

How to 'Cook' Merging Binary Black Holes as Discovered by Advanced LIGO

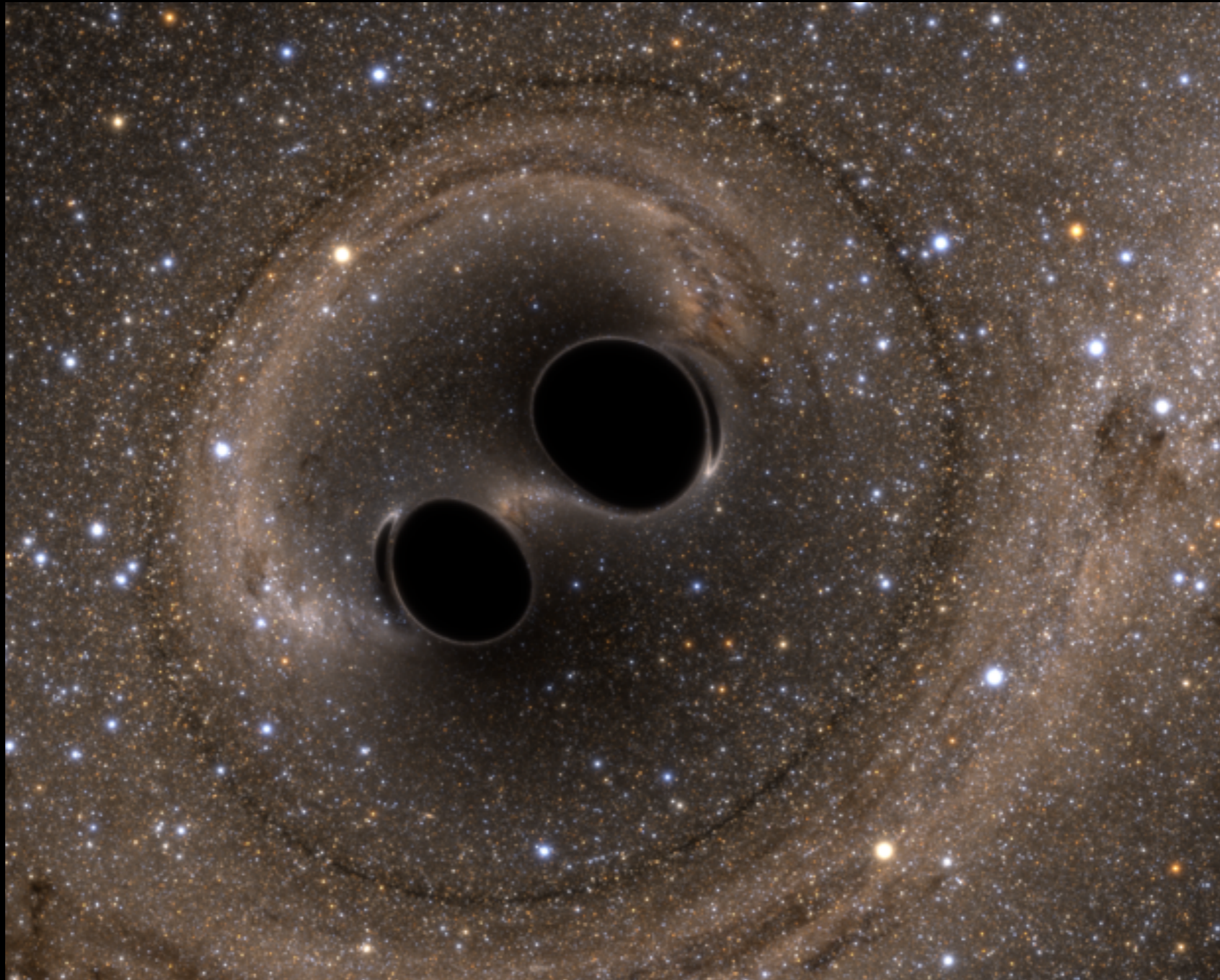
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Advanced School on Gravitational Waves
Presidency University
December 13, 2016

C I E R A

**CENTER FOR INTERDISCIPLINARY EXPLORATION
AND RESEARCH IN ASTROPHYSICS**

The Youngest Revolution in Astrophysics



Gravitational Waves from
Binary Black Hole Mergers

“... we have detected gravitational waves...”-

LSC (Feb. 11, 2016)

Hanford



Livingstone



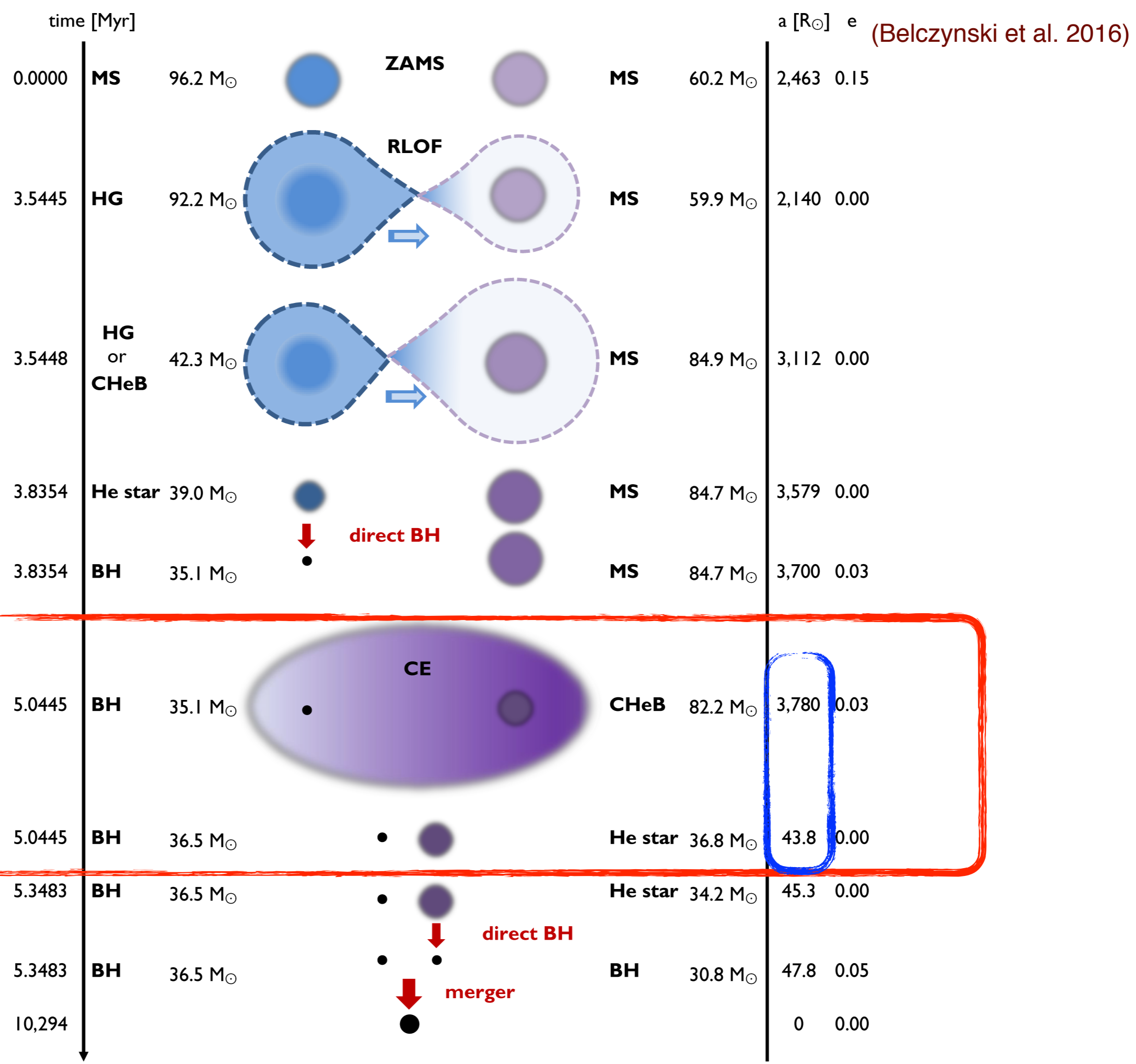
- GWs from merging binary black holes are detected!
- Three Detections in O1 Run (50 days):
 - GW150914: $M_{1,2} \sim [36, 29] M_{\text{sun}}$, $z \sim 0.1$
 - LVT151012: $M_{1,2} \sim [23, 13] M_{\text{sun}}$, $z \sim 0.2$
 - GW151226: $M_{1,2} \sim [14, 8] M_{\text{sun}}$, $z \sim 0.1$

Plan of the talk

- Astrophysical channels to form binary black holes that would merge within a Hubble time
 - In isolation
 - Dynamical channels
- Dynamical formation of BH—BH binaries in star clusters
 - Physical processes, properties of BH binaries, key differences from field (undisturbed) population, implications for LIGO
- Future goals on this topic
 - Including, extending simulations to nuclear clusters, distinguishing formation channels based on observed properties
- Summary

How do Merging Black Hole Binaries Form?

- **From (isolated) massive binary star evolution**
 - Traditional channel

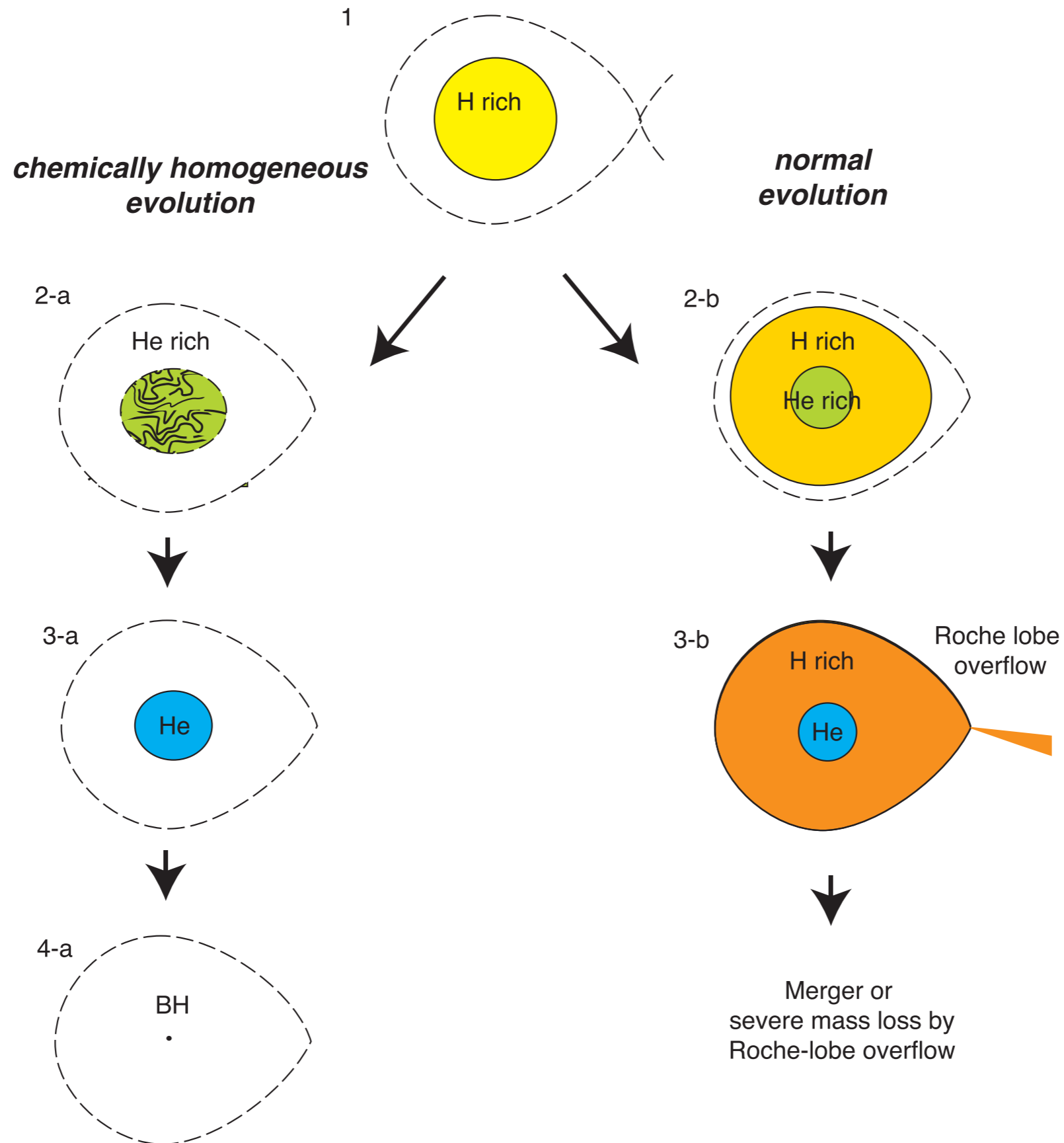


How do Merging Black Hole Binaries Form?

- **From (isolated) massive binary star evolution**
 - Traditional channel
 - Chemically homogeneous evolution

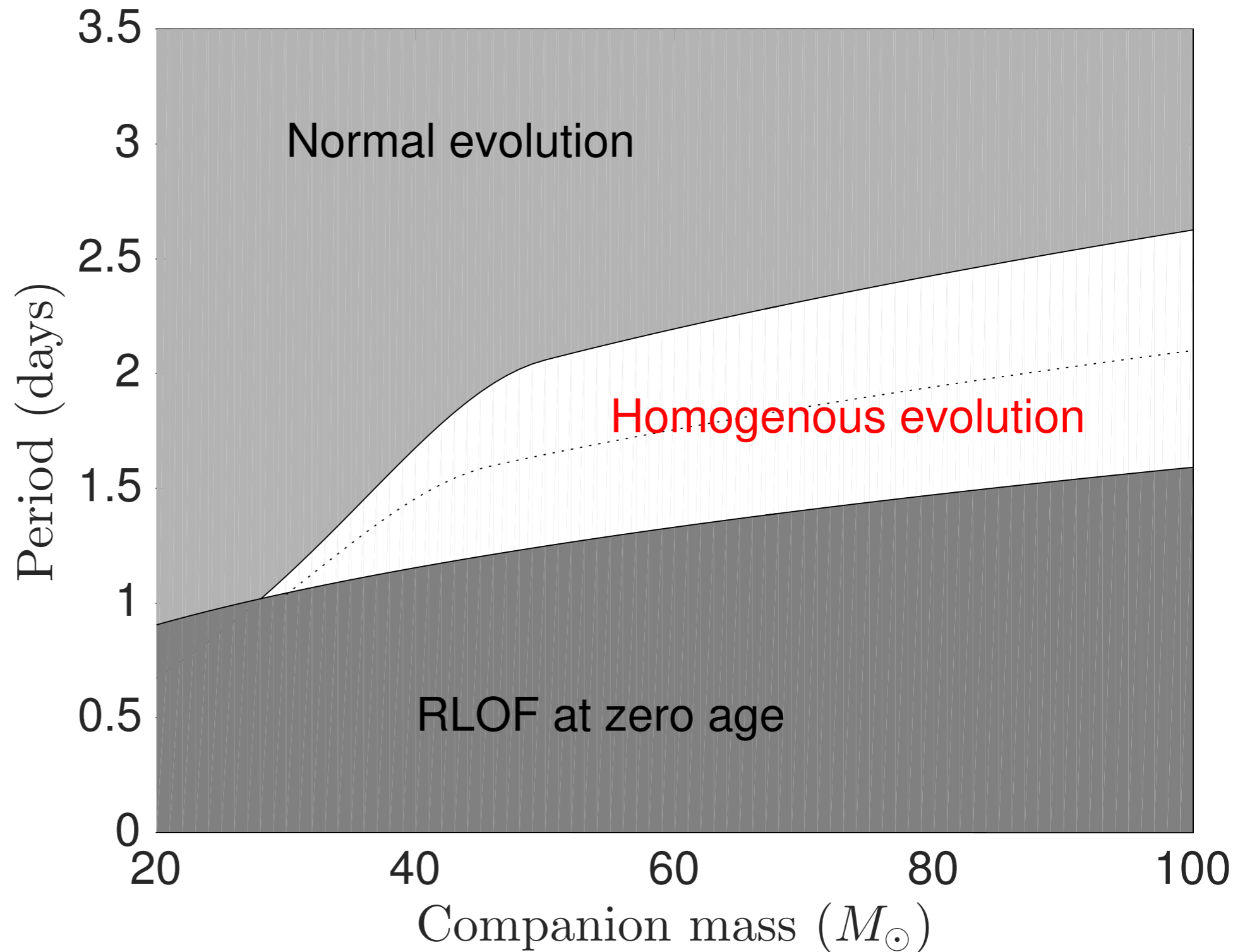
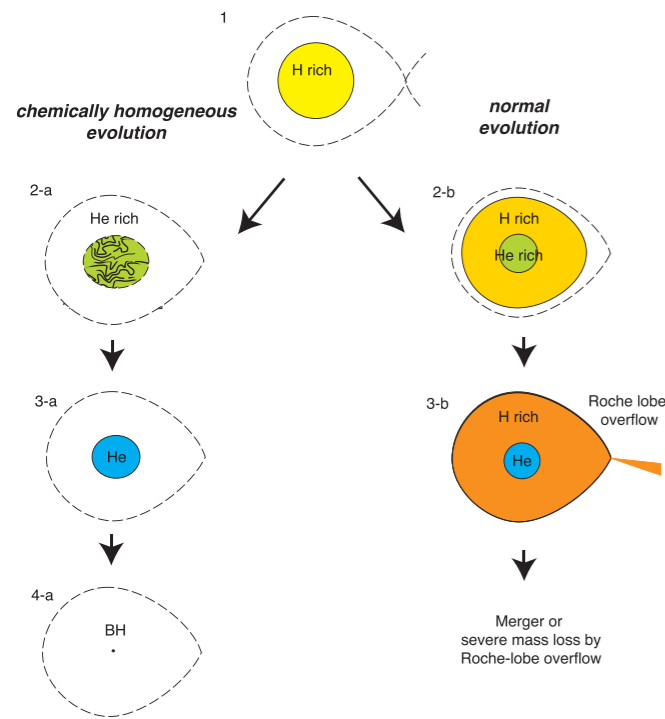
Chemically Homogeneous Evolution

Mandell & de Mink 2016



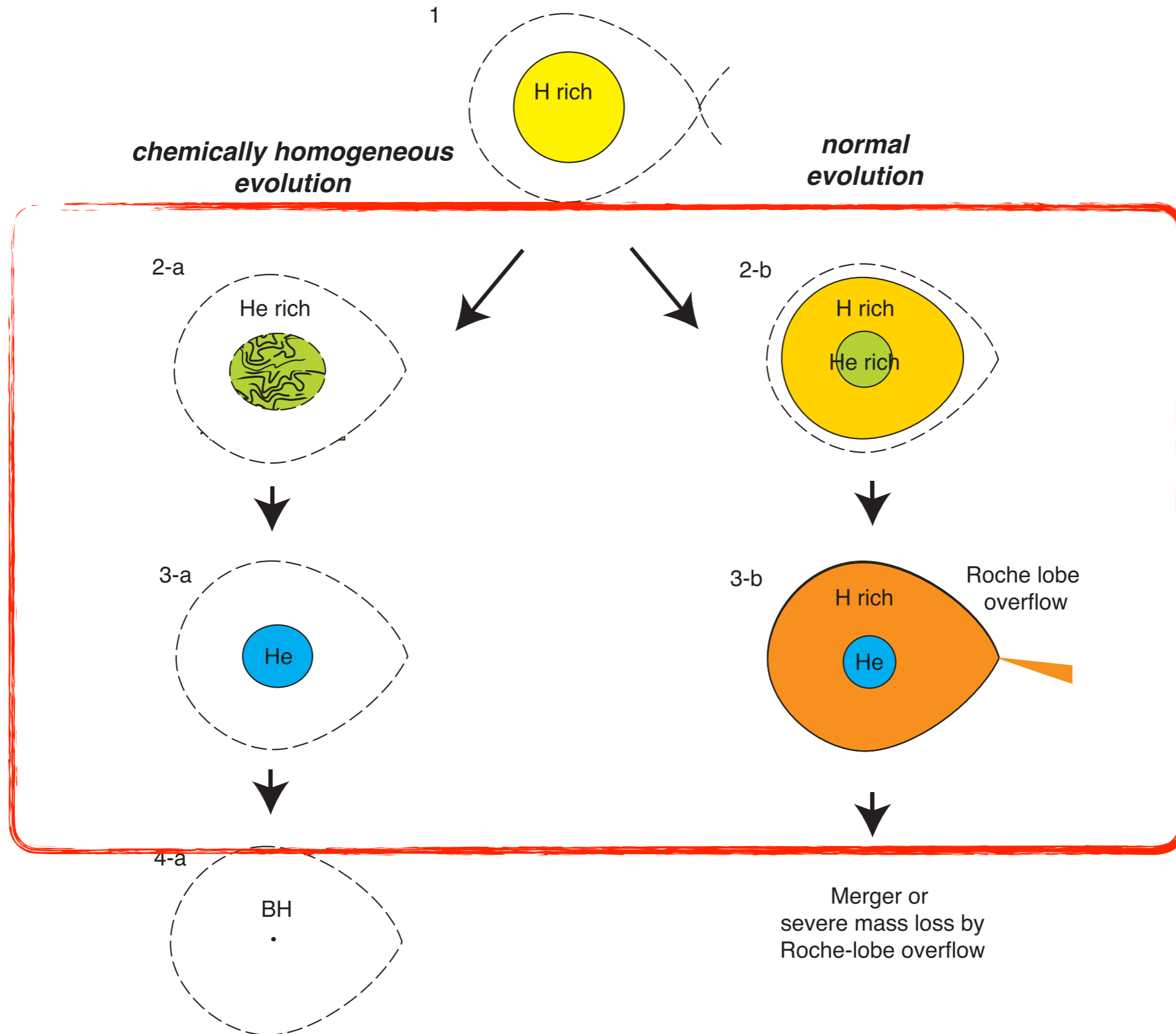
Chemically Homogeneous Evolution

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Chemically Homogeneous Evolution

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- From (isolated) massive binary star evolution
 - Traditional channel
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- As part of 'primordial' black holes
- **Through stellar dynamics in dense star clusters**

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Collaboration



Fred Rasio



Vicky Kalogera



Fabio Antonini



Carl Rodriguez



Meagan Morscher



**Bharath
Pattabiraman**



Katie Breivik



Carl-Johan Haster