The Making-of … a Binary Black Hole

formation channels of stellar origin

Credit background NASA Paresce., Design E. Butink

BinCosmos

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Silvia Toonen VENI fellow

?

?

Selma E. de Mink

MacGillavry / Marie Curie Fellow, University of Amsterdam

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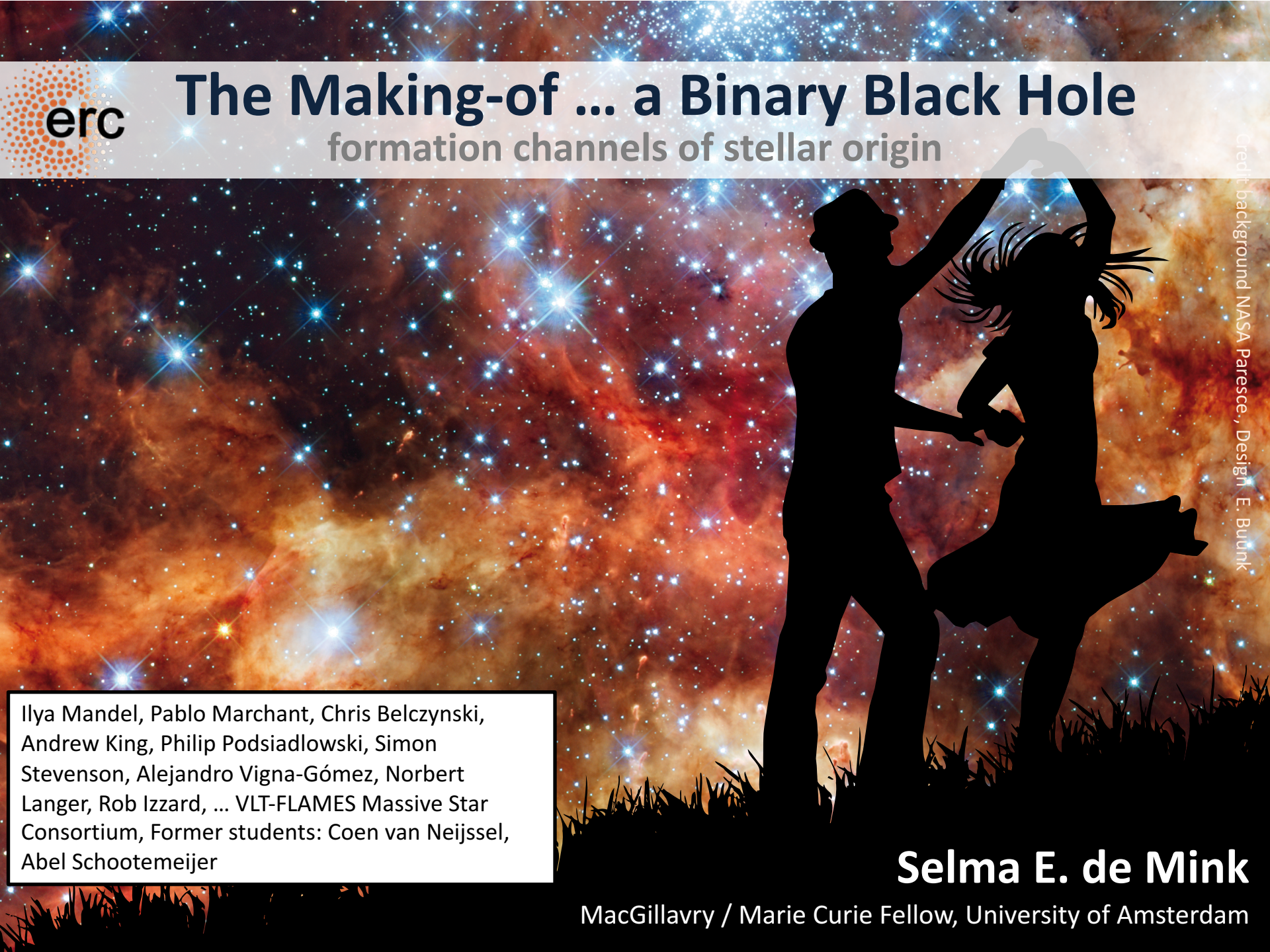

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Ilya Mandel, Pablo Marchant, Chris Belczynski, Andrew King, Philip Podsiadlowski, Simon Stevenson, Alejandro Vigna-Gómez, Norbert Langer, Rob Izzard, … VLT-FLAMES Massive Star Consortium, Former students: Coen van Neijssel, Abel Schootemeijer

Selma E. de Mink

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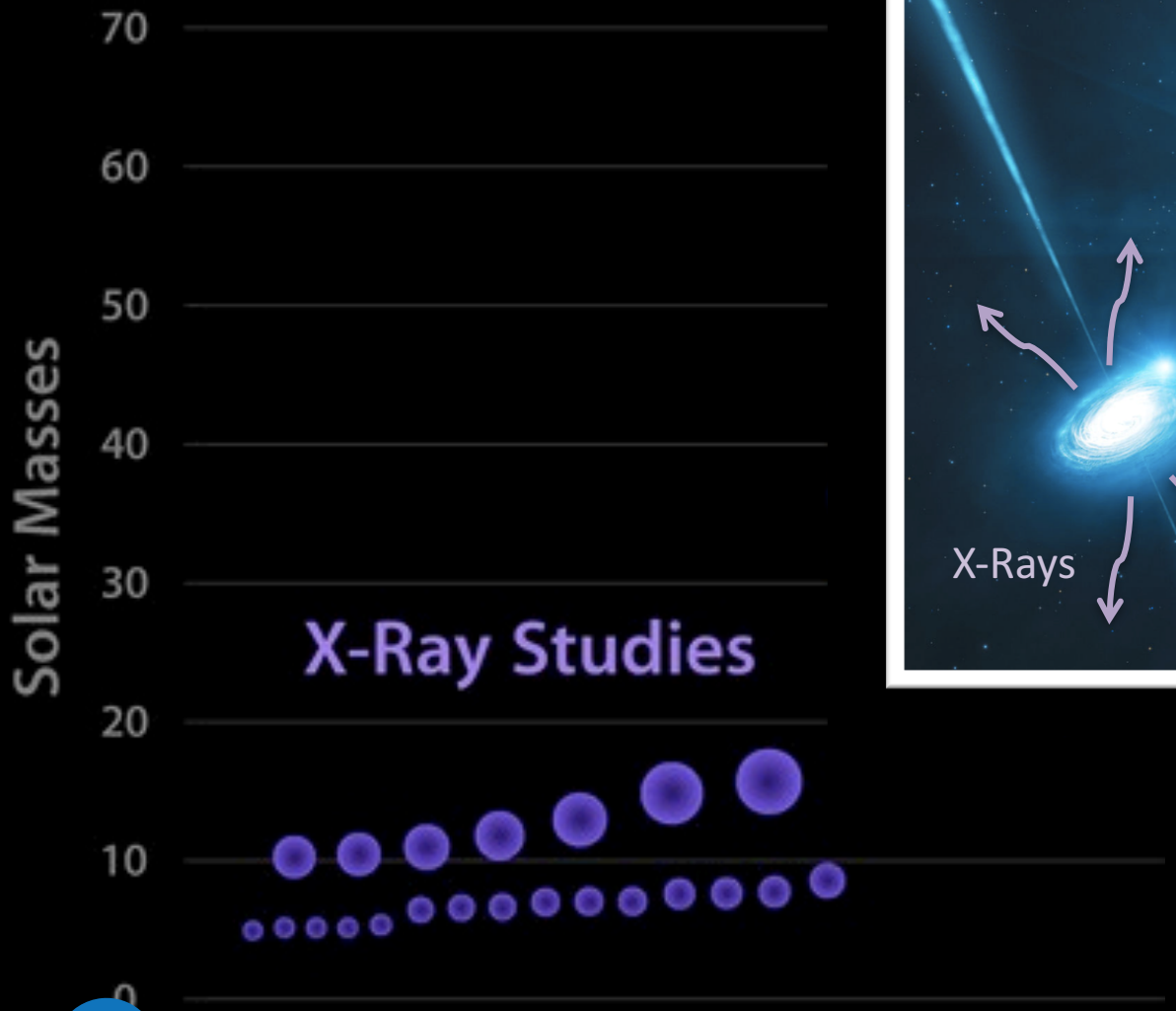
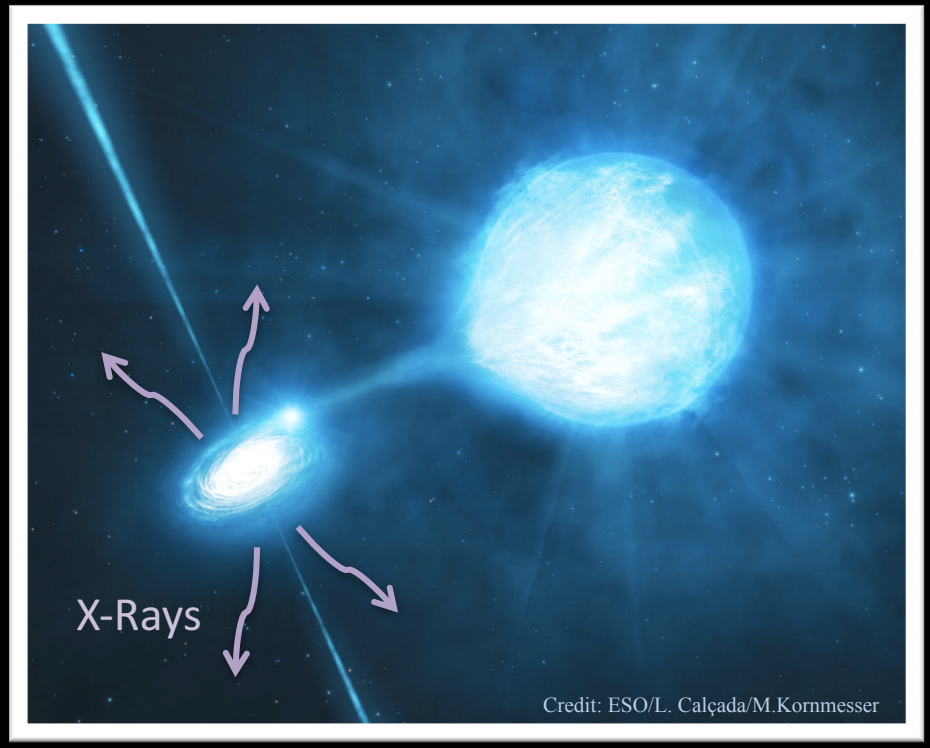
Known Black Holes*

*of stellar mass





Courtesy Caltech/MIT/LIGO Laboratory

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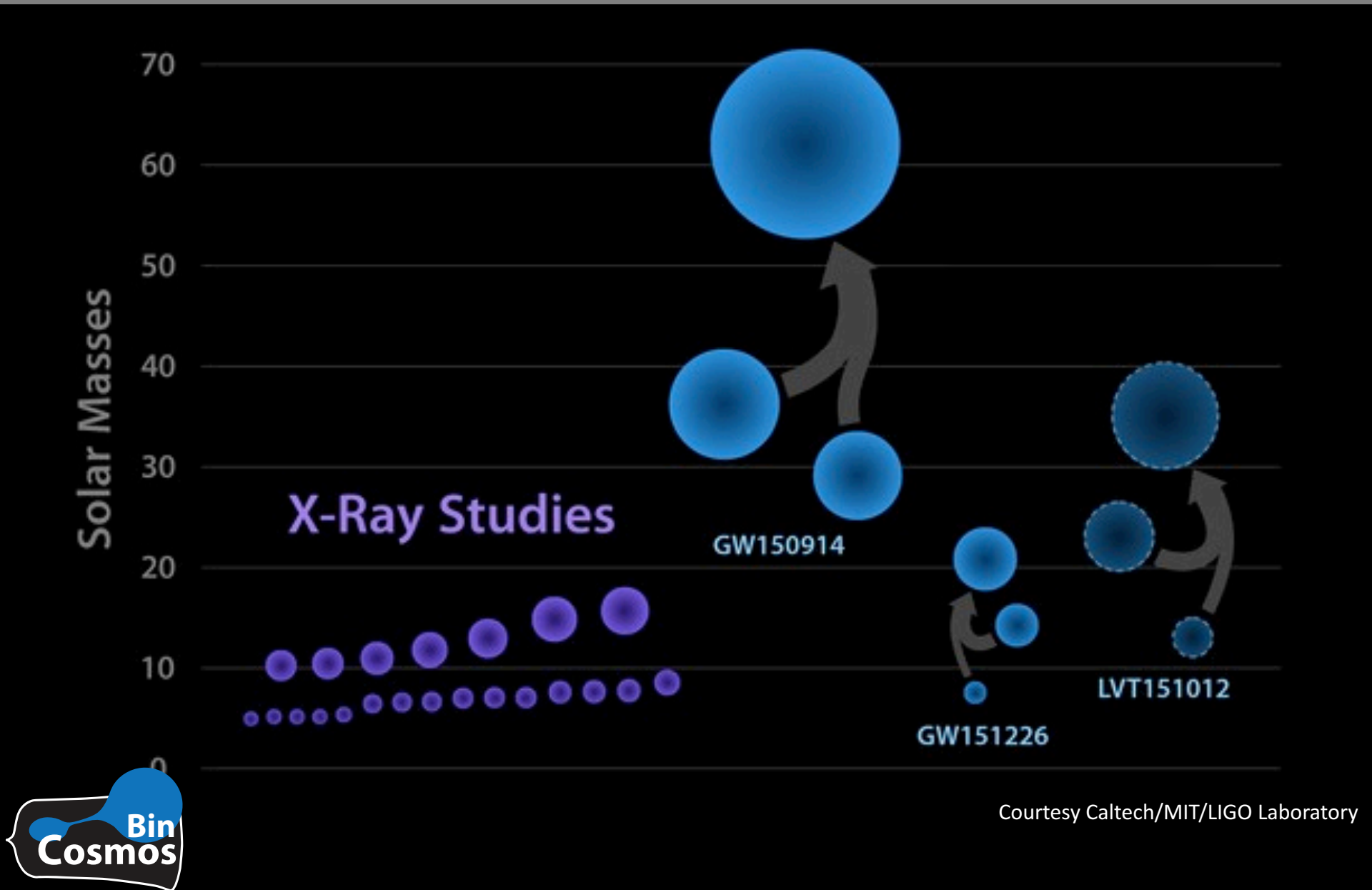
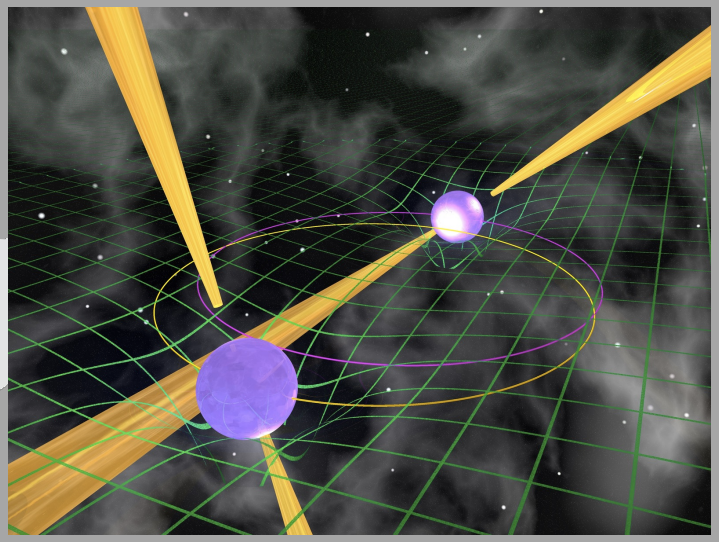
Known Black Holes*

*of stellar mass



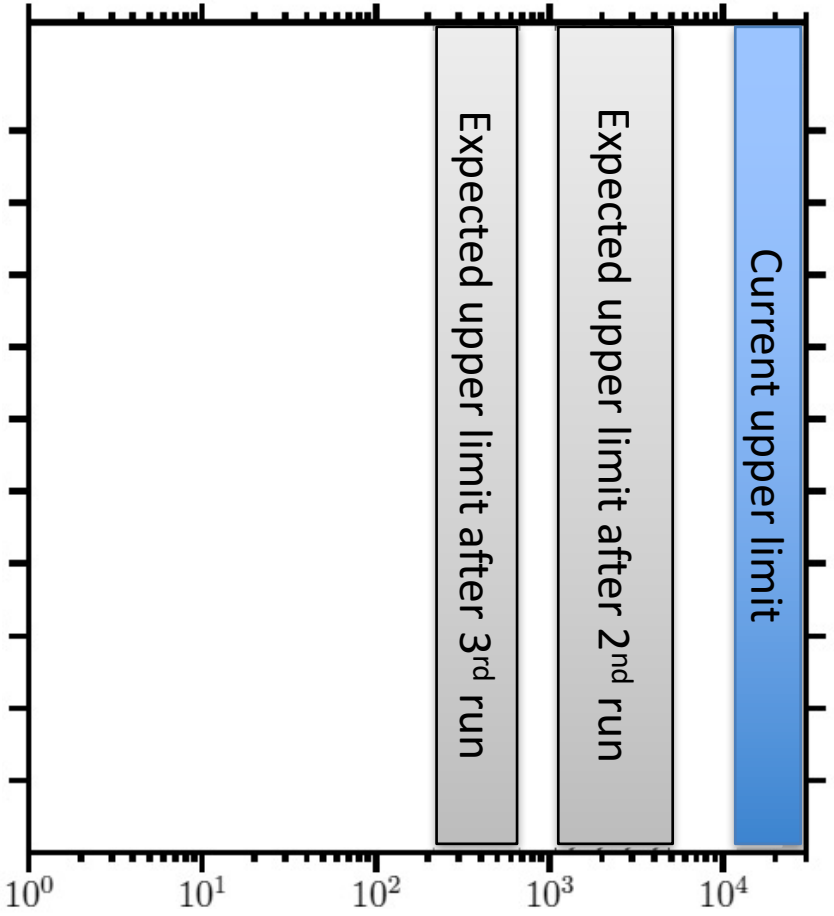
Courtesy Caltech/MIT/LIGO Laboratory

We weren't even really expecting a binary black hole*



Expectations for NS-NS mergers

Fig. adapted from LIGO+2016 ArXiv 1607.07456v1



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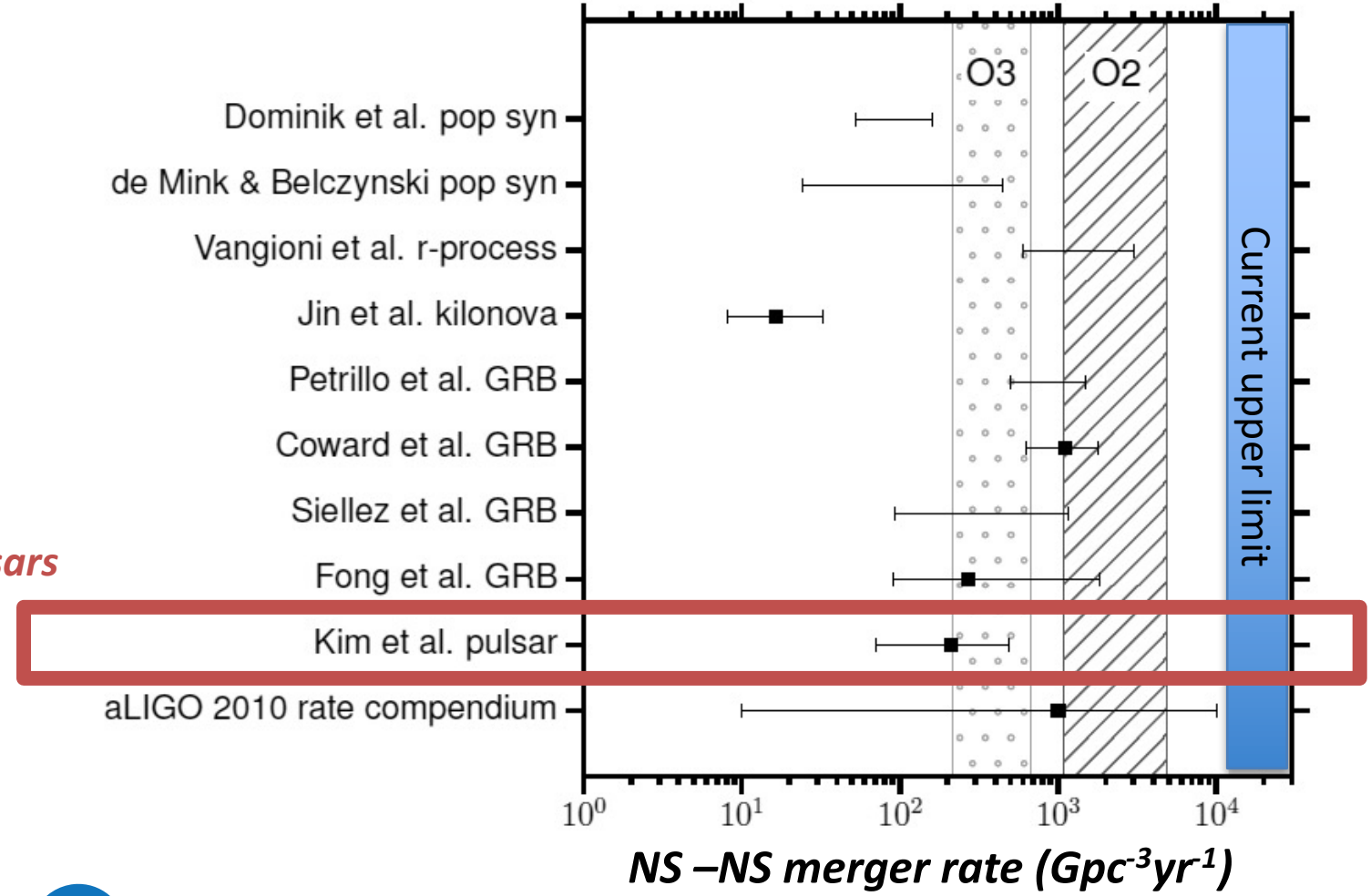
Expectations for NS-NS mergers

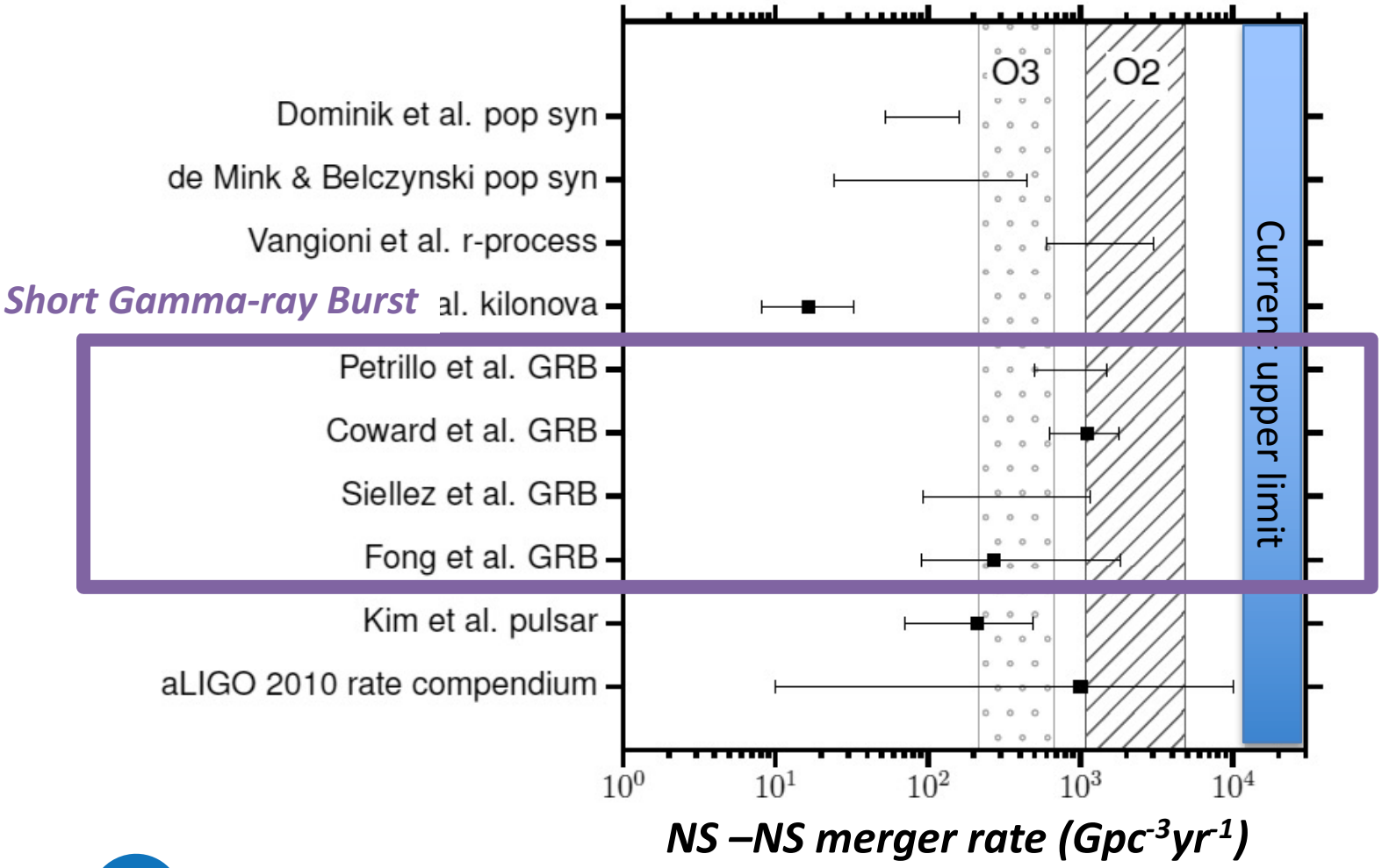
Fig. adapted from LIGO+2016 ArXiv 1607.07456v1



Pulsars

Expectations for NS-NS mergers

Fig. adapted from LIGO+2016 ArXiv 1607.07456v1



Expectations for NS-NS mergers

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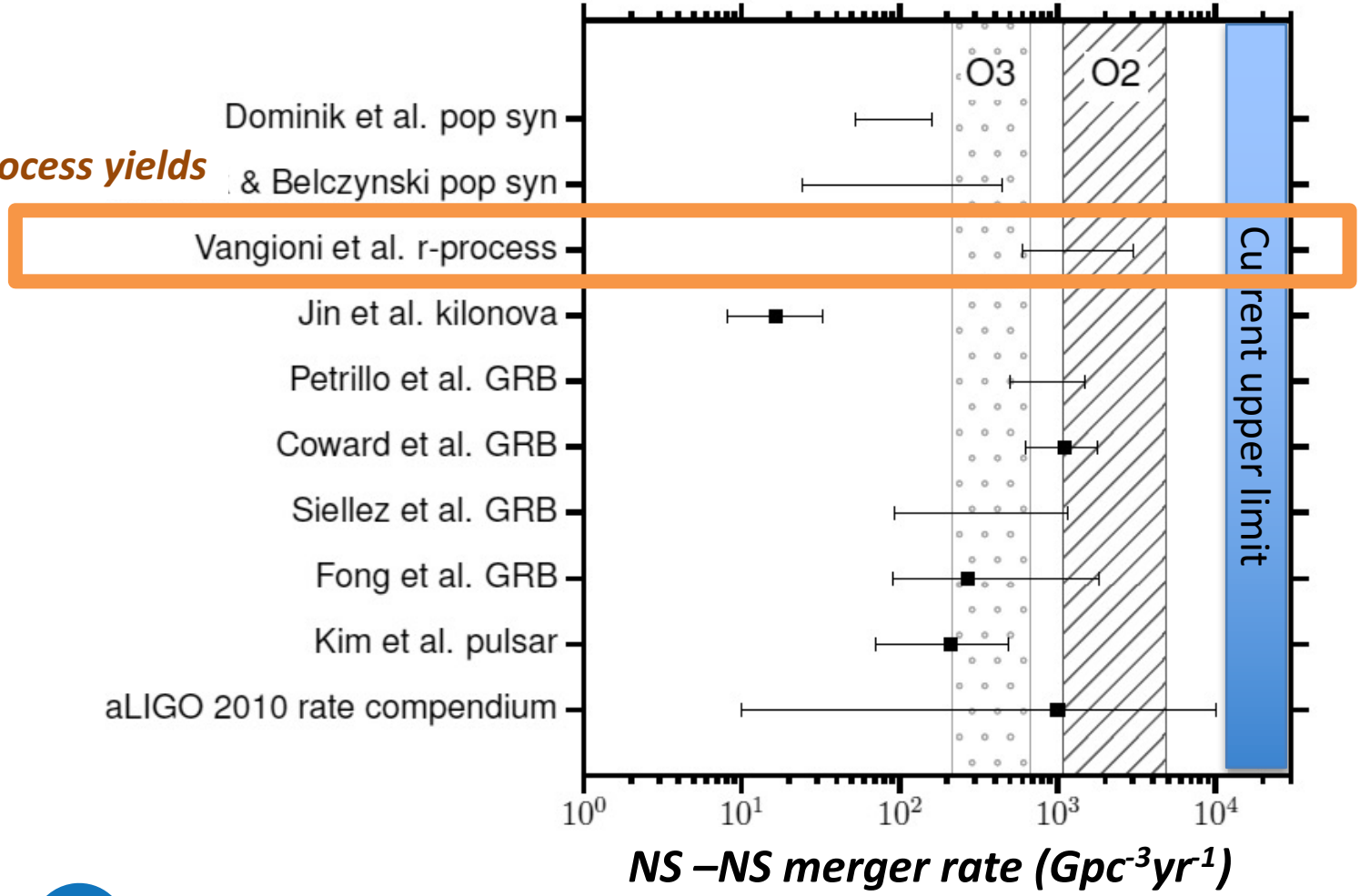
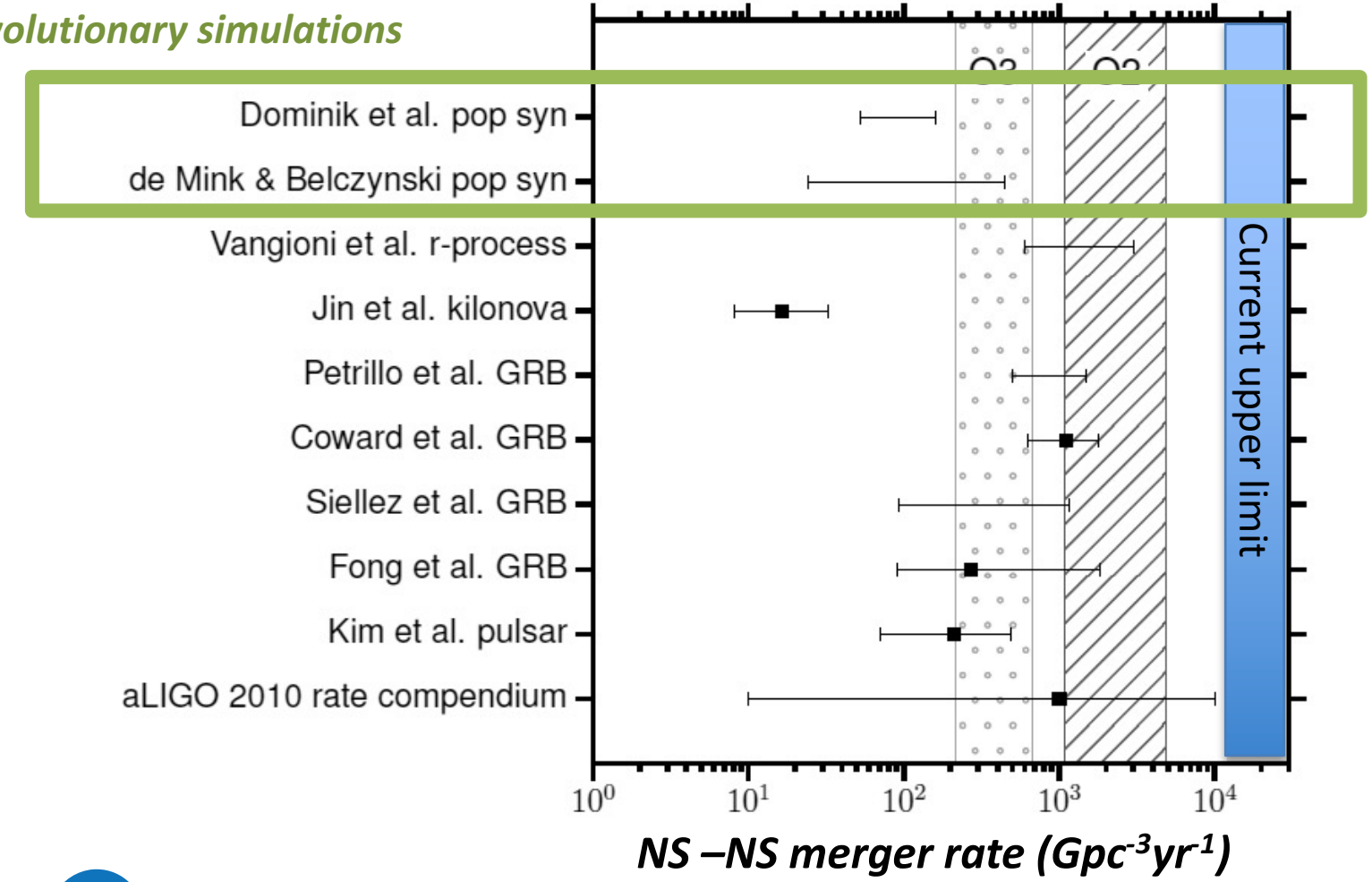


R-process yields

Expectations for NS-NS mergers

Fig. adapted from LIGO+2016 ArXiv 1607.07456v1



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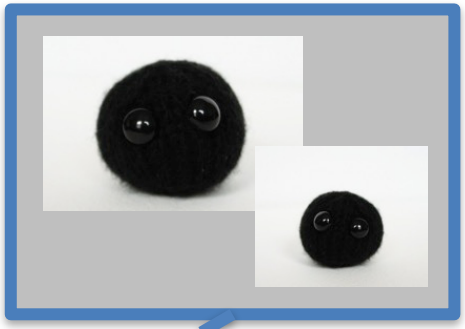
How, When, Where?

When?

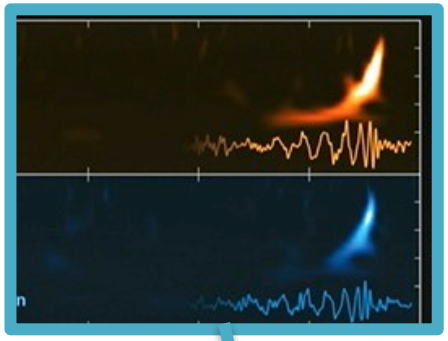
4. Birth of progenitors stars

3. Formation binary black holes



2. Merger

1. Detection of signal



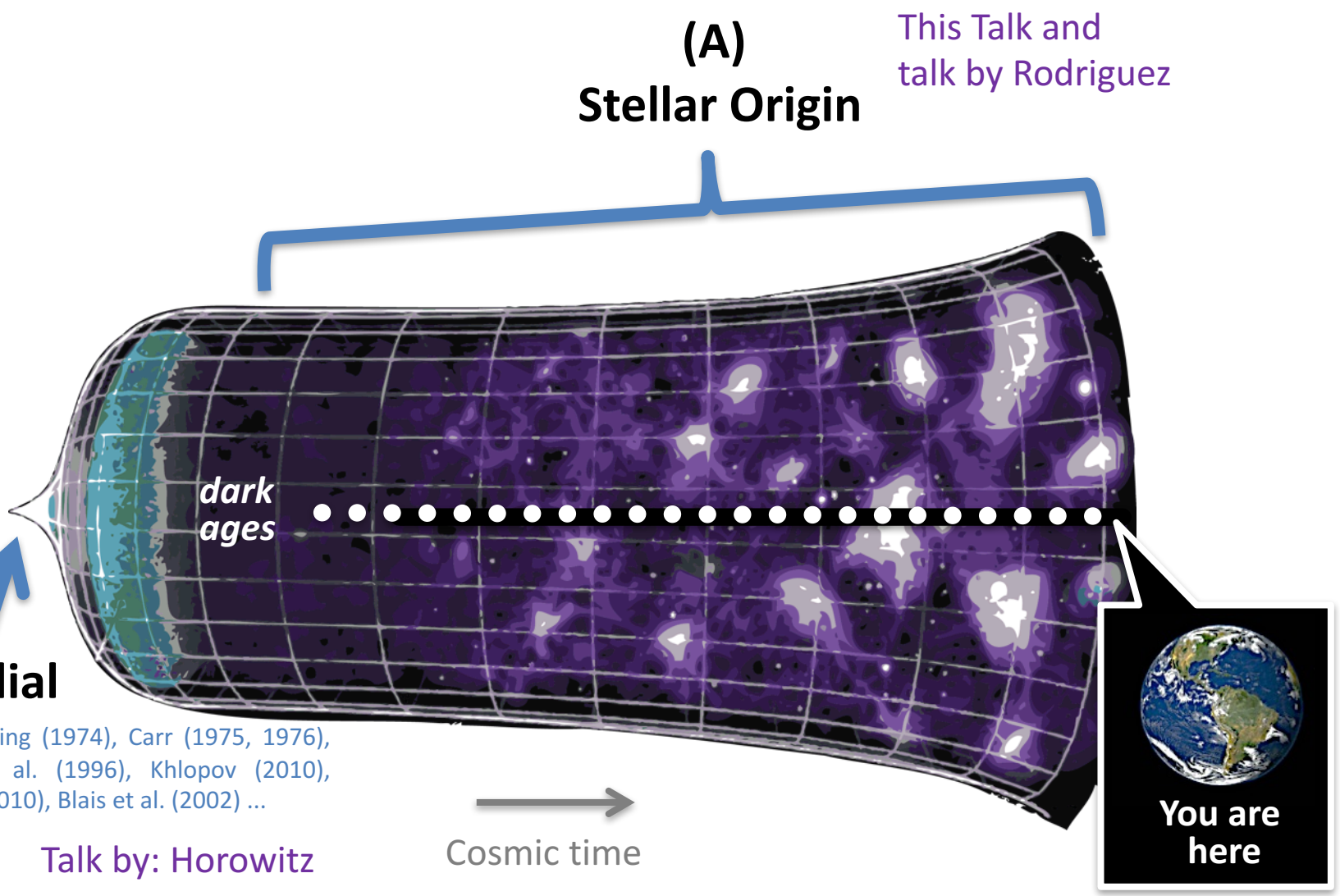
Myrs

+ A few Gyrs

+ 1.4Gyrs

Time

Bin Cosmos


(A)
Stellar Origin
This Talk and
talk by Rodriguez
dark
ages
(B)
Primordial
e.g. Carr & Hawking (1974), Carr (1975, 1976), Garcia-Bellido et al. (1996), Khlopov (2010), Frampton et al. (2010), Blais et al. (2002) ...
Talk by: Horowitz
Cosmic time
You are
here

Two Main Challenges

for all progenitor scenarios

Progenitors

1. *"Separation Challenge"*

2. *"Mass Challenge"*

Separation

1. "Separation Challenge"

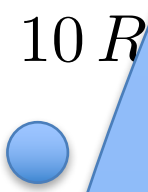
How to get Black holes close enough to coalesce in a Hubble time?

$10\ R_\odot$

Separation

1. "Separation Challenge"

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



Separation

1. "Separation Challenge"

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

2. "Mass Challenge"

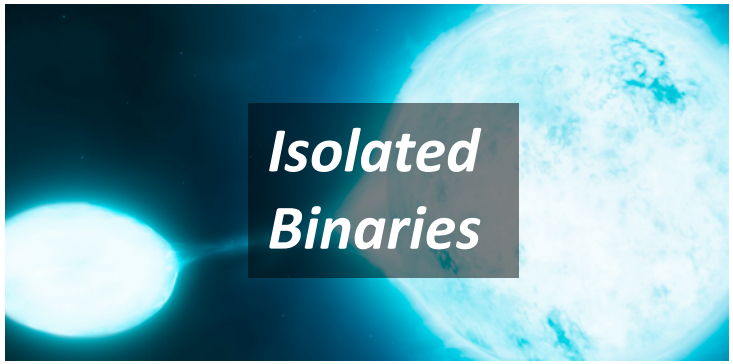
How to avoid excessive Mass loss?

Bin Cosmos

Formation Channels

Formation Channels

1. Evolutionary formation channels



2. Dynamical formation channels

Stellar Density

Two types of Formation Channels

1. Evolutionary formation channels

- ✓ **Classical channels** (involving a common envelope or other highly non-conservative mass transfer)
- ✓ **Chemically Homogeneous Channel** (mixing processes in near contact binaries)
- ✓ Hybrid channels & Pop III stars …

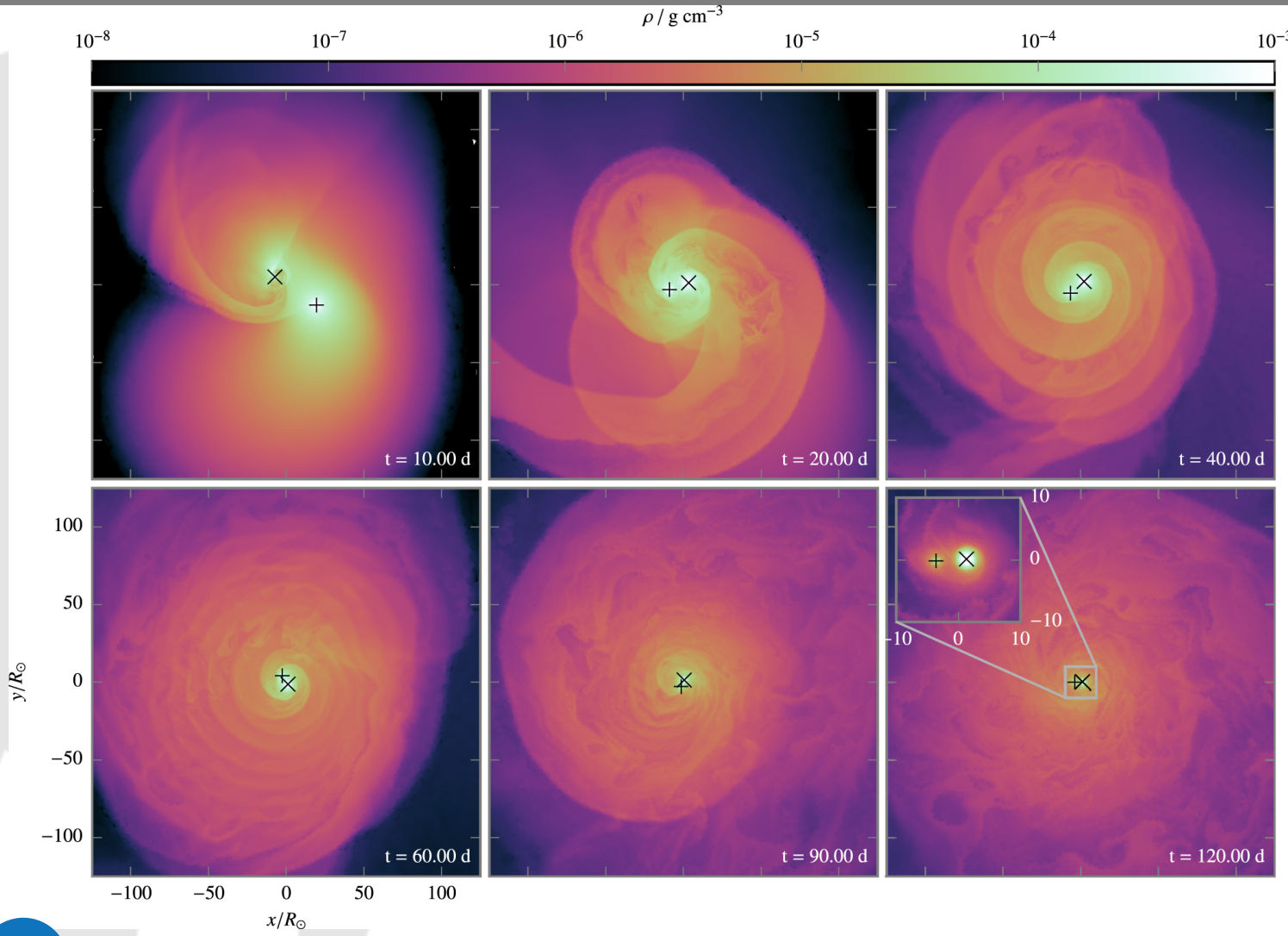
2. Dynamical formation channels

- ✓ 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
- ✓ …

(1 a)
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, , Kruckow et al. (2016)...

Common Envelope
a very hard problem computationally



HYDRODYNAMIC MOVING-MESH SIMULATIONS

Ohlmann et al. 2015

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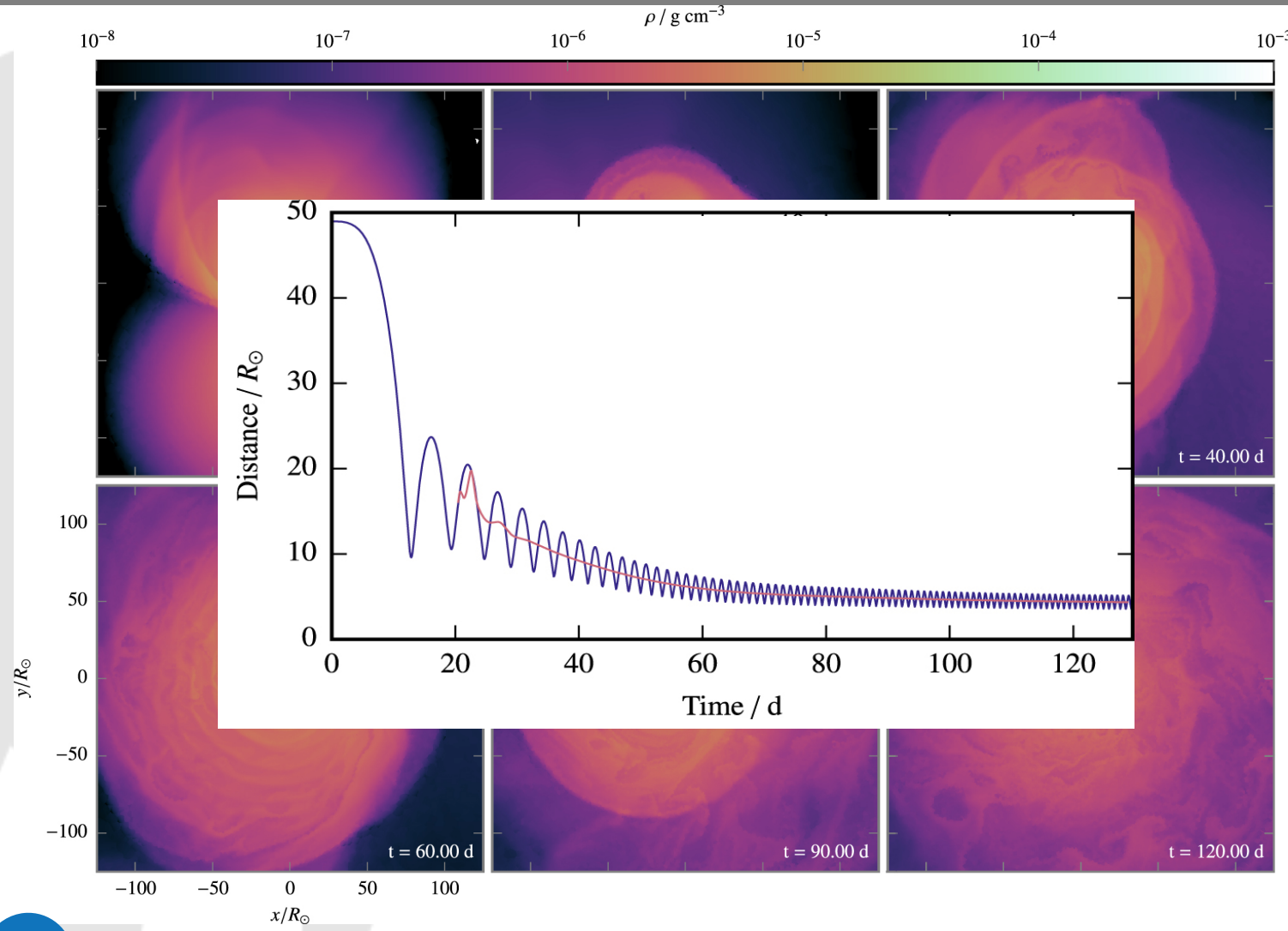
Common Envelope
a very hard problem computationally



HYDRODYNAMIC MOVING-MESH SIMULATIONS

Ohlmann et al. 2015

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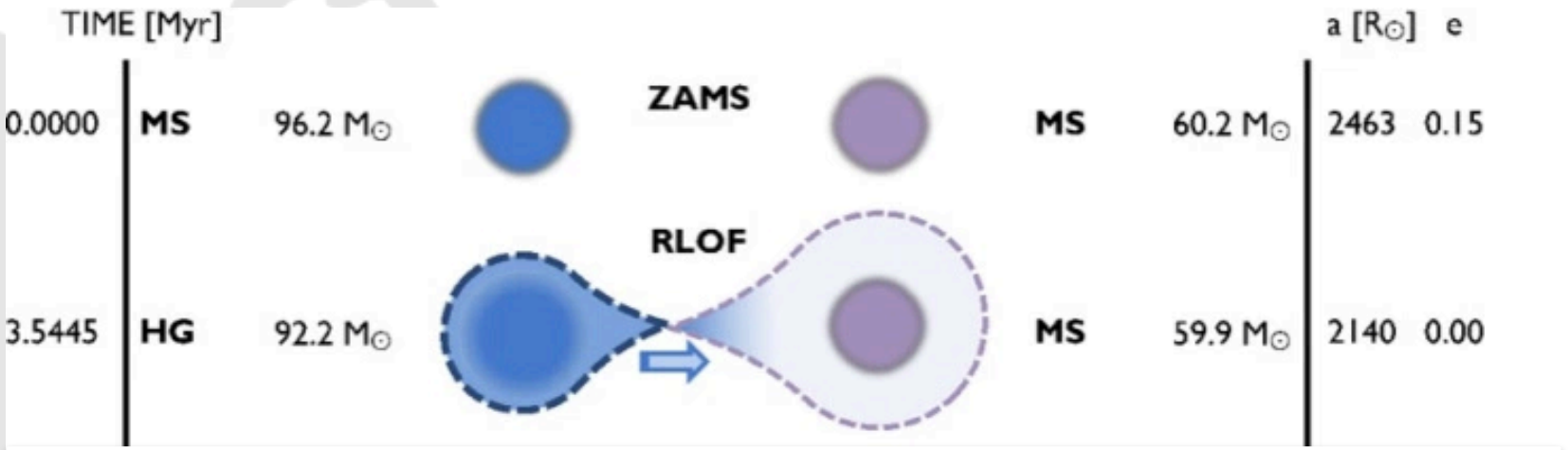
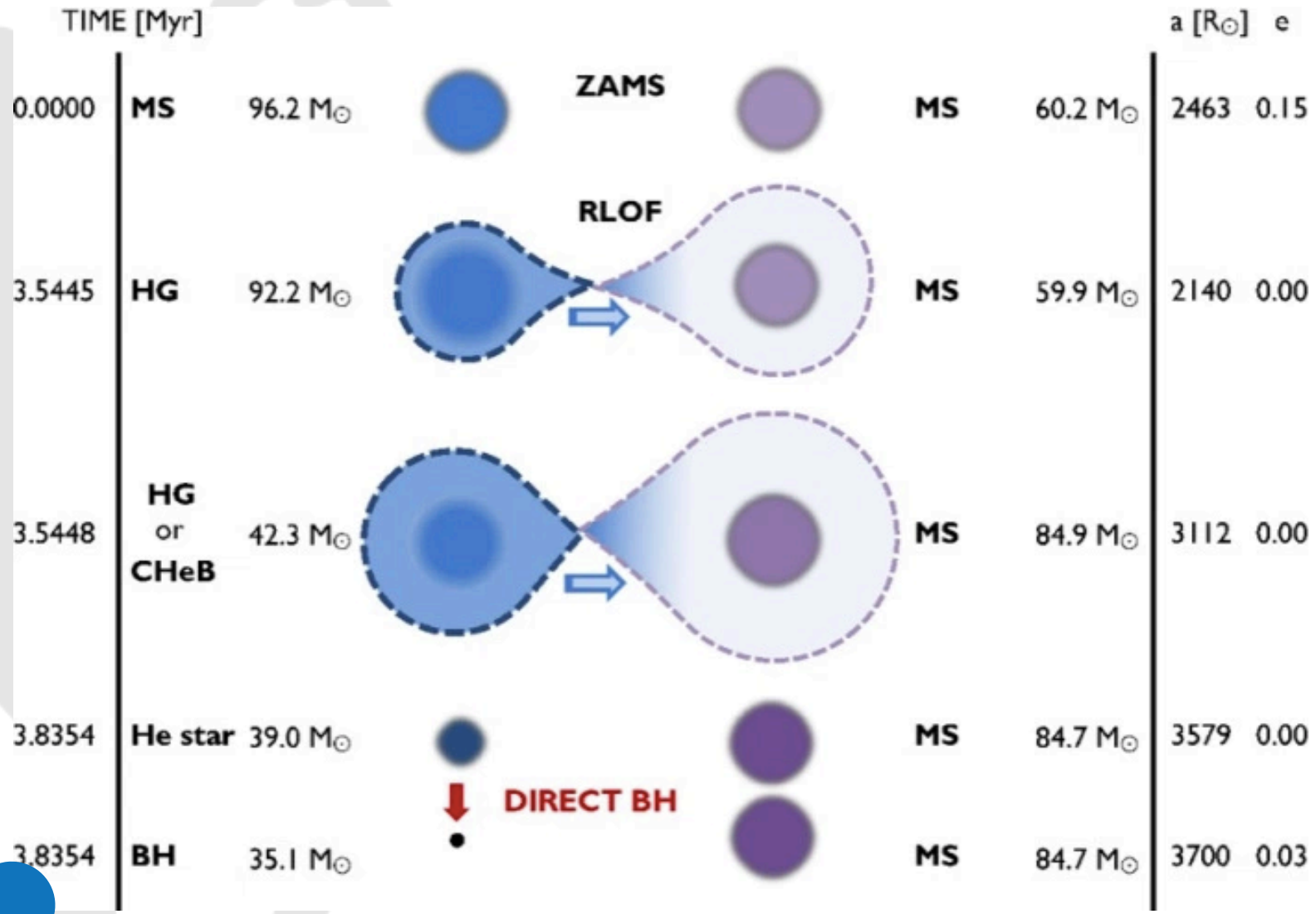
Classic Channel

Belczynski et al. 2016



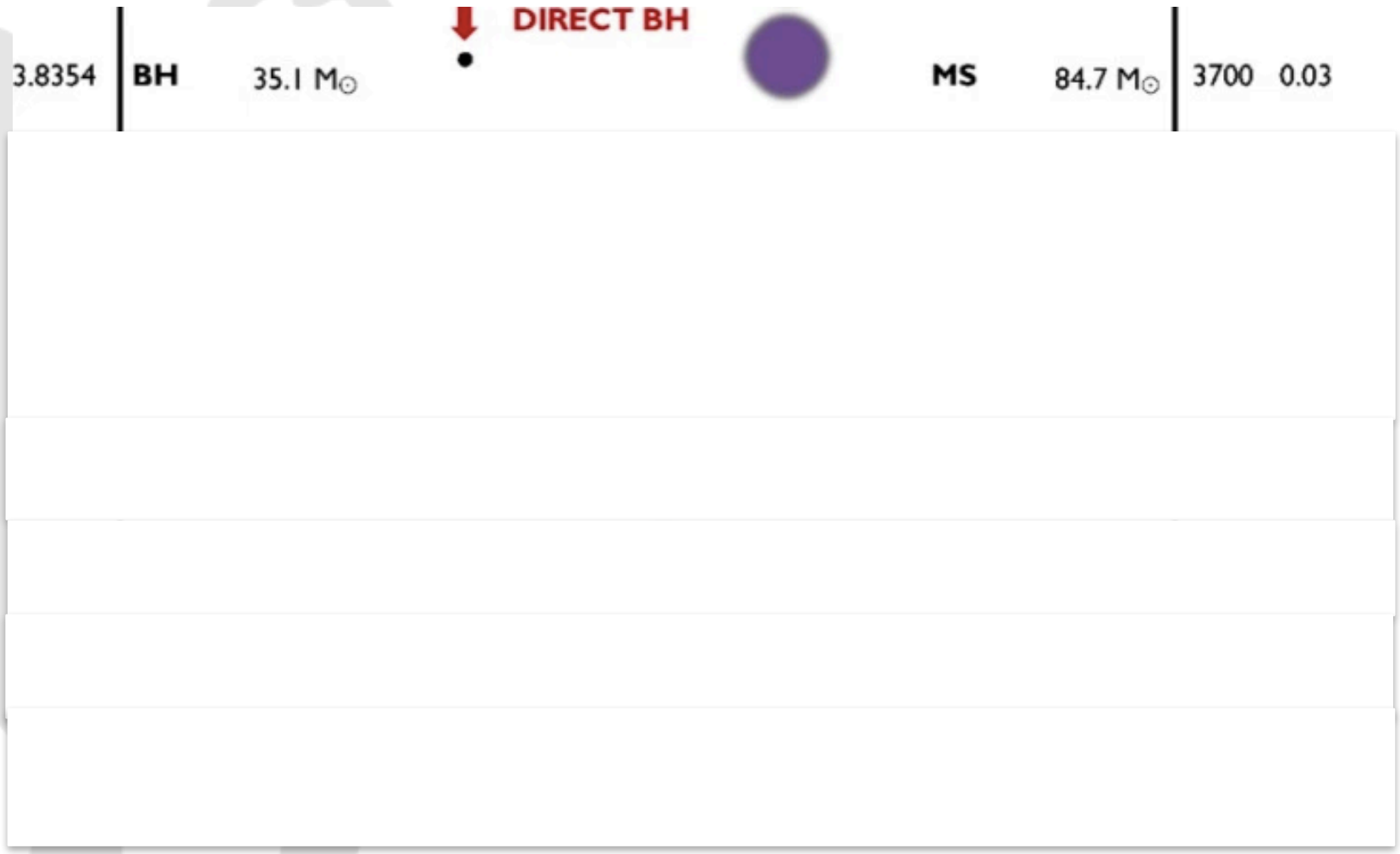
Classic Channel

Belczynski et al. 2016



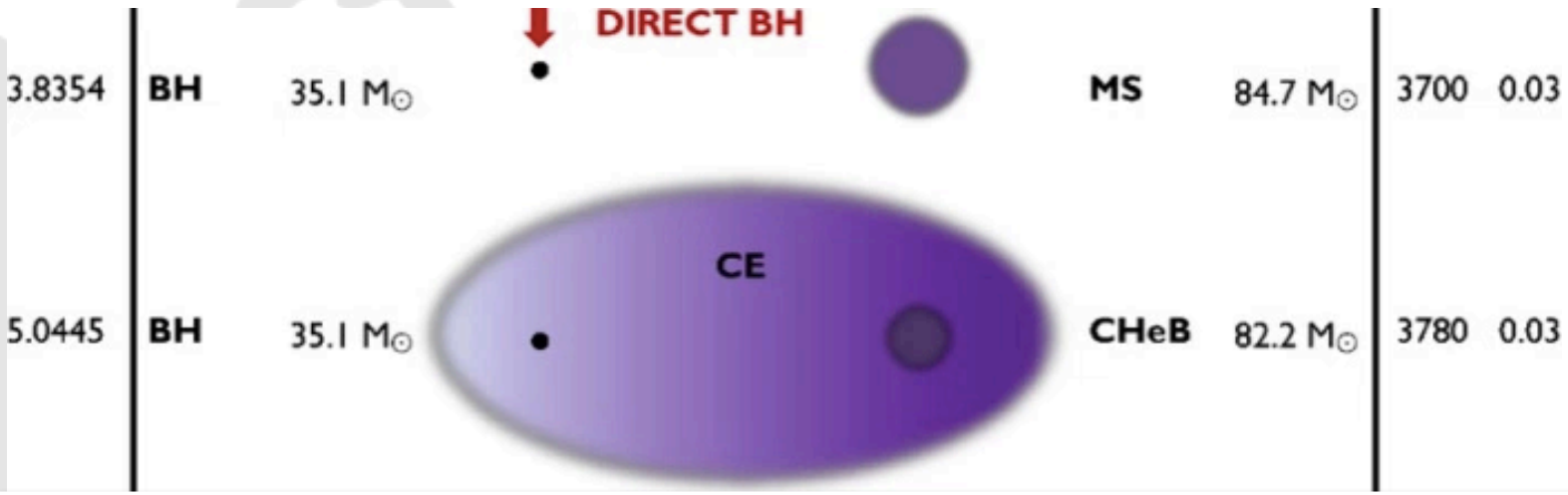
Classic Channel (part 2)

Belczynski et al. 2016



Classic Channel (part 2)

Belczynski et al. 2016



Classic Channel (part 2)

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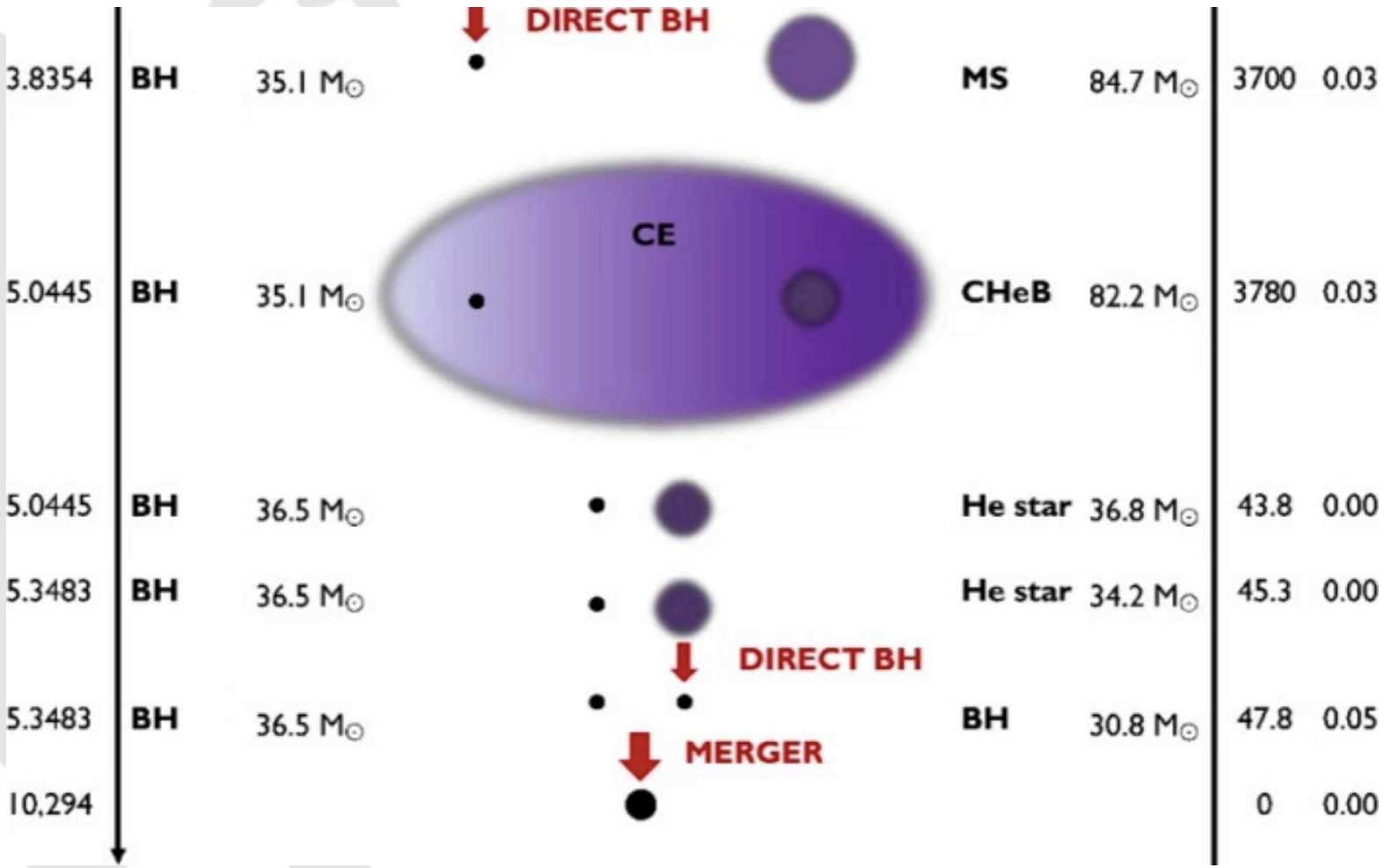
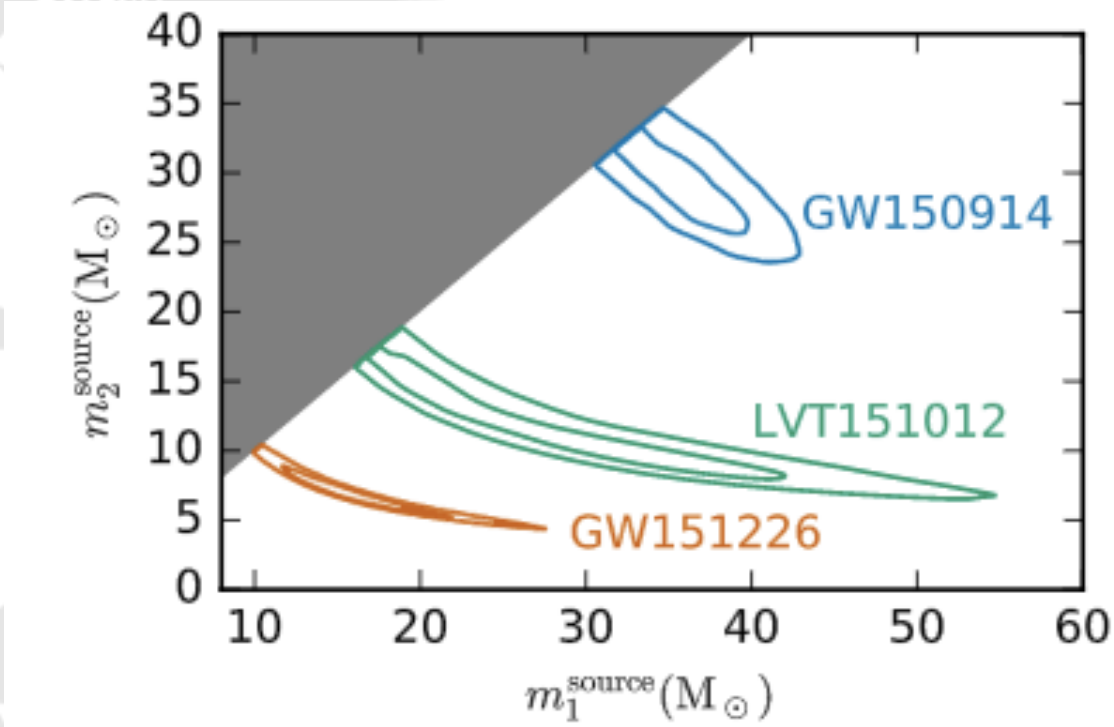
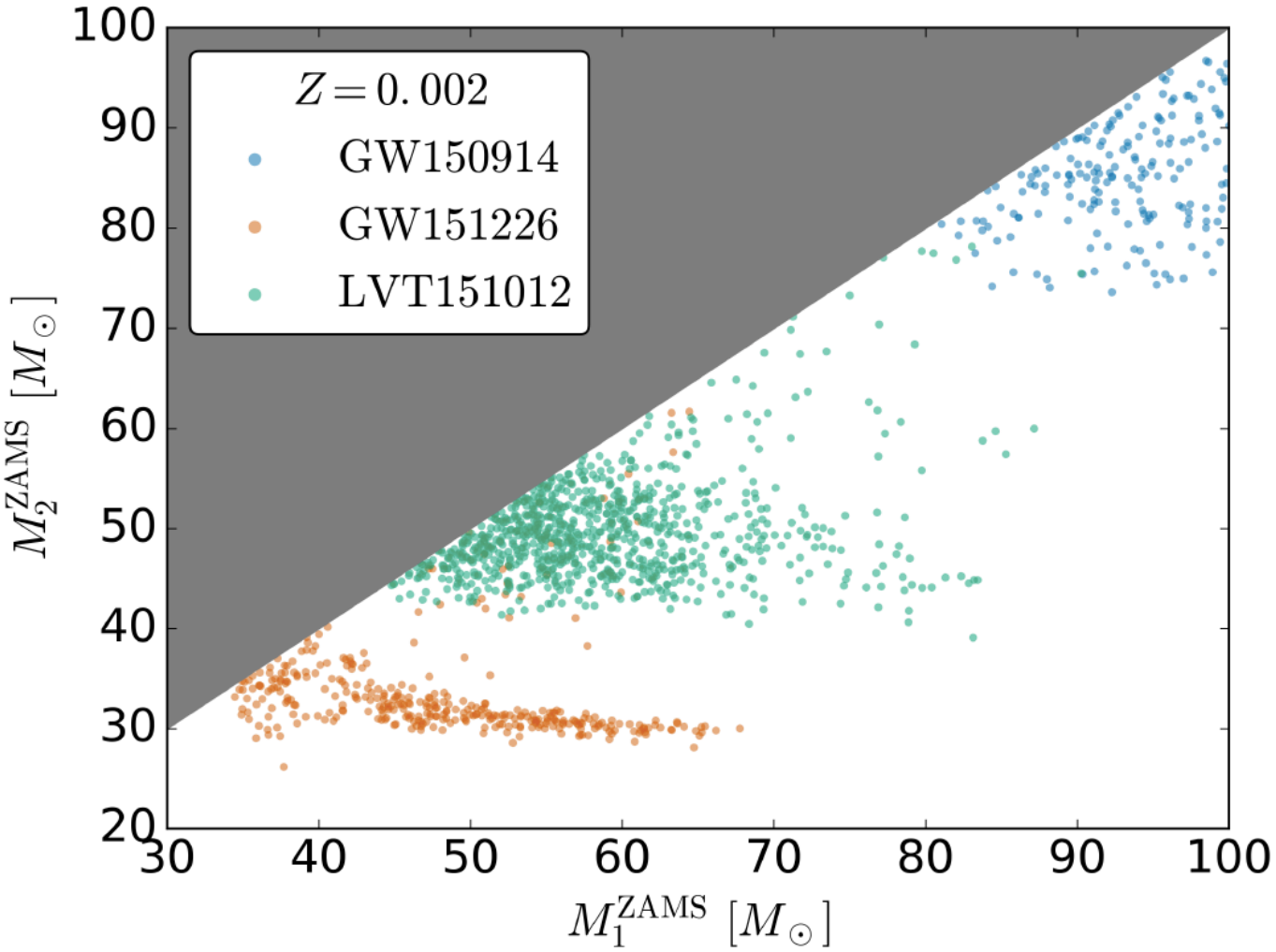


Can the classical channel explain all three events?



Can the classical channel explain all three events?

Yes*



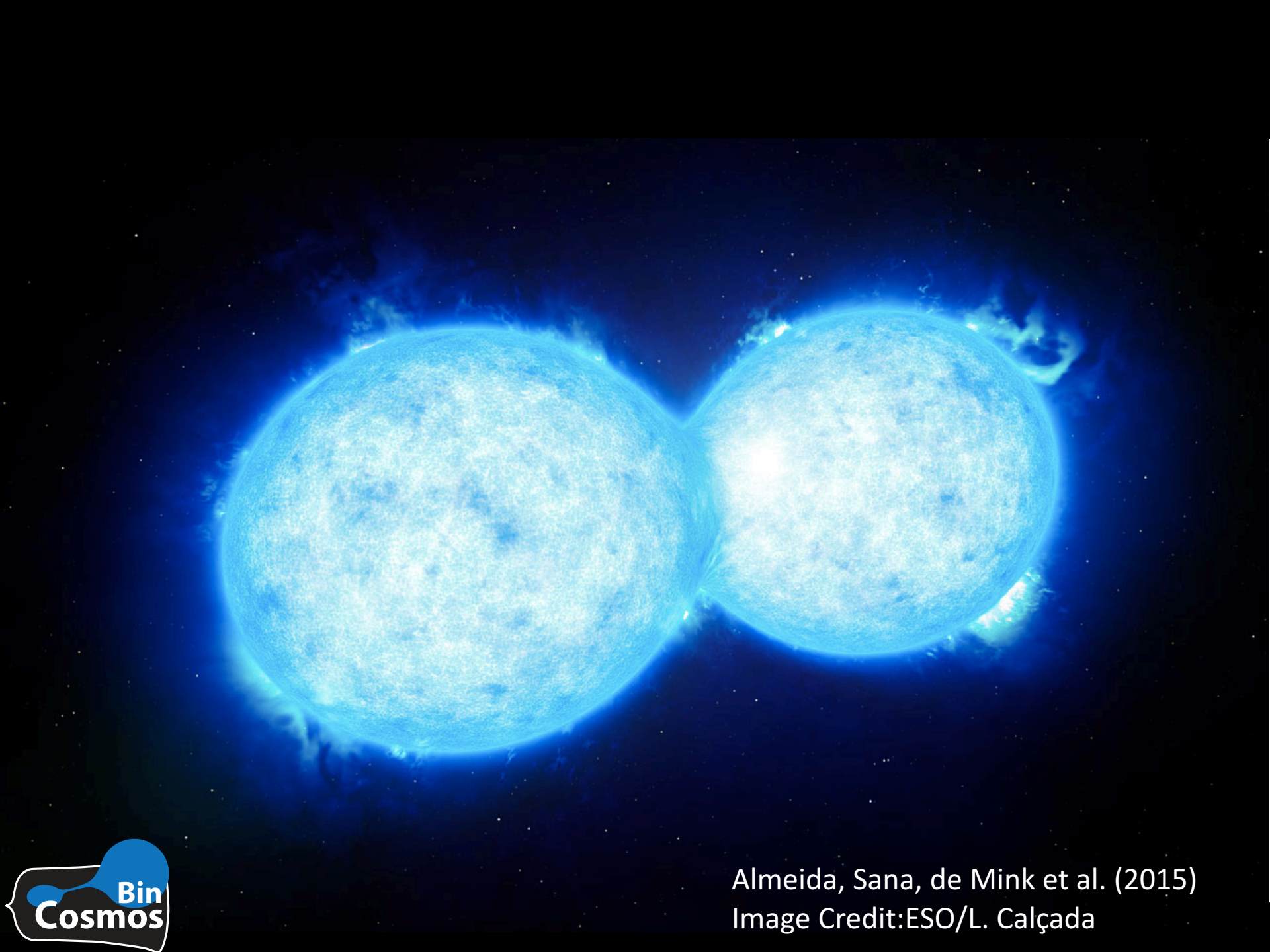
Stevenson, Vigna-Gomez, Mandel, Perkins, Barrett, de Mink (2017)

(1.b)

Chemically Homogeneous Channel

(Other names: Case M, Tidal mixing channel,
Massive Overcontact Binary Channel)

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



Almeida, Sana, de Mink et al. (2015)
Image Credit:ESO/L. Calçada

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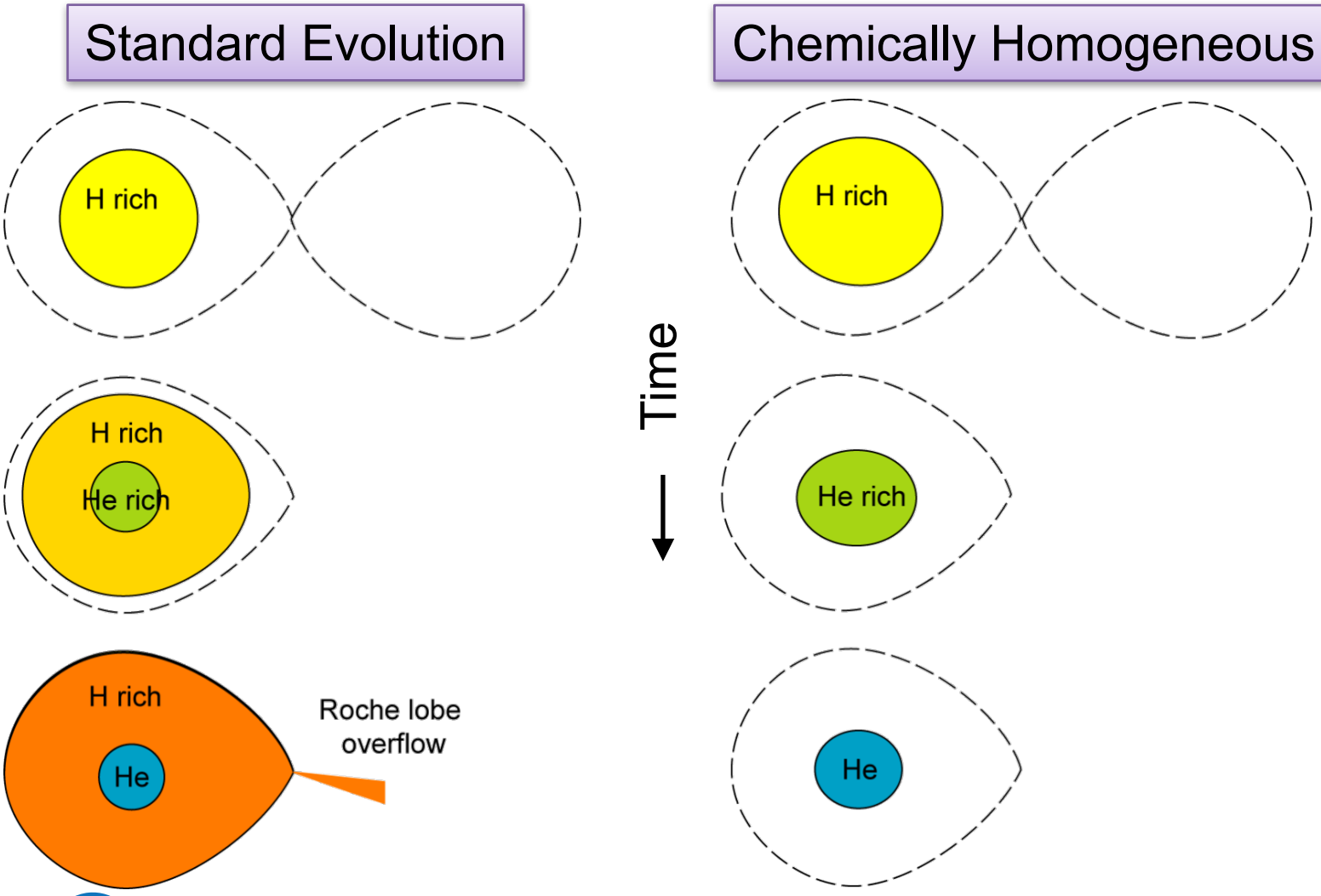
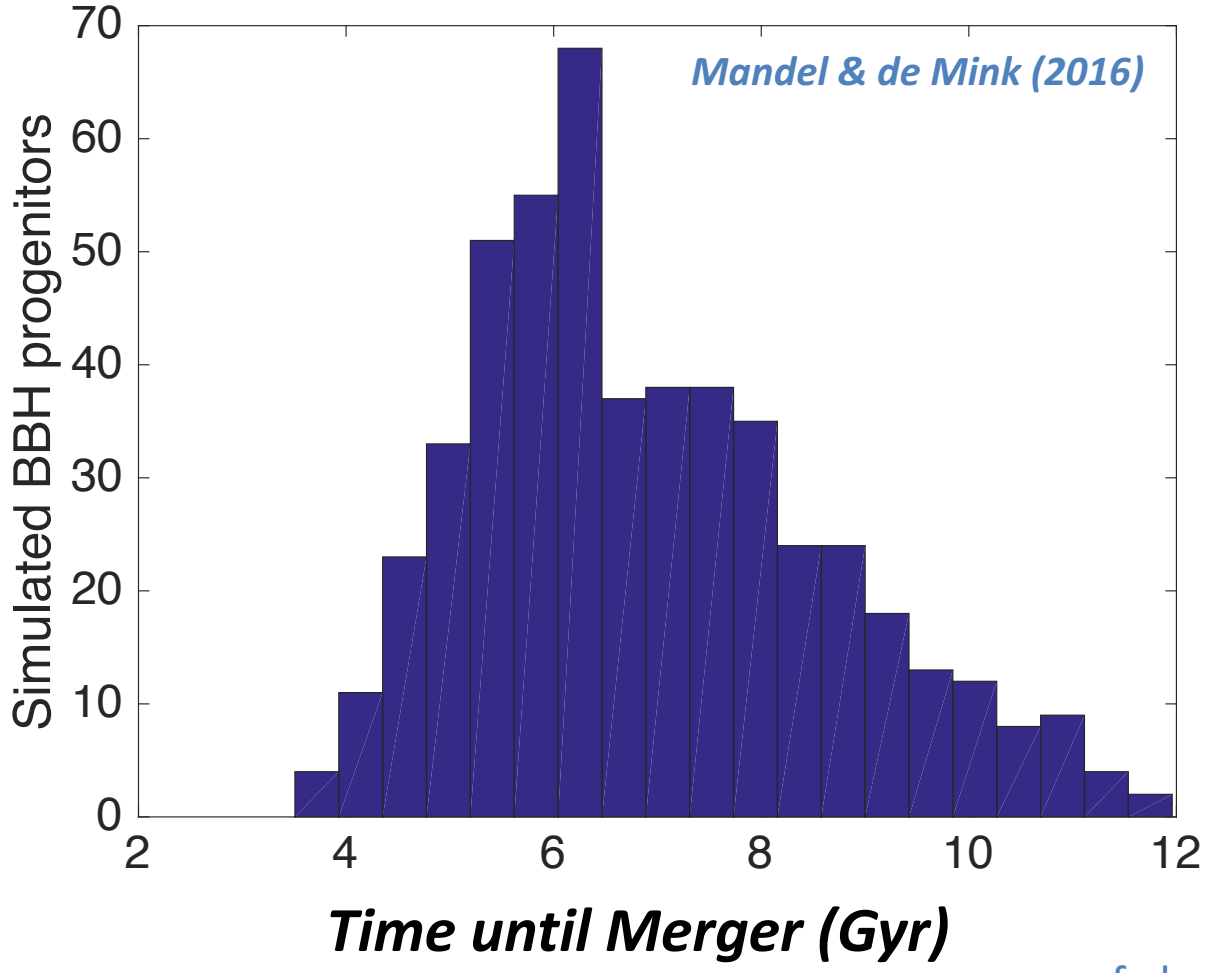

Standard Evolution
Chemically Homogeneous
H rich
H rich
He rich
H rich
He rich
Time
H rich
He
Roche lobe overflow
He

De Mink+'08,'09

Do they merge within a Hubble time?

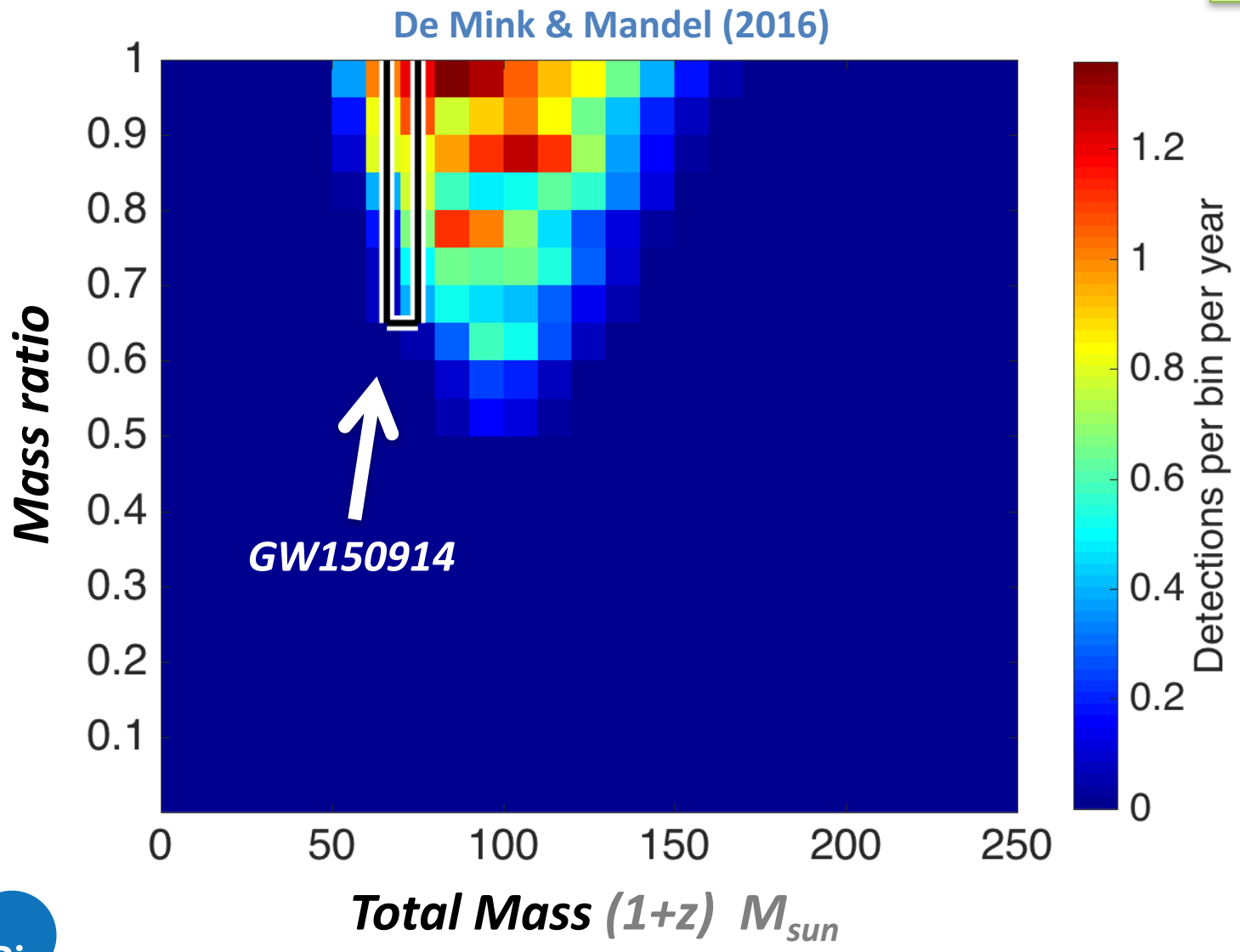
Yes.



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

Can it reproduce high masses?

Yes*



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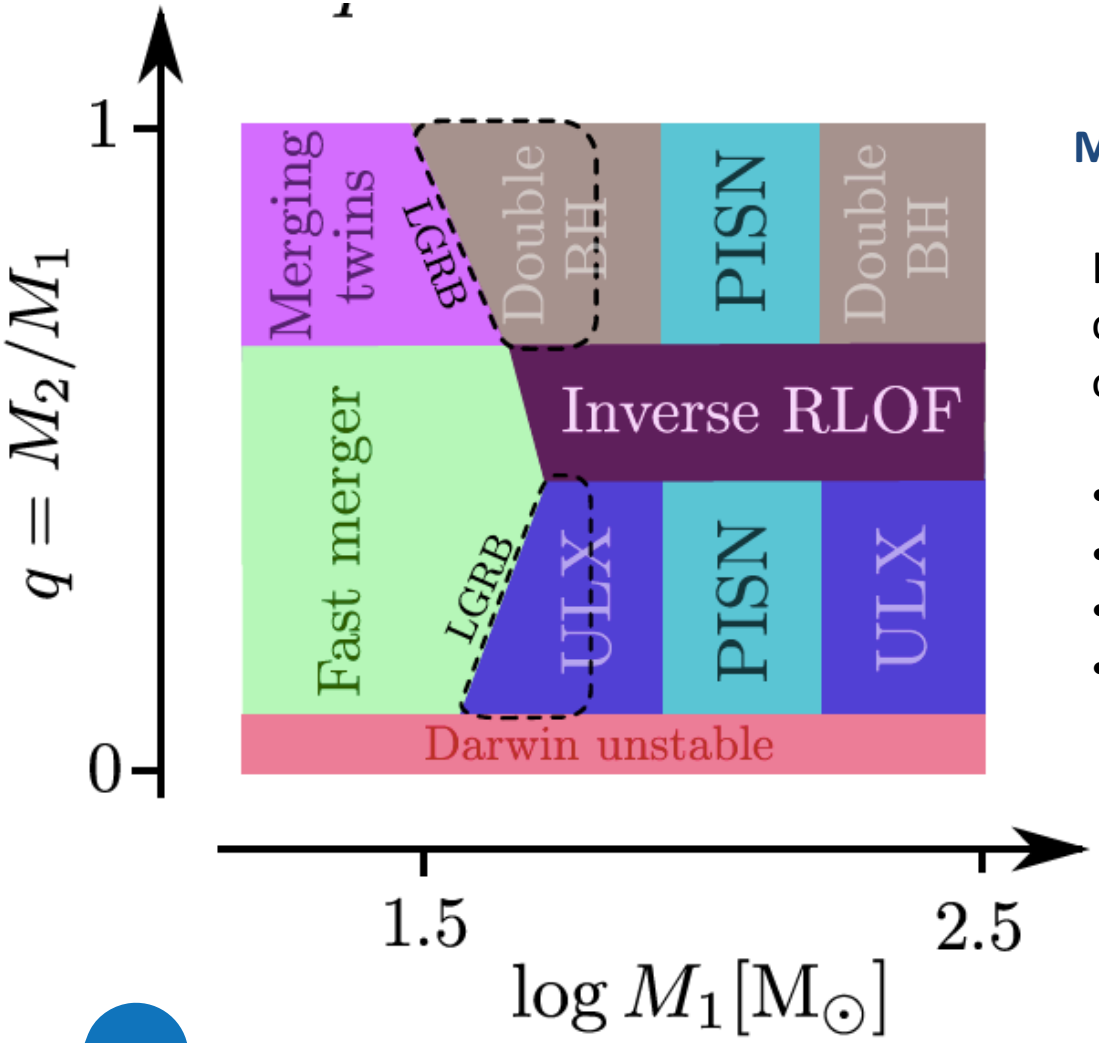
How to proceed from here?

Homework for (Evolutionary) Theorists

Astrophysical “side products”



Marchant, … w/SdM (2017, subm.)

Independent observational constraints from EM observations of side products:

- Pair Instability Supernova
- Ultra Luminous X-ray sources
- Contact binaries
- Merger events

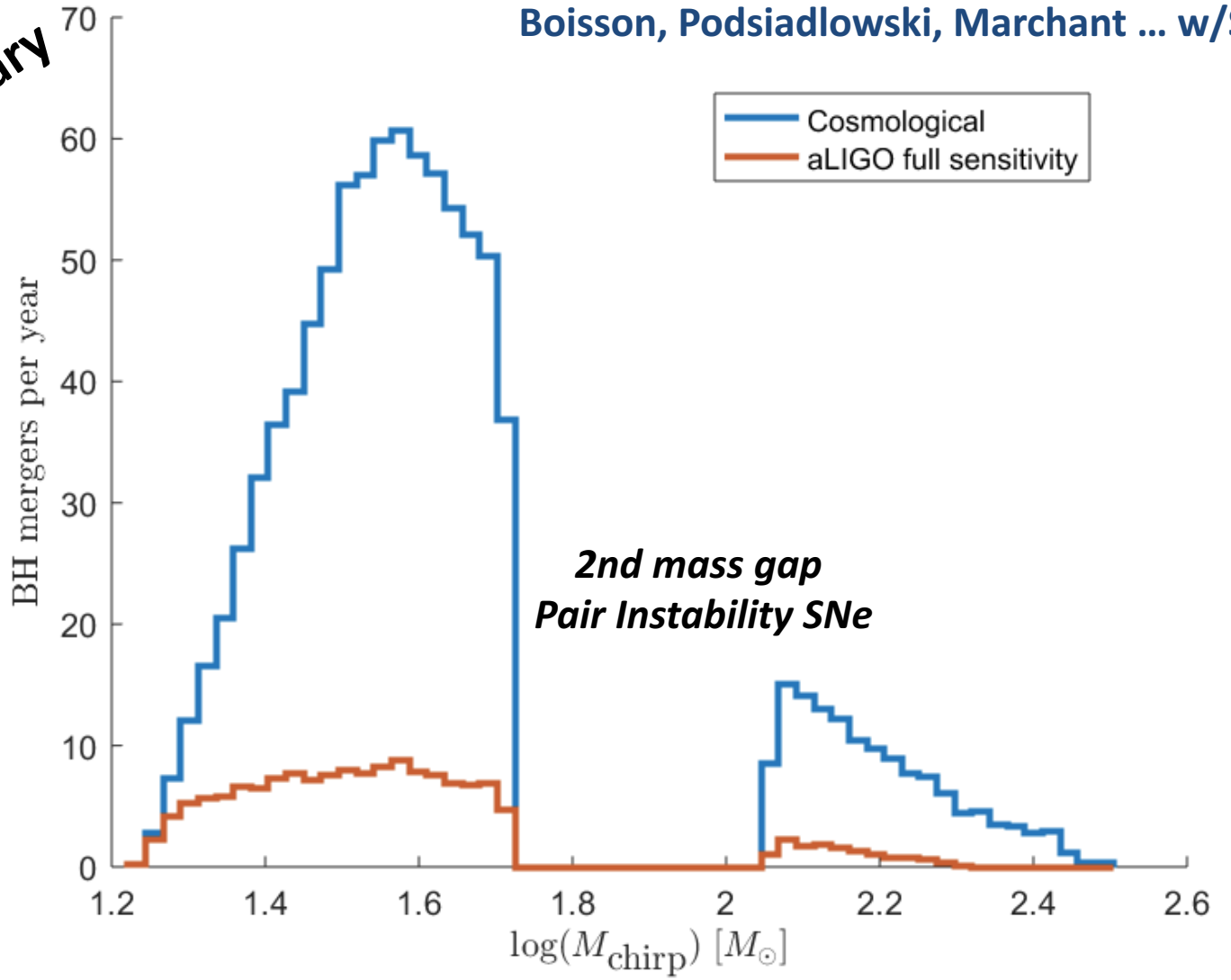
MESA

BinCosmos

We need to understand the predicted demographics of the Black Holes

Preliminary

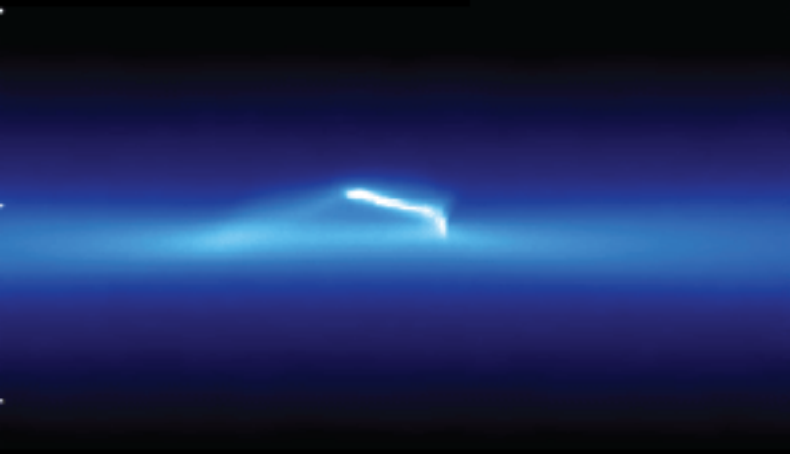
Boisson, Podsiadlowski, Marchant … w/SdM (in prep)



Are BH-BH mergers really dark? EM counterparts

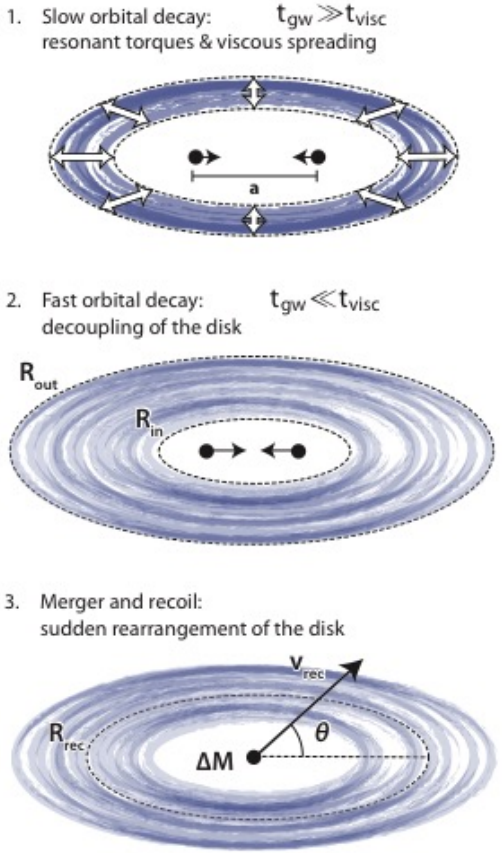
Timescale: Hours after GW event
Assumption: Needs disk 10^{-3} M_{bin}
Signal: 10^{42} erg/s, medium energy X-rays extending to longer wavelengths

Warning: Large Uncertainties



Rossi et al. (2010)

De Mink & King (2017)



Conclusions

Summary

How did they form?

- Separation Challenge & Mass challenge

- **Stellar origin** vs Primordial origin
  - **Evolutionary scenarios** vs Dynamical scenarios
    - **Classic:** Common Envelope
    - **New:** Homogeneous Evolution channel

New results

- **By products**: Pair Instability SN, ULXs)
- **BH merger demographics:** (Mass gap)
- **EM Counter parts:**
  Hours after GW event from circumbinary disk responding to recoil, if present Caveat: Very Large Uncertainties.

Teaser: Review for Annual Review in A&A in prep.

Acknowledgements

BinCosmos Group, University of Amsterdam

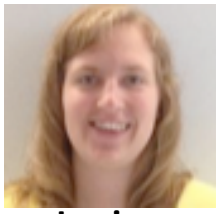
Manos Zapartas PhD

Ylva Götberg PhD

Mathieu Renzo PhD

Ehsan Moravveji MARIE CURIE

Silvia Toonen VENI fellow



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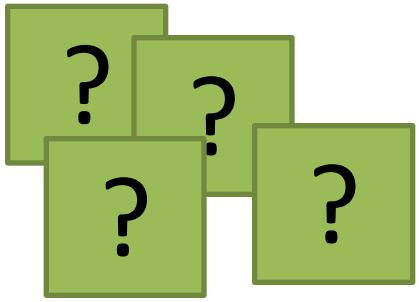

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NWO

SURF SARA

NOVA

MARIE CURIE ACTIONS

MacGillavry Fellowship

Recently graduated students: Abel Schootemeijer, Coen van Neijssel, Ruben Boots, Max Briel

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