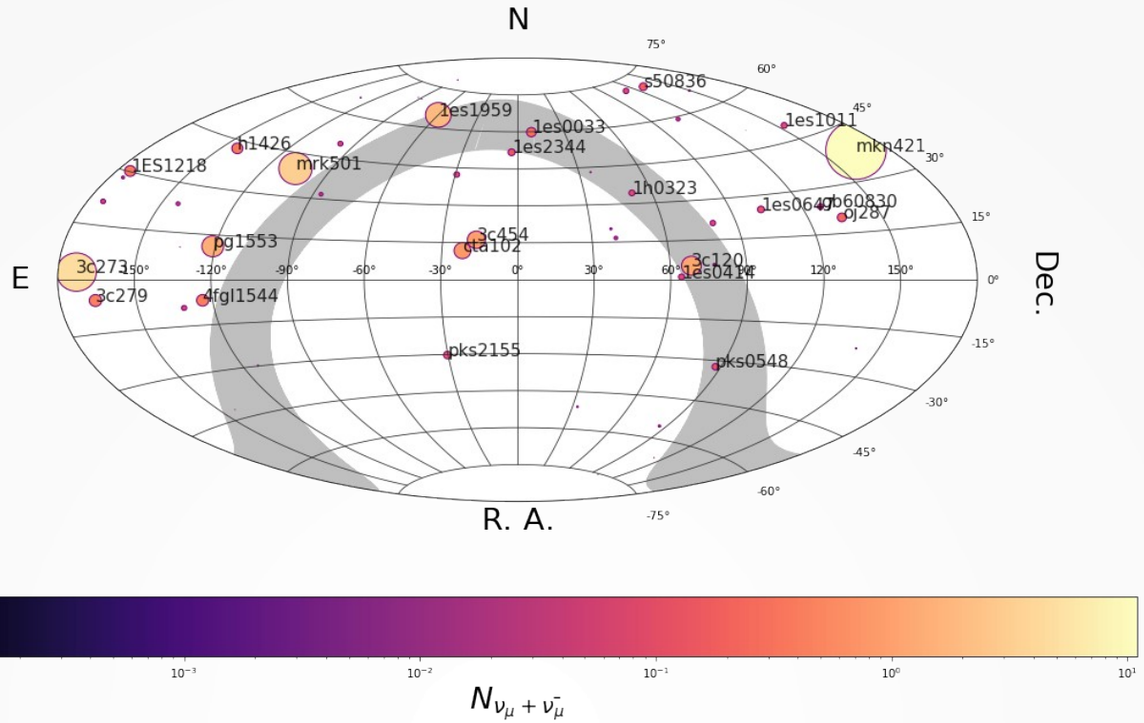
Multimessenger emission from hadronic X-ray Blazar Flares



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In collaboration with: M. Petropoulou, P. Giommi, G. Vasilopoulos, P. Padovani, A. Mastichiadis,

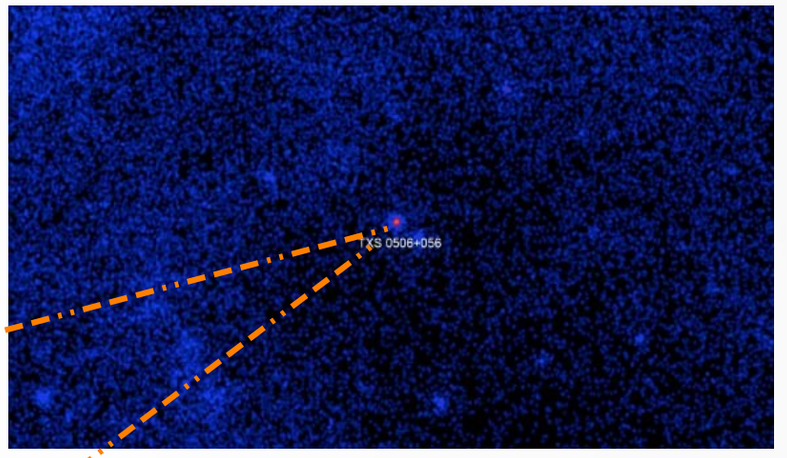
National and Kapodistrian University of Athens

37th International Cosmic Ray Conference
12-23 July 2021

MERAC

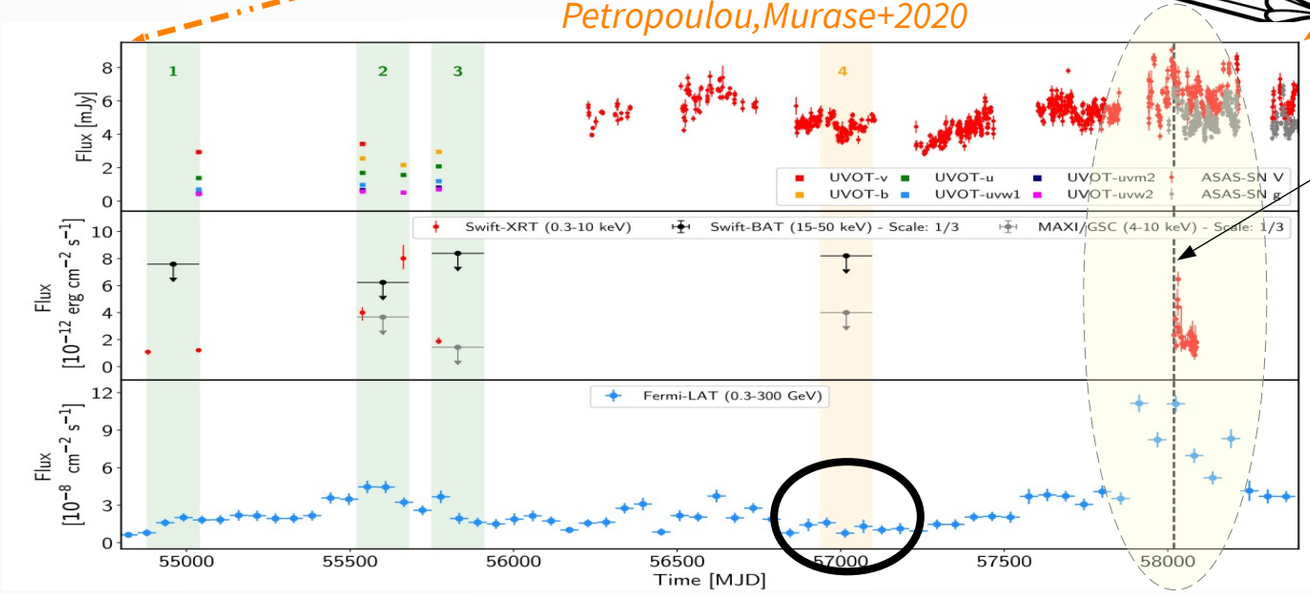
High Energy Neutrinos from TXS 0506+056

- *IC-170922A (290 TeV muon neutrino)*
- *13.5 neutrino events during 2014-15*

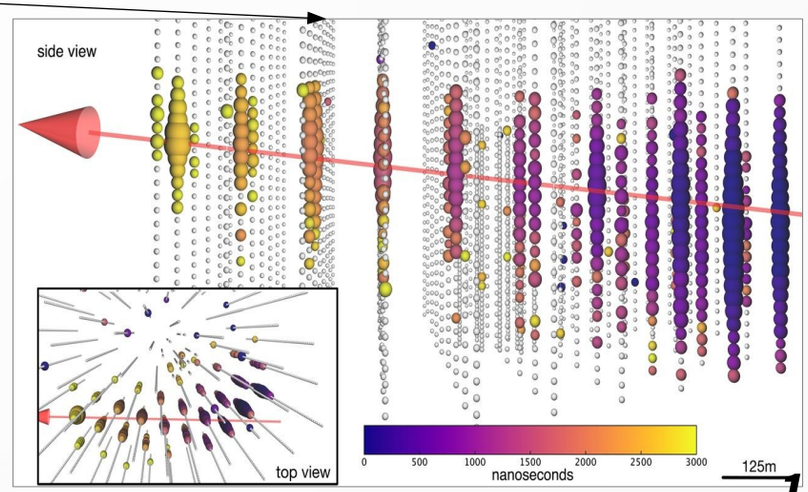


Science 13 Jul 2018:
Vol. 361, Issue 6398, eaat1378

Petropoulou,Murase+2020



H-E Neutrino



Motivation of This Work

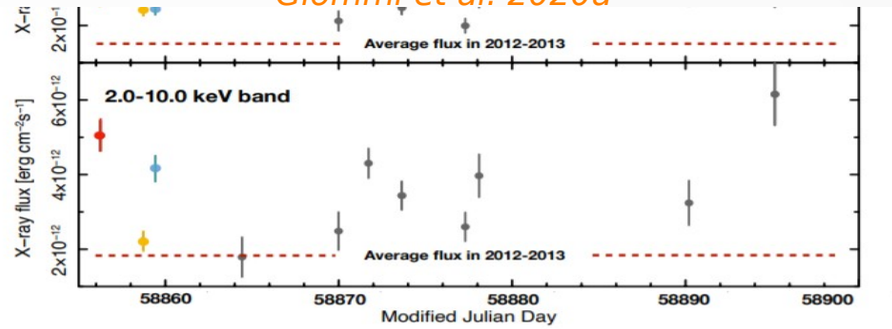
- No γ-ray activity during the neutrino excess in 2014/15

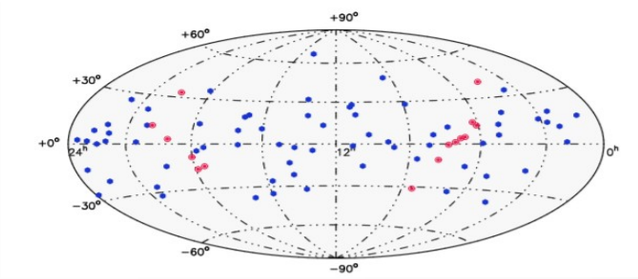
- IceCube200107A/3HSP J095507.9+355101
  High, very hard and variable X-ray state
  No γ-ray activity

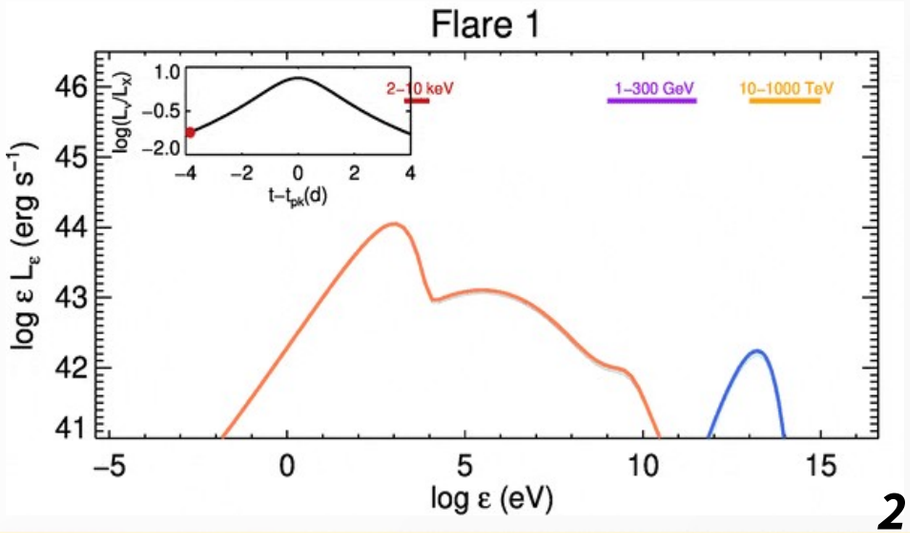
- Blazars associated with muon neutrino tracks
  Giommi et al. 2020A

- Hadronic X-ray flares from Blazars (Theoretical Study)
  Mastichiadis & Petropoulou 2020

Giommi et al. 2020a



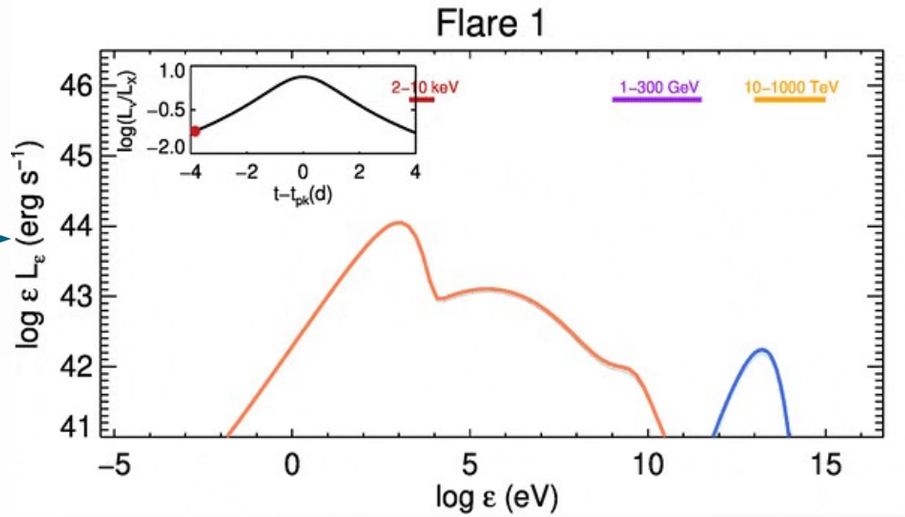




Hadronic X-ray Flares From Blazars

Lorentzian pulse
Power law Protons

Magnetic field B



During the hadronic X-ray Flare:

Bolometric Luminosity: $L_\nu \simeq L_X$

Peak neutrino energy : $\varepsilon_{\nu,\mathrm{pk}} \simeq 2\, \varepsilon_{ph,\mathrm{keV}} B_{1.2}^{'-1} \gamma_{p,6}^{'-1}$

Mastichiadis & Petropoulou 2020

Theoretical Model

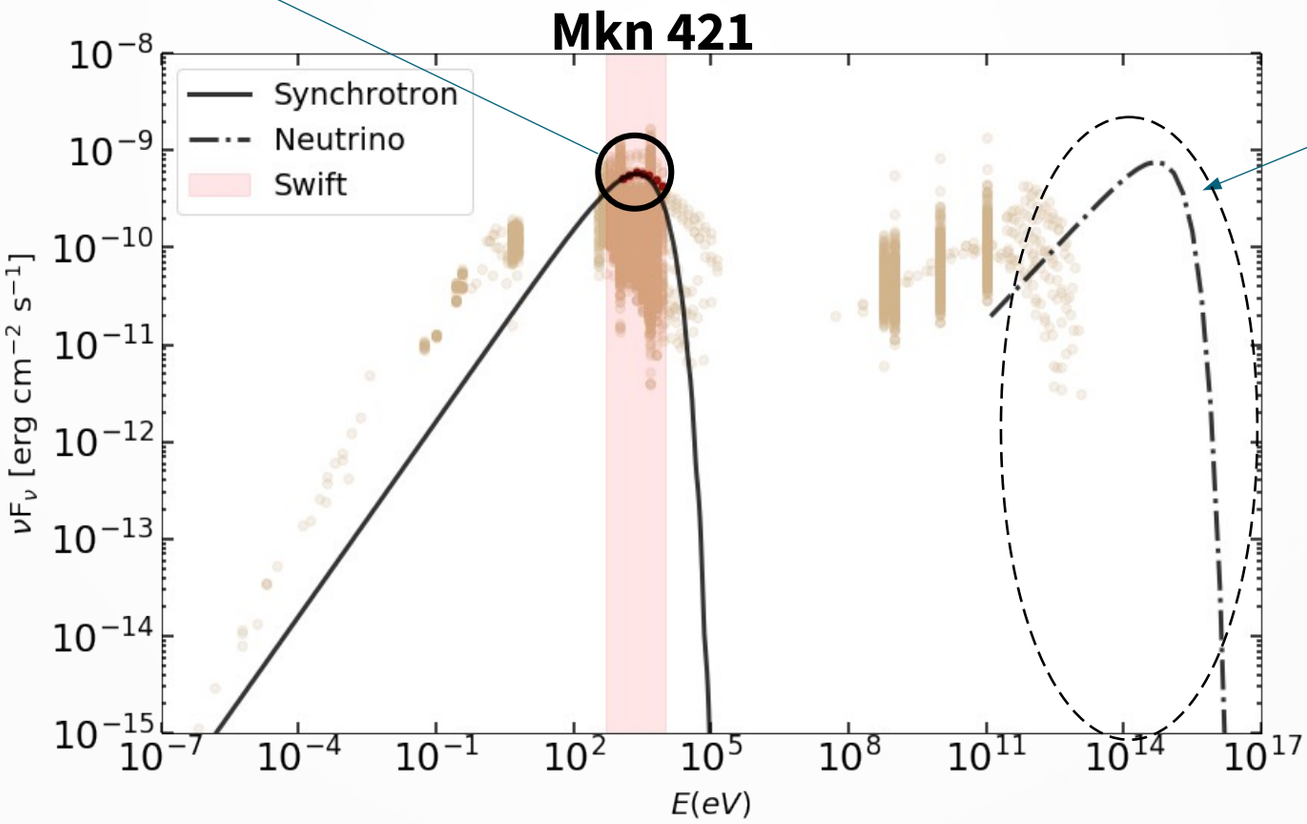
$$\nu_{s,obs} = \mathcal{D}(1+z)^{-1} h^{-1} \frac{B}{B_{cr}} \frac{m_e^2}{m_p} c^2 \gamma_p'^2$$

$$\gamma_p' \simeq 1.4 \times 10^6 \sqrt{\mathcal{D}_1^{-1} B_1'^{-1} \varepsilon_{\rm keV}(1+z)}$$

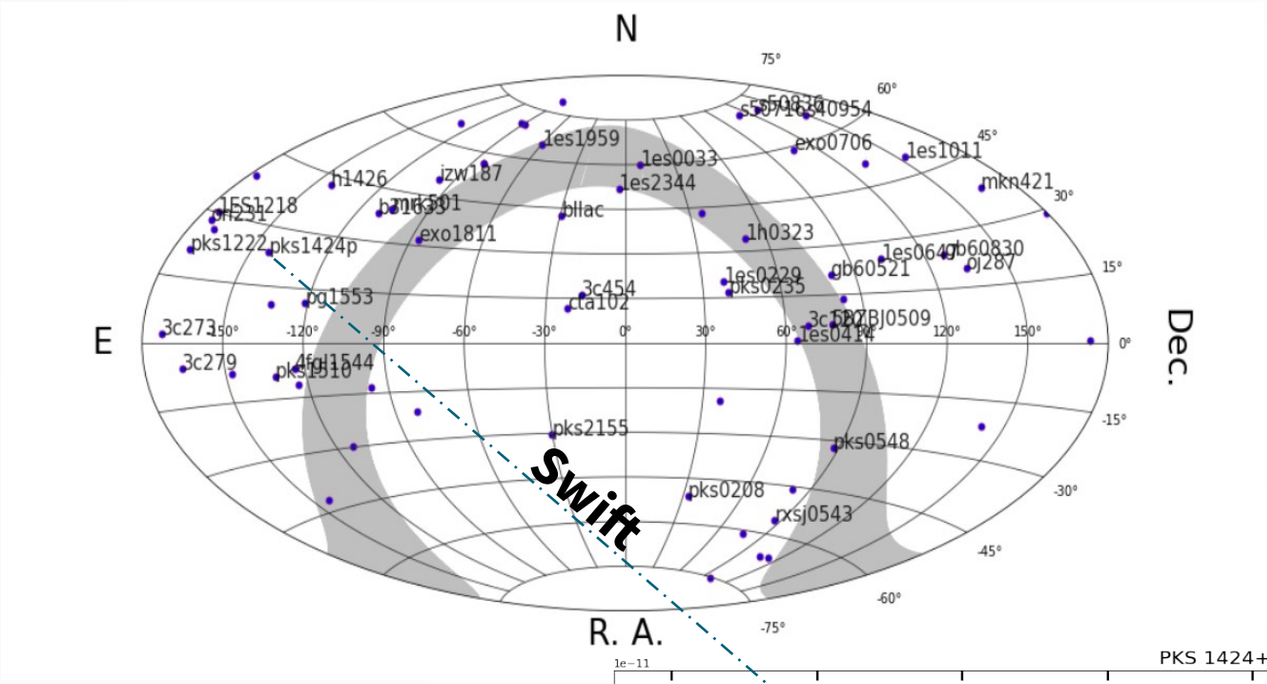
$$\varepsilon_{\nu,c} \simeq 0.6 \sqrt{\mathcal{D}_1 B_1'^{-1} \varepsilon_{\rm keV}(1+z)^{-1}}\ {\rm PeV}$$

$$F_{\nu+\bar{\nu}}(\varepsilon_\nu, t) = F_0(t) \varepsilon_\nu^{-s(t)} e^{-\varepsilon_\nu/\varepsilon_{\nu,c}}$$

$$L_\nu \simeq L_X$$



X-ray Lightcurves



Sample

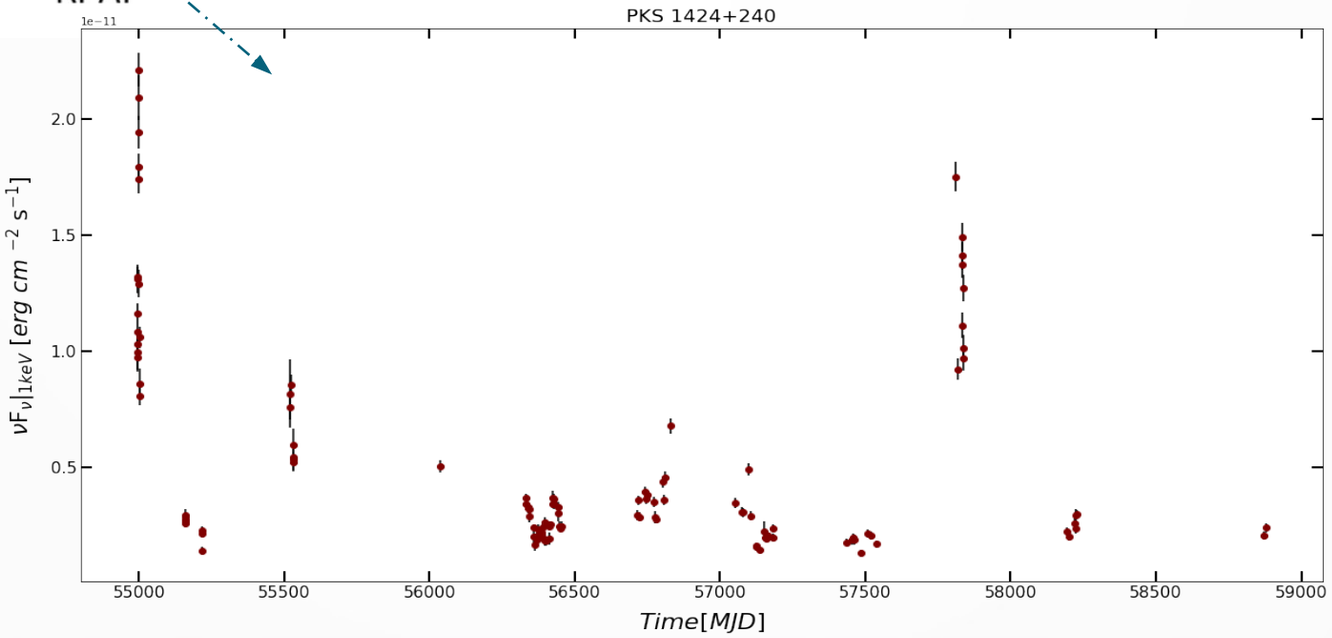
66 Blazars frequently observed by Swift
[Giommi et al., 2021, submitted]

Data

1keV lightcurves & Flux 0.5-10 keV

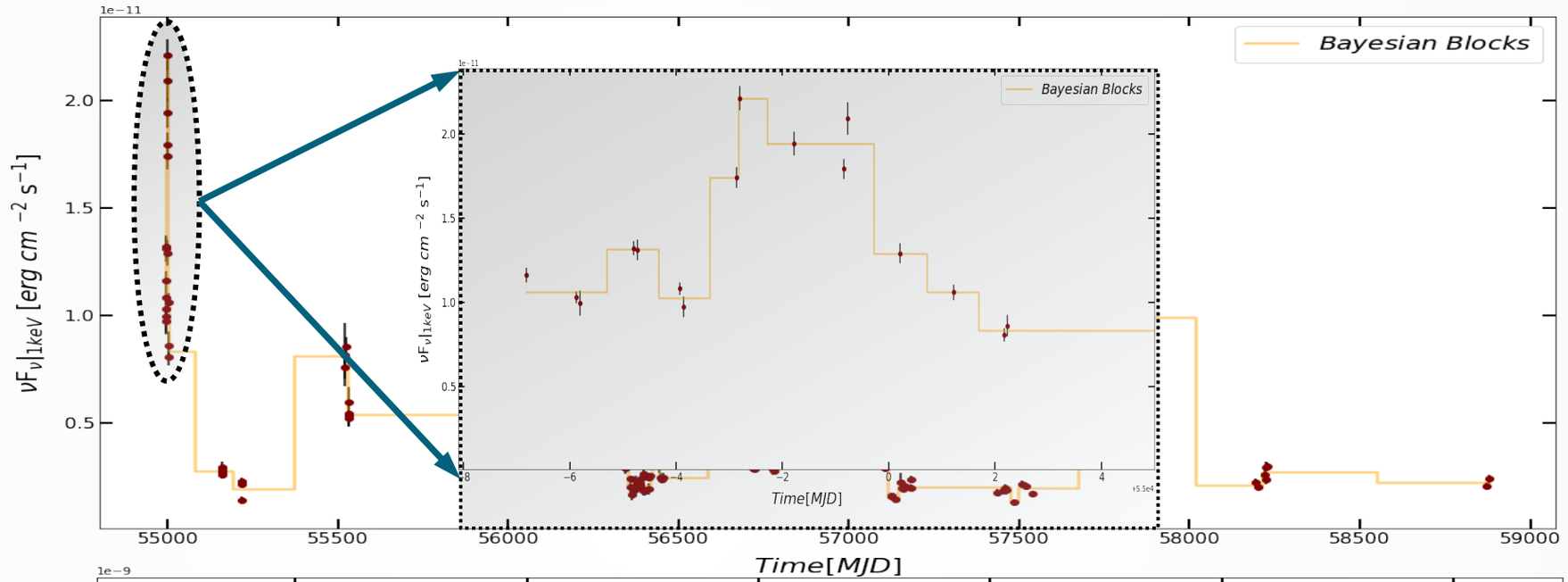
Difficulties

- *Irregular data*
- *Number of measurements*
- *Large gaps*

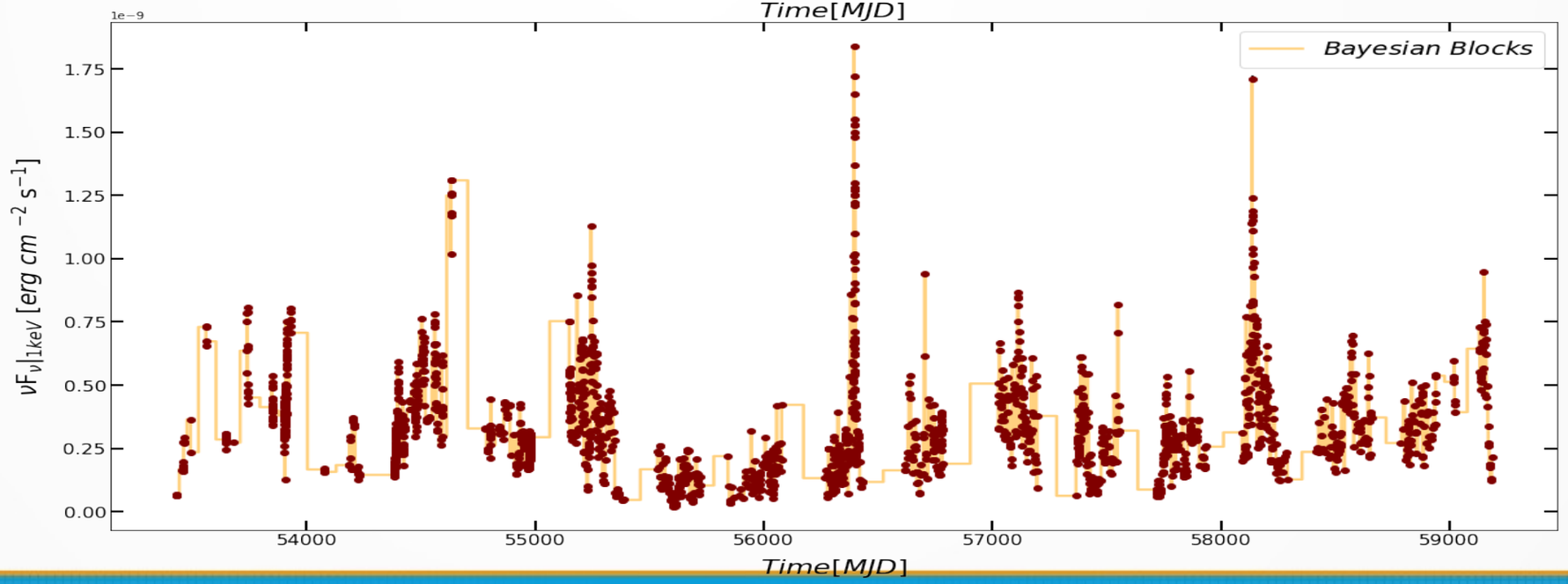


Definition of Flares

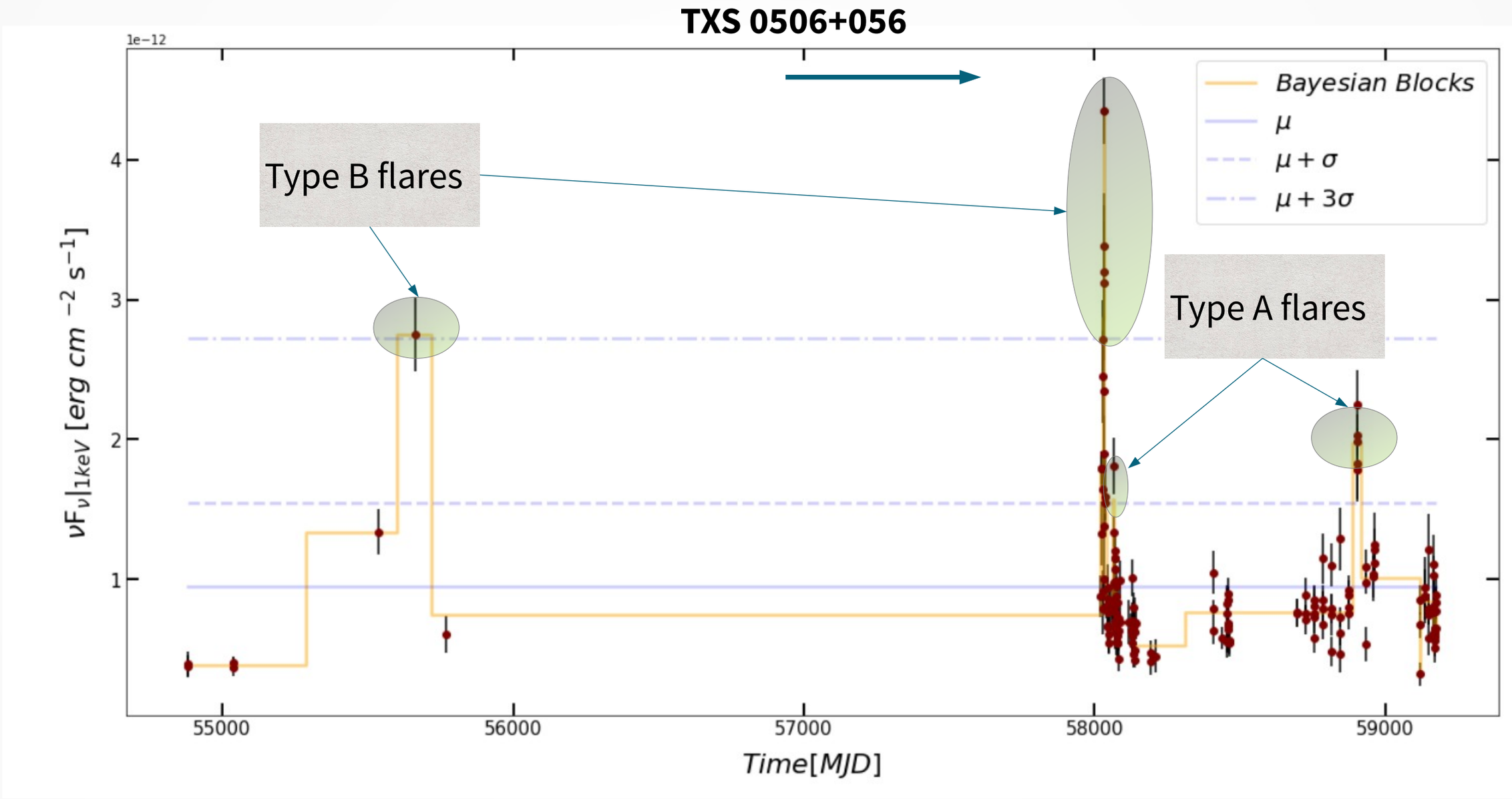
PKS 1424+240



Mkn 421



Definition of Flares



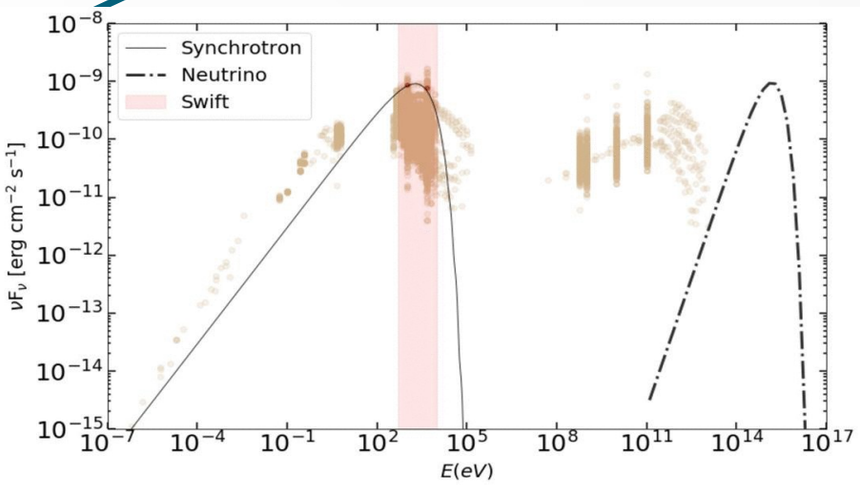
Expected Neutrino Event Counts

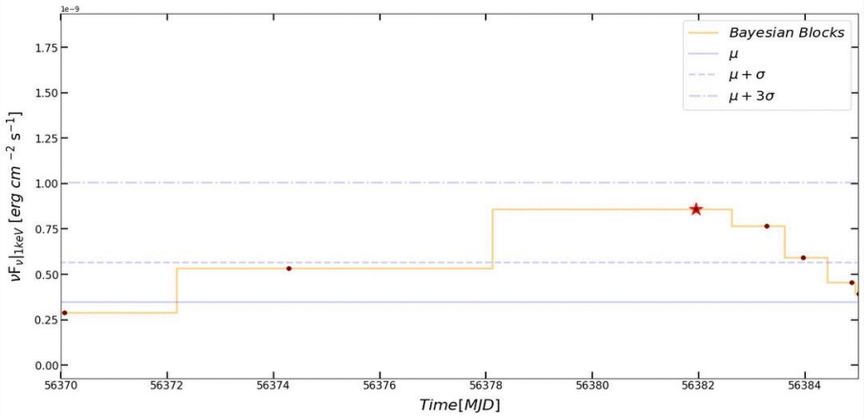
Parameter values

- *B=10 G*
- *Doppler Factor = 10*

$$N_{\nu_\mu+\bar{\nu}_\mu} = \frac{1}{3}\int_{t_{init}}^{t_{end}} dt \int_{E_{\nu,min}}^{E_{\nu,max}} dE_\nu A_{eff}(E_\nu,\delta) F_{E_\nu}(E_\nu,t)/E_\nu$$

$$F_{\nu+\bar{\nu}}(\varepsilon_\nu,t) = F_0(t)\varepsilon_\nu^{-s(t)} e^{-\varepsilon_\nu/\varepsilon_{\nu,c}}$$



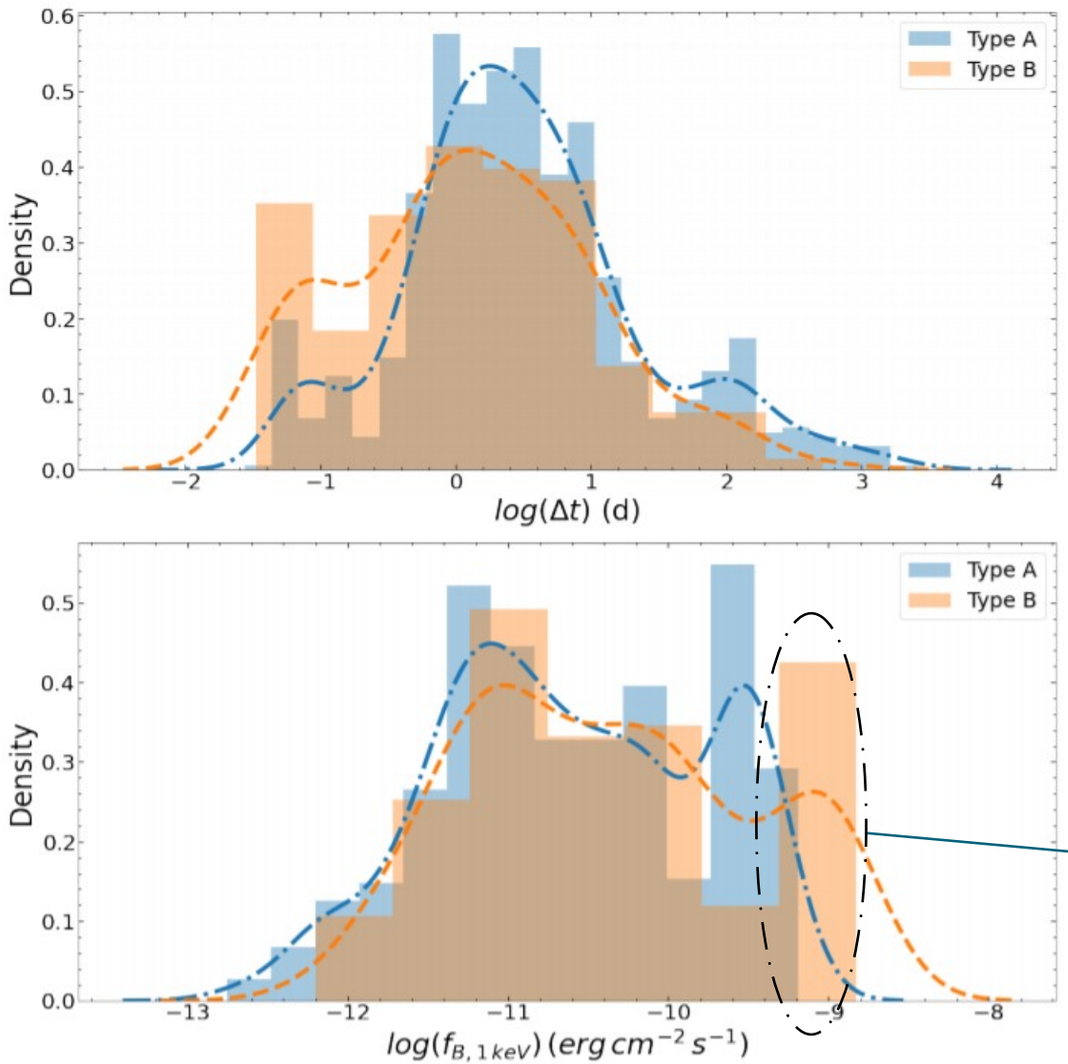


Duration of the flux blocks

IceCube configuration	Season (MJD)
IC40	54562 – 54971
IC59	54971 – 55347
IC79	55347 – 55694
IC86-I	55694 – 56062
IC86-II	> 56062

RESULTS

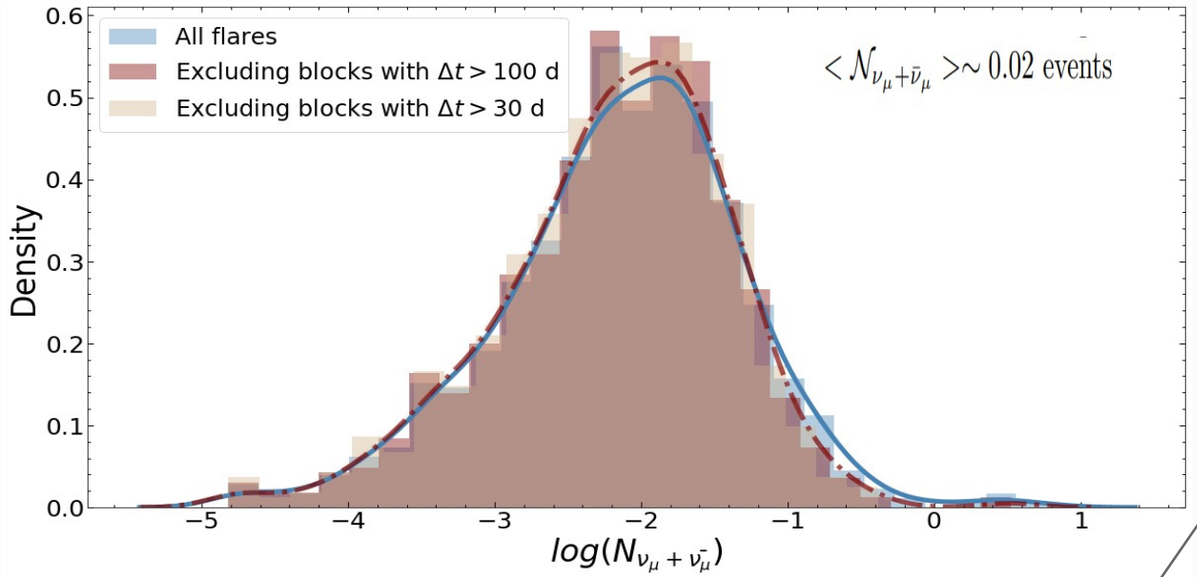
X-ray Flares



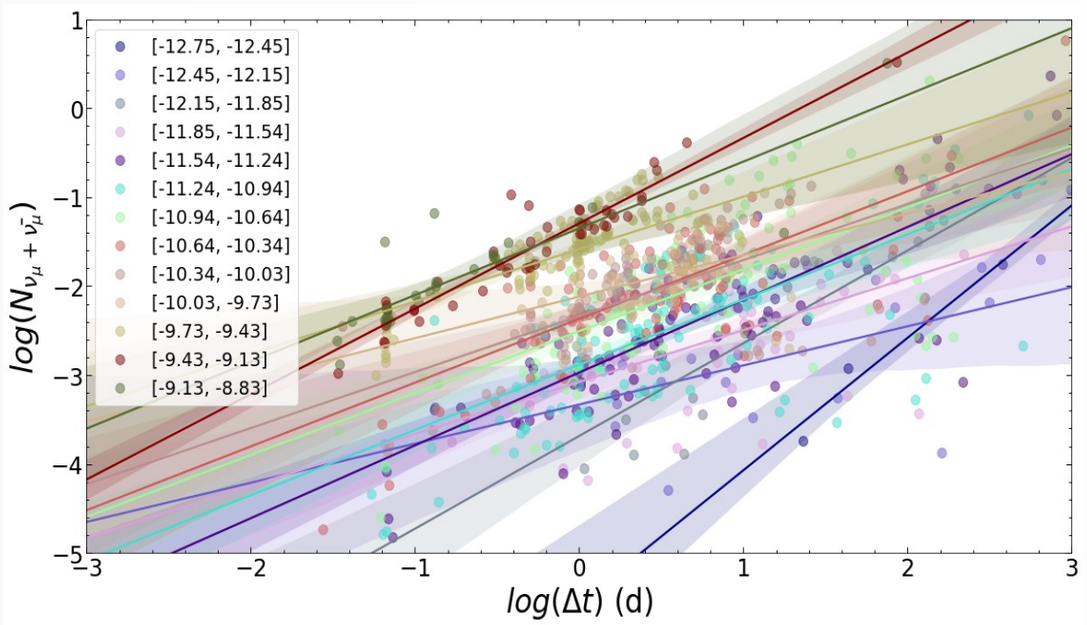
- **967** flaring states
- **Typical Duration of flaring states**: 1-5 days
- **Mkn 421** most flaring states

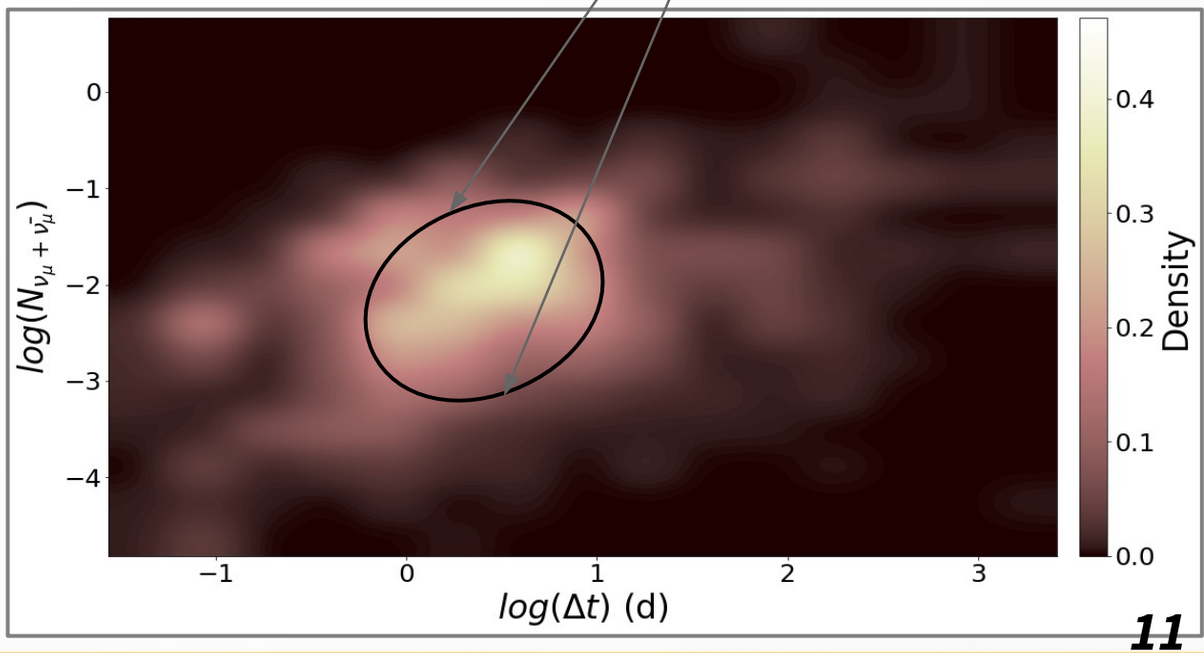
Mkn 421

Expected Neutrino Events From X-ray Flares



Most events are found here



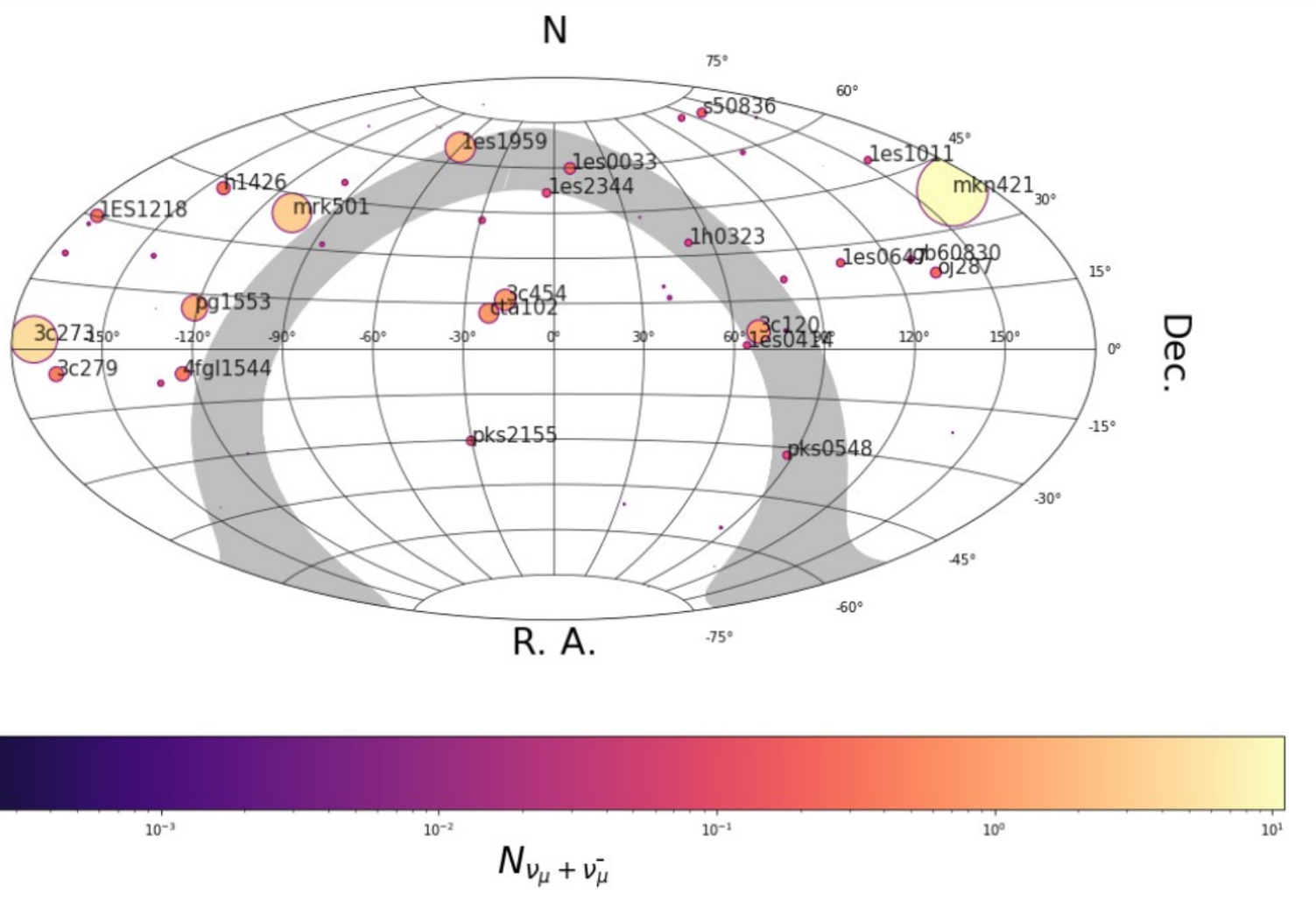


Neutrino All-Sky Plot

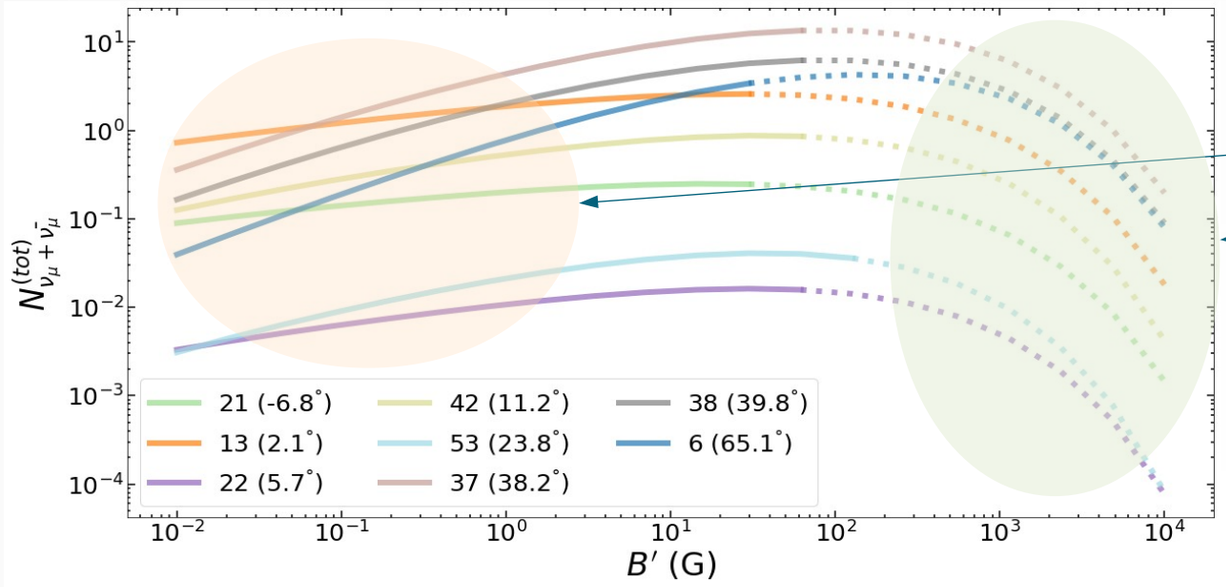
Parameter values

- *B=10 G*
- *Doppler Factor = 10*

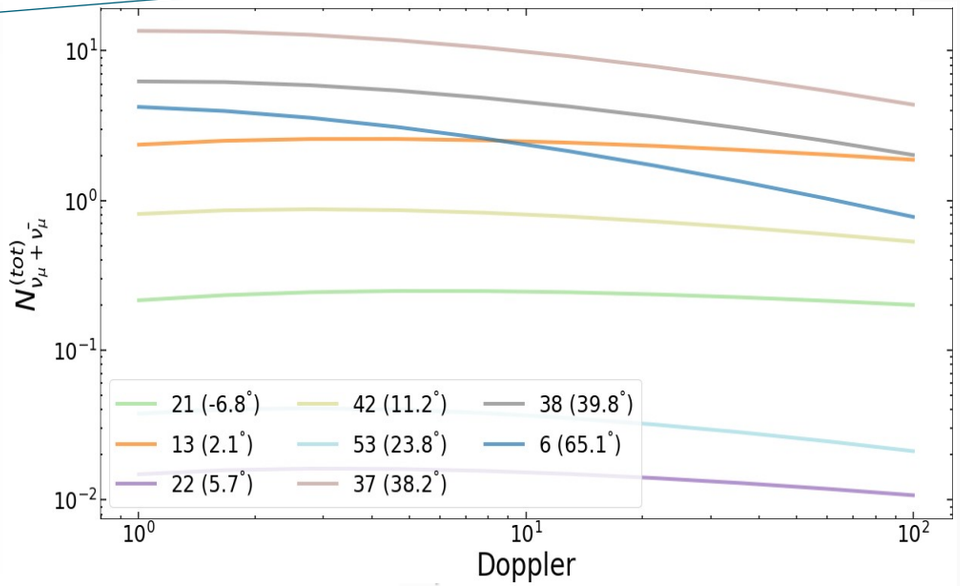
Source name[1]	$N^{(\mathrm{tot})}_{\nu_\mu+\bar{\nu}_\mu}$
1ES 1959+650	1.42 ± 0.04
3C 273	3.9 ± 0.3
4FGL J1544.3-064	0.21 ± 0.03
TXS 0506+056	0.02 ± 0.01
Mkn 421	13.0 ± 0.1
Mkn 501	2.02 ± 0.06
PG 1553+113	1.18 ± 0.09
PKS 1424+240	0.26 ± 0.05

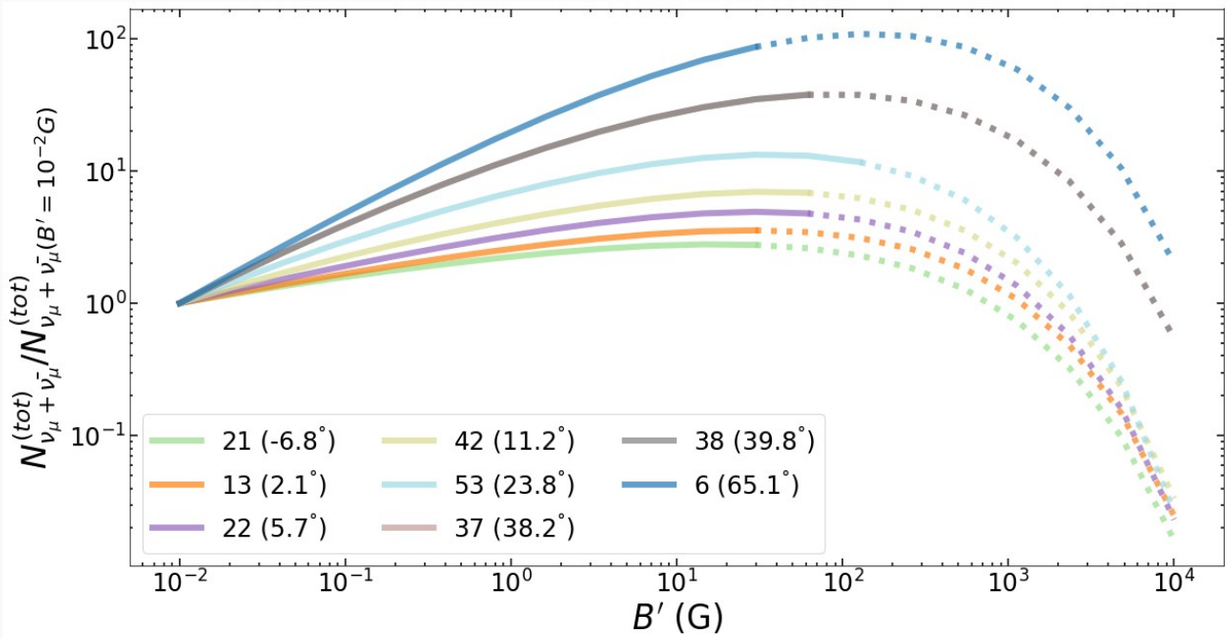


Effects of Model Parameters and Source Declination



$$N_{\nu_\mu+\bar{\nu}_\mu}(B',\delta) \propto B'^{(1-s)/2} \int_{E_{\nu,\min}}^{E_{\nu,\max}} \mathrm{d}\varepsilon_\nu \varepsilon_\nu^{-s-1} A_{\mathrm{eff}}(\varepsilon_\nu,\delta) e^{-a\varepsilon_\nu B'^{1/2}}$$





Source index	Source name[1]
6	1ES 1959+650
13	3C 273
21	4FGL J1544.3-0649
22	TXS 0506+056
37	Mkn 421
38	Mkn 501
42	PG 1553+113
53	PKS 1424+240

Conclusions

- Classification of flares
- Theoretical scenario + Hadronic X-ray Flares → Neutrino predictions
- Number of neutrinos per flare → 0.02 events per flare
- How model parameters affect the the predictions

Thank you !

Stathopoulos et. al. 2021 in prep.