Selma E. de Mink

Black-hole Binary Formation*

Sackler Conference 2018

*Field, Non Common Envelope

Background design E. Buunk. Creidt: NASA Paresce

With credit to the following external collaborators: Chris Belczynski, Ilya Mandel, Matteo Cantiello, Andrew King, Norbert Langer, Pablo Marchant, Philip Podsiadlovski, Hugues Sana, Simon Stevenson, Ed van den Heuvel, Alejandro Vigna-Gómez, Nathan Smith, Maria Drout, Thomas Kupfer, Sung-Chul Yoon, Wolfgang Kerzendorf, Jose Groh, Carles Badenes, Simon Portegies-Zwart, Rob Izzard, Coen van Neijssel, Abel Schootemeijer, Onno Pols, Tom Maccarone, Chris Evans, Ori Fox, Schuyler van Dyk, Claus Leitherer, Leonardo Almeida, Alex de Koter, Tony Piro, Paul Crowther, Danny Lennon, Imants Platais, VLT-FLAMES Massive Star Consortium

Background design E. Buunk. Creidt: NASA Paresce

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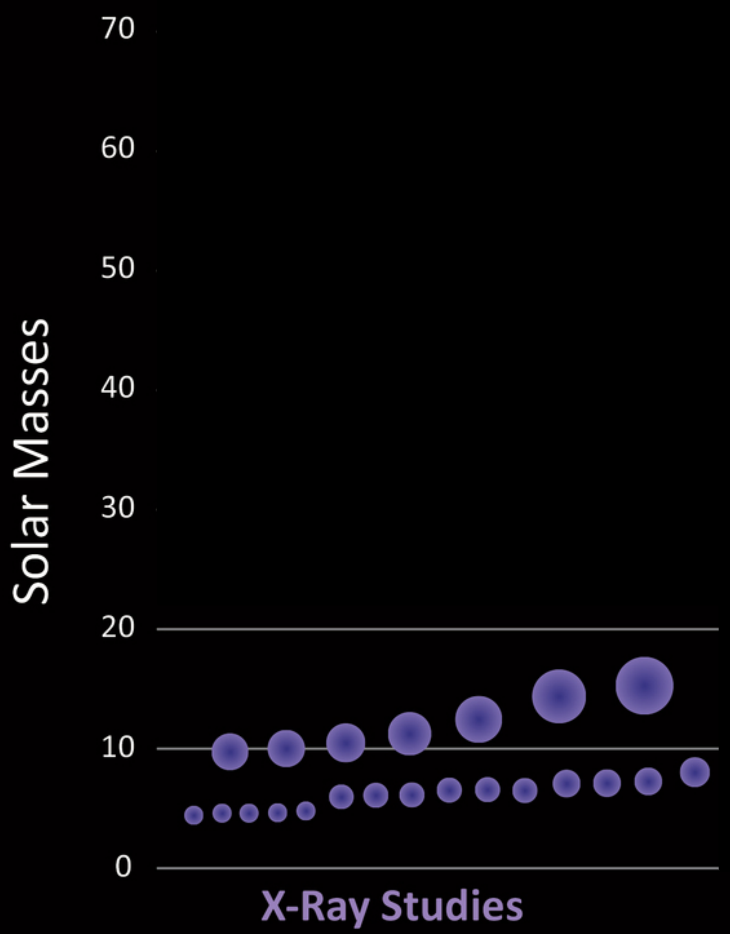
70
60
50
40
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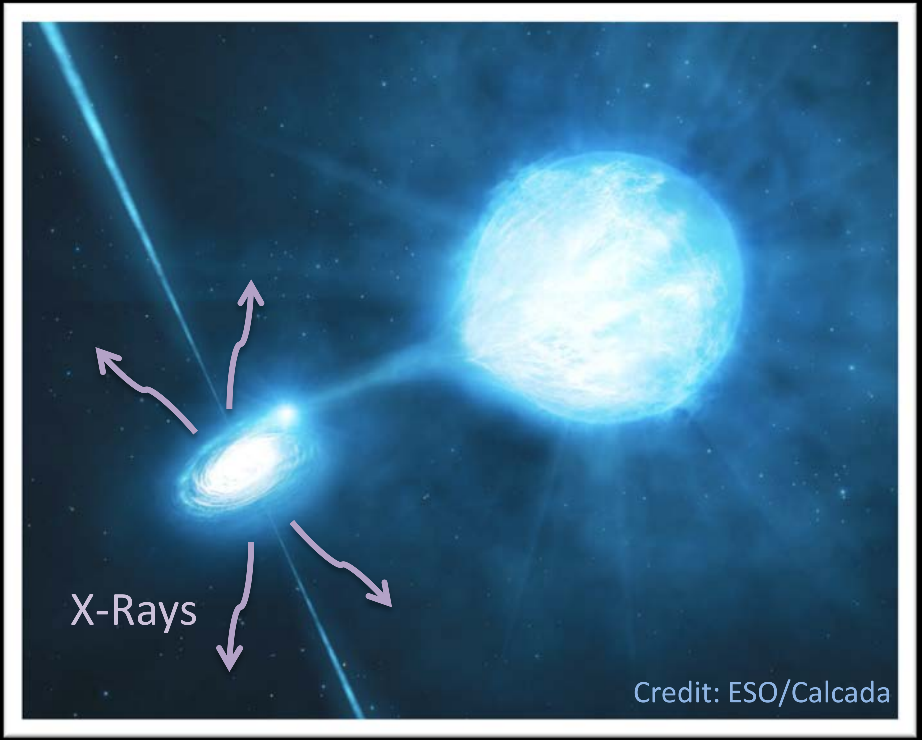
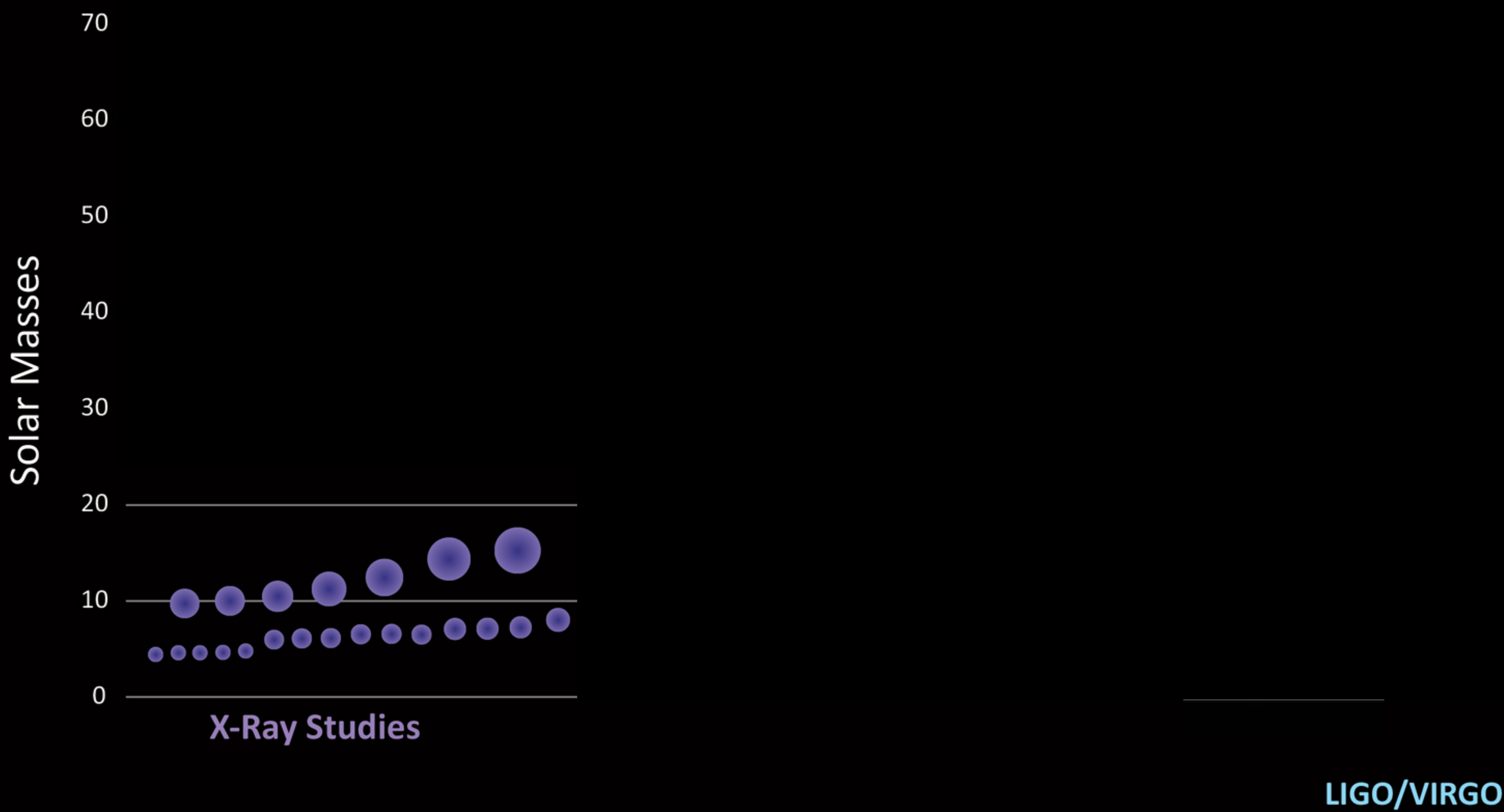
0
Solar Masses
X-Ray Studies


X-Rays
Credit: ESO/Calcada

LIGO/VIRGO

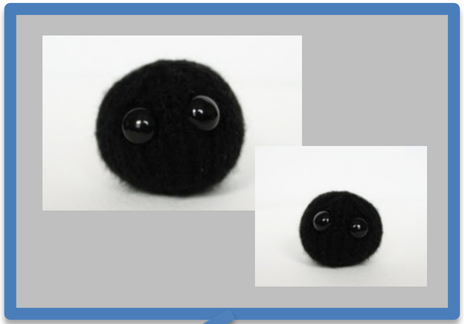


Solar Masses
70
60
50
40
30
20
10
0
X-Ray Studies
LIGO/VIRGO

Intuition for the timescales

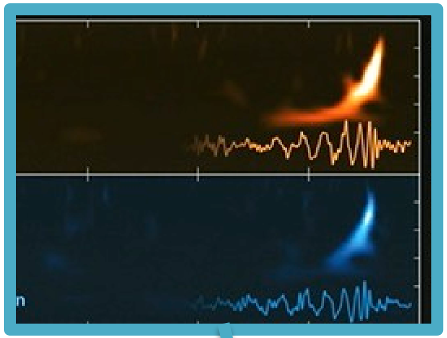
4. Birth of progenitors stars

3. Formation binary black holes



2. Merger

1. Detection of signal



“a few” Myrs

- “a few” Gyrs

- 1.4 Gyrs

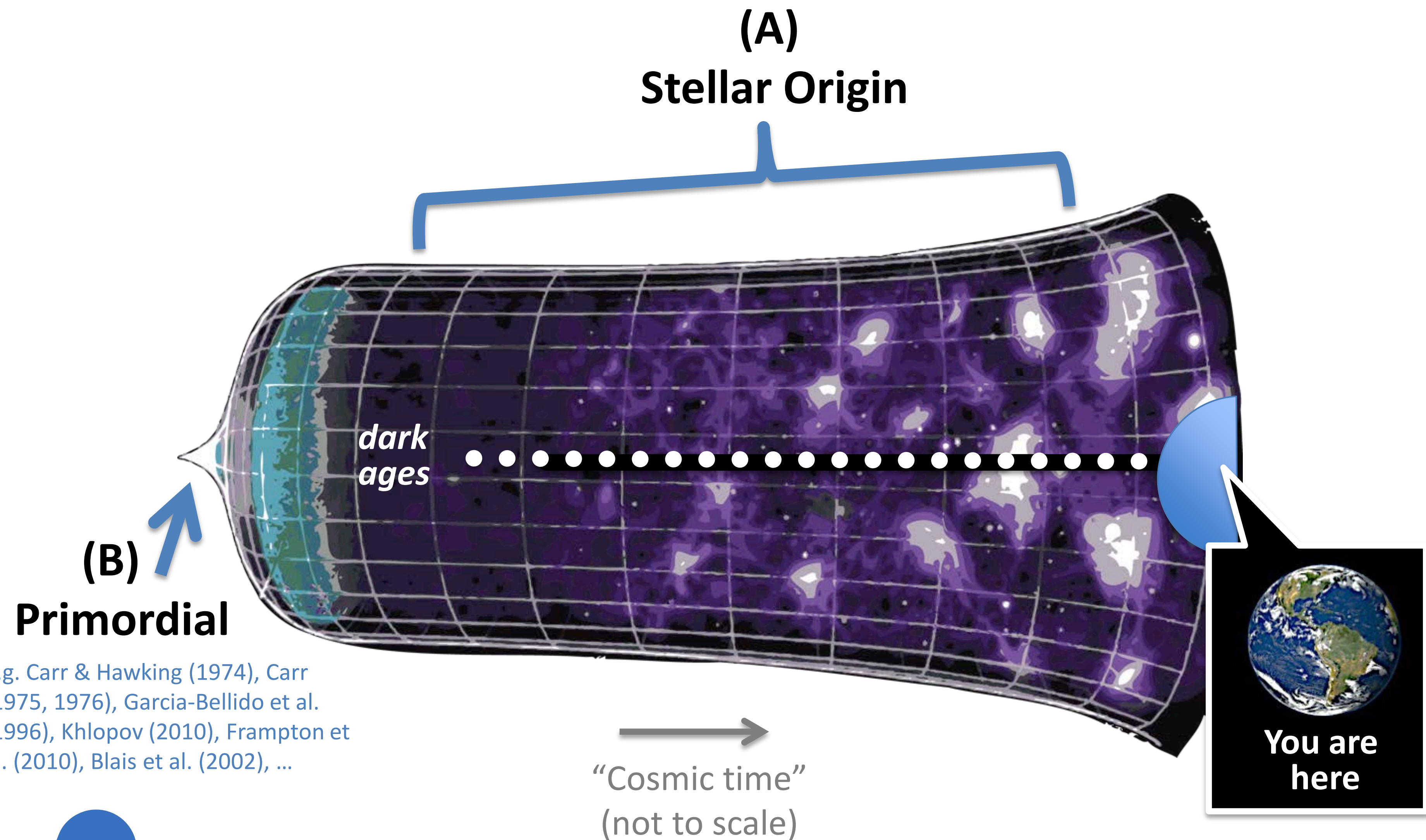
Time

Sept 14 2015

GW detections still probe relatively local events for now,
but the already probed stellar endpoints at very substantial redshifts.

Bin Cosmos

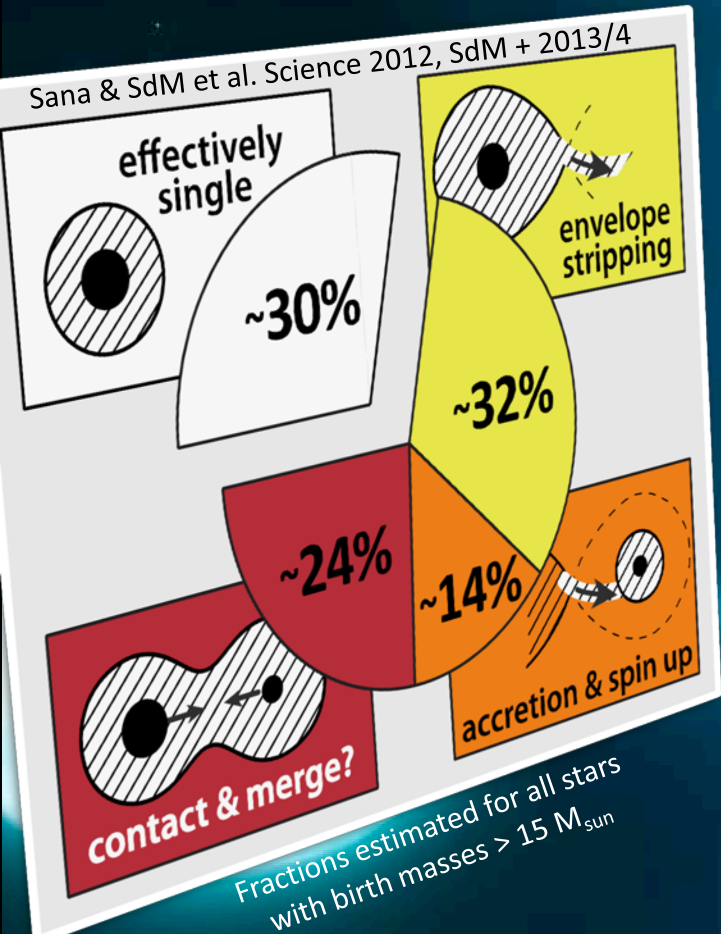
Probing how stars die across cosmic time



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

BinCosmos

This is not exotic



Initial distributions of

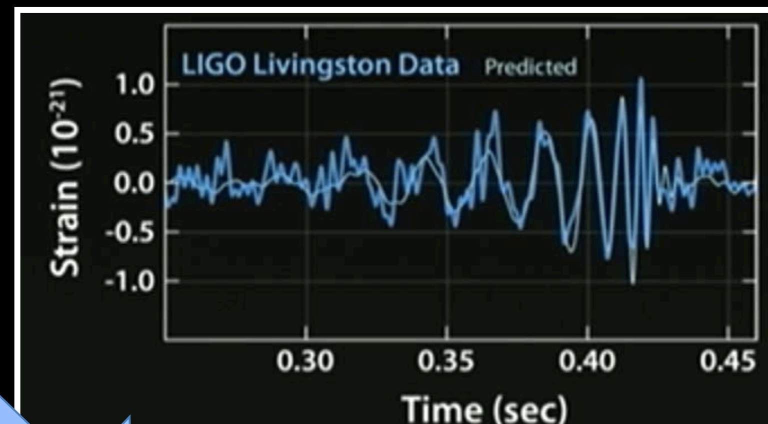
- Masses
- Mass ratios
- Separations/Periods
- …
- Cosmic Starfomation history f(Z, z)

cf. Abt+78, Kobulnicky+Fryer07, Mason+09, Chini+12, Sana,SdM+12, Sana,deKoter,SdM+13, Kobulnicky+14, Dunstall+w/SdM15, Moe+16, Almeida+w/SdM17, ...

This is not Exotic …

… but this is.

?



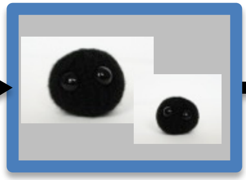
Other exciting objects

Formation Channels

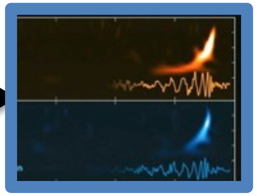
Why is it so hard to make close double compact objects

Birth

Formation BHs



Coalescence



1. "Separation Challenge"

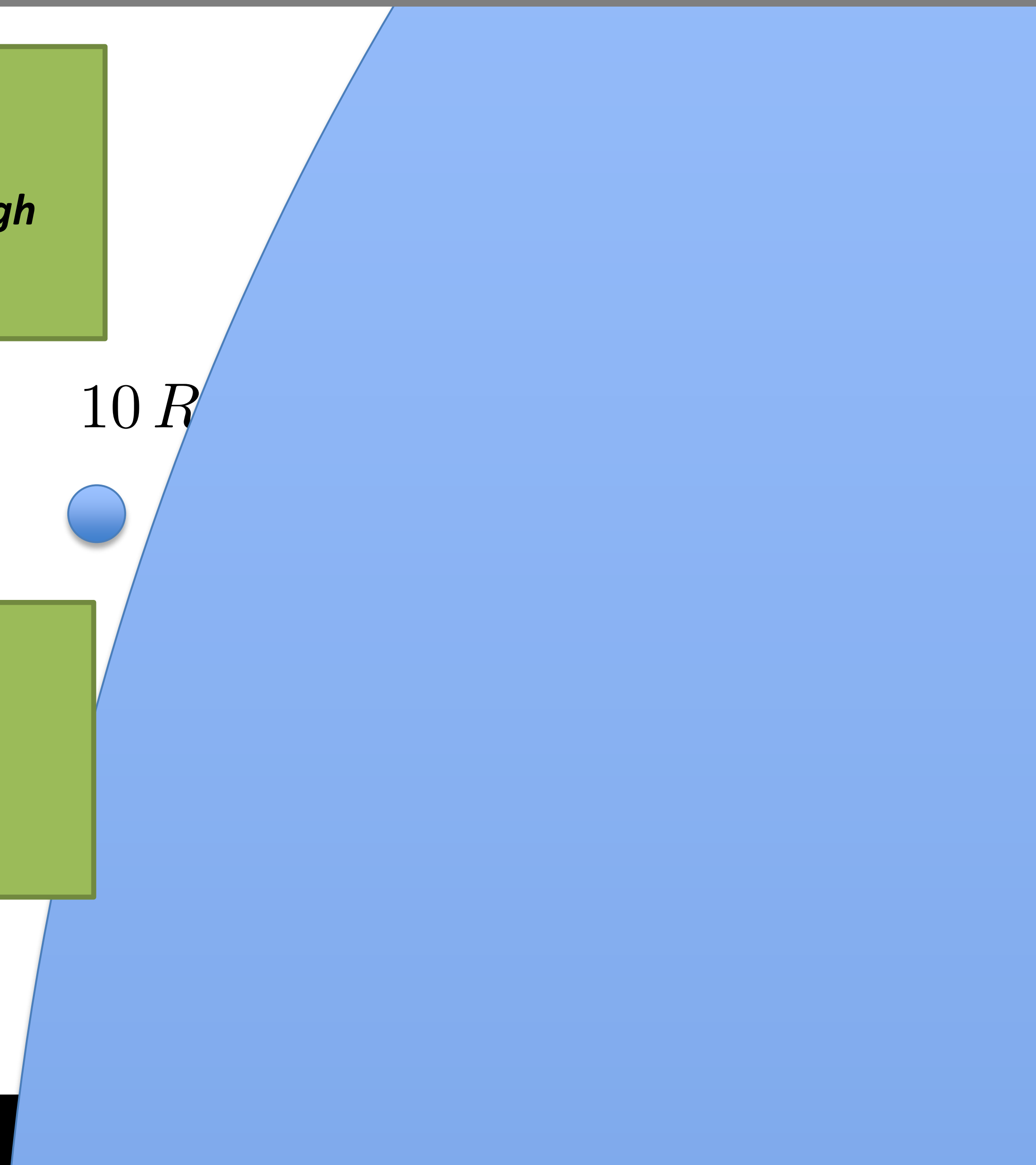
***2. "Mass Challenge"** (for BHs)*

BinCosmos

Why is it so hard to make close double compact objects

1. "Separation Challenge"

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

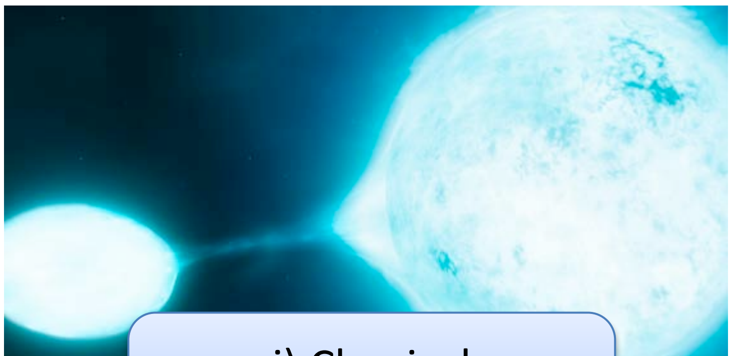


2. "Mass Challenge"

How to avoid excessive Mass loss?

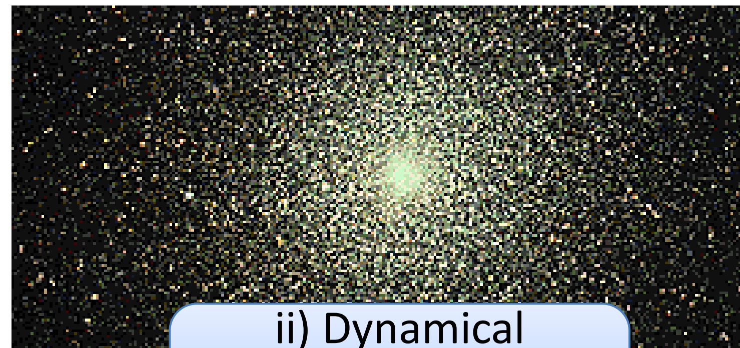
Formation Channels
Traditional Division

“Evolutionary Channels” (Field)



i) Classical (Common Envelope)

“Dynamical Channels”

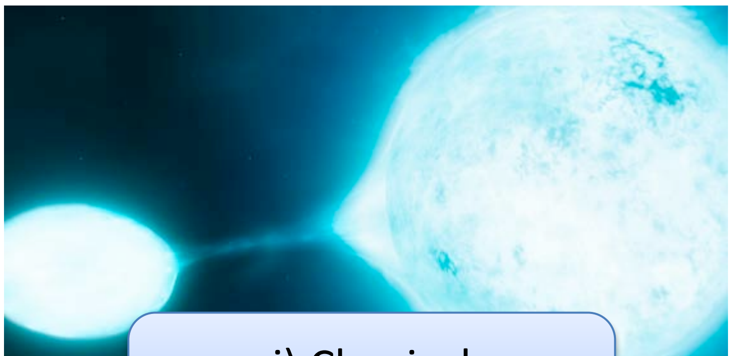


ii) Dynamical formation in massive star clusters

Cf. talks by Mandel, Rasio, Naoz, Shoemaker, Holz, …

Formation Channels

"Evolutionary Channels" (Field)



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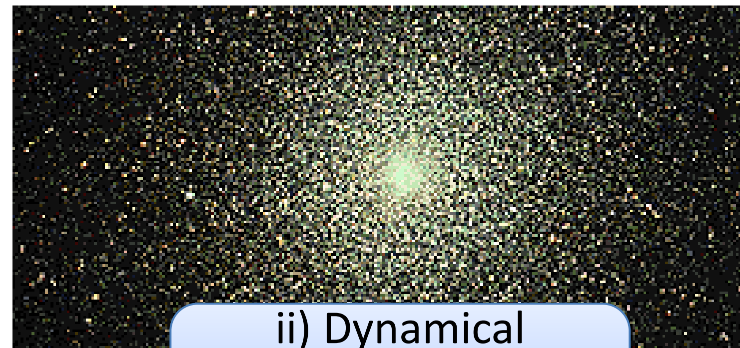


ii) Dynamical formation in massive star clusters

iii) Chemically Homogeneous Channel

iv) Kozaii resonance with SMBH

v) In gas disk of Active Galactic Nuclei

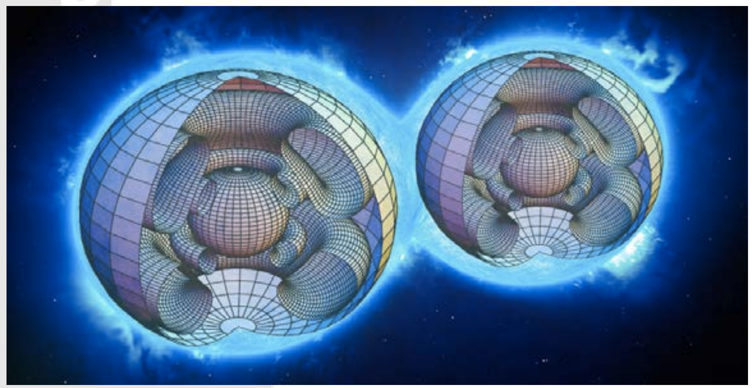
vi) Triples

vii) Stable non-conservative mass transfer

...?...

See talks by Mandel, Rasio, Naoz, Shoemaker, Holz, ...

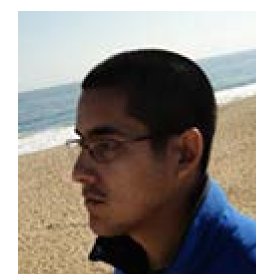
Chemically Homogeneous Channel



“Case M Evolution”,
“The Rotational Channel”,
“Tidally Induced Mixing Channel”

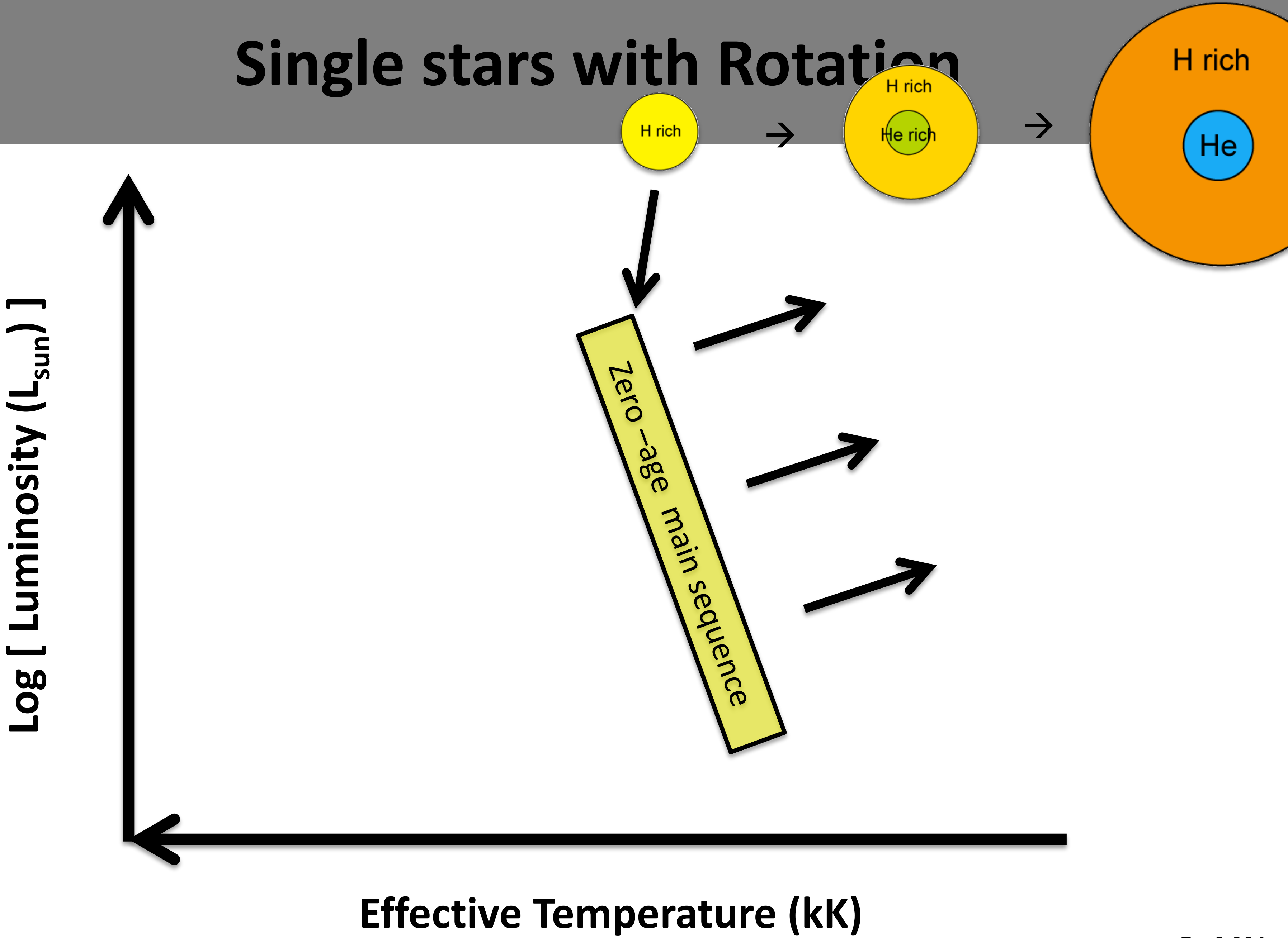
de Mink et al. (2008, 2009), Mandel & de Mink (2016), Song et al. 2016;
Marchant et al. (2016), de Mink & Mandel (2016), Marchant et al. (2017)
Marchant et al. (to be subm.)

Primary Collaborators:
Ilya Mandel (2016), Matteo Cantiello (2009)



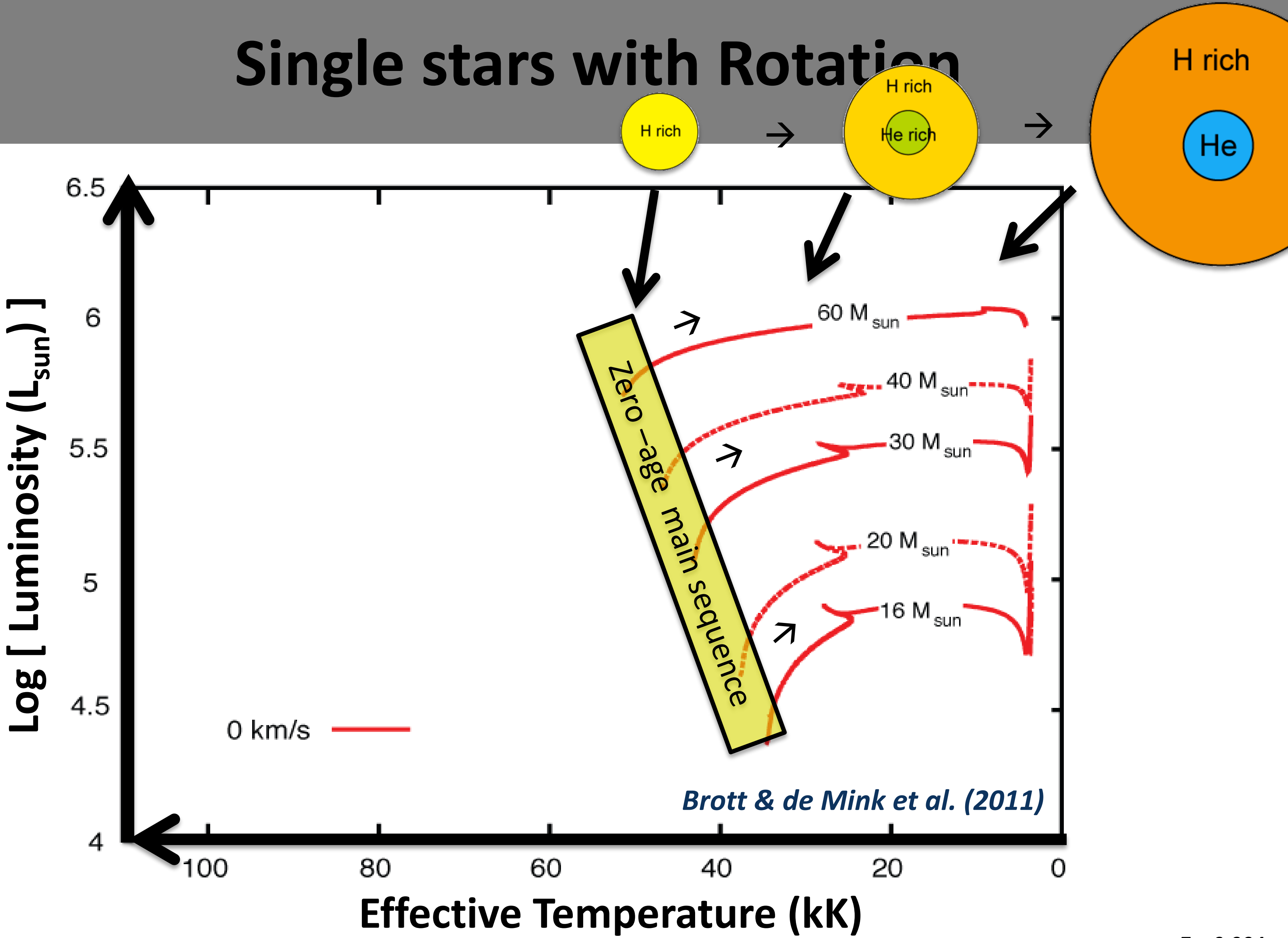
Pablo Marchant

Single stars with Rotation



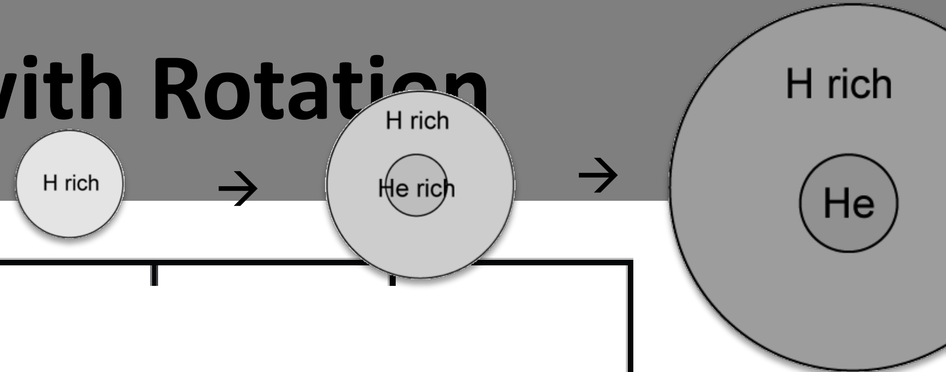
Z = 0.004

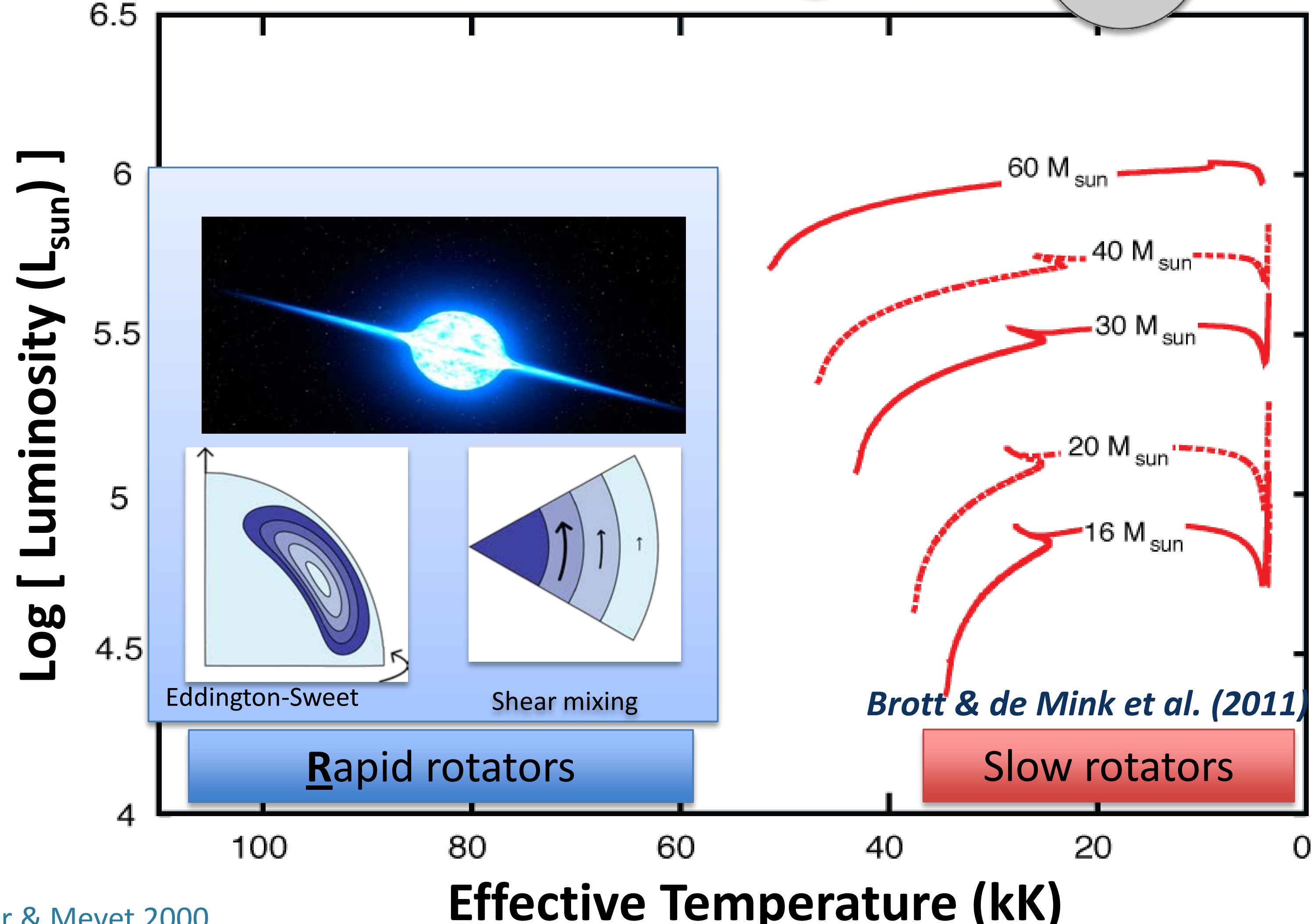
Single stars with Rotation



Z = 0.004

Single stars with Rotation

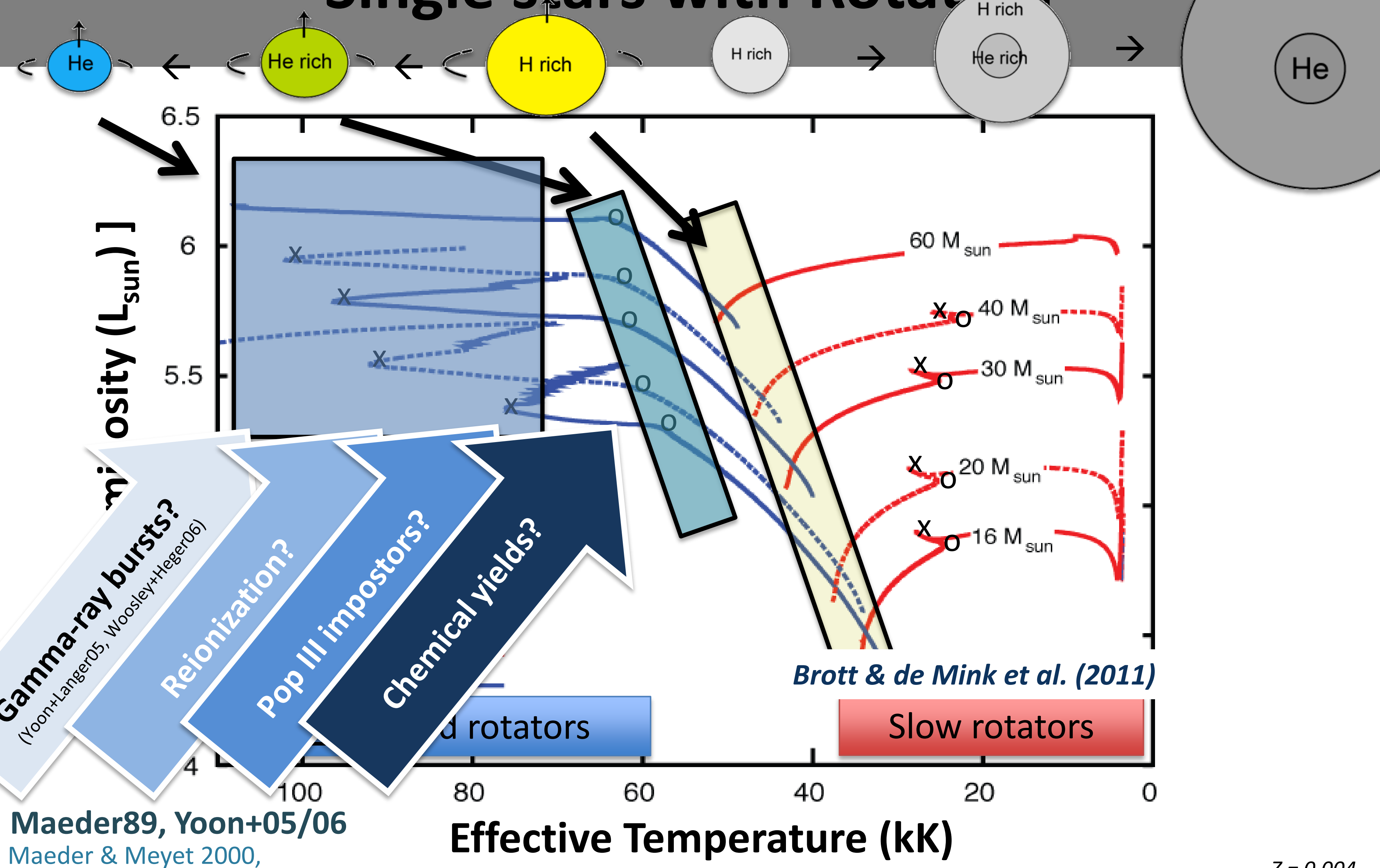




Maeder & Meyet 2000,
Heger et al 2000, Yoon et al 2006,Hirschi 2007, Ekstroem et al 2012, Georgy et al. 2014, Kohler et al. 2015

$Z = 0.004$

Single stars with Rotation



Maeder89, Yoon+05/06

Maeder & Meyet 2000,

Heger et al 2000, Yoon et al 2006, Hirschi 2007, Ekstroem et al 2012, Georgy et al. 2014, Kohler et al. 2015

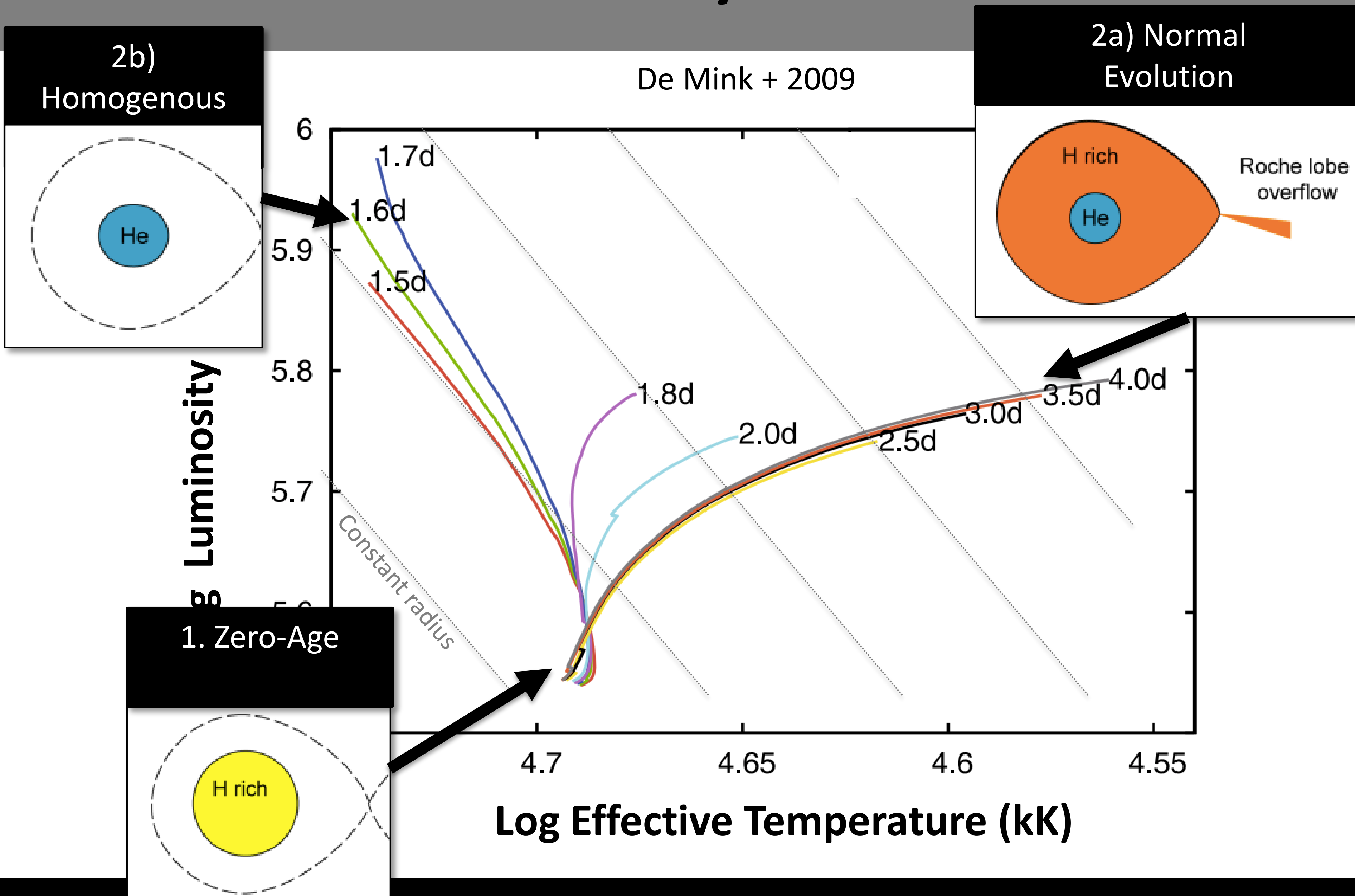
What if you could do this in a close binary?

Standard Evolution

Chemically Homogeneous

De Mink+08,'09

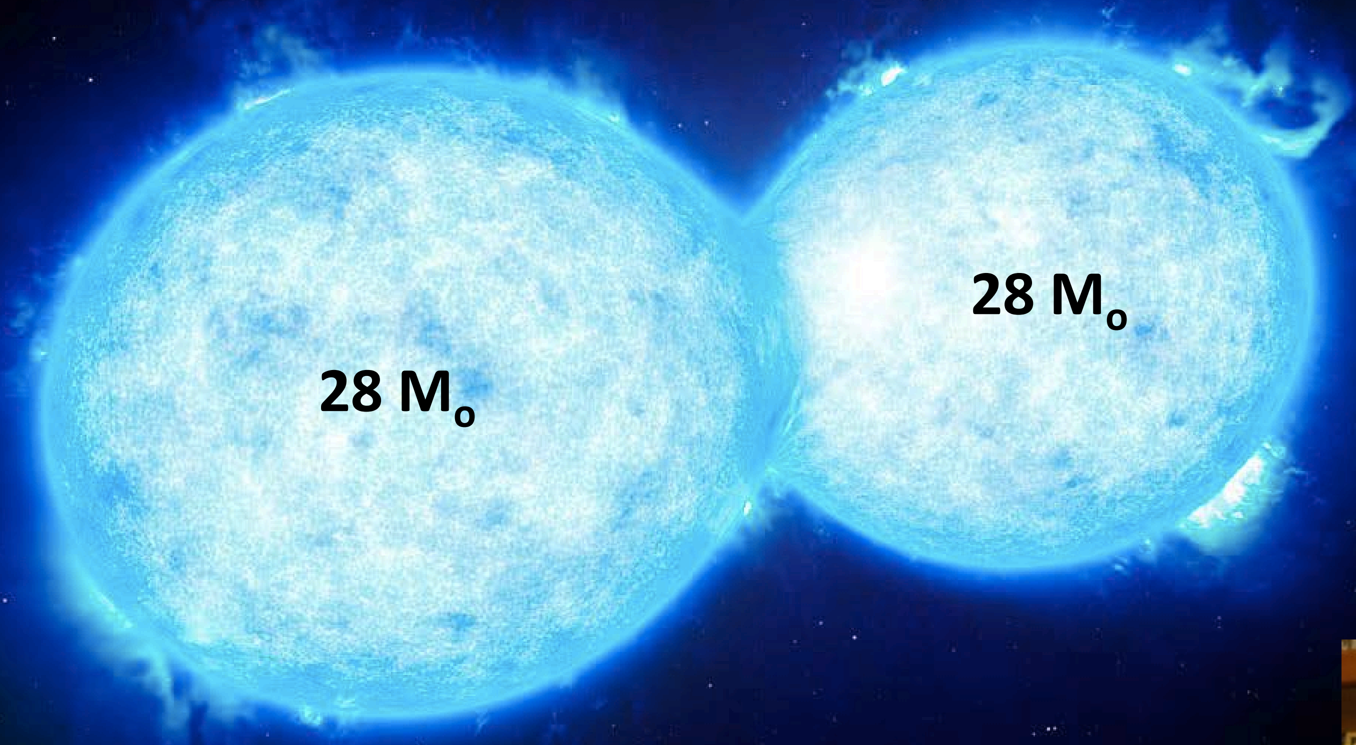
Full Evolutionary Calculations



Do such tight binaries exist?

VFTS 352 - Orbit: 1.1 Day

A case for (partial)Chemically Homogeneous Evolution?



Leonardo Almeida

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

Image Credit:ESO/L. Calçada

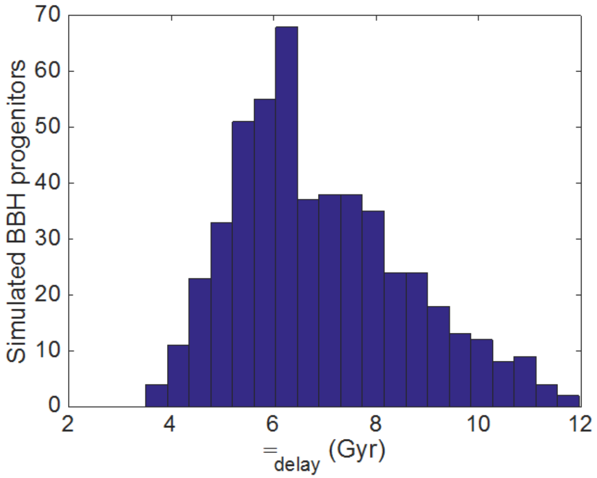
Animation credit: ESO: L. Calcada

Predictions for the Chemically Homogeneous Channel

(Take these with a grain of salt)

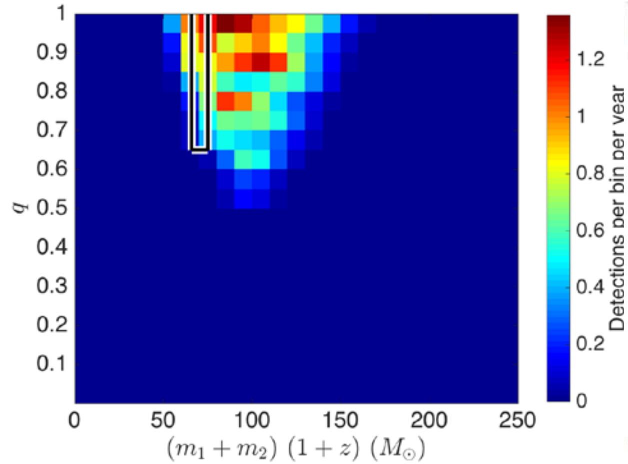
Delay Time

Mandel & de Mink (2016)



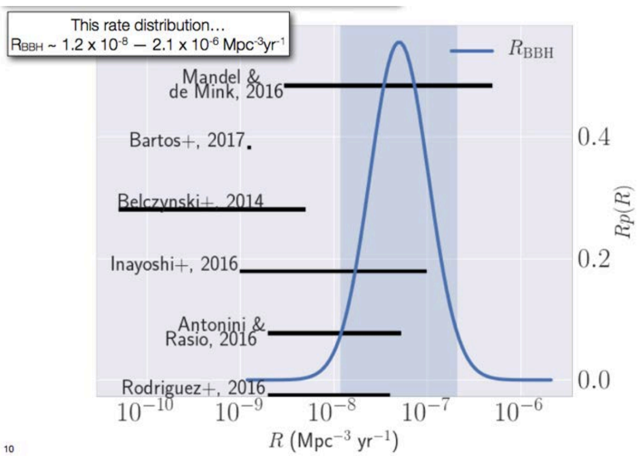
Masses

de Mink & Mandel (2016)



Rates

DCC: LIGO-G1800370



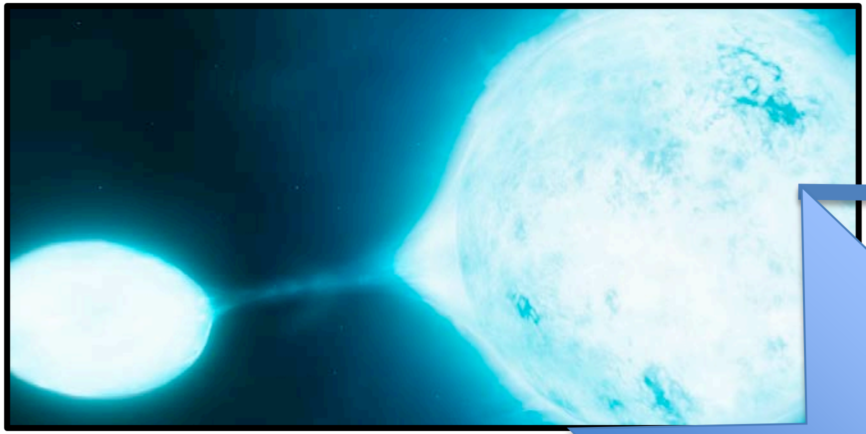
Open Questions:

- ***What about Spins?* - *Open question, hard to predict***
- ***Lower mass events? – Probably only massive***
- ***What about side products? - ….***

Cf. Marchant et al. (2016)

How to Proceed from here

How to Proceed from here?



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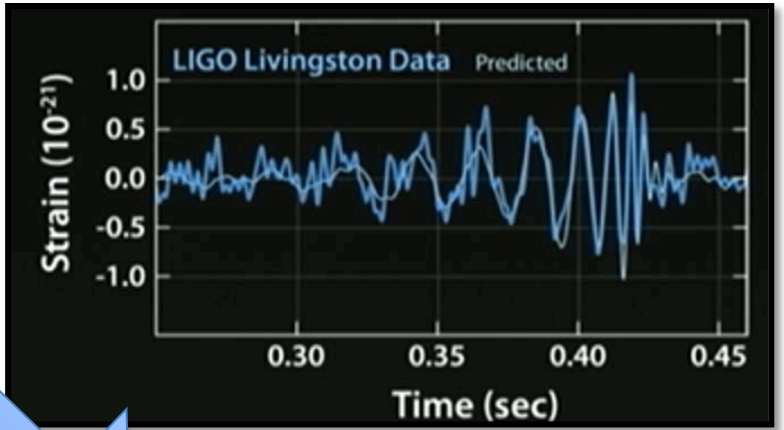
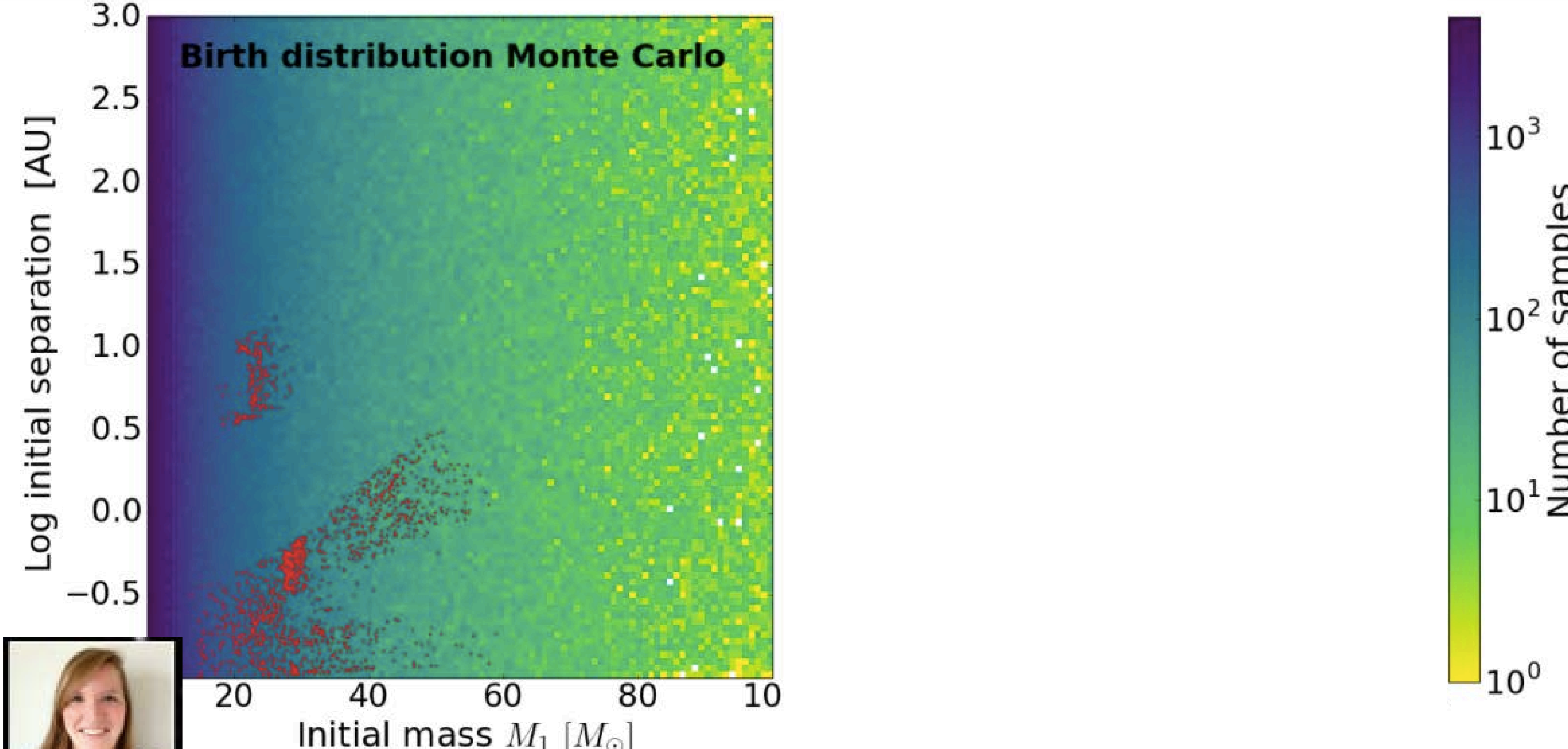


Side Products

- *Runaway stars*
- *Overcontact binaries*
- *Stellar mergers*
- *(Ultra Luminous) X-ray Sources*
- *(Pair Instability) Supernovae*
- *….*

Challenge of Simulating Rare Events
(such as BH-NS systems)



Floor Broekgaarden

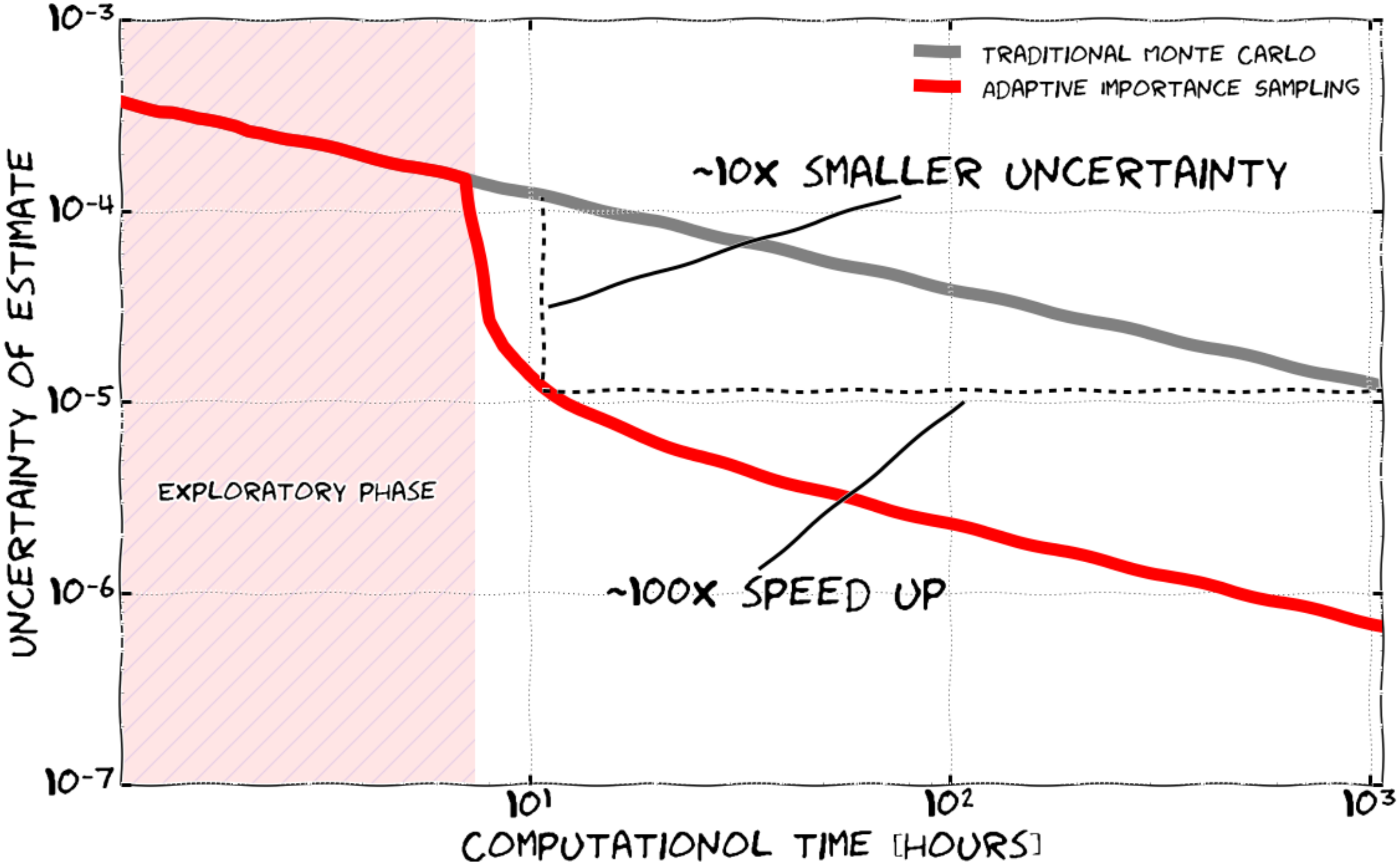
BH-NS systems

1 Million Binaries ~ 90 CPU hours, w/ Compas

w/ Gair, Justham, Barett, Justham, Mandel, Stevenson, Vigna-Gomes

Challenge of Simulating Rare Events

Broekgaarden et al. in prep.



Floor Broekgaarden

How not to make a binary black hole

Cosmos

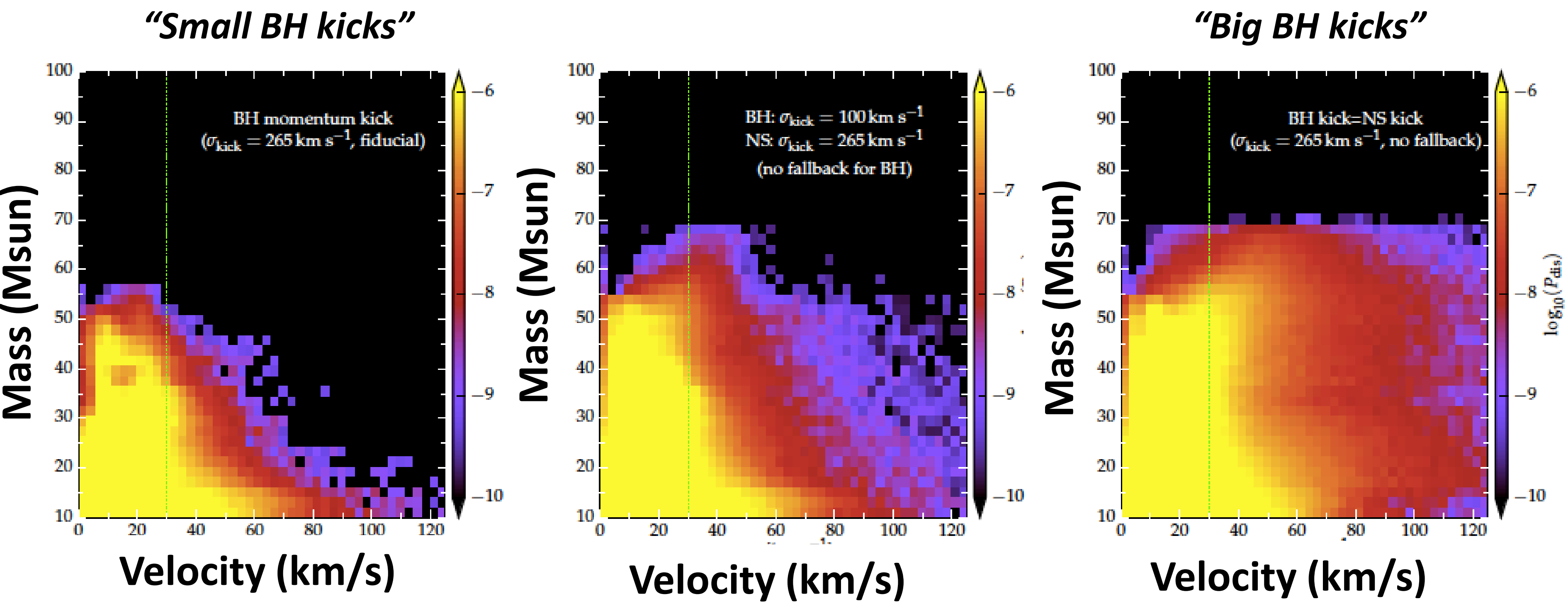
Animation: ESO: Calçada/Kornmesser/de Mink

Side Products (1): Can Gaia Help?

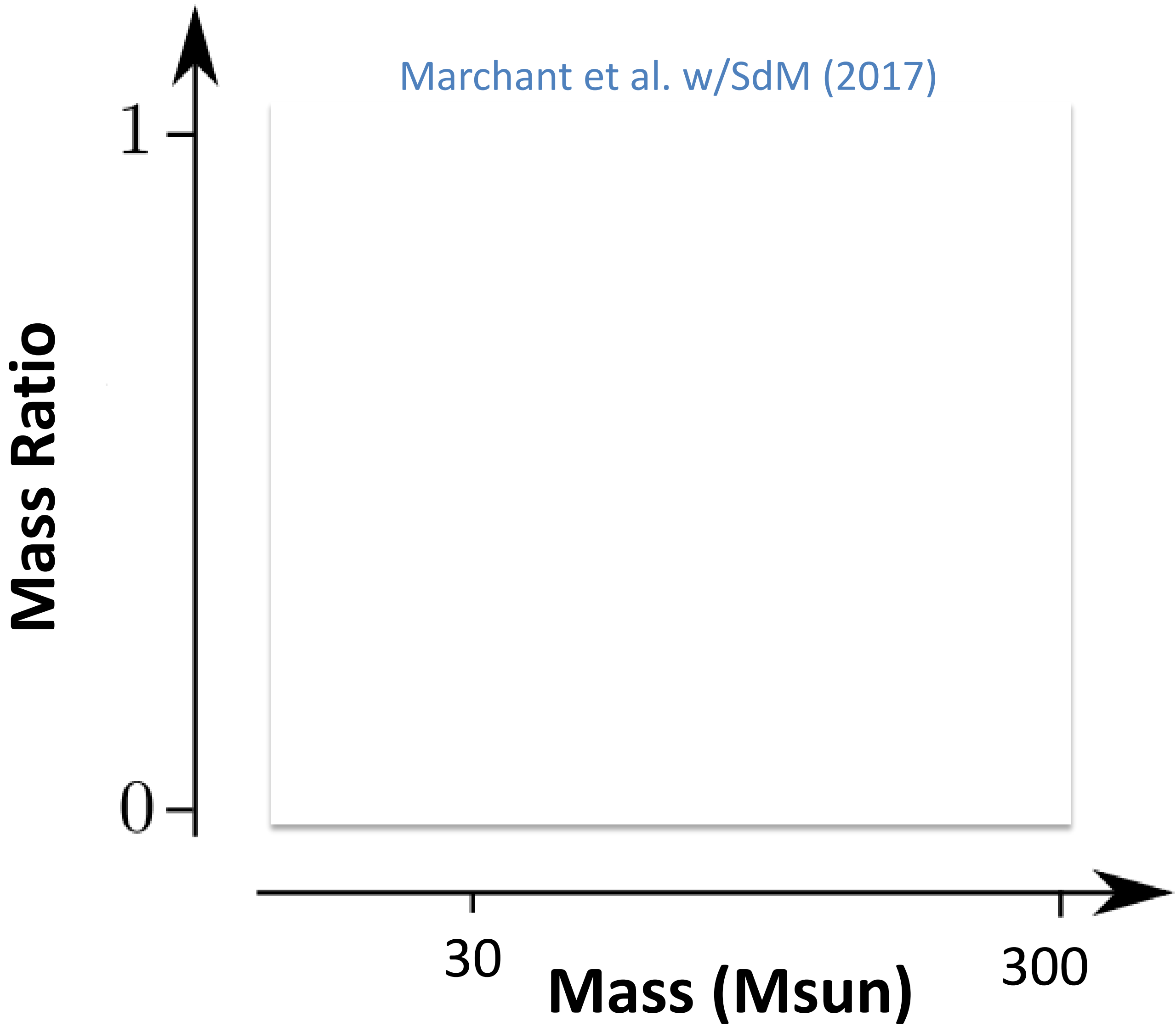
Mathieu Renzo

Runaway and Walkaway Stars

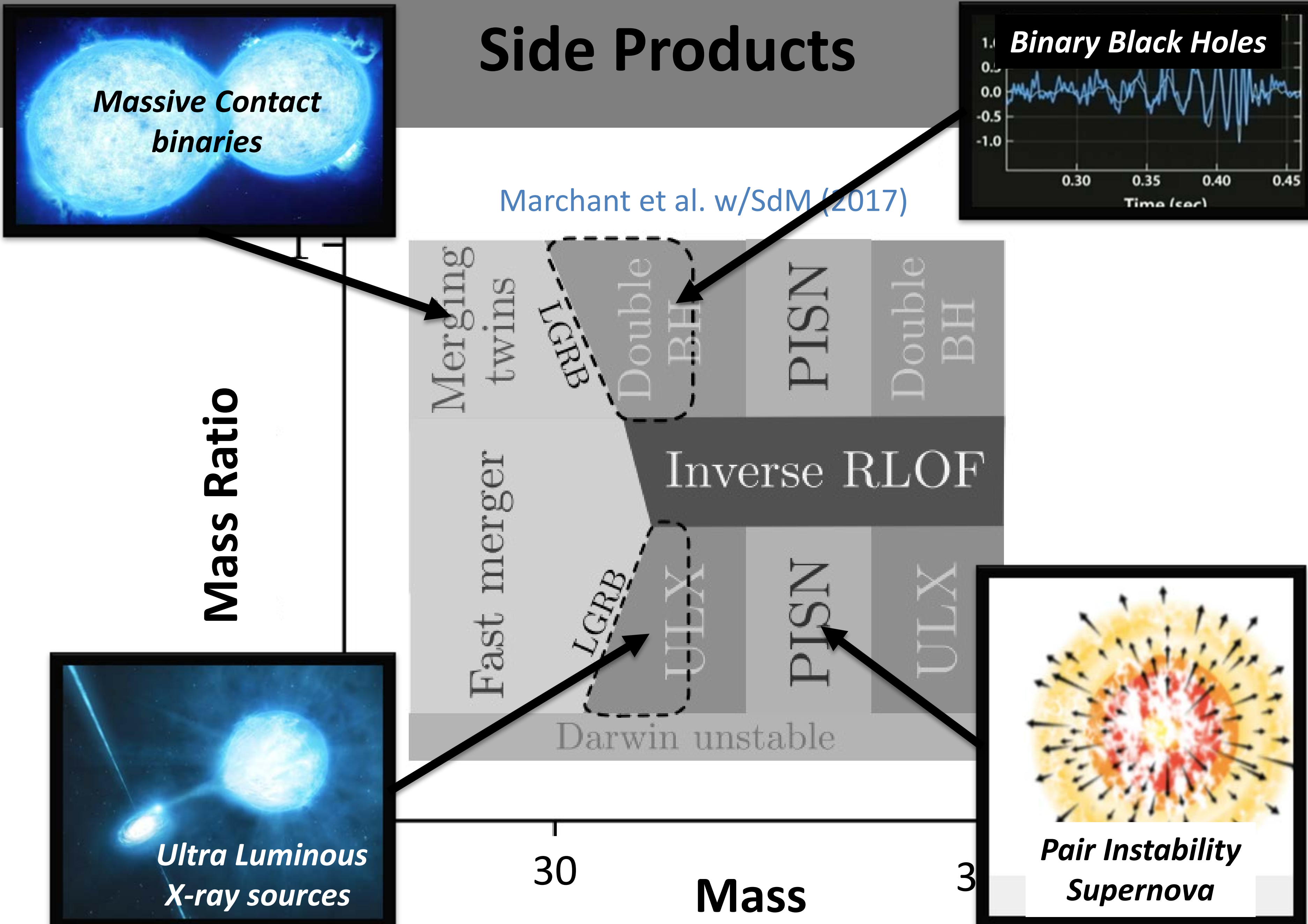
Renzo et al. w/SdM 2018



Side Products (2)



Side Products

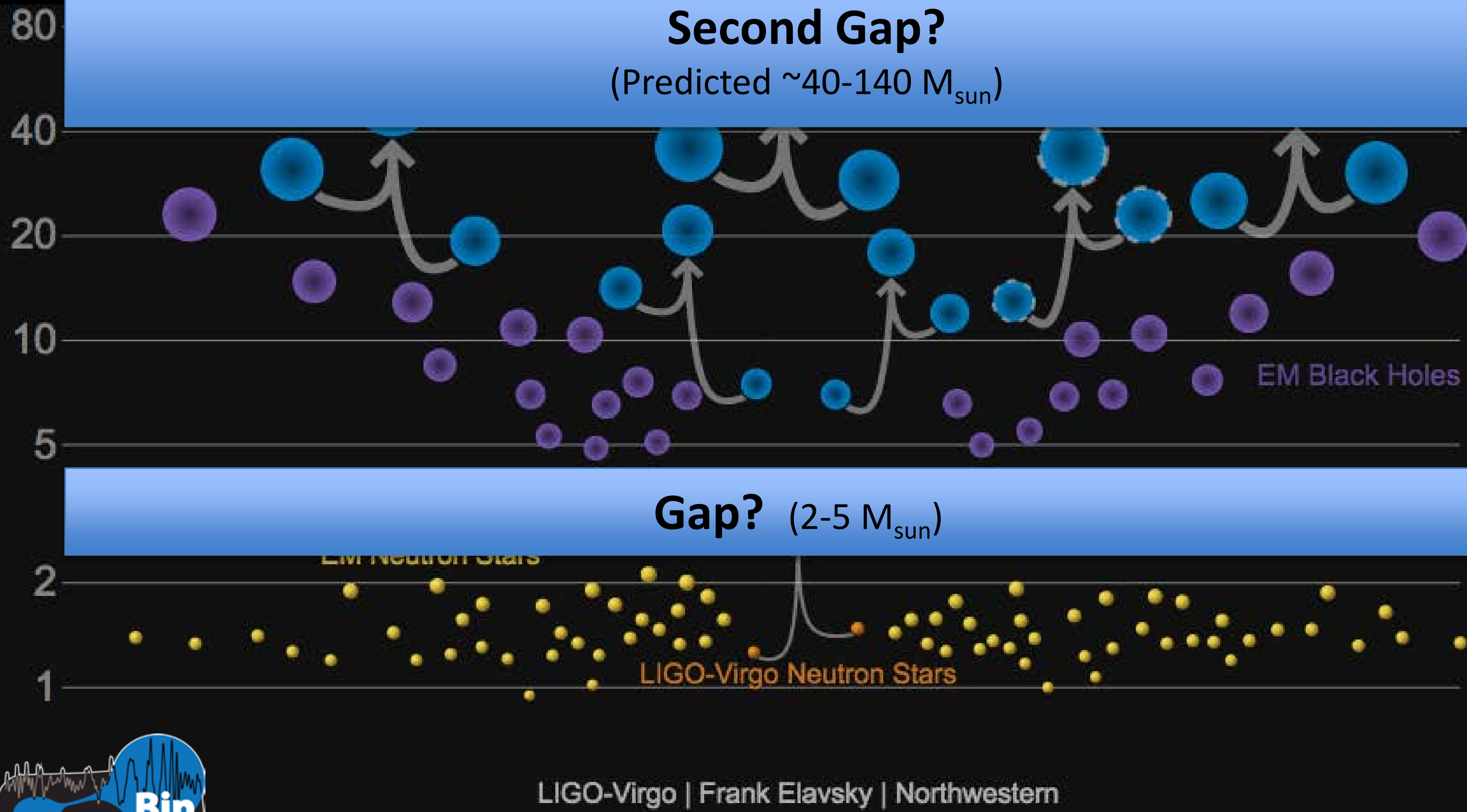


Rob Farmer

Second Gap?

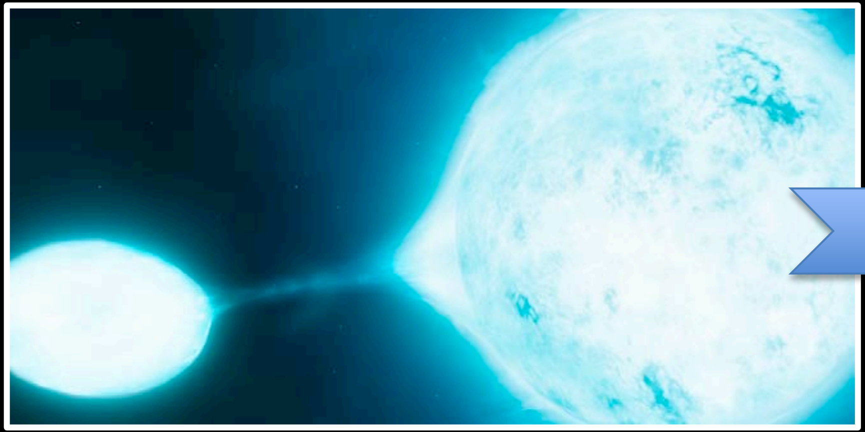
(Predicted ~40-140 M_{sun})

Gap? (2-5 M_{sun})



Wrap up

This is not Exotic … *… but this is.*



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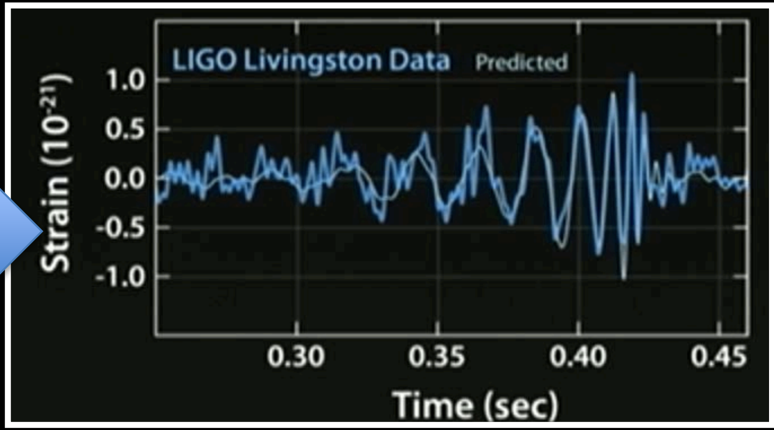

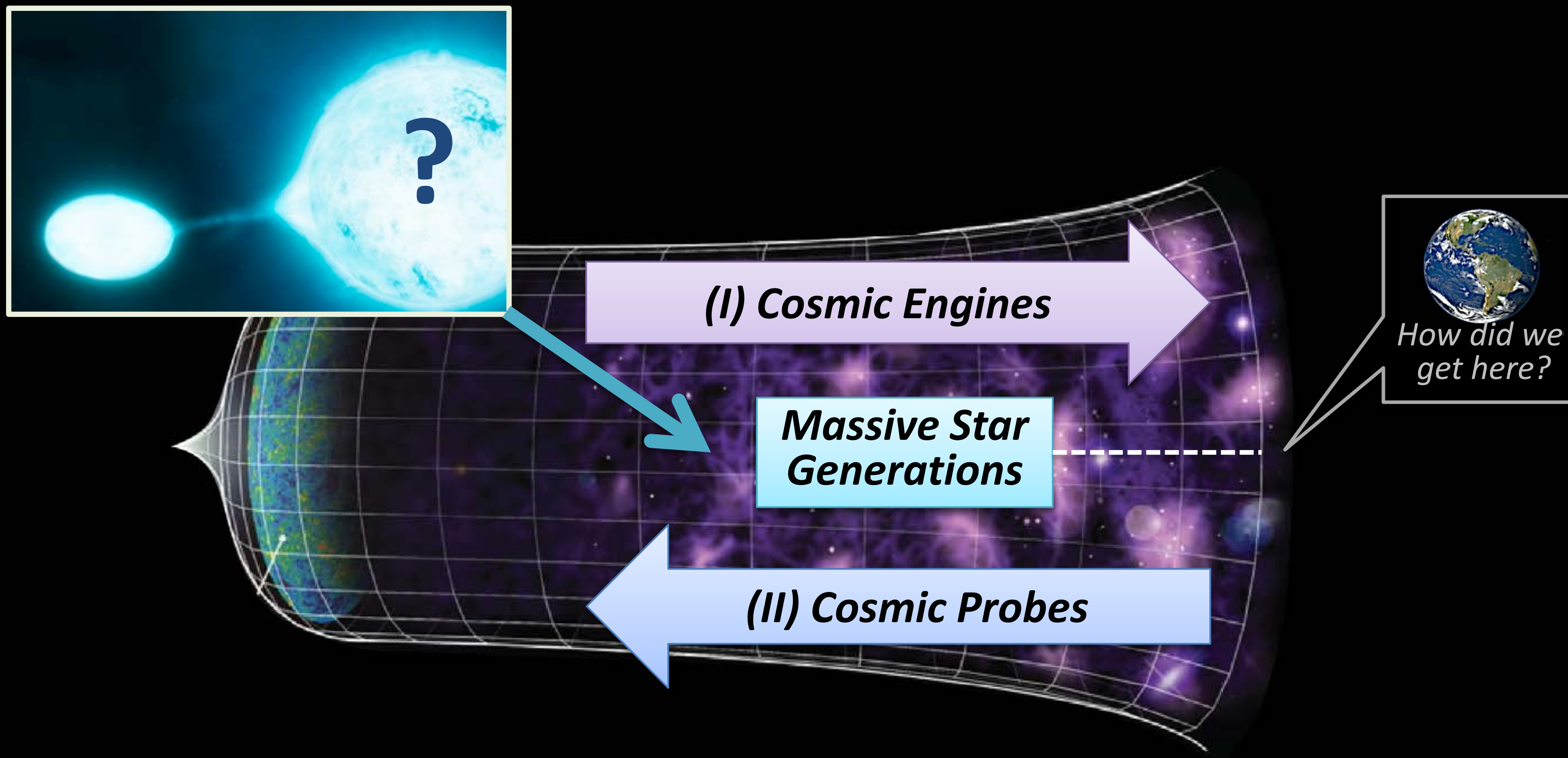
?
(I) Cosmic Engines
Massive Star Generations
(II) Cosmic Probes
How did we get here?

Bin Cosmos


Selma
de Mink
PI
Stephen
Justham
Associate '18-
Silvia
Toonen
VENI fellow '17-
Rob
Farmer
Postdoc '17-
Athira
Menon
Postdoc '18 -
Ylva
Götberg
PhD '18
Manos
Zapartas
PhD '18
You?
...
...
PhD '22
Mathieu
Renzo
PhD '19
Eva
Laplace
PhD '21
Floor
Broekgaarden
MSc
Walter
van Rossem
MSc
David
Hendriks
MSc
Karel
Temmink
MSc
Thomas
Dodds
BSc
Bin
Cosmos