The Making-of … a Binary Black Hole

formation channels of stellar origin

erc

In collaboration with: BinCosmos group in Amsterdam, Hugues Sana, Leonardo Almeida, Ilya Mandel, Chris Belczynski, Andrew King, Pablo Marchant, Philip Podsiadlowski, Matteo Cantiello , Simon Stevenson, Alejandro Vigna-Gómez, VLT-FLAMES Massive Star Consortium, and many others

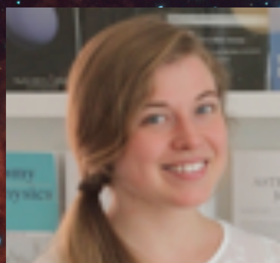
Bin Cosmos

Selma E. de Mink

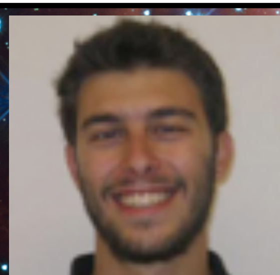
Anton Pannekoek Institute for Astronomy, University of Amsterdam

BinCosmos Group @Amsterdam

PhD Students



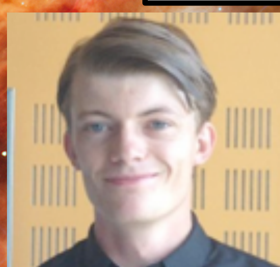
Ylva Götberg



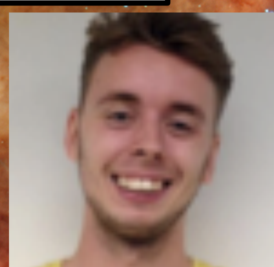
Manos Zapartas

Mathieu Renzo

MSc Students



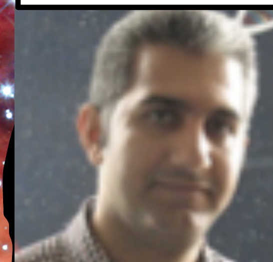
Abel Schootemeijer
→ Langer



Coen Neijssel
→ Mandel

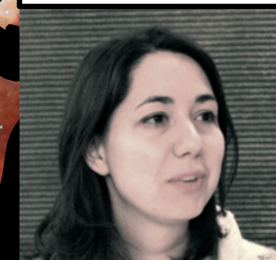
Incoming Prize Fellows

Marie Curie



Ehsan Moravveji

VENI

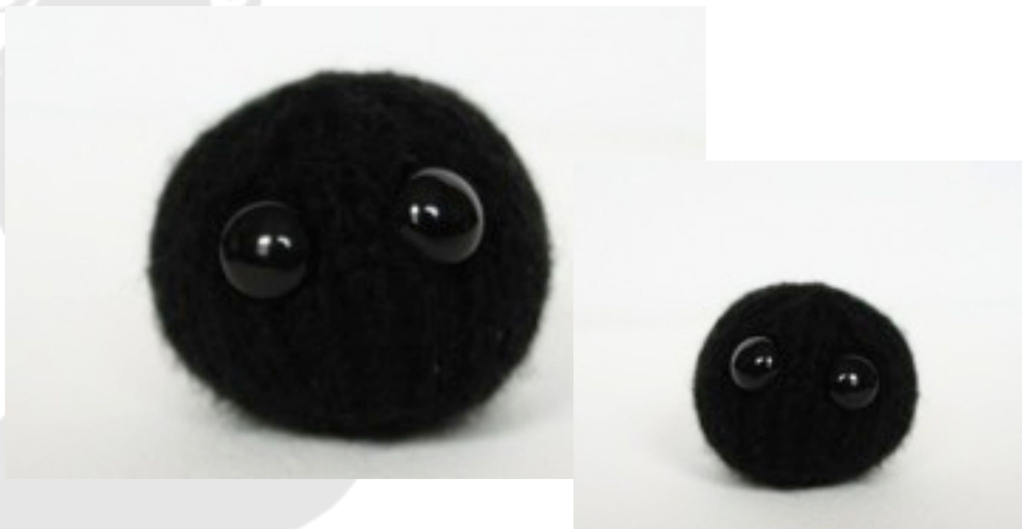


Silvia Toonen

? ? ? ?

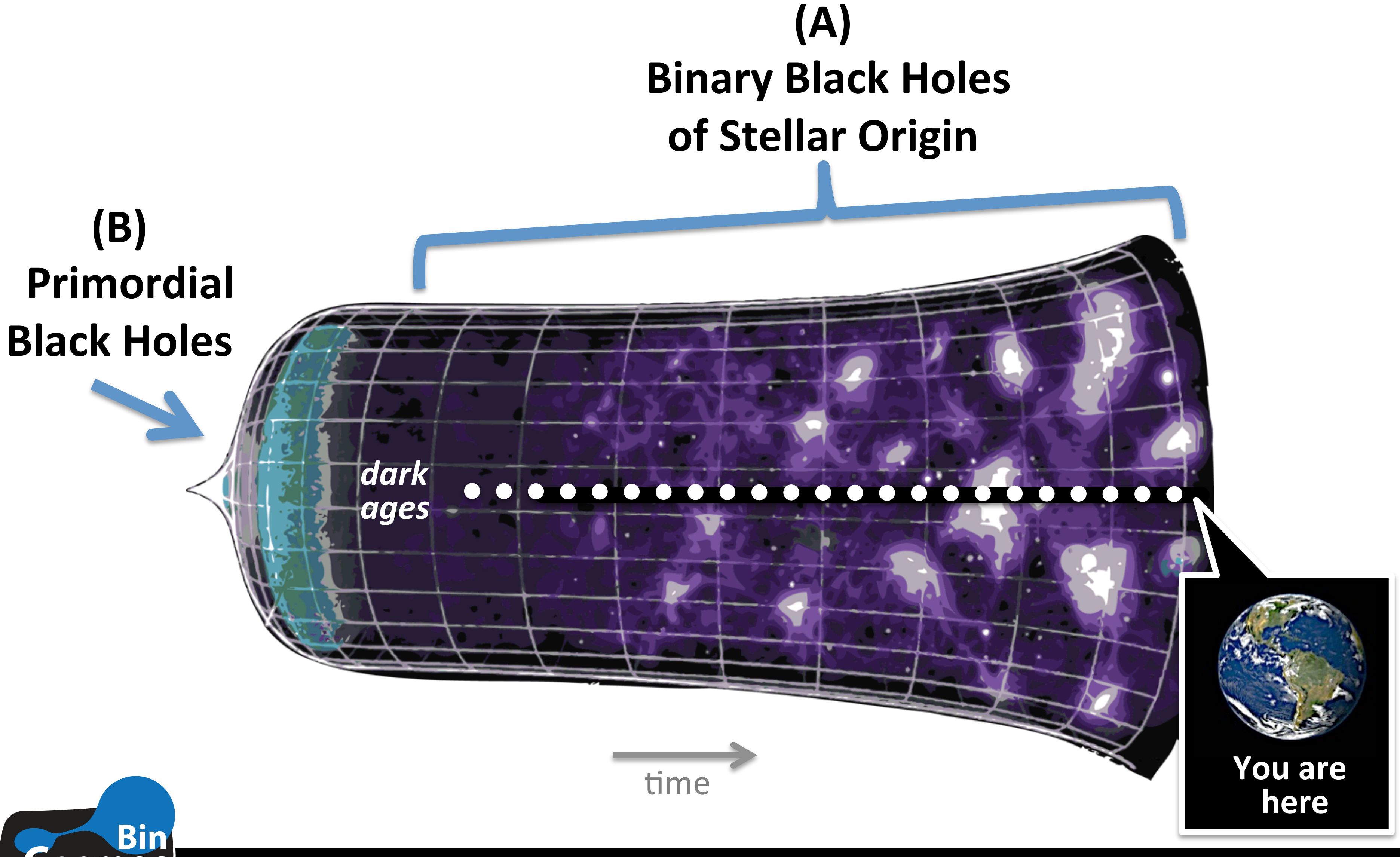
Selma E. de Mink
Anton Pannekoek Institute for Astronomy, University of Amsterdam

Scope of this talk



*Merchandise: Baby black hole, comes with adoption certificate www.etsy.com

Making-of ...



(A)
Binary Black Holes
of Stellar Origin
(B)
Primordial
Black Holes
dark
ages
time
You are
here

Scope

(A) Stellar Origin Black Holes

This Talk

✓ Gravitational Collapse of
(the core of) a massive star

✓ Observed
(albeit at somewhat lower mass)

(B) Primordial Black Holes

✓ Gravitational Collapse of
extreme densities at high redshift

✓ Constituent of Dark Matter
(instead / in addition to more popular
but still elusive WIMPs)

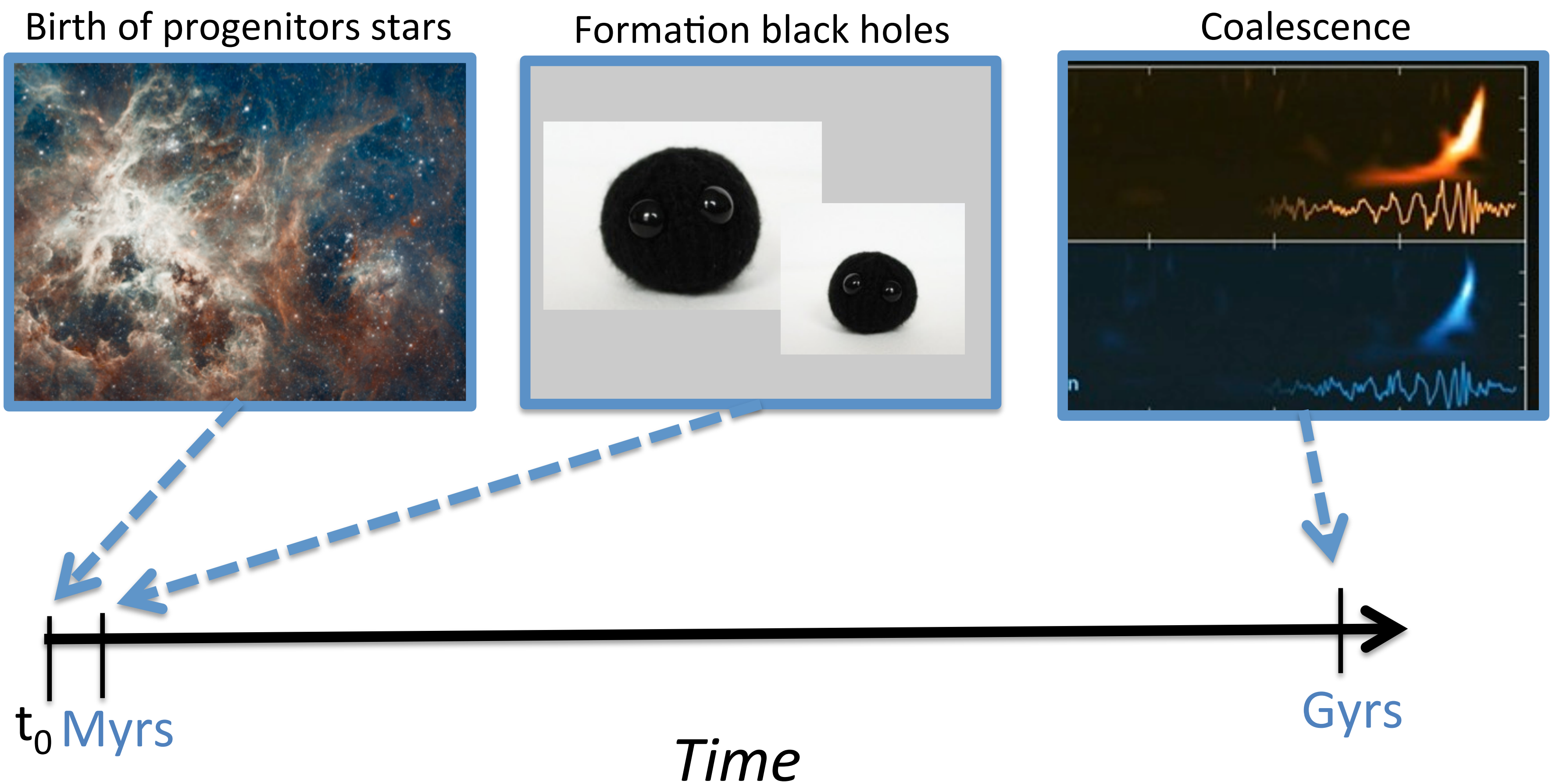
✓ Somehow evaded strong constraints by
- Micro lensing events
- CMB spectral distortions

✓ Still hypothetical … (so far)

Carr & Hawking (1974), Carr (1975, 1976), Garcia-Bellido et al. (1996), Khlopov (2010), Frampton et al. (2010), Blais et al. (2002), …

BinCosmos

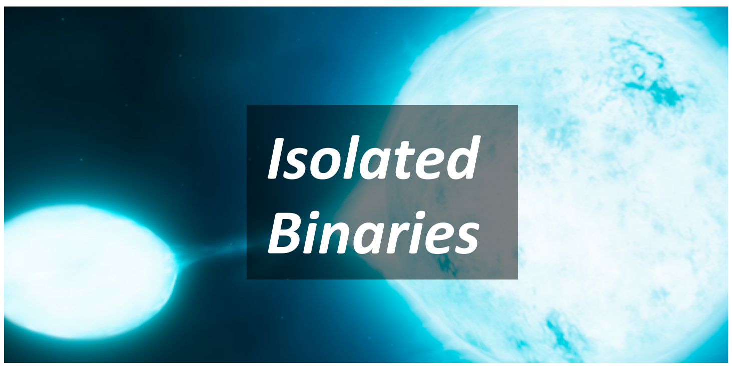
Stellar Origin



Two types of Formation Channels

1. Evolutionary formation channels

2. Dynamical formation channels



Stellar Density

Two types of Formation Channels

1. Evolutionary formation channels

- ✓ **Classical channel** (involving common envelope or other forms of mass transfer)
- ✓ **Chemically Homogeneous Channel** (mixing processes in near contact binaries)
- ✓ …

2. Dynamical formation channels

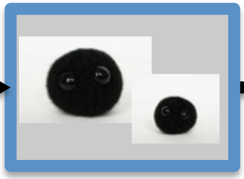
- ✓ Chaotic Dynamics in **dense Star Clusters** or Nuclear star clusters
- ✓ Resonances in **Triple systems**
- ✓ Gaseous **AGN discs** near supermassive black holes in centers of galaxies
- ✓ …

Two Main Challenges for all progenitor scenarios

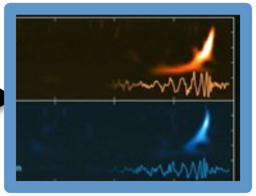
Progenitors

Birth

Formation BHs



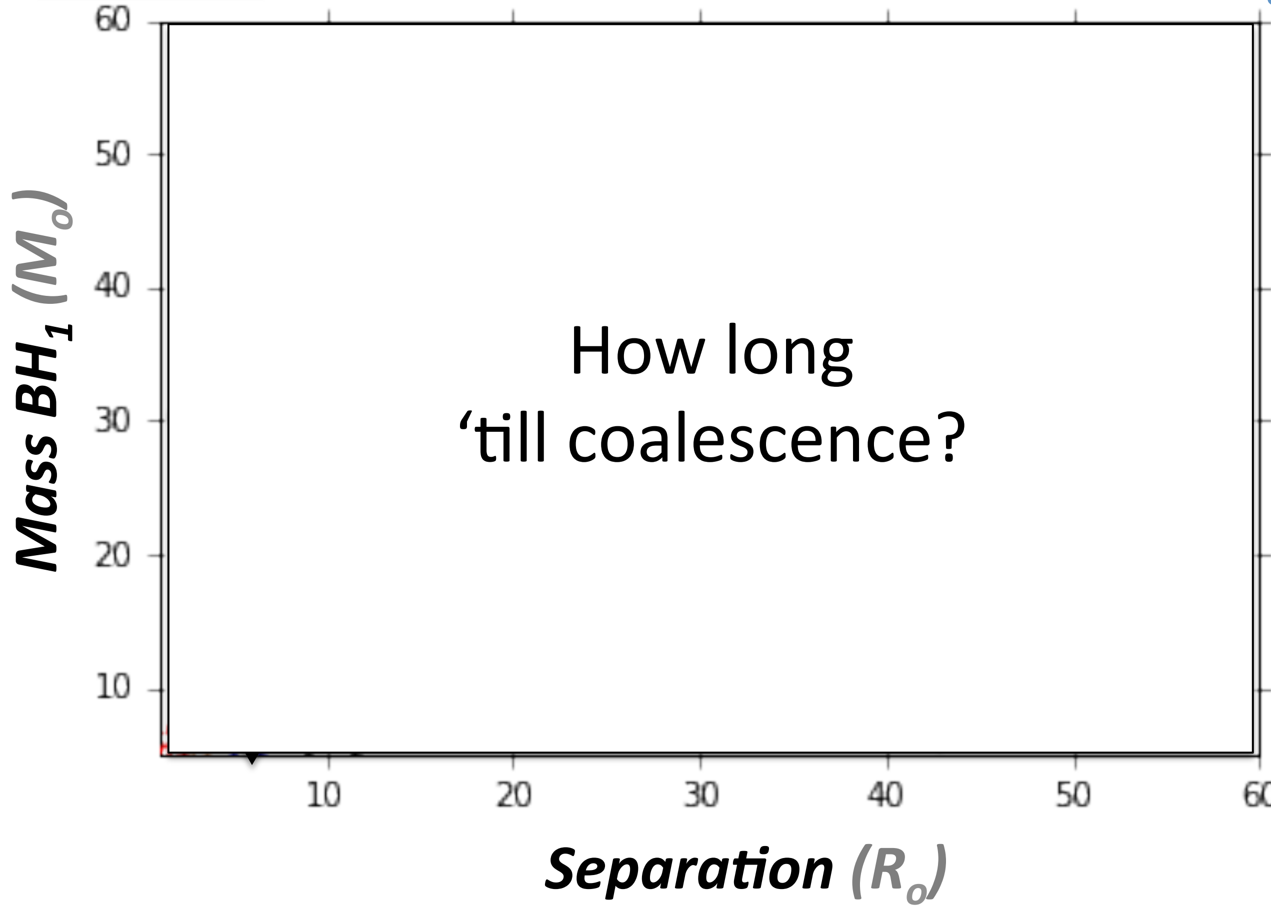
Coalescence



1."Separation Challenge"

2. "Mass Challenge"

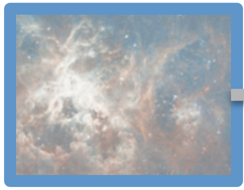
Separation



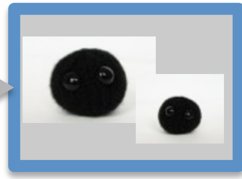
Using Peters '64

Separation

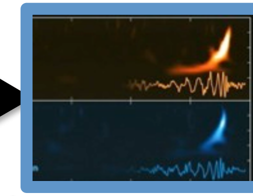
Birth

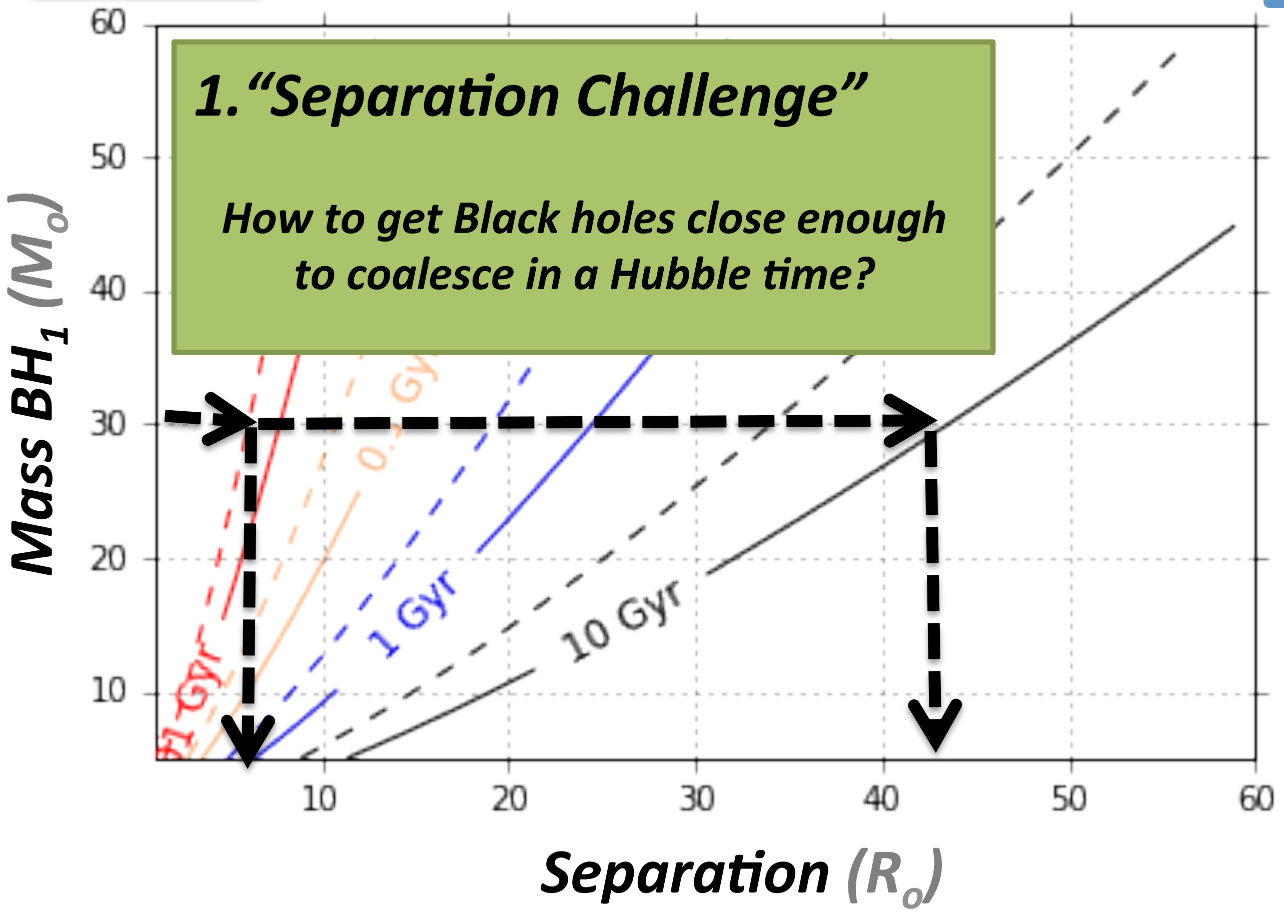


Formation BHs



Coalescence





1. "Separation Challenge"

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

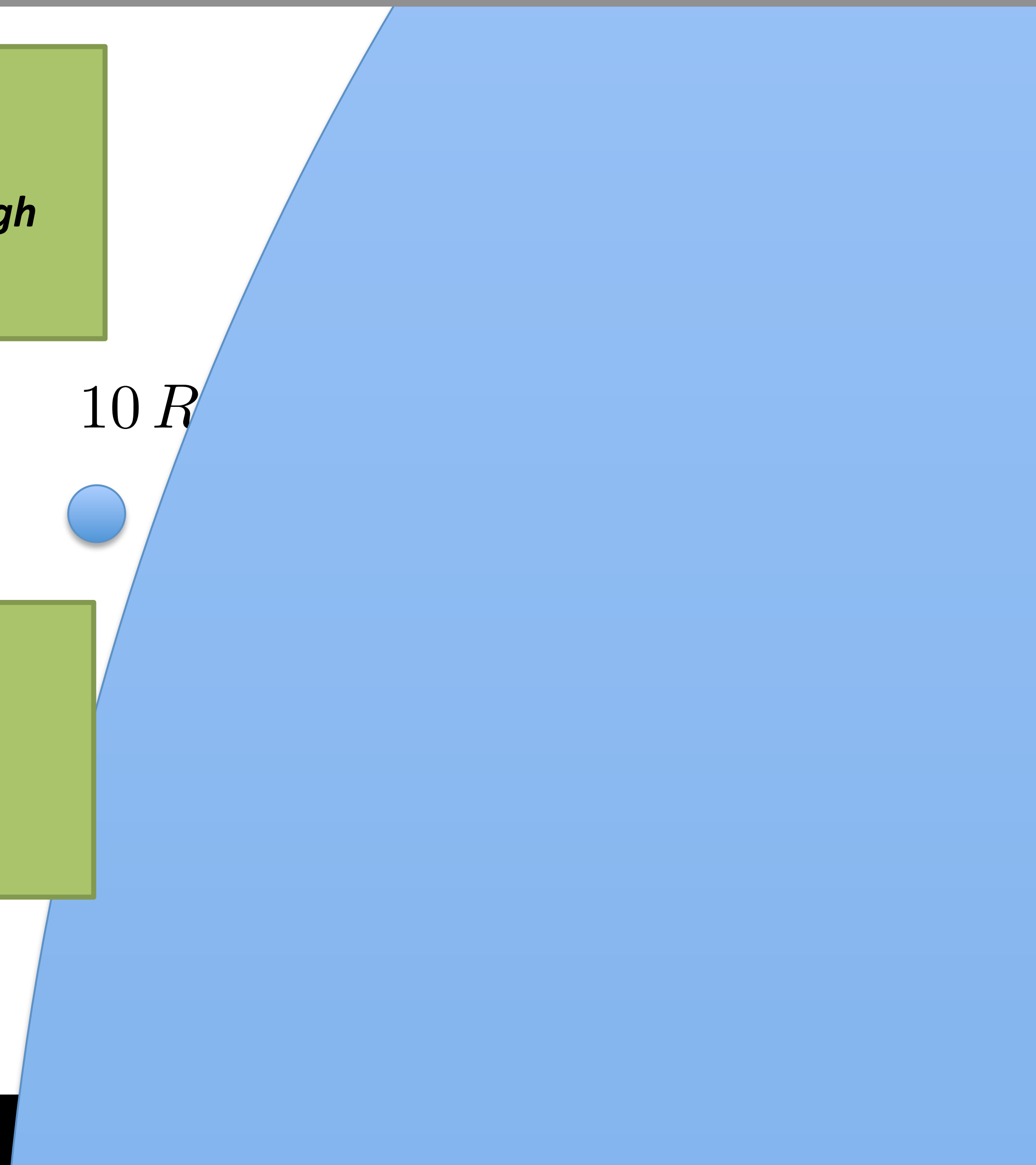
R_o ~ 7e10 cm

Using Peters '64

Separation

1."Separation Challenge"

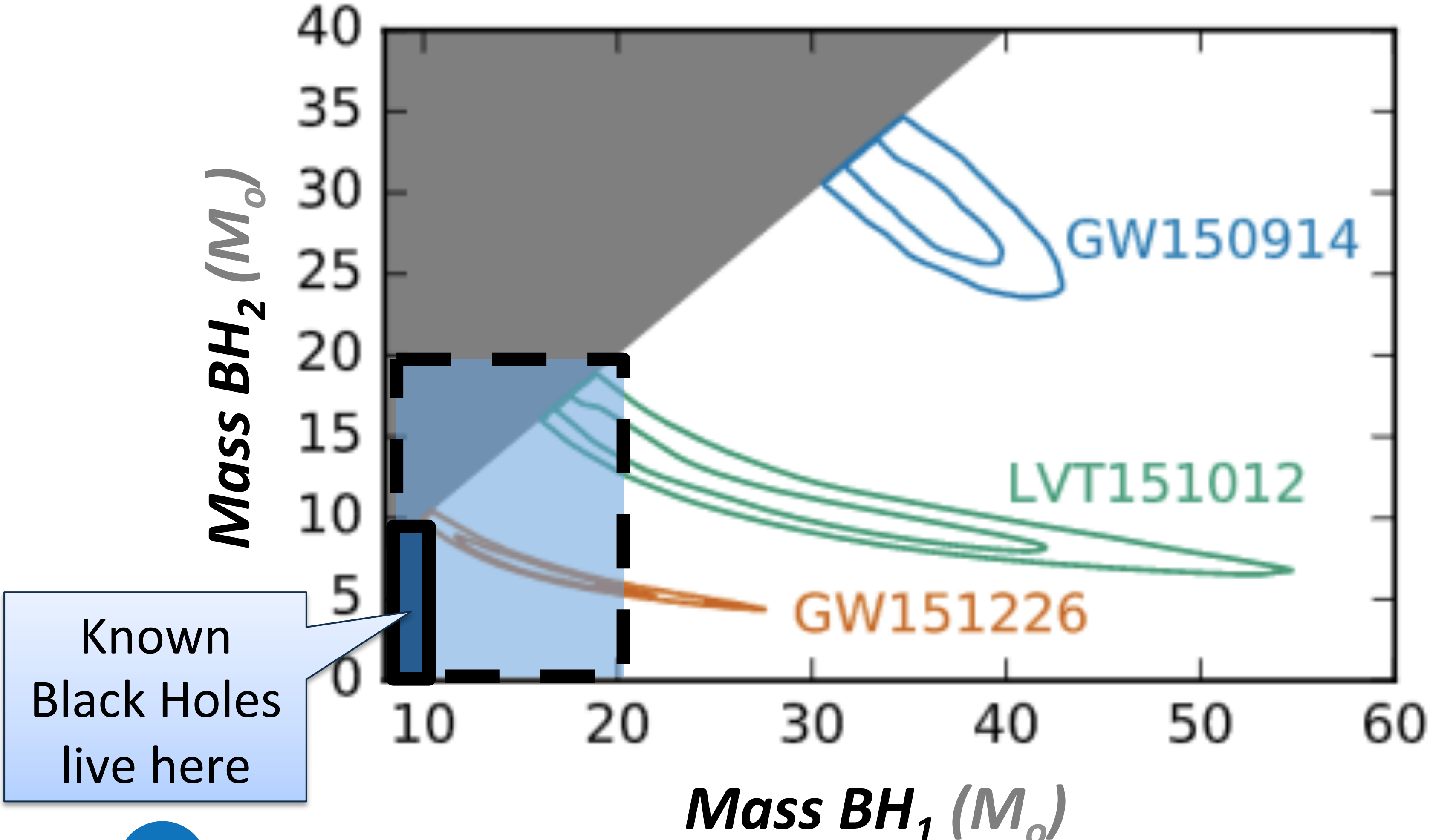
How to get Black holes close enough to coalesce in a Hubble time?



2. "Mass Challenge"

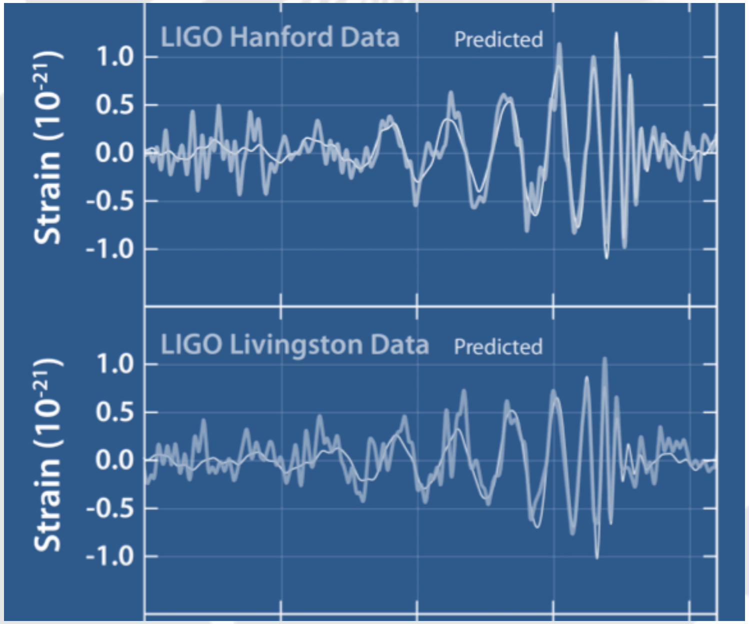
How to avoid excessive Mass loss?

Masses



Arxiv:1606.04856v2

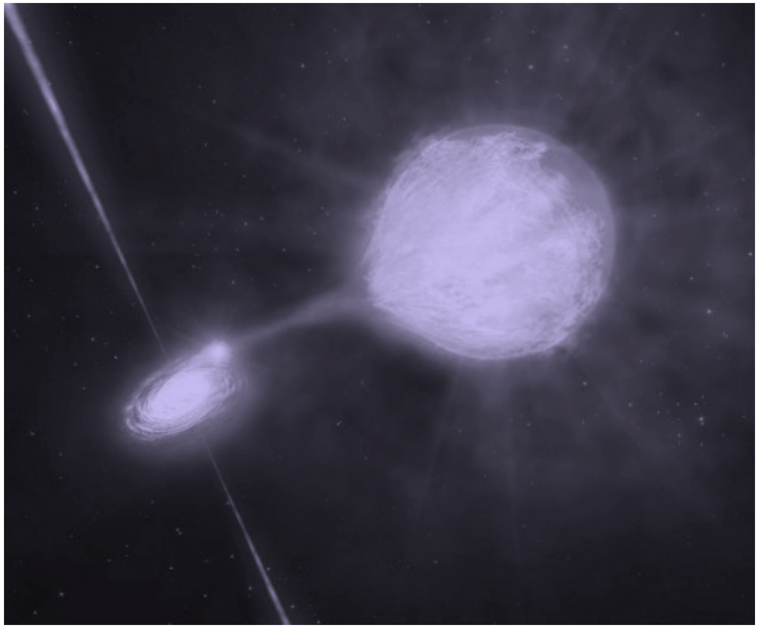
Masses



Gravitational Waves

Caltech/MIT/LIGO Lab

VS

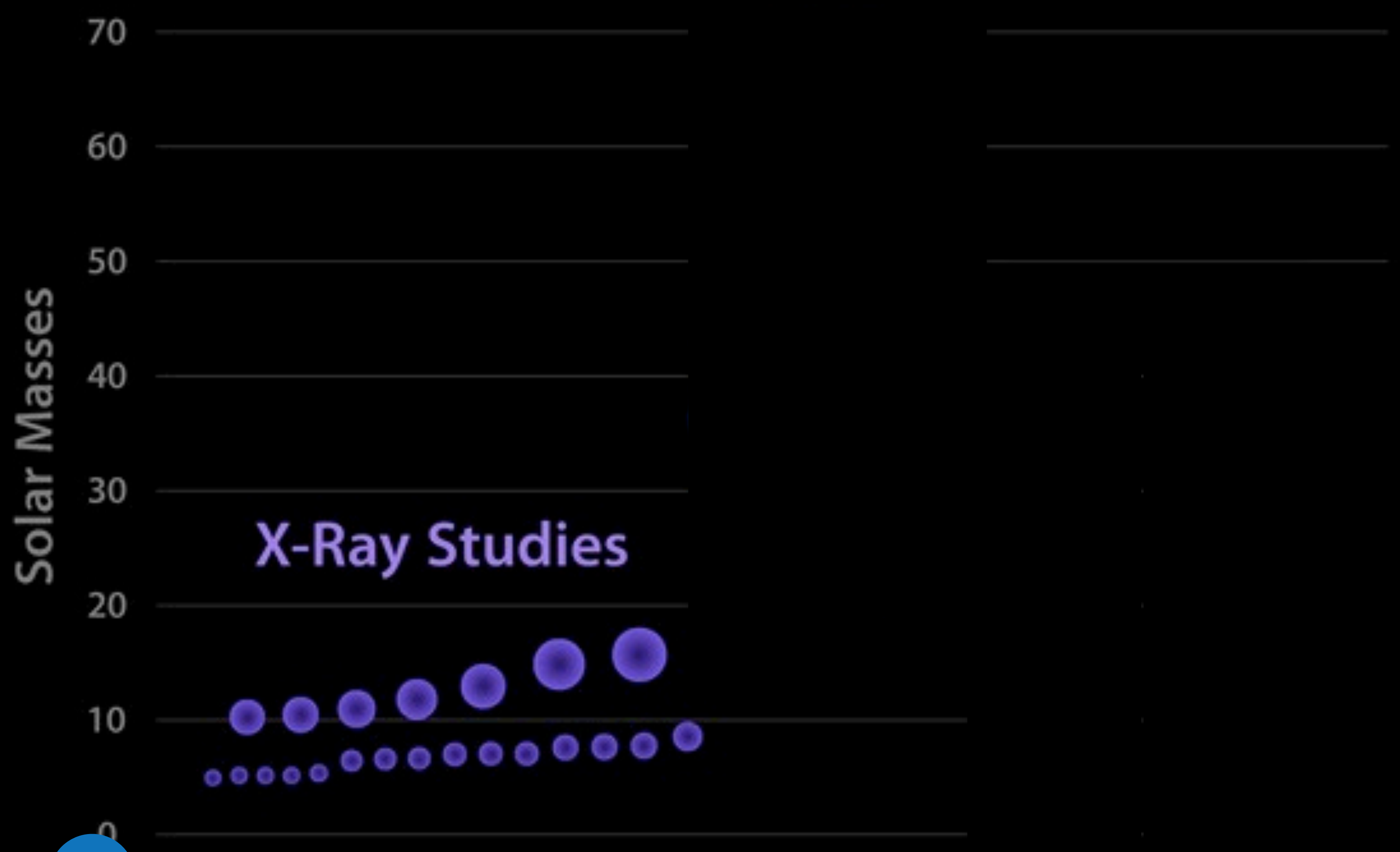


X-ray Binaries

ESO/L. Calçada/M.Kornmesser

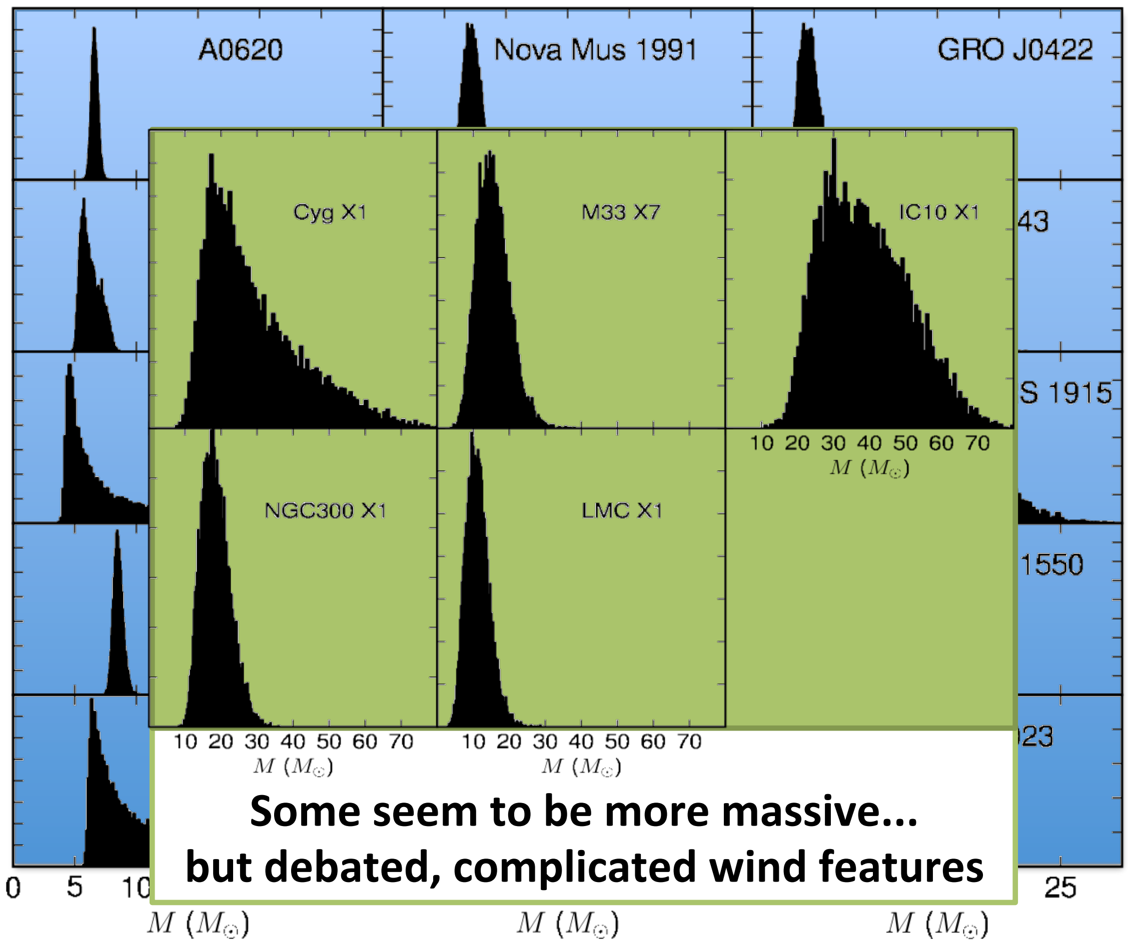
BinCosmos

Masses



Courtesy Caltech/MIT/LIGO Laboratory

Black holes with Known Masses: Typically: 5-10 M_o



Farr et al. (2011)

Greiner et al. (2001) Gelino et al. (2008) Harlaftis & Filippenko (2005) Orosz et al. (2004) Filippenko et al. (1999) Cantrell et al. (2010) Neilsen et al. (2008) Gelino & Harrison (2003) Gelino et al. (2001) Greene et al. (2001) Orosz (2003) Orosz et al. (2011) Orosz (2003) Charles & Coe (2006) Khargharia et al. (2010) Casares et al. (2009) Charles & Coe (2006) Charles & Coe (2006) Gies et al. (2003) Orosz et al. (2007) Crowther et al. (2010) Orosz et al. (2009) Prestwich et al. (2007) Silverman & Filippenko (2008)

Are local X-ray binaries Representative?

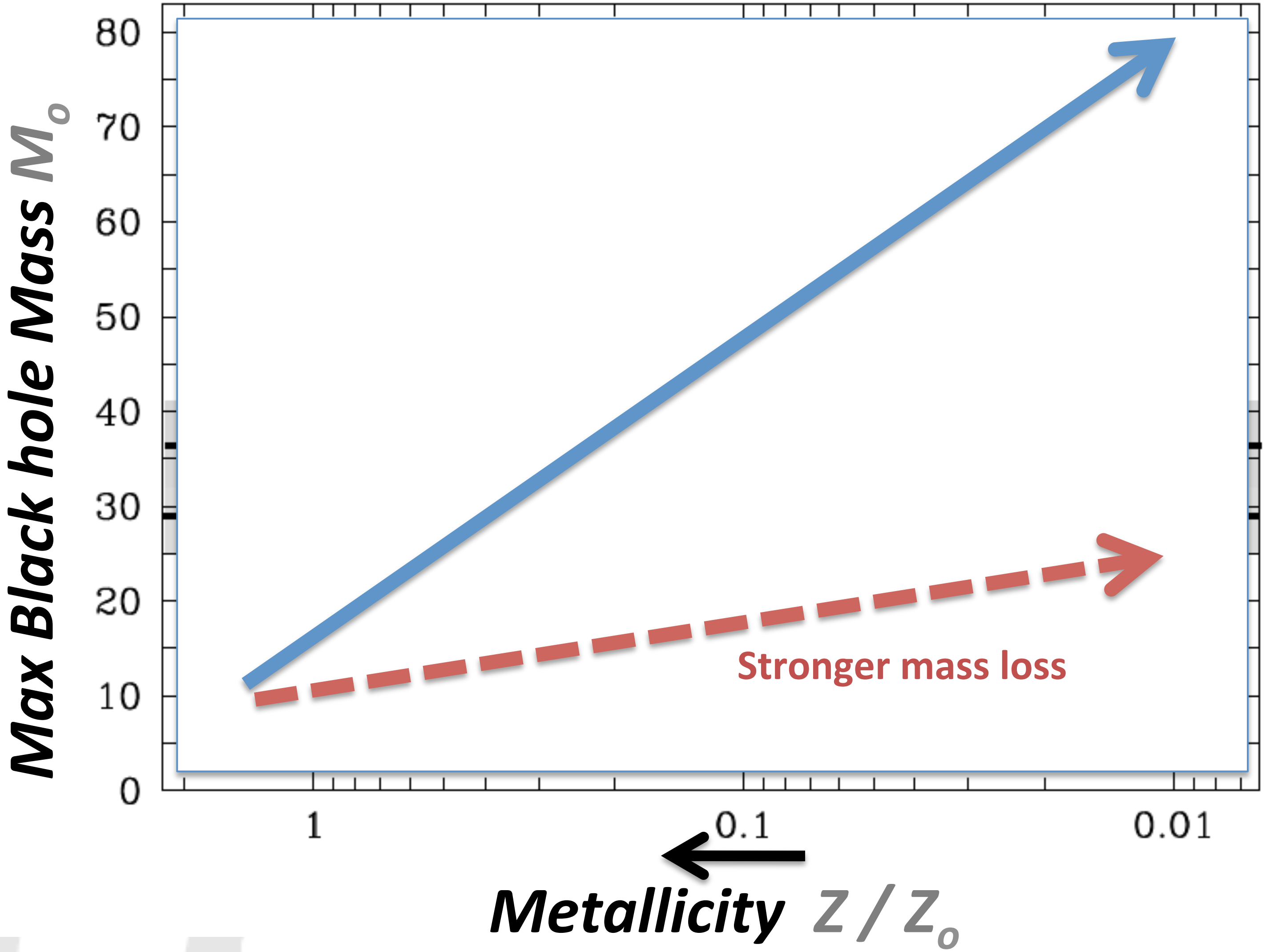
“Mass Challenge”

How to avoid
excessive Mass loss?

Need for reduced winds

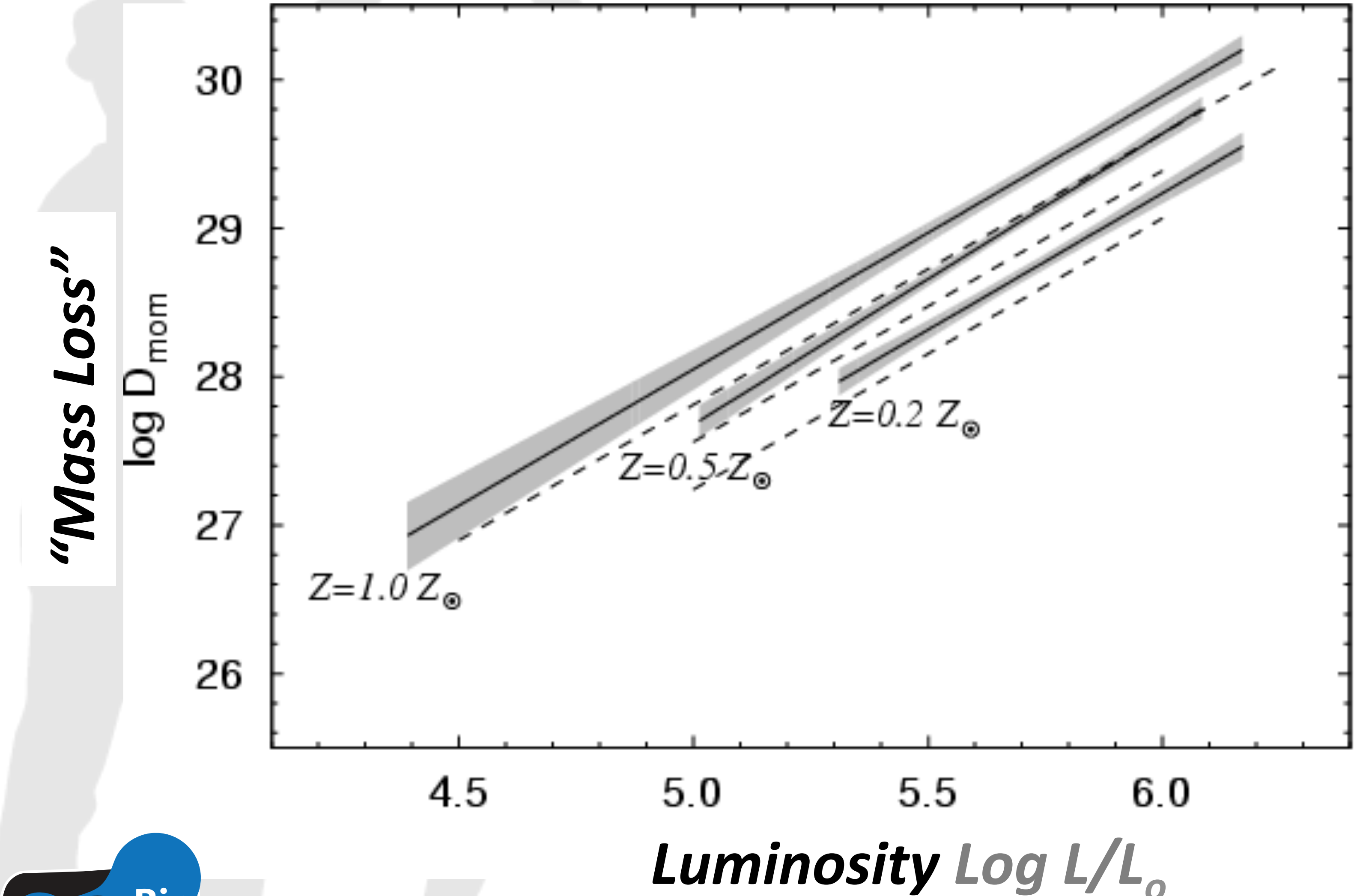
Belczynski et al. 2010

Astrophysical implications paper



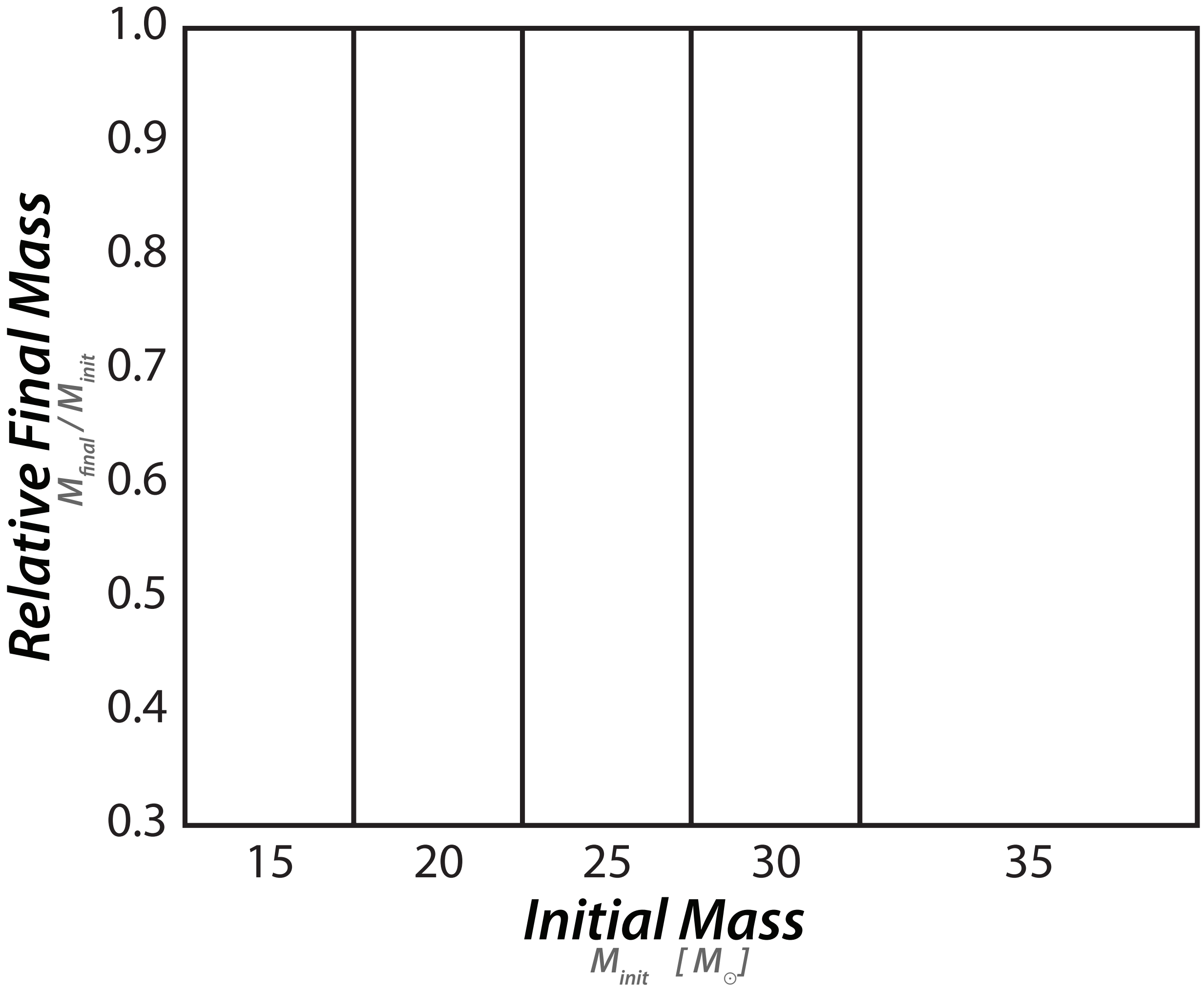
Reduced (line driven) winds at lower metallicity

Vink et al. 2000, Mokiem et al. 2005



Mass loss uncertainties

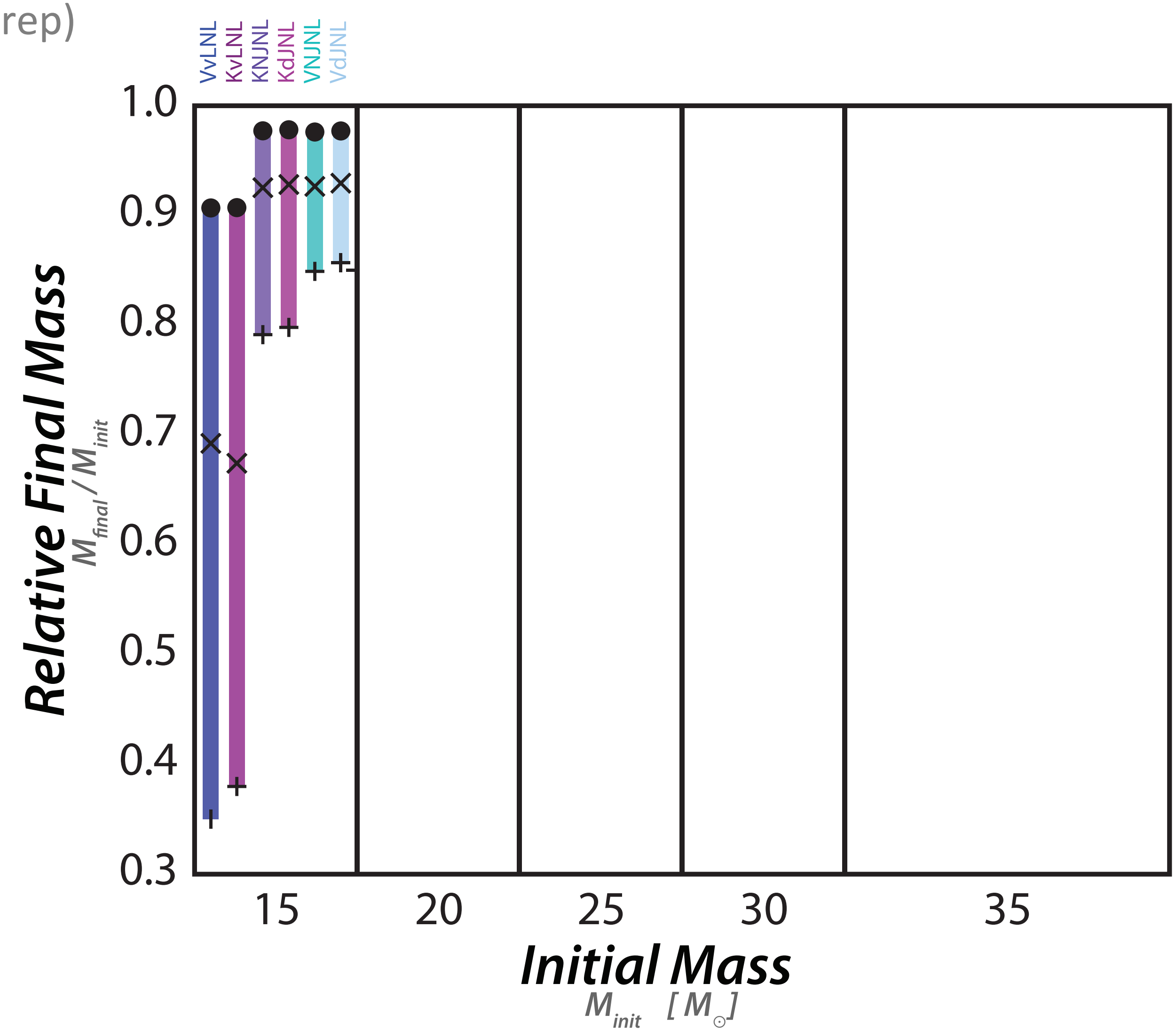
Renzo et al. (in prep)



Mathieu Renzo

Mass loss uncertainties

Renzo et al. (in prep)

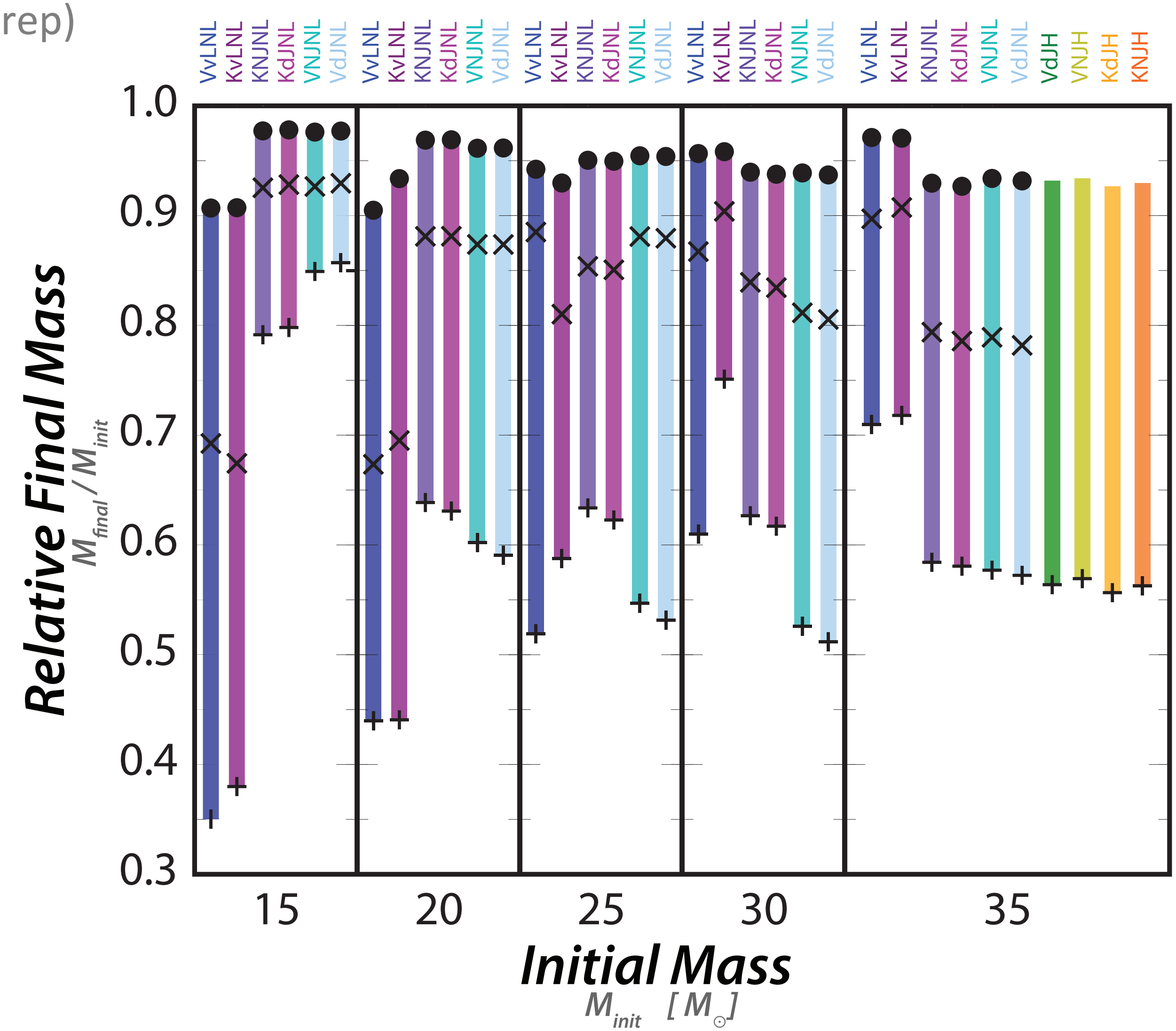


Mathieu Renzo

BinCosmos

Mass loss uncertainties

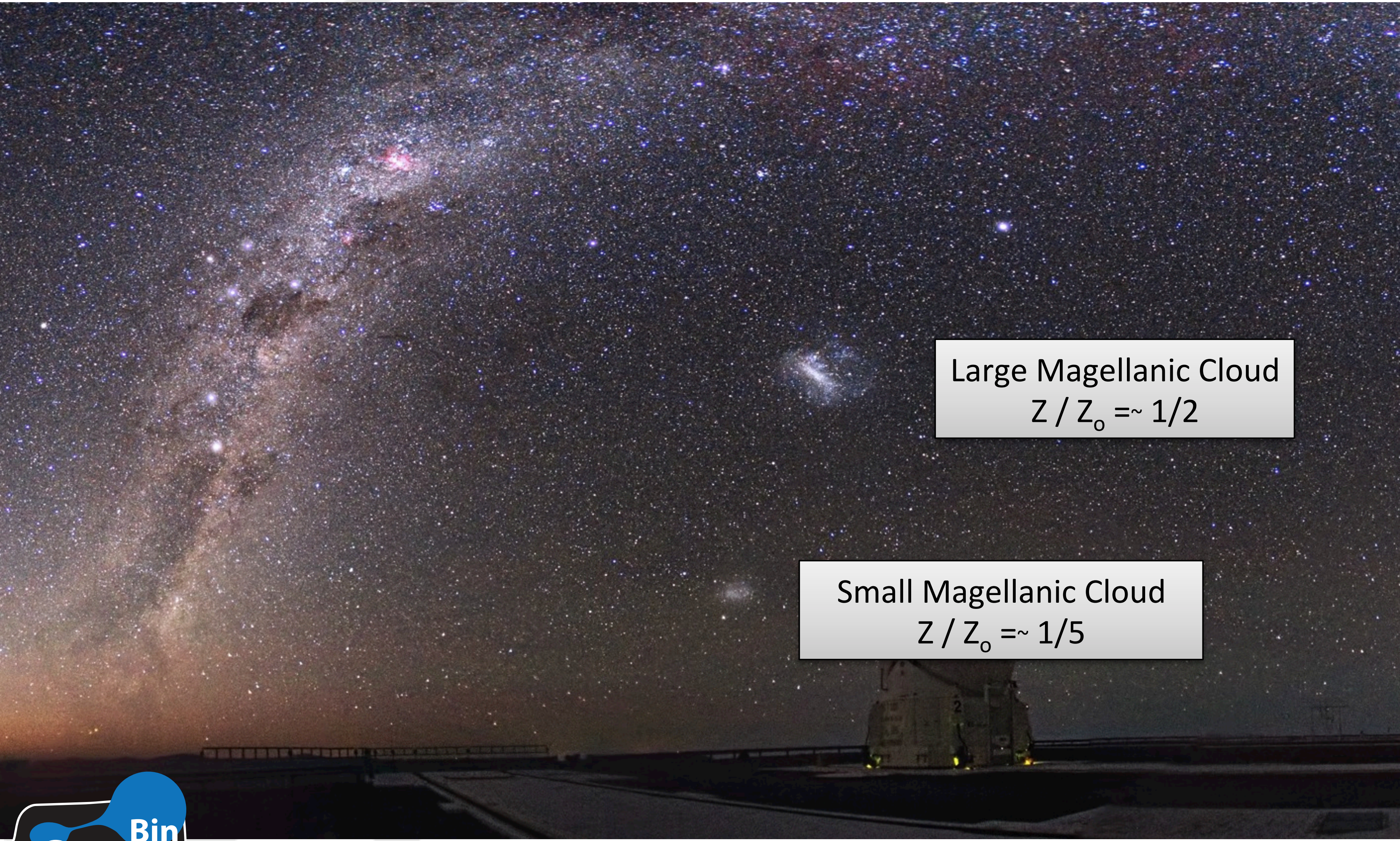
Renzo et al. (in prep)



Mathieu Renzo

What do we know about the progenitors

Closest Peak at their Progenitors

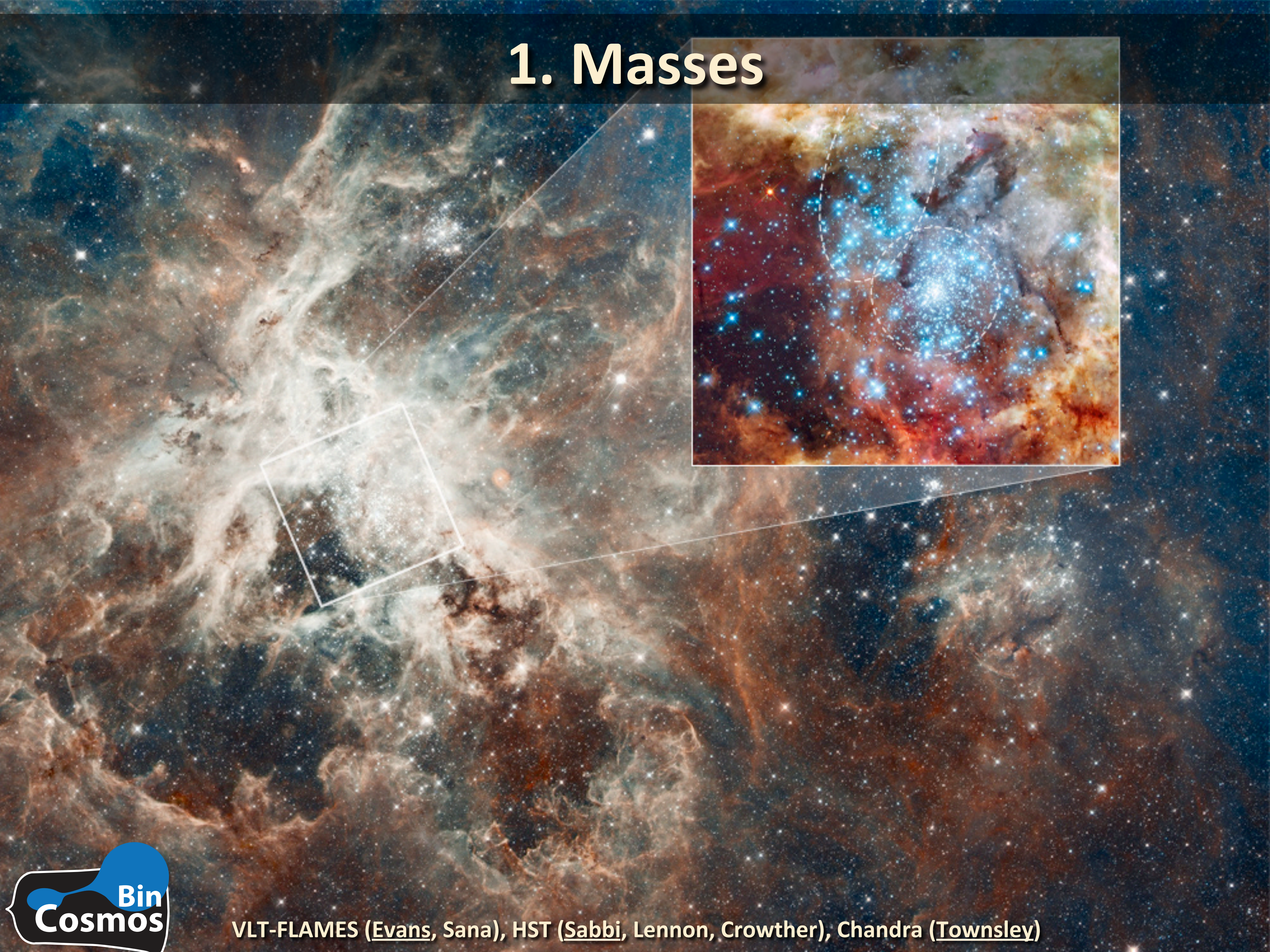


Black Holes in the making: Tarantula Nebula

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

BinCosmos

1. Masses



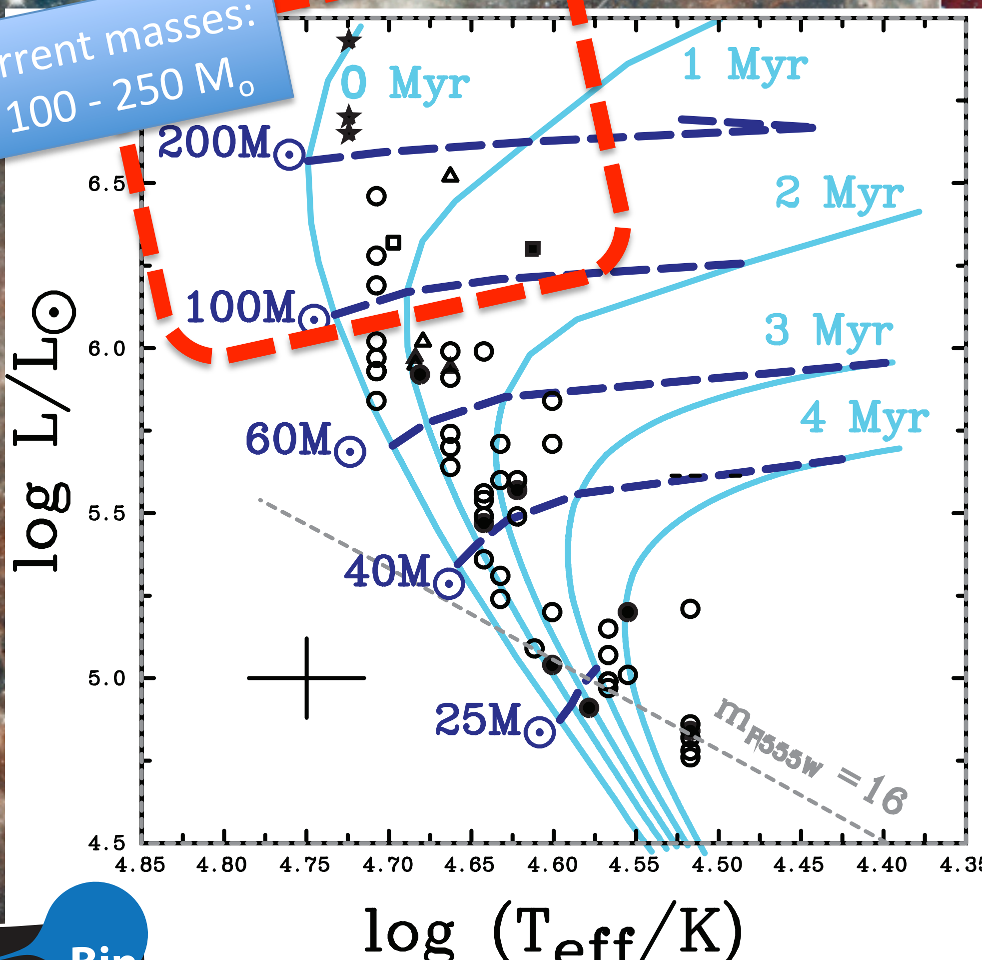
Bin Cosmos

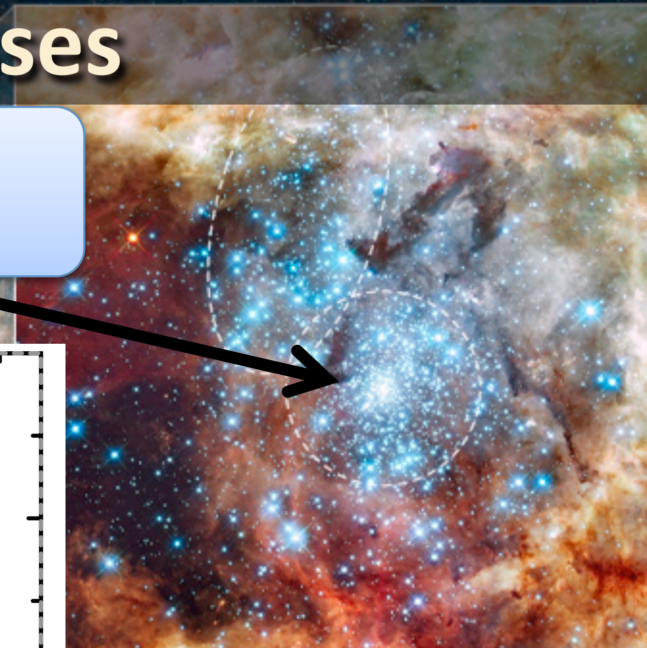
VLT-FLAMES (Evans, Sana), HST (Sabbi, Lennon, Crowther), Chandra (Townsley)

1. Masses

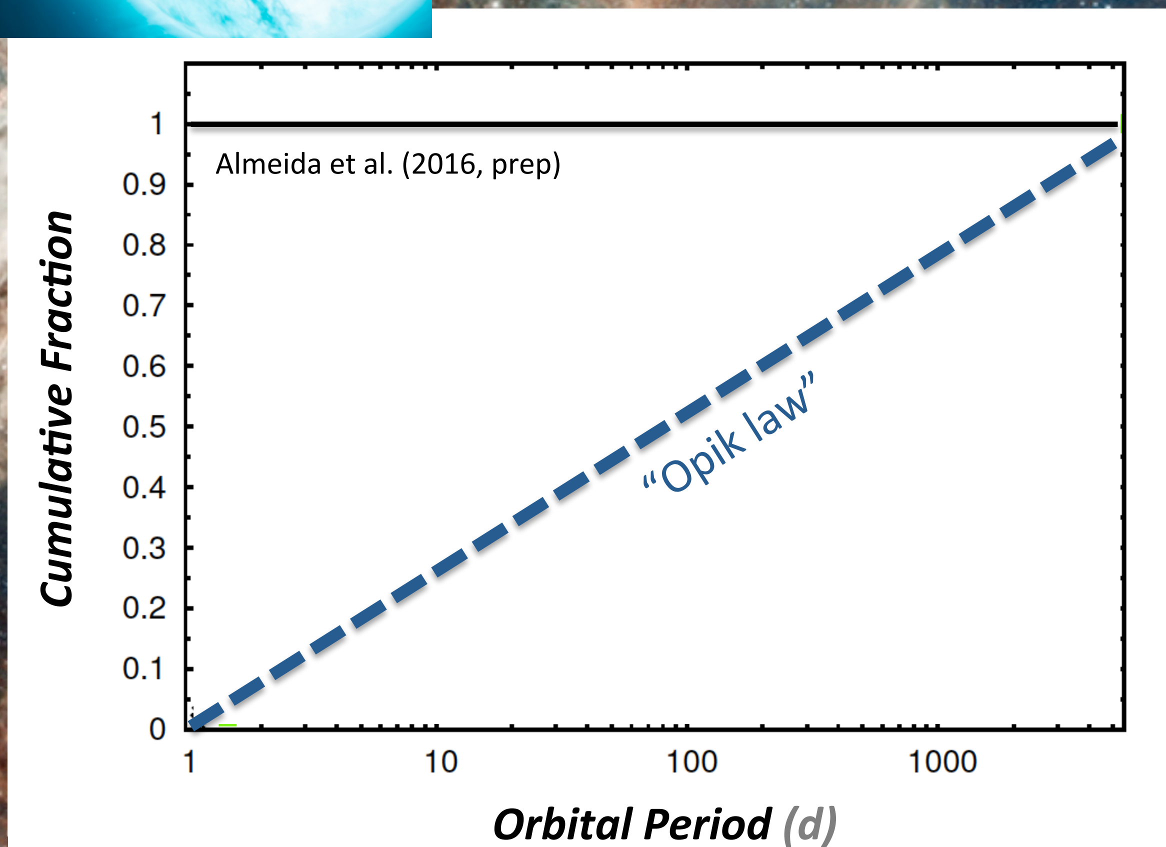
Nine "Monster" stars
Crowther+10,+15

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





2. Binary Separations

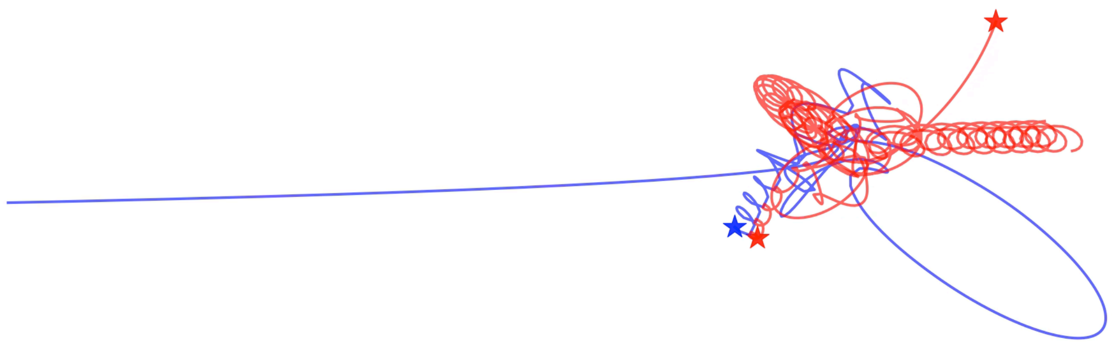


VLT-FLAMES (Evans, Sana), HST (Sabbi, Lennon, Crowther), Chandra (Townsley)

Dynamical formation Channels

cf. Sigurdsson & Hernquist 1993; Portegies Zwart & McMillan 2000; Miller & Lauburg 2009; Rodriguez et al. 2015, 2016; Antonini et al. 2016, …
(incomplete)

single – binary scattering



Credit – Carl Rodriguez

Inside a dense star cluster

Movie available through Carl's website

Credit – Northwestern Visualization, Carl Rodriguez

Evolutionary

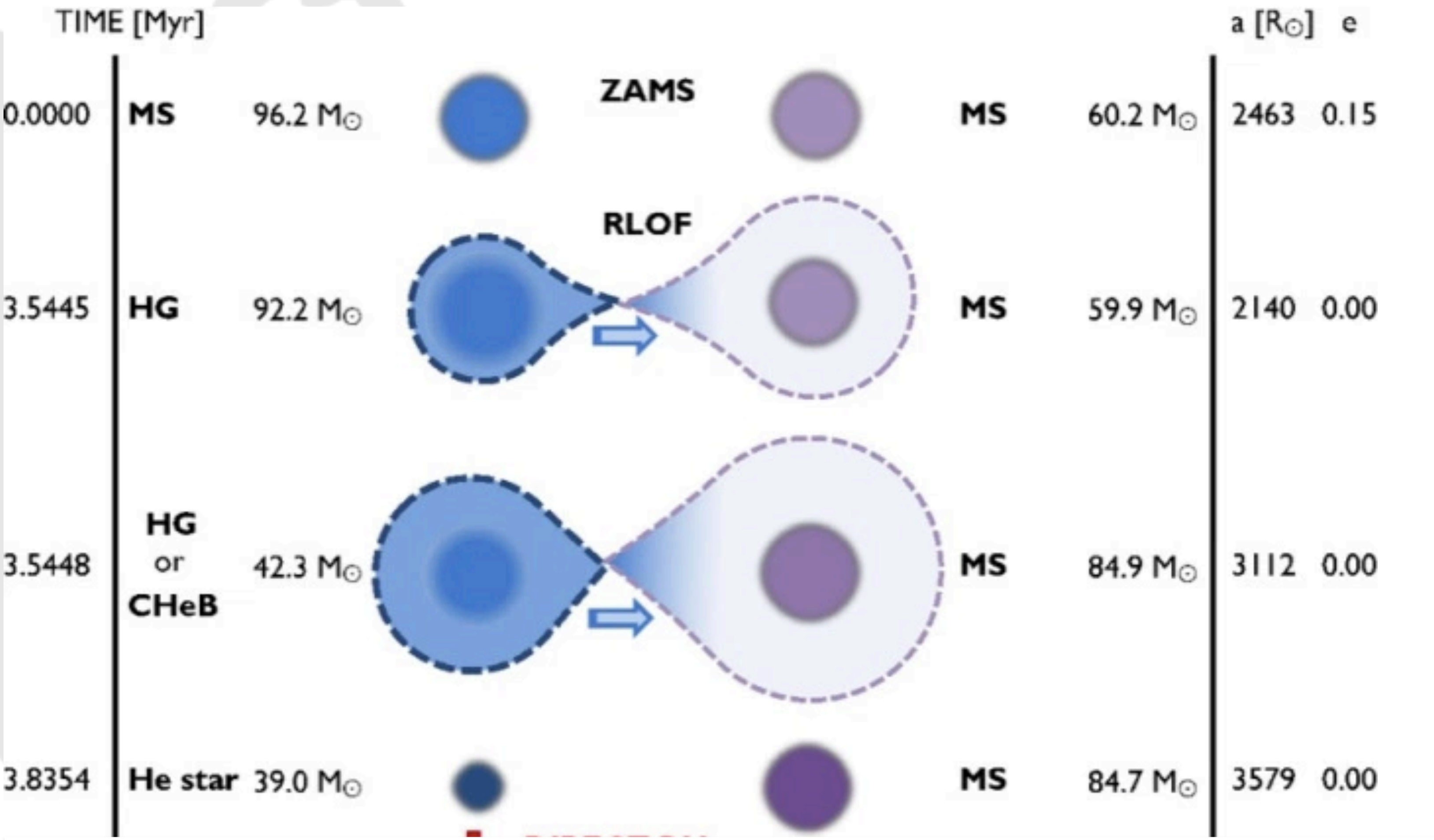
1. Classic Common Envelope Channel

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, ...

BinCosmos

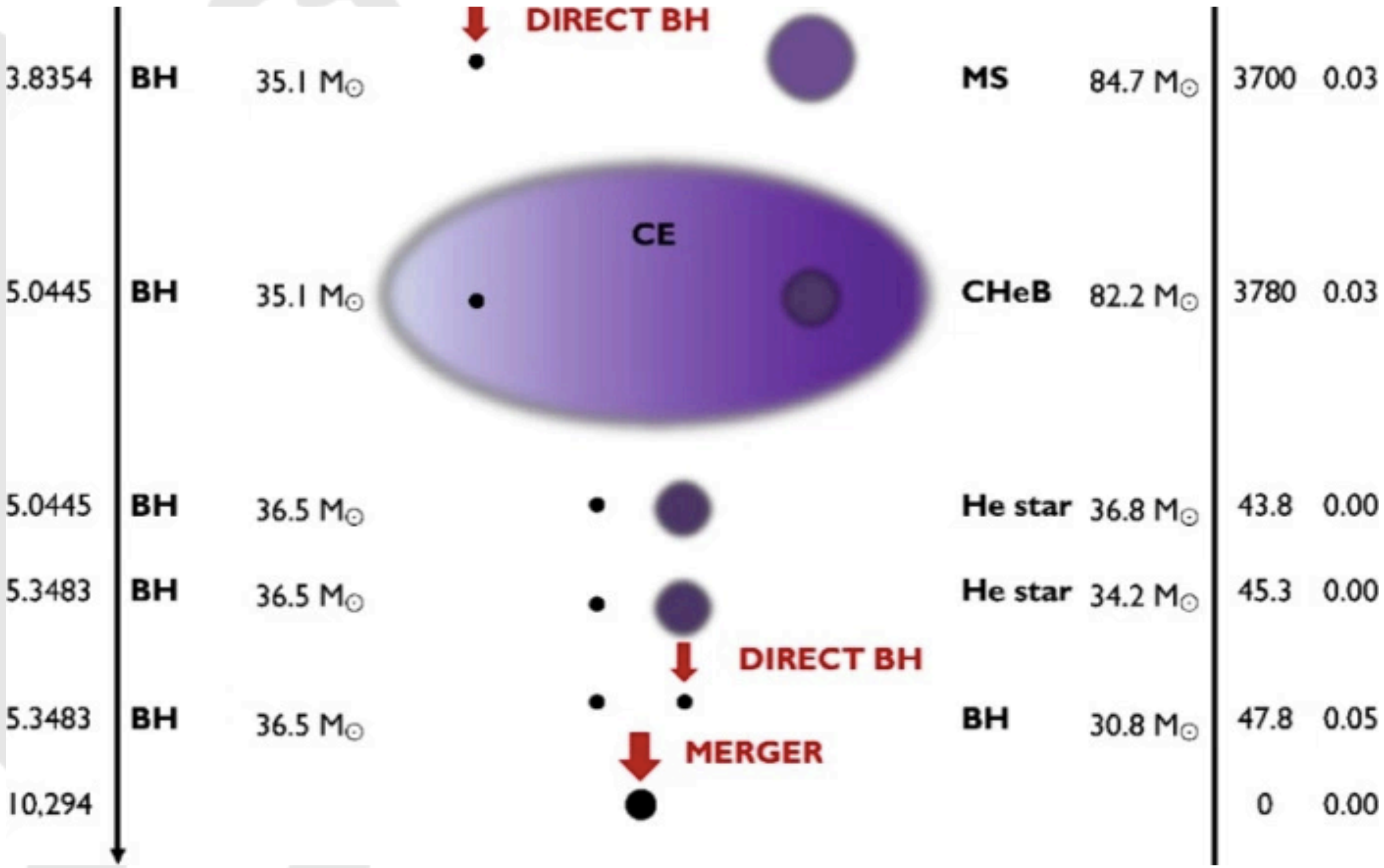
Classic Channel

Belczynski et al. 2016



Classic Channel (part 2)

Belczynski et al. 2016

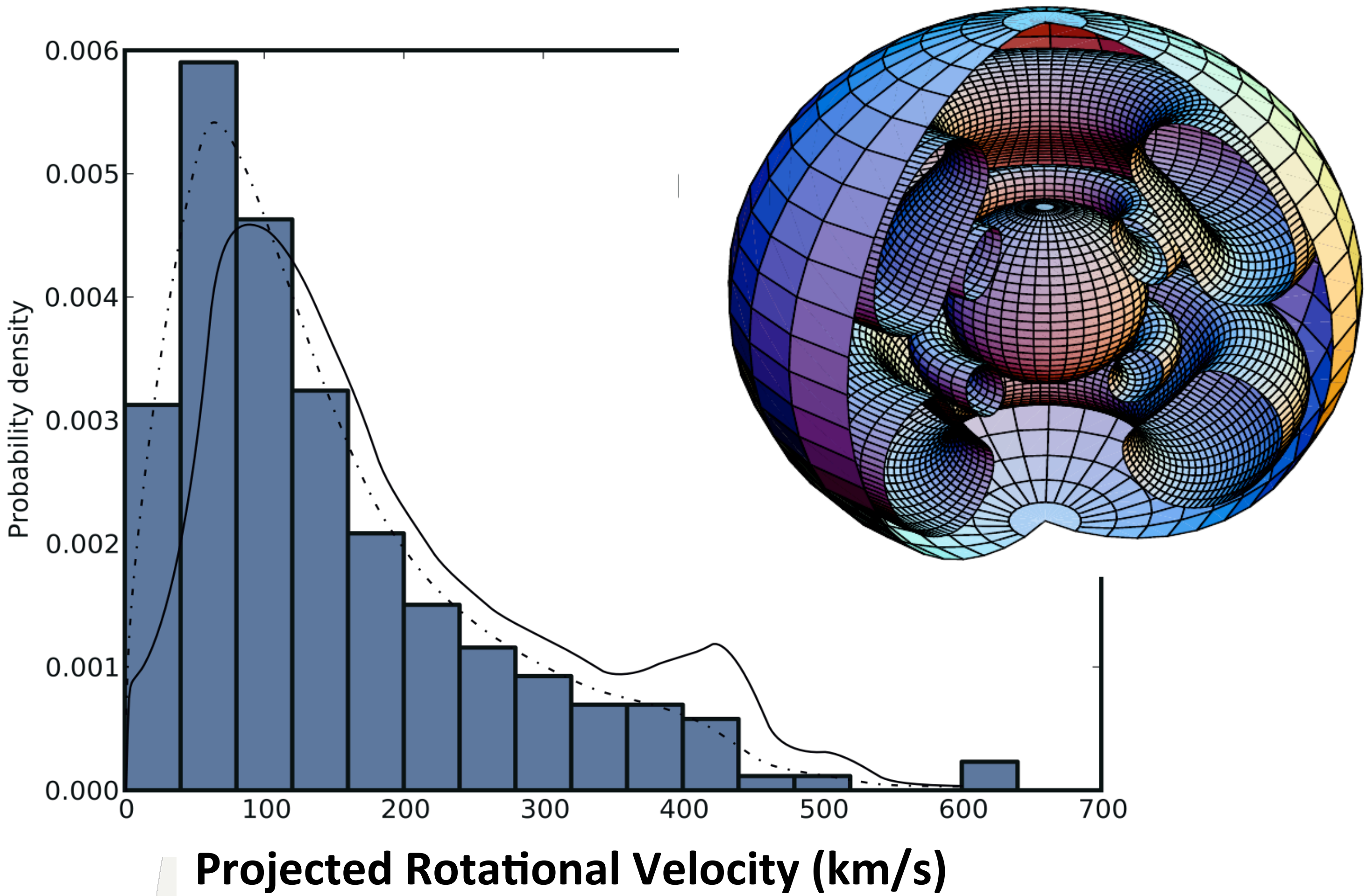


2. Chemically Homogeneous Channel

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

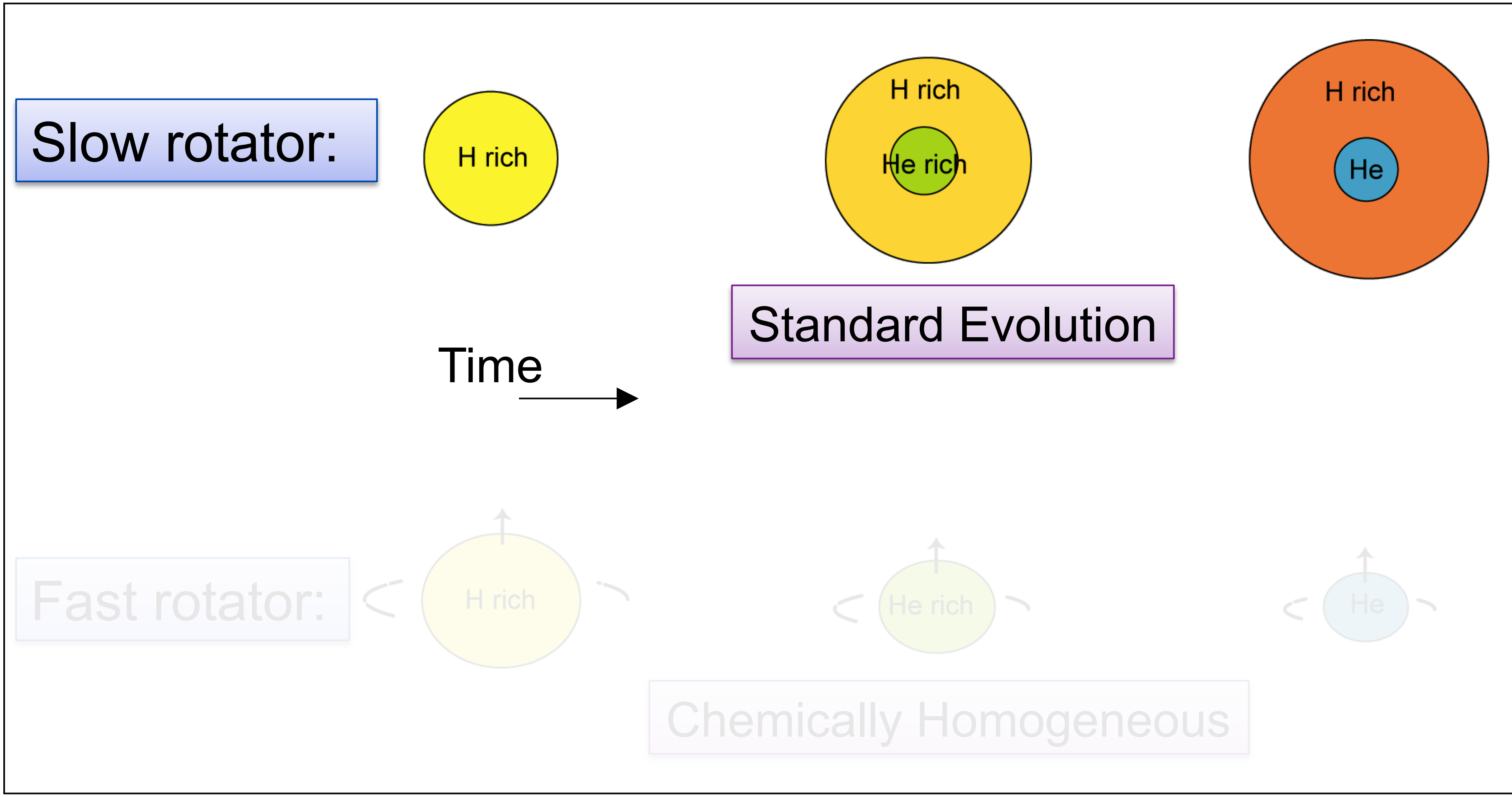
de Mink et al. (2008, 2009), Mandel & de Mink (2016), Song et al. 2016; Marchant et al. (2016), de Mink & Mandel (2016), …

… very rapidly rotating single stars …



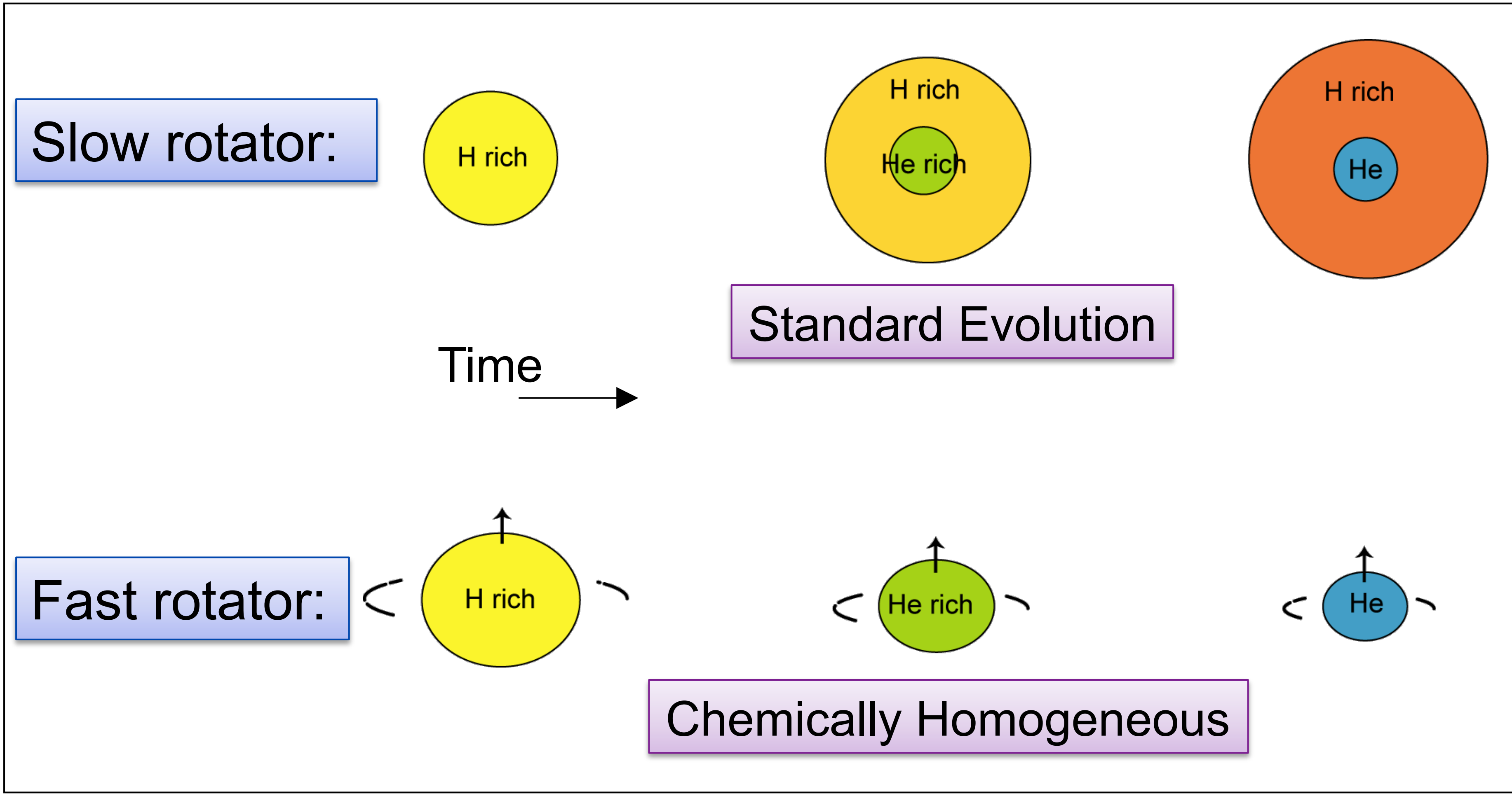
Ramirez-Agudelo et al. (2013, 2015)

Effect on the stellar structure



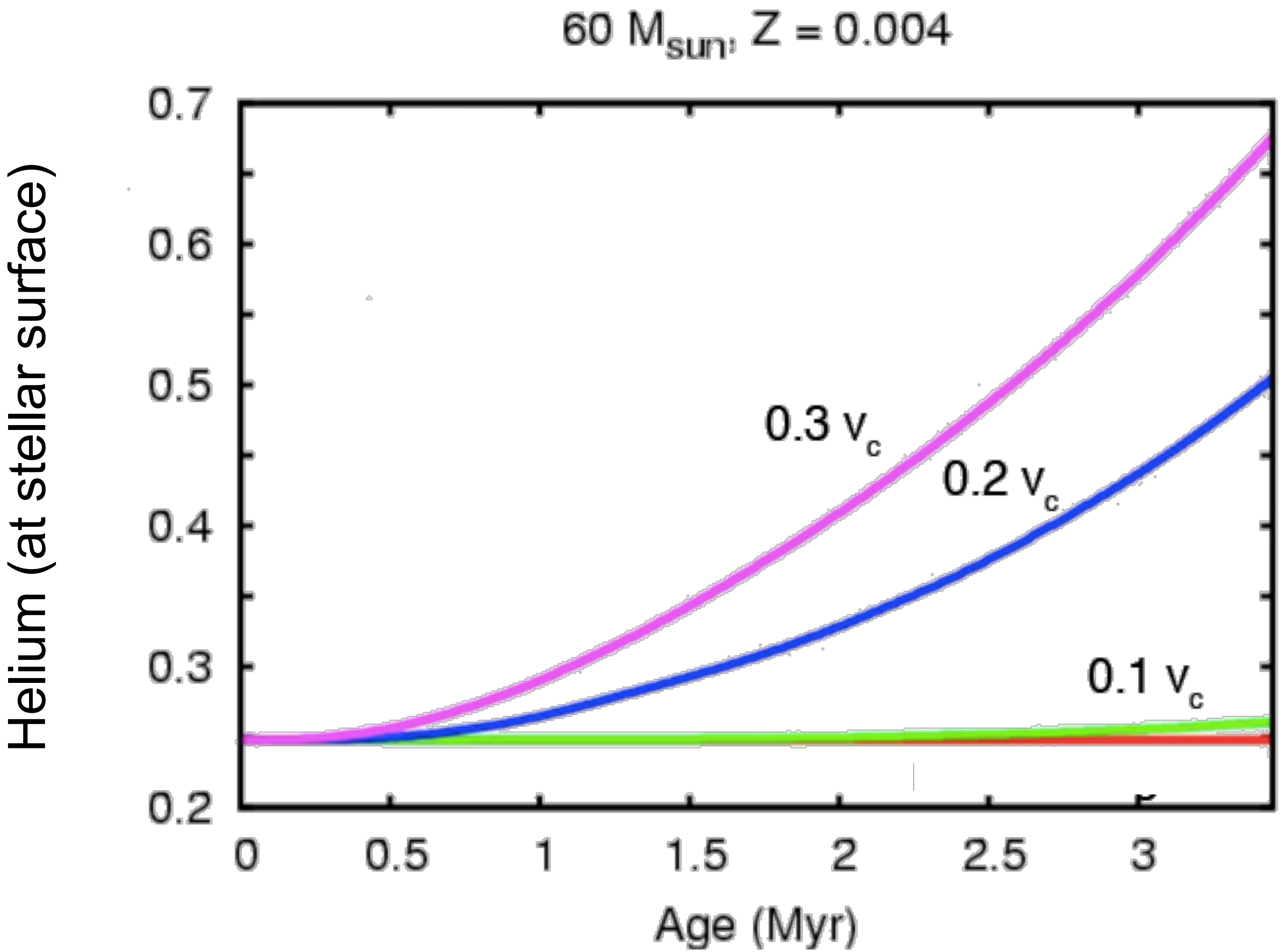
Maeder 87, Yoon & Langer 05

Effect on the stellar structure



Maeder 87, Yoon & Langer 05

Surface composition

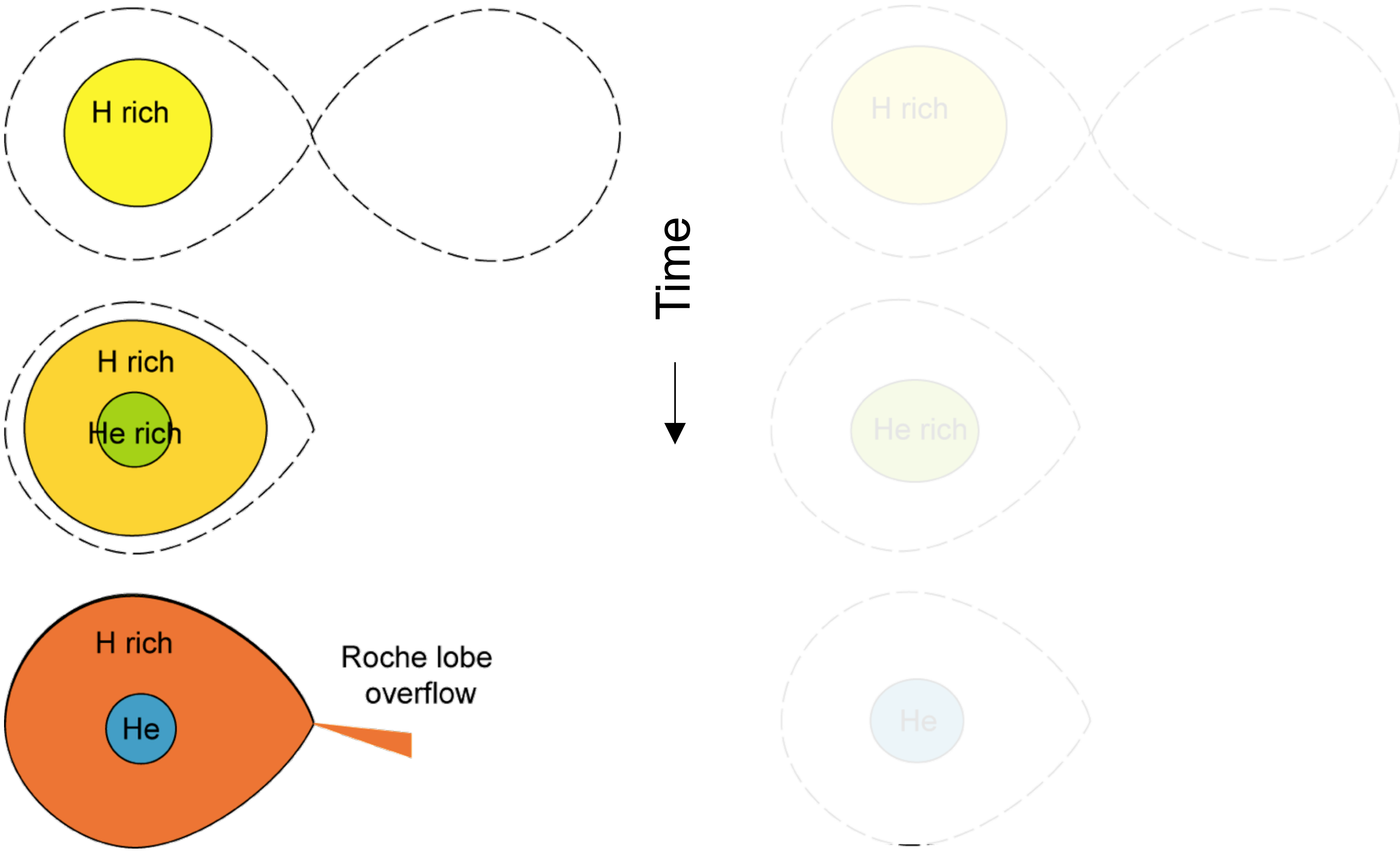


Yoon + 06

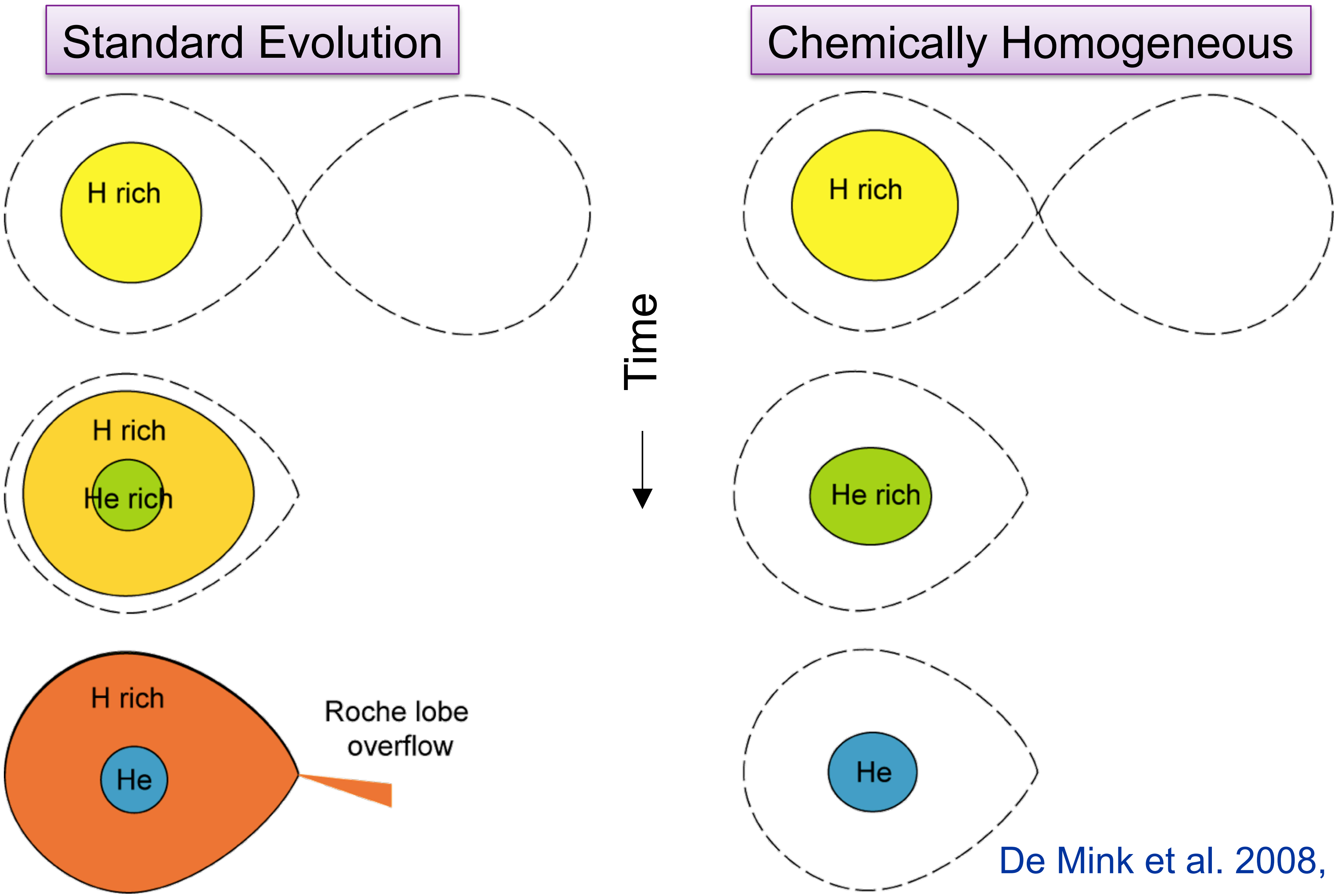
What about binaries?

Standard Evolution

Chemically Homogeneous

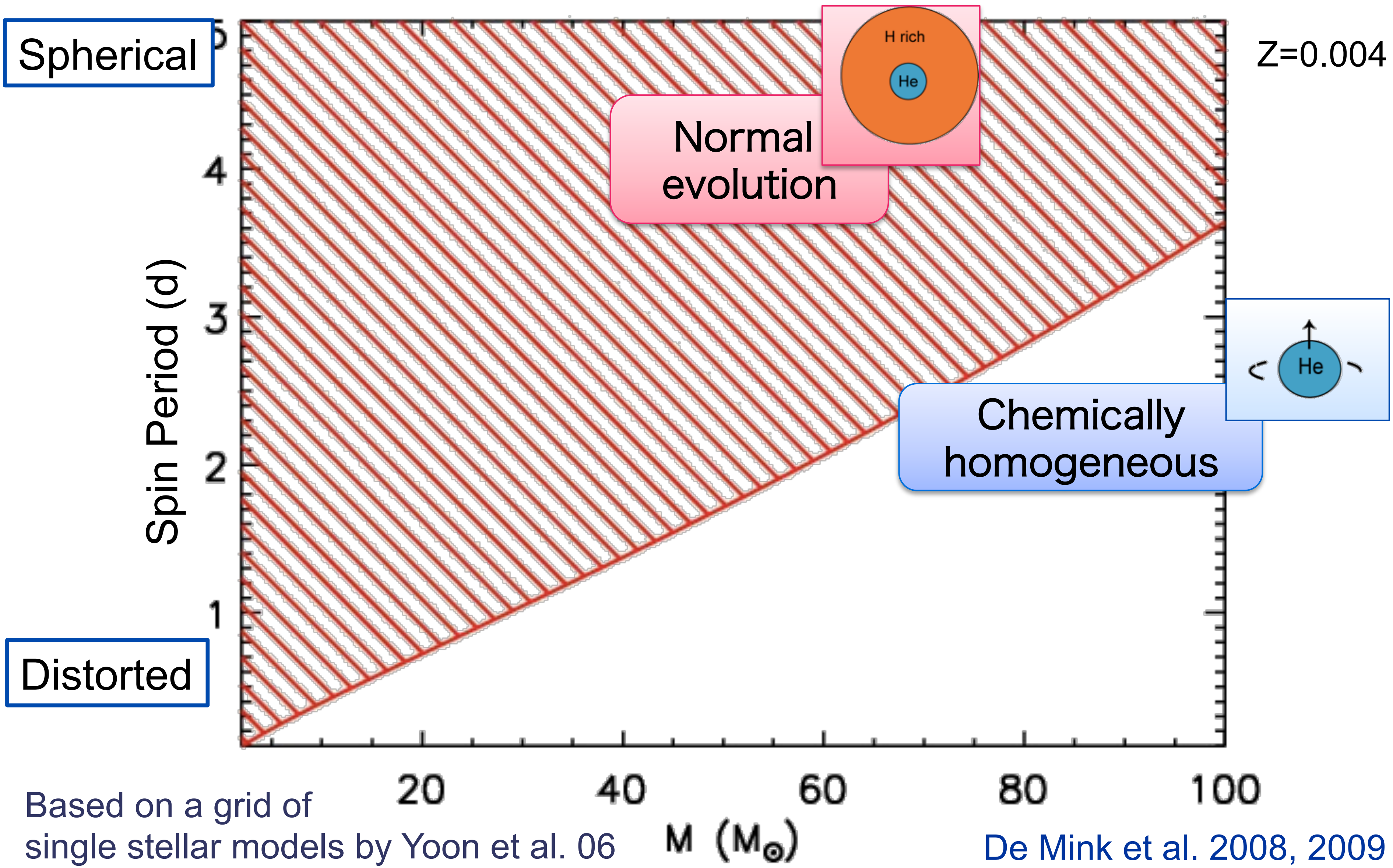


What about binaries?



De Mink et al. 2008, 2009

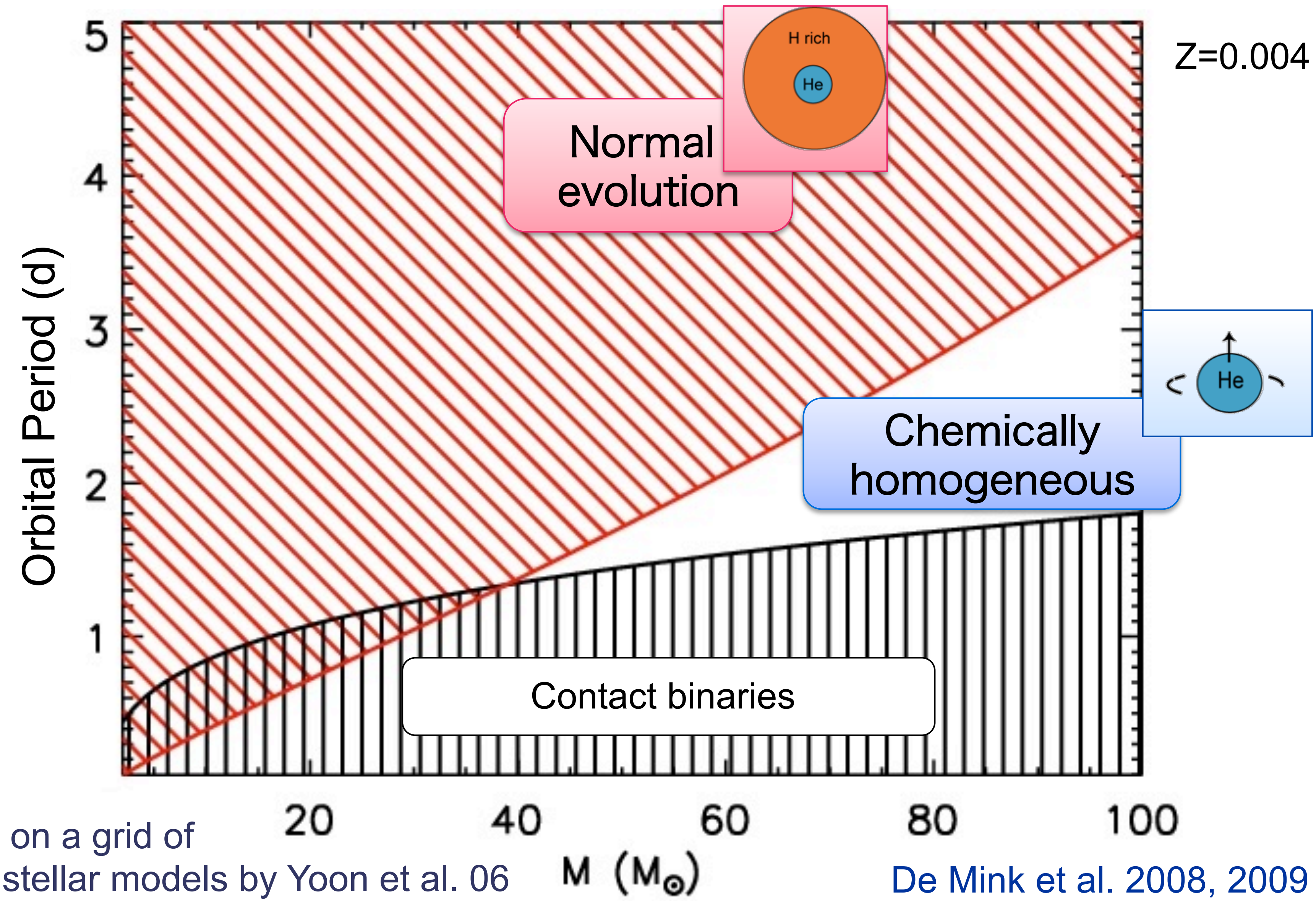
Which stars evolve homogeneously?



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

De Mink et al. 2008, 2009

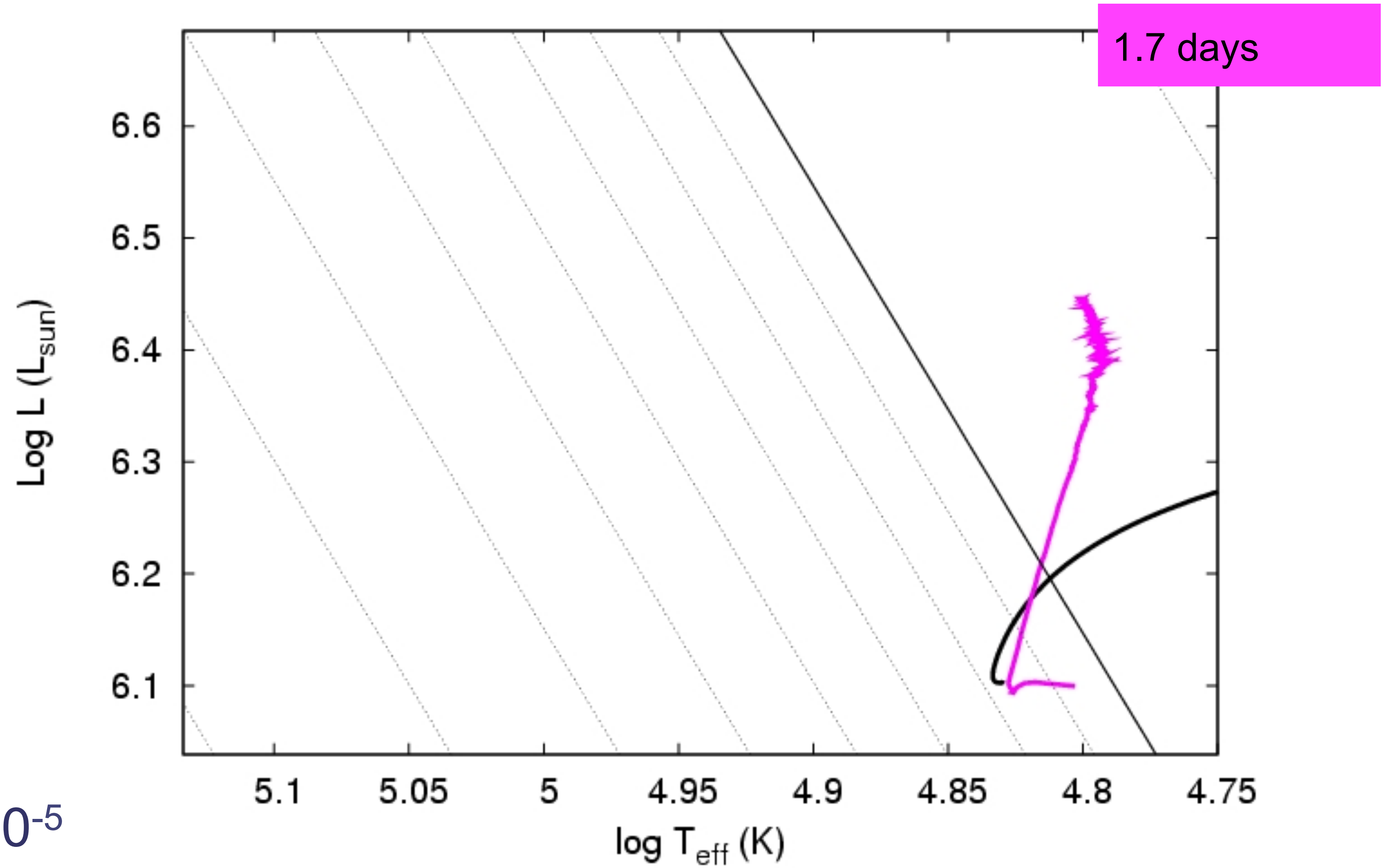
For tidally locked binaries



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

De Mink et al. 2008, 2009

Proof of principle

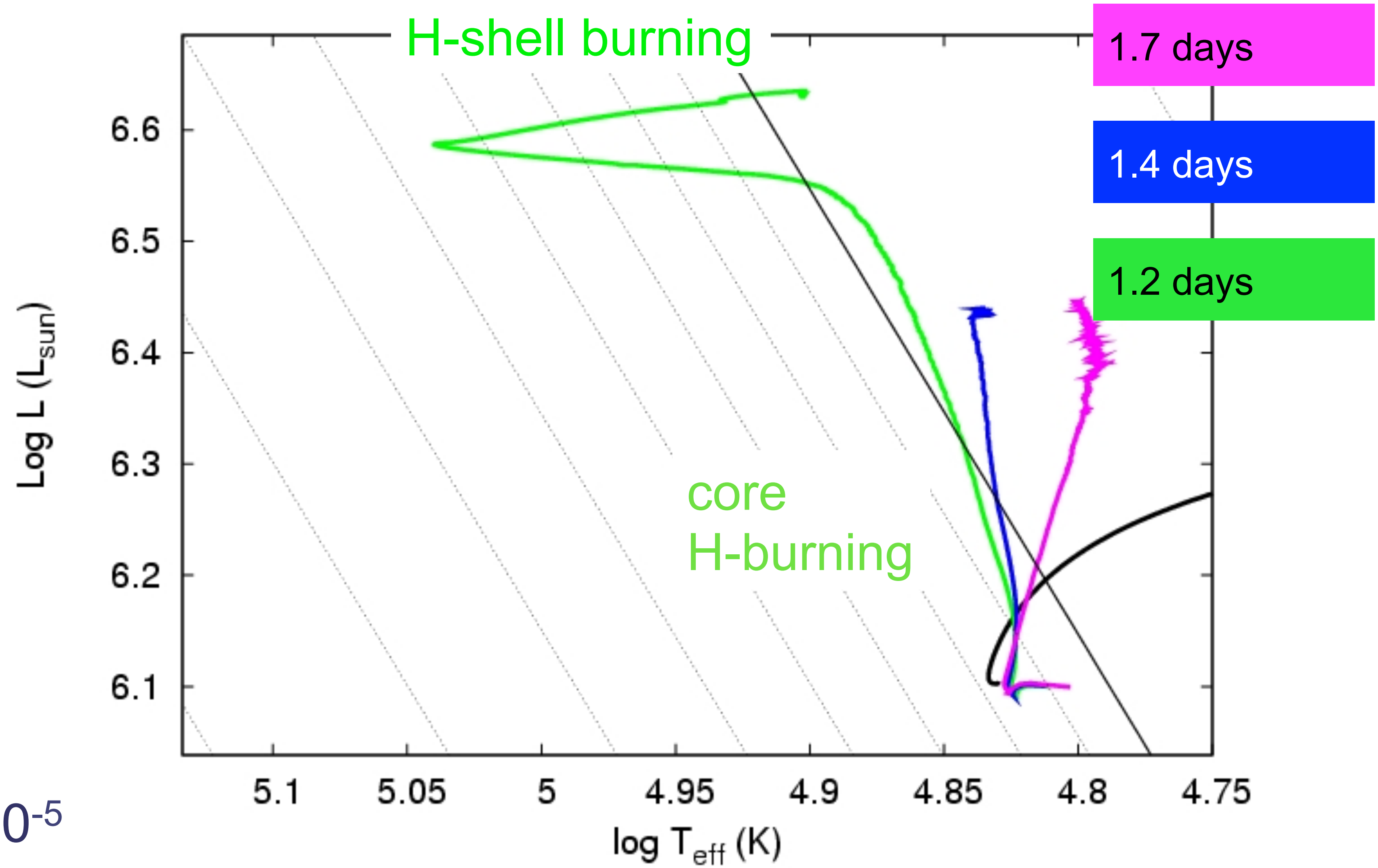


$Z = 10^{-5}$

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

De Mink et al. 2008, 2009

Binary models

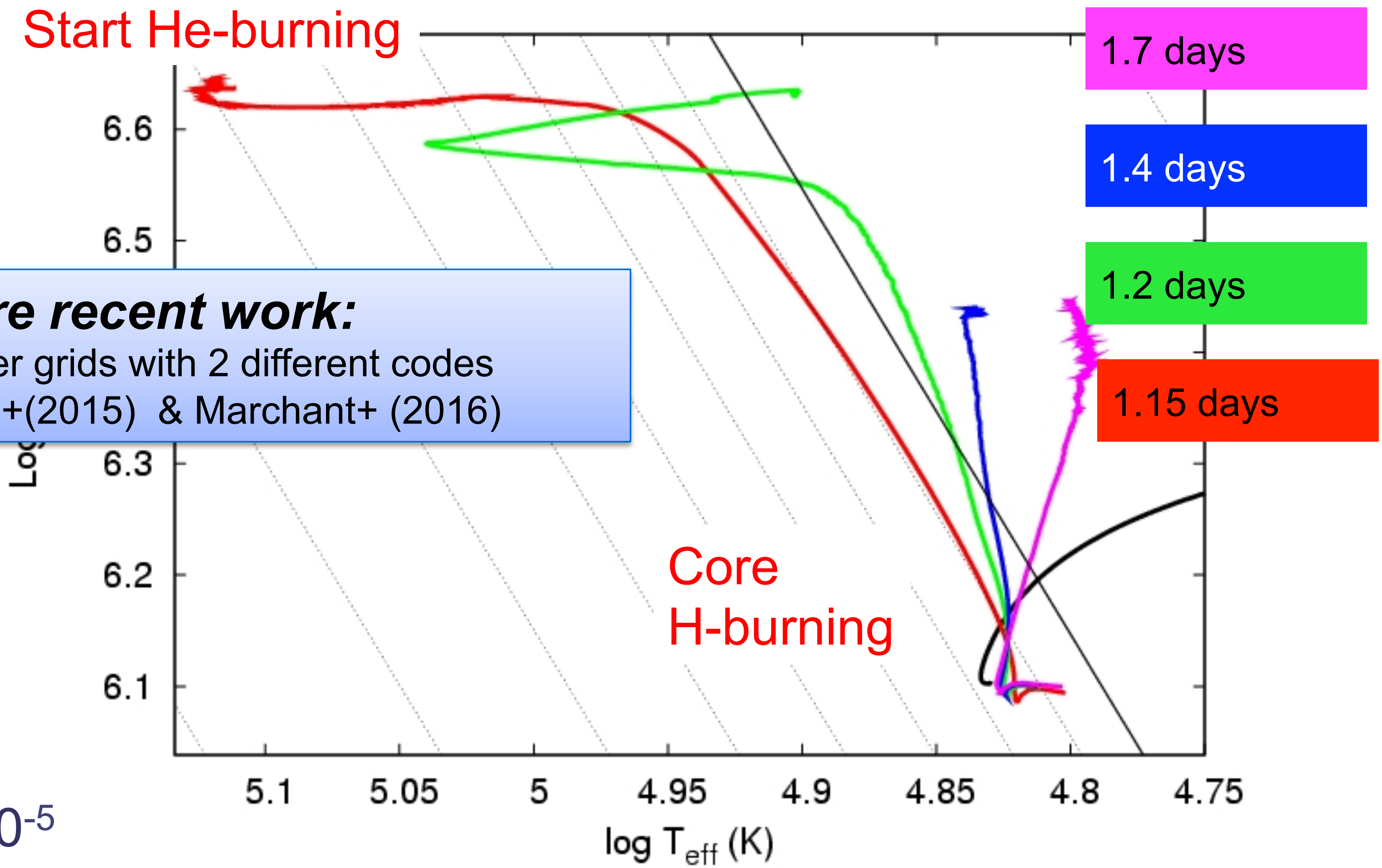


$Z = 10^{-5}$

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

De Mink et al. 2008, 2009

Binary models



More recent work:

Larger grids with 2 different codes

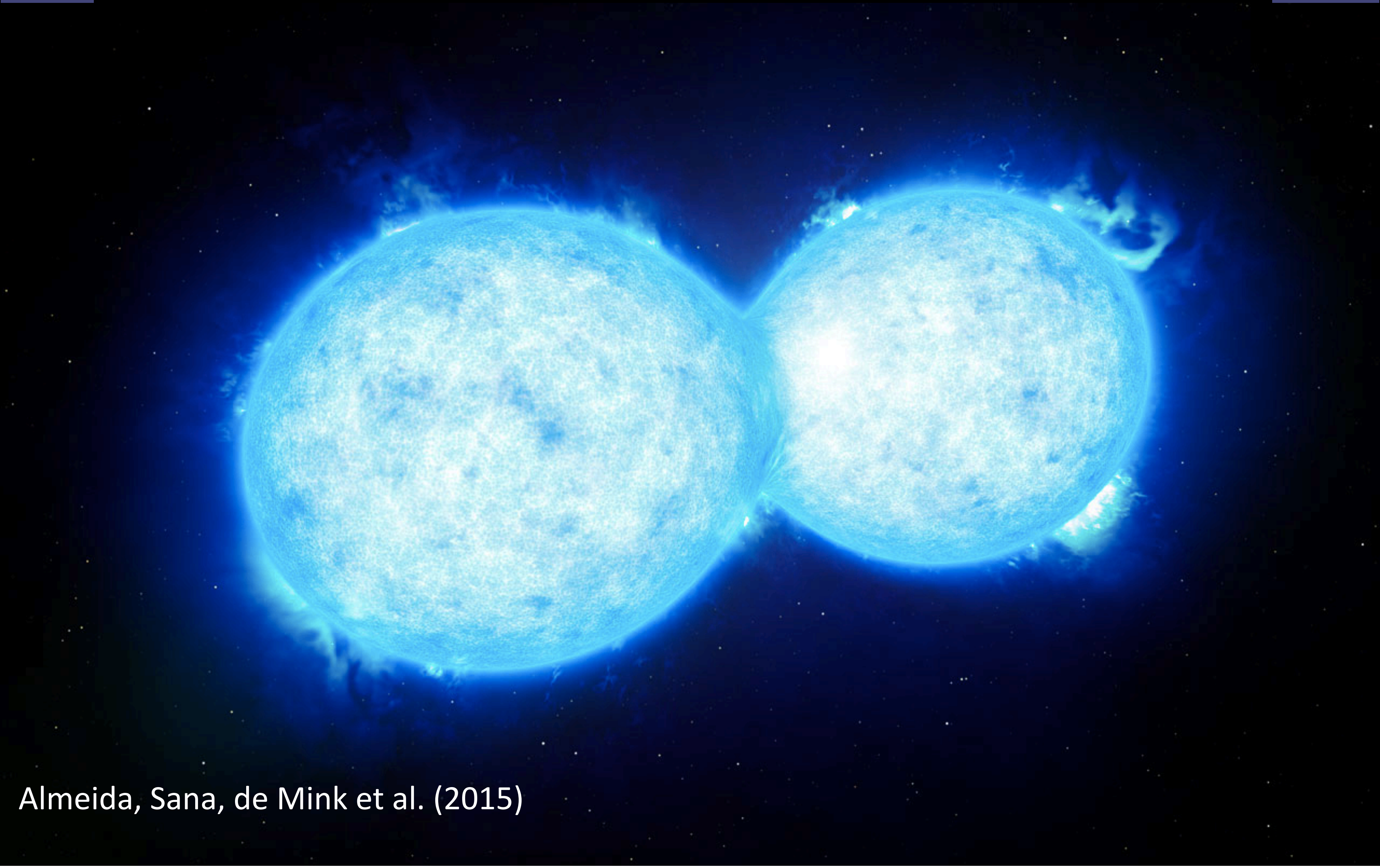
Song+(2015) & Marchant+ (2016)

$Z = 10^{-5}$

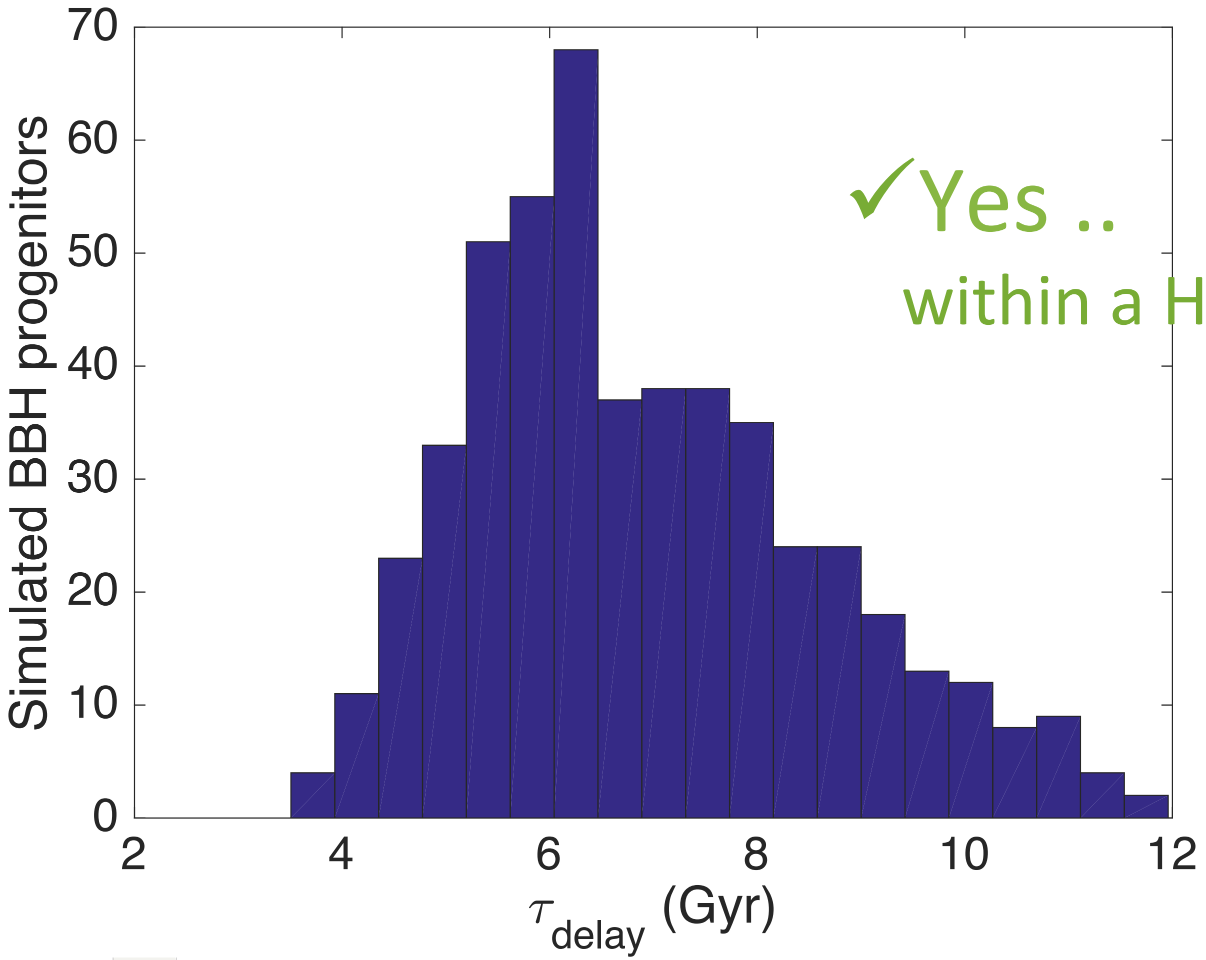
$M_1 \sim M_2 \sim 100 M_\odot$

De Mink et al. 2008, 2009

Is this really happening?


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

Do the Binary BHs merge?

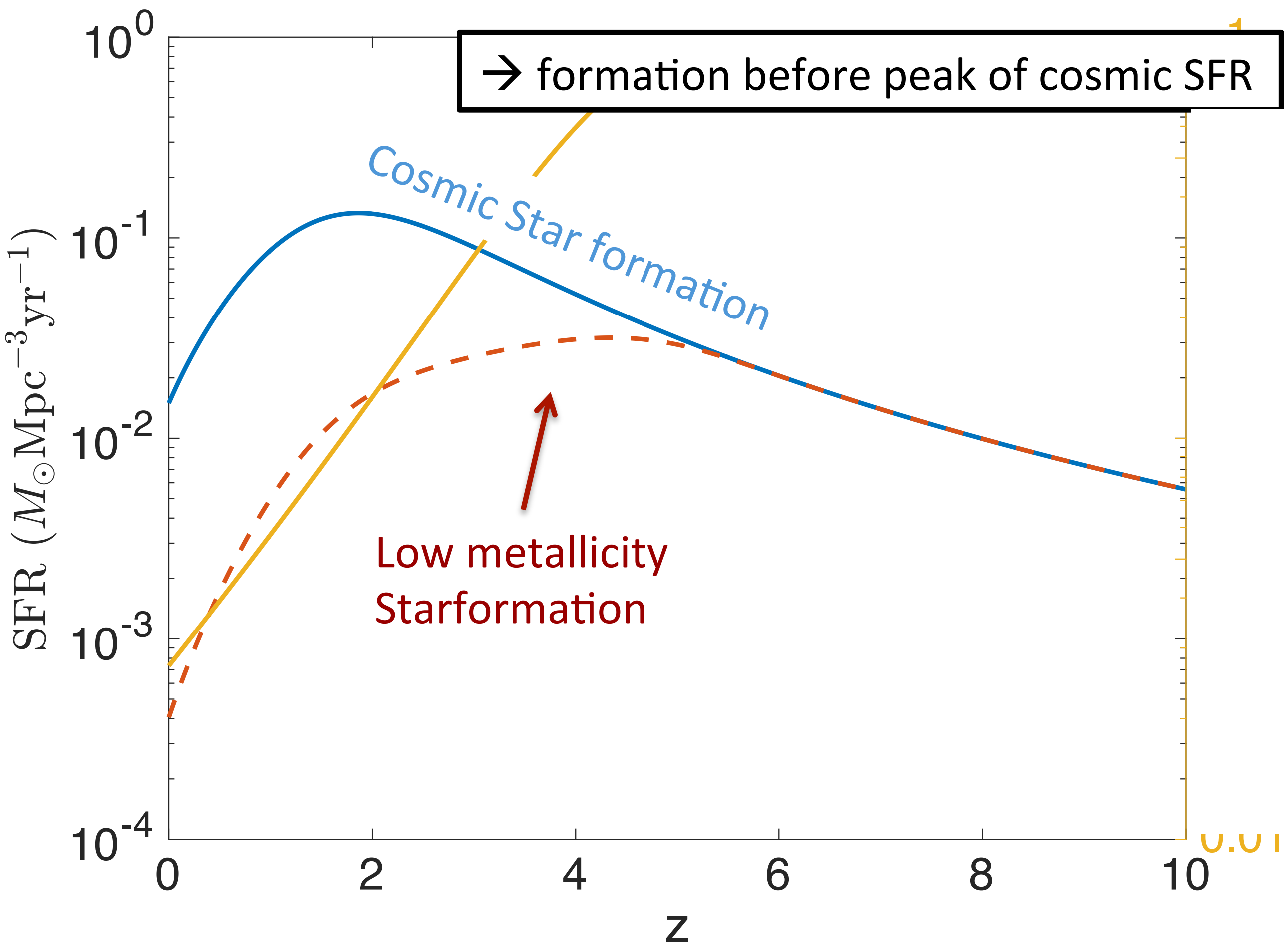


✓Yes ..

within a Hubble time

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

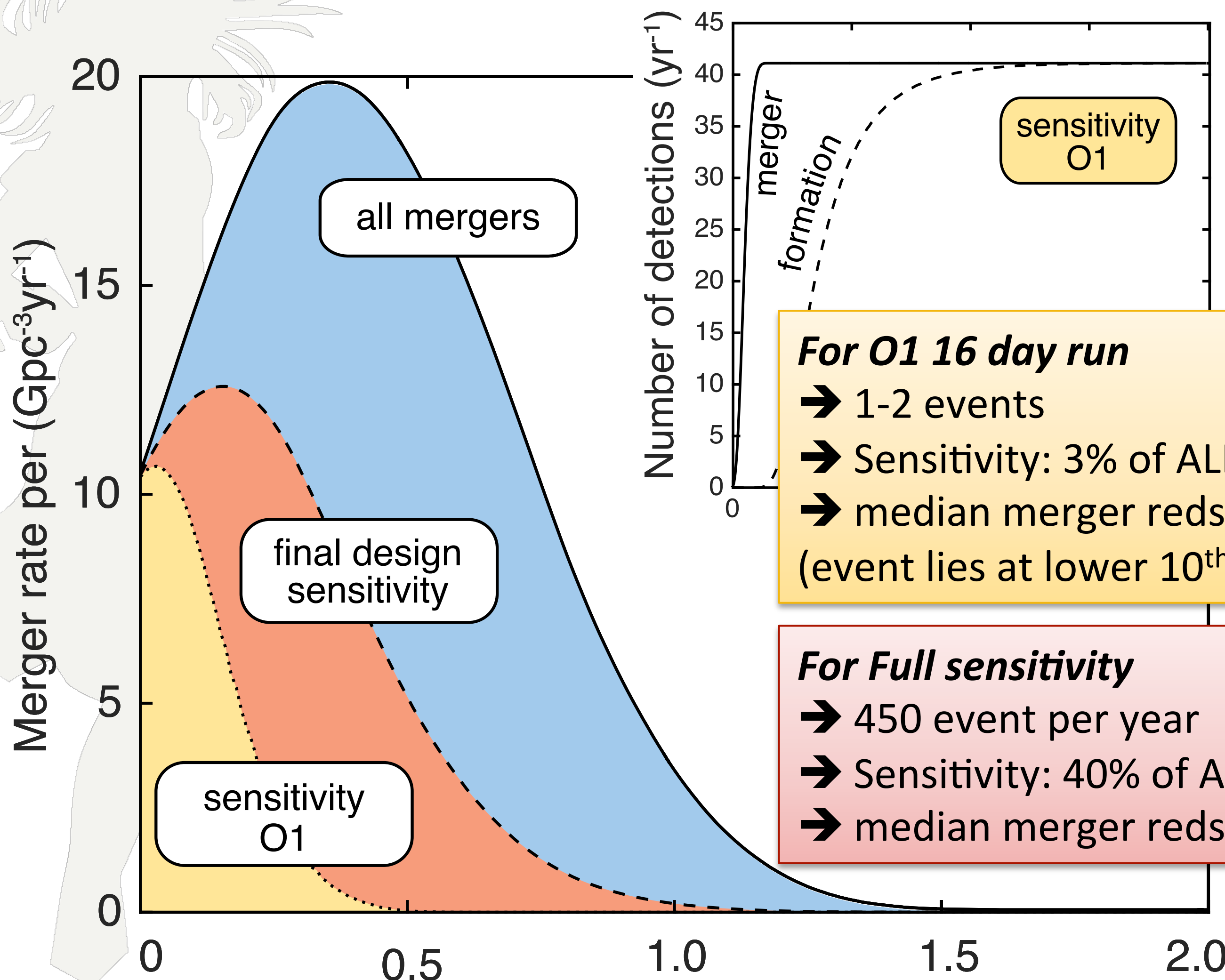
Cosmic Star formation



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

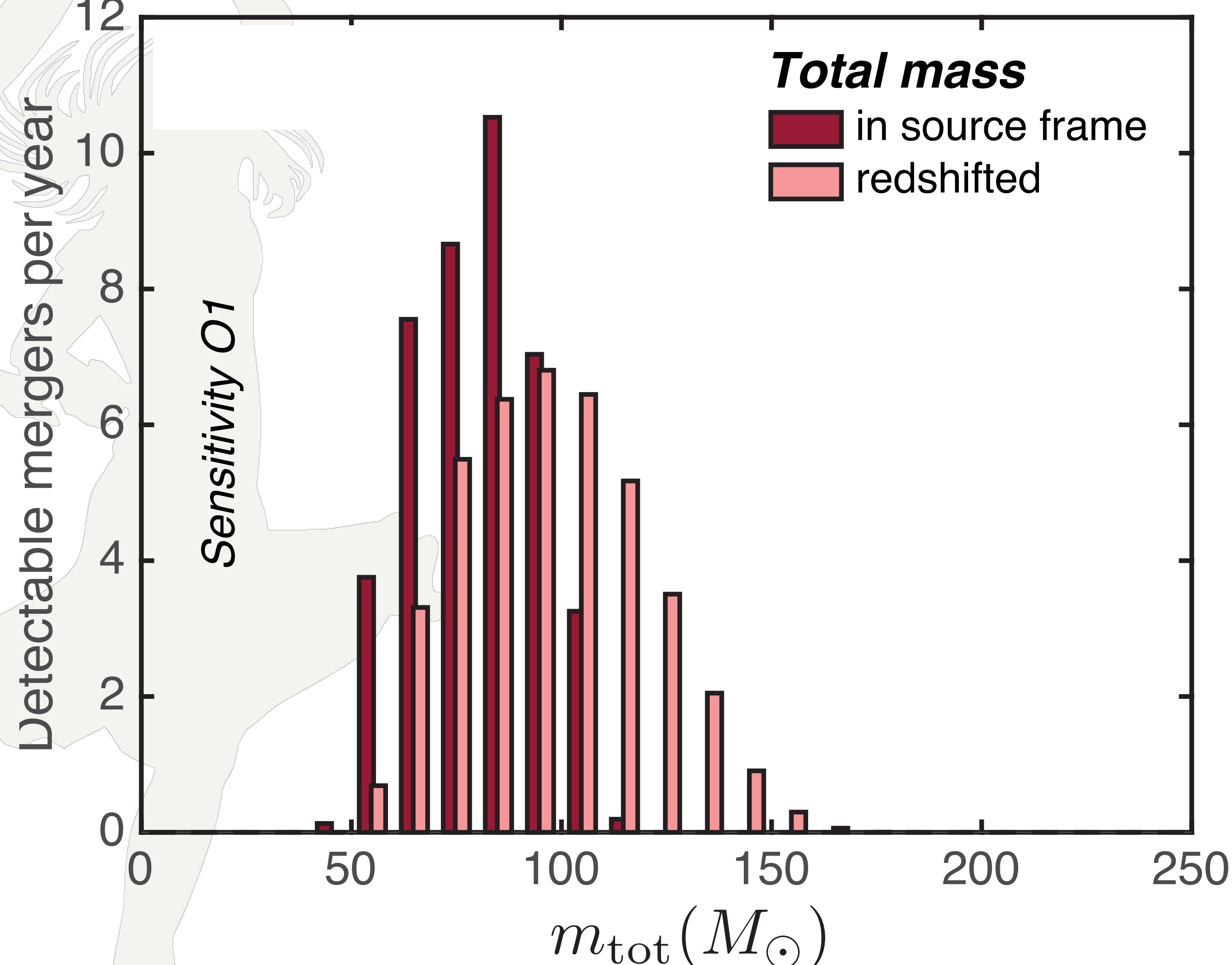
➔ 450 event per year

➔ Sensitivity: 40% of ALL events

➔ median merger redshift = 0.5

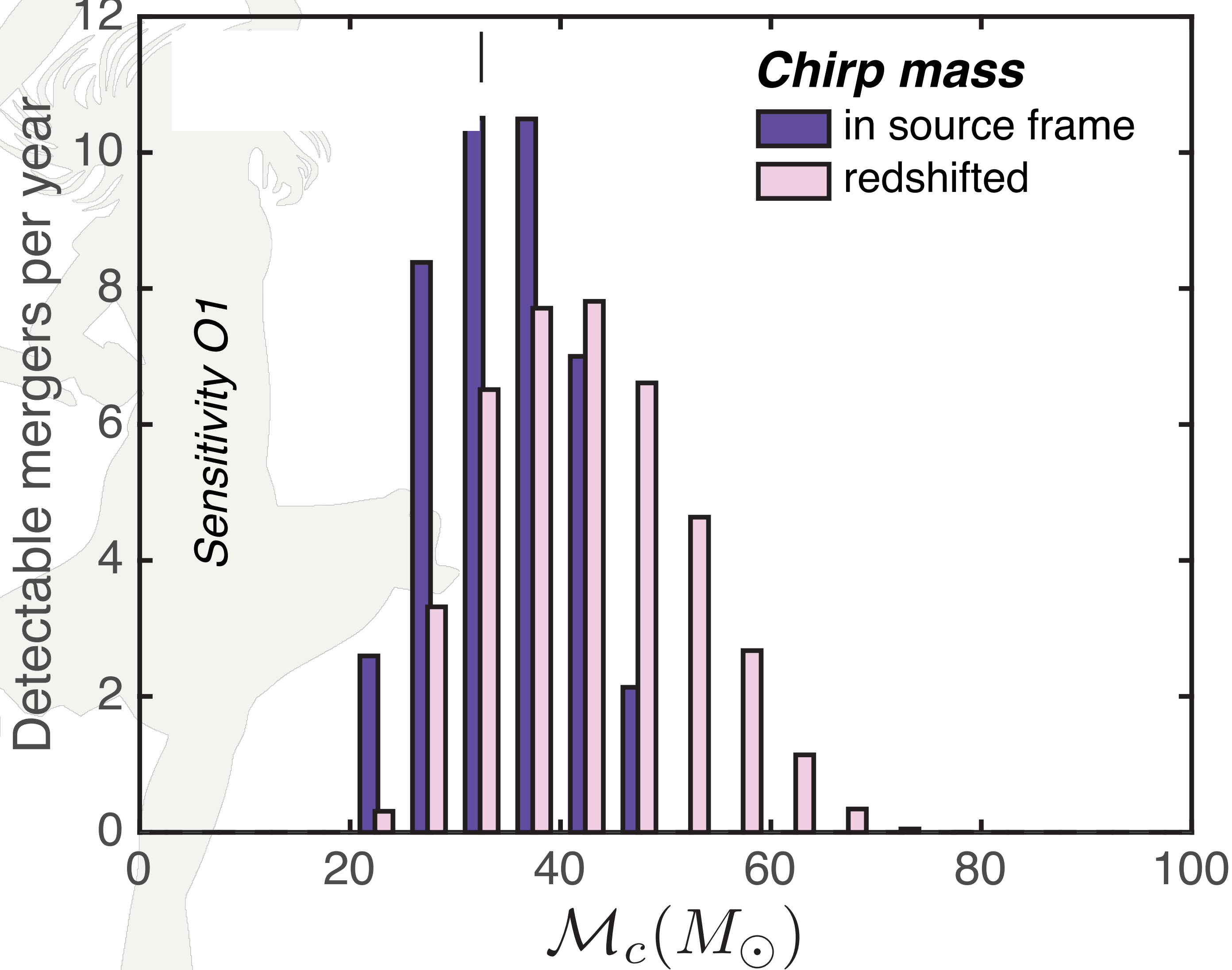
“Predicted” Total Masses

De Mink & Mandel (2016)



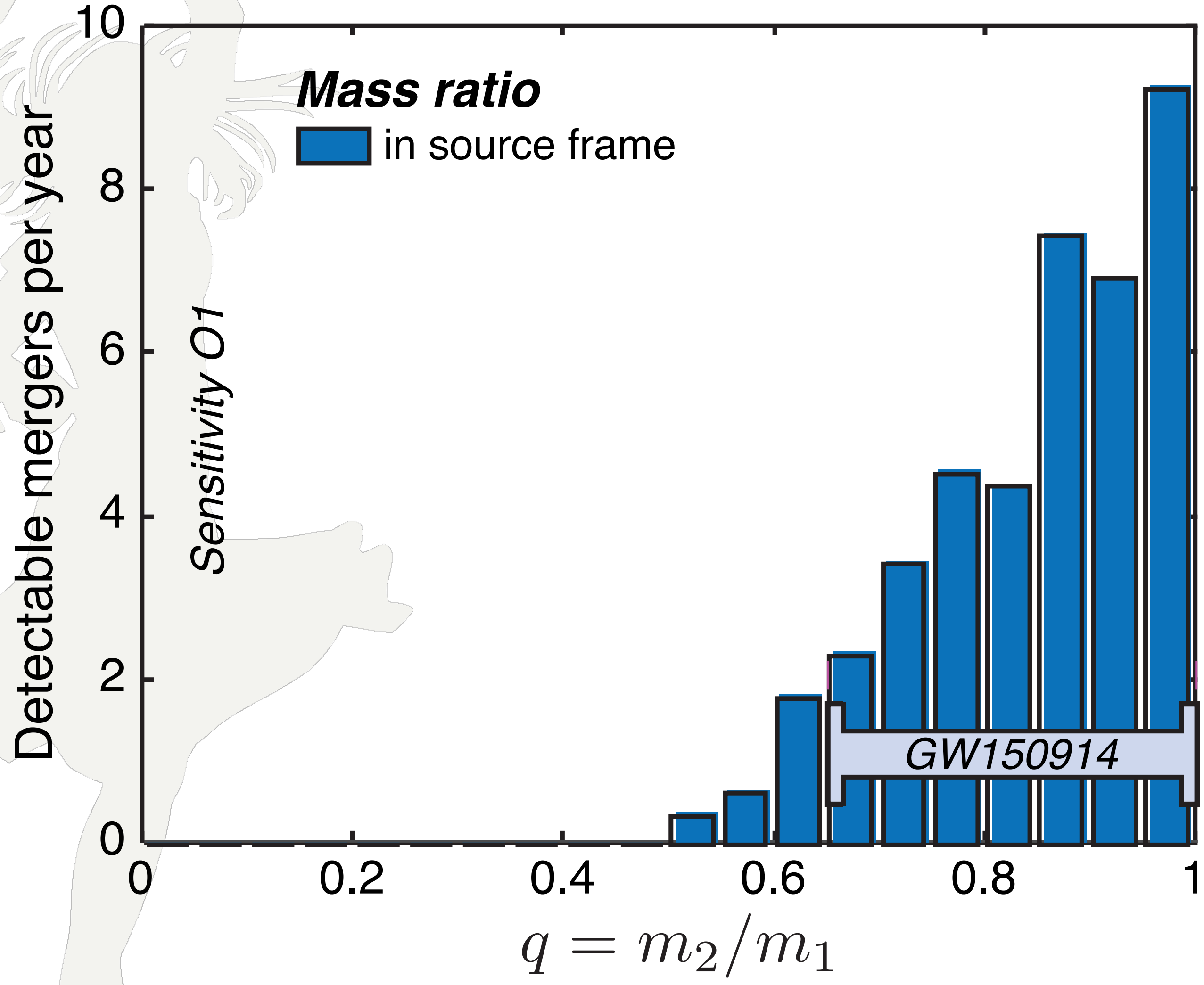
“Predicted” Chirp Masses

De Mink & Mandel (2016)

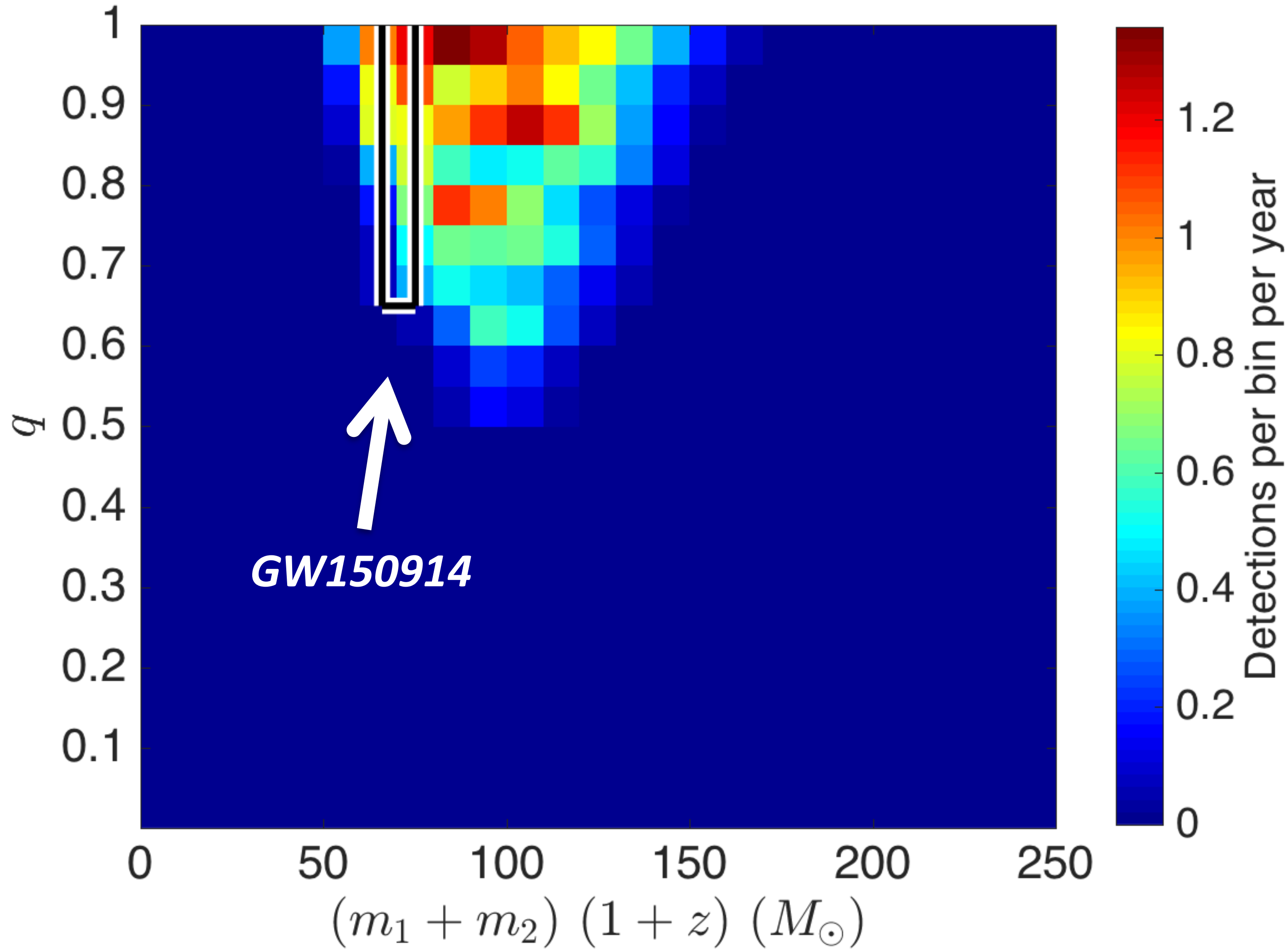


"Predicted" Mass Ratios

De Mink & Mandel (2016)

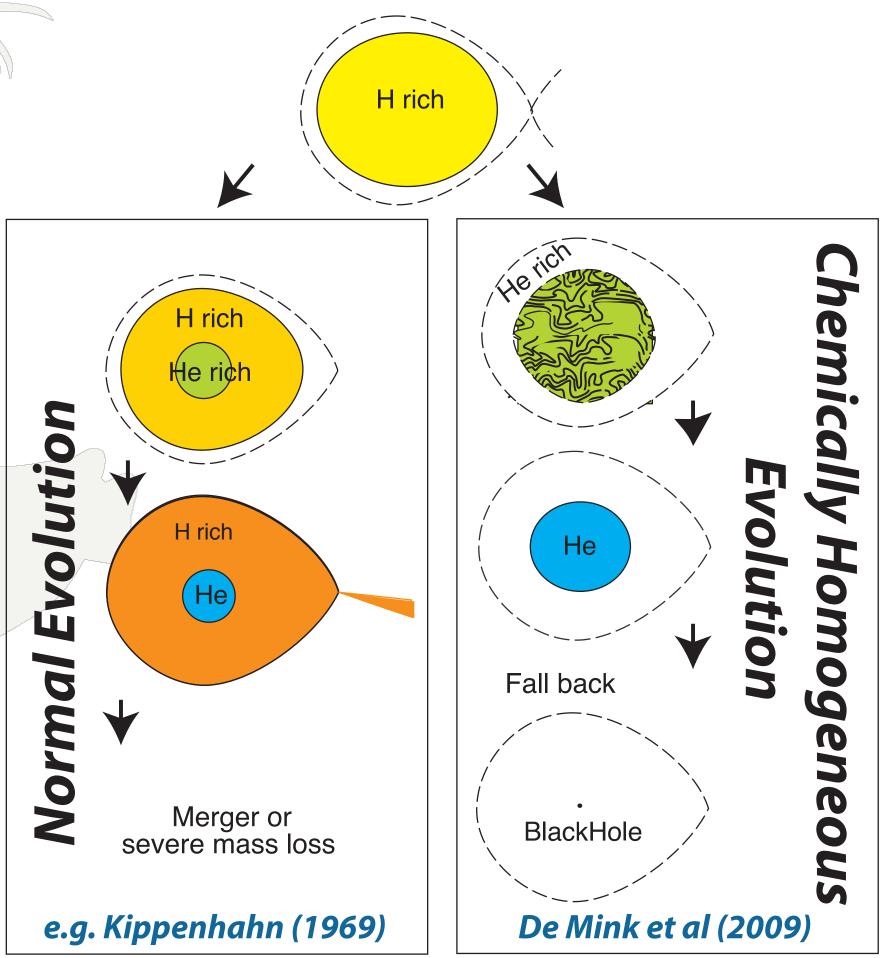


De Mink & Mandel (2016)



Chemically Homogeneous Channel to form BH-BH mergers

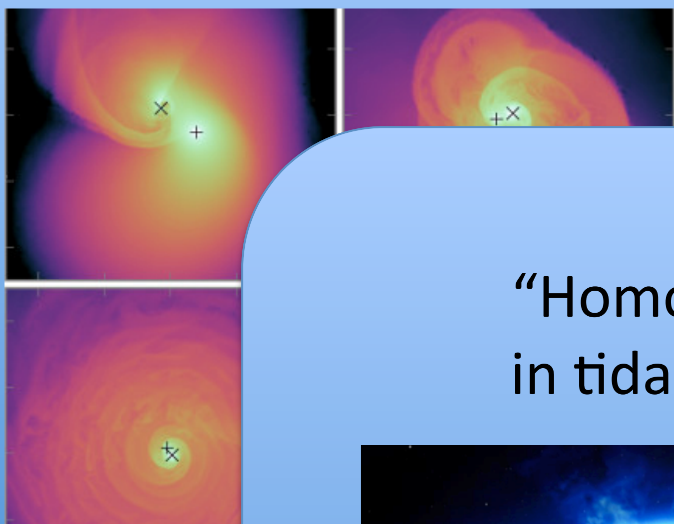
Mandel & De Mink, Marchant et al. (2016), De Mink & Mandel (2016)



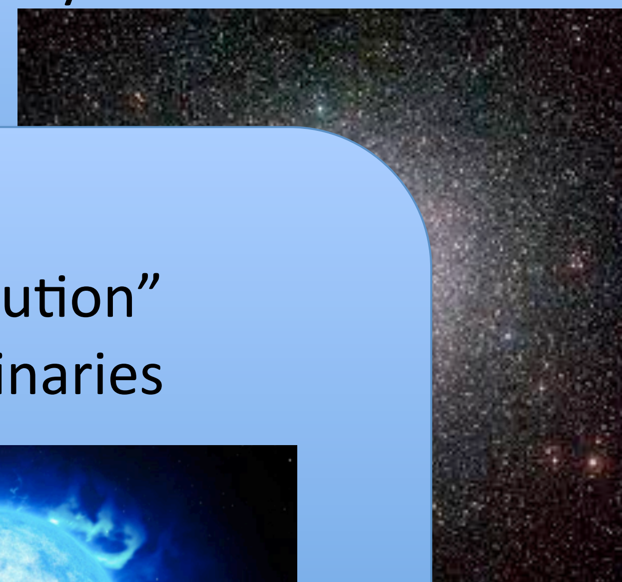
Wrap Up

Making-of

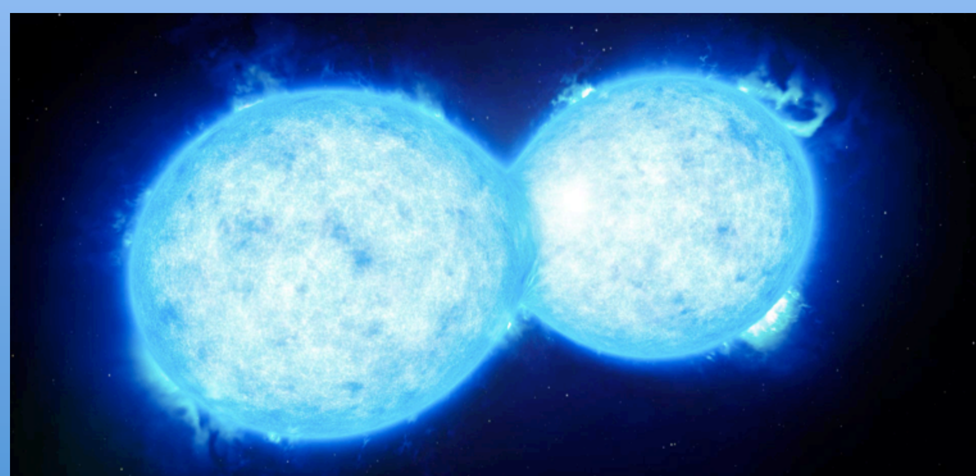
(i)
"Classical" Channel



(ii)
Dynamical interactions



(iii)
"Homogeneous evolution"
in tidally distorted binaries




… Positions opening in Amsterdam
to work on massive binaries