Astrophysics with ET detections of compact binaries: *a call to action*

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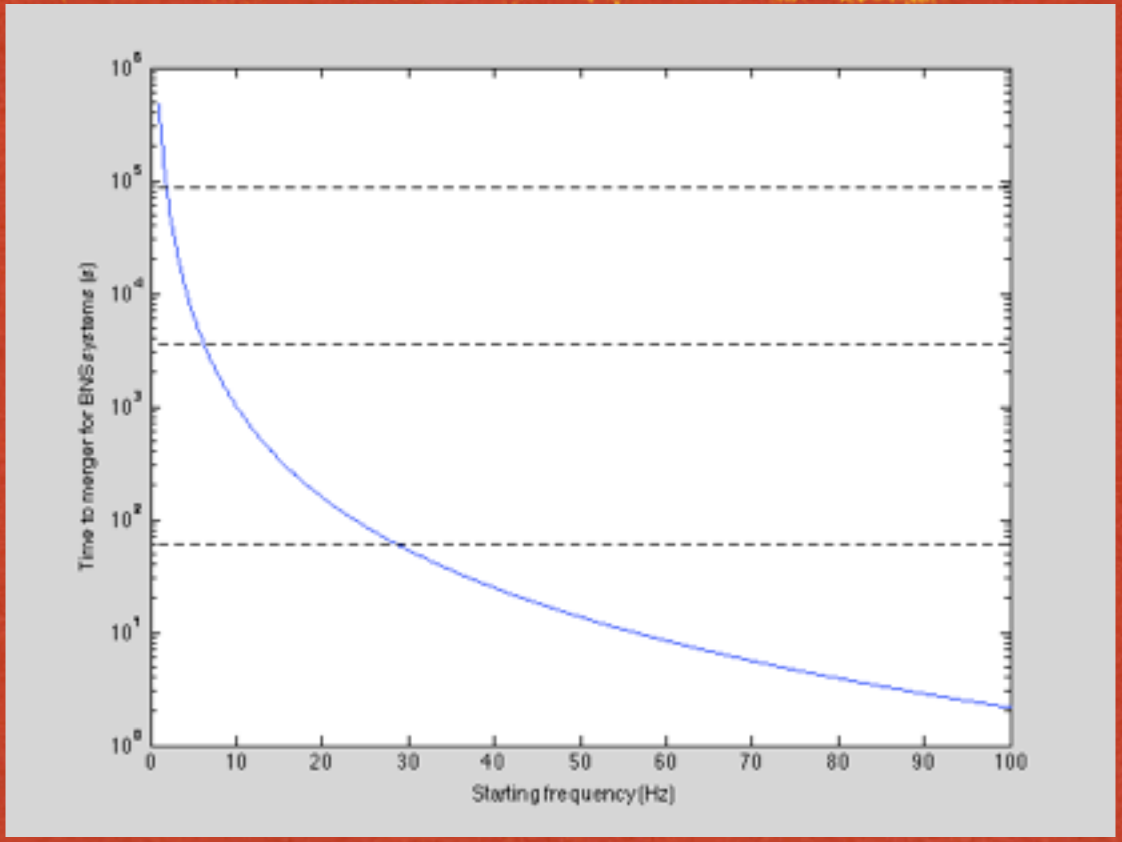
University of Birmingham
October 22, 2013

WHAT THIS TALK IS NOT

- Not a comprehensive discussion of ET science -- see science case
- E.g., no comments on EM counterparts -- because I don't know what EM facilities will be available on the right timescale
- NB: Scientific relevance changes -- i.e., to maximize scientific payoff, we want to have ET *today!*



Determining the Hubble constant from gravitational wave observations

NATURE VOL. 323 25 SEPTEMBER 1986

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any assumptions about the masses of the stars. Ten events out to 100 Mpc may suffice to measure the Hubble constant to 3% accuracy.

SCIENCE EXPLOITATION: THE FOURTH ESTATE

I) Building ultra-sensitive detectors

II) Searching for signals buried in noise

III) Parameter estimation on individual signals

IV) ... Population inference and scientific exploitation

ORDINARY VS EXTRAORDINARY, MODELED VS UNMODELED

1. Do we expect to learn most from a single truly unexpected detection, or from a large population of anticipated sources?

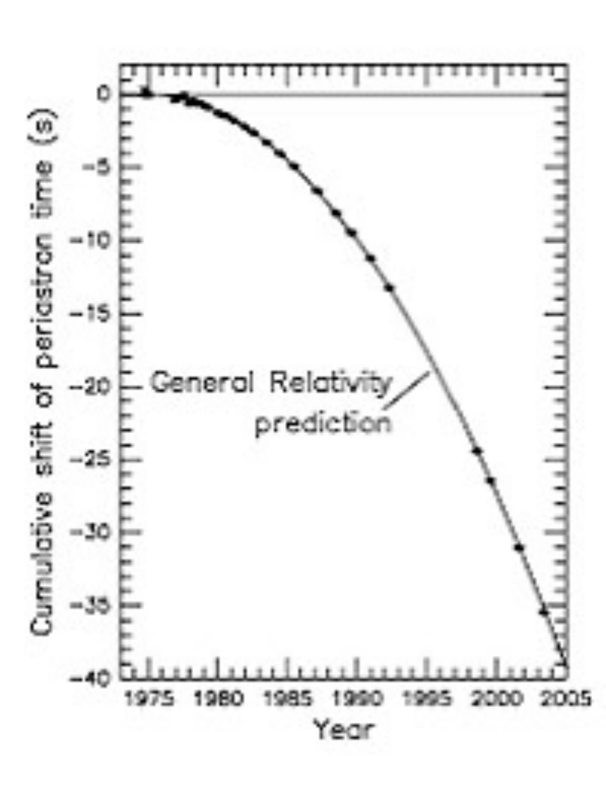
2. Can we rely on good models whose parameters need constraining, or do we need to look for unmodeled science opportunities because we don't trust the mdoels enough?

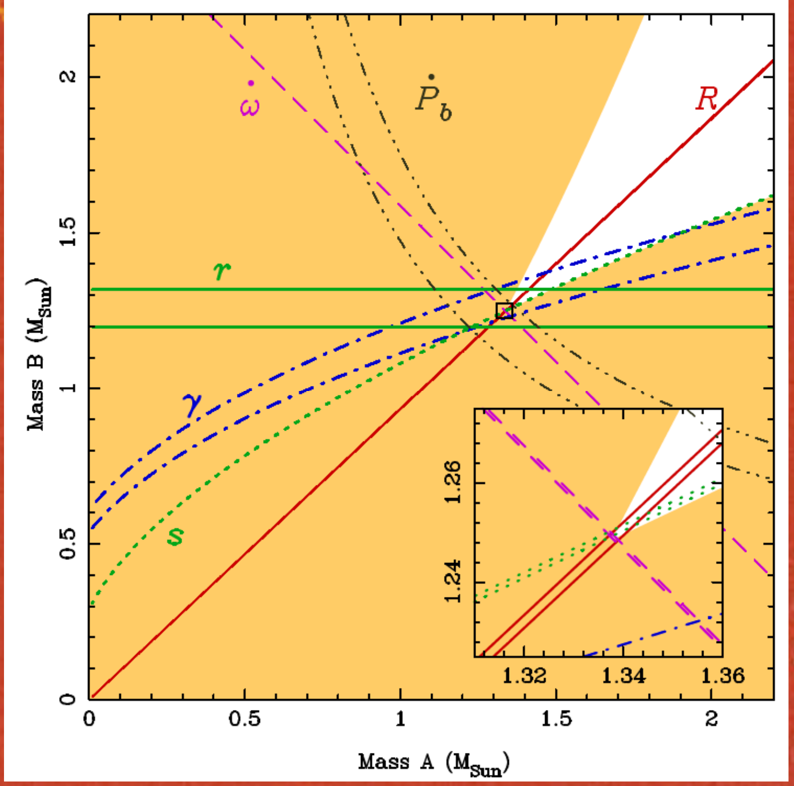
ORDINARY VS EXTRAORDINARY, I

- Extraordinary examples:
  - Intermediate-mass black hole
  - NS below 1 or above 2.few solar masses -- or perhaps a BH below 2 solar masses?
  - GWs of cosmological origin
  - Continuous waves (do they belong here?)
  - Binaries with high eccentricity

ORDINARY VS EXTRAORDINARY, 2

- So what's ordinary?
  - Binary neutron stars!
  - Maybe NS-BH and BBH binaries
    - Will know what's ordinary after aLIGO/ aVirgo...
  - So what can we do with populations of sources?





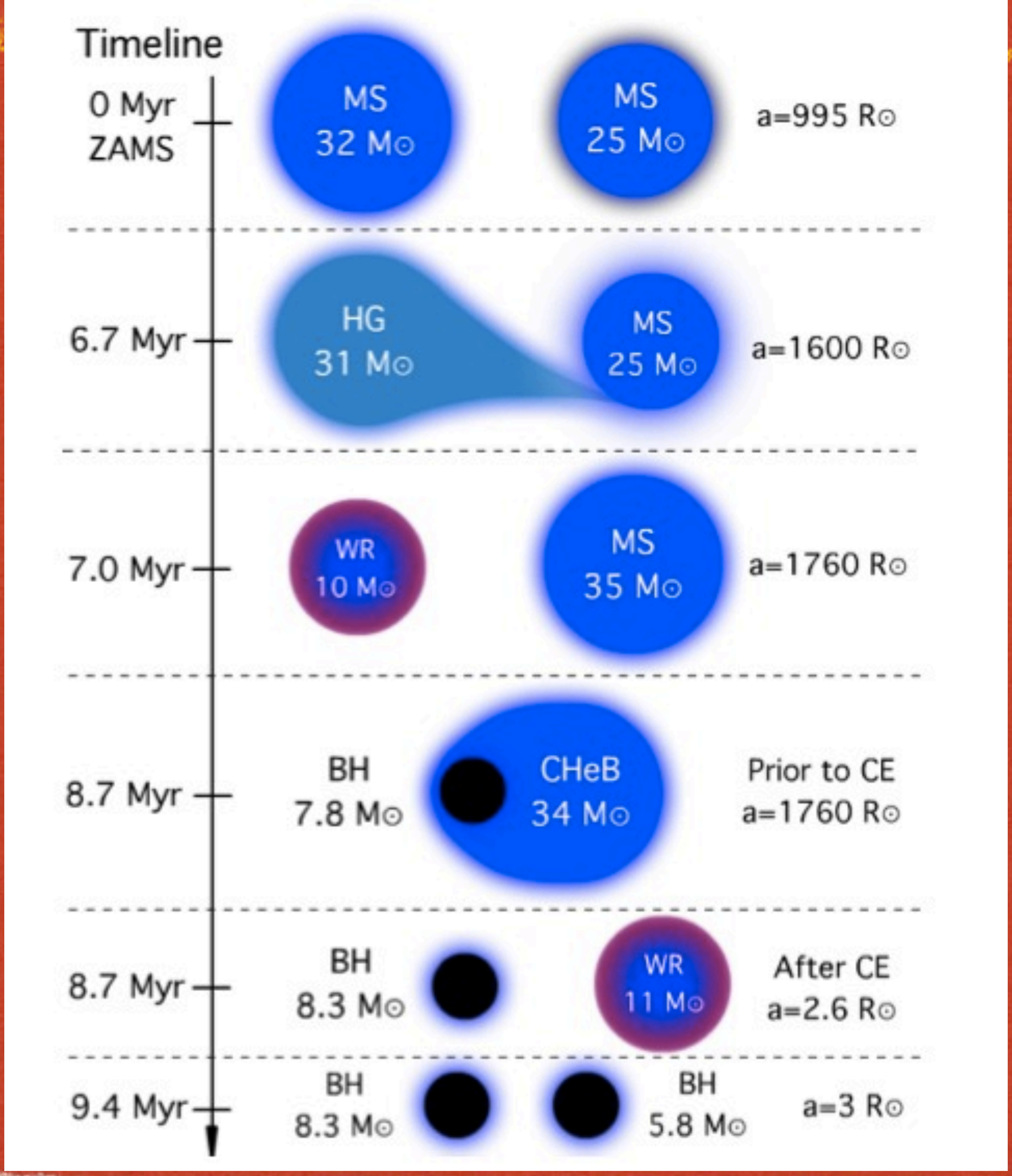
Source	R_{low}	R_{re}	R_{high}
NS-NS ($MWEG^{-1}$ Myr^{-1})	1	100	1000
NS-BH ($MWEG^{-1}$ Myr^{-1})	0.05	3	100
BH-BH ($MWEG^{-1}$ Myr^{-1})	0.01	0.4	30

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

MODELED VS UNMODELED, 1

- Have good models of isolated binary evolution: *population synthesis*!

POPULATION SYNTHESIS



[Dominik et al., 2013]

MODELED VS UNMODELED, 1

- Have good models of isolated binary evolution: *population synthesis*!

TABLE 2
GALACTIC MERGER RATES, $Z_{\odot}$ [Myr^{-1}] [a]

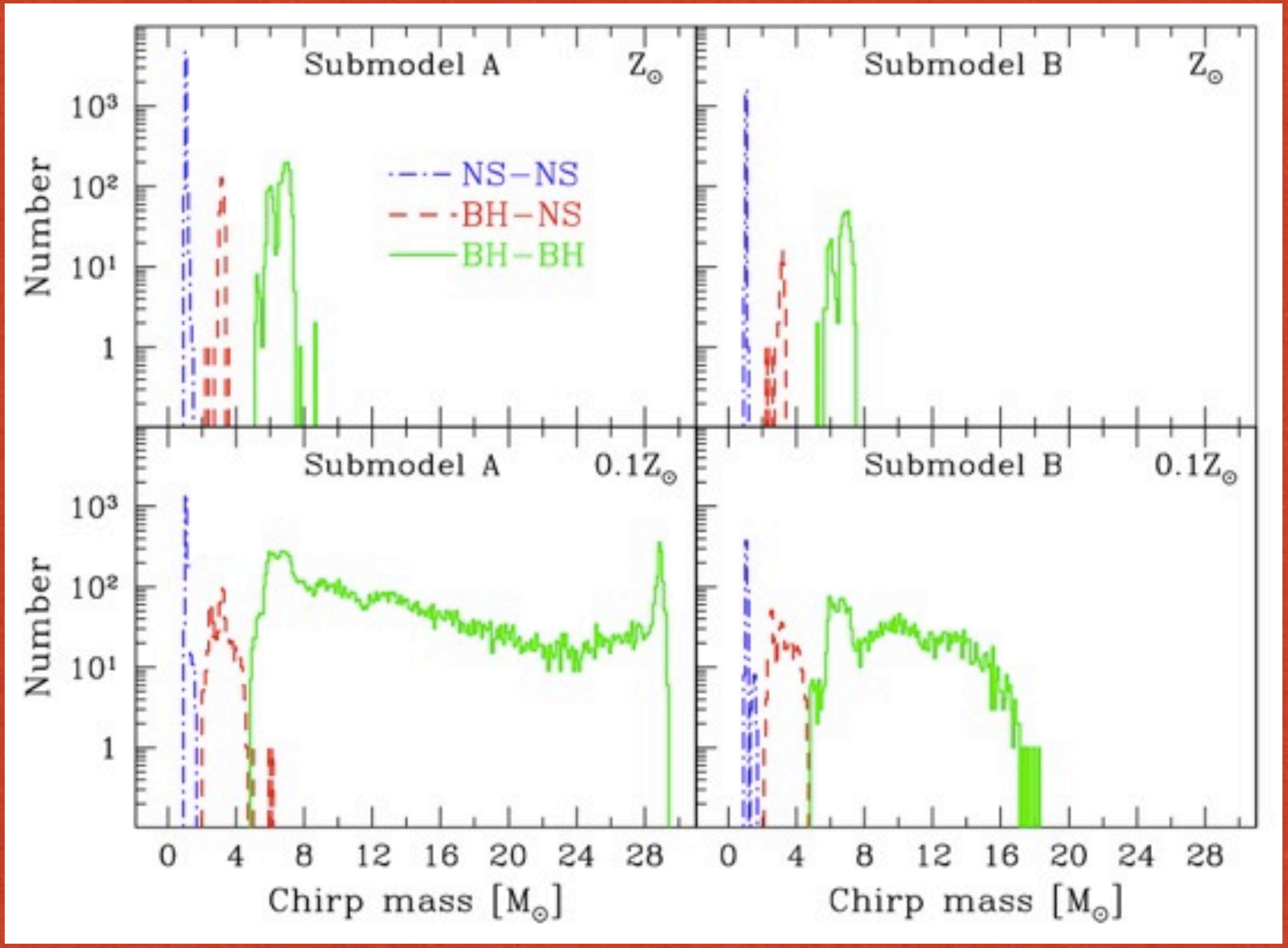
Model	NS-NS	BH-NS	BH-BH
S	23.5 (7.6)	1.6 (0.2)	8.2 (1.9)
V1	0.4 (0.4)	0.002 (0.002)	1.1 (1.1)
V2	11.8 (1.1)	2.4 (0.08)	15.3 (0.4)
V3	48.8 (14.3)	4.6 (0.03)	5.0 (0.03)
V4	20.8 (0.3)	0.9 (0.0)	0.3 (0.0)
V5	24.1 (8.1)	1.4 (0.2)	8.3 (2.0)
V6	24.1 (8.3)	1.4 (0.2)	8.0 (1.9)
V7	32.4 (9.5)	1.9 (0.3)	10.4 (2.1)
V8	23.3 (7.7)	0.03 (0.004)	0.05 (0.005)
V9	23.4 (8.0)	1.4 (0.2)	16.9 (4.2)
V10	25.6 (8.9)	0.07 (0.03)	0.6 (0.08)
V11	24.2 (6.5)	1.2 (0.2)	29.7 (3.6)

[Dominik et al., 2012]

- Observed GW event rates (or even upper limits) can be compared with models

COMPARISON WITH MODELS, I

- Can do much more by comparing mass, mass ratio, ... distributions to models



COMPARISON WITH MODELS, 2

- Requirements:
  - accurate parameter estimation on individual events
  - combining information from multiple events to construct statement about population distribution (accounting for selection bias, etc.)
  - a library of catalogs of simulations based on different assumed astrophysical parameters
  - a pipeline for comparing observations and catalogs

MODELED VS UNMODELED, 2

- Have good models of isolated binary evolution: *population synthesis*! .... Or do we?

ON THE RARITY OF DOUBLE BLACK HOLE BINARIES: CONSEQUENCES FOR GRAVITATIONAL WAVE DETECTION

Krzysztof Belczynski,[1,2] Ronald E. Taam,[3] Vassiliki Kalogera,[3] Frederic A. Rasio,[3] and Tomasz Bulik[4,5]

Received 2006 December 1; accepted 2007 January 31

quite high for double neutron stars (~20 yr^{-1}). If double black holes were found to be dominant in the detected inspiral signals, this could indicate that they mainly originate from dense star clusters (not included here) or that our theoretical understanding of the CE phase requires significant revision.

DOUBLE COMPACT OBJECTS I: THE SIGNIFICANCE OF THE COMMON ENVELOPE ON MERGER RATES

Michal Dominik[1], Krzysztof Belczynski[1,2], Christopher Fryer[3], Daniel E. Holz[4,5], Emanuele Berti[6,7], Tomasz Bulik[1], Ilya Mandel[8], Richard O'Shaughnessy[9],

A TEST OF BLACK HOLE NATAL KICK MECHANISM BY THE FIRST GRAVITATIONAL RADIATION DETECTIONS

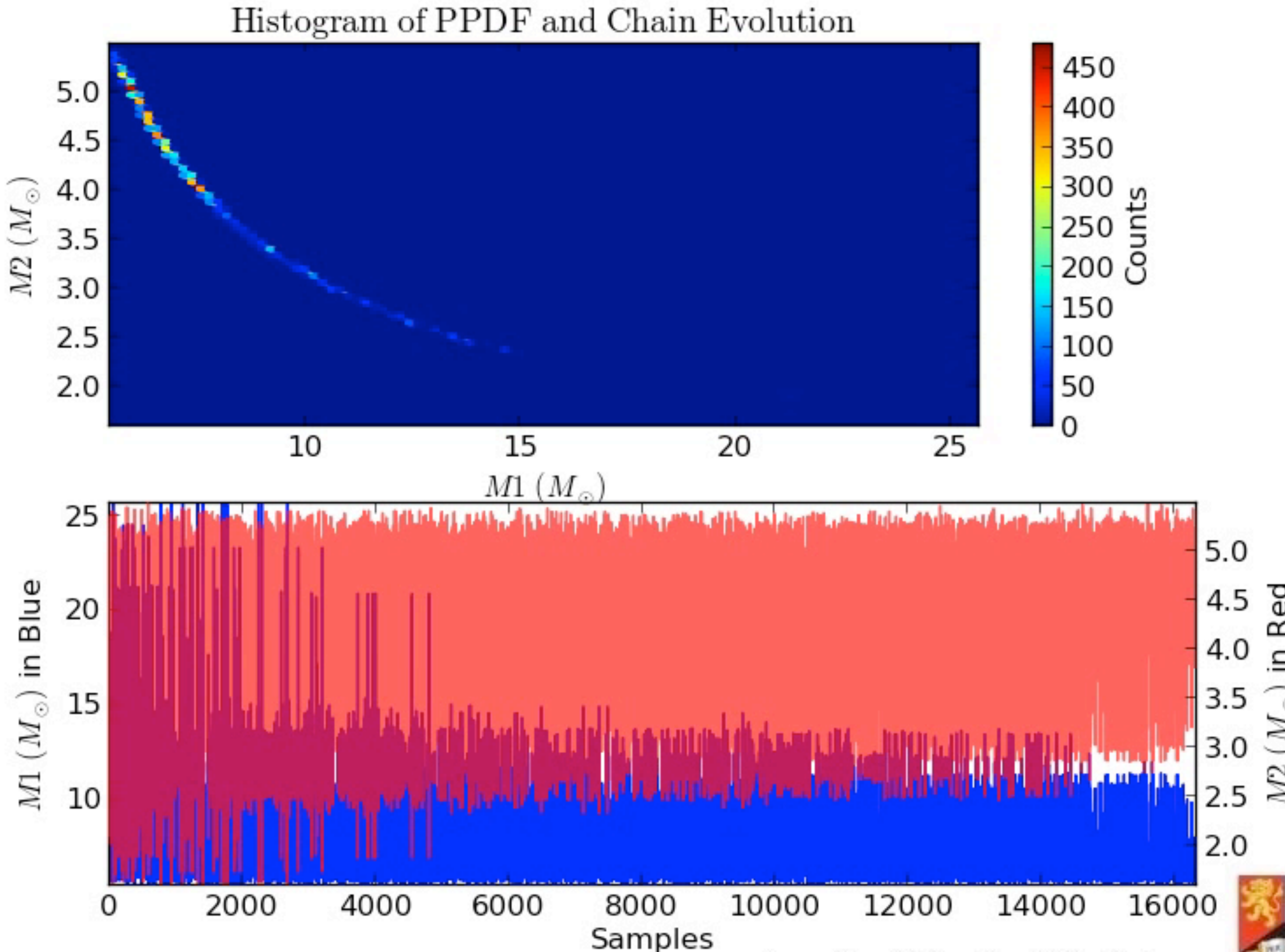
Krzysztof Belczynski[1,2], Michal Dominik[1]
[1] Astronomical Observatory, University of Warsaw, Al. Ujazdowskie 4, 00-478 Warsaw, Poland
[2] Center for Gravitational Wave Astronomy, University of Texas at Brownsville, Brownsville, TX 78520, USA

Draft version August 3, 2012

It is found that BH-BH mergers vastly dominate GR source population independent of evolutionary uncertainties. For example, in our standard evolutionary scenario BH-BH is $\gtrsim$ 400 times more likely to be the first ever detected GR source than NS-NS merger. Only in one model

MODELED VS UNMODELED, 3

- We shouldn't just rely on fitting parameters within a model; we also need to be able to test whether a model is good enough!
- I.e., need to over-determine the parameters... how many detections will this require?
- Even if we are convinced that the basic model is right, there will be correlations/degeneracies in astrophysical parameter space



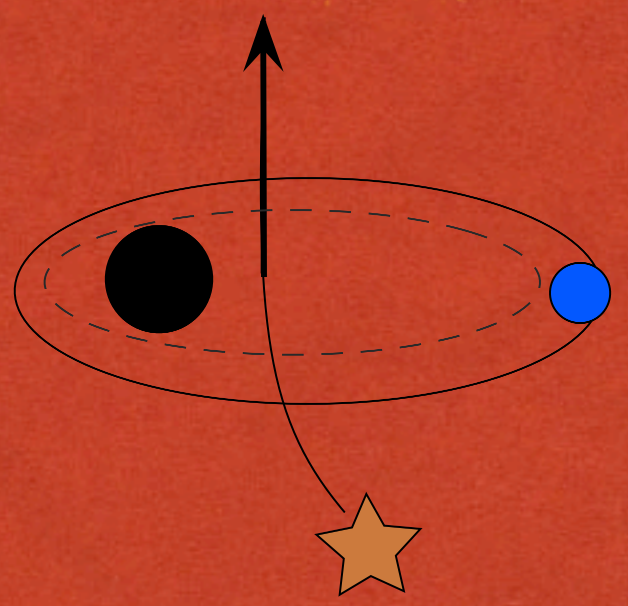
Jason Tye, University of Birmingham

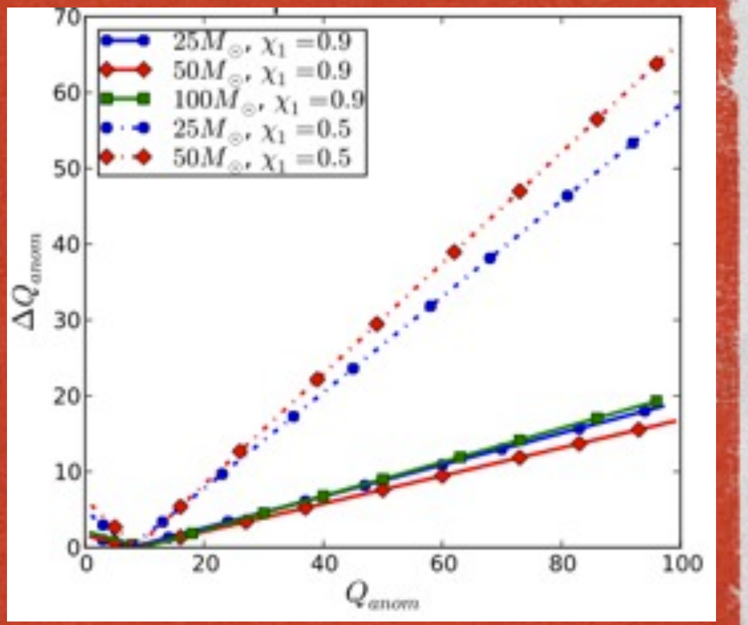
MODELED VS UNMODELED, 3

- We shouldn't just rely on fitting parameters within a model; we also need to be able to test whether a model is good enough!
- I.e., need to over-determine the parameters... how many detections will this require?
- Even if we are convinced that the basic model is right, there will be correlations/degeneracies in astrophysical parameter space [analogy with CBC parameter estimation]
- What about unmodeled searches in astrophysical parameter space [analogy with burst searches]

UNMODELED SCIENCE EXPLOITATION, I

- Possible examples of "unmodeled" or "weakly modeled" astrophysical inference:
  - subpopulations of sources that are clustered in parameter space -- e.g., BBHs from isolated binaries or dynamically formed sources in dense stellar environments
  - phenomenological deviations from basic GR assumptions (e.g., independently measuring mass quadrupole moment)

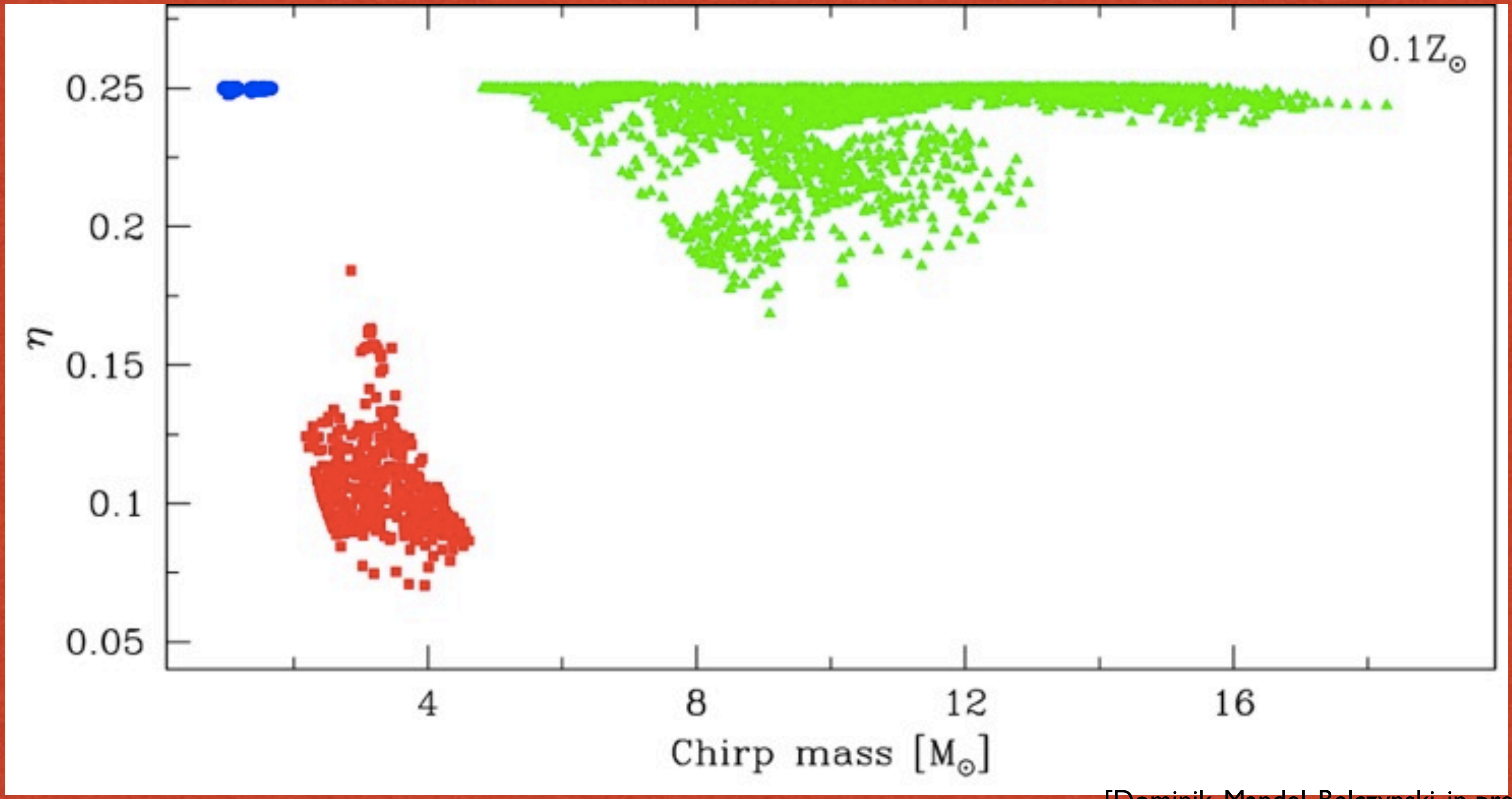




[Rodriguez Mandel, Gair, 2012]

UNMODELED SCIENCE EXPLOITATION, 2

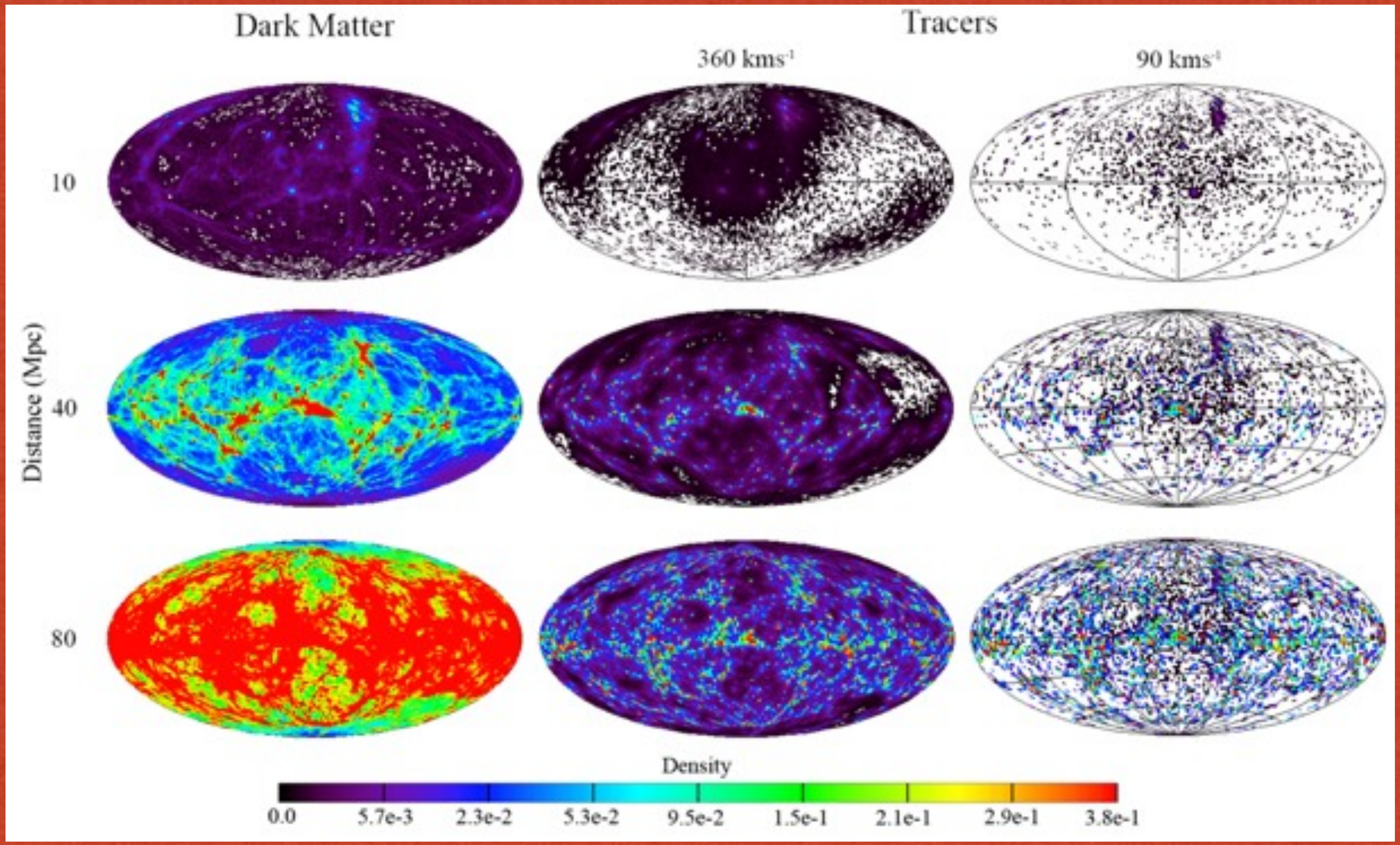
- Evidence for a mass gap?



[Dominik, Mandel, Belczynski, in prep.]

UNMODELED SCIENCE EXPLOITATION, 3

- Measure binary kick velocities from GWs without EM counterparts

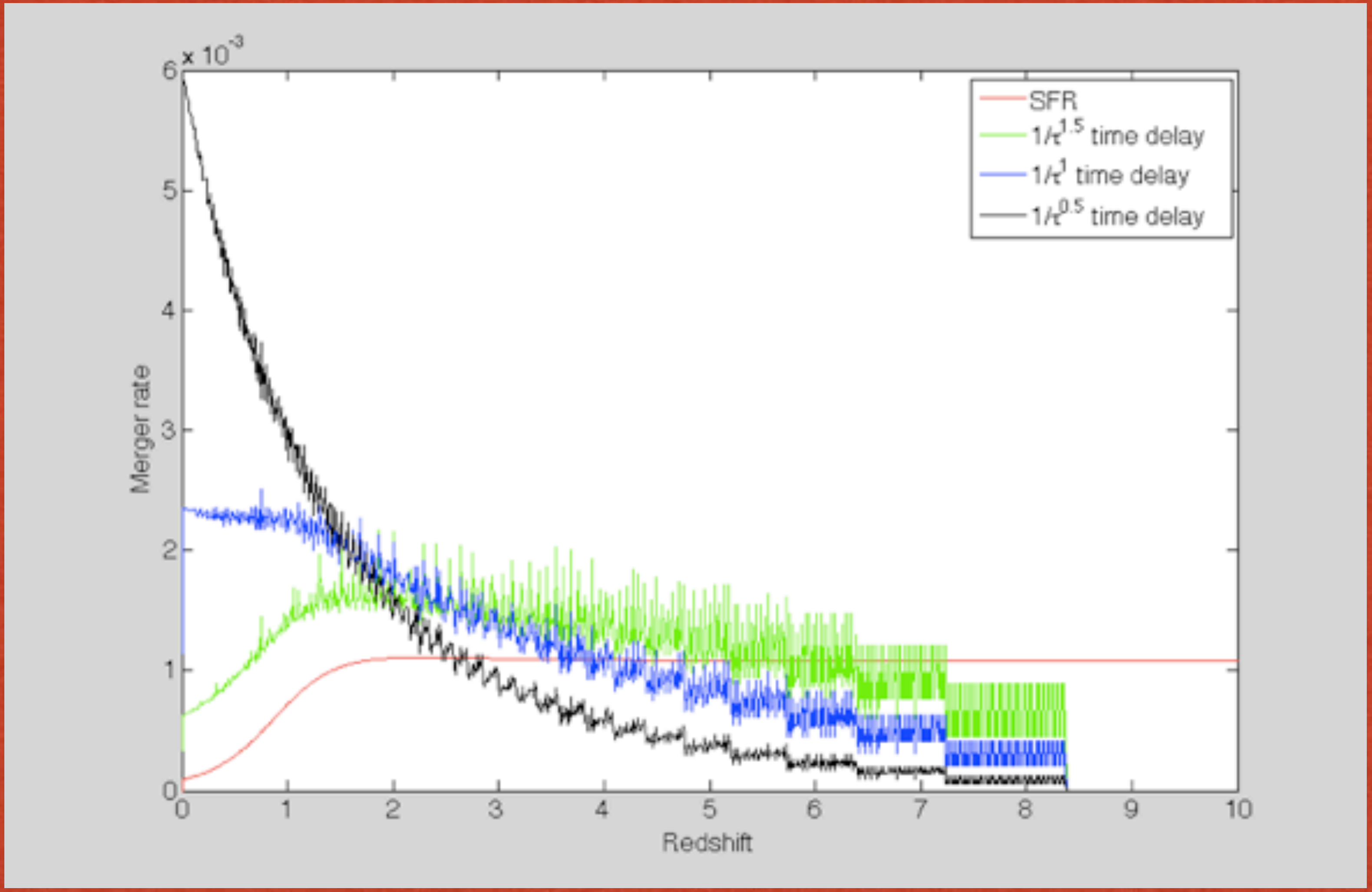


[Kelley et al., 2010]

- Level of anisotropy is a measure of kick velocity

UNMODELED SCIENCE EXPLOITATION, 4

- Directly measure time delays by observing dependence of merger rate on redshift

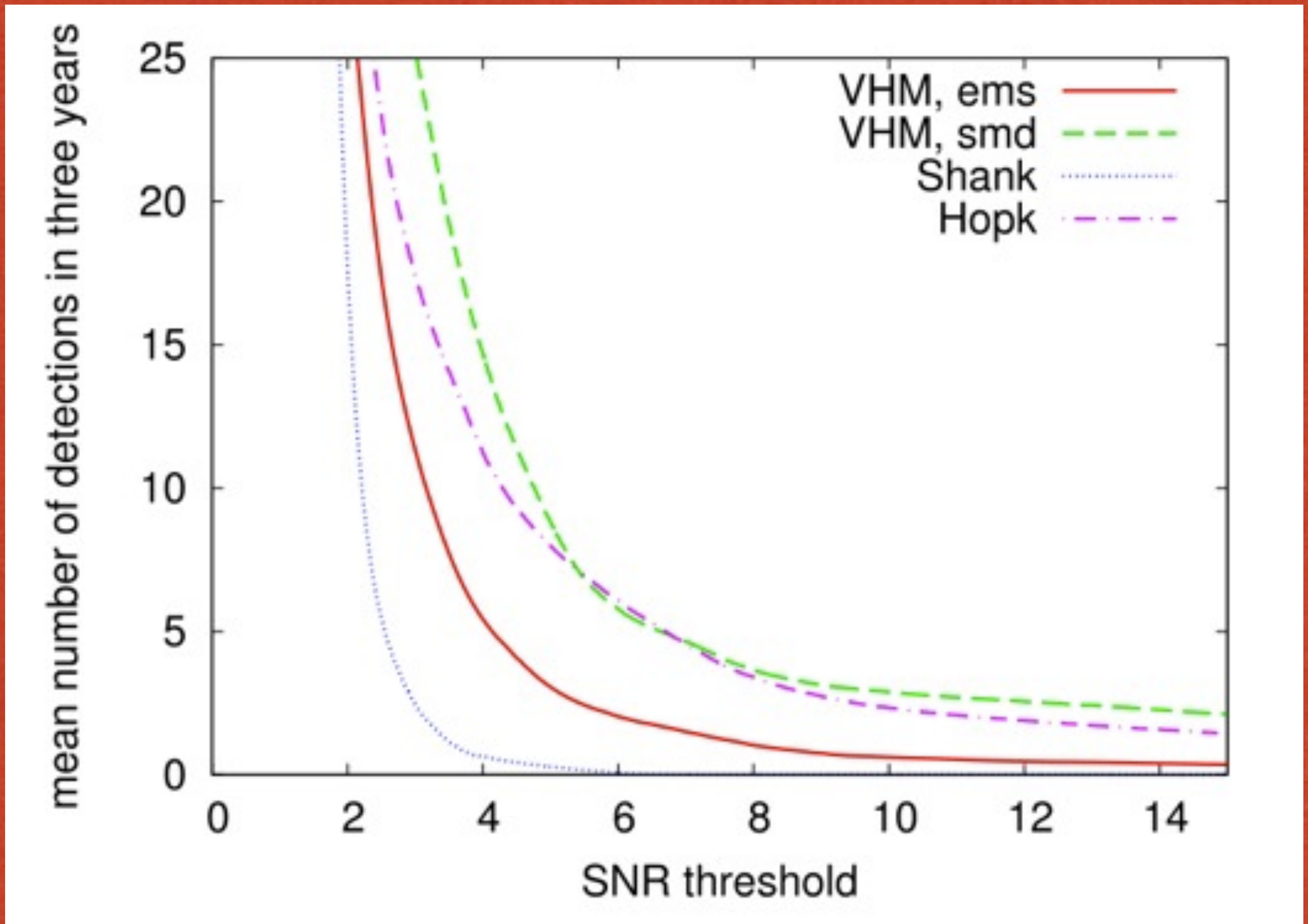


[Mandel et al., in prep]

EXCLUSIVE ET ASTROPHYSICS?

- Low-frequency sensitivity: can probe WDs, Intermediate mass black hole binaries [Gair, Mandel, Miller, Volonteri, 2011]

- Exciting science example: mergers of light seeds of massive black holes at high redshifts



[Sesana, Gair, Mandel, Vecchio, 2009]

CAN ASTROPHYSICS INFORM DESIGN DECISIONS?

Technical Note	LIGO-T1200099–v4	2013/10/22

Astrophysical Motivations for the Third Generation LIGO Detectors

R. Adhikari, Y. Chen, C. D. Ott, N. Fotopoulos, I. Mandel, V. Dergachev, P. Ajith, J. G. Rollns, J. Read, P. Kalmus

	Science Goals	NN	Sei	SUS	SPOT/CTN
§6.1	CW blind search volume	3.8×10^{-14}	0	0.0012	0.079
	ϵ limit (HF targ search)	0	0	-6.2×10^{-8}	−0.027
§4.1	NS-NS population	0.0039	0.0018	0.041	0.71
	BH-BH (10+10) population	0.0034	0.0016	0.034	0.56
	BH-BH (20+20) population	0.0031	0.0014	0.031	0.5
	CBC early warning	0.11	0.085	0.22	−0.0024
§6.2	NS-NS post-merger SNR				
	tidal deformability from NS-NS				
	tidal deformability from NS-BH				
	NS f-mode 1590 Hz (SGR)	5.6×10^{-11}	0	2.0×10^{-06}	0.0047
	NS mode 100-200 Hz (SGR)	2.1×10^{-06}	2.2×10^{-13}	3.3×10^{-03}	0.30
	LMXBs				
§5.1	Typical Galactic SNe	2.3×10^{-5}	7.3×10^{-6}	3.5×10^{-3}	0.12
	Extragalactic SNe/ GRB Engines	1.6×10^{-11}	7.5×10^{-13}	5.8×10^{-5}	0.07
	Galactic SN GW Memory	3.3×10^{-3}	5.4×10^{-4}	2.5×10^{-3}	0.24
§7.1	Cosmic Domains				

CONCLUSIONS

- There is a wealth of information to be gained... but we need to do the following:
  - seriously work on developing *practical tools* for extracting it
  - *prioritize* realistic goals
  - explore ways to *test validity* of models, as well as possibilities of *weakly modeled* science exploitation
  - hope for exciting *surprises*