Feedback effects

at high redshift

Benedetta Ciardi

MPA

Introduction

Once upon a time, the first sources were formed. Their mass deposition, energy injection, emitted radiation has deeply affected the subsequent galaxy/star formation process and the

Mechanical feedback

Chemical feedback

Radiative feedback

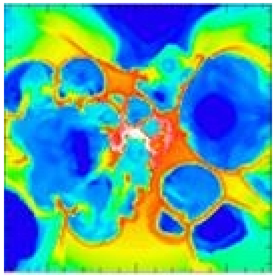
See Ciardi & Ferrara 2005
& 2008 update on astro-ph

Chapter 1

Mechanical feedback

Mechanical energy injection from winds and/or SN

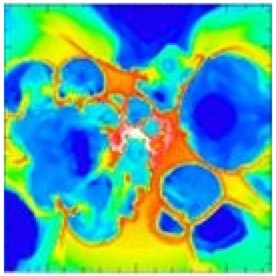
Mori, Ferrara & Madau 2002



Mechanical feedback

Ferrara 1998
Mac Low & Ferrara 1999
Nishi & Susa 1999
moto, Shigeyama & Yoshii 1999
Ciardi et al. 2000
apieco, Ferrara & Broadhurst 2000
Mori, Ferrara & Madau 2002
mm, Yoshida & Hernquist 2003
chey, Bromm & Hernquist 2003
Wada & Venkatesan 2003
lterra, Ferrara & Schneider 2003
Kitayama & Yoshida 2005
ard, Ferrara & Scannapieco 2005
Greif et al 2007

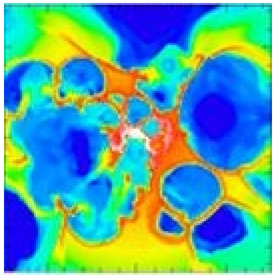
Mori, Ferrara & Madau 2002



Mechanical feedback: depletion of gas re

SN explosions can expel gas out of the host halo a
reduce the reservoir for subsequent star formatio

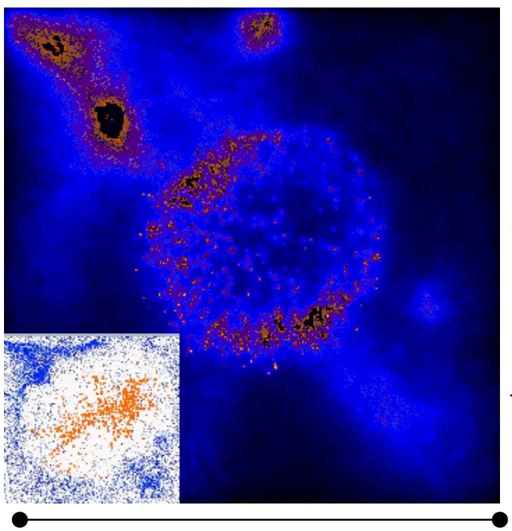
Mori, Ferrara & Madau 2002



Mechanical feedback: depletion of gas re

Cosmological simulation + zoom 6 on SN explosi

Gas distribution 10^6 yr after explosion with 10^{53} ergs



1 kpc

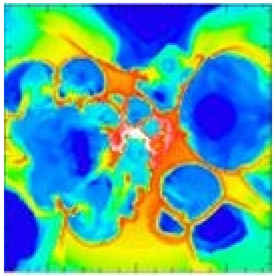
Bromm, Yoshida & Hernquist 2003

$$E_{SN} = 10^{51} \text{ergs} \; (M_* = 150 M_{sun}) \Rightarrow \text{inta}$$

$$E_{SN} = 10^{52} \text{ergs} \; (M_* = 200 M_{sun}) \Rightarrow \text{disrup}$$

Greif et al 2007

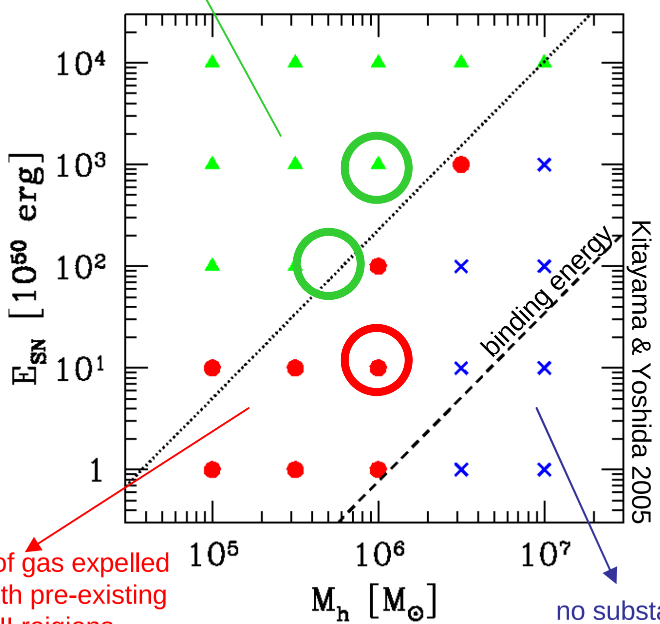
$$E_{SN} = 10^{53} \text{ergs} \; (M_* = 250 M_{sun}) \Rightarrow \text{disrup}$$



Mechanical feedback: depletion of gas re

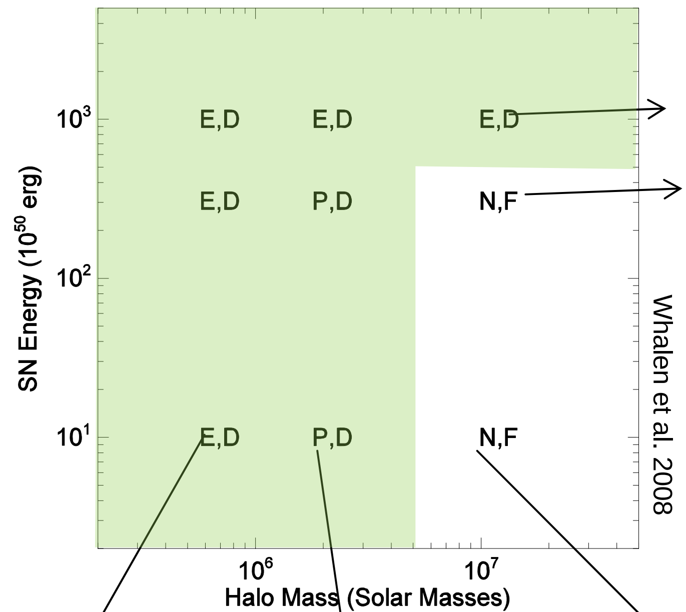
Parametric study of SN explosions

>90% of gas expelled also without pre-existing HII regions



>90% of gas expelled only with pre-existing HII reigions

no substantial gas outflow



Destroyed

Fallback

Evaporated

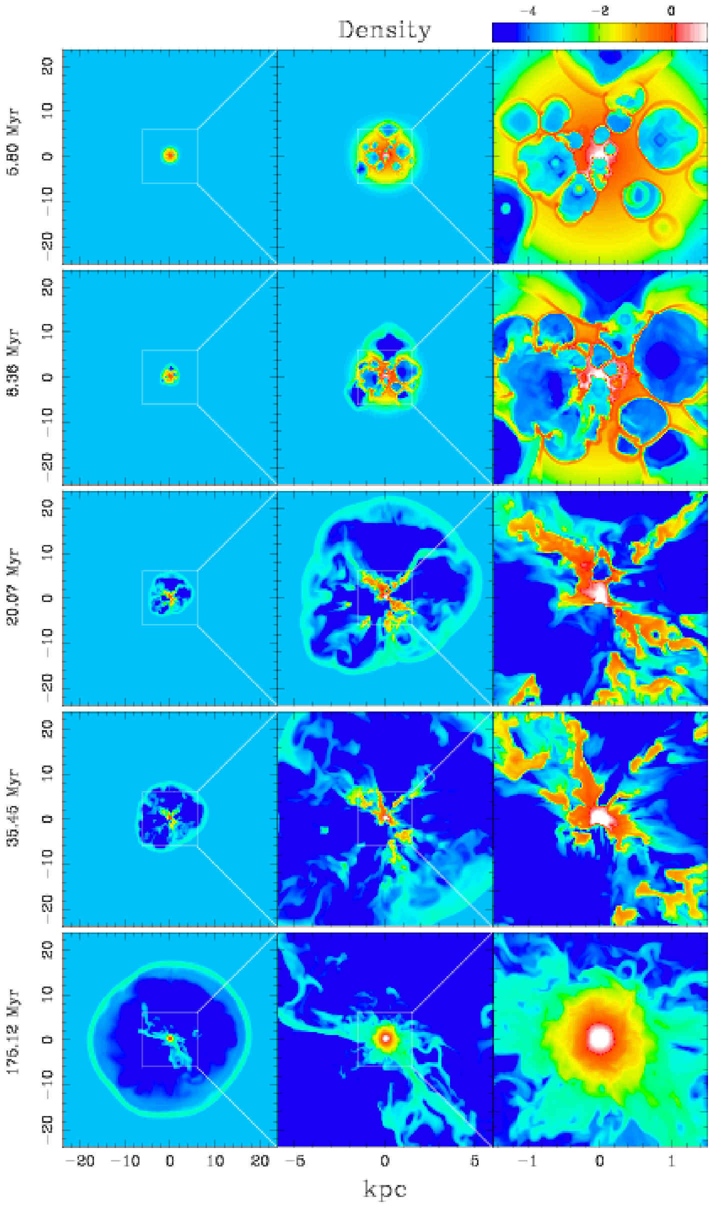
Partially ionized

Neutral

Mechanical feedback: depletion of gas re

AMR simulation of multiple SN^8 explosions in M

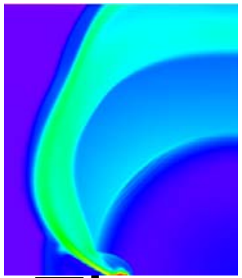
Mechanical feedback: depletion of gas re



Mori, Ferrara & Madau 2002

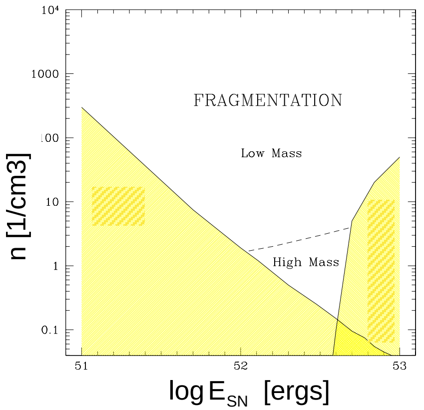
Off-center SN explosions c
propagating shocks that pr
second SF episode in the

MacLow & Ferrara 1998



Mechanical feedback: SF induced by sho

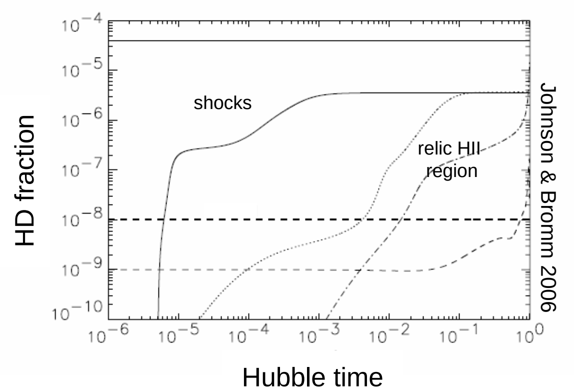
The gas swept by shocks is compressed and can induce a positive feedback on star formation



Salvaterra et al 2004

- The dense shell can fragment a

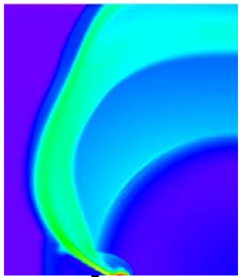
Mackey, Bromm & Hernquist 2003; Salvaterra, Ferrara & Schneider 2004



Johnson & Bromm 2006

- HD formation is promoted and

Vasiliev & Shchekinov 2005; Johnson & Bromm 2006; Greif et al 2007



MacLow & Ferrara 1998

Mechanical feedback: SF induced by sho

The gas swept by shocks is compressed and can induce a positive feedback on star formation

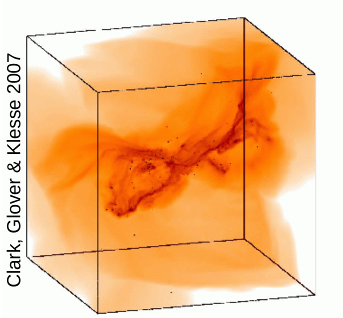
2nd generation stars are smaller than 1st generation ⇒ low-metallicity, low-mass stars

Would 3D studies find the same resul

Chapter 2

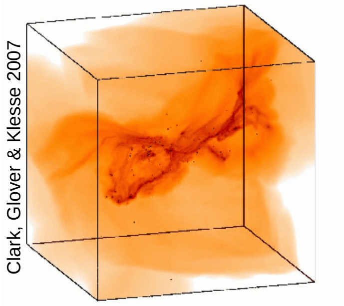
Chemical feedback

Critical metallicity of the gas that induces a transition from massive to more standard star formation



Chemical feedback

Bromm et al 2001
Schneider et al 2002
Bromm & Loeb 2003
Omukai et al 2005
Santoro & Shull 2006
Schneider et al 2006
Tsuribe & Omukai 2006
ark, Glover & Klessen 2007
Smith & Sigurdsson 2007
tore, Schneider & Ferrara 2007
Tsuribe & Omukai 2008



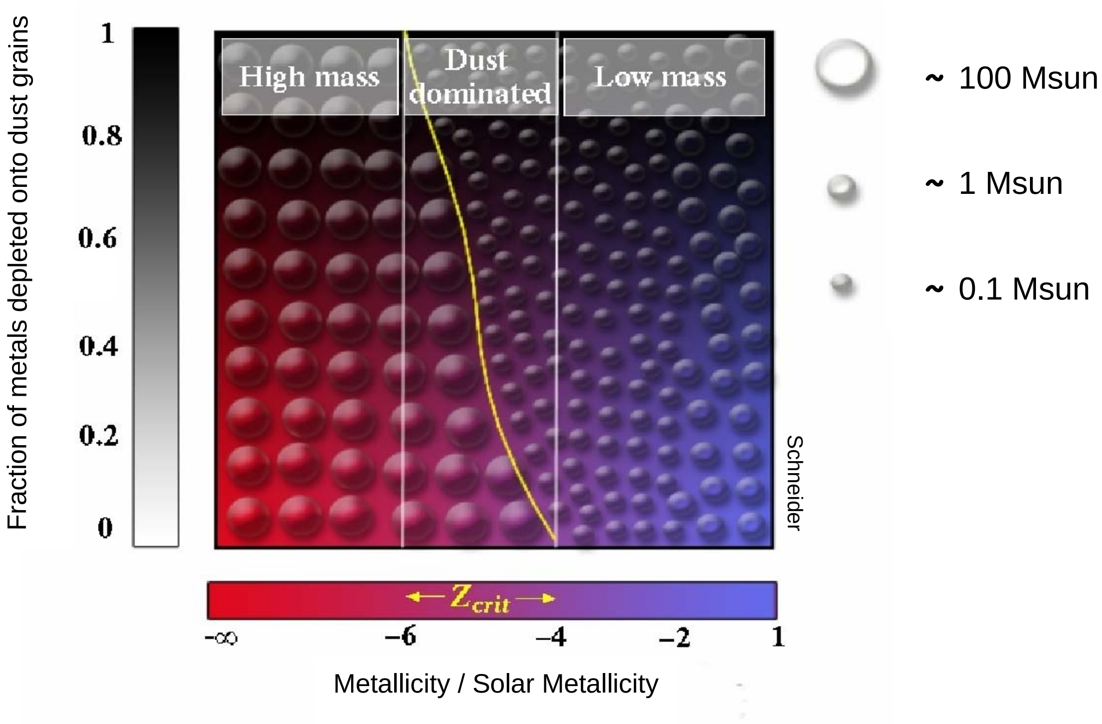
Chemical feedback: fragmentation of gas

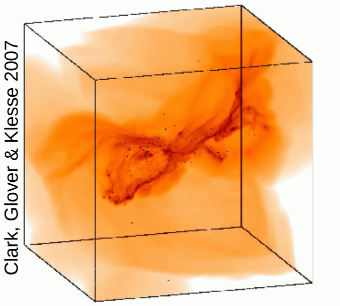
1D/3D simulations; cosmological IC or single clou

Chemistry: H, He, metals (Z) + Dust

+ CII, OI, SiII, FeII + H2 + D

Schneider et al 2002, 2006
Omukai et al 2005
Tsuribe & Omukai 2006, 2008
Clark, Glover & Klessen 2007





Clark, Glover & Klesse 2007

Chemical feedback: fragmentation of gas

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Bromm et al 2001
Bromm & Loeb 2003
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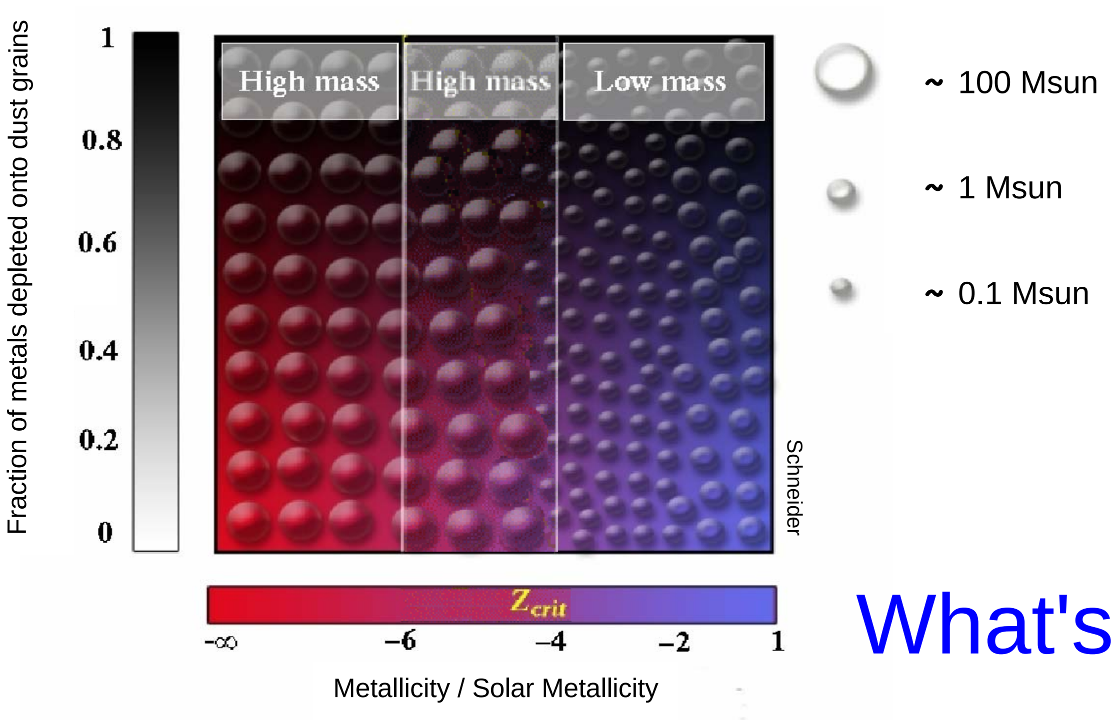
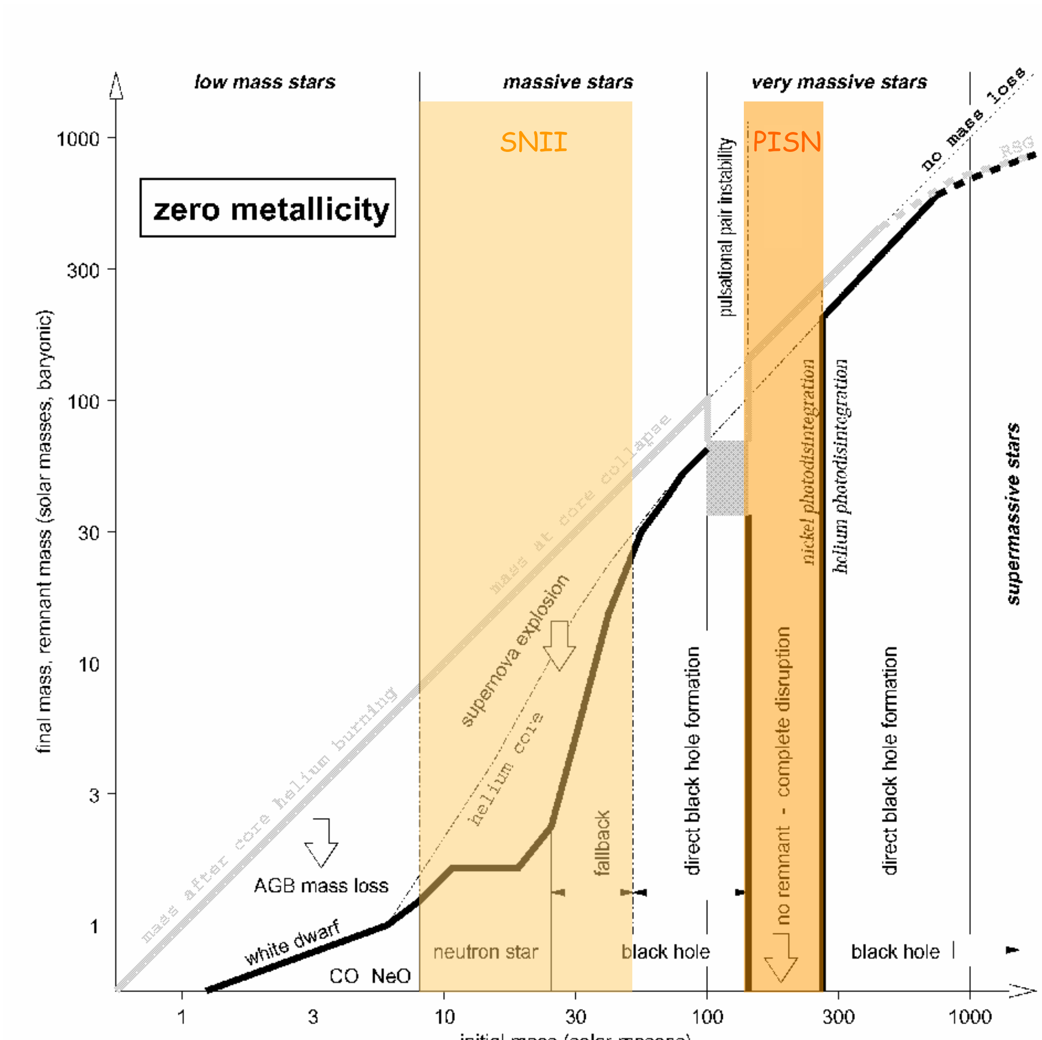


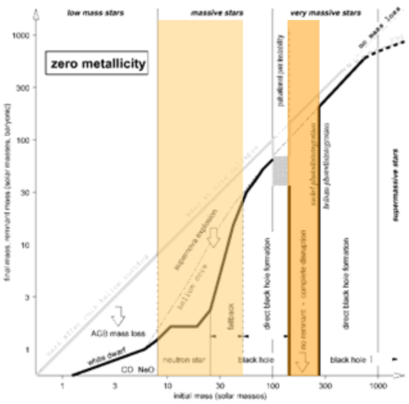
What's the role o

Chemical feedback: missing ingredients



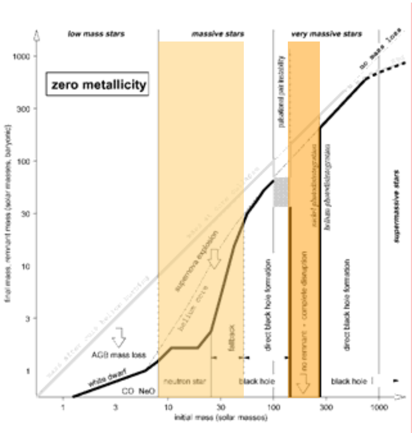
Heger & Woosley 2002

Chemical feedback: missing ingredients

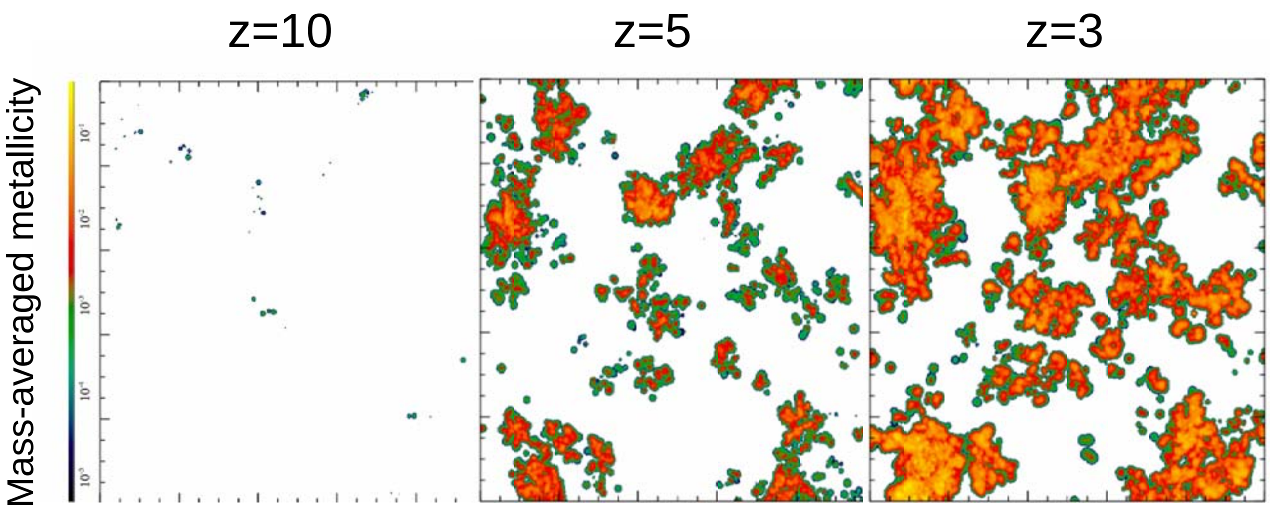


IMF of the first stars → abundance of

Chemical feedback: missing ingredients

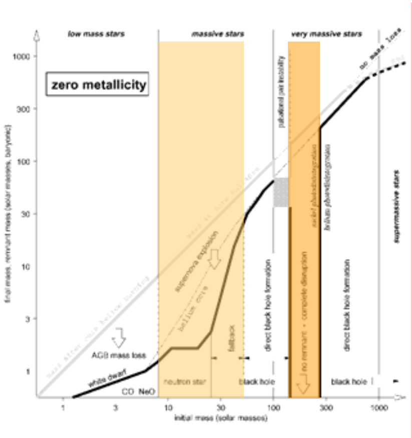


IMF of the first stars → abundance of

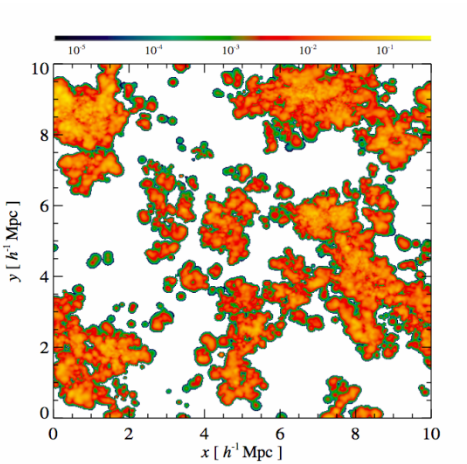


Tornatore, Schneider & Ferrara 2007

Chemical feedback: missing ingredients



IMF of the first stars → abundance of

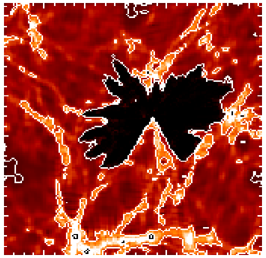


efficiency of metal enrichment → loca

Chapter 3

Radiative feedback

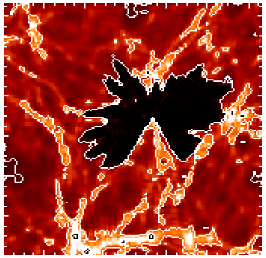
Ionization/dissociation of atoms/molecules & heating



Ciardi et al 2001

Radiative feedback

Haiman, Rees & Loeb 1997
Ciardi, Ferrara & Abel 2000
Ciardi et al 2000
Haiman, Abel & Rees 2000
Susa & Kitayama 2000
Haiman, Abel & Madau 2001
Kitayama et al 2000, 2001
Machacek, Bryan & Abel 2001
Ricotti, Gnedin & Shull 2002
Yoshida et al 2003
Dijkstra et al 2004
Shapiro, Iliev & Raga 2004
Susa & Umemura 2004
Alvarez, Bromm & Shapiro 2006
Ahn & Shapiro 2007
Ciardi & Salvaterra 2007
Johnson, Greif & Bromm 2008
McGreer & Bryan 2008
Mesinger & Dijkstra 2008
Whalen et al. 2008

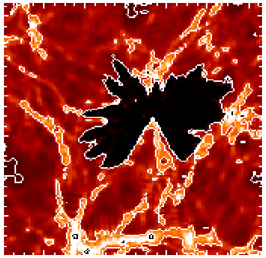


Ciardi et al 2001

Radiative feedback: ionization/dissociatio

The minimum mass of objects in the absence of $M_{min} \gtrsim 10^5 M_\odot$

In the presence of UV/SUV radiation objects dow M_{mi}
and collapse, but the star formation can be dela
radiation intensity, mass and evolutionary stage



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Radiative feedback: ionization/dissociatio

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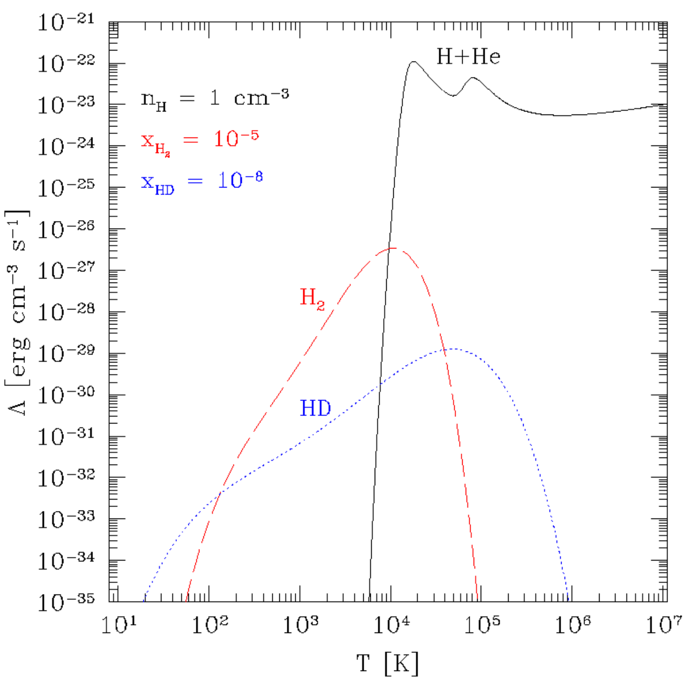
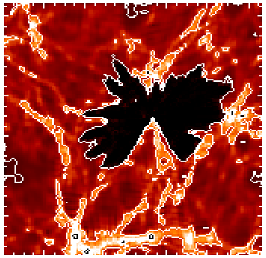


Maio et al. 2008

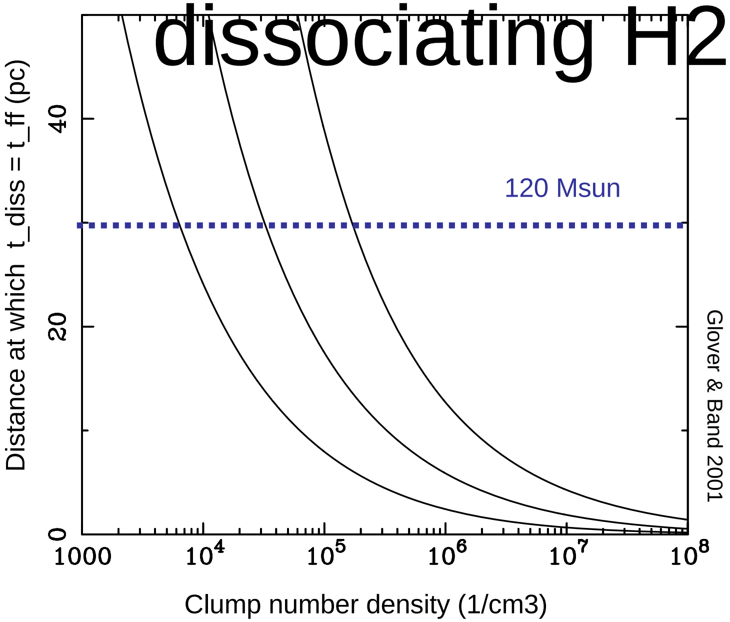
- T>10000K halo formation reli
- T<10000K halo formation reli
- H2 easily dissociated by Lym

$$H_2 + \gamma_{(11.2-13.6)eV} \rightarrow H + H$$



Radiative feedback: ionization/dissociatio

Once the first generation of stars has formed in an object, it can affect the subsequent SF process by dissociating H2 in star forming clouds.



- 1 massive star produces eno dissociate the entire host ha

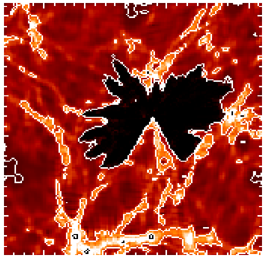
Omukai & Nishi 1999; Nishi & Tashiro 2000

- If star forming clumps are de enough from the star, SF pr

Glover & Band 2001; Susa & Umemura 2006

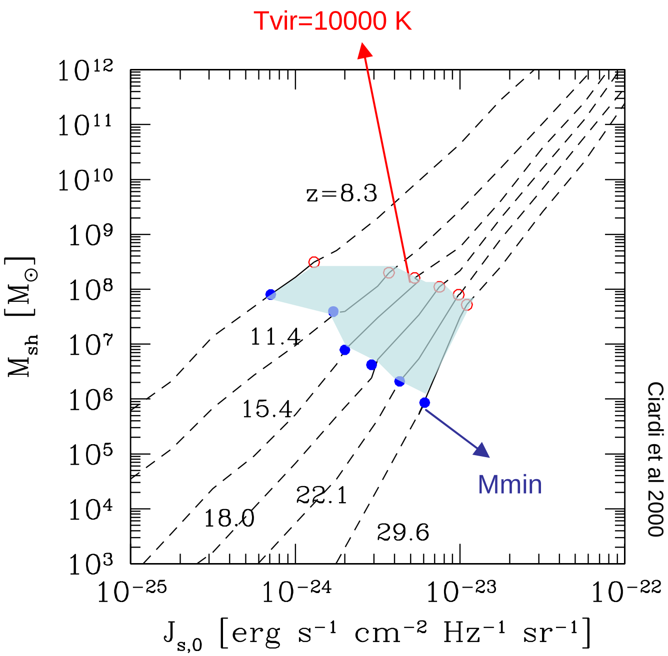
r_{vir} ($M = 10^6 M_{sun}$; $z = 30$) ~ 100pc

Ciardi et al 2001



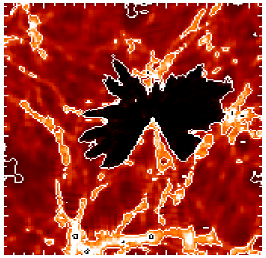
Radiative feedback: ionization/dissociatio

Ability of a halo to self-shield against an exter



- Range affected by feedbac

Ciardi et al 2001



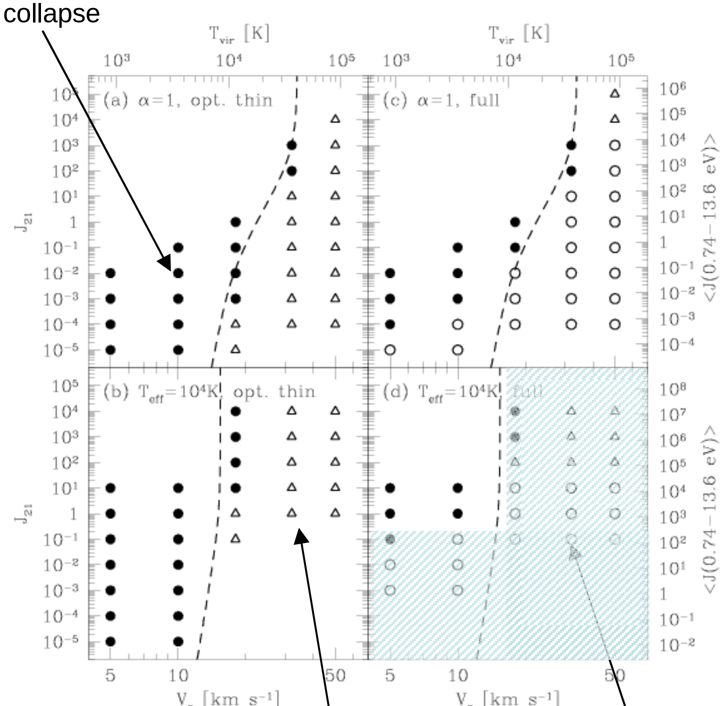
Radiative feedback: ionization/dissociatio

1D and 3D simulations of collapse of single halo

Susa, Kitayama, Umemura et al

z ~ 10

no collapse

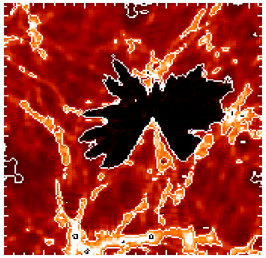


Kitayama et al. 2001

collapse

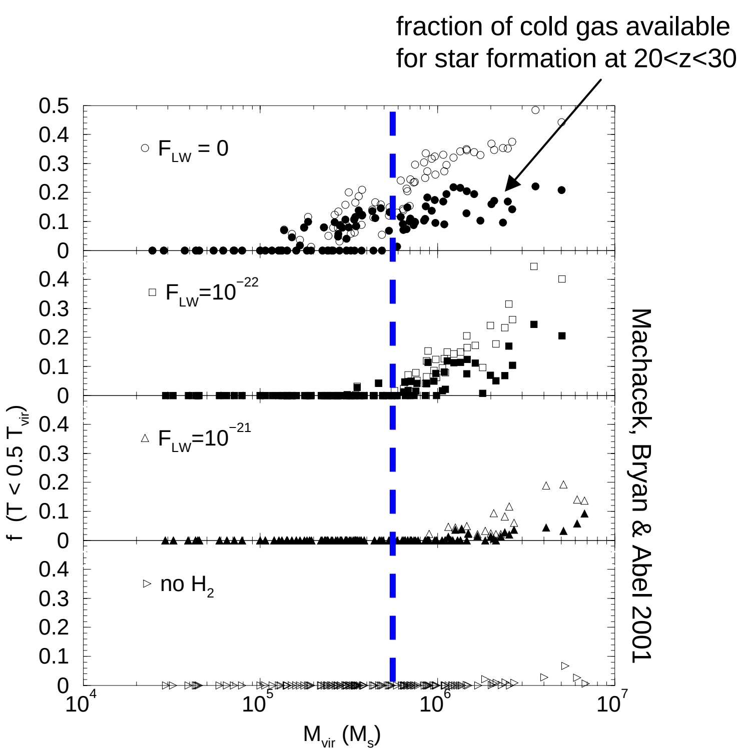
collapse & cooling

- If $J < 10^{-22}$ halos with $M > 10^6 M_{su}$
- If $M > 10^8 M_{su}$ objects collapse
- Otherwise the fate depends o

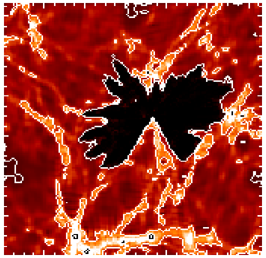


Radiative feedback: ionization/dissociatio

Cosmological simulations + SUVB to study the fa



- Collapse and cooling delaye
- The amount of cold gas depe
- Objects with $M \approx$ few 10^5 M_{su} ca
  if $J < 10^{22}$



Ciardi et al 2001

Radiative feedback: ionization/dissociatio

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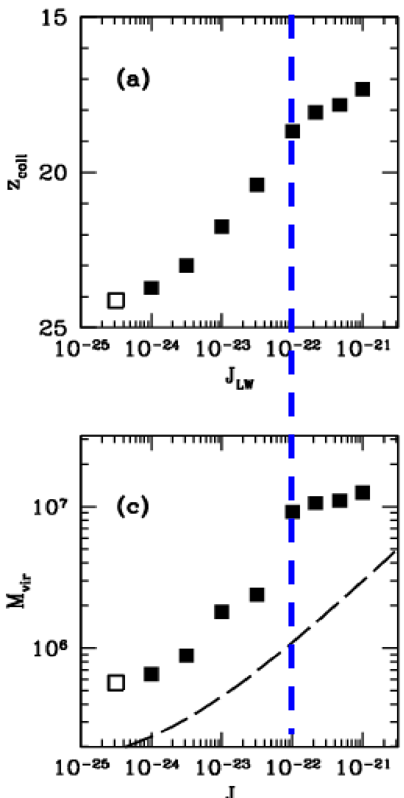
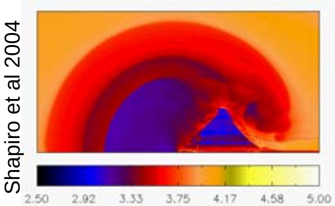


O'Shea & Norman 2007

- Collapse and cooling delaye
- The amount of cold gas depe
- Objects with $M \approx few \cdot 10^5 M_{su}$ ca
  if $J < 10^{22}$
- Objects with $M \approx few \cdot 10^5 M_{su}$ c
  also if $J > 10^{22}$

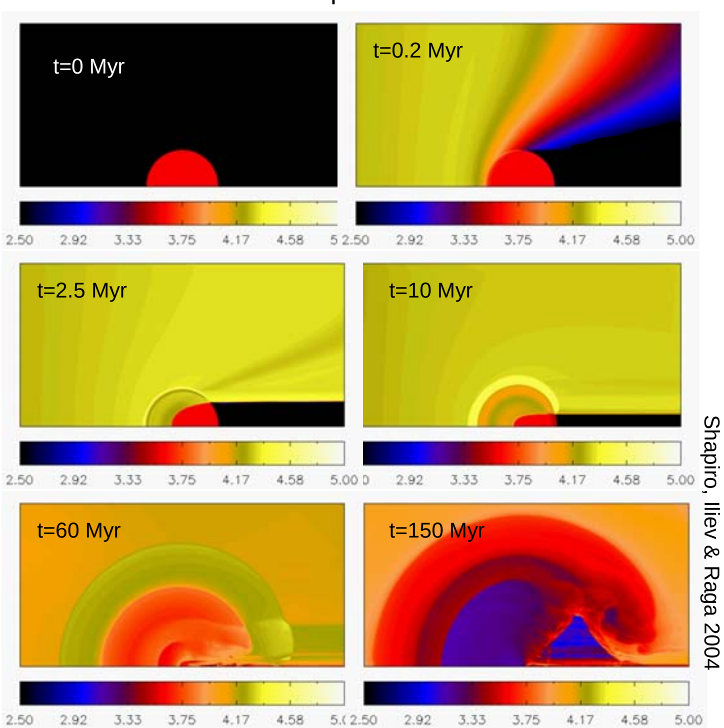
Shapiro et al 2004



Radiative feedback: photoevaporation

Small mass halos can be photoevaporated by ra

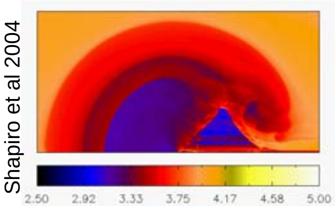
Temperature



Shapiro, Iliev & Raga 2004

- The degree of photoevapor
  the evolutionary stage of h
- The time scale for complete
  is generally larger than a m
- Minihalos can survive photo

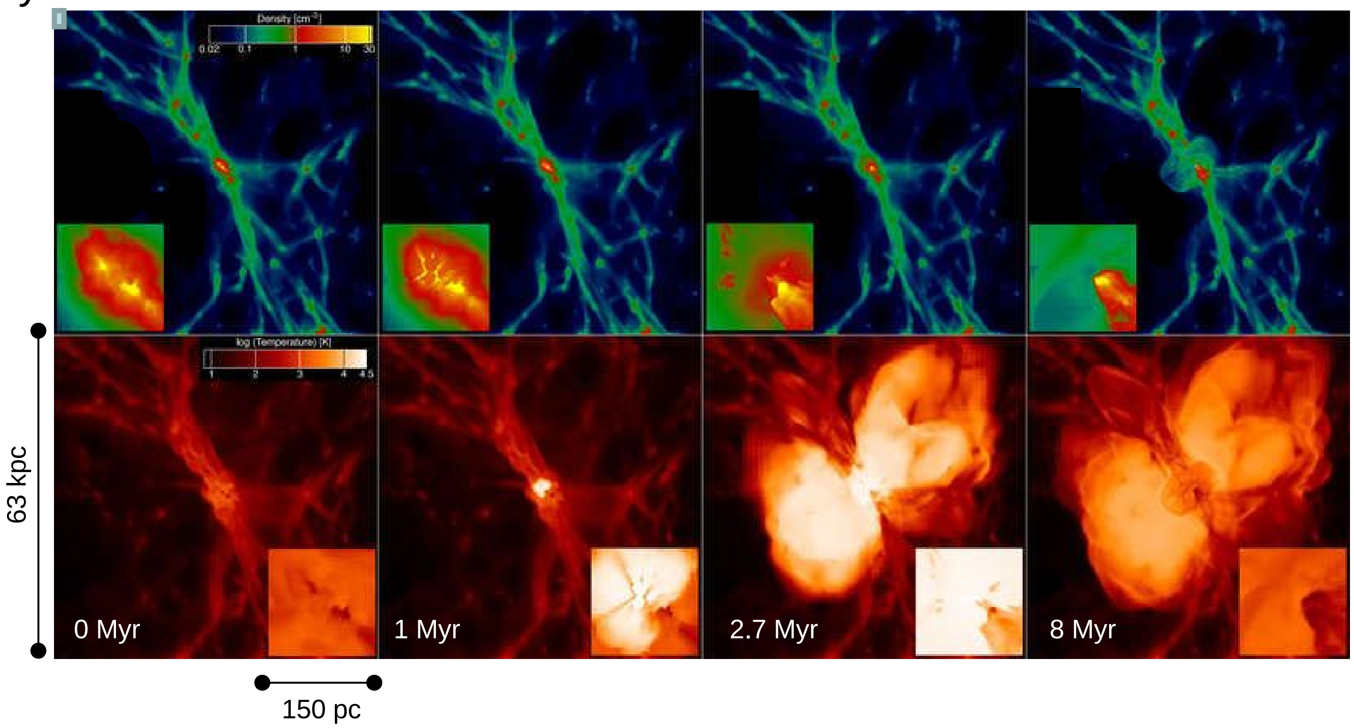
Alvarez, Bromm & Shapiro 2006; Abel, Wise & Bryan 2007;
Ahn & Shapiro 2007; Yoshida et al. 2007; Whalen et al. 2008



Shapiro et al 2004

Radiative feedback: photo-ion./-diss./-eva

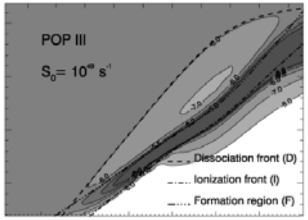
Density



Abel, Wise & Bryan 2007

Temperature

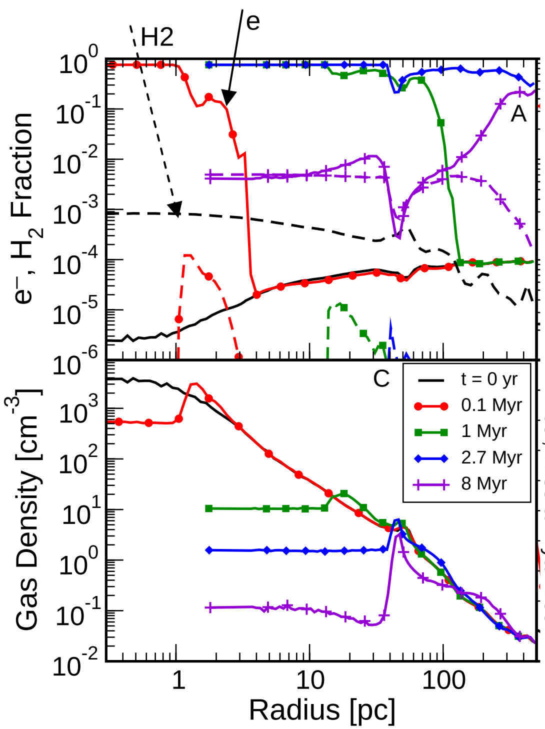
Ricotti et al 2001



Radiative feedback: positive feedback

Molecules can re-form e.g. inside relic HII regions

Ricotti, Gnedin & Shull 2001; Nagakura & Omukai 2005; O'Shea et al 2005; Abel, Wise & Bryan 2007; Mashchenko, Couchman & Sills 2006; Yoshida et al 2007; Johnson, Greif & Bromm 2008; McGreer & bryan 2008



Abel, Wise & Bryan 2007

- H2 is efficiently re-formed in re
- HD is formed and lowers T ev

Nagakura & Omukai 2005; Johnson & Bromm 2006; Yoshida et al 2007; McGrrer & Brian 2008

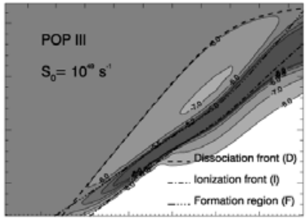
- Typically the mass of these se stars is smaller

see also Yoshida, Omukai & Hernquist 2007

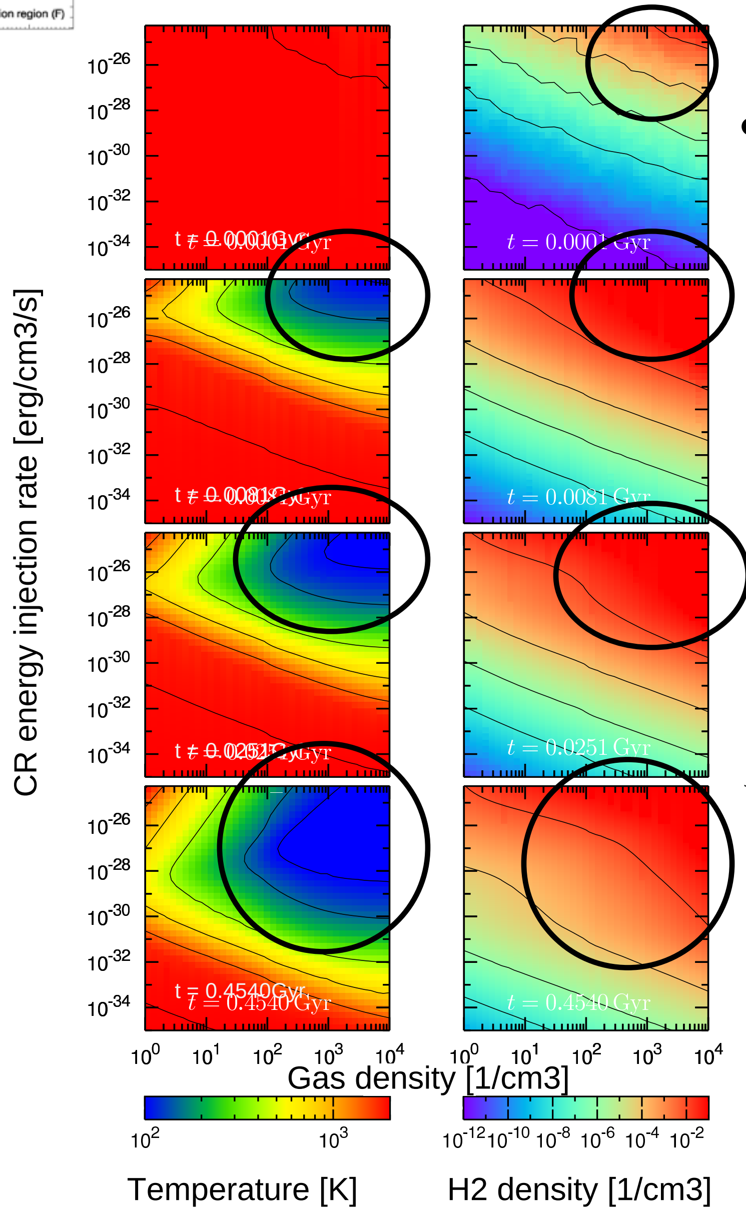
- Molecules formation promoted x-rays or cosmic rays

Shchekinov & Vasiliev 2004; Kuhlen & Madau 2005; Jasche, Ciardi & Ensslin 2007; Stacy & Bromm 2007; Ripamonti, Mapelli & Zaroubi 2008

Ricotti et al 2001



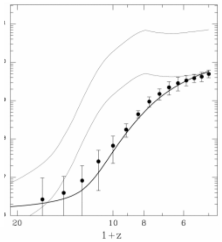
Radiative feedback: positive feedback



Jasche, Ciardi & Ensslin 2007

- For given $\dot{\epsilon}_{CR}$ n_{gas} and H2 is promoted and T dro

(Gnedin 2000



Radiative feedback: photoheating

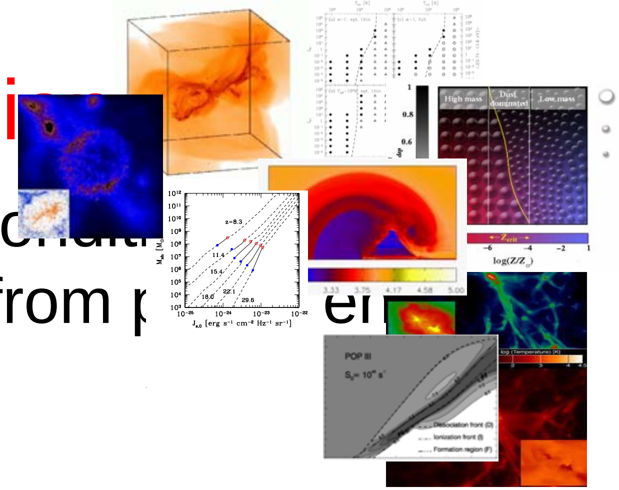
- Relic HII regions have an entropy floor that prev
  cooling in subsequent generations of small hal

Oh & Haiman 2003; Kramer, Haiman & Oh 2006

- Heating associated with photoionization and Ly
  a suppression of the fraction of gas in small ma

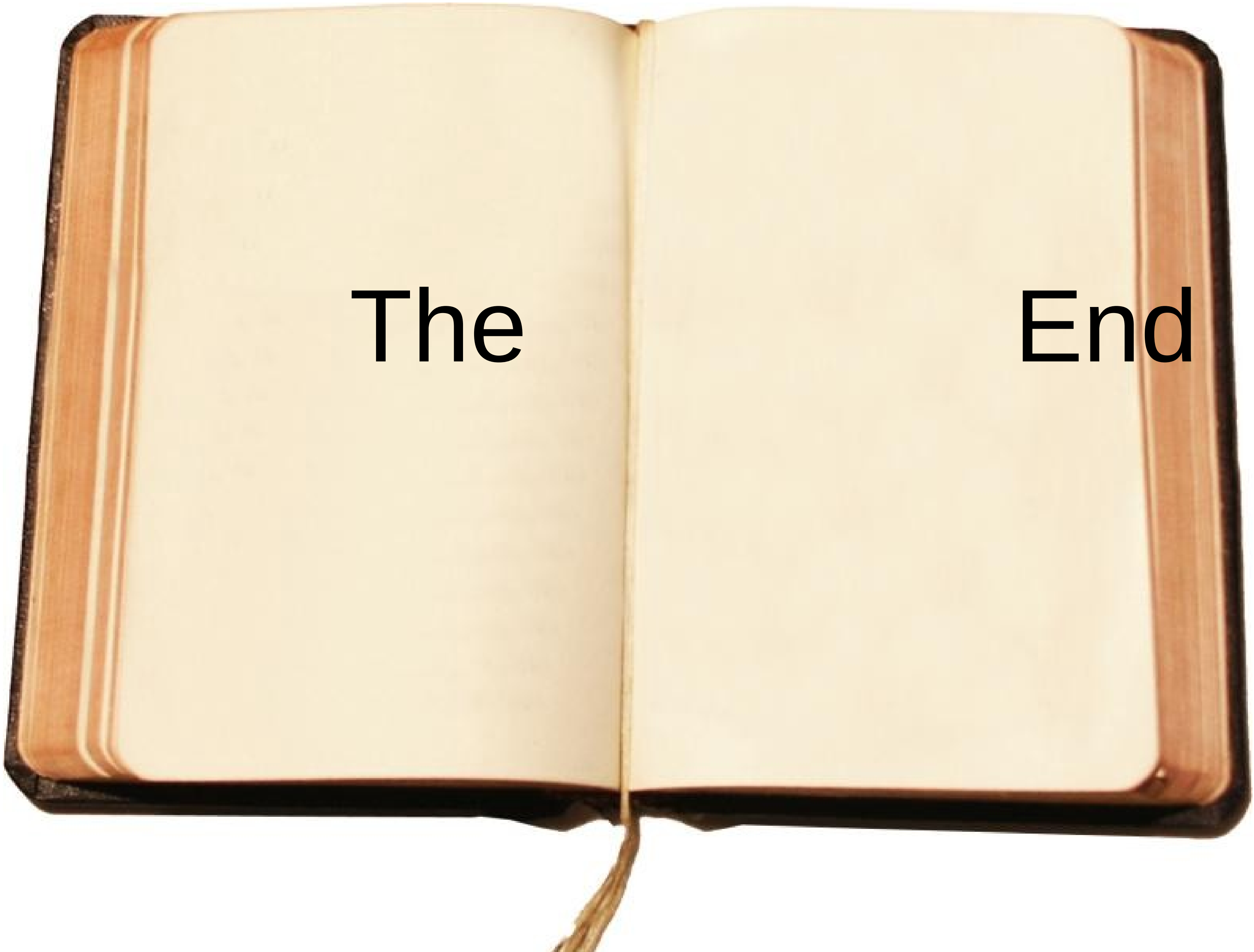
e.g. Gnedin 2000; Ciardi & Salvaterra 2007

Conclusi



1. Feedback depends on the specific local co
2. Feedback is not as efficient as expected from p er estimates
3. Star forming regions further than few tens of pc not affected by its radiation
4. Its UV radiation delays and limit the collapse of cold gas in nearby objects
5. Photoevaporation of nearby minihalos seems to be inefficient
6. Formation of H2 and HD in relic HII regions promote structure formation

7. The host halo is completely disrupted if $M < few \cdot 10^6 M_{sun}$
8. After explosion gas in shells can fragment and form stars
9. Metals/dust are expelled and induce a transition to standard SF


The End