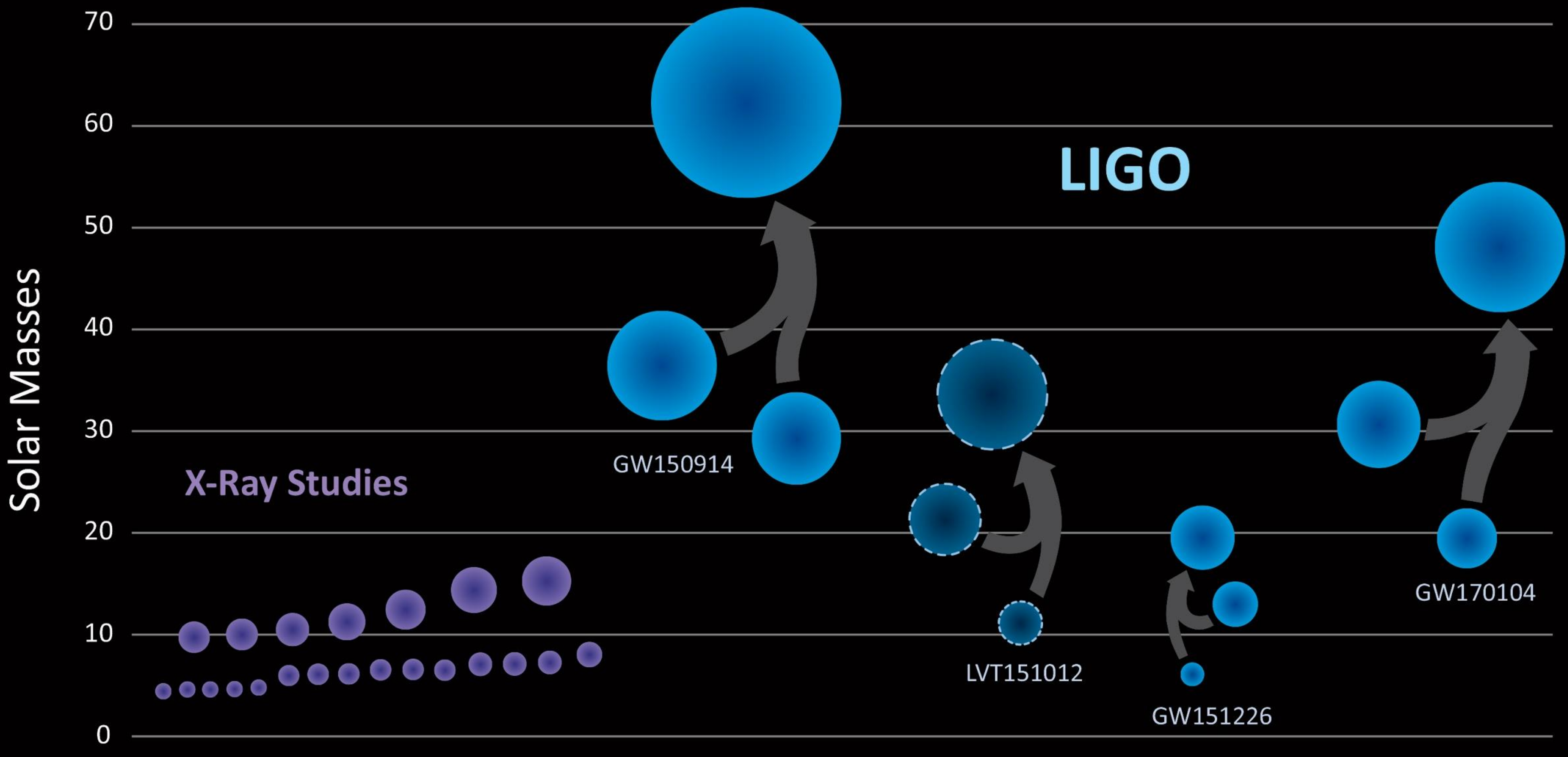
Black Holes of Known Mass



www.ligo.caltech.edu/page/press-release-gw170104

Four

Formation of the first ~~three~~ gravitational-wave observations through isolated binary evolution

Simon Stevenson, Alejandro Vigna-Gómez, Ilya Mandel, Jim W. Barrett, Coenraad J. Neijssel, David Perkins, Selma E. de Mink

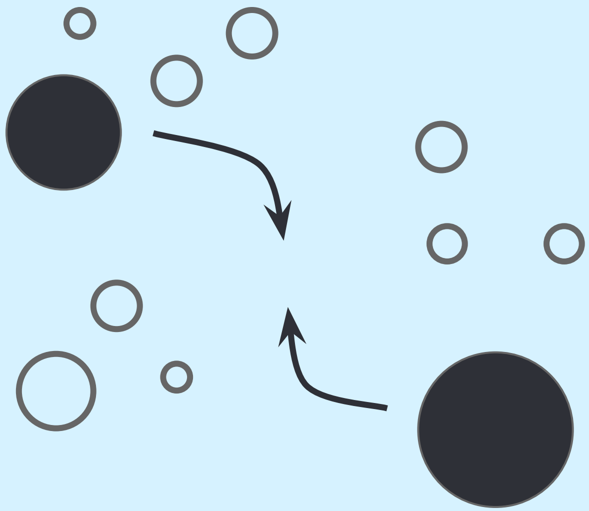
me

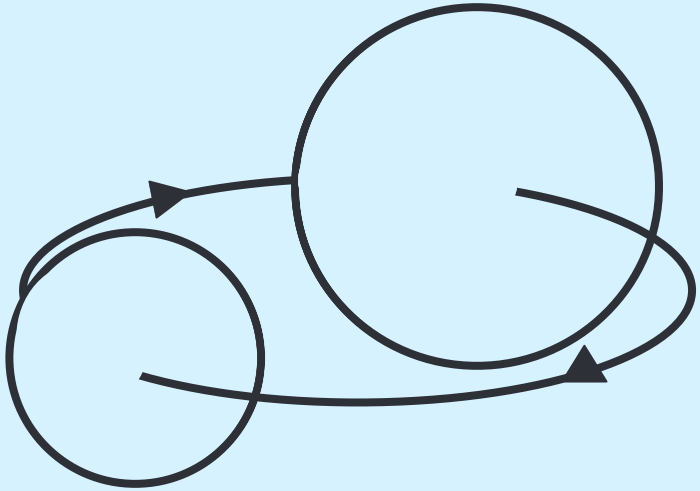
arXiv:1701.07032

dynamical formation

vs

isolated binary evolution

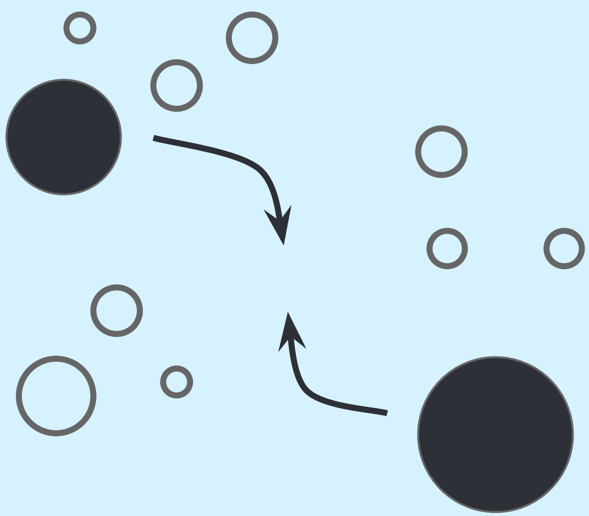


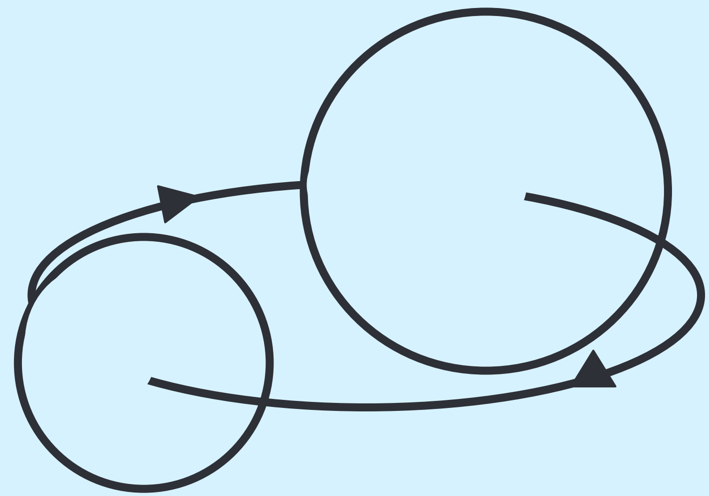


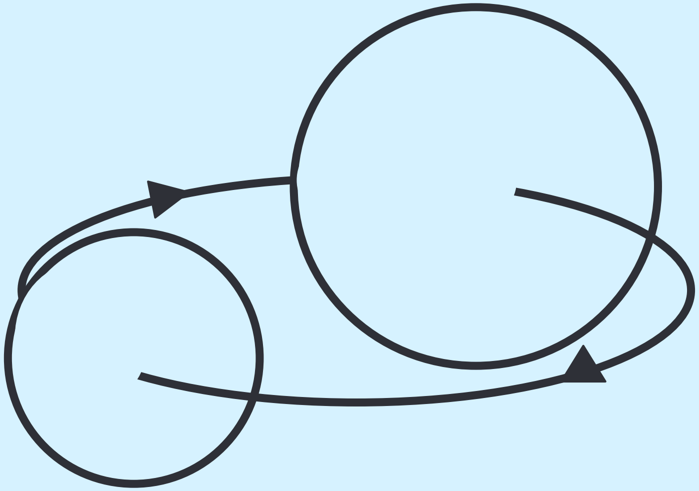
dynamical formation

~~vs~~

isolated binary evolution

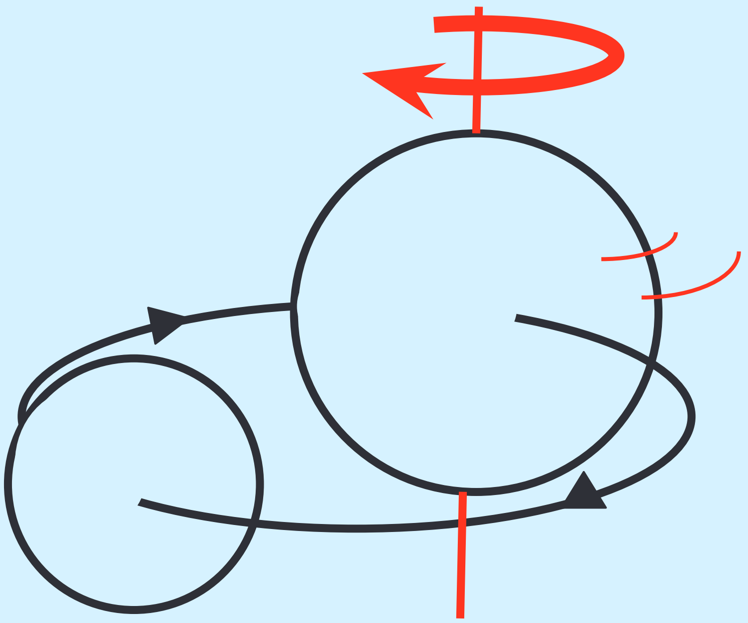


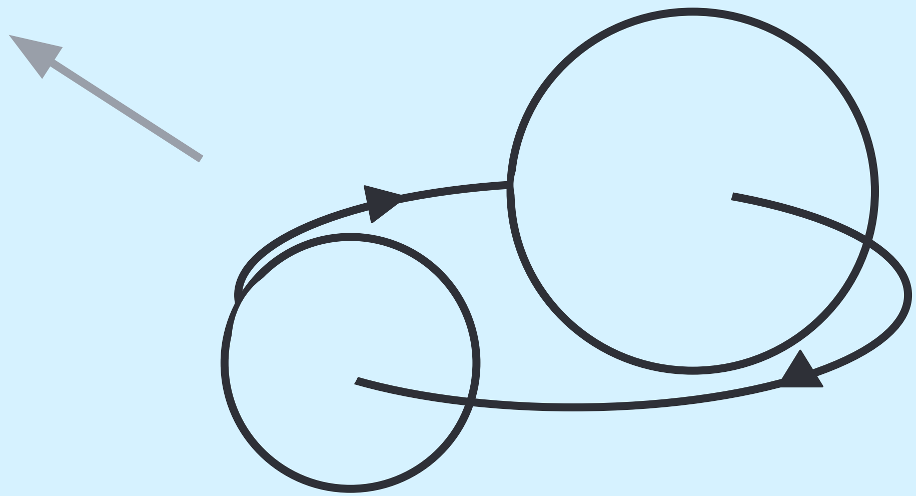


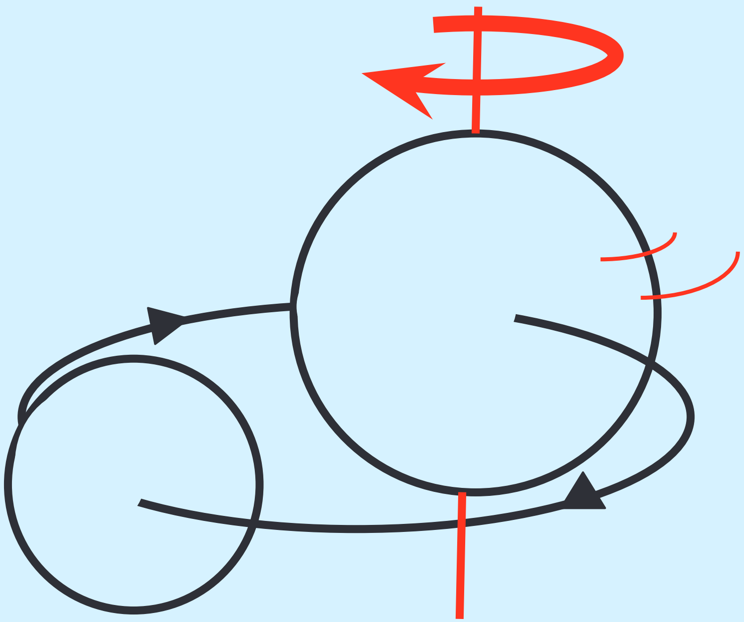


chemically homogeneous evolution

stellar rotation, mixing, no RLOF

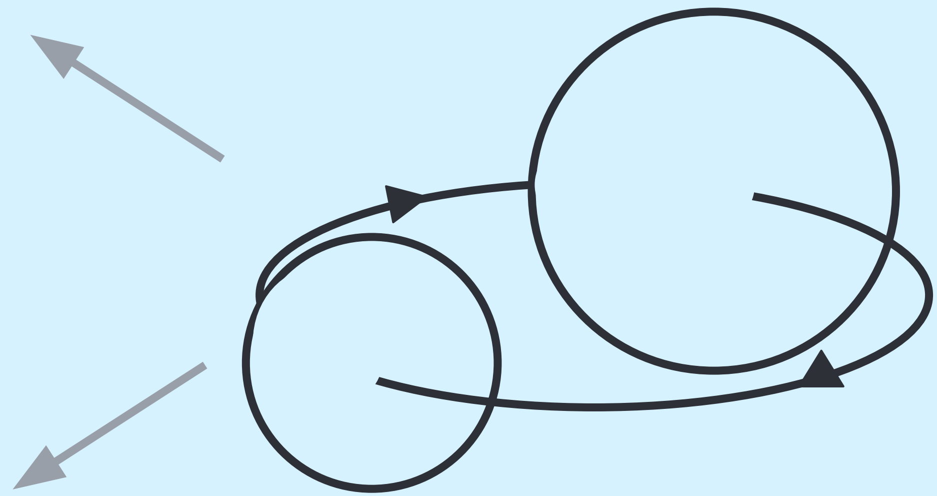


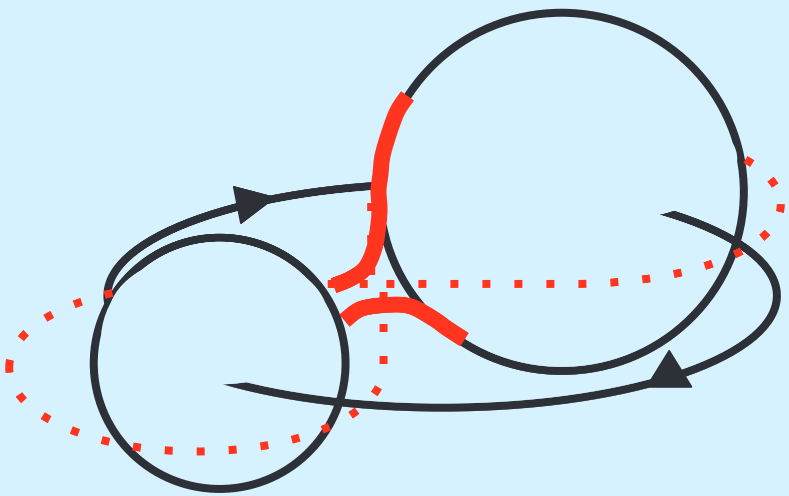




chemically homogeneous evolution

stellar rotation, mixing, no RLOF





“classical” evolution

RLOF, common envelope

COMPAS

Compact Object Mergers: Population Astrophysics and Statistics

www.sr.bham.ac.uk/compas

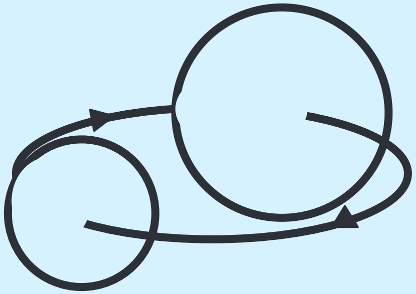
Team:

Supervisor Dr. I. Mandel, S.Stevenson, J.Barrett, A.Vigna-Gomez, C.J.Neijssel, + others

Pop synth in a nutshell

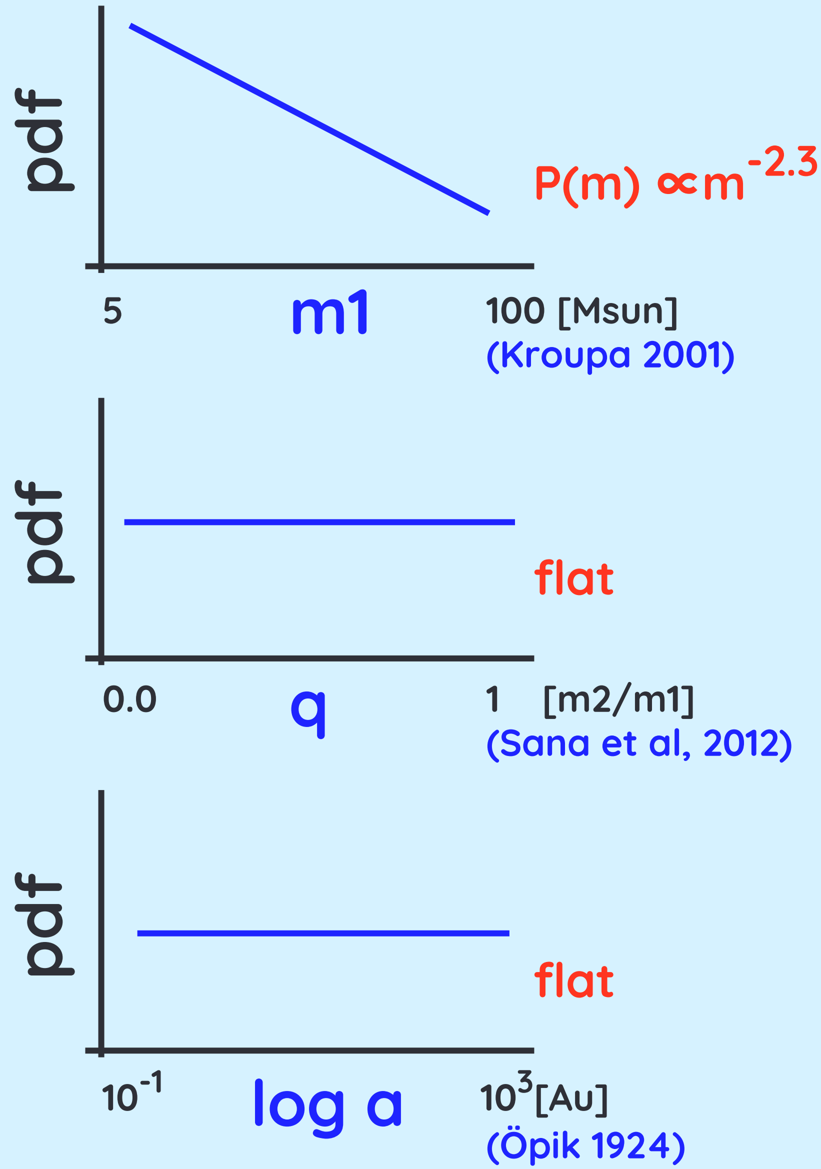
Create large samples for better statistics

Steps



create binary

Input



We assume assume zero eccentricity at ZAMS

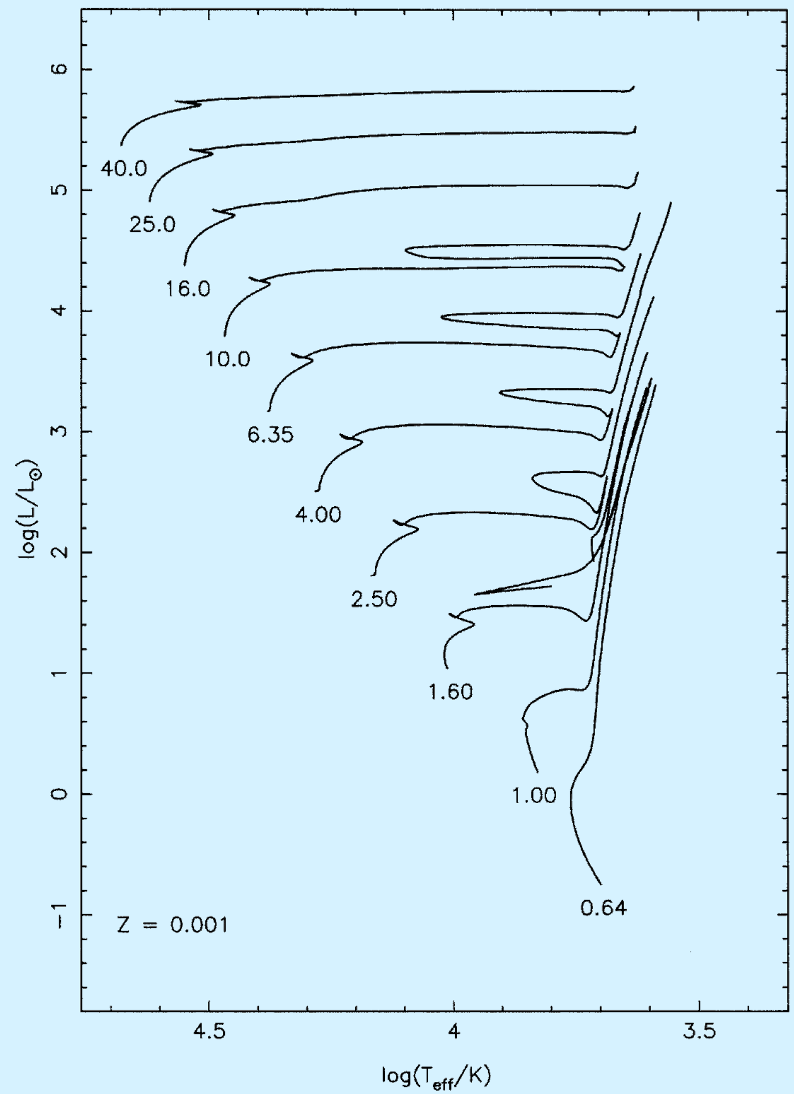
Steps

evolve stars

time

Mass, Lum, Teff, Radius etc

Input



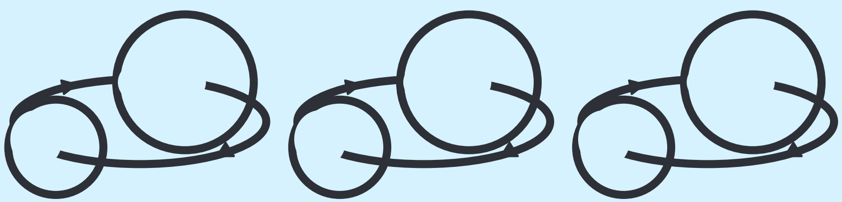
Pols et al 1998,
Hurley, Pols, and Tout 2000/2002

Steps

time Mass, Lum, Teff, Radius etc

binary interaction

examples



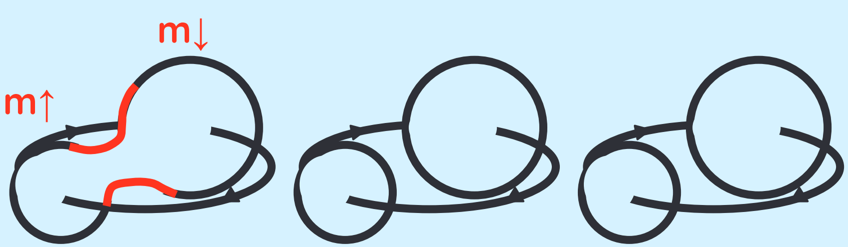
Input

Steps

time Mass, Lum, Teff, Radius etc

binary interaction

examples



RLOF

Input

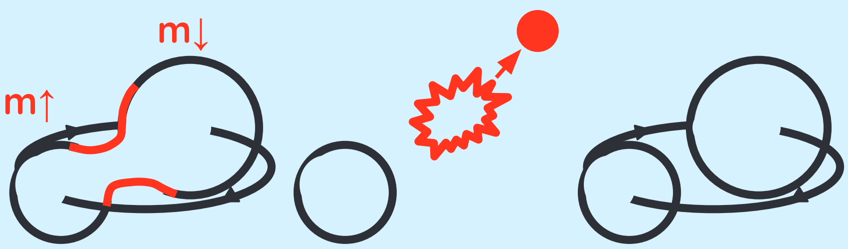
Accreting star can only accrete on thermal timescale

Hurley, Pols, and Tout 2002
Schneider et al 2015

Steps

binary interaction

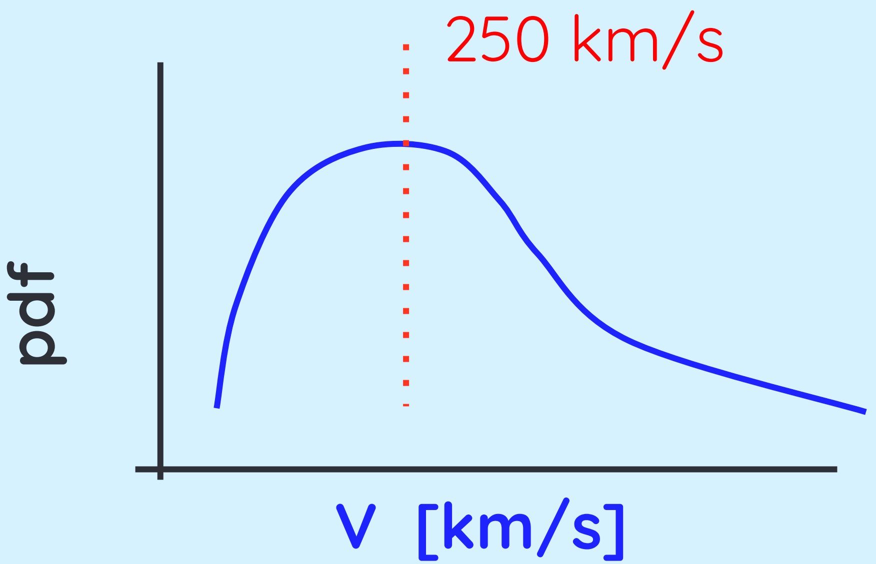
examples



RLOF

supernovae

Input



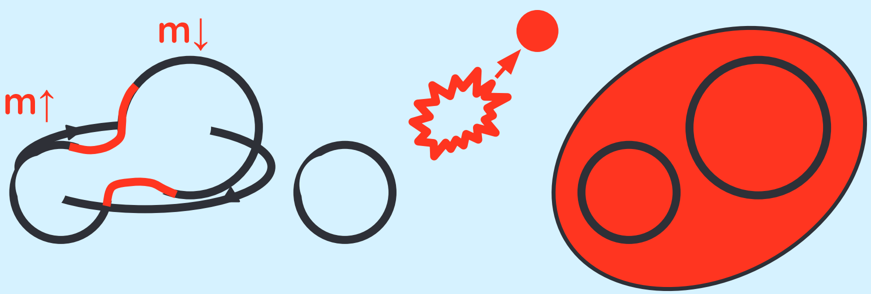
Hobbs et al. 2005

Steps

time Mass, Lum, Teff, Radius etc

binary interaction

examples



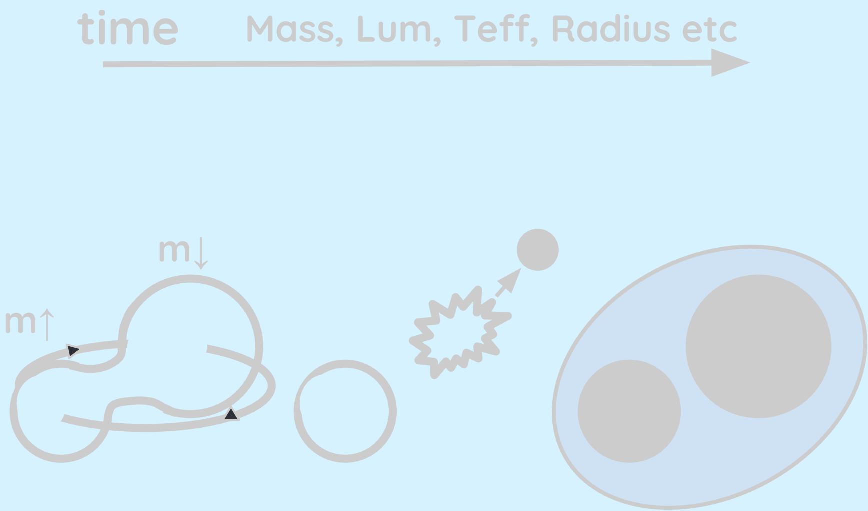
RLOF supernovae common-envelope

Input

$\alpha=1.0 \quad \lambda=0.1$

Webbink et al. 1984 Hurley et al. 2002

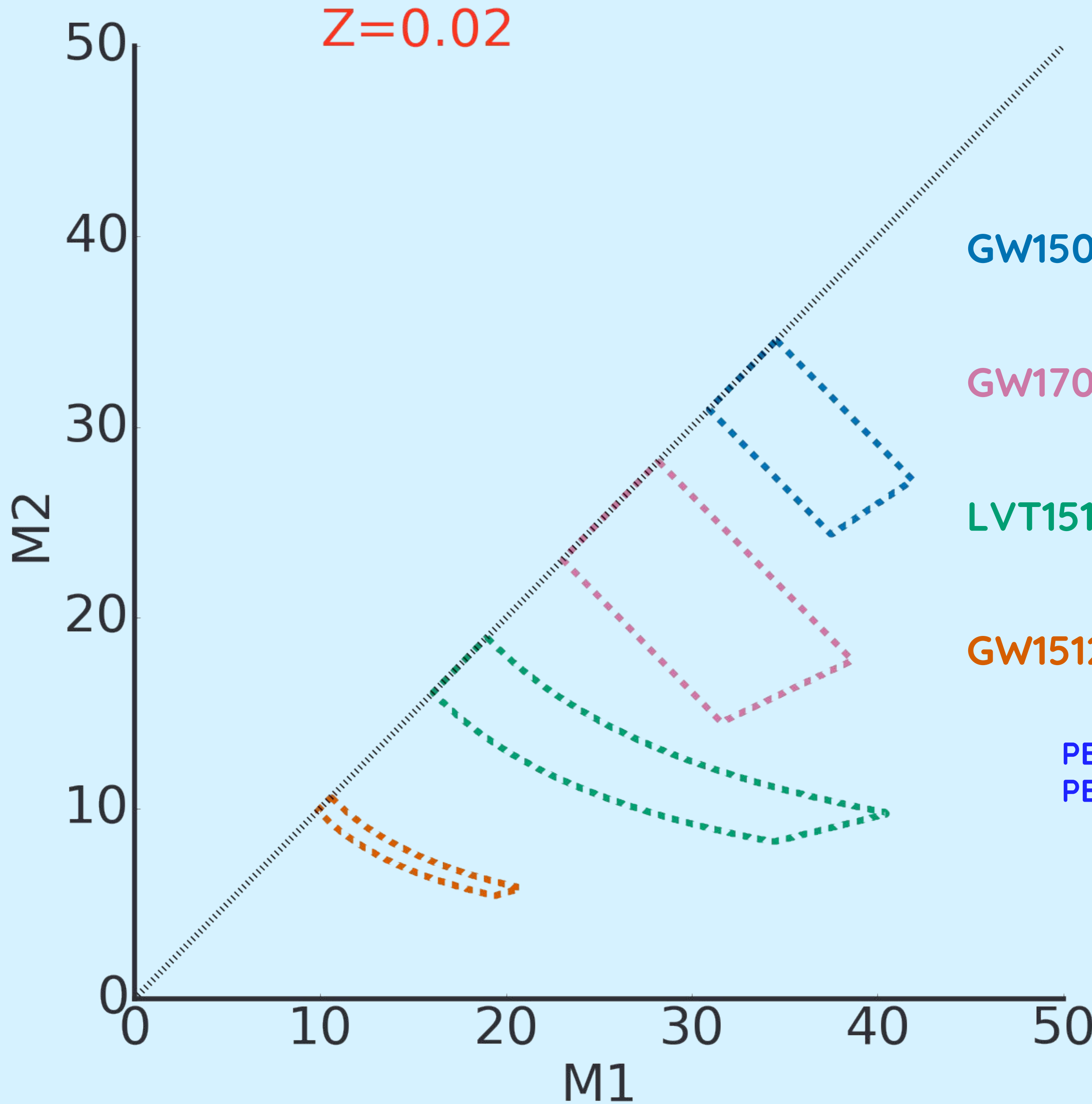
Steps



Output

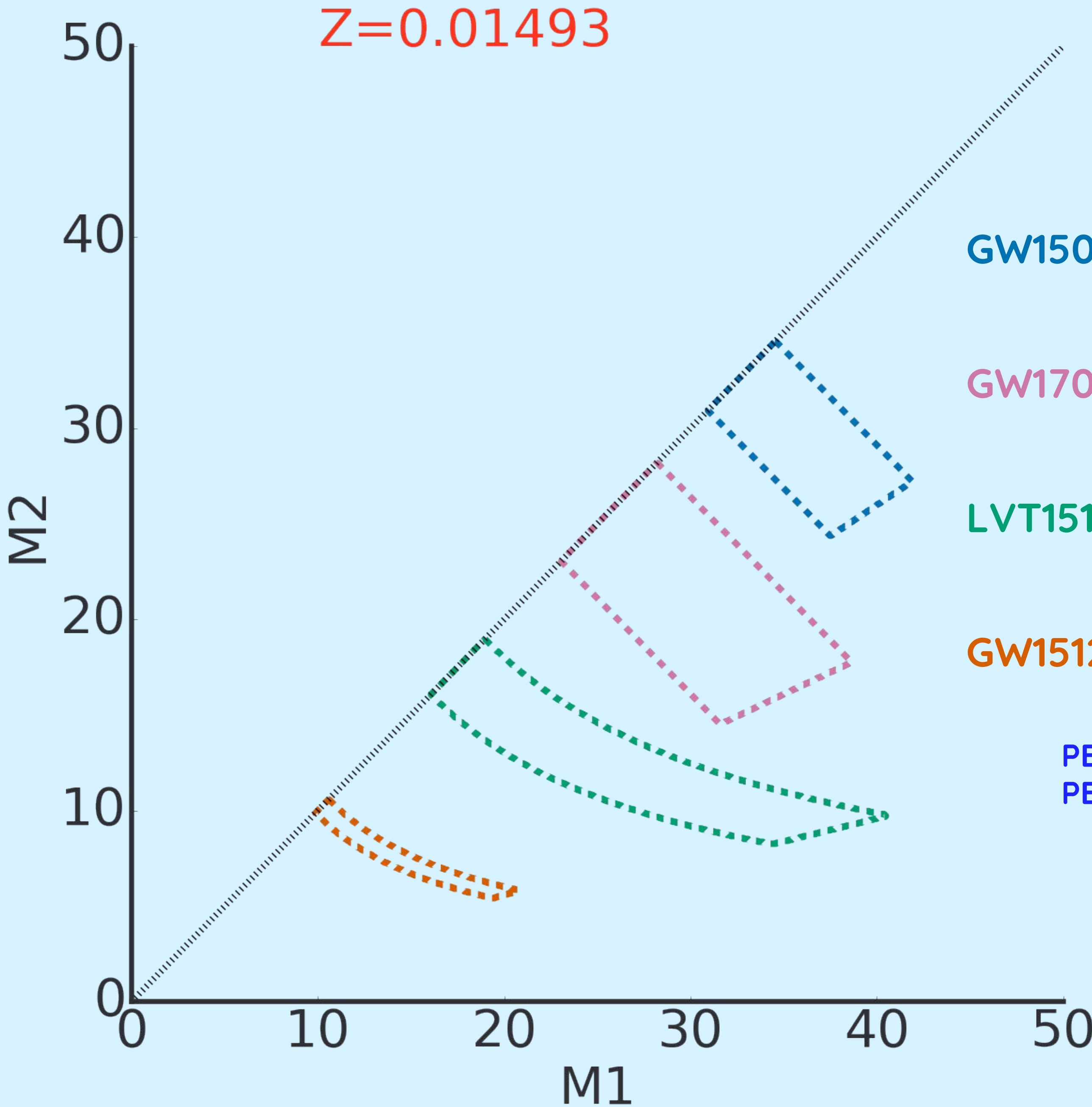
Rapid population synthesis

On average less than
0.3 seconds per binary



	Mtot [$M_\odot$]	M2/M1
GW150914	= $65.3^{+3.8}_{-3.4}$	q>0.65
GW170104	= $50.7^{+5.7}_{-4.6}$	q>0.46
LVT151012	= $37.0^{+13.0}_{-4.0}$	q>0.24
GW151226	= $21.8^{+5.9}_{-1.7}$	q>0.28

PB Abott et al. 2016 (O1 BBH),
PB Abott et al. 2017 (GW170104)



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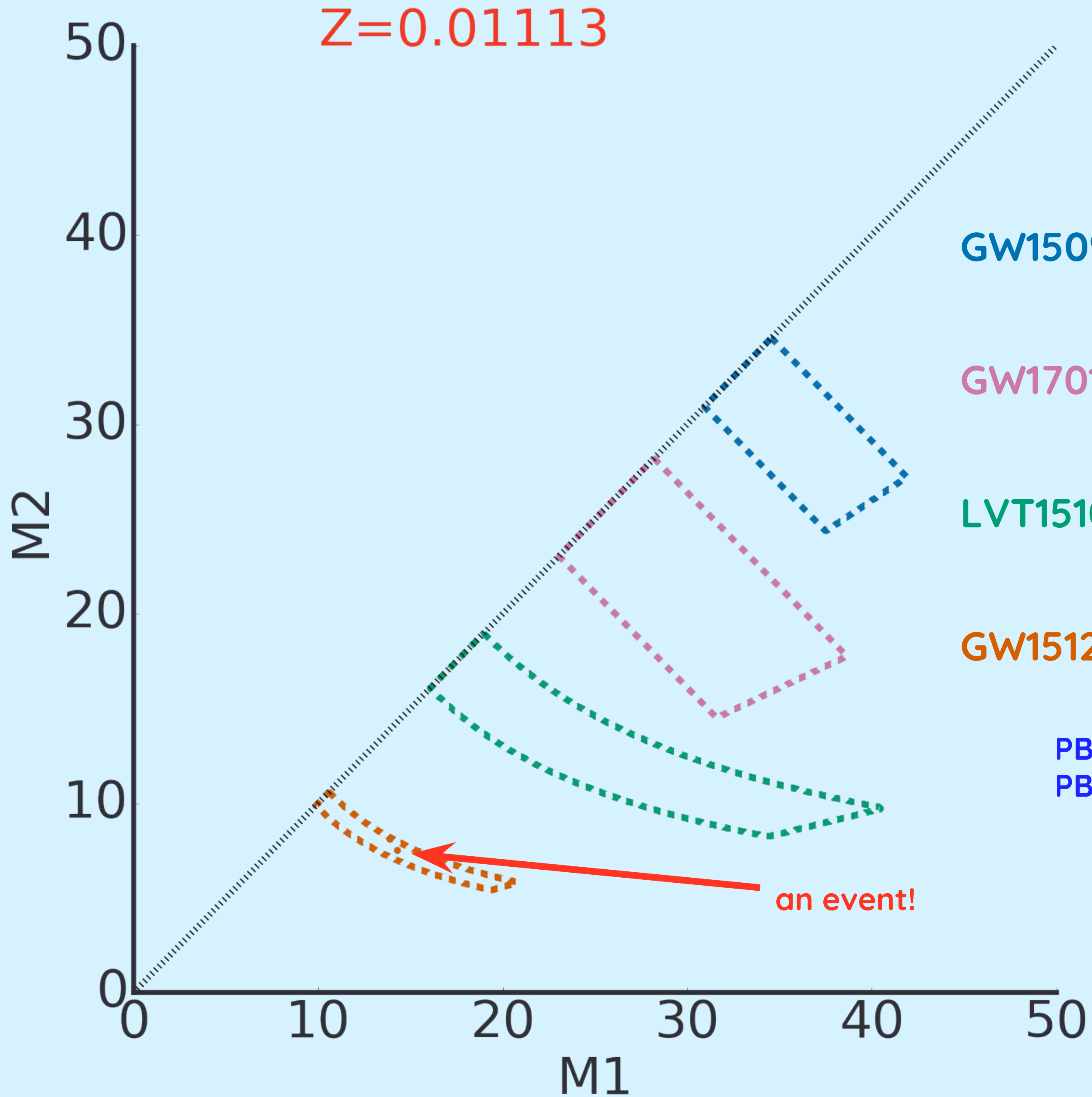

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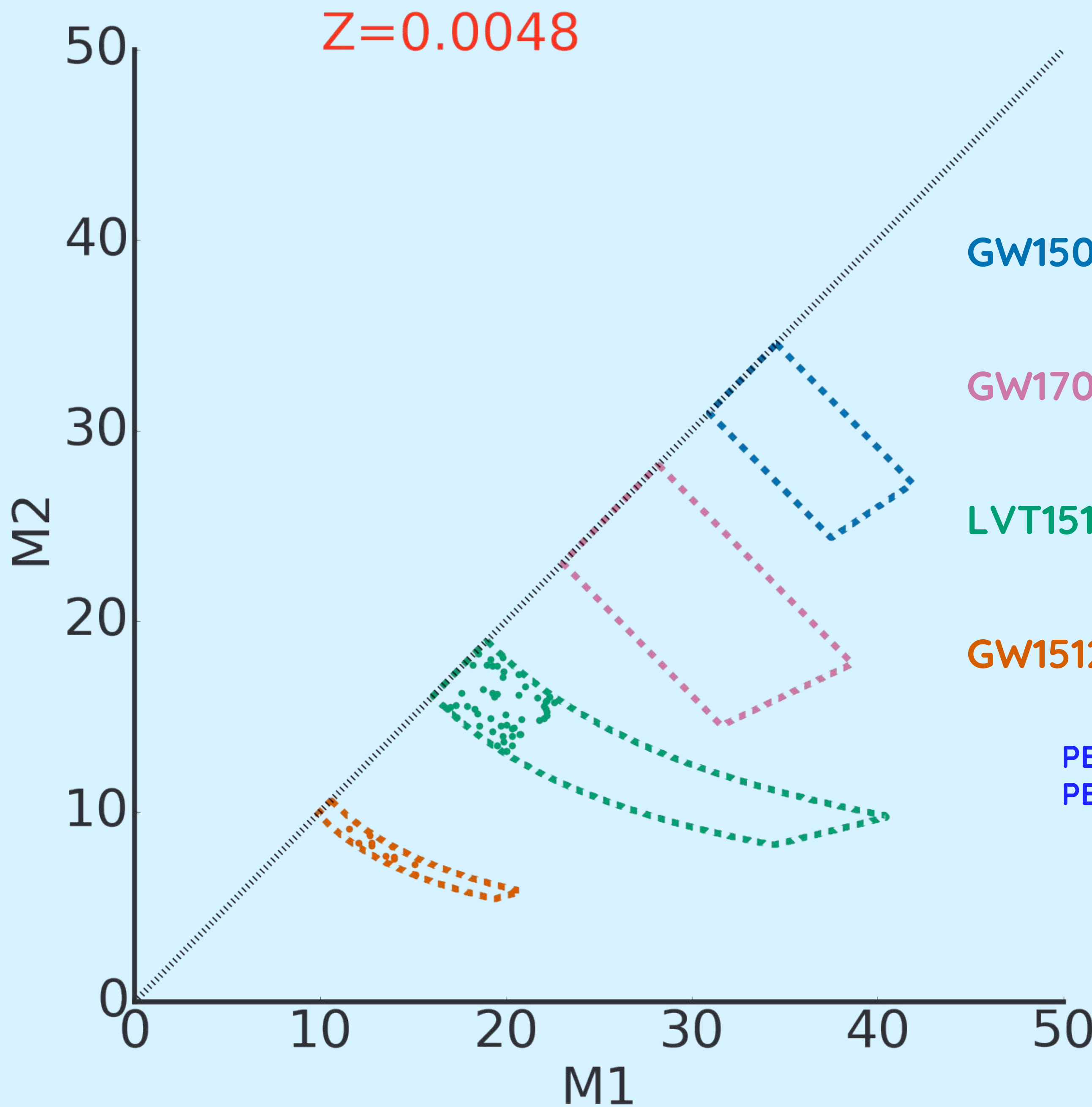

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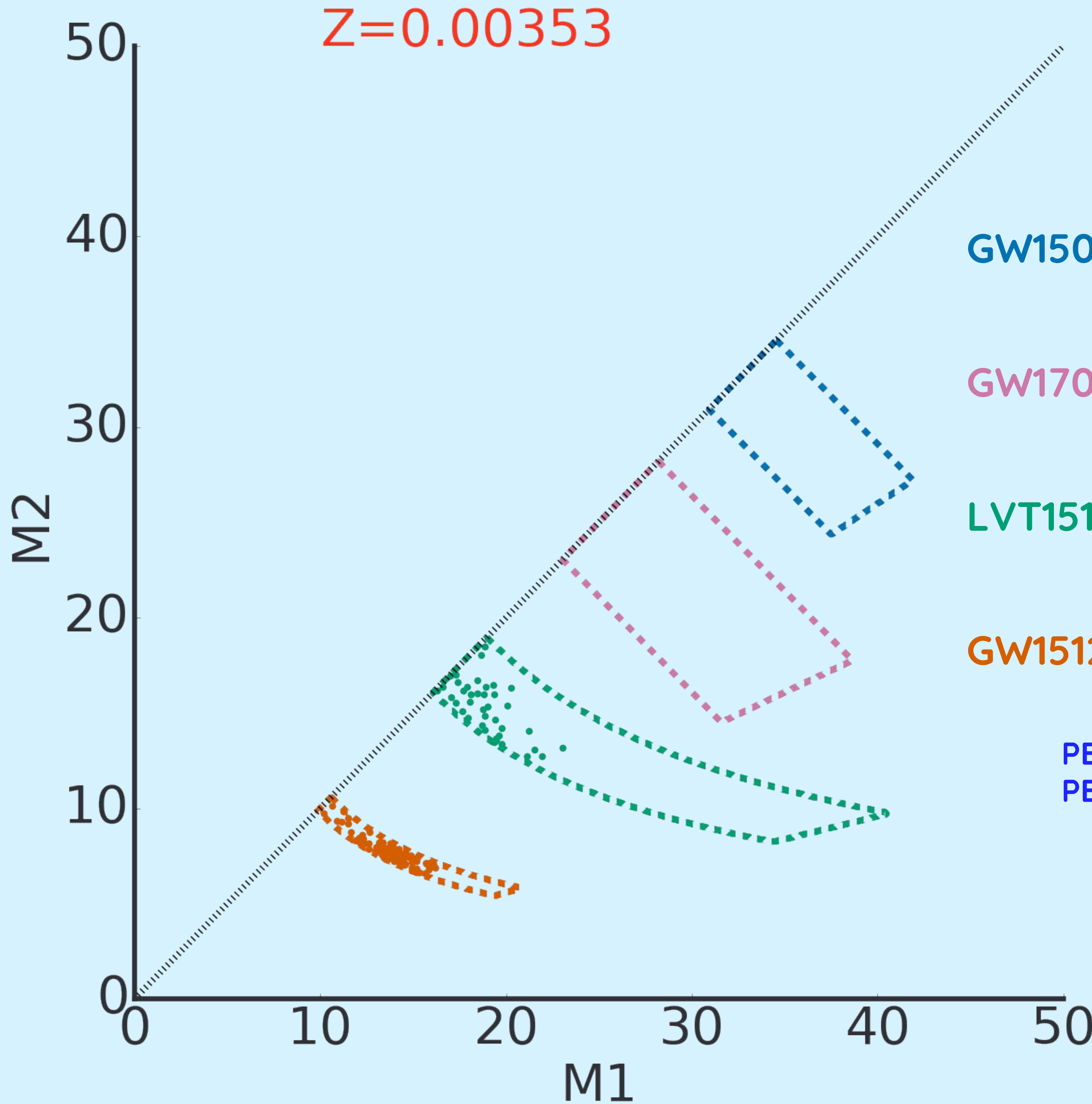

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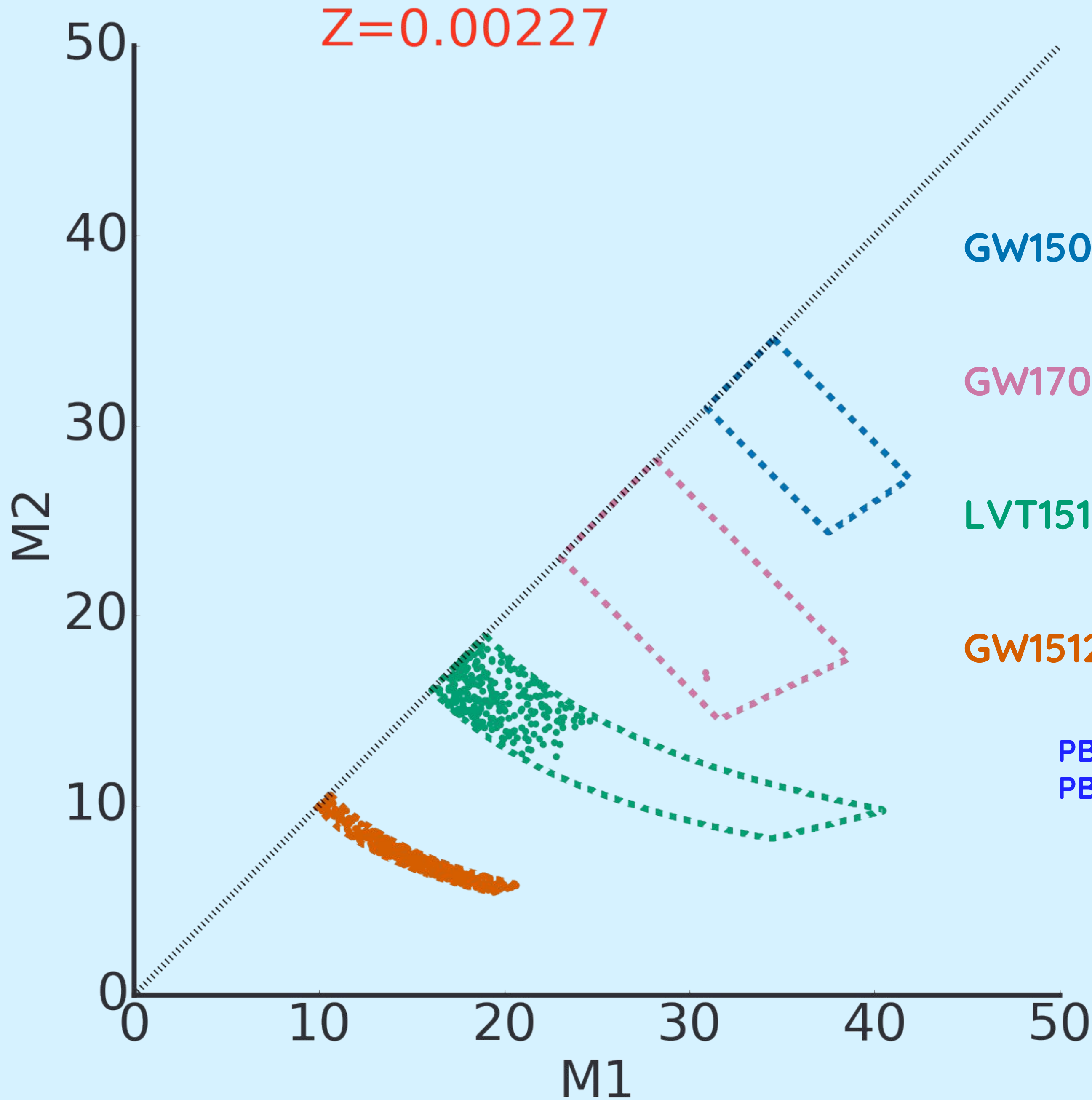

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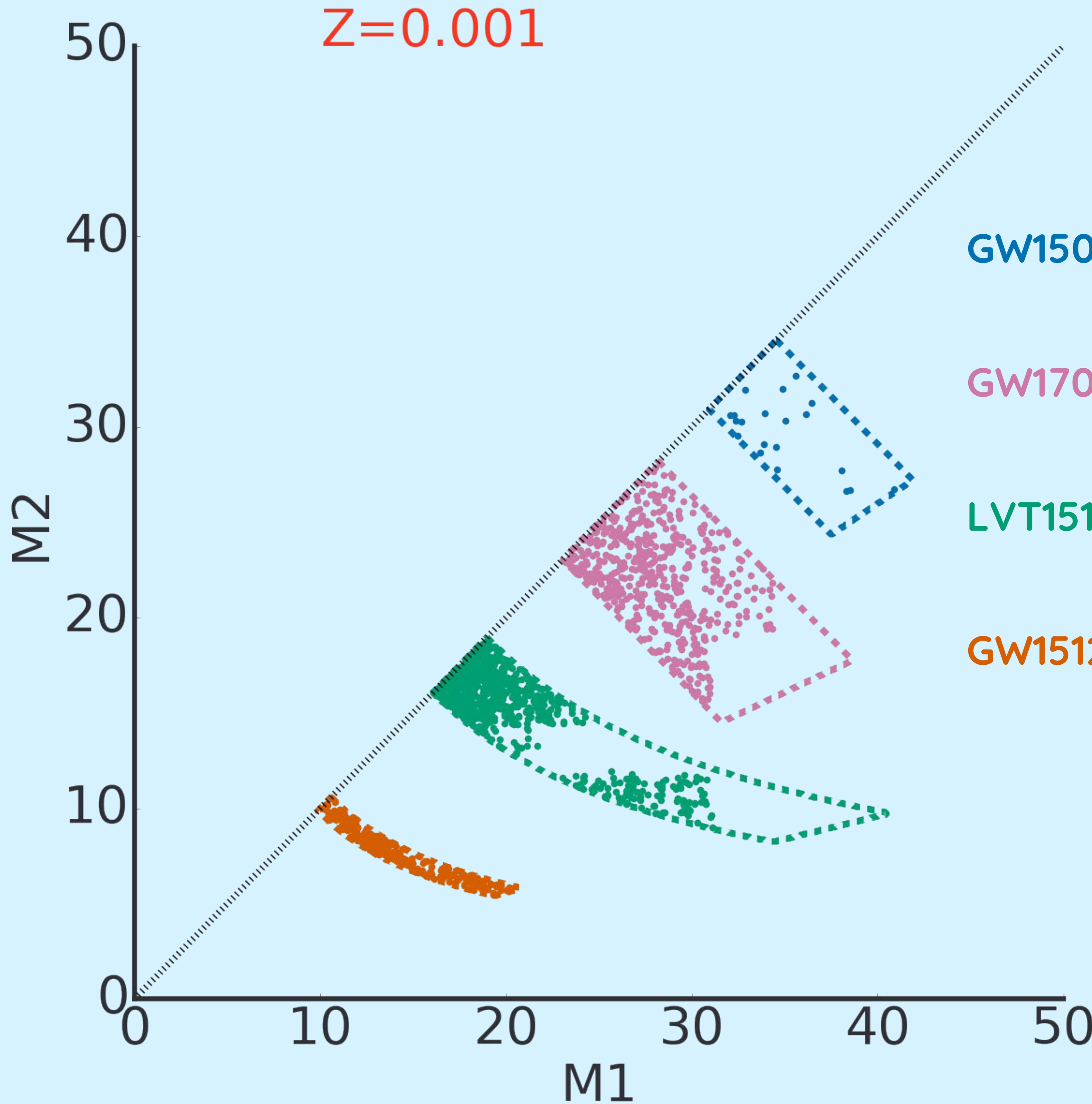

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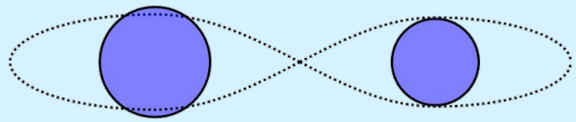
PB Abbott et al. 2016,
PB Abbott et al. 2017

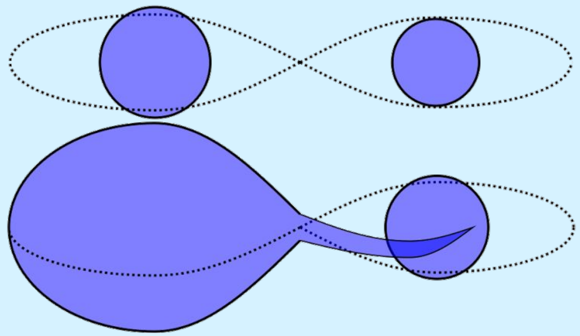
GW151226 $M_{tot} = 21.8^{+5.9}_{-1.7}$ $q>0.28$

GW151226

Time	M_1	ST_1		ST_2	M_2	a
[Myr]	[$M_\odot$]	–		–	[$M_\odot$]	[$R_\odot$]
0.0	63.6	MS		MS	27.8	729.93

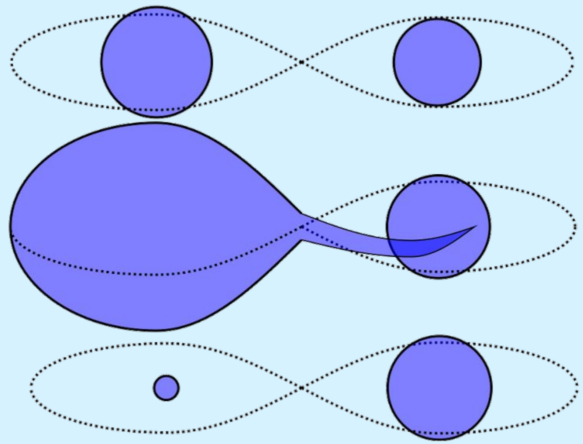
GW151226

Time	M_1	ST_1	ST_2	M_2	a
[Myr]	[$M_\odot$]	–	–	[$M_\odot$]	[$R_\odot$]
0.0	63.6	MS	MS	27.8	729.93
4.1	60.4	HG	MS	27.7	757.5



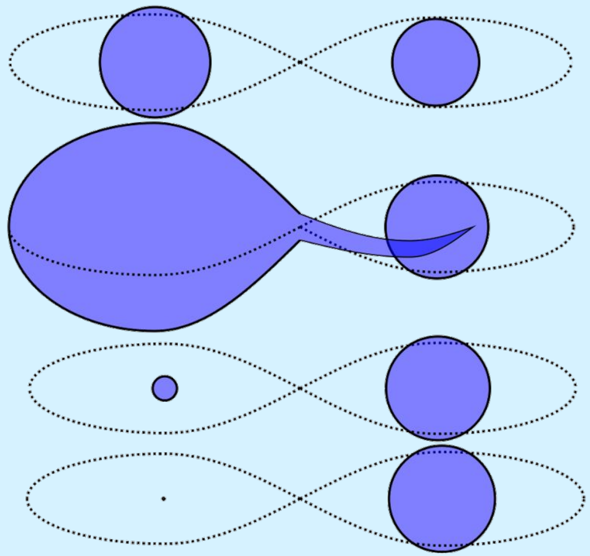
GW151226

Time [Myr]	M_1 [$M_\odot$]	ST_1 –	ST_2 –	M_2 [$M_\odot$]	a [$R_\odot$]
0.0	63.6	MS	MS	27.8	729.93
4.1	60.4	HG	MS	27.7	757.5
4.12	24.6	HeMS	MS	30.6	622.07



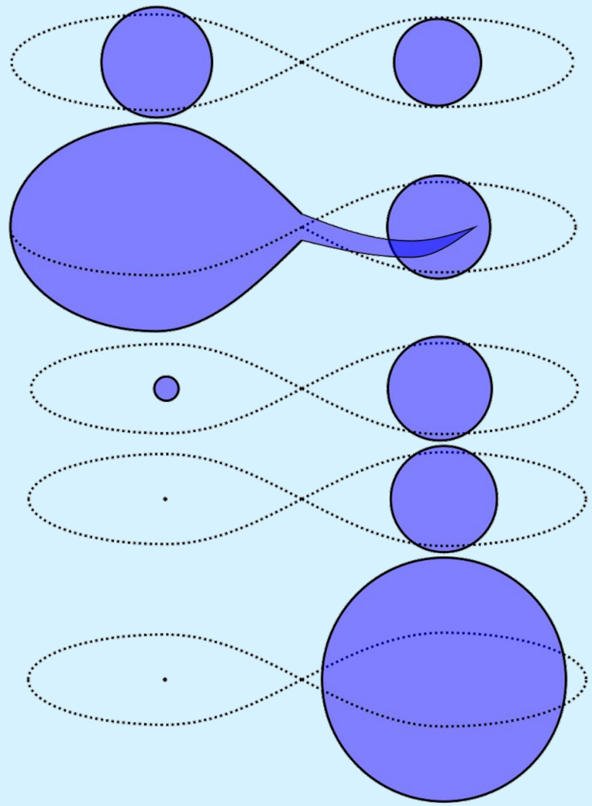
GW151226

Time	M_1	ST_1	ST_2	M_2	a
[Myr]	[$M_\odot$]	–	–	[$M_\odot$]	[$R_\odot$]
0.0	63.6	MS	MS	27.8	729.93
4.1	60.4	HG	MS	27.7	757.5
4.12	24.6	HeMS	MS	30.6	622.07
4.49	19.1	BH	MS	30.6	692.7



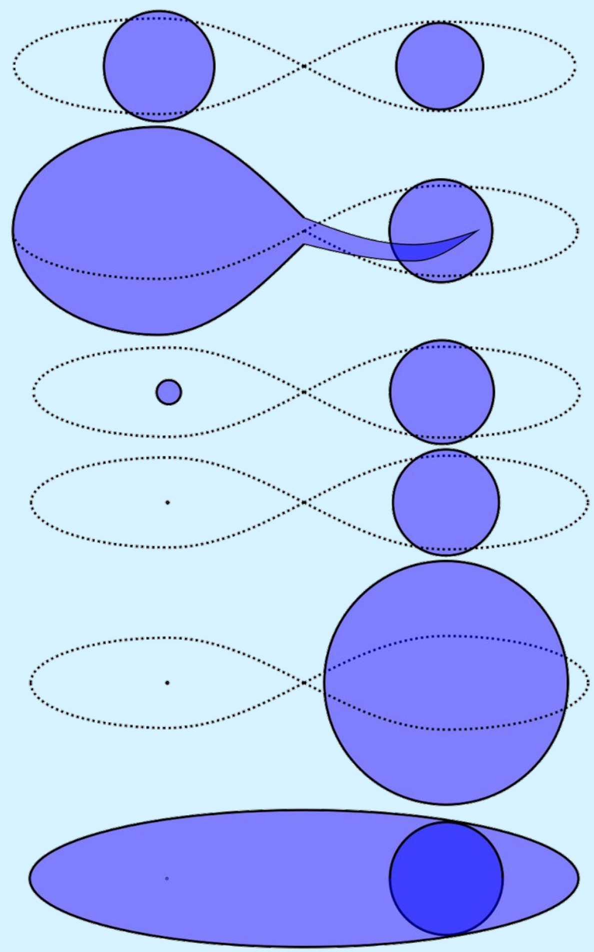
GW151226

Time [Myr]	M_1 [$M_\odot$]	ST_1 –	ST_2 –	M_2 [$M_\odot$]	a [$R_\odot$]
0.0	63.6	MS	MS	27.8	729.93
4.1	60.4	HG	MS	27.7	757.5
4.12	24.6	HeMS	MS	30.6	622.07
4.49	19.1	BH	MS	30.6	692.7
7.21	19.1	BH	CHeB	30.3	697.48



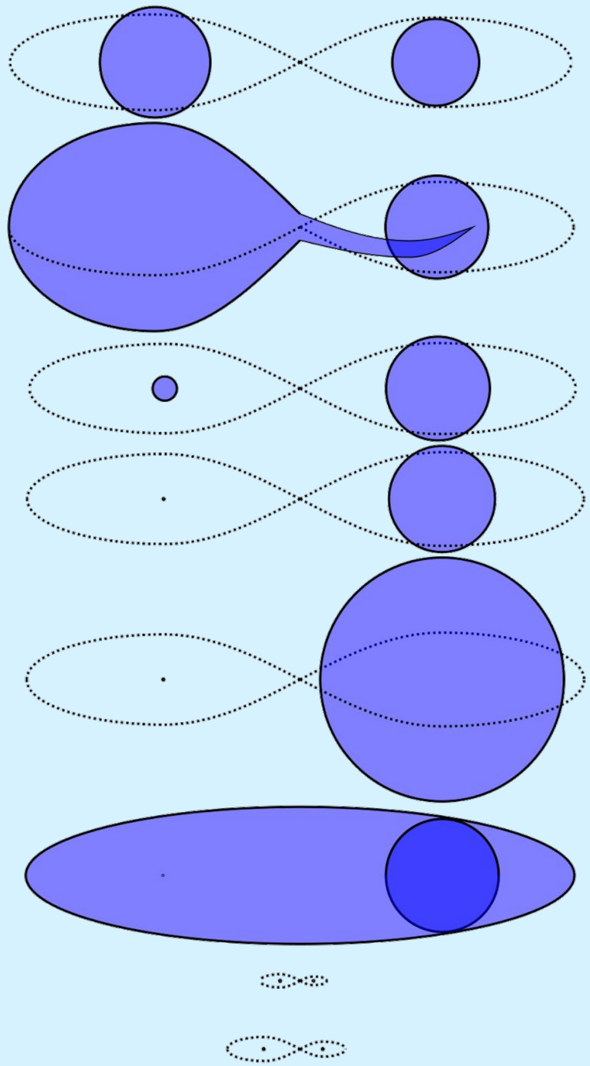
GW151226

Time [Myr]	M_1 $[M_\odot]$	ST_1 –	ST_2 –	M_2 $[M_\odot]$	a $[R_\odot]$
0.0	63.6	MS	MS	27.8	729.93
4.1	60.4	HG	MS	27.7	757.5
4.12	24.6	HeMS	MS	30.6	622.07
4.49	19.1	BH	MS	30.6	692.7
7.21	19.1	BH	CHeB	30.3	697.48
7.42	19.1	BH	CHeB	29.7	706.33



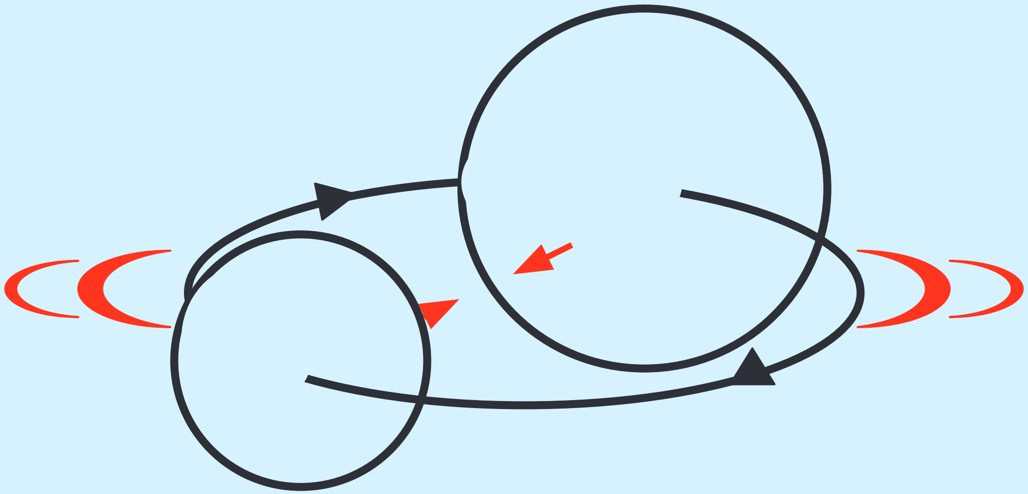
GW151226

Time [Myr]	M_1 [$M_\odot$]	ST_1 –	ST_2 –	M_2 [$M_\odot$]	a [$R_\odot$]
0.0	63.6	MS	MS	27.8	729.93
4.1	60.4	HG	MS	27.7	757.5
4.12	24.6	HeMS	MS	30.6	622.07
4.49	19.1	BH	MS	30.6	692.7
7.21	19.1	BH	CHeB	30.3	697.48
7.42	19.1	BH	CHeB	29.7	706.33
7.42	19.1	BH	HeMS	10.6	5.18
7.88	19.1	BH	BH	5.7	8.82



Ligo estimated rate Black Hole Binaries = 9-240 $Gpc^{-3}\ yr^{-1}$

Abbott et al. 2016 (O1 Results)

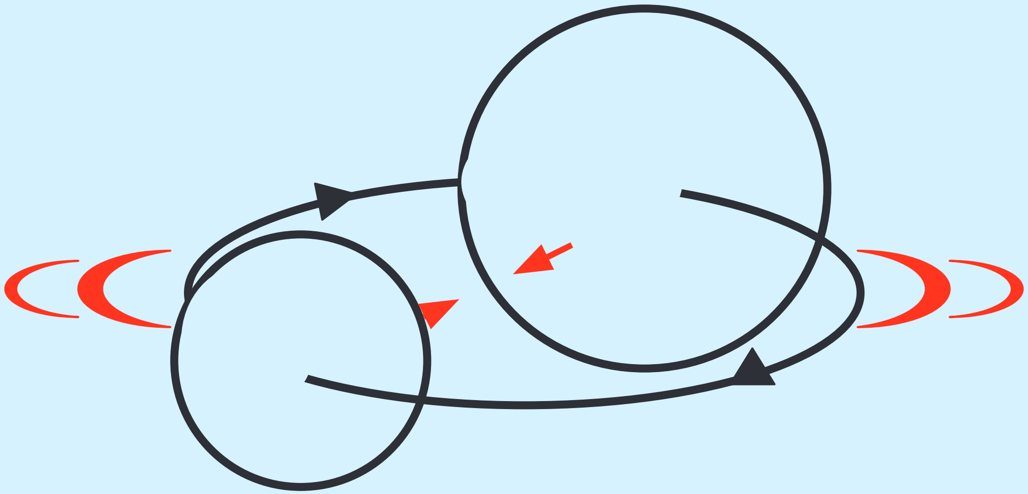


From Z=0.002 run

COMPAS estimate ~300 per $Gpc^{-3}\ yr^{-1}$

Ligo estimated rate Black Hole Binaries = 9-240 Gpc^{-3} yr^{-1}

Abbott et al. 2016 (O1 Results)



COMPAS estimate ~70 per Gpc^{-3} yr^{-1}

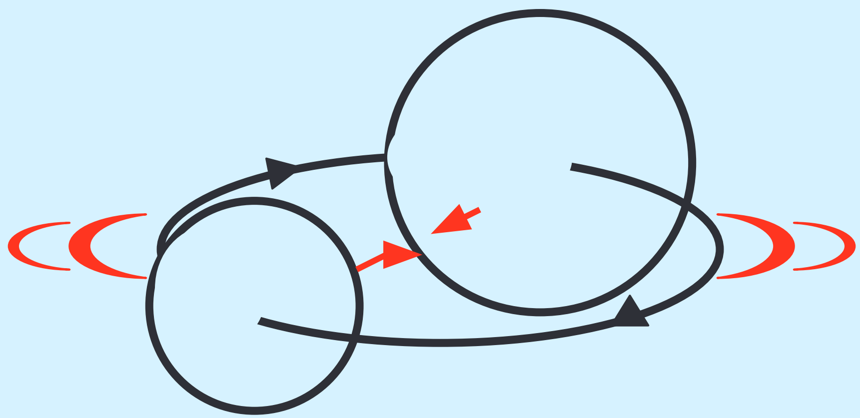
Neijssel et al. in prep

COMPAS

www.sr.bham.ac.uk/compas

Yes binaries can create the LIGO events

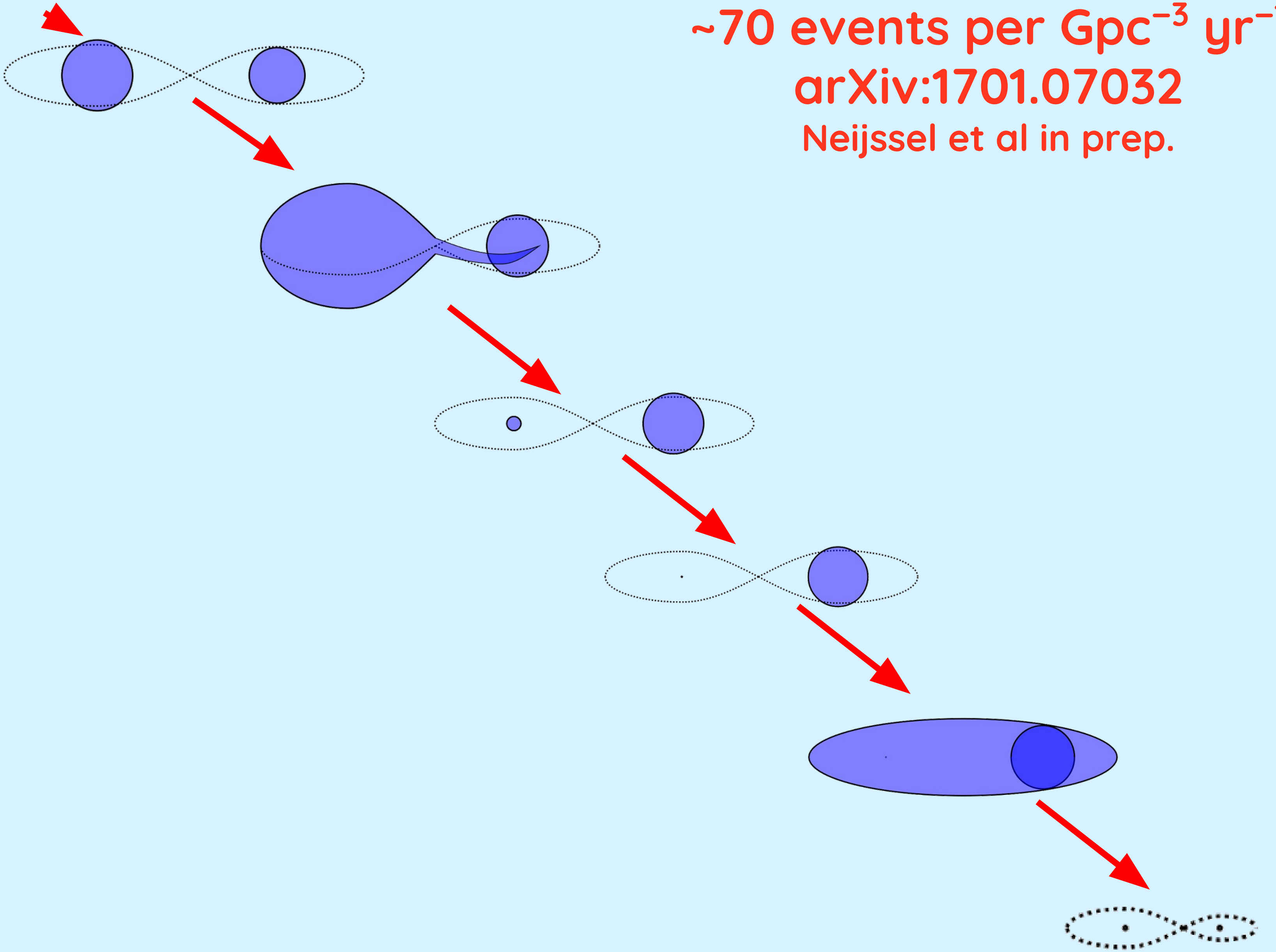
arXiv:1701.07032



Our current prediction ~70 per Gpc^{-3} yr^{-1} at redshift z=0.0

Neijssel et al in prep.

COMPAS estimates
~70 events per Gpc^{-3} yr^{-1}
arXiv:1701.07032
Neijssel et al in prep.



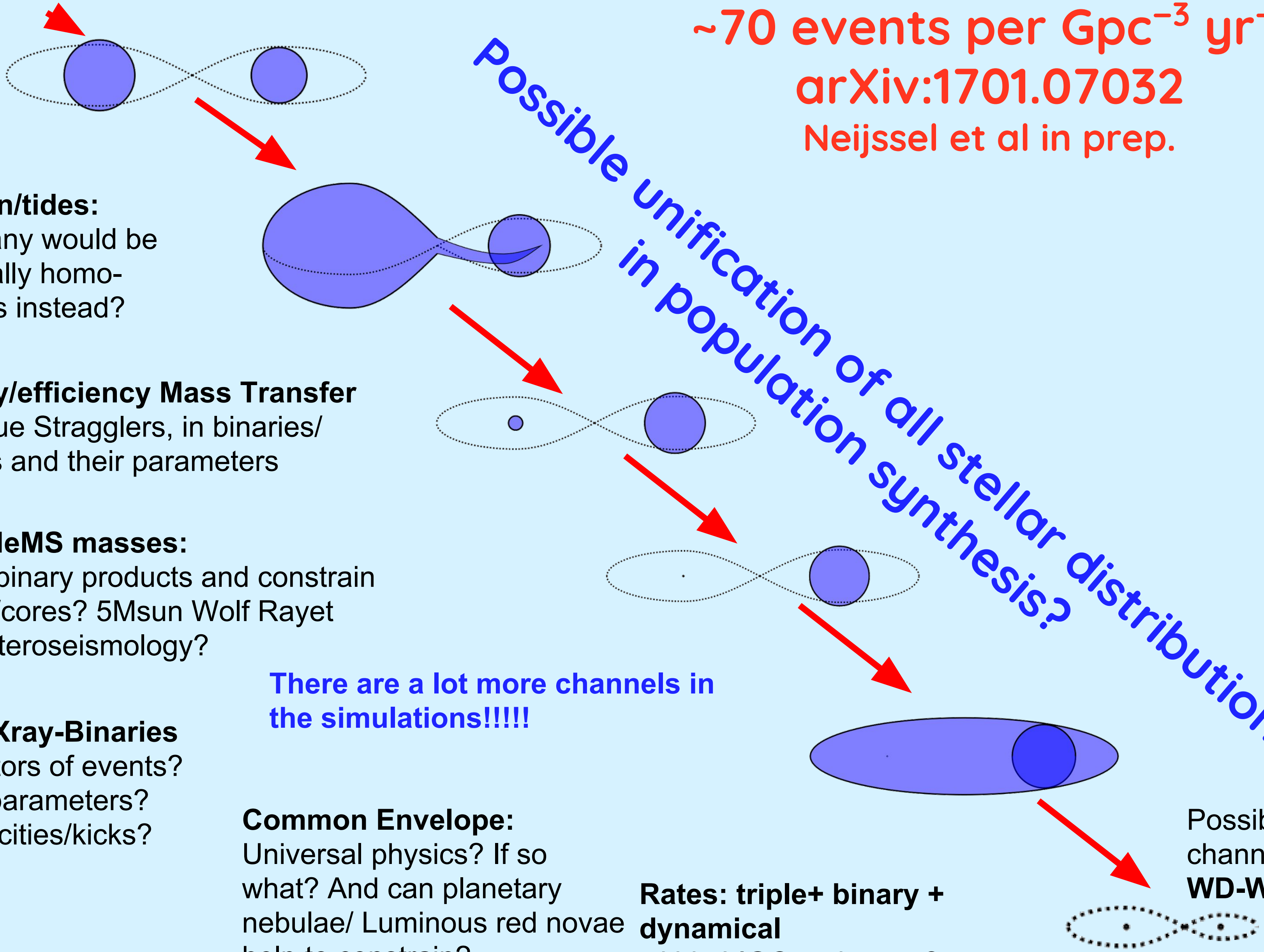
Rate estimates/normalization depends on metallicities, multiplicity, and IMF of all stars.

COMPAS estimates

~70 events per Gpc^{-3} yr^{-1}

arXiv:1701.07032

Neijssel et al in prep.



Possible unification of all stellar distributions in population synthesis?

Rotation/tides:
How many would be chemically homo-geneous instead?

Stability/efficiency Mass Transfer
Nr of Blue Stragglers, in binaries/ mergers and their parameters

Cores/HeMS masses:
Identify binary products and constrain masses/cores? 5Msun Wolf Rayet stars/Asteroseismology?

There are a lot more channels in the simulations!!!!!

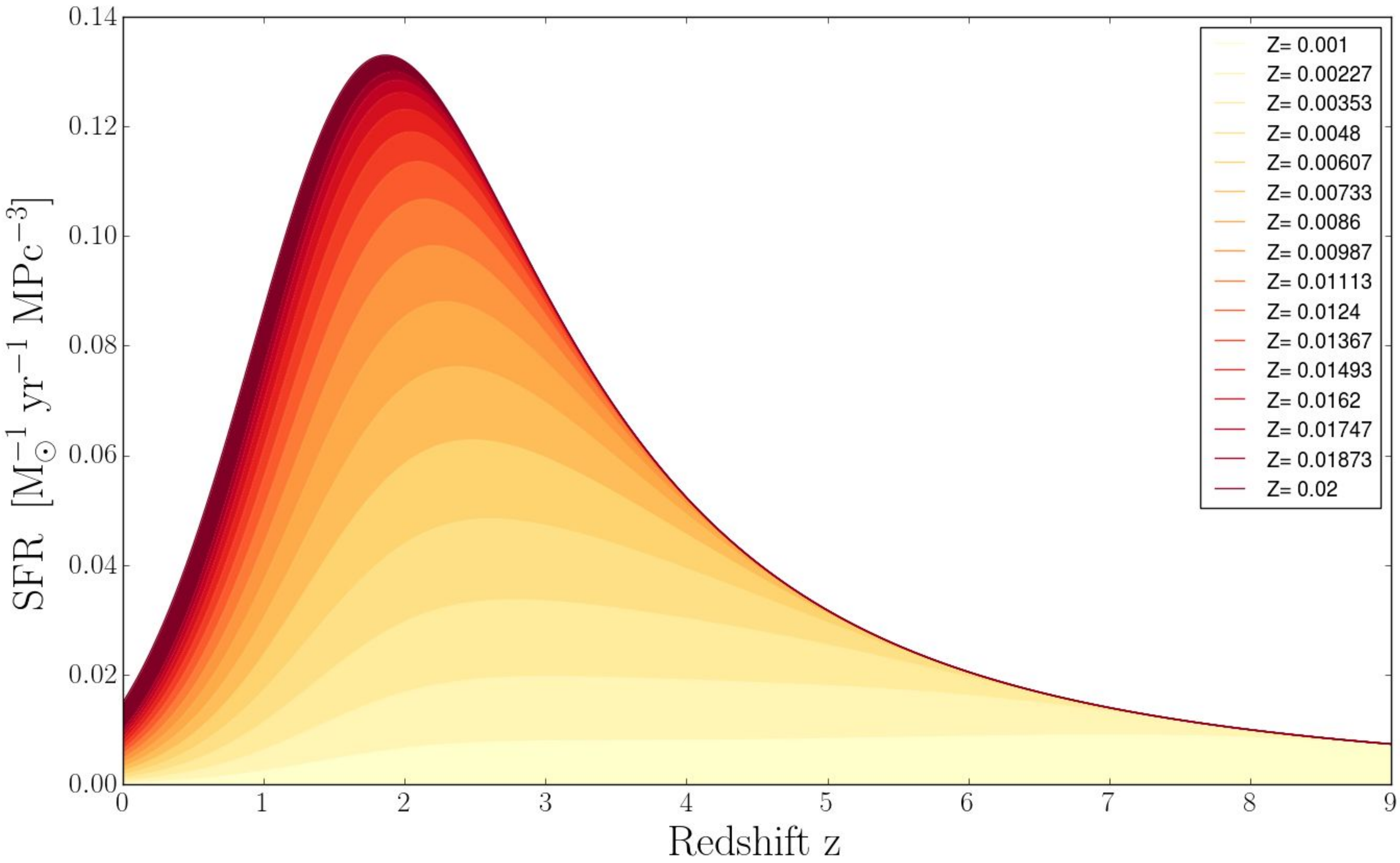
Be/HM Xray-Binaries
Progenitors of events?
Orbital parameters?
Eccentricities/kicks?

Common Envelope:
Universal physics? If so what? And can planetary nebulae/ Luminous red novae help to constrain?

Rates: triple+ binary + dynamical
within LIGO estimates?

Possible channel for **WD-WD?**

SFR -> Madau & Dickinson 2014 metallicty fraction -> Norman & Langer 2005



HMXB, Giant Stars
Luminous red novae

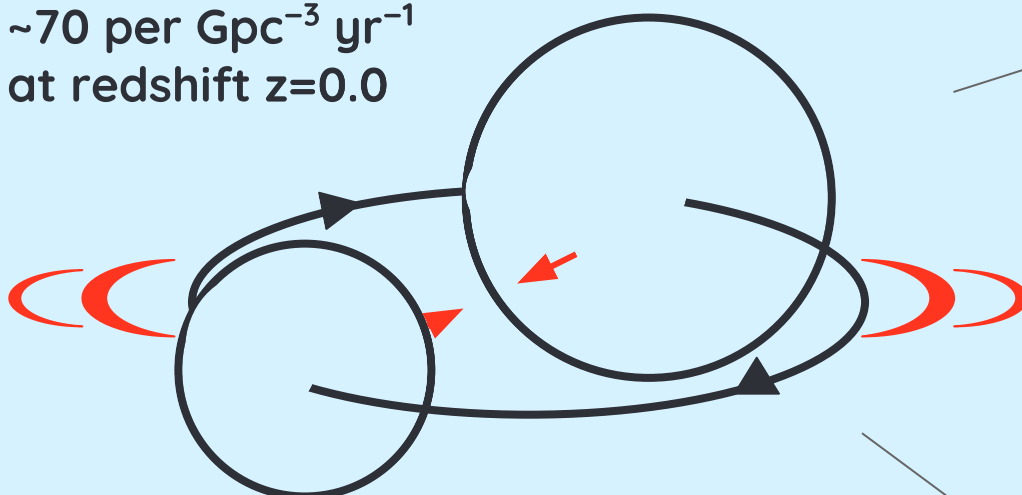
Single star
uncertainties

Common envelope prescriptions,
mass transfer stabilities.

Parameter
correlations

~70 per $Gpc^{-3}\ yr^{-1}$
at redshift z=0.0

Methods of sampling
distributions



Formation
Channels

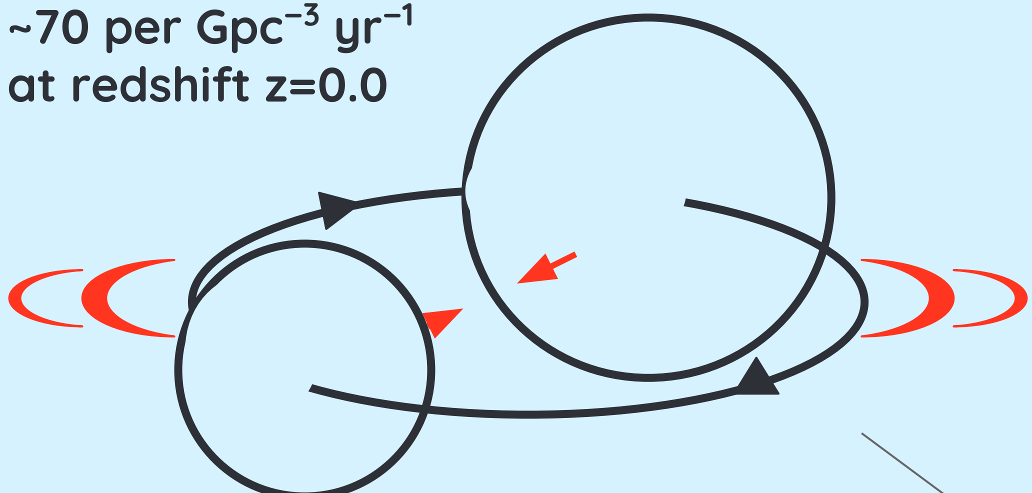
Integrating rates over
metallicities, redshifts,
and SFR

Bayesian Inference on
model assumptions from
LIGO O2 results.

HMXB, Giant Stars
Luminous red novae

Common envelope prescriptions,
mass transfer stabilities.

~70 per Gpc^{-3} yr^{-1}
at redshift z=0.0



Integrating rates over
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Bayesian Inference on
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