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# Search for neutrino counterparts of cataloged gravitational-wave events detected by Advanced-LIGO and Virgo during run O2 with ANTARES

M.Colomer Molla, Christophe Baret, A. Coleiro, D. Dornic, T. Pradier

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# Search for neutrino counterparts of gravitational-wave events with ANTARES



ICRC 2019, Madison  
Marta Colomer Molla,  
On behalf of the ANTARES collaboration



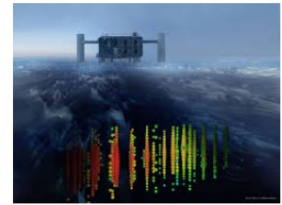


# The ANTARES neutrino telescope in the multi-messenger context

## Multi-messenger approach:

Look for neutrinos in coincidence in space and time with signals detected by other observatories.

- Background reduction
- Increase of discovery potential
- Full sky search

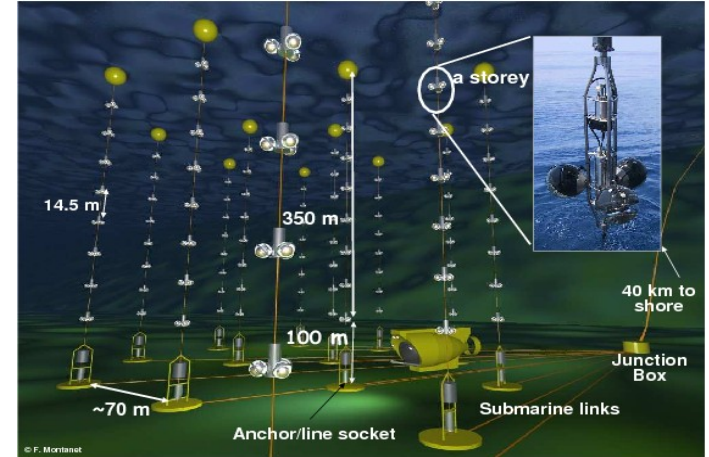
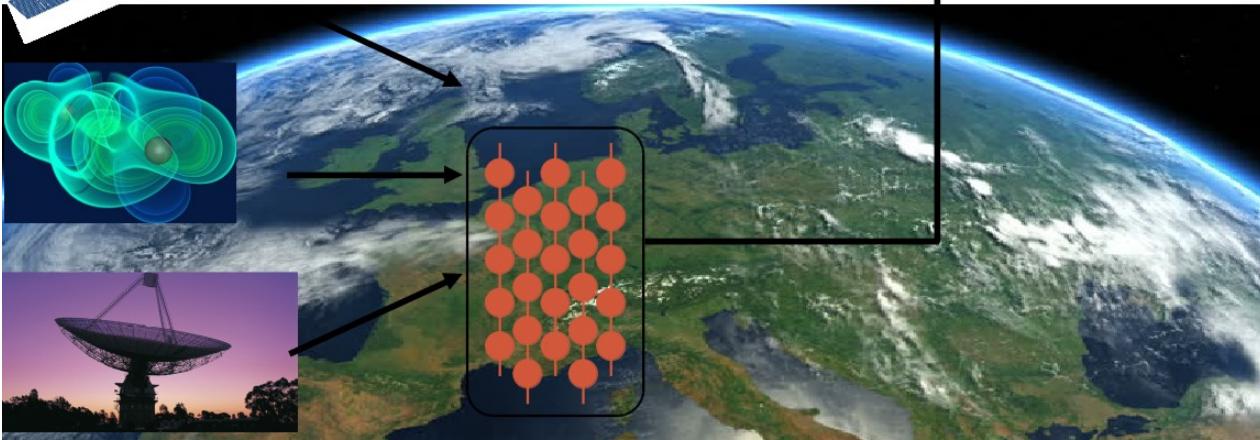


D.Dornic et al.  
- Poster: PS1-100  
- Talk: NU9e

Real time

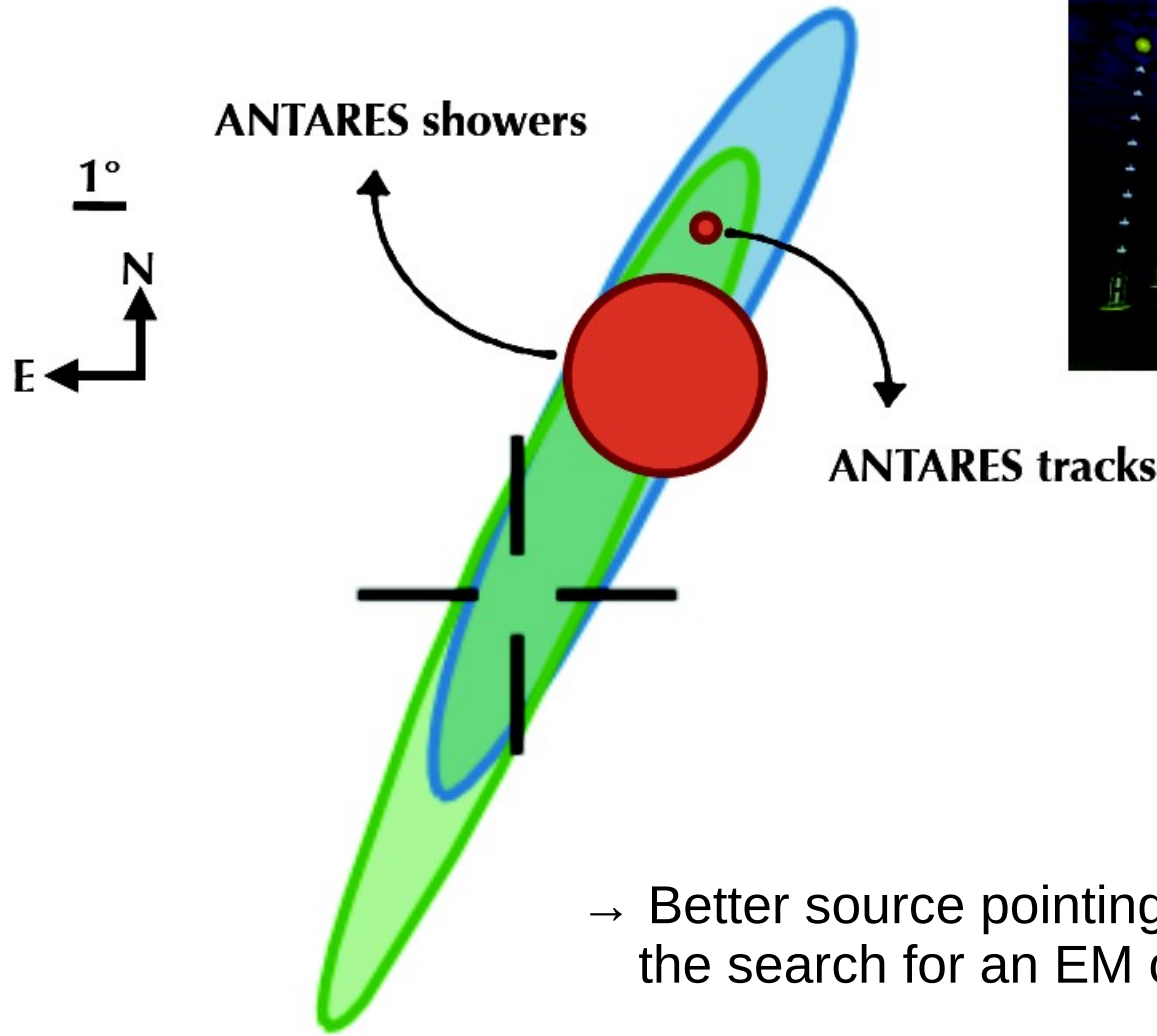
Offline: Refined

**Time dependent searches**



- Typical signal: High-energy muon neutrino-induced upgoing tracks in the detector

# Where can neutrinos help?



**angular resolution:**

*<deg (tracks)*

*~deg (showers)*

**field-of-view:**

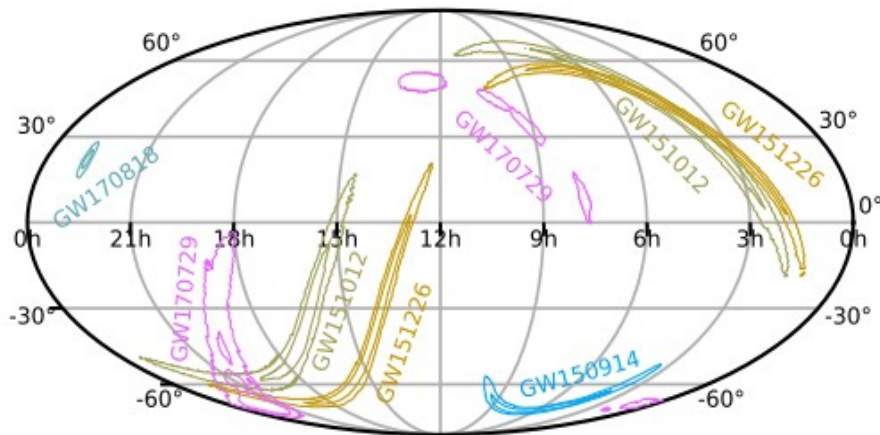
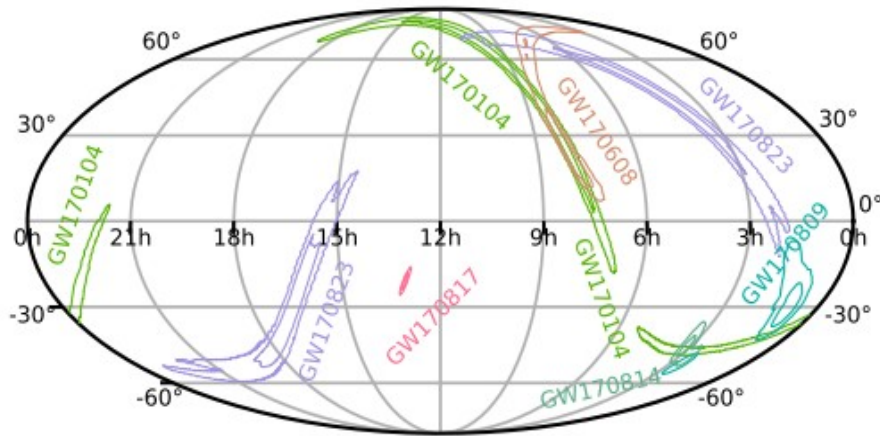
*> 2π sr*

→ Better source pointing helps for the search for an EM counterpart



# State of the art of GW astronomy:

Cataloged GW events from O1+O2:



- 11 BBH events:
  - 5 followed by ANTARES + **6 NEW here**
- 1 BNS event
- With Multi-Messenger observation
- Joint search ANTARES+IC+Auger

Since the beginning of O3:

- 18 (?) BBH candidates
- 3 (?) BNS candidates
- 1<sup>st</sup> (?) NSBH candidate:

**Preliminary results here**  
*(and counting...)*

# Neutrino search in coincidence with GWs: Method and samples

---

- Search during  $\pm 500$  s around the merger
- Search below (upgoing events) & above (downgoing) the horizon
- Selection: 1 event passing the cuts found inside the GW 90% localization error box in the time window  $\rightarrow 3\sigma$  detection
- Optimization and background estimation done on data
- Only muon neutrinos for the moments: all flavor coming
- Six new O2 GW events (BBHs) considered:

+ 1<sup>st</sup> NSBH candidate from O3 (S190426c)

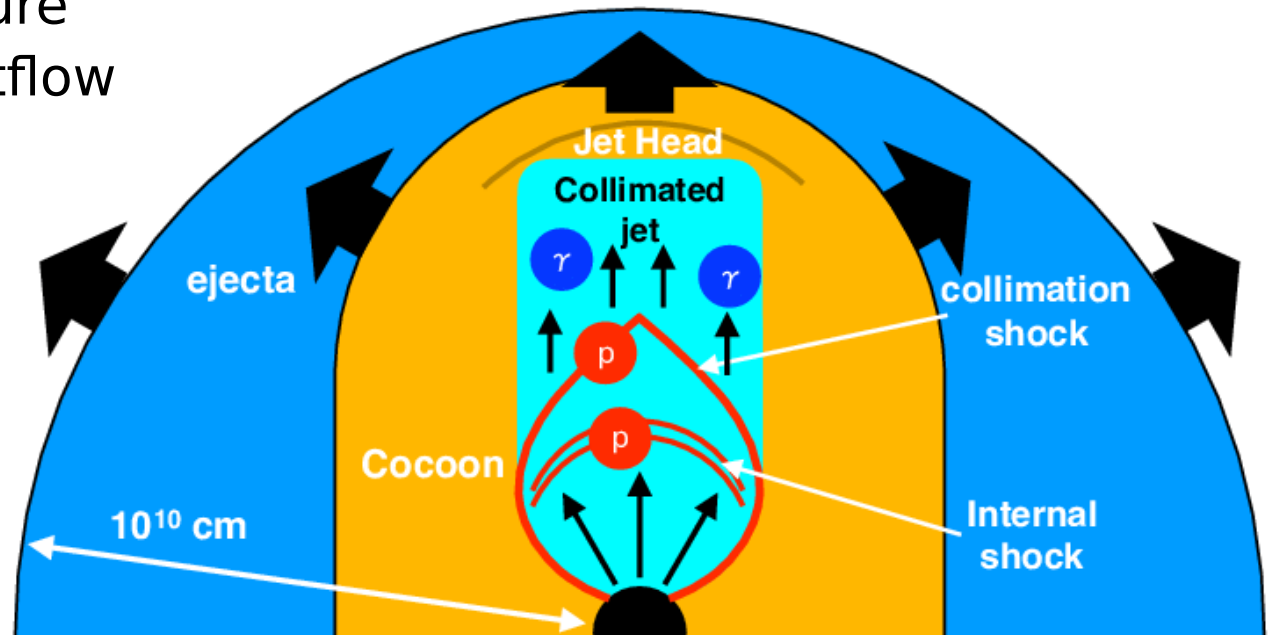
- GW170608
- GW170729
- GW170809
- GW170814
- GW170818
- GW170823

# Offline follow-up of BNS-NSBH events (candidates from O3 + GW170817)

# Neutrino emission from BNS/NSBH events

## Expected if:

- **ejection process with hadronic component**
  - **cosmic-ray acceleration related to magnetar**
- Confirm hadronic content of ejecta
- Constrain the structure of the relativistic outflow





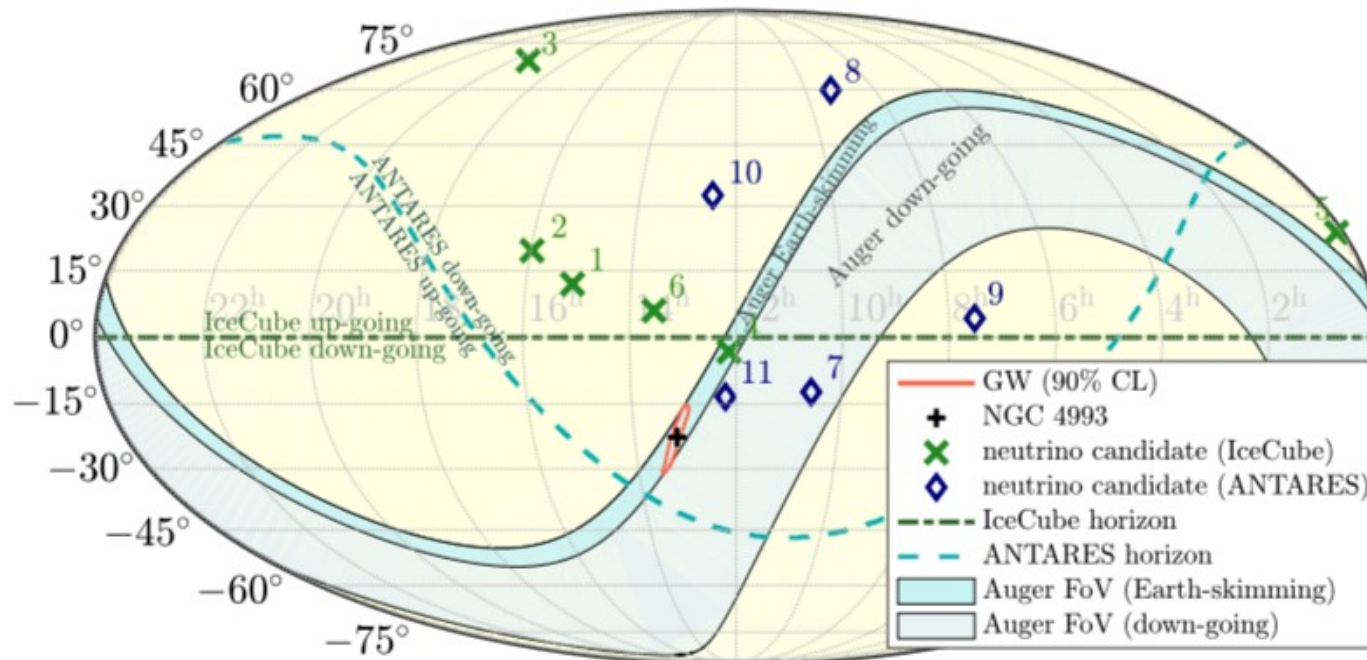
# Joint follow-up of GW170817: ANT-IC-Auger

## ANTARES:

Search over  $\pm 500$  s and +14 days

Track + shower events (all flavors)

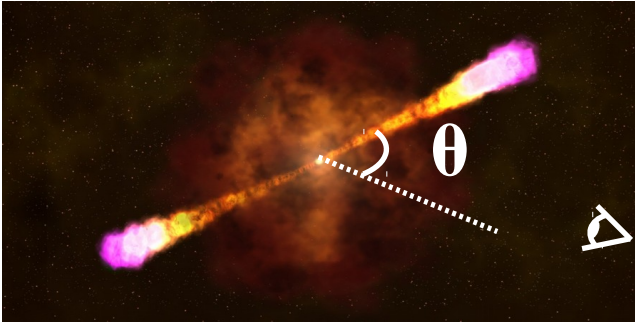
## Over $\pm 500$ s around the merger:



Albert et al., ApJL, 850, 2 (2017)

No counterpart over +14 days either

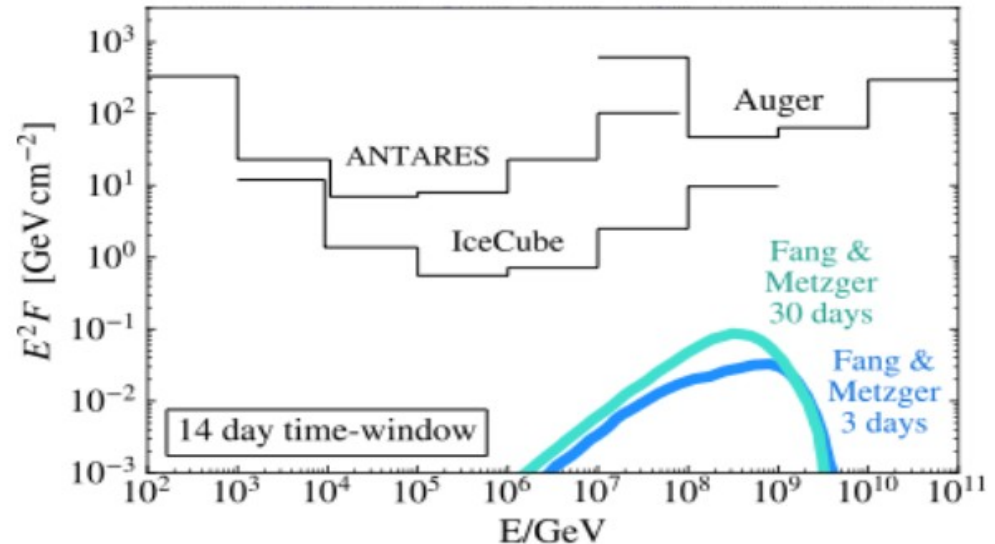
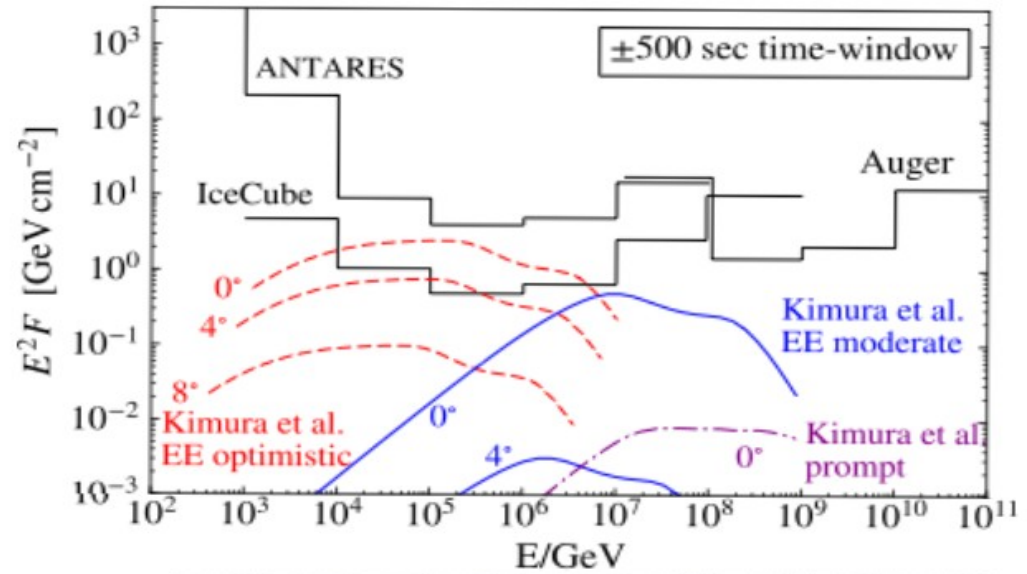
# Constraints on the source: GW170817



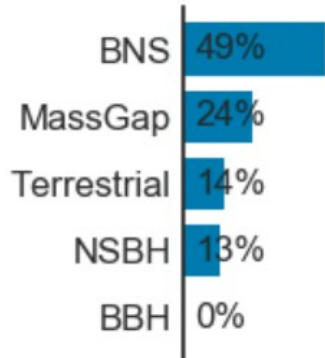
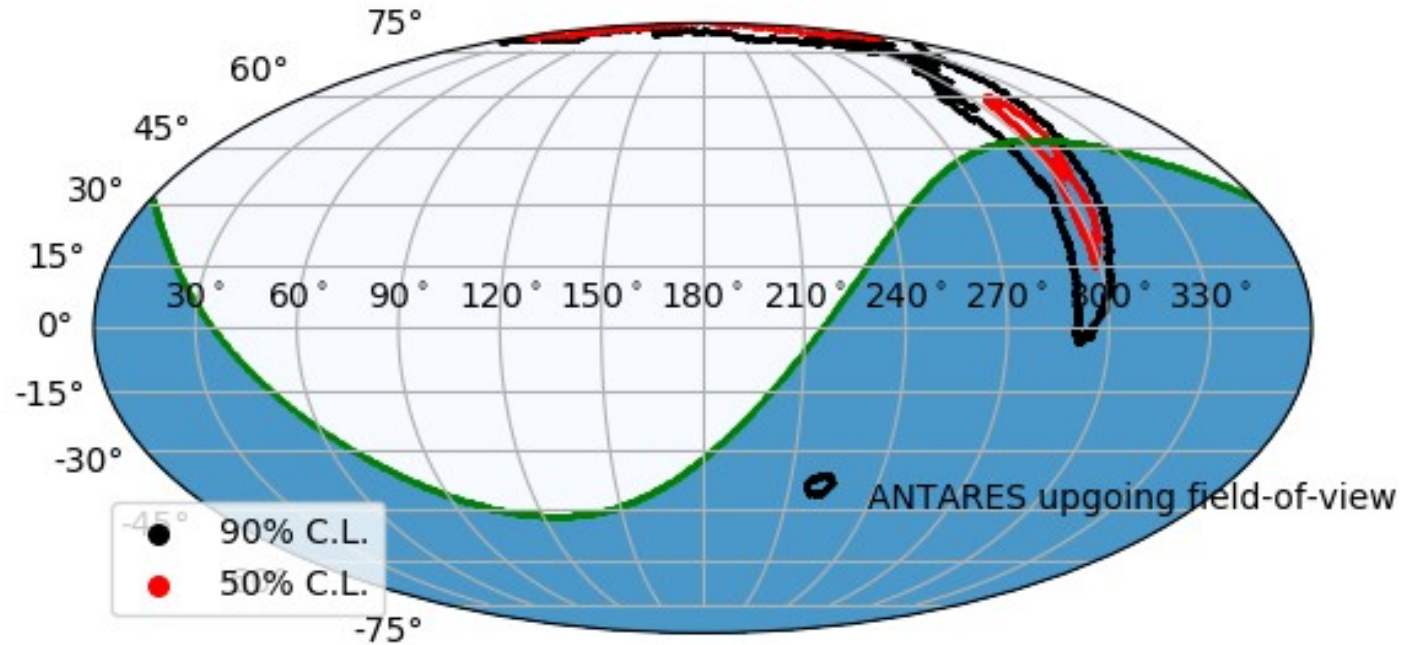
Neutrino emission related to the prompt/extended high-energy emission (**Kimura et al., 2017**)



**Fang & Metzger 2017:**  
Magnetar + ejected material from the coalescence:  
↳ HE cosmic ray acceleration  
↳ HE neutrino production

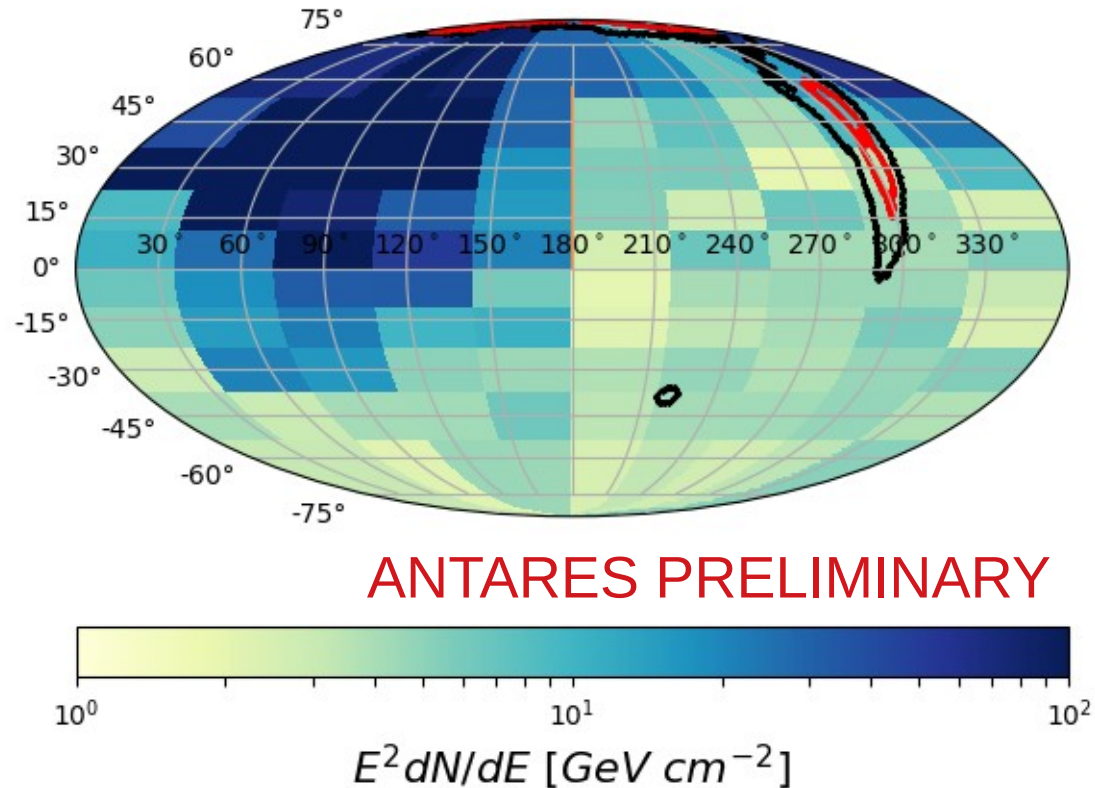


# 1st NS-BH candidate of O3: S 190426c



- ANTARES visibility, 90% error box:  
55% downgoing, 45% upgoing
- Distance:  $377 \pm 100$  Mpc
- Relative probabilities (GCN 24411):  
NSBH 12/3 : MassGap 5/3 : BNS 3/3

# S190426c: ANTARES preliminary result



No matching neutrino found in ANTARES data with S190426c





Offline follow-up of binary black holes



# Neutrino and EM emission from BBHs ?

General understanding:

No EM or neutrino emission expected

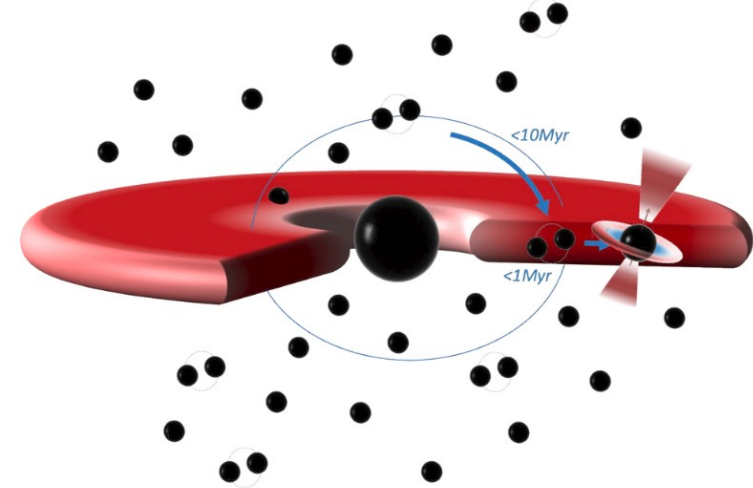
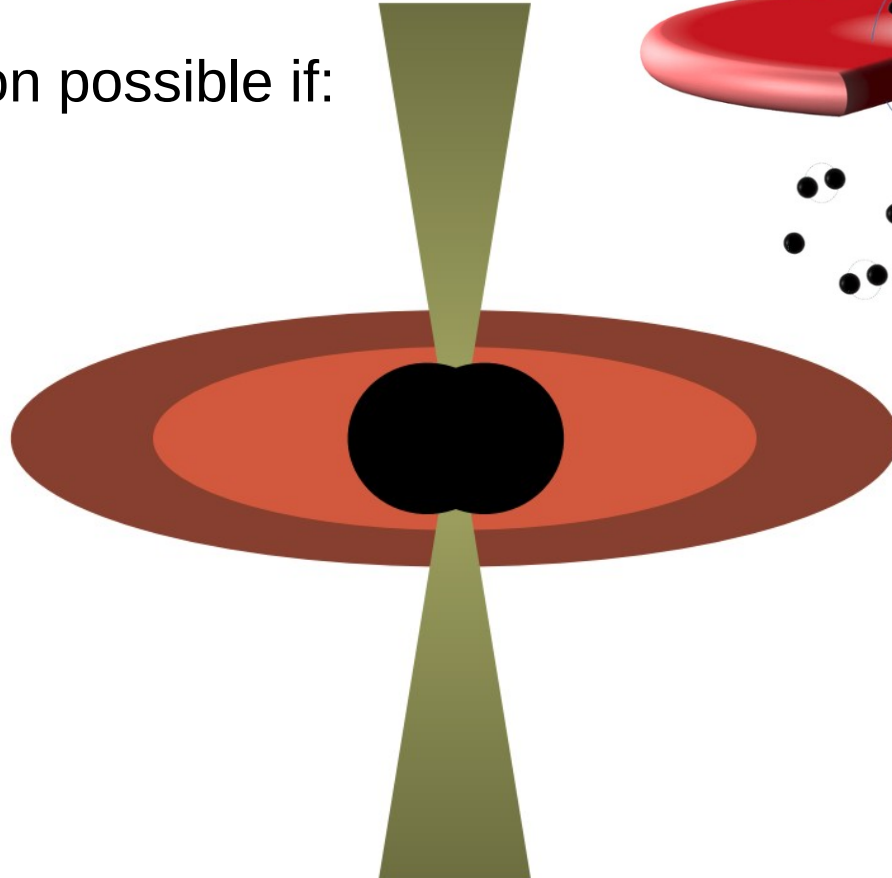
But...

EM and neutrino emission possible if:

- Hadronic environment
- Strong magnetic field



- Accretion disk
- Relativistic jet
- Mergers in AGNs



*Perna et al., 2016*

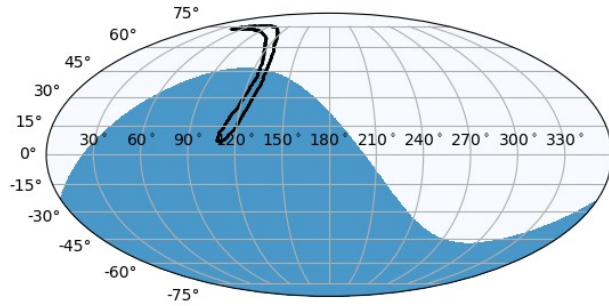
*Kotera & Silk, 2017*

*I.Bartos et.al, APJ, 2017*

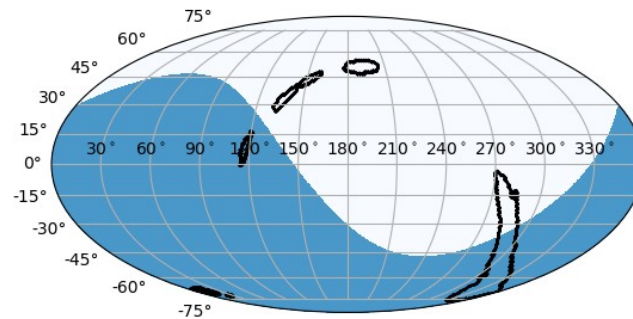


# Localization of the events of the search:

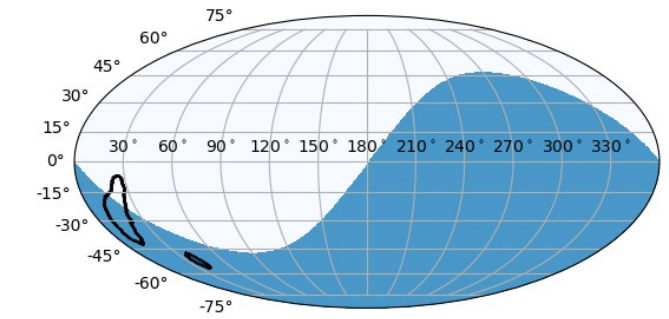
GW170608



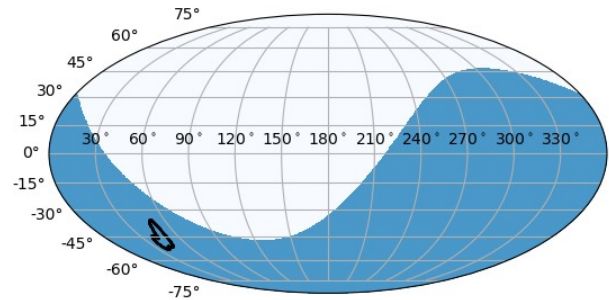
GW170729



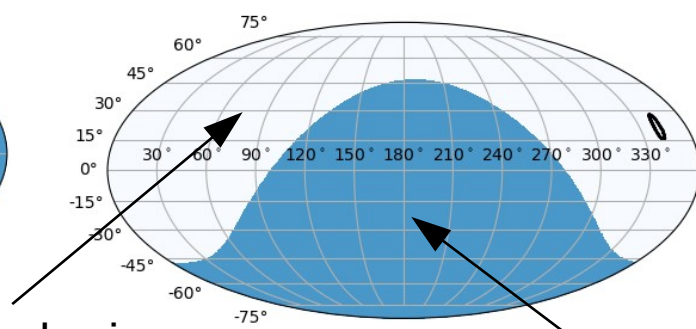
GW170809



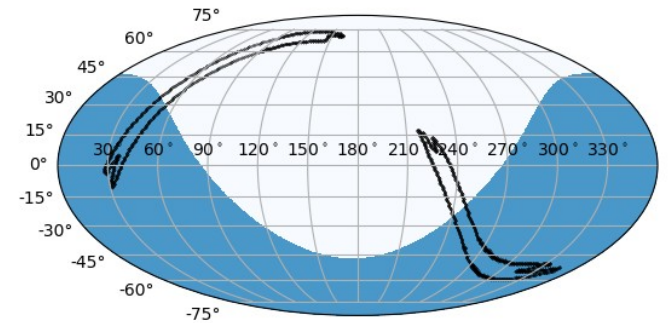
GW170814



GW170818



GW170823

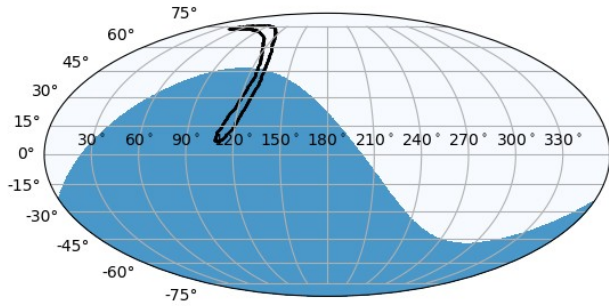


above the horizon

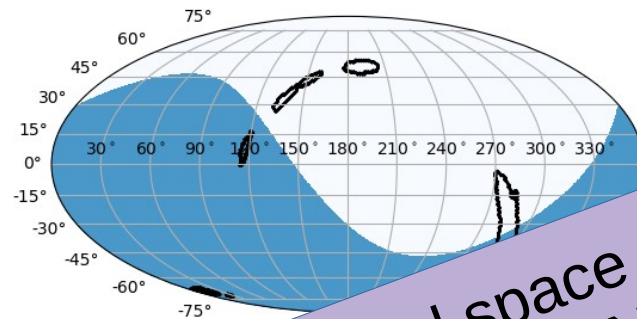
below the horizon

# Results of the ANTARES search:

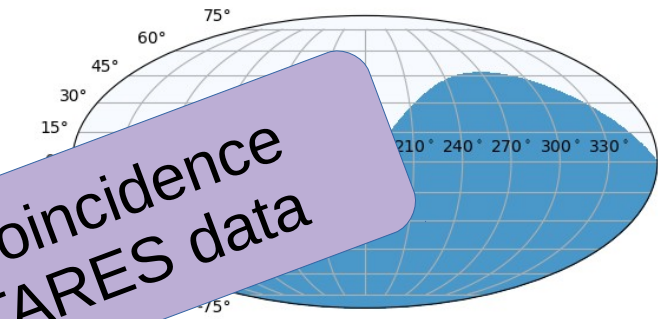
GW170608



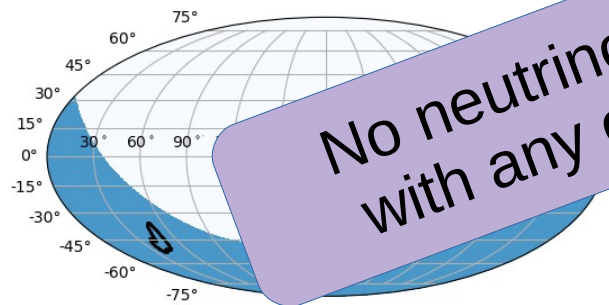
GW170729



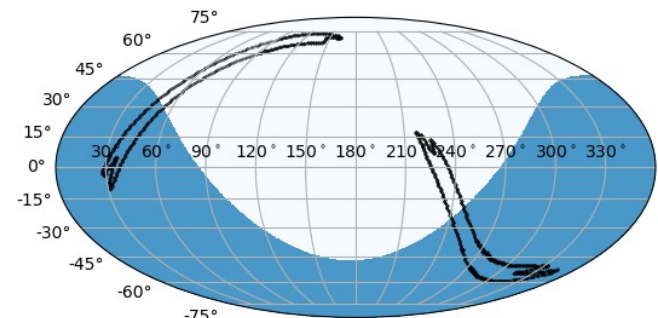
GW170809



GW170814



GW170823



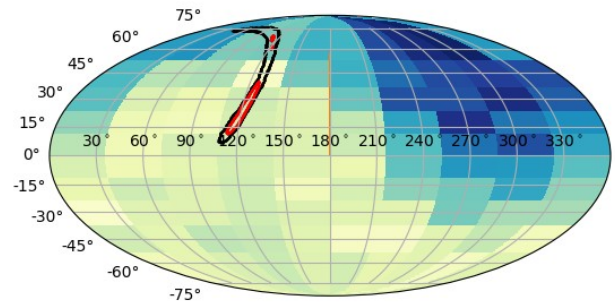
No neutrino found in time and space coincidence with any of the six GW events in ANTARES data

above the horizon

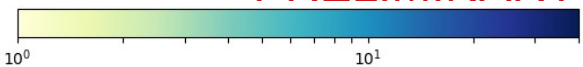
below the horizon

# ANTARES constraints on the neutrino fluence

GW170608

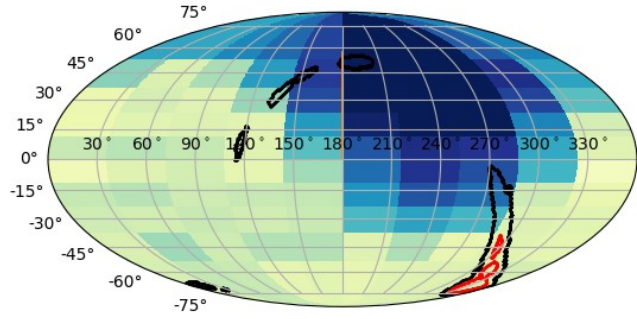


PRELIMINARY



$E^2 dN/dE$  [ $\text{GeV cm}^{-2}$ ]

GW170729

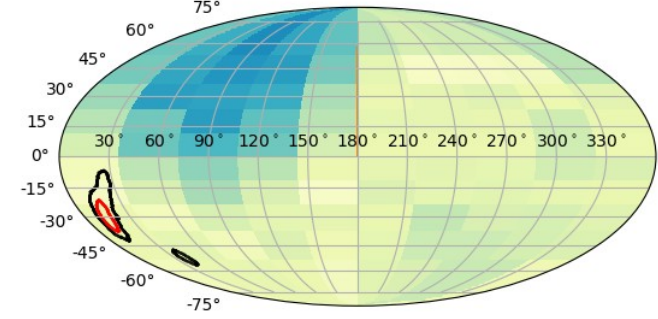


PRELIMINARY

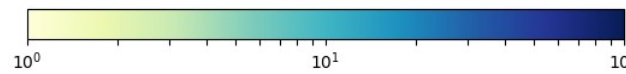


$E^2 dN/dE$  [ $\text{GeV cm}^{-2}$ ]

GW170809

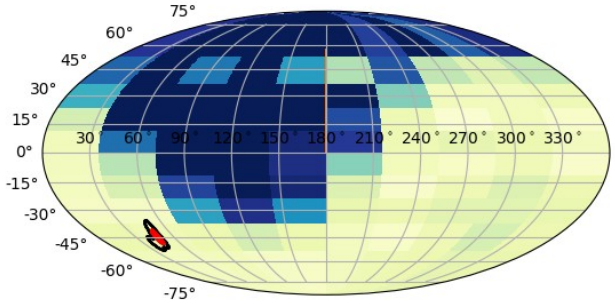


PRELIMINARY

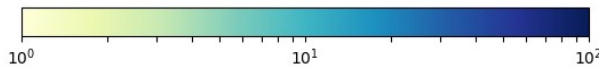


$E^2 dN/dE$  [ $\text{GeV cm}^{-2}$ ]

GW170814

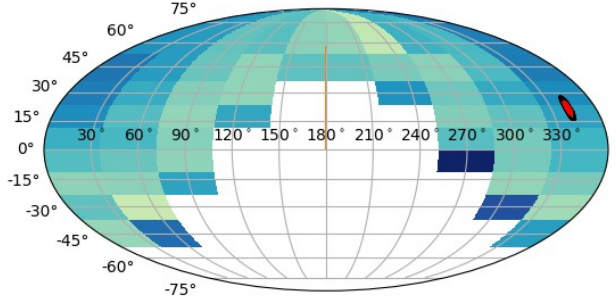


PRELIMINARY

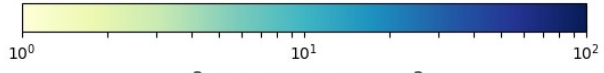


$E^2 dN/dE$  [ $\text{GeV cm}^{-2}$ ]

GW170818

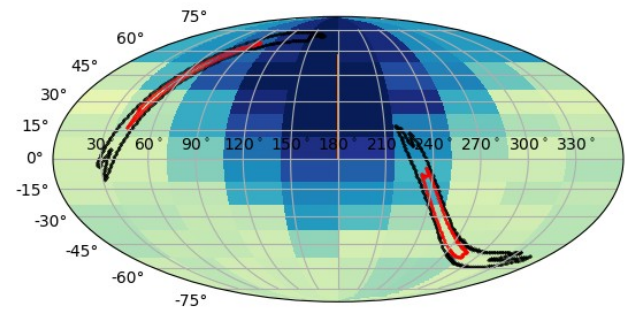


PRELIMINARY

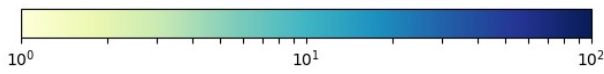


$E^2 dN/dE$  [ $\text{GeV cm}^{-2}$ ]

GW170823



PRELIMINARY

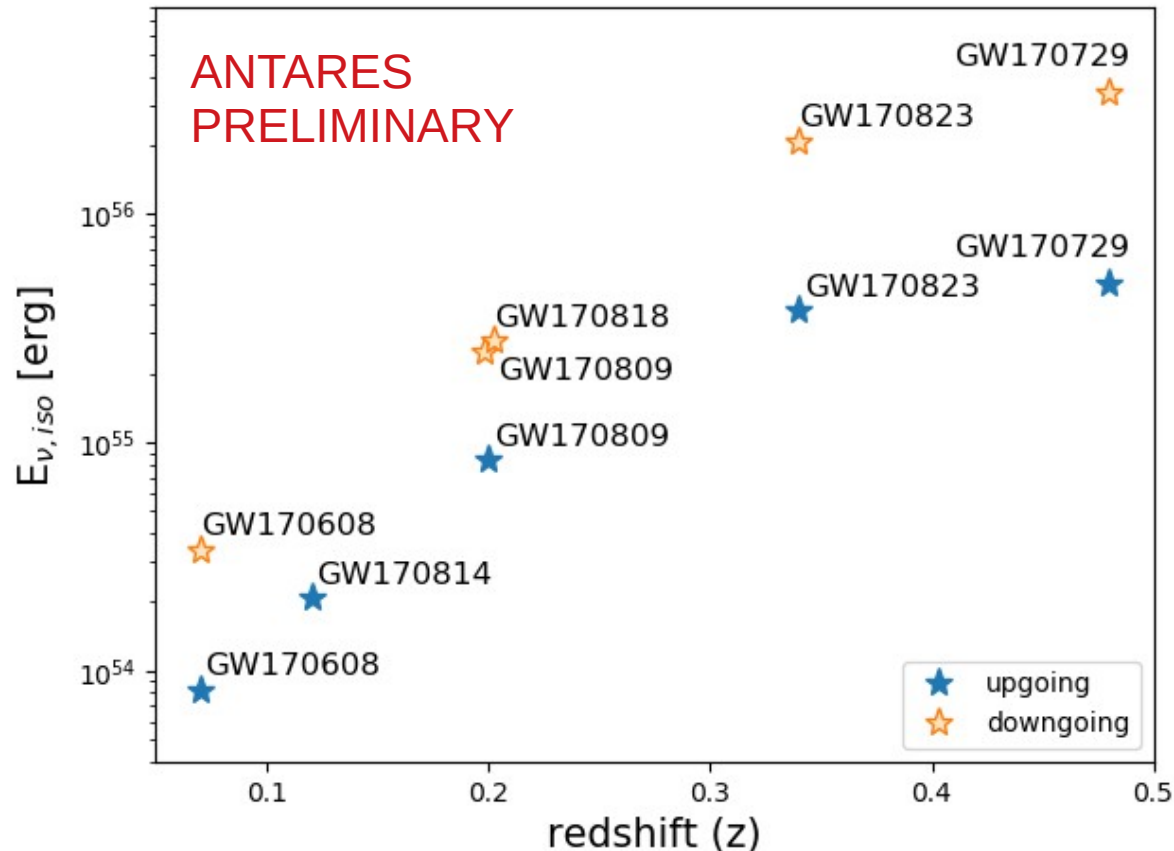


$E^2 dN/dE$  [ $\text{GeV cm}^{-2}$ ]



# ANTARES constraints on $E_{\nu, iso}$ from BBHs

- Energy range : [ 100 GeV, 100 PeV ]
- Redshift : from mean of the  $L_{dist}$  distribution
- Average upper limit (up/down) used



# CONCLUSIONS AND OUTLOOK

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- All GW O2 events have been followed with the ANTARES telescope: no neutrino in correlation with GW emission was found:
  - Constrains on the neutrino fluence and isotropic energy
- Preliminary results for 1<sup>st</sup> NSBH candidate: no coincident neutrino
- Multi-messenger approach allows for all-sky search and background reduction with an increase of discovery potential
- Same approach can be used for localized transient sources (GRBs, FRBs), also above the horizon!

## Coming soon...

- From muon neutrinos to all flavor search for O2 BBH events
- Stacking analysis of all BBH events will come after the end of O3
- Interesting O3 events (BNS, NSBH) will be followed using the approach presented here

Thanks for your attention



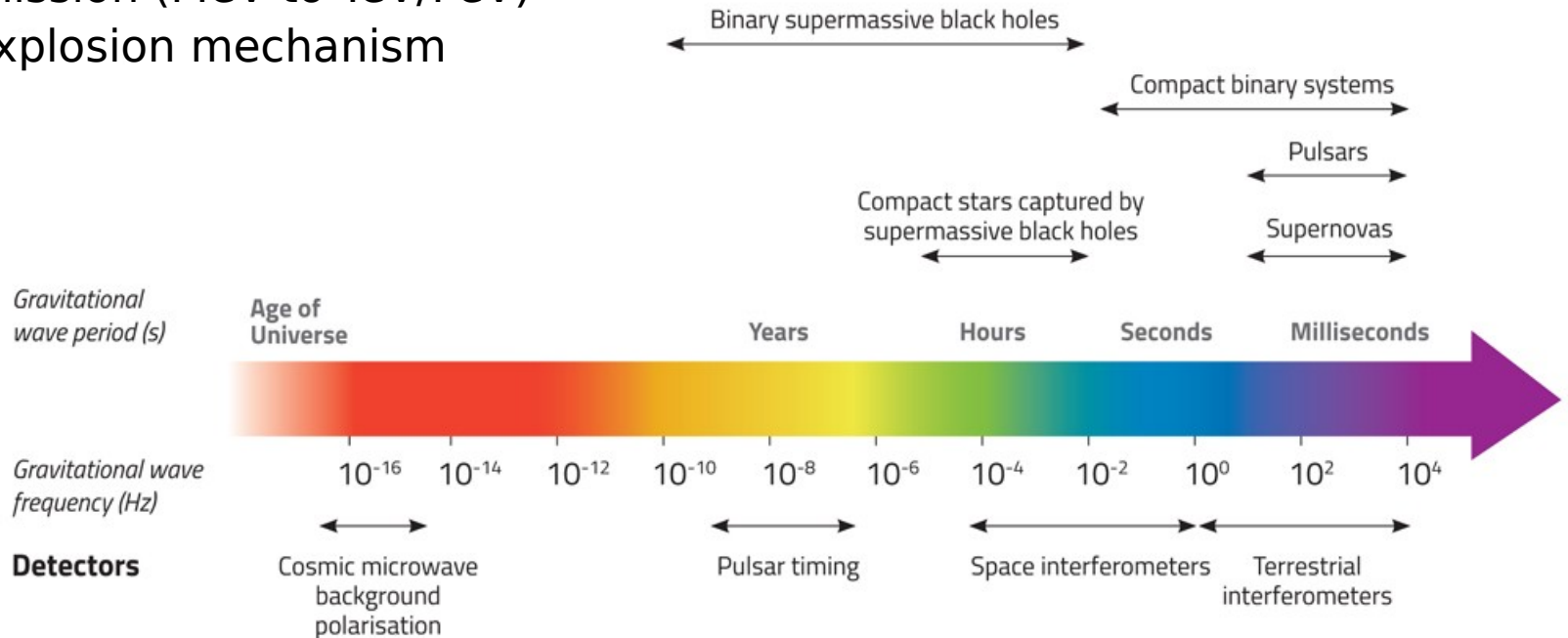
*Stay tuned...*

Multi-messenger astronomy is the way!  
(and it never sleeps)

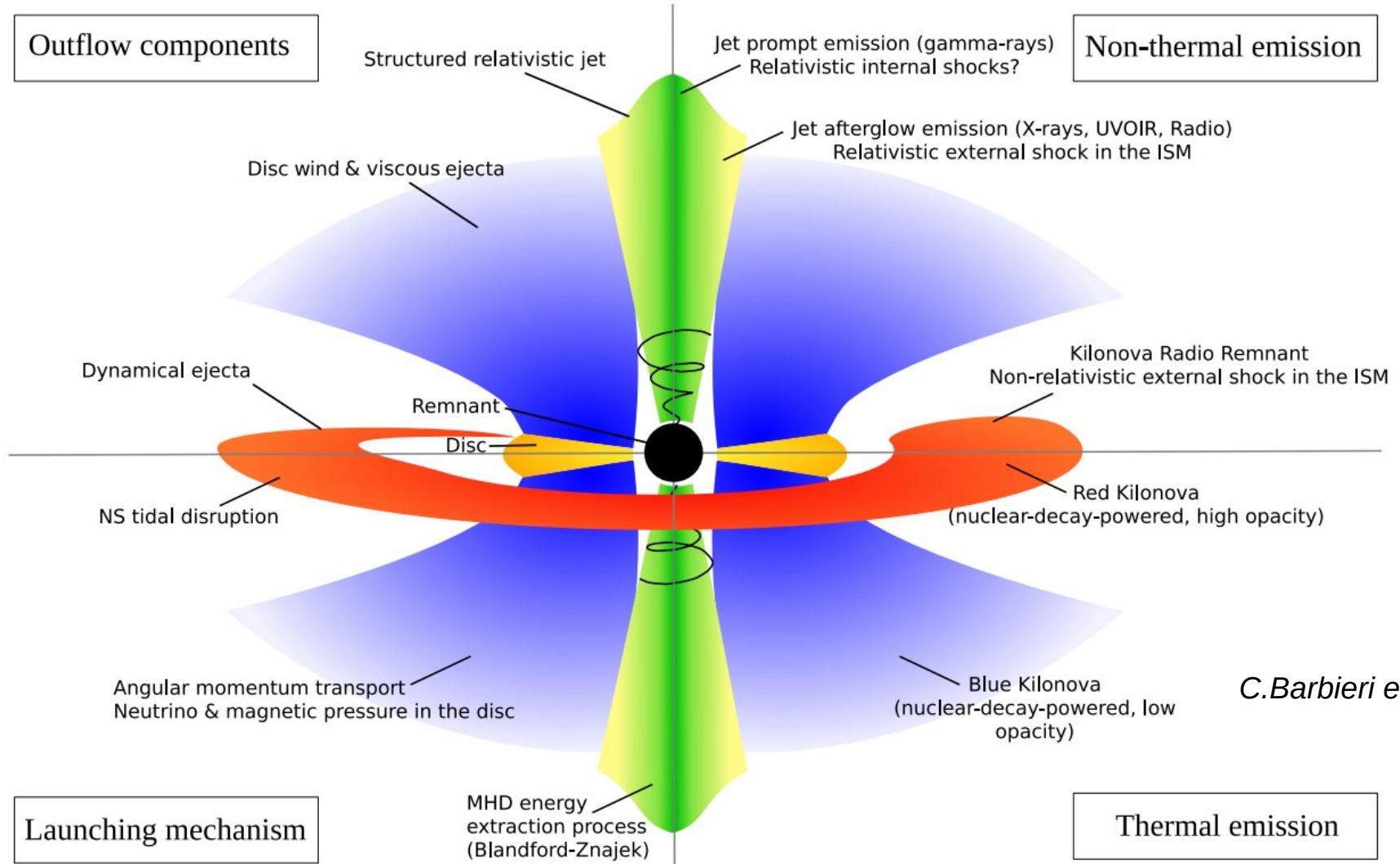


# Different types of GW sources:

- **Compact binary mergers:**  
(BBH, BNS, NSBH)
  - Test particle acceleration
  - Reveal ejecta structure (GRB physics)
- **Core-Collapse Supernova:**
  - Neutrino emission (MeV to TeV/PeV)
  - Constrain explosion mechanism
- **Pulsars**
- **Primordial**
- ...



# What we learnt from GW170817:



*C.Barbieri et al. (2019)*