First stars first galaxies and massive black holes

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Outline

Motivations

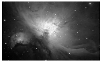
Goal: Understand the formation of the first stars, galaxies and massive black holes:
→ *What is the formation epoch of first objects?*
→ *What is the role of early molecules and metals?*
→ *How relevant is PopIII for star formation and metal spreading?*
→ *What are the effects of different IMFs on SFR?*
→ *What is the formation path of early massive BHs?*
→ *What are the implications for early observables (LF, GRB)?*
→ *What are the effects on cosmic reionization?* → *What are the effects of the underlying matter distribution?*

Requirements: Study the chemical properties of cosmic medium during cosmological evolution.

Techniques: N-body/Sph chemistry (RT) simulations

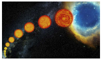
For a complete picture

⟶ follow gravity and hydrodynamics *coupled* to molecule formation and metal production from stellar evolution through cosmic time



molecules determine *first* gas collapsing events

metals determine *subsequent* structure formation

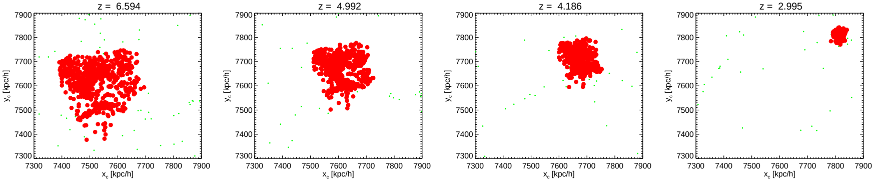


stellar evolution determines *yields*, γ and *timescales*

Following and implementing metal and molecule evolution in numerical codes (e.g Gadget, etc.) required

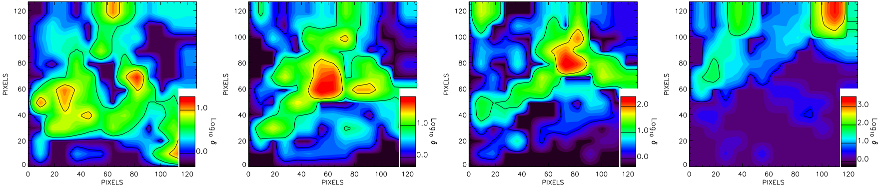
(Springel, 2001, 2005; Yoshida+, 2003; Tornatore+, 2007; Maio+, 2007, 2010, 2011; Biffi & Maio, 2013)

H/H_2-driven gas collapse (inflows)...

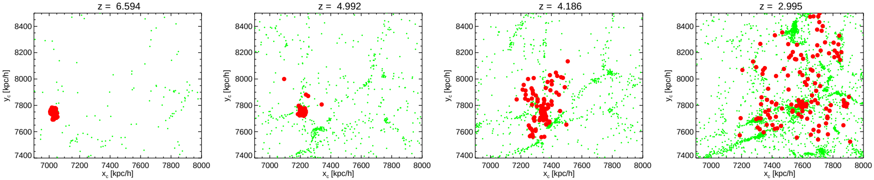


$z \simeq 6.6 \quad \longrightarrow$

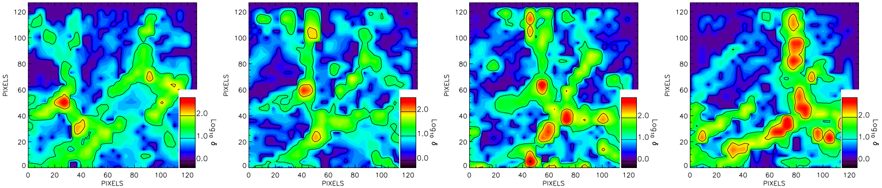
$z \simeq 2.9$



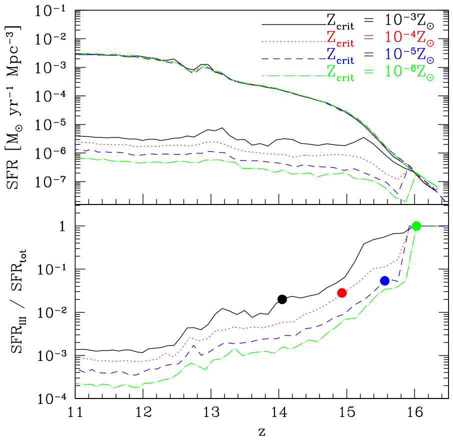
... star formation and disruption (outflows) ...



$z \simeq 6.6 \quad \longrightarrow \quad z \simeq 2.9$



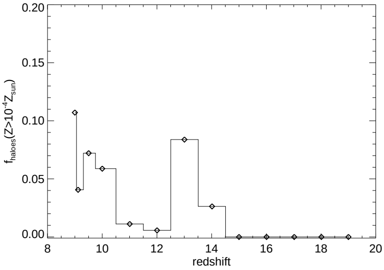
The 1st Gyr: the epoch of the first stars



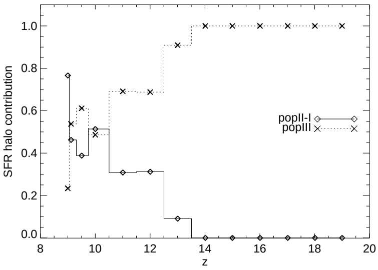
box: $1 Mpc^3$; PopIII IMF: top-heavy with slope=-1.35, range=[$100 M_\odot$, $500 M_\odot$]; Maio et al., 2010

Primordial populations in the first galaxies

Fraction of popII haloes (i.e. with mean $Z_{\rm halo} > Z_{\rm crit}$) vs. z



SFR contribution from popII and popIII haloes vs. z



For further investigations and dynamical features see Biffi & Maio (2013)

Observables

Theoretical models must be compared against observational findings. The main observables that will be considered are:
– LF
– (S)SFR
– DLA abundances
– GRB host properties
– SMBHs at $z \gtrsim 6$

Luminosity functions

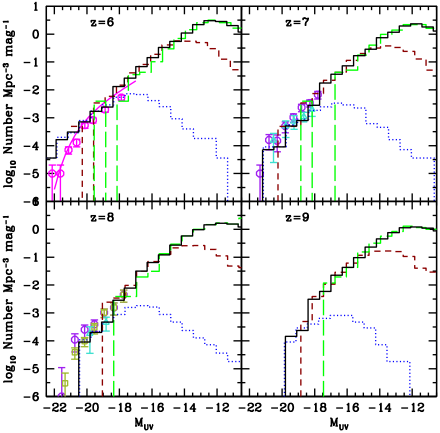
For each galaxy: $L_\lambda = L_\lambda^{\mathrm{II}} + L_\lambda^{\mathrm{III}}$
in L5, L10, L30

PopII-I SEDs from Starbust99 (Vazquez & Leitherer, 2005).
PopIII SEDs from Schaerer (2002).
No dust assumed: fair at $z > 6$

Observational data points from:

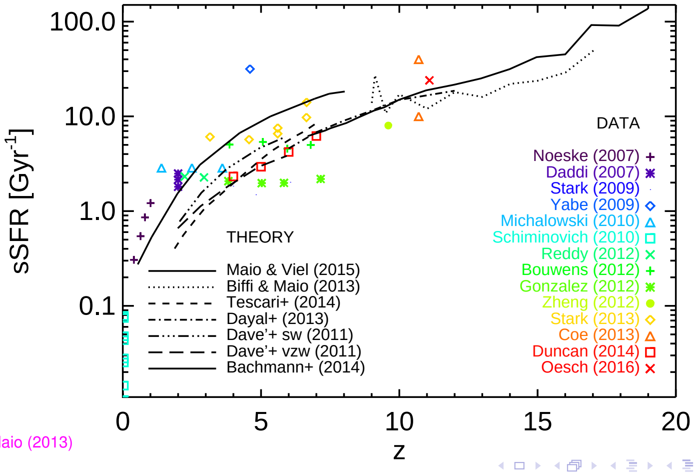
Bouwens et al., 2007 (circles); z=6
Bouwens et al., 2011 (circles); z=7-8
McLure et al., 2010 (triangles); z=7-8
Oesch et al., 2012 (squares); z=8

Fit: Su et al., 2012 (solid line); z=6.



Salvaterra, Maio, Ciardi, Campisi; 2013

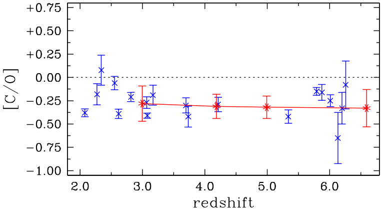
SSFR – early bursty Universe



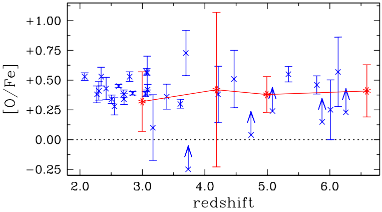
Biffi & Maio (2013)

DLA abundance redshift evolution

mean [C/O] vs z



mean [O/Fe] vs z



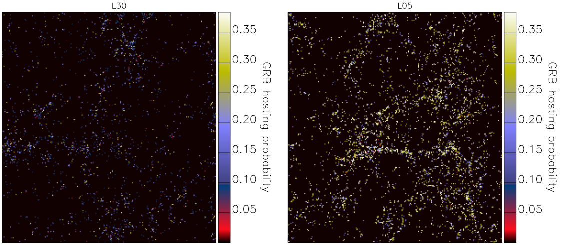
SNII/AGB $\longrightarrow$ left; SNIa $\longrightarrow$ right (more line broadening at $z < 5$?)

No PopIII needed to explain current low-z DLA data?

Simulations with N-body/hydro + molecules + metals + feedback: Maio & Tescari (2015)

Implications for high-z GRBs

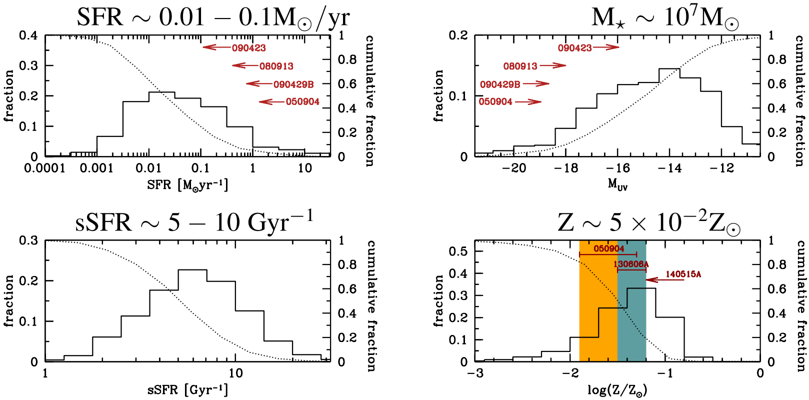
Primordial (Long) Gamma Ray Bursts are originated by collapse of the first massive stars and accompany the formation of BHs
$\longrightarrow$ Early GRBs provide infos about SFR in the first galaxies



Differential GRB hosting probability $\rightarrow \mathrm{d}P = \dfrac{\mathrm{d}N_{GRB}(\mathrm{Log}_{10}(SFR[\mathrm{M}_\odot/yr]))}{N_{GRB}\,\mathrm{dLog}_{10}(SFR[\mathrm{M}_\odot/\mathrm{yr}])}$

High-z GRBs are more likely found in intermediate-, low-size objects: large objects (high SFR) are rarer than small objects (low SFR)

Statistical properties of the first GRB hosts



GRB Data: Tanvir et al. (2012); Thöne et al. (2013); Hartoog et al. (2014); Chornock et al. (2014)
See: Campisi et al. (2011); Salvaterra et al. (2013, 2015); Ma et al. (2015, 2017)

GRB abundance ratios: stellar populations at high z

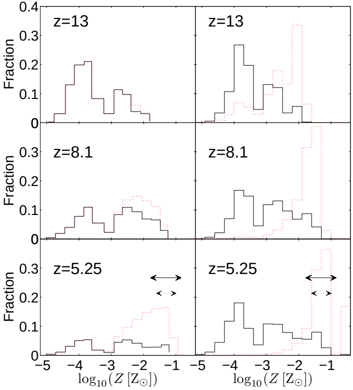
Indirect signatures: abundance ratios

GRB 050904 ($z = 6.3$): no PopIII
$[C/O] = -0.1$, $[S/O] = 1.3$
$[Si/O] = -0.3$, $Z \simeq 0.03\,Z_\odot$
(Kawai et al., 2006; Thöne et al., 2013)

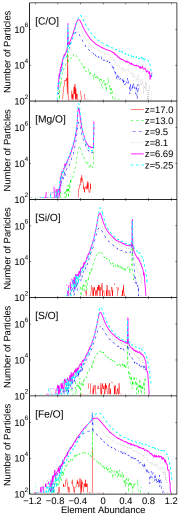
GRB 130606A ($z = 5.9$): unlikely PopIII
$[S/O] < 1.24$, $[Si/O] < 0.55$
$[Fe/O] < -0.34$,
$Z \simeq 0.1\,Z_\odot - 0.01\,Z_\odot$
(Castro-Tirado et al., 2013)

GRB 111008A ($z = 5.0$): unlikely PopIII
$[S/H] = -1.7$, $Z \gtrsim 0.01\,Z_\odot$
(Sparre et al., 2014)

GRB 100219A ($z = 4.7$): unlikely PopIII
$[C/H] = -2.0$, $[Fe/H] = -1.9$
$[O/H] = -0.9$, $[S/H] = -1.1$
$Z \simeq 0.1\,Z_\odot$
(Thöne et al., 2013)



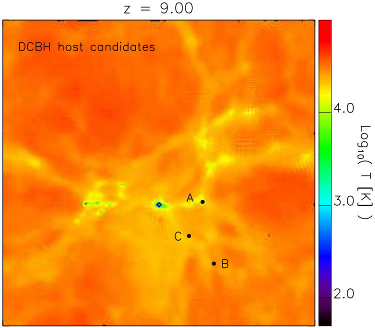
PopII-I star forming haloes
PopII-I star forming haloes pre-enriched by popIII

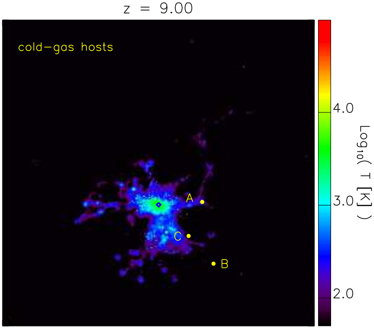


Ma, Maio, Ciardi, Salvaterra (2015,2017)

MBHs: DCBHs as seeds of SMBHs at $z \gtrsim 6$?

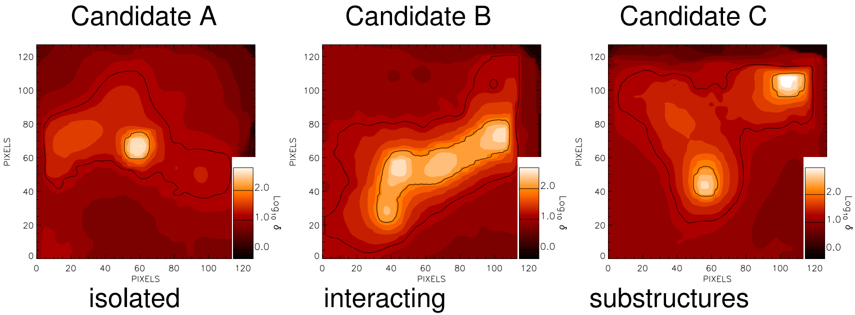
Look for haloes which host gas direct collapse (no fragmentation!):
$\longrightarrow$ pristine non-SF haloes with $\mathrm{T} \sim 10^4$ K, dark mass $\gtrsim 2 \times 10^6 \, \mathrm{M}_\odot$,
no H_2 content (destroyed by nearby LW radiation)





See: Maio et al. (2017)

L=0.5Mpc/h

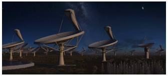


Gas mass: $\sim 2 - 4 \times 10^5\,\mathrm{M}_\odot$

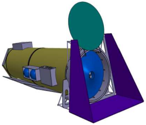
Turbulent gas regimes: $Re \sim 10^4 - 10^8$

Future perspectives

– JWST space telescope: early Universe, reionization; launch: 2018+; costs: ~ 11 Bln \$ (NASA, ESA, Canada)



– SKA radio telescope: HI, reionization, galaxy formation, radio transients; construction 2020+; costs: ~ 8 Bln EUR (Int. coll.)



– Athena space satellite: hot gas, clusters, BHs, GRB X-ray afterglows up to $z \sim 6-10$; launch 2028+; costs: ~ 1.3 Bln EUR (ESA, Thales-Alenia, Airbus)

Summary...

- We have presented results from cosmological N-Body hydrodynamical chemistry RT simulations
- We study early objects (PopIII stars, DLAs, GRB hosts, MBHs) and their interplay with the surroundings (SFR, Z, T, [/])

Conclusions...

- First star/galaxy formation episodes are very ‘bursty’ and feature rapid metal enrichment
- DLA and GRB host observables help constrain early populations
- DCBHs can be seeds of SMBHs in peculiar conditions
- Results are not very sensitive to the assumed parameters although effects from WDM can be important (Maio & Viel, 2015)

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