MMAJC — Session 3 (May 9th 2019, APC)

Light-curve models of black hole - neutron star mergers: steps towards a multi-messenger parameter estimation*

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Received xxx / Accepted: xxx

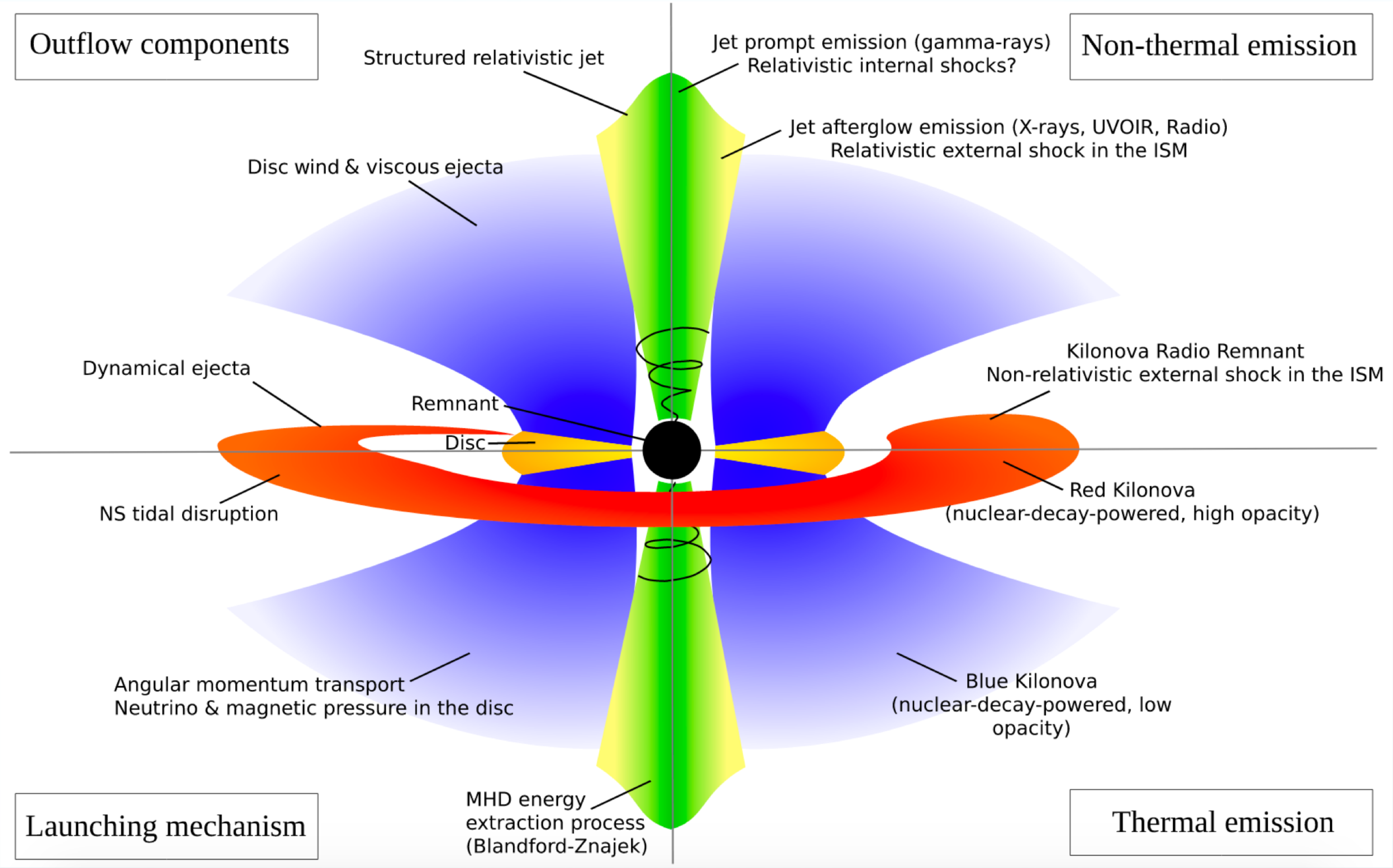
Interest:

- Also applicable to BNS
- Good summary of expected EM counterparts
- New semi-analytical model for the KN
- Straightforward MM parameter estimation
- GW190426 candidate NSBH

Context:

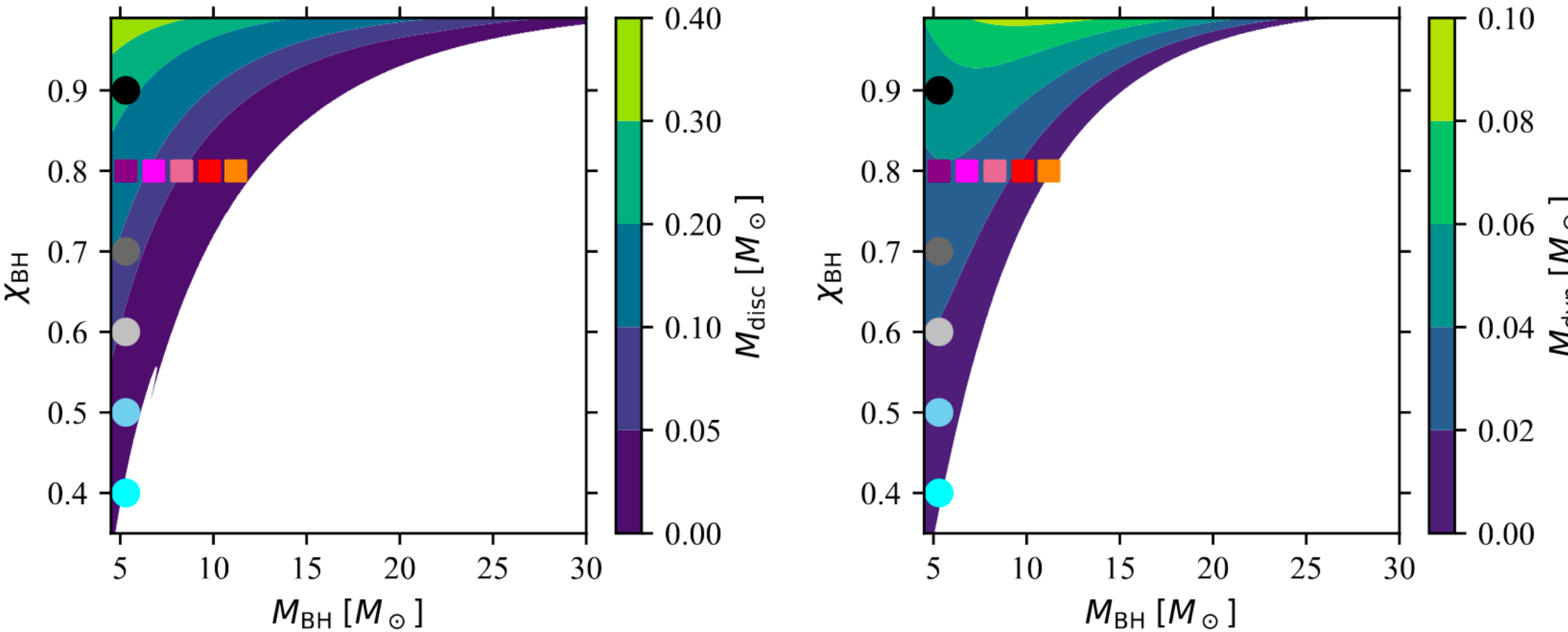
- BHNS rate ~1-1000 $Gpc^{-3}yr^{-1}$ → **First event likely in O3**
- Indeed! GW190426 has p[NSBH] = 60% (p[BNS] = 15%)
- EM counterparts: more mass → stronger EM signals
- May also be progenitor of sGRB, more variability than in BNS?

Physical setup



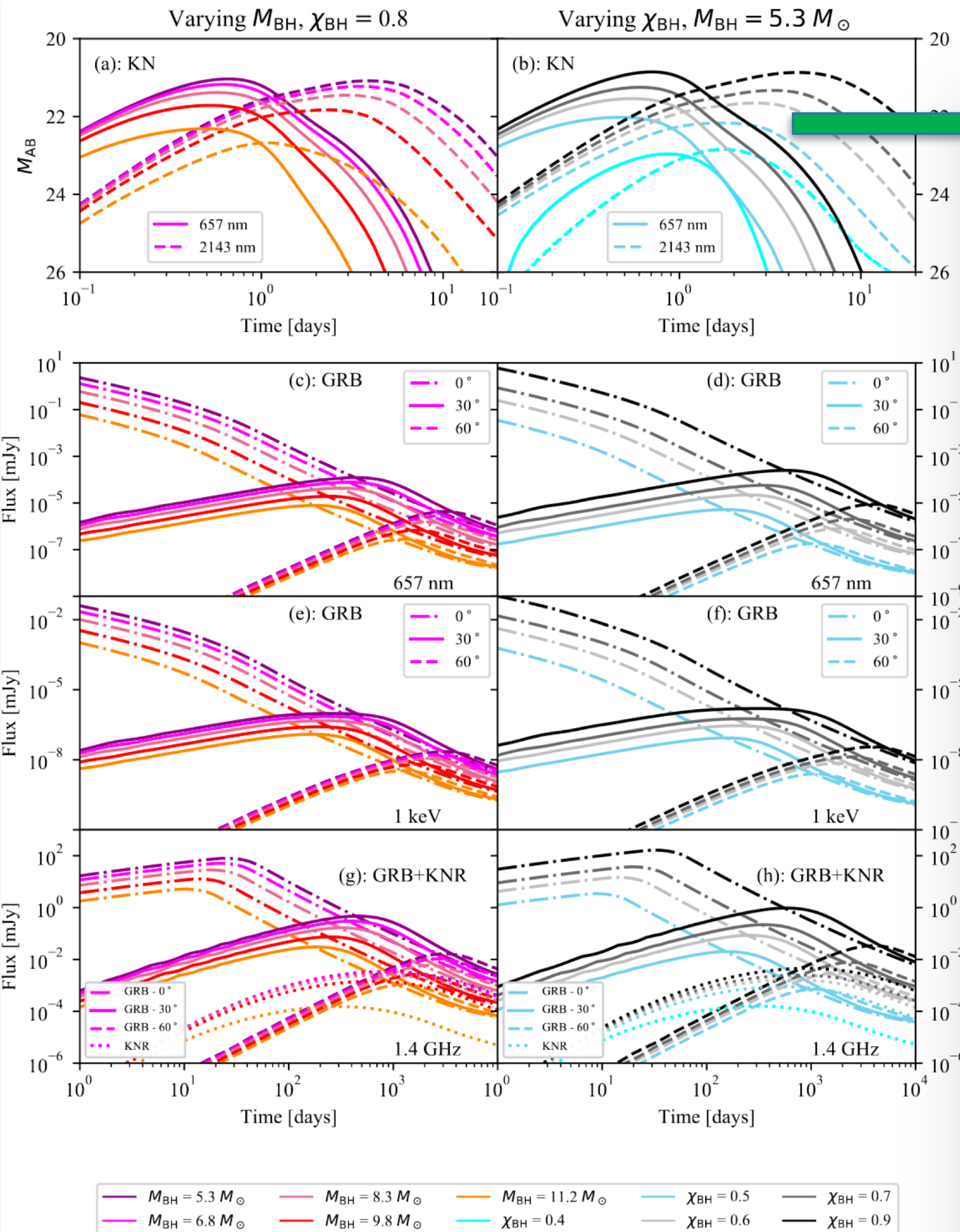
Parametrization: $\mathbf{M_{BH}}$, $\mathbf{X_{BH}}$ (M_{NS}, i_{tilt}, X_{NS}, Λ_{NS}, D, θ_v fixed)

Ejecta masses



- Masses much larger (x100) than in BNS
- Eventuality of dynamical (unbound) ejecta without disc...
- Interplay between d_{tidal} and R_{ISCO}

  → **small BH mass or high spin = high ejecta mass**

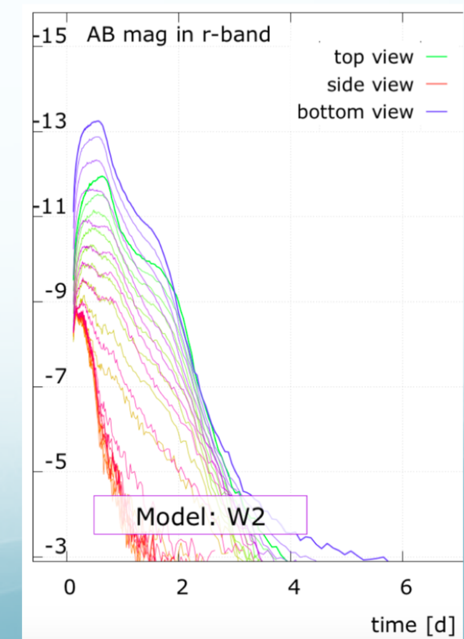


- Stronger signals for smaller BH mass / high spin
- Degeneracy in parameters → **MM analysis with GW!**

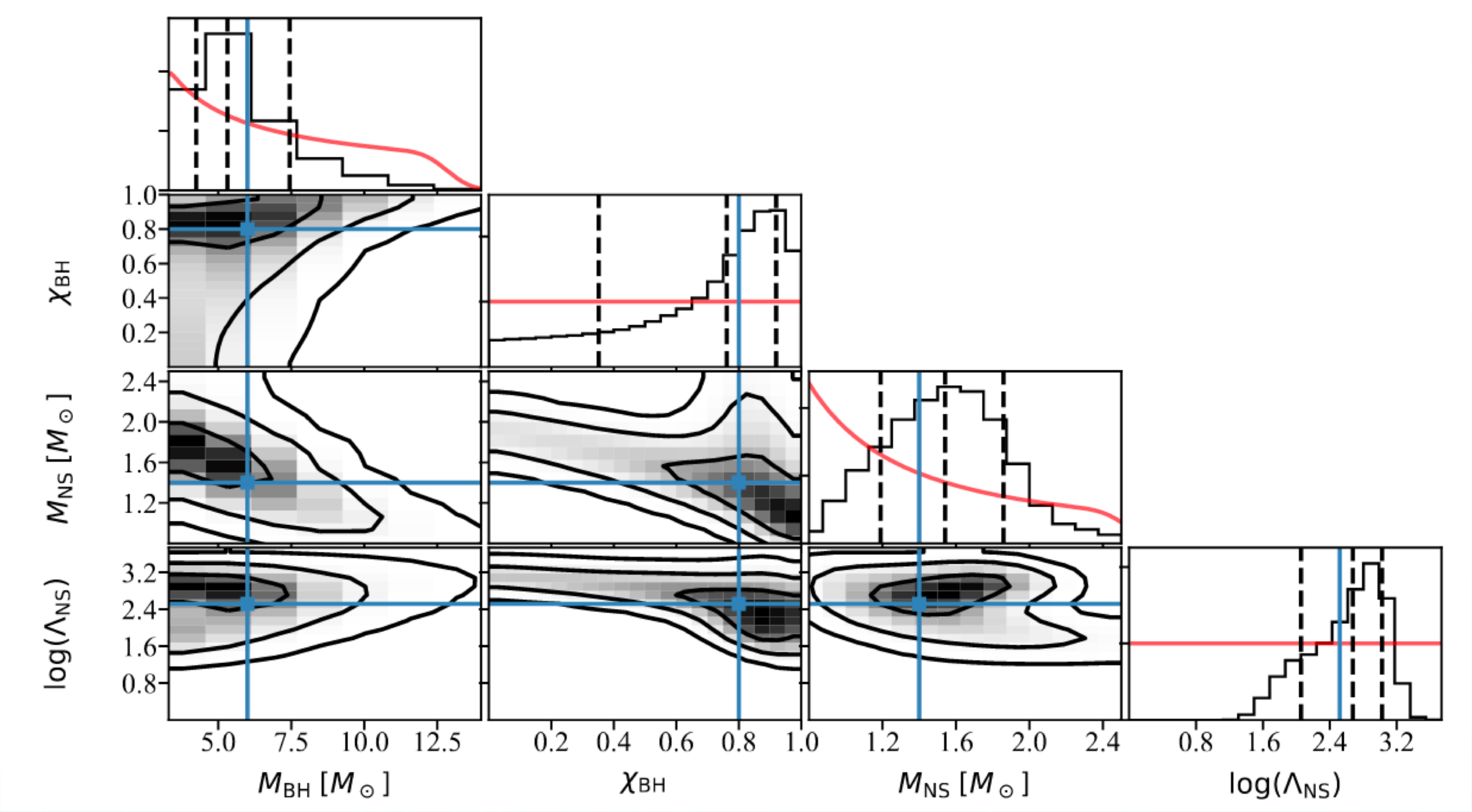
Small KN **variability with viewing angle**? Only dependency in their mode is the projection factor

Wollaeger+18:

- Based on numerical hydro + nuclear processes
- Large **KN variability** with viewing angle



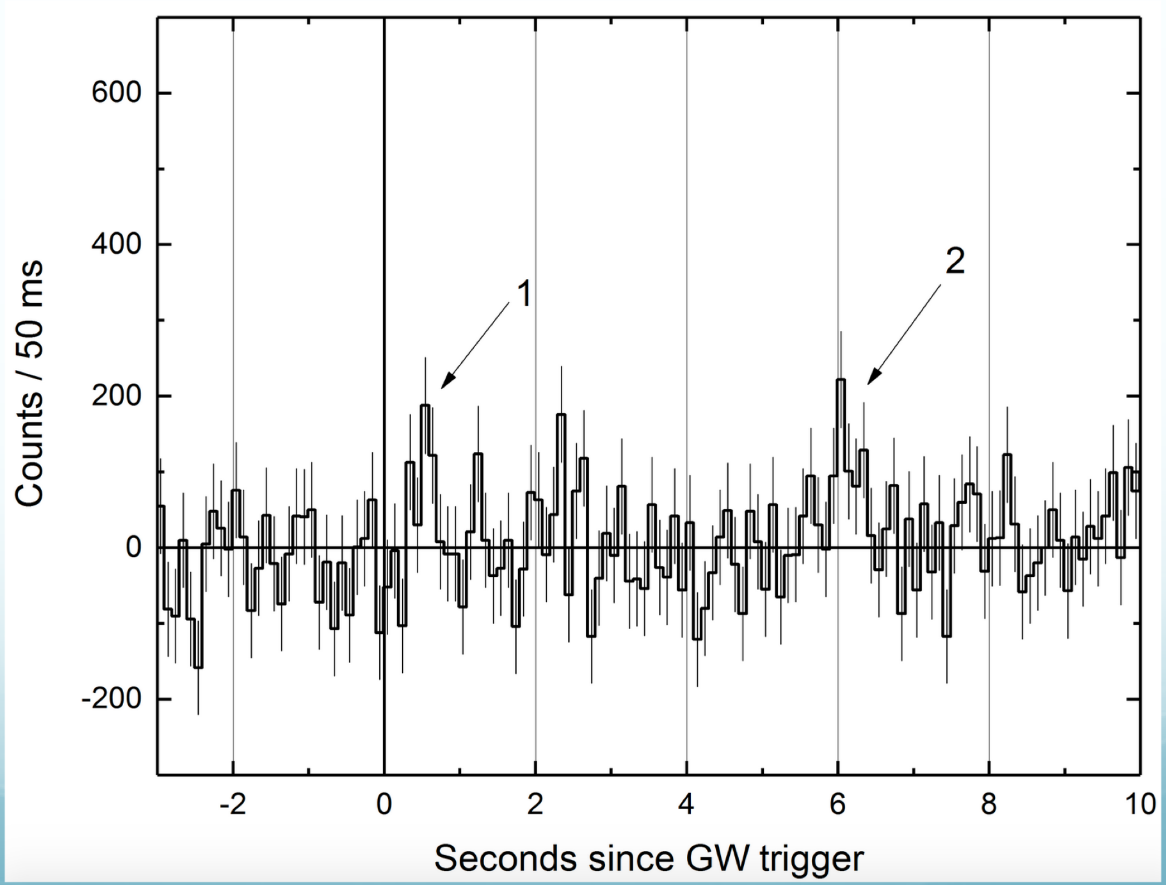
MM parameter estimation



- GW chirp mass estimation as prior
- Break degeneracy with a **sparsely-sampled** KN light curve

Questions

- Include **other EM counterparts** in parameter estimation?
- GW constraints on distance and viewing angle?
- Only small dependence of KN on viewing angle in this model...
- BNS in GW190425: **KN not found** (too faint, too poorly localized?)
- **INTEGRAL detection** with two pulses after this event? (GCN #24170)
- **Viewing angle constraints from GW** in GW alerts?



Population Prospects for Electromagnetic Counterparts to Neutron Star Mergers in the Gravitational Wave Era

R. Duque, F. Daigne & R. Mochkovitch

May. 9th 2019

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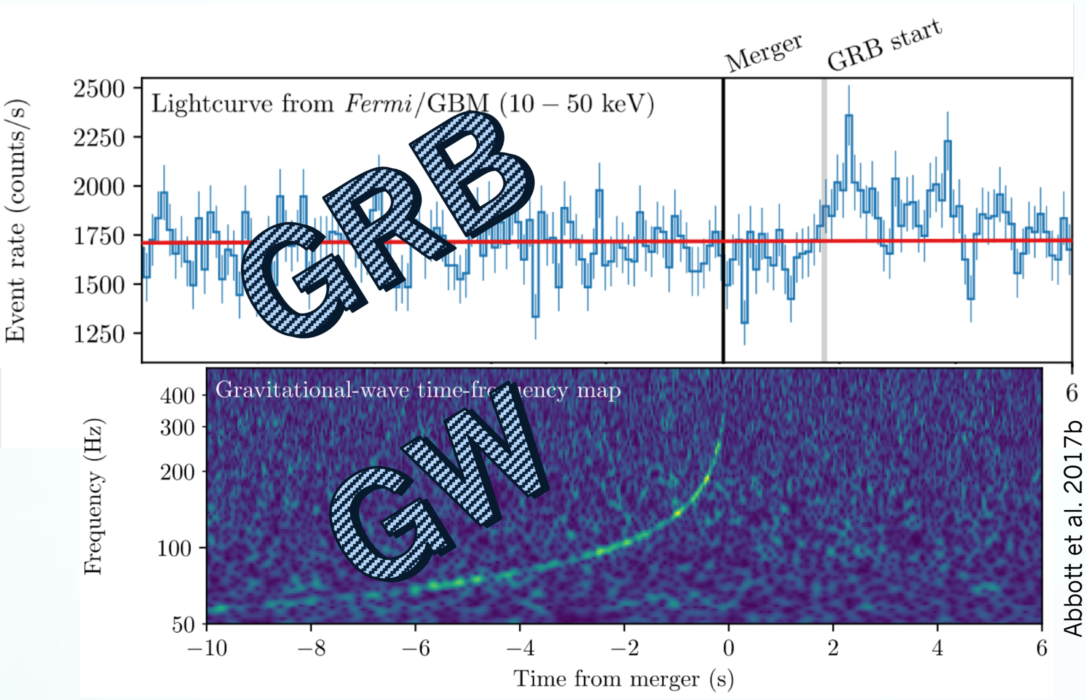
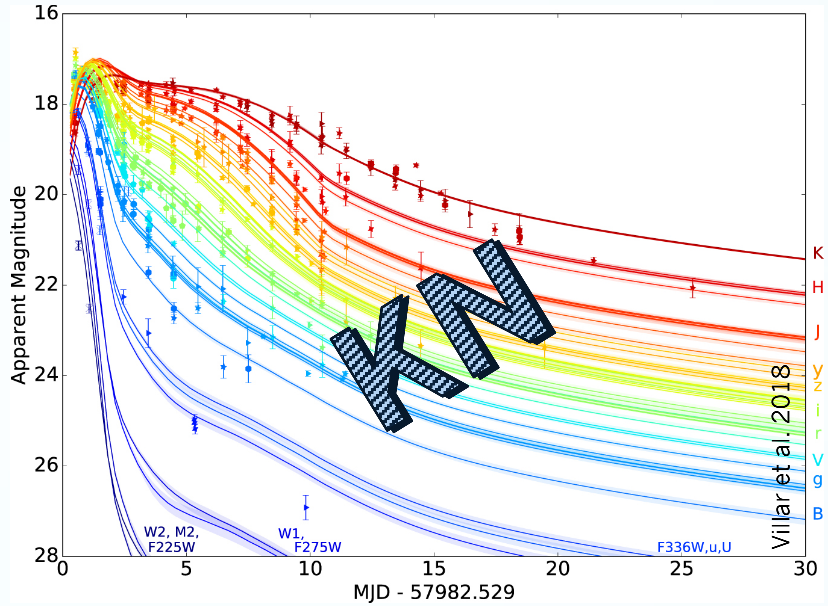
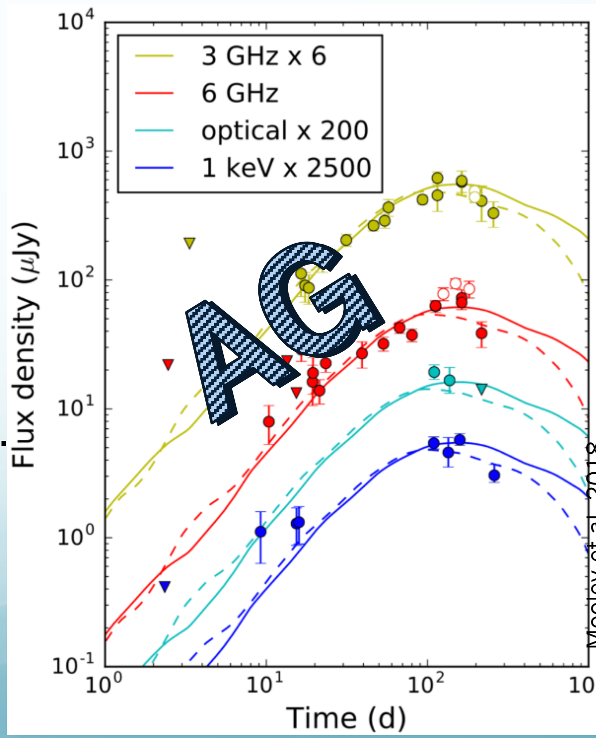
Multi-Messenger Astronomy Journal Club

On August 17th 2017…





- Confirmed NS-NS mergers as **progenitors for short GRBs**
- Inauguration of the **era of multi-messenger astronomy with GW**
- Other fundamental (astro-)physics: GR, NS EOS, Hubble constant measurement, r-process nucleosynthesis, etc.

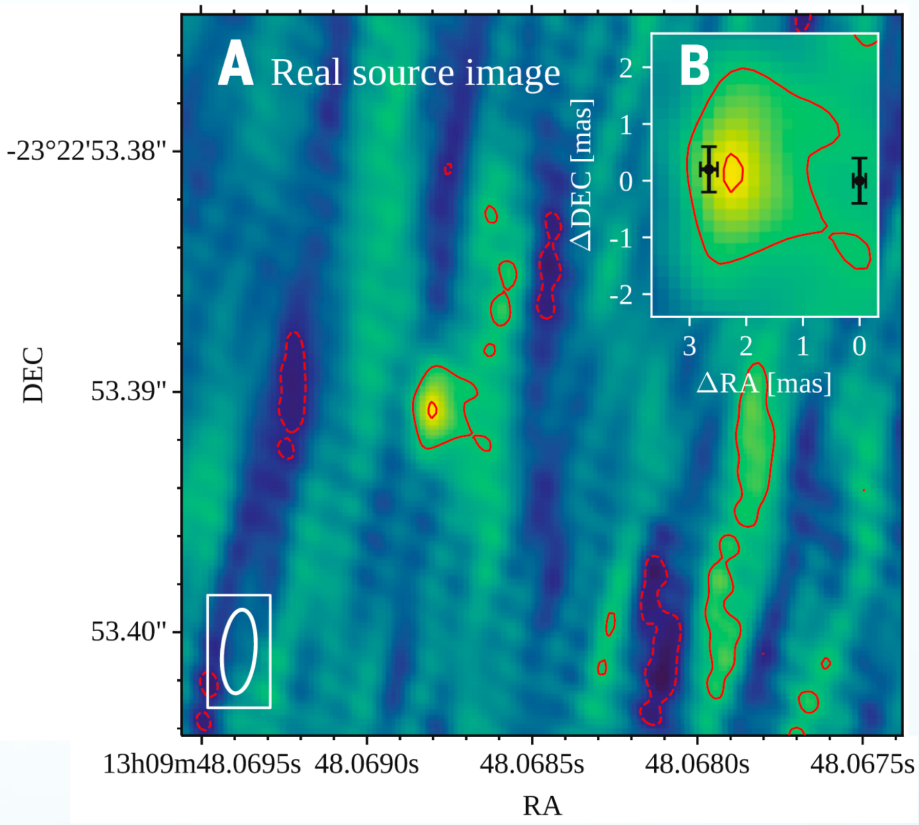


Afterglows and kilonovae: What should we expect for O3?

Context

Afterglow, kilonova
= great wealth of information!

- ✓ Localization
- ✓ External medium density
- ✓ Jet kinetic energy
- ✓ Jet geometry
- ✓ Viewing angle
- ✓ Magnetic field
- ✓ And more!



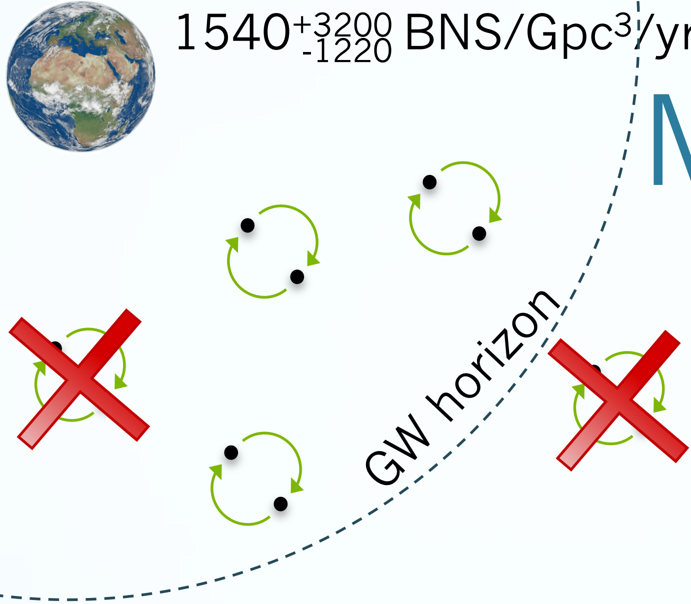
Ghirlanda et al. 2018

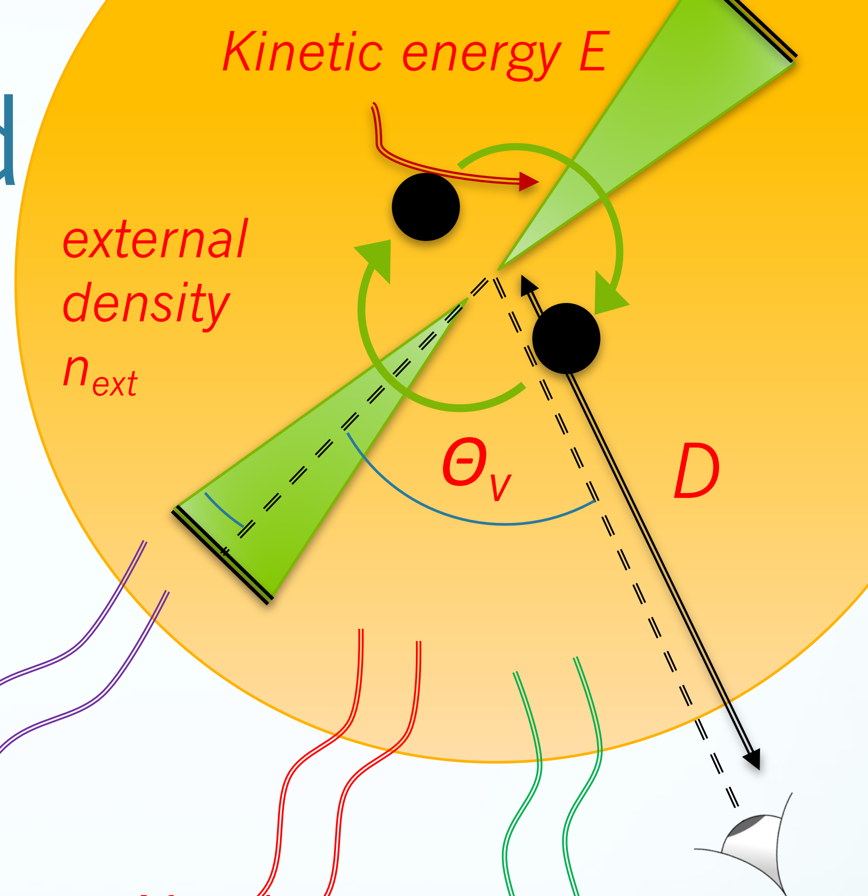
O3 is coming (April 2019)
→ More GW with afterglow and kilonova!

- Which **kilonovae and afterglows** to expect and **what will they look like**?
- How will they help to study **the environments of NS binaries**?
- What insight will they bring on the **origin of the jet structure**?
- What will they tell us on **GRBs** and their **dissipation mechanisms**?

Method

1540^{+3200}_{-1220} BNS/Gpc^3/yr (Abbott+2018)





Population model with ingredients: *D*, Θ_v, *E*, n_{ext}, ...
+ **Detection criterion**
→ Deduce **GW+AG observed** population of mergers

Gravitational wave

Afterglow

Kilonova

Detection depends on *D*, Θ_v
... and ***GW horizon***

O3: 250 Mpc
Design: 450 Mpc

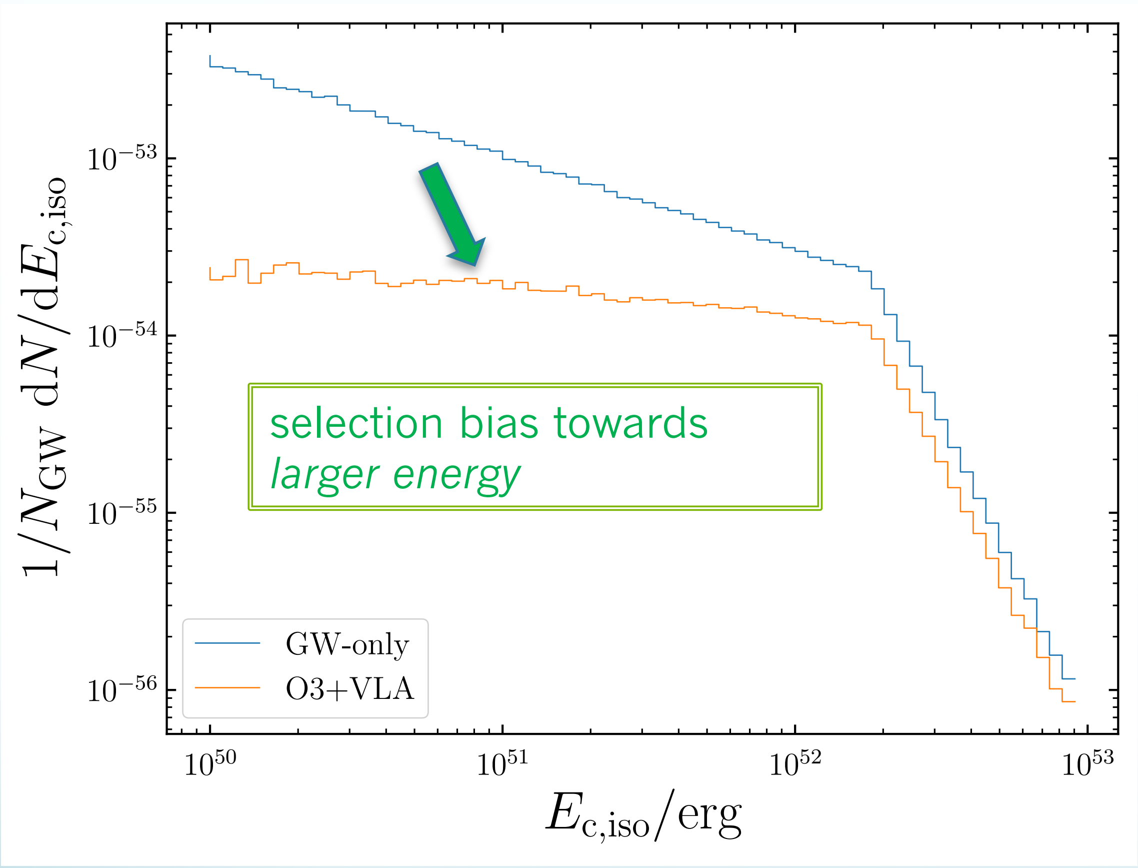
Detection depends on *D*, Θ_v, *E*, n_{ext},
... and ***radio sensitivity***

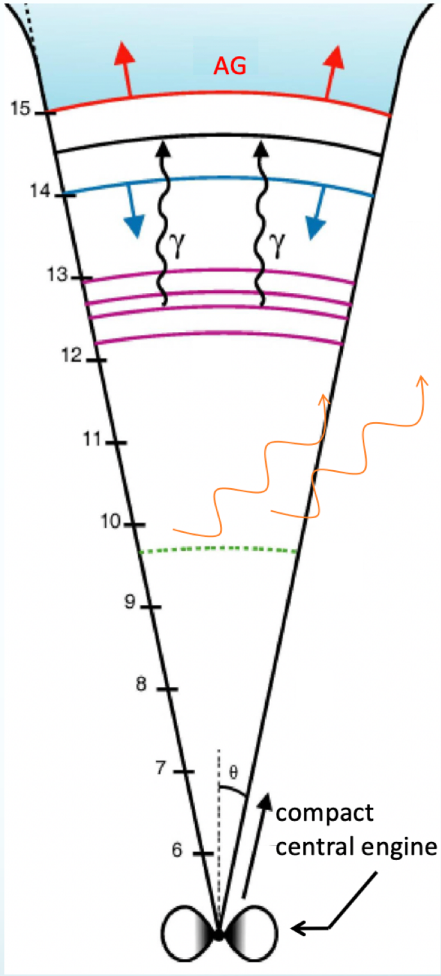
VLA: 10 µJy @ 3GHz
SKA1-Mid: 1 µJy

Detection depends on *D*, Θ_v
... and ***Vis.-IR follow-up depth***

Population model distributions:

Energy





Reference model:

➢ *Energy*: BPL, break energy 2.10^{52} erg, slopes +0.5 and -2 (Ghirlanda et al. 2016)

(Detectable) Event rates for NS-NS

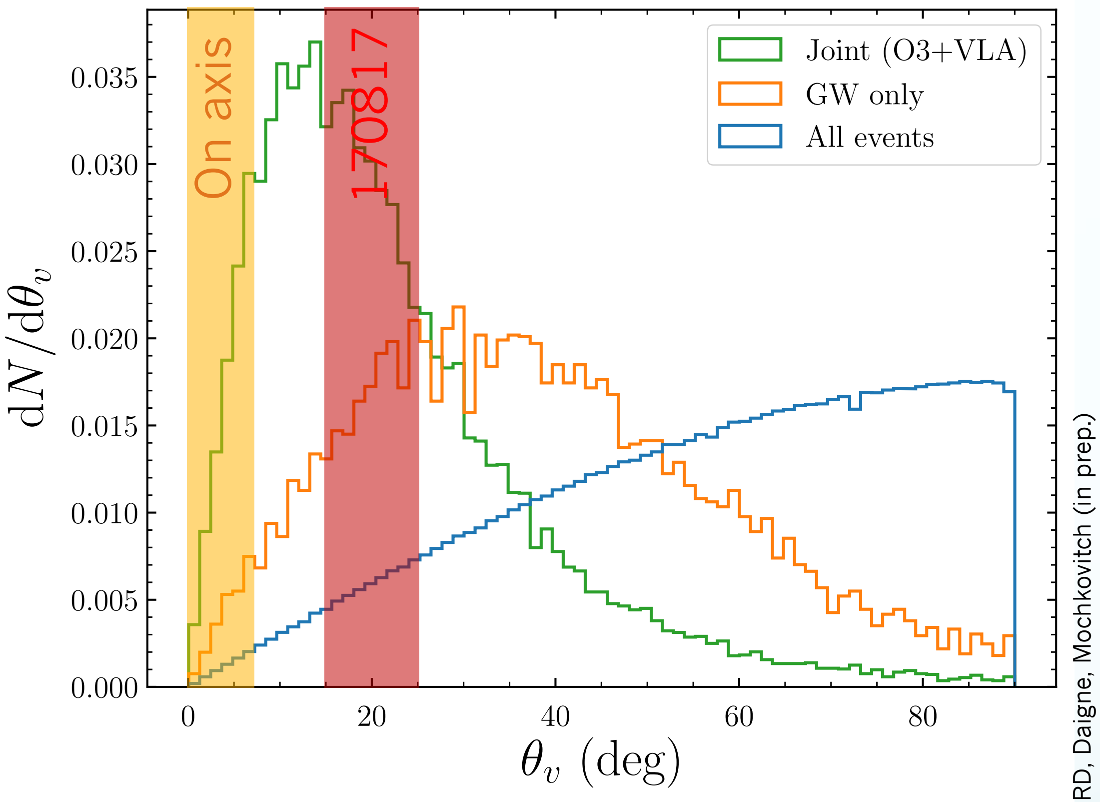
<table>
<tr><th>Detector conf.</th><th>#GW</th><th>#(GW+AG)</th><th>#(GW+KN)</th></tr>
<tr><td>O3 + VLA</td><td>9</td><td>3</td><td rowspan="3">100%</td></tr>
<tr><td>Design + VLA</td><td>21</td><td>5</td></tr>
<tr><td>Design + SKA</td><td>21</td><td>10</td></tr>
</table>

Can we **detect** all **detectable** events?

Uncertainties: $^{+200\%}_{-73\%}$ (intrinsic rate from LIGO-Virgo O2/O3)
+ uncertainty on population model

- In general: **10-30% events have detectable AG** (depending on energy distribution)
- Large deviation from this **= constraints on population!**

Properties of joint events: viewing angle



- Most events seen off axis!
- Mean angle ~20-30°
- New insight on GRB physics

→ ***Jet geometry? Origin of lateral structure?***

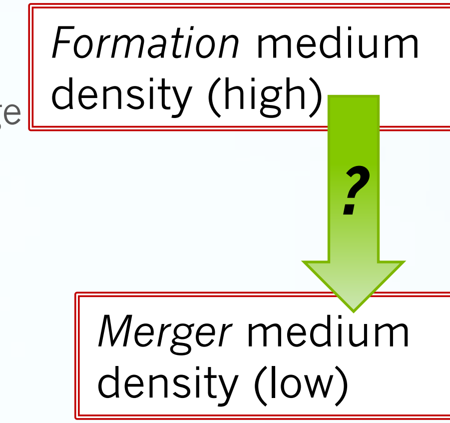
→ **GRB dissipation mechanisms** (thermal tail?)

→ $\lesssim$10% **on axis (GRB!)**

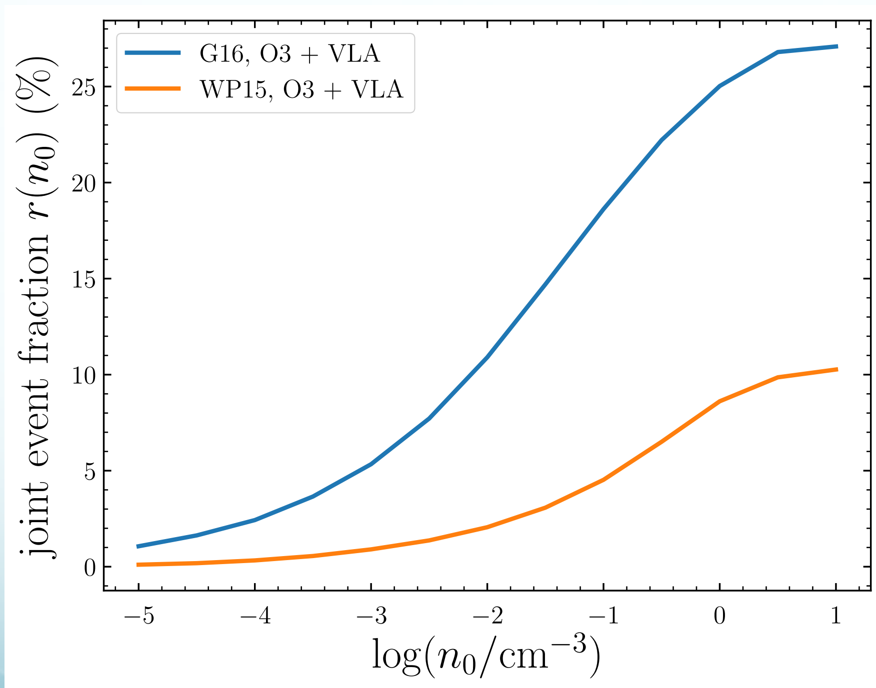
GW+GRB ~ 1-10% (O3)
(Beniamini et al. 2018)

+ Other distributions:
distance, peak flux, proper motion, ...

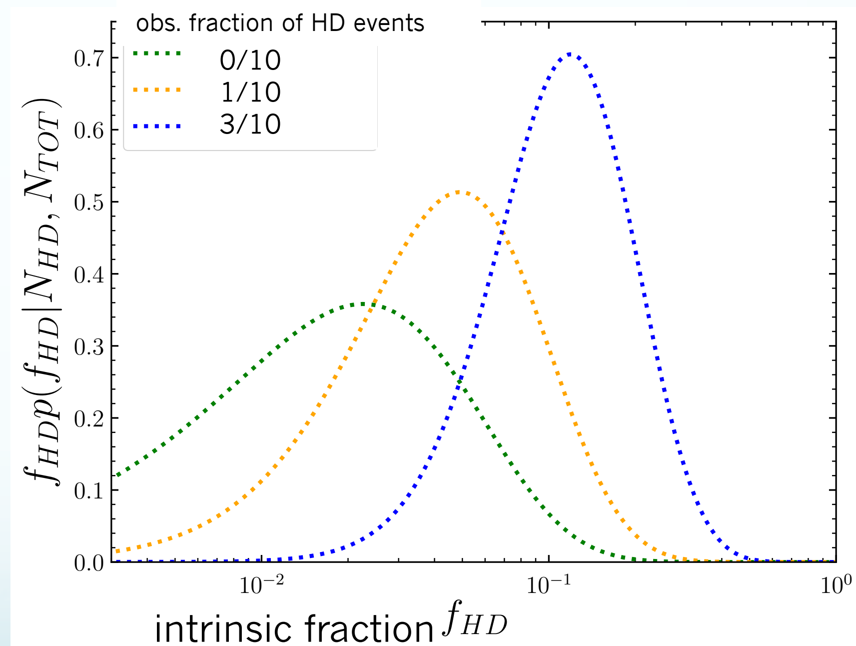
Binaries in high density media



- NS binaries with high **eccentricity** or efficient **common envelope** phase merge in high density media after **short delay time** (Beniamini+2016)
- **Evidence found** for this population by various authors (*r*-process element abundance, sGRB rate vs. cosmic SFR, Galactic binary population)
- Mergers occurring in dense media produce **brighter AG** and are **more likely detected** ($F \sim n^{4/5}$)



Beniamini, RD, Mochkovitch, Daigne (in prep.)

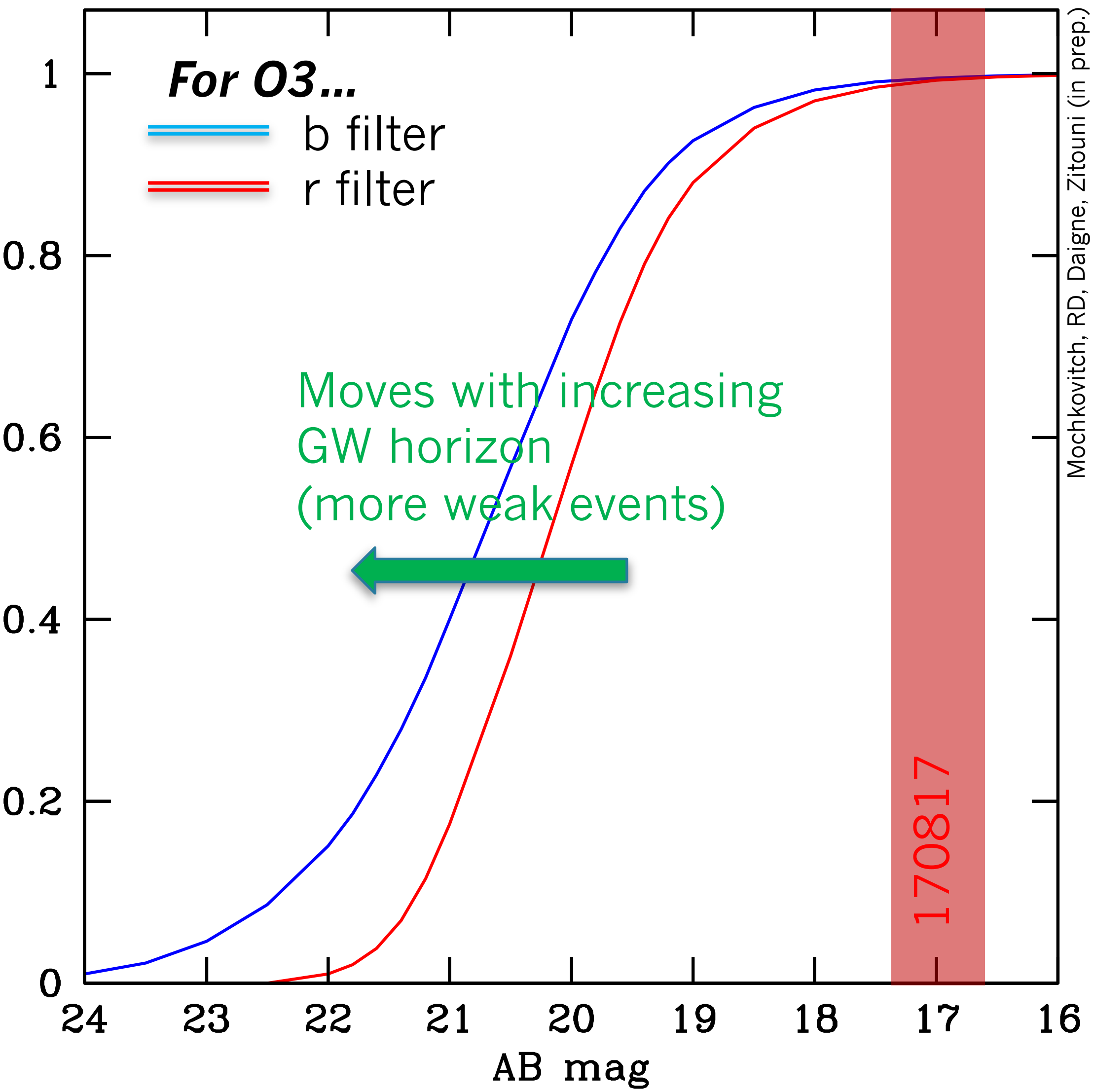


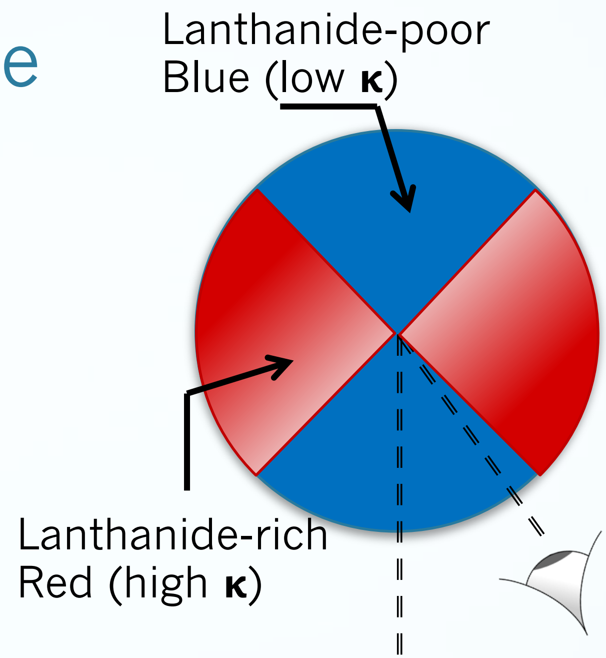
Beniamini, RD, Mochkovitch, Daigne (in prep.)

→ **Tight constraints** on fast merging binaries **from only a few events**

Observation of *3 high-density out of 10*
→ **log(f$_{HD}$) = - 1 ± 0.6**

Expectations for kilonovae





- Vis.-IR signal depends on **viewing angle** because of ejecta contrasts in physical conditions

For O3:

✓ **Magnitude OK** *a priori*

✗ Volume to explore potentially **100x larger** than for 170817

✗ Contrast with host galaxy

→ **Finding the OT challenging!**

Conclusion

- **Afterglows and KN are important** to understand the **local and viewing conditions** of **NS-NS mergers**
- O3 is coming: **several** NS-NS GW events, **a few** with afterglow, **all with *detectable* KN**
- ***Detectable*** is not ***detected!*** Difficulty to find KN during O3…
- Actual **fraction of AG/GW will constrain population** of NS-NS merger population (jet parameters, external density, etc.)
- Most events are seen **off-axis,** allowing to **probe the jet geometry** and **emission therein**
- **High-density mergers** will allow to study **fast-merging binaries**. Only a **few events** are necessary **to constrain this** particular binary **NS evolution channel**.

Long run

Link pop. coalescence — pop. sGRB

Interpretation tools for observations of GRBs in the multi-messenger context:

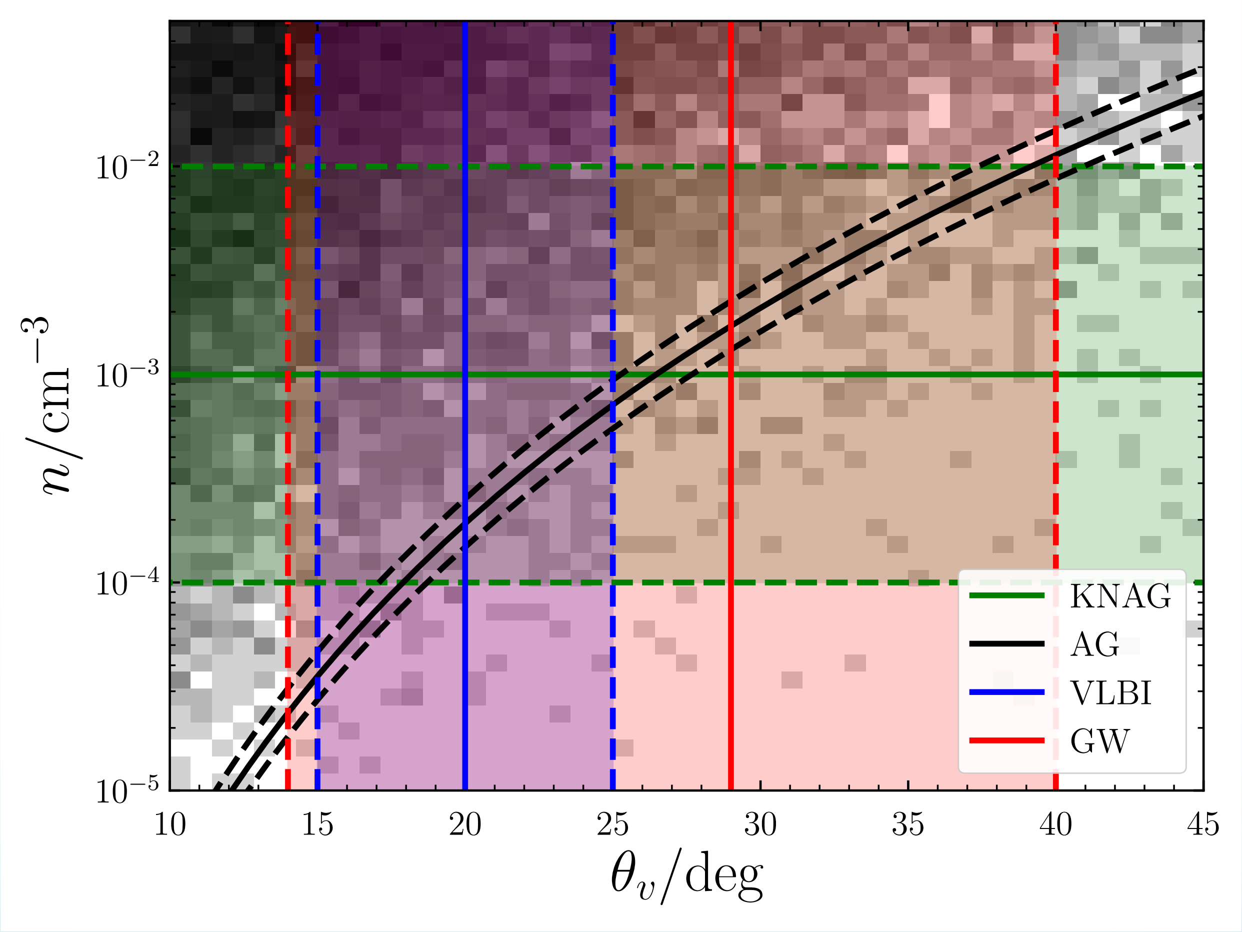
① Modeling of EM counterparts of CO fusions: sGRBs and afterglows

➡ Context: observations by LIGO–Virgo (~2019)

② Modeling of the general population of GRBs and afterglows

➡ Context: present and future observations: Swift, Fermi, INTEGRAL, **SVOM**

Determining viewing angle and density from multi-messenger observations



1: GRBs & CO fusions

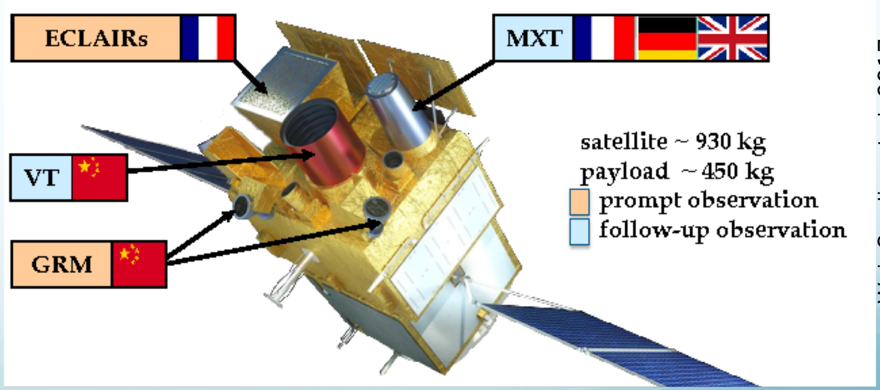
- Distinguish NS-NS and BH-NS?
- Nature of final object? Link with ring-down signal?
- **Systematic fusion/GW/sGRB/kilonova/afterglow association?**
- **GW/GRB delay?**

2: General population of GRBs

Rates: (Wei, Cordier et al. 2017a):

- SVOM: 60-70 yr^{-1}
- Swift, Fermi, INTEGRAL: ~100 yr^{-1}

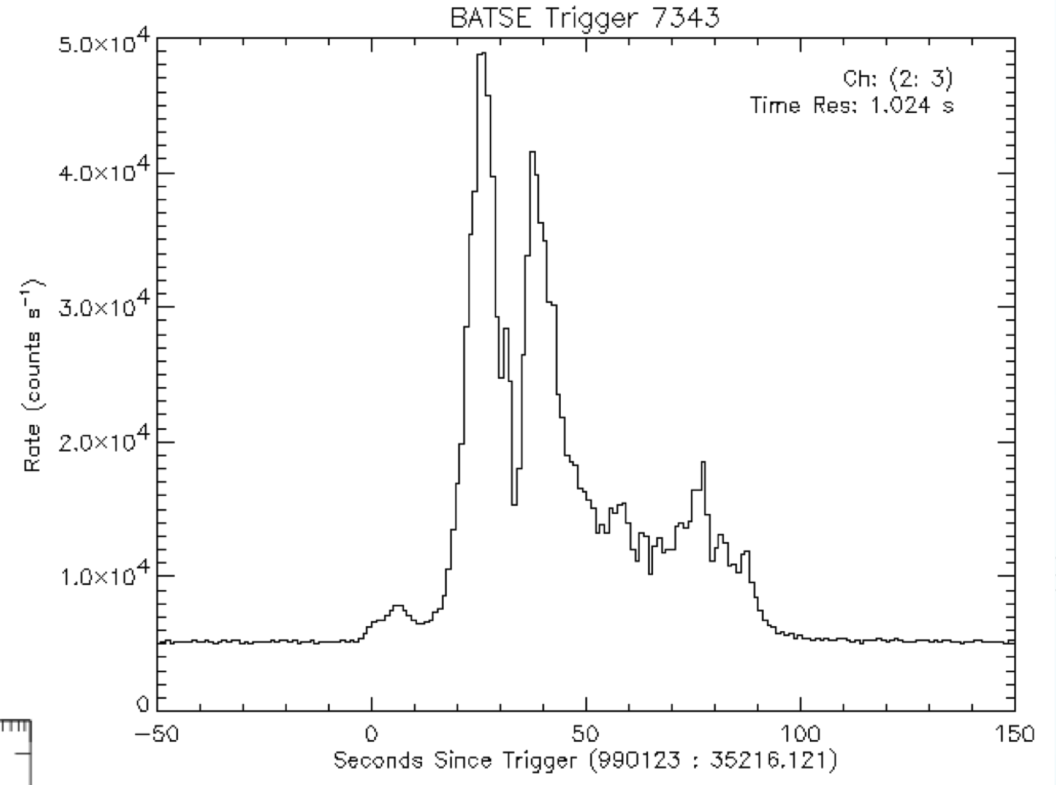
- **Radiative processes in GRB (shocks/magnetic reconnection)?**
- Ejecta magnetization?
- **Other afterglow observables (polarization, imaging)?**



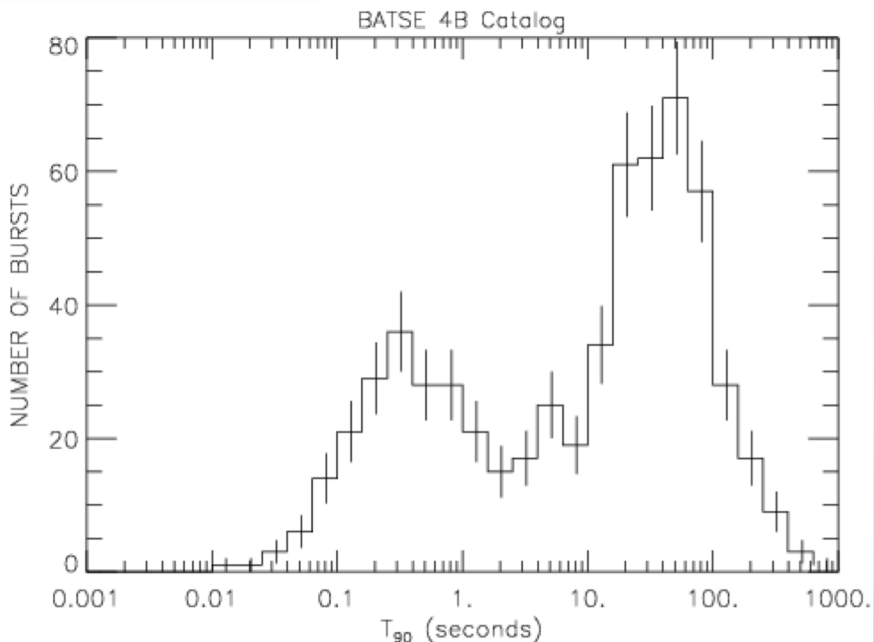
Wei, Cordier et al. 2017a

Gamma-ray bursts

Light curves:
- Strong variability
- Shape diversity
- Variation time-scale diversity



Paciesas et al. 1996



Duration

Paciesas et al. 1996

Longs (ccSNe):
- > 2s
- Soft
- High SFR galaxies

Short (compact object mergers):
- < 2s
- Hard
- Early-type galaxies

Gamma-ray bursts