Elusive, Rare, Hidden: First Stars

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DAVID

The Dark Ages VIrtual Department

http://www.arcetri.astro.it/twiki/bin/view/DAVID/WebHome


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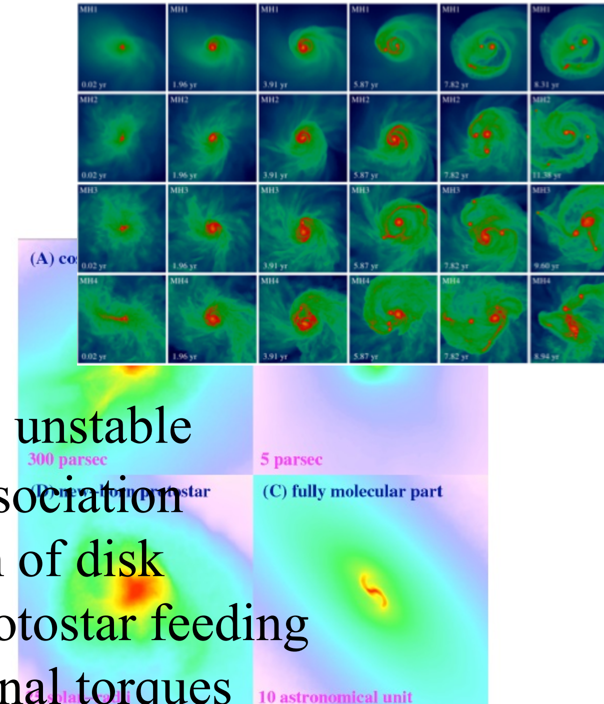
FORMATION

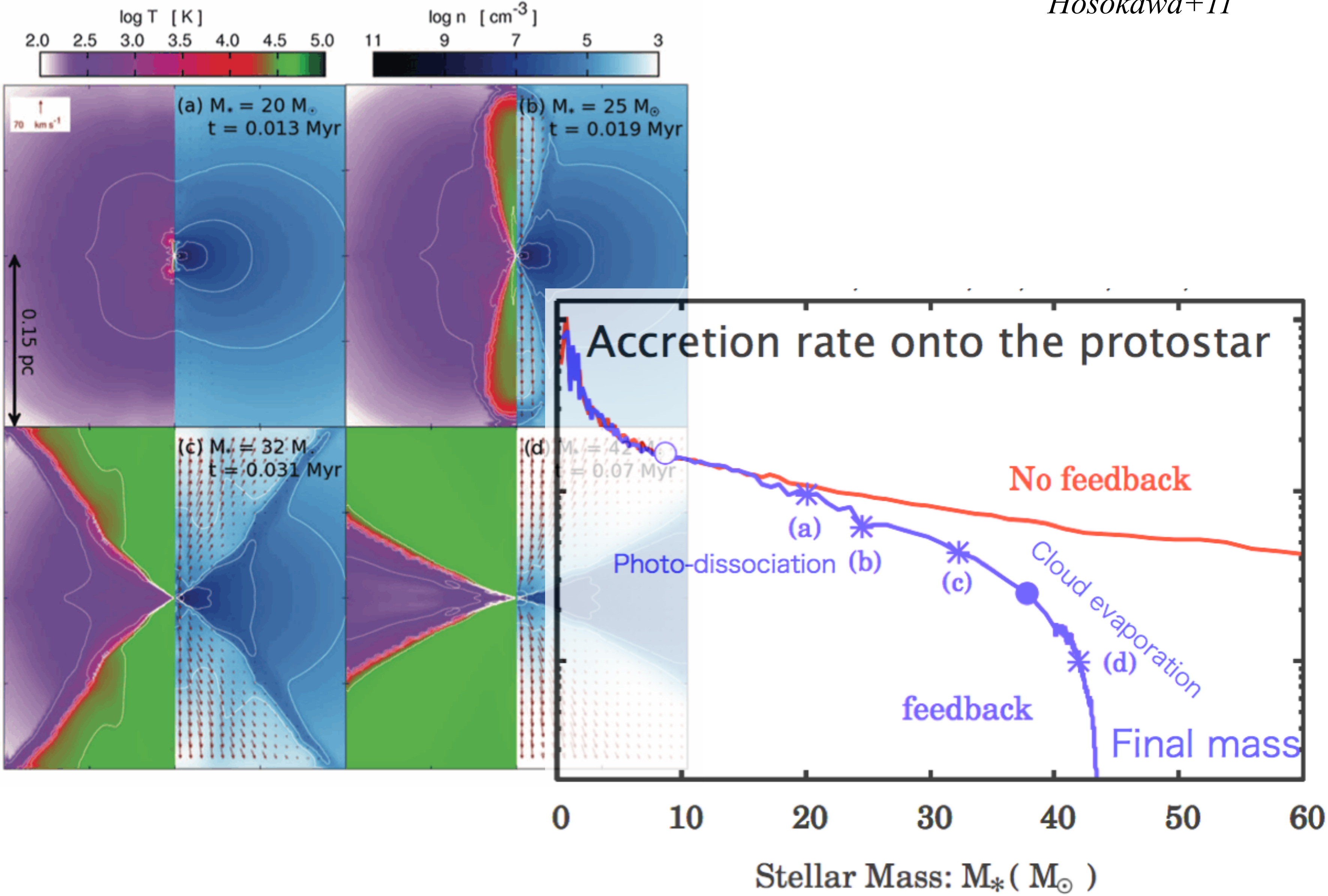


THE KEY ROLE OF DISKS

- Rotationally supported disk becomes Toomre unstable
- Cooling provided by H_2 lines > CIE > H_2 dissociation
- Fragments form in the central/external region of disk
- Disk continue to accrete at faster rate than protostar feeding
- Fragments migrate to center due to gravitational torques
- Half of them merge with central protostar: accretion bursts ?
- Some of them are slingshot: brown dwarfs/very low mass stars at z=0 ?
- But.. Are these fragments bound ? Will they survive ?
- No-sink-particle simulations timescale limited to < 10 yr

FINAL OUTCOME YET UNKNOWN

Hosokawa+11



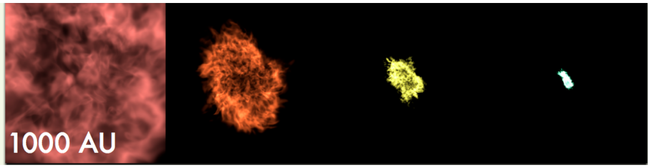
log T [K]
2.0 2.5 3.0 3.5 4.0 4.5 5.0
log n [cm^{-3}]
11 9 7 5 3
(a) $M_* = 20\ M_\odot$
t = 0.013 Myr
(b) $M_* = 25\ M_\odot$
t = 0.019 Myr
(c) $M_* = 32\ M_\odot$
t = 0.031 Myr
(d) $M_* = 42\ M_\odot$
t = 0.07 Myr
0.15 pc
Accretion rate onto the protostar
No feedback
Photo-dissociation
(a)
(b)
(c)
(d)
Cloud evaporation
feedback
Final mass
0 10 20 30 40 50 60
Stellar Mass: M_* ($M_\odot$)

FORMATION

THE ROLE OF RADIATIVE FEEDBACK

- Quenches accretion by disconnecting disk edge from envelope
- Final mass of star limited to < 50 $M_{\odot}$. Also PopIII.2 mass decreases
- Implies no Pair Instability Supernovae
- 3D RHD simulations substantially confirm this result
- Long integration time ($>10^5$ yr) required to follow accretion evolution

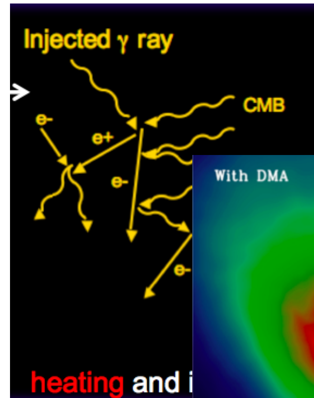
CAN FRAGMENTATION OCCUR WITH FEEDBACK ?

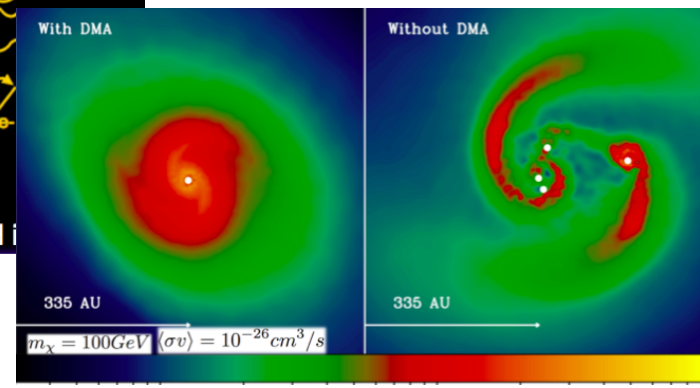


THE ROLE OF TURBULENCE

- Turbulence might prevent disk formation by providing pressure support
- Increases core temperature (additional thermal support)
- Its role seems to be underestimated by <32 cell/Jeans length experiments
- Interpretation ? Too much dissipation ? Short integration time ?

FORMATION



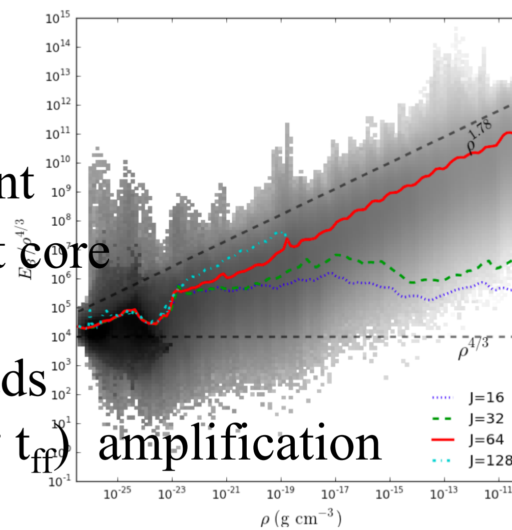


THE ROLE OF DARK MATTER

- Produces heating/ionization of gas
- Reduces fragmentation
- Dark stars: conditions on DM cusp/protostar displacement (<100 AU) ?

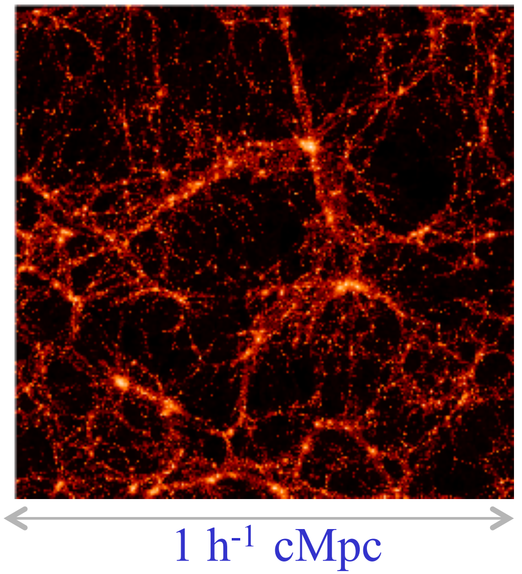
THE ROLE OF MAGNETIC FIELD

- At formation of first core E_{kin}/E_B=3600, i.e. subdominant
- However, strength not yet saturated at formation of first core
- Grows faster than flux freezing ($B \approx \rho^{1.78}$)
- Due to vorticity generated by shocks/chemothermal grads
- If *small-scale turbulent dynamo* operates very fast (10^{-4} t_{ff}) amplification



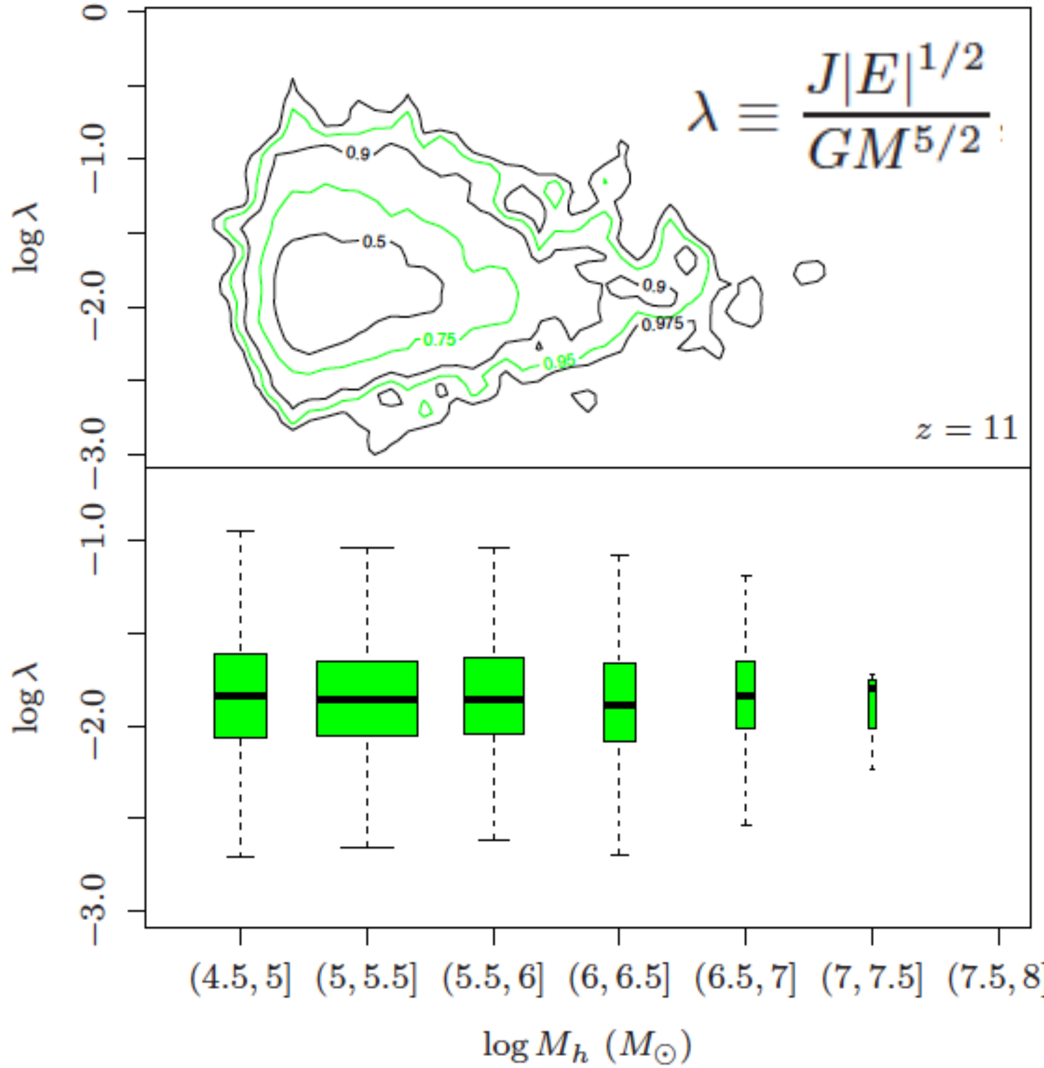
deSouza+12

HALO – IMF CONNECTION



GADGET-2
$2{\times}(320)^3$ particles
$m_{dm} \approx 755\ h^{-1}\ M_\odot$
Z-dependent cooling
PopIII/II transition
Feedback and winds,
Metal enrichment by SNII/Ia

Halo spin parameter



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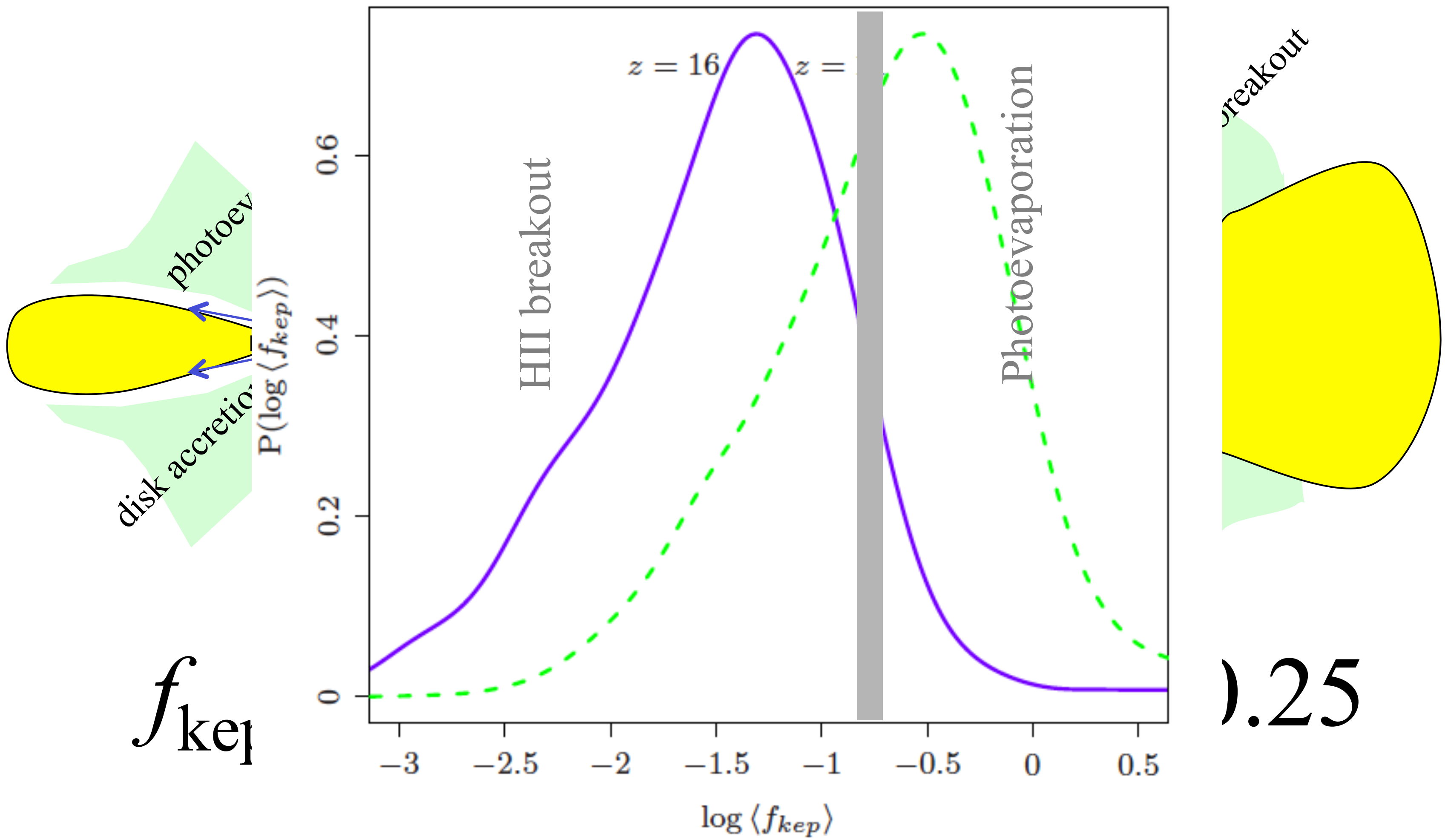
HALO ROTATION IS THE KEY



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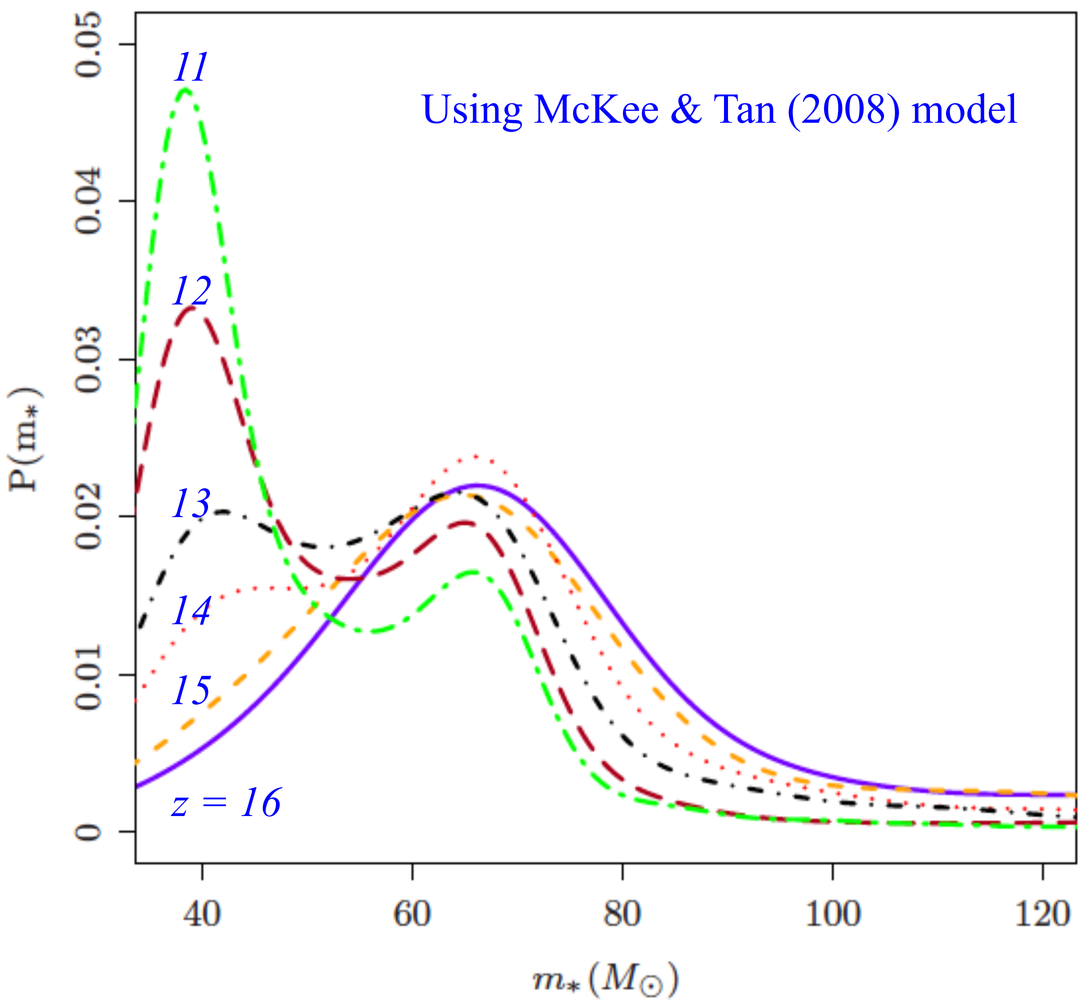
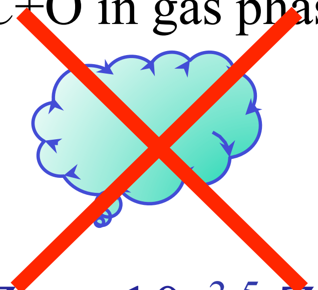
POPIII IMF



CRITICAL METALLICITY

Frebel, Bromm, Loeb

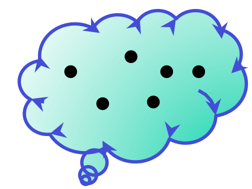
C+O in gas phase



$Z_{cr} = 10^{-3.5}\ Z_{\odot}$

CONFLICTING THEORIES

C+O in gas phase + dust

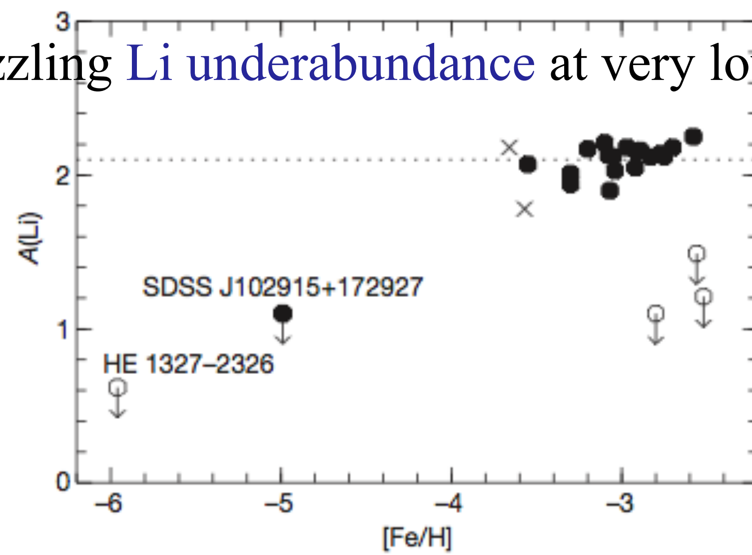


$Z_{cr} = 10^{-5\pm1}\ Z_{\odot}$

Schneider, Ferrara, Omukai

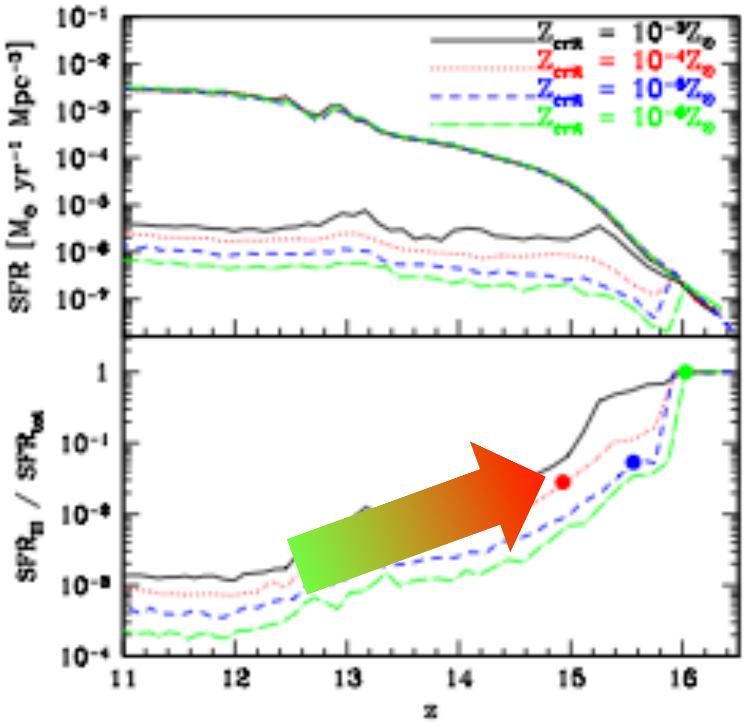
Caffau+2011 star: $Z=10^{-4.35}$ (low mass)

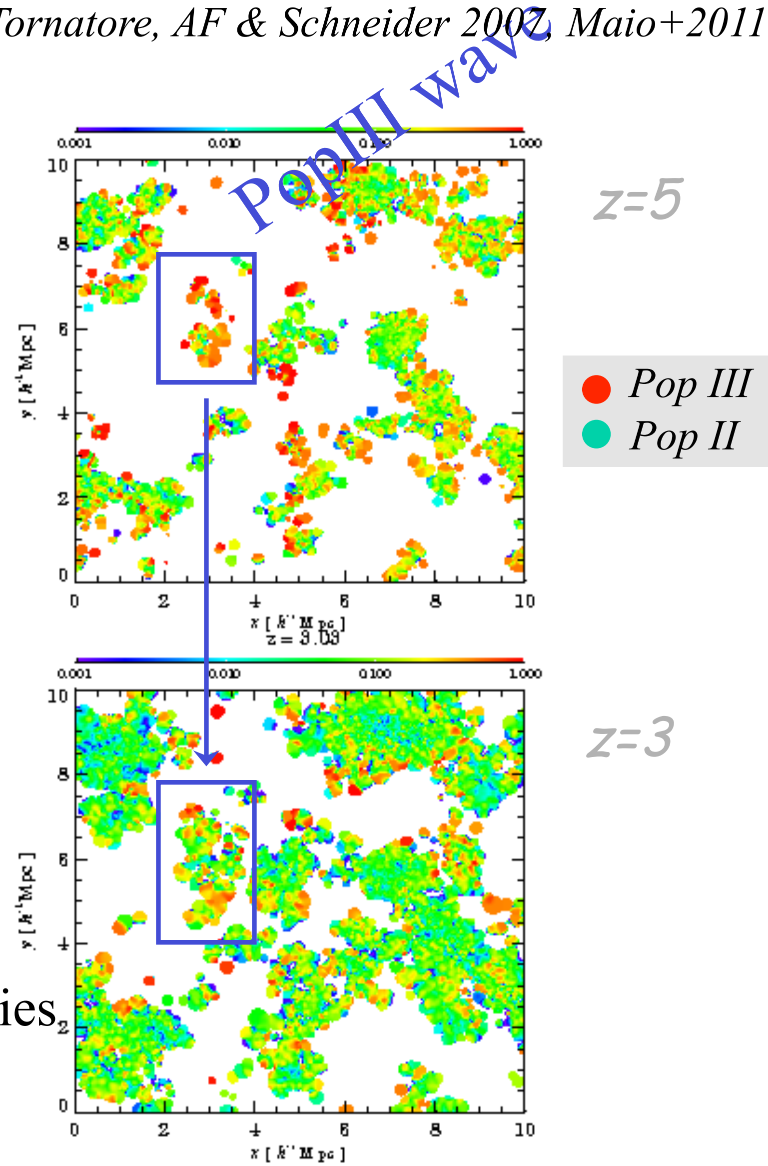
Puzzling Li underabundance at very low [Fe/H]



POPIII/II TRANSITION

Tornatore, AF & Schneider 2007, Maio+2011

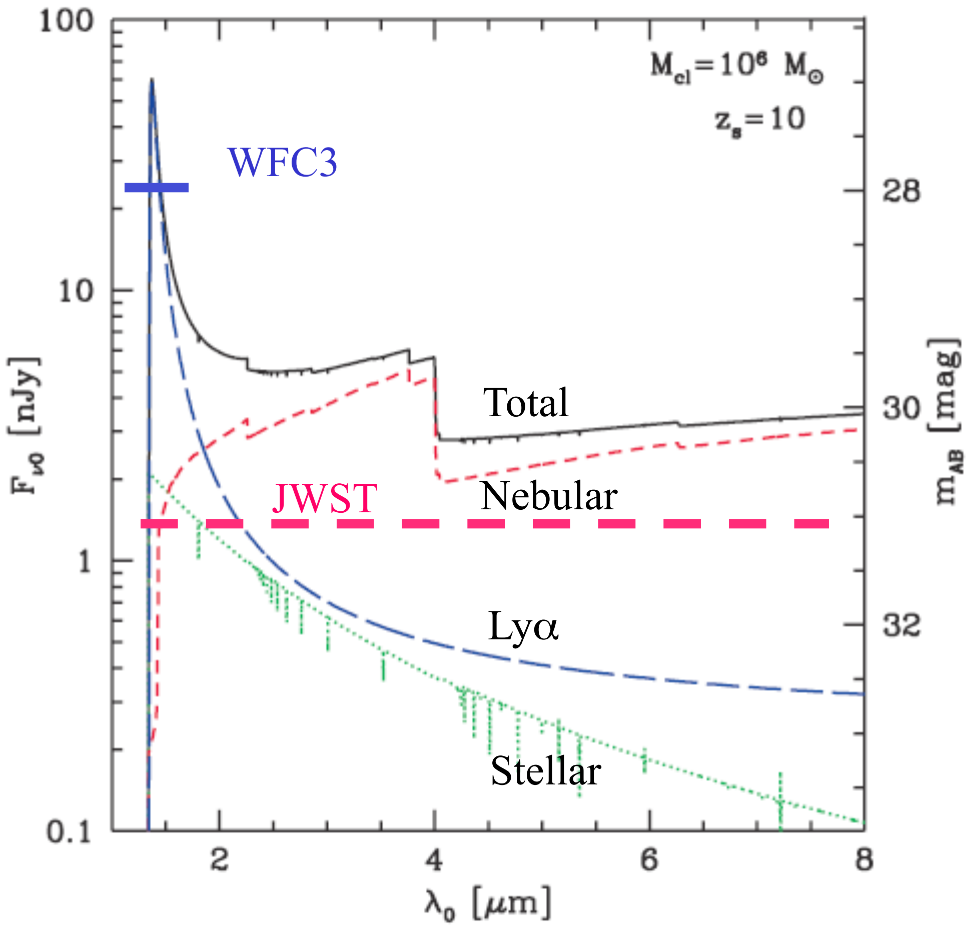




OBSERVATIONAL IMPLICATIONS

- Increasing fraction of PopIII galaxies
- PISN and CC supernovae
- Increasing rate of PopIII GRBs

DIRECT DETECTABILITY



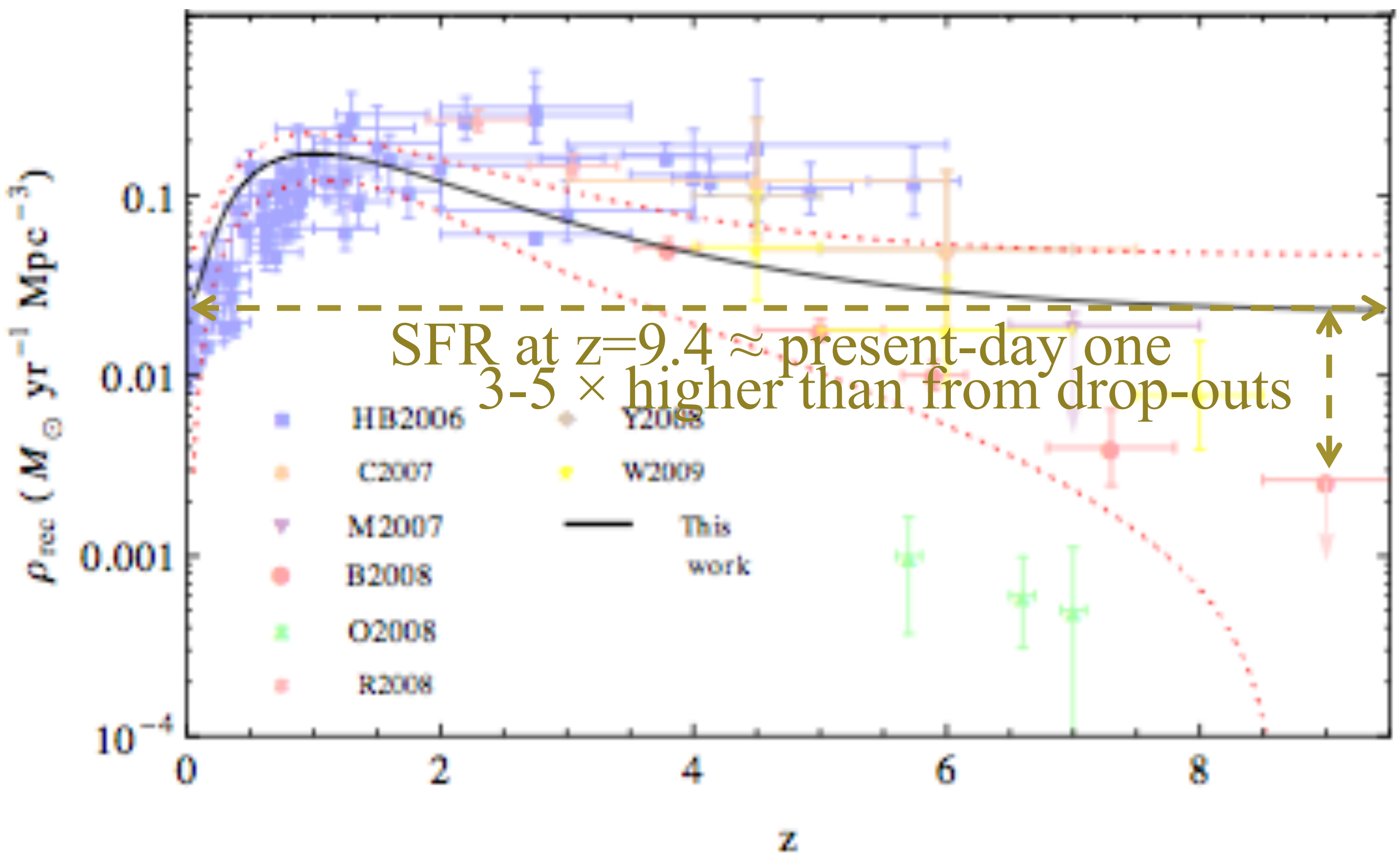
Pop III cluster

$M = 10^6\,M_\odot$
$z = 10$
$M_\star = 300\,M_\odot$

Ishida, de Souza & AF 2011

HINTS FROM GRBs

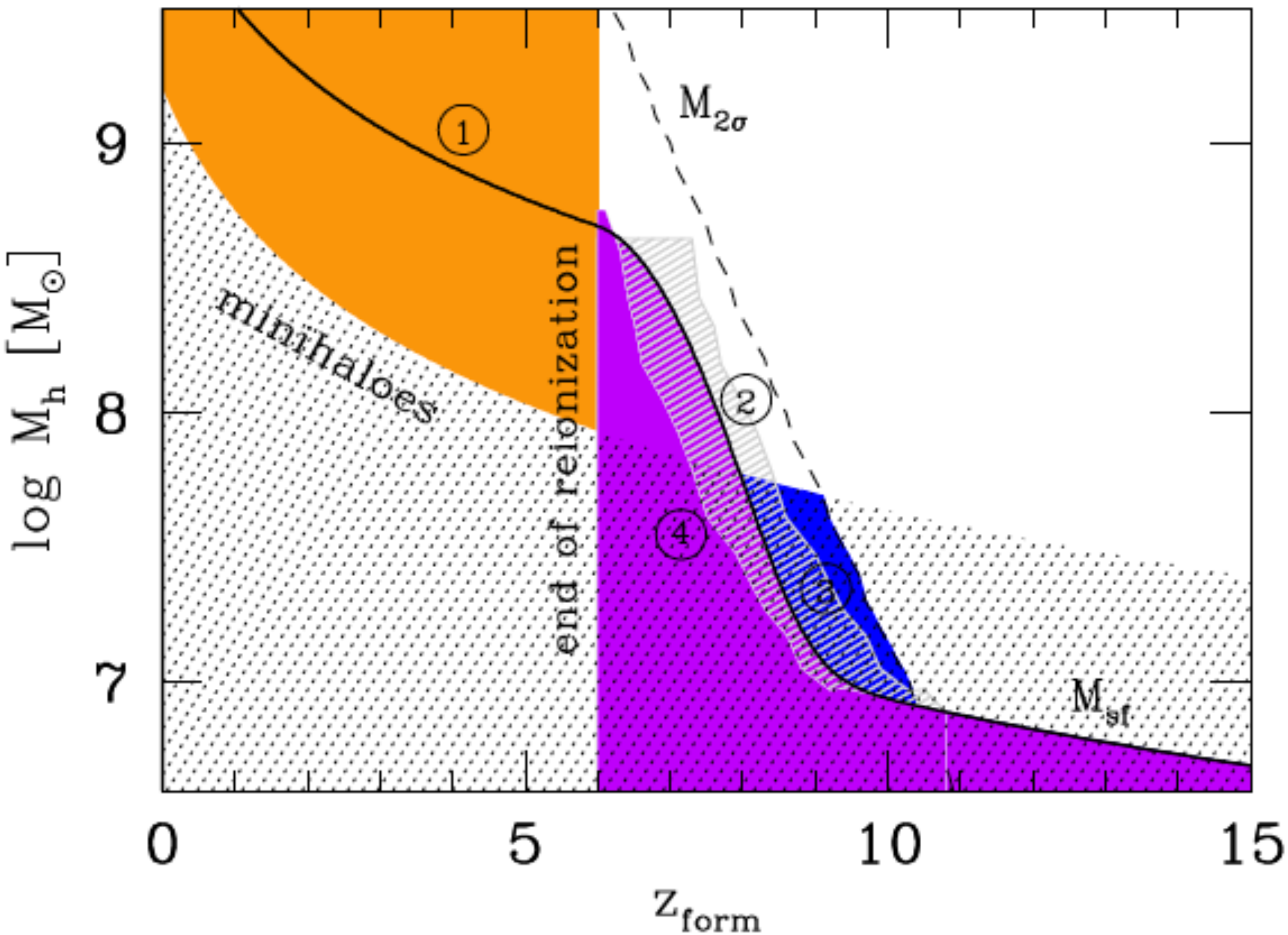
Cosmic SFH deduced from PCA of GRB data



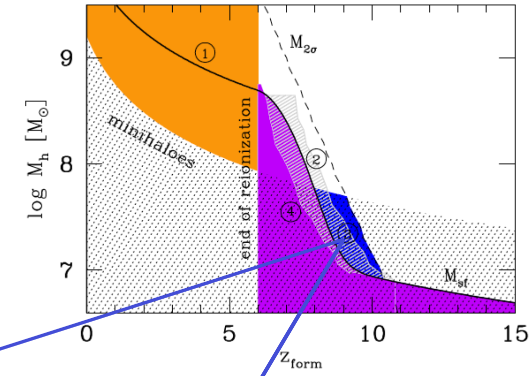
Where should we look for the first stars ?

Salvadori & AF 2012

FEEDBACKS IN ACTION

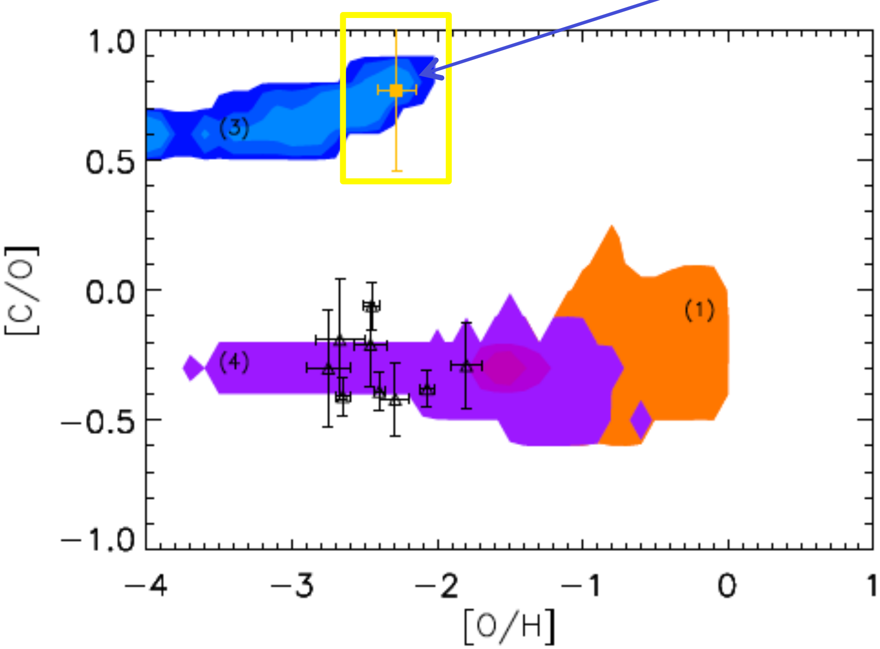


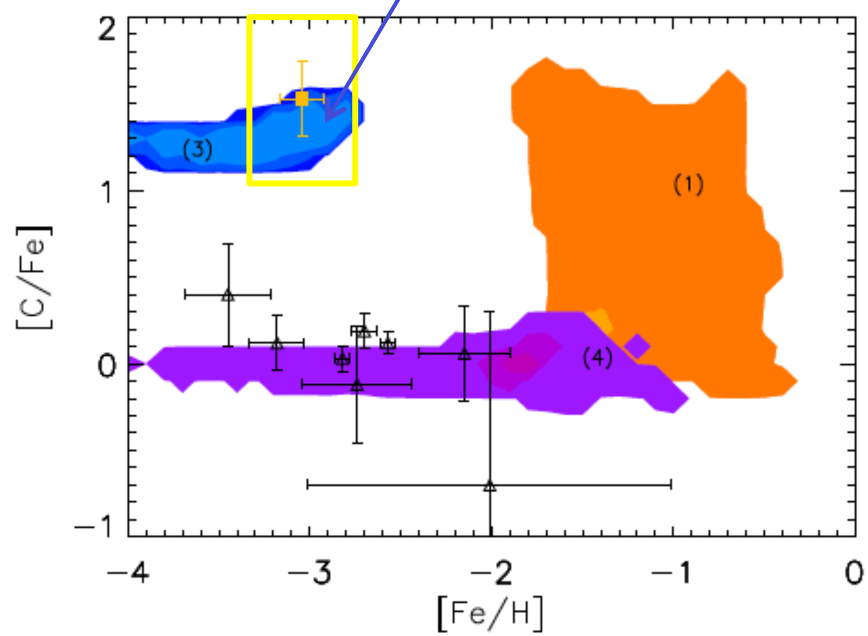
NEW DLA DISCOVERY



QSO J0035-0918 at $z_{abs} \approx 2.34$ (Cooke+11)
Log $N_{HI} = 20.55 \pm 0.10$
[Fe/H] = −3

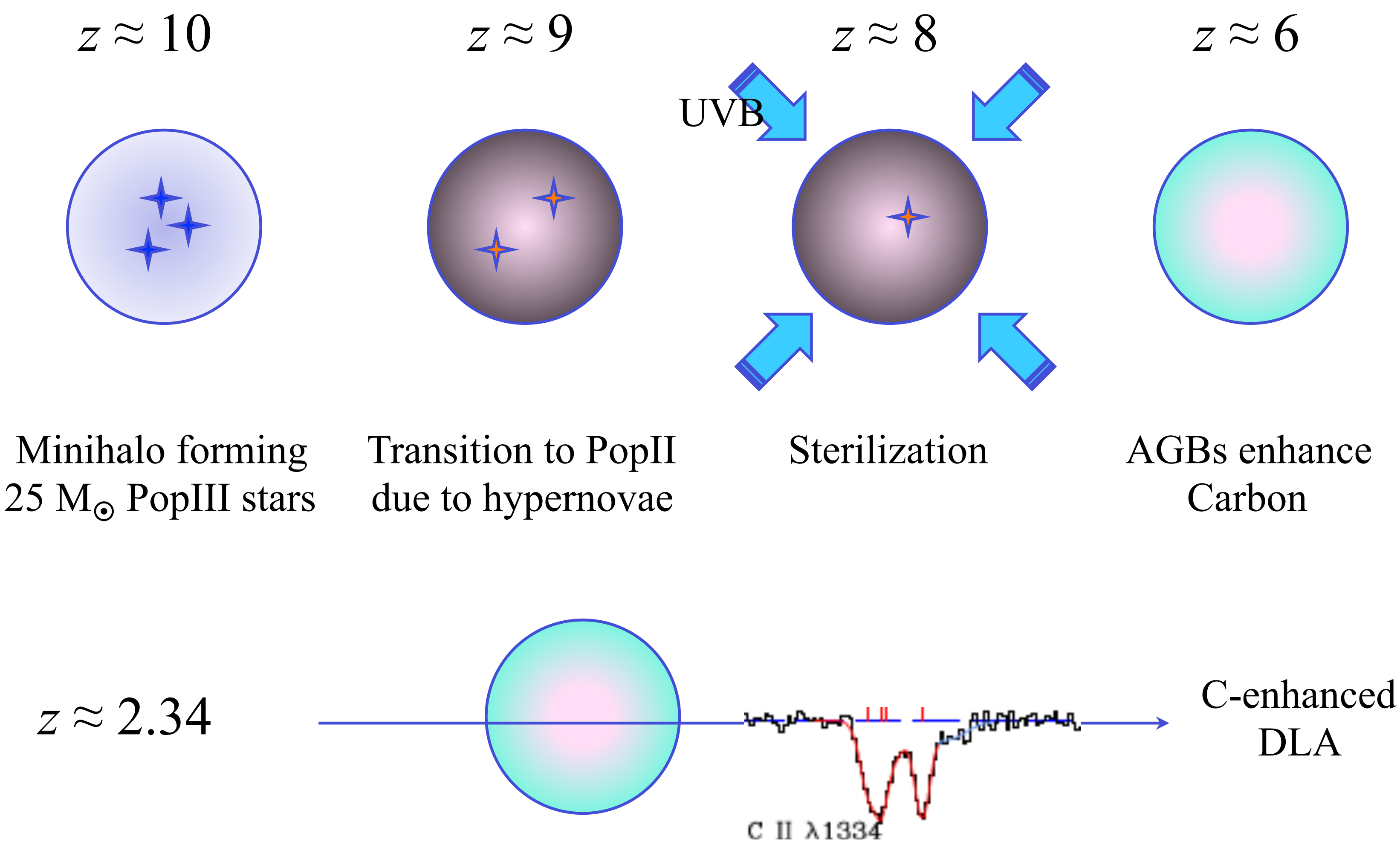
[C/Fe] = 1.53, i.e. 20× any other DLA!





Salvadori & AF 2012

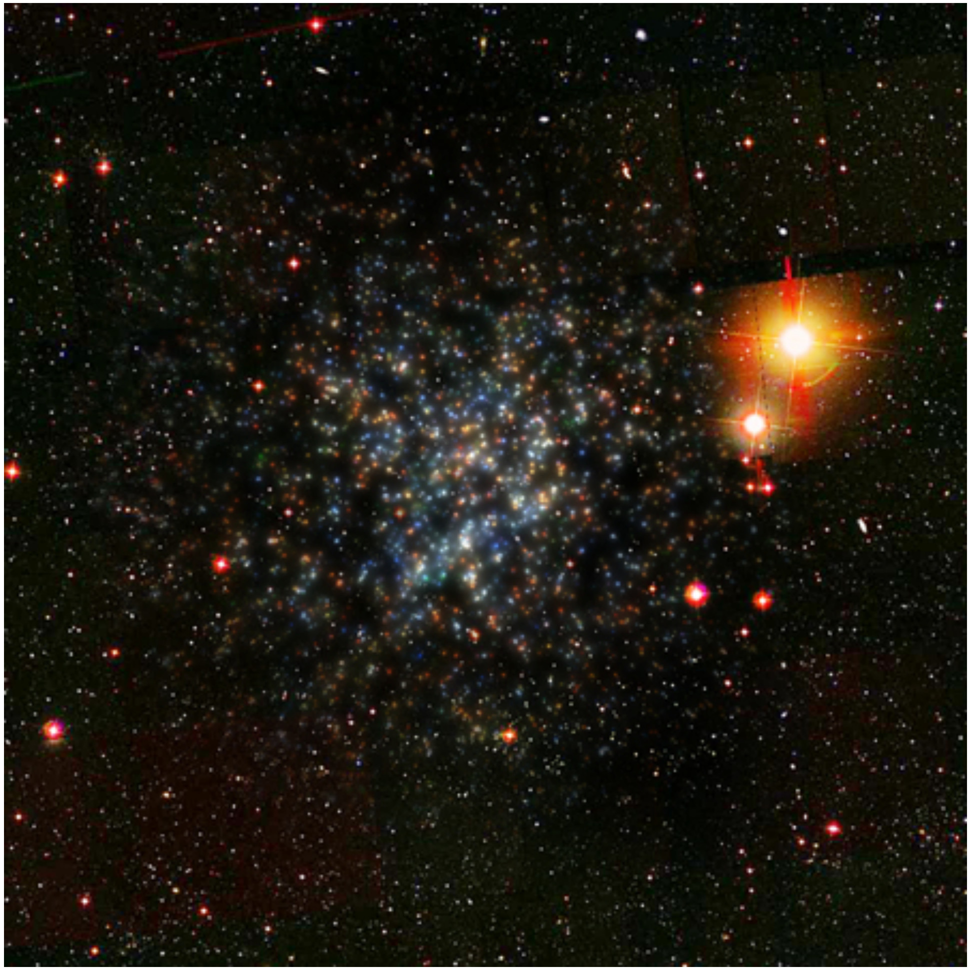
THE SCENARIO



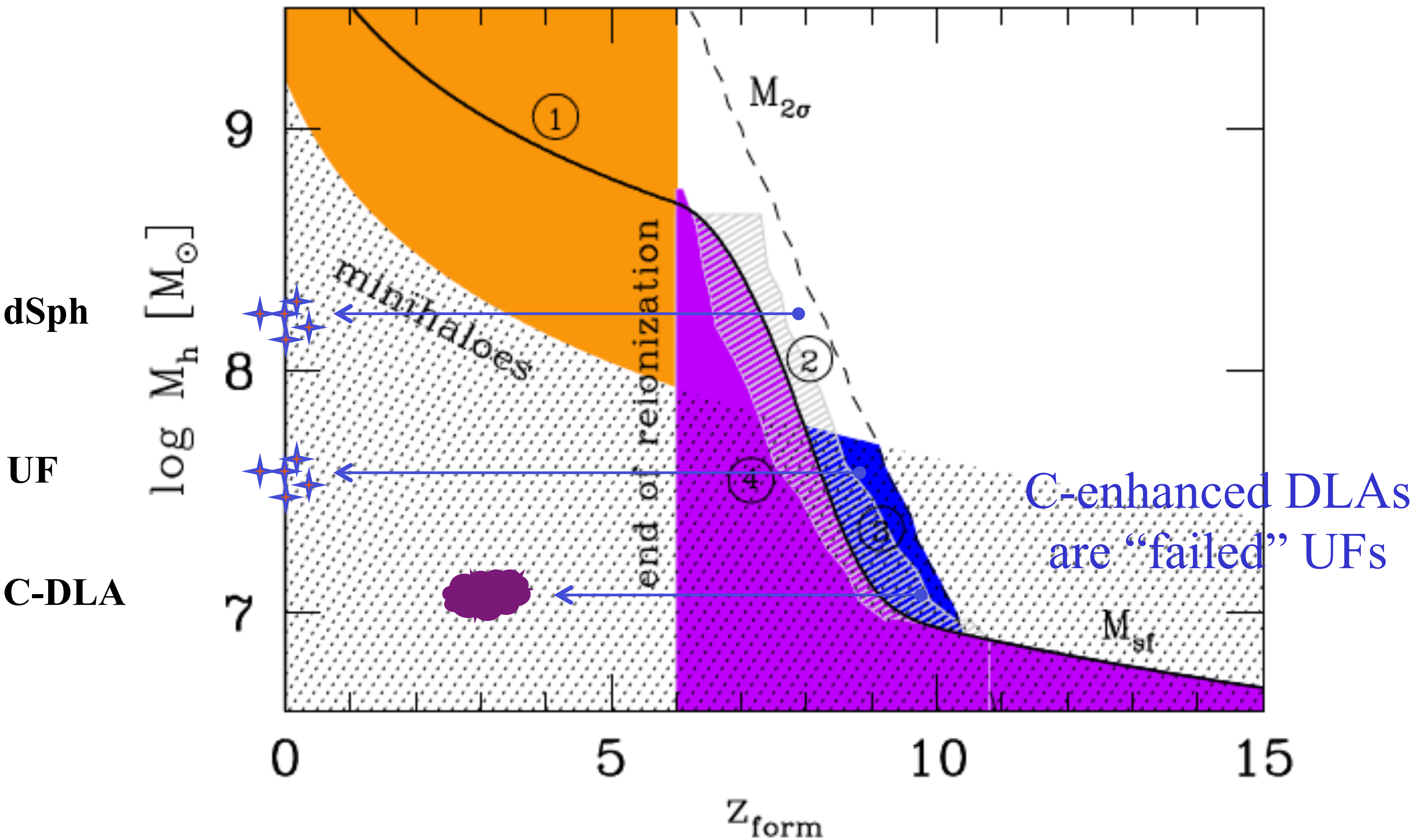
Willman+ 2006, Simon & Geha 2007

WHAT ARE THEY ?

Boötes Ultra Faint Dwarf Galaxy from SDSS



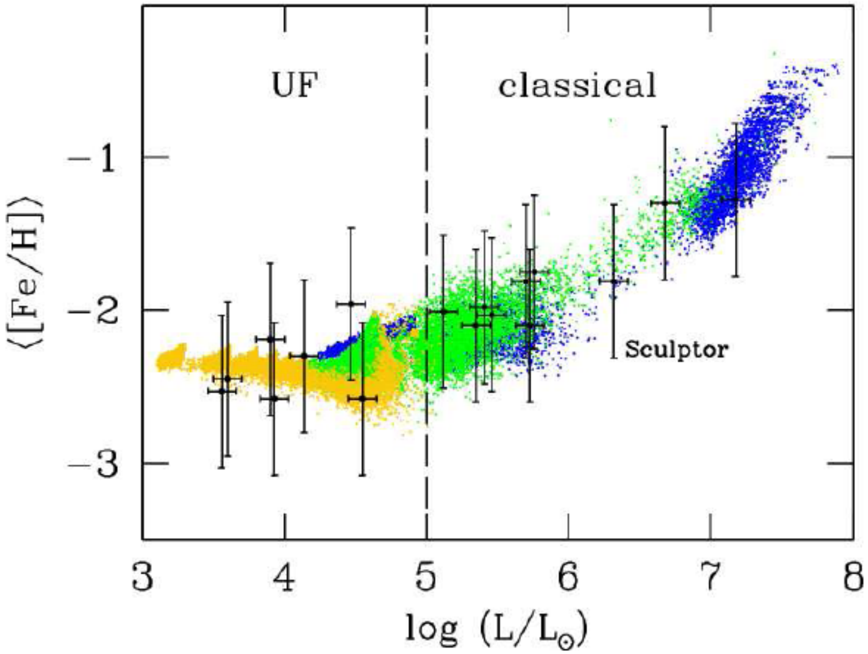
FEEDBACKS (RELOADED)

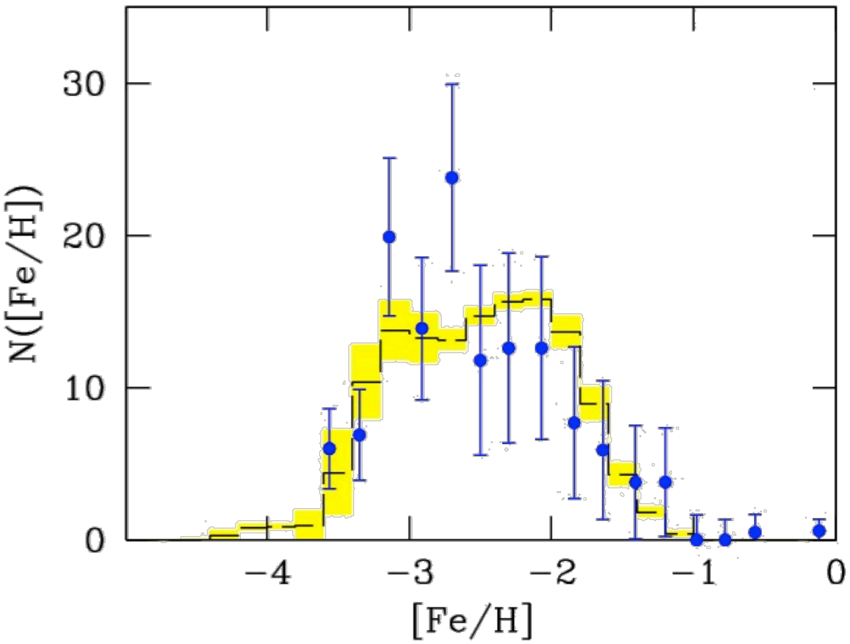


Salvadori & AF 2009, Bovill & Ricotti 2009, Wyse+2010

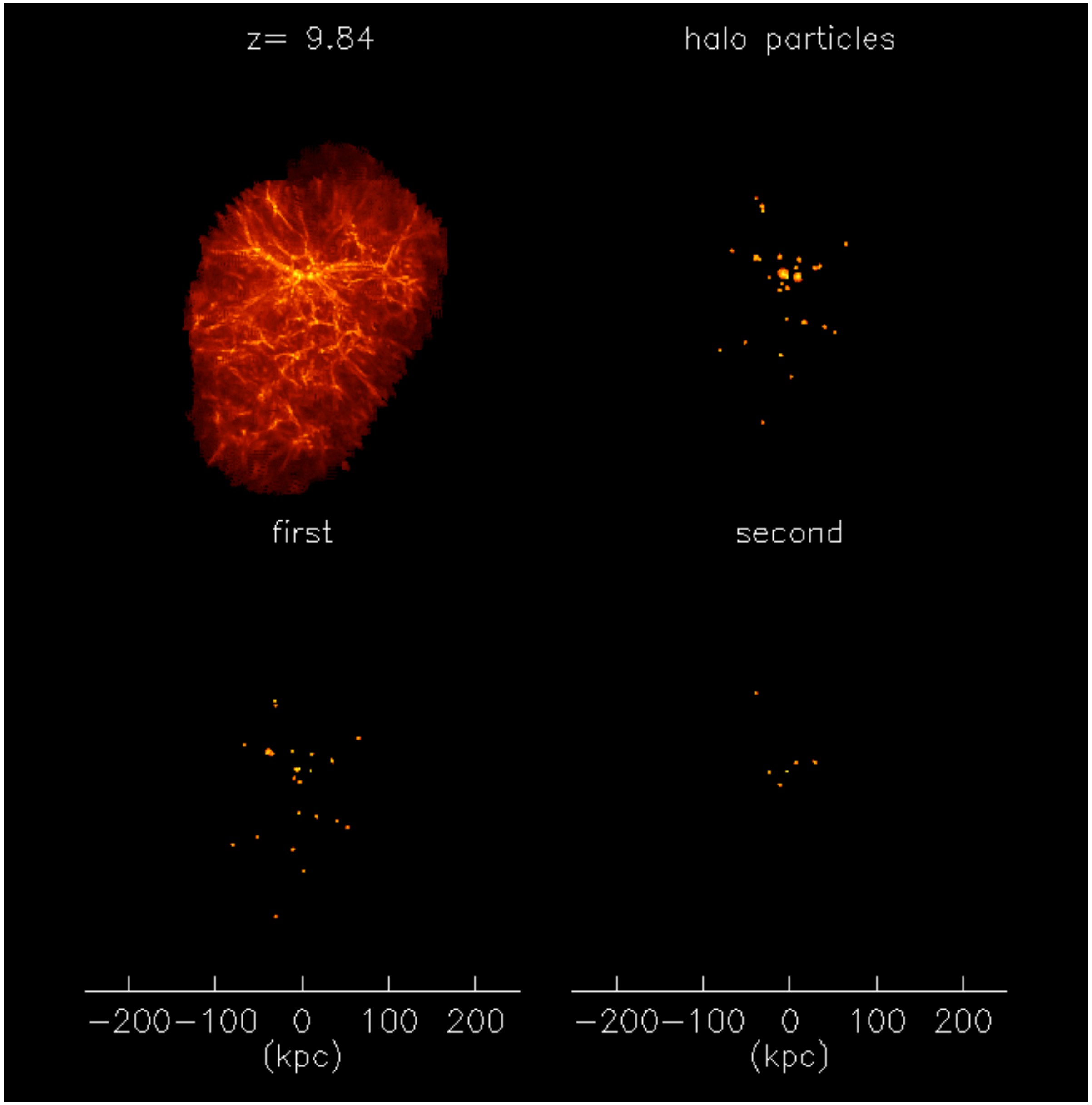
ULTRA FAINT DSPHs: METALLICITY

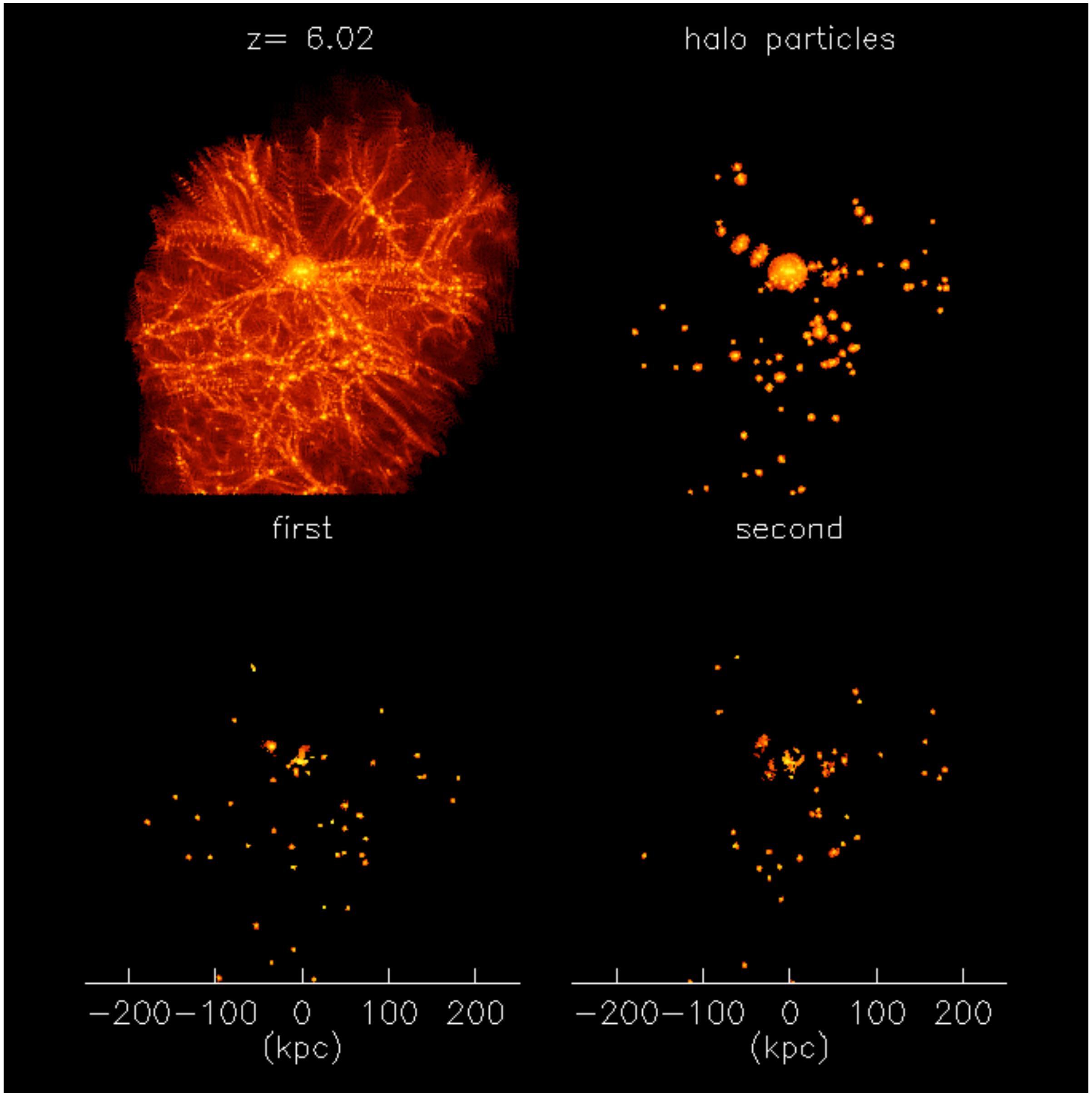
data: Kirby+2007

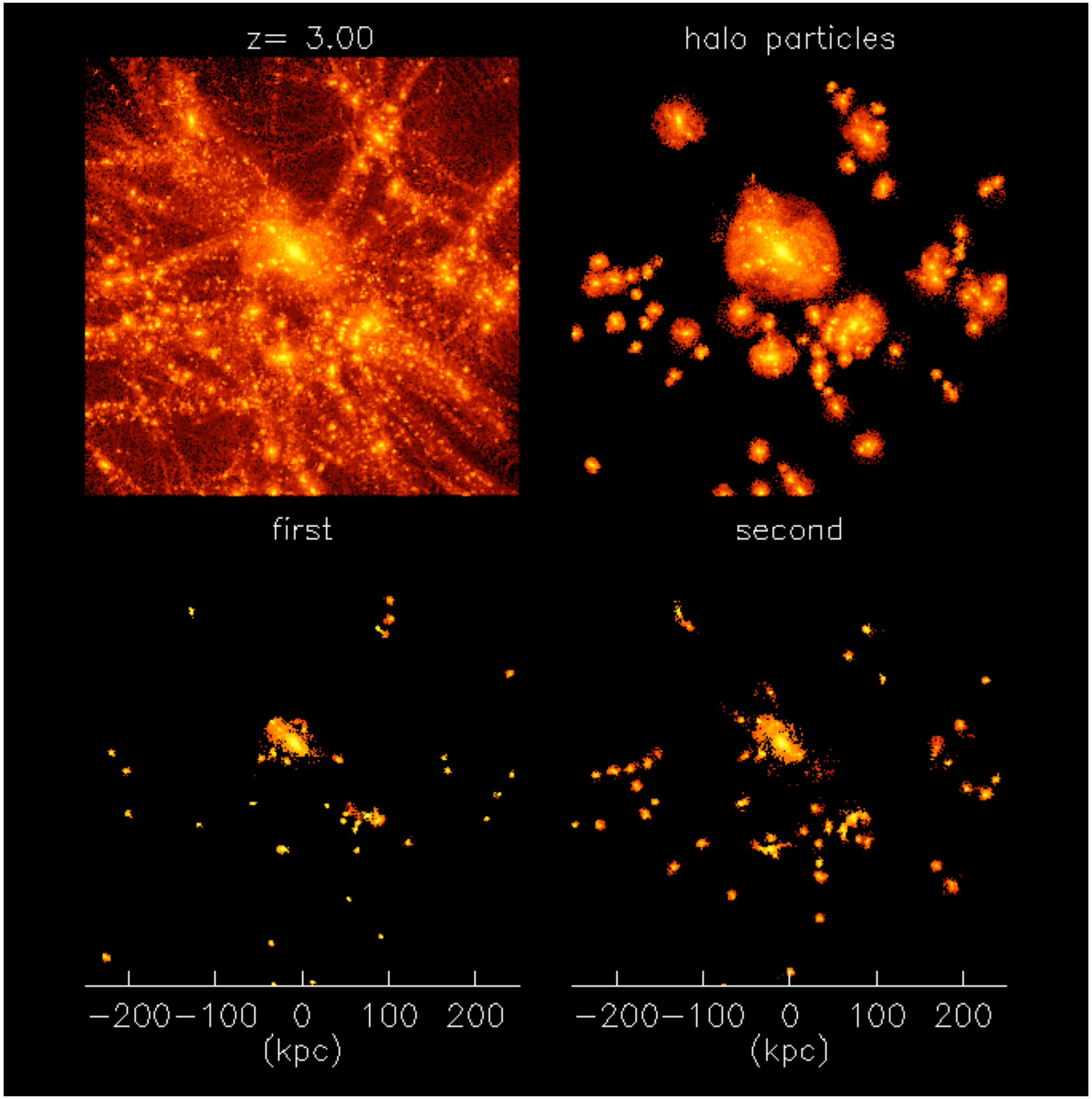


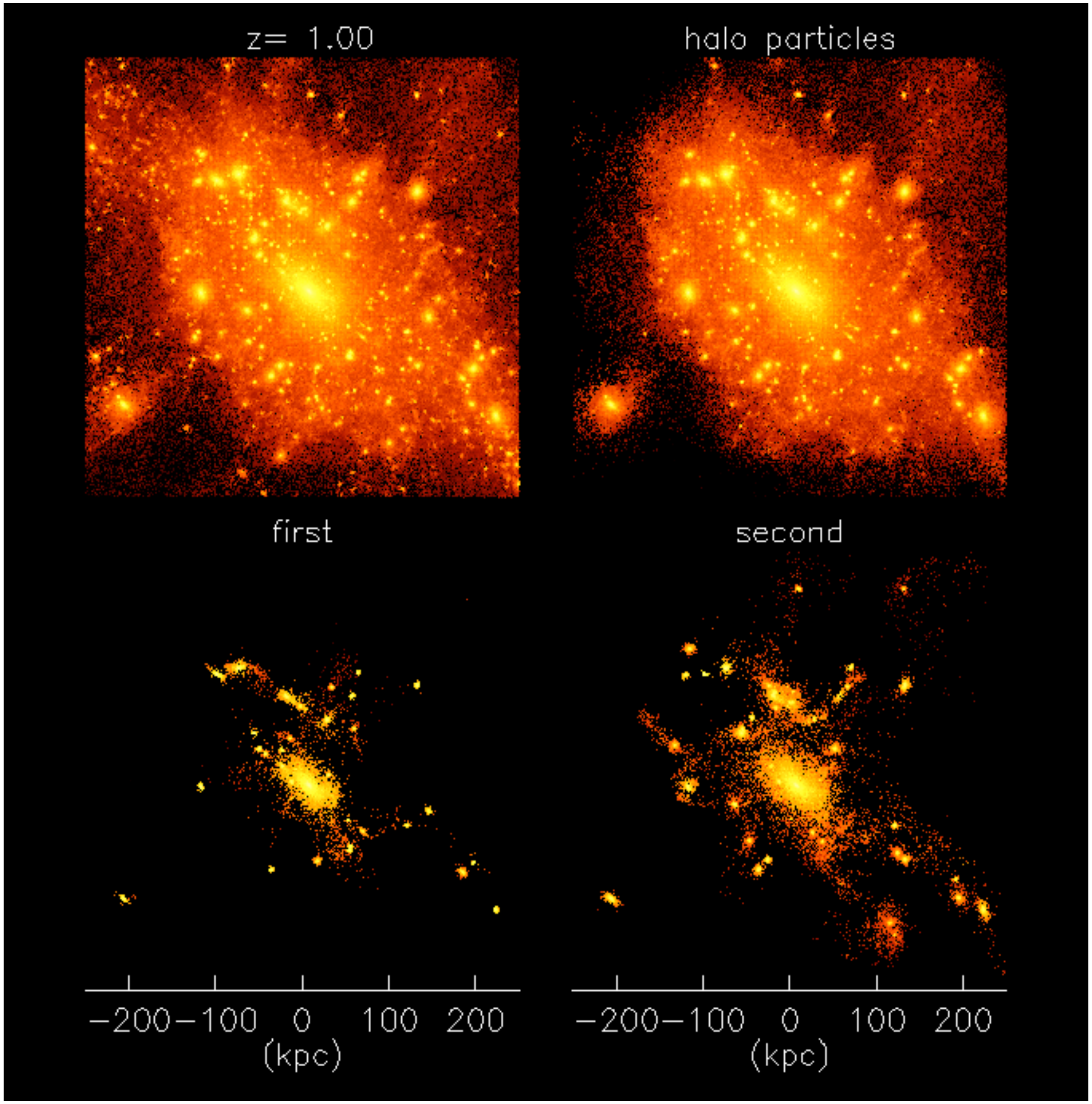


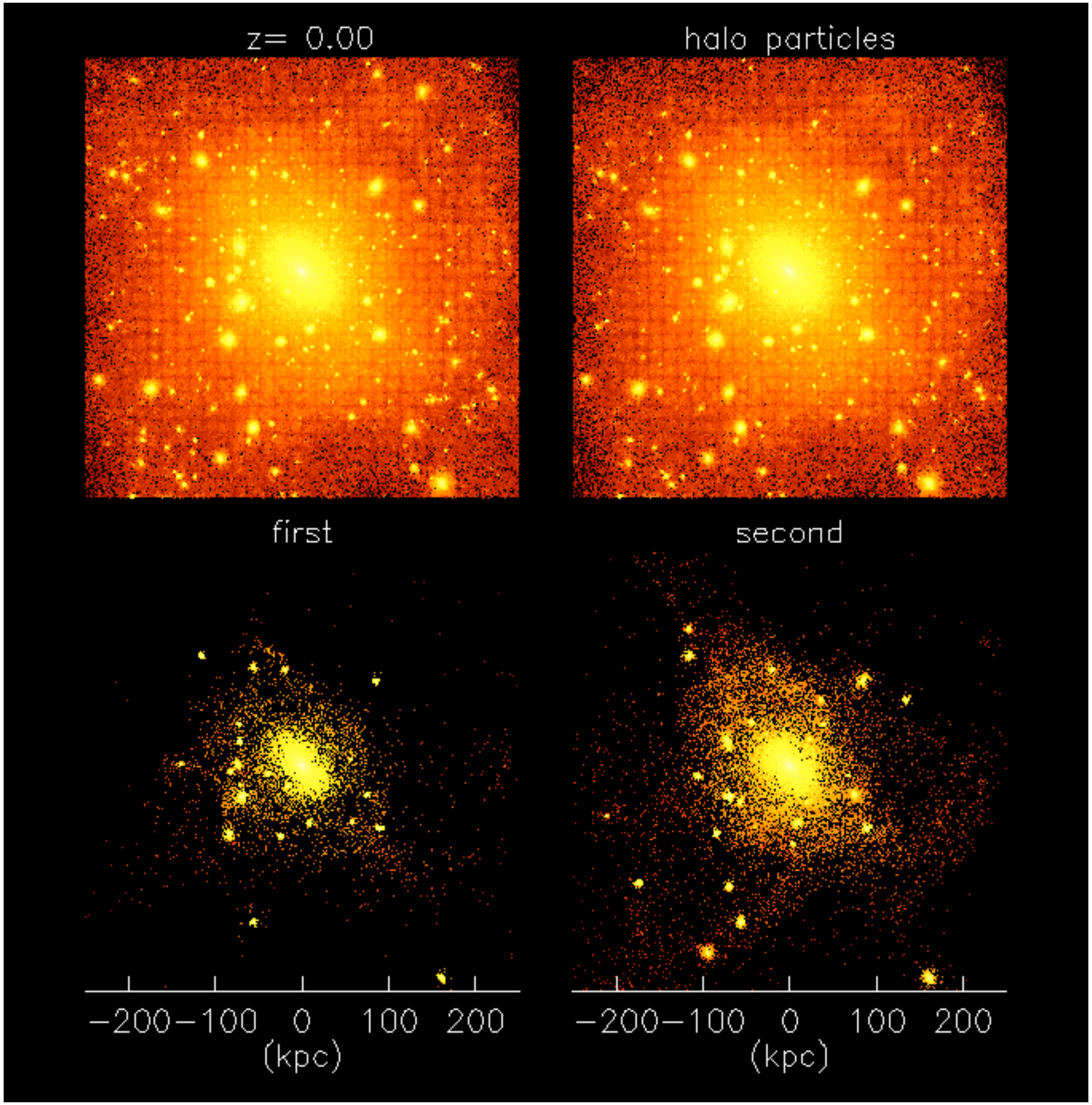
Scannapieco+ 2006




z= 6.02
halo particles
first
second
−200−100 0 100 200
(kpc)
−200−100 0 100 200
(kpc)


z= 3.00
halo particles
first
second
−200−100 0 100 200
(kpc)
−200−100 0 100 200
(kpc)


z= 1.00
halo particles
first
second
−200 −100 0 100 200
(kpc)
−200 −100 0 100 200
(kpc)

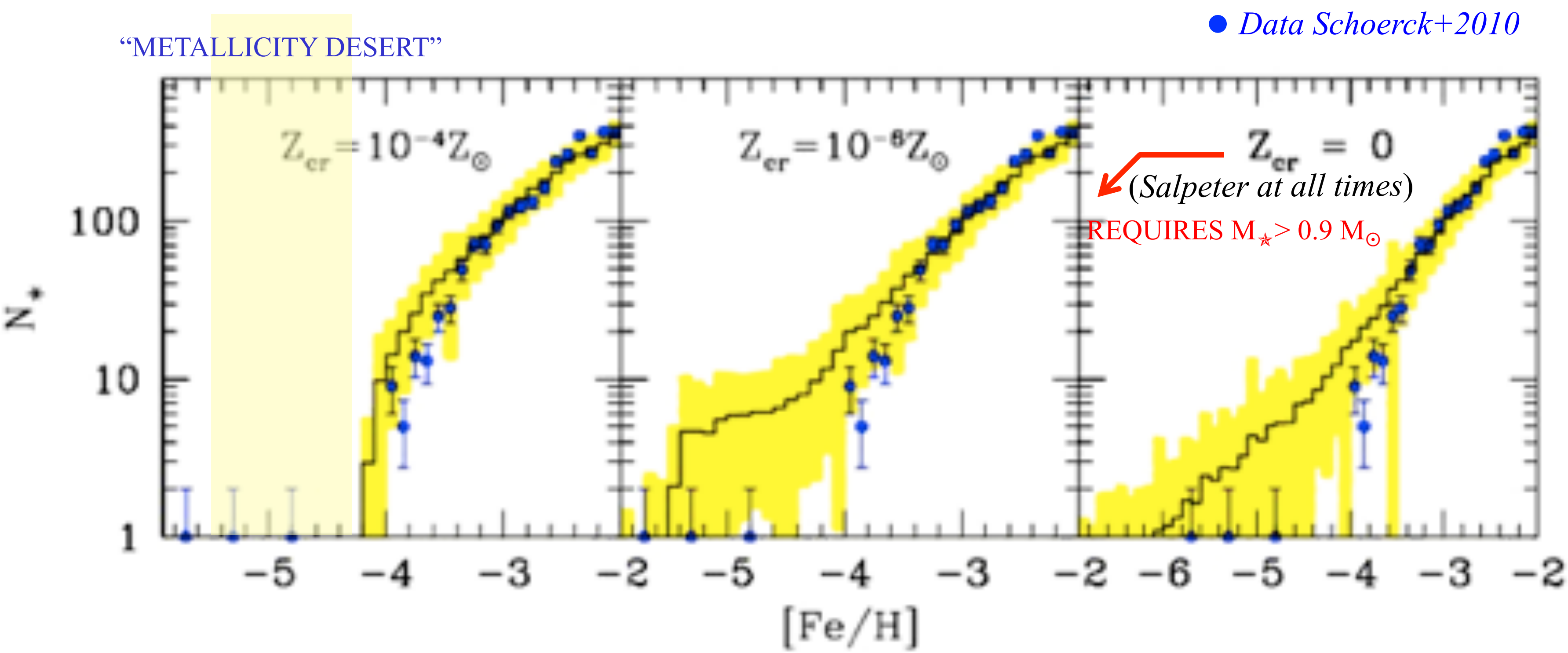


z= 0.00
halo particles
first
second
−200 −100 0 100 200
(kpc)
−200 −100 0 100 200
(kpc)

Salvadori, Schneider, AF 2007, Tumlinson 2007

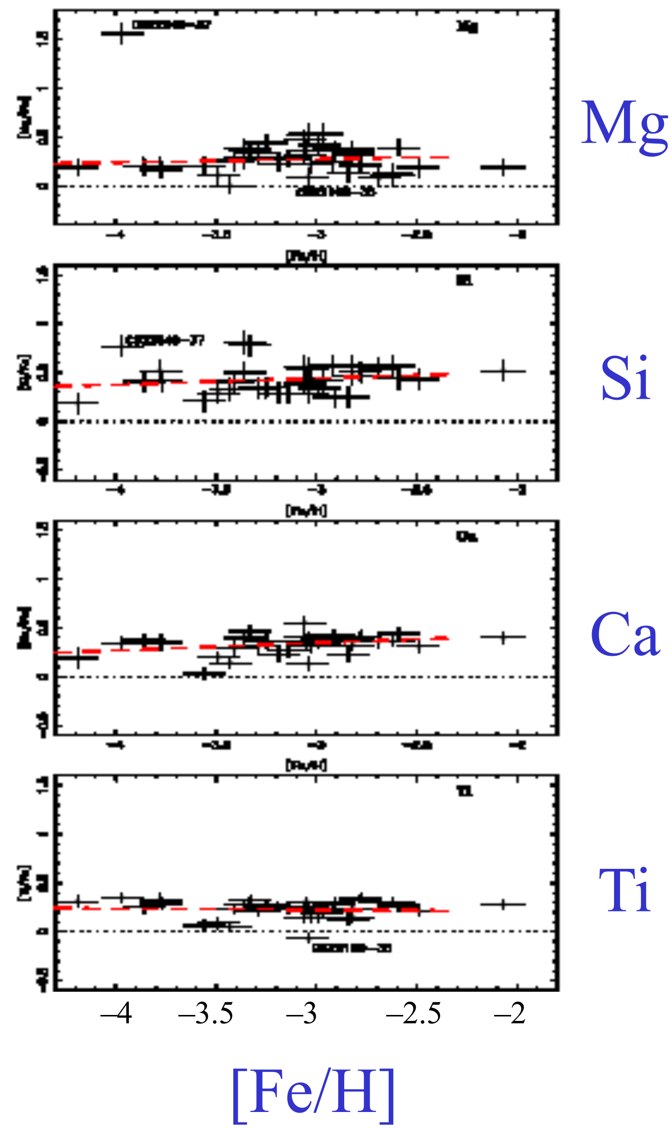
MDF INTERPRETED

- ✓ Stellar / chemical evolution of the Milky Way based on ΛCDM merger-tree
- ✓ Joint HK/HES Metallicity Distribution Function, 2756 stars with [Fe/H] < – 2.



Cayrel+ 2004

ABUNDANCE PATTERNS



- ✓ 30/35 stars with –4.1 < [Fe/H] < –2.7
- ✓ 17 elements from C to Zn measured

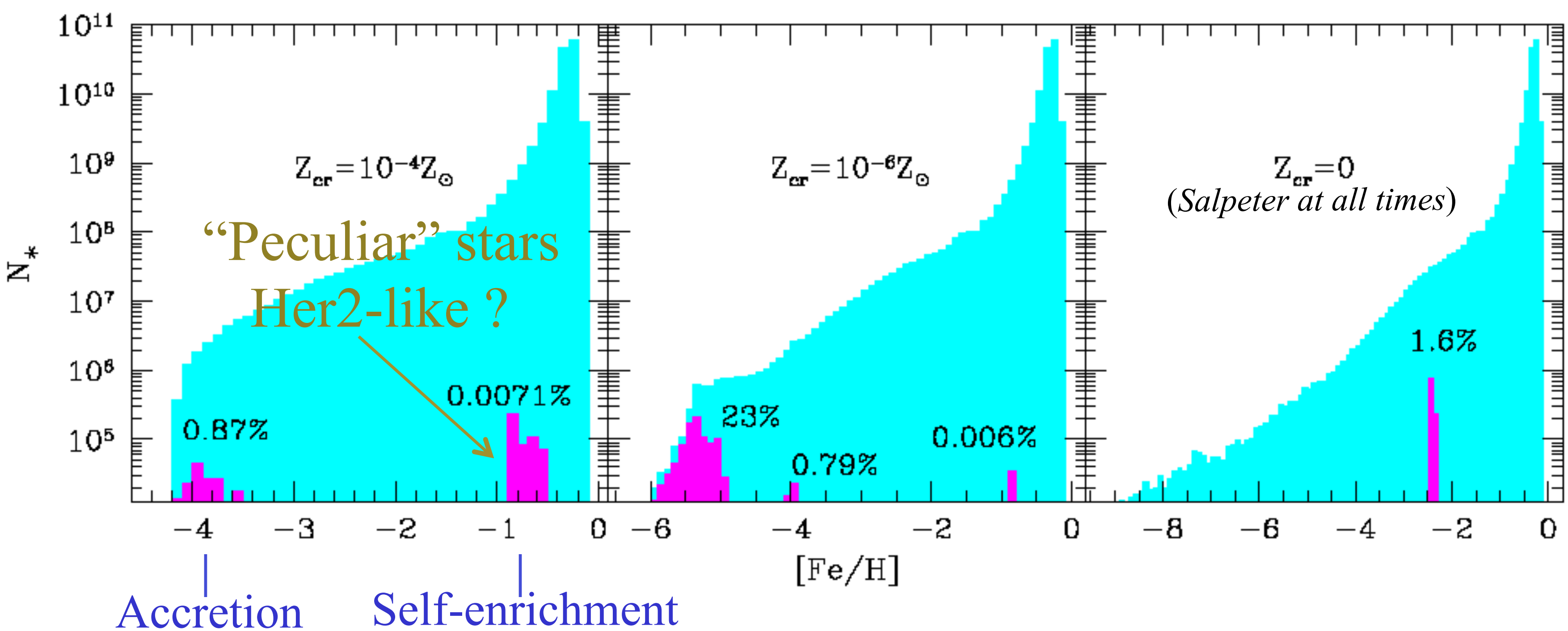
Very small scatter: σ < 0.05 dex

▷ Unlikely resulting from *individual* SN ejecta

▷ Ratios *do not* match PISN yields

Salvadori+06

SECOND GENERATION STARS



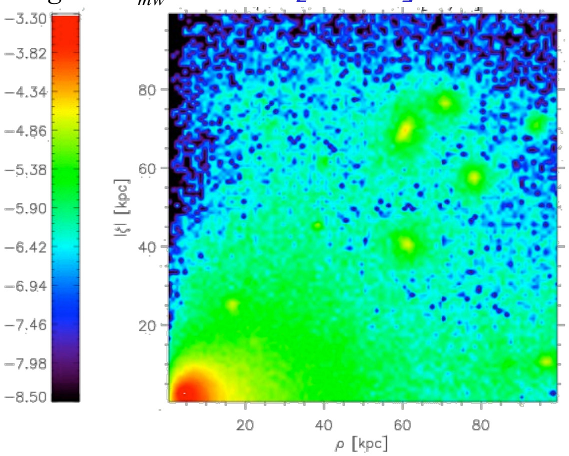
Joint HK/HES sample: 2756 stars with [Fe/H] < – 2.

Z_{crit}	Expected number of second-generation stars
10^{-4} $Z_\odot$	1.3
10^{-6} $Z_\odot$	0.3
0	0 06

Salvadori+10

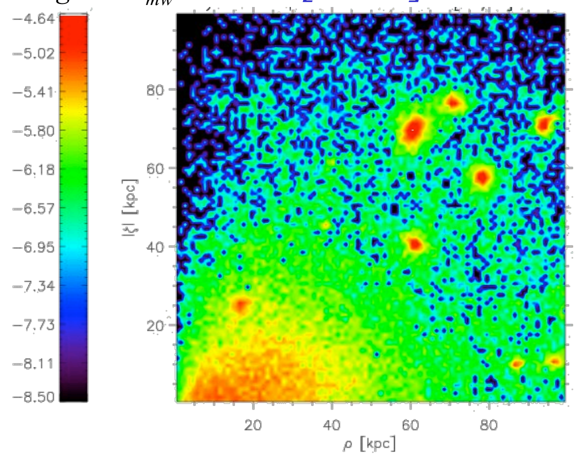
MP

$-2 < [Fe/H] < -1$



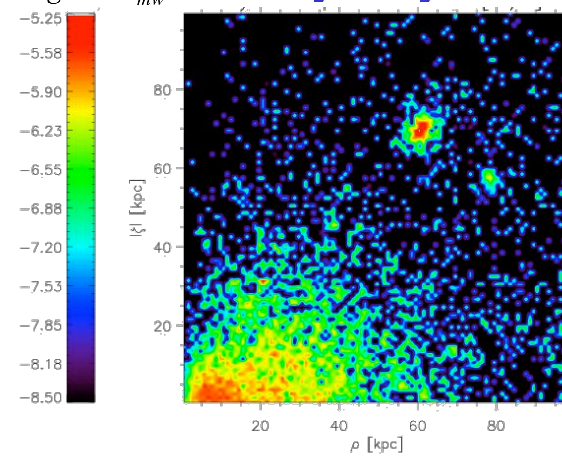
VMP

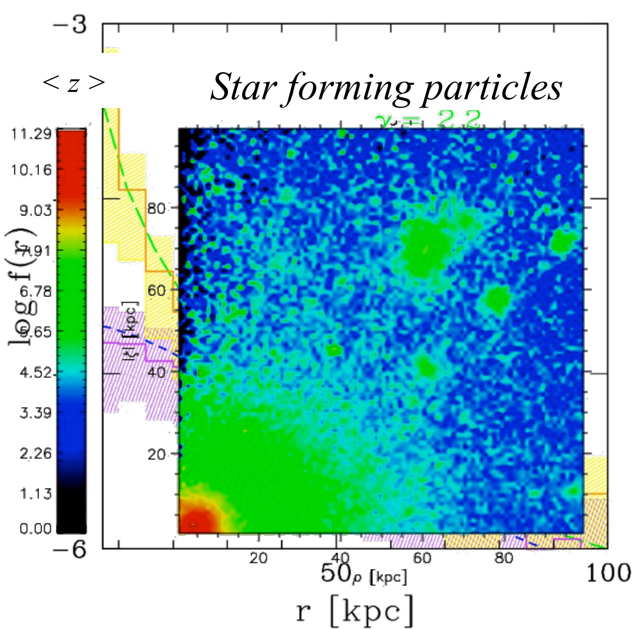
$-3 < [Fe/H] \leq -2$



EMP

$-4 < [Fe/H] \leq -3$





The relative contribution of $[Fe/H] < -2$ stars increases from 17% for $r < 20$ kpc up to > 40% for $r > 20$ kpc

(Carollo+07/09; DeLucia & Helmi 08; Zolotov+10)

- Fragmentation, feedback, merging, B-fields not yet understood. IMF uncertain
- IMF of first stars might be governed by halo rotation
- Critical metallicity is low, $Z_{crit} = 10^{-5\pm1} Z_{\odot}$ and primarily governed by dust cooling
- GRBs (EXIST) and SN (JWST) rates will probe nature and formation rate of first stars
- C-enhanced DLAs and Ultra Faints dwarfs are the counterpart of minihalos
- Metallicity Distribution Function of EMPs in the MW halo: hints on primordial IMF
- The outer halo (20 kpc < r < 40 kpc) is the most promising region for EMP searches
- UFs MDF shifted towards lower [Fe/H] with respect to classical dSphs