Multi-messenger astronomy and neutrinos

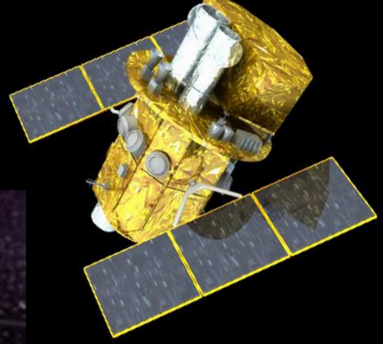
Liliana Caballero
University of Guelph

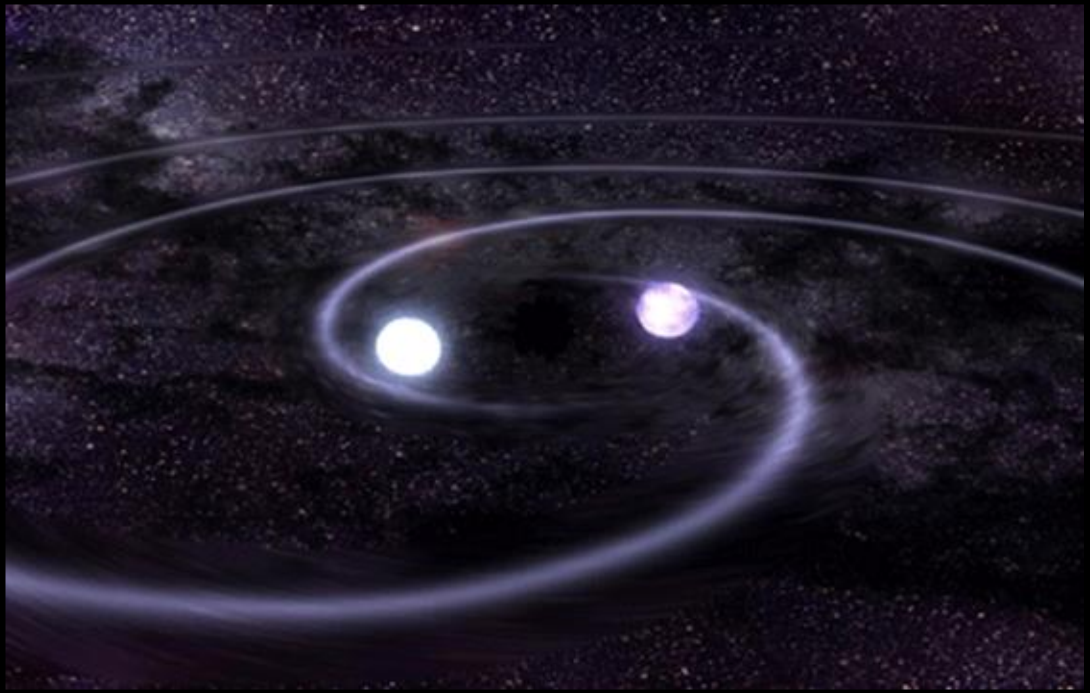
CAP
Neutrino Symposium
June 8 2021

Multi-messengers

Hubble Space Telescope

Swift: Gamma-rays





SuperK: Neutrinos

LIGO: Gravitational Waves

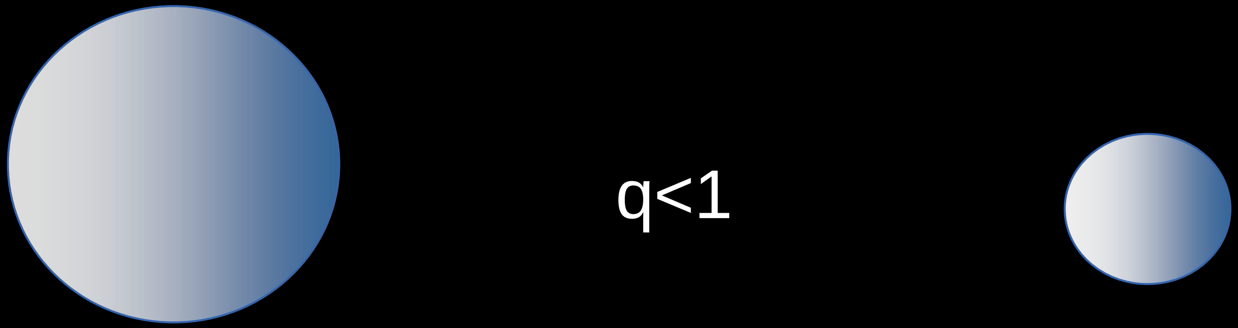
Neutrinos determine the evolution of mergers and supernova, AND the synthesis of elements

Neutrino emission is influenced by the properties of nuclear matter

Neutrino spectra is affected by strong gravitational fields

Neutrino signals combined with other observations will lead to better understanding of several phenomena

Neutrinos and Gravitational waves in Neutron star mergers



$$q = m_1/m_2$$

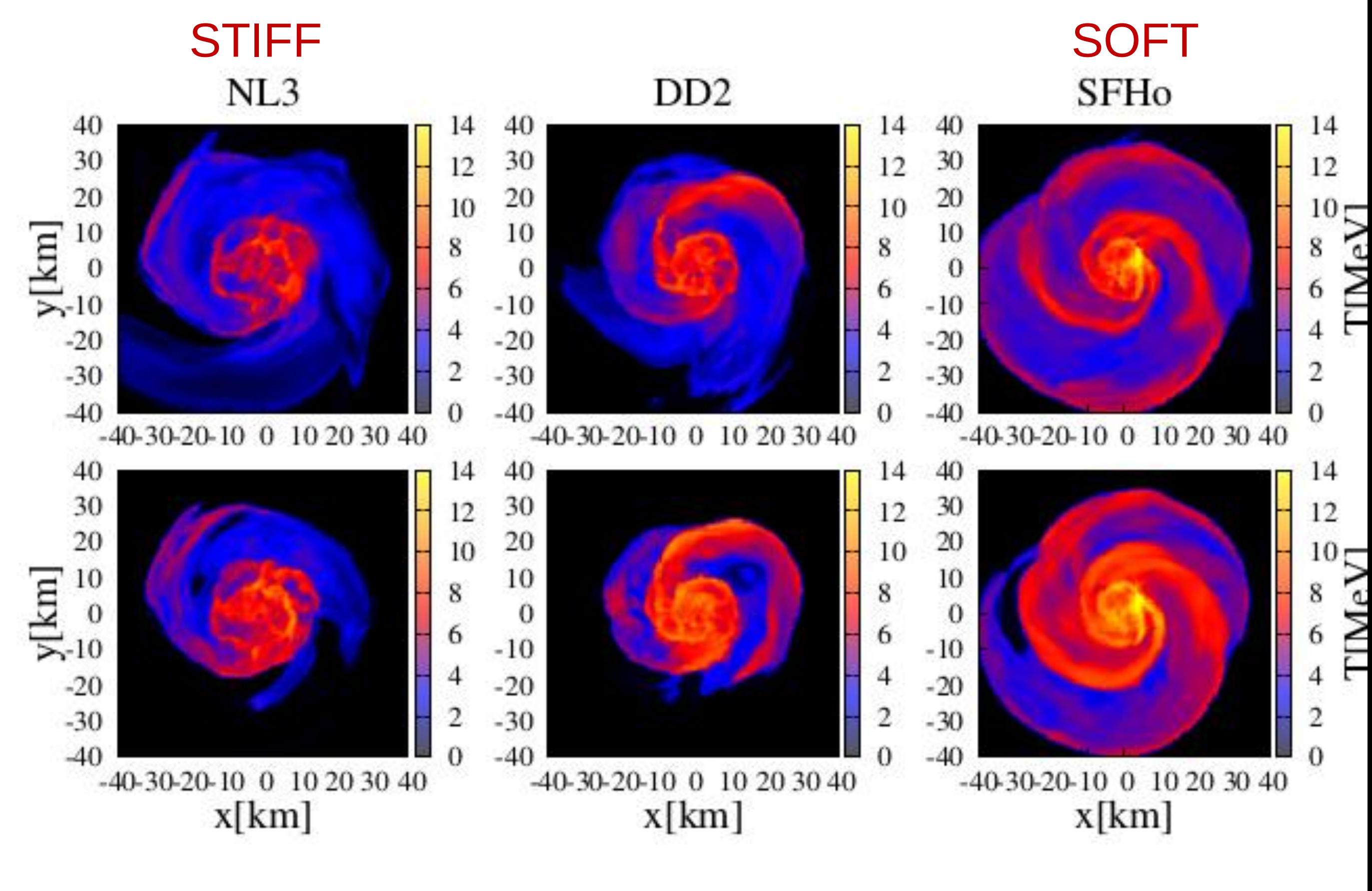
Merger of unequal mass magnetized NSs

(CQG 2016, L. Lehner et al)

Effect of the mass ratio

$q = m_1/m_2$

$q = 0.85$



Tidal effects are more pronounced with stiffer EoS

Hotter matter for softer EoS

Neutrinos in SK: NS-NS merger at 10 kpc

EoS	q	t [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]
NL3	1.0	3.4	18.5 (22.4)	15.2 (18.3)	0.7	18
NL3	0.85	3.0	15.6 (18.7)	12.6 (15.1)	0.8	18
DD2	1.0	3.3	18.3 (22.1)	14.6 (17.4)	1.1	28
DD2	0.85	2.8	18.1 (21.7)	15.1 (18.0)	1.0	25
DD2	0.76	2.4	19.7 (23.9)	14.8 (17.9)	1.3	36
SFHo	1.0	3.5	24.6 (29.7)	23.5 (28.3)	3.5	121
SFHo	0.85	3.9	17.8 (21.3)	15.3 (17.9)	2.0	50

Supernova: R= 1/ms,

L=10^{52} erg/s, E~ 11 MeV

t=10 sec

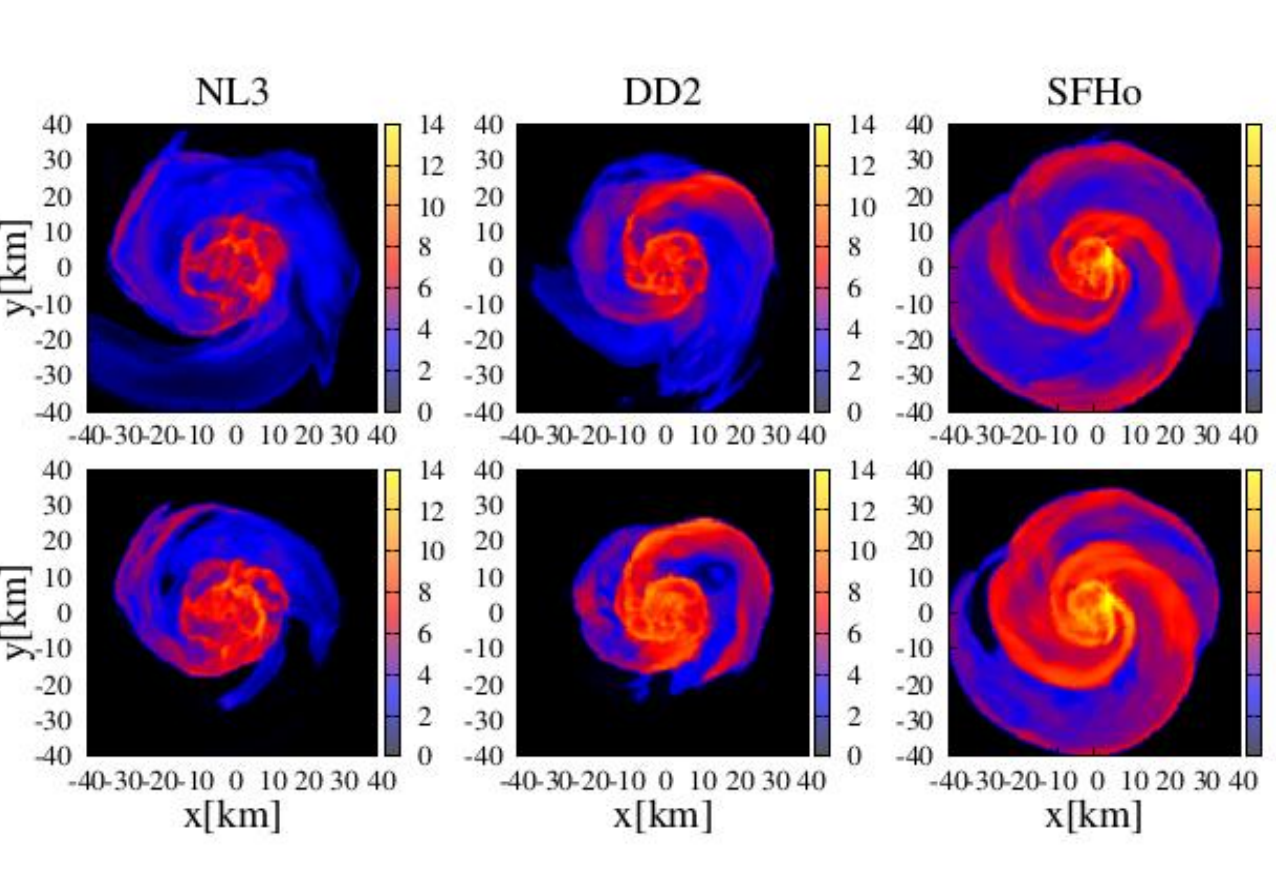
Larger changes with soft EoS when q decreases

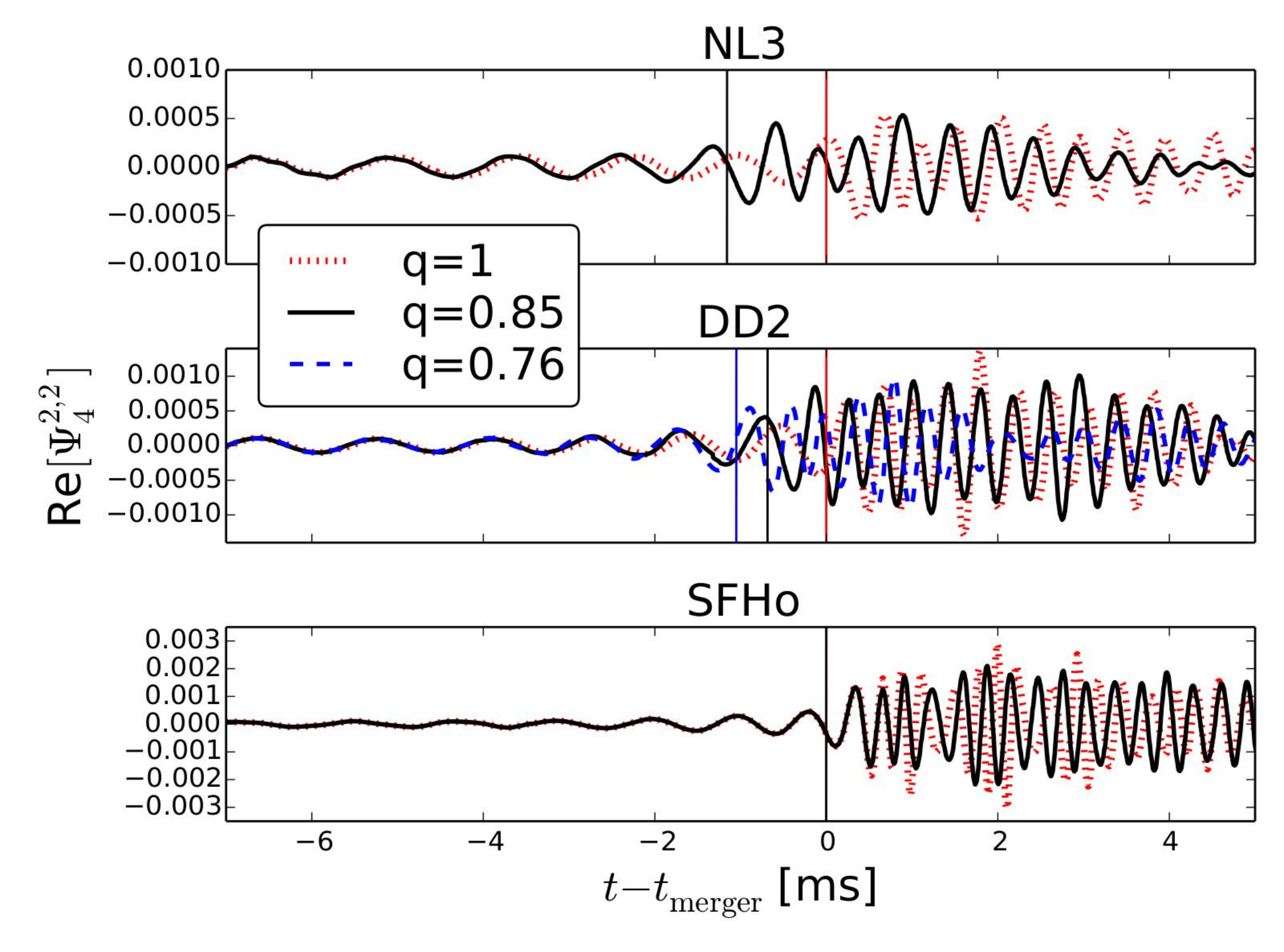
Merger of unequal mass magnetized NSs

(CQG 2016, L. Lehner et al)

Effect of the mass ratio

$q=m_1/m_2$ $q=0.85$



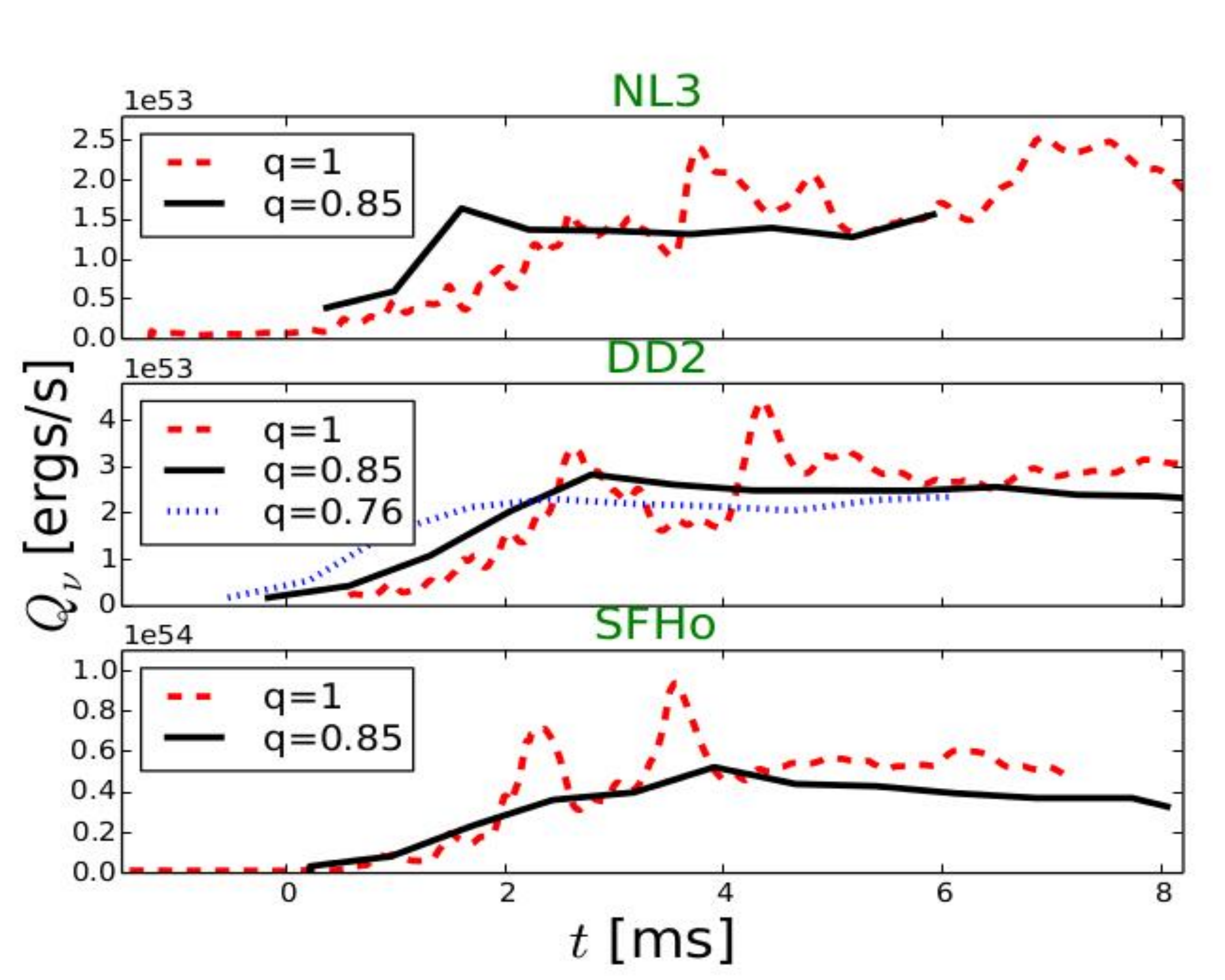


Tidal effects are more pronounced with stiffer EoS

Reduction of the mass ratio disrupts the star earlier

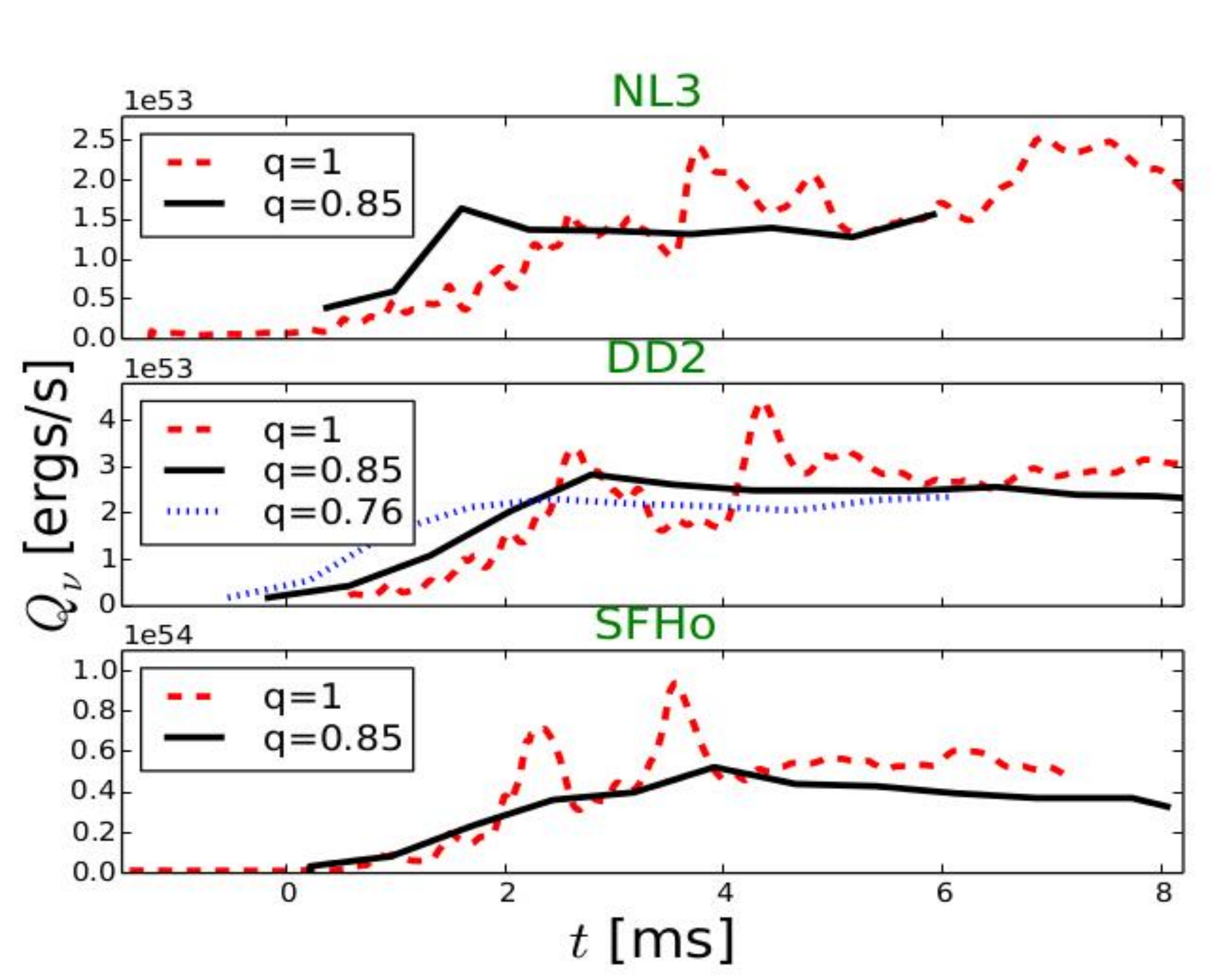
As q decreases the stronger are the tidal effects

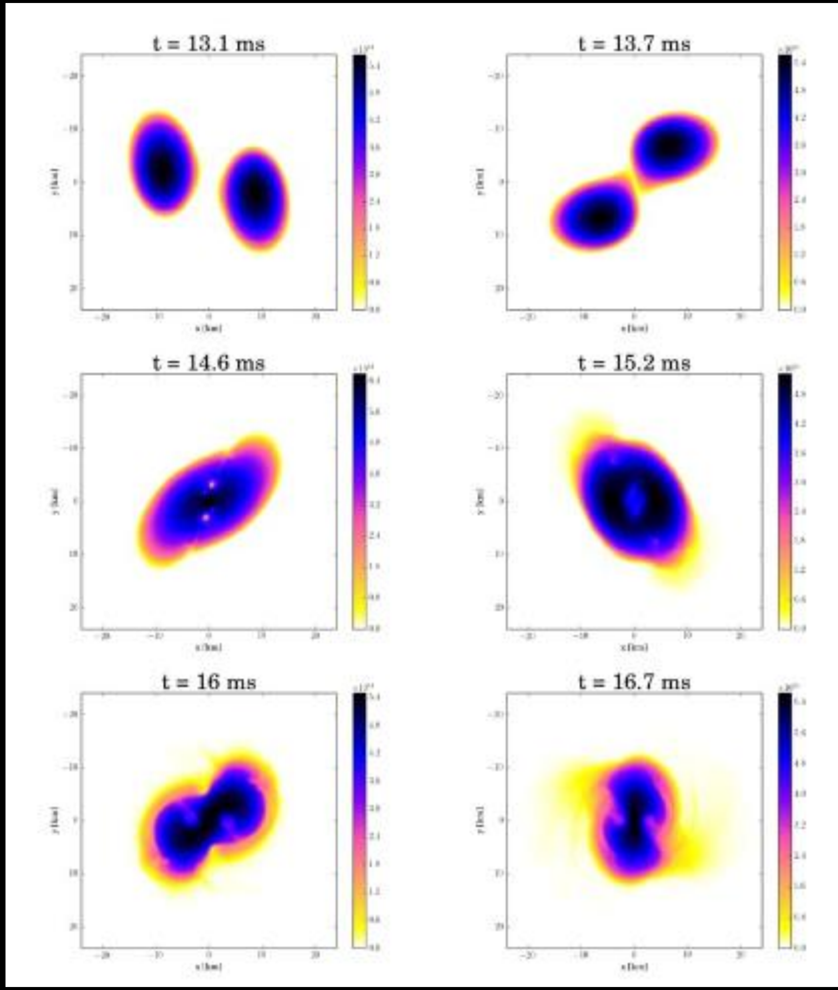
Neutrino luminosity evolution



Luminosity oscillates for q=1

Neutrino luminosity evolution

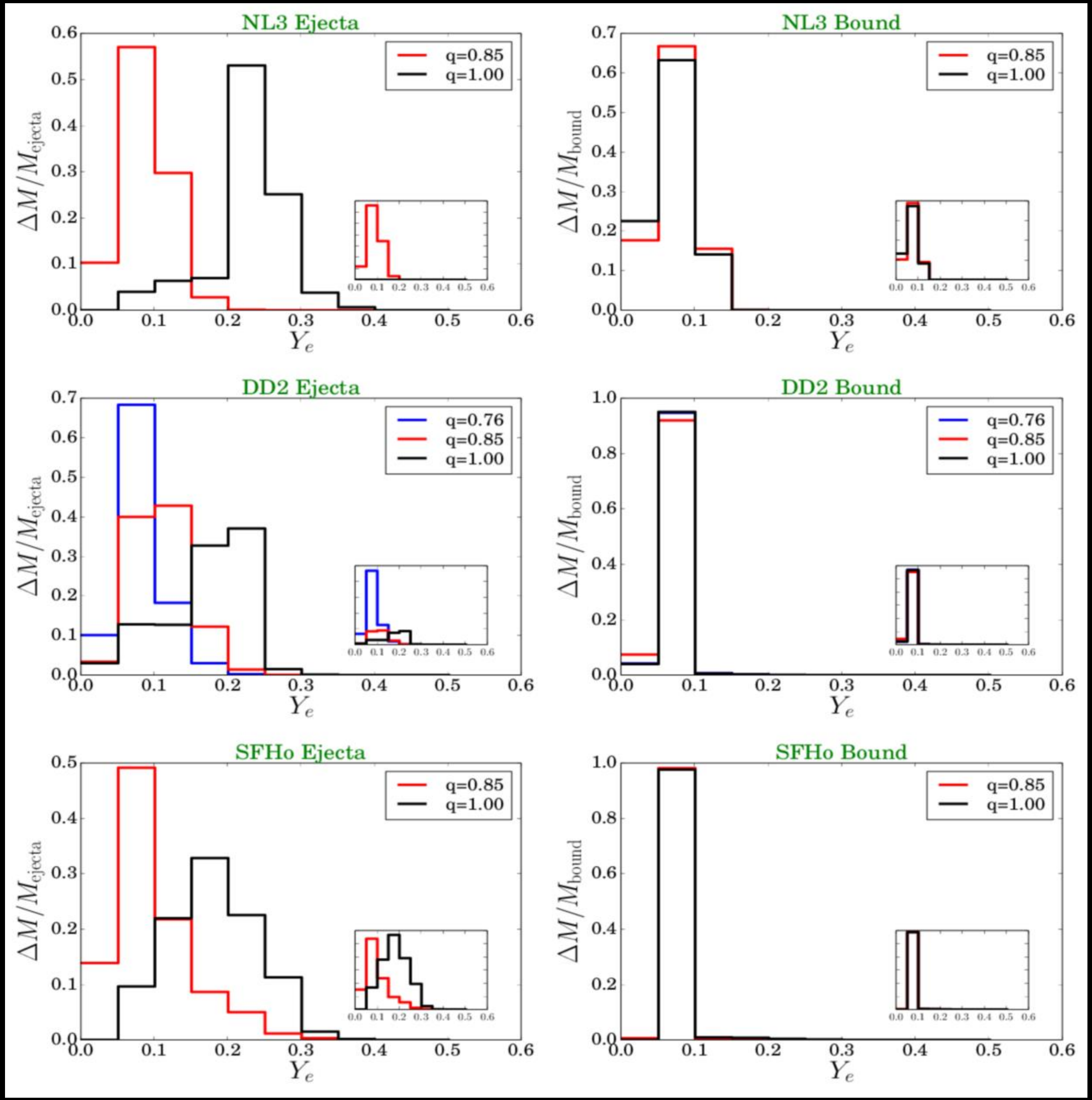




Luminosity oscillates for q=1

Electron fraction distribution for unbound and bound material

Electron fraction decreases
as q decreases,
compatible with
r-process nucleosynthesis
and kilonova



Remarks

- Neutrinos from mergers will not be mistaken for Supernova neutrinos

- We could detect neutrinos from:
  - Milky way and satellite galaxies in SuperK
  - Andromeda (780 kpc) in HyperK

  - Note that 2017 NS-NS merger observation lead to a source distance of 40 Mpc.

Remarks

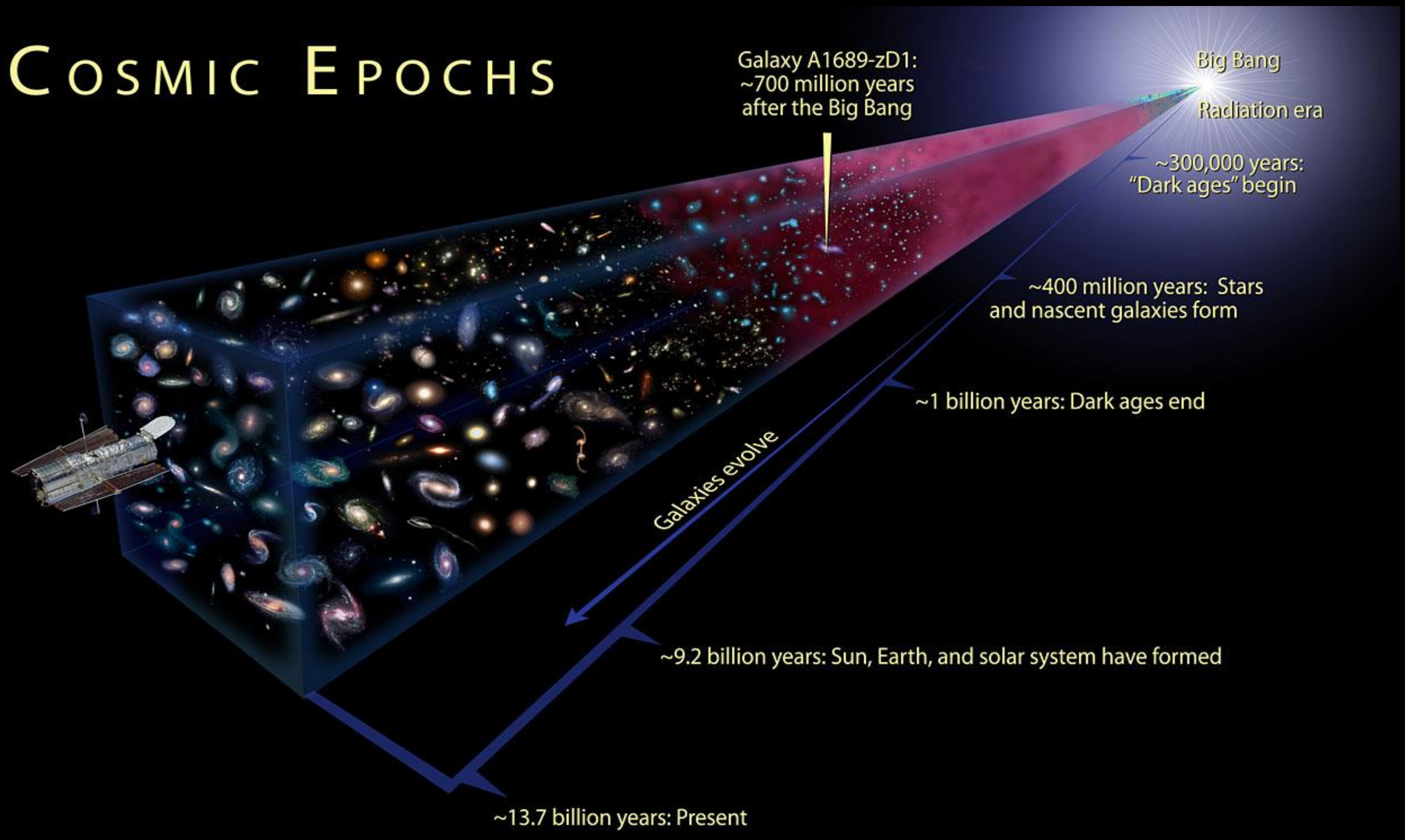
- Soft EOS would produce a stronger (more energetic and more counts) neutrino signal compared to a stiff EOS.

- Neutrino average energies are more sensitive to the mass ratio in the case of a soft EOS.

- Ejecta with Ye < 0.2 could be produced regardless of the EoS

- Given several observations of q and GW neutrinos we could decipher the EoS

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

Relic Neutrinos

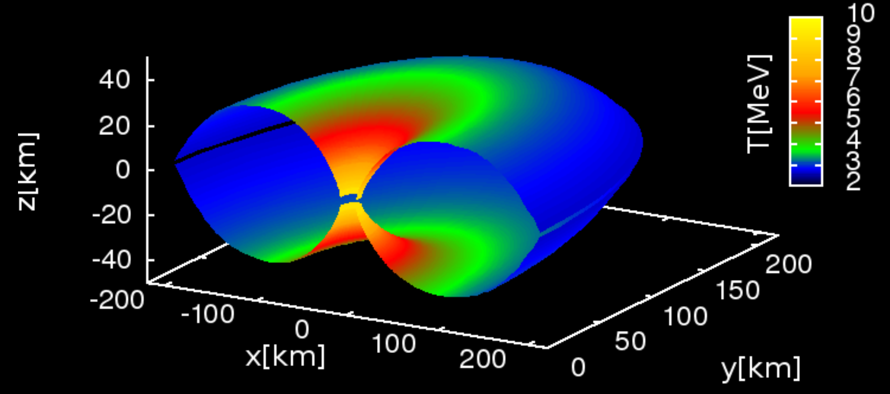
$$\frac{dF}{dE_o} = c\int (1+z_c) R(z_c) \frac{dN}{dE_\infty} \frac{dt}{dz_c} dz_c$$

Cosmological redshift

Event rates

Neutrino spectrum

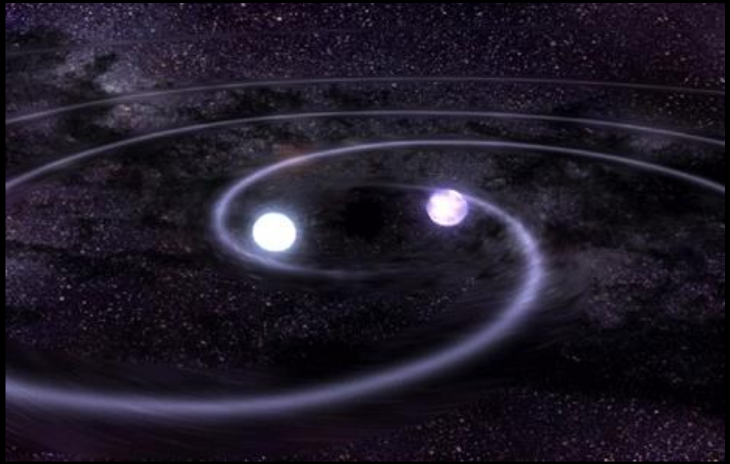
Universe expansion



Accretion disk relic neutrinos

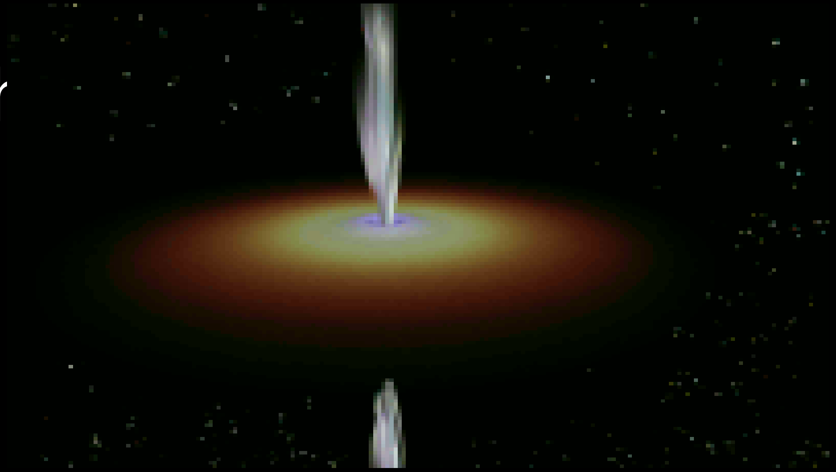
Mergers:

- Neutron star- Neutron star
- Neutron star -Black Hole

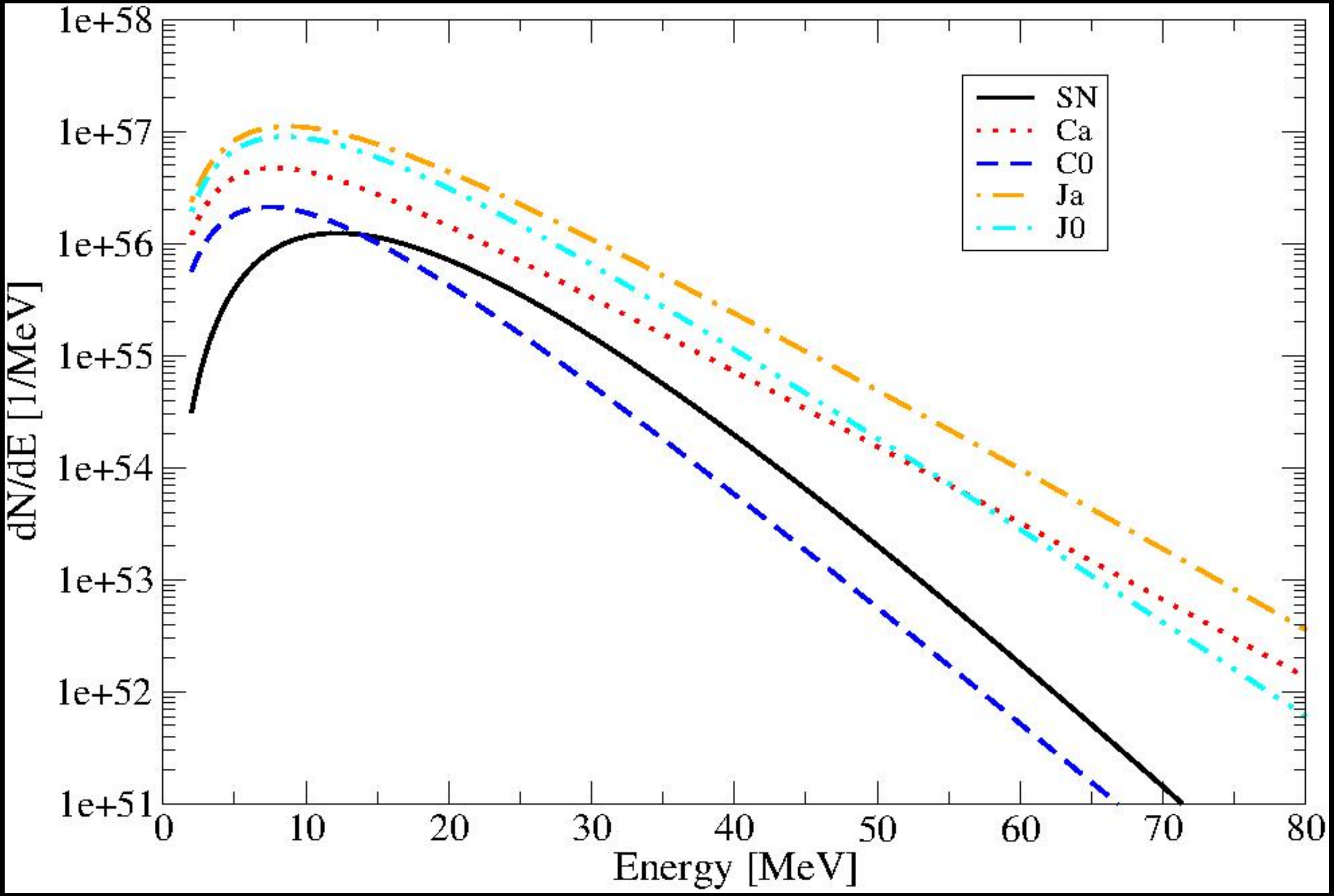


Collapsars :

- rotating massive star collapsing to black h



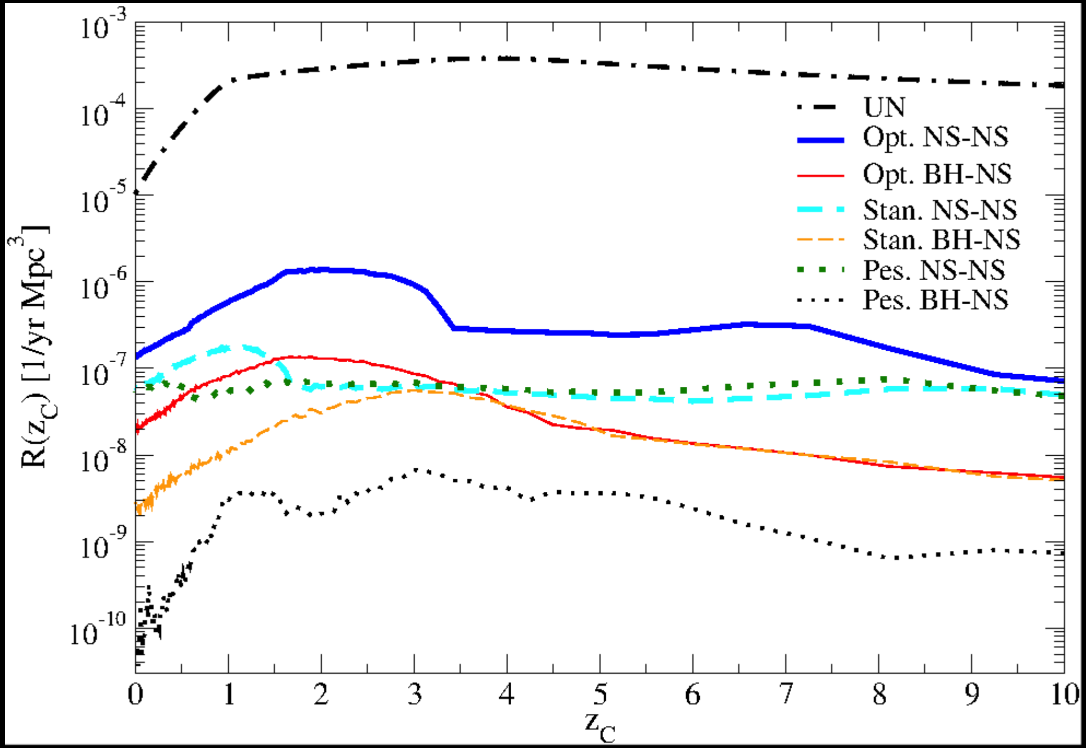
Neutrino Spectra from accretion disks

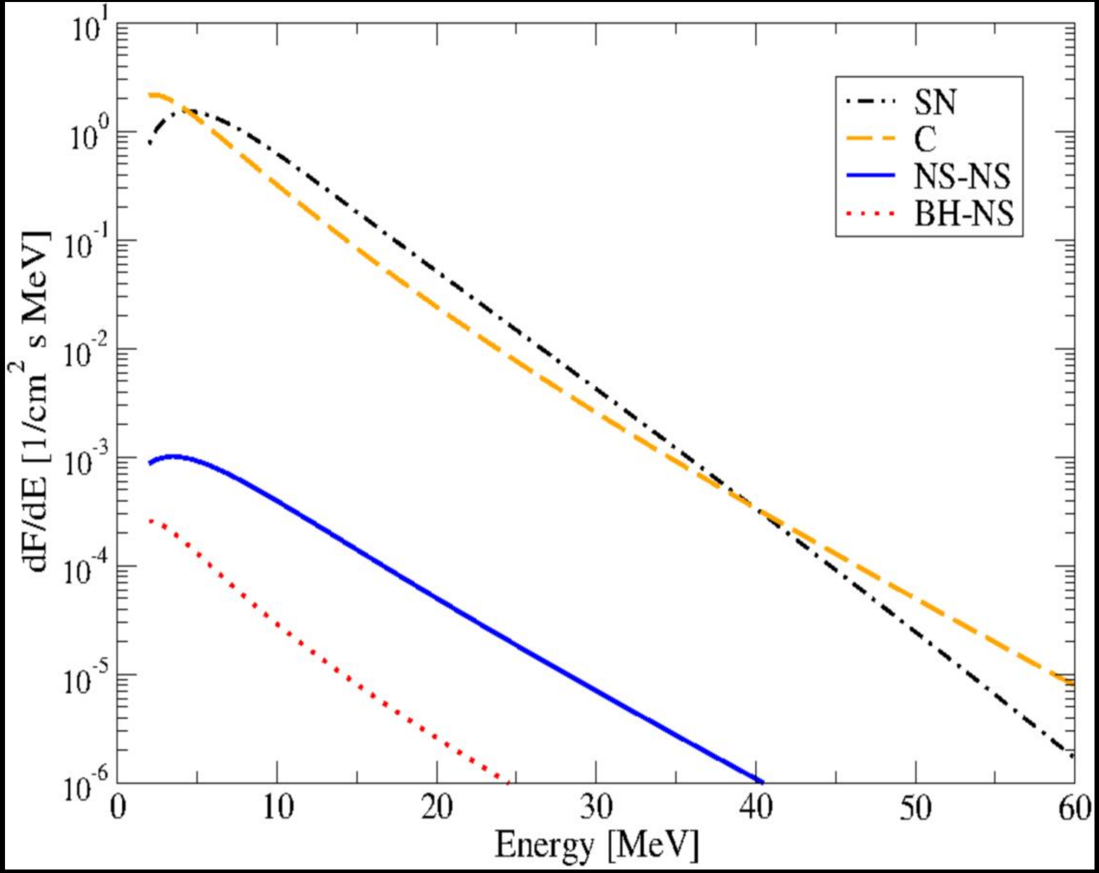


Observed at 10 kpc from the source

T. Schilbach*, O. L. Caballlero, McLaughlin (PRD, 2018)

Accretion disk relic neutrinos

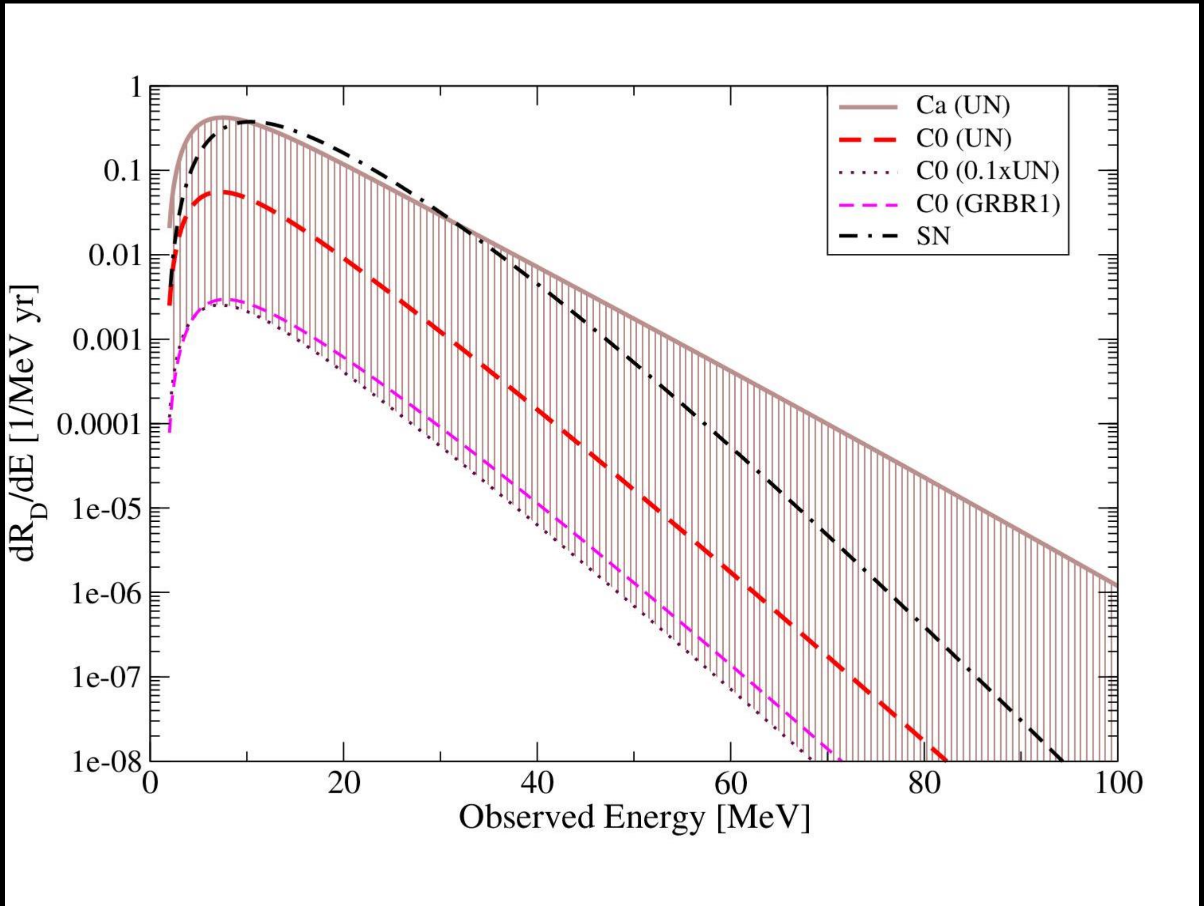




SN and UN rates from GRB burst from *Swift*,
Yuksel et al ApJ (2008), PLB (2013)
Merger rates Dominik et al ApJ (2013)

Collapsar relic neutrinos at SuperK and HyperK

T. Schilbach*, O. L. Caballero, McLaughlin (PRD, 2018)



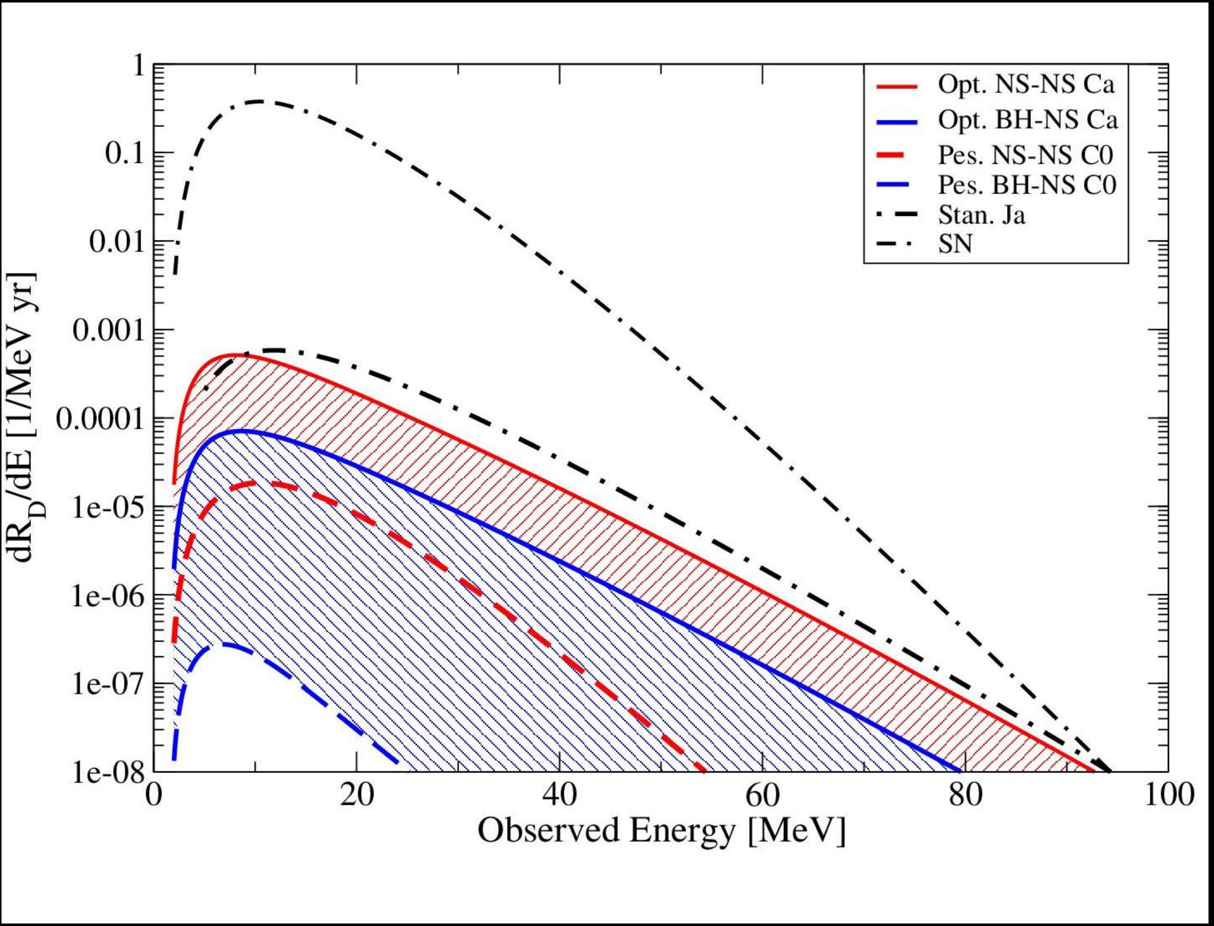
Scenario	Formation Rate	Disk Model	$\dot{M}$ $[M_\odot/s]$	R_D SK [1/yr]	R_D HK [1/yr]
Collapsar	UN	Ca	9	5.2	91
	0.1xUN	C0	3	0.02	0.35
NS-NS Merger	Opt.	Ca	7	7.0×10^{-3}	0.12
	Pes.	C0	3	2.7×10^{-4}	0.004
	Opt.	Ja	-	3.3×10^{-2}	0.57
	Pes.	J0	-	4.5×10^{-3}	0.08
	Stan.	Ja	-	1.0×10^{-2}	0.17
BH-NS Merger	Opt.	Ca	7	1.0×10^{-3}	1.7×10^{-2}
	Pes.	C0	3	2.4×10^{-6}	4.2×10^{-5}
	Opt.	Ja	-	4.7×10^{-3}	8×10^{-2}
	Pes.	J0	-	4.4×10^{-5}	8×10^{-4}

SuperK in 5 years: 0.2-25 neutrinos from Collapsars

HiperK in 10 years: ~900 from collapsars, 6 from NS-NS

Merger relic neutrinos at SuperK and HyperK

T. Schilbach*, O. L. Caballlero, McLaughlin (2018)



Scenario	Formation Rate	Disk Model	$\dot{M}$ $[M_\odot/\text{s}]$	R_D SK [1/yr]	R_D HK [1/yr]
	UN	Ca	9	5.2	91
Collapsar	0.1xUN	C0	3	0.02	0.35
	Opt.	Ca	7	7.0×10^{-3}	0.12
NS-NS	Pes.	C0	3	2.7×10^{-4}	0.004
Merger	Opt.	Ja	-	3.3×10^{-2}	0.57
	Pes.	J0	-	4.5×10^{-3}	0.08
	Stan.	Ja	-	1.0×10^{-2}	0.17
	Opt.	Ca	7	1.0×10^{-3}	1.7×10^{-2}
BH-NS	Pes.	C0	3	2.4×10^{-6}	4.2×10^{-5}
Merger	Opt.	Ja	-	4.7×10^{-3}	8×10^{-2}
	Pes.	J0	-	4.4×10^{-5}	8×10^{-4}

SuperK in 5 years: 0.1-25 neutrinos from Collapsars
HiperK in 10 years: ~900 from collapsars, 2 from NS-NS

Conclusions

This is a new era in Astronomy: neutrino physics expertise is integral to the success of multi-messenger studies.

Experimental facilities around the world will bring insights on nuclear properties at an unprecedented scale.

Neutrinos provide information about the explosive stellar mechanisms by direct detection and by their influence on their by-products (e.g. heavy element synthesis).

Neutrinos from the past can tell us about the star formation rate, mergers and collapsar rates, and cosmic metallicity.

Collaborators

- Tyson Schilbach* (U. Of Guelph), G. McLaughlin (North Carolina State University)
- Luis Lehner (Perimeter Institute), Carlos Palenzuela (University of the Balearic Islands), David Neilsen (Bringham Young U.), Steve Liebling (Long Island U.), Evan O’Connor (North Carolina State University)

NSERC
CRSNG