Dust Obscured Blazars as Sources of High-Energy Neutrinos

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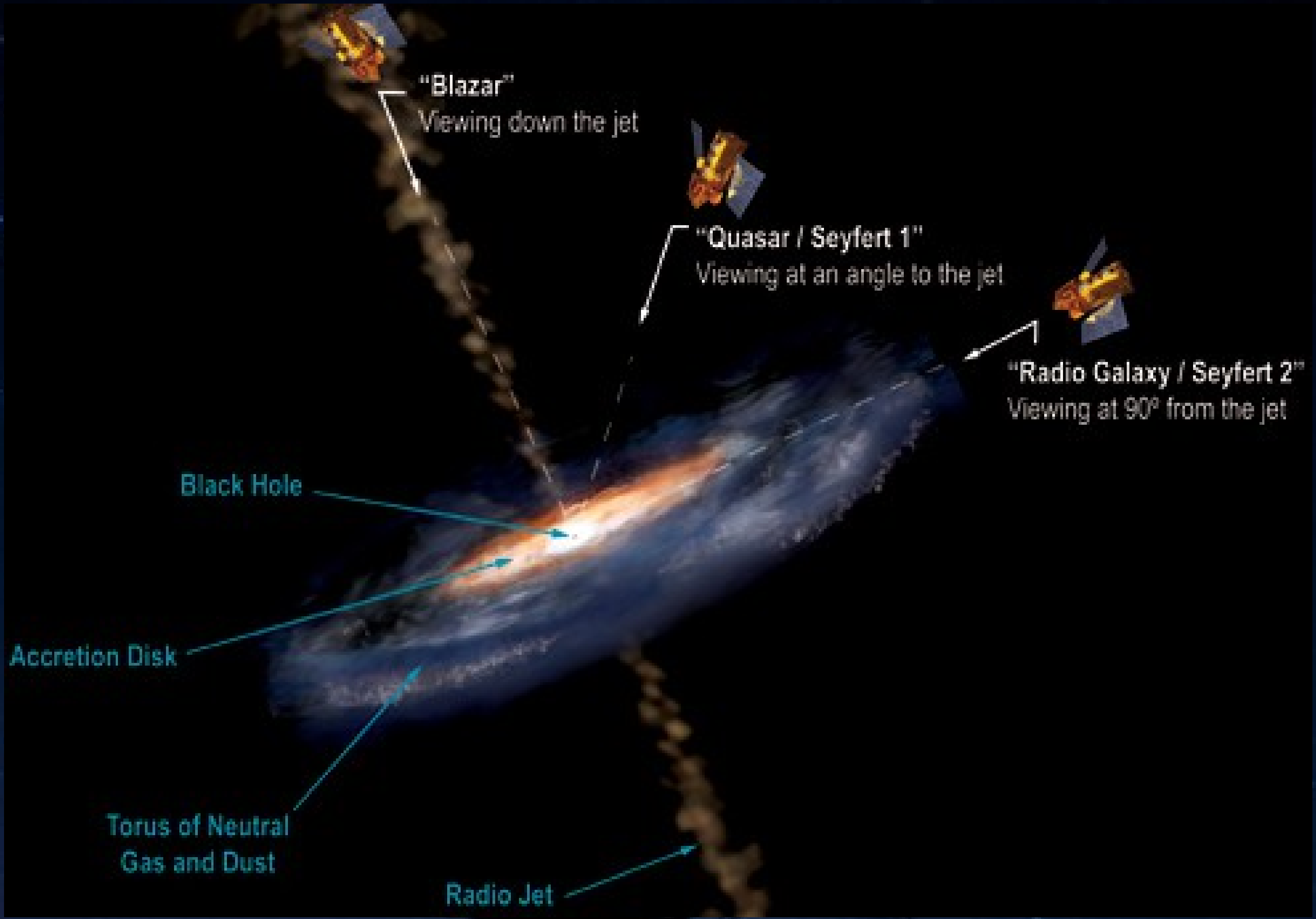
Motivation

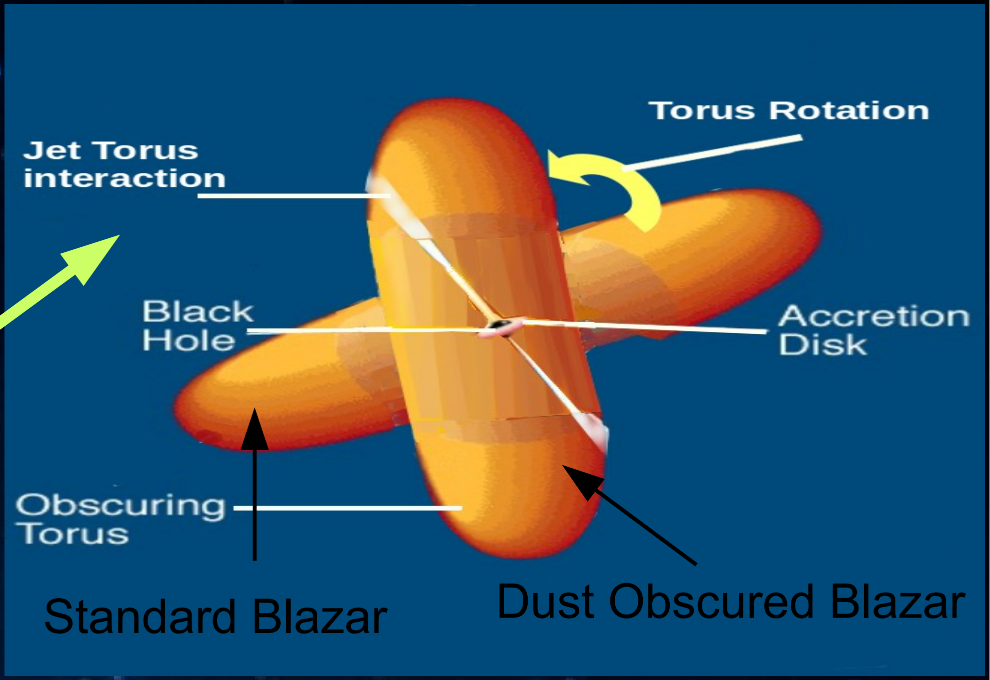
- The IceCube collaboration has detected more than 50 High energy Astrophysical Neutrinos.
- Their sources are unknown.
- Some classes of GRBs and AGN have been investigated, with no significant evidence. Consequently, upper limits are set.
- A natural question that arises is: What kind of objects are emitting the High-Energy Neutrinos detected by IceCube.
- We propose a specific kind of AGN: Dust Obscured Blazar.

AGN classification



Standard Blazars vs Dust Obscured Blazars

- A. Lawrence, M. Elvis. Misaligned Disc as Obscurers in Active Galaxies (2010).
- S. Bianchi et al. AGN Obscuration and the Unified Model (2012).



- If this is the case, we talk about a **Dust Obscured Blazar.**

- Then protons would
  not only interact with gammas,
  also with the matter in the dust

  → "Beam Dump"

- In this case the neutrino flux would be increased.

$$p_{jet} + \gamma \rightarrow \Delta^{+} \rightarrow n + \pi^{+}$$

$$\rightarrow \quad \pi^{+} \rightarrow \mu^{+} + \nu$$

$$p_{jet} + p_{matter} \rightarrow hadrons$$

$$\rightarrow \quad \pi^{+} \rightarrow \mu^{+} + \nu$$

NGC 1068

Dust Obscured Blazars

The main feature of Dust Obscured Blazars.

Due the tilted Torus (or another kind of dust) in between the line of sight of a blazar and the observer

Emission at high frequencies will be attenuated where low frequency emission will pass through the dust un-attenuated

⇓

Low X-ray emission is expected
and
Radio emission would be strong.

Additional neutrino production

Fermi acceleration → Proton Spectrum: E^-2

$$p_{jet} + \gamma \rightarrow \Delta^{+} \rightarrow n + e^{+} + \nu_e + \nu_\mu + \overline{\nu}_\mu$$ ← Total Proton fraction : 5 – 20 %

$$p_{jet} + p_{dust} \rightarrow X$$ ← Total Proton Fraction : 80 – 95 %

+

$$n + p_{dust} \rightarrow X$$ ← Total Proton Fraction : 5 – 20 %

X : Set of hadrons (pions, kaons, etc)

The catalogs

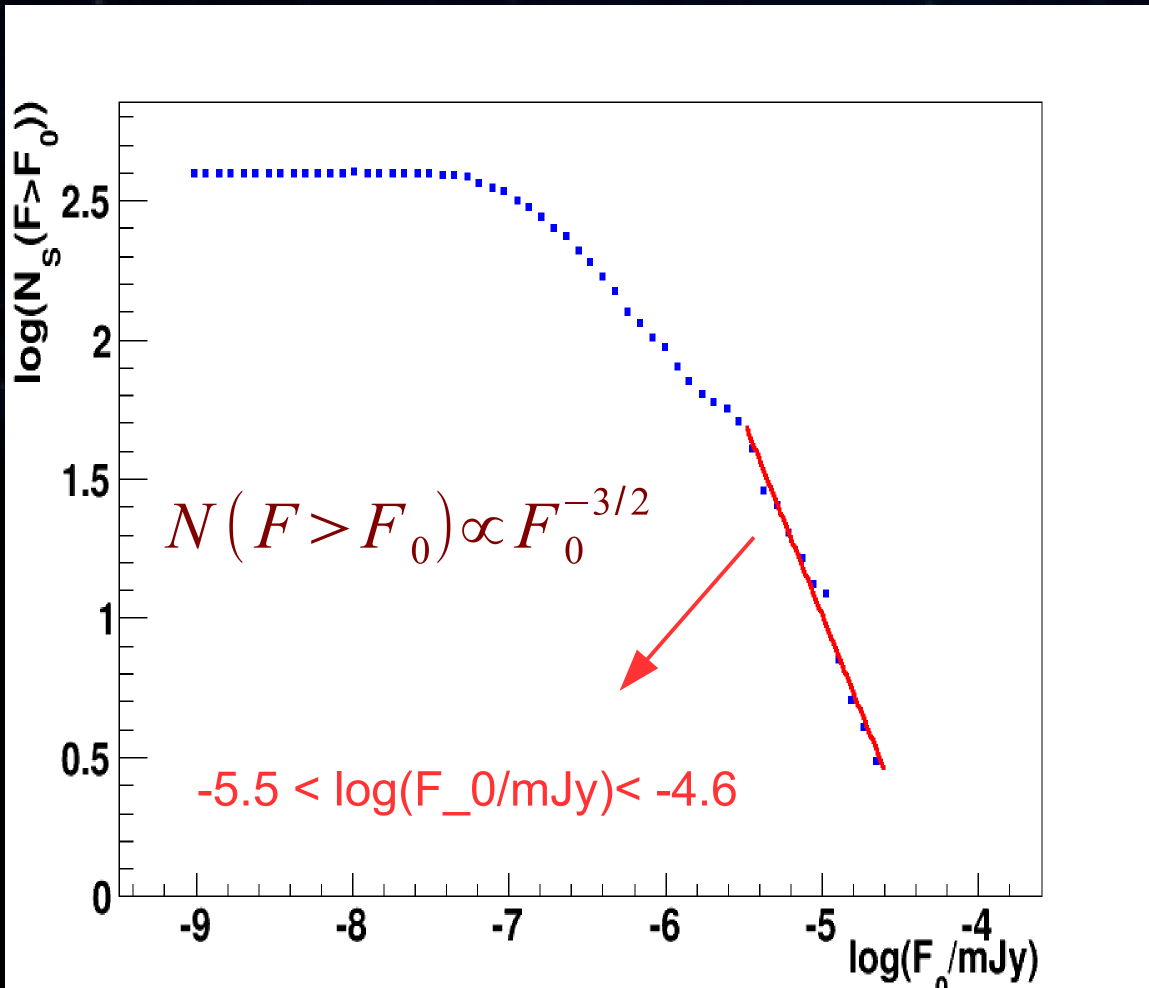
- Radio Galaxies of the Local Universe:
  - ✓ Composed by 575 objects with different morphologies, covering 88% of the Sky, and within a redshift (z) < 0.1
  - ✓ The sources here have been selected to be potential candidates of UHECRs.
- 2LAC:
  - ✓ Formed by 1017 gamma-ray sources in different categories, |b|>10 degrees, within a redshift < 3.1.
  - ✓ Most of the objects are in the category of FSRQ and BLLac.

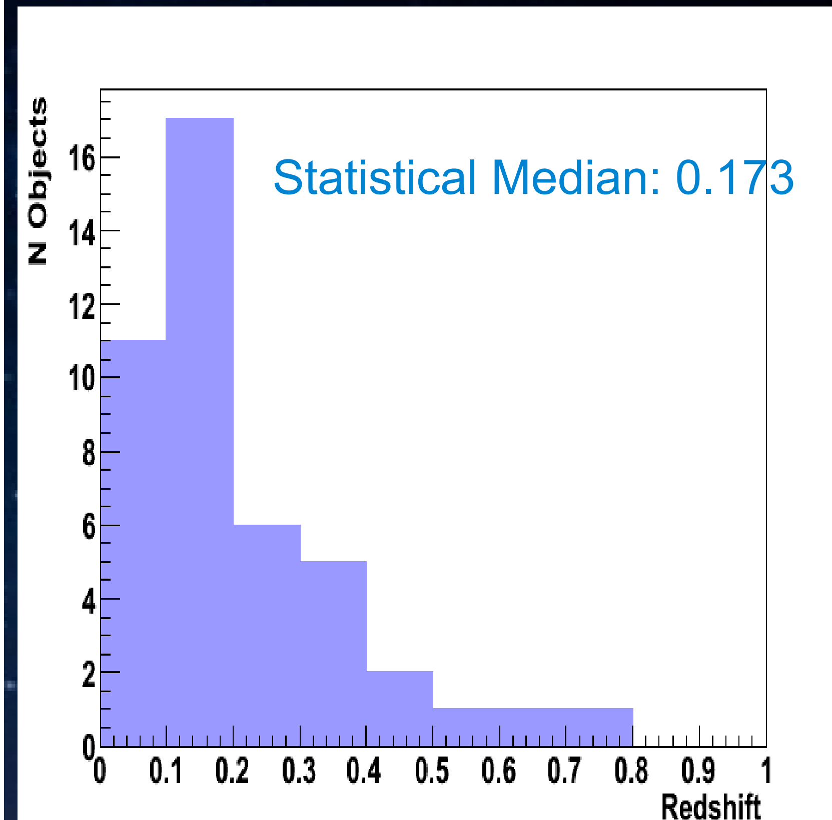
The flux attenuation at high frequencies must be because of the surrounding dust, and no others effects

- Those effects might be:
  - ✔ Intergalactic medium.
  - ✔ The flux goes down as R^-2, needs good detector sensitivity.
  - ✔ Cosmological Redshift.
- To prevent that, we select nearby sources.
- When one looks at a distance r towards the sky:

$$N(r) = \frac{4}{3} n \pi r^3 \qquad F_\nu = \frac{E}{4 \pi r^2}$$

A limited Volume Sample



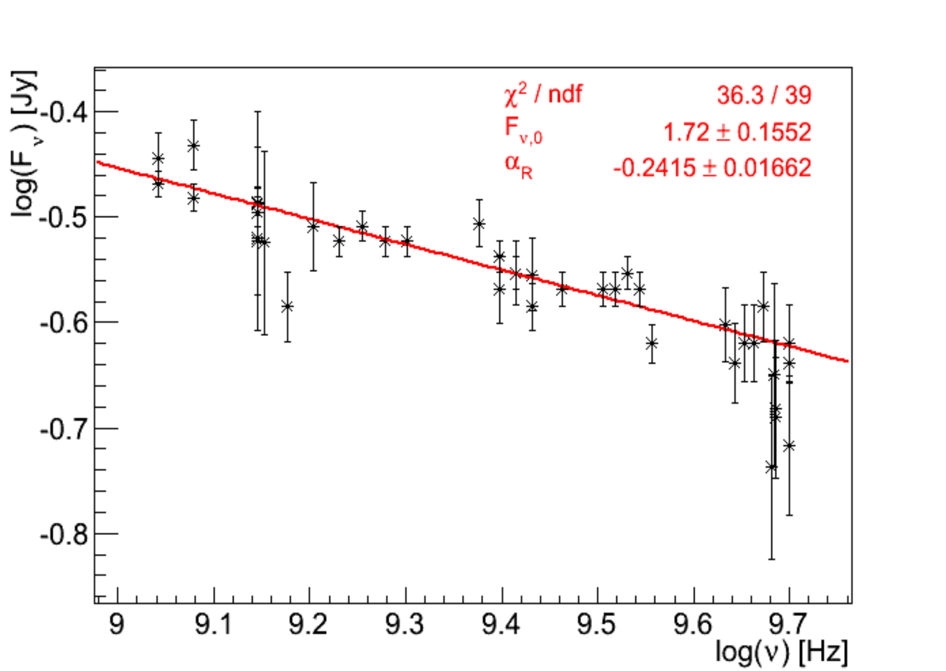


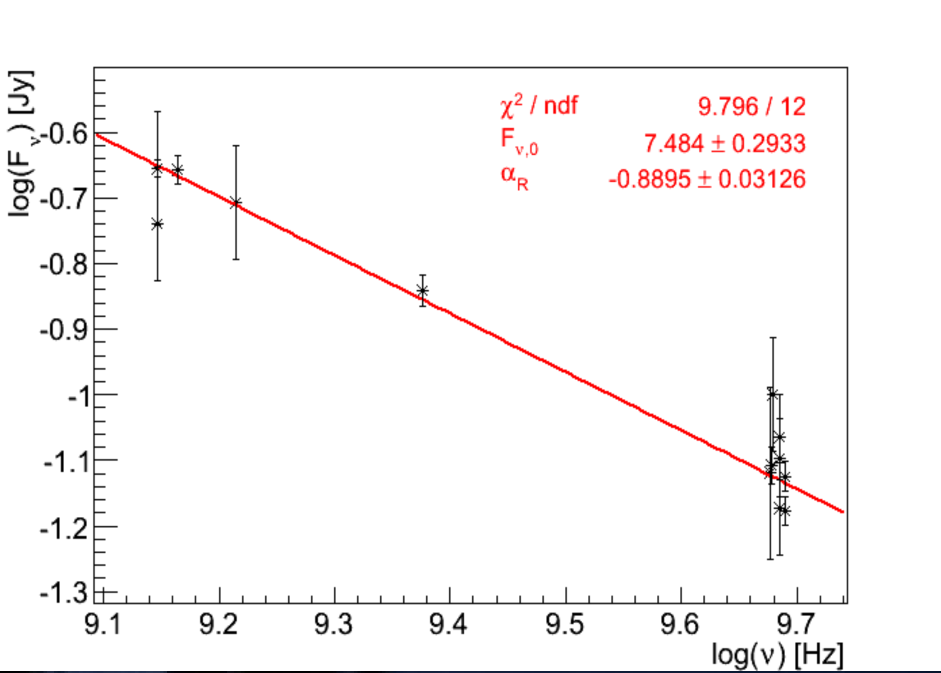
Blazar-Features

- We request an AGN with a radio-jet pointing towards us (Blazar characteristic).
  - We performance a fit in a frequency range 0.843-5.0 [GHz], given by

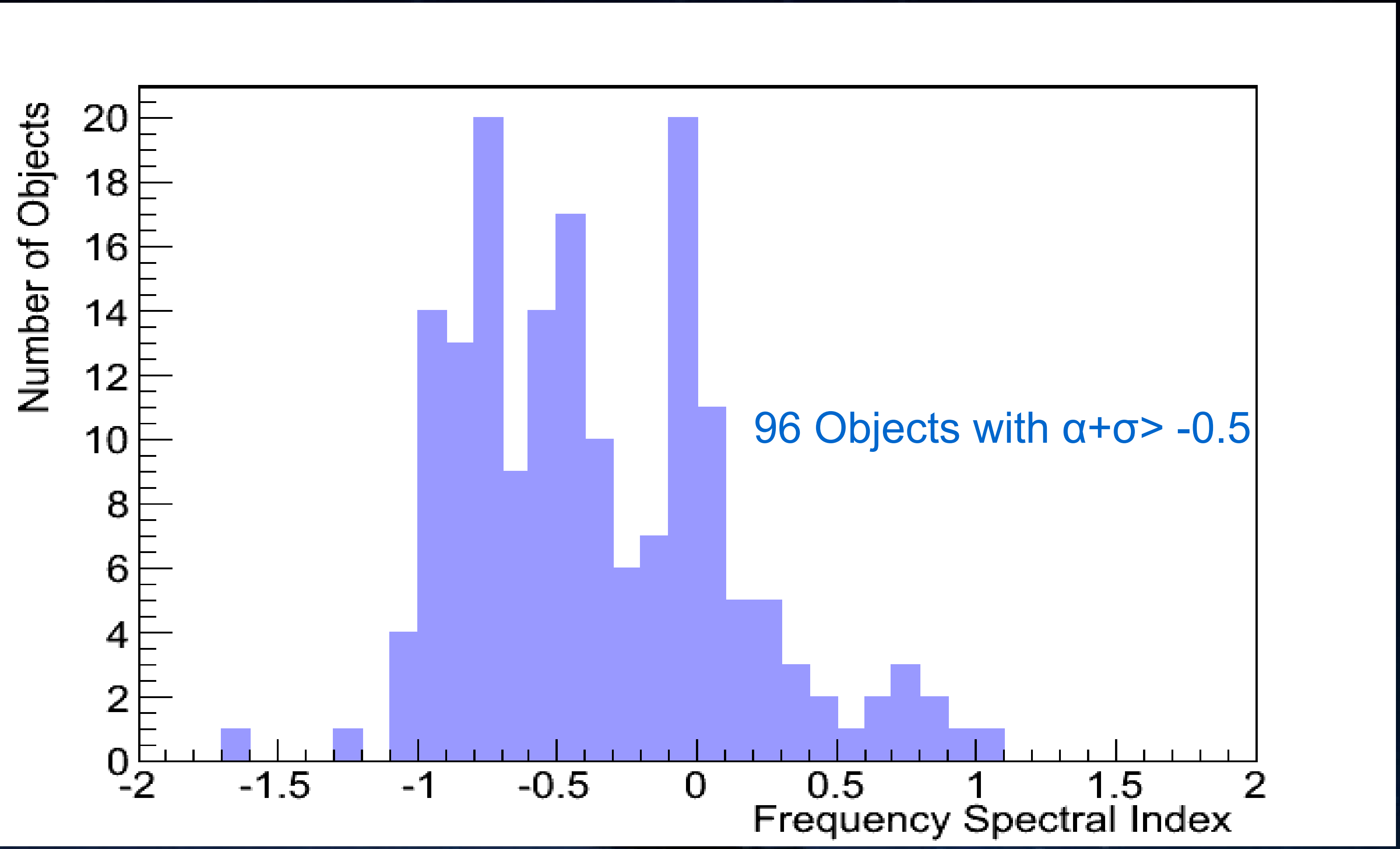
$$F_\nu \sim \nu^{\alpha_R}$$

  - Objects with Frequency Spectral index α+σ > -0.5 are classified as Flat Spectrum Radio Quasars (FSRQ) or BL Lac





Blazar-Features



Select Dust Obscured Blazars from a limited volume sample and with Blazar-Feature

- A weak emission at a X-ray frequency is expected (BLLac):

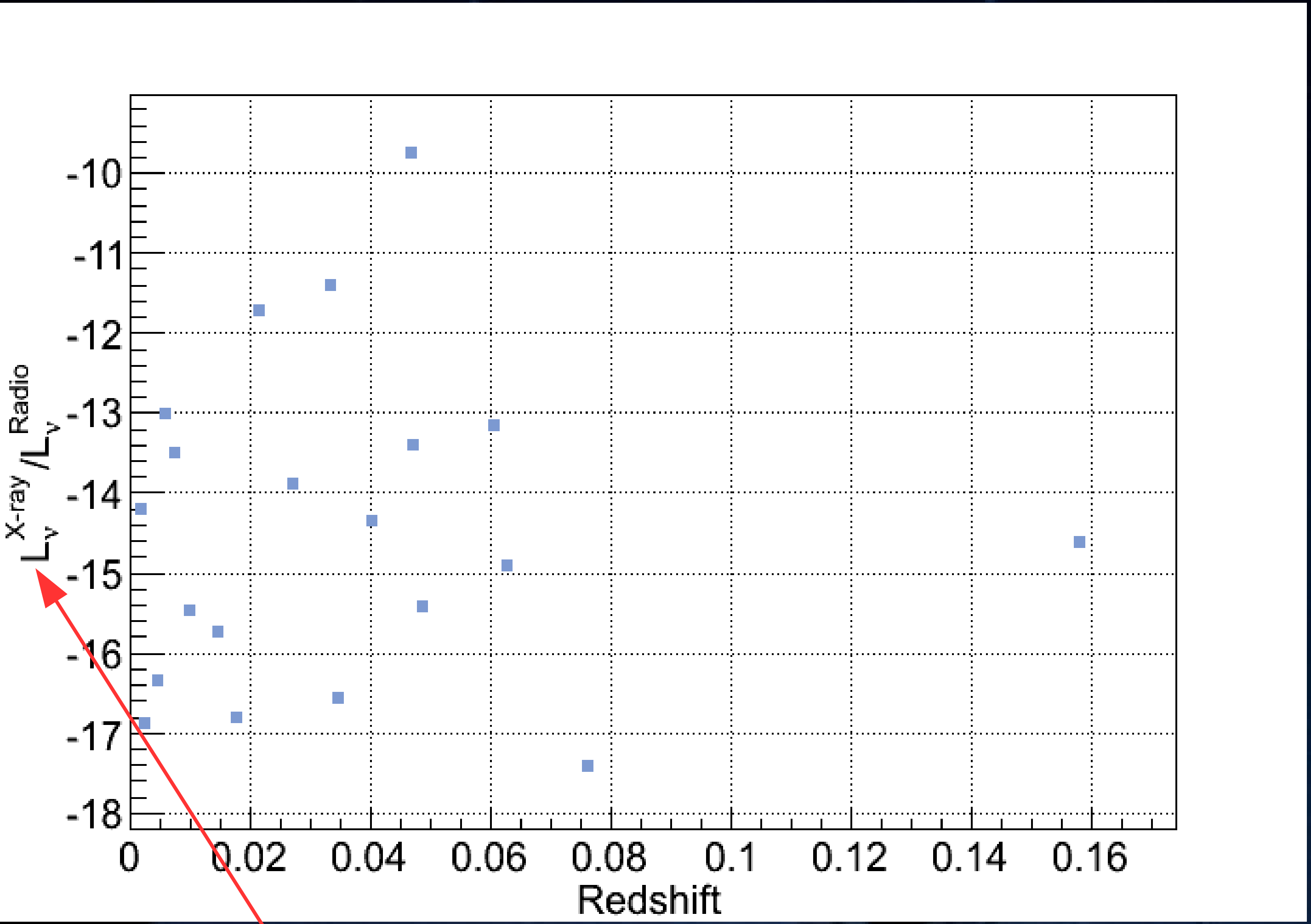
$$I_x^{obs} = I_x^0 e^{-X/\lambda_x}$$

- Avoid to select sources with a weak engine (NO-BLLac):

$$\frac{I_x^{obs}}{I_R^{obs}} = \frac{I_x^0}{I_{Radio}^0} e^{-X/\lambda_x}$$

X : is the amount of dust determined by the condition of 98% of the protons are absorbed

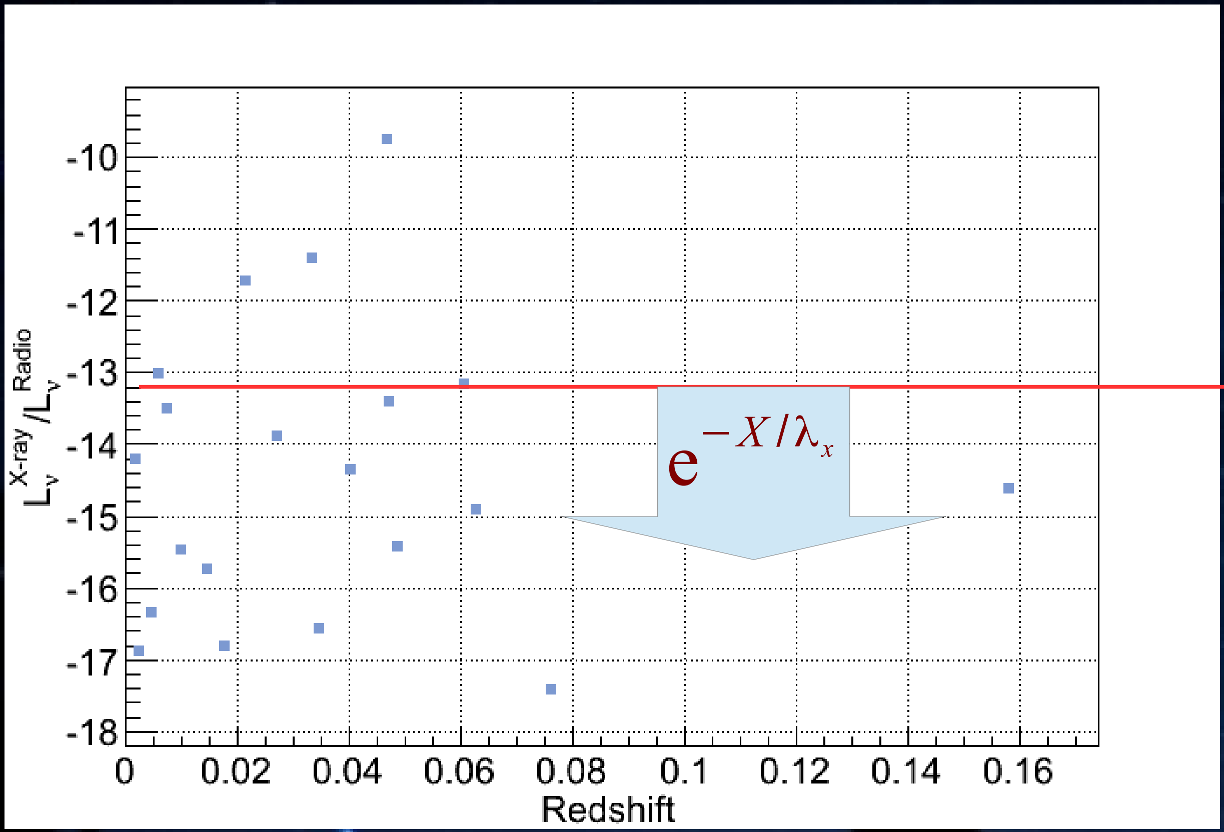
The selection of Dust Obscured Blazars



$$\frac{I_x^{obs}}{I_R^{obs}} = \frac{I_x^0}{I_{Radio}^0} e^{-X/\lambda_x}$$

Luminosity (L) ~ Intensity (I)

The selection of Dust Obscured Blazars



$$\frac{I_x^{obs}}{I_R^{obs}} = \frac{I_x^0}{I_{Radio}^0} e^{-X/\lambda_x}$$

Split the sample with highest ratio by the median

$$\frac{I_x^0}{I_{Radio}^0}$$

Final Sample of Dust Obscured Blazars

Dust Composition	N Sources	Sources
Oxygen	13	PKS1717+177, GB6J1053+4930, SBS1200+608, 4C+04.77, TXS1148+592, RGBJ1534+372, GB6J1542+6129, B21811+31, ARP220, MRK0668, NGC3628, NGC1052, 2MASXJ05581173+5328180
Nitrogen	5	PKS1717+177, RGBJ1534+372, ARP220, MRK0668, NGC3628
Carbon	2	RGBJ1534+372, MRK0668,
Iron	1	RGBJ1534+372

Summary

- The main Feature of Dust Obscured Blazars is an AGN with a radio jet pointing towards us, and low flux at highest frequencies.
- The Neutrino Flux increases due to p-N interaction.
- A selection of possible Dust Obscured Blazars has been made.
- From these objects additional neutrino production is expected, increasing the probability for being detected using IceCube.
- An analysis with IceCube data is in progress.

BACK UP

Jet Matter Interaction

- The amount of protons surviving after passing a through a column of dust X is:

$$\frac{I_p}{I_p^0} = e^{-X/\lambda_p}$$

- For the proton interaction depth we use Pierre Auger measurement for Proton-Air interaction:

$$\lambda_{p-air} = 56\, g\, cm^{-2},\, E_{proton} = 10^{18.24}\, eV$$

- The X-ray attenuation due to the column of dust X:

$$\frac{I_x}{I_x^0} = e^{-X/\lambda_x}$$

Jet Matter interaction

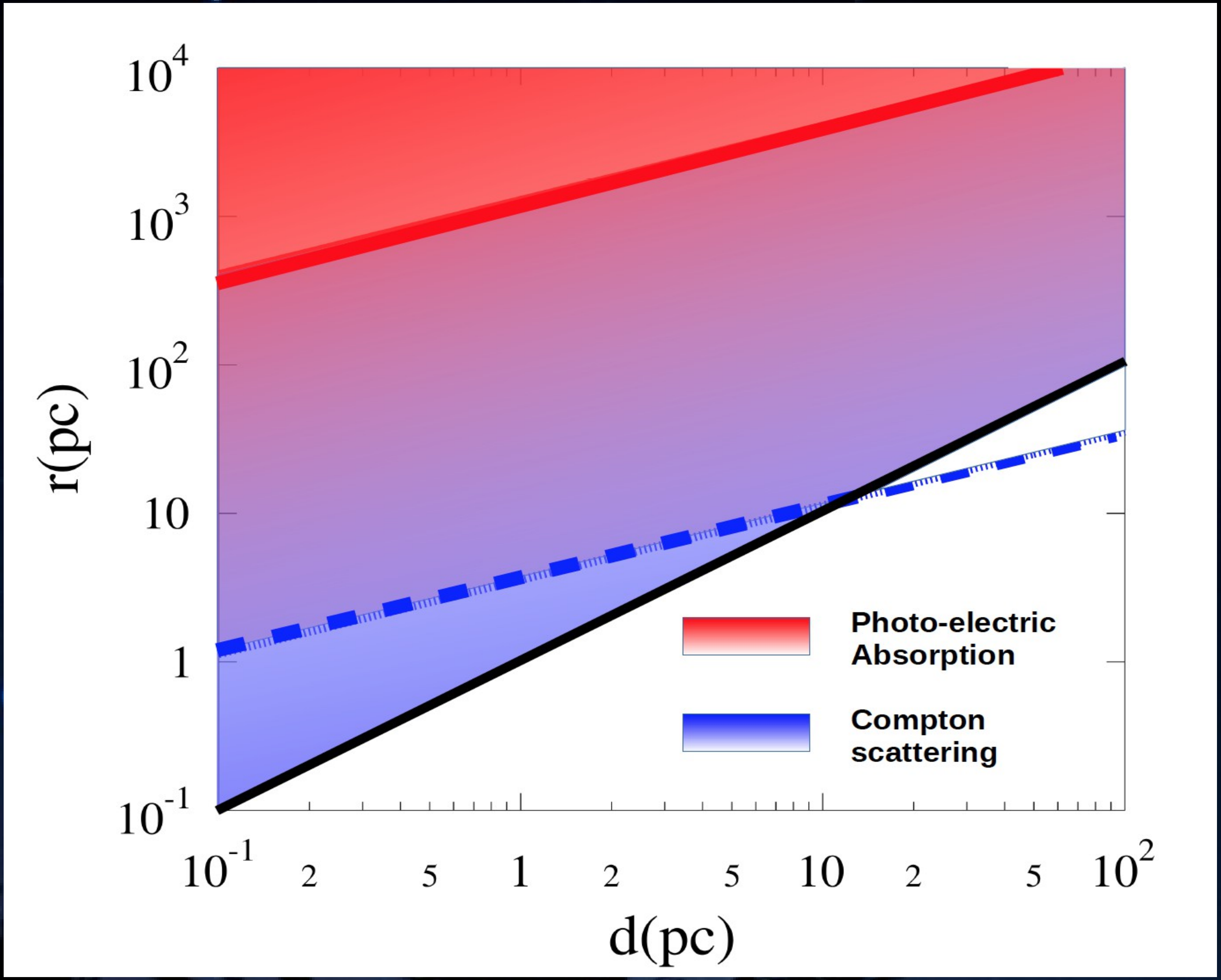
- The attenuation depth for X-ray is obtained from XCOM (Photon Cross Section Database).
  - The X-ray energy that we are interested is at 1.24 KeV.
  - Assuming a highly ionized material, implying that the main process is due to X-ray Compton Scattering:

$$\lambda_{X-ray} = 65\, g\, cm^{-2},\ E_{X-ray} = 1.24 \times 10^{3}\, eV$$

- We can estimate the interaction depths for other materials, by considering :

$$\lambda_{p-N} = (\sigma n)^{-1}, \sigma \propto A^{2/3}, n \propto A^{-1}$$

Dust composition	λ_{p-N} (g cm^{-2})	λ_X (g cm^{-2})	λ_{p-N}/λ_X
H(A=1)	23	14	1.6
C(A=12)	53	55	1.0
N(A=14)	56	62	0.9
O(A=16)	59	80	0.7
Si(A=28)	71	55	1.3
Fe(A=56)	89	84	1.1



10^4
10^3
10^2
10
1
10^{-1}
r(pc)
10^{-1}
2
5
1
2
5
10
2
5
10^2
d(pc)
Photo-electric Absorption
Compton scattering

A limited Volume Sample

$$N(r)=\frac{4}{3}n\pi r^3$$

Cumulative AGNs inside of a sphere

$$F_\nu=\frac{E}{4\pi r^2}$$

Flux at a frequency v

$$\Rightarrow \quad N(F>F_0)\propto F_0^{-3/2}$$

The catalogs

- Sources in two catalogs are investigated:
  - ✓ Radio Galaxies of the Local Universe. Formed by 575 sources.
  - ✓ The Second Catalog of Active Galactic Nuclei by the Fermi Large Area Telescope (2LAC). Composed by 1017 sources.

- We remove duplicated objects by name.
- We remove objects with the same right ascension and declination.
- We ended up with **735 unique galaxies**.
- Data in this analysis is extracted from Nasa Extragalactic DataSet (NED)

The catalogs

Radio Galaxies of the Local Universe:

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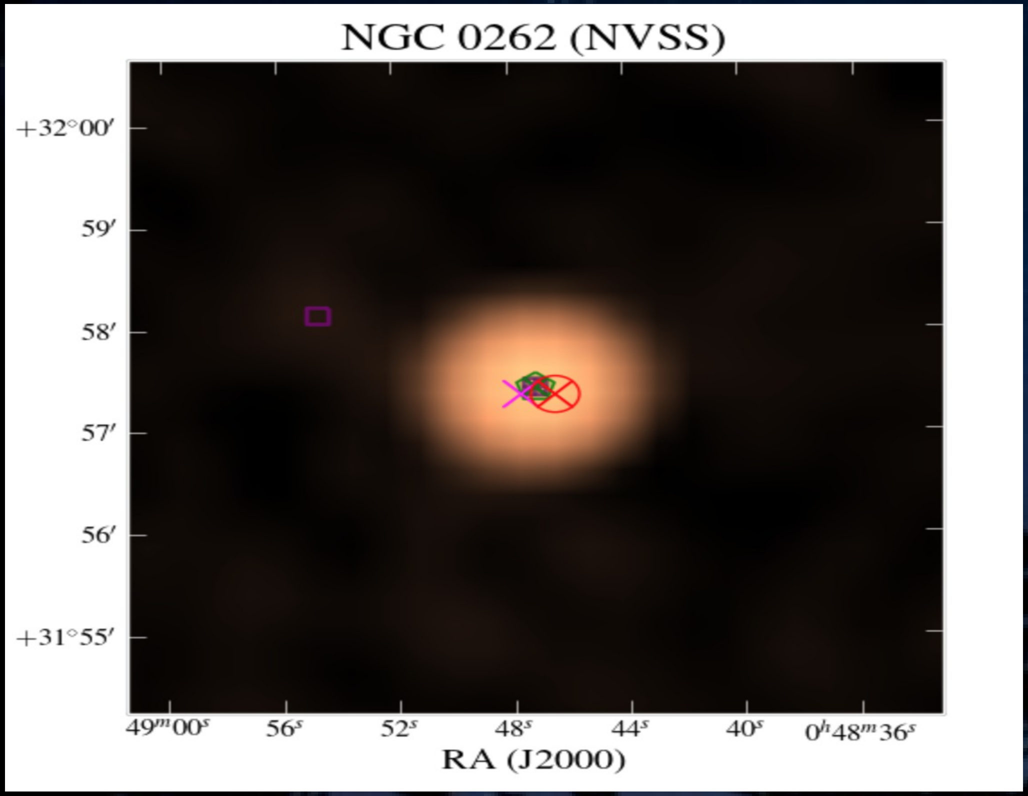

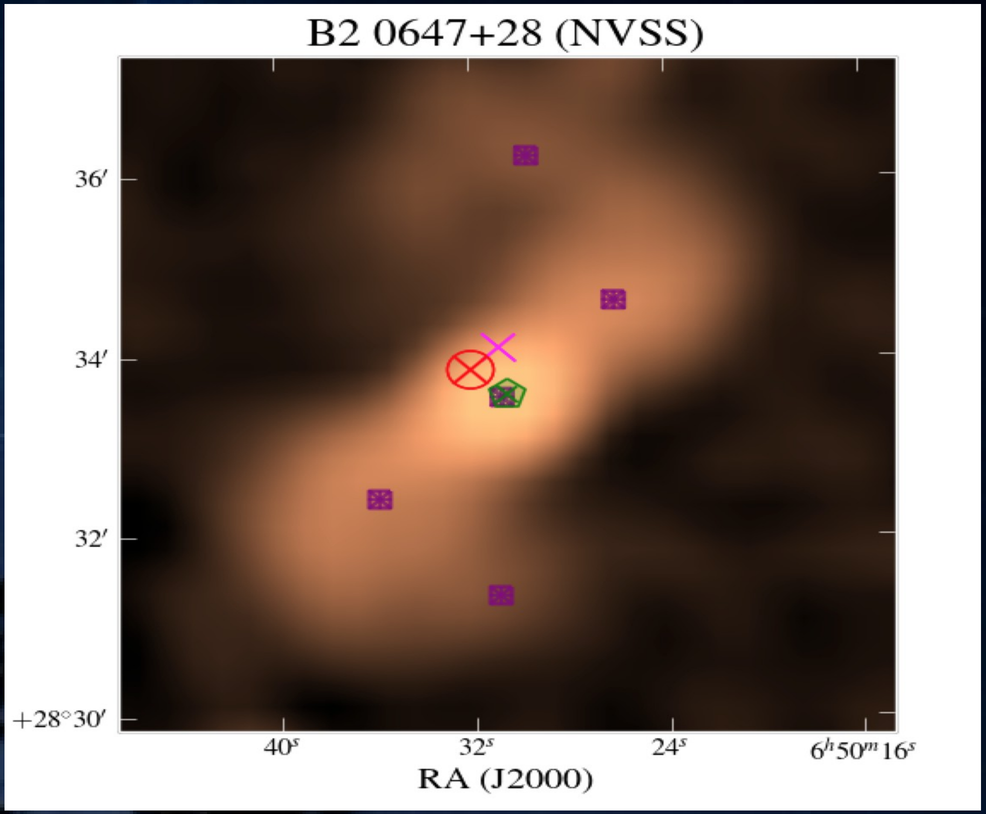

The catalogs

2LAC:

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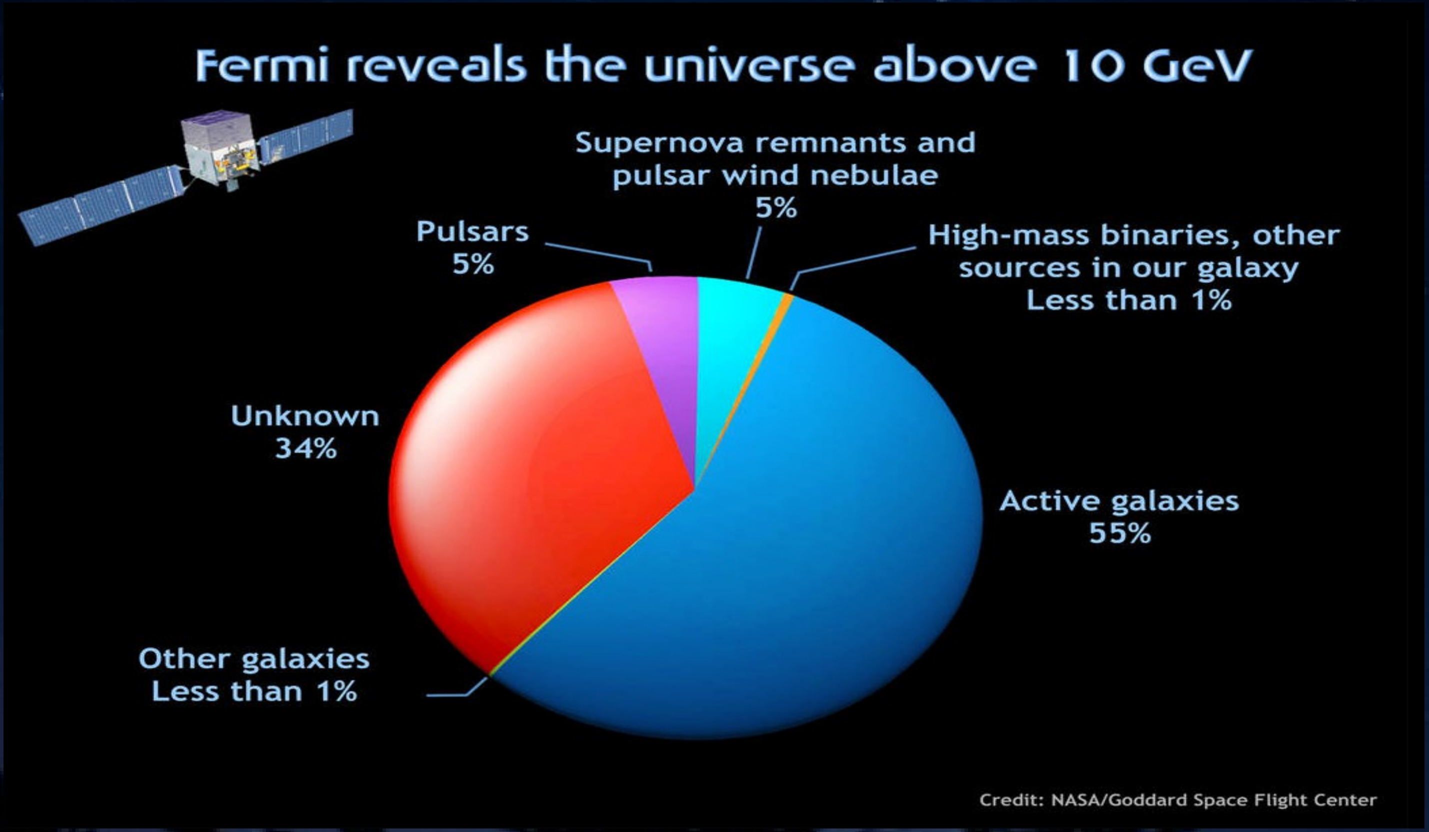
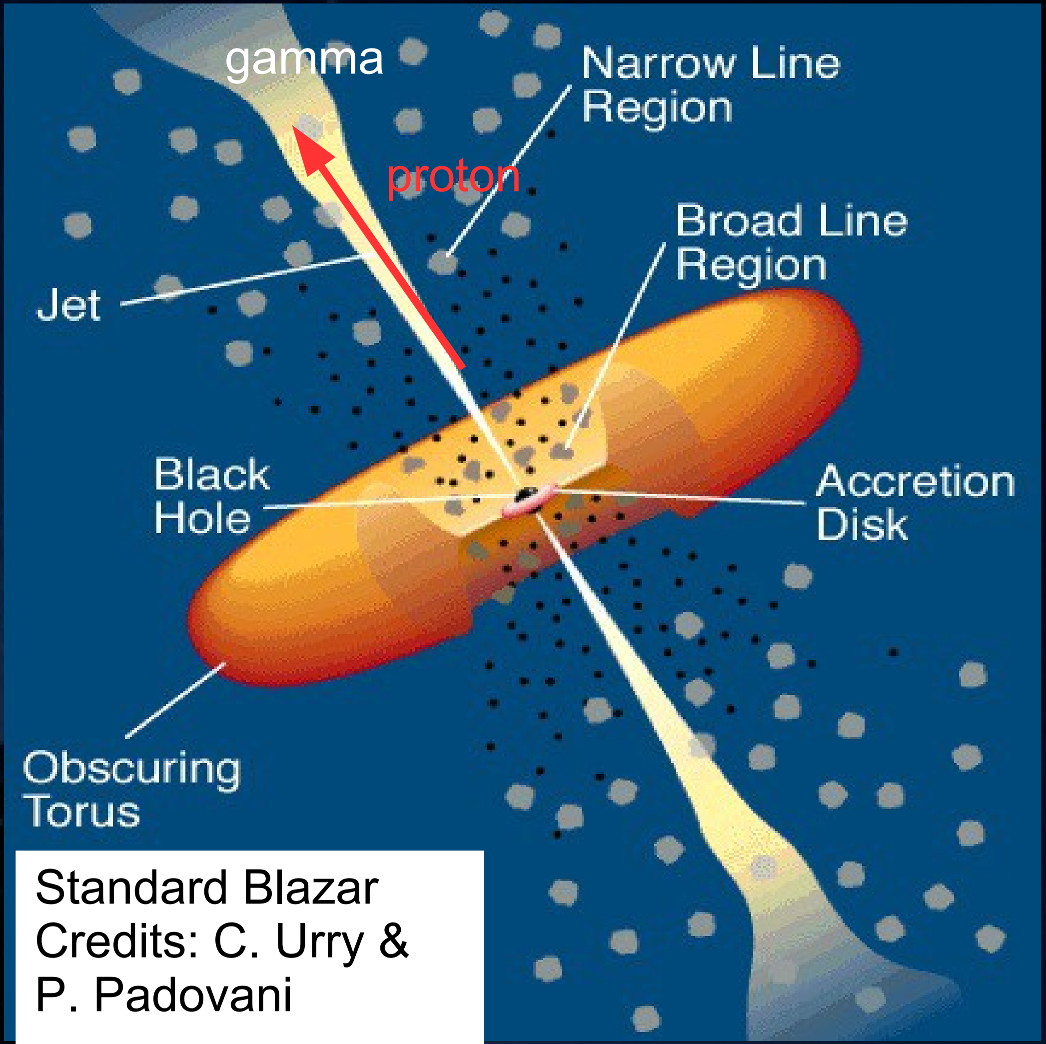


Blazars and neutrino production.

- A Blazar is an AGN with its jet pointing towards the earth (observer).
- Neutrinos would be created after proton+gamma interaction through charged pion decay.

$$p_{jet} + \gamma \rightarrow \Delta^{+} \rightarrow n + \pi^{+}$$

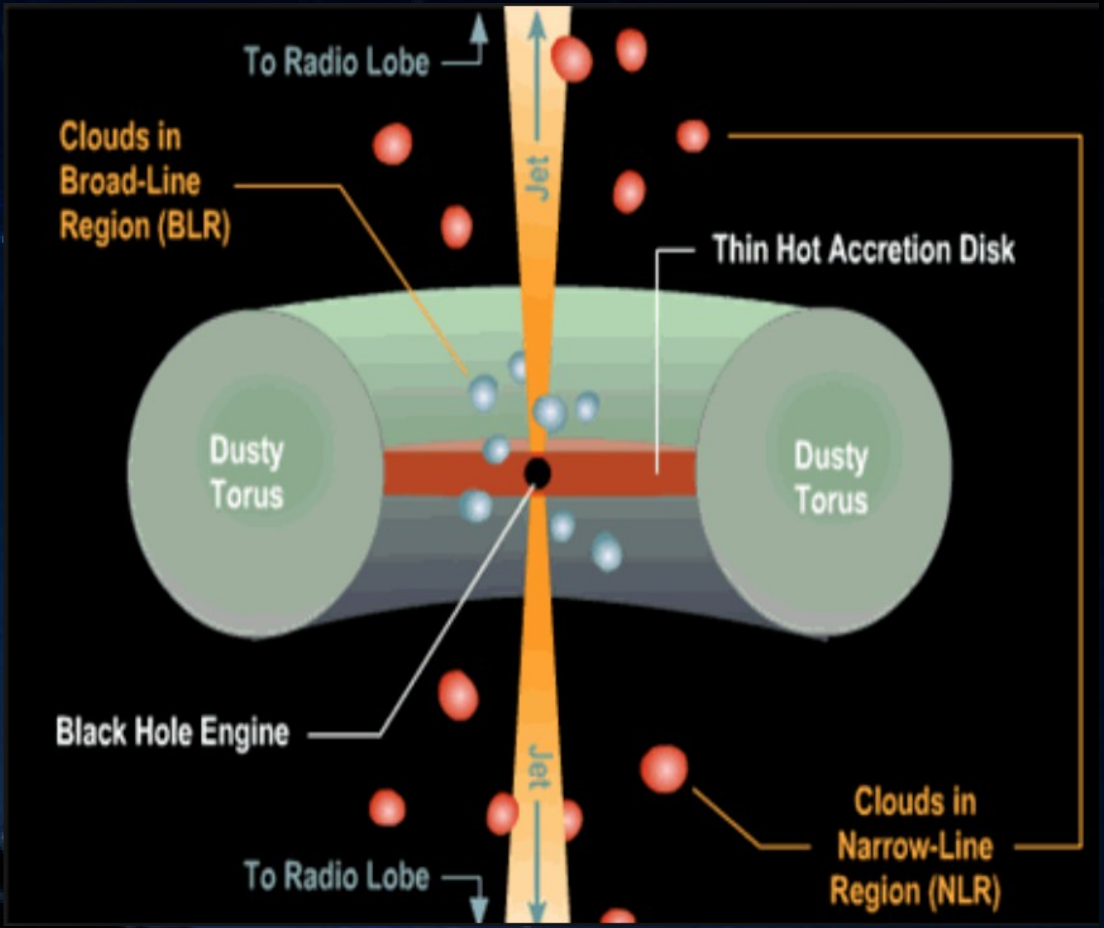
$$\rightarrow \quad \pi^{+} \rightarrow \mu^{+} + \nu$$

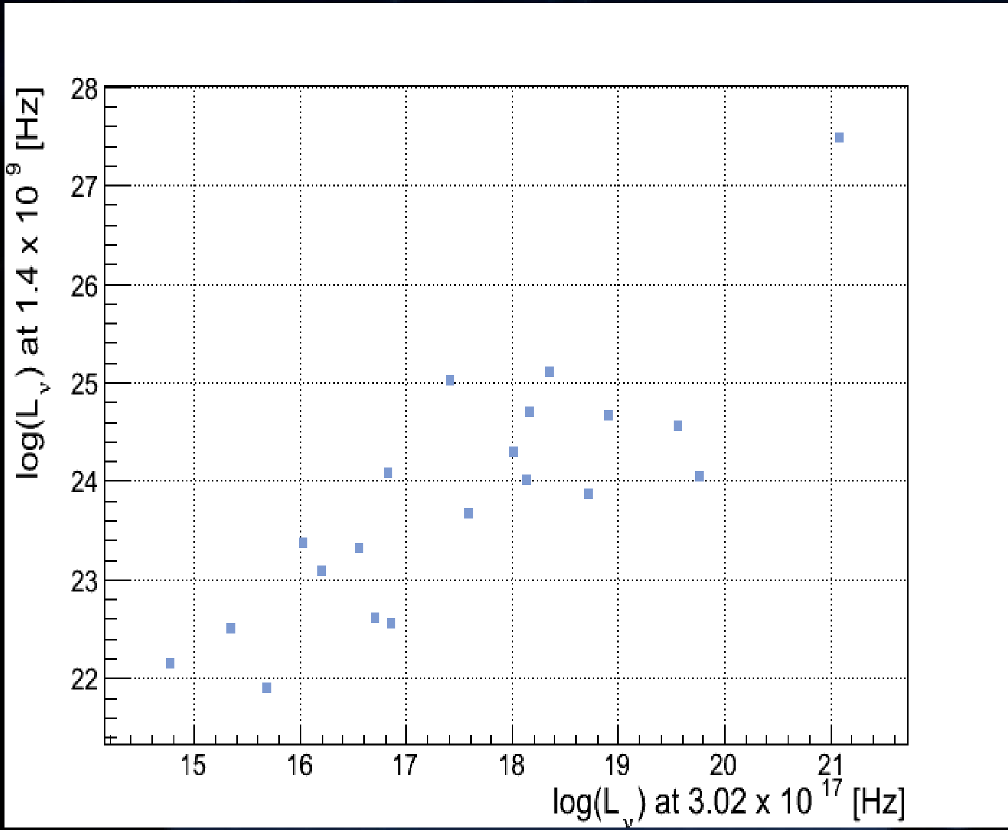


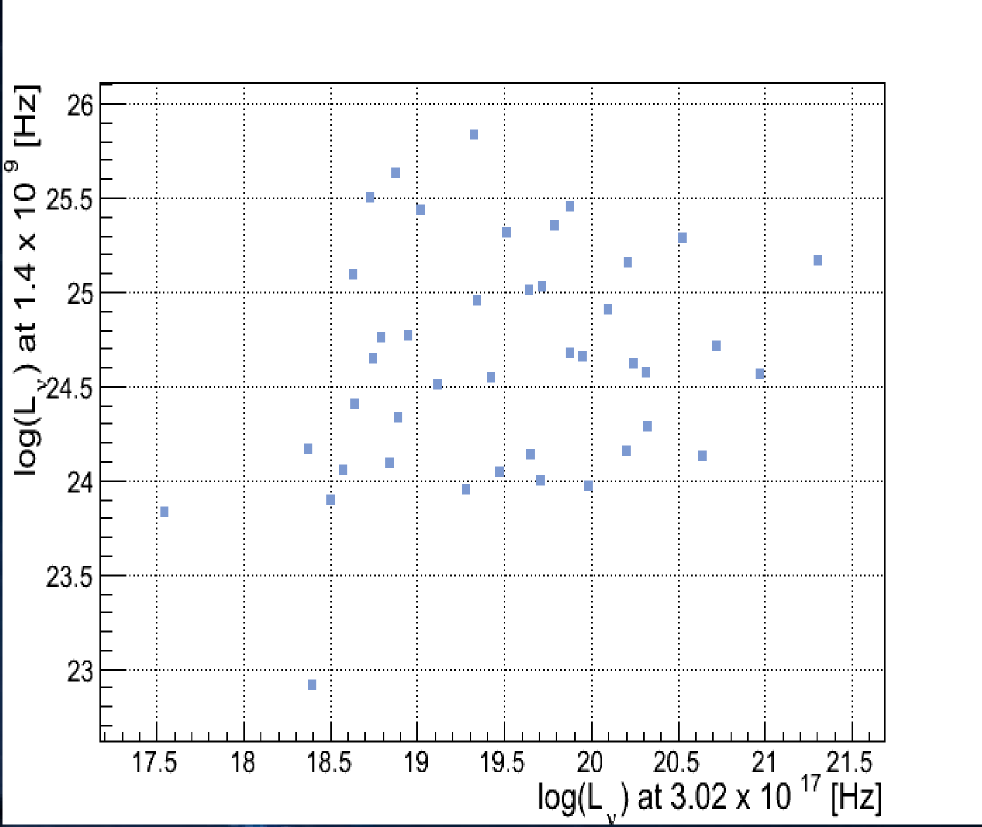
Standard Blazar
Credits: C. Urry & P. Padovani

What does AGN mean?

- AGN: Active Galactic Nuclei.
- Compact core of a galaxy.
- Black Hole in its center.
- Hot matter falls into the Black hole.

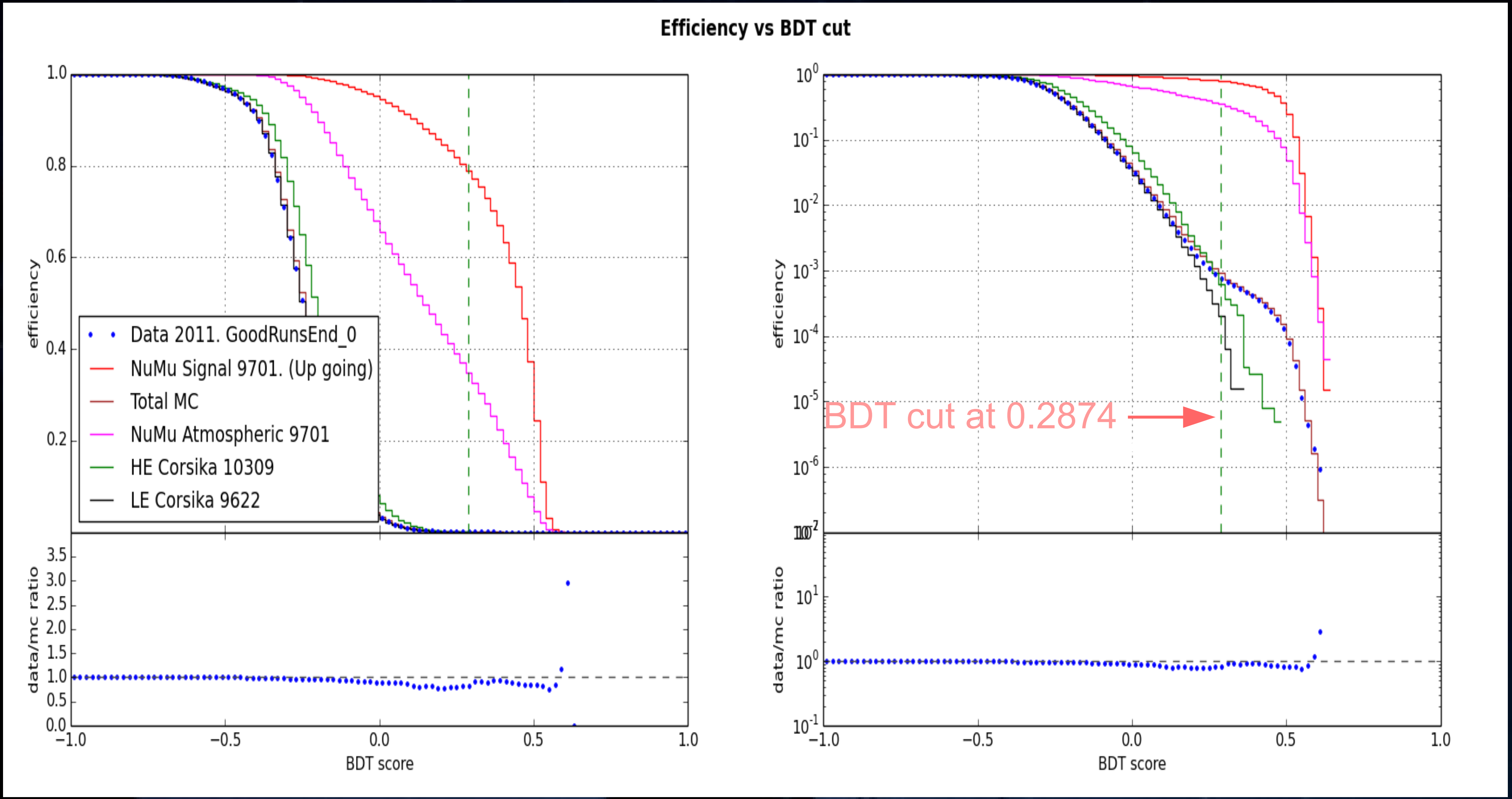



log(L_ν) at 1.4 x 10^9 [Hz]
28
27
26
25
24
23
22
15
16
17
18
19
20
21
log(L_ν) at 3.02 x 10^17 [Hz]


log(L_ν) at 1.4 x 10^9 [Hz]
26
25.5
25
24.5
24
23.5
23
17.5
18
18.5
19
19.5
20
20.5
21
21.5
log(L_ν) at 3.02 x 10^17 [Hz]

Efficiency.

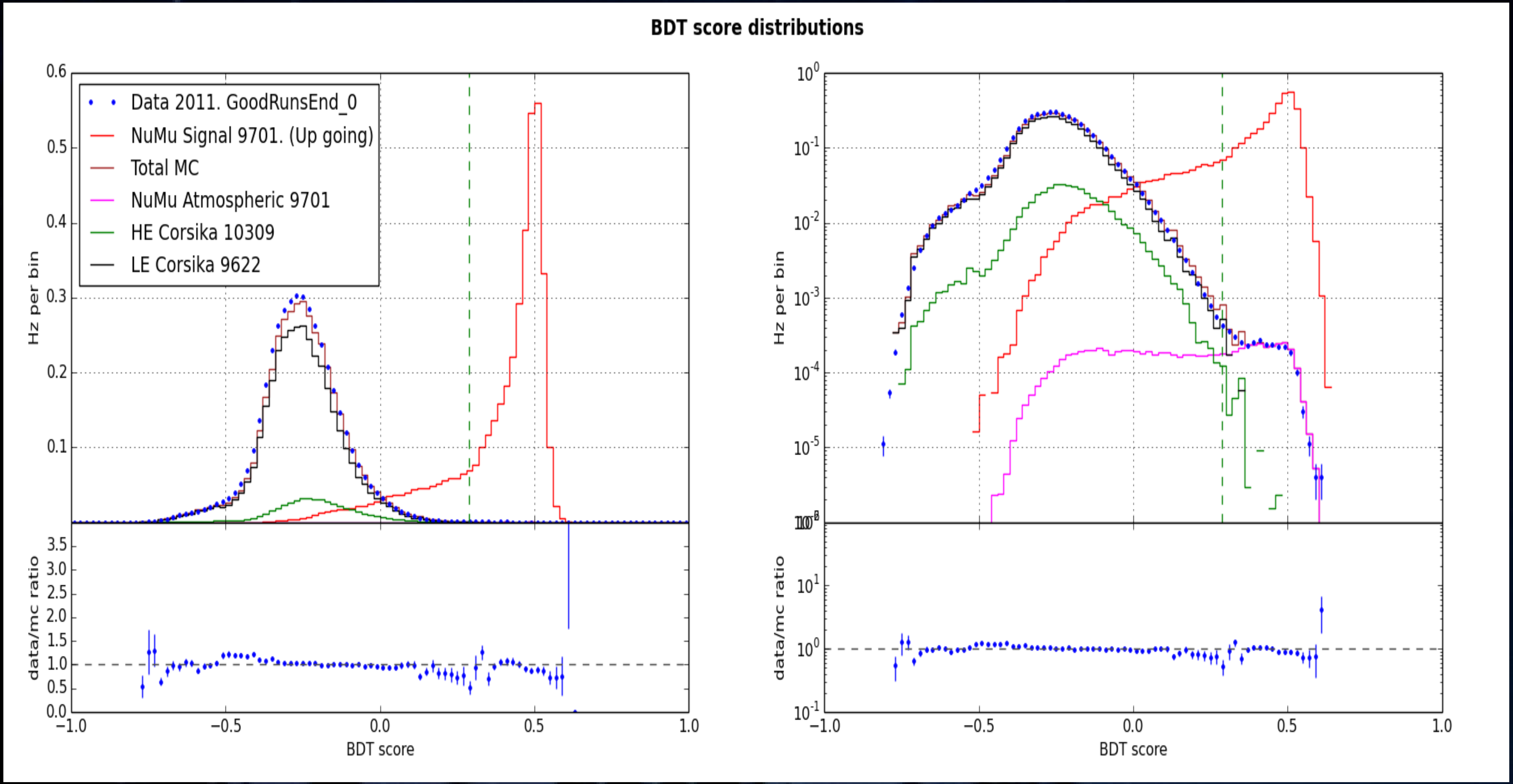
For Training, only NuMu Signal and Burn Sample are used.



http://code.icecube.wisc.edu/projects/icecube/browser/IceCube/sandbox/gmaggi/analysis/cutsonL2/releases/V15-08-11/resources/examples/fullpybdt.py

Rate.

(Signal is scaled to 10^-9)



Effective area per declination band