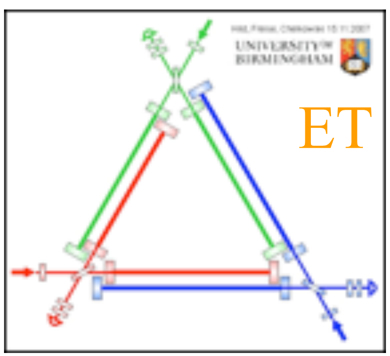
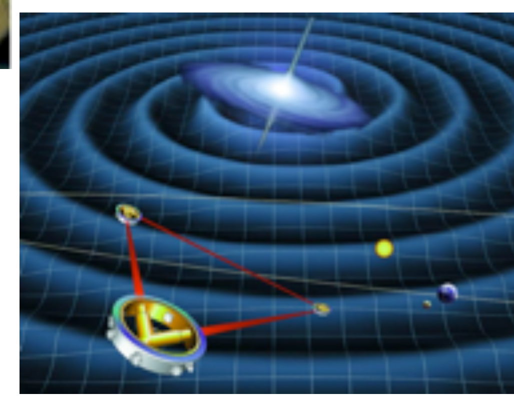
Gravitational Waves and LOFT

Virgo



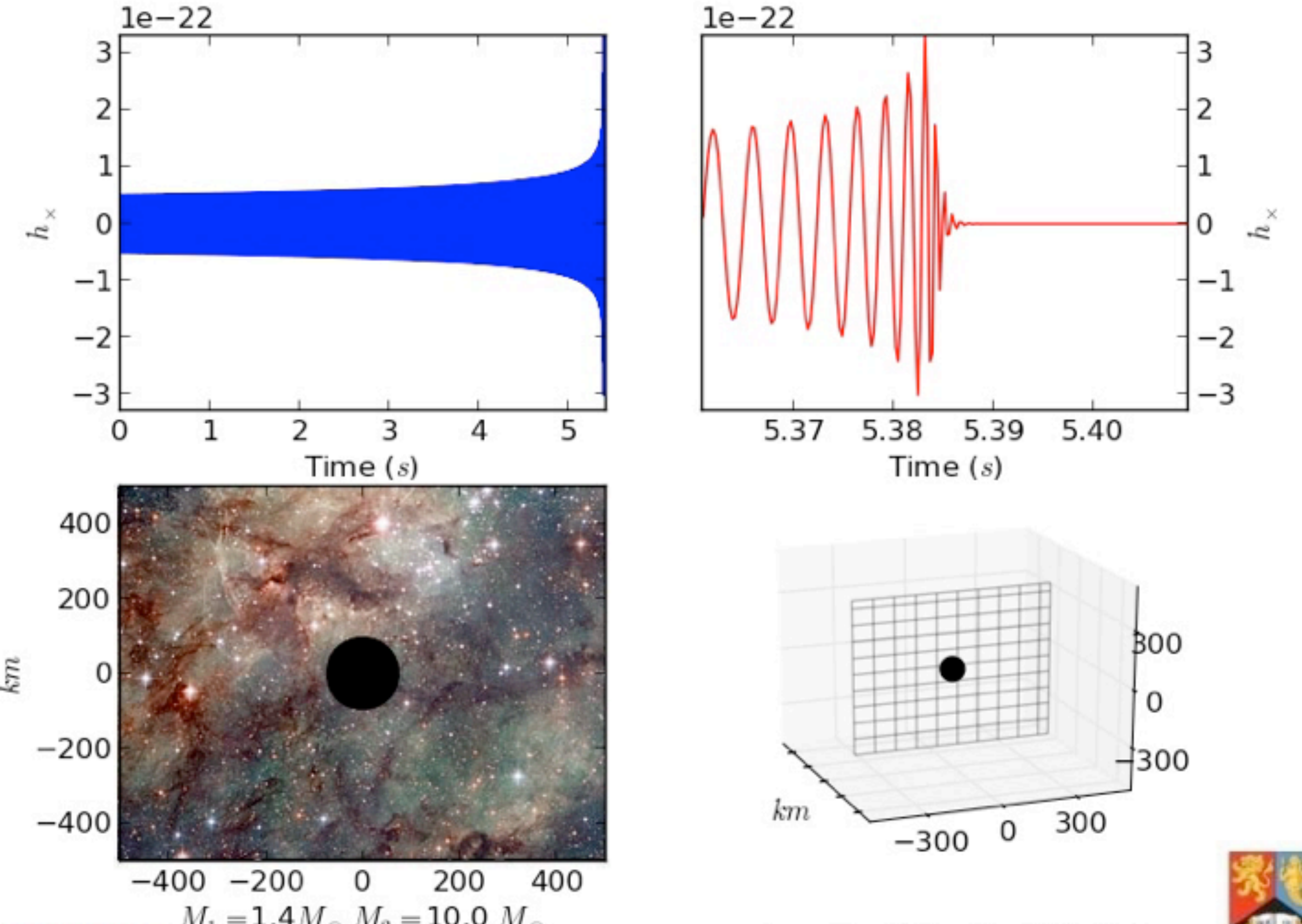
LISA



Ilya Mandel
(University of Birmingham)

June 25, 2013

First UK LOFT Science meeting, London



mage:ESA/Hubble

Jason Tye, University of Birmingham

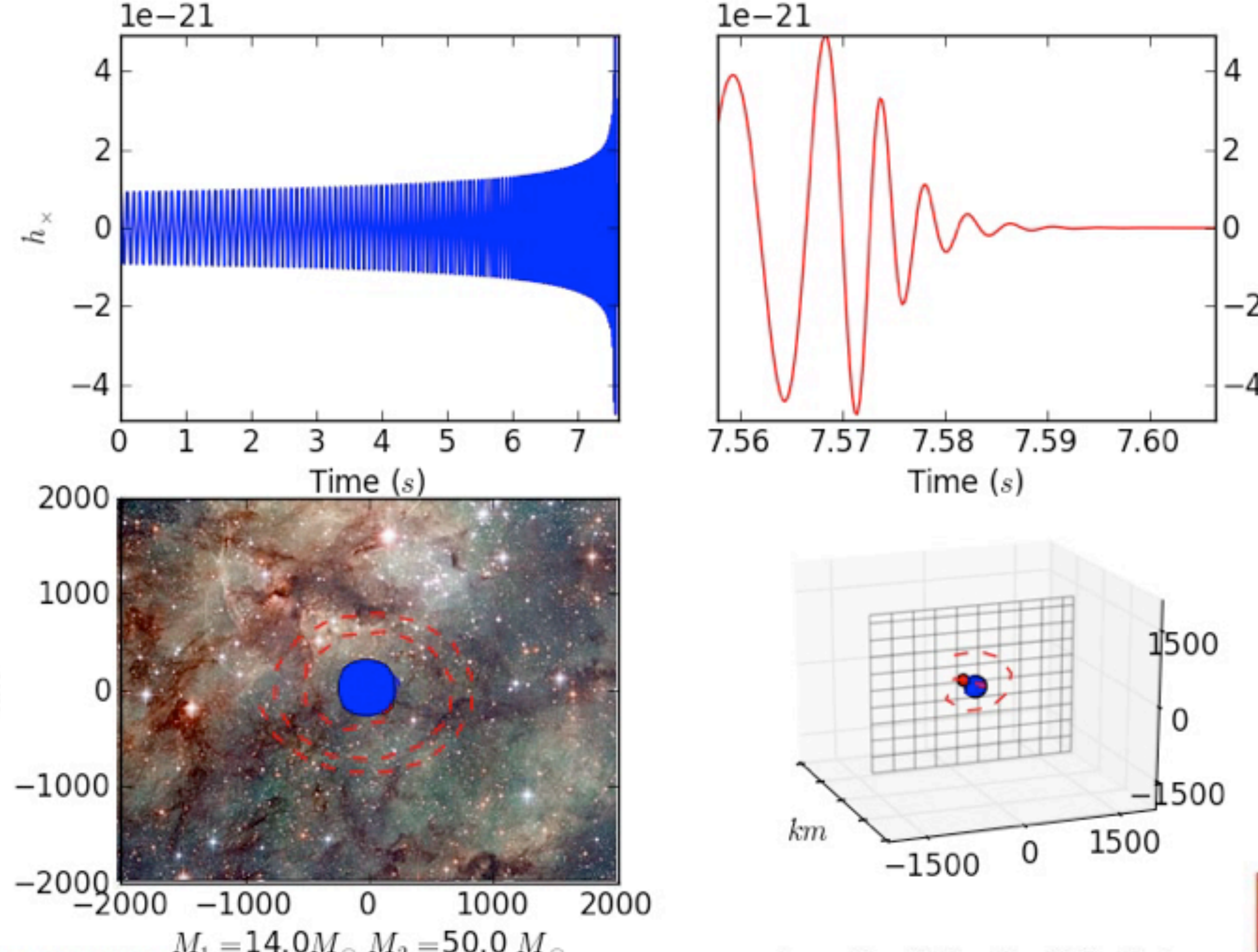
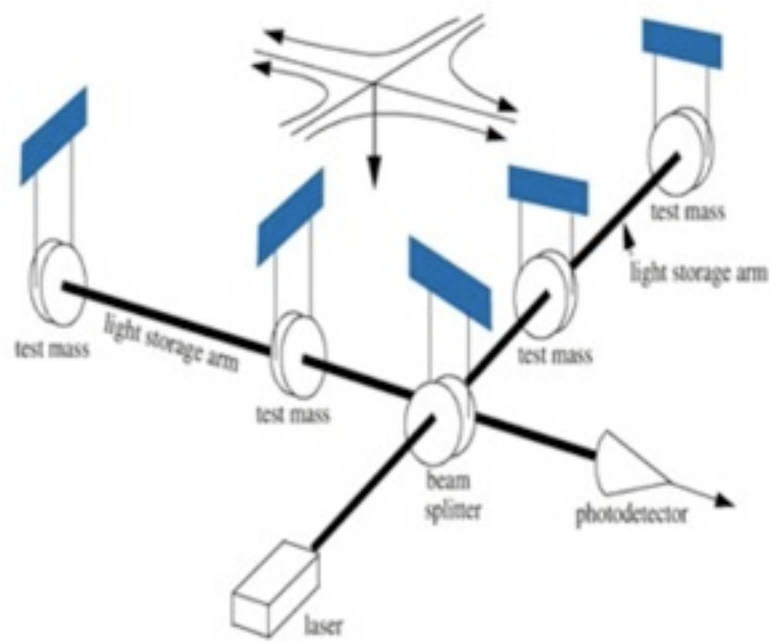


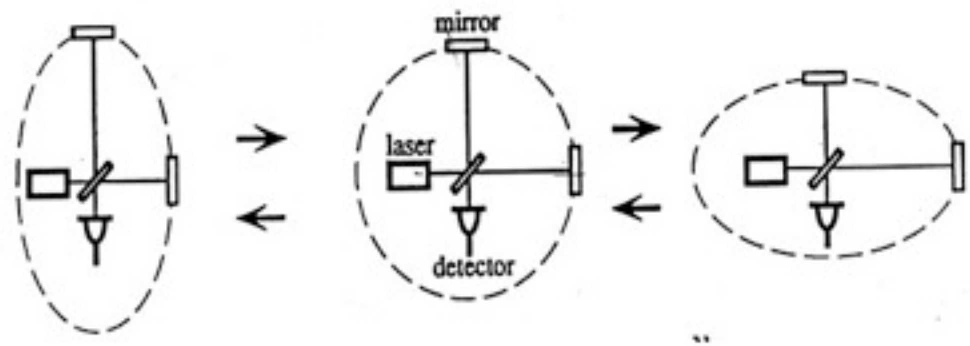
Image:ESA/Hubble

Jason Tye, University of Birmingham

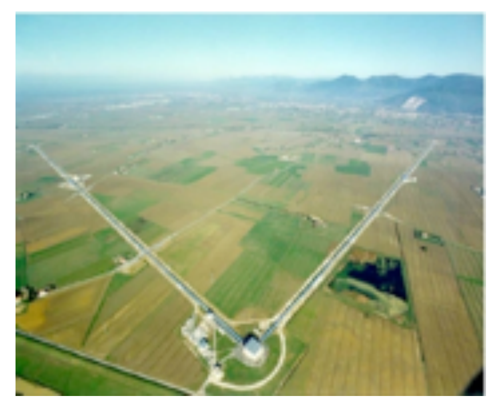
Opportunity and Challenge

GWs carry a lot of energy, but interact weakly: can pass through everything, including detectors!

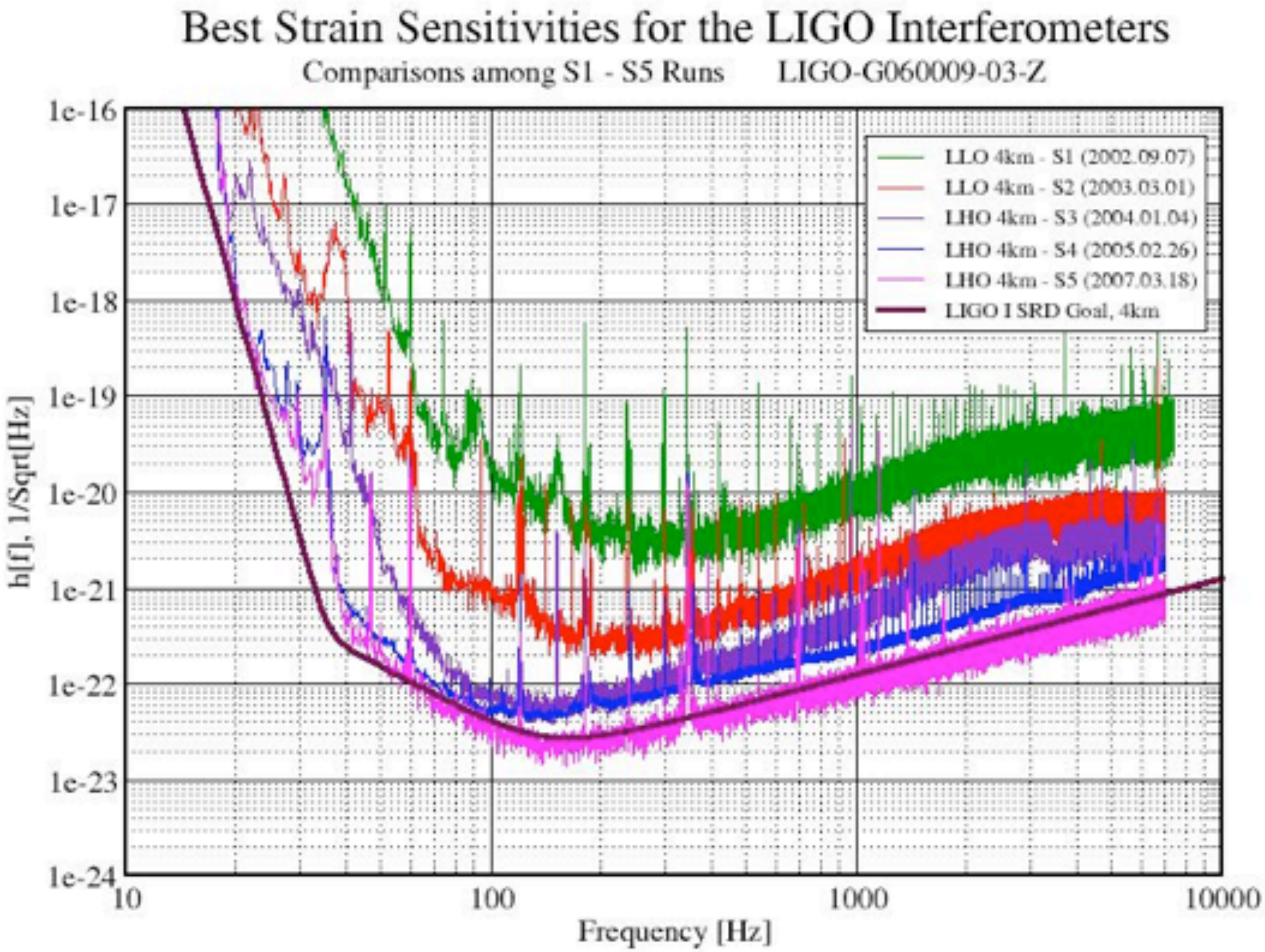




Michelson-type interferometers



LIGO Noise Spectrum



Predicting merger rates

Method	Strength	Weakness
Direct extrapolation from observed Galactic binaries	Most direct available probe; ~10 known (~5 merging) Galactic binary pulsars	Low statistics, poorly known selection effects, only relevant for BNS systems
Extrapolation from short GRB rates	Potentially direct probe of mergers involving NS out to large distances (z~2)	Uncertain provenance, ill-constrained beaming factors and selection effects
Population synthesis of isolated binaries	Applies to all binary types, creates models for future astrophysical inference	A number of poorly known input parameters (SNe kicks, winds, common envelope)
Forward evolution of observed X-ray binaries	Combination of observations and population synthesis	Uncertain selection effects, mass measurements, and modeling assumptions
Dynamical formation in dense environments	Independent scenario, less sensitive to binary evolution	Poorly known dynamics of globular and nuclear clusters

[IM and O'Shaughnessy, 2010]

Merger Rate Predictions

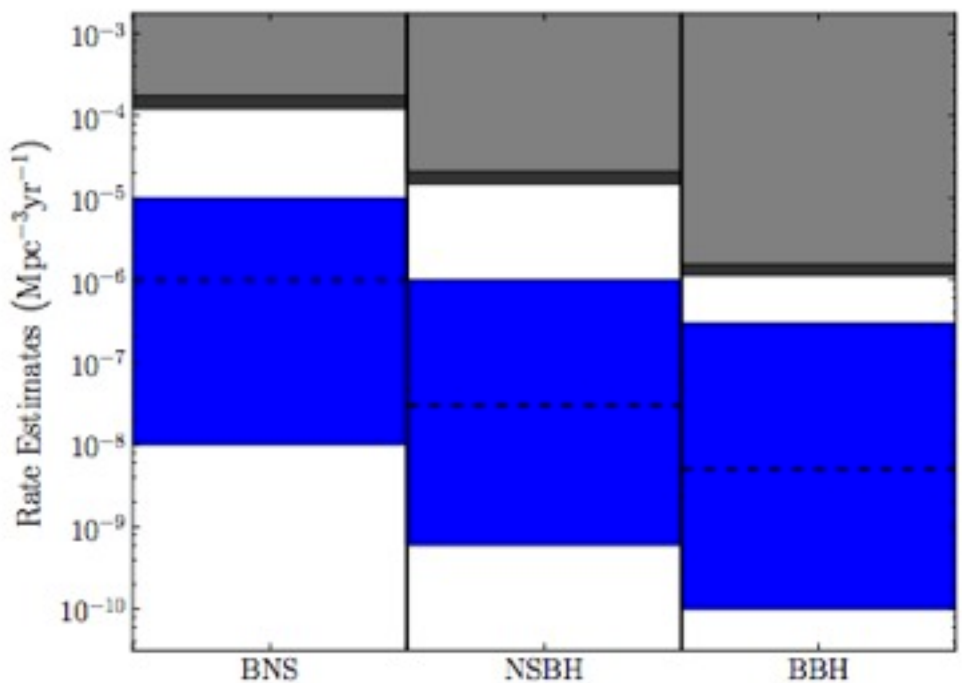
Predicted rates

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

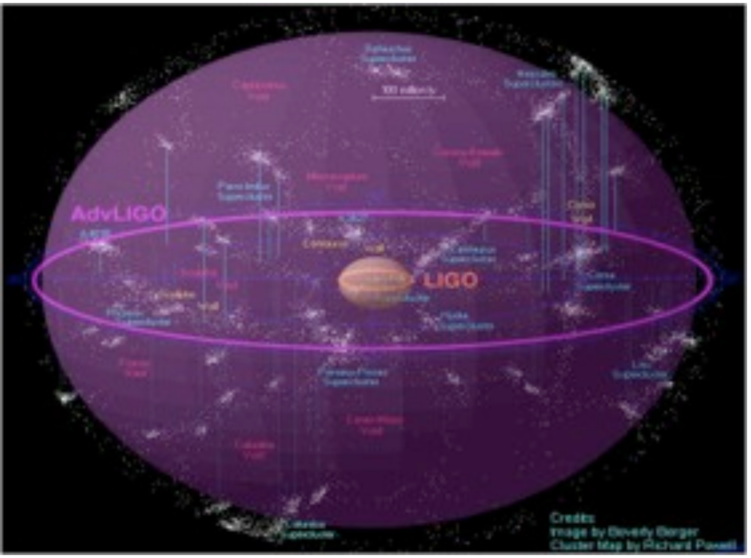
[Abadie et al., CQG 27:173001,2010]

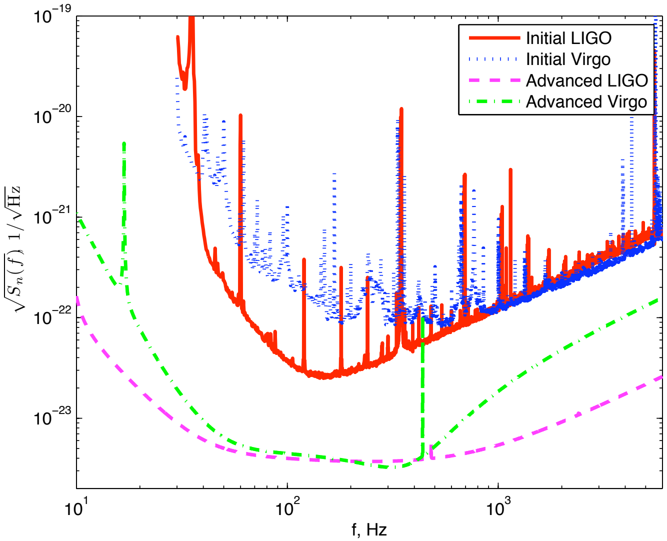
S6 Upper Limits

[Abadie et al., 2011]



Merger and Detection Rates

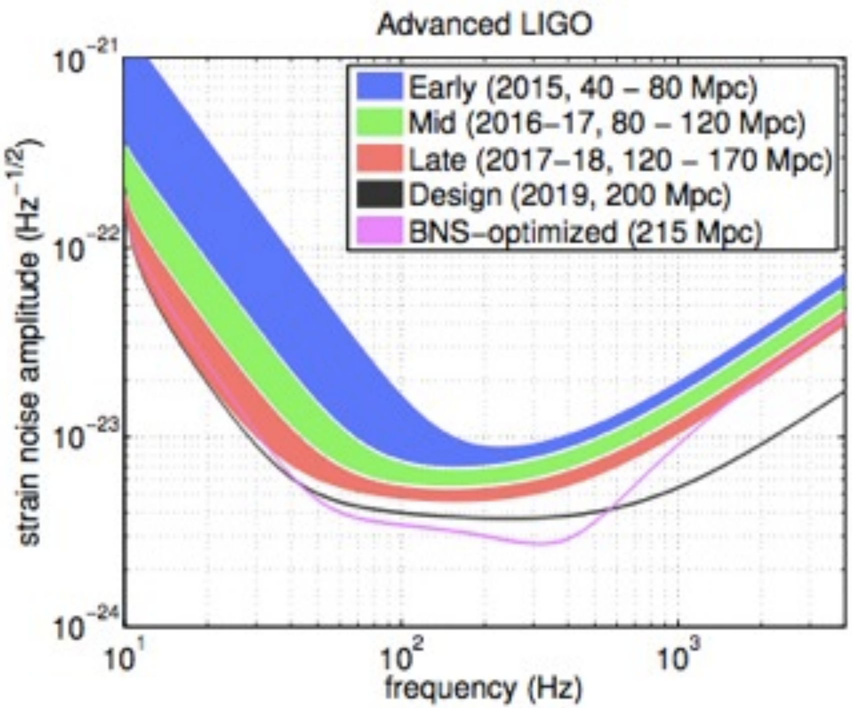


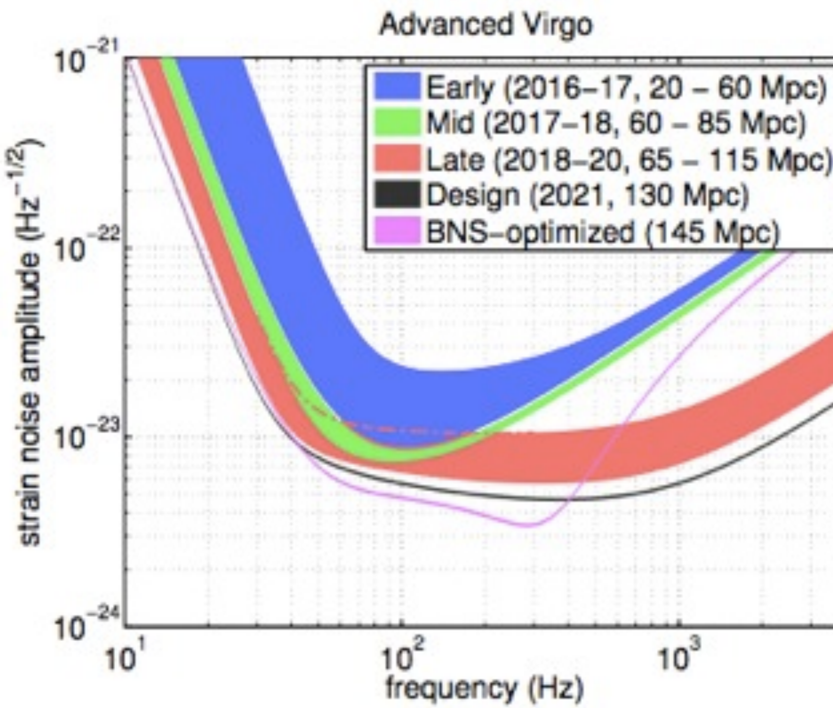


[IM & O'Shaughnessy, 2010, CQG 27 114007; Abadie et al., 2010, arXiv:1003.2480]

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

Advanced detector prospects





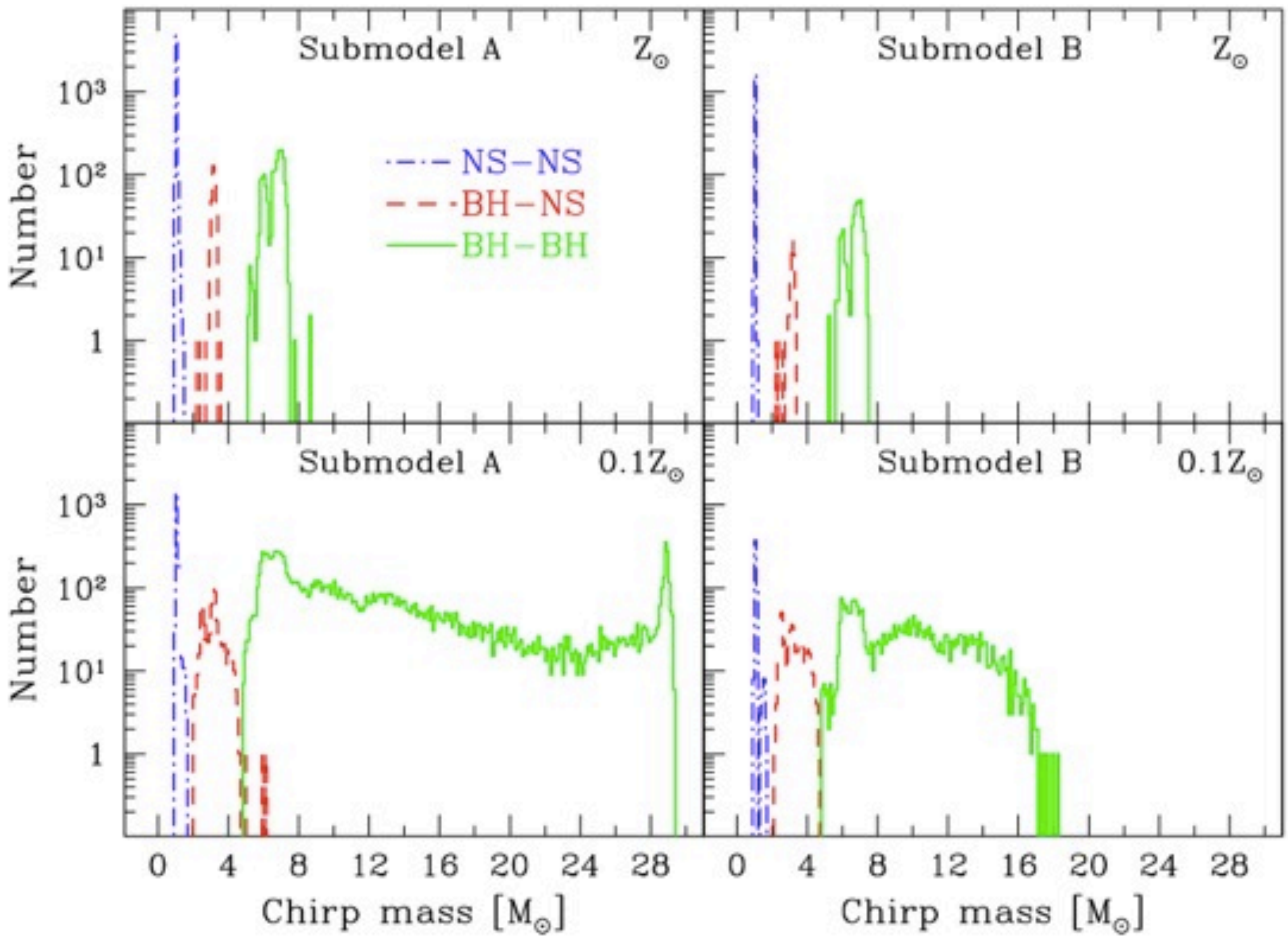
Epoch	Estimated Run Duration	$E_{\rm GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within $5\,\mathrm{deg}^2$	$20\,\mathrm{deg}^2$
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	105	40 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

[Aasi+ (LSC+Virgo), arXiv:1304.0670]

Astrophysics: the Inverse Problem

- Comparing predicted rates of binary mergers with model predictions can allow us to constrain the input (astro)physics
- Can learn a lot more by comparing distributions of observed parameters (masses, spins) with model predictions

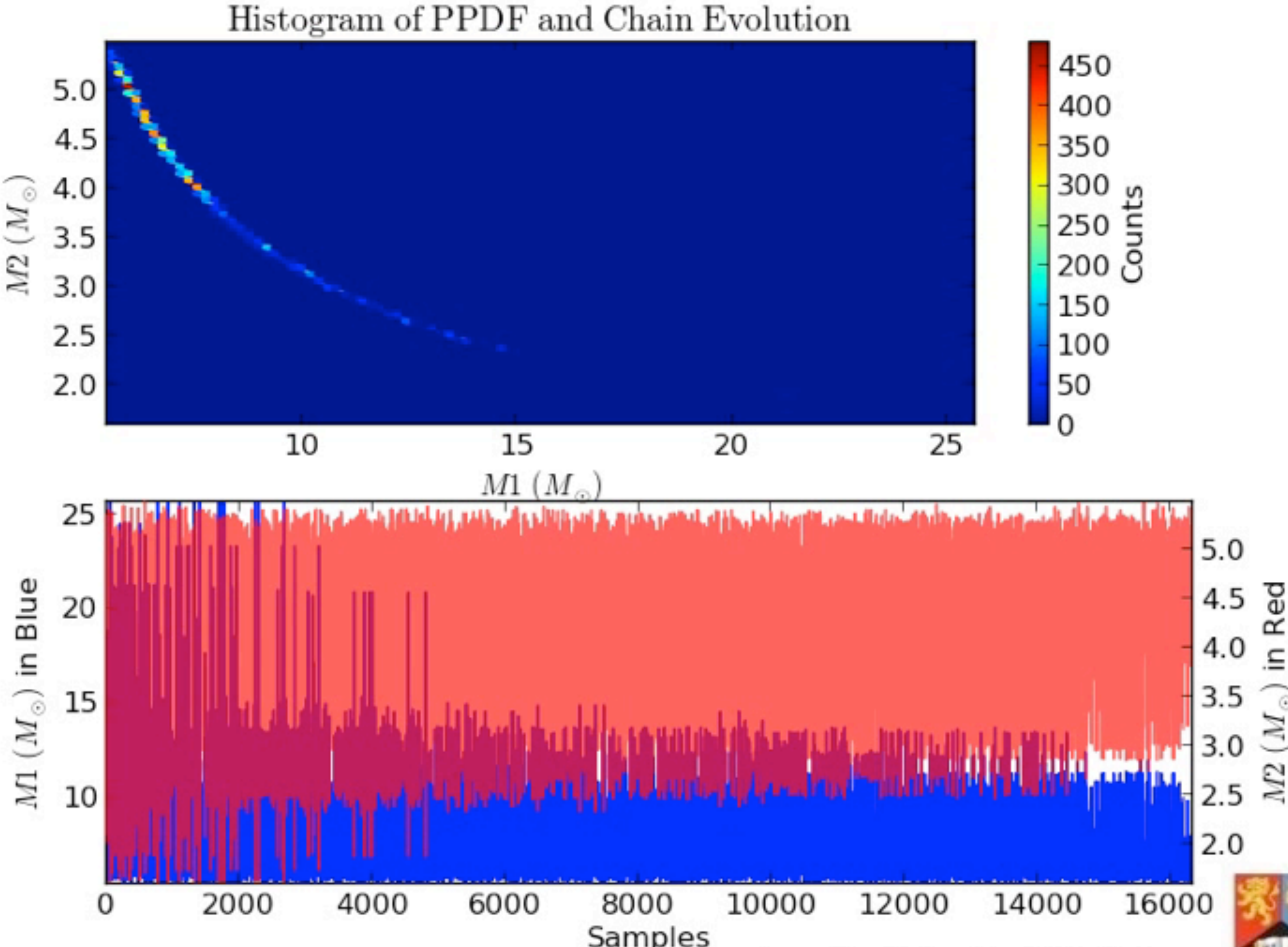
Predictions of component mass distributions



[Dominik et al., 2012 ApJ, 759, 52]

Astrophysics: the Inverse Problem

- Comparing predicted rates of binary mergers with model predictions can allow us to constrain the input (astro)physics
- Can learn a lot more by comparing distributions of observed parameters (masses, spins) with model predictions
  - Requires accurate parameter estimation on individual sources



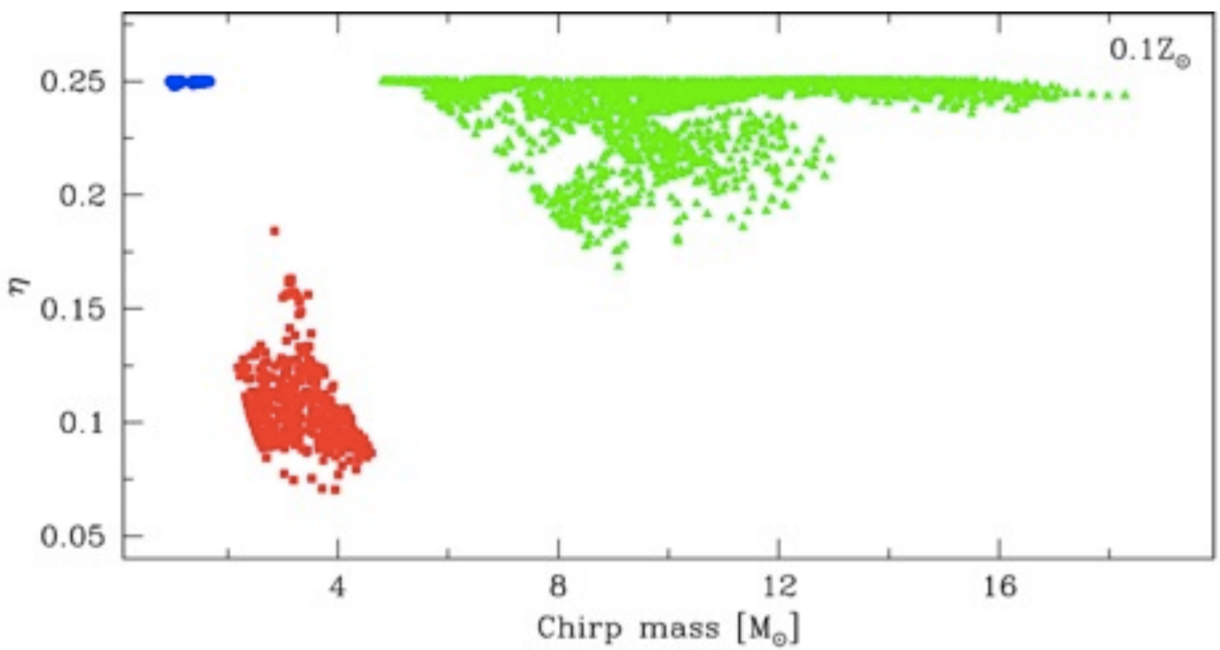
Jason Tye, University of Birmingham

Astrophysics: the Inverse Problem

- Comparing predicted rates of binary mergers with model predictions can allow us to constrain the input (astro)physics
- Can learn a lot more by comparing distributions of observed parameters (masses, spins) with model predictions
  - » Requires accurate parameter estimation on individual sources
  - » Requires combining information from multiple events to construct a statement about population distribution (accounting for selection bias, etc.)
  - » Requires a library of catalogs of simulations based on different assumed astrophysical parameters
  - » Requires a pipeline for comparing observations and catalogs
  - » We need to be able to test population synthesis models themselves: need to over-determine the parameters... how many detections will this require? what will be the correlations/degeneracies in the astrophysical parameter space?

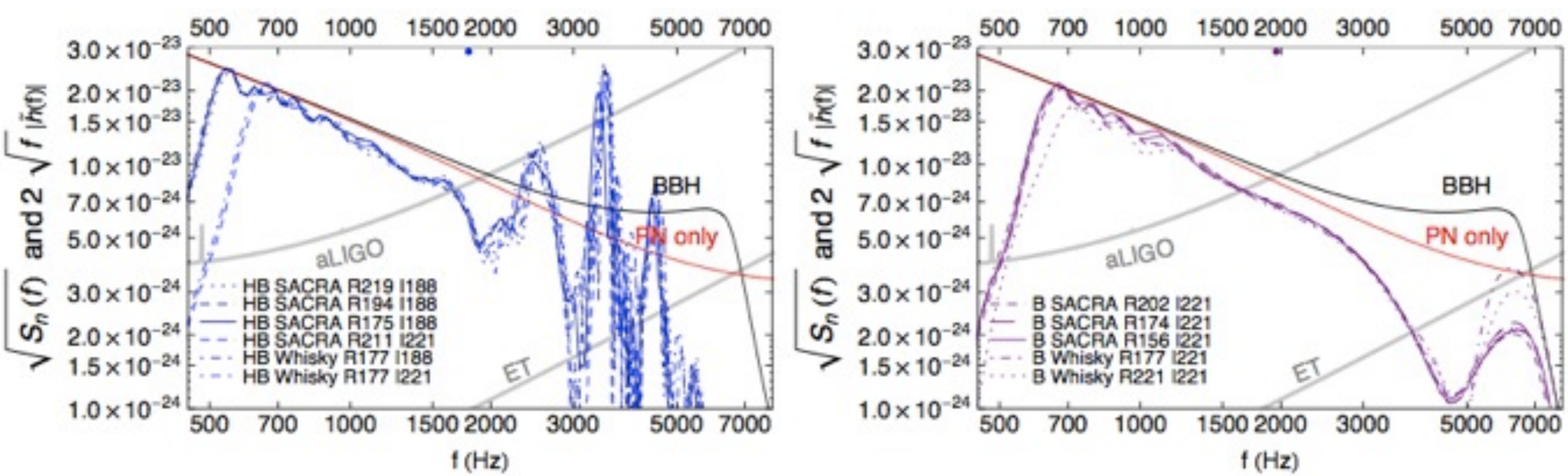
Astrophysics: the Inverse Problem

- Comparing predicted rates of binary mergers with model predictions can allow us to constrain the input (astro)physics
- Can learn a lot more by comparing distributions of observed parameters (masses, spins) with model predictions
- (Almost) Model-independent inference
    - » Evidence for a mass gap? [Dominik, IM, Belczynski, in prep.]



Where does LOFT fit in?

- Complementary observations of similar source types vs. multi-messenger observations of the same sources
- Why complementary?
  - » Different selection effects -> sensitivity to different subpopulations when measuring distributions of a property -- e.g., masses for mass gap
  - » Sensitivity to different aspects of a source -- e.g., bulk properties vs. surface properties for neutron stars



[Read+, arXiv:1306.4065]

Multimessenger astronomy

- "Holy grail of GW astronomy"

EM transient

survey

Targeted archival search →

GWs from binary merger

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); also learn 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:

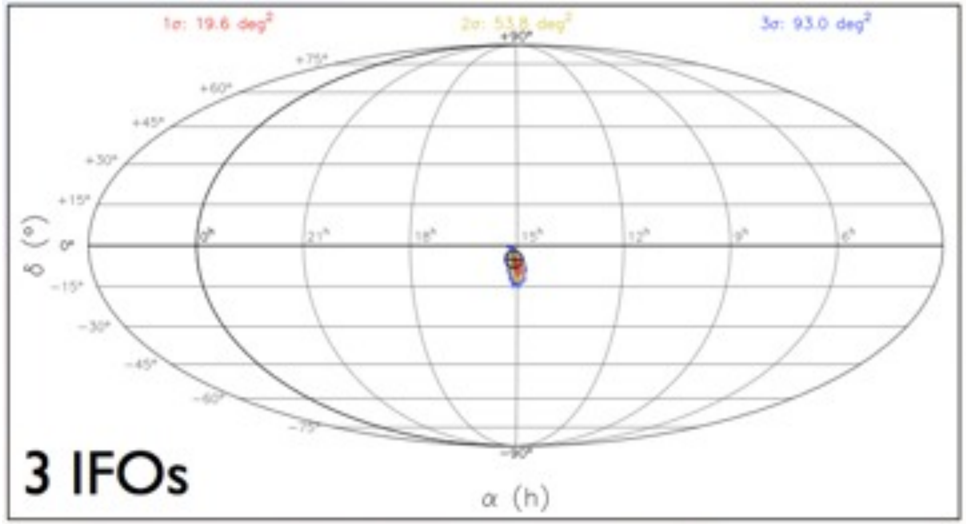
$$\zeta_{\mathrm{SNR}} \equiv \frac{\mathrm{SNR_{EM}}}{\mathrm{SNR}} = \left[\frac{\ln\left(\mathcal{O}_{\mathrm{EM}} \cdot \left[\frac{p(\mathrm{GW}|\mathrm{EM})}{p(\mathrm{N}|\mathrm{EM})} \cdot \eta_{\mathrm{EM}}\right]^{-1}\right)}{\ln\left(\mathcal{O} \cdot \left[\frac{p(\mathrm{GW})}{p(\mathrm{N})}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

- Could increase rate of multi-messenger observations by up to 40% [Kelley, IM, Ramirez-Ruiz, arXiv:1209.3027]
- But nearest confident SGRB detection only at z=0.12...

Following up GW triggers with LAD

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

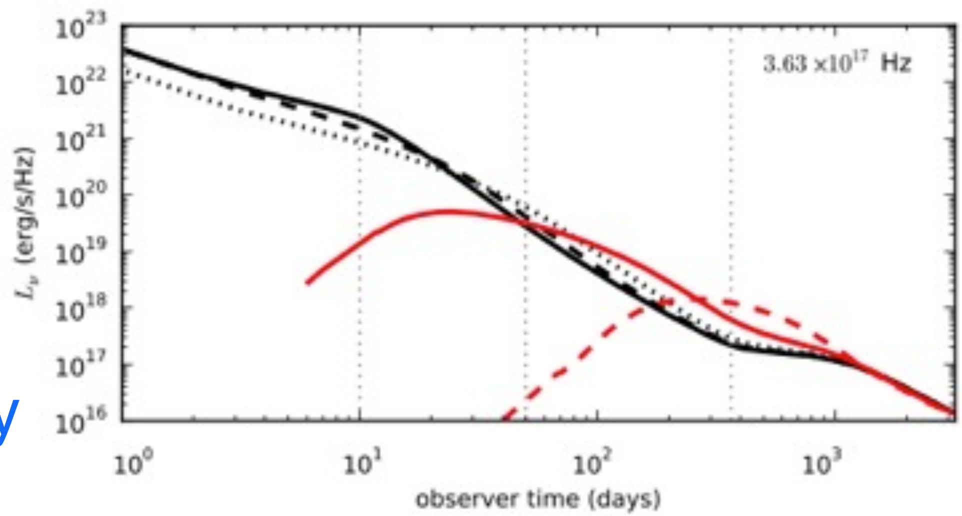
Need to cover a large uncertainty region (FOV)



[Raymond et al., 2009; Veitch+, 2012]

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

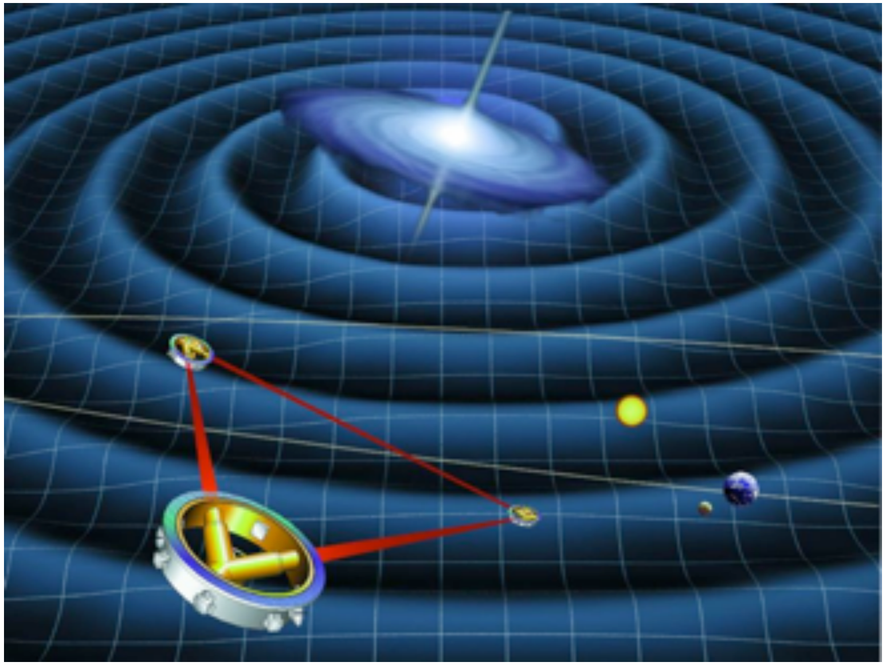
Need to slew quickly or point *very* deeply



@1.5keV [van Eerten & MacFadyen, 2011]

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
- Observations of different systems could yield complementary information about populations
- 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