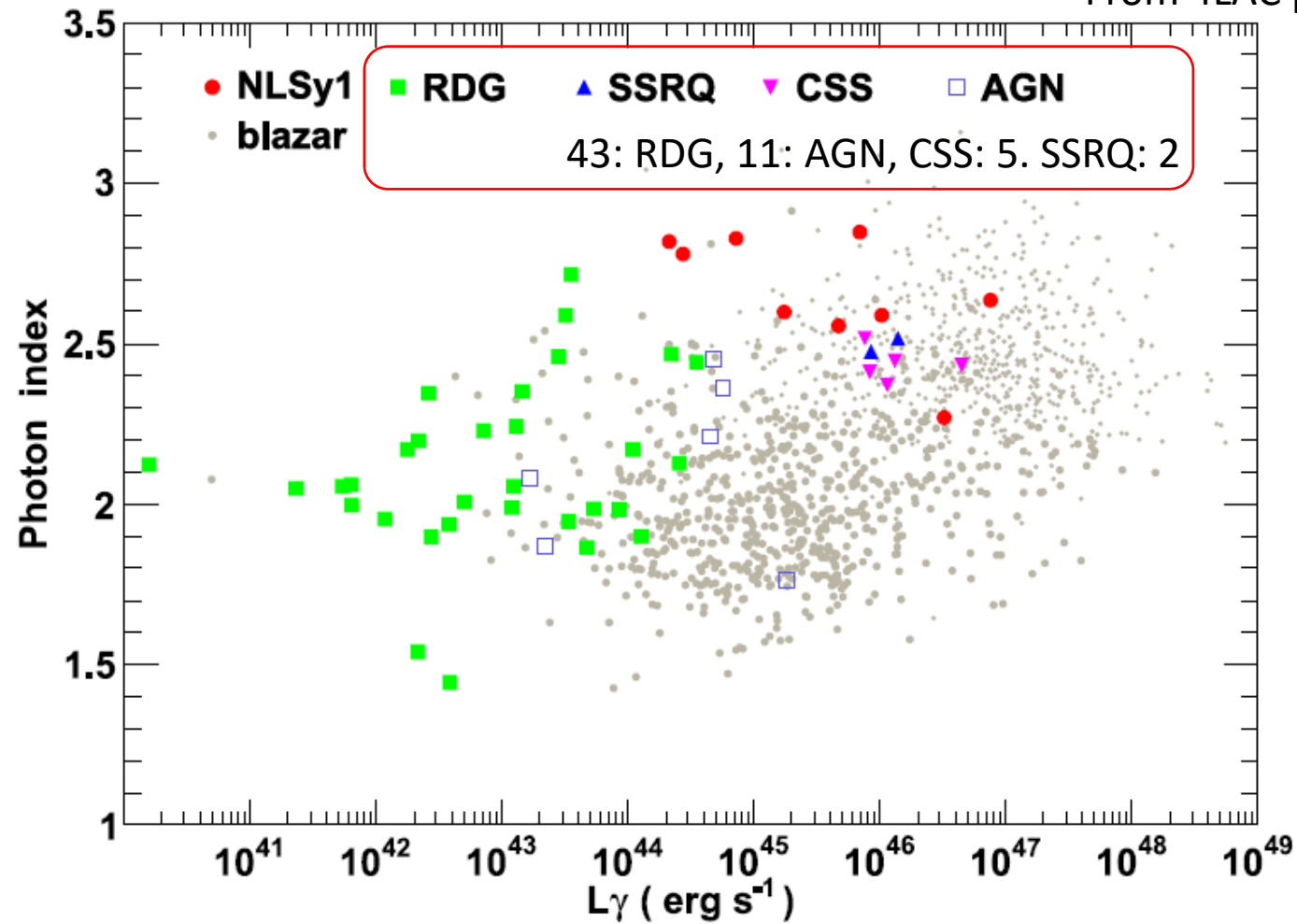
Relation with Blazars ?



4th Fermi Catalog (4FGL-DR2): Misaligned AGN (61 galaxies)

We performed systematic analysis and derived gamma-ray luminosity function.

From 4LAC paper



X-ray data

We searched for X-ray data with a priority order of XMM-Newton, Chandra, Swift, RASS. 8 bright objects are from Fukazawa+15 Suzaku results..

XMM-Newton	20
Chandra	14
Swift	9
NuSTAR	1
RASS	5
XMM slew	1
Suzaku	7
No X-ray data	4

Fitted with powerlaw to obtain a photon index and flux.

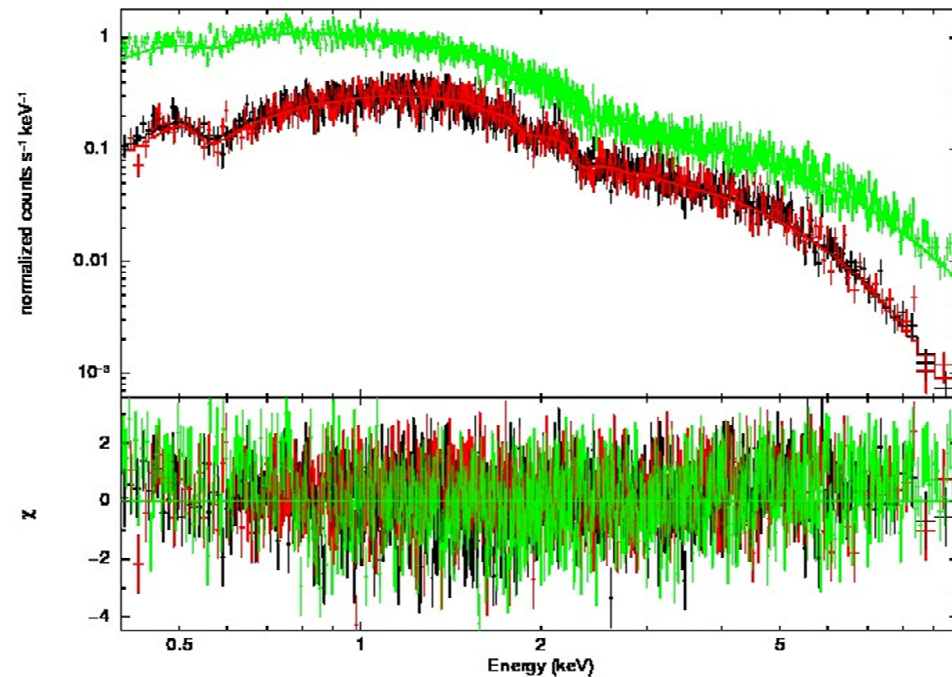
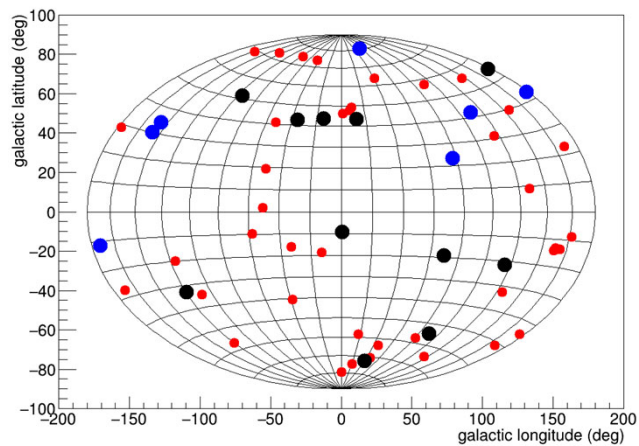
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RDG

AGN

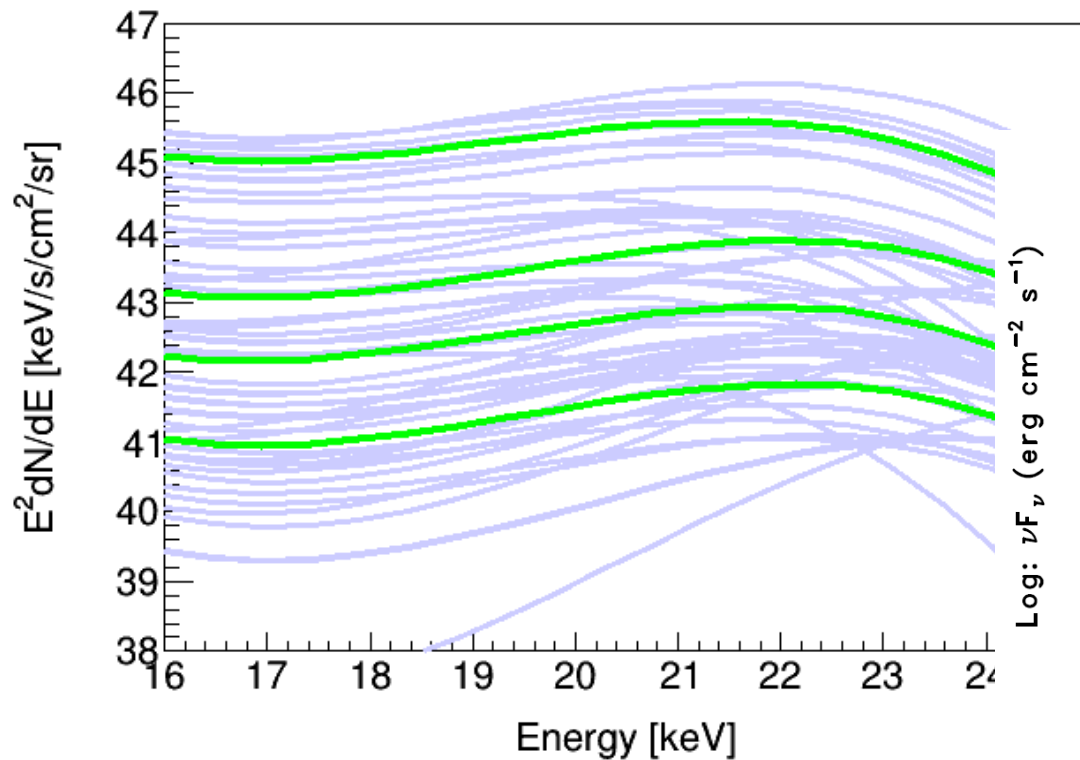
CSS/SSRQ



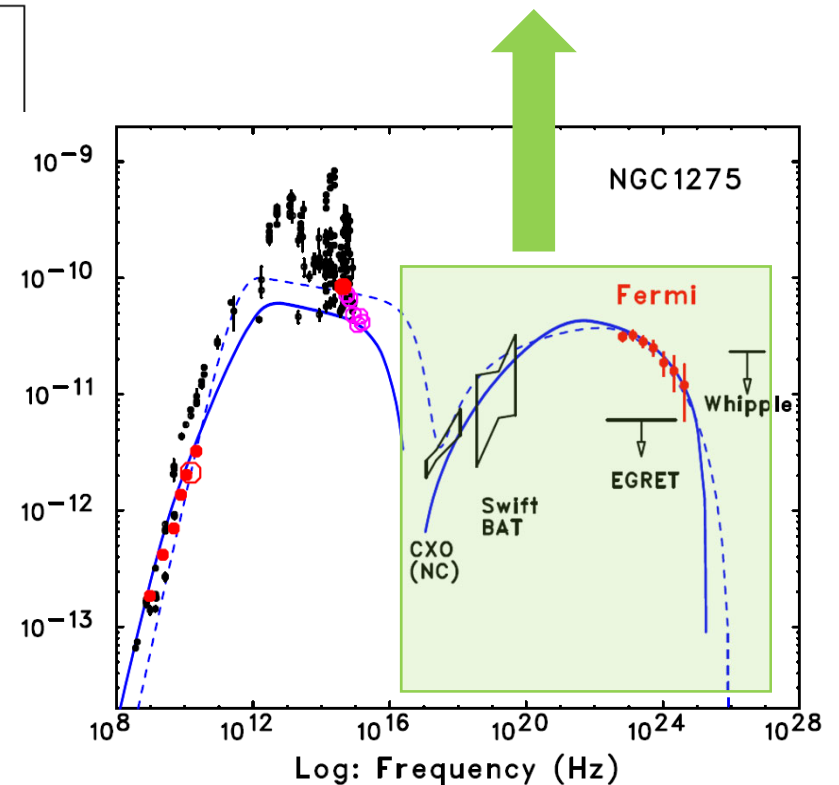
SED analysis from X-ray to GeV gamma-ray

Fitted X-ray and gamma-ray spectra with 4-th polynomial function.

Plot of obtained SED curves for each galaxy
Average SEDs of 4 luminosity regimes



High energy (H.E.) emission
Jet, disk/corona

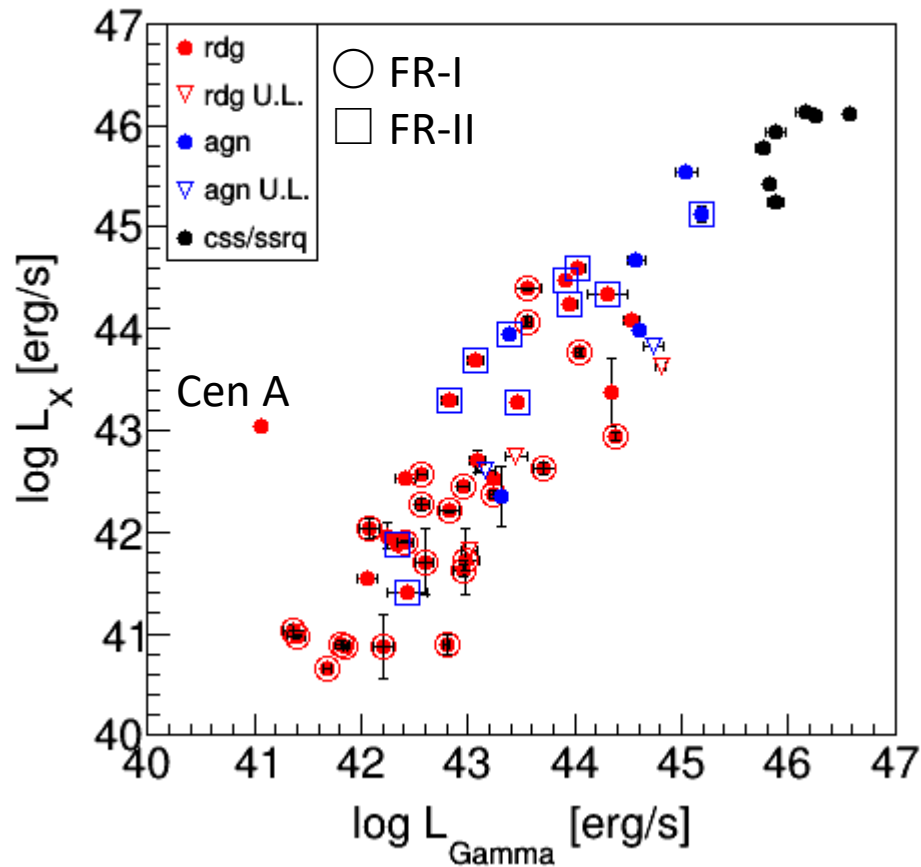


Correlation of luminosity between X-ray and GeV.

X-ray L ighly correlates with GeV L.

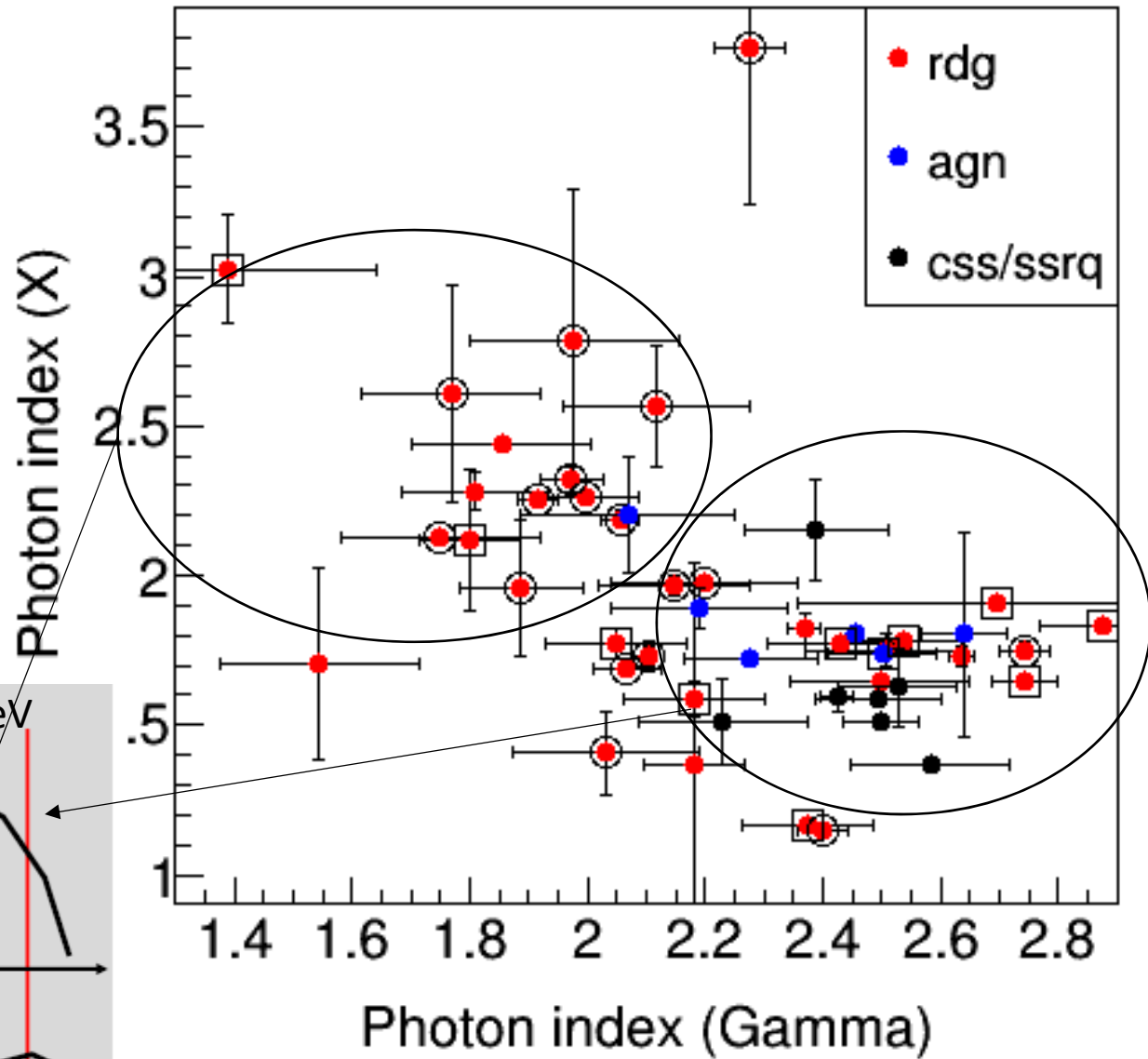
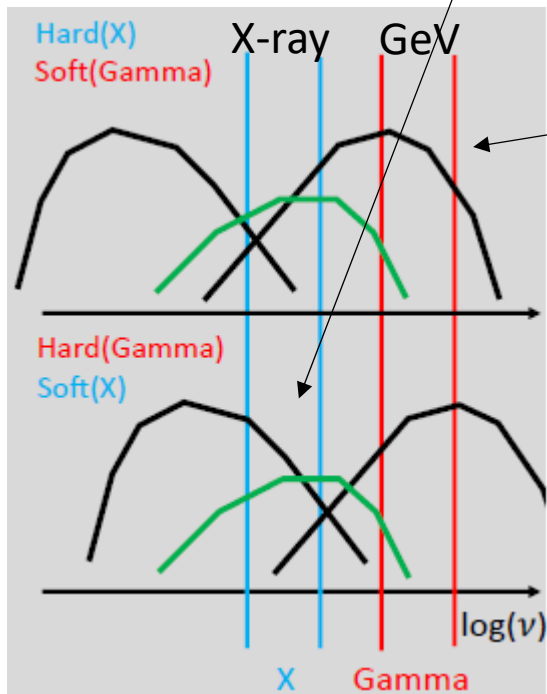
FR-II is not always bright.

CSS/SSRQ are the brightest in both X-ray and GeV.



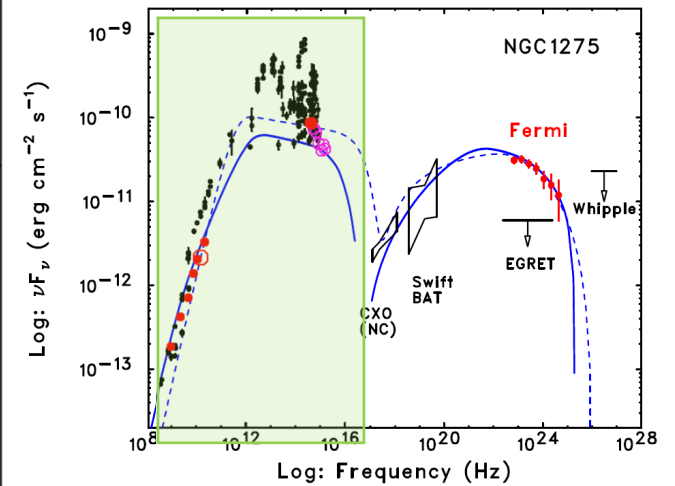
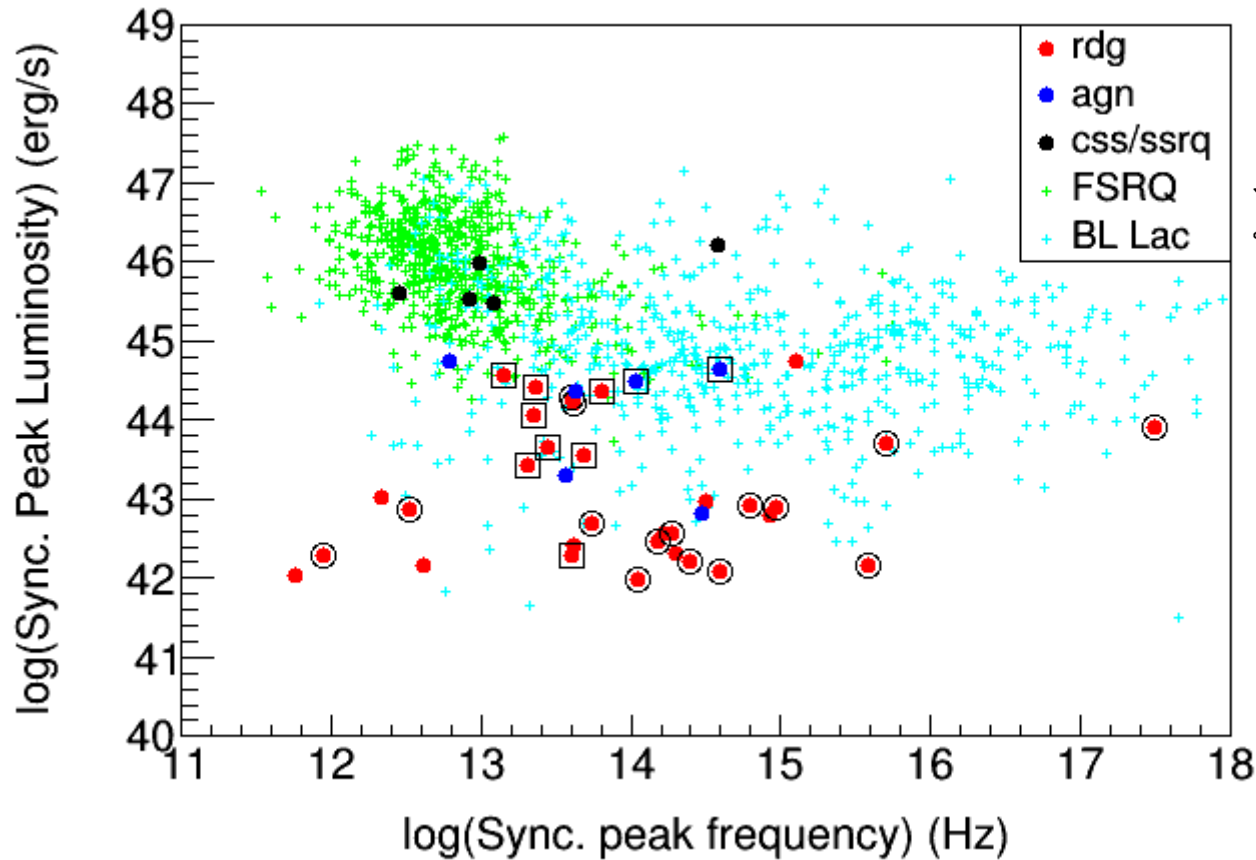
Correlation of photon index between X-ray and GeV

SED

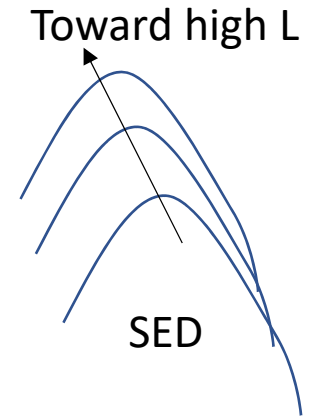


Synchrotron Peak (from 4LAC(-DR2))

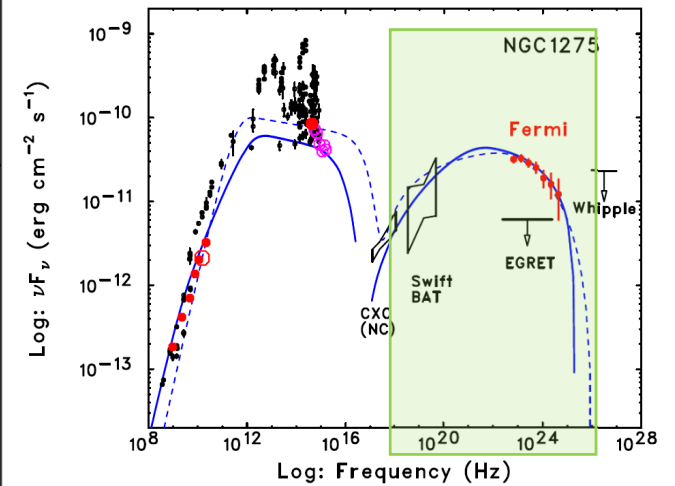
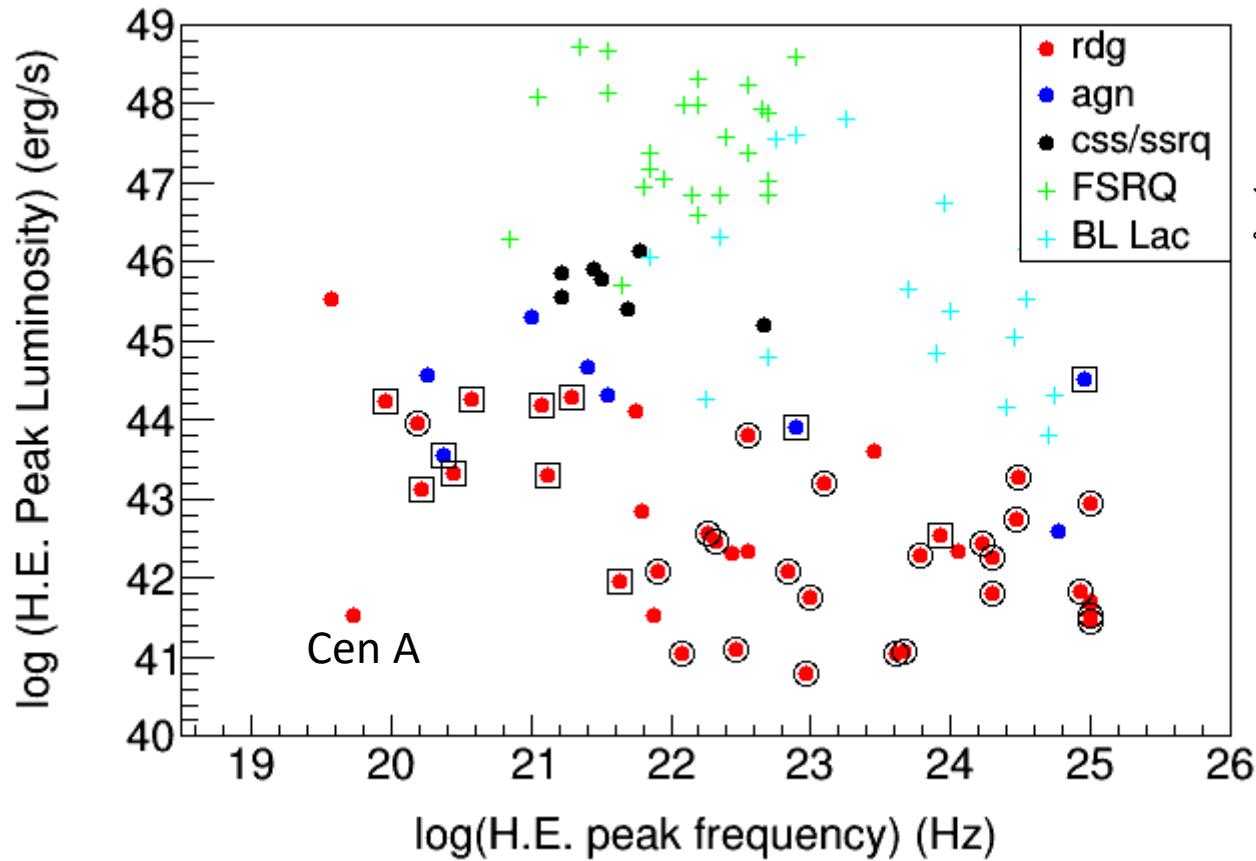
Note that SED in IR, Opt, and X-ray could be contaminated by non-jet emissions.



H.E. component peak (from SED fit)

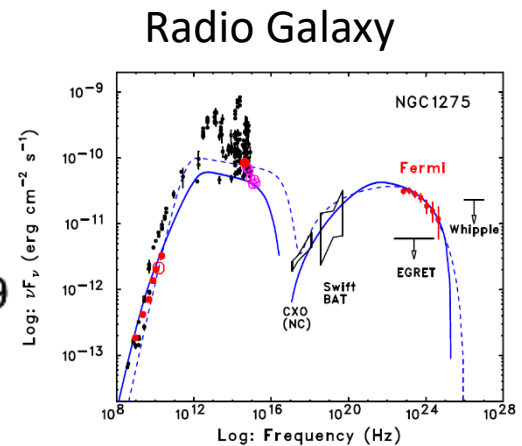
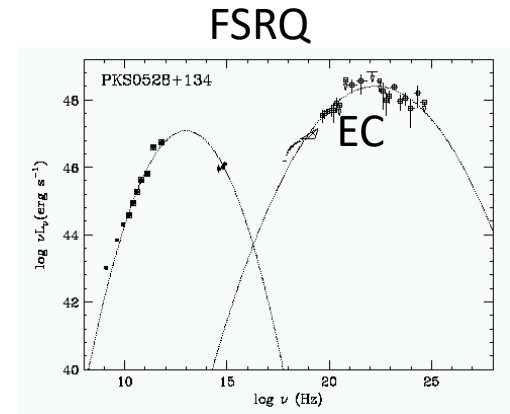
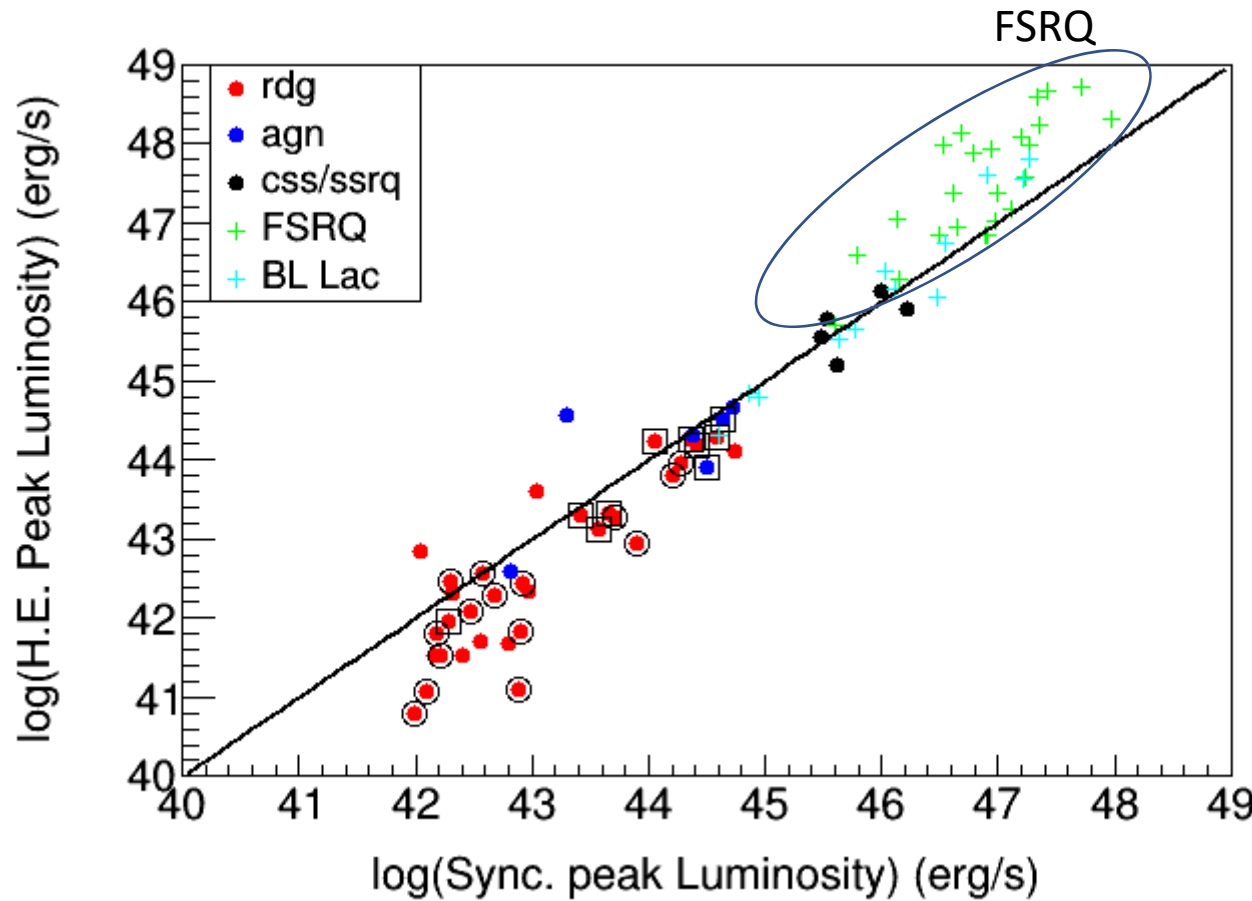


Wide dist. of peak frequency, and blazar-like seq. is seen.



Correlation of luminosity between Sync-peak and H.E. peak.

Compton dominance of RGs is similar to or less than that of BL Lac.
 EC is not seen in FR-II, unlike FSRQ.



Population (1)

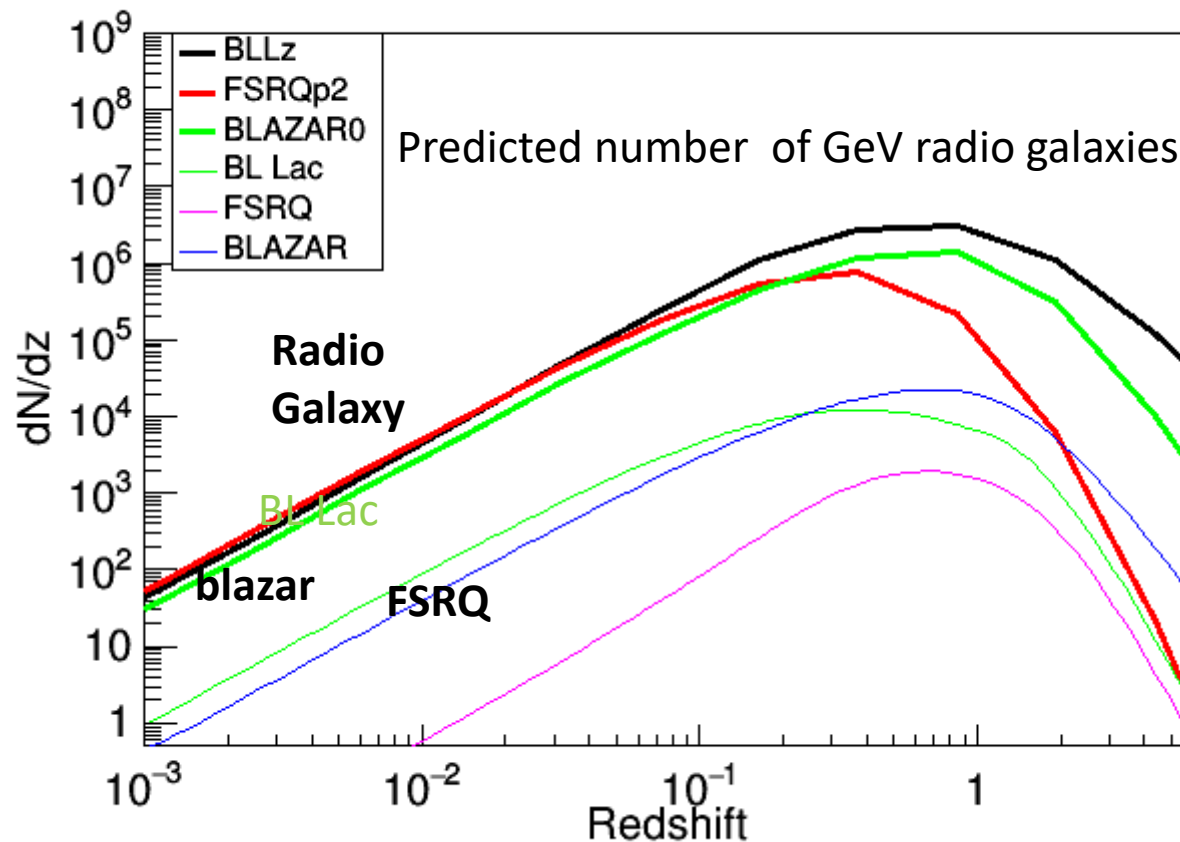
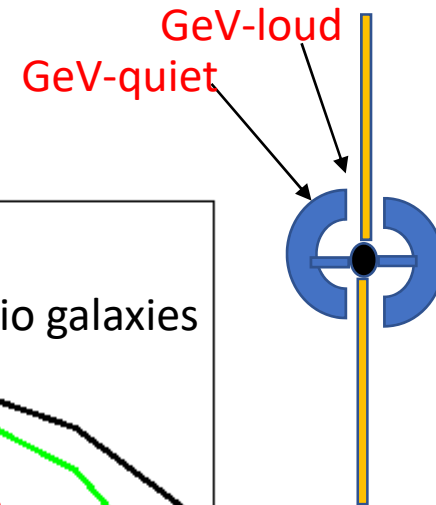
GeV radio galaxies are 10—30 times as numerous as blazars.

↔ Viewing angle of blazars is 0-10deg.

Only 10% of 2 Jy flux-limited radio-sample RG (Mingo+14) are detected in GeV.

X-ray $N_H > 1E22 \text{cm}^{-2}$ GeV-quiet 53% GeV-loud 8% (Kayanoki+22)

Only RGs with a small viewing angle are detected in GeV.



Population (3)

35 FR-I vs 17 FR-II in GeV **FR-IIs are lacking.**

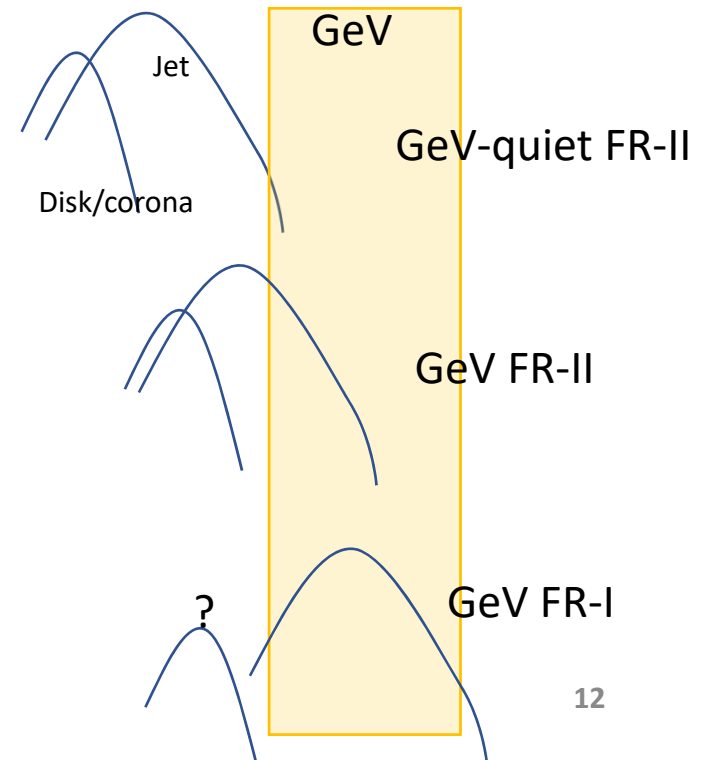
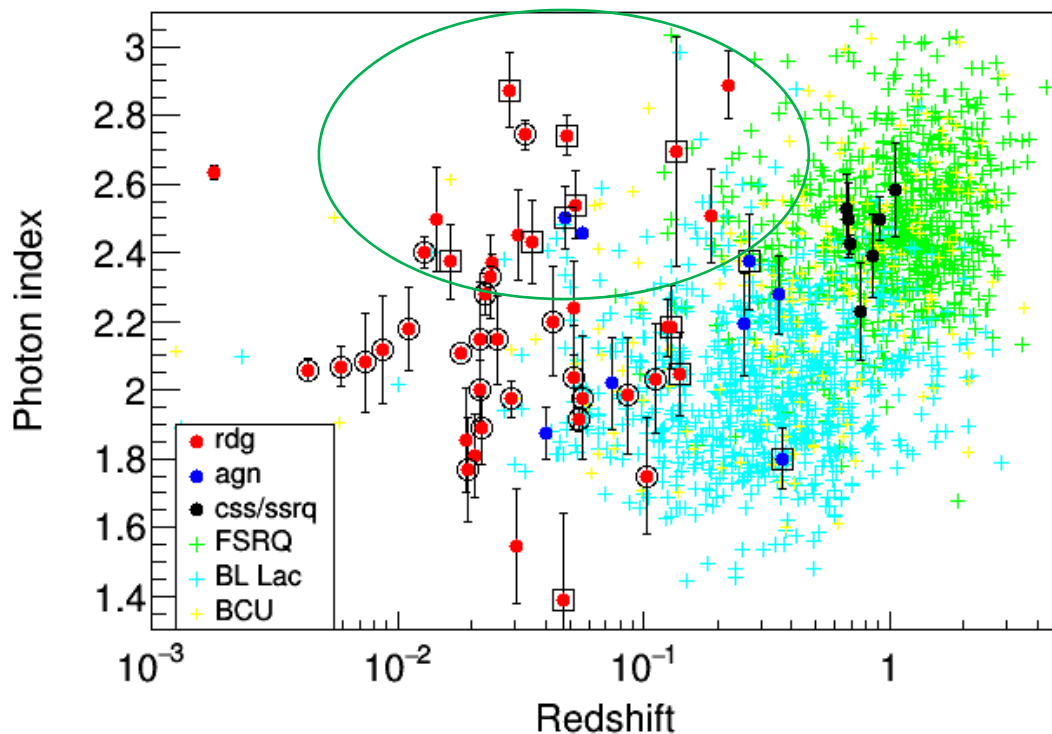
6 FR-I vs 33 FR-II in radio flux-limited (Dicken+18).

80% of X-ray RGs are FR-II (80%) (Rusinek+20).

H.E. component peak freq. is lower for FR-II. -> soft GeV spectrum

SED of many FR-II could not reach GeV.

Beaming is more significant for FR-II while FR-I is less due to structured jet.



GeV gamma-ray luminosity function of radio galaxies

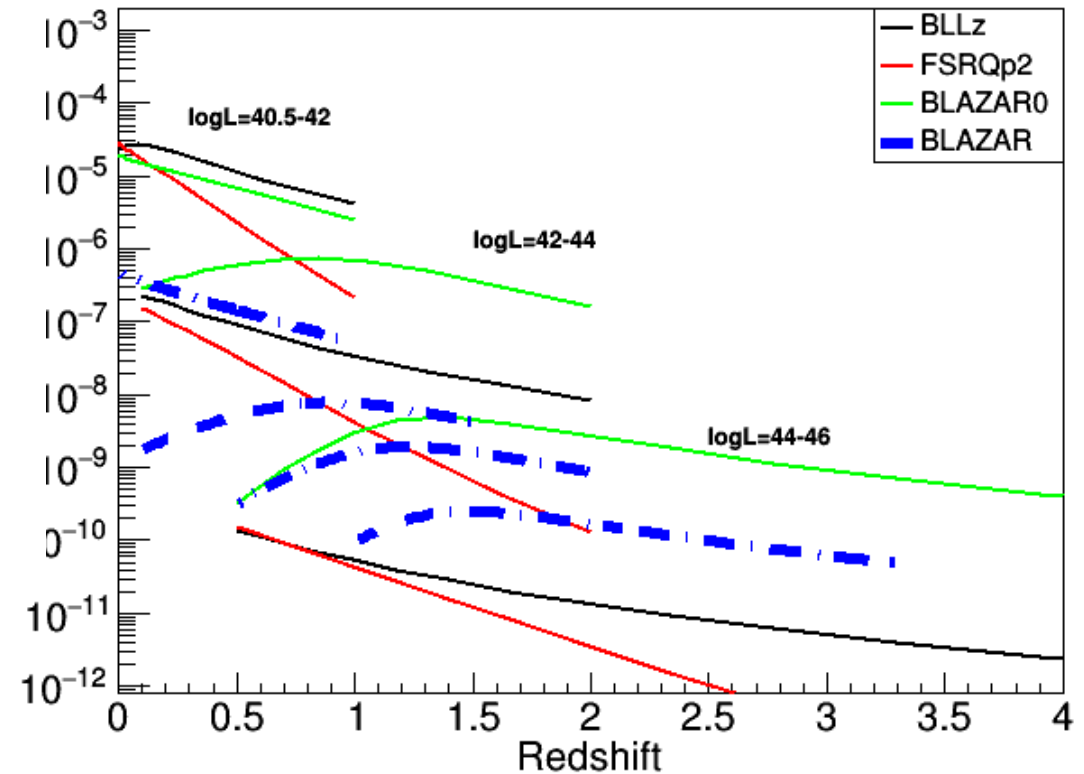
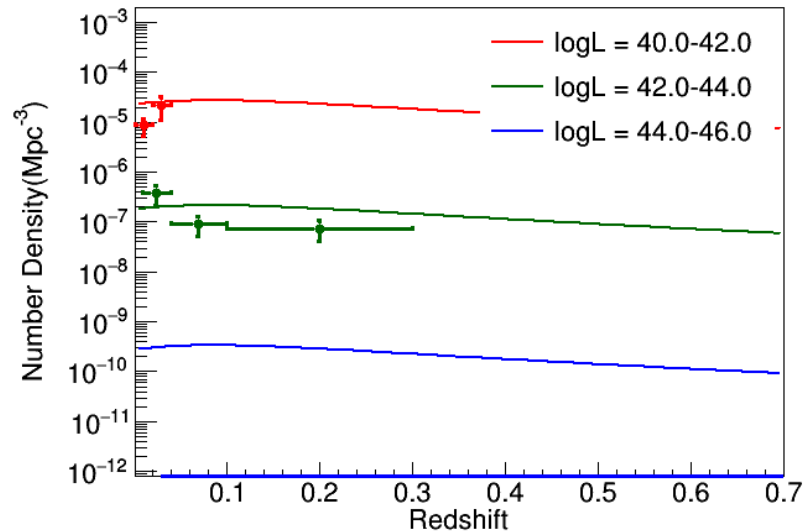
Negative evolution in nearby universe

Many low-power gamma-ray L galaxies exit in low-z.

FR-0s (Paluya+21)

Parent population of elliptical-like blazars ? (Itoh+20)

Emission other than the core jet; (e.g. Cen-A kpc jet by HESS)



Conclusion

GeV-loud RG has a blazar-like Sequence on H.E. SED.

GeV-loud RG is a small part of radio-loud RG; only beamed ones are seen in GeV.

FR-I/II vs BL Lac/FSRQ correspondence is consistent with our results.

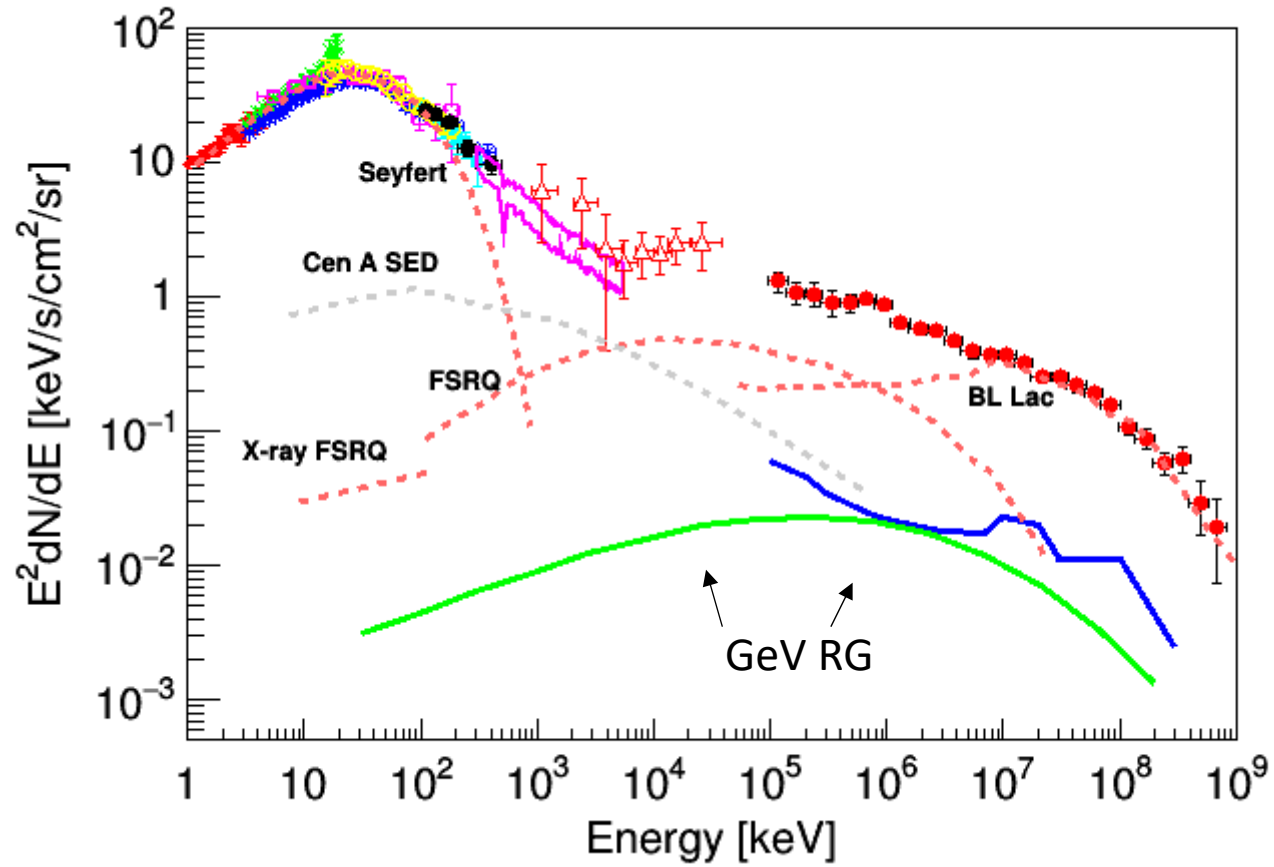
FR-II is lacking in GeV; H.E. SED peak freq. is lower.

Many GeV-undetected FR-IIs are there.

Possible significant contribution to MeV gamma-ray background

GeV-loud RG has a negative evolution in nearby universe.

Contribution of GeV-loud RG to the EGB



Radio galaxy contribution to EGB

Inoue+11

Using 10 galaxies in Fermi 1st Catalog

Assuming a luminosity function of radio galaxies in the radio band (Willott+01)

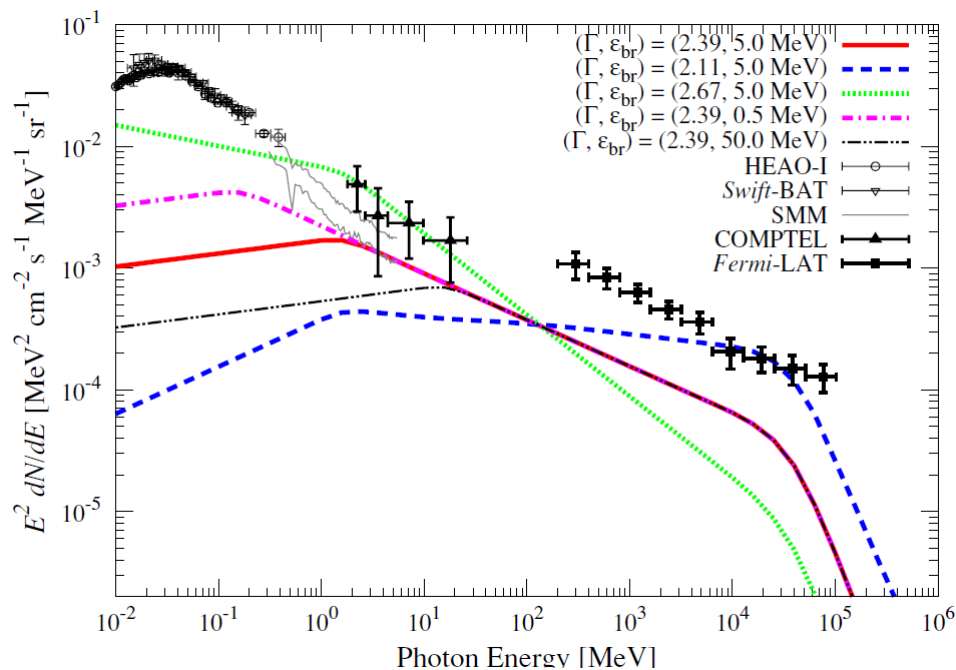
Normalization of LF from Lradio vs Lgamma via logN-logS

Di Mauro+14

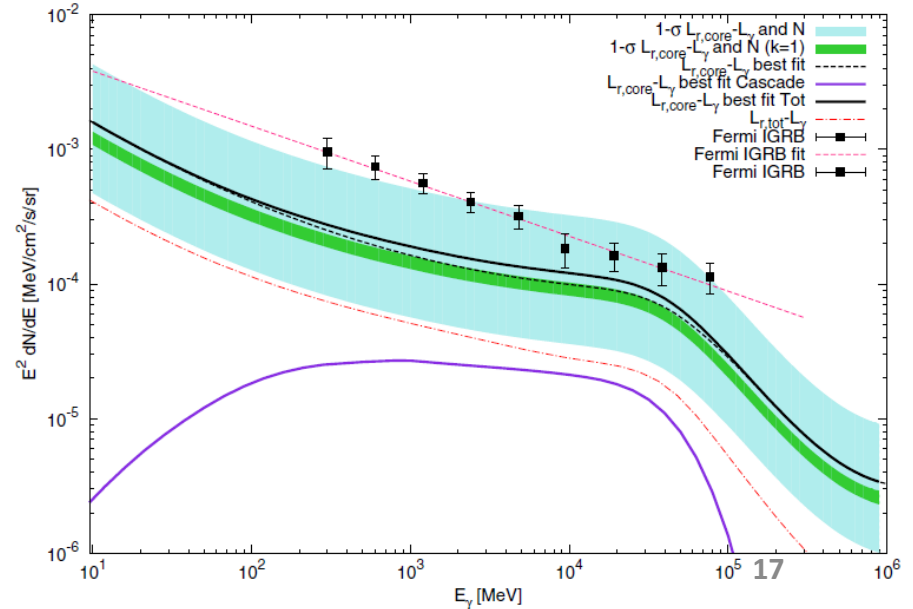
Basically following Inoue+11

Using 12 galaxies in Fermi 2nd Catalog

Inoue+11



Di Mauro+14



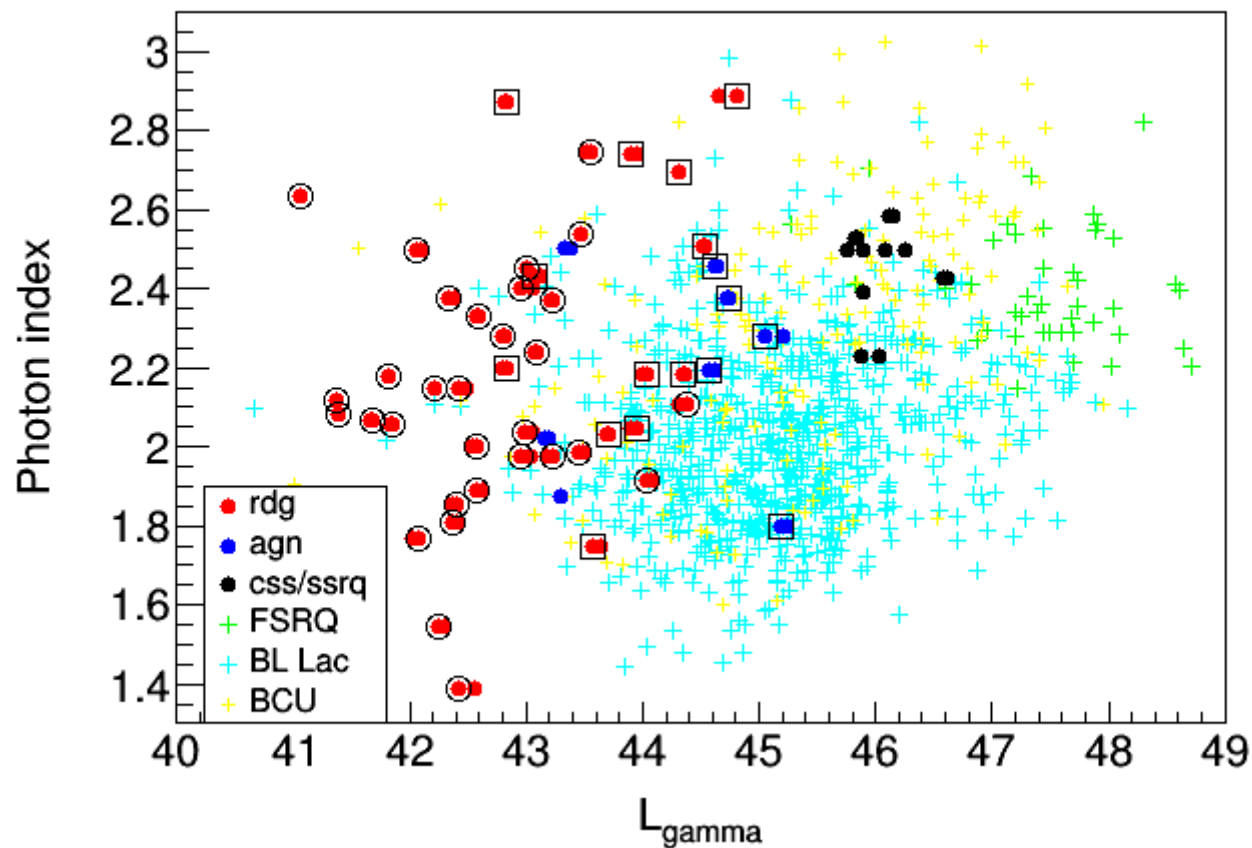
Population (2)

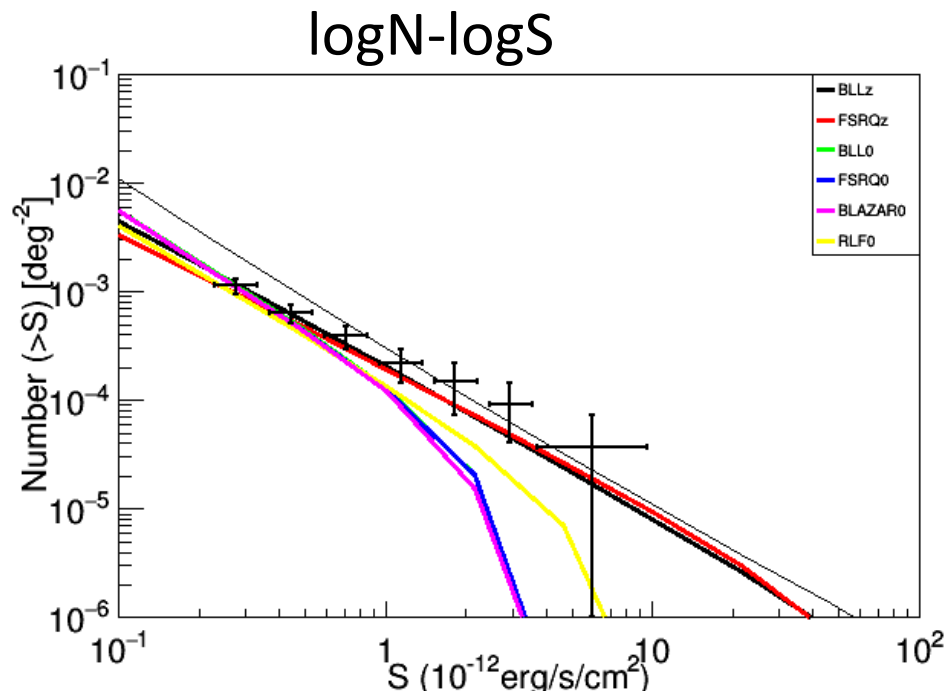
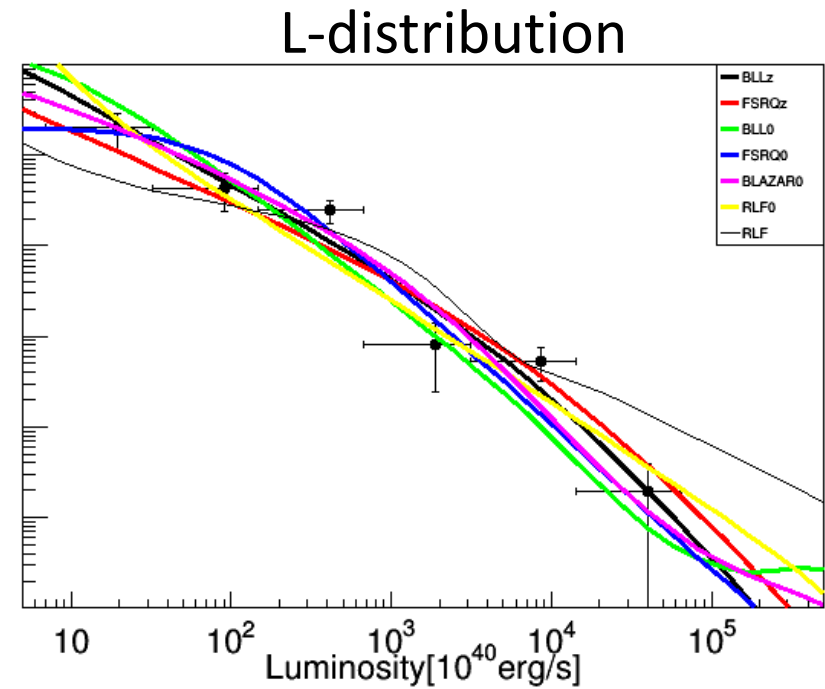
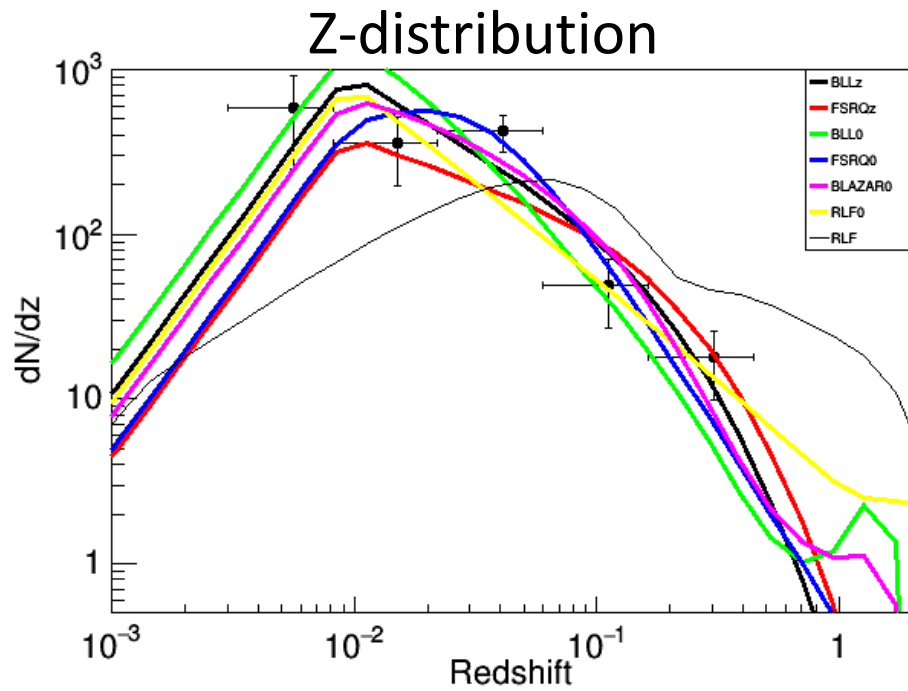
FR-I / FR-II \leftrightarrow BL Lac / FSRQ

Blazar seq of H.E. emission component is common.

“ No FR-II with as large Compton dominance can be due to difference of beaming pattern between external Compton and SSC (Finke+13).

Some FR-lis may correspond to BL Lac (LBL)?





6 types of LF reproduce a redshift and luminosity distribution, but radio-band LF of radio galaxies does not fit.

LFs with low-z peak reproduce a logN-logS relation.