Prospects for Joint Gravitational Wave and Electromagnetic Observations of Neutron-Star–Black-Hole Coalescing Coalescing Binaries

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GRBs in the Multi-Messenger Era, Paris - June 19, 2014



Introduction

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- Given a GW observation, do we expect an EM counterpart?
- Ø Given an SGRB trigger, can we improve a GW offline search?
- Given a joint GW+EM observation, can we constrain the NS equation of state (EOS)?



 GW detection will not be able to determine all parameters with high accuracy [Ohme, Nielsen, Keppel, & Lundgren (2013)]



 Understanding the waveform structure throughout the parameter space allows for efficient search strategies and correct interpretations of future observations



Principal component analysis (PCA)

PCA of post-Newtonian expansion coefficients: computationally cheap and accurate waveform (dis)agreement calculation technique [Tanaka & Tagoshi 2000, Sathyaprakash & Schutz 2003, Pai & Arun 2013, Brown *et al* 2012]



Eigenvectors μ_i represent *principal directions* ranked by their eigenvalues λ_i

$$\left\|\Delta h\right\|^2 = \sum_i \lambda_i (\Delta \mu_i)^2$$

Degeneracies

- $\mu_1 \sim M_{\rm Chirp} = (M_{\rm NS} M_{\rm BH})^{3/5} / (M_{\rm NS} + M_{\rm BH})^{1/5}$ (extremely well measurable)
- μ₂ : mass-ratio/spin degeneracy (well constrainable)
- Higher components add less information, neglected here
- \Rightarrow GW measurement \rightarrow 1D line in the $M_{\rm BH}-M_{\rm NS}-\chi_{\rm L,BH}$ space







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Part II: EM counterparts



- Disk mass: $10^{-3} 0.1 M_{\odot}$
- Size: 10-1000km
- Density: 10⁸⁻¹²g/cm³
- Temperature: >MeV
- Accretion rate

• Angular momentum distribution

- Magnetic field configuration
- ν cooling
- Composition
- Unbound tidal tails





Part II: EM counterparts



EM counterpart production condition (SGRB ignition)

 $M_{
m b,disk} > M_{
m b,Threshold} \gtrsim 0.01 M_{\odot}$



Part III: Combining the information

Algorithm

- Pick a class of target systems ($\chi_{\rm BH}=$ 0.998 to maximize $M_{\rm b,disk}$)
 - (A) Constant chirp mass, as accurately determined by GW measurement.

(B) Systems degenerate with $M_{\rm NS} = 1.35 M_{\odot}$, $\chi_{\rm \hat{L},BH} = {\rm const.}$

- Perform PCA, identify GW degeneracies through constant principal components (Advanced LIGO ZDHP, 15 Hz cutoff)
- Pick an equation of state
- Calculate M_{b,disk} for each point along the GW degeneracy
- Segions with $M_{b,disk} > M_{b,Threshold} = 0.03 M_{\odot}$ are EM loud
- Overlay GW degeneracies with EM loud parameter space regions



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Part IV: Results





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- Regions in which EM follow-ups are favourable/unfavourable
- Increasing(decreasing) the target χ_{L,BH}(M_{Chirp}) enhances the chances of having an EM counterpart



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Part IV: Results



- GW degeneracies hardly intersect with EOS thresholds
- Joint GW+EM detection \rightarrow lower bound on the NS EOS stiffness
- Low $\chi_{\hat{L},BH} \rightarrow$ exclude soft EOSs (possibly strange quark matter) for most M_{Chirp} values



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Part V: Improving offline searches

An SGRB is detected and it triggers and offline NS-BH GW search:

• $M_{\rm NS} \in [1, 2.8] M_{\odot}, M_{\rm BH} \in [3, 15] M_{\odot}, \chi_{\hat{\rm L}, \rm BH} \in [-0.95, 0.95]$

Conservatively estimate the size of parameter space where an SGRB counterpart cannot be ignited:

- χ_{BH} = 0.998
- $\bullet\,$ 2H 2-piecewise-polytrope \rightarrow high $\textit{M}_{NS}^{Max} \sim$ 2.8 \textit{M}_{\odot} and large \textit{R}_{NS}
- No SGRB counterpart for $M_{\rm b,disk} = 0 M_{\odot}$



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- ⇒ At most 35%(25%) of the parameter space is useful in following up an SGRB trigger
- \Rightarrow 43%(48%) of the templates cover the SGRB silent region
- \Rightarrow Increase in speed and sensitivity



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Conclusions

- Conventional wisdom (high $\chi_{\rm BH}$, low $M_{\rm BH}$ favour SGRBs) translated into quantitative predictions for CBC searches
- Joint GW+EM detection potentially places lower bound on EOS stiffness
- Developed framework to assess the importance of an EM follow-up



- Can easily be turned into an add-on for search/parameter-estimation pipelines
- Potential speed-up in offline GW searches following SGRB triggers CARDIE