

# Cooling

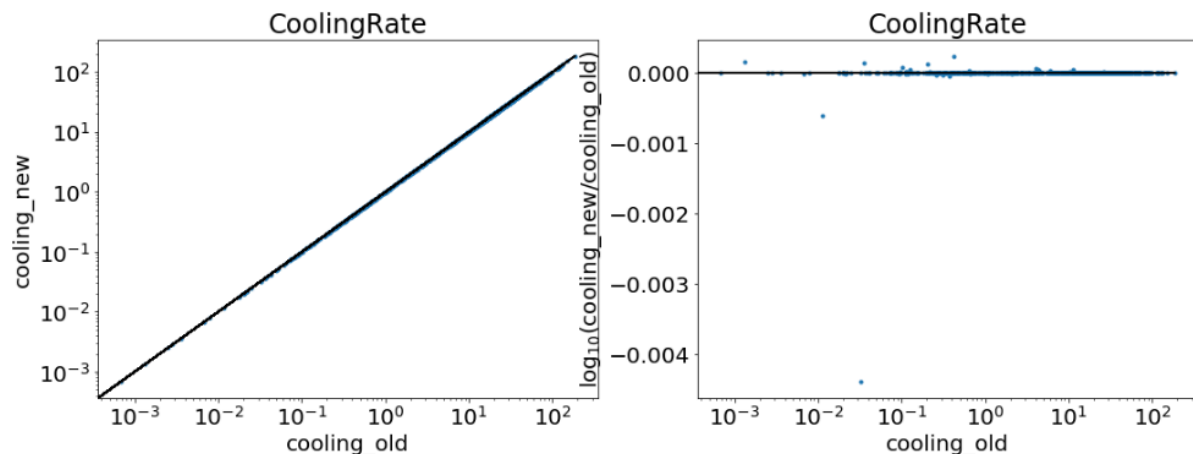
## Testing

### Tidying up of model\_cooling

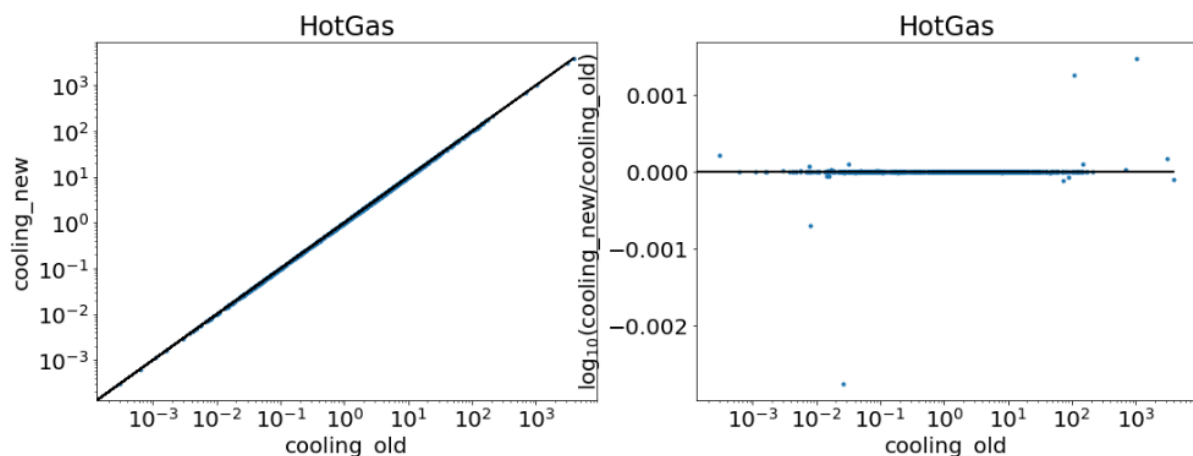
I have tidied up model\_cooling so that, as far as I can tell, it does the same as previously. The new routine is called model\_cooling\_new.c and the old one has been renamed to model\_cooling\_old.c.

Unfortunately, the number of output galaxies produced is not **exactly** the same, although it is very similar. If we restrict to those galaxies in common, then this is what we get:

Amount of gas cooled:



Hot gas in halo:



– that's good enough for me.

model\_cooling.c is a logical link to model\_cooling\_new.c

## New cooling routine

Is as described in Paper\_cooling draft.

The basic idea is that we model the HotGas atmosphere as a  $\beta=2/3$  model. Then the cooling rate can be calculated, and an isothermal cooling flow model assumed to determine the amount of cooled gas.

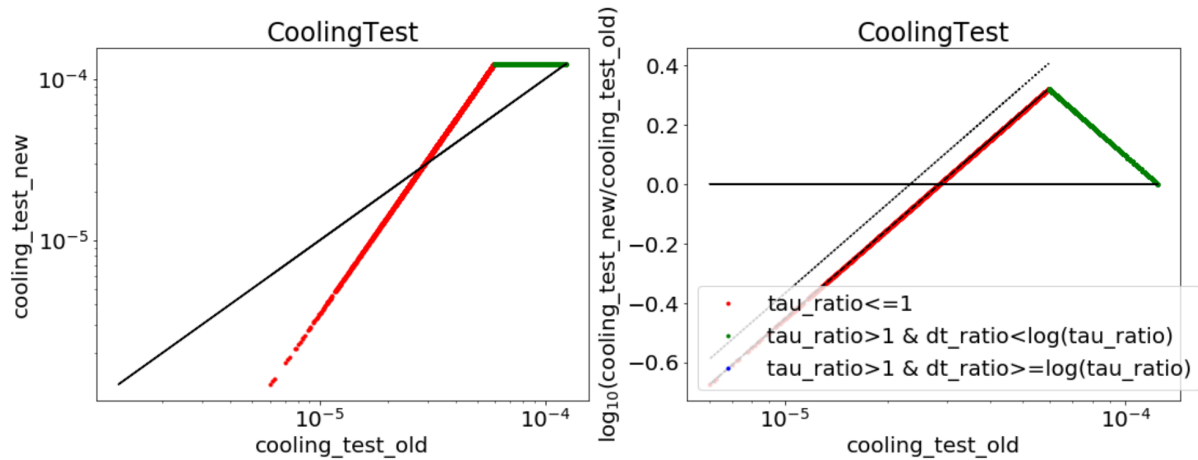
## Testing

Is tricky. The paper does idealised tests of the concept, but we want to make sure that we have implemented it properly in L-Galaxies. The only way that I can think to do it is to force idealised properties for all halos. So the following sets  $T=T_{\text{vir}}$ ,  $\text{hotMass}=f_{\text{fac}} \times \text{BaryonFrac} \times M_{\text{vir}}$ ,  $\text{tot\_metals}=Z \times \text{hotMass}$ ,  $\text{dt}=t_{\text{fac}} \times \text{dt}$ .

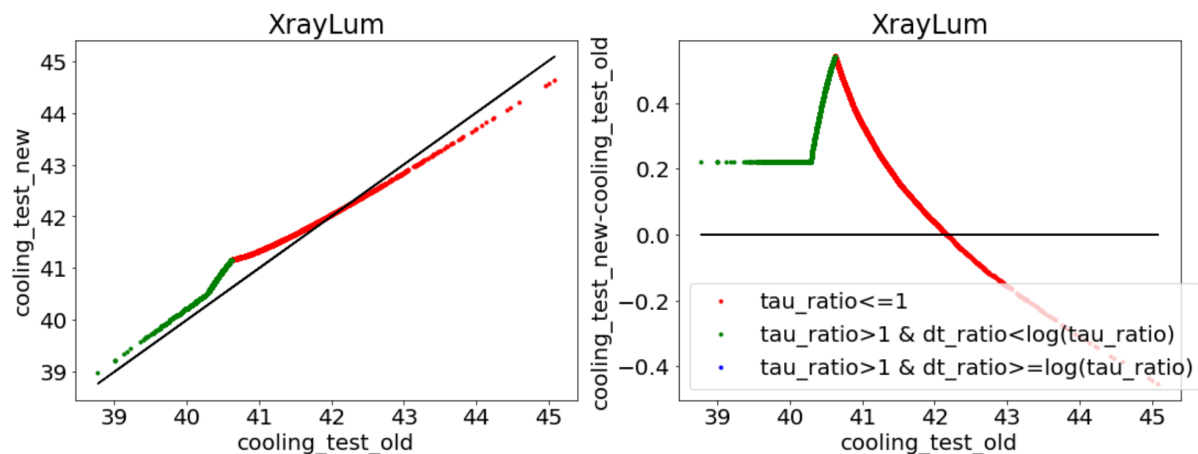
(0)  $f_{\text{fac}}=1$ ,  $Z=0.$ ,  $\text{dt}=0.01 \times \text{dt}$

A regime in which there is likely to be little cooling

This first plot shows the ratio of the fraction of gas cooled in each case



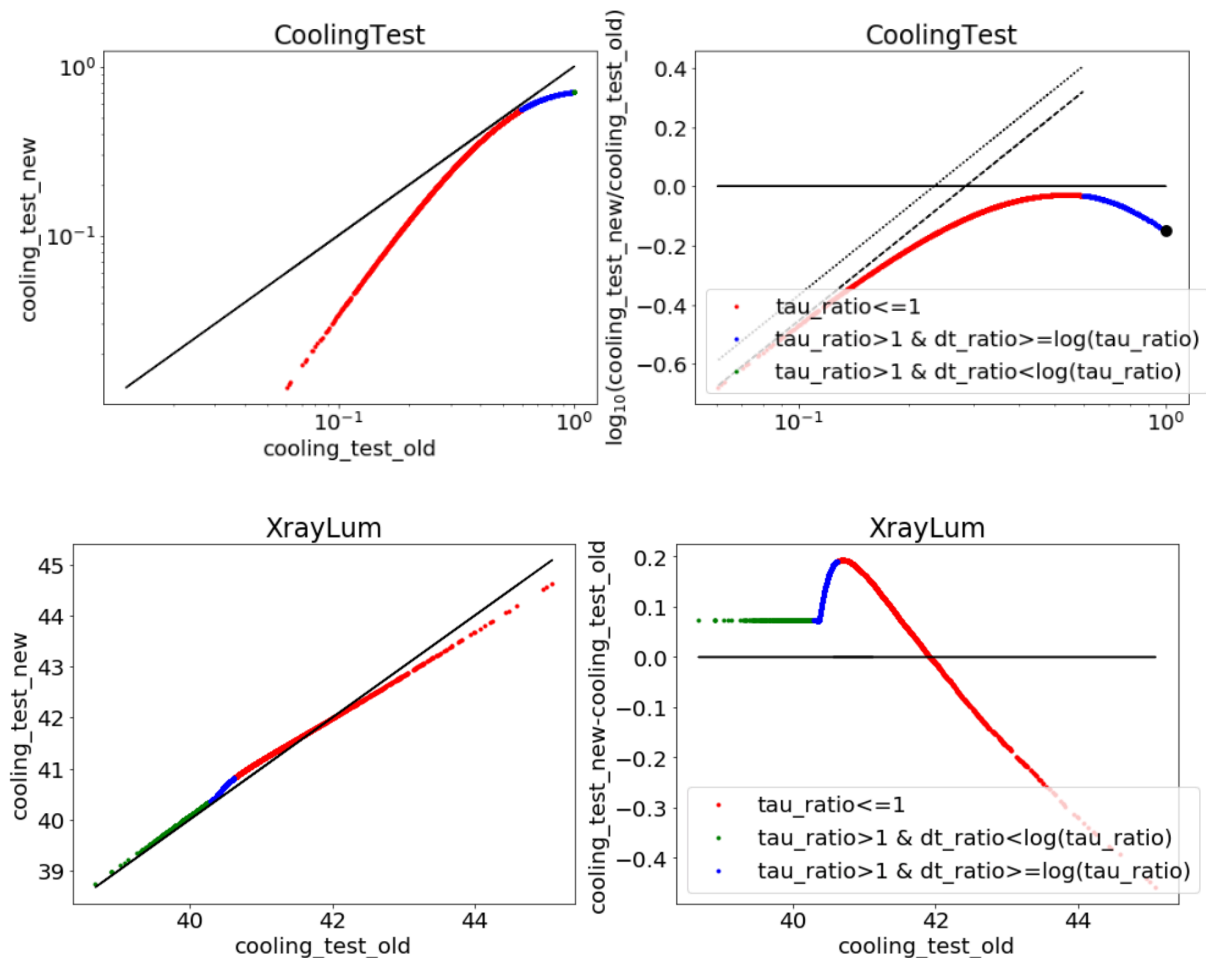
and this shows the ratio of the calculated X-ray luminosity



## Notes:

- Where  $\tau_{\text{ratio}} > 1$  then we have a constant fraction of gas cooled in the new regime. This is where the cooling time of the halo is less than the dynamical time. The model then restricts the amount of gas that can cool to the amount that can flow inwards in a dynamical time, so this is correct.
- $dt_{\text{ratio}}$  is the same (and very small) for all these halos, so the line sloping down to the left follows the increase in cooling time / reduction in  $\tau_{\text{ratio}}$ . The dotted line shows the expected ratio of the two cooling methods; the dashed line (ie the one that fits well) shows the ratio after correcting the original code for a missing Hubble<sub>h</sub> factor.
- In the case of small mass deposition, the ratio of the X-ray luminosities should be  $\text{new/old} = 2.5/1.5 = 5/3 \approx 1.67$ , which it is:  $\log_{10}(1.67) \approx 0.22$ .
- Both methods estimate X-ray luminosity from the amount of energy emitted by cooling gas, so the ratio simply depends upon the ratio of cooled gas.

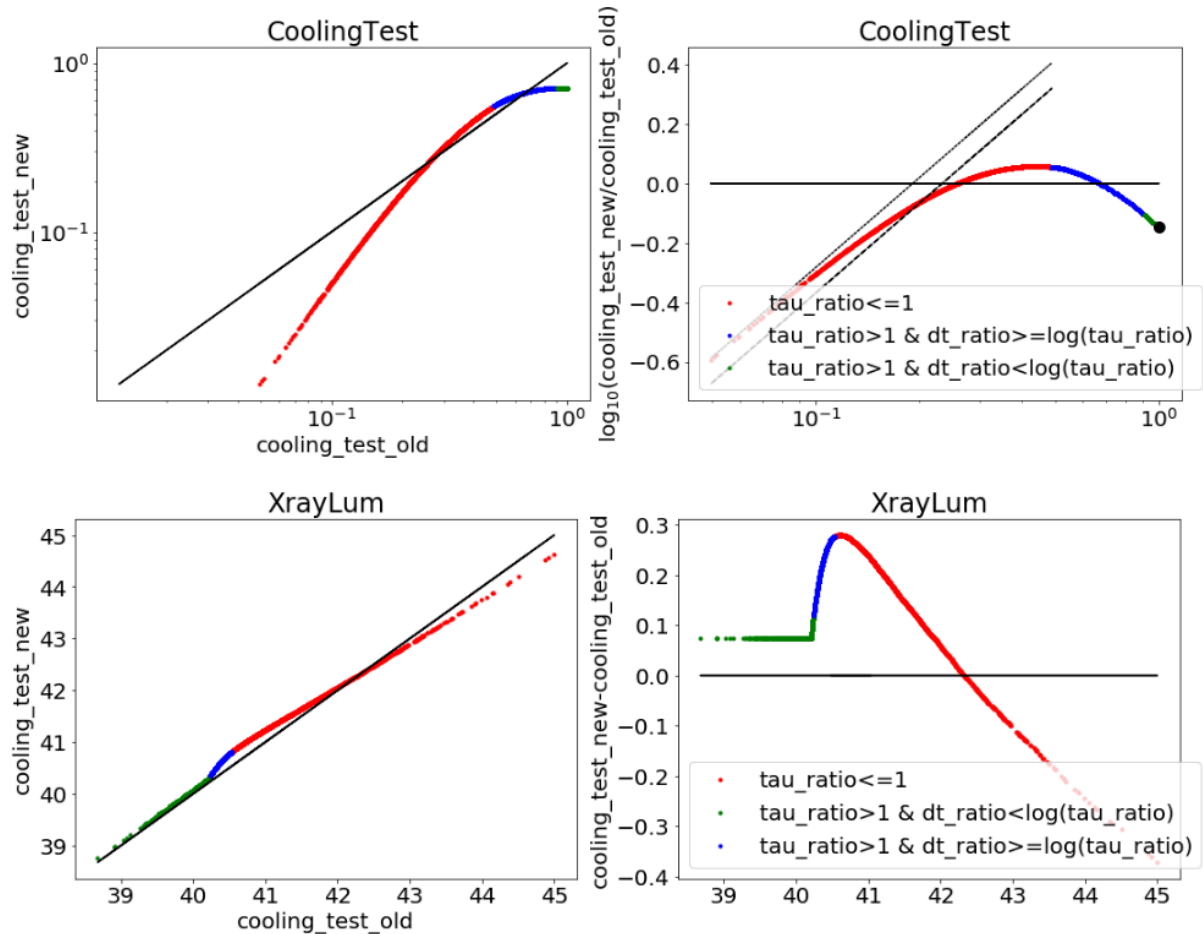
(1)  $f_{\text{fac}}=1$ ,  $Z=0.$ ,  $dt=100*dt$  (ie cool for long time)



Notes:

- In this regime,  $dt\_ratio$  is (just) bigger than unity (but less than unity for the original model). The very right-hand tip of cooled fraction curve corresponds to small  $dt\_ratios$ . In this regime we expect the ratio of cooling times to correspond to the marked dot.

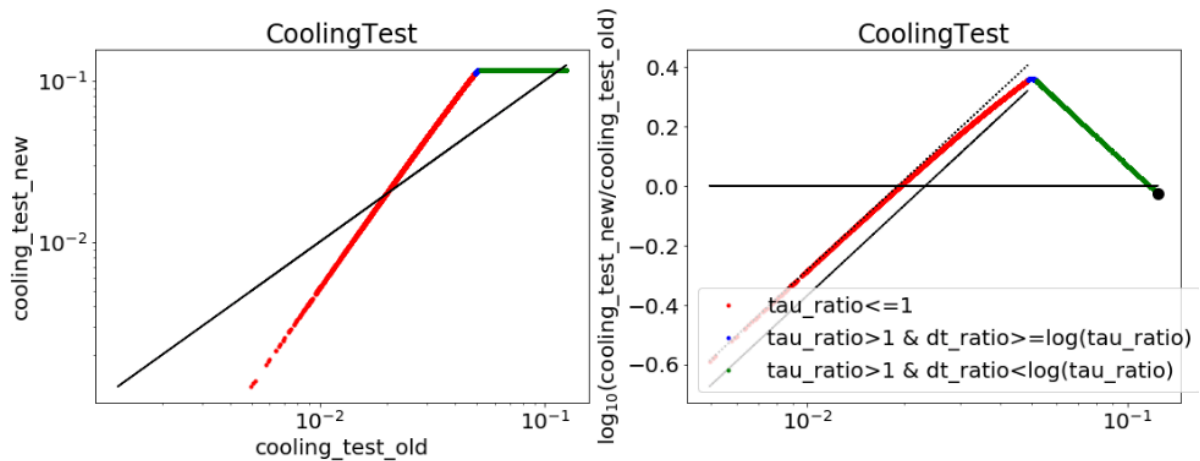
(2) As for (1) but with missing  $h$  added to cooling\_old



Notes:

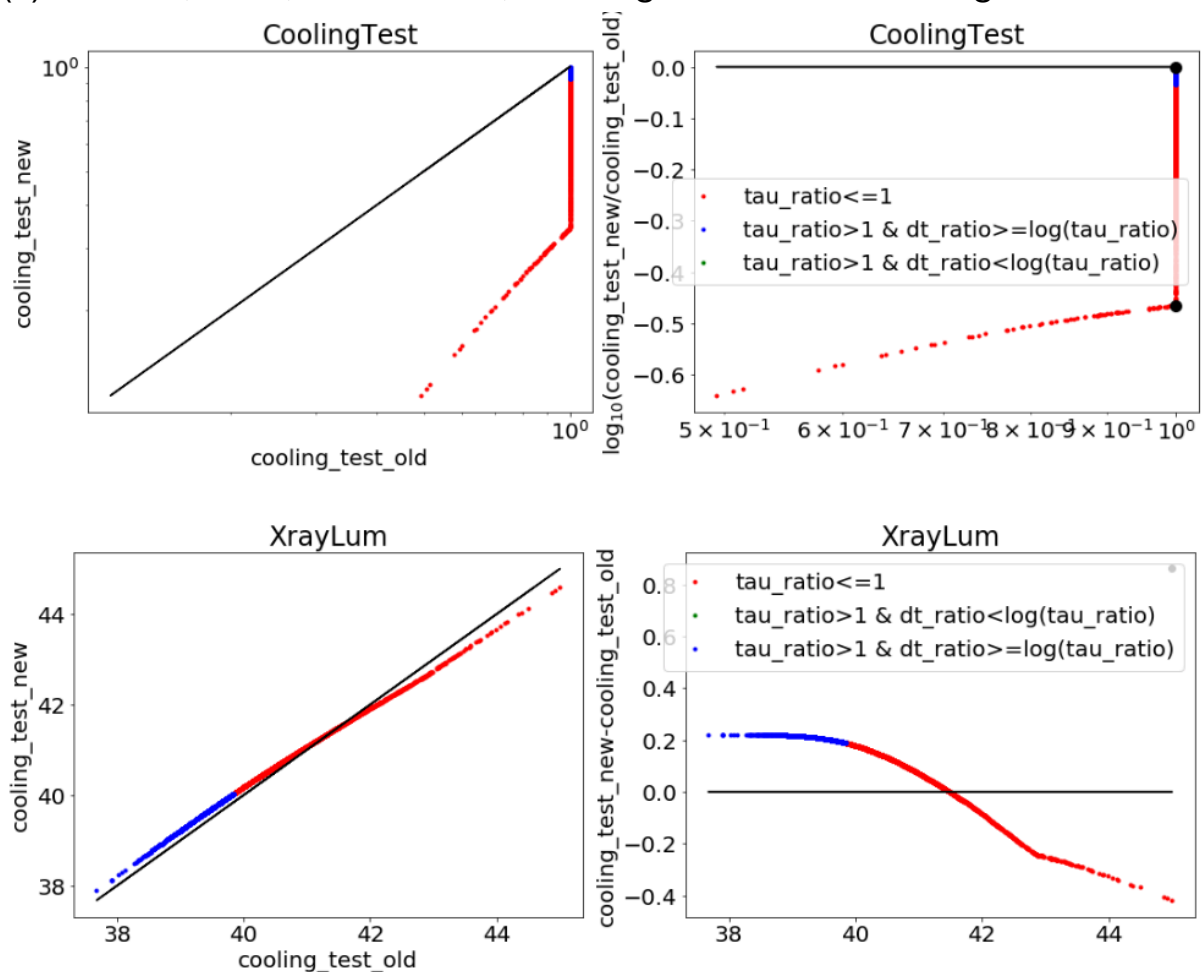
- The two cooled fractions now match correctly onto the expectations for small cooled fractions.

(3)  $f_{\text{fac}}=1$ ,  $Z=0$ ,  $dt=10*dt$ , missing  $h$  added to  $\text{cooling\_old}$



Note: to show that works in this regime also. Again the black dot is the theoretical ratio, this time for a cooled fraction less than unity.

(4)  $f_{\text{fac}}=1$ ,  $Z=0$ ,  $dt=1000*dt$ , missing  $h$  added to  $\text{cooling\_old}$

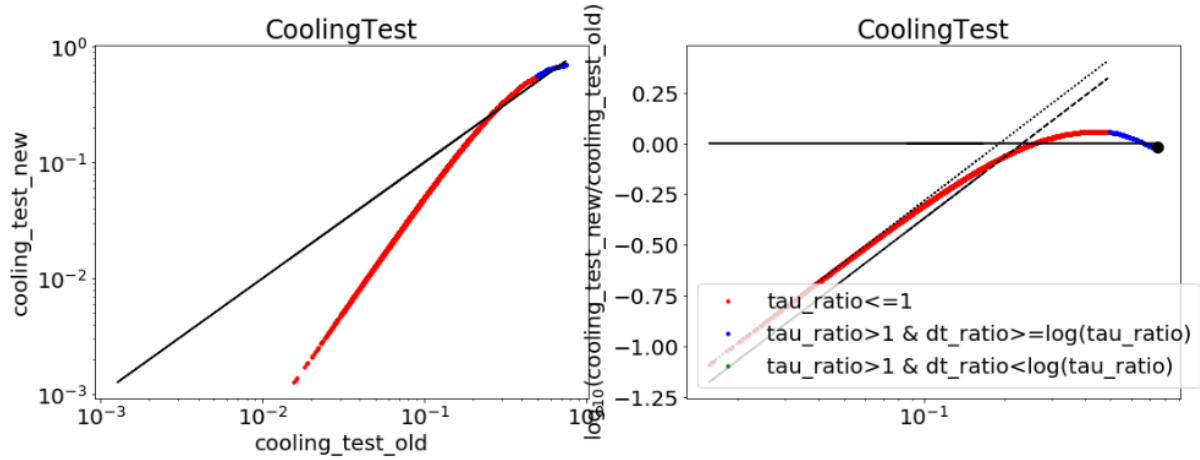


Notes:

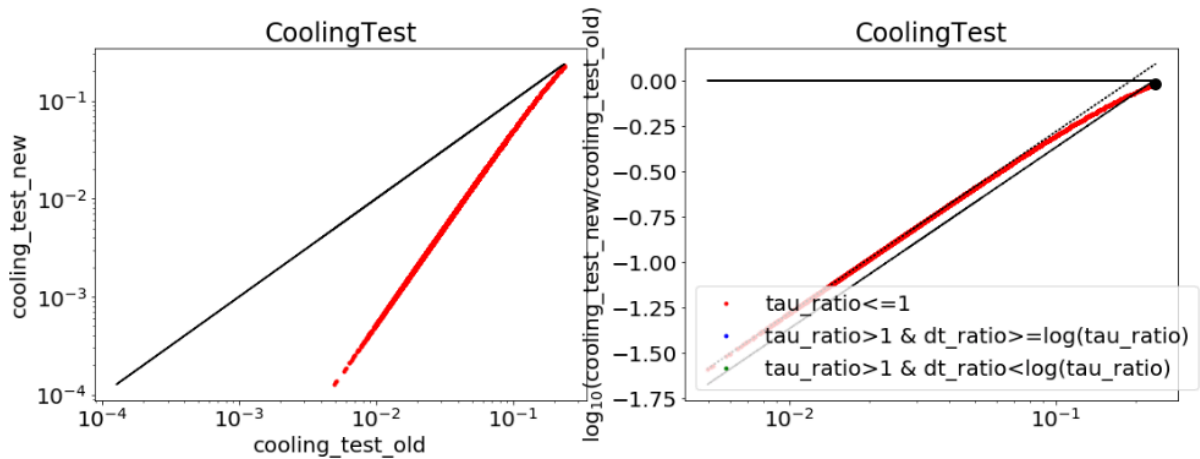
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- Both cooling fractions should saturate at 1 and they do.
- The ratio of the gas cooled when the old method saturates to unity is shown by the location of the lower black dot in the cooling test plot and is exactly correct.

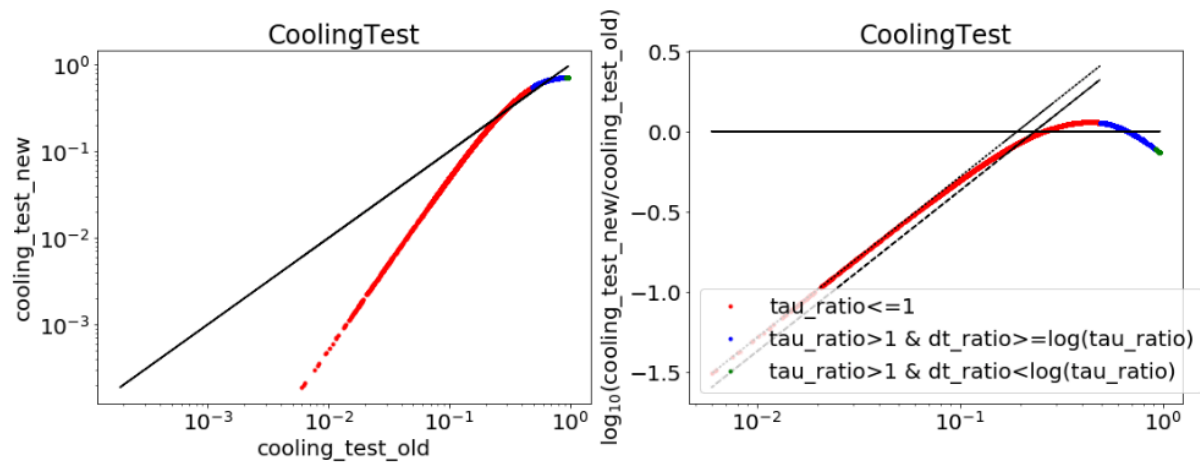
(5)  $f_{\text{fac}}=0.1$ ,  $Z=0$ ,  $dt=100*dt$ , missing  $h$  added — ie cooling time mostly now longer than dynamical time



(6)  $f_{\text{fac}}=0.01$ ,  $Z=0$ ,  $dt=100*dt$ , missing  $h$  added — ie cooling time everywhere longer than dynamical time



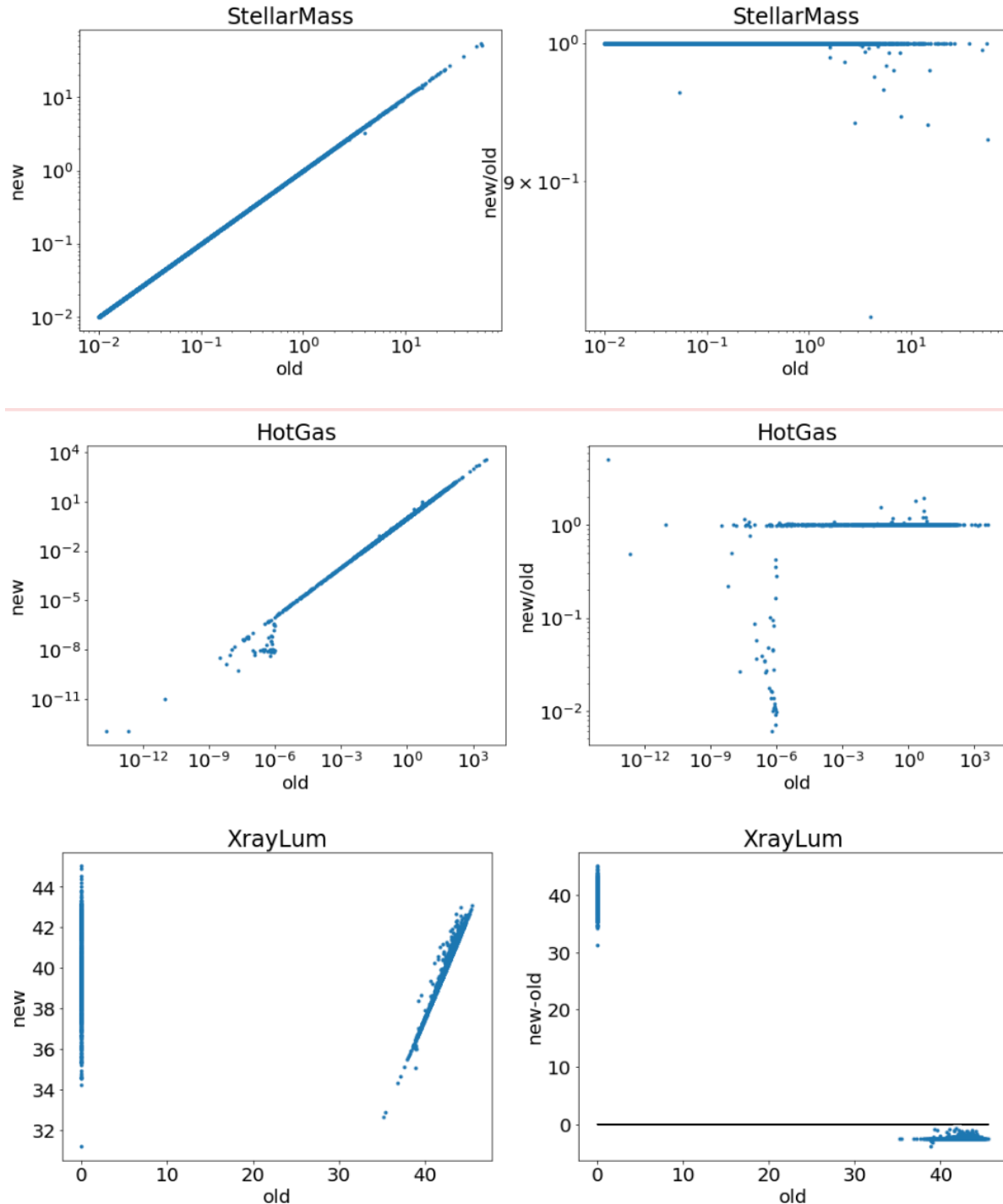
(7)  $f_{\text{fac}}=0.01$ ,  $Z=0.02$ ,  $dt=100*dt$ , missing  $h$  added — to test the introduction of extra cooling from metallicity



## Effect on Hen15 results

The following shows the results of the new cooling method on the Hen15 results, without adjusting any of the other parameters to match constraints.

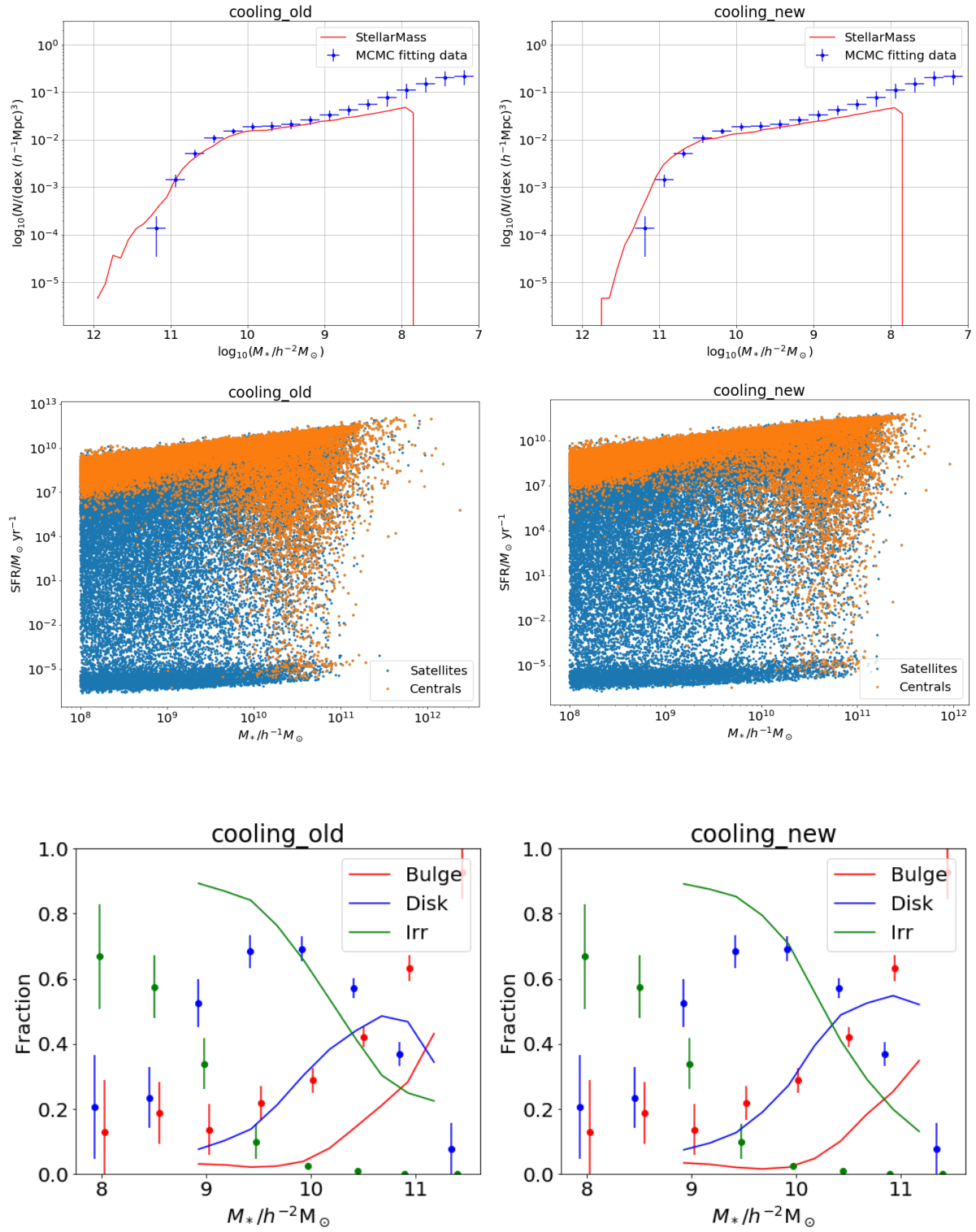
These first few are direct comparisons of individual halos; they may not match up exactly as there are very slightly different numbers of halos in the two runs.





## Comparisons of populations

Using files 0-9



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