High Energy Neutrinos from GRB & Blazar Flares

Shan Gao

Collaborators:
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Martin Pohl, Walter Winter, Markus Boettcher, Xuhui Chen (AGN).

Dec. 10, 2016

GRB and blazars: OverView

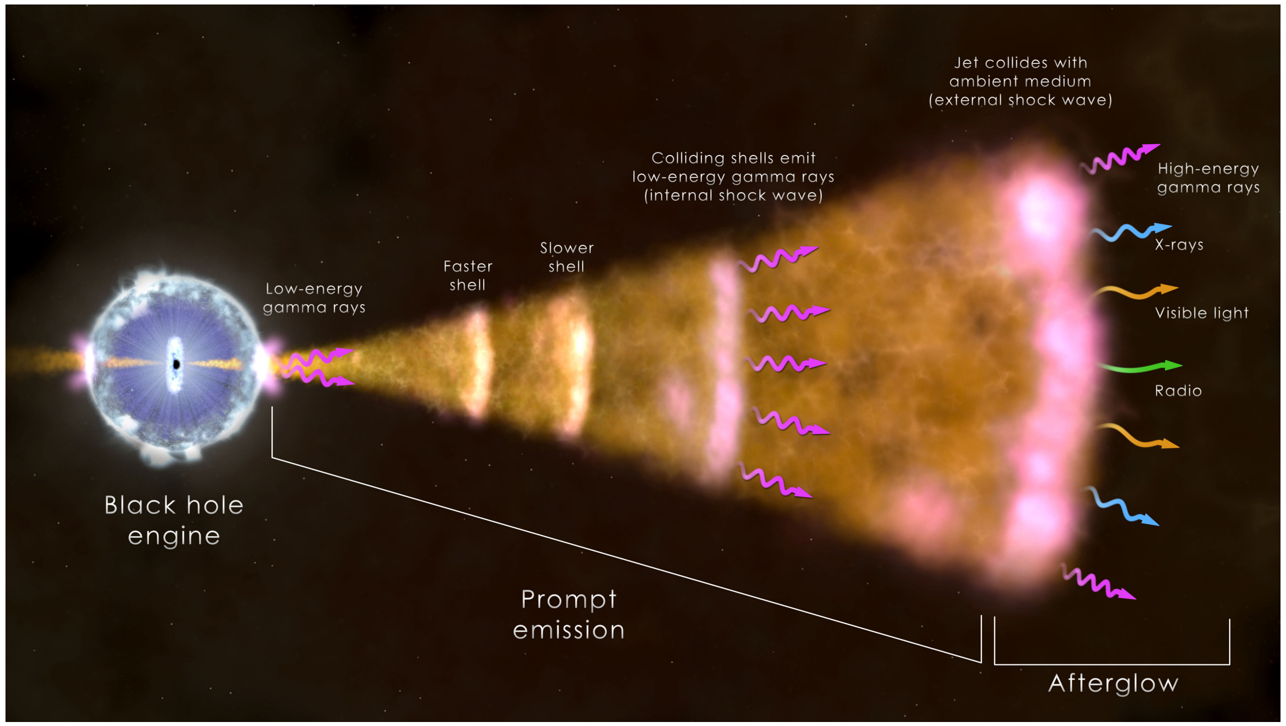

Figure: GRB portrait by NASA

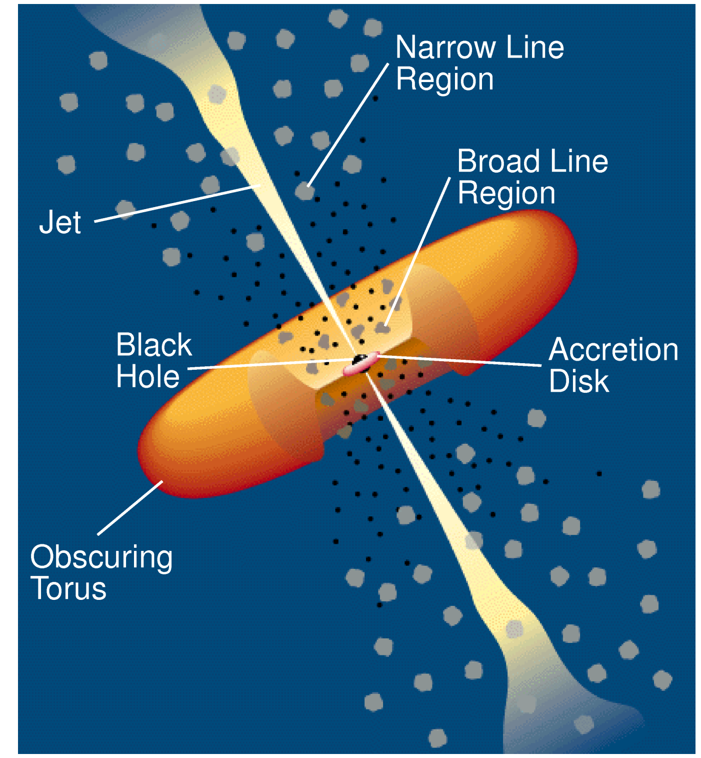

Figure: blazar, Urry & Padovani 95

- Relativistic jets & Doppler boosting; Γ_{GRB}~300 ; Γ_{blazar}~30
- Powered by: Stellar BH (GRB) ; SMBH (AGN)
- Spectrum: broken power-law (GRB) double hump SED (blazar)
- Duration: seconds (GRB) persistent (blazar)
- Population: GRB ~ 700/yr ; blazar 745 (3LAC)
- Sky Distribution: isotropic
- Luminosity: L_{GRB}~$10^{51\text{-}54}$ erg/s; L_{blazar}~$10^{44\text{-}49}$ erg/s.
- Component: unknown - leptonic, hadronic, magnetic, …
- Variability: GRB ~ ms; blazar ~ hr-yr scale

1. Gamma-ray Bursts

Outline

Internal Shock (IS) Model

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Revised IS Model

↓

Elaborate IS Model

Photospheric model

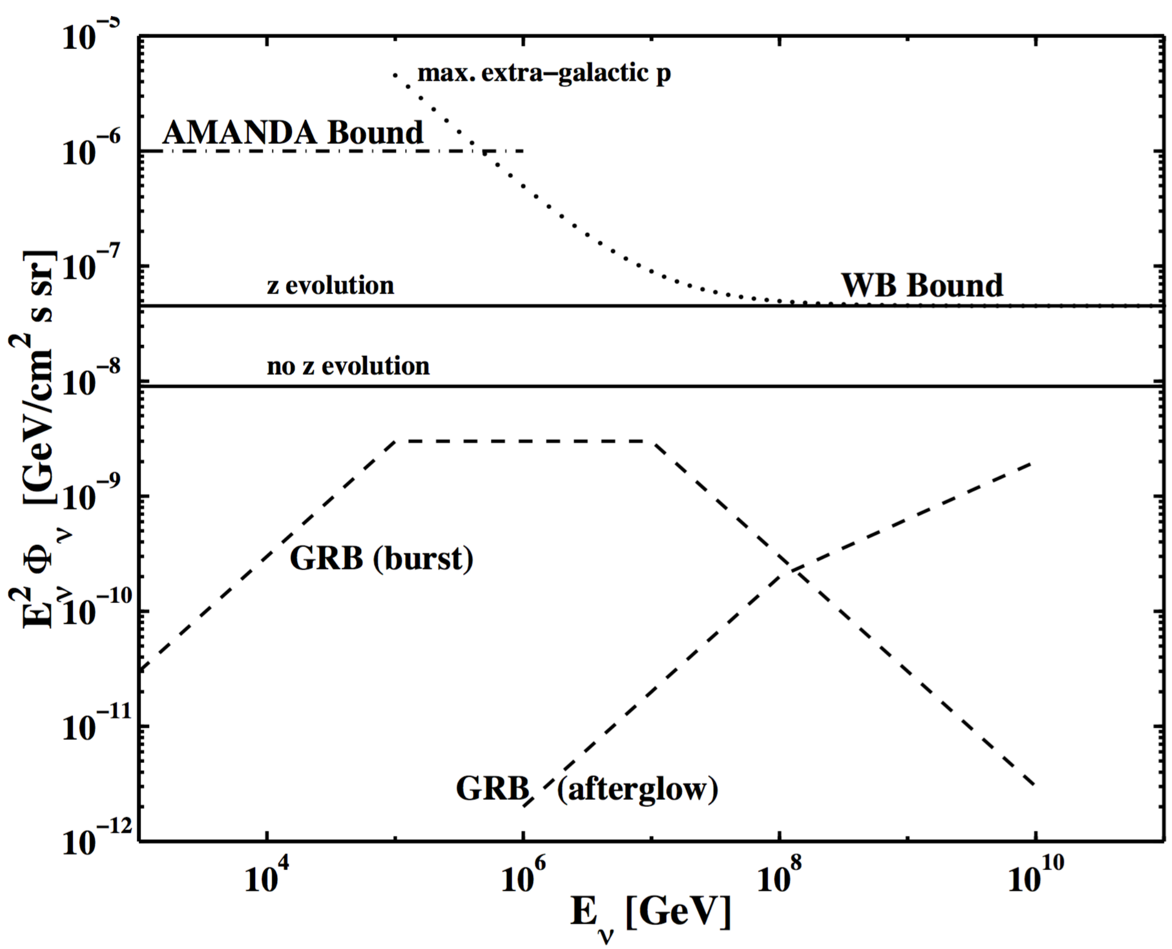
↙ ↘

baryonic

magnetic

*partial list…

Internal Shock Model and neutrino production



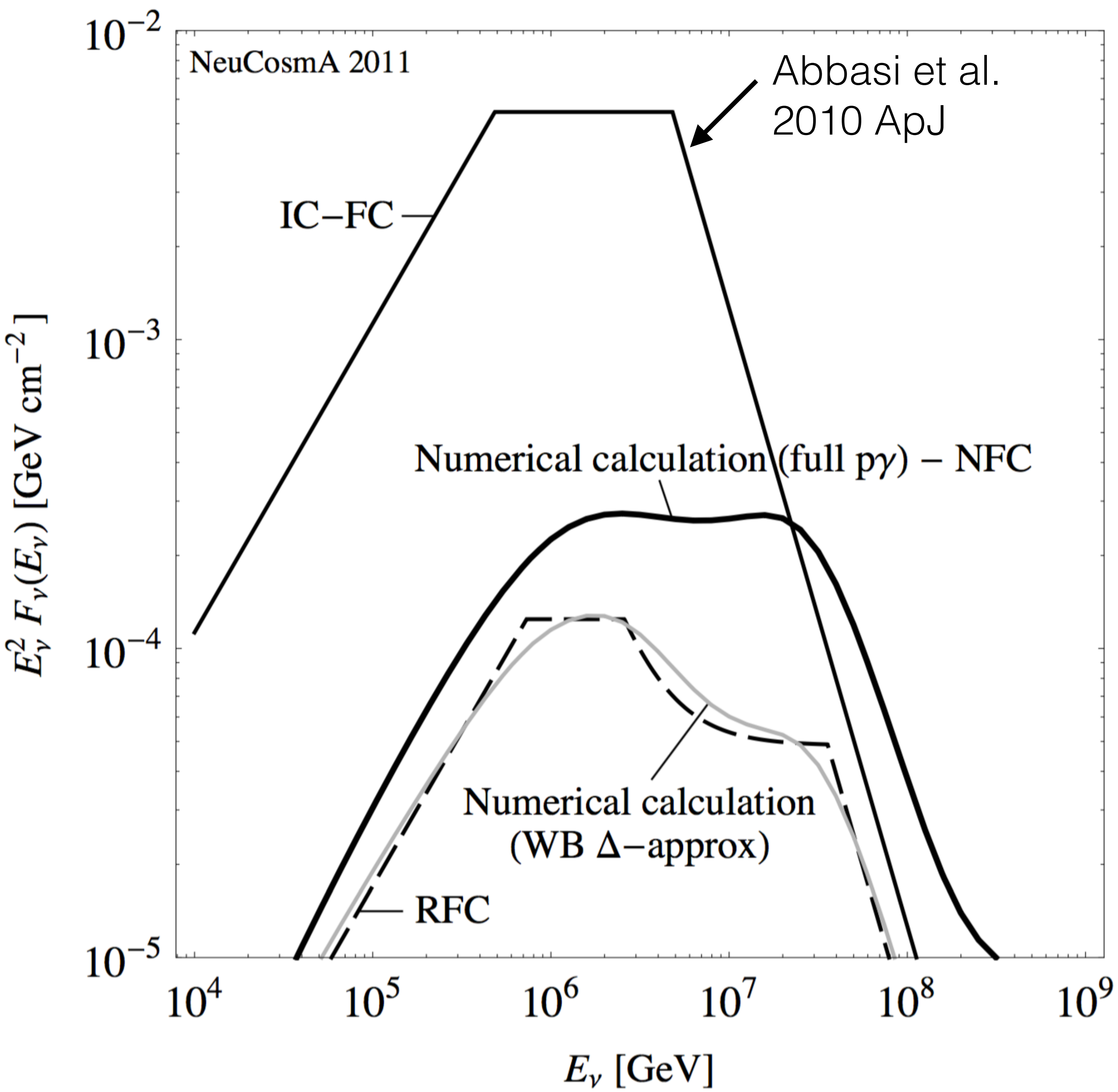
Waxman & Bahcall 97, muon nu sp.

- Collision between two shells of different speed
- Non-rel shock formation
- Fermi-acceleration
- γ-ray by syn + IC
- ν by pγ or pp interaction

$$p+\gamma(p) \rightarrow \pi + p(n)$$
$$\pi^0 \rightarrow 2\gamma$$
$$\pi^+(\pi^-) \rightarrow \nu_\mu(\bar{\nu}_\mu) + \mu^+(\mu^-)$$
$$\rightarrow \nu_\mu + \bar{\nu}_\mu + \nu_e(\bar{\nu}_e) + e^+(e^-)$$

- ν production channel same for AGN
- each final lepton energy ~ 5% of parent p

Revised Internal Shock model



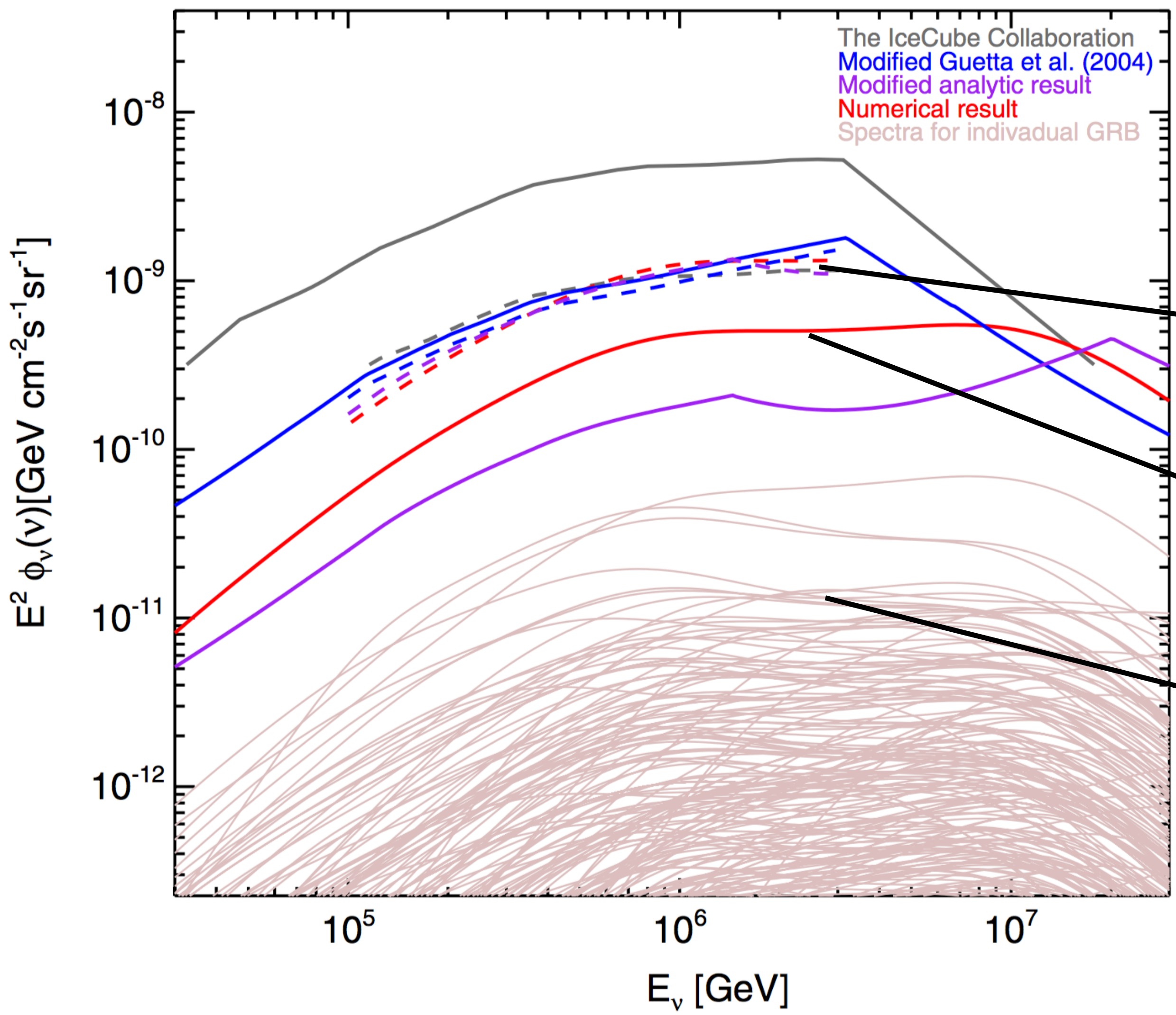
Hümmer,Baerwald and Winter, PRL 2012

- beyond Δ-resonance (higher resonances,multi-pion…)
- beyond pions (Kaon…)
- realistic redistribution functions
- cooling effect
- realistic neutrons

↓

lower overall flux
+
modified spectrum

Stacking Analysis



$L_p/L_\gamma = 10$
$\Gamma_{bulk} = 300$
$R = 10^{12.5}$ cm

IC 40+59 limit

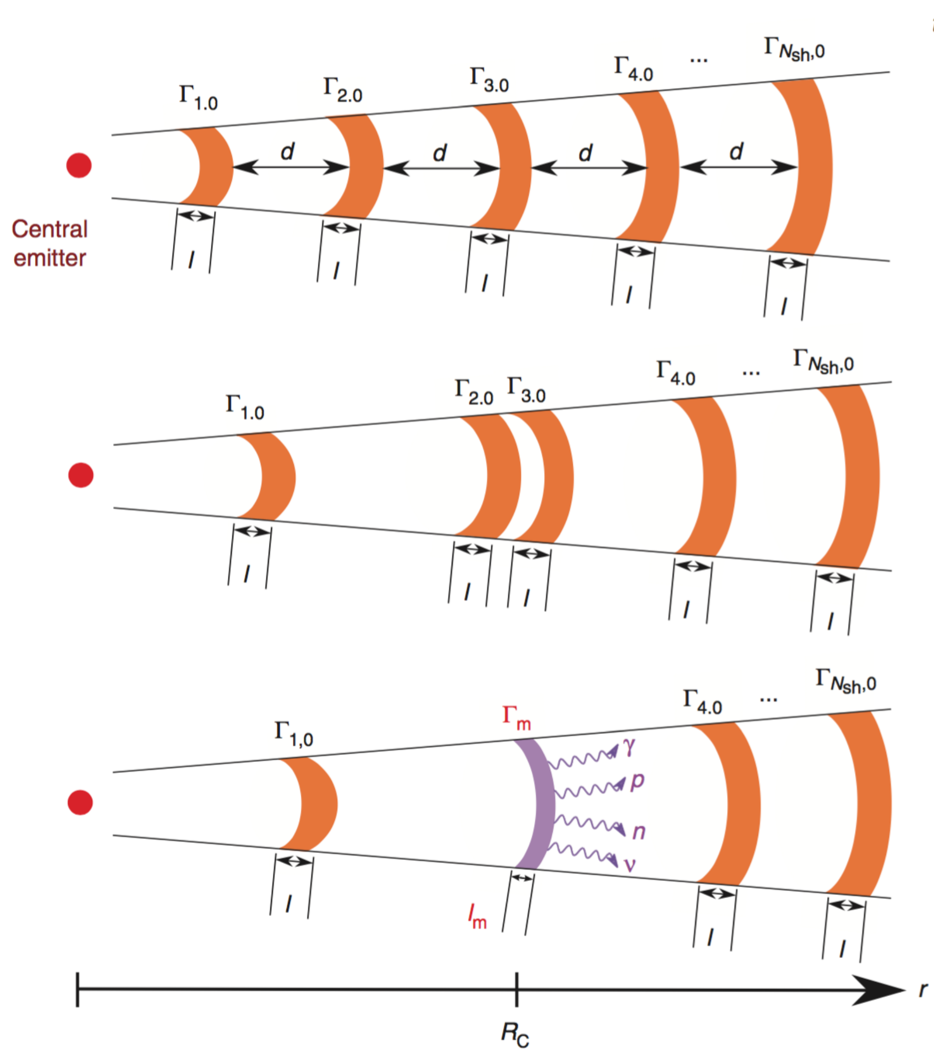
total (215 GRBs)

individual spectrum

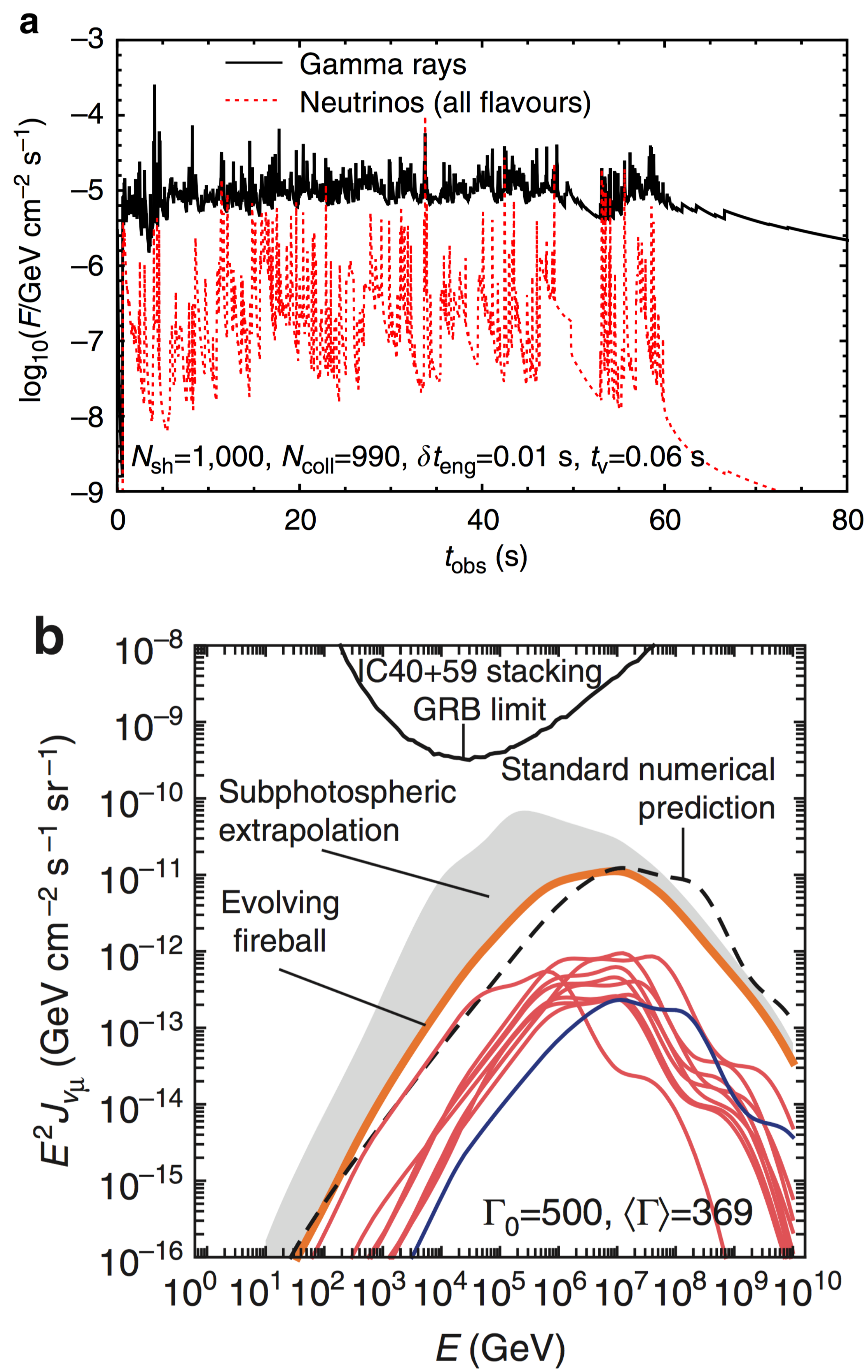
Haoning He et al.ApJ,2012

- factor ~3 below IC limit
- only extreme parameters or luminosity functions excluded

An advanced IS model : multi-shell collision

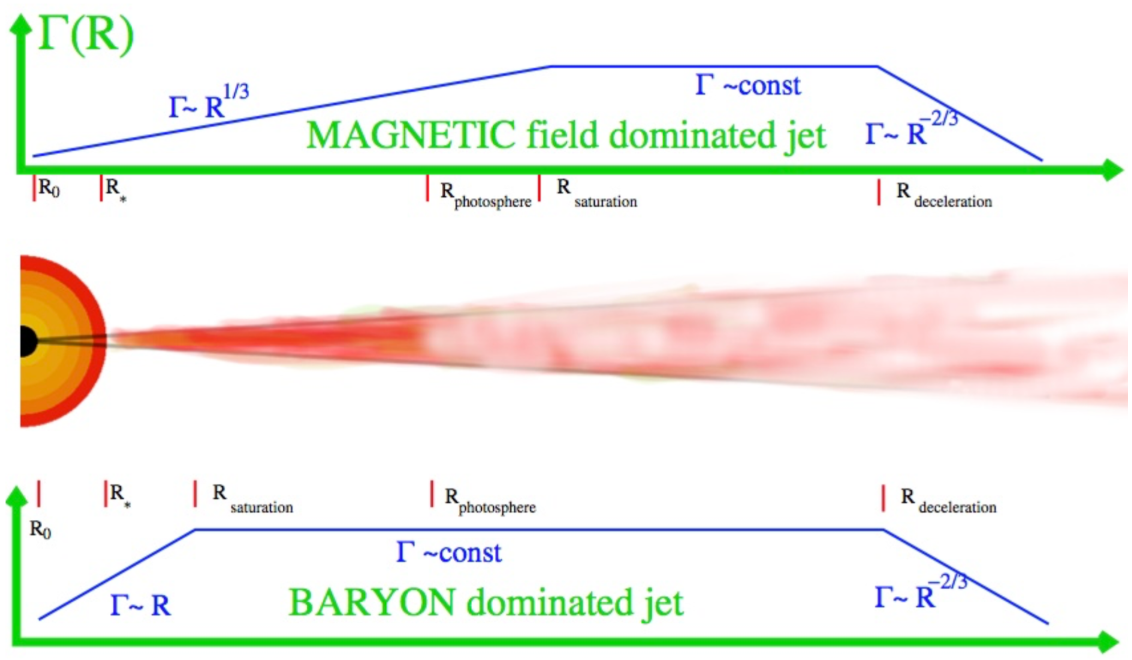


Bustamante et al. 2015 NatComm.

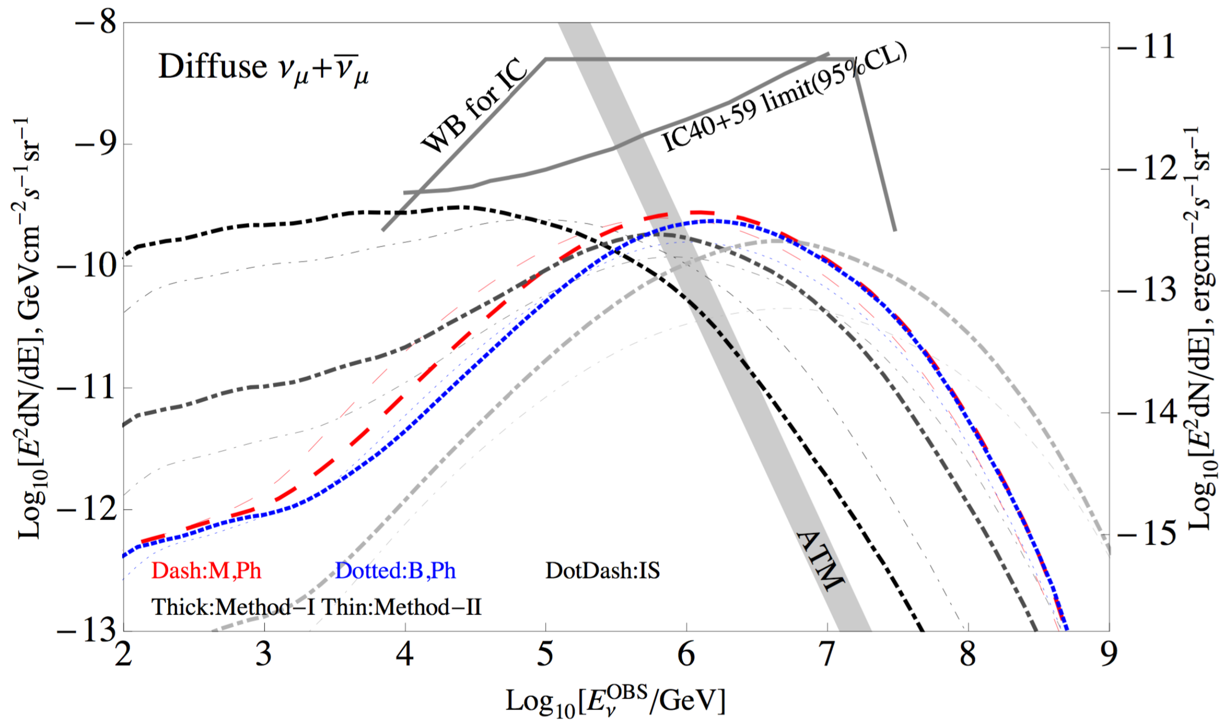


- below IC limit
- ν emission dominated by near-photosphere collisions

Dissipative Photospheric Models



Meszaros, talk at Gran Sasso 2014

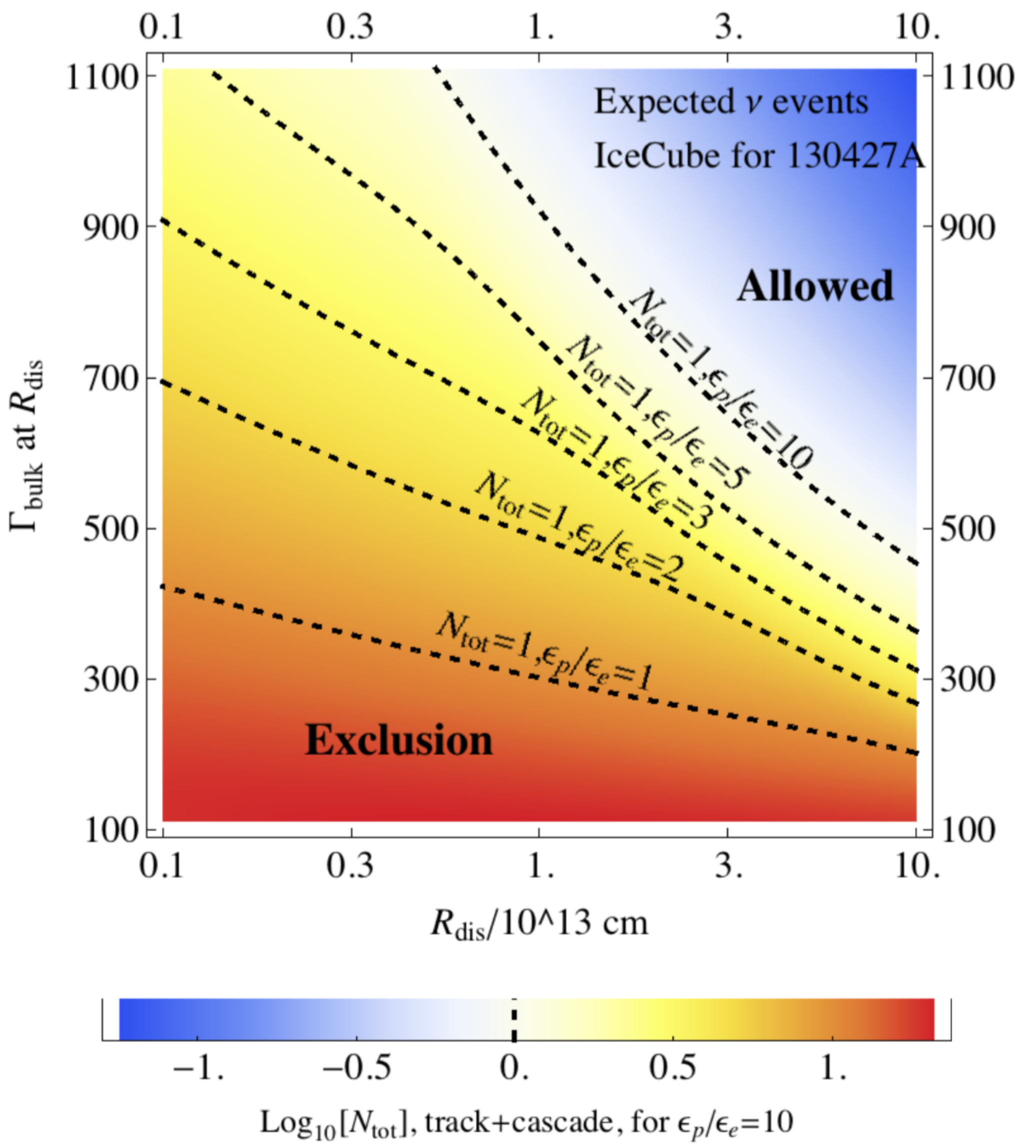


SG, Asano, Meszaros, JCAP, 2013

- stacking analysis satisfies IC limit for all models
- baryonic phot and mag. phot. model have a similar diffuse neutrino spectrum

Constraints on individual GRBs

GRB 130427A



SG,Kashiyama,Meszaros,ApJL,2013

- brightest GRB
- best-studied GRB
- neutrino null-detection

Constraints from neutrino channel:
— null detection not a surprise
— only extreme para. excluded

Needs better time-dependent model
Effects of pairs

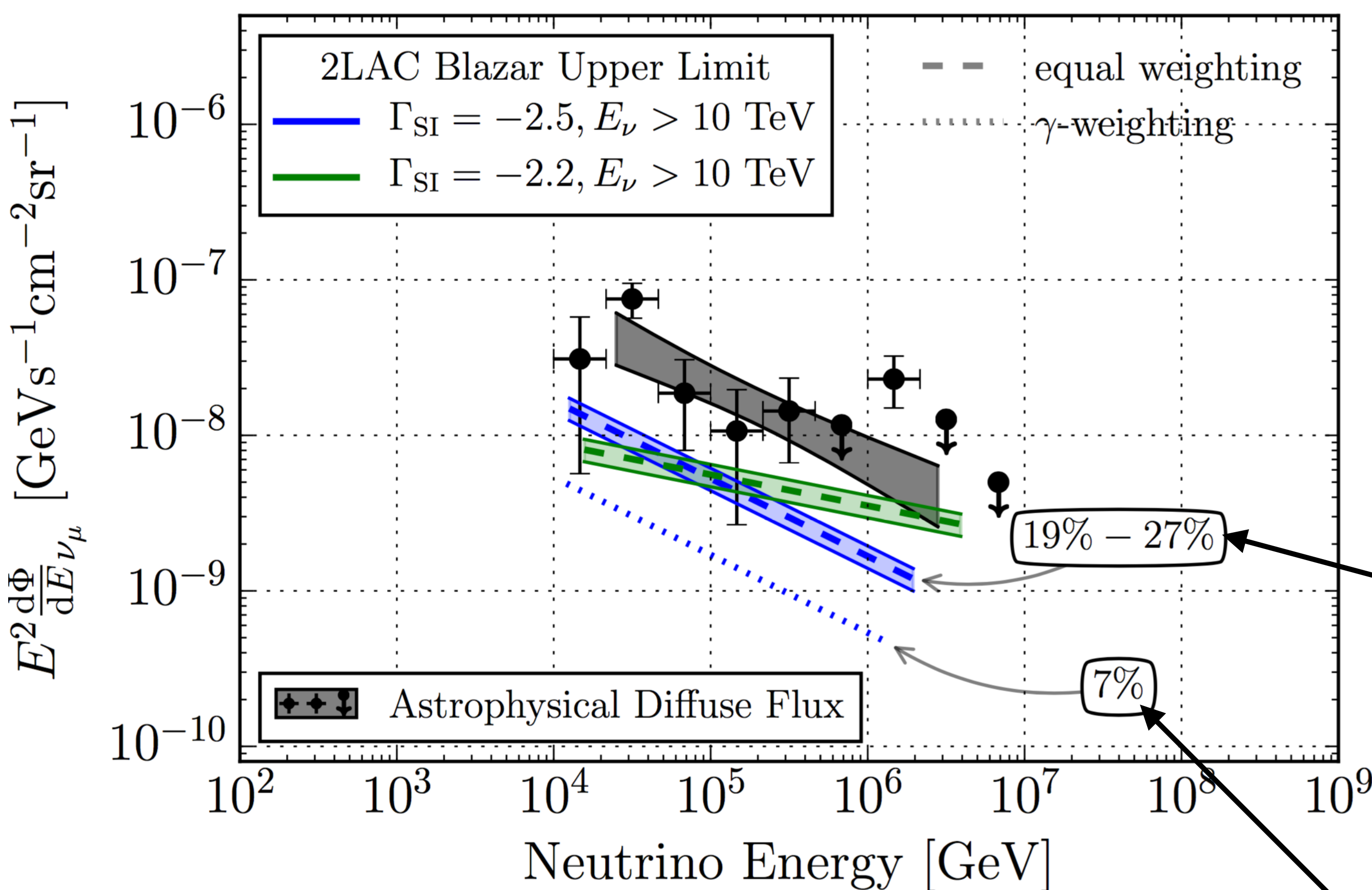
With IceCube full arrays now, expect
stronger constraints on GRB baryonic loading

2. Blazars

Outline

- IceCube analysis on all blazars
- List of models
- 3C 279 Flare
- Mrk 421 Flare
- PKS B1424-418 Flare

Blazar: IceCube Results



All 2LAC blazars (862 objects, FSRQ,LBL,IBL,HBL)

equal weighting

γ-weighting

IceCube collaboration, arXiv: 1611.03874

γ-weighting: $L_\nu = L_\gamma$ for each source

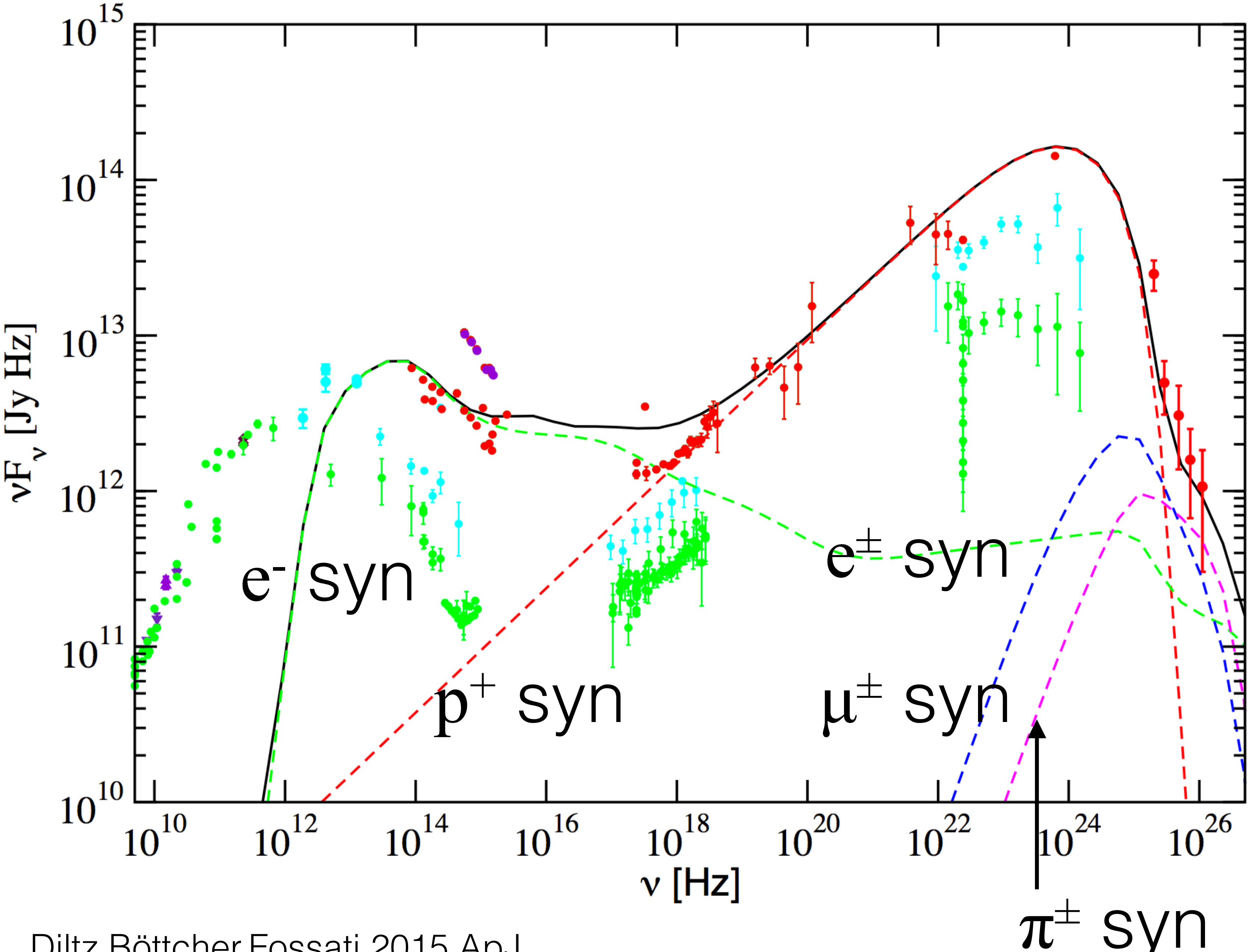
equal weighting: dN/dS follows the same as γ-rays; No correlation for individual source

Conclusion: 2LAC blazars difficult to explain all astrophys. ν-events; no prediction for individual source/flares.

List of models

	1st peak (eV-keV)	middle range (keV-MeV)	2nd peak (MeV-TeV)	Example
Pure Leptonic	**L** primary e-syn	**L** Synchrotron-Self Compton (**SSC**)	**L** SSC or External-IC	can explain most blazars
LH-SSC	**L** primary e-syn	**H** secondary lep emission	**L** SSC	PKS B1424-418
LHπ	**L** primary e-syn	**H** secondary lep emission	**H** π^0 decay or secondary lep	Mrk 421
LHs	**L** primary e-syn	**H** secondary lep emission	**H** proton syn	3C 279
Pure Hadronic	**H** proton-syn	**H** secondary lep emission	**H** π^0 decay or secondary lep	postulated

3C 279, Steady-state, proton-synchrotron model



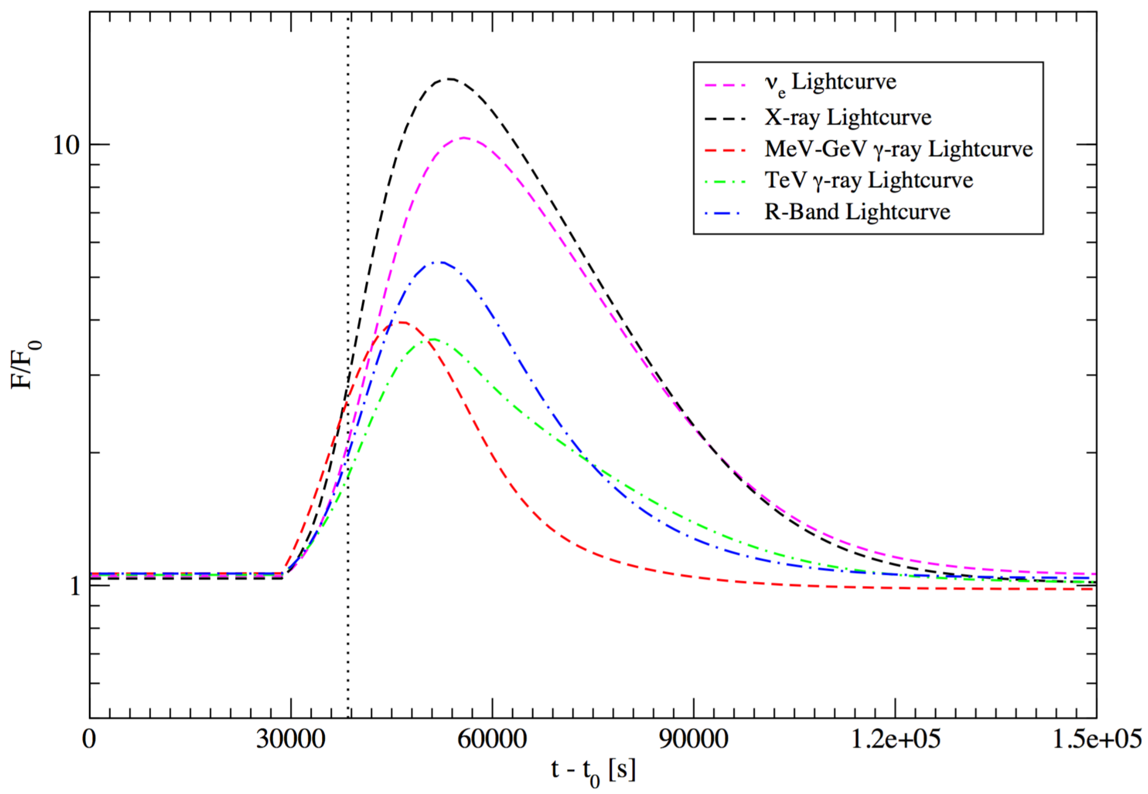
B = 150 G
$L_e = 10^{41.9}$ erg/s
$L_p = 10^{46.5}$ erg/s
$\Gamma_{bulk} = 21$
$R = 10^{15.9}$ cm

$E_\nu \sim 300$ PeV

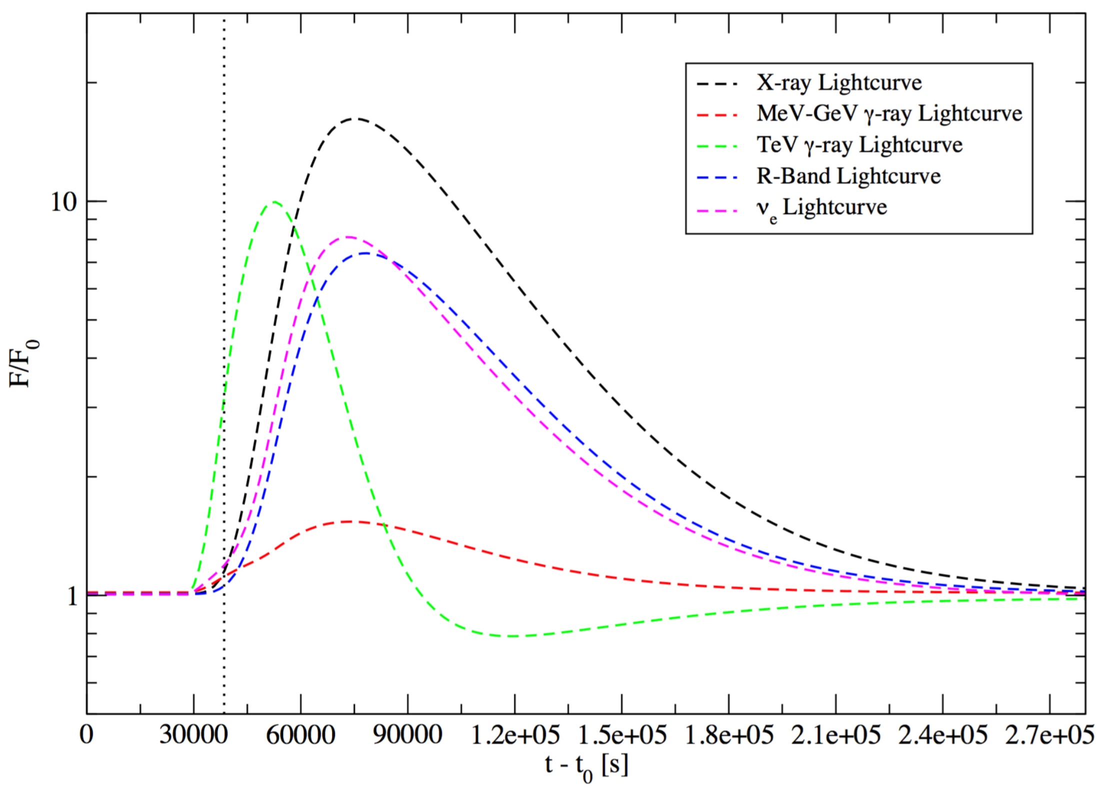
Diltz,Böttcher,Fossati 2015 ApJ

Generating a flare by perturbing a parameter

Normalized Lightcurves (B-Field Perturbation) :



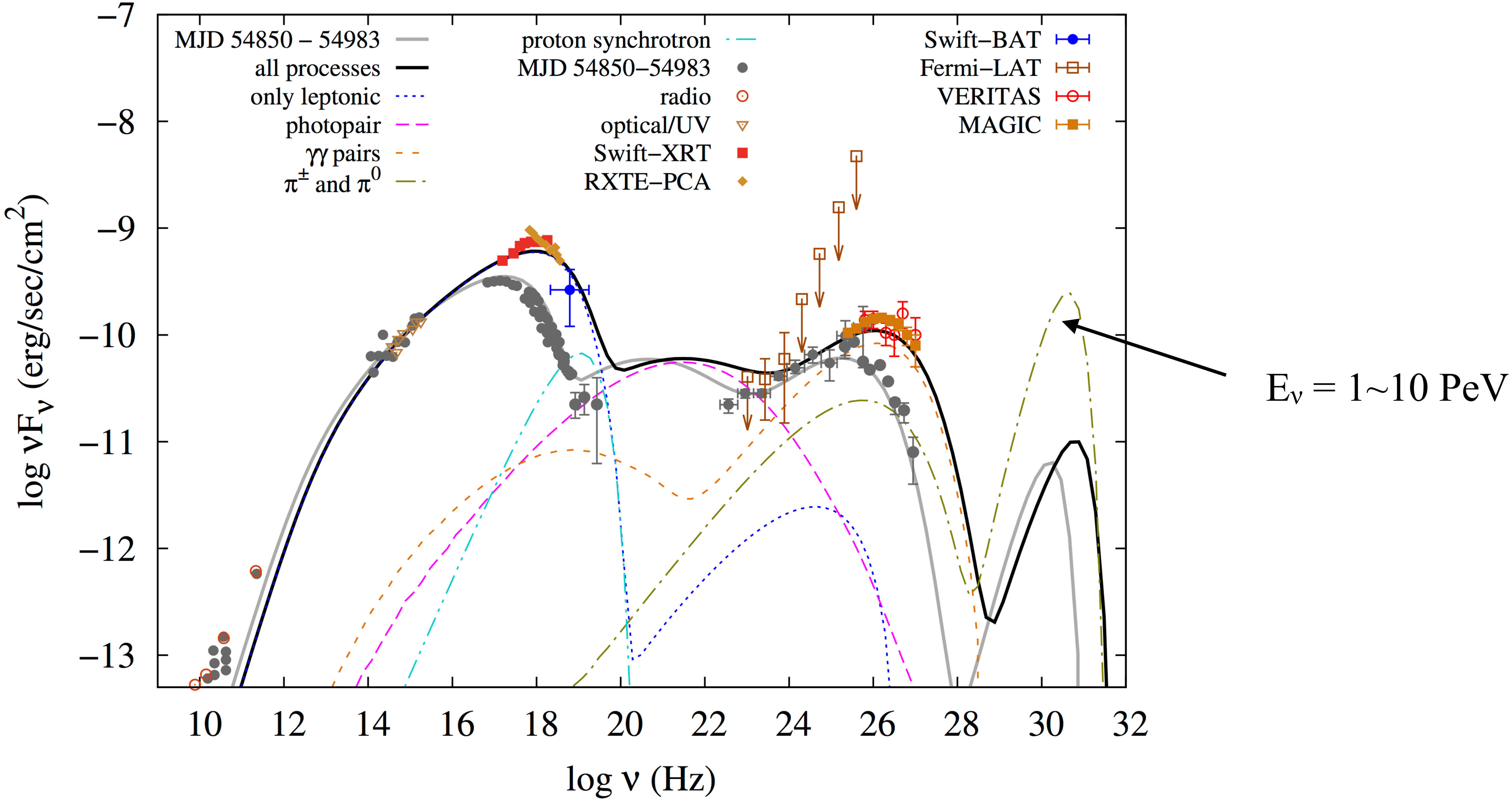
Normalized Lightcurves (q_p Perturbation):



Diltz,Böttcher,Fossati 2015 ApJ

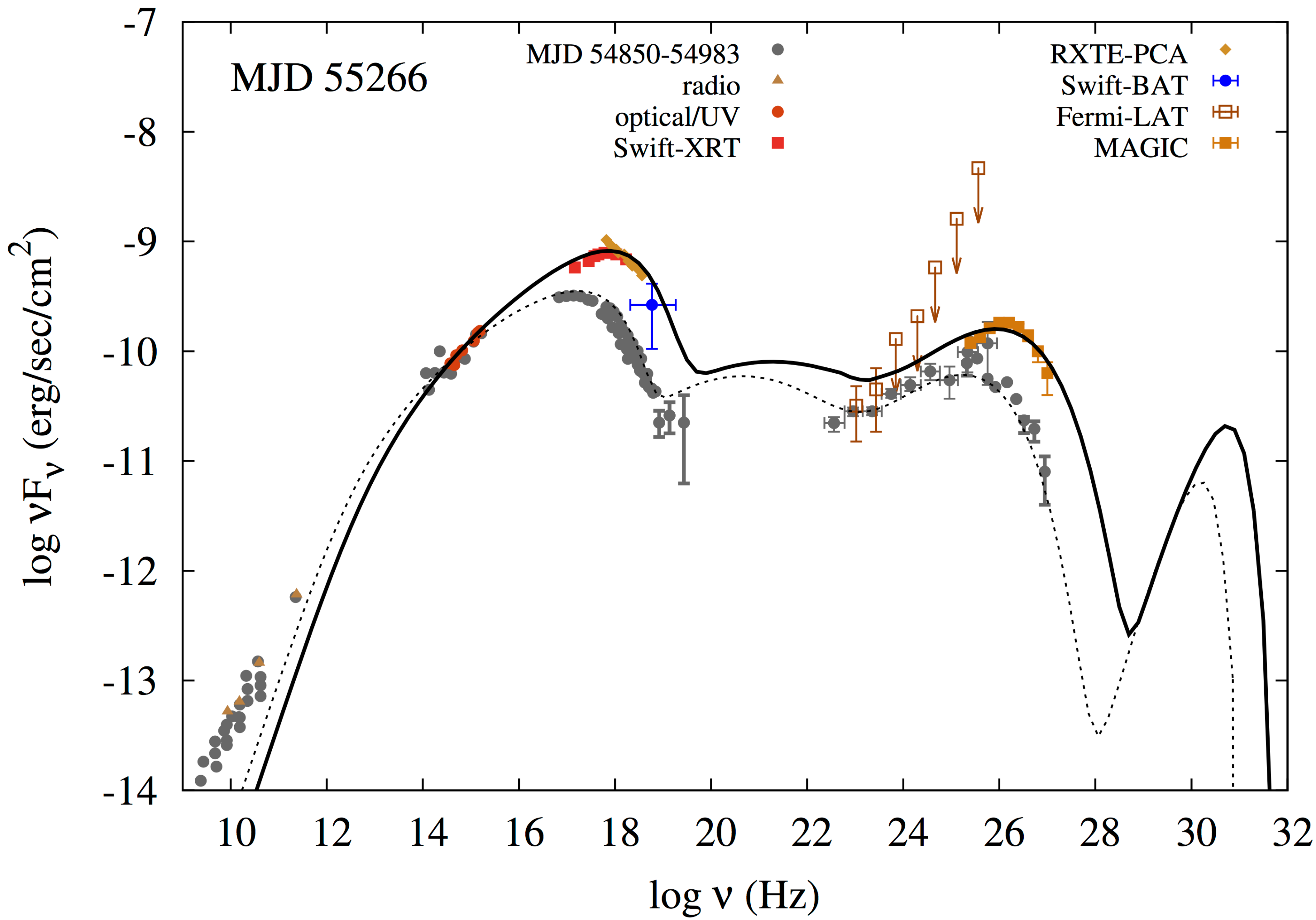
- Time delays
- Amplitude correlation (and anti-correlation)

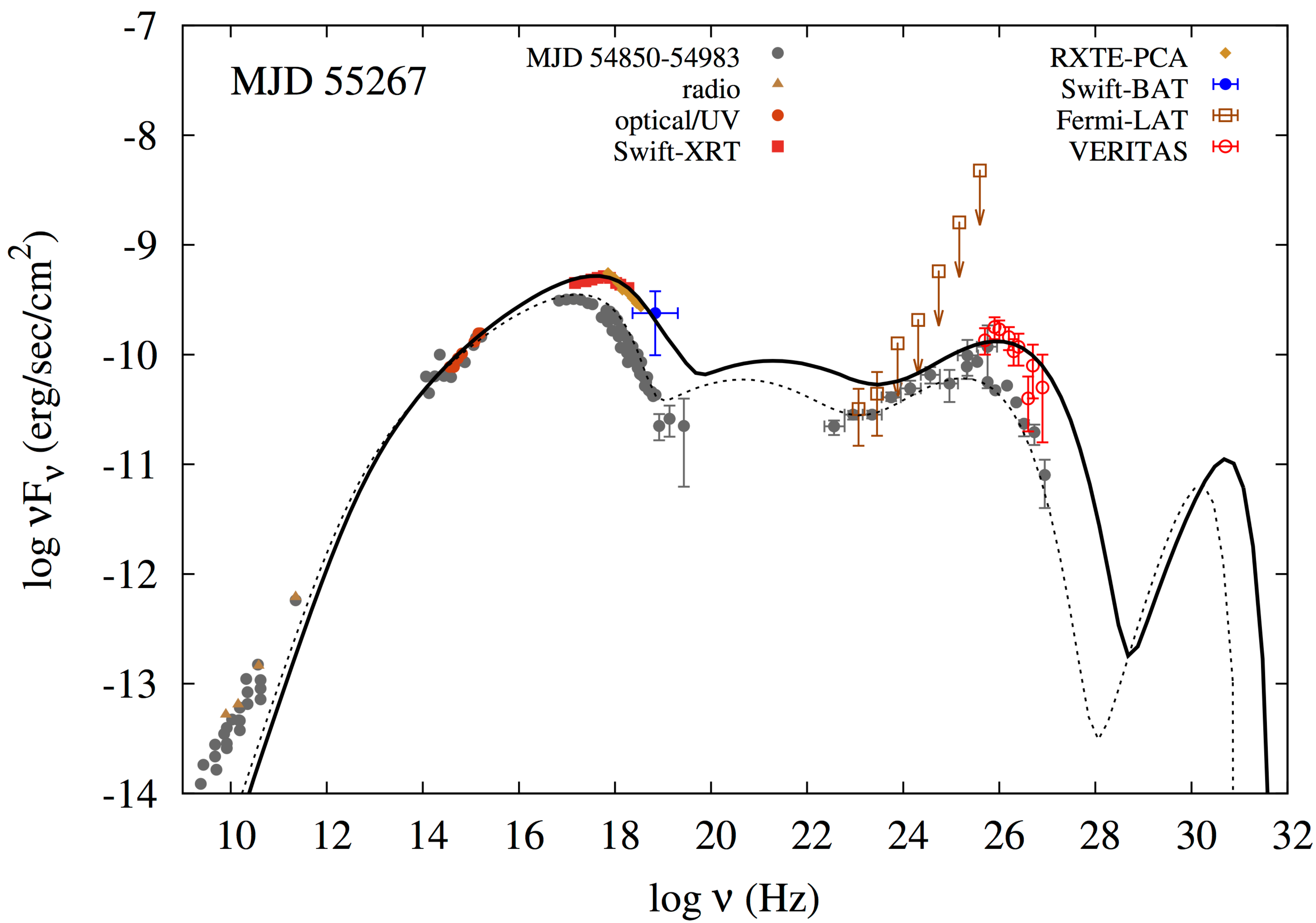
Mrk 421, Steady-state, LHπ model



Petropoulou et al. Astropart. Phys. 2016

Mrk 421, flare state, daily SED





MJD 55267
MJD 54850-54983
radio
optical/UV
Swift-XRT
RXTE-PCA
Swift-BAT
Fermi-LAT
VERITAS
log νF_ν (erg/sec/cm^2)
log ν (Hz)
-7
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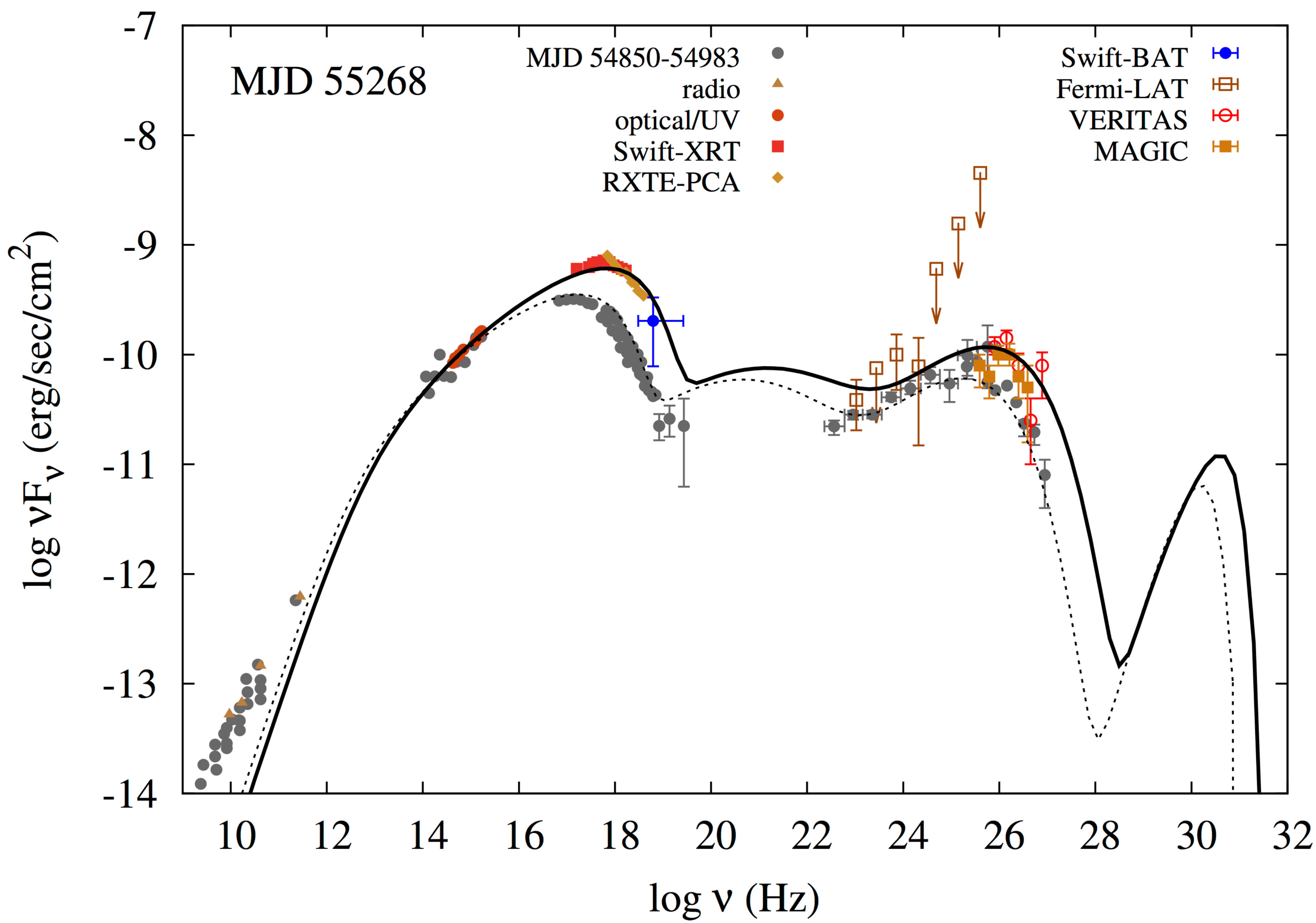

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MAGIC
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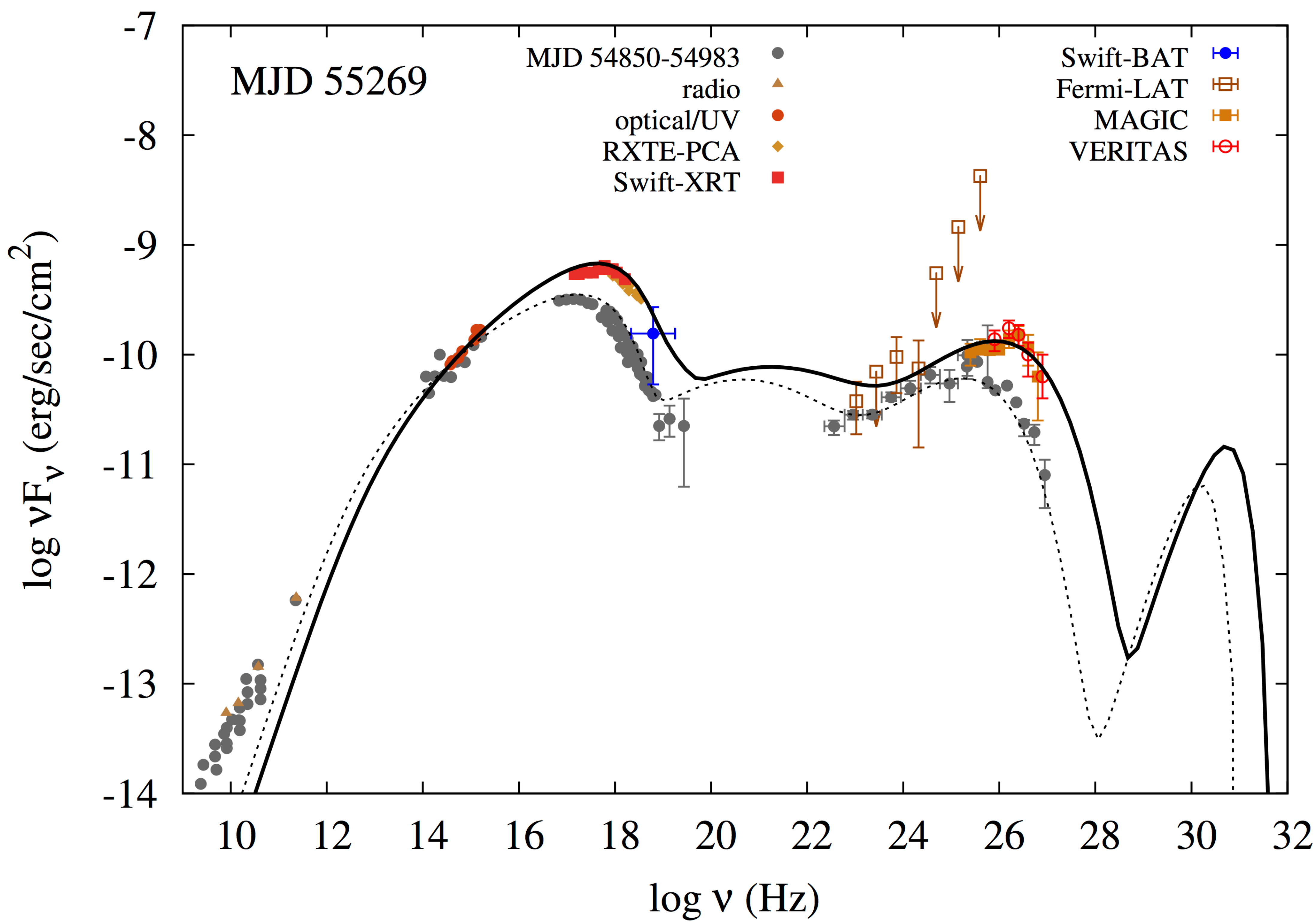

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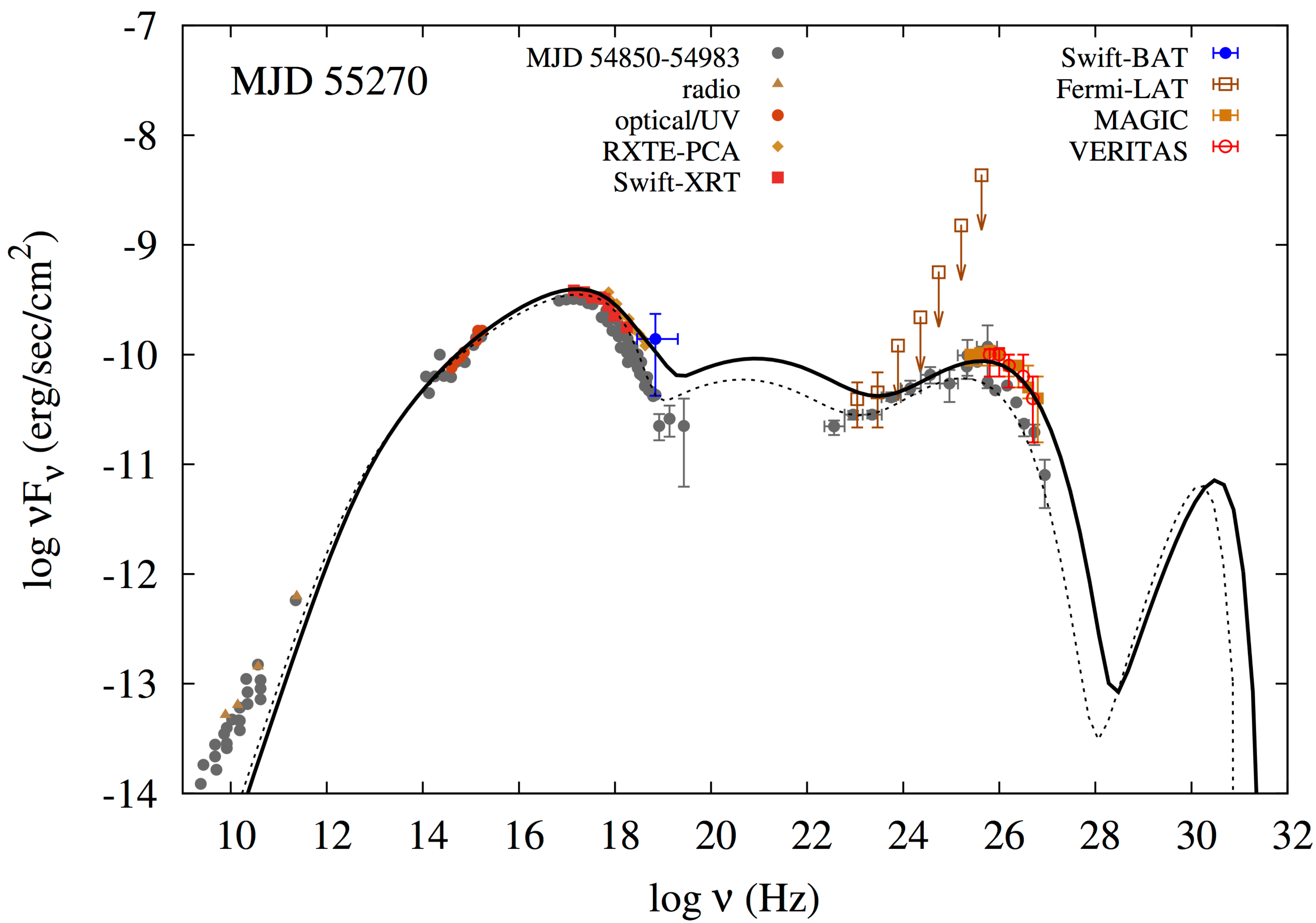

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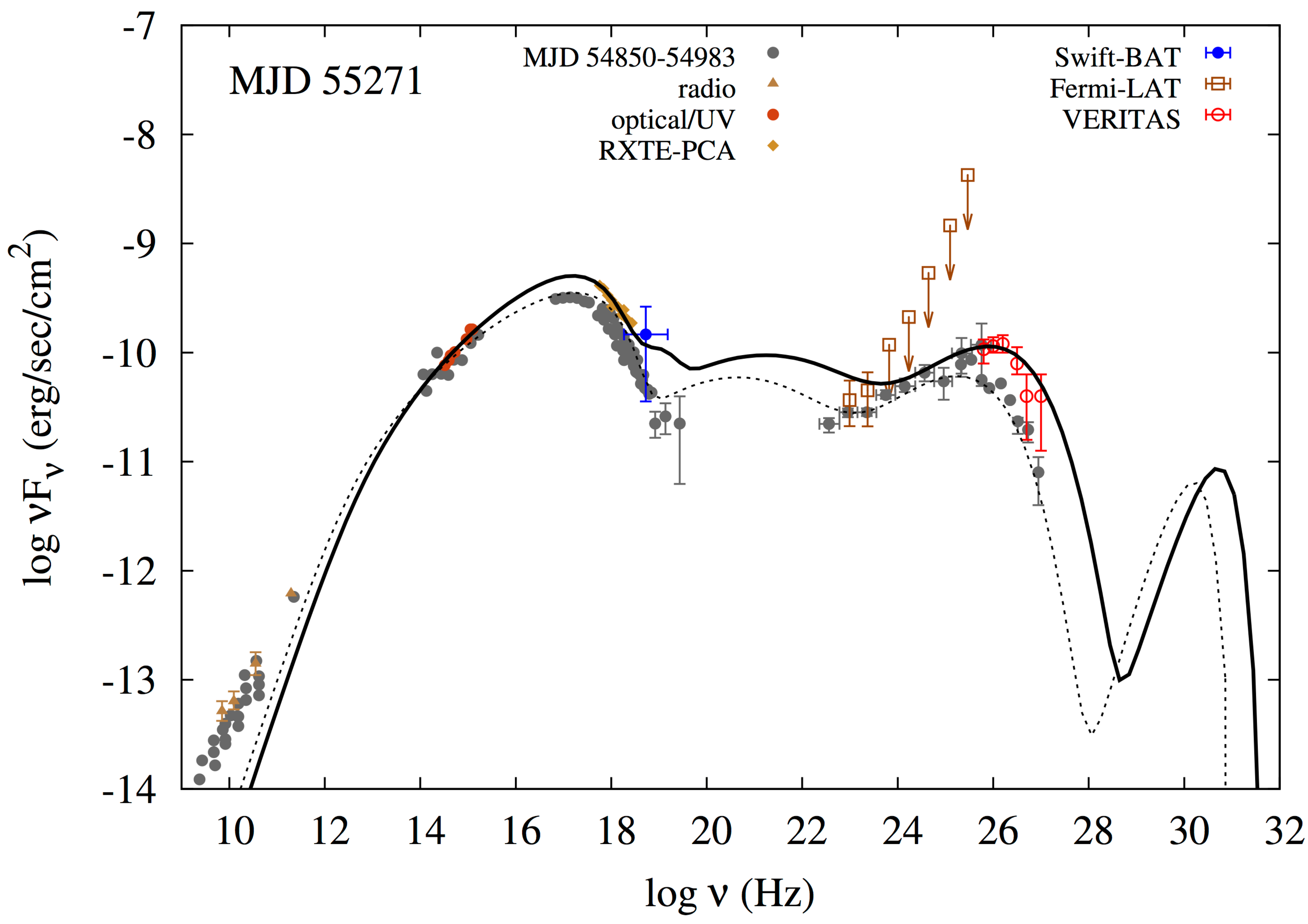

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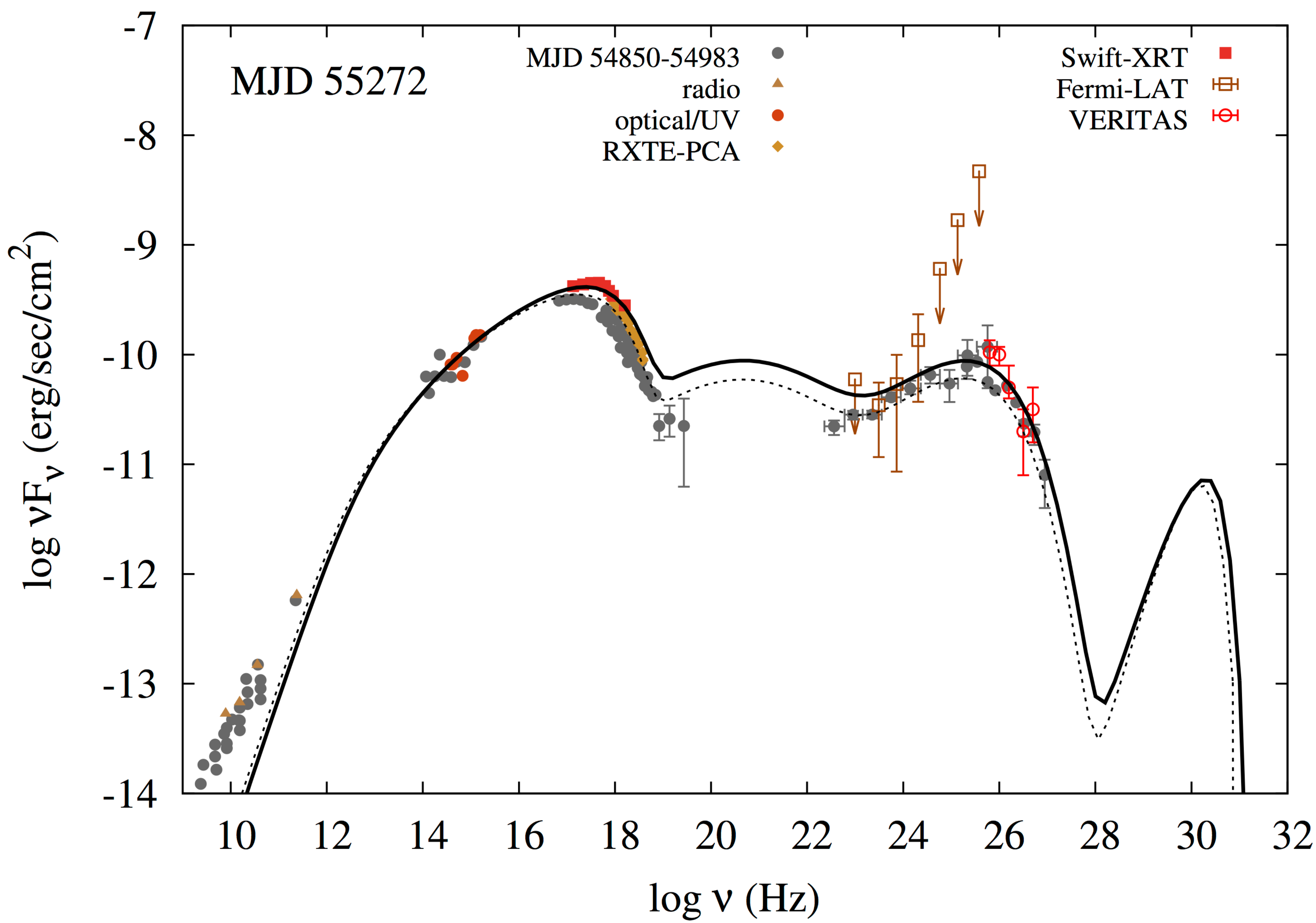

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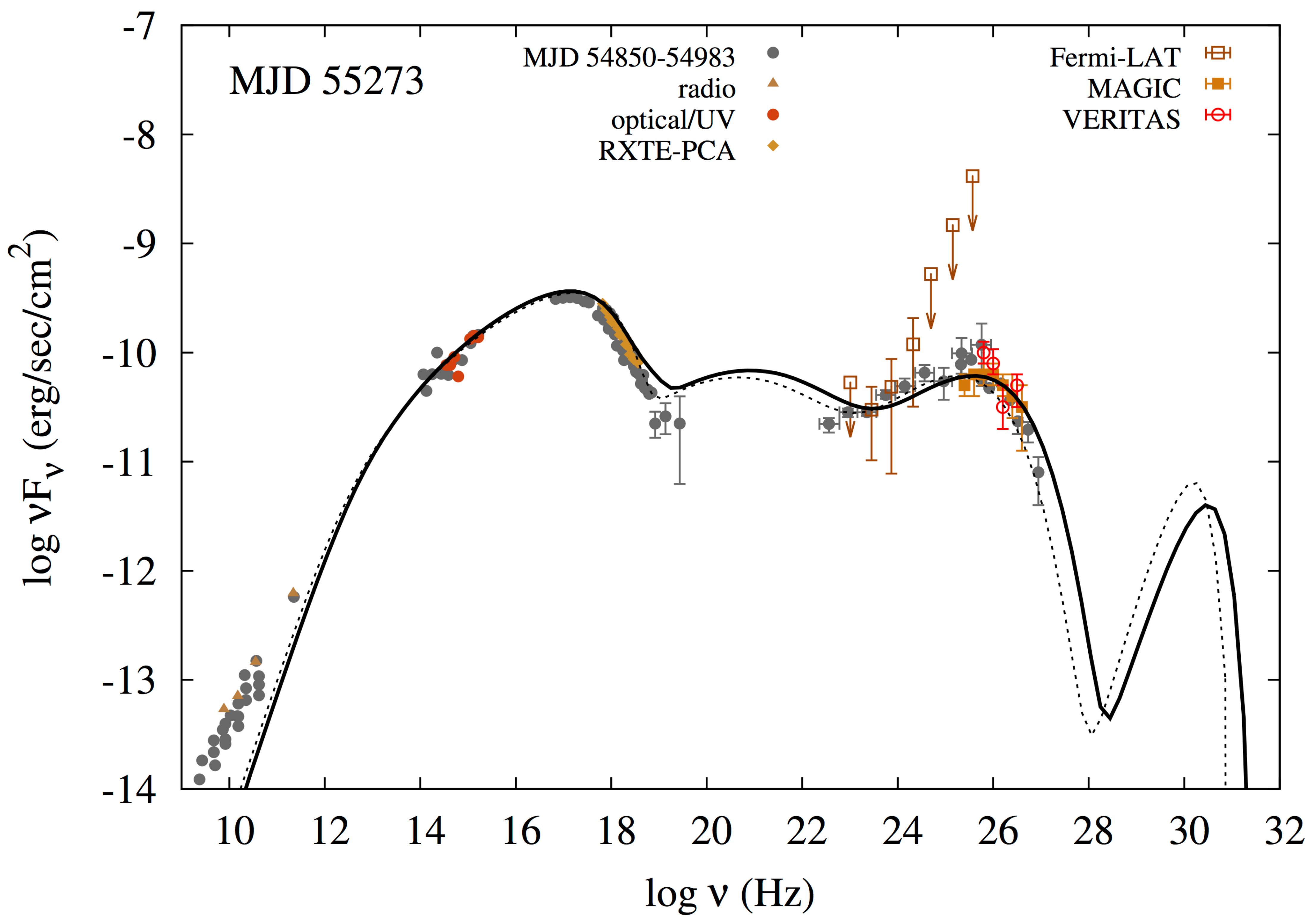

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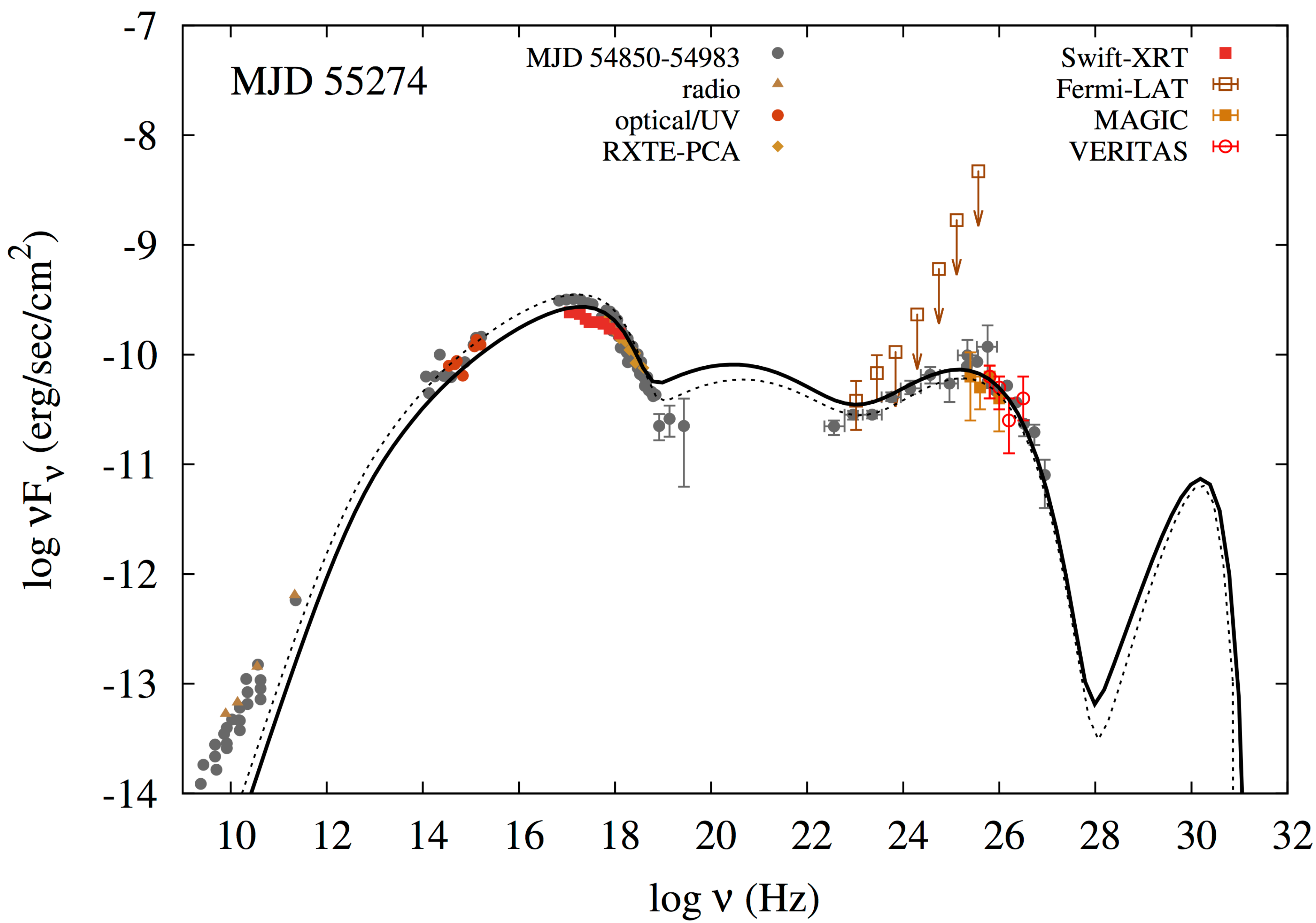

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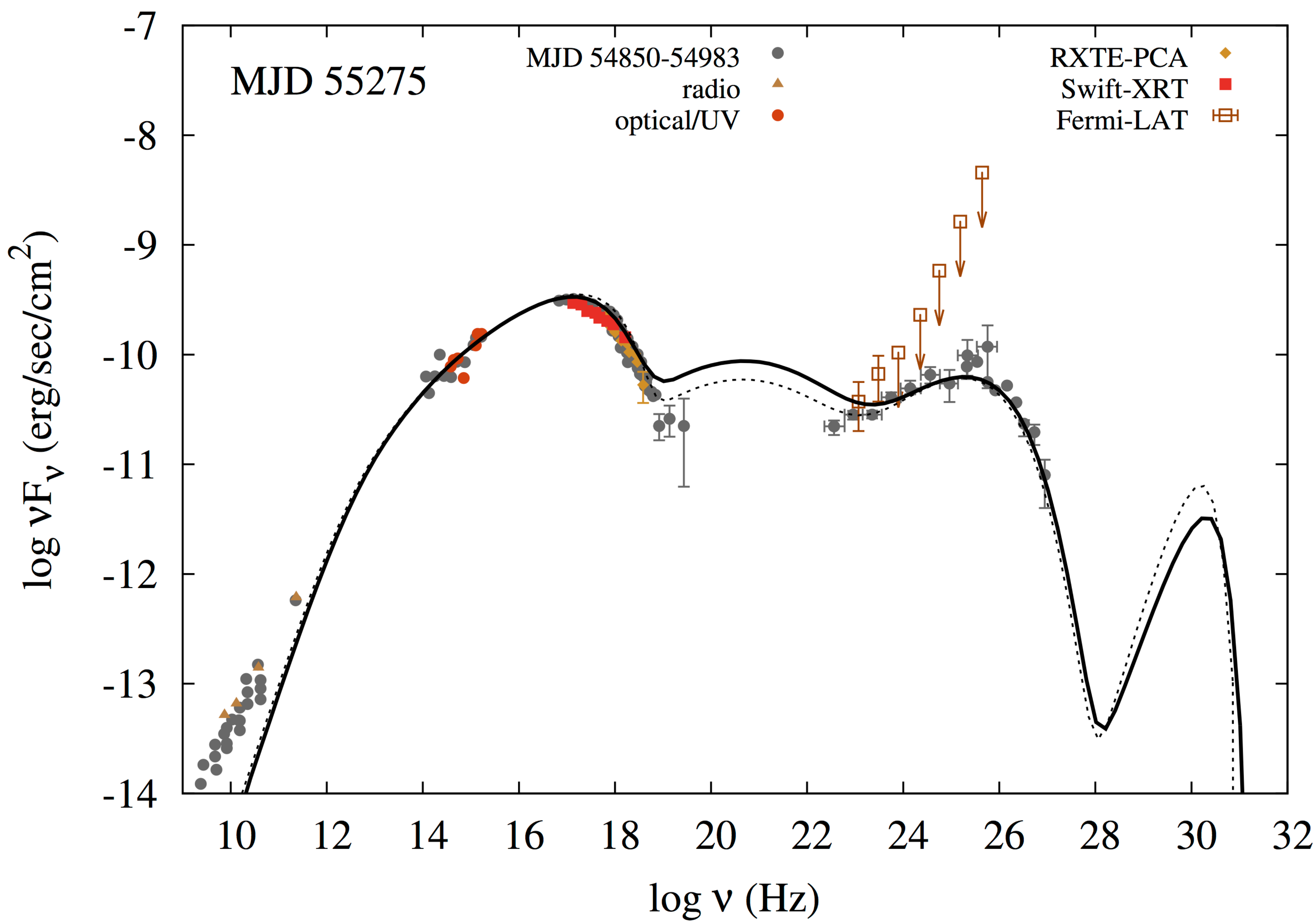

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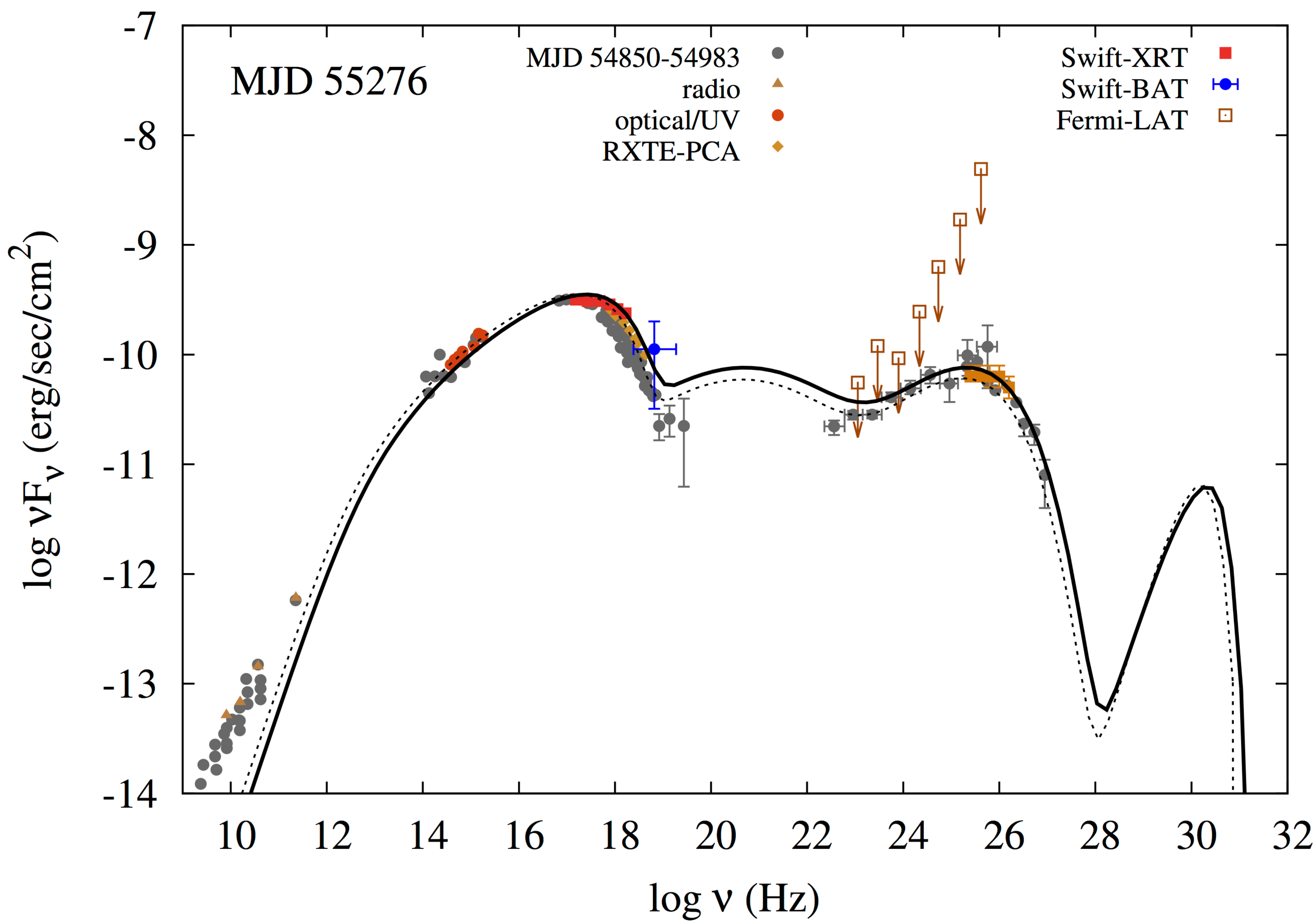

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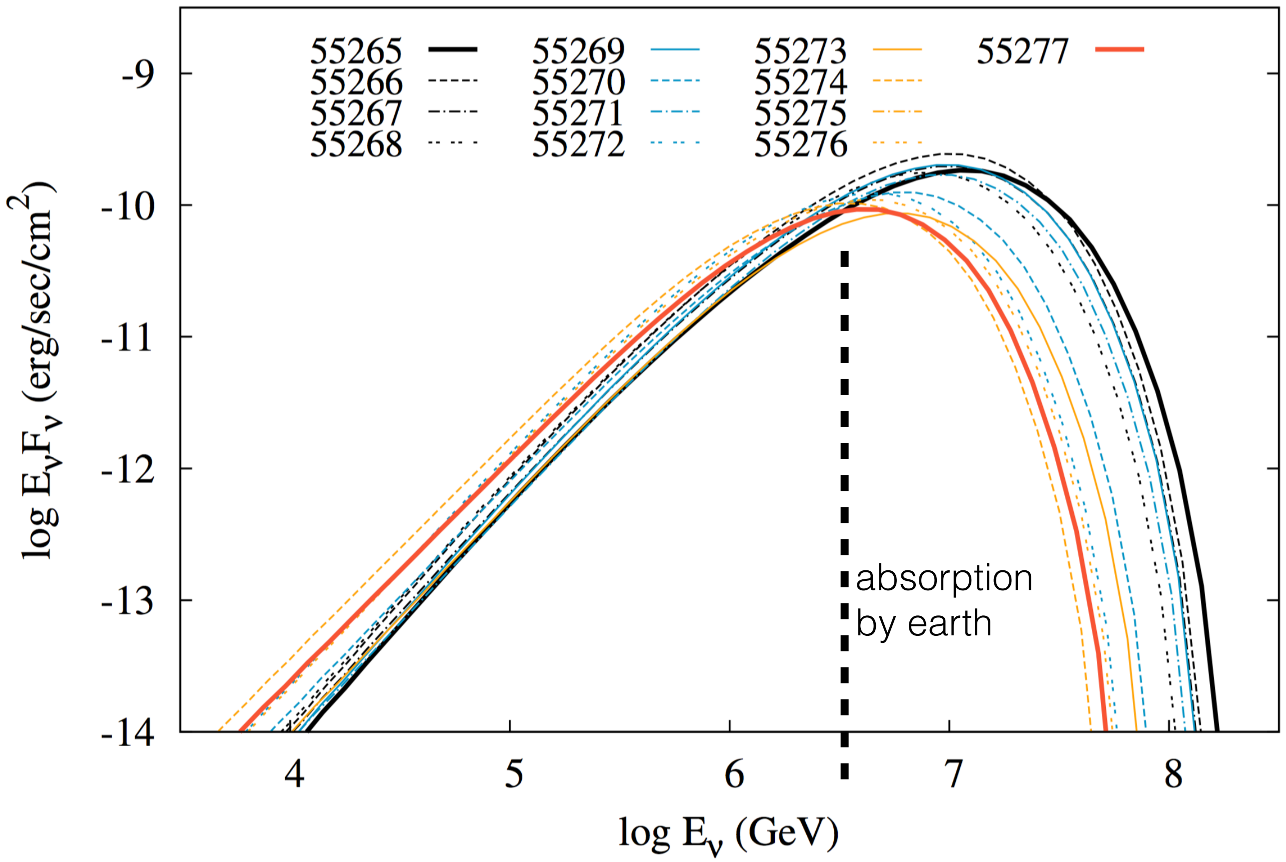
Mrk 421, flare state, daily neutrino spectrum



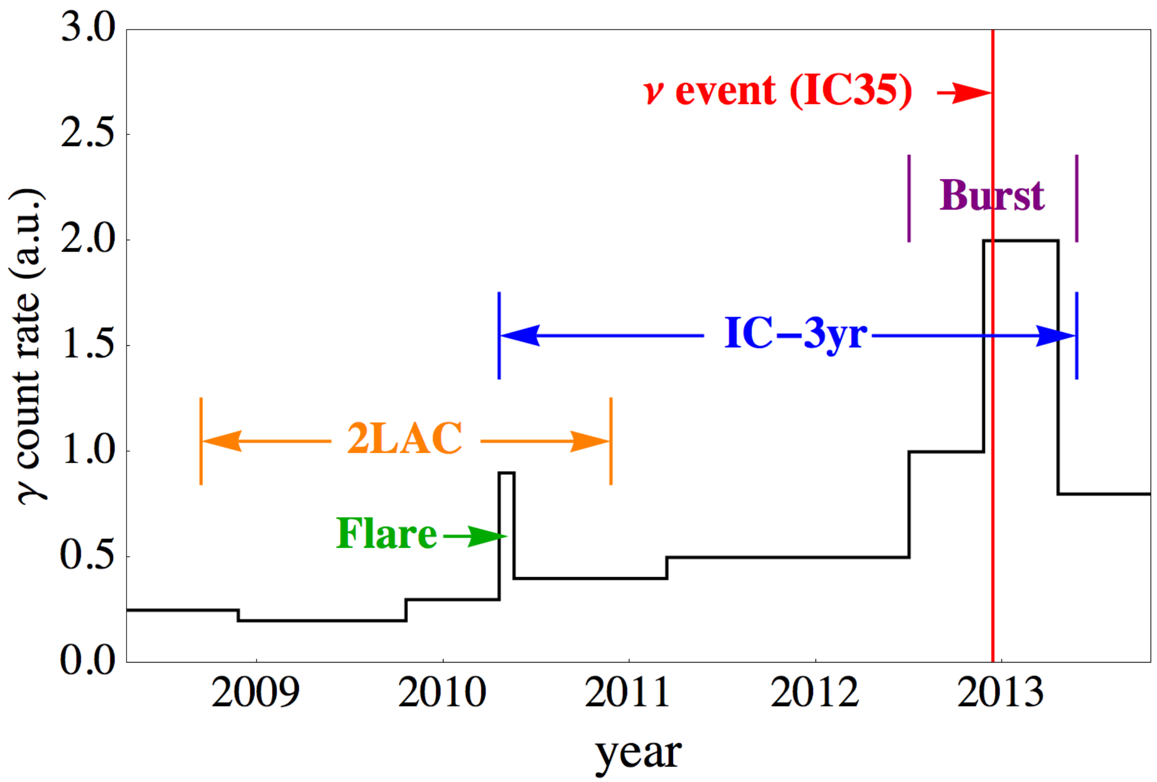
Petropoulou et al. Astropart. Phys. 2016

The boost of neutrino event rate for this flare is insignificant.

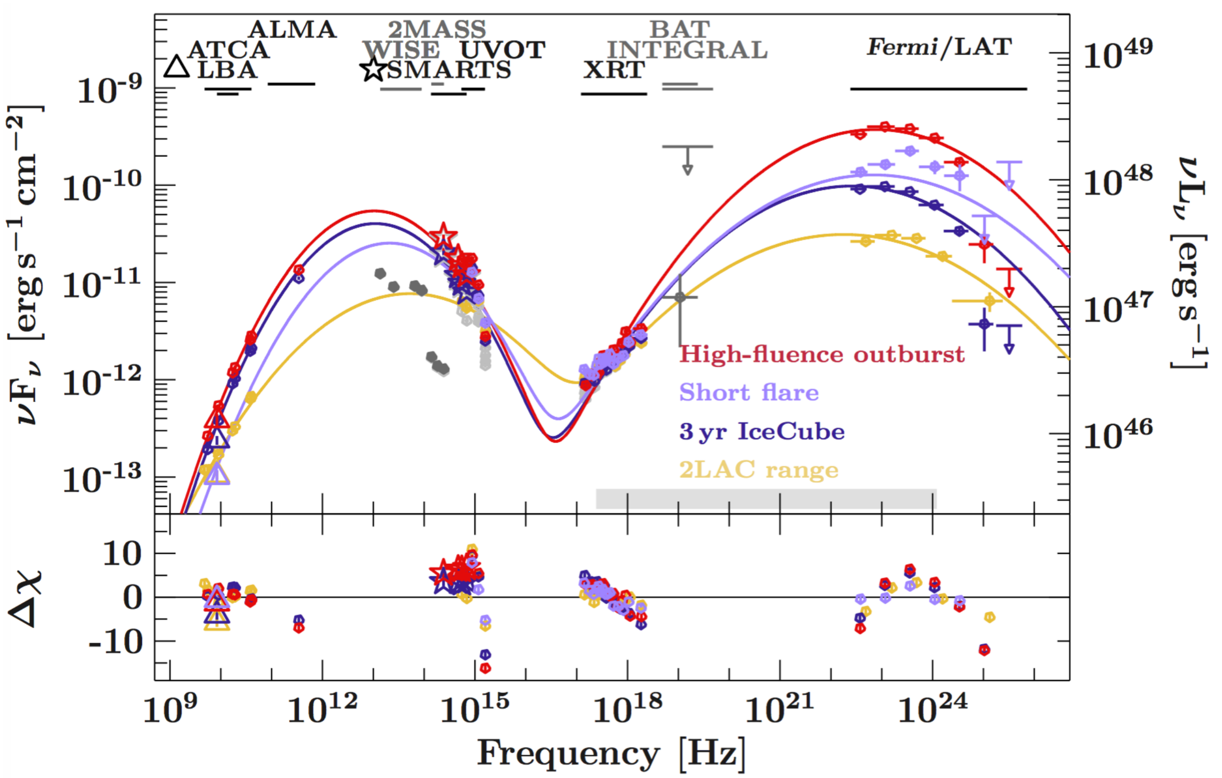
Predicts ~ 3.5 PeV-events from Mrk 421 during IceCube lifetime.

	Mrk 421[a]		Background[b]	
E_ν (TeV)	13-day flare (55265-55277)	quiescent (54850-54983)	atmospheric	diffuse
0.1 – 100	0.023	0.019	7.371	0.010
100 – 10^3	0.264	0.282	1.852×10^{-3}	2.203×10^{-3}
$10^3 - 5 \times 10^4$	0.306	0.288	4.554×10^{-6}	2.236×10^{-4}

PKS B1424-418



SG,Pohl,Winter arxiv:1610.05306



Kadler et al. NatPhys 2016

on PKS B1424 418

	1st peak (eV-keV)	middle range	2nd peak (MeV-TeV)	Example	
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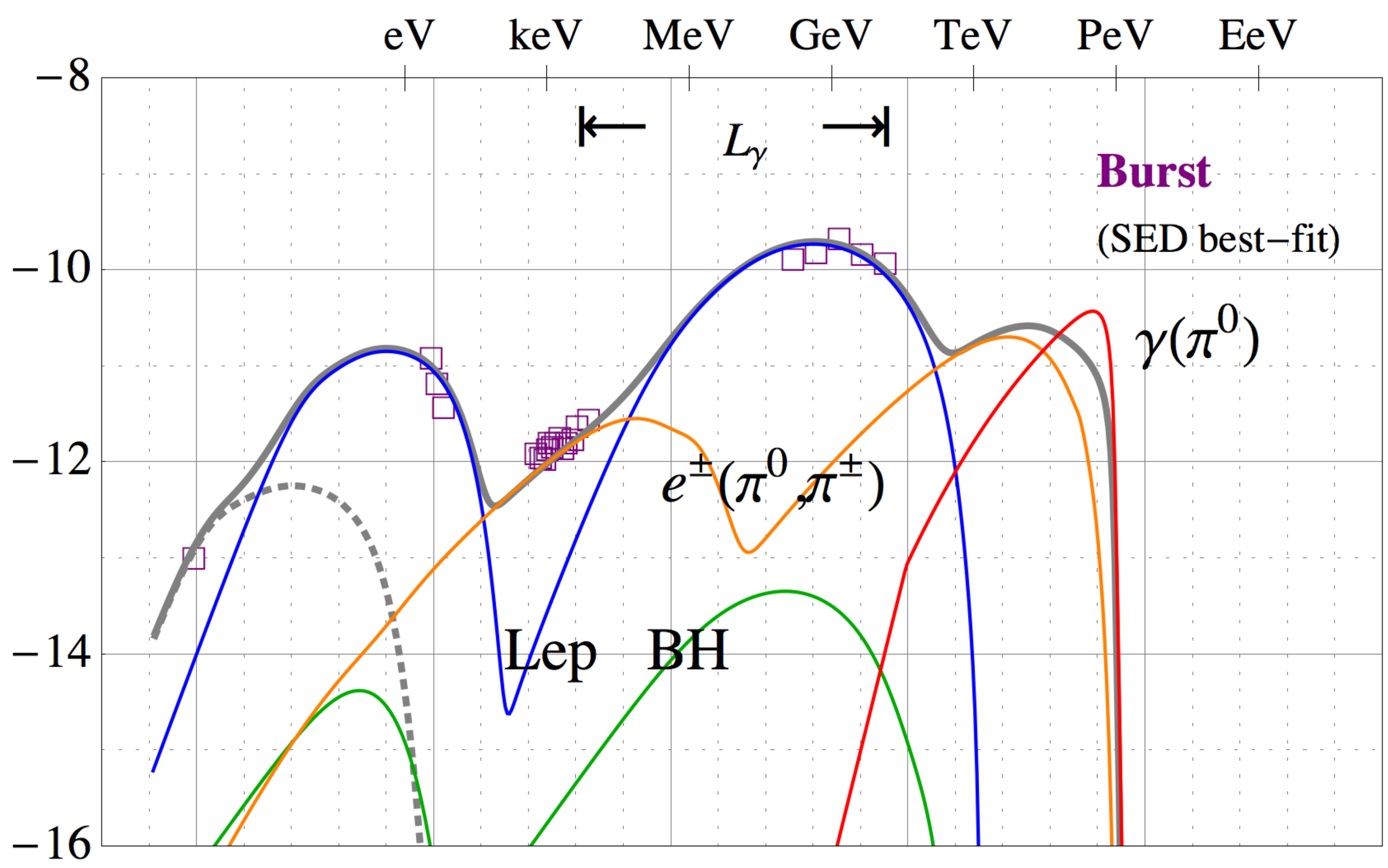
LHπ	**L** primary e-syn	**H** secondary lep emission	**H** π^0 decay or secondary lep	Mrk 421	✗
LHs	**L** primary e-syn	**H** secondary lep emission	**H** proton syn	3C 279	✗
Pure Hadronic	**H** proton-syn	**H** secondary lep emission	**H** π^0 decay or secondary lep	postulated	✗

E_{peak}, L_{peak}, E_ν must be consistent with observation; BH, psyn not overshooting SED, etc.

Components of the SED

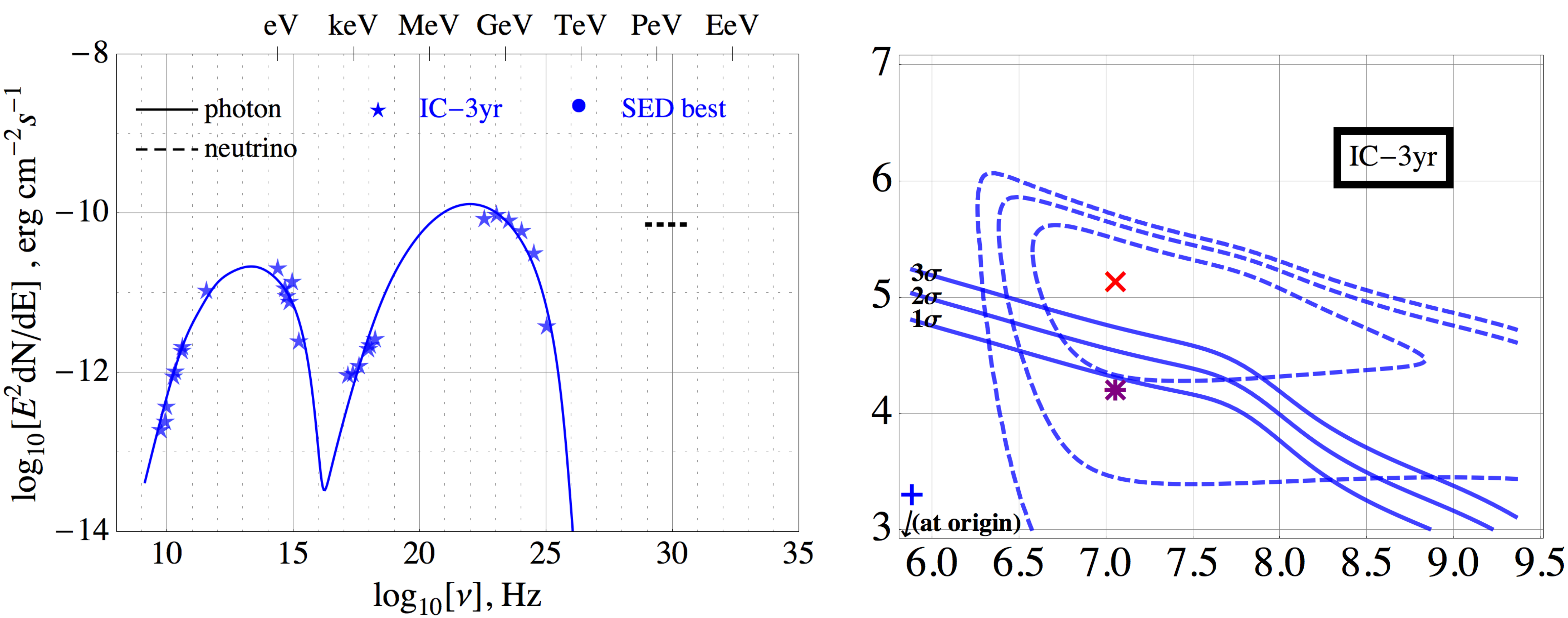


SG,Pohl,Winter arxiv:1610.05306

Hadronic explains X-rays

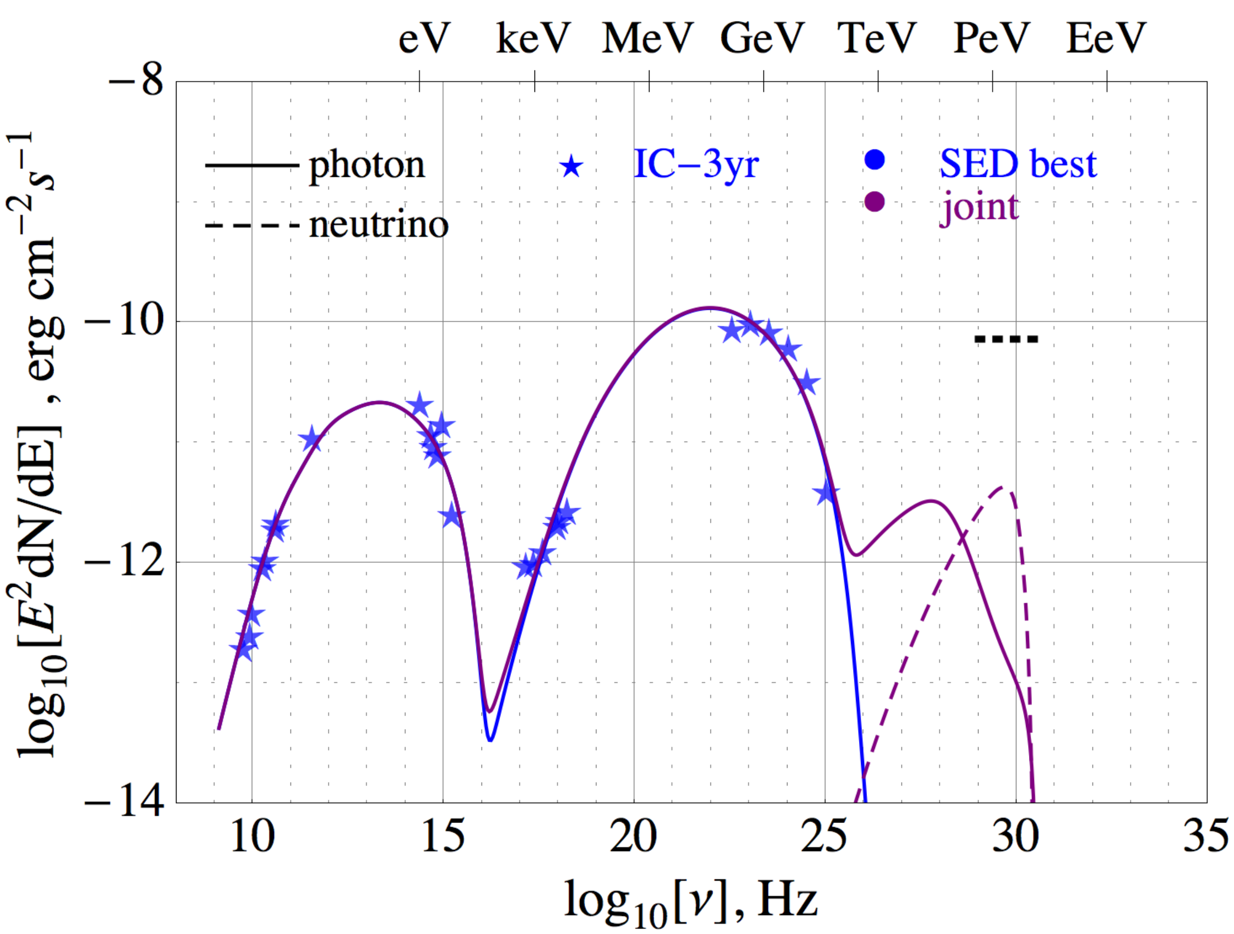
Suggesting $L_\nu \neq L_\gamma$

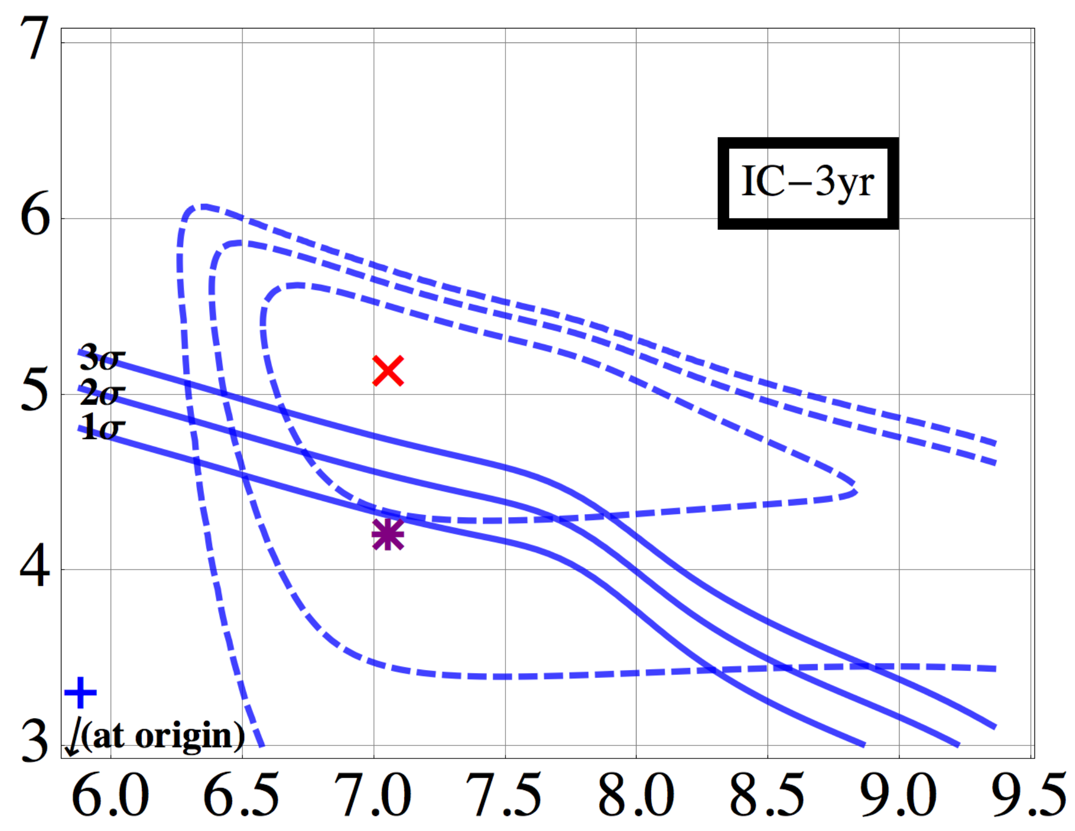
IC-3yr phase



SED best fit, a leptonic SSC-model

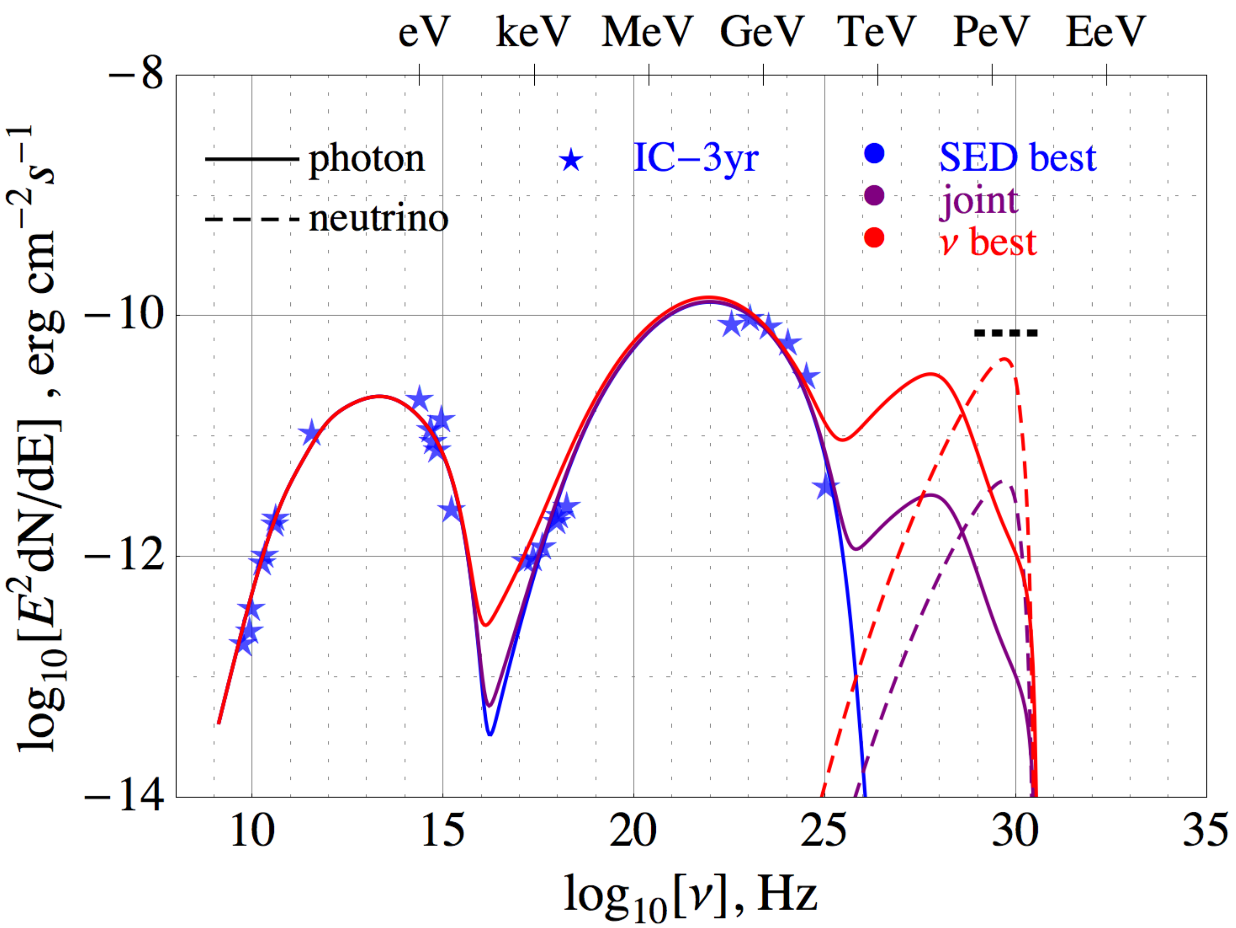
IC-3yr phase

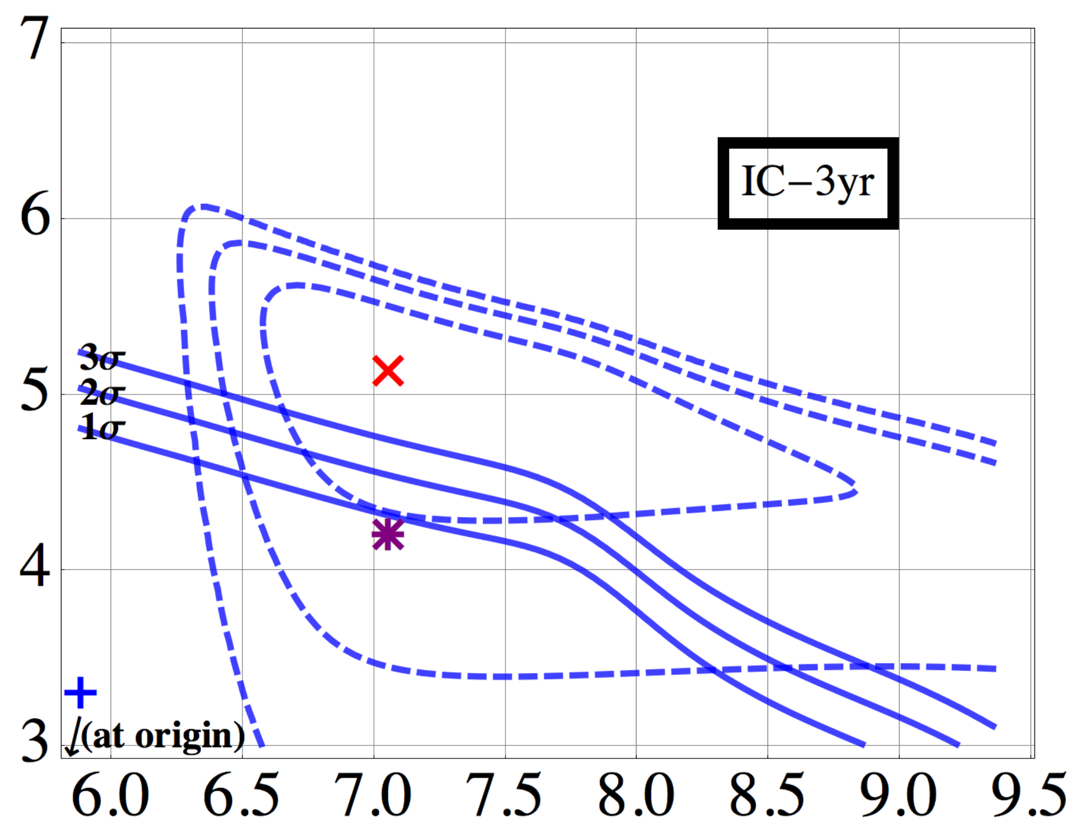




SED - neutrino joint best-fit, $L_p/L_e \sim 10^4$

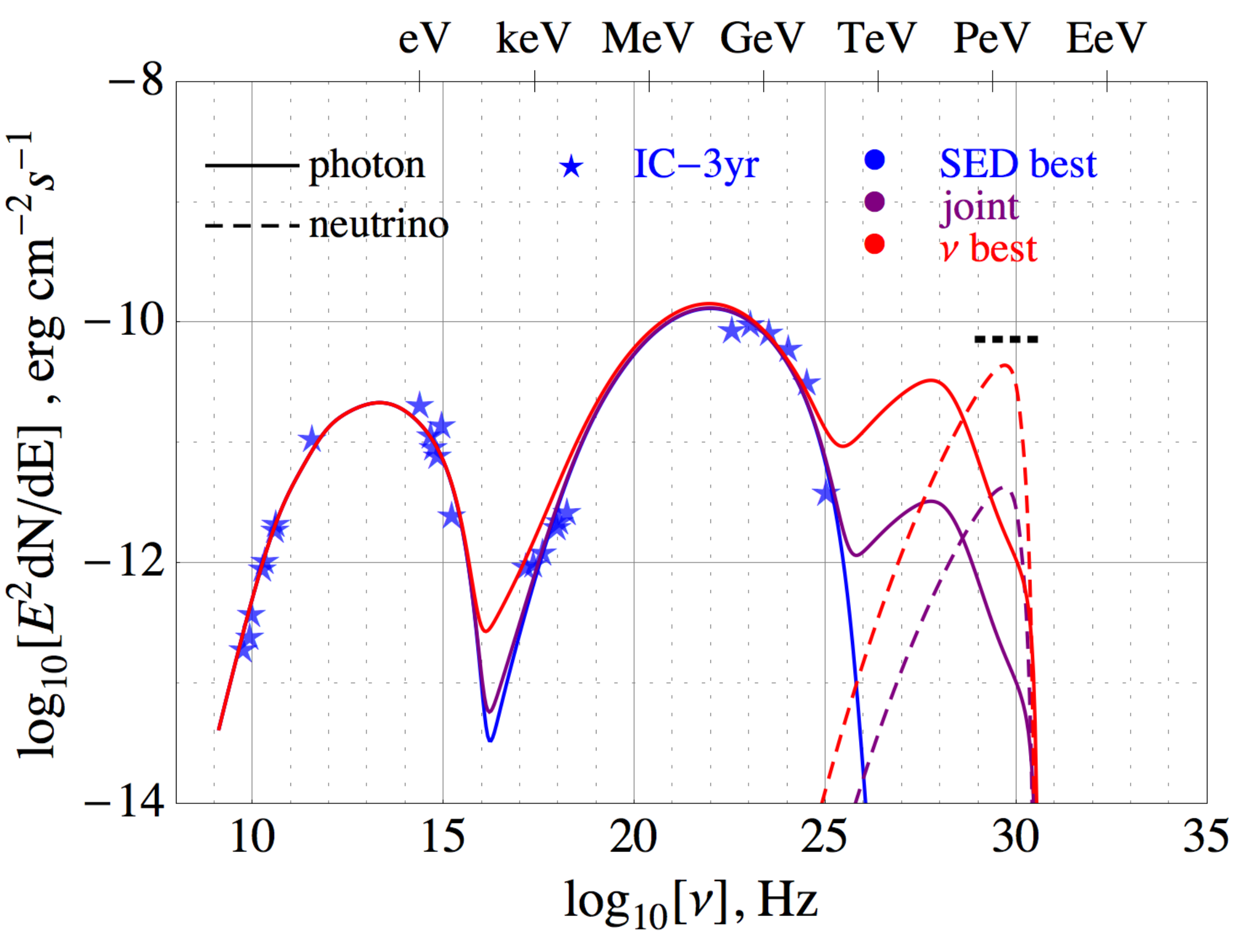
IC-3yr phase

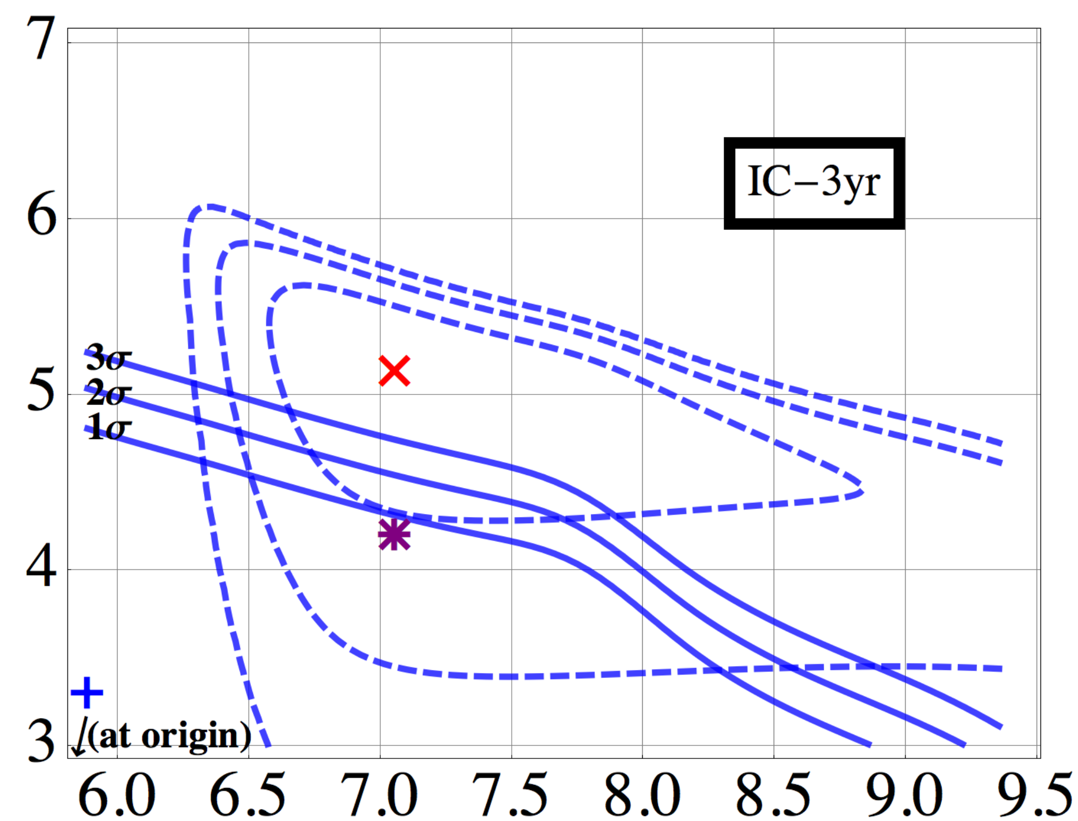




neutrino best-fit, $L_p/L_e \sim 10^5$

IC-3yr phase





Max amount hadrons can a leptonic model tolerate

NU best-fit is in tension with SED best-fit (overshooting X-ray band)

Joint-fit gives ~5% probability to reproduce “big-bird” within this phase

Conclusion

- Neutrino null detection from GRB not a surprise
- Current and future IceCube may put stringent constraits on baryonic component of GRB
- MWL & MMsg. method crucial for modeling blazar emission
- Amplitude and temporal correlation between neutrino and MWL provides unique information on models from blazar flares, must be carefully examined
- Still promising to detect neutrinos from blazar flares in future years and if so, it breaks the degeneracies of models significantly
- GRB + blazar cannot account for all IceCube events, interesting to look for other source (diffuse or hidden sources…)