Relic Neutrinos from Collapsars and Neutron Star Mergers

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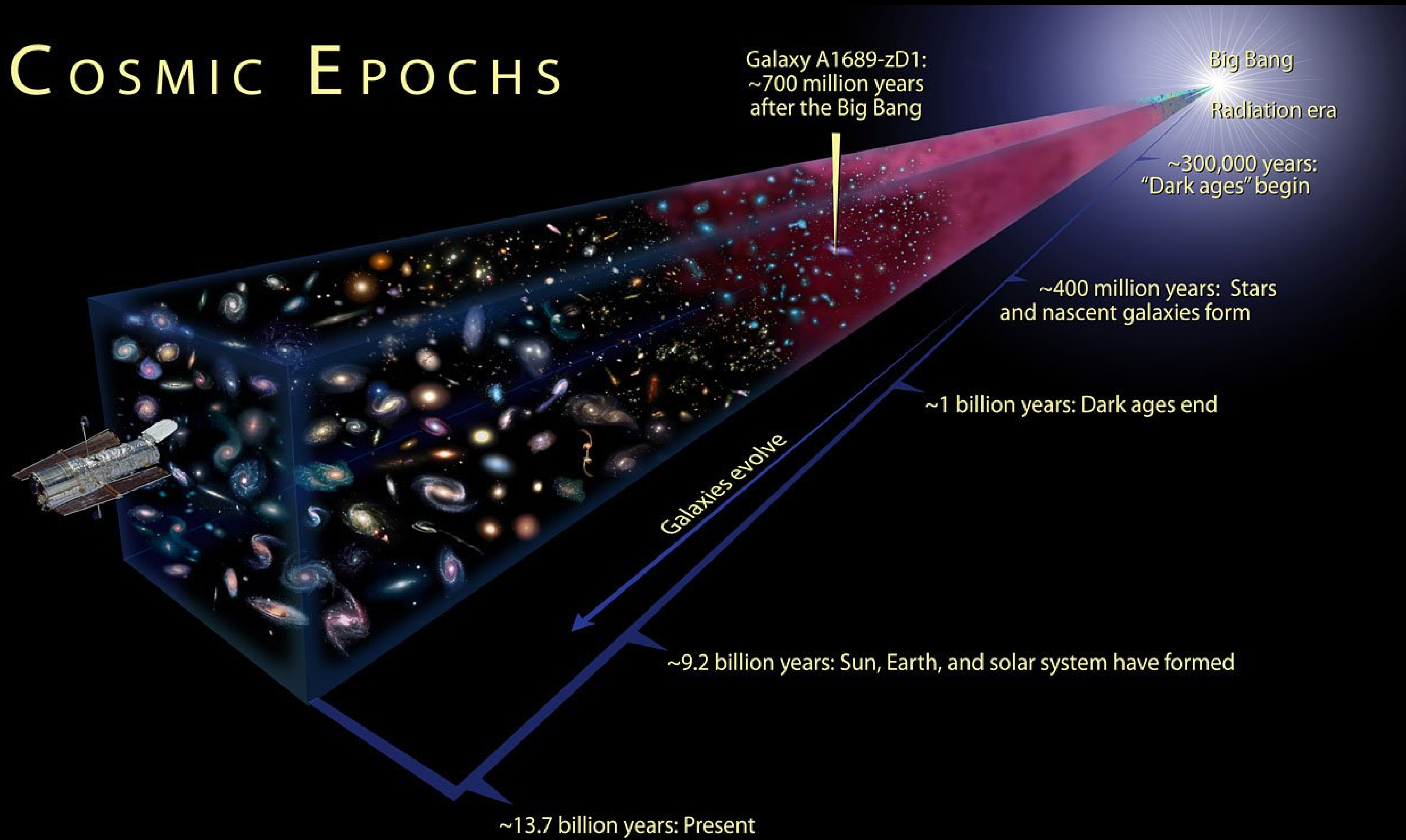
University of Guelph

Neutrinos in Cosmology and Astrophysics
TRIUMF, March 7, 2024

200,000 relic neutrinos from collapsars and
200 relic neutrinos from neutron star mergers
pass through a human body per second

Relic neutrinos



Relic Neutrinos

$$\frac{dF}{dE_o} = c \int (1+z_c) R(z_c) \frac{dN}{dE_\infty} \frac{dt}{dz_c} dz_c$$

Cosmological redshift

Event rates

Neutrino spectrum

Universe expansion

Supernova relic neutrinos

The Diffuse Supernova Neutrino Background is detectable in Super-Kamiokande

Shunsaku Horiuchi,[1,2,3] John F. Beacom,[2,3,4] and Eli Dweck[5]

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(Dated: May 1, 2009)

New Test of Supernova Electron Neutrino Emission using Sudbury Neutrino Observatory Sensitivity to the Diffuse Supernova Neutrino Background

John F. Beacom[1,2,*] and Louis E. Strigari[1,†]

[1] *Department of Physics, The Ohio State University, Columbus, OH 43210, USA*
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(Dated: 18 August 2005)

Modern Physics Letters A | Vol. 35, No. 25, 2030011 (2020) | Brief Review

Review of uncertainties in the cosmic supernova relic neutrino background

G. J. Mathews, L. Boccioli, J. Hidaka, and T. Kajino

Diffuse supernova neutrinos: oscillation effects, stellar cooling and progenitor mass dependence

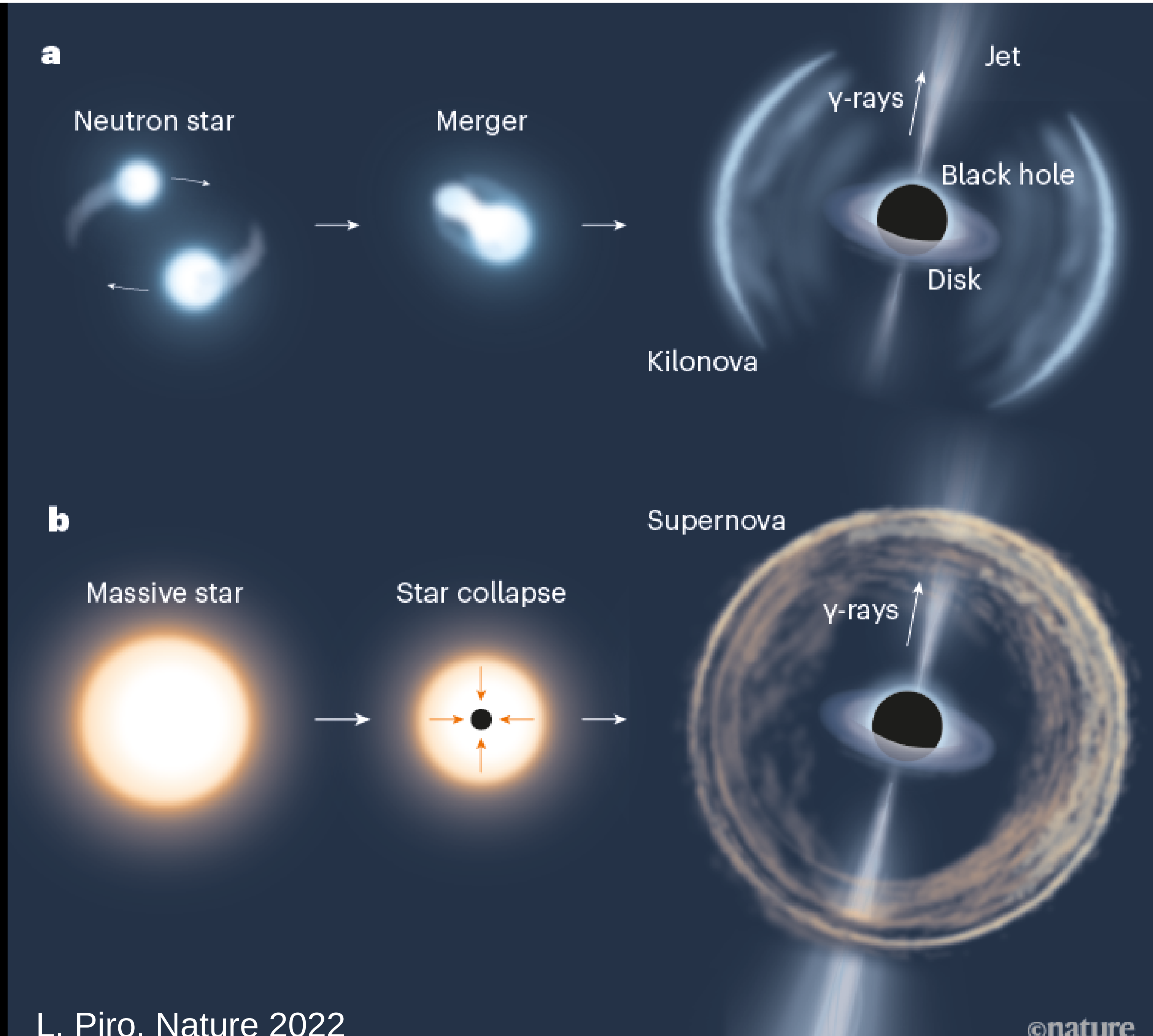
Cecilia Lunardini[1,2] and Irene Tamborra[3]

Published 4 July 2012 • Published under licence by IOP Publishing Ltd

Journal of Cosmology and Astroparticle Physics, Volume 2012, July 2012

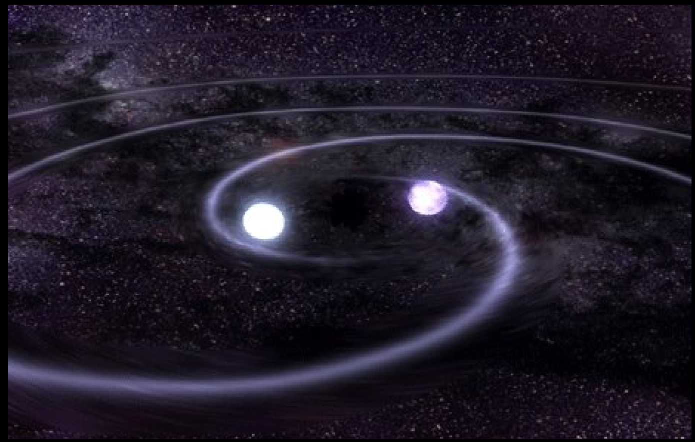
Citation Cecilia Lunardini and Irene Tamborra JCAP07(2012)012

DOI 10.1088/1475-7516/2012/07/012



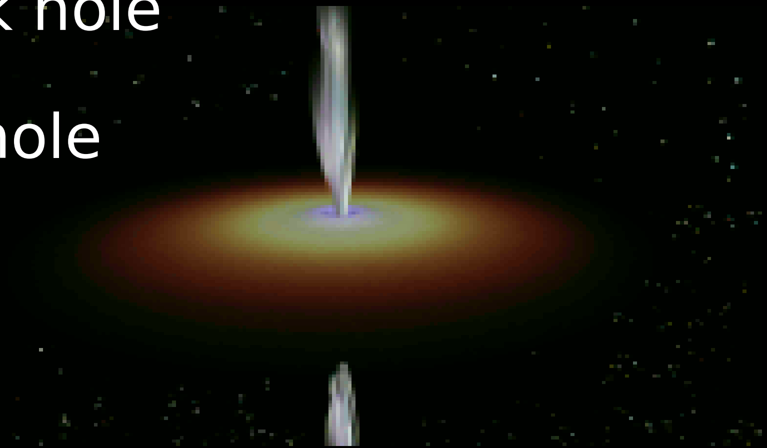
L. Piro, Nature 2022

Scenarios



Mergers:
- Neutron star- Neutron star
- Neutron star -Black Hole

Collapsars :
- rotating massive star collapsing into a black hole



Both scenarios will eventually lead to a black hole accretion disk

Relic Neutrinos

$$\frac{dF}{dE_o} = c \int (1+z_c) R(z_c) \frac{dN}{dE_\infty} \frac{dt}{dz_c} dz_c$$

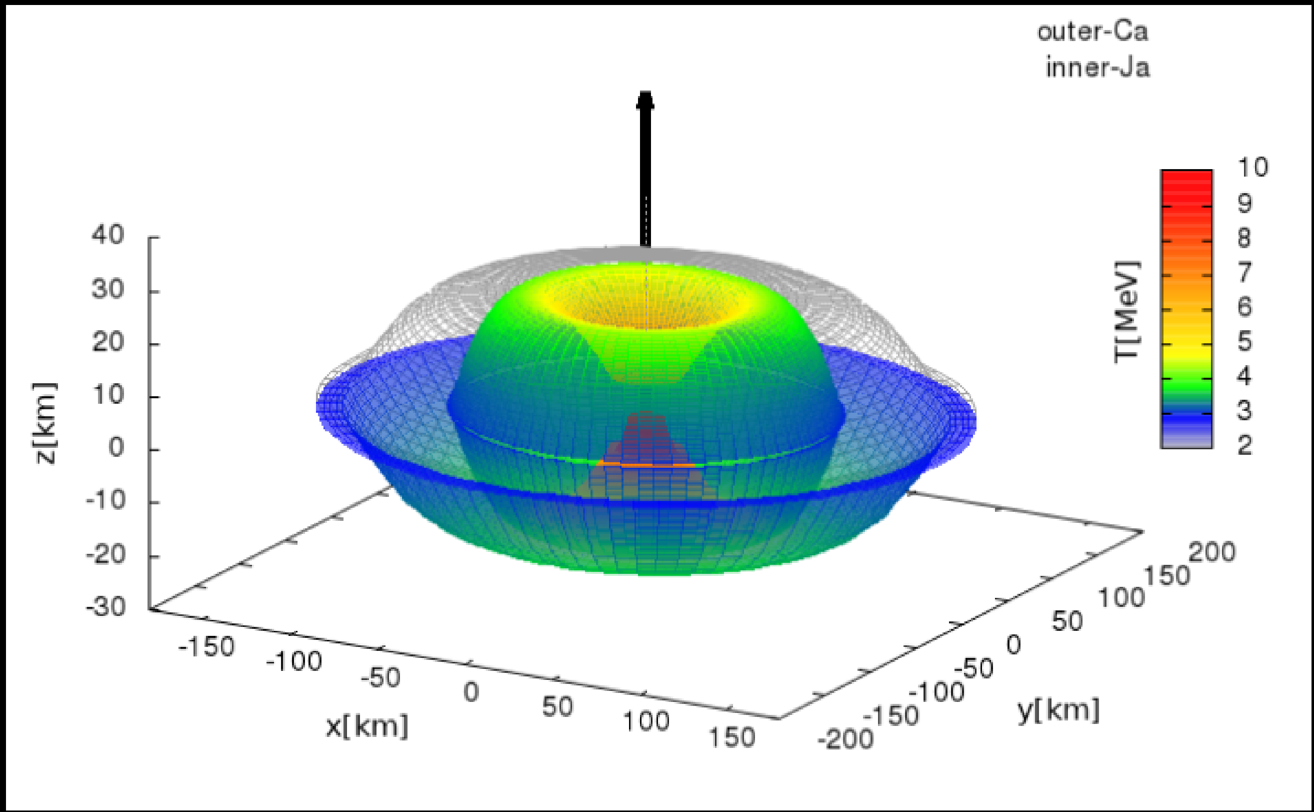
Cosmological redshift

Event rates

Neutrino spectrum

Universe expansion

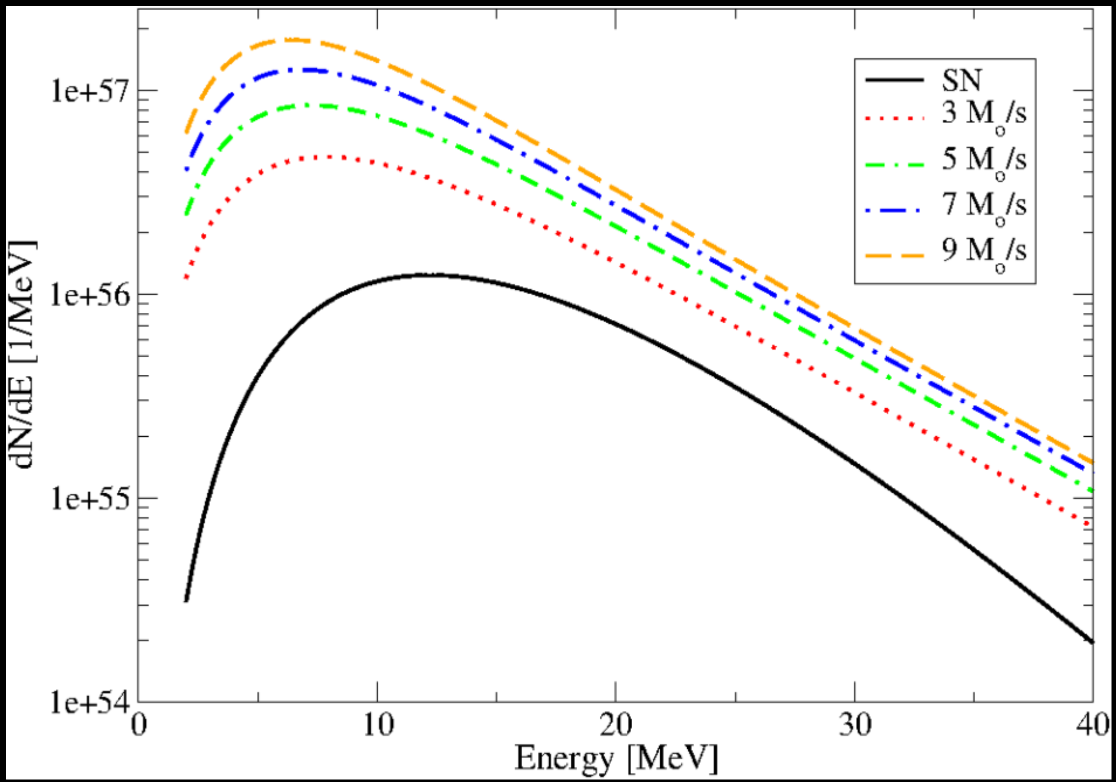
Accretion disk models

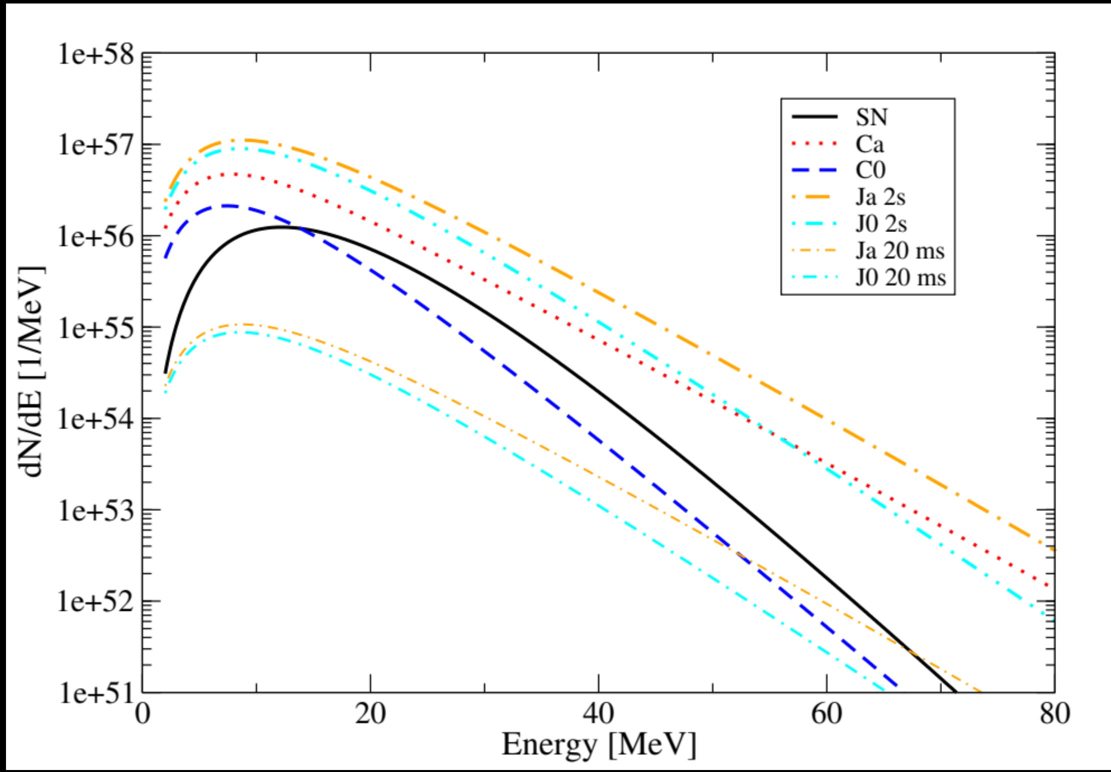


Ca =Steady state, relativistic, NSE, Chen & Belobodorov.

Ja = Steady state, pseudo-Newtonian, NSE, 44Mn, O. Just et al MNRAS, 2015.

Neutrino Spectra from accretion disks





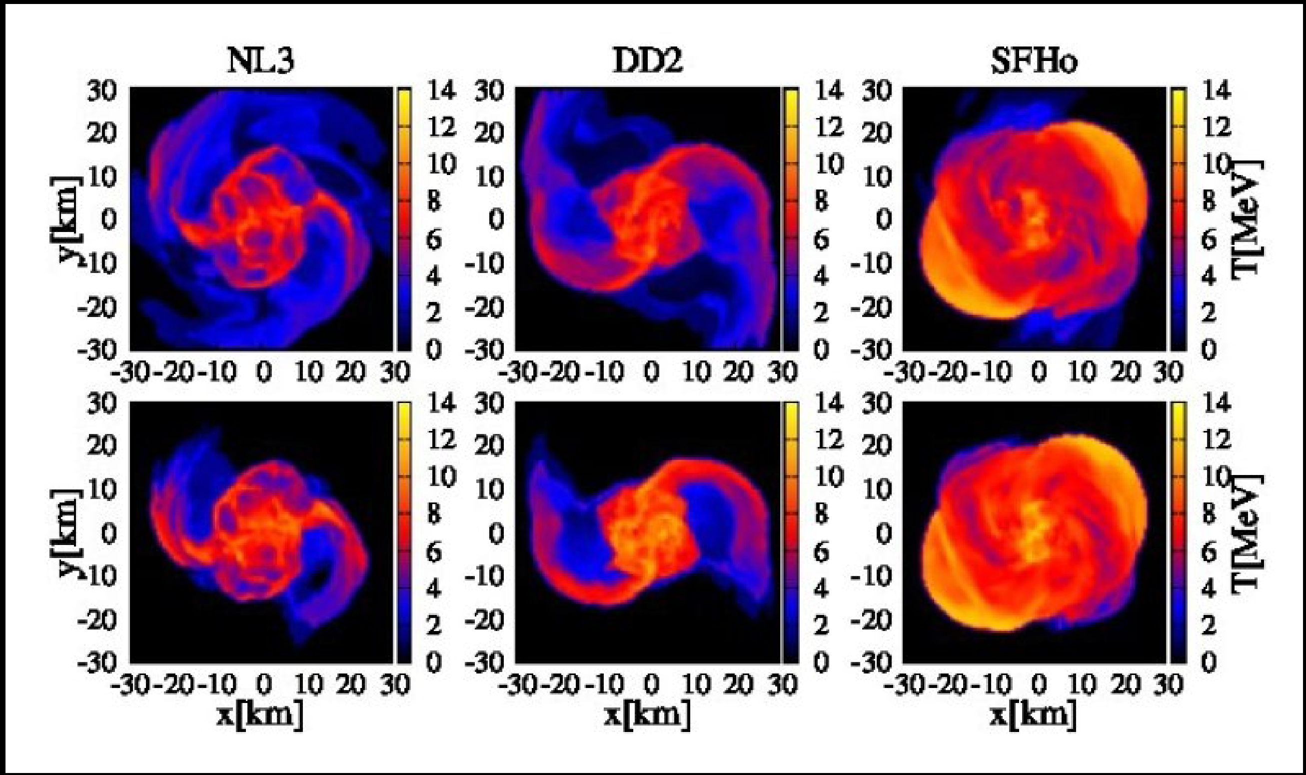
Observed at 10 kpc from the source

T. Schilbach*, O. L. C, McLaughlin PRD (2019)

Neutron Star mergers : EoS

e-neutrino

e-antineutrino



General relativistic, hydrodynamical, magnetized NS-NS
C. Palenzuela et al, PRD 2015, L. Lehner et al CQG 2016

Neutron Star mergers : EoS

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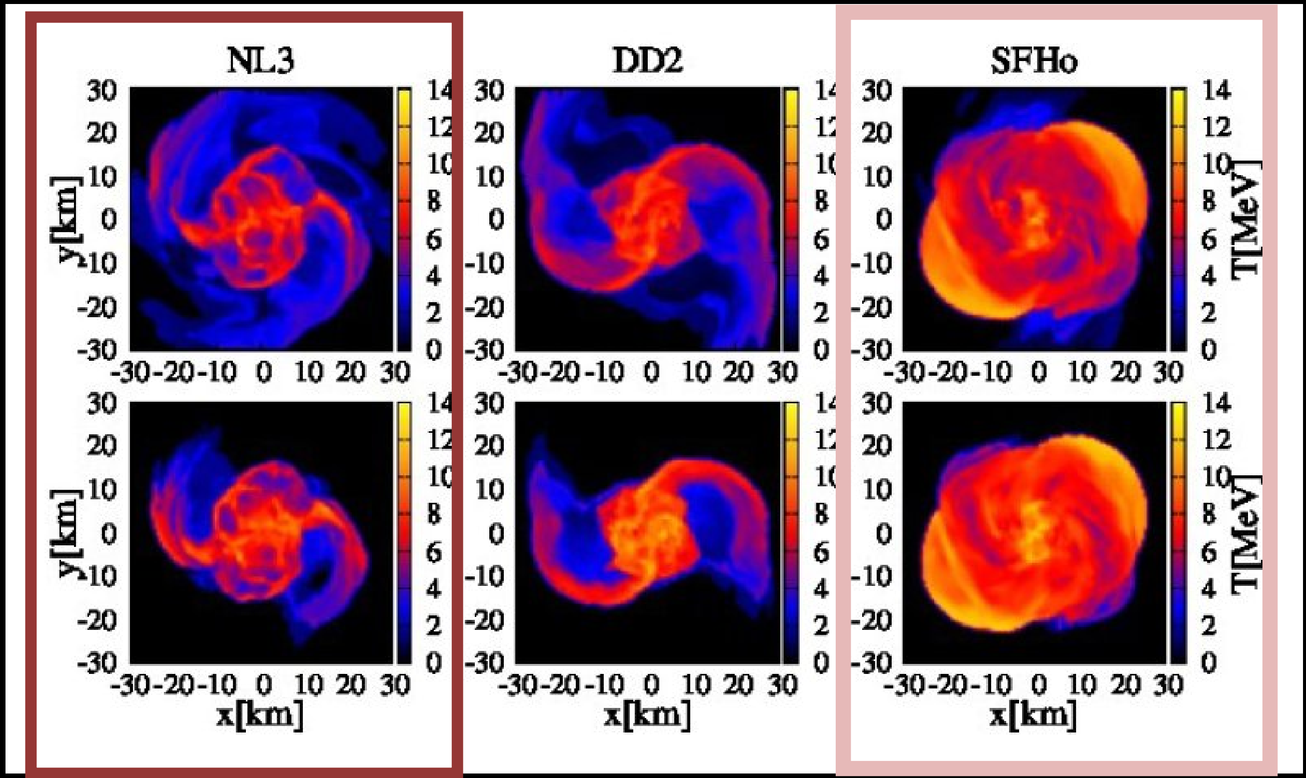
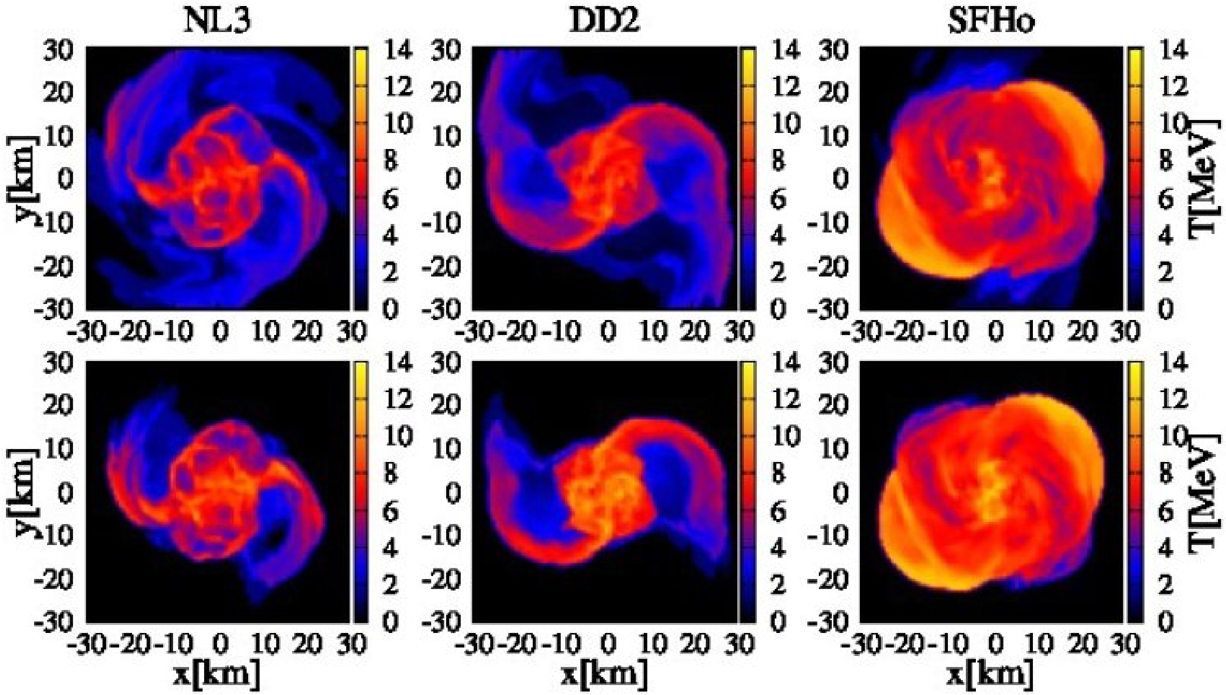


General relativistic, hydrodynamical, magnetized NS-NS
C. Palenzuela et al, PRD 2015, L. Lehner et al CQG 2016

Could we add constraints to the EoS from neutrino detections?

e-neutrino

e-antineutrino



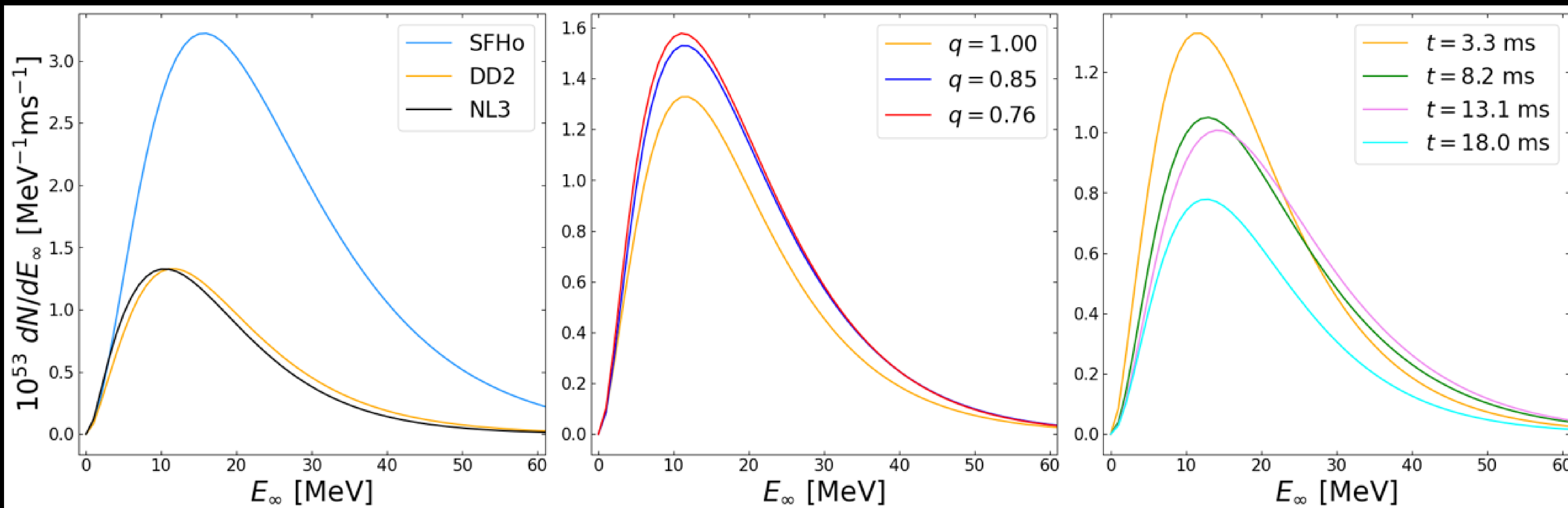
Time [ms]	$\langle E_{\bar{\nu}_e} \rangle$ [MeV]	$\langle E_{\nu_e} \rangle$ [MeV]	$L_{\bar{\nu}_e}$ [10^{53} erg/s]	R_{ν} [#/ms]
2.5 (NL3)	18.5 (22.4)	15.2 (18.3)	0.71	18.1
3.0 (DD2)	18.3 (22.1)	14.6 (17.4)	1.1	28.2
3.2 (SFHo)	24.6 (29.7)	23.5 (28.3)	3.5	120.8

Supernova:
R= 1/ms, E~ 11 MeV,

$L=10^{52}$ erg/s
t=10 sec

Neutrinos in SK: NS-NS merger at 10 kpc

Neutrino spectra from neutron star mergers



EoS (q=1) | Mass ratio (DD2) | Time evolution (q=1,DD2)

$q = m_1/m_2$

P. Deguire* , OLC, L. Lehner, **in progress**

Relic Neutrinos

$$\frac{dF}{dE_o} = c \int (1+z_c) R(z_c) \frac{dN}{dE_\infty} \frac{dt}{dz_c} dz_c$$

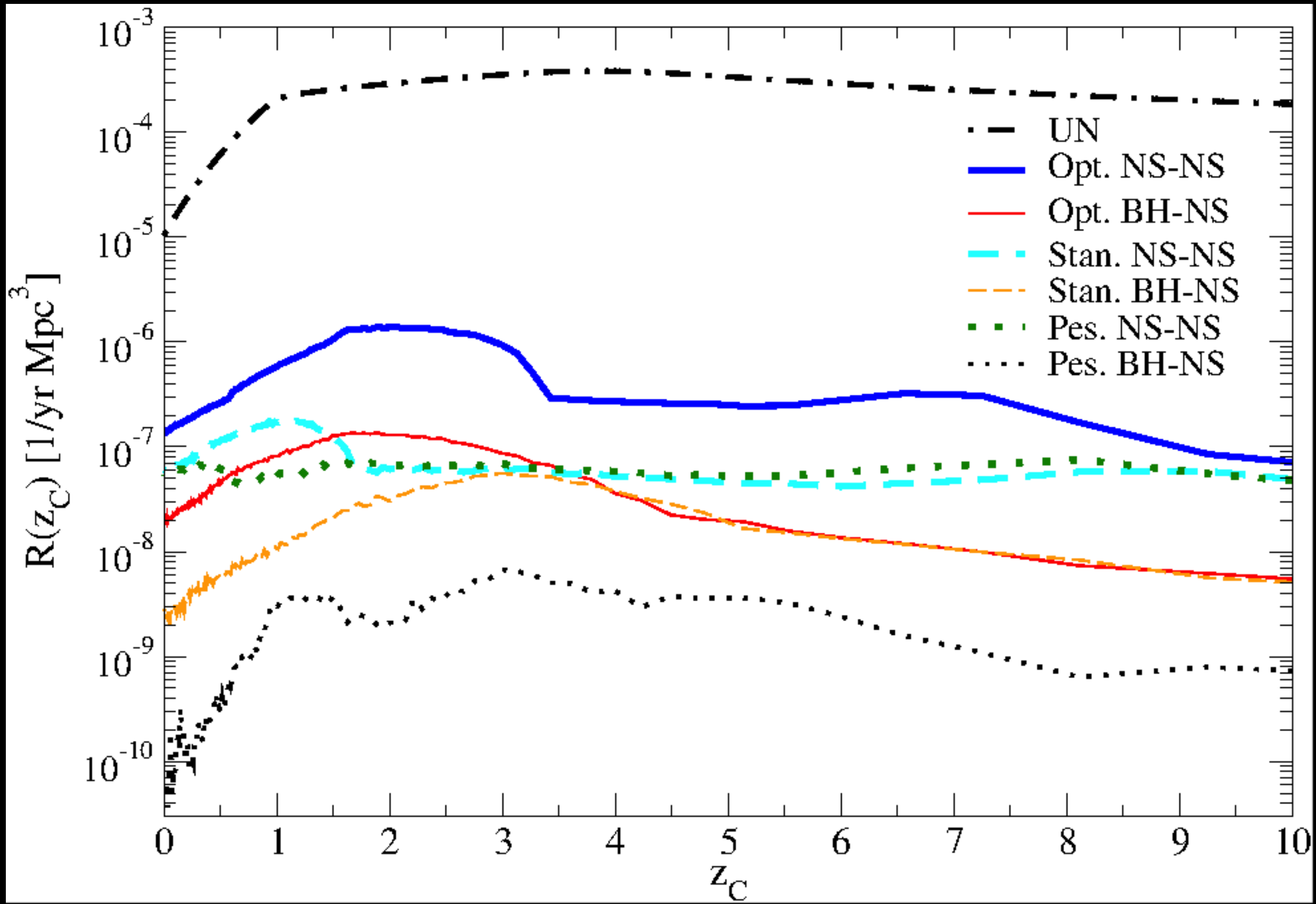
Cosmological redshift

Event rates

Neutrino spectrum

Universe expansion

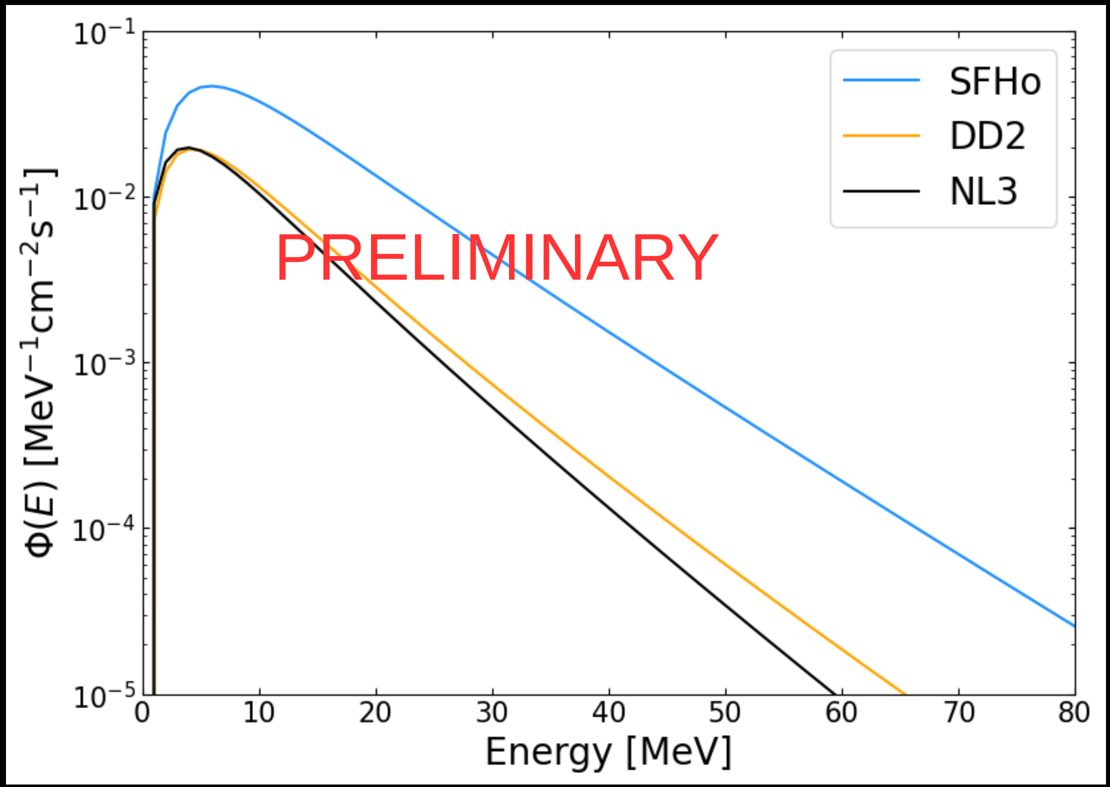
Formation rates

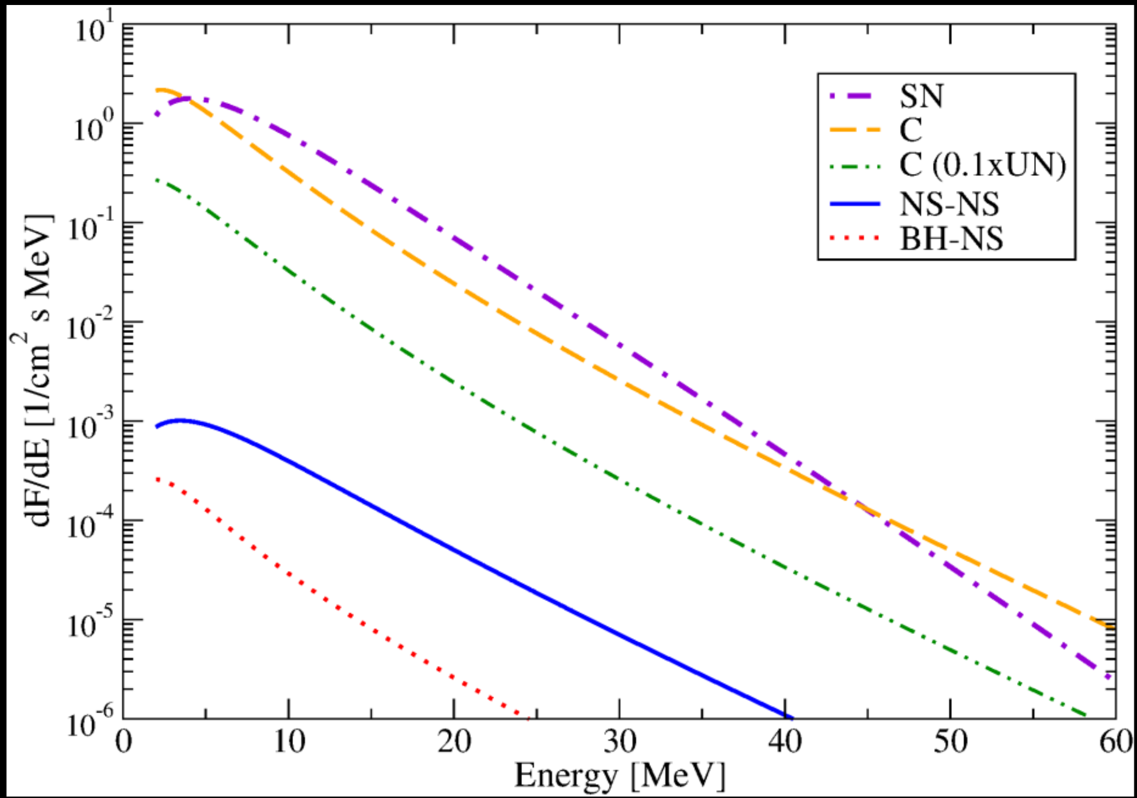


SN and UN rates from GRB burst from *Swift,* Yuksel et al ApJ (2008), PLB (2013)
Merger rates Dominik et al ApJ (2013)

Relic flux

$$\frac{dF}{dE_o} = -c\int_0^{z_{max}} (1+z_C)R(z_C)\frac{dN(E_\infty)}{dE_\infty}\frac{dt_C}{dz_C}dz_C$$





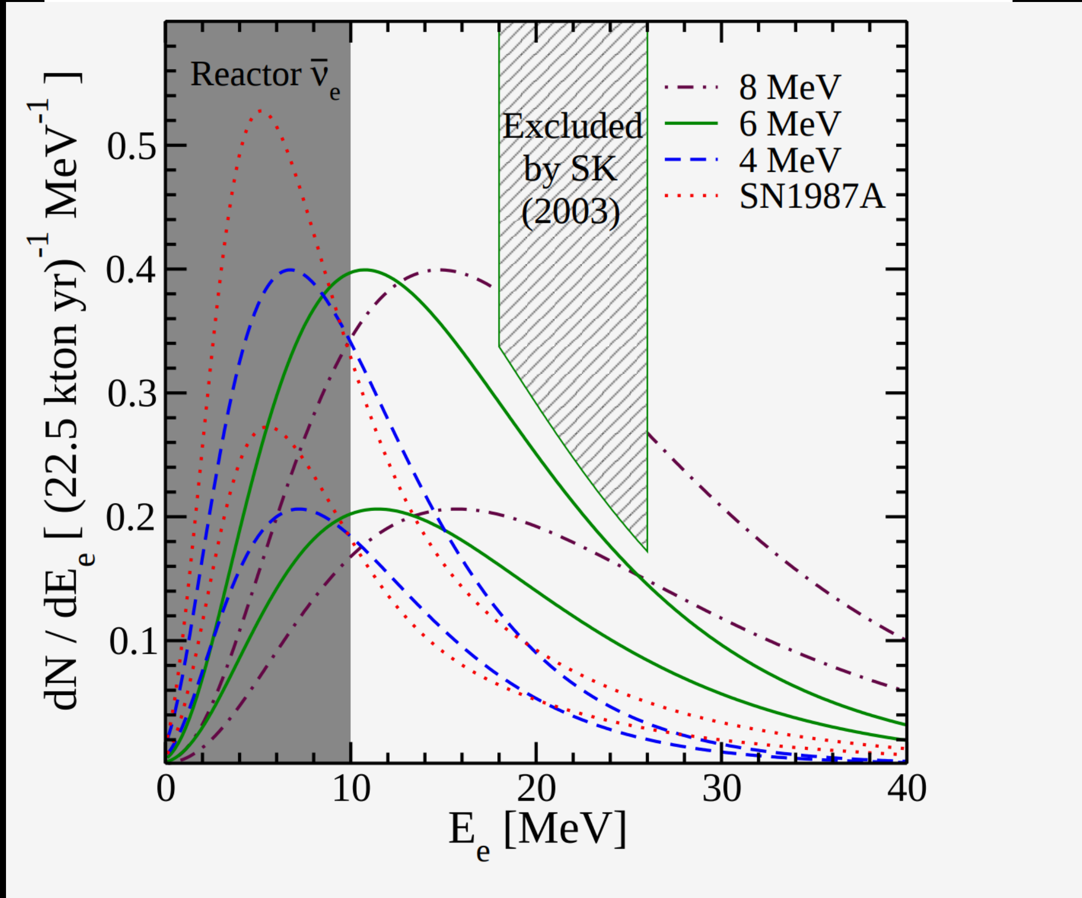
EoS Neutron star mergers (dynamical)
P. Deguire* , OLC, L. Lehner, in progress

Accretion disk: collapsars and mergers
T. Schilbach*, OLC, G. McLauhgin, PRD 2019

How many relic neutrinos per year in SK?

Detetion rates : SN

$$R_D = N_T \int_{E_{th}} \sigma(E_o) \frac{dF}{dE_o} dE_o.$$

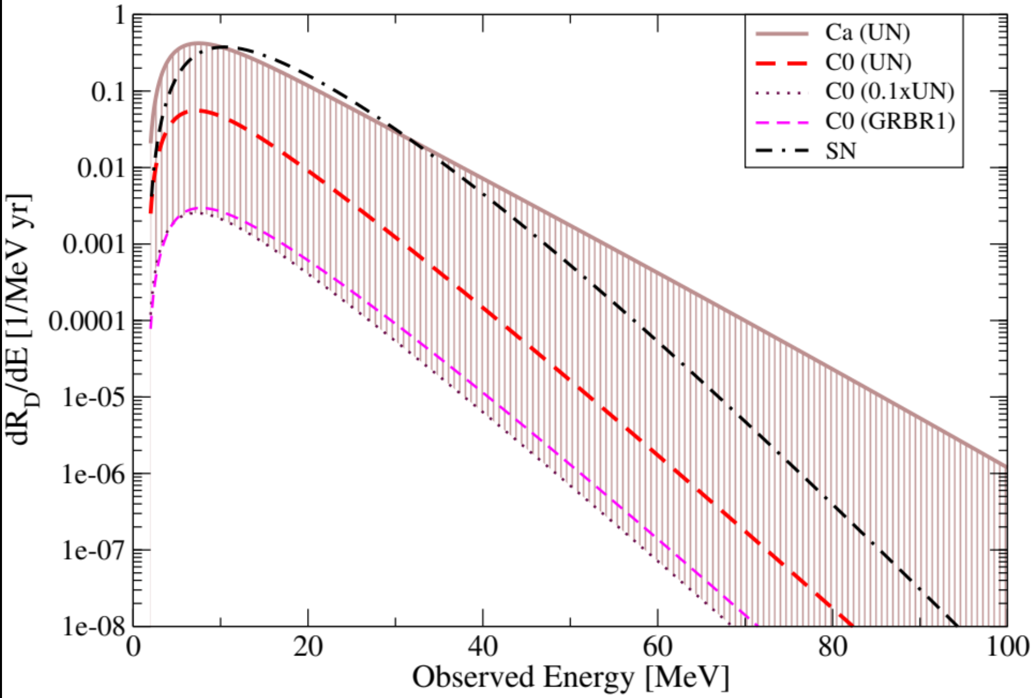


: Predicted DSNB $\bar{\nu}_e$ event rate spectrum in positron energy.

Horiushi, Beacom, Dwek
PRD 2009

Detection Rates

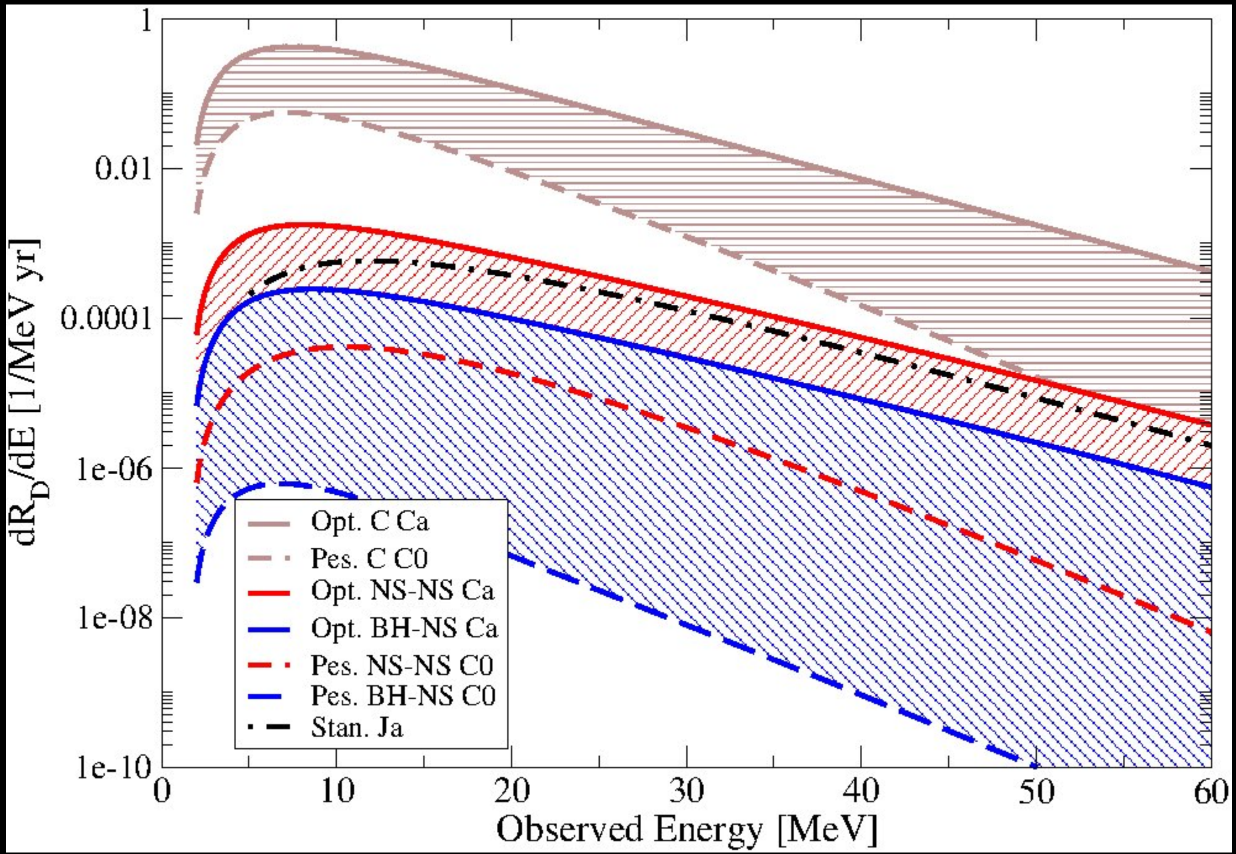
$$R_D = N_T \int_{E_{th}} \sigma(E_o) \frac{dF}{dE_o} dE_o.$$



$E_{\bar{\nu}_e} > 5\text{MeV}$				
R_D [1/yr]	Collapsar		NS-NS ($\times 10^{-3}$)	
$\dot{M}$	$a=0$	$a=0.95$	$a=0$	$a=0.95$
$3M_\odot/s$	0.5	2.3	0.4	1.7
$5M_\odot/s$	0.8	3.4	0.7	2.1
$7M_\odot/s$	1.0	4.4	0.8	2.3
$9M_\odot/s$	1.3	5.2	−−	−−
SN	5.3			
$11 < E_{\bar{\nu}_e} < 30\text{MeV}$				
$3M_\odot/s$	0.2	1.2	0.23	1.1
$5M_\odot/s$	0.3	1.8	0.4	1.3
$7M_\odot/s$	0.4	2.3	0.5	1.4
$9M_\odot/s$	0.5	2.6	−−	−−
SN	3.3			

Disk relic neutrinos at SK and HK

T. Schilbach*, O. L. C, McLaughlin PRD (2019)



Scenario	**Formation Rate**	**Disk Model**	R_D SK [1/yr]	R_D HK [1/yr]
Collapsar	UN	Ca	5.2	91
	UN	C0	0.6	10.5
NS-NS Merger	Opt.	Ca	2.5×10^{-2}	0.43
	Pes.	C0	6.0×10^{-4}	0.01
	Opt.	Ja	3.3×10^{-2}	0.57
	Pes.	J0	4.5×10^{-3}	0.08
	Stan.	Ja	1.0×10^{-2}	0.17
BH-NS Merger	Opt.	Ca	3.6×10^{-3}	6×10^{-2}
	Pes.	C0	5.4×10^{-6}	9×10^{-5}
	Opt.	Ja	4.7×10^{-3}	8×10^{-2}
	Pes.	J0	4.4×10^{-5}	8×10^{-4}

SuperK in 5 years: 3-25 neutrinos from Collapsars
HiperK in 10 years: ~900 from collapsars, 6 from NS-NS

Conclusions

Diffuse neutrinos can provide information on :

- Evolution of compact object mergers and collapsars
- Astrophysical event rates
- EoS constraints

....in the next few years…

More work is needed regarding the extraction of the diffuse background from detectors.

Neutrinos provide information about the explosive stellar mechanisms by direct detection and by their influence on their byproducts (e.g. heavy element synthesis). Potential for relic neutrinos relation to chemical evolution.

Collaborators

- Paul Deguire*, T. Schilbach* (U. Of Guelph)

- G. McLaughlin (North Carolina State University), L. Lehner (Perimeter Institute), C. Palenzuela (University of the Balearic Islands), D. Neilsen (Bringham Young U.), S. Liebling (Long Island U.), E. O’Connor (North Carolina State University)

NSERC
CRSNG