BPASS predictions for Binary Black-Hole Mergers

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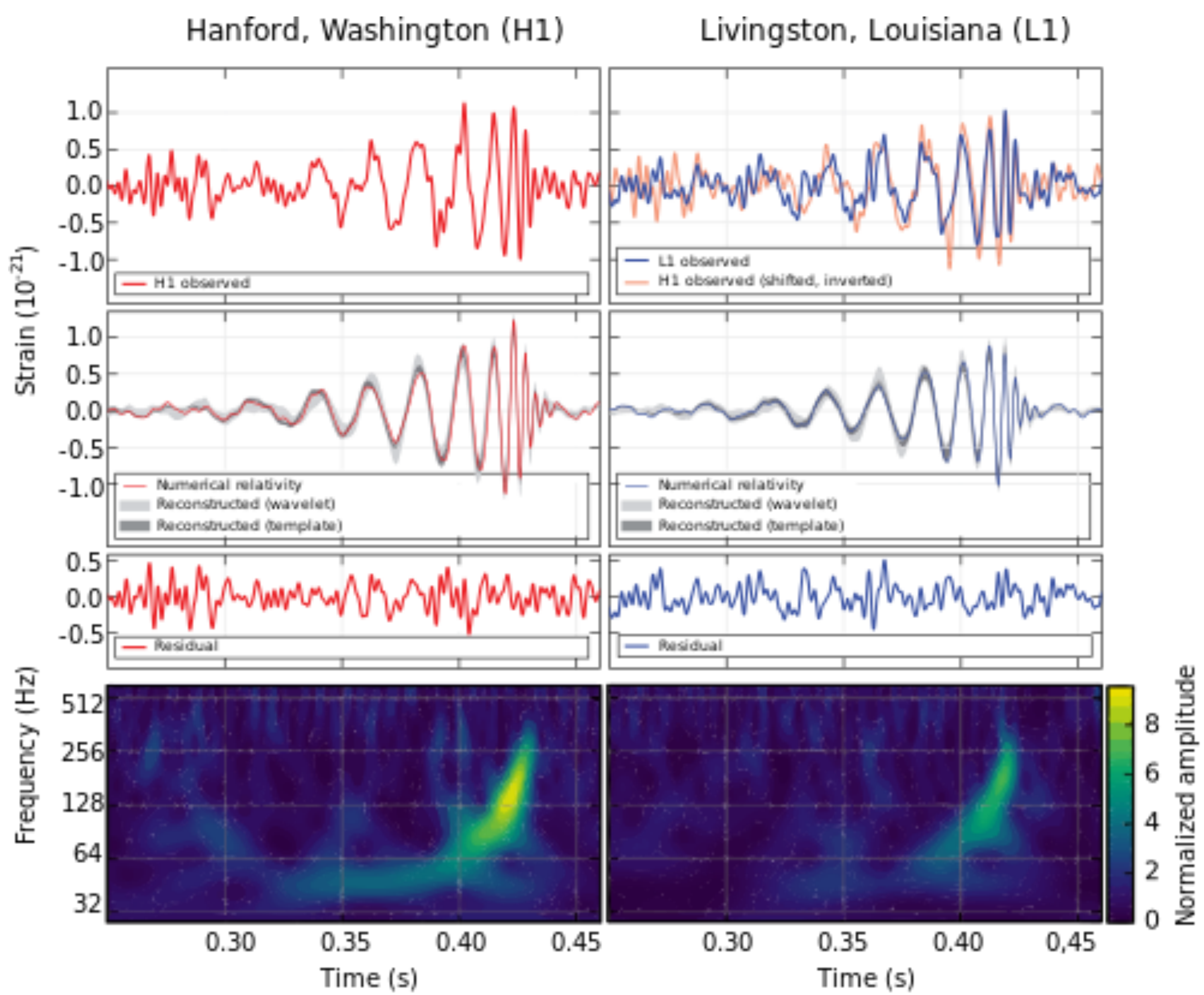
GW 150914

- Motivated by the 1st LIGO event - 36±5 & 29±4 M⊙
- Low probability for Z > 0.5 Z⊙
- Age is unimportant
- electromagnetic follow-up



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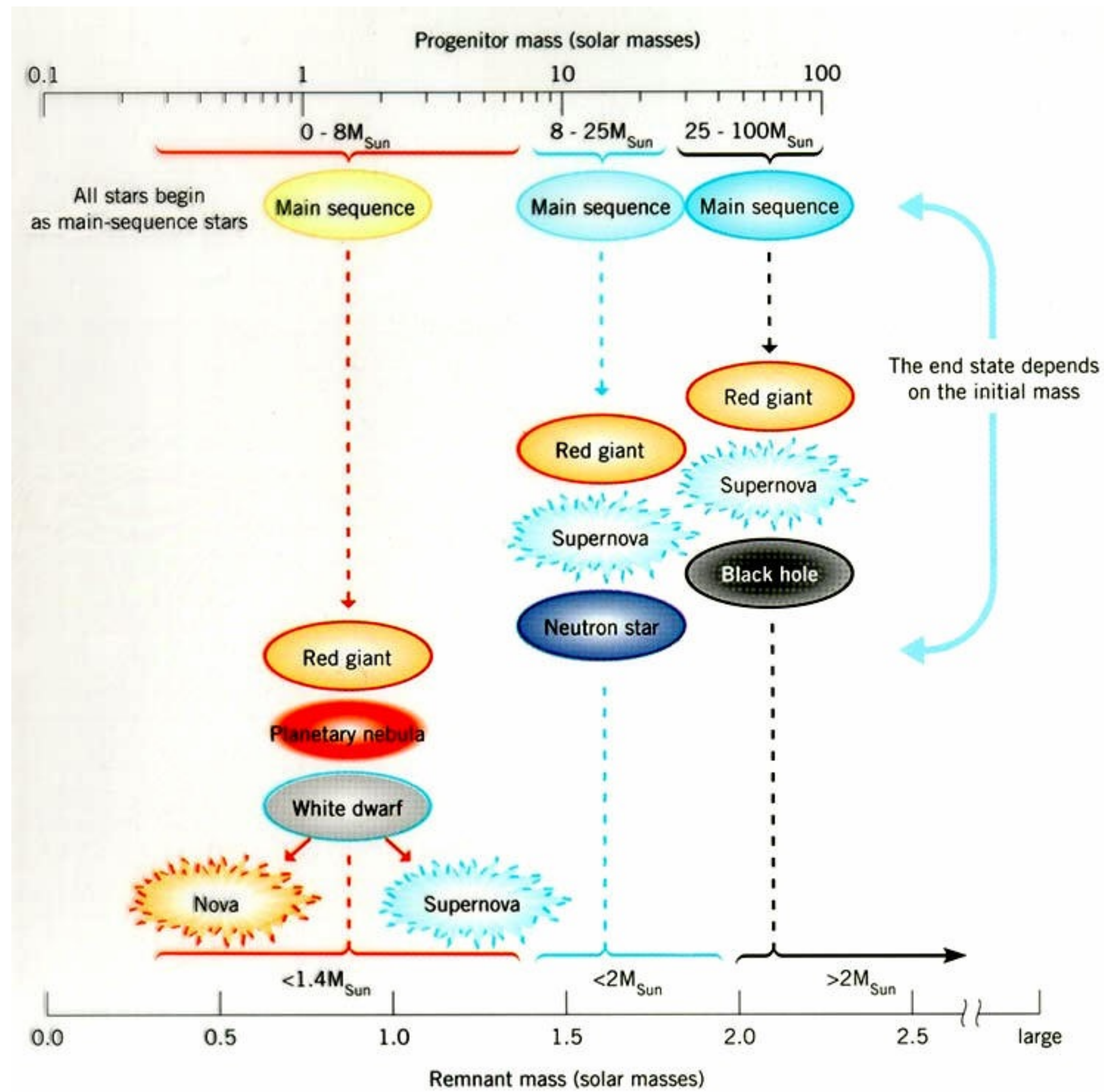
BH-BH mergers

- All BHs are thought to be the end of stellar evolution
- initial mass needed > 20 $M_\odot$
- Stellar Population Synthesis is necessary to predict the rates of BH formation and BH binary objects
- Most massive stars may be in binary interactions (70 %)



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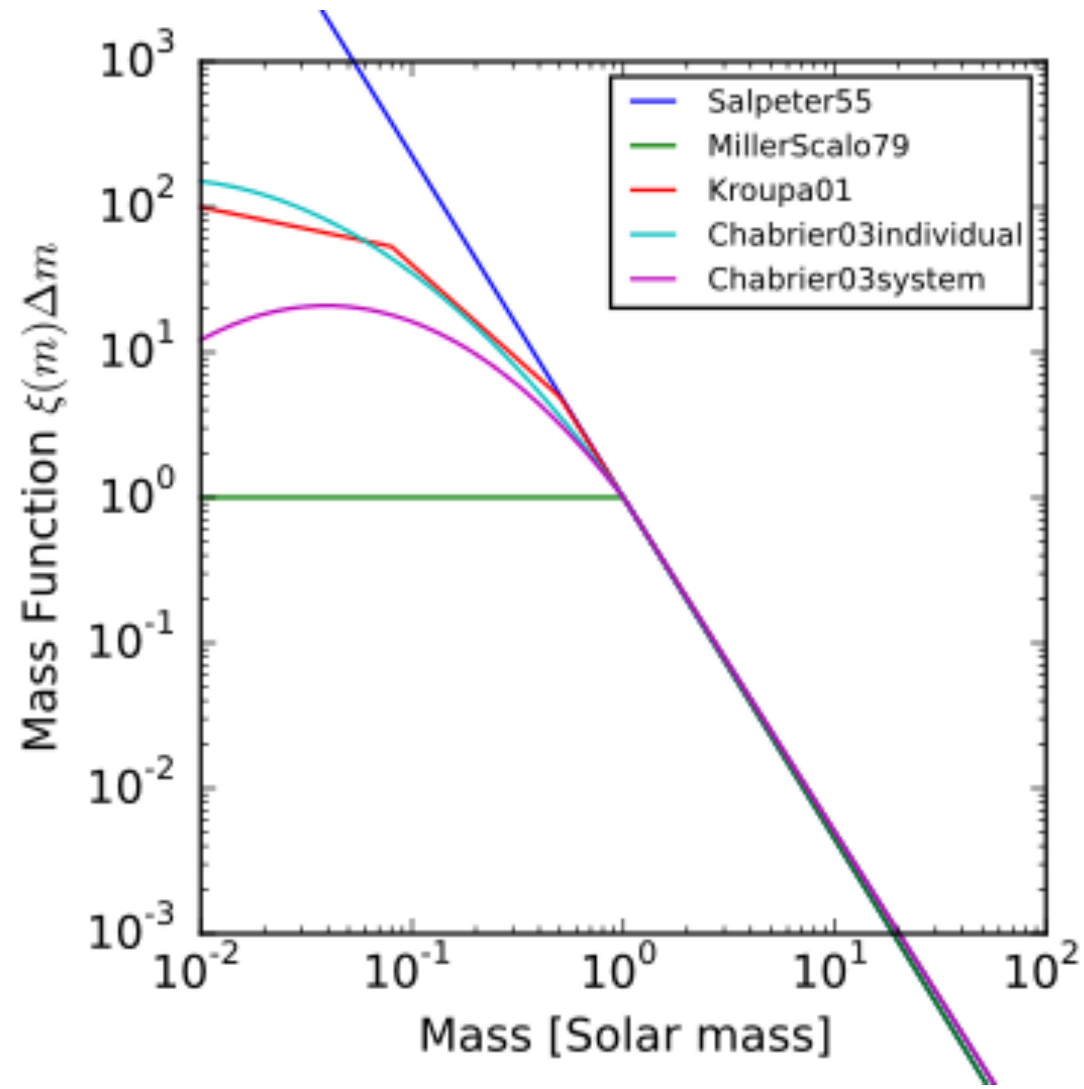
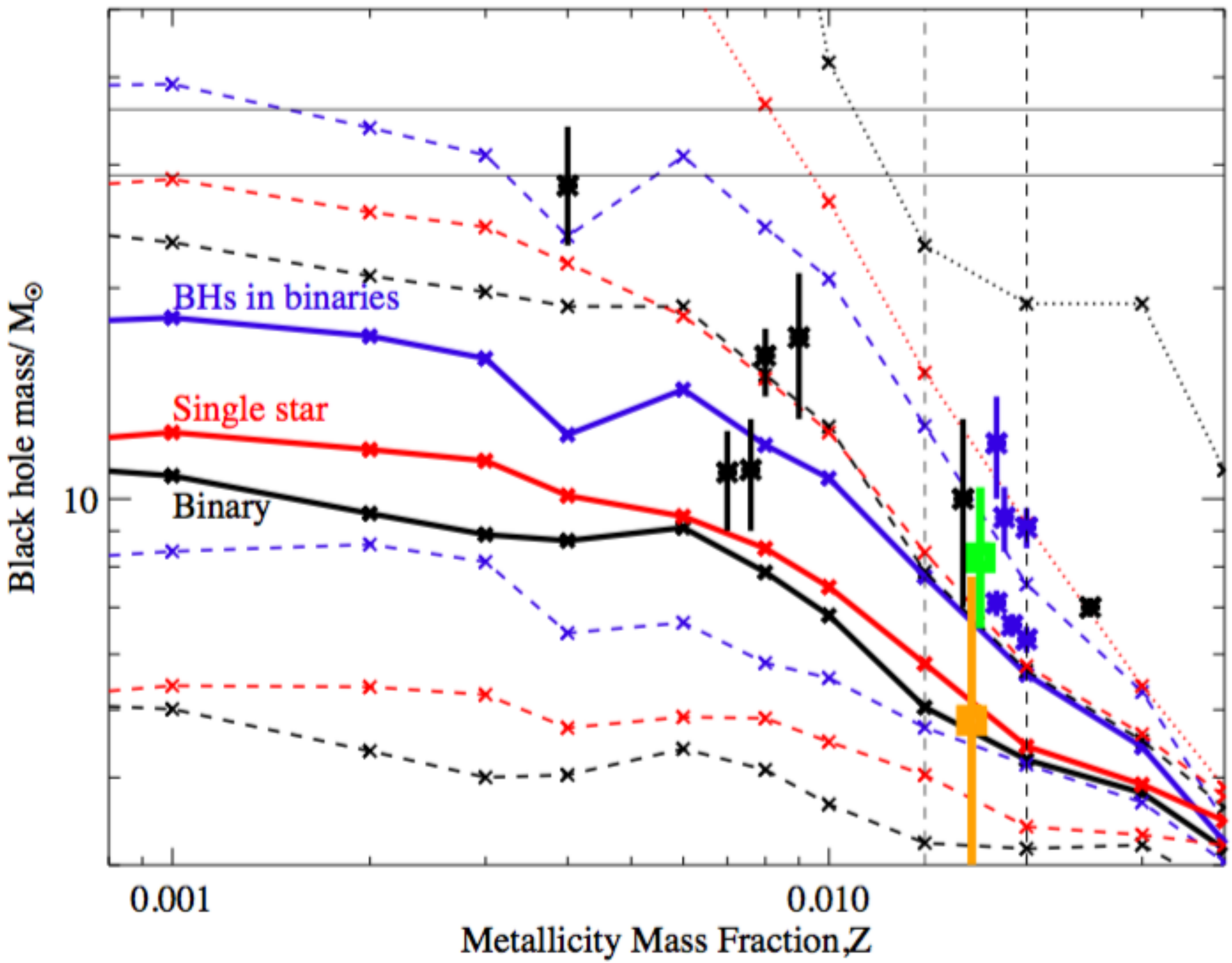
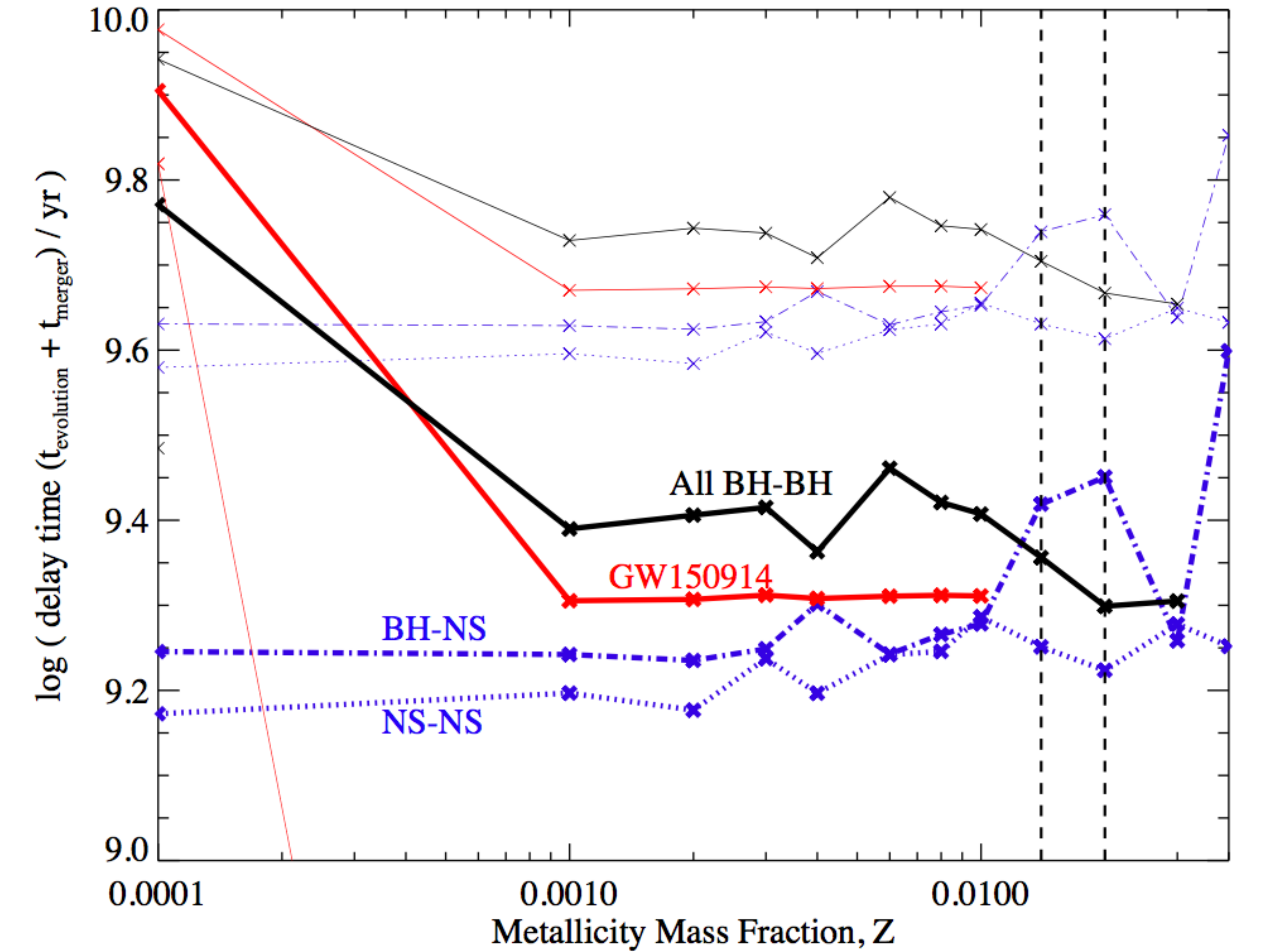
BPASS v2.0

- Large Star evolution grid compared to rapid population synthesis codes (RSCodes)
- Models are improved by including the effect of binaries
- Uncertainties can't be explored as with RSCodes
- IMF power law slope of -1.3 0.1-0.5 and -2.35 from 0.5-300

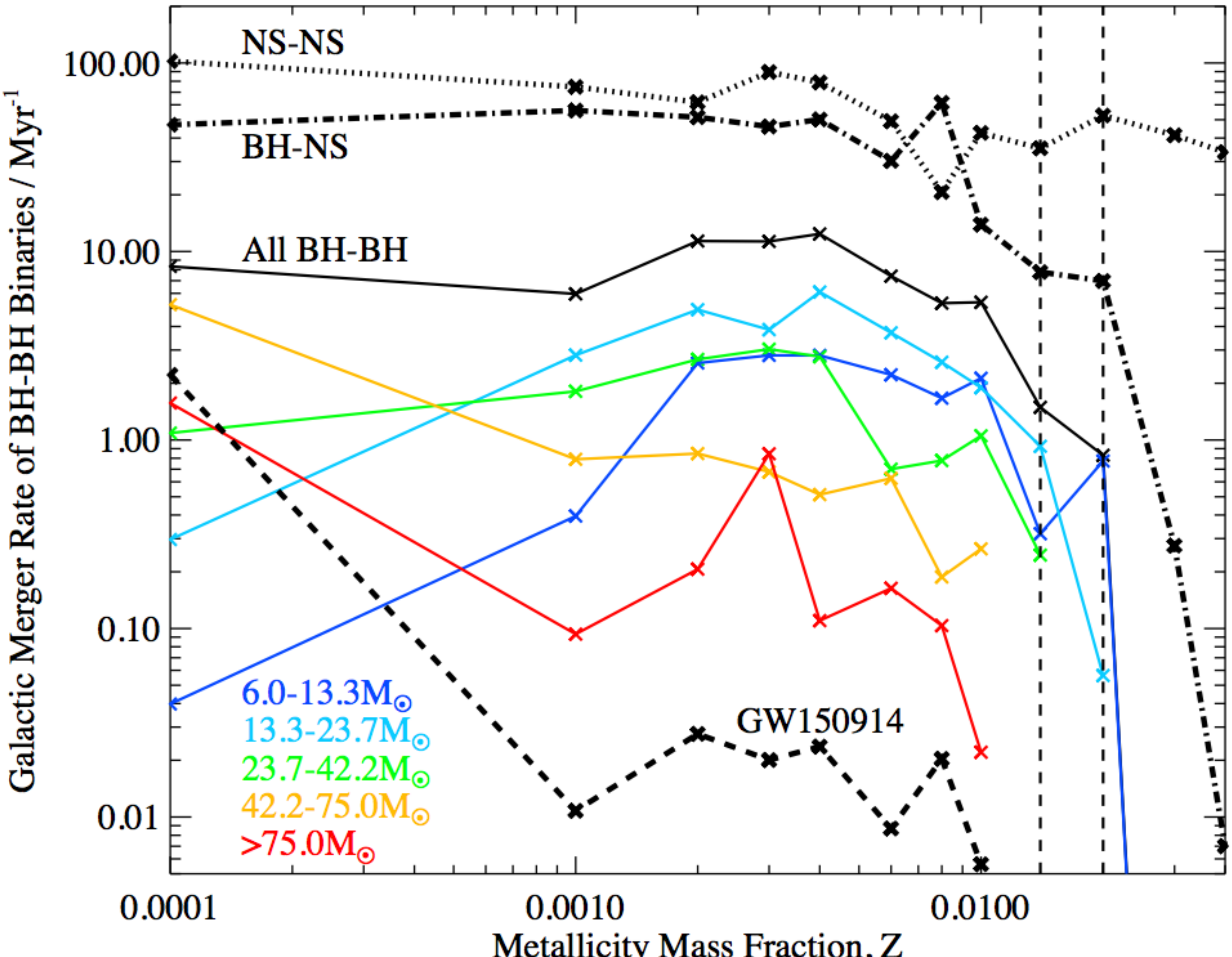


Predicted BH masses to those in nature





10.0
9.8
9.6
9.4
9.2
9.0
log (delay time ($t_{evolution}$ + t_{merger}) / yr)
All BH-BH
GW150914
BH-NS
NS-NS
0.0001
0.0010
0.0100
Metallicity Mass Fraction, Z



NS-NS
BH-NS
All BH-BH
GW150914
6.0-13.3M$_\odot$
13.3-23.7M$_\odot$
23.7-42.2M$_\odot$
42.2-75.0M$_\odot$
>75.0M$_\odot$
100.00
10.00
1.00
0.10
0.01
0.0001
0.0010
0.0100
Galactic Merger Rate of BH-BH Binaries / Myr^{-1}
Metallicity Mass Fraction, Z

Typical orbital parameters for binary BH mergers

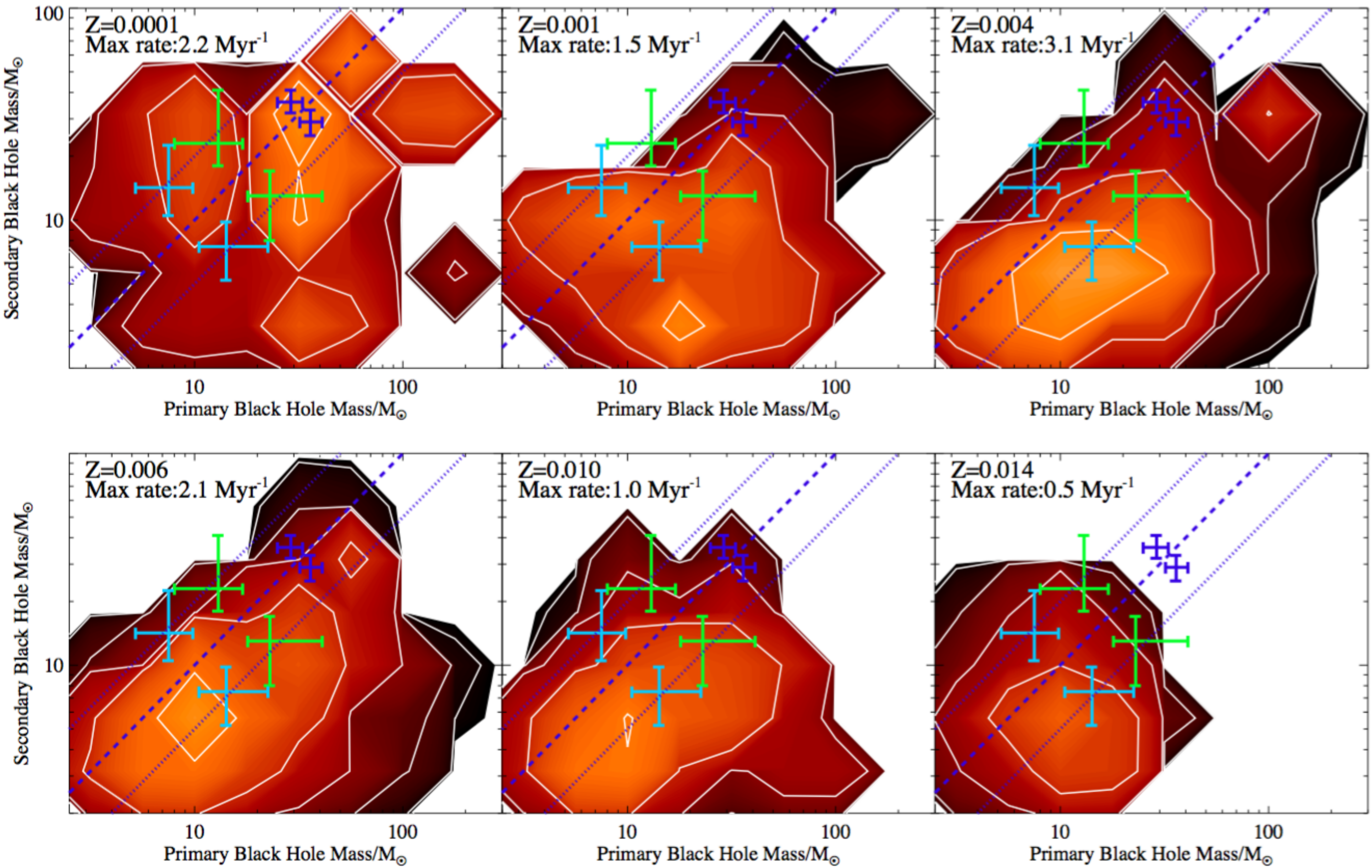
Z	Fraction of QHE systems NS-NS	BH-NS	BH-BH	GW150914	Galactic Merger Rate / Myr^{-1} NS-NS	BH-NS	BH-BH	GW150914	e	M_{BHtot} $/M_{\odot}$	$\log(P/$ days)
10^{-5}	0	0.061	0.878	0.989	160	29	3.1	0.14	0.34±0.32	72±49	0.7±0.7
10^{-4}	0	0.008	0.858	0.988	100	47	8.3	2.2	0.24±0.31	67±36	0.7±0.6
0.001	0	0.011	0.721	0.000	75	56	6.0	0.011	0.92±0.16	28±15	1.7±0.9
0.002	0	0.023	0.692	0.000	62	52	11	0.028	0.91±0.19	24±19	1.5±0.8
0.003	0.024	0.026	0.653	0.0002	89	46	11	0.021	0.86±0.27	29±29	1.4±0.8
0.004	0.033	0.024	0.685	0.049	79	50	12	0.024	0.93±0.14	21±13	1.5±0.8
0.006	0	0	0	0	49	30	7.4	0.009	0.84±0.26	21±16	1.2±0.8
0.008	0	0	0	0	21	62	5.3	0.019	0.89±0.16	21±20	1.2±0.9
0.010	0	0	0	0	43	14	5.4	0.006	0.87±0.22	20±12	1.4±0.8
0.014	0	0	0	0	35	7.8	1.5	0	0.95±0.11	17±5	1.8±0.7
0.020	0	0	0	0	52	7.0	0.82	0	0.98±0.02	10±2	1.6±0.5
0.030	0	0	0	0	41	0.27	2×10^{-7}	0	0.9996±0.0003	8	3.6±0.1
0.040	0	0	0	0	34	0.007	0	0	0	0	0

System that look like those of GW 150914

Z	$M_{1,i}$ / $M_\odot$	$M_{2,i}$ / $M_\odot$	$\log(P_{i,1}$ /days)	$M_{1,BH}$ / $M_\odot$	$M_{2,pSN}$ / $M_\odot$	$\log(P_{i,2}$ /days)	$M_{1,BH}$ / $M_\odot$	$M_{2,BH}$ / $M_\odot$	e	M_{BHtot} / $M_\odot$	$\log(P/$ days)
10^{-5}	40–80, 100	20–90	$\geq$0	25–40	35–100	0.6–0.8, $\geq$3.8	20–40	27–40	0.05$\pm$0.08	79$\pm$4	0.7$\pm$0.2
10^{-4}	60–80, 120	24–65	$\geq$0.6	25–40	40–70	$\geq$3.6	25–40	24–40	0.07$\pm$0.06	69$\pm$6	0.6 $\pm$0.2
0.001	80, 100	40–72	$\geq$0.6	32–40	70–100	$\geq$3.6	32–41	28–41	0.9994$\pm$0.0006	67$\pm$6	4.0$\pm$0.3
0.002	120	40–110	$\geq$0.8	32–40	70–100	$\geq$3.2	25–41	25–35	0.9994$\pm$0.0006	64 $\pm$6	4.0$\pm$0.3
0.003	100–200, 300	60–180	$\geq$0.8	32–40	80–100	$\geq$3.4	32–40	24–31	0.9993$\pm$0.0006	63$\pm$6	4.0$\pm$0.4
0.004	120–200, 300	75–180	$\geq$1	25–40	100–120	$\geq$3.2	25–40	27–38	0.9994$\pm$0.0006	62$\pm$7	4.1$\pm$0.4
0.006	100–300	70–150	$\geq$0	32–40	120–150	$\geq$3.4	25–40	24–41	0.9994$\pm$0.0007	68$\pm$9	4.1$\pm$0.5
0.008	200	180	$\geq$1.4	25–32	120–200	$\geq$2.4	25–34	26–37	0.9994$\pm$0.0007	57$\pm$6	4.1$\pm$0.5
0.010	200	120	1.2	16–25	120	$\geq$2	25–40	25	0.9991$\pm$0.0008	50$\pm$1	3.8$\pm$0.4

	Mean Chirp Mass, $\mathcal{M}_0$			Relative detection rate		
Z	NS-NS	BH-NS	BH-BH	NS-NS	BH-NS	BH-BH
10^{-5}	1.22	3.08±1.04	27.3±18.1	2.44	4.52	115
10^{-3}	1.22	3.15±0.93	25.5±12.9	1.58	7.80	258
0.001	1.22	3.06±0.86	9.47±4.40	1.16	8.64	15.5
0.002	1.22	2.93±0.82	8.77±7.18	0.96	7.13	24.5
0.003	1.22	2.88±0.72	10.9±11.3	1.38	6.10	42.1
0.004	1.22	2.66±0.63	7.79±4.30	1.22	5.48	19.9
0.006	1.22	2.61±0.61	8.07±5.64	0.76	3.13	12.9
0.008	1.22	3.99±1.79	7.18±3.64	0.32	18.4	6.94
0.01	1.22	2.54±0.61	7.21±3.42	0.66	1.35	7.07
0.014	1.22	2.55±0.96	6.45±1.60	0.55	0.77	1.49
0.02	1.22	2.14±0.41	4.07±0.68	0.81	0.44	0.26
0.03	1.22	2.52±0.47	3.29±0.00	0.64	0.03	5×10^{-8}
0.04	1.22	1.87±0.10	0.00±0.00	0.52	0.0003	–
Mean	1.22	2.8	11	1	4.9	42

BH Mass Ratio

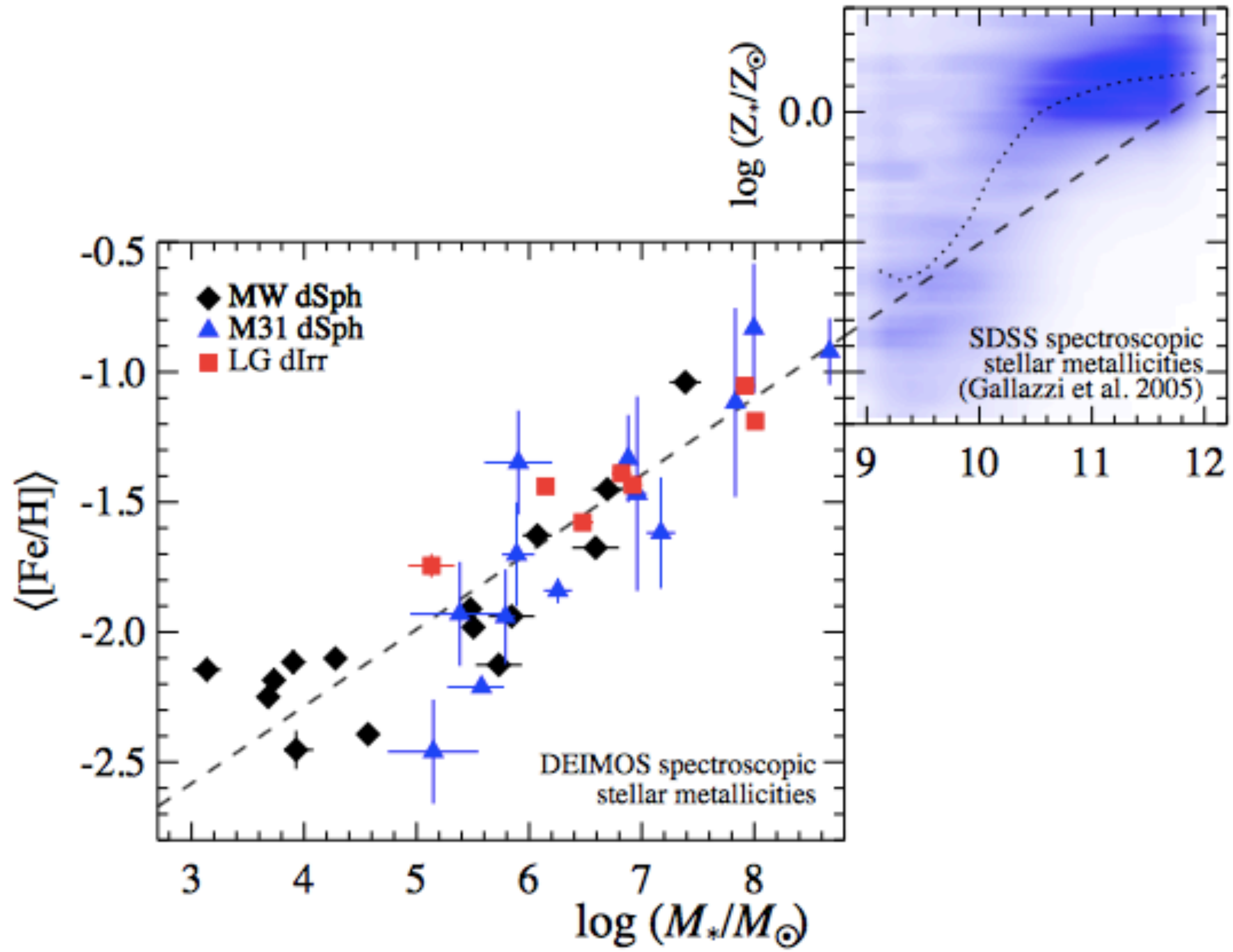


- strong relation between metallicity and both stellar mass and luminosity

- may be pockets of low metallicity they are not likely to form high mass BH-BH mergers

- Dwarf galaxies have low metallicities (significantly less than solar)

- Tidal forces may be more important in dwarf galaxies



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EM Follow - Up

- BH-BH mergers are considered poor candidates for EM detection
- Given the strong metallicity dependence of our results, using such catalogues may not be a optimal strategy for binary black hole mergers.
- the stars that ended their lives in GW 150914 likely formed at $z \sim 2$, and at metallicities significantly lower than those estimated in the star forming galaxy population at that redshift
- short-timescale binary black hole merger events are more likely to be associated with low mass, less luminous regions
- the most likely evolutionary path- way for GW 150914 is standard binary evolution