Short GRBs, Multimessengers & Neil's pioneer role

Peter Mészáros

Pennsylvania State University

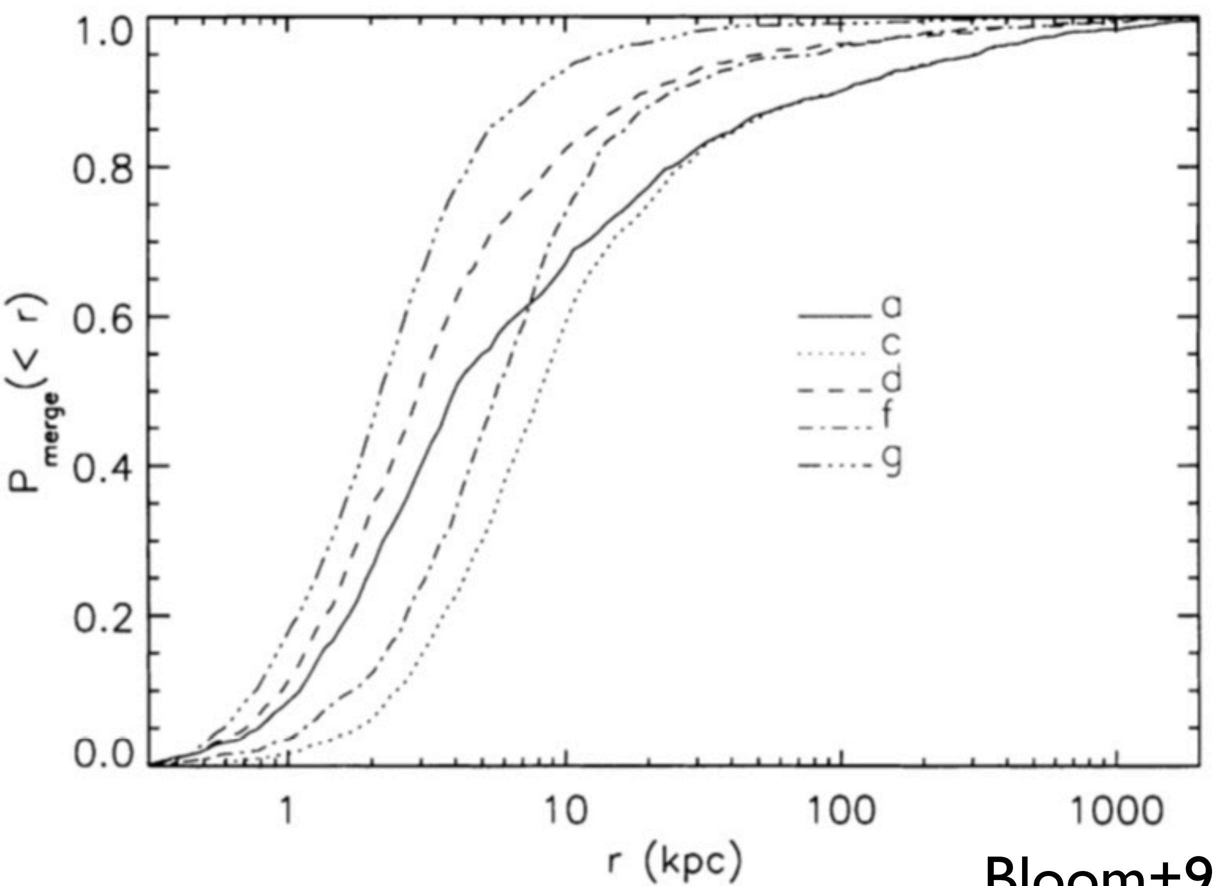
NAS, May 21-22, 2018

BNS mergers as SGRBs:

Early on,

- E.g. Paczynski, 1986; Goodman, 1986, etc.
- To be found in ***old***, "early" type galaxies, e.g. ellipticals, as well as in Pop. II (old) regions of young, e.g. halos of spiral/SFR galaxies.
- But- location could be ***offset*** from host galaxy, due to kicks during SN explosion

NS kick → offset to merger

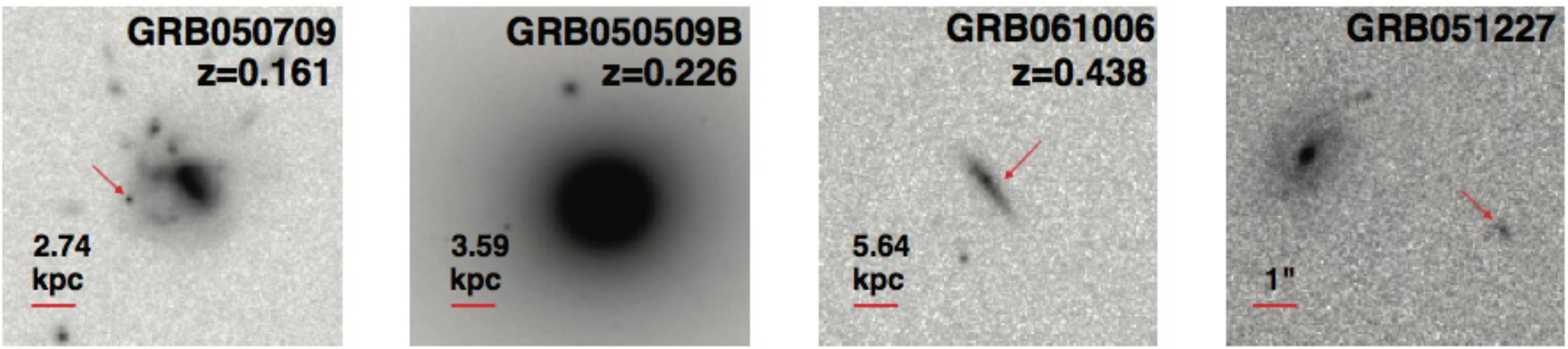


Bloom+99, MN 305:763

Figure 3. The radial distribution of coalescing neutron stars around galaxies of various potentials. The letters refer to runs in table 1. In all scenarios, at least 50% of the mergers occur within 10 kpc of the host galaxy. The wider radial distribution of in the underluminous galaxy scenarios (a,c) reflects the smaller gravitational potential of underluminous galaxies.

Verified thanks to Swift :

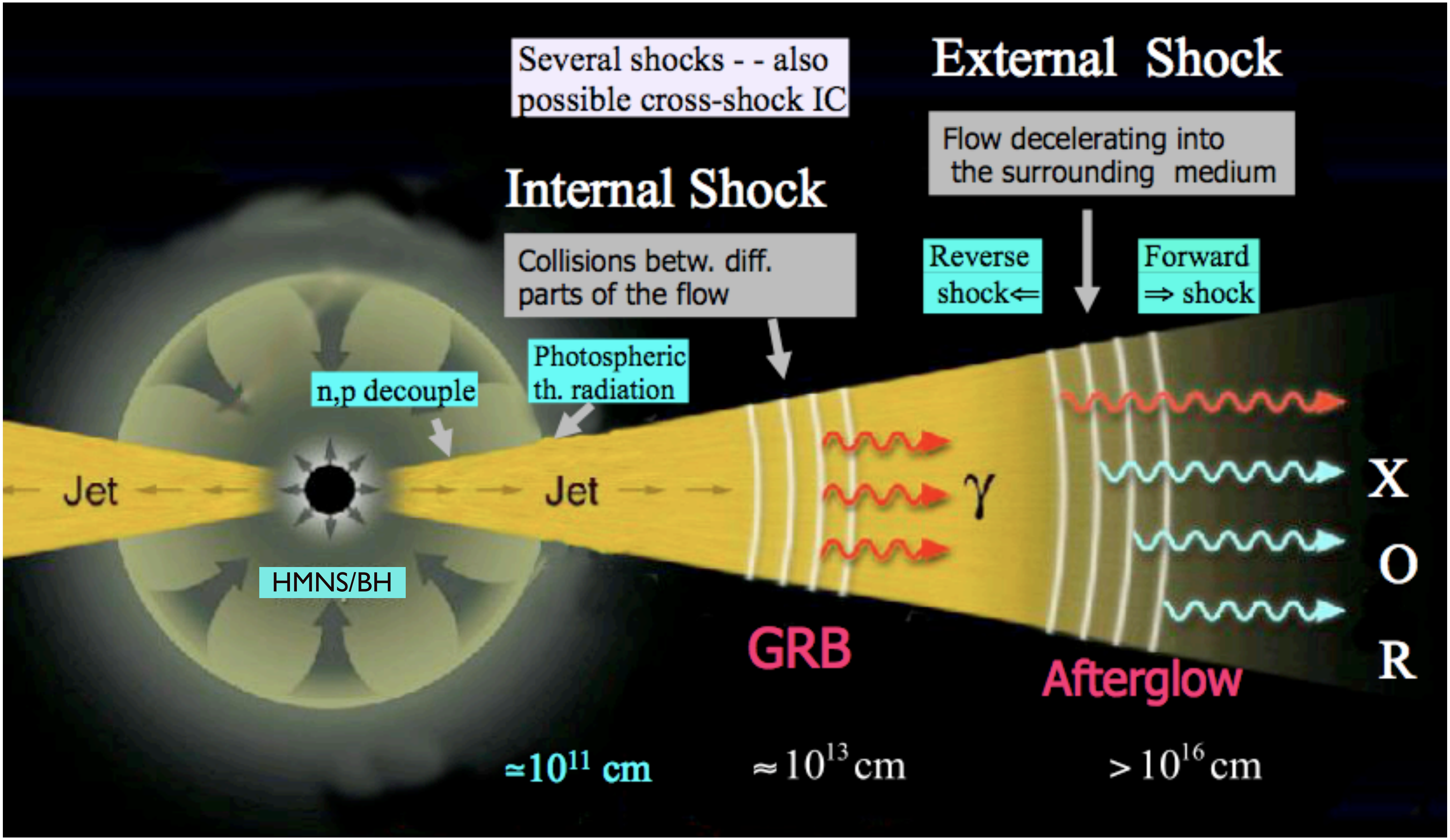
SGRB afterglows & hosts



data from D.B. Fox

e.g., Gehrels, Ramirez-Ruiz, Fox, 99, ARAA 47:567

SGRB standard paradigm

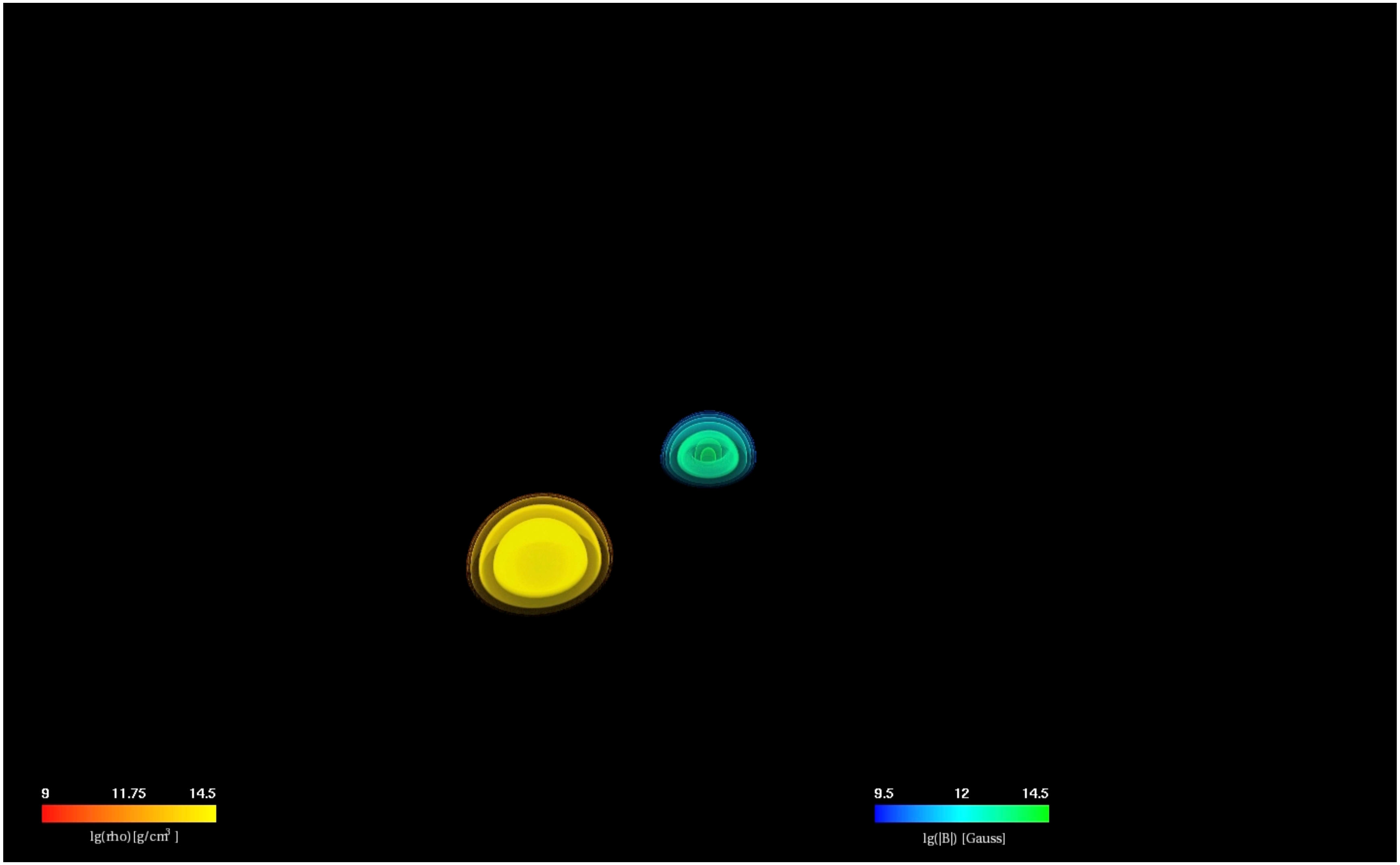


- E.g. Rees & Mészáros, '92, '94, Mészáros & Rees '97

BNS merger →MHD jets

requisite for GRB rel. jet-shock model

gas dens



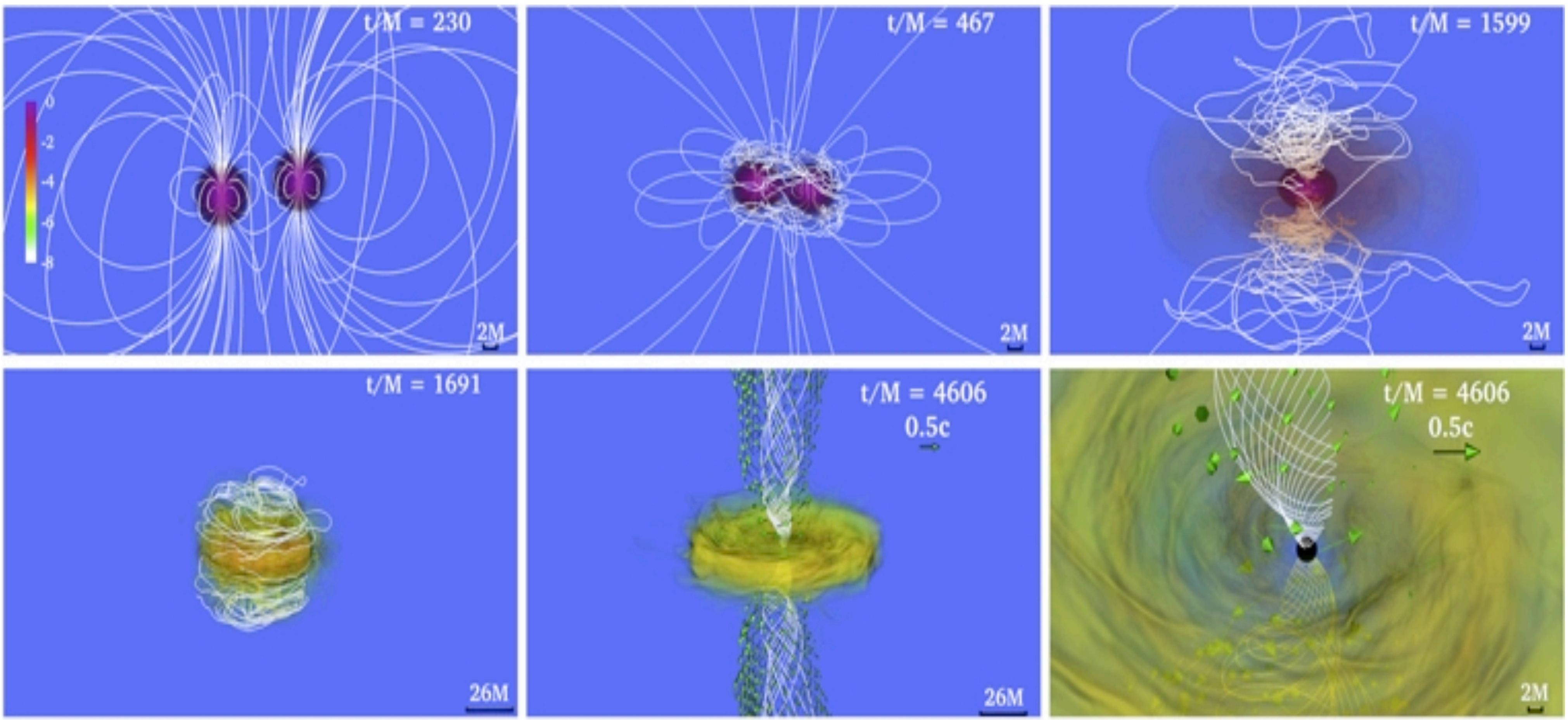
mag field

Jet indeed forms: Rezzolla, Kouveliotou et al ’11, ApJ 732:L6, ✔

In greater detail in GRMHD:

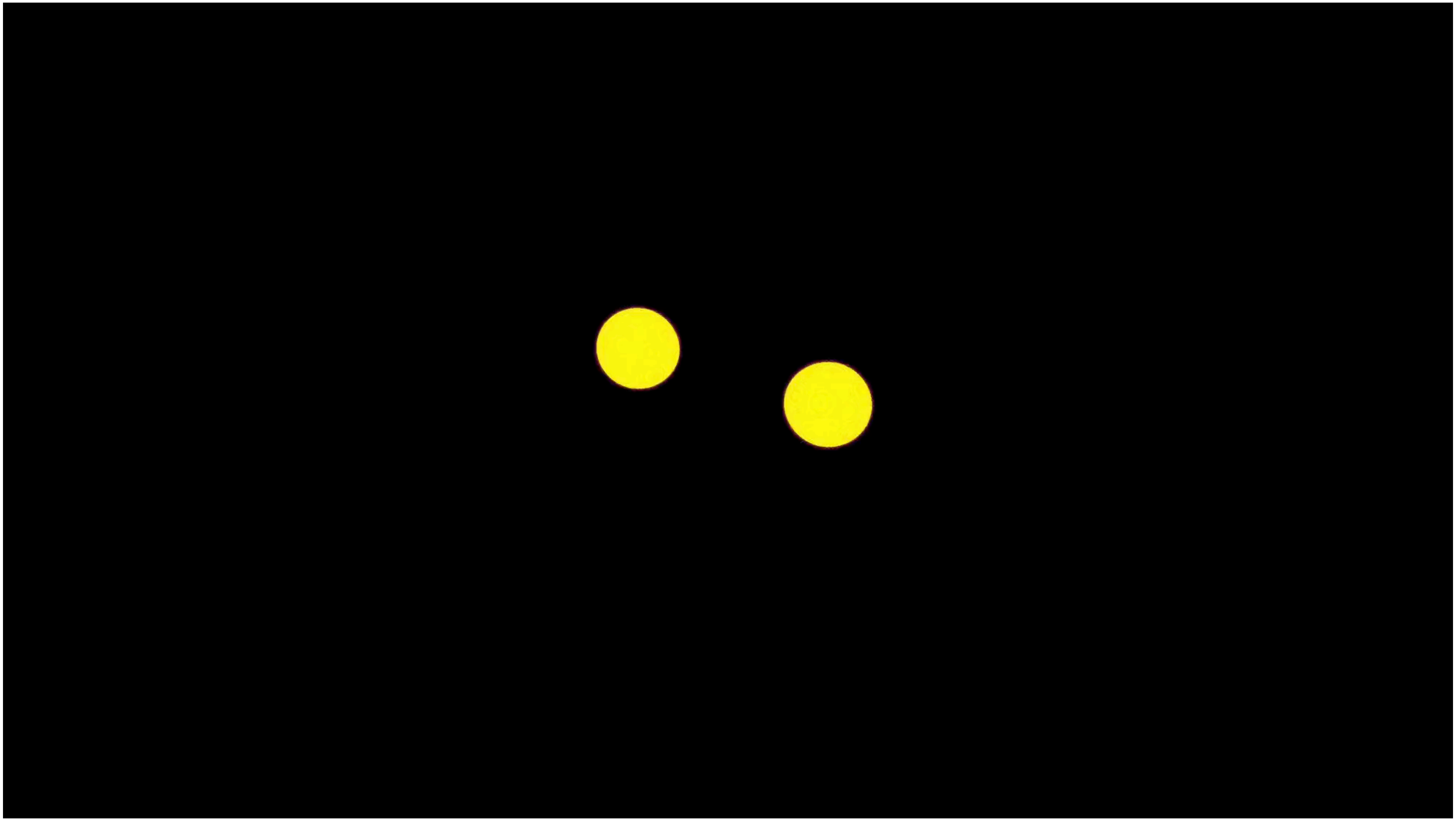
BNS merger→HMNS→jet, ✓

M. Ruiz+16 ApJL 824:L6



(But: no jet if prompt BH? Ruiz+17 PRD 96:084063)

Also…***dynamical ejecta*** (→**Kilonova ✔**)



Simulations: D. Radice, visualization C. Breu (see 1601.02426)

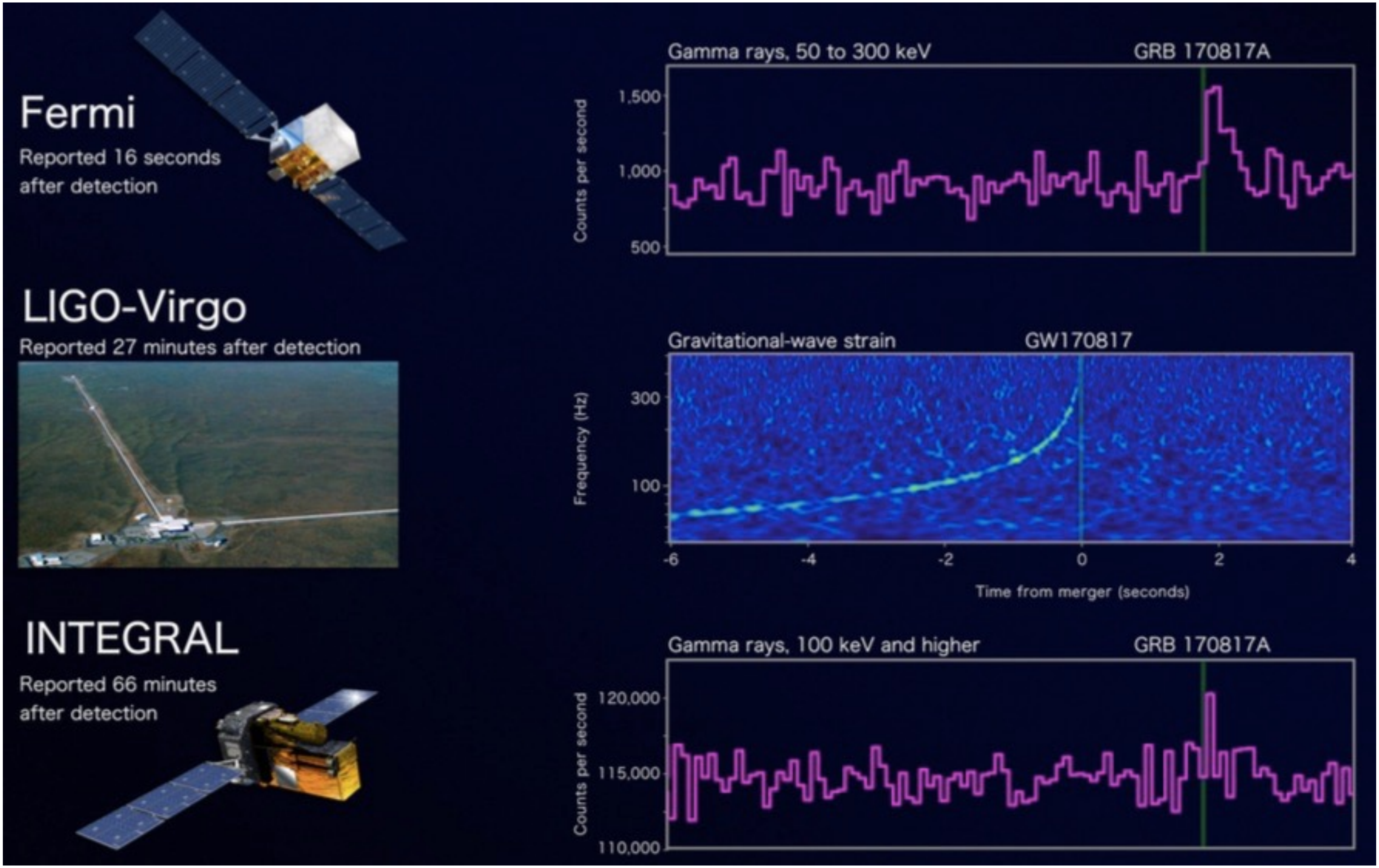
Density, bright yellow @ 1E13 g/cc, transparency @ 1E9 g/cc,

EoS: Lattimer-Swesty w. nuclear compressibility K=220 MeV

One of Neil's major pushes:
confirm the BNS nature through

GW & EM coincidences

Strongest proof : **GRB/GW 170817**



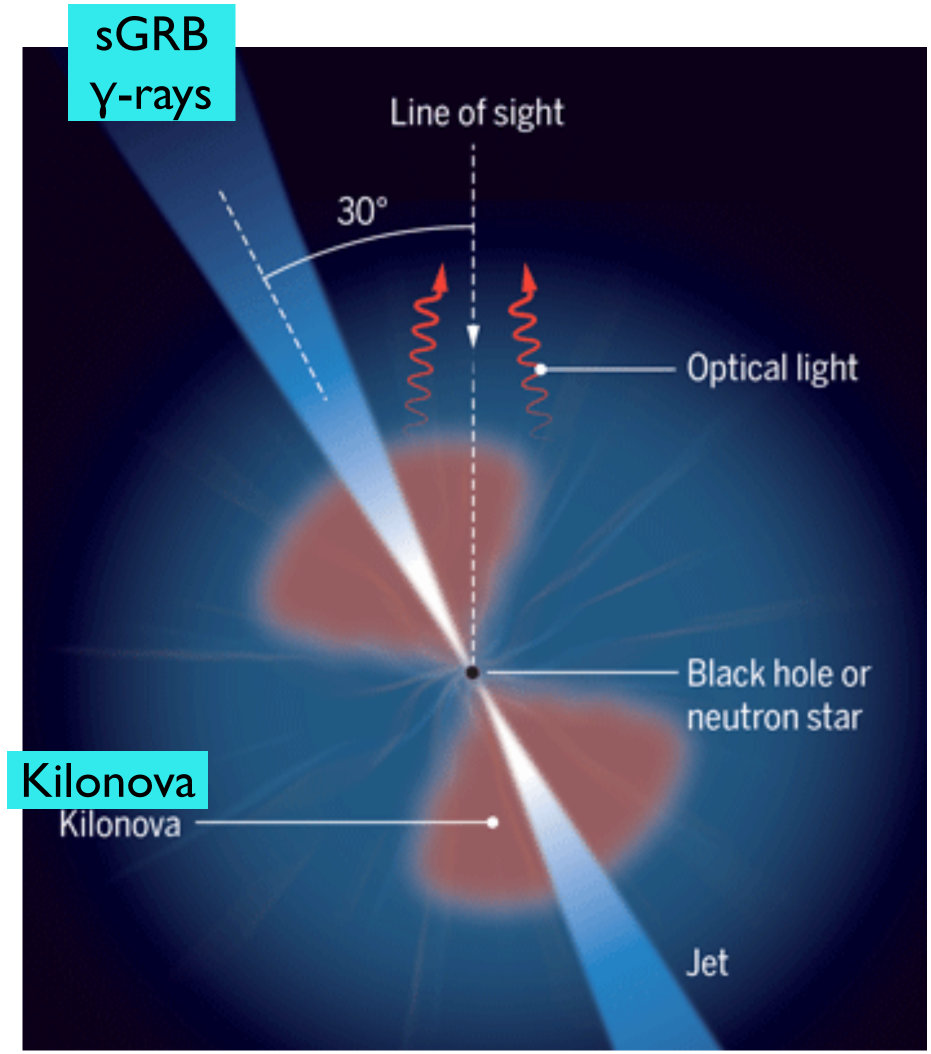
i.e.

BNS → [GW, sGRB, KN]

- Along and off-axis of structured jet (or cocoon), see the ***SGRB*** γ-rays

- at large angles, see ***kilonova*** caused by slower neutron-rich outflow where rapid neutron-capture ***r-process*** →very heavy elements, whose opacity and slow decay → **optical/IR**

- at all angles, see **GWs**



so, with

SGRB/GW 170817

re-confirmed that:

- SGRBs are indeed BNS mergers
- and BNS/SGRBs are also GW sources
- Multi-messenger astronomy now takes off in earnest (beyond SN1987a 1/100 yr events)
- A main goal of Neil's vision achieved !

What other

cosmic
channels / messengers
can we hope for?

Another of Neil's major pushes:
look for

HENU & EM coincidences

So far, progress understanding BNS γ and GW emission
- but there may be **other things** *to look for*

UHE Cosmic rays,
& VHE Neutrinos

from

BNS (short GRBs) ?

expected & plausible

But ... hard to detect !

BNS merger: NS+NS $\rightarrow$ HMNS $\xrightarrow{\text{(delay?)}}$ BH?

- Merger: $E_{grav} \sim GM^2/R_{HMNS} \sim 3\text{x}10^{53}$ erg

Energy is emitted mostly as neutrinos:

$$e^+ + e^- \rightarrow \nu + \bar{\nu}$$
$$N + N \rightarrow N + N + \nu + \bar{\nu}$$

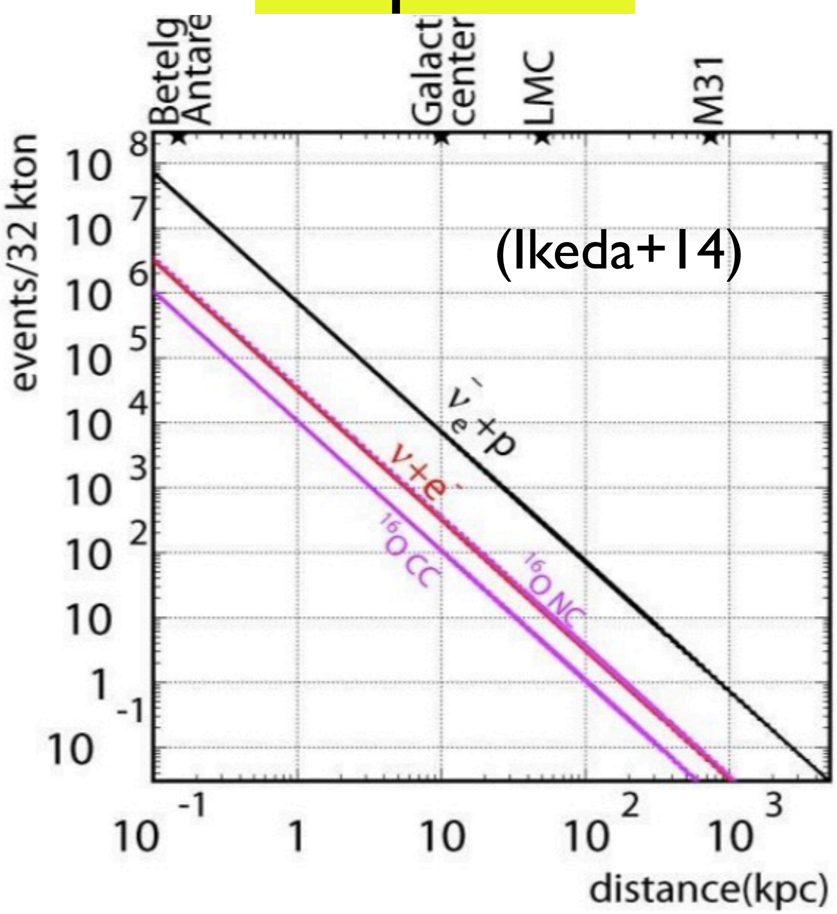
$\Rightarrow \nu_e,\ \bar{\nu}_e,\ \nu_\mu,\ \bar{\nu}_\mu,\ \nu_\tau,\ \bar{\nu}_\tau$, <E_ν>~15 MeV

Detection mainly through CC int.: $\bar{\nu}_e + p \rightarrow n + e^+$

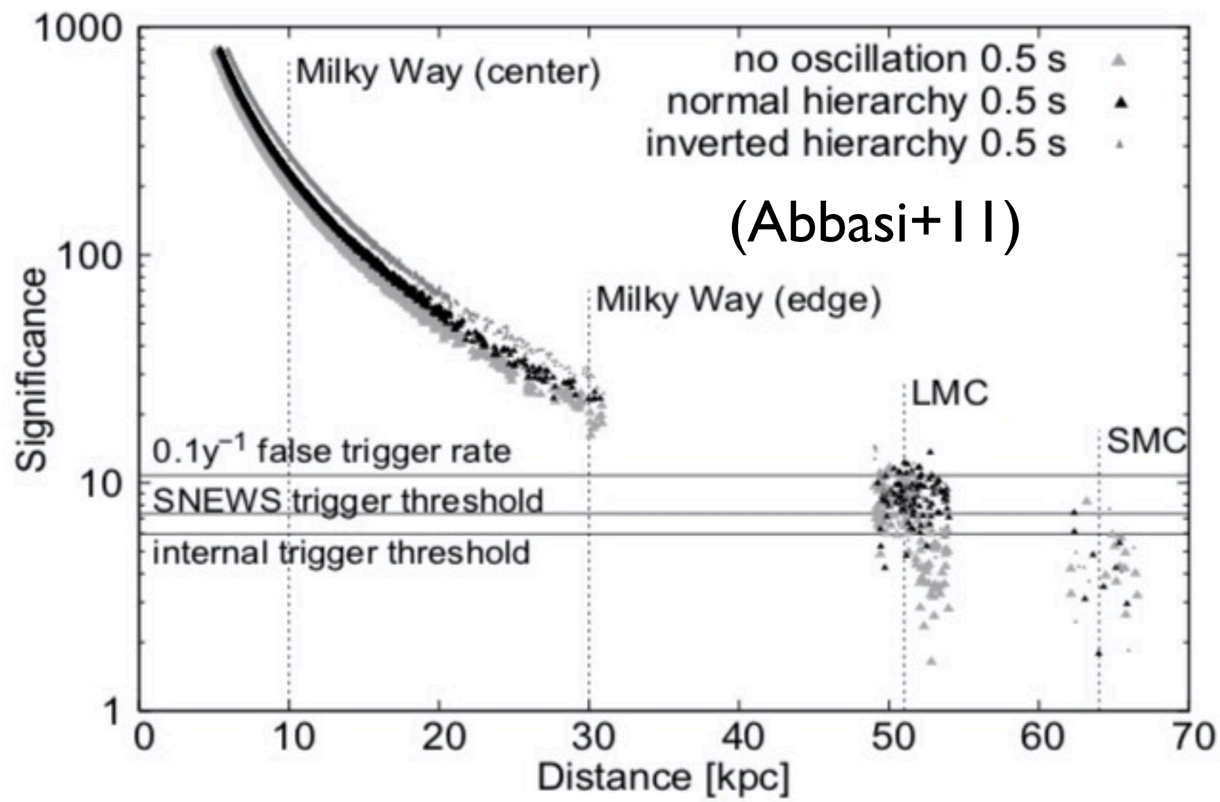
BNS→SN-like ν-events vs. distance

(low-energy thermal νs, <E_ν>~15 MeV)

Super-K



IceCube



Rate too small - even with HyperK(Gd) or IceCube Gen2

What about

high-energy neutrinos?

e.g.

TeV-PeV $\boldsymbol{\nu}$s in IceCube

pp or pγ neutrino production

$$p + p/\gamma \rightarrow N + \pi^{\pm} + \pi^0 + \ldots$$

$$\begin{aligned} \pi^+ &\rightarrow \mu^+ + \nu_\mu \,, \\ & \quad\;\; \mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu \end{aligned}$$

$$K^+ \rightarrow \mu^+ + \nu_\mu$$

$$n \rightarrow p + e^- + \bar{\nu}_e$$

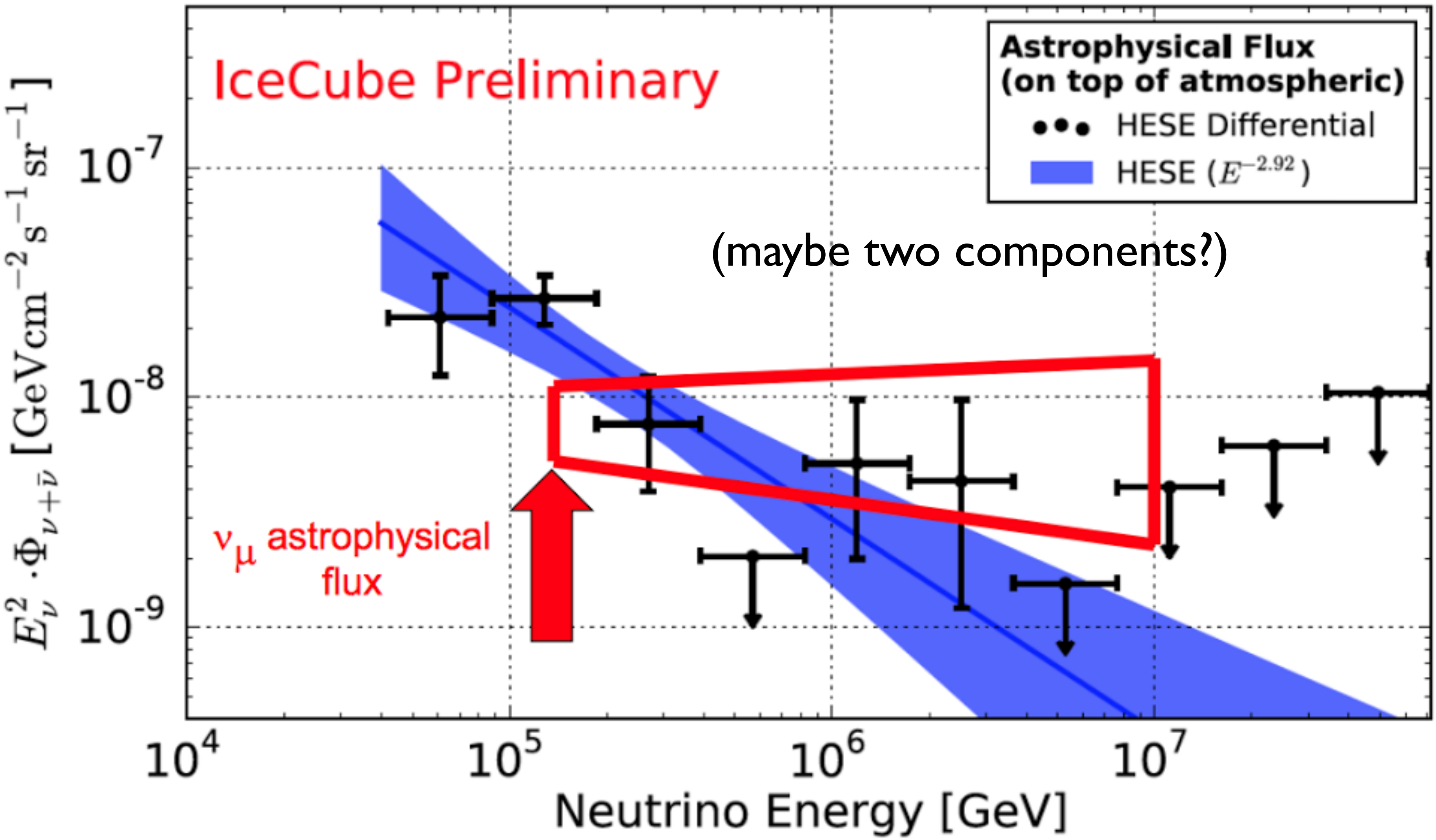
$$\begin{aligned} \pi^- &\rightarrow \mu^- + \bar{\nu}_\mu \,, \\ & \quad\;\; \mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu \end{aligned}$$

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

- Both ν_e and ν_μ are produced by charged pion decay,
- γ-ray photons are produced by neutral pion decay

IceCube diffuse astrophysical neutrino background

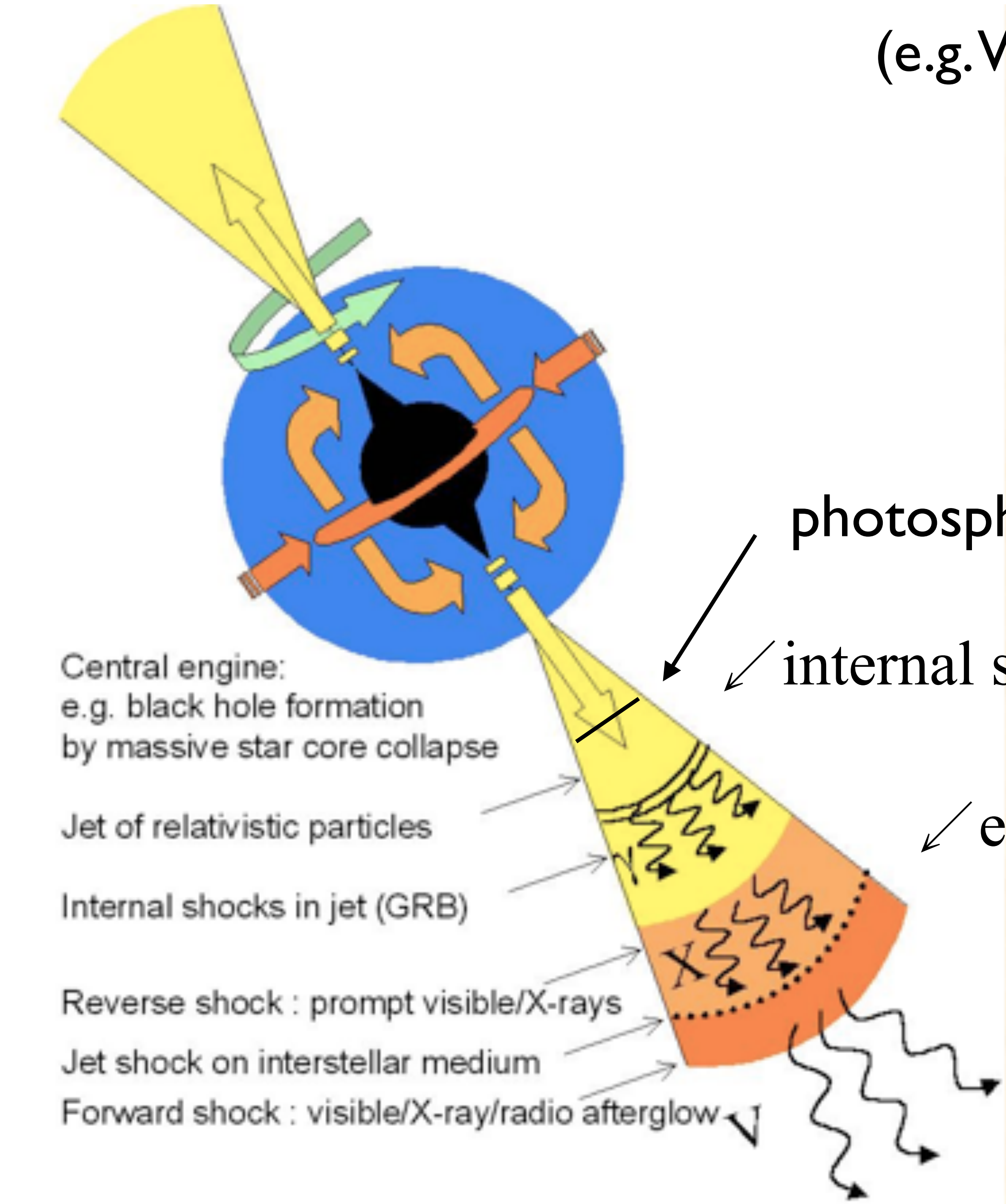
(Halzen, 2017, TeVPA)



But: no obvious sources !

Standard Model of GRB prompt CR/Nu

(e.g. Waxman '95, Waxman & Bahcall '97)



Internal, external & photosphere shocks ***do*** Fermi-accelerate electrons, and make e,B $\rightarrow\gamma$ (***leptonic***);

So then …

same shocks must must accel. protons too (right?) $\rightarrow$ ***CRs*** ***and***
p$\gamma\rightarrow$***ν, γ*** (***hadronic***)

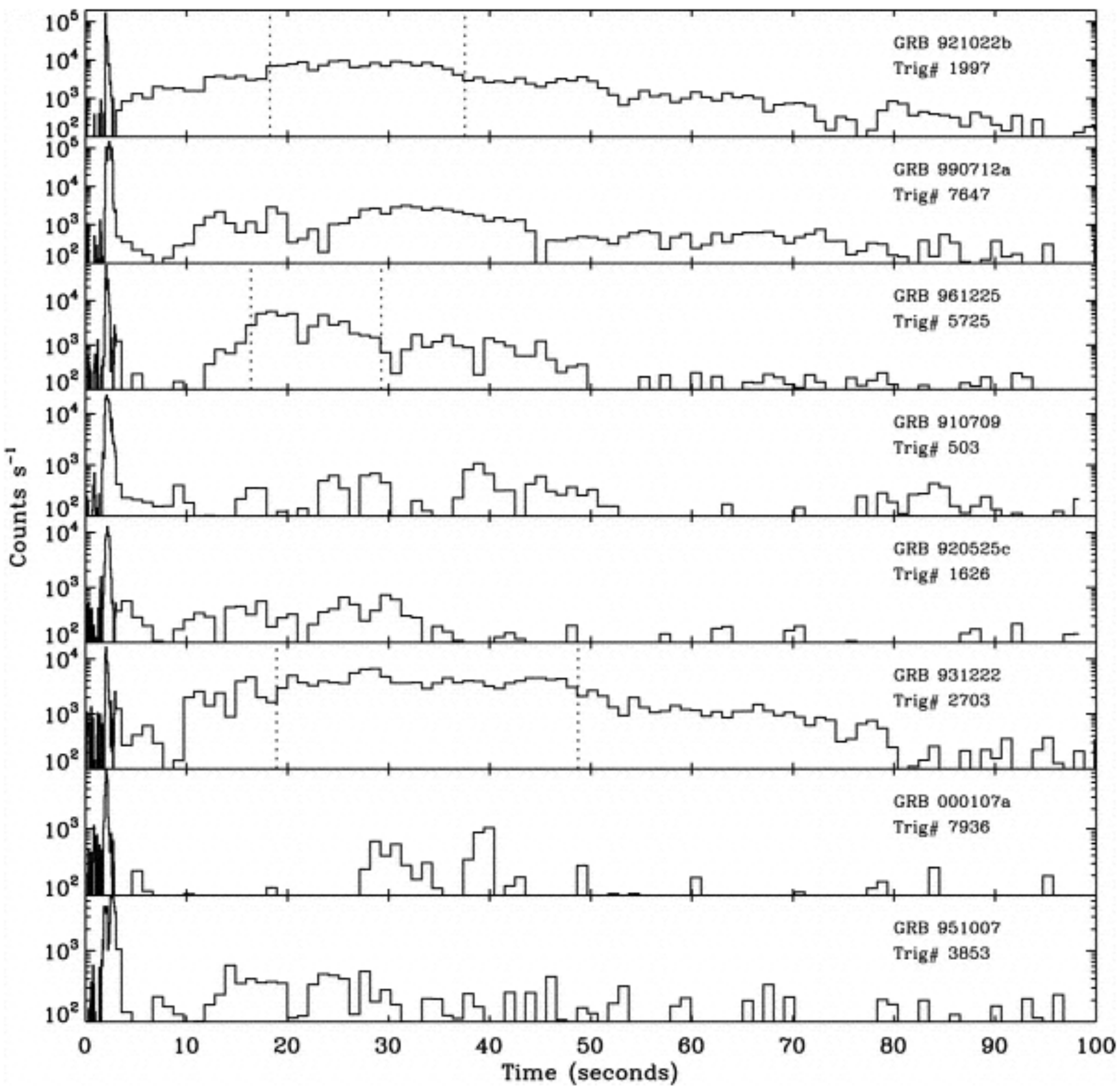
Observed VHE neutrinos apparently **do not** come from ***Classical GRBs***

- IceCube finds that <1% of the EM-observed "classical" long, bright GRBs can be contributing to this observed neutrino flux (time/direction)
- This tests for neutrinos in close time/direction coincidence with ***prompt*** (main) jet MeV gammas
- But these are mostly **long GRBs** from ccSNe; and **short GRB**s (BNS) are much **fainter;** not surprisingly,

These neutrinos DO NOT come from SGRB PROMPT emissions either !

However:

SGRB are *not* always "short"



Norris+06, ApJ 643:266

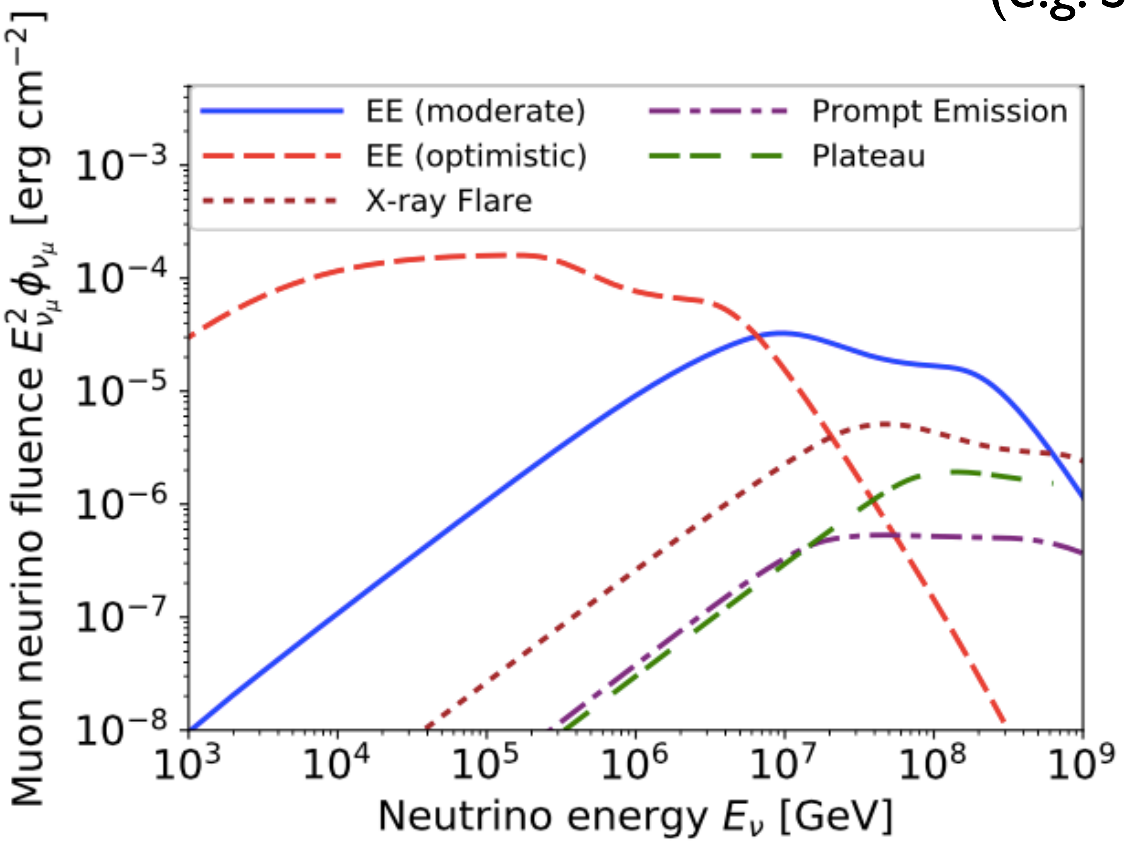
in 30-50% of cases:

- ***Extended*** emission (EE) in 30-50% cases
- EE spectrum is ***softer*** than that of the "prompt"
- Prompt: E~1-3 MeV
- Ext'd: E~ 30-60 KeV
- $\Delta t_{EE} \sim\leq 10^2$ s

calculate now BNS Merger
Neutrino light curves

including also ***delayed*** components

(e.g. SGRB extended tail emission, etc)



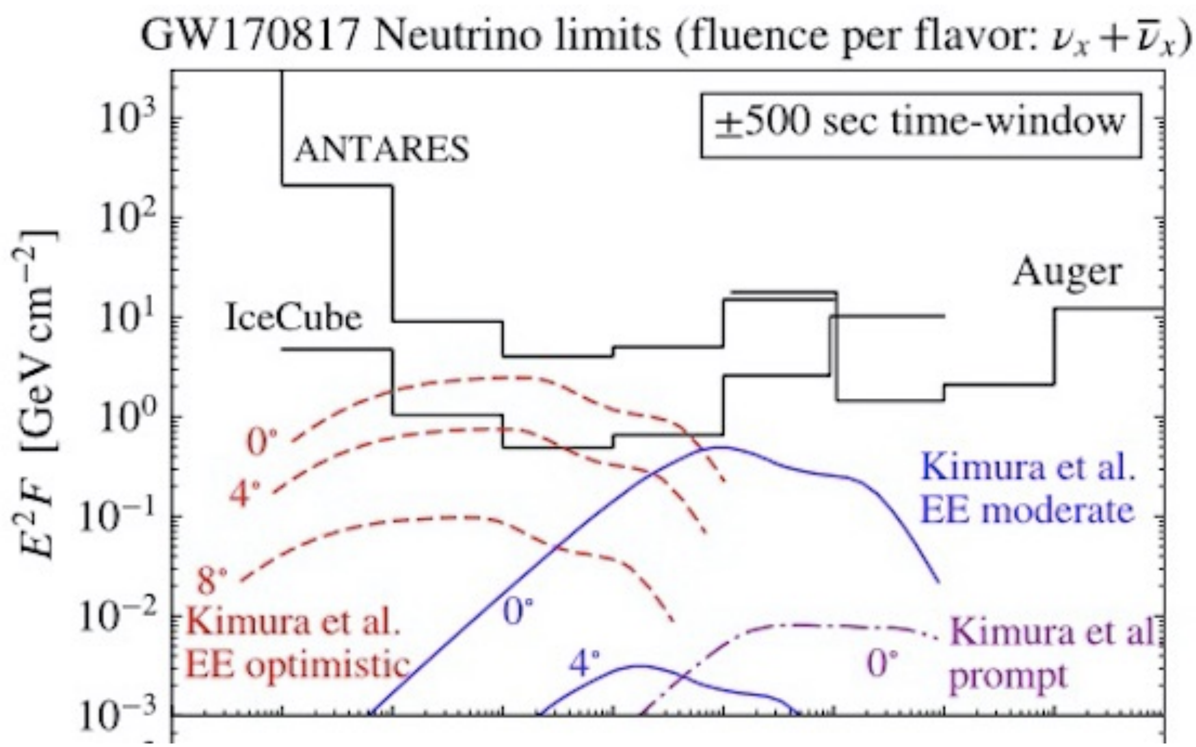
Neutrino fluence from *on-axis* SGRB for EE-mod, EE-opt, prompt, flare & plateau component @ d_L=200 Mpc (e.g. aLIGO)

Kimura, Murase, Mészáros & Kiuchi, 2017, ApJL, 848:L4

ν-dominance of BNS EE:

- Caused by ***lower*** Γ, ***higher baryon*** load
- $\Rightarrow$ ***higher photon*** density and ***shorter*** $\boldsymbol{t_{p\gamma}}$
- $\rightarrow$***higher B***-field, stronger ***pion cooling***
- $\rightarrow$***lower*** pion cooling break, TeV-PeV spectra
- ***Still***, fluence ***low*** for IC3, unless ***very*** nearby

IceCube, Antares, Auger ν-limits on GW170817:



- GW indicates off-axis jet, $\theta_{obs} \in [0°, 36°]$,
- Kimura et al. models for Doppler factor at various θ_{obs}-θ_j offset
- No detection (OK, ✔)

Antares, IceCube, Auger, LIGO-Virgo coll, 2017, ApJ 850:L35

Det. Prob.(≥k events)

Det.Prob(≥1 event) vs. d_L

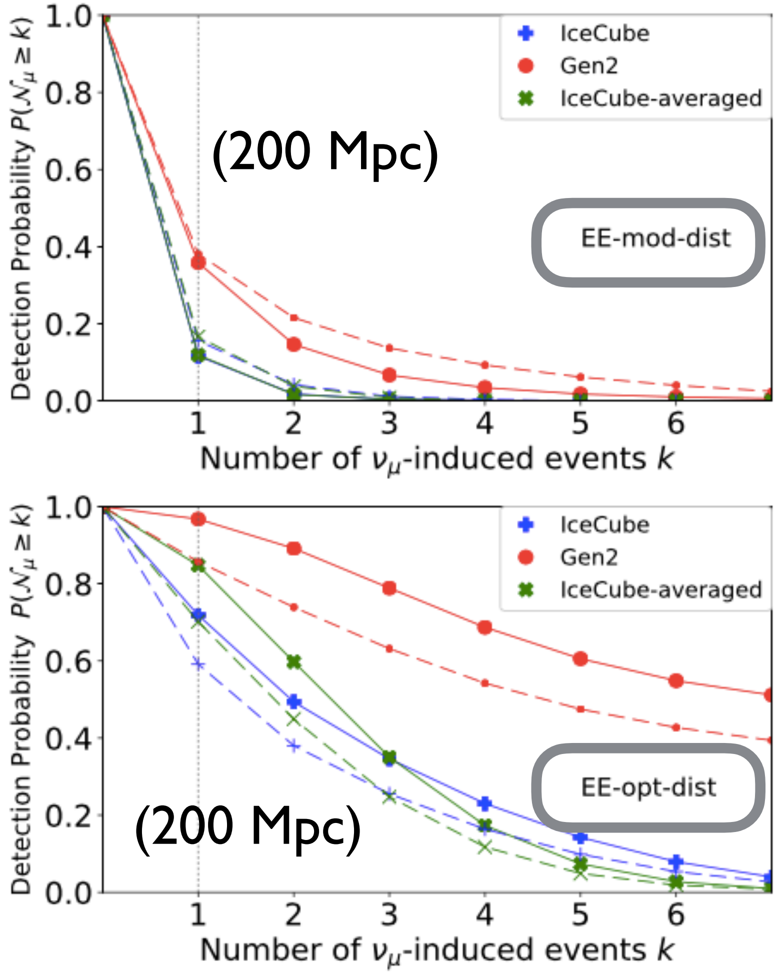


Figure 2. The detection probability $P(\mathcal{N}_\mu \geq k)$ for d_L = 200 Mpc. The upper and lower panels are for EE-mod-dist and EE-opt-dist, respectively. The solid and dashed lines are for the cases with $\sigma_\Gamma = 2$ and $\sigma_\Gamma = 4$, respectively. The vertical thin-dotted line shows $\mathcal{N}_\mu = 1$.

(IceCube-averaged includes down-going events)

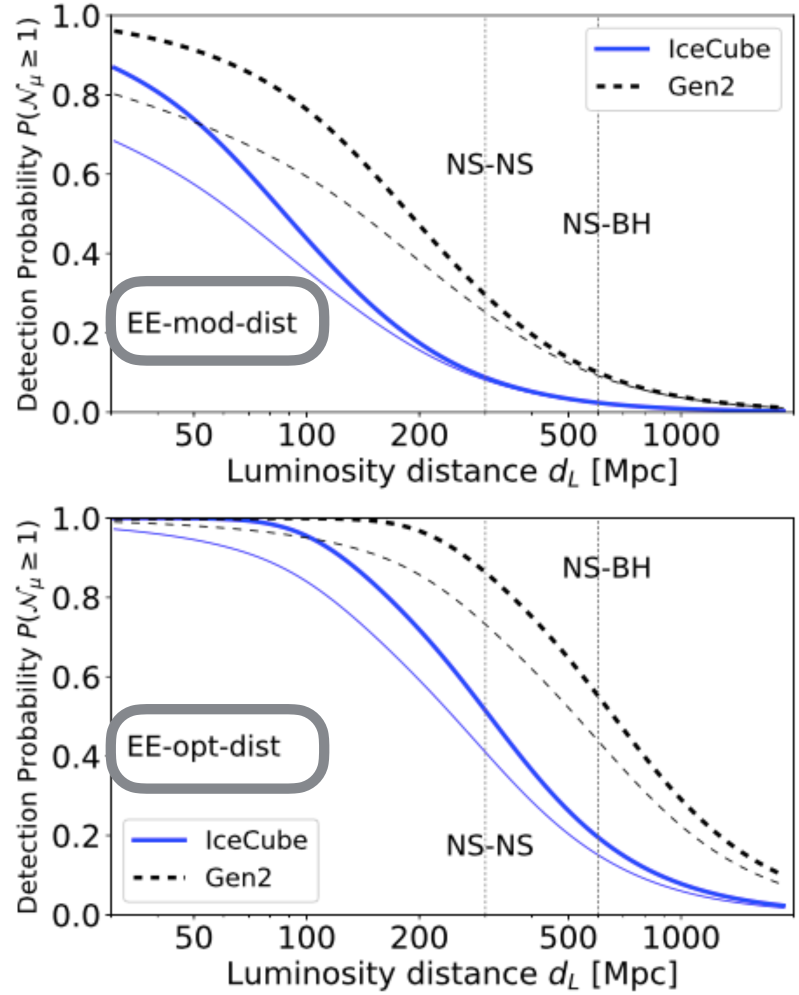


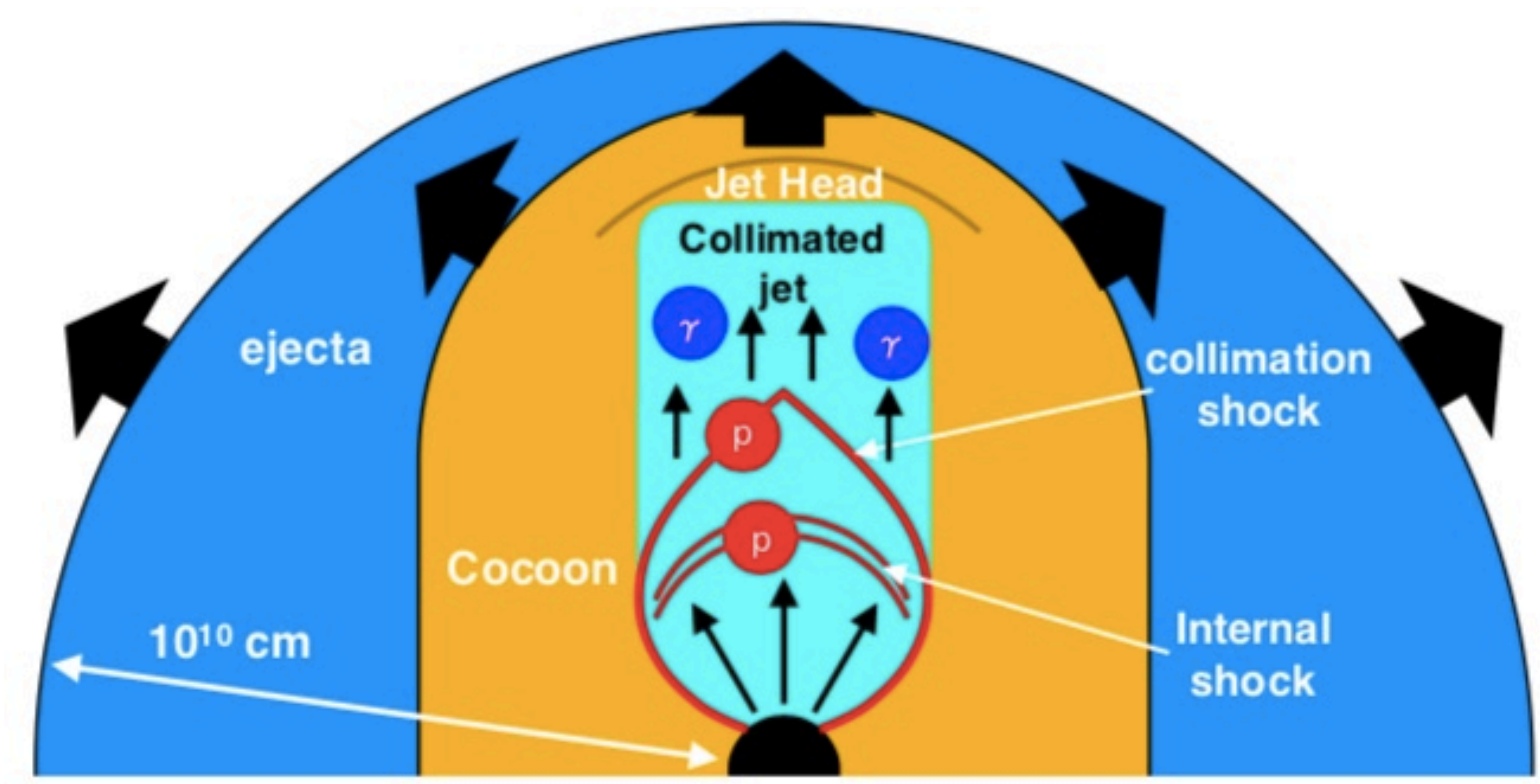
Figure 3. The detection probability $P(\mathcal{N}_\mu \geq 1)$ as a function of luminosity distance d_L. The upper and lower panels are for EE-mod-dist and EE-opt-dist, respectively. The thick and thin lines are for the cases with $\sigma_\Gamma = 2$ and $\sigma_\Gamma = 4$, respectively. The vertical thin-dotted lines show $d_L = 300$ Mpc and $d_L = 600$ Mpc.

i.e., IC3: maybe - Gen-2: likely

Kimura, Murase, Mészáros & Kiuchi, 2017, ApJL, 848:L4

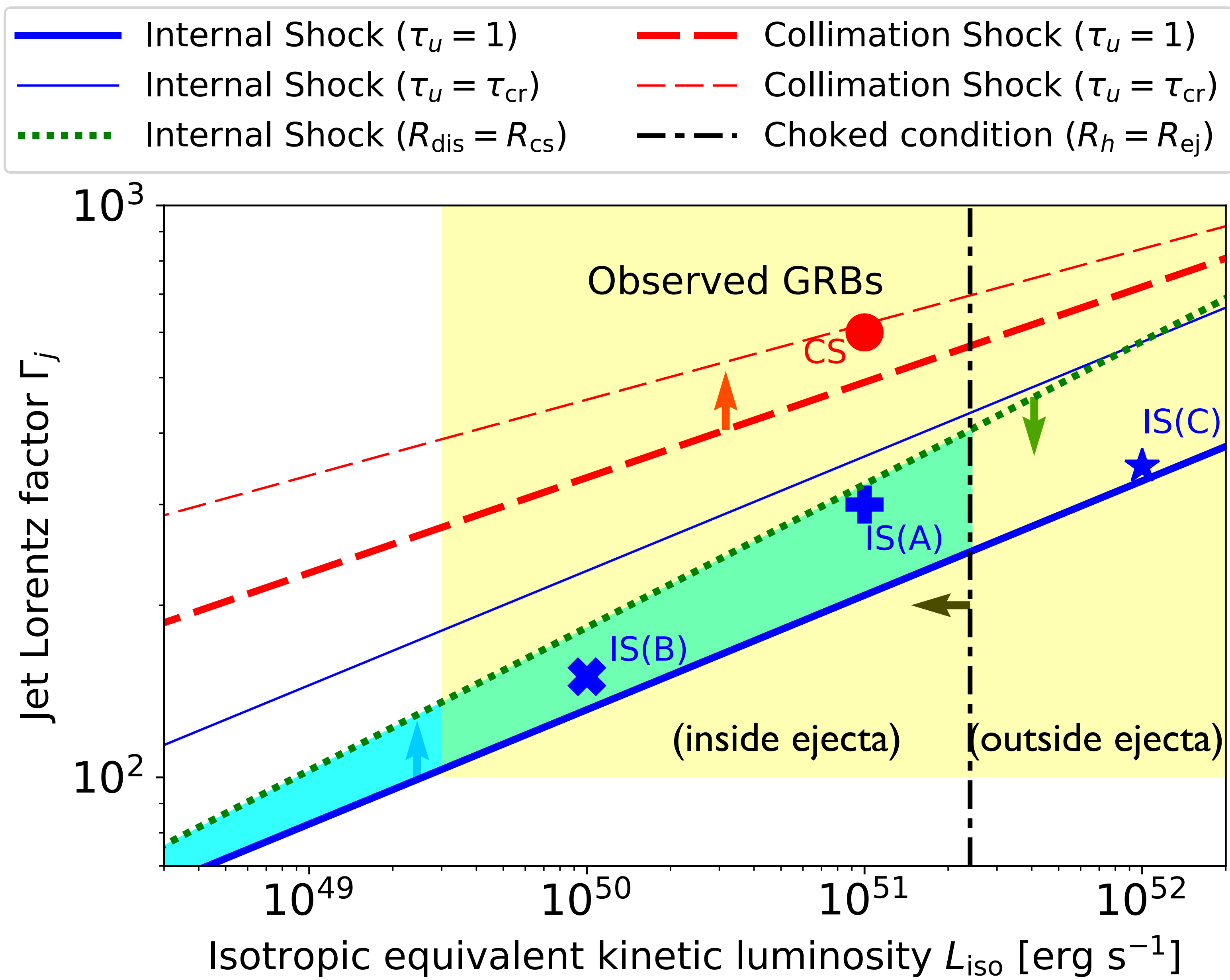
Another possible HENU mechanism for SGRB :

Internal and collimation shocks in BNS jet-cocoons within the dynamical ejecta

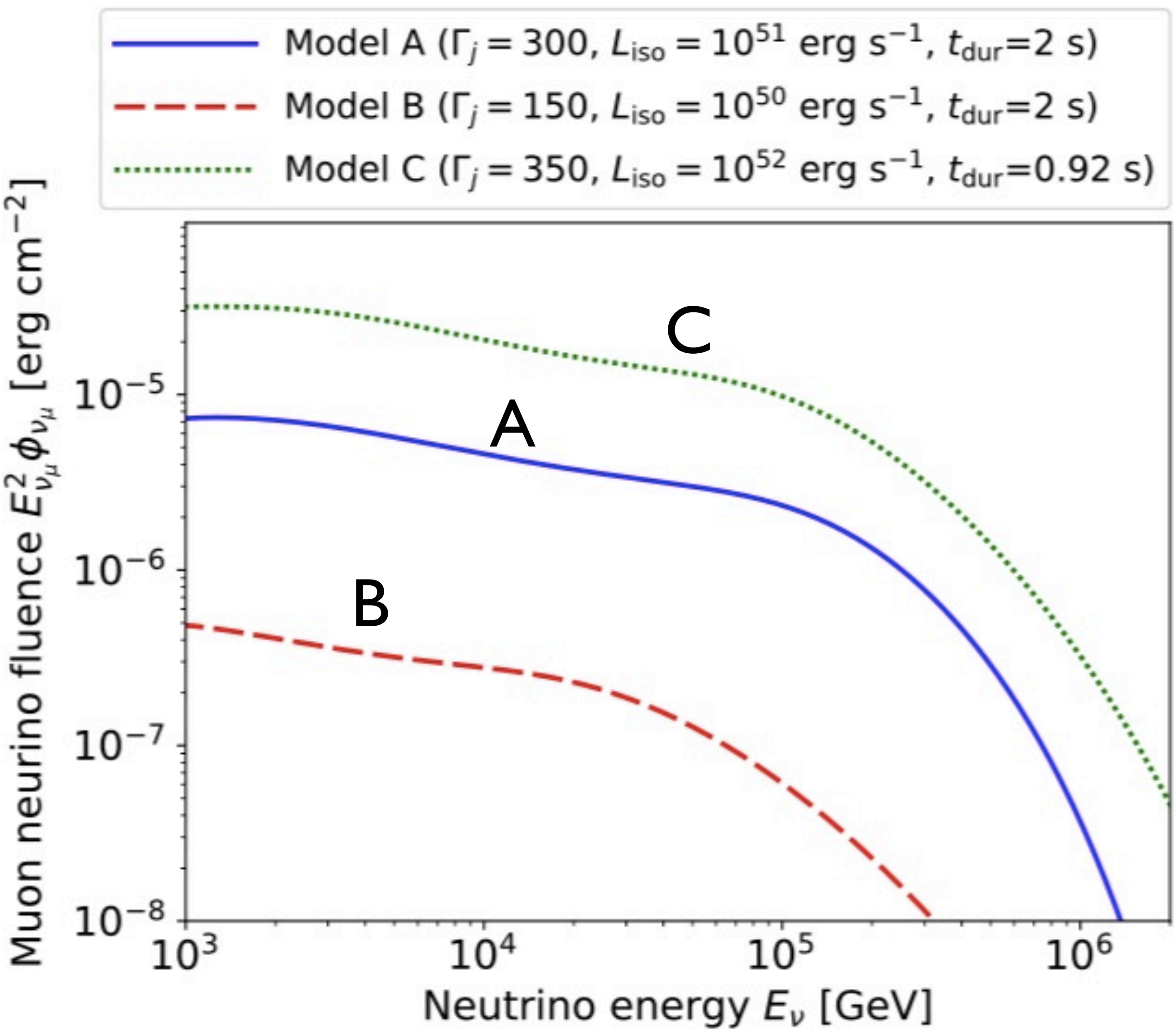


Kimura, Murase, Bartos, Mészáros+18

Allowed parameters for Fermi acceleration by internal & collimation shocks inside ejecta



Spectral nu-flux @ 300 Mpc



Detection probability

TABLE II. Detection probability of neutrinos by IceCube and IceCube-Gen2

Number of detected neutrinos from single event at 40 Mpc			
model	IceCube (up+hor)	IceCube (down)	Gen2 (up+hor)
A	6.6	0.55	29
B	0.36	0.023	1.5

Number of detected neutrinos from single event at 300 Mpc			
model	IceCube (up+hor)	IceCube (down)	Gen2 (up+hor)
A	0.12	9.7×10^{-3}	0.52
B	6.2×10^{-3}	4.2×10^{-4}	0.027

GW+neutrino detection rate [yr^{-1}]		
model	IceCube (up+hor+down)	Gen2 (up+hor)
A	1.1	2.6
B	0.076	0.28

possible ↗ (?)

Kimura, Murase, Bartos, Mészáros+18

21th Century: Multi-Messenger Era

(slide: K. Ioka)

The future is bright for
Multi-messenger Astrophysics

Neil
pointed the way with his pathbreaking initiatives