Multi-Messenger Astronomy with Gravitational Waves

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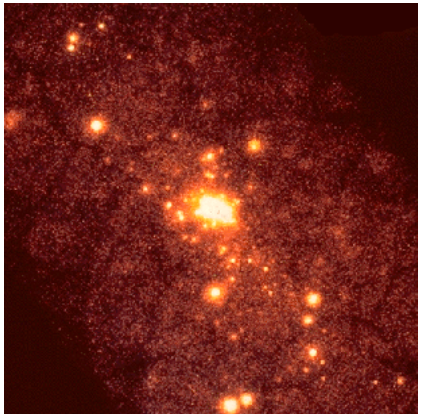
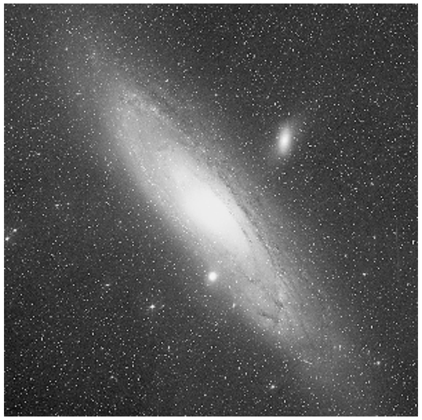
Multi-messenger astronomy is the natural extension of multi-spectral astronomy



X-ray

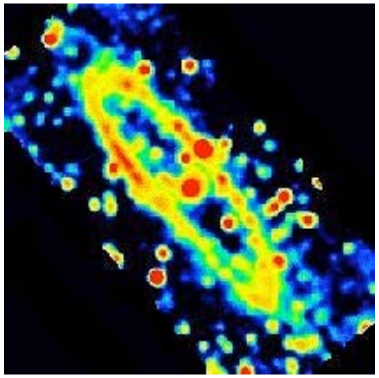
UV



Optical

mid-IR

far-IR



Radio

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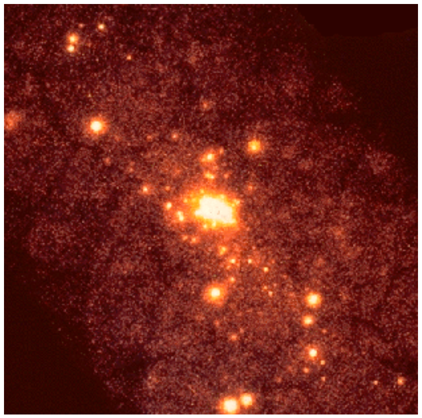
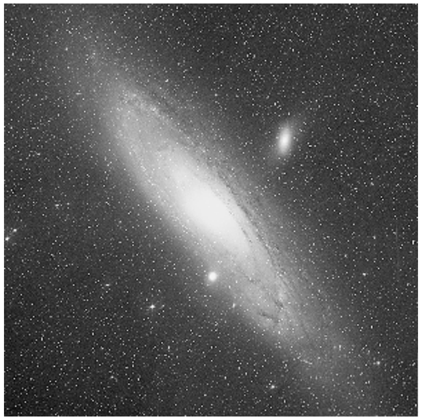


X-ray

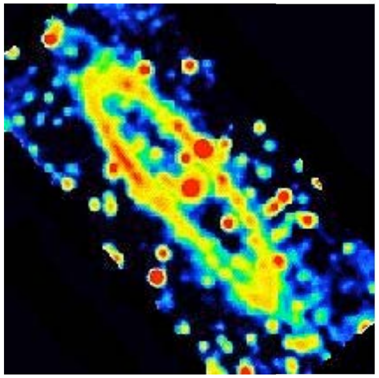
UV



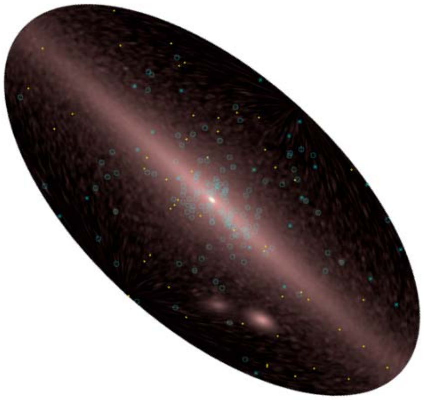
Optical

mid-IR

far-IR



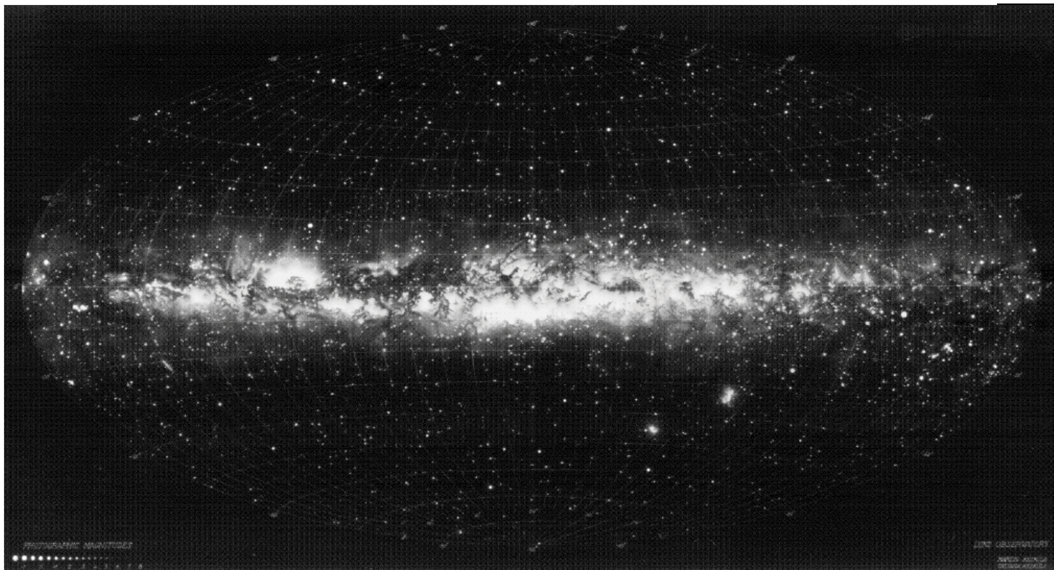
Radio

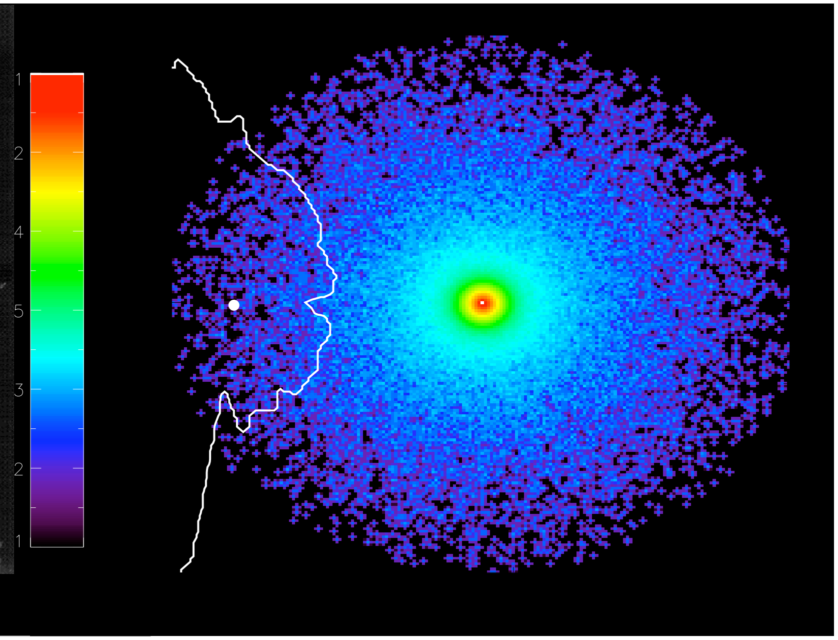


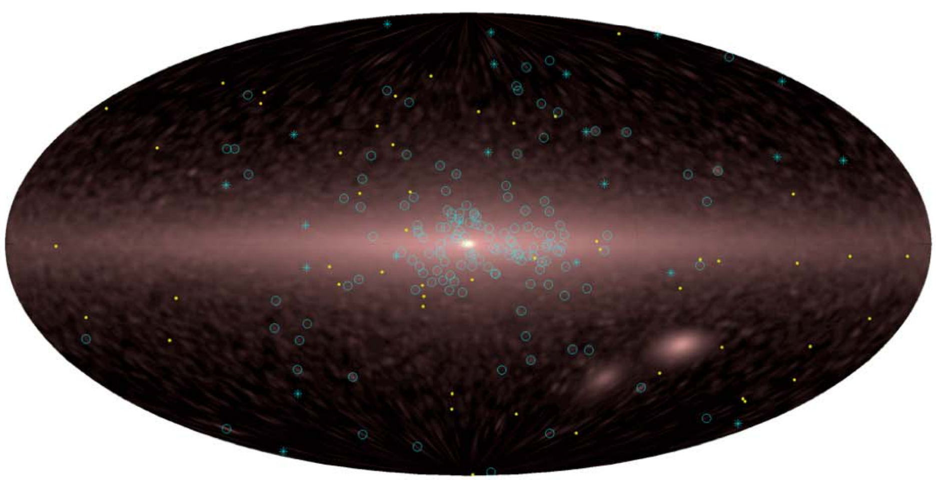
Grav-Wave

LISA will observe more CWDBs than any optical telescope

Hubble limits for white dwarf observations







LISA *resolvable* compact binaries

Type	Resolved	With *df/dt*
(wd, wd)	$>10^4$	~600
AM CVn	$>10^4$	~50
(ns,wd)	21	3
Other	2	0

Nelemans 2003

Knowing the period, inclination angle, and sky location of a CWDB enables a targeted search for an optical counterpart

Gravitational wave observations:

Orbital frequency $f / 2$

Orbital sin i

Ratio $(\pi f \mathcal{M})^{2/3} \mathcal{M} / d_L$

Optical observations:

Mass function f_m

$a \sin i$

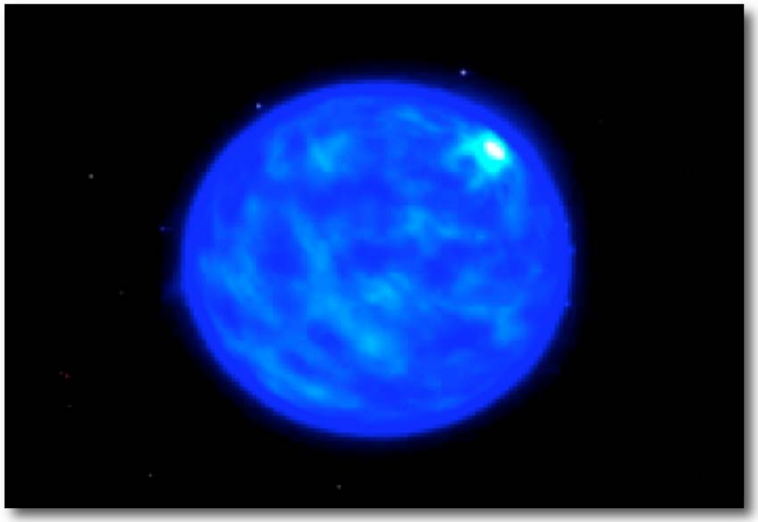
Gravitational + Optical:

a, m_1, m_2, d_L !

$$
\begin{aligned}
h_+ &= \frac{2\mathcal{M}}{d_L}\left(1+\cos^2 i\right)(\pi f \mathcal{M})^{2/3}\cos\Phi(t) \\
h_\times &= \frac{4\mathcal{M}}{d_L}\cos i\,(\pi f \mathcal{M})^{2/3}\sin\Phi(t) \\
f &= \frac{1}{\pi\mathcal{M}}\left(\frac{5}{256}\frac{\mathcal{M}}{T-t}\right)^{3/8} \\
\Phi &= -2\left(\frac{T-t}{5\mathcal{M}}\right)^{5/8} \\
\mathcal{M} &= \left(\mu^2 M^3\right)^{1/5}
\end{aligned}
$$

Joint optical, gw observations will enable census of white dwarf masses and improve calibration of the first rung of the cosmic distance ladder

Gravitational wave observations can distinguish between proposed GRB progenitors



Credit NASA

Collapsar

~10^{-8} $M_{\odot}$ in 10 – 100 ms linearly polarized burst

NS, NS/BH merger:

~20s inspiral plus 3 – 10% $M_{\odot}c^2$ merger burst; circularly polarized

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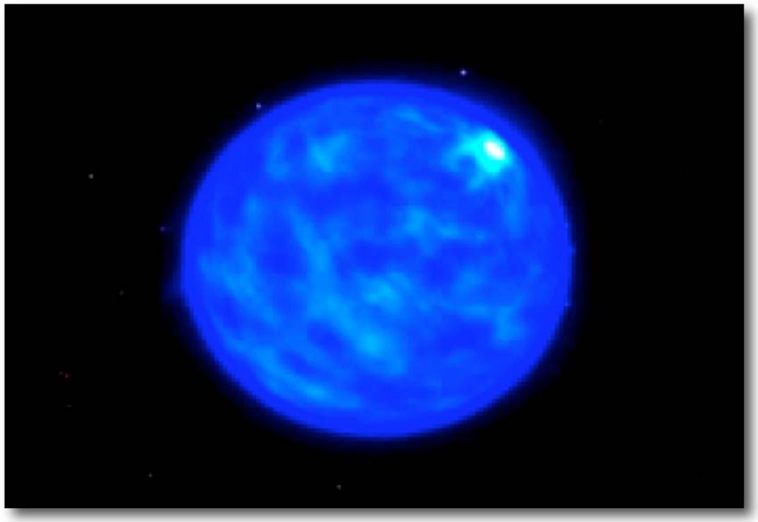

Collapsar

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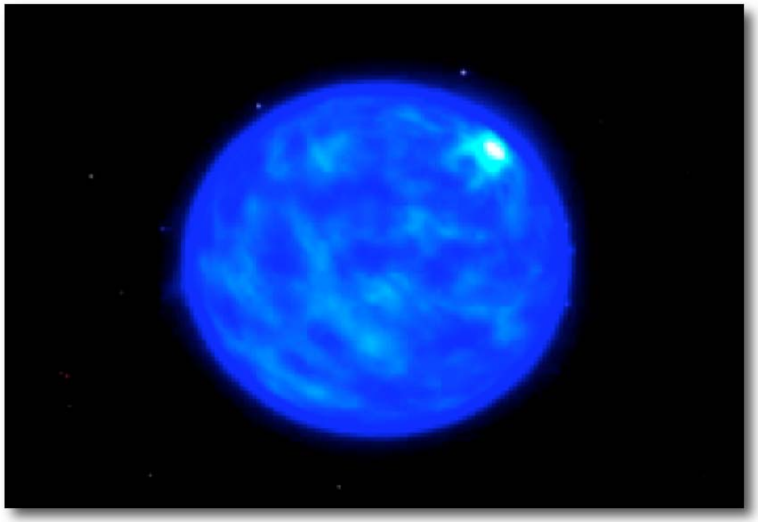
Credit NASA

Gravitational wave observations can test emission mechanism models

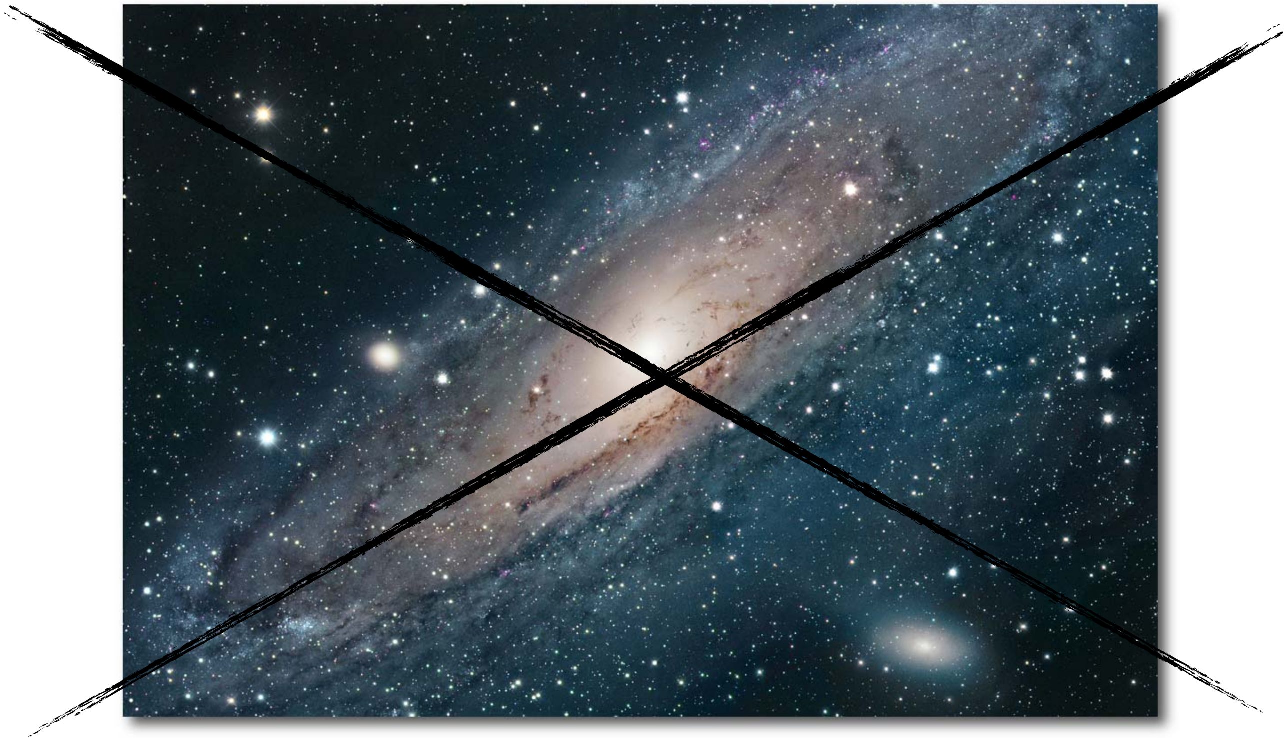
GW polarization measures angle between J, line-of-sight

Interval between gravitational wave, gamma-ray arrival distinguishes between internal shock, external shock emission



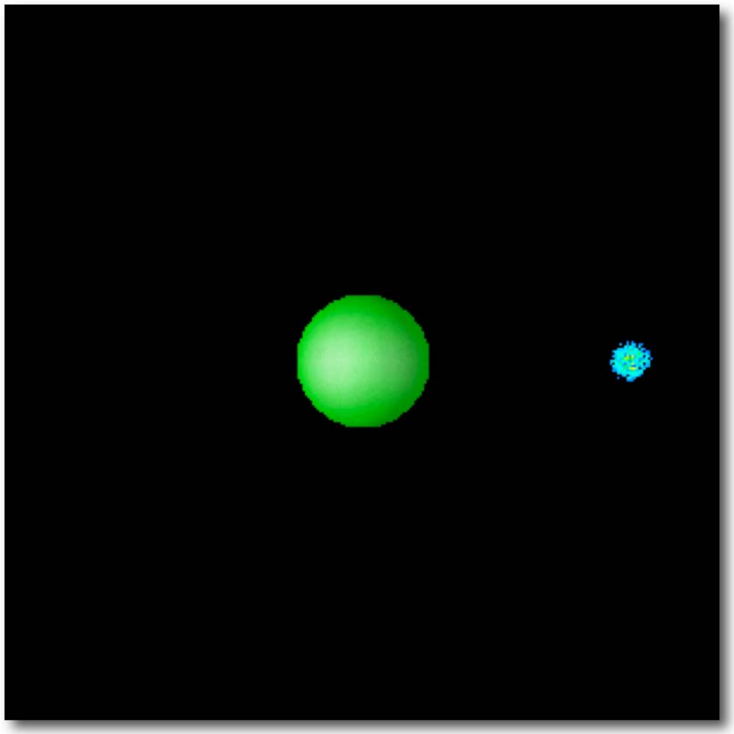
Credit NASA

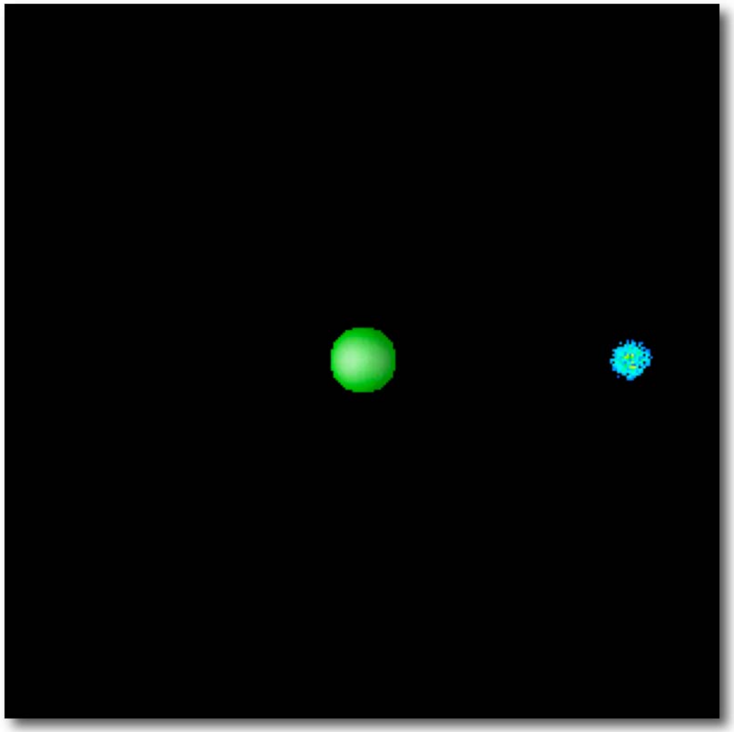
Even credible absence of GW emission may be significant



GRB070201 can't be local

Coincident gw, X-ray flares accompanying tidal disruption of stars by $10^2 - 10^5 M_\odot$ black holes diagnose bh spin





Laguna, Rasio, Rantsiou, Kobayashi

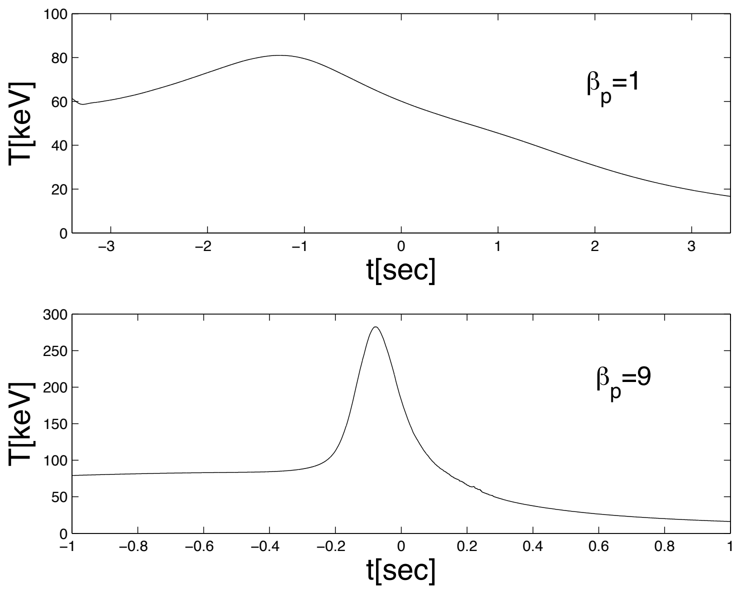
Disruption by Schwarzschild black hole

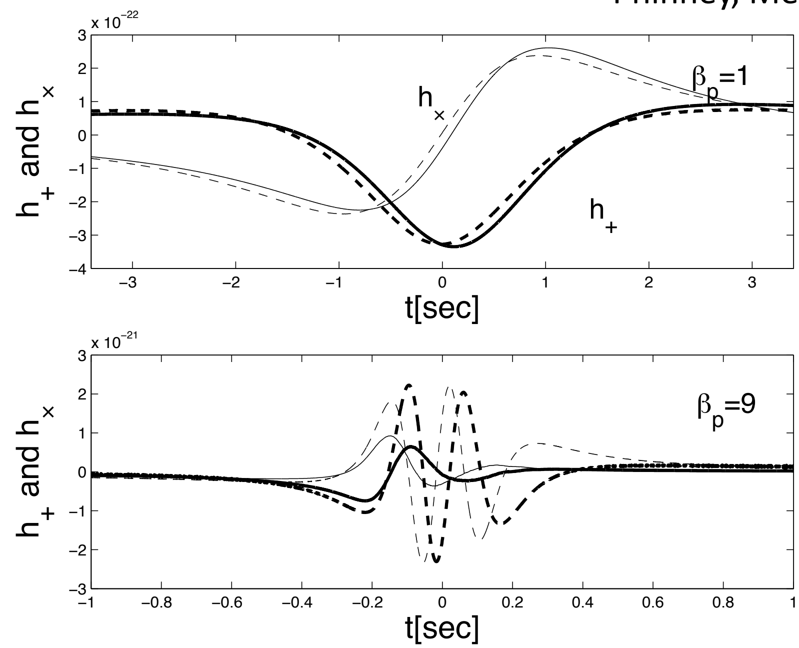
Disruption by maximal Kerr black hole

Multi-messenger signals disruption distinguish between deep, shallow disruptions

“shallow” impact parameter

Kobayashi, Laguna, Phinney, Mészáros





“deep” impact parameter

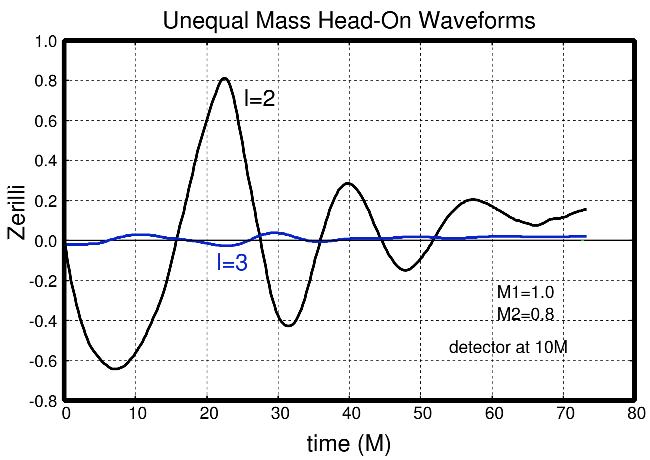
Prompt X-ray Signal

GW in LISA

Prompt multi-channel signals from white dwarf disruption by $10^3\ M_\odot$ black hole

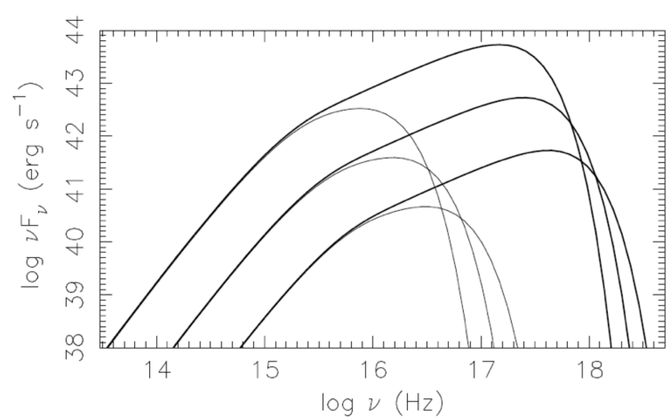
X-ray emission following SMBH coalescence in merged galaxies may provide optical counterpart to gw burst

Binary sweeps the central region free of gas, dust & stars, truncating accretion disk, reducing X-ray emission



gw from inspiral localizes host galaxy

Milosavljevic & Phinney



Post-merger accretion disk is restored on timescale of ~$7(1+z)(M/10^6 M_\odot)^{1.32}$ yr, with thermal emission tracing accretion disk formation

Optical counterpart with redshift of binary inspiral allows *absolute* calibration of cosmological parameters

Polarization ratio measures inclination

Rate of f measures $\mathcal{M}$, T

h_+, h_x amplitudes measure d_L

Optical counterpart gives z

Result: $d_L(z)$!

$$
\begin{aligned}
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