COSMOLOGICAL PERSPECTIVES ON VERY-METAL POOR STARS

E. Rollinde

E. Vangioni

D. Maurin

K. Olive

F. Daigne

Daigne et al., 2006, ApJ, 647, 773

RVMODV, 2008, ApJ, 0806.2663

INSTITUT D'ASTROPHYSIQUE DE PARIS

Unité mixte de recherche 7095 IAP CNRS - Université Pierre et Marie Curie

UPMC PARISUNIVERSITAS

CONTEXT :

From first stars to galactic halo stars, and back to first stars…

DIFFERENT INPUTS :

Simulations – PopIII stars

Observations – Metal poor halo galactic stars

Link

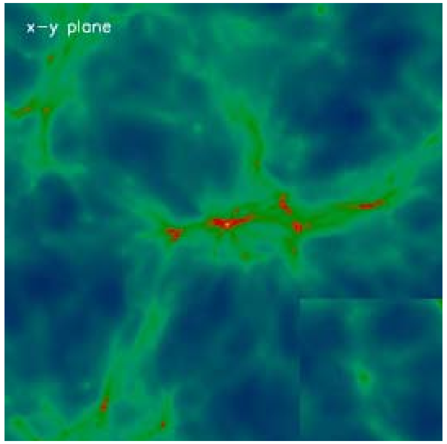
MODELS and RESULTS :

PopII / PopIII.1 / PopIII.2 stars

Cosmological perspectives

CONCLUSION

Formation of the first (Massive) Stars



Greif, Johnson, Bromm al. 07

0.1 Gyr (z~30)

0.2 Gyr (z~20)

See also Wise & Abel, 2007 ; O'Shea et al 20007 ; Smith et al. 2008; Johnson et al. 2007 ; Yoshida et al. 2007

?

Formation of low mass stars

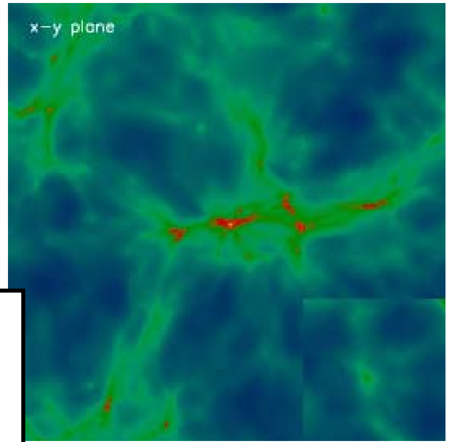
13.6 Gyr

Observation of halo stars

Abundances (H, Fe, C, O, Si…)

HK-HES surveys (Beers et al.1992) ; Hamburg-ESO survey (Christlieb et al. 2002)
ESO-LP "First Stars" (Cayrel et al. 2004) ; Frebel ; Aoki ; Cohen ; Norris…

Formation of the first (Massive) Stars



Greif, Johnson, Bromm al. 07

0.1 Gyr (z~30)

0.2 Gyr (z~20)

bel, 2007 ; O'Shea et al 20007 ; Smith et al. 2008;
; Yoshida et al. 2007

NEW AREA…

From first stars feedback (0.1-0.2 Gyr)…

To observed abundances in galactic halo stars

→ Constraints on cosmological history of different (massive) stars

ation of low mass stars

13.6 Gyr

Observation of halo stars

Abundances (H, Fe, C, O, Si…)

HK-HES surveys (Beers et al.1992) ; Hamburg-ESO survey (Christlieb et al. 2002)
ESO-LP "First Stars" (Cayrel et al. 2004) ; Frebel ; Aoki ; Cohen ; Norris…

Inputs from simulations

Hierarchical formation
Massive stars
Yields

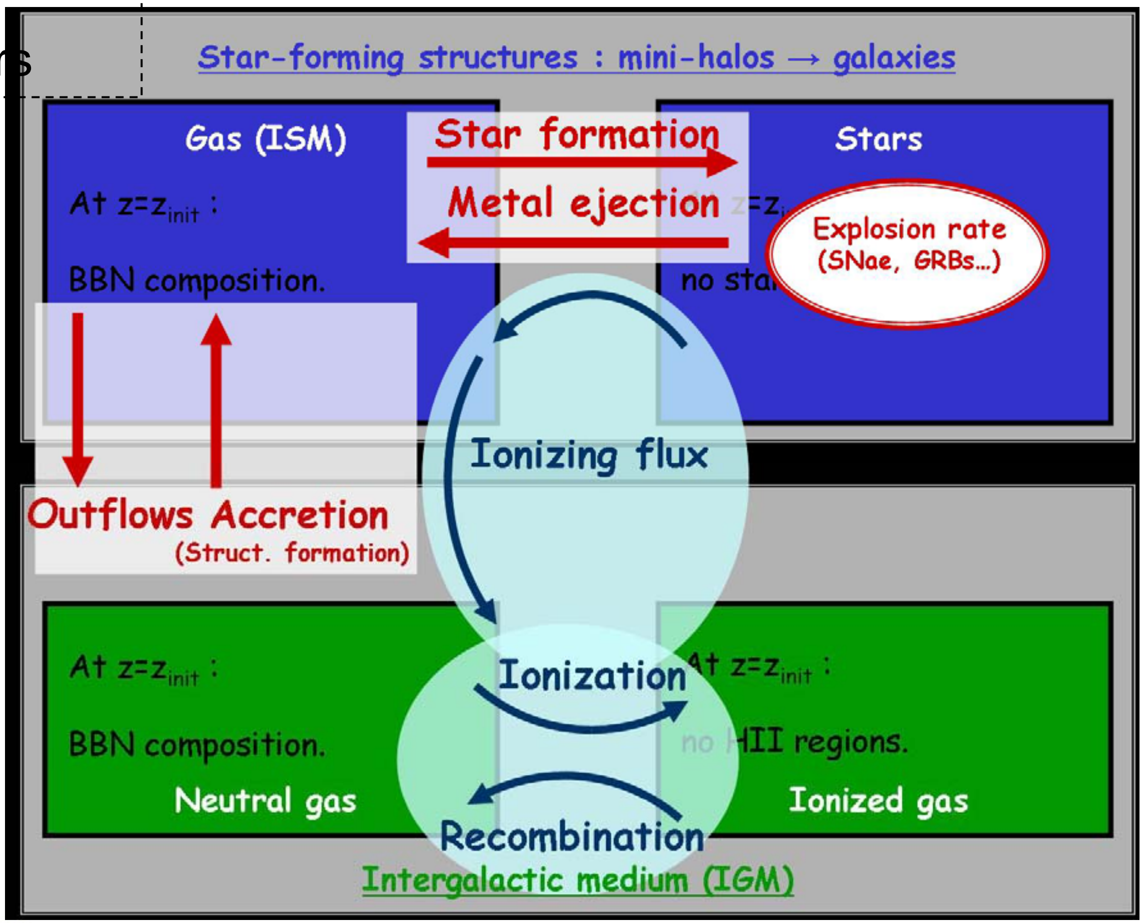
Model of star formation

1. Structures follow Press Schechter
2. Follow mean IGM / ISM / Stars

(Daigne et al. 2006)

Press Schechter
SFR
Yields

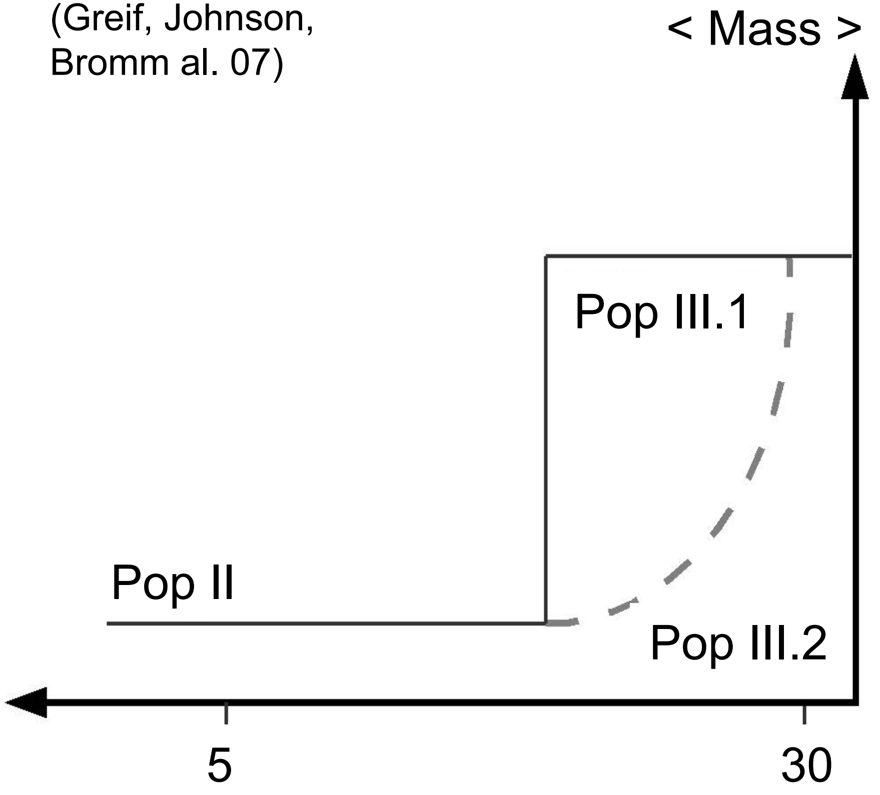
Abundances



See poster by
D. Maurin
(CCR + LiBeB)

Massive stars

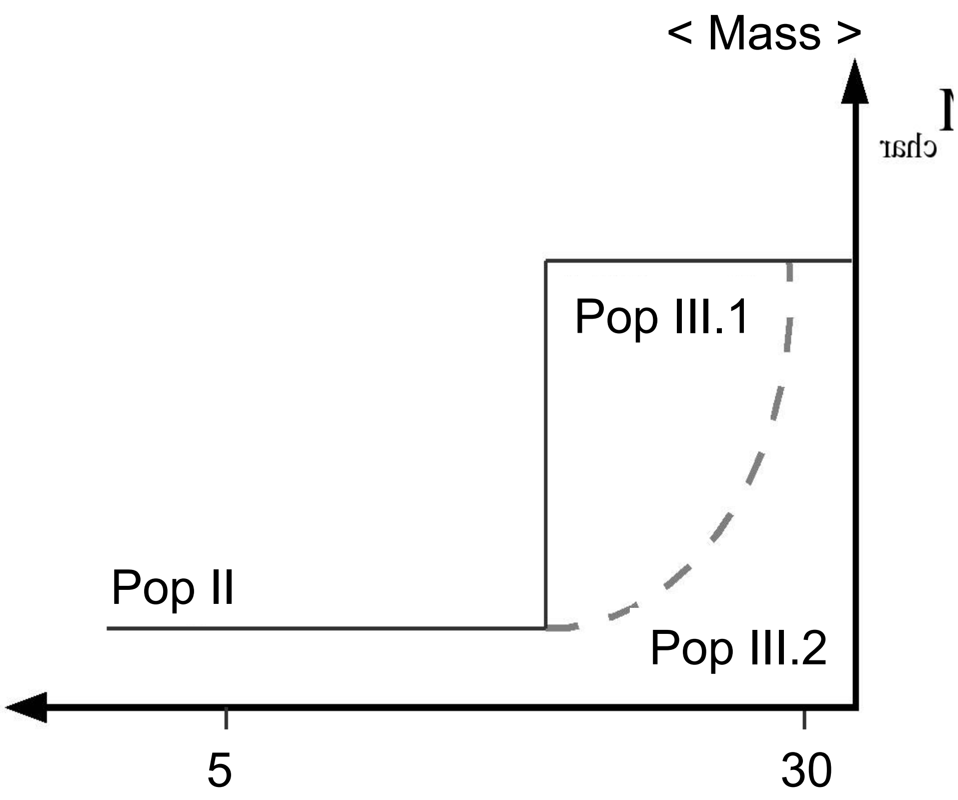
(Greif, Johnson, Bromm al. 07)

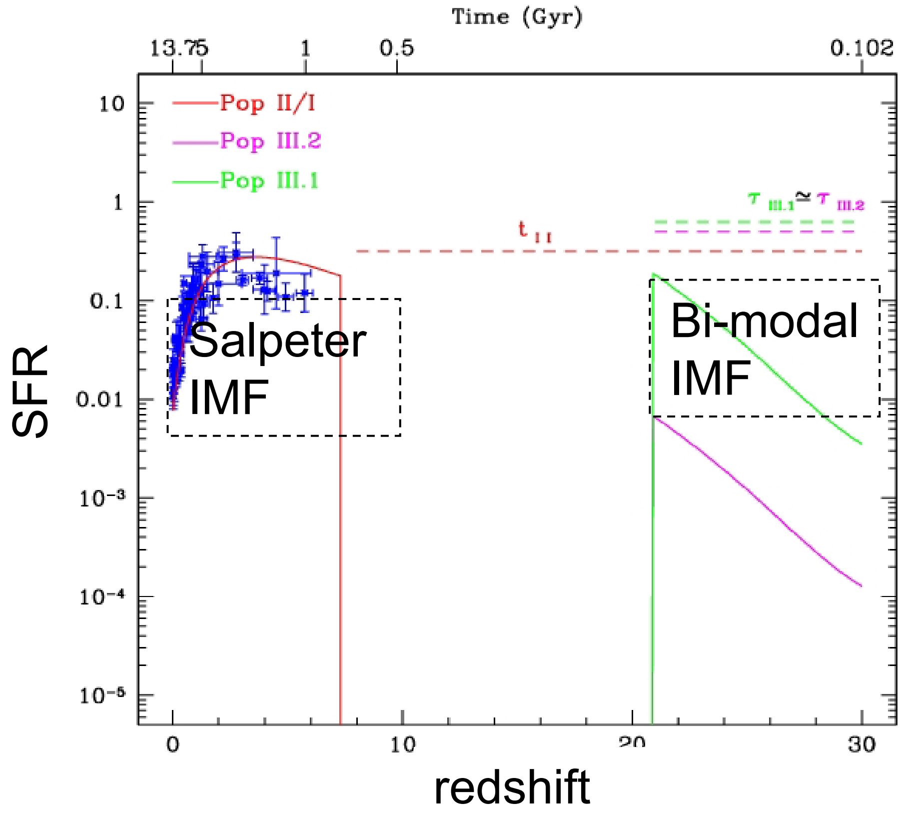


Three modes of star formation triggered by metallicity

- Very massive PopIII.1 (>100 Msun)
- Massive PopIII.2 (few 10 Msun)
- Intermediate mass PopII
- Low-Mass stars at high z ? (Smith et al. 2008)

Model of star formation





Press Schechter
SFR
Yields

→ Abundances

Yields

Massive stars yields…

- Yields of
  D, He, C, N, O, Mg, Si, S, Ca, Fe, Zn
- For different mass, metallicity
- Scenario for the stellar explosion

< 8 Msun : Van den Hoek & Groenewegen 1997

8 – 100 : Woosley & Weaver 1995 (HW08)

> 100 : Heger et al. 2003

> 270 : massive black holes…

Pop III Stars 10–100 M 21

TABLE 7
Postsupernova Yields in Solar Masses, 0.6B, Standard Mixing, S = 4 Piston

isotope	10 M	12 M	15 M	20 M	25 M	35 M	50 M	75 M	100 M
^{1}H	5:29	6:23	7:43	9:03	1:03 10^{1}	1:13 10^{1}	1:63 10^{1}	2:10 10^{1}	2:74 10^{1}
^{2}H	2:22 10^{7}	1:25 10^{6}	1:04 10^{6}	9:26 10^{7}	8:71 10^{7}	7:60 10^{7}	3:10 10^{8}	3:40 10^{8}	4:91 10^{9}
^{3}He	5:83 10^{5}	6:18 10^{5}	6:58 10^{5}	7:22 10^{5}	6:98 10^{5}	8:07 10^{5}	9:13 10^{5}	1:15 10^{4}	1:53 10^{4}
^{4}He	3:25	3:82	4:34	5:44	6:50	5:65	1:52 10^{1}	2:35 10^{1}	2:81 10^{1}
^{6}Li	1:53 10^{12}	6:26 10^{12}	1:72 10^{12}	4:17 10^{13}	1:71 10^{12}	5:98 10^{14}	7:49 10^{12}	6:82 10^{13}	1:36 10^{12}
^{7}Li	8:24 10^{8}	1:66 10^{7}	4:14 10^{7}	5:29 10^{7}	1:93 10^{7}	2:93 10^{7}	4:94 10^{8}	5:22 10^{8}	2:17 10^{9}
^{9}Be	7:87 10^{12}	1:05 10^{11}	1:32 10^{12}	9:56 10^{13}	7:03 10^{12}	1:49 10^{14}	2:05 10^{11}	3:22 10^{12}	7:55 10^{12}
^{10}B	2:00 10^{10}	1:96 10^{10}	1:17 10^{10}	7:03 10^{11}	1:46 10^{10}	5:05 10^{12}	5:53 10^{10}	5:25 10^{10}	1:24 10^{10}
^{11}B	1:48 10^{7}	1:67 10^{7}	8:64 10^{8}	7:08 10^{8}	1:04 10^{7}	3:46 10^{9}	5:74 10^{7}	2:90 10^{7}	6:84 10^{8}
^{12}C	3:39 10^{2}	5:06 10^{2}	4:58 10^{2}	4:11 10^{2}	4:53 10^{2}	4:52 10^{3}	9:15 10^{1}	8:76 10^{1}	4:00 10^{1}
^{13}C	7:02 10^{7}	2:06 10^{6}	1:11 10^{4}	1:64 10^{6}	1:46 10^{4}	1:06 10^{7}	3:07 10^{2}	2:95 10^{2}	1:07 10^{4}
^{14}N	9:98 10^{7}	1:18 10^{6}	1:03 10^{4}	1:17 10^{5}	9:88 10^{3}	7:63 10^{8}	1:05 10^{1}	2:01 10^{1}	2:24 10^{4}
^{15}N	1:79 10^{4}	4:78 10^{6}	4:42 10^{4}	3:62 10^{6}	1:76 10^{5}	2:81 10^{7}	1:93 10^{5}	2:92 10^{5}	6:58 10^{4}
^{16}O	3:53 10^{2}	1:27 10^{1}	1:22 10^{1}	9:75 10^{2}	1:53 10^{1}	2:11 10^{2}	3:26	2:00	5:18
^{17}O	4:01 10^{7}	1:13 10^{6}	1:48 10^{4}	1:41 10^{6}	3:86 10^{4}	1:16 10^{7}	5:42 10^{4}	1:34 10^{4}	8:19 10^{4}
^{18}O	1:21 10^{8}	2:65 10^{8}	3:32 10^{8}	2:74 10^{8}	9:66 10^{8}	1:45 10^{9}	7:80 10^{7}	1:95 10^{4}	1:34 10^{4}
^{19}F	1:54 10^{4}	6:84 10^{8}	3:67 10^{4}	1:58 10^{6}	9:78 10^{7}	1:10 10^{7}	7:46 10^{6}	8:27 10^{4}	5:51 10^{7}
^{20}Ne	1:28 10^{2}	8:62 10^{4}	3:71 10^{2}	1:81 10^{2}	1:33 10^{2}	3:02 10^{3}	2:50 10^{1}	3:03 10^{1}	4:10 10^{1}
^{21}Ne	6:14 10^{4}	9:00 10^{8}	1:72 10^{5}	5:83 10^{6}	1:90 10^{4}	8:23 10^{7}	2:89 10^{3}	9:99 10^{5}	6:75 10^{5}
^{22}Ne	3:58 10^{4}	4:34 10^{8}	3:64 10^{4}	1:00 10^{6}	7:26 10^{7}	2:59 10^{7}	8:36 10^{3}	4:19 10^{5}	5:23 10^{5}
^{23}Na	1:53 10^{4}	1:74 10^{6}	3:34 10^{4}	9:96 10^{5}	3:25 10^{5}	1:02 10^{5}	2:90 10^{4}	4:69 10^{4}	7:79 10^{5}
^{24}Mg	1:76 10^{3}	1:58 10^{3}	6:44 10^{3}	3:66 10^{3}	7:37 10^{3}	5:69 10^{4}	2:53 10^{2}	8:91 10^{2}	8:84 10^{2}
^{25}Mg	2:85 10^{5}	1:38 10^{5}	9:82 10^{5}	4:14 10^{5}	5:02 10^{5}	4:76 10^{6}	7:11 10^{3}	7:06 10^{4}	3:23 10^{4}
^{26}Mg	2:39 10^{5}	4:43 10^{6}	1:27 10^{4}	5:85 10^{5}	5:96 10^{5}	5:31 10^{6}	7:70 10^{3}	7:95 10^{4}	9:99 10^{5}
^{27}Al	6:03 10^{5}	1:19 10^{4}	1:64 10^{4}	7:55 10^{5}	2:36 10^{4}	1:08 10^{5}	3:31 10^{4}	2:05 10^{3}	6:52 10^{4}
^{28}Si	2:17 10^{2}	4:89 10^{2}	4:96 10^{3}	1:34 10^{3}	2:24 10^{3}	4:68 10^{5}	3:66 10^{3}	1:17 10^{2}	5:34 10^{2}
^{29}Si	3:04 10^{5}	1:54 10^{4}	2:03 10^{5}	8:13 10^{6}	3:33 10^{5}	7:64 10^{7}	3:66 10^{5}	2:05 10^{4}	2:81 10^{4}
^{30}Si	7:53 10^{6}	7:53 10^{5}	1:41 10^{5}	5:14 10^{6}	3:49 10^{5}	6:40 10^{7}	2:57 10^{5}	2:01 10^{4}	1:06 10^{4}
^{31}P	6:06 10^{5}	2:50 10^{4}	1:59 10^{5}	4:39 10^{6}	1:49 10^{5}	1:96 10^{7}	1:19 10^{5}	6:69 10^{5}	8:80 10^{5}
^{32}S	2:15 10^{2}	5:32 10^{2}	3:80 10^{3}	9:68 10^{4}	9:32 10^{4}	1:76 10^{5}	2:38 10^{3}	4:30 10^{3}	1:49 10^{2}
^{33}S	5:67 10^{5}	3:74 10^{4}	1:18 10^{5}	2:72 10^{6}	2:27 10^{6}	2:42 10^{8}	2:68 10^{6}	5:51 10^{4}	4:54 10^{5}
^{34}S	2:71 10^{4}	1:03 10^{3}	2:92 10^{5}	5:45 10^{6}	5:56 10^{6}	3:24 10^{8}	4:04 10^{6}	1:11 10^{5}	3:27 10^{5}
^{36}S	1:46 10^{8}	7:22 10^{8}	3:25 10^{9}	8:57 10^{10}	7:64 10^{10}	6:02 10^{12}	9:67 10^{10}	1:10 10^{9}	2:38 10^{9}
^{35}Cl	5:31 10^{5}	3:00 10^{4}	7:30 10^{6}	1:69 10^{6}	1:37 10^{6}	1:18 10^{8}	1:66 10^{6}	4:77 10^{6}	1:09 10^{5}
^{37}Cl	1:12 10^{5}	1:06 10^{4}	1:78 10^{6}	4:49 10^{7}	2:37 10^{7}	2:57 10^{9}	3:94 10^{7}	1:06 10^{6}	5:30 10^{6}
^{36}Ar	3:17 10^{3}	1:31 10^{2}	5:62 10^{4}	1:57 10^{4}	1:33 10^{4}	2:89 10^{6}	3:91 10^{4}	6:42 10^{4}	1:77 10^{3}
^{38}Ar	3:51 10^{4}	1:26 10^{3}	2:99 10^{5}	7:97 10^{6}	3:33 10^{6}	1:74 10^{8}	2:17 10^{6}	1:21 10^{5}	3:15 10^{5}
^{40}Ar	3:10 10^{10}	4:33 10^{9}	5:46 10^{11}	1:75 10^{11}	1:06 10^{11}	1:76 10^{13}	1:77 10^{10}	1:13 10^{10}	2:18 10^{10}
^{39}K	6:03 10^{5}	3:64 10^{4}	6:37 10^{6}	2:00 10^{6}	7:77 10^{7}	8:25 10^{9}	1:54 10^{6}	4:54 10^{6}	6:80 10^{6}
^{40}K	5:71 10^{8}	4:50 10^{7}	8:56 10^{9}	2:41 10^{9}	1:03 10^{9}	8:52 10^{12}	1:32 10^{9}	2:68 10^{9}	3:53 10^{9}
^{41}K	3:19 10^{6}	4:82 10^{5}	4:43 10^{7}	1:49 10^{7}	6:47 10^{8}	1:02 10^{9}	1:62 10^{7}	4:30 10^{7}	1:82 10^{6}
^{40}Ca	2:27 10^{3}	4:79 10^{3}	3:84 10^{4}	1:20 10^{4}	9:74 10^{5}	2:33 10^{6}	3:18 10^{4}	4:93 10^{4}	1:23 10^{3}
^{42}Ca	1:00 10^{5}	7:57 10^{5}	8:26 10^{7}	2:76 10^{7}	6:91 10^{8}	4:40 10^{10}	5:98 10^{8}	3:74 10^{7}	6:86 10^{7}
^{43}Ca	8:20 10^{7}	8:70 10^{7}	5:01 10^{8}	1:06 10^{8}	2:08 10^{9}	1:72 10^{11}	1:06 10^{8}	1:33 10^{8}	1:05 10^{8}
^{44}Ca	1:21 10^{5}	9:60 10^{6}	1:69 10^{4}	3:82 10^{7}	4:34 10^{7}	9:03 10^{9}	1:45 10^{6}	1:04 10^{4}	5:85 10^{7}
^{46}Ca	2:99 10^{12}	9:95 10^{12}	1:38 10^{12}	1:69 10^{13}	7:87 10^{13}	2:52 10^{15}	3:18 10^{11}	6:02 10^{12}	7:02 10^{12}
^{48}Ca	4:56 10^{16}	1:43 10^{12}	1:71 10^{12}	2:02 10^{17}	1:57 10^{14}	7:13 10^{18}	3:74 10^{12}	4:24 10^{14}	3:42 10^{13}
^{45}Sc	1:44 10^{7}	4:72 10^{7}	3:63 10^{8}	1:28 10^{8}	2:77 10^{9}	3:29 10^{11}	4:14 10^{9}	9:36 10^{9}	3:89 10^{8}
^{46}Ti	6:41 10^{6}	9:32 10^{6}	4:13 10^{7}	2:56 10^{7}	3:00 10^{8}	2:90 10^{10}	3:22 10^{8}	2:89 10^{7}	4:36 10^{7}
^{47}Ti	1:74 10^{6}	9:49 10^{7}	1:56 10^{7}	4:31 10^{8}	1:46 10^{8}	2:45 10^{10}	4:30 10^{8}	2:13 10^{8}	3:72 10^{8}
^{48}Ti	5:01 10^{5}	3:17 10^{5}	8:16 10^{6}	1:99 10^{6}	2:20 10^{6}	4:58 10^{8}	6:71 10^{6}	5:18 10^{6}	1:80 10^{6}
^{49}Ti	1:82 10^{6}	1:50 10^{6}	3:49 10^{7}	1:08 10^{7}	7:72 10^{8}	1:53 10^{9}	1:95 10^{7}	1:83 10^{7}	2:38 10^{7}
^{50}Ti	1:13 10^{10}	1:76 10^{10}	1:61 10^{11}	1:14 10^{11}	2:46 10^{12}	3:31 10^{14}	1:54 10^{10}	1:21 10^{10}	1:51 10^{10}
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^{51}V	6:17 10^{6}	4:19 10^{6}	1:01 10^{6}	3:82 10^{7}	1:88 10^{7}	3:89 10^{9}	4:87 10^{7}	2:73 10^{7}	2:96 10^{7}
^{50}Cr	1:59 10^{5}	9:62 10^{6}	1:66 10^{4}	1:22 10^{6}	1:96 10^{7}	2:94 10^{9}	3:55 10^{7}	1:41 10^{4}	2:54 10^{4}
^{52}Cr	3:26 10^{4}	2:32 10^{4}	6:38 10^{5}	2:03 10^{5}	1:99 10^{5}	4:82 10^{7}	6:20 10^{5}	5:19 10^{5}	1:25 10^{5}
^{53}Cr	3:04 10^{5}	2:07 10^{5}	5:22 10^{6}	2:11 10^{6}	1:41 10^{6}	3:02 10^{8}	4:02 10^{6}	4:55 10^{6}	2:01 10^{6}
^{54}Cr	3:54 10^{7}	3:00 10^{7}	7:22 10^{8}	5:45 10^{8}	9:70 10^{9}	1:45 10^{10}	1:92 10^{8}	1:66 10^{8}	7:29 10^{8}
^{55}Mn	1:71 10^{4}	1:12 10^{4}	2:96 10^{5}	1:35 10^{5}	6:59 10^{6}	1:37 10^{7}	1:96 10^{5}	1:15 10^{5}	9:50 10^{6}
^{54}Fe	6:51 10^{4}	3:87 10^{4}	8:78 10^{5}	5:97 10^{5}	1:48 10^{5}	2:50 10^{7}	3:22 10^{5}	9:40 10^{5}	1:23 10^{4}
^{56}Fe	3:40 10^{2}	1:62 10^{2}	5:11 10^{3}	1:86 10^{3}	1:62 10^{3}	3:93 10^{5}	6:19 10^{3}	3:63 10^{3}	9:08 10^{4}
^{57}Fe	1:49 10^{3}	6:44 10^{4}	1:76 10^{4}	6:21 10^{5}	4:46 10^{5}	1:03 10^{6}	1:78 10^{4}	8:58 10^{5}	3:94 10^{5}
^{58}Fe	4:81 10^{7}	2:14 10^{7}	4:97 10^{8}	6:21 10^{8}	6:61 10^{9}	6:33 10^{11}	5:80 10^{8}	1:74 10^{9}	8:78 10^{8}

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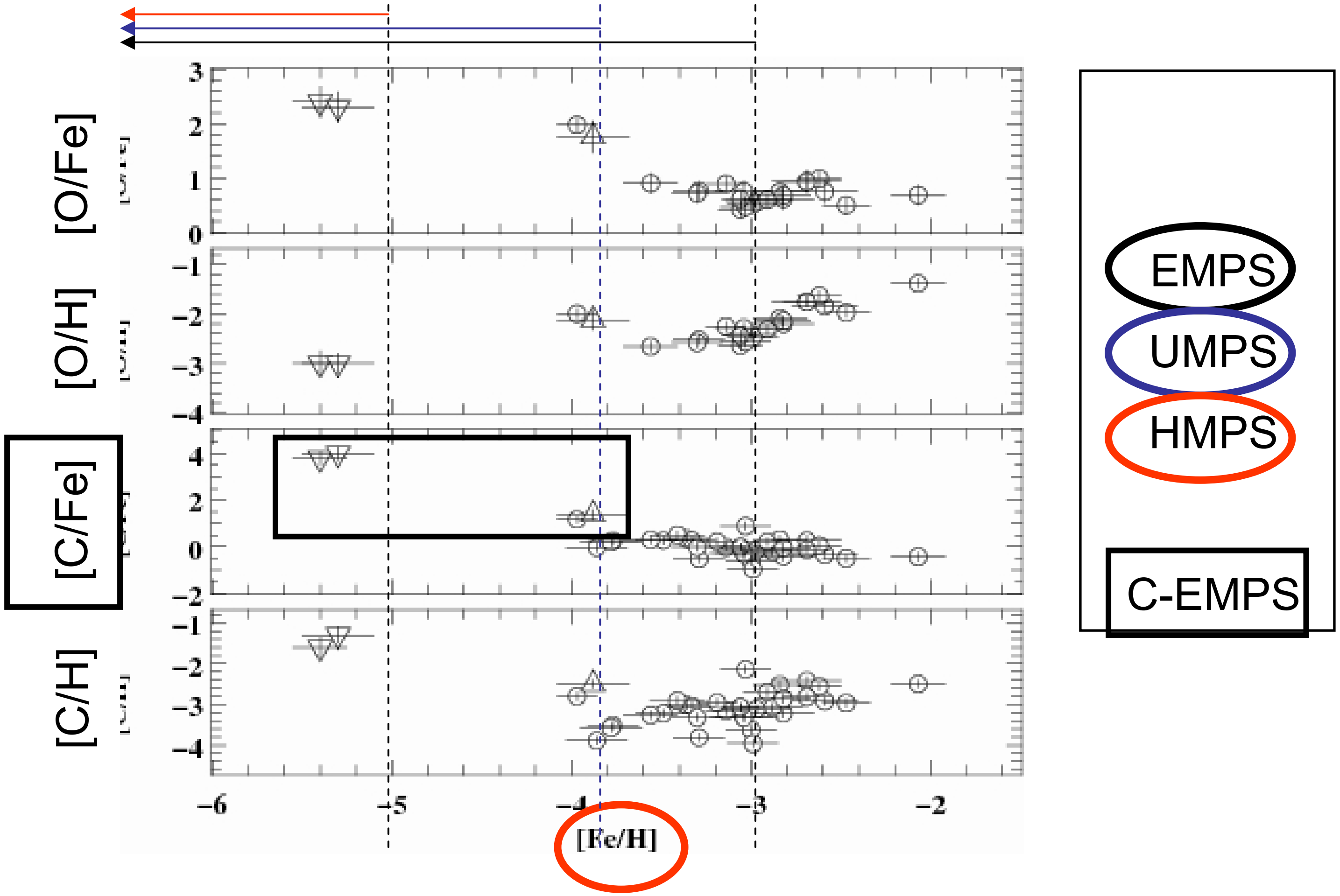
Galactic halo stars

ESO – LP (Cayrel et al. 2004) + peculiar stars

Abundances, [Fe/H] counts of individual stars

Abundances

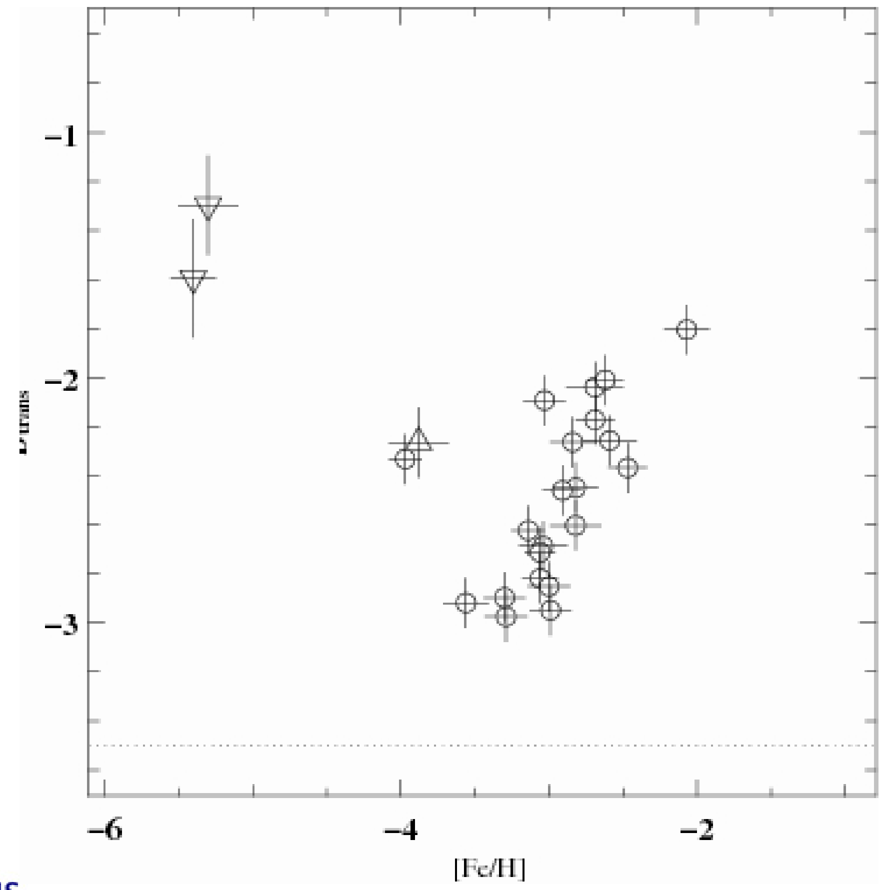


Existence of UMPS…

D_{trans} =
$\text{Log}(10^{[C/H]}+0.3 \times 10^{[O/H]})$

Low-mass criterium :
$D_{trans} > -3.5$
(Bromm & Loeb, 2003
Santoro & Shull, 2006
Frebel et al. 2007)

D_{trans} vs Fe/H



Metallicity Distribution Function

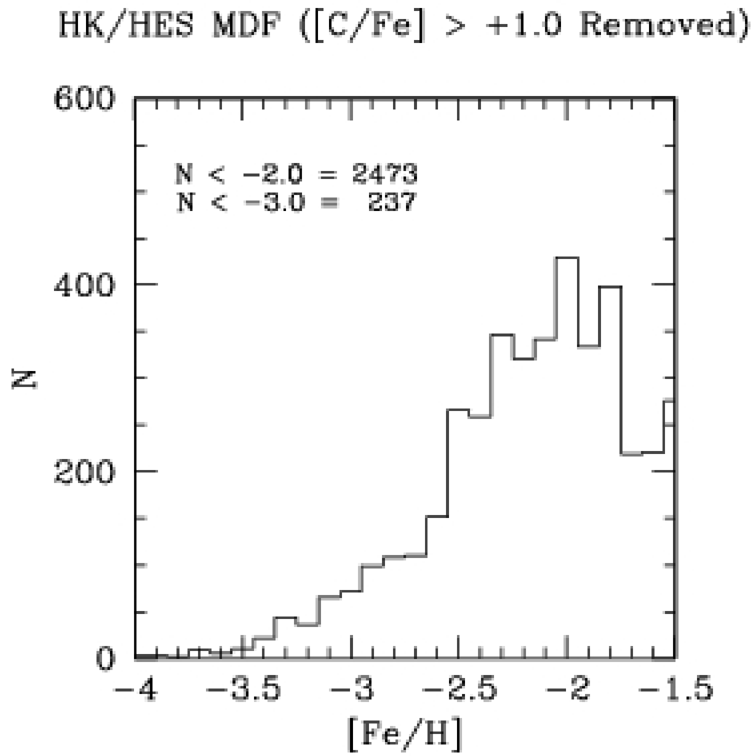
MDF counts the number of

Observed galactic halo stars

At a given Iron abundance

→ Mass of gas, metallicity, SFR

→ When and how many low-mass stars are formed



Galactic halo stars
in a cosmological context

- Constraints on SFR
- Cosmological formation of low-mass stars…

EMPS and PopII

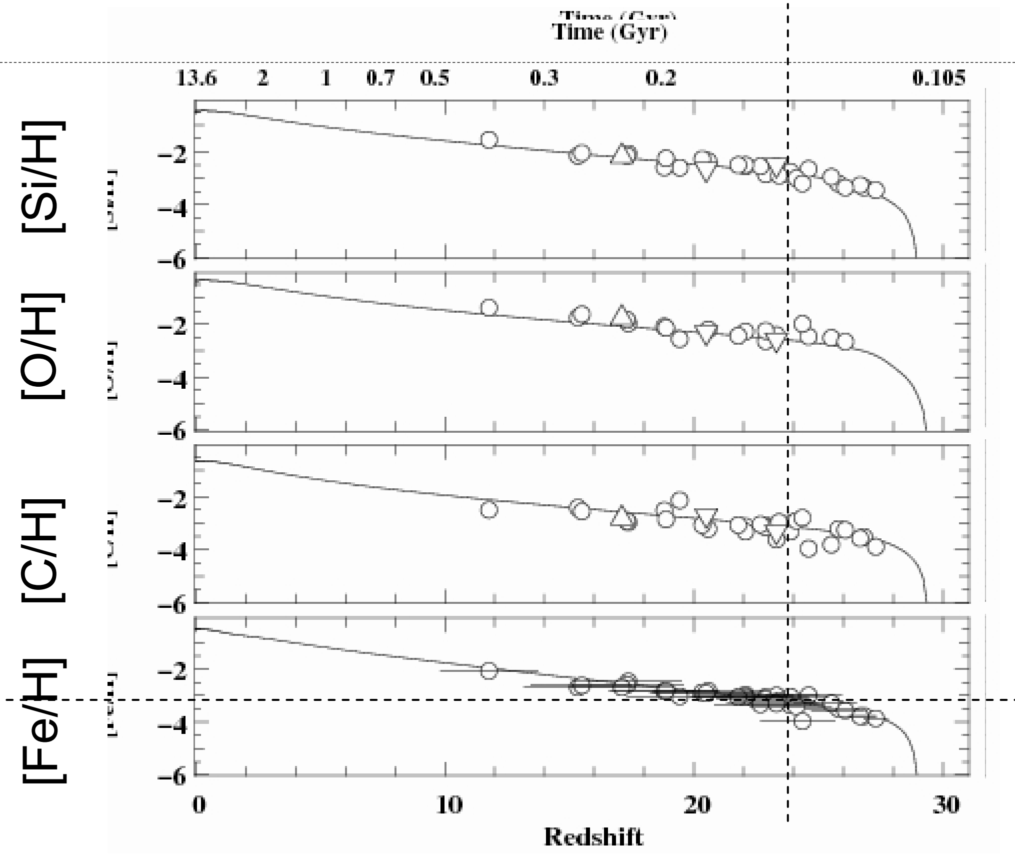
Assumption : Intermediate mass stars – Salpeter IMF + WW95…

ESO-LP only

Yields of

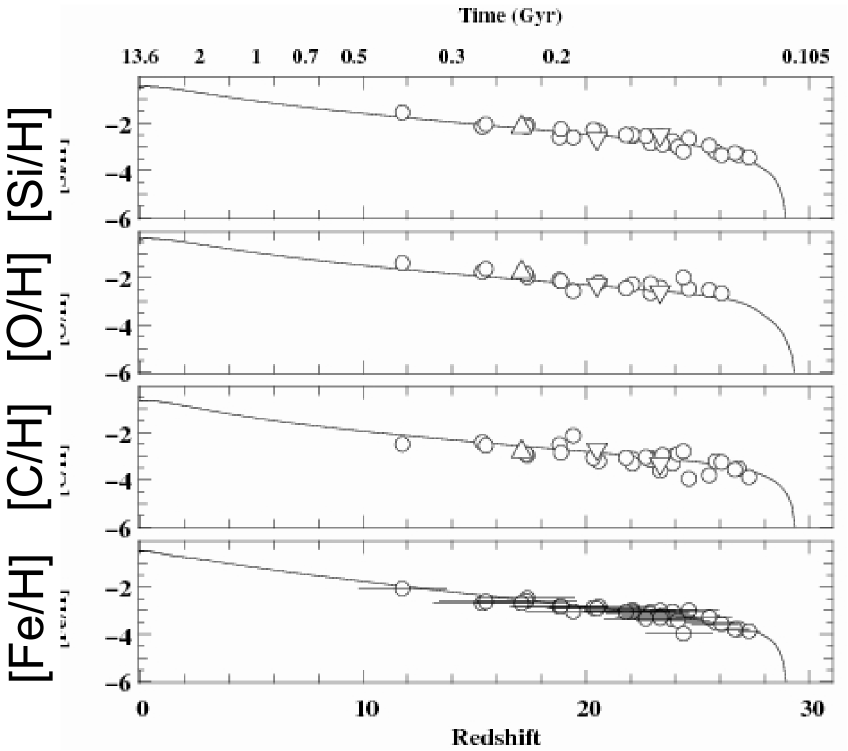
WW95 reproduce

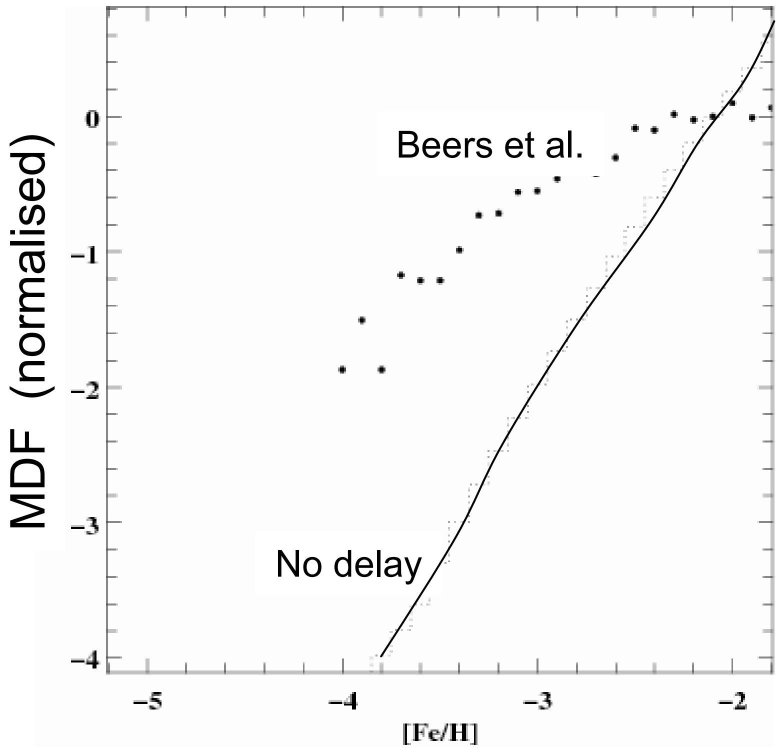
Observed EMPS abundances !



EMPS and PopII

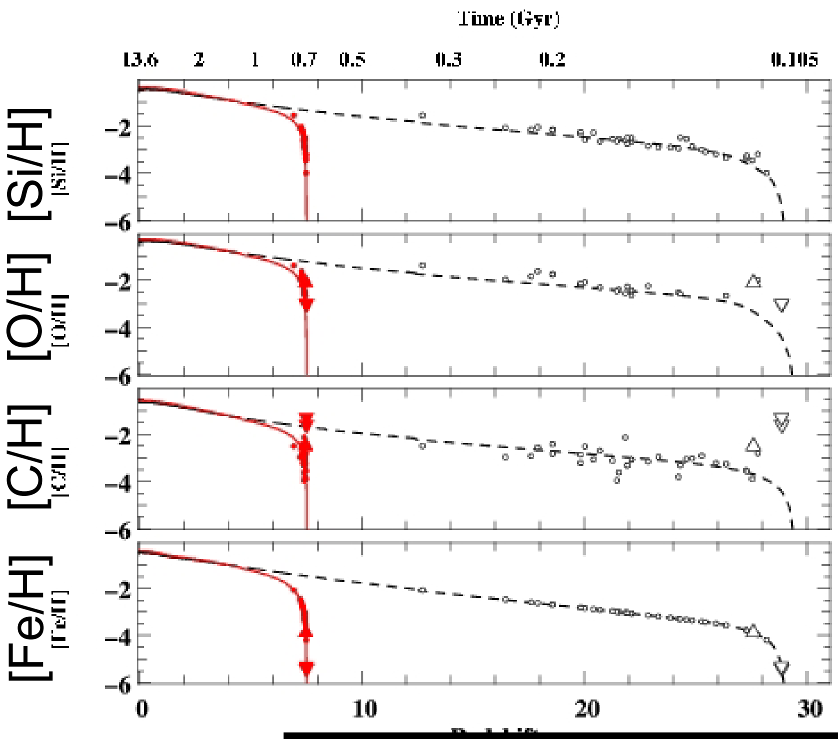
Assumption : Intermediate mass stars – MDF constraint…

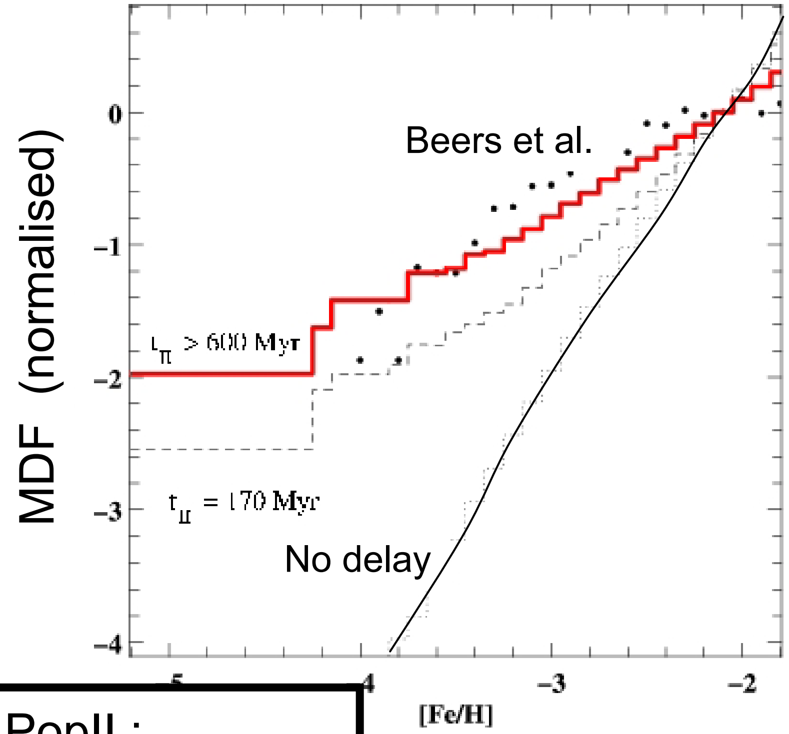




EMPS and PopII

Assumption : Intermediate mass stars – MDF constraint…



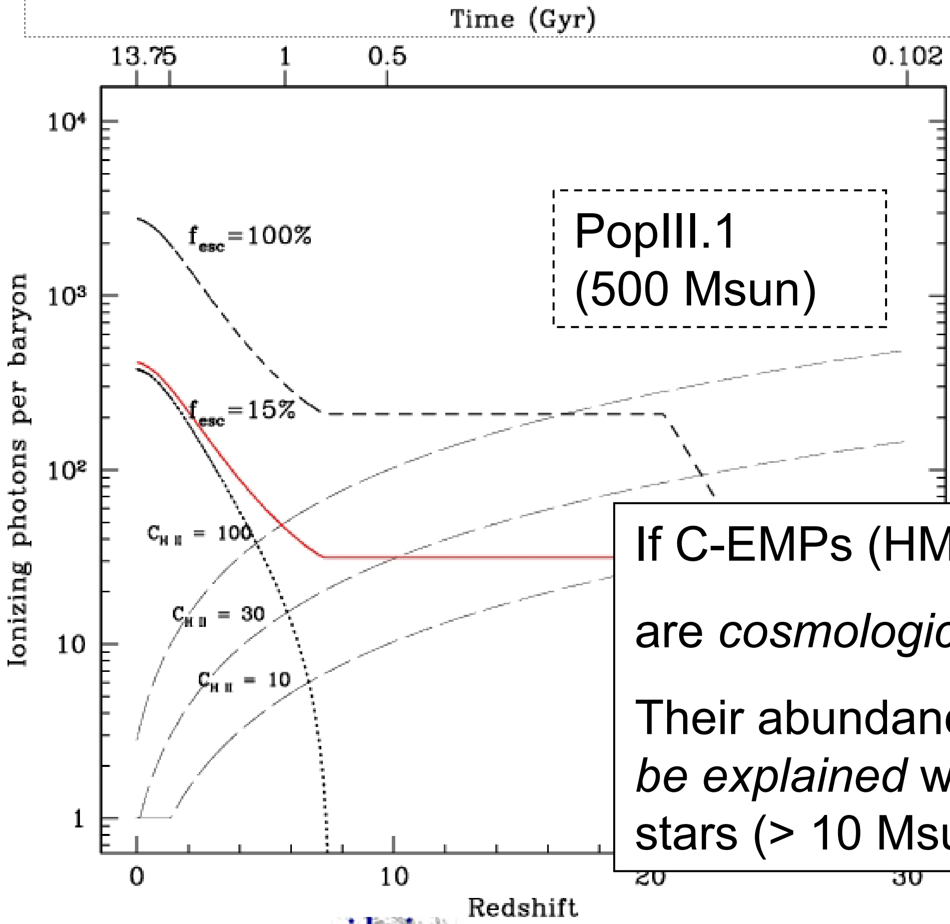


Delayed formation of PopII :

Consistent with hydro-simulation results !!

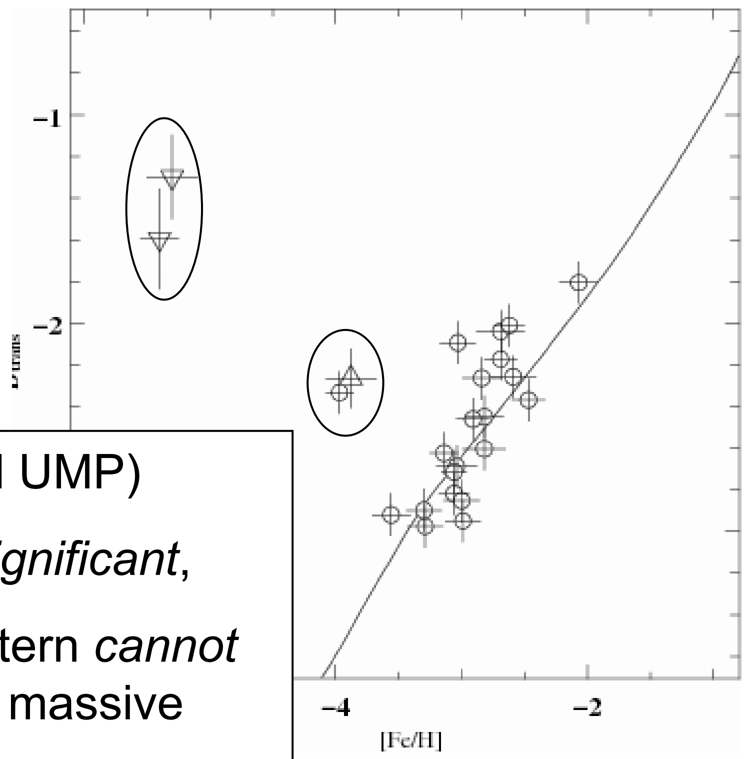
Massive Stars

Intermediate mass stars do not allow for an early reionization
Very massive stars do not explain C-EMPS abundances



PopIII.1
(500 Msun)

D_{trans} vs Fe/H



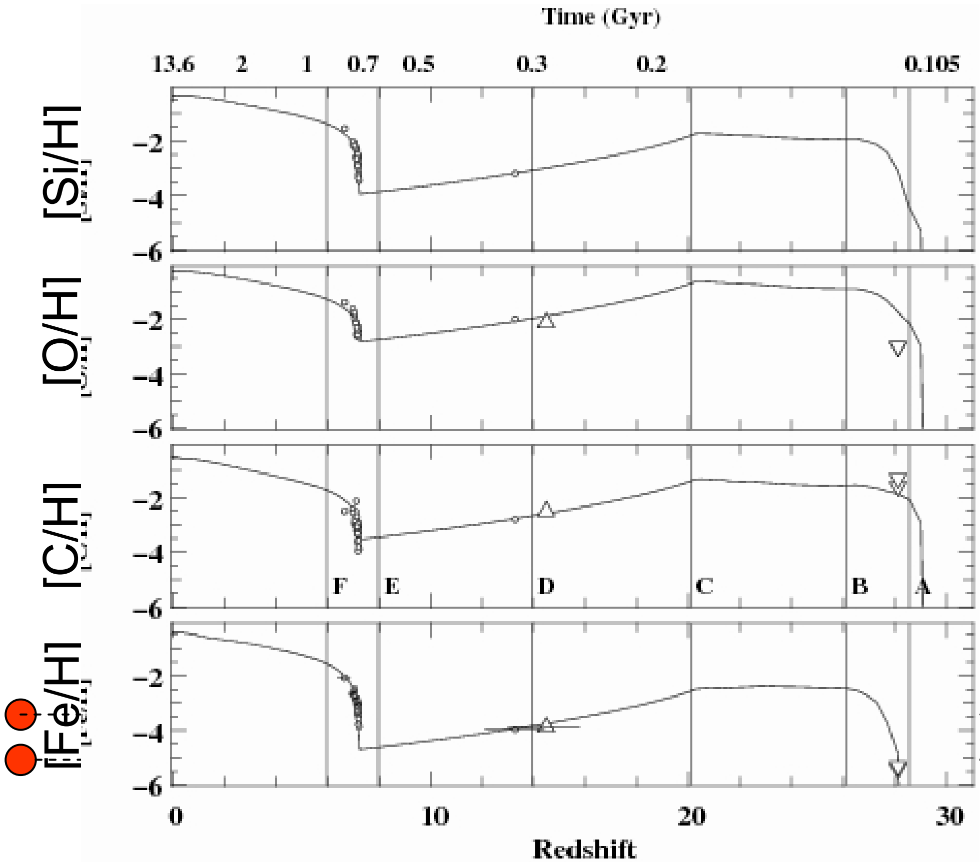
If C-EMPs (HMP and UMP)

are *cosmologically significant*,

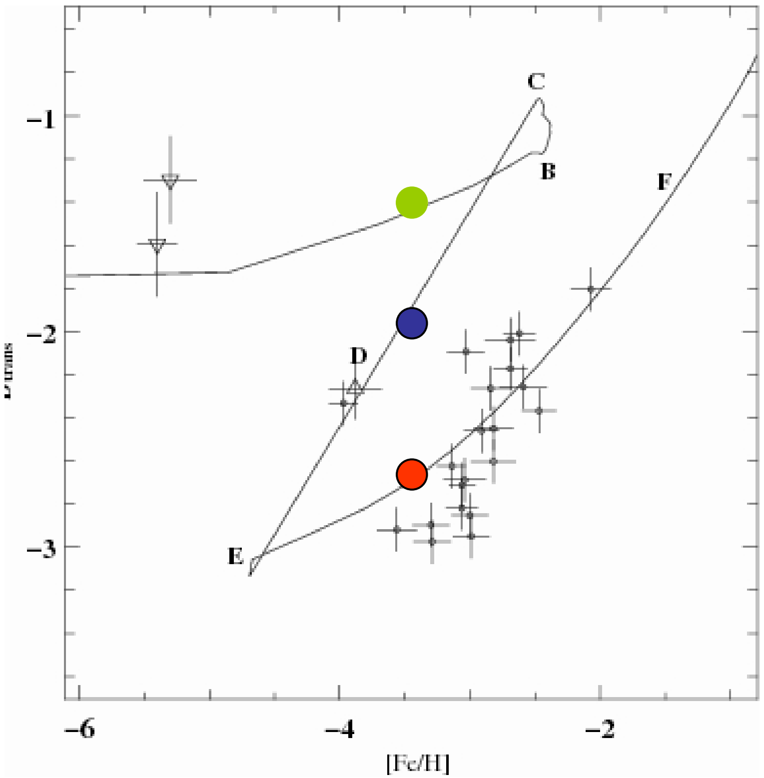
Their abundance pattern *cannot be explained* without massive stars (> 10 Msun)

HMPS and PopIII.2

Assumption : delayed PopII ; PopIII.1 **and** PopIII.2

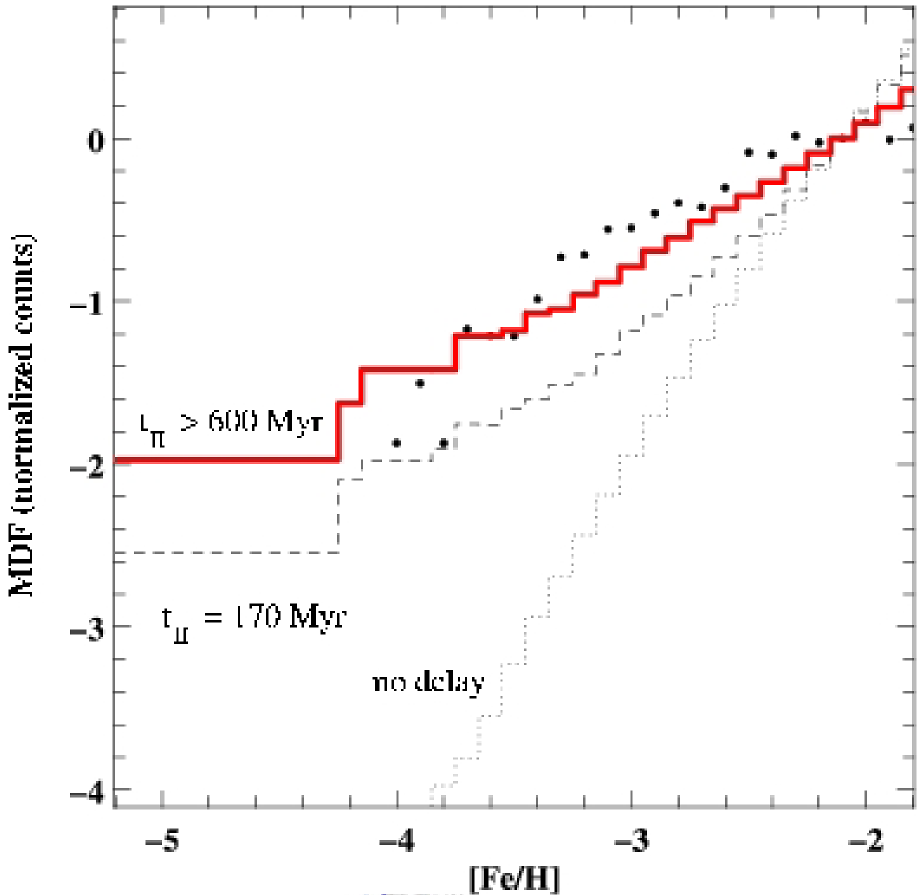


D_{trans} vs Fe/H



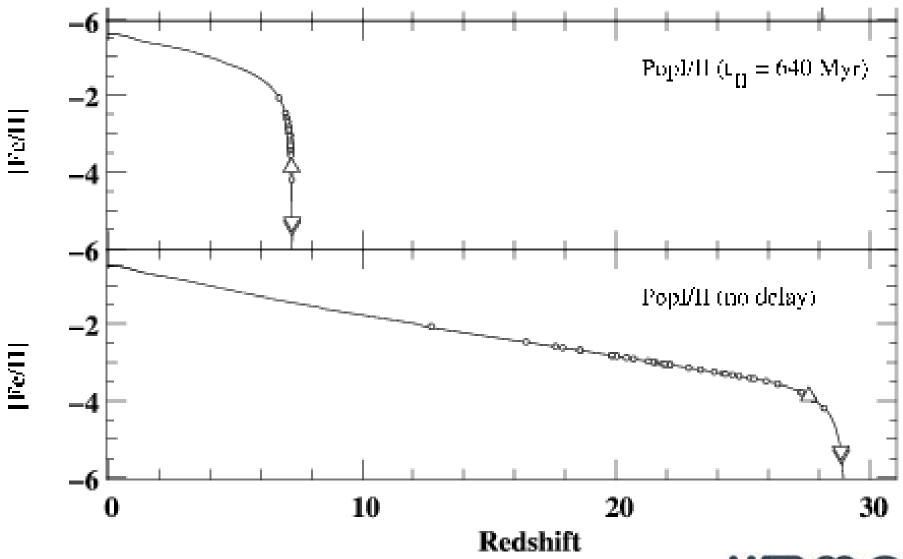
Pop II / Pop III.2 / PopIII.1 stars

Assumption : PopII +….



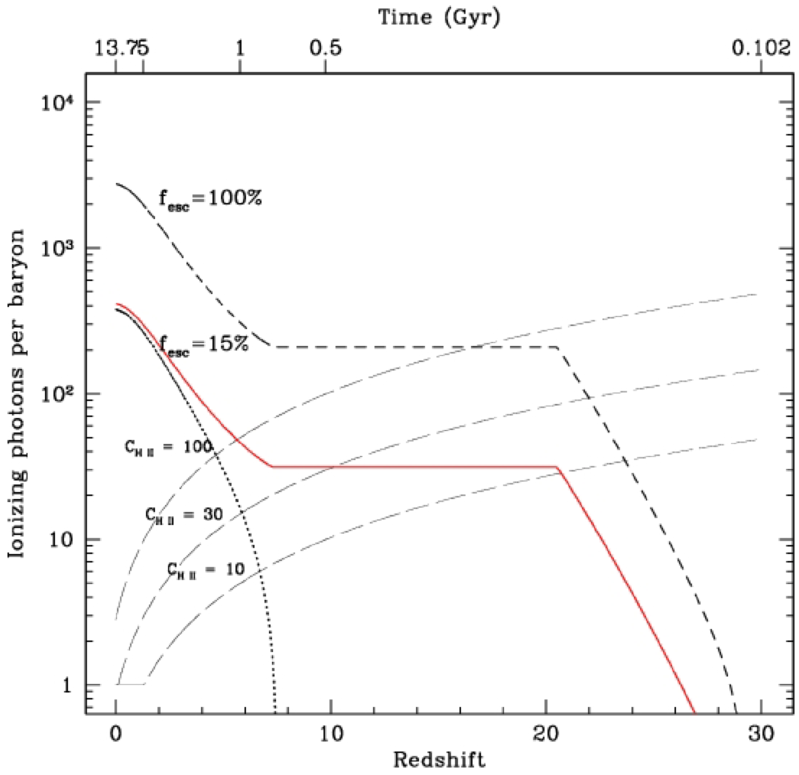
Requirement (time evolution):

delay for PopII (MDF)



Pop II / Pop III.2 / PopIII.1 stars

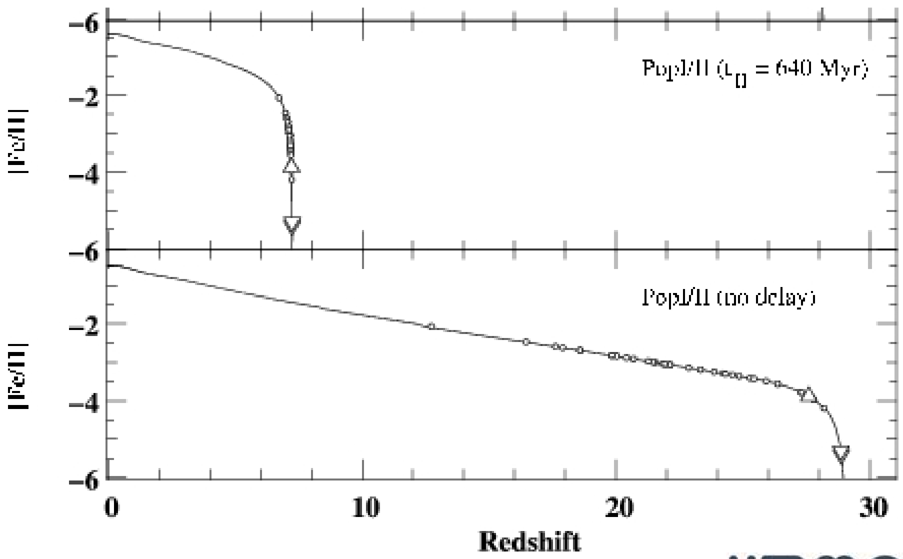
Assumption : PopII + PopIII.1 +….



Requirement (time evolution):

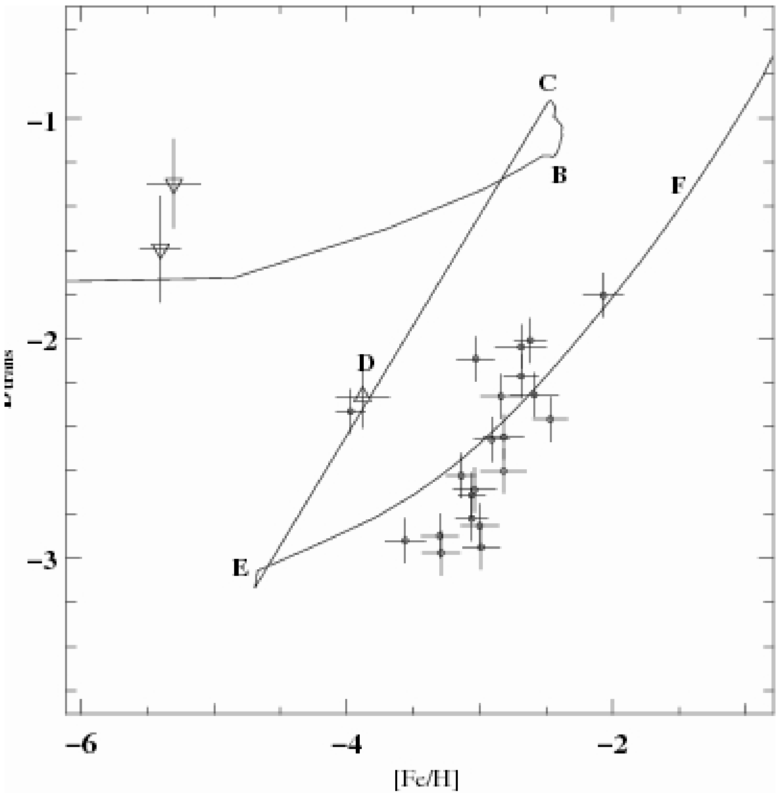
delay for PopII (MDF)

PopIII.1 (reionization)



Pop II / Pop III.2 / PopIII.1 stars

Assumption : three modes of star formation +….

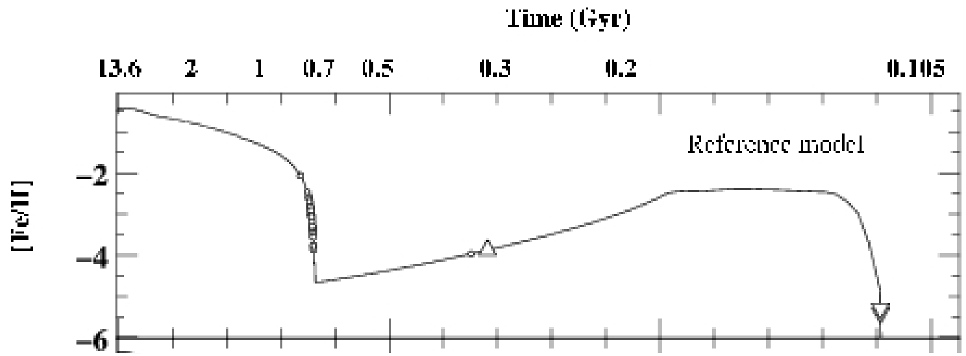


Requirement (time evolution):

delay for PopII (MDF)

PopIII.1 (reionization)

limited PopIII.2 (CEMP HMP-UMP / EMP)



Link between low and high redshift

New area : First stars and halo stars

- constraints on IMF and SFR cosmological history
- accurate determination of the formation epoch of halo stars

Link with nuclear physics and stellar evolution

Needs for yields at zero *and* low metallicities

Still some (too) simple assumptions

homogeneity / average values ?

Yet, reasonable fit to mean trend of all data

global picture similar to simulation outputs !

Larger samples of MPS…

Number of HMP, UMPS ? C-EMPS ?

Evolution in D_{trans} ?