

# KM3NET-LVK GWHEN SEARCHES :

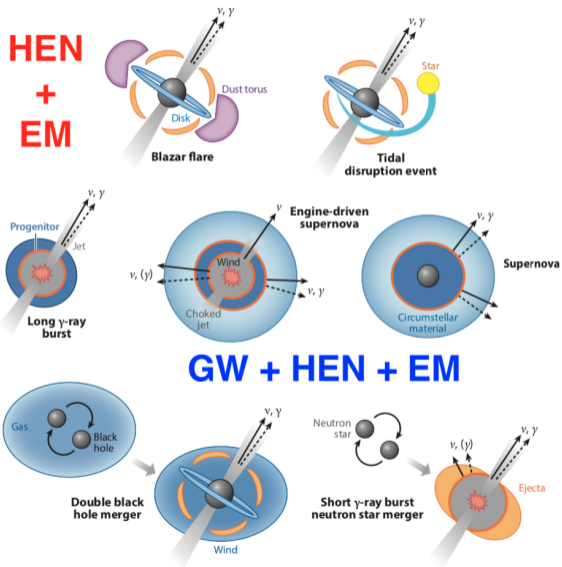
Ideas & Proposals

Thierry Pradier

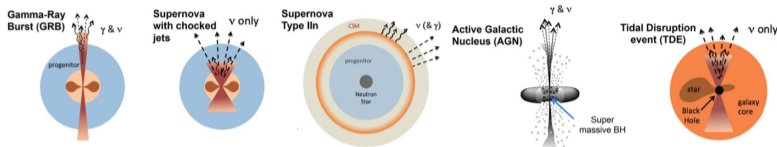
▶ [thierry.pradier@iphc.cnrs.fr](mailto:thierry.pradier@iphc.cnrs.fr)



# GW, HEN and other messengers - the Cosmic-Ray Connection

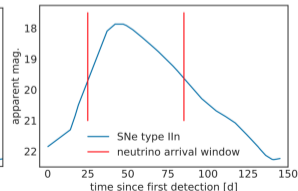
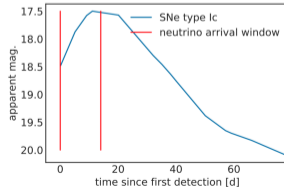
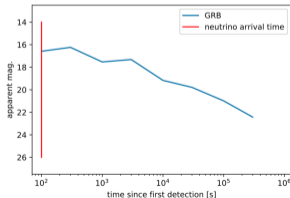


# A large diversity of HEN sources...



## ...and of their signals

- Short duration Transients - GRB-like - few hours
- Medium duration - SNIc, Kilonova - few weeks
- Long duration - SNIIn, TDE, AGN - few months



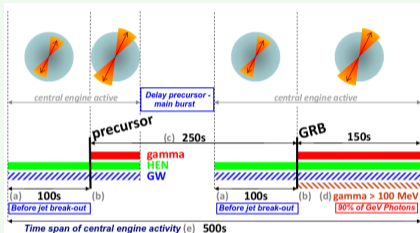
# Astrophysical delay GW-HEN (GRBs) & sources



## Prompt GWHEN - Initial Constraints

► B. Baret et al. - Astropart.Phys. 35 :1-7, 2011

- Based on Long GRBs  $\Rightarrow t_{\text{GW}} - t_{\text{GRB}} \approx t_{\text{HEN}} - t_{\text{GRB}} \in [-350\text{s}, +150\text{s}] \Rightarrow \Delta t_{\text{GW-HEN}} = \pm 500\text{s}$



- active central engine before relativistic jet has broken out of stellar envelope
  - active central engine with relativistic jet broken out of envelope
  - delay between onset of precursor and main burst
  - 90% of GeV photon emission
  - time span of central engine activity
- $\Rightarrow$  Short GRBs 10  $\times$  less likely to have precursor

## Prompt - More recent constraints

► e.g. B. Zhang - Frontiers of Physics, 14(6), 64402 (2019)

- Short GRBs CBC -  $\Delta t_{\text{GW-GRB}}$  up to 10s - **What about  $\Delta t_{\text{GW-HEN}}$ ?**
- Long GRBs Collapsars -  $\Delta t_{\text{GW-GRB}}$  up to  $10^3 - 10^4\text{s}$

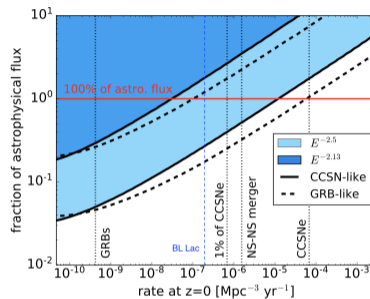
## Delayed GWHEN from BBH with dead disk / BBH in AGN disk

- Dead disk [Perna et al 1602.05140], AGN [Zhou et al, 2310.15832]  $\rightarrow$  tens of days

## Astrophysical delay GW-HEN (GRBs) &amp; sources



source class	local density [Mpc <sup>-3</sup> (yr <sup>-1</sup> )]	min. dist. [Mpc]	limit	source energy [erg]	max. fluence [GeV <sup>-1</sup> cm <sup>-2</sup> ]
long GRBs	$4 \times 10^{-10}$	470	< 1% (stacked)	$< 6 \times 10^{51}$	$< 4 \times 10^{-3}$
short GRBs	$3 \times 10^{-9}$	220	< 32% (OFU)	$< 3 \times 10^{52}$	$< 9 \times 10^{-2}$
llGRBs	$1.6 \times 10^{-7}$	64	< 100% (flux)	$< 1.5 \times 10^{51}$	$< 6 \times 10^{-2}$
SNe Ic broad.	$1.4 \times 10^{-6}$	30	< 100% (flux)	$< 2 \times 10^{50}$	$< 4 \times 10^{-2}$
SNe IIn	$4 \times 10^{-6}$	20	< 66% (stacked)	$< 4 \times 10^{49}$	$< 1.4 \times 10^{-2}$
SNe Ib/c	$1.7 \times 10^{-5}$	12	< 32% (stacked)	$< 5 \times 10^{48}$	$< 5 \times 10^{-3}$
CCSNe	$7 \times 10^{-5}$	8	< 100% (flux)	$< 4 \times 10^{48}$	$< 8 \times 10^{-3}$
FSRQs	$6 \times 10^{-10}$	1000	< 17% (EHE)	$< 1.6 \times 10^{53}$	$< 3 \times 10^{-2}$
BL Lac objects	$2 \times 10^{-7}$	120	< 25% (EHE)	$< 3 \times 10^{51}$	$< 2.5 \times 10^{-2}$
all AGN	$10^{-3}$	7	< 100% (flux)	$< 3 \times 10^{46}$	$< 8 \times 10^{-5}$
jetted TDEs	$3 \times 10^{-11}$	1000	< 100% (flux)	$< 10^{54}$	$< 1.4 \times 10^{-1}$
galaxy cluster	$5 \times 10^{-6}$	40	< 100% (flux)	$< 3 \times 10^{50}$	$< 3 \times 10^{-2}$
starburst gal.	$3 \times 10^{-5}$	22	< 100% (flux)	$< 2 \times 10^{49}$	$< 2 \times 10^{-3}$

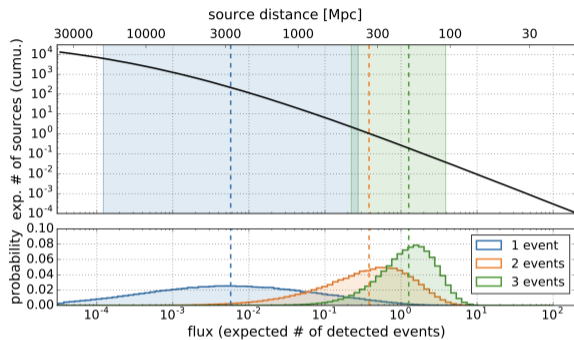


N. L. Strotjohann, PhD, <https://edoc.hu-berlin.de/handle/18452/21791>

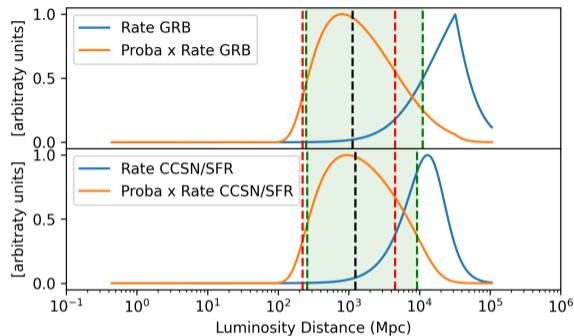
## What are the sources of HEN?

- Short duration - GRB-like - **GRBs disfavored as HEN sources** (prompt phase)  $\Rightarrow$  **what about precursor/afterglow?**
- Medium duration - SNIc, Kilonova - **mostly unconstrained**
- Long duration - SNIIn, TDE, AGN - **unconstrained**

# Astrophysical delay GW-HEN (GRBs) & sources



N. L. Strotjohann et al, A& A 622, L9 (2019)



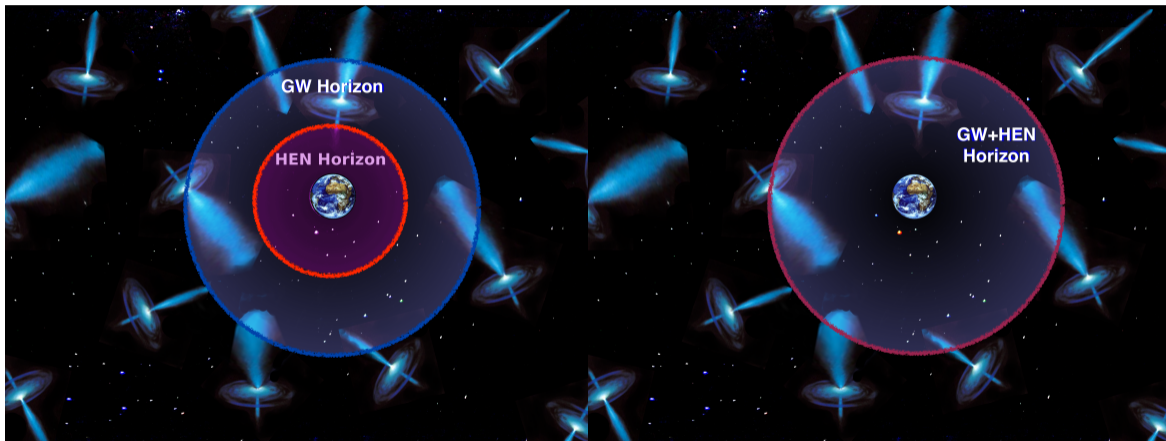
T. Pradier, A& A 674, L11 (2023)

## Caution - Eddington Bias

- With only 1 neutrino  $\rightarrow D \sim 0.5 - 20$  Gpc 90% (here BL Lac density, 10 events in 10 yrs for <30% detected HEN flux)

- $\Rightarrow$  Chances to detect GW counterpart for CBC NS-NS sources?
- $\Rightarrow$  Possibility to define a 3D volume for HEN, given  $N_{\text{HEN}}^{\text{obs}}(\Delta\Omega)$

# GW-HEN search optimization



# GW-HEN search optimization



## Optimize Number of detectable GWHEN sources

$$\mathcal{N}_{\text{GWHEN}}(\text{selection}) = \iiint dt d^3\Omega \epsilon_{\text{HEN}}(\text{selection}, E_{\text{HEN}}, r) \epsilon_{\text{GW}}(\text{selection}, E_{\text{GW}}, r) \mathcal{R}(r, t)$$

- with  $\mathcal{R}(r, t) = R \times P(N_{\text{HEN}} > 0, r, E_{\text{HEN}}) \propto R/r^2$  for small fluxes
- $\epsilon_{\text{GW}}(\text{selection}, E_{\text{GW}}, r) \approx$  step-like at  $D_{\text{Horizon}}$  and  $\rho_{\text{threshold}} \propto D_{\text{Horizon}}^{-1}$

$$\Rightarrow \mathcal{N}_{\text{GWHEN}}(\text{selection}) \approx \frac{\epsilon_{\text{HEN}}(\text{selection}, E_{\text{HEN}}, r)}{\rho_{\text{threshold}}}$$

- Used in 2009-2010 analysis (see B. Bouhou PhD Thesis, 2012)
- $\Rightarrow$  improves by a factor 10 the limits on  $E_{\text{HEN}}^{\text{iso}}$  for realistic GW energies  $E_{\text{GW}} < 10^{-2} M_{\odot} c^2$
- $\Rightarrow$  B. Baret et al, Moriond Grav. 2015

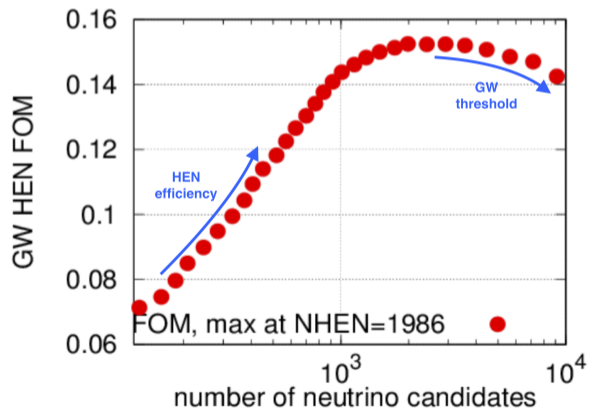
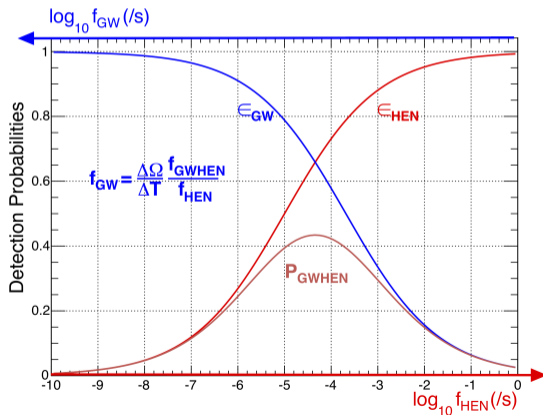


## GW-HEN search optimization



## Optimize Number of detectable GWHEN sources

$$\Rightarrow \mathcal{N}_{\text{GWHEN}}(\text{selection}) \approx \frac{\epsilon_{\text{HEN}}(\text{selection}, E_{\text{HEN}}, r)}{\rho_{\text{threshold}}}, \text{ for a predefined joint FAR}$$



# Conclusions



## What we know

- BBH (with gas) or BNS/NSBH possible HEN sources + Burst sources
- Observed HEN source likely to be  $\approx$  Gpc - depends on HEN selection !
- GRBs (prompt) disfavored as HEN sources - unlike other transients

## What we don't know

- Distance of HEN source - but distance constrained by observed Number of HEN vs  $E_{\text{HEN}}$
- Time Window from seconds to 2 weeks after merger - months for sources involving AGNs ?

## Different analyses are possible

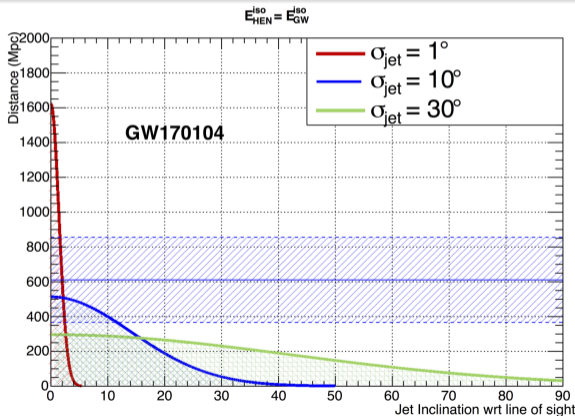
- Prompt GWHEN - CBC sources, even SN ?
- Delayed GWHEN - no timing information ?
- **No need to be member of LVK to contribute !!**

# Conclusions - possible analyses & outputs



## Offline - Single (exceptional) events

- Distance constrained through  $E_{\text{HEN}}^{\text{iso}}$  and  $N_{\text{obs}}$
- Constrain Jet opening/inclination (depends on  $E_{\text{HEN}}^{\text{iso}}$ )



# Conclusions - possible analyses & outputs



## Online - GW ↔ HEN counterpart searches

- HEN → GW :
  - ⇒ RAVEN, for public KM3NeT alerts - **private?**
  - ⇒ **Other methods for public/private alerts?**
- GW → HEN
  - ⇒ SN / MeV pipeline
  - ⇒ ORCA+ARCA
    - **Correlate e.g. with Galaxy Catalogues before search?** depends on GW distance

## Offline - CBC Subthreshold search

- M. Pillas (OCA, Fr) Inspired from LVK + Fermi-GBM
- ⇒ See *Deep Multimessenger Search for Compact Binary Mergers in LIGO, Virgo, and Fermi/GBM Data from 2016–2017*
- Iara with X-Pipeline

## Offline - BBH in AGNs

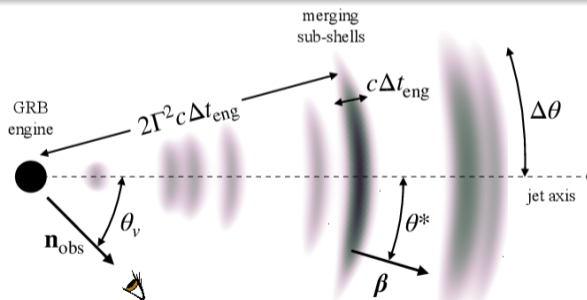
- UCLouvain (Gwen et al) ⇒ Correlate with AGN catalogue
- **Probably no Timing information, as  $\Delta T_{\text{GW-HEN}} \approx$  tens of days - months?**

# Conclusions



## Common features

- Which constraints ? only rates /Mpc<sup>3</sup>/yr ?
- Inclination/aperture of jet ?
- Jet Structure - emission wrt  $\theta$
- Relate Distance and Flux/Nb of neutrinos



# Conclusions



The proposal from LVK is to have one joint LVK-KM3NeT paper. The exact analysis and analysis team for this are still to be defined, and can only be decided upon in discussion between both collaborations. While I did say that one candidate from the LVK side is the analysis by Marion, it was meant as nothing more than mentioning one option, with the intention of seeing what other options there are on the KM3NeT side.

At the moment, the only question to be answered together are :

- Does everyone agree to have one joint paper between LVK and KM3NeT ?
- What is the science question this paper seeks to answer ? (sub-threshold coincidences between GW events and KM3NeT neutrinos)
- Do we believe we have the person power available to make such an analysis and paper happen ?

In order to have the proposal be accepted by the LIGO, Virgo, and KAGRA councils, we just need to make a believable proposal, specifics are not needed at this point. In any case, all of this is already mentioned in the MoU as a goal. The only change is the publication plan : going from a joint paper between IceCube, KM3NeT, and LVK to one between KM3NeT and LVK.

As you know, one of the goals for such a paper is to tighten the collaboration between LVK and KM3NeT, such that we are ready if/when a significant coincidence would happen. Making sure everyone interested in such an analysis is on board is an important part of that.