Local photo-ionization radiation, Circum-galactic gas cooling and galaxy formation

or

A "critical" Star-Formation-Rate divides hot-mode from cold-mode accretion

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Chandra - M101

Outline:

- Introduction/motivation

- The effect of local ionization sources on gas cooling

- Application to "hot-mode/cold-mode" accretion model

- Work in progress

- Summary

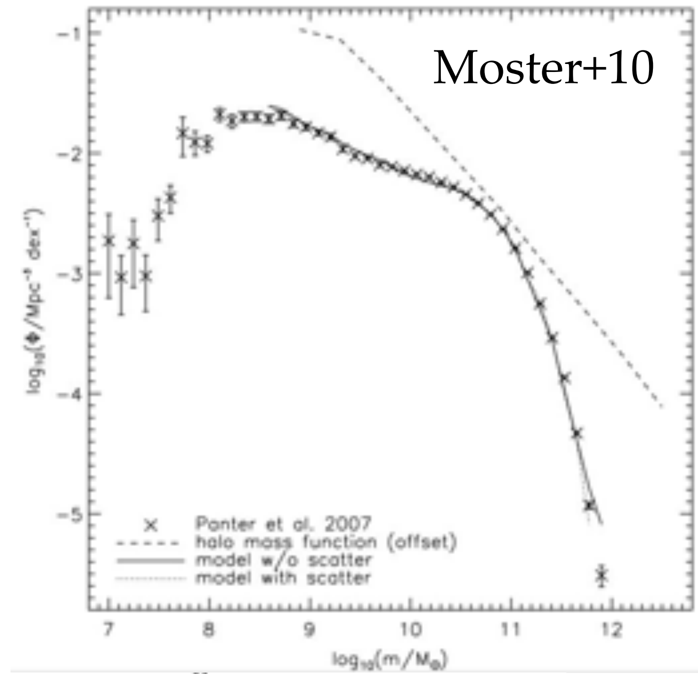
"We understand everything about gas cooling thanks to our hydrodynamical simulations, so we only need to focus on SN and AGN feedback."

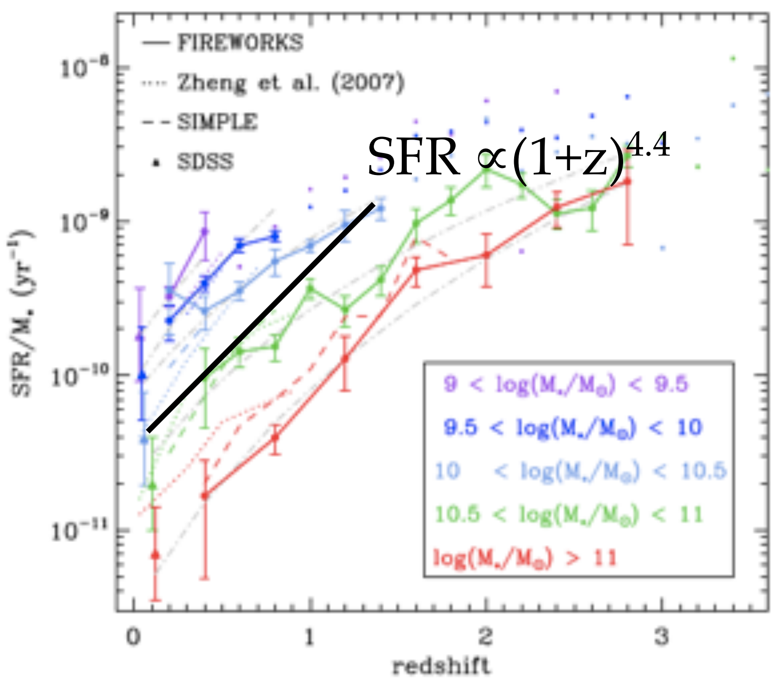
A Colloquium Speaker, IoA, 2009

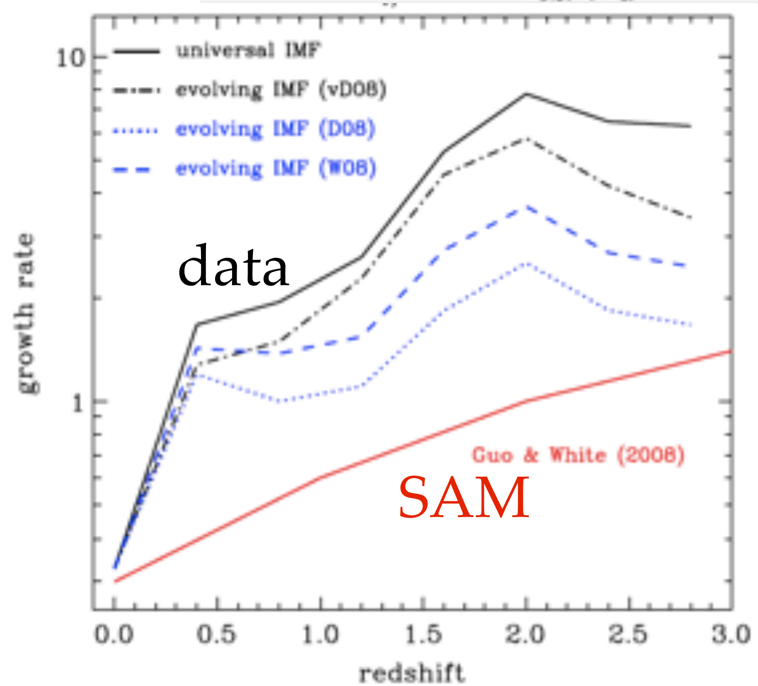
Introduction/Motivation: some QNQ problems

- Low SFR efficiency at low (and high) masses.

- Very steep redshift evolution of the specific SFR.







Damen+09 (see also Daddi+09, Oliver+10, Karim+11)

How to regulate the SFR at the low mass end

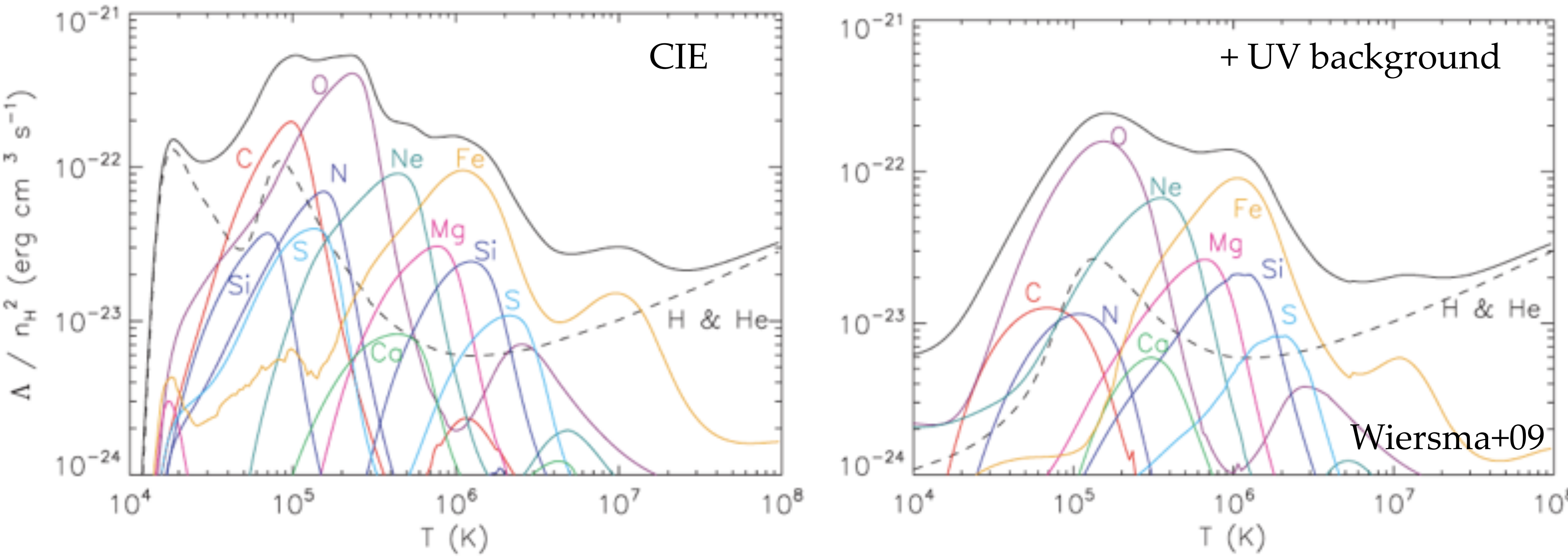
1) removing the gas from the galaxy (e.g., SN feedback, "ejective feedback").
2) reducing/stopping cooling gas accretion from halo ("preventive feedback").

ejective feedback: may work well if you fix just right a list of unconstrained physical parameters (winds, mass loading factor, etc.). See, e.g., rest of the workshop.

preventive feedback: cooling gas accretion is governed by "simple" atomic physics, ions abundances and gas temperature.

→ basic idea (e.g., Efstathiou 1992): every process that is able to change cooling ions abundances is able to change cooling and gas accretion (e.g. UV background kills formation of low mass haloes).

Cooling Function: the basics



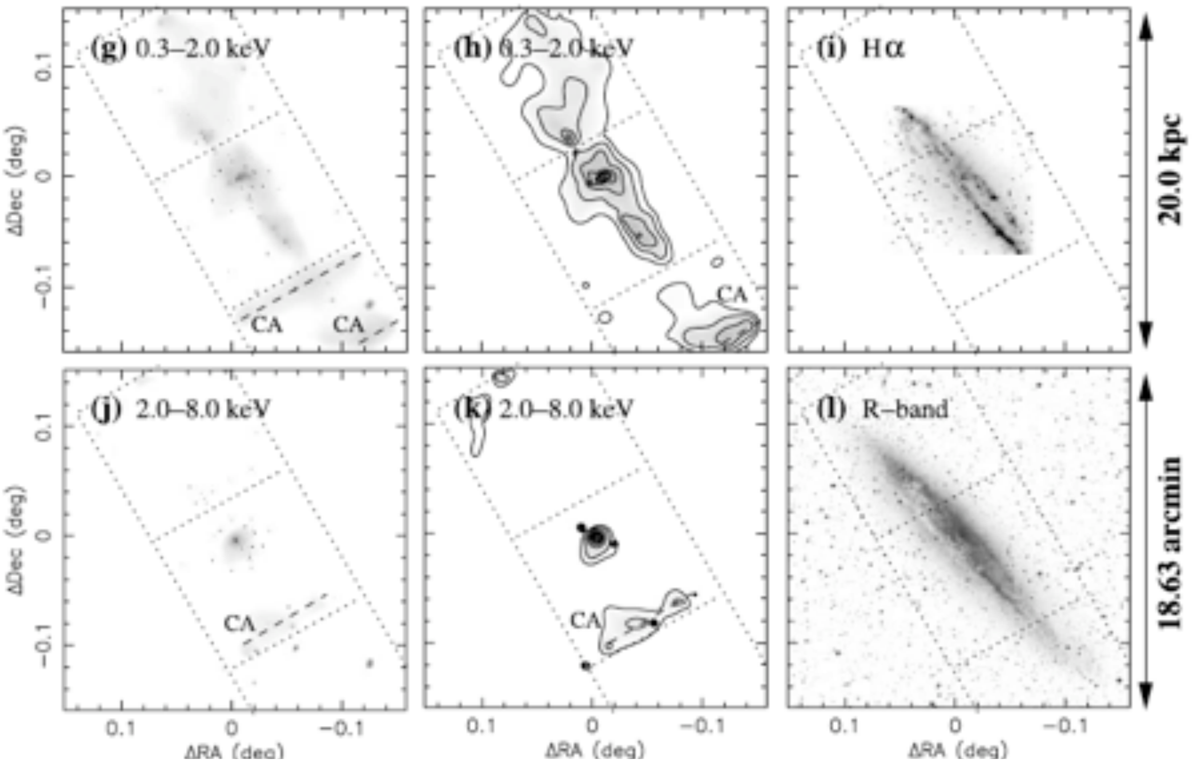
Main coolants:

ion	*line*	*Ion.Potential+1*
O^{4+}	OV[630A]	113.9 eV
Ne^{5+}	NeVI[400A]	157.9 eV
Fe^{8+}	FeIX[169A]	233.6 eV

In order to "kill" the cooling at the peak of the cooling function we need soft X-ray photons

Observed Soft X-ray emission from Star Forming galaxies

Strickland+04

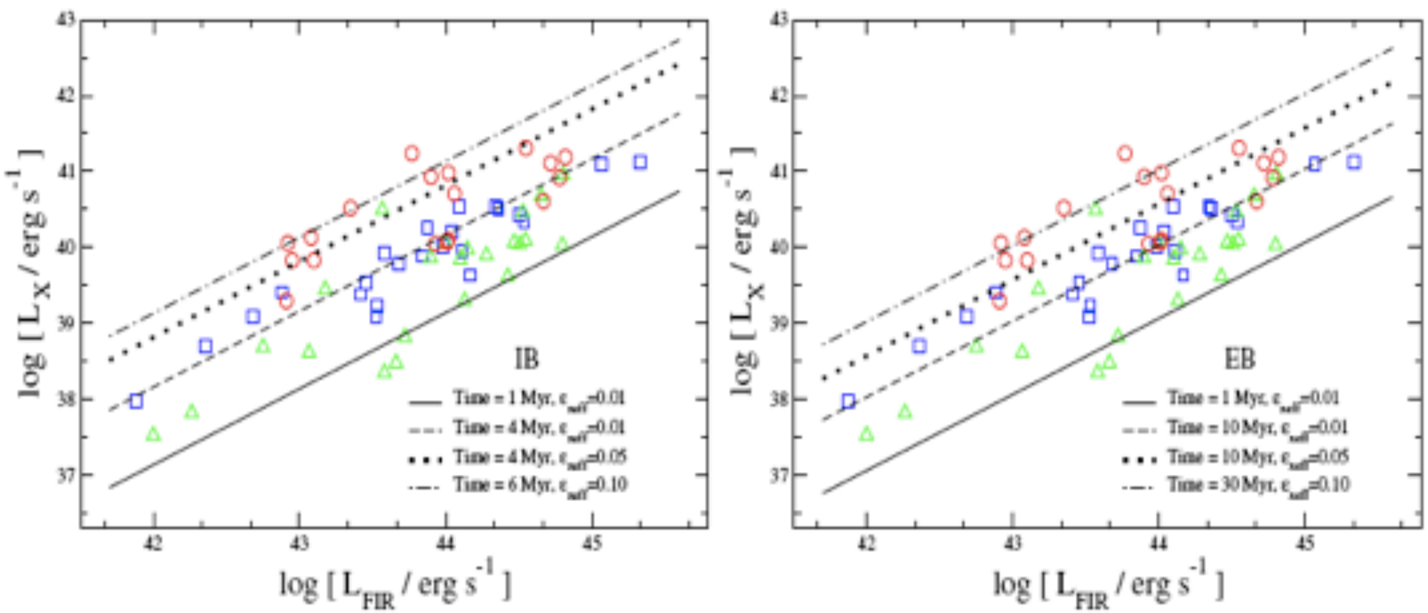


Extended emission from SN bubbles.

compact emission from X-ray binaries (dominate hard X-ray).

See Marat Gilfanov's talk.

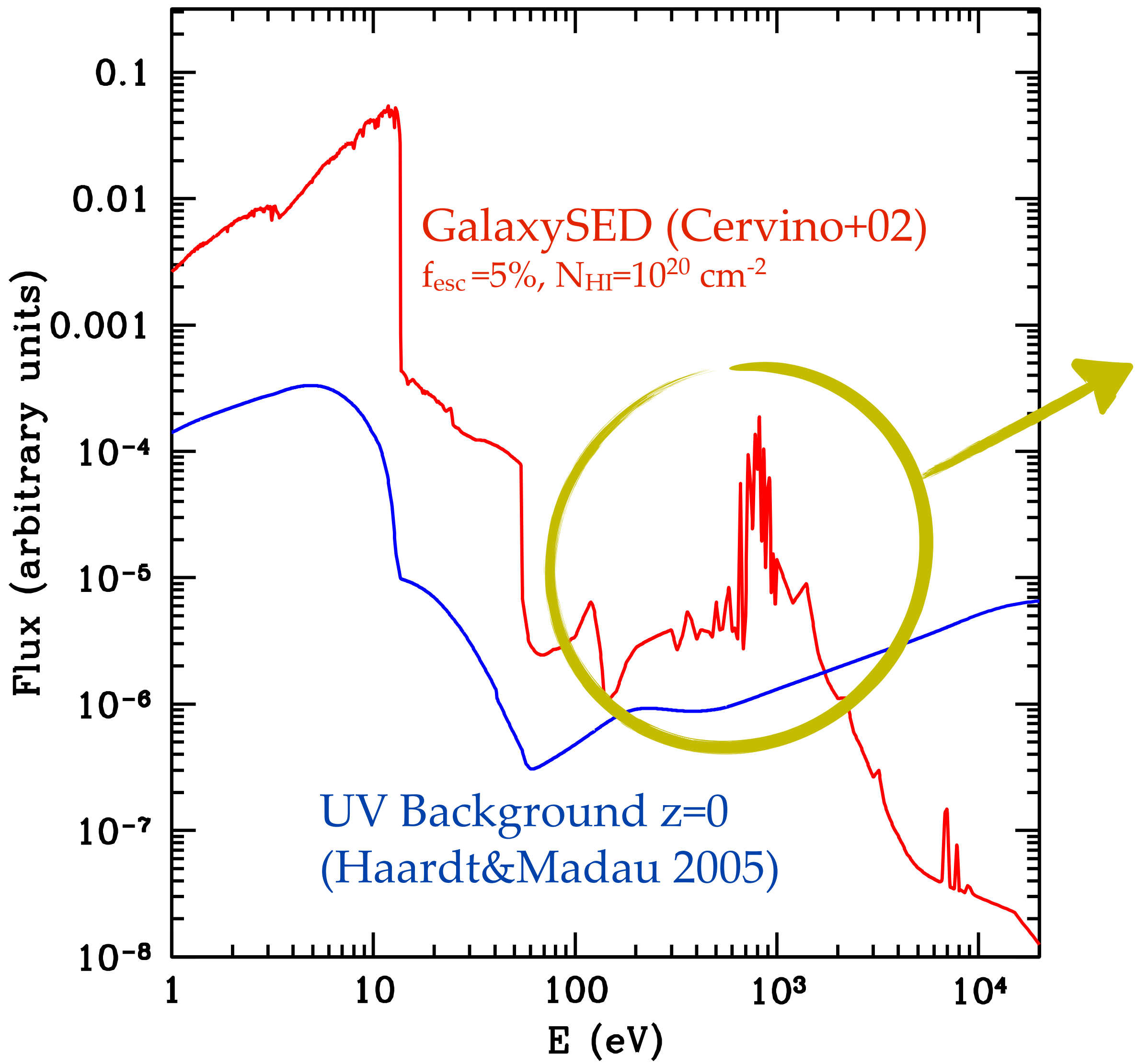
Mas-Hesse+08



Linear L_{softX}-SFR relation (with significant scatter).

L_{softX}-10^{40} × SFR erg/s

Soft X-ray emission from galaxies: SED



Soft X-ray (model) produced by SN bubbles, calibrated to reproduce observed SFR - Soft Xray relation.

NB: X-ray binaries not included.

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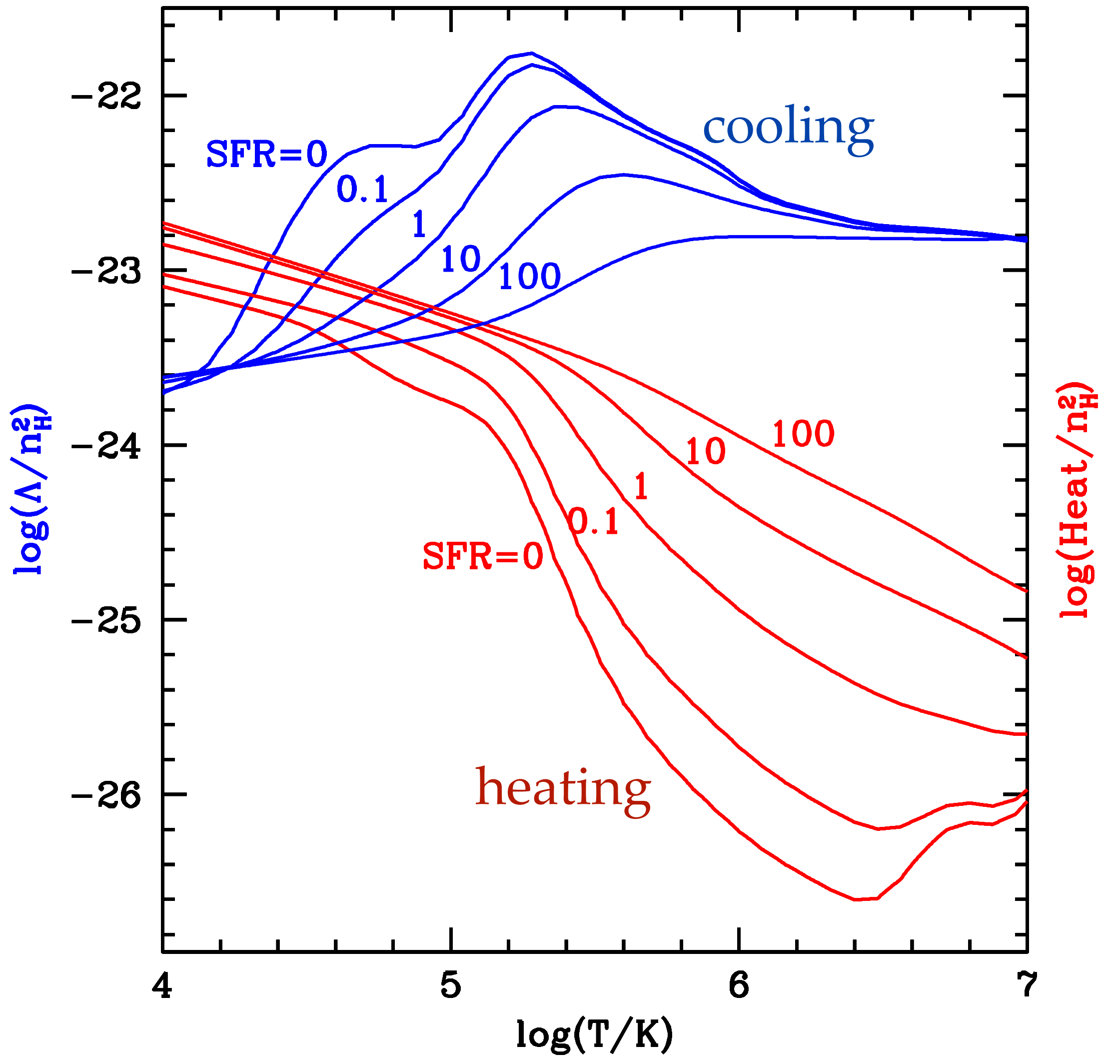
Effect on gas cooling: Cloudy modeling for "typical" CGM



$n_H = 10^{-3}\ cm^{-3}$ ($\delta \sim 5\times10^3$ @ z=0)
($\delta \sim 6\times10^2$ @ z=1)
d=5 kpc from galaxy
$Z = 0.03\ Z_\odot$

$\Lambda(n, T, Z, U^* + U_{UVB})$

$U^* \propto SFR \times d^{-2} \times n_H^{-1}$

NB: for isothermal halo profile:
$U^* \propto SFR \times M_{vir}^{-2/3} \times (1+z)^{-1}$

dramatic effect of local sources on cooling rates of CGM gas (+ some extra heating).

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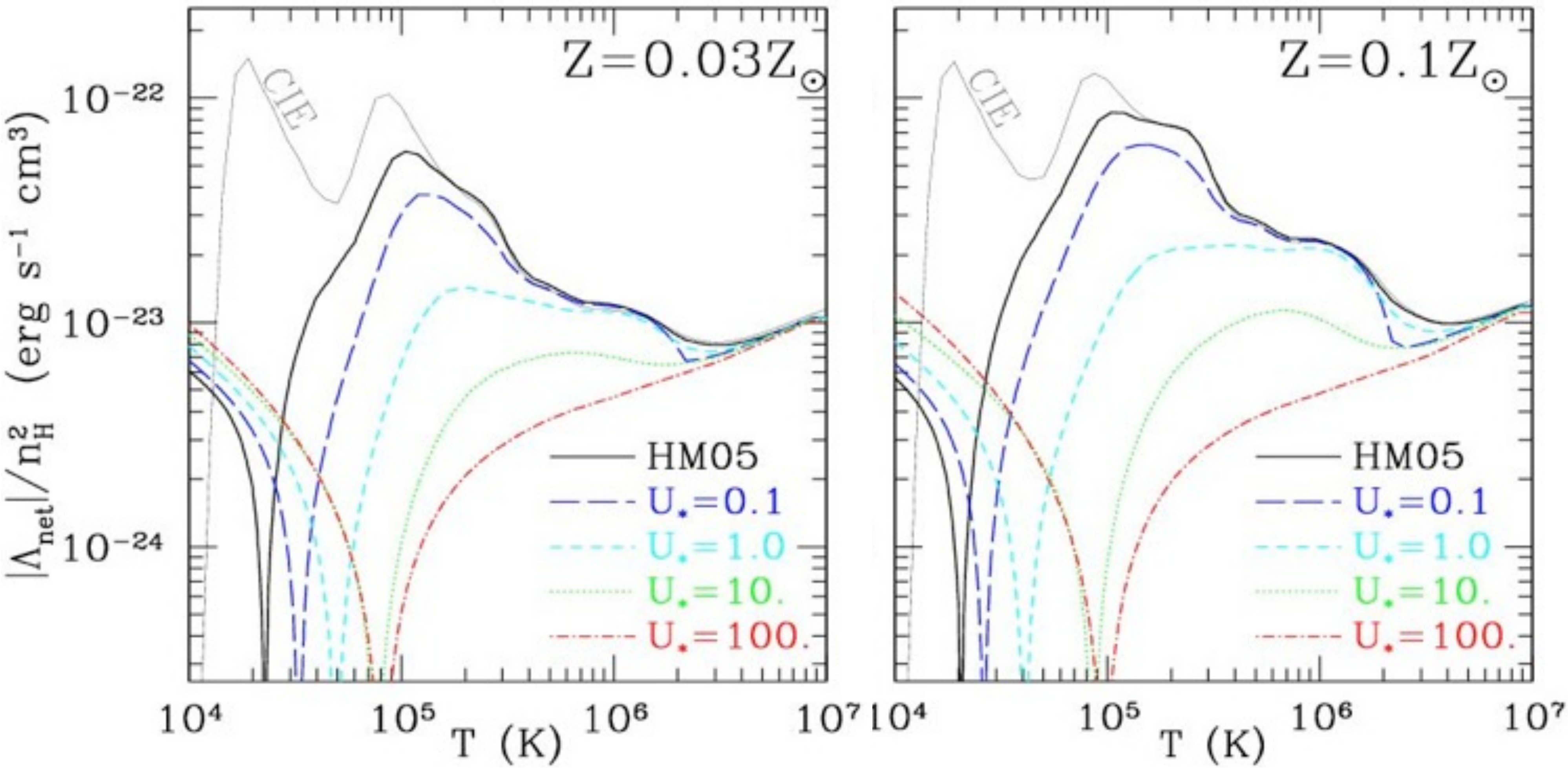
Dependence on Metallicity:



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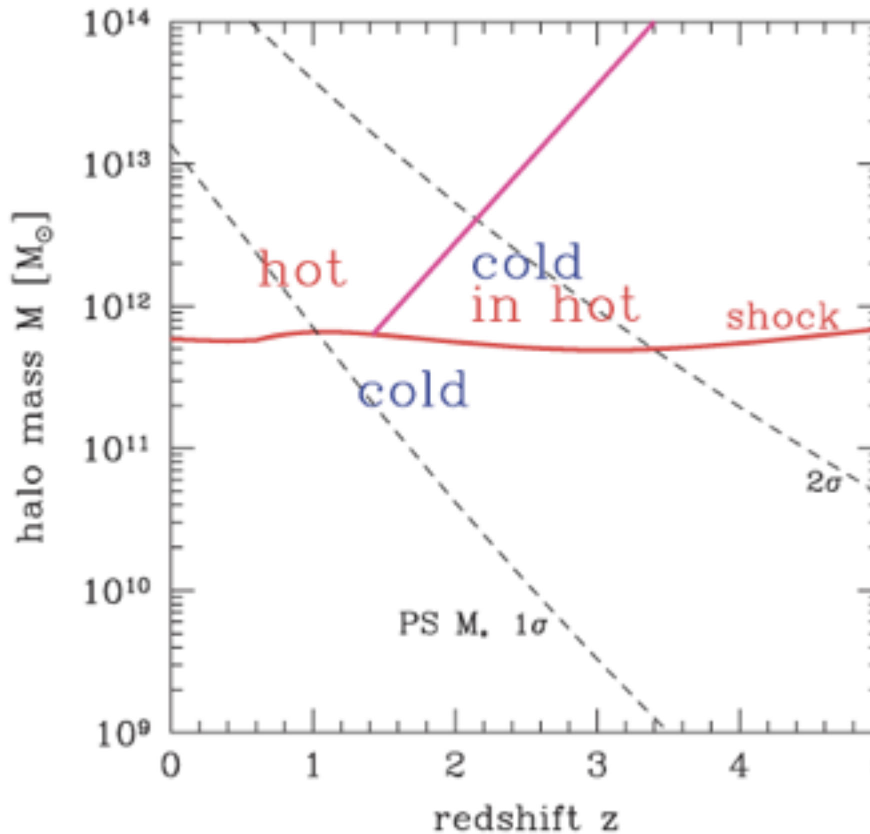
The "hot-mode"/"cold-mode" transition revisited

Basic relations:

$$t_{\rm cool} = \frac{3}{2}\frac{n_{\rm H} k_{\rm B} T}{\Lambda_{\rm net}(T, n_{\rm H}, Z, U_*, z)}$$

$$t_{\rm comp} \simeq 0.57 \times (1+z)^{-3/2}\,{\rm Gyr} \quad @ \; 0.1 R_{\rm vir}$$

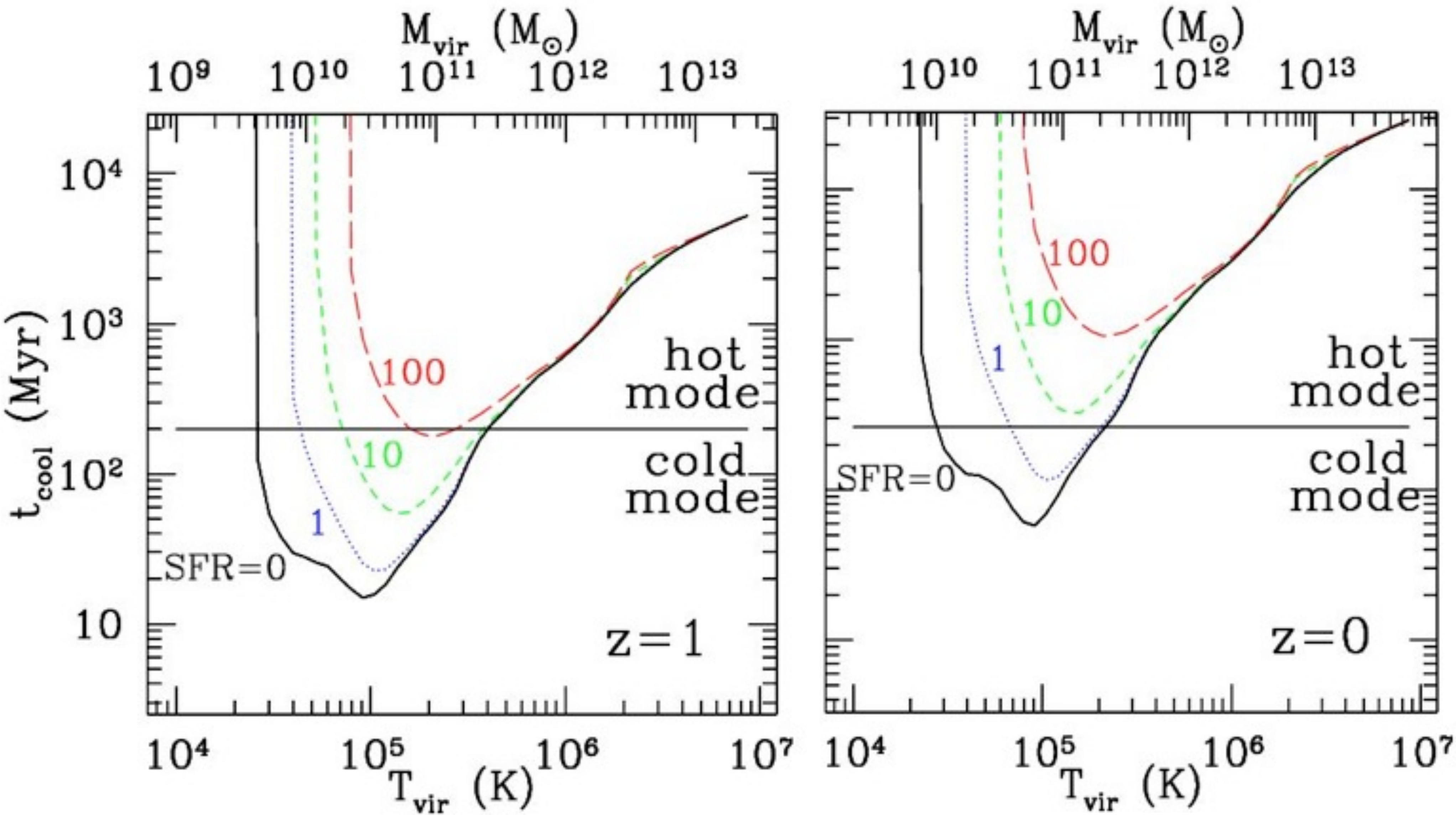
Stable shock ("hot mode")
if $t_{cool} > t_{comp}$



Dekel & Birnboim 2006

How this changes including local sources in the cooling function?

Result: transition depends on SFR.
For high SFR there is no "critical halo mass".



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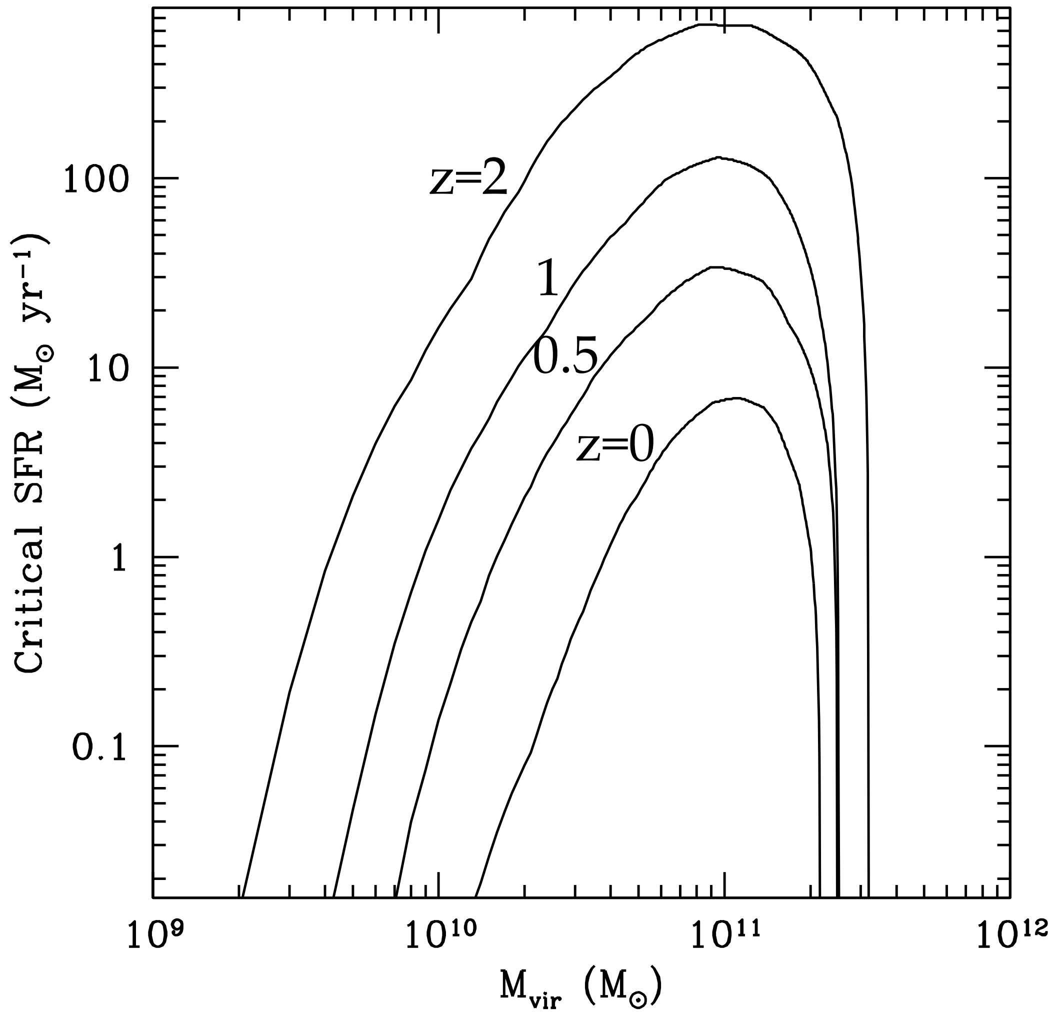
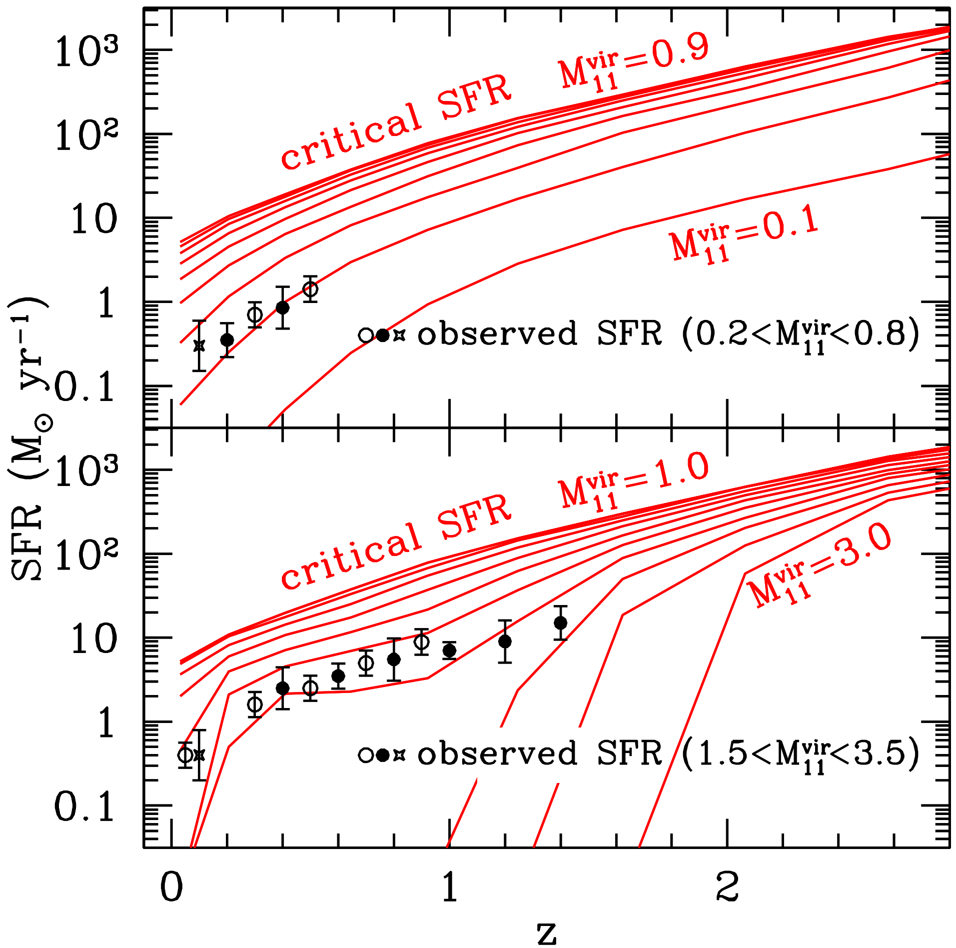
Critical SFR(M_{vir},Z, z) := SFR where t_{cool}=t_{comp}

SFR> Critical SFR --> "hot-mode"
SFR< Critical SFR --> "cold-mode"





Same steep redshift evolution as observed SFR!

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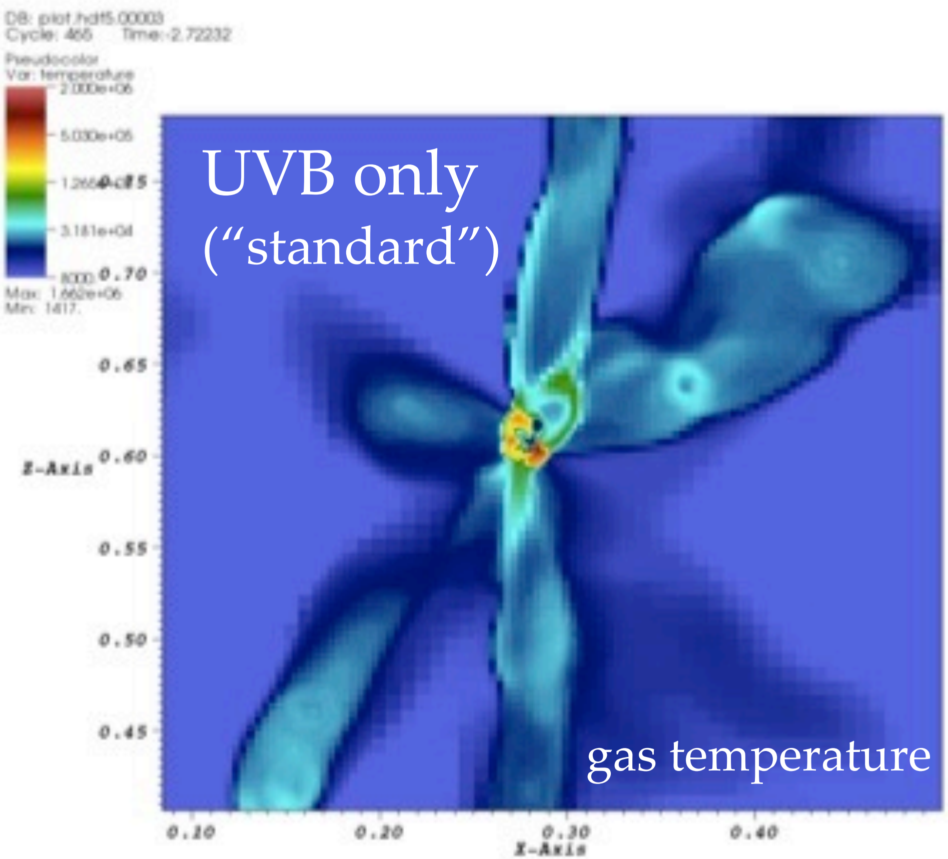
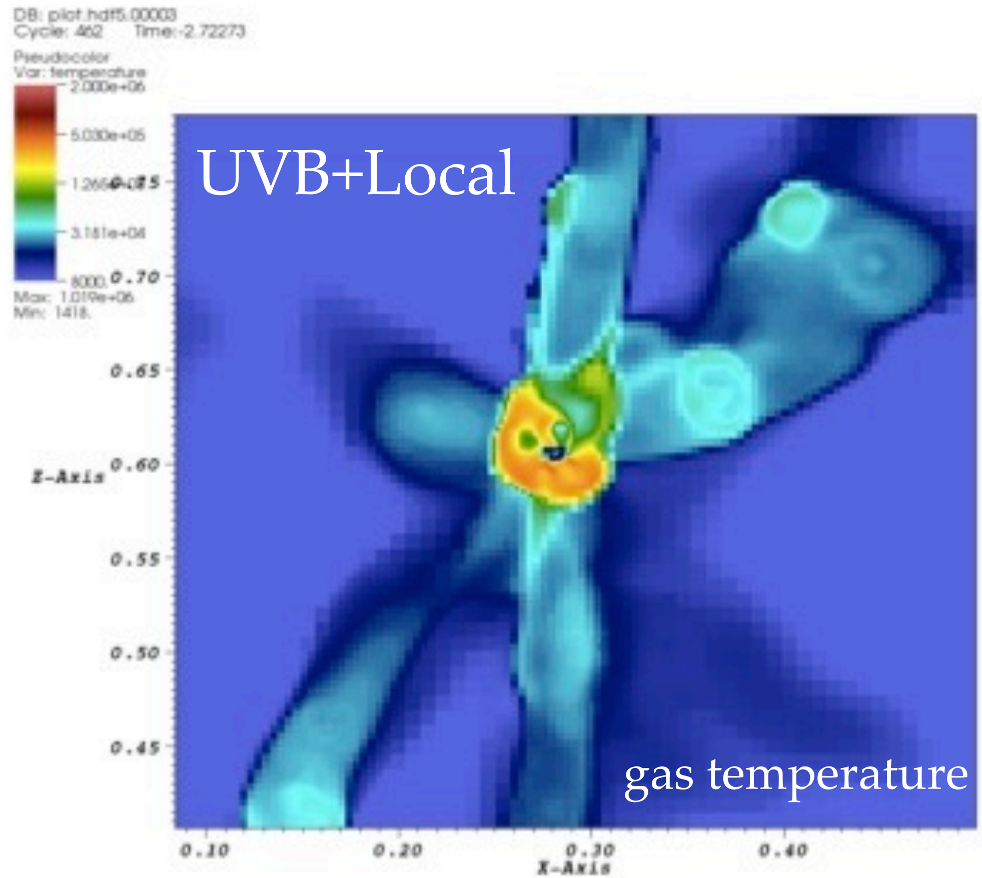
- RAMSES:

~10^{11} M_{sun} halo @ z=1





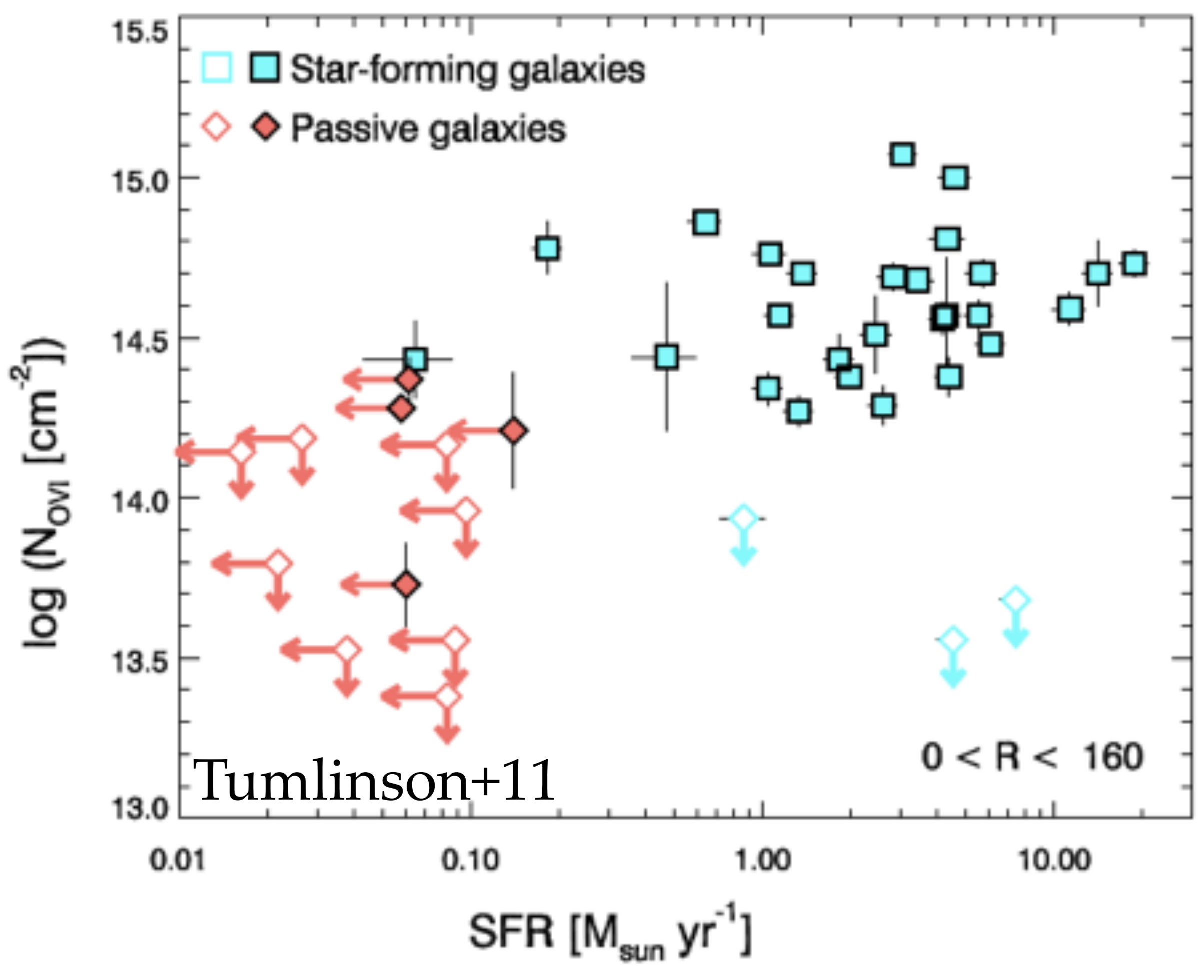
Cantalupo, in prep

- SPH (Gasoline):

Kannan...SC+14 --> See Rahul Kannan’s talk

Observational evidences for cooling modification around SF galaxies?

- "absence" of the main cooling line (OV630A) is difficult to probe directly.
- indirect evidence: excess of O^{5+} (OVI) or higher potential ions.



Enhancement of OVI around "critical SFR" consistent with local soft-Xray effect.

See also Jess Werk's talk

Detailed comparison in progress (Werk,SC+, in prep)

Other photo-ionizing sources and open questions

- AGN:
will totally dominate X-ray SED, *increasing substantially* the strength of the effect presented here. But: one needs to deal with duty cycle and beaming effects + other AGN "mess". Not necessarily working as "thermostat" of SF regulation.

- X-ray binaries:
will dominate hard X-ray (little effect on cooling function). If contribution at ~0.1-0.5 keV is substantial, they will help reducing cooling rates
(inclusion in models in progress).

- Accreting WDs:
if confirmed, they may be *very* important, but there is a delay of ~1Gyr w.r.t. SF.

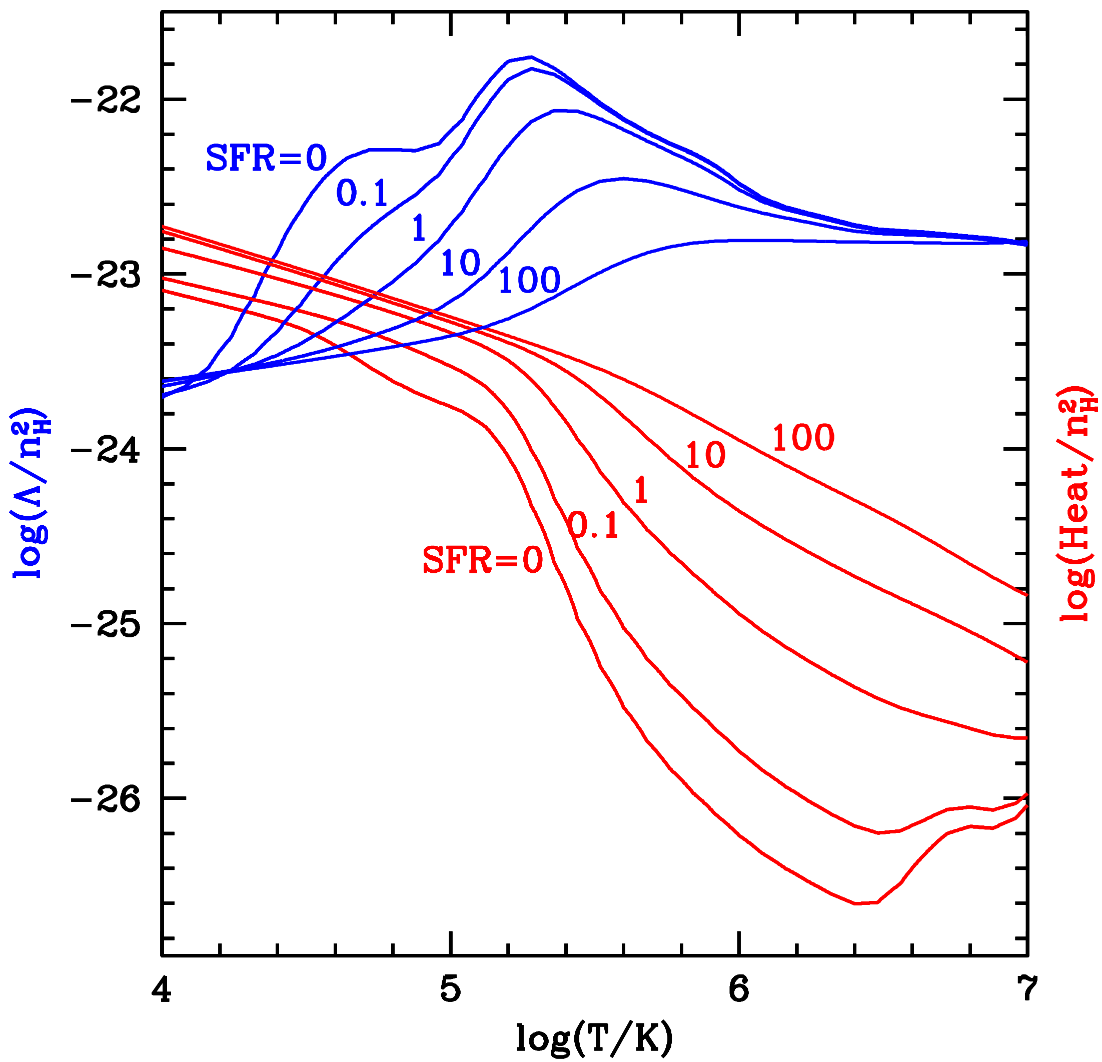
Other photo-ionizing sources and open questions

- Quenching / keeping quenched high mass galaxies with local photoionizing sources?

because L_x ($M^*=10^{11}$ M_{sun}) ~ L_x (SFR=few M_{sun}/yr), previous analysis may be applied to ISM of massive elliptical as well, noting that:

+ passive galaxies are compact (increases ionization parameter)
- higher densities than CGM analysis
- higher metallicity (higher cooling rate but may be partially balanced by photo-heating)

detailed cloudy analysis in progress.



Summary

- Cooling and accretion rate of halo gas is reduced by orders of magnitude around star forming galaxies when local EUV and Soft-X-ray radiation is included.
- Shock stability analysis including local sources shows the existence of a "critical SFR" for which "hot-cold mode" transition occurs, even for haloes with masses *well below* the "classical" $M_{crit}=10^{11.5}\,M_{sun}$.
- The value of the "critical SFR" is of the same order of the SFR of observed galaxies and steeply evolves with redshift, as found by observations. This suggests that the local radiation field is able to regulate SFR without the need of strong SN feedback.