UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département d'astronomie

Black-Holes' Spin

Predicting the effective inspiral spin parameter distribution of binary black-hole mergers detected by current and future gravitational waves observatories

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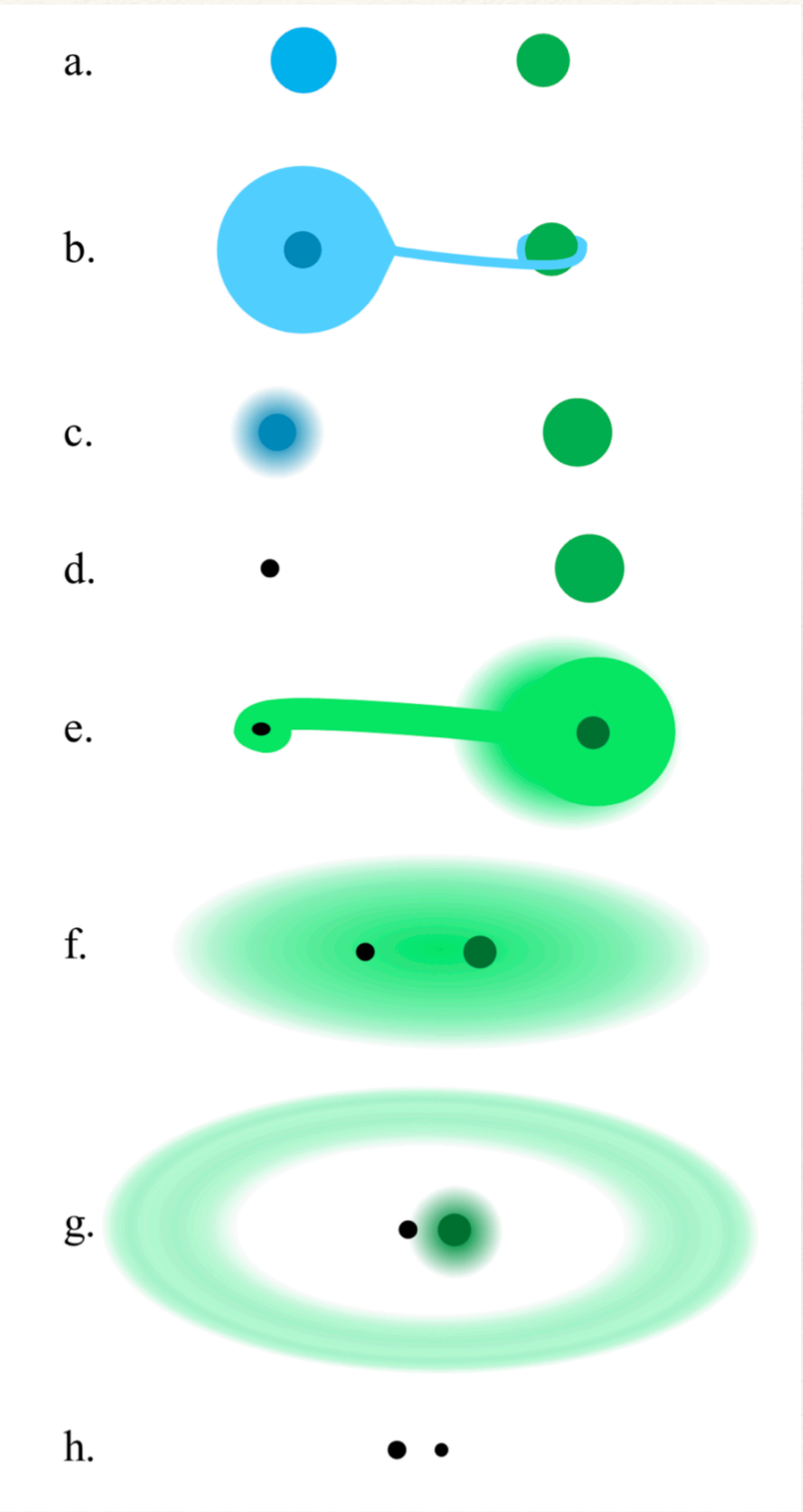
Collaborators: Tassos Fragos, Ying Qin, Ilya Mandel, Coenraad Neijssel, Sebastian Gaebel, Aldo Batta, Chase Kimball

1st LISA Astrophysics Working Group Workshop

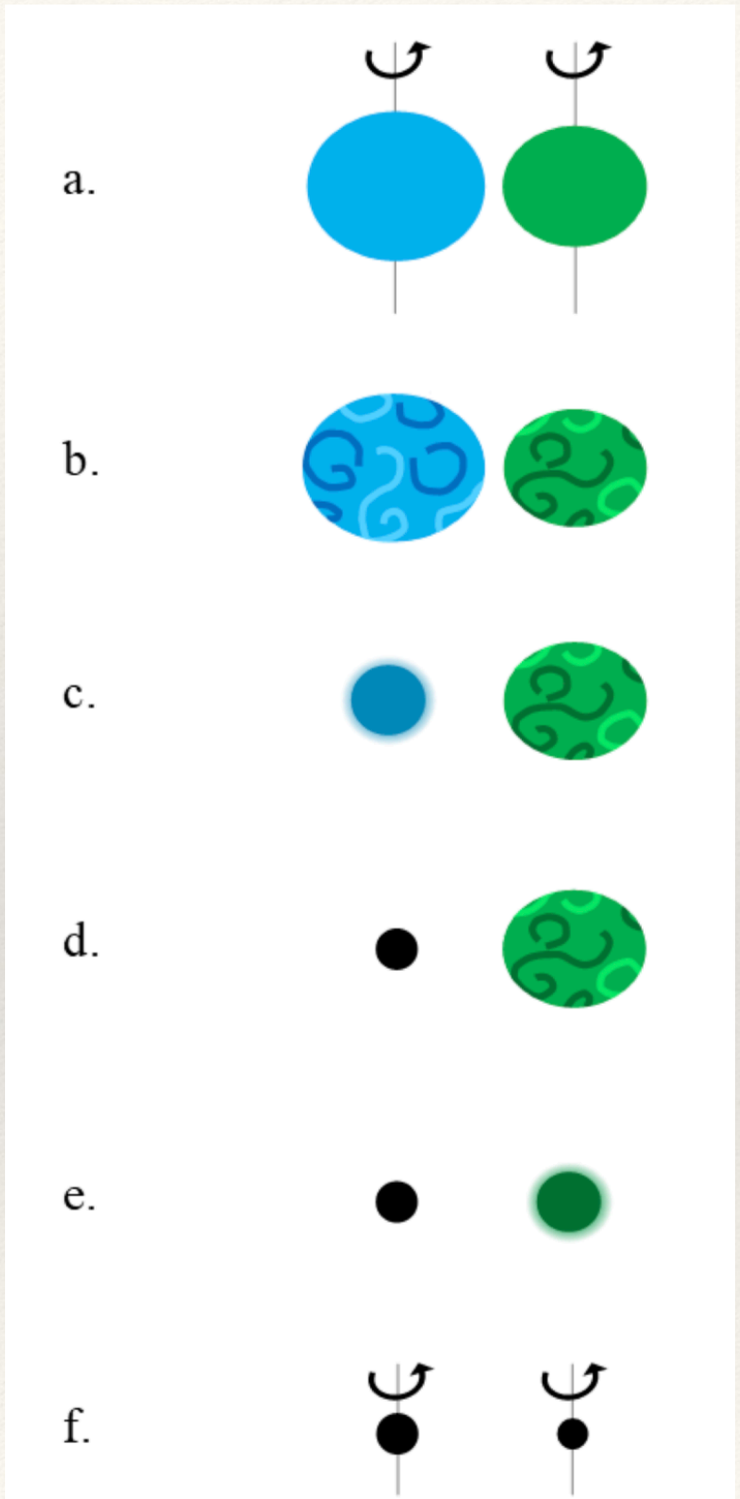
Institut d'Astrophysique de Paris, 13th December 2018

Formation scenarios

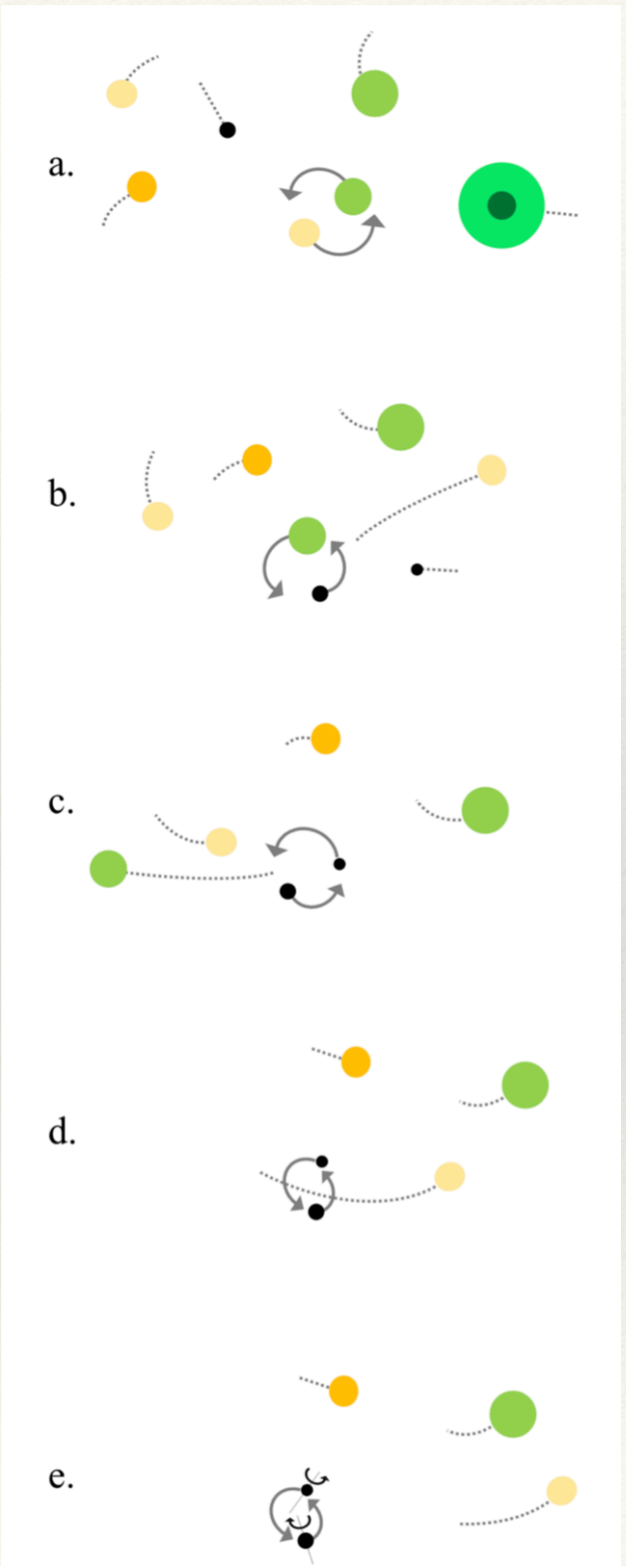
Common envelope channel



Chemical homogeneous evolution channel

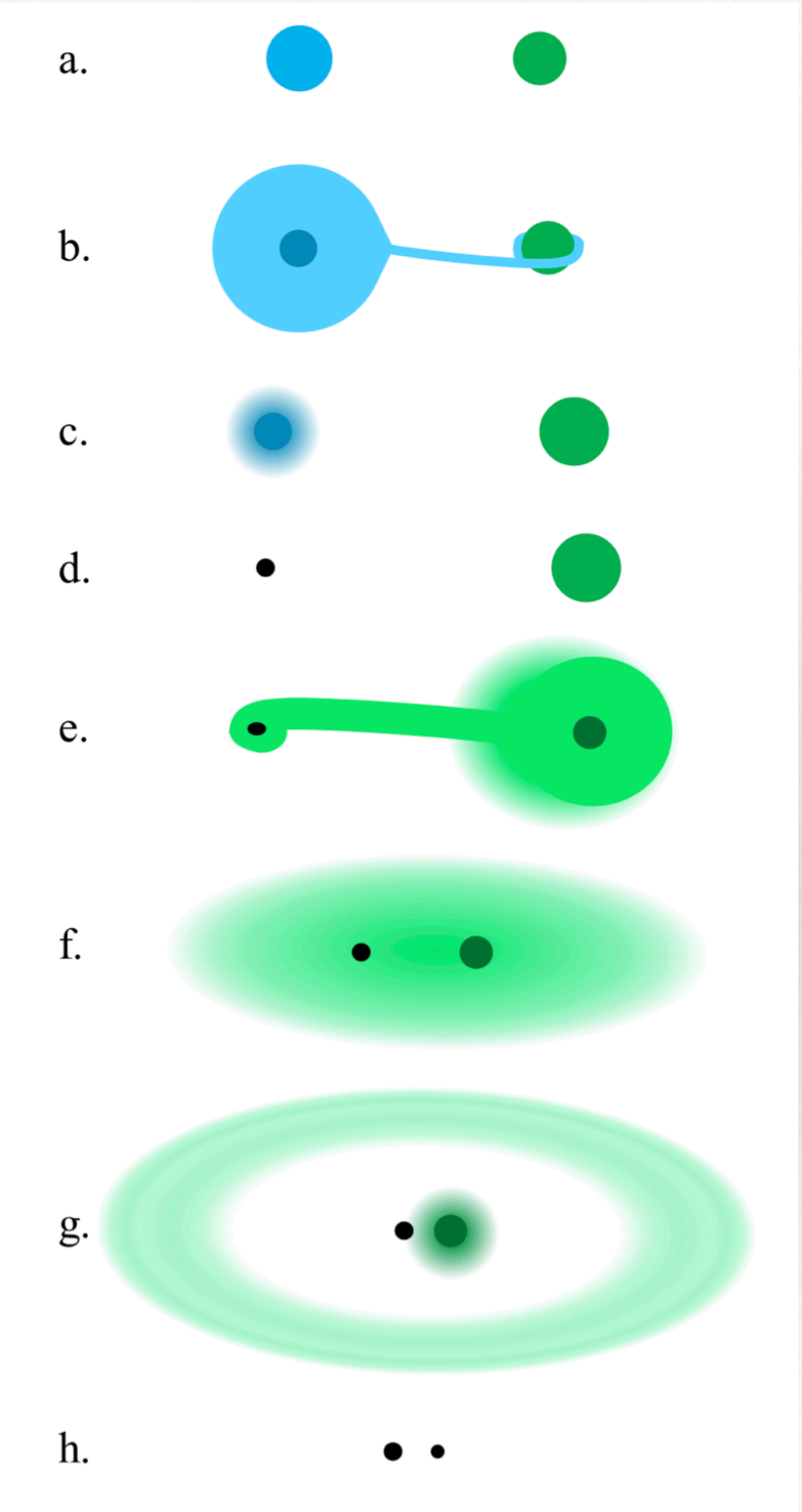


Dynamical channel

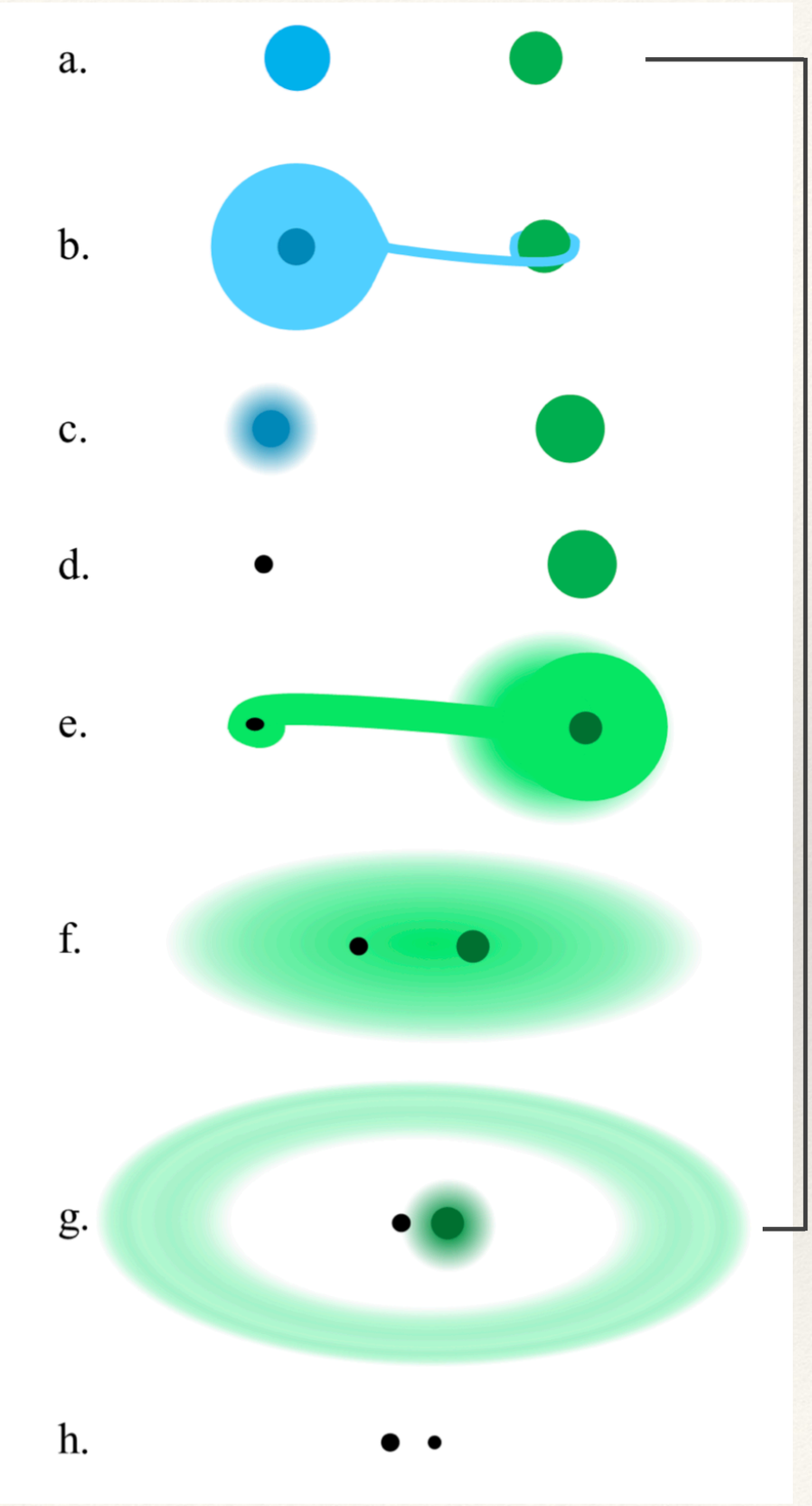


Pictures: Mandel & Farmer (2018)

Common envelope channel



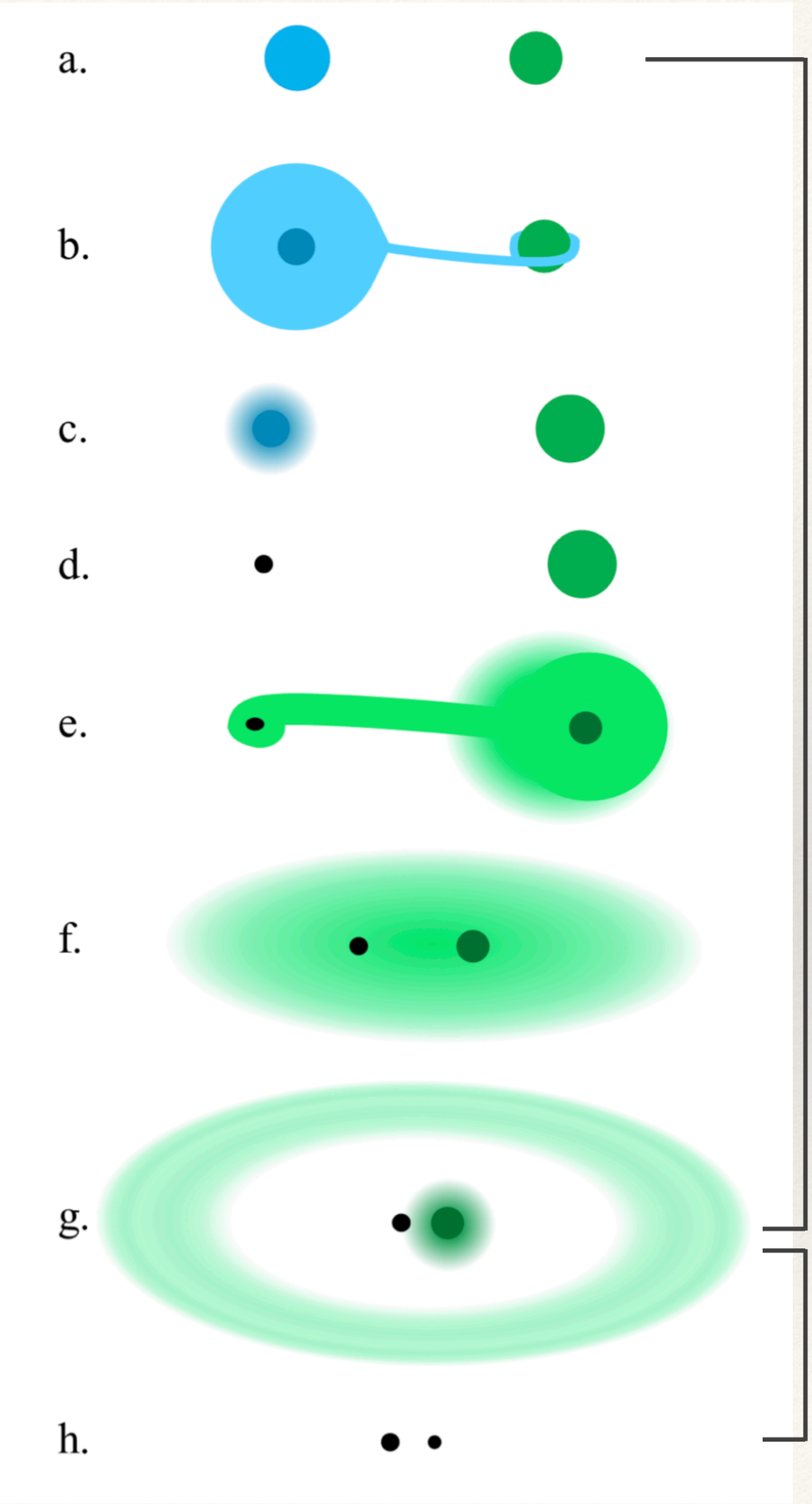
Common envelope channel



COMPAS

Stevenson et al. (2017, 2015), Barrett et al (2017), Mandel et al. (2016)

Common envelope channel



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MESA

Paxton et al. (2009, 2013, 2015, 2017)

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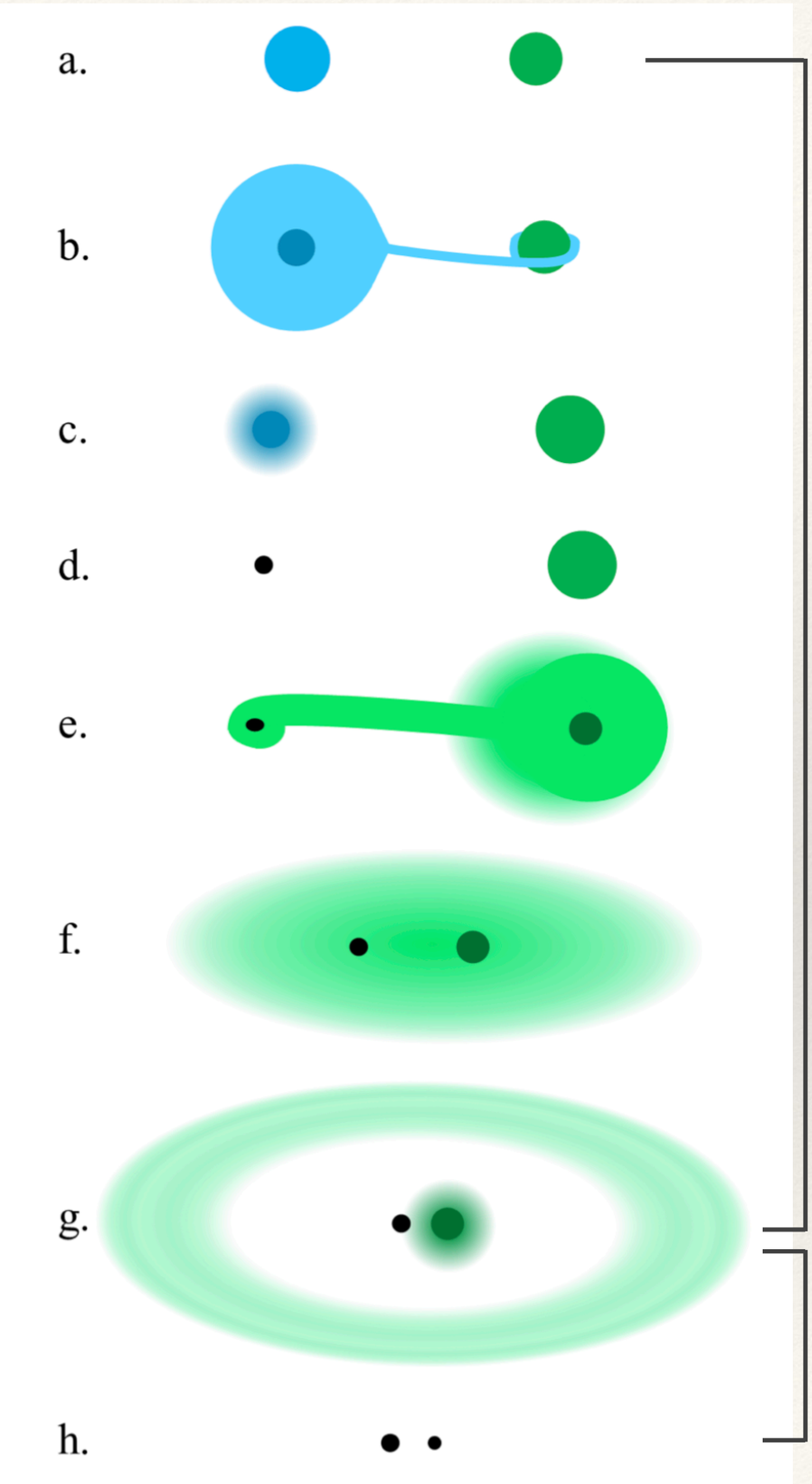

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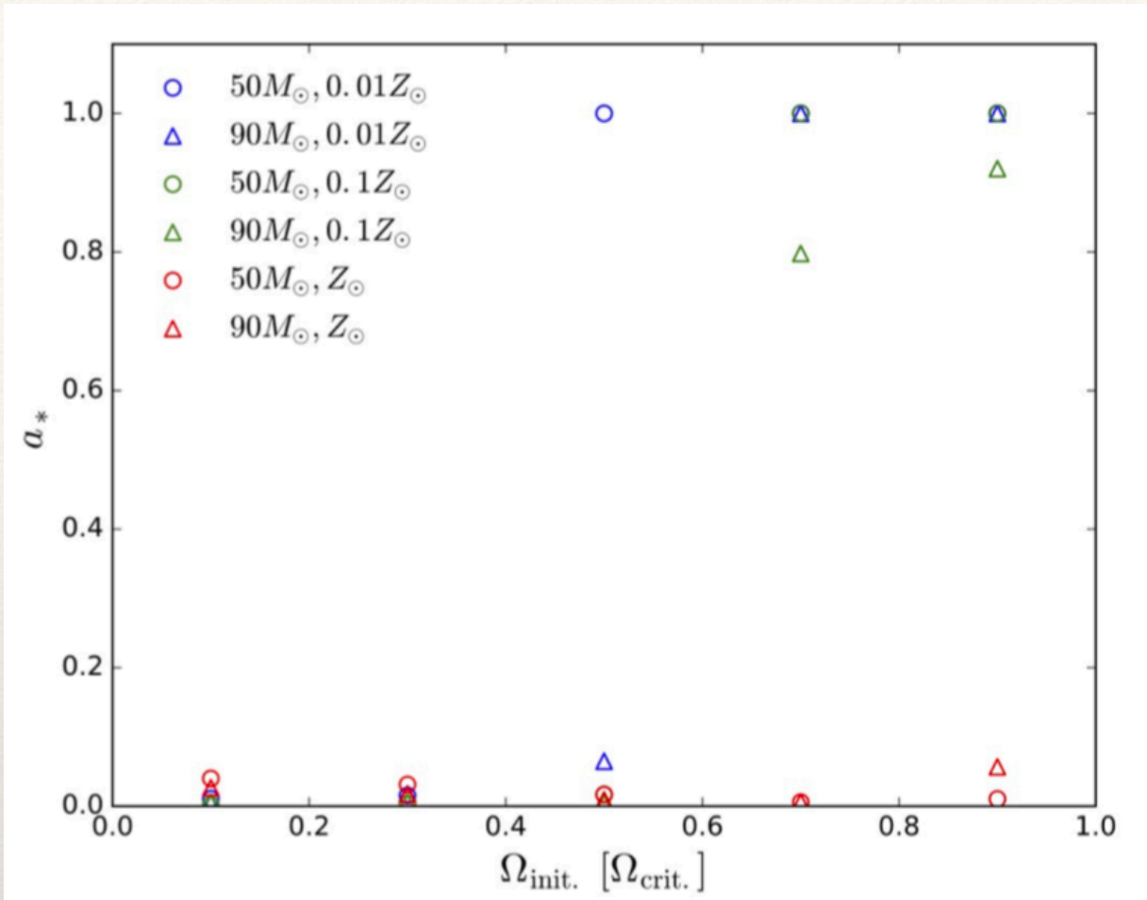


Qin et al. (2018)

Assumptions:

- **1st BH point-like**, i.e. not spinning
- He-star after CE not spinning

Physics of the model

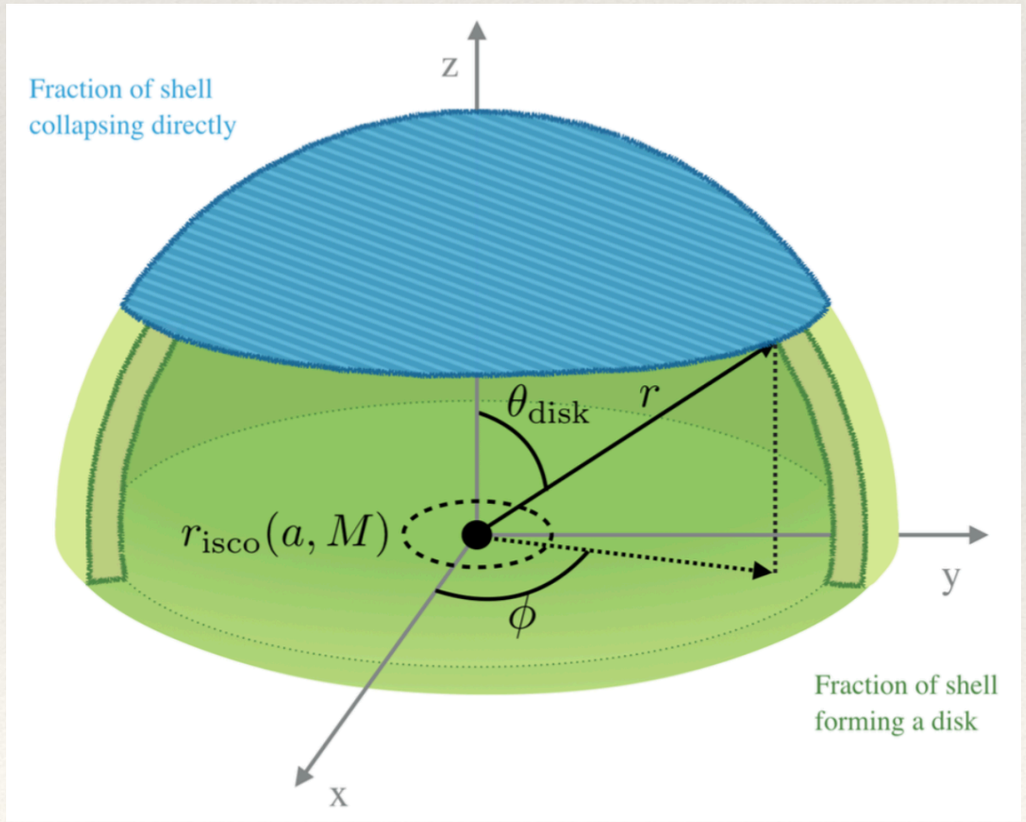
Winds: Hamann & Koesterke (1998), Vink & de Koter (2005)

Tides: Zahn (1975, 1979), Hut (1981) $\quad E_2 = 10^{-0.93}\left(\frac{R_{conv}}{R}\right)^{6.7}$ Qin et al. (2018)

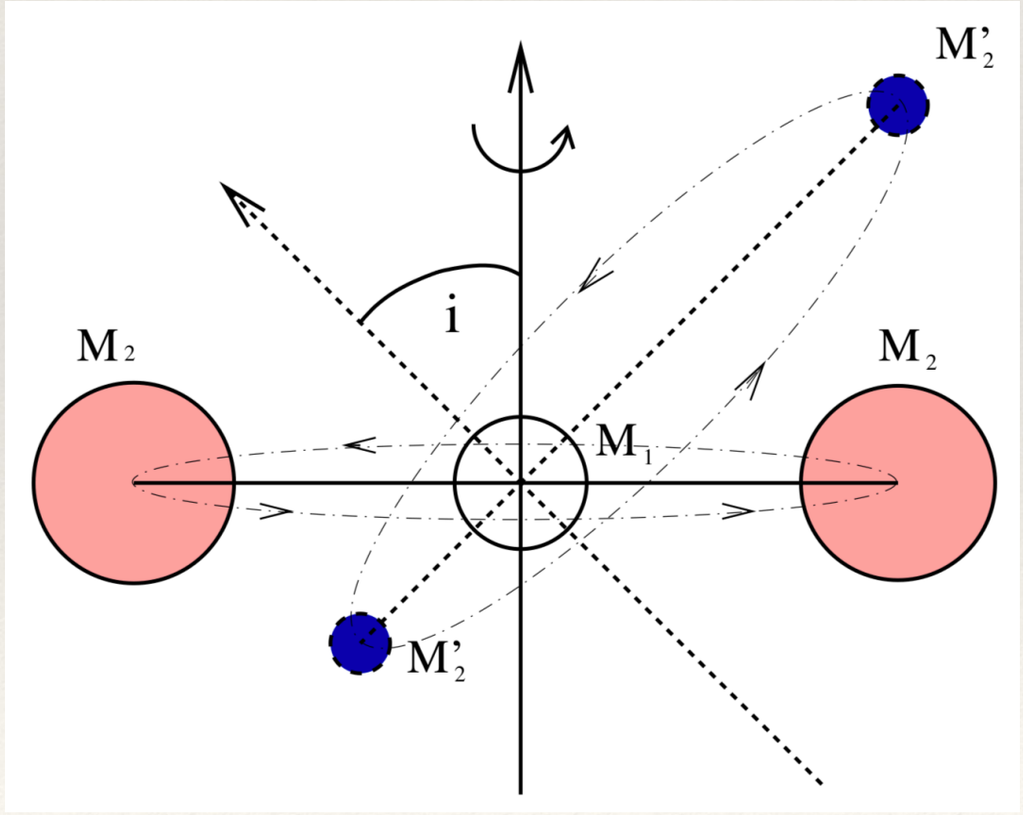
Supernova: Fryer et al. (2011) $\Rightarrow$ Rapid & Delayed mechanism

Star collapse: Bardeen (1970) & Thorne (1974)

Kiks: Kalogera (1996), Hobbs et al. (2005)



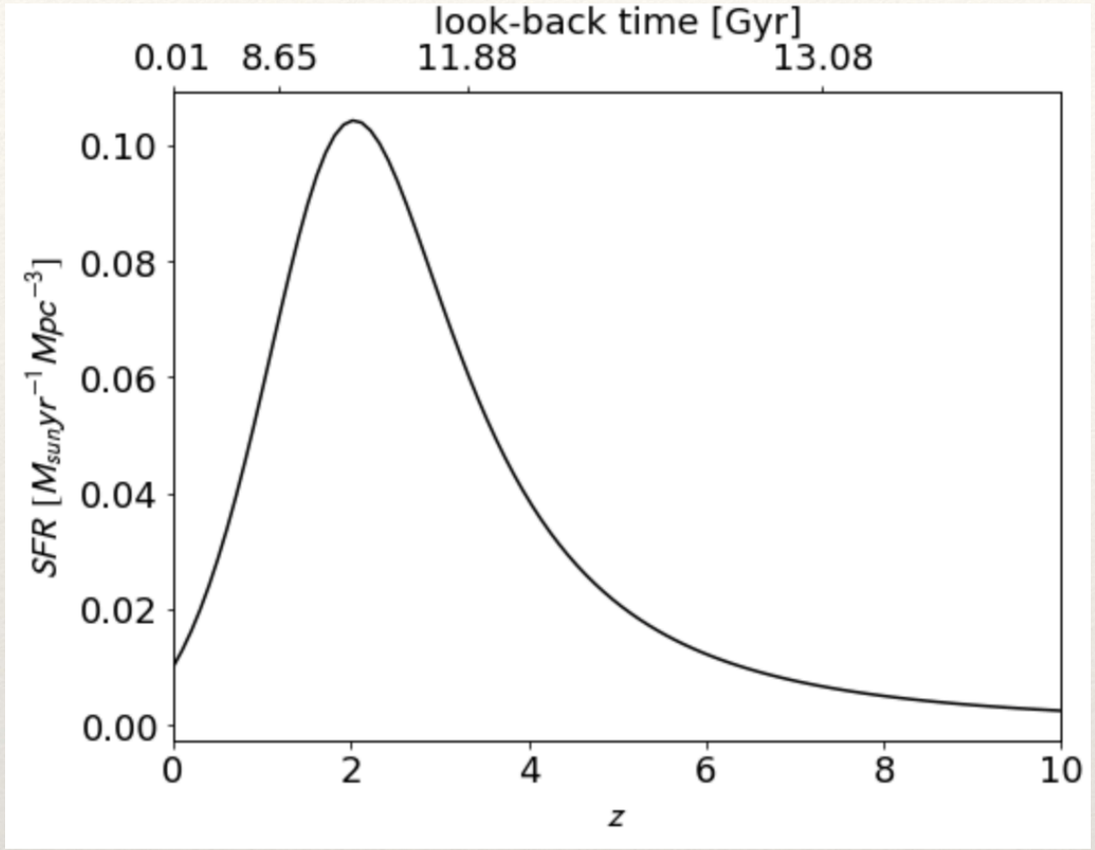
Picture: Batta (2018)



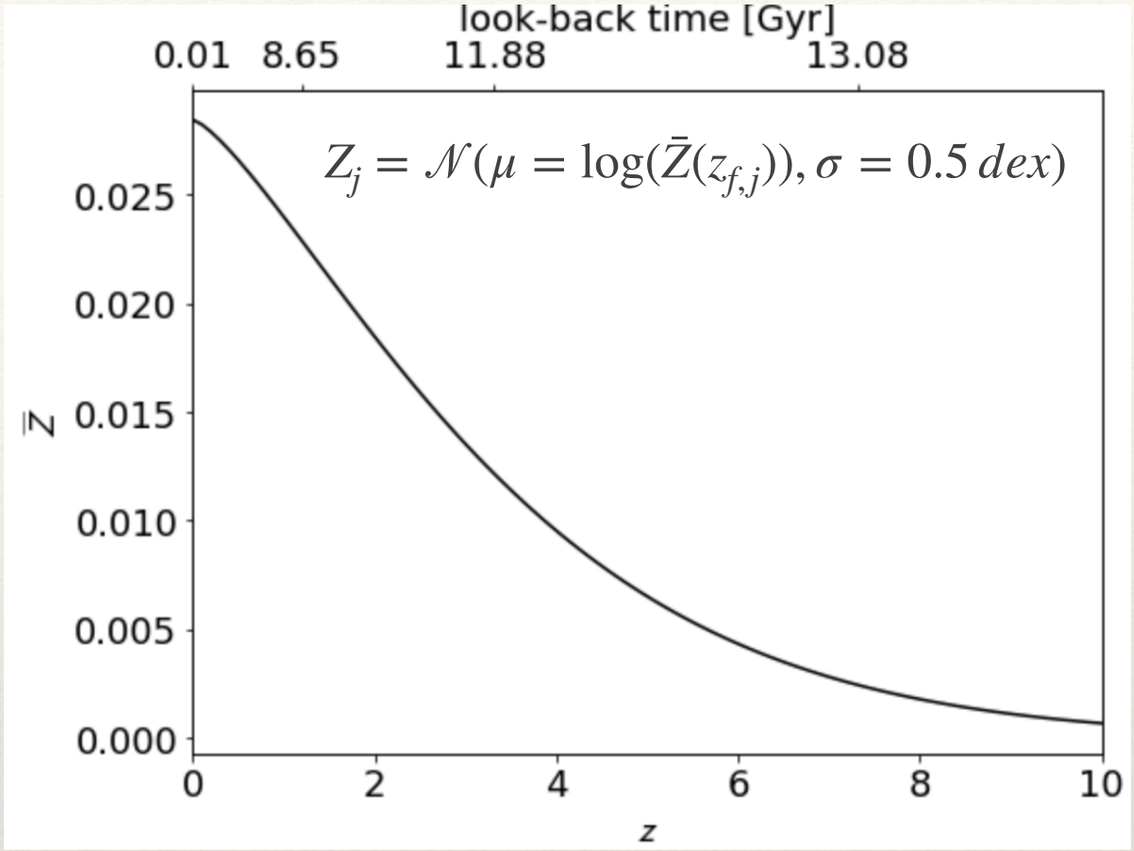
Picture: Martin et al. (2009)

Cosmology: SFR and Metallicity

Star formation rate: Madau & Dickinson (2014)



Mean metallicity: Madau & Fragos (2017)



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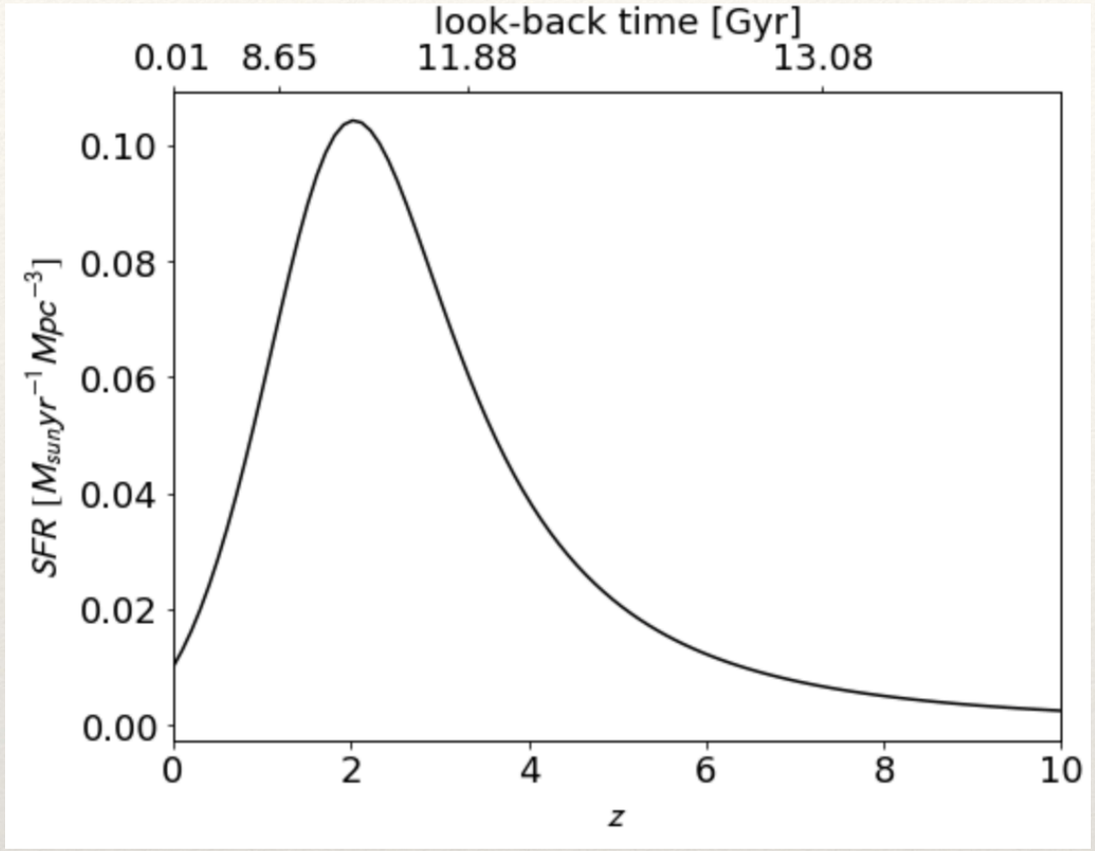

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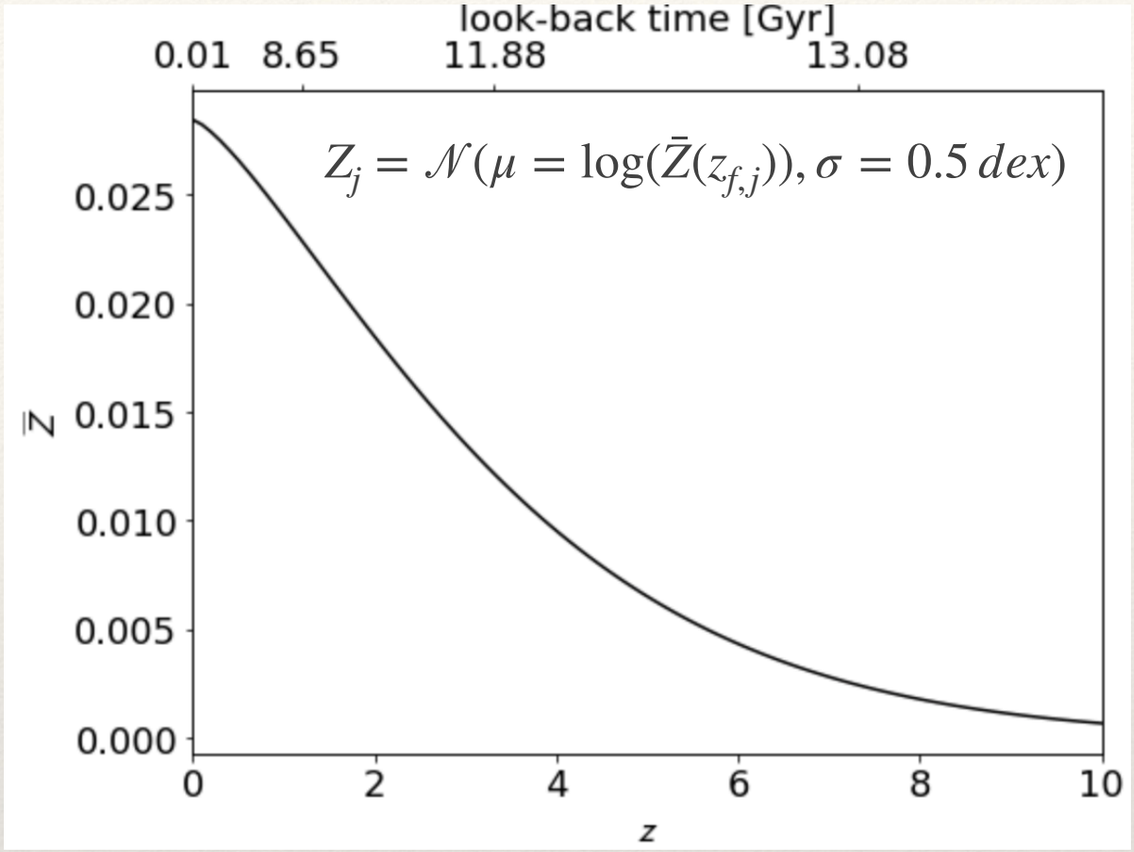


Detection rate: Belczynski et al. (2016), Dominik et al. (2015)

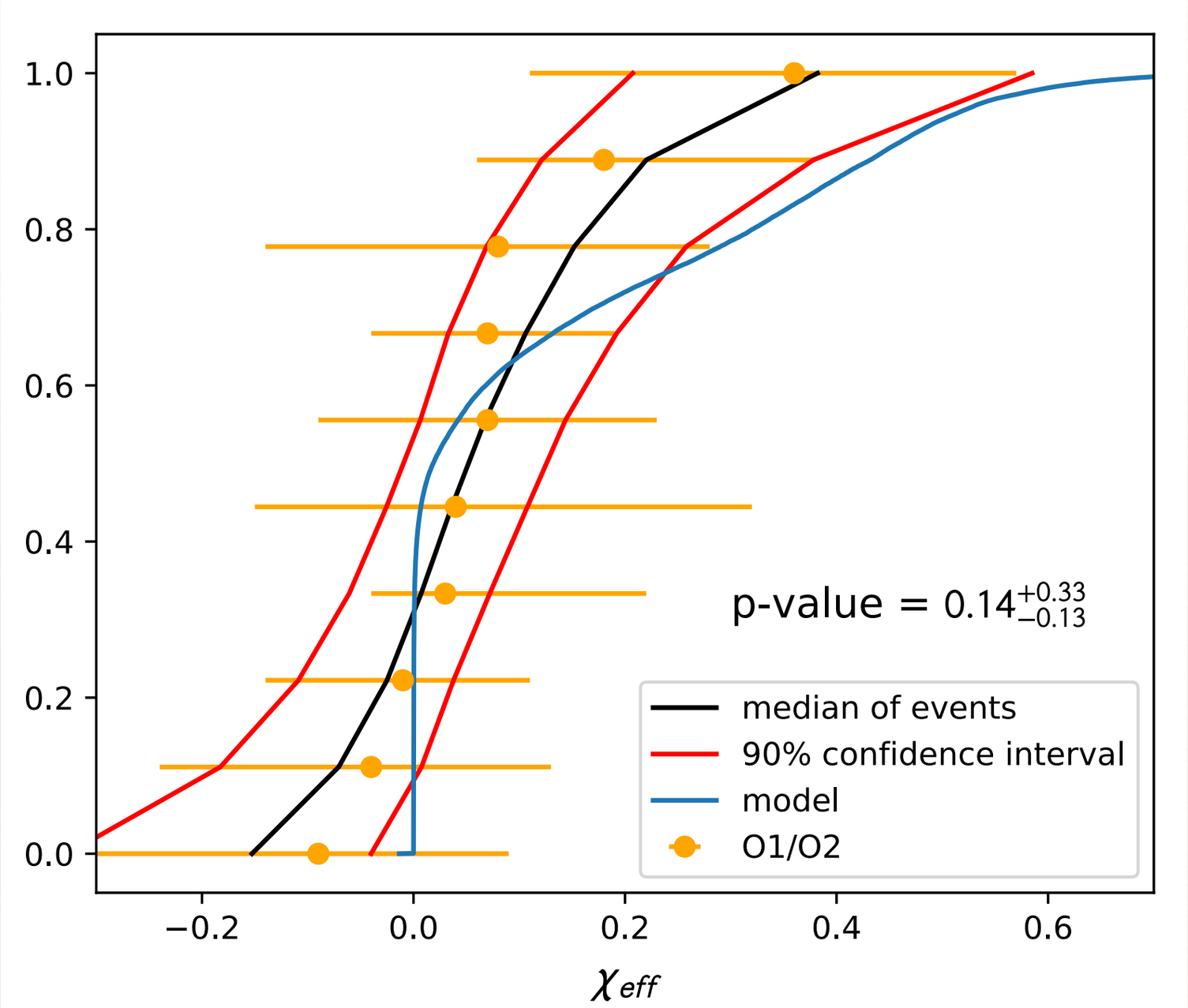
$$R_{det} = \iiint R(z_f, z_m, m_1, m_2) p_{det}(z_m, m_1, m_2) \frac{dt_m}{dt_{det}} \frac{dV_c}{dz_m} \frac{dz_m}{dt_m} dm_1 dm_2 dt_m =$$

$$= \sum_{\Delta t_i} \sum_{j} \frac{fSFR(z_{f,j})}{M_{sim,\Delta Z_j}} f_{corr}\, 4\pi c\, D_c^2(z_{m,j})\, p_{det}(z_{m,j}, m_{1,j}, m_{2,j})\, \Delta t_i$$

where $\quad fSFR(z_{f,j}) = SFR(z_{f,j}) \left[CDF\left(Z_j + \frac{\Delta Z_j}{2} \right) - CDF\left(Z_j - \frac{\Delta Z_j}{2} \right) \right]$

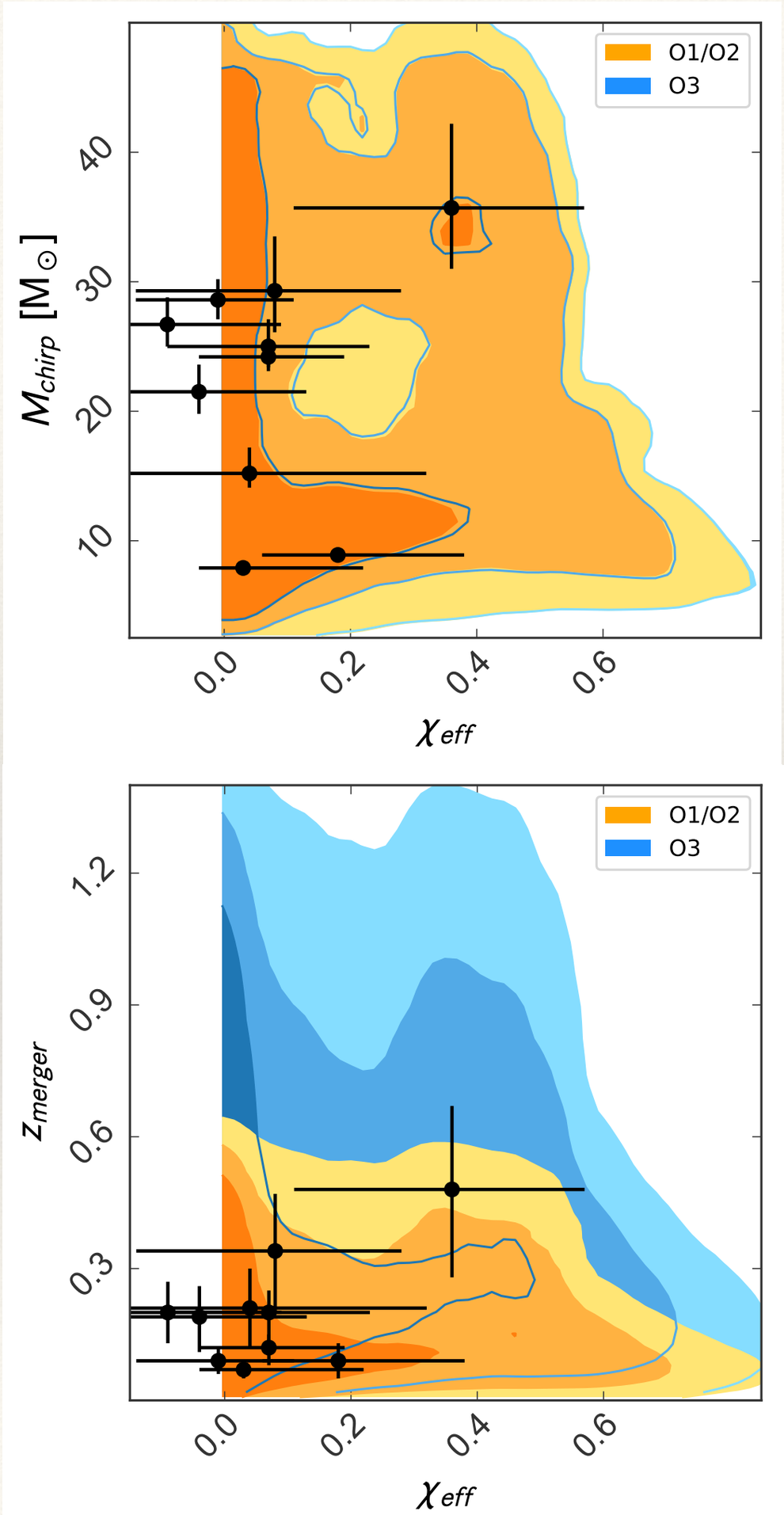
Model predictions

Cumulative distributions of χ_{eff} vs. data



$$\chi_{eff} = \frac{m_1 \mathbf{a}_1 + m_2 \mathbf{a}_2}{m_1 + m_2} \hat{\mathbf{L}} \qquad \text{where} \quad a_i = \frac{cJ_i}{GM_i^2} \quad \text{is the dimensionless spin}$$

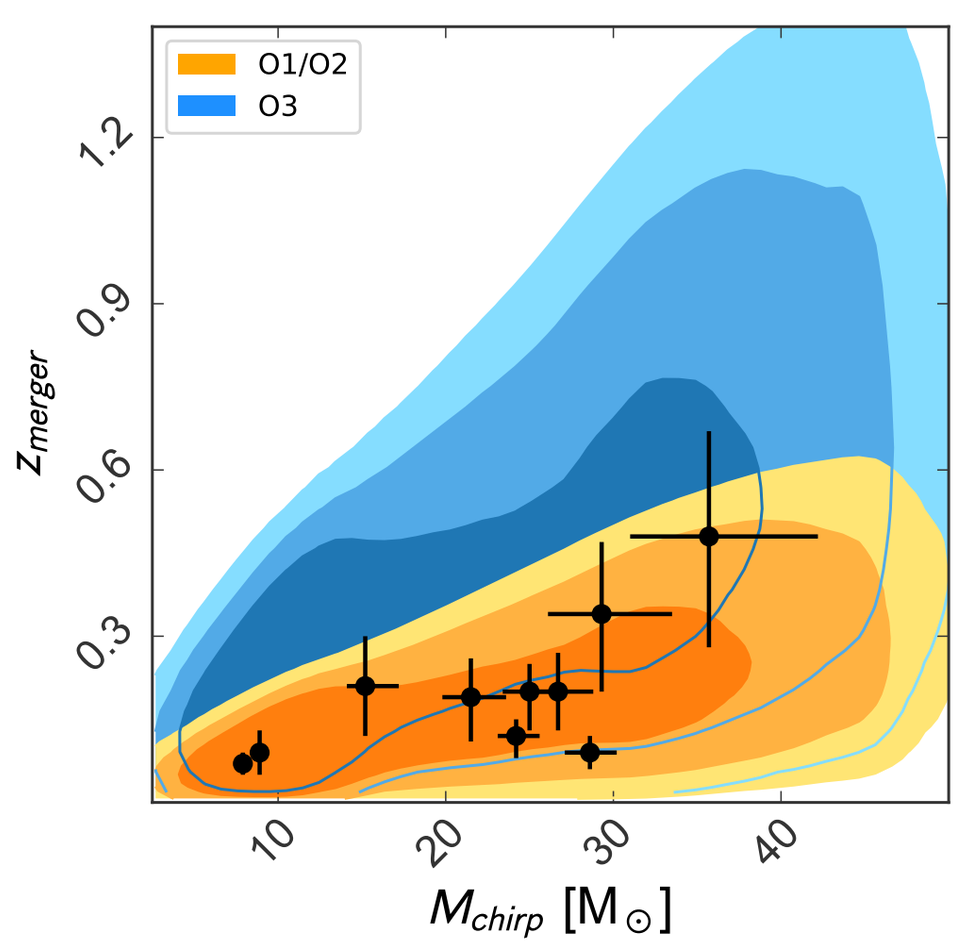
in out model $a_1 = 0$



$$M_{chirp} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}} \qquad \chi_{eff} = \frac{m_1 \mathbf{a}_1 + m_2 \mathbf{a}_2}{m_1 + m_2} \hat{\mathbf{L}}$$

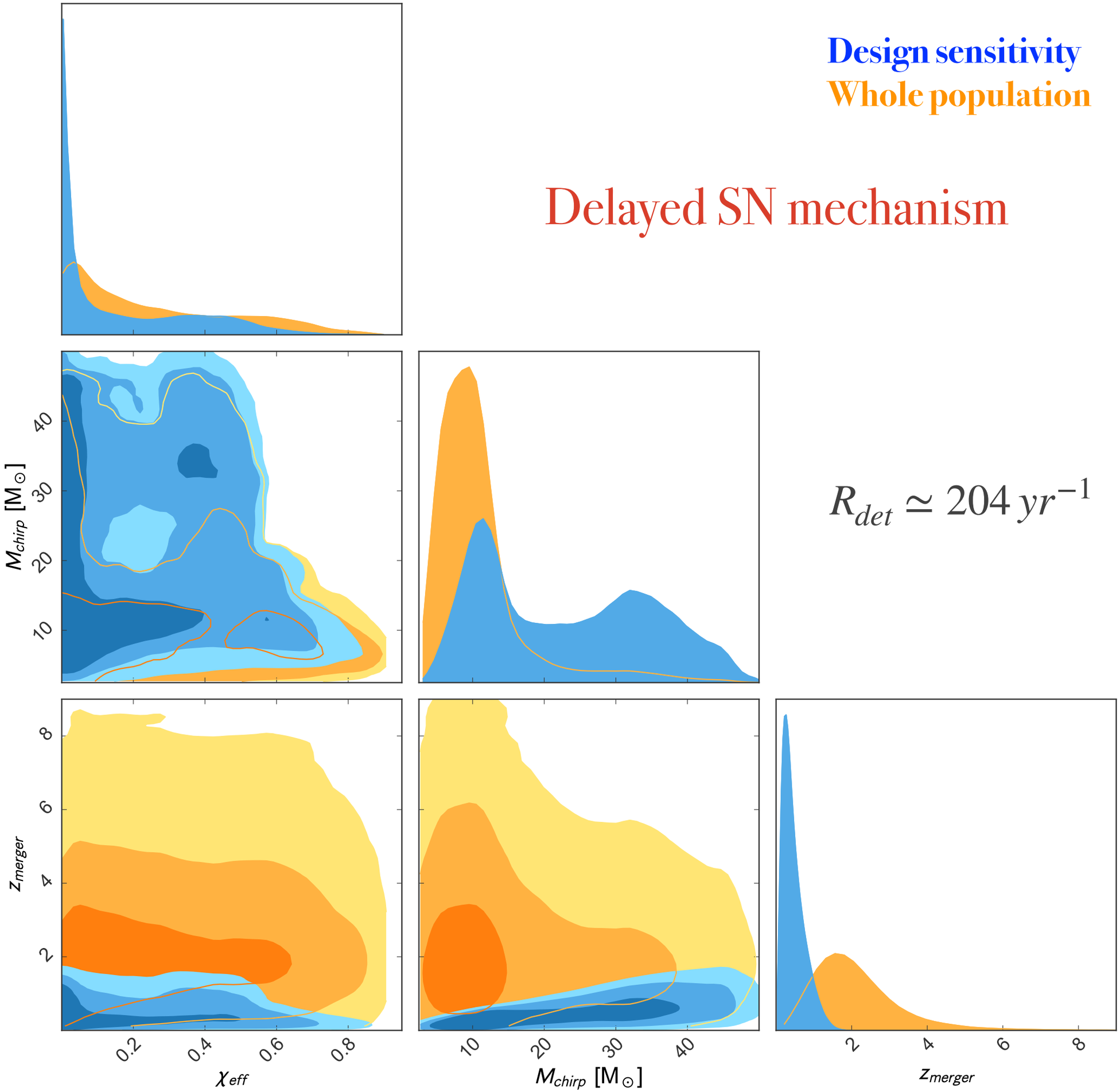
Delayed SN mechanism
aLIGO O1/O2 sensitivity

$$R_{det} \simeq 13\, yr^{-1}$$

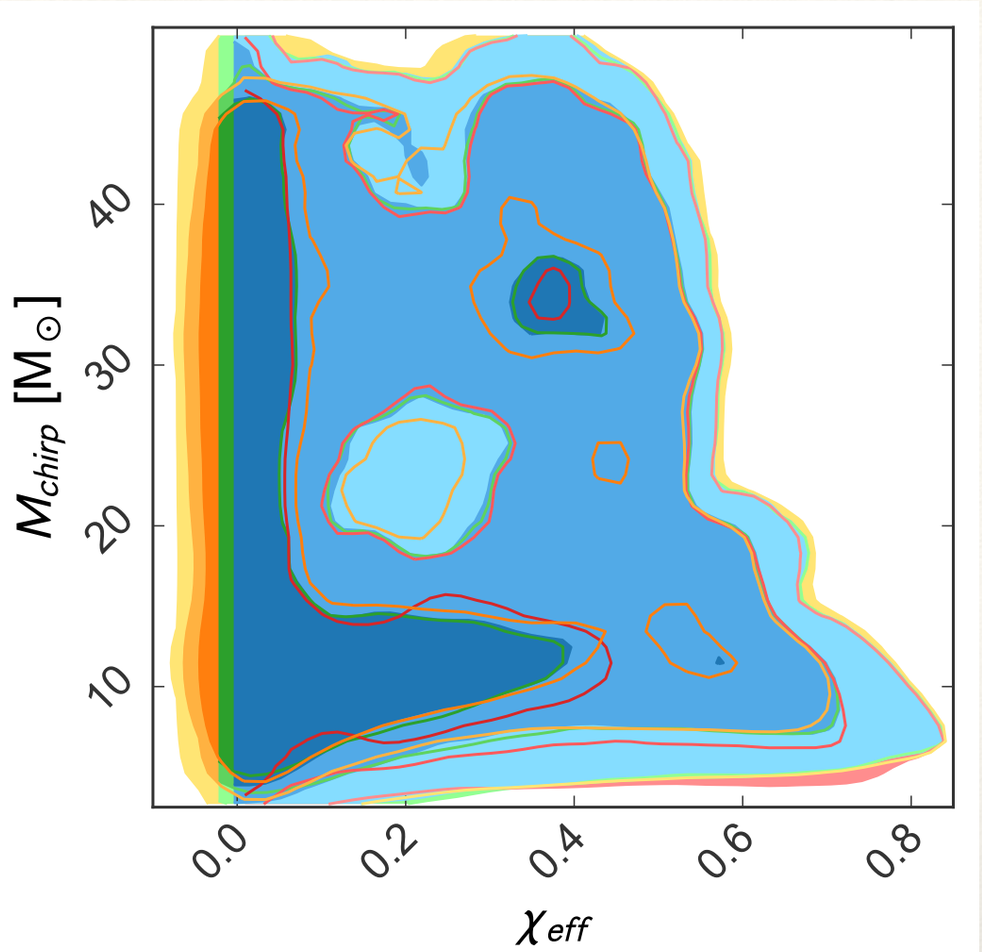


Design sensitivity
Whole population

Delayed SN mechanism



$$R_{det} \simeq 204\, yr^{-1}$$



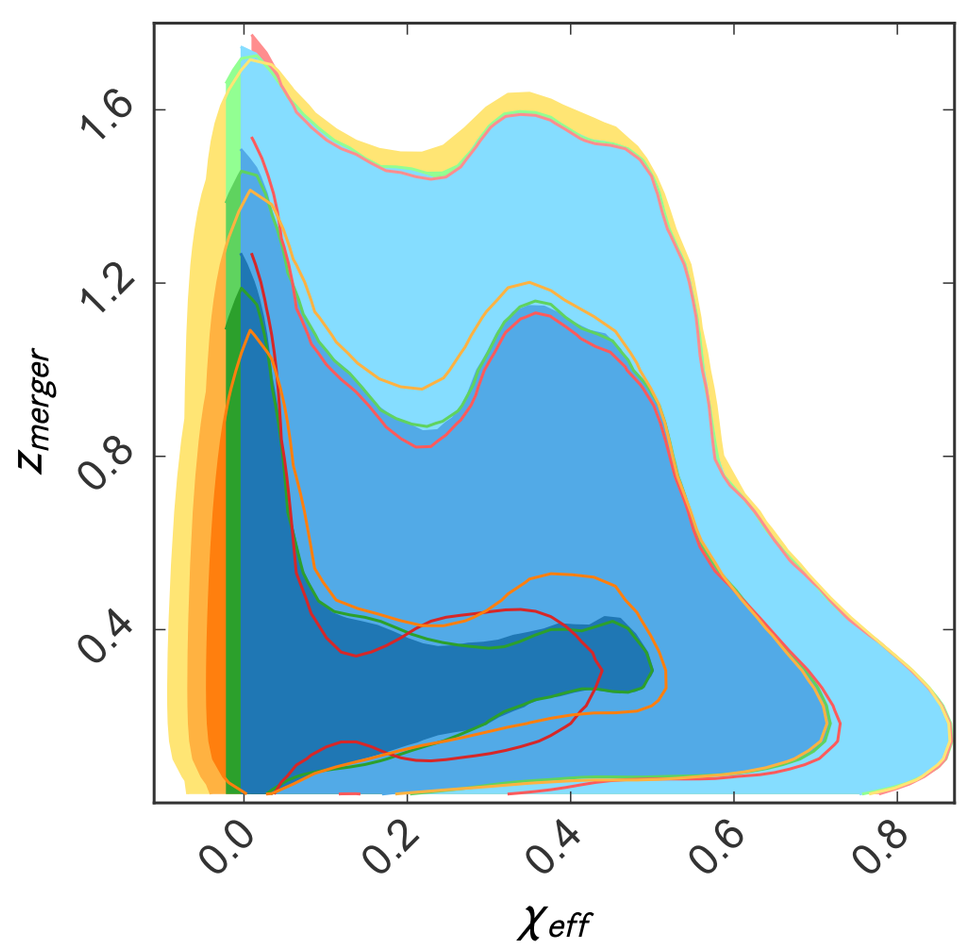
aLIGO design sensitivity

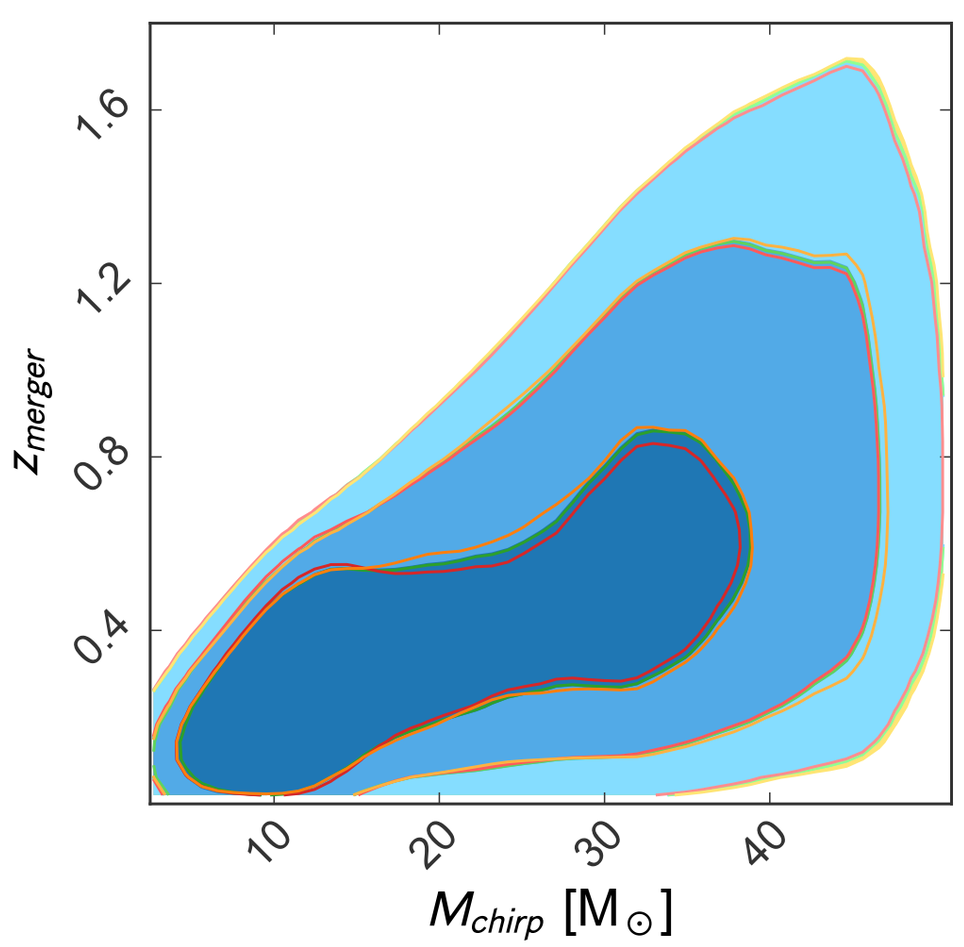
Delayed mechanism $R_{det} \simeq 204\, yr^{-1}$

Rapid mechanism $R_{det} \simeq 205\, yr^{-1}$

Direct collapse (NO kicks) $R_{det} \simeq 221\, yr^{-1}$

Delayed mec. (FULL kicks) $R_{det} \simeq 152\, yr^{-1}$





LISA

How to constrain the SN mechanism?

Which events? Breivik (2016), Nishizawa et al. (2016), Seto (2016)

LISA can detect BBHs with **eccentricities** ≥ 0.001 $\Rightarrow$ new constrains for the SN mechanism

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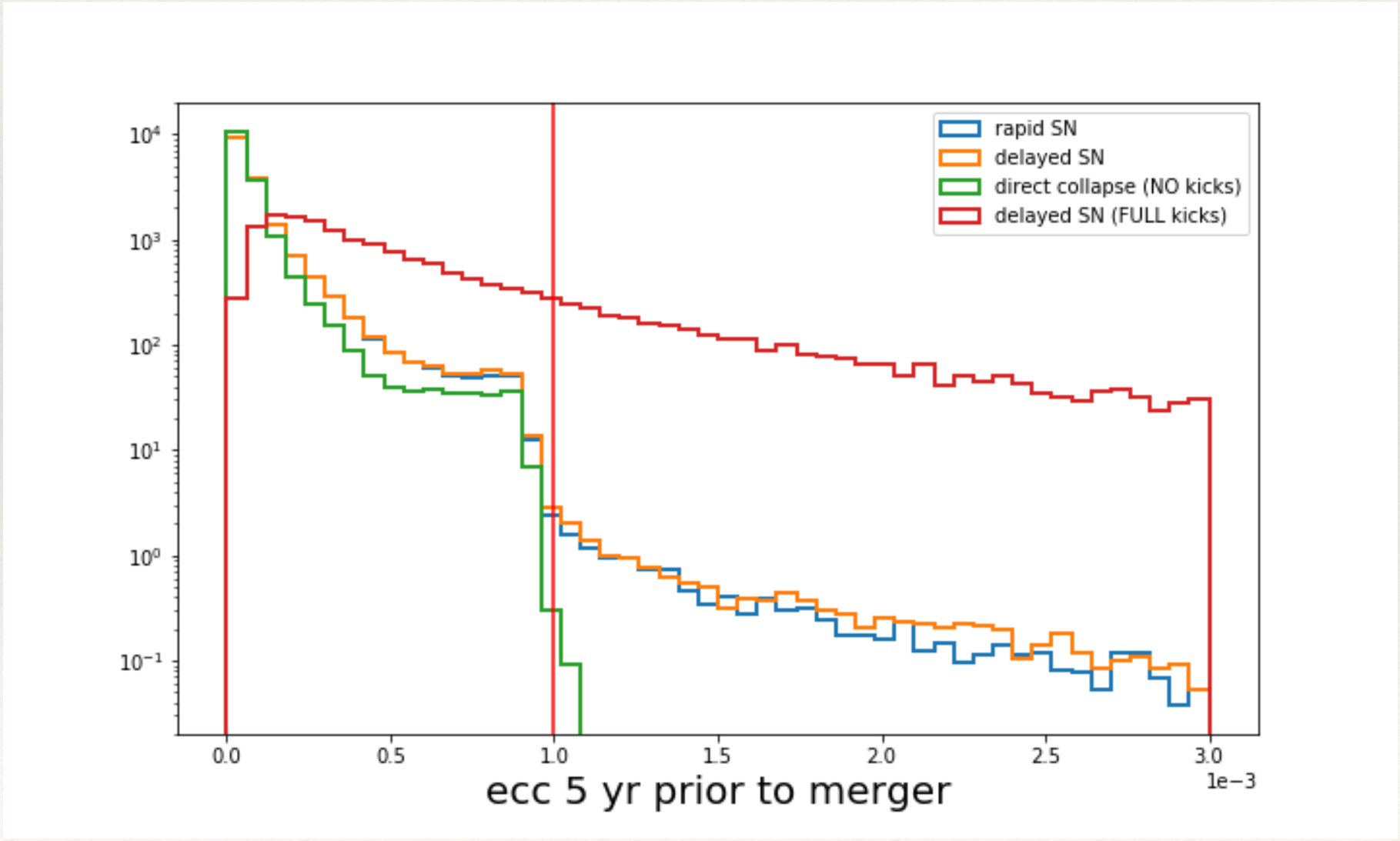
LISA can detect BBHs with **eccentricities** ≥ 0.001 $\Rightarrow$ new constrains for the SN mechanism

Model predictions for aLIGO at design sensitivity:

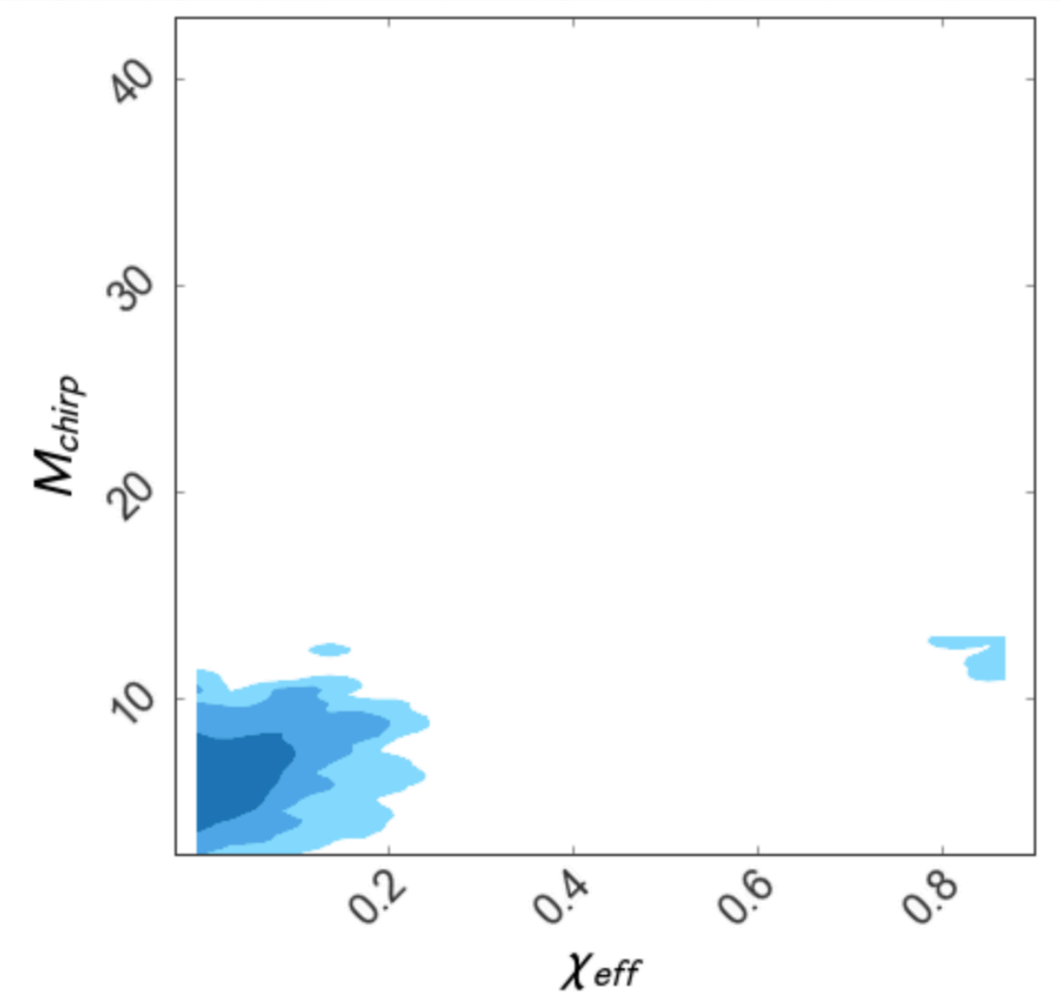
0.1% (**rapid** SN mechanism), 0.1% (**delayed** SN mechanism) ,
0.01% (direct collapse **NO kicks**), 24 % (delayed SN **FULL kicks**)
of detections have $e \geq 0.001$ 5 yr prior to merger



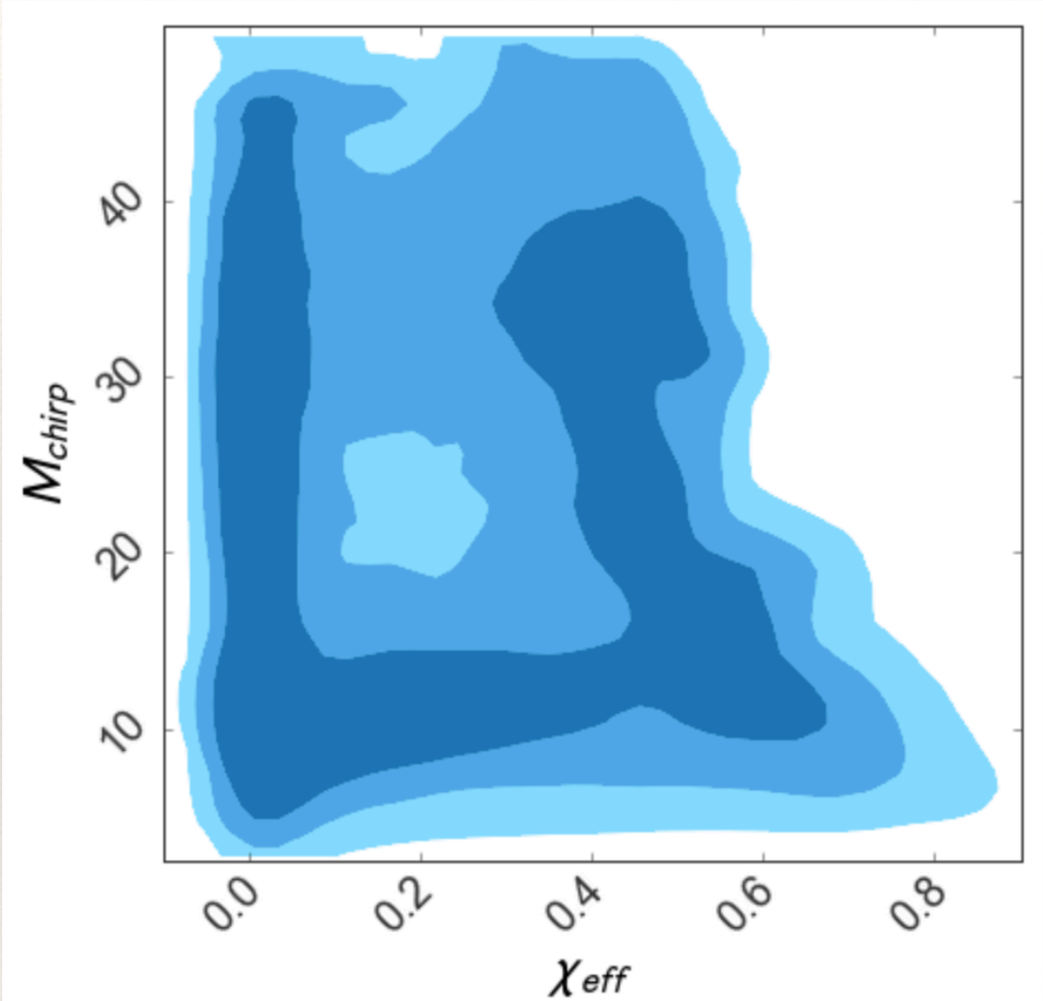
Predictions

Events with $e \geq 0.001$ 5 yr prior to the merger that will be detected by ground based detectors:

Delayed SN mechanism



Delayed SN mechanism (FULL kicks)



Conclusions

Results:

1. Our model is capable of predicting **simultaneously** the **three main observables** inferred from current GWs detections

2. The model can make **predictions for LISA**

3. Detection of highly eccentric BBHs in the LISA bend might put **constrains on the SN mechanism** of the common envelope formation channel