AGN theory group

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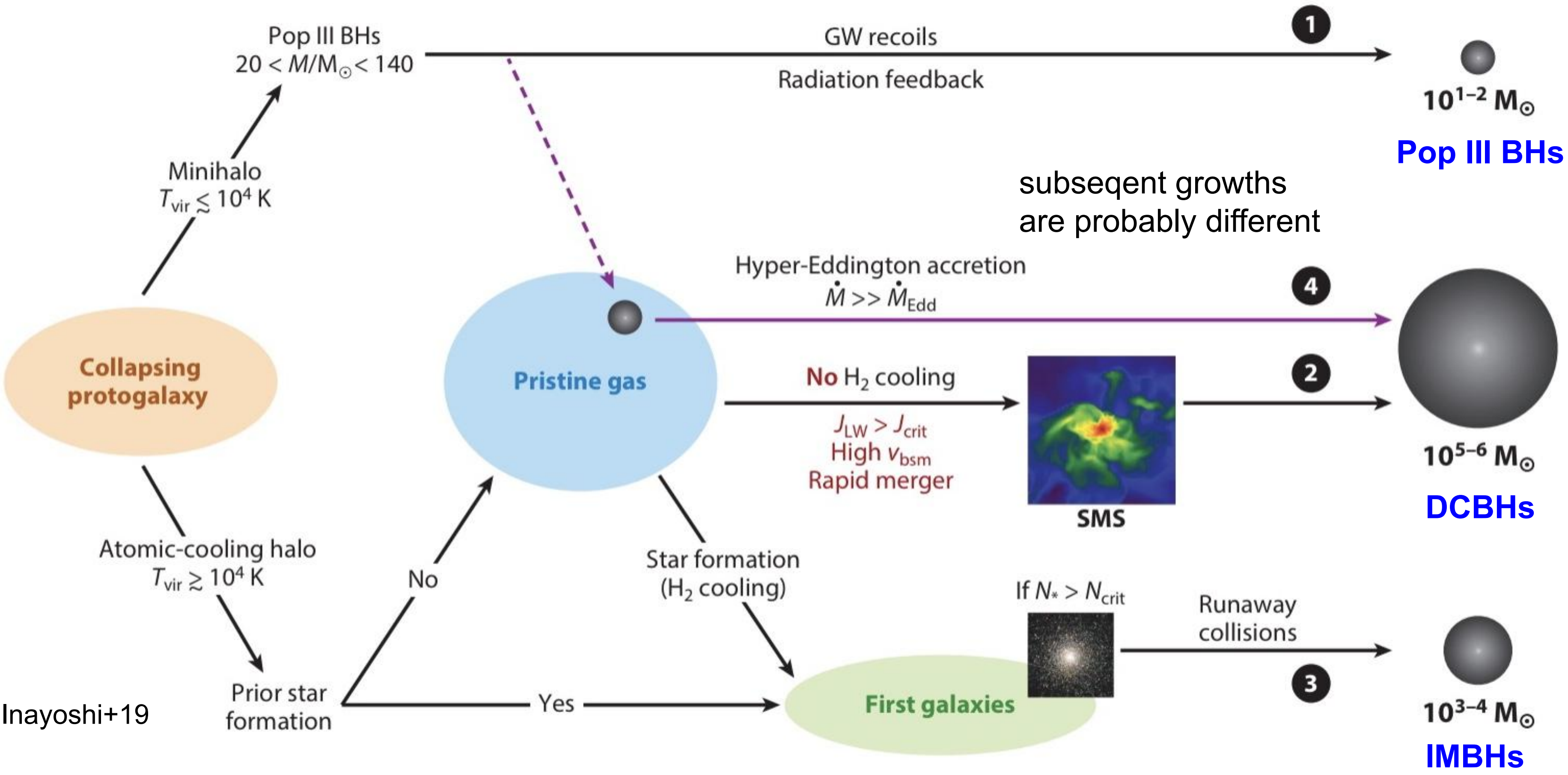
課題：宇宙論的な枠組みにおけるブラックホール形成

1. 参考文献の中からあなたが気に入ったブラックホール形成シナリオ（天体現象起源のもの）を選んで、そのシナリオの長所・短所、気に入った理由をまとめてください (新しく考案したシナリオでも可です)。
2. high-z 宇宙に観測されている超巨大ブラックホールは非常に珍しい天体で、急成長した銀河の中心に存在していると考えられる。上で選んだシナリオに対して、銀河やハローの急成長が与える役割、またそれによってもたらされるメリット・ デメリットを考察せよ

Topics: Formation of SMBHs in the framework of the cosmological structure formation

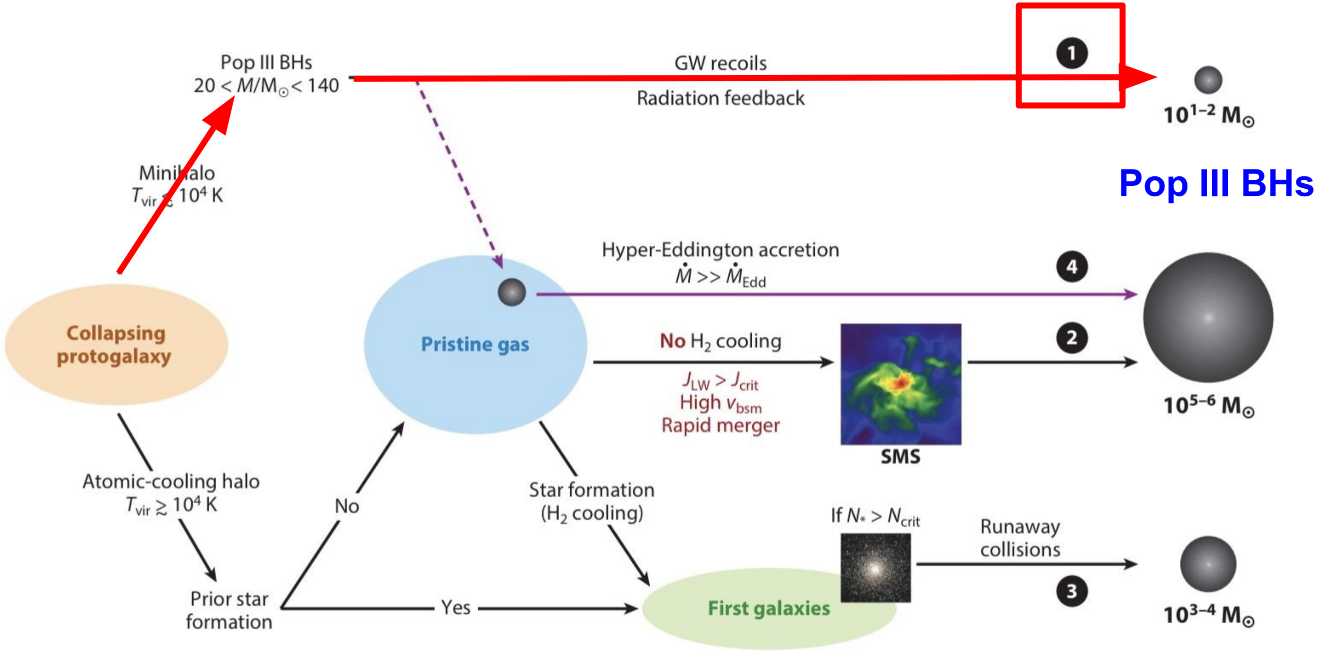
1. Let us choose a BH-formation scenario you would prefer from the literature (hopefully, not PBH models…) and discuss merits/demerits of the scenario. If you propose a new scenario, it would be great! If it’s really new, write a draft.
2. High-redshift SMBH populations are rare objects and considered to grow fast at the center of its host galaxy. Please discuss merits/demerits of the scenario you pick up in terms of BH growth process

Formation



Inayoshi+19

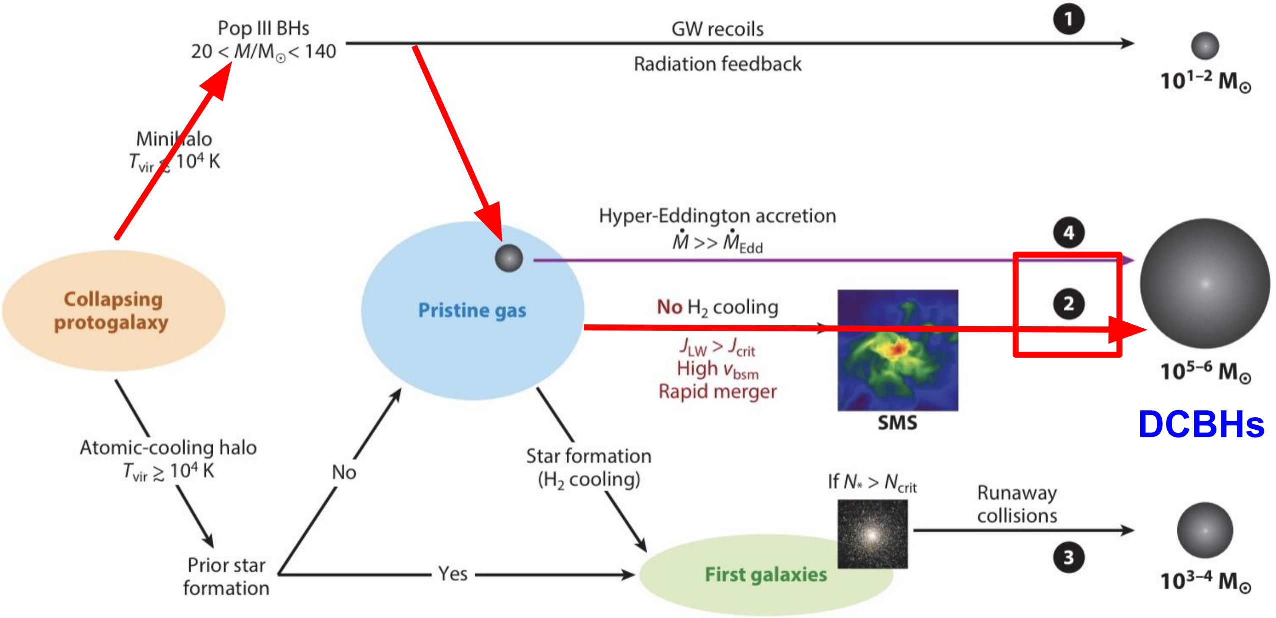
Merits & Demerits (Scenario 1)



Merit: A natural result from Pop III star remanants assuming a top-heavy IMF.

Demerit: Not able to reach the BH mass at z ~ 6 (timecale issue).

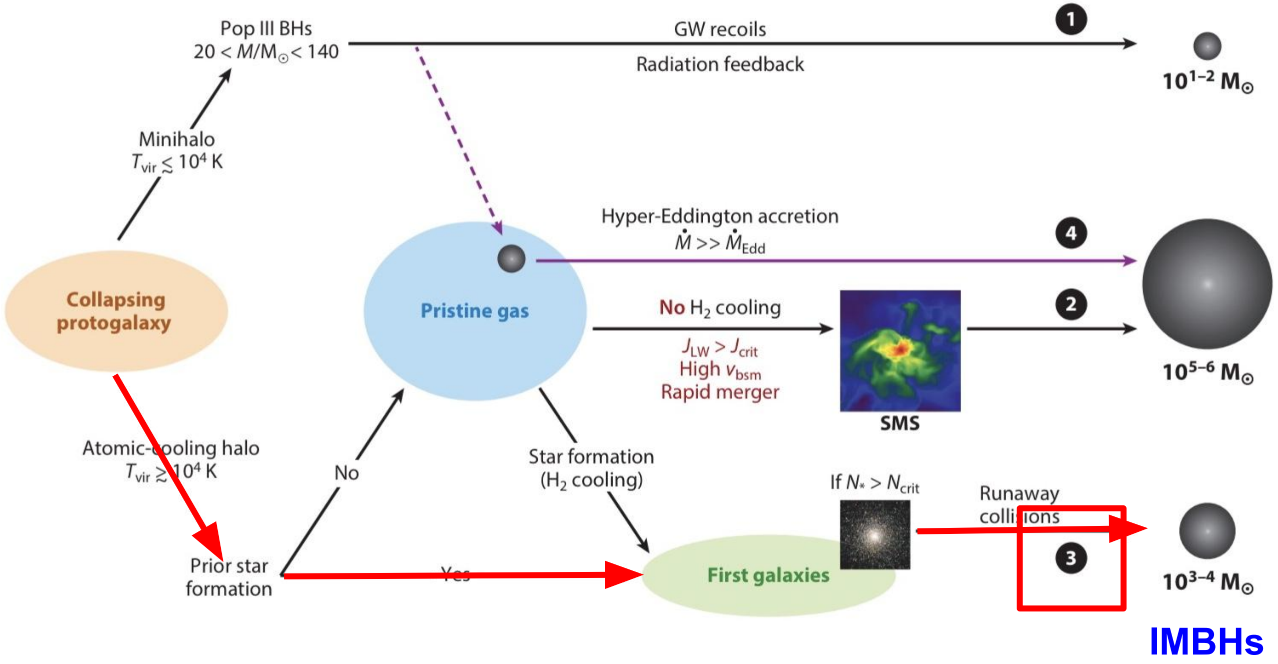
Merits & Demerits (Scenario 2)



Merit: Rapid mass accretion is not necessary.

Demerit: Circumstances are too peculiar to be realized.

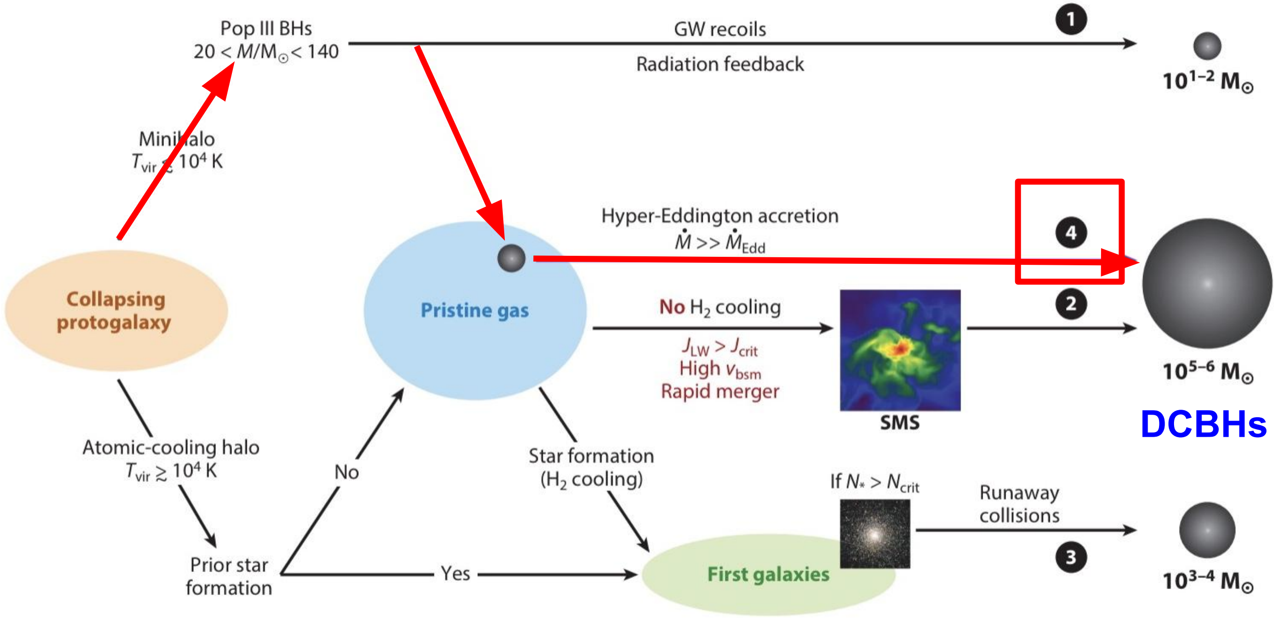
Merits & Demerits (Scenario 3)



Merit: We don’t have to consider peculiar circumstances.

Demerit: Not able to reach the BH mass at z ~ 6 (timecale issue).

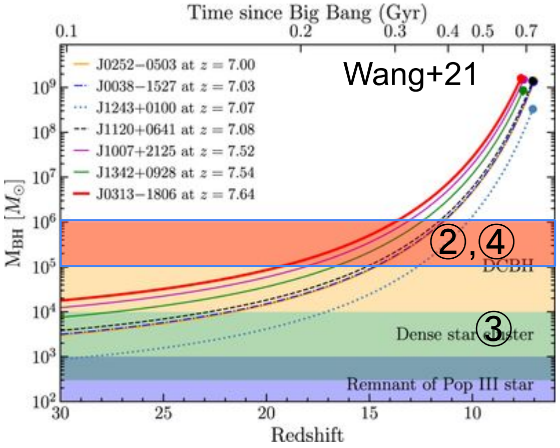
Merits & Demerits (Scenario 4)



Merit: Abundant, light seed BHs can contribute to the SMBH formation.

Demerit: We have to consider rapid accretion.

Coevolution of BH and DM halo



- Eddington accretion

  Can Eddington accretion continue? (∵ negative feedback)

  Differences in growth rates among BH seed formation scenarios

  (Can radiation feedback from nearby halos prevent BHs from accreting?)

- Mergers

  Will merger grow BH seeds?

  (Soltan's argument shows that it is inefficient)

  Is the BH seed incorporated into the galaxy by z~7?

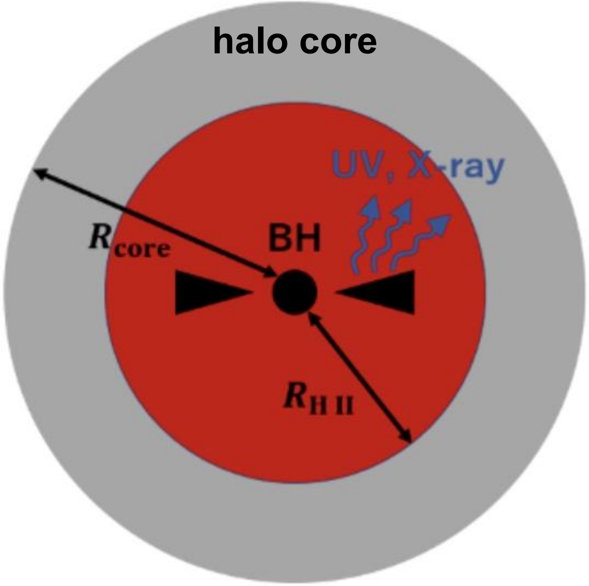
  (Only 13% of BH seeds can become SMBH progenitor (Valiante+16))

To Observation

The conditions for a halo to confine seed IMBHs : R_HII < R_core

$$M_h > 3.2 \times 10^9 M_\odot \left(\frac{M_{BH}}{10^5 M_\odot}\right)\left(\frac{n_{core}}{10^3\ \mathrm{cm}^{-3}}\right)^{-\frac{1}{2}}\left(\frac{1+z}{21}\right)^{-\frac{3}{2}}$$

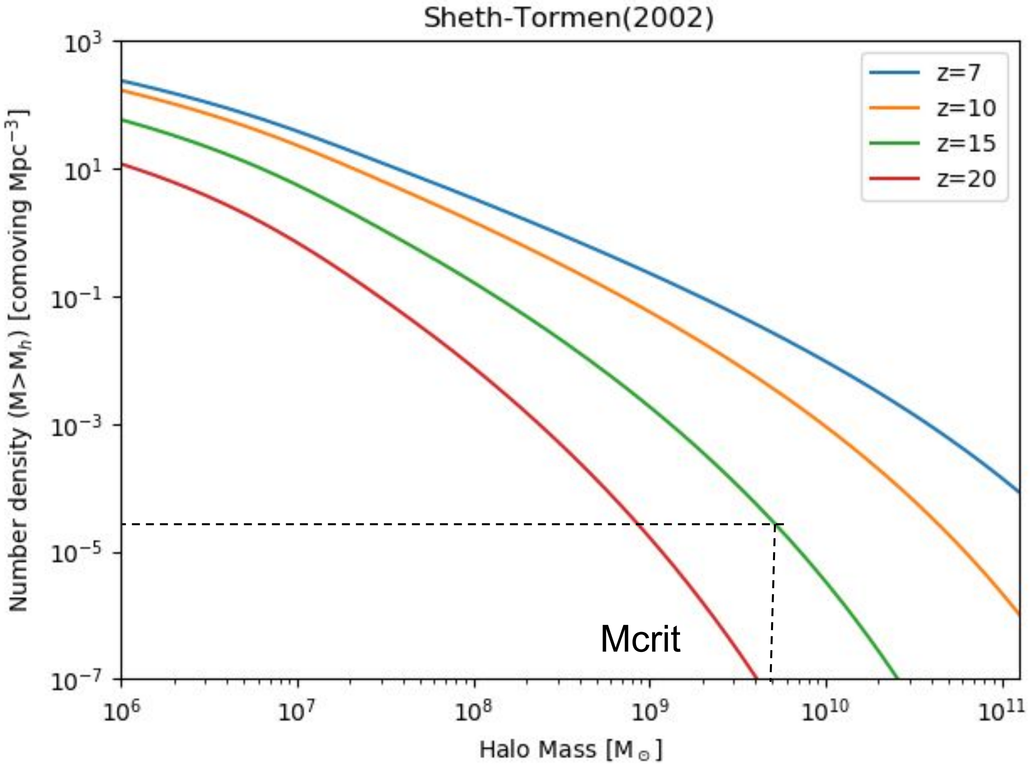
$$T_{vir} > 1.9 \times 10^5 \mathrm{K} \left(\frac{M_{BH}}{10^5 M_\odot}\right)^{\frac{2}{3}}\left(\frac{n_{core}}{10^3\ \mathrm{cm}^{-3}}\right)^{-\frac{1}{3}}$$



M_h: halo mass
n_{core}: number density of the core
z: redshift
T_{vir}: virial temperature

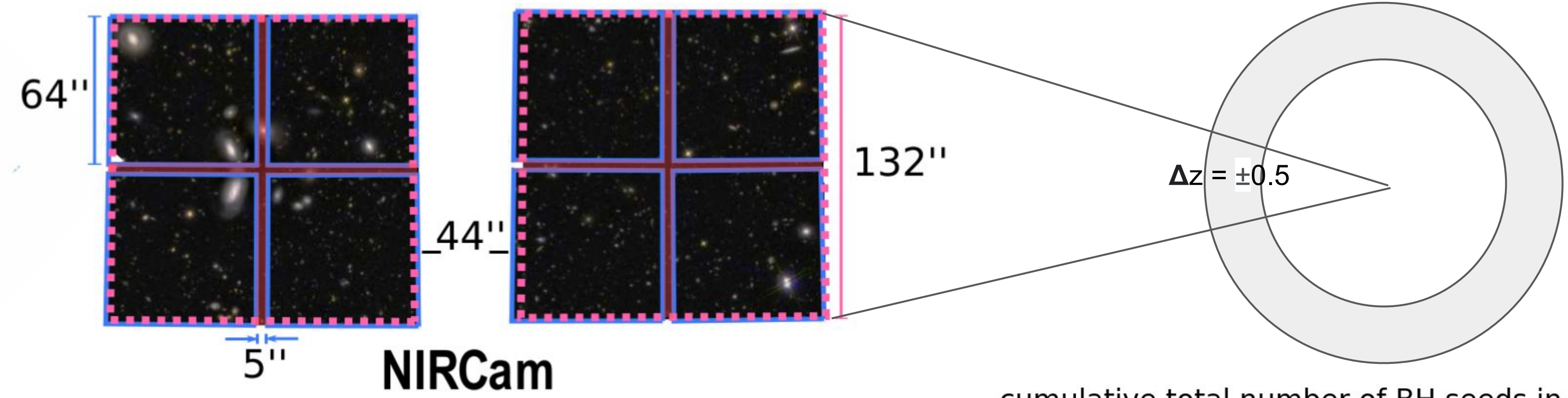
To Observation

Estimating the number density of halos where the condition M_h > M_crit is satisfied, using the Sheth-Tormen halo mass function.



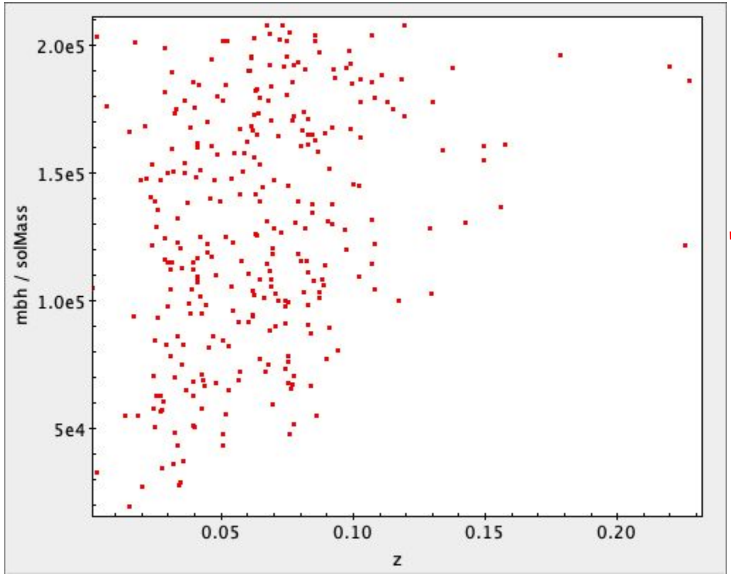
@z=15, M_BH = 10^5 M☉,
Mcrit = 4×10^9 M☉

When Mcrit=4×10^9 M☉,
there are ~ 3e-5 halos
in 1 Mpc^3 with Mh>Mcrit.

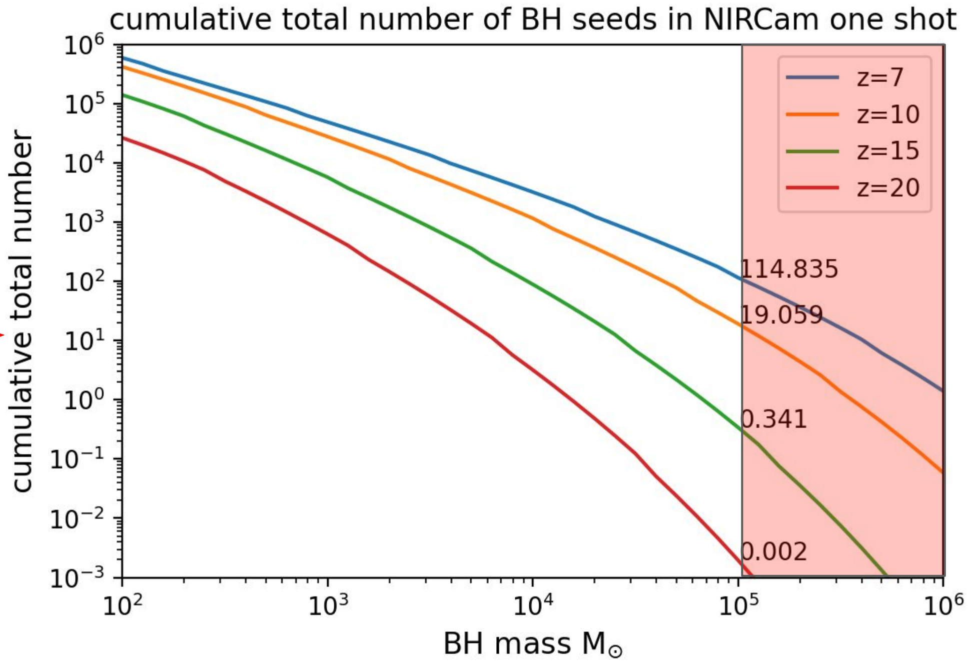


JWST/NIRCam one shot ~ 10000 Mpc^3 at z=6.5~7.5

IMBHs discovered in literature (IV Chilingarian 2018)



great increase



Conclusion

・We summurize the formation and growth of SMBHs.

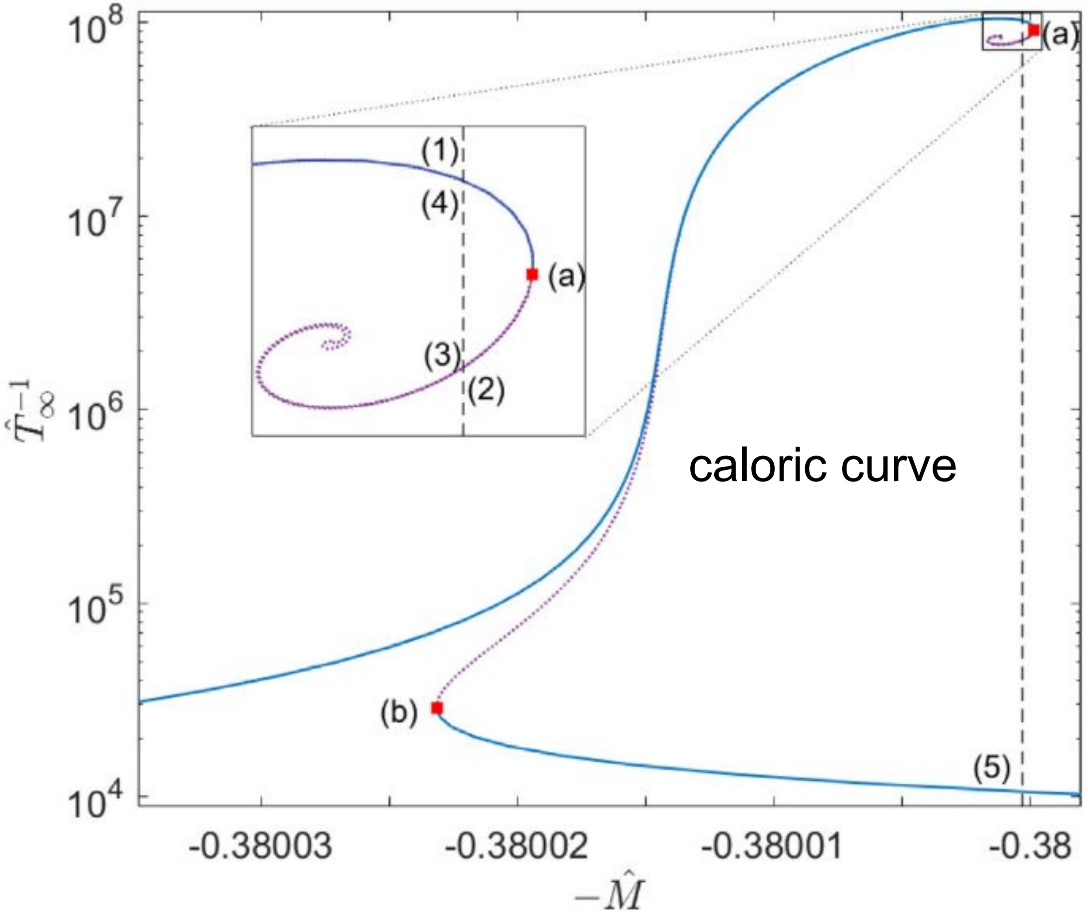
・We estimate the total number of massive halos that can host seed BHs.

・We estimate the detectability of them by JWST/NIRCam.

・We could detect a number of ~100 seed BHs with M_BH ~ 10^5 solar mass in z ~ 7 by NIRCam one shot, and 1 seed BHs with M_BH ~ 10^5 solar mass at z ~ 15 by three shot with NIRCam (if L/L_Edd ~ 1- 10 is assumed; see AGN observation group)

Backup slides

beyond the standard senario -- DM fake BH formation



Carlos R. Arguelles et al. 2021

Via Fermi–Dirac phase-space distribution, DM fermions can develop a degenerate compact core surrounded by a diluted halo. The latter is able to explain the galaxy rotation curves, while the DM core can mimic the central black hole.

No need for early stars, no need for unrealistic accretion rate.

Thermodynamic stability analysis under box-confined DM haloes and mc^2 = 10 keV

redshift	MBH = 10^2 Msolar	MBH = 10^3 Msolar	MBH = 10^4 Msolar	MBH = 10^5 Msolar	MBH = 10^6 Msolar
	N / cMpc^3				
7	2.8e1	2.3	1.5e-1	5.5e-3	6.7e-5
10	2.7e1	1.8	7.4e-2	1.2e-3	3.6e-6
15	1.3e1	5.4e-1	8.5e-3	3.3e-5	5.2e-9
20	3.4	8.2e-2	4.2e-4	2.6e-7	1.4e-12

JWST/NIRCam one shot ~ 10000 Mpc^3 at z=6.5~7.5

JWST FoV = 9.7 arcmin^2 = 8.2e-7 Sr.
JWST NIRCam FoV = 2 arcmin ^ 2
2*(132^2) arcsec^2 = 2*(132/60)^2 arcmin^2 ~ 9.68 arcmin^2

Pop III BHs

number density?

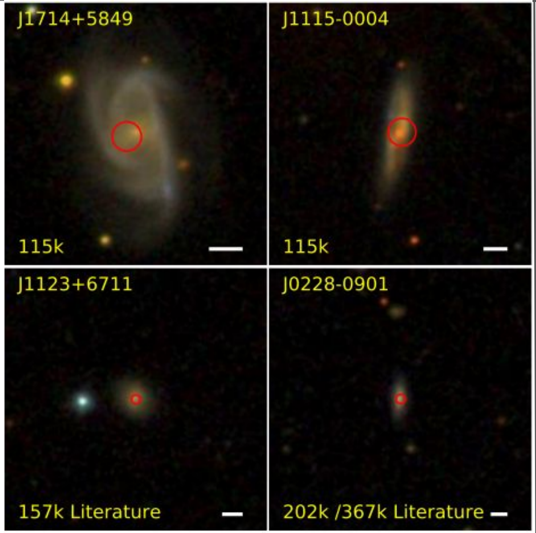
No Pop III stars have been found

No H2 cooling DCBHs

IMBHs

IV Chilingarian 2018 catalog included 305 IMBHs

also detected by GW: GW190521



super Eddington DCBHs

Merit and demerit

1

2 merit : 初めから重いので異常な降着を考えなくてよい、実現後はgrowth rateが上がりやすい（high density）

demerit : 特殊な環境なので実現するか微妙

3 see p.44 of Inayoshi+ 2019 review

4 merit : 初期質量が軽くても良い（そこそこ重くて数も多い）

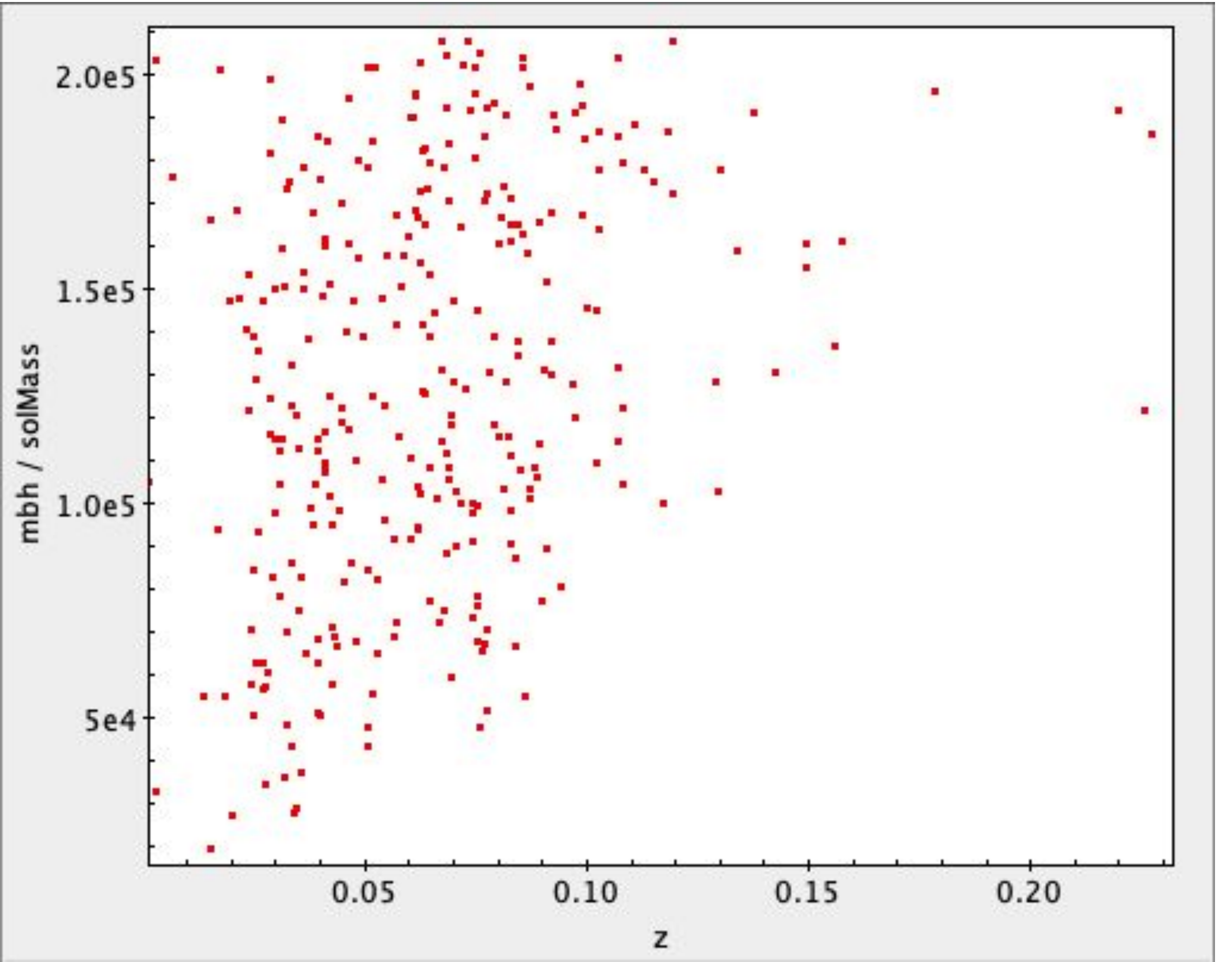
demerit : Eddington accretionでは間に合わない、Eddington降着率がずっと続くわけではない

IMBH supplement information

Table 2. IMBHs identified as AGN and some of their properties.

Object	$M_{\rm BH}$ ($10^3 M_\odot$)	Lit.$M_{\rm BH}$ ($10^3 M_\odot$)	$\sigma_{\rm BLR}$ (km s^{-1})	$L_{\rm BLR}$ Hα (10^{39} erg s^{-1})	z	$M_{\rm abs}^{\rm sph}$ (mag)	$M_{\rm sph}^{*}$ ($10^9 M_\odot$)	$L_{\rm X}$ (10^{40} erg s^{-1})
This work								
J122732.18+075747.7	43 ± 10[1] 36 ± 7[2]		214 ± 20 200 ± 10	1.5 ± 0.4 1.4 ± 0.4	0.033	−17.8 (r)	0.9	0.55 (*XMM*)
J134244.41+053056.1	65 ± 7[1] 96 ± 13[2]		216 ± 10 286 ± 13	3.5 ± 0.4 2.4 ± 0.5	0.037	−20.7 (r)	3.5	13.5 (*Swift*)
J171409.04+584906.2	115 ± 24[1]		373 ± 31	1.1 ± 0.3	0.030	−17.4 (F814W)	0.7	2.5 (*XMM*)
J111552.01−000436.1	115 ± 38[1]		315 ± 41	2.3 ± 0.9	0.039	−16.8 (r)	0.4	4.9 (*XMM*)
J110731.23+134712.8	122 ± 18[1] 71 ± 10[2]		269 ± 17 244 ± 10	5.1 ± 0.8 2.5 ± 0.6	0.045	−18.0 (K)	0.3	190 (*Chandra*)[*]
Previously known								
J152304.97+114553.6[a]	70 ± 20[1]	50	350 ± 30	0.5 ± 0.2	0.024		0.7	0.4 (*Chandra*)[a]
J153425.58+040806.7[b]	111 ± 7[1]	130	246 ± 6	6.2 ± 0.3	0.039		1.3	85 (*Chandra*)[d]
J160531.84+174826.1[b]	116 ± 11[1]	160	316 ± 12	2.3 ± 0.2	0.032		1.7	12.7 (*XMM*)
J112333.56+671109.9[c]	157 ± 36[1]	200	341 ± 34	3.1 ± 0.6	0.055		2.4	53.5 (*XMM*)
J022849.51-090153.8[c]	202 ± 13[1] 367 ± 27[2]	316	250 ± 7 340 ± 9	21 ± 1 19 ± 2	0.072		0.7	275 (*Chandra*)[d]

IMBH supplement information (distribution of discovered IMBH)



IMBH supplement information

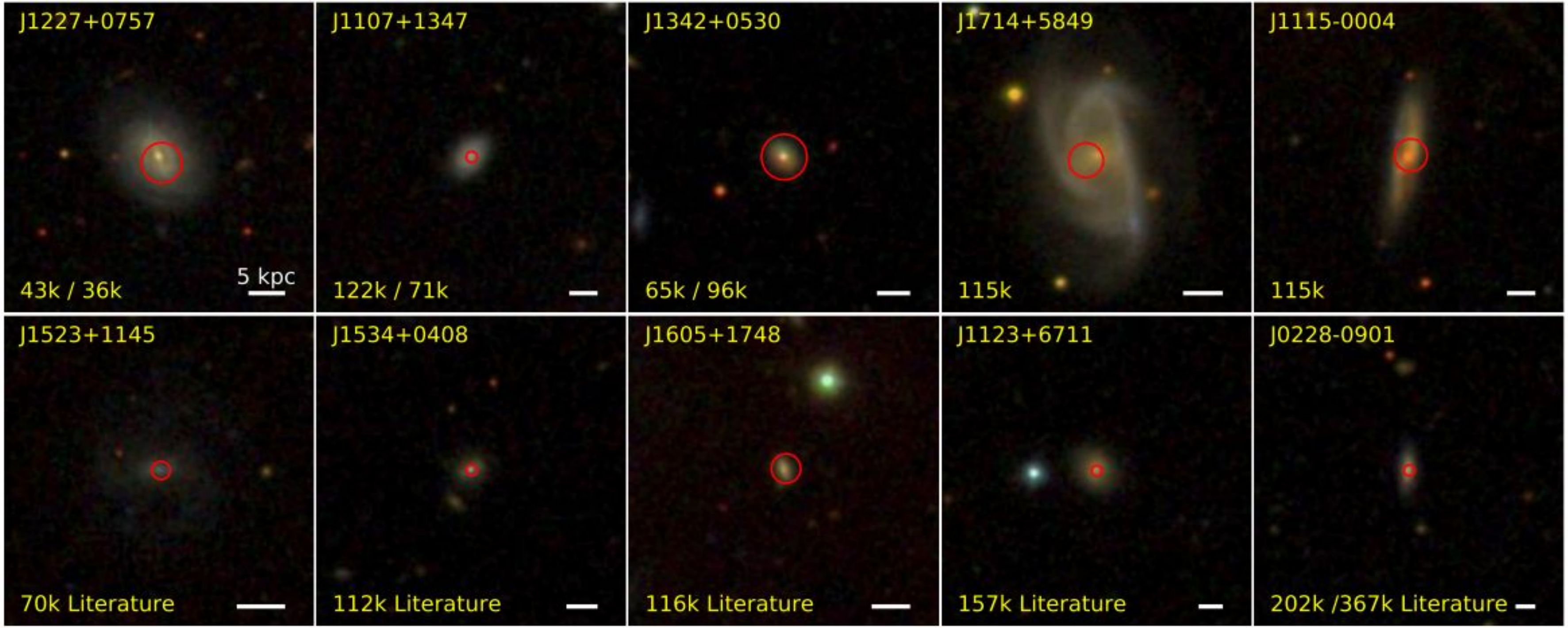


Figure 2. Optical images of ten IMBH host galaxies. Sloan Digital Sky Survey images of galaxies hosting IMBHs detected by our automated data analysis workflow demonstrate low luminosity spheroidal stellar systems or spiral galaxies with small bulges. The locations of X-ray counterparts with the corresponding 3σ positional uncertainties is shown by red circles. The bottom row displays objects mentioned in the literature previously, which our workflow has successfully recovered. A virial mass estimate in $M_\odot$ from the analysis of SDSS spectra is shown in the bottom left corner of every panel followed by an estimate from MagE when available, the physical scale in the host galaxy plane is in the bottom right.

To Observation

Mass function of BH mass using halo mass function of Sheth-Tormen(2002).