Progenitors of Binary Black Holes
"Formation in the Field"

Credit background NASA Paresce, Design E. Buunk

BinCosmos

Selma E. de Mink
Anton Pannekoek Institute for Astronomy, University of Amsterdam

PhD Students

Ylva
Götberg

Manos
Zapartas

Mathieu
Renzo

MSc Students

Abel
Schootemeijer
→ Bonn
w/Langer

Coen
Neijssel
→Birmingham
w/Mandel

Incoming Postdoctoral Fellows

Marie Curie

Ehsan
Moravveji

VENI Fellow

Silvia
Toonen

?

… 4 new ERC funded PhD/PD positions
→ inquiries through email

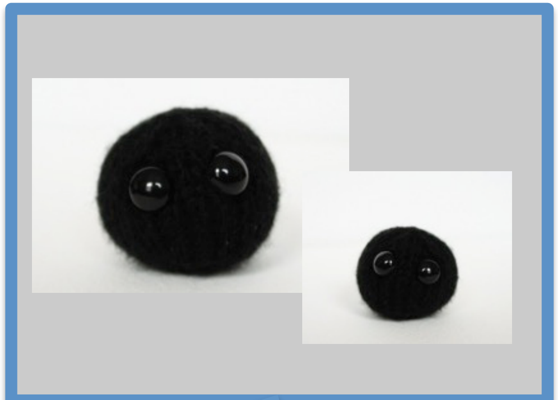
BinCosmos

Scope of this talk

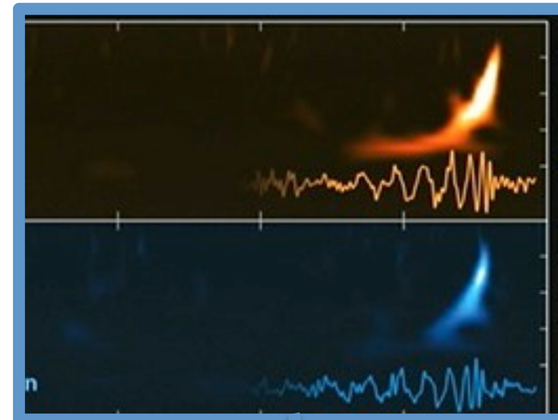
Progenitors

Birth of progenitor stars

Formation black holes



Coalescence



t_0 Myrs

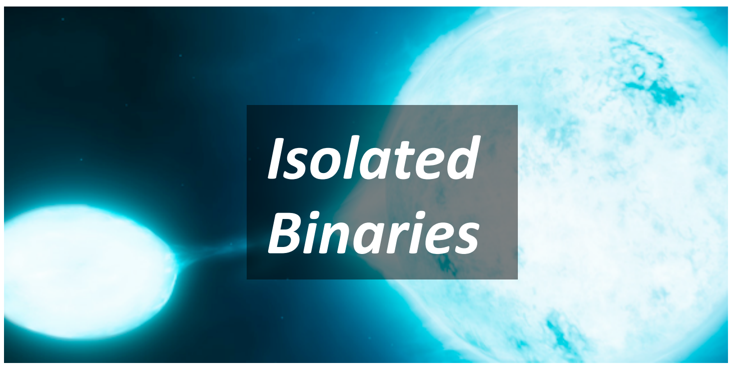
Gyrs

Time

Formation Channels

1. "Evolutionary" formation channels

2. Dynamical formation channels



Stellar Density

Bin
Cosmos

Scope

1. "Evolutionary" formation channels

I. Classic "Common Envelope" Channel

(or other forms of highly non conservative mass transfer)

Tutukov & Yungelson 1973, 1993; Lipunov, Postnov & Prokhorov (1997), Bethe & Brown (1998), Bloom, Sigurdsson & Pols (1999), De Donder & Vanbeveren (2004), Grishchuk et al. (2001), Nelemans (2003), Voss & Tauris (2003), Pfahl, Podsiadlowski & Rappaport (2005), Dewi, Podsiadlowski & Sena (2006), Kalogera et al. 2007; O'Shaughnessy et al. (2008), Mennekens & Vanbeveren (2014), Dominik et al. (2015), de Mink & Belczynski (2015), Belczynski et al. 2016, ...

II. "Chemically Homogeneous" Channel

(Other names: Case M, Rotational channel, Tidal mixing channel)

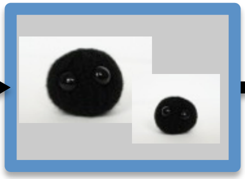
de Mink et al. (2008, 2009), Mandel & de Mink (2016), Song et al. 2016; Marchant et al. (2016), de Mink & Mandel (2016), ...

Two Challenges
for all formation scenarios

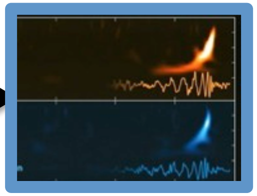
Progenitors

Birth

Formation BHs



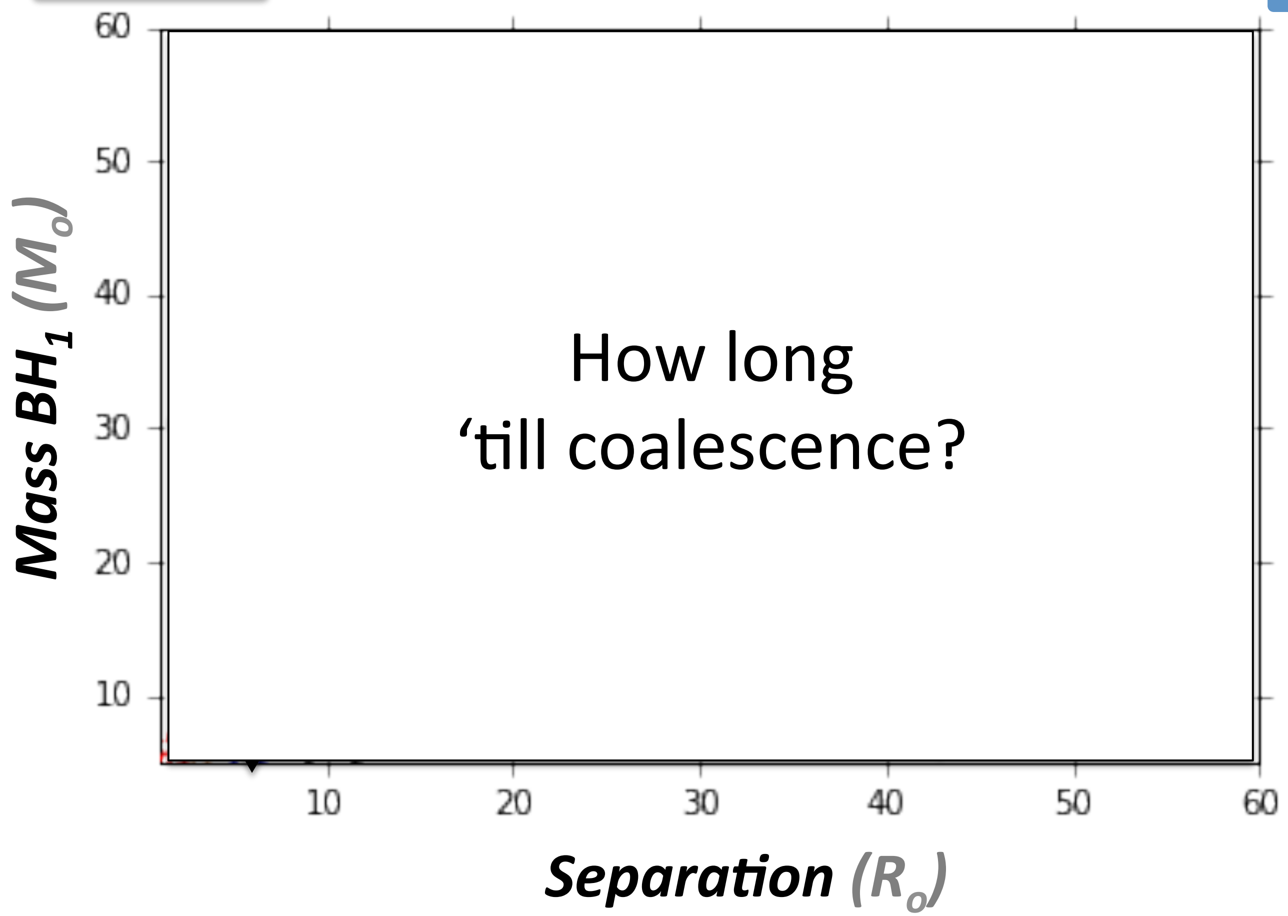
Coalescence



1.“Separation Challenge”

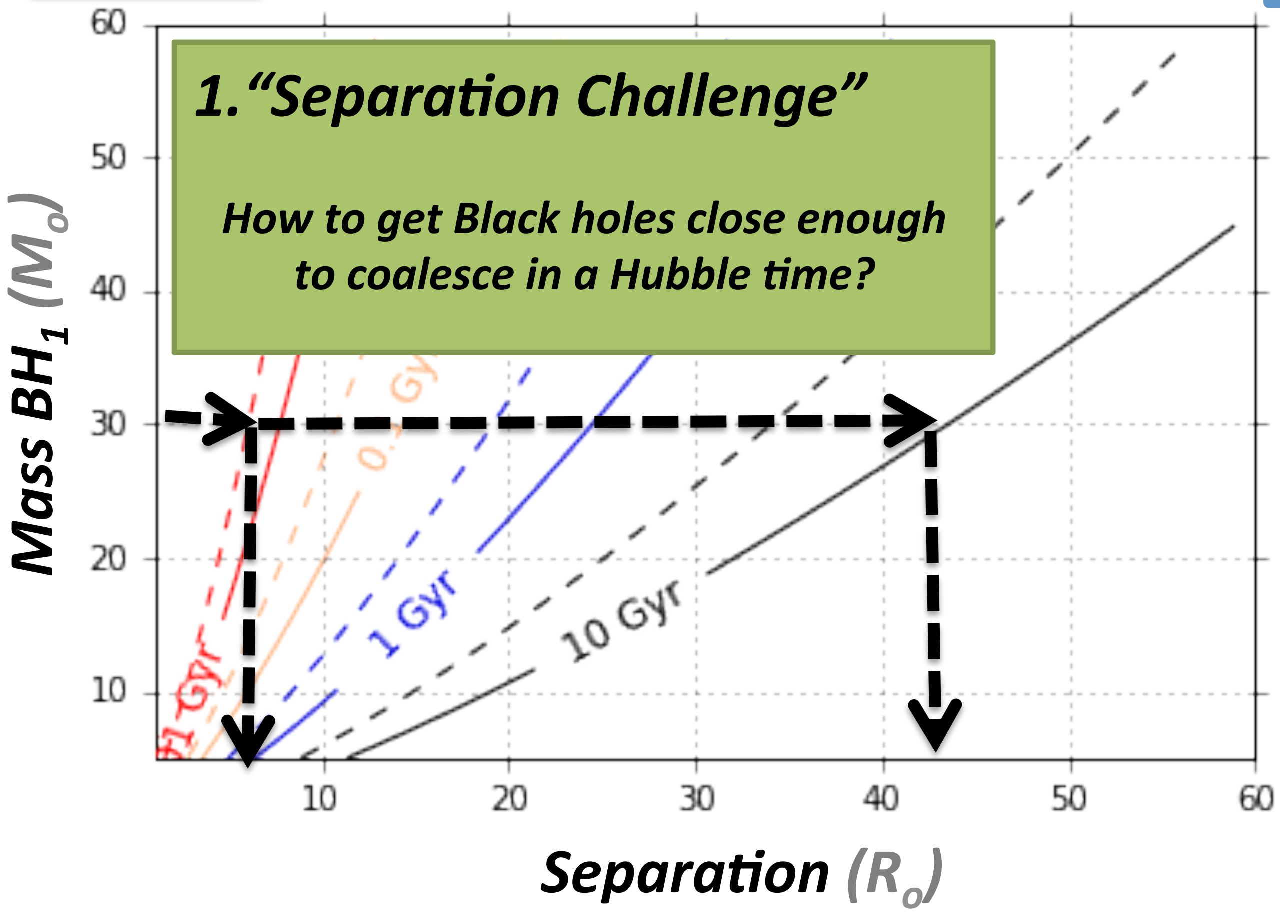
2. “Mass Challenge”

Progenitors



Using Peters '64

Progenitors



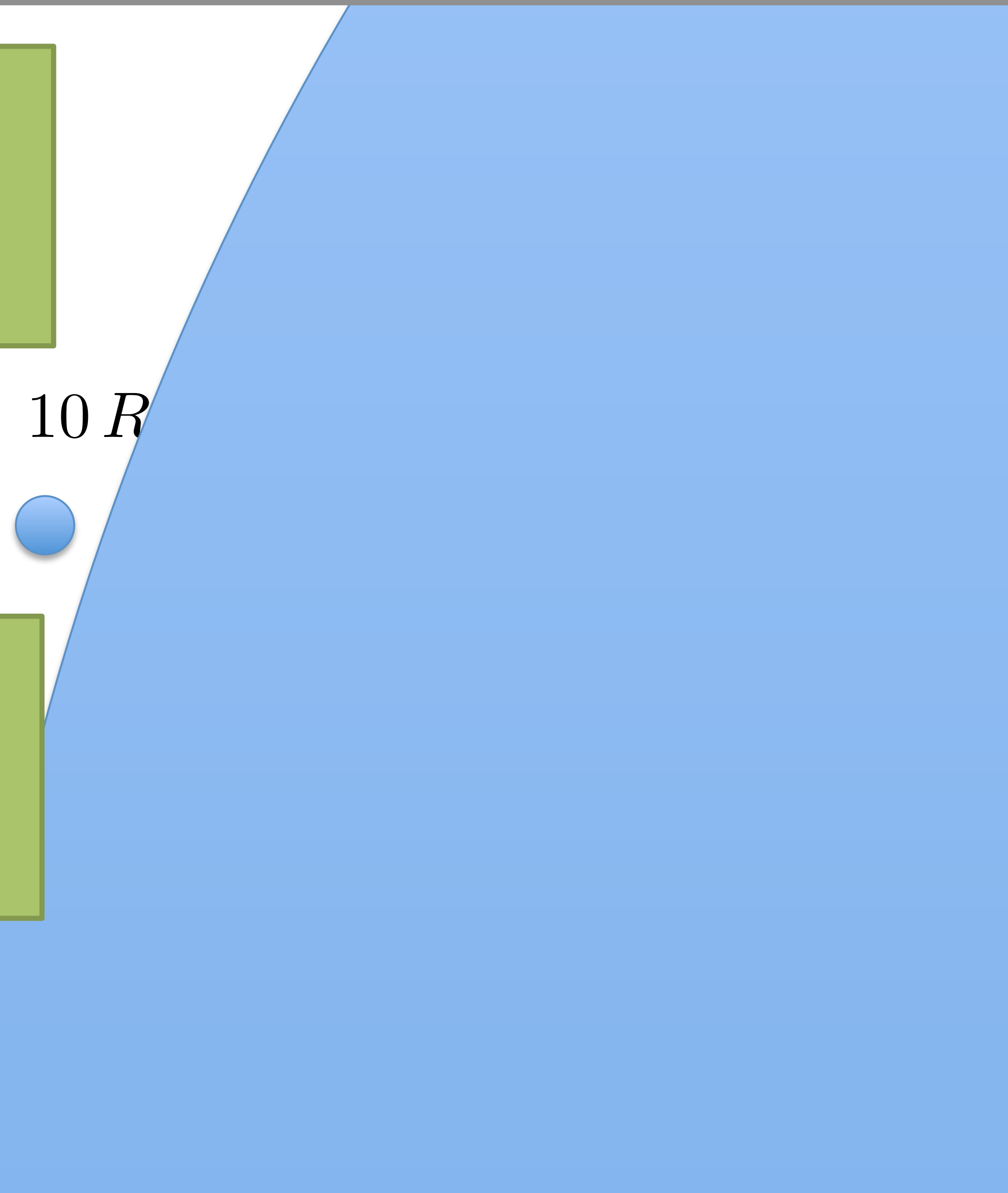
1. "Separation Challenge"

How to get Black holes close enough to coalesce in a Hubble time?

Using Peters '64

1. "Separation Challenge"

How to get Black holes close enough to coalesce in a Hubble time?

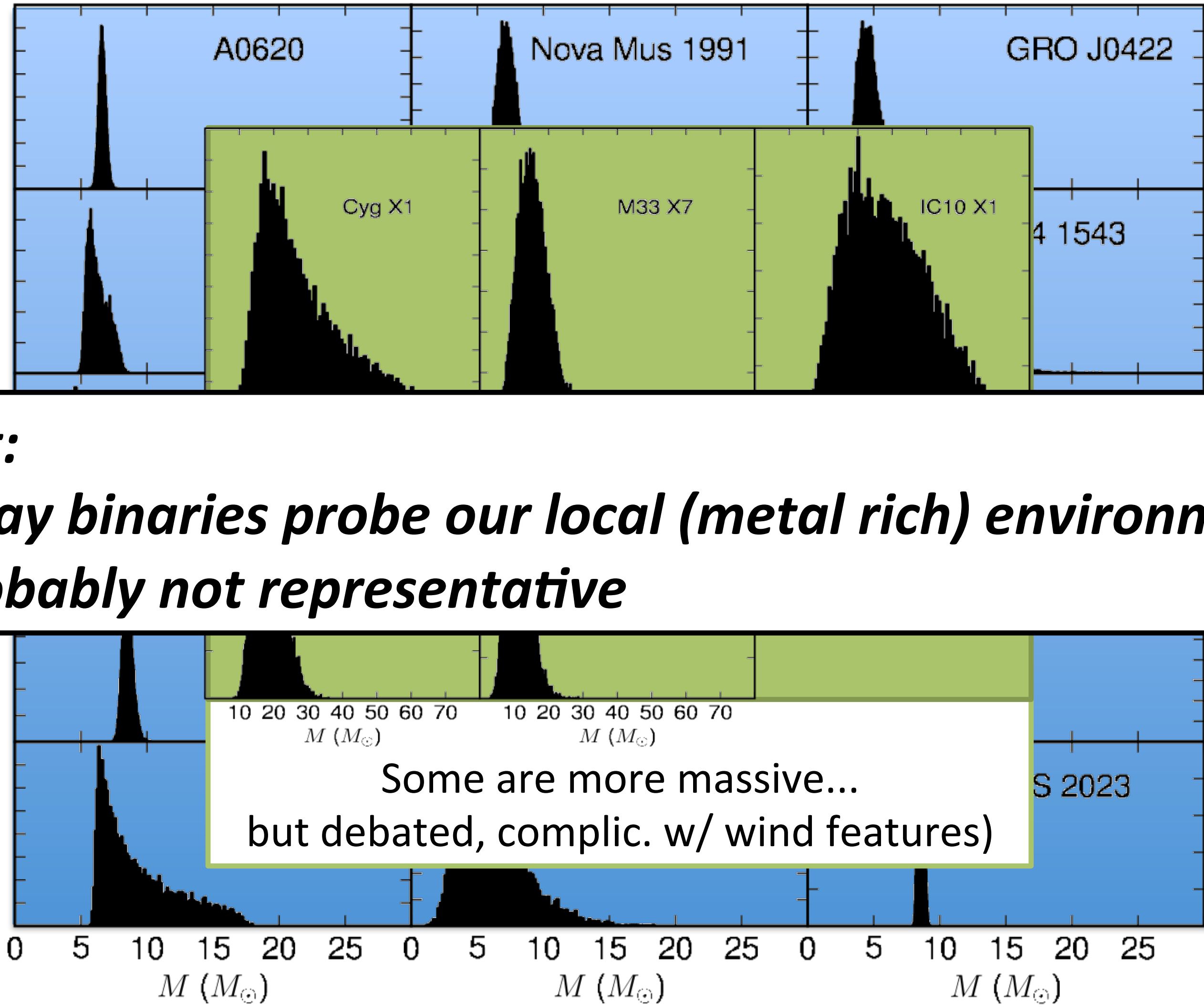


2. "Mass Challenge"

How to avoid excessive Mass loss?

30 solar masses is rather massive …
typical range inferred from X-ray binaries is 5-10 M_o

Farr et al. 201x



Caveat:

X-ray binaries probe our local (metal rich) environment

Probably not representative

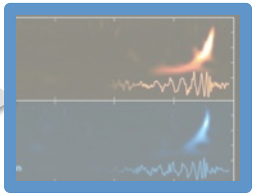
Farr et al.

BinCosmos

Birth

Formation BHs

Coalescence

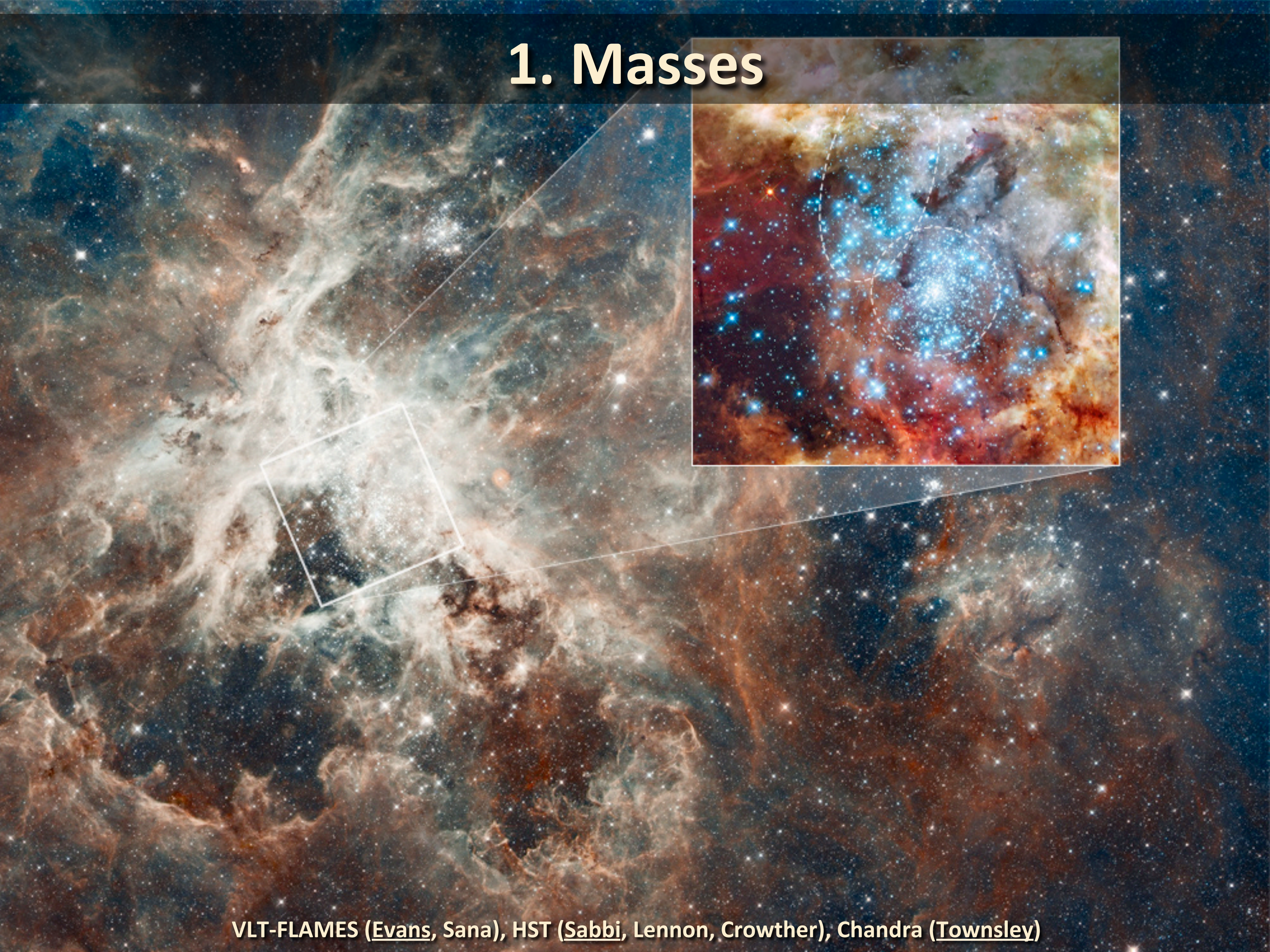


The Initial conditions

Black Holes in the making: Tarantula Nebula

VLT-FLAMES (Evans, Sana), HST (Sabbi, Lennon, Crowther), Chandra (Townsley)

1. Masses

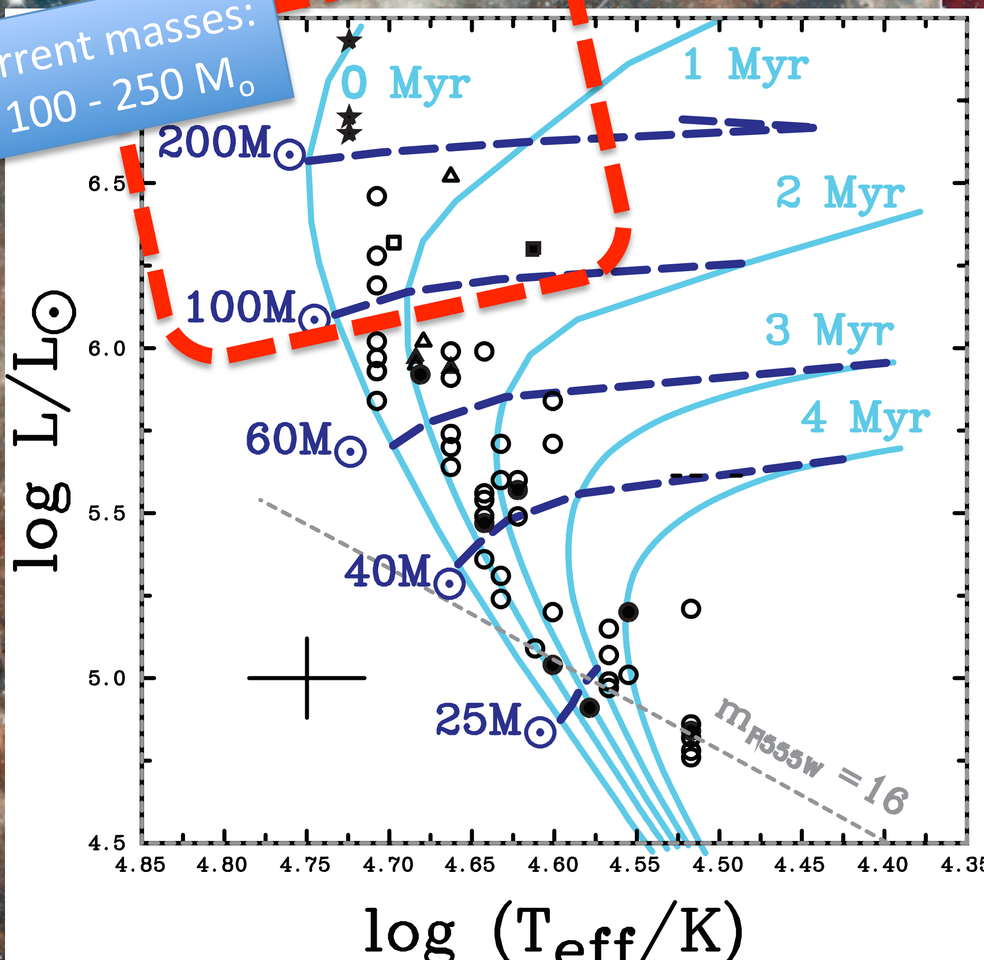


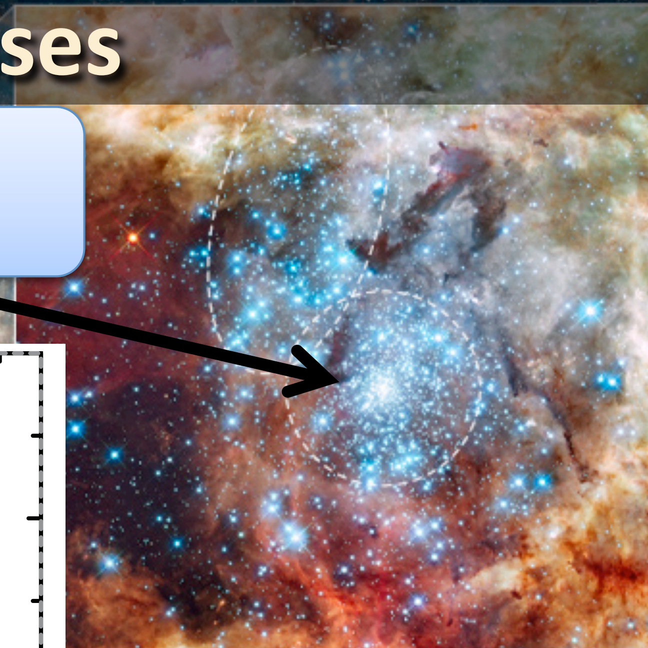
VLT-FLAMES (Evans, Sana), HST (Sabbi, Lennon, Crowther), Chandra (Townsley)

1. Masses

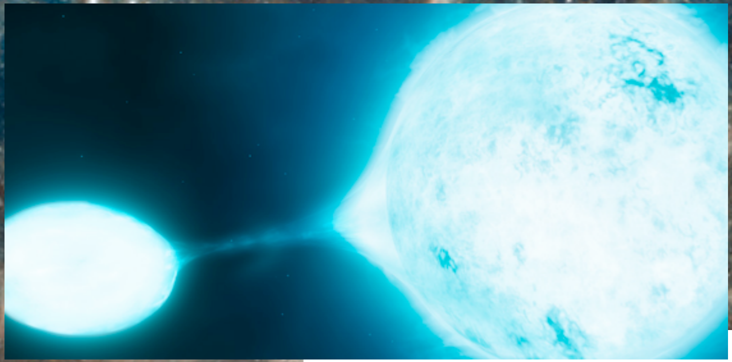
Nine "Monster" stars
Crowther+10,+15

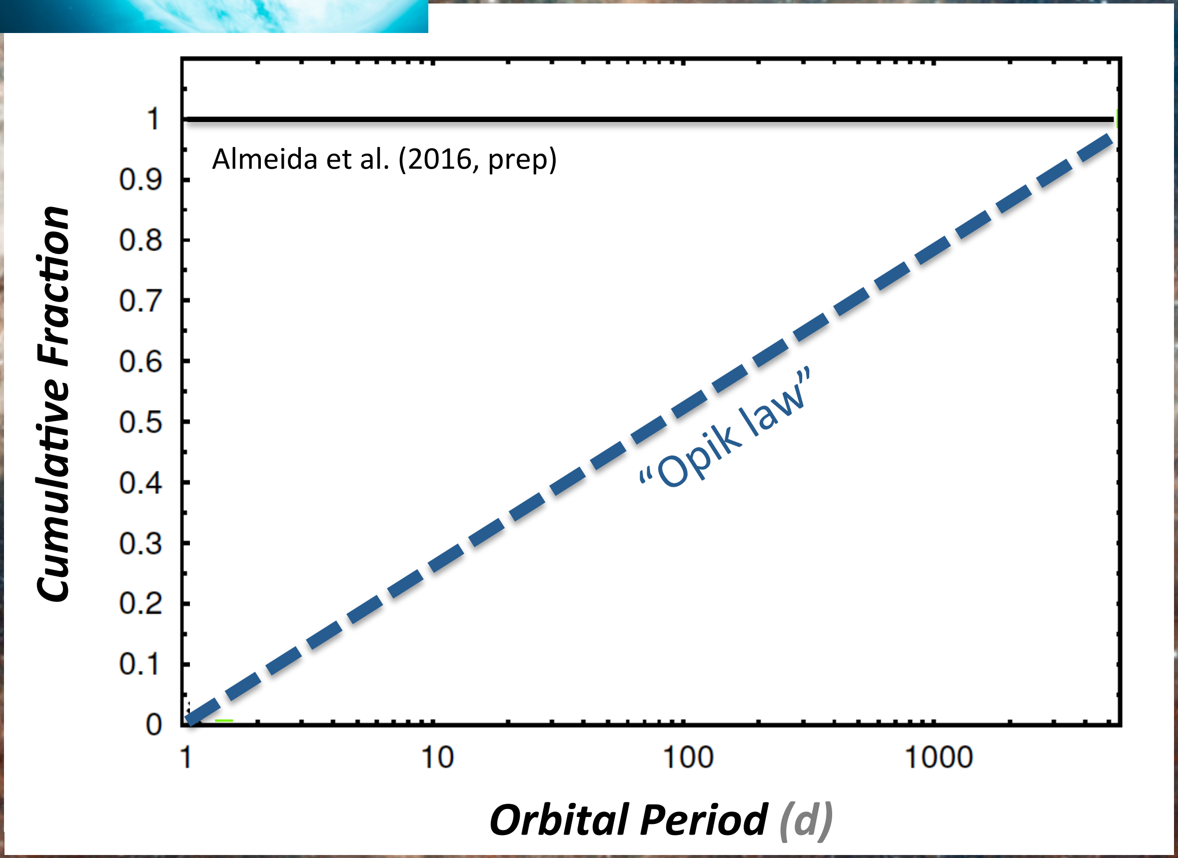
Current masses:
~ 100 - 250 $M_\odot$





2. Binary Separations





VLT-FLAMES (Evans, Sana), HST (Sabbi, Lennon, Crowther), Chandra (Townsley)

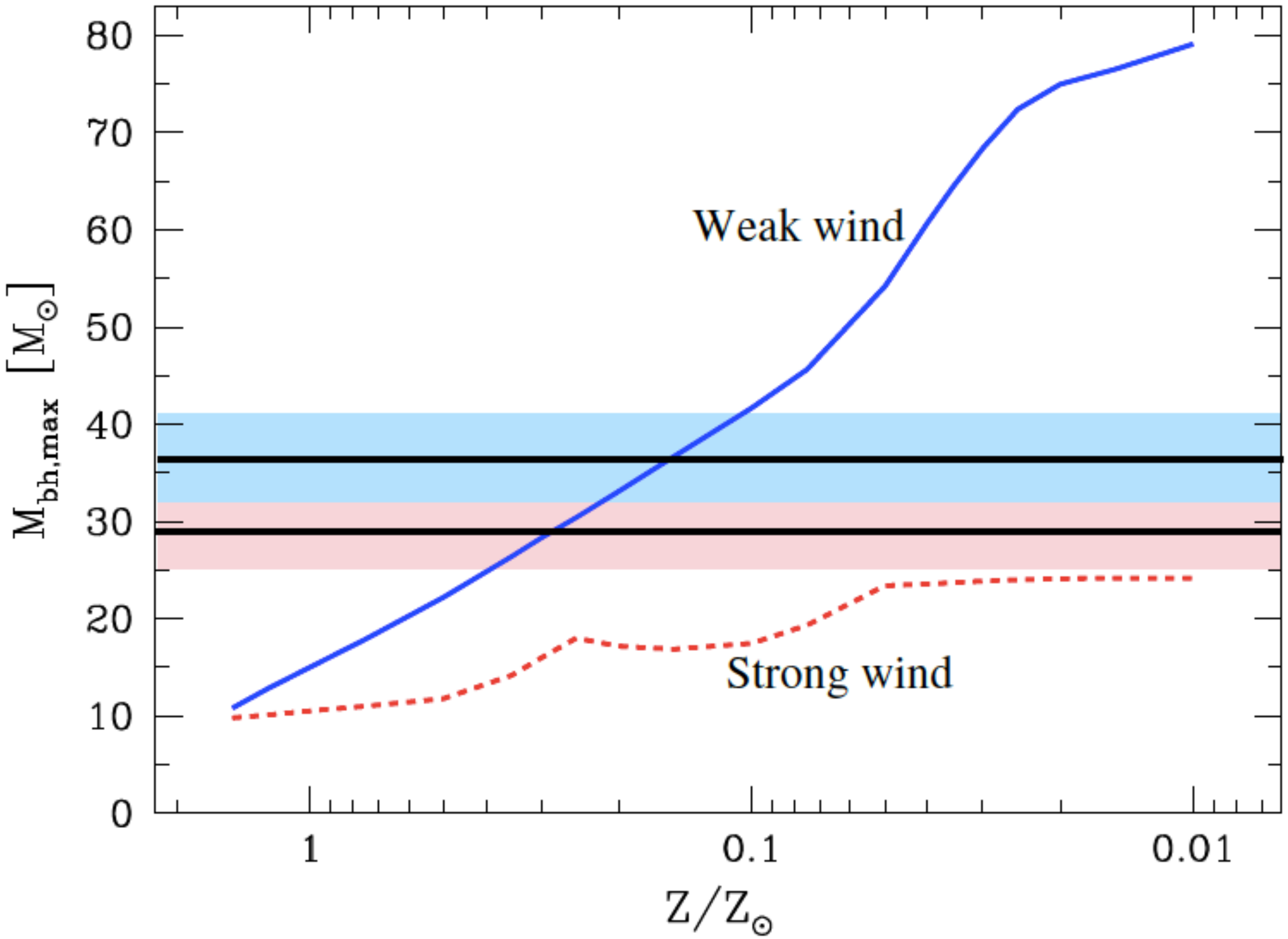
1. Mass Challenge

Bin Cosmos

Need for reduced winds

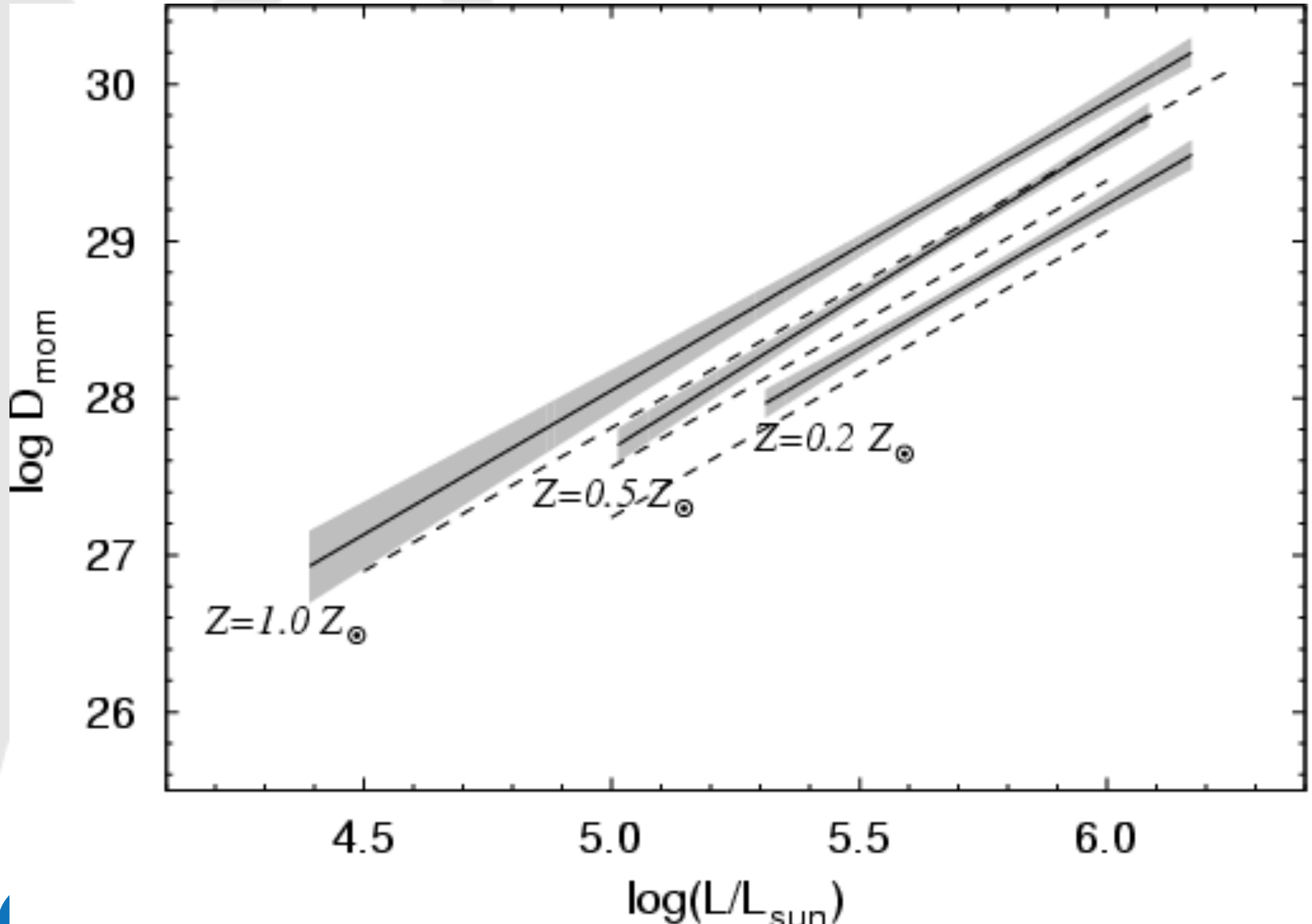
Belczynski et al. 2010

Astrophysical implications paper



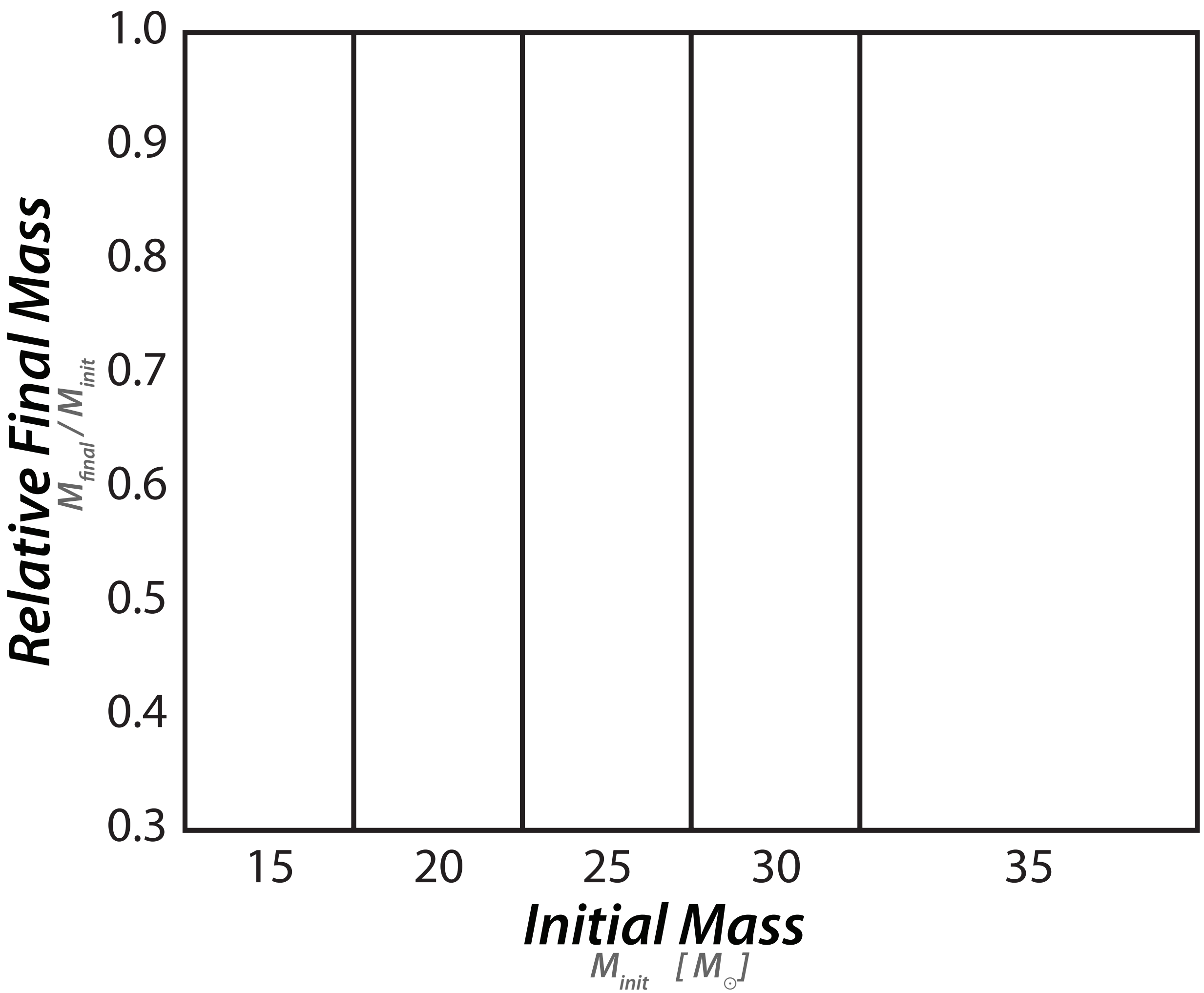
Reduced (line driven) winds at lower metallicity

Vink et al. 2000, Mokiem et al. 2005



Mass loss uncertainties

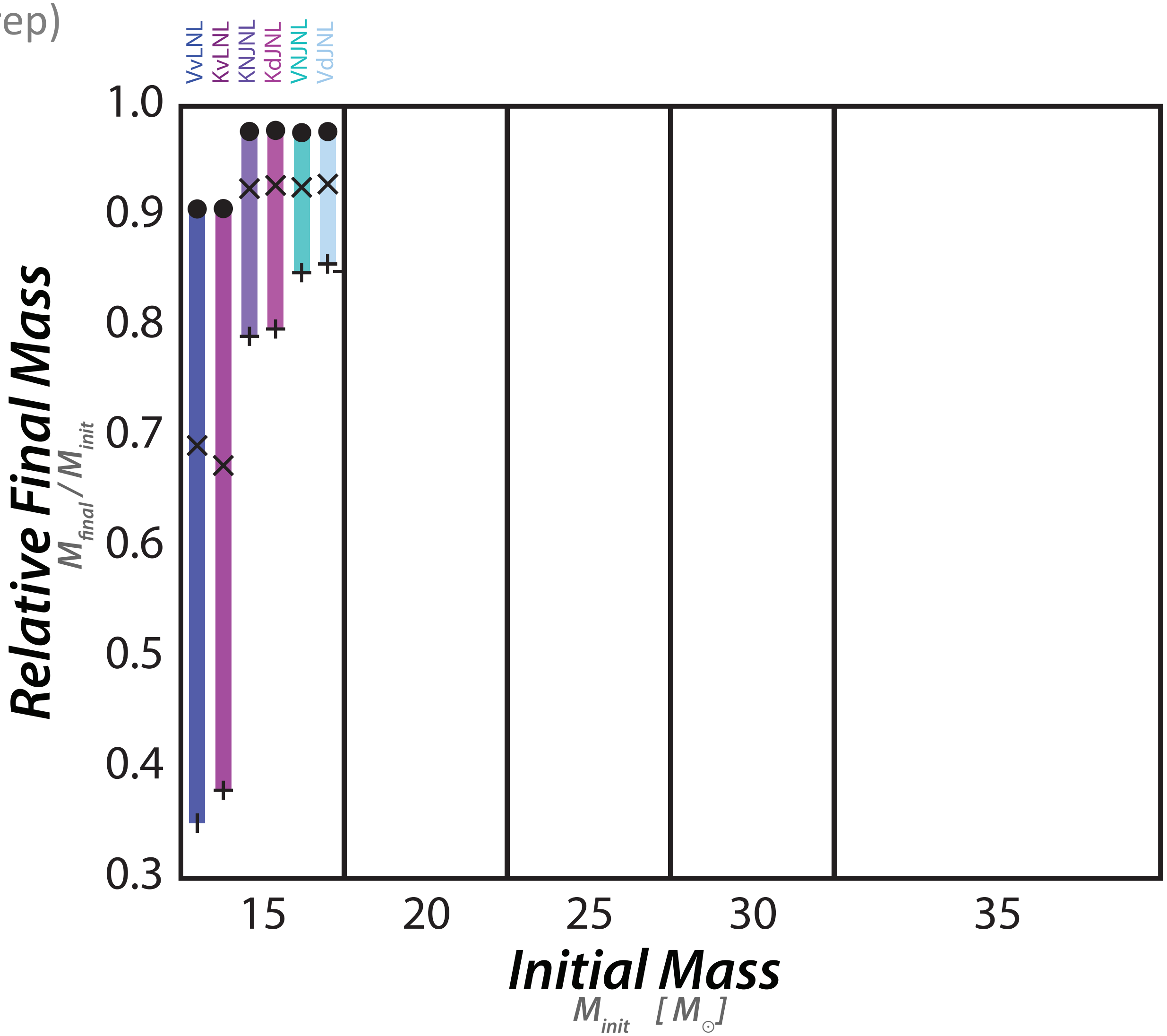
Renzo et al. (in prep)



Mathieu Renzo

Mass loss uncertainties

Renzo et al. (in prep)



Mathieu Renzo

Mass loss uncertainties

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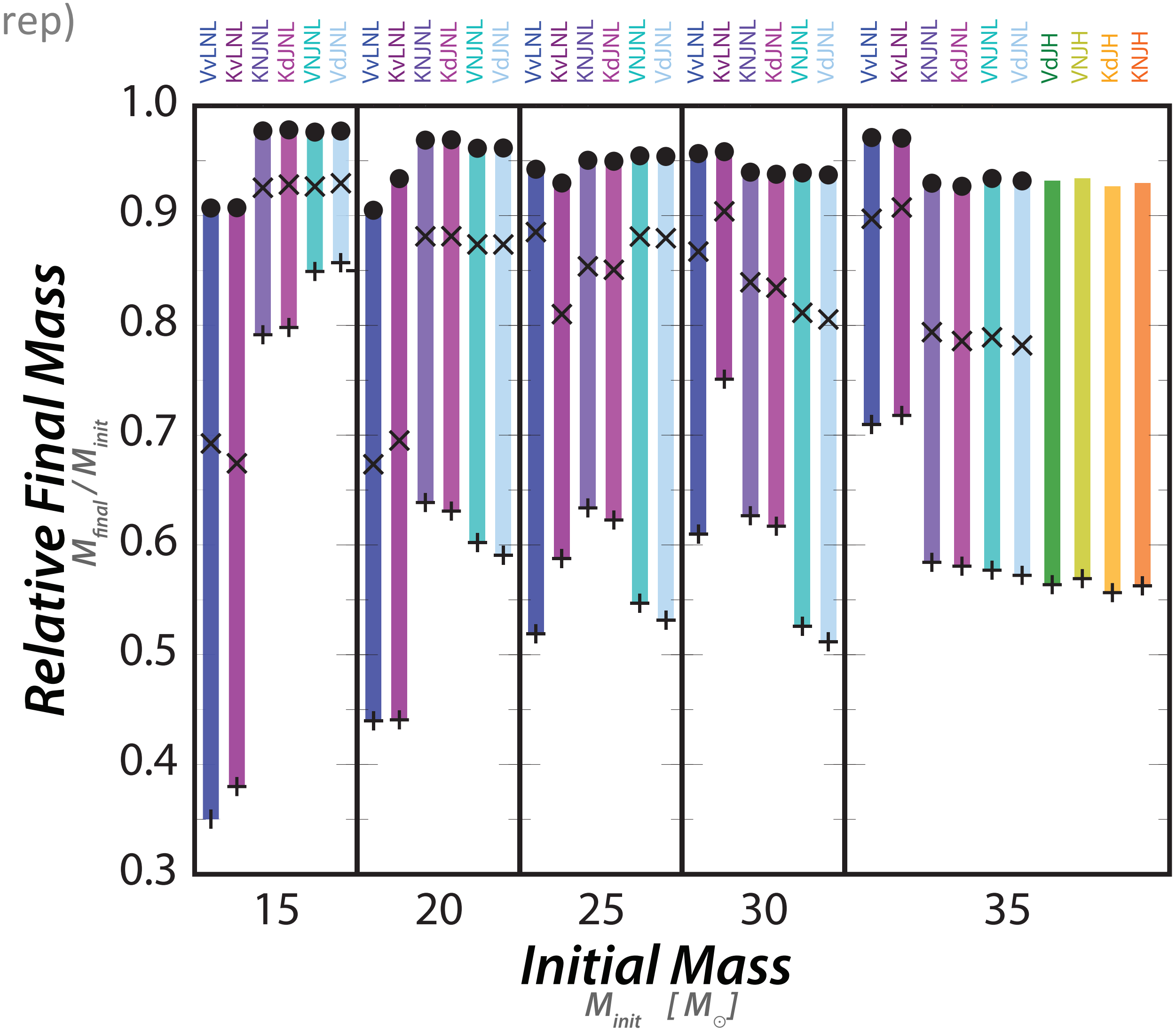


Mathieu Renzo

2. Separation Challenge

1. Classic
Common Envelope Channel

Tutukov & Yungelson 1973, 1993; Lipunov, Postnov & Prokhorov (1997), Bethe & Brown (1998), Bloom, Sigurdsson & Pols (1999), De Donder & Vanbeveren (2004), Grishchuk et al. (2001), Nelemans (2003), Voss & Tauris (2003), Pfahl, Podsiadlowski & Rappaport (2005), Dewi, Podsiadlowski & Sena (2006), Kalogera et al. 2007; O'Shaughnessy et al. (2008), Mennekens & Vanbeveren (2014), Dominik et al. (2015), de Mink & Belczynski (2015), Belczynski et al. 2016, ...

Classic Channel

Belczynski et al. 2016

Classic Channel (part 2)

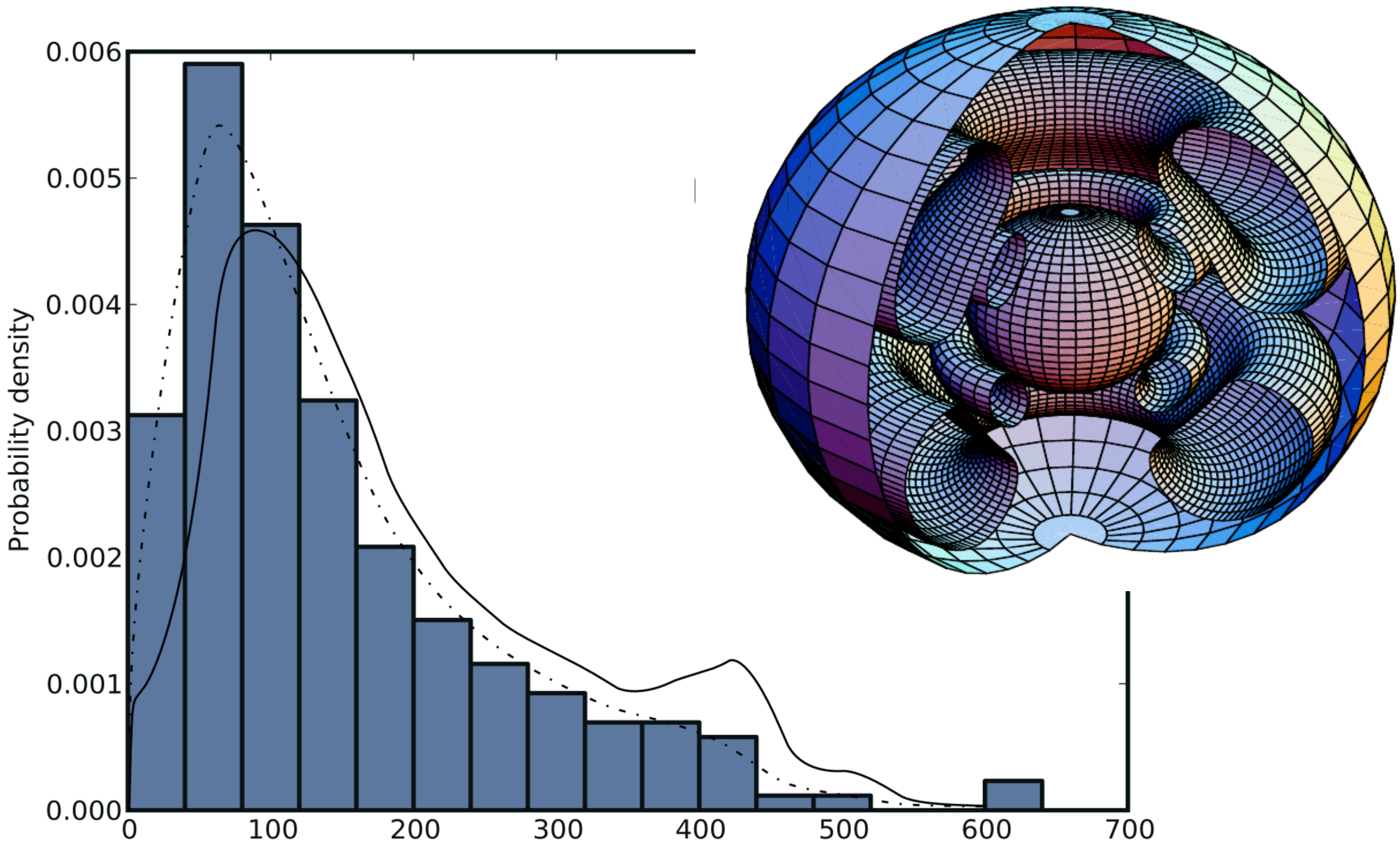
Belczynski et al. 2016

2. Chemically Homogeneous Channel

(Other names: Case M, Rotational channel, Tidal mixing channel)

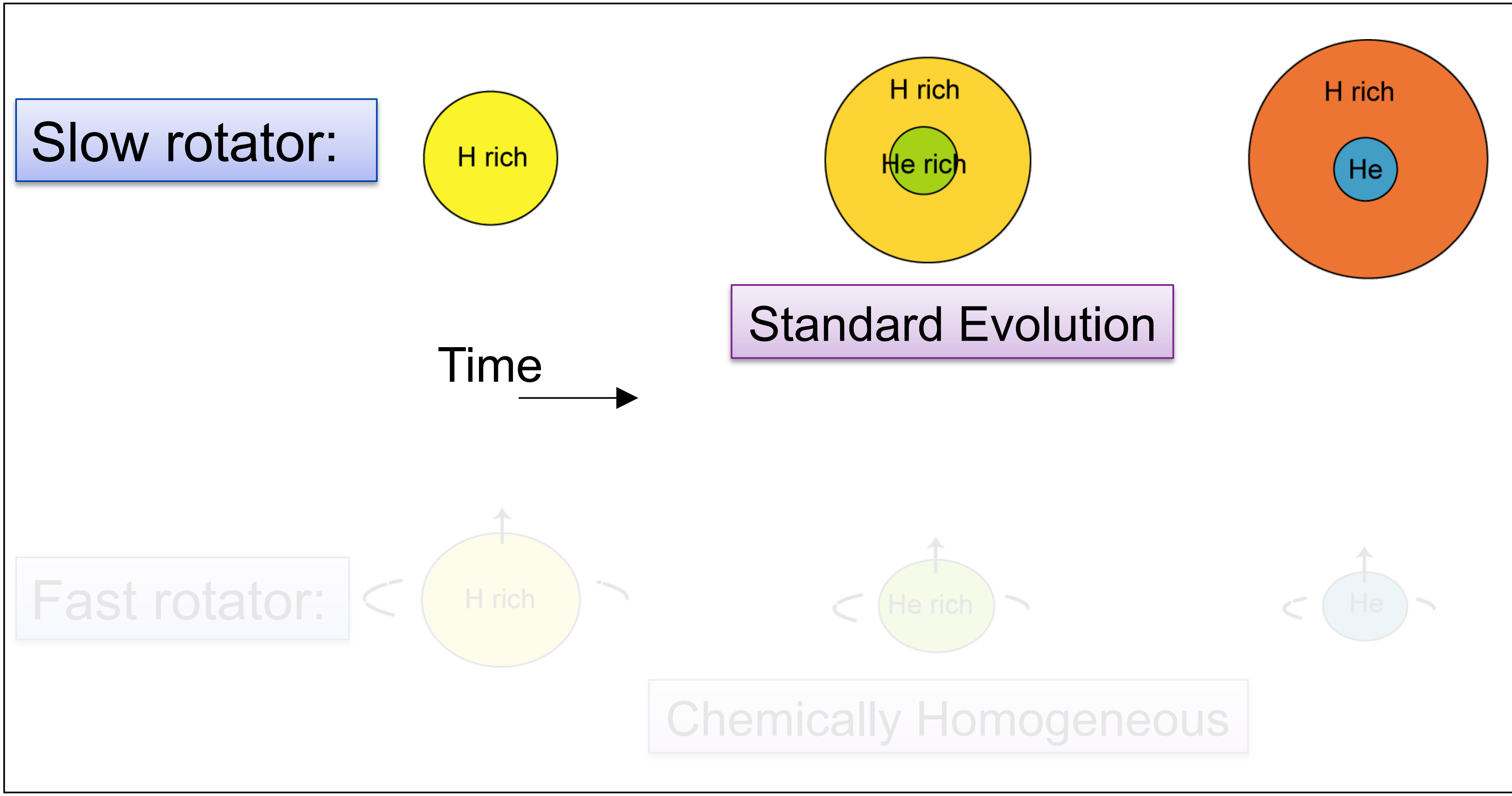
de Mink et al. (2008, 2009), Mandel & de Mink (2016), Song et al. 2016; Marchant et al. (2016), de Mink & Mandel (2016), …

… very rapidly rotating single stars …



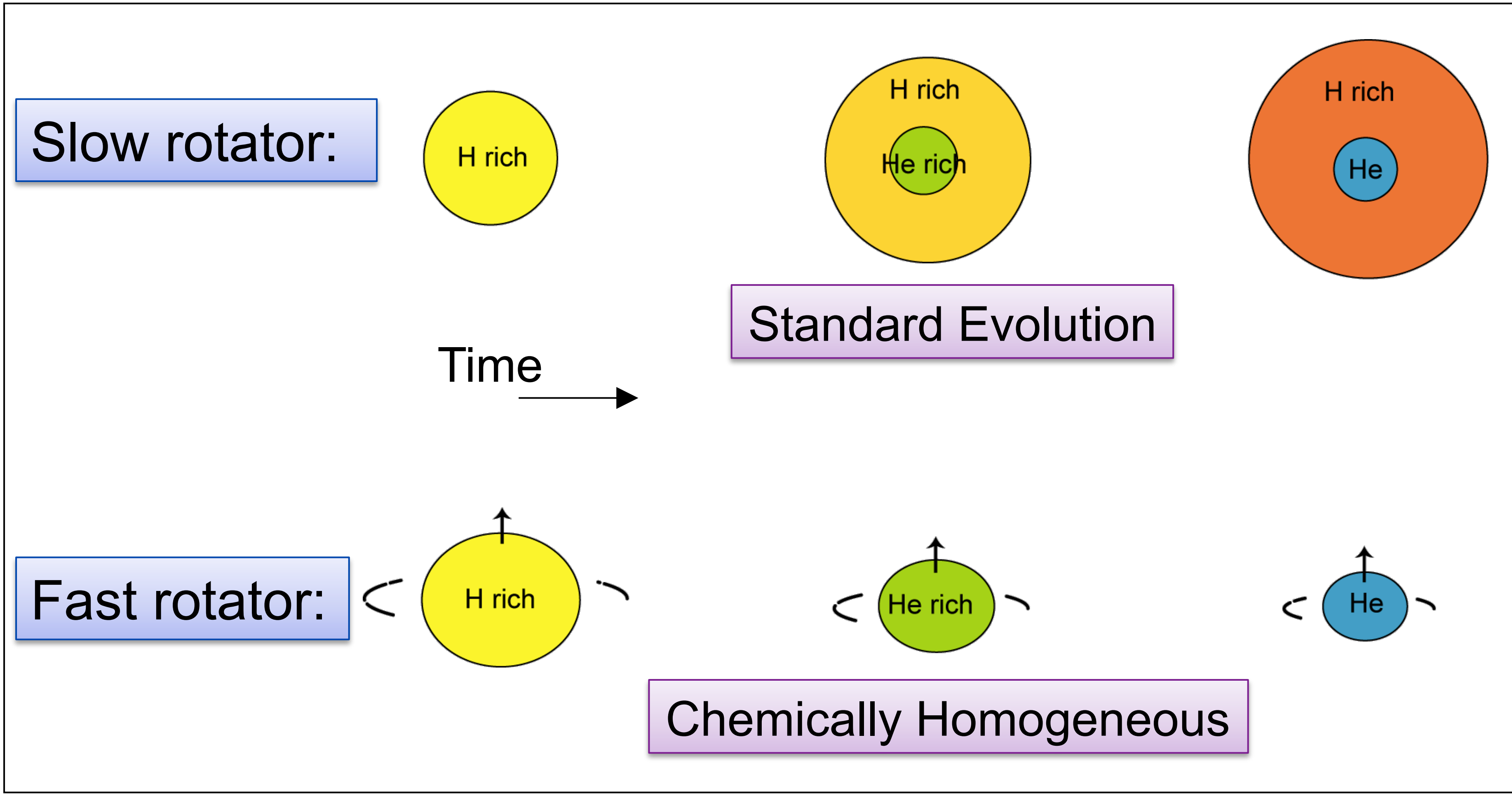
Ramirez-Agudelo et al. (2013, 2015)

Effect on the stellar structure



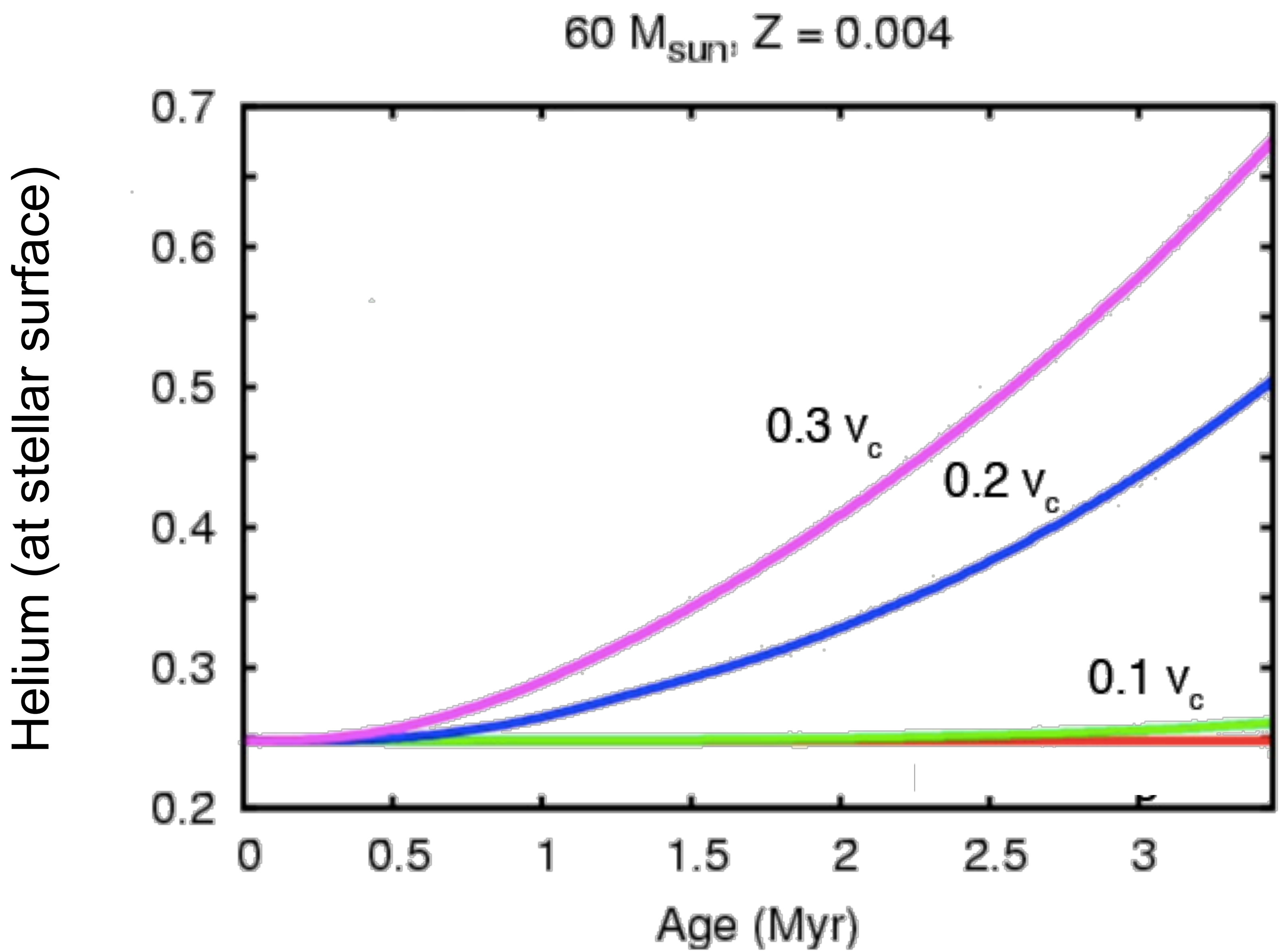
Maeder 87, Yoon & Langer 05

Effect on the stellar structure



Maeder 87, Yoon & Langer 05

Surface composition

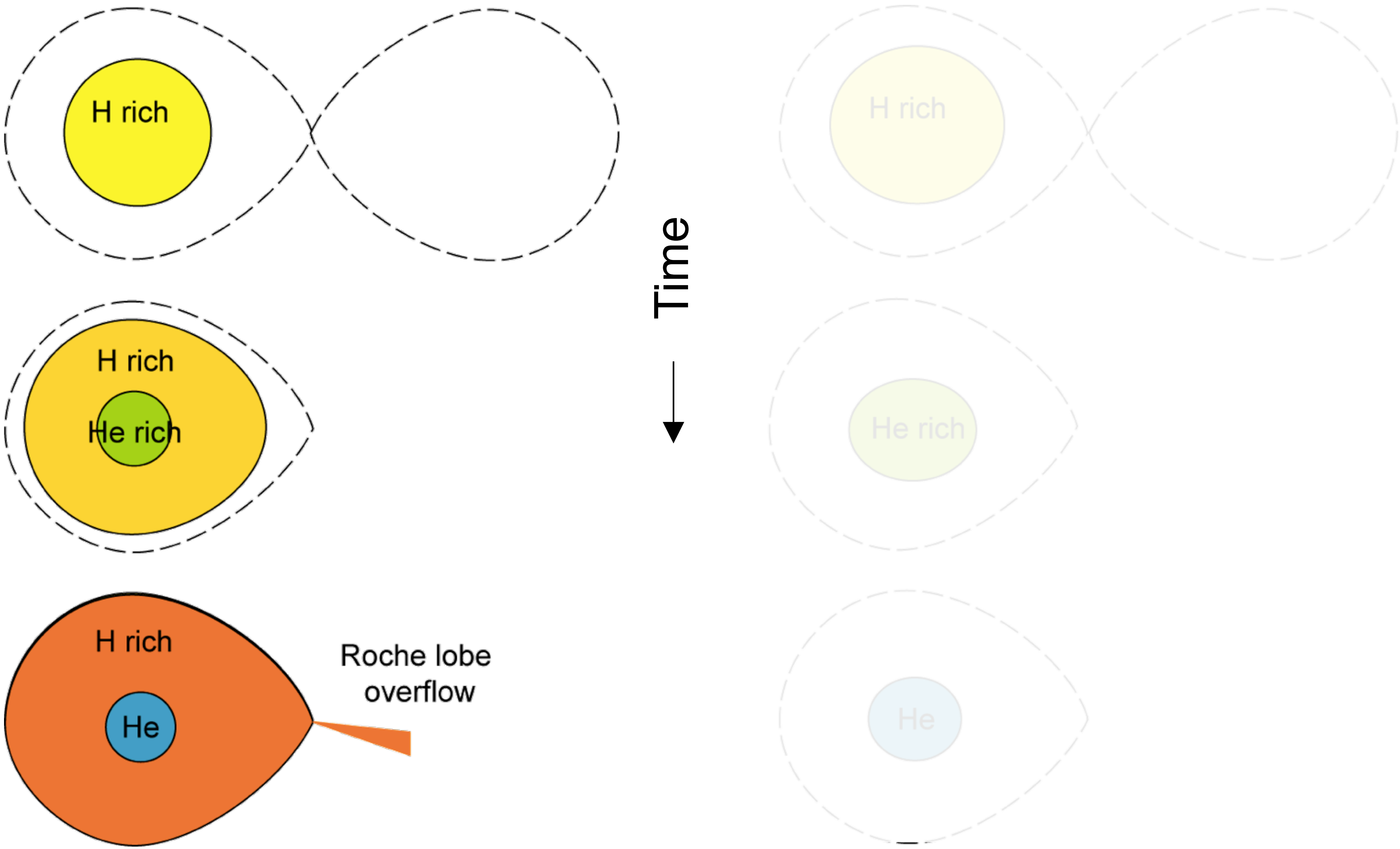


Yoon + 06

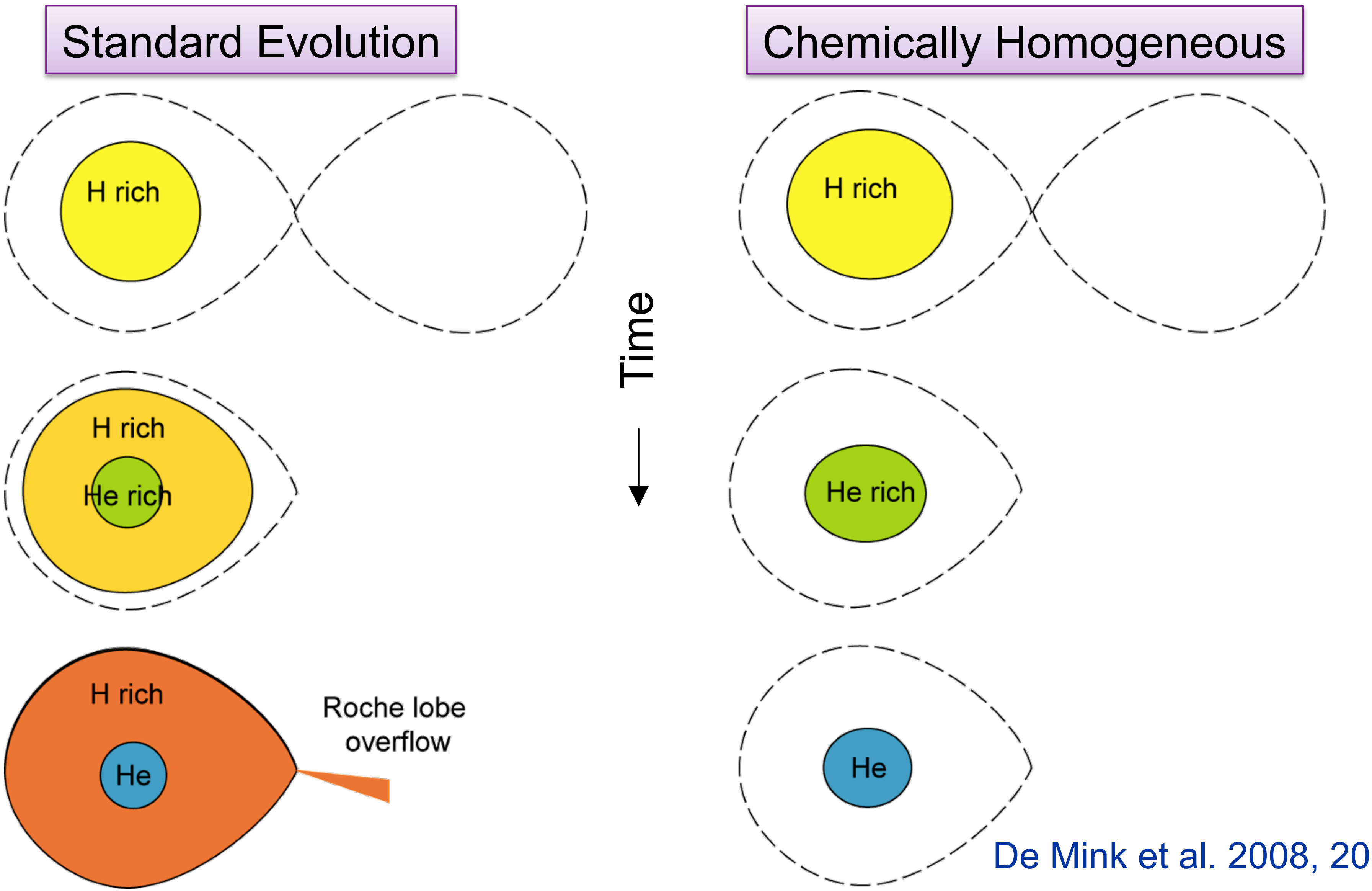
What about binaries?

Standard Evolution

Chemically Homogeneous

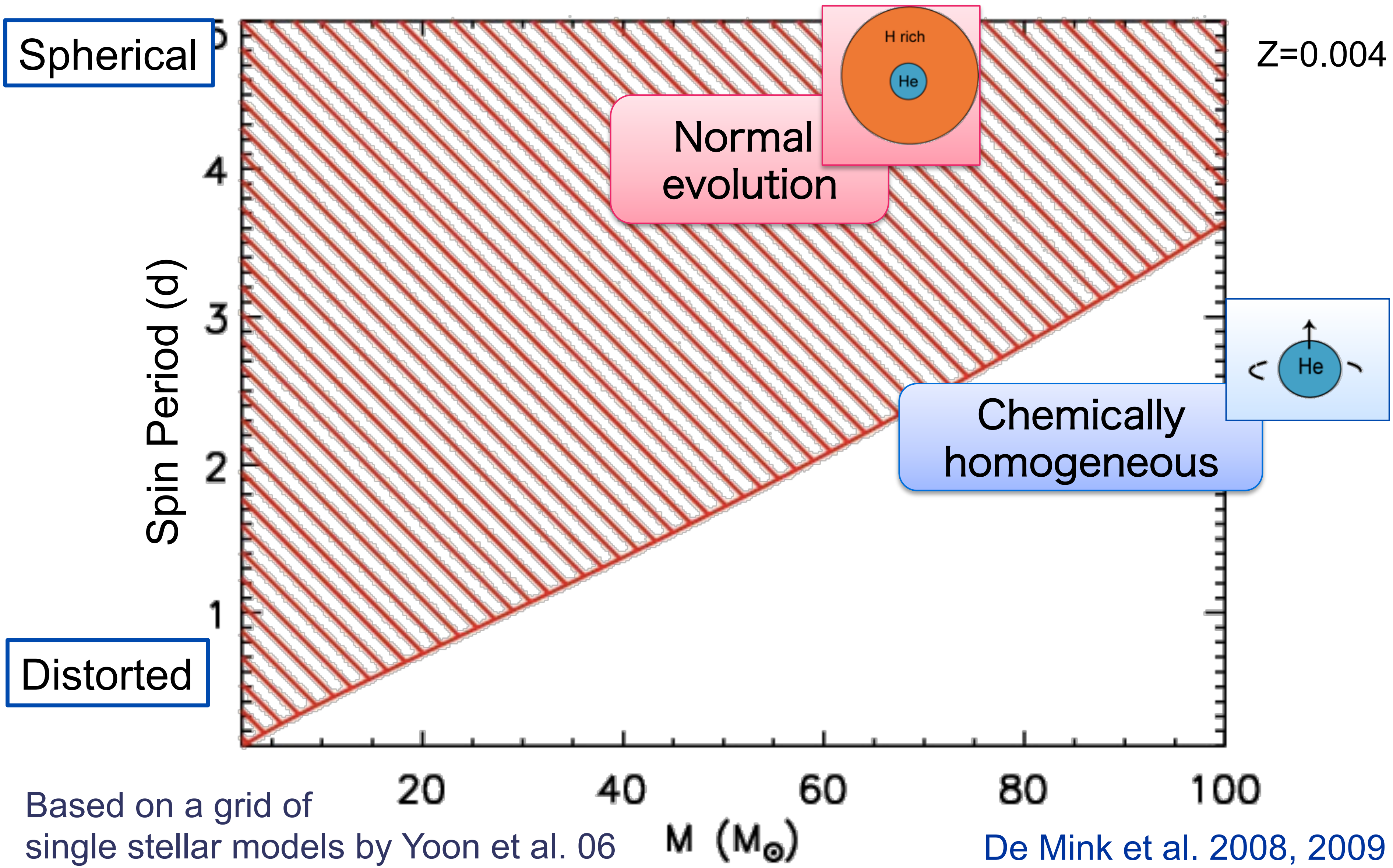


What about binaries?



De Mink et al. 2008, 2009

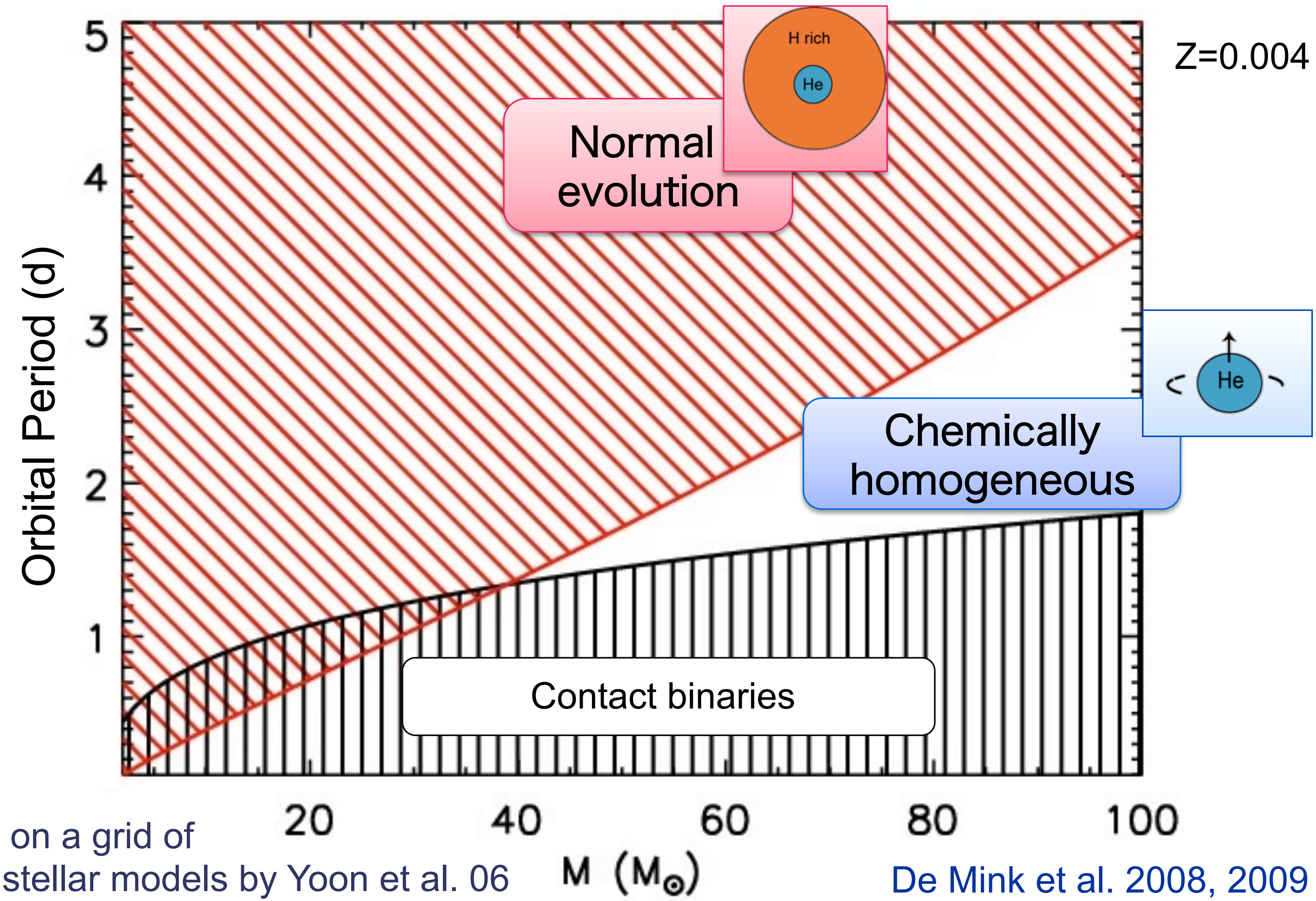
Which stars evolve homogeneously?



Based on a grid of single stellar models by Yoon et al. 06

De Mink et al. 2008, 2009

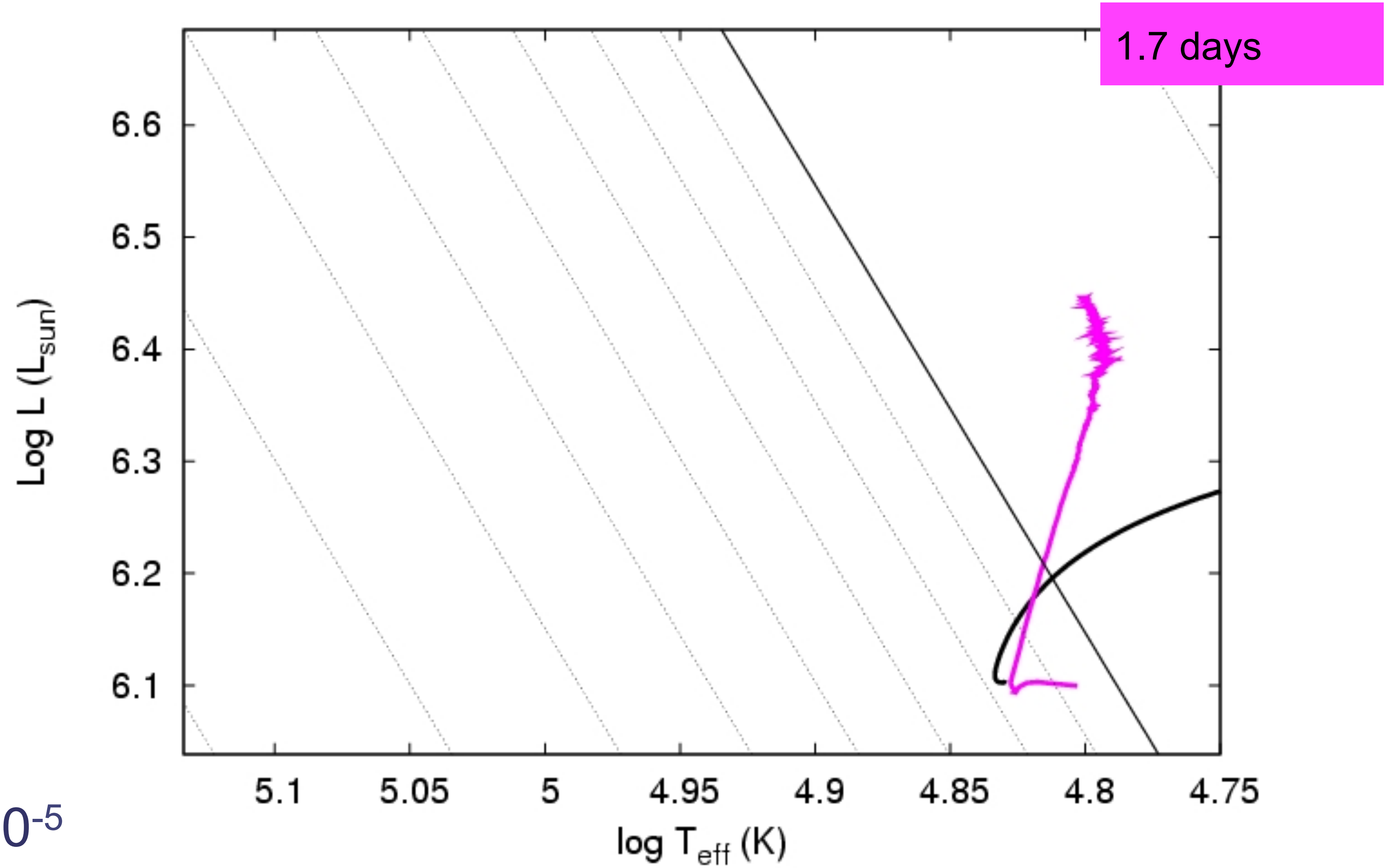
For tidally locked binaries



Based on a grid of
single stellar models by Yoon et al. 06

De Mink et al. 2008, 2009

Proof of principle

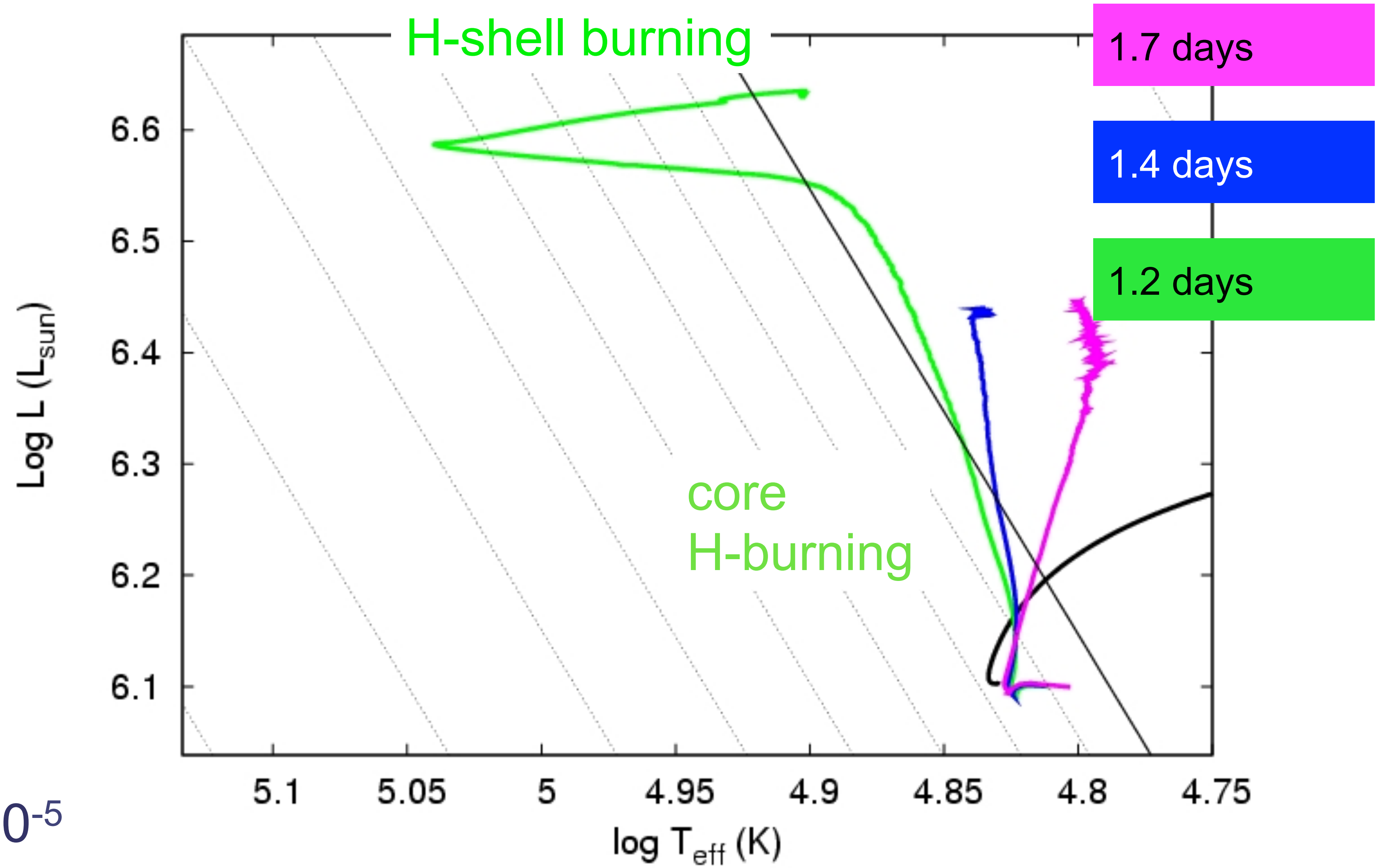


$Z = 10^{-5}$

$M_1 \sim M_2 \sim 100 M_\odot$

De Mink et al. 2008, 2009

Binary models



$Z = 10^{-5}$

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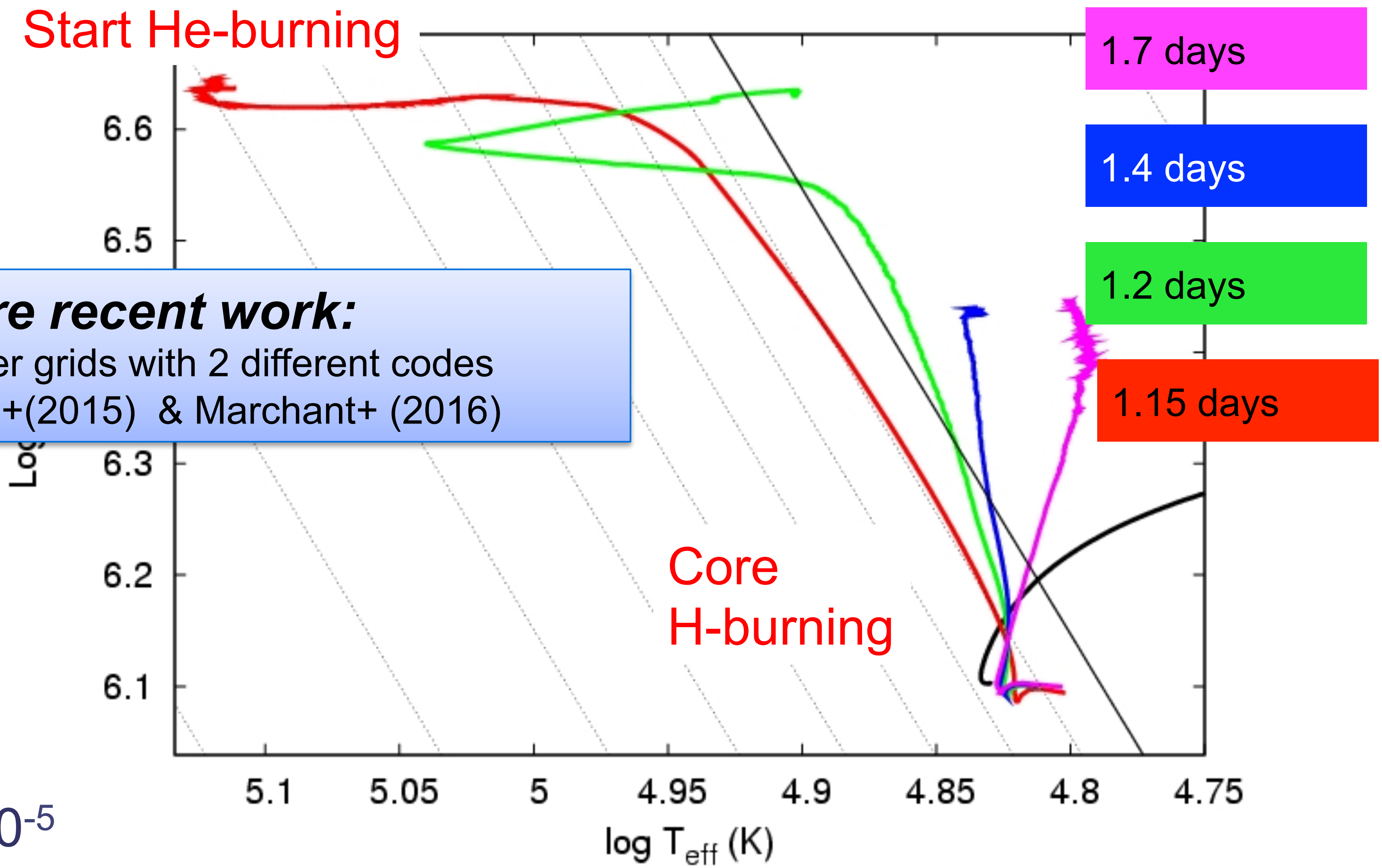
De Mink et al. 2008, 2009

Binary models



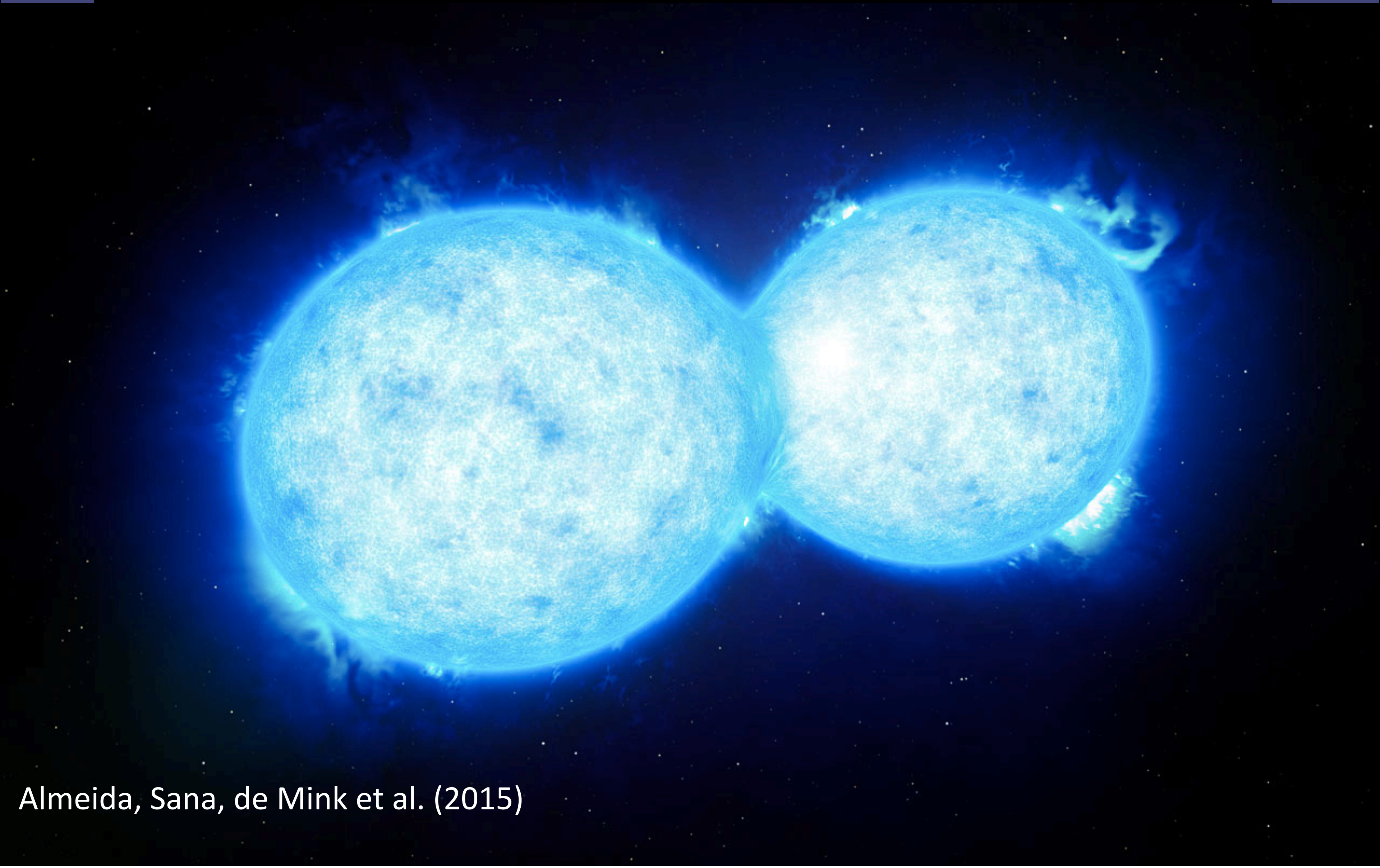
More recent work:
Larger grids with 2 different codes
Song+(2015) & Marchant+ (2016)

$Z = 10^{-5}$

$M_1 \sim M_2 \sim 100 M_\odot$

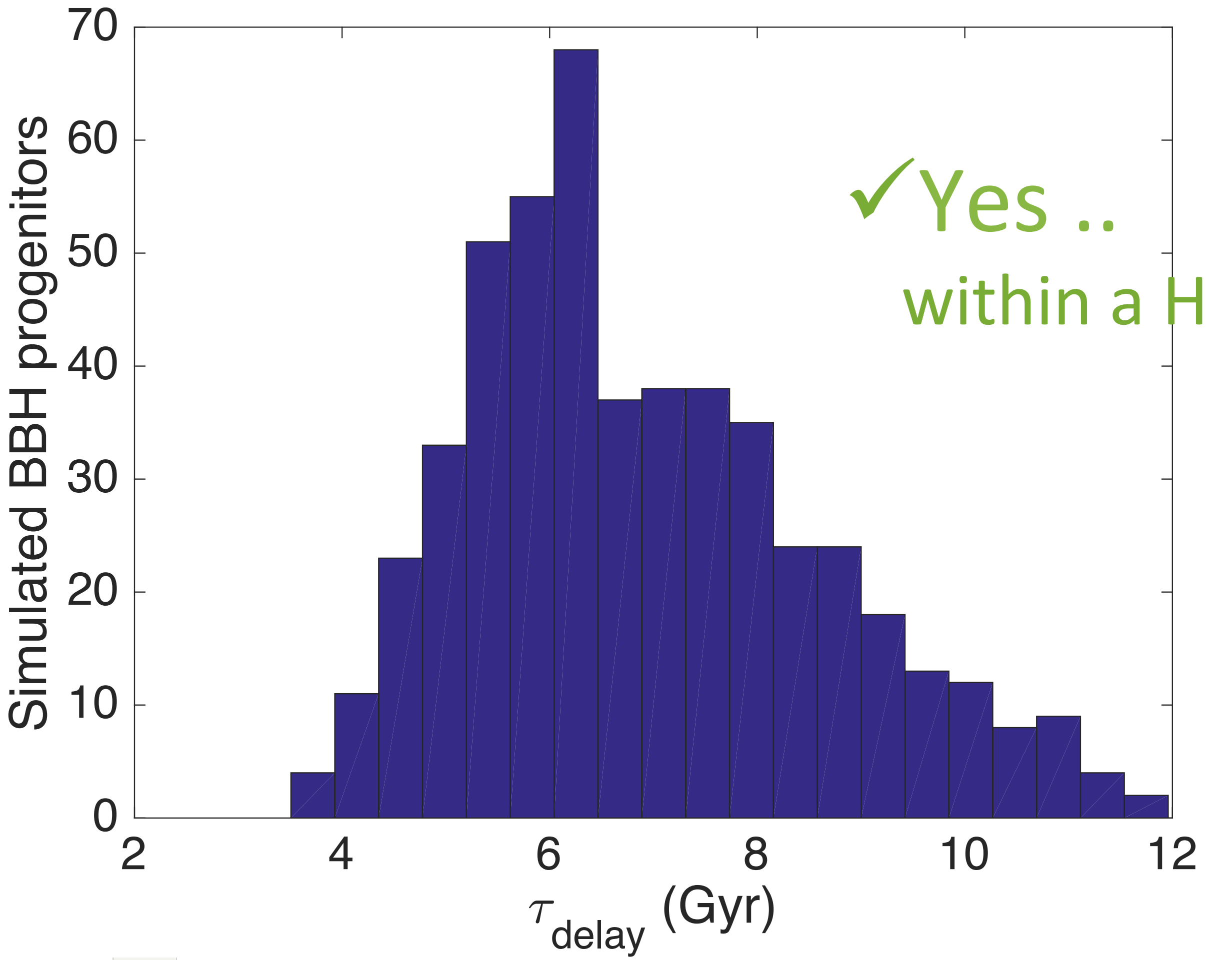
De Mink et al. 2008, 2009

Is this really happening?



Almeida, Sana, de Mink et al. (2015)

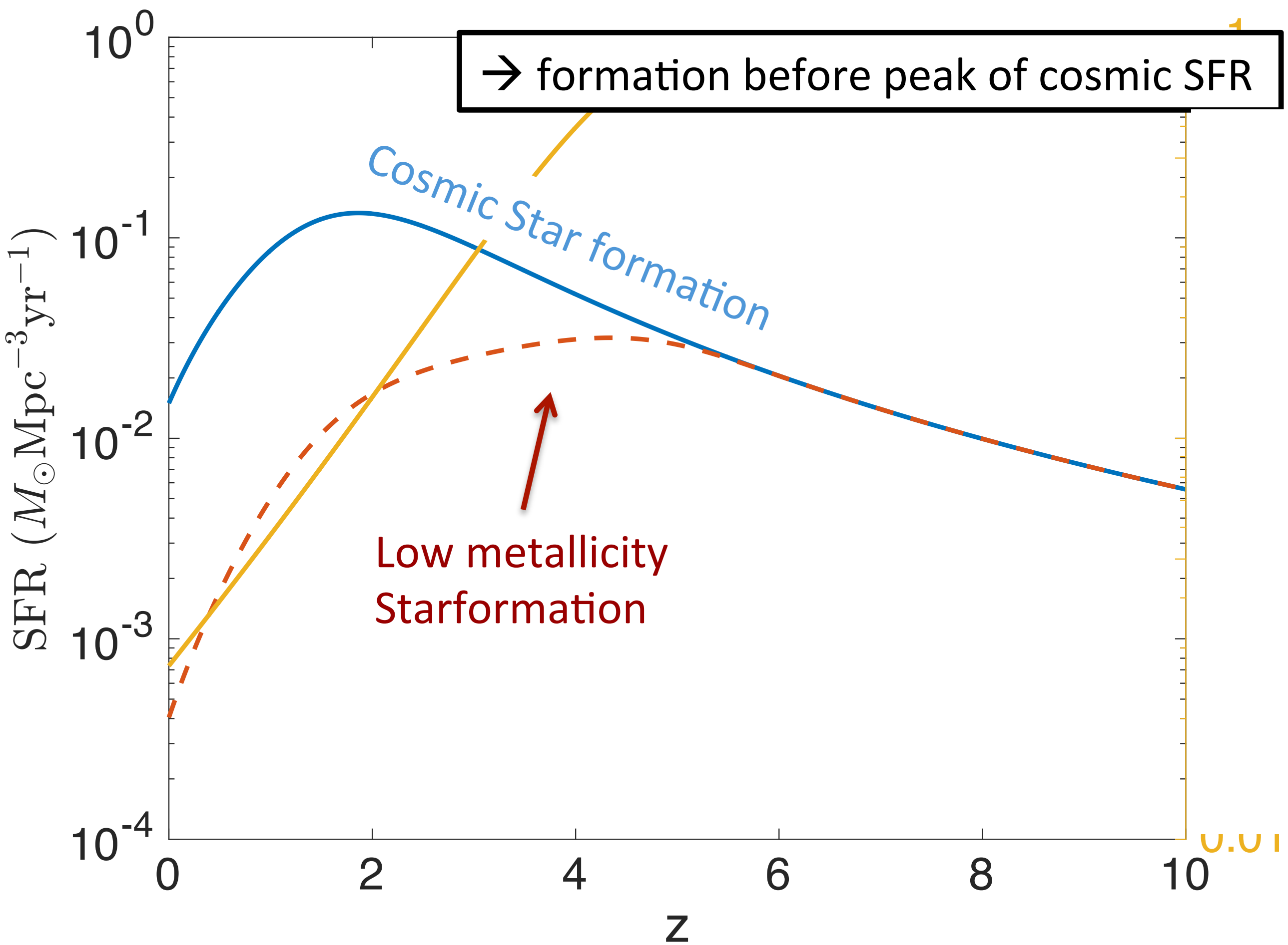
Do the Binary BHs merge?



✓Yes ..
within a Hubble time

Mandel & De Mink (2016)   cf. Marchant et al. (2016)

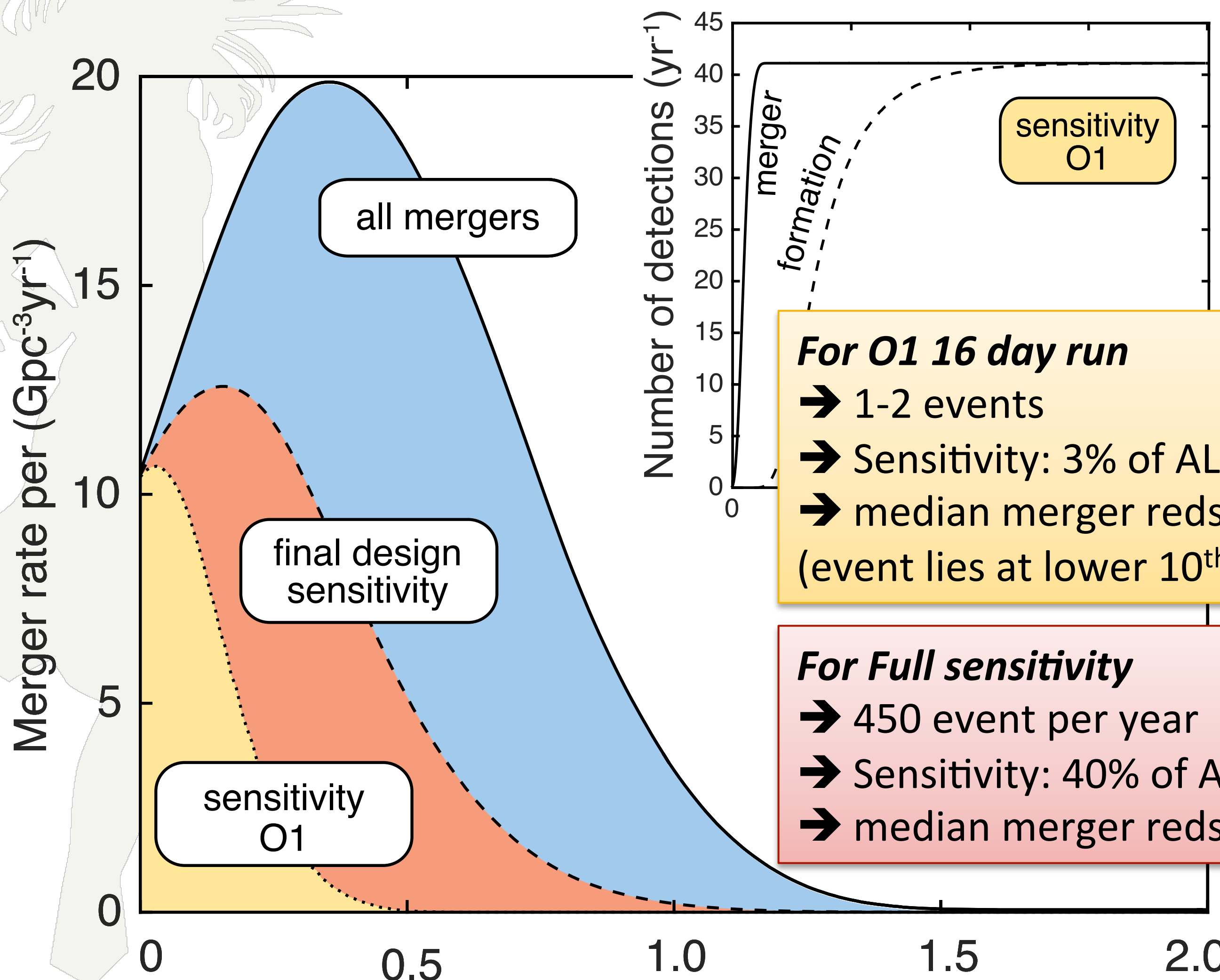
Cosmic Star formation



S.E. de Mink

Cosmic Merger Rate

De Mink & Mandel (2016)



For O1 16 day run

➔ 1-2 events

➔ Sensitivity: 3% of ALL events

➔ median merger redshift = 0.2

(event lies at lower 10th percentile)

For Full sensitivity

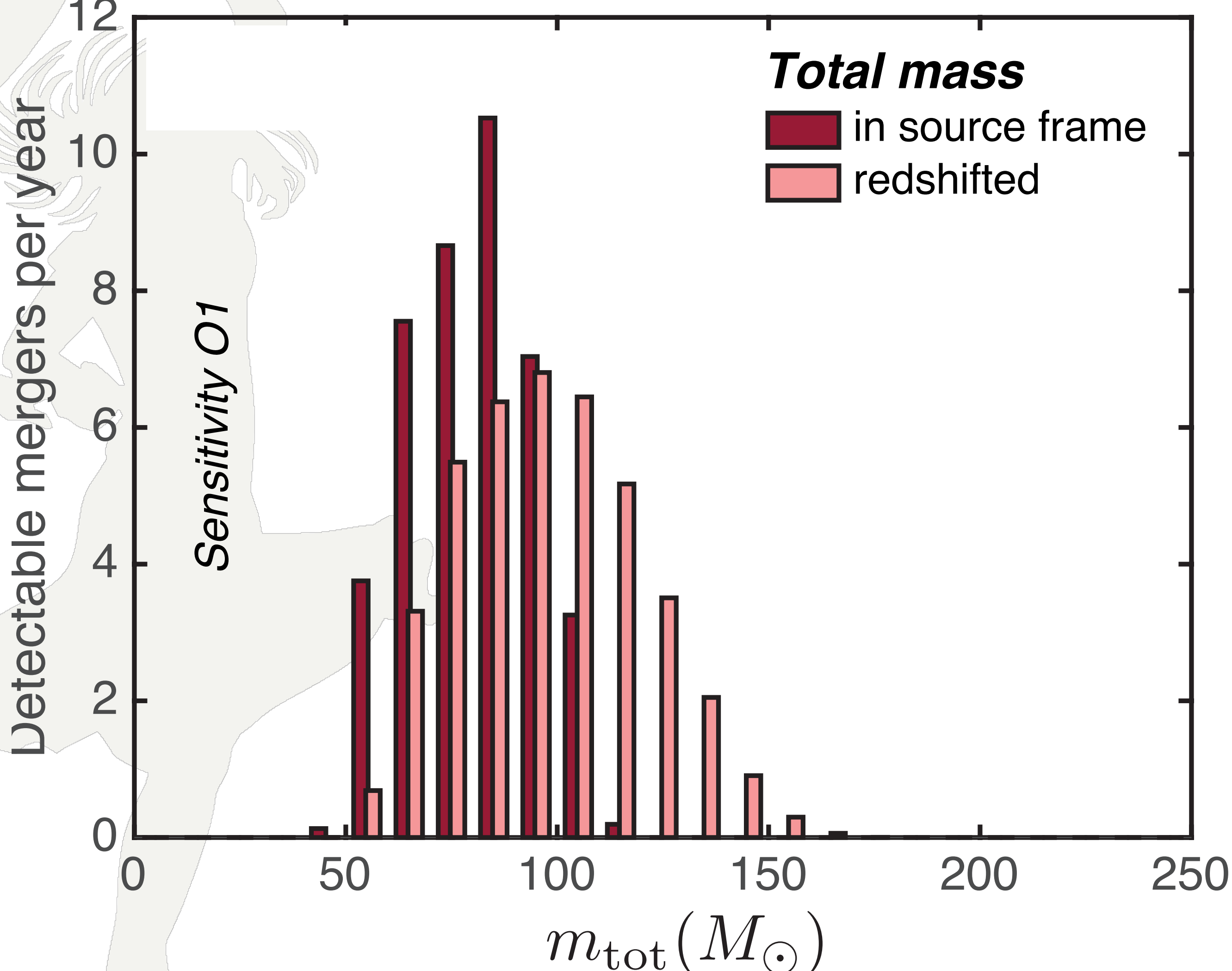
➔ 450 event per year

➔ Sensitivity: 40% of ALL events

➔ median merger redshift = 0.5

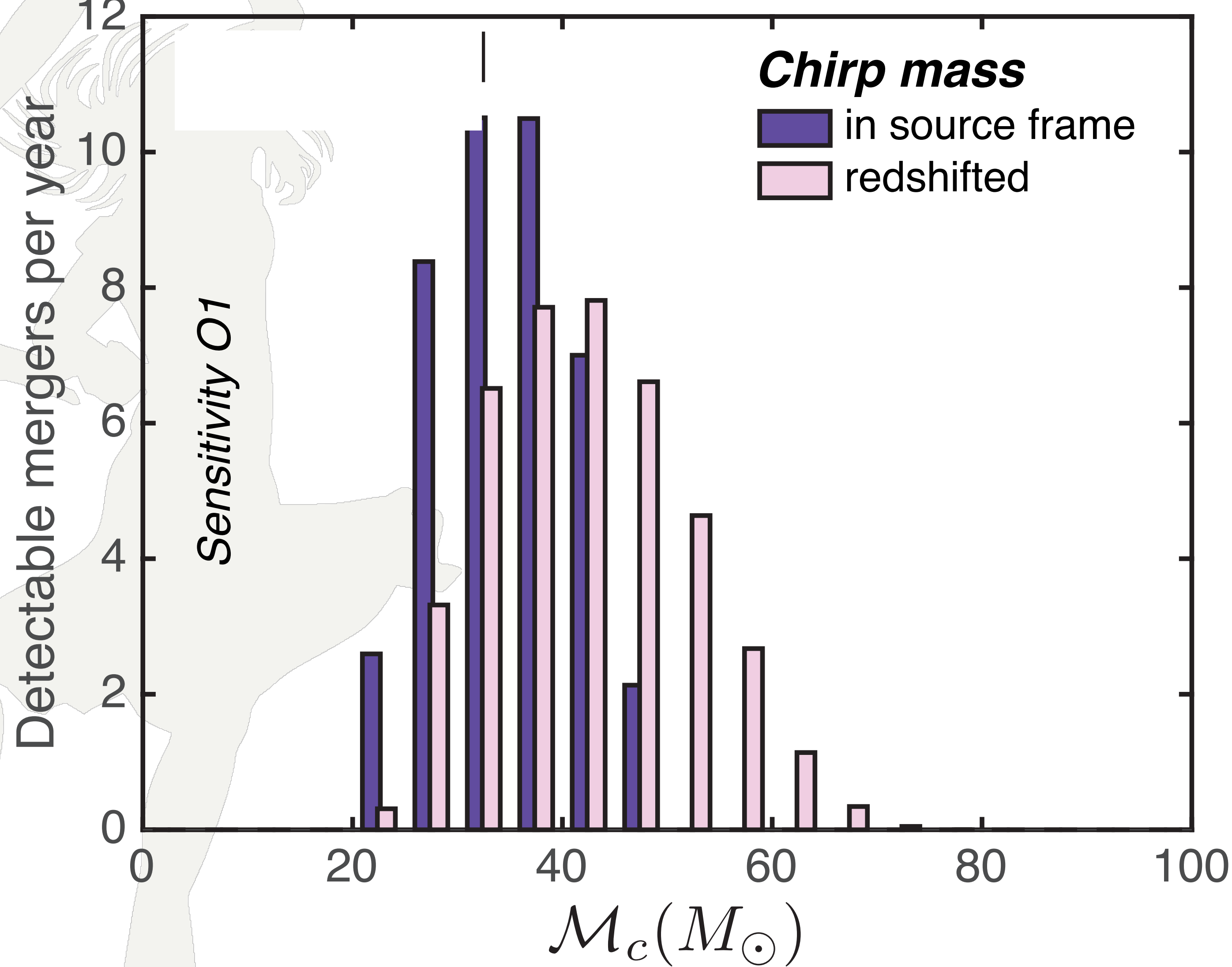
“Predicted” Total Masses

De Mink & Mandel (subm)



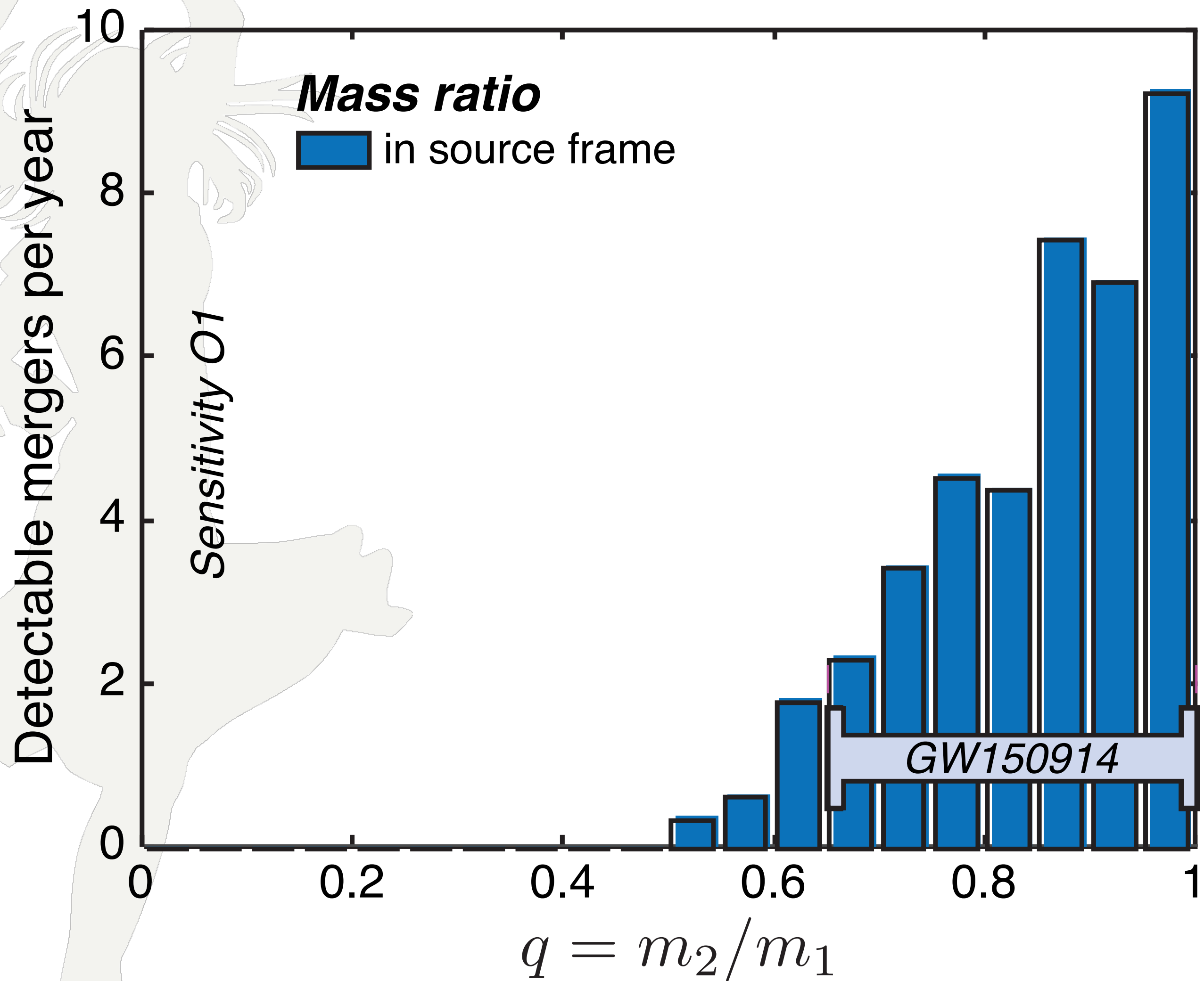
"Predicted" Chirp Masses

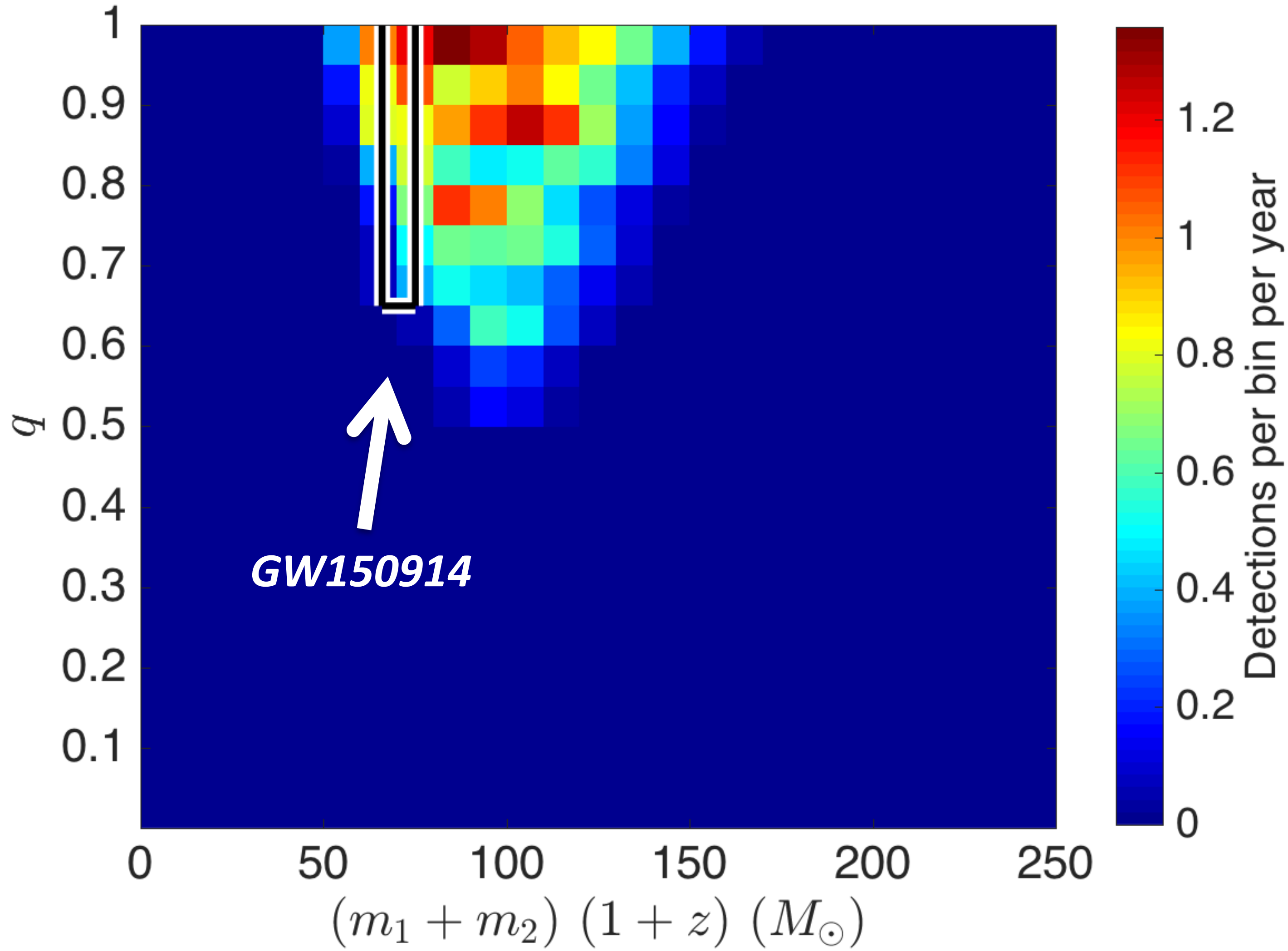
De Mink & Mandel (subm)



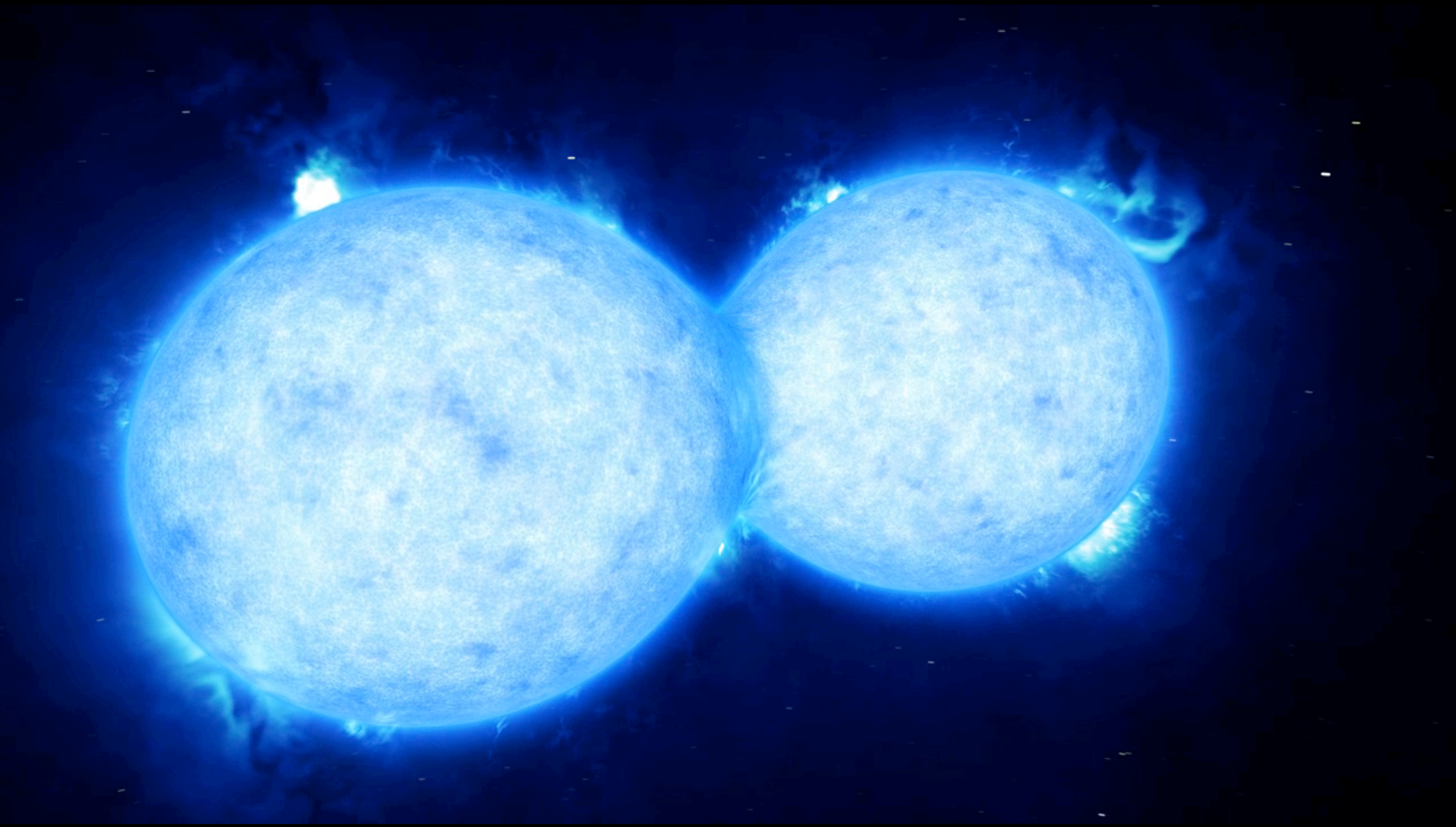
“Predicted” Mass Ratios

De Mink & Mandel (subm)





GW150914
q
$(m_1 + m_2)\ (1+z)\ (M_\odot)$
Detections per bin per year
0
50
100
150
200
250
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.2

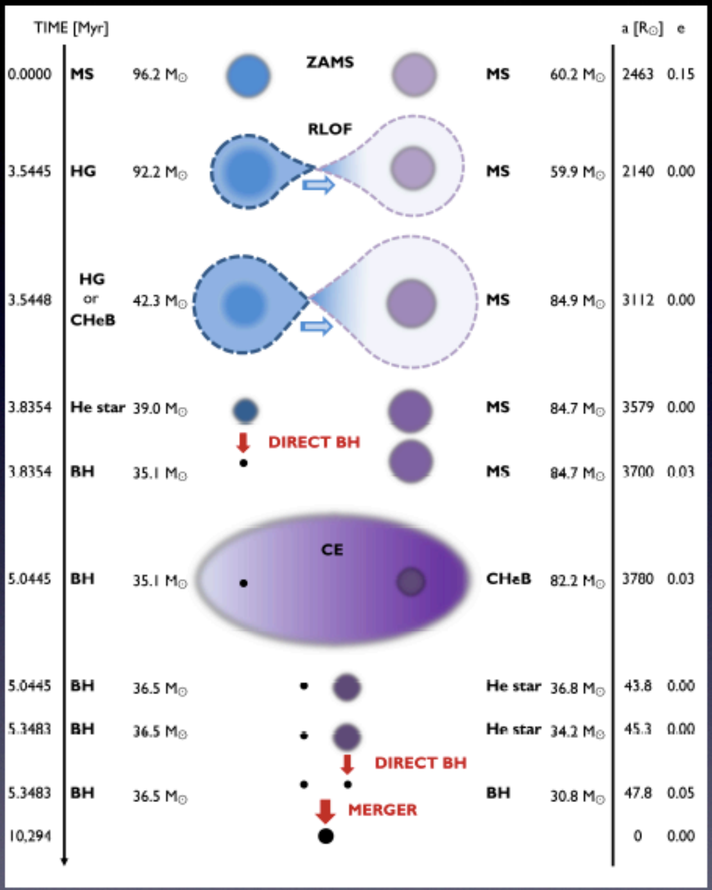


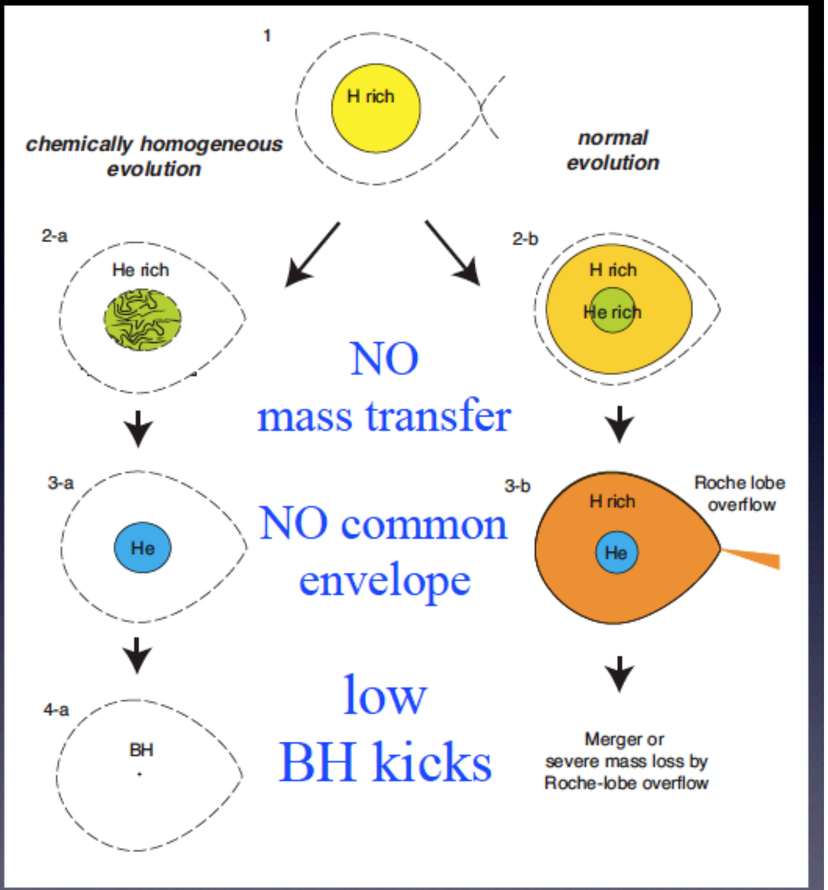
Almeida, Sana, de Mink et al. (2015)

Animation credit: ESO: L. Calcada

Summary

Summary


TIME [Myr]
a [R⊙] e
ZAMS
0.0000 MS 96.2 M⊙ MS 60.2 M⊙ 2463 0.15
RLOF
3.5445 HG 92.2 M⊙ MS 59.9 M⊙ 2140 0.00
3.5448 HG or CHeB 42.3 M⊙ MS 84.9 M⊙ 3112 0.00
3.8354 He star 39.0 M⊙ MS 84.7 M⊙ 3579 0.00
DIRECT BH
3.8354 BH 35.1 M⊙ MS 84.7 M⊙ 3700 0.03
CE
5.0445 BH 35.1 M⊙ CHeB 82.2 M⊙ 3780 0.03
5.0445 BH 36.5 M⊙ He star 36.8 M⊙ 43.8 0.00
5.3483 BH 36.5 M⊙ He star 34.2 M⊙ 45.3 0.00
DIRECT BH
5.3483 BH 36.5 M⊙ BH 30.8 M⊙ 47.8 0.05
MERGER
10.294 0 0.00


1
H rich
chemically homogeneous evolution
normal evolution
2-a
He rich
2-b
H rich
He rich
NO mass transfer
3-a
He
3-b
H rich
He
Roche lobe overflow
NO common envelope
4-a
BH
low BH kicks
Merger or severe mass loss by Roche-lobe overflow