Neutrinos from Galactic Microquasars

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Outline

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- The µQSO population in the Milky Way
- ν's from Galactic µQSOs
- Conclusions

Motivation

- The IceCube Collaboration has quite recently reported the discovery of extraterrestrial neutrinos, including three events with well-measured energies around 1PeV*(Phys. Rev. Lett. 111, 021103 (2013); Science 342, 1242856 (2013); Phys. Rev. Lett. 113, 101101 (2014))*

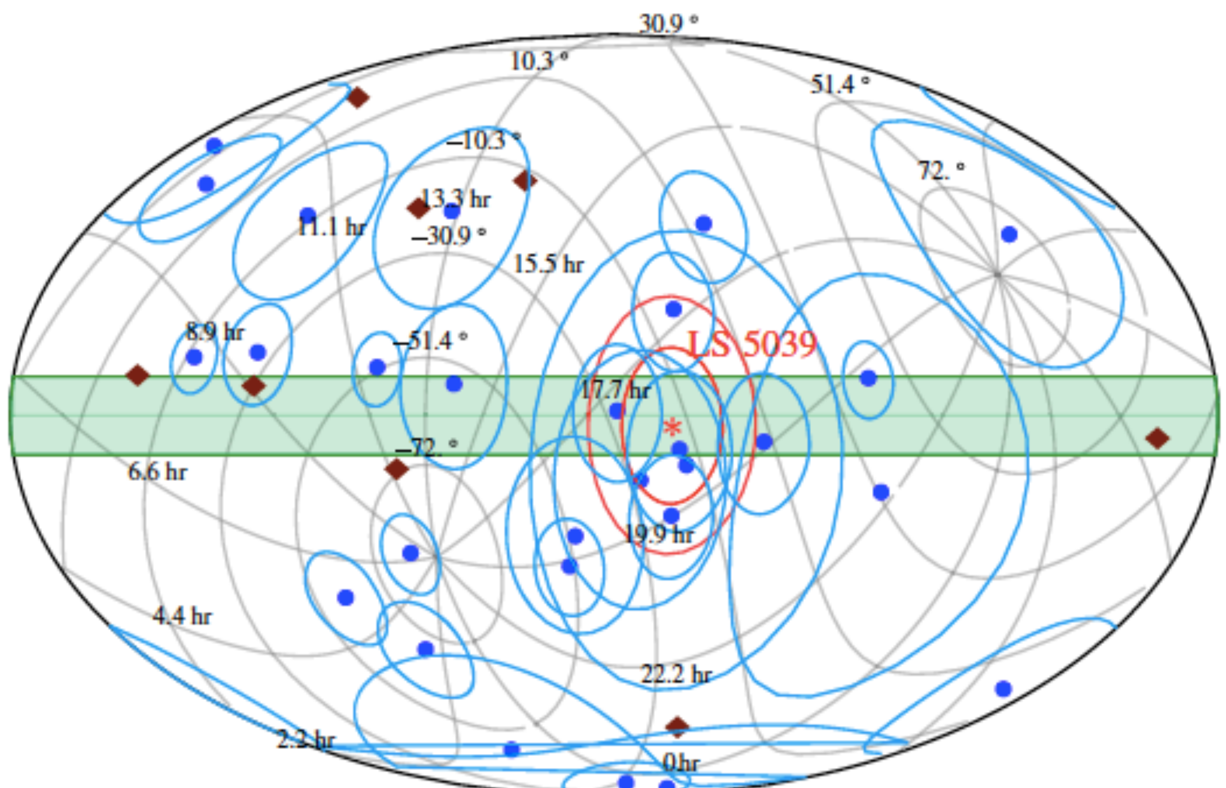
- Many candidates for sources; Galactic origin of events not ruled out yet.

- By looking at μQSOs, we may find a significant contribution to the diffuse flux observed.

- Strategy: using a well known μQSO to typify the population across the Milky Way, look at how those sources are distributed and obtain the total neutrino flux.

The case of LS 5039

- TeV neutrinos are produced in pp or pγ interactions through the decay of secondary charged pions
- TeV γ rays are generally produced in a comparable rate
- Powerful γ ray emitters are natural candidates for good neutrino sources



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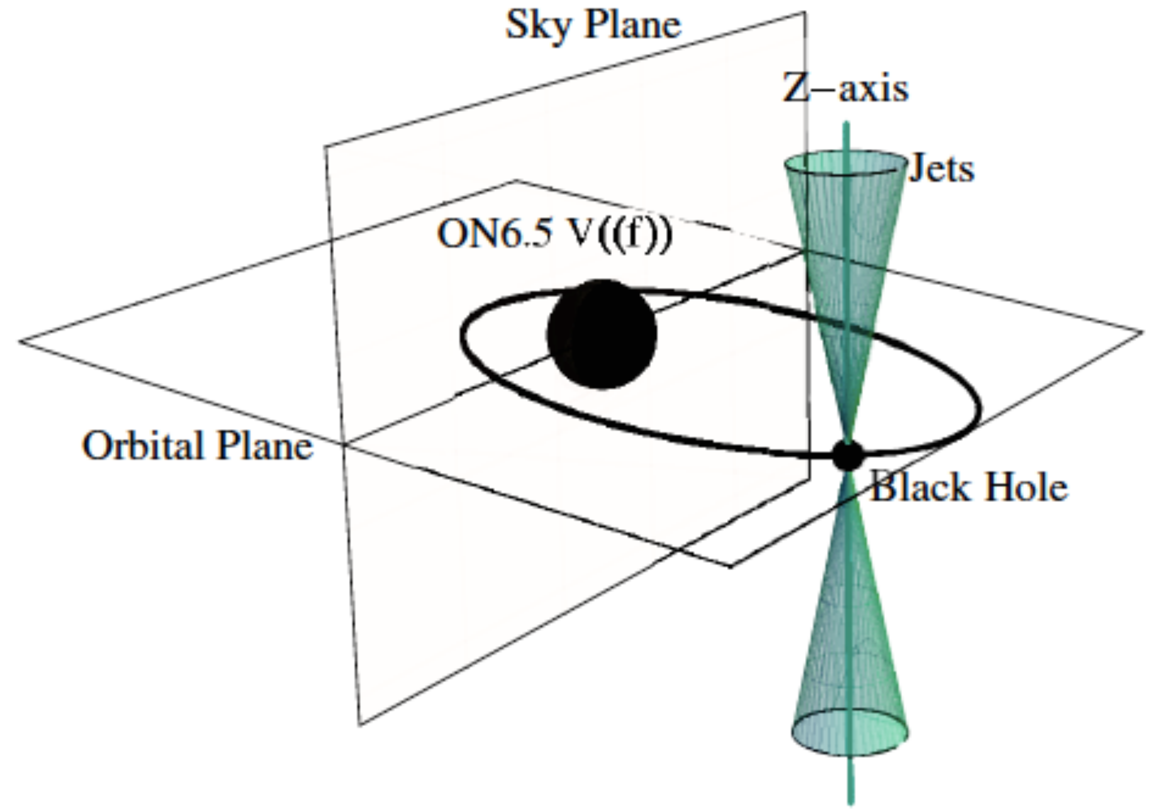
- HMXB, non-thermal emission from radio to high-energy (HE), above 100 MeV, and very-high energy (VHE), above 100 GeV, γ rays
- $L \sim 10^{35}$ erg s^{-1} for KeV < Eγ <TeV
- Compact object of unknown nature (most likely black hole) with mass between 1.4 and 5 solar masses
- Located at 2.9±0.8 Kpc from Earth



- Simultaneous production of gamma rays and neutrinos requires a good proton accelerator and good converter (target); jet is the most likely site for this.

- If γ's and ν's are simultaneously produced,

$$\phi_\nu = \zeta E_\nu^{-2} \ [GeV^{-1} cm^{-2} s^{-1}]$$

$$1.8 \times 10^{-9} < \zeta < 1.6 \times 10^{-8}$$

- For a source 3 Kpc away, we get an integrated luminosity per decade of energy

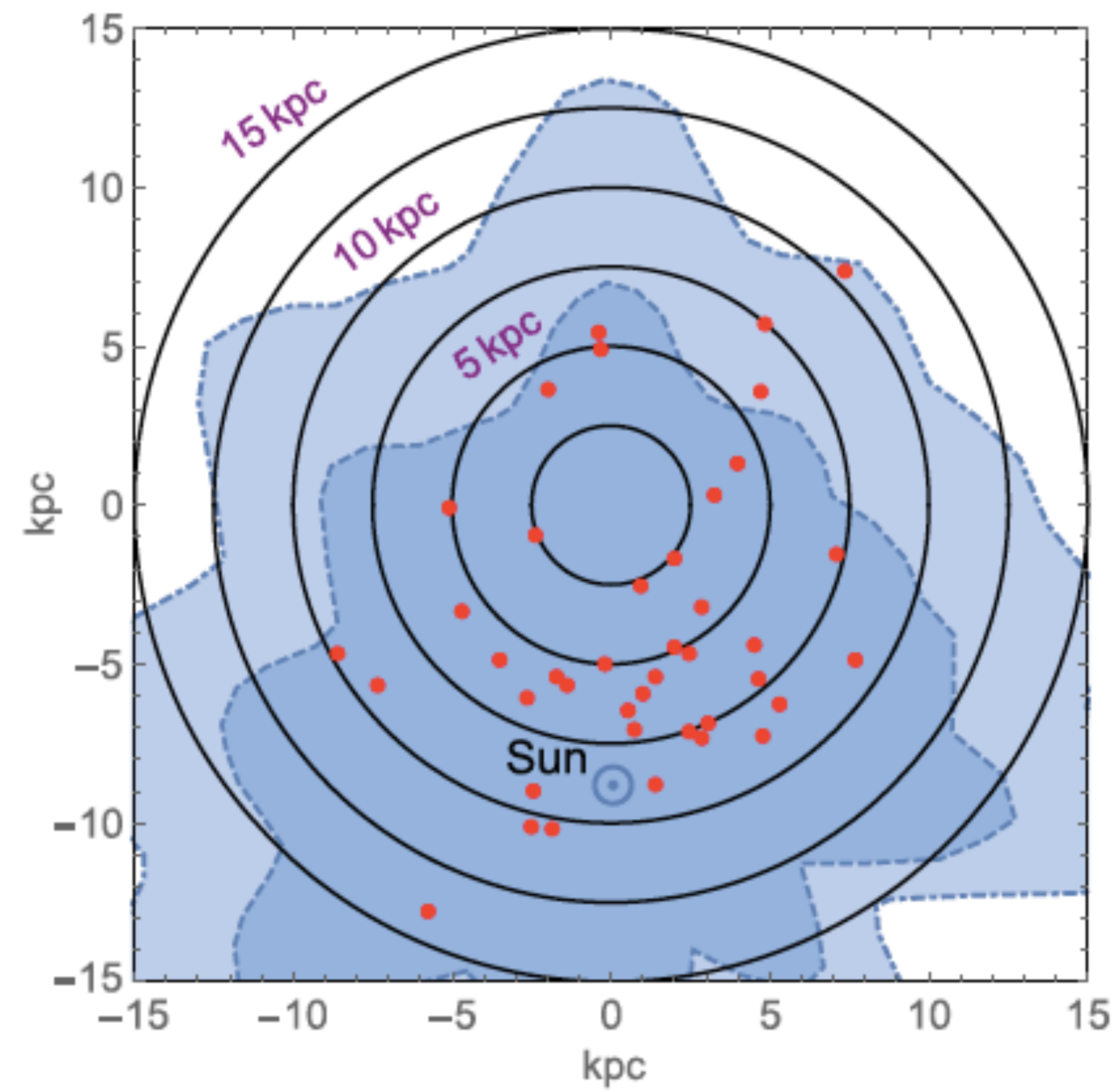
$$L_\nu^{LS\ 5039} = 4\pi d^2 \int_{E_1}^{E_2} E_\nu \phi(E_\nu) dE_\nu = 4\pi \left(\frac{d}{cm}\right)^2 \zeta ln10 \ [GeV\, s^{-1}]$$

The µQSO population in the Milky Way

- Most recent catalogues show 114 HMXBs and about 130 LMXBs
  (Astron.Astrophys-455,1165(2006), Astron.Astrophys-469,807(2007))

- The INTEGRAL/IBIS galactic plane survey contains 82 high mass and 108 low mass sources.
  (Astron. Astrophys. 545, A27 (2012))

- The number of X- ray binaries in the Galaxy brighter than 2 x10^{34} erg s^{-1} is thought to comprise 325 HMXBs and 380 LMXBs (up to a factor of two)



- One system is of particular interest for us, LS I+ 61 303. It is a source similar to LS 5039, periodically monitored by AMANDA and IceCube
  (Phys. Rev. D, 077102(2005), Phys. Rev. D 79, 062001(2009))

- The most recent analysis leads to a 90% C.L. upper limit on the neutrino flux at the level
  (ArXiv:1406.6757)

$$E_\nu^2 \Phi_{90}(E_\nu) = 1.95 \times 10^{-9} \ [GeV\, cm^{-2} s^{-1}]$$

- To consider LS 5039 as a standard neutrino source of the µQSO population the γ's and ν's should be produced well above the jet, without γ ray absorption

- $L_\nu \approx 10^{33}$ erg s^{-1} (conservative approach)

Classification	Name	Position (J2000.0)	Distance (kpc)	L_{jet} (erg/s)
HMXB	LS I + 61 303	$(02^h40^m31.70^s, +61°13'45.6'')$	2	5.69×10^{36}
HMXB	CI Cam	$(04^h19^m42.20^s, +55°59'58.0'')$	1	5.66×10^{37}
LMXB	GRO J0422 + 32	$(04^h21^m42.70^s, +32°54'27.0'')$	3	4.35×10^{37}
LMXB	XTE J1118 + 480	$(11^h18^m10.79^s, +48°02'12.3'')$	1.9	3.49×10^{37}
LMXB	GS 1354-64	$(13^h58^m09.70^s, -64°44'05.0'')$	10	3.62×10^{37}
LMXB	Circinus X-1	$(15^h20^m40.84^s, -57°10'00.5'')$	10	7.61×10^{38}
LMXB	XTE J1550-564	$(15^h50^m58.67^s, -56°28'35.3'')$	2.5	2.01×10^{38}
LMXB	Scorpius X-1	$(16^h19^m55.09^s, -15°38'24.9'')$	2.8	1.04×10^{38}
LMXB	GRO J1655-40	$(16^h54^m00.16^s, -39°50'44.7'')$	3.1	1.6×10^{40}
LMXB	GX 339-4	$(17^h02^m49.40^s, -48°47'23.3'')$	8	3.86×10^{38}
LMXB	1E 1740.7-2942	$(17^h43^m54.82^s, -29°44'42.8'')$	8.5	$10^{36} - 10^{37}$
LMXB	XTE J1748-288	$(17^h48^m05.06^s, -28°28'25.8'')$	8	1.84×10^{39}
LMXB	GRS 1758-258	$(18^h01^m12.40^s, -25°44'36.1'')$	8.5	$10^{36} - 10^{37}$
HMXB	V4641 Sgr	$(18^h19^m21.63^s, -25°24'25.9'')$	9.6	1.17×10^{40}
HMXB	LS 5039	$(18^h26^m15.06^s, -14°50'54.3'')$	2.9	8.73×10^{36}
HMXB	SS 433	$(19^h11^m49.57^s, +04°58'57.8'')$	4.8	1.00×10^{39}
LMXB	GRS 1915+105	$(19^h15^m11.55^s, +10°56'44.8'')$	12.5	2.45×10^{40}
HMXB	Cygnus X-1	$(19^h58^m21.68^s, +35°12'05.8'')$	2.1	$10^{36} - 10^{37}$
HMXB	Cygnus X-3	$(20^h32^m25.77^s, +40°57'28.0'')$	10	1.17×10^{39}

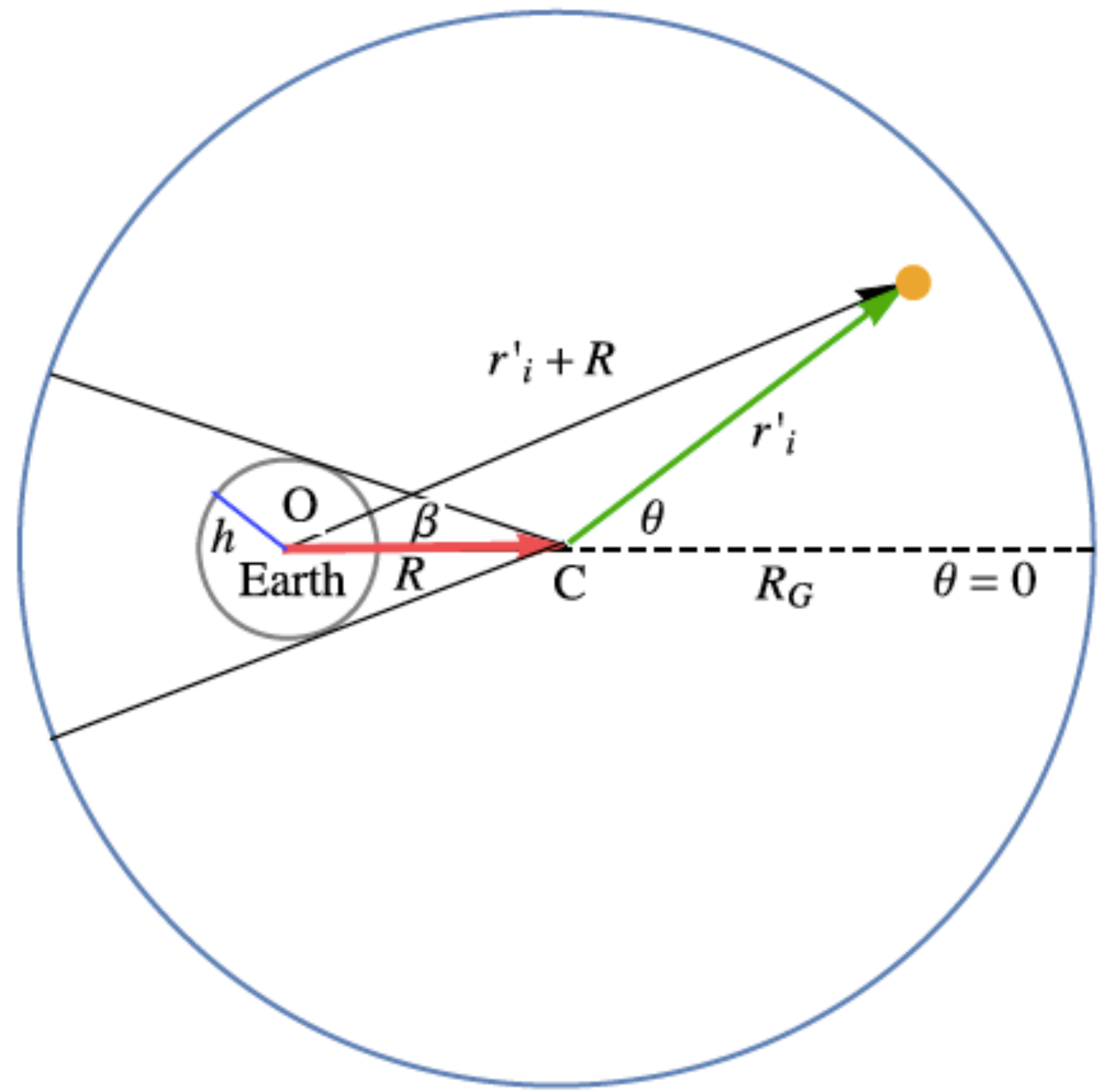
Astrophys. J. 575, 378 (2002), R. Astron. Soc. 351, 791 (2004), Astron. Astrophys. 457, 1011 (2006), arXiv:1103.3009

ν's from Galactic μQSOs

- We model our Galaxy as a cylinder of radius Rg = 15 Kpc and thickness 1 Kpc
- The integrated energy weighted total neutrino flux from the isotropic Galactic source distribution with normal incidence at O is

$$4\pi \int_{E_1}^{E_2} E_\nu \Phi(E_\nu) dE_\nu = \frac{1}{4\pi} \sum_i \frac{L_{\nu,i}}{r_i^2}$$

$$= \frac{1}{4\pi} \sum_i \frac{L_{\nu,i}}{R^2 + 2Rr' cos(\theta) + r'^2}$$



r'ᵢ: position of source
h=exclusion radius
RG=Galactic radius,15 kpc
R=position of Earth, 8.3 kpc

- Assuming equal power for all sources (equal to the power of LS 5039), we write, with σ(r') as the source number density,

$$4\pi \int_{E_1}^{E_2} E_\nu \Phi_\nu dE_\nu = \frac{L_\nu^{LS\ 5039}}{4\pi} \int\int \frac{\sigma(r')r'dr'd\theta}{R^2 + 2Rr'cos(\theta) + r'^2} \equiv \frac{L_\nu^{LS\ 5039}}{4\pi}\mathcal{I}$$

- With the energy ranging from 100 TeV to 1 PeV, we obtain,

$$E_\nu^2\Phi_\nu = \frac{L_\nu^{LS\ 5039}}{16\pi^2 ln10}\mathcal{I} \approx 1.27 \times 10^{-19} \left(\frac{\mathcal{I}}{kpc^2}\right)[GeV\ cm^{-2}\ s^{-1}\ sr^{-1}]$$

- The IceCube collaboration reports (assuming isotropic sources and democratic flavor ratios)
(Science 342, 1242856 (2013))

$$\Phi_\nu = 1.5 \times 10^{-8} \left(\frac{E_\nu}{100\ TeV}\right)^{-2.15\pm0.15} [GeV\ cm^{-2}\ s^{-1}\ sr^{-1}]$$

- The integral $\mathcal{I}$ is carried out numerically. Assuming a source density distribution of the following form, with Ro = 4 Kpc:
  (Mon. Not. R. Astron. Soc. 294, 429 (1998))

$$\sigma_{\mu QSO}(r') = N_0 exp\left(-\frac{R_0}{r'} - \frac{r'}{R_0}\right)$$

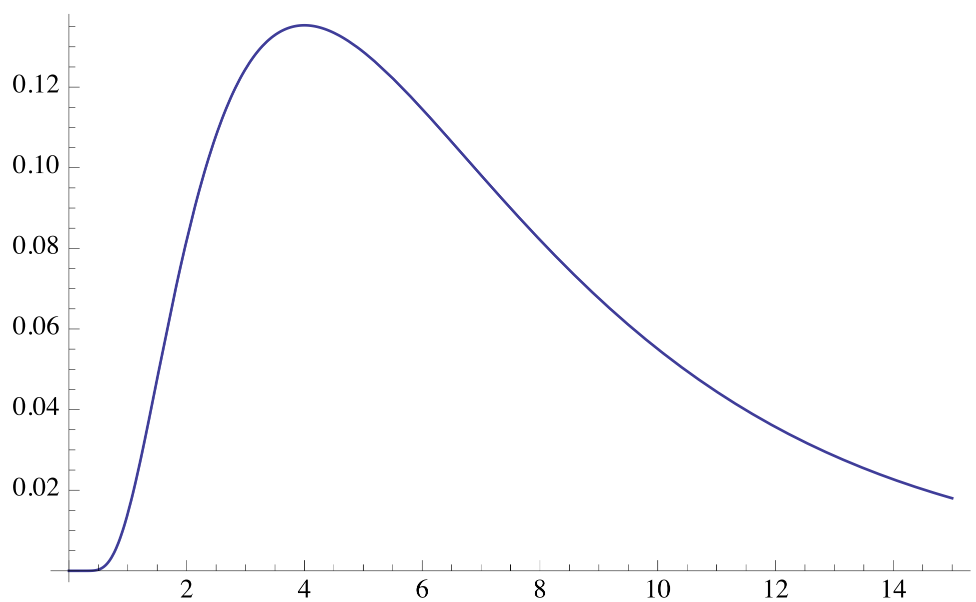


Table : Results of integration

h (kpc)	$\mathcal{I}$	$N_{\mu QSO}$
1	0.0273 N	433
2	0.0193 N	612
3	0.0143 N	809
4	0.0113 N	1045
5	0.0088 N	1342

- Only lower bound on µQSO considered

Conclusions

- We have revisited µQSOs as potential neutrino sources
- LS 5039 can be used as a model, with neutrino production most likely happening and the end of the jets
- By looking at the µQSO population on the Milky Way, we see that those objects could give a significant contribution to the diffuse neutrino flux observed by IceCube
- Waiting for future observations!