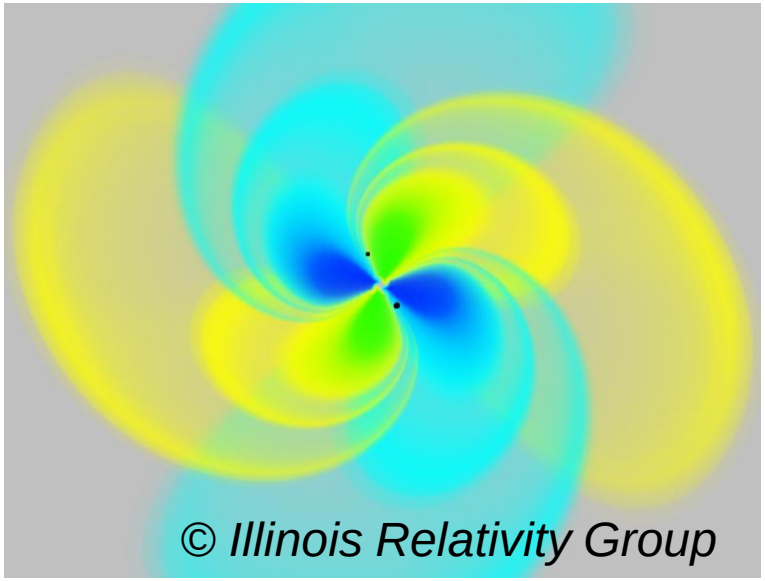
What was the Initial Mass of Merging Black Holes in GW150914?

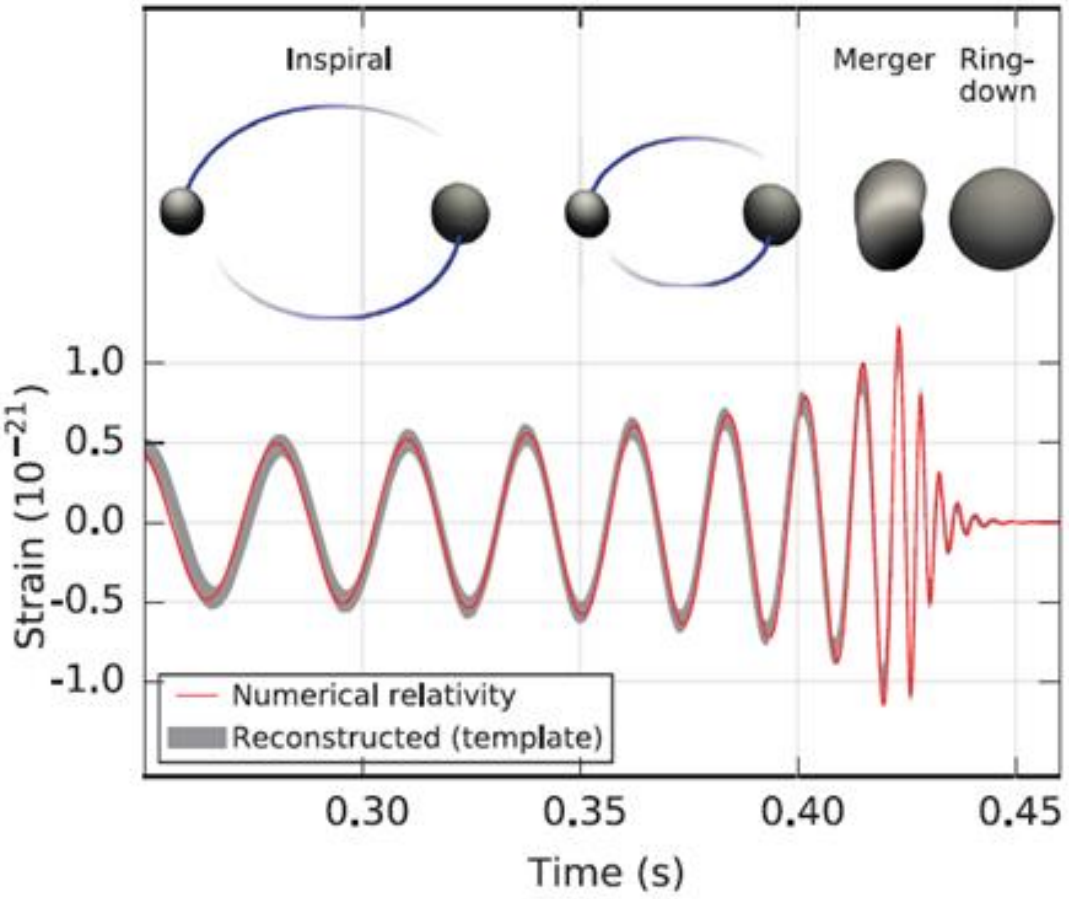


Hiromichi Tagawa (University of Tokyo)

In collaboration with:
Masayuki Umemura (University of Tsukuba)

Observation of GW150914

Abbott et al. (2016)

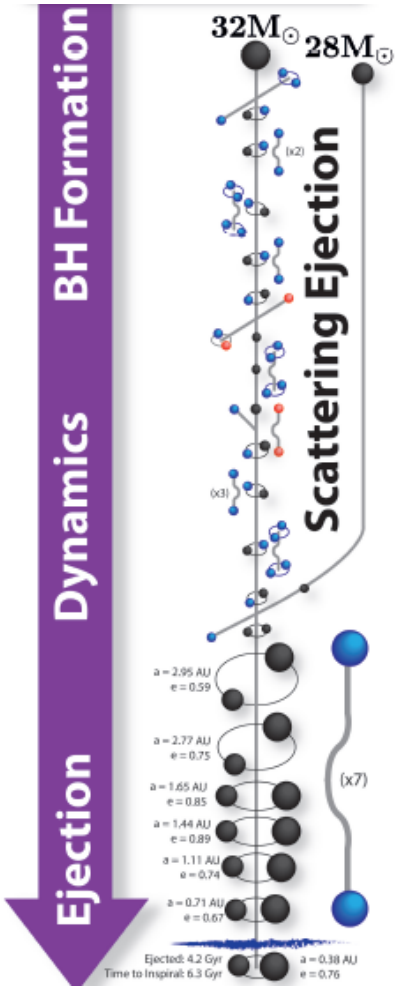


- GW150914 shows the existence of 30 M_{sun} BH binary and its merger.

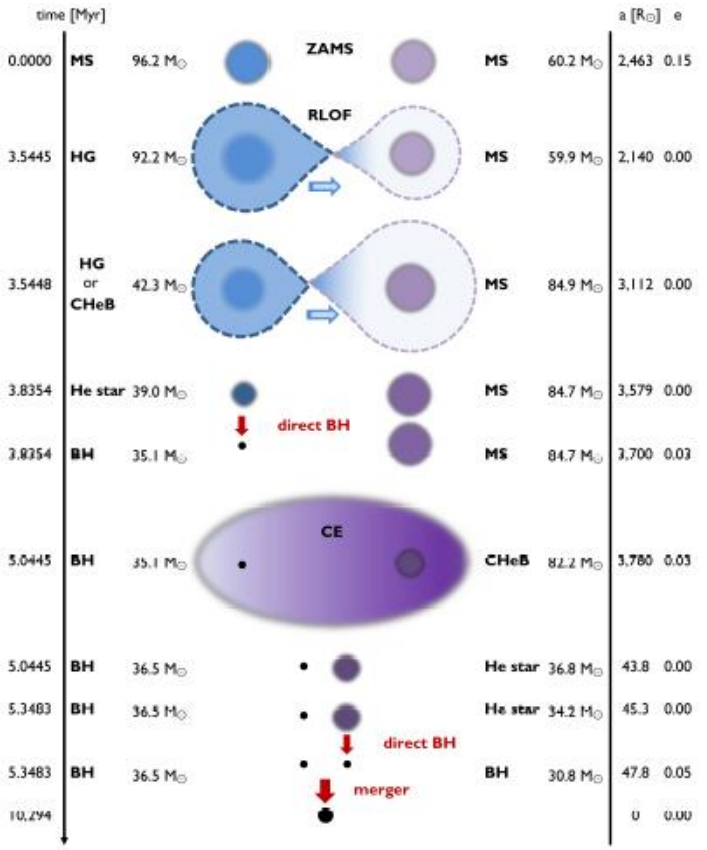
Evolutional channels for GW150914

1. Dynamical formation in a dense star cluster
   (e.g. Rodriguez et al. 2016)
2. Binary star evolution
   (e.g. Belczynski et al. 2016;
   Marchant et al. 2016;
   de Mink & Mandel 2016)

Rodriguez et al. (2016)



Belczynski et al. (2016)



We newly propose "Merger from non-binary stars"

Origin of GW150914

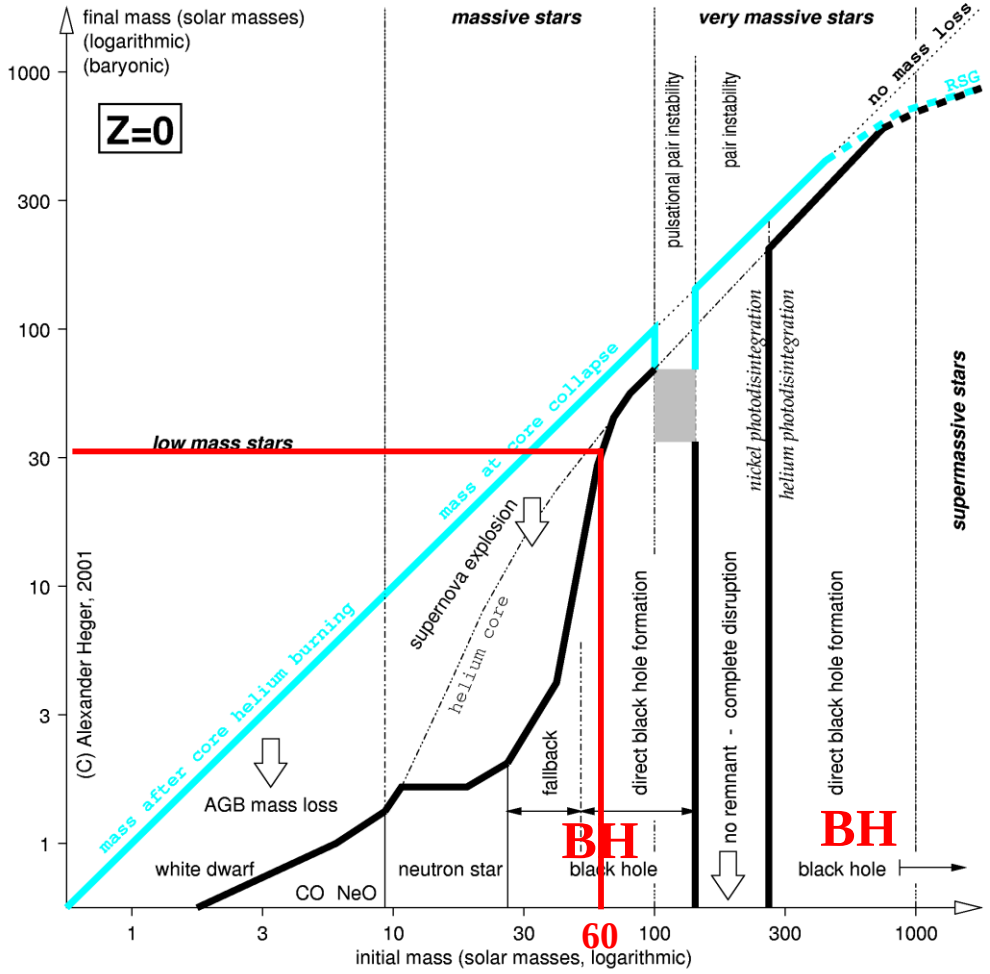
Binary Stars

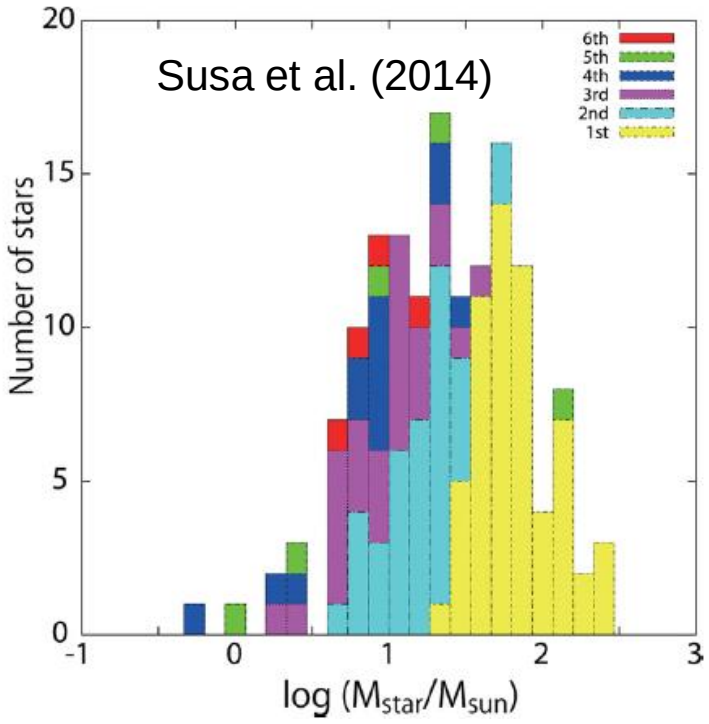
vs

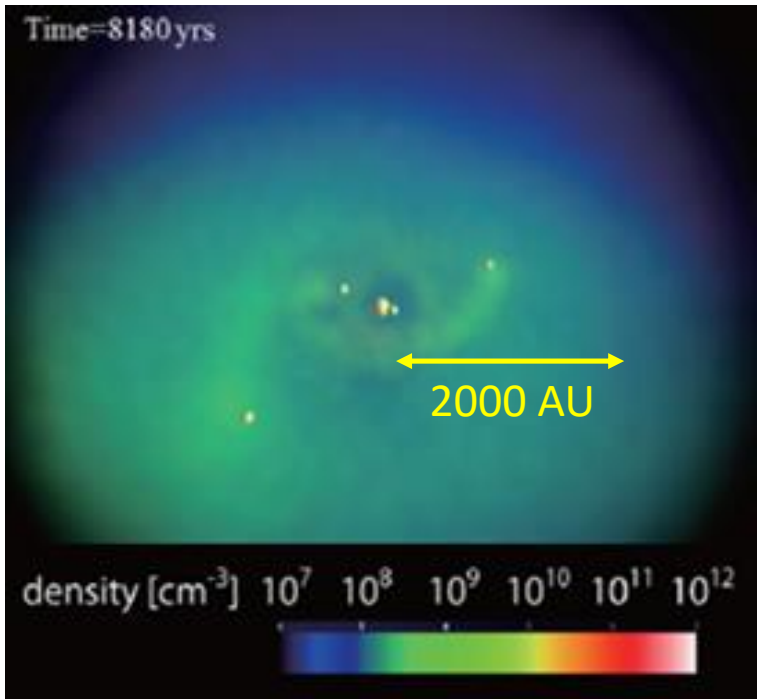
Non-Binary Stars

Multiple BHs from non-binary first stars

Heger & Woosley (2002)

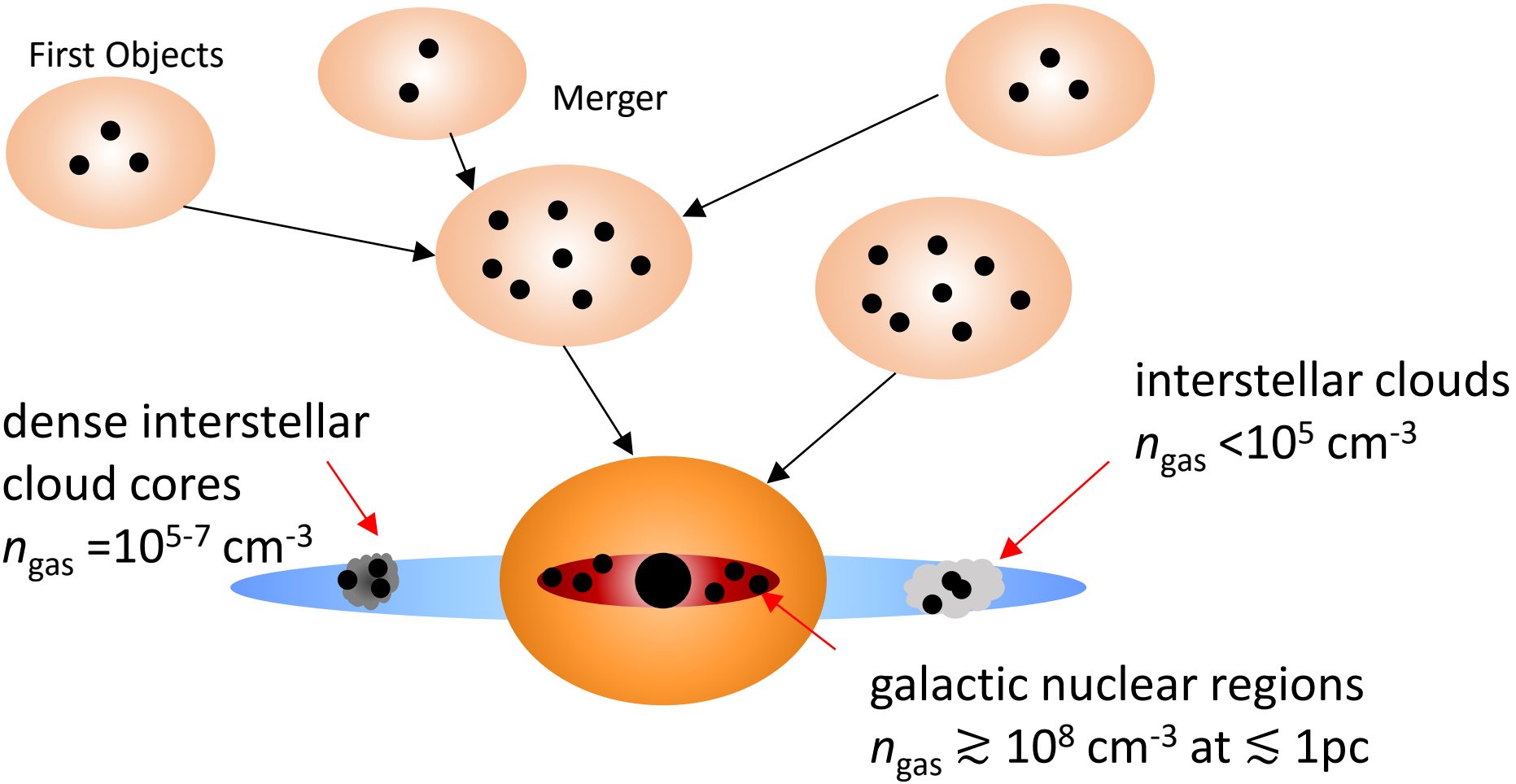






Mergers from multiple non-binary BHs

Tagawa, Umemura, Gouda, Yano & Yamai, 2015, MNRAS, 451, 2174
Tagawa, Umemura, Gouda, 2016, MNRAS, 462, 3812

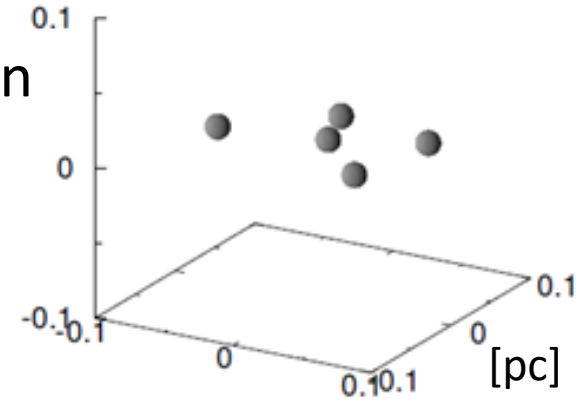


Objectives: Investigate conditions or environments that BHs merge at masses of GW150914 from smaller mass BHs and large separation.

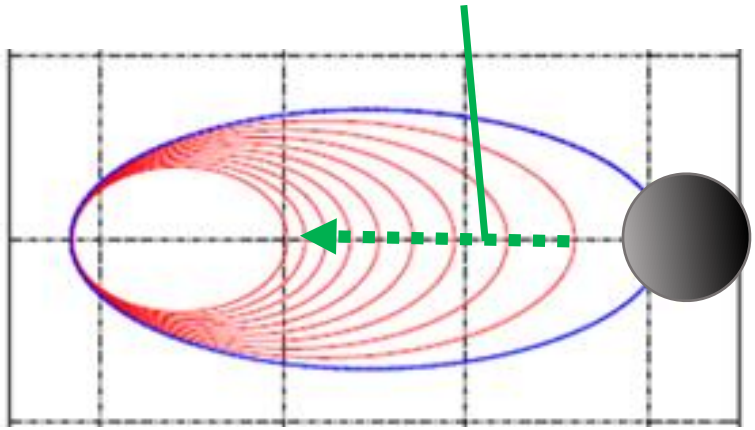
Fundamental processes for BH merger

Initial condition

$M_{gas}=10^5\,M_{sun}$

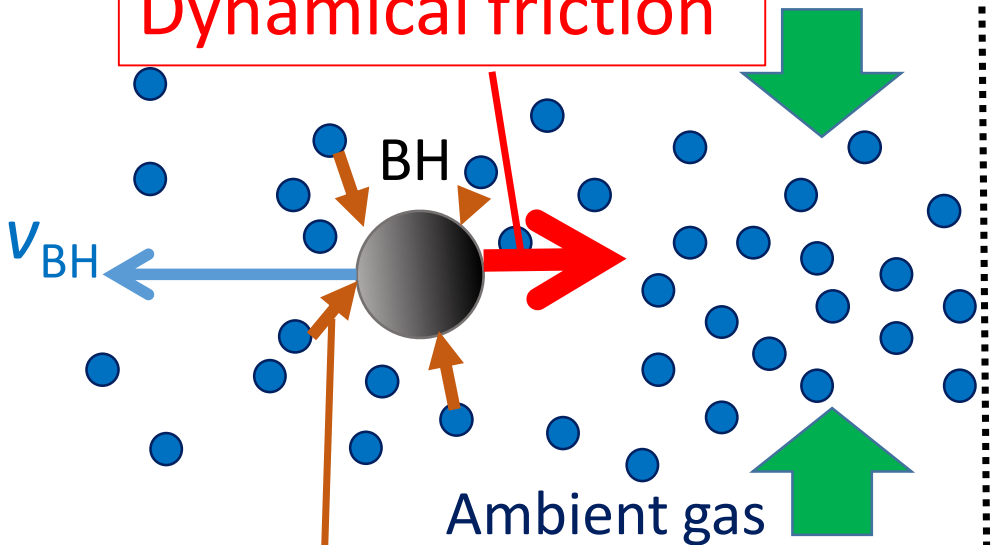


Gravitational wave radiation



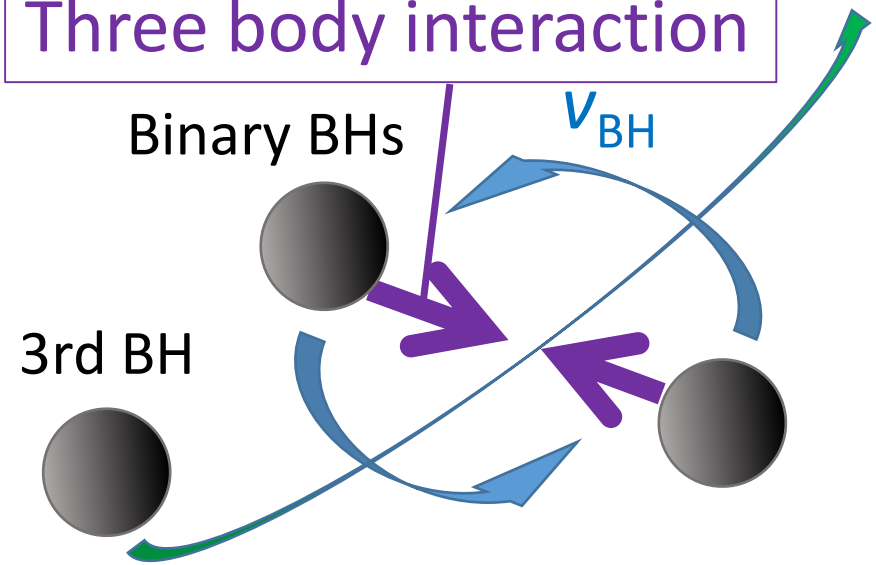
Reduced mass

Dynamical friction



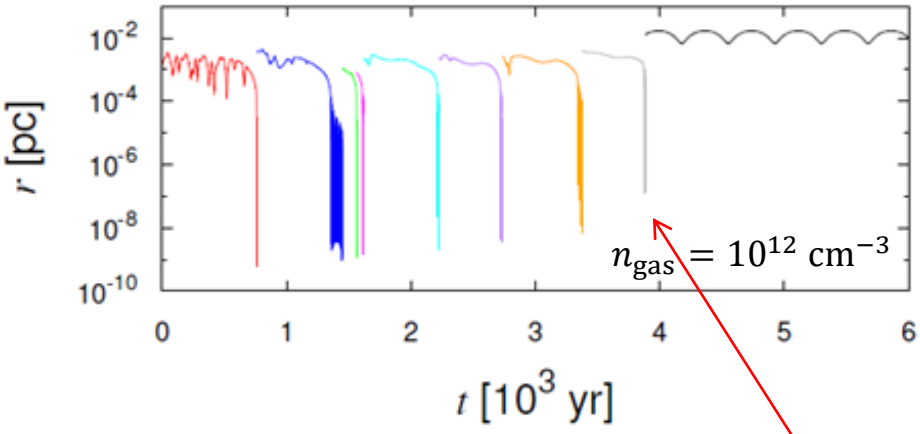
Bondi-Hoyle-Lyttleton accretion

Three body interaction

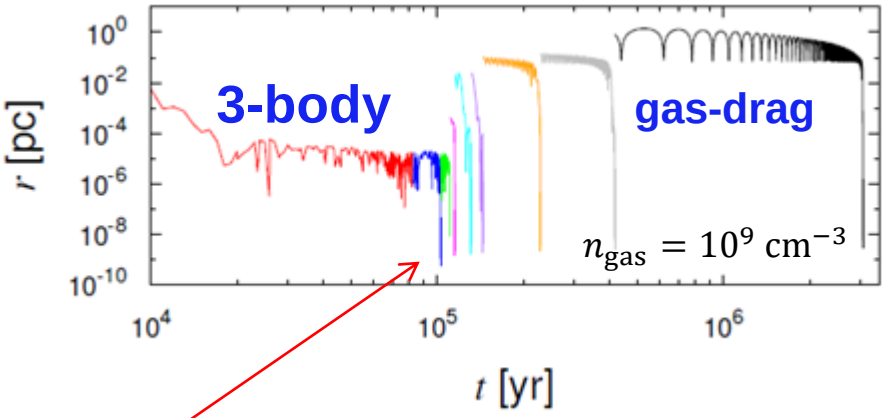


Classification of merger mechanisms

Type A
Gas drag-driven merger

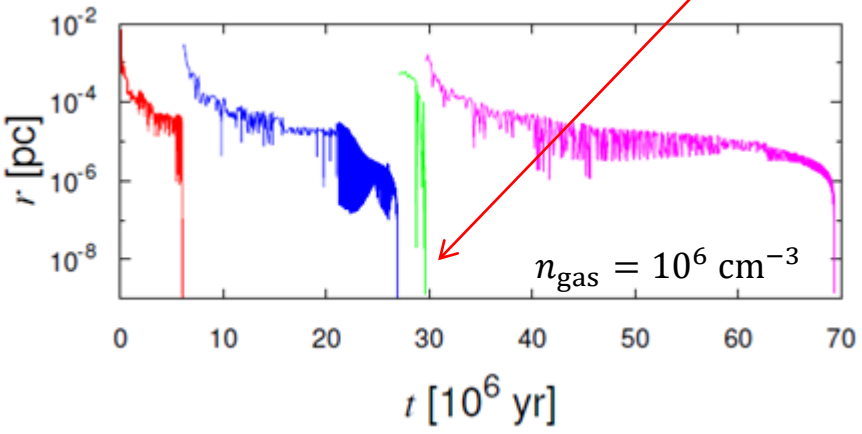


Type B
Interplay-driven merger

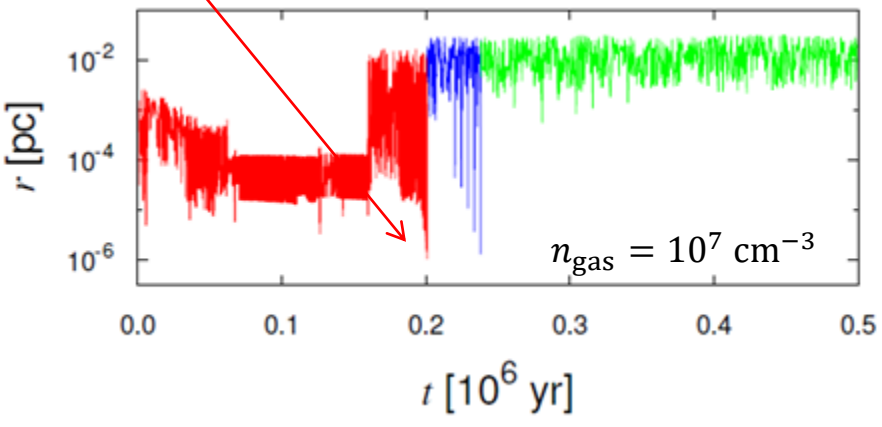


Gravitational Waves

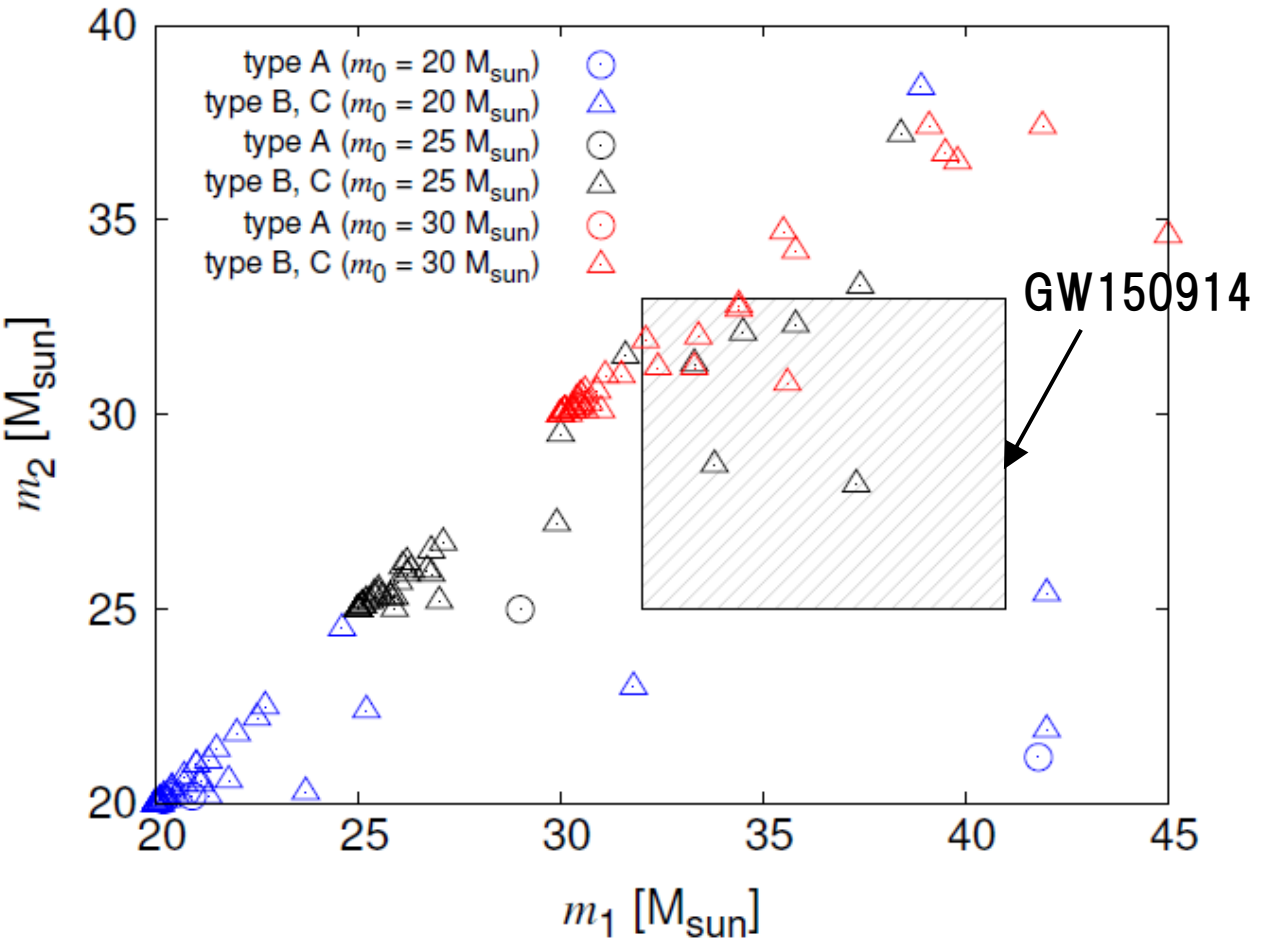
Type C
Three body-driven merger



Type D
Accretion-driven merger



Initial and merged BH masses



$m_0 \gtrsim 25\ M_{\rm sun}$, type B or C

($\dot{m} \sim 0.01\ \dot{m}_{\rm HL}, r_{\rm typical} \lesssim 1$ pc)

Preferable environments

- Environments would vary within 10^8 yr

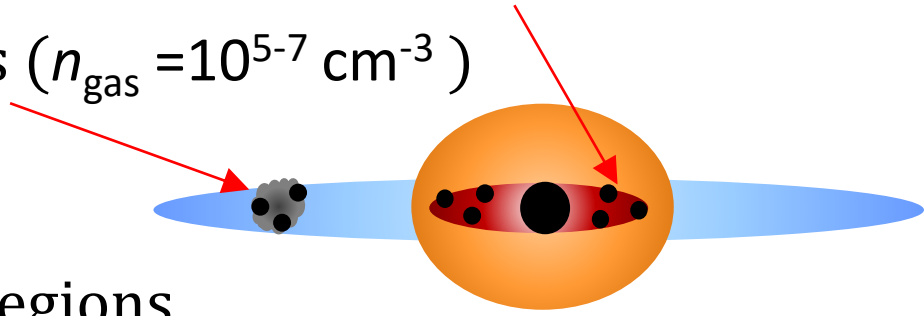
  (AGN duty cycle, galactic rotation timescale)

  - $t_{\rm merge} < 10^8\,{\rm yr}$
- $t_{\rm merge} \propto {n_{\rm gas}}^{-1}$ (Tagawa et al. 2015)

  $\rightarrow n_{\rm gas} > 10^5\,{\rm cm}^{-3}$

<u>Possible environments:</u>

- Galactic nuclear regions ($n_{\rm gas} \gtrsim 10^8$ cm^{-3} at $\lesssim$ 1pc)
- Dense interstellar cloud cores ($n_{\rm gas}$ =$10^{5\text{-}7}$ cm^{-3})



<u>Event rate</u> (LIGO O1)

- 0.6-6 yr^{-1} in galactic nuclear regions
- 2-20 yr^{-1} in dense interstellar cloud cores

Disk galaxies are preferred as host galaxies

Conclusions

1. The multiple non-binary BHs can account for the merger in the GW150914 event.

2. Required conditions are

$$\dot{m} \sim 0.01\, \dot{m}_{\rm HL}, \quad r_{\rm typical} \lesssim 1\ {\rm pc},$$

$$m_0 \gtrsim 25\, M_{\rm sun}, \ \text{type B or C}$$

$$n_{\rm gas} > 10^5\ {\rm cm}^{-3}, \ t_{\rm merge} < 10^8\ {\rm yr}.$$

3. Event rates by the LIGO O1 are
   - 0.6-6 $\rm yr^{-1}$ in galactic nuclear regions
   - 2-20 $\rm yr^{-1}$ in dense interstellar cloud cores

Conclusions

1. The multiple non-binary BHs can account for the merger in the GW150914 event.

2. Required conditions are

$$\dot{m} \sim 0.01\, \dot{m}_{\rm HL}, \quad r_{\rm typical} \lesssim 1\ {\rm pc},$$

$$m_0 \gtrsim 25\, M_{\rm sun}, \ \text{type B or C}$$

$$n_{\rm gas} > 10^5\ {\rm cm}^{-3}, \ t_{\rm merge} < 10^8\ {\rm yr}.$$

3. Event rates by the LIGO O1 are
   - 0.6-6 $\rm yr^{-1}$ in galactic nuclear regions
   - 2-20 $\rm yr^{-1}$ in dense interstellar cloud cores

Thank you!