Electromagnetic counterparts to gravitational wave transients in the MeV range

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Summary

- Introduction
- Multi-messenger astronomy
- 3 EM counterparts to GWs: Gamma Ray Bursts
- 4 e-ASTROGAM contribution
- Conclusions

The beginning of GW astronomy

Four GW signals from BBH mergers and a GW candidate have been reported by Advanced LIGO and Virgo until now (Abbott et al. 2016,2017)

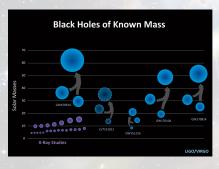




Image credits:

LIGO/Caltech/Sonoma State (A. Simonnet); LIGO/Caltech/MIT/Leo Singer/Axel Mellinger

⇒ Where did the mergers occur? Multi-messenger astronomy is needed!

Why multi-messenger astronomy?

GWs and photons provide complementary information about the physics of the sources and their environments

GW

- mass
- spin
- eccentricity
- system orientation
- luminosity distance
- compact object binary merger rate

EM

- precise (arcsec) sky localization
- host galaxy
- redshift
- local environment
- emission processes
- acceleration mechanisms

Joint GW and EM detections

Two possible scenarios:

• EM follow-up:

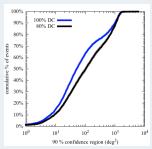


• Externally-triggered GW searches: an EM transient event is detected and GW data are analyzed to look for possible associated GW events (see, e.g., Abbott et al. 2017, ApJ 841, 89).

EM follow-up of GW transients

EM follow-up challenges:

Poor sky localization of GW events



Patricelli et al. 2016, JCAP, 56, 011

- large FoV telescopes and/or optimized observational strategies are needed to cover the GW error box
- broadband observations and spectroscopy are needed to identify the EM counterparts among many transient contaminants

- Latency to send the GW alert (∼ tens of minutes)
 - very sensitive instruments and/or long monitoring periods are needed to detect faint and fading sources

Why e-ASTROGAM?

- Large FOV (> 2.5 sr):
 - monitoring of a large portion of the sky → higher probability of detecting a transient source
 - good coverage of the large GW error boxes (tens to hundreds of square degrees)
- γ-ray domain:
 - γ -ray sky less "crowded" \Rightarrow clearer association of an EM transient to the GW event
- Accurate sky localization (< 1 deg² at 1 MeV)
 - easier follow-up of the GW events by other telescopes with smaller FOV
- Possibly coincident observational schedule with 3rd generation interferometers
 (Einstein Telescopes and Cosmic Explorer) and space-based GW detectors
 (eLISA)
 - higher detection rate and possibility to investigate new sources (e.g., massive BHs)

Which sources e-ASTROGAM will be able to detect?

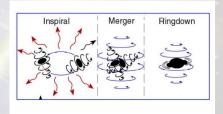
BBH mergers are not expected to have an EM counterpart...

Besides BBH mergers, which are the other transient GW sources detectable by LIGO and Virgo?

Do they have an EM gamma-ray counterpart?

Other GW sources

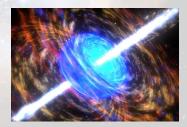
Other promising sources for the next GW detections by Advanced LIGO and Advanced Virgo are mergers of binary systems formed by two neutron stars (NS-NS) or a neutron star and a black hole (NS-BH)





NS-NS and NS-BH mergers are expected to be associated with short GRBs

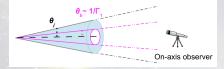




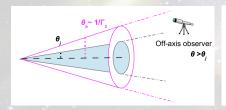
Gamma Ray Bursts: why joint GW and EM observations?

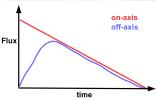
GRB emission - on/off axis

The prompt emission is tipically observed only if the GRB is on-axis



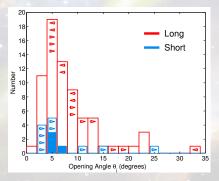
The afterglow emission can be potentially observed also if the GRB is off-axis





GRB jet opening angle

• GRB jet opening angle is not well constrained by observations (see, e.g., Berger et al. 2014):



• Numerical studies suggest that $\theta_i \leq 30^\circ$ (see, e.g., Rezzolla et al. 2011)

How many on-axis/off-axis short GRBs in the local universe?

Local (on-axis) short GRB rate:

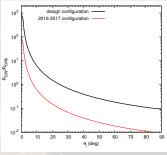
 $ho_{\rm GRB} = 0.1$ -40 Gpc⁻³ yr⁻¹ (e.g., Ghirlanda et al. 2016, Wanderman & Piran 2015) $ightharpoonup {\rm R}_{\rm GRB}$ (300 Mpc*)=0.01-4.5 yr⁻¹

short GRB rate \Rightarrow NS-NS merger rate

Assuming that all NS-NS mergers are progenitors of short GRBs:

$$R_{\text{NS-NS}} = \frac{R_{\text{GRB}}}{1 - \cos(\theta_j)}$$

- $\theta_j = 10^\circ$: R_{NS-NS}(200 Mpc)=0.2-90 yr⁻¹
- θ_j =30°: R_{NS-NS}(200 Mpc)=0.02-10 yr⁻¹



Patricelli et al. 2016, JCAP, 11, 56

Joint GW and EM observations will help to constrain the jet opening angle and the fraction of NS-NS progenitors

^{*}The distance range for NS-NS of 200 Mpc is expected to be a factor 1.5 greater for face-on systems

Expectations with e-ASTROGAM - preliminary

Assumptions

- Maximum sGRB distance: 500 Mpc
- sGRB spectrum: Band function, with parameters of sGRBs observed by Fermi-GBM (Nava et al. 2011)
- e-ASTROGAM sensitivity for an observation period of 1 s: 0.05 ph cm $^{-2}s^{-1}$ (Tatischeff et al. 2017)

Expectations

e-ASTROGAM will be able to detect sGRBs down to a minimum luminosity $L_{\rm min} \sim 10^{48}~\text{erg/s}$

The estimated L_{\min} is lower than the typical luminosity of short GRB (D'Avanzo et al. 2014)



e-ASTROGAM is sensitive enough to detect all the on-axis short GRBs in the local universe; furthermore, it will possibly detect also off-axis and/or sub-luminous sources, with the consequent sizeable increase in the detection rates

Expectations with e-ASTROGAM - preliminary

We use the sample of NS-NS mergers and associated GW signal and detection from Patricelli et al. 2016, to investigate the expected detection rates

Assumptions

- All NS-NS mergers are associated to a sGRB
- Only on-axis sources are considered ($\theta < \theta_j$); $0.3^\circ \le \theta_j \le 30^\circ$ (Panaitescu et al. 2011, Rezzolla et al. 2011, Coward et al. 2012)
- All the sGRBs have $L > L_{\min}$
- e-ASTROGAM FOV: 2.5 sr; duty cycle: 100 %

Expectations

- The expected detection rate of on-axis sGRB by e-ASTROGAM in coincidence with a GW detections is up to 1.5 events per year (Patricelli et al., WB contribution)
- joint GW and EM detection rate will double after the incorporation of KAGRA and LIGO-India into the GW network (\$\leq\$ 2029)

Conclusions

The era of GW astronomy has just begun: many other GW detections are expected in the future!

e-ASTROGAM will be crucial for multi-messenger astronomy

- e-ASTROGAM will be able to promptly cover the large GW error boxes
- e-ASTROGAM will be a key instrument for the identification of on-axis sGRBs associated with NS-NS mergers
- e-ASTROGAM will be able to detect sub-luminous and/or off-axis sGRBs (accurate modeling in progress)