Multimessenger Astronomy: Overview

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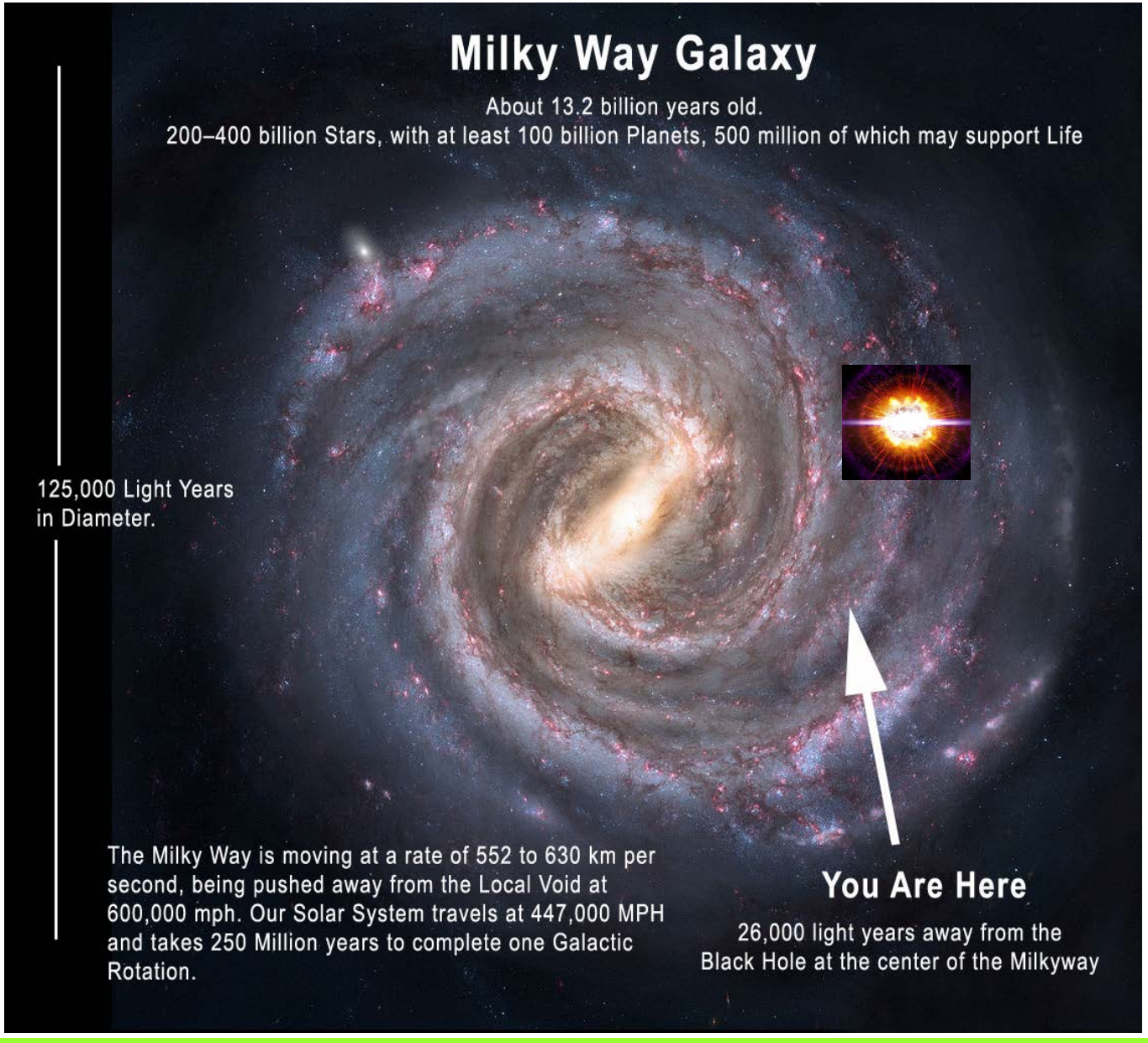
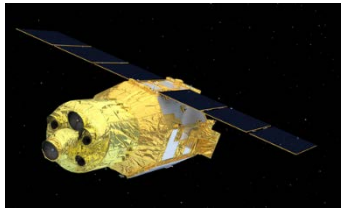
(Institute for Cosmic Ray Research)

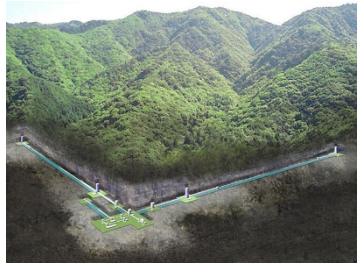
"Typical" Multi-messenger Event you imagine

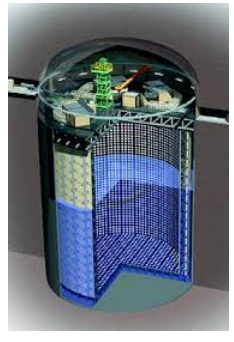


Simultaneous detection of

- Optical emission
- X-ray
- Gamma-ray
- Radio
- Neutrino
- Gravitational Wave

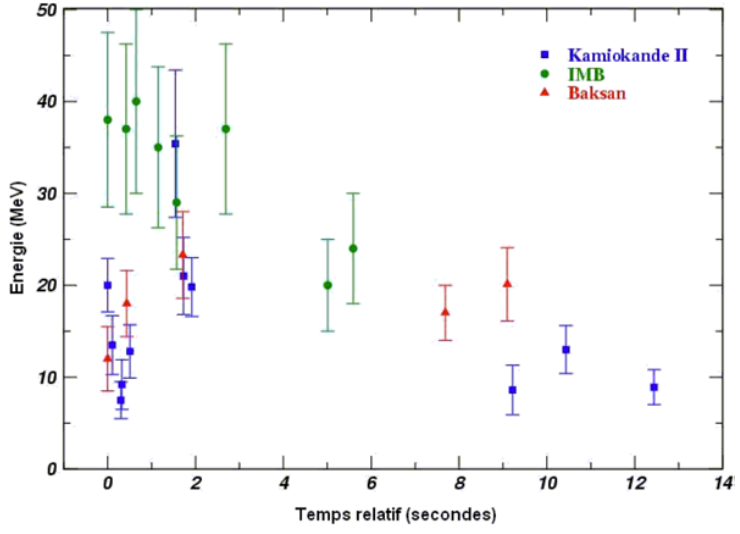






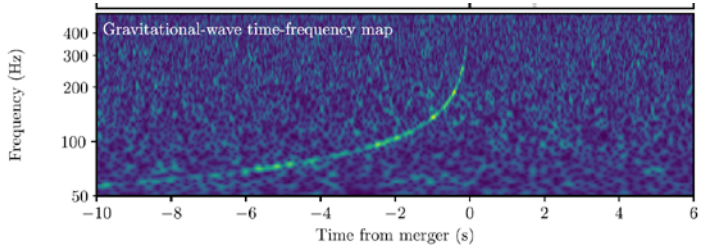
Rare Transient Phenomena

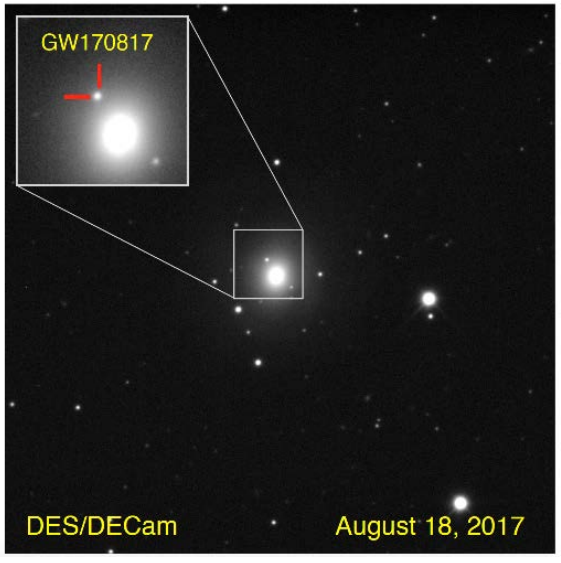
1987A Kamiokande



Once per 30-100yr

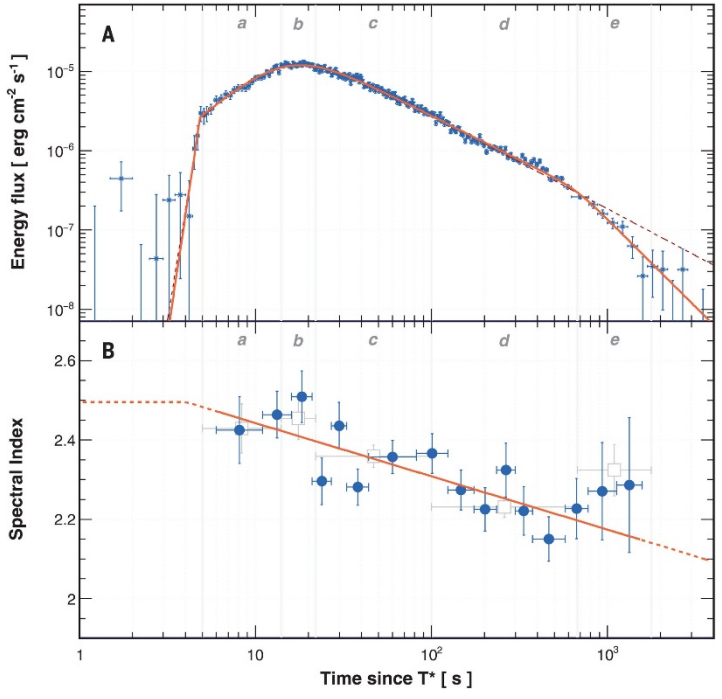
GW170817A
NS-NS Merger at 40 Mpc





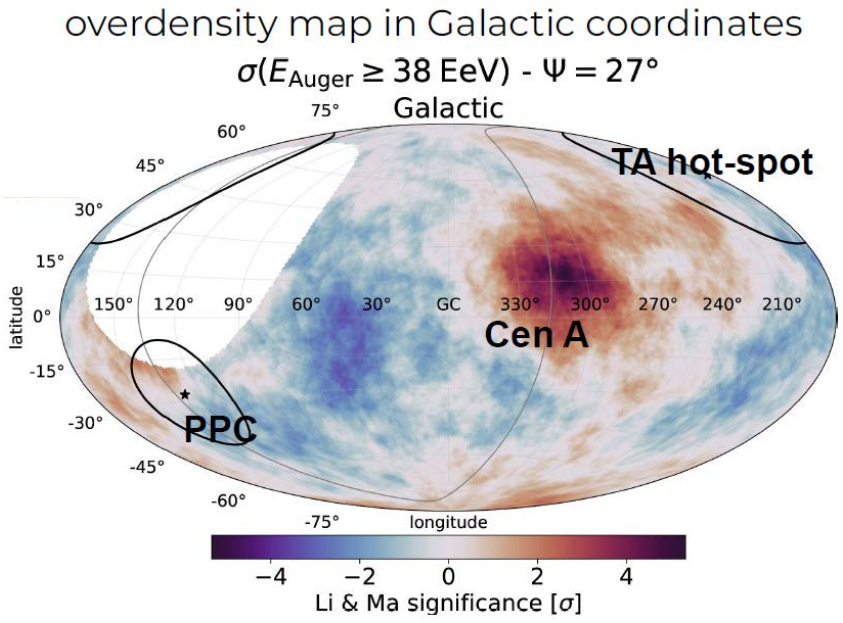
GWTC-3: ~105 Gpc^{-3} yr^{-1}
→ Once per 36yr

GRB 221009A
brightest of all time GRB

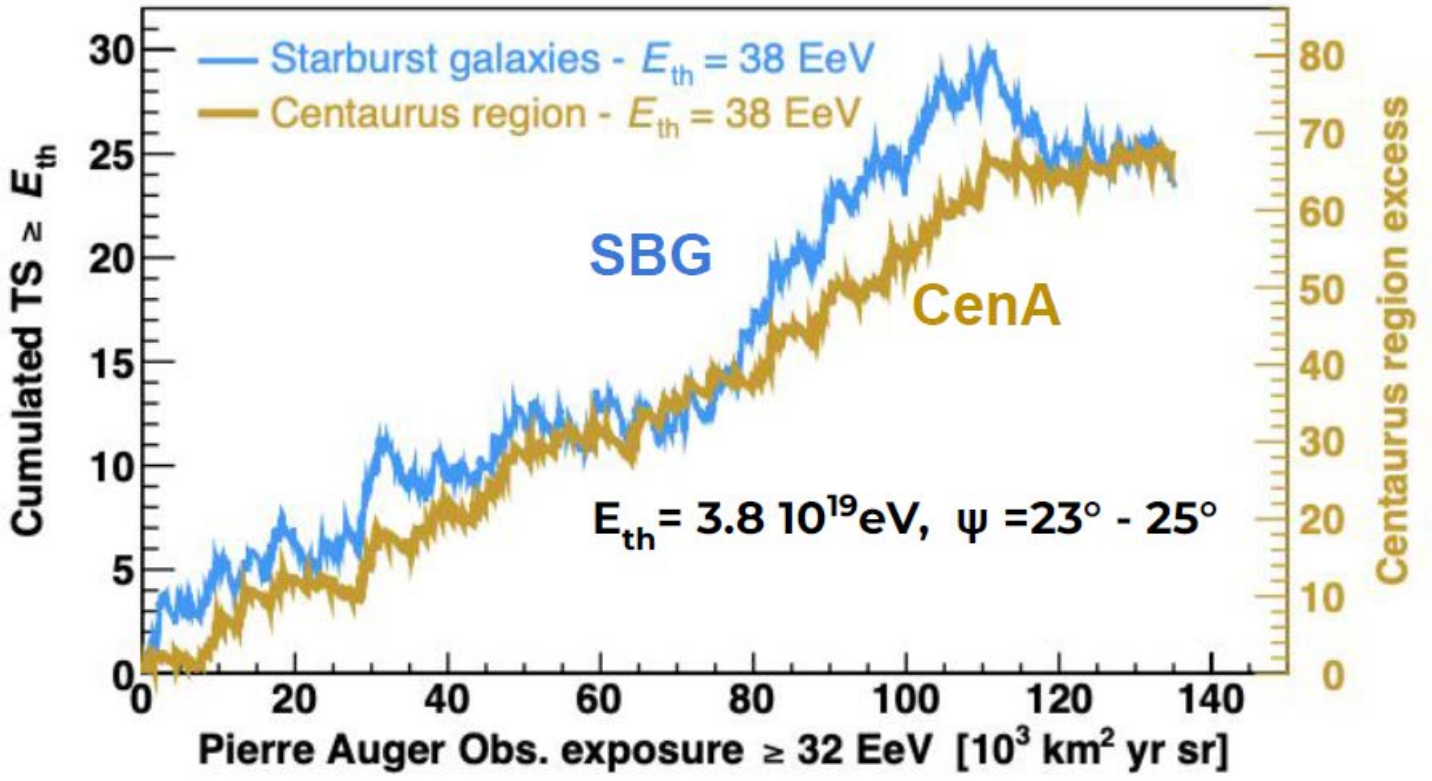


Once per 10,000 yr

Multi-messenger astronomy with Ultra High-energy Cosmic-rays



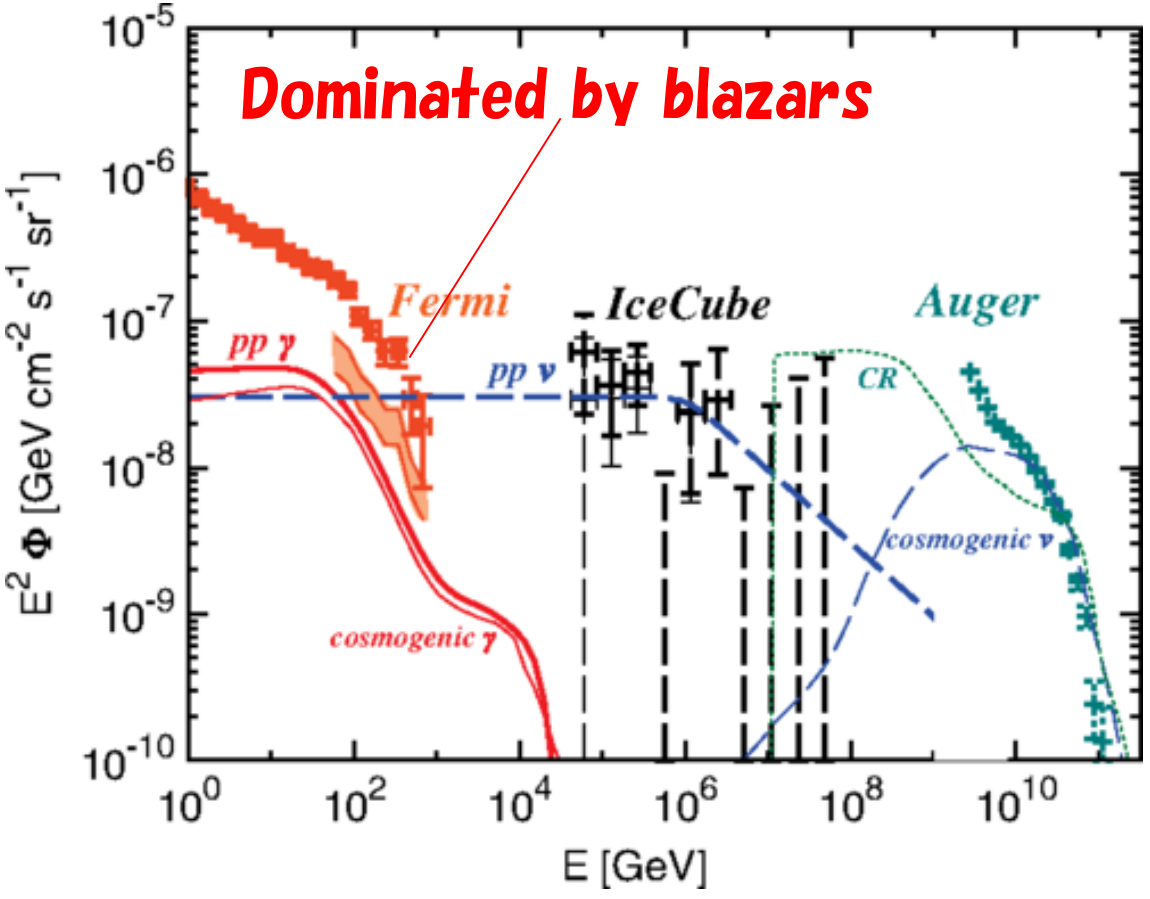
AUGER ICRC23



Correlation search for: Infra-red catalog
Gamma-ray catalog
Radio catalog etc.

Non-thermal phenomena (Extra-galactic)

Murase & Waxman 16



Common Source?

Starburst Galaxy

Galactic Wind
Turbulence
Hypernova

Seyfer Galaxy

Accretion Flow
AGN Corona
Disk Wind

$$p + p \rightarrow p + p + \pi^0$$

$$\rightarrow p + n + \pi^+$$

$$\pi^0 \rightarrow \gamma + \gamma$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

Blazars are not dominant neutrino source

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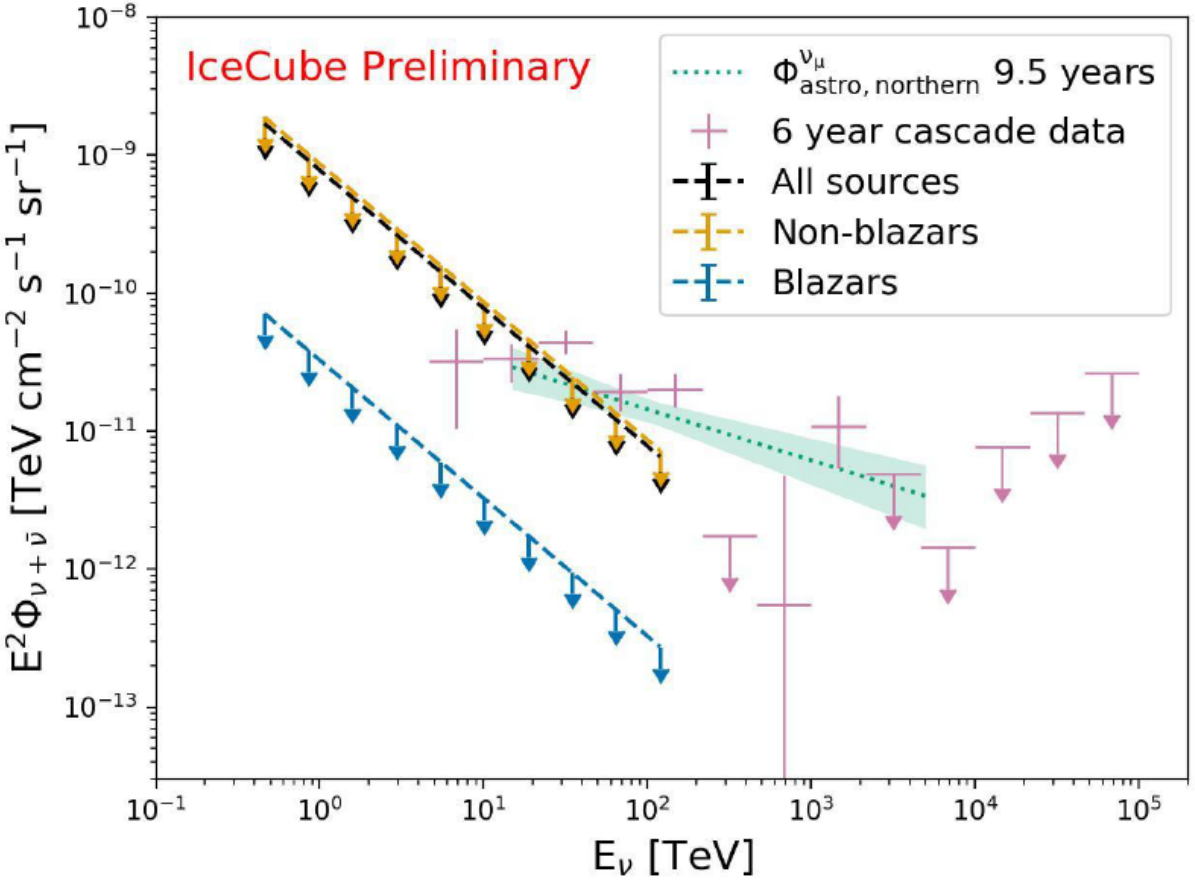
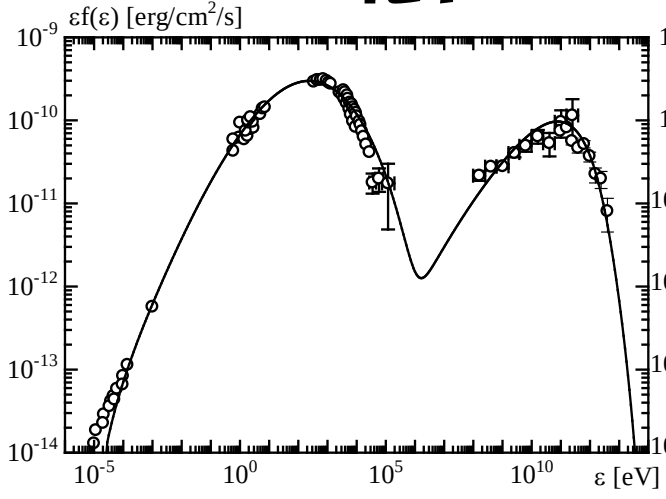
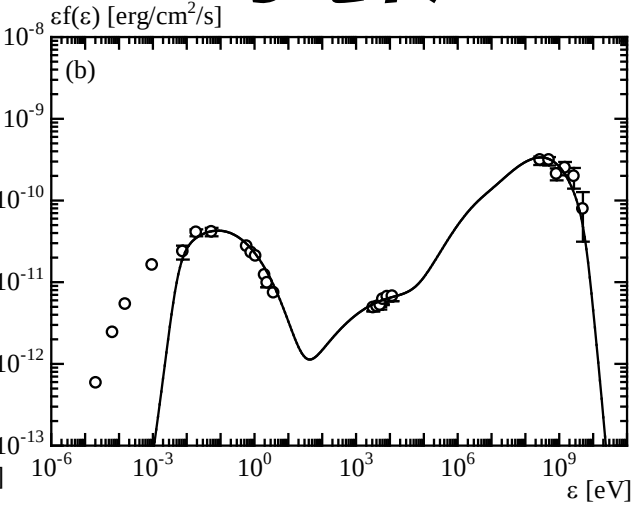


Blazar <7%
GRB <1%

Mrk421



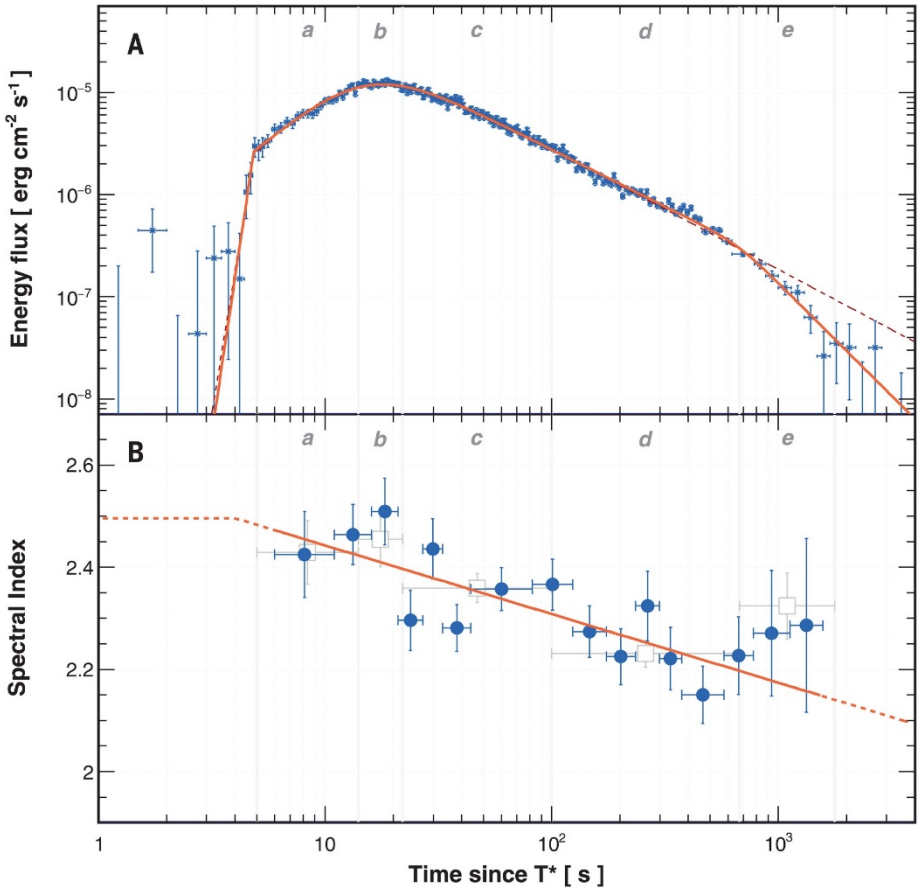
3C279



Leptonic process is likely.
Maximum energy of electrons suggests low acceleration efficiency.
Turbulence Acceleration?
Maximum Energy of Protons is also low.

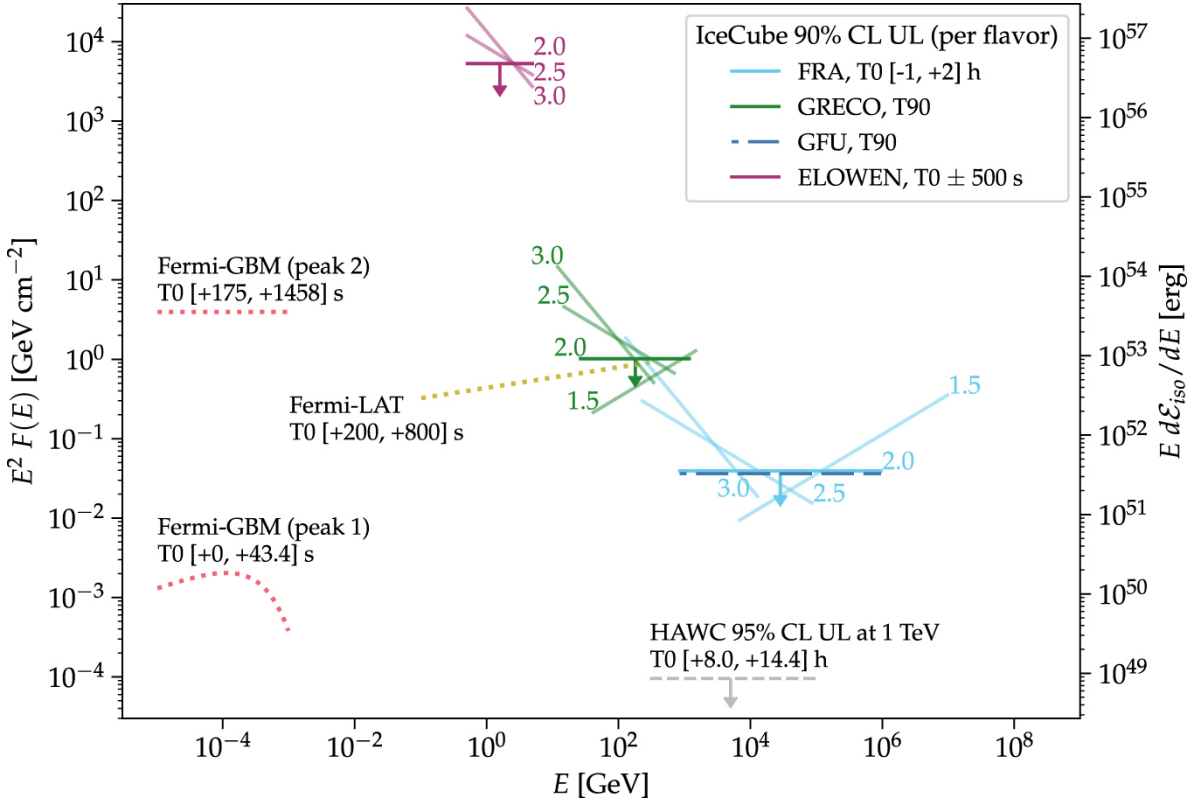
Neutrino Limit for BOAT GRB

GRB 221009A
brightest of all time GRB



LHAASO Detection
>65,000 events

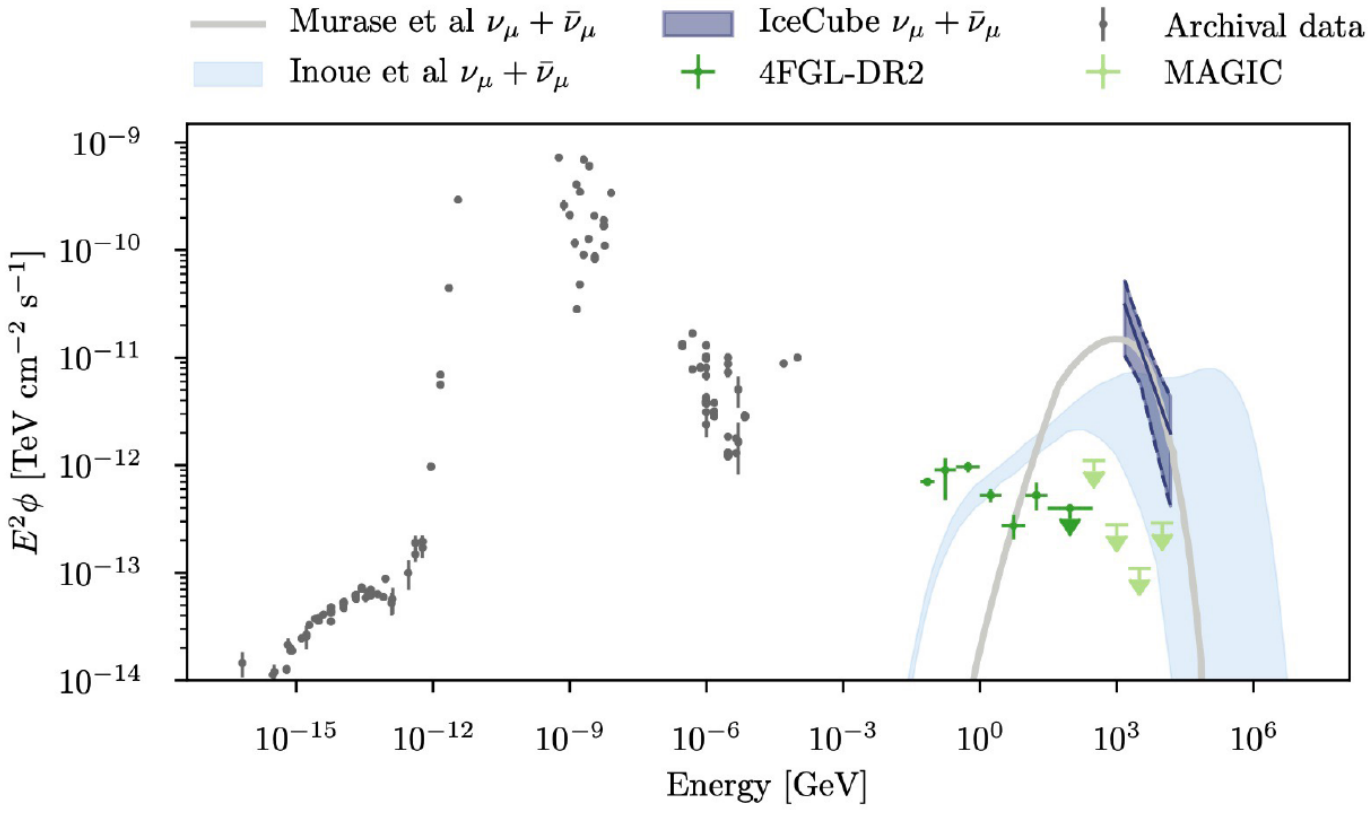
IceCube Upper Limit



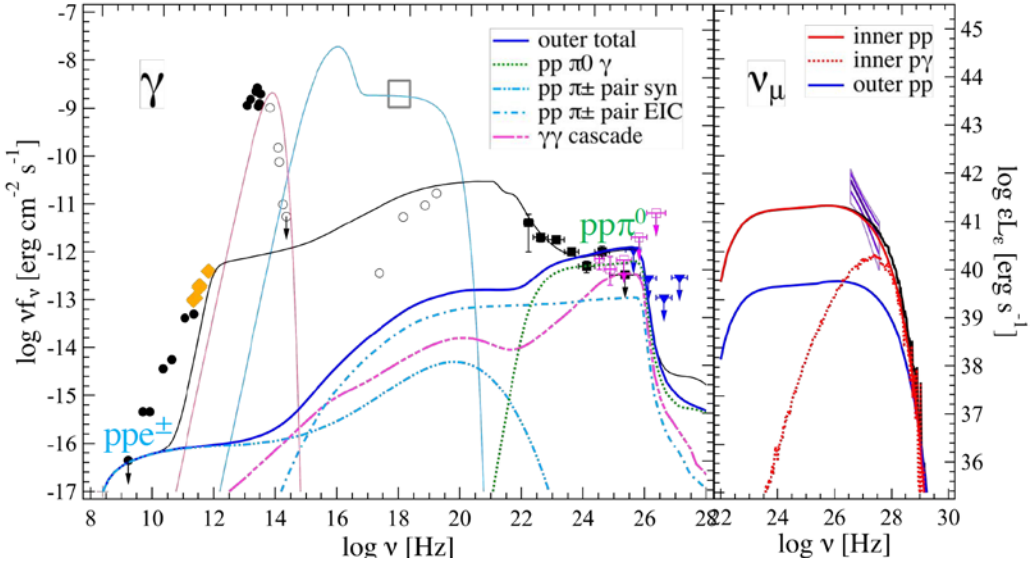
Deficit of Proton Acceleration?
See also Liu+ 23 for Fermi-LAT Constraint

Neutrinos from Seyfert, beyond one-zone model

NGC1068 IceCube Collab. 22

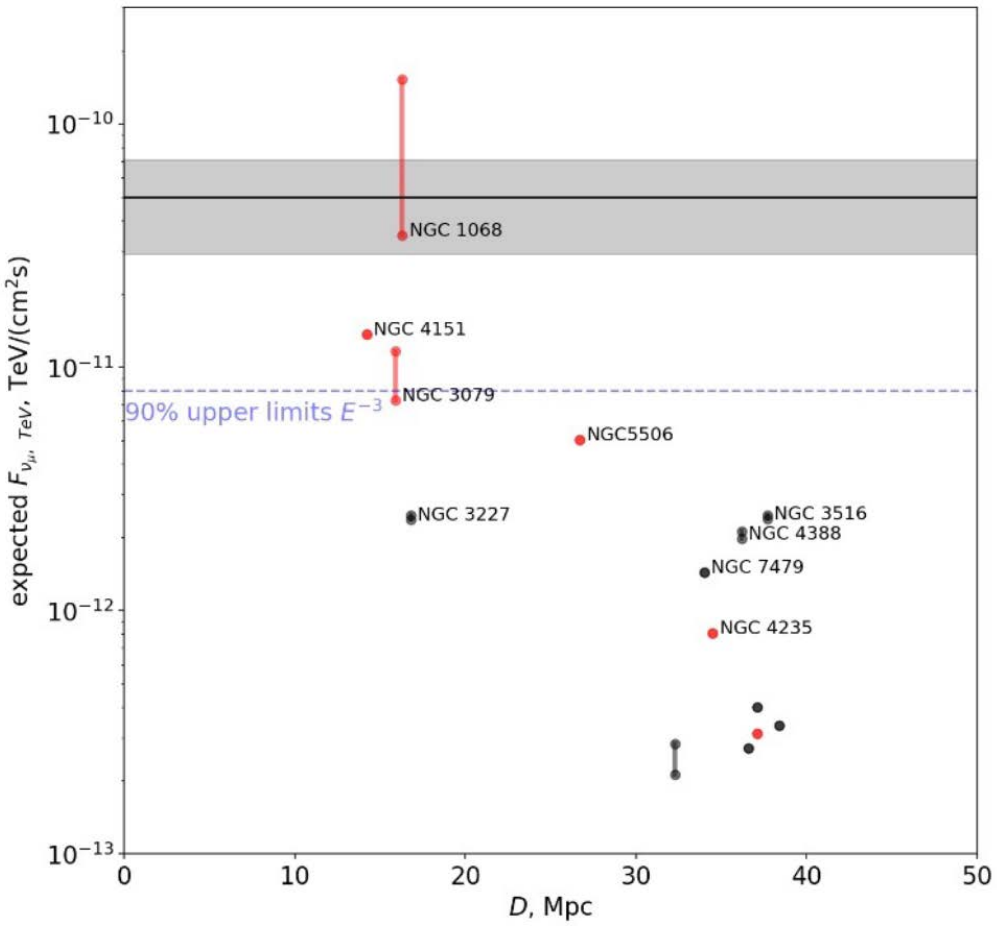


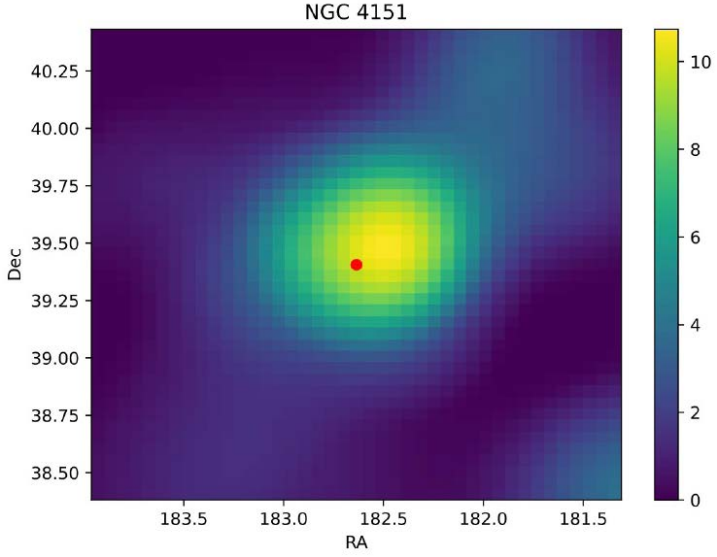
Inoue+22 Wind model

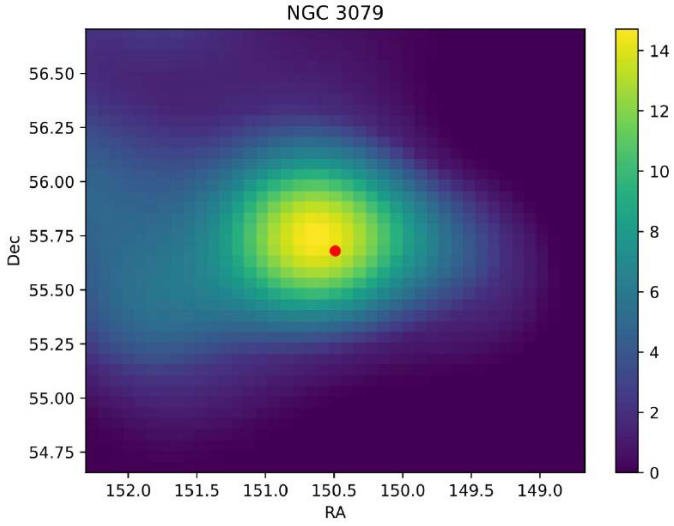


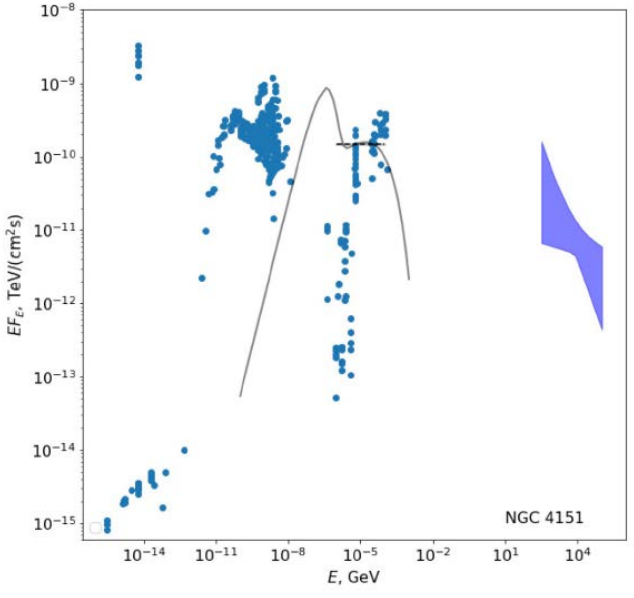
Gamma-rays are absorbed.
Compact region for neutrino source
Different spectrum from the neutrino background.

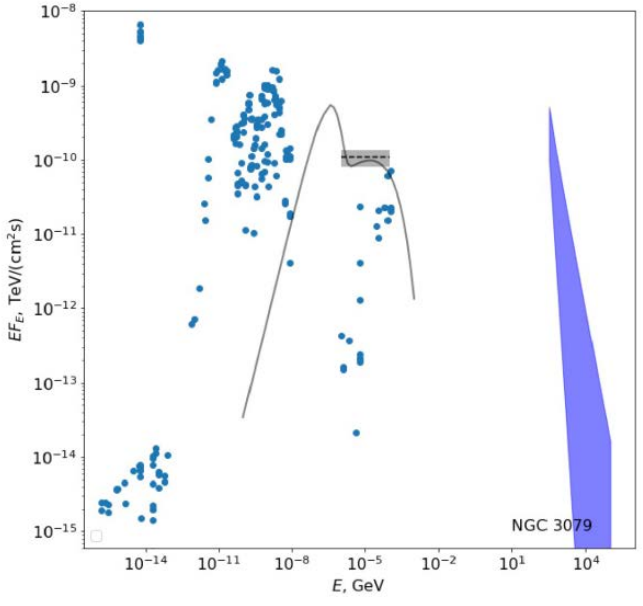
Other Seyferts







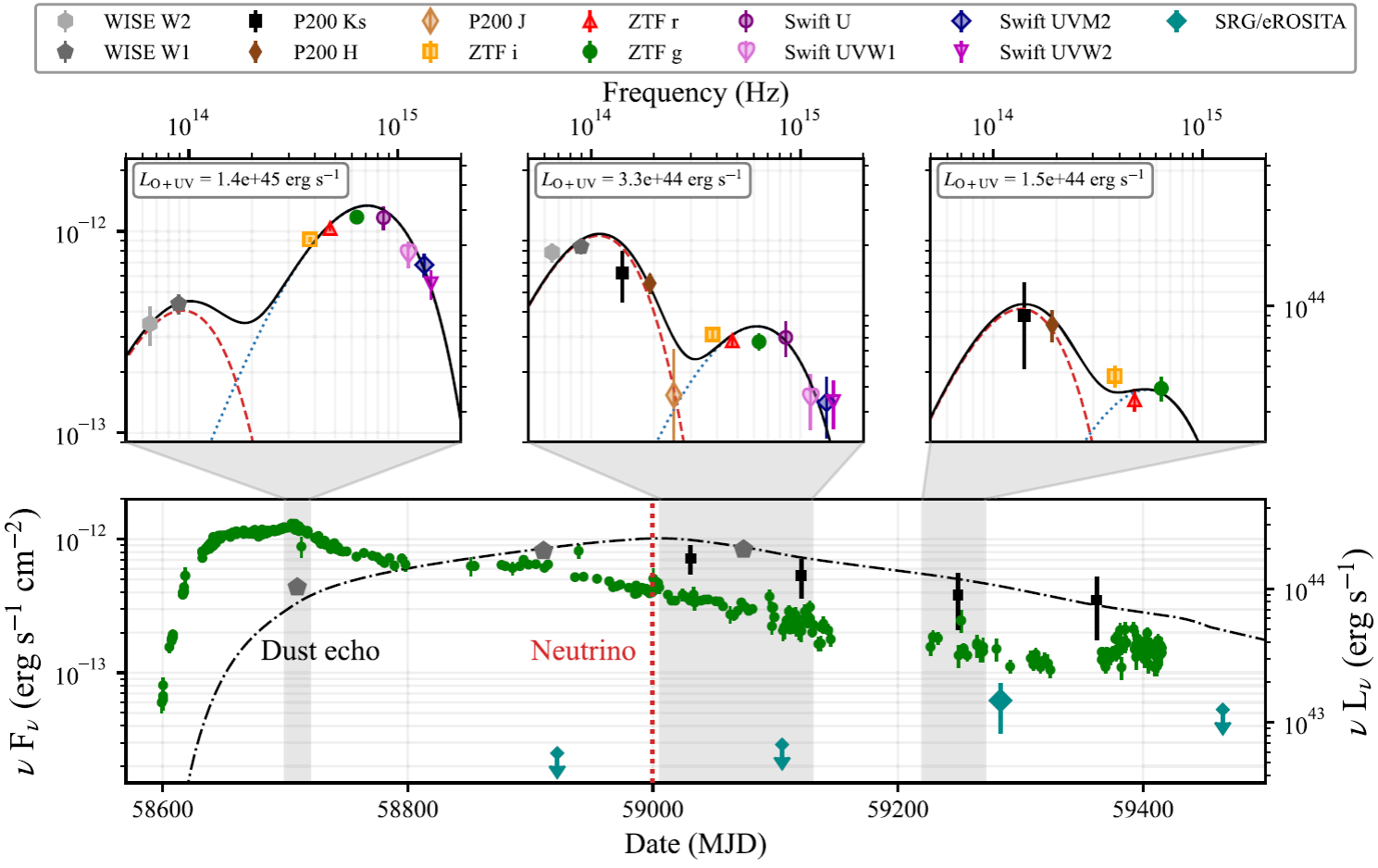




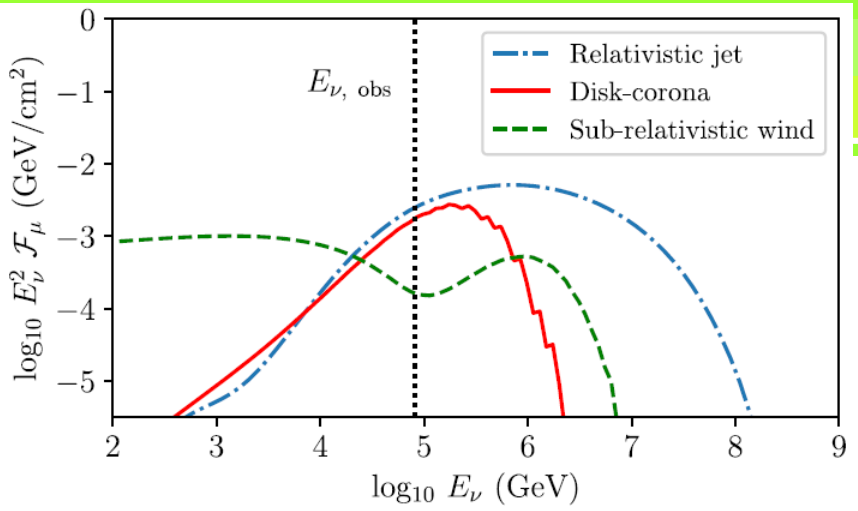
Semikoz TeVPA Talk

Tidal disruption event

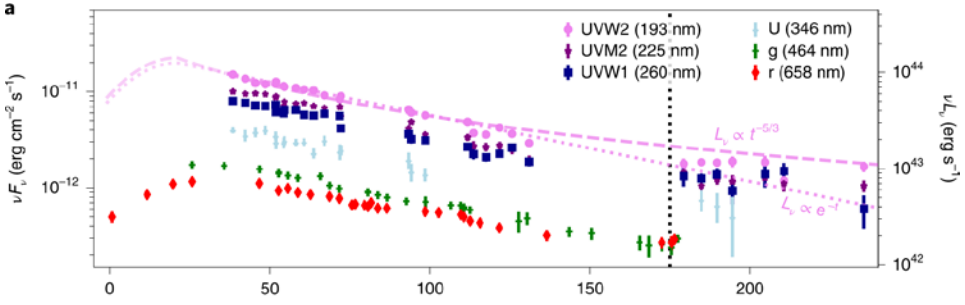
AT2019fdr



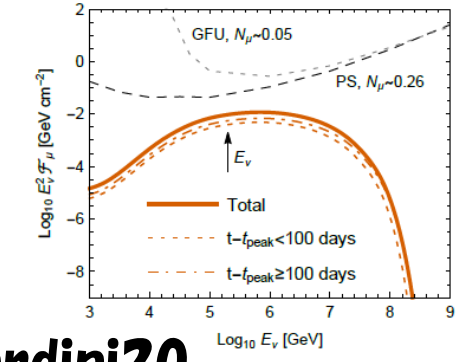
Reusch+22



0.002-0.027events



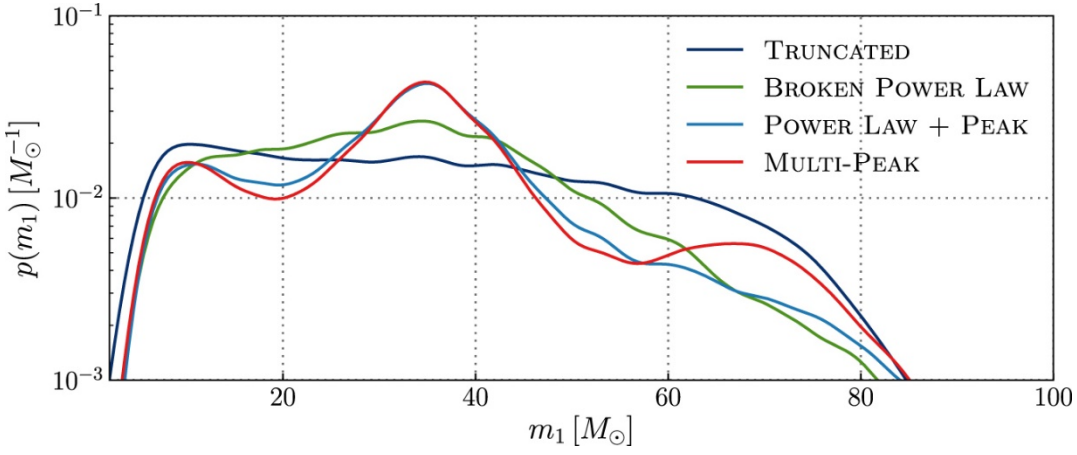
AT2019dsg
Stein+21



Jet model Winter & Lunardini20

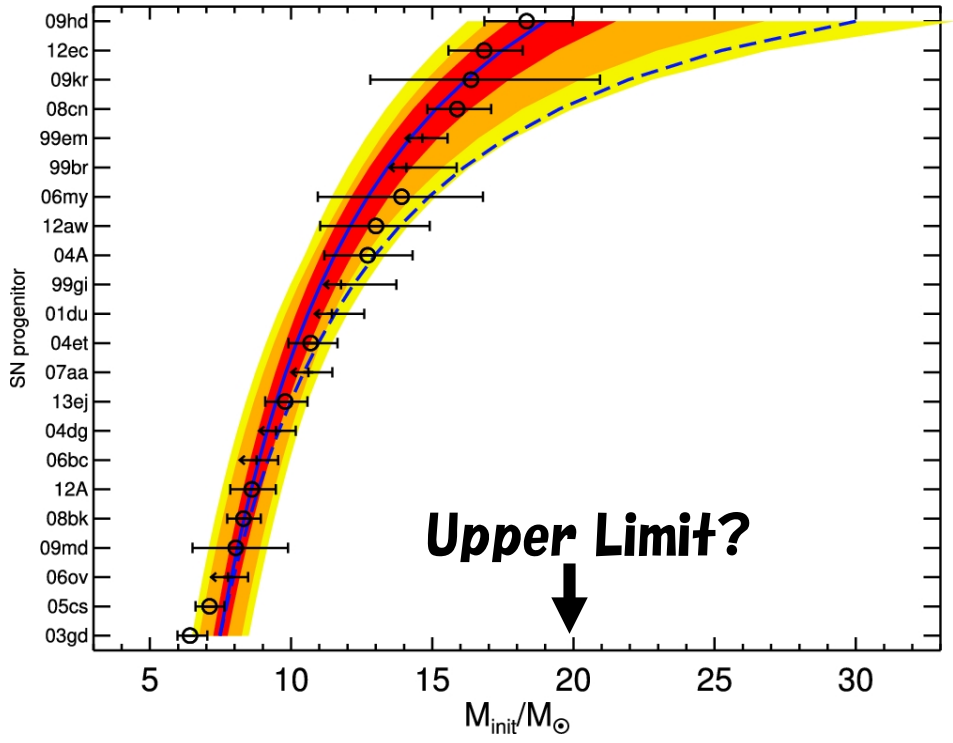
Star Formation History

Abbott+21

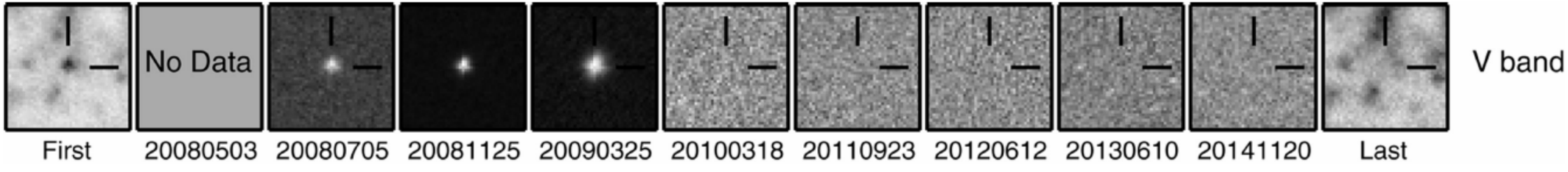


Black hole mass distribution

Davies & Beasor 18
red supergiant problem

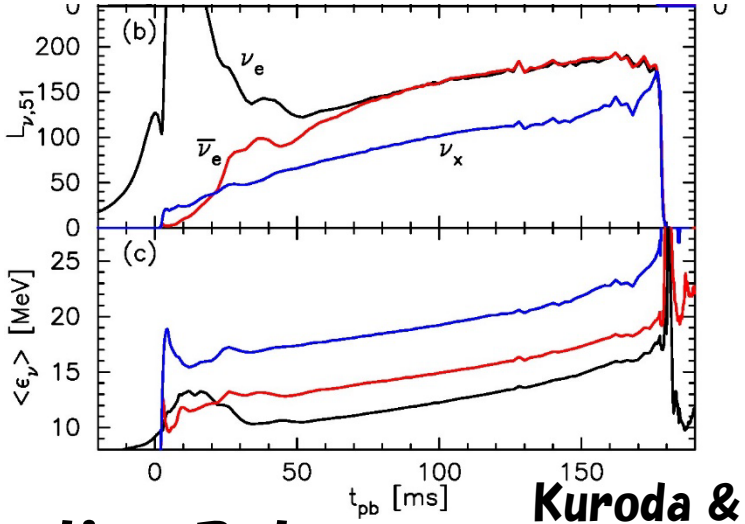


Failed SN candidate (NGC 6946) 18-25 Msun



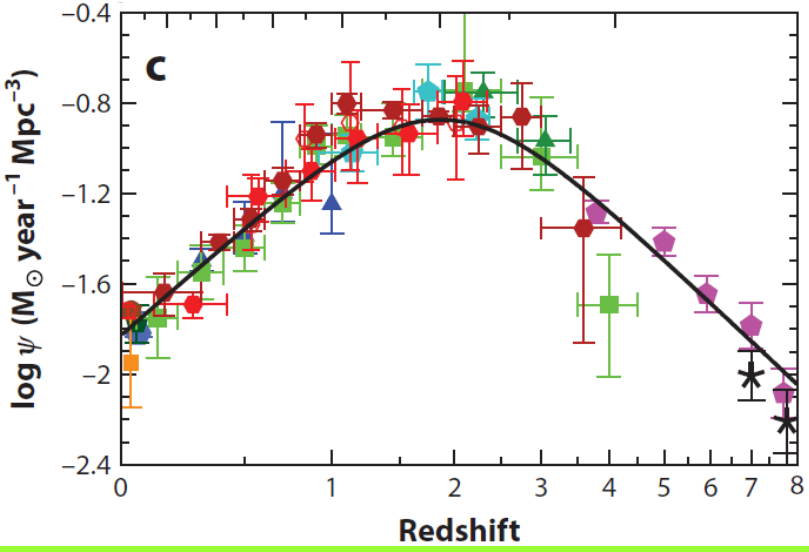
BH Formation History

Neutrinos from Failed SN

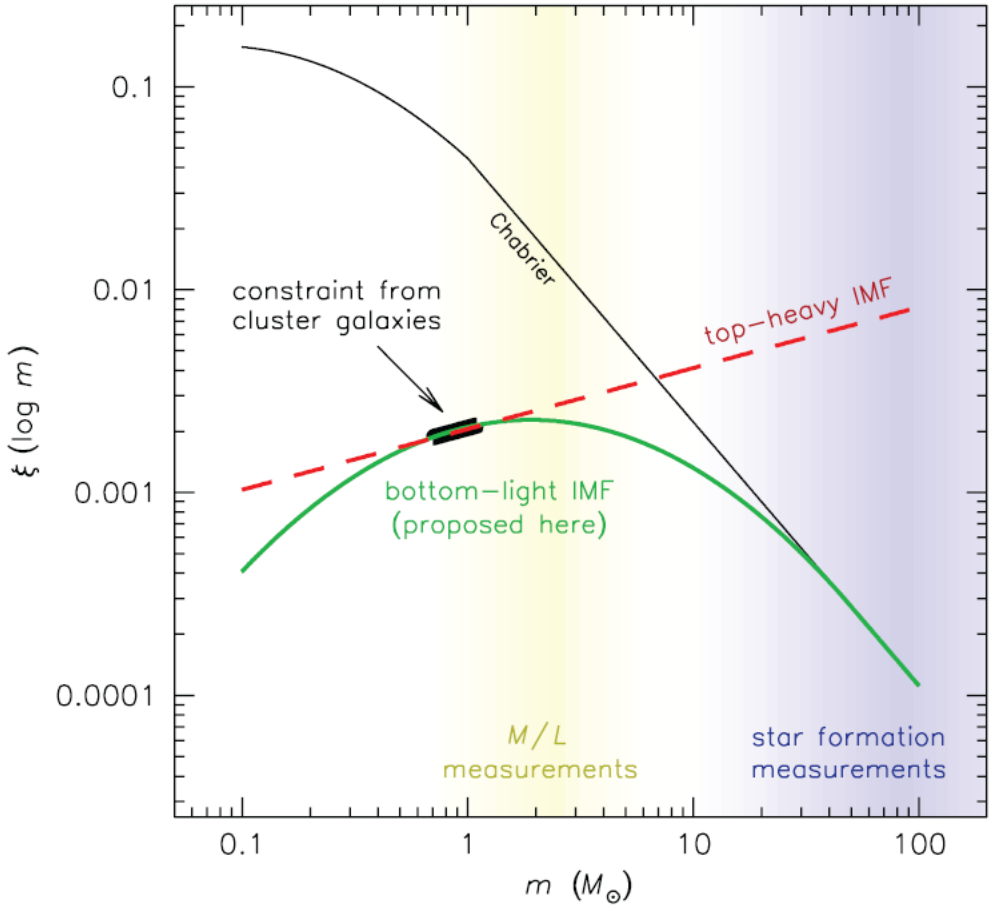


Kuroda & Shibata 23

Star Formation Rate



Initial Mass Function

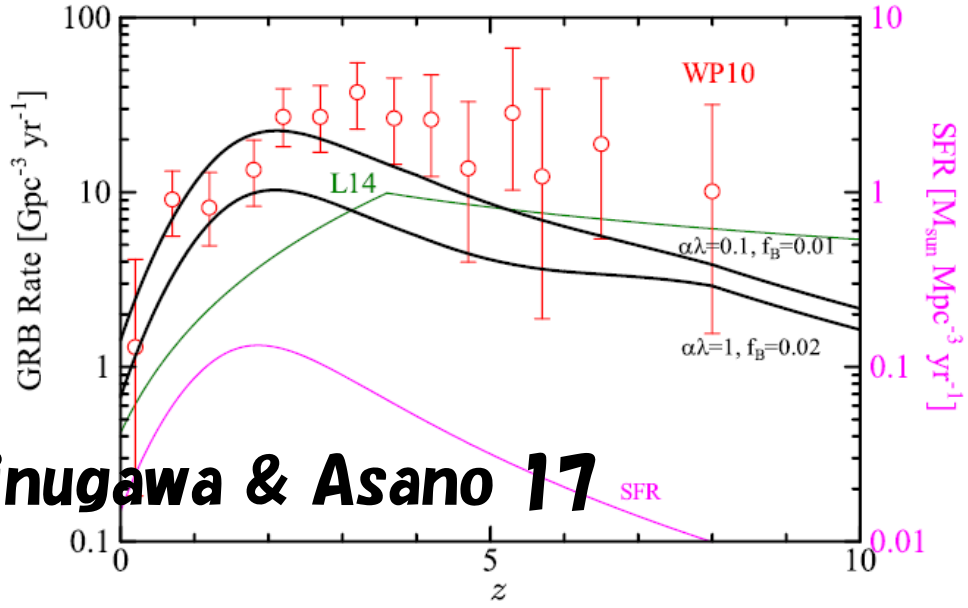


van Dokkum 08

Note: Uncertainty in Binary Evolution

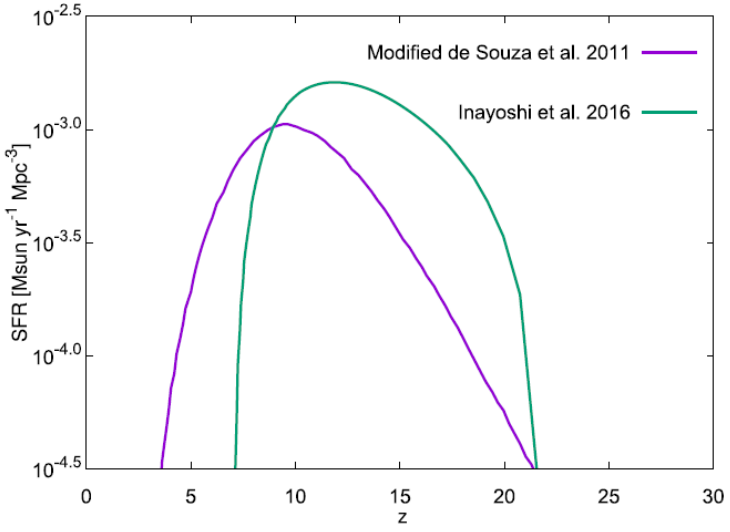
Origin of Massive BH

GRB Rate

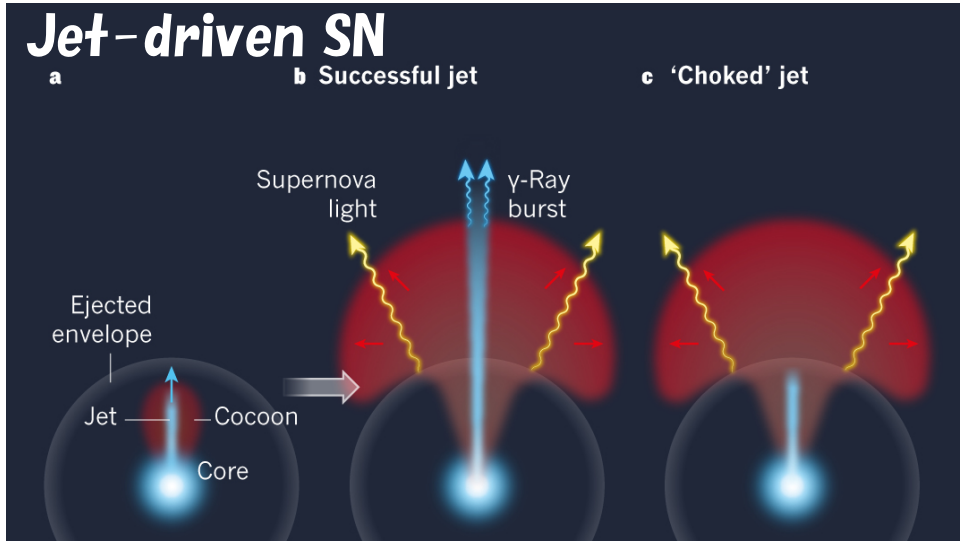


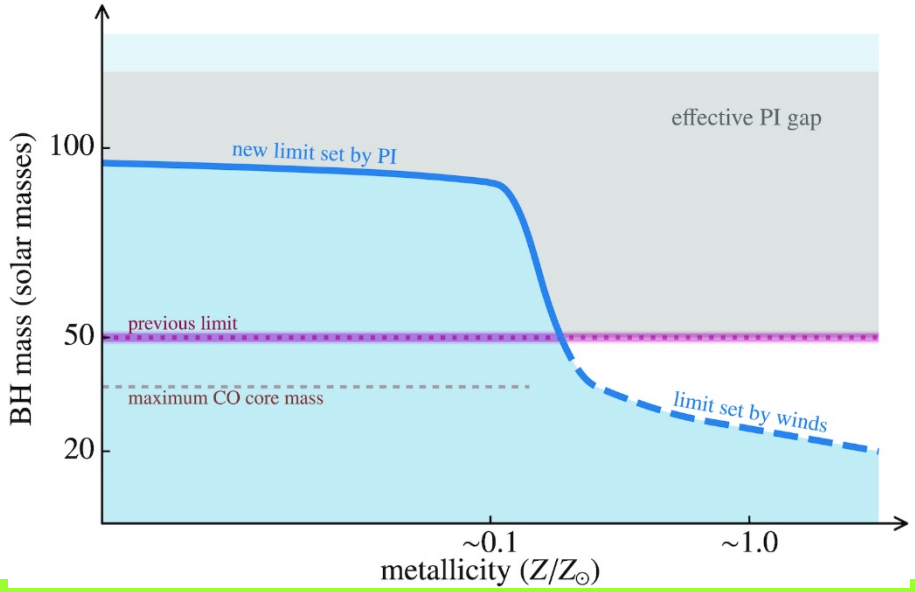
Kinugawa & Asano 17

Pop III SF History



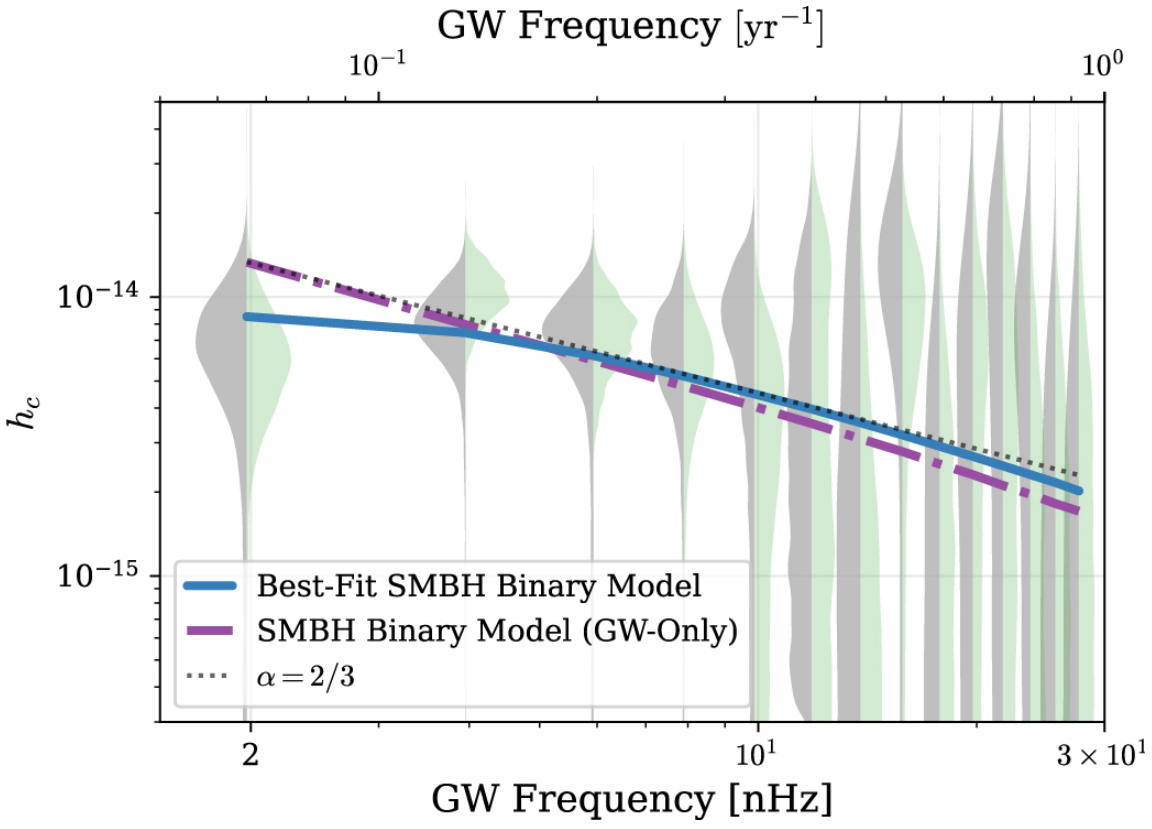
First Stars born with zero metallicity. Massive BH at high z?



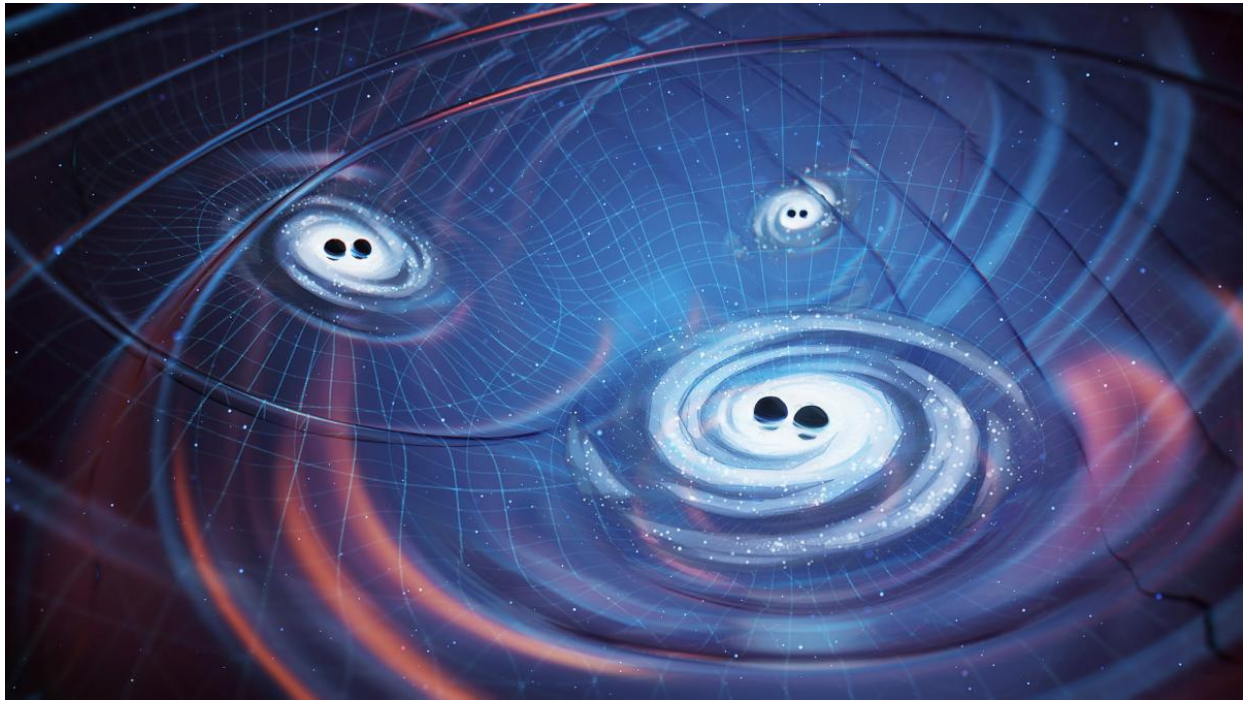


Updated physics for wind mass loss (Vink+ 21)

Gravitational Wave Background

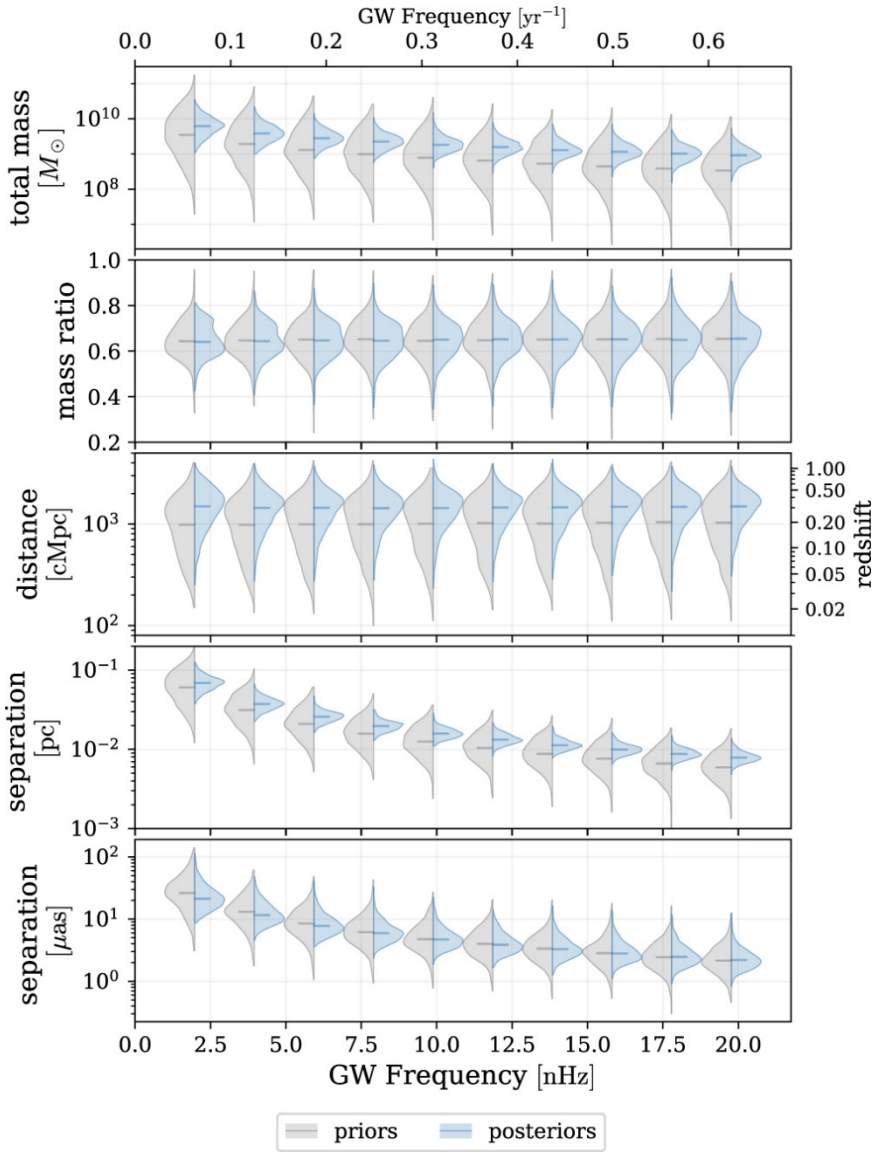


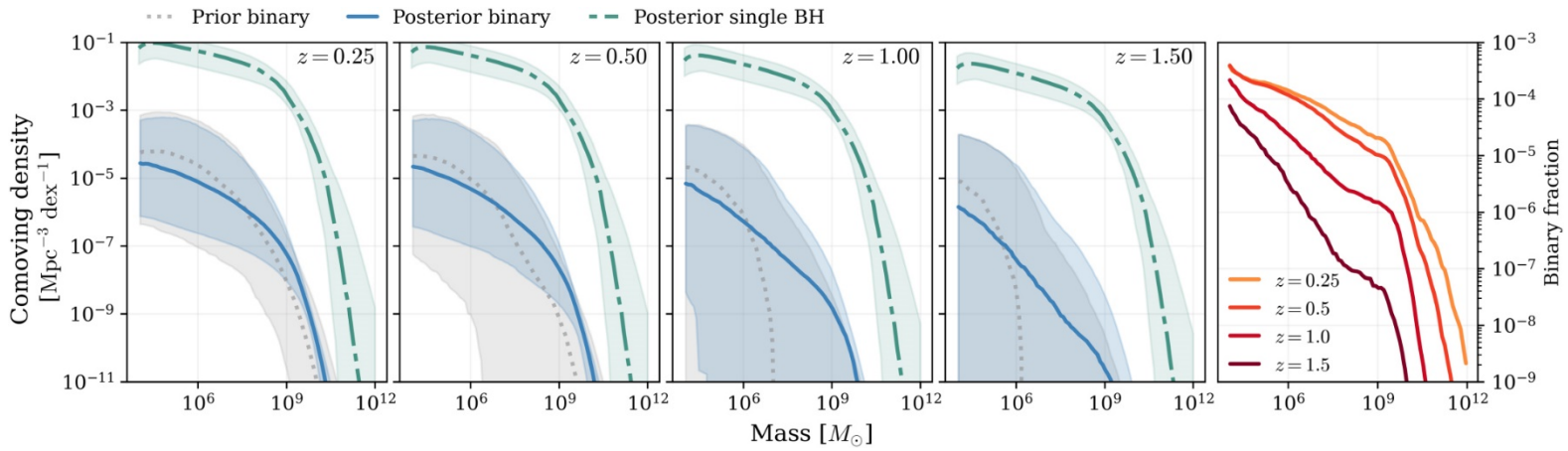
nHz GW detection
by NANOGrav 15 yr observation



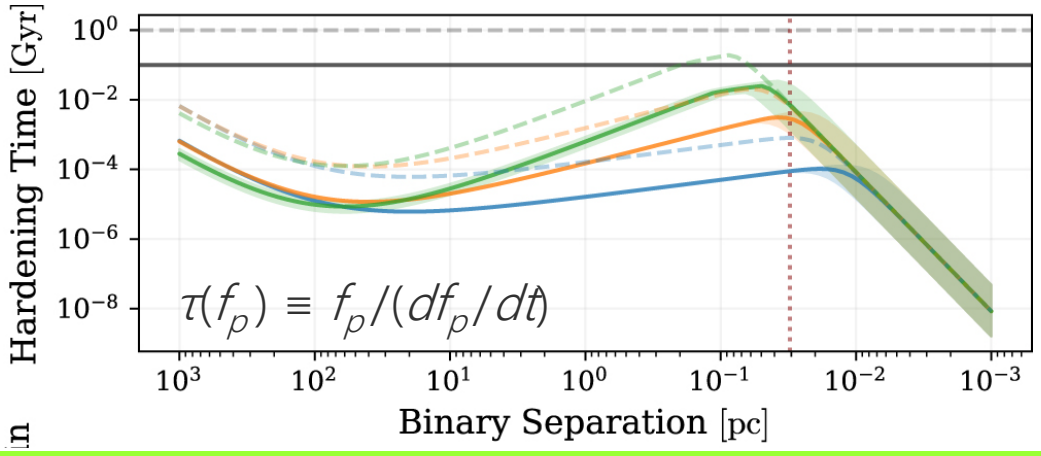
Binary Super Massive BHs

SMBH binary with sub-pc separation

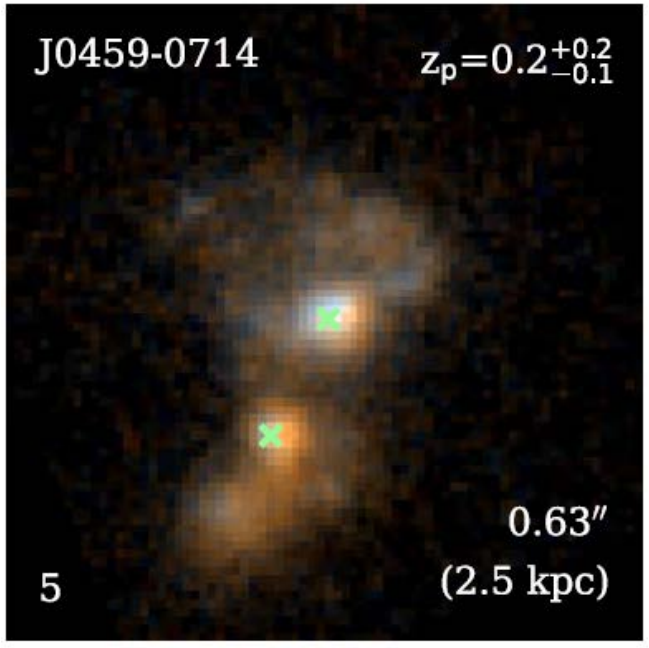


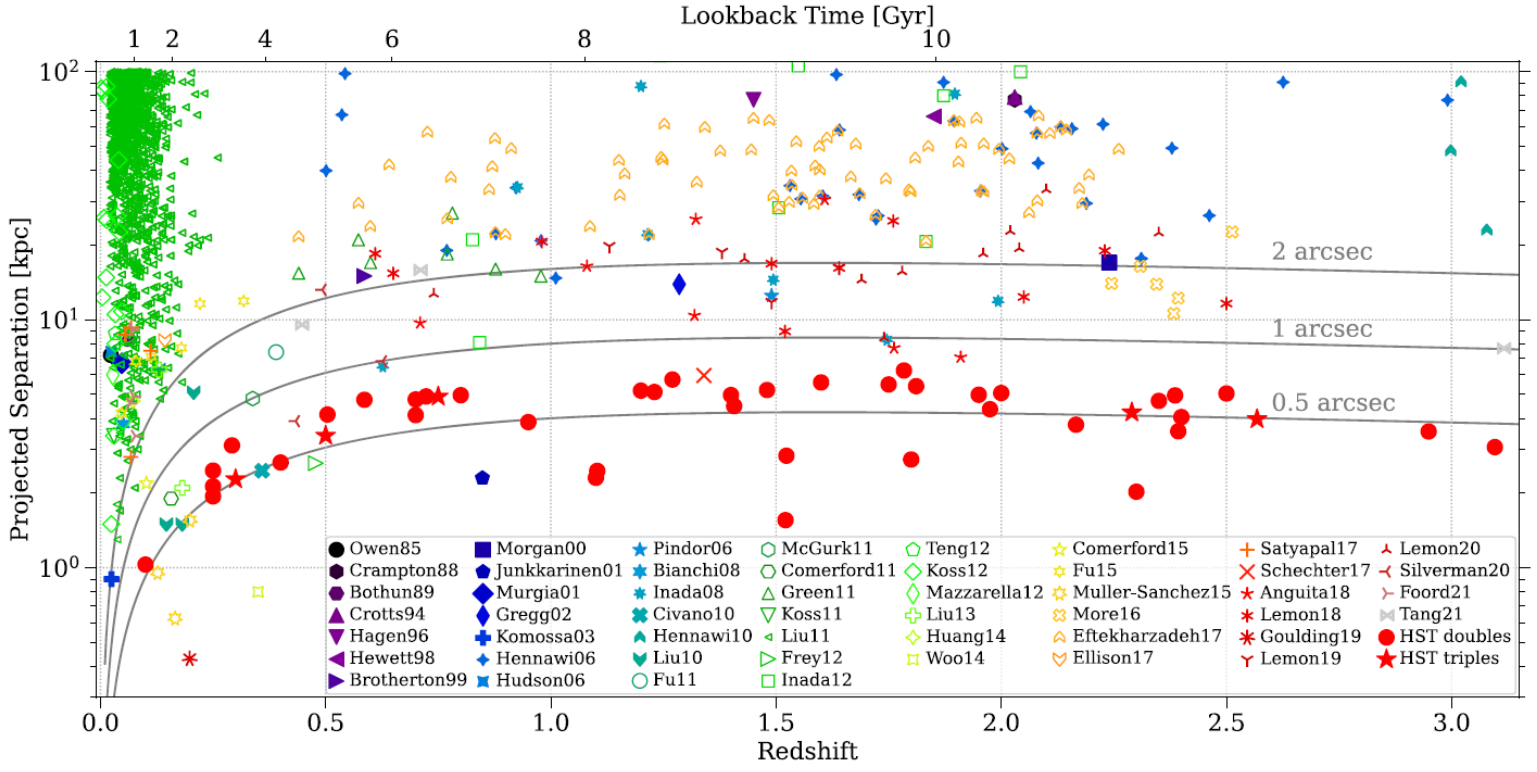


Population study by Agazie+ 23
Contribution of 10^9 M_{sun} BH binary with sub-pc separation.
Binary fraction is small (?)



SMBH with kpc separation

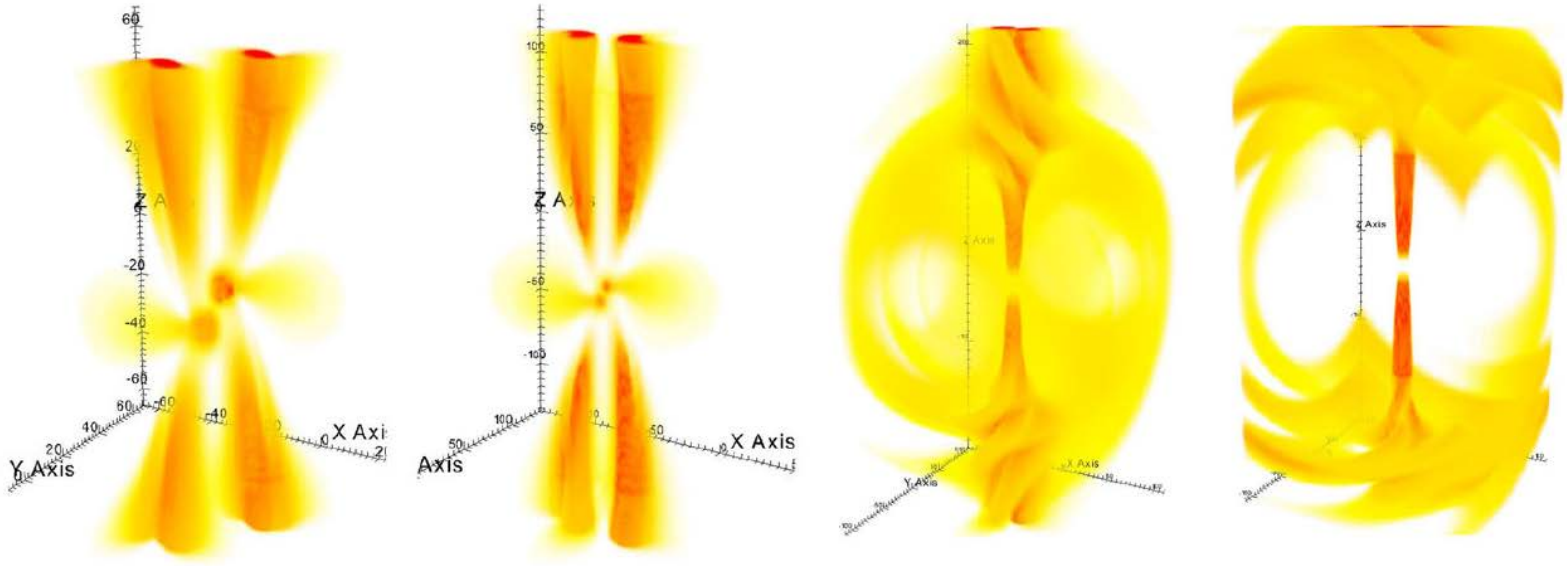


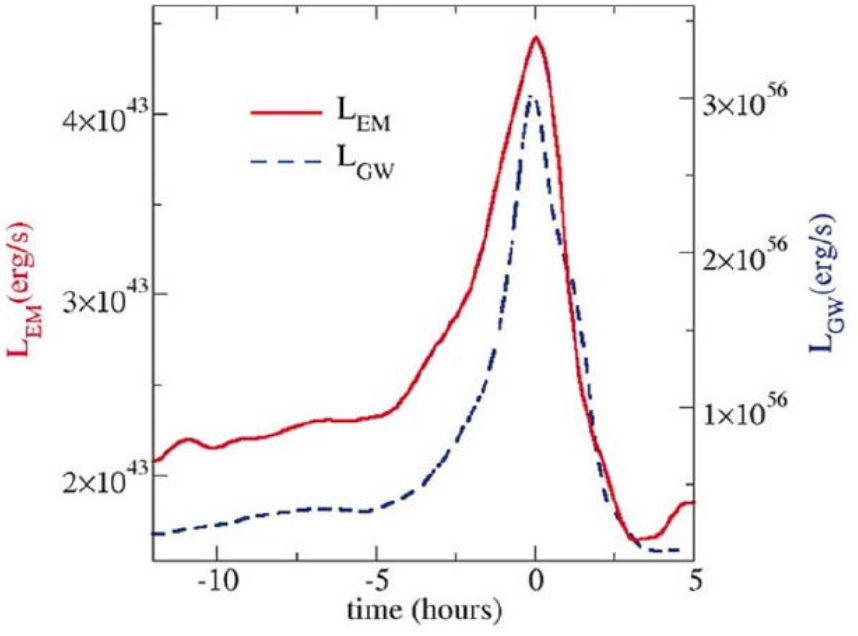


Chen+ 22

SMBH merger

Palenzuela+ 10





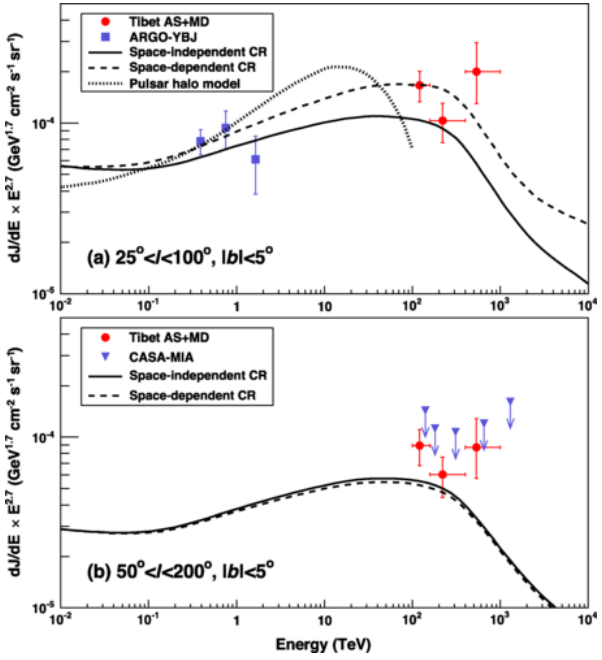
Magnetized binary

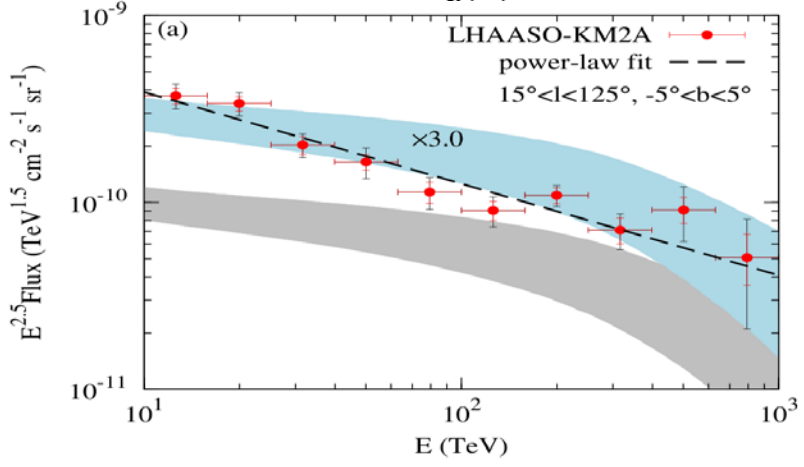
$$L_{\rm Poynt,peak} \approx 3 \times 10^{43}\ {\rm erg\ s^{-1}} \left(\frac{B_0}{10^4\ {\rm G}}\right)^2 \left(\frac{M}{10^8\ M_\odot}\right)^2$$

How much fraction for emission?

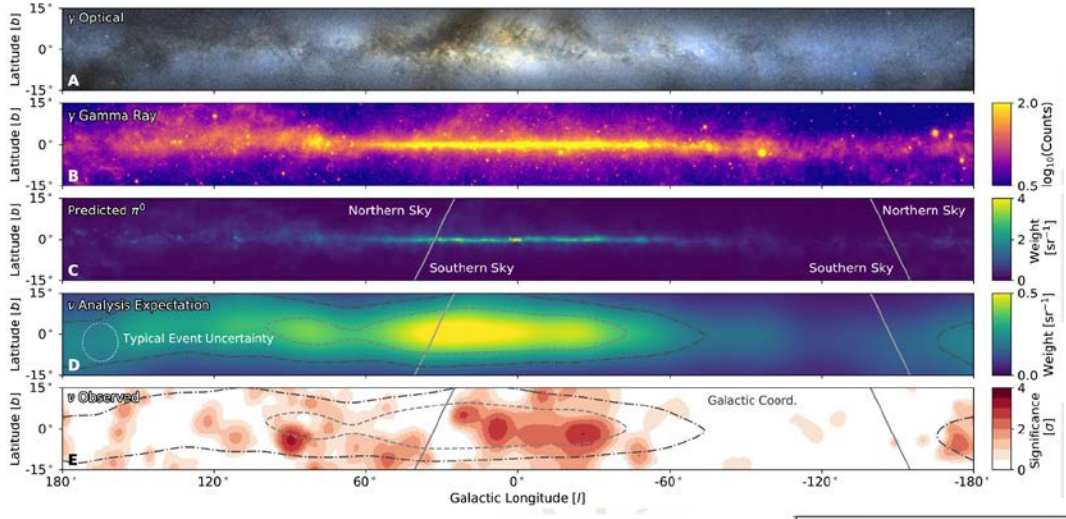
Galactic Diffuse

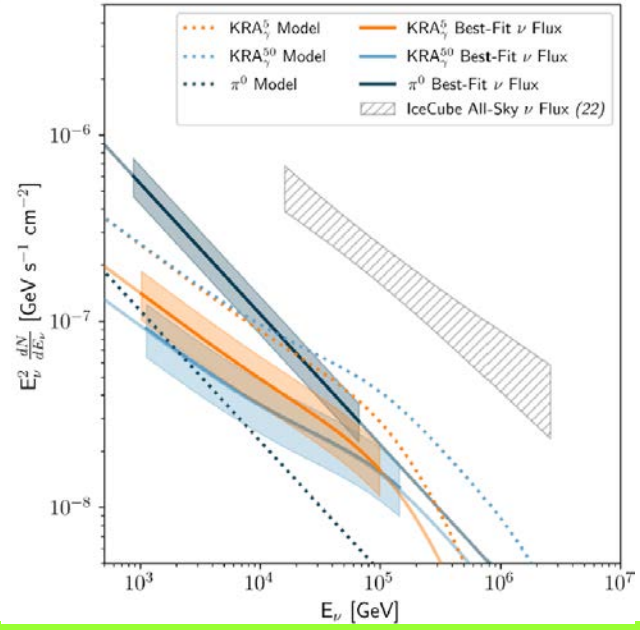
Diffuse Gamma-Ray





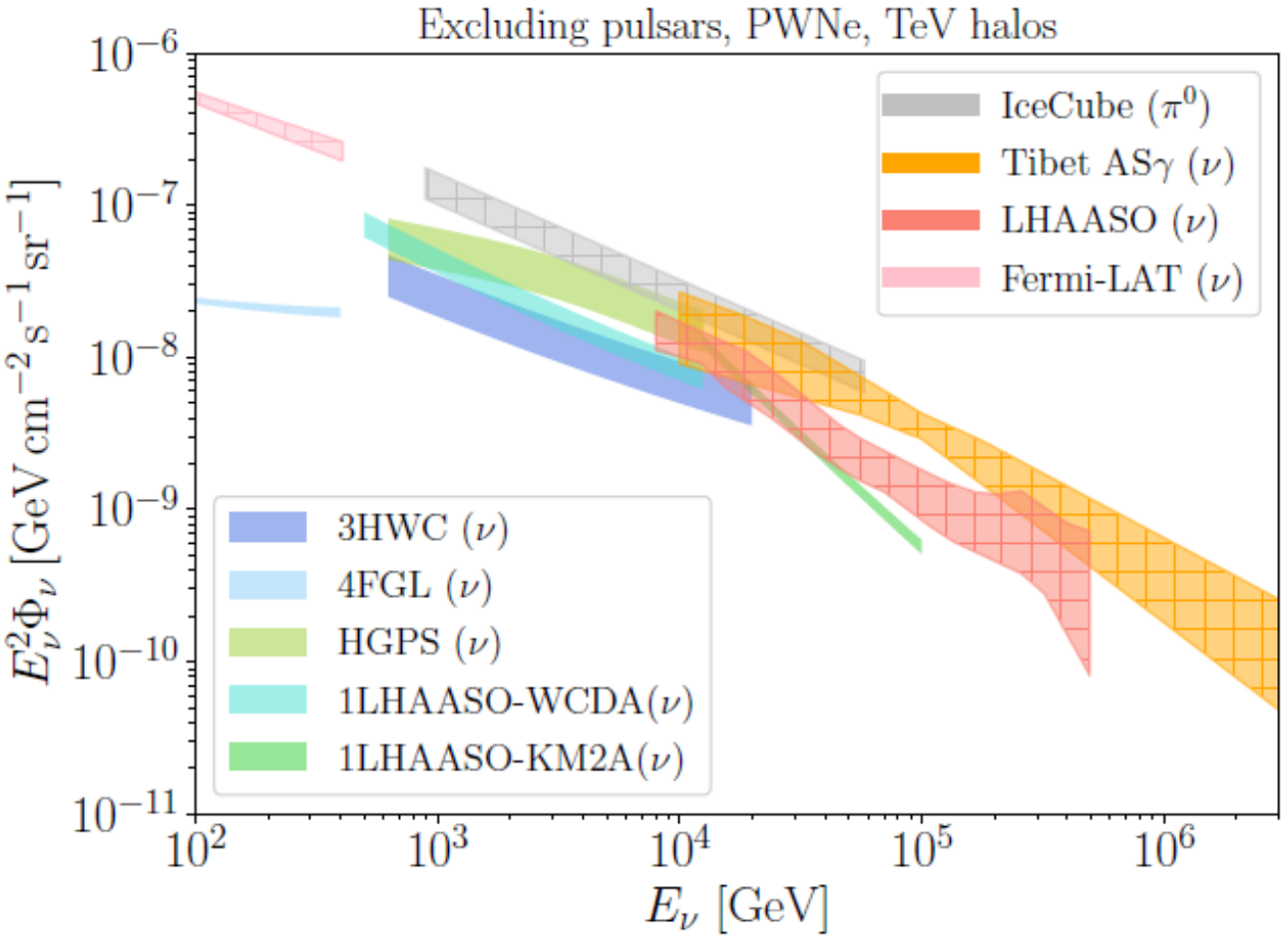
Neutrinos from Galactic Disk



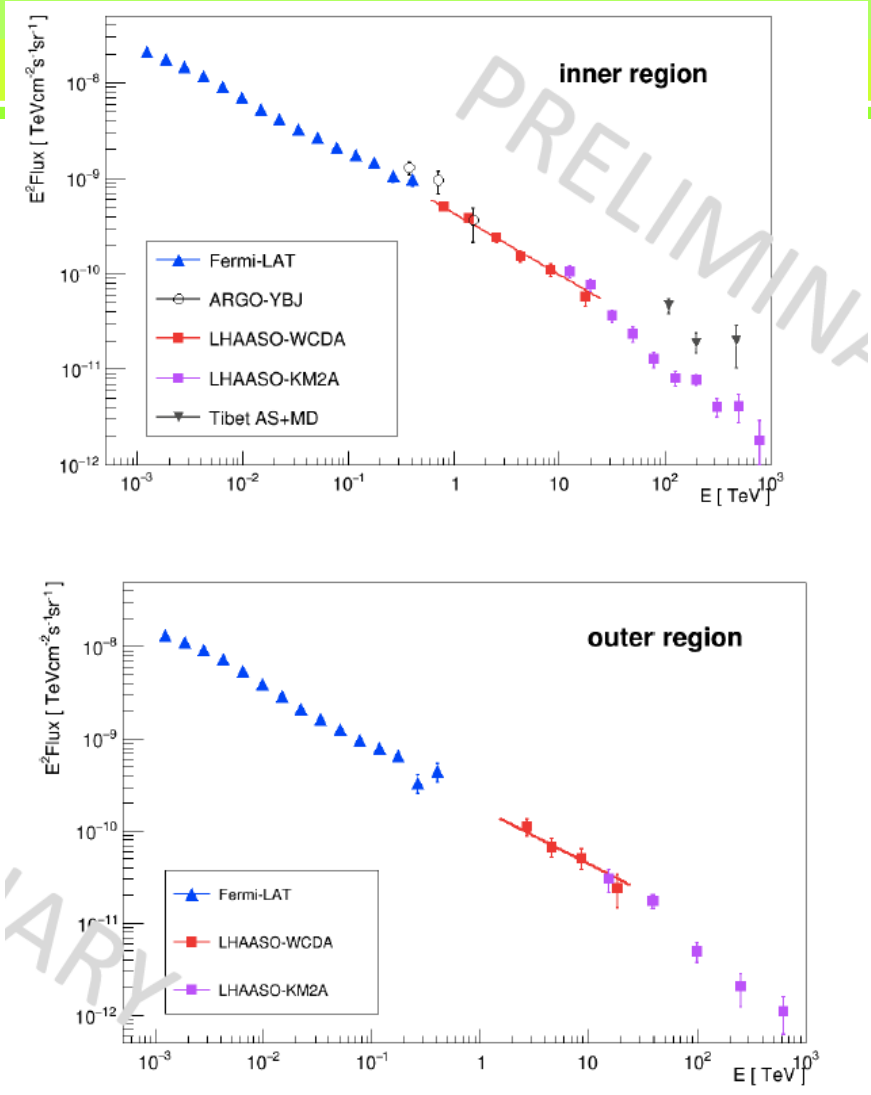


IceCube+LHAASO+Tibet

Converted to neutrino flux



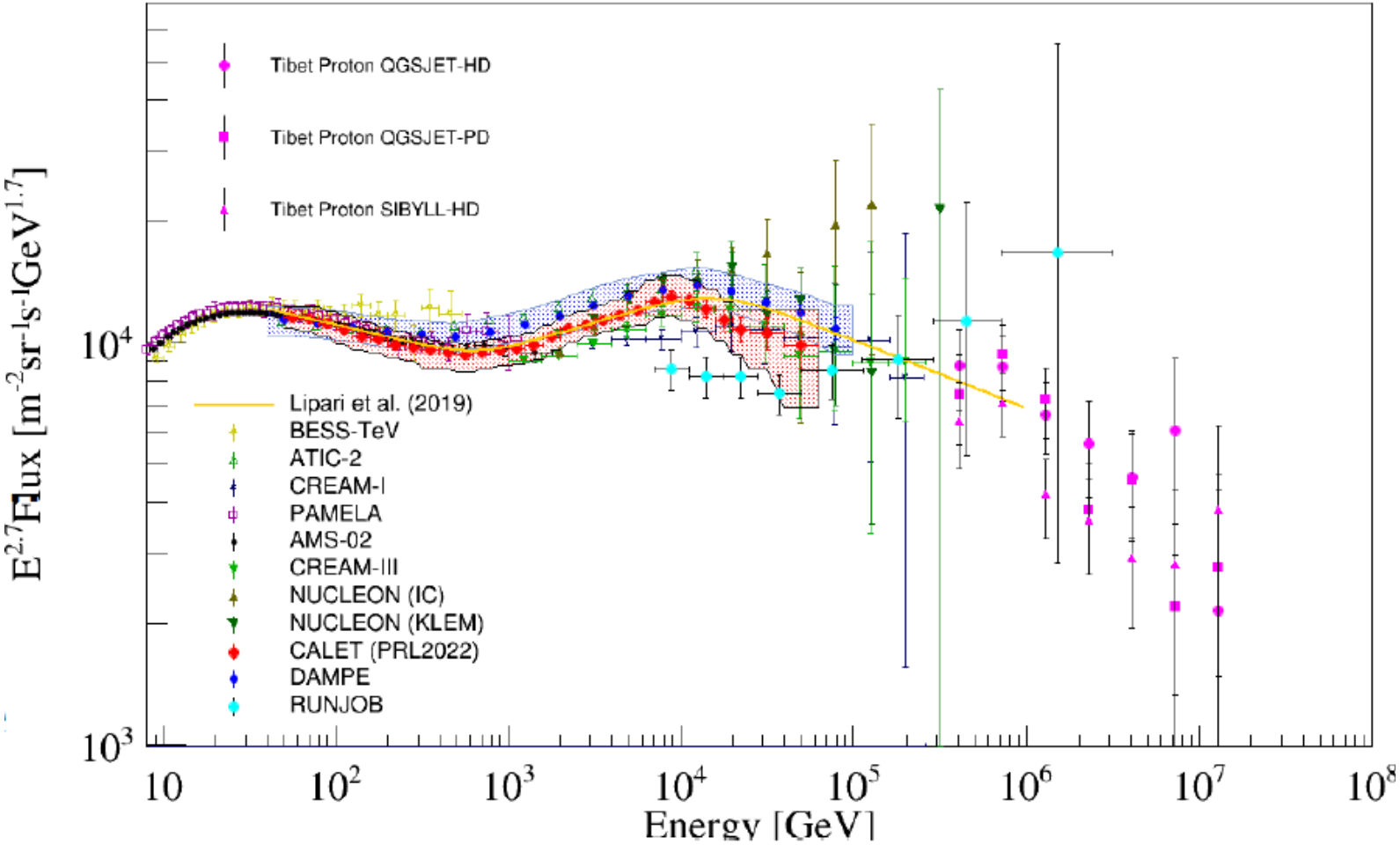
Fang & Murase 23



LHAASO TeVPA23
Spectral Break

Cosmic-Ray Direct Detection

Proton spectrum
Close to the knee?



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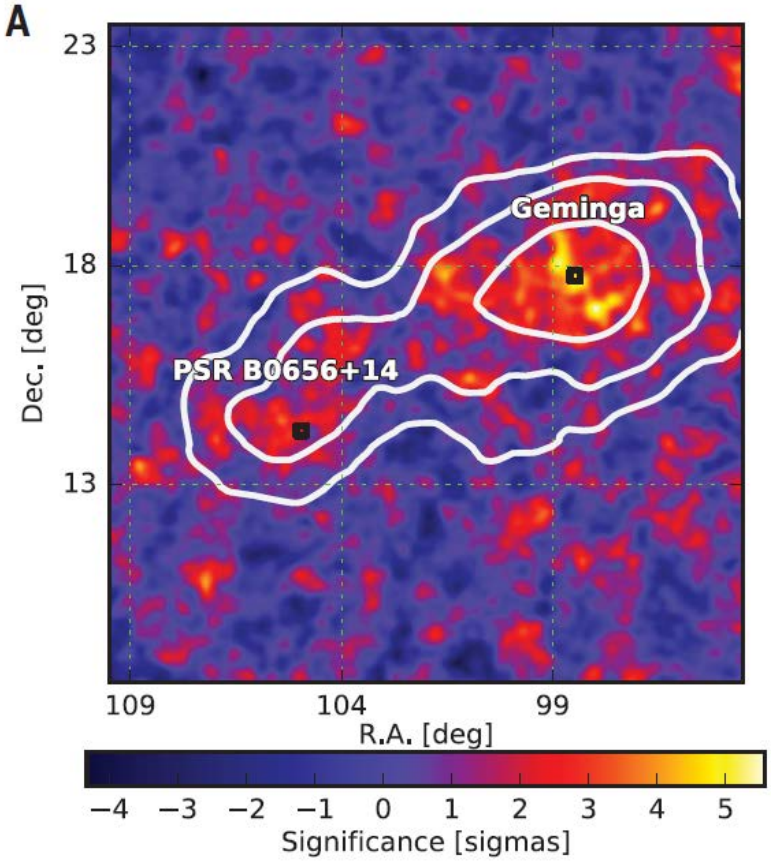
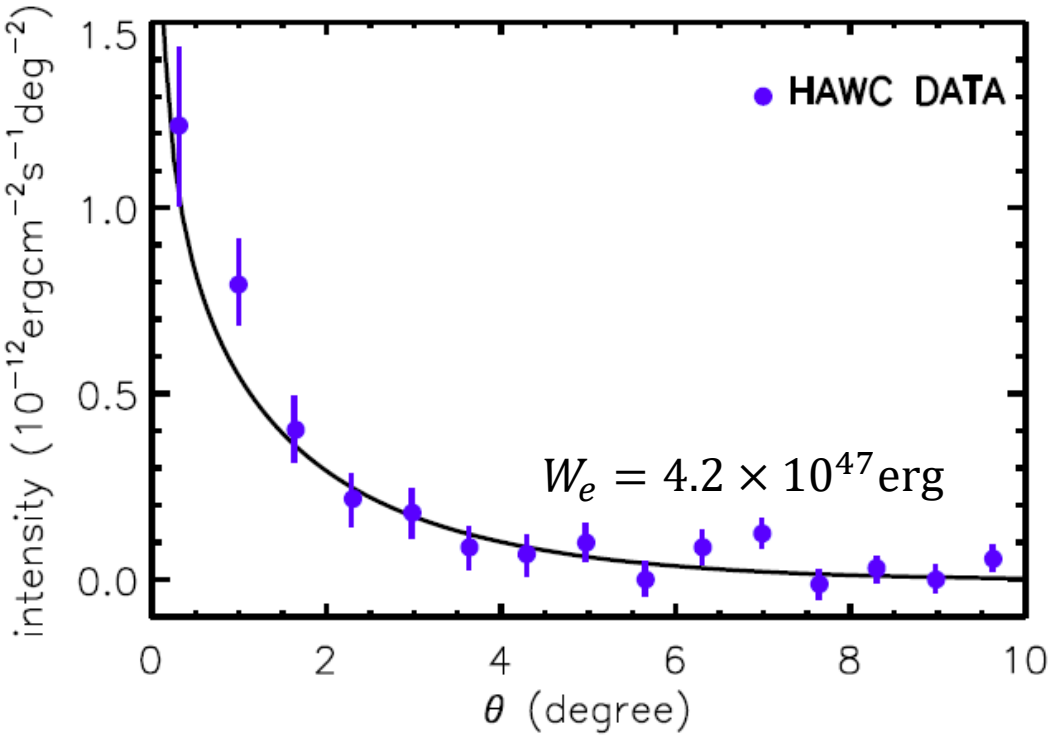
Note: how to distinguish diffuse and sources?

Abeysekara+ 17

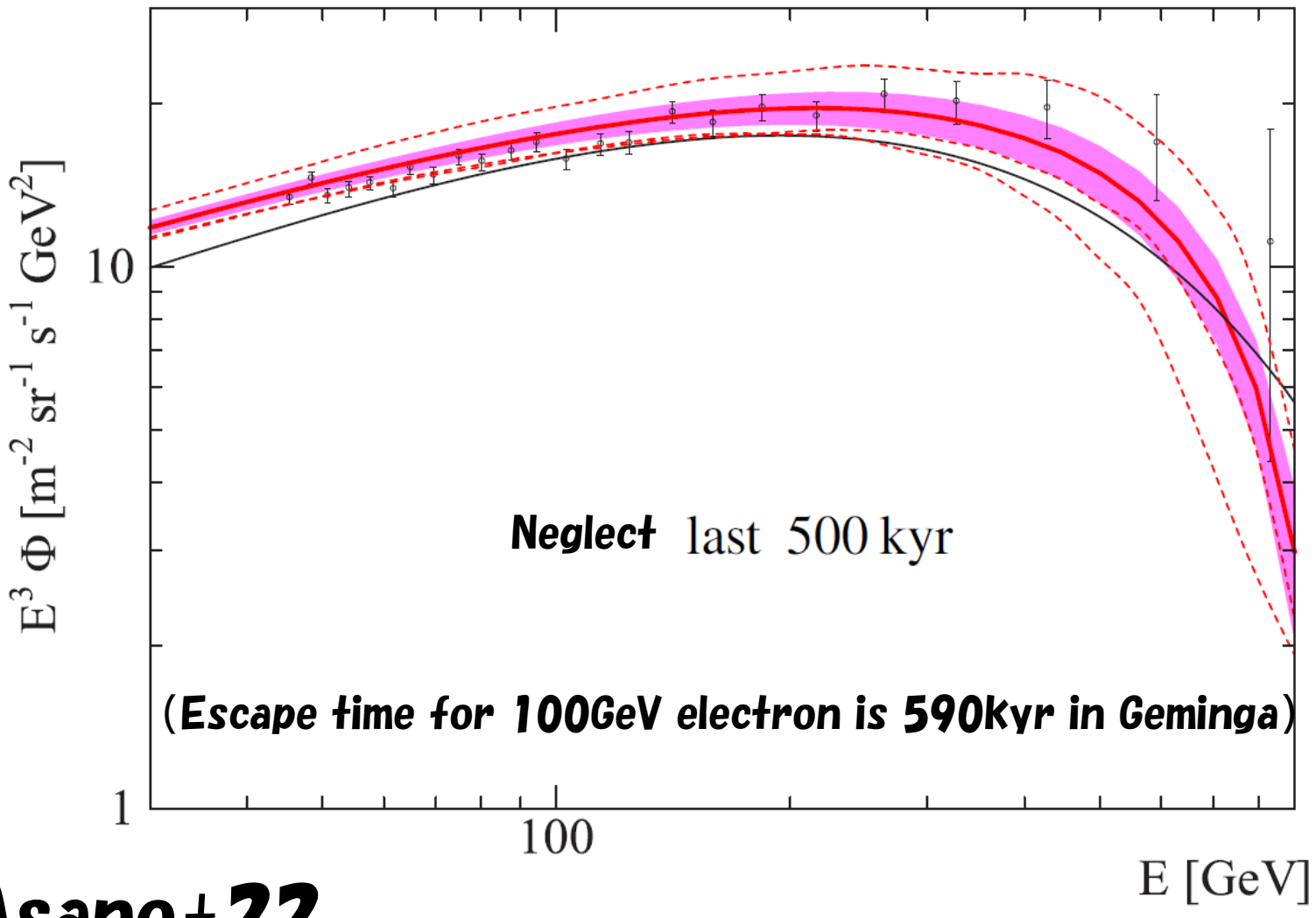


Liu+ 2019



Slow electron escape from pulsar wind nebula typically a few hundreds kyr
Important for study of escape with TeV Obs.

Pulsar component consistent with positron CRs



Asano+22

rate of $1.0 \times 10^{-2}\,\mathrm{kpc}^{-2}\,\mathrm{kyr}^{-1}$

$E_{\mathrm{tot}} = 6.5 \times 10^{47}\,\mathrm{erg}$

$\alpha = 1.9$

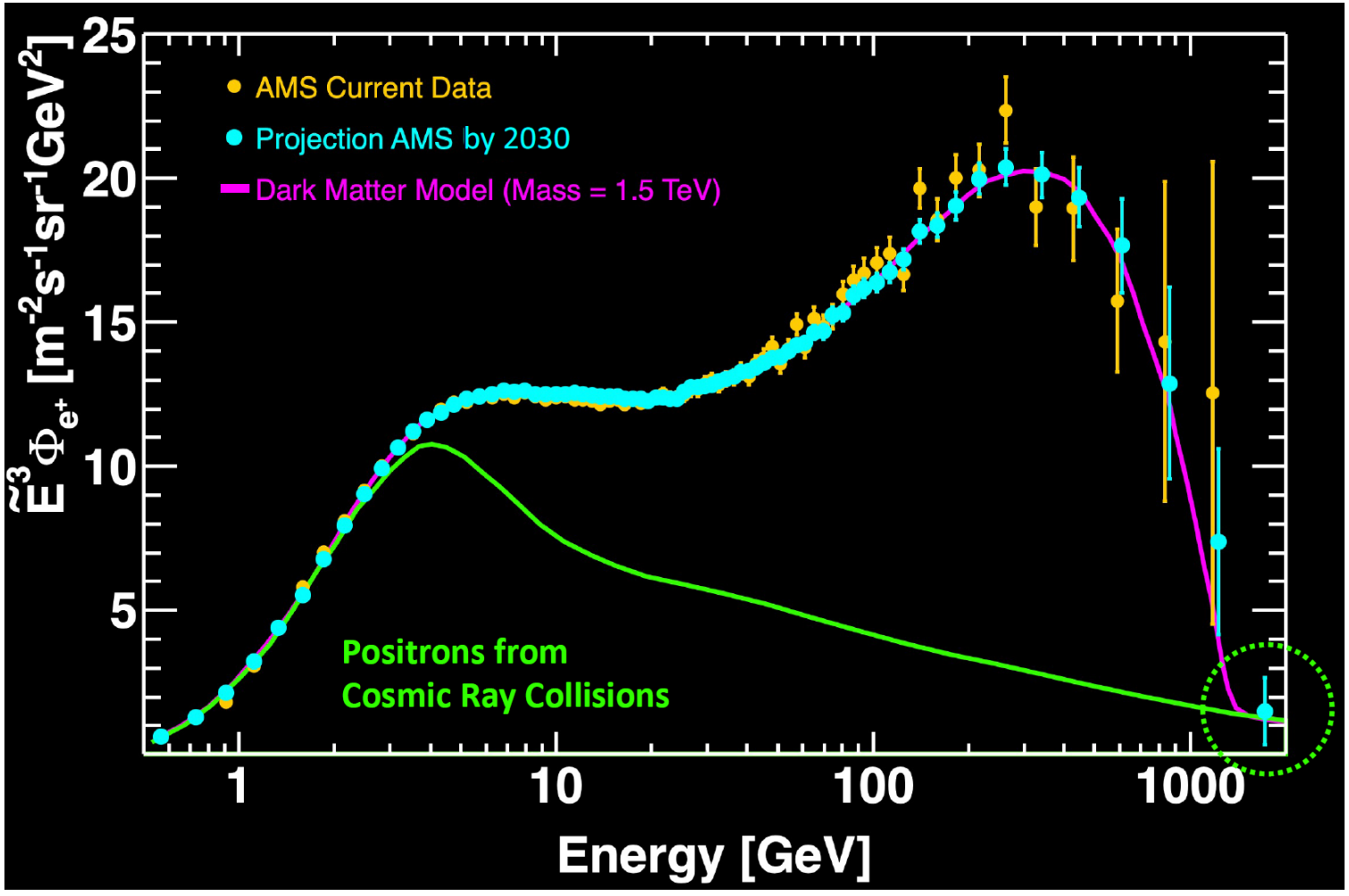
$\gamma_{\mathrm{max}} m_{\mathrm{e}} c^2 = 10\ \mathrm{TeV}$

Energetics

$$\mathcal{R} E_{\mathrm{tot}} = 6.5 \times 10^{45}\,\mathrm{erg\,kpc}^{-2}\,\mathrm{kyr}^{-1}$$

Future AMS data for positrons

AMS-02 ICRC2023



Check with PWN obs. with TeV

Summary

- Transient
- Extragalactic Non-Thermal Phenomena
- Massive Star Formation History
- Galactic Diffuse