Formation of supermassive black holes

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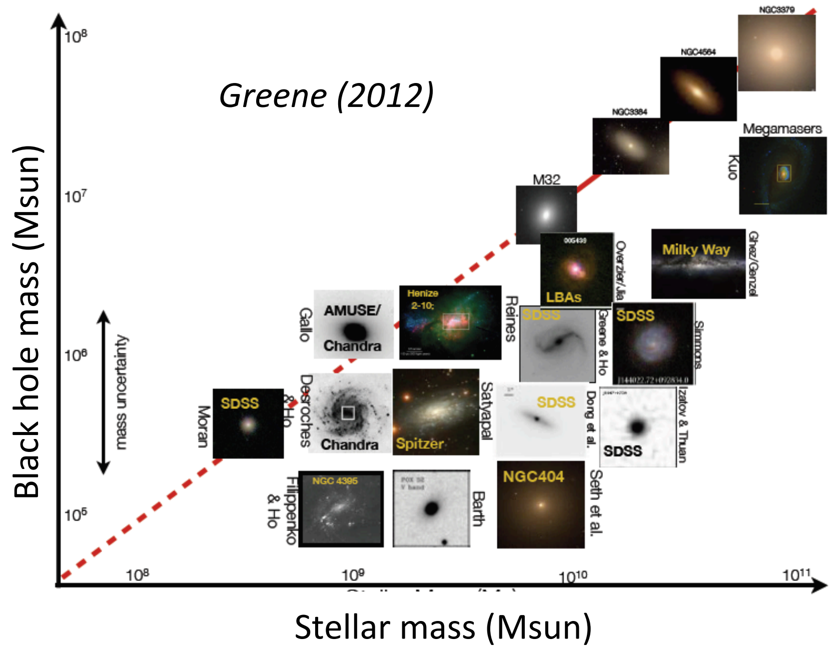
Two main scenarios to form supermassive black hole seeds

SMBHs reside in the center of most local galaxies, including our Milky Way



Discovery of Quasars at redshift z=6-7 (BH as massive as redshift z=0)
Fan et al. 2012

→ BHs acquire 10^9 $M_\odot$ for 1Gyr
→ BHs must have been formed in the very early Universe with 100 -10^5 $M_\odot$ seeds

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Two scenarios to form BH seeds:

- Pop III star remnants

Madau & Rees 2001
Volonteri, Haardt, Madau 2003

- Direct collapse

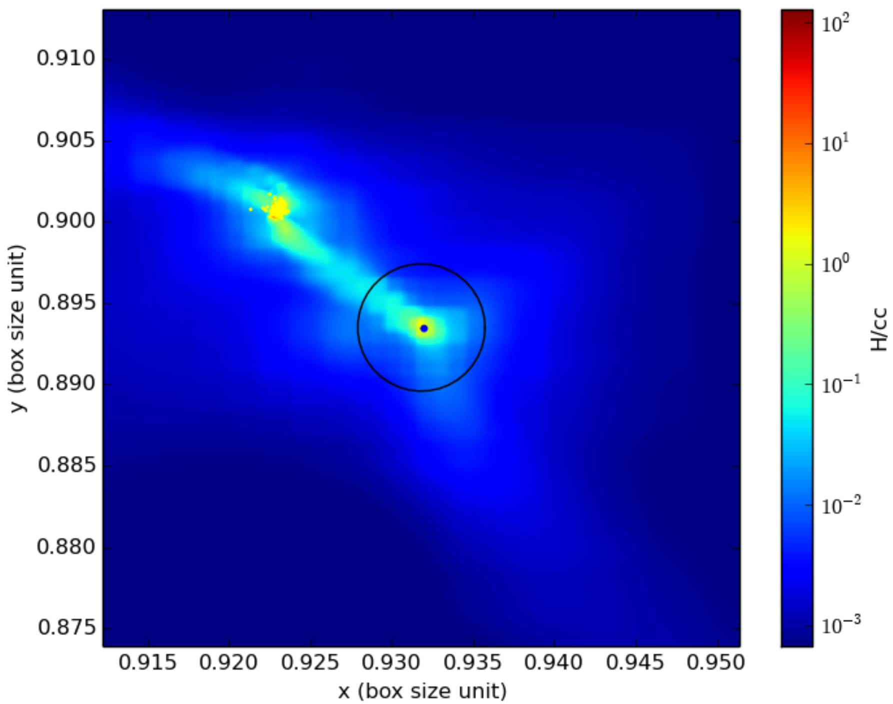
Loeb & Rasio 1994
Bromm & Loeb 2003
Begelman et al. 2006
Latif et al. 2013

Direct collapse scenario:

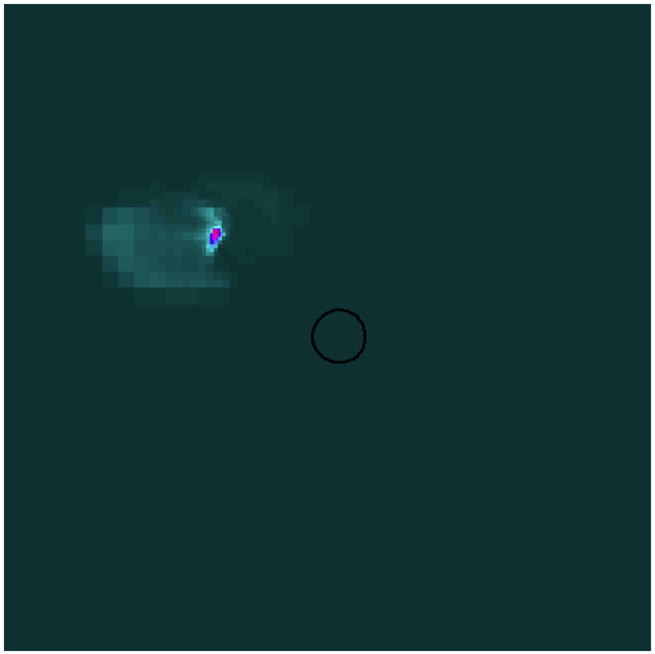
Redshift z=20 and later
Metal-poor halo → Primordial environment
No molecular hydrogen → Strong photo dissociating flux from star-forming galaxies
Cooling by atomic hydrogen
Inflow rate on the central object > 0.1 $M_{\odot}$/yr

BH mass seed of 10^4 - 10^6 $M_{\odot}$

Gas density map (H/cc)



Metallicity map



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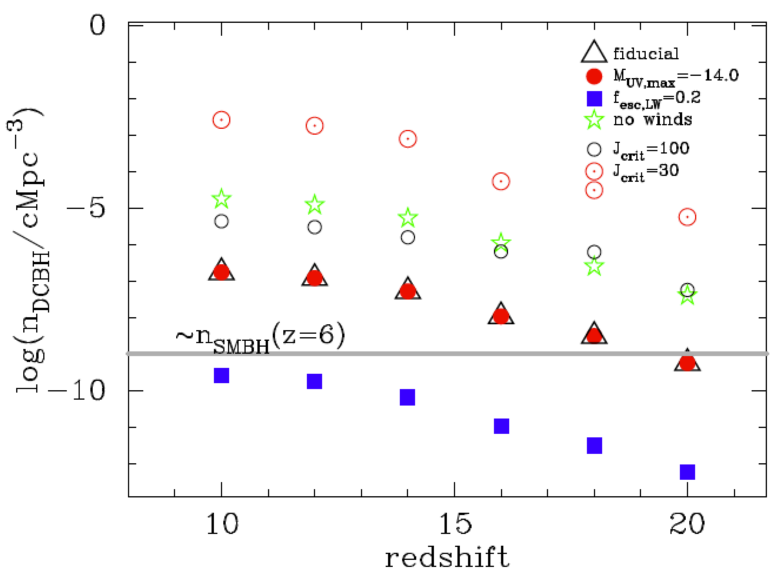
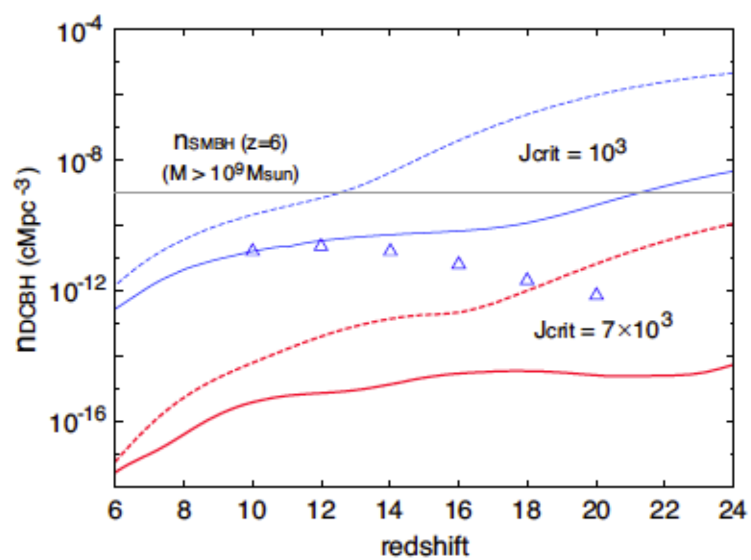
BH number density:

Dijkstra et al. 2014



Inayoshi et al. 2014, Latif et al. 2015



Non-Gaussianities can increase the number density of BHs

Initial perturbations in the density field evolve with time, and cause the collapse of dark matter particles (and at later times of baryons) into halos.

Planck mission measured the temperature fluctuation of the cosmic microwave background radiation on the full sky (scale of galaxy cluster and larger)

f_{NL} = 2.7 +/- 5.8 *Planck collaboration 2013b*

→ Initial density perturbations are nearly Gaussian on large scales

What about smaller scales? On galactic scales?

Non-Gaussianities can increase the number density of BHs

Dark matter simulations
with either Gaussian or scale-dependent non-Gaussian primordial density perturbations initial conditions

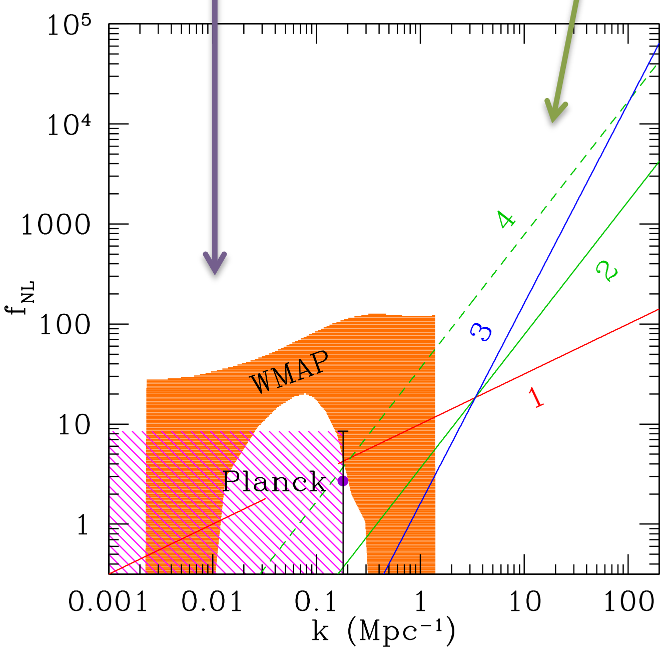
$f_{NL}(k) = f_{NL,0}\,(k/k_0)^{\alpha}$
with $\alpha=4/3$, $k_0 = 100\ h\ \mathrm{Mpc}^{-1}$, $f_{NL,0}=10^4$

Gadget-2
Box 50 h^{-1} Mpc, 1024^3 particles
Planck cosmology
Mass resolution ~ 9.9 $10^6\ h^{-1}\ M_\odot$
Redshift 200-6.5

Halo finder - HaloMaker
Merger tree - TreeMaker

Low level of NG on large scales to be consistent with Planck (2013)

Higher level of NG on galactic scales



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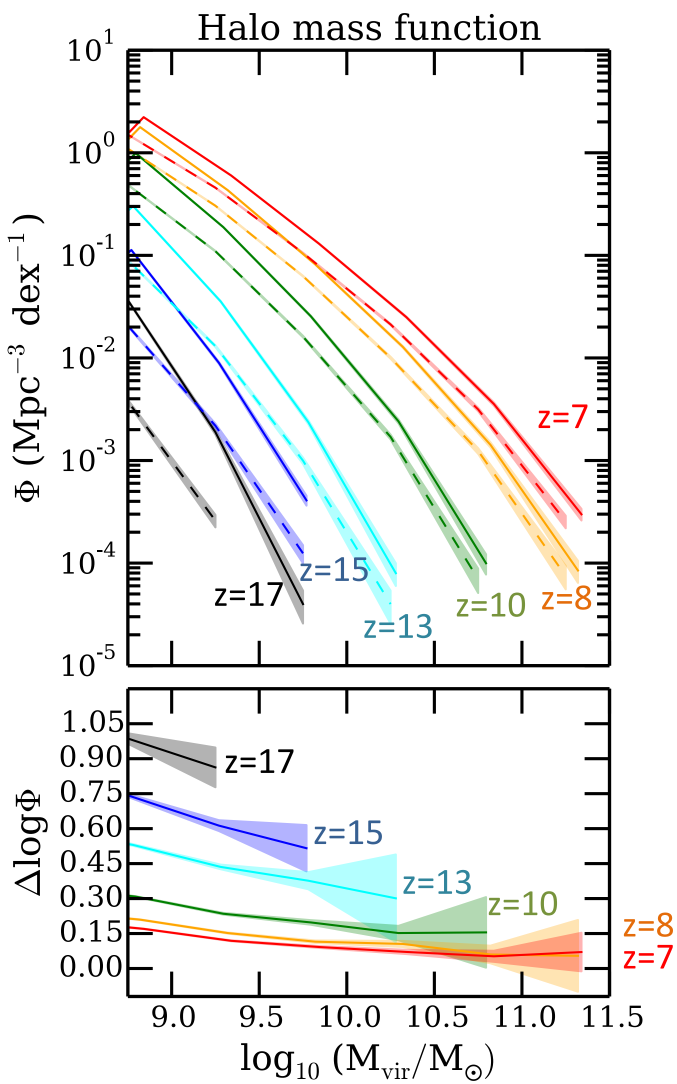

NG lead to an enhancement in the halo mass function,
which increases with redshift and decreases with halo mass.

Habouzit et al. 2014

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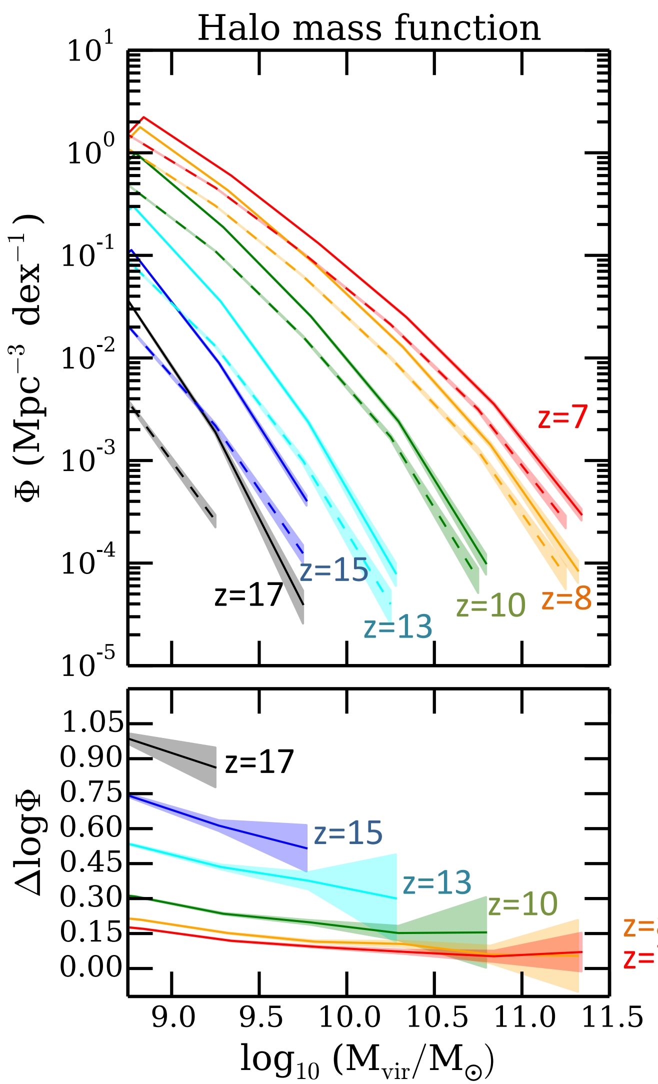

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Habouzit et al. 2014

Consequences for BH formation:

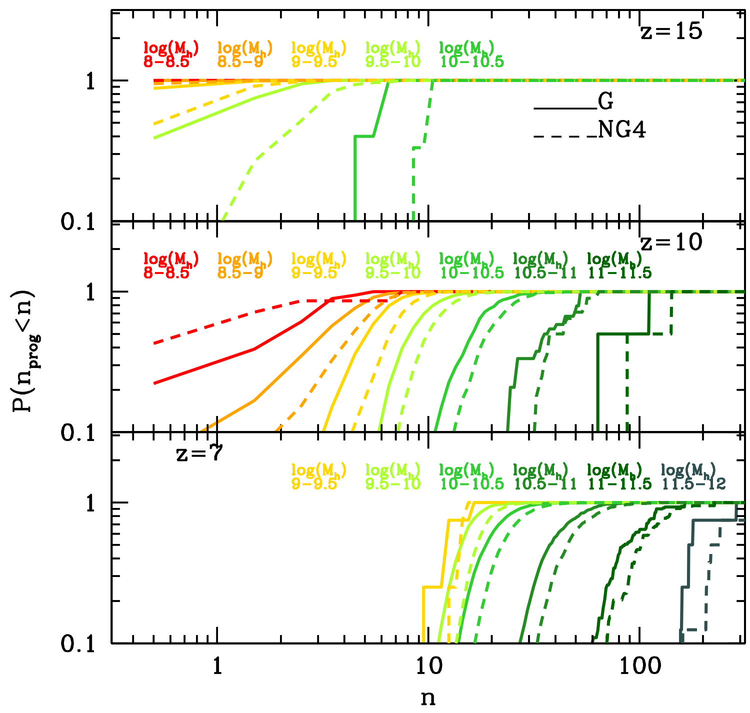
- a larger number of galaxies may be able to form BHs
- increase the number of halos producing stars, hence increasing the radiation intensity seen by halos
- increase the metal pollution ?

Non-Gaussianities can increase the number density of BHs

Modeling of **DC scenario** on top of dark matter simu (modified model of *Dijkstra et al. 2014*)

- Probability for halos to be star-forming
- Probability for halos to be metal-free, considering heritage pollution and galactic winds metal pollution
- Strong photo-dissociating radiation intensity $J_{LW,21} > 300$

Number of progenitors for the 2 simulations



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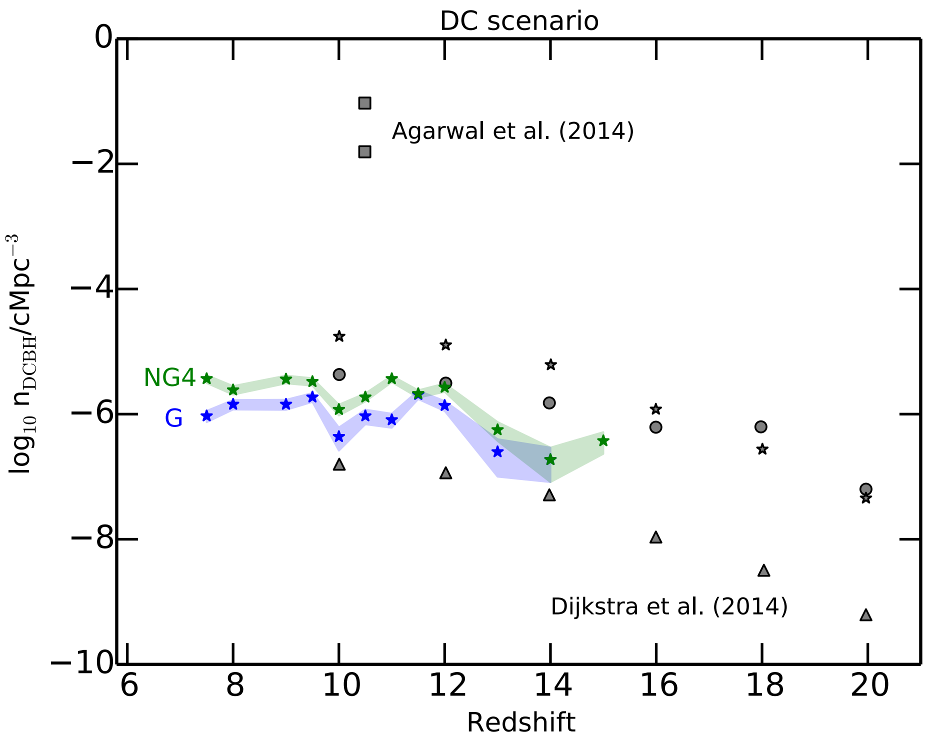
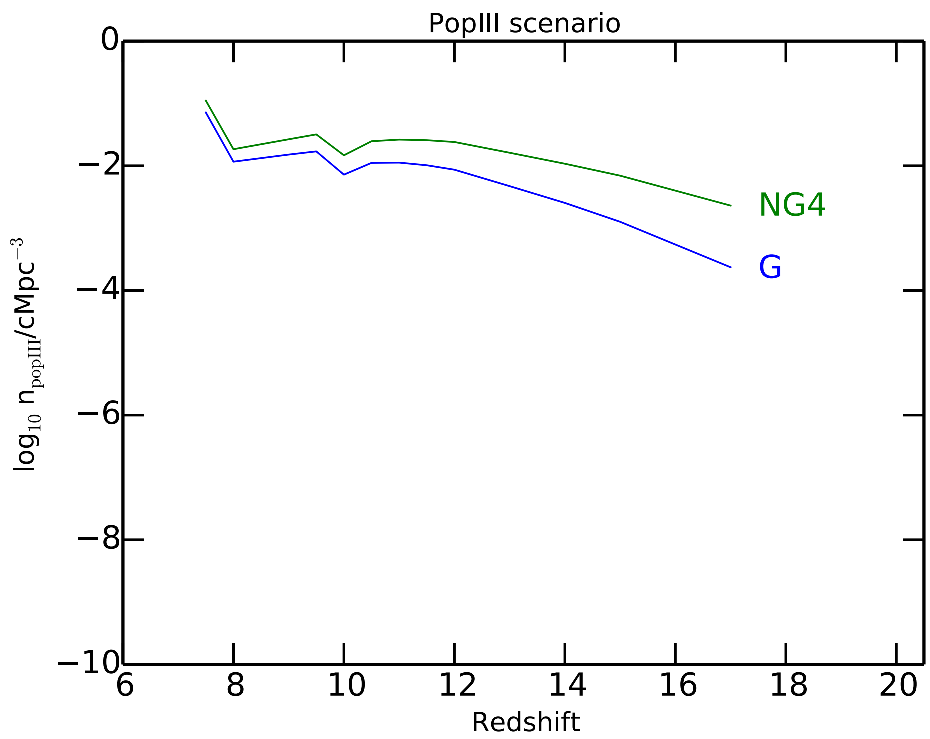


Non-Gaussianities can increase the number density of BHs

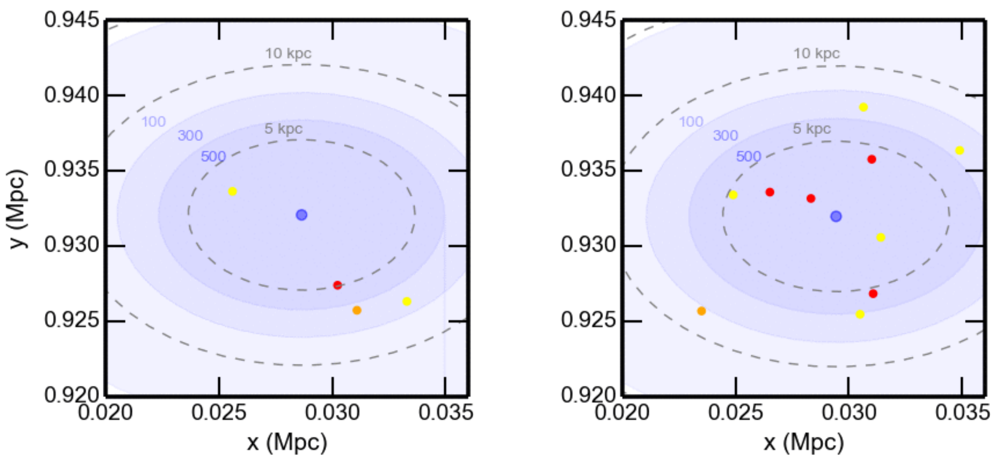
Modeling of **PopIII scenario** on top of dark matter simu (modified model of *Dijkstra et al. 2014*)
- Probability for halos to be star-forming
- Probability for halos to be metal-free, considering heritage pollution and galactic winds metal pollution

Number density of BHs for the 2 simulations



<u>Non-Gaussianities can increase the number density of BHs</u>

In the vicinity of the most massive BH: Metal enrichment by galactic winds



Blue point: $10^{11}\ M_{\odot}$ halo

Yellow $J_{LW,21} > 100$
Orange $J_{LW,21} > 300$
Red $J_{LW,21} > 500$

Blue ellipses: expansion of the metal polluted bubble every 1 Myr

After 10 Myr, all the nearby galaxies are polluted by galactic winds from the $10^{11}\ M_{\odot}$ halo

Non-Gaussianities also affect the growth of BHs

Merger tree

- How many halos host BHs?
- The influence of merger-driven BH growth?

Most massive halos at z=6.5
$M_h > 10^{11}\ M_\odot$

→ More progenitors for NG
→ Slightly more major merger episodes (mass ratio > 0.1)

→ From the mass evolution of these halos, we derive the evolution of hypothetical BH growth assuming different occupation fraction and accretion models

Non-Gaussianities also affect the growth of BHs

***Experiment** 1*

- 100 $M_\odot$ BH in each halos
- After a major-merger, the BH accrete at the Eddington limit for one dynamical time

BH > 10^4 $M_\odot$ G 57, NG 58 BH > 10^5 $M_\odot$ G 3, NG 8

***Experiment** 2*

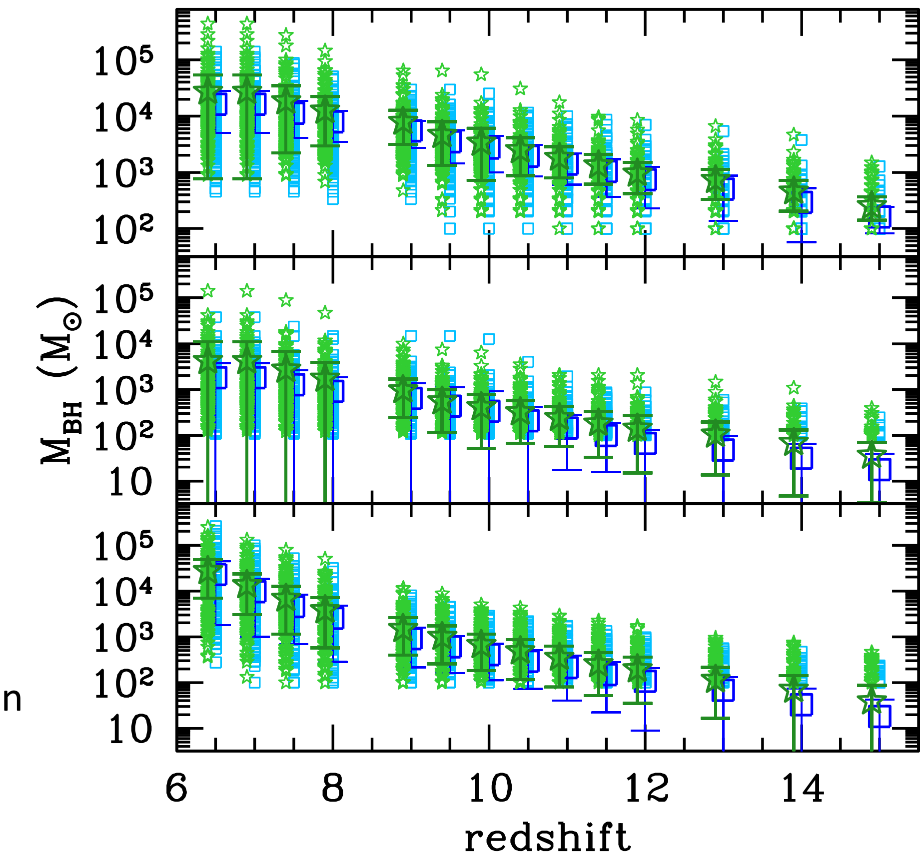
- 10 % proba of hosting a 100 $M_\odot$ BH
- After a major-merger, the BH accrete at the Eddington limit for one dynamical time

BH > 10^4 $M_\odot$ G 3, NG 12 BH > 10^5 $M_\odot$ G 0, NG 1
Occ fraction: G 80%, NG 90%

***Experiment** 3*

- 10 % proba of hosting a 100 $M_\odot$ BH
- BHs accrete at an accretion rate randomly drawn from Horizon-AGN (*Dubois et al. 2014*)

BH > 10^4 $M_\odot$ G 51, NG 67 BH > 10^5 $M_\odot$ G 9, NG 10
Occ fraction: G 80%, NG 90%



Conclusion

BH formation

Interplay between the radiation intensity needed to avoid the halo fragmentation and the metal pollution from galactic winds is difficult to predict.

Using a semi-analytical model, we find that the BH-Halo occupation fractions are similar, but the number density of BHs is boost with non-Gaussianities.

BH growth

With non-Gaussianities, the number of most massive BHs and the mean BH mass at z=6.5 are larger.

A population of SMBHs would grow faster and have more more massive BHs in the presence of non-Gaussianities.

Summary

Direct collapse scenario and non-Gaussianities on galactic scales

- Direct collapse scenario can take place in very specific conditions halos: primordial conditions, no metal pollution, strong photo-dissociating radiation intensity.

- Non-Gaussianities on galactic scales increase the number density of SMBH seeds, as well as their growth, by a factor of few.

More information: *Habouzit et al. 2014* (ArXiv:1407 8192) and *Habouzit et al. 2015* submitted

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Direct collapse scenario

- Disagreement between the number density of DC SMBHs predicted by semi-analytical models and hydro simulations.
    - Development of a DC regions finder for hydro simulations
    - Comparison with semi-analytical models/prescriptions

PopIII remnant scenario

- New way of seeding cosmological hydro simulations (Ramses) with PopIII remnant BHs to predict BH formation in dwarf galaxies.