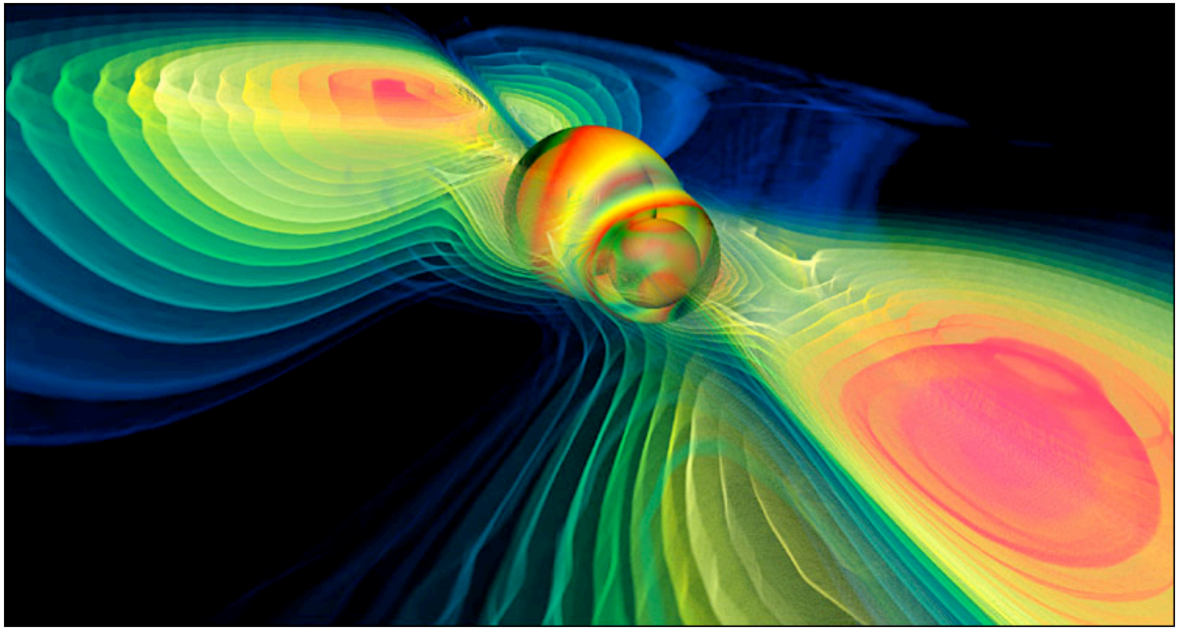
LOFT and the electromagnetic counterparts to gravitational-wave sources



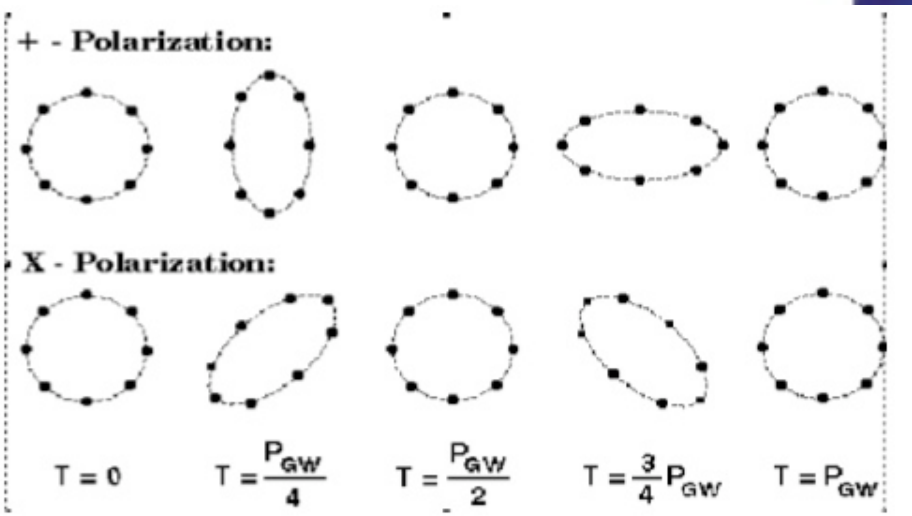
(Image: MPI for Gravitational Physics / W.Benger-ZIB)

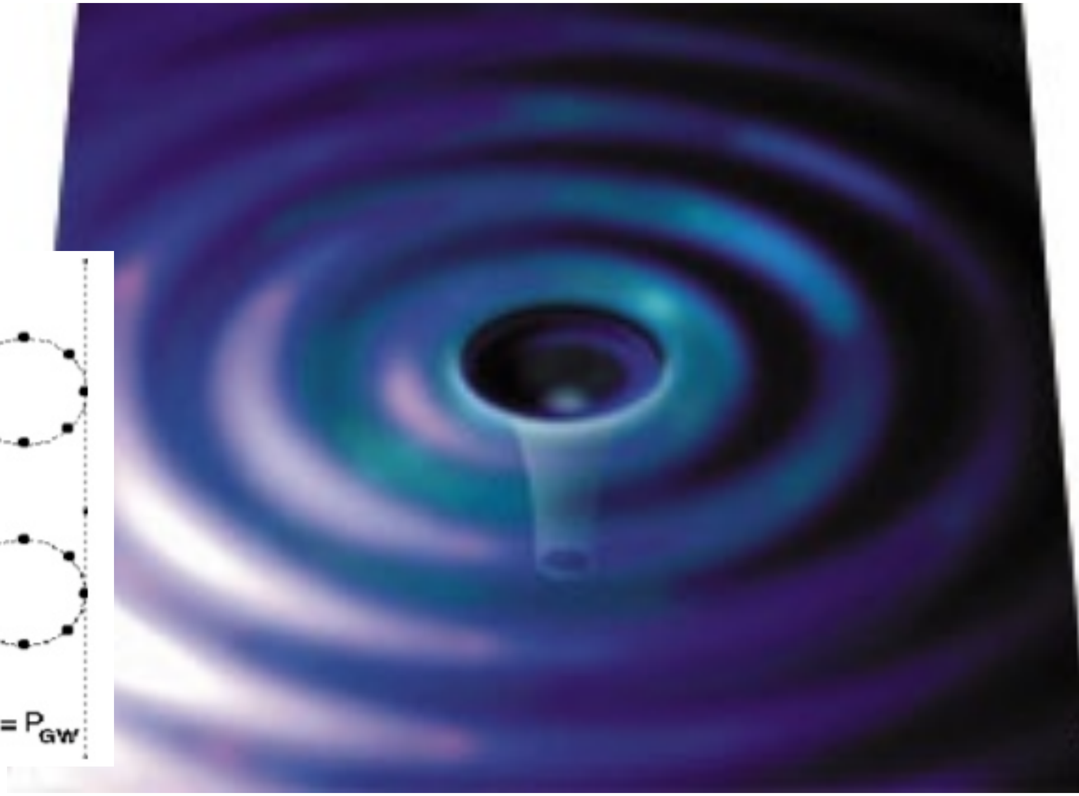
Ilya Mandel
(University of Birmingham)

December 9, 2011
RAS LOFT meeting, London

Gravitational Waves

- Ripples in spacetime:



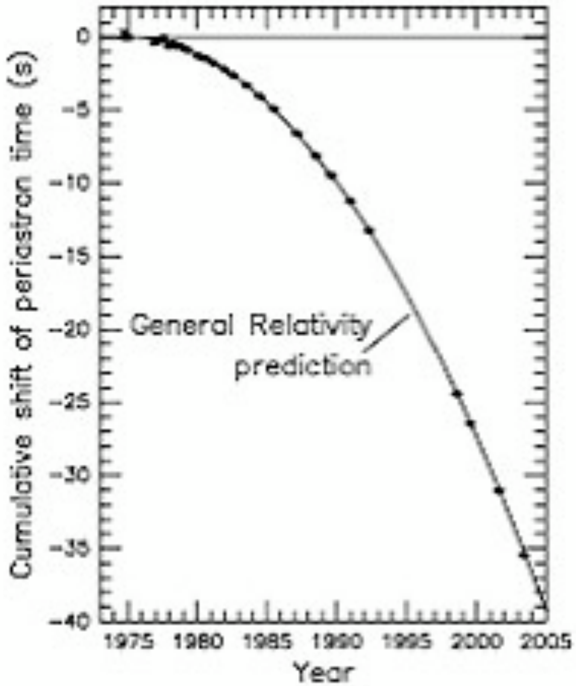


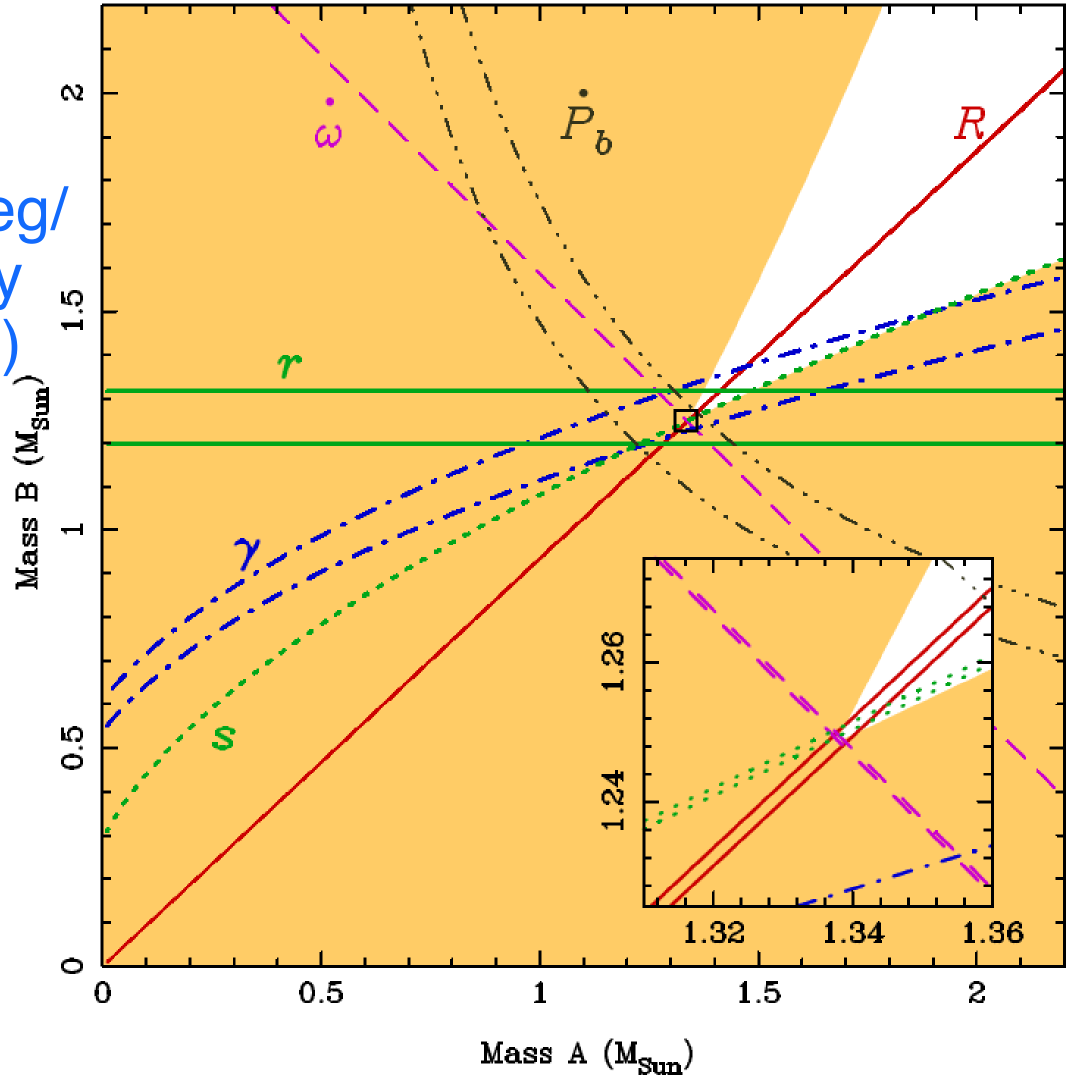
- Caused by time-varying mass quadrupole moment; GW frequency is twice the orbital frequency for a circular, non-spinning binary

Inspiral sound borrowed from Scott Hughes

Indirect observations of GWs

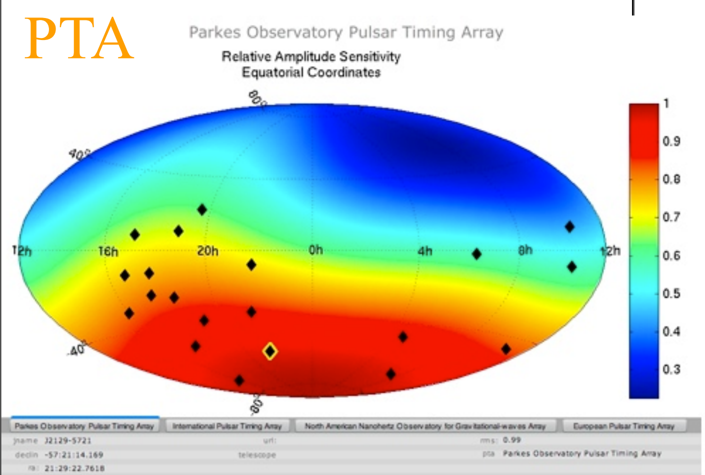
- PSR 1913+16
- Discovered in 1974
- GR precession of 4.2 deg/yr (vs. 43 arcsec/century for Mercury, out of 5600)

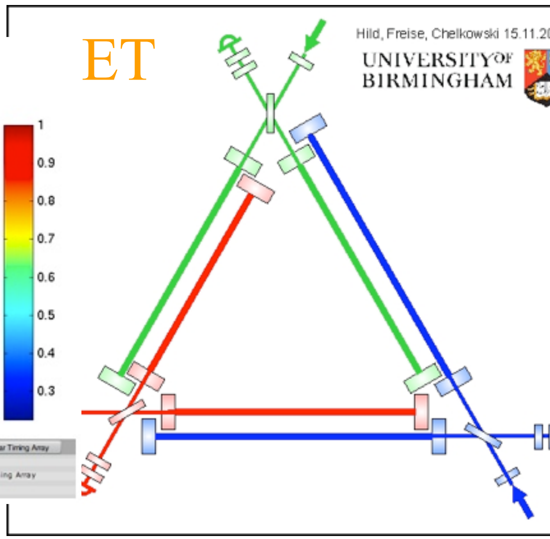


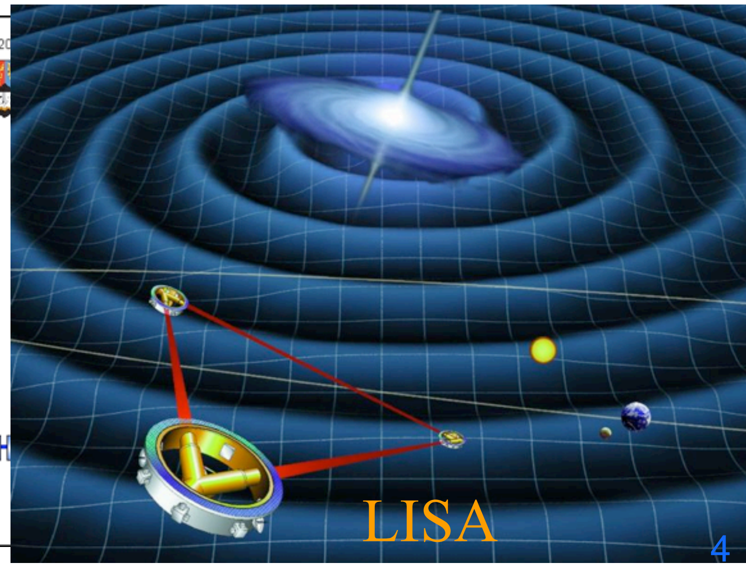


J0737-3039A: [Kramer et al., 2005]

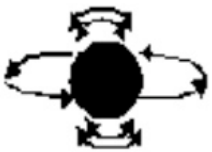
Gravitational-wave observatories



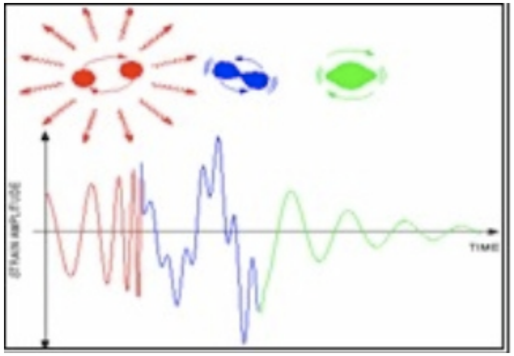




Types of GW sources

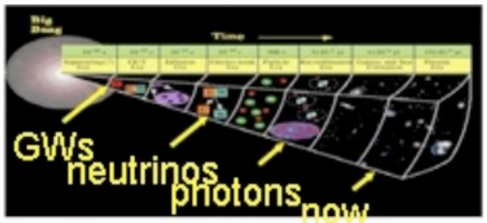


- Continuous sources [sources with a slowly evolving frequency]: e.g., non-axisymmetric neutron stars, slowly evolving binaries



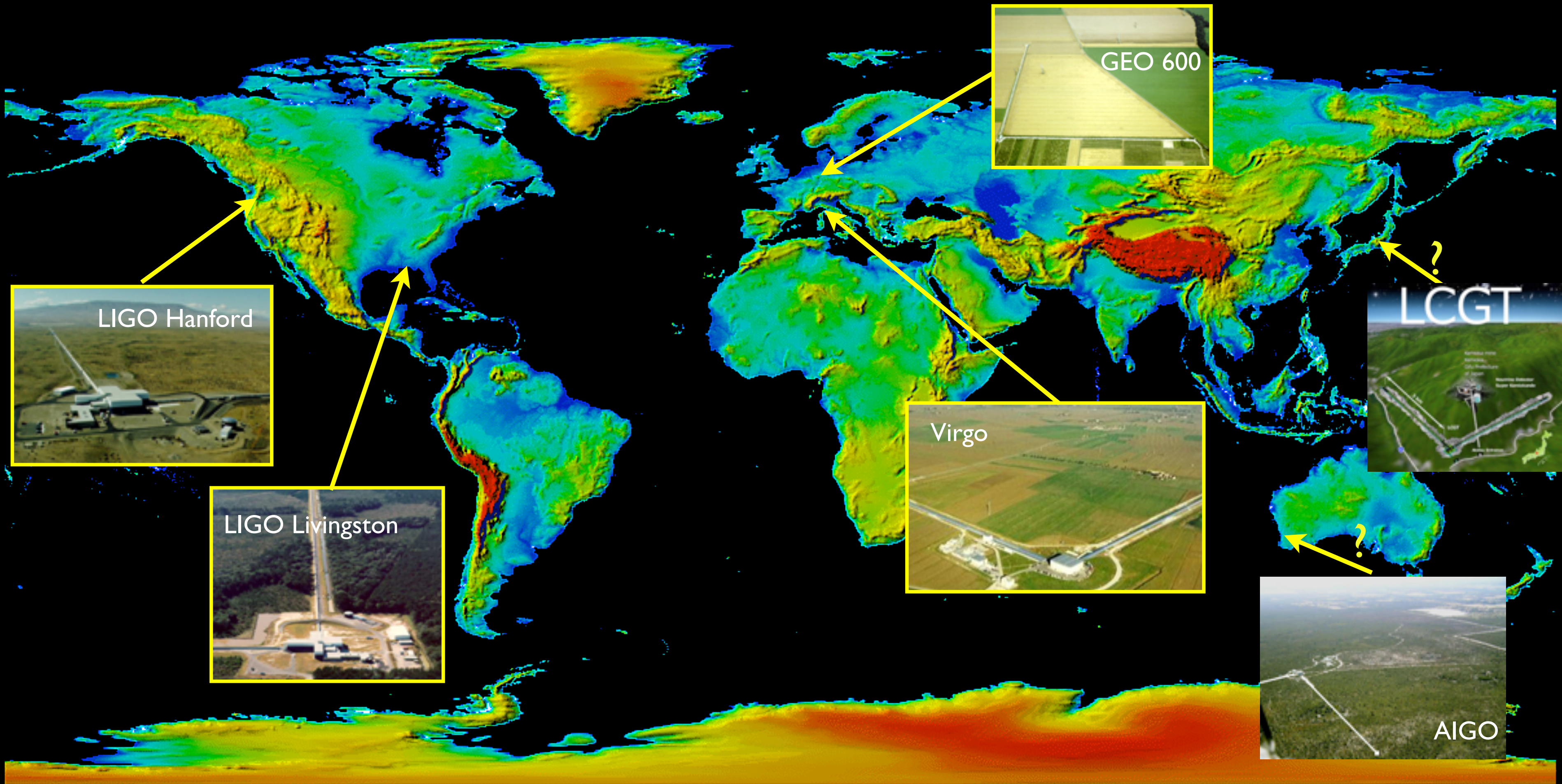
- Coalescence sources [known waveforms, matched filtering]: compact object binaries

- Burst events [unmodeled waveforms]: e.g., asymmetric SN collapse, cosmic string cusps



- Stochastic GW background [early universe]
- ??? [expect the unexpected]

The global network of laser interferometers



Merger Rate Predictions

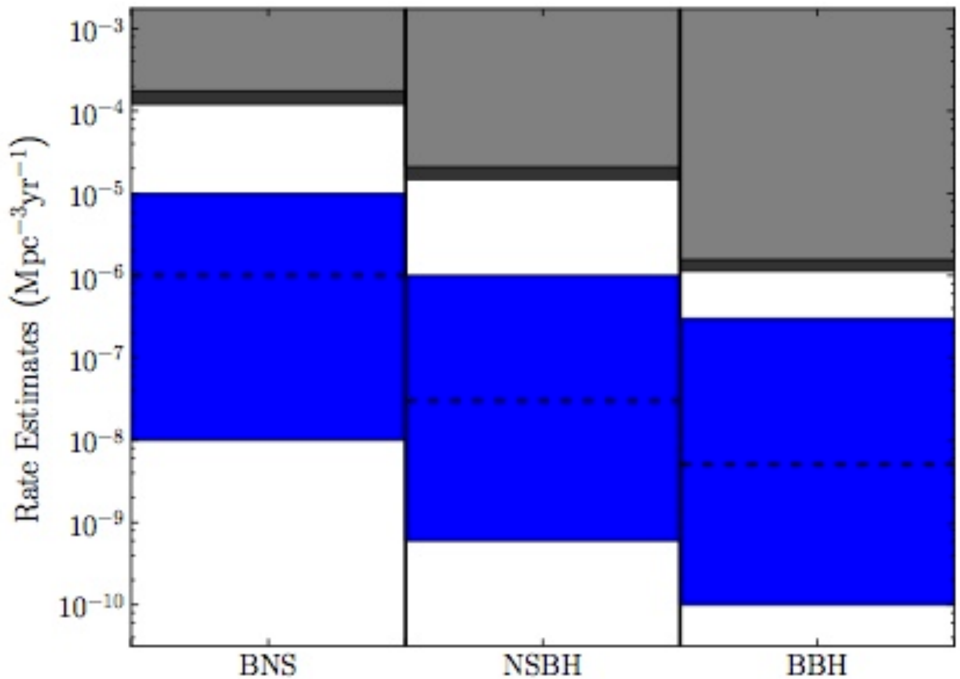
Predicted rates

Source	R_{low}	R_{re}	R_{high}
NS-NS (MWEG^{-1} Myr^{-1})	1	100	1000
NS-BH (MWEG^{-1} Myr^{-1})	0.05	3	100
BH-BH (MWEG^{-1} Myr^{-1})	0.01	0.4	30

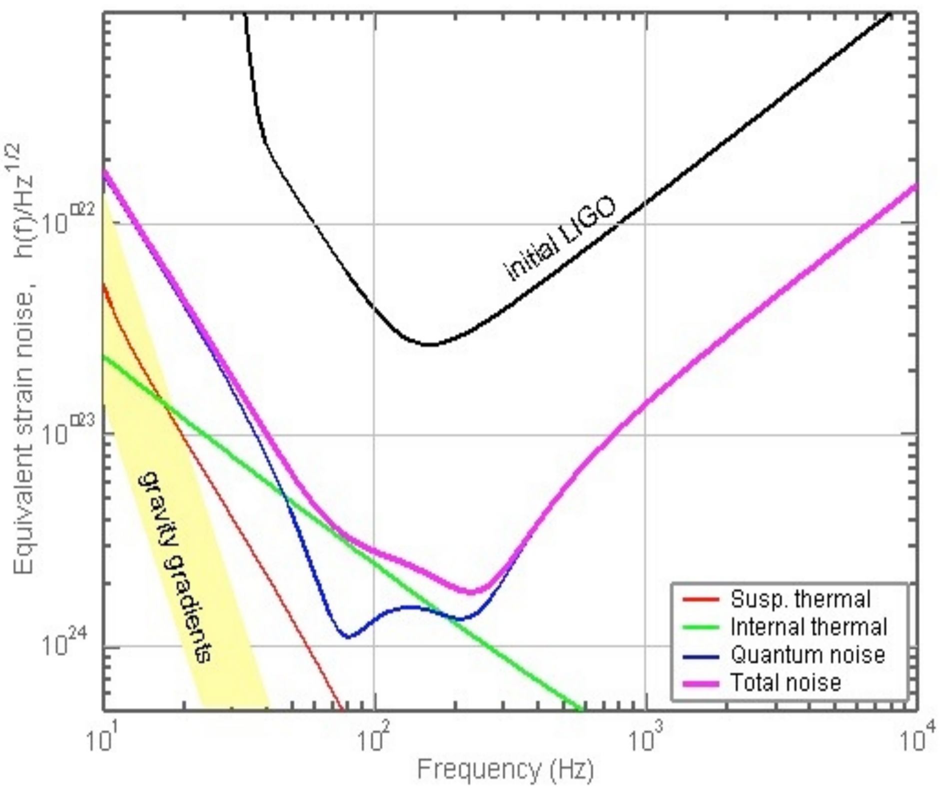
[Abadie et al., CQG 27:173001,2010]

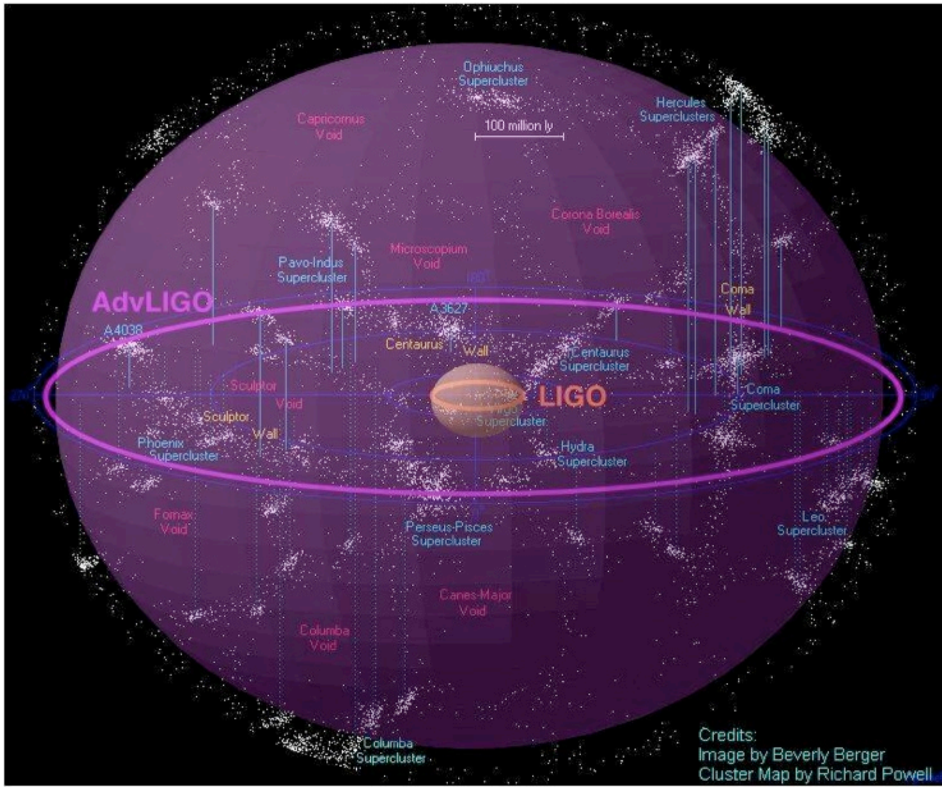
S6 Upper Limits

[Abadie et al., 2011]



Advanced LIGO/Virgo Detectors

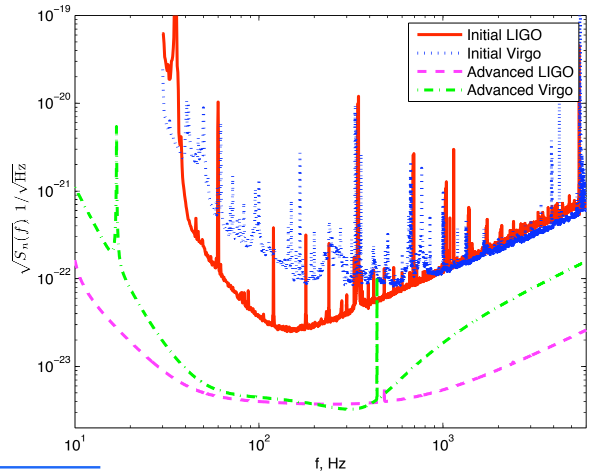




- ~ x10 in range -> ~ x1000 in event rate
- 10 Hz low frequency cutoff
- 2015+ timescale

Merger and Detection Rates

Source	$R_{\rm low}$	$R_{\rm re}$	$R_{\rm high}$
NS-NS (MWEG^{-1} Myr^{-1})	1	100	1000
NS-BH (MWEG^{-1} Myr^{-1})	0.05	3	100
BH-BH (MWEG^{-1} Myr^{-1})	0.01	0.4	30



IFO	Source	$\dot{N}_{\rm low}$ yr^{-1}	$\dot{N}_{\rm re}$ yr^{-1}	$\dot{N}_{\rm high}$ yr^{-1}
Initial	NS-NS	2×10^{-4}	0.02	0.2
	NS-BH	7×10^{-5}	0.004	0.1
	BH-BH	2×10^{-4}	0.007	0.5
Advanced	NS-NS	0.4	40	400
	NS-BH	0.2	10	300
	BH-BH	0.4	20	1000

[IM & O'Shaughnessy, 2010, CQG 27 114007; Abadie et al., 2010, arXiv:1003.2480]

Saturday, January 14, 2012

Multimessenger astronomy

- "Holy grail of GW astronomy"

EM transient → Targeted archival search → GWs from binary merger

survey

GW candidate → Rapid(?) followup → EM counterpart

deep pointing

Targeting GW searches on WFM transients

- EM transient tells us there is a high probability of a signal present (depends on timing accuracy and confidence of association with binary merger)
- EM transient tells us some of the binary's parameters (sky location; possibly distance; possibly inclination)
- This allows for a reduction in threshold for detection for a given false alarm:

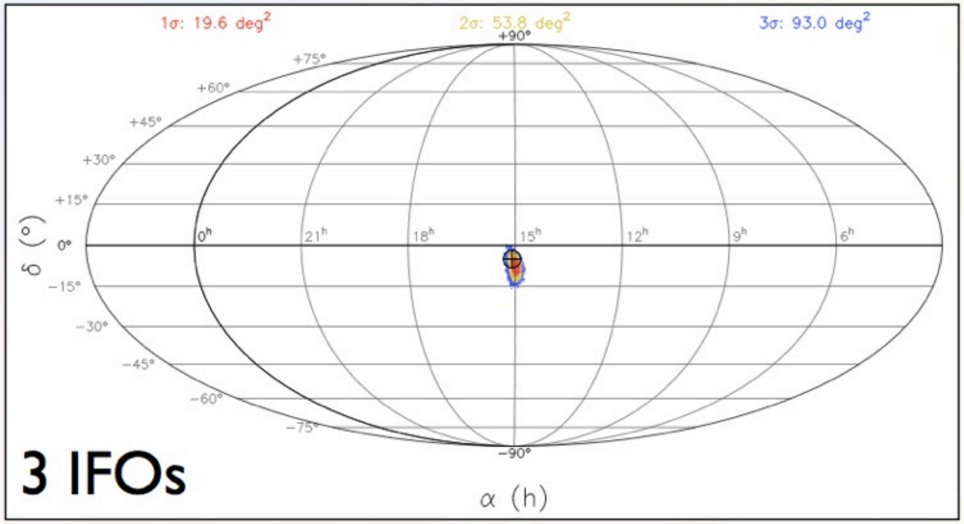
$$\zeta_{\mathrm{SNR}} \equiv \frac{\mathrm{SNR}_{\mathrm{EM}}}{\mathrm{SNR}} = \left[\frac{\ln\left(\mathcal{O}_{\mathrm{EM}} \cdot \left[\frac{p(\mathrm{GW}|\mathrm{EM})}{p(\mathrm{N}|\mathrm{EM})} \cdot \eta_{\mathrm{EM}} \right]^{-1} \right)}{\ln\left(\mathcal{O} \cdot \left[\frac{p(\mathrm{GW})}{p(\mathrm{N})} \cdot \eta \right]^{-1} \right)} \right]^{\frac{1}{2}}$$

- In optimal case, could reduce detection threshold by 60--80%
- Even more because all-sky searches are suboptimal

Following up GW triggers with LAD

GW sky localization is poor, tens to hundred(s) sq. deg.

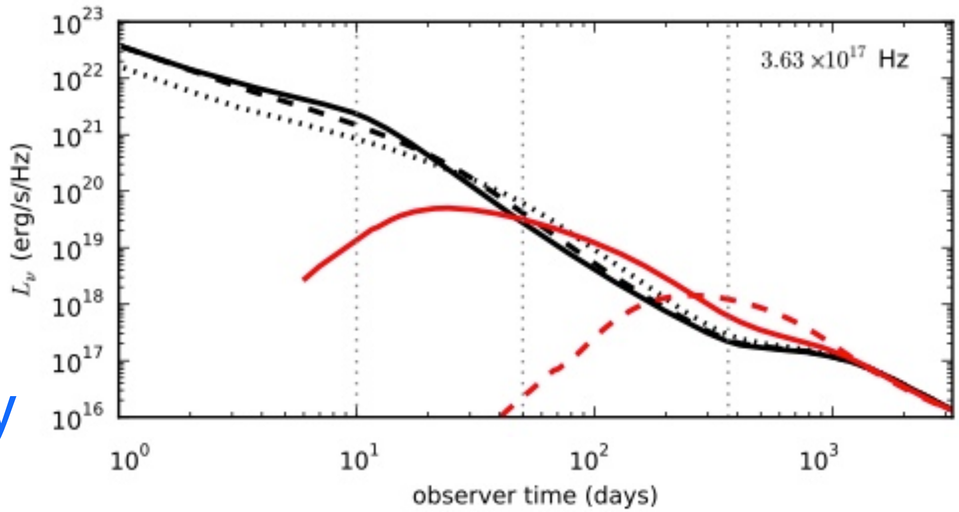
Need to cover a large uncertainty region (FOV)



[Raymond et al., 2009]

X-ray prompt emission is short, and afterglows are weak

Need to slew quickly or point *very* deeply

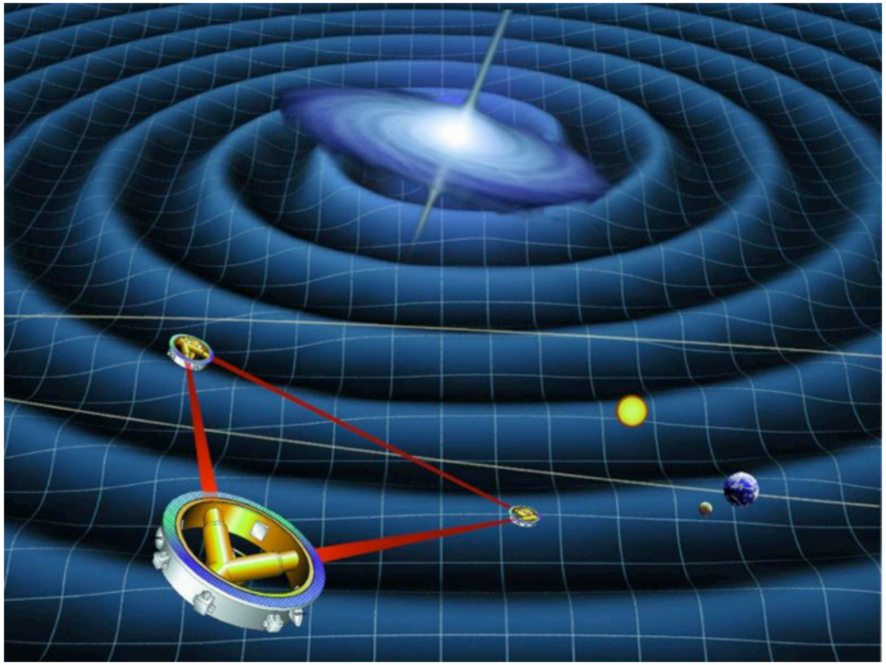


@1.5keV [van Eerten & MacFadyen, 2011]

Saturday, January 14, 2012

A few other possibilities

- X-ray signatures accompanying massive black hole mergers [e.g., Bode et al.] vs. LISA observations
- Precise timing observations of neutron stars could increase the sensitivity of targeted searches for “continuous” GWs [e.g., Owen, 2009]



- Search for GWs from excited NS vibrational modes
- Complementary information about masses, spins of NSs and BHs (e.g., IMBH discovery)
- Complementary tests of GR, NS EOS measurements

Summary

- Advanced LIGO/Virgo are likely to see multiple NS-NS, NS-BH, BH-BH coalescences; tens or more coalescences may be seen according to some models
- Detections of X-ray transients in all-sky-monitor surveys will make it easier to search for GW signatures in archival data
- X-ray followups of GW triggers with LAD will be difficult
- More opportunities for multimessenger observations with LISA, continuous GW sources
- Observations of different systems could yield complementary information about populations